Polarized observables from from Deeply Virtual π^0 and η Production with CLAS

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for the EMP workshop

DVMP structure functions

$$\frac{2\pi}{\Gamma}\frac{d^4\sigma}{dQ^2 dx_B dt d\phi_\pi} =$$

unpolarized terms

$$\sigma_T + \epsilon\sigma_L + \epsilon\sigma_{TT}\cos 2\phi + \sqrt{\epsilon(1+\epsilon)}\,\sigma_{LT}\cos\phi$$

longitudinally polarized beam

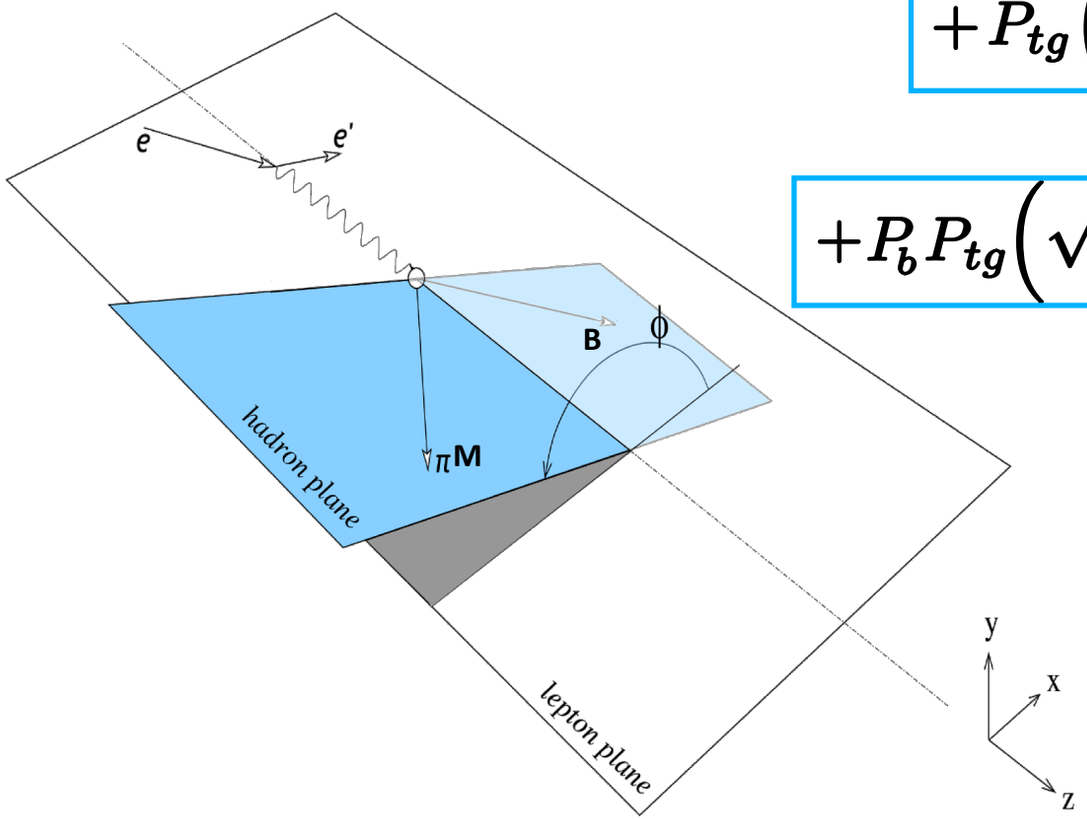
$$+P_b\sqrt{\epsilon(1-\epsilon)}\,\sigma_{LT'}\sin\phi$$

longitudinally polarized target

$$+P_{tg}\left(\sqrt{\epsilon(1+\epsilon)}\,\sigma_{UL}^{\sin\phi}\sin\phi + \epsilon\sigma_{UL}^{\sin 2\phi}\sin 2\phi\right)$$

$$+P_b P_{tg}\left(\sqrt{1-\epsilon^2}\,\sigma_{LL} + \sqrt{\epsilon(1-\epsilon)}\,\sigma_{LL}^{\cos\phi}\cos\phi\right)$$

longitudinally polarized beam
and
longitudinally polarized target



Model frameworks: GK and GL models

$$\langle F \rangle = \sum_{\lambda} \int_{-1}^{1} dx \mathcal{H}_{0\lambda,\mu\lambda}(x,\xi,Q^2,t) F(x,\xi,t)$$

Simplified formulae:

UNPOLARIZED STRUCTURE FUNCTIONS:	POLARIZED OBSERVABLES:
$\sigma_L \sim \left\{ (1-\xi^2) \left\lvert \langle \tilde{H} \rangle \right\rvert^2 - 2\xi^2 \mathrm{Re}\left[\langle \tilde{H} \rangle^* \langle \tilde{E} \rangle \right] - \frac{t'}{4m^2} \xi^2 \left\lvert \langle \tilde{E} \rangle \right\rvert^2 \right\}$	$A_{LU}^{\sin\phi} \sigma_0 \sim \mathrm{Im}\left[\langle H_T \rangle^* \langle \tilde{E} \rangle \right]$
$\sigma_T \sim \left[(1-\xi^2) \left\lvert \langle H_T \rangle \right\rvert^2 - \frac{t'}{8m^2} \left\lvert \langle E_T \rangle \right\rvert^2 \right]$	$A_{UL}^{\sin\phi} \sigma_0 \sim \mathrm{Im}\left[\langle \bar{E}_T \rangle^* \langle \tilde{H} \rangle + \xi \langle H_T \rangle^* \langle \tilde{E} \rangle \right]$
$\sigma_{TT} \sim \left\lvert \langle \bar{E}_T \rangle \right\rvert^2$	$A_{LL}^{\cos 0\phi} \sigma_0 \sim \left\lvert \langle H_T \rangle \right\rvert^2$
$\sigma_{LT} \sim \mathrm{Re}\left[\langle H_T \rangle^* \langle \tilde{E} \rangle \right]$	$A_{LL}^{\cos\phi} \sigma_0 \sim \mathrm{Re}\left[\langle \bar{E}_T \rangle^* \langle \tilde{H} \rangle + \xi \langle H_T \rangle^* \langle \tilde{E} \rangle \right]$

- **Quark flavor decomposition:** $F_i^{\pi^0} = \frac{(e_u F_i^u - e_d F_i^d)}{\sqrt{2}}$ $F_i^{\eta} = \frac{(e_u F_i^u + e_d F_i^d)}{\sqrt{6}}$

