E12-07-108:
HRS Cross Section Analyses

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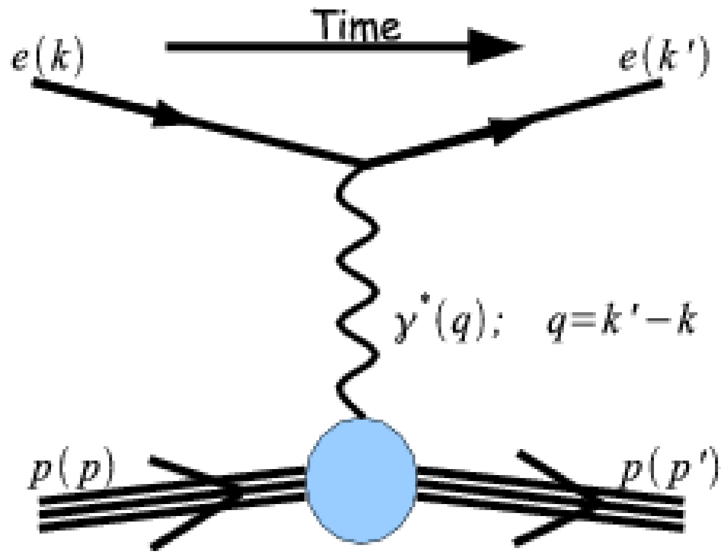
GMp Collaboration Meeting
September 24th, 2012

Elastic *ep* Cross Section



$$\frac{d\sigma}{d\Omega} = \sigma_{\mathrm{Mott}} \frac{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}{\epsilon (1+\tau)},$$

where

$$\sigma_{\mathrm{Mott}} = \left(\frac{\alpha}{2E} \frac{\cos\frac{\theta}{2}}{\sin^2\frac{\theta}{2}} \right)^2 \frac{E'}{E},$$

and $\tau = Q^2/4M_p$ and $\epsilon = [1 + 2(1+\tau)\tan^2\theta/2]^{-1}$

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Measured Differential Cross Section

$$\frac{d^2\sigma}{d\Omega dE'}(E',\theta) = \left(\frac{N_{det}(E',\theta) - N_{BG}(E',\theta)}{N_{inc}\cdot\rho\cdot\Delta z\cdot\varepsilon_{det}\cdot LT}\right)\cdot A(E',\theta)$$

Spectrometer Acceptance:

$$A(E',\theta) = \frac{1}{\Delta\Omega(E',\theta)\Delta E'}$$

- N_{det}: number of scattered electrons detected
- N_{BG}: events from background processes
- $N_{inc} = Q/e$: number of incident electrons
- Δz: target length
- $\Delta\Omega$: solid angle acceptance

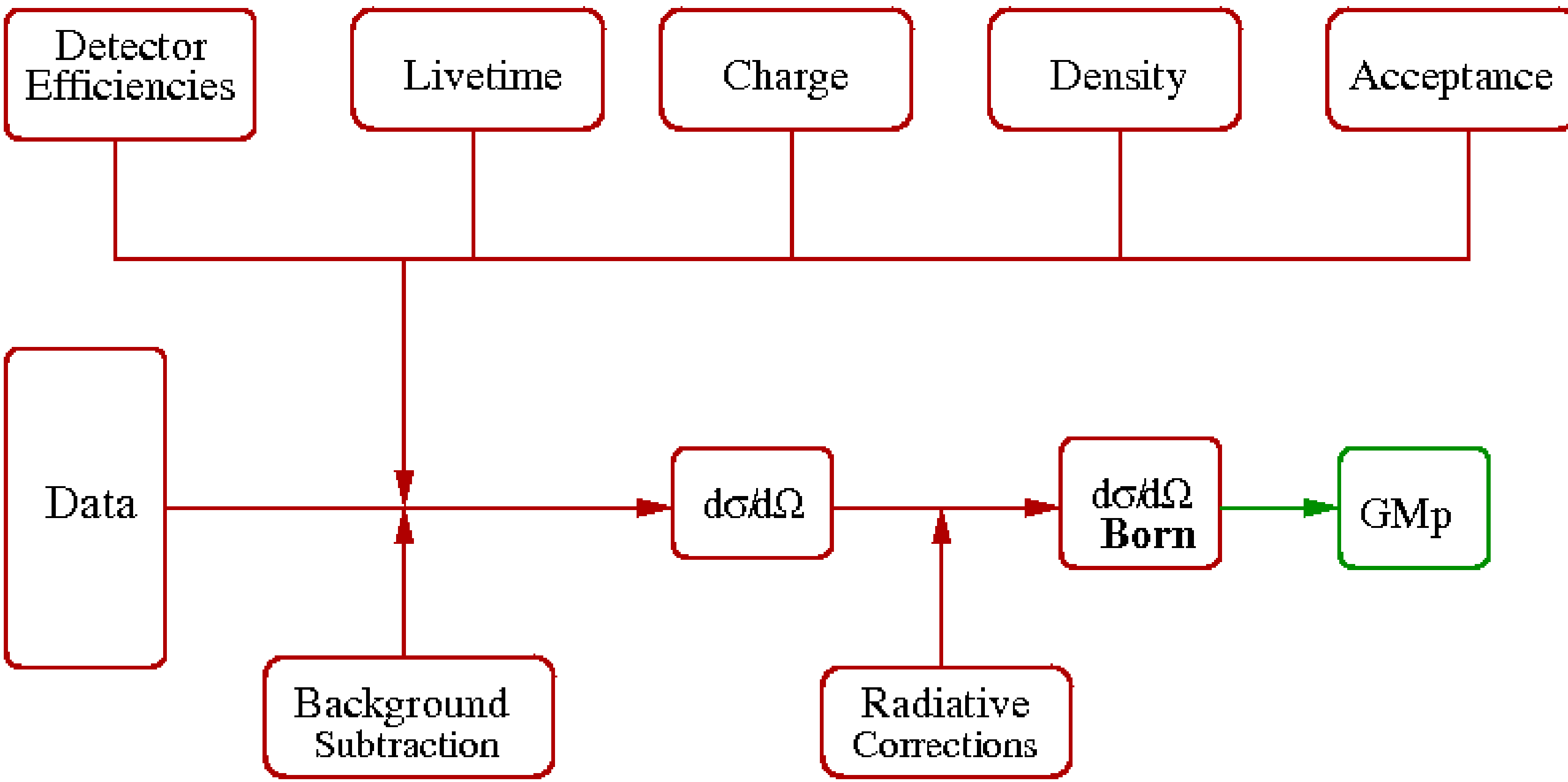
Extracted "Born" Cross Section

$$\frac{d^2\sigma_{1\gamma}}{d\Omega dE'}(E',\theta) = RC \cdot \left(\frac{N_{det}(E',\theta) - N_{BG}(E',\theta)}{N_{inc} \cdot \rho \cdot \Delta z \cdot \varepsilon_{det} \cdot LT}\right) \cdot A(E',\theta)$$

The elastic cross section requires integration over the elastic peak:

$$\frac{d\sigma_{1\gamma}}{d\Omega}(\theta) = RC \cdot \int dE' \left(\frac{N_{det}(E',\theta) - N_{BG}(E',\theta)}{N_{inc} \cdot \rho \cdot \Delta z \cdot \varepsilon_{det} \cdot LT}\right) \cdot A(E',\theta)$$

Analysis Procedure



$$\frac{d\sigma_{1\gamma}}{d\Omega}(\theta) = RC \cdot \int dE' \left(\frac{N_{det}(E',\theta) - N_{BG}(E',\theta)}{N_{inc} \cdot \rho \cdot \Delta z \cdot \varepsilon_{det} \cdot LT} \right) \cdot A(E',\theta)$$

