第16回 高エネルギーQCD・核子構造 勉強会
日時：2020年2月19日（水）
場所：東北大学　理学合同AB棟721棟

山形大学
Yamagata University

レプトン散乱実験による一般化パートン分布研究

宮地 義之 (山形大学)

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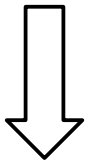
世話人からのリクエスト

"*Transverse extension of partons in the proton probed in the sea-quark range by measuring the DVCS cross section*",
COMPASS, PLB793(2019)188



"*Experiments on generalized parton distributions*",
Progress on QCD and nucleon structure in 2019
02/28 – 03/01 in 2019 @ KEK

をベースに、更新

Contents

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- Proton Structure and **G**eneralized **P**arton **D**istribution
  - Total angular moment of quarks
- Hard Exclusive Production and **GPD**
  - **D**eeply **V**irtual **C**ompton **S**cattering (DVCS)
  - Hard Exclusive Meson Production (HEMP)
- Experiments on GPDs
  - Focusing on DVCS measurements
- Summary and Outlook

How to study “Structure of the proton”

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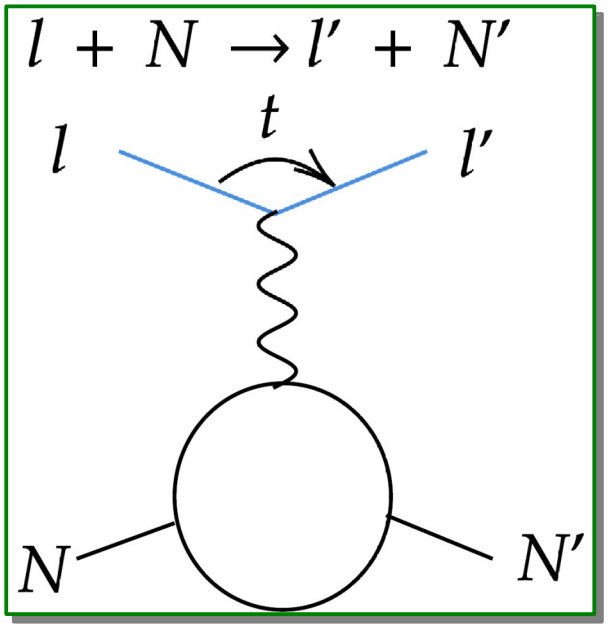
Elastic scattering

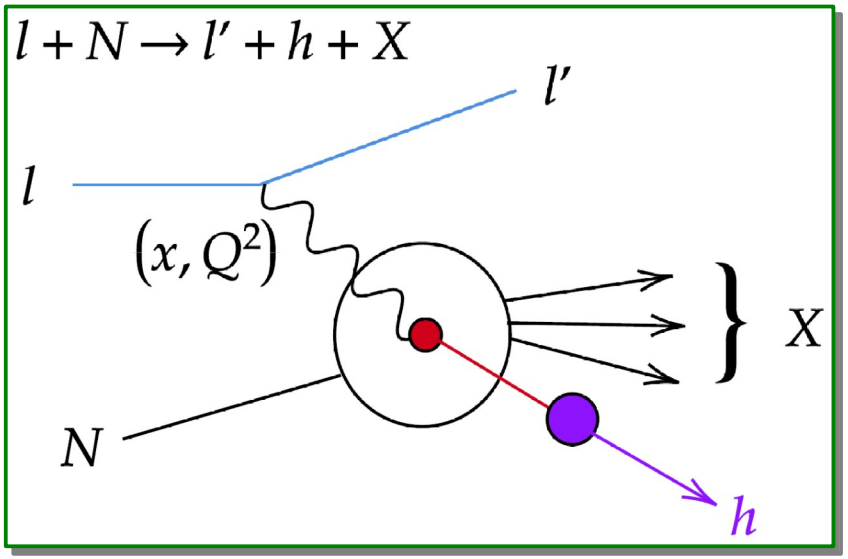


Form factors

→ spatial distribution

$$\langle r^2 \rangle = -6 \frac{dF(\vec{q})}{d\vec{q}^2}\bigg|_{\vec{q}^2 \to 0}$$

Deep Inelastic Scattering



Parton distributions

→ momentum distribution

Proton Structure and **G**eneralized **P**arton **D**istributions

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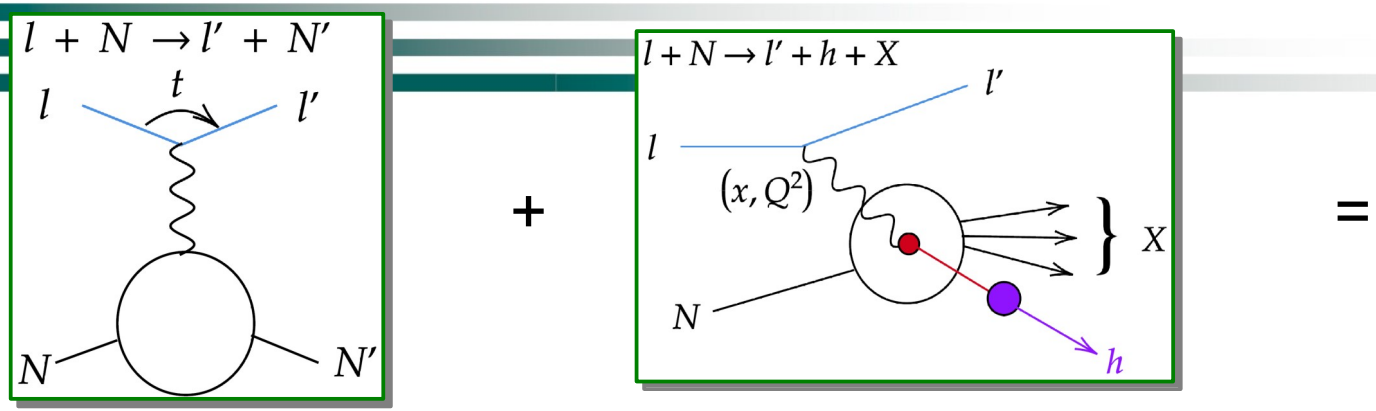
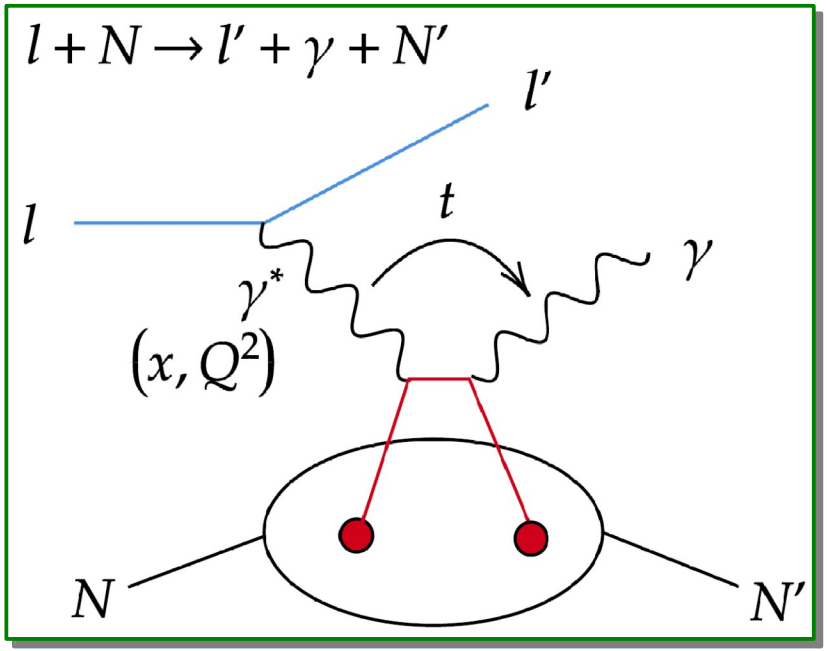


"*virtual photon elastic scattering*"



- Virtual photon probes a quark
- Momentum transfer
  spatial distribution of quarks

Generalized Parton Distribution

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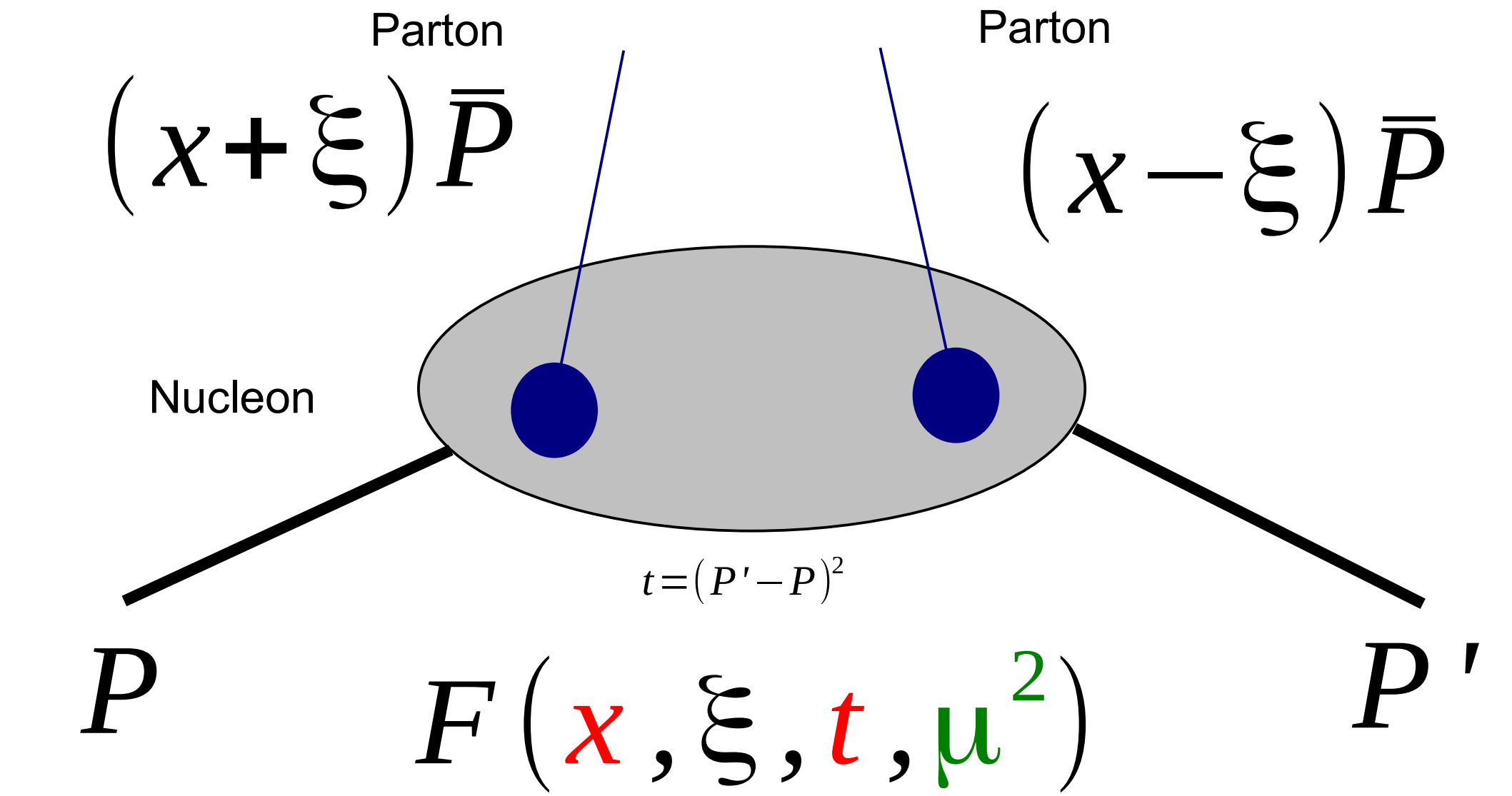
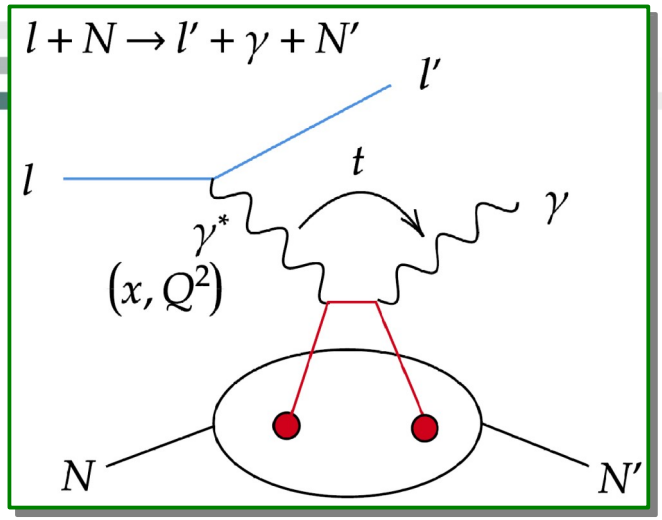
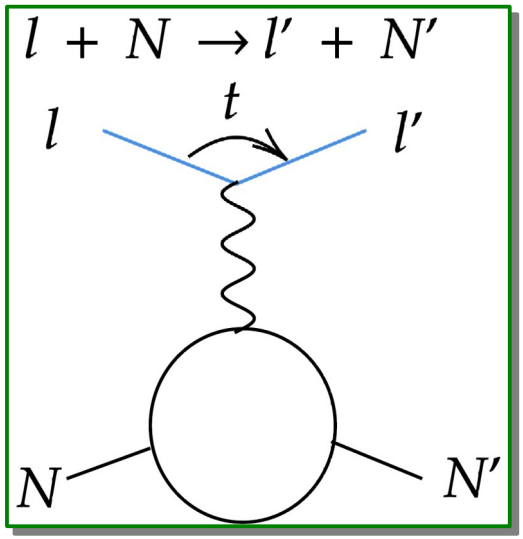


