# ESPACE (espas)

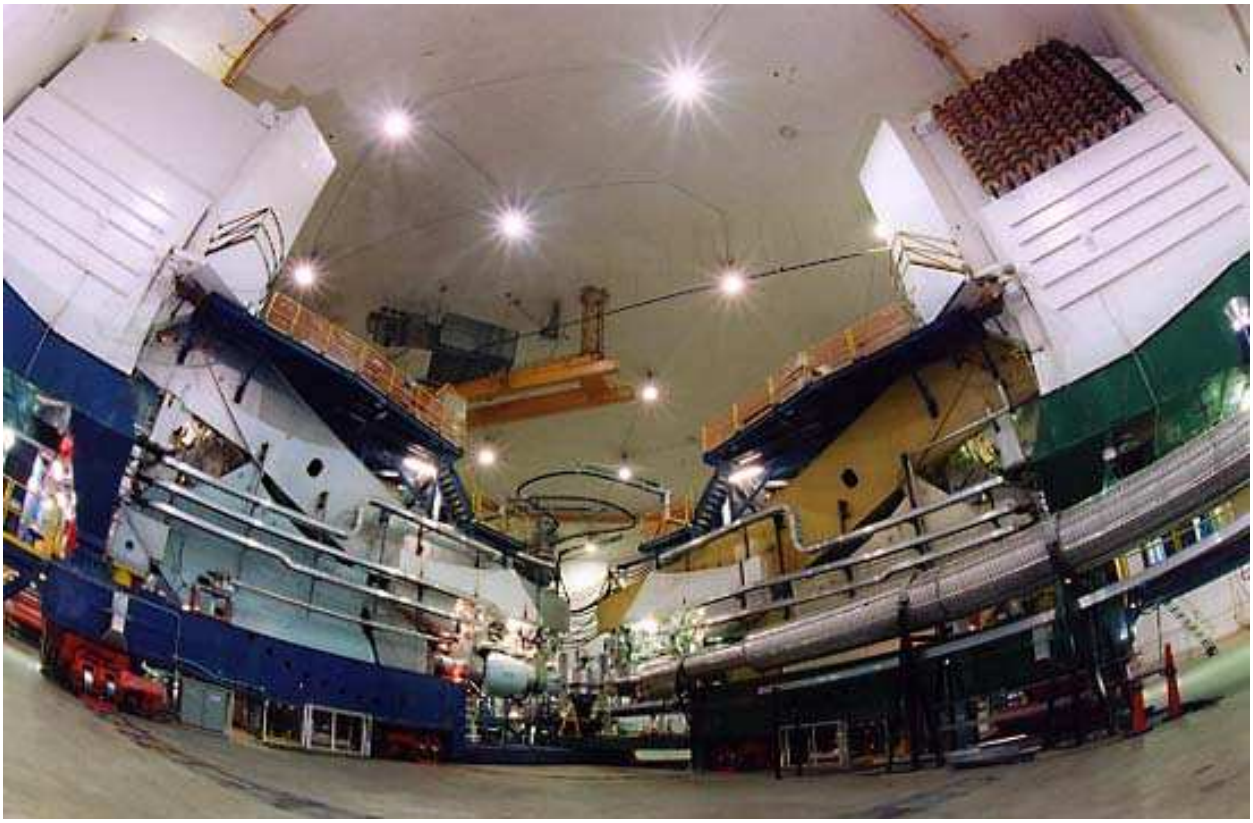
# MANUAL

# VERSION 2.7.0

**E**vent **S**canning **P**rogram for Hall **A** **C**ollaboration **E**xperiments

The Hall A Collaboration

March 27, 1999



# Contents


**1 General Information** **1**
- 1.1 Program Concept . . . 1
- 1.2 How to Start? . . . 3
  - 1.2.1 The ESPACE binary . . . 3
    - 1.2.1.1 System installation . . . 3
    - 1.2.1.2 Private installation . . . 4
  - 1.2.2 Getting ready . . . 8

**2 Variables** **13**
- 2.1 Units of the Variables . . . 13
- 2.2 Overview of Pre-Defined Variables . . . 13
- 2.3 Coding New Variables . . . 26
- 2.4 Defining New Variables . . . 28

**3 Defining Histograms, Logicals and Filters** **29**
- 3.1 Histograms . . . 29
- 3.2 Logicals . . . 30
- 3.3 Filters . . . 32
- 3.4 Global Conditions . . . 33
- 3.5 When is What Stored? . . . 34

**4 Coordinate Systems** **35**
- 4.1 Definition of Coordinate Systems . . . 35
  - 4.1.1 Hall A Laboratory Coordinate System . . . 35
  - 4.1.2 Spectrometer Reconstructed Coordinate System . . . 35
  - 4.1.3 Spectrometer Detector Coordinate System . . . 37
  - 4.1.4 Spectrometer Focal-Plane Coordinate System . . . 37
- 4.2 Calculation of Coordinates . . . 37
  - 4.2.1 Detector Vertex . . . 38
  - 4.2.2 Focal-Plane Vertex . . . 41
  - 4.2.3 Hall A Laboratory Vertex . . . 42
- 4.3 Calibration of Coordinates . . . 43

**5 Tracking** **45**
5.1 Program Flow for Tracking . . . 45
5.2 Minimum Spanning Tree Algorithm . . . 45
5.3 Definition of Wire Chamber Hit Type HPCH . . . 45
5.4 Tracking Efficiency . . . 46

**6 Calibration** **47**
6.1 ADC Gains and Pedestals . . . 48
6.2 Čerenkov ADC . . . 52
6.3 Shower and Pre-Shower Calibration . . . 52
6.4 Scintillator Timing . . . 53
6.5 VDC Time Offets . . . 53
6.6 VDC Time to Distance . . . 53
6.7 Vertex Reconstruction . . . 53
6.7.1 Non-Dispersive Position $\boldsymbol{y}_{\mathrm{tg}}$ . . . 56
6.7.2 Angles . . . 56
6.7.3 Momentum Aberrations . . . 56
6.8 Coincidence Time . . . 60
6.9 Missing Energy . . . 60
6.10 Adding a new Optimization . . . 60

**A Header File Description** **61**

**B Database File Description** **67**

**C Transformation between Different Coordinate Systems** **71**

**D ESPACE Reference Manual** **73**
D.1 Espace/Debug . . . 73
D.2 Espace/SEt . . . 74
D.2.1 Espace/SEt/File . . . 75
D.2.2 Espace/SEt/TIming . . . 75
D.2.3 Espace/SEt/TYpe . . . 76
D.2.4 Espace/SEt/Fit . . . 77
D.2.4.1 Espace/SEt/Fit/Adc . . . 77
D.2.4.2 Espace/SEt/Fit/Time . . . 77
D.2.4.3 Espace/SEt/Fit/Momentum . . . 78
D.2.5 Espace/SEt/Spectrum . . . 78
D.2.5.1 Espace/SEt/Spectrum/Window . . . 78
D.2.5.2 Espace/SEt/Spectrum/Bins . . . 79
D.2.6 Espace/SEt/Vdc . . . 79
D.3 Espace/Define . . . 80
D.3.1 Espace/Define/Cut . . . 81

D.4 Espace/SPectra . . . . . 82
D.5 Espace/File . . . . . 83
D.6 Espace/Calibrate . . . . . 85

**E Flow Diagram** **87**

**F COOLHANDS Programming Guide** **119**
F.1 Concept . . . . . 119
F.2 FORTRAN Components . . . . . 119
F.3 FORTRAN Unit Numbers and Common Blocks . . . . . 120
F.4 User-Supplied Subroutines . . . . . 121
F.4.1 `input` . . . . . 122
F.4.2 `variable` . . . . . 125
F.4.3 `user_init` . . . . . 129
F.4.4 `user_exit` . . . . . 130
F.4.5 `filter_open`, `filter_event` and `filter_close` . . . . . 130
F.4.6 `option_do` . . . . . 131

# Chapter 1

# General Information

The program ESPACE can analyze experiments performed with one or two high-resolution spectrometers. In this manual we will discuss the implementation specific to the setup in hall A at TJNAF.

ESPACE can filter, histogram and/or calibrate variables of the experimental setup while applying conditions on the incoming data. The variables range from raw detector signals, like the value of a scintillator TDC channel to much more elaborate ones like the coordinates of the reaction point in the target.

The program interface is supplied by the KUIP CERNLIB and, therefore, the program has a PAW-like look. Details about this interface can be found in the CERN documentation of [1] and [2].

## 1.1 Program Concept

Let's try to explain the history and the concepts behind the analysis program ESPACE[1]. The program is build up in three layers where each layer on top of the lower one adds more information specific to the experiments.

The first layer performs operations on variables defined in higher layers, for each event input. These operations can be histogramming, filtering, evaluating conditions and/or accumulating data for an optimization cycle. The routines are collected in the COOLHANDS[2]-library. The first version of this package was written by Joe Mandeville [3]. In COOLHANDS it is possible to define 'on the fly' new variables as a function of existing ones with a FORTRAN expression evaluator contained in the FCALC-library (also written by Joe).

Figure 1.1 shows how the data flow from a COOLHANDS perspective. After initialization in COOLHANDS and possibly in a routine supplied by the upper ESPACE-layer, commands supplied through the KUIP interpreter are executed. The most important ones are:

- definition of an ntuple or histogram through the `save` command which triggers a call to the MBOOK4D library, an interface to the CERN HBOOK-library.

[1] ESPACE: Experiment Scanning Program for hall A Collaboration Experiments
[2] COOLHANDS: Command Oriented Off-Line Histogramming AND Scanning program

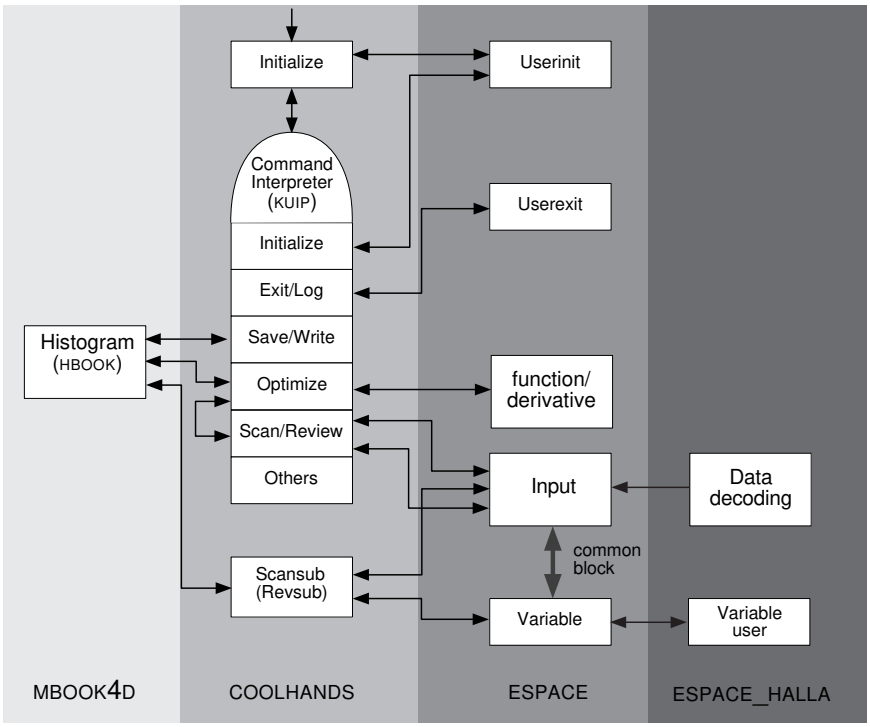



Figure 1.1: Diagram showing the flow of data around the COOLHANDS library.

- the `scan` command which calls in the ESPACE library the `input` routine. It opens all the necessary files and calls on its turn the raw data decoding routine in the top layer, which is experiment specific (Here at TJNAF it is a set of CODA routines [4]). After receiving data, `input` will call the routine `scansub`, the central routine of COOLHANDS. This routine first evaluates all the logical definitions, and then stores the data through MBOOK for histogramming and optimization, applying all the cuts defined. To analyze the logical definitions and to store the appropriate values, `scansub` has to call the ESPACE-routine `variable` where the different variables have been defined.

The story looks a bit different from an ESPACE-perspective (Fig. 1.2). After the `scan` command has been issued, COOLHANDS calls the ESPACE routine `input` which takes over till the data file has been analyzed. The data file and some other necessary files are opened and in `process_data` a loop is started over all data events. This is the center piece of the two-spectrometer analysis in ESPACE.

`process_data` will call for each spectrometer the routine `process_spectrometer` which digests all the detector information and for instance, evaluates all the tracks through the wire chamber package. The track that made the trigger signal is determined and traced back through the magnet to the spectrometer entrance. Next, the reaction point in the target is determined with the vertex information of both spectrometers and the information of the beam position monitors for the incoming beam (`reaction_z`). Having the reaction

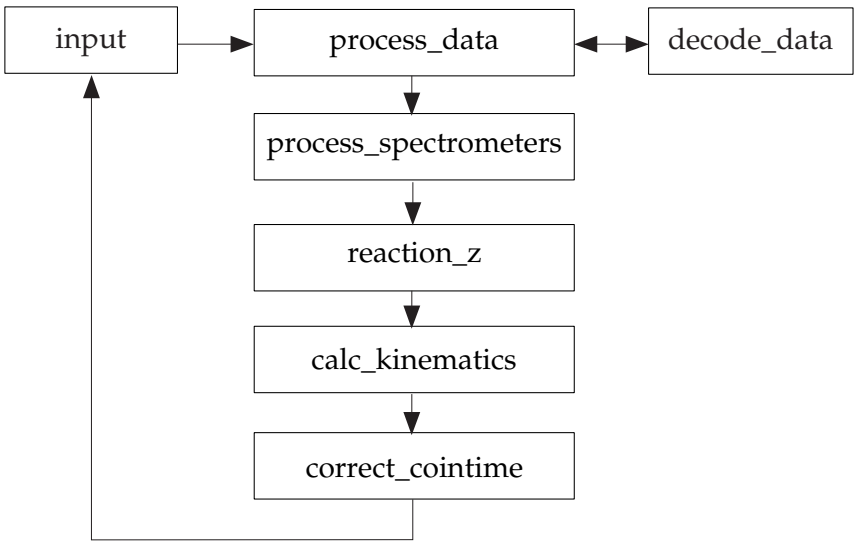



Figure 1.2: Diagram showing the flow of data in the ESPACE library.

point and the target geometry, corrections can be made for the energy losses of incoming and outgoing particles in the target. This is coordinated by the routine `calc_kinematics`, together with calculation of numerous kinematical variables (`kinematics` library). After correcting the coincidence time between the two spectrometers for flight-path differences wrt. the central ray (`correct_cointime`), control is given back to the routine `input` which will call the COOLHANDS-routine `scansub` to evaluate all the logicals, histograms, ...

## 1.2 How to Start?

The ESPACE `Makefile` supports the operating systems HP-UX, SunOS, OSF1 and Linux. Nowadays, most development is done on Linux. Before submitting a new version, the code is also checked on HP-UX and SunOS (both onsite) and OSF1 machines.

### 1.2.1 The ESPACE binary

#### 1.2.1.1 System installation

Onsite, ESPACE binaries are stored in the `/work/halla/software/bin/$OSNAME` directories. Here `$OSNAME` stands for either HP-UX, SunOS or Linux. To execute espace, you have to modify your shell initialization (`rc`) file[3]. For `bash` and `sh`, you should add/modify the

[3]If you choose to edit your login file (either `~/.bash_profile`, `~/.bash_login` or `~/.profile` for `bash` and `sh`, `~/.login` for `tcsh` and `csh`) you get the definitions for an interactive shell but not for an non-interactive (batch) shell, where only the `rc` file is executed. For `bash` and `sh` there is the additional problem, that for an interactive shell only the login file is executed. However, in a standard installation the `~/.bashrc` should be called by the login file. Check your login file for that.

following lines in ~/.bashrc:

```
export HALLA_DIR=/work/halla/software
export OSNAME=‘uname -s‘
export PATH=$HALLA_DIR/bin/$OSNAME/bin:PATH
```

For tcsh and csh, you should add/modify the following lines in ~/.tcshrc or ~/.cshrc (you should have exactly one of those):

```
setenv HALLA_DIR /work/halla/software
setenv OSNAME ‘uname -s‘
setenv PATH $HALLA_DIR/bin/$OSNAME/bin:PATH
```

The definitions of HALLA_DIR and OSNAME[4] are needed[5] to run espace. Appending the espace binary directory to the PATH is not really neccessary. Calling ESPACE by typing $HALLA_DIR/bin/$OSNAME/espace (either exactly that way or with HALLA_DIR and OSNAME expanded) does the job too. Though it works it is not recommended too copy the binary to the directory were you (think you) need it. In a multi-OS environment like the CUE you will loose track for which OS that particular file was compiled. To conclude, the only two definitions you really need are HALLA_DIR and OSNAME, PATH is for convenience.

#### 1.2.1.2 Private installation

If you want to have your own version of ESPACE, you will find online help by clicking on ESPACE on the Hall A web page. Currently, this will lead to

```
http://www.jlab.org/Hall-A/data_reduc/calibrations/software.html
```

**Downloading the source distribution** You have to decide where you want to store your ESPACE sources. Generally, users create an espace directory in their $HOME, but this is not neccessary. Whatever you do, define this directory as your HALLA_DIR. On the ESPACE web page you will find a link to download the latest ESPACE version[6] as a GNU-zipped tar file. The default filename is distribution-2.6.1-src.tar.gz (I will use 2.6.1 in this example), save it into your $HALLA_DIR. To unpack, you can either use first GNU unzip (type gunzip distribution-2.6.1-src.tar.gz), and then extract the source files with tar -xvf distribution-2.6.1-src.tar, or directly using GNU-tar (type tar -zxvf distribution-2.6.1-src.tar.gz). On Linux systems, the binary tar is actually GNU-tar. You can check by typing tar --version. GNU-tar will give you the version

[4] OSNAME may be already defined by the system-wide login or initialization file. Check with echo $OSNAME.

[5] ESPACE reads the masses of particles from binary files. ESPACE searches for files called $HALLA_DIR/db/masses_$OSNAME.dat, with the shell environment variables HALLA_DIR and OSNAME expanded into their predefined values. The origin of those binary files is unclear, they were probably obtained from the “Particle Data Group”. Things would be much easier if this file would be a text file.

[6] At date of print, 2 is the major, 6 the minor version number and 1 the patch level.

number, the normal tar program does not understand `--version` and will produce a warning message, continued by a `Usage` line.

The espace sources you will find in `src/r2-6`. Additionally, you need to define `OSNAME`[7].

**Compilation and installation** To compile, go into the directory `$HALLA_DIR/src/r2-6`. To actually compile ESPACE, you need several things:

- GNU-make. The standard make cannot parse the ESPACE makefile. However, the binary `make` on most systems is actually GNU-make. You can check with `make -v`. If `make` is not GNU-make you can try if you find `gnumake` or `gmake`. Compilation works with version 3.74 (installed at JLAB), but probably older versions too.

- CERNLIB. You may have it installed anyway if you use PAW.

- A VAX-style FORTRAN compiler which understands structures and unions. It has to be installed as `f77`. On SunOS, HP-UX and OSF1 such a compiler is ususally part of the installation. If not, bug your system manager. For Linux, there are two commercial compilers that may work. The Absoft FORTRAN F77 v4.4 compiler does work. The Portland Group f77 compiler may work but was not tested.

Also, for Linux you have to take care which CERNLIB you are using and which Linux you actually have installed. See for reference the "Linux installation notes" you find on the ESPACE web page. Depending on your system you have to modify the master makefile (`$HALLA_DIR/src/r2-6/Makefile`). Simple modifications, and you will find instructions there. Different Linux distributions and versions come with different `f2c` libraries. Also, if you have a PENTIUM processor or less, you need to disable the PENTIUMPRO specific optimizations. If this is done, type `make espace` or simply `make`.

While you drink a coffee[8] ESPACE compiles everything, and finally you should have an output like

```
f77  -X -defsym -X MAIN__=main -X -defsym -X open_database_=open_database__
-X -defsym -X close_database_=close_database__ block_data_decode.o calc_char
ge.o cbuffchk.o cfp.o coda.o config_parse.o corrupt_synch.o detmap_datastrea
m.o det_sub_user.o espace.o filter.o filter_til_eof.o get_bcm.o get_epics_bp
m.o get_fpd_vertex.o get_pos.o get_wires.o index_range_user.o ini_rawdata.o
interpret_bpm_rast.o interpret_event_coin.o interpret_event_e.o interpret_ev
ent_h.o open_database.o option.o pulser_fired.o rawdata_til_eof.o read_argli
st.o read_cher_e.o read_cher_h.o read_fpp_h.o read_helicity_h.o read_scint_e
.o read_scint_h.o read_show_e.o read_spare.o read_vdc_e.o read_vdc_h.o scale
r_history.o scaler_update.o shcal.o superperiod_check.o tot_shower.o variabl
```

[7] For SunOS, previous manuals requested to add the path to the MOTIF libraries to the shared library path, e.g. with `export LD_LIBRARY_PATH=/usr/dt/lib` for `bash`. This is not neccessary anymore since the routines of ESPACE which require X-libraries are disarmed.

[8] Depending on your system, you should drink fast (few minutes) or take the time ($\infty$).

```
e_user.o variable_user_init.o kludge.o ../espace_lib/block_data_const.o ../e
space_lib/block_data_var.o /home/kees/espace/lib/Linux/coolhands.o -L/home/k
ees/espace/lib/Linux -lespace -lkinematics -lspectra -lfcalc -lmbook4d -lplo
t -lstat -lutil -lvms -levio -L/app/cernlib/98egcs/lib -lgraflib -lgrafX11 -
lpacklib -L/usr/X11R6/lib -lXt -lX11 -lm -lU77 -lg77 -o espace
make[1]: Leaving directory `/home/kees/espace/src/r2-6/espace_halla'
```

and `ls -l espace_lib/espace` should show something like

```
-rwxrwxr-x   1 kees     kees      3697023 Mar 22 20:49 espace_halla/espace
```

If there is no `espace` binary with your actual system date, and the last lines of your compilation session does not look like the above, they even show some error messages, then something went wrong. Reasons can be:

**wrong or missing `HALLA_DIR`:** The espace sources are grouped (the term **organized** would be flattering) into several source directories. The master makefile loops over all those directories and calls local makefiles which actually do the compilation. Include files needed by the FORTRAN files are searched first locally, and if not found there in the directory path defined in the `Makefile` by `$FINCLUDE` (path includes currently only `$HALLA_DIR/src/r2-6`)[9]. Actually, the most lucky case is that `HALLA_DIR` is undefined. You will quickly get an error message like

```
f77 -I/src/r2-6 -N22 -N90 -B108 -f -o dynaparams dynaparams.f
FORTRAN 77 Compiler 4.4, Copyright (c) 1987-1997, Absoft Corp.
 error on line 13 of parameter.h: invalid INCLUDE
make[1]: *** [dynaparams.h] Error 1
make[1]: Leaving directory `/home/kees/espace/src/r2-6/espace_lib'
make: *** [subdirectories] Error 2
```

In this example, it indicates that the file to be included in line 13 of `parameter.h` (included by `dynaparams.f`) could not be found. As an experienced human compiler you will also notice that the directory after the `-I` flag is not correct, it should be `$HALLA_DIR/src/r2-6`, i.e. `/home/kees/espace/src/r2-6` and not `/src/r2-6`.

If `$HALLA_DIR` is defined but wrong the results are unpredictable. If there is a source distribution at that place, some of your include files will be included locally and some via the `$FINCLUDE` path. Also, the same include file may be included either locally or via the path, for different FORTRAN source files. Most likely something will be incompatible, and you will get at least some errors for some files. In worst case, compilation may be successful, you even get no runtime errors, but your results will be strange.

[9] Let's distinguish two cases. Files included via `#include <filename>` are searched locally (in `.`), those with `#include <directory>/<filename>` in the `$FINCLUDE` path.).

**wrong or missing** PERL**:** ESPACE uses the script `util_notsource/sfmakedepend` which parses through the entire FORTRAN sources and creates in each subdirectory the dependency files `.depend`. It does not matter if you don't know what this is all about. Important is that this script is written in the script language perl. Depending on your system manager it is installed in `/usr/bin`, `/usr/local/bin`, elsewhere or not at all. If you have the wrong path you will find an error message like that:

```
make[1]: /home/kees/espace/src/r2-6/util_notsource/sfmakedepend: Comman
d not found
make[1]: *** [.depend] Error 127
make[1]: Leaving directory `/home/kees/espace/src/r2-6/espace_lib'
make: *** [subdirectories] Error 2
```

Important is the first message ...`Command not found`. It may mean that the command `util_notsource/sfmakedepend` could not be found, but more probable the first line in that file specifies a wrong path to PERL. Check with `type perl` if and where PERL is installed, correct the first line of `util_notsource/sfmakedepend` and try again. If you don't have perl you should install it. As a workaround you can replace `util_notsource/sfmakedepend` by a simple file which contains two lines only:

```
#!/bin/sh
echo>.depend
```

This file creates a phony `.depend` file. Compilation will then work, and if you edit a FORTRAN source file make will still recognizes this (because those dependencies are declared in the `Makefiles`) and recompiles the file. However, if you edit an include file `make` has no track which FORTRAN source files need that and thus have to be recompiled, and thus does nothing. If you really decide for some dirty hack like that you should remove all non-source files with `make realclean` and recompile everything again. Get PERL!

Besides compiling the espace binary more files were created. You will find several libraries in `$HALLA_DIR/lib/$OSNAME`, each reflecting one of the source directories. Really useful is only one of them, `libevio.a`. It contains the routines needed to open and close a data file and extract the event headers and contents.

If the compilation was successful, you may want to install ESPACE. Type `make install`[10]. It will copy the ESPACE binary into `$HALLA_DIR/bin/$OSNAME` and the `masses_$OSNAME.dat` into `$HALLA_DIR/db`. Thus, after installation you will have four subdirectories in your `$HALLA_DIR`, `bin`, `db`, `lib` and `src`. To invoke ESPACE by simply typing `espace` you should add `$HALLA_DIR/bin/$OSNAME` to your environment path.

[10] Actually, `make espace` is a dependency of `make install`, thus it would have execute `make espace` if needed.

### 1.2.2 Getting ready

Before starting, you need a few additional files.

**detmap file:** You won't want to create this file by yourself. Usually, it is inherited from the preceeding experiment. In the detmap file, ususally called `detmap.config`, the physical detectors are described. It is specified by which "Read Out Controller" (ROC), crate, slot and channel a particular detector information can be accessed. The detmap file is analyzed by ESPACE, and the information is used by the event decoder to fill internal variables with the raw detector information. It is not really needed, because it is stored in every data file. If no detmap file is specified by the user, ESPACE will read this information and writes it to the current working directory as `detmap_temp.config`. However, if the information in that detmap file is not accurate, it has to be modified and ESPACE has to be instructed to use the correct file. The header of the detmap file gives enough information to modify it.

**database:** You don't want to create this file by yourself. Usually, it is inherited from the preceeding experiment. The database contains two sets of information. At first, it contains the location of your detectors, going down to the position of each wire in the VDCs, for example. Additionally, it contains all the parameters which are assumed to stay constant for a certain hardware setup. Those parameters are, e.g.

- matrix elements which are used to transform from the focal plane to the target coordinate system.
- pedestals and gains of ADCs, coefficients for walk correction.
- offsets for TDCs.
- ranges of ADCs and TDCs, TDC resolutions.
- drift speeds in the VDCs, light propagation speeds and attenuation lengths in the scintillators.
- coefficients to convert drift time into distance.

See App. B for a complete reference.

**header file:** The header file contains information which may vary run by run, but are specific to that run. They are either created separately for each data file or, more clever, for one particular setting. See App. A for a full description of the header file. Parameters it contains are, e.g.

- spectrometer angle, momentum (dipole $\vec{B}$-field) and pointing offset.
- parameters specifying the target, describing its geometry, position, composition and thickness.
- beam energy.

- reaction to analyze.

Some parameters, like the reaction, are not compliant to the above mentioned. In a future ESPACE version, all parameters which are related to a specific analysis should be specified in kumac file. Examples are the reaction (one may want to analyze $(e, e')$, $(e, p)$ and $(e, e'p)$ for the same run) or the question whether or not use the beam position monitors for beam reconstruction. Essentially, those parameters are flags specified by the user but no parameters describing the hardware.

`rastconsts.dat` **file:** The `rastconsts.dat` file was a weird way to implement the calibration of the fast raster and the beam position monitors. Things got more complicated by the fact that the bpm information is not synchronized with the event but shows a (fortunately constant) delay (phase slippage of the bpm versus raster). The `rastconsts.dat` file provided the tools to correct for that. However, this information is now stored in the database, header file and kumac file, respectively[11].

ESPACE **kumac file:** Actually, now you would be able to start an ESPACE session and use all the commands described in App. D to analyze your data file. However, this is not very convenient. It is more practical to group all neccessary commands in a script file which is then executed from within the ESPACE session. To parse this script file ESPACE is using the KUIP[1] interpreter. Thus, the files look like a kumac file and the extension is `.kumac`, but users should keep in mind that ESPACE and PAW kumac files are two different things.

