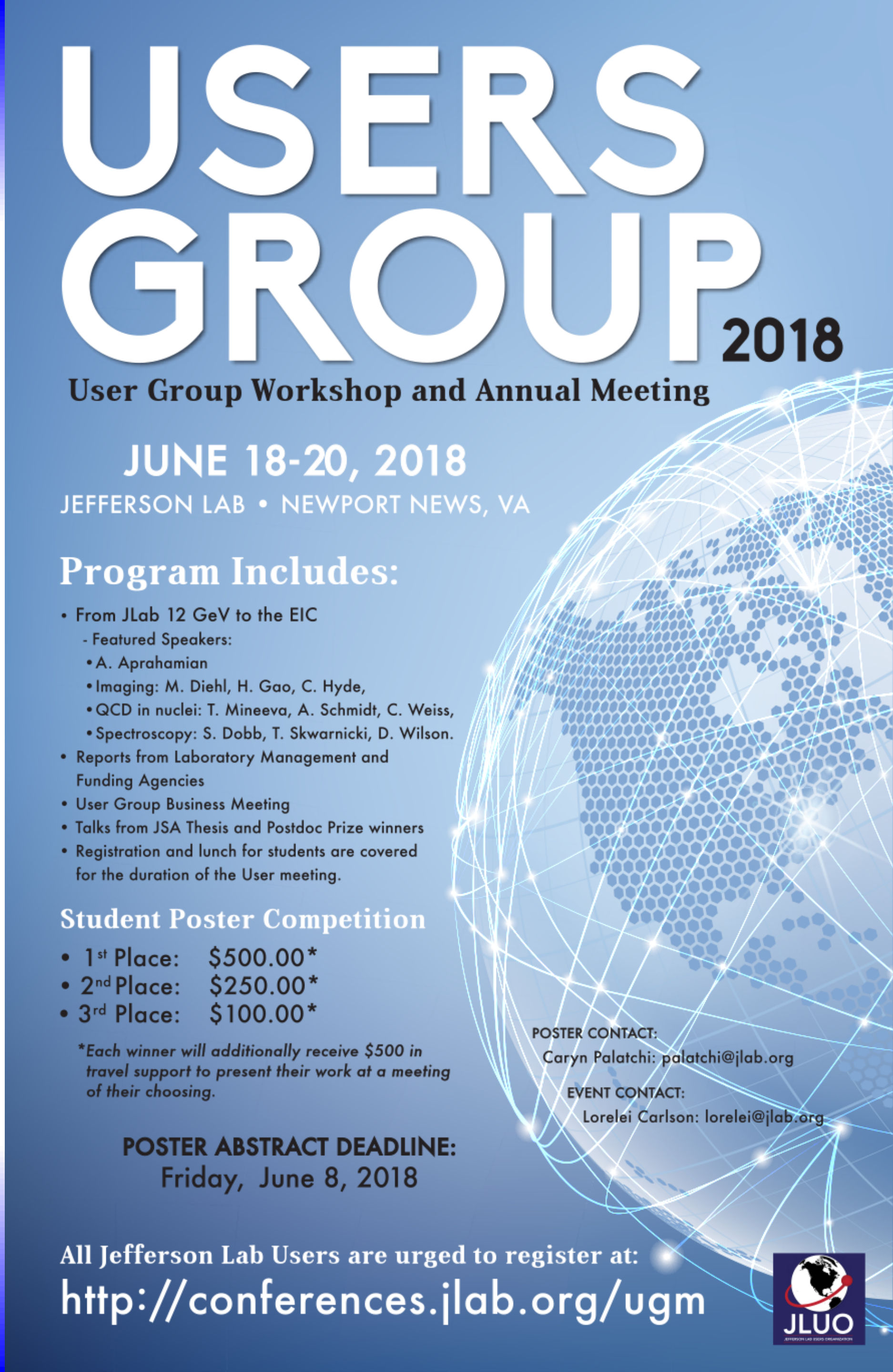
From JLab @12 GeV to the Electron Ion Collider: Generalized Parton Distributions

Charles Hyde*
Old Dominion University

OLD DOMINION UNIVERSITY

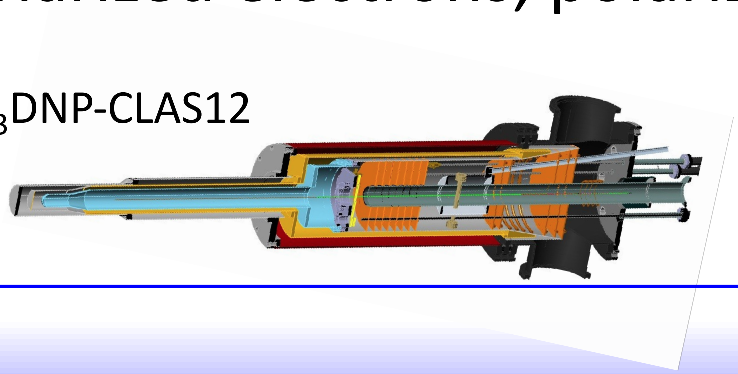
*Funding from DOE



Deep Virtual Exclusive Scattering (DVES)

- Fully exclusive final states
  - e p → e p $\boldsymbol{\gamma}$, ep → e N meson
  - e d → e pn $\boldsymbol{\gamma}$, etc.
- Nuclei
  - e d → e d $\boldsymbol{\gamma}$, mesons…
  - e ^{4}He →e^{4}He $\boldsymbol{\gamma}$ …
- Time-like Compton Scattering (TCS)
  - $\boldsymbol{\gamma}\, p \rightarrow l^{+}\, l^{-}\, p$
- Polarized electrons, polarized target nuclei

$\overrightarrow{NH_3}$DNP-CLAS12



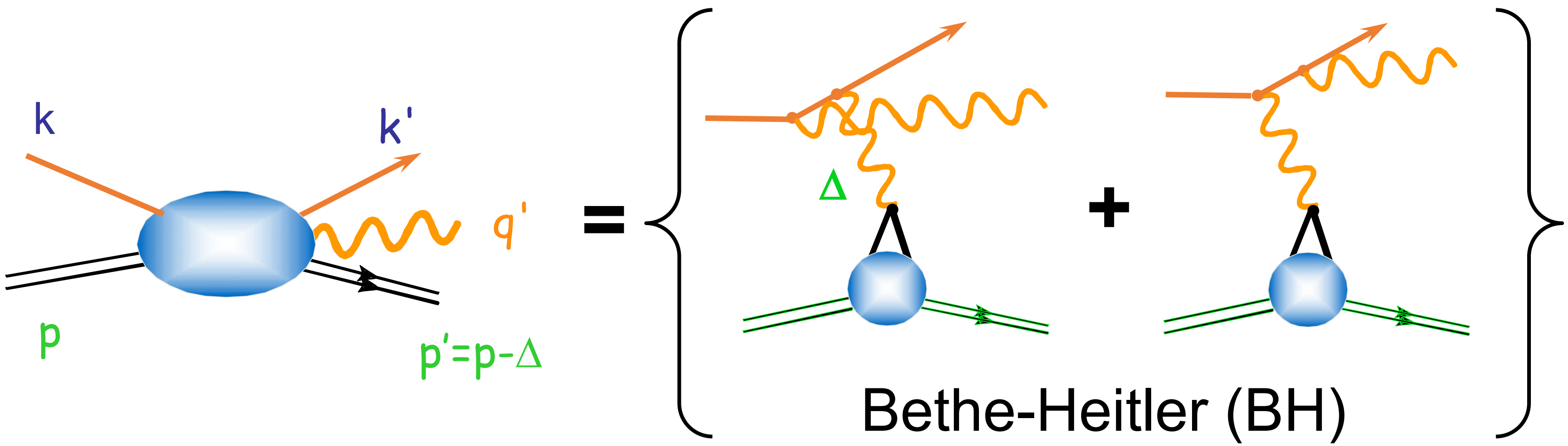
Polarized DVES (JLab 12 ➔ EIC)

- JLab at 12 GeV
  - Polarized electrons
  - Longitudinal polarized p, d
    - NH_3, ND_3, CLAS12
    - NH_3, Hall C: Wide Angle C.S.
  - Longitudinal & Transverse polarized ^{3}He (Hall A/C)
    - GPD program with SOLiD
  - Transverse polarized HD_{ice}
    - (test-beam studies in prep.)
  - Transverse polarized NH_3
    - Time-like CS in Hall C Proposal PAC 46

- Electron Ion Collider
  - Polarized electrons,
  - Polarized p, d, ^{3}He, Li
    - Transverse & Longitudinal
    - *Polarized deuterons now in eRHIC planning*
    - Zero target dilution
    - Spectators boosted by beam $\boldsymbol{\gamma}$-value
  - Precision ion polarimetry remains a challenging & critical R&D topic

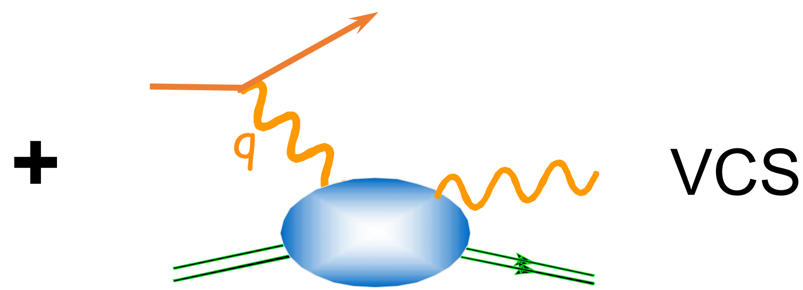
Bethe-Heitler (BH) and Virtual Compton Scattering (VCS)

$\boxed{e\,p \rightarrow e\,p\,\gamma}$



$\Delta^{\mu} = (p'-p)^{\mu}$

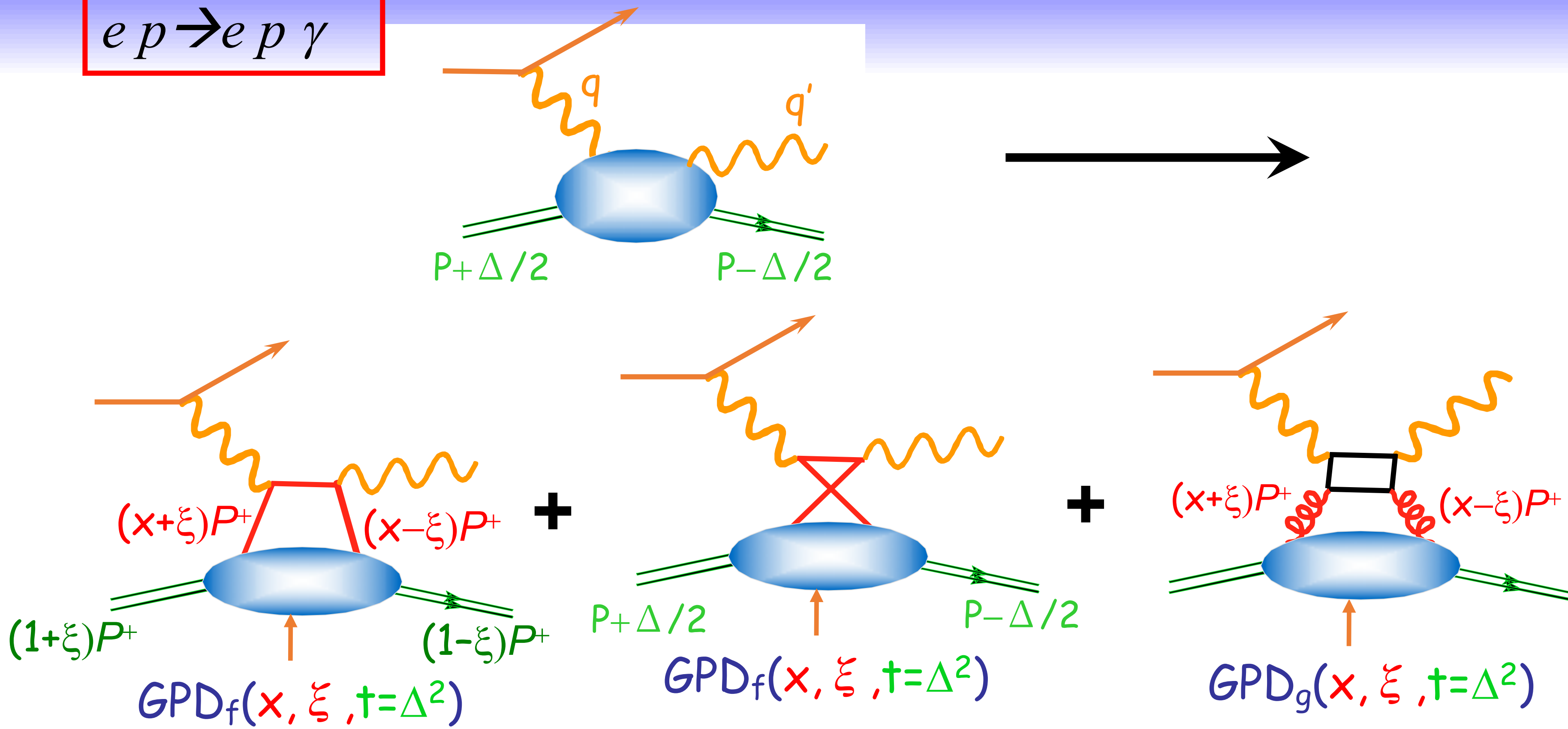
$t = (p'-p)^2 = \Delta^2$



- BH-VCS interference
  - Access to VCS amplitude, linear in GPDs

QCD Factorization of DVCS (Co-Linear)

$e\,p \rightarrow e\,p\,\gamma$



- Symmetrized Bjorken variable: $\xi = \frac{-(q+q')^2}{2(q+q')\cdot P} \xrightarrow[\Delta^2 << Q^2]{} \frac{x_B}{2-x_B}$

- SCHC: Transversely polarized virtual photons dominate to $O(1/Q)$

Poincaré Invariance & Spatial Imaging

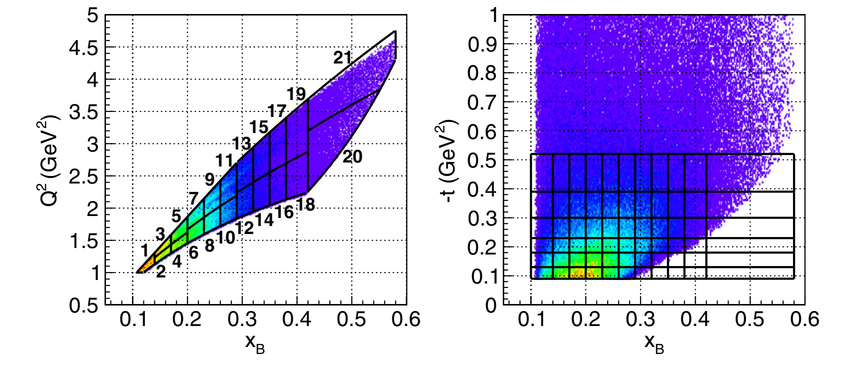
- Physics is fully Poincaré invariant
- High energy reactions (and target-polarization states) select preferred frames:
  - DIS: **q, P** anti-collinear ("DIS" frame, P = initial proton)
  - DVCS, DVMP:
    - DIS frame
    - **q+q', P** anti-collinear
    - **q+q', P+P'** anti-collinear ("Symmetrized frame")
    - …
    - All equivalent as $\Delta^2/Q^2 \to 0$
    - Magnitude and form of "higher-twist" = *qqg*… correlations depend upon frame at finite Q^2, Δ^2/Q^2

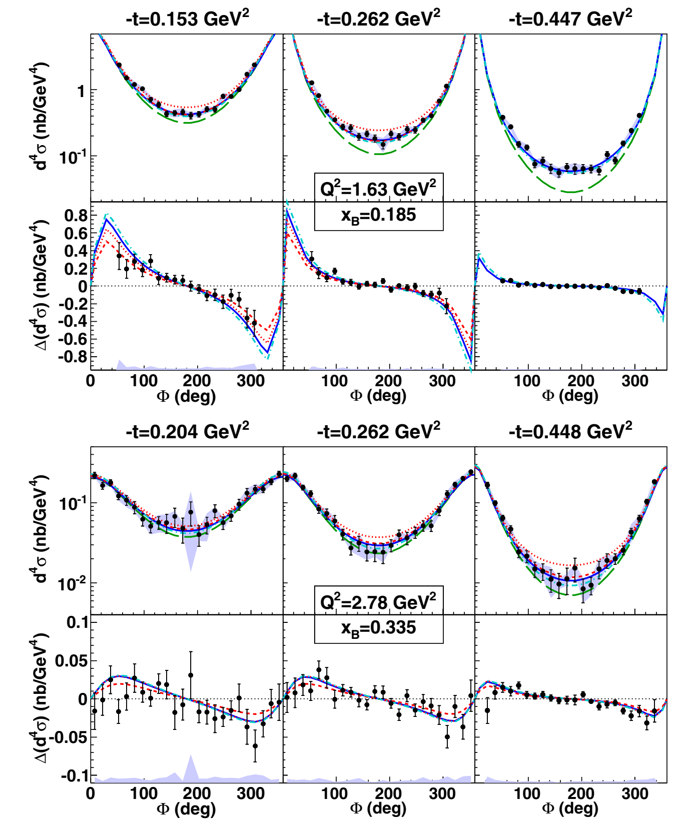
Spatial Imaging at finite skewness (ξ)

- DVES reference frame defines light-like vectors $n^\mu, \tilde{n}^\mu$:
  - $n^2 = \tilde{n}^2 = 0$, • $n \cdot \tilde{n} = 1$
  - Lorentz invariant definition of $\mathbf{\Delta}_\perp$:
    $\Delta_\perp^2 = 2(\Delta \cdot n)(\Delta \cdot \tilde{n}) - \Delta^2$
    $\Delta_\perp^2 \to -\Delta^2$ as $\xi \longrightarrow 0$
- $\xi = 0$: GPD($x,0,\Delta^2;Q^2$) = parton density at resolution scale Q^2
  - $\mathbf{\Delta}_\perp$ Fourier conjugate to **b** = trans. distance from target CoM
- $x = \xi$: Measured by Im part of DVES amplitudes
  - GPD($\xi,\xi,\Delta^2;Q^2$) = parton transition amplitude ($0 \to 2\xi$)
  - $\mathbf{\Delta}_\perp$ Fourier conjugate to $\mathbf{r}_\perp$ = trans. distance from CoM of target *spectators.*

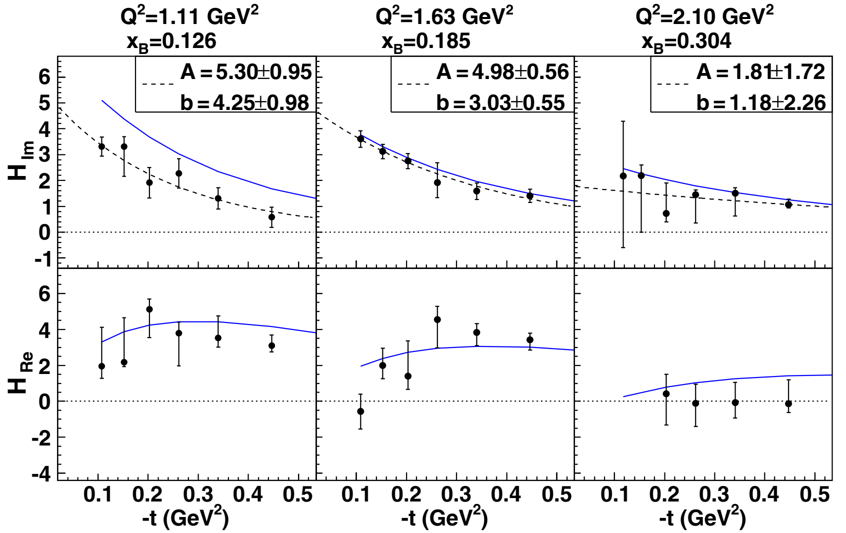
CLAS: H($\vec{e}$,e’p$\boldsymbol{\gamma}$)

