Out-of-plane Measurements of the Structure Functions of the Deuteron

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- Physics Motivation
- Formalism
- Current Status
- Extracting Response Functions with CLAS
- Preliminary Results
- Conclusions

Physics Motivation

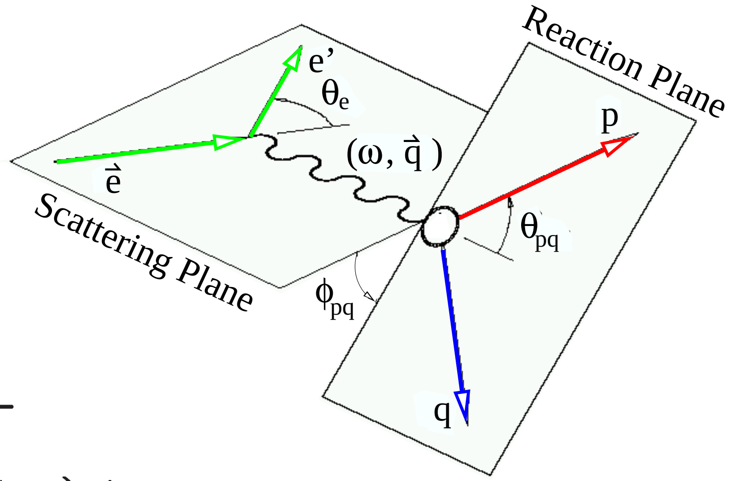
1. Can the deuteron be understood with the 'standard model' (or coherent hadronic model) of nuclear physics?

   - Can we properly incorporate relativistic effects into our description of the deuteron and few-body nuclei?
   - Can we account for final-state interactions (FSI)?
   - What other effects are needed (meson-exchange currents, isobar configurations, *etc.*)?
   - These were raised as 'Key Questions' in the PAC14 Few-Body Workshop.

2. How do we distinguish between quark-gluons effects and the less-well-understood effects of 'conventional nuclear physics' in the 1 GeV energy region?

3. Necessary for understanding color transparency.

Kinematics and Formalism



- Kinematics:

$$d(\vec{e}, e'p)n$$

- Cross section:

$$\frac{d^3\sigma}{d\omega d\Omega_e d\Omega_p} = \sigma^{\pm} = \sigma_L + \sigma_T + \sigma_{LT}\cos(\phi_{pq}) + \sigma_{TT}\cos(2\phi_{pq}) + h\sigma'_{LT}\sin(\phi_{pq})$$

- Conventional asymmetries are proportional to the corresponding structure function:

$$A_{LT} = \frac{\sigma_0 - \sigma_{180}}{\sigma_0 + \sigma_{180}} = \frac{\rho_{LT} f_{LT}}{\rho_L f_L + \rho_T f_T + \rho_{TT} f_{TT}}$$

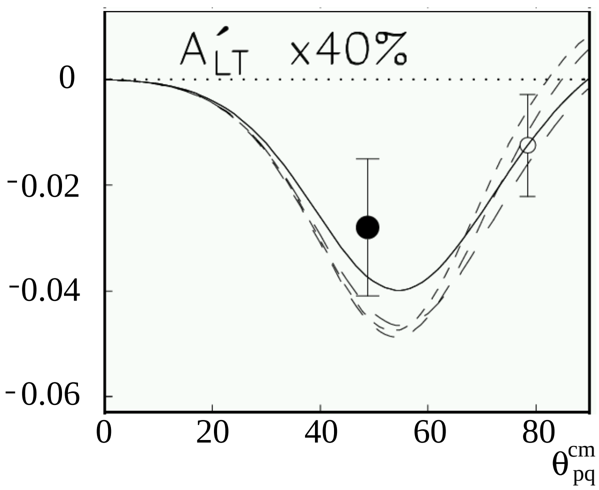
$$A_{TT} = \frac{\sigma_0 + \sigma_{180} - 2\sigma_{90}}{\sigma_0 + \sigma_{180} + 2\sigma_{90}} = \frac{\rho_{TT} f_{TT}}{\rho_L f_L + \rho_T f_T}$$

$$A'_{LT} = \frac{\sigma_{90}^{+} - \sigma_{90}^{-}}{\sigma_{90}^{+} + \sigma_{90}^{-}} = \frac{\rho' f'_{LT}}{\rho_L f_L + \rho_T f_T - \rho_{TT} f_{TT}}$$

Subscripts - ϕ_{pq}. Superscripts - beam helicity.

Experimental Status

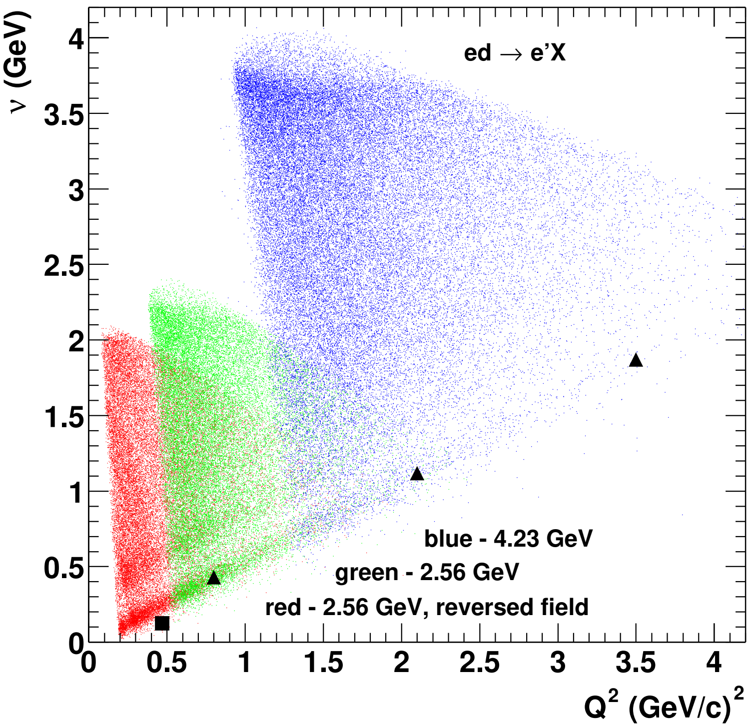
- Some measurements have already been made for $Q^2 \approx 0.1 - 0.3\ (GeV/c)^2$, but suffer from limited statistics or angular range. The plot is from S.Gilad, *et al.*, NP **A631**, 276c, 1998.



- Hall A experiment E01-020 will determine cross sections and σ_{LT} at $Q^2 = 0.8, 2.1, 3.5\ (GeV/c)^2$.

- Hall A experiment E02-101 will measure all five structure functions near threshold at Q^2 =0.47 $(GeV/c)^2$.

- This project will analyze data from the E5 run period.



Data Selection and Corrections

- For electrons.