Because the ESPACE kumac file is the heart of what the ordinary user has to program in order to analyze his data file, an example should be given.

```
******************** define FILES ************************
*
set/file/output carbon_1434.hbook
set/file/database db_845_e
set/file/header hdr_1434
set/file/detmap detmap.config
*
******************** define CUTS ************************
*
define/cut/1d spec_e.th_tg-1 -0.03 0.03
define/cut/1d spec_e.ph_tg-1 -0.06 0.6
define/cut/1d spec_e.p_kin-1 825.0 850.0
define/cut/1d spec_e.gas.adc-1 0.0 150.0
define/logical accept_e spec_e.th_tg-1&&spec_e.ph_tg-1
*
```

[11] If, at the time of print of this manual, you still need that weird `rastconsts.dat` file, you have the right to bug Michael Kuss once a day.

```
******************** spectrometer E ******************
*
set/hitbits (+spec_e.gas)
set/auto_window on
set/spectrum/bins/x1 1
spectra/save spec_e.s1.hp_r,spec_e.s2.hp_r
spectra/save spec_e.s1.adc_r,spec_e.s1.adc_l, _
             spec_e.s2.adc_r,spec_e.s2.adc_l accept_e
set/ntuple on
spectra/save spec_e.s1.adc_r/spec_e.s2.adc_r/spec_e.s1.adc_l/ _
             spec_e.s2.adc_l accept_e
set/ntuple off
set/auto_window off
set/spectrum/bins/x1 300
set/spectrum/window/x1 -0.15 0.15
spectra/save spec_e.th_tg-1,spec_e.ph_tg-1 accept_e&&spec_e.p_kin-1
set/spectrum/bins/x1 100
set/spectrum/window/x1 -0.025 0.025
spectra/save spec_e.y_tg-1
set/spectrum/bins/x1 250
set/spectrum/window/x1 825.0 850.0
spectra/save spec_e.p_kin-1 accept_e&&spec_e.gas.adc
*
******************** scanning and output *****************
*
file/scan carbon_1434.dat FIRST=1 LAST=10000
spectra/write
quit
```

In the first few lines the names of the hbook, database and header file are given. File names can be referenced either with an absolute path or a relative (descending from the current working directory) path. Here the detmap file is specified explicitly, overriding the detmap contained in the data file.

The next lines contain the definition of cuts on ESPACE variables. A complete list of valid ESPACE variables can be found in Sec. 2. Here are used variables like the ADC value of the gas Čerenkov in the electron spectrometer (`spec_e.gas.adc`) or the reconstructed angles of the scattered electron, $\theta_{\rm tg}$ (`spec_e.th_tg`) and $\phi_{\rm tg}$ (`spec_e.ph_tg`). Logical definitions can be defined by combining cuts and logical conditions defined previously. Here, the two cuts on the angles are combined to a cut on solid acceptance.

In the next part histograms and ntuples are defined through `spectra/save` commands of ESPACE variables. The first parameter is a list of ESPACE variables, the second (optional) parameter a logical or a logical condition. Histograms and ntuples in the list are separated by ','s, two-dimensional histograms ($y/x$) and ntuples can be defined by separating ESPACE

variables by '/'s. To store variables into a ntuple you actually have to set a flag with `set/ntuple on` and return to histogram mode with `set/ntuple off`.

To start a scanning session type the command `espace`. The prompt `espace>` has appeared and commands can be typed in, or the ESPACE kumac can be executed by typing `exec <filename>`.

# Chapter 2

# Variables

As was pointed out in Sect. 1.1, the COOLHANDS subroutine `scansub` evaluates logical expressions and increments histograms by obtaining the variable values through the routines `variable` in the ESPACE library or `variable_user` in the experiment-specific `espace_halla` part. The different locations where the variable can be defined is not important for the usage of the program, however, for maintenance/changes of the program care should be taken where one installs them. If the variable is of interest to may users, it should be installed in the ESPACE library. However, if it is only useful for testing purposes, installation should be done in `variable_user`.

In the first section an overview is given of the variables that have already been installed in the ESPACE library, followed by a section giving instructions for implementing new ones in the code. Finally, it is shown how new variables can be defined on-the-fly in a command file.

## 2.1 Units of the Variables

Before discussing which variables are installed in ESPACE and how to install new ones, a few words about the unit definition in ESPACE. We have tried to express variables that are going in and out of the program in one consistent set of units, as shown in Tab. 2.1.

However, from Tab. 2.1 it is clear that for the angle variables, besides degrees, an other unit is also used. The angles of the particle vertex as measured at the target or in the detecor hut are actually tangents of angles, so dimensionless. Since the angles are fairly small, the tangents of an angle is close to the angle when expressed in radians.

## 2.2 Overview of Pre-Defined Variables

In this section we want to give an overview of the variables that are defined in the program and, therefore, can be histogrammed and used in the definition of logicals. Most of the variable names are preceded by a string indicating to which spectrometer and/or detector they belong. Figure 2.1 gives an overview of the variables and a tree-like structure guiding

Table 2.1: Set of units used for ESPACE variables

| QUANTITY | PURPOSE | UNITS |
|---|---|---|
| length | target parameters | meters |
| angles | vertex angles at target and focal plane wrt. spectrometer central axis | degrees dimensionless |
| momenta | | MeV/c |
| energy | | MeV |
| field | | kG |
| time | | seconds |

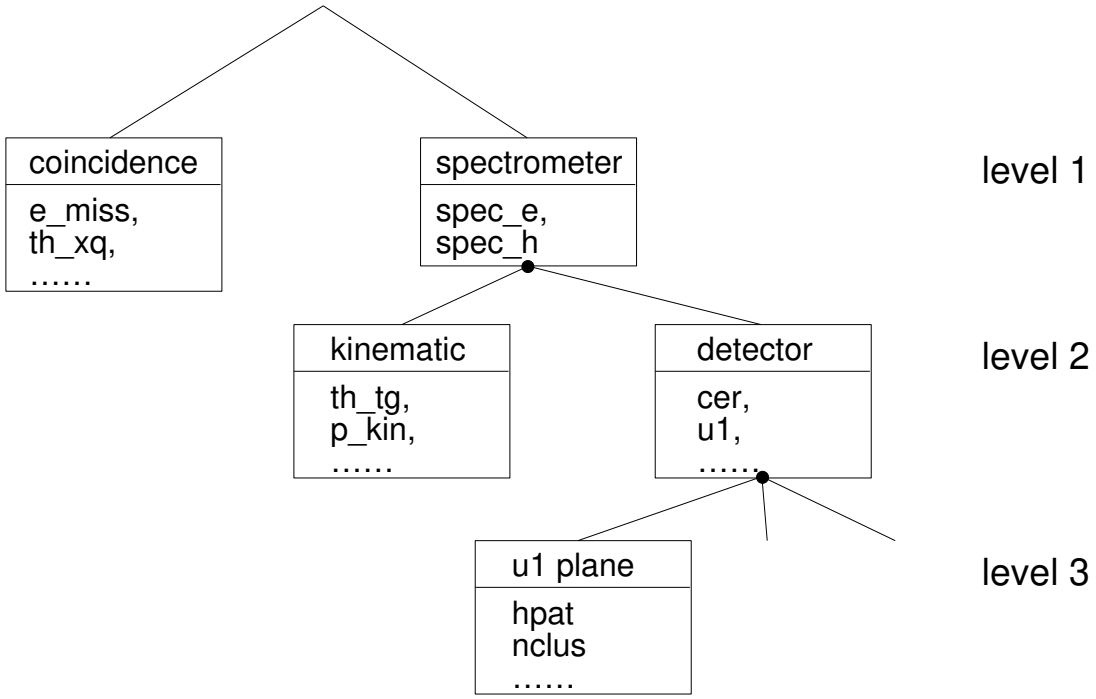



Figure 2.1: Structure guiding the user how to compose the variable string.

the user how to compose the variable string.

Starting at the top of the tree, the user has two options: choose a variable which is a function of the output of both spectrometers or select a variable linked to one of the spectrometers. In the first case there is no string, so the missing energy is simply referenced by `e_miss`. However, in the second case the string will start with the spectrometer name: `spec_e` or `spec_h`. The black dot at the bottom of the box indicates that the user should go at least one level deeper to have a valid variable name. The next choice is between

a kinematic variable or a variable connected to one of the detectors, e.g. `spec_e.p` (the momentum of the particle detected in the electron spectrometer) or `spec e.s1`. In the last case the user has to go one level deeper, indicating the variable of that detector.

Below we will discuss four tables in which the variables are grouped according to the number of levels in the variable string. In Tab. 2.2, we start with the variables giving

Table 2.2: Level one variables, giving CODA and EPICS information.

| variable | class | type | sub | dim | description |
|---|---|---|---|---|---|
| clock_e* | i | s | no | s | time since CODA start |
| clock_h* | i | s | no | s | time since CODA start |
| run_number* | i | s | no | | CODA run number |
| event_type* | i | s | no | | CODA event type |
| event_nr* | i | s | no | | CODA event number |
| cur_cav_e* | r | s | no | | current (unscaled) in the upstream (?) beam cavity |
| cur_cav_h* | r | s | no | | current (unscaled) in the downstream beam cavity |
| cur_cav_cal* | r | s | no | | current (calibrated) in Unser monitor??? |
| det_mon_e* | r | s | no | | electron spectrometer detector package rate (???) |
| det_mon_h* | r | s | no | | hadron spectrometer detector package rate (???) |

information about the CODA properties of the event. For each variable the parameters **class**, **type**, **size** and **sub** have been defined. The meaning of the parameters is the following:

class : The class of a variable is either real or integer. Its value will determine the result of the command `set/spectrum/bins`. In case of a real-variable, it means the number of bins of the histogram, otherwise the number of channels that will be grouped together.

type : The type of a variable is either scalar or array. If a variable has a type value of scalar, a histogram of this variable can only be incremented once for each CODA event. However, an array variable can be incremented multiple times. An example of an scalar variable is `event_type`. `tdc` (TDC values of drift times in a VDC wire plane) is an array variable and will contain the drift time of each wire exited by the tracks passing through this particular wire plane.

sub : Finally one can add to some variables a sub-detector number in order to be more specific when defining a cut or a histogram of a variable. For example, one could histogram the `tdc` times of wires 100 up to 200 of the `u1` plane in spectrometer `spec_e` with the command `spectra/save spec_e.u1.tdc[100;200]`. The command `spectra/save spec_e.u1.tdc` would have saved the `tdc` spectrum of the whole `u1` plane. Table 2.3 gives a summary of what the meaning of the sub detector number is for the different detectors.

Table 2.3: Meaning of sub-detector numbers for the variables of different detectors.

| detector | sub-detector |
|---|---|
| wire plane | wire number |
| scintillator | paddle number |
| Čerenkov | mirror number |
| shower | block number |

Tables 2.4, 2.5 and 2.6 list the level-one variables. Contained are in Tab. 2.4 the variables which are independent of the spectrometers, in Tab. 2.5 which are reconstructed with the electron spectrometer only, and in Tab. 2.6 which are reconstructed with both spectrometers.

Table 2.4: Level one variables, involving no spectrometer.

| variable | class | type | sub | dim | description |
|---|---|---|---|---|---|
| pb | r | s | no | MeV | beam energy, after energy loss correction |
| pb_loss | r | s | no | MeV | beam energy-loss |
| rast1adc<br>rast2adc | i | s | no | | current in the raster deflection magnets, in x (1) and y (2) direction, read with VMIC3123 ADC |
| rast3adc<br>rast4adc | i | s | no | | derivative of the rast1adc and rast2adc signals |
| rast5adc<br>rast6adc | i | s | no | | current in the raster deflection magnets, in x (1) and y (2) direction, read with LeCroy1182 ADC |
| rast_adc | i | a | yes | | raster adc values, with the same meaning as rast*i*adc |
| rast_x | r | s | no | m | raster amplitude, derived from the VMIC3123 read-out |
| rast_y | r | s | no | m | |
| rast2_x | r | s | no | m | raster amplitude, derived from the LeCroy1182 read-out |
| rast2_y | r | s | no | m | |
| bpma1adc<br>bpma2adc<br>bpma3adc<br>bpma4adc | i | s | no | | beam position monitor cavity IPM1H03A read-out |
| bpmb1adc<br>bpmb2adc<br>bpmb3adc<br>bpmb4adc | i | s | no | | beam position monitor cavity IPM1H03B read-out |

continued on next page ...

Table 2.4: ... continued from previous page ...

| variable | class | type | sub | dim | description |
|---|---|---|---|---|---|
| bpmaxraw<br>bpmayraw | r | s | no | m | beam position in IPM1H03A |
| bpmbxraw<br>bpmbyraw | r | s | no | m | beam position in IPM1H03B |
| bpma_x<br>bpma_y | r | s | no | m | beam position in IPM1H03A, corrected for read-out phase shift |
| bpmb_x<br>bpmb_y | r | s | no | m | beam position in IPM1H03B, corrected for read-out phase shift |
| beam_x<br>beam_y | r | s | no | m | beam position at z=0 (practically the target), derived from the bpm positions |
| beam_ph<br>beam_th | r | s | no | rad | tangents of the beam angles in the HLCS (see Sec. 4.1.1 on p. 35 |
| rastxphs<br>rastyphs | r | s | no | rad | absolute phase of the horizontal/vertical raster |
| bpmaxphs<br>bpmayphs | r | s | no | rad | absolute phase of the read-out in IPM1H03A, horizontal/vertical |
| bpmbxphs<br>bpmbyphs | r | s | no | rad | absolute phase of the read-out in IPM1H03B, horizontal/vertical |

Table 2.5: Level one variables, involving one spectrometer.

| variable | class | type | sub | dim | description |
|---|---|---|---|---|---|
| omega | r | s | no | MeV | energy transfer |
| q | r | s | no | MeV/c | momentum transfer |
| q2 | r | s | no | $(\mathrm{MeV/c})^2$ | four-momentum transfer squared |
| w2 | r | s | no | $(\mathrm{MeV/c^2})^2$ | Mandelstam variable s |
| mandelt | r | s | no | $(\mathrm{MeV/c^2})^2$ | Mandelstam t |
| mandelu | r | s | no | $(\mathrm{MeV/c^2})^2$ | Mandelstam u |
| scattang | r | s | no | deg | electron scattering angle |
| epsilon | r | s | no | | virtual photon polarization |

Table 2.6: Level one variables, involving both spectrometers.

| variable | class | type | sub | dim | description |
|---|---|---|---|---|---|
| e_miss | r | s | no | MeV | missing energy (in the definition of the old electron scatterer) |

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Table 2.6: ... continued from previous page ...

| variable | class | type | sub | dim | description |
|---|---|---|---|---|---|
| emiss | r | s | no | MeV | missing energy (energy of the missing particle) |
| p_miss | r | s | no | MeV/c | missing momentum |
| p_missx | r | s | no | MeV/c | |
| p_missy | r | s | no | MeV/c | |
| p_missz | r | s | no | MeV/c | |
| m_miss | r | s | no | $MeV/c^2$ | missing mass |
| m_miss2 | r | s | no | $(MeV/c^2)^2$ | missing mass square |
| tc | r | s | no | TDC chan | coincidence time |
| tc_cor | r | s | no | TDC chan | coincidence time corrected for path length difference wrt. the central rays |
| ts_tdc | i | a | yes | TDC chan | TDC time of the first hit in the multi-hit TDC |
| ts_patt | i | s | no | | hitpattern of the multi-hit TDC |
| ts_mult | i | a | yes | | multiplicity of channel $i$ in the multi-hiy TDC |
| tstdcall | i | a | yes | TDC chan | all tdc times of all hits in the multi-hit TDC. The $j^{th}$ hit in the $i^{th}$ channel is at position 6*(i-1)+j. |
| th_xq<br>ph_xq | r | s | no | deg | spherical angles between momentum of particle x and the momentum transfer in the reaction A$(e,e'x)$B. The z-axis is defined by the momentum transfer and the x-z plane by the electron scattering plane. |
| th_xq_cm<br>ph_xq_cm | r | s | no | deg | same angles, but in the c.m. system |
| th_bq<br>ph_bq | r | s | no | deg | spherical angles between momentum of particle B and the momentum transfer in A$(e,e'x)$B |
| th_bq_cm<br>ph_bq_cm | r | s | no | deg | same angles, but in the c.m. system |
| react_x | r | s | no | m | x-coordinate of reaction point in the target given in the laboratory frame |
| react_y | r | s | no | m | y-coordinate |
| react_z | r | s | no | m | z-coordinate |

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Table 2.6: ... continued from previous page ...

| variable | class | type | sub | dim | description |
|---|---|---|---|---|---|
| mlu_in1*<br>mlu_in2*<br>mlu_in3*<br>mlu_in4*<br>mlu_in5* | r | s | no | | coincidence event rate into the different channels of the memory lookup unit MLU. For coincidences, only channel 5 is meaningful. |
| mlu_out* | r | s | no | | coincidence event rate coming out of the MLU |
| dead_time* | r | s | no | | dead time in coincidence events |

A '*' behind the variable name of the Tabs. 2.2, 2.5, 2.6, 2.7 and 2.8 indicates that the histogram of this particular variable is updated even when the necessary detectors did not fire. For instance, the number of hits in a scintillator would be updated even when this detector did not fire. For level-three variables which detector had to fire is obvious from the variable string. Level-two variables are a bit more complicated variables which are composed out of the response of several detectors. Here, the histogram is updated when the trigger detector of the spectrometer fired. For level-one variables either the trigger detectors of both spectrometers should have fired in case of coincidence variables or no detector is necessary at all like for the variable `event_type`.

Table 2.7: Level two variables, involving one spectrometer.

| variable | class | type | sub | dim | description |
|---|---|---|---|---|---|
| omega | r | s | no | MeV | energy transfer |
| q | r | s | no | MeV/c | momentum transfer |
| q2 | r | s | no | $(\mathrm{MeV/c})^2$ | four-momentum transfer squared |
| w2 | r | s | no | $(\mathrm{MeV/c^2})^2$ | Mandelstam s |
| reactx | r | s | no | m | x-coordinate of the crossing of the beam and one spectrometer vertex |
| reacty | r | s | no | m | y-coordinate |
| reactz | r | s | no | m | z-coordinate |
| twoarm_x | r | s | no | m | x-coordinate of the crossing of the two spectrometer vertices |
| twoarm_z | r | s | no | m | z-coordinate |
| xeb_xhb | r | s | no | m | spec_e.reactx-spec_h.reactx |
| xeb_xeh | r | s | no | m | spec_e.reactx-twoarm_x |
| xhb_xeh | r | s | no | m | spec_h.reactx-twoarm_x |
| zeb_zhb | r | s | no | m | spec_e.reactz-spec_h.reactz |
| zeb_zeh | r | s | no | m | spec_e.reactz-twoarm_z |

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Table 2.7: ... continued from previous page ...

| variable | class | type | sub | dim | description |
|---|---|---|---|---|---|
| zhb_zeh | r | s | no | m | spec_h.reactz-twoarm_z |
| x_rot | r | s | no | m | dispersive position x of the "golden track" in the u1 plane in the rotated c.s. [1] |
| th_rot | r | s | no | | tangent of angle $\theta$ of the particle track in the focal plane in the dispersive direction wrt. the local central ray |
| y_rot | r | s | no | m | non-dispersive position y in the u1 plane in the rotated c.s. |
| ph_rot | r | s | no | | tangent of angle $\phi$ of the particle track in the non-dispersive plane at the focal plane |
| xr_abr | r | s | no | m | dispersive position `x_rot` corrected for spectrometer aberations |
| xr_kin | r | s | no | m | dispersive position `x_rot` corrected for spectrometer aberations and for deviations of the nuclear recoil momentum [2] |
| x_tra<br>th_tra<br>y_tra<br>ph_tra | r | s | no | | coordinates of the golden track defined as above but now in the transport c.s. |
| beta | r | s | no | | $\beta$ of the particle, as calculated by the time-of-flight between s1 and s2. |
| beta_ratio | r | s | no | | beta, divided by the $\beta$ as derived from the particle momentum. |
| p | r | s | no | MeV/c | momentum of the particle after exiting the target corrected for spectrometer aberations |
| px | r | s | no | MeV | momentum of the particle, after energy loss correction |
| px_loss | r | s | no | MeV | particle momentum-loss |
| p_kin | r | s | no | MeV/c | momentum of the particle after exiting the target corrected for spectrometer aberations and for deviations of the nuclear recoil momentum |
| dp | r | s | no | | like `p` but relative to the central ray |

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[1] The golden track is defined as the track having a `tzero_av` closest to zero, therefore, most likely being the particle track that made the trigger.

[2] This correction is different for electrons and protons. It makes only sense to use it for the hadron arm in case of H$(e, e'p)$.

Table 2.7: ... continued from previous page ...

| variable | class | type | sub | dim | description |
|---|---|---|---|---|---|
| dp_kin | r | s | no | | like `p_kin` but relative to the central ray |
| dp_cor | r | s | no | | momentum relative to the central ray corrected only for spectrometer aberations |
| th_tg | r | s | no | | tangent of angle $\theta_{\rm tg}$ of the particle track in the dispersive plane at the scattering point at the target |
| ph_tg | r | s | no | | tangent of angle $\phi_{\rm tg}$ of the particle track in the non-dispersive plane at the scattering point at the target |
| y_tg | r | s | no | | the non-dispersive position `y_tg` at the scattering point at the target |
| x_sieve | r | s | no | m | dispersive position at the position of the collimator |
| y_sieve | r | s | no | m | non-dispersive position at the position of the collimator |
| path_diff | r | s | no | m | difference in path length between this track and the central ray through the spectrometer |
| track* | i | s | no | | number of reconstructed particle tracks |
| tzero_av* | i | s | no | TDC chan | average time offset of TDC times in the clusters of the different planes that are in the track |
| mlu_in1*<br>mlu_in2*<br>mlu_in3*<br>mlu_in4*<br>mlu_in5* | r | s | no | | single event rate into the different channels of the memory lookup unit MLU; only channels 1 and 2 are meaningful for `spec_e` and 3 and 4 for `spec_h`. |
| mlu_out* | r | s | no | | pre-scaled single event rate coming out of the MLU |
| dead_time* | r | s | no | | dead time in pre-scaled single |

Table 2.8: Level three variables, involving detectors in the spectrometers. `spec_s` can be either `spec_e` or `spec_h`.

| variable | class | type | sub | detector | dim | description |
|---|---|---|---|---|---|---|
| hit_type* | i | s | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | | hitpattern of wire plane, see description in section ?? |
| clus | i | s | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | | number of clusters in the wire plane |
| tdc | i | a | yes | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2<br>spec_s.aero<br>spec_s.gas | TDC chan | TDC values of drift times in wire plane or of photo multipliers in Čerenkov |
| tdc_c | i | a | yes | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | TDC chan | TDC values of drift times in wire plane, corrected for COMMON STOP shifts due to path length differences to the time defining scintilator and for drift to path length conversion |
| tdc_cor | i | a | yes | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | TDC chan | correction to TDC values of drift times in wire plane |
| tdc_diff | i | a | yes | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | TDC chan | drift time difference determined by comparing measured drift time to the distance between wire plane and global fit divided through the drift velocity obtained from the database |
| wire | i | a | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | | wire numbers that fired in wire plane |

continued on next page ...

Table 2.8: ... continued from previous page ...

| variable | class | type | sub | detector | dim | description |
|---|---|---|---|---|---|---|
| coars | i | a | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | | wire number with the shortest drift time in each cluster |
| slope | r | a | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | | slope of track through wire plane, determined for each cluster |
| pos | r | a | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | m | position where track passed through the wire plane given in the local wire plane coordinate system, determined for each cluster |
| tzero | r | a | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | TDC chan | time offset of TDC times in cluster |
| chisq | r | a | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | | reduced $\chi^2$ of fit to the drift times in the wire plane for each cluster |
| drift | r | a | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | m/s | ????reduced $\chi^2$ of fit to the drift times in the wire plane for each cluster |
| angle_diff | r | a | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2 | | difference in slope as determined from the drift times in one plane and two planes |

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Table 2.8: ... continued from previous page ...

| variable | class | type | sub | detector | dim | description |
|---|---|---|---|---|---|---|
| mult* | i | s | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2<br>spec_s.s1<br>spec_s.s2<br>spec_s.aero<br>spec_s.gas<br>spec_e.preshow<br>spec_e.show<br>spec_h.s3 | | number of hits on detector |
| hp_l*<br>hp_r* | i | a | yes | spec_s.s1<br>spec_s.s2<br>spec_h.s3 | | paddle hit pattern for photo multipliers on the left/right side |
| adc | i | a | yes | spec_s.aero<br>spec_s.gas<br>spec_e.preshow<br>spec_e.show | ADC chan | ADC channel of Čerenkov mirrors or (pre)shower blocks |
| adc_c | i | a | yes | spec_s.aero<br>spec_s.gas<br>spec_e.preshow<br>spec_e.show | ADC chan | ADC channel of Čerenkov mirrors or (pre)shower blocks corrected for pedestal and gain, |
| adc_l<br>adc_r | i | a | yes | spec_s.s1<br>spec_s.s2<br>spec_h.s3 | ADC chan | ADC channel of scintillator paddles on the left/right side |
| adc_l_c<br>adc_r_c | i | a | yes | spec_s.s1<br>spec_s.s2<br>spec_h.s3 | ADC chan | ADC channel of scintillator paddles on the left/right side corrected for pedestal and gain |
| adcsum_t | r | s | no | spec_s.gas<br>spec_s.aero | | sum of all ADC channels, corrected for pedestal and gain |
| tdc_l<br>tdc_r | i | a | yes | spec_s.s1<br>spec_s.s2<br>spec_h.s3 | TDC chan | TDC channel of scintillator paddles on the left/right side |

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Table 2.8: ... continued from previous page ...

| variable | class | type | sub | detector | dim | description |
|---|---|---|---|---|---|---|
| tdc_l_c<br>tdc_r_c | i | a | yes | spec_s.s1<br>spec_s.s2<br>spec_h.s3 | TDC chan | TDC channel of scintillator paddles on the left/right side, corrected for timing offset |
| x_det<br>y_det | r | s | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2<br>spec_s.s1<br>spec_s.s2<br>spec_s.aero<br>spec_s.gas<br>spec_e.preshow<br>spec_e.show<br>spec_h.s3 | m | coordinates of crossing point of VDC track with detector plane, given in the detector's local coordinate system and manipulated if the particle track exceeds the detector dimensions specified in detmap.config |
| xdetgeom<br>ydetgeom | r | s | no | spec_s.u1<br>spec_s.v1<br>spec_s.u2<br>spec_s.v2<br>spec_s.s1<br>spec_s.s2<br>spec_s.aero<br>spec_s.gas<br>spec_e.preshow<br>spec_e.show<br>spec_h.s3 | m | coordinates of crossing point of VDC track with detector plane, given in the detector's local coordinate system |
| rate | r | a | yes | spec_s.aero<br>spec_s.gas<br>spec_e.preshow<br>spec_e.show | | count rate in mirrors and blocks, resp. |
| rate_l<br>rate_r | r | a | yes | spec_s.s1<br>spec_s.s2<br>spec_h.s3 | | count rate in paddles on the left or right side, resp. |

A word of caution is necessary for the usage of variables that give the rates of the scalers in the experimental setup. Realize that the whole histogramming procedure in ESPACE is event-interrupt driven. So if you would save a one-dimensional histogram of, for instance, the coincidence rate in paddle 3 of scintillator s1 and its value is always 100 Hz and 1000 events are scanned, you will end up with a sharp spike at 100 containing 1000 entries. This

is probably not very useful. If you are interested in the time evalution of this rate, its better to save a 2-dim ntuple of rate versus time.

## 2.3 Coding New Variables

In this section we discuss how to install in the code a new variable. It is assumed that the new variable is installed in the ESPACE library. Installation in the `espace_halla` part would proceed along the same lines. The routines that should then be modified will have the same names as the ones shown below, however, the extension `user` has to be added.

In our example, we want to install the ADC value of the left side of the scintillator paddle in both spectrometer `spec_e` and `spec_h`. Realize that per interrupt the scintillator's left side could have more than one entry and that one would like to specify the paddle number of the scintillator. In other words, this variable will be an array and could be specified with a sub-detector number. The consequence is that the last two routines below (`index range.f`, for array variables and `det sub.f`, for variables with sub-detector numbers) need to be modified.