GMp Systematics: Point-to-Point

Source	$\Delta\sigma/\sigma$ (%)
Point to point uncertainties	
Incident Energy	<0.3
Scattering Angle	0.1–0.3
Incident Beam Angle	0.1–0.2
Radiative Corrections*	0.3
Beam Charge	0.3
Target Density Fluctuations	0.2
Spectrometer Acceptance	0.4–0.8
Endcap Subtraction	0.1
Detector efficiencies and dead time	0.3
Sum in quadrature	*0.8–1.1*

* Not including TPE

GMp Systematics: Normalization

Source	$\Delta\sigma/\sigma$ (%)
Normalization uncertainties	
Beam Charge	0.4
Target Thickness/Density	0.5
Radiative Corrections*	0.4
Spectrometer Acceptance	0.6–1.0
Endcap Subtraction	0.1
Detector efficiencies and dead time	0.4
Sum in quadrature	*1.0–1.3*
Statistics	*0.5–0.8*
Total (Scale+Rand.+Stat.)	**1.2–1.7**

* Not including TPE

Key Systematics

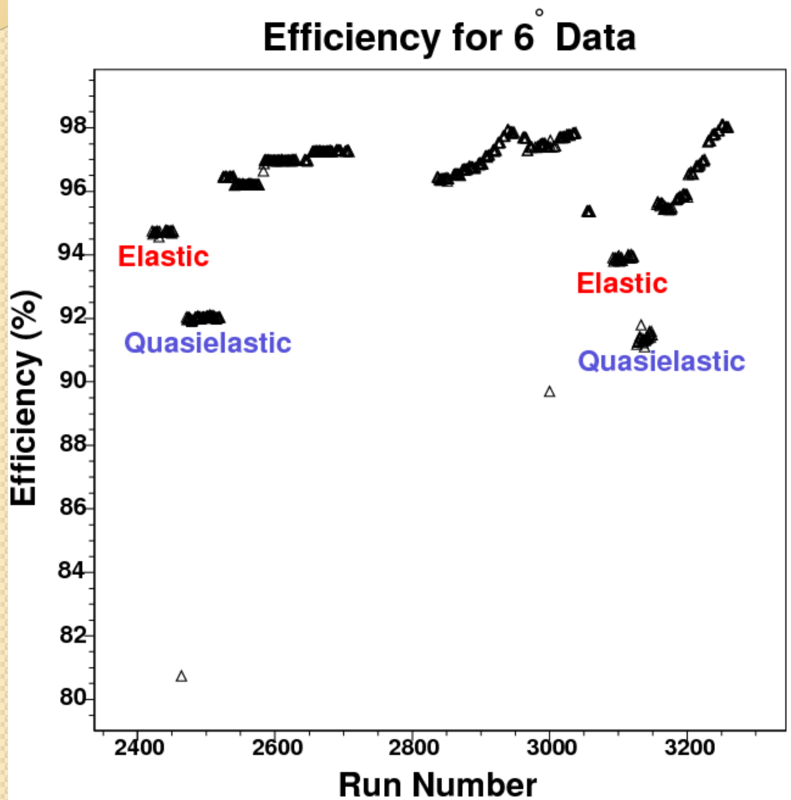
- Detector Efficiencies
  - Multi-tracks
  - Trigger
- Spectrometer Optics
  - Spectrometer mispointing and angle
  - Vertex reconstruction
- Spectrometer Acceptance/Solid Angle
- Beam Charge

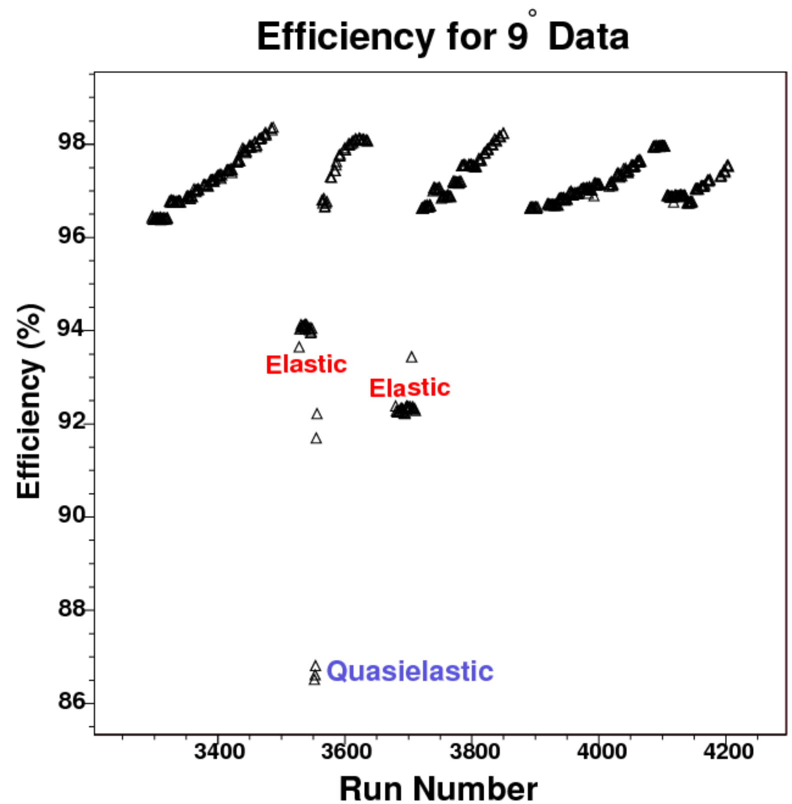
Detector Efficiencies

- Detector Efficiencies:
  - With well maintained detectors, the efficiencies are typically very high **> 99%**
  - Issues occur due to PMT aging and ^{4}He gas
  - Mirrors on the left HRS gas Cherenkov are less than ideal
  - The pion rejector would benefit to converting it to a full calorimeter

Multi-Tracks and VDCs

- Data from E97-110; $\mathcal{L} < 1 \times 10^{36}$ cm^{-2}s^{-1}
- Elastic raw rates: 5-240 kHz





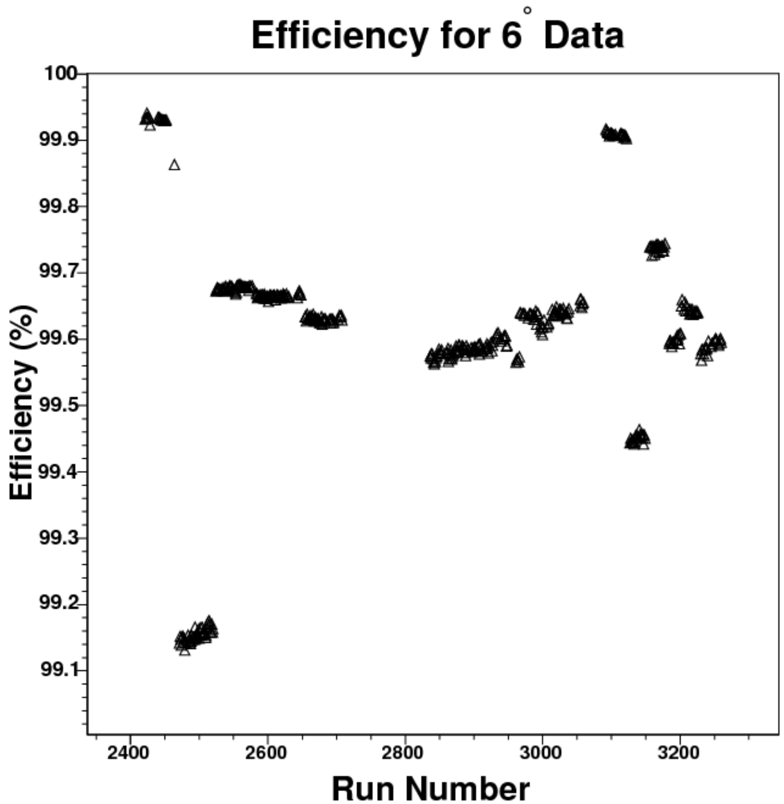
$$\epsilon_{1track} = \frac{N_1}{\sum_i N_i}$$