- H.Jo, *et al.* [CLAS], PRL **115** (2015)





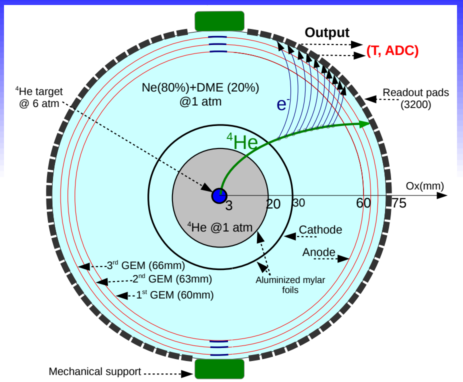
- Constrained Fits to Re, Im [H(x,t)]

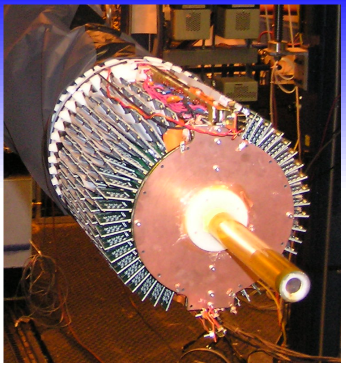


- Im[H(x,t)] ~ $e^{b(x)t}$
  - ➜ *b* decreases as x_B increases
  - ➜ Proton is shrinking! (model dependent)

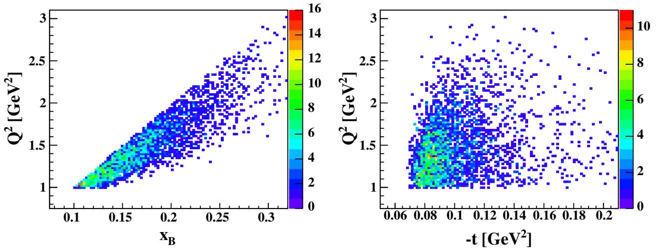
CLAS: $^4He(\vec{e},e'\gamma\alpha)$

M.Hattawy *et al.*, PRL **119 (2017)**

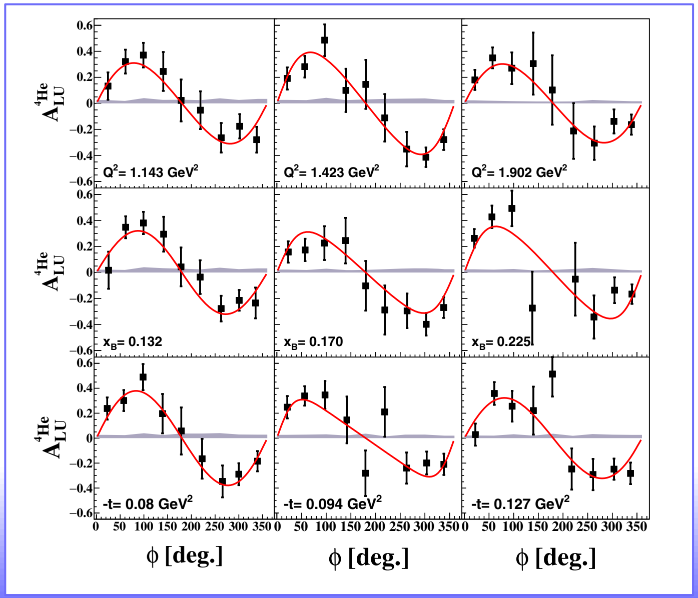


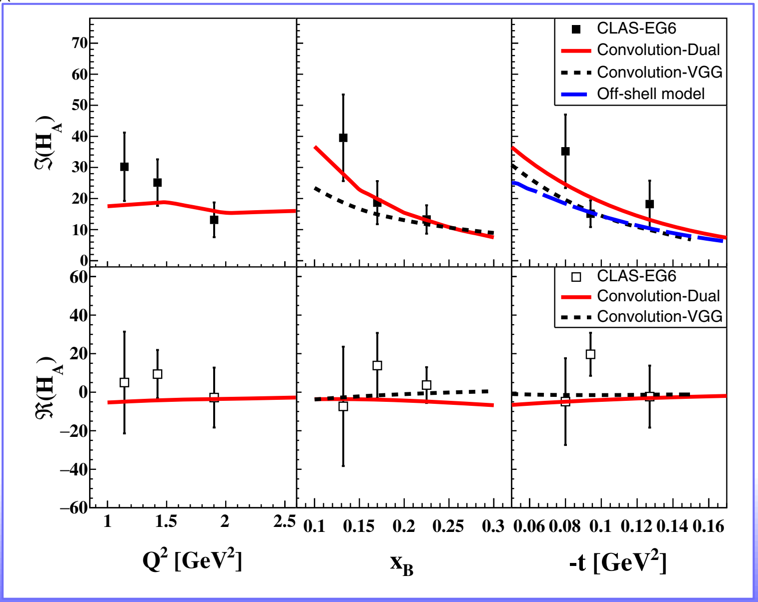


- Radial TPC for recoil α
  - 250mm z ⊗ 160 mm ⌀
- Only one GPD: *H(x,ξ,t)*
  - Compton Form Factor $\mathcal{H}(\xi,t)$



$$A_{LU}(\phi) = \frac{\alpha_0(\phi)\Im(\mathcal{H}_A)}{\alpha_1(\phi)+\alpha_2(\phi)\Re(\mathcal{H}_A)+\alpha_3(\phi)[\Re(\mathcal{H}_A)^2+\Im(\mathcal{H}_A)^2]}.$$



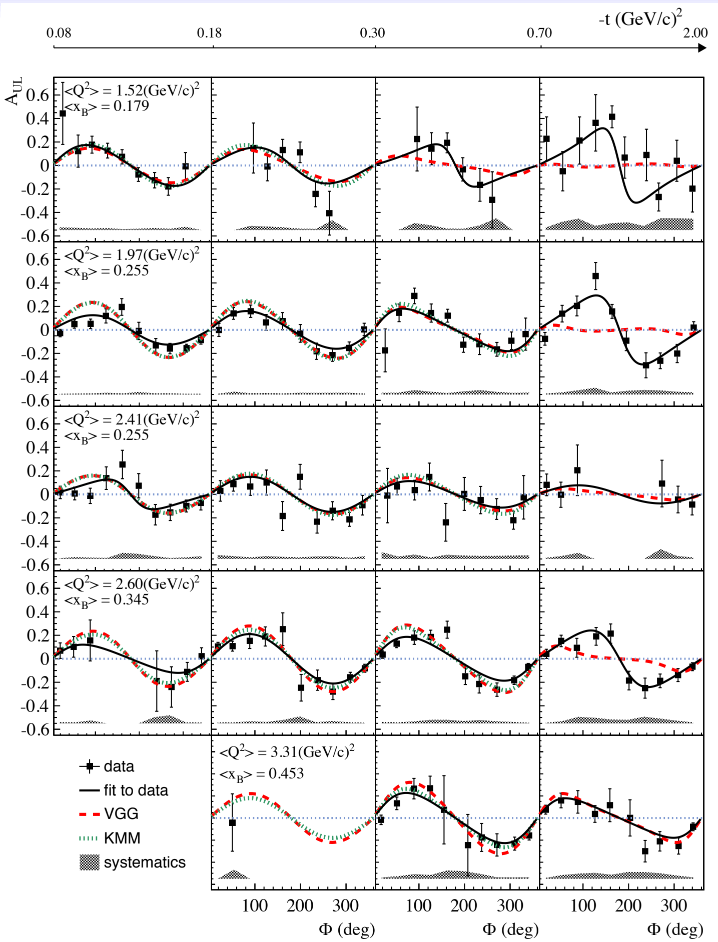


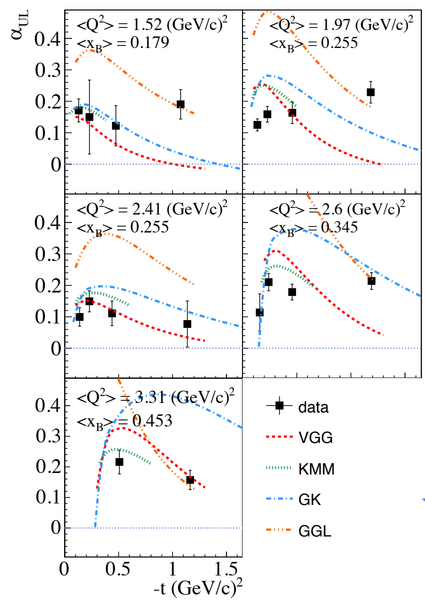
CLAS: Longitudinally Polarized Protons Target-Spin Asymmetries

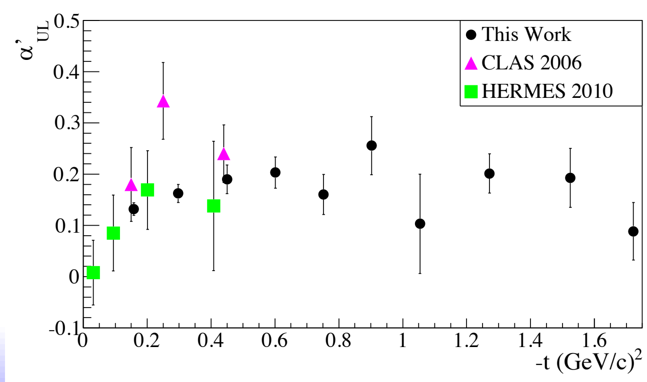
A_{UL}

S. Pisano, *et al.*, Phys.Rev. **D91** (2015) 5, 052014

Q^2, x_B







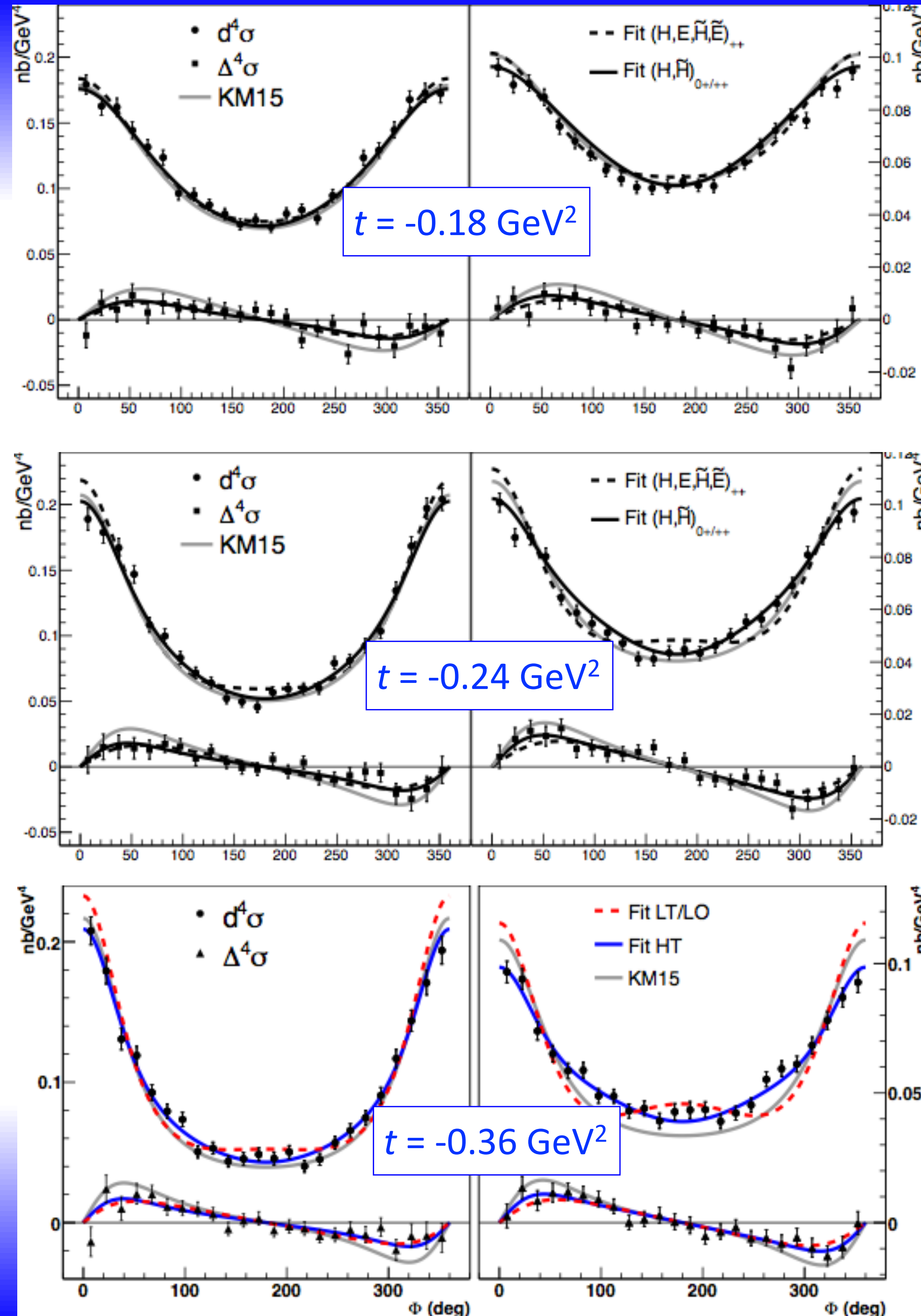
- Spatial distribution of quark helicity

Hall A: H(e,e'$\boldsymbol{\gamma}$)

x_B = 0.36, Q^2=1.5, 1.75, 2.0 GeV^2

M.Defurne *et al., "A Glimpse of Gluons"*, Nat. Comm.**8** (2017)

- Q^2 = 1.75
  - E_e = 4.455 (left), 5.55 (right) GeV
- $d^4\sigma/[dQ^2 dx_B dt d\phi_{\gamma\gamma}]$
  $\Delta^4\sigma = d^4\sigma(h=+) - d^4\sigma(-)$
- Solid Grey Line = KM2015
- Dashed: Leading Twist / Leading Order (LT/LO) fit with V. Braun Kinematic Twist-4 constrained by LO/LT:
  - Global fit at each *–t :* *3⊗Q^2 & 2⊗E_e*
  - Poor χ^2

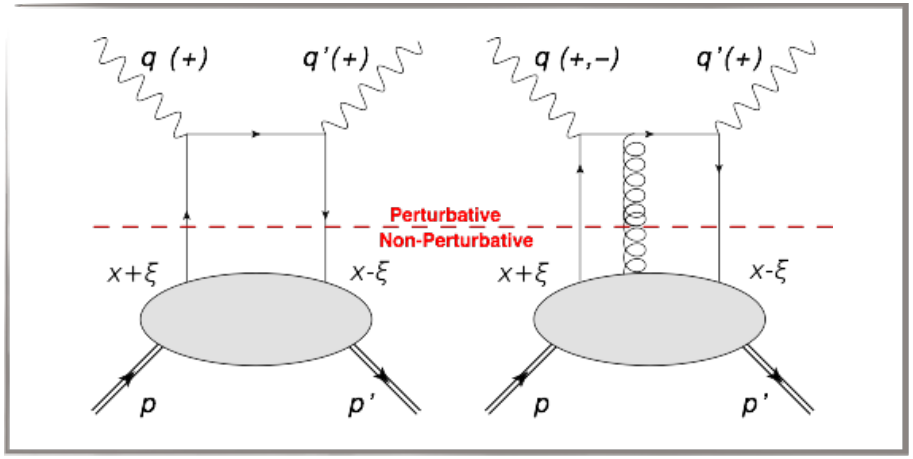


Two Fit-Scenarios

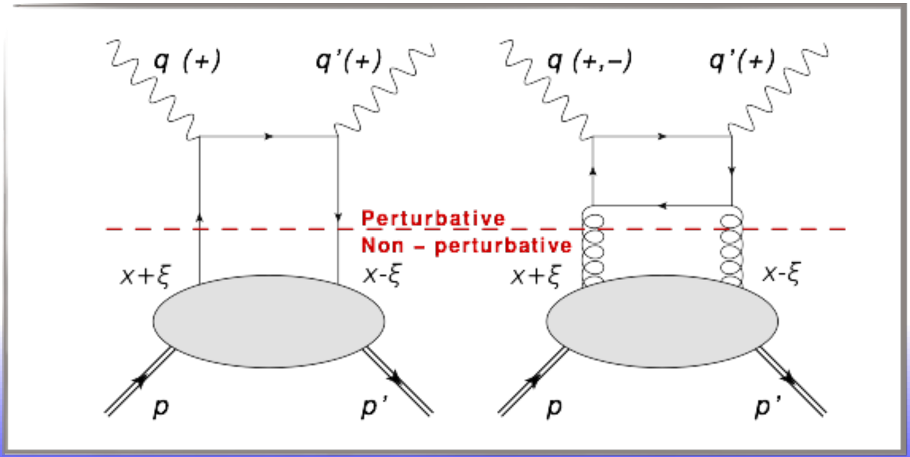
[Using V. Braun et al, PRD **89**, 074022 (2014)]

