# *Mott Electron Polarization Results*

Riad Suleiman

July 10, 2013

# Mott Scattering

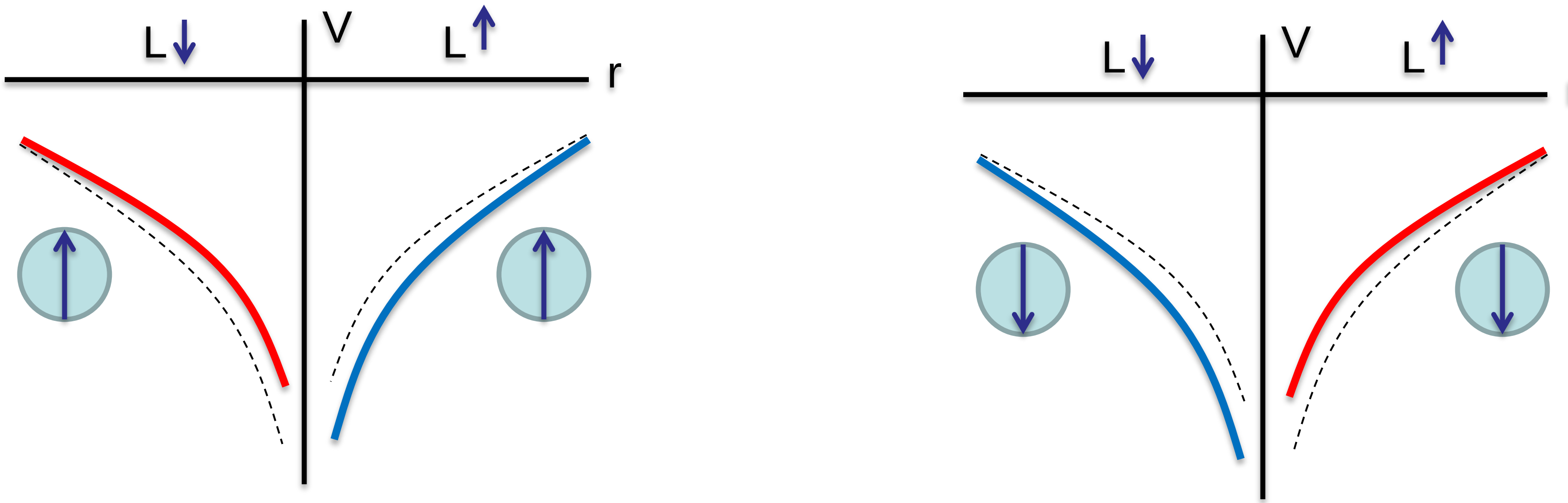
- Electron motion in nucleus electric field results in magnetic field in electron rest frame, $\vec{B} = -\frac{1}{c}\vec{v} \times \vec{E}$ , if $\vec{r}$ is nucleus-electron separation, then $\vec{E} = \frac{Ze}{r^3}\vec{r}$ and

$$\vec{B} = \frac{Ze}{cr^3}\vec{r} \times \vec{v} = \frac{Ze}{mcr^3}\vec{L}$$

- Interaction of this magnetic field with electron (spin) magnetic moment introduces a term $V_{so} = -\vec{\mu}_s \bullet \vec{L}$ in the scattering potential,

$$V = V_c + V_{so} = \frac{Ze}{r} + \frac{Ze^2}{2m^2c^2r^3}\vec{S} \bullet \vec{L}$$

- Presence of spin-orbit term in scattering potential introduces spin dependence in scattering cross section $\sigma(\theta)$ which could be detected as a left/right count rate asymmetry




*Note*:

- Parity-conserving: Measure spin-momentum correlation of the type: $\vec{S}.\left(\vec{k}_1 \times \vec{k}_2\right)$

  Transverse (or Normal) Beam Asymmetry measured recently using the setup of parity-violating experiments at high energies (due to two-photon exchange) probes the same spin-momentum correlation as Mott Asymmetry at low energies (due to spin-orbit interaction of electron moving in a Coulomb field).

- Parity-violating: Measure spin-momentum correlation of the type: $\vec{S}.\vec{k}_1$

# Mott Cross Section and Sherman Function

- Mott cross section:

$$\sigma(\theta) = I(\theta)[1 + S(\theta)\vec{P} \bullet \hat{n}]$$

where, $I(\theta)$ is the un-polarized cross section,

Non-spin-flip Amplitude

Spin-flip Amplitude

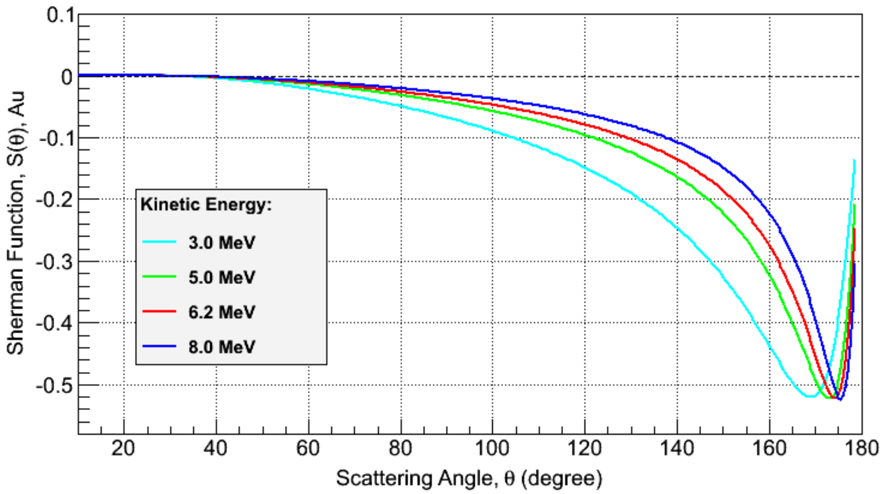
$$I(\theta) = \left(\frac{\hbar c}{p}\right)^2 \left[\left(\frac{Ze^2}{\hbar c\beta}\right)^2 (1-\beta^2)\frac{|F(\theta)|^2}{\sin^2(\theta/2)} + \frac{|G(\theta)|^2}{\cos^2(\theta/2)}\right]$$

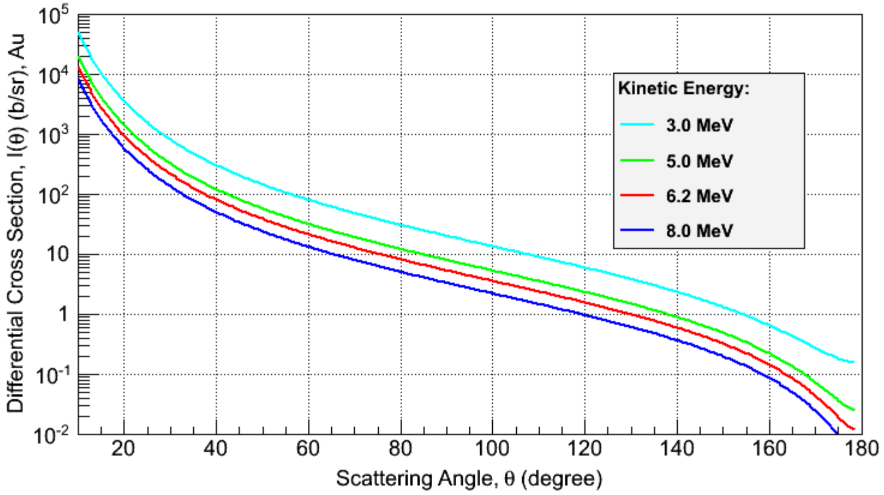
and $S(\theta)$ is the analyzing power (Single-Atom Sherman Function),

$$S(\theta) = 2\times\left(\frac{\hbar c}{p}\right)^2\left(\frac{Ze^2}{\hbar c\beta}\right)\frac{\sqrt{1-\beta^2}}{\sin(\theta/2)I(\theta)}\left[F(\theta)G^*(\theta) + F^*(\theta)G(\theta)\right]$$