The following routines have to be changed in the ESPACE library:

block_data_var.f : In this file the string array `var_txt` is initialized. It contains all the necessary parameter input for each variable. Each variable should have an entry of one line in the data statement:

```
data (var txt(i),i=1,199)
 ............
> 'adc_l 5-6,21-22,49 none none 0.0 4095.0 i a y',! 49
 ............
```

The description of these entries (possible values between square brackets):

name [*alphabetic characters including '_' and '-'*] Variable name.

detector [`numeric characters` *or* `all` *or* `none`] String of numbers indicating which detectors have access to this variable. A '-' in the string indicates a 'from-to', so `5-7` means `5,6,7`. The correspondance between number and detector string is given by the array `det_txt`, also initialized in `block_data_var.f`. As you can see in Tab. 2.8 with the `adc_l` entry, the string `5-6,21-22,49` corresponds to detectors `spec_e.s1`, `spec_e.s2`, `spec_h.s1`, `spec_h.s2` and `spec_h.s3`.

optimize [`numeric characters` *or* `all` *or* `none`]

fire string [`numeric characters` *or* `all` *or* `none`] String of numbers pointing at detectors that should have fired in addition to the one whose variable is asked for. This is a useful feature if a variable is referenced that has a detector in both spectrometers, like all variables of Tab. 2.6.

range [numeric characters] Default range of the variable which is used when the command set/auto-window on was given.

class [i,r] integer- or real-variable

type [s,a] scalar or array variable

sub [y,n] sub-detector number allowed, y(es) or n(o)

variable.f : The function variable.f should return the value of the variable pointed at by ispec and det txt. ispec corresponds to the entry number in the array det_txt, see routine block_data_var.f.

indx is the hit number on the detector and its value is given by the routine det_sub.f, see below.

```
 .............
 else if (ivar.eq.49) then
   if (ip_sc.ne.0) then
     ip_pad = spdetector.sp(ispectro).trigger.
>                         sc(ip_sc).padnr(indx).adc.left
     ip_hit = spdetector.sp(ispectro).trigger.
>                         sc(ip_sc).hitnr(indx).adc.left
     dvar = dble(spdetector.sp(ispectro).trigger.
>                         sc(ip_sc).pad(ip_pad).val(ip_hit).adc.left)
   endif
 else
 .............
```

In the example given above, first the pointers to the correct scintillator paddle and position in the array containing the different hits (ip_pad and ip_hit) have to be determined. Then the variable dvar is filled.

index_range.f Changing this routine is only necessary for array variables. This subroutine should return through imax the number of entries for the variable pointed at by ivar.

```
 .............
 else if (ivar.eq.49) then
   if (ip_sc.ne.0) then
     imax = spdetector.sp(ispectro).trigger.sc(ip_sc).nhits.adc.left
   endif
   imax = max(1,imax)
 else
 .............
```

The example above shows how imax is set if ivar equals 49.

det_sub.f This routine has to be changed only for variables with subdetector indices. It should return the sub-detector number pointed at by `ivar` and `indx`.

```
 ............
 else if (ivar.eq.49) then
   if (ip_sc.ne.0) then
     det_sub = spdetector.sp(ispectro).trigger.
>                          sc(ip_sc).padnr(indx).adc.left
   endif
 else
 ............
```

## 2.4 Defining New Variables

Instead of coding a variable into ESPACE, a new one can also be defined on the fly through the command interface. For example, suppose the missing mass has to be defined for the reaction H$(e, e'p)$. This would be done through the following steps:

```
espace > m_proton=938
espace > e0 = 845
espace > omega:e0-spec_e.p
espace > tx:sqrt(spec_e.p**2+m_proton**2)-m_proton
espace > m_miss:sqrt((omega-tx)**2-p_miss**2)
```

Notice that constants are assigned through an equal sign: `m_proton=938`. Variables are assigned through a colon: `omega:e0-spec_e.p`. After this assignment the new variable can be used, like the coded ones, in logical statements, histograms and ntuples.

Before summarizing the syntax for these assigments, notice the following restriction:

> In the definition of a new variable, only scaler variables can be used.

New variables are defined by combining existing variables through the following operations:

```
( ) + - * / **
```

and intrinsic functions

```
abs acos acosd asin asind atan atand cos
cosd cosh deg exp log log10 rad sin
sind sinh sqrt tan tand tanh
```

The definition string should look like, `NEW : operation(OLD1,OLD2,...)`. Notice the assignment with ':'. Constants are defined by a string like, `PI=3.142`. Notice the assignment with '='.

# Chapter 3

# Defining Histograms, Logicals and Filters

In the previous section was described how to access a particular variable. What still has to be explained is how to histogram that variable and how to use it in the defining a condition.

## 3.1 Histograms

A histogram is defined with the command:

```
spectra/save variable_string condition_string
```

The `variable_string` can be any variable or combination of variables (for multi-dimensional histos and ntuples) as defined in Tabs. 2.2, 2.5, 2.6, 2.7 and 2.8 The condition string string is discussed in the next section.

A multi-dimensional histogram or ntuple (give command `set/ntuple on`) is created by making a variable string like `var2/var1`. For a histogram this has to be limited to two variables, an ntuple can contain upto 12 variables. The first variable mentioned in the `variable_string` is the last one in the histogram, so `var2/var1` will result in a 2-dim histogram with `x=var1` and `y=var2`.

A group of variables can be saved several times with different logical conditions. In this case the user has to supply at the end of the variable string either a counting index or leave it up to the program ESPACE to increment it internally. For instance,

```
spectra/save spec_e.dp condition1
spectra/save spec_e.dp condition2
```

or

```
spectra/save spec_e.dp-1 condition1
spectra/save spec_e.dp-2 condition2
```

will have the same result, however in the second case the user has explicitly given the counter numbers and has, therefore, its values under control. As shown in the previous chapter, a variable has several parameters which can influence the `spectra/save` command. Before histogramming a variable one should check whether its `class` is real or integer. In the

example below the command `set/spectrum/bins/x1 10` makes a histogram of the real-variable `spec_e.th_tg` containing 10 bins between 100.0 and 200.0 while for the integer-variable `spec_e.u1.tdc` it means that a histogram running from 100 to 200 should be made with a bin size of 10.

```
set/spectrum/window/x1 100 200
   set/spectrum/bins/x1 10
  spectra/save spec_e.th_tg
```

or

```
set/spectrum/window/x1 100 200
   set/spectrum/bins/x1 10
  spectra/save spec_e.u1.tdc
```

The `sub-detector` parameter for the variable allows to specify a subset of the detector for which the variable should be stored (see Sec. 2.2 for the meaning of `sub-detector` for the different detectors). The syntax for the `sub-detector` range is

```
spectra/save var[start;stop] condition
```

This can be used to create an ADC spectrum for the read-out of every paddle on the right side of scintillator `s1` (notice the usage of the do-loop as implemented in the KUIP command interpreter):

```
do i=1,6
spectra/save spec_e.s1.adc_r[[i];[i]] condition
enddo
```

## 3.2 Logicals

The definition of logicals can be done in two different ways:

- Define logicals by making cuts on the variables, either one- or two-dimensional.
- Define new logicals by combining the previously defined logicals through logical operators.

The syntax of the cut command in one dimension is

```
define/cut/1d variable string start_value stop_value
```

The syntax of the `variable_string` is exactly along the lines of defining a variable string in the `spectra/save` command. The logical value of the cut is .TRUE. if `start_value` $\geq$ `variable_string` $\geq$ `stop_value`.

In two dimensions a cut can be defined in two ways:

- Define a curve with a $2^{\text{nd}}$-order polynomial, and demand that a point is below or above it. The syntax is

  ```
  define/cut/2d variable_string direction p0,p1,p2
  ```

Here the variable_string has the same syntax as for a 2-dim histogram, so var2/var1. The parameters p0, p1 and p2 are polynomial coefficients describing the line var2=p0+p1∗var1+p2∗var1$^2$. The parameter direction should have the value above (var2≤p0+p1∗var1+p2∗var1$^2$) or below (var2≥p0+p1∗var1+p2∗var1$^2$).

- Define a region with a polygon and demanding that the data point is inside the polygon. Syntax for this command is:

  ```
  define/cut/polygon variable_string file_name
  ```

  file_name is the name of a file containing the coordinates of the polygon corners. The numbers of points is limited to 20!

  A way to make such a file is by plotting the appropriate 2-dim histogram or ntuple in PAW and then execute the following lines in PAW:

  ```
  vector/delete x,y
  vlocate x y -LPS
  write x,y file_name '(g13.7,2x,g13.7)' 'OC'
  ```

  This command sequence will generate a file called file name in which the x- and y-coordinates are written on each left-button mouse-click. It stops after a right-button mouse click.

In both 1-dim and 2-dim cut commands one is allowed to use variables of type array. This can make cuts more specific, e.g. define/cut/1d spec_e.s1.adc_r[2;2] 100 200 is only .TRUE. when paddle 2 of s1 has a value between 100 and 200. A statement like define/cut/1d spec_e.s1.adc_r 100 200 is .TRUE. if any of the paddles had a value between 100 and 200. New logicals can be defined by combining existing ones through logical operands. A list of the implemented operands is given in Tab. 3.1. The order of

Table 3.1: Logical operands allowed in ESPACE.

| symbol | operation |
|---|---|
| ! | negation |
| && | AND |
| \|\| | OR |

operations can be guided by brackets. For the moment, a logical definition containing an OR should be surrounded by quotes because the KUIP command interpreter will otherwise stop reading at the appearance of a — character. It is important to realize that logical definitions are expanded only upon execution, so during scanning an event file. For example,

```
define/logical new 'old1 && old2'
spectra/save spec_e.th_tg-1 new
```

followed by

```
define/logical new 'old1 || old2'
spectra/save spec_e.th_tg-2 new
```

will result in two `th_tg` spectra stored under identical conditions, namely the logical OR of `old1` and `old2`.

## 3.3 Filters

A filter is defined with the command:

```
file/filter file_name condition_string ,
```

where file name is the file into which the data will be stored if it fulfills `condition_string`. Currently the filtered data is stored again in CODA format so that it can be replayed with the same input routines as the raw data. However, the user can change that; all it takes is a change of the routines in the file **filter.f** in the `espace_halla` package. The current version is shown below:

```
      subroutine filter_event(ihandle)
c
c-----------------------------------------------------------------------
c
      implicit none

      include 'coda.h'

      integer ihandle
      character filename*(*)
      integer evopen
      integer istatus

c Write CODA event

      call evwrite(ihandle,evbuffer)
      return


      entry filter_open(ihandle,filename)
```

```
c Open CODA file

      istatus = evopen(filename,'w',ihandle)

      if (istatus.ne.0) then
         call derror('FILTER_OPEN: error opening CODA output file')
      endif

      return


      entry filter_close(ihandle)

c Close CODA file

      call evclose(ihandle)

      return
      end
```

The file should contain the routines

filter_open This routine opens the filtered data file.

filter_event This routine is called for each event that fulfills the filter condition. In it is defined what data is stored and in which format.

filter_close The closing of the data file is performed here.

If the user prefers a format different from CODA and wants to be able to replay it later again with ESPACE, the input routines, controlled by `filter_til_eof.f` (`espace_halla`) should be changed too. When scanning the file, one should not forget to give the `f` option with the `scan` command so that `filter_til_eof.f` controls the input instead of `rawdata_til_eof.f`.

## 3.4 Global Conditions

In the previous sections was discussed how to provide selection criteria when saving histograms or defining filters through the `command_string`. It is also possible to define more global conditions, meaning that it is applied to all following commands. This global condition is defined with the command:

```
set/hitbits (+detector1,-detector2,...) ,
```

where one can fill in the list any `detector` as mentioned in Tab. 2.8. Each `detector` should be preceded by a `+` or `-`. A `+` means that the condition is only .TRUE. if the `detector` has fired while a `-` means just the opposite, so .TRUE. if the `detector` did not fire. The total condition is the obtained by AND'ing the result of each detector in the list.

## 3.5 When is What Stored?

For calculating absolute numbers, it is important to understand what is stored in a histogram or the filter file when or a condition is not fulfilled or a detector does not fire. If the condition for a particular operation in ESPACE is not fulfilled, then it will not be executed for that event. So if the operation was histogramming a variable, saving data in a filter file, accumulating data for an optimization, etc., it will not be performed for this event. After a global condition all further operations are skipped up to the point where a new global condition was defined.

If a detector did not fire either of the following can happen:

- The variable of this detector is well defined even when the detector did not fire. For example, the multiplicity of the detector event, being zero. These variables have an '*' in Tabs. 2.2, 2.5, 2.6, 2.7 and 2.8 behind their name.
- The variable of the detector is undefined, ESPACE puts it on a very large number ($10^9$).

In either case, the number of entries in the histogram/ntuple should reflect the number of times the condition was fulfilled. For variables not directly linked to one particular detector (so level-one and level-two) it is not immediately clear which detectors should be checked. For the moment the following convention has been adapted. Level-two variables are linked to the trigger detectors (s1 and s2) in the appropriate spectrometer (see Tab. 2.7 while part of the level-one variables are linked to the trigger packages in both spectrometers, see Tab. 2.6, some depend on the electron spectrometer only (Tab. 2.5), and the rest is completely detector independent, see Tab. 2.2.

# Chapter 4

# Coordinate Systems

## 4.1 Definition of Coordinate Systems

In this section five coordinate systems are discussed. One coordinate system is connected to the hall while a second one is a coordinate system in the hall that is connected to each of the magnetic spectrometers. Coordinate systems three, four and five are linked to the detector packages in the focal planes of the spectrometers.

### 4.1.1 Hall A Laboratory Coordinate System

The origin of the **h**all A **l**aboratory **c**oordinate **s**ystem (HLCS) is defined by the intersection (or at least the point of closest approach) of the non-rastered electron beam and the axis of rotation of the solid-target system. The non-rastered electron beam direction is defined by the last two beam-position monitors. The incident unscattered beam leaves the target along the positive z direction. The y-axis is pointing upward as defined by gravity.

Angles are defined with respect to this origin and a ray pointing along the positive z-axis. Convenient is the use of geographical angles. Here, the angle $\theta$ is 0 along z and covers a 0 to 180 deg range in the x-z plane. $\phi$ is the out-of-plane angle formed between the vector under consideration and its projection on the x-z plane. In contrast to the spherical angle system, geographical angles can be added and subtracted, see Sec. 4.2.3. In App. C an overview is given of available algorithms that translate between the different systems.

### 4.1.2 Spectrometer Reconstructed Coordinate System

The origin of the spectrometer reconstructed coordinate system is defined as a point at a distance of 1.25 m from center of the central sieve-slit hole. The line going from the origin to the center of this hole is perpendicular to the sieve-slit surface and defines the z-axis. The x-axis is the line going through the center sieve-slit holes and points downward. Under optimal circumstances this origin should coincide with the origin of the hall A laboratory coordinate system and the center of rotation of the spectrometer. The x-z plane and the y axis of the hall system should be parallel.

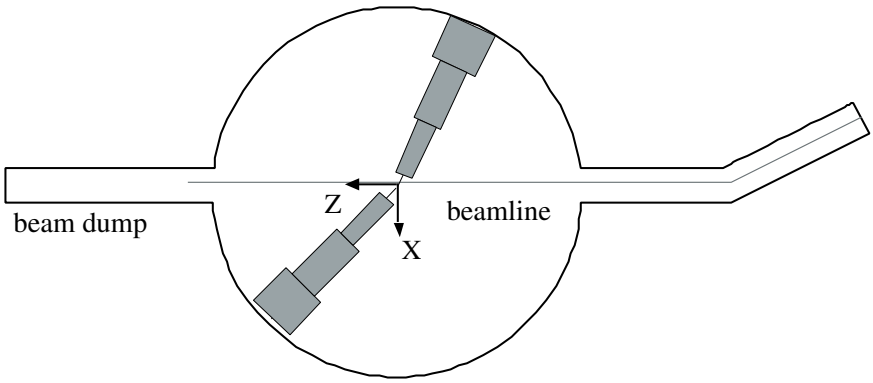


Figure 4.1: Hall A laboratory coordinate system.

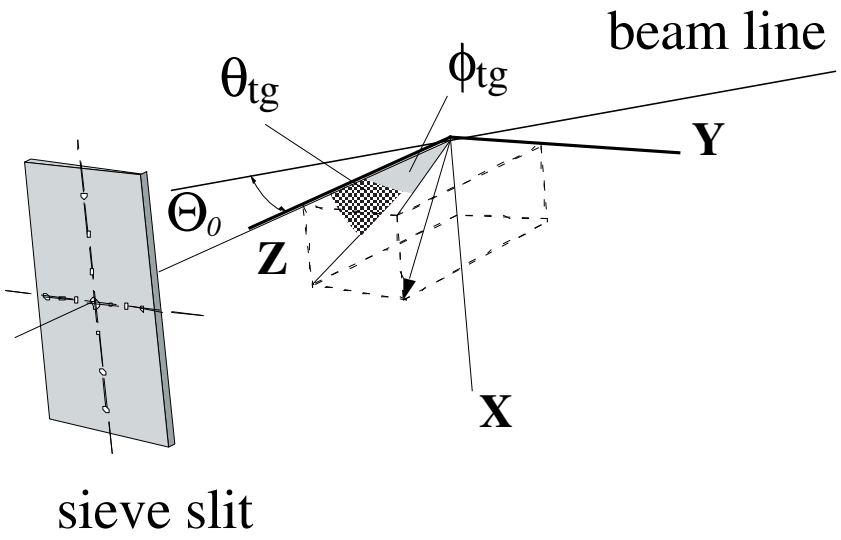


Figure 4.2: Spectrometer reconstructed coordinate system

### 4.1.3 Spectrometer Detector Coordinate System

The origin of the Spectrometer Detector Coordinate System (SDCS) is defined by the intersection of wire 184 in the first wire plane and the projection on the first wire plane of wire 184 in the second plane (assuming 368 wires in each plane). The z axis is perpendicular to the wire planes and its direction is fixed by demanding that its product with the central spectrometer ray (see Sec. 4.1.4) is larger than zero. The x axis is defined as the projection on the first wire plane of the vector difference between the the spectrometer central ray and a ray for which the momentum has been increased by an infinitesimal amount. Its direction is fixed by requiring an increase in momentum. It would be optimal if the x-z plane would coincide with the spectrometer symmetry plane. In Sec. 4.2 we will discuss how these coordinates can be calculated with the wire chamber information and how corrections can be performed for misalignments of the detector package.

### 4.1.4 Spectrometer Focal-Plane Coordinate System

The Spectrometer Focal-Plane Coordinate System SFPCS shares its origin with the detector system and the x-z planes coincide. However, its z-axis (and therefore also its x-axis) has a different orientation. The z axis is is defined as the projection of the local central ray on the x-z plane. The consequence is that x and z axis are a function of the fractional particle momentum $\Delta p/p$.

## 4.2 Calculation of Coordinates

In this section is discussed how the coordinates are calculated in the different coordinate systems. We will start in the detector system and will finish with the particle vertex in the hall A system. Along the way offsets are introduced to correct for misalignments. Of course, there are many ways in which parameters can be introduced to make these corrections, however, it is our goal to choose that set that fulfills the following two important requirements:

1. The parameter set that corrects for the misalignments should be as small as possible.

2. There should be a clear procedure how to determine each of them in a unique way.

After this section the experimental procedures will be discussed with which the parameters will be calibrated.

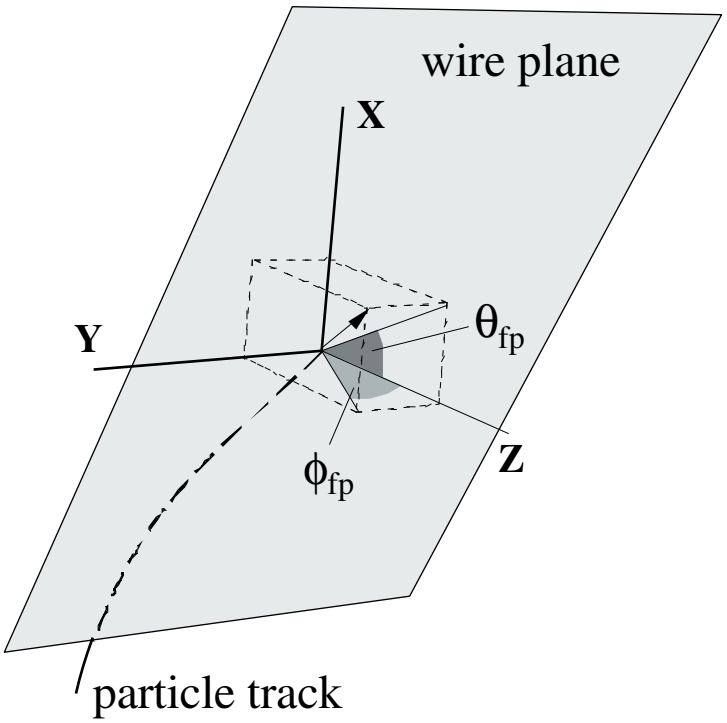


Figure 4.3: Spectrometer focal plane coordinate system.

### 4.2.1 Detector Vertex

A particle track $p$ in the detector package of a magnetic spectrometer can be written in the detector coordinate system as

$$\begin{pmatrix} p_{\mathrm{x}} \\ p_{\mathrm{y}} \\ p_{\mathrm{z}} \end{pmatrix} = \begin{pmatrix} x_{\mathrm{ds}} \\ y_{\mathrm{ds}} \\ 0 \end{pmatrix} + \lambda \begin{pmatrix} \sin\theta_{\mathrm{ds}} \cos\phi_{\mathrm{ds}} \\ \sin\phi_{\mathrm{ds}} \\ \cos\theta_{\mathrm{ds}} \cos\phi_{\mathrm{ds}} \end{pmatrix} \quad , \tag{4.1}$$

where $\theta_{\mathrm{ds}}$ and $\phi_{\mathrm{ds}}$ are geographic angles, see Sec. 4.1.1. The four unknowns ($x_{\mathrm{ds}}$, $y_{\mathrm{ds}}$, $\theta_{\mathrm{ds}}$ and $\phi_{\mathrm{ds}}$) are determined with four measurements in the drift-chamber package.

In Fig. 4.4 the wire direction in the first plane is shown making an angle of $-\xi$ with the y-axis of the detector coordinate system. Indicated also is a particle track through the plane. The drift chamber can measure the projection of this track on a plane perpendicular to its wire plane. The projection of an arbitrary vector $v = (v_{\mathrm{x}}, v_{\mathrm{y}}, v_{\mathrm{z}})$ is

$$\begin{pmatrix} v_{\mathrm{x}} \\ v_{\mathrm{y}} \\ v_{\mathrm{z}} \end{pmatrix} \overset{\text{projection}}{\longrightarrow} \begin{pmatrix} v_{\mathrm{x}} \cos^2\xi - v_{\mathrm{y}} \cos\xi \sin\xi \\ v_{\mathrm{y}} \sin^2\xi - v_{\mathrm{x}} \cos\xi \sin\xi \\ v_{\mathrm{z}} \end{pmatrix} \quad . \tag{4.2}$$

The projection is characterized by two quantities: the angle $\eta$ (see Fig. 4.4 and the position $p_{\mathrm{vdc}}$ where the projected track crosses the wire plane relative to the projection of

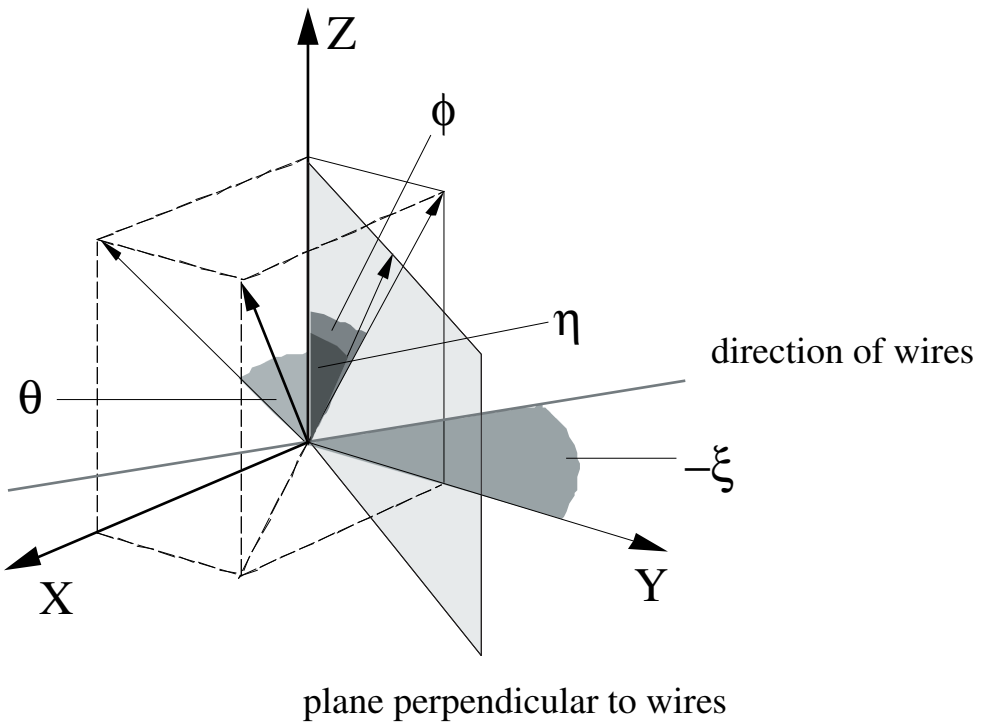


Figure 4.4: Spectrometer detector coordinate system. Two track angles $\theta_{\rm ds}$ and $\phi_{\rm ds}$ are indicated together with the angle $\eta$ that is measured with one or two wire plane(s).

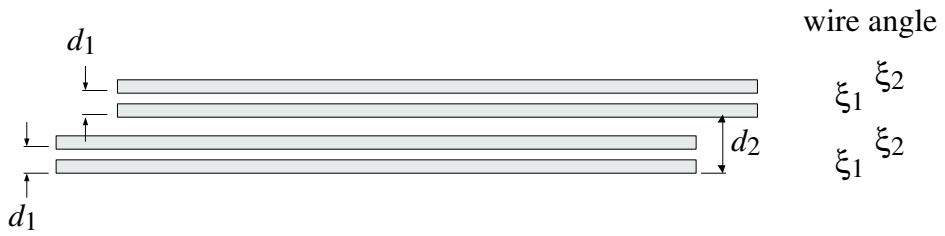


Figure 4.5: Configuration of the wire chamber package.

the origin of the detector coordinate system on this wire plane. Using Eq.(4.2), the expression for $\eta$ and $p_{\rm vdc}$ in terms of the unknowns of Eq.(4.1) are:

$$\begin{aligned} \tan\eta_{\rm n} &= \tan\phi_{\rm ds}\sin\xi_{\rm n} + \tan\phi_{\rm ds}\cos\xi_{\rm n} \\ p_{\rm vdc,n} &= p_{\rm x}\cos\xi_{\rm n} - p_{\rm y}\sin\xi_{\rm n} \end{aligned} \tag{4.3}$$

where the index n refers to the wire-plane number.

Equation 4.3 shows that two independent measurements of $\eta$ will give $\phi_{\rm ds}$ and $\theta_{\rm ds}$. This can be done with two drift chamber planes with different wire angles. However, in this configuration the $\eta$-resolution is limited to typically 8 mrad (FWHM). This can be improved by adding two more drift chamber planes, resulting in a configuration with two wire lanes with wire angle $\xi_1$ and two with wire angle $\xi_2$. In Fig. 4.5 the spatial configuration of the wire planes is sketched.

Using only the position information $p_{\rm vdc,n}$, n=1...4, we can calculate the vertex parameters in the SDCS as follows:

$$\begin{aligned} \tan\eta_1 &= \frac{p_{\rm vdc,3} - p_{\rm vdc,1}}{d_2} \\ \tan\eta_2 &= \frac{p_{\rm vdc,4} - p_{\rm vdc,1}}{d_2} \\ \tan\theta_{\rm ds} &= \frac{\tan\eta_1\sin\xi_2 + \tan\eta_2\sin\xi_1}{\sin(\xi_2-\xi_1)} \\ \tan\phi_{\rm ds} &= \frac{\tan\eta_2\cos\xi_1 + \tan\eta_1\cos\xi_2}{\sin(\xi_2-\xi_1)} \\ \tan x_{\rm ds} &= \frac{p_{\rm vdc,1}\sin\xi_2 - (p_{\rm vdc,2} - d_1\tan\eta_2)\sin\xi_1}{\sin(\xi_2-\xi_1)} \\ \tan y_{\rm ds} &= \frac{p_{\rm vdc,1}\cos\xi_2 - (p_{\rm vdc,2} - d_1\tan\eta_2)\cos\xi_1}{\sin(\xi_2-\xi_1)} \end{aligned}$$

Note that the coordinates of the point where the particle crosses the first plane are calculated with information mainly coming from the first two planes. This minimizes the effects on $x_{\rm ds}$ of multiple scattering in the drift chambers. A correction has been applied to

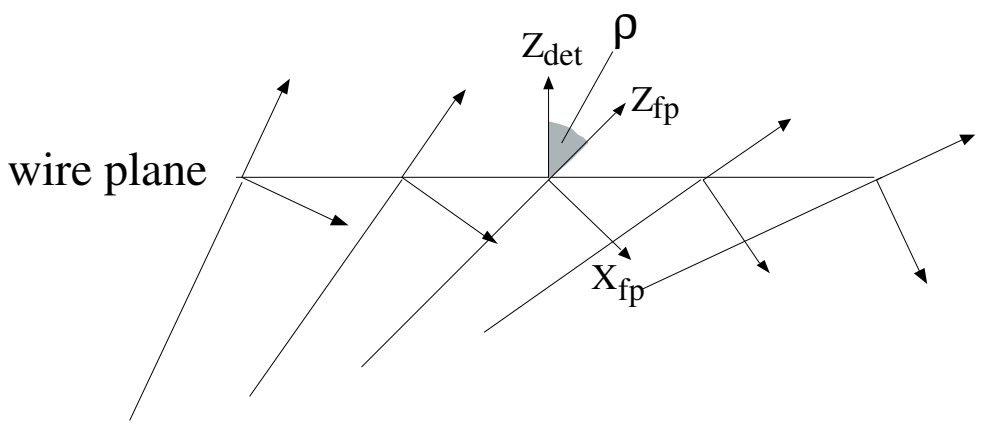


Figure 4.6: Spectrometer focal plane coordinate system which is rotated over an angle $\rho$ along the y-axis wrt the SDCS. $\rho$ is a function of the relative momentum.

the position $p_{\mathrm{vdc},2}$ for the fact that the first two planes are separated by a distance $d_1$. Some assumptions have been made in this derivation:

- Wire angles are known and constant.
- Wires are positioned in planes.
- Planes are parallel and at known distances.
- Location of the center of the wire planes wrt. the SDCS origin is known.

Deviations from the nominal values will lead to offsets in the SDCS coordinates. In order to correct for these deviations at least four offsets have to be introduced. In principle one could introduce offsets to correct for each of the items mentioned above, however, this would result in a set of highly correlated parameters. Therefore, we prefer to have one offset for each of the coordinates, $x_{\mathrm{ds}}$, $\theta_{\mathrm{ds}}$, $x_{\mathrm{ds}}$ and $\phi_{\mathrm{ds}}$. The offsets will be introduced in this two sections describing the transformation of the vertex to the spectrometer focal plane coordinate system and the spectrometer reconstructed coordinate system (SRCS). Some of the offsets can be combined with parameters describing these transformations.

