Experimental GPD overview

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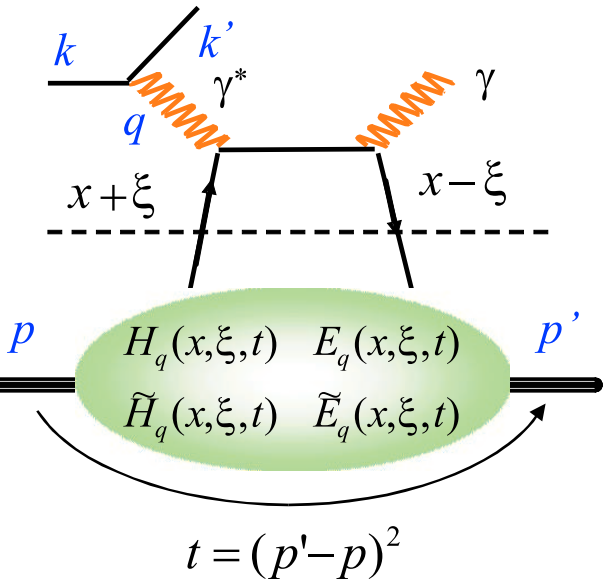
Outline

1. Introduction: how GPD can be accessed in experiment
2. Experimental overview:
   - HERMES at DESY
   - Hall A and Hall B at Jefferson Lab
3. Outlook
   - Jefferson Lab at 12 GeV
   - COMPASS-II at CERN

Generalized Parton Distributions



- Correlate between different partonic states
- Correlate momentum and position of partons
- Access to new fundamental properties of the nucleon

Contribution of the **angular momentum of quarks** to proton spin:

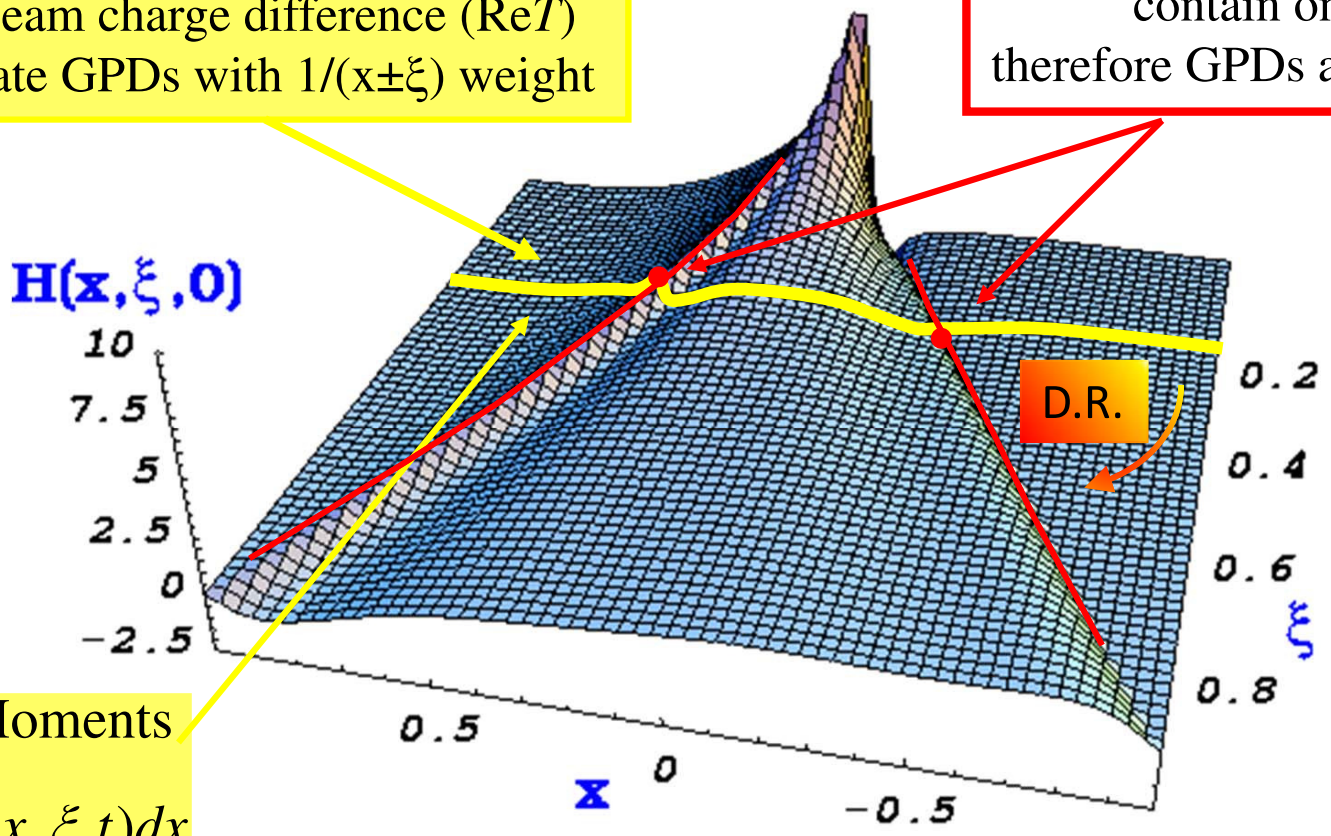
$$\frac{1}{2} = \underbrace{\frac{1}{2}\Delta\Sigma + L_q}_{J_q} + J_g \quad \Rightarrow \quad J_q = \frac{1}{2}\int_{-1}^{1} dx\, x[H^q(x,\xi,0) + E^q(x,\xi,0)]$$

DVCS cleanest process to access GPDs

GPD experimentally: Compton Form Factors (CFFs)

Cross-section (σ) measurement and beam charge difference (ReT) integrate GPDs with $1/(x\pm\xi)$ weight

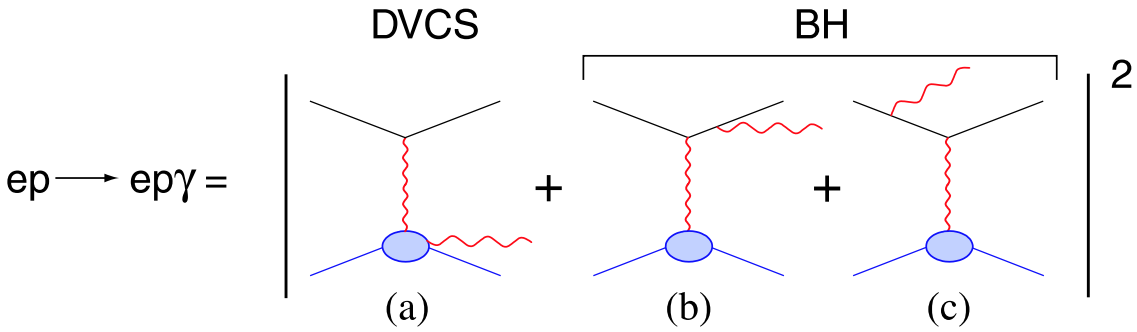
Beam or target spin $\Delta\sigma$ contain only ImT, therefore GPDs at $x = \xi$ and $-\xi$



Lattice Moments

$$= \int x^n H(x,\xi,t)dx$$

DVCS experimentally: interference with Bethe-Heitler (BH)



At leading twist:

$$d^5\overrightarrow{\sigma} - d^5\overleftarrow{\sigma} = \Im m\left(T^{BH}\cdot T^{DVCS}\right)$$

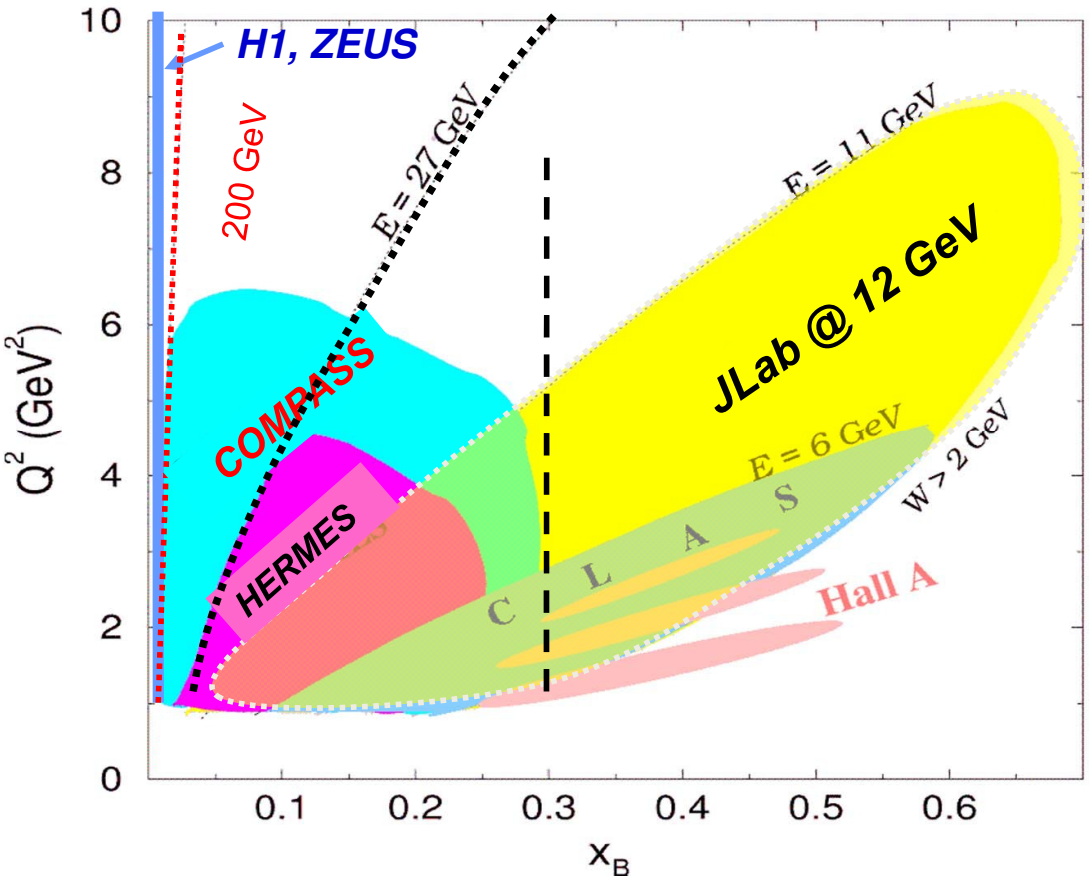
$$d^5\overrightarrow{\sigma} + d^5\overleftarrow{\sigma} = |BH|^2 + \Re e\left(T^{BH}\cdot T^{DVCS}\right) + |DVCS|^2$$

$$\mathcal{T}^{DVCS} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\epsilon} + \cdots =$$

$$\underbrace{\mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}}_{\text{Access in helicity-independent cross section}} - \underbrace{i\pi\, H(x=\xi,\xi,t)}_{\text{Access in helicity-dependent cross-section}} + \ldots$$

Kinematic coverage

Kinematic complementarity between different facilities



COMPASS covering part of JLab and HERMES kinematics and extending into the low x region

The DVCS program "worldwide"

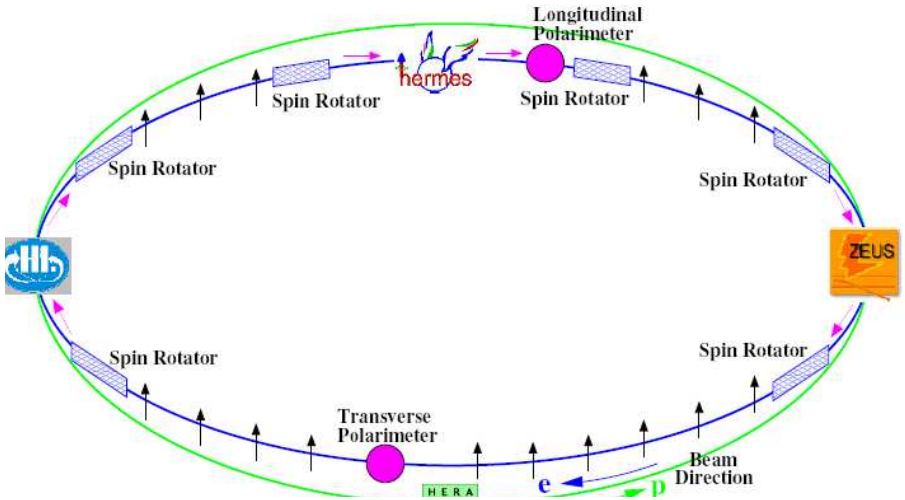
- HERMES at DESY:
  - Beam (BSA), charge (BCA) and transverse target (TSA) asymetries published
  - Several ongoing analysis + recoil detector installed 1 year before shutdown: results to come...
- Hall A and Hall B partially overlapping, partially complementary, active programs:
  - Hall A: high accuracy, limited kinematics
  - Hall B: wide kinematic range, limited accuracy
  - Very different systematics
- COMPASS at CERN
- The roadmap:
  - Early results (≈ 2001) from non-dedicated exp. (HERMES+CLAS)
  - First round of dedicated experiments in Halls A/B in 2004/5
  - Second round on 2008–2010
  - Compeling DVCS experiments in Halls A/B at 11 GeV (≈2014-16)
  - Exciting program at COMPASS (2015–2016)