$$\mathbb{H}(x,\xi,t), \quad \widetilde{\mathbb{H}}(x,\xi,t)$$

- LO/LT + Twist-3 + Kinematic Twist-4

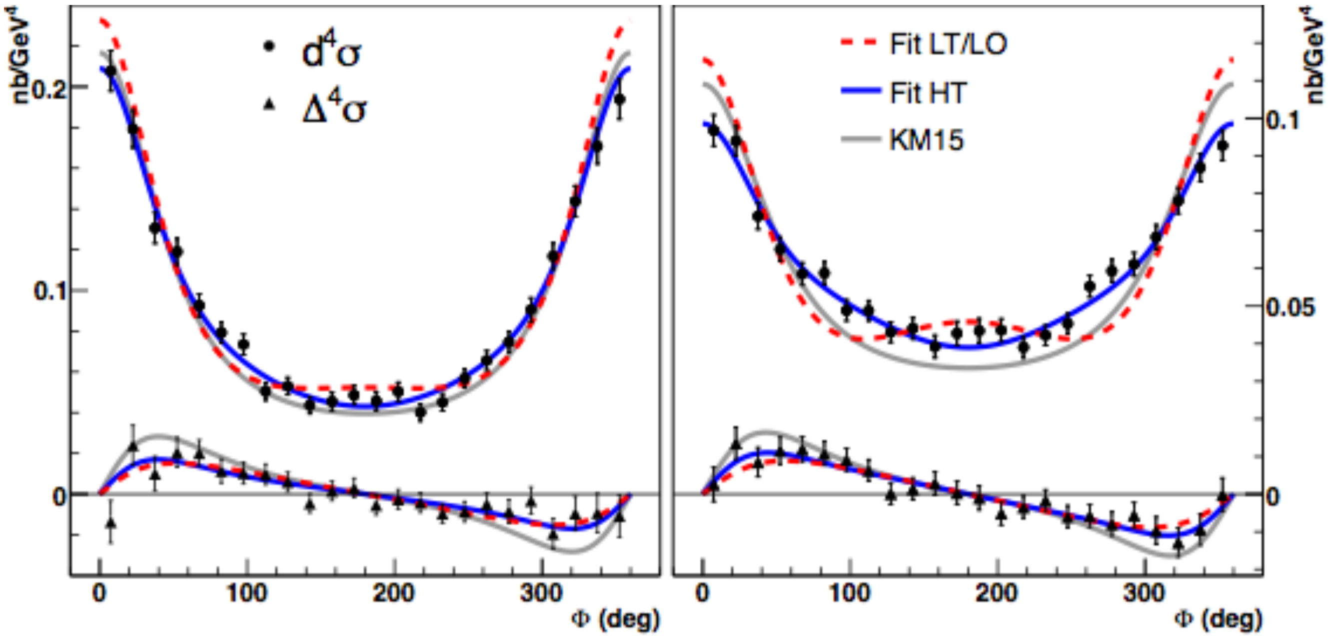


- LO+ NLO (gluon transversity) + Kinematic Twist-4



`Global' Fit:
Q^2=1.5, 1.75, 2.0 GeV^2 & E_e = 4.45, 5.55 GeV

Displayed at Q^2 = 1.75 for $-t$ = 0.030 GeV^2

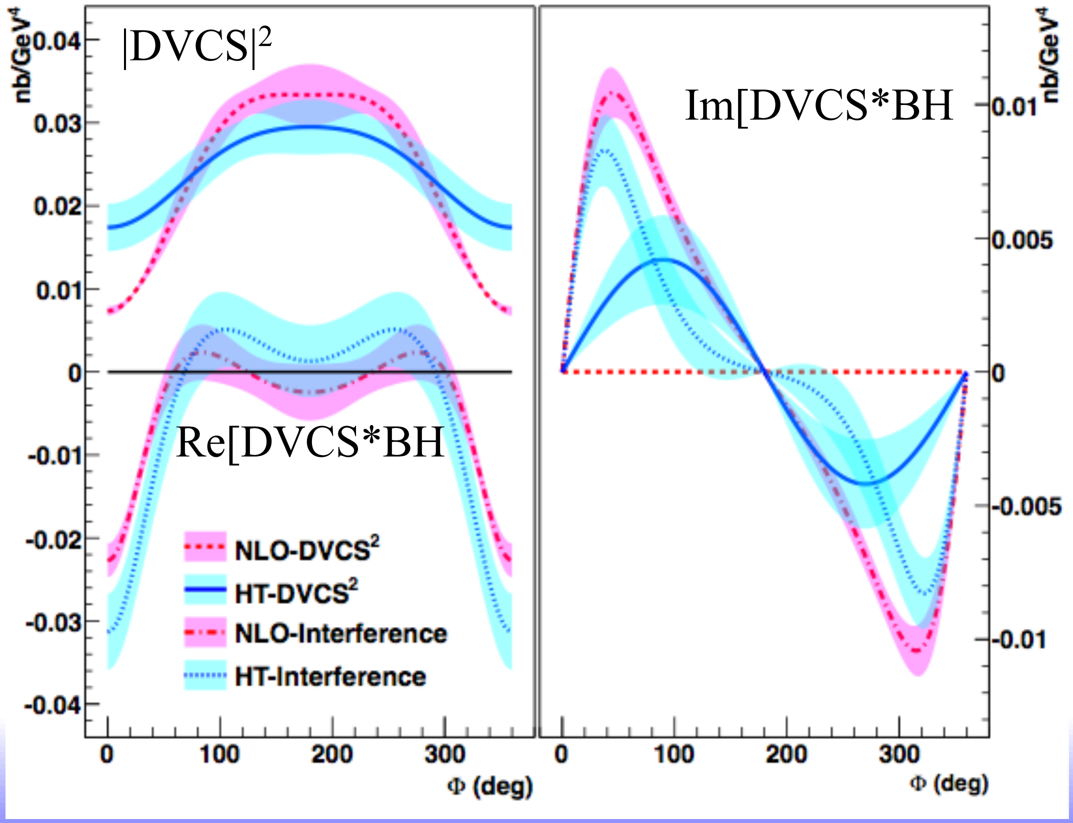


Identical fit (blue⬆) for either: Twist-3 or NLO (gluon) scenarios.
Both fits have Kinematic Twist-4 contribution constrained from Twist-2 component of fit

E07-007 `Global' Fit

Separations of Re,Im[DVCS†BH], |DVCS|^2

-t = 0.030 GeV^2 (of three t-bins): Displayed at Q^2 = 1.75



Total Fit (previous slide blue)
⇐Sum of Pink (LO+NLO)
OR
⇐Sum of Cyan (LO+HT)

Model dependence, but full measurement of interference: amplitude & phase

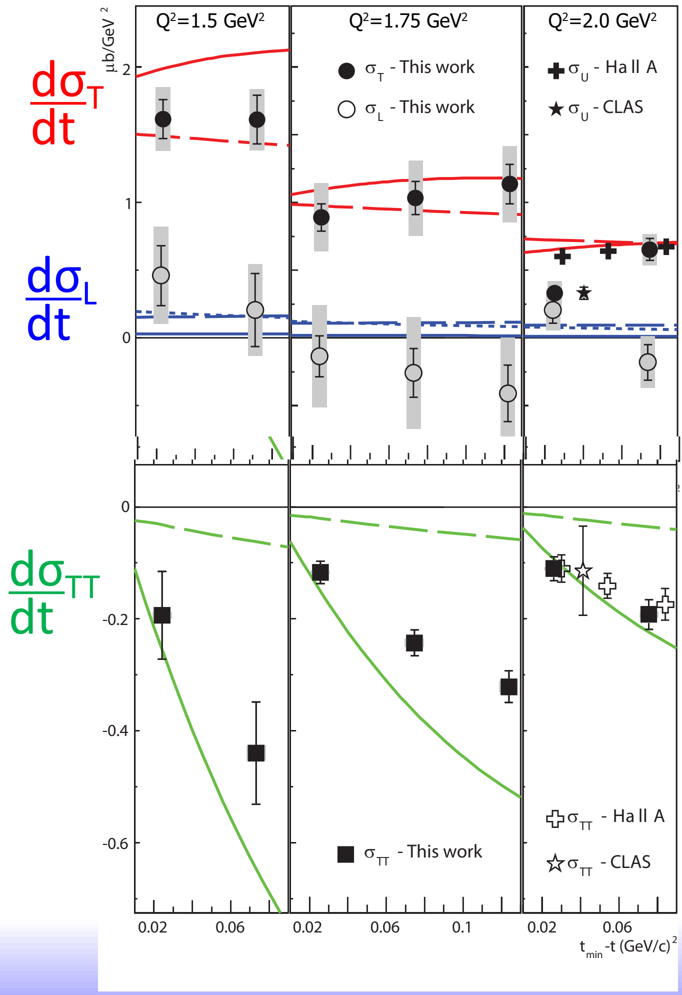
14

Pseudo-Scalars

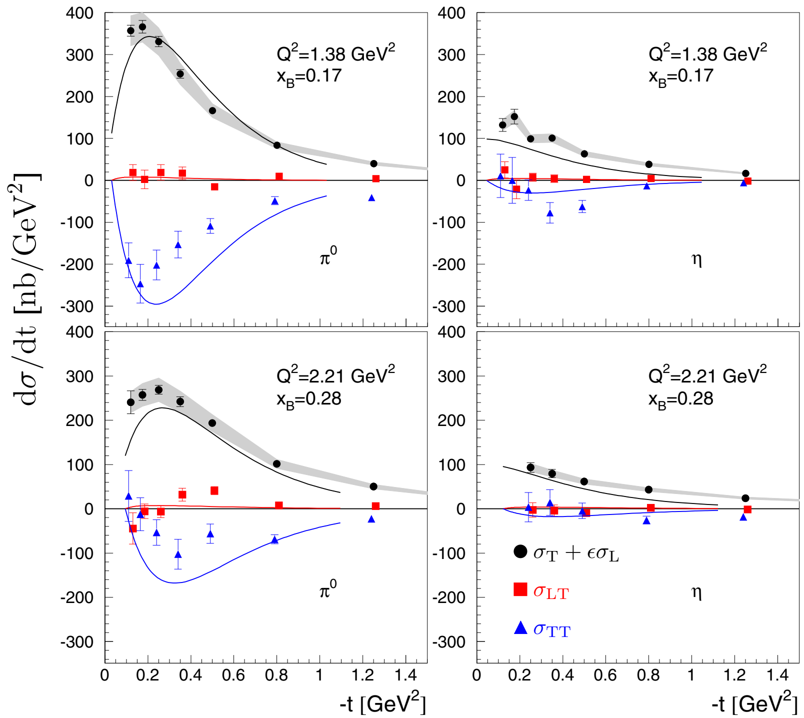
- JLab Hall A
  - L/T separation for H(e,e' π^0)p and D(e,e' π^0)pn
  - $\sigma_T >> \sigma_L$
- JLab CLAS
  - $\sigma_T + \epsilon\, \sigma_L$ for H*(e,e' p* π^0*)*, H*(e,e' p η)*
    - $\sigma_T + \epsilon\, \sigma_L >> \sigma_L$ [naïve collinear factorization].
- Twist-3 helicity flip meson Distribution Amplitude enhanced by χSB ➔ coupling to nucleon transversity GPD: $\langle \pi(q') \left| \overline{\psi} \sigma^{+-} \psi \right| 0 \rangle \otimes \mathcal{H}_T$
  - S. Goloskokov, P. Kroll, Eur. Phys. J. A 47, 112 (2011).
  - S. Ahmad, G. R. Goldstein, and S. Liuti, Phys. Rev. D 79, 054014 (2009).

DVMP: π^0, η @ 6 GeV

M.Defurne *et al* [Hall A] PRL **117** (2016)



I.Bedlinskiy *et al* [CLAS] PRC **95** (2017)



Solid Curves: S. Goloskokov and P. Kroll, Eur. Phys. J. A **47**, 112 (2011).

Dashed: G. R. Goldstein, J. O. Hernandez, and S. Liuti, Phys. Rev. D **84**, 034007 (2011).

[Flavor ⊗ Spin]-Structure Separation

- Hall A: D$(e,e'\pi^0)pn$–H$(e,e'\pi^0)p$,
  - M.Mazouz *et al* PRL **118** (2017)
- CLAS: H$(e,e'\pi^0)p$ ± H$(e,e'\eta)p$
  - I. Bedlinskiy PRC **95** (2017)
  - V. Kubarovsky SPIN2014

$$\frac{d\sigma_T}{dt} = \Lambda\left[(1-\xi^2)|\langle H_T\rangle|^2 - \frac{t'}{8M^2}|\langle \bar{E}_T\rangle|^2\right],$$

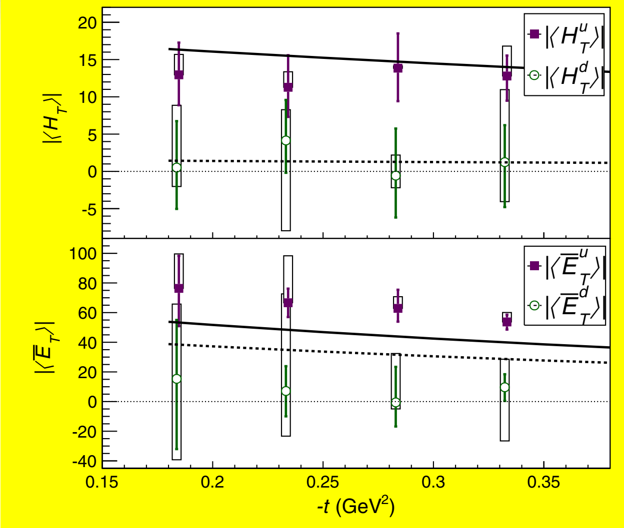
$$\frac{d\sigma_{TT}}{dt} = \Lambda\frac{t'}{8M^2}|\langle \bar{E}_T\rangle|^2.$$

$$\pi^0 \quad |\langle H_T^{p,n}\rangle|^2 = \frac{1}{2}\left|\frac{2}{3}\langle H_T^{u,d}\rangle + \frac{1}{3}\langle H_T^{d,u}\rangle\right|^2,$$

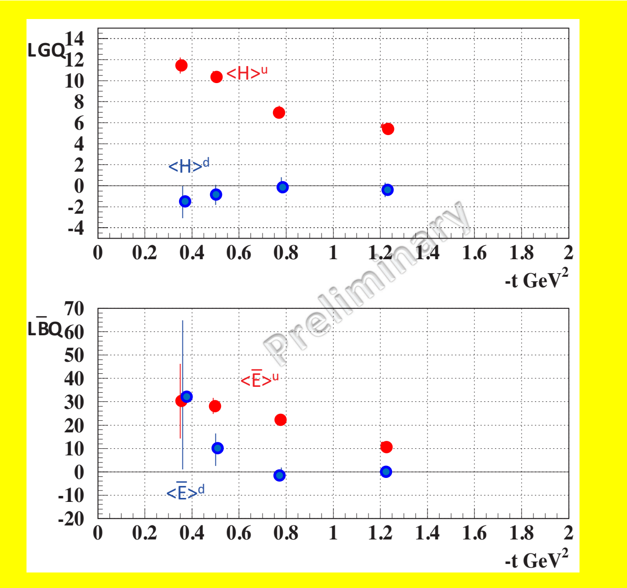
$$\eta \quad |\langle H_T^{p,n}\rangle|^2 = \frac{1}{2}\left|\frac{2}{3}\langle H_T^{u,d}\rangle - \frac{1}{3}\langle H_T^{d,u}\rangle\right|^2,$$

Hall A
Q^2=1.75 GeV^2
x_{Bj} = 0.36

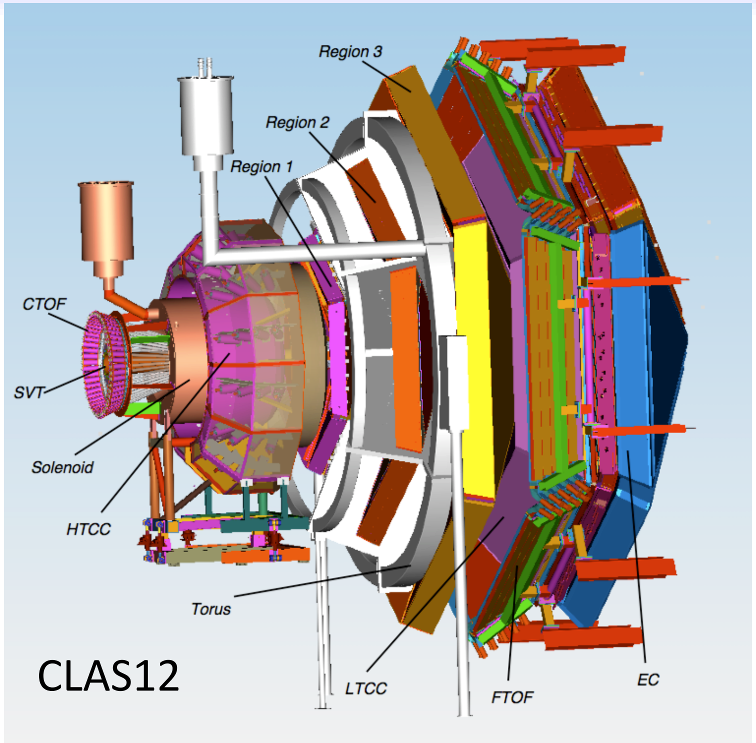
Error boxes are phase ambiguity, resolvable with η

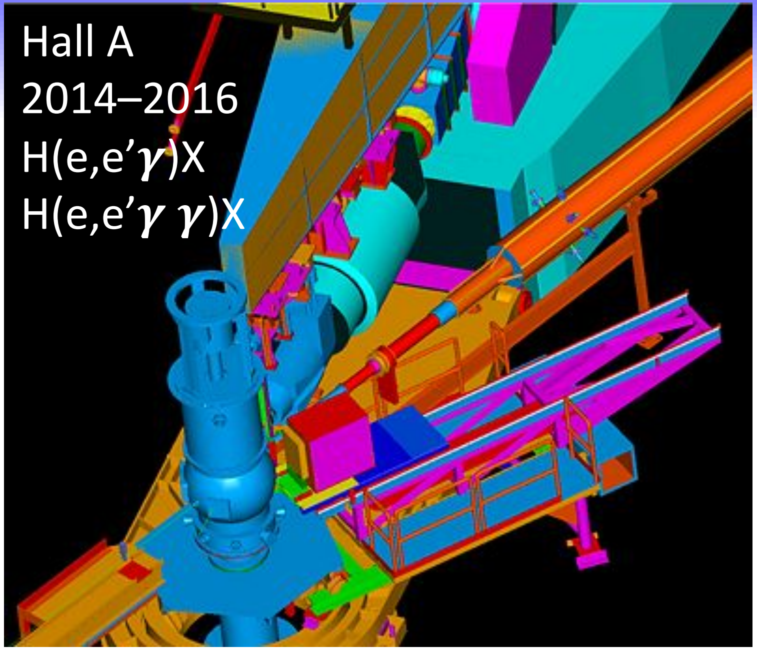


CLAS
Q^2=2.2GeV^2
x_{Bj} = 0.27
Assume $\sigma_T \gg \sigma_L$

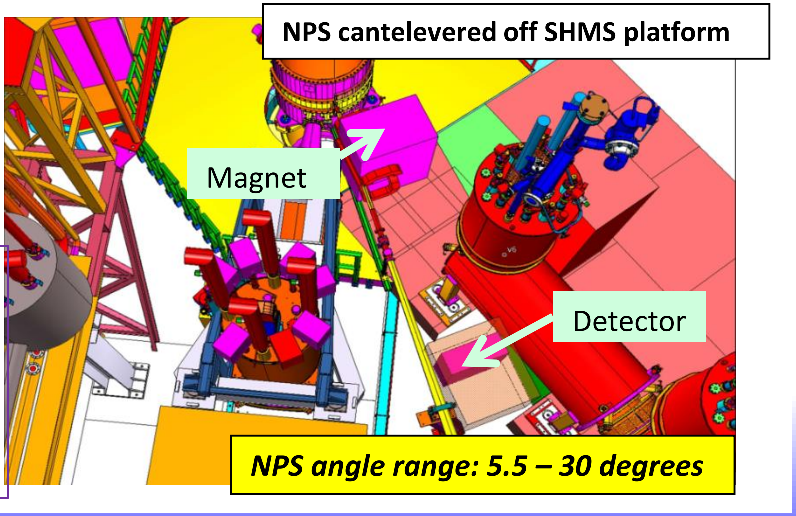


On to ~~12~~ ~~(11)~~ 10.6 GeV!

