CLAS Approved Analysis Proposal

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

G.P.Gilfoyle
University of Richmond

W.K.Brooks, B.A.Mecking
Jefferson Lab

S.Kuhn, L.Weinstein
Old Dominion University

M.F.Vineyard
Union College

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

Physics Motivation

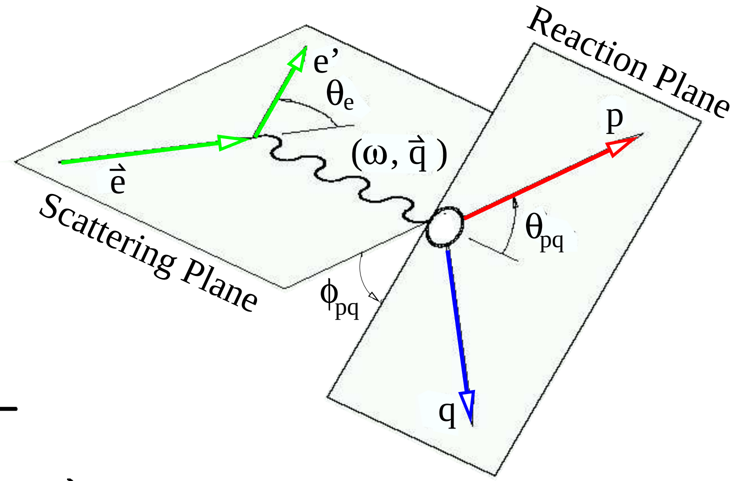
1. Can the deuteron be understood with the coherent hadronic model of nuclear physics?

    - 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 PAC 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. The fifth structure function (the imaginary part of the longitudinal-transverse interference) can be investigated only with out-of-plane measurements and is largely unexplored territory.

Kinematics and Formalism



- Kinematics:

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

- Cross section:

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

- Missing momentum: $\vec{p}_m = \vec{q} - \vec{p}_p$.

- Conventional asymmetries are proportional to the corresponding structure function:

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

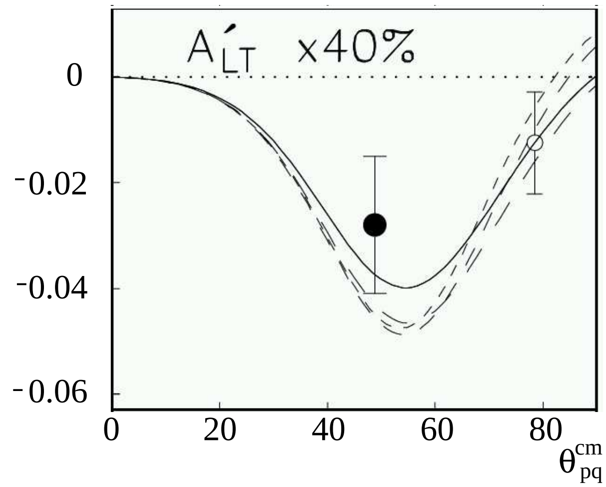
$$A_{TT} = \frac{\sigma_0 + \sigma_{180} - 2\sigma_{90}}{\sigma_0 + \sigma_{180} + 2\sigma_{90}} = \frac{\rho_{TT} f_{TT}}{\rho_L f_L + \rho_T f_T}$$

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

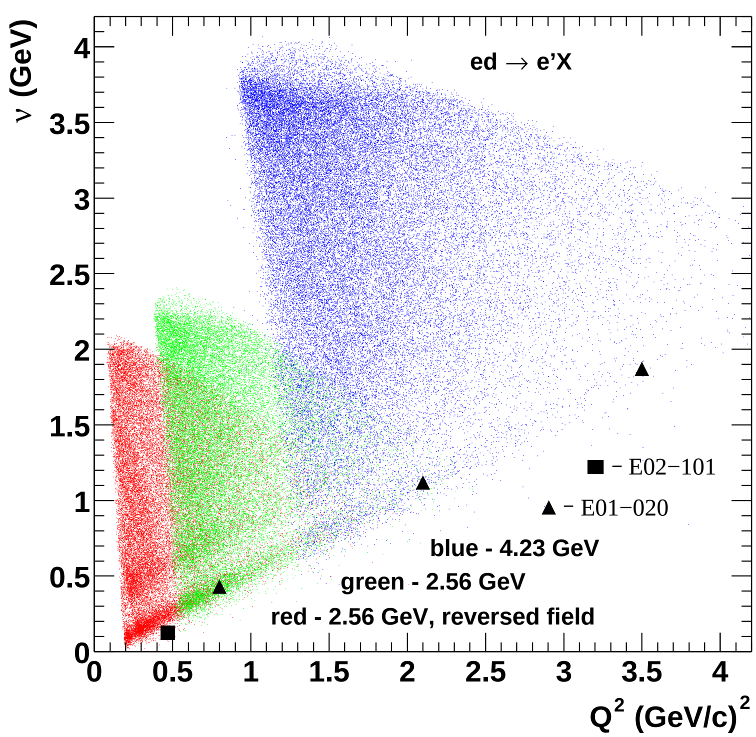
Subscripts - ϕ_{pq}. Superscripts - beam helicity.

Current 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.