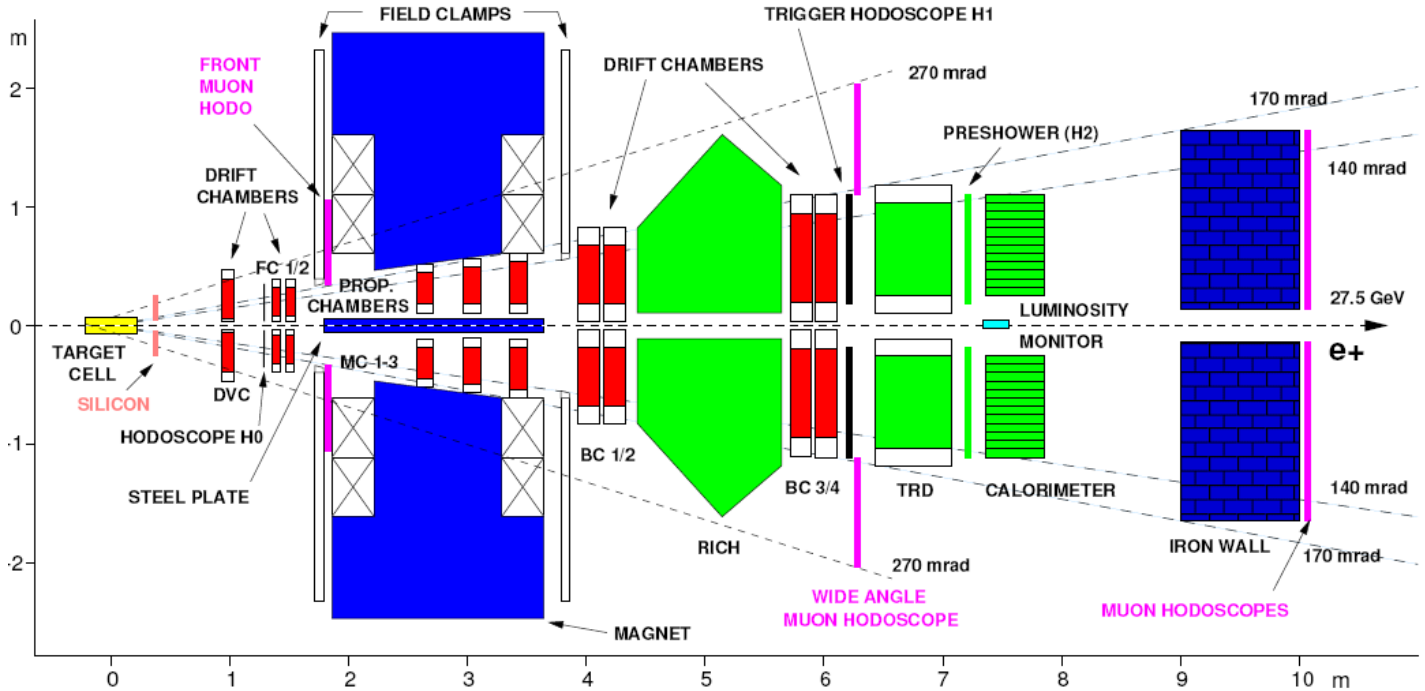
HERMES

27.5 GeV polarised e^+/e^- beam of HERA

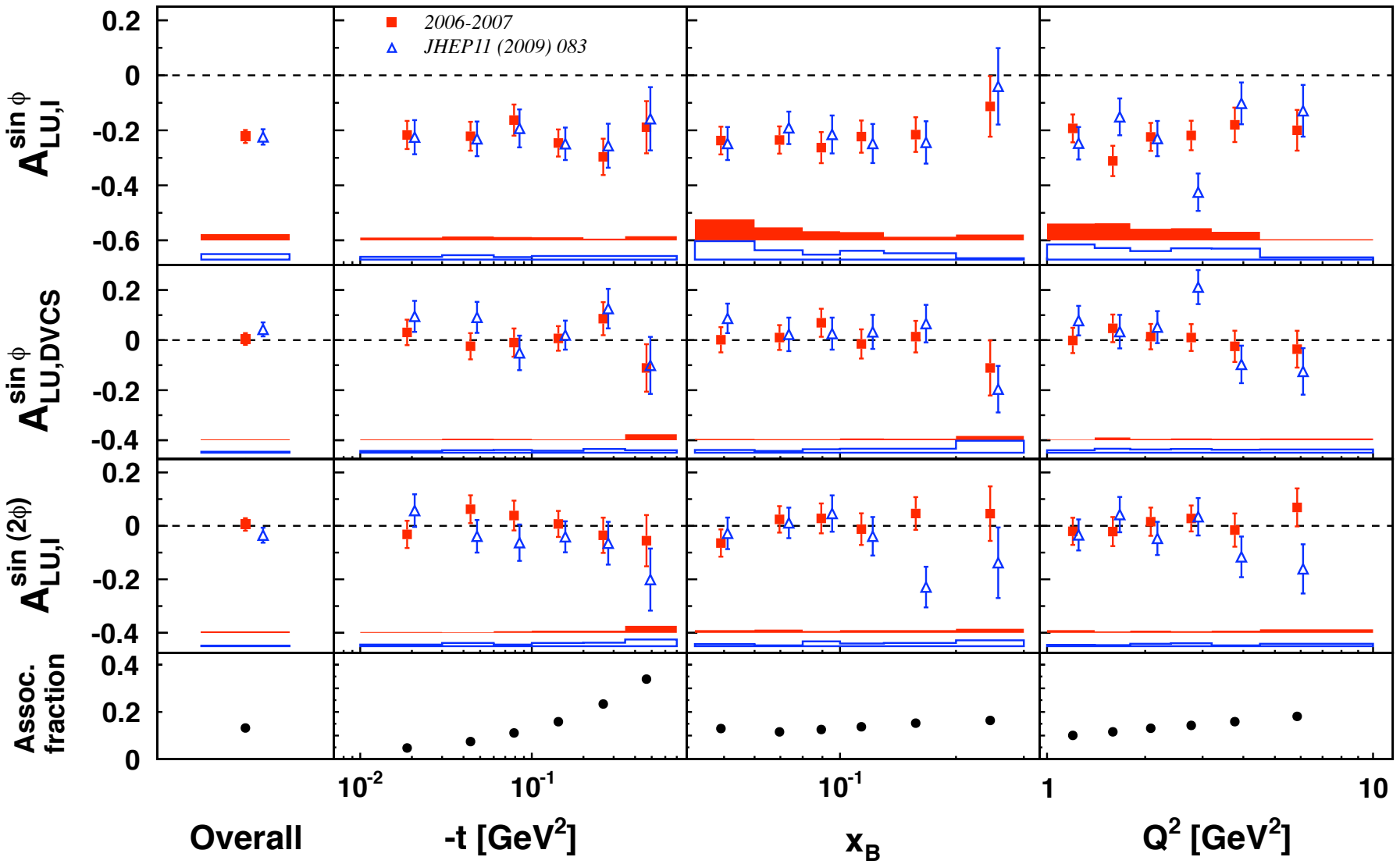
Data taking 95–07

- 96–00 (H/D) Lpol + Upol
- 02–05 (H) Tpol+ Upol
- 06–07 (H/D) Upol+Recoil



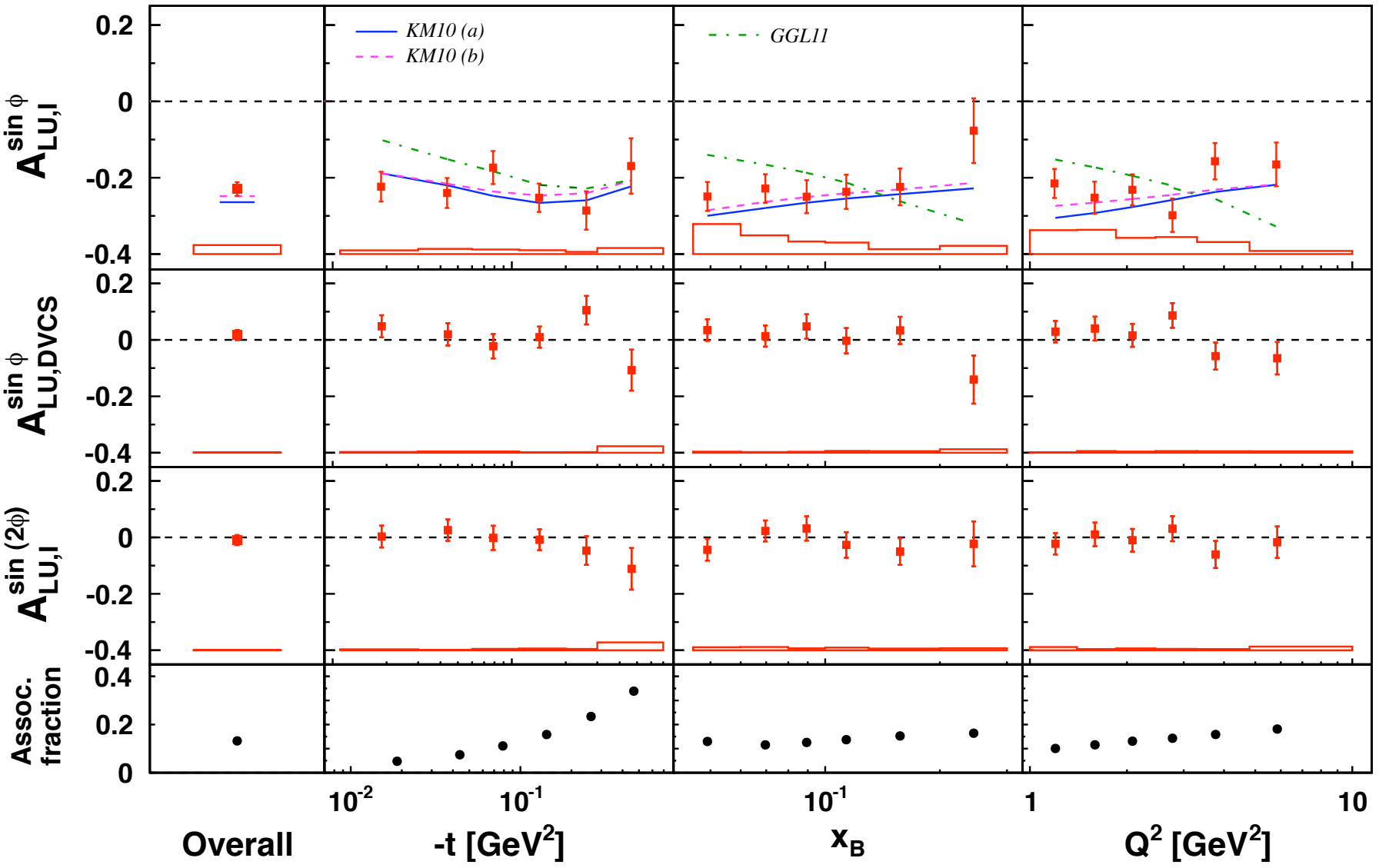


HERMES: compatibility of old and new datasets



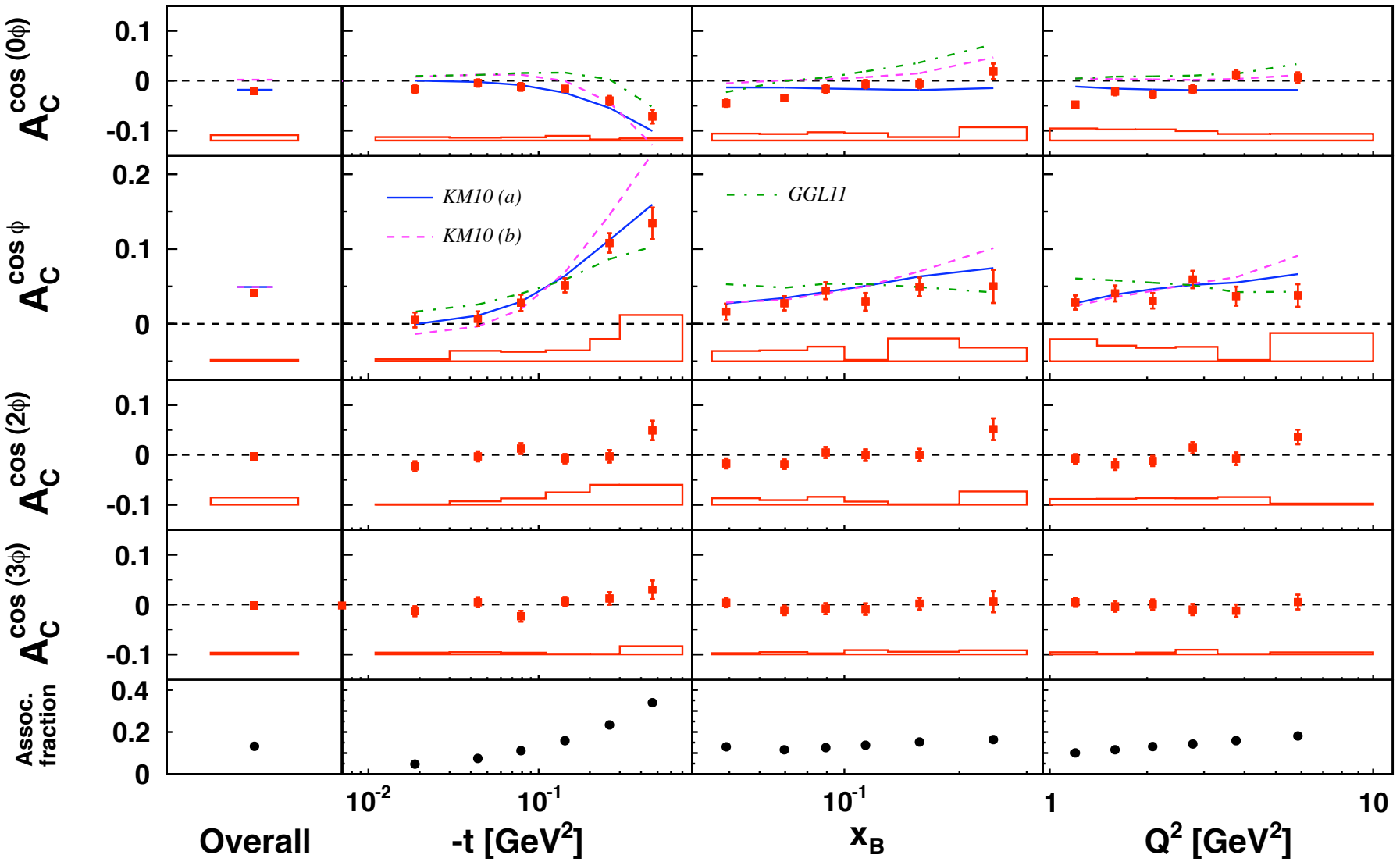
arXiv:1203.6287

New HERMES results: combined DVCS BSA



arXiv:1203.6287

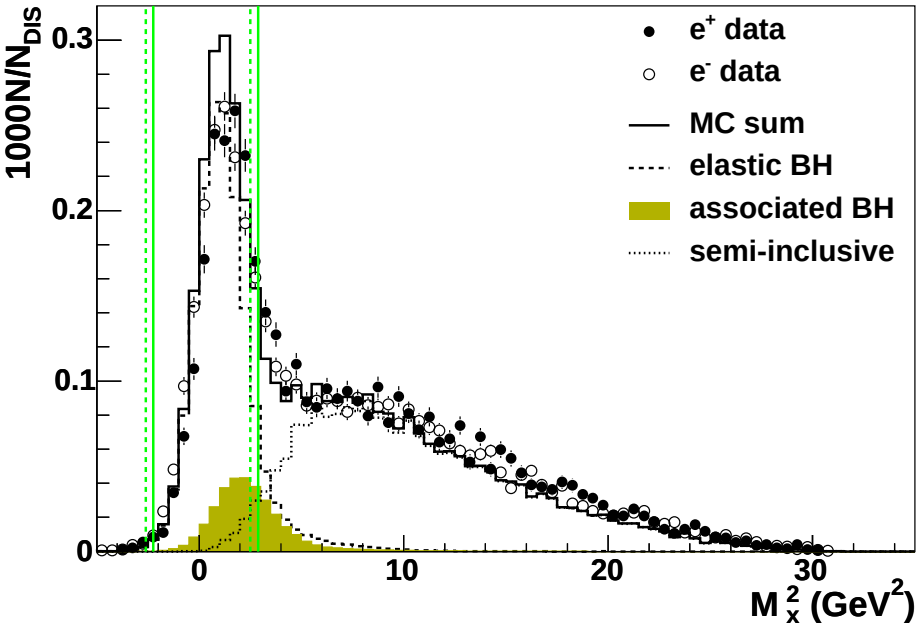