Good CC, EC, SC status	$cc > 0$, $ec > 0$, $sc > 0$
Energy-momentum match	$0.325p_e - 0.13 < E_{total} < 0.325p_e + 0.06$
Reject pions	$ec\_ei \geq 0.100$ and $nphe \geq 25$
EC fiducial	No tracks within 10 cm of the end of a strip
Electron fiducial	Modified e1 cut, Gegham Asryan fits
Quasi-elastic scattering	$0.8\ GeV \leq W \leq 1.02$

- For protons.

Proton fiducial cut	Modified e1 cut
ep vertex cut	$\lvert v_z(e) - v_z(proton)\rvert \leq 1.5\ cm$

- For neutrons.

Missing mass cut	$0.90\ GeV^2 \leq MM^2 \leq 0.98\ GeV^2$

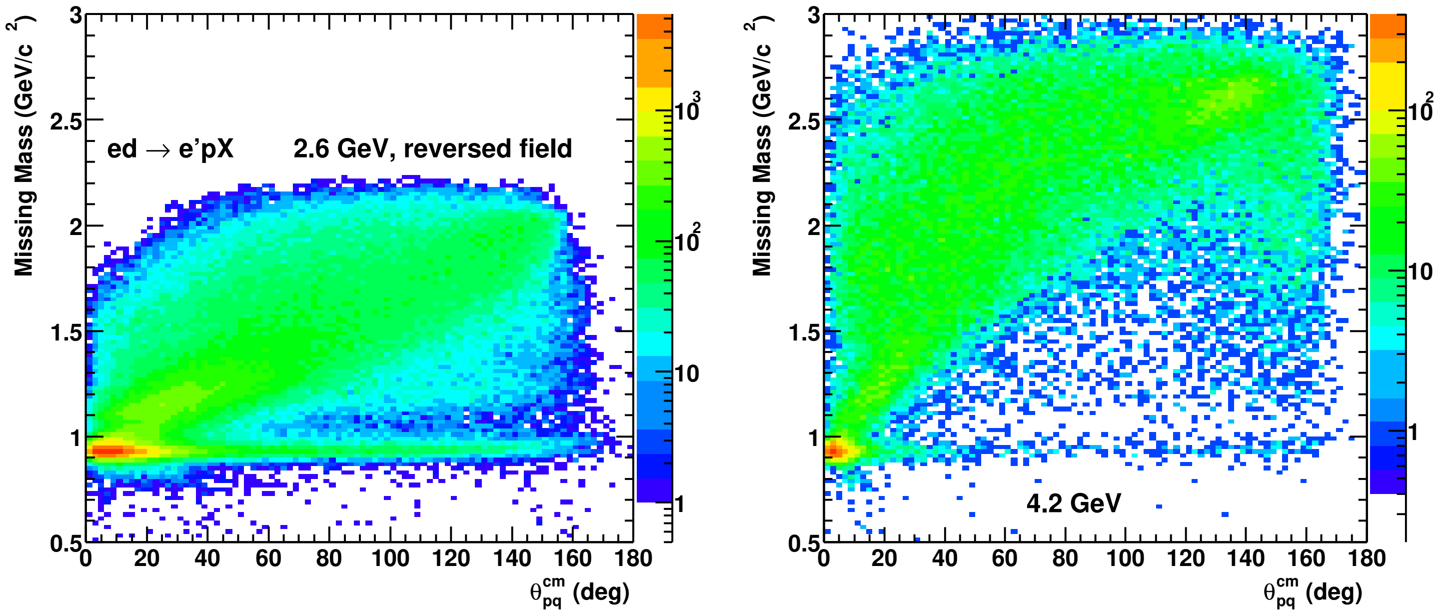
- Electron momentum corrections are small.
- Beam charge asymmetry.

2.6 GeV, reversed field	0.9934 ± 0.0007
2.6 GeV, normal field	0.9952 ± 0.0007

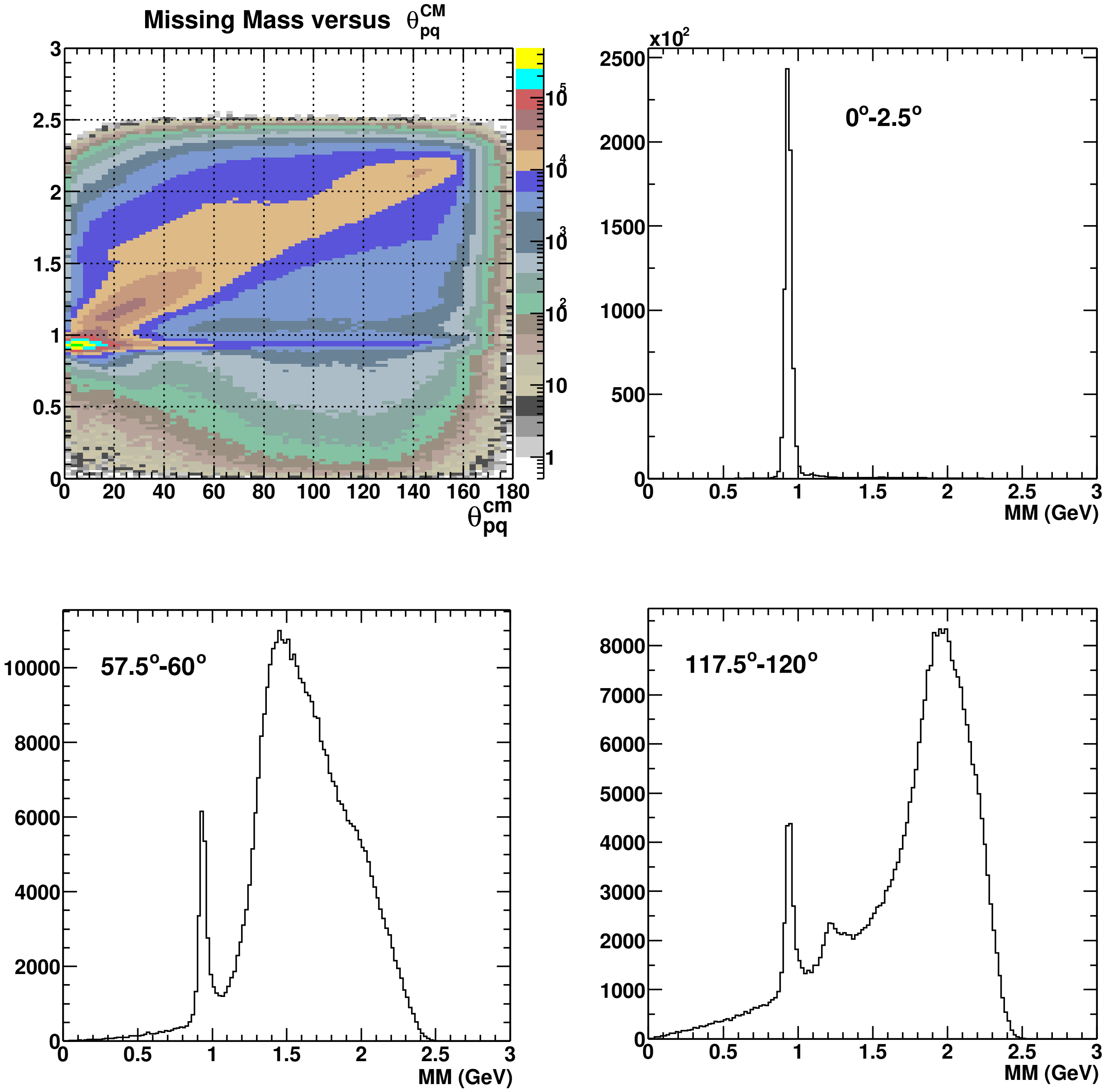
- First pass at radiative corrections has been made.

