Exclusive Hard Processes with CLAS and Generalized Parton Distributions

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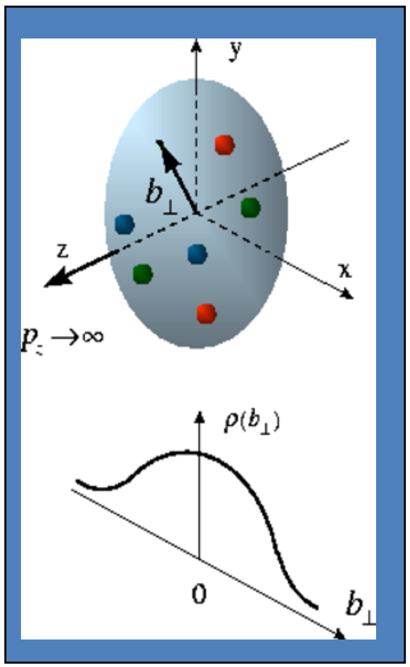
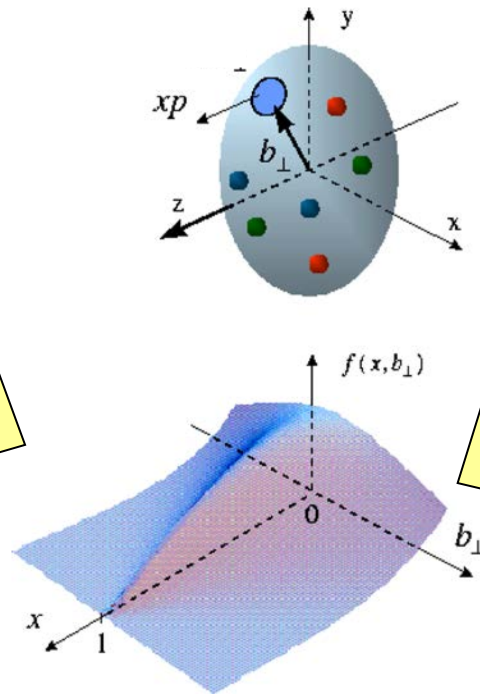
Generalized Parton Distributions and 3D Quark Imaging

Last 50 years



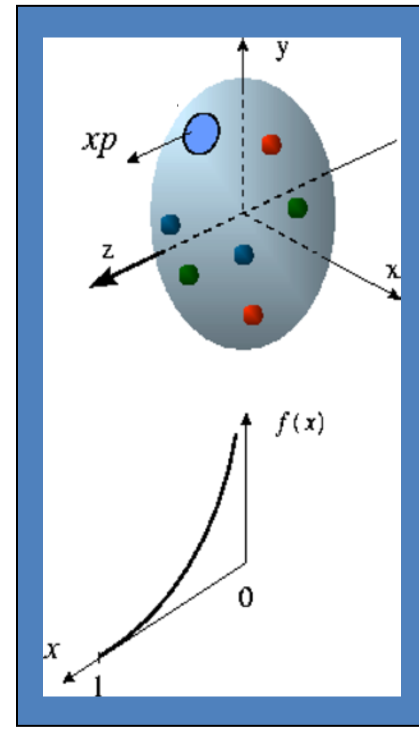
Proton form factors, transverse charge & current densities

Last 10 years



Correlated quark momentum and helicity distributions in transverse space - GPDs

Last 40 years



Structure functions, quark longitudinal momentum & spin distributions

Generalized Parton Distributions

H^q	$\tilde{H}^q$	E^q	$\tilde{E}^q$	**parton helicity conserving (chiral-even) GPDs**
H_T^q	$\tilde{H}_T^q$	E_T^q	$\tilde{E}_T^q$	**parton helicity-flip (chiral-odd) GPDs**

The GPDs depend on three kinematic variables:

e.g. $F^q(x, \xi, t)$

x

average parton momentum fraction

$$\xi \simeq \frac{2x_B}{2-x_B}$$

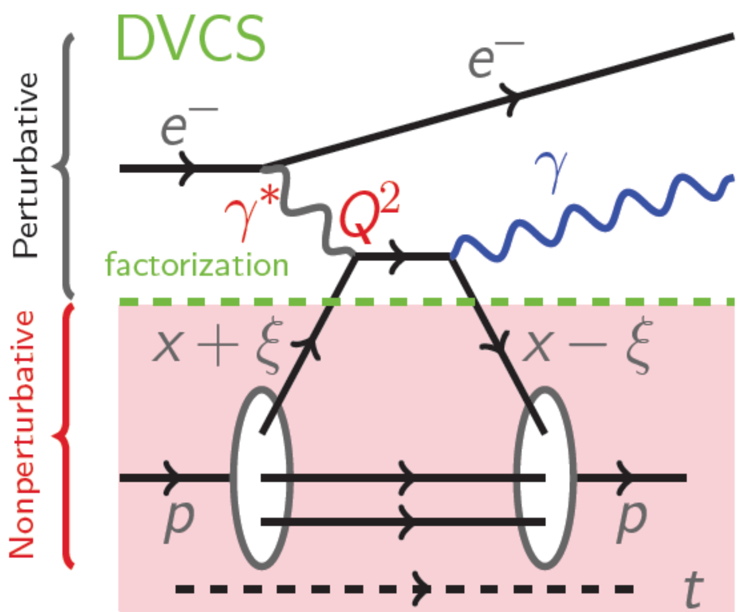
(skewness) difference between the initial and final fractions of the longitudinal momentum carried by the struck parton

$$t = (p - p')^2$$

momentum transfer between initial and final nucleons

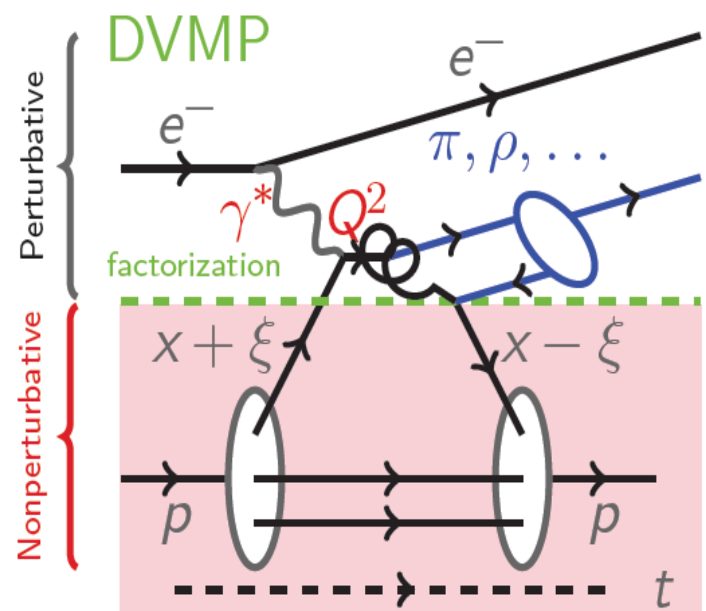
Deeply Virtual Exclusive Process

Deeply Virtual Compton Scattering (DVCS)



$H, \tilde{H}, E, \tilde{E}$

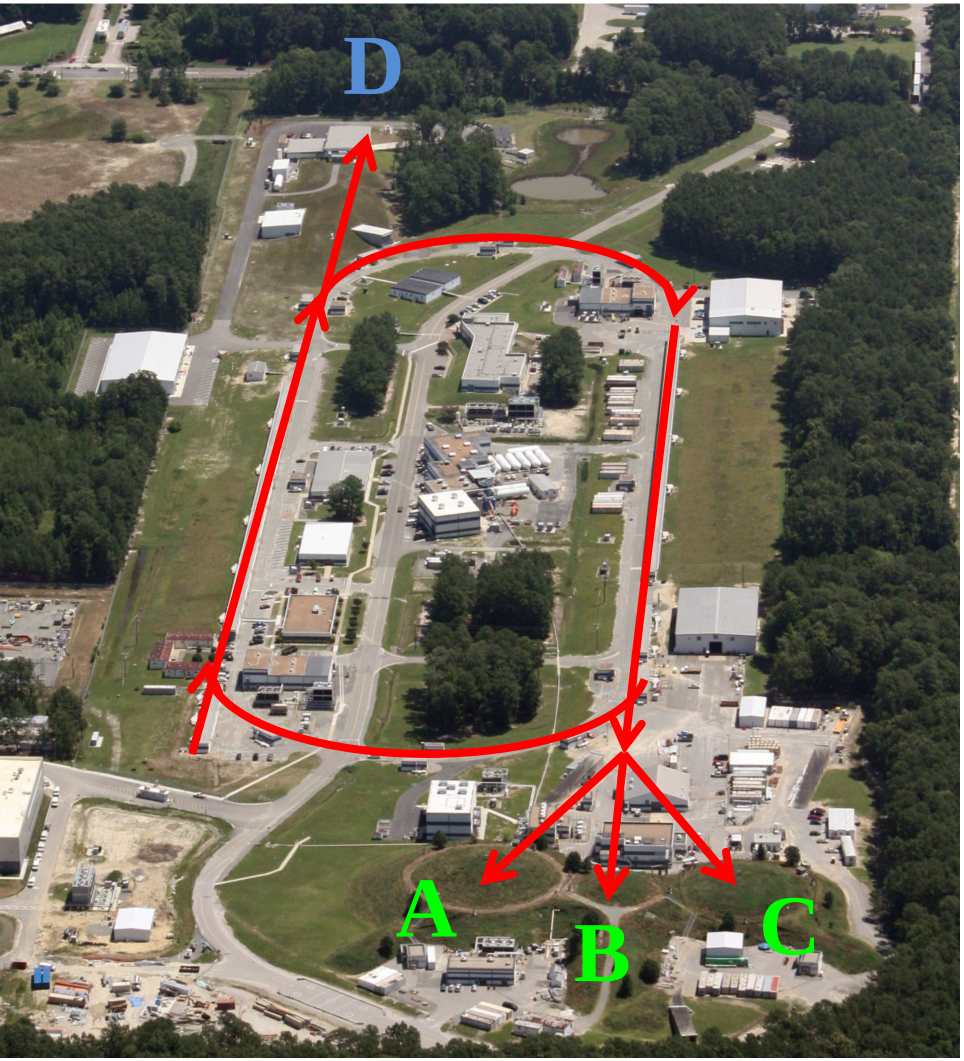
Deeply Virtual Meson Production (DVMP)