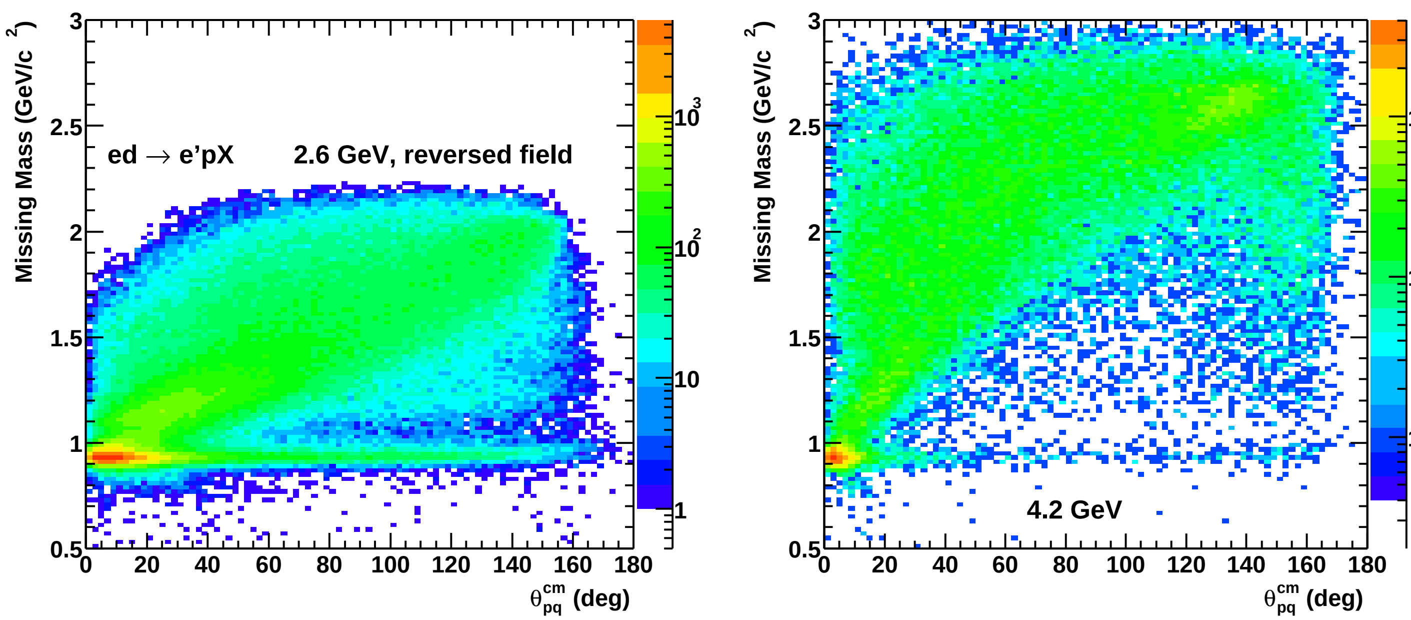
Physics Program

- Measure A'_{LT} from $\vec{e}d \rightarrow e'p(n)$ in quasi-elastic kinematics in the region $Q^2 = 0.2 - 5.0\ (GeV/c)^2$.
  - Quasielastic kinematics are better understood.
  - Use missing mass to identify the neutron.
- Fifth structure (A'_{LT}) function analysis.
  - Use $\langle \sin\phi \rangle_{\pm}$ and/or fits to the helicity asymmetry to extract A'_{LT}.
  - $ep \rightarrow e'\pi^+ n$ and $ep \rightarrow e'p\pi^0$ reactions to test algorithms.
  - Cross checks with different running conditions.
  - Comparison with theoretical calculations.
  - Corrections, uncertainties, *etc.*.