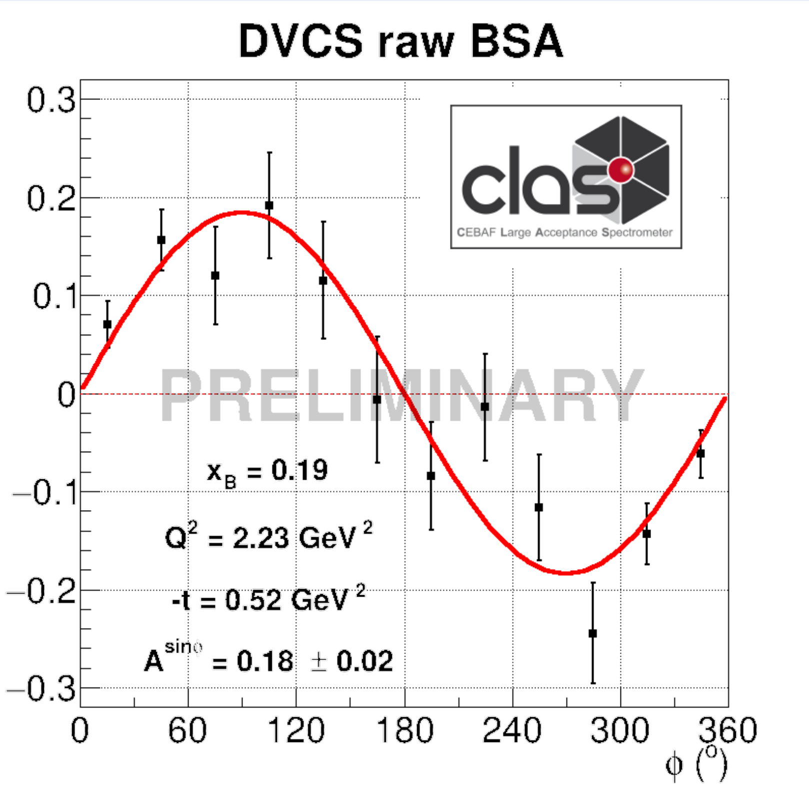


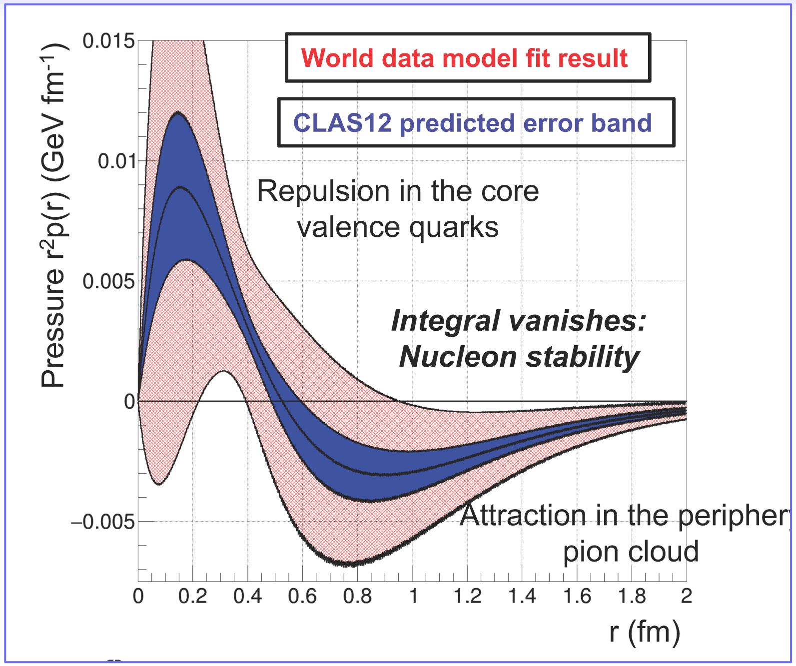


Hall C:NPS
NSF MRI + JLab
PbWO4 + Sweep
magnet



CLAS12 First Physics Run: Jan 11-May 7 2018



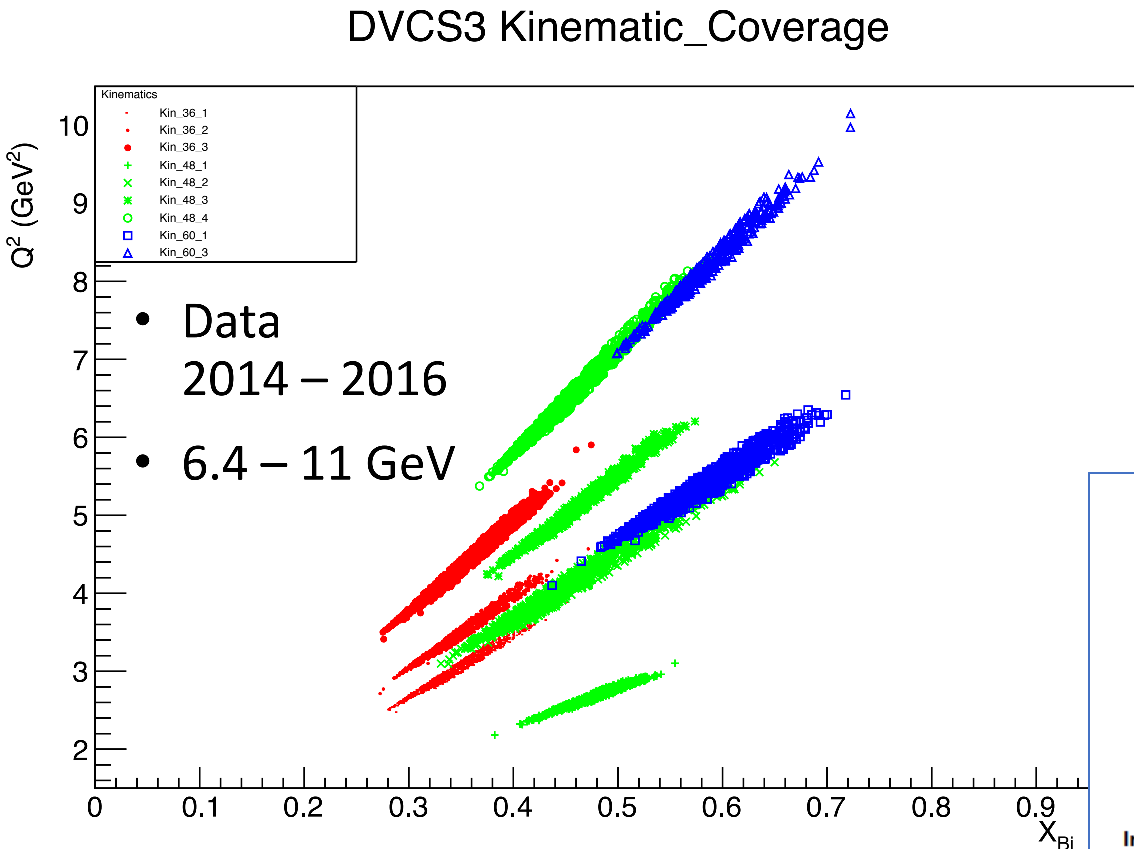


$$\int x\,[H(x,\xi,t) - H(x,0,t)]\,dx = \frac{4}{5}\xi^2 d_1(t)$$

- 0.3% of data analyzed.
- Calibrations in continuous progress
- More data in Fall 2018

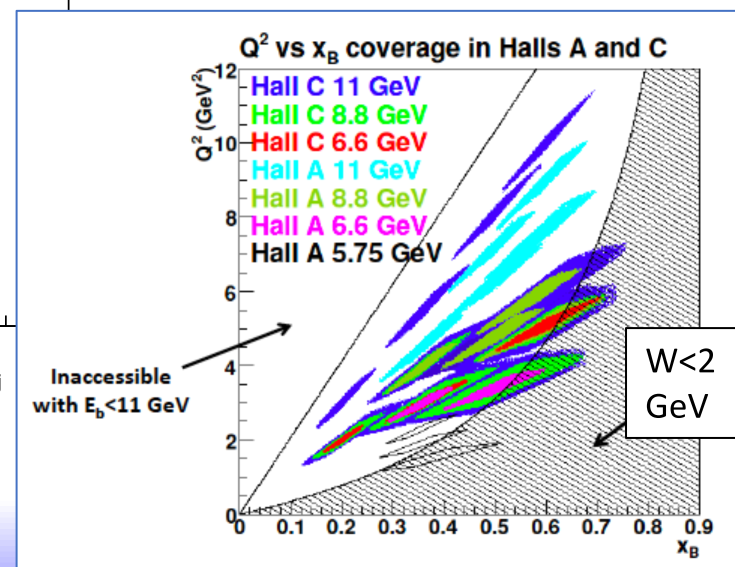
V.Burkert, L.Elourdrhiri, F.X.Girod,
Nature **557** (2018) 396

Hall A DVCS, Deep π^0

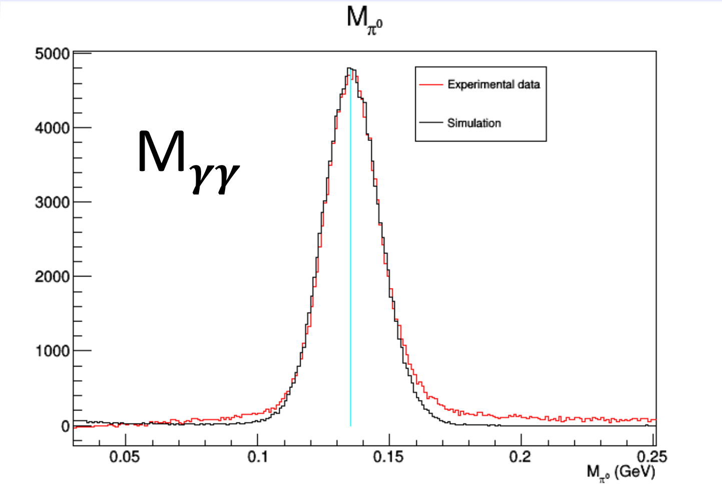


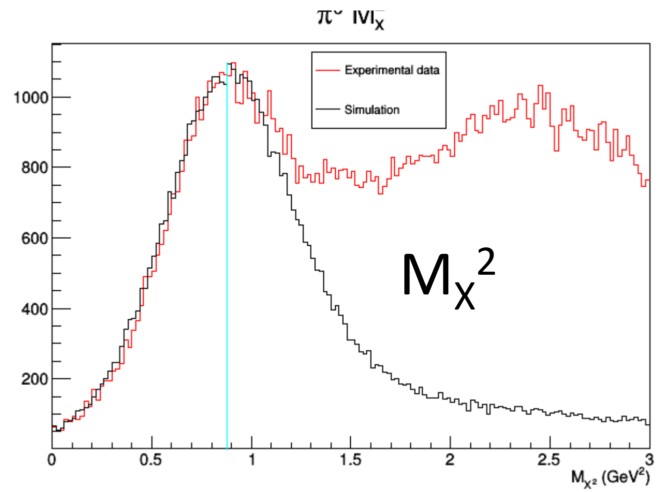
- Data 2014 – 2016
- 6.4 – 11 GeV

Previous, present, + approved

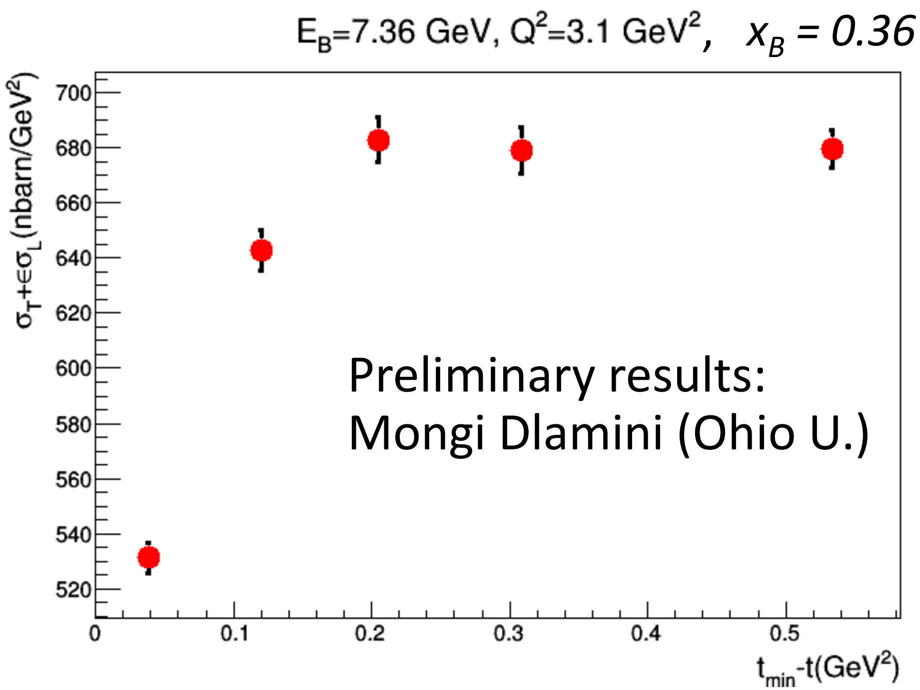


Hall A: Deep π^0, $E_e = 7.4$ GeV





- H(e,e'$\gamma\gamma$)X

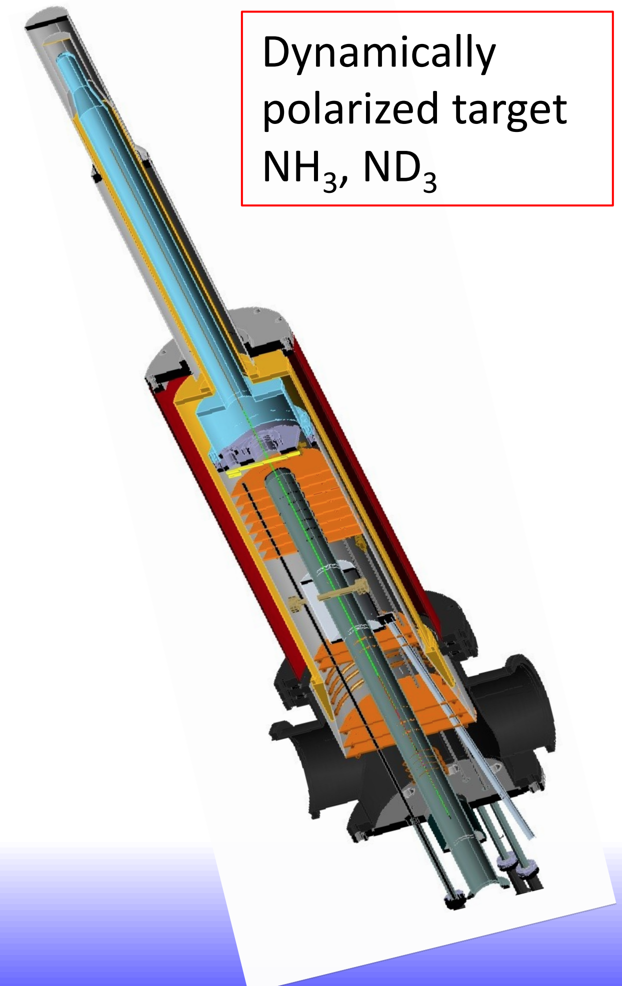


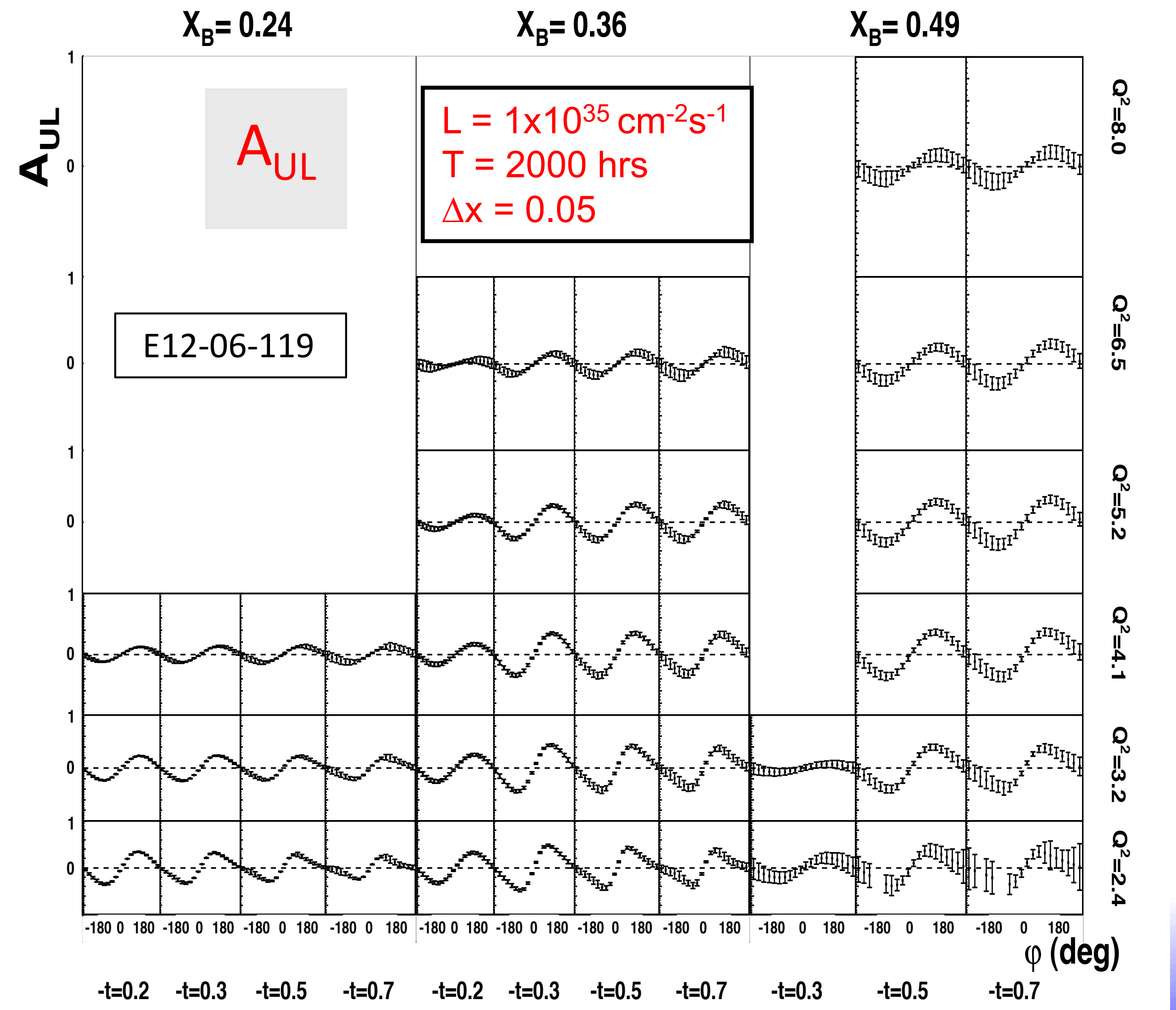
A_{UL} projections for protons

$e\,\vec{p} \longrightarrow e p \gamma$

$\Delta\sigma_{UL} \sim \sin\phi\,\{F_1\widetilde{H}+\xi(F_1+F_2)(H+\xi/(1+\xi)E)\}d\phi$