DVMP 4-dimensional kinematic binning

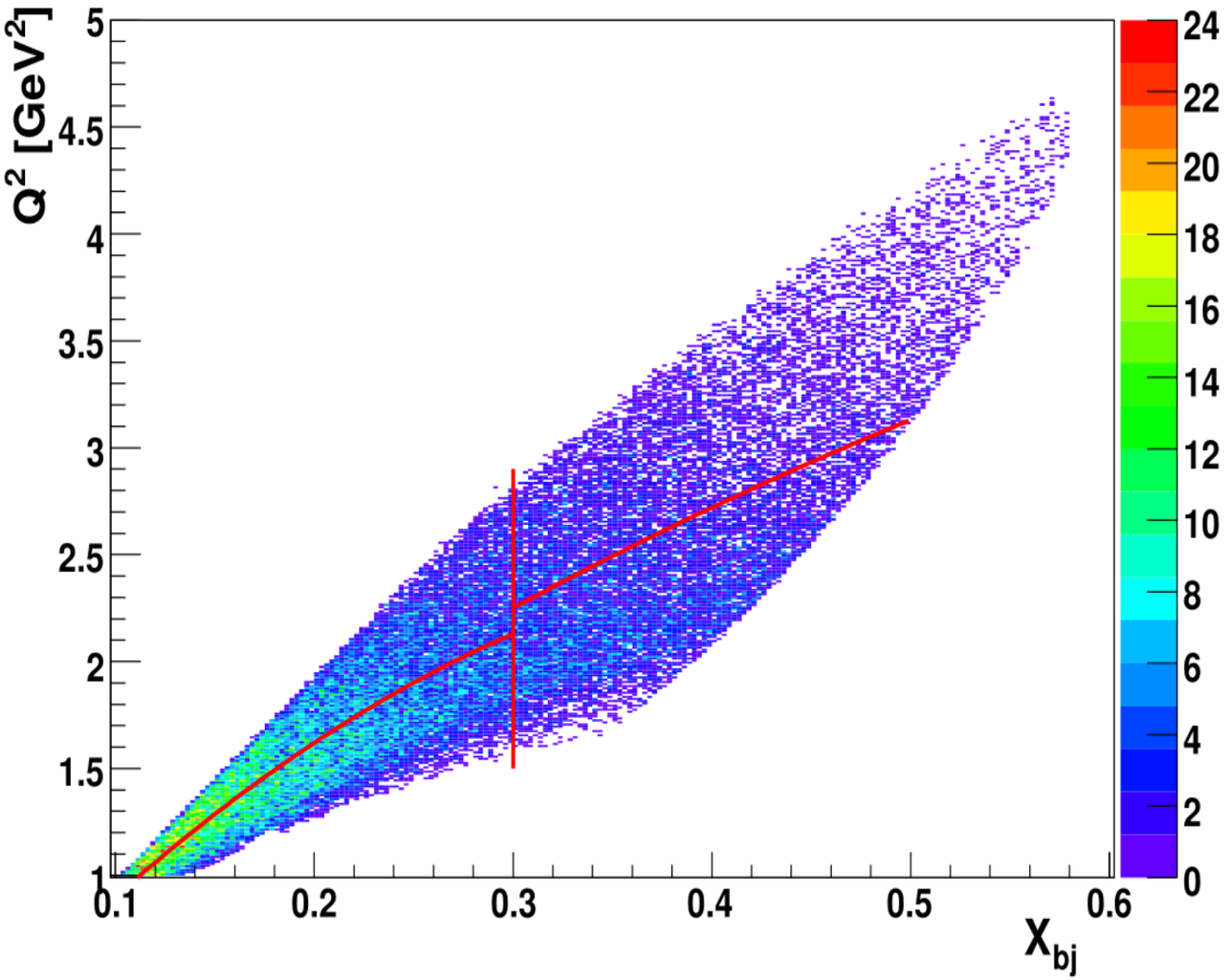
$$A = \frac{N_1 - N_2}{f(N_1 + N_2)}$$

where

$N_{1(2)}$ - number of events normalized to the beam intensity

1(2) - indices represent different combinations of beam/target/double polarizations

f - correction factor (e.g. dilution, polarization etc)

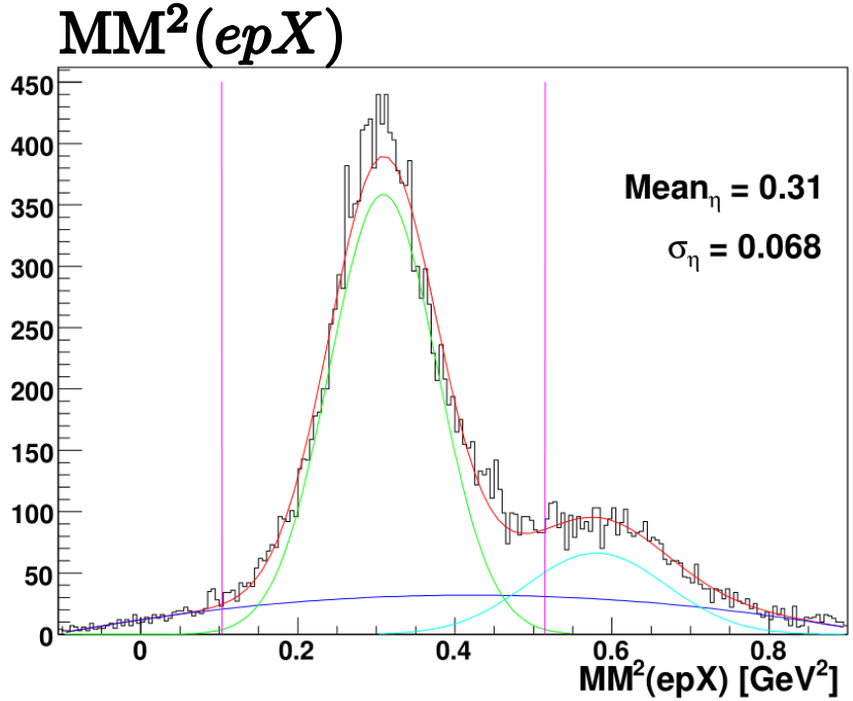


	$\{Q^2, x_B\}$	$-t$	ϕ
η	4 bins	3 bins	12 bins
π^0	2 bins	5 bins	11 bins

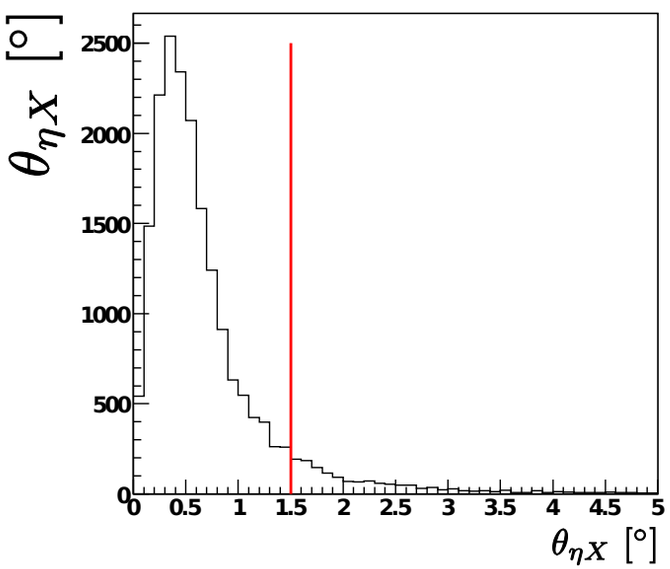
Exclusive events: $ep \rightarrow ep\eta$

All four final-state particles are detected

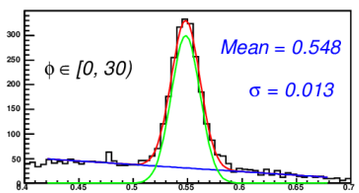
$$ep \rightarrow ep\eta \begin{cases} \nearrow \gamma \\ \searrow \gamma \end{cases}$$

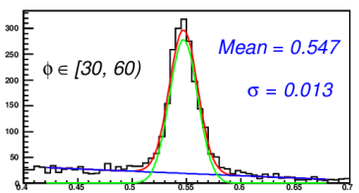


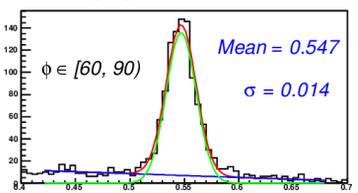
Angle between detected and reconstructed eta