- Measure the fifth structure function at higher W, *i.e.,* the 'dip' region.
- Do other structure functions A_{LT} and A_{TT}.
  - More vulnerable to acceptance effects.

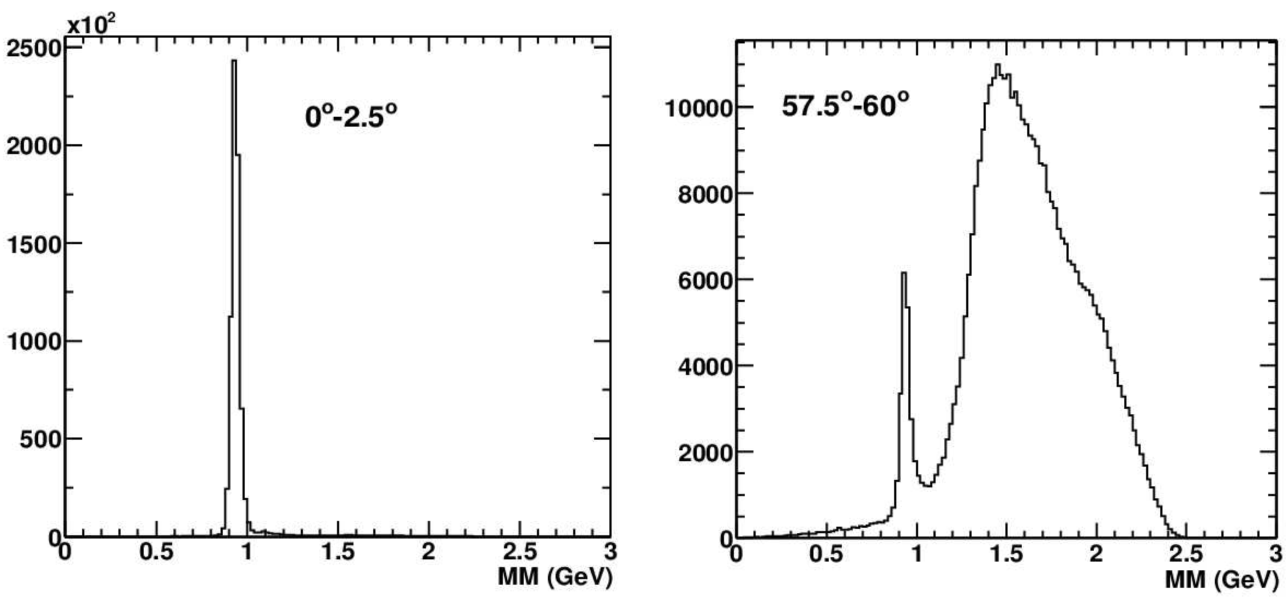
Extracting Structure Functions with CLAS

Measuring $\vec{e}p \to e'p(n)$

- Use missing mass technique to isolate neutrons.



- Neutrons are clearly visible (2.6 GeV, normal polarity).



Extracting Structure Functions with CLAS

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	$0.91\ GeV \leq W \leq 0.97\ GeV$

- 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.

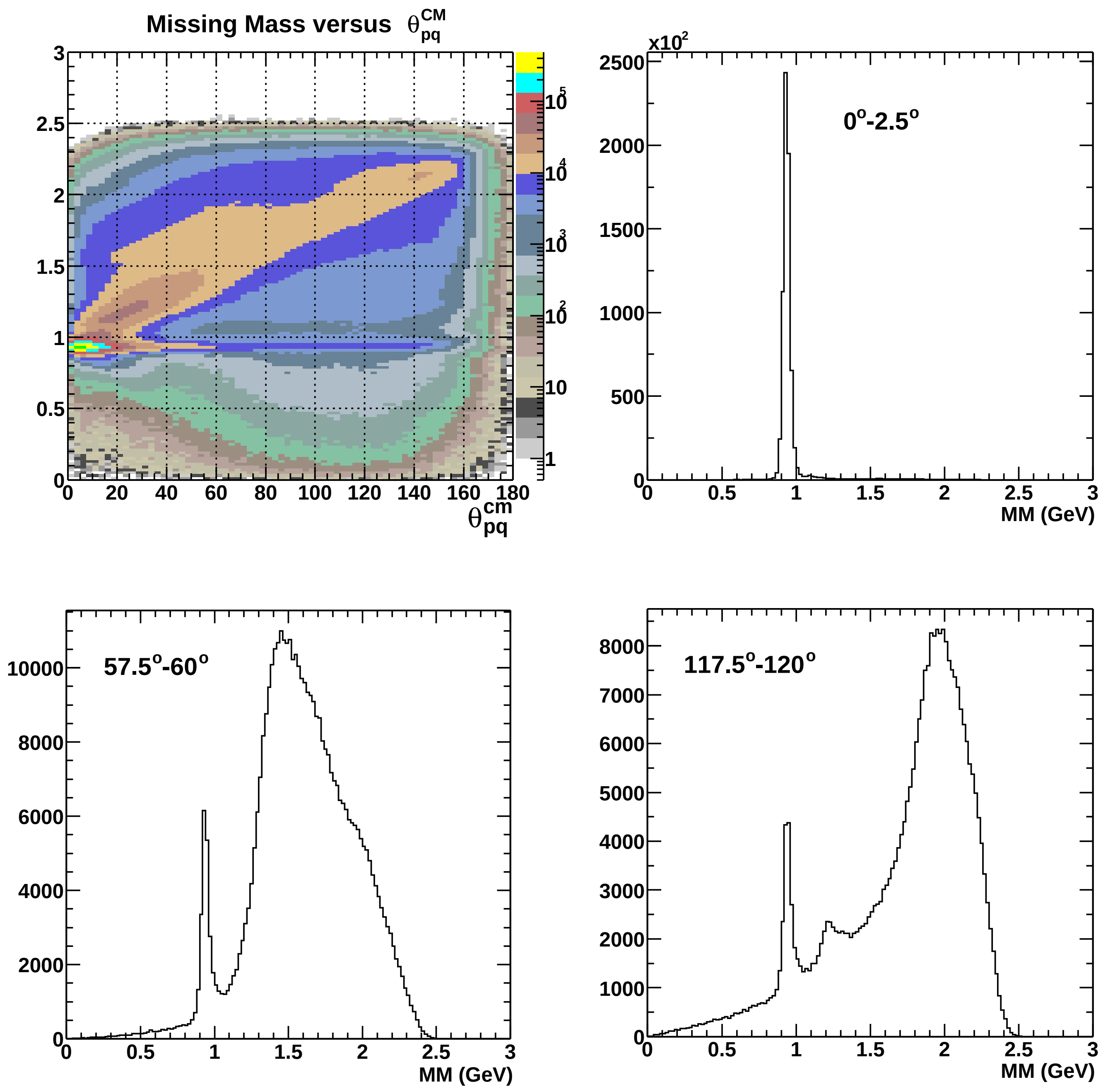
- Beam charge asymmetry.

