

# REPORT FOR THE E00-102 ANALYSIS GROUP

University of Lund – [Sweden]

(13 June – 15 August)

This document has been written as a complement of the internal report submitted to the E00-102 collaboration. It shows most of the relevant details about the creation of the MCEEP+RDWIA tool for the analysis of the E00-102 experiment.

It was written as a logbook. This implies that some information can be repeated or that it may appear in several sections. On the other hand this format shows better how the work was organized, the problems that we found and how we solved them.

## REPORT FOR THE MAILING LIST

13/JULY/06

Hi all

We (Kevin Fissum and me, Joaquin Lopez Herraiz, Ph.D. student from Madrid) have been preparing in Lund the simulation tool for the analysis of the e00102 experiment. Now that the code is running and the output has been checked, we are ready to start the analysis.

I will summarize the main steps that we have follow and the results we have yield so far.

### 1 ) MOTIVATION FOR A [ mceep+RDWIA ] CODE

Theoretical calculations for (e,e'p) bound-state proton knock-out, in general neglect many effects present in the experiment, like the energy spread of the beam or the spectrometer acceptances. To compare with experimental data, theoreticians usually take kinematical values at central values of the spectrometer acceptances. Although a good agreement has been achieved between fully relativistic theoretical calculations and experimental measurements for many (e,e'p) observables, analysis of high Q<sup>2</sup> experiments require a more realistic treatment of the experimental acceptances. On the other hand, simulation codes developed to take into account experimental effects, like mceep, have usually employed very simple models of the (e,e'p) reaction, in order to avoid long computational time.

### 2 ) MOTIVATION FOR A [ mceep+RDWIA ] CODE based on a grid of response functions

In this work, we perform an analysis combining the best of both approaches in order to obtain results suitable for comparison with experimental data. Response functions are obtained with a Relativistic Distorted Wave Impulse Approximation (RDWIA) calculation from the code of Udias and Vignote (thanks for their help). These response functions are evaluated for a range of values of the kinematic variables that covers the full acceptance of the experiment, and are stored in a file. The MCEEP code was improved with the ability to read these response files and to interpolate them to obtain the results for the actual kinematics of each simulated event. With this procedure, we can introduce a very sophisticated fully relativistic code, without the drawback of a extremely long computational time for the simulated events.

### 3 ) CHECKING mceep

Before starting with the mceep+RDWIA code, we compared the results from mceep v3.9 and mceep v3.5 using the same input decks and a default model for the physics model of the ee'p

reaction in  $^{16}\text{O}$ . We found some important differences, but with the help of P.E.Ulmer we found that they were due to different default values in v3.5 and v3.9 of the nucleon form factors. Using same form factors in both versions we got the same results.

#### 4 ) CHECKING mceep+RDWIA

Before starting the analysis of the e00102 experiment, we decided to check the output of the mceep+RDWIA code using the results of the previous calculations for the experiment e89003.

Mceep+RDWIA is supposed to be more accurate than RDWIA alone, because RDWIA codes assume central values of the kinematics variables. Nevertheless, if we reduce the acceptances of the spectrometers, set the energy spread of the beam to 0, and not consider radiation effects in mceep, we expect to have similar results with mceep+RDWIA and RDWIA alone.

We performed simulations for the  $1p_{1/2}$  state for 8 different kinematics corresponding to  $\theta_{pq}$  (angle between the ejected proton and the virtual photon) =  $\{-20^\circ, -16^\circ, -8^\circ, -2.5^\circ, +2.5^\circ, +8^\circ, +16^\circ, +20^\circ\}$ , using an energy of the beam of 2442 GeV. Two different settings of the spectrometer acceptances were considered: Extended acceptances corresponding to (4.5% momentum,  $\pm 25$  mrad (in-plane) and  $\pm 50$  mrad (out-of-plane) angles) and reduced acceptances to (1.0% momentum,  $\pm 2.5$  mrad (in-plane) and  $\pm 5.0$  mrad (out-of-plane) angles).

In the first figure, we have compared our results for these 8 kinematics (using expanded and reduced acceptances settings) with Udias and Vignote calculations (Madrid group) as published in Kevin et al. [PRC 70, 034606]. An excellent agreement between them can be noticed, especially with the reduced acceptances one, as we expected.

