Studies of GPDs at Jefferson Lab

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CIPANP 2015
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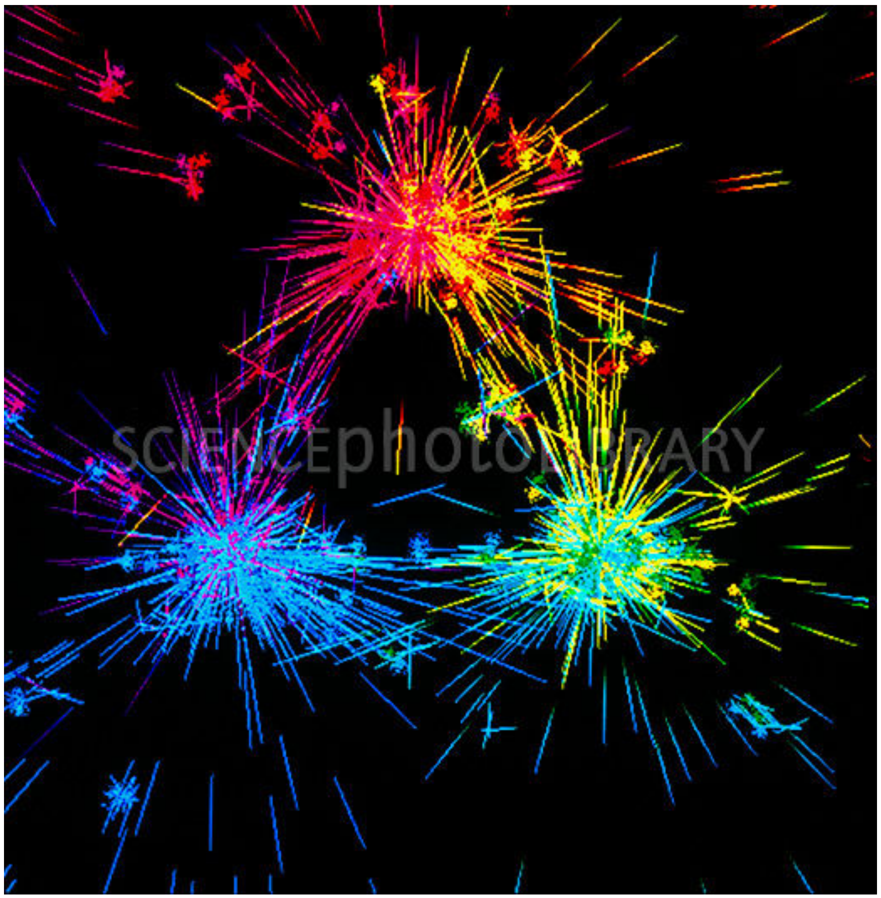
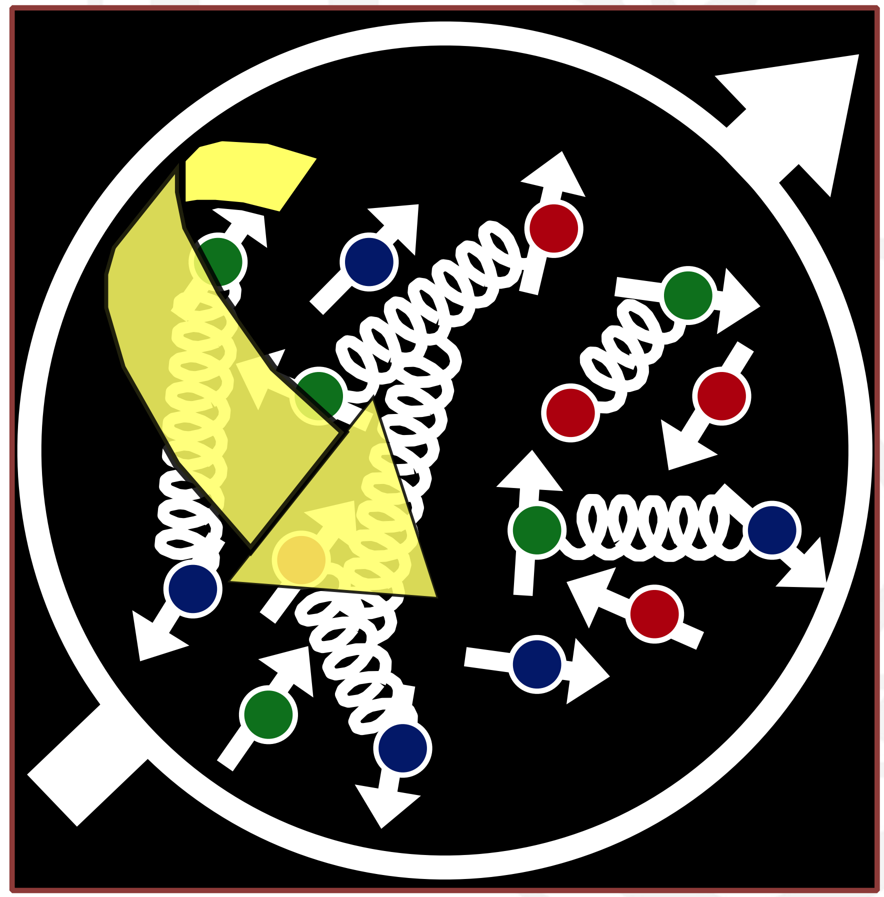
Some open questions on hadronic structure

- Can we describe nucleons in terms of their constituents?
- Where does the spin of the nucleon come from?





Courtesy of A. Bacchetta

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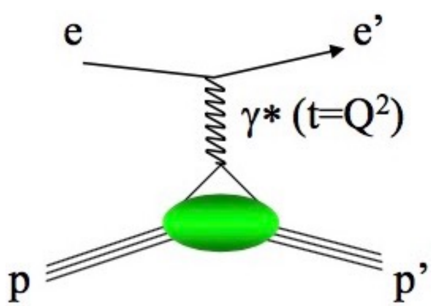
Structure of the nucleon 50 years ago

1950

Elastic scattering

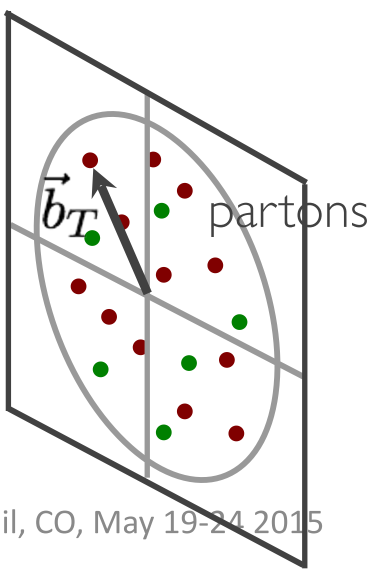
ep → e'p'

Hofstadter



Spatial distributions of electric charge and current

Form Factors



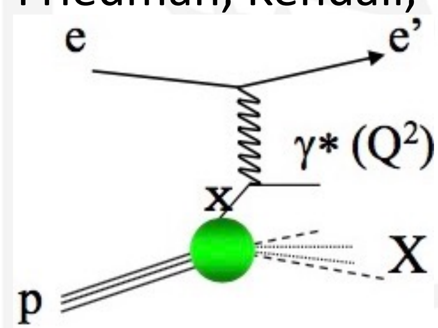
Q^2

1967

Deep inelastic scattering

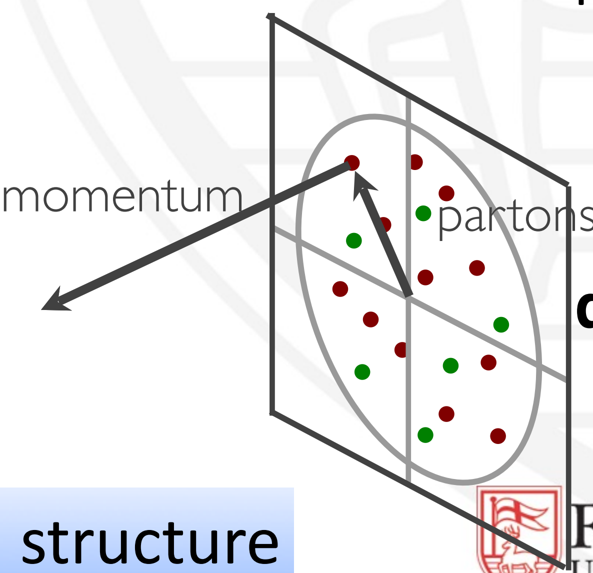
ep → e'X

Friedman, Kendall, Taylor



Momentum and spin distributions of quarks

Longitudinal momentum



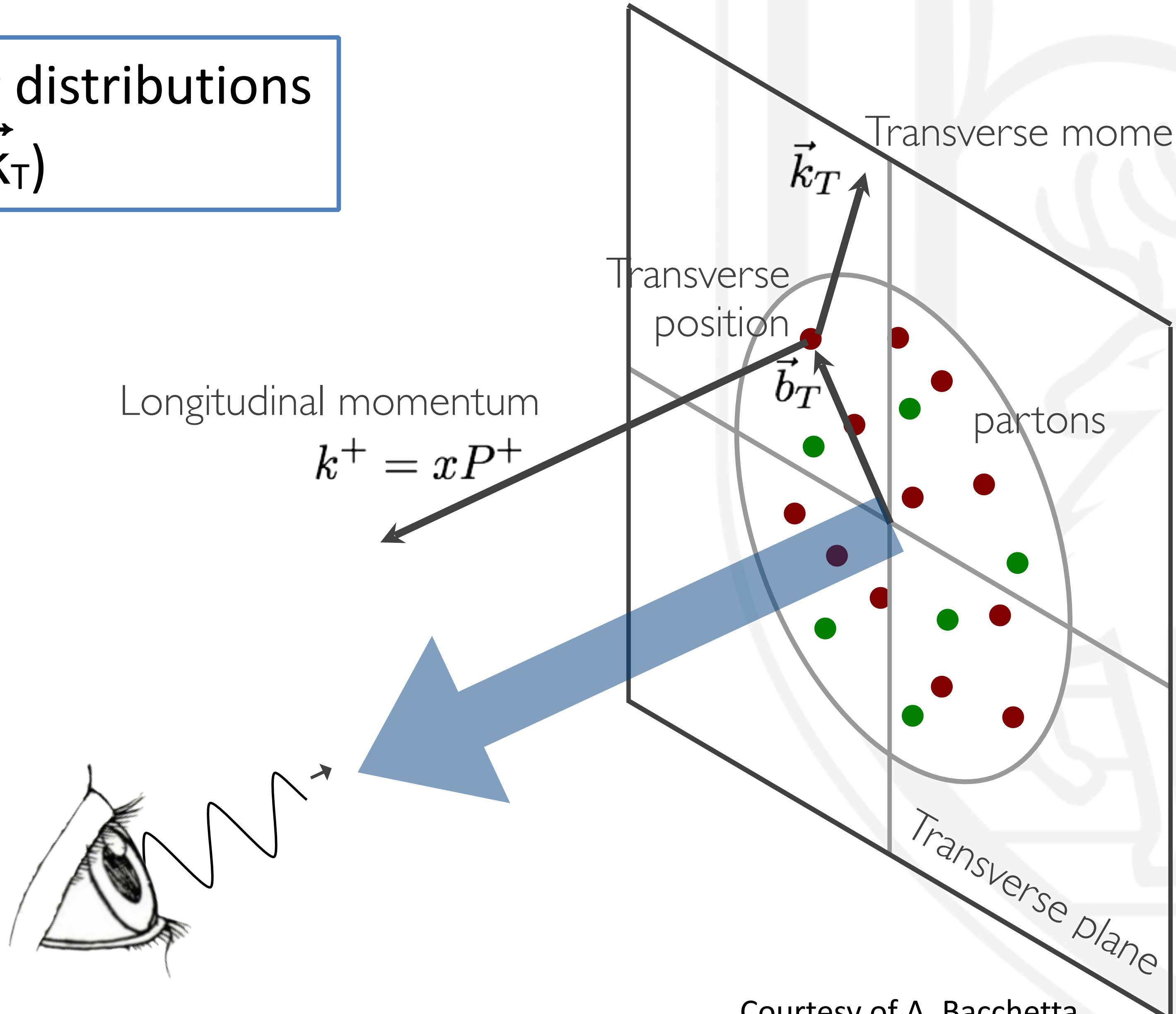
PDF

q(x), Δq(x)

multi-dimensional structure

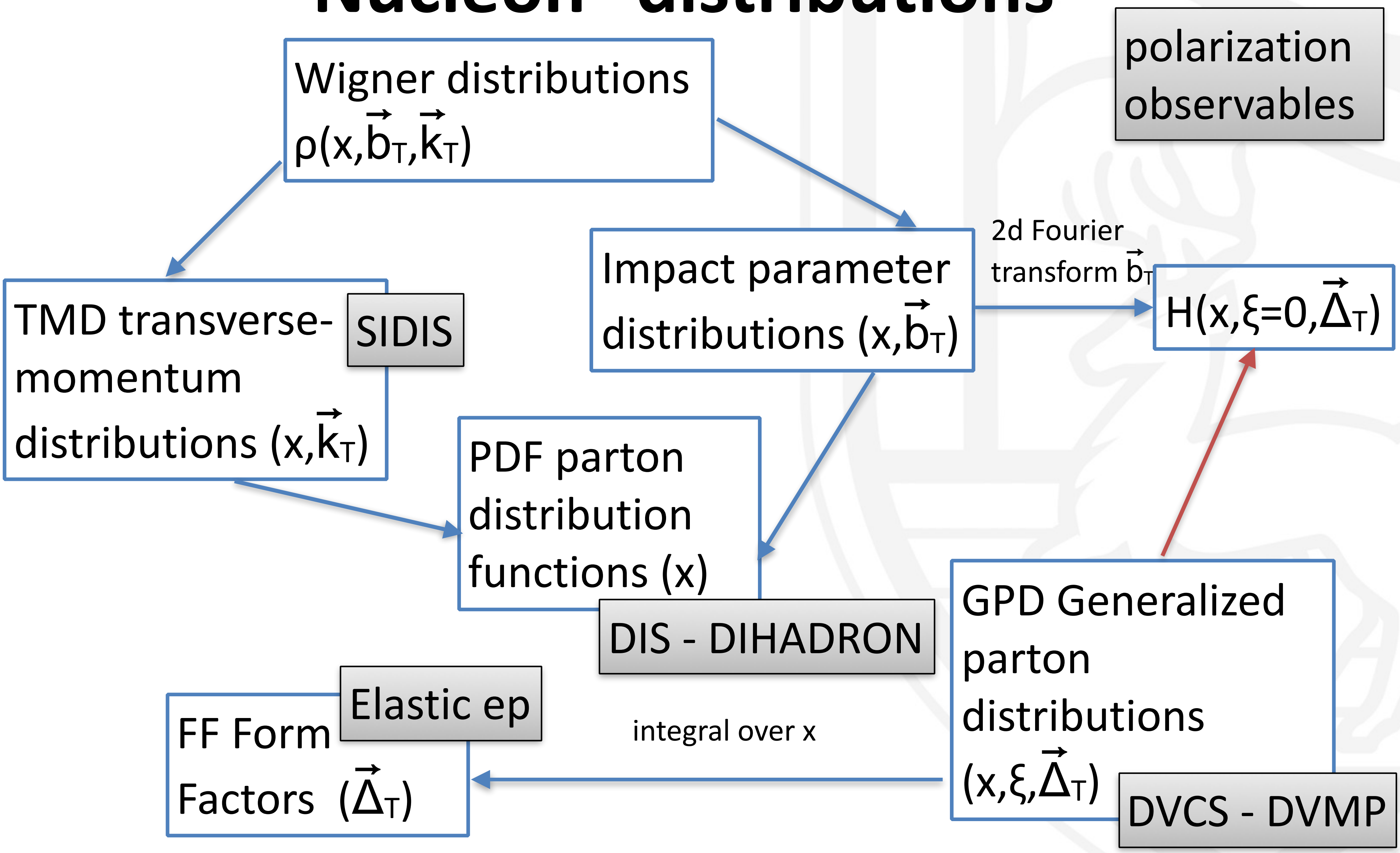
5 Dimensional Structure of the nucleon

Wigner distributions
$\rho(x,\vec{b}_T,\vec{k}_T)$



Courtesy of A. Bacchetta

Nucleon "distributions"



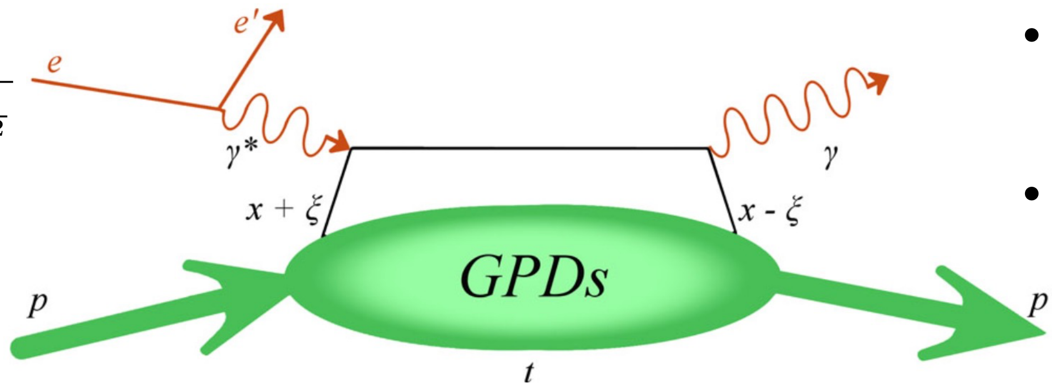
GPDs: fully-correlated quark distributions in both coordinate and momentum space

Deeply Virtual Compton Scattering and GPDs

$$ep \to ep\gamma$$

$$\xi = x_B \frac{1 + \frac{t}{Q^2}}{2 - x_B + x_B \frac{t}{Q^2}}$$

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



- x longitudinal quark momentum fraction
- 2ξ longitudinal momentum transfer to the struck quark
- t momentum transfer to the nucleon