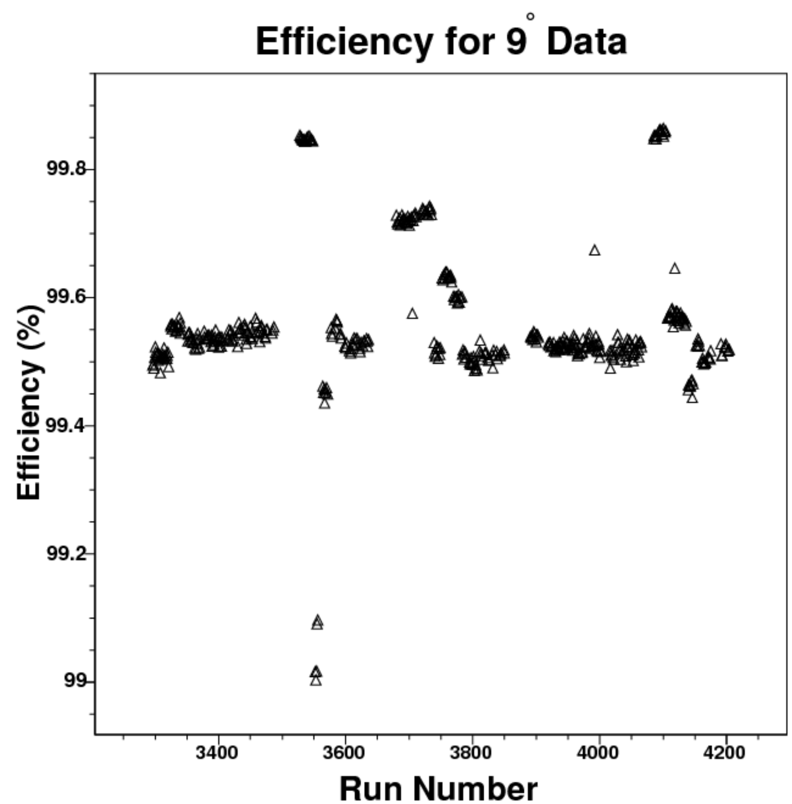
Multi-Tracks and VDCs

- Data from E97-110; $\mathcal{L} < 1 \times 10^{36}$ $cm^{-2}s^{-1}$
- Elastic raw rates: 5-240 kHz
- To recover the lost events, the multi-track events were projected to the shower and examined
- Using a typical shower cut on *E/P* on two-track events, **nearly 70% are good events**

Trigger Efficiency

- Main Trigger formed from two scintillators
- Efficiency trigger 2-of-3 including Cherenkov





$$\epsilon_{trig} = \frac{T_1}{T_1 + T_2}$$

Spectrometer Optics

- Requires **precise knowledge** of target position, spectrometer central angle and mispointing, position of sieve-slit central hole and location of BPMs
- Data that can be used to calibrate the entire spectrometer acceptance
- Well determined material thicknesses for all materials the electrons will pass through for energy loss calculations

Spectrometer Mispointing

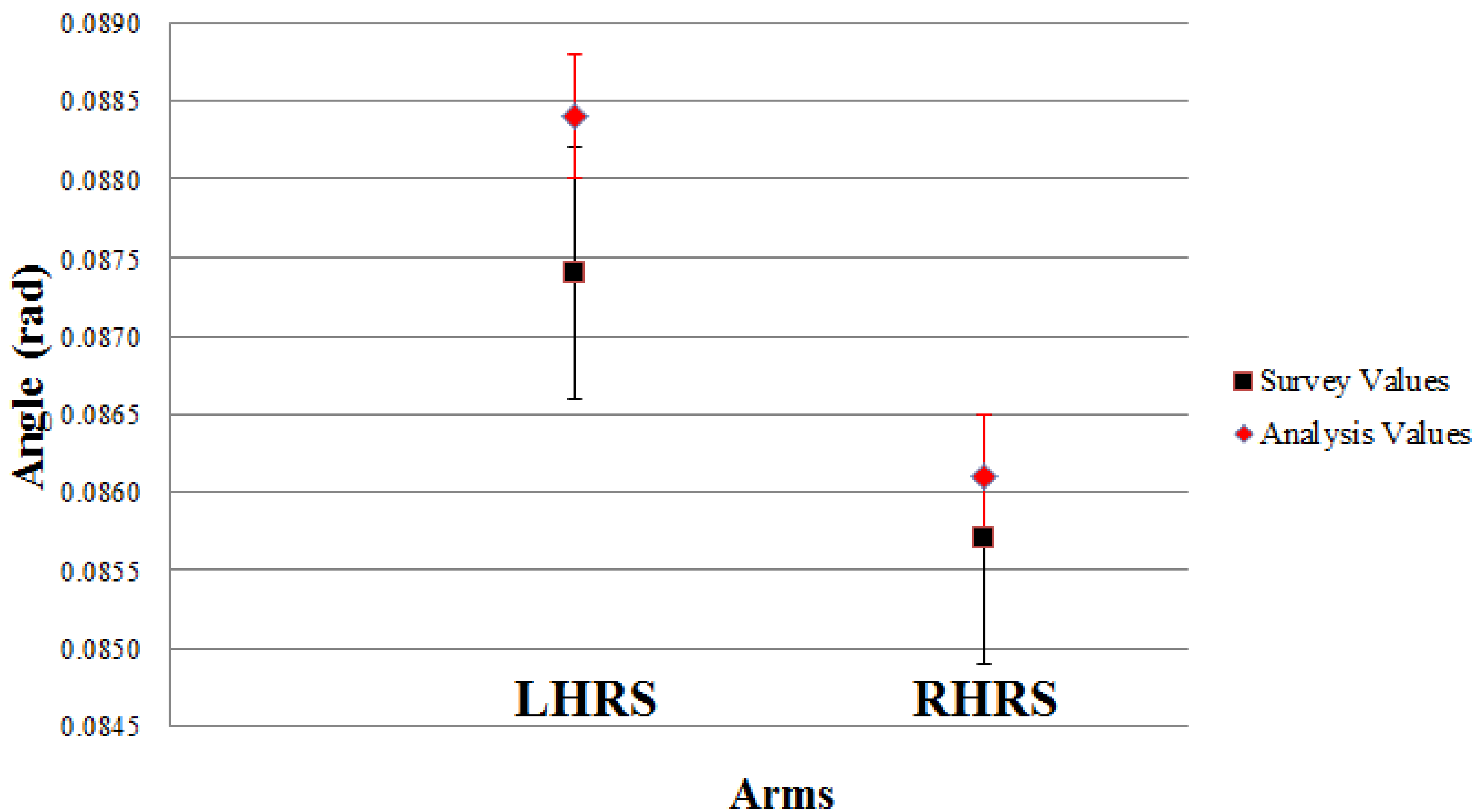
- With multiple production angle settings, it is impractical to survey each angle
- Pointing data should be taken for each angle with a foil located at the center of the target
- Spectrometer front and back floor marks can also be recorded for each angle to verify the mispointing
- This will require making sure both cameras work and the floor marks are clearly visible, i.e., **the floor marks will need to be remarked**