$H_T, \tilde{H}_T, E_T, \tilde{E}_T$

Flavor Decomposition

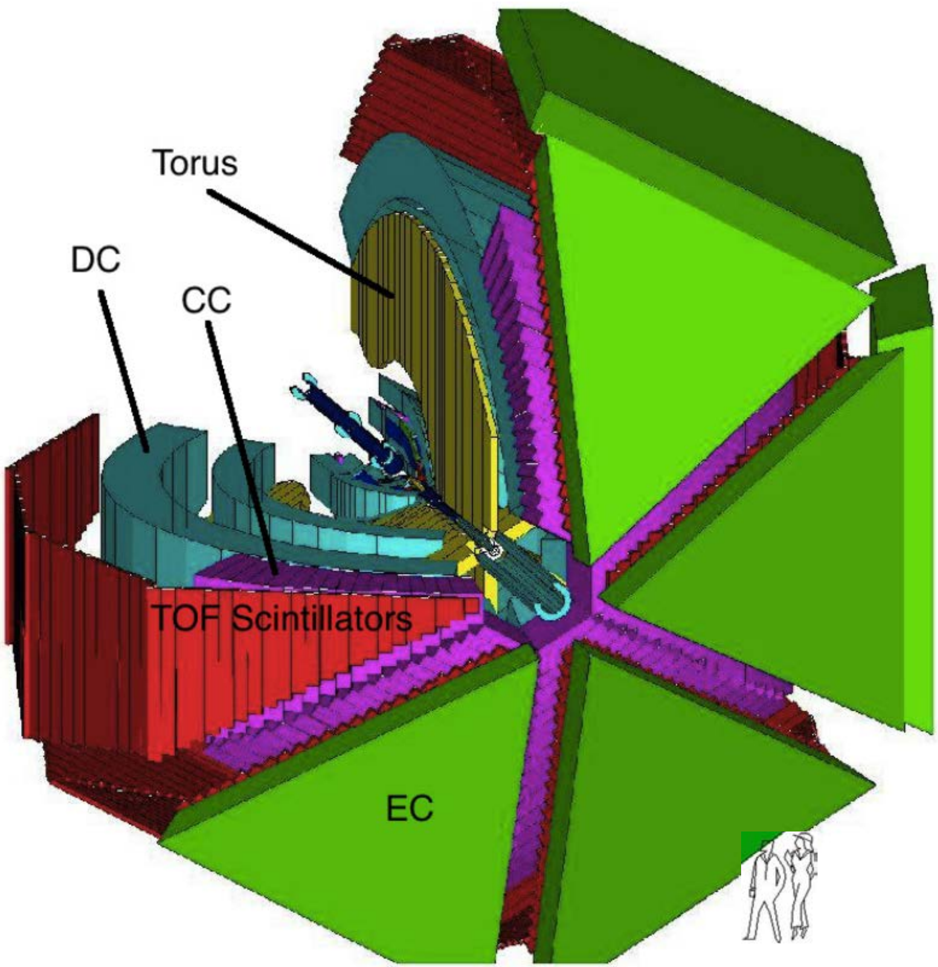
Thomas Jefferson National Accelerator Facility (Jefferson Lab)



Site Aerial, June 2012

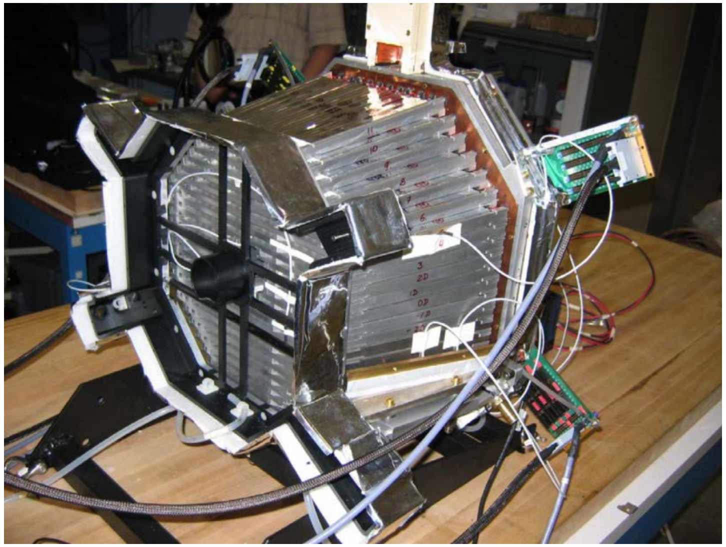
- Superconducting RF electron linacs with up to 5X recirculation
- CW (100% duty factor) operation
- Polarized source: up to 85% polarization
- Three experimental Halls
- Energy up to 6 GeV (upgrade will increase to 11(12) GeV to Halls A/B/C (D))

CEBAF Large Acceptance Spectrometer (CLAS) in Hall B



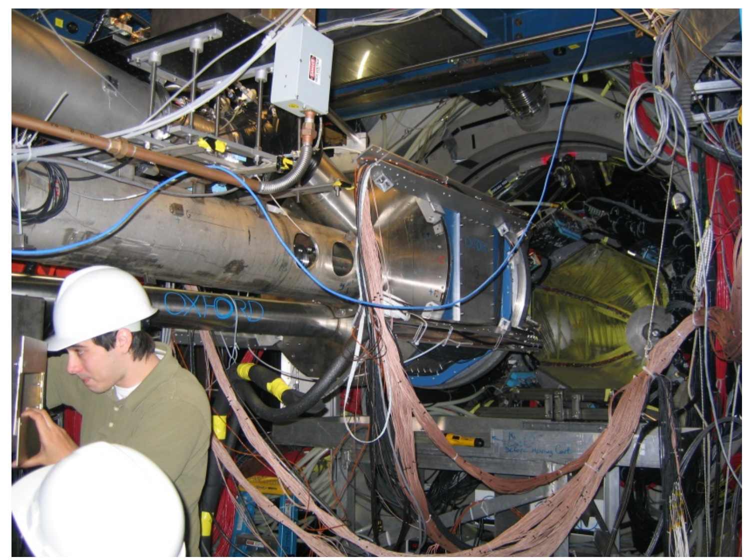
- Electromagnetic Calorimeter (EC) and Čerenkov Counter (CC) used in electron identification.
- Drift Chamber (DC) (3 regions) and time of flight Scintillators (SC) record position and timing information for each charged track.
- Torus magnet creates toroidal magnetic field which causes charged tracks to curve whilepreserving the φlab angle.

E1-DVCS and EG1-DVCS for DVCS and DVMP



Inner Calorimeter (IC)

- 424 $PbWO_4$ crystals, 16 cm long, 1.3x.13 cm^2
- High resolution calorimeter to detect photons at small angles (4-15^o).



Longitudinally polarized solid NH_3

- Dynamically Nuclear Polarization (DNP) with high polarizability (~80%)
- Resistant to radiation damage
- 5T holding field
- Carbon target

Deeply Virtual Compton Scattering

Unpolarized cross sections, unpolarized beam and target

$$\sigma_0 \sim \mathrm{Re}\{F_1 H - \frac{t}{4M^2} F_2 E - \xi^2 (F_1 + F_2)(H + E)\}$$

Polarized beam and Unpolarized target (BSA)

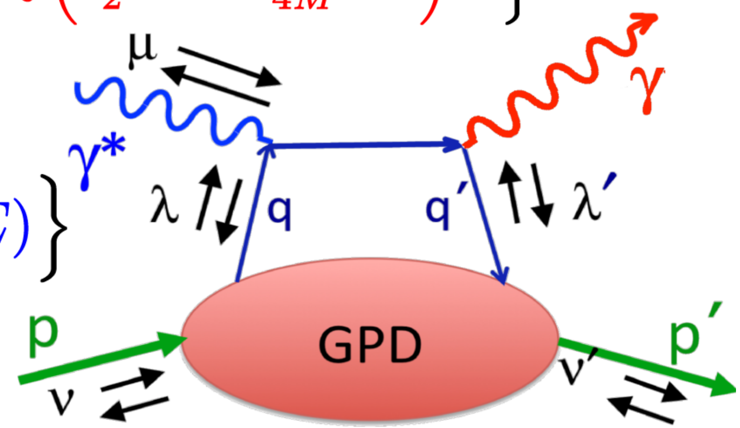
$$A_{LU} \sim \mathrm{Im}\left\{F_1 H + \xi(F_1 + F_2)\tilde{H} + \frac{t}{4M^2} F_2 E\right\}$$

Unpolarized beam and Polarized target (TSA)

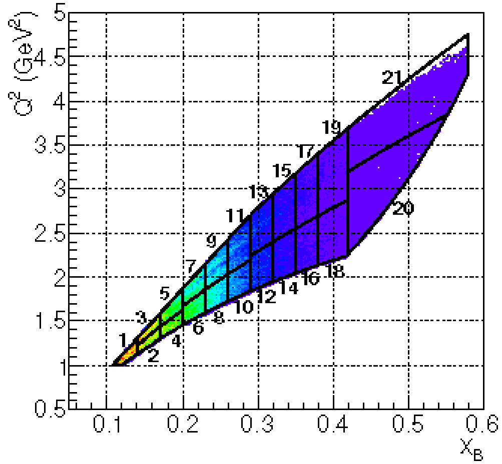
$$A_{UL} \sim \mathrm{Im}\left\{F_1 \tilde{H} + \xi(F_1 + F_2)\left(H - \frac{x_B}{2} E\right) - \xi\left(\frac{x_B}{2} F_1 - \frac{t}{4M^2} F_2\right)\tilde{E}\right\}$$