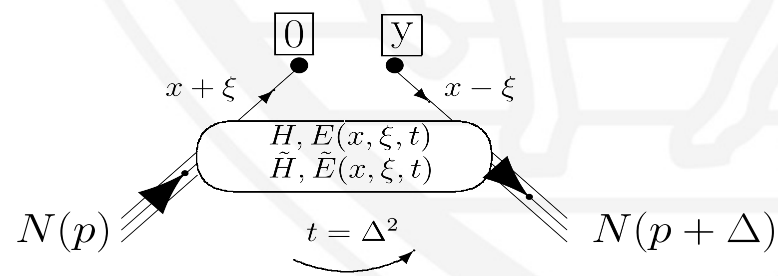
Large Q^2, $t \ll Q^2$ and fixed x_B :
- factorization
- soft part: 4 GPDs at LO

$$GPDs \text{ “}F\text{” } : H, \tilde{H}, E, \tilde{E}$$

$$F(x, \xi, t)$$

4 GPDs for each quark flavor

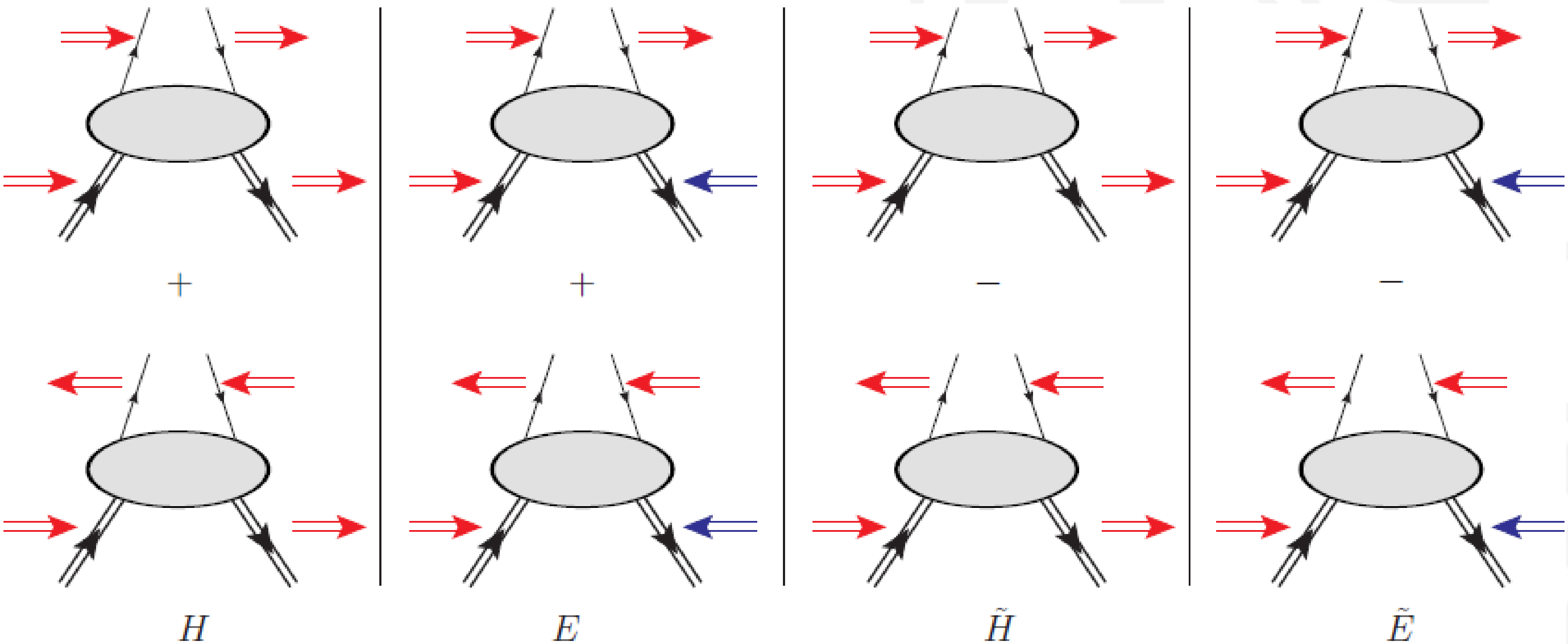
Fourier transforms of QCD non-local and non-diagonal operator $\langle p' | \bar{\psi}_q(0) \mathcal{O} \psi_q(y) | p \rangle$



Deeply Virtual Compton Scattering and GPDs

Average over quark helicity
unpolarized GPDs

Difference of quark helicity
polarized GPDs

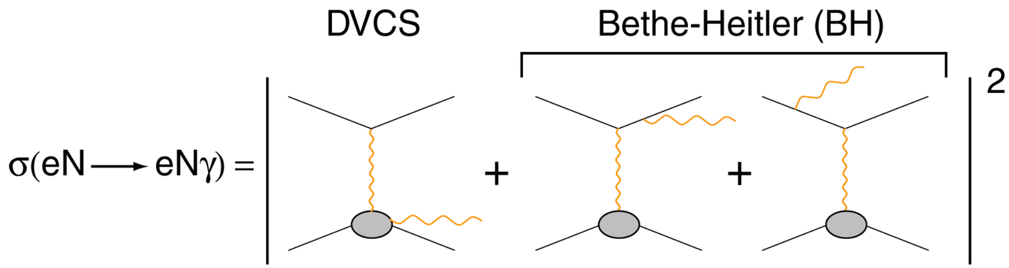


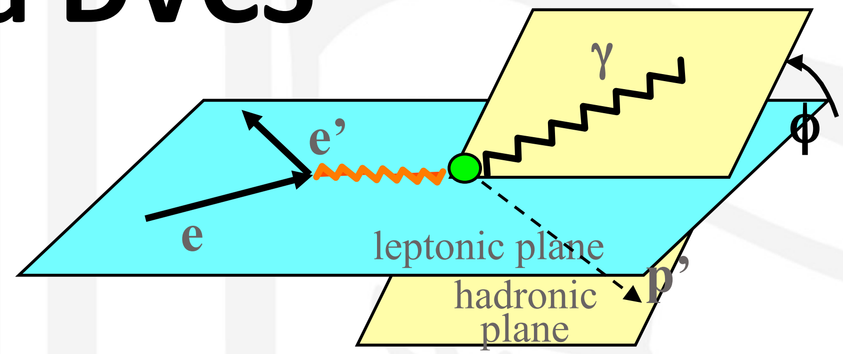
Hs conserve nucleon spin

Es flip nucleon spin

Quark helicity is conserved

Accessing GPDs via DVCS





Bethe Heitler experimentally indistinguishable from DVCS

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} \propto |T_{\mathrm{DVCS}} + T_{\mathrm{BH}}|^2 = |T_{\mathrm{DVCS}}|^2| + |T_{\mathrm{BH}}|^2 + I$$

- Cross section measurement
- Polarization measurements: asymmetries and cross-section differences ⇒ $\sigma^+ - \sigma^- \propto I = T_{\mathrm{DVCS}} T^*_{\mathrm{BH}} + T^*_{\mathrm{DVCS}} T_{\mathrm{BH}}$

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \propto \frac{I}{|T_{\mathrm{DVCS}}|^2 + |T_{\mathrm{BH}}|^2 + I}$$

$$\boxed{T_{\mathrm{DVCS}} \propto \mathcal{P}\int_{-1}^{1} dx \left[\frac{1}{x-\xi} \mp \frac{1}{x+\xi}\right] F(x,\xi,t) - i\pi[F(\xi,\xi,t) \mp F(-\xi,\xi,t)]}$$

GPDs sensitivity of DVCS spin observables

Compton Form Factors: 8 GPD-related quantities

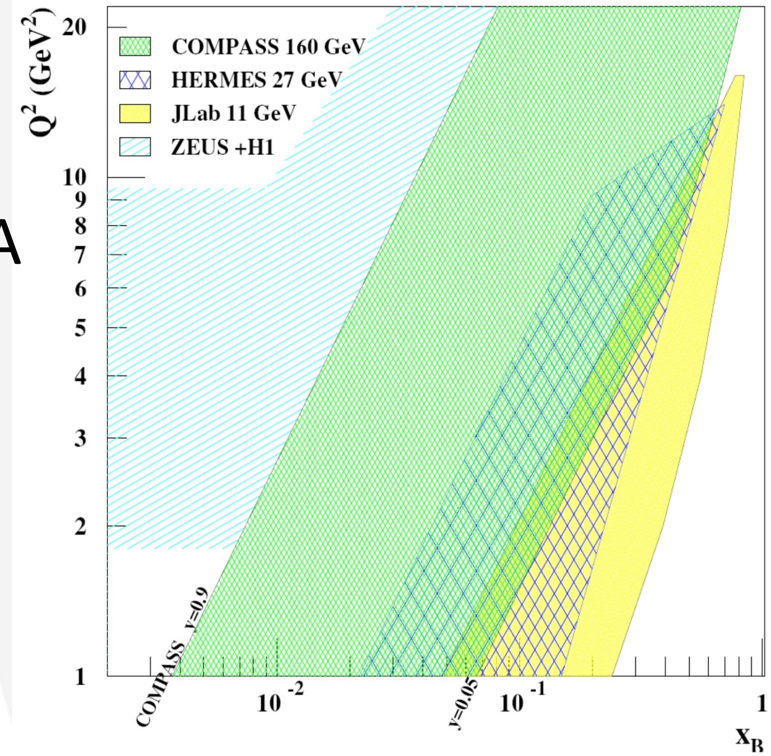
$$\Re\mathrm{e}\mathcal{F} = \mathcal{P}\int_{-1}^{1} dx \left[\frac{1}{x-\xi} \mp \frac{1}{x+\xi}\right] F(x,\xi,t)$$

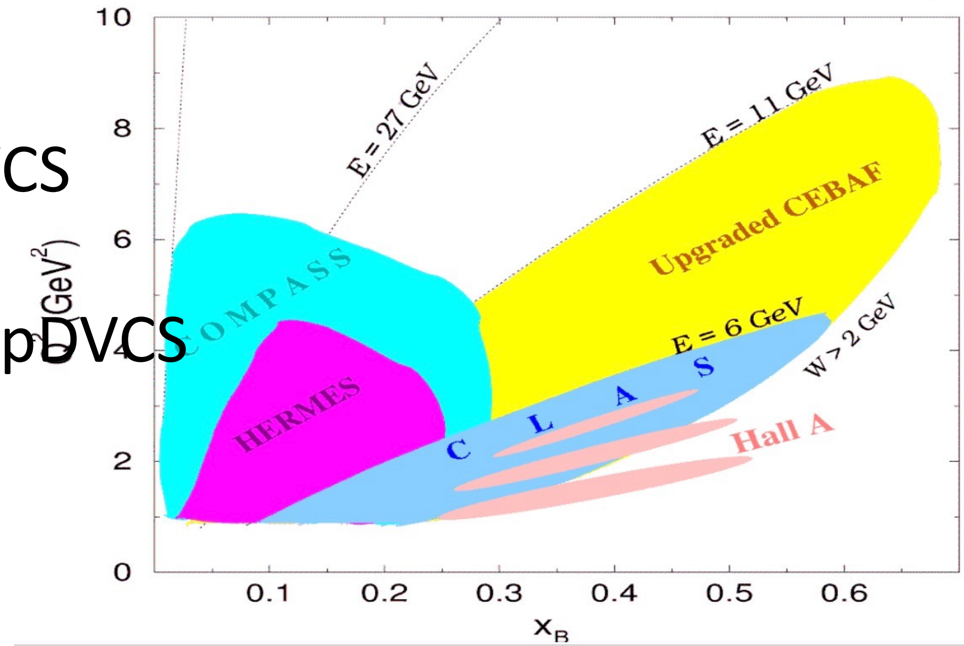
$$\Im\mathrm{m}\mathcal{F} = \pi\left[F(\xi,\xi,t) \mp F(-\xi,\xi,t)\right]$$

Observable	***Proton***	***Neutron***
Beam Spin Asymmetry A_{LU}		
$A_{\mathrm{LU}}(\phi) \propto \Im\mathrm{m}[F_1\mathcal{H} + \xi(F_1+F_2)\widetilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}]\sin\phi$	$\Im\mathrm{m}\{\mathcal{H}_p, \widetilde{\mathcal{H}}_p, \mathcal{E}_p\}$	$\Im\mathrm{m}\{\mathcal{H}_n, \widetilde{\mathcal{H}}_n, \boldsymbol{\mathcal{E}_n}\}$
Target Spin Asymmetry A_{UL}		
$A_{\mathrm{UL}}(\phi) \propto \Im\mathrm{m}[F_1\widetilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + \frac{x_B}{2}\mathcal{E}) - \xi(\frac{x_B}{2}F_1 + \frac{t}{4M^2}F_2)\widetilde{\mathcal{E}}]\sin\phi$	$\Im\mathrm{m}\{\boldsymbol{\mathcal{H}}_p, \boldsymbol{\widetilde{\mathcal{H}}_p}\}$	$\Im\mathrm{m}\{\boldsymbol{\mathcal{H}}_n, \widetilde{\mathcal{H}}_n, \mathcal{E}_n\}$
Double Spin Asymmetry A_{LL}		
$A_{\mathrm{LL}}(\phi) \propto \Re\mathrm{e}[F_1\widetilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + \frac{x_B}{2}\mathcal{E}) - \xi(\frac{x_B}{2}F_1 + \frac{t}{4M^2}F_2)\widetilde{\mathcal{E}}](A + B\cos\phi)$	$\Re\mathrm{e}\{\boldsymbol{\mathcal{H}}_p, \boldsymbol{\widetilde{\mathcal{H}}_p}\}$	$\Re\mathrm{e}\{\boldsymbol{\mathcal{H}}_n, \widetilde{\mathcal{H}}_n, \mathcal{E}_n\}$
Transverse Target Spin Asymmetry A_{UT}		
$A_{\mathrm{UT}}(\phi) \propto \Im\mathrm{m}[k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots]\sin\phi$	$\Im\mathrm{m}\{\boldsymbol{\mathcal{H}}_p, \boldsymbol{\mathcal{E}_p}\}$	$\Im\mathrm{m}\{\boldsymbol{\mathcal{H}}_n\}$

Overview of DVCS experiments in the world

- COMPASS
  - Momentum 100-190 GeV
  - p-DVCS X-sec,BSA,BCA, tTSA,lTSA,DSA
- H1 ZEUS
  - p-DVCS X-sec,BCA
- HERMES
  - 27 GeV beam
  - p-DVCS BSA,BCA, tTSA,lTSA,DSA
- JEFFERSON LAB -
  - 6 GeV e beam
  - Hall A high precision X-sec pDVCS nDVCS, X-sec, ΔX-sec
  - CLAS wide kinematic coverage pDVCS BSA, lTSA, DSA, X-sec, ΔX-sec

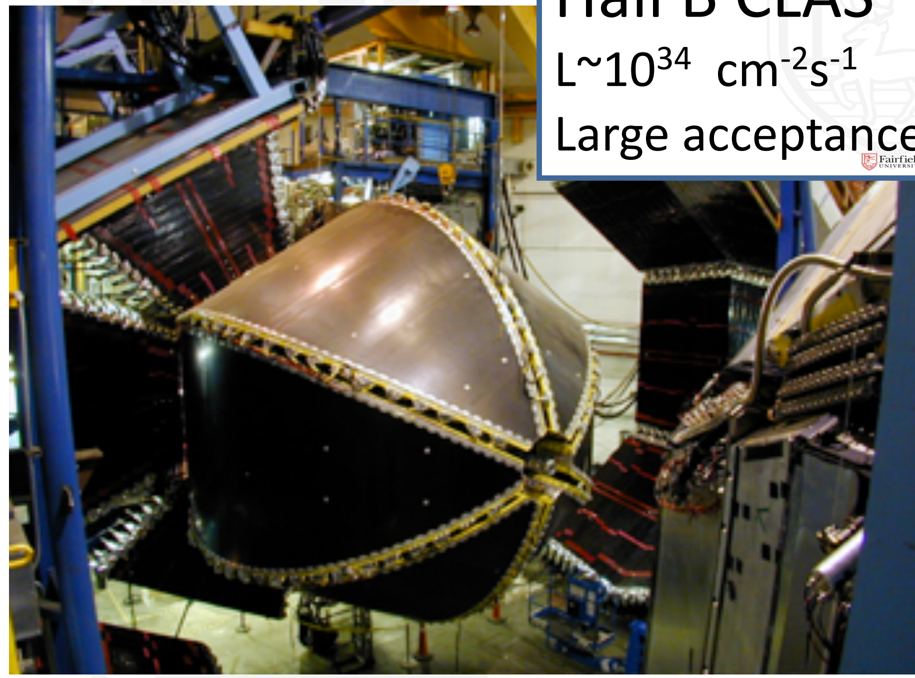




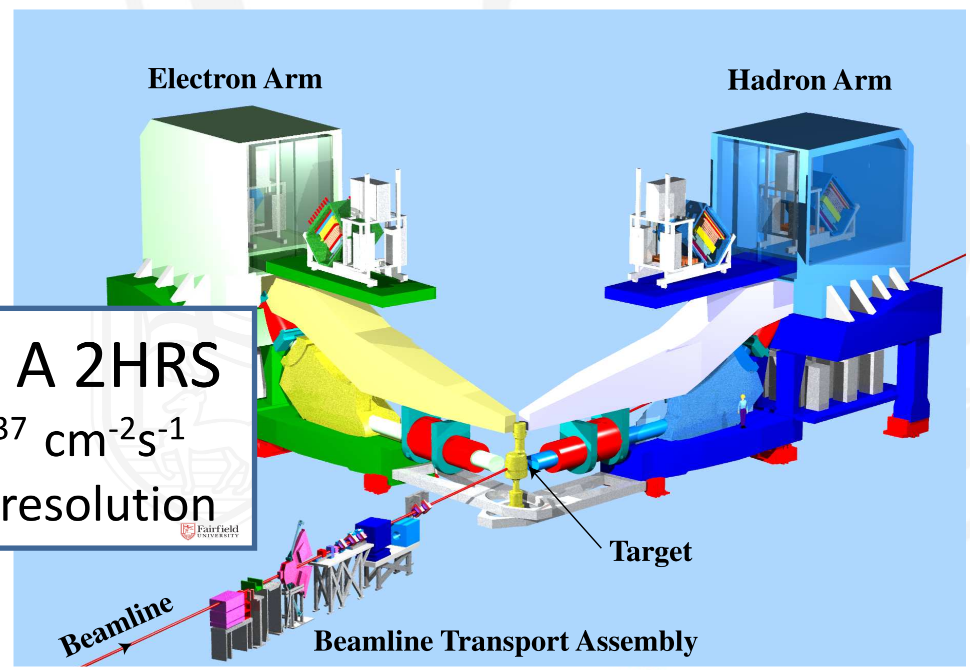
DVCS at Jefferson Lab

Continuous
Electron
Beam
Accelerator
Facility

$I_{max}=200\mu A$
$E_{max}=6$ GeV
$\sigma_E/E\sim 2.5\ 10^{-5}$
Beam Pol~80%



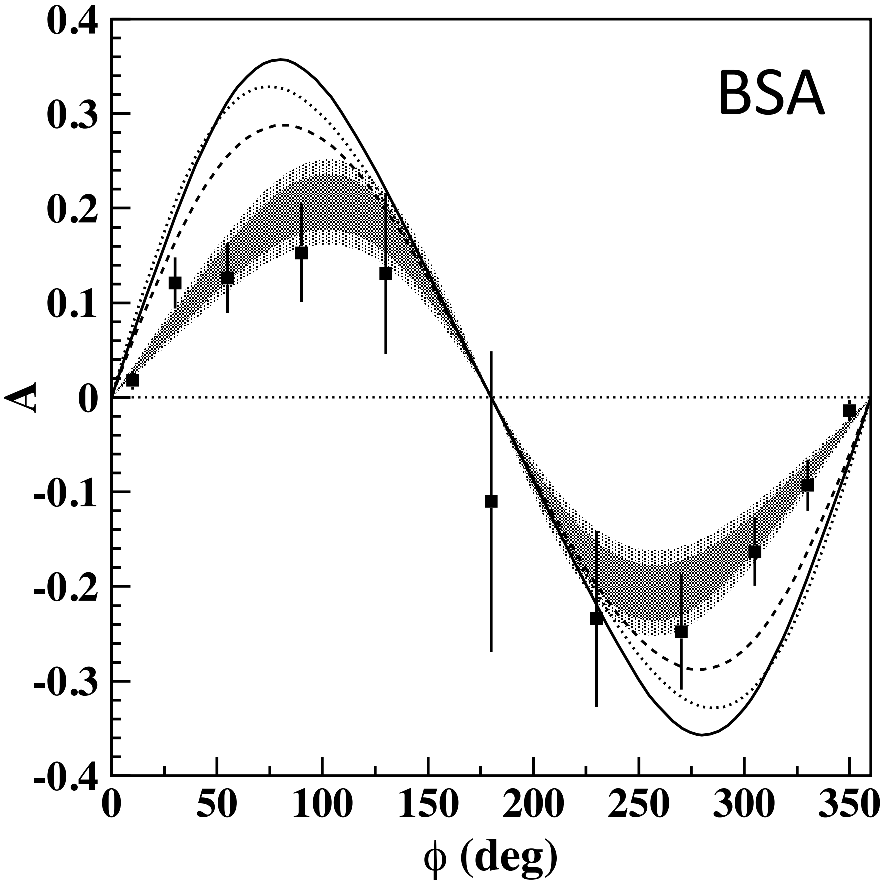
Hall B CLAS
$L\sim 10^{34}\ cm^{-2}s^{-1}$
Large acceptance