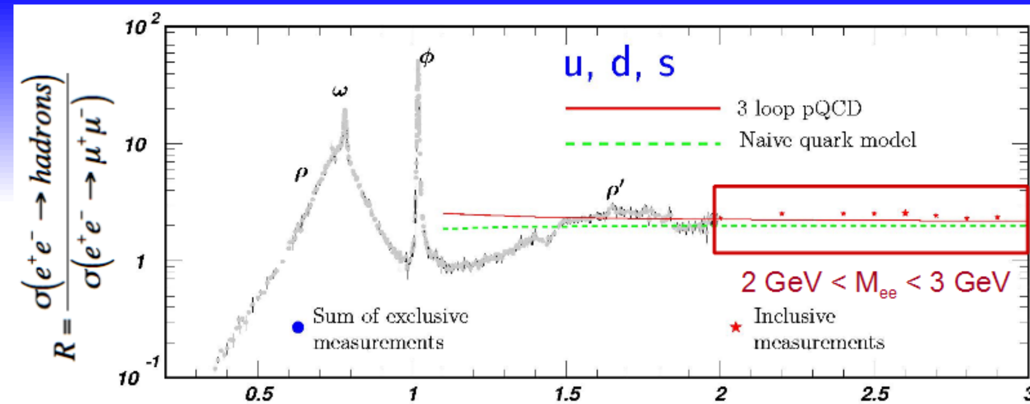
Dynamically polarized target
NH_3, ND_3





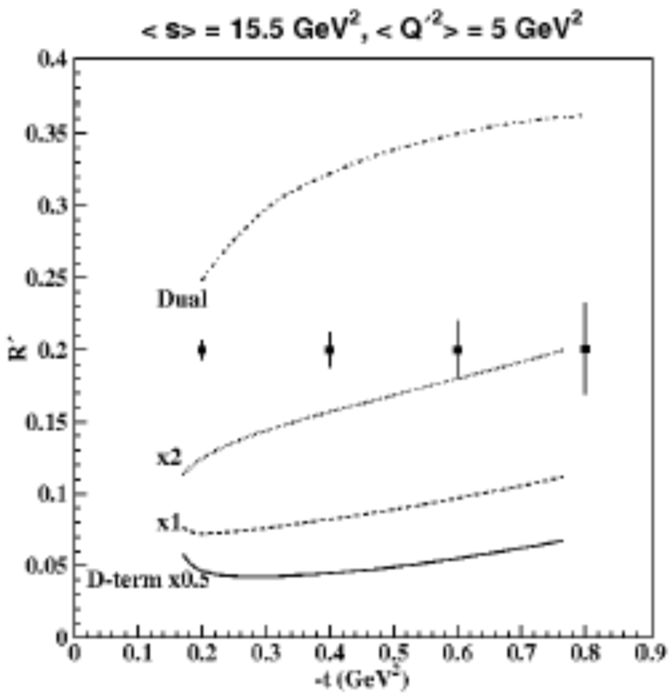
CLAS 12 TCS

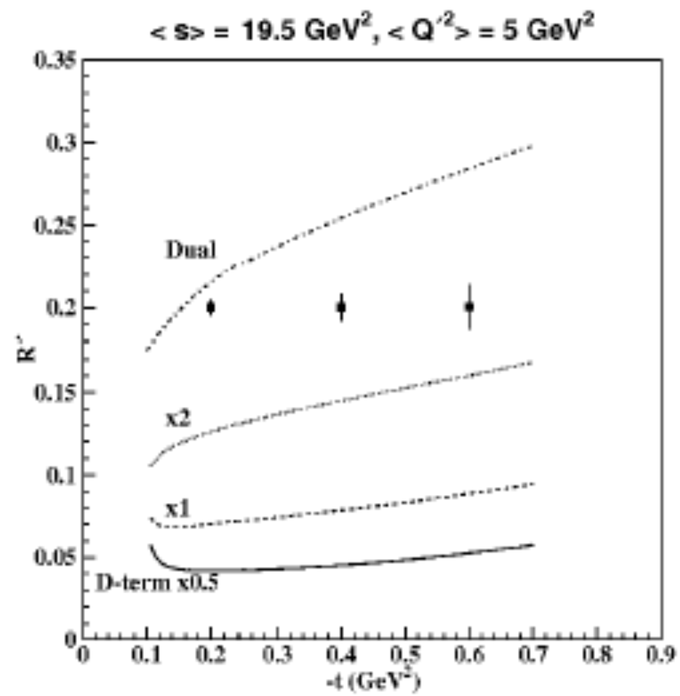
- Ratio of $e^+e^- \rightarrow$ *Hadrons / di-muons* versus e^+e^- mass



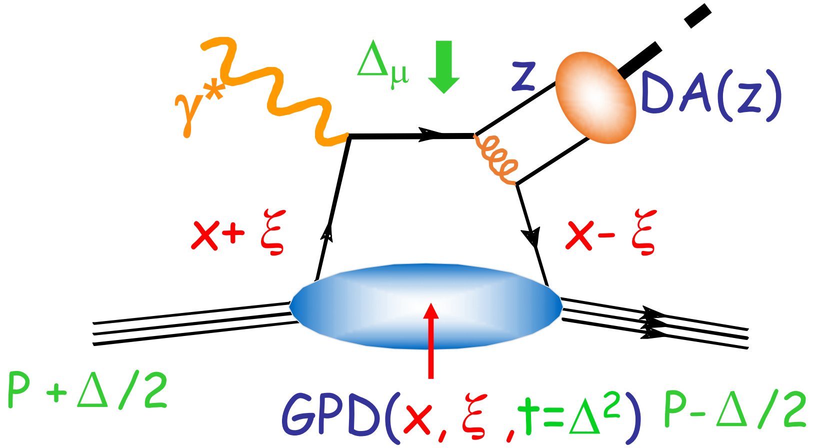
- Two bins in s
- Lowest bin in Q'^2
- *t*-dependence of Interference observable
- Illustrative GPD models

Statistical uncertainties for 100 days at a luminosity of 10^{35} cm^{-2}s^{-1}

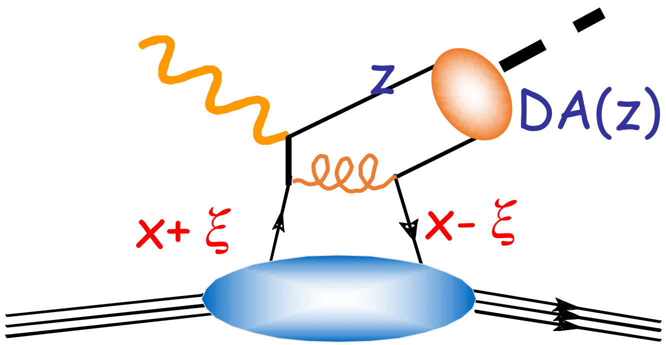




Leading Order (LO) QCD Factorization of DVES

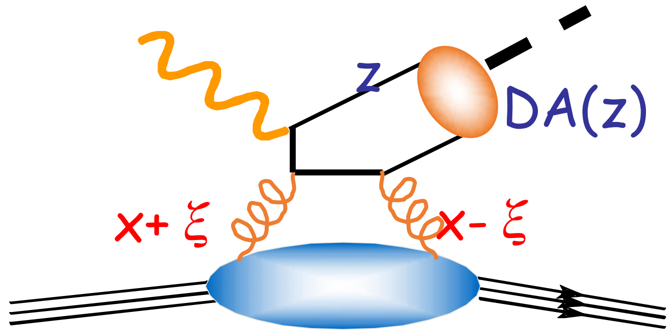


+



Gluon and quark GPDs enter to same order in α_S.
SCHC: σ_L~ $[Q^2]^{-3}$ σ_T~ $[Q^2]^{-4}$
Spin/Flavor selectivity

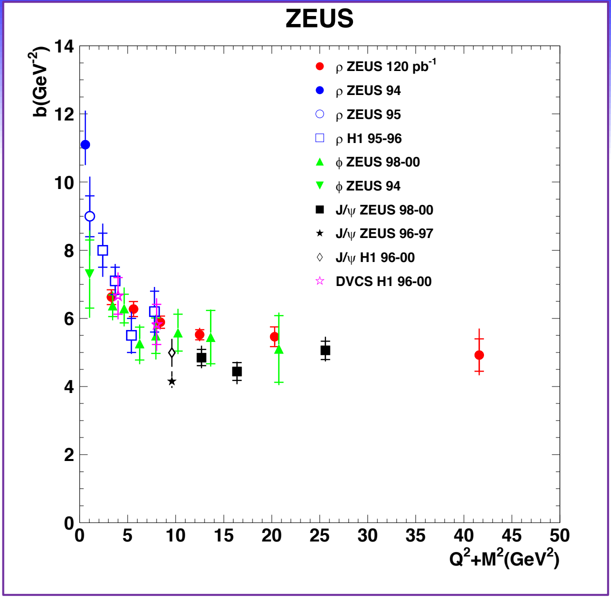
+



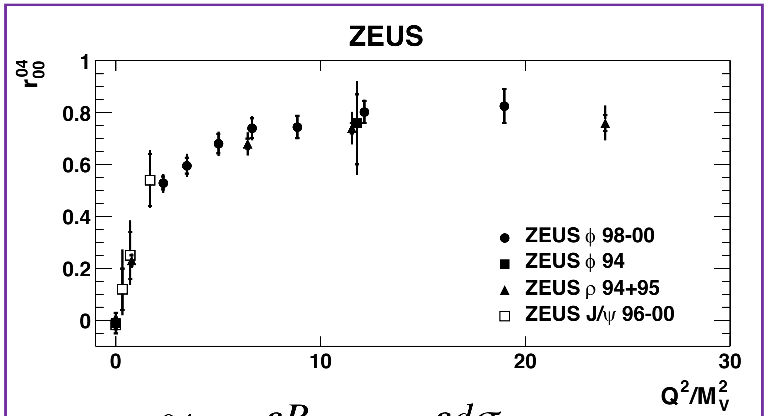
[Gluon GPDs in Diffractive channels only]

Vector mesons

- ϕ: JLab12 kinematics, predictions:
  - Gluon GPDs + ≤20% gluon⊗strange
- J/Psi: seen in Hall D.
  - Threshold production → large $-t_{min}$.
  - CLAS12 search for LHCb J/ψ⊗p states



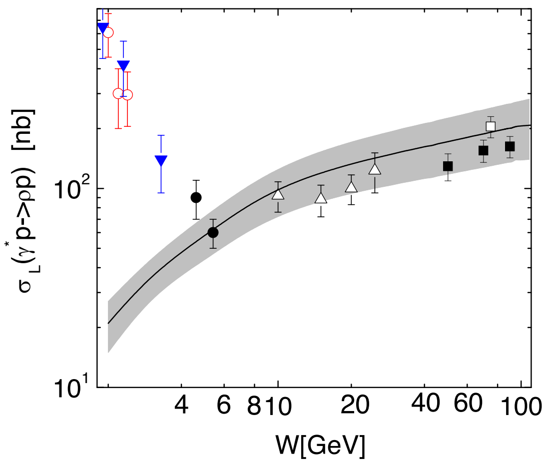
- ρ, ω
  - Slow approach to longitudinal dominance in HERA ρ data
  - Unexplained enhancement in ρ-production at low W^2 in CLAS data.
    - Helicity violating amplitudes ➔ Transversity GPDs *à la* pseudo-scalars?
  - ω: strong violation of SCHC @ CLAS

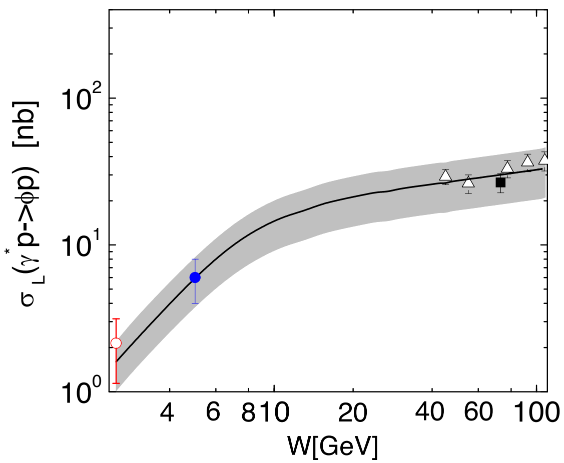


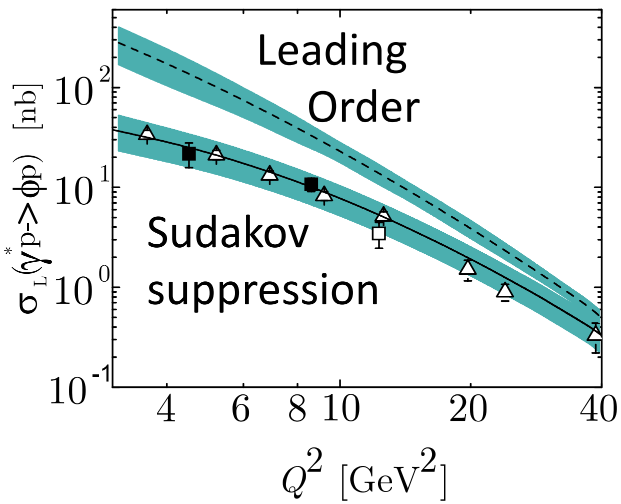
$$r_{00}^{04} = \frac{\varepsilon R}{1+\varepsilon R} = \frac{\varepsilon d\sigma_L}{d\sigma_T + \varepsilon d\sigma_L}$$

Deep rho, Deep phi

S. Goloskokov, P. Kroll EPJC **50** (2007) 829







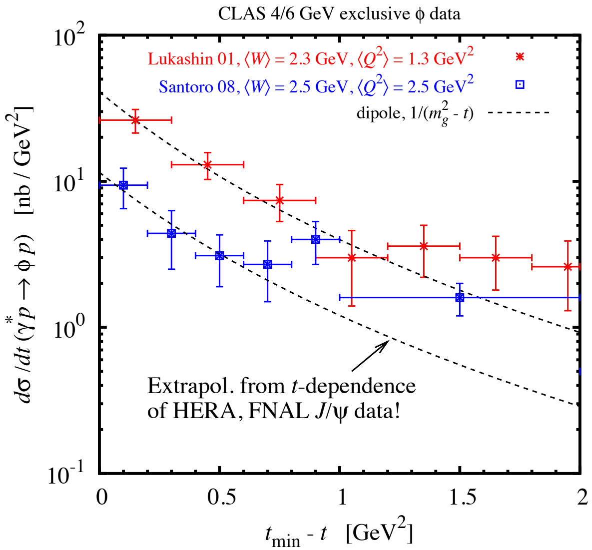
$Q^2 = 4\,\mathrm{GeV}^2$

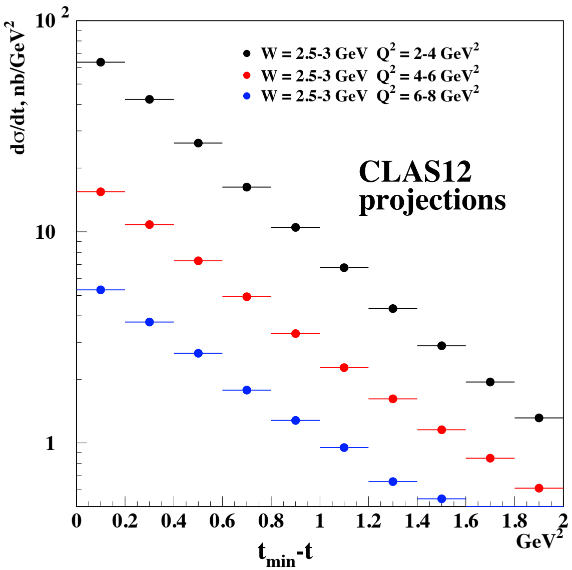
E665 (△), HERMES (●), CORNELL (▲)
ZEUS (□), H1 (■), CLAS (○)

- Calculations of S. Goloskokov, P. Kroll EPJC **50** (2007) 829

- Vector and pseudo-scalar mesons show evidence for Hard/Soft separation ➔ [nucleon structure] ⊗ [γ^*→meson amplitude].
- Strong corrections, new amplitudes for $Q^2 \leq 10$ GeV^2.

Exclusive ϕ: CLAS12 experiment





- t–dependence of 6 GeV ϕ data consistent with gluonic radius measured at high energies
  Extrapolation of HERA, FNAL J/ψ results

- CLAS12: Test reaction mechanism and harden GPD–based description

  When does t–slope become independent of Q^2?

  How does W–dependence change with Q^2?

  L/T ratio from vector meson decay and s–channel helicity conservation

- CLAS12: Extract t–dependence of gluon GPD at $x = 0.2 - 0.5$

  Obtained from relative t–dependence of $d\sigma_L/dt$

First accurate gluonic image of nucleon at large x!

What about the Ji Sum-Rule?

- $lim_{t\rightarrow 0} \int x dx [H_f(x,\xi,t)+E_f(x,\xi,t)] = 2\ J_f$
  - Skewing effects, Extracting *E* ?
  - *u,d* flavor separations from proton, neutron
  - $E^{(n)}$ dominates unpolarized $n(e,e'\gamma)n$ ➔ CLAS12 RG-B
  - $E^{(p)}$ requires transversely polarized targets
    - HD_{ice} for CLAS12
    - NH_3, ^3He with SOLiD or TCS?
  - Glue from Deep ϕ at JLab12 and Deep ϕ & J/ψ at EIC
    - ~50% of momentum sum rule comes from gluons
    - ~50% of gluon momentum is at $x_g > 0.1$
    - Important role for JLab12!

Constraints on Ji Sum Rule

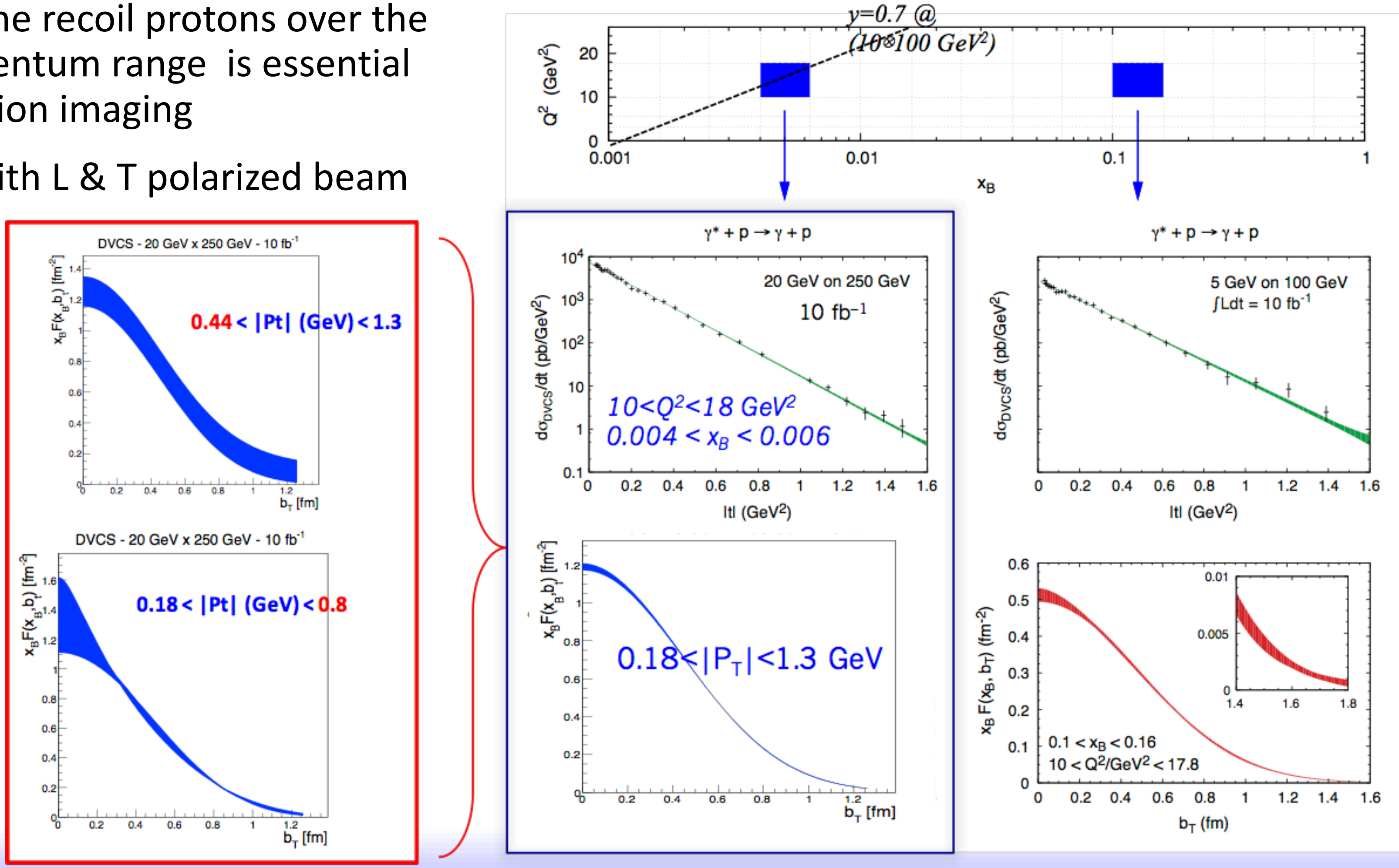
- $H_f(x,0,t)$ **valence** essentially known from fits to $F_{1f}(-t) \otimes q_f(x)$ .... *Diehl (2013), Ahmad (2007)*
  - Measure $H_f(x,x,t)$ → Determines DD Profile function
    - *Calibrate "skewing effect"*
- $E_f(x,0,t)$ constrained from $F_{2f}(-t)$ and *assumption* $e_f(x)$ does not change sign.
  - Test this assumption
    - x≈0.1 COMPASS ⊕ x≈0.4 JLab12 ⊕ Lattice QCD ⊕ …
- Transverse polarization data + Theory + Models → Tight constraint on $q - \bar{q}$ contribution to Ji Sum Rule from JLab 12 GeV era.
- Need the EIC to constrain the sea & gluons