Extracting Structure Functions with CLAS

- Can we demonstrate that we can measure small asymmetries especially A'_{LT}?
- Analysis methods.
  - Analysis of moments (*e.g.* $\langle \sin \phi_{pq} \rangle$ and others).
  - Helicity asymmetry analysis for A'_{LT}.
- Restrict the analysis for now to the quasi-elastic peak.
  - Comparison with other results at low Q^2.
  - Theory is better understood (MEC and IC less important).
- Use missing mass technique to isolate neutrons.

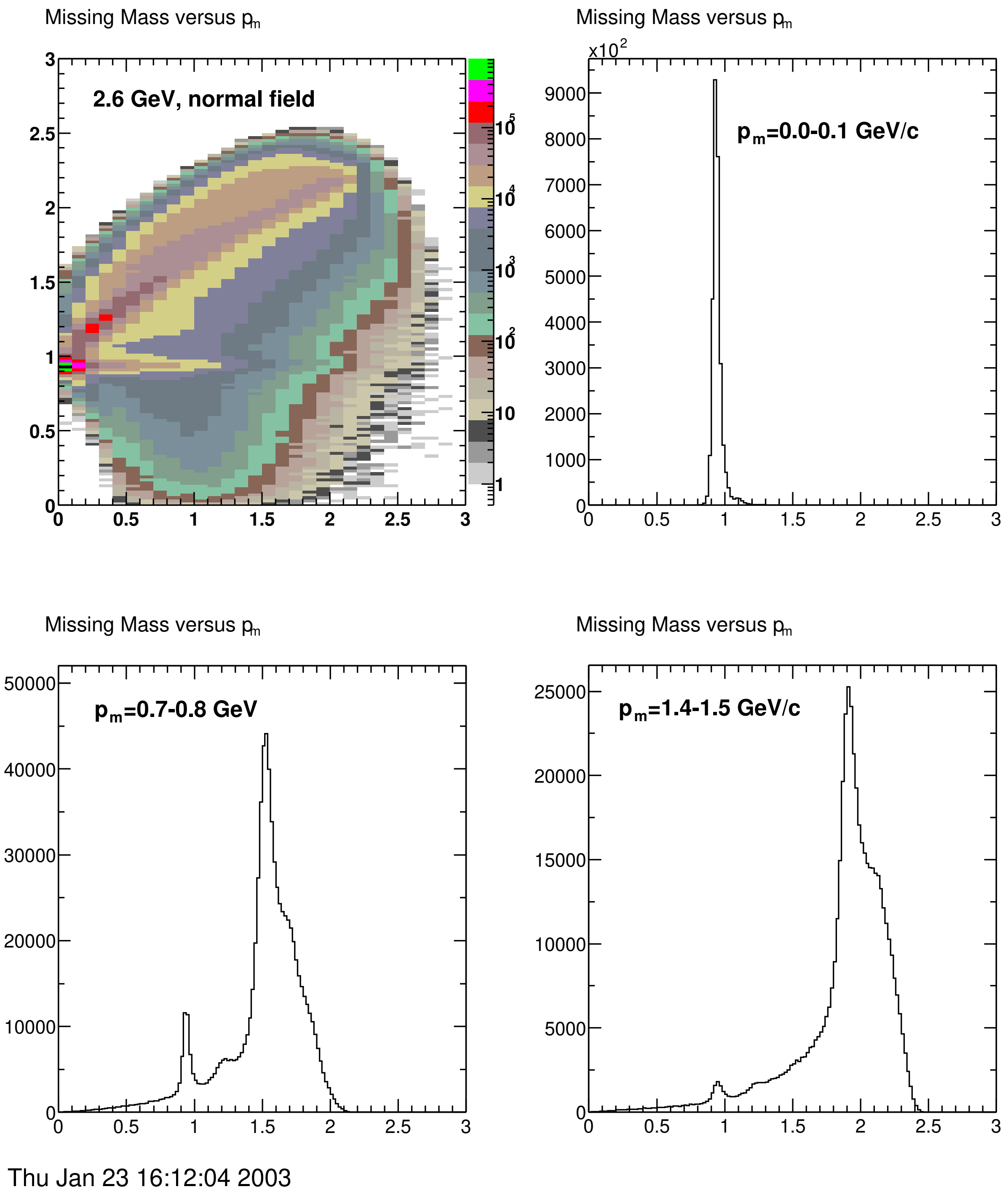


How high in θ_{pq} can we go?



Missing mass spectrum for $d(\vec{e}, e'p)n$, 2.558 GeV, normal field, not acceptance corrected.

How high in p_m can we go?



Missing mass spectrum for $d(\vec{e}, e'p)n$, 2.558 GeV, normal field, not acceptance corrected.

$\langle \sin \phi_{pq} \rangle_{\pm}$ Moments Analysis For A'_{LT}

- Recall

$$\sigma^{\pm} = \sigma_L + \sigma_T + \sigma_{LT} \cos(\phi_{pq}) + \sigma_{TT} \cos(2\phi_{pq}) + h\sigma'_{LT} \sin(\phi_{pq})$$