New HERMES results: combined DVCS BCA

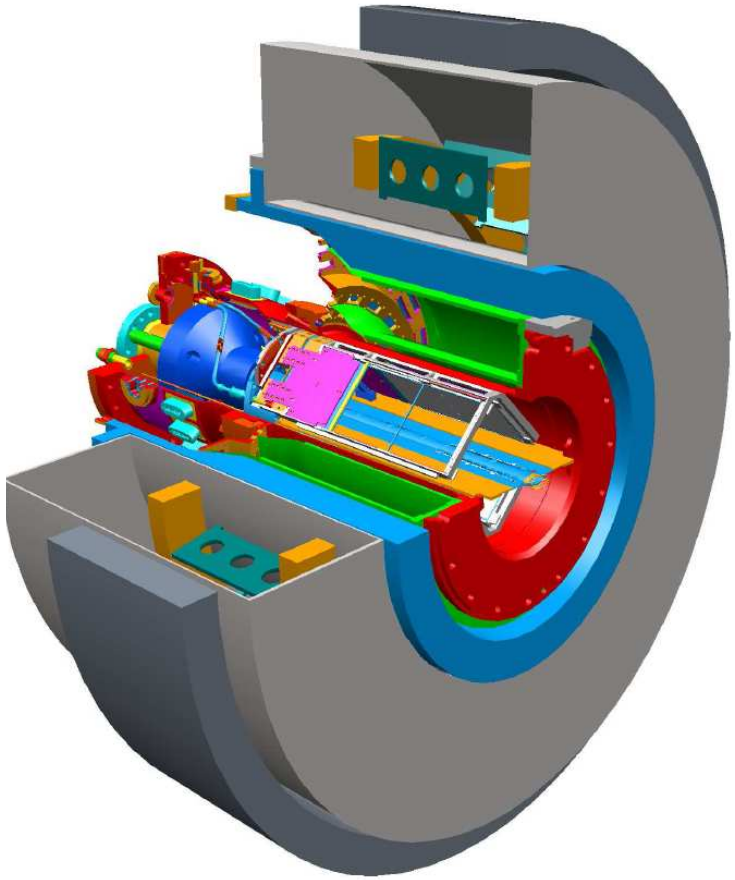


arXiv:1203.6287

Recoil detector at HERMES

Missing mass squared $ep \to e\gamma X$

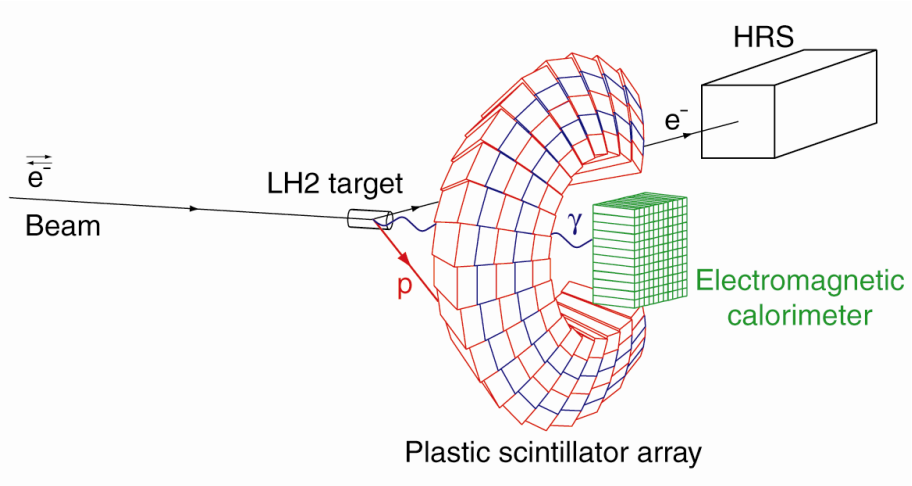




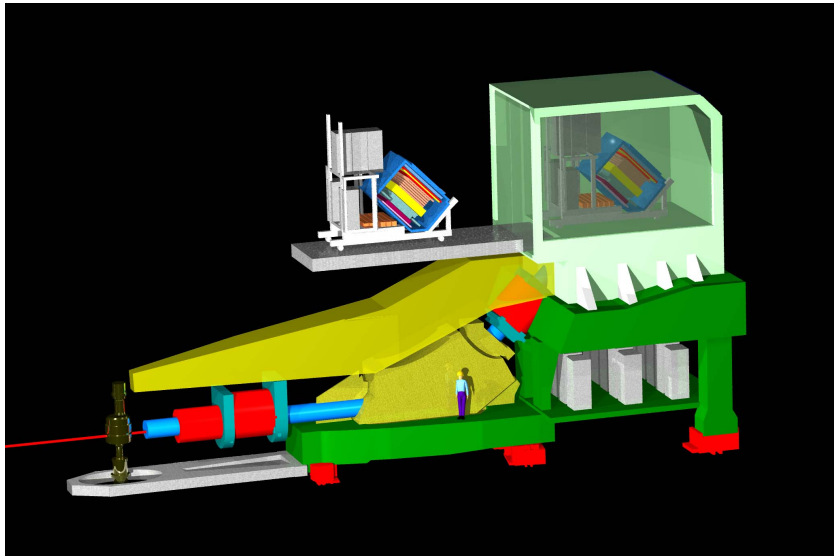
Integration window:
$-2.25\ \text{GeV}^2 < M_x^2 < 2.89\ \text{GeV}^2$

- Not fully exclusive
- Recoil detector operated during last year of data taking
- Analysis underway and results to come