In the second figure, four different kinematics are shown:  $\theta_{pq} = (+2.5^\circ \text{ and } +20^\circ)$ . The effect of reducing the acceptances is clearly noticed.

#### 5 ) FOLLOWING STEPS

We are starting to create the grid of response functions for the e00102 experiment. We are temporarily focusing on  $1p_{1/2}$ , but will add the other "states" once we are convinced the most simply situation is working to perfection.

Once we are happy with the behaviour of the realistic physics for simple cases (no energy loss, no radiation), we will make the simulations more and more realistic and start comparing to data

#### 6 ) FINAL REMARKS

- A formal written report will be created for submission to the collaboration.
- Please check the on-line logbook periodically to view our progress.
- We are open to comments, suggestions, and criticisms.
- We anticipate a meeting at Jlab in late Sept to go over the results in detail.

#### FIGURE CAPTIONS:

Fig. 1. A comparison between the cross-section output for the removal of protons from the  $1p_{1/2}$ -state of  $^{16}\text{O}$  as a function of  $P_{\text{miss}}$  for the e89003 experiment using mceep(with extended and reduced acceptances)+RDWIA and RDWIA alone (From the calculations of Udias and Vignote (Madrid Group) for the e89003 experiment [PRC 70, 034606])

Fig. 2. Cross-Section as a function of  $P_{\text{miss}}$  for 4 different kinematics of the e89003 experiment. Results obtained with mceep+RDWIA code. Contour plots correspond to extended acceptances (4.5% momentum,  $\pm 25$  mrad (in-plane) and  $\pm 50$  mrad (out-of-plane) angles) and black boxes to reduced acceptances (1.0% momentum,  $\pm 2.5$  mrad (in-plane) and  $\pm 5.0$  mrad (out-of-plane) angles).

# UPDATE OF THE 803 PHYSICS OPTION of MCEEP

13/JULY/06

In order to include the information of the parameters chosen to create each grid file, like the kind of optical potential or the nucleon form factors employed, inside the grid file itself, I have added some lines at the beginning of the grid files: response\_cc1.out and response\_cc2.out. Doing so, we avoid future problems with messing up this information when different grid files are used.

This also involved some minor changes into the subroutine udias\_response.f to skip these initial lines when reading the grid. In addition to this, in this new version, the user is not asked to give mceep the number of points of the grid, as it finds these values from the grid file. So now, after having chosen the 803 physics option in mceep, the user only have to introduce the file name (absolute path) of the proper grid file. (See example)

```
RUNNING MCEEP:  mceep < mceep.in
```

```
MCEEP.IN:
```

```
mceep_input          # File with the inputs for mceep
b                    # Bound state
0                    # No radiation
803                  # Udias physics option (grid RDWIA)
p                    # Proton
/home/user/response_cc2.out      # Grid file
n                        # No
```

To merge the information of how the grid was created with the rest of parameters of each mceep simulation, some additional lines have been added into the subroutine summary.f of mceep. As a result, if the 803 physics option is now chosen, the main information of the grid is displayed at the end of the .sum files (See example). This is expected to be useful when different grid files were used.

Example of .sum file:

[...]

```
(e,e'N) rate after cuts:          0.58558E+01 sec^-1
sigma after global cuts:         0.26587E-07 fm^2/MeV/sr^2
```

```
Bad interpolation (extrapolation):      0
Expon. interpolation failures:          0
Spectral function out-of-range:         0
```

## TRANSPORT HISTOGRAM SUMMARY

```
ID   OOB   Sum     X-cent.   Y-cent.
--   ---   ---     -
-----
```

## KINEMATICS HISTOGRAM SUMMARY

ID    OOB    Sum    X-cent.    Y-cent.

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Using Udias Response Functions from file /home/minilobito/eep/exec/response\_cc2.out