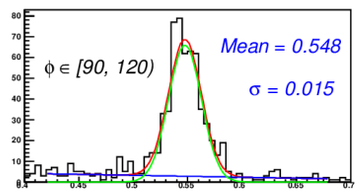


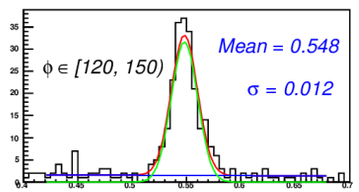
invariant mass of two photons: $M_{\gamma\gamma}$

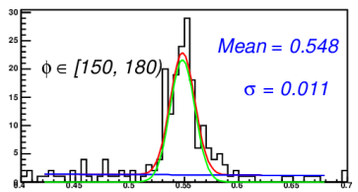


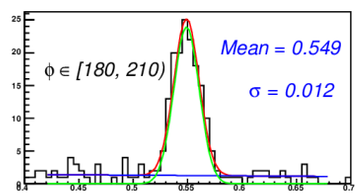


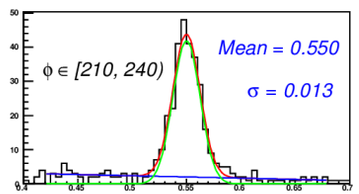


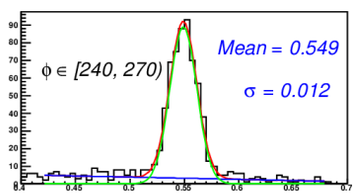


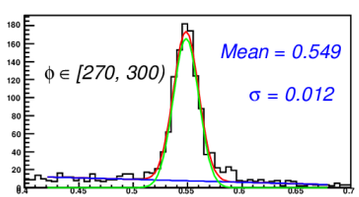


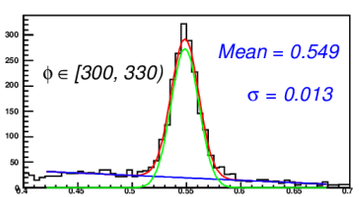


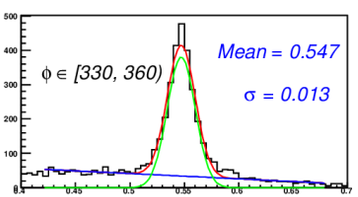










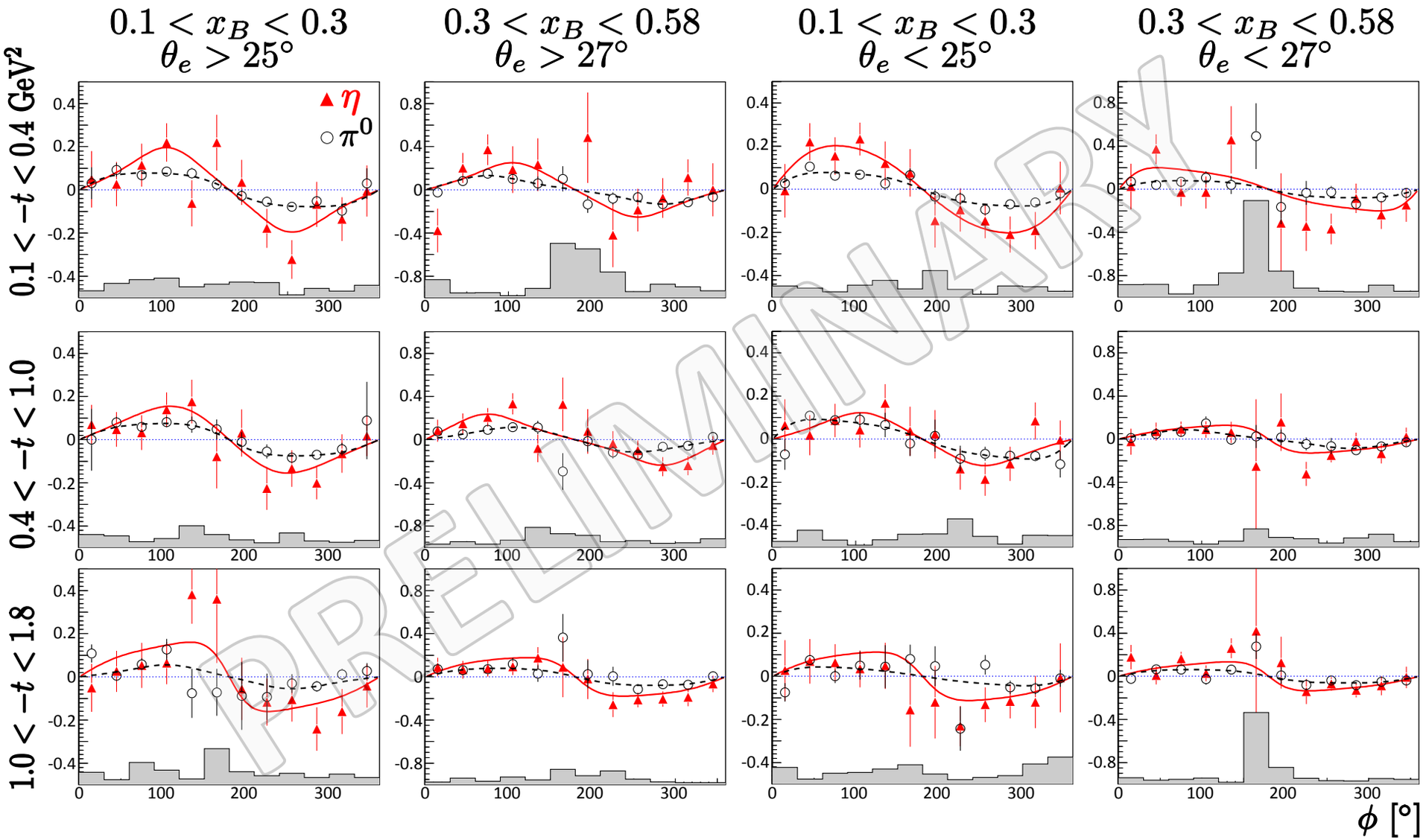


Beam Spin Asymmetries: $ep \to ep\eta$ and $ep \to ep\pi^0$

Azimuthal dependence of BEAM spin asymmetries in different kinematic bins

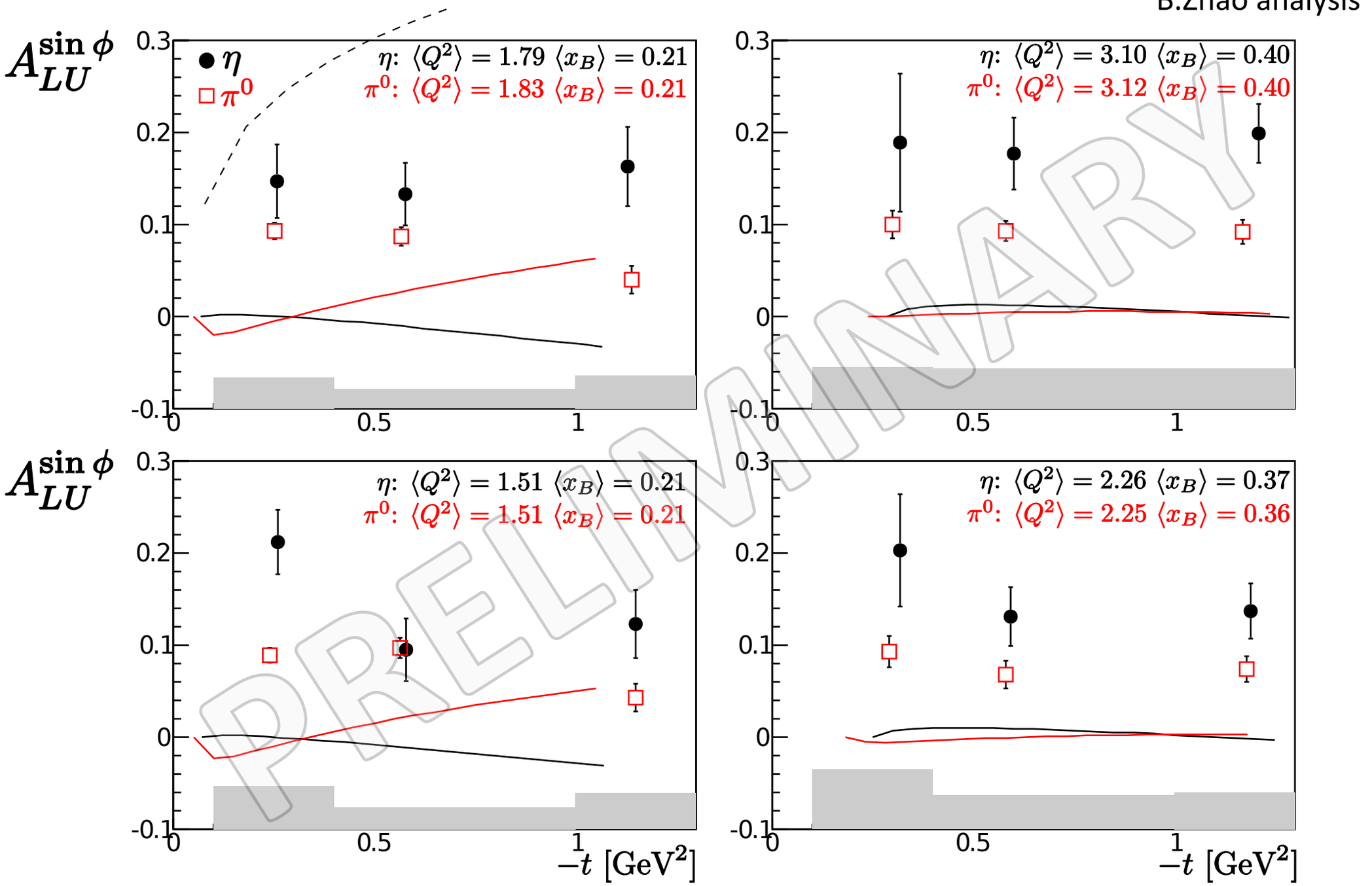
B.Zhao analysis

$$A_{LU}(\phi) = \frac{\alpha \sin\phi}{1+\beta\cos\phi+\gamma\cos 2\phi}$$



Beam Spin Asymmetries: $ep \to ep\eta$ and $ep \to ep\pi^0$

B.Zhao analysis

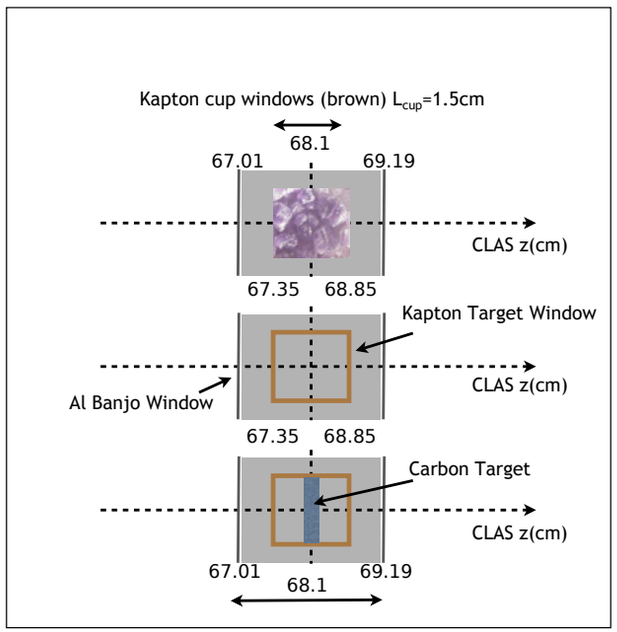


solid: GK model, dashed: GL model

