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To: A_1^n/g_2/GDH Collaboration
From: Xiaochao Zheng, Nov., 07, 2000
Subject: Efficiency Analysis of Hall-A Gas Cherenkov Detectors
URL: http://www.jlab.org/~xiaochao/testrun/checkgc.ps.gz

Contents:

1. Calibration of Gas Cherenkov ADCs

Calibration of the pedestals and software gains for the gas cherenkov ADCs needs to be done whenever any replacement of phototubes took place or at the begining of an experiment.

Pedestals can be obtained by observing the first ADC channel with non-zero signal (threshold). First use Espace[1] to observe the raw Cherenkov ADC as follows:

```
set/spectrum/bins/x1 1
set/spectrum/window/x1 0 4000
do i=1,10
spectra/save spec_e.gas.adc[[i];[i]]
enddo
```

According to ESPACE manual[1] (page 51), the pedestal position should be 10 channels below this threshold.

Then the software gain can be calculated by lining up the single photo-electron peaks. Here the single photo-electron peaks are fitted by gaussian function, superimposed on a linear polynomial (which can be used to simulate the pedestal tail near the single photo-electron peak). As an example, the following paw kumac file has been used for ADC channel 5:

```
v/cr par(6) r 150. 287. 50. 492. 20.
v/cr step1(6) r 0.1 0.01 0.01 0.1 0.01 0.01
message fit channel #5
```

hi/fit [hnum]([range1]:[range2]) p1+g ' QE' 5 par1 step1

The initialization of parameters and the range of single photoelectron peak are obtained by observing the spectrum. [hnum] is the histogram ID corresponding to spec_e.gas.adc[5;5]. After fit the position of single photoelectron peak is par(5).

Run #1381 of Hall-A experiment e97111 with kinematics PY-1D was used to do the calibration of gas cerenkov detector ADCs on the left arm. During this experiment the left arm is used to detect electrons and the right arm for hadrons (one should use the switched detector map for espace). The kinematics is:

Beam 2.384 GeV, $\theta_e = 16.88^o$, $p_e = 1.765$ GeV/c, $\theta_p = 36.40^o$, $p_p = 1.1935$ GeV/c.
Target: 10 cm cryo ^{4}He;

At this kinematics the pion/electron ratio is low. To lower the pion contamination, only event type 5 was chosen in the calibration. Figure 1 (a) shows the raw spectra of gas cherenkov ADCs on the left arm (spec_e.gas.adc); (b) shows the calibrated spectra (spec_e.gas.adc_c). Single photoelectron peaks on the left arm are aligned to channel 250.

Pedestals and software gains for the left arm gas cherenkov ADCs are:
2.89E+02 3.35E+02 3.08E+02 2.59E+02 3.46E+02
2.87E+02 3.38E+02 3.23E+02 3.50E+02 3.20E+02
1.299399 1.053029 0.7892491 0.8120987 1.682789
1.226820 1.102841 0.8938647 0.9992915 0.6980919

Similarly, run #2162 of the same experiment was chosen to do the calibration of gas cerenkov detector ADCs on the right arm. This run has negative polarimetry on both arms. The kinematics is:

Beam 2.392 GeV, $\theta_e = 38.714^o$, $p_e = 1.000$ GeV/c, $\theta_p = 38.698^o$, $p_p = 1.000$ GeV/c.
Target: ^{12}C, 300 mg/cm^2;