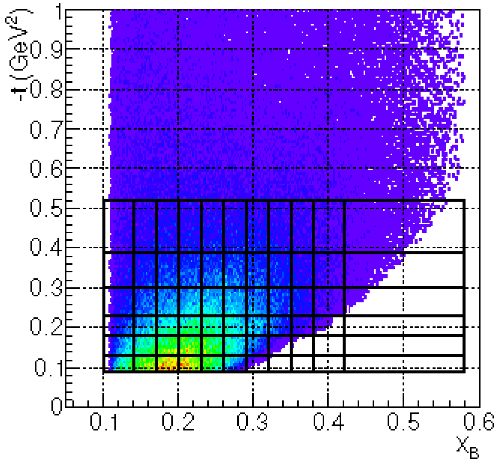
Polarized beam and Polarized target (DSA)

$$A_{LL} \sim \mathrm{Re}\left\{F_1 \tilde{H} + \xi(F_1 + F_2)(H + \frac{x_B}{2} E)\right\}$$



DVCS Unpolarized Cross Sections and Cross Section Differences

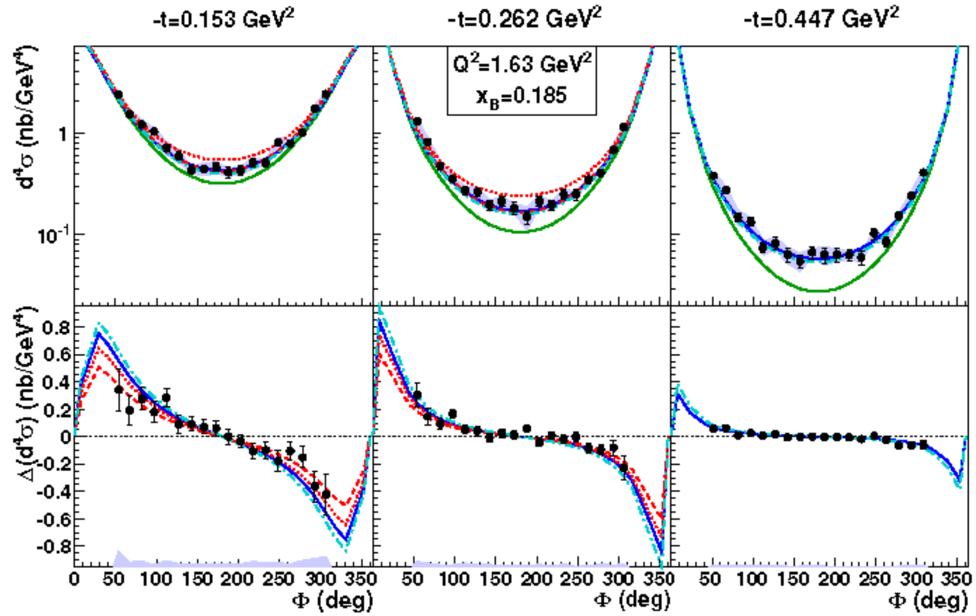




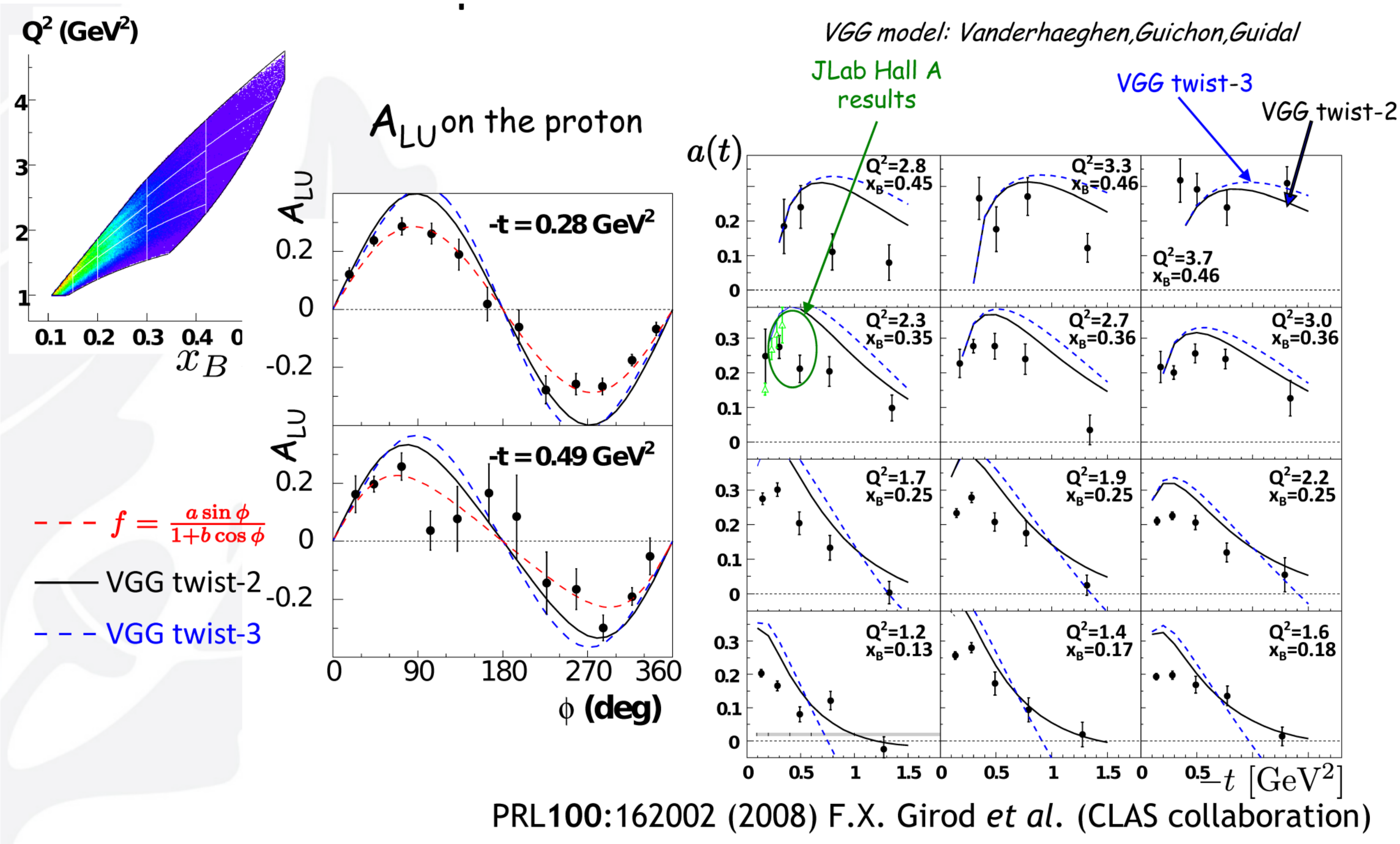
Extraction of 4 fold cross sections:
H. Jo, PRL 115 212003 (2015)

$$\frac{d^4\sigma_{ep\to ep\gamma}}{dQ^2 dx_B dt d\Phi}$$

$$\frac{1}{2}\left(\frac{d^4\overrightarrow{\sigma}_{ep\to ep\gamma}}{dQ^2 dx_B dt d\Phi} - \frac{d^4\overleftarrow{\sigma}_{ep\to ep\gamma}}{dQ^2 dx_B dt d\Phi}\right)$$

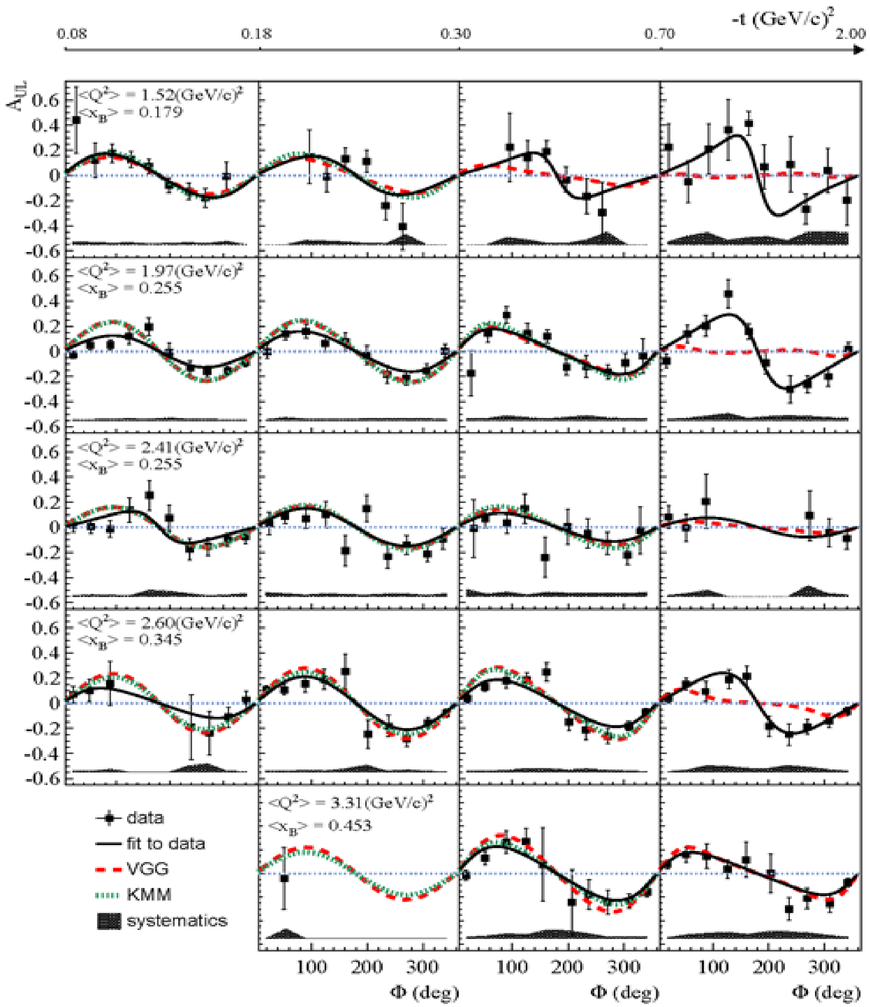


DVCS Beam Spin Asymmetries (A_{LU})