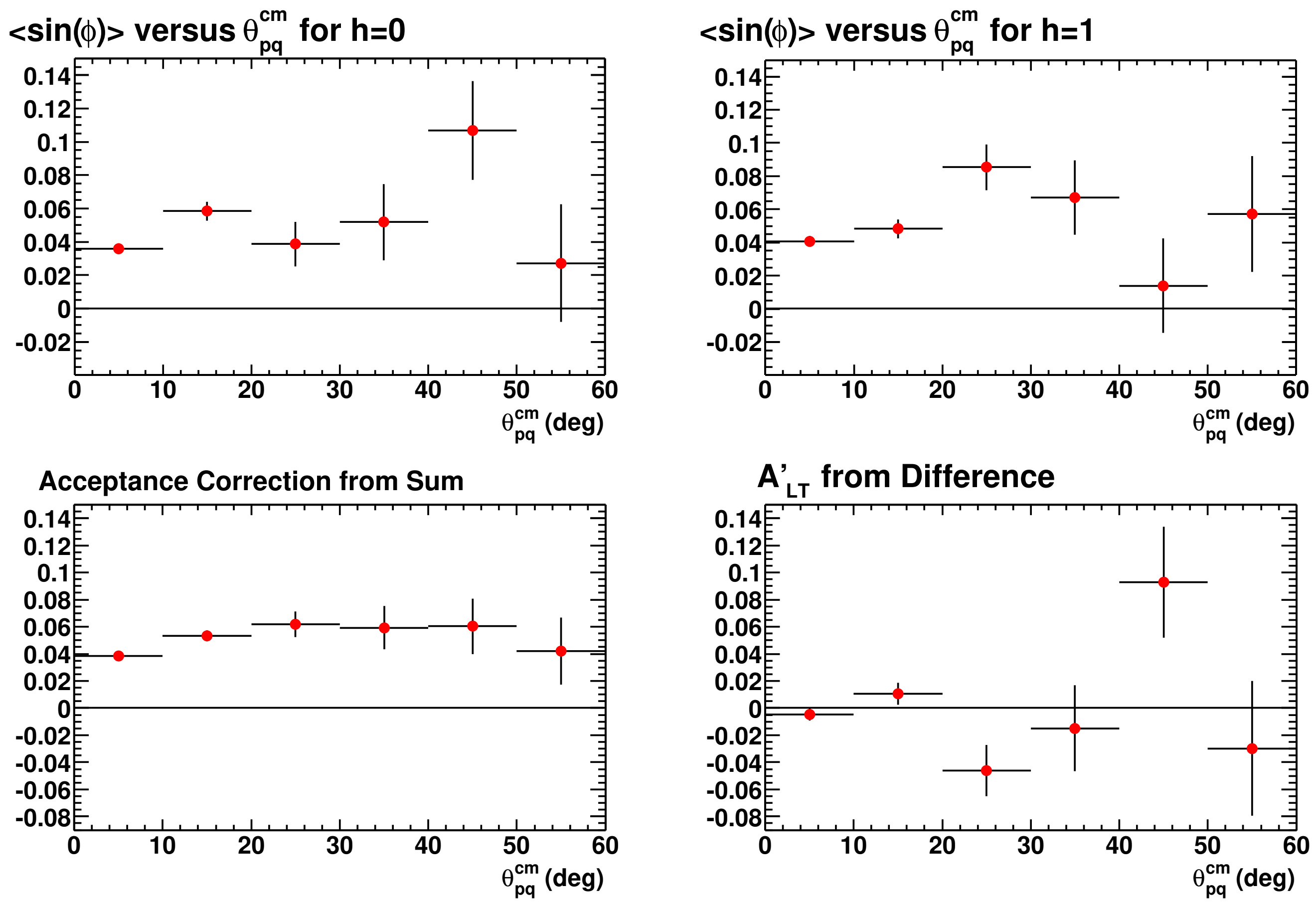
- Let

$$\langle \sin \phi_{pq} \rangle_{\pm} = \frac{\int_{-\pi}^{\pi} \sigma^{\pm} \sin \phi_{pq} d\phi}{\int_{-\pi}^{\pi} \sigma^{\pm} d\phi} = \frac{\sum_{\pm}^{\phi} \sin \phi_i}{N^{\pm}} = \pm \frac{\sigma'_{LT}}{2(\sigma_L + \sigma_T)} \approx \pm \frac{A'_{LT}}{2}$$

- For a sinusoidally-varying component to the acceptance

$$\langle \sin \phi_{pq} \rangle_{\pm} = \pm \frac{A'_{LT}}{2} + \alpha_{acc} \qquad .$$

- Preliminary results for 2.56 GeV, normal field, not acceptance corrected, $0.8 < Q^2 < 1.0 \ (GeV/c)^2$, $0.95 < x_B < 1.05$.



Other Moments for A_{LT} and A_{TT}

- Recall

$$\sigma^{\pm} = \sigma_L + \sigma_T + \sigma_{LT}\cos(\phi_{pq}) + \sigma_{TT}\cos(2\phi_{pq}) + h\sigma'_{LT}\sin(\phi_{pq})$$

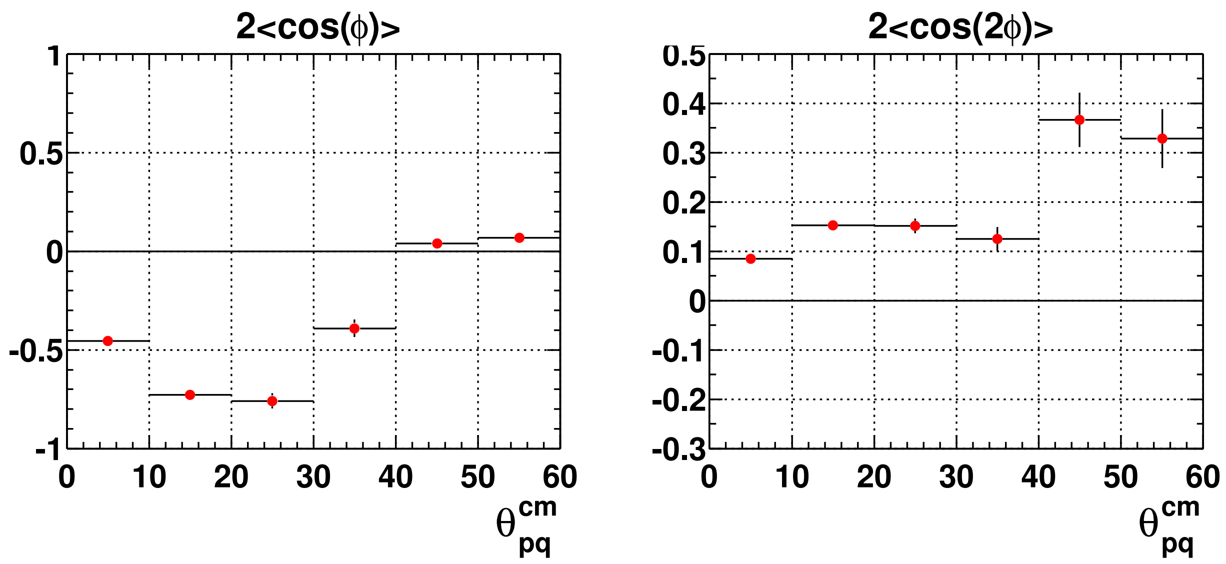
- In a way similar to relating $\langle \sin\phi_{pq}\rangle$ and A'_{LT}

$$\langle \cos\phi_{pq}\rangle = \frac{\sigma_{LT}}{2(\sigma_L + \sigma_T)} \approx \frac{A_{LT}}{2}$$

and

$$\langle \cos 2\phi_{pq}\rangle = \frac{\sigma_{TT}}{2(\sigma_L + \sigma_T)} = \frac{A_{TT}}{2}$$

- Preliminary results for 2.56 GeV, normal field, not acceptance corrected, $0.8 < Q^2 < 1.0\ (GeV/c)^2$, $0.95 < x_B < 1.05$.