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

- Beam polarization.

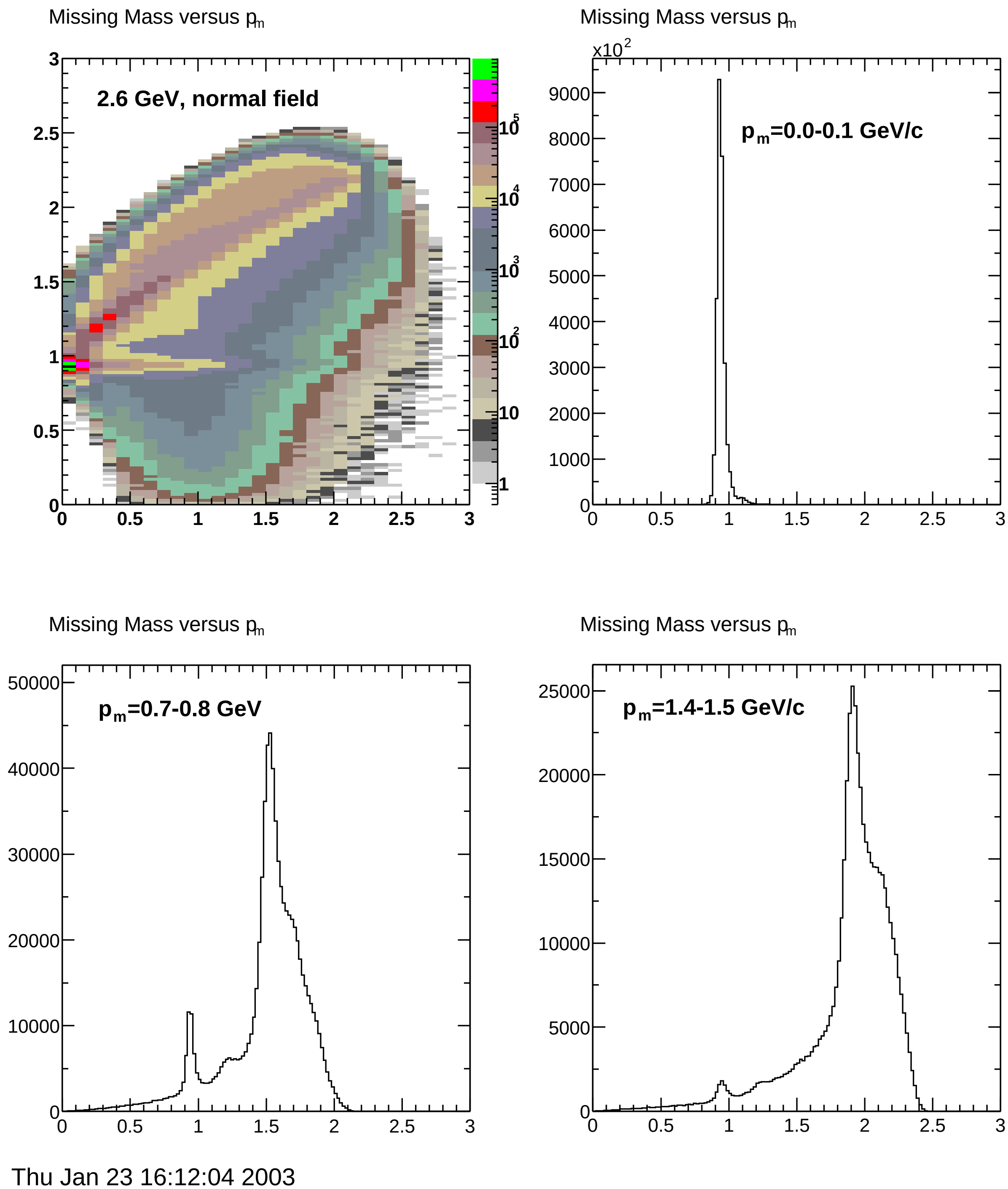
All Runs	0.736 ± 0.017

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

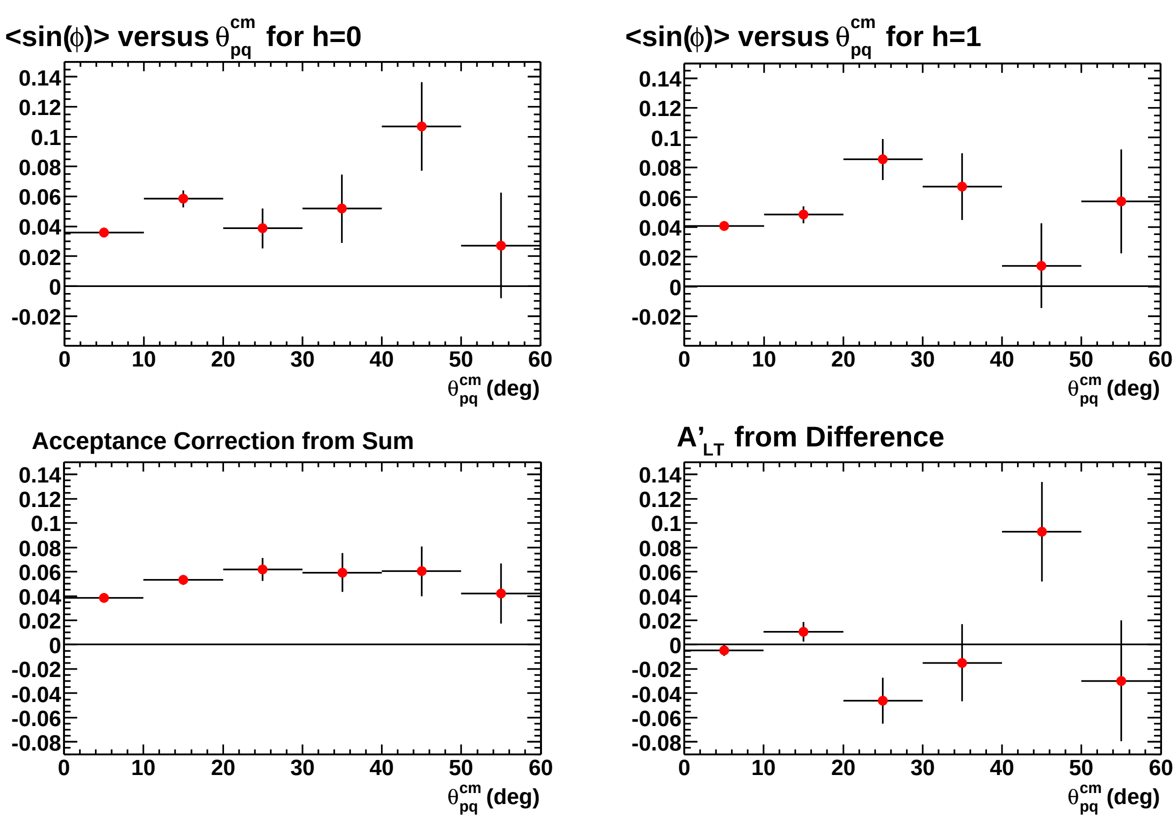
$$\langle \sin\phi_{pq}\rangle_{\pm} = \frac{\int_{-\pi}^{\pi}\sigma^{\pm}\sin\phi_{pq}d\phi}{\int_{-\pi}^{\pi}\sigma^{\pm}d\phi} = \frac{\sum_{\pm}^{\phi}\sin\phi_i}{N^{\pm}} = \pm\frac{\sigma'_{LT}}{2(\sigma_L+\sigma_T)} \approx \pm\frac{A'_{LT}}{2}$$

- For a sinusoidally-varying component to the acceptance

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

$$\langle \sin\phi_{pq}\rangle_{+} - \langle \sin\phi_{pq}\rangle_{-} = A'_{LT} \quad \text{and} \quad \langle \sin\phi_{pq}\rangle_{+} + \langle \sin\phi_{pq}\rangle_{-} = 2\alpha_{acc}$$

- 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

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

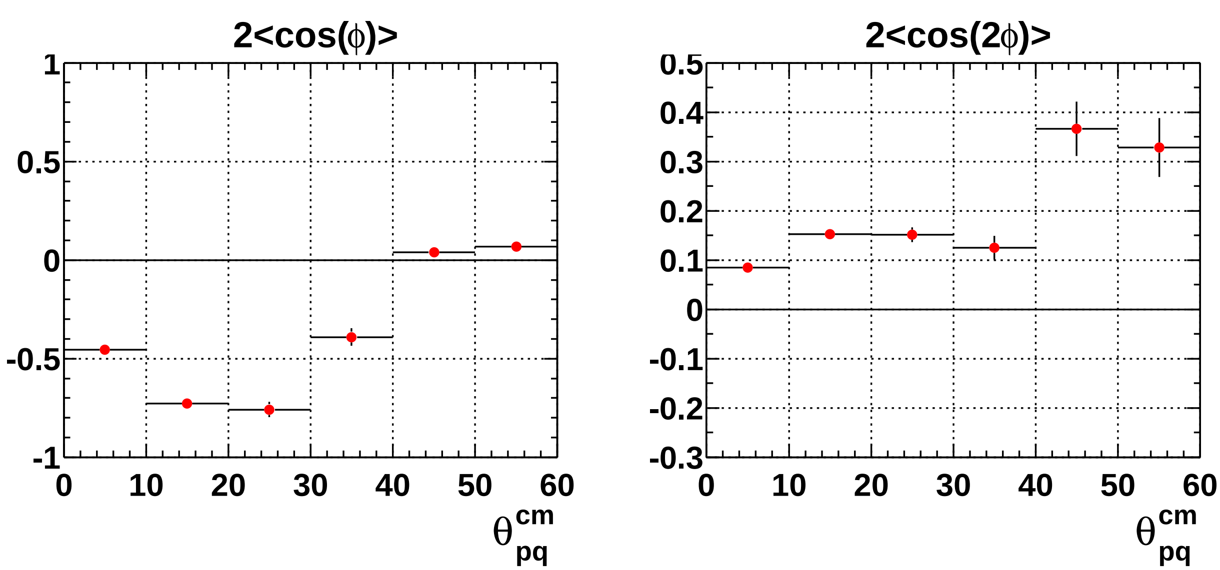
- In a way similar to relating $\langle \sin\phi_{pq}\rangle$ and A'_{LT}

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

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 fi eld, 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}