PRL**100**:162002 (2008) F.X. Girod *et al.* (CLAS collaboration)

DVCS Target Spin Asymmetries (A_{UL})

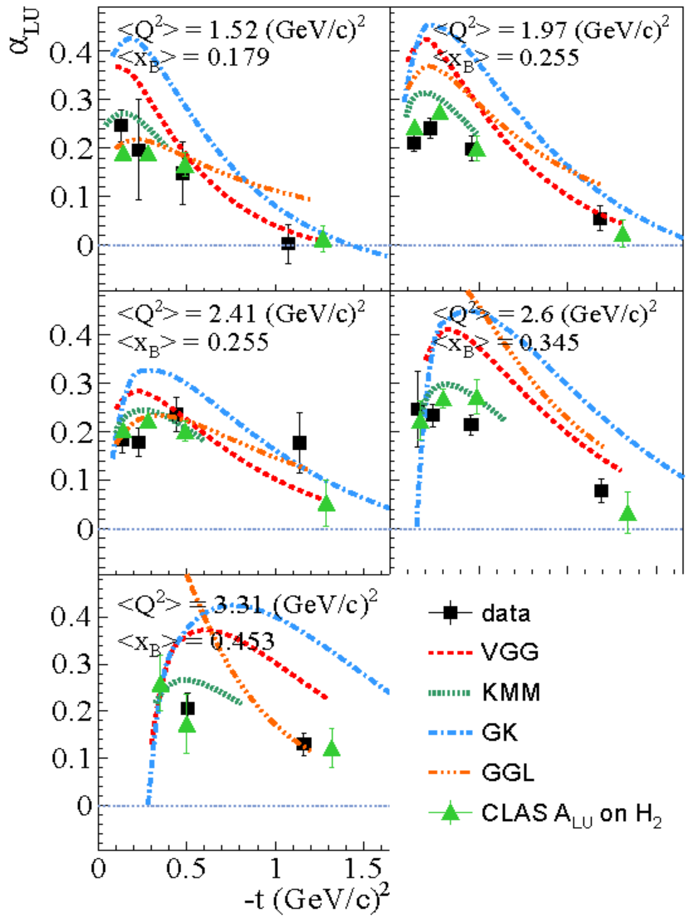


$$A_i = \frac{\alpha_i \sin\phi}{1 + \beta_i \cos\phi}$$

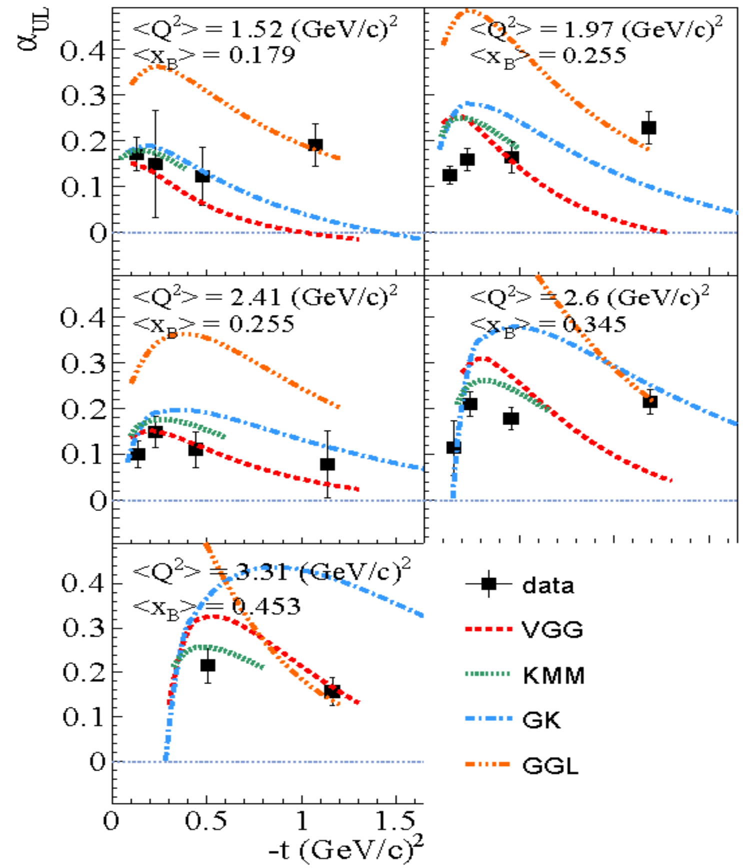
Seder et. al Phys. Rev. Lett. 114, 032001 (2015) , Pisano et al. Phys. Rev. D 91, 052014 (2015)

DVCS α_{LU} and α_{UL}

the α_{LU} from A_{LU}



the α_{UL} from A_{UL}



Seder et. al Phys. Rev. Lett. 114, 032001 (2015) , Pisano et al. Phys. Rev. D 91, 052014 (2015)

Deeply Virtual Meson Production (DVMP)

unpolarized terms

$$\frac{2\pi}{\Gamma}\frac{d^4\sigma}{dQ^2\,dx_B\,dt\,d\phi_\pi} = \boxed{\sigma_T + \epsilon\sigma_L + \epsilon\sigma_{TT}\cos 2\phi + \sqrt{\epsilon(1+\epsilon)}\,\sigma_{LT}\cos\phi}$$

longitudinally polarized beam

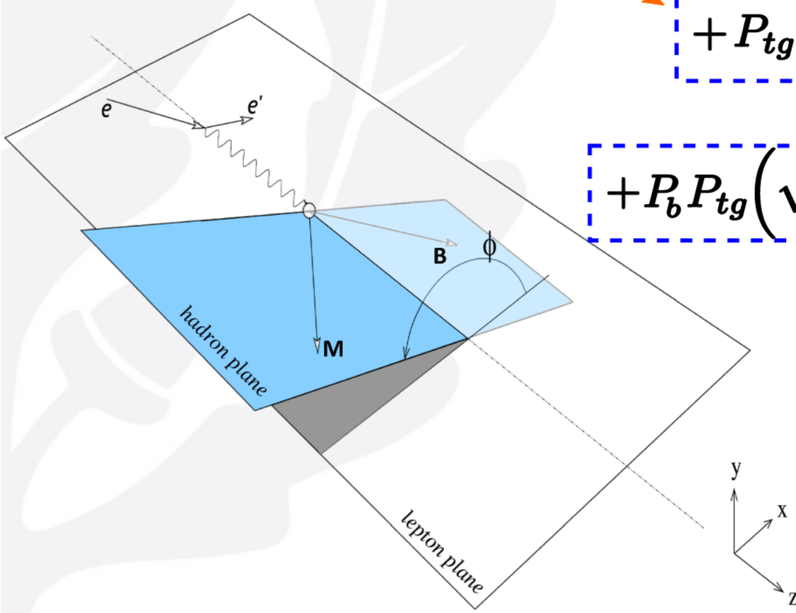
$$\boxed{+P_b\sqrt{\epsilon(1-\epsilon)}\,\sigma_{LT'}\sin\phi}$$

longitudinally polarized target

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

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

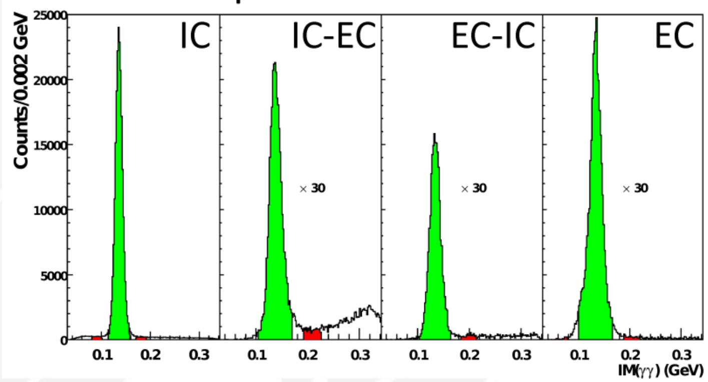
longitudinally polarized beam
and
longitudinally polarized target