Hall A 2HRS
$L\sim 10^{37}\ cm^{-2}s^{-1}$
High resolution

CLAS: DVCS Beam Spin Asymmetry

S. Stepanyan et al., PRL 87 (2001)

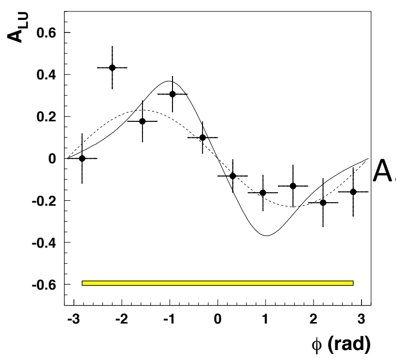


First measurement of the BSA in exclusive electro- production of real photons in the deeply inelastic regime

$\langle Q^2 \rangle = 1.25$ GeV^2
$\langle x_B \rangle = 0.19$
$\langle -t \rangle = 0.19$ GeV^2

E = 4.3 GeV
e p → e p X
CLAS
Target LH_2

A=a sinϕ+b sin 2ϕ
a>>b twist 2 dominance



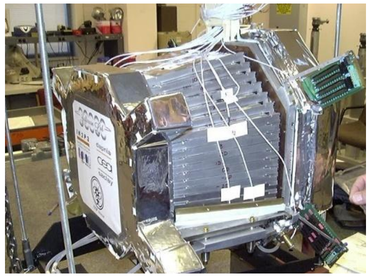
BSA@Hermes

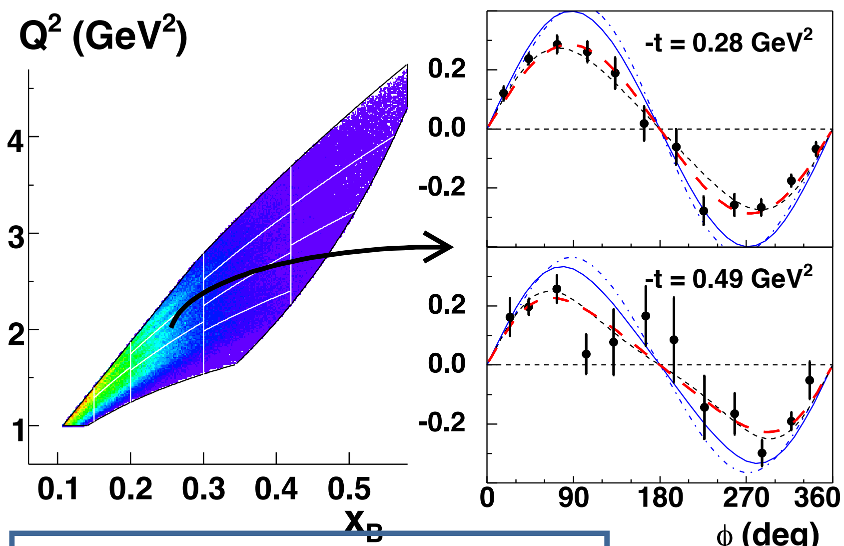
A. Airapetian et al. Phys. Rev. Lett. 87, 182001 (2001)

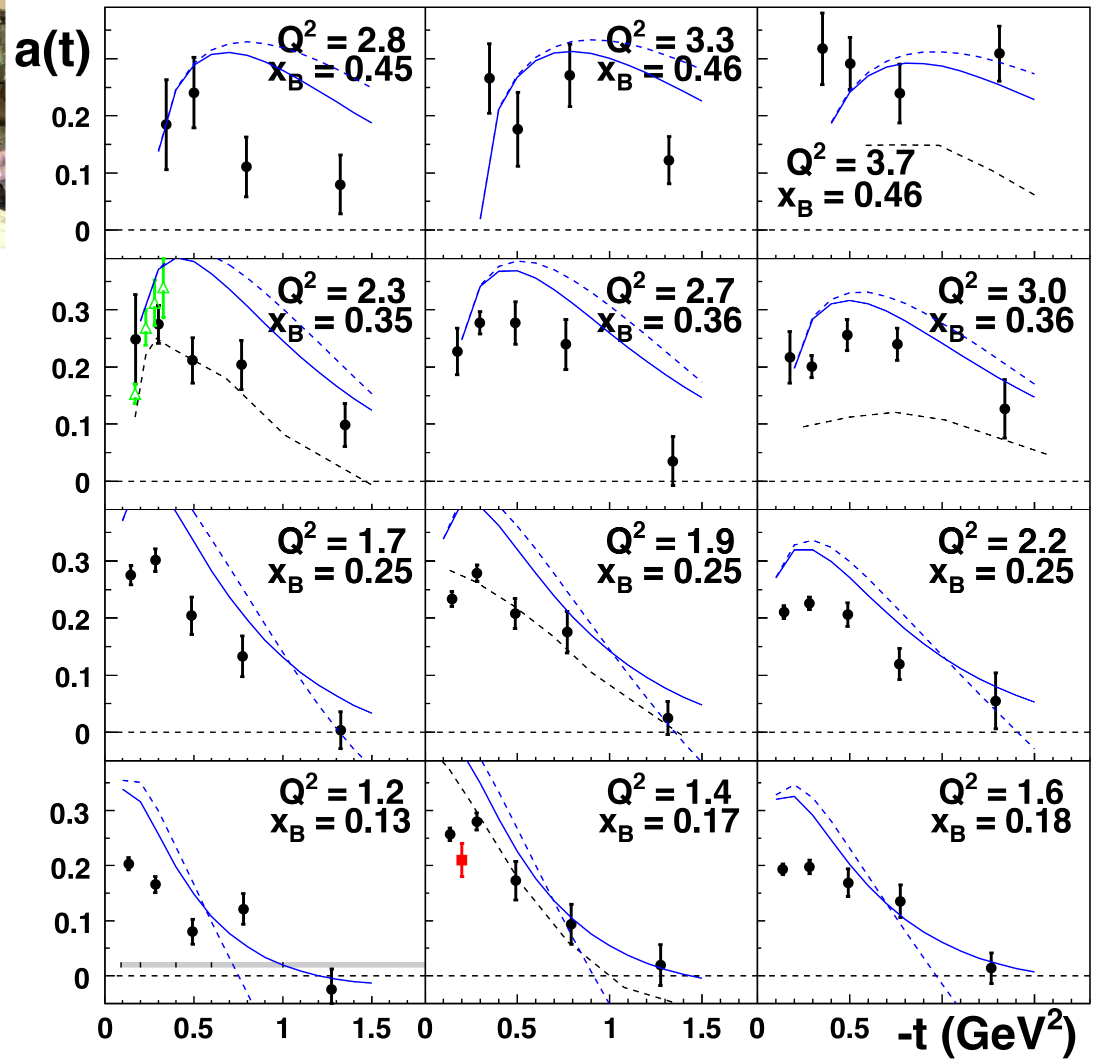
CLAS: dedicated BSA measurement

F.X. Girod et al., PRL 100 (2008)

E = 5.75 GeV
$\vec{e}\, p \rightarrow e\, p\, \gamma$
CLAS+Inner Cal







$A = a \sin\phi / (1 + \cos\phi)$

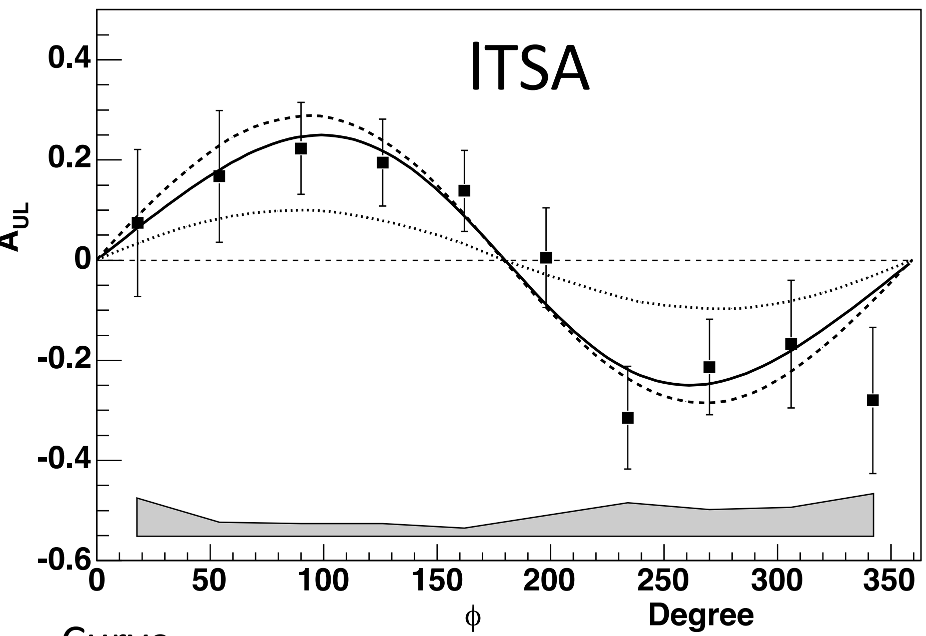
Sensitivity to Im{H}

More data taken in 2008

Models
— VGG* twist 2
-·- VGG* twist 3 and 3
- - Regge model (Laget)
*Vanderhaegen, Guichon, Guidal

Data
● e1dvcs data
△ Hall cross-section
■ CLAS@ 4GeV

CLAS: Target spin asymmetry



Curve
— fit
- - VGG twist 3 and 3
… VGG $\tilde{H}$=0

Sensitivity to Im{$\tilde{H}$}

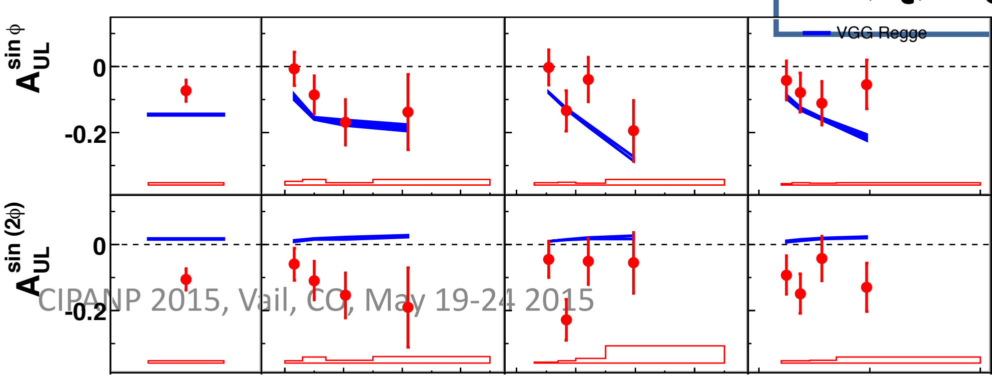
S. Chen et al Phys. Rev. Lett. 97, 072002

E = 5.75 GeV
$\vec{e}\,\vec{p} \to e\,p\,\gamma$
CLAS
Target NH_3

First measurement of the longitudinal TSA in exclusive electro- production of real photons in the deeply inelastic regime

$\langle Q^2 \rangle$=1.82 GeV^2
$\langle x_B \rangle$=0.16
$\langle -t \rangle$=0.31 GeV^2

A=a sinϕ+b sin 2ϕ
a>>b twist 2 dominance
Handbag dominance
confirmed @Hermes



TSA@Hermes
A. Airapetian et al., JHEP 1006 (2010)

Non-zero sin2ϕ

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CLAS: polarized target DVCS dedicated run

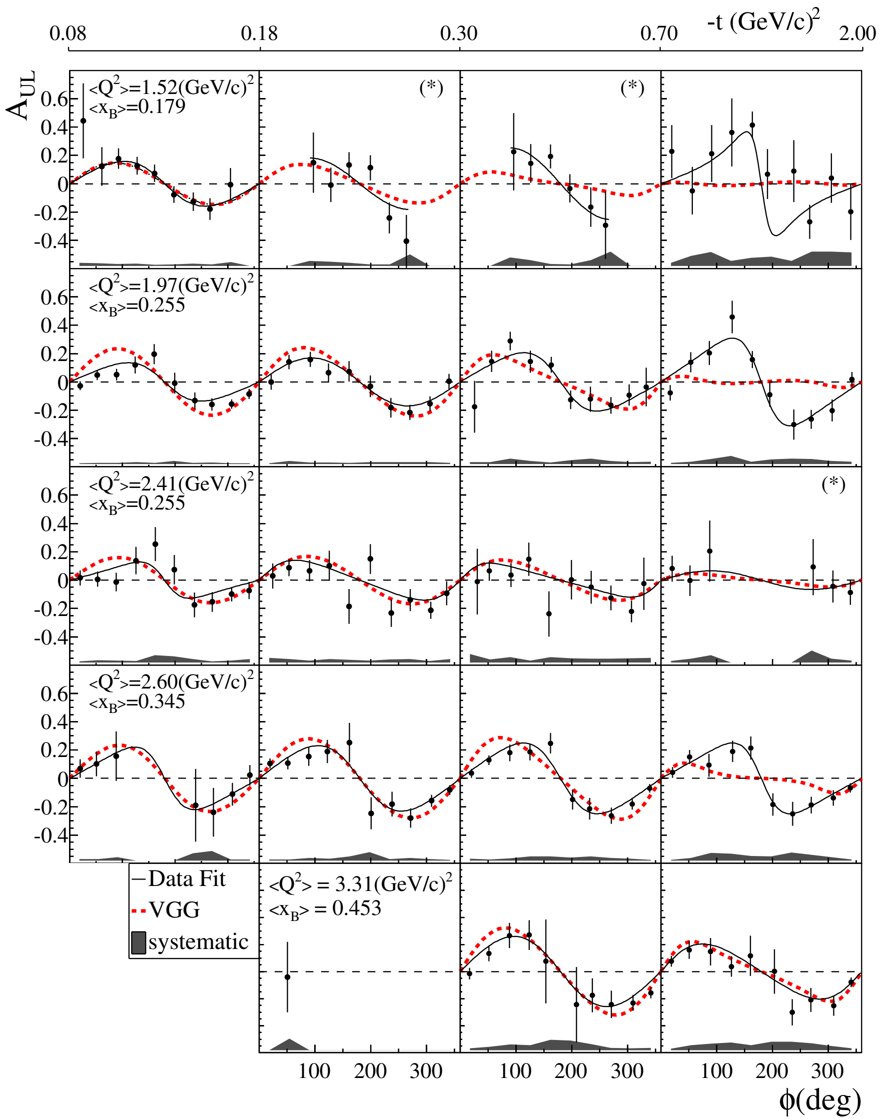
- **High statistics**, improvement of a factor 10 over previous target asymmetry measurement (S. Chen et al)
- Complete detection of the final state ->small nuclear background
- Large kinematic range
- **Simultaneous measurement of all three Beam, Target, and Double spin asymmetries in the same kinematic range**
  - simultaneous fit
  - Compton Form Factors

Observable	*Sensitivity to CFFs*	*Experiment*	*Notes*
$\Delta\sigma_{beam}(p)$	Im $\mathcal{H}_p$	Hall A	High statistics, limited coverage, 4 dimensional
A_{LU} (p)	Im $\mathcal{H}_p$	HERMES CLAS	High statistics and coverage, 4 dimensional
$\Delta\sigma_{beam}(n)$	Im $\mathcal{E}_n$	Hall A	One (Q^2,x_b) bin, 7 -t bins, low statistics, high
A_{UL} (p)	Im $\tilde{\mathcal{H}}_p$,Im $\mathcal{H}_p$	HERMES CLAS	Low statistics integrated over 3/4 variables
A_{LL} (p)	Re $\tilde{\mathcal{H}}_p$,Re $\mathcal{H}_p$	HERMES	Low statistics integrated over 3/4 variables
A_{UT} (p)	Im $\mathcal{H}_p$,Im $\mathcal{E}_p$	HERMES	Low statistics integrated over 3/4 variables

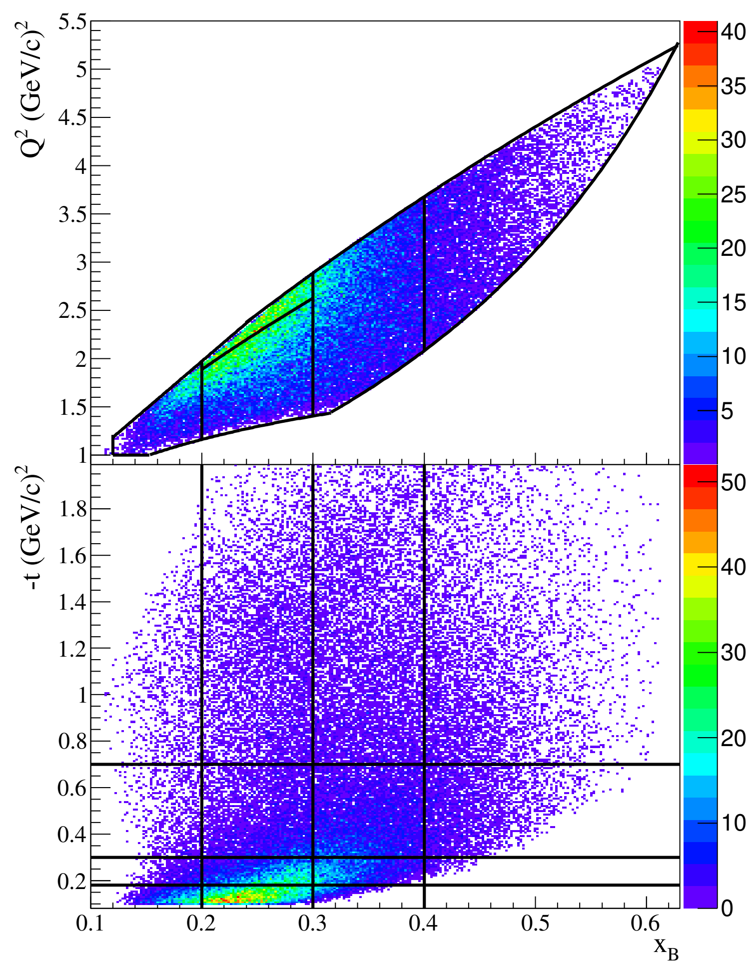
Analysis work by:
Biselli
Niccolai
Pisano
Seder