Longitudinally polarized target

- Frozen ammonia was used as a target
- It was longitudinally polarized using Dynamic Nuclear Polarization (DNP) in a 5 Tesla homogeneous magnetic field
- The polarization was monitored using a Nuclear Magnetic Resonance (NMR) system

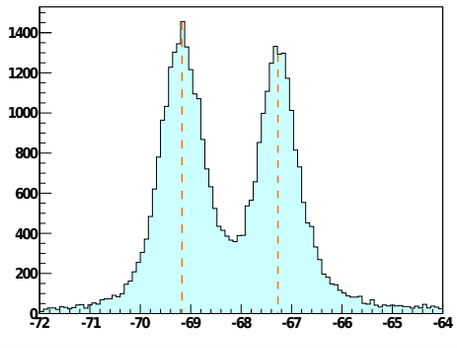
The side view of the target material in CLAS. Ammonia, empty and carbon (top to bottom) targets are shown here with a central nominal vertex.

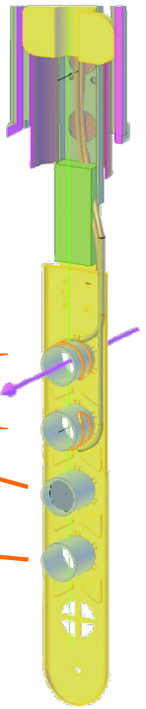


Al Banjo Windows L ~ 2.18 cm

Liquid ^{4}He filled (light gray shading)

Reconstructed electron vertex for run with empty target. Two peaks corresponds to the aluminum banjo windows





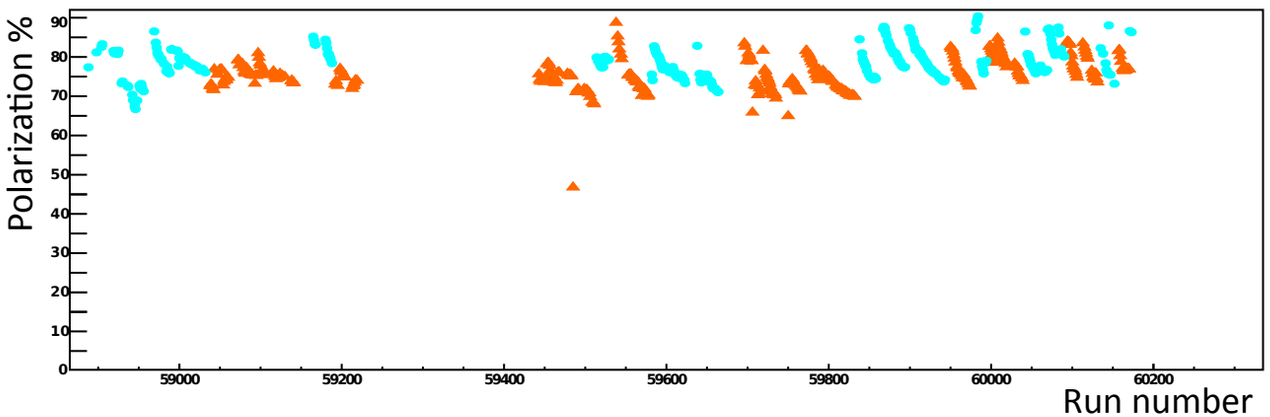
· Crushed beads of irradiated ammonia prepared at University of Virginia

· Disk of amorphous carbon

· Empty

The last two cells are utilized for background studies.