Spatial Imaging with the EIC

- Improved neutron DVES via tagging of spectator proton over full range of Deuteron wave-function
- Precision DVES measurements with transverse polarized targets
- Exclusive DVES on nuclei
- Low-x_B, high Q^2: Imaging gluons and the quark-sea in the nucleon and in nuclei
  - n-p density differences in N>Z nuclei ≙ u-d differences in GPDs of N>Z nuclei

DVCS on the Proton at the EIC:
Transverse Imaging vs x_B

- Tagging the recoil protons over the full momentum range is essential for precision imaging
- Repeat with L & T polarized beam

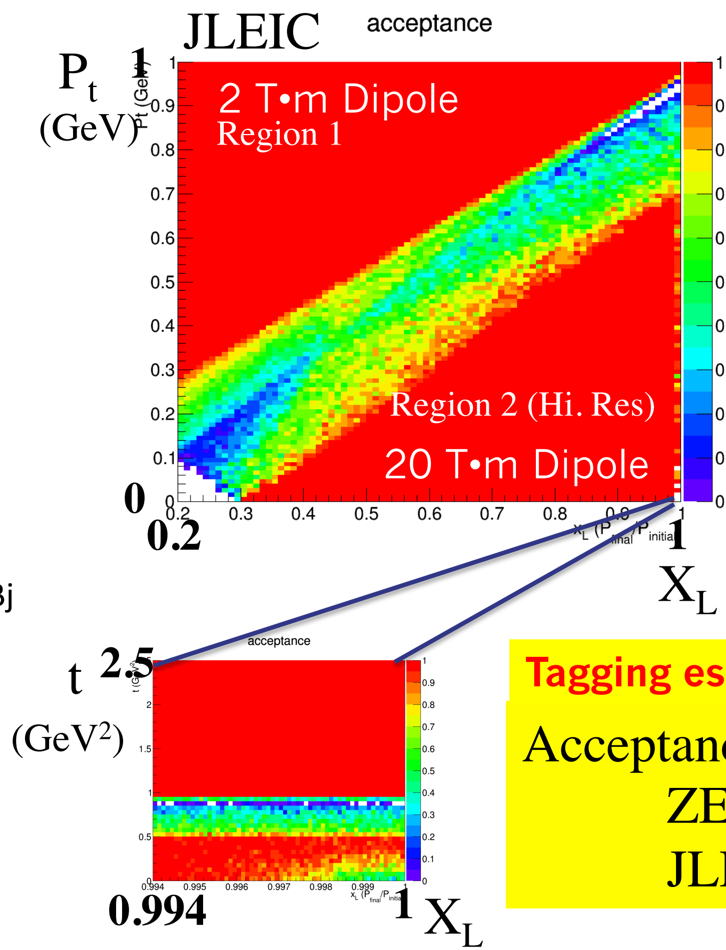


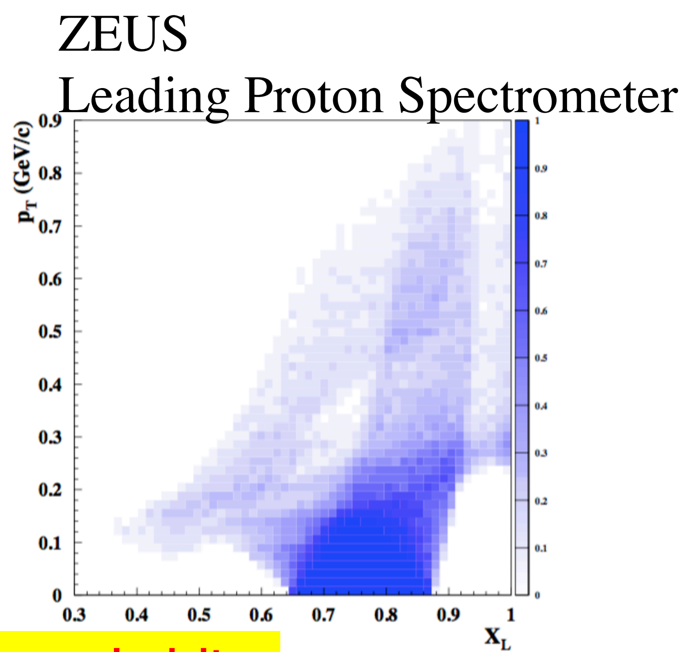
Diffractive DIS and DVES: gaining a factor 5000.

- EIC Luminosity⊗Acceptance = HERA × (100x50)

- Full proton detection acceptance to “Beam-Stay-Clear (BSC)” limit of ~10×rms emittance:
- JLEIC: $\theta_p > 3$ mrad OR $|\Delta p_L/p_0| \approx x_{Bj} > 0.003$

Acceptance for p’ in DDIS/DVES





Tagging essential for exclusivity

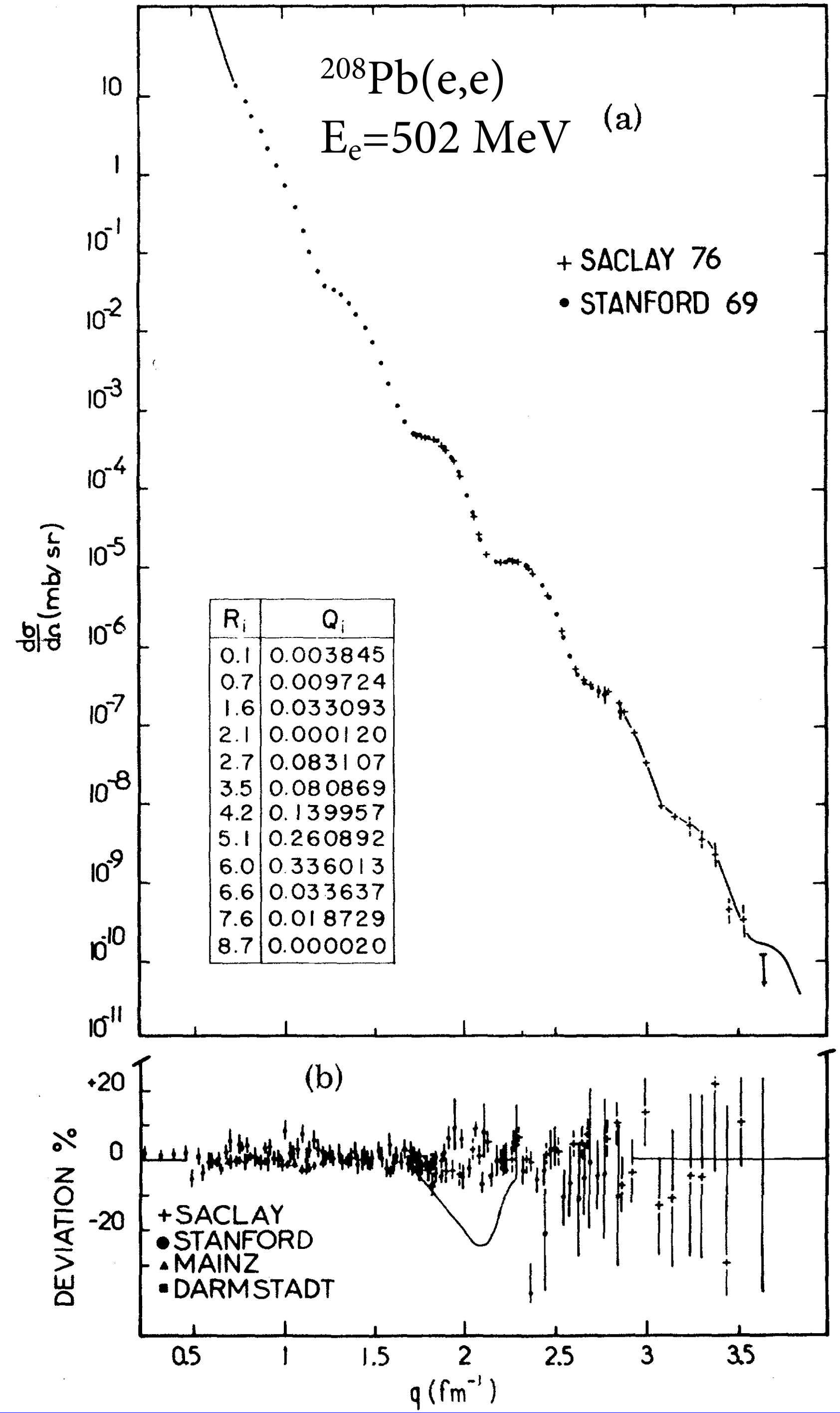
Acceptance in diffractive peak (X_L>~.98)

ZEUS: ~2%

JLEIC: ~100%

DVES on Nuclei

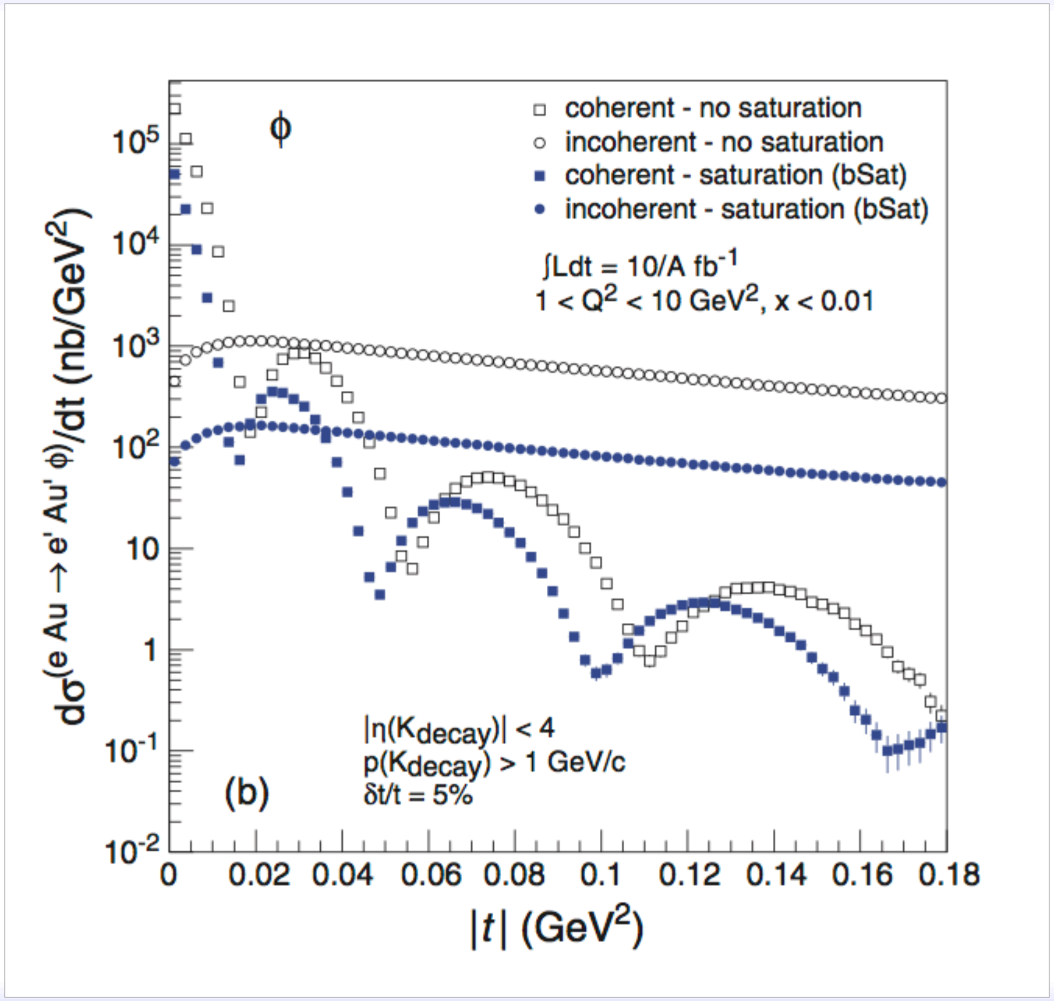
- Precision charge densities measured in 1970s ☛
- "Neutron Skin" of heavy nuclei has implications for nuclear equation of state & neutron star structure.
    - p–n ≅ u-quark – d-quark
    - $\boldsymbol{\rho}$,ω: DVES amplitude has charge weight $e_u \mp e_d$.
        - q + q-bar
- Gluon profiles of nuclei from J/Ψ and ϕ



R_i	Q_i
0.1	0.003845
0.7	0.009724
1.6	0.033093
2.1	0.000120
2.7	0.083107
3.5	0.080869
4.2	0.139957
5.1	0.260892
6.0	0.336013
6.6	0.033637
7.6	0.018729
8.7	0.000020

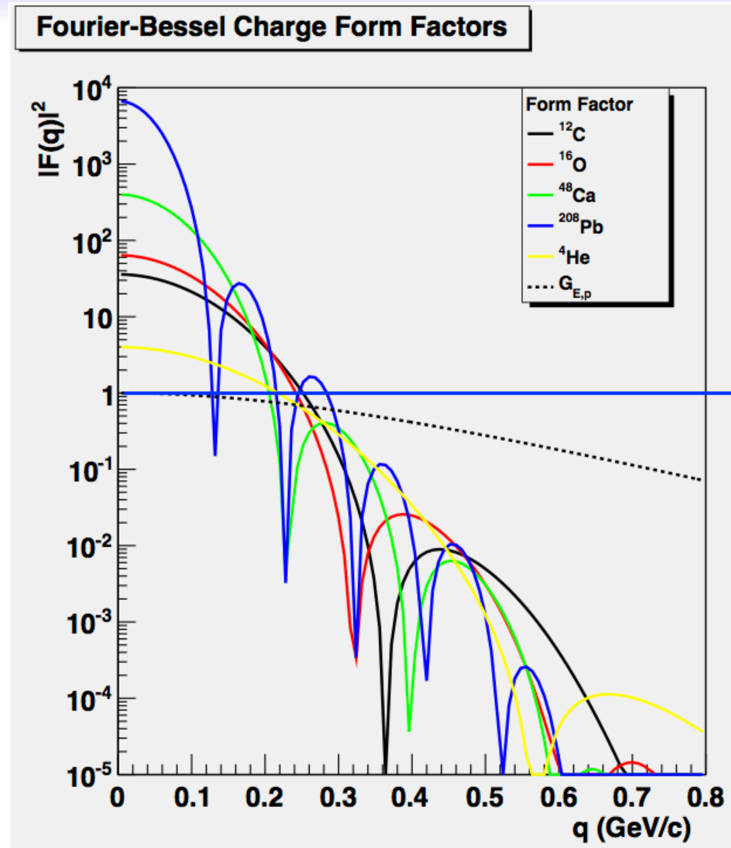
Gluon Imaging of Nuclei: Deep-ϕ

- Luminosity per nucleus ~1/A.
- $d\sigma/dt(t=0) \sim A^2$
- $|t| \approx \Delta_\perp^2$ resolved by ${}^{A}Z(e,e'K^+K^-)X$ kinematics
- Recoil nucleus lost in 10σ Beam envelope
  - Break-up channels vetoed by ZDC & forward trackers



Nuclear DVES and Exclusivity: ^{208}Pb

- Unresolved bound-excited states smooth out diffraction pattern.
  - 3^-(2.6MeV), 5^-(3.2 MeV), 2^+(4.1MeV), 4^+(4.3MeV)
- In DVES@EIC, γ-cascade boosted (×40 JLEIC, ×100 eRHIC)
- High Resolution ($PbWO_4$) forward EMCal can veto (~50%) E_γ >100 MeV



- Doubly Magic nuclei, bound-state decay-energies are large

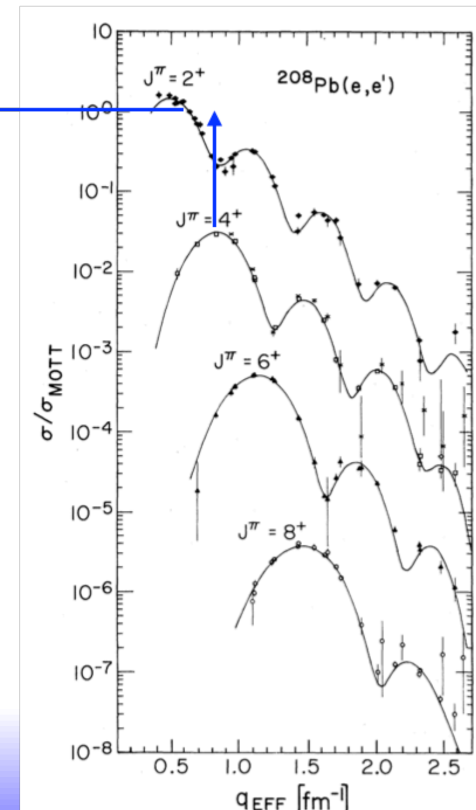


FIG. 3. Cross section for the even spin natural parity states in ^{208}Pb divided by (the cross section for a unit-point charge). Data and best fit for the 4^+ level are scaled down a factor of 0.03, for the 6^+ level a factor of 0.001, and for the 8^+ level a factor of 0.00003.

EIC Users Group: 788 members

- 788 Members
- 169 Institutions
- 29 Countries
- Join us!

Backup Slides

Double-Distribution GPDs at $x=\pm\xi$

- Compton Form Factor: $\xi = x_{Bj}/(2-x_{Bj})$
  $Im[\mathcal{H}_f(\xi,\Delta^2)] = \pi[H_f(\xi, \xi, \Delta^2) - H_f(-\xi, \xi, \Delta^2)]$
- $$\cdot\xi\,\mathrm{Im}\left[H_f\left(\xi,\Delta^2\right)\right] = \pi\int_0^{x_{Bj}} d\beta\left[q_f(\beta)+\bar{q}_f(\beta)\right]\left[h_f(\alpha,\beta)\right]_{\alpha=1-\beta/\xi} e^{\Delta^2 B_{1f}(\beta)}$$
- Profile functions $h(\alpha,\beta)$ arbitrary (symmetric in α,β):
  - Use: $$h(\alpha,\beta) = N_1\frac{\left[\left(1-|\beta|\right)^2-\alpha^2\right]}{\left(1-|\beta|\right)^3}$$ $$\Delta^2 = -\frac{4\xi^2M^2+\Delta_\perp^2}{1-\xi^2}$$
- M. Burkardt, arXiv:*0711.1881*
  $\boldsymbol{\Delta}_\perp$: Fourier Conjugate to $\mathbf{r}_\perp$, the transverse spatial separation between the active parton and the transverse spatial Center-of-Momentum of ***the spectator system***.