### 4.2.2 Focal-Plane Vertex

Before reconstructing the particle vertex at the spectrometer entrance the particle vertex in the detector system is transformed to the spectrometer focal-plane coordinate system (a name slightly misleading as one will see further on). This coordinate system is obtained by rotating SDCS along its y-axis over an angle $\rho$, where $\rho$ is the angle between the projection of the local central ray ($\theta_{\mathrm{tg}} = \phi_{\mathrm{tg}} = 0$), see Sec. 4.1.4 on the x-z plane and the z-axis of the

SDCS[1]. So the new z-axis rotates as a function of the relative particle momentum $\Delta p/p$. The main advantage of expressing the vertex in this system is the fact that the dispersive angle $\theta$ will be small making the expressions for the reconstructed vertex converge faster.

Writing down the expressions for the new coordinates, the following points should be noted:

1. Offset correction and rotation can be combined in one parameter.
2. Since the particle momentum is the variable with the highest resolution (and therefore most sensitive) we do not want to apply a rotation to this coordinate that is not constant. Then, a new calibration of the momentum dependence of $\rho$ would immediately have consequences for the dispersion constants, see Eq.(6.4) on p. 55.

The offset for $x_{\rm ds}$ will be introduced when calculating the particle momentum and the $\theta_{\rm ds}$ offset will be absorbed in the transformation to the spectrometer focal-pane coordinate system. So up to here we have:

$$\begin{aligned}
x_{\rm fp} &= \cos\rho_0(x_{\rm ds} - x_{\rm offset}) \\
y_{\rm fp} &= y_{\rm ds} - y_{\rm offset} \\
\tan\theta_{\rm fp} &= \frac{\tan\theta_{\rm ds} - \tan\rho}{1 - \tan\theta_{\rm ds}\tan\rho} \\
\tan\phi_{\rm fp} &= \frac{\tan\phi'_{\rm ds}}{\cos\rho - \sin\rho\tan\theta_{\rm ds}} \\
\tan\phi'_{\rm ds} &= \frac{\tan\phi_{\rm ds} - \tan\phi_{\rm offset}}{1 + \tan\phi_{\rm ds}\tan\phi_{\rm offset}}
\end{aligned}$$

### 4.2.3 Hall A Laboratory Vertex

Suppose the normal to the sieve slit surface that goes through the central hole is given by the geographical angles $\Theta_0$ and $\Phi_0$ in the hall A laboratory coordinate system[2]. The geographical angles of the particle vertex in the HLCS is given by:

$$\begin{aligned}
\theta_{\rm HLCS} &= \theta_0 \pm \phi_{\rm tg} \\
\phi_{\rm HLCS} &= \phi_0 + \theta_{\rm tg}
\end{aligned}$$

The question whether to add or subtract $\phi_{\rm tg}$ depends on the position of the spectrometer with respect of the beam line. In order to calculate the reaction point $(x, y, z)$ additional

[1] Under ideal conditions, such as spectrometer mid-plane symmetry, the local central ray is in the x-z plane.

[2] I guess some of you will argue that to define the orientation of the spectrometer uniquely in space also the rotation around this normal should be specified. I guess you are right but usually spectrometer can not (or better formulated should not) perform this motion.

information is needed from another spectrometer, detecting a particle in coincidence, and/or the beam position from the rastering system.

## 4.3 Calibration of Coordinates

Up to now we have defined the different coordinate systems and discussed how the particle vertex as determined in the spectrometer detector package leads to the vertex of the particle emerging from the reaction point in the target. However, the usefulness of all this stands or falls with the existence of procedures to calibrate these coordinates.

In the following discussion it is assumed that the orientation of the sieve slit with respect to the HLCS is aligned carefully through optical procedures. At this point we assume also that the HLCS itself can be checked through a straightforward procedure. So starting with a well calibrated system of sieve slit and magnet positions wrt. the HLCS, elastic electron scattering measurements should be performed so that a sharp peak in momentum is detected. This measurement should be repeated after changing the magnetic field, thereby after several changes covering the whole momentum acceptance. The central hole of the sieve slit provides us with data to determine the offsets introduced in the SDCS for $\theta$, $y$ and $\phi$. The offset in $x$ is absorbed in the dispersion coeficient $d_0$ of Eq.(6.4) on p. 55. Determination of this coefficient needs different type of measurements as discussed in [5]

# Chapter 5

# Tracking

In this chapter we will discuss the track reconstruction with the spectrometer VDC package. This is the most important part in the data analysis with a high-resolution spectrometer, justifying a whole chapter about this subject. First, the program flow for tracking will be discussed, followed by an explanation of the minimum spanning tree algorithm, used in disentangling multiple tracks. We finish with showing the tracking efficiency of the algorithm by analyzing simulated $^{16}\mathrm{O}(e, e'p)$ data.

## 5.1 Program Flow for Tracking

## 5.2 Minimum Spanning Tree Algorithm

## 5.3 Definition of Wire Chamber Hit Type HPCH

Each wire chamber hit is assigned a hit type. At the moment the following seven different conditions are being distinguished:

Table 5.1: Hit types for a wire chamber hit.

| HPCH value | | Description |
|---|---|---|
| dec | bin | |
| 2 | 00000010 | a nohit or all clusters are of ERR1 type. |
| 4 | 00000100 | number of wires hit is $\geq$64 |
| 8 | 00001000 | some drift times resulting in drift distances larger than 1.25 times the distance between wire plane and cathode |
| 16 | 00010000 | some drift times are correcting for the stop offset negative |

For an error condition HPCH has a value $\geq$2. In this case the hit type can be a combination of several error conditions.

## 5.4 Tracking Efficiency

# Chapter 6

# Calibration

The resolution and position of several variables can be optimized. To start an optimization give the command

`optimize/calibrate variable_string condition_string`

The `condition_string` can be any valid logical statement. The variable combinations that can be optimized are given in Tab. 6.1.

Table 6.1: Variable combinations that can be optimized. spec_s can be either spec_e or spec_h, s*num* either s1 or s2, and *side* can be either l (left) or r(right).

| variable | comments |
|---|---|
| spec_s.th_tg/spec_s.ph_tg | Reconstructed $\theta$ and $\phi$ target coordinates. These angles can only be optimized for a measurement with a sieve collimator. Both of them are optimized at the same time, see Ref. [6]. |
| spec_s.y_tg | Reconstructed $y_{\rm tg}$ coordinate. The non-dispersive position can be optimized after a series of measurements have been performed in which the beam spot has been put at different positions. |
| tc_cor | Coincidence time between HRSE and HRSH after correction for path length differences wrt. the central rays and time offsets between the scintillators. |
| e_miss | Missing energy for $(e, e'x)$. |
| e_miss/p_miss | Missing energy and momentum for H$(e, e'p)$. |
| spec_s.s*num*.adc_*side*_c | Scintillator ADC values corrected for pedestals and attenuation. |
| spec_s.beta | particle $\beta$ as calculated by the time-of-flight between s1 and s2. |

There, spec_s can be either spec_e or spec_h, s*num* either s1 or s2, and *side* can be either l (left) or r (right). Except for the optimization of tc_cor, an additional input file has to

be supplied. Since the selection of events used in the optimization procedure is usually too complicated to be accomplished through a series of cuts defined in ESPACE, this file contains information for the event selection. The file can be assigned through the command `set/file/fit input`, see Sec. D (pp. 73).

For the different optimization options this file has a different format. First we discuss the case that the vertex reconstruction of a spectrometer is optimized, so `dp_kin`, `th_tg/ph_tg` and `y_tg`. Then this file should contain in the first line the number of positions along the focal plane where one wants to optimize, followed by a line for each position containing the center of this region, its new position (only useful when `dp_kin` is being optimized) and the half-width of this region.

If one wants to optimize `th_tg/ph_tg` or `y_tg` additional data have to be supplied. In case of `th_tg/ph_tg` this should be the number of holes in the sieve collimator. It has to be followed by a line for each hole giving the center of the hole in `th_tg` before optimization, `th_tg` hole position after optimization and half the width of the ellipse in the $\theta$ direction which will be put around the initial coordinates of the hole center. The same should be given for `ph_tg`. Only those events are used which have their initial values inside one of the ellipses. The beginning of a fit-file for optimizing `th_tg/ph_tg` with a 77-hole sieve-collimator would look like

```
77 (theta_ini, theta_final, dtheta, phi_ini, phi_final,  dphi)
     -0.04500     -0.07024  0.0075 -0.08600   -0.09757 0.0050
```

The input for optimizing `y_tg` would consist out of first a line with the number of beam-spot positions which is being used in the optimization. It is followed by a line for each beam-spot position with the initial position, final position and half the width of the region around the initial position containing the events that are accepted for the optimization.

An important parameter in the optimization procedure is the variable that controls the number of events per peak per file that is being used (command `set/fit/npts`). With this variable one can prevent that the data used in the fit is coming from just the first few files being scanned.

If `e_miss` is optimized the file should contain in the first line the number of peaks in the missing energy spectrum that one wants to optimize. This is followed by a line for each peak containing the center of this region, its new position and the half width of this region. All in units of MeV.

## 6.1 ADC Gains and Pedestals

The first calibration that has to be done is the calibration of the pedestals and gains for the scintillator ADCs. This has to be done whenever any replacement of phototubes took place or at the begining of an experiment.

Let us consider what determines the ADC value for a given event. An ionizing particle passes a scintillator paddle. The amount of light produces is proportional to the energy loss times the pathlength in the paddle. For good events, the pathlength is somewhat a constant,

because they intersect the paddle planes almost perpendicular. The light propagates through the scintillator to the PMTs. Because of non-100% transparence and reflection at the paddle surfaces the signal is attenuated. This is usually, though not exactly correct, described by a exponential. This attenuation constant is somehow empirical, one finds different coefficients for paddles made of the same material, but, e.g., different thicknesses. Furthermore, you get a signal loss coupling the scintillator paddle to the light guide and to the PMT window. The quality of the coupling may vary and may cause different losses for different paddles. The remaining photons knock electrons off a photo kathode which are multiplied by the PMT. This resulting signal is converted by an ADC into a digital signal and fed into the data stream. All these effects cause an per PMT individual reduction of the deposited signal, additionally to a statistical broadening. The goal of the optimization is to correct for the pedestals and all these losses to reconstruct the differential energy loss of the particle, e.g. for particle discrimination purposes. Currently, ESPACE corrects for pedestals and gain only and calls this new variable `adc_<side>_c`[1]. Calibrating pedestals and gain may be done separately using the `/Espace/SEt/Fit/Adc/Pedestal` (see description on p. 77) and `/Espace/SEt/Fit/Adc/Gain` (p. 77) commands. The attenuation is not corrected.

For normal data acquisition mode the pedestals are supressed. Consequently to do scintillator ADC optimization, one has to take data with pedestal unsupressed. This can be done by setting the pedestal position at zero in a file that is read by CODA. It might be useful to point out that this is not what is usually called a pedestal run. The pedestal run purpose is to find the position of the actual pedestal to write it in the files that CODA uses for pedestal suppression. Data used for the purpose of fitting the pedestal and the gain can be either cosmics or beam data, the only condition is to cover the whole plane.

A typical phototube ADC spectra consists from a peak for the pedestal and a physical signal zone; the purpose of finding the pedestal position and set a gain is to apply a correction to the physical signal so that the maximum of the physical signal zone to correspond to same ADC value (compare Figs. 6.1 and 6.2). By representing `adc_<side>_c` we can check if the calibration/optimization was successful or not. The optimization can be done simultaneously for the left and right phototubes in electron or hadron arm.

Choosing an appropiate data set for optimization one has to distinguish two conditions:

pedestals: If one is interested in the pedestals only (which are important for the time walk correction) and does not care about particle identification, any data (without pedestal suppression) are good. If you have production run data only, most of the pedestals are suppressed, and you will find only the tail extending to higher energies plotting the ADC spectra. Identify the threshold. The pedestal position should be 10 channels below that threshold. Put this number into the database, by hand.

gain: Best suited for gain calibration are real data illuminating the whole focal/detector

[1] The ADC value in not used in ESPACE except in calculating the time walk correction for the timing. For that one should use the raw ADC value, subtracted by the pedestal. This is the "real" ADC value that was fed into the discriminator and ADC. Thus, in future the definition of `adc_<side>_c` should be changed to reflect `adc_<side>`-pedestal, and the full correction should be stored in a variable called `dEdx_<side>`.

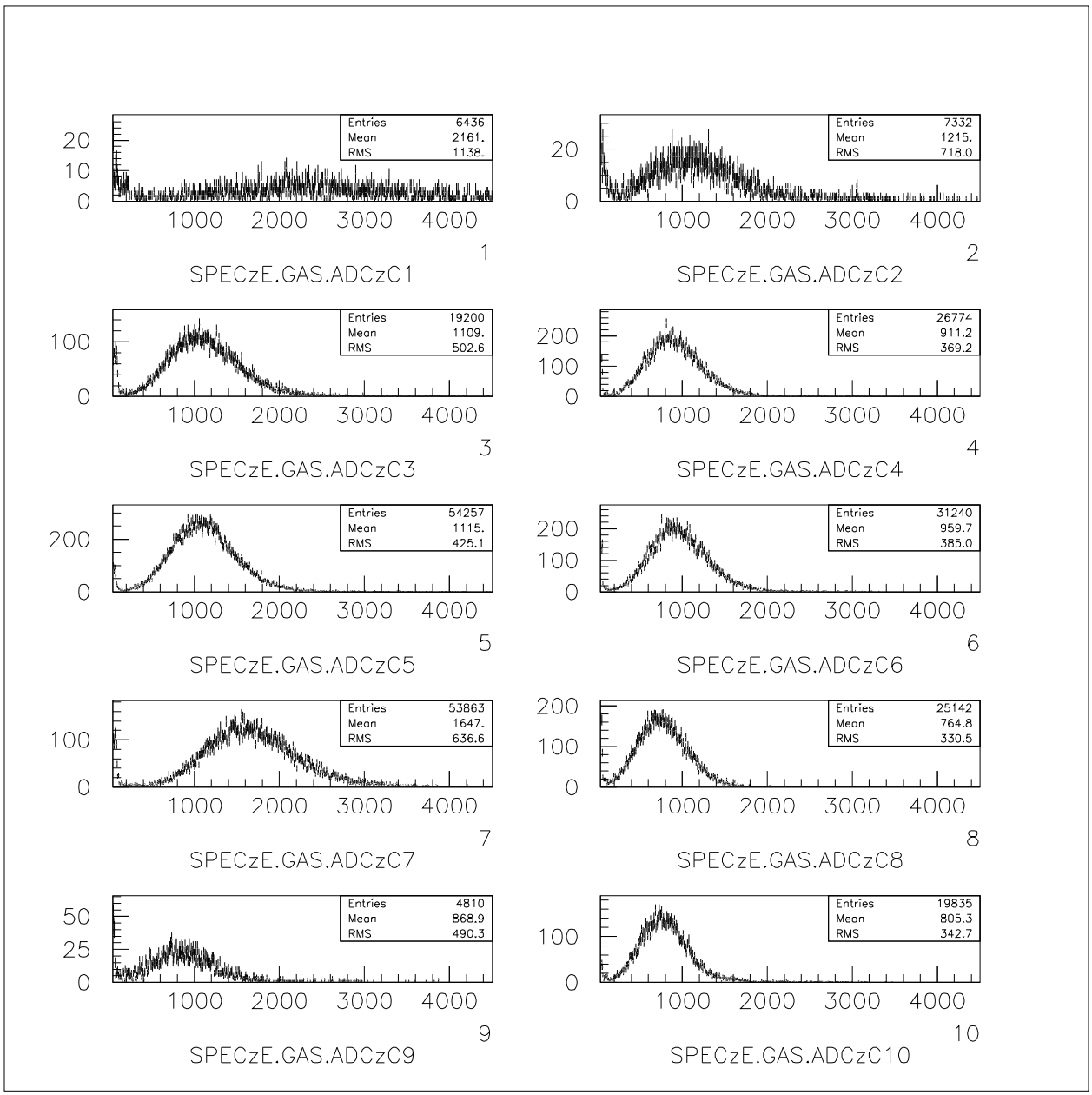


Figure 6.1: Čerenkov ADC signal before optimization.

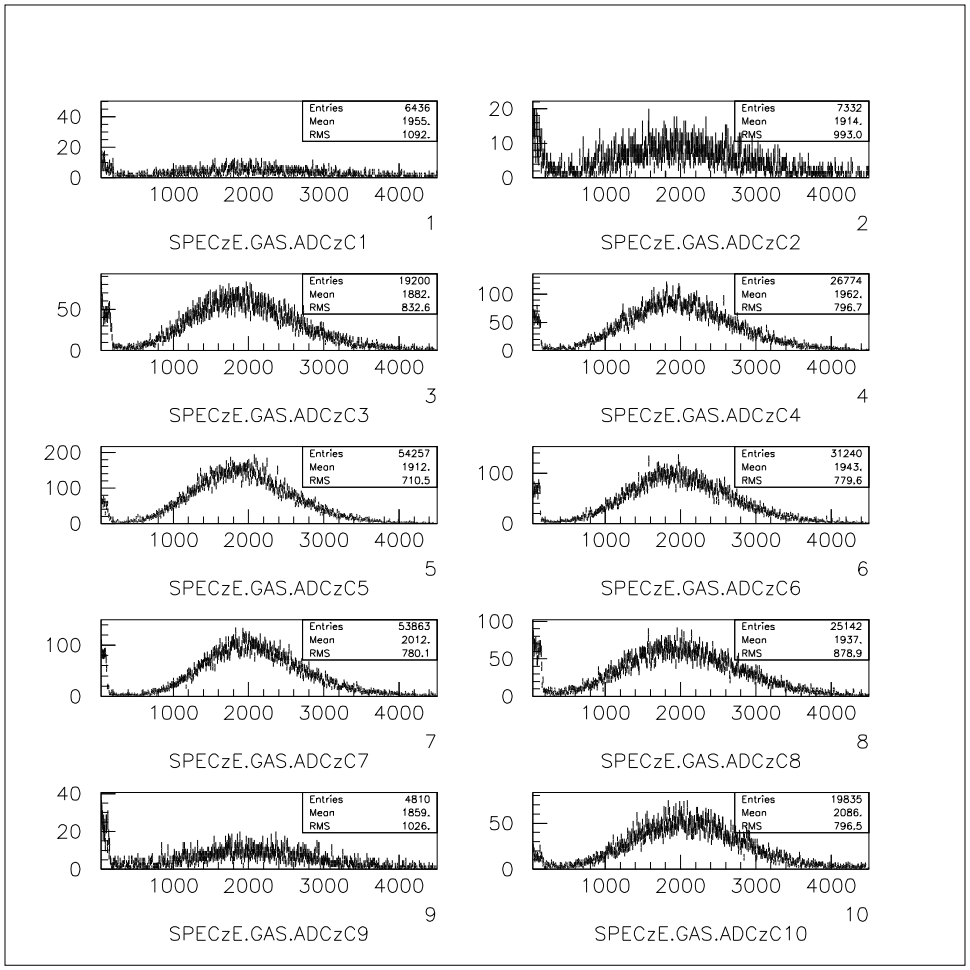


Figure 6.2: Čerenkov ADC signal after optimization.

plane. Good are singles, but not from elastic scattering, and quasi-elastic data. Elastic scattering data show a correlation between momentum and scattering angle, i.e. between paddle number and `ydetgeom` where the paddle is hit. Thus, the attenuation correction is folded into the gain, and the resulting data base may not be applicable to any other kinematical setting. Cosmics may be good to, especially for uniform illumination, but depending on which other conditions may be applied, the intersection with the paddle may not be perpendicular nor the mean uniform in paddle number. Thus, different individual path lengths may be fitted into the gain.

To clean up the events on should consider a few cuts:

- No multi hits in ADC, e.g. `define/cut/1d spec_e.s1.mult  0.5 1.5`
- coincidence of `s1` and `s2`, i.e.
  `define/logical one_sc_hit_e spec_e.s1.mult&&spec_e.s2.mult`
- adding the VDCs, cutting on one cluster `def/cut/1d spec_e.u1.clus  0.5 1.5` and good multiplicity `define/cut/1d spec_e.u1.mult  1.5 7.5`
- Using the VDC reconstructed track a cut on the intersection angle with the scintillator plane can be applied.

The more cuts you apply, the more reliable your calibration will be, but consider e.g. using cosmics you may need a lot of events getting a small sample of good events.

Thus, an ESPACE kumac file for ADC calibration could look like:

```
set/fit/adc/pedestal off
define/cut/1d spec_e.s1.mult     0.5 1.5
define/cut/1d spec_e.s2.mult     0.5 1.5
define/logical one_sc_hit_e spec_e.s1.mult&&spec_e.s2.mult

calibrate/optimize spec_e.s1.adc_l_c one_sc_hit_e
calibrate/optimize spec_e.s2.adc_l_c one_sc_hit_e
calibrate/optimize spec_e.s1.adc_r_c one_sc_hit_e
calibrate/optimize spec_e.s2.adc_r_c one_sc_hit_e
```

After the optimization, of the database the lines containing the offsets (pedestal positions) and amplification factors (gains) for the paddles in the respective HRS should have been altered.

## 6.2 Čerenkov ADC

## 6.3 Shower and Pre-Shower Calibration

Please see Ref. [7].

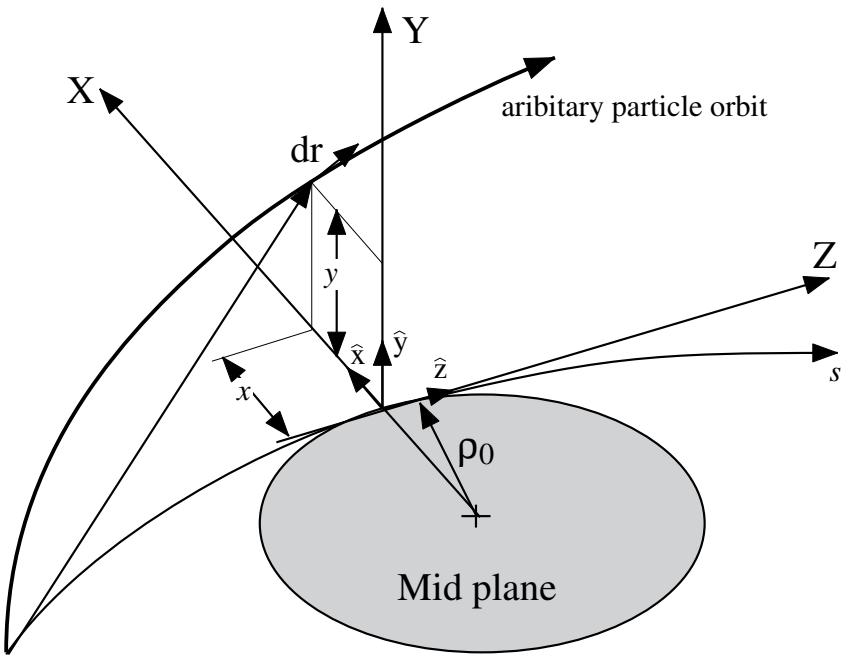


Figure 6.3: Spectrometer transport coordinate system.

## 6.4 Scintillator Timing

## 6.5 VDC Time Offets

## 6.6 VDC Time to Distance

## 6.7 Vertex Reconstruction

Well, one could devote a whole chapter to this topic, actually a whole book. But let's not get carried away and just explain the basics to get you prepared to do your spectrometer calibration.

The basis for magnetic design and discussion is a six dimensional vector and the corresponding transfer tensor calculated by such programs as TRANSPORT [8]. The components of this vector include position and tangent of angle in the dispersive plane (usually designated $x$ and $\theta$), the nondispersive coordinates ($y$ and $\phi$), and the fractional deviation of the momentum from the central design momentum ($\delta$). A sixth dimension describing ray path length variations is included, but it is ignored in our discussion for simplicity. Note that all tensor elements in this document with subscript '5' correspond to the TRANSPORT element with subscript '6'.

The positions $x$ and $y$ are defined in a right-handed rectangular coordinate system with $\hat{z}$ along the particle direction and $\hat{x}$ directed away from the center of curvature in the bending

plane. Thus, for upward bending spectrometer like HRS, at the target $\hat{x}$ points downward. The angles $\theta$ and $\phi$ are measured from the $z$-axis to the projection of the particle vector onto the $x$-$z$ and $y$-$z$ planes, respectively. At any position through the spectrometer, these coordinates are measured with respect to the central ray (i.e., $\hat{z}$ points along the central ray), where the central ray is defined to be that ray with all initial coordinates equal to zero at the target.

The form of the first-order forward transfer tensor is shown in Eq.(6.1). tg designates a vector at the target, and fp designates a vector measured in the focal plane region.

$$\begin{pmatrix} x \\ \tan\theta \\ y \\ \tan\phi \\ \delta \end{pmatrix}_{\rm fp} = \begin{pmatrix} \langle x|x\rangle & \langle x|\theta\rangle & 0 & 0 & \langle x|\delta\rangle \\ \langle \theta|x\rangle & \langle \theta|\theta\rangle & 0 & 0 & \langle \theta|\delta\rangle \\ 0 & 0 & \langle y|y\rangle & \langle y|\phi\rangle & 0 \\ 0 & 0 & \langle \phi|y\rangle & \langle \phi|\phi\rangle & \langle \phi|\delta\rangle \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ \tan\theta \\ y \\ \tan\phi \\ \delta \end{pmatrix}_{\rm tg} \tag{6.1}$$

Notice that symmetry in the $x$-$z$ plane is enforced by making several tensor elements zero. We can easily find the inverse matrix which is shown in Eq.(6.2). Again, those elements which are explicitly zero result from midplane symmetry. In the notation below, $\langle a|b\rangle^{-1}$ means $(\langle a|b\rangle^{-1})_{ij}$ and not $(\langle a|b\rangle_{ij})^{-1}$.

$$\begin{pmatrix} x \\ \tan\theta \\ y \\ \tan\phi \\ \delta \end{pmatrix}_{\rm tg} = \begin{pmatrix} \langle x|x\rangle^{-1} & \langle x|\theta\rangle^{-1} & 0 & 0 & \langle x|\delta\rangle^{-1} \\ \langle \theta|x\rangle^{-1} & \langle \theta|\theta\rangle^{-1} & 0 & 0 & \langle \theta|\delta\rangle^{-1} \\ 0 & 0 & \langle y|y\rangle^{-1} & \langle y|\phi\rangle^{-1} & 0 \\ 0 & 0 & \langle \phi|y\rangle^{-1} & \langle \phi|\phi\rangle^{-1} & \langle \phi|\delta\rangle^{-1} \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ \tan\theta \\ y \\ \tan\phi \\ \delta \end{pmatrix}_{\rm fp} \tag{6.2}$$

The representation above is not adequate, however, to describe the reconstruction of target variables from measured ones. The full five-dimensional vector is not detected by the focal plane instrumenation, which measures only positions and angles; the momentum information $\delta$, is absent. Thus, only two ($\delta$ and $y_{\rm tg}$) of the three dispersive coordinates can be reconstructed. The third dispersive target coordinate must in principle be fixed to allow a solution for the problem. The logical choice is to constrain, of course, $x_{\rm tg}$.

A matrix representation appropriate to the reconstruction procedure is trivially related to the above matrix by using

$$\delta = \frac{x_{\rm tg} - \langle x|x\rangle^{-1} x_{\rm fp} - \langle x|\theta\rangle^{-1}}{\langle x|\delta\rangle^{-1}}$$

which results in the relation

$$\begin{pmatrix} \delta \\ \tan\theta \\ y \\ \tan\phi \\ x \end{pmatrix}_{\rm tg} = \begin{pmatrix} \langle \delta|x\rangle^* & \langle \delta|\theta\rangle^* & 0 & 0 & \langle \delta|x_{\rm tg}\rangle^* \\ \langle \theta|x\rangle^* & \langle \theta|\theta\rangle^* & 0 & 0 & \langle \theta|x_{\rm tg}\rangle^* \\ 0 & 0 & \langle y|y\rangle^* & \langle y|\phi\rangle^* & 0 \\ 0 & 0 & \langle \phi|y\rangle^* & \langle \phi|\phi\rangle^* & \langle \phi|\delta\rangle^* \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_{\rm fp} \\ \tan\theta_{\rm fp} \\ y_{\rm fp} \\ \tan\phi_{\rm fp} \\ x_{\rm tg} \end{pmatrix} \tag{6.3}$$

This will hereafter be referred to as the reverse tensor (as opposed to the inverse tensor above). The dependence of $\delta$ and $\theta_{\rm tg}$ on $x_{\rm tg}$ is explicit.

In practice (ESPACE) one proceeds a bit different. Only the the upper 4×4 part can be calibrated for a known $x_{\rm tg}$ position (hopefully zero). In the analysis the $x_{\rm tg}$ position is determined with the information of the beam position on target and the reconstructed $\theta$, $y$ and $\phi$ position in the target of one or two spectrometers. This value of $x_{\rm tg}$ is used together with Eq.(6.3) to correct the focal plane coordinates to values corresponding to $x_{\rm tg} = 0$[2] Realize that one has to obtain part of the tensor coefficients in Eq.(6.3) from a program like RAYTRACE [9] or COSY [10]. The new focal-plane vertex is used in the calculation of the reconstructed target vertex.