- Sherman Function is largest for high-Z (Gold, Z=79) targets and low-energy electrons

# Theoretical Corrections

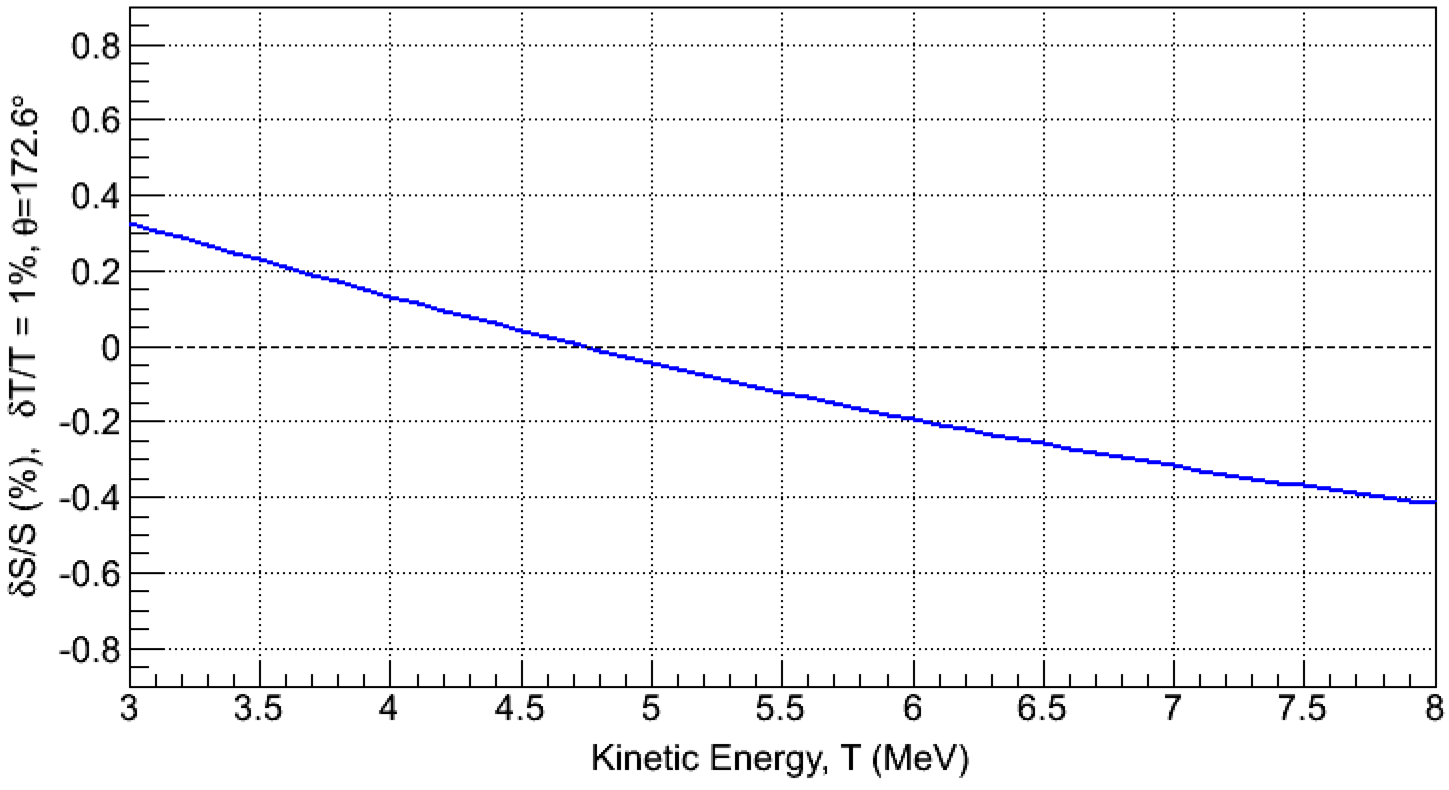



- Radiative corrections
- Screening by atomic electrons
- Finite nuclear size

# Energy Sensitivity

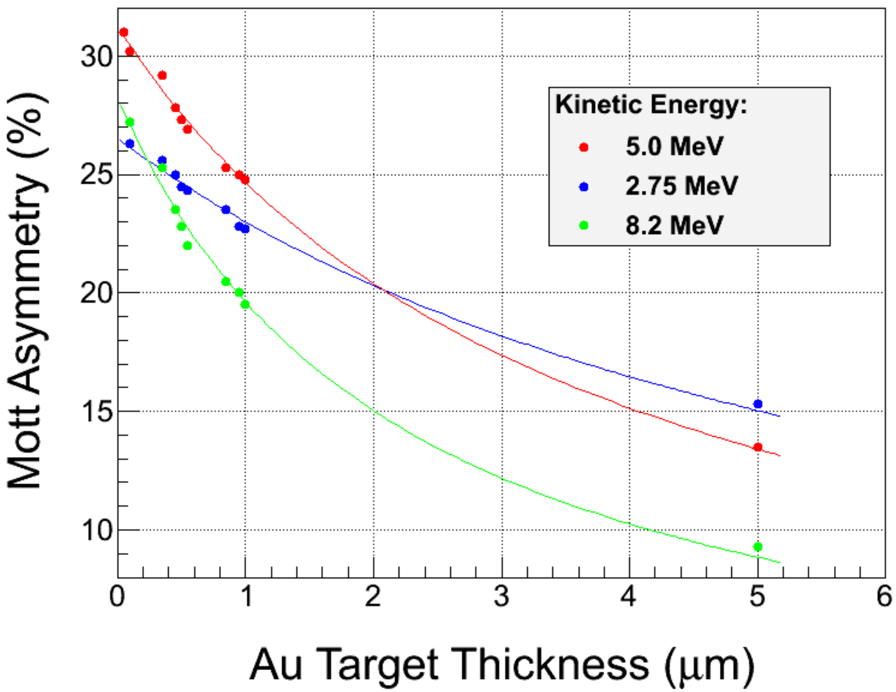
- For T=5.0 MeV, p=5.5 MeV/c. However, momentum was measured to be p=5.336 ± 0.023 MeV/c, or T=4.850 MeV
- For δT/T=3%, δS/S(T=4.850)=0.09%



# Sherman Function and Target Thickness

$$S_{eff}(\theta, d) = \frac{S_{SA}(\theta)}{1+\alpha(\theta)\cdot d}$$

- Single-Atom Sherman Function $S_{SA}(\theta)$ must be corrected for plural scattering (a few large angle scattering) in the target:




- $S_{SA}$(d=0, T=5.0 MeV) = -0.5215,
- $S_{eff}$(d=1.0 μm, T=5.0) = -0.4006
- Systematic Error (ΔS/S) = 2.8%

| Effective Sherman Function | Error (ΔS/S) |
|---|---|
| Theoretical corrections | 2.0% |
| Target thickness extrapolation | 2.0% |
| Scattering angle (0.1°) | 0.1% |
| Electron energy (1.0%) | 0.03% |

# Measuring Mott Asymmetry

- How to measure the Mott Asymmetry $A_{LR}$?
  - For one helicity state, measure the number of left and right detector events, $N_L^{\uparrow}$ and $N_R^{\uparrow}$
  - Flip the electron polarization, measure the number of events again, $N_L^{\downarrow}$ and $N_R^{\downarrow}$
  - Calculate the *cross-ratio* (r),

$$r = \sqrt{\frac{N_L^{\uparrow} N_R^{\downarrow}}{N_L^{\downarrow} N_R^{\uparrow}}}$$