### PARAMETERS USED FOR THE GRID CALCULATION:

-----  
8. 16. 7. 15.    Z,A of target nucleus and Z,A of residual nucleus  
0.06 11.0    Step, rfin for numerical radial integrals (fm)  
0 60    I\_min and I\_max in partial waves expansion for photon  
1    No cc (0),impose by subs.J\_Z(1) or rho(2)  
20 0    Form factor model and QMC option: 1 on, 0 off  
2    Recoil options (see comments in main code)  
4 0    Opt pot (see code),(-9) read it from file. img: (1) => wv=ws=0  
-0.00 -0.00    Coulomb distortion of initial and final electron in MeV  
2442    Incident e- energy in MeV  
390 460 3    Transfer Energy (MeV) wi, wf, Number of wsteps (NMAX = 15)  
925 1075 3    Transfer Momentum (MeV/c) qi,qf,Number of qsteps (NMAX = 15)  
-26 26 3    Theta\_pq (deg) (Initial, Final, Number of gsteps (NMAX = 75)  
12.0    Missing energy in MeV  
180    Phi angle in degrees (Not used)[Th>0,PM<0,Phi=0;Th<0,PM>0,Phi=180]  
1    2J of Bound Proton (BP)  
1    L of BP  
0    If 1, projecting over E>0 the wave function of BP  
0    If 1, EMA-noSV aproximation for wave function of BP  
0    Ejected proton: 0 DWIA, 1 PWIA, -9 opt potential, 5 ~pot0.pot  
0    If 1 E>0 projection for ejected proton (EP)  
0    If 1 EMA-noSV for EP  
'../16O\_SHELLS/o16nlsh.1p1p'

## e00102 – NUMBER OF POINTS AND RANGE OF THE GRID

**13/JULY/06**

Once that mceep+RDWIA(grid) method has been checked with previous calculations from the e89003 experiment, we are ready to create a grid for the e00103 one. In this case, we want to be more accurate than previous tests and this involves that more number of points (finer grid) should be used.

1 ) We have to set the ranges of the variables q, omega, theta\_pq

2 ) We have to set the number of points of each variable.

### 1 ) RANGES

The results from mceep with a previous (15x15x75) grid with the ranges: omega=460..550 MeV, q=950..1250 MeV/c and theta\_pq=-35..45° were used to evaluate which are the optimal values of the ranges and the number of points.

## FIGURE CAPTIONS:

Fig. 3. Histogram with the distribution of theta\_pq values for the different kinematics (i\_minus to k\_plus) of the e00102 experiment as obtained from a previous test simulation with mceep. Note that the range is not symmetric and covers a long number of angles.

Fig. 4. Histograms of the q and omega variables for two different kinematics of the e00102 experiment. Minor differences can be noticed in the ranges.

From this figures, we may set the ranges of omega,q, and theta\_pq as:

```
omega = 460..540 MeV
q=925..1250 MeV/c
theta_pq=-35..50°
```

NOTE: Nevertheless, these values have been obtained without any radiation included in the simulation...

## 2 ) NUMBER OF POINTS

In the previous test for the e00103 experiment, a grid with 15(q)x15(omega)x75(theta\_pq) was created. The size of each output file (response\_cc1.out and response\_cc2.out) was 2.5Mb and its generation took about 25' in my laptop. These numbers are proportional to the number of points chosen, so: 16875 points --> 2.5 Mb and 25'. Increasing the number of points by a factor of 100 is reasonable --> 250 Mb and 2 days of computing time.

We may think about using 3x3x10 time more points in each variable. It will depend on the kind of dependence of the response functions on the values of each one.

# UPDATE (II) OF THE 803 PHYSICS OPTION

## 19/JULY/06

In order to have a deeper insight about how the grid works for a certain simulation, I've added some lines to the summary file for the 803 physics option. In these lines, the number of events which fall inside/outside the grid is shown. The information is given for each variable (q, omega, theta\_pq). It can be useful to find some possible problems with the ranges selected.

In the example shown, it is clear that the ranges of qmag chosen are wrong for this simulation:

summary file:

```
[...]
0          If 1 E>0 projection for ejected proton (EP)
0          If 1 EMA-noSV for EP
'./160_SHELLS/o16nlsh.1p1p'
-----
qmag --> IN= 73. OUT= 104098.
omega --> IN= 94229. OUT= 9942.
theta --> IN= 104170. OUT= 1.
-----
```

# NUMBER OF POINTS FOR THE INPUT GRID

**19/JULY/06**

Comparing the results from mceep+RDWIA for the E00-103 experiment using a coarse and a fine input grid, we may conclude that we obtain the same result within statistical uncertainties with both of them. This is due to the fact that response functions have in general a smooth behaviour when we change the values of  $q, \omega$  and  $P_{\text{miss}}$ . This result will allow us to work with a number of points small enough to be calculated in less than 1 hour in a single computer, without any need of using more CPUs or long computational times.