Spectrometer Central Angle

- Requires surveys of both target position and sieve-slit position
- Errors from these measurements combined result in a final error as much as **0.7 mrads** **(0.046°)**
- HAPPEX II, III and PREx used pointing measurements from differential recoil in elastic scattering
- The accuracy of method is greatly enhanced by consider elastic scattering off Hydrogen and heavier nuclei
- Clearly this will only work at low beam energies due to the fall off of the nuclear elastic cross section

Pointing Versus Survey

Results from PREx: **0.4 mrads** **(5º central angle)**



http://hallaweb.jlab.org/12GeV/experiment/E12-07-108/Documents/Q2_PREX.pdf

Vertex Reconstruction

- In general, y_{tg} **resolution** is 4 mm at 1 GeV/c and 1 mm at 4 GeV
- Having foils spaced 1-2 cm in zreact over 20 cm could be problematic
- However during the first part of spring 2011, we had **13 foils over 30 cm**

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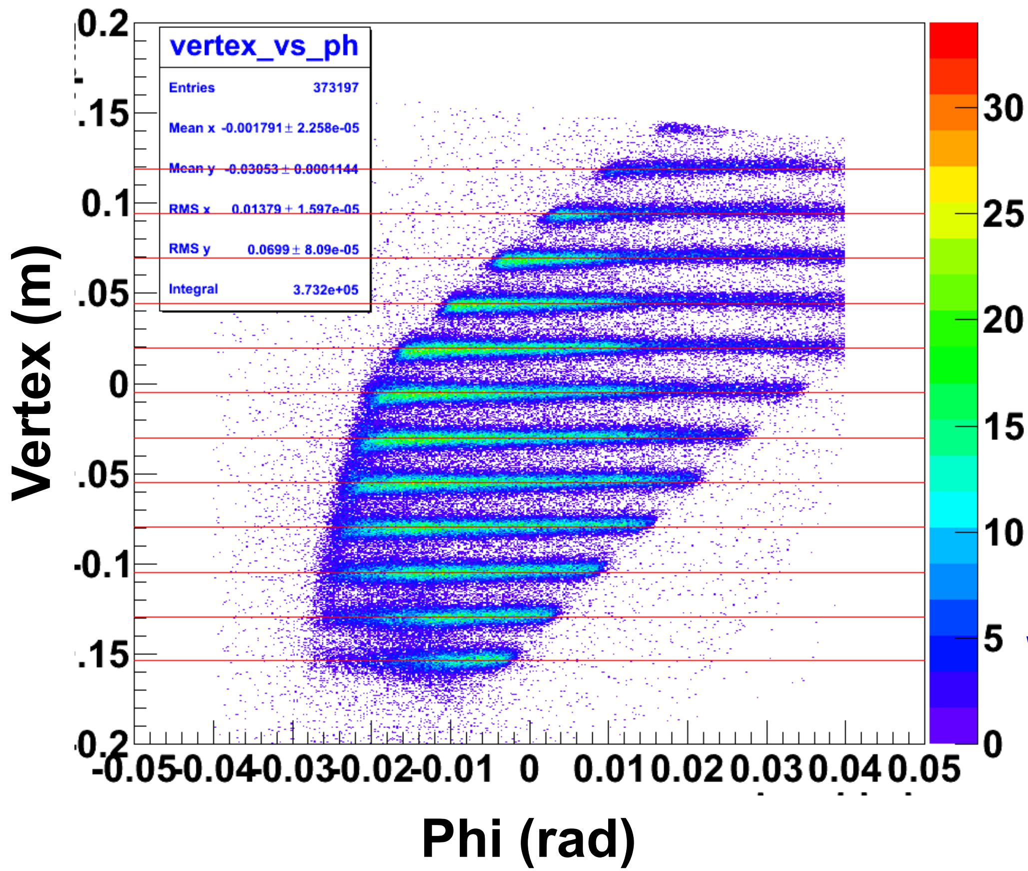
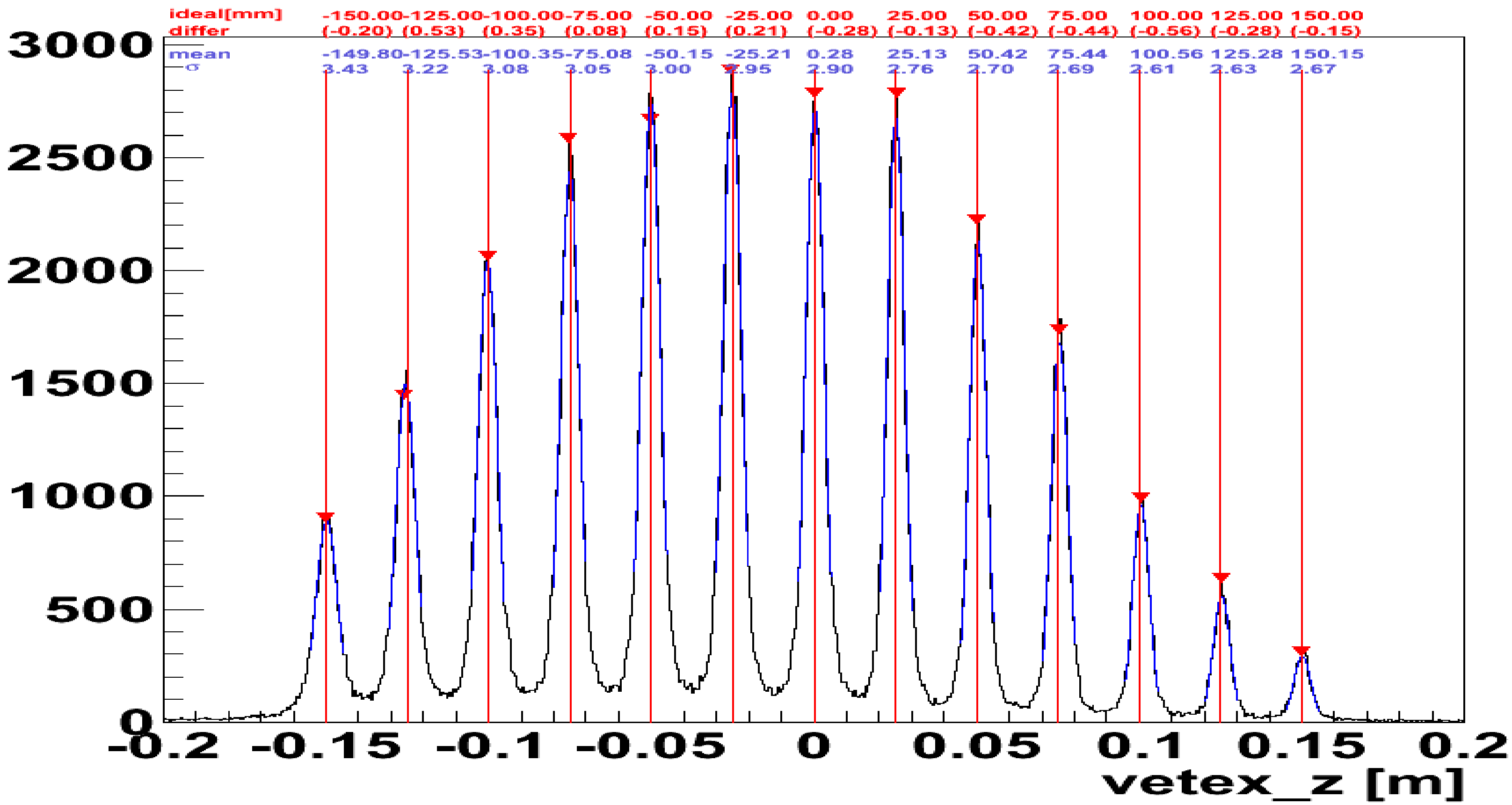
Vertex Reconstruction