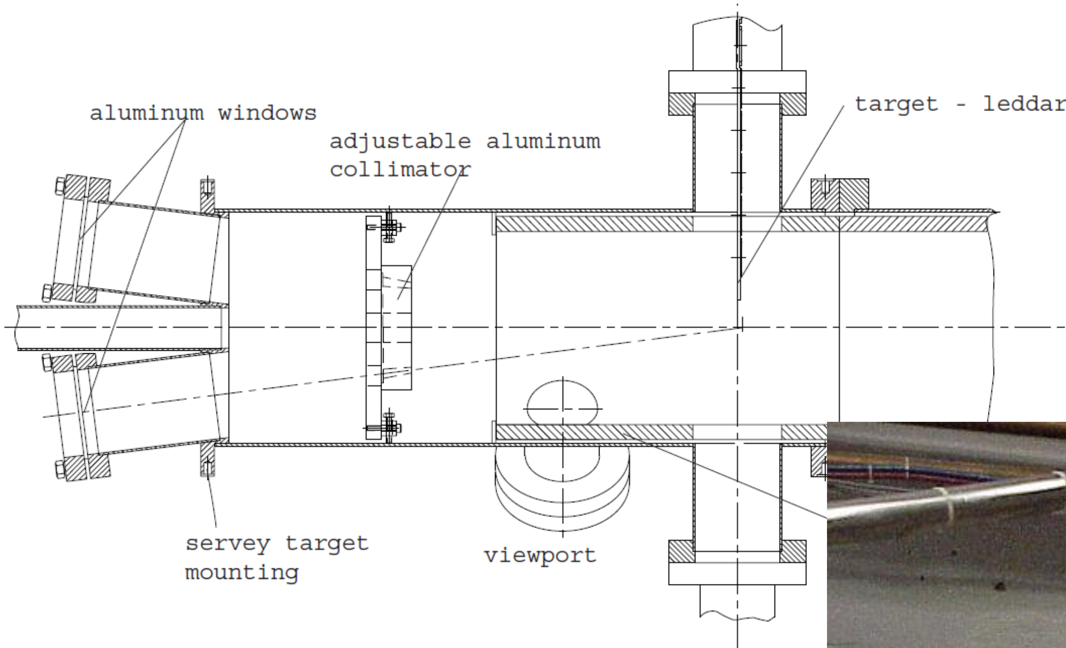
  - Then, the Mott Asymmetry:

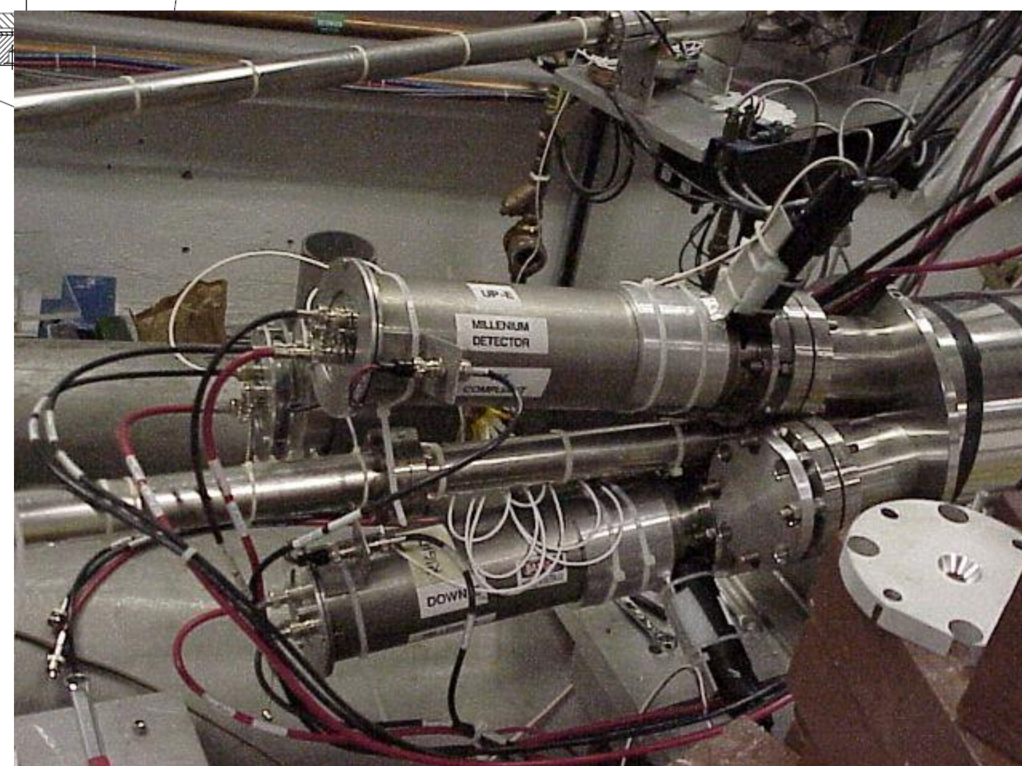
$$A_{LR} = \frac{1-r}{1+r} \qquad P_y = \frac{A_{LR}}{S_{eff}}$$

- Same for $A_{UD}$

- False Asymmetries:
  - Cancel to all orders: beam current, target thickness, solid angle, detector efficiency and dead time (due to slow DAQ common to all detectors)
  - Cancel to first order: differences in beam polarization between the two helicity states and misalignment errors resulting in detectors at different scattering angle