# ATL EXTRACTION FROM SIMULATION

**20/JULY/06**

Results from mceep+RDWIA with realistic acceptances are similar to experimental data. Therefore, they should be treated as real data in order to obtain the values of ATL and RTL for different values of  $P_{\text{miss}}$ . This involves doing some cuts in the variables and some rebinning of the data. For doing so, different methods and criteria can be chosen.

We have spent some time discussing about the best way to perform the ATL extraction. Udias has also sent an email talking about it, so we have now different points of view and it is going to be interesting to compare the results of these approaches.

All of these analysis was already done with the data from the e89003 experiment (as it is described, for example, in the thesis of Gao), so we can use it (the cuts, the criteria and the final resulting 4 points) to check our method. As in previous checks we will focus on the  $p_{1/2}$  shell. After that, we will apply the checked method to the simulated results of the e00102 experiment.

**24/JULY/06**

The phase space for this kind of experiments can be determined by  $(E_{\text{miss}}, Q^2, \omega, P_{\text{miss}})$ . If we focus on a given shell (i.e. fixing a certain value for  $E_{\text{miss}}$ ) we'll have a 3-Dimensional phase space  $(q, \omega, P_{\text{miss}})$ .

The output data with the cross section from mceep simulations can be histogrammed into these 3D bins. In order to obtain the Asymmetry Transversal-Longitudinal (ATL), we compare cross sections using bins in both sides of  $P_{\text{miss}}$  ( $\pm P_{\text{miss}}$ ) with some criteria imposed on them.

In the thesis of Gao and Liyanage, it is explained that only those pair of bins  $(q, \omega, |P_{\text{miss}}|)$  with a phase space volume greater than 50% of the maximum were considered.

In this work we may use a more general approach: No criteria of 50% is applied a priori. We may then compare the impact of the criteria imposed on the results.

The calculation of ATL for a given pair of kinematics is a weighted mean of the ATLs corresponding to each phase space bin. The weights depend on the population of each pair of bins. Of course, some other weights can be considered, although we are not planning to use them.

In the following lines we describe the definitions that we are going to use in this study.

We may define the Phase Space Overlap (PSO) of a given bin i,j,k of a pair of 3D histograms as the ratio of the number of events from mceep simulations at that bin in each histogram:

$$PSO_{ijk} \equiv \frac{N_{ijk}^+(q_i, w_j, |Pm|_k)}{N_{ijk}^-(q_i, w_j, |Pm|_k)} * NF$$

NOTE: This is based on the fact that mceep uses uniform distributions for generating random values around the central ones in the simulations. This makes the number of events in each bin (q,w,Pm) to be proportional to the phase space volume of that bin.

The Normalization Factor (NF) makes the values of the PSO to be in the [0,1] range, and is defined as:

$$NF \equiv \frac{1}{Max(PSO_{ijk})}$$

We define the Phase Space Population (PSP) of a given bin i,j,k as the ratio of the number of events in that bin and the maximum number of events in a bin of the 3D histogram:

$$PSP_{ijk} \equiv \frac{N_{ijk}(q_i, w_j, |Pm|_k)}{MAX[N_{ijk}(q_i, w_j, |Pm|_k)]}$$

We may define the weight for the contribution of each bin to the final values of the ATL, RTL as a function of the PSO, or the PSP.

$$W_{ijk} \equiv W(PSO_{ijk}) \quad ; \quad W_{ijk} \equiv W(PSP_{ijk})$$

In the e89003 experiment the weights were defined as a step function:

$$W_{ijk}(e89003) \equiv \begin{cases} 1, & PSP_{ijk}^+ > 0.5 \ \& \ PSP_{ijk}^- > 0.5 \\ 0, & \text{Other cases} \end{cases}$$

NOTE: Some other choices can be considered. For example:

$$W_{ijk}(linear) \equiv PSO_{ijk}$$

Therefore, we may define the ATL for a specific kinematical setting as the weighted mean over the q,w,pmiss grid:

$$A_{TL} \equiv \frac{\sum_{i,j,k} W_{ijk} \cdot \left[ \frac{\sigma_{ijk}^- - \sigma_{ijk}^+}{\sigma_{ijk}^- + \sigma_{ijk}^+} \right]}{\sum_{i,j,k} W_{ijk}}$$

# **EXTREMELY REDUCED ACCEPTANCES**

**27/JULY/06**

Solved our “problem” with mceep when using a extremely reduced acceptances configuration (pinhole, reduced momentum acceptances). Central values of the kinematics used before (as they appear in the .inp file of mceep) were not very accurate. We also removed some global cuts that were in the .inp file. Doing so we were able to reduce acceptances much more than before without getting null output files.