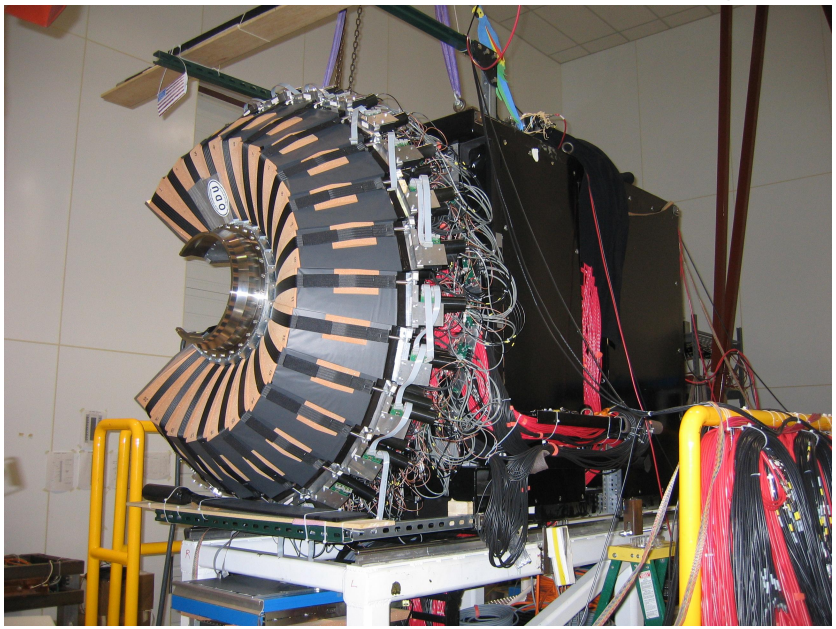
E00-110 experimental setup



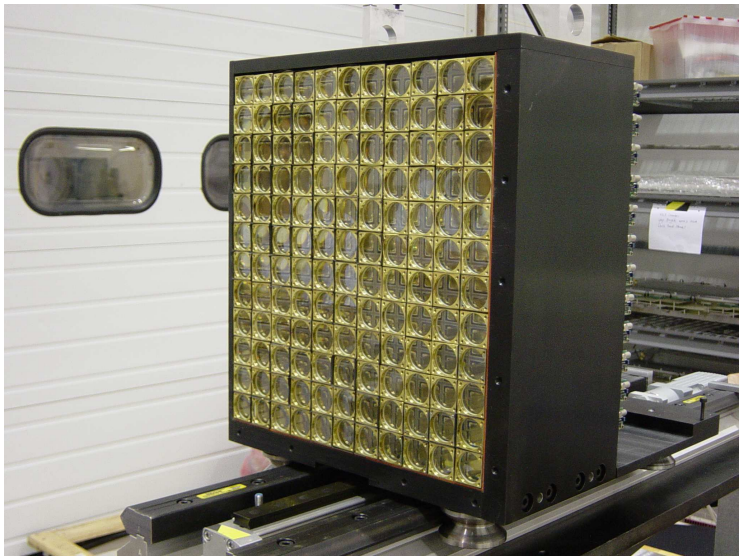
High Resolution Spectrometer



100-channel scintillator array

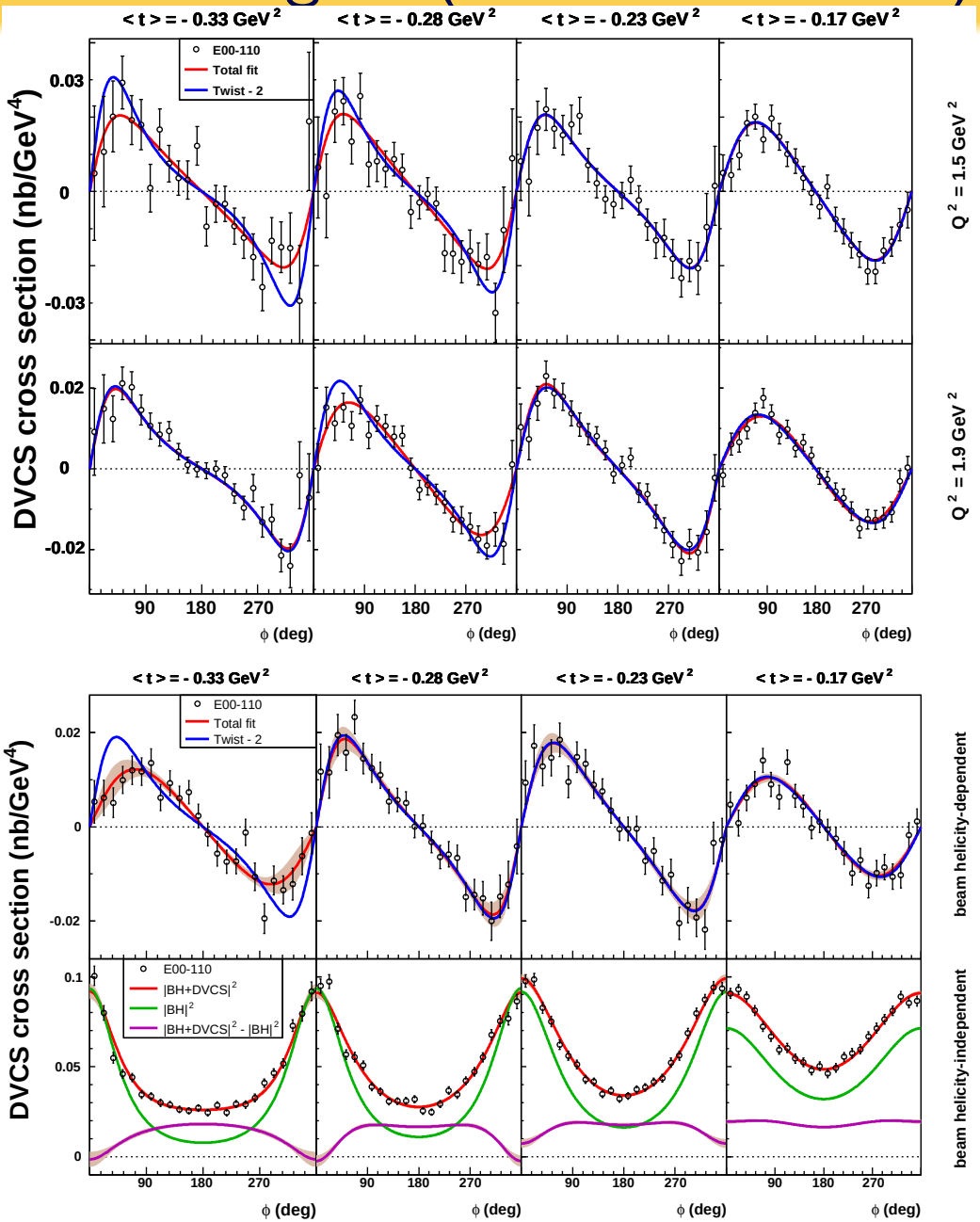


132-block PbF_2 electromagnetic calorimeter

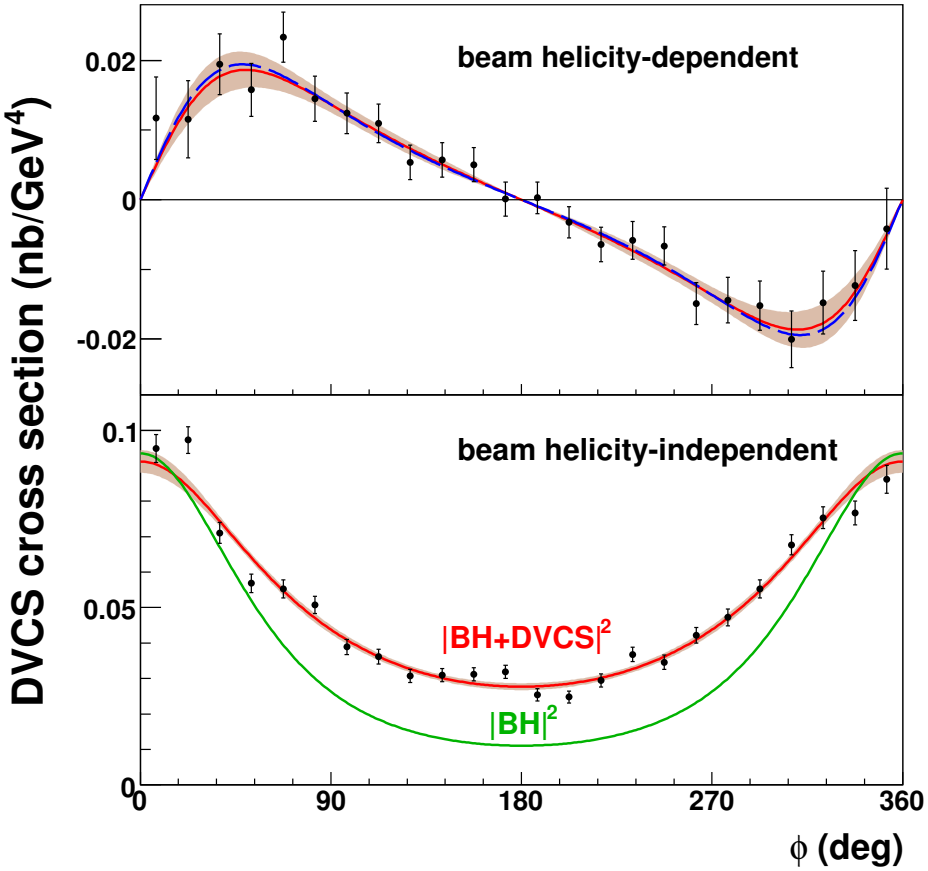


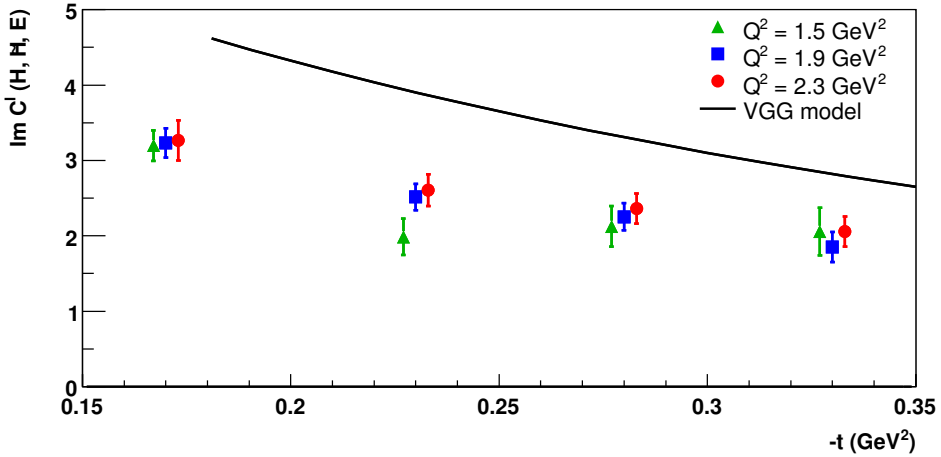
DVCS cross section in the valence region (Hall A: E00-110)

- **Helicity-dependent** cross section $(\overrightarrow{\sigma} - \overleftarrow{\sigma})$ at $Q^2 = 1.5$, 1.9 and 2.3 GeV^2.
- **Helicity-independent** cross section $(\overrightarrow{\sigma} + \overleftarrow{\sigma})$ at $Q^2 = 2.3$ GeV^2 *only*.



E00-110 results





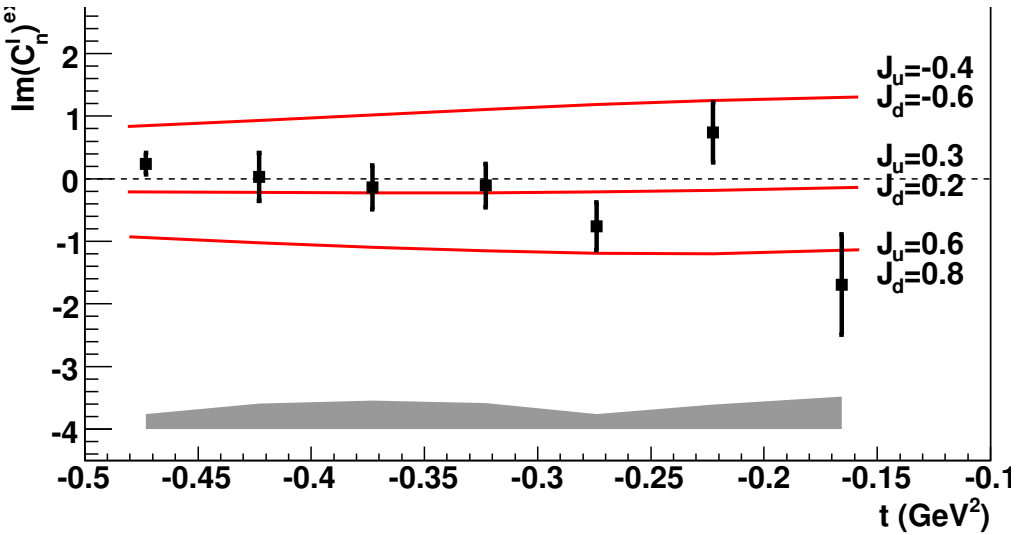
Twist-2: dominant contribution

Contributions from BH^2, $DVCS^2$ and BH-DVCS interference

Phys. Rev. Lett. **97**, 262002 (2006)

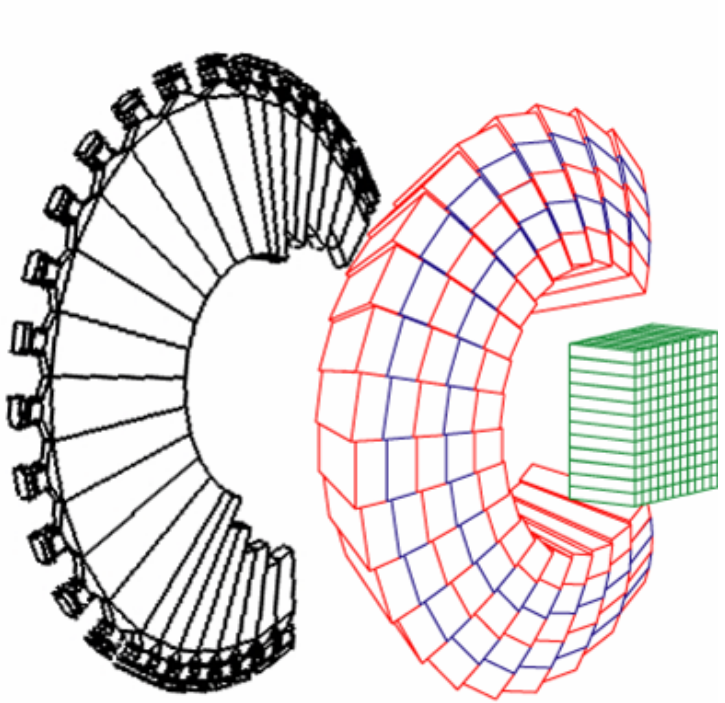
DVCS on the neutron: experiment E03-106 at JLab

LD$_2$ target ($F_2^n(t) \gg F_1^n(t)$!)



$$\sigma^{\rightarrow} - \sigma^{\leftarrow} = \Gamma(A \sin\varphi + \dots)$$

Charged particle veto
in front of scintillator array

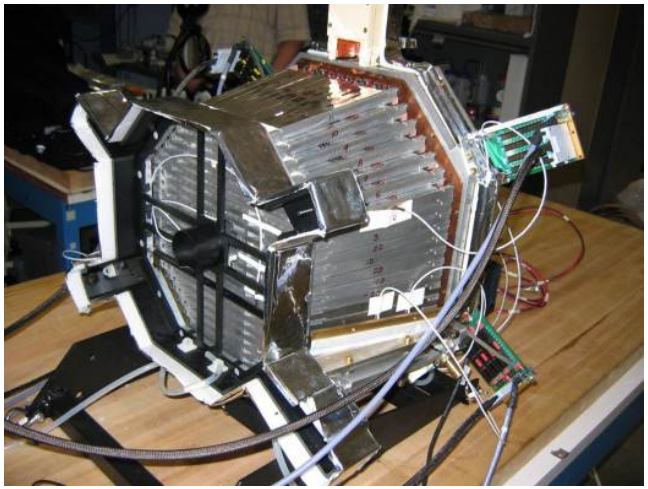


$$A = F_1(t)\mathcal{H} + \frac{x_B}{2 - x_B}[F_1(t) + F_2(t)]\tilde{\mathcal{H}} - \underbrace{\frac{t}{4M^2} \cdot F_2(t) \cdot \mathcal{E}}$$