# 5 MeV Mott Beamline

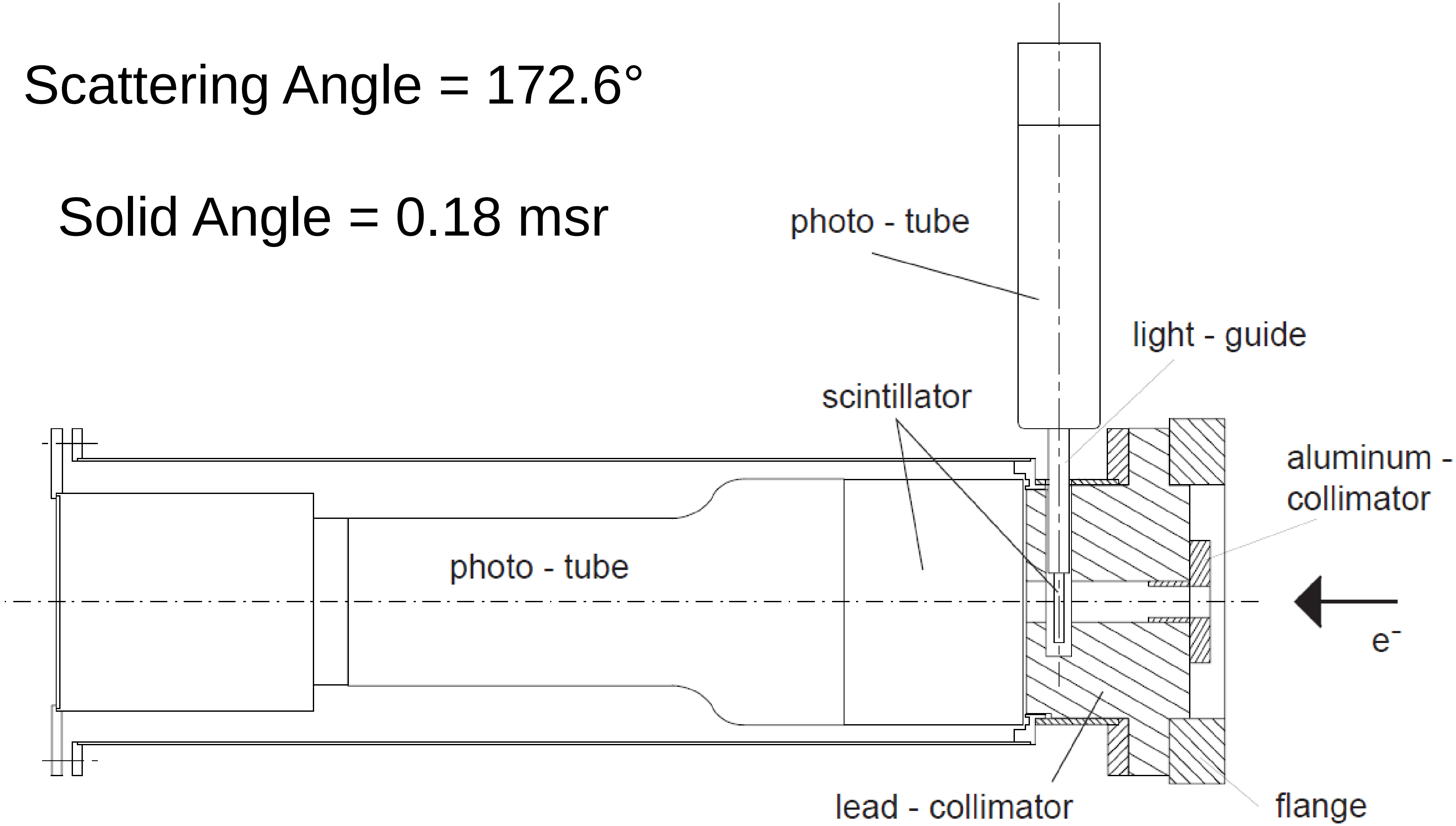


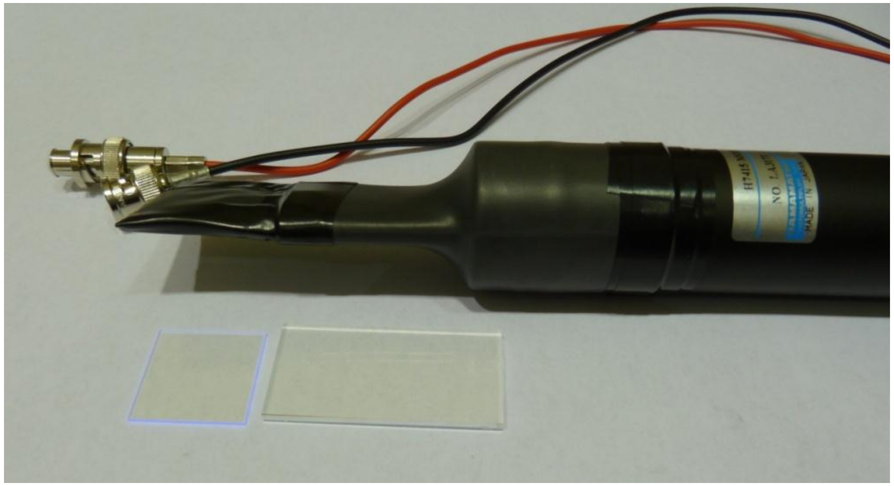
# Detector Assembly

I. Scattering Angle = 172.6°

II. Solid Angle = 0.18 msr



# ΔE and E Detectors

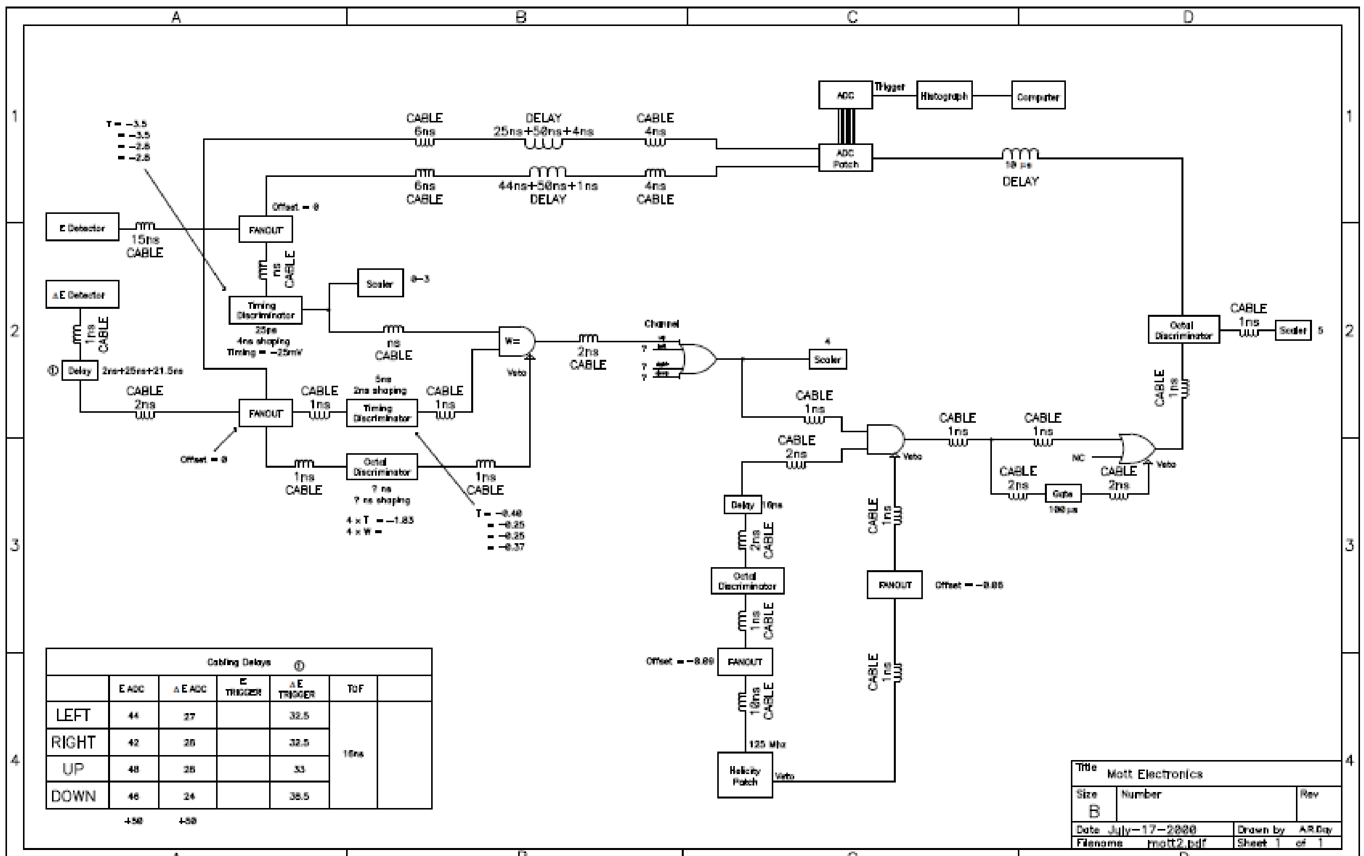


- H7415 (R6427) 1" PMT
- 1 mm x 1" x 1" EJ-212 Plastic Scintillator
- 0.125" x 1" x 2" Acrylic Light Guide

- H6559 (R6091) 3" PMT
- 3" diameter x 2.5" long EJ-200 Plastic Scintillator painted with EJ-510