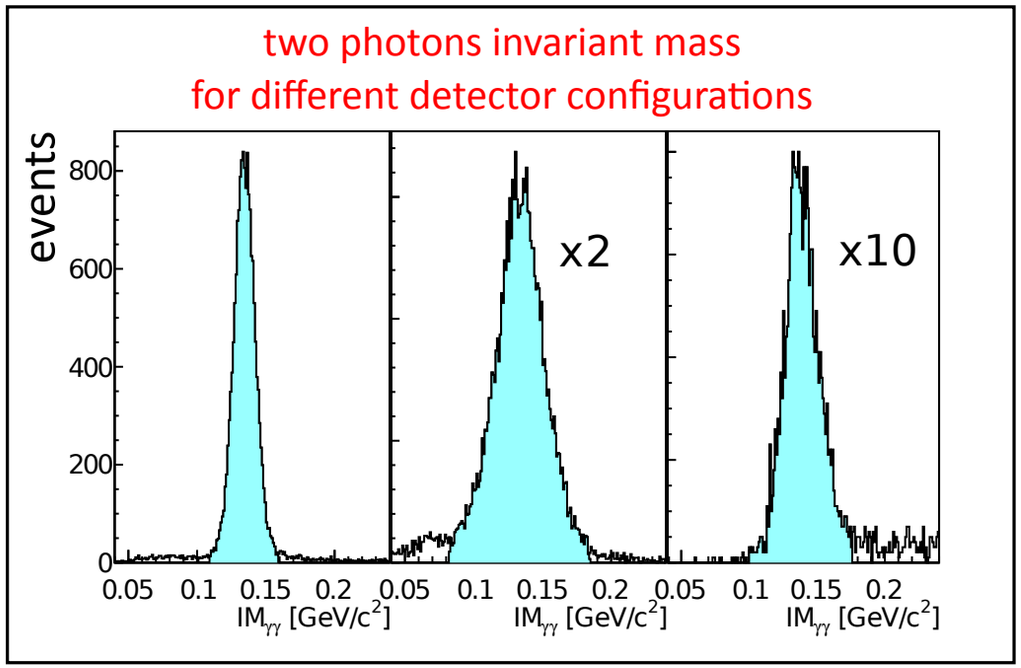
NRM target polarization during eg1dvcs experiment