- These asymmetries are large, but are not corrected for acceptance.

Helicity Asymmetry Analysis for A'_{LT}

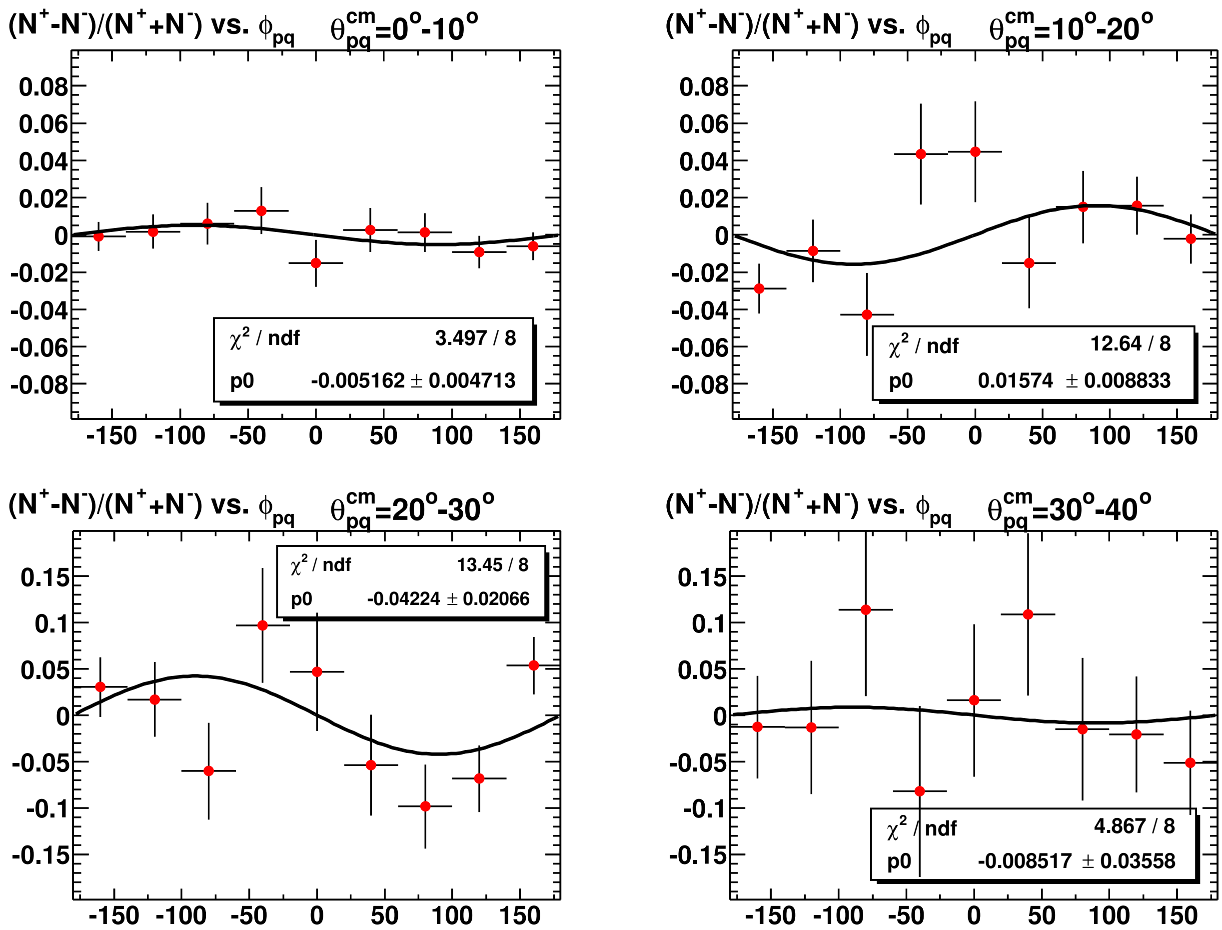
- Recall

  $\sigma^{\pm} = \sigma_L + \sigma_T + \sigma_{LT}\cos(\phi_{pq}) + \sigma_{TT}\cos(2\phi_{pq}) + h\sigma'_{LT}\sin(\phi_{pq})$

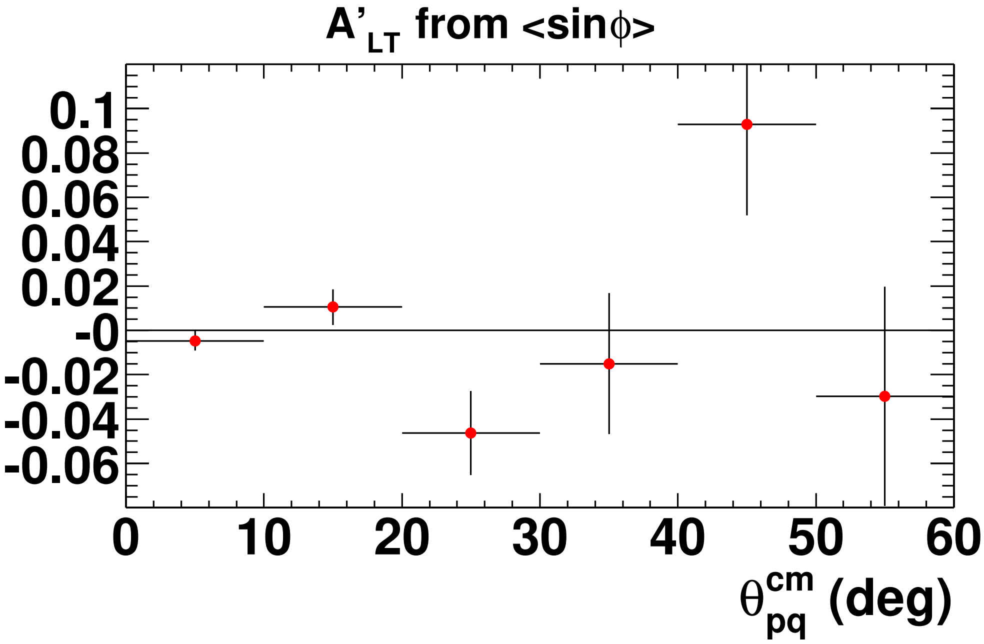
- Define A'_{LT} in a more general way.