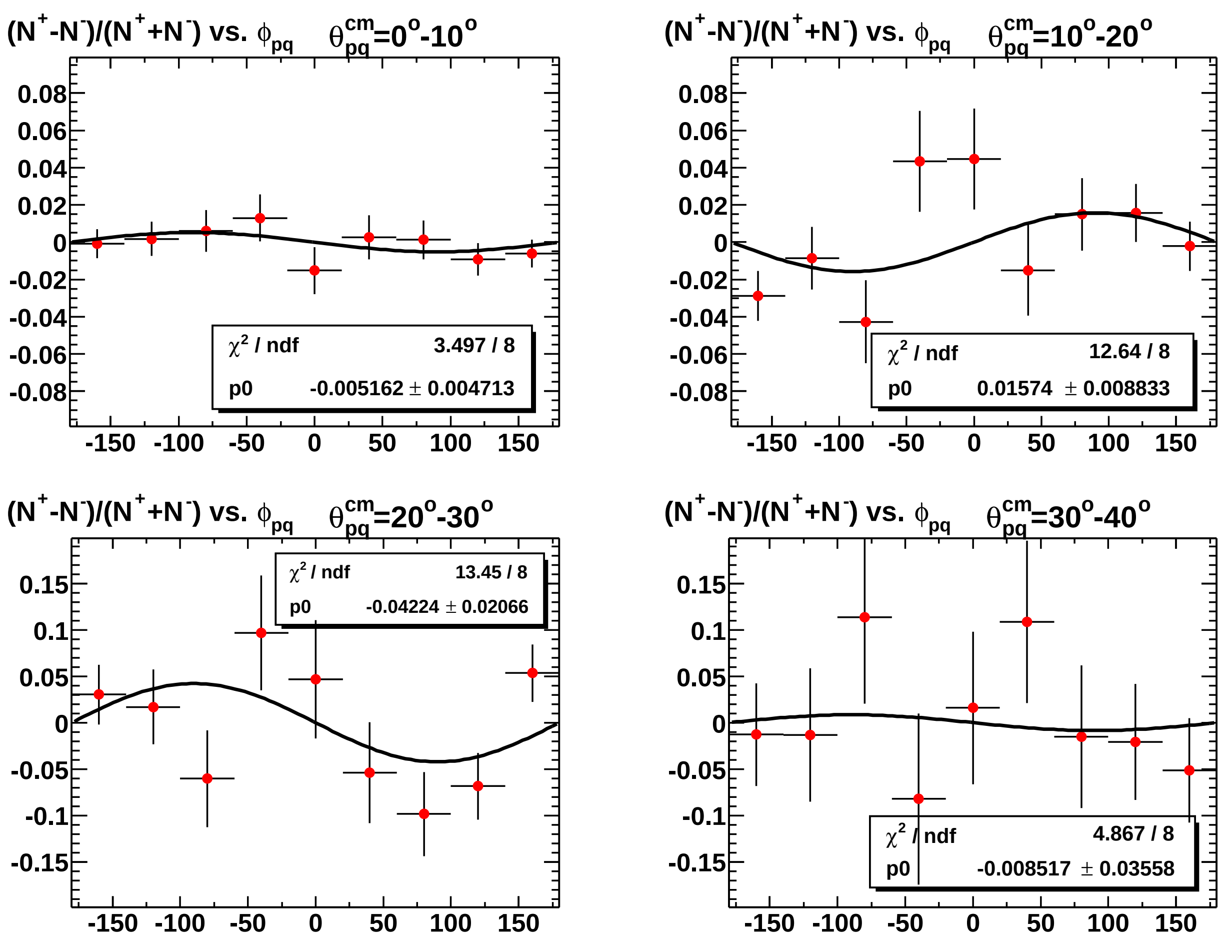
- Recall

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

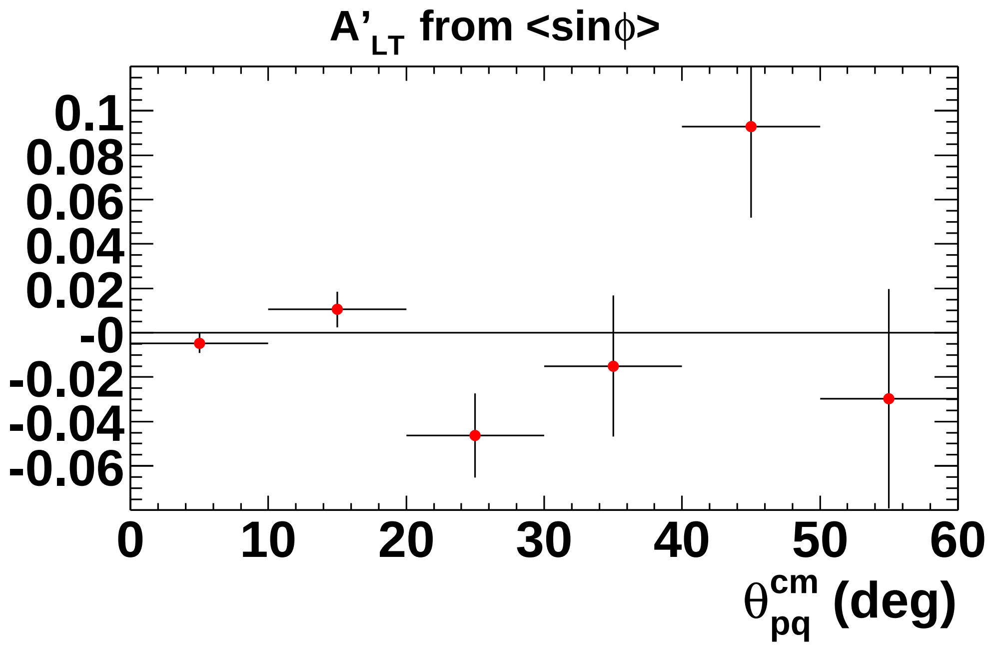
- Define A'_{LT} in a more general way.

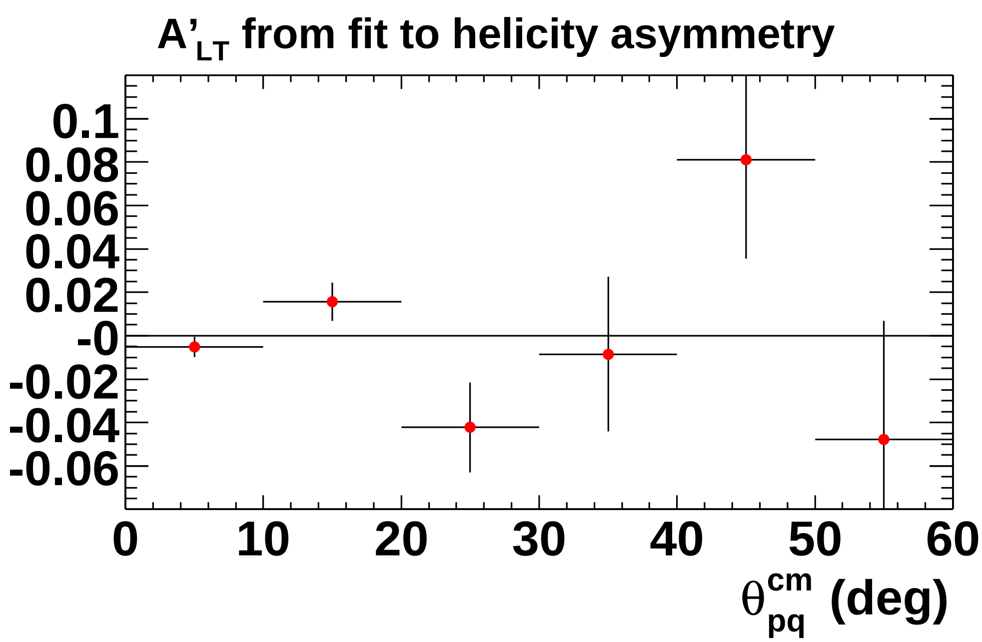
$$\frac{N^+ - N^-}{N^+ + N^-} = \frac{\sigma'_{LT}\sin\phi_{pq}}{\sigma_L + \sigma_T + \sigma_{LT}\cos(\phi_{pq}) + \sigma_{TT}\cos(2\phi_{pq})}$$
$$\approx A'_{LT}\sin\phi_{pq}$$