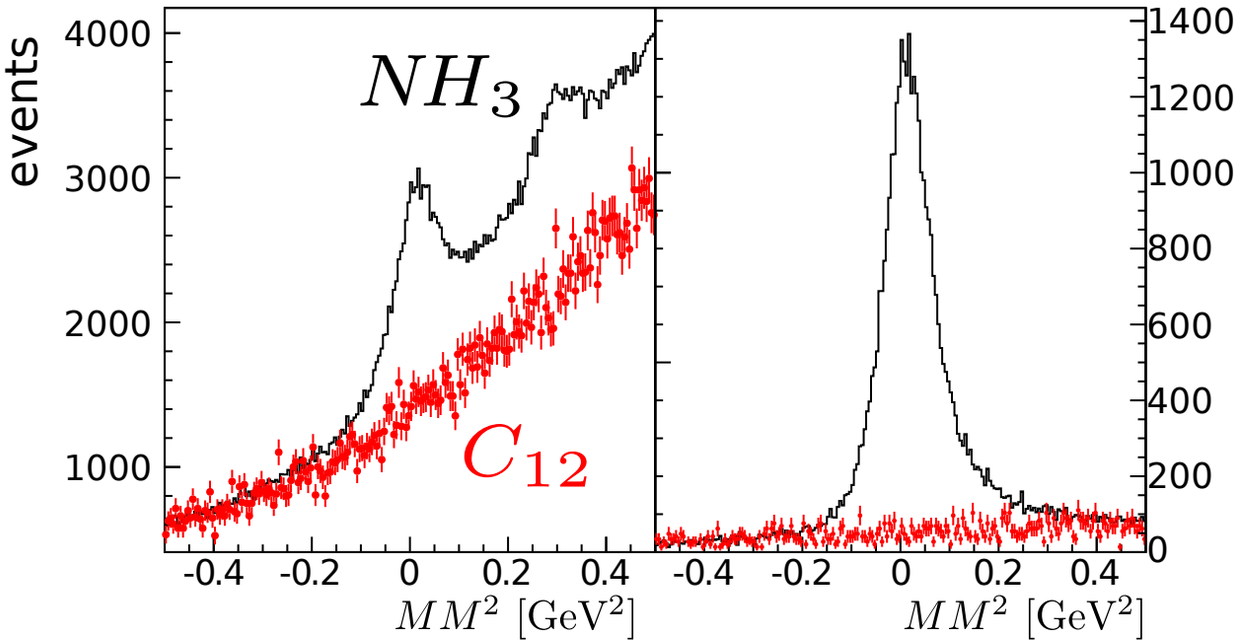


Exclusive events: $ep \rightarrow ep\pi^0$

All four final-state particles are detected

$$\vec{e}\vec{p} \rightarrow ep\pi^0 \nearrow \gamma \; \searrow \gamma$$

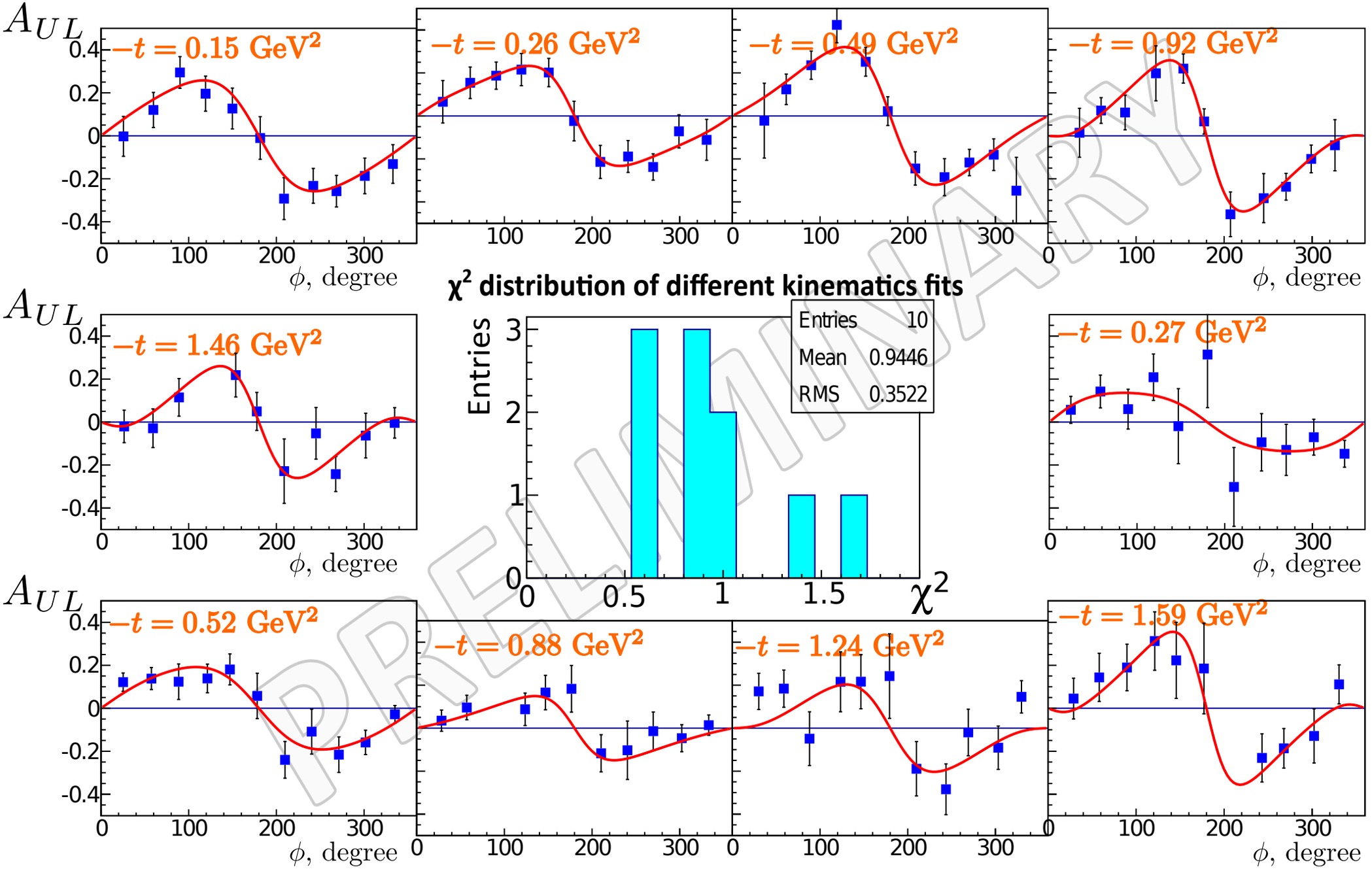




- **Invariant Mass of two photons** $M_{\gamma\gamma}$
- **Missing Mass Squared** MM_{epX}
- **Angle between predicted and detected pions** $\theta_{X\pi^0}$
- **Missing energy** $\Delta E_{ep\gamma\gamma}$

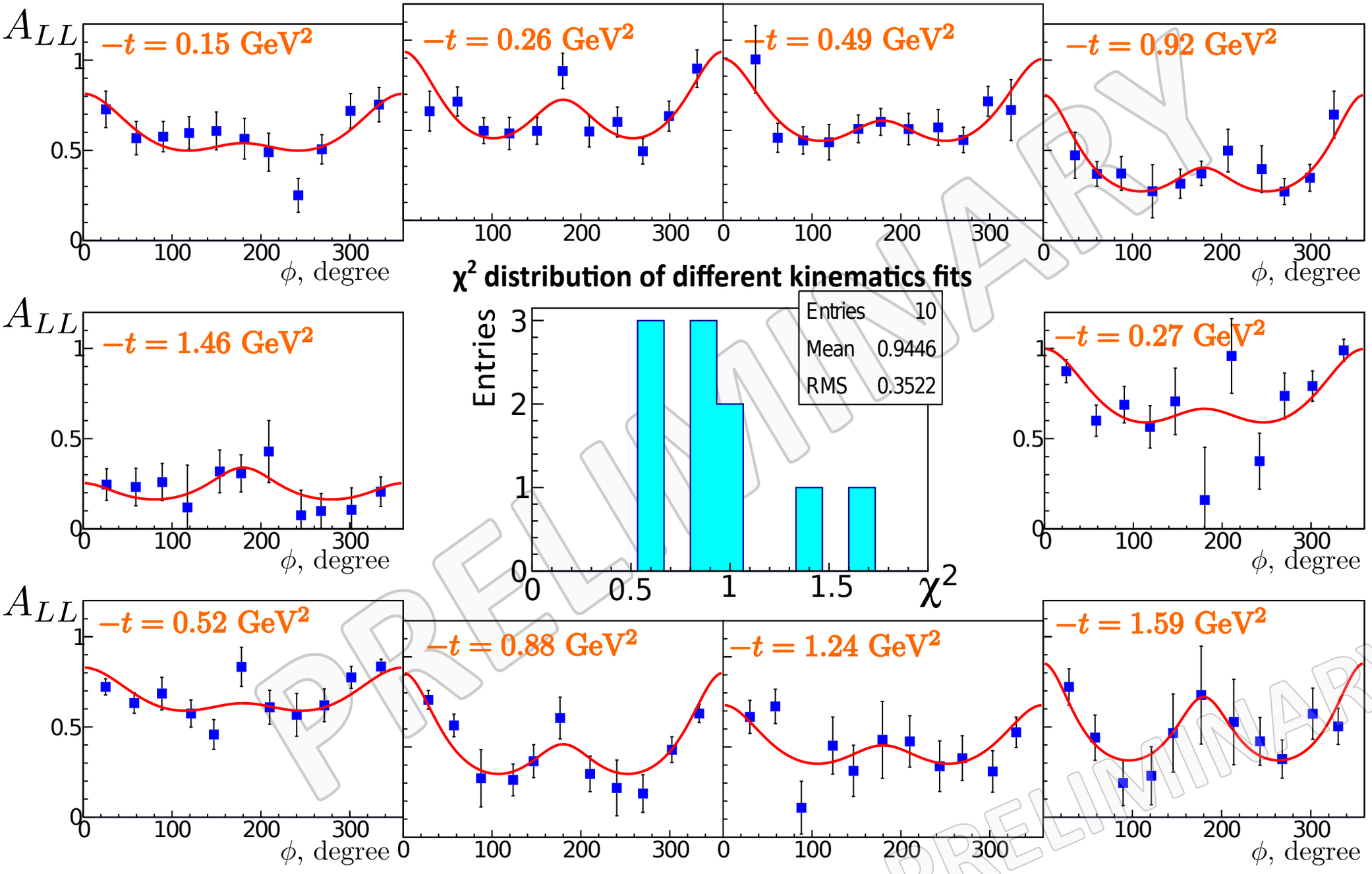
Target Spin Asymmetries: $ep \to ep\pi^0$