Deep ω

- L. Morand [CLAS] EPJ A **24**, (2005) 445.
  - $r_{0,0}^{04} \approx 0.5 \rightarrow \sigma_T \sim \sigma_L$
  - $r_{1,-1}^{04} \approx -0.2 \rightarrow$ ~~SCHC~~
    - $\gamma^*_T \rightarrow \omega_L$
    - $\gamma^*_L \rightarrow \omega_T$
    - $\gamma^*(\pm) \rightarrow \omega(\mp)$

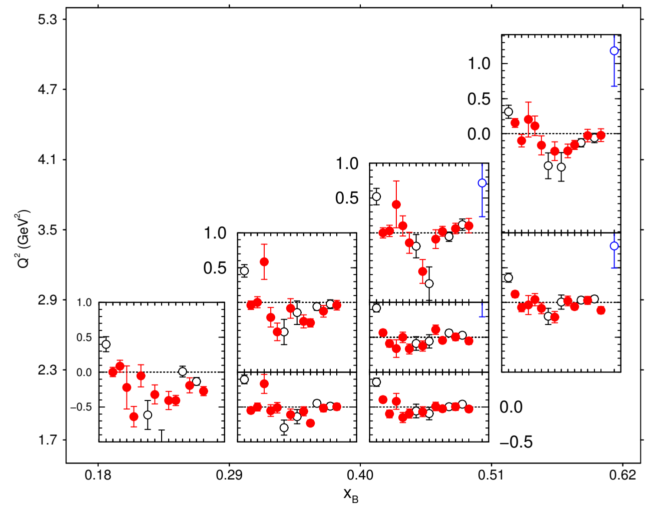
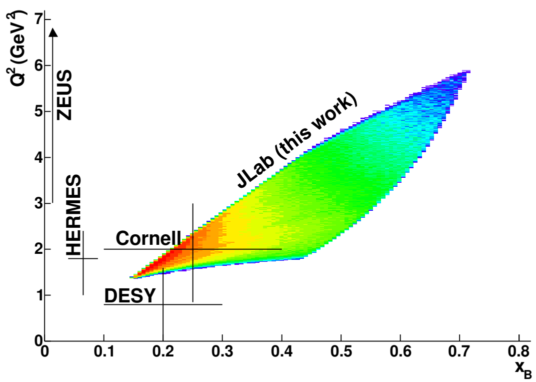


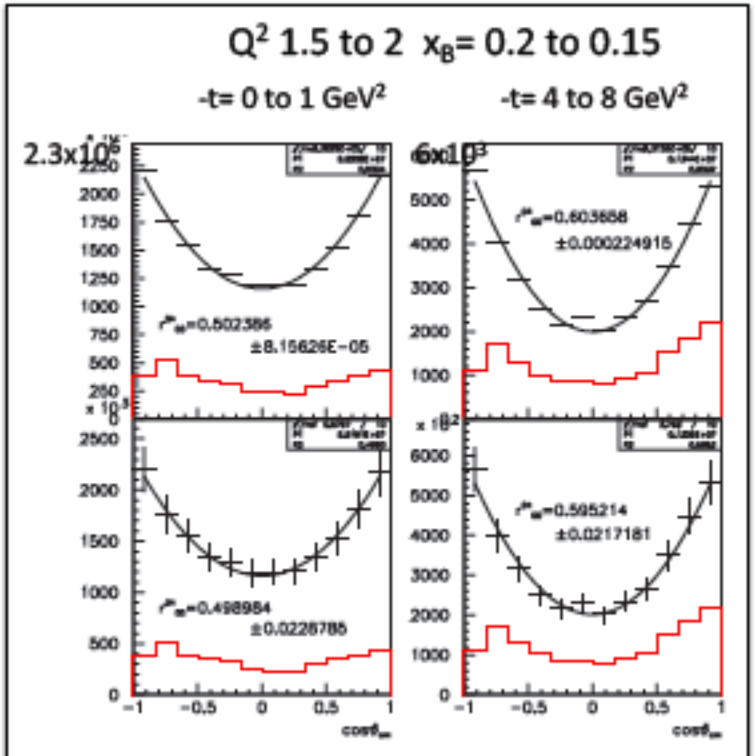
Fig. 18. (Color online) r_{ij}^{α} extracted with the method of moments for 8 bins in (Q^2, x_B) and for $t' < 0.5$ GeV^2. The location and size of each graph correspond to the (Q^2, x_B) range over which the data is integrated, but the scale is the same on all graphs. The abscissa on each graph corresponds to the following list of matrix elements: r_{00}^{04}, Rer_{10}^{04}, r_{1-1}^{04}, r_{00}^{1}, r_{11}^{1}, Rer_{10}^{1}, r_{1-1}^{1}, Imr_{10}^{2}, Imr_{1-1}^{2}, r_{00}^{5}, r_{11}^{5}, Rer_{10}^{5}, r_{1-1}^{5}, Imr_{10}^{6}, Imr_{1-1}^{6}. The filled symbols (red online) indicate those matrix elements which are zero if SCHC applies. The 16th entry (empty circle, blue online, in some cases off scale) is the combination of r_{ij}^{α} given by eq. (11). Error bars include systematic uncertainties added in quadrature.

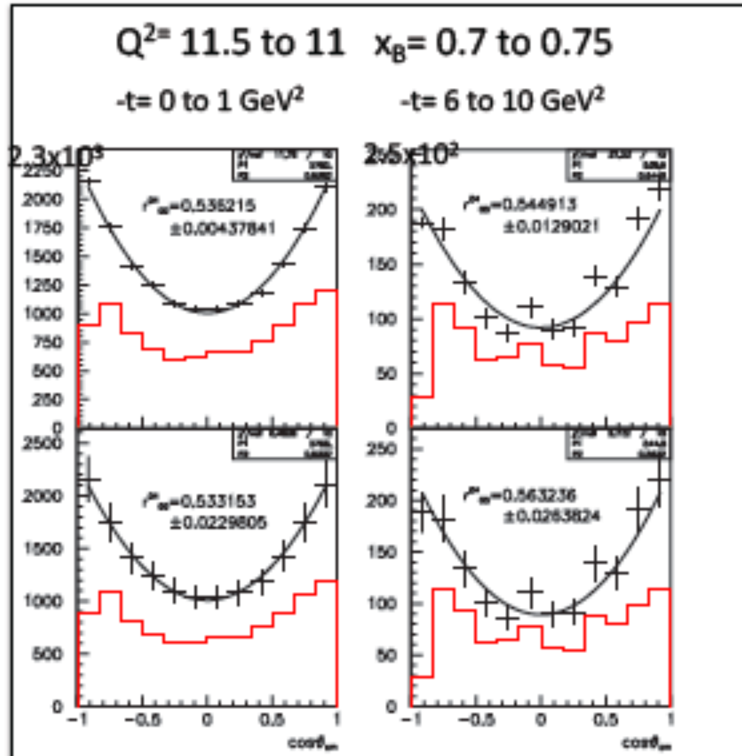


DVCS/DVMP with CLAS at 12 GeV

- 80 days on H_2 target at ~10^{35} /cm^2/s
  - DVCS/Vector Meson production/ TCS with low-Q^2 tagger concurrent
- 120 days on Longitudinally Polarized NH_3 target
  - Total Luminosity 10^{35} /cm^2/s, dilution factor ~1/10
- 90 days: $D(e,e'\gamma n)p_S$
- $^4He(e,e'\,\gamma\alpha)$ with upgraded BoNUS detector
  - GEM based radial TPC for recoil α-detection
- Ambitions/options for Transversely polarized targets
  - NH_3 target has 5 T transverse field
    - need to shield detectors from "sheet of flame"
    - Reduce (Luminosity)•(Acceptance) by factor of 10 (my guess)
  - HD-ice target: Transversely polarized H
    - 110 Days approved
    - Luminosity•(polarization)^2 not yet known

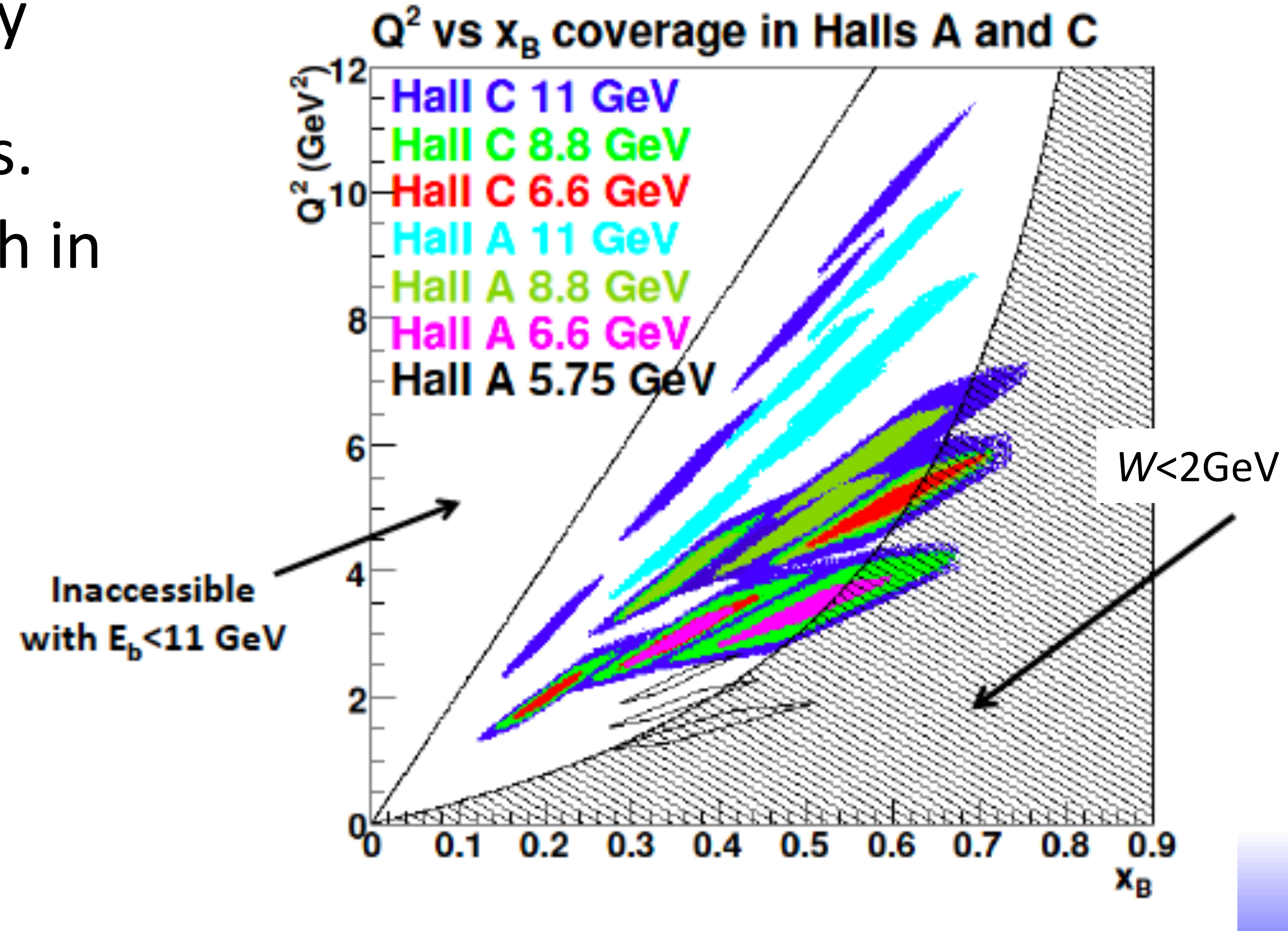
Exclusive $\rho^0 \rightarrow \pi\pi$ L/T separation from SCHC





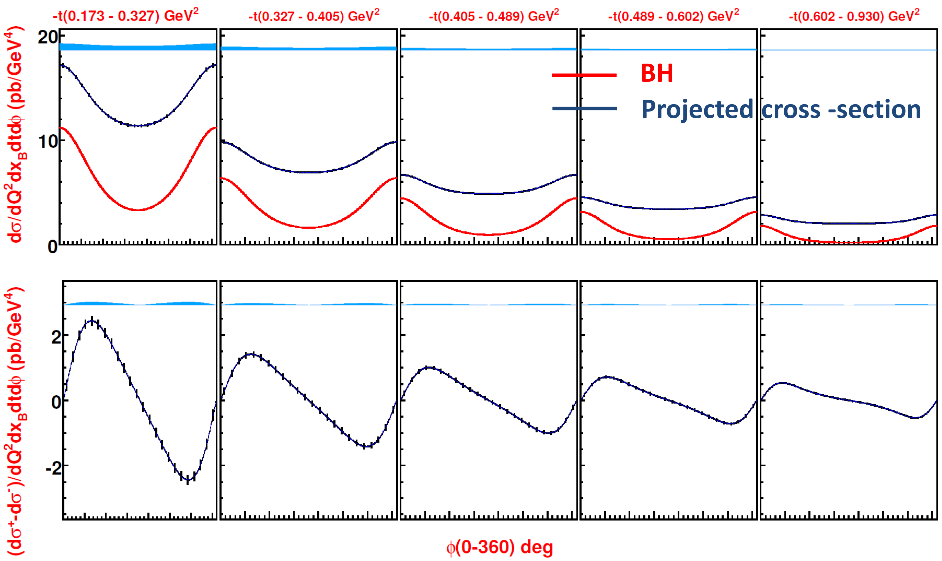
Impact of Hall A+C DVCS Kinematics

- Multiple Energy settings at key (x_B, Q^2) settings.
- Expanded reach in x_B and Q^2.
- Beam time adjusted for ≈equal statistics in each bin

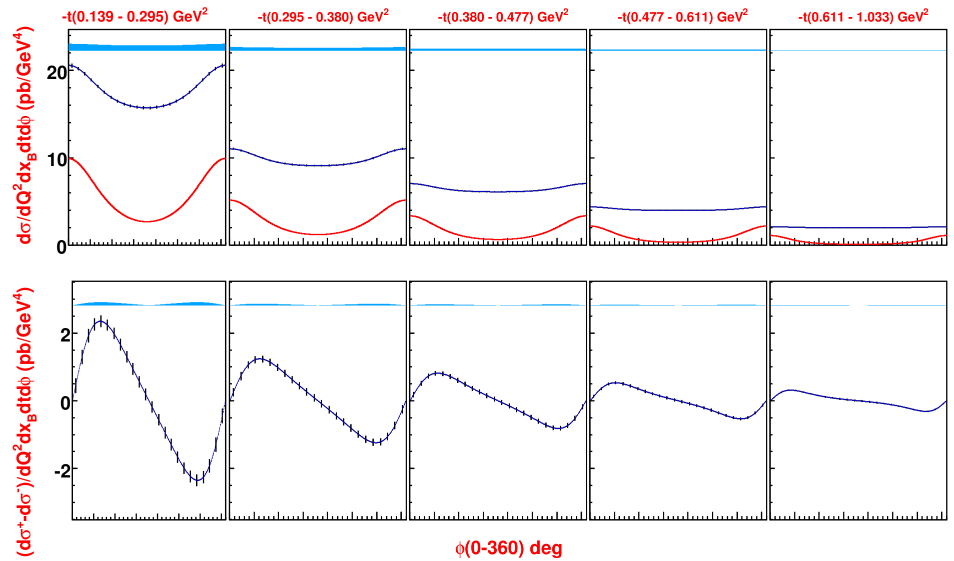


DVCS: Energy separation setting ($Q^2 = 3.4$ GeV^2, $x_B = 0.5$)

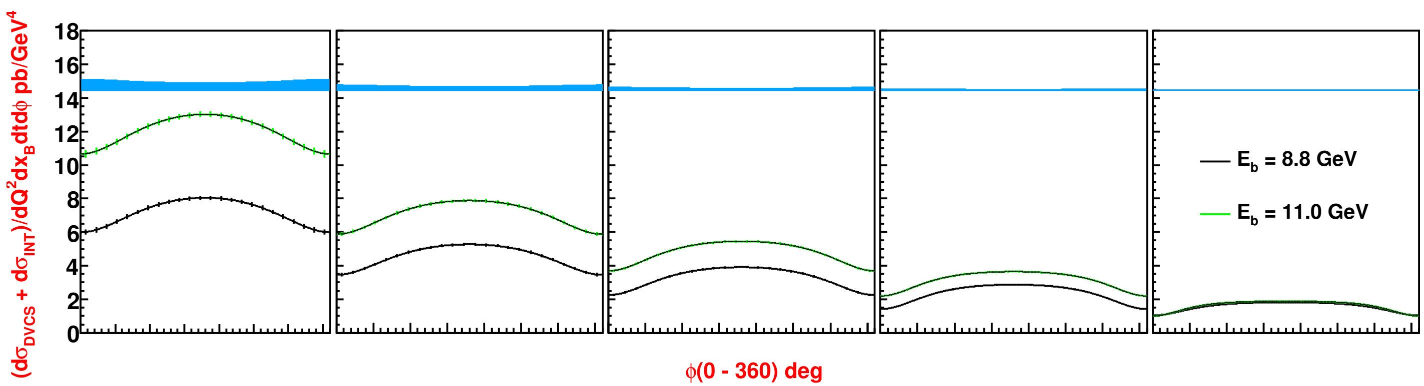
$E_b = 8.8$ GeV



$E_b = 11$ GeV



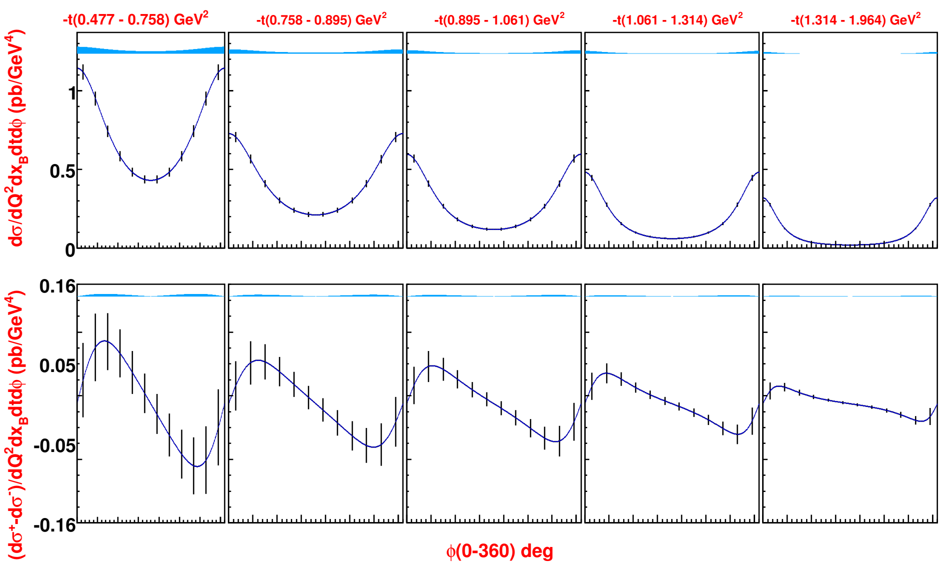
Cross section as a function of ϕ for different bins in t