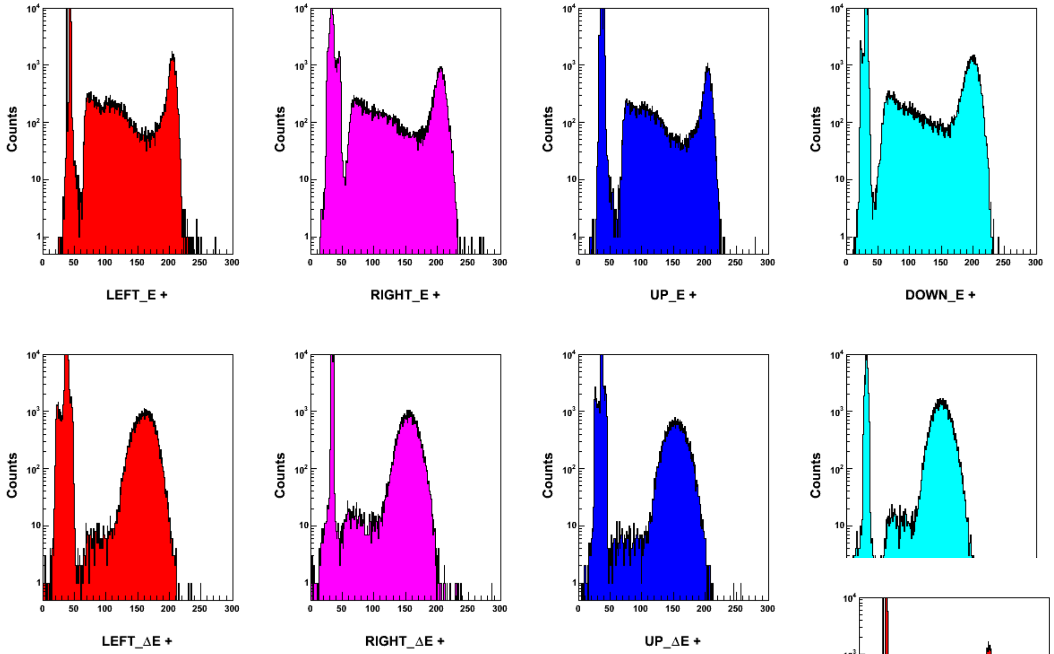
# Old 5 MeV Mott DAQ

- LeCroy CAMAC 4300B Fast Encoding and Readout ADC (FERA), 10 Bit
- ORTEC CAMAC HM 413 HISTO-MEMORY

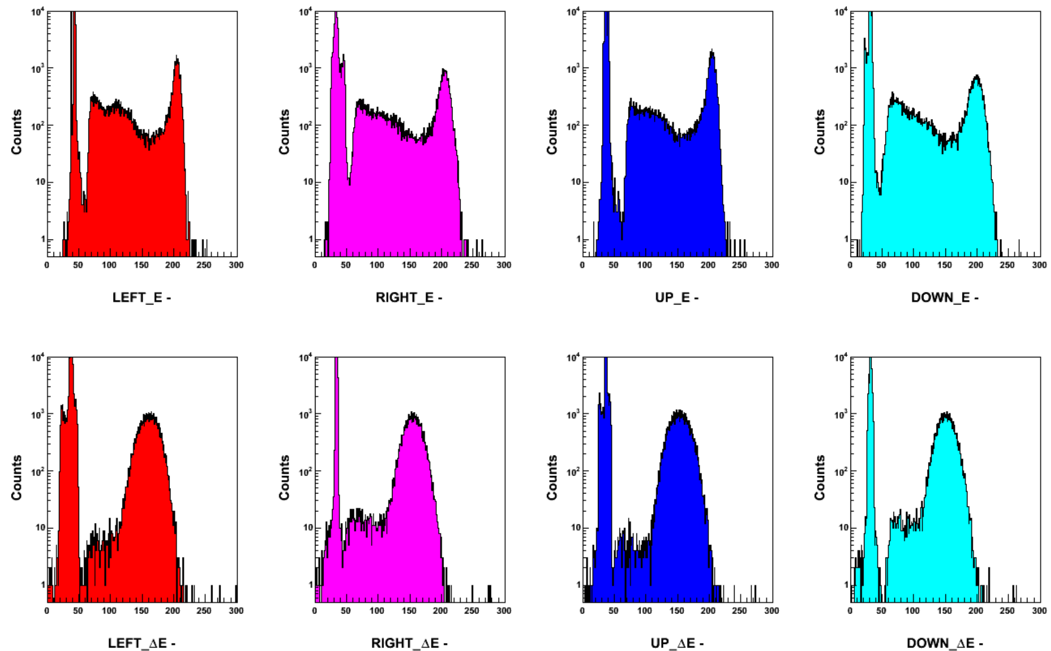



| Cabling Delays | | | | | | |
|---|---|---|---|---|---|---|
| | E ADC | ΔE ADC | E TRIGGER | ΔE TRIGGER | TOF | |
| LEFT | 44 | 27 | | 32.5 | 16ns | |
| RIGHT | 42 | 26 | | 32.5 | | |
| UP | 48 | 26 | | 33 | | |
| DOWN | 46 | 24 | | 36.5 | | |
| | +50 | +50 | | | | |

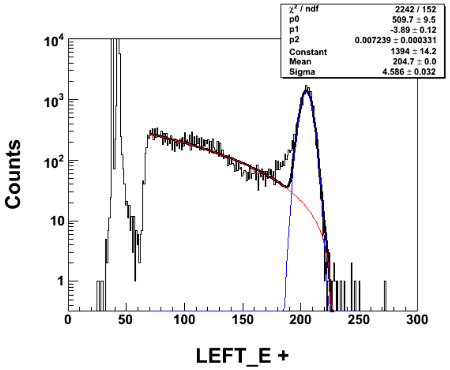
# Detectors Spectra

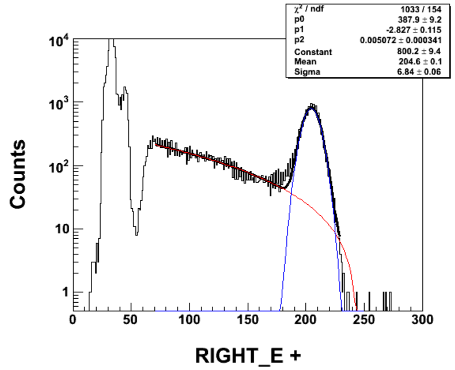


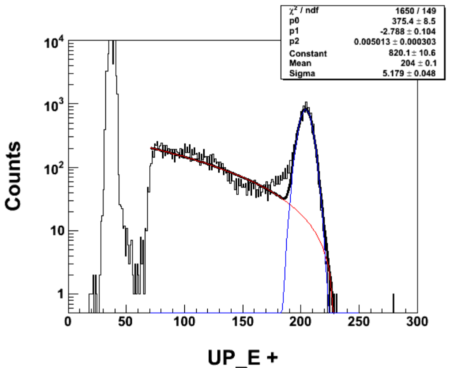

- Beam Current = 1.0 μA
- Gold Target 1.0 μm
- Trigger Rate 1 kHz
- 5 minutes of data