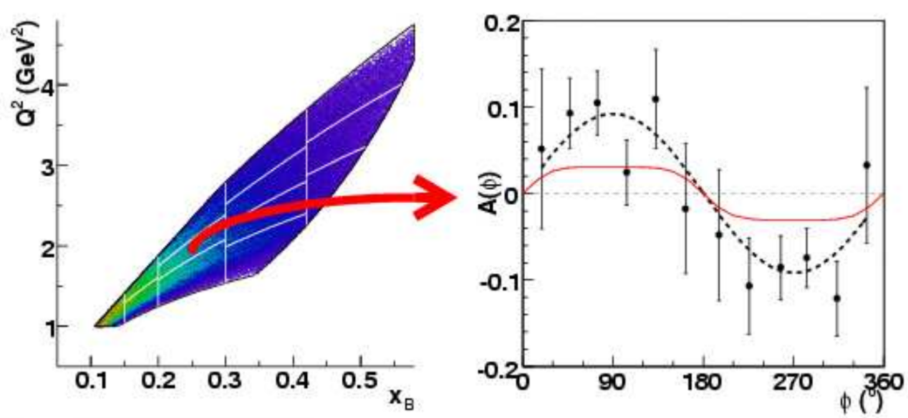


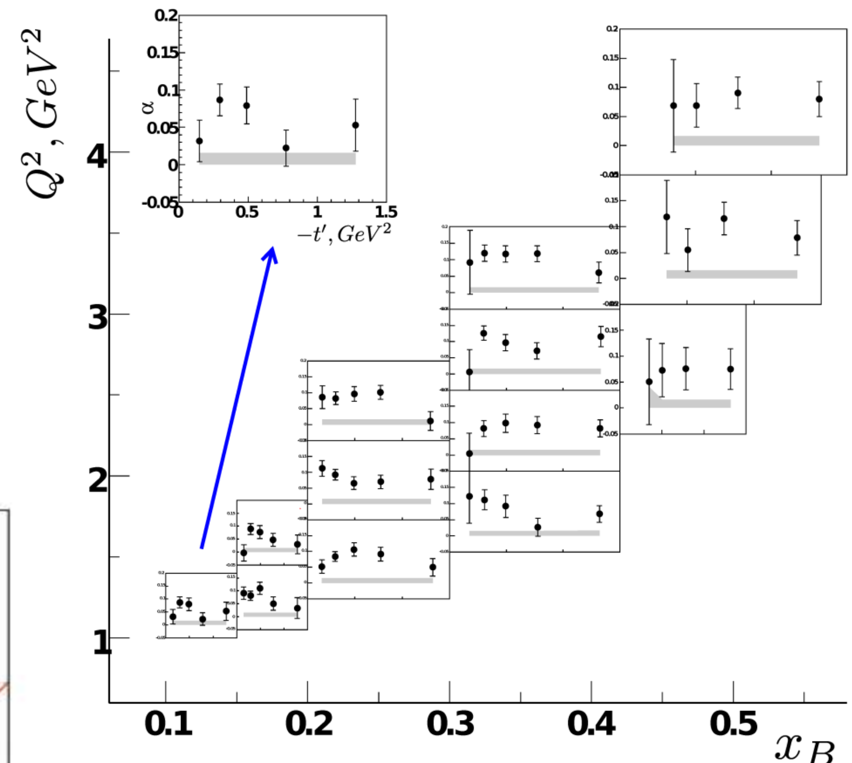
DVπ^0P Beam Spin Asymmetries (A_{LU})

First round experiment at Hall B: E01-113

Two-photon invariant mass





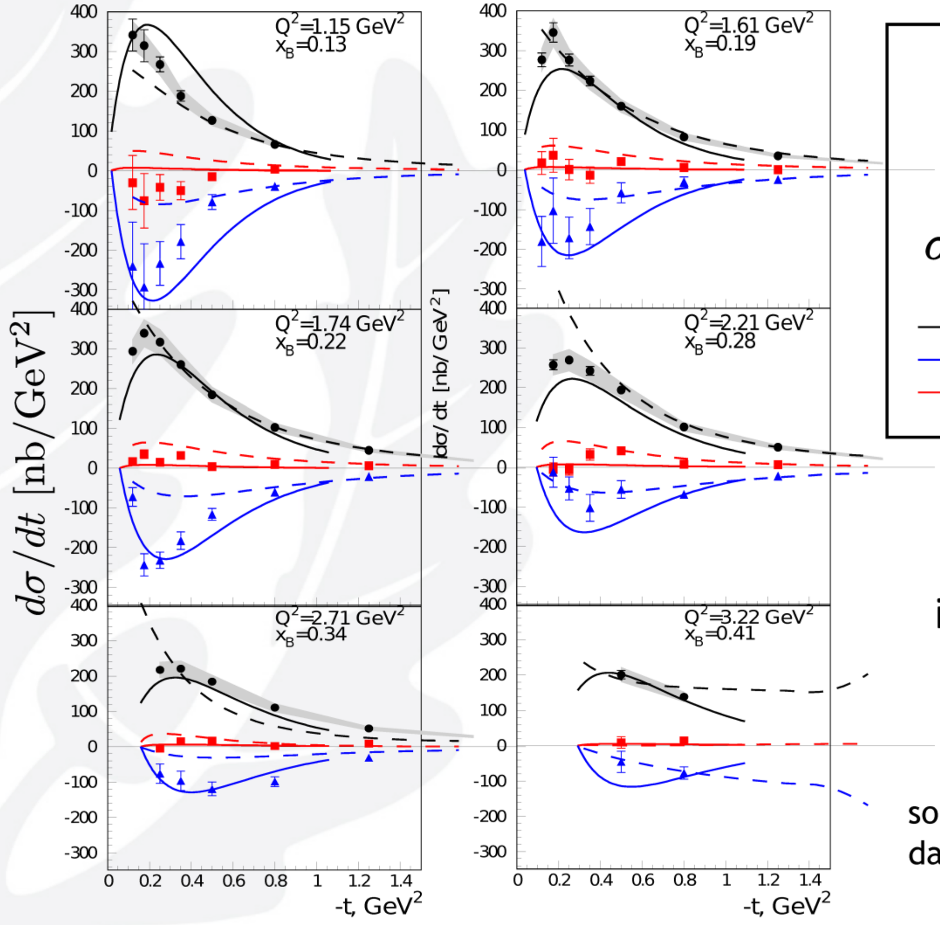


R. De Masi et al. Measurement of $ep\text{->}ep\pi^0$ **beam spin asymmetries above the resonance region. Phys.Rev., C77:042201, 2008.**

PRC**77**:042201 (2008), R. De Masi *et al.* (CLAS collaboration)

DVπ^0P Unpolarized Cross Sections (σ_0)

First round experiment at Hall B: E01-113



Inclusion of the Chiral-odd GPDs brings theoretical calculations into moderate agreement with the data.

$$\sigma_T \sim (1-\xi^2)|H_T|^2 - \frac{t'}{8m^2}|\bar{E}_T|^2$$

— $\sigma_0 = \sigma_T + \epsilon\sigma_L$

— σ_{TT}

— σ_{LT}

$$\sigma_{TT} \sim \frac{t'}{8m^2}|\bar{E}_T|^2$$

π^0 electroproduction

is uniquely sensitive process to access

transversity GPDs.

solid: P.Kroll & S.Goloskokov

dashed: G.R. Goldstein, J.O. Gonzalez & S.Liuti

PRL109:112001 (2012) I. Bedlinskiy et al. (CLAS collaboration)

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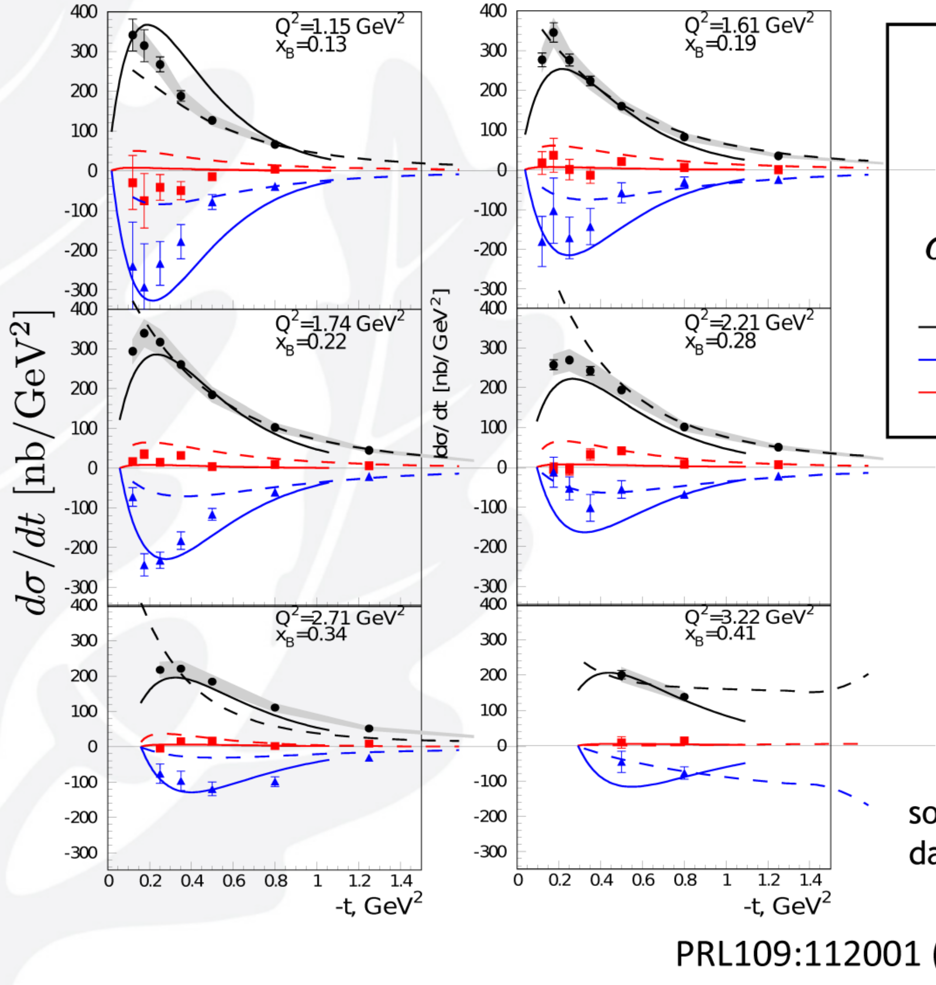