The transformation from the focal plane to the spectrometer entrance is described with a set of tensors, $D_{ijkl}$, $T_{ijkl}$, $Y_{ijkl}$ and $P_{ijkl}$:

$$\begin{aligned}
\frac{\Delta p}{p} &= \sum_{ijkl} D_{ijkl} x_{\rm fp}^i \tan^j\theta_{\rm fp}\, y_{\rm fp}^k \tan^l\phi_{\rm fp} \\
\tan\theta_{\rm tg} &= \sum_{ijkl} D_{ijkl} x_{\rm fp}^i \tan^j\theta_{\rm fp}\, y_{\rm fp}^k \tan^l\phi_{\rm fp} \\
y_{\rm tg} &= \sum_{ijkl} D_{ijkl} x_{\rm fp}^i \tan^j\theta_{\rm fp}\, y_{\rm fp}^k \tan^l\phi_{\rm fp} \\
\tan\phi_{\rm tg} &= \sum_{ijkl} D_{ijkl} x_{\rm fp}^i \tan^j\theta_{\rm fp}\, y_{\rm fp}^k \tan^l\phi_{\rm fp}
\end{aligned}$$

If the spectrometer has a symmetry plane that coincides with the $x$-$z$ plane of the SRCS, the following restrictions should be imposed on the tensor coefficients: only combinations of powers of $y_{\rm fp}$ and $\tan\phi_{\rm fp}$ with even values for the power sum $k+l$ occur in the calculation of $\Delta p/p$ and $\tan\theta_{\rm tg}$, while only odd values for $k+l$ are in the calculation of $y_{\rm tg}$ and $\tan\phi_{\rm tg}$.

It is important to notice that $\Delta p/p$ for particles entering the spectrometer with $\theta_{\rm tg} = \phi_{\rm tg} = 0$ only depends on $x_{\rm fp}$. The expression for the absolute momentum of these particles is given by:

$$p_{\rm f} = p_{\rm centr}\left(1 + \sum_{j=1}^{n} d_j x_{\rm fp}^{\rm j}\right) \qquad , \tag{6.4}$$

where $p_{\rm centr}$ is the central momentum setting of the spectrometer and $d_j$ the spectrometer dispersion coefficients. Under ideal circumstances its dependence on the spectrometer magnetic field is linear. However, saturation effects will introduce non-linear terms:

$$p_{\rm centr} = \sum_{j=0}^{m} \Gamma_j B^j$$

This simple relation is due to the choice of our focal-plane coordinate system. In the next section where the calibration of the different coordinates is discussed we will see that as a result of this choice a special calibration procedure will give information about the important spectrometer dispersion coefficients.

[2]So, this $x_{\rm tg}$ correction is only correct upto first order.

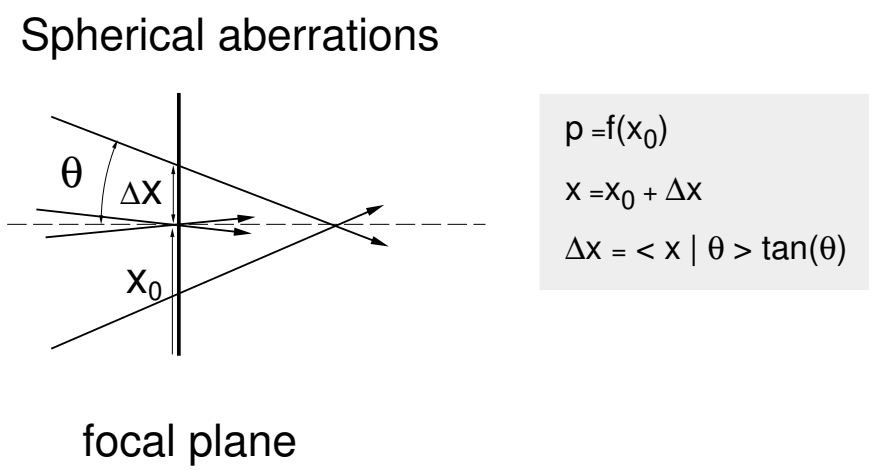


Figure 6.4: Explanation of spherical momentum aberations in the focal plane of a magnetic spectrometer. The dashed line is made by a ray with momentum $p$ and $\theta_{\rm tg} = 0$.

### 6.7.1 Non-Dispersive Position $y_{\rm tg}$

### 6.7.2 Angles

### 6.7.3 Momentum Aberrations

To give you some idea how a scanning session with optimization will look like, an example is discussed in which the transfer tensor for calculation of momentum aberations is being optimized. In Fig. 6.4 the dispersive projection of the focal plane is drawn. Imagine that the spectrometer momentum setting is such that we observe the elastic peak of $^{12}{\rm C}(e,e)$. The ray with momentum $p$ and $\theta_{\rm tg} = 0$ is indicated by a dashed line. The position where it crosses the first wire plane is indicated by $x = 0$. Rays with the same momentum and an infinitesimal small $\theta_{\rm tg}$ cross this wire plane at the same spot and a relation can be established between momentum and $x$-position in that wire plane. However, rays entering the spectrometer collimator with the same momentum but a larger $\theta_{\rm tg}$ will typically cross the wire plane at a different spot. In other words, the particle momentum can not be deduced solely from the dispersive position $x$, unfortunately all the focal plane vertex parameters ($\theta_{\rm fp}$, $y_{\rm fp}$, $\phi_{\rm fp}$) are involved. It is now our task to describe this deviation $\Delta x$ as a function of the focal plane vertex, the so-called transfer tensor for the momentum aberrations. Most spectrometer designs are such that the dependence on $\theta_{\rm fp}$ is the most important one.

Below an example of a KUMAC-file is given in which the transfer tensor for the momentum aberrations is being optimized. Seven measurements of an elastic electron scattering peak have been made at different values of $\Delta p/p$. After the assignment of the different input files and definitions of `cut`'s, histograms and scatter plots are defined. Especially the `th_tra/dp_kin` ($\theta_{\rm fp}/{\rm d}p_{\rm kin}$) plots around the seven elastic peak positions are of interest since they will reveal the momentum aberration as a function of $\theta_{\rm fp}$. This is followed by

a command indicating that at the end of the event-by-event scan an optimization of the momentum transfer tensor has to be performed.

```
define/batch on
set/file/output c12_full conv1.hbook
set/file/database db_hrs_7x7
set/file/opt database db_hrs_7x7_opt
set/file/detmap detmap.config
set/file/fit_input fit_full_conv1.inp

********** Define cuts ************************

define/cut/1d spec_e.y_tra-1 -0.144 0.144
define/cut/1d spec_e.x_tra-1 -0.749 0.749
define/cut/1d spec_e.th_tg-1 -0.07 0.07
define/cut/1d spec_e.ph_tg-1 -0.030 0.030
define/logical vdc_hole spec_e.y_tra-1&&spec_e.x_tra-1
define/logical accept_e spec_e.th_tg-1&&spec_e.ph_tg-1

********** spectrometer HRS ******************

set/hitbits (+spec_e.s1)
set/auto_window off
set/spectrum/bins/x1 560
set/spectrum/window/x1 -0.07 0.07
spectra/save spec_e.th_tg
set/spectrum/bins/x1 320
set/spectrum/window/x1 -0.04 0.04
spectra/save spec_e.ph_tg
set/spectrum/bins/x1 500
set/spectrum/window/x1 -0.065 0.065
spectra/save spec_e.dp-1
spectra/save spec_e.dp_kin-1
set/spectrum/window/x1 -0.7 0.7
spectra/save spec_e.x_tra-1
set/ntuple 5000

**** dp-aberration plots

set/spectrum/window/x2 -0.5 0.5
set/spectrum/window/x1 -0.06 -0.04
spectra/save spec_e.th_tra/spec_e.dp_kin-1
set/spectrum/window/x1 -0.035 -0.0275
```

```
spectra/save spec_e.th_tra/spec_e.dp_kin-2 vdc_hole
set/spectrum/window/x1 -0.025 -0.0175
spectra/save spec_e.th_tra/spec_e.dp_kin-3 vdc_hole
set/spectrum/window/x1 -0.015 0.015
spectra/save spec_e.th_tra/spec_e.dp_kin-4 vdc_hole
set/spectrum/window/x1 0.015 0.0225
spectra/save spec_e.th_tra/spec_e.dp_kin-5 vdc_hole
set/spectrum/window/x1 0.0225 0.030
spectra/save spec_e.th_tra/spec_e.dp_kin-6 vdc_hole
set/spectrum/window/x1 0.040 0.060
spectra/save spec_e.th_tra/spec_e.dp_kin-7 vdc_hole

***** optimize momentum resolution in electron spectrometer

calibrate/optimize spec_e.dp_kin

******************** scanning and output *****************

set/file/header hdr_c12_dpm5.prm
file/scan ../monte_car/data_full_conv1_dpm5 LAST=1000 FIRST=1
set/file/header hdr_c12_dpm4.prm
file/scan ../monte_car/data_full_conv1_dpm4 LAST=1000 FIRST=1
set/file/header hdr_c12_dpm3.prm
file/scan ../monte_car/data_full_conv1_dpm3 LAST=1000 FIRST=1
set/file/header hdr_c12.prm
file/scan ../monte_car/data_full_conv1 LAST=1000 FIRST=1
set/file/header hdr_c12 dpp3.prm
file/scan ../monte_car/data_full_conv1_dpp3 LAST=1000 FIRST=1
set/file/header hdr_c12 dpp4.prm
file/scan ../monte_car/data_full_conv1_dpp4 LAST=1000 FIRST=1
set/file/header hdr_c12 dpp5.prm
file/scan ../monte_car/data_full_conv1_dpp5 LAST=1000 FIRST=1 CHOPT=-o

spectra/write
quit
```

Which parts of the tensor should be optimized is indicated in the database, see App. B. The first number in each line of the tensor elements indicates whether it is kept fixed or is being fitted. A summary of the fitting is listed in a file which name is deduced from the command `fit_input`, f.i. `fit_full_conv1.inp` produces `fit_full_conv1.res`.

In Fig. 6.5 the result of such an optimization is shown. On the left side the scatter plot of `th_rot/dp_kin` is shown for elastic $^{12}$C$(e,e)$ scattering without any aberration corrections. On the right is shown the same data but now after correction for momentum aberations.

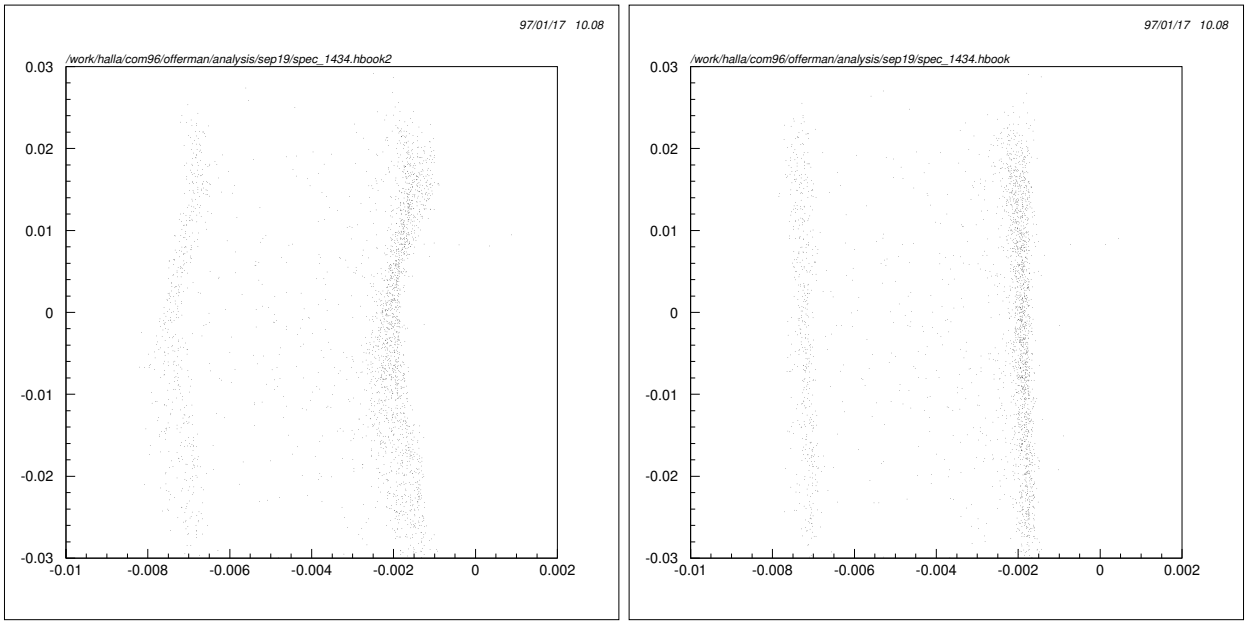


Figure 6.5: Two scatter plots showing $\theta_{\rm rot}$ versus dp/p for elastic $^{12}$C$(e,e)$ scattering. In the one on the left side, no aberration corrections have been performed on the calculated momentum. The plot on the right is the result of an optimization like the example shown in this section.

## 6.8 Coincidence Time

## 6.9 Missing Energy

## 6.10 Adding a new Optimization

# Appendix A

# Header File Description

The header file contains information which is needed during the scan to construct some of the variables. At the end of the scan this information is saved with each histogram. This way it is available to the next programs in the analysis chain. An example of a header file for analyzing $^{12}$C$(e,e)$ at 845 MeV is given below:

```
reaction c (e,e)
e0 r 1 845.0
particle e c lepton
spece r 5 3.4730 +16.00 0.0 0.030 0.060
target r 5 0.05580 2.20 2 1 1
tar_angle r 1 +8.00
isotope1_name c 12C
isotope1 r 3 0.989 12.000 6
isotope2_name c 13C
isotope2 r 3 0.011 13.003 6
```

The order of the lines is not important. They are built up in the following way. The first string indicates the name of the item. It is followed by a character which should be either `c` which stands for character string or `r` which indicates that real-number will follow. The next number gives the number of fields if a real-number follows. Finally, the values of the item should be given. Table A.1

Table A.1: Description of header file items.

| item | type | field | units | description |
|---|---|---|---|---|
| reaction* | c | | | reaction string |
| e0* | r | | MeV | electron beam energy |
| particle_e* | c | | | particle in HRSE |
| particle_h* | c | | | particle in HRSH |

continued on next page ...

Table A.1: ... continued from previous page ...

| item | type | field | units | description |
|---|---|---|---|---|
| spece* | r | | | parameters of the electron spectrometer |
| | | field | kG | magnetic induction of the dipole |
| | | angle | deg | angular position of spectrometer in-plane |
| | | | deg | angular position of spectrometer out-of-plane |
| | | solid | | spectrometer collimator acceptances |
| | | | rad | half horizontal acceptance |
| | | | rad | half vertical acceptance |
| spece_offset | r | | | position of the electron spectrometer optical point in the hall coordinate system |
| | | x | m | x component |
| | | y | m | |
| | | z | m | |
| spech* | r | | | parameters of the hadron spectrometer |
| | | field | kG | magnetic induction of the dipole |
| | | angle | deg | angular position of spectrometer in-plane |
| | | | deg | angular position of spectrometer out-of-plane |
| | | solid | | spectrometer collimator acceptances |
| | | | rad | half horizontal acceptance |
| | | | rad | half vertical acceptance |
| spech_offset | r | | | position of the hadron spectrometer optical point in the hall coordinate system |
| | | x | m | x component |
| | | y | m | |
| | | z | m | |
| target* | r | | | target parameters |
| | | d | g/cm$^2$ (cm) | total target thickness (model 1), target radius (model 2), target length (model 3). Is ignored for model 1 if foils are specified. |
| | | rho | g/cm$^3$ | target density |
| | | niso | | number of isotopes |
| | | isop | | isotope being investigated |
| | | model | | target model (1:foil; 2:circular; 3:cylindrical) |
| | | diam | cm | diameter of cylinder (only model 3) |
| foil | r | | | target foil parameters |
| | | d | g/cm$^2$ | target thickness |

continued on next page ...

Table A.1: ... continued from previous page ...

| item | type | field | units | description |
|---|---|---|---|---|
| | | width | cm | foil width |
| | | pos_x | | |
| | | pos_y | | |
| | | pos_z | cm | distance of foil from target center |
| tar_angle* | r | | | target angle parameters; only for model=1 |
| | | tangle | deg | angle between target coordinate system z-axis and HLCS z-axis |
| | | fangle | deg | angle between normal to target foil and target c.s. z-axis |
| tar_offset | r | | | position of target center in the hall coordinate system; it is assumed that this is also the center of rotation for the target. |
| | | x | m | x component |
| | | y | m | ignored for target model 1 |
| | | z | m | |
| isotope1_name* | c | | | name of isotope 1 |
| isotope1* | r | | | |
| | | f | | abundance ($\leq$1.0) |
| | | A | amu | atomic mass |
| | | Z | | isotope charge |
| isotope2_name* | c | | | name of isotope 2 |
| isotope2* | r | | | |
| | | f | | abundance ($\leq$1.0) |
| | | A | amu | atomic mass |
| | | Z | | isotope charge |
| reconstruct | r | | | parameter controling extended target corrections |
| | 0 | | | It is assumed that the reaction happened in the center of the target. No `x_tg` correction is applied. |
| | 1 | | | The position information of the beam and the vertex reconstructed with the spectrometers are used to calculate the reaction point in the target. This information is used to calculate the energy loss of the beam before and of the emitted particles after the reaction. |

continued on next page ...

Table A.1: ... continued from previous page ...

| item | type | field | units | description |
|---|---|---|---|---|
| | 2 | | | In addition to option 1 the vertices of all spectrometers are corrected for the fact that the particle did not emerge from the optical point[1]. |
| eloss | r | | | energy loss, additional to the energy loss in the target ... |
| | | loss_b | MeV | ... of the beam before the reaction |
| | | loss_e | MeV | ... of the particle detected in HRSE |
| | | loss_h | MeV | ... of the particle detected in HRSH<br>If only three parameters are specified, ESPACE does not distinguish between passing the cylinder wall or the end cap of the target cell (model 3). Two optional parameters, useful for cylindrical targets. For the other target models they are ignored. Here the two latter parameters are used only if the particle exits trough the cylinder wall. |
| | | loss_e | MeV | ... of the particle detected in HRSE, if passing the end cap |
| | | loss_h | MeV | ... of the particle detected in HRSH, if passing the end cap |

gives a description of each item and its entries. Note that items followed by an '*' are mandatory, you will have to give it in the header file, otherwise an error message will appear.

All values are initialized on zero. Although `spece` and `spech` are mandatory items, entry of one will suffice, the same is true for the isotope information.

In Fig. A.1 the configuration of the three target models is shown. Indicated are the different parameters describing the target. Realize that if target model 1 is chosen and a foil card is not given, the number of foils is assumed to be 1 with a target thickness as given in the target card. When the foil card is given, the target thickness in the target card is ignored.

[1]This is realized in the following way: a) the matrix elements are used to transform the focal plane coordinates into target coordinates. b) `x_tg`, the vertical position at the target, is calculated and replaces `dp`. c) "forward matrix elements" (determined from a SNAKE simulation) are used to transform those coordinates back into the focal plane. d) those manipulated focal plane coordinates are transformed into the final target coordinates.

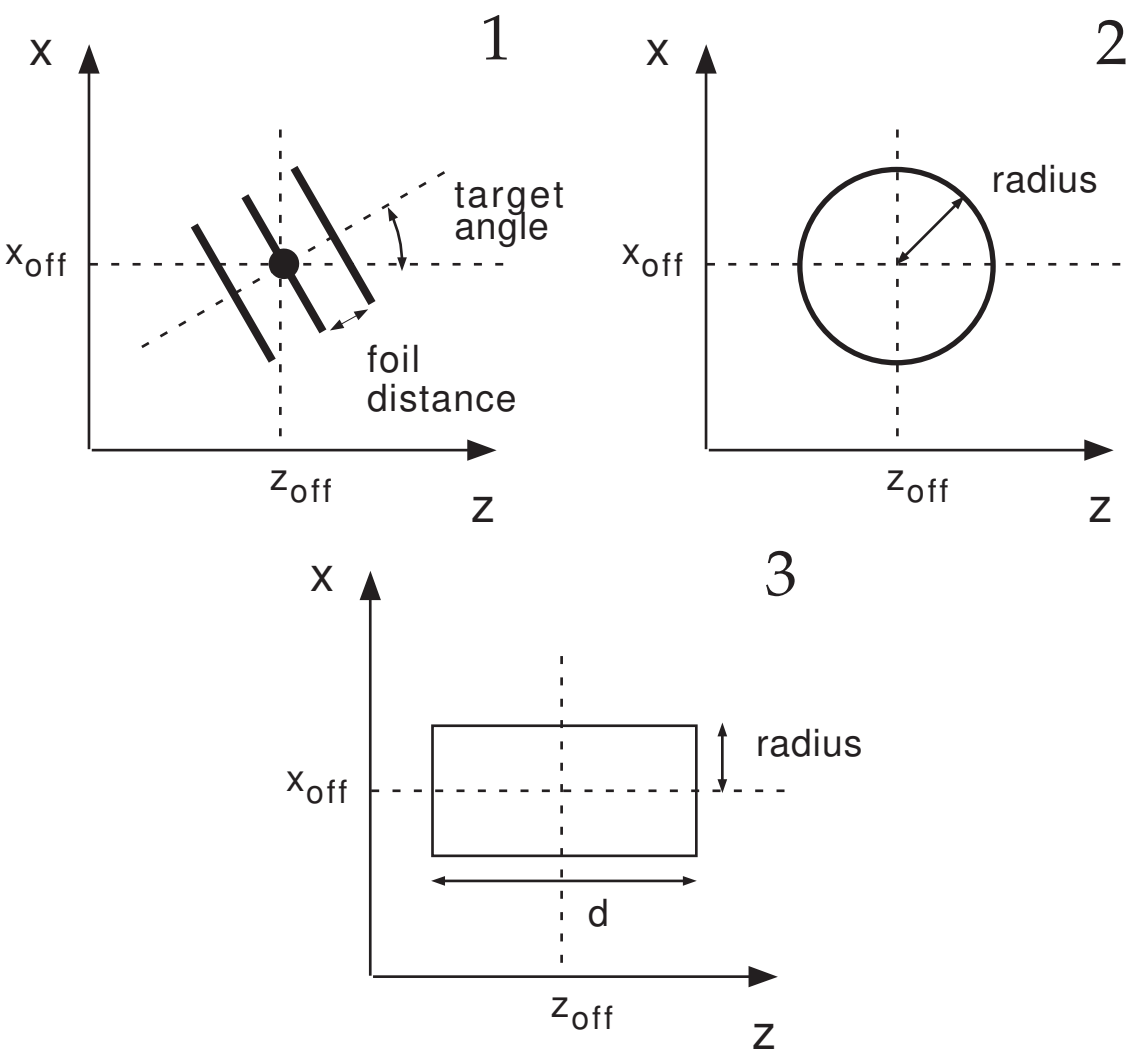


Figure A.1: Shown are the various target models and their parameters.

# Appendix B

# Database File Description

The database file contains constants of the spectrometers and their detectors. In the future this database can be accessed with a package developed around HEPDB. For the time being it is a plain ASCII file. We describe here how the part for spectrometer HRSE looks like, the part for the other spectrometer has the same structure.

The first seven lines of the database file contain drift chamber information and should look as follows:

```
10.0 10.0 10.0 10.0
5.7e+04 5.7e+04 5.7e+04 5.7e+04
4096. 4096. 4096. 4096.
5.0e-10 5.0e-10 5.0e-10 5.0e-10
2.0 0.0 0.0 0.0 -4.479051e-5 1.588897e-4 3.861646e-4 -6.223269e-5
```

The meaning of these lines is:

| line | Description |
|---|---|
| 1 | estimate of drift time resolution (chan) |
| 2 | electron drift velocity (m/s) |
| 3 | range of the VDC-TDC |
| 4 | VDC-TDC resolution (s/chan) |
| 5 | coefficients of a polynomial for drift length correction in the VDC(m) |

Next lines contain for each wire plane and each wire, the wire number and the TDC offsets. Each line contains information for five wires, f.i.:

```
1 503.0 2 503.0 3 503.0 4 503.0 5 503.0
```

If the wire number is negative then this wire will not be used in the analysis. This should be followed by lines containing wire number and position:

```
1 1.42057 2 1.41557 3 1.41057 4 1.40557 5 1.40057
```

Now information about the trigger detectors comes (first s1, followed by the same information for s2)

```
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0
0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0
0.700
1.9e+8
1.0e-10
0.00 42.46 37.18 36.65 39.97 36.02
30.57 16.25 37.34 18.28 74.78 66.88
0.0
0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0
0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0
```

The meaning of these lines is:

| line | Description |
|---|---|
| 1-2 | Parameters for correction of amplification of the ADC signal for each Čerenkov mirror. For each mirror first the offset is given and then an amplification factor. |
| 3 | Inverse of attenuation length of light in the scintillator ($m^{-1}$) |
| 4 | Speed of light in scintillator (m/s) |
| 5 | TDC resolution in scintillator plane (s/chan) |
| 6-7 | Time offset of each scintillator paddle on both sides (chan) |
| 8 | Parameter for correction timewalk effects in the scintillator timing with the ADC signal |
| 9-10 | Parameters for correction of amplification of the ADC signal for paddle on the right side, followed by the left side. For each paddle an offset and an amplification factor is given. |

At the end of the database the transport information of the spectrometer is given. The first number is the radius of the central ray through the dipoles. Then the coefficients for polynome of the spectrometer constant $\Gamma$ (in MeV/kG) are given and it is followed by the dispersion constants $d_i$ which together link dispersive position $x_{\rm fp}$ and momentum $p$ through the relation:

$$p = \left(\sum_{i=0}^{2} \Gamma_i B^i\right) \left(\sum_{i=1}^{6} d_i x_{\rm fp}^i\right)$$

The number following the dispersion constants indicates the definition of the transport matrix:

| # | Matrix definition |
|---|---|
| 1 | Transport elements using focal plane coordinates defined wrt. the local central ray |
| 2 | Transport elements using focal plane coordinates defined wrt. the detector system |

```
1.400
41.972 0.0 0.0
1.2063E-01 1.1105E-02 -1.0599E-03 -1.1160E-04 -1.2408E-04 0.0
2
```

It is completed with a list of the transfer elements. Each line contains the following information. The first integer tells whether the transfer element will be fitted when an OPTIMIZE command has been given. A 0 means keep fixed, a 1 means fit it and -1 indicates that when reconstructing the vertex at the target the first time use the values in the database but keep them fixed on zero during the fit. This is followed by the $x_{\rm fp}$ dependence of the particular transfer coefficient and its name:

$$M(x_{\rm fp}) = \sum_{i=1}^{6} M_i x_{\rm fp}^i$$

For example, the line for $\langle\theta|\theta\rangle$ looks like

```
1 1 0 0 -5.748E-1 1.254E-3 -1.028E-5 6.655E-8 0.000E+0 -1.21E-12 'T100'
```

# Appendix C

# Transformation between Different Coordinate Systems

In this section we will use the following abbreviations for the different coordinate systems:

SDCS Spectrometer Detector Coordinate System

SFPCS Spectrometer Focal Plane Coordinate System

SRCS Spectrometer Reconstructed Coordinate System

HLCS Hall A Laboratory Coordinate System

In Tab. C.1 a set of FORTRAN routines is described that transforms a vector between the different coordinate systems. These routines are part of the kinematics package. Sources are located in the directory `$HALLA_DIR/src/kinematics` and the library is in the directory `$HALLA_DIR/lib/$OSNAME`.

Table C.1: FORTRAN routines used to transform vectors between the different ESPACE coordinate systems.

| Routine | Description |
|---|---|
| `beam_to_transport` | This routine transforms a HLCS-vector in spherical coordinates to the SRCS in transport coordinates. This transformation is defined by a call to the routine `define_beam_to_transport`. |
| `define_beam_to_transport` | Initialization routine for the transformation used in beam to transport. |
| `transport_to_beam` | This routine converts a SRCS-vector in transport coordinates to the HLCS in cartesian coordinates. This transformation is defined by a call to the routine `define_trans`. |
| `define_transport_to_beam` | Initialization routine for the transformation used in transport to beam. |
| `ctrans` | Routine transforming geographical angles to spherical angles and vice versa. |
| `spherang` | Routine transforming geographical angles to spherical angles and vice versa. This routine gives also the option to switch HLCS and a variant of the HLCS with the $z$-axis along the momentum transfer $q$. |
| `newang` | |

# Appendix D

# ESPACE Reference Manual

Event Scanning Program for hall A Collaboration Experiments

## D.1 Espace/Debug

This menu contains several switches controling output for debugging purposes. At the moment the CODA event stream and the VDC tracks can be monitored.

**vdc** [ **vdc** ] `vdc` C "vdc tracking" `D='off'`
Possible `vdc` values are:
`off`

`on`

Switch the VDC debug mode. In the VDC debug mode, a graphics window will pop up and for each CODA event a track will be shown for each cluster in the U1,V1,U2 and V2 plane.

**coda** [ **coda** ] `coda` C "coda" `D='off'`
Possible `coda` values are:
`off`

`on`

Switch the CODA debug mode. In the CODA debug mode, part of the raw CODA data is displayed.

**sync** [ **sync** ] `sync` I "synchronization" `D=0 R=0:3`
Switch the synchronization debug mode. In the SYNC debug mode, CODA information is displayed together when synchronization problems appear.

**hbook** [ **hbook** ] `hbook` C "hbook" `D='off'`
Possible `hbook` values are:
`off`

`on`

Switch the HBOOK debug mode. In the HBOOK debug mode, HBOOK memory headers are displayed.

## D.2 Espace/SEt

Menu to assign parameters to ESPACE variables.

**test** [ **test** ] `test` C "test mode" `D='off'`
Possible `test` values are:
`on`

`off`

Switch the test mode. If the test mode is on, the command syntax and the existance of data files is checked. No scanning or optimizing is performed.