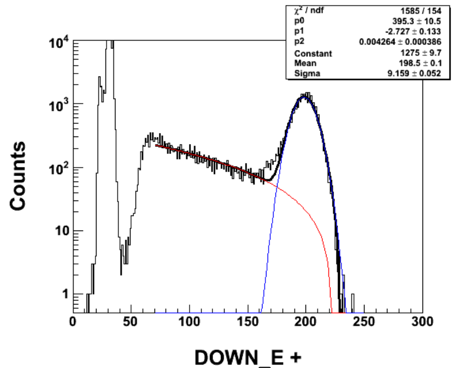


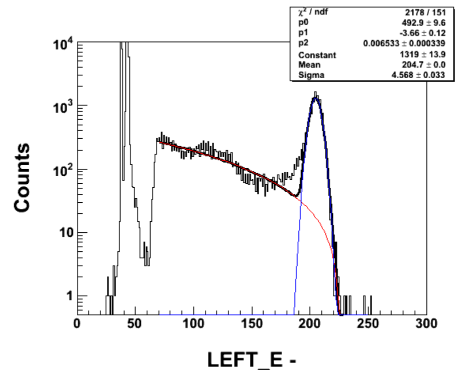
# E Detectors Spectra

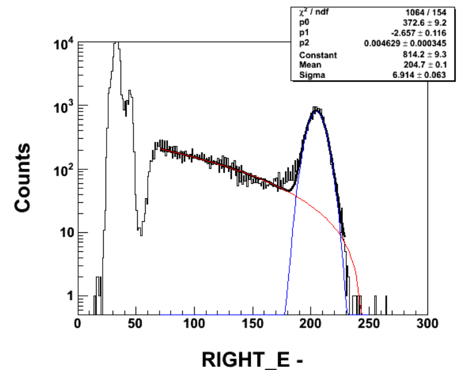


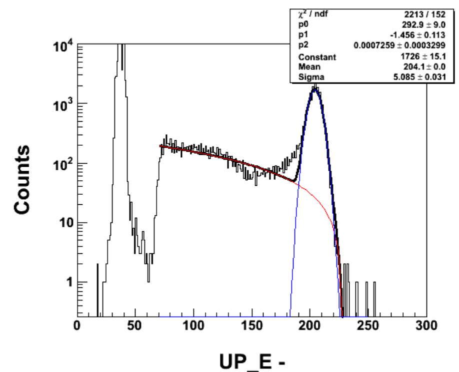



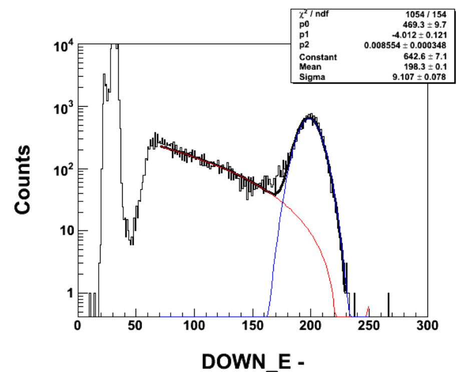



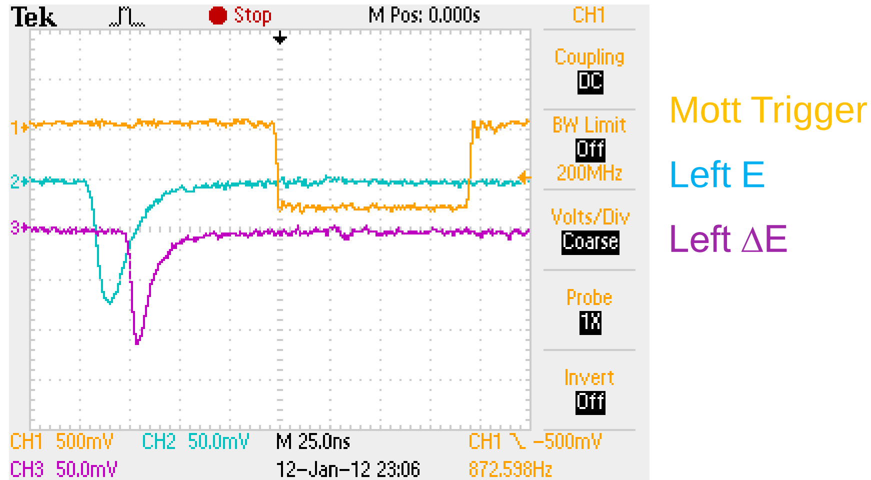



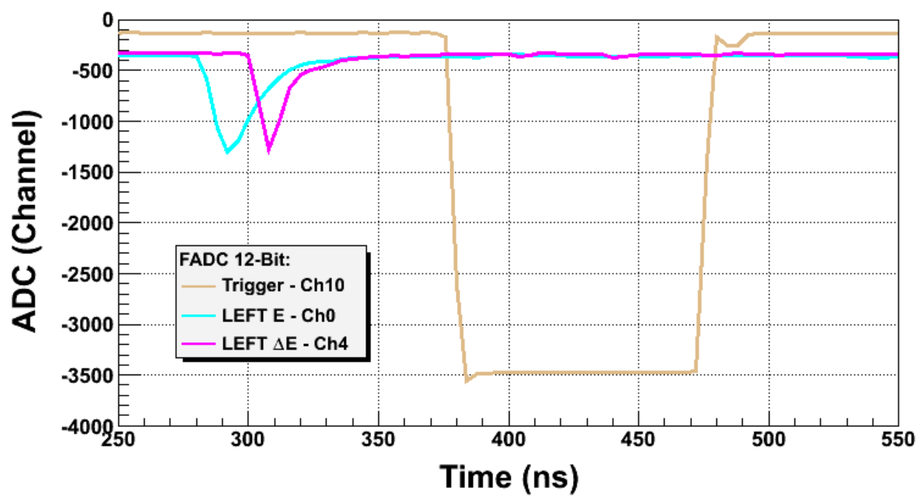
# New 5 MeV Mott DAQ

| FADC Chan | Signal |
|---|---|
| 0 | E LEFT |
| 1 | E RIGHT |
| 2 | E UP |
| 3 | E DOWN |
| 4 | ΔE LEFT |
| 5 | ΔE RIGHT |
| 6 | ΔE UP |
| 7 | ΔE DOWN |
| 8 | BFM |
| 9 | |
| 10 | Mott Trigger |
| 11 | |
| 12 | Delayed Helicity |
| 13 | T_Settle |
| 14 | Pattern-Sync |
| 15 | Pair-Sync |