- 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}

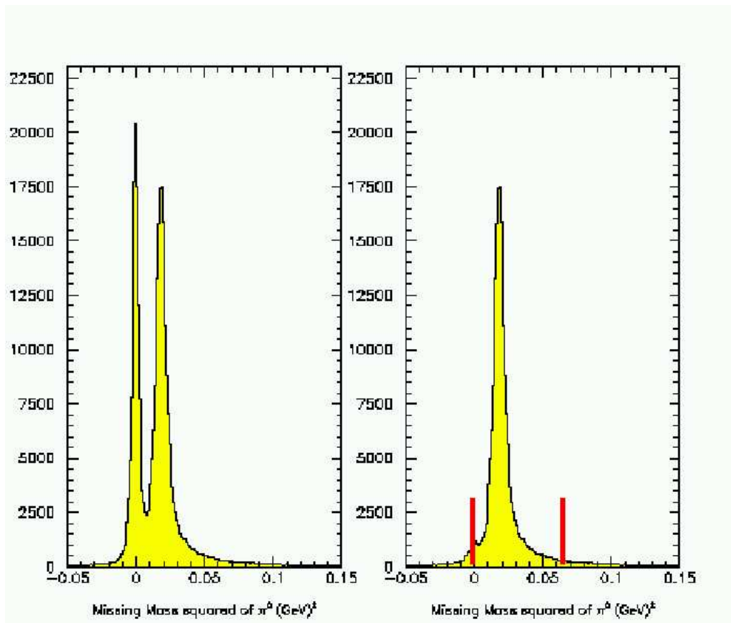




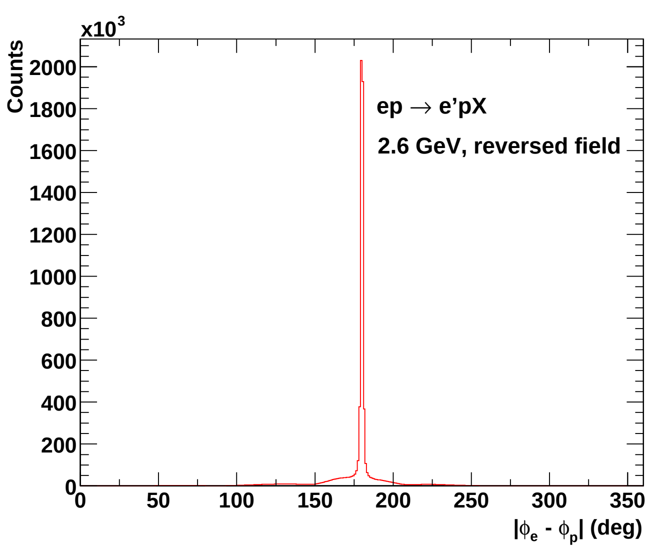
- The shapes and uncertainties are consistent. We can measure small A'_{LT}.
- 2.56 GeV, normal field, not acceptance corrected, $0.8 < Q^2 < 1.0\ (GeV/c)^2$, $0.95 < x_B < 1.05$.

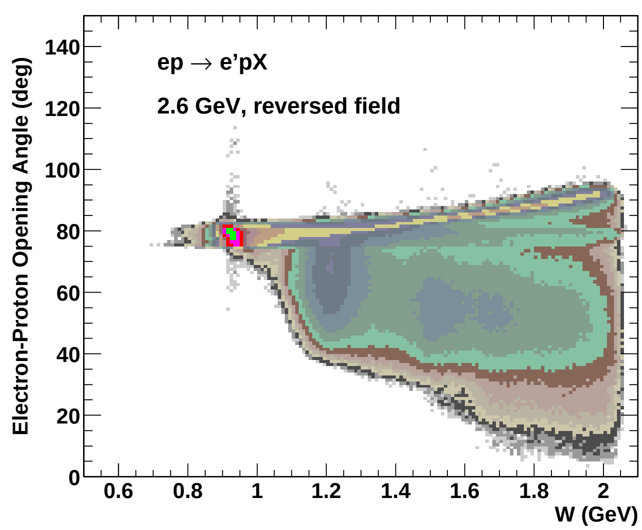
$ep \rightarrow e'p\pi^0$ Analysis

- Comparison with analysis of K. Joo and C. Smith to measure A'_{LT} in the resonance region at 1.52 GeV.
- Bethe-Heitler events overlap with missing mass of π^0.



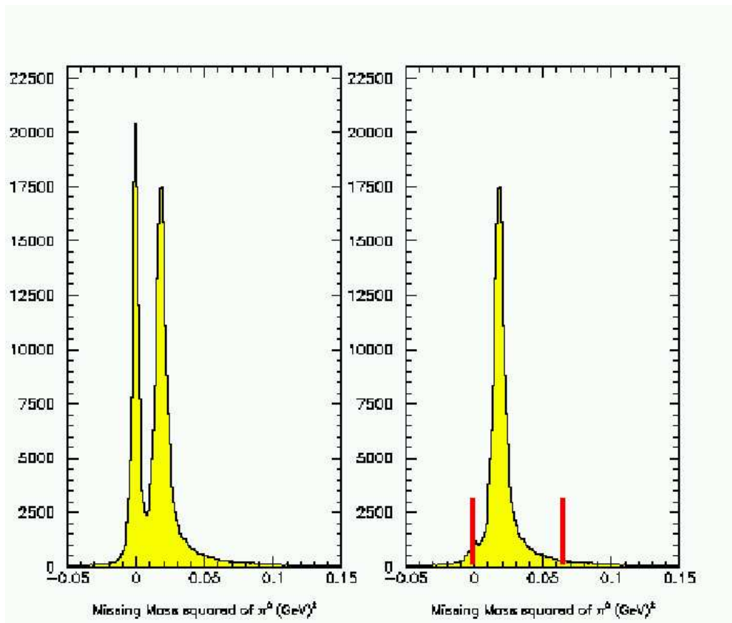
- Use kinematic constraints to identify Bethe-Heitler events and remove them.



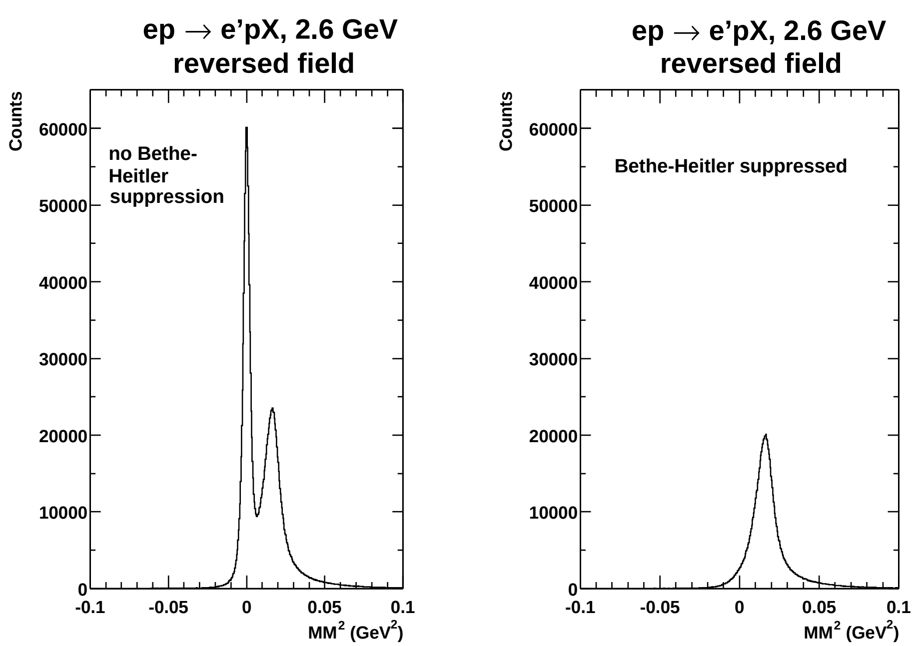


Results of Bethe-Heitler suppression for $ep \to e'p\pi^0$.