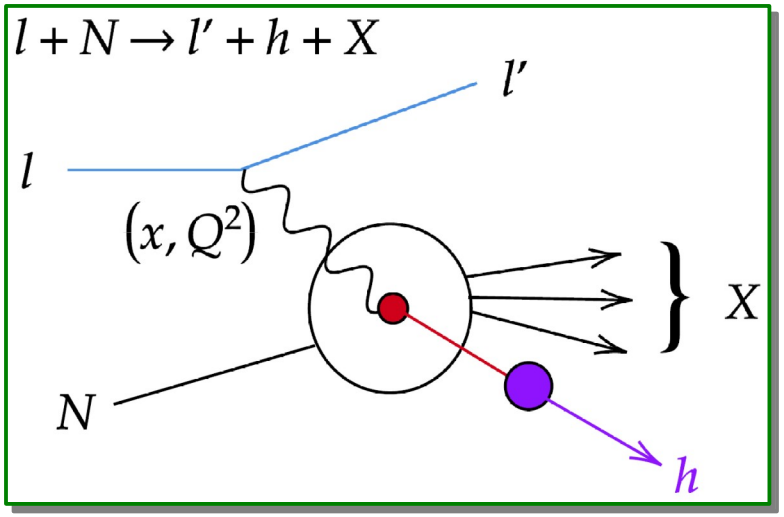
GPDs, Form Factors, PDFs

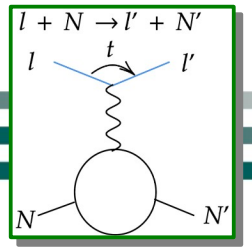


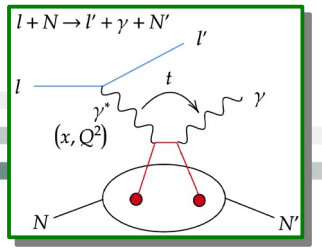
$$\int dx$$

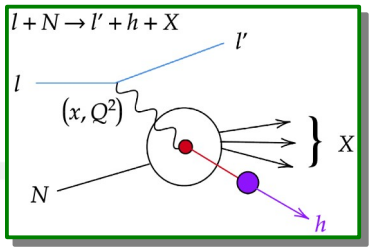
$$t \to 0$$











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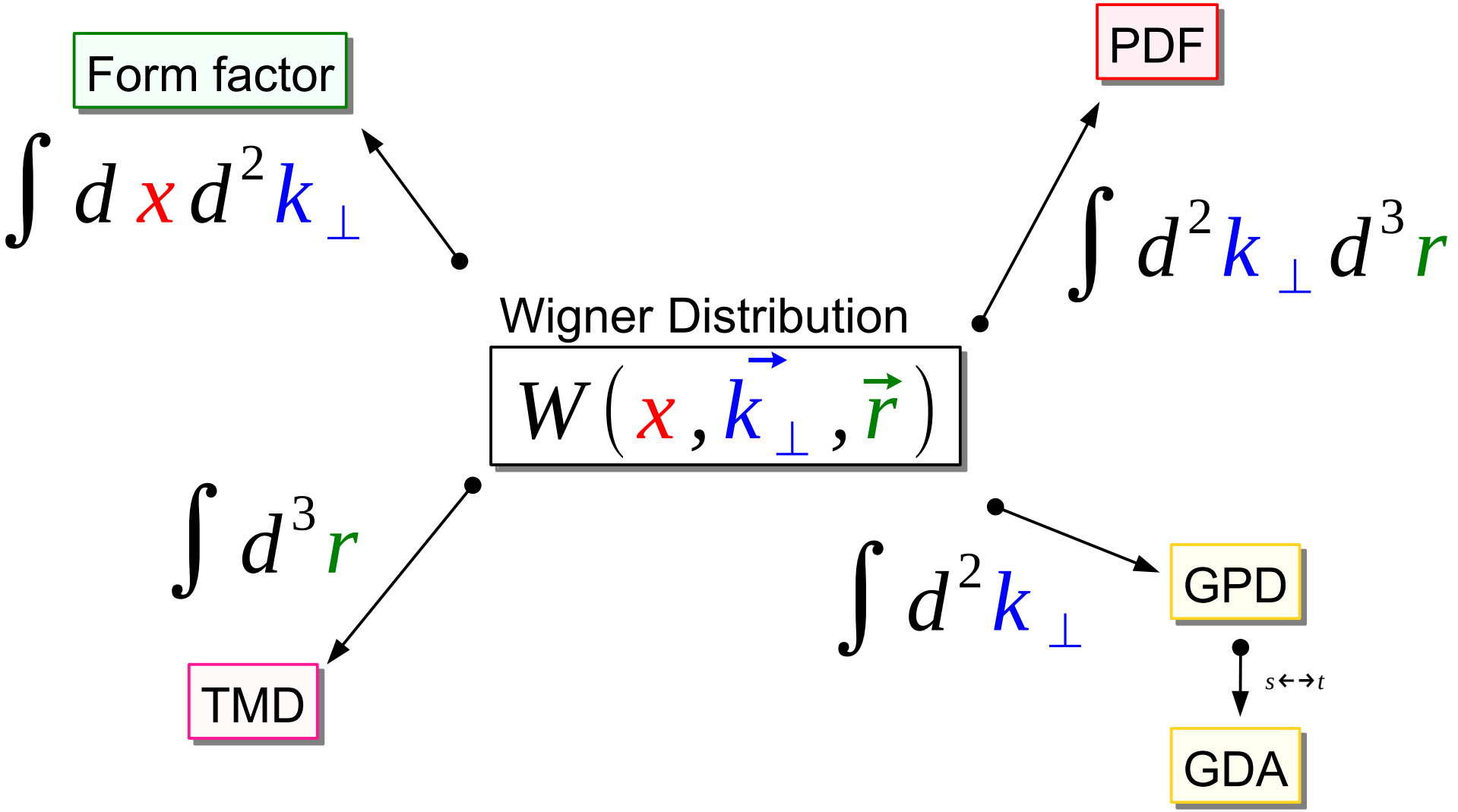
Form Factor	GPD	PDF
$F_1(t)$	$H(x,\xi,t)$	$f_1 \quad q(x)$
$F_2(t)$	$E(x,\xi,t)$	$f_{1T}^{\perp}$
$G_A(t)$	$\widetilde{H}(x,\xi,t)$	$g_1 \quad \Delta q(x)$
$G_p(t)$	$\widetilde{E}(x,\xi,t)$	g_{1T}

Mother distribution of the proton



Total angular momentum of quarks

$$J_N = \underbrace{\sum_{q=u,d,s,c\cdots} \left(\frac{1}{2}\Delta\Sigma_q + L_q\right)} + J_g$$

X.-D. Ji, PRL78(1997)610

$$J_q = \frac{1}{2}\int dx\, x\,[H_q(x,0,0) + E_q(x,0,0)]$$

X.-D. Ji, PRD55(1997)7114

Hard Exclusive Production and GPDs

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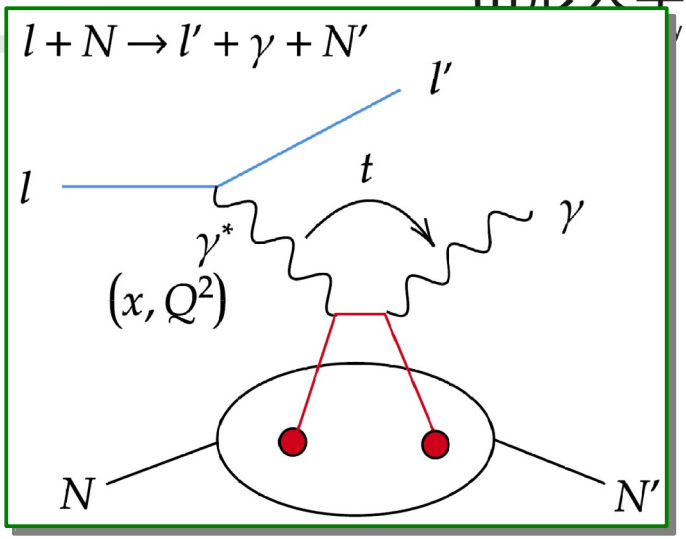
Deeply Virtual Compton Scattering (DVCS):

$$e + N \rightarrow e' + N' + \gamma$$

Involved GPDs: $H,\ E,\ \tilde{H},\ \tilde{E}$

clean reaction



Hard Exclusive Meson Production (HEMP)
Deeply Virtual Meson Production (DVMP):

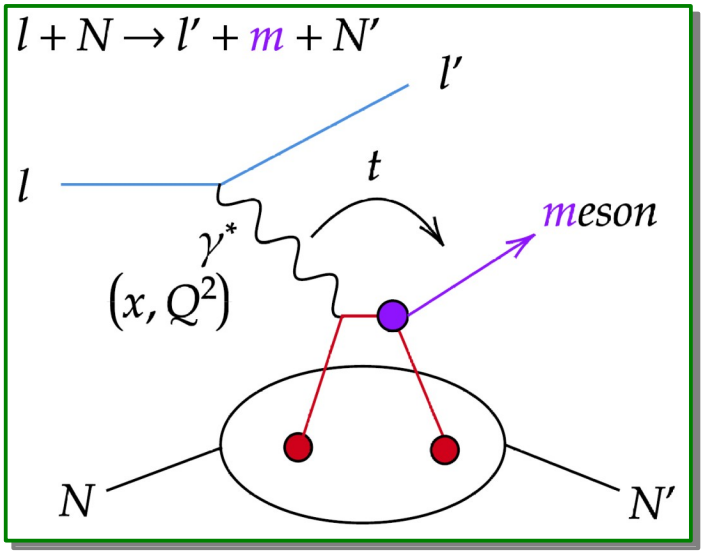
$$e + N \rightarrow e' + N' + \{\rho,\ \pi, \ldots\}$$

vector meson: $H,\ E$

pseudo-scalar meson: $\tilde{H},\ \tilde{E}$

Quark flavor sensitivity

Meson amplitude involved



Chiral-odd GPDs

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DVCS

Chiral-even GPDs

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

HEMP

Chiral-odd GPDs

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

$$H_T \longleftrightarrow h_1$$

$$2H_T + E_T \longleftrightarrow h_1^{\perp}$$

Exclusive Process and GPDs

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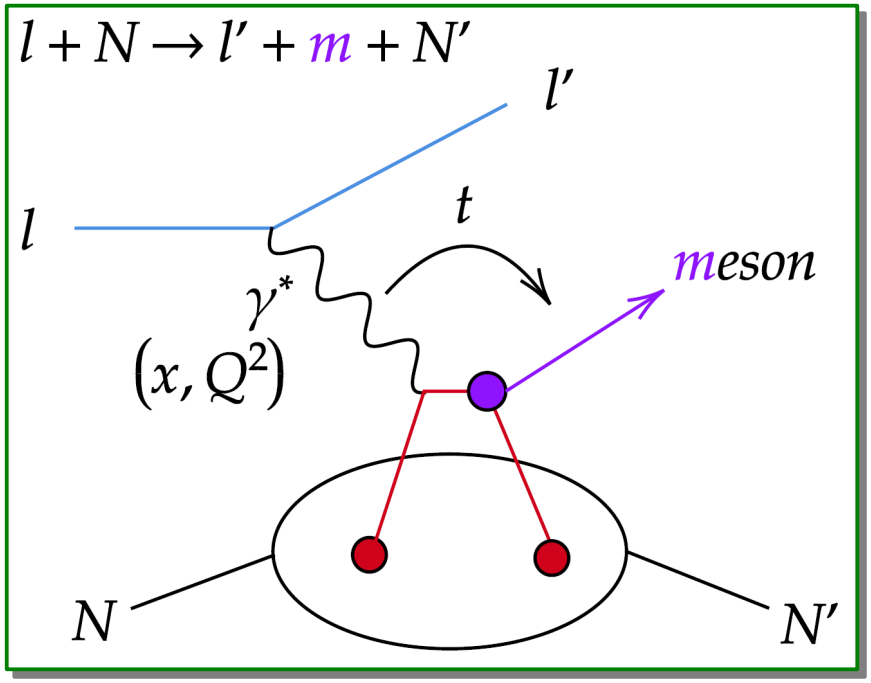
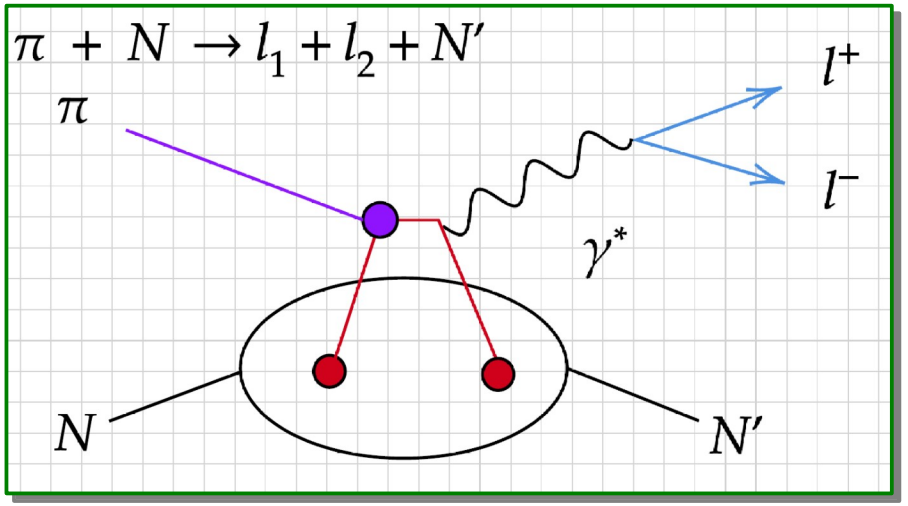
Hard Exclusive Meson Production



Exclusive Drell-Yan Process



Experiments on Deeply Virtuial Compton Scattering

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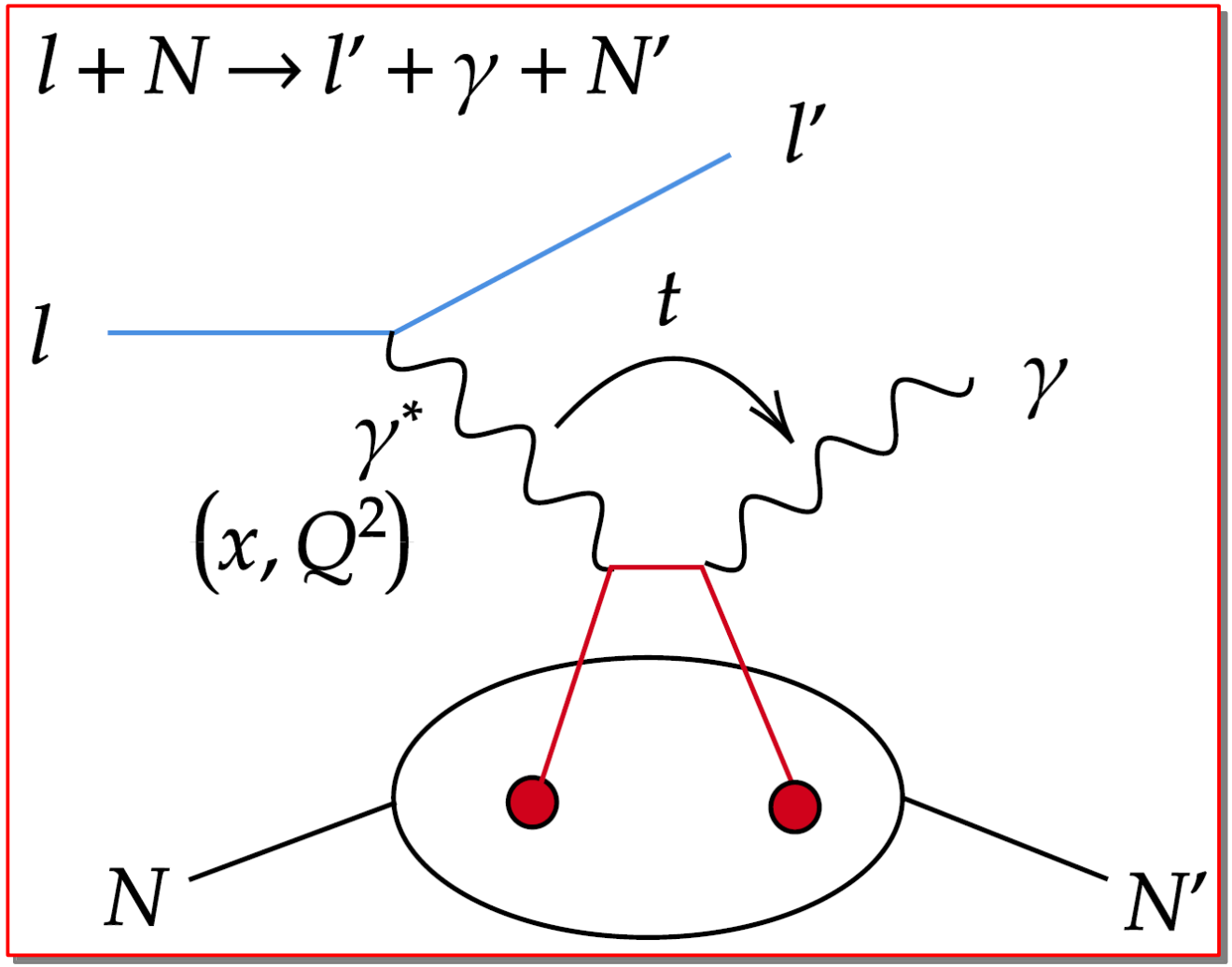

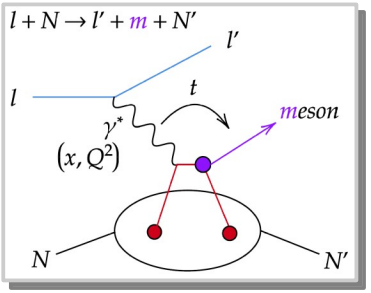

Experiments on DVCS

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H1, ZEUS **σ**

COMPASS II

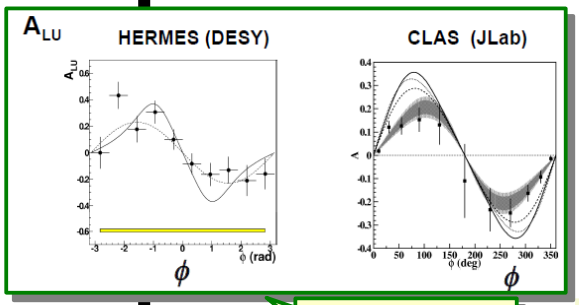
160 GeV μ,

σ, BSA+BCA

HERMES

26.7 GeV electron, H, D, A

σ, BSA, BCA, TSA(L+T)



PRL**87**(2001)

JLab

Electron (4 GeV→ 6 GeV→ 12 GeV)

σ, BSA

DVCS vs Bethe-Heitler

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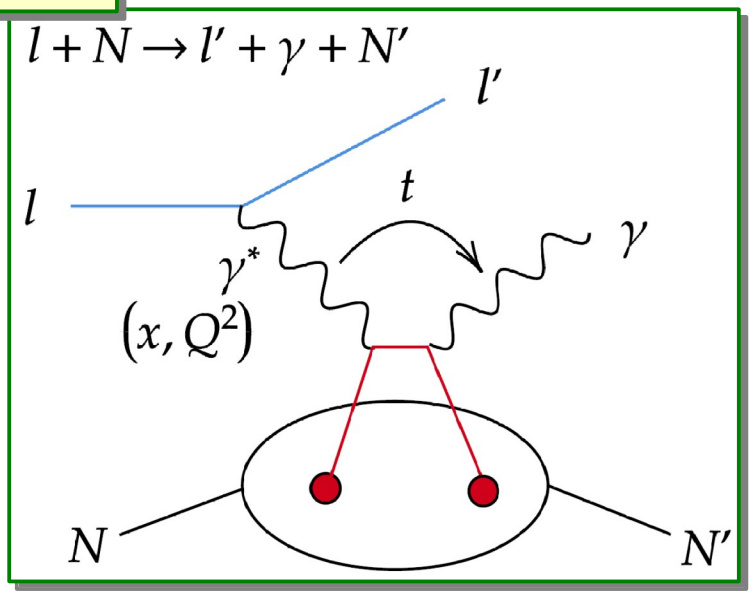
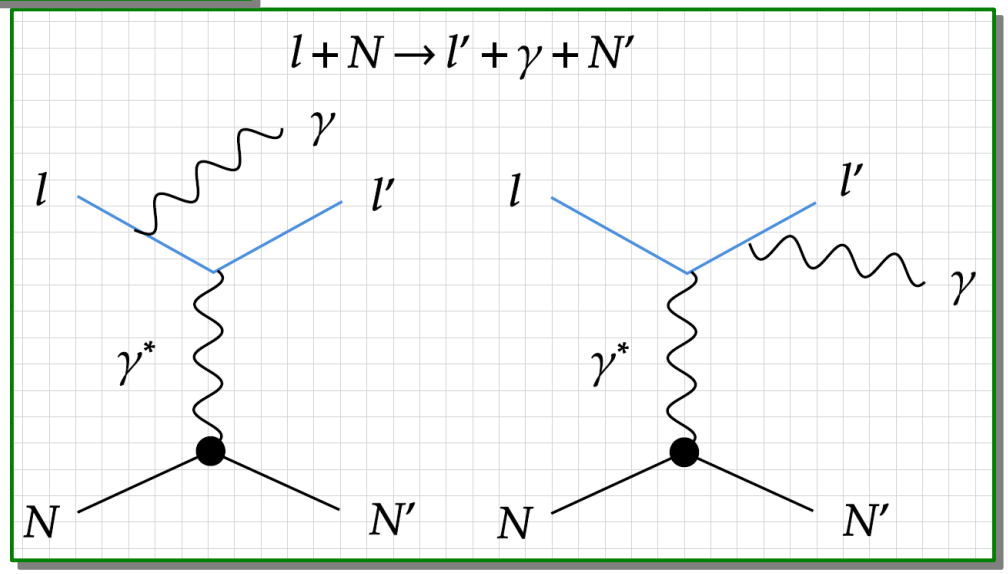
DVCS