CLAS:Target Spin Asymmetries for DVCS

E. Seder et al Phys. Rev. Lett. 114 (2015) 032001

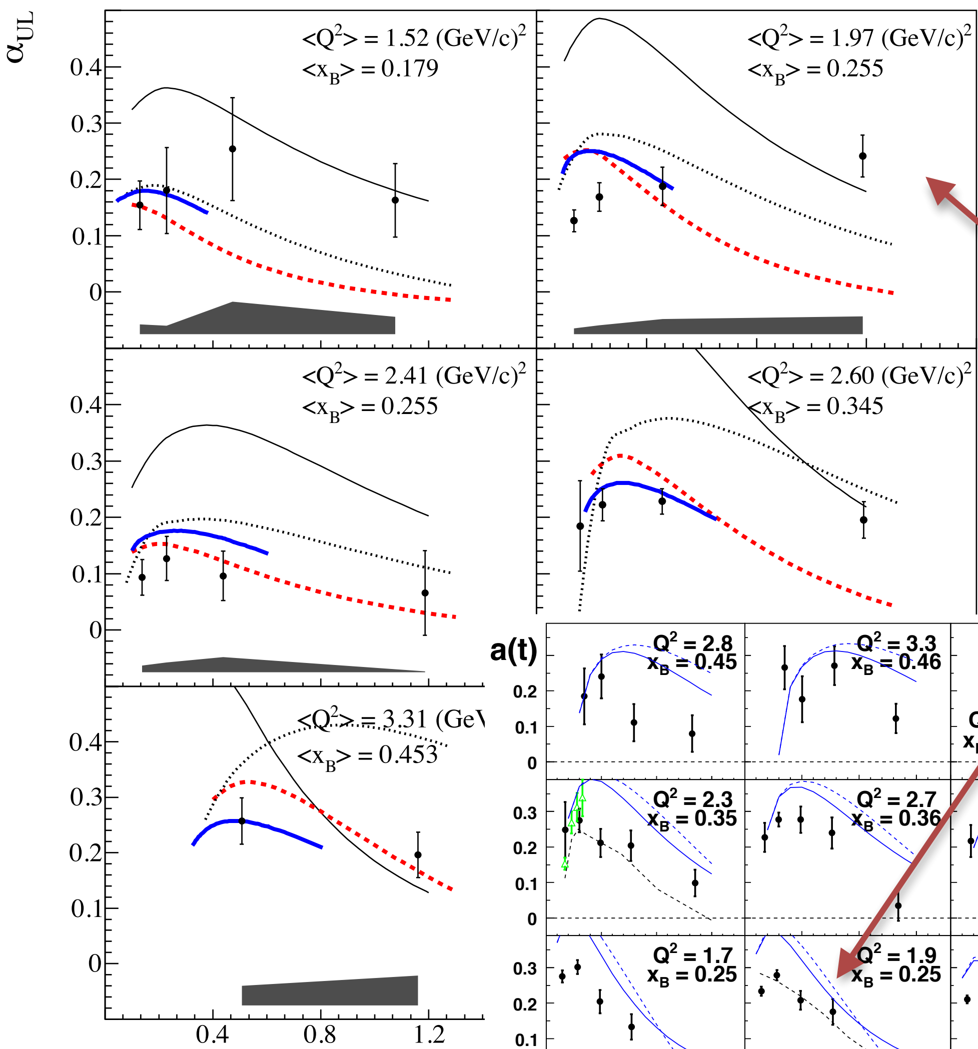


5 (Q^2,x$_b$) bins x 4 -t bins



CLAS:Target Spin Asymmetries for DVCS

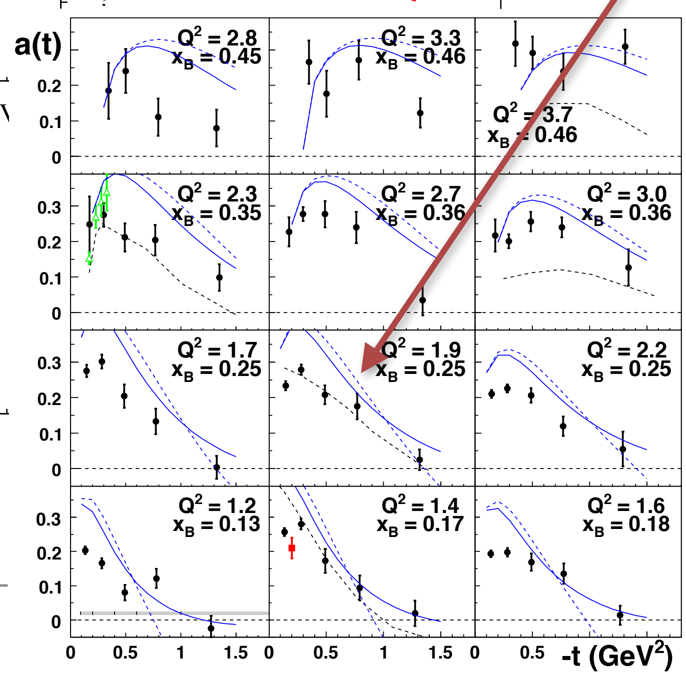
E. Seder et al Phys. Rev. Lett. 114 (2015) 032001



$$A_{UL} = \frac{\alpha_{UL} \sin\phi}{1 + \beta \cos\phi}$$

- Agreement with Hermes & CLAS
- Qualitative agreement VGG & GK low t
- Good agreement KMM12 for $t<Q^2/4$
  - Weaker drop in -t than A_{UL}

⇨Axial charge $\mathrm{Im}\tilde{\mathcal{H}}$ ⇔ A_{LU} is more concentrated than electric charge $\mathrm{Im}\mathcal{H}$ ⇔ A_{LU}

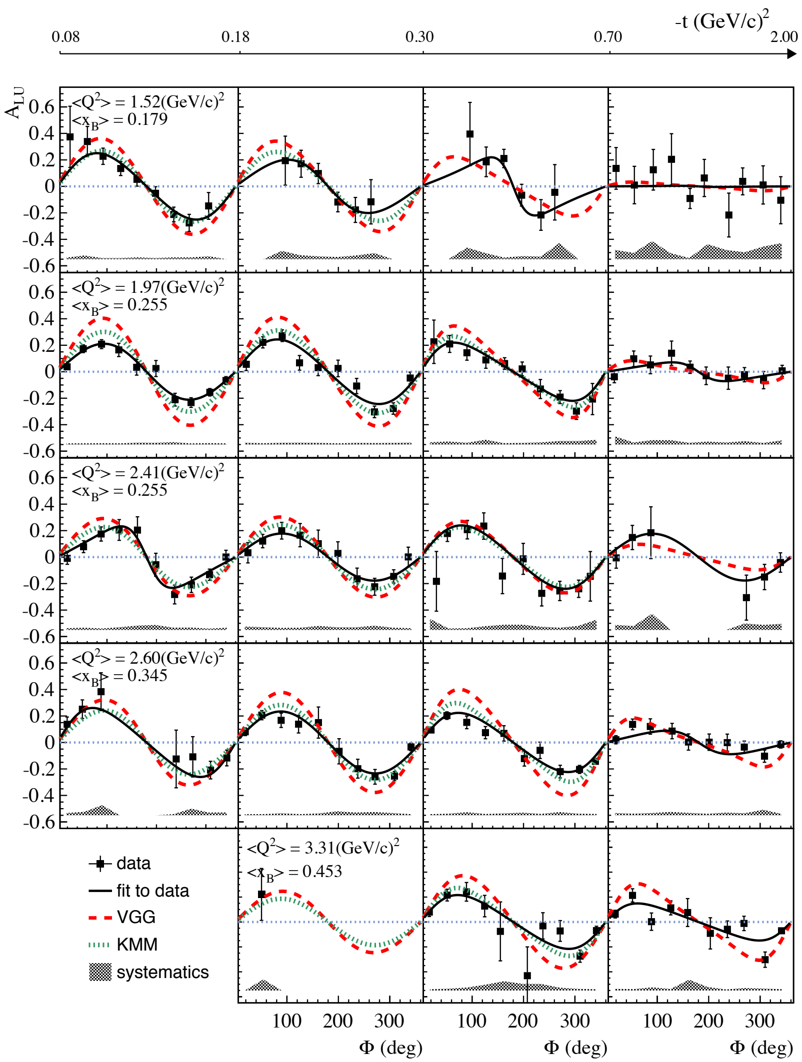


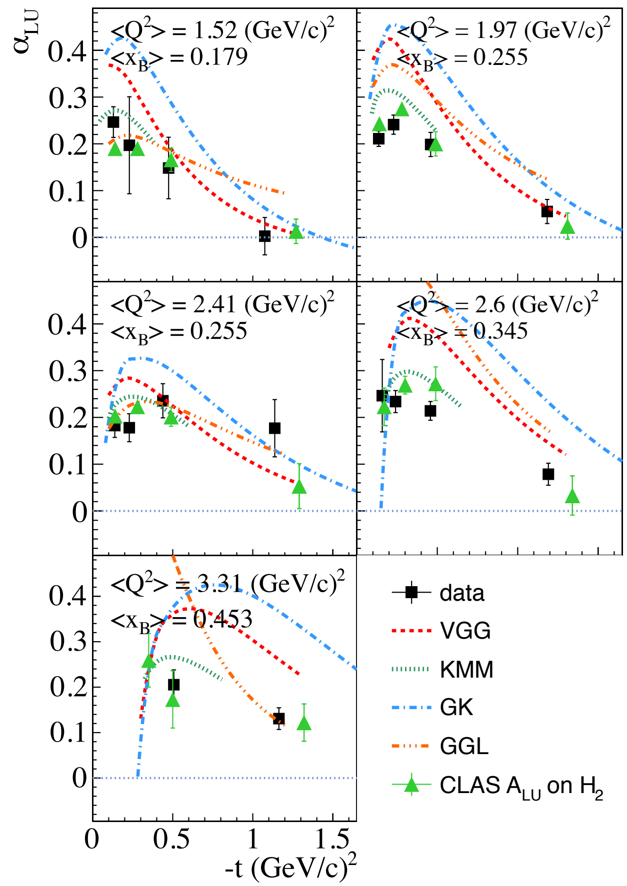
Models

- - - VGG Vanderhaeghen, Guidal, Guichon
- .... GK Goloskokov, Kroll
- — KMM12 Kumericki, Müller, Murray
- — GGL Gonzalez, Goldstein, Liuti

CLAS: Beam Spin Asymmetries for DVCS

S. Pisano *et al* arXiv:1501.07052 - PRD Accepted





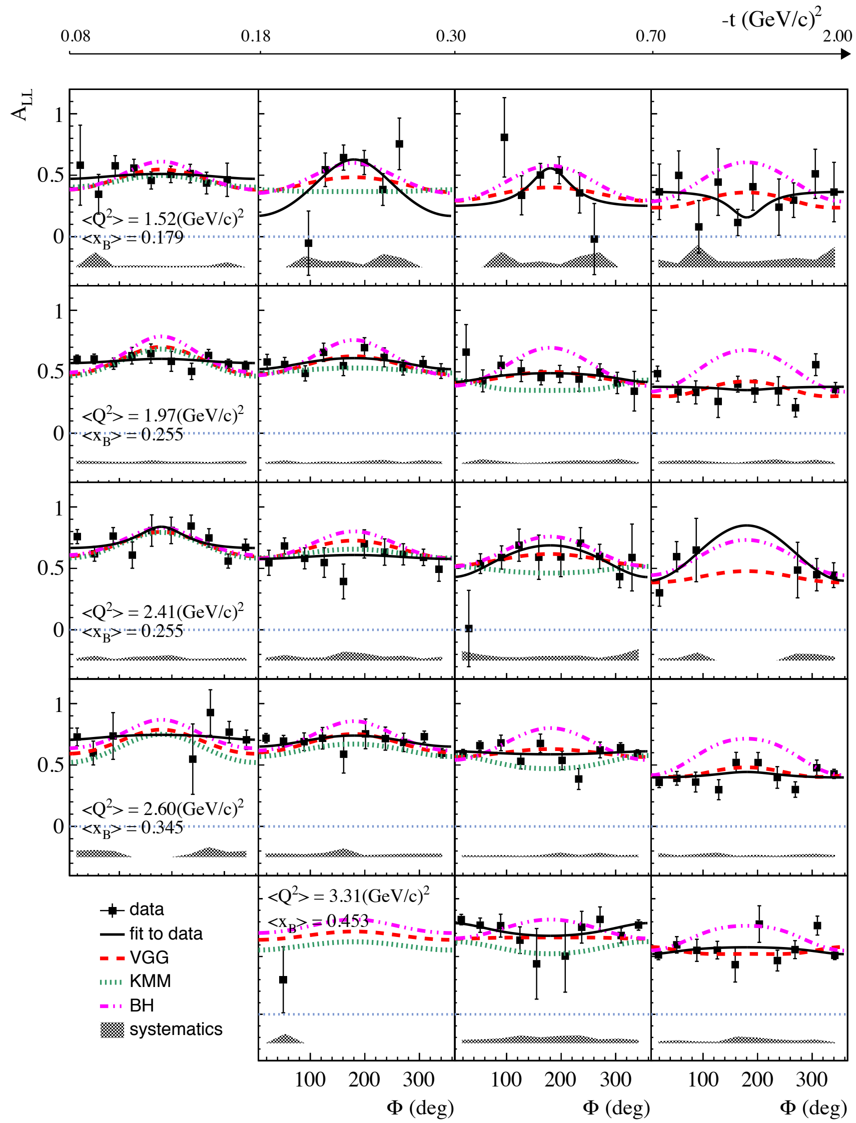
- Agreement with CLAS on H_2
- No sensitivity to nuclear effects
- Sensitivity to Im $\mathcal{H}_p$
- Fast drop in -t
- Good agreement KMM12 but t<Q^2/4
- Good agreement GL in some bins
- VGG & GK overestimate

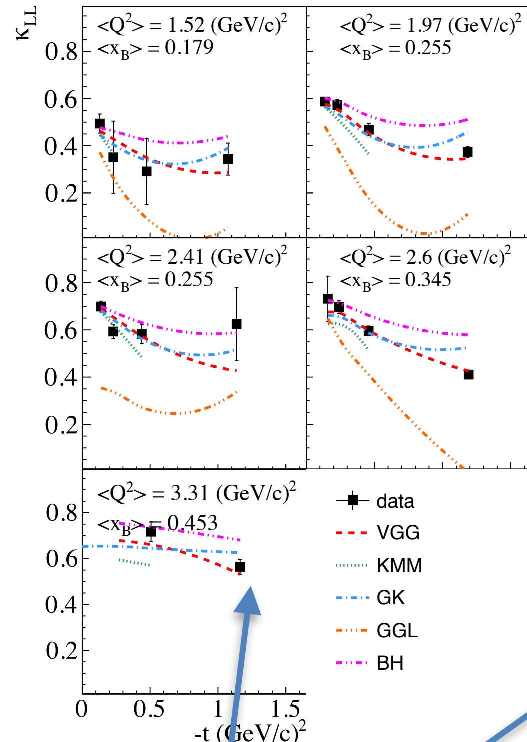
$$A_{LU} = \frac{\alpha_{LU} \sin\phi}{1 + \beta\cos\phi}$$

CLAS: Double Spin Asymmetries for DVCS

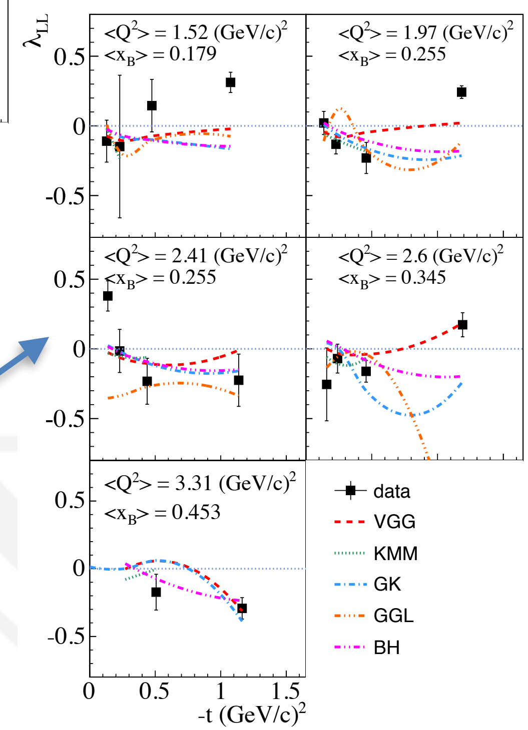
S. Pisano *et al* Phys. Rev. D.91 052014

- Constant term dominated by BH
- cosϕ term small and dominated by BH
- Agreement with VGG, GK, KMM



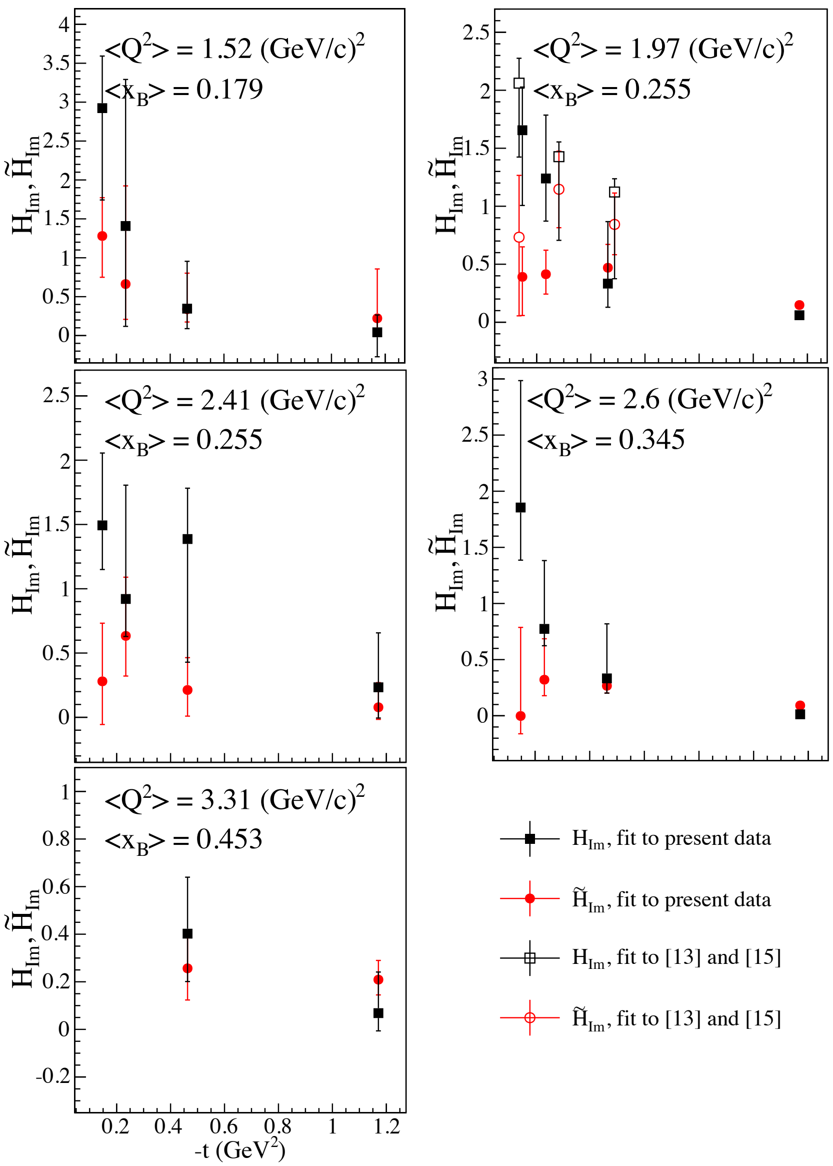


$$A_{LL} = \frac{k_{LL} + \lambda_{LL} \cos\phi}{1 + \beta\cos\phi}$$



CLAS: Compton Form Factors

S. Pisano *et al* Phys. Rev. D.91 052014



- M. Guidal, Eur. Phys. J. A 37, 319 (2008)
- Local fitting at each experimental Q^2, x_B, t
- Quasi model-independent: bounding the domains of variation of the CFFs (5xVGG)
- 8 unknowns, non linear problem, strong correlations

- Mostly sensitive to Im$\tilde{\mathcal{H}}$
- Im$\mathcal{H}$ has a steeper slope than Im$\tilde{\mathcal{H}}$ - axial charge more concentrated?
- Slope of Im$\mathcal{H}$ decreasing as x_b increases - fast quarks (valence) more concentrated in the nucleon's center, slow quarks (sea) more spread out
- Not enough A_{LL} statistical precision to extract real parts Re$\tilde{\mathcal{H}}$ Re$\tilde{\mathcal{E}}$