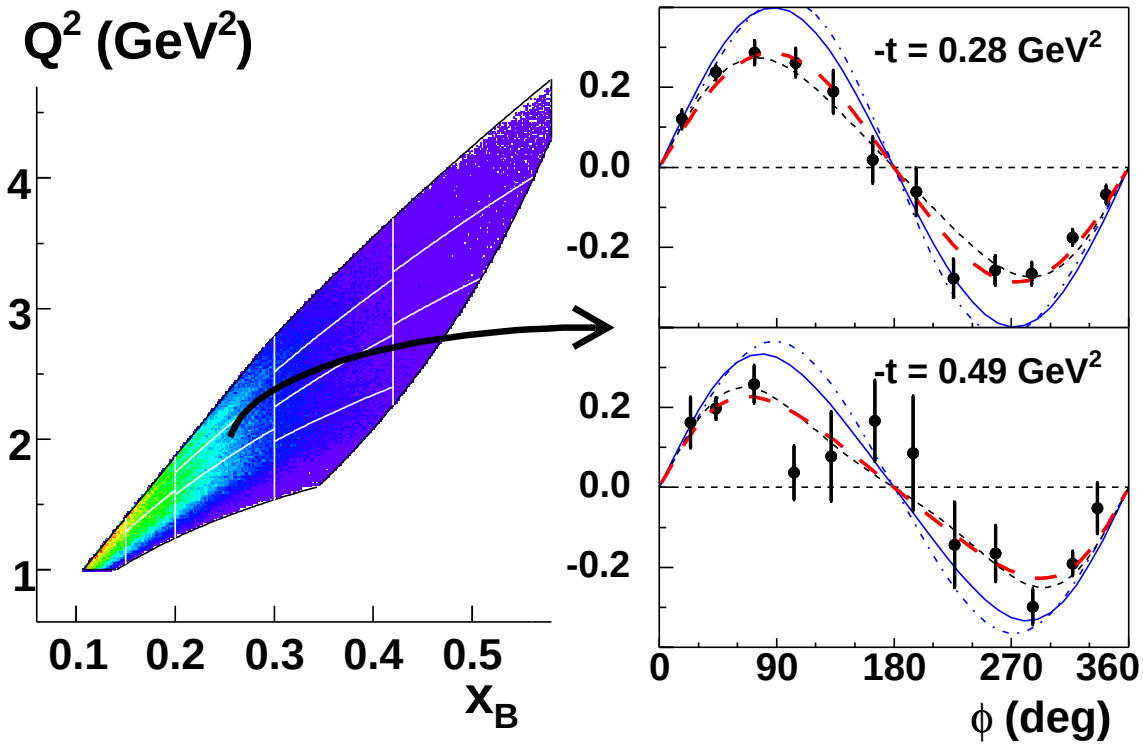
Main contribution for neutron

E01-113: BSA in a large kinematic domain (Hall B)

CLAS+
dedicated calorimeter



$$A = \frac{\overrightarrow{\sigma} - \overleftarrow{\sigma}}{\overrightarrow{\sigma} + \overleftarrow{\sigma}} \approx \frac{\alpha \sin\phi}{1 + \beta \cos\phi}$$



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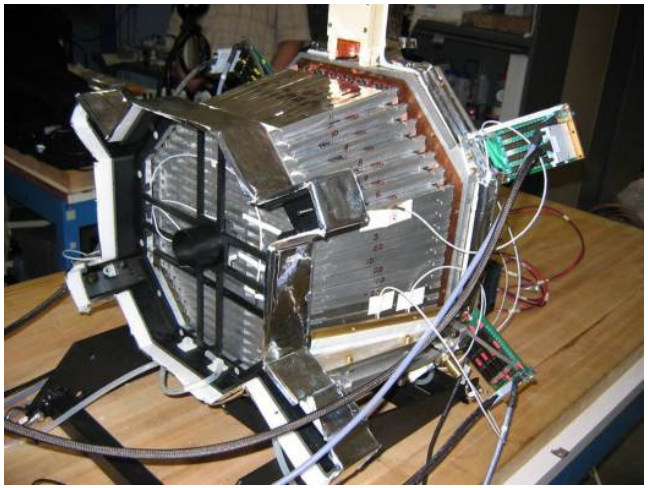

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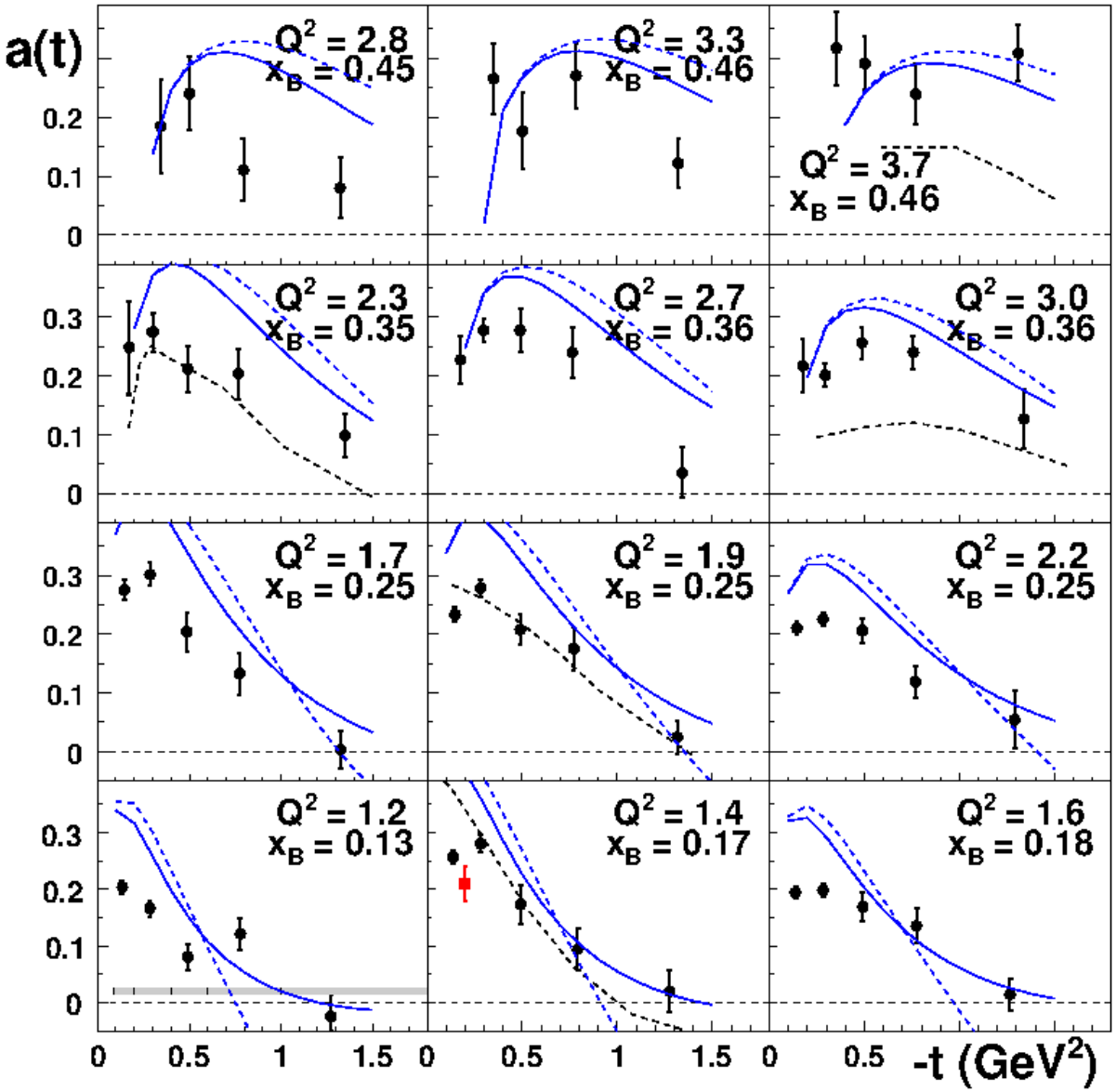
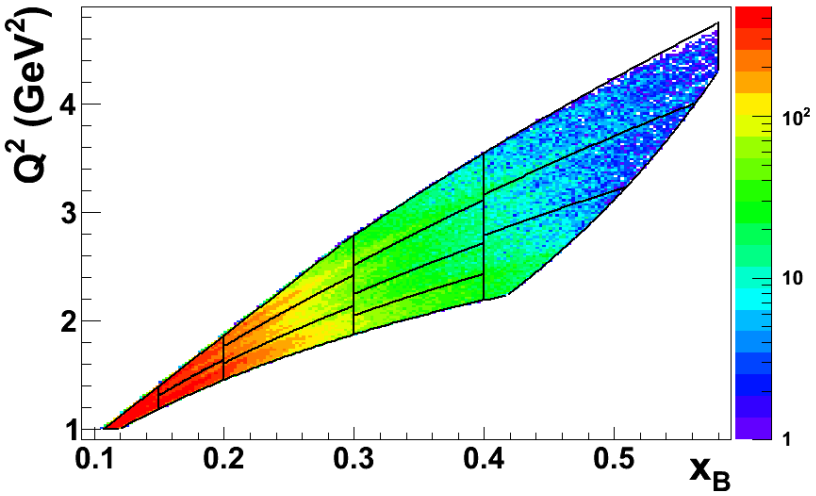
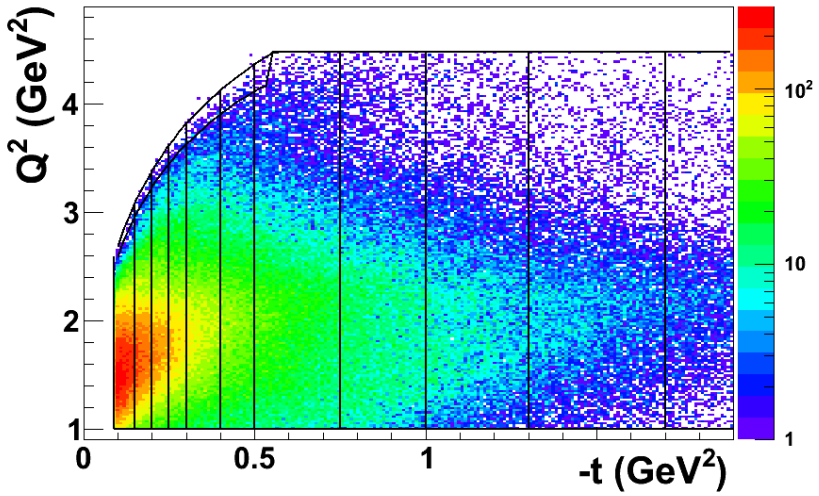
Simple models do not reproduce the data

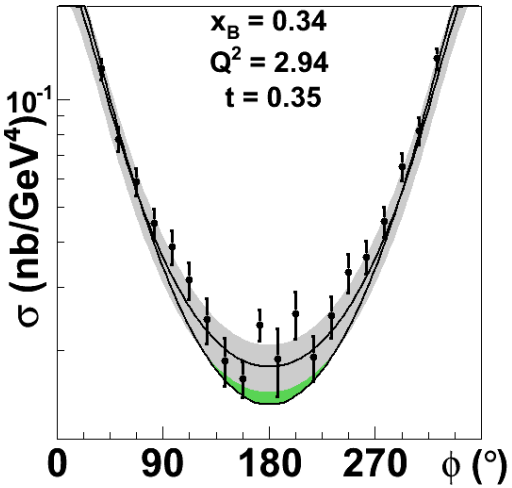


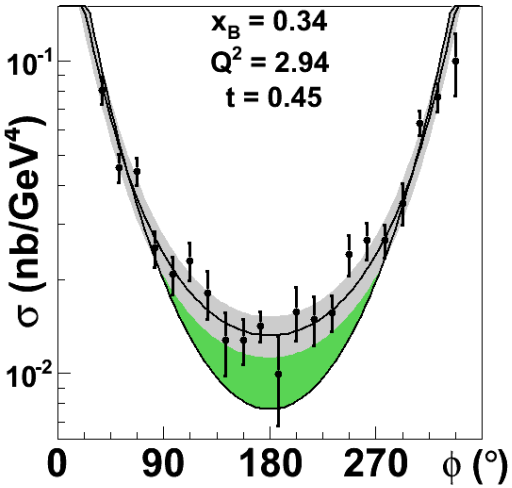
Analysis of cross sections underway

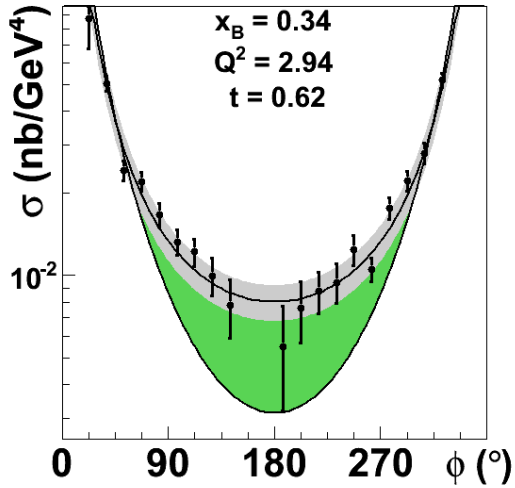
JLab Hall B cross-sections: preliminary





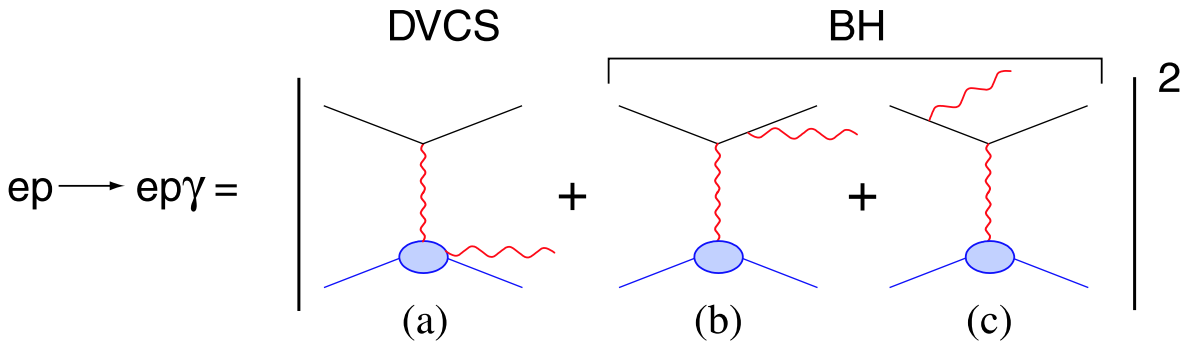






- Large data set under analysis
- Compatible within errors with Hall A in overlap region