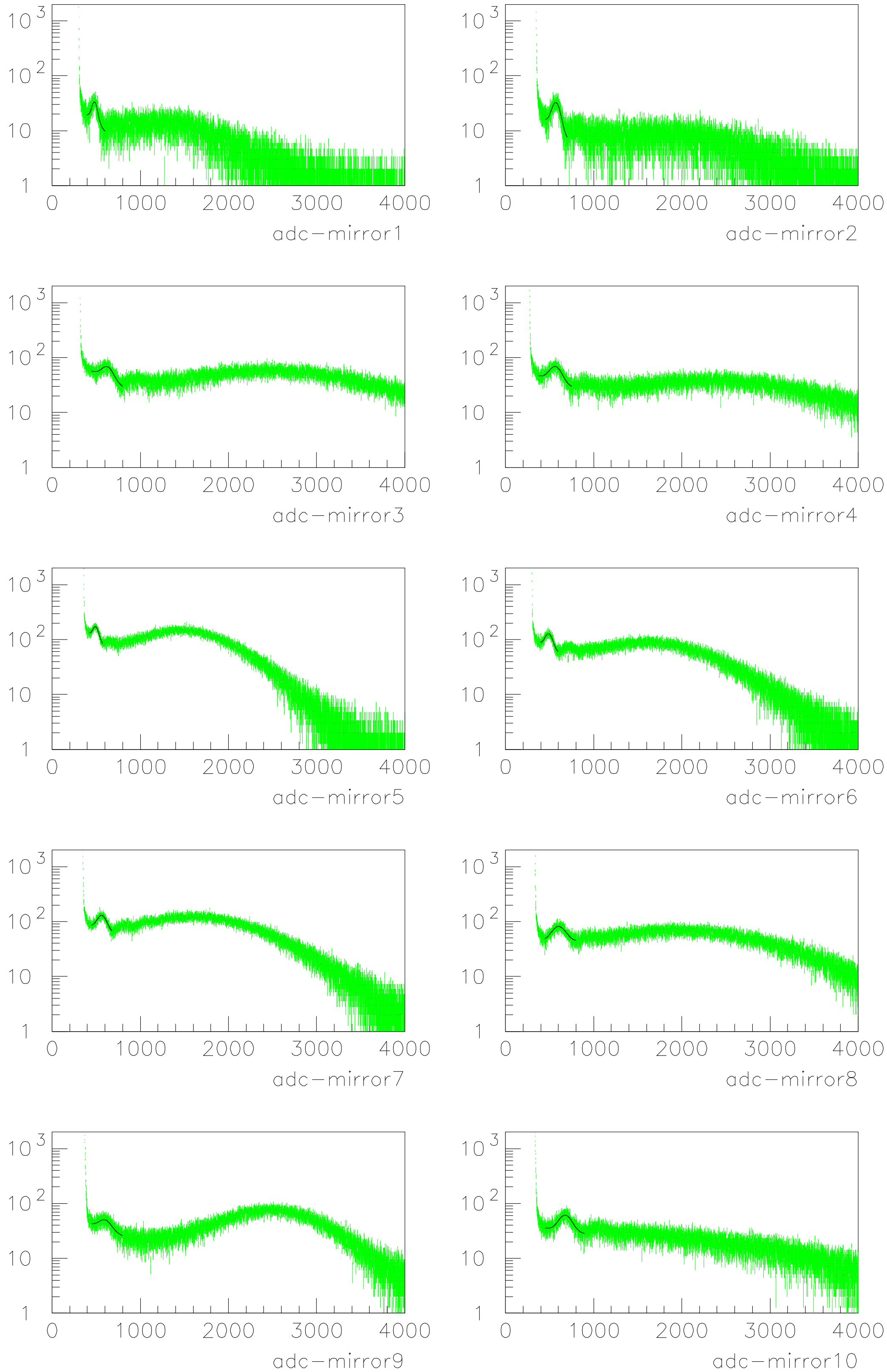
Pedestals and software gains for the right arm gas cherenkov ADCs are:
5.13E+02 4.45E+02 3.07E+02 3.23E+02 4.44E+02
5.54E+02 4.40E+02 4.60E+02 4.85E+02 5.51E+02
2.690281 2.625315 2.906272 2.736847 2.591728
2.758467 3.058258 2.509079 2.314978 3.144456

Single photoelectron peaks on the right arm are aligned to channel 200.