## **MCEEP OUTPUT**

**27/JULY/06**

As Paw doesn't allow to create 3D histograms (Root does) we had to create a tool (a kumac file) which allows us to cope with it.

## **MCEEP OUTPUT – TOOL CREATED**

**1/AUGOST/06**

We have created a tool with PAW which allows us to easily create 3D histograms from hbook files. Using it we can generate an ascii file with the phase space and the cross section as a function of  $q, \omega$  and  $P_{miss}$  with a given bin volume.

The output file has 5 columns  $average\_q, average\_w, average\_p_{miss},$  number of events in that bin (proportional to the phase space volume) and the  $average\_cross$  section for each bin of the 3D histogram.

With this format, it's easy to work with the file, study the impact of using different criteria for the phase space overlapping with the output of the kinematics on the other side of  $P_{miss}$  and obtain the ATL (using an external code or working inside paw)

For the RTL we will need a factor with some kinematical variables.

## ATL – EXTREMELY REDUCED ACCEPTANCES

8/AUGUST/06

[FIG. 9] ATL plot for the p12 shell of the 16O (e89003 experiment). After having solved a problem when reducing the spectrometer acceptances, we have extremely reduced them ( $\pm 0.1$  mrad in the angles  $\theta_e, \phi_e, \theta_p, \phi_p$ ) and ( $\pm 0.1\%$  in the momentum acceptance) in order to see the impact on the cross sections and [the ATL](#).

It can be seen in the figure that in this ideal case, we obtain the same results as Udias calculations, as we expected. It is important to note that Data points are placed with  $P_{\text{miss}} = \text{Mean}(P_{\text{miss}})$  (the average of  $P_{\text{miss}}$  of the bins which passed all the cuts). [\[See previous plot in this logbook\]](#). On the other hand, in this ideal simulation, the results have the same value of  $P_{\text{miss}}$  as the one which can be obtained just from kinematics. A mismatched between these values can be noticed for low  $P_{\text{miss}}$ .

## q,omega Vs spectrometer variables

8/AUGUST/06

We have been using q and omega as our main variables in all these calculations (for example, making cuts in them). Nevertheless, from an experimental point of view, we can't make these cuts in q,omega directly and we have to use cuts in the spectrometer variables: ( $\theta_e, \phi_e, p_{f_e}, \theta_p, \phi_p, p_{f_p}$ ). We wanted to know the relation between q,omega and these variables in order to see how to make these cuts. REMARK: In mceep, theta is the out-of-plane angle and phi is the in-plane angle

[FIGURES](#) [Fig.10]

In the first figure, q is plotted against them. It is clear that only a cut in  $\phi_e$  (in plane angle) allows us to reduce the range of q.

In the second figure, w is also plotted against them. It is clear that in this case, a cut in  $p_{f_e}$  (limiting the range of acceptable values of the momentum of the electron) reduce very effectively the range of w.

## SPECTROMETER VARIABLES

8/AUGUST/06

After having discussed it with Kevin I have realised that in the previous figure I was using the angles  $\theta_e, \phi_e, \theta_p, \phi_p$  referred to the lab coordinate system [Variable numbers of mceep: 2,4,8,10 respectively] not to the target one (as it is usually done, for example, in the analysis of the e89003 experiment). [Variables of mceep: 62,64,72,74]. This mistake only occur in this specific plot.

We have also checked that the global cuts included in the .inp file of mceep and applied to the spectrometer variables was the same as in the ones applied to the data in the e89003 experiment, as shown in the thesis of Gao (central foil).

# SUMMARY OF TOOLS CREATED SO FAR

9/AUGUST/06

A lot of tools have been created so far in order to create, histogram, analyse and plot the results of the simulation. In addition, some scripts have been made to work with large number of simulations without being prompted for input data.