E07-007 (Hall A)

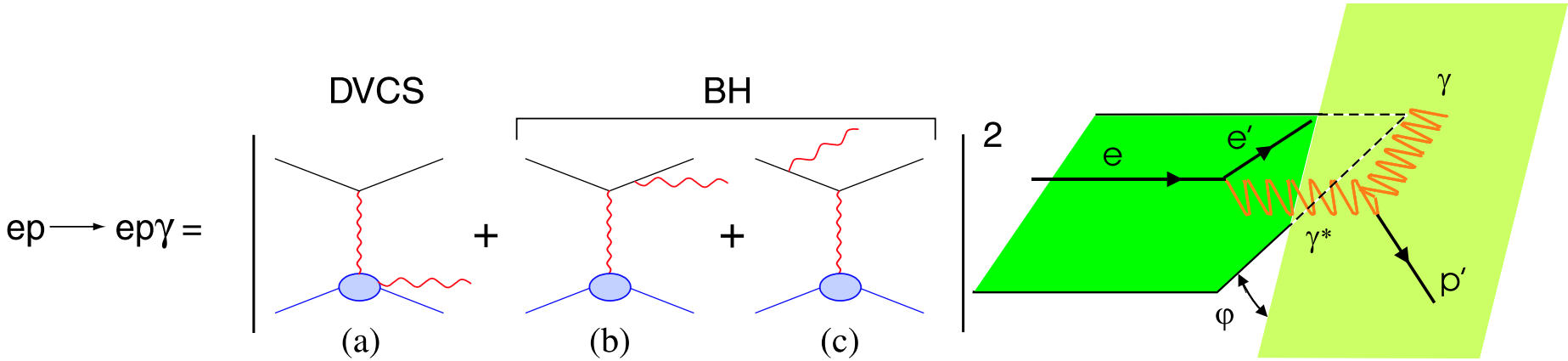


$$\sigma(ep \to ep\gamma) = \underbrace{|BH|^2}_{\text{Known to } \sim 1\%} + \underbrace{\mathcal{I}(BH \cdot DVCS)}_{\text{Linear combination of GPDs}} + \underbrace{|DVCS|^2}_{\text{Bilinear combination of GPDs}}$$

DVCS cross section has a very rich azimuthal structure:

- Azimuthal analysis allows the separation of the different contributions to $\mathcal{I}$ if DVCS^2 is negligeble.
- If DVCS^2 is important, $\mathcal{I}$ and DVCS^2 terms **MIX** in an azimuthal analysis.
- The **different energy dependence** of $\mathcal{I}$ and DVCS^2 allow a full separation.

E07-007 (Hall A)



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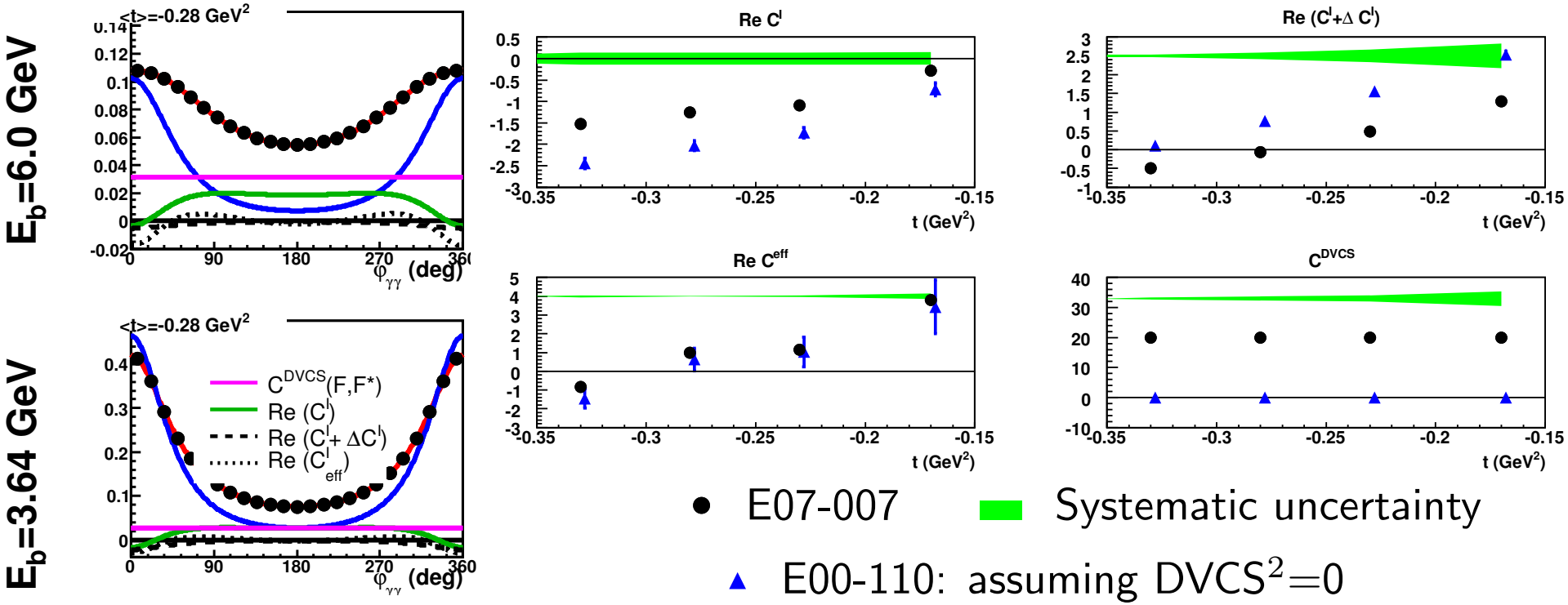
E07-007: Rosenbluth-like DVCS^2–$\mathcal{I}$ separation in Hall A

- Clean separation of BH-DVCS intereference term from pure DVCS^2
- Scaling test on the real part of the DVCS amplitude
- Rosenbluth separation of σ_L/σ_T for $ep \to ep\pi^0$

$d^4\sigma$ (nb/GeV^4)

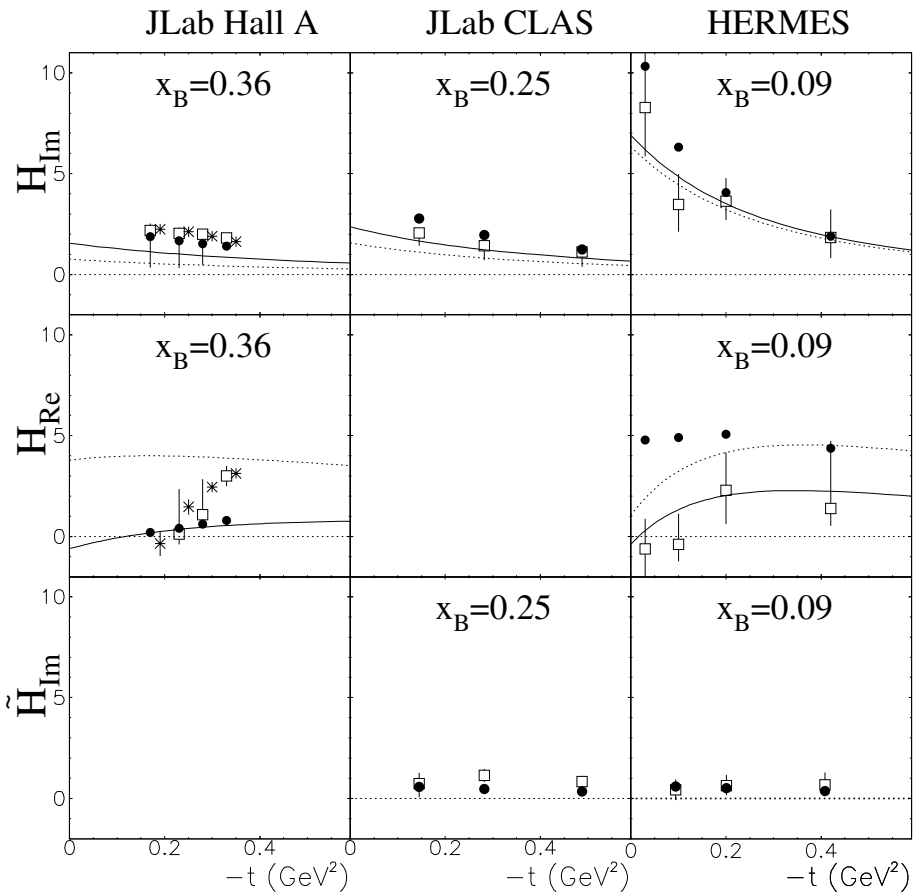


- E07-007 — Systematic uncertainty
- E00-110: assuming DVCS^2=0

Overview of current approaches

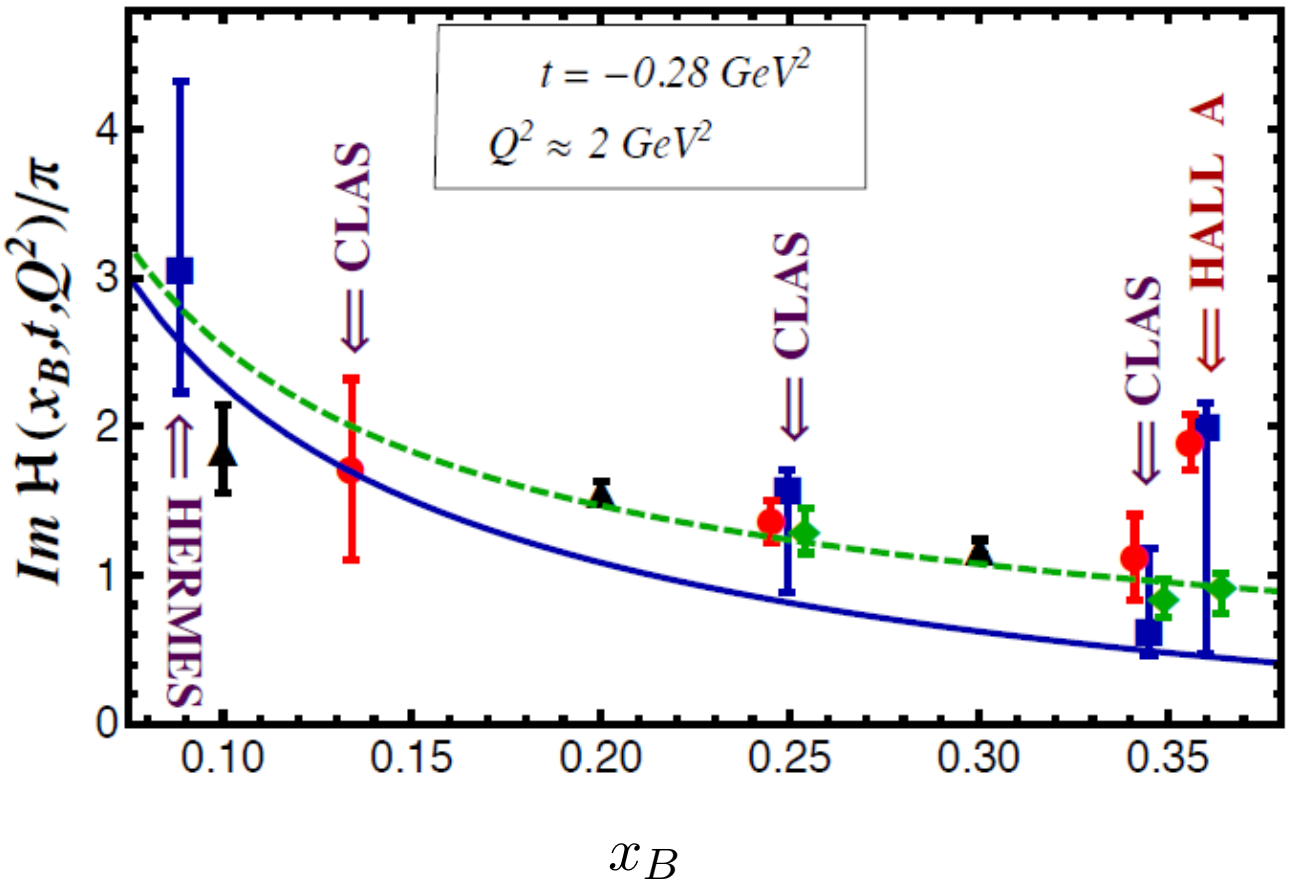
- **Local fits:**
  Take each kinematic bin independently.
  Fit $\mathcal{R}e(\mathcal{H})$, $\mathcal{I}m(\mathcal{H})$, ... independently.
  M. Guidal
- **Global fits:**
  Take all kinematic bins at the same time.
  Use a parametrization of CFFs or GPDs.
  G. Goldstein et al., K. Kumericki and D. Müller...
- **Hybrid local/global fits:**
  Combine 2 previous methods to estimate systematic errors
  H. Moutarde
- **Neural netwoks:**
  Already used for PDFs fits. In progress for GPDs.
  K. Kumericki and D. Müller