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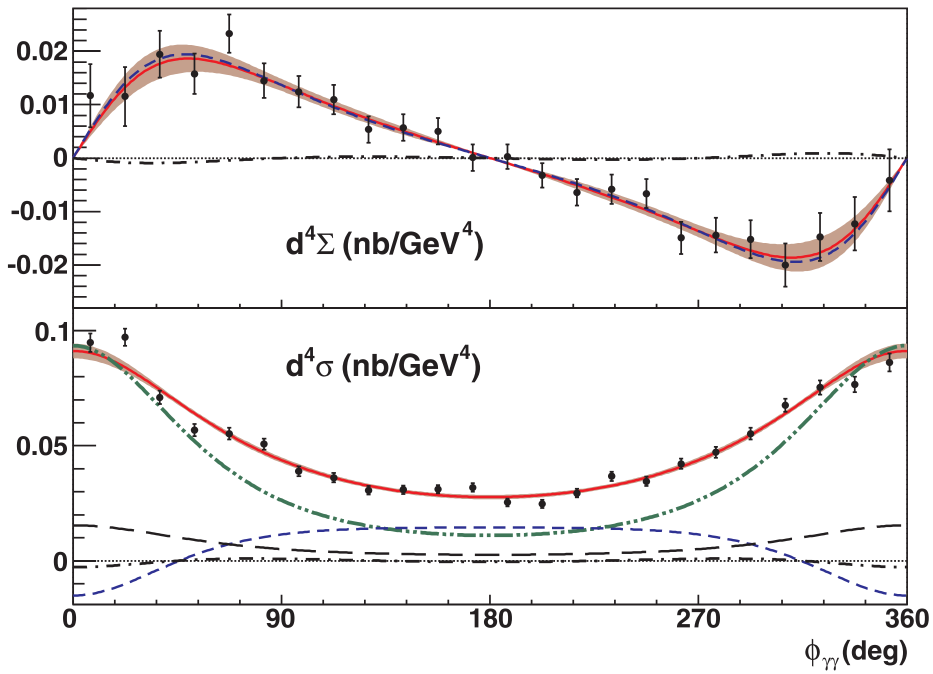
Hall A - cross section result (2006)

C.M. Camacho et al., PRL 97 (2006)



- Fit
- Only BH
- CFF twist-2
- CFF twist-2 for x-section
- CFF twist-3

Non zero DVCS contribution to σ

Negligible twist 3

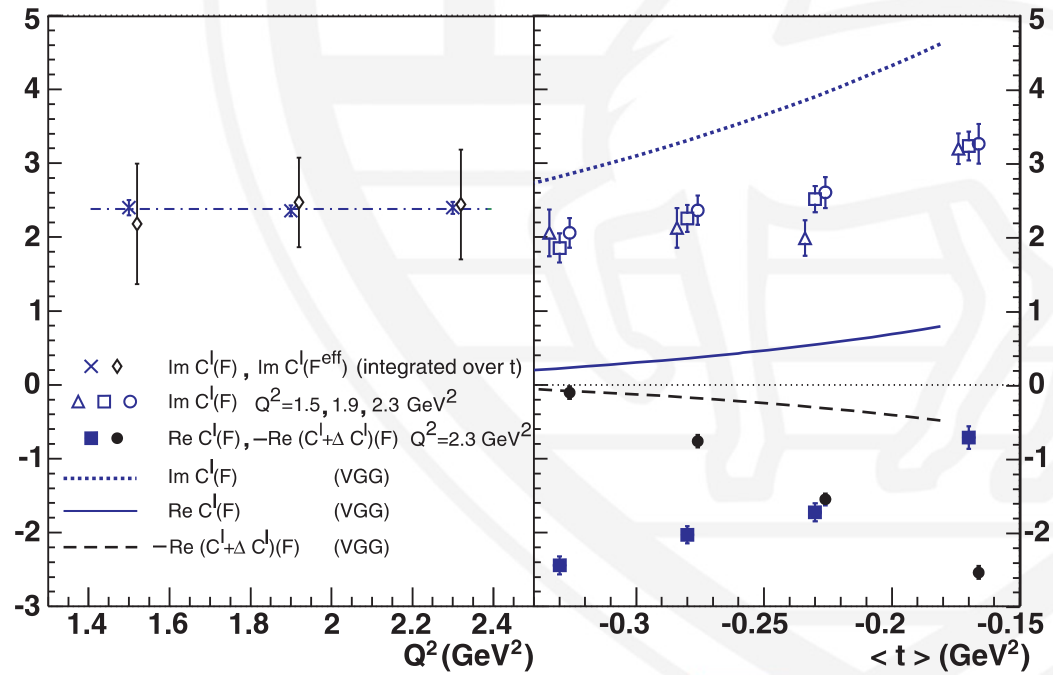
σ and Δσ

$\vec{e}p \rightarrow epX$

Q^2=1.5 2.3 GeV^2
$\langle x_B \rangle$=0.36
-t=0.11-0.33 GeV^2

small Q range

Q^2 independence of CFF ⇒ scaling



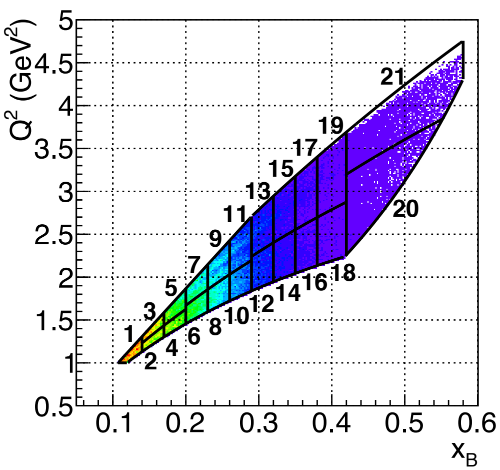
CLAS - DVCS cross section results

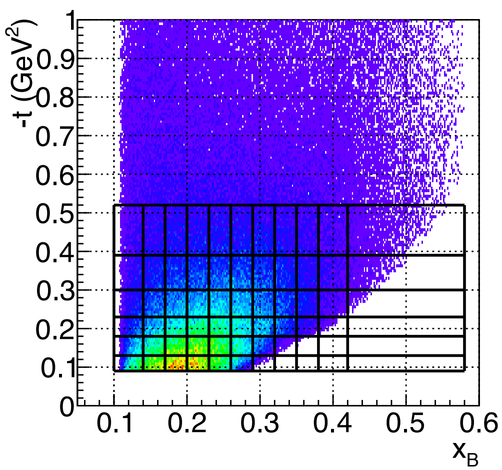
H. S. Jo *et al* arXiv:1501.07052 - PRL submitted

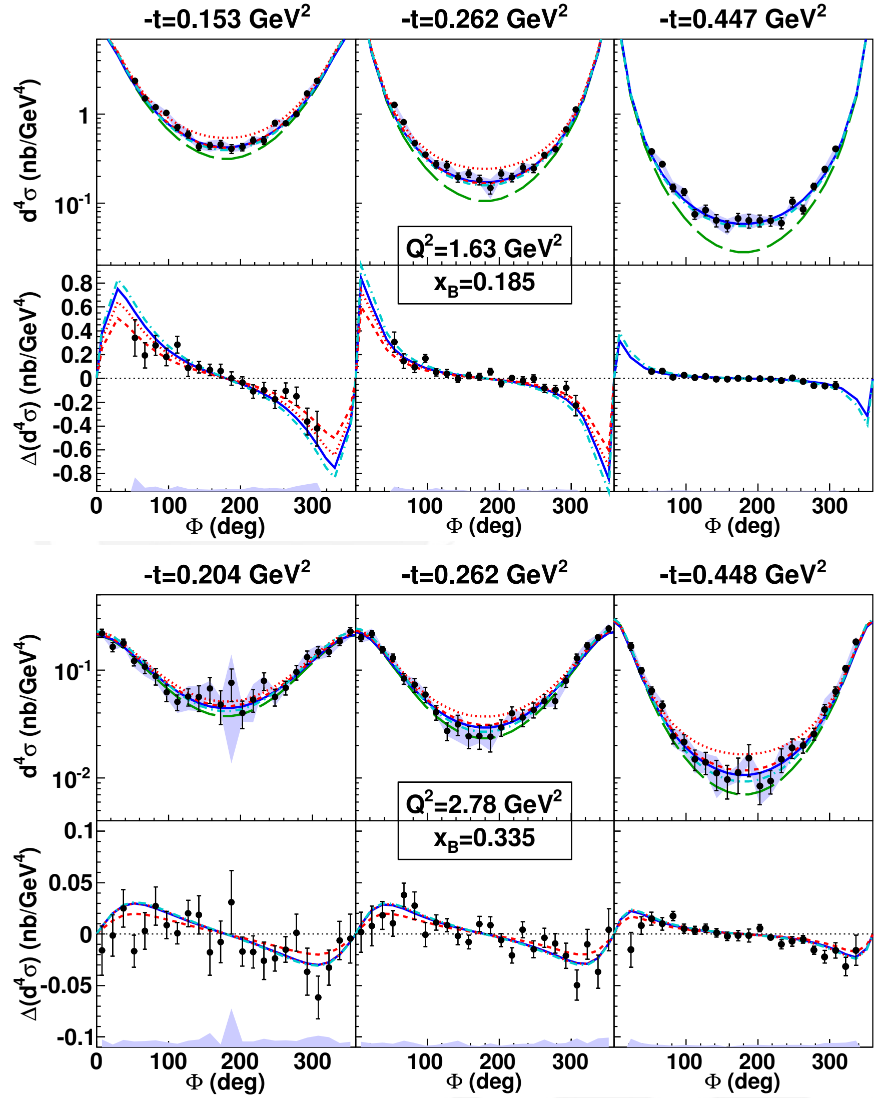
110 bins
Q^2=1-4.6 GeV^2
x_B=0.1-0.58
-t=0.09-0.52 GeV^2

σ and Δσ

$$\Delta(d^4\sigma) = \frac{1}{2}\left[\frac{d^4\overrightarrow{\sigma}_{ep\to e'p'\gamma}}{dQ^2dx_Bdtd\phi} - \frac{d^4\overleftarrow{\sigma}_{ep\to e'p'\gamma}}{dQ^2dx_Bdtd\phi}\right]$$







- - BH only

— VGG Vanderhaeghen, Guidal, Guichon — only H, Double dist

-.-. KMS Kroll, Moutarde, Sabati´e, — Double dist

.... KM10 Kumerick Mueller — 4 GPDs, fit JLAB HERMES, ZEUS

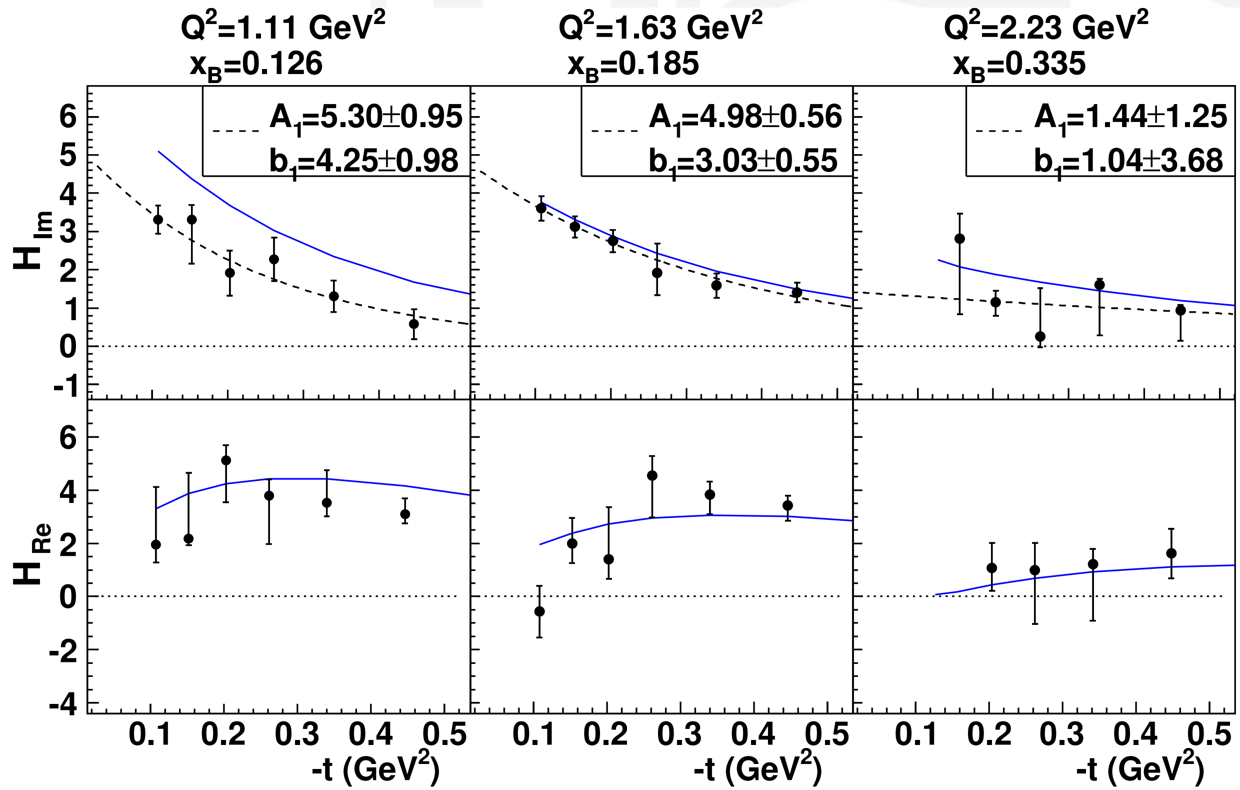
- - KM10a — no Hall A, H̃=0

Cross-section favors H̃=0 KM10a

CLAS - DVCS cross section differences

H. S. Jo *et al* arXiv:1501.07052 - PRL submitted

- M. Guidal, Eur. Phys. J. A 37, 319 (2008)
- Local fitting at each experimental Q^2, x_B, t
- Quasi model-independent: bounding the domains of variation of the CFFs (5xVGG)
- E and $\tilde{E}$ set to zero to limit free parameters
- well-defined minimizing values for H_{Im} and H_{Re}

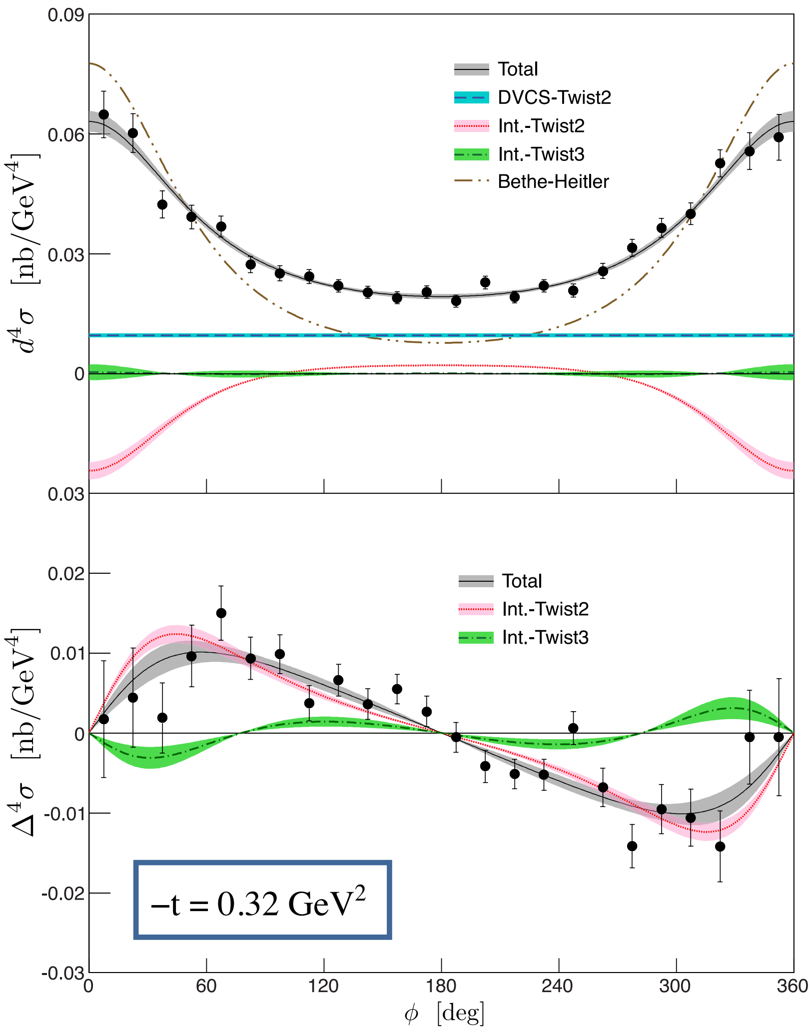


- VGG model > fitted H_{Im} @ the smallest values of x_B
- A, b decrease with increasing x_B
  - b⇔transverse size
  - A ⇔partonic content

⇒ size and partonic content are bigger at smaller momentum fractions

— VGG
- - fit Ae^{-bt}

Hall A - Recent cross section results



Defurne *et al* arXiv:1504.05453

σ and Δσ $\vec{e}p \to epX$

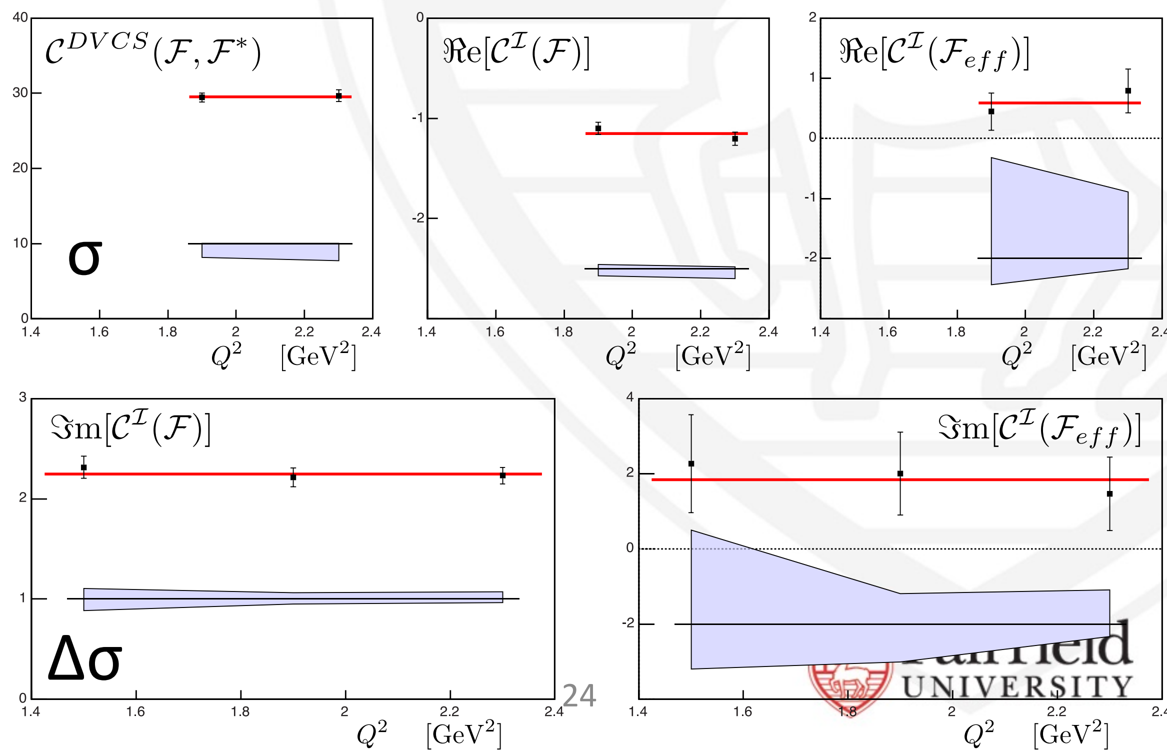
Reanalysis of data published in 2006

Q^2 dependence
Q^2=1.5-2.3 GeV^2
$\langle x_B \rangle$=0.36
-t=0.11-0.37 GeV^2
5 bins in t
(also x_B dep.)