Azimuthal dependence of TARGET spin asymmetries in different kinematic bins

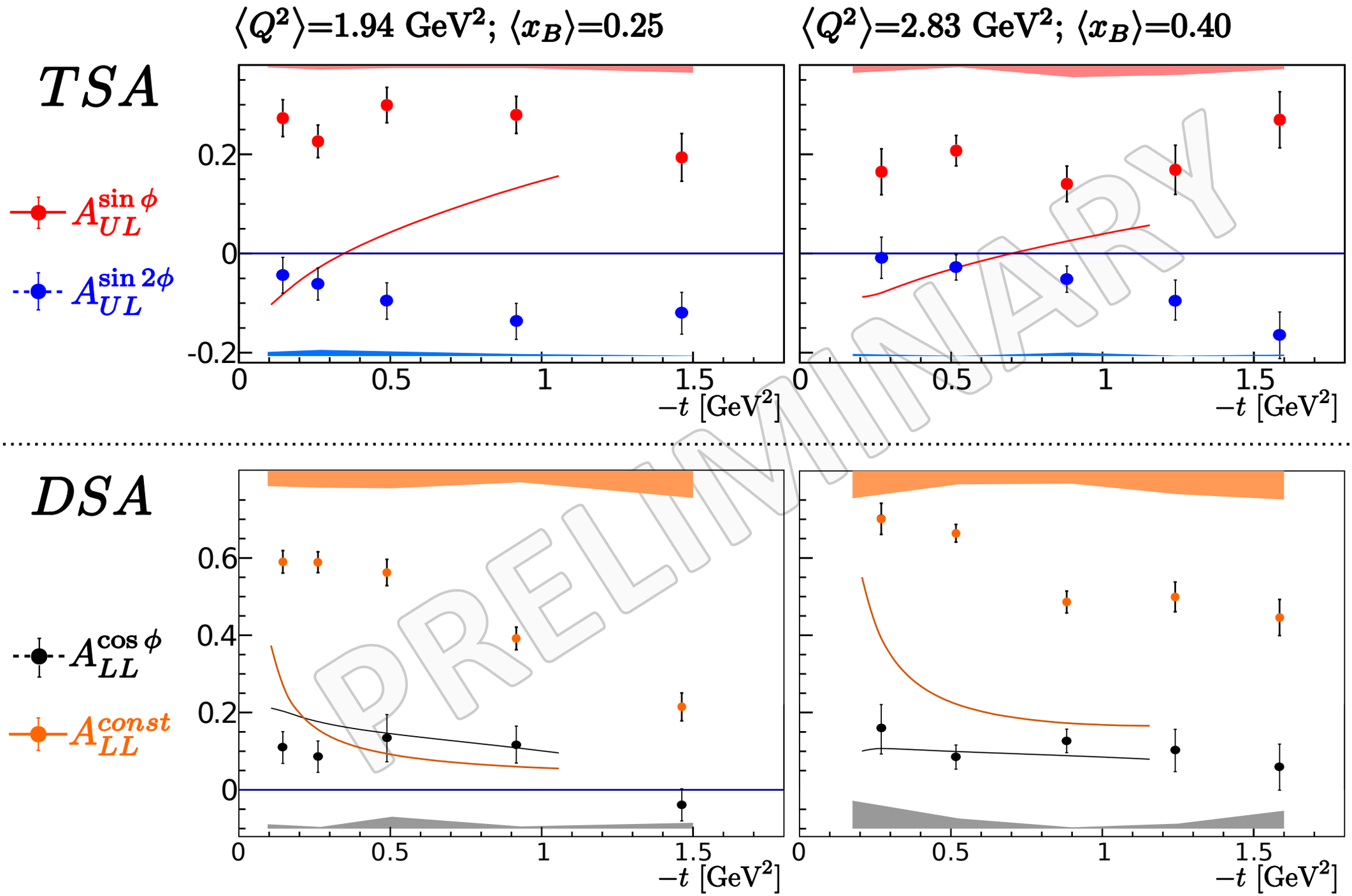


Double Spin Asymmetries: $ep \to ep\pi^0$

Azimuthal dependence of DOUBLE spin asymmetries in different kinematic bins



Target and Double Spin Asymmetries: $ep \to ep\pi^0$

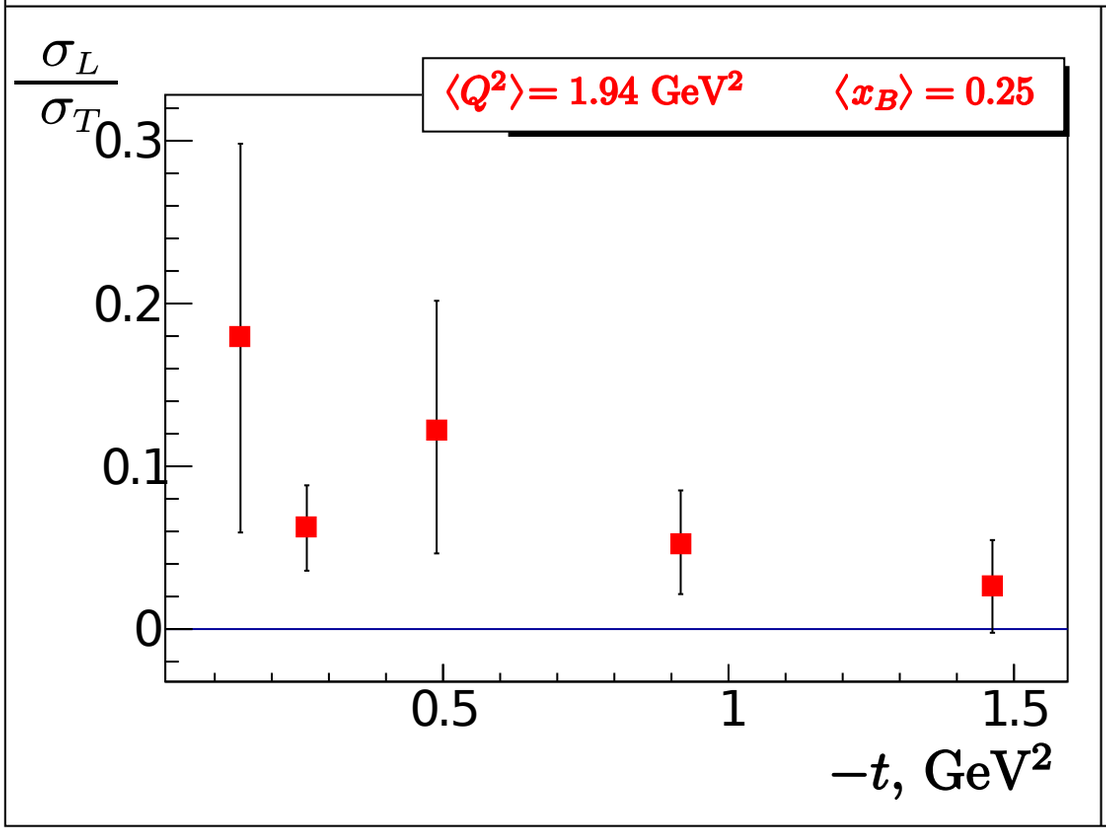


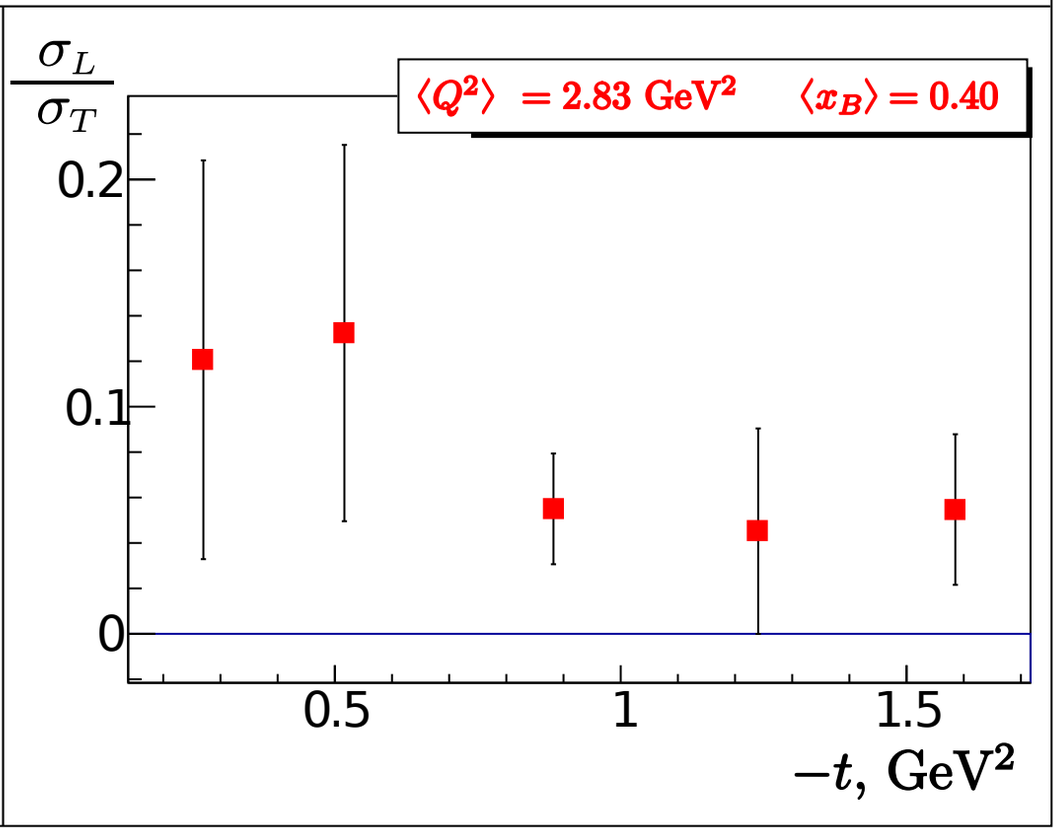
σ_L/σ_T: first steps to synergy

- Skip parametrizations of GPDs involved
- Use the data to constrain GPDs
- Confirmed expectations of dominant transverse photon amplitudes