Compton Form Factors local fits



- t–slope related to the size of the object (Fourier transform)
- Valence (large x) quarks are more concentrated than the sea (low x)
- Axial charge (H) more concentrated than electromagnetic charge ($\tilde{H}$)

CFF global fits

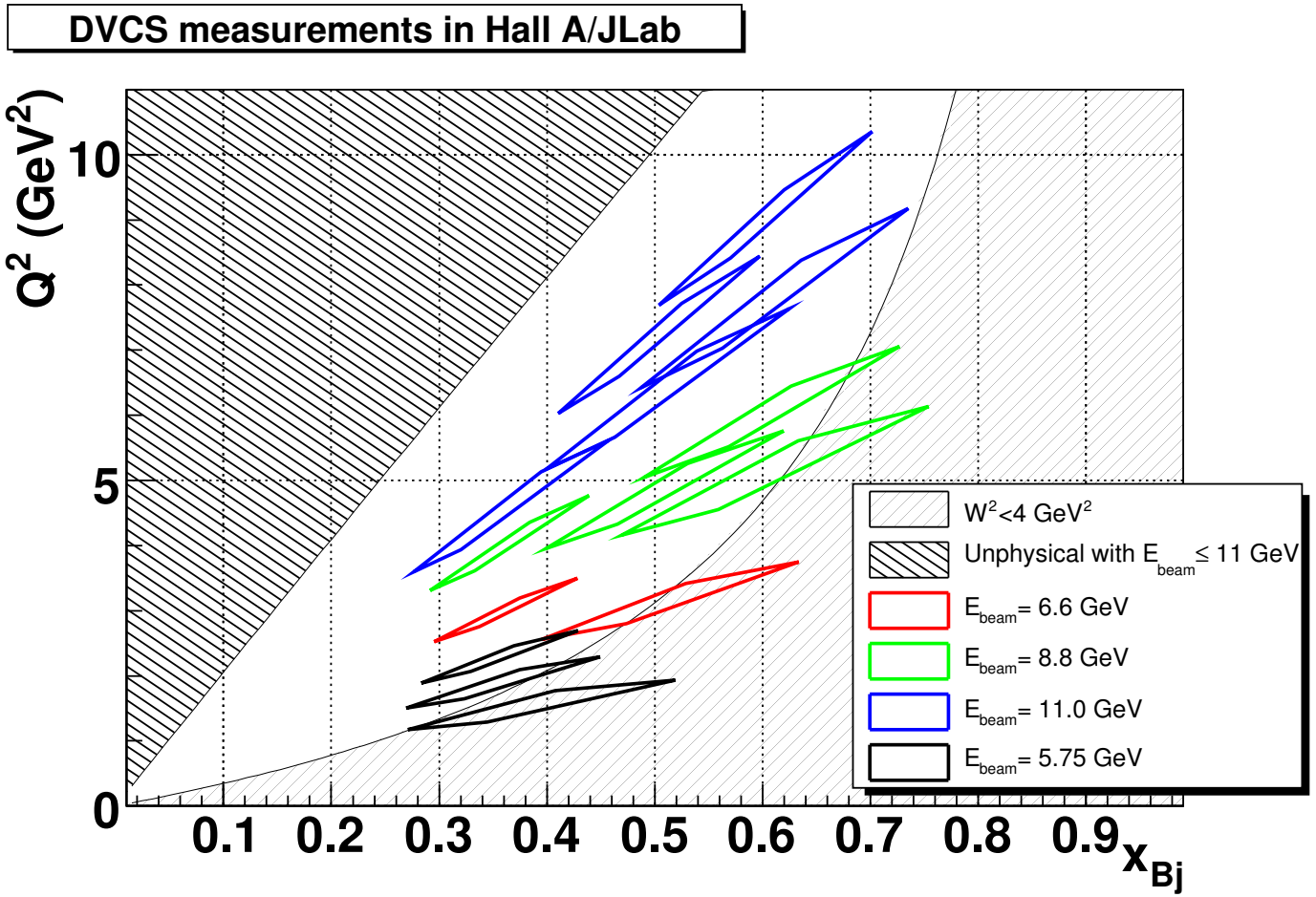


- Without Hall A data.
- With Hall A data.
- △ : neural network.
- □ : "7-CFF" fit results.
- ◇ : "$\mathcal{H} - \tilde{\mathcal{H}}$".
- ○ : hybrid fits.

Compatibility between different fit approaches

E12-06-114: JLab Hall A at 11 GeV

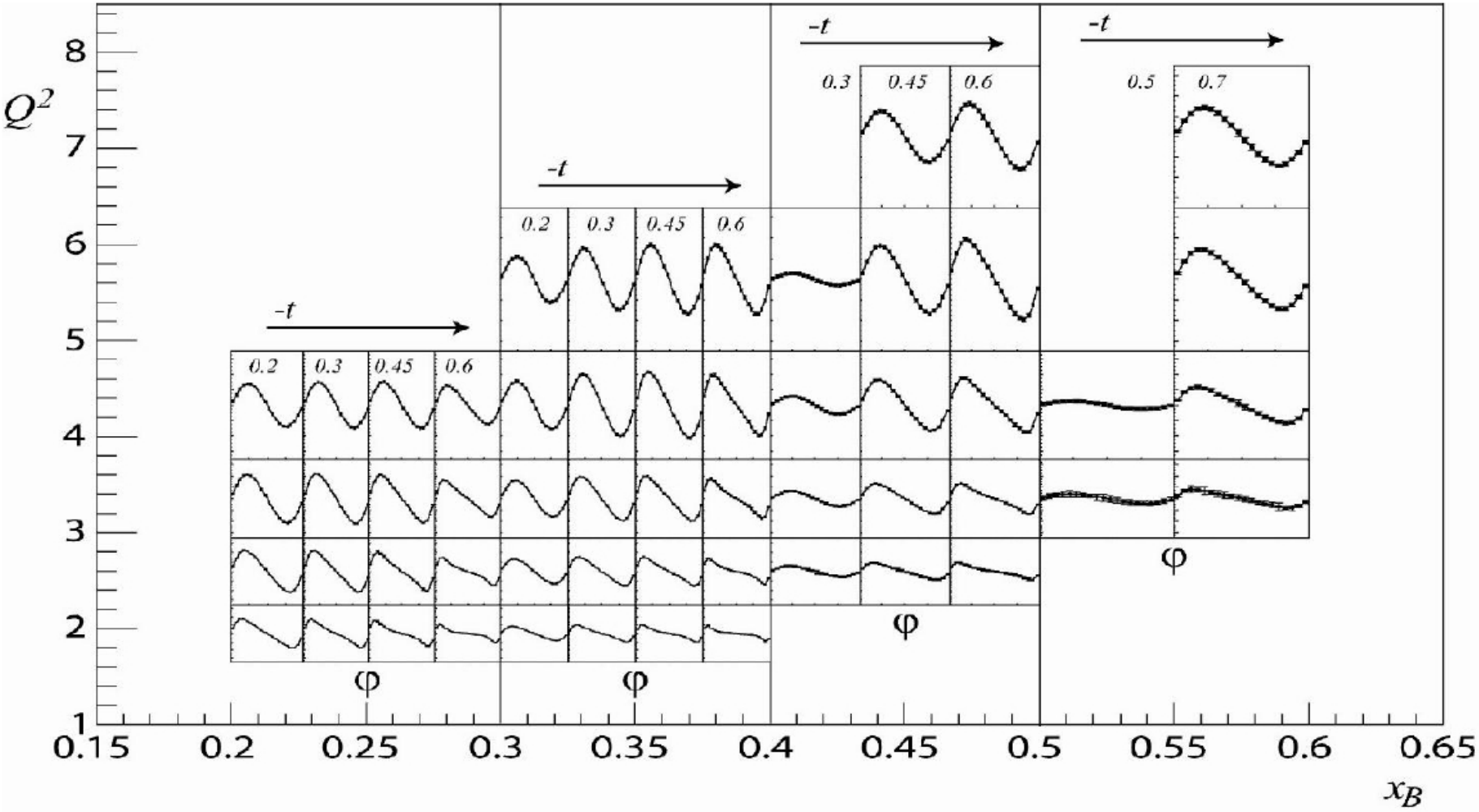
JLab12 with 3, 4, 5 pass beam
(6.6, 8.8, 11.0 GeV beam energy)



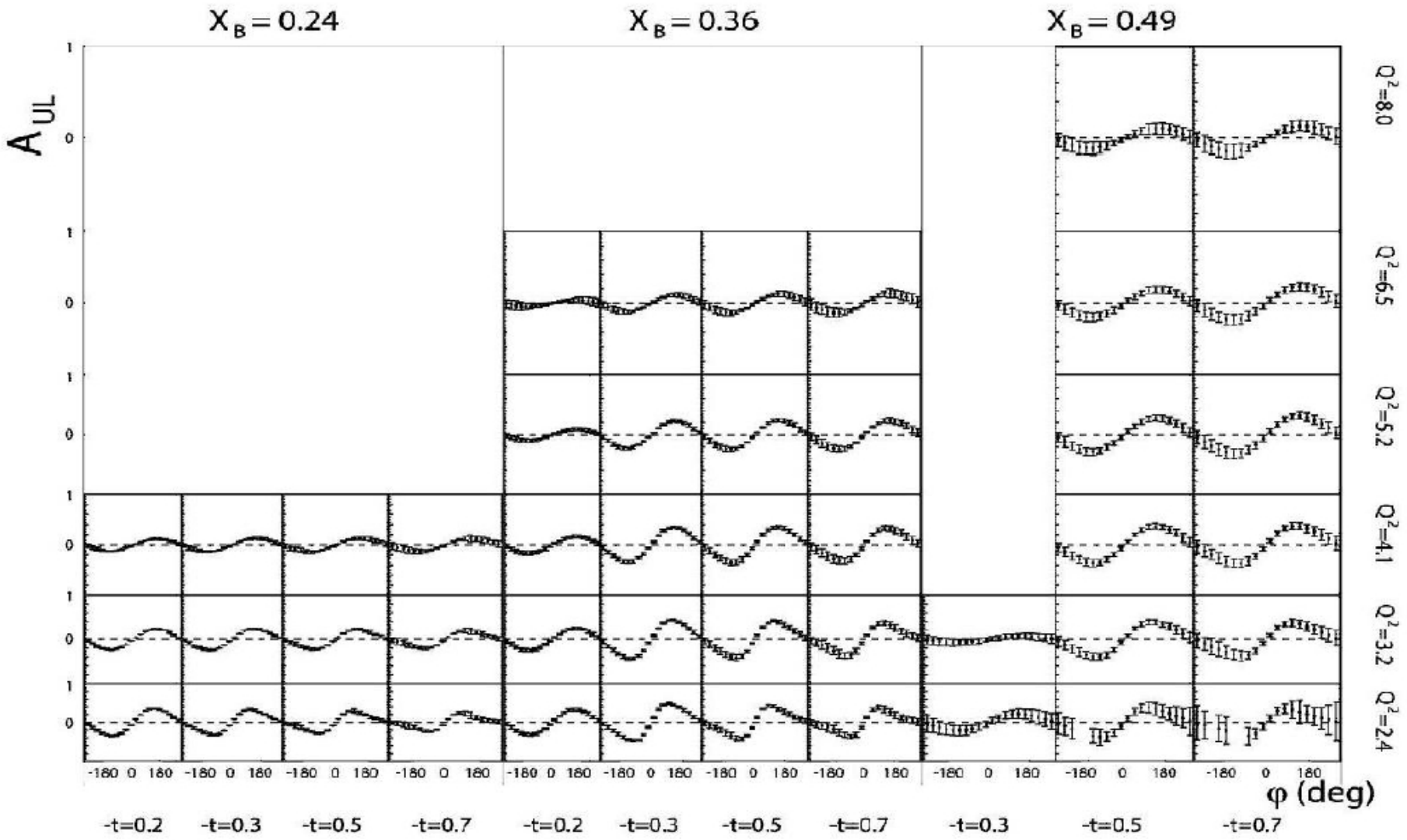
88 days
250k events/setting

1 year of operations in JLab/Hall A

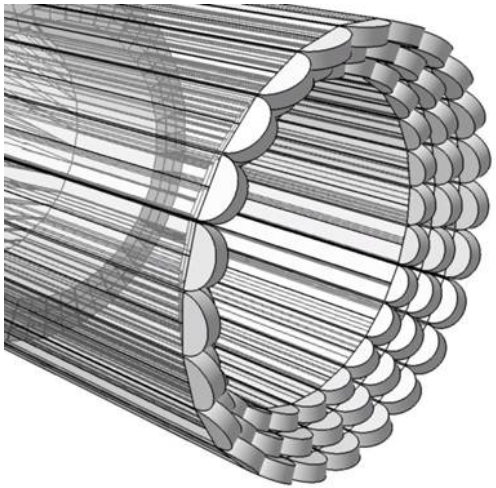
E12-06-119: DVCS on the proton with CLAS12