Cross section after BH subtraction: large variation with E_b

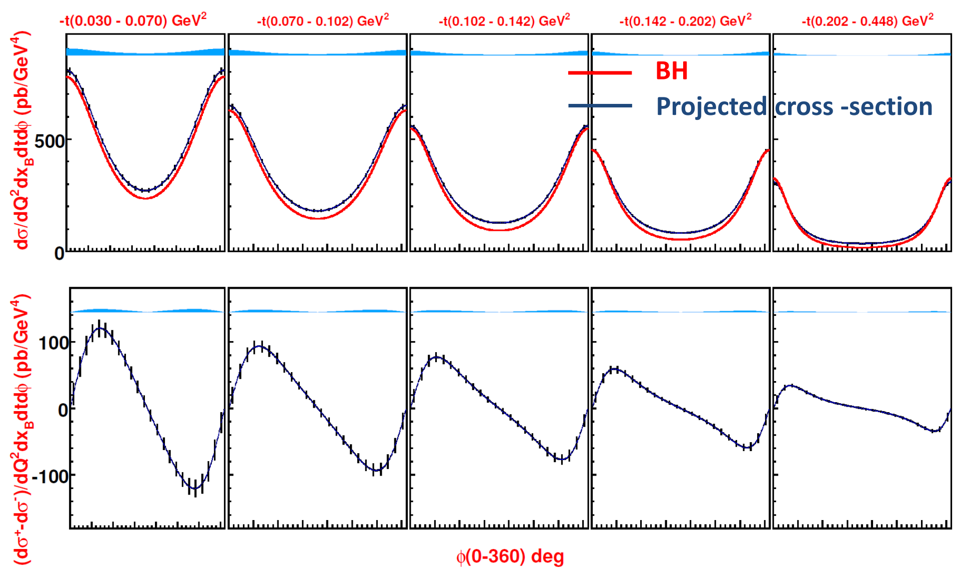
DVCS: high-Q^2 and low-x_B extension

$Q^2 = 10$ GeV^2, $x_B = 0.6$



12 days

$Q^2 = 3$ GeV^2, $x_B = 0.2$

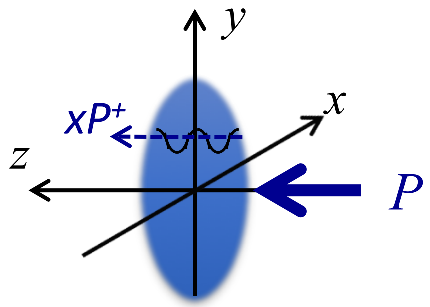


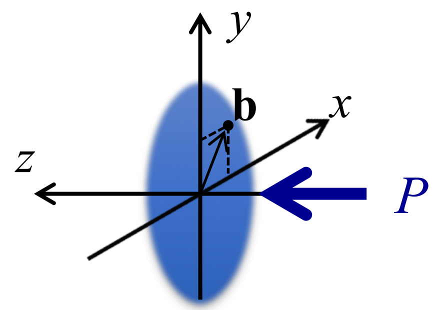
1 day

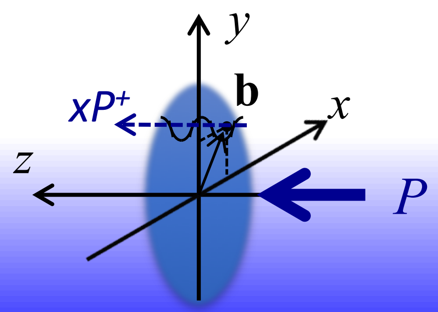
Partonic Structure of the Nucleon

Studying matter as it is illuminated by a light-front

- DIS: H*(e,e')X*
  - Longitudinal (light-cone) Momentum distributions
- Elastic Electro-Weak Form Factors: H*(e,e')p…*
  - Fourier Transform of spatial impact-parameter distributions
  - 2-D formalism fully compatible with Q.M. and Relativity
- Generalized Parton Distributions Deeply Virtual Exclusive Scattering
  - $eN \rightarrow eN\gamma$, $eN \rightarrow eN(\pi, \rho, \phi)$, etc
  - Correlations of longitudinal momentum fraction with transverse spatial position

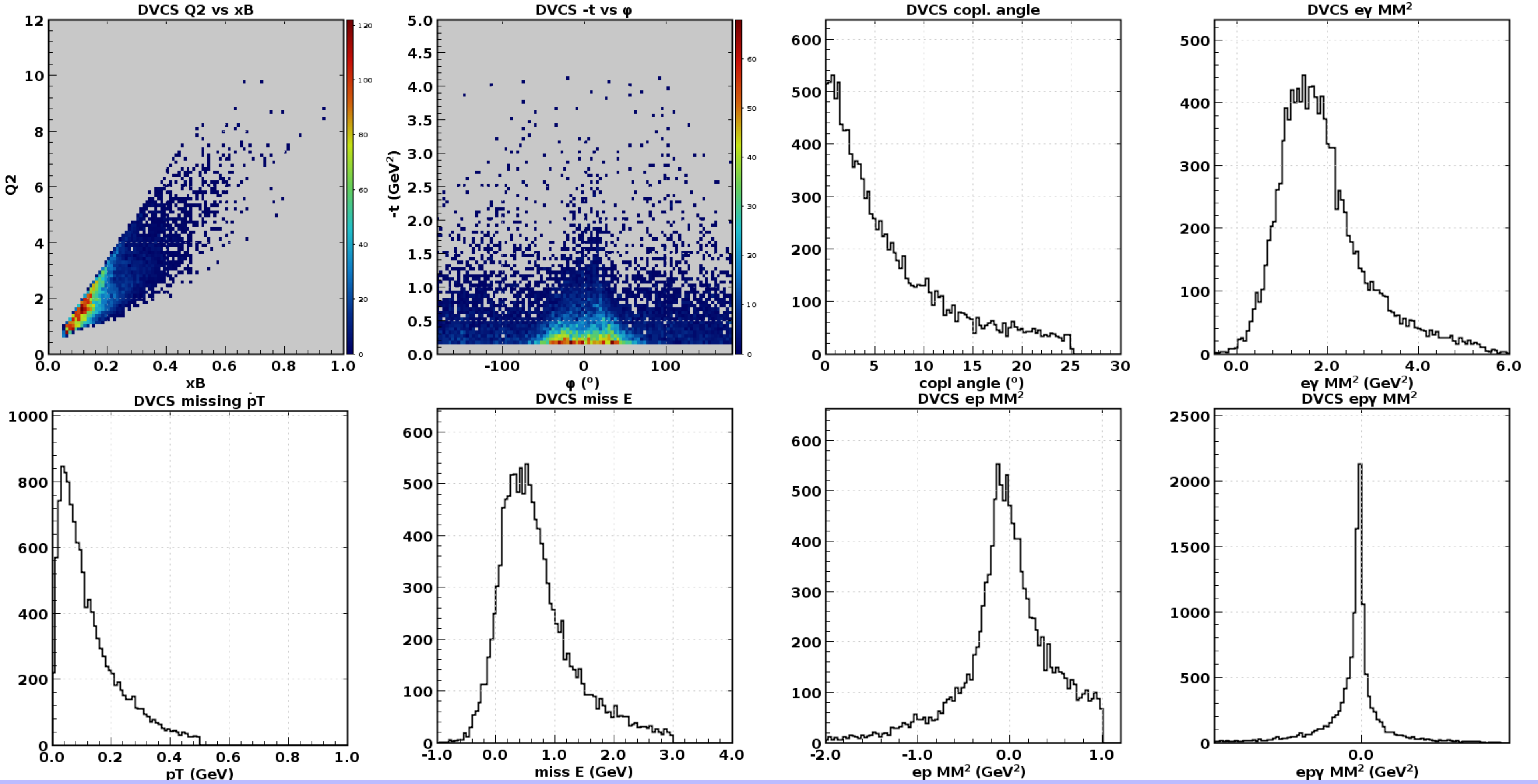






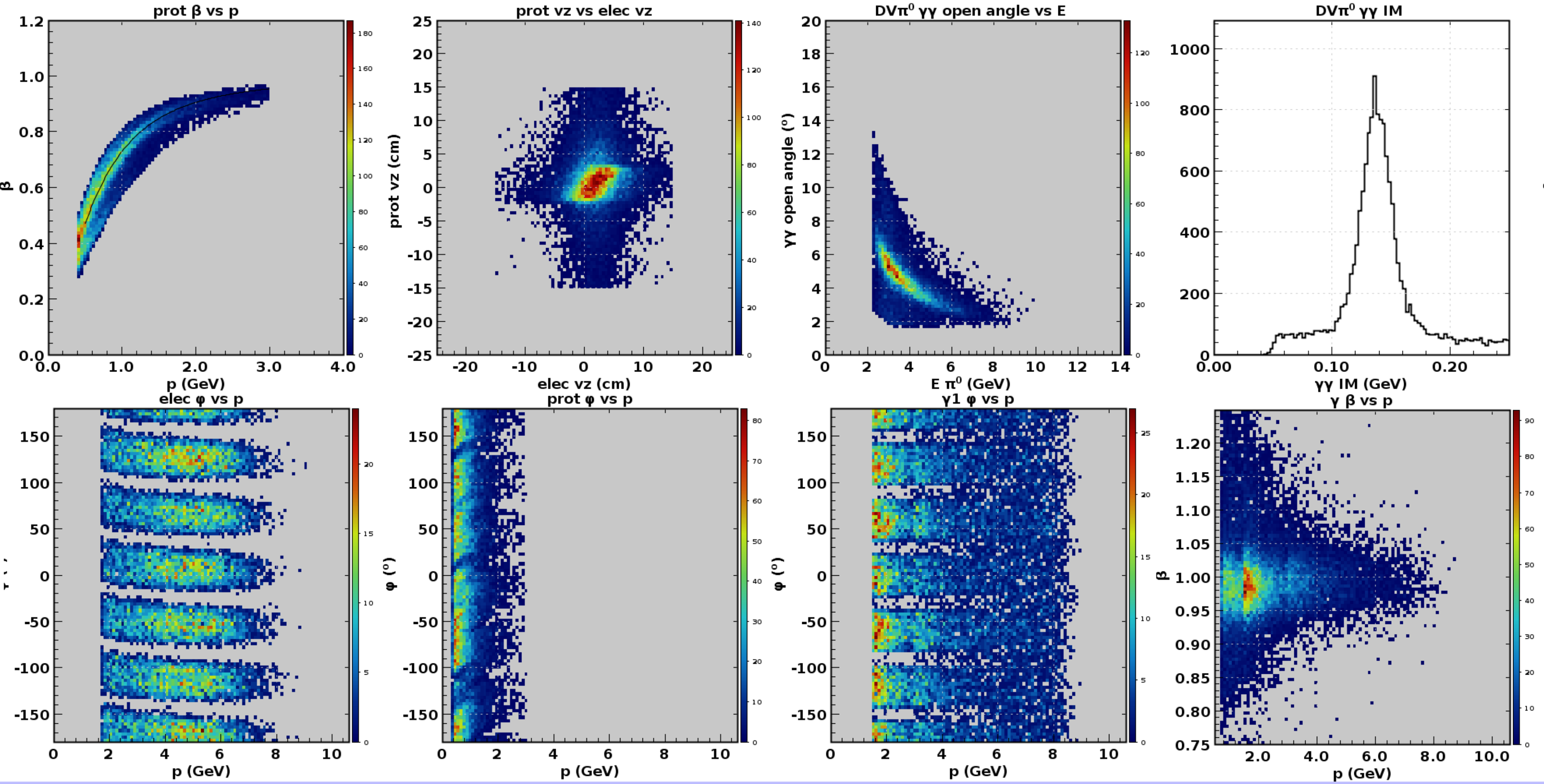
DVCS : CLAS12 Run Group A

- 0.3% of statistics on tape.



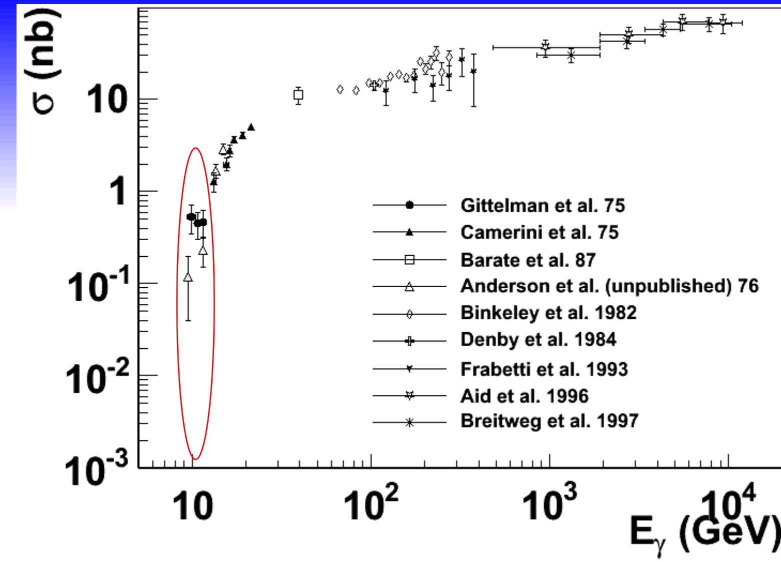
Deep π^0 : CLAS12 Run Group A

- 0.3% of the statistics on tape.

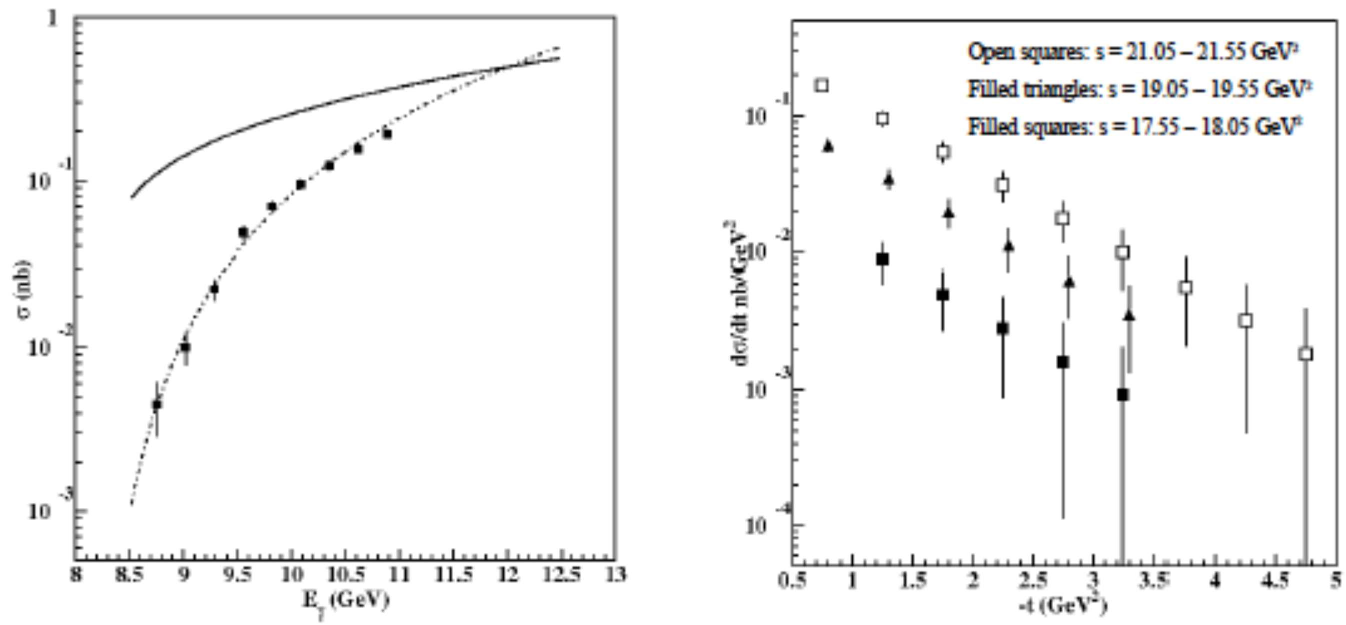


CLAS 12 Exclusive J/Ψ

- Threshold region poorly measured
- CLAS 12:
  - Full *t*-distrbution
  - fine bins in *s* at threshold
- SoLID,
  - Electro-production
  - Polarized Target



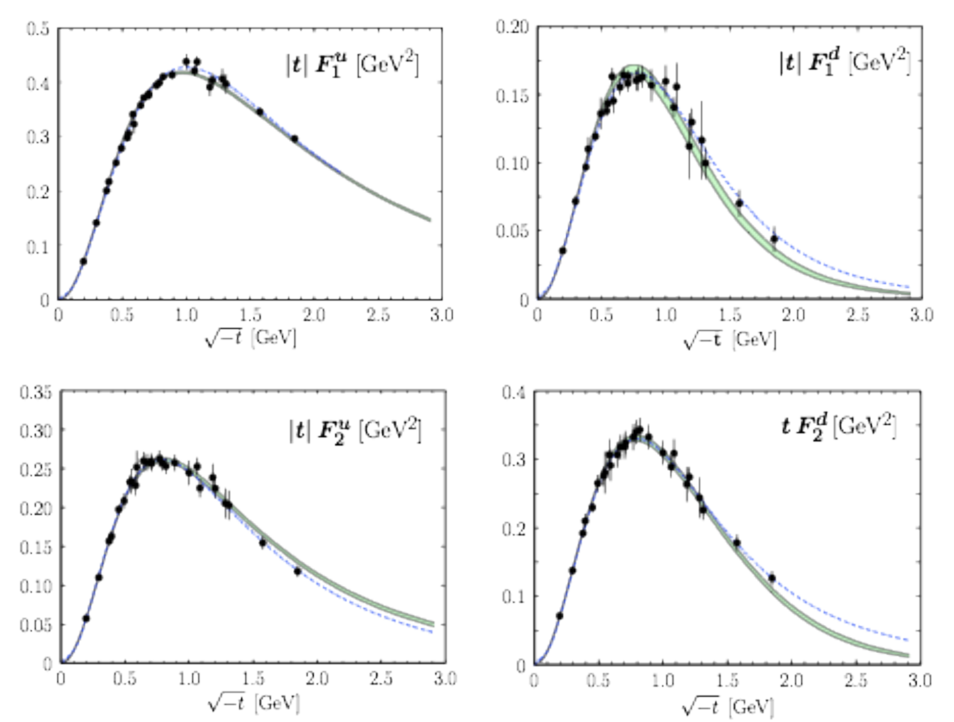
Statistical uncertainties for 100 days at a luminosity of 10^{35} $cm^{-2}s^{-1}$



Example Regge-Inspired Model of GPDs

M.Diehl, … EPJC **73** (2013)

(also S. Liuti *et al.*)



$H_f(x,0,\Delta^2) = q_f(x) exp[\Delta^2 B_{1f}(x)]$
$E_f(x,0,\Delta^2) = e_f(x) exp[\Delta^2 B_{2f}(x)]$

- $q_f(x)$: *ABM2011*
  $e_f(x) = \kappa_f N_f\, x^{-\alpha f} (1-x)^{-\beta f} (1-\gamma_f\, x^{1/2})$
- $B_{nf}(x) = \alpha_f' (1-x)^3 \log(1/x) + A_{nf}\, x(1-x)^2 + B_{nf}\,(1-x)^3$
- Fit:
  $\int dx\, H_f(x,0,\Delta^2) = F_{1f}(-\Delta^2)$
  $\int dx\, E_f(x,0,\Delta^2) = F_{2f}(-\Delta^2)$

❖ Compton Form Factors: $\xi = x_{Bj}/(2-x_{Bj})$
$Im[\mathcal{H}_f(\xi,\Delta^2)] = \pi[H_f(\xi, \xi, \Delta^2) - H_f(-\xi, \xi, \Delta^2)]$

$$\xi\, \mathrm{Im}\left[H_f\left(\xi,\Delta^2\right)\right] = \pi \int_0^{x_{Bj}} d\beta \left[q_f(\beta) + \bar{q}_f(\beta)\right]\left[h_f(\alpha,\beta)\right]_{\alpha=1-\beta/\xi} e^{\Delta^2 B_{1f}(\beta)}$$

❖ Profile functions $h(\alpha,\beta)$ arbitrary (symmetric in α,β):

$$h(\alpha,\beta) = N_1 \frac{\left[\left(1-|\beta|\right)^2 - \alpha^2\right]}{\left(1-|\beta|\right)^3}$$