Bethe-Heitler



$$\frac{\mathrm{d}^4\sigma}{\mathrm{d}Q^2\,\mathrm{d}x_\mathrm{B}\,\mathrm{d}t\,\mathrm{d}\phi} = \frac{x_\mathrm{B}e^6}{32(2\pi)^4Q^4\sqrt{1+\epsilon^2}}|\mathcal{T}_{ep\to ep\gamma}|^2,$$

$$|\mathcal{T}_{ep\to ep\gamma}|^2 = |\mathcal{T}_\mathrm{BH}|^2 + |\mathcal{T}_\mathrm{DVCS}|^2 + \mathcal{I},$$

DVCS @ COMPASS II

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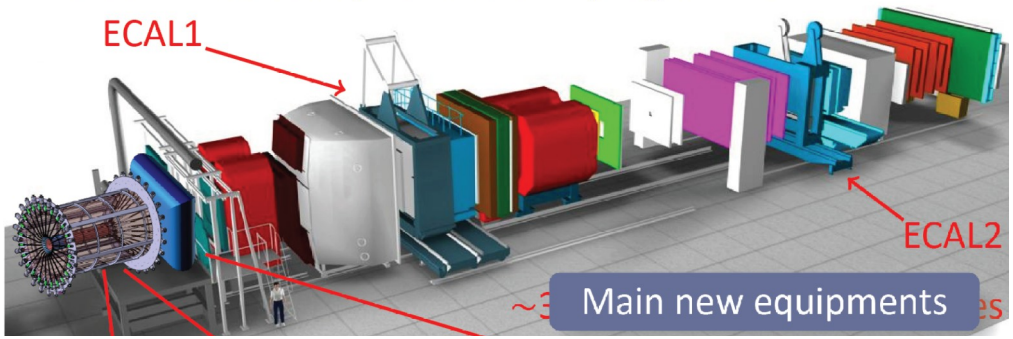
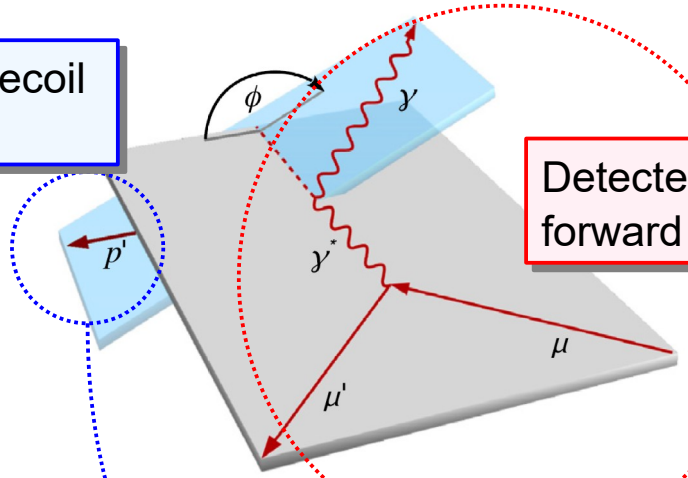
Detected in the recoil detector

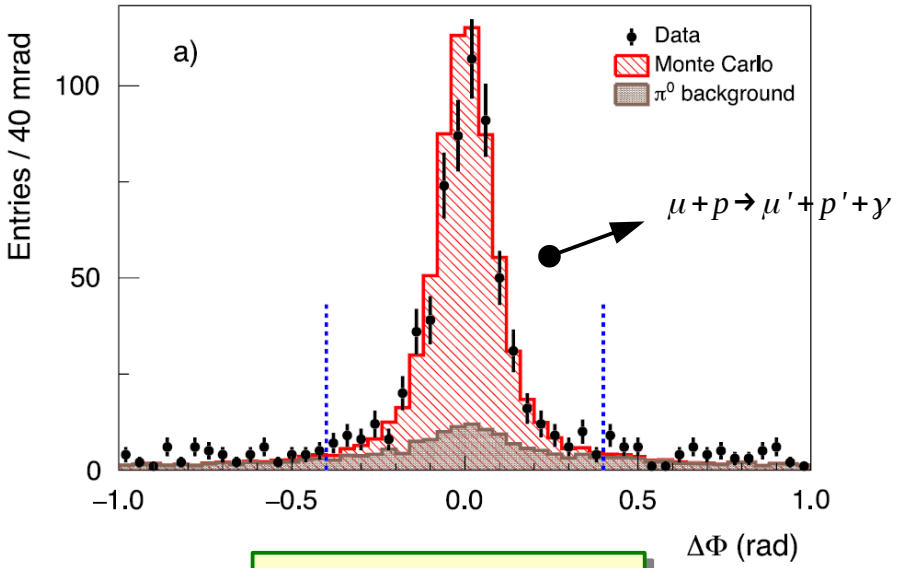
Detected in the forward spectrometer





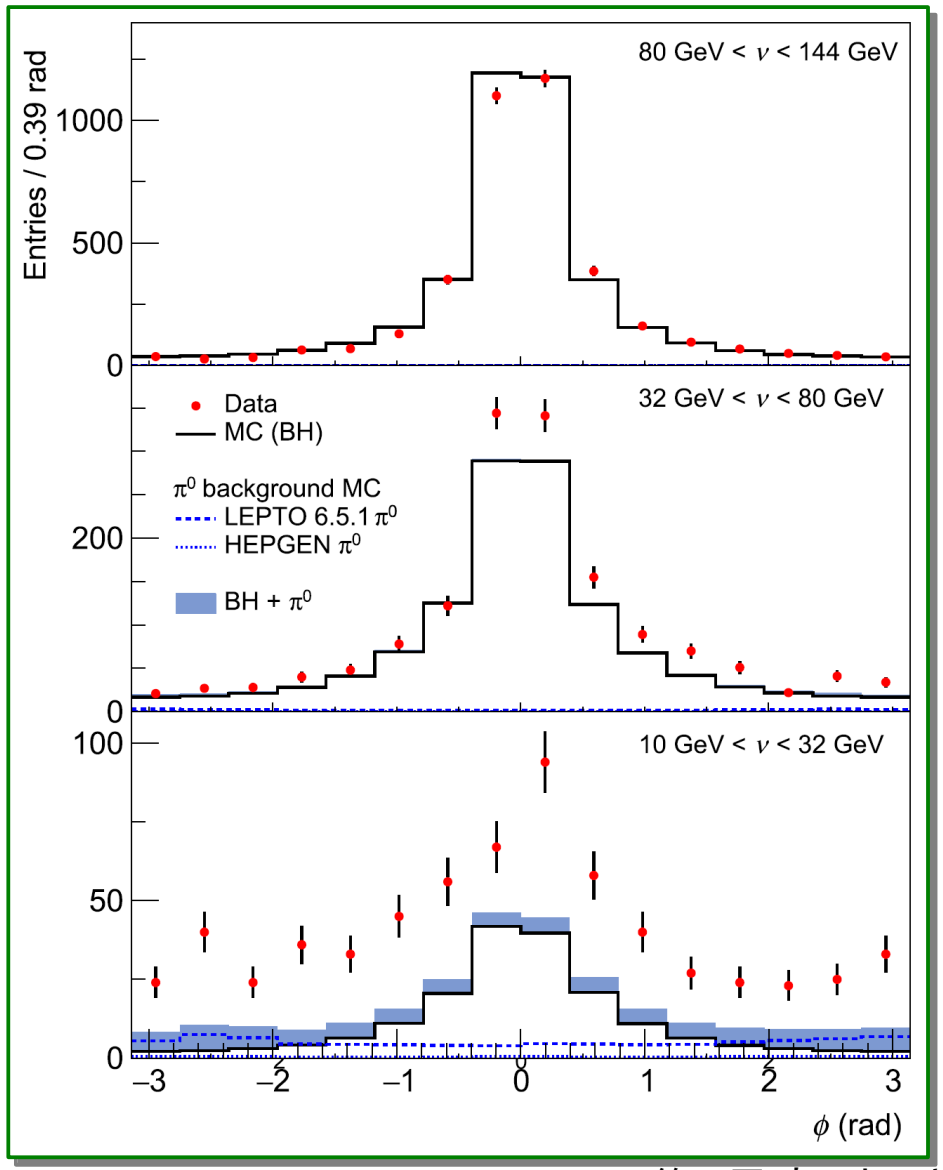
$$\Delta\Phi = \Phi_{predicted} - \Phi_{measured}$$

- Liq. H target + Recoil proton detector
- Pol. Muon @ 190 GeV
- Data taking: 2009 (test), 2012 (pilot), 2016-17
  - Results from 2012 data are available.
- Event selection
  - Incoming muon (μ)
  - single outgoing charged particle (μ')
  - One neutral cluster in ECAL (γ)
  - Recoil particle $\Delta\Phi\sim0$ and $\Delta p_T\sim0$



PLB793(219)188

DVCS @ COMPASS II



$$1\,(\mathrm{GeV}/c)^2 < Q^2 < 5\,(\mathrm{GeV}/c)^2$$
$$0.08\,(\mathrm{GeV}/c)^2 < |t| < 0.64\,(\mathrm{GeV}/c)^2$$

BH Monte Carlo normalization based on integrated luminosity

BH process dominant at the middle and large ν

π^0 background contributing at the small ν

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DVCS cross section @ COMPASS

PLB793(219)188

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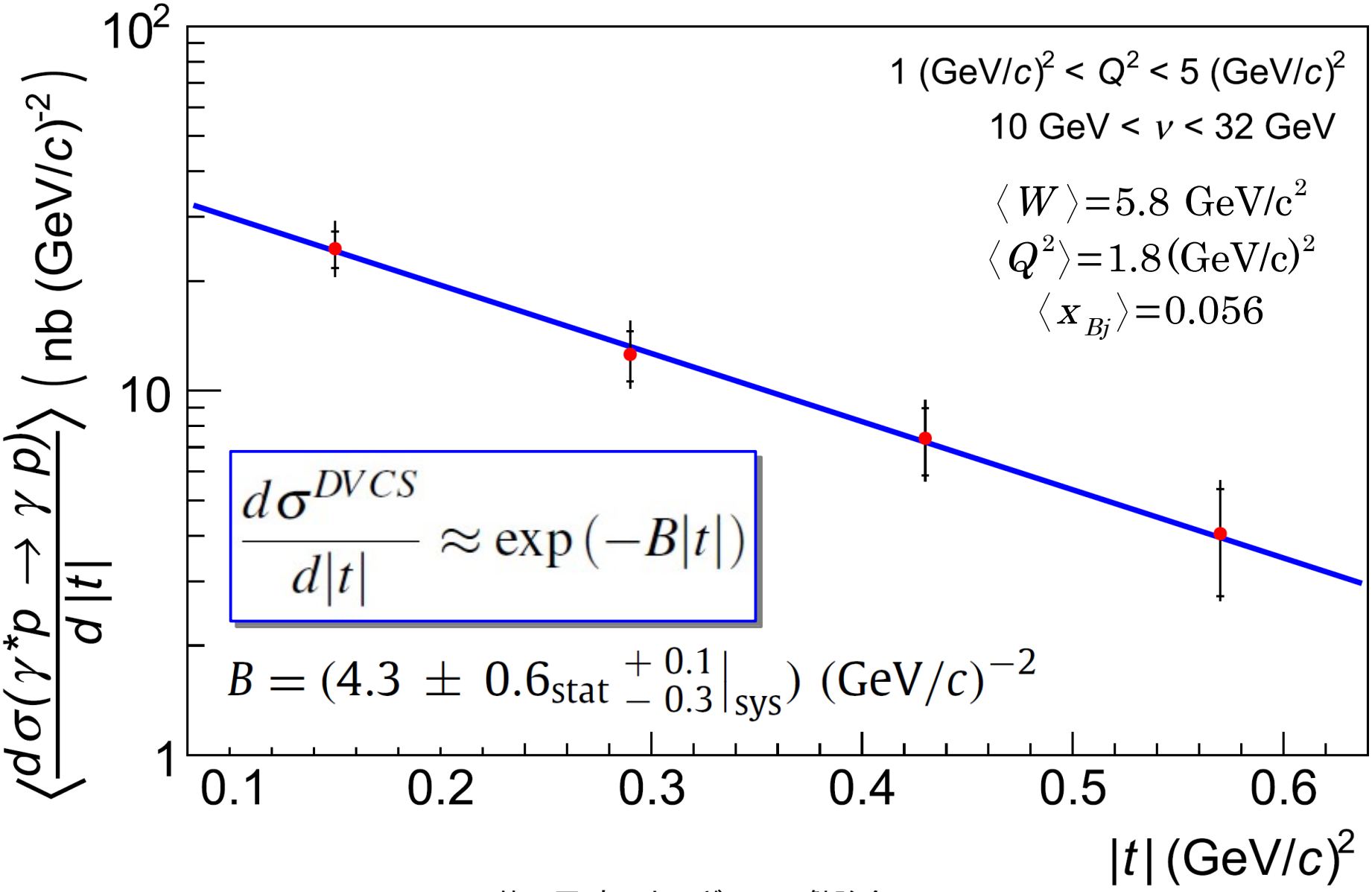

Proton tomography

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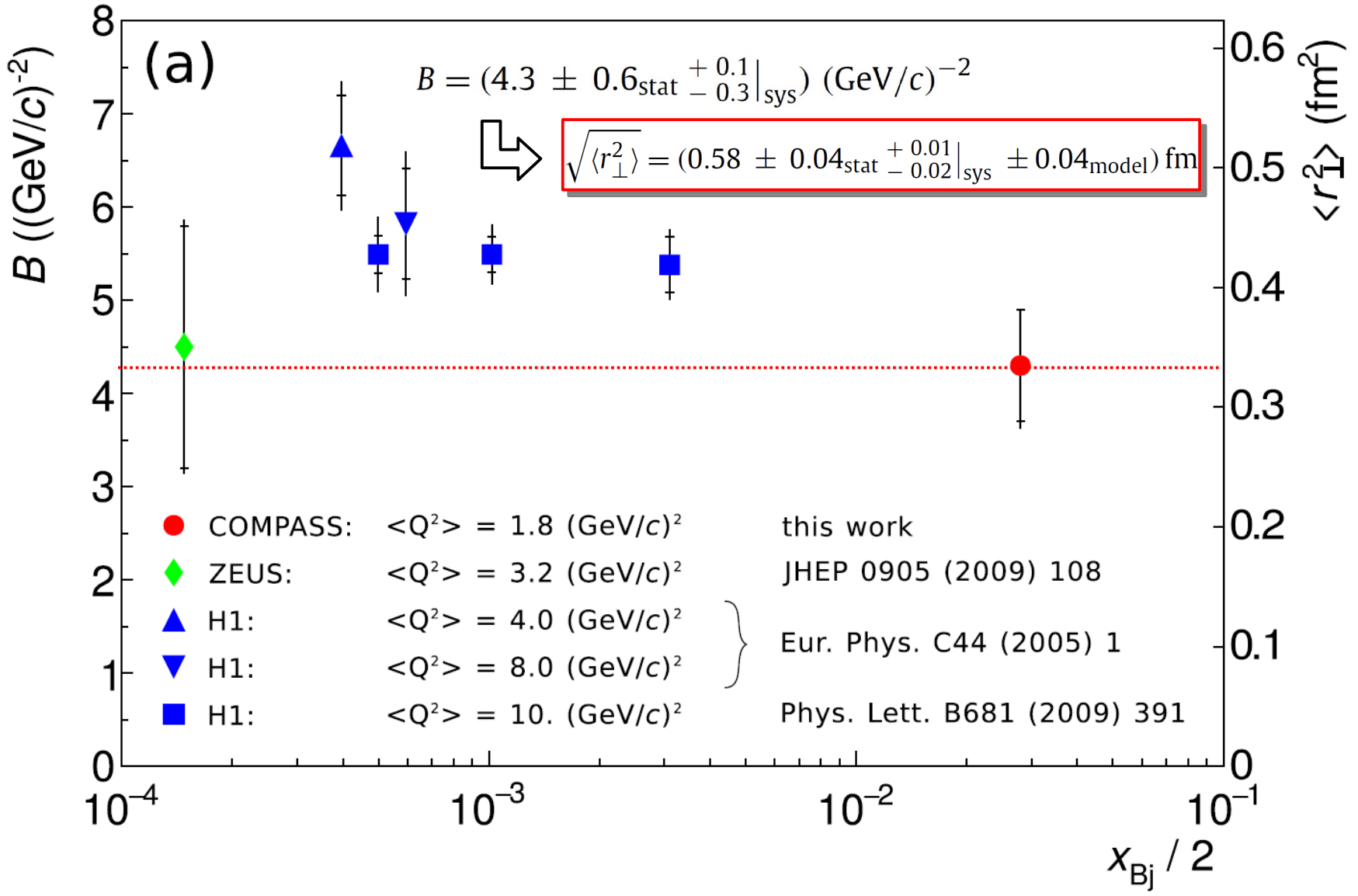