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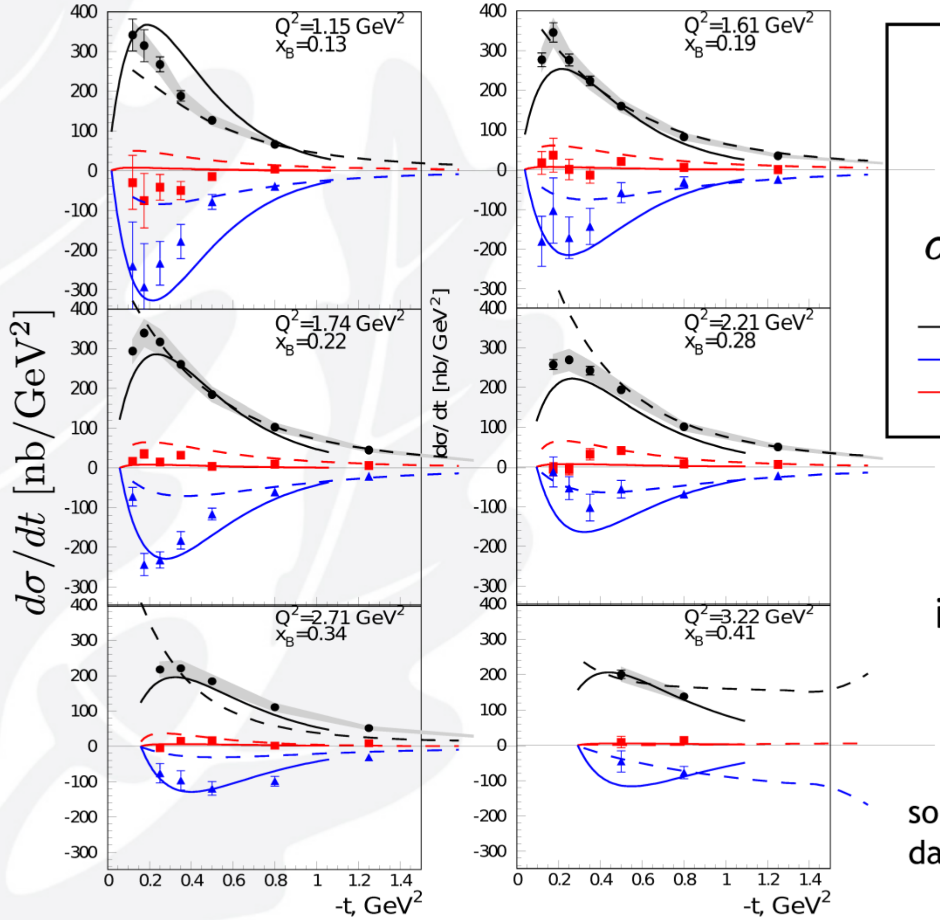

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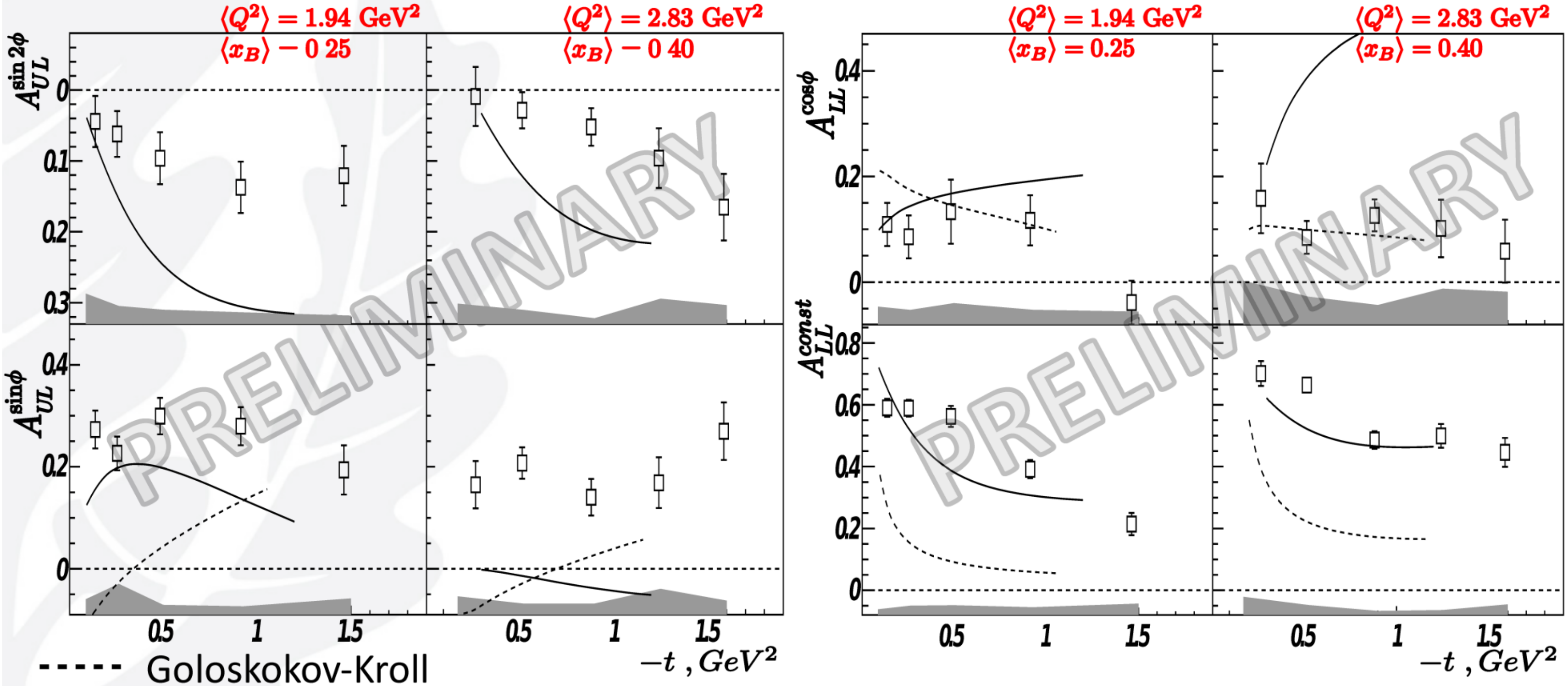
DVπ^0P Target and Double Spin Asymmetries (A_{UL}, A_{LL})

Second round experiment at Hall B: E05-114 (longitudinally polarized target)

DVπ^0P single and double spin asymmetry measurements are underway

TARGET SPIN ASYMMETRY

DOUBLE SPIN ASYMMETRY



- - - - Goloskokov-Kroll

—— Goldstein-Liuti

A. Kim (UConn)

GPD Flavor Decomposition

$$H_T^{\pi} = \frac{1}{3\sqrt{2}}[2H_T^u + H_T^d]$$

$$H_T^{\eta} = \frac{1}{\sqrt{6}}[2H_T^u - H_T^d]$$

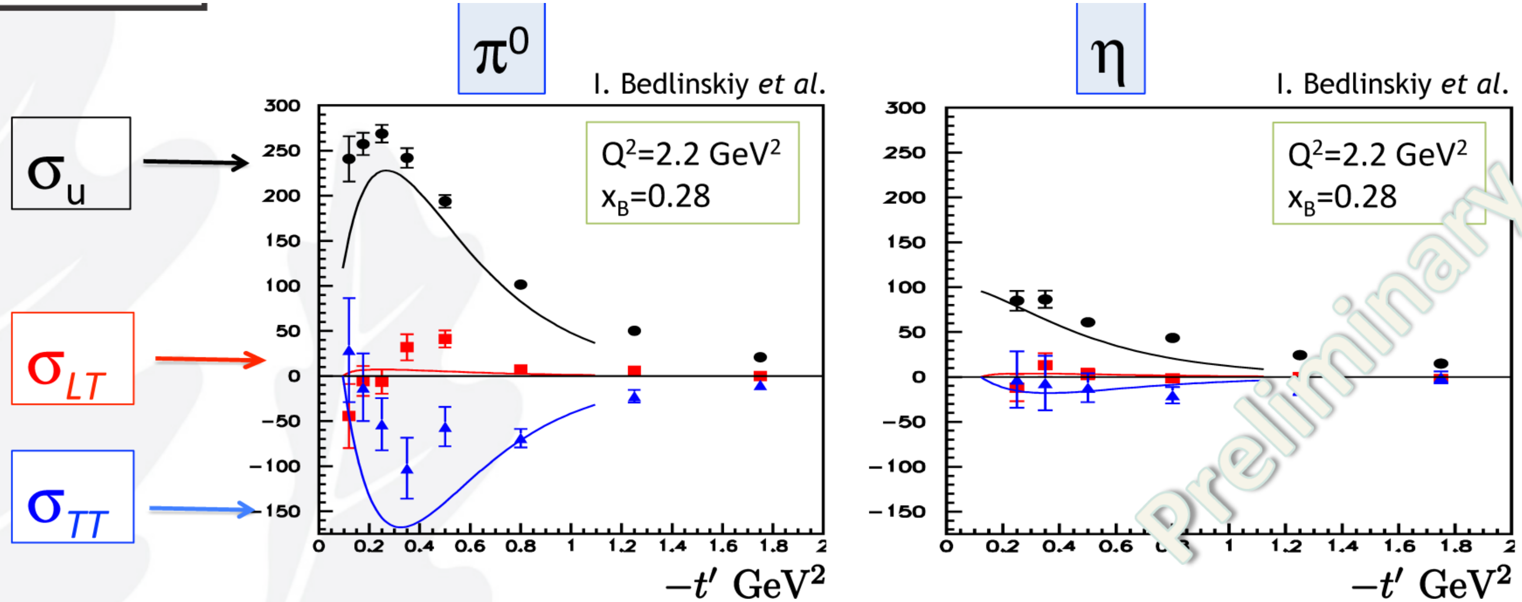
$$H_T^u = \frac{3}{2\sqrt{2}}[H_T^{\pi} + \sqrt{3}H_T^{\eta}]$$

$$H_T^d = \frac{3}{\sqrt{2}}[H_T^{\pi} - \sqrt{3}H_T^{\eta}]$$

Similar expressions for $\bar{E}_T$

- GPDs appear in different flavor combinations for π^0 and η
- The combined π^0 and η data permit the flavor (u and d) decomposition for GPDs H_T and E_T
- The u/d decomposition was done under simple assumption that the relative between u and d is 0 or 180 degrees.