**auto_window** [ **awindc** ] `awindc` C "auto-windowing" `D='on'`
Possible `awindc` values are:
`on`

`off`

Switch the automatic histogram windowing. If the auto-window mode is on, the LOW_X, HIGH_X and NUM_X parameters are put on the default values for the particular variable to be histogrammed.

**hitbits hitbits** `hitbits` C "hitbits" `D='␣'`
Choose the condition, which detector should have fired or not, that is imposed on all histograms defined after this point.

**ntuple** [ **ntuple** ] `ntuple` C "NTUPLE format" `D='off'`
Possible `ntuple` values are:
`on`

`off`

If the NTUPLE switch is on, the data are store in NTUPLE format, otherwise it will be a multi-dimensional histogram.

**cosmic_rays [cosmic_rays]** `cosmic_rays` C "cosmic corr." `D='off'`
Possible `cosmic_rays` values are:

`on`

`off`

If COSMIC_RAYS is switched on, the VDC TDC drift times are corrected with an opposite sign since the cosmic rays drift from timing scintillator to VDC.

### D.2.1 Espace/SEt/File

Assign file names.

**header hdr_file** `hdr_file` C "header file" `D='␣'`
Set the name of the header file.

**database db_file** `db_file` C "database file" `D='␣'`
Set the name of the database file.

**opt_database optdb_file** `optdb_file` C "opt database file" `D='datab_opt'`
Set the name of the optimized database file in which results are stored of an optimization triggered with the FIT command.

**detmap detmap_file** `detmap_file` C "detmap_config file" `D='tstand_detmap.config'`
Set the name of the detector configuration file. This file describes how the raw data of the data acquisition code CODA should be interpretted.

**fit_input fit_file** `fit_file` C "fit input file" `D='fit.inp'`
Set the name of the input file containing parameters for optimization. This file contains starting parameters for fitting th_tg, ph_tg, y_tg, t_c, e_miss and e_miss/p_miss.

**output output_file** `output_file` C "output file" `D='espace.hbook'`
Set the name of the HBOOK output file containing histograms and Ntuples.

### D.2.2 Espace/SEt/TIming

Assign trigger definition parameters.

**e plane [ side ]**
`plane` C "scintillator plane" `D='s2'`
`side` C "paddle side" `D='right'`

Possible `plane` values are:
`s1`
`s2`

Possible `side` values are:
`left`
`right`

Choose the number scintillator plane and the paddle side that will define the trigger timing for e-spectrometer.

**h plane [ side ]**
`plane` C "scintillator plane" `D='s1'`
`side` C "paddle side" `D='left'`

Possible `plane` values are:
`s1`
`s2`

Possible `side` values are:
`left`
`right`

Choose the number scintillator plane and the paddle side that will define the trigger timing for h-spectrometer.

### D.2.3 Espace/SEt/TYpe

Assign CODA event types

**e type** `type` C "e-spec type" `D='1,2'`
Choose the CODA event type for single e-spectrometer event.

**h type** `type` C "h-spec type" `D='3,4'`
Choose the CODA event type for single h-spectrometer event.

**coin type** `type` C "coin type" `D='5'`
Choose the CODA event type for coincidence event.

**scal type** `type` C "scaler type" `D='140'`
Choose the CODA event type for scaler event.

### D.2.4 Espace/SEt/Fit

Assign fit parameters.

**npts npts_file** `npts_file` I "max points/file" `D=10000 R=0:5000000`
Set the maximum number of data points accumulated in one file for optimization.

#### D.2.4.1 Espace/SEt/Fit/Adc

Assign control parameters for the spectrometer path length fit.

**pedestal [ fit_pedestal ]** `fit_pedestal` C "fit adc offsets" `D='on'`
Possible `fit_pedestal` values are:
`on`
`off`
Fit the adc offsets of the scintillators when adc_⟨side⟩_c is being optimized.

**gain [ fit_gain ]** `fit_gain` C "fit adc gains" `D='on'`
Possible `fit_gain` values are:
`on`
`off`
Fit the adc gains of the scintillators when adc_⟨side⟩_c is being optimized.

#### D.2.4.2 Espace/SEt/Fit/Time

Assign control parameters for the spectrometer path length fit.

**paddle_e [ fit_paddle_e ]** `fit_paddle_e` C "fit time-offset paddles spec e" `D='off'`
Possible `fit_paddle_e` values are:
`on`
`off`
Fit the time offsets of the scintillator used in the trigger of the electron spectrometer when t_c is being optimized.

**paddle_h [ fit_paddle_h ]** `fit_paddle_h` C "fit time-offset paddles spec h" `D='off'`
Possible `fit_paddle_h` values are:
`on`
`off`
Fit the time offsets of the scintillator used in the trigger of the hadron spectrometer when t_c is being optimized.

**time_walk [ fit_timewalk order ]**

| | | | |
|---|---|---|---|
| `fit_timewalk` | C | "fit time walk coefficients" | `D='off'` |
| `order` | I | "order of polynome" | `D=1 R=1,2,3` |

Possible `fit_timewalk` values are:

`on`

`off`

Fit the time walk of the timing scintillator signals. It is assumed that it is the same for all scintillators of the electron and hadron spectrometer when t_c is being optimized.

#### D.2.4.3 Espace/SEt/Fit/Momentum

Assign control parameters for the spectrometer momentum fit.

**gamma_e [ fit_gamma_e ]** `fit_gamma_e` C "fit gamma spec E" `D='off'`

Possible `fit_gamma_e` values are:

`on`

`off`

Fit the electron spectrometer constant defining the central momentum.

**gamma_h [ fit_gamma_h ]** `fit_gamma_h` C "fit gamma spec H" `D='off'`

Possible `fit_gamma_h` values are:

`on`

`off`

Fit the hadron spectrometer constant defining the central momentum.

### D.2.5 Espace/SEt/Spectrum

Set histogram parameters.

#### D.2.5.1 Espace/SEt/Spectrum/Window

Set range.

**x1 low high**

| | | |
|---|---|---|
| `low` | R | "x1 lower limit" |
| `high` | R | "x1 upper limit" |

LOW and HIGH value of the x1 variable

**x2 low high**

| | | |
|---|---|---|
| `low` | R | "x2 lower limit" |
| `high` | R | "x2 upper limit" |

LOW and HIGH value of the x2 variable

**x3 low high** `low` R "x3 lower limit"
`high` R "x3 upper limit"
LOW and HIGH value of the x3 variable

**x4 low high** `low` R "x4 lower limit"
`high` R "x4 upper limit"
LOW and HIGH value of the x4 variable

#### D.2.5.2 Espace/SEt/Spectrum/Bins

Set number of bins.

**x1 num** `num` I "number of bins x1" `D=1`
Number of X1 bins for REAL variable, binsize for INTEGER variable.

**x2 num** `num` I "number of bins x2" `D=1`
Number of X2 bins for REAL variable, binsize for INTEGER variable.

**x3 num** `num` I "number of bins x3" `D=1`
Number of X3 bins for REAL variable, binsize for INTEGER variable.

**x4 num** `num` I "number of bins x4" `D=1`
Number of X4 bins for REAL variable, binsize for INTEGER variable.

### D.2.6 Espace/SEt/Vdc

Assign VDC analysis parameters.

**iterate iterate_vdc** `iterate_vdc` I "iterate VDC" `D=1 R=1:4`
Choose the number of iterations in the determination of a track through a VDC plane. If ITERATE_VDC ⟩ 1 the global angle coming from two wire planes is used in the calculation of several corrections.

**trig_cor [ trig_cor ]** `trig_cor` C "vdc COMMON STOP corr." `D='on'`
Possible `trig_cor` values are:
`on`
`off`
If TRIG_COR is switched on, the VDC TDC drift times are corrected for time of flight to the timing scintillator and signal propagation through this scintillator.

**tx_cor icor [ spectro tx_table ]**

```
icor       I   "vdc t-x switch"  D=1 R=0:3
spectro    C   "spectrometer"  D='e'
tx_table   C   "t-x HBOOK lookup table"  D='tx_table.hbool
```

Possible `spectro` values are:

`e`

`h`

The TX_COR parameter controls the drift time to position correction in the VDC's.

**tdc_cut tdc_cut** `tdc_cut I "TDC cut option" D=0 R=0,1,2`

With the TDC_CUT command the range of drift times that will used in the VDC analysis can be controlled. The default setiing is zero. The different cut options are (larger number means more restrictive condition):

0: For each wire only the largest TDC value is stored. In COMMON STOP

`mode this corresponds (no noise !) to the shortest drift time.`

1: 0 + TDC values larger than the TDC offset are not used (corresponding

`to negative drift times)`

2: 0 + 1 + TDC values corresponding to drift distances 50% larger than

`than the wire plane / cathode distance are not used.`

Notice that in options 1 and 2 the TDC offset for the corresponding wire is used. So an incorrect offset will result in loss of data !!

## D.3 Espace/Define

Menu to define logicals and variables.

**init** Set all parameters back on their default values.

**batch [ batch ]** `batch C "batch mode" D='off'`

Possible `batch` values are:

`on`

`off`

Stop execution if an error condition has occured.

**reset hist** `hist` C "hist list" `D='all'`
Empty contents of histograms in list. Correct syntax for the list is e.g. all: empty all histograms, 1-3,10: histograms 1,2,3 and 10. The numbers refer to the histogram HBOOK identifier.

**logical name str** `name` C "logical name"
`str` C "logical expr"
Define a new logical by combining existing logical through the following operations:

```
!   negate
&&  logical AND
||  logical OR
```

The order of operations can be guided by brackets.

**variable str** `str` C "expression"
With this command, constants and new variables can be defined.
New variables are defined by combining existing variables through the following operations:

```
( ) + - * / ^ **
```

and intrinsic functions

```
abs     acos    acosd   asin    asind   atan    atand   cos
cosd    cosh    deg     exp     log     log10   rad     sin
sind    sinh    sqrt    tan     tand    tanh
```

The definition string should look like, NEW : operation(OLD1,OLD2). Notice the assignment with ':'.
Constants are defined by a string like, PI=3.142 . Notice the assignment with '='.

### D.3.1 Espace/Define/Cut

Define cuts n varaibles calculated on a event-by-event base.

| | | | |
|---|---|---|---|
| | var_1d | C | "1d variable string" D='␣' |
| **1d var_1d xmin xmax** | xmin | R | "low range" D=-100. |
| | xmax | R | "high range" D=100. |

Define a window on a variable. This definition results in a logical which is TRUE if the variable value is inside the window and FALSE otherwise. The variable can be a scalar or an array. If it is an array the logical is TRUE if the contents of the whole array fulfill the condition.
Examples:

```
scalar cut:  define/cut/1d spec_e.ph_tg -0.03 0.03
array  cut:  define/cut/1d spec_e.u1.tdc  2000 2500
             define/cut/1d spec_e.u1.tdc[100;200] 2000 2500
The last cut is performed on the TDC values of wires 100 upto 200.
```

| | | | |
|---|---|---|---|
| | var_2d | C | "2d variable string" D='␣' |
| **2d var_2d direction par** | direction | C | "cut direction" D='above' |
| | par | C | "polynome parameters" D='1,0,0' |

Possible `direction` values are:
`above`

`below`

Define a region in 2 dimensions. This definition results in a logical which is TRUE if the combination of the values of the 2 variables is on the right side of the given polynomial, which is either ABOVE or BELOW. Again variables can be scalars or arrays.
Example:

```
define/cut/2d spec_e.ph_tg/spec_e.th_tg above 0.,1.,0.
```

| | | | |
|---|---|---|---|
| | var_2d | C | "2d variable string" D='␣' |
| **polygon var_2d file** | file | C | "cut data file" D='cut.dat' |

Define a polygon in 2 dimensions. This definition results in a logical which is TRUE if the combination of the values of the 2 variables is inside this polygon.
Example:

```
define/cut/polygon spec_e.ph_tg/spec_e.th_tg acceptance.dat
```

## D.4 Espace/SPectra

Histograms commands.

**save spec [ condition ]**

| | | | |
|---|---|---|---|
| spec | C | "spectrum list " | D='␣' |
| condition | C | "logical expr" | D='␣' |

Define a histogram of a particular variable. In this command several histograms can be defined by giving a list of variables separated by commas. After the the variable list a logical expression can be given which has to be fulfilled for incrementing the histograms.
Examples:

```
1-dim histogram: spectra/save spec_e.p_kin  spec_e.ph_tg&&spec_e.th_tg
2-dim histogram: spectra/save spec_e.th_fp/spec_e.p_kin
spec_e.ph_tg&&spec_e.th_tg
a 'set/ntuple on ' before the last save statement would result in a
ntuple instead of a histogram.
1-dim histogram of an array variable:
                spectra/save spec_e.u1.tdc[100;200]
This results in 1-dim histogram containing the TDC values of wires 100-200.
DO I = 1,368
   ISTA = [I]
   ISTO = [I]
   spectra/save spec_e.u1.tdc[[ISTA];[ISTO]]
ENDDO
This will give you a TDC histogram of each wire in the U1 VDC plane of the
electron spectrometer. Notice that the KUIP macro language has been used.
```

**rotate list rot**

| | | | |
|---|---|---|---|
| list | C | "list of spectra" | D='1-100' |
| rot | I | "rotation number" | D=1 |

Do not use this command.

**write [ list ]** list C "list of spectra" D='1-4999'
Save the defined spectra to a file. Correct syntax for the spectra list is e.g. all: save all histograms, 1-3,10: histograms 1,2,3 and 10. The numbers refer to the histogram HBOOK identifier.

## D.5 Espace/File

Menu containing commands related to the data file.

**scan file [ first last chopt rvf ]**

| | | |
|---|---|---|
| file | C | "file name" D='␣' |
| first | I | "first event" D=1 |
| last | I | "last event" D=-1 |
| chopt | C | "options" D='␣' |
| rvf | C | "review file" D='review.dat' |

Possible chopt values are:
'␣'

- o fit : Start fitting after scanning file
- r review : review file
- w write review : write review report after this file
- f format : not rawdata input
- l loop : Do not open the file again but continue scan

Scan a file. Start a scanning session in which the previously defined histograms and logicals are updated event-by-event with the specified file. In the scan command parameters like the first interrupt, last interrupts and several options can be specified.
Among the options are for instance the possibility to incorporate the data from this file in an optimization (specified before through a calibrate/fit statement) or to specify the format of the incoming data.
Example:

```
file/scan file.dat 1 1000 -f
```

In this example the first 1000 interrupts of the file 'file.dat' are analyzed. The data is not in raw format but specifid by the routine FILTER_TIL_EOF

**review file [ first last chopt rvf ]**

| | | |
|---|---|---|
| file | C | "file name" D='␣' |
| first | I | "first event" D=1 |
| last | I | "last event" D=-1 |
| chopt | C | "options" D='␣' |
| rvf | C | "review file" D='review.dat' |

Possible chopt values are:
'␣'

- w write review : write review report after this file
- f format : input data format

Review the detector coincidences. Issueing this command results in a review file in which a summary is given of the hit pattern of the detectors: how many times did a detector fire and how many coincidences and between which detectors are there.

**option name** `name` C "option name" `D='␣'`
Execute a USER defined command. The command file/option NAME executes the part in the user subroutine OPTION_DO linked to the string NAME as defined in the user subroutine OPTION_DEFINE.

**filter file condition** `file` C "file name" `D='␣'`
`condition` C "logical expr" `D='␣'`
The name of the file in which the filtered data are stored is defined here and the LOGICAL condition for the filtering. The data format of the file is the same as the one of the input data.

## D.6 Espace/Calibrate

This menu contains commands defining the optimization to be performed after scanning a CODA data file.

**optimize spec [ condition ]**

| | | | |
|---|---|---|---|
| spec | C | "spectrum name" | D='␣' |
| condition | C | "logical expr" | D='␣' |

Start an optimization. Possible variables that can be optimized:

| | |
|---|---|
| spec_e.dp_kin | Relative momentum after correction for aberations and kinematic broadening. |
| spec_e.th_tg/spec_e.ph_tg | Reconstructed theta and phi target coordinate of the electron spectrometer. |
| spec_h.th_tg/spec_h.ph_tg | Reconstructed theta and phi target coordinate of the hadron spectrometer. |
| spec_e.y_tg | Reconstructed y target coordinate of the the electron spectrometer. |
| spec_h.y_tg | Reconstructed y target coordinate of the the hadron spectrometer. |
| tc_cor | Coincidence time between e and h spectrometer after correction for time-of-flight and paddle offsets. |
| e_miss | Missing energy. |
| e_miss/p_miss | Missing energy and momentum for H(e,e'p). |
| spec_e.s1.adc_l_c | |
| spec_e.s1.adc_r_c | |
| spec_e.s2.adc_l_c | |
| spec_e.s2.adc_r_c | |
| spec_h.s1.adc_l_c | |
| spec_h.s1.adc_r_c | |
| spec_h.s2.adc_l_c | |
| spec_h.s2.adc_r_c | |
| spec_h.s3.adc_l_c | |
| spec_h.s3.adc_r_c | |
| spec_e.s1 | |
| spec_h.s2 | |

A LOGICAL condition can be specified for selection of the data to be used in the optimization.

# Appendix E

# Flow Diagram

The ESPACE sources were analyzized with the source code analyzer FORCHECK. From that output this flow diagram was created automatically. To date, there are several problems with that automatic generation.

- EXTERNAL statements and function declarations (like REAL SQRT) in a calling routine are treated as a call to that function.
- Functions which are parameters in a call of another function are treated as if both are called sequentially, rather that the called is executed by the calling.
- The flow diagram may be misleading because due the usage of the KUIP interpreter in ESPACE routines are not called sequentially. One can consider this as an IF ... ELSEIF ... ELSE ... ENDIF construct.
- Some functions should be skipped due to non-relevance, e.g. like NOSPAC (stripping blanks off a string).