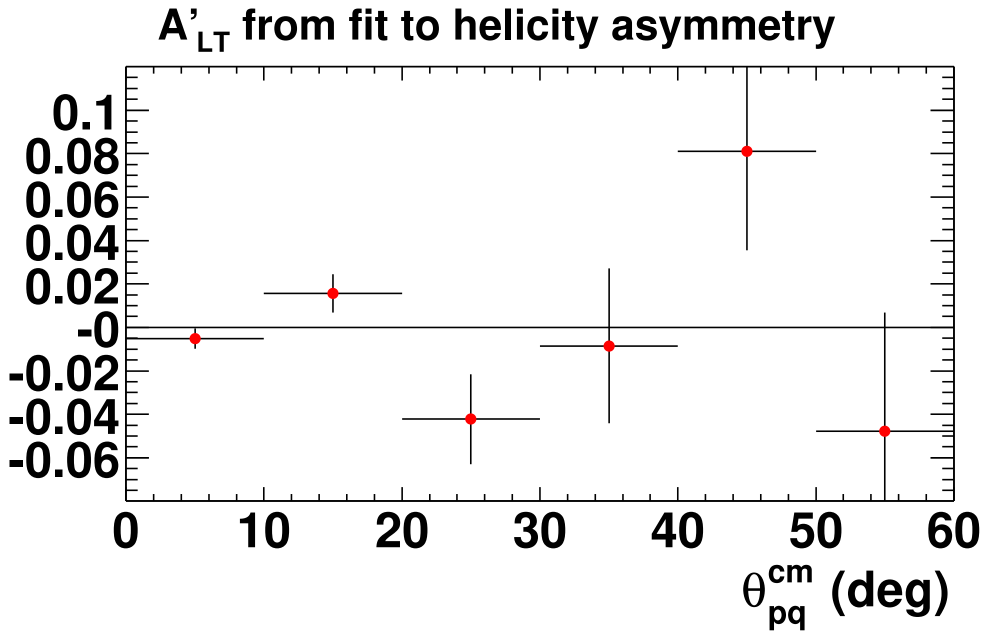
$$\frac{N^+ - N^-}{N^+ + N^-} = \frac{\sigma'_{LT}\sin\phi_{pq}}{\sigma_L + \sigma_T + \sigma_{LT}\cos(\phi_{pq}) + \sigma_{TT}\cos(2\phi_{pq})}$$

- Less sensitive to acceptance corrections, but extracting results may be more complex since the denominator depends on ϕ_{pq}.
- Preliminary results for 2.56 GeV, normal field, not acceptance corrected, $0.8 < Q^2 < 1.0\ (GeV/c)^2$, $0.95 < x_B < 1.05$.



Comparison of Different Analysis Methods for A'_{LT}





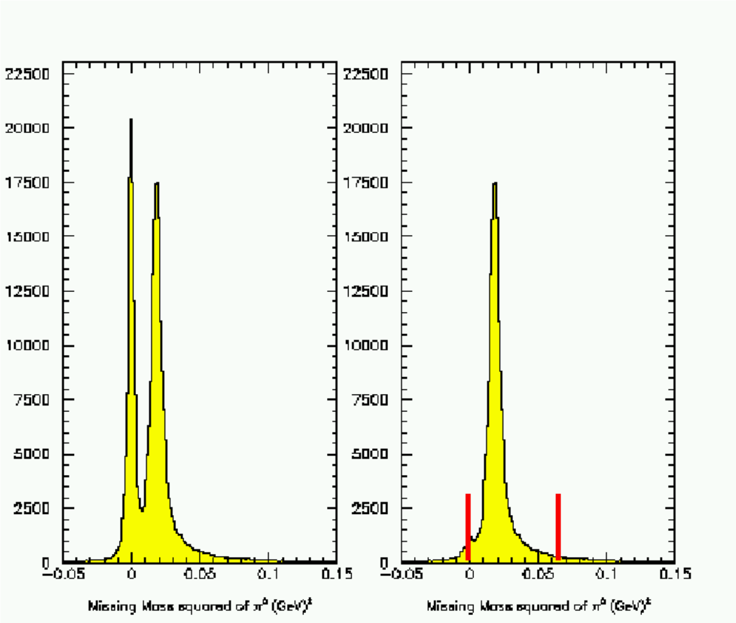
- The shapes and uncertainties are consistent. We can measure small A'_{LT}.
- 2.56 GeV, normal field, not acceptance corrected, $0.8 < Q^2 < 1.0\ (GeV/c)^2$, $0.95 < x_B < 1.05$.

Analysis Cross Checks for A'_{Lt}

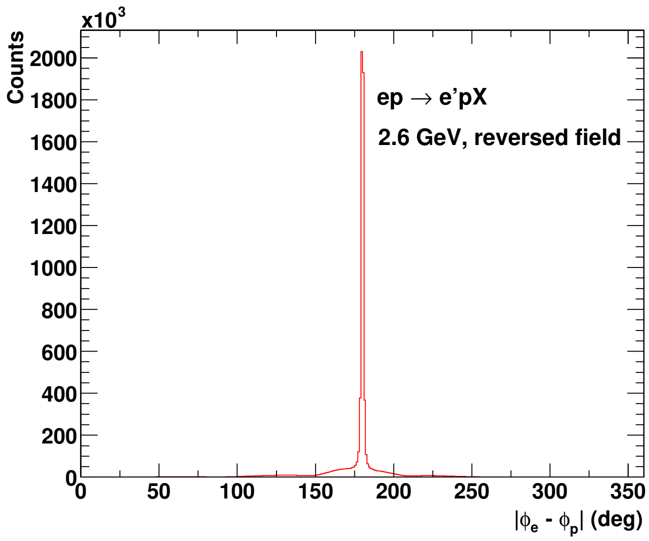
- $ep \rightarrow e'p\pi^0$
  - Test our analysis against the known results from 'Single π^0 Electroproduction in the $\Delta(1232)$ Resonance from E1A Data' by K. Joo and C. Smith (CLAS Analysis 2001-008).
  - Check the helicity signal on a run-by-run basis.
  - Takes advantage of the *in situ* hydrogen calibration target.
  - Similar data selection, but requires Bethe-Heitler suppression to use missing mass to measure the π^0.
- $ep \rightarrow e'\pi^+ n$
  - Test our analysis against the known results from 'Measurement of Polarized Structure Function σ'_{LT} for $p(\vec{e}, e'\pi^+)n$ in the $\Delta(1232)$ Resonance Region' ' by K. Joo and C. Smith (CLAS Analysis 2001-009).
  - Second check on the helicity signal on a run-by-run basis.
  - Similar data selection.
- Overlaps of different running conditions.