π^0 and η Unpolarized Structure Functions



- σ_U - drops by a factor of 2.5 for η
- σ_{TT} - drops by a factor of 10
- GK model (curves) follows the experimental data
- The statement about the transversity GPD dominance in the pseudoscalar electroproduction becomes more solid with inclusion of η data

η / π^0 Ratio

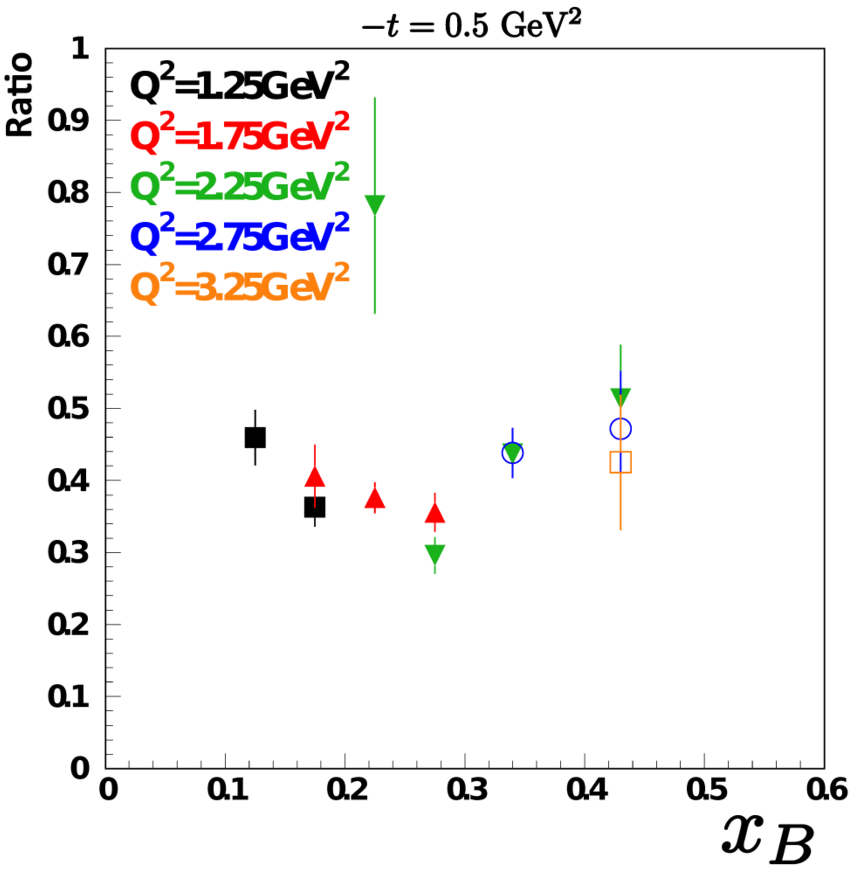
$$F_i^{\pi^0} = \frac{(e_u F_i^u - e_d F_i^d)}{\sqrt{2}}$$

$$F_i^{\eta} = \frac{(e_u F_i^u + e_d F_i^d)}{\sqrt{6}}$$

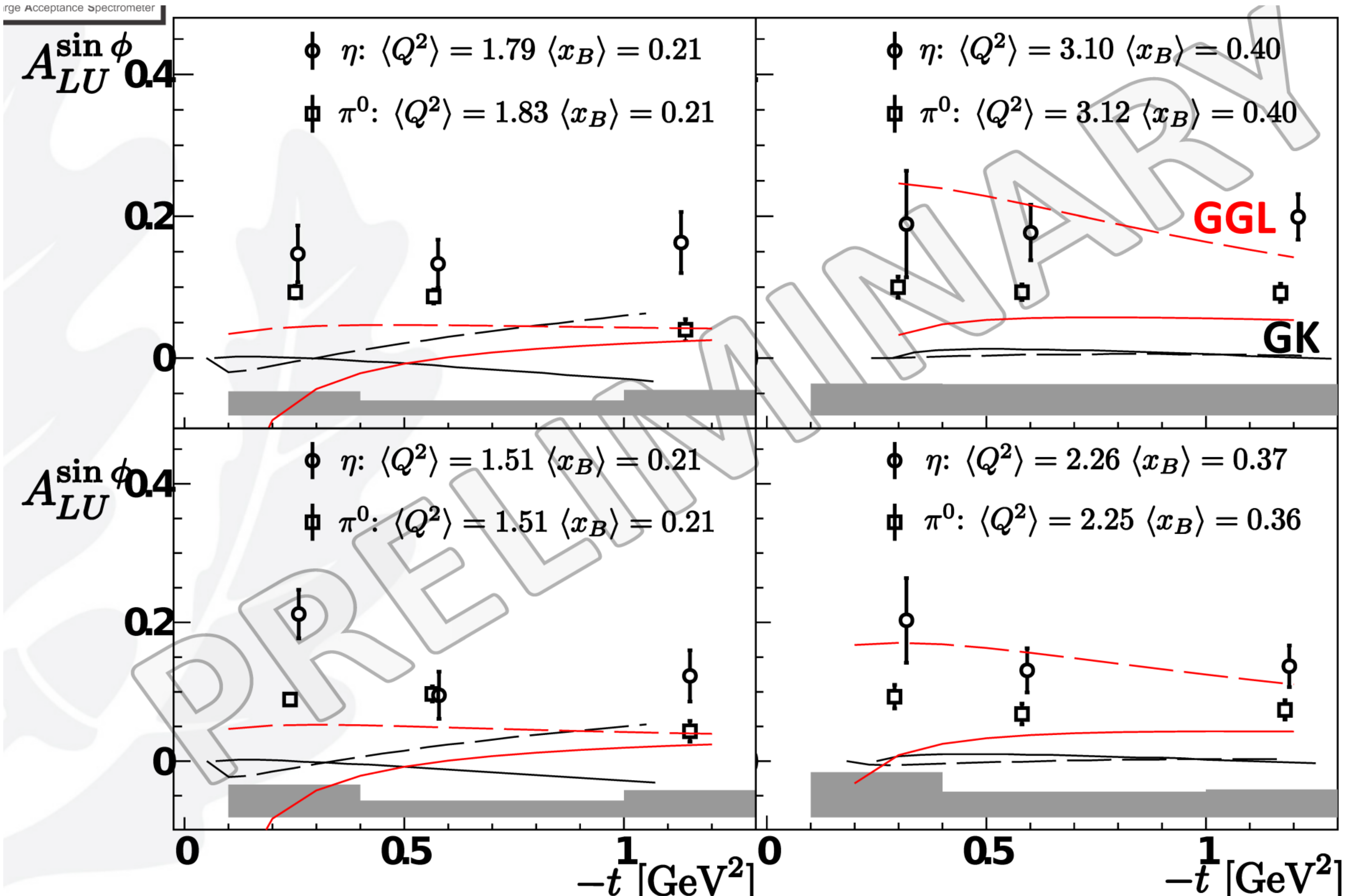
$$\frac{d\sigma(\eta)}{d\sigma(\pi^0)} \simeq \left(\frac{f_\eta}{f_\pi}\right)^2 \frac{1}{3} \left|\frac{2\langle F_T^u\rangle - \langle F_T^d\rangle}{2\langle F_T^u\rangle + \langle F_T^d\rangle}\right|^2$$

Chiral-odd GPD models predict this ratio to be ~1/3 at CLAS kinematics

Chiral-even GPD models predict this ratio to be around 1

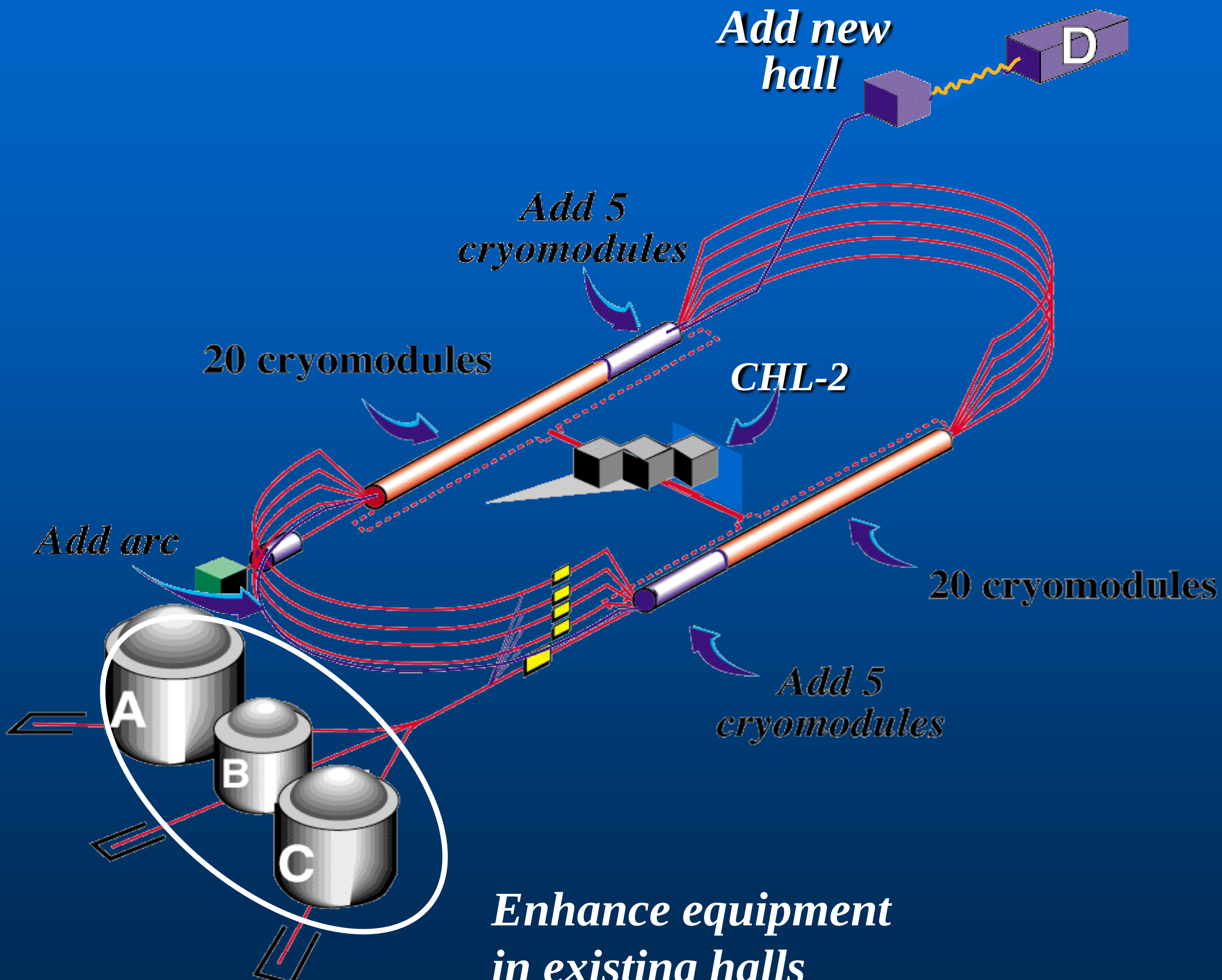


Beam spin asymmetries: $\vec{e}p \to e'p'\eta$ and $\vec{e}p \to e'p'\pi^0$



A. Kim (UConn)

JLab Upgrade to 12 GeV



Enhance equipment in existing halls

Base equipment

Forward Detector (FD)