- K. Joo and C. Smith results.

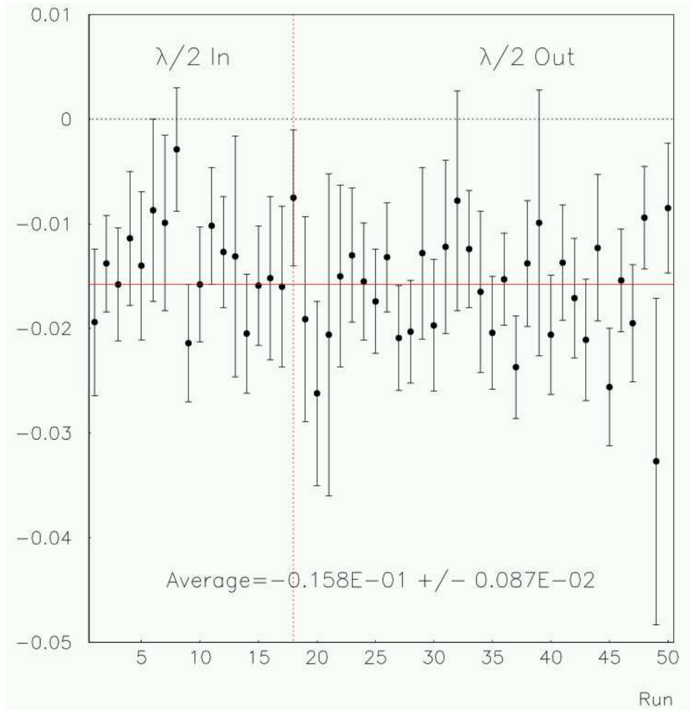


- This analysis for 2.6 GeV, reversed field.

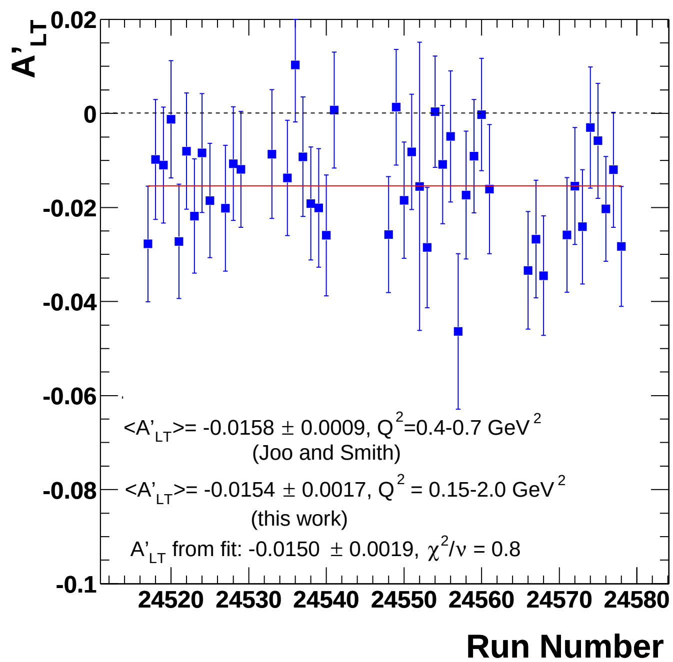


Comparison of Asymmetries Run By Run for $ep \to e'p\pi^0$.

- K. Joo and C. Smith for Δ resonance at 1.52 GeV, CLAS Analysis 01-008.



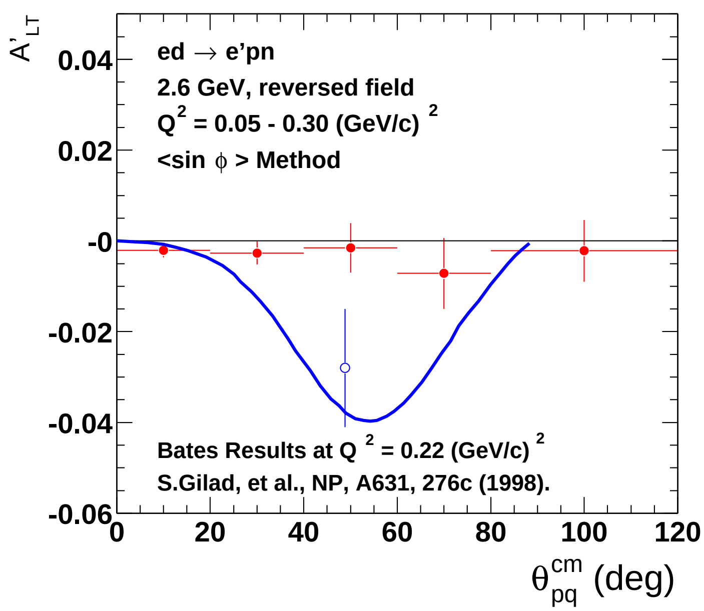
- This analysis for 2.6 GeV, reversed field.

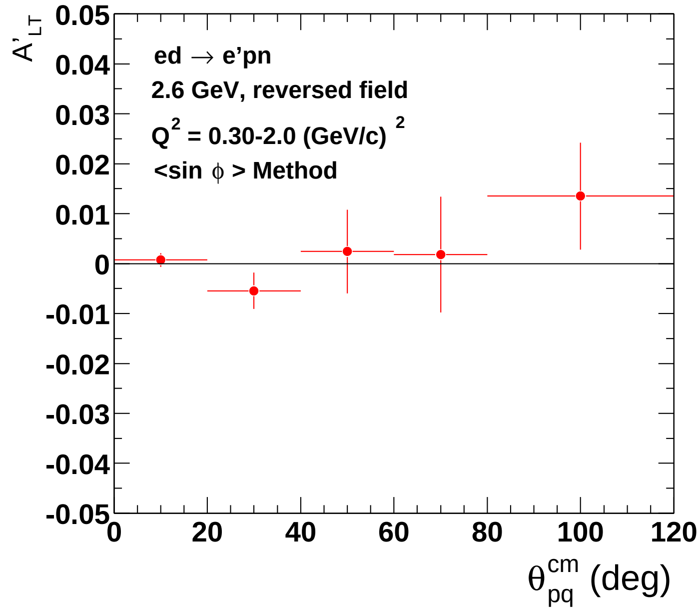


- Our results for A'_{LT} here are consistent with K. Joo and C. Smith in sign (the two experiments use different ϵ and Q^2 ranges) and with helicity sign recorded in the elog.