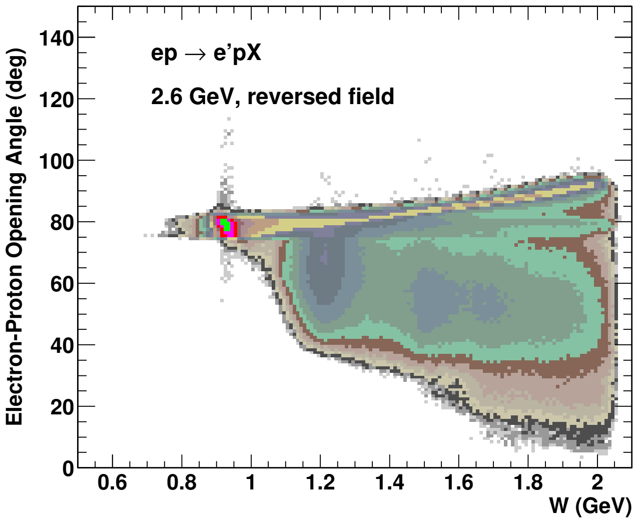
$ep \to e'p\pi^0$ **Analysis**

- Bethe-Heitler events overlap with missing mass of π^0.



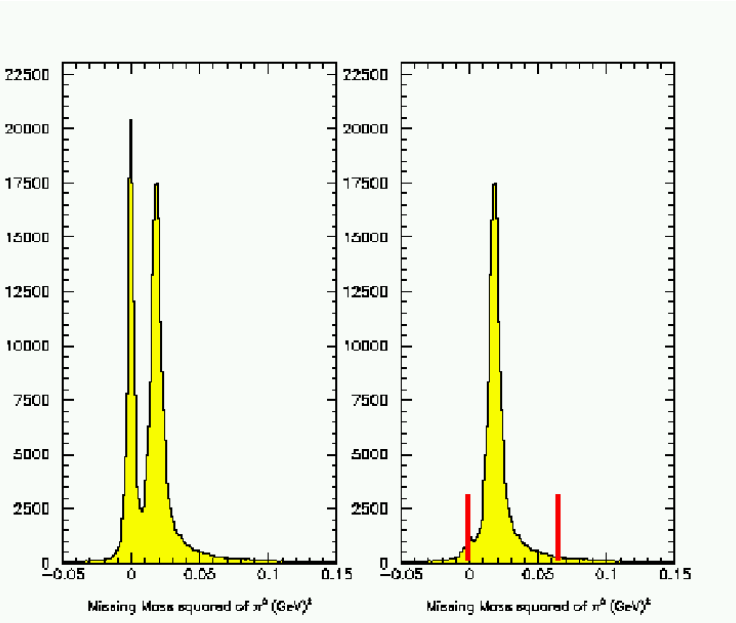
- Use kinematic constraints to identify Bethe-Heitler events and remove them.



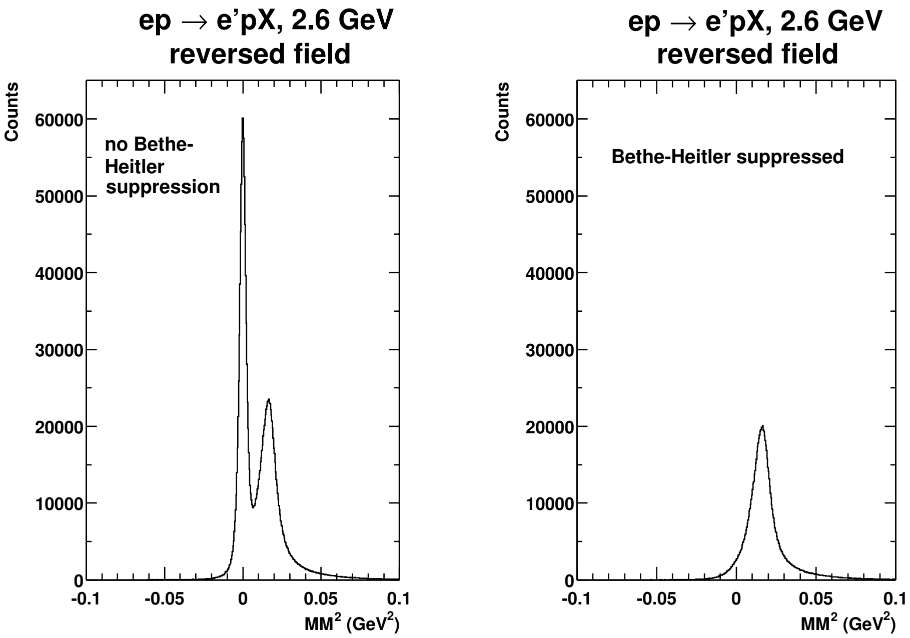


Results of Bethe-Heitler suppression for $ep \to e'p\pi^0$.

- K. Joo and C. Smith results.

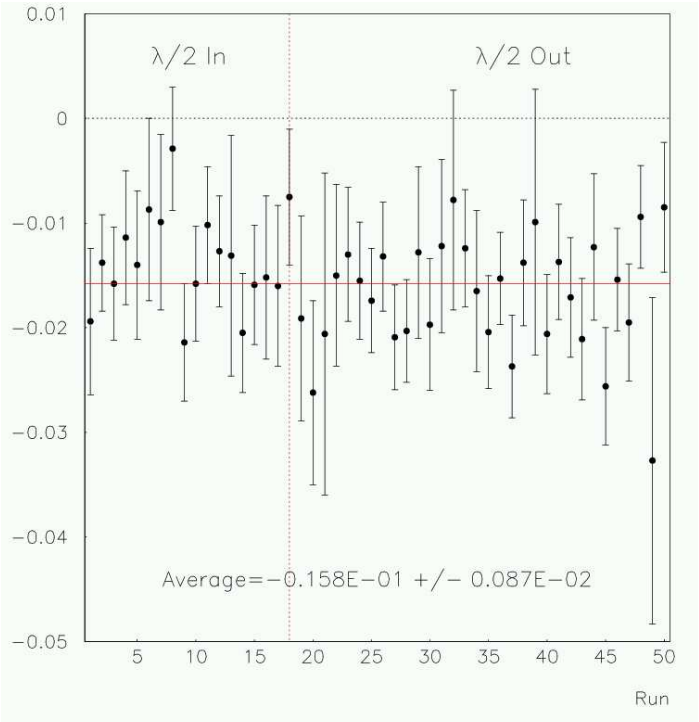


- This analysis for 2.6 GeV, reversed field.