Proton tomography

PLB793(219)188

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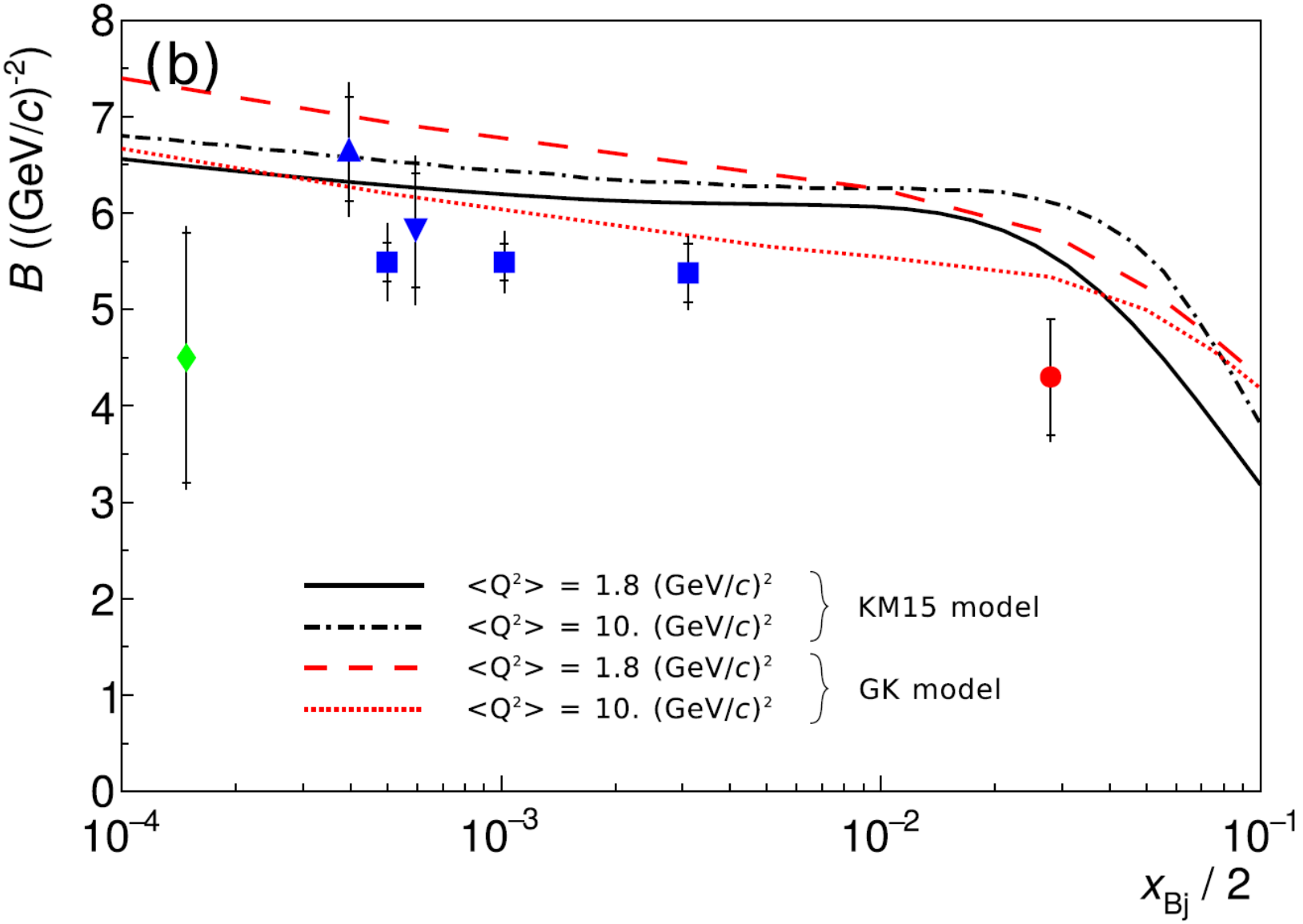

COMPASS 2016 ~ 2017 (2 × 6 months)

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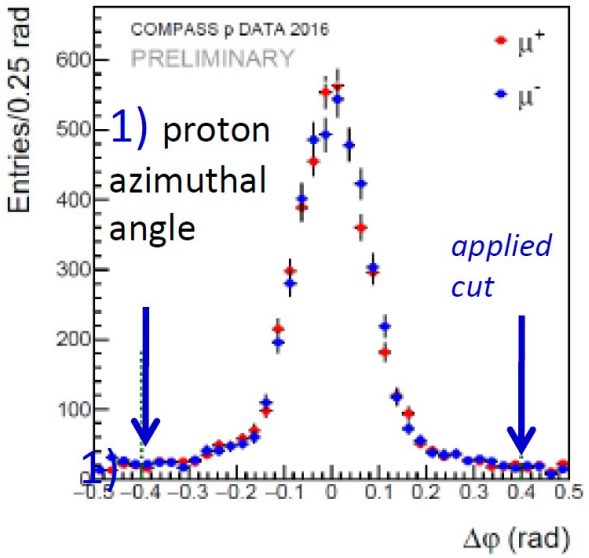
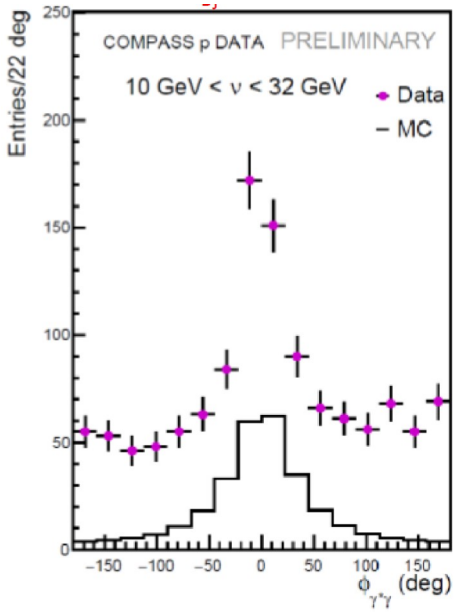
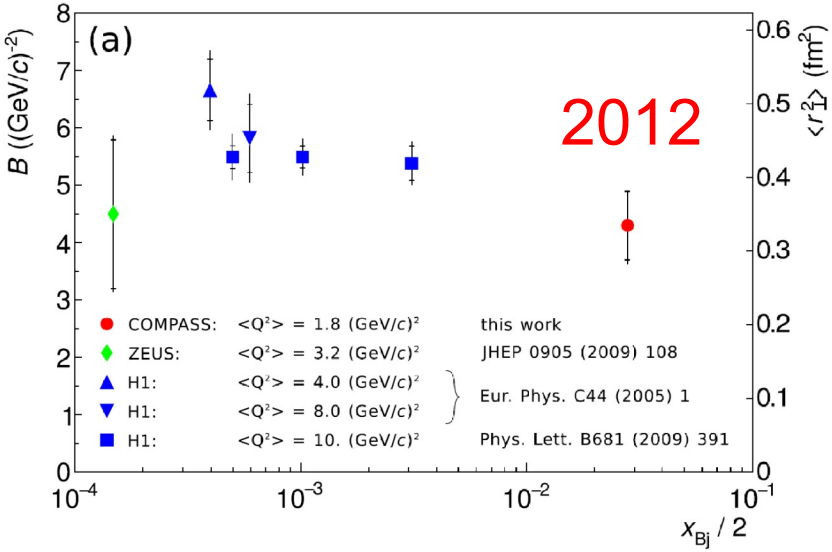
10 times more statistics in 2016 ~ 2017







w/ 13% of 2016-2017 data

DVCS @HERMES, JLab

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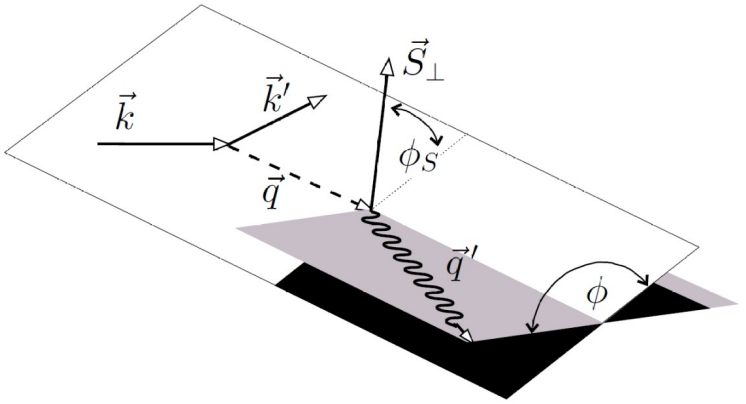
$$\frac{\mathrm{d}^4\sigma}{\mathrm{d}Q^2\,\mathrm{d}x_\mathrm{B}\,\mathrm{d}t\,\mathrm{d}\phi} = \frac{x_\mathrm{B}e^6}{32(2\pi)^4Q^4\sqrt{1+\epsilon^2}}|\mathcal{T}_{ep\to ep\gamma}|^2,$$

$$|\mathcal{T}_{ep\to ep\gamma}|^2 = |\mathcal{T}_\mathrm{BH}|^2 + |\mathcal{T}_\mathrm{DVCS}|^2 + \mathcal{I},$$

$\sigma_\mathrm{DVCS} \ll \sigma_\mathrm{BH}$ @HERMES, JLab

Differential cross section

Unpol. target



$$d\sigma \propto |\mathcal{T}_{\rm BH}|^2 + |\mathcal{T}_{\rm DVCS}|^2 + \mathcal{I},$$

$$|\mathcal{T}_{\rm BH}|^2 = \frac{K_{\rm BH}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left(c_0^{\rm BH} + \sum_{n=1}^{2} c_n^{\rm BH} \cos(n\phi) \right),$$

$$|\mathcal{T}_{\rm DVCS}|^2 = K_{\rm DVCS} \left(c_0^{\rm DVCS} + \sum_{n=1}^{2} c_n^{\rm DVCS} \cos(n\phi) + \lambda s_1^{\rm DVCS} \sin\phi \right),$$

$$\mathcal{I} = \frac{-e_\ell K_{\mathcal{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left(c_0^{\mathcal{I}} + \sum_{n=1}^{3} c_n^{\mathcal{I}} \cos(n\phi) + \lambda \sum_{n=1}^{2} s_n^{\mathcal{I}} \sin(n\phi) \right).$$

Beam Charge

Beam helicity

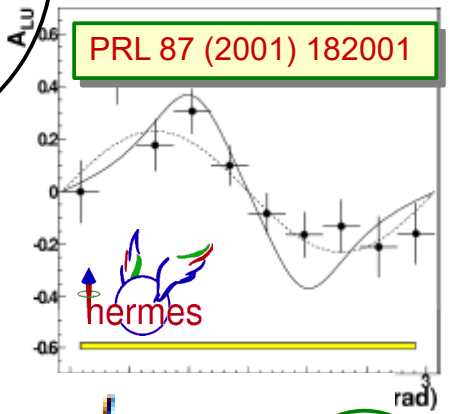
Cross section asymmetries and GPDs

A_C

A_{LU}

$$\mathcal{I} = \frac{-e_\ell K_\mathcal{I}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left(c_0^\mathcal{I} + \sum_{n=1}^{3} c_n^\mathcal{I} \cos(n\phi) + \lambda \sum_{n=1}^{2} s_n^\mathcal{I} \sin(n\phi) \right)$$

$$s_1^\mathcal{I} \approx 8 \frac{\sqrt{-t}}{Q} y(2-y)\, \Im\mathrm{m}(\mathcal{C}_{\mathrm{unp}}^\mathcal{I}).$$



$$\mathcal{C}_{\mathrm{unp}}^\mathcal{I} = F_1 \mathcal{H} + \frac{x_\mathrm{B}}{2-x_\mathrm{B}} (F_1 + F_2) \tilde{\mathcal{H}} - \frac{t}{4M_p^2} F_2 \mathcal{E}$$

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$$\mathcal{C}^{\mathcal{I}}_{\rm unp} = F_1\mathcal{H} + \frac{x_{\rm B}}{2-x_{\rm B}}(F_1+F_2)\widetilde{\mathcal{H}} - \frac{t}{4M_p^2}F_2\mathcal{E}$$

Compton form factors

NPB629 (2002) 323-392

$$\left\{\mathcal{H},\mathcal{E},\mathcal{H}^3_+,\mathcal{E}^3_+,\widetilde{\mathcal{H}}^3_-,\widetilde{\mathcal{E}}^3_-\right\}(\xi) = \int_{-1}^{1} dx\, C^{(-)}(\xi,x)\left\{H,E,H^3_+,E^3_+,\widetilde{H}^3_-,\widetilde{E}^3_-\right\}(x,\eta)_{|\eta=-\xi},$$

$$\left\{\widetilde{\mathcal{H}},\widetilde{\mathcal{E}},\widetilde{\mathcal{H}}^3_+,\widetilde{\mathcal{E}}^3_+,\mathcal{H}^3_-,\mathcal{E}^3_-\right\}(\xi) = \int_{-1}^{1} dx\, C^{(+)}(\xi,x)\left\{\widetilde{H},\widetilde{E},\widetilde{H}^3_+,\widetilde{E}^3_+,H^3_-,E^3_-\right\}(x,\eta)_{|\eta=-\xi},$$

Sum of quark flavors

$$\mathcal{C}^{\mathcal{I}}_{\rm unp} = F_1\mathcal{H} + \frac{x_{\rm B}}{2-x_{\rm B}}(F_1+F_2)\widetilde{\mathcal{H}} - \frac{t}{4M_p^2}F_2\mathcal{E}$$

Negligible

Beam spin asymmetry $A_{LU} \Rightarrow \propto \Im m\mathcal{H}$

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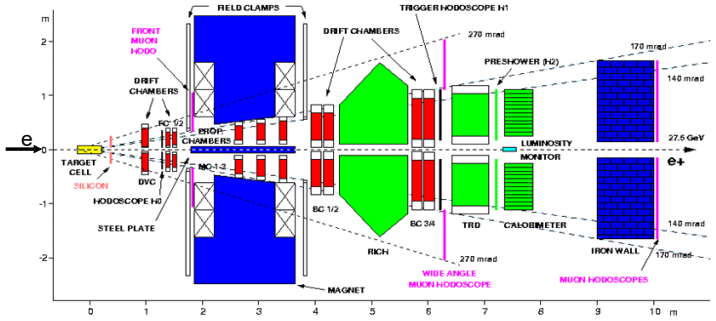
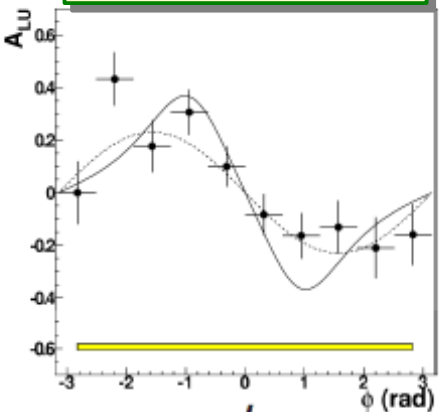
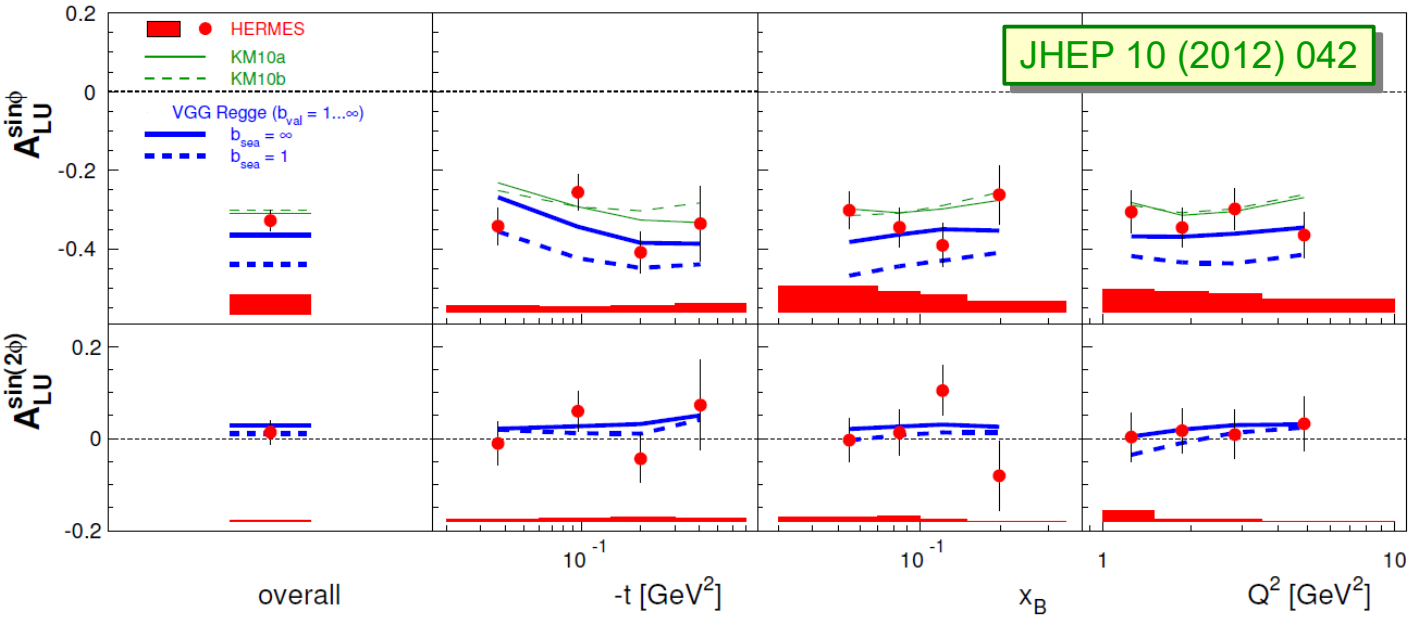