The tree of a called function is shown only once. For subsequent calls is referenced the position where the complete tree can be found. The literals !"#$%&'()*+,- are used to indicate the call level and to guide the eye scrolling through the flow diagram.

```
ESPACE          1
    ! READ_ARGLIST          2
        " IARGC          3
        " GETARG          4
    ! ESPACE_REG          5
        " INIT_COOLHANDS          6
            # NR_ITEMS          7
                $ GETPIECE          8
                    % NSP1          9
                    % NSP2          10
                    % NSP1        (see 9)
```

```
        % NSP2        (see 10)
# VARIABLE         11
    $ VARIABLE_USER         12
# MINIT         13
# INIT_REVIEW         14
# FF_INIT         15
    $ FF_DEFVARF         16
        % EXMATCH         17
            & NOSPAC         18
                ' NSP1        (see 9)
                ' NSP2        (see 10)
                ' NSP1        (see 9)
                ' NSP2        (see 10)
        % FF_LOCIND         19
            & EXMATCH        (see 17)
            & VOFCALC         20
                ' CODE_VAR         21
                    ( CODE1         22
                        ) CONDENSE         23
                            * NOSPAC        (see 18)
                        ) EXMATCH        (see 17)
                        ) NON_ANUMERIC         24
                            * NOSPAC        (see 18)
                        ) NOSPAC        (see 18)
                        ) NON_ANUMERIC        (see 24)
                        ) CONDENSE        (see 23)
                        ) NOSPAC        (see 18)
                        ) EXMATCH        (see 17)
                    ( CODE2         25
                        ) CONDENSE        (see 23)
                        ) REVERSE         26
                        ) EXMATCH        (see 17)
                        ) NON_ANUMERIC        (see 24)
                        ) NOSPAC        (see 18)
                        ) NON_ANUMERIC        (see 24)
                        ) CONDENSE        (see 23)
                        ) REVERSE        (see 26)
                        ) NOSPAC        (see 18)
                        ) EXMATCH        (see 17)
                        ) NOSPAC        (see 18)
                        ) EXMATCH        (see 17)
        % FF_EVAL         27
```

```
            & VAR_FCALC         28
                ' USERVAR         29
                    ( FF_EVAL        (see 27)
                    ( VARIABLE        (see 11)
                    ( FF_EVAL        (see 27)
                    ( VARIABLE        (see 11)
            & RPOP          30
            & VAR_FCALC        (see 28)
            & RPUSH          31
        % NOSPAC        (see 18)
        % VOFCALC        (see 20)
        % EXMATCH        (see 17)
        % FF_LOCIND        (see 19)
        % FF_INTCHAR          32
            & EXMATCH        (see 17)
            & FF_LOCIND        (see 19)
            & NOSPAC        (see 18)
            & EXMATCH        (see 17)
            & FF_LOCIND        (see 19)
        % FF_TESTRANK          33
            & FF_RANK          34
        % FF_RPN         35
            & CPOP          36
            & IPOP          37
            & FF_IPF          38
            & FF_RANK        (see 34)
            & FF_SPF          39
            & FF_IPF        (see 38)
            & FF_SPF        (see 39)
            & IPOP        (see 37)
            & CPOP        (see 36)
            & FF_IPF        (see 38)
            & FF_SPF        (see 39)
            & FF_RANK        (see 34)
            & IPUSH          40
            & CPUSH          41
        % FF_ELFUN          42
        % FF_EVAL        (see 27)
    $ DINFO         43
    $ FF_DEFVARF        (see 16)
    $ DINFO        (see 43)
# DEFINE_VAR          44
```

```
            $ NR_ITEMS        (see 7)
            $ READSET         45
                % CONDENSE        (see 23)
                % NON_ANUMERIC        (see 24)
                % CONDENSE        (see 23)
                % NON_ANUMERIC        (see 24)
                % DERROR         46
        # NR_ITEMS        (see 7)
        # USER_INIT         47
            $ RAN2         48
            $ CPUBGN         49
                % INIT_TIMER         50
                % STAT_TIMER         51
                % INIT_TIMER        (see 50)
                % STAT_TIMER        (see 51)
            $ RESET_ALLSCALERS         52
                % RESET_SCALER         53
                    & EXMATCH        (see 17)
            $ RAN2        (see 48)
            $ VARIABLE_USER_INIT         54
                % DEFINE_VAR        (see 44)
        # NOSPAC        (see 18)
        # DERROR        (see 46)
! NOSPAC        (see 18)
! KUWHAT         55
    " DEBUG_PARAMETER         56
        # SETLOG         57
            $ COMPAR         58
                % NOSPAC        (see 18)
            $ NOSPAC        (see 18)
            $ COMPAR        (see 58)
        # DERROR        (see 46)
        # SETLOG        (see 57)
        # PLOT_INIT         59
        # SETLOG        (see 57)
    " SET_PARAMETER         60
        # GETERR         61
        # SETLOG        (see 57)
        # CONDENSE        (see 23)
        # DERROR        (see 46)
        # SETLOG        (see 57)
        # SET_BITS         62
```

```
        $ CONDENSE        (see 23)
        $ EXMATCH        (see 17)
        $ NON_ANUMERIC        (see 24)
        $ CONDENSE        (see 23)
        $ DERROR        (see 46)
        $ NON_ANUMERIC        (see 24)
        $ DERROR        (see 46)
        $ NOSPAC        (see 18)
        $ EXMATCH        (see 17)
        $ DERROR        (see 46)
    # SETLOG        (see 57)
    # CONDENSE        (see 23)
    # NOSPAC        (see 18)
    # OPEN_FILE         63
        $ DERROR        (see 46)
    # CLOSE_FILE         64
    # OPEN_FILE        (see 63)
    # CONDENSE        (see 23)
    # READSET        (see 45)
    # GETERR        (see 61)
    # SETLOG        (see 57)
    # CONDENSE        (see 23)
    # OPEN_FILE        (see 63)
    # DINFO        (see 43)
    # CLOSE_FILE        (see 64)
    # SHORTSTRING         65
    # DERROR        (see 46)
    # SETLOG        (see 57)
" DEF_PARAMETER         66
    # SETLOG        (see 57)
    # DERROR        (see 46)
    # INIT_COOLHANDS        (see 6)
    # SETLOG        (see 57)
    # CRESET         67
        $ COMPAR        (see 58)
        $ GETERR        (see 61)
        $ MEXIST         68
        $ COMPAR        (see 58)
        $ MRESET         69
            % MIDENT         70
            % MEXIST        (see 68)
            % MERROR         71
```

```
        % MIDENT        (see 70)
    $ READSET        (see 45)
    $ GETERR        (see 61)
    $ MEXIST        (see 68)
    $ DERROR        (see 46)
    $ MRESET        (see 69)
# DEFINE_LOGIC         72
    $ EXMATCH        (see 17)
    $ GETERR        (see 61)
    $ DERROR        (see 46)
    $ CODE_VAR        (see 21)
    $ DERROR        (see 46)
    $ READ_LOGIC         73
        % EXMATCH        (see 17)
        % GETERR        (see 61)
        % INDX_CUT_SP         74
            & SAMESPEC         75
            & DERROR        (see 46)
        % CONDENSE        (see 23)
        % NOSPAC        (see 18)
        % CONDENSE        (see 23)
        % DERROR        (see 46)
        % EXMATCH        (see 17)
        % NOSPAC        (see 18)
        % DERROR        (see 46)
        % CODE_VAR        (see 21)
        % DERROR        (see 46)
        % CODE_VAR        (see 21)
        % DERROR        (see 46)
        % INDX_CUT_SP        (see 74)
        % GETERR        (see 61)
        % DERROR        (see 46)
        % RPN         76
            & IPF         77
            & IPOP        (see 37)
            & IRNK         78
            & ISPF         79
            & DERROR        (see 46)
            & IPF        (see 77)
            & ISPF        (see 79)
            & IPOP        (see 37)
            & IPF        (see 77)
```

```
            & ISPF        (see 79)
            & DERROR        (see 46)
            & IRNK        (see 78)
            & DERROR        (see 46)
            & IPUSH        (see 40)
            & DERROR        (see 46)
    $ GETERR        (see 61)
    $ EXMATCH        (see 17)
    $ NOSPAC        (see 18)
# DEFINE_VARF         80
    $ FF_INT         81
        % FF_ELALLFUN         82
            & FF_ELFUN        (see 42)
    $ FF_LOCIND        (see 19)
    $ DERROR        (see 46)
    $ FF_DEFVARF        (see 16)
    $ DERROR        (see 46)
    $ FF_INT        (see 81)
    $ DERROR        (see 46)
    $ FF_LOCIND        (see 19)
# GETCUTS_1D         83
    $ GETERR        (see 61)
    $ CODE_CUT         84
        % SAMESPEC        (see 75)
        % INDX_CUT_SP        (see 74)
        % CODE_VAR        (see 21)
        % DERROR        (see 46)
        % CODE_VAR        (see 21)
        % DERROR        (see 46)
        % SAMESPEC        (see 75)
        % INDX_CUT_SP        (see 74)
        % DERROR        (see 46)
    $ GETERR        (see 61)
# GETCUTS_2D         85
    $ COMPAR        (see 58)
    $ GETERR        (see 61)
    $ CODE_CUT        (see 84)
    $ GETERR        (see 61)
    $ COMPAR        (see 58)
# GETCUTS_POLYGON         86
    $ GETERR        (see 61)
    $ SHORTSTRING        (see 65)
```

```
        $ NOSPAC        (see 18)
        $ DERROR        (see 46)
        $ CODE_CUT        (see 84)
        $ GETERR        (see 61)
" DEF_SPECTRA         87
    # GETERR        (see 61)
    # CONDENSE        (see 23)
    # DERROR        (see 46)
    # CONDENSE        (see 23)
    # SAVE_IT         88
        $ GETERR        (see 61)
        $ READ_LOGIC        (see 73)
        $ GETERR        (see 61)
        $ NOSPAC        (see 18)
        $ CODE_SAVE         89
            % INDX_SAVE_SP         90
                & SAMESPEC        (see 75)
            % SAMESPEC        (see 75)
            % DERROR        (see 46)
            % CODE_VAR        (see 21)
            % DERROR        (see 46)
            % SAMESPEC        (see 75)
            % INDX_SAVE_SP        (see 90)
        $ GETERR        (see 61)
        $ MAP_CURRENT         91
            % CH_FUN         92
            % CH_SP         93
                & NOSPAC        (see 18)
            % REVERSE        (see 26)
            % MGETERR         94
            % OUTFILE         95
                & REVERSE        (see 26)
                & NOSPAC        (see 18)
                & REVERSE        (see 26)
            % CH_FUN        (see 92)
            % CH_SP        (see 93)
            % NOSPAC        (see 18)
            % REVERSE        (see 26)
            % NOSPAC        (see 18)
            % REVERSE        (see 26)
            % DERROR        (see 46)
            % NOSPAC        (see 18)
```

```
% MBOOK1         96
    & MEXIST        (see 68)
    & MIDENT        (see 70)
    & MERROR        (see 71)
    & MROOM         97
    & MEXIST        (see 68)
    & MIDENT        (see 70)
    & MERROR        (see 71)
    & MDELETE         98
        ' MEXIST        (see 68)
        ' MIDENT        (see 70)
        ' MINIT        (see 13)
        ' MEXIST        (see 68)
        ' MERROR        (see 71)
        ' MIDENT        (see 70)
    & MERROR        (see 71)
    & MCOMMENT         99
        ' MEXIST        (see 68)
        ' MERROR        (see 71)
% MBOOKN         100
    & MEXIST        (see 68)
    & MIDENT        (see 70)
    & MERROR        (see 71)
    & MROOM        (see 97)
    & MEXIST        (see 68)
    & MIDENT        (see 70)
    & MDELETE        (see 98)
    & MCOMMENT        (see 99)
% MBOOK2         101
    & MEXIST        (see 68)
    & MIDENT        (see 70)
    & MERROR        (see 71)
    & MROOM        (see 97)
    & MEXIST        (see 68)
    & MIDENT        (see 70)
    & MERROR        (see 71)
    & MDELETE        (see 98)
    & MERROR        (see 71)
    & MCOMMENT        (see 99)
% DERROR        (see 46)
% MGETERR        (see 94)
% DERROR        (see 46)
```

```
    $ GETERR        (see 61)
    $ ASSIGN_SPECTRUM         102
# GETERR        (see 61)
# CONDENSE        (see 23)
# ROTDET         103
    $ READSET        (see 45)
    $ DERROR        (see 46)
# CONDENSE        (see 23)
# WRITEOUT         104
    $ GETERR        (see 61)
    $ READSET        (see 45)
    $ GETERR        (see 61)
    $ NOSPAC        (see 18)
    $ PREPARE_INFO         105
        % ICHFUN         106
        % RCHFUN         107
        % CH_RPN         108
            & CH_SPEC         109
                ' CH_FUN        (see 92)
                ' CH_SP        (see 93)
                ' CH_FUN        (see 92)
                ' NOSPAC        (see 18)
            & DERROR        (see 46)
        % CH_SPEC        (see 109)
        % CH_RPN        (see 108)
        % CH_SPEC        (see 109)
        % RCHFUN        (see 107)
        % ICHFUN        (see 106)
        % RCHFUN        (see 107)
        % ICHFUN        (see 106)
        % MCOMMENT        (see 99)
    $ INSERT_HEADER         110
        % RCHFUN        (see 107)
        % CHANGE_HEADER         111
        % MCOMMENT        (see 99)
        % NOSPAC        (see 18)
        % RCHFUN        (see 107)
        % NOSPAC        (see 18)
        % MCOMMENT        (see 99)
# CLOSE_FILE        (see 64)
# OPEN_FILE        (see 63)
# GETERR        (see 61)
```

```
    # MAKE_ALIAS         112
        $ GETERR        (see 61)
        $ CH_FUN        (see 92)
        $ CONDENSE        (see 23)
        $ NOSPAC        (see 18)
        $ READSET         (see 45)
        $ GETERR        (see 61)
        $ CONDENSE        (see 23)
        $ CH_FUN        (see 92)
        $ NOSPAC        (see 18)
        $ DERROR        (see 46)
    # DINFO        (see 43)
    # DERROR         (see 46)
" SCAN_FILE         113
    # GETERR         (see 61)
    # CONDENSE         (see 23)
    # DERROR         (see 46)
    # CONDENSE         (see 23)
    # DERROR         (see 46)
    # DINFO        (see 43)
    # FF_ELALLFUN         (see 82)
    # DERROR         (see 46)
    # INPUT         114
        $ GETERR        (see 61)
        $ READ_DATABASE         115
            % NR_ITEMS         (see 7)
            % GETERR        (see 61)
            % SHORTSTRING         (see 65)
            % OPEN_DATABASE          116
            % CLOSE_DATABASE          117
            % DINFO        (see 43)
            % DERROR         (see 46)
            % OPEN_DATABASE         (see 116)
            % READ_GEOMETRY          118
                & CH_FUN         (see 92)
                & DERROR         (see 46)
                & COPY_GEOM_GL          119
                & COPY_GEOM_SB          120
            % GETERR        (see 61)
            % CLOSE_DATABASE         (see 117)
            % DERROR        (see 46)
            % NR_ITEMS         (see 7)
```

```
    % DINFO        (see 43)
    % DERROR        (see 46)
    % NR_ITEMS        (see 7)
    % DINFO        (see 43)
    % NR_ITEMS        (see 7)
    % DINFO        (see 43)
    % DERROR        (see 46)
$ READ_HEADER         121
    % EXMATCH        (see 17)
    % GETPIECE        (see 8)
    % INI_HEADER         122
        & GETPIECE        (see 8)
        & READ_HDRLINE         123
            ' GETPIECE        (see 8)
            ' DINFO        (see 43)
            ' GETPIECE        (see 8)
            ' DINFO        (see 43)
        & GETPIECE        (see 8)
        & DINFO        (see 43)
        & GETPIECE        (see 8)
        & DINFO        (see 43)
        & DERROR        (see 46)
    % READ_HDRLINE        (see 123)
    % INI_HEADER        (see 122)
    % DERROR        (see 46)
    % SHORTSTRING        (see 65)
    % DINFO        (see 43)
    % MCGIVE         124
        & MEXIST        (see 68)
        & MIDENT        (see 70)
        & MEXIST        (see 68)
        & MERROR        (see 71)
        & MIDENT        (see 70)
    % GETPIECE        (see 8)
    % DERROR        (see 46)
    % READ_HDRLINE        (see 123)
    % EXMATCH        (see 17)
    % DERROR        (see 46)
    % EXMATCH        (see 17)
    % DERROR        (see 46)
$ SETUP_DET_LOGIC         125
    % EXMATCH        (see 17)
```

```
$ DERROR        (see 46)
$ READ_HEADER        (see 121)
$ DERROR        (see 46)
$ HEADER_TO_PROGRAM         126
    % NOSPAC        (see 18)
    % PROCESS_REACTION         127
        & REACTION         128
            ' NOSPAC        (see 18)
            ' CAPITALIZE         129
            ' SPSET         130
            ' GET_MASS         131
                ( CAPITALIZE        (see 129)
                ( ORDERNAME         132
                ( LOOKUP         133
            ' LOOKUP        (see 133)
        & DERROR        (see 46)
$ SETUP_DET_LOGIC        (see 125)
$ GETERR        (see 61)
$ DERROR        (see 46)
$ READ_DATABASE        (see 115)
$ GETERR        (see 61)
$ DERROR        (see 46)
$ INI_RAWDATA         134
    % DETMAP_DATASTREAM         135
        & NOSPAC        (see 18)
    % NOSPAC        (see 18)
    % LOAD_DETMAP         136
        & INIT_DECODER         137
    % LIST_DETMAP         138
    % DETMAP_DATASTREAM        (see 135)
    % DERROR        (see 46)
    % LOAD_DETMAP        (see 136)
    % LIST_DETMAP        (see 138)
    % INIT_RUNCOUNTERS         139
$ INI_SPEC_DETECTOR         140
    % FPP_INIT         141
$ INI_SPEC_TRANSPORT         142
    % POLY         143
    % CTRANS         144
    % POLY        (see 143)
$ SHORTSTRING        (see 65)
$ NOSPAC        (see 18)
```

```
$ RESET_ALLSCALERS        (see 52)
$ PROCESS_DATA         145
    % FILTER_TIL_EOF          146
        & INTERPRET_EVENT_COIN          147
            ' READ_CHER_E          148
                ( WHICH_CHER_MIRROR          149
            ' READ_SCINT_E          150
                ( WHICH_SCINT_PADDLE          151
            ' READ_SHOW_E          152
                ( WHICH_SHOW_BLOCK          153
                ( READ_SHOW_COEF          154
                    ) SHCAL_COEF_IO          155
                        * NOSPAC         (see 18)
                ( WHICH_SHOW_BLOCK         (see 153)
            ' READ_VDC_E          156
                ( SELECT_PADDLE          157
                ( GET_FPD_VERTEX          158
                    ) CALC_MATRIX          159
                        * POLY         (see 143)
                ( GET_POS          160
                ( GET_WIRES          161
                    ) RANGAUSS          162
                        * RAN2         (see 48)
                    ) HUNT          163
                    ) RANGAUSS         (see 162)
                ( TDC_COR_INI          164
                ( TDC_COR_TRIG          165
                    ) DIST_DET_VERTEX          166
                    ) POLY         (see 143)
                    ) CALC_MATRIX         (see 159)
                    ) DIST_DET_VERTEX         (see 166)
                    ) POLY         (see 143)
                ( TDC_COR_TX1          167
                    ) POLY         (see 143)
            ' READ_CHER_H          168
                ( WHICH_CHER_MIRROR         (see 149)
            ' READ_FPP_H          169
            ' READ_SCINT_H          170
                ( WHICH_SCINT_PADDLE         (see 151)
            ' READ_VDC_H          171
                ( SELECT_PADDLE         (see 157)
                ( GET_FPD_VERTEX         (see 158)
```

```
        ( GET_POS        (see 160)
        ( GET_WIRES        (see 161)
        ( TDC_COR_INI        (see 164)
        ( TDC_COR_TRIG        (see 165)
        ( TDC_COR_TX1        (see 167)
    ' PULSER_FIRED         172
    ' READ_HELICITY_H         173
        ( SUPERPERIOD_CHECK         174
    ' READ_SCINT_E        (see 150)
    ' READ_CHER_E        (see 148)
    ' READ_SHOW_E        (see 152)
    ' READ_VDC_E        (see 156)
    ' READ_SCINT_H        (see 170)
    ' READ_CHER_H        (see 168)
    ' READ_VDC_H        (see 171)
    ' READ_FPP_H        (see 169)
    ' READ_HELICITY_H        (see 173)
    ' PULSER_FIRED        (see 172)
& INTERPRET_EVENT_E         175
    ' READ_CHER_E        (see 148)
    ' READ_SCINT_E        (see 150)
    ' READ_SHOW_E        (see 152)
    ' READ_VDC_E        (see 156)
    ' PULSER_FIRED        (see 172)
    ' READ_SCINT_E        (see 150)
    ' READ_CHER_E        (see 148)
    ' READ_SHOW_E        (see 152)
    ' READ_VDC_E        (see 156)
    ' PULSER_FIRED        (see 172)
& INTERPRET_EVENT_H         176
    ' READ_CHER_H        (see 168)
    ' READ_FPP_H        (see 169)
    ' READ_SCINT_H        (see 170)
    ' READ_VDC_H        (see 171)
    ' PULSER_FIRED        (see 172)
    ' READ_HELICITY_H        (see 173)
    ' READ_SCINT_H        (see 170)
    ' READ_CHER_H        (see 168)
    ' READ_VDC_H        (see 171)
    ' READ_FPP_H        (see 169)
    ' READ_HELICITY_H        (see 173)
    ' PULSER_FIRED        (see 172)
```

```
    & NOSPAC        (see 18)
    & DERROR        (see 46)
    & INTERPRET_EVENT_COIN        (see 147)
    & INTERPRET_EVENT_E        (see 175)
    & INTERPRET_EVENT_H        (see 176)
    & DERROR        (see 46)
% GETERR        (see 61)
% RAWDATA_TIL_EOF         177
    & INTERPRET_EVENT_COIN        (see 147)
    & INTERPRET_EVENT_E        (see 175)
    & INTERPRET_EVENT_H        (see 176)
    & CORRUPT_SYNCH         178
        ' NOSPAC        (see 18)
        ' DERROR        (see 46)
    & INTERPRET_BPM_RAST         179
    & NOSPAC        (see 18)
    & DERROR        (see 46)
    & NOSPAC        (see 18)
    & CORRUPT_SYNCH        (see 178)
    & CONFIG_PARSE         180
    & SCALER_UPDATE         181
        ' SUPERPERIOD_CHECK        (see 174)
        ' CALC_CHARGE         182
        ' SUPERPERIOD_CHECK        (see 174)
        ' DERROR        (see 46)
        ' CALC_CHARGE        (see 182)
    & DERROR        (see 46)
    & GET_BCM         183
        ' GET_VALUE         184
    & INIT_EVENTCOUNTERS         185
    & EVENT_DECODER         186
    & DERROR        (see 46)
    & INTERPRET_BPM_RAST        (see 179)
    & INTERPRET_EVENT_COIN        (see 147)
    & INTERPRET_EVENT_E        (see 175)
    & INTERPRET_EVENT_H        (see 176)
    & READ_SPARE         187
% DOT3         188
% REACTION_Z         189
    & YTG_ERROR         190
        ' POW         191
    & TRANSPORT_TO_BEAM         192
```

```
        ' DERROR        (see 46)
    & YTG_ERROR        (see 190)
% RAWDATA_TIL_EOF        (see 177)
% FILTER_TIL_EOF        (see 146)
% GETERR        (see 61)
% DERROR        (see 46)
% FILTER_EVENT         193
    & DERROR        (see 46)
% PROCESS_SPECTROMETER         194
    & SPECTROMETER_RECONSTRUCT         195
        ' VDC_PRESORT         196
            ( ORDER_VDC_WIRES         197
            ( FIND_CLUSTERS         198
            ( VDC_PATTERN         199
        ' VDC_TRACKS         200
            ( FIND_TRACKS         201
                ) SETUP_TREE         202
                    * FIT_TRACK         203
                        + FDERIV_CLUS         204
                            , DERROR        (see 46)
                        + FUNCTN_CLUS         205
                            , DERROR        (see 46)
                        + CURFIT         206
                            , FCHISQ         207
                            , MATINV         208
                                - DERROR        (see 46)
                                - LUDCMP         209
                                - LUBKSB         210
                            , PROTECT         211
                            , FCHISQ        (see 207)
                        + FDERIV_CLUS        (see 204)
                        + FUNCTN_CLUS        (see 205)
                ) CLIMB_TREE         212
                    * SAVE_PATH         213
                ) ORDER_PATHS         214
                ) FILL_TRACK         215
                    * LAYER_TO_WC         216
                        + DERROR        (see 46)
            ( TDC_COR_INI        (see 164)
            ( TDC_COR_TRIG        (see 165)
            ( TDC_COR_TX1        (see 167)
            ( TDC_COR_TX2         217
```

```
        ) POLY        (see 143)
    ( TDC_COR_TX3         218
    ( FINECH_FIT         219
        ) POLFIT         220
            * MATINV        (see 208)
    ( FINECH_INTER         221
    ( FINECH_FIT_CL         222
        ) FDERIV_CLUS        (see 204)
        ) FUNCTN_CLUS        (see 205)
        ) CURFIT        (see 206)
        ) FDERIV_CLUS        (see 204)
        ) FUNCTN_CLUS        (see 205)
        ) CURFIT        (see 206)
        ) FDERIV_CLUS        (see 204)
        ) FUNCTN_CLUS        (see 205)
    ( FIND_TRACKS        (see 201)
' VDC_VERTEX         223
' VDC_VERTEX_GLOB         224
' CHERENKOV_PARAMETERS         225
    ( DET_VERTEX         226
' SCINT_CORRECTIONS         227
    ( POLY        (see 143)
    ( DET_VERTEX        (see 226)
    ( POLY        (see 143)
' SELECT_PADDLE        (see 157)
' VDC_PRESORT        (see 196)
' VDC_TRACKS        (see 200)
' VDC_VERTEX        (see 223)
' VDC_VERTEX_GLOB        (see 224)
' CONSISTENT_SC_VDC         228
' FP_VERTEX         229
    ( CALC_MATRIX        (see 159)
' SCINT_CORRECTIONS        (see 227)
' UPDATE_SCINT_TDC         230
' BETA_CALC         231
    ( DIST_DET_VERTEX        (see 166)
' CHERENKOV_PARAMETERS        (see 225)
' UPDATE_SCINT_TDC        (see 230)
' BETA_CALC        (see 231)
' PLOT_TRACKS_GLOB         232
    ( DERROR        (see 46)
    ( DEFINE_TRANSFORMATION         233
```

```
            ( FRAME          234
            ( LABEL          235
          ' TG_VERTEX        236
            ( CALC_VAR_TG          237
            ( POLY_INV          238
               ) POLY         (see 143)
            ( POW         (see 191)
            ( CALC_MATRIX         (see 159)
            ( CALC_VAR_TG         (see 237)
            ( POLY_INV         (see 238)
            ( DERROR         (see 46)
          ' CALC_COVARIANCE_FPD          239
          ' CALC_COVARIANCE_FPR          240
            ( POW         (see 191)
          ' CALC_COVARIANCE_FPT          241
            ( POW         (see 191)
          ' ADD_MS_COVARIANCE          242
            ( DIST_PLANE_VERTEX          243
            ( CALC_COVARIANCE_MS          244
            ( DIST_PLANE_VERTEX         (see 243)
            ( CALC_COVARIANCE_MS         (see 244)
            ( DIST_PLANE_VERTEX         (see 243)
            ( CALC_COVARIANCE_MS         (see 244)
          ' FPP_TRACK          245
            ( FPP_DRIFT_DIST          246
            ( TRK4          247
               ) TRACKIT          248
                  * SETI          249
            ( FPP_ALIGN_CORR_FRONT          250
            ( FPP_ALIGN_CORR_REAR          251
            ( FPP_ALIGN_SUMS          252
            ( FPP_PLOT_TRACKS          253
               ) DEFINE_TRANSFORMATION         (see 233)
               ) FRAME         (see 234)
               ) LABEL         (see 235)
          ' TOT_SHOWER          254
            ( DET_VERTEX         (see 226)
            ( SH_CLU_FIND          255
            ( SH_PRESORT          256
% REACTION_Z         (see 189)
% TRANSPORT_TO_BEAM         (see 192)
% DOT3         (see 188)
```

```
% BEAM_VERTEX          257
    & ELOSS_ELECTRON          258
    & ELOSS_HADRON          259
    & TRANSPORT_TO_BEAM         (see 192)
    & CTRANS         (see 144)
    & NEWANG          260
        ' ROTATE          261
            ( ROTATE3V          262
        ' CTRANS         (see 144)
        ' ROTATE         (see 261)
        ' CTRANS         (see 144)
        ' DERROR         (see 46)
    & EXT_TAR_COR          263
        ' CORRECT_FP          264
            ( CALC_VAR_FP          265
            ( POW         (see 191)
            ( CALC_VAR_FP         (see 265)
            ( POW         (see 191)
            ( CALC_VAR_FP         (see 265)
        ' TRANSPORT_TO_BEAM         (see 192)
        ' BEAM_TO_TRANSPORT          266
            ( DERROR         (see 46)
        ' CORRECT_FP         (see 264)
        ' FP_VERTEX         (see 229)
        ' TG_VERTEX         (see 236)
    & TARGET_EXIT          267
        ' FLAT_TARGET          268
        ' CIRCULAR_TARGET          269
        ' CYLINDRICAL_TARGET          270
    & ELOSS_ELECTRON         (see 258)
    & TARGET_EXIT         (see 267)
    & ELOSS_ELECTRON         (see 258)
    & TARGET_EXIT         (see 267)
    & ELOSS_HADRON         (see 259)
% CALC_KINEMATICS          271
    & ELECTRON_CALC          272
        ' CONTRACT          273
        ' PMAG          274
        ' PUT4V          275
        ' CONSERVE          276
        ' CONTRACT         (see 273)
        ' PMAG         (see 274)
```

```
        ' BOOST         277
        ' PMAG        (see 274)
        ' EXTANG4V         278
        ' PMAG        (see 274)
        ' CONTRACT        (see 273)
    & SECONDARY_CALC         279
        ' PMAG        (see 274)
        ' PUT4V        (see 275)
        ' NEWANG        (see 260)
        ' CONSERVE        (see 276)
        ' EXTANG4V        (see 278)
        ' NEWANG        (see 260)
        ' PMAG        (see 274)
        ' PUT4V        (see 275)
        ' ROTATE4V         280
            ( ROTATE3V        (see 262)
        ' BOOST        (see 277)
        ' EXTANG4V        (see 278)
        ' PMAG        (see 274)
    & CORRECT_KINEMATICS         281
        ' POLY        (see 143)
        ' POLY_INV        (see 238)
        ' DERROR        (see 46)
        ' POLY        (see 143)
% CORRECT_COINTIME         282
    & CALC_PATHDIFF         283
    & POW        (see 191)
    & CALC_PATHDIFF        (see 283)
% REVSUB         284
% SCANSUB         285
    & BOUNDS_I         286
    & BOUNDS_R         287
    & INSIDE_POLYGON         288
        ' ANGLE_BETWEEN         289
    & STACK_CRAWL         290
        ' LPOP         291
        ' DINFO        (see 43)
        ' DERROR        (see 46)
        ' LPUSH         292
        ' DINFO        (see 43)
        ' DERROR        (see 46)
    & USERVAR        (see 29)
```

```
& DET_SUB         293
    ' DET_SUB_USER         294
& VARIABLE        (see 11)
& INDEX_RANGE         295
    ' INDEX_RANGE_USER         296
    ' DERROR        (see 46)
& DET_SUB        (see 293)
& BOUNDS_I        (see 286)
& USERVAR        (see 29)
& BOUNDS_R        (see 287)
& DET_SUB        (see 293)
& BOUNDS_I        (see 286)
& USERVAR        (see 29)
& INSIDE_POLYGON        (see 288)
& STACK_CRAWL        (see 290)
& SAVESPEC         297
& VARIABLE        (see 11)
& STACK_CRAWL        (see 290)
& FILTER_EVENT        (see 193)
& OPTIMIZE_EVENT         298
    ' IN_EM_WINDOW         299
    ' IN_SP_WINDOW         300
        ( STACK_CRAWL        (see 290)
    ' SPECTROMETER_RECONSTRUCT        (see 195)
    ' DIST_DET_VERTEX        (see 166)
    ' POLY_INV        (see 238)
    ' DERROR        (see 46)
    ' SPECTROMETER_RECONSTRUCT        (see 195)
    ' IN_SP_WINDOW        (see 300)
    ' IN_EM_WINDOW        (see 299)
    ' POLY_INV        (see 238)
    ' DIST_DET_VERTEX        (see 166)
& INDEX_RANGE        (see 295)
& DET_SUB        (see 293)
& BOUNDS_I        (see 286)
& SAVEDIM         301
& USERVAR        (see 29)
& MFILL         302
    ' MEXIST        (see 68)
    ' MIDENT        (see 70)
    ' MEXIST        (see 68)
    ' MERROR        (see 71)
```

```
                ' MIDENT        (see 70)
                ' MLOCK         303
                    ( MIDENT        (see 70)
                    ( MEXIST        (see 68)
                    ( MERROR        (see 71)
                    ( MIDENT        (see 70)
        % SHCAL_EVENTS         304
        % FILTER_EVENT        (see 193)
    $ ACCUMULATE_RUNS         305
    $ WRITEOUT_ALLSCALERS         306
        % EXMATCH        (see 17)
        % NOSPAC        (see 18)
        % EXMATCH        (see 17)
        % WRITEOUT_SCALER         307
            & EXMATCH        (see 17)
            & RCHFUN        (see 107)
            & EXMATCH        (see 17)
            & RCHFUN        (see 107)
            & EXMATCH        (see 17)
            & RCHFUN        (see 107)
            & EXMATCH        (see 17)
            & RCHFUN        (see 107)
    $ ACCUMULATE_RUNS        (see 305)
    $ WRITEOUT_ALLSCALERS        (see 306)
    $ ACCUMULATE_RUNS        (see 305)
    $ WRITEOUT_ALLSCALERS        (see 306)
    $ ACCUMULATE_RUNS        (see 305)
    $ WRITEOUT_ALLSCALERS        (see 306)
    $ PROGRAM_TO_HEADER         308
    $ DERROR        (see 46)
# GETERR        (see 61)
# OPTIMIZE_DO         309
    $ DERROR        (see 46)
    $ OPTIMIZE_TRANSPORT         310
        % POLY_INV        (see 238)
        % DERROR        (see 46)
        % FILENAME         311
            & NOSPAC        (see 18)
        % POLY_INV        (see 238)
        % DERROR        (see 46)
        % CALC_MATRIX        (see 159)
        % TRANSPORTFIT         312
```

```
& ALLOCATE_MEM          313
& DEALLOCATE_MEM          314
& DPKIN_ERROR          315
    ' POW         (see 191)
& PHTG_ERROR          316
    ' POW         (see 191)
& THTG_ERROR          317
    ' POW         (see 191)
& YTG_ERROR         (see 190)
& FCHISQ_TRANSP_INDV          318
& FTEST          319
    ' BETAI          320
        ( BETACF          321
            ) DERROR         (see 46)
        ( GAMMLN          322
        ( DERROR         (see 46)
        ( GAMMLN         (see 322)
        ( BETACF         (see 321)
& ALLOCATE_MEM         (see 313)
& NOSPAC         (see 18)
& DERROR         (see 46)
& DEALLOCATE_MEM         (see 314)
& CURFIT_TRANSP          323
    ' FCHISQ_TRANSP          324
    ' PNTR2          325
    ' ALLOCATE_MEM         (see 313)
    ' DEALLOCATE_MEM         (see 314)
    ' ALLOCATE_MEM         (see 313)
    ' DERROR         (see 46)
    ' FUNCTN_TRANSP1          326
        ( CALC_VAR_TG         (see 237)
        ( POW         (see 191)
        ( CALC_MATRIX         (see 159)
        ( POW         (see 191)
        ( CALC_VAR_TG         (see 237)
    ' FUNCTN_TRANSP2          327
        ( CALC_VAR_TG         (see 237)
        ( POW         (see 191)
        ( CALC_MATRIX         (see 159)
        ( POW         (see 191)
        ( CALC_VAR_TG         (see 237)
    ' FCHISQ_TRANSP         (see 324)
```

```
' FDERIV_TRANSP1         328
    ( CALC_VAR_TG        (see 237)
    ( FOC_DERIV         329
    ( POW        (see 191)
    ( PNTR2        (see 325)
    ( CALC_MATRIX        (see 159)
    ( POW        (see 191)
    ( CALC_VAR_TG        (see 237)
    ( PNTR2        (see 325)
    ( FOC_DERIV        (see 329)
    ( PNTR2        (see 325)
    ( FOC_DERIV        (see 329)
    ( PNTR2        (see 325)
    ( FOC_DERIV        (see 329)
    ( PNTR2        (see 325)
    ( FOC_DERIV        (see 329)
    ( PNTR2        (see 325)
' FDERIV_TRANSP2         330
    ( CALC_VAR_TG        (see 237)
    ( FOC_DERIV        (see 329)
    ( POW        (see 191)
    ( PNTR2        (see 325)
    ( CALC_MATRIX        (see 159)
    ( POW        (see 191)
    ( CALC_VAR_TG        (see 237)
    ( PNTR2        (see 325)
    ( FOC_DERIV        (see 329)
    ( PNTR2        (see 325)
    ( FOC_DERIV        (see 329)
    ( PNTR2        (see 325)
    ( FOC_DERIV        (see 329)
    ( PNTR2        (see 325)
    ( FOC_DERIV        (see 329)
    ( PNTR2        (see 325)
' PNTR2        (see 325)
' MATINV        (see 208)
' PROTECT_TRANSP         331
' FUNCTN_TRANSP1        (see 326)
```

```
            ' FUNCTN_TRANSP2        (see 327)
            ' FCHISQ_TRANSP        (see 324)
            ' DEALLOCATE_MEM        (see 314)
        & DERROR        (see 46)
        & DEALLOCATE_MEM        (see 314)
        & DPKIN_ERROR        (see 315)
        & THTG_ERROR        (see 317)
        & YTG_ERROR        (see 190)
        & PHTG_ERROR        (see 316)
        & DPKIN_ERROR        (see 315)
        & THTG_ERROR        (see 317)
        & YTG_ERROR        (see 190)
        & PHTG_ERROR        (see 316)
        & CURFIT_TRANSP        (see 323)
        & FTEST        (see 319)
        & CURFIT_TRANSP        (see 323)
        & FCHISQ_TRANSP_INDV        (see 318)
        & DEALLOCATE_MEM        (see 314)
    % DERROR        (see 46)
    % POLFIT        (see 220)
    % LINSOLV        332
        & DERROR        (see 46)
        & LUDCMP        (see 209)
        & LUBKSB        (see 210)
    % TRANSPORTFIT        (see 312)
    % WRITE_DATABASE        333
        & DERROR        (see 46)
$ OPTIMIZE_COINTIME        334
    % DERROR        (see 46)
    % FILENAME        (see 311)
    % DERROR        (see 46)
    % PATHLENGTH_FIT        335
        & TC_ERROR        336
            ' POW        (see 191)
        & ALLOCATE_MEM        (see 313)
        & DEALLOCATE_MEM        (see 314)
        & ALLOCATE_MEM        (see 313)
        & NOSPAC        (see 18)
        & DERROR        (see 46)
        & DEALLOCATE_MEM        (see 314)
        & DERROR        (see 46)
        & DEALLOCATE_MEM        (see 314)
```

```
        & TC_ERROR        (see 336)
        & CURFIT_PATH         337
            ' FCHISQ_PATH         338
            ' PNTR2        (see 325)
            ' ALLOCATE_MEM        (see 313)
            ' DEALLOCATE_MEM        (see 314)
            ' ALLOCATE_MEM        (see 313)
            ' FUNCTN_PATH         339
                ( CALC_PATHDIFF        (see 283)
                ( POW        (see 191)
                ( CALC_PATHDIFF        (see 283)
                ( POW        (see 191)
                ( CALC_PATHDIFF        (see 283)
            ' FCHISQ_PATH        (see 338)
            ' FDERIV_PATH         340
                ( POW        (see 191)
                ( PNTR2        (see 325)
                ( POW        (see 191)
                ( PNTR2        (see 325)
            ' PNTR2        (see 325)
            ' MATINV        (see 208)
            ' PROTECT_PATH         341
            ' FUNCTN_PATH        (see 339)
            ' FCHISQ_PATH        (see 338)
            ' DEALLOCATE_MEM        (see 314)
        & DERROR        (see 46)
        & DEALLOCATE_MEM        (see 314)
    % WRITE_DATABASE        (see 333)
$ OPTIMIZE_EM         342
    % FILENAME        (see 311)
    % DERROR        (see 46)
    % EM_FIT         343
        & POLY        (see 143)
        & ALLOCATE_MEM        (see 313)
        & DEALLOCATE_MEM        (see 314)
        & ALLOCATE_MEM        (see 313)
        & NOSPAC        (see 18)
        & DERROR        (see 46)
        & DEALLOCATE_MEM        (see 314)
        & CURFIT_EM         344
            ' FCHISQ_EM         345
            ' PNTR2        (see 325)
```

```
                ' ALLOCATE_MEM        (see 313)
                ' DEALLOCATE_MEM        (see 314)
                ' ALLOCATE_MEM        (see 313)
                ' FUNCTN_EM         346
                    ( POLY        (see 143)
                ' FCHISQ_EM         (see 345)
                ' FDERIV_EM         347
                    ( POLY        (see 143)
                    ( PNTR2         (see 325)
                    ( POLY        (see 143)
                    ( PNTR2         (see 325)
                    ( POLY        (see 143)
                    ( PNTR2         (see 325)
                    ( POLY        (see 143)
                    ( PNTR2         (see 325)
                ' PNTR2         (see 325)
                ' MATINV         (see 208)
                ' PROTECT_EM          348
                ' FUNCTN_EM         (see 346)
                ' FCHISQ_EM         (see 345)
                ' DEALLOCATE_MEM         (see 314)
            & DERROR         (see 46)
            & DEALLOCATE_MEM         (see 314)
            & POLY         (see 143)
            & DEALLOCATE_MEM         (see 314)
        % WRITE_DATABASE         (see 333)
    $ OPTIMIZE_HEEP          349
        % FILENAME         (see 311)
        % DERROR         (see 46)
        % HEEP_FIT          350
            & POLY         (see 143)
            & ALLOCATE_MEM         (see 313)
            & DEALLOCATE_MEM         (see 314)
            & ALLOCATE_MEM         (see 313)
            & NOSPAC         (see 18)
            & DERROR         (see 46)
            & DEALLOCATE_MEM         (see 314)
            & CURFIT_HEEP          351
                ' FCHISQ_HEEP          352
                ' FUNCTN_HEEP          353
                    ( POLY        (see 143)
                ' WEIGHT_HEEP          354
```