- Vertex calibration with 13 carbon foils with 2.5 cm separation (30 cm total length)
- Achieved resolution of 2.5 to 3.5 mm



Work by N. Muangma

Vertex Reconstruction



Work by N. Muangma

Spectrometer Acceptance

- Magnetic elements of the spectrometer result in a complicated acceptance shape, which is dependent on the reconstructed target variables.
- Acceptance shape can be determined by comparing a simulation of the spectrometer to data.
- In Hall A, **SNAKE** is used to generate trajectories through a model of the spectrometer.

$$A(E',\theta) = \frac{1}{\Delta\Omega(E',\theta)} = \frac{N_{mc}^{tot}}{N_{mc}^{acc} \cdot \Delta\Omega_{mc}}$$

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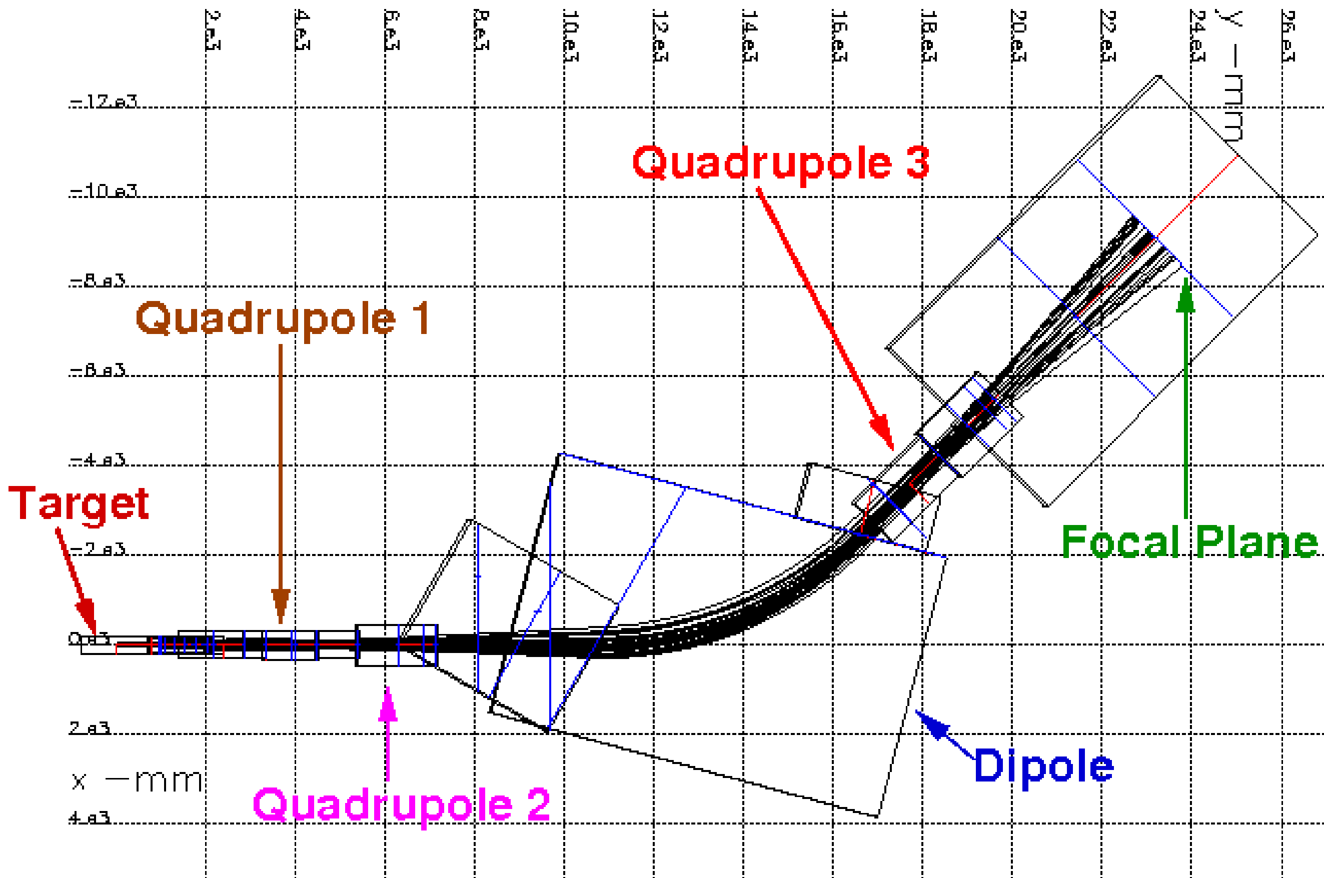
SNAKE Model



Quadrupole 3
Quadrupole 1
Target
Focal Plane
Dipole
Quadrupole 2
x —mm
y —mm

HRS Monte-Carlos

- MCEEP – no longer maintained
- SIMC – Hall C code modified for HRS
- HRS transfer functions – SNAKE model of the HRS spectrometers
- SAMC – Single Arm Monte-Carlo (A. Deur)
- HAMC – Hall A Monte-Carlo (B. Michaels)