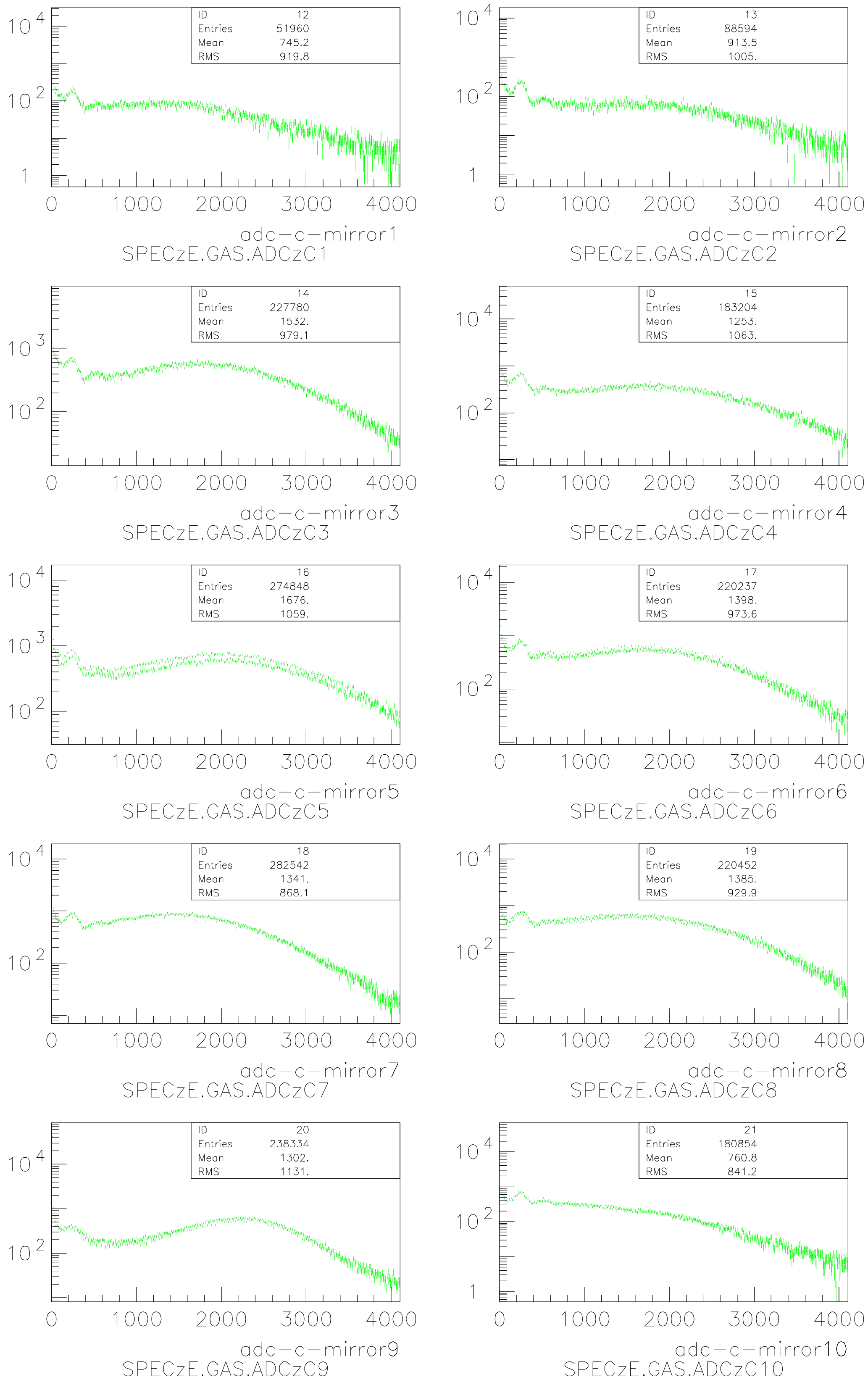
The pedestals and software gains have been put into the database located at:
adaq@adaql1:/adaql1/home/adaq/e99007/twoarm/espace/db_new_e840_h840_gc

Figure 1: Gas cherenkov ADC spectra on the left arm

(a) raw spec_e.gas.adc;



(b) calibrated spec_e.gas.adc_c;



2. Efficiency Analysis - Pion Contamination and Electron Efficiency

Run e97111-#2162 and #2172 are used to compare the performance of two gas cherenkov detectors. First the adc_sum spectrum is fitted and separated into two spectra containning pion events and pure electron events. The cut in adc_sum can be obtained by minimizing the pion contamination and maximizing the electron efficiency, which will be used to optimize the efficiency of particle identification. This cut-optimization is found to be kinematic-dependent so it needs to be done for each different kinematics.