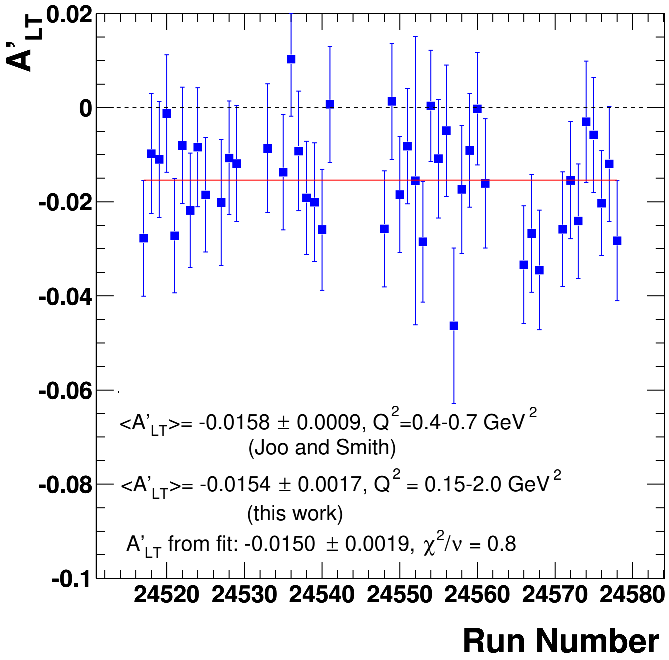


Comparison of Asymmetries Run By Run.

- K. Joo and C. Smith for 1.52 GeV.



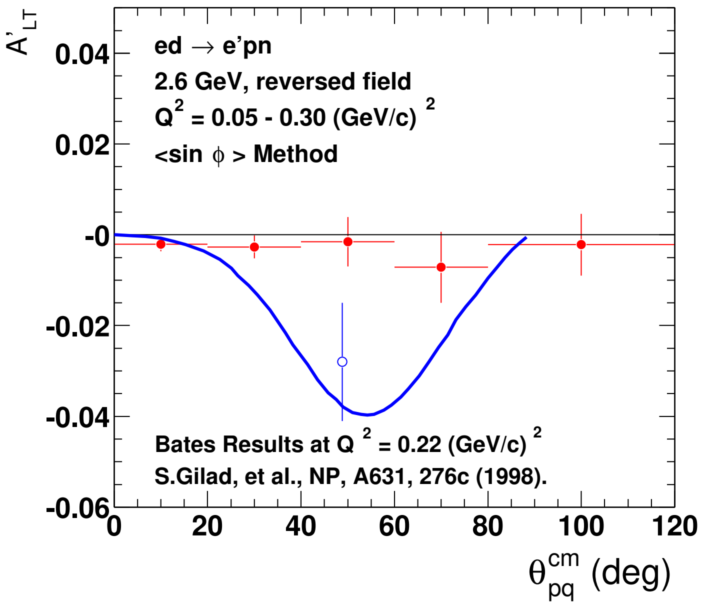
- This analysis for 2.6 GeV, reversed field.

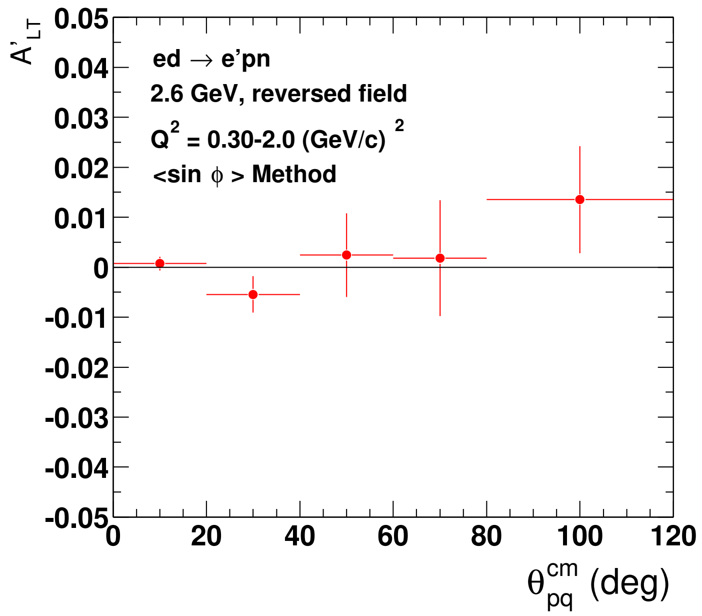


- Our results for A'_{LT} here are consistent with K. Joo and C. Smith in sign (the two experiments use different ϵ and Q^2 ranges) and with helicity sign recorded in the elog.

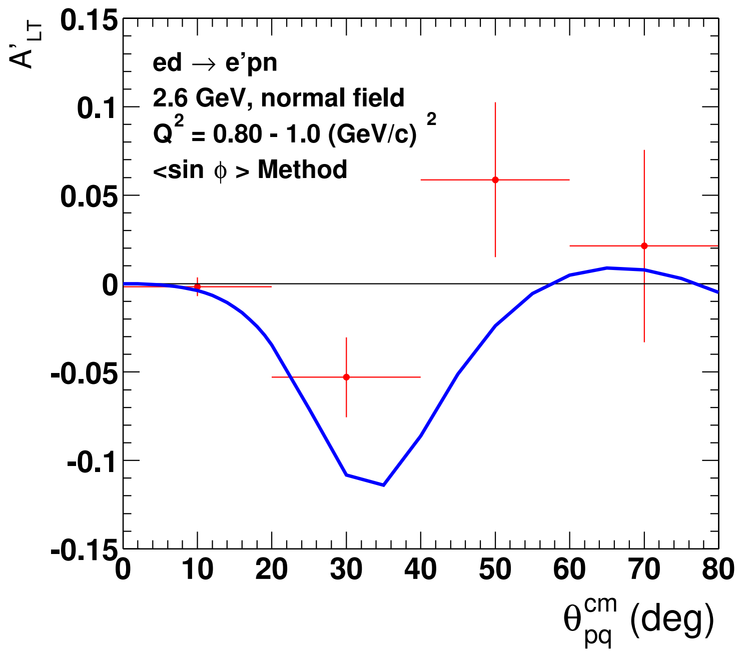
Preliminary Results (not for distribution)

- For 2.6 GeV, reversed field.





- For 2.6 GeV, normal field.



Work Plan

- Complete data selection cuts and corrections.
- Complete radiative corrections.
- Use the $ep \to e'\pi^+ n$ reaction to further test our algorithms.
- Simulations.
  - Acceptance effects and systematic uncertainties for A'_{LT} first.
  - Test sensitivity of A'_{LT} measurement.
  - Acceptance for A_{LT} and A_{TT}.
  - Estimate systematic errors.
- Cross checks in overlap regions for different running conditions.
- Comparison with several theoretical calculations.
- Push on to higher W, *i.e.,* the ‘dip’ region.

Conclusions

- Strong physics motivation to test the nuclear 'coherent hadronic model' in a new energy range.
- Two methods of measuring A'_{LT} using $\langle \sin \phi_{pq} \rangle$ and a fit to the helicity asymmetry are consistent with each other.
- There is significant structure in A_{LT} and A_{TT} (and σ_{LT} and σ_{TT}).
- Our analysis of A'_{LT} from the hydrogen target is consistent with an earlier study by Joo and Smith.
- The preliminary A'_{LT} results show this structure function is close to zero at low Q^2. This is a surprising difference with previous results and calculations by Arenhoevel. At higher Q^2 the agreement is better.