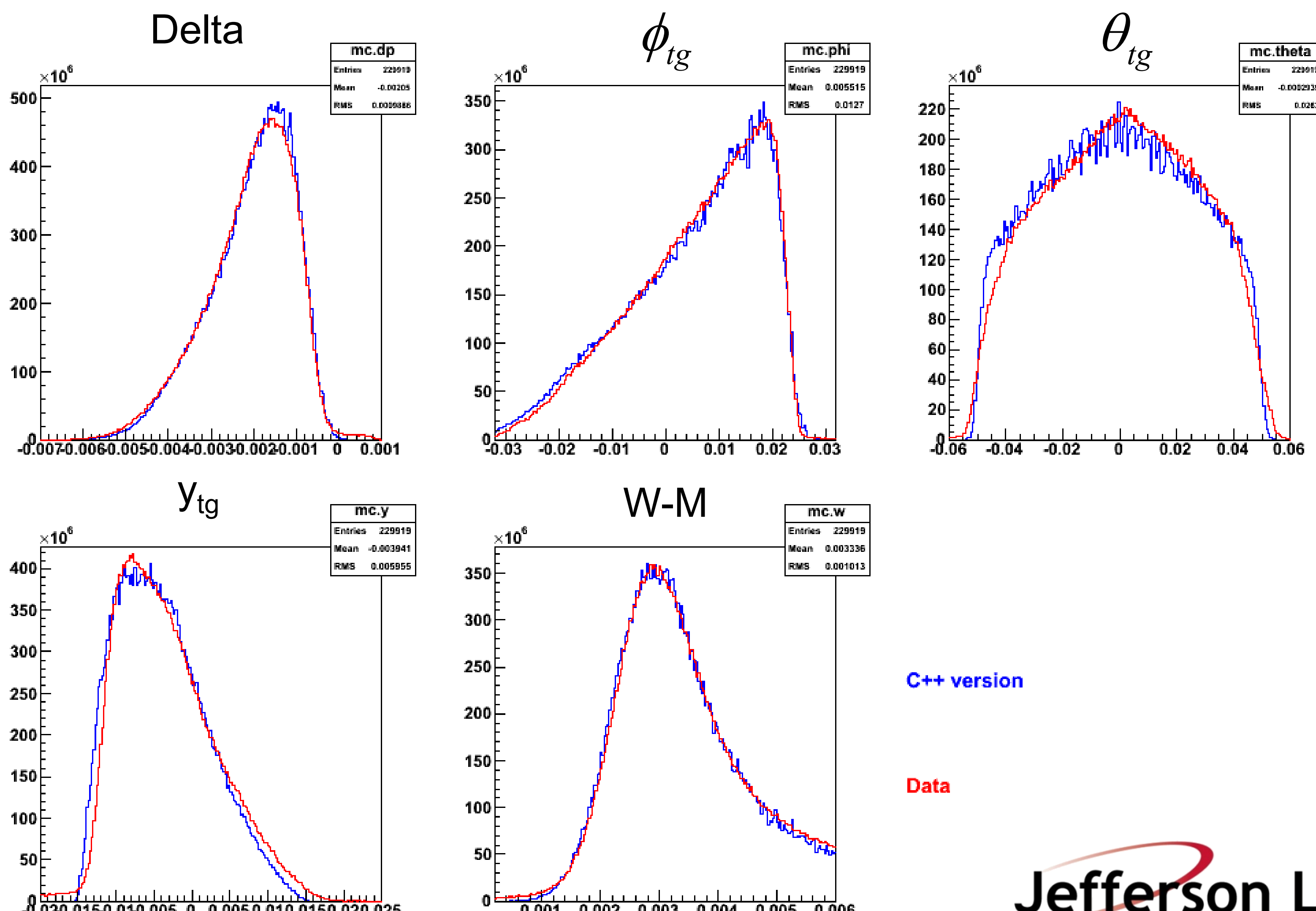
More information can be found at
http://hallaweb.jlab.org/data_reduc/mc/mc.htm

Single Arm Monte-Carlo (SAMC)

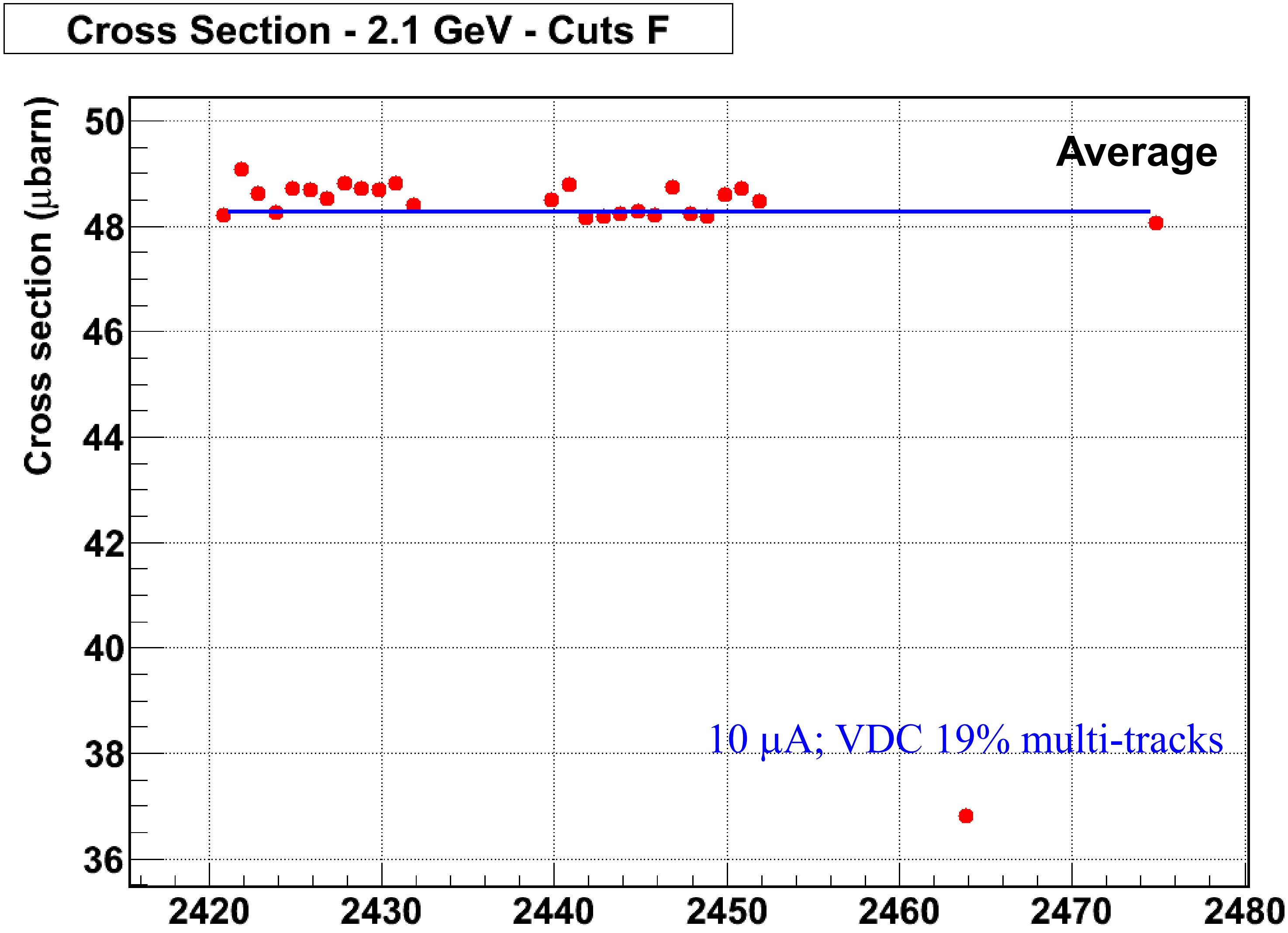
- Developed by Alexandre Deur for E94-010
- Uses John LeRose transport functions from SNAKE
- Includes:
  - Inclusive measurements
  - Point and extended targets
  - Elastic radiative corrections (internal and external), multiple scattering and Landau straggling
- Reactions:
  - Unpolarized elastic: ^{3}He, ^{4}He, carbon, nitrogen
  - Polarized elastic: ^{3}He
  - Program utilizes the parameterized cross section for A> 2 from P. Bosted: https://userweb.jlab.org/~bosted/F1F209.f