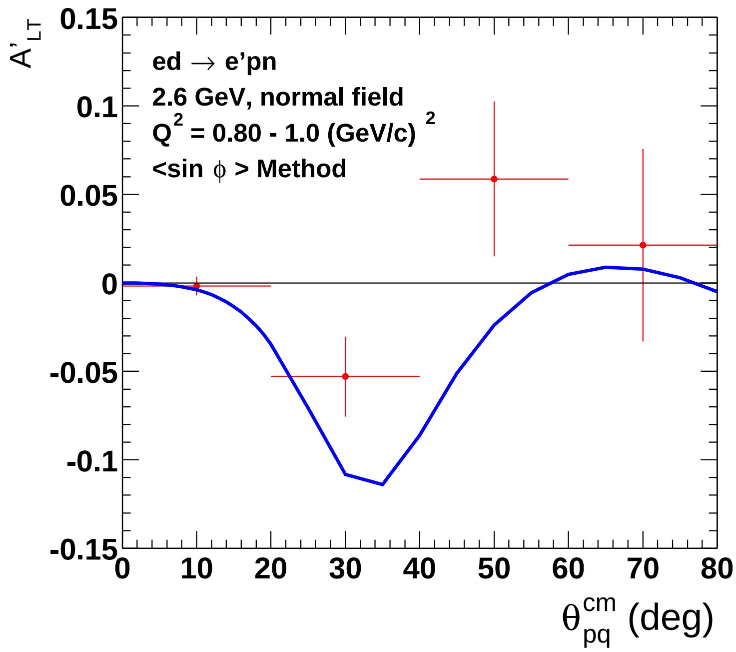
Preliminary Results (not for distribution)

- For 2.6 GeV, reversed field.





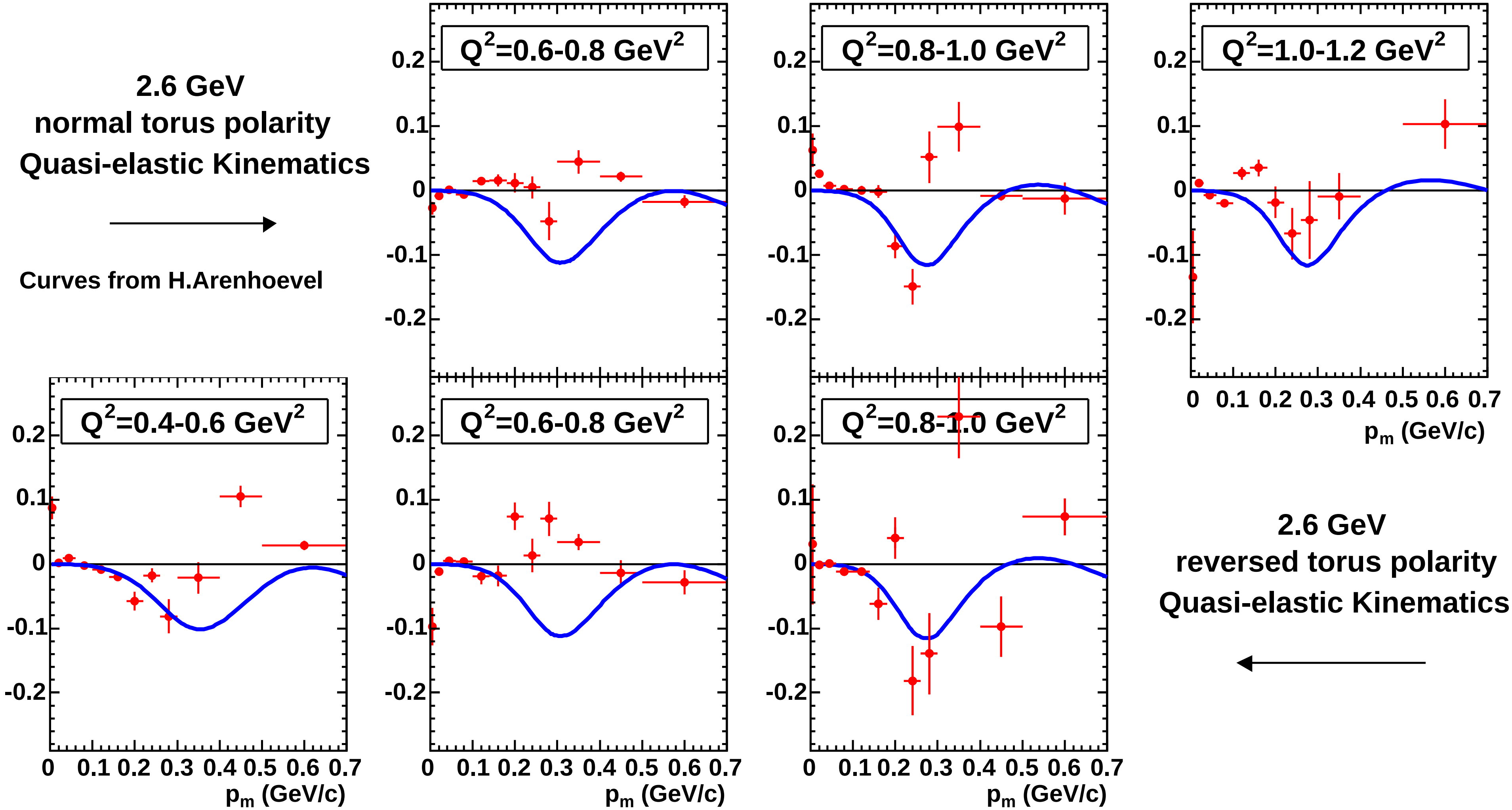
- For 2.6 GeV, normal field.



Preliminary Results for A'_{LT} from $d(\vec{e}, e'p)n$ (not for distribution)

2.6 GeV
normal torus polarity
Quasi-elastic Kinematics

Curves from H.Arenhoevel



2.6 GeV
reversed torus polarity
Quasi-elastic Kinematics

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.
- Our analysis of A'_{LT} from the hydrogen target is consistent with an earlier study by Joo and Smith.
- Preliminary results for A'_{LT} reveal a significant structure dip at $Q^2 \approx 0.9\ (GeV/c)^2$ and $p_m \approx 0.25\ GeV/c$.
- There is significant structure in A_{LT} and A_{TT} (and σ_{LT} and σ_{TT}).

A written version can be found in the E5 portion of the Hall B secure website.

www.jlab.org/Hall-B/secure/e5/gilfoyle/deuteron_electrodisintegration.ps