The responce function of photomultiplier tube (PMT) can be described by the following function[3]:

$$\begin{aligned} N(x) &= \Big(\frac{1-\omega}{\sigma_0\sqrt{2\pi}}\exp\Big(-\frac{(x-Q_0)^2}{2\sigma_0^2}\Big) + \omega\theta(x-Q_0)\alpha e^{-(x-Q_0)}\Big)e^{-\mu} \\ &+ \sum_{n=1}^{\inf}\frac{\mu^n e^{-\mu}}{n!}\times\frac{1}{\sigma_1\sqrt{2\pi n}}\exp\Big(-\frac{(x-Q_0-Q_{sh}-nQ_1)^2}{2n\sigma_1^2}\Big) \end{aligned}$$

where the first line is the pedestal. The second line is the main peak, which obeys the Poisson statistics broadened by a gaussian.

For simplicity, we didn't analysis the response function for each channel separately. Instead, the adc_sum spectrum is fitted by a combination of gaussians and exponentials, which can be separated into three parts. First the pedestal is fitted by the sum of a gaussian and an exponential, times a second exponential.

$$N_{ped}(x) = p_1 e^{p_2+p_3x} p_4 \exp\Big\{-\frac{(x-p_5)^2}{2p_6^2}\Big\} + p_{10}e^{p_{11}+p_{12}x}e^{p_{13}+p_{14}x}$$

Then the single photoelectron peak is fitted by a gaussian.

$$N_{single}(x) = p_7 \exp\Big\{-\frac{(x-p_8)^2}{2p_9^2}\Big\}$$

Next the main peak is also fitted by a gaussian since Poisson distribution approaches to gaussian as its mean value increases.

$$N_{main}(x) = p_{15} \exp\Big\{-\frac{(x-p_{16})^2}{2p_{17}^2}\Big\}$$

The meanvalue of number of photoelectron is p_{16}. For run #2162 it is found to be $1960/250 = 7.84$ for left arm and $1673/200 = 8.37$ for right arm. For run #2172 it is $1966/250 = 7.86$ for left arm and $1652/200 = 8.26$ for right arm. In principle from Monte Carlo simulation the number of photo-electron should be 13.8 for 1m long gas cherenkov detector [3].

Table 1: Pion rejection and electron efficiency of gas cherenkov detector

run #	arm	cut	$\eta_{e,eff}$	$\eta_{\pi,rej.}$
2162	left	adc_sum>343	98.36%	99.00%
2162	right	adc_sum>265	99.25%	99.95%
2172	left	adc_sum>275	98.43%	99.00%
2172	right	adc_sum>250	98.63%	99.00%

The pedestal tail and single photoelectron peak are interpreted as pions and the main peak around $n_{photoelectron} \sim 8$ is interpreted as electrons. Figure 2 shows the adc_sum spectrum and the fit result. The event distribution is reproduced by the fit parameters and a cut in adc_sum can be optimized by chosing the crossing point of electron loss and pion contamination. The reproduced pion contamination from run #2172 (which has high pion rate) and electron efficiency (loss) from run #2162 (high electron rate) are combined together. Figure 3 shows the overall efficiency vs. cut channel. Here the pion rejection efficiency is defined as:

$$
\begin{aligned}
\eta_{\pi,rejection} &= \frac{N_\pi(x < cut)}{N_\pi} \\
\eta_{\pi,contamination} &= 1 - \eta_{\pi,rejection} \\
N_\pi(x) &= N_{ped}(x) + N_{single}(x)
\end{aligned}
$$

and the electron efficiency is defined as:

$$
\begin{aligned}
\eta_{e,eff.} &= \frac{N_e(x > cut)}{N_e} \\
\eta_{e,loss} &= 1 - \eta_{e,eff.} \\
N_e(x) &= N_{main}(x)
\end{aligned}
$$

In principle, the cut can be optimized by choosing the crossing point of pion contamination and electron efficiency given above, which is adc_sum=298 for the left arm, and adc_sum=285 for the right arm. But in practice the particle identification efficiency is dependent on the specific kinematics, e.g., the real noise and pion/electron ratio. So the cut should be adjusted so as to achieve a high electron efficiency, while keeping the pion contamination as low as possible. If a minimal pion rejection of 99.0% is fixed then the optimized cut for run #2162 and #2172 are shown in table 1.