^{3}He Elastic Comparison

Effective Target length ~ 20 cm

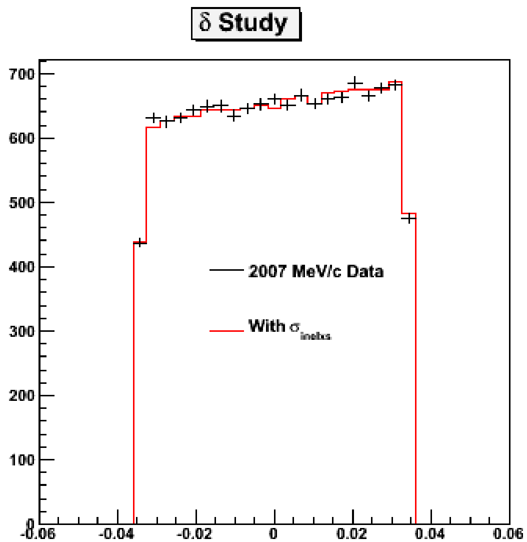


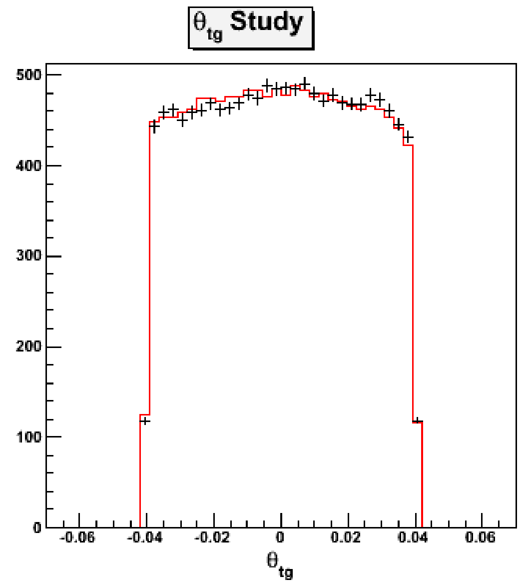
Elastic Cross Section Analysis

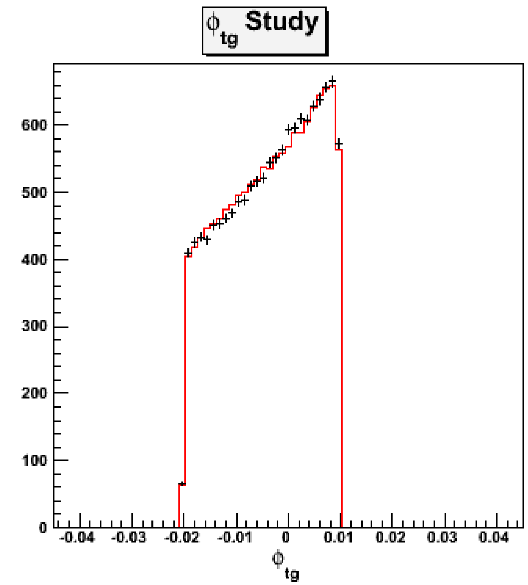


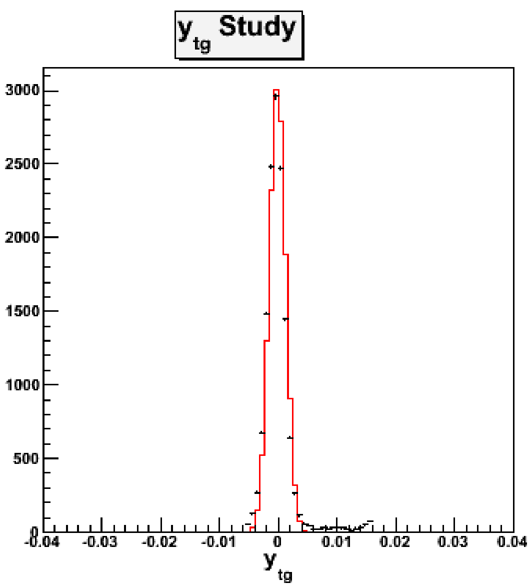
Work by V. Laine`

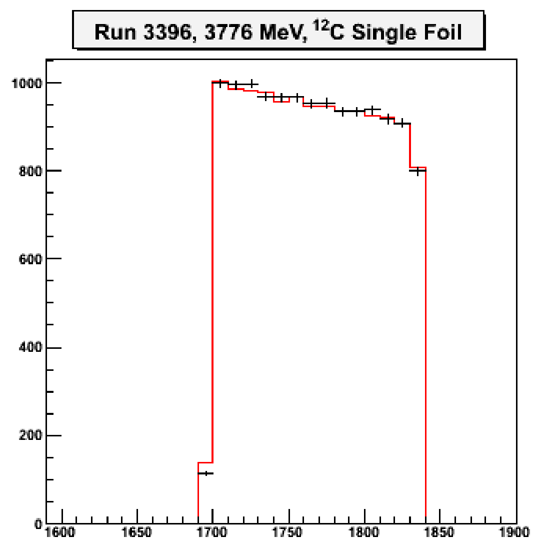
Carbon Inelastic Cross Section











E = 3.8 GeV; P0 = 2.0 GeV/c

$\sigma_{Data}/\sigma_{MC}$ = 1.061630

$|\delta| < 3.5\%$

$|\theta_{tg}| < 40$ mrads

$|y_{tg}| < 4$ cm

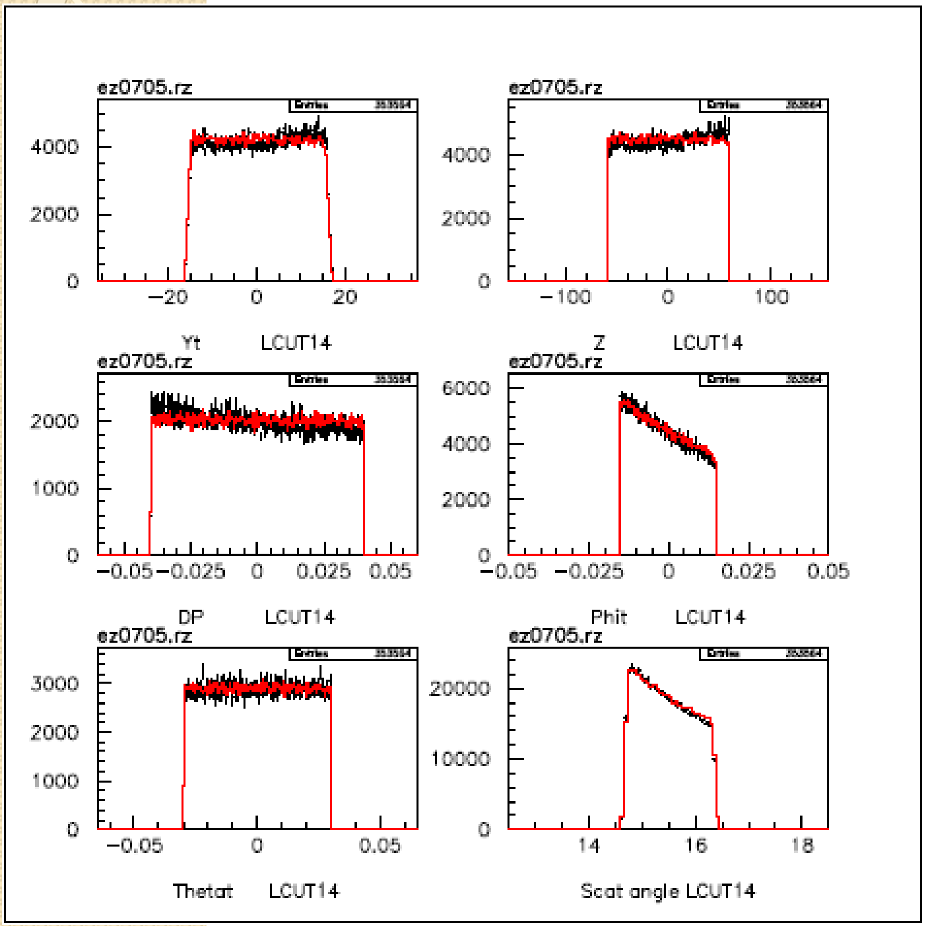
$-20 < \phi_{tg} < 10$ mrads

Acceptance and Vertex Length

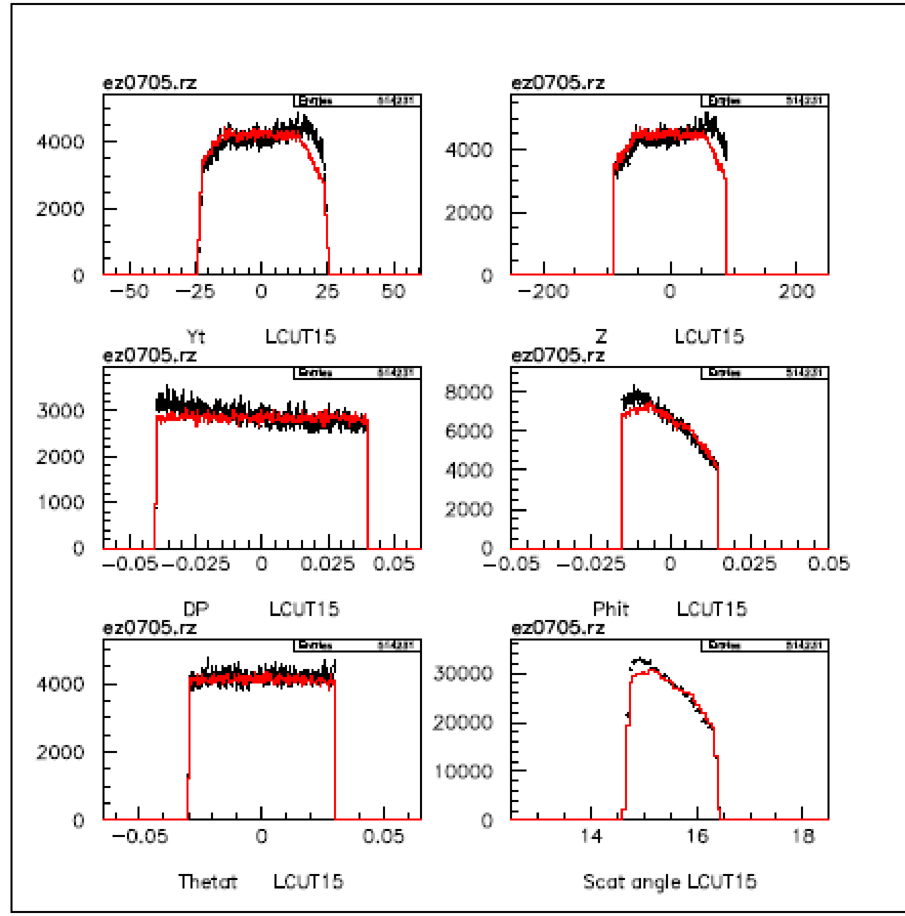
- The Polarized 3He target is 40 cm long, though only 32 cm is effectively used due to the end windows
- For cross sections, even less of the target length is kept: E94010 (12 cm), E97110 ($<$ 20 cm)
- 12 cm was chosen, since φ_{tg} has the best agreement near the center of the target
- The uncertainty due to acceptance for long targets has typically been found to be 1-3%