CFF extraction vs Q^2

σ: Big twist-2 T_{DVCS}^2 term

σ: Small twist-3 contributions

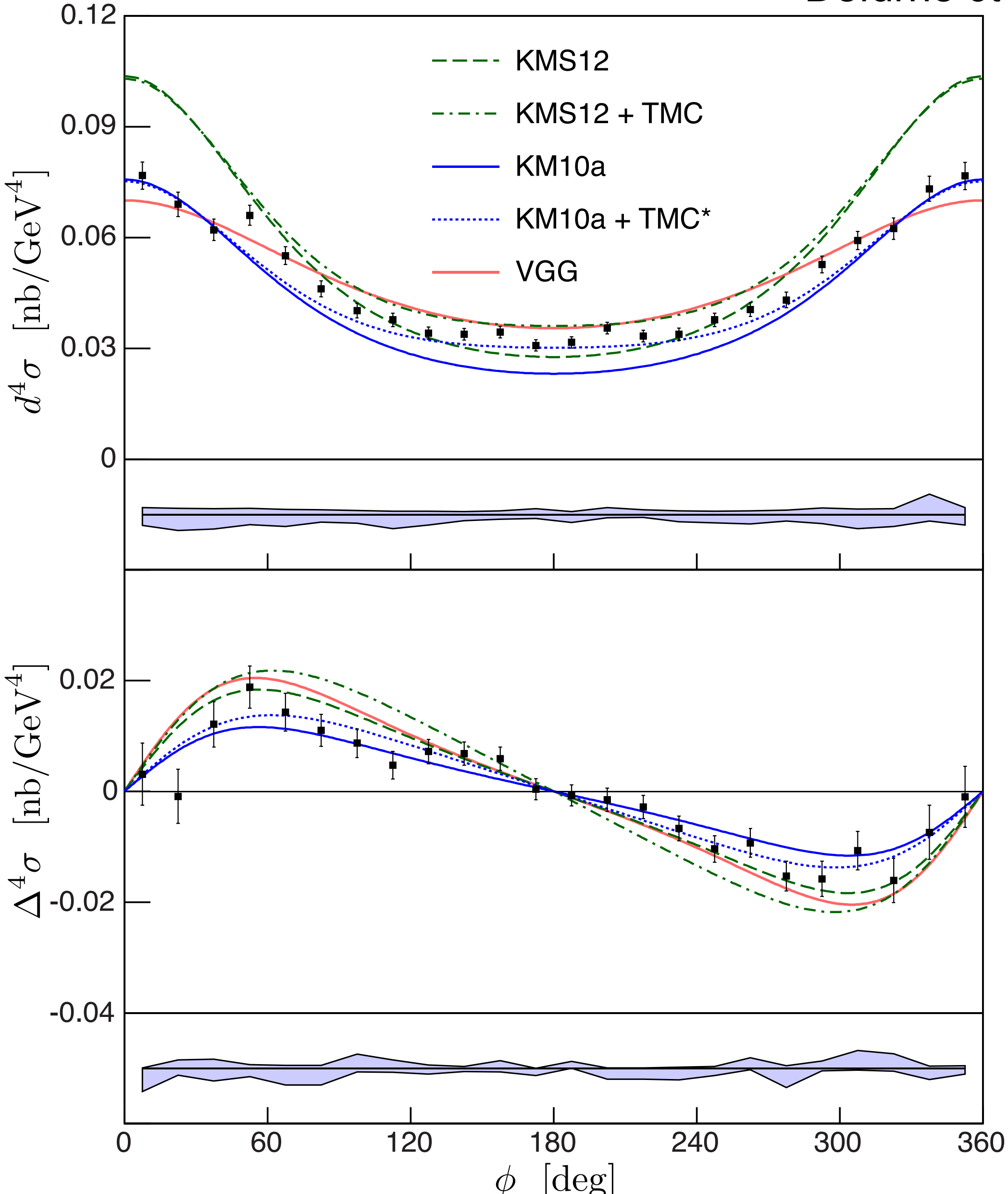


Δσ: Dominant twist-2 C^I term

Δσ: Small twist-3 C^I, large errors

Hall A - Recent cross section results

Defurne *et al* arXiv:1504.05453



- VGG better than KMS12 for σ
- both VGG and KMS12 overshoot Δσ
- KM10a good for Δσ
- KM10a underestimate σ at 180
- TMC (twist-4 target mass, finite t correction) on KMS12 and KM10a improves the agreement

KM10a tuned to all DVCS data but Hall A cross section

KM12 not adapted to valence region (tuned to vector meson data very low xB)

Hall A - Rosenbluth-like separation of DVCS

Experiment E07-007

Data taken in 2010

Analysis underway

Analysis technique:

- Measure σ and Δσ @fixed x_B, for 3 Q^2 bins and 2 beam energies
- Extract CFF coefficients using azimuthal dependence
- Use energy dependence of the coefficients to separate DVCS from I

$$\Im\mathrm{m}[\mathcal{C}^{\mathcal{I},\exp}(\mathcal{F})] = \Im\mathrm{m}[\mathcal{C}^{\mathcal{I}}(\mathcal{F})] + \langle\eta_{s1}\rangle \Im\mathrm{m}[\mathcal{C}^{DVCS}(\mathcal{F}^*,\mathcal{F}^{\mathrm{eff}})]$$

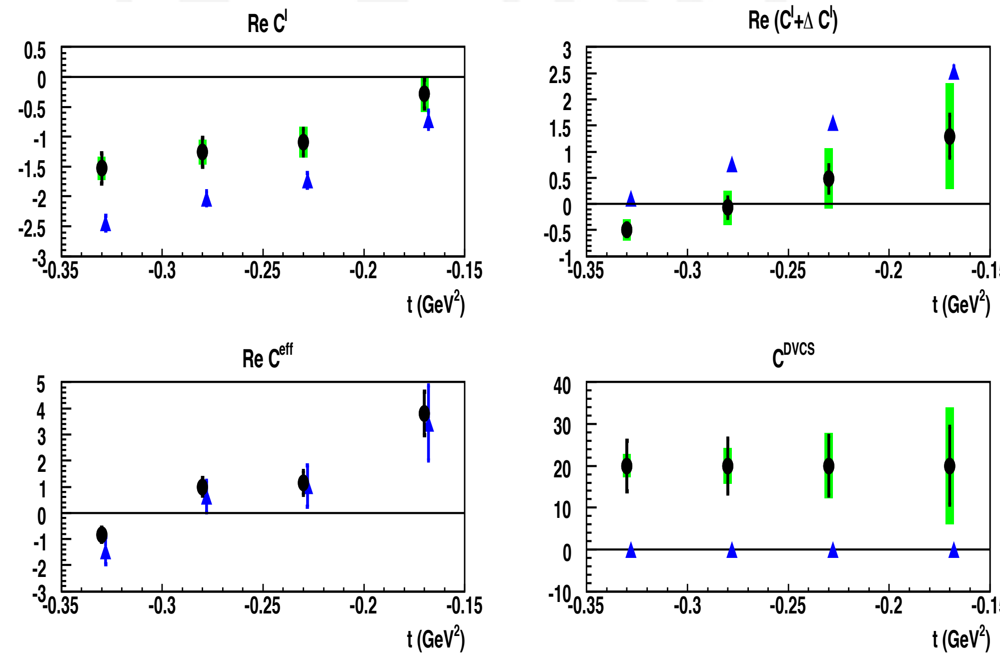
$$\Re\mathrm{e}\left\{[\mathcal{C}+\Delta\mathcal{C}]^{\mathcal{I},\exp}(\mathcal{F})\right\} = \Re\mathrm{e}\left\{[\mathcal{C}^{\mathcal{I}}+\Delta\mathcal{C}^{\mathcal{I}}](\mathcal{F})\right\} + \langle\eta_0\rangle \Re\mathrm{e}\left[\mathcal{C}^{\mathrm{DVCS}}(\mathcal{F}^*,\mathcal{F})\right]$$

$$\Re\mathrm{e}\left\{\mathcal{C}^{\mathcal{I},\exp}(\mathcal{F})\right\} = \Re\mathrm{e}\left\{\mathcal{C}^{\mathcal{I}}(\mathcal{F})\right\} + \langle\eta_{c1}\rangle \Re\mathrm{e}\left\{\mathcal{C}^{\mathrm{DVCS}}(\mathcal{F}^*,\mathcal{F})\right\}.$$

$$\Im\mathrm{m}[\mathcal{C}^{\mathcal{I},\exp}(\mathcal{F}^{\mathrm{eff}})] = \Im\mathrm{m}[\mathcal{C}^{\mathcal{I}}(\mathcal{F}^{\mathrm{eff}})] + \langle\eta_{s2}\rangle \Im\mathrm{m}[\mathcal{C}^{DVCS}(\mathcal{F}^*,\mathcal{F}^{\mathrm{eff}}))]$$

$$\Re\mathrm{e}[\mathcal{C}^{\mathcal{I},\exp}(\mathcal{F}^{\mathrm{eff}})] = \Re\mathrm{e}[\mathcal{C}^{\mathcal{I}}(\mathcal{F}^{\mathrm{eff}})] + \langle\eta_{c2}\rangle \Re\mathrm{e}[\mathcal{C}^{DVCS}(\mathcal{F}^*,\mathcal{F}^{\mathrm{eff}})].$$

Projected results



▲ E00-110 extraction of phenomenological coefficients DVCS²+I

- project results (different if DVCS² term is large)

Stay tuned for results

DVCS on the neutron

- We can extract GPDs for proton or neutron but we want GPDs for quark flavors

$$(H,E)_u(\xi,\xi,t) = 9/15[4(H,E)_p(\xi,\xi,t) - (H,E)_n(\xi,\xi,t)]$$
$$(H,E)_d(\xi,\xi,t) = 9/15[4(H,E)_n(\xi,\xi,t) - (H,E)_p(\xi,\xi,t)]$$

- H,E for both proton and neutron are needed
  - E_n BSA on neutron
  - E_p TTSA on proton
  - H_n TSA on neutron
  - H_p BSA on proton

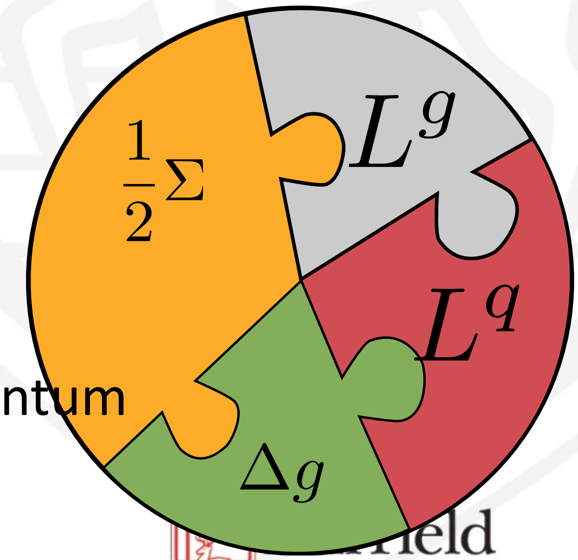
nDVCS important for flavor separation

- with H_q,E_q can extract the quark angular momentum (Ji's sum rule)

$$J_N = \frac{1}{2} = J^q + J^g = \frac{1}{2}\Sigma + L^q + \Delta g + L^g$$

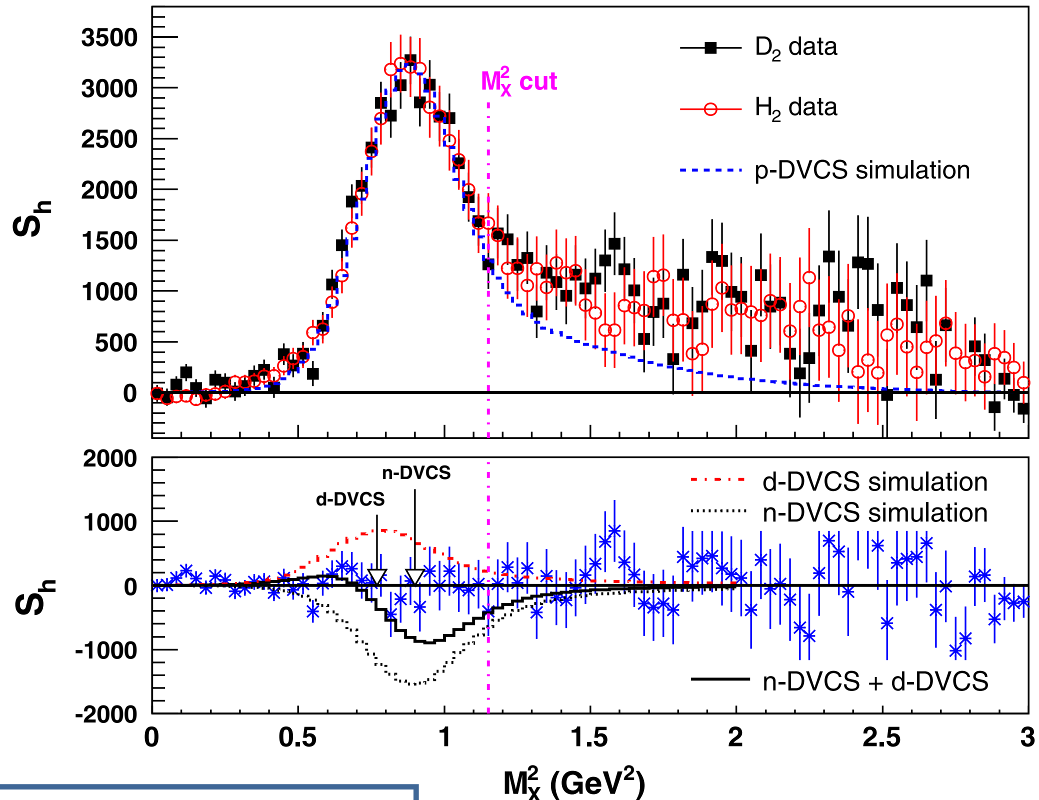
$$J^q = \frac{1}{2} - J^g = \frac{1}{2}\int_{-1}^{+1} x dx [H^q(x,\xi,0) + E^q(x,\xi,0)]$$

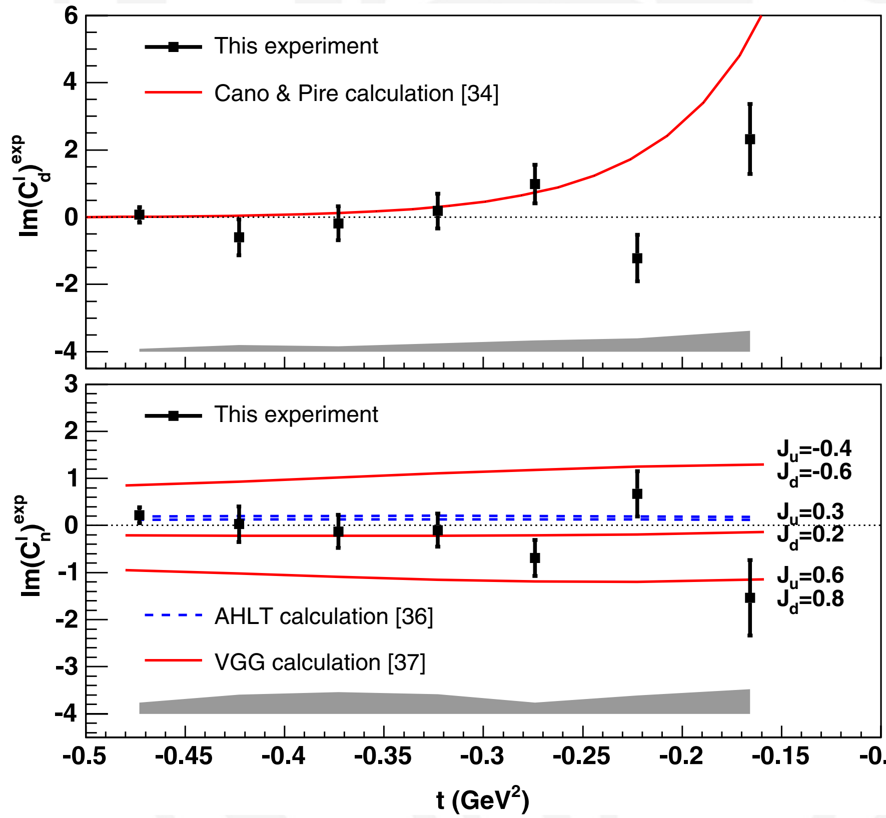
information on quark orbital angular momentum



Hall A: DVCS neutron $D(\vec{e},e',\gamma)X$

M. Mazouz et al., PRL 99,242501 (2007)





$\langle Q^2\rangle$=1.9 GeV^2

$\langle x_B\rangle$=0.36

-t=0.1-0.5 GeV^2

$$D(\vec{e},e',\gamma)X = d(\vec{e},e',\gamma)d + n(\vec{e},e',\gamma)n + p(\vec{e},e',\gamma)p + \ldots$$

$$\frac{d^5\Sigma_{D-H}}{d^5\Phi} = \frac{1}{2}\left(\frac{d^5\sigma^+}{d^5\Phi} - \frac{d^5\sigma^-}{d^5\Phi}\right) = \left(\Gamma_d^{\mathcal{I}}\mathcal{I}\mathrm{m}[\mathcal{C}_d^I]^{exp} + \Gamma_n^{\mathcal{I}}\mathcal{I}\mathrm{m}[\mathcal{C}_n^I]^{exp}\right)\sin(\phi_{\gamma\gamma})$$