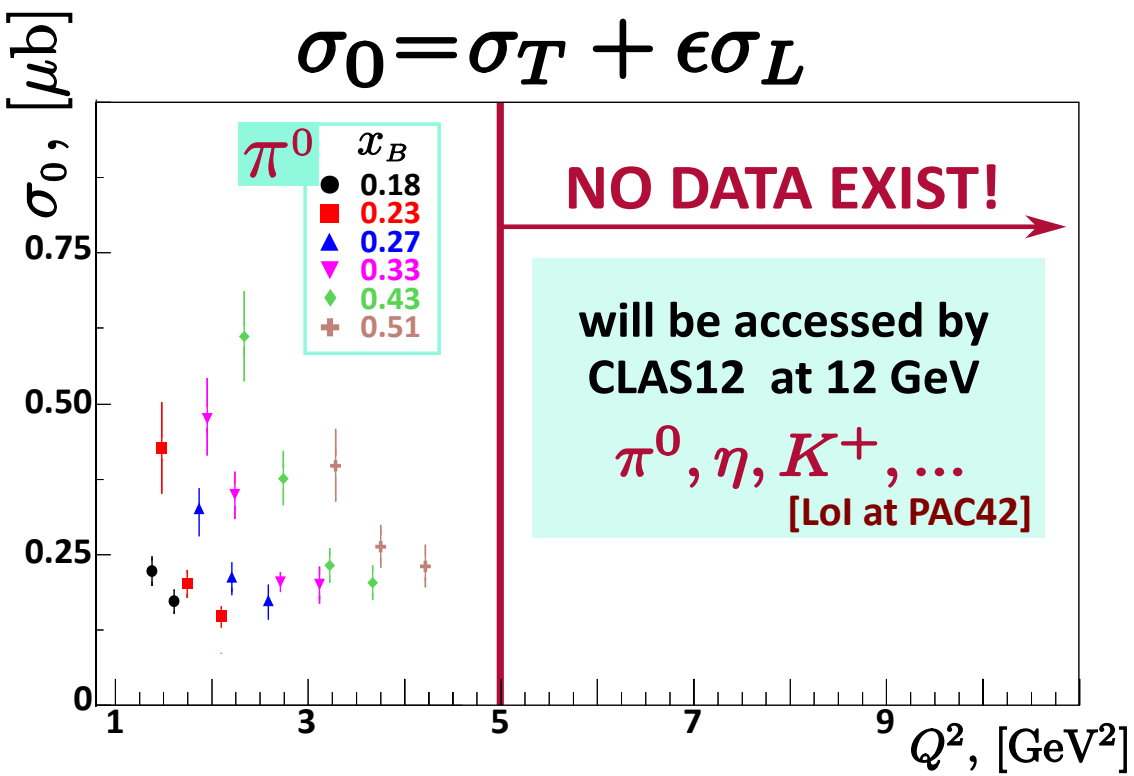
within Goloskokov-Kroll model framework!!!

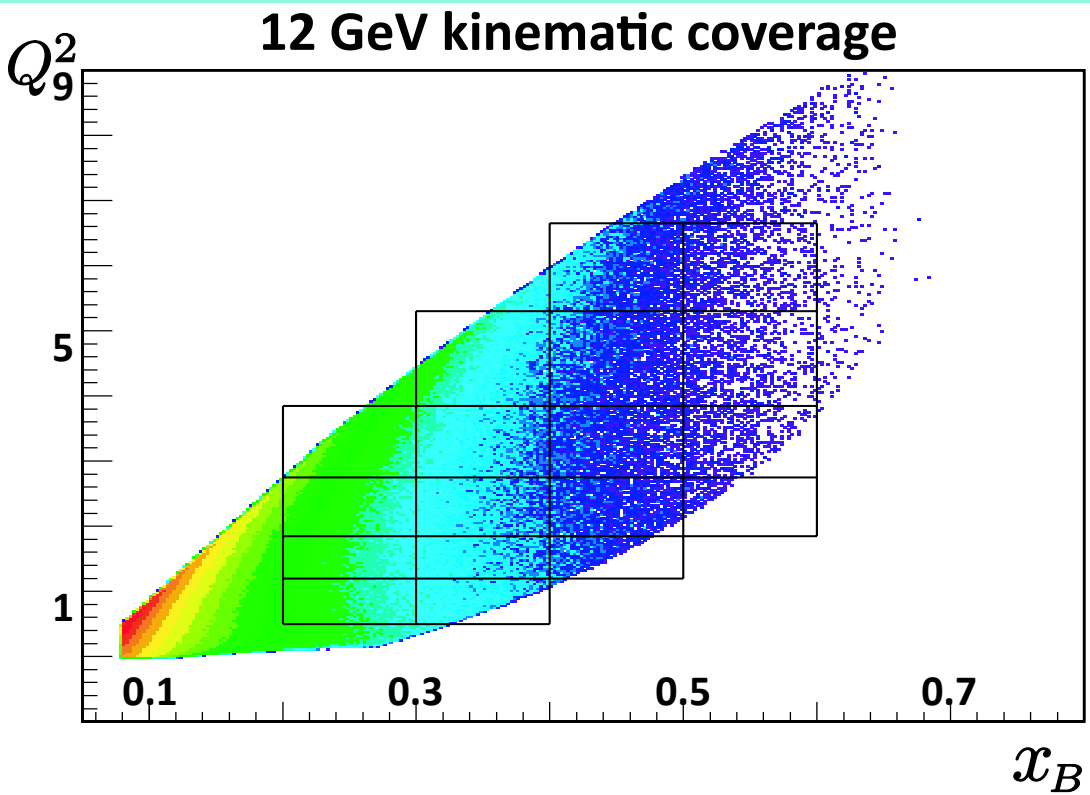
Ratio of structure functions: σ_L/σ_T





CLAS12 UPGRADE





- The combination of high beam intensity with large acceptance detectors allows for precise measurements of "rare" processes such as deep exclusive reactions: CLAS12 is uniquely suited for simultaneous detection of various DVMP channels
- Expansion of the kinematic coverage provides the opportunity to test the mechanism of pseudoscalar meson electroproduction in great details and perform the separation of the contributions from the different chiral-odd GPDs

Summary

- The beam spin asymmetries for exclusive η electroproduction, target and double spin asymmetries for π^0 have been extracted for the first time
- Hard exclusive production of pseudoscalar mesons provide access to the chiral-odd GPDs
- Beam Spin Asymmetries of pseudoscalar meson production provide access to polarized structure functions and, therefore, to imaginary part of chiral-odd GPDs
- CLAS provides the most extensive set of polarized structure functions from π^0 and η electroproduction data
- Large number of experimental observables provide tighter constraints for parametrizations of underlying transverse GPDs
- The variety of deeply virtual meson production channels provide and opportunity to perform flavor decomposition of GPDs
- CLAS12 upgrade will extend the current analysis adding new and sensitive information that will impact the extraction of the GPDs from the data