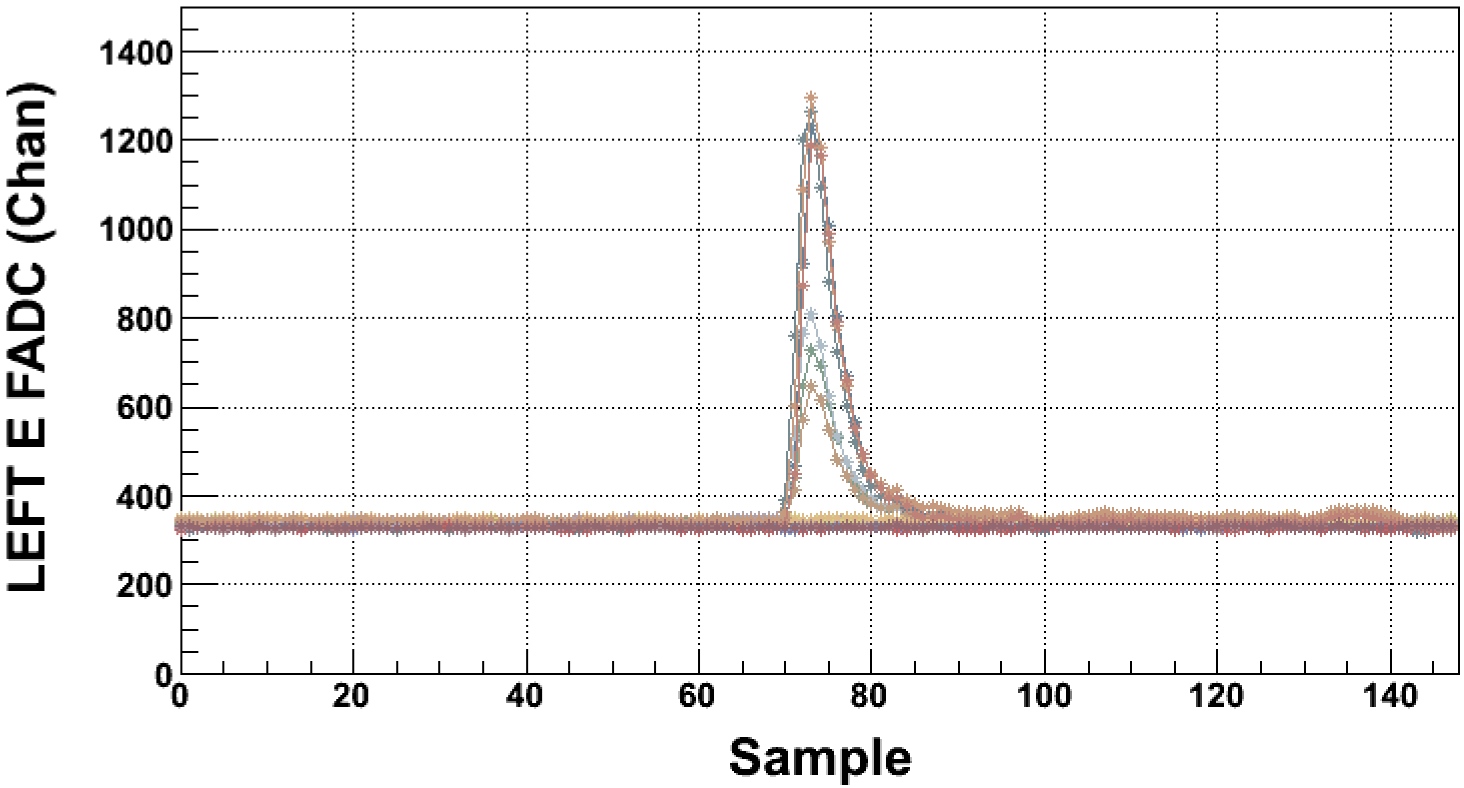
## Signals on Scope




## Signals in FADC Data



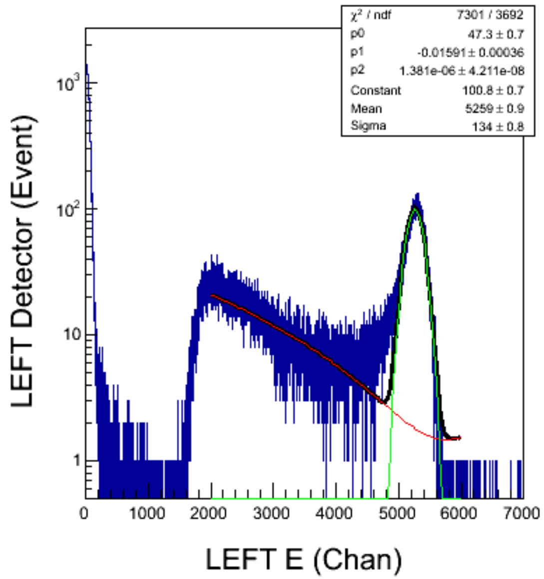
# Few FADC Events in LEFT Detector



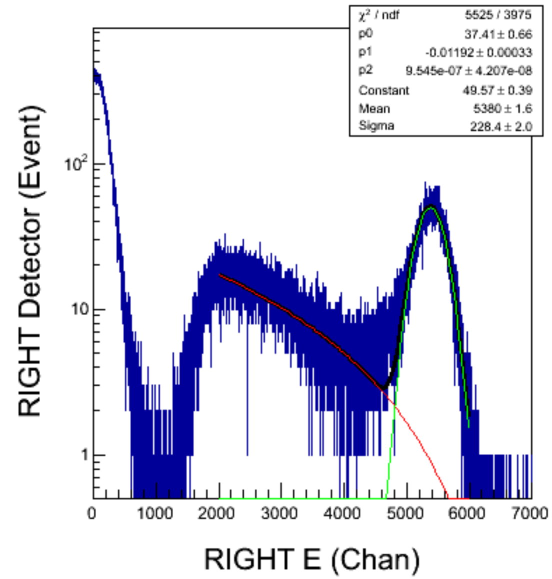

Calculate pedestal and Energy:

$$Pedestal = \frac{1}{5}\sum_{sample=60}^{64} FADC$$

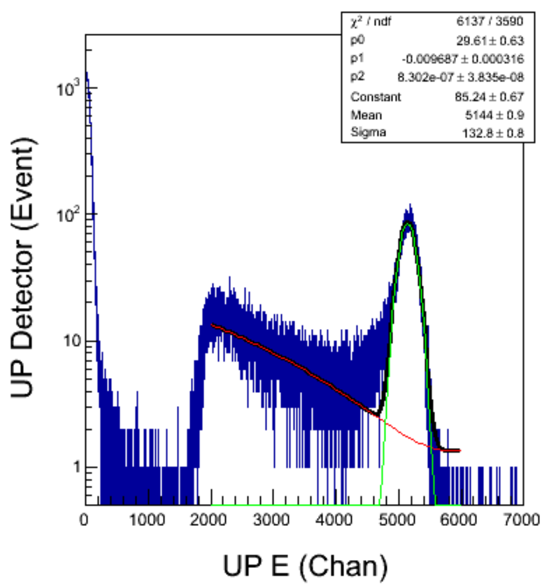
$$E = \sum_{sample=60}^{97} FADC - 38 \times Pedestal$$



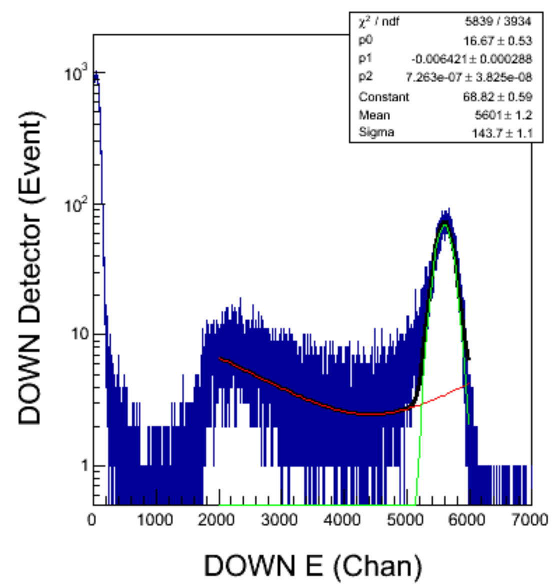
χ² / ndf 7301 / 3692
p0 47.3 ± 0.7
p1 -0.01591 ± 0.00036
p2 1.381e-06 ± 4.211e-08
Constant 100.8 ± 0.7
Mean 5259 ± 0.9
Sigma 134 ± 0.8
LEFT Detector (Event)
LEFT E (Chan)

χ² / ndf 5525 / 3975
p0 37.41 ± 0.66
p1 -0.01192 ± 0.00033
p2 9.545e-07 ± 4.207e-08
Constant 49.57 ± 0.39
Mean 5380 ± 1.6
Sigma 228.4 ± 2.0
RIGHT Detector (Event)
RIGHT E (Chan)

χ² / ndf 6137 / 3590
p0 29.61 ± 0.63
p1 -0.009687 ± 0.000316
p2 8.302e-07 ± 3.835e-08
Constant 85.24 ± 0.67
Mean 5144 ± 0.9
Sigma 132.8 ± 0.8
UP Detector (Event)
UP E (Chan)

χ² / ndf 5839 / 3934
p0 16.67 ± 0.53
p1 -0.006421 ± 0.000288
p2 7.263e-07 ± 3.825e-08
Constant 68.82 ± 0.59
Mean 5601 ± 1.2
Sigma 143.7 ± 1.1
DOWN Detector (Event)
DOWN E (Chan)

# Maximize Longitudinal Polarization on June 04, 2012

- By adjusting INJTWF, $P_x$ and $P_y$ were minimized and beam polarization was measured:

| Run | IHWP | $P_x$ (%) ± Stat | $P_y$ (%) ± Stat |
|---|---|---|---|
| **04Jun12 16:50:12** | OUT | 0.82 ± 0.92 | -1.22 ± 0.90 |
| **04Jun12 16:57:48** | IN | 0.45 ± 1.05 | 1.80 ± 1.02 |
| **04Jun12 17:03:38** | OUT | 0.42 ± 0.85 | -2.75 ± 0.85 |
| **04Jun12 17:11:00** | IN | -0.15 ± 0.80 | 2.55 ± 0.80 |