Beam: 27.6 GeV polarized e-/e+ @HERA
1997 ~ 2005: H, D, L-pol H, L-pol D, T-pol H
2006 – 2007: H and D w/ recoil detector

w/ recoil proton detection

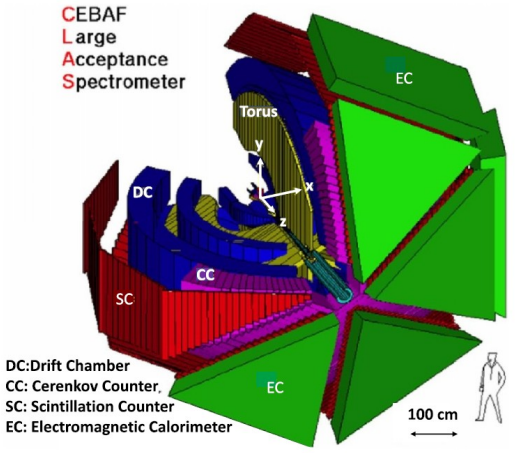
PRL 87 (2001) 182001

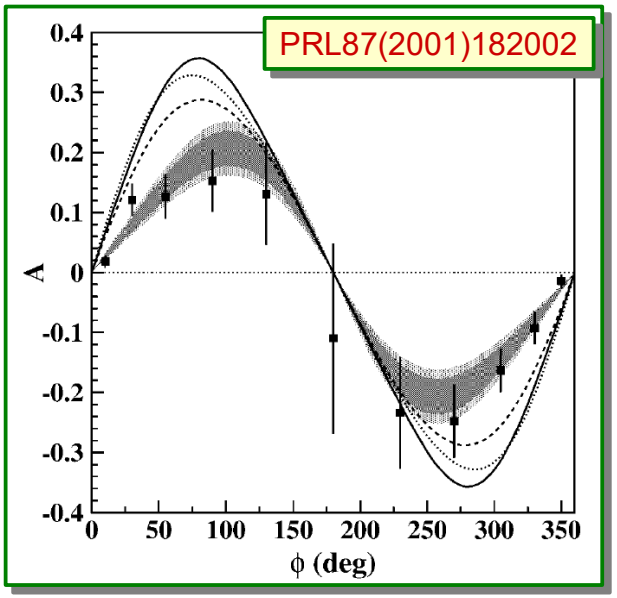




JHEP 10 (2012) 042

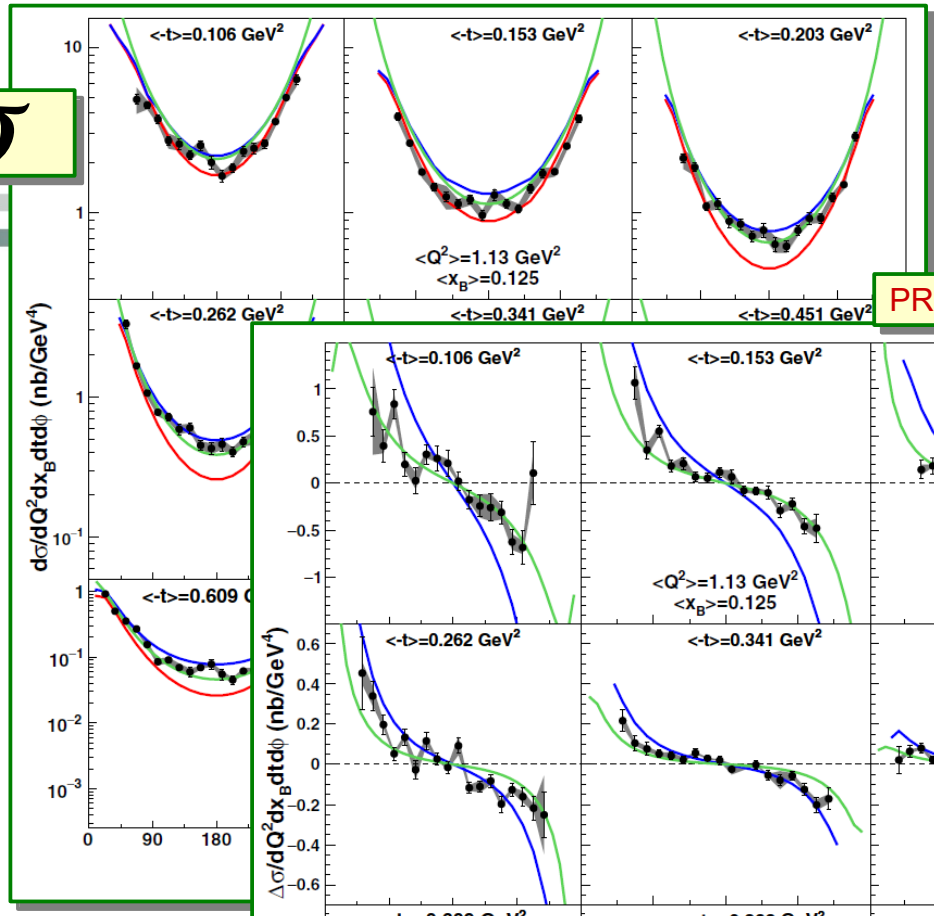
DVCS @ CLAS



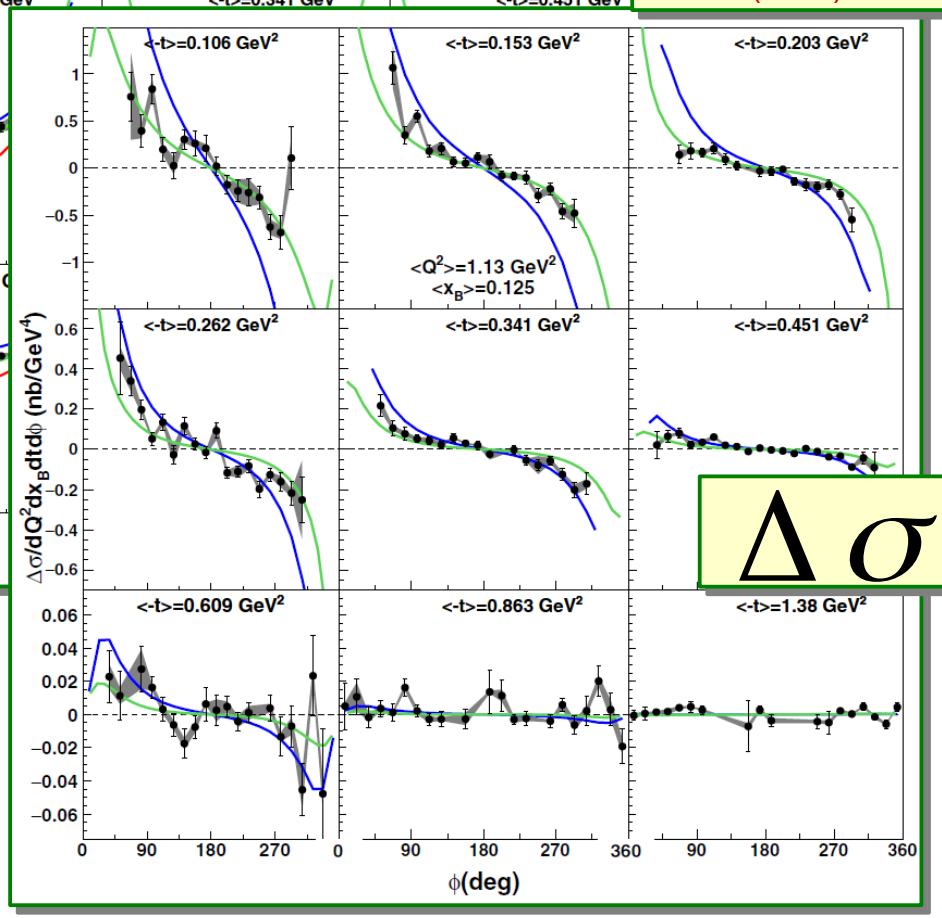


Pol. 4 GeV electron

σ



PRC98(2018)045203



$\Delta\sigma$

Pol. 6 GeV electron

$$\langle Q^2 \rangle = 1.13, 1.67, 2.86\,\mathrm{GeV}^2$$
$$\langle x_{Bj} \rangle = 0.125, 0.187, 0.335$$

with a transversely polarized target

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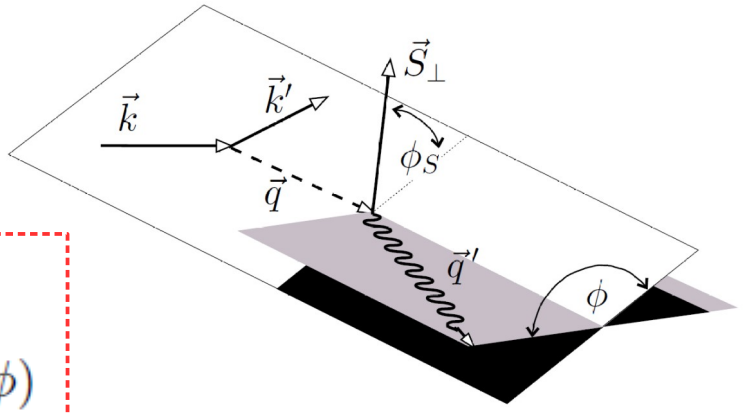
$$|\mathrm{T_{BH}}|^2 = \frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left(c^{\mathrm{BH}}_{0,\mathrm{UU}} + \left\{c^{\mathrm{BH}}_{1,\mathrm{UU}}\cos\phi + \left\{c^{\mathrm{BH}}_{2,\mathrm{UU}}\cos(2\phi)\right\}\right\}\right),$$

$$|\mathrm{T_{DVCS}}|^2 = K_{\mathrm{DVCS}}\left(c^{\mathrm{DVCS}}_{0,\mathrm{UU}} + c^{\mathrm{DVCS}}_{2,\mathrm{UU}}\cos(2\phi) + \left\{c^{\mathrm{DVCS}}_{1,\mathrm{UU}}\cos\phi\right\}\right.$$

$$+S_\perp\left[\boldsymbol{c^{\mathrm{DVCS}}_{0,\mathrm{UT}}\sin(\phi-\phi_S)} + c^{\mathrm{DVCS}}_{2,\mathrm{UT}}\sin(\phi-\phi_S)\cos(2\phi)\right.$$
$$+s^{\mathrm{DVCS}}_{2,\mathrm{UT}}\cos(\phi-\phi_S)\sin(2\phi)$$
$$\left.\left.+\left\{c^{\mathrm{DVCS}}_{1,\mathrm{UT}}\sin(\phi-\phi_S)\cos\phi + s^{\mathrm{DVCS}}_{1,\mathrm{UT}}\cos(\phi-\phi_S)\sin\phi\right\}\right]\right)$$

$$\mathrm{I} = \frac{-K_{\mathrm{I}}e_l}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left(c^{\mathrm{I}}_{1,\mathrm{UU}}\cos\phi + c^{\mathrm{I}}_{3,\mathrm{UU}}\cos(3\phi)\right.$$
$$\left.+\left\{c^{\mathrm{I}}_{0,\mathrm{UU}} + c^{\mathrm{I}}_{2,\mathrm{UU}}\cos(2\phi)\right\}\right.$$

$$+S_\perp\left[c^{\mathrm{I}}_{1,\mathrm{UT}}\sin(\phi-\phi_S)\cos\phi + s^{\mathrm{I}}_{1,\mathrm{UT}}\cos(\phi-\phi_S)\sin\phi\right.$$
$$+c^{\mathrm{I}}_{3,\mathrm{UT}}\sin(\phi-\phi_S)\cos(3\phi) + s^{\mathrm{I}}_{3,\mathrm{UT}}\cos(\phi-\phi_S)\sin(3\phi)$$
$$+\left\{\boldsymbol{c^{\mathrm{I}}_{0,\mathrm{UT}}\sin(\phi-\phi_S)} + c^{\mathrm{I}}_{2,\mathrm{UT}}\sin(\phi-\phi_S)\cos(2\phi)\right.$$
$$\left.\left.\left.+s^{\mathrm{I}}_{2,\mathrm{UT}}\cos(\phi-\phi_S)\sin(2\phi)\right\}\right]\right).$$



DVCS with a transversely polarized target

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$$c_{0,\mathrm{UT}}^{\mathrm{DVCS}} \propto -\frac{\sqrt{-t}}{M}\mathrm{Im}\left\{\mathcal{H}\mathcal{E}^* - \mathcal{E}\mathcal{H}^* + \xi\tilde{\mathcal{E}}\,\tilde{\mathcal{H}}^* - \tilde{\mathcal{H}}\,\xi\tilde{\mathcal{E}}^*\right\},$$

$$c_{1,\mathrm{UU}}^{\mathrm{I}} \propto \frac{\sqrt{-t}}{Q}\mathrm{Re}\left\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}\right\},$$

$$c_{0,\mathrm{UU}}^{\mathrm{I}} \propto -\frac{\sqrt{-t}}{Q}c_{1,\mathrm{UU}}^{\mathrm{I}},$$

UT → GPD E

$$c_{1,\mathrm{UT}}^{\mathrm{I}} \propto -\frac{M}{Q}\mathrm{Im}\left\{\frac{t}{4M^2}\left[(2-x_B)F_1\mathcal{E} - 4\frac{1-x_B}{2-x_B}F_2\mathcal{H}\right] + x_B\xi\left[F_1(\mathcal{H}+\mathcal{E}) - (F_1+F_2)\left(\tilde{\mathcal{H}} + \frac{t}{4M^2}\tilde{\mathcal{E}}\right)\right]\right\}$$

$$c_{0,\mathrm{UT}}^{\mathrm{I}} \propto -\frac{\sqrt{-t}}{Q}c_{1,\mathrm{UT}}^{\mathrm{I}},$$

$$s_{1,\mathrm{UT}}^{\mathrm{I}} \propto -\frac{M}{Q}\mathrm{Im}\left\{\frac{t}{4M^2}\left[4\frac{1-x_B}{2-x_B}F_2\tilde{\mathcal{H}} - (F_1+\xi F_2)x_B\tilde{\mathcal{E}}\right] + x_B\left[(F_1+F_2)\left(\xi\mathcal{H} + \frac{t}{4M^2}\mathcal{E}\right) - \xi F_1\left(\tilde{\mathcal{H}} + \frac{x_B}{2}\tilde{\mathcal{E}}\right)\right]\right\}$$