3. Efficiency of Gas Cherenkov Mirrors on the Left Arm

The efficiency of each channel is a combined result of mirror efficiency, PMT efficiency and also the alignment condition. First of all, the mean value of number of photoelectrons can be found by fitting the adc_c signal with distribution or gaussian distribution. From figure 1 can see that mirror #7 and #8 have lower mean value for number of photoelectrons (around 6), compared to other mirrors.

Figure 2: Gas cherenkov ADC_SUM spectra for run # 2162

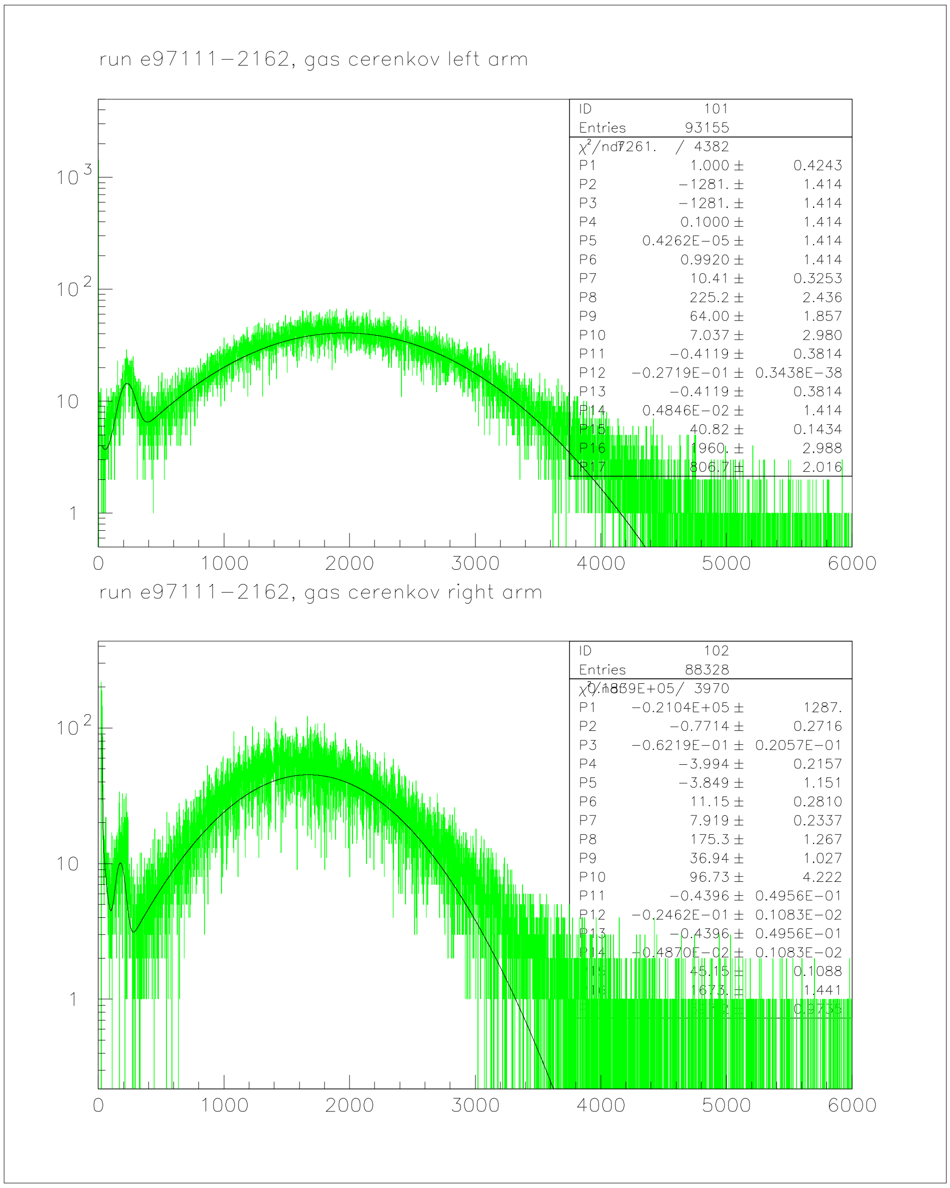
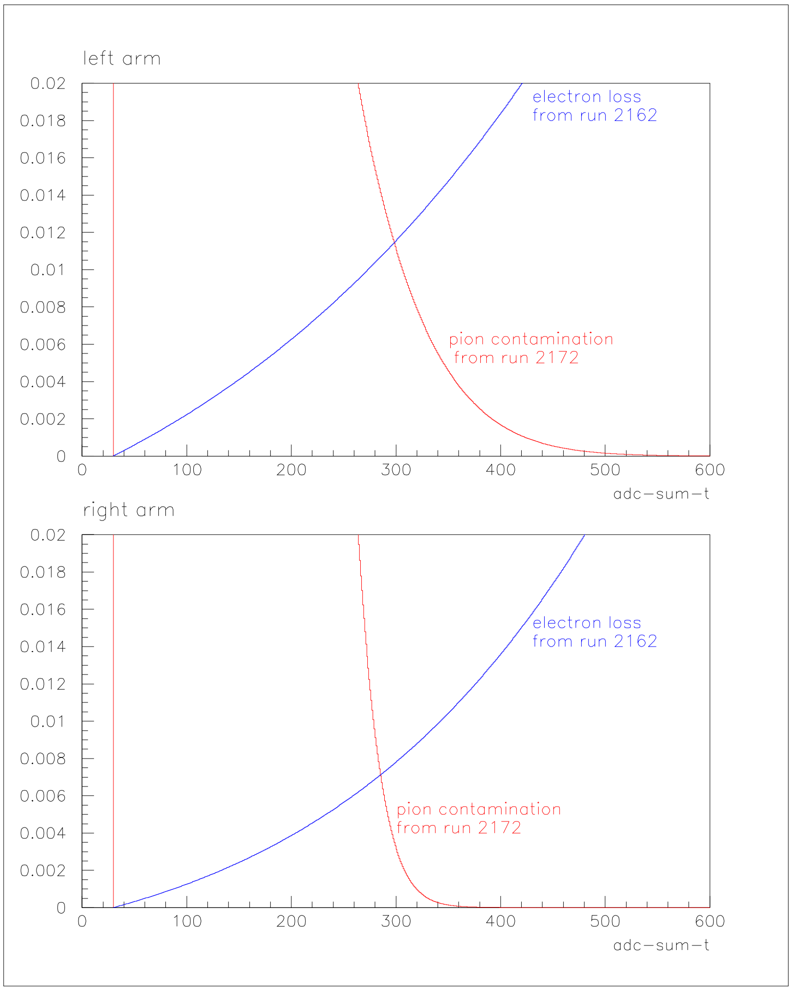


Figure 3: Cut-dependence of pion rejection and electron efficiency



Secondly, to check the efficiency for each channel, plot of adc_sum vs. det_xgeom for each channel of gas cherenkov on the left arm is given in Figure 4. Here a cut in adc_c[i;i] >chan_{single} is used to choose the i^{th} mirror, where chan_{single} is the channel number of the upper edge of single photoelectron peak in adc_c spectra. Part of the espace_kumac file is shown as follows:

```
define/variable 'eadcgas:spec_e.gas.adc_sum_t'
define/variable 'egasxg:spec_e.gas.xdetgeom'
define/variable 'egasyg:spec_e.gas.ydetgeom'

do i=1,10
   define/cut/1d spec_e.gas.adc_c[[i];[i]]-1 130. 6000.        /* cut #1 */
   define/cut/1d spec_e.gas.adc_c[[i];[i]]-2 380. 6000.        /* cut #2 */
   define/cut/1d spec_e.gas.adc_c[[i];[i]]-3 130. 380.         /* cut #3 */
   define/logical egc1[i] spec_e.gas.adc_c[[i];[i]]-1
   define/logical egc2[i] spec_e.gas.adc_c[[i];[i]]-2
   define/logical egc3[i] spec_e.gas.adc_c[[i];[i]]-3
enddo


do i=1,10
set/ntuple on
   spectra/save event_type/eadcgas/egasxg/egasyg egc1[i]
   spectra/save event_type/eadcgas/egasxg/egasyg egc2[i]
   spectra/save event_type/eadcgas/egasxg/egasyg egc3[i]
set/ntuple off
enddo
```