Fit of 2520 bins in M_x, t and $\phi_{\gamma\gamma}$ to extract CFFs

Sensitivity to Im{E}

Sensitivity to quark angular momentum J_u J_d

CLAS: DVCS neutron

$$e + \vec{d} \rightarrow e' + \gamma + n + (p_s)$$

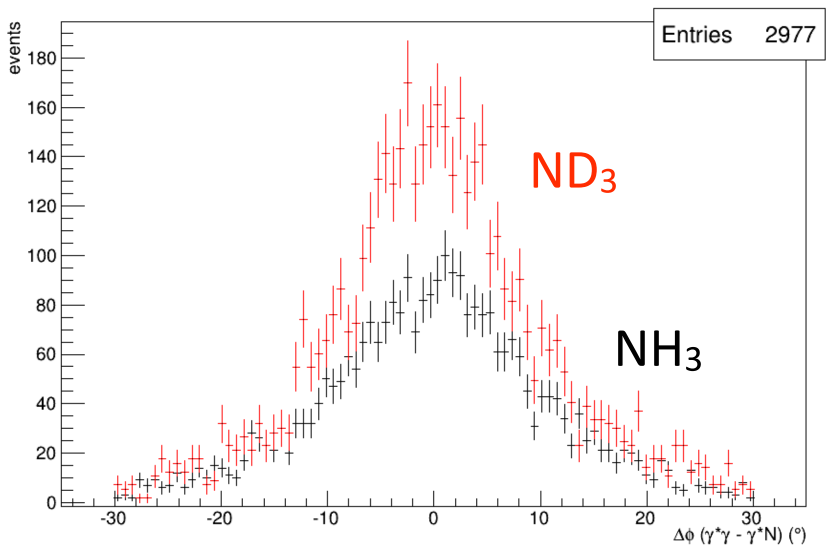
Work by D. Sokhan

eg1-dvcs run
CLAS+IC
- NH3 95 days
- ND3 33 days

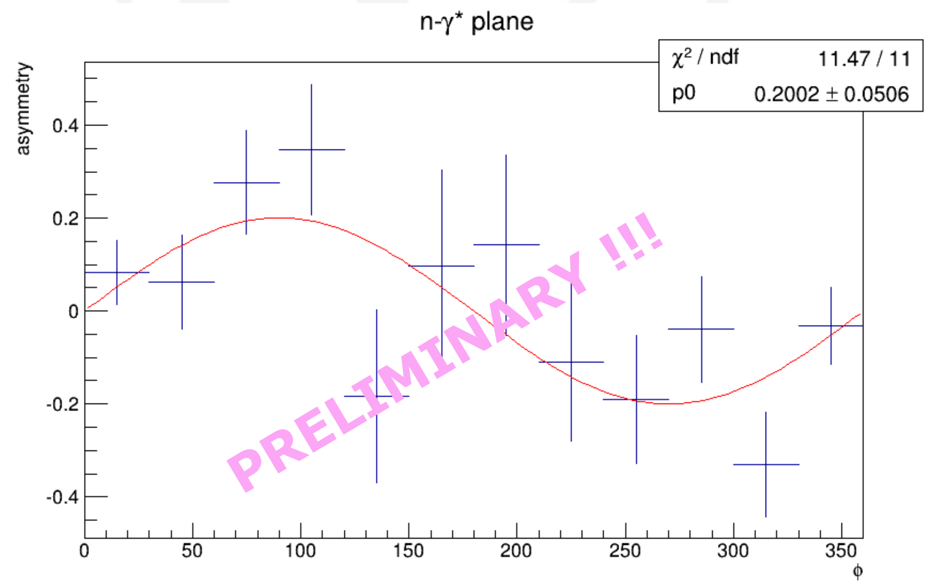
Analysis underway

E_b=6 GeV
beam pol=80%
neutron pol 30%

Non-zero BSA

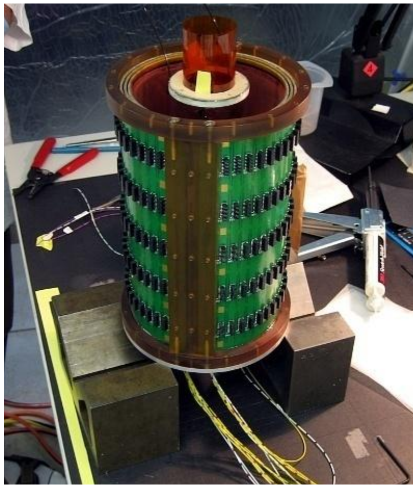


Use NH_3 to subtract nuclear background



CLAS: DVCS on nuclei

Work by M. Hattawy

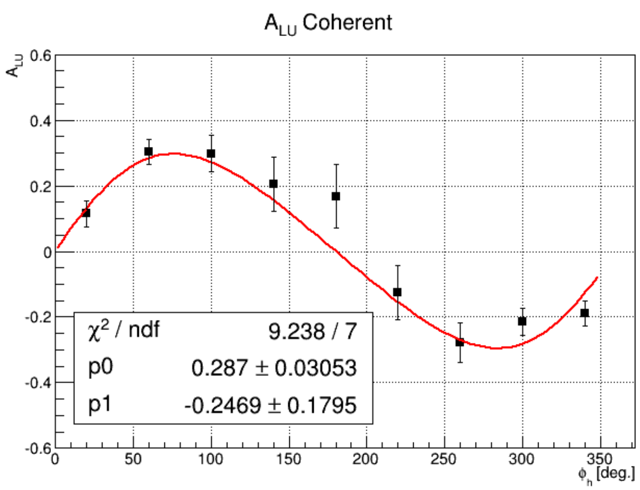


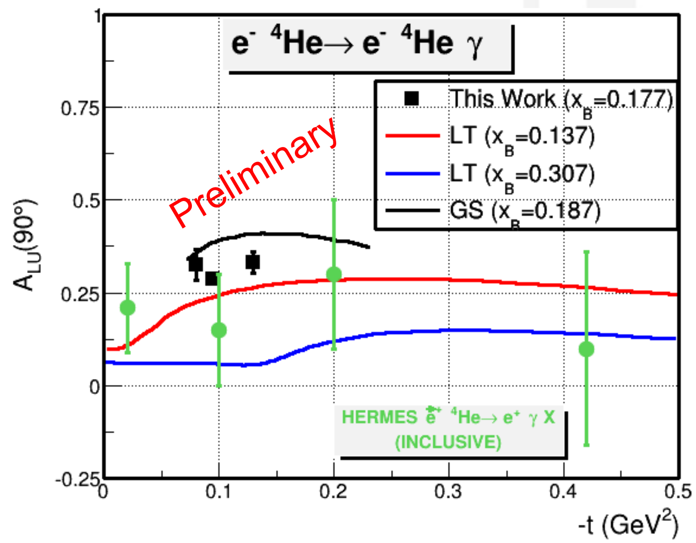
eg6 run
CLAS+IC+RTCP
^{4}He target
Beam: 6GeV
Analysis underway

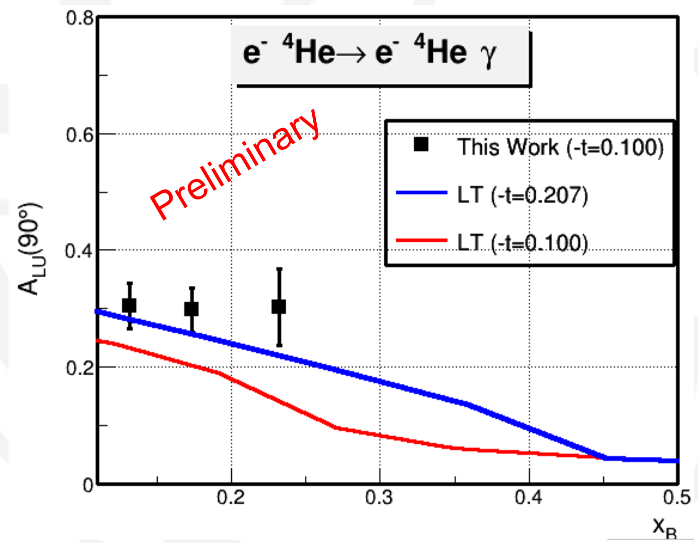
Measure of coherent and incoherent DVCS

^{4}He spin 0, only one GPD at twist-2 in DVCS BSA

$$A_{LU}^{^4He}(\phi) = \frac{a_0(\phi)F_A(t)\mathcal{I}\mathrm{m}[\mathcal{H}_A]}{a_1(\phi)F_A^2(t) + a_2(\phi)F_A(t)\mathcal{R}\mathrm{e}[\mathcal{H}_A] + a_3(\phi)\mathcal{R}\mathrm{e}[\mathcal{H}_A]^2 + a_3(\phi)\mathcal{I}\mathrm{m}[\mathcal{H}_A]^2}$$







only stat errors

Fit ALU signals: p0$*$sin(ϕ)/(1+ p1$*$cos(ϕ))

LT: S. Liuti and S. K. Taneja.Phys. Rev., C72:032201, 2005.
GS: V. Guzey and M. Strikman. Phys. Rev., C68:015204, 2003.
HERMES: F. Ellinghaus, R. Shanidze, and J. Volmer. AIP Conf. Proc., 675:303–307, 2003

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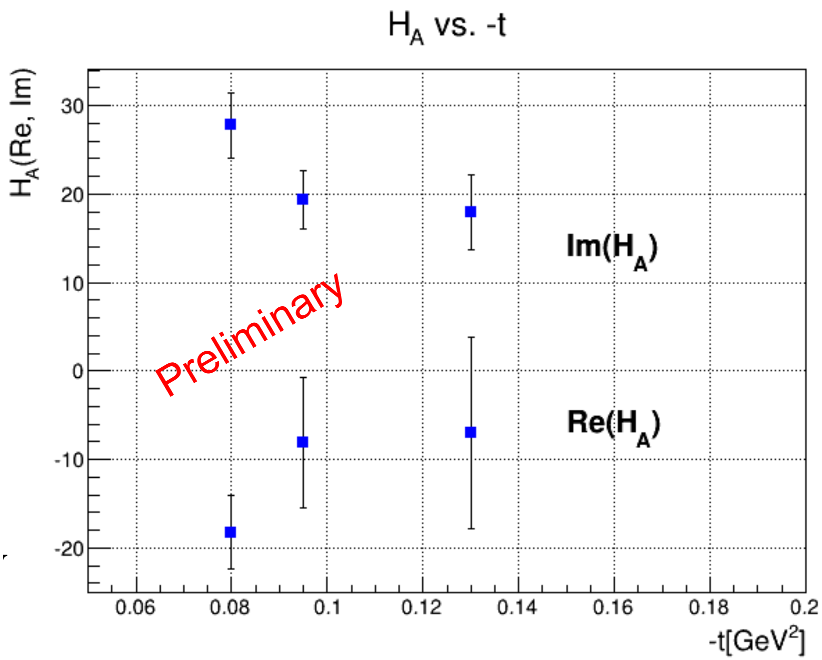
CLAS: DVCS on nuclei (cont.)

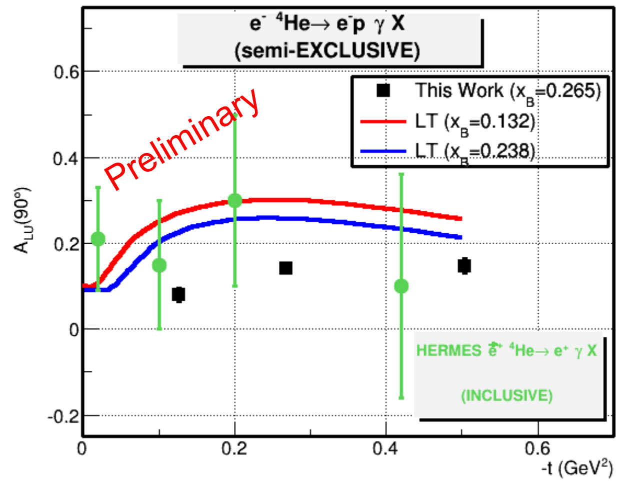
Work by M. Hattawy

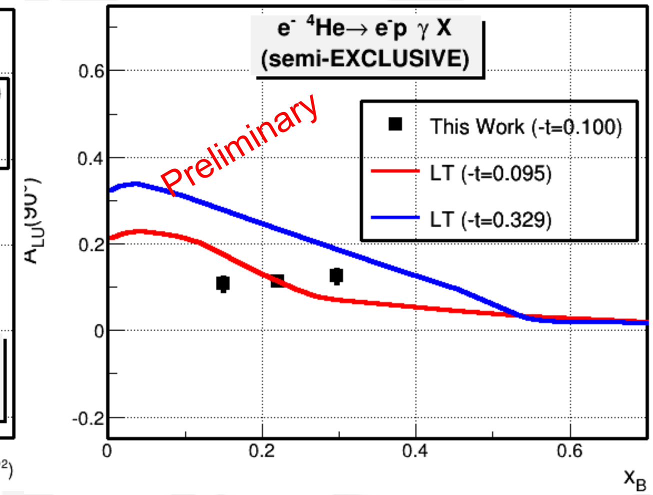
Fit of ALU@90 vs t

Extraction of the CFF



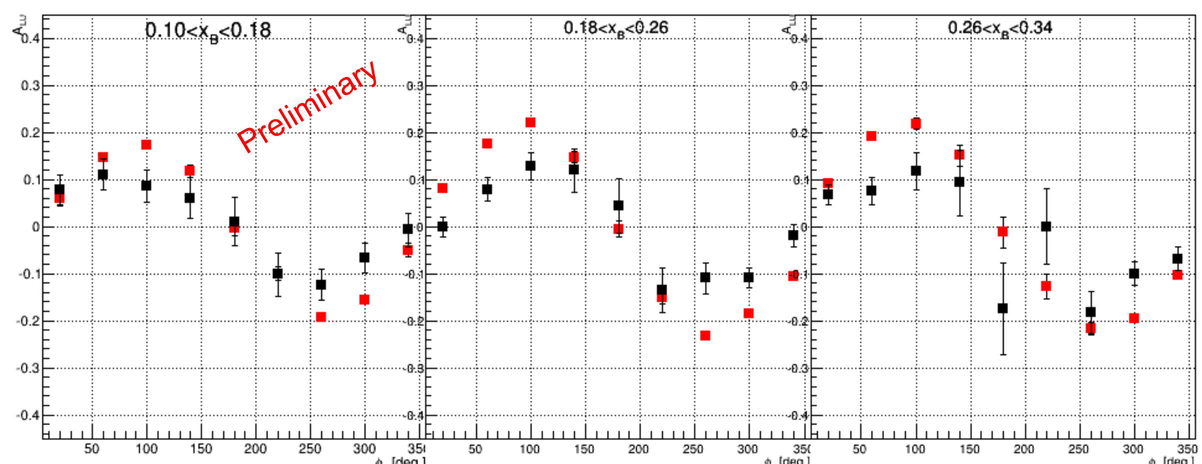
Incoherent DVCS





Comparison coherent and incoherent

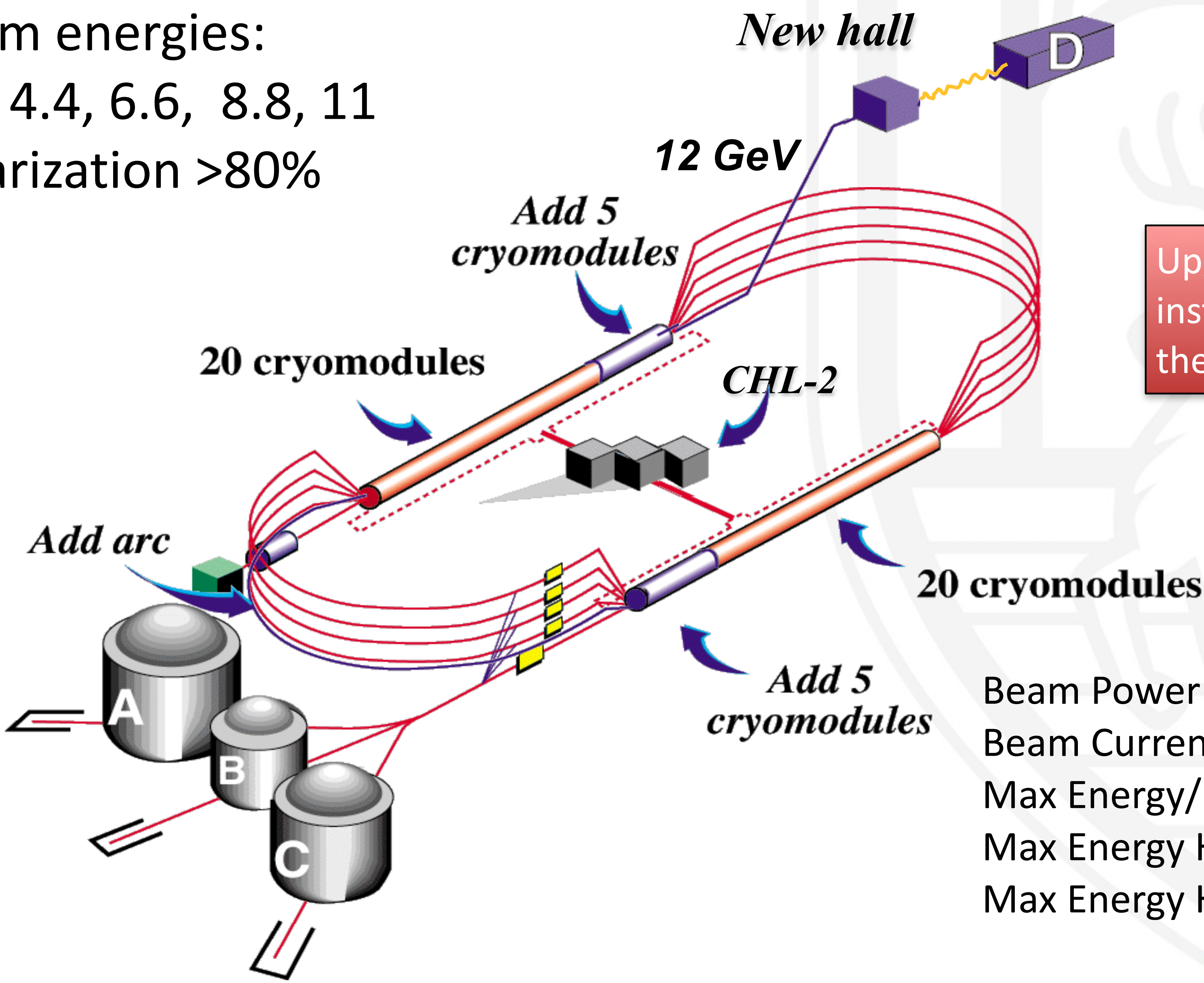
A_{LU} vs. φ in x_B bins



The bound proton shows a lower asymmetry relative the free one in the different bins in x_B

Upgrade of Jefferson Lab

Beam energies:
2.2, 4.4, 6.6, 8.8, 11
Polarization >80%



Upgrade of the instrumentation in the three Halls

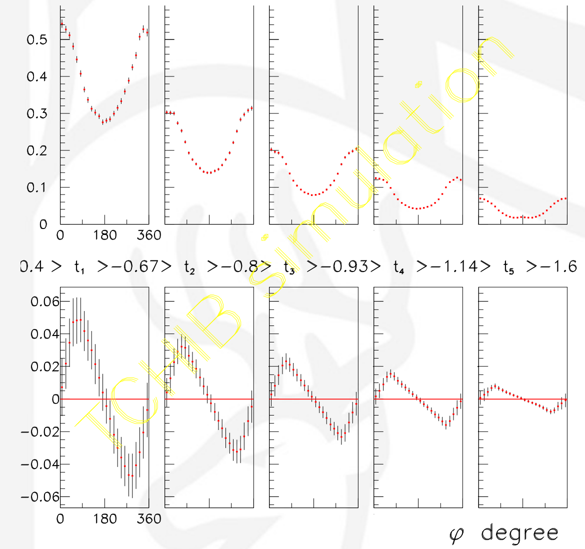
Beam Power: 1MW
Beam Current: 90 μA
Max Energy/pass: 2.2 GeV
Max Energy Hall A-B-C: 11 GeV
Max Energy Hall D: 12 GeV

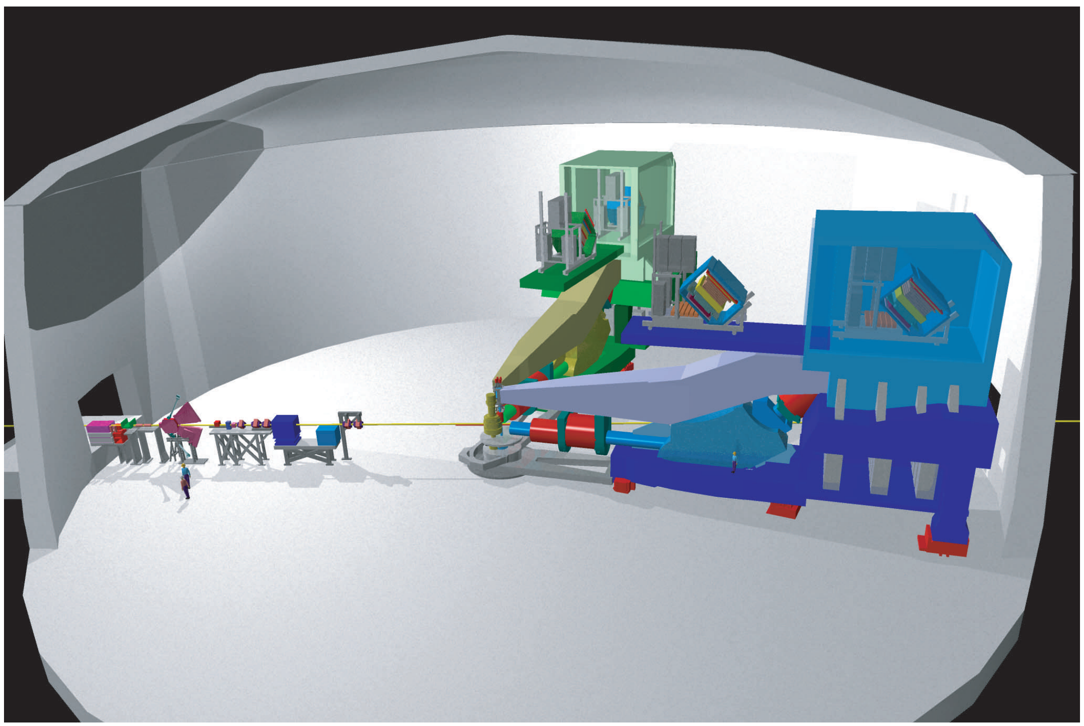
Hall A DVCS @ 12 GeV

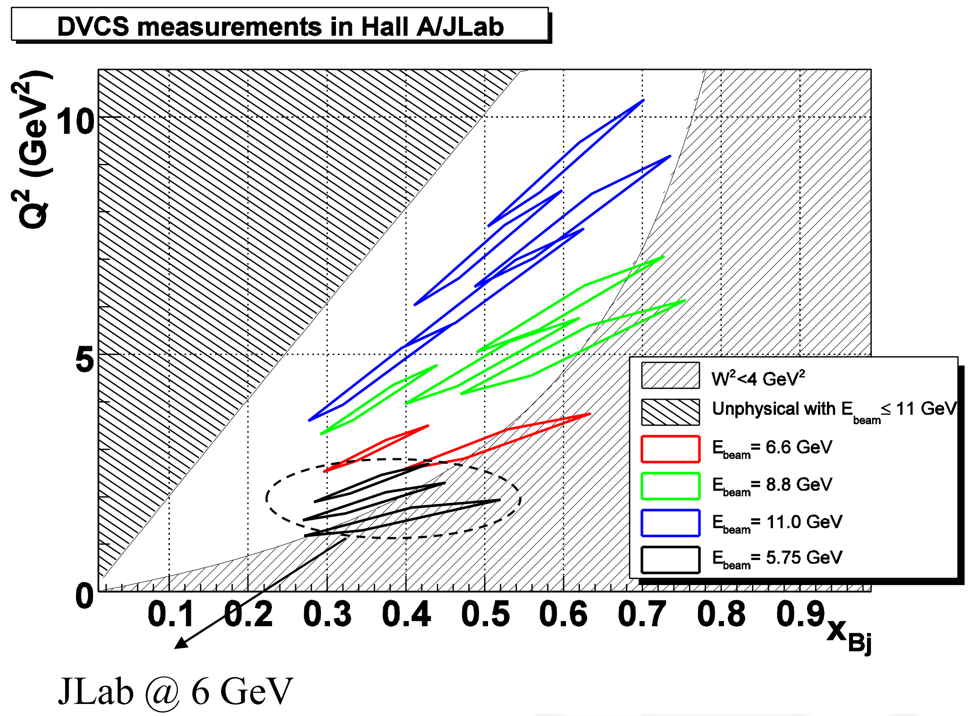
E12-06-114: HRS-L +PbF2 calorimeter

- Absolute cross sections
- Test of scaling: Q^2 dependence of s for fixed x_B
- increased kinematic coverage