DVCS with T-pol. H target

HERMES, JHEP06 (2008) 066

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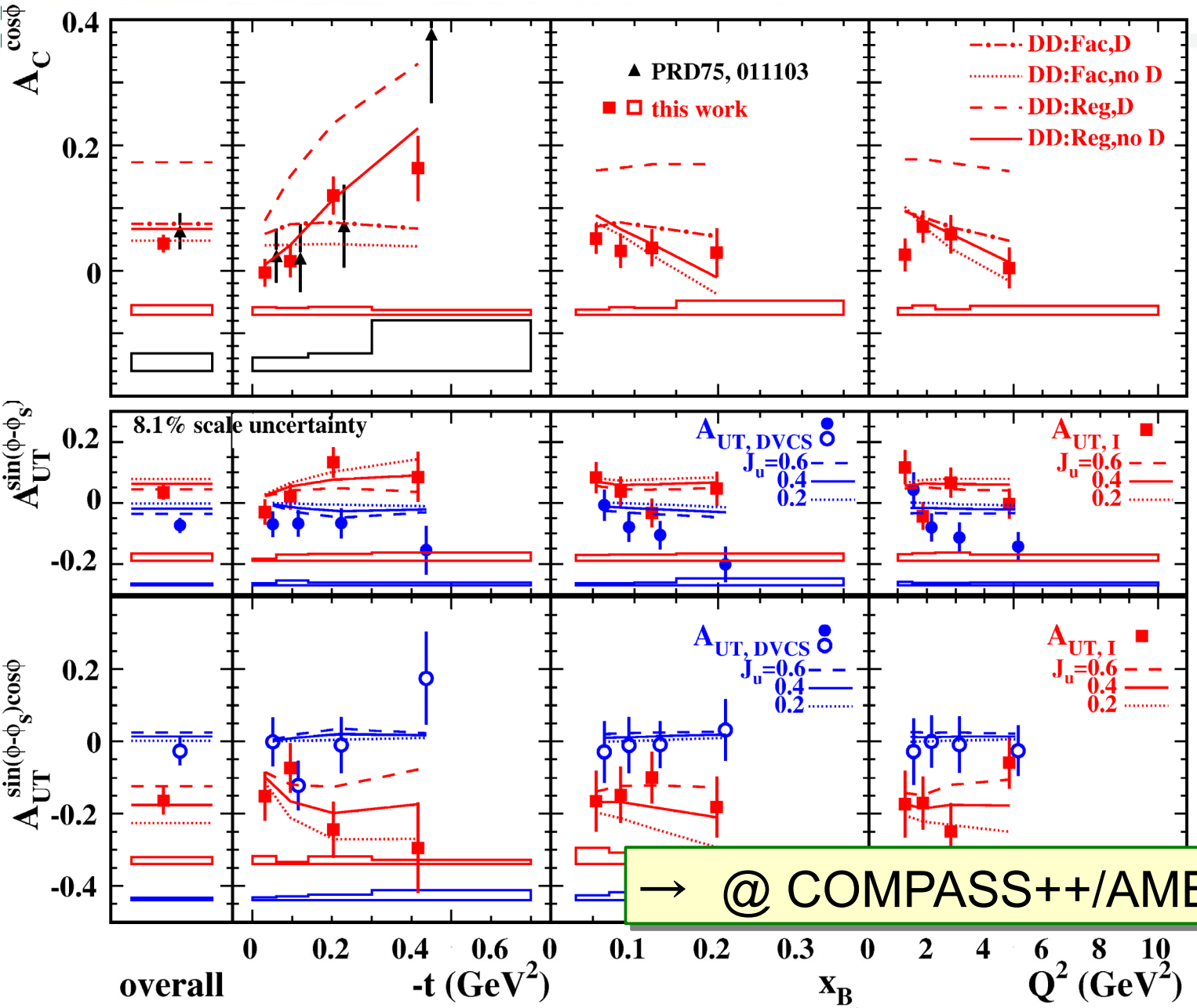


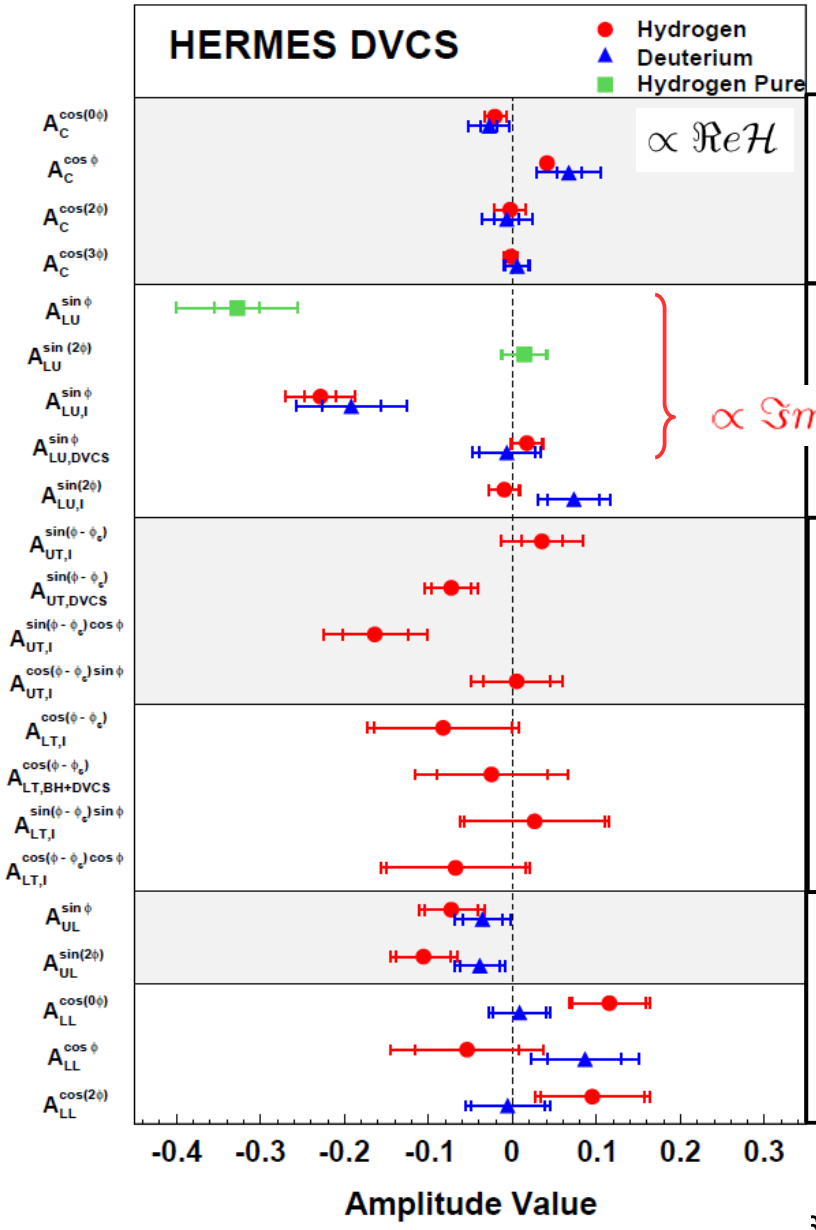
$$A_C^{\cos\phi} \propto \Re\left[F\mathcal{H} \right]$$

$$A_{UT,DVCS}^{\sin(\phi-\phi_S)} \propto \Im\left[\mathcal{H}\mathcal{E}^* - \mathcal{E}\mathcal{H}^* + \xi\tilde{\mathcal{E}}\tilde{\mathcal{H}}^* - \tilde{\mathcal{H}}\xi\tilde{\mathcal{E}}^* \right]$$

$$A_{UT,I}^{\sin(\phi-\phi_S)} \propto -A_{UT,I}^{\sin(\phi-\phi_S)\cos\phi} \propto \Im\left[F_1\mathcal{E} - F_2\mathcal{H} \right]$$

→ @ COMPASS++/AMBER, JLab12GeV

Extracted overall asymmetries @ HERMES



GPD

Beam Charge Asymmetries

Beam Spin Asymmetries

PRL 87 (2001) 182001
PRD 75 (2007) 011103
JHEP 11 (2009) 083
JHEP 07 (2012)032
JHEP 10 (2012) 042
NPB 829 (2010) 1

H

T-pol. target

Target Spin Asymmetries

Double Spin Asymmetries

JHEP 06 (2008) 066
PLB 704 (2011) 15

E

L-pol. target

Target Spin Asymmetries

Double Spin Asymmetries

JHEP 06 (2010) 019
NPB 842 (2011) 265

$\tilde{H}$

DVCS @CLAS

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"*First Observation of Exclusive Deeply Virtual Compton Scattering in Polarized Electron Beam Asymmetry Measurements*", Phys. Rev. Lett. 87, 182002 (2001)

"*Measurement of Deeply Virtual Compton Scattering with a* ***Polarized Proton Target***", Phys. Rev. Lett. 97, 072002 (2006)

"*Deeply Virtual Compton Scattering* ***Beam-Spin Asymmetries***", Phys. Rev. Lett. 100, 162002 (2008)

"***Longitudinal Target-Spin Asymmetries*** *for Deeply Virtual Compton Scattering*", Phys. Rev. Lett. 114, 032001 (2015)

"***Single and Double Spin Asymmetries*** *for Deeply Virtual Compton Scattering Measured with CLAS and a* ***Longitudinally Polarized Proton Target***", Phys. Rev. D 91, 052014 (2015)

"*First Exclusive Measurement of* ***Deeply Virtual Compton Scattering off 4He****: Toward the 3D Tomography of Nuclei*", Phys. Rev. Lett. 119, 202004 (2017)

"*Measurement of* ***Unpolarized and Polarized Cross Sections*** *for Deeply Virtual Compton Scattering on the Proton at Jefferson Laboratory with CLAS*", Phys. Rev. C 98, 045203 (2018)

"*Exploring the Structure of the* ***Bound Proton*** *with Deeply Virtual Compton Scattering*", Phys.Rev.Lett. 123 (2019) no.3, 032502

COMPASS 2016 ~ 2017 (2 × 6 months)

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(1) The beam charge & spin sum of cross sections

$$\mathcal{S}_{CS,U} \equiv \mathrm{d}\sigma^{\overleftarrow{\pm}} + \mathrm{d}\sigma^{\overrightarrow{-}} = 2(\mathrm{d}\sigma^{BH} + \mathrm{d}\sigma^{DVCS}_{unpol} + e_\mu P_\mu \mathrm{Im}\, I),$$

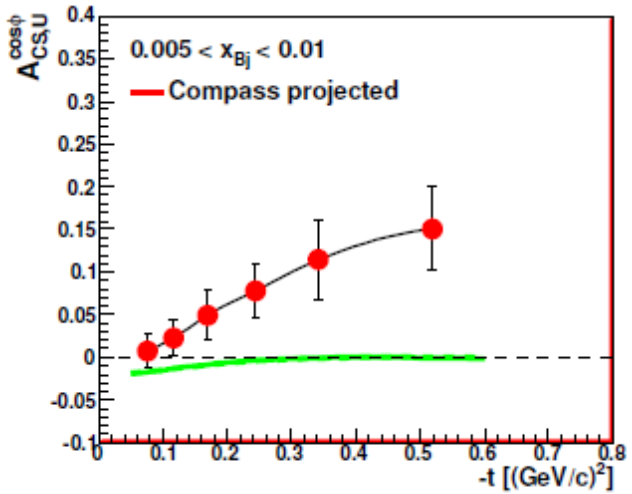
(2) The beam charge & spin difference of cross sections

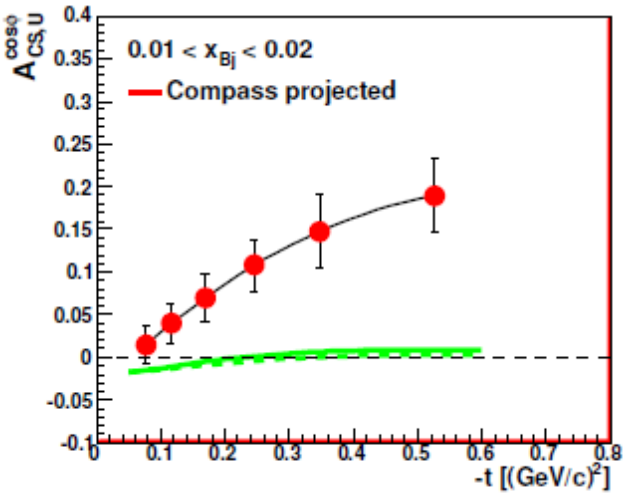
$$\mathcal{D}_{CS,U} \equiv \mathrm{d}\sigma^{\overleftarrow{\pm}} - \mathrm{d}\sigma^{\overrightarrow{-}} = 2(P_\mu \mathrm{d}\sigma^{DVCS}_{pol} + e_\mu \mathrm{Re}\, I),$$

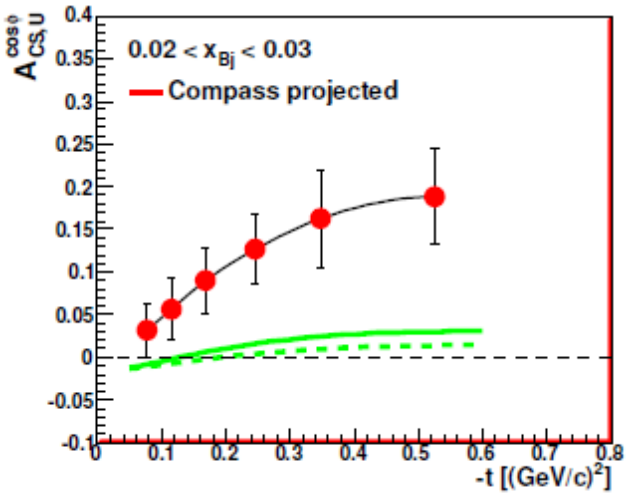
(3) The beam charge & spin asymmetry of cross sections

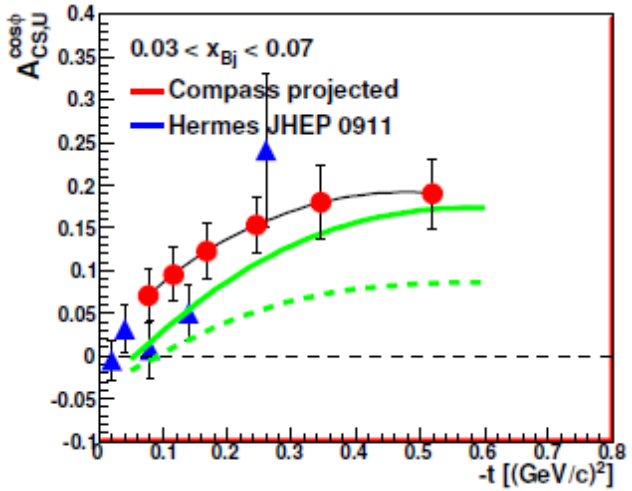
$$\mathcal{A}_{CS,U} \equiv \frac{\mathrm{d}\sigma^{\overleftarrow{\pm}} - \mathrm{d}\sigma^{\overrightarrow{-}}}{\mathrm{d}\sigma^{\overleftarrow{\pm}} + \mathrm{d}\sigma^{\overrightarrow{-}}} = \frac{\mathcal{D}_{CS,U}}{\mathcal{S}_{CS,U}},$$

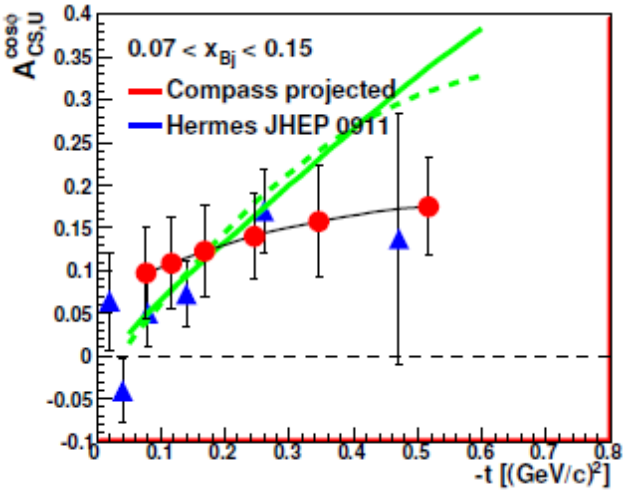
Expected beam charge spin asymmetries

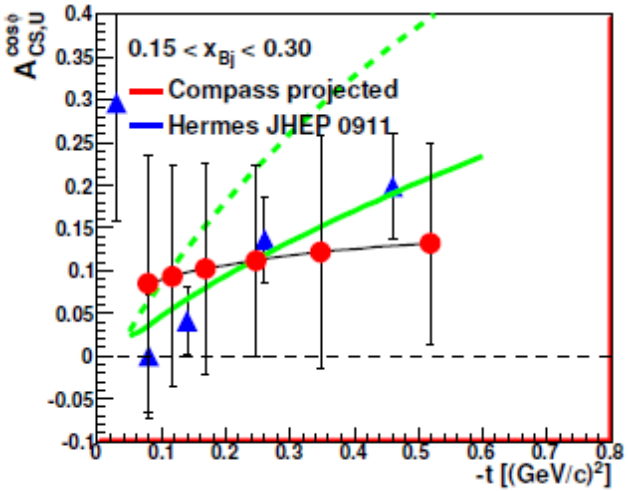












DVCS @ JLab 12 GeV

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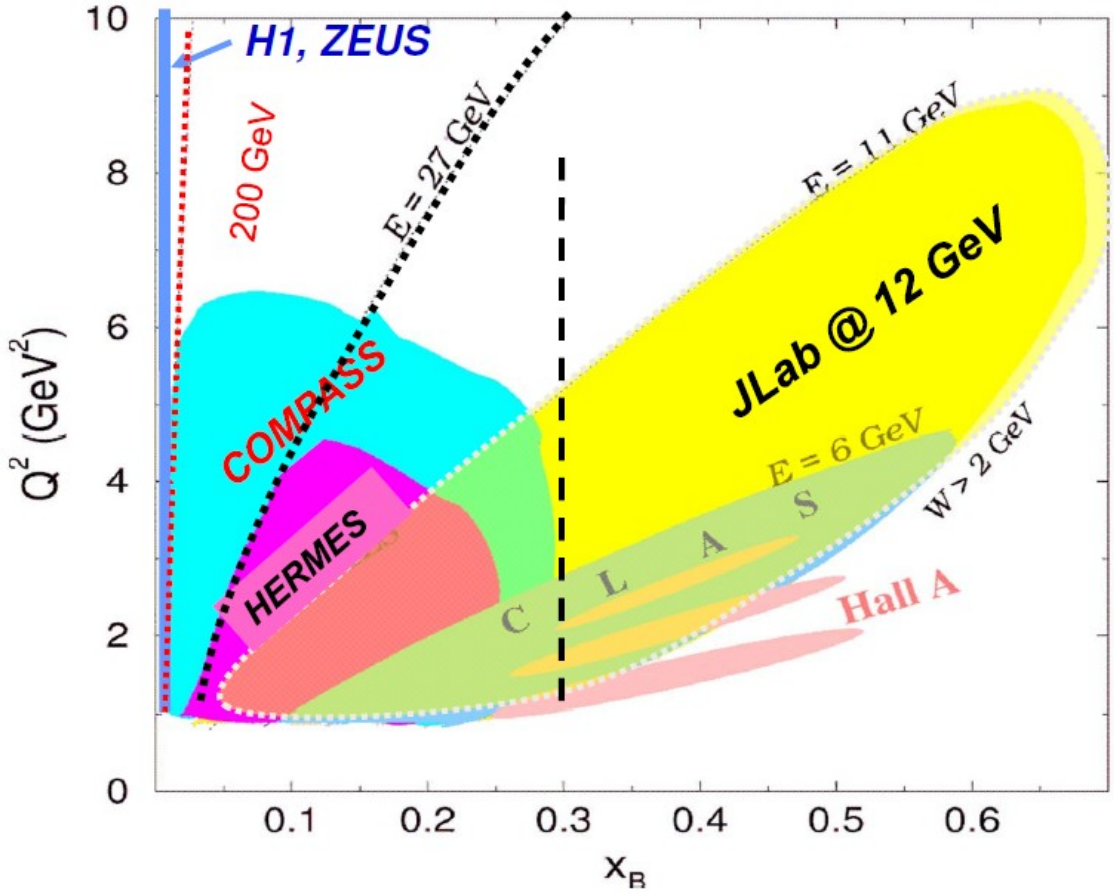