- TORUS magnet (6 coils)
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Pre-shower calorimeter
- E.M. calorimeter

Central Detector (CD)

- SOLENOID magnet
- Barrel Silicon Tracker
- Central Time-of-Flight

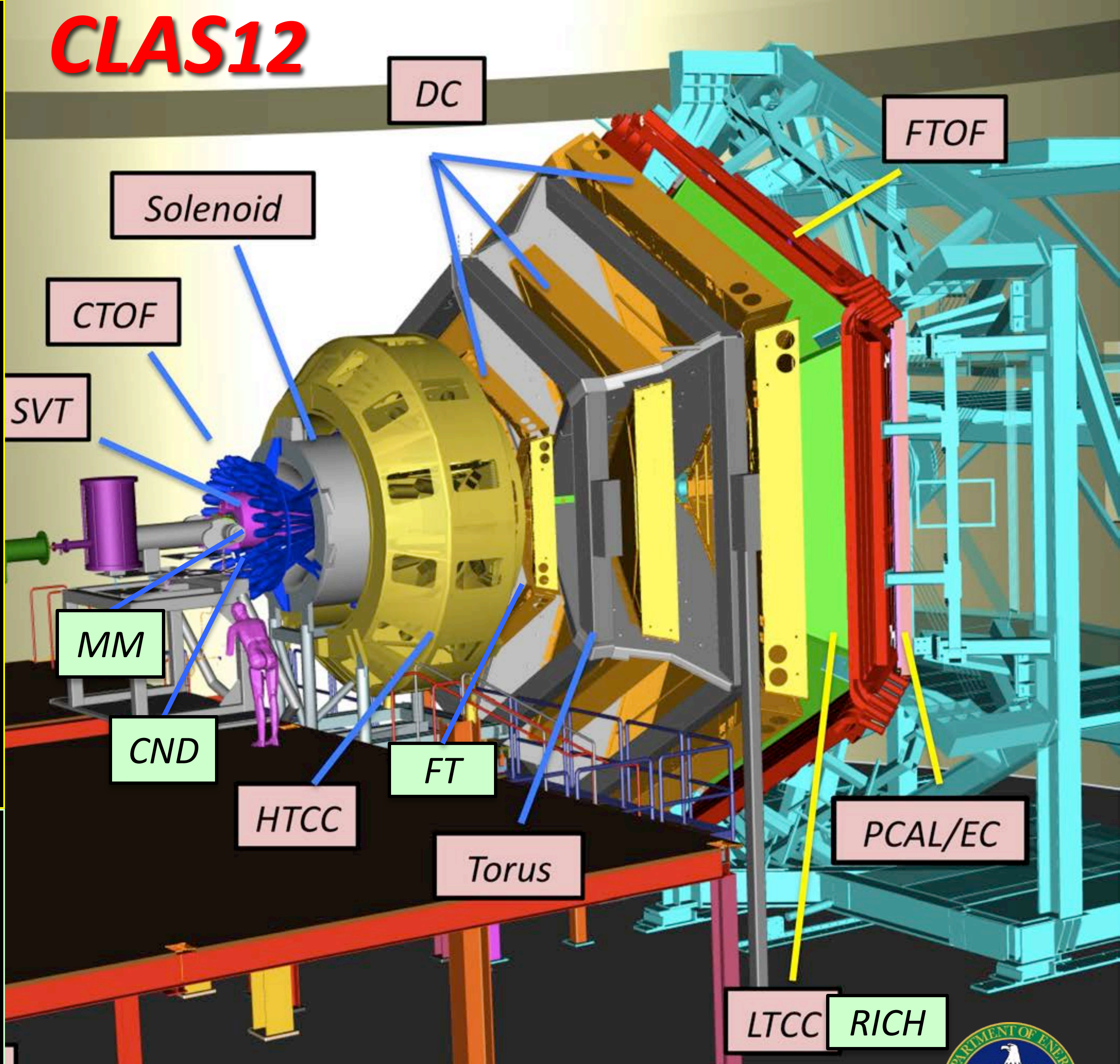
Beamline

- Targets
- Moller polarimeter
- Photon Tagger

Upgrade to base equipment

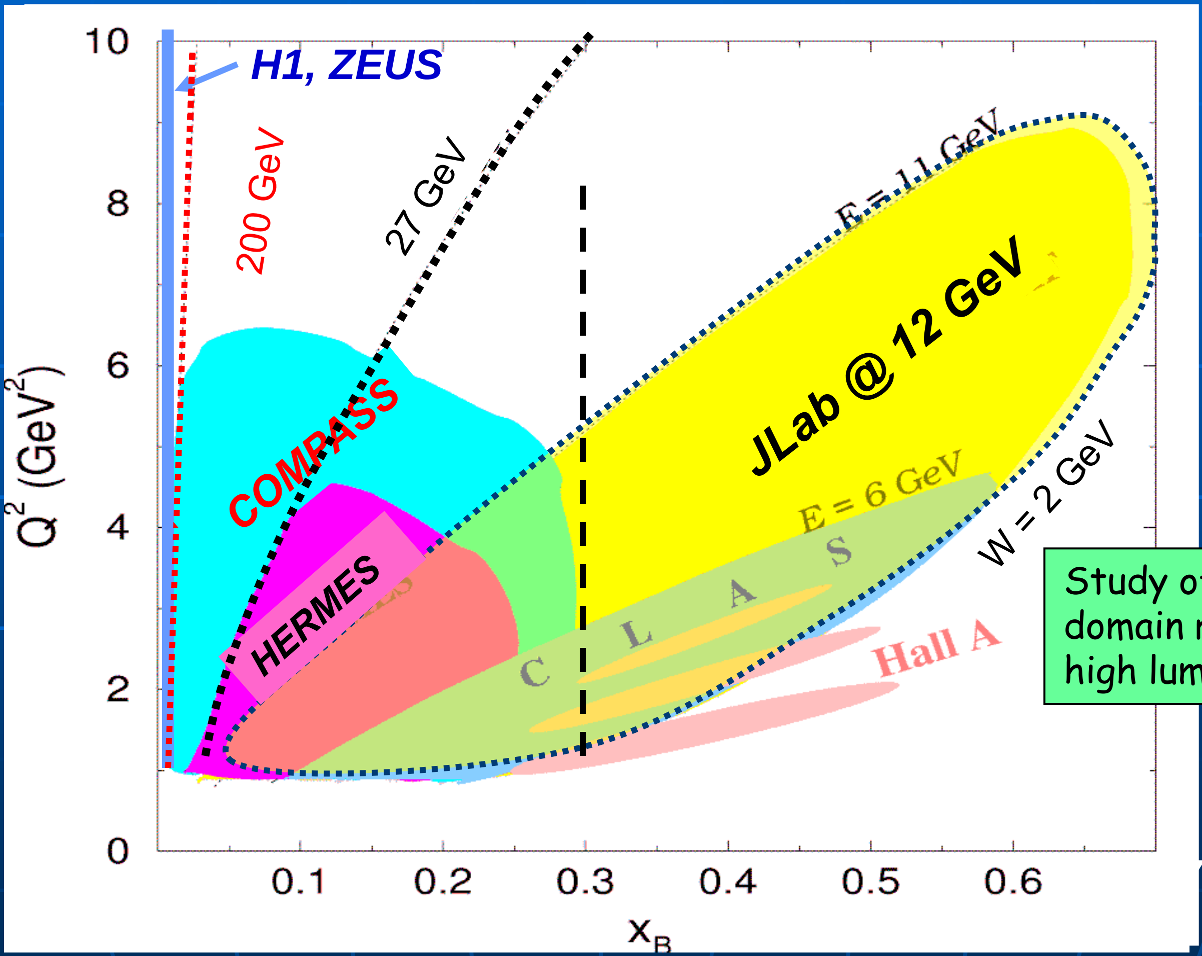
- MicroMegas
- Central Neutron Detector
- Forward Tagger
- RICH detector (1 sector)
- Polarized target (long.)

CLAS12



http://www.jlab.org/Hall-B/clas12-web/

Kinematics of deeply virtual exclusive processes



Study of high x_B domain requires high luminosity

Summary

- Large data set (cross secions, single and double spin asymmetries) in a wide kinematic region is available.
- Large number of experimental observables provide better constraints for parameterizations of underlying GPDs.
- DVCS and DVMP provide access to the chiral-even and chiral-odd GPDs.
- Compelling GPD program in the future at JLab at 12 GeV.