- Indicates we do not understand the acceptance further away from the center of the target
- A collimator that defines the solid angle acceptance will definitely help

Acceptance and Vertex Length

dZ = 12 cm



dZ = 18 cm



Work by K. Slifer

Jefferson Lab

Beam Charge

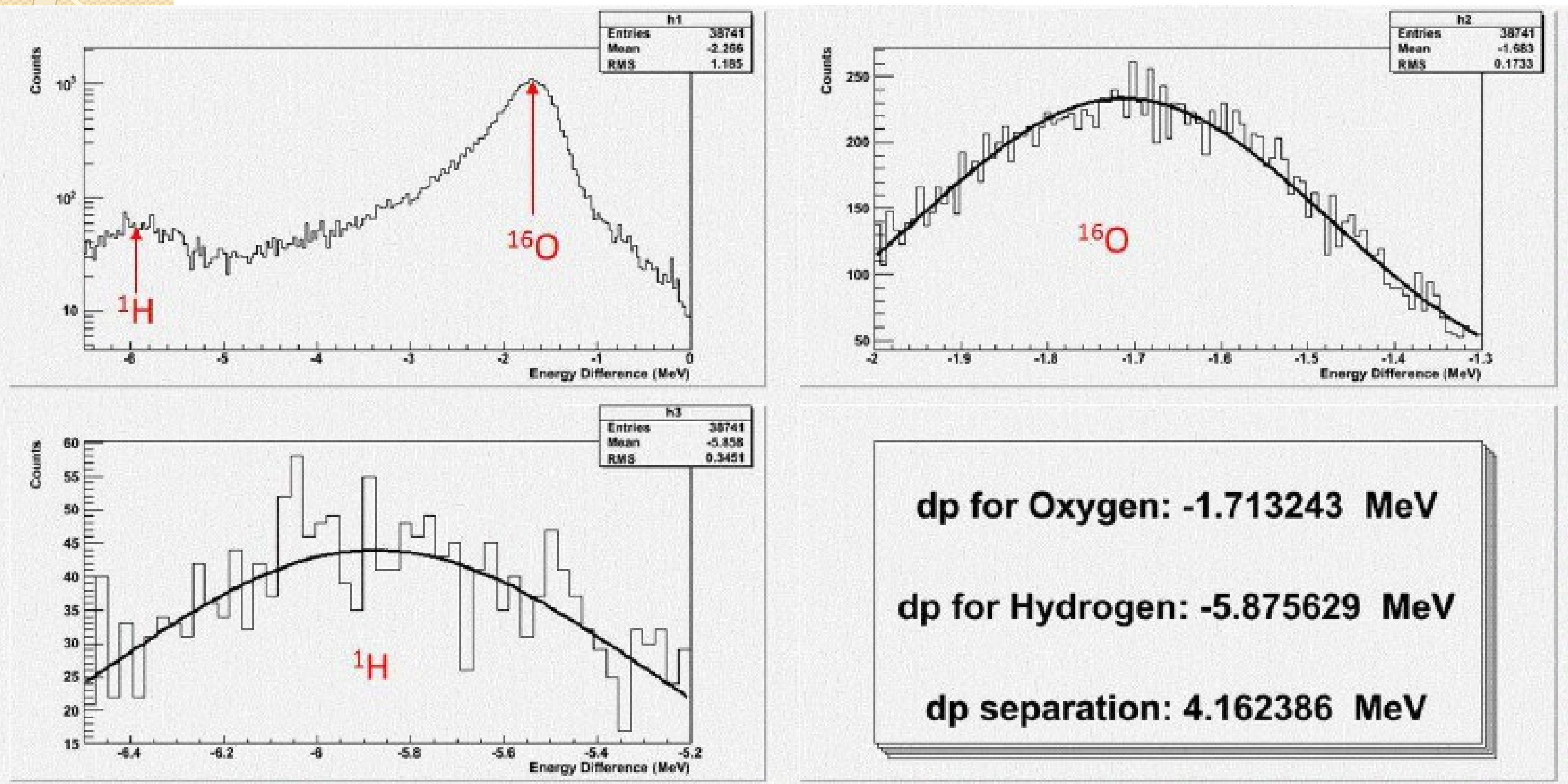
- Hall A BCMs once calibrated can provide 0.5% or better knowledge of the charge
- However issues have occurred in both the scaler readings in the HRS and in the gains of the upstream and downstream BCMs wrt each other for DVCS, g2p, and other experiments
- More than one calibration is recommended with careful monitoring of the BCMs' stability

Summary

- Achieving the needed accuracy for GMp is challenging but doable.
- Main sources of systematics:
  - Multi-tracks in the VDCs, **rate dependent**
  - Knowledge of the scattering angle
  - Solid angle for a 20 cm long target

Water Cell Target

Results from PREx: **0.4 mrads** **(5º central angle)**



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