DVCS experiments @ Jlab 12 GeV

Hall-A

E12-06-114 Measurements of Electron-Helicity Dependent Cross Sections of Deeply Virtual Compton Scattering with CEBAF at 12 GeV

Hall-B CLAS12

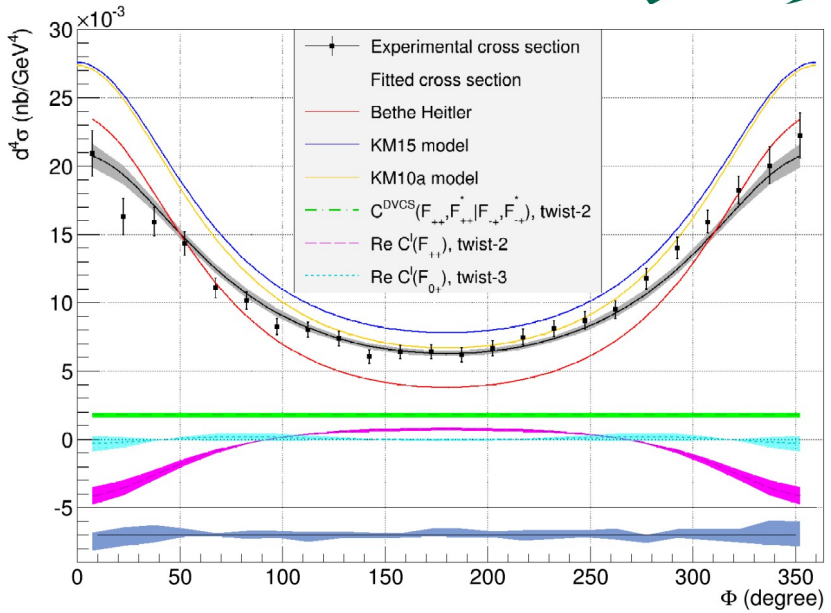
E12-06-119 Deeply Virtual Compton Scattering with CLAS at 11 GeV

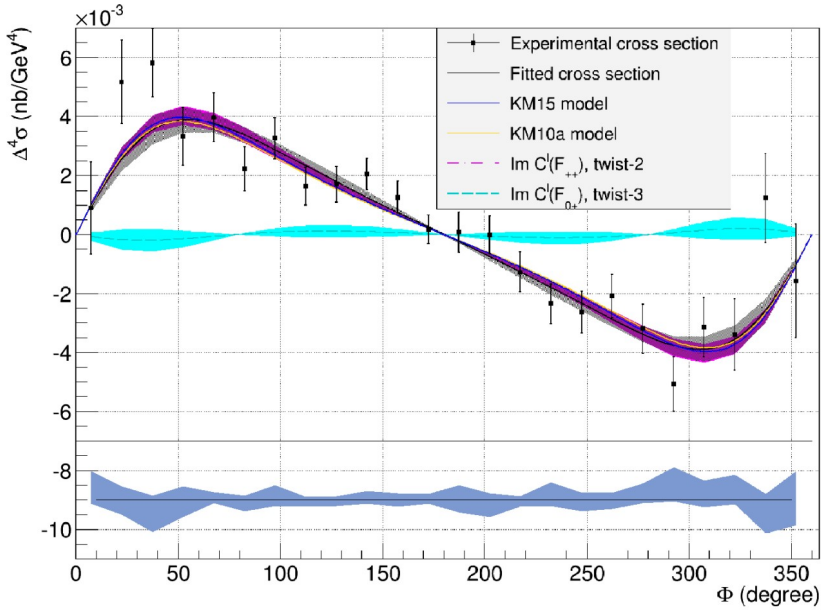
E12-11-003 Deeply Virtual Compton Scattering on the Neutron with CLAS12 at 11 GeV

E12-06-109A Deeply virtual Compton scattering on the neutron with a longitudinally polarized deuteron target

Hall-C

E12-13-010 Exclusive Deeply Virtual Compton and Neutral Pion Cross-Section Measurements in Hall C





E12-06-114 preliminary

DVCS @ Electron Ion Collider

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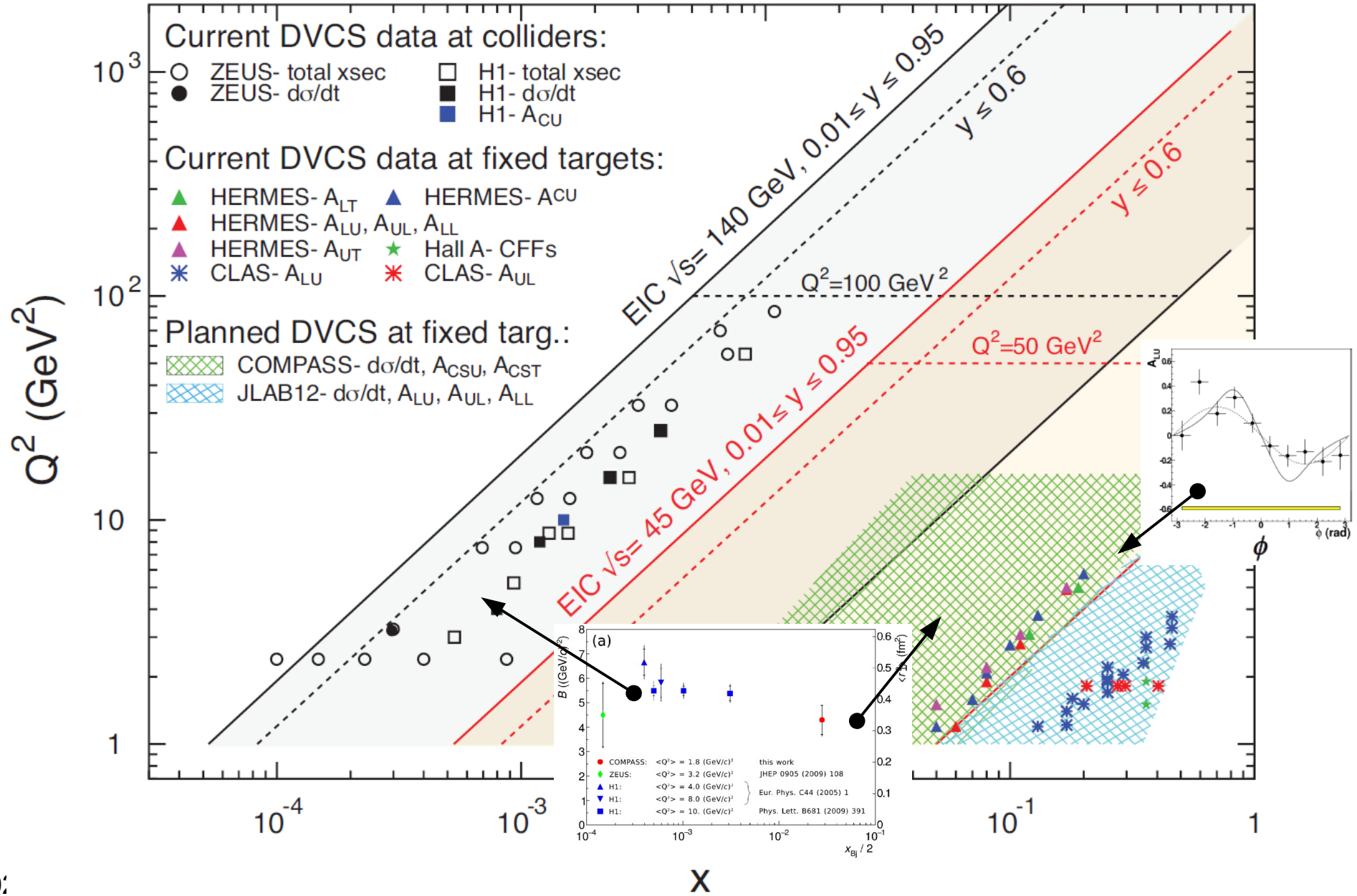
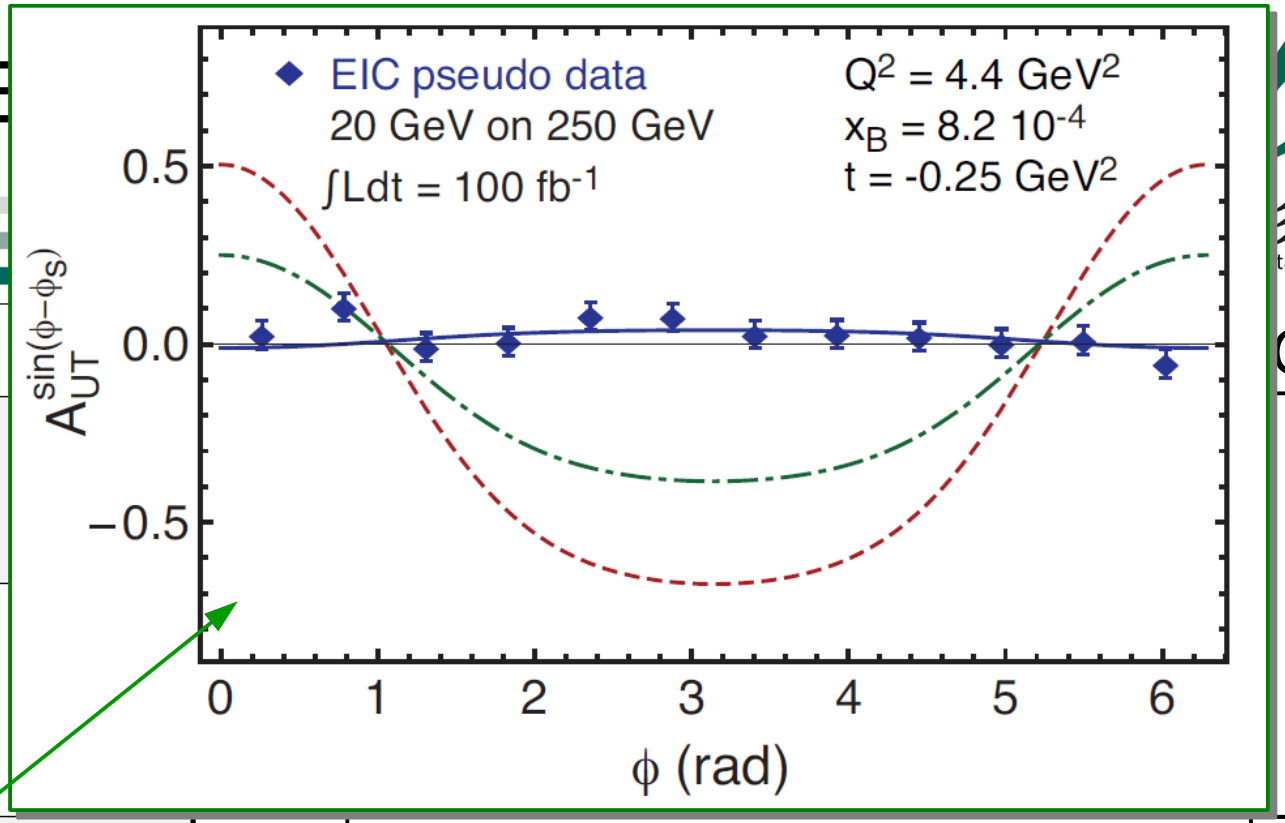
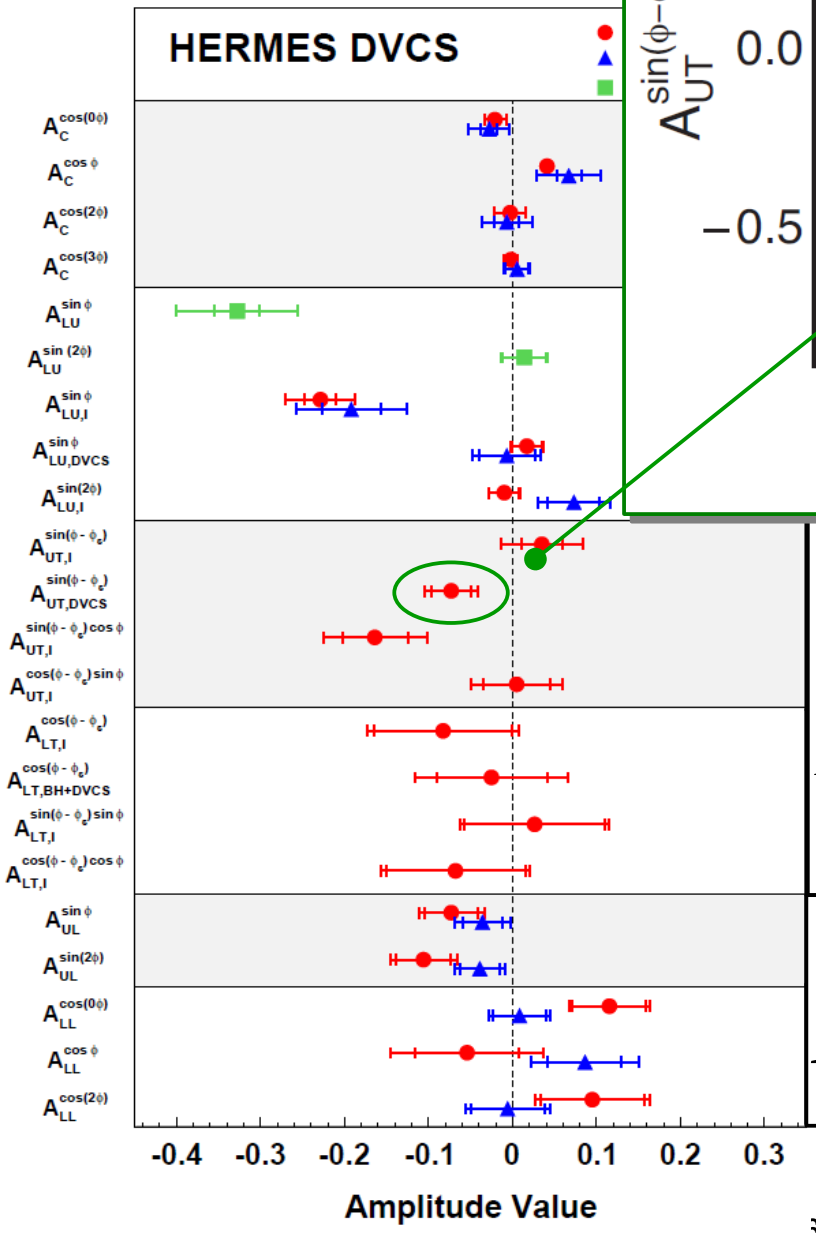