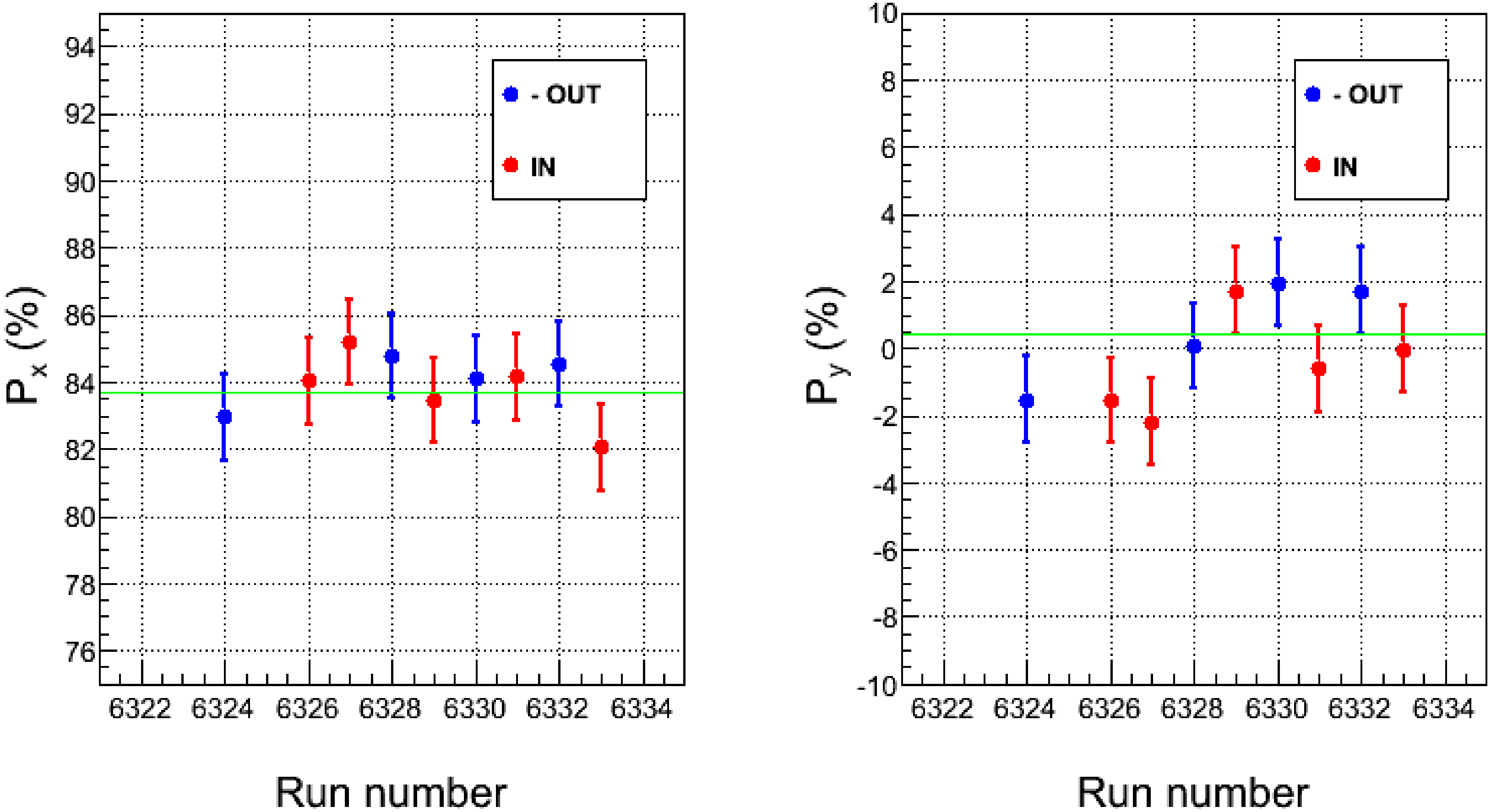
- After minimization, new nominal Injector Two-Wien-Flipper (INJTWF) settings during PEPPo data taking are:

| | |
|---|---|
| Vertical Wien Angle | +90.00˚ |
| Solenoids Angle | -91.45˚ |
| Horizontal Wien Angle | +86.70˚ |

# Measure Longitudinal Polarization on June 10, 2012

- Beam polarization was changed to horizontal transverse ($P_x$) with Horizontal Wien Angle changed from +86.70˚ to 0.00˚

| Run | IHWP | $P_x$ (%) ± Stat | $P_y$ (%) ± Stat |
|---|---|---|---|
| 6324 | OUT | -82.96 ± 1.28 | 1.53 ± 1.28 |
| 6326 | IN | 84.03 ± 1.27 | -1.53 ± 1.27 |
| 6327 | IN | 85.20 ± 1.27 | -2.19 ± 1.28 |
| 6328 | OUT | -84.76 ± 1.27 | -0.07 ± 1.28 |
| 6329 | IN | 83.45 ± 1.28 | 1.71 ± 1.28 |
| 6330 | OUT | -84.09 ± 1.27 | -1.95 ± 1.28 |
| 6331 | IN | 84.16 ± 1.28 | -0.61 ± 1.28 |
| 6332 | OUT | -84.54 ± 1.28 | -1.72 ± 1.28 |
| 6333 | IN | 82.06 ± 1.28 | -0.02 ± 1.28 |



94
92
90
88
86
84
82
80
78
76
$P_x$ (%)
- OUT
IN
6322
6324
6326
6328
6330
6332
6334
Run number
10
8
6
4
2
0
-2
-4
-6
-8
-10
$P_y$ (%)
- OUT
IN
6322
6324
6326
6328
6330
6332
6334
Run number

# Polarization Precession in 5 MeV Dipole

- $P_y$ is the same in Mott and Compton Polarimeters

- $P_x$ and $P_z$ polarization precession is: $\theta_{spin} = a\gamma\theta_{bend}$

where $a$ is electron anomalous magnetic moment,

  - Mott $\theta_{bend} = -12.5^\circ$
  - Compton $\theta_{bend} = +25.0^\circ$

- Mott, T = 5.0 MeV, $\theta_{spin} = -0.16^\circ$

- Compton, p = 8.25 MeV/c, $\theta_{spin} = +0.47^\circ$

- Total polarization precession, $\theta_p = 0.63^\circ$

# Polarization at Compton Polarimeter

- At Mott: measurements on June 4 and June 10:
  - $P_x = -0.6\% \pm 0.6\%$ (stat)
  - $P_y = 1.2\% \pm 0.4\%$ (stat)
  - $P_z = 83.7\% \pm 0.6\%$ (stat)

- At Compton:

$$\begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}_{Compton} = \begin{bmatrix} \cos\theta_p & 0 & \sin\theta_p \\ 0 & 1 & 0 \\ -\sin\theta_p & 0 & \cos\theta_p \end{bmatrix} \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}_{Mott}$$

  - $cos(0.63^\circ) = 1.000$
  - $sin(0.63^\circ) = 0.011$

  - $P_x = 0.3\% \pm 0.6\%$ (stat)
  - $P_y = 1.2\% \pm 0.4\%$ (stat)
  - $P_z = 83.7\% \pm 0.6\%$ (stat)

# Summary

- The electron beam polarization during PEPPo experiment is:

$$\mathbf{P_x = 0.3\% \pm 0.6\%\ (stat) \pm 2.8\%\ (sys)}$$

$$\mathbf{P_y = 1.2\% \pm 0.4\%\ (stat) \pm 2.8\%\ (sys)}$$

$$\mathbf{P_z = 83.7\% \pm 0.6\%\ (stat) \pm 2.8\%\ (sys)}$$

- More work this Fall to reduce the systematic error

  I. New theoretical calculations
  II. New target thickness extrapolation