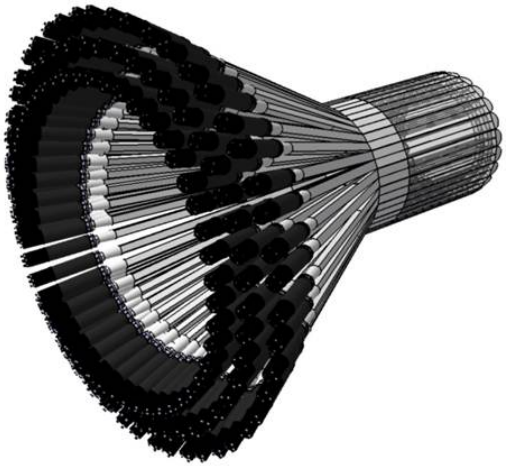


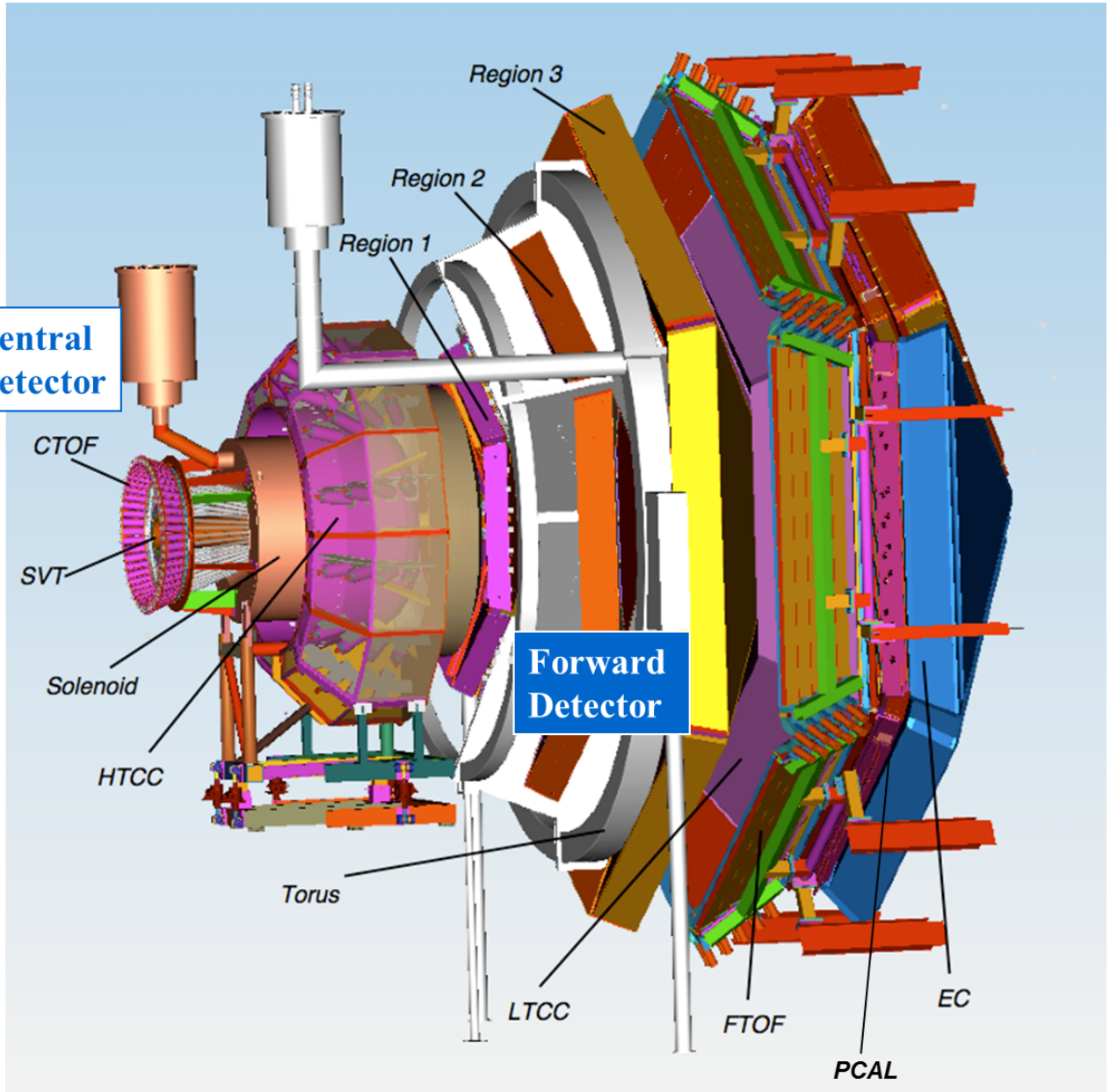
E12-06-119: DVCS on the proton with CLAS12



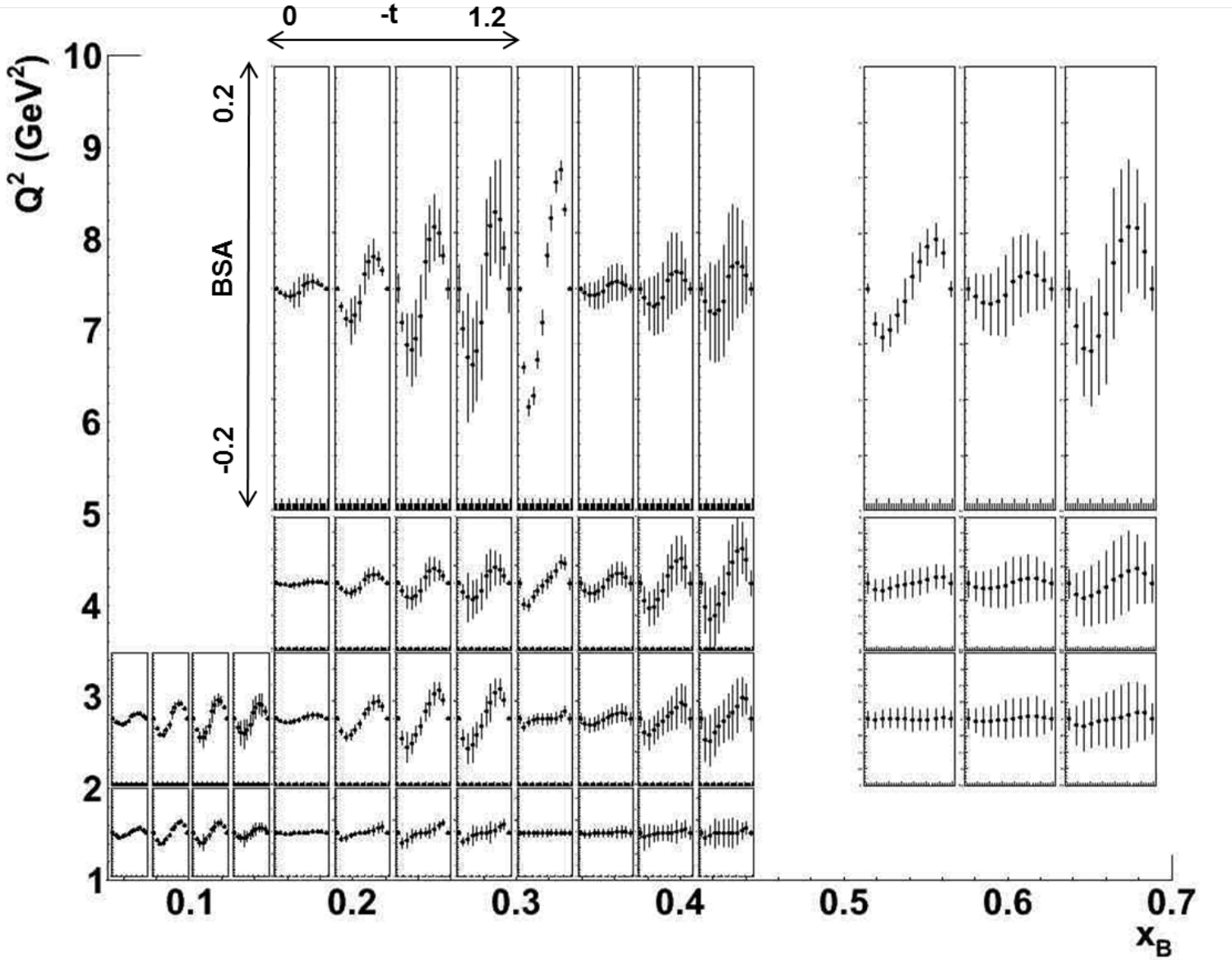
E12-11-003: DVCS sur le neutron avec CLAS12





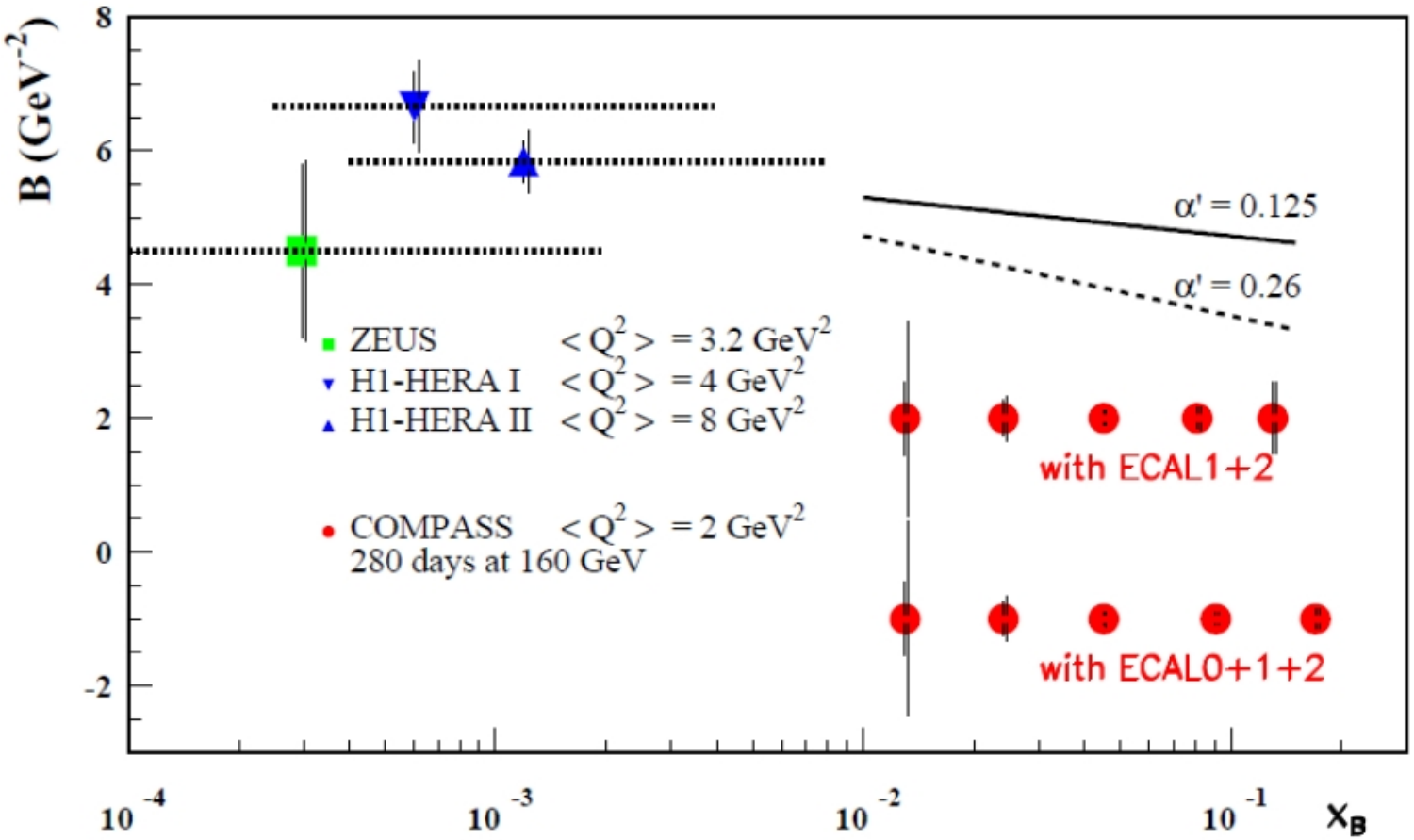


E12-11-003: projections