DVCS @ HERME





GPD

H

$p^{\uparrow\downarrow}$

Target Spin Asymmetries

JHEP 06 (2008) 066
PLB 704 (2011) 15

Double Spin Asymmetries

E

クォーク全角運動量⇔

$p^{\leftrightarrow}$

Target Spin Asymmetrie

JHEP 06 (2010) 019
NPB 842 (2011) 265

Double Spin Asymmetries

$\tilde{H}$

GPD extraction from data

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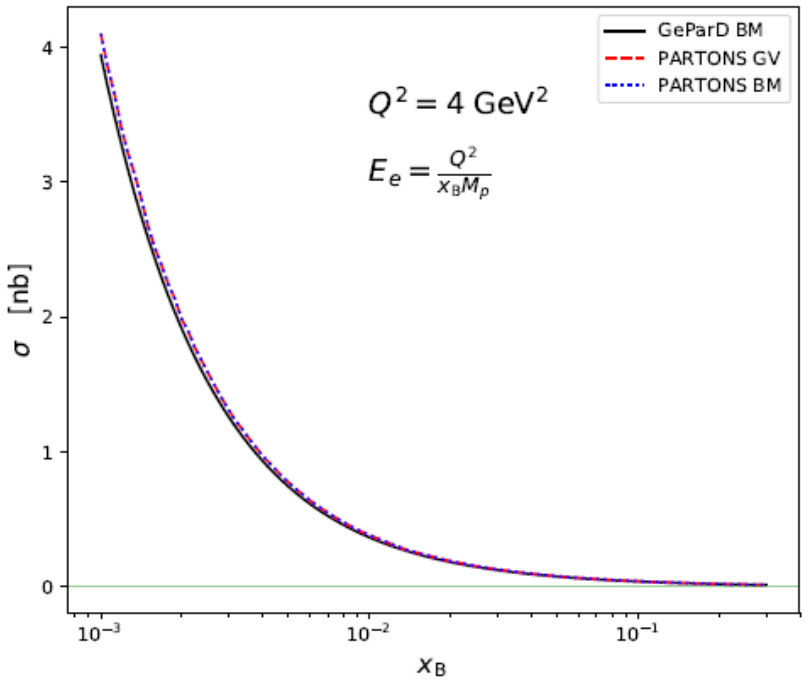
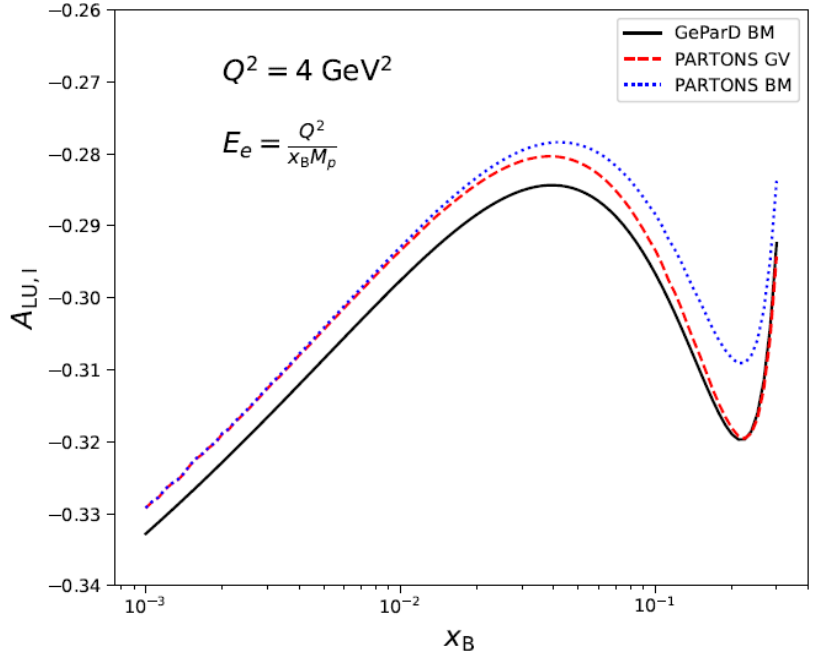
GPD based analysis frameworks:

GeParD	http://calculon.phy.hr/gpd/
PARTON(EPJC78(2018) 478)	https://drf-gitlab.cea.fr/partons/core





GPD extraction from data

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GPD based analysis frameworks:

GeParD http://calculon.phy.hr/gpd/

PARTON http://partons.cea.fr/partons/doc/html/index.html

[K.K., Müller '09-'15]

Collaboration	Observable	Ref.	n_{pts}	KMM12		KM15	
				χ^2/n_{pts}	pull	χ^2/n_{pts}	pull
ZEUS	σ_{DVCS}	[19] [20]	11	0.49	-1.76	0.51	-1.74
ZEUS,H1	$d\sigma_{DVCS}/dt$	[19] [21] [22]	24	0.97	0.85	1.04	1.37
HERMES	$A_C^{\cos 0\phi}$	[23]	6	1.31	0.49	1.24	0.29
HERMES	$A_C^{\cos\phi}$	[23]	6	0.24	-0.56	0.07	-0.20
HERMES	$A_{LU,I}^{\sin\phi}$	[23]	6	2.08	-2.52	1.34	-1.28
CLAS	$A_{LU}^{\sin\phi}$	[24]	4	1.28	2.09		
CLAS	$A_{LU}^{\sin\phi}$	[4] [25]	13			1.24	0.63
CLAS	$\Delta\sigma^{\sin\phi,w}$	[7]	48			0.41	-1.66
CLAS	$d\sigma^{\cos 0\phi,w}$	[7]	48			0.16	-0.21
CLAS	$d\sigma^{\cos\phi,w}$	[7]	48			1.16	6.36
Hall A	$\Delta\sigma^{\sin\phi,w}$	[5]	12	1.06	-2.55		
Hall A	$d\sigma^{\cos 0\phi,w}$	[5]	4	1.21	2.14		
Hall A	$d\sigma^{\cos\phi,w}$	[5]	4	3.49	-0.26		
Hall A	$\Delta\sigma^{\sin\phi,w}$	[6]	15			0.81	-2.84
Hall A	$d\sigma^{\cos 0\phi,w}$	[6]	10			0.40	0.92
Hall A	$d\sigma^{\cos\phi,w}$	[6]	10			2.52	-2.42
HERMES,CLAS	$A_{UL}^{\sin\phi}$	[18] [26]	10	1.90	-1.89	1.10	-1.94
HERMES	$A_{LL}^{\cos 0\phi}$	[26]	4	3.44	2.17	3.19	1.99
HERMES	$A_{UT,I}^{\sin(\phi-\phi_S)\cos\phi}$	[27]	4	0.90	0.61	0.90	0.71
CLAS	$A_{UL}^{\sin\phi}$	[4]	10			0.76	0.38
CLAS	$A_{LL}^{\cos 0\phi}$	[4]	10			0.50	-0.22
CLAS	$A_{LL}^{\cos\phi}$	[4]	10			1.54	2.40

[Moutarde, Sznajder, Wagner, '18]

Data used in global fit

No.	Collab.	Year	Ref.	χ^2	n	χ^2/n
1	HERMES	2001	13	9.8	10	0.98
2		2006	114	2.9	4	0.72
3		2008	115	24.2	18	1.35
4		2009	116	40.1	35	1.15
5		2010	117	40.3	18	2.24
6		2011	118	14.5	24	0.60
7		2012	119	25.4	35	0.73
8	CLAS	2001	14	—	0	—
9		2006	120	0.9	2	0.47
10		2008	121	371.1	283	1.31
11		2009	122	36.4	22	1.66
12		2015	123	351.4	311	1.13
13		2015	124	937.9	1333	0.70
14	Hall A	2015	112	220.2	228	0.97
15		2017	113	258.8	276	0.94
16	COMPASS	2018	55	10.7	1	10.67

Fit with PARTONS (arXiv:1807.07620)

PARTONS18
GK model
VGG model

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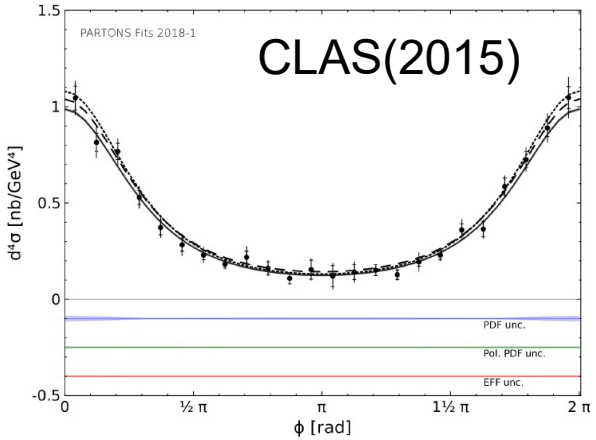
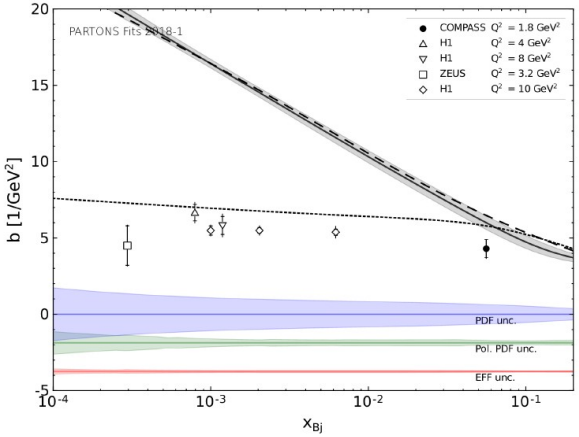
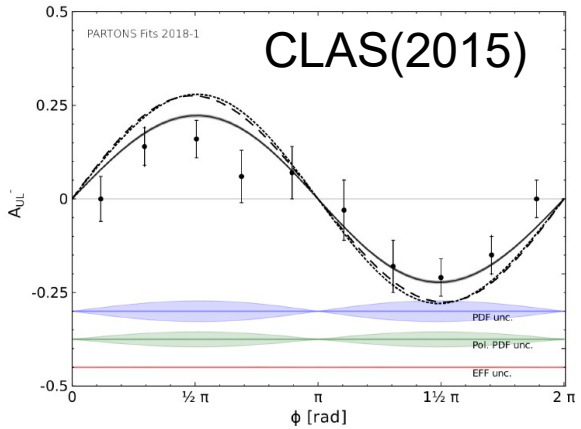
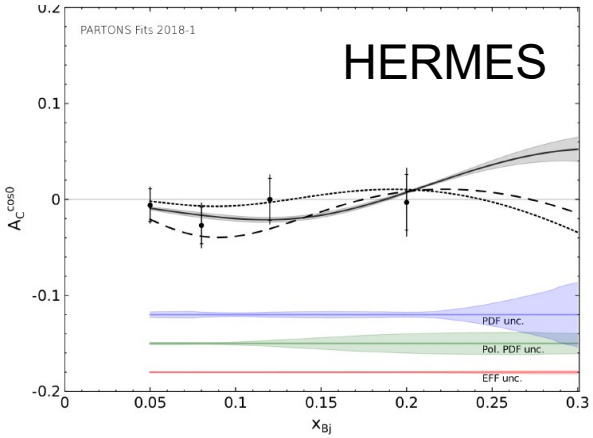
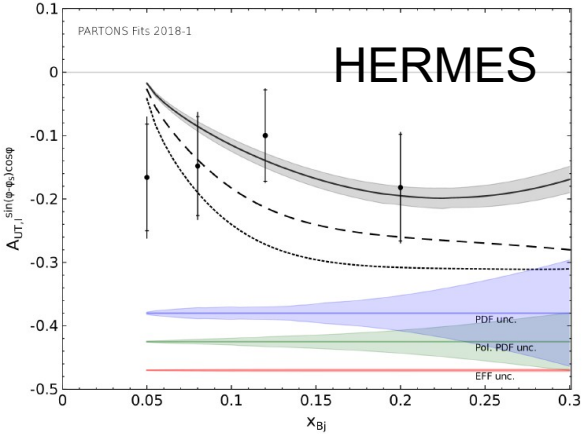




HERA&COMPASS







Fit with PARTONS (arXiv:1807.07620)

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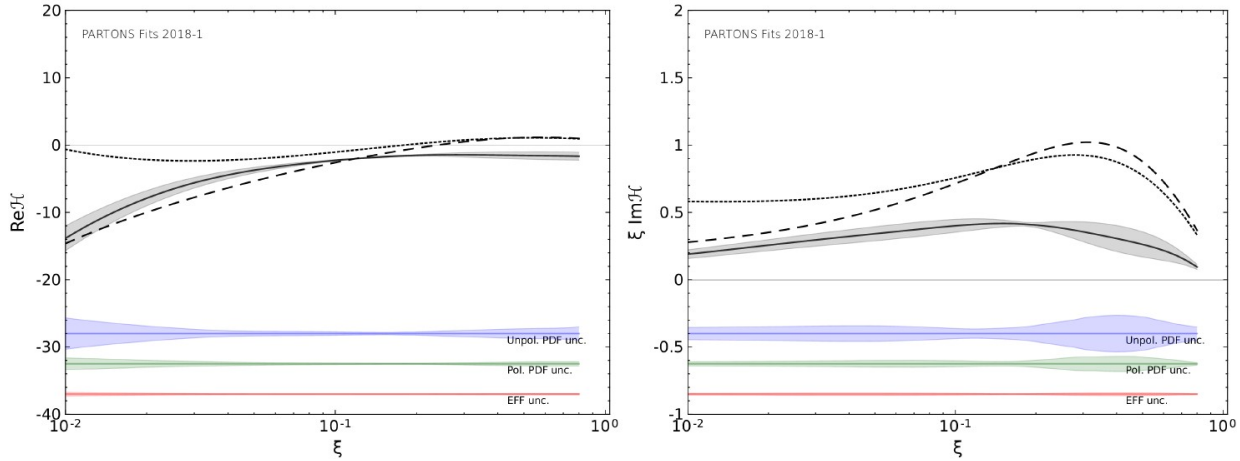
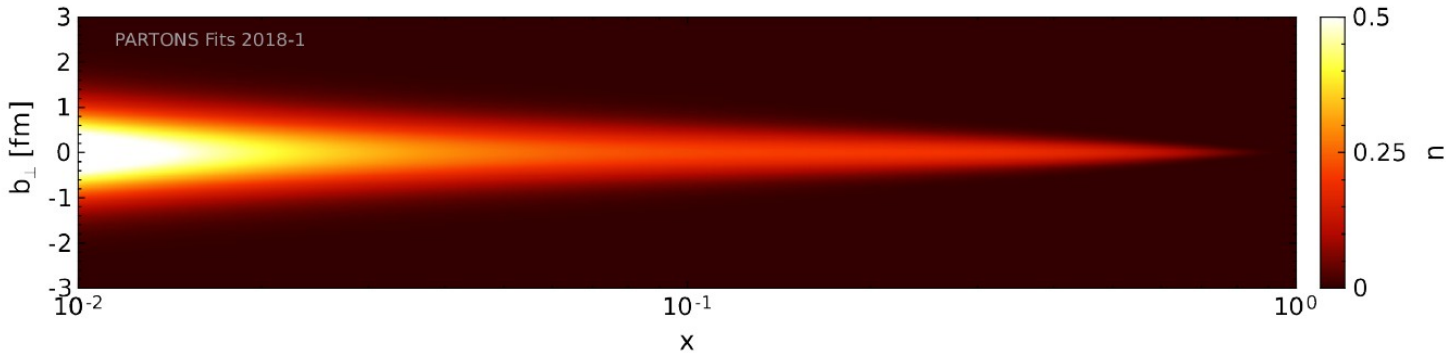
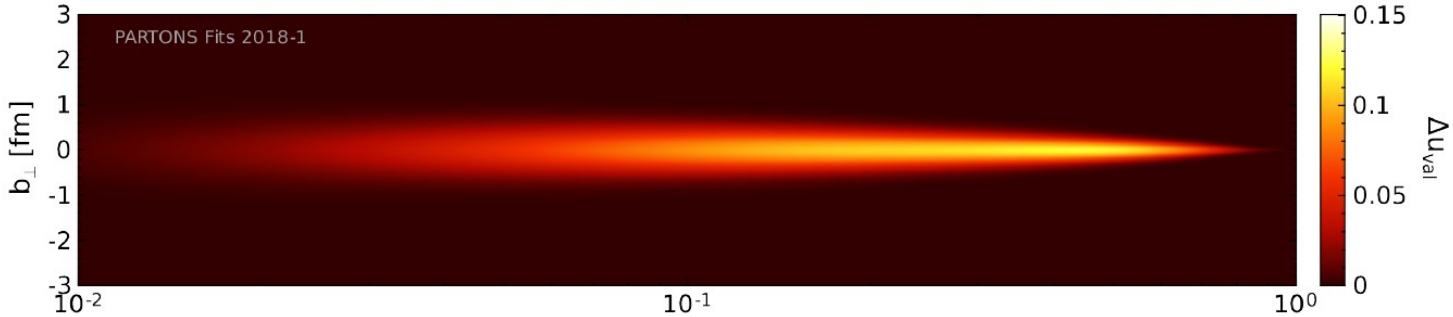


$t = -0.3\ \mathrm{GeV}^2$, $Q^2 = 2\ \mathrm{GeV}^2$





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

no uncertainties!

Summary and Outlook

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H1, ZEUS **σ**

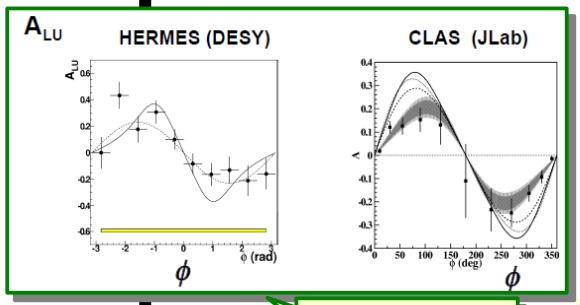
EIC

COMPASS II

COMPASS++/
AMBER

160 GeV μ,
σ, BSA+BCA

HERMES



PRL**87**(2001)

26.7 GeV electron, H, D, A
σ, BSA, BCA, TSA(L+T)

JLab

Electron (4 GeV→ 6 GeV→ 12 GeV)
σ, BSA

Observation

Precice determination of GPD