The plot shows that mirror # 10 has a high single photo-electron peak, which means it probablly have problem in alignment. Figure 5 shows the performance of mirror # 9 and # 10 during E94-010 (GDH) experiment in 1998. Can see that mirror # 9 had alignment problem during E94-010. Obviously when redoing the alignment after E94-010 mirror # 9 was fixed but # 10 was affected. The overall efficiency is probablly not optimized and furthur work needs to be done if high pion rejection efficiency is required.

Figure 6 shows the event distribution for each gas cherenkov mirror on the left arm. For the i^{th} mirror, the grey region shows the events which has only one photoelectron in it (cut#3: adc_c[i;i]<chan_{single}). Here the grey region shows the edge of each mirror.

From these plots can see that the outgoing particles are not pointing to the center of the detector, mirror #1 and #2 are not fully covered. The overall efficiency could be improved by moving the whole detector lower by 1/4 of the mirror size (vertical). By doing this the bad performance of mirror #10 can also be partially avoided.

4. Conclusion

Figure 4: Gas cherenkov ADC_SUM vs. position on the left arm

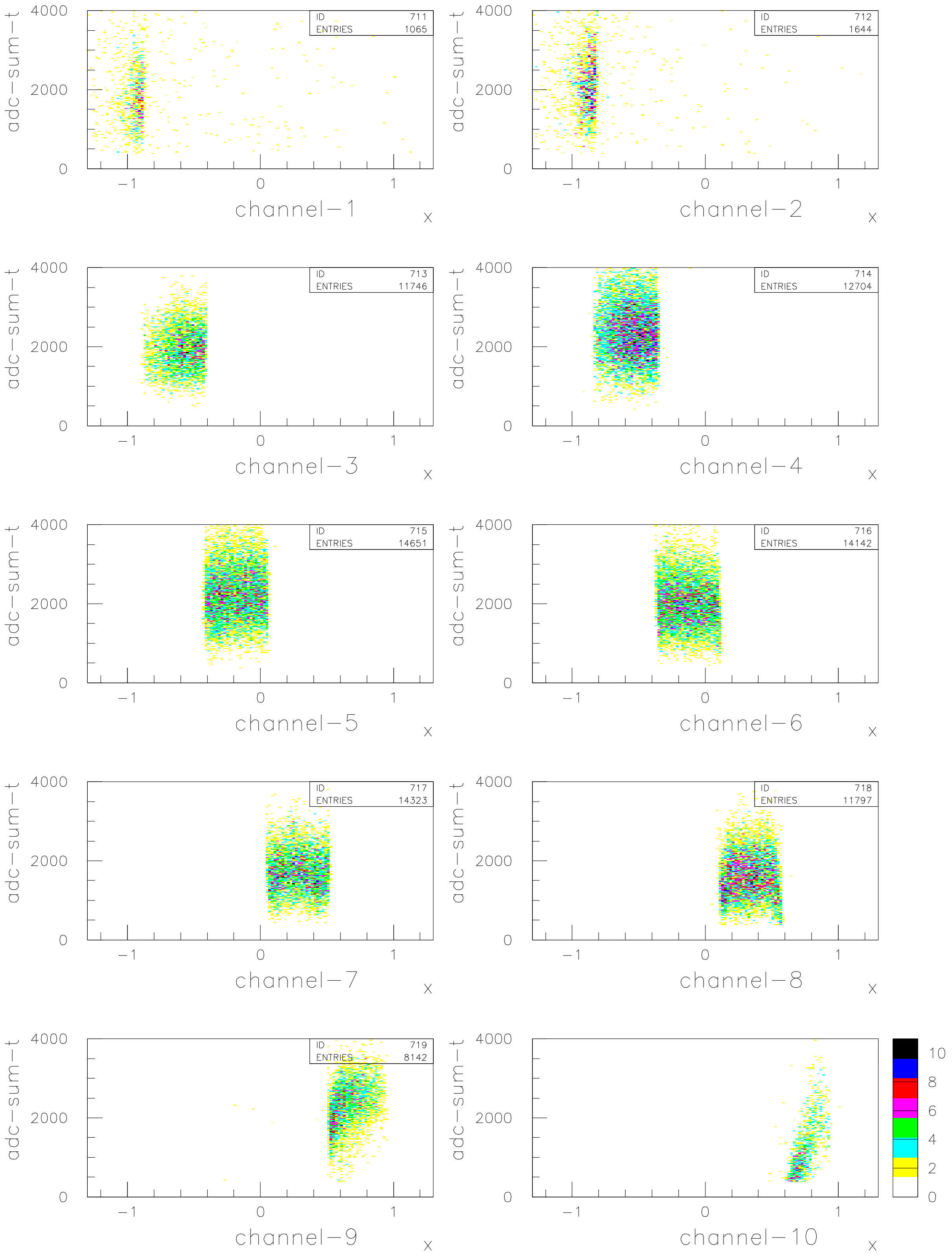
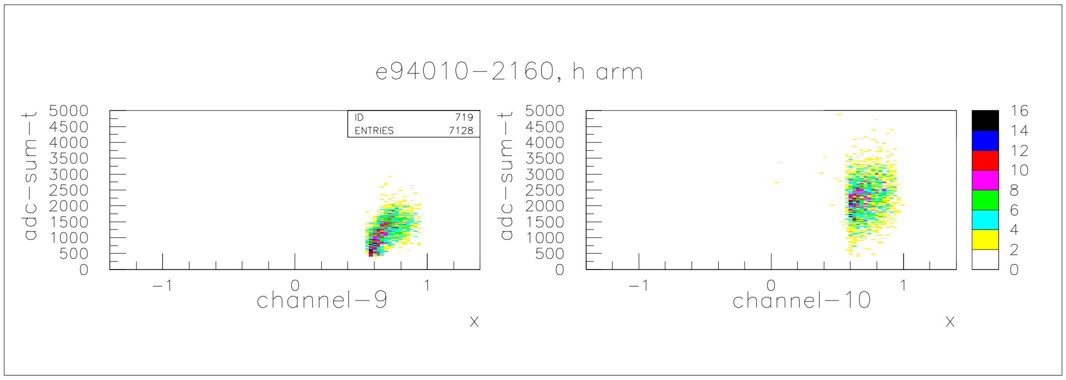


Figure 5: Gas cherenkov ADC_SUM vs. position on the left arm during E94-010 (h-arm)



Calibration of gas cherenkov detector ADCs has been done for both arms. The efficiency of each detector has been analyzed and the cut in adc_sum is optimized for particle identification. Further analysis has been done for left arm gas cherenkov. The result shows that mirror #7 and #8 have low efficiency. Mirror # 10 is not aligned well and it needs to be fixed if high pion rejection efficiency is required.

References

[1] Espace manual (temporary), August 11, 2000, http://www.jlab.org/~kuss/work/manual.ps.gz

[2] Analysis of the Hall A HRS Cherenkov Detectors for E94010, by Karl Slifer, July 2000, E94010 technical notes #32, http://www.jlab.org/e94010/tech_note_32.ps.gz

[3] The CO_2 Gas Cherenkov Detectors for the Jefferson Lab Hall-A Spectrometers, by M. Iodice, E. Cisbani et. al., http://hallaweb.jlab.org/publications/Talks/1998/Publications/Iodice-instruments-98.ps

Figure 6: Event distribution of gas cherenkov on the left arm