First experiment to run after the 12 GeV upgrade







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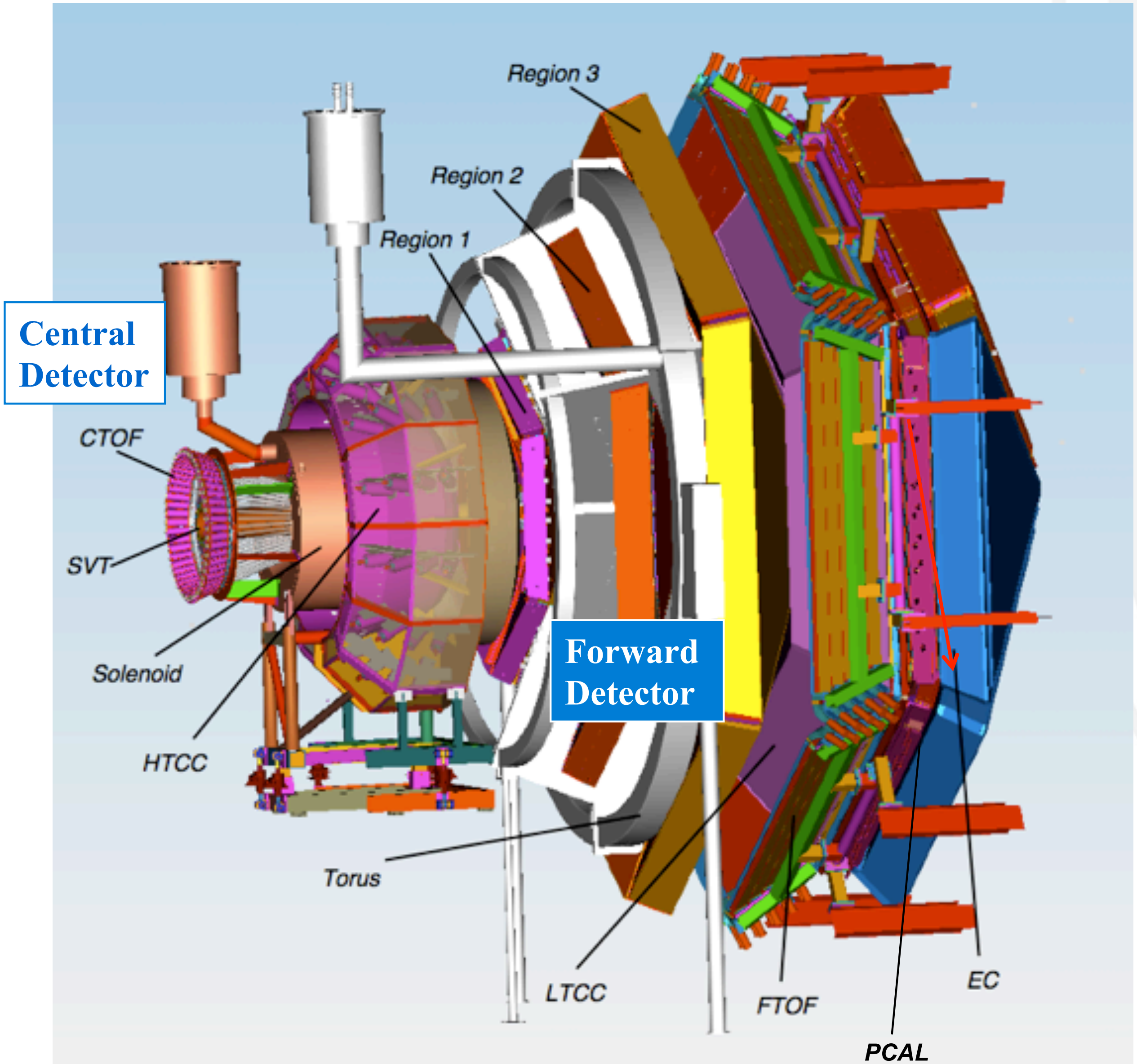
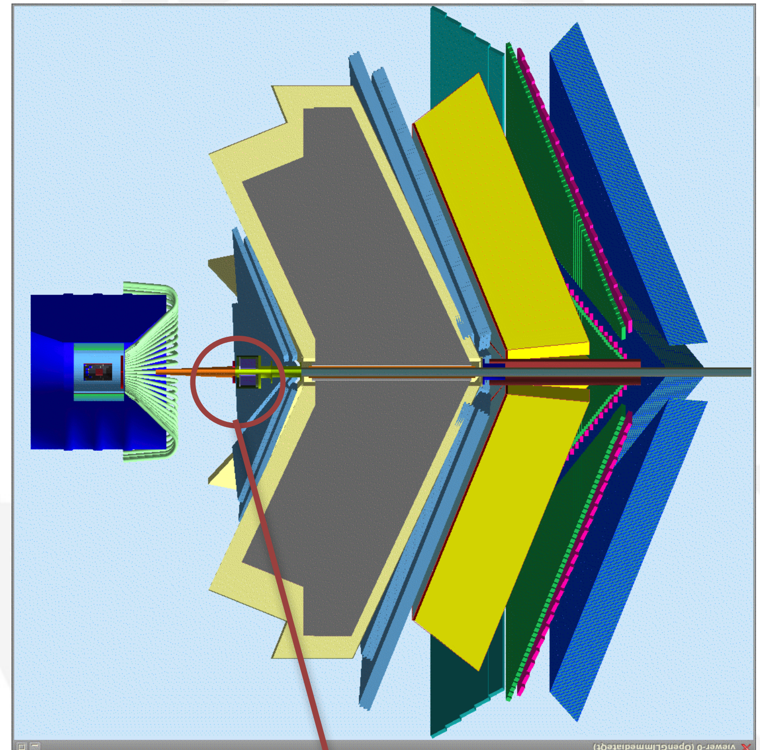
CLAS12





Forward Tagger
2.5-5 deg photons

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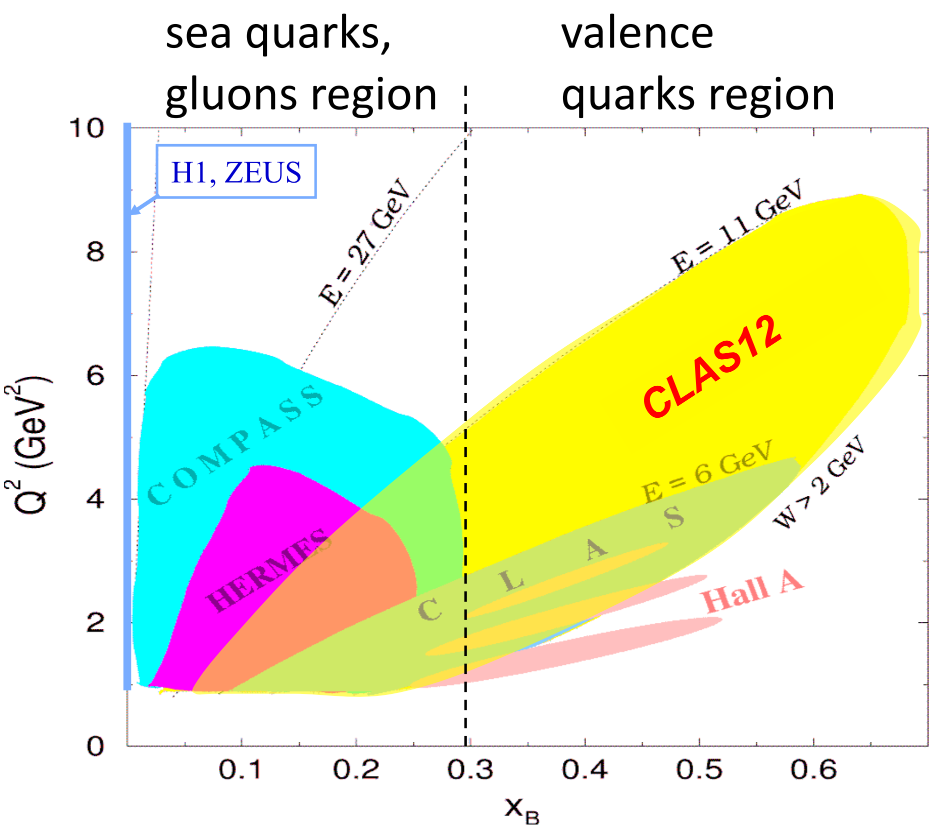
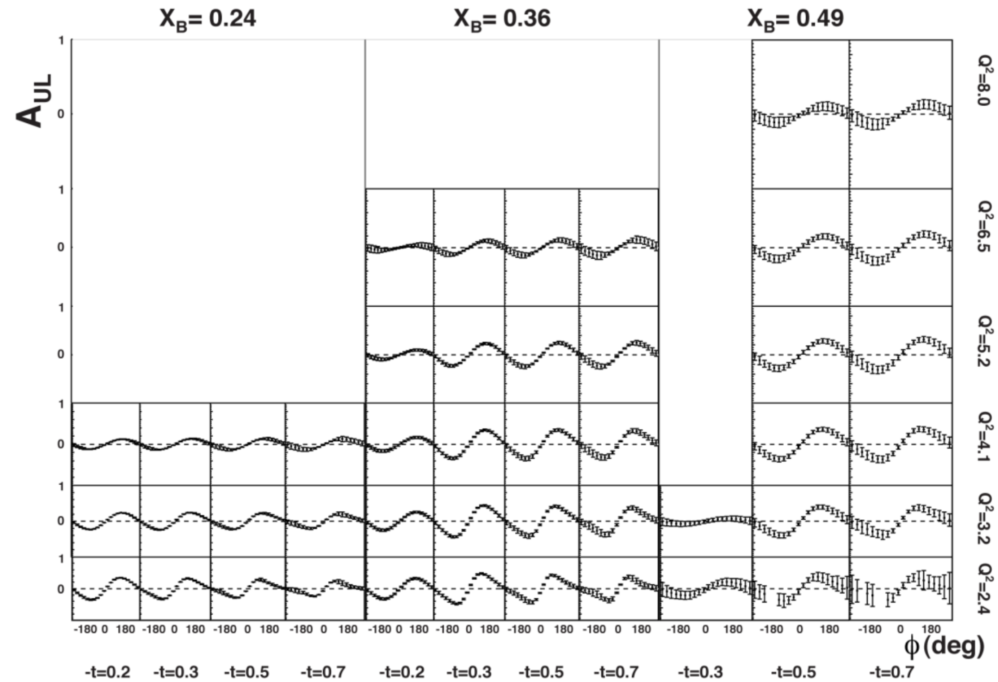
CLAS12 DVCS experiments

CLAS12,FT,CND,NH3,HDIce

- Large kinematic coverage
- BSA, TSA, DSA, tTSA
- cross-section
- CFF extraction





CLAS exper.	*physics*
E12-06-112	DVCS BSA TSA
E12-11-003	nDVCS BSA
E12-06-119	pol target DVCS
	pDVCS transverse TSA

Luminosity up to saf1

Pb~85% NH_3 ~80%

$1<Q^2<10$ GeV^2

$0.1<x_B<0.65$

$-t_{min}<-t<2.5$ GeV^2

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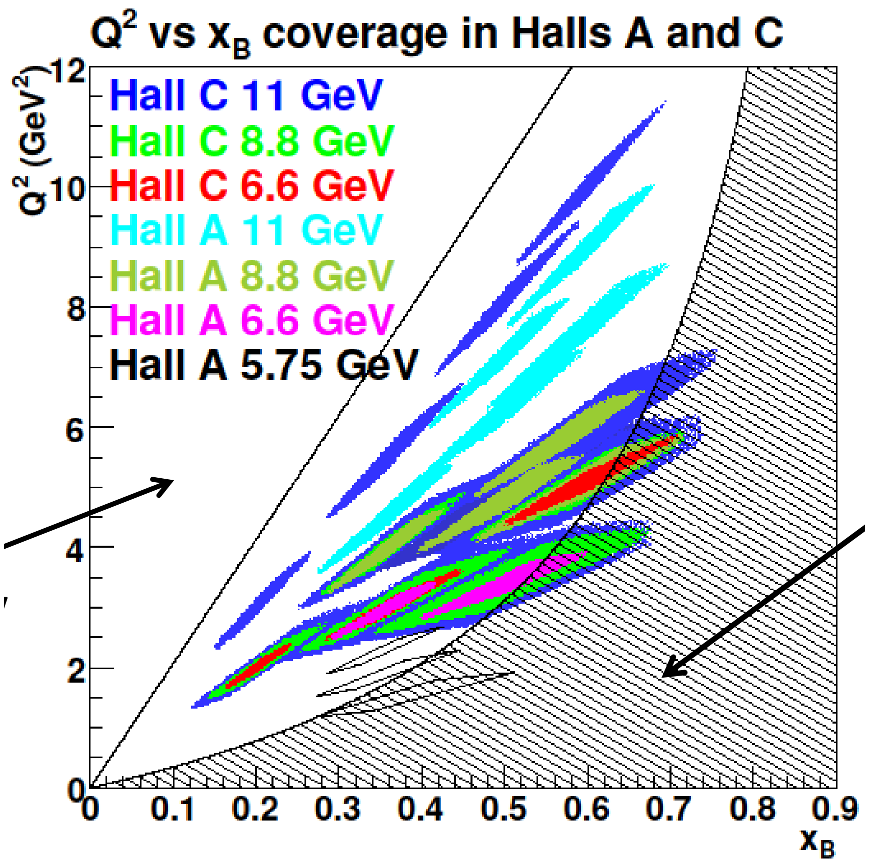
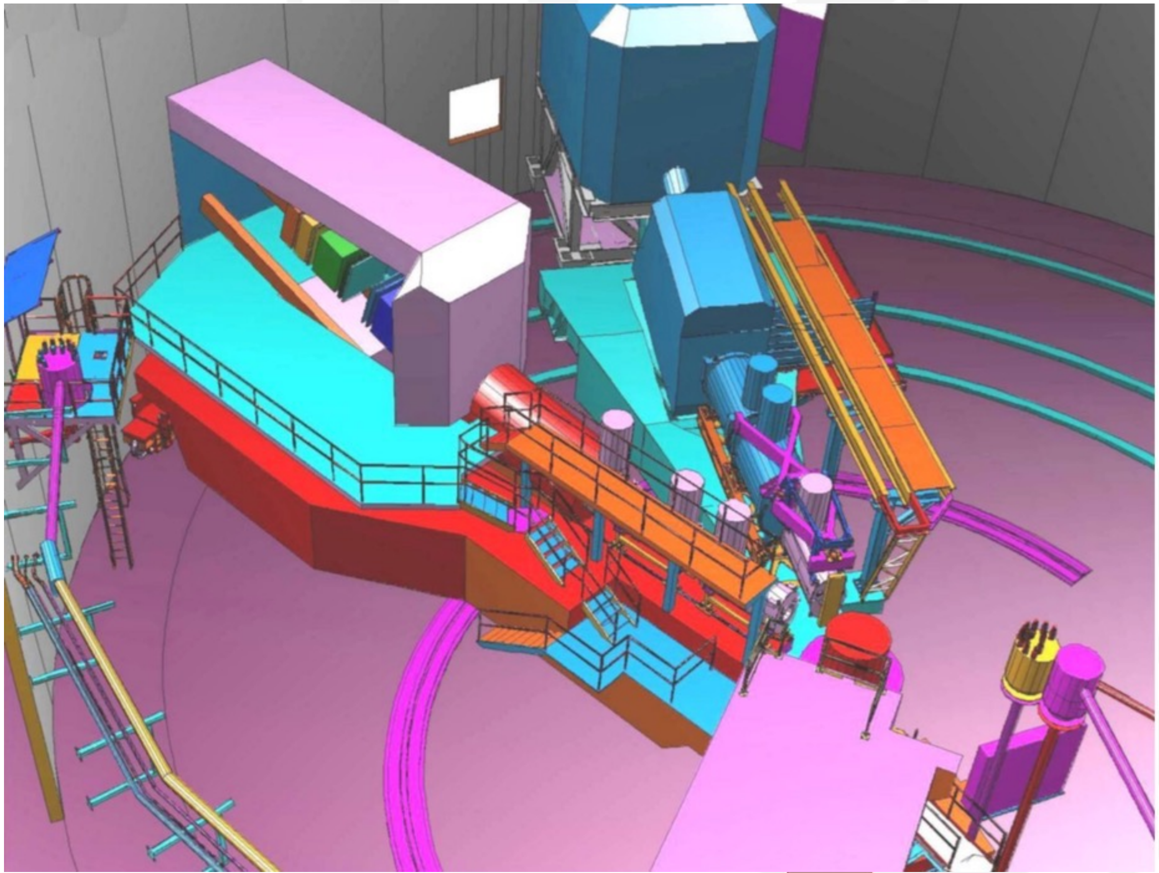
Hall C DVCS @ 12 GeV

E12-13-010: HMS +PbWO4 calorimeter

- Energy separation of the DVCS cross-section
- Higher $Q^{2:}$ measurement oh higher twist contribution
- Low xB extension





Conclusions

- GPD are a powerful and unique tool explore the structure of the nucleon
- GPDs are fully-correlated quark distributions in both coordinate and momentum space -> 3D imaging
- Complex extraction from data
  - 4 GPD for each quark flavor
  - GPDs depend on 3 variables but only two are experimentally accessible. Need models to map the x dependence
  - Cross sections depend on integrals of GPDs
- Need extensive measurements of different observables for both proton and neutron over a large kinematic range for a reliable extraction of GPDs
- 6 GeV program was very successful and gave us a first look at the structure of the nucleon
- Rich experimental program planned at Jefferson Lab@12GeV in the 3 halls to complete this study in the valence region

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Thank you for the invitation.

Next time let's organize the conference during winter

Vail Feb 2007