- 1 ) INPUT GRID FOR MCEEP (Generated using Udias RDWIA code)
- 2 ) CHANGES IN MCEEP SOURCE FILES (summary.f, udias\_response.f)
- 3 ) SCRIPT (experiment.sh) TO RUN MCEEP SIMULATIONS FOR ALL .INP FILES IN A DIRECTORY
- 4 ) SCRIPT (mceep2hbook.sh) TO CONVERT .NTU FILES IN A DIRECTORY INTO HBOOK FILES
- 5) SCRIPT (mceep\_input\_creator\_acceptances.sh), FORTRAN CODE (mceep\_inp\_creator.f --> creator) and TEMPLATE (mceep\_inp\_creator.tpl) TO CREATE .INP FILES WITH DIFFERENT ACCEPTANCES FOR MCEEP
- 6 ) KUMAC FILES TO PLOT THE RESULTS WITH PAW (EACH ONE IS INSIDE THE FOLDERS WITH THE FIGURES)
- 7 ) KUMAC FILE TO MAKE WITH PAW 3D HISTOGRAMS (q,w,Pm) IN ASCII FORMAT (.H3DAT) FROM HBOOK FILES --> [OUTPUT GRID FROM MCEEP]
- 8 ) SCRIPT (hbook2h3d.sh) and TEMPLATE (h3d.tpl) TO MAKE .H3DAT FILES FROM ALL HBOOK FILES IN A DIR.
- 9 ) SCRIPT (hbook2h3d\_2.sh) and TEMPLATE (h3d\_2.tpl) TO MAKE .H3DAT FILES FROM ALL HBOOK FILES IN A DIR, USING FOR EACH THETA\_PQ ANGLE THE SAME GRID FOR THE + AND - FILES.
- 10 ) SCRIPT (hbook2h3d\_2KTL.sh) and TEMPLATE (h3d\_2KTL.tpl) TO MAKE .H3DAT FILES FROM ALL HBOOK FILES IN A DIR, USING FOR EACH THETA\_PQ ANGLE THE SAME GRID FOR THE + AND - FILES. IT EVALUATES THE CROSS SECTION AND THE KTL VARIABLE FOR THE RTL CALCULATION.
- 11 ) FORTRAN CODE (ATL\_RTL.f) TO OBTAIN THE ATL AND RTL FROM A PAIR (+ AND -) OF .H3DAT FILES. IT INCLUDES DIFFERENT OPTIONS AND CRITERIA TO WORK WITH THE BINS
- 12 ) SCRIPT (h3d2ATL.sh) TO APPLY THE ATL ANALYSIS TO ALL .H3DAT FILES IN A DIR.
- 13 ) .PLT FILES TO PLOT THE RESULTS WITH GNUPLOT (EACH ONE IS INSIDE THE FOLDERS WITH THE FIGURES)

# RTL FROM MCEEP SIMULATIONS

15/AUGUST/06

The RTL can be obtained using data with Pmissing in both sides of  $q$ . Making use of equation [-] it is easily derived that:

$$R_{TL} \equiv \frac{\sum_i W^i \cdot \left[ \frac{\sigma_i^- - \sigma_i^+}{2 \cdot R^i \cdot K^i \cdot V_{TL}^i} \right]}{\sum_i W^i}$$

in this expression,

$W_i$  is given by the number of events in each bin which passed all the cuts. The sum uses all those bins which match a imposed phase-space volume criteria.

$$R^i \text{ is the recoil factor: } R^i \equiv \left| 1 - \frac{E_F^i \cdot \vec{p}_F^i \cdot \vec{p}_R^i}{E_R^i \cdot \vec{p}_F^i \cdot \vec{p}_F^i} \right|^{-1}$$

$$K^i \equiv \frac{E_F^i \cdot p_F^i}{(2\pi)^3} \cdot \sigma_M^i \quad ,, \quad \sigma_M^i \equiv \left[ \frac{\alpha \cdot \cos(\theta_e^i/2)}{2 E_I^i \cdot \sin^2(\theta_e^i/2)} \right]^2$$

$$V_{TL}^i \equiv \left| \frac{(Q^i)^2}{(q^i)^2} \right| \sqrt{\frac{(Q^i)^2}{(q^i)^2} + \tan^2(\theta_e^i/2)} = \left[ 1 + \left( \frac{\omega^i}{q^i} \right)^2 \right] \sqrt{1 + \left( \frac{\omega^i}{q^i} \right)^2 + \tan^2(\theta_e^i/2)}$$

It is clear from these equations that in order to create a RTL plot, we have to make previously another 3D histogram with the information from all these variables. Therefore we create a variable called  $K_{TL}^i$ :

$$K_{TL}^i \equiv 2 \cdot R^i \cdot K^i \cdot V_{TL}^i = f(E_I, \theta_e, E_F, E_R, E_p, \vec{p}_F, \vec{p}_R, \omega, q)$$

For each bin  $i$  ( $q^i, \omega^i, p_{miss}^i$ ) we evaluate the mean value of this new variable and make a 3D histogram  $\overline{K_{TL}^i}(q^i, \omega^i, p_{miss}^i)$  in the same way we did with the cross section. Having done this previous step we can obtain easily the RTL for a specific kinematical setting as:

$$R_{TL} \equiv \frac{\sum_i W^i \cdot \left[ \frac{\sigma_i^- - \sigma_i^+}{K_{TL}^i} \right]}{\sum_i W^i}$$

We expect a similar behaviour as ATL, that is, central  $q$ ,  $\omega$  bins will lay very close to theoretical calculations, but acceptance effects will be important for low P missing.

# RTL FROM MCEEP SIMULATIONS (II)

16/AUGUST/06

MCEEP was written in such a way that adding more physics options or kinematical variables were easy. Therefore we can add some useful kinematical variables in mceep output. This allows us to obtain the variable KTL in a more easy way.

Meanwhile we can obtain KTL combining the output of several kinematical variables as follows:

mceep variable 27 ( $f_{rec}$ ) represents the recoil factor:  $R^i = 1 / f_{rec}^i$

$\sigma_M^i$  can be obtained using the var 2 (TH\_E\_I) and var 13 (E0\_I)

$$K^i \equiv \frac{E_F^i \cdot p_F^i}{(2\pi)^3} \cdot \sigma_M^i = \frac{(p_F^i)^2 \sqrt{(1 + (m_p / p_F^i)^2)}}{(2\pi)^3} \cdot \sigma_M^i \quad \text{can be obtained with var. 12 (PF_P_I)}$$

$$V_{TL}^i = \left[ 1 + \left( \frac{\omega^i}{q^i} \right)^2 \right] \sqrt{1 + \left( \frac{\omega^i}{q^i} \right)^2 + \tan^2(\theta_e^i / 2)}$$

requires the knowledge of w,q and th\_e\_i.

Therefore we only need 2 more variables that are not already included in our ntuples: The recoil factor (var 27) and the E0\_I (var 12), although this is still more a parameter than a variable.

$$\text{UNITS: } \frac{d^5 \sigma}{d\omega d\Omega_e dE_{miss} d\Omega_p} = R \cdot K \cdot \sigma_{Mott} \cdot [v_L R_L + v_T R_T + v_{LT} R_{LT} \cos(\phi) + v_{TT} R_{TT} \cos(2\phi)]$$

$$\left[ \frac{d^5 \sigma}{d\omega d\Omega_e dE_{miss} d\Omega_p} \right] = fm^2 / MeV$$

$$[K] = MeV^2$$

$$[\sigma_{Mott}] = fm^2$$

$$[v_{LT}] = [Adim]$$

$$[R_{LT}] = fm^3$$

There is a factor  $\hbar c^3$  missing to convert RLT into  $[MeV^{-3}]$  units.

# RTL FROM MCEEP SIMULATIONS (III)

18/AUGUST/06

We have decided to evaluate the recoil factor instead of using MCEEP' variable number 27, because we were not fully convinced about the meaning of this variable. It is not difficult to obtain the recoil factor  $R^i$  given the energy and momentum of the ejected proton and the nucleus:

$$R^i \equiv \left| 1 - \frac{E_F^i \cdot \vec{p}_F^i \cdot \vec{p}_R^i}{E_R^i \cdot \vec{p}_F^i \cdot \vec{p}_F^i} \right|^{-1}$$

With the new variable  $K_{TL}$  we can obtain plot of the  $R_{TL}$  the same way we did with the  $A_{TL}$ .

NOTE: We have to include the spectroscopic factor (=0.7) in the evaluation of the RTL. This step is not required in the ATL extraction.

We have done some tables with the statistics of each bin and the impact of the overlap criterium in the results of the ATL and the RTL. All these tables are shown in the report.