( POLY (see 143)
( DERROR (see 46)
( POLY (see 143)
( MATINV (see 208)
' FCHISQ_HEEP (see 352)
' FDERIV_HEEP 355
( POLY (see 143)
' WEIGHT_HEEP (see 354)
' MATINV (see 208)
' PROTECT_HEEP 356
' FUNCTN_HEEP (see 353)
' WEIGHT_HEEP (see 354)
' FCHISQ_HEEP (see 352)
& DERROR (see 46)
& DEALLOCATE_MEM (see 314)
& POLY (see 143)
& DEALLOCATE_MEM (see 314)
% WRITE_DATABASE (see 333)
$ OPTIMIZE_ADC_SC 357
% DERROR (see 46)
% NOSPAC (see 18)
% WRITE_DATABASE (see 333)
$ OPTIMIZE_BETA 358
% ALLOCATE_MEM (see 313)
% DEALLOCATE_MEM (see 314)
% PNTR2 (see 325)
% DERROR (see 46)
% ALLOCATE_MEM (see 313)
% NOSPAC (see 18)
% POLFIT (see 220)
% PNTR2 (see 325)
% FILENAME (see 311)
% CURFIT_BETA 359
& BOUNDARY_BETA 360
& FCHISQ (see 207)
& PNTR2 (see 325)
& ALLOCATE_MEM (see 313)
& DEALLOCATE_MEM (see 314)
& ALLOCATE_MEM (see 313)
& DERROR (see 46)
& FUNCTN_BETA 361
' POLY (see 143)

```
            & FCHISQ        (see 207)
            & FDERIV_BETA         362
                ' PNTR2        (see 325)
            & PNTR2        (see 325)
            & BOUNDARY_BETA        (see 360)
            & PNTR2        (see 325)
            & MATINV        (see 208)
            & PROTECT_BETA         363
            & FUNCTN_BETA        (see 361)
            & FCHISQ        (see 207)
            & DEALLOCATE_MEM        (see 314)
        % DERROR        (see 46)
        % DEALLOCATE_MEM        (see 314)
        % WRITE_DATABASE        (see 333)
    $ OPTIMIZE_VDC_T0         364
        % NOSPAC        (see 18)
        % DERROR        (see 46)
        % WRITE_DATABASE        (see 333)
    $ OPTIMIZE_VDC_DRIFT         365
        % NOSPAC        (see 18)
        % WRITE_DATABASE        (see 333)
    $ OPTIMIZE_VDC_TX         366
        % ALLOCATE_MEM        (see 313)
        % DEALLOCATE_MEM        (see 314)
        % ALLOCATE_MEM        (see 313)
        % OPEN_FILE        (see 63)
        % NOSPAC        (see 18)
        % ALLOCATE_MEM        (see 313)
        % DEALLOCATE_MEM        (see 314)
        % CLOSE_FILE        (see 64)
    $ OPTIMIZE_ADC_CH         367
        % NOSPAC        (see 18)
        % WRITE_DATABASE        (see 333)
    $ DERROR        (see 46)
# DINFO        (see 43)
# SHCAL_DOFIT         368
    $ SHCAL_COEF_IO        (see 155)
    $ READ_SHOW_PEDS         369
    $ FUMILI         370
        % SGZ         371
            & ARITH1         372
            & ARITH2         373
```

```
                & ARITH3         374
            % MCONV         375
            % MONITO         376
        $ SHCAL_COEF_IO        (see 155)
        $ READ_SHOW_COEF        (see 154)
    # WREV         377
    # GETERR        (see 61)
    # NOSPAC        (see 18)
    # WRITE_CUT_SUM         378
        $ NOSPAC        (see 18)
    # CONDENSE        (see 23)
    # FF_ELALLFUN        (see 82)
    # DERROR        (see 46)
    # INPUT        (see 114)
    # GETERR        (see 61)
    # CONDENSE        (see 23)
    # FILTER_IT         379
        $ GETERR        (see 61)
        $ READ_LOGIC        (see 73)
        $ GETERR        (see 61)
        $ ASSIGN_FILTER         380
    # GETERR        (see 61)
    # NOSPAC        (see 18)
    # WRITE_CUT_SUM        (see 378)
    # DERROR        (see 46)
" DEF_CALIBRATION         381
    # GETERR        (see 61)
    # CONDENSE        (see 23)
    # DERROR        (see 46)
    # CONDENSE        (see 23)
    # OPTIMIZE_IT         382
        $ GETERR        (see 61)
        $ READ_LOGIC        (see 73)
        $ GETERR        (see 61)
        $ ASSIGN_OPTIMIZE         383
            % DERROR        (see 46)
            % CODE_VAR        (see 21)
            % DERROR        (see 46)
            % OPTIMIZE_INI         384
                & DERROR        (see 46)
                & READFIT         385
                    ' NR_ITEMS        (see 7)
```

```
                    ' GETERR        (see 61)
                    ' SHORTSTRING        (see 65)
                    ' DERROR        (see 46)
                    ' NR_ITEMS        (see 7)
                    ' READ_LOGIC        (see 73)
                    ' GETERR        (see 61)
                    ' DERROR        (see 46)
                    ' NR_ITEMS        (see 7)
                & NOSPAC        (see 18)
                & OPEN_FILE        (see 63)
            % DERROR        (see 46)
    # GETERR        (see 61)
" PLOTIT         386
" USER_EXIT         387
    # EXVERIFY         388
        $ NOSPAC        (see 18)
    # CLOSE_FILE        (see 64)
    # WRITEOUT_ALLSCALERS        (see 306)
    # SCALER_HISTORY         389
        $ NOSPAC        (see 18)
    # OPTIMIZE_END         390
        $ NOSPAC        (see 18)
        $ CLOSE_FILE        (see 64)
        $ NOSPAC        (see 18)
    # FPP_LAST         391
        $ DT         392
    # FPP_PULS_OUT         393
    # TOD         394
    # DINFO        (see 43)
```

# Appendix F

# COOLHANDS Programming Guide

## F.1 Concept

The COOLHANDS[11] system is designed to attack the problem of scanning and histogramming event-mode data in a flexible and general way. The program assumes only that the data contain events in which one can define

1. the number of words in the event,
2. the detector firing sequence (or hitbit pattern),
3. a set of variables which the user may wish to histogram and make cuts upon.

If the data can be represented in these general terms, then it can be scanned with COOLHANDS by attaching a few simple subroutines. The program is designed so that a user-programmer needs to know very little about the bulk of the program to interface a particular system to it.

## F.2 FORTRAN Components

The executable scanning program is formed by linking several object files together. Some of the components have been made into libraries. The following shows the makefile which is used to obtain the executable of a program called analyzer.

```
LOC_HALLA_LIB = /work/halla/com96/offerman/halla/lib/SunOS
LDFLAGS       = -L$(LOC_HALLA_LIB)
LIBS          = $(LOC_HALLA_LIB)/coolhands.o -lcool default -lfcalc
                                             -lmbook4d -lutil -lvms
FC            = f77
LINKER        = f77
MAKEFILE      = Makefile
OBJS          = analyzer.f
```

```
PROGRAM       = analyzer
SRCS          = analyzer.f
all:          $(PROGRAM)
$(PROGRAM):   $(OBJS)
        $(LINKER) $(LDFLAGS) $(OBJS) $(LIBS) -o $(PROGRAM)
```

The source file `analyzer.f` should contain the main program and a group of subroutines describing the processing of an event. Further on in this document is described the contents of the `analyzer.f` file. If the user is not interested in defining some of the routines one has to include the library `cool_default.f` at the end of the library list. It contains a default set of user subroutines and by including it in the linking process, routines not found in the user files, will be picked up from here.

The object file `coolhands.o` contains the important routines for scanning, cutting and histogramming the event stream. The user-supplied file `analyzer.f` contains all routines which are specific to the data acquisition of the event stream. Included here are an input subroutine to read data and interpret the event format and a routine to define and return variables for scanning and histogramming. These routines are described later in this document.

The library of default routines COOL_DEFAULT exists so that options may be added which the user need not know about. Many of the subroutines which may be included in the user set are not essential and the default routines may suffice. Since object libraries such as this only look for routines which have not been found in the linking process, the user may supercede any or all of these routines in the user set.

The histogram manipulation library `mbook4d` provides an interface to the CERN HBOOK package for initializing, defining, filling, and storing histograms. The `util` library contains very general routines which are used in many programs. Most of the routines in this library are all simple 'independent' routines which do not require routines from other libraries.

## F.3 FORTRAN Unit Numbers and Common Blocks

The FORTRAN components of COOLHANDS, excluding the user-written subroutines (e.g., `analyzer.f`), use the following FORTRAN unit numbers:

5 standard program input (STDIN)

6 standard program output (STDOUT)

29 graphical cut info are being used

The following named common blocks are used in the COOLHANDS system and should not be redefined by the user.

| common | file |
|---|---|
| cool_i<br>cool_r<br>cool_c<br>cool_l<br>cool_rec | coolhands/coolhands.h |
| defvars | coolhands/defspec.h |
| mbook_i<br>mbook_l<br>mbook_s<br>mbook_comm | mbook4d/mbook.h |
| menu | util/util.h |
| fcalc1<br>fcalcpass | fcalc/fcalc.h |

The problem of duplicating subroutine names should be taken care of by the compiler.

## F.4 User-Supplied Subroutines

The coolhands user-programmer must supply a set of routines. All but the first two of these listed below may be included by linking to the default set `cool_default.f`.

- `input`
- `variable`
- `det_sub.f`
- `filter_close`
- `filter_event`
- `filter_open`
- `index_range.f`
- `insert_header`
- `optimize_do`
- `optimize_event`
- `optimize_ini`
- `option_do`
- `option_setup`

- `user_exit`
- `user_init`

The `input` routine reads the event format for a file name which is passed. It is called after a `scan` command. This routine should read a block of data and, for each event, call one or both of `scansub` and `revsub`. `scansub` makes cuts and increment histograms, whereas `revsub` acquires statistics on the data. The routines `scansub` and `revsub`, which are found in the main set of COOLHANDS routines, call the second required user routine `variable` to get information for a given spectrum from each event. This routine should communicate with the `input` routine via user-defined common blocks. The routine `user_init` is called upon program entry and after the command `initialize`. Its function is to initialize the histogram package or to begin a CPU clock or define names needed for the option command to work. The routine `user_exit` is called only after the `exit` command and may be used by the user for miscellaneous purposes. For instance, one might stop the CPU clock and print the elapsed time. After the return from this routine to the main COOLHANDS program, a FORTRAN stop is encountered. The `filter_event` and `filter_open` routines allow the user to accomplish filtering.

What follows now are examples of the routines the user has to provide to COOLHANDS for some fictitious data stream.

### F.4.1 input

```
SUBROUTINE INPUT(SCANFILE,TEST,SCAN,REVIEW,LOOP,FIRST,LAST)
CHARACTER SCANFILE*(*)
LOGICAL TEST,SCAN,REVIEW,LOOP
INTEGER FIRST,LAST
```

The function of this routine is to read the data, interpret the event format, and call the proper COOLHANDS routines to perform the action desired. SCANFILE is name of the data file to be scanned. TEST is a logical telling the routine that it is to simply open the file to test for its existence and output an error message if necessary before closing the file and returning. SCAN tells whether or not to call a COOLHANDS routine for each event to scan the file, make cuts, and accumulate histograms. REVIEW tells whether to call the proper COOLHANDS routine for reviewing each file to accumulate statistics. See the reference chapter for explanations of these functions.

The routine should be organized to first open the file, then to return if test is .TRUE. or otherwise to read in a block of data. This data should then enter a loop in which each event is interpreted and placed into a common block (e.g., `common /event/`) which is shared with the user-supplied function `variable` described below. This common block should contain the number of words in the event, the hitbit pattern, and a list of variables required by the function variable. The hitbit pattern is a 32 bit integer in which each bit represents a detector and is set if that detector fired. An example of such a common is shown in the example routine below.

After an event has been decoded into the common block within this loop, the user should call the appropriate COOLHANDS routines:

```
      IF (SCAN) CALL SCANSUB
      IF (REVIEW) CALL REVSUB
```

An example of an input subroutine is shown below.

```
      SUBROUTINE INPUT(SCANFILE,TEST,SCAN,REVIEW,LOOP,FIRST,LAST)

      IMPLICIT NONE

      CHARACTER SCANFILE*(*)
      LOGICAL TEST,SCAN,REVIEW,LOOP
      INTEGER FIRST,LAST

C This routine reads and interprets the event buffer from interrupt
C FIRST upto LAST and sends events to
C subroutines SCANSUB or REVSUB to either execute desired cuts in spectra
C or get statistics on the data, respectively.
C     SCANFILE........ the name of the event file to be scanned
C     TEST ........... a logical which, if true, tells the routine to
C                      simply try to open the file, close it, and return
C     SCAN ........... a logical which, if true, tells the routine to
C                      call for each event the routine SCANSUB
C     REVIEW ......... a logical which, if true, tells the routine to
C                      call for each event the routine REVSUB
C     LOOP ........... a logical indicating whether the routine INPUT
C                      is being called in a loop and therefore the input
C                      file should not be opened at each entry.
C     FIRST .......... first interrupt to be analyzed
C     LAST ........... last interrupt to be analyzed

      INTEGER NRECORD
      PARAMETER(NRECORD=500)

C The data will be read into the following array

      INTEGER IBLOCK(NRECORD)

C To make the example simple, suppose we have fixed records of 500 I*4
C words per record and events with a constant length of 100 words. The
C event format will be (1) the number of words in the event, (2) the event
C type, (3) the event hitbit pattern, (4) 32 adc words, each corresponding
```

```
C to a bit in the hitbit pattern, (5) 32 TDC words, each corresponding to
C a bit in the hitbit pattern, (6) 33 electron words, where the first electron
C word is the on-line calculated fine momentum and other electron words may
C be drift times, ...etc. Each event will be placed into the following
C common block to be passed to function VARIABLE

      INTEGER NWIE,TYPE,HITBIT,ADC(0:31),TDC(0:31),ELE(0:31),FINE_MOM
      COMMON/EVENT/NWIE,TYPE,HITBIT,ADC,TDC,ELE,FINE_MOM

C miscellaneous declaration
      INTEGER IWORD,JEVENT,J,NR_EVENT
C open the event file to be scanned
      OPEN(1,FILE=SCANFILE,FORM='UNFORMATTED',STATUS='OLD',READONLY,
     &ERR=1000)
C if the "test" command is in effect, then it is enough to open the file and
C make sure it is there; in this case, close and return.
      IF (TEST) THEN
         CLOSE(1)
         RETURN
      ENDIF
      NR_EVENT=0
C read in an event record
10    READ(1,END=100,ERR=2000) (IBLOCK(J), J=1,NRECORD)
      IWORD=0
C decode the 5 events in the record and "scan" or "review" each event
      DO JEVENT=1,NRECORD/100
         NR_EVENT=NR_EVENT+1
         IF (NR_EVENT.GE.FIRST) THEN
            NWIE=IBLOCK(IWORD+1)
            TYPE=IBLOCK(IWORD+2)
            HITBIT=IBLOCK(IWORD+3)
            DO JDETECTOR=0,31
               ADC(JDETECTOR)=IBLOCK(IWORD+JDETECTOR+4)
               TDC(JDETECTOR)=IBLOCK(IWORD+JDETECTOR+36)
               ELE(JDETECTOR)=IBLOCK(IWORD+JDETECTOR+69)
            ENDDO
            FINE_MOM=IBLOCK(IWORD+68)
C The event is decoded, now scan or review:
            IF (SCAN) CALL SCANSUB
            IF (REVIEW) CALL REVSUB
C move onto the next event in the record
            IWORD=IWORD+NWIE
```

```
         ENDIF
      ENDDO
C now read another record
      IF (NR_EVENT.LT.LAST) GOTO 10
C
100   RETURN

C the following calls are to a routine in the MLIB library.
1000  CALL DERROR(' Error opening the event file.')
      RETURN
2000  CALL DERROR(' Error reading the event file.')
      END
```

### F.4.2 variable

```
      REAL FUNCTION VARIABLE(IVAR,IDET,INDX,NWORDS,EVENT HBIT,SETBIT,WEIGHT)
      INTEGER IVAR,IDET,INDX,NWORDS
      LOGICAL*1 EVENT_HBIT(*)
      LOGICAL SETBIT
      REAL WEIGHT
```

This routine is the function which returns event variables.

`ivar` specifies the variable type to return by indicating the index in character array `goodsp` below. The variable type `adc`, for example, would be named in `goodsp` and assigned within the routine as `variable=adc(idet)`, where the `adc` array is contained in the event common block. There are two special cases. If `ivar` is 0, `intvar` should return the number of words in the event. If `ivar` is less than 0, `intvar` should return the hitbit pattern.

`idet` is the detector number.

`intvar` returns the integer-variables which specify the hit pattern and the number of words in the event.

`setbit` is an output logical which tells the calling routine if the bit `idet` was set in the hit pattern for the event. Additionally, special cuts may be accomplished by using `setbit`.

`weight` is the weight to give the event in a histogram.

The variables returned are defined in the common block `defspec`, which is the only common block shared with the main program COOLHANDS. This common block is contained in the include file `defspec.h`.

```
structure /var_type/
   character*12 name
   integer intbin
   logical array
   logical subdet
   logical*1 all_det(32),all_det_opt(32)
   logical*1 enf_det(32)
   real range(2)
end structure

structure /det_type/
   character*80 string
   integer number
end structure

record /det_type/ defdet(32)
record /var_type/ defvar(10)
character var_txt(10)*80,det_txt(32)*80

common /defvars/ defdet,defvar,var_txt,det_txt
```

`goodsp` defines the names of the spectra as they will be identified in `input` by the user.

`iadet` is an array of integers which specifies allowed detectors for each spectrum; e.g., if detector 7 is allowed to be associated with spectrum 4, then bit 7 of `iadet(4)` will be set.

`iadetopt` is an array of integers which specifies allowed detectors for each spectrum which can be optimized.

`range` provides low and high limits for each spectrum. The spectrum range is used only by the `review` facility and as a window for the spectrum when `auto-window` is .TRUE.. Out-of- bounds variables are not corrected to the nearest window.

`intbin` is an array which types each defined spectrum as an integer or a real one. If the $i^{\text{th}}$ element of `intbin` is 1, the corresponding spectrum will be declared to be an integer one and thus integer-binning will be done. Otherwise, real-binning will be used. If the spectrum is set up as an integer one, the values will still be returned in the real variable but should be truncated to an integer number. See the COOLHANDS user manual[11] for a description of each type of binning.

The variable `ivar` in the calling sequence corresponds to the index of dimension `NSTYPES` for each of these arrays. Sample data statements to define the spectra are:

```
      DATA GOODSP /'adc','tdc','fm','mom',26*' '/
      DATA IADET / -2 , -2 , 1 , 1, 26*0 /
      DATA IADETOPT / 30*0 /
      DATA INTBIN /1,1,1,0,26*0/
      DATA RANGE / 0.,2047. , 0.,2047. , 0.,2047. , 0.,5. , 52*0. /
```

The above data statements define 4 variables:

`adc` is an integer variable within an allowed range of 0 to 2047; it may correspond to detectors 1-31 but not to detector 0

`tdc` is an integer variable within an allowed range of 0 to 2047; it may correspond to detectors 1-31 but not to detector 0

`fm` is an integer variable within an allowed range of 0 to 2047; it may correspond to detector 0 but not to detectors 1-31

`mom` is a real variable with an allowed range of 0. to 5.; it may correspond only to detector 0

An example of the function is

```
      REAL FUNCTION VARIABLE(IVAR,IDET,INDX,NWORDS,EVENT_HBIT,
     >                       SETBIT,WEIGHT)

C input: ivar,idet
c output: variable,intvar,setbit,weight

      IMPLICIT NONE

      INTEGER IVAR,IDET,INDX,NWORDS
      LOGICAL*1 EVENT_HBIT(*)
      LOGICAL SETBIT
      REAL WEIGHT

C include the common block /defspec/
      INCLUDE 'DEFSPEC.H'
C the following common block should be shared with the input routine
      INTEGER NWIE,TYPE,HITBIT,ADC(0:31),TDC(0:31),ELE(0:31),FINE_MOM
      COMMON /EVENT/ NWIE,TYPE,HITBIT,ADC,TDC,ELE,FINE_MOM
C miscellaneous declarations
      REAL UNBIN,CALC_MOM
      INTEGER ISEED
      DATA ISEED/536543/
C define the spectra
```

```
      DATA GOODSP /'Adc','Tdc','Fm','Mom',16*' '/
      DATA IADET / -2 , -2 , 1 , 1, 16*0 /
      DATA IADETOPT / 20*0 /
      DATA INTBIN /1,1,1,0,16*0/
      DATA RANGE / 0.,2047. , 0.,2047. , 0.,2047. , 0.,5. , 32*0. /
C initialize returned values
      WEIGHT = 1.0
      VARIABLE = 0.
      INTVAR = 0.
C did the detector IDET fire for this event?
      SETBIT = BTEST(HITBIT,IDET)
C return the appropriate variable for each spectrum type
      IF (IVAR.EQ.0) THEN
         INTVAR = NWIE
      ELSE IF (IVAR.LT.0) THEN
         INTVAR = HITBIT
      ELSE IF (.NOT.SETBIT) THEN
C
C Detector did not fire.
C
      ELSE
C
C Detector fired.
C
         IF (IVAR.EQ.1) THEN
            VARIABLE = ADC(IDET)
         ELSE IF (IVAR.EQ.2) THEN
            VARIABLE = TDC(IDET)
         ELSE IF (IVAR.EQ.3) THEN
            VARIABLE = FINE_MOM
         ELSE IF (IVAR.EQ.4) THEN
C the variable unbin spans one channel and simply "unbins" data to
C prevent problems associated with binning discrete data with bin sizes
C not the same as the original binning done by the tdc's and adc's.
C Note that a second course of action could have been taken here. The
C variable "fine_mom" could have set up as an integer variable by
C multiplying the actual calculated momentum by a number sufficiently
C large to gain the desired precision and then truncating it to an
C integer value.
            UNBIN = 0.5*( 1 -2.*RAN(ISEED))
            FINE_MOM = FINE_MOM+UNBIN
C the routine "calc_mom" below should be a routine to take the fine
```

```
C momentum and spectrometer field and generate the electron momentum
            VARIABLE = CALC_MOM(FINE_MOM)
         ELSE
            STOP 'Illegal spectrum type in module scan'
         ENDIF
      ENDIF
C
      RETURN
      END
```

### F.4.3 user_init

USER_INIT is called upon program entry and simply defines default values for some program variables upon entry. Other functions (like beginning the CPU clock or defining names for the option command) may be included here. The default routine which is provided in the COOL_DEFAULT library is shown below.

```
      SUBROUTINE USER_INIT(AWIND,NDIM,W1,W2,NBIN,DO_NTUPLE)
c
c-----------------------------------------------------------------------
c
      IMPLICIT NONE

c all passed variables are output
      LOGICAL AWIND,DO_NTUPLE
      INTEGER NDIM,NBIN(*)
      REAL W1(*),W2(*)
      LOGICAL first
      INTEGER jdim

      SAVE FIRST

      DATA FIRST /.true./

c for the 1st time through...
      IF (FIRST) THEN
c call a routine to begin accumulating cpu and real time (this routine is
c in MENU library)
         CALL CPUBGN
c set up the names for the option command
         CALL OPTION_SETUP
         FIRST = .FALSE.
      ENDIF
```

```
c assign default values for windows, \# bins, and ascii logical
      AWIND = .FALSE. ! autowindow
      DO JDIM = 1,NDIM
         W1(JDIM) = 0. ! lower window
         W2(JDIM) = 2048. ! upper window
         NBIN(JDIM) = 50 ! number of bins
      ENDDO
      DO_NTUPLE = .FALSE. ! multi-dim histograms, no ntuple format
      RETURN
      END
```

### F.4.4 user_exit

USER_EXIT is called upon a quit command and may be used for any purpose. The default routine which is provided in the COOL_DEFAULT library is shown below.

```
      SUBROUTINE USER_EXIT

      IMPLICIT NONE

      REAL TIMCPU,TIMCLK
      CHARACTER TIME*8,DAY*8,TEXT*80
C find the time of day and stop the cpu clock (these routines are in MLIB)
      CALL TOD(TIME,DAY)
      CALL CPUEND(TIMCPU,TIMCLK)
C
      WRITE(TEXT,100) TIMCPU/60.,TIMCLK/60.
      WRITE(6,110) TIME,DAY,TEXT
C
100   FORMAT(' CPU time (min):',F6.2,' Real time (min):',F6.2)
110   FORMAT(' Ending time: ',A,' Ending day: ',A,/A)
C
      RETURN
      END
```

### F.4.5 filter_open, filter_event and filter_close

If one wishes to filter data based upon certain cuts, these routines can accomplish that. filter_open is called to allow the user to open the filter file. filter_event is called each time an event has passed the specified cuts for that filter. Multiple filters may be accomplished simultaneously. The default routines supplied in the COOL_DEFAULT library are shown below.

```
      SUBROUTINE FILTER_EVENT(IUNIT)

      IMPLICIT NONE

      INTEGER IUNIT
      CHARACTER*(*) FNAME

C this entry is called only when the event has passed the conditions
C placed upon the filter specified by IUNIT
      RETURN
C
      ENTRY FILTER_OPEN(IUNIT,FNAME)
C this entry opens filter files
      RETURN
C
      ENTRY FILTER_CLOSE(IUNIT)
C this entry closes filter files
      RETURN
      END
```

### F.4.6 option_do

If the user wished to provide himself with options given during normal COOLHANDS input, he may supply this routine to accomplish that. Calls to option define (a COOLHANDS library routine) define the option names (one per call), and this routine executes them. The default routine supplied in COOL_DEFAULT library is shown below.

```
      SUBROUTINE OPTION_DO(IOPTION,ARGUMENT)

      IMPLICIT NONE

      INTEGER NOPTIONS,IOPTION
      PARAMETER (NOPTIONS=20)
      CHARACTER OPTION(NOPTIONS)*80,ARGUMENT*(*)
      INTEGER*4 JO

      DATA OPTION/20*' '/
C IOPTION gives the option number, and ARGUMENT is its argument
      RETURN
C
      ENTRY OPTION_SETUP
C This entry should be called from USER_INIT
C DO JO = 1,NOPTIONS
```

```
C CALL OPTION_DEFINE(OPTION(JO))
C ENDDO
C
      RETURN
      END
```

# Bibliography


[1] KUIP, CERN Program Library Long Writeup I102, version 2.05; Manual can be obtained at the anonymous ftp-site asis01.cern.ch in the directory doc/cernlib.

[2] PAW, CERN Program Library Long Writeup Q121; Manual can be obtained at the anonymous ftp-site asis01.cern.ch in the directory doc/cernlib.

[3] J.B. Mandeville, Ph.D. thesis, University of Illinois at Urbana-Champaign, 1993.

[4] G. Heyes *et al.*, www-site http://alcor.cebaf.gov/coda .

[5] E.A.J.M. Offermann, White paper for calibrating the High Resolution Spectrometers in hall A, TJNAF (1995)

[6] Backtracing particle rays through magnetic spectrometers: avoiding systematic errors in the reconstruction of target coordinates, Th. Veit, J. Friedrich and E.A.J.M. Offermann, Nucl. Instr. and Meth. **A336** (1993) 572.

[7] A. Ketikyan, H. Voskanyan, and B. Wojtsekhovski, *About Shower Detector Software*, Sept. 1997, http://www.jlab.org/Hall-A/data_reduc/calibrations/shower.ps.gz

[8] K.L. Brown, D.C. Carey, C. Iselin, and F. Rothacker, TRANSPORT: A Computer Program for Designing Charged Particle Beam Transport Systems, Stanford Linear Accelerator Center, 1991, SLAC-91, NAL-91, and CERN-73-16.

[9]

[10]

[11] COOLHANDS programming guide, J. Mandeville and E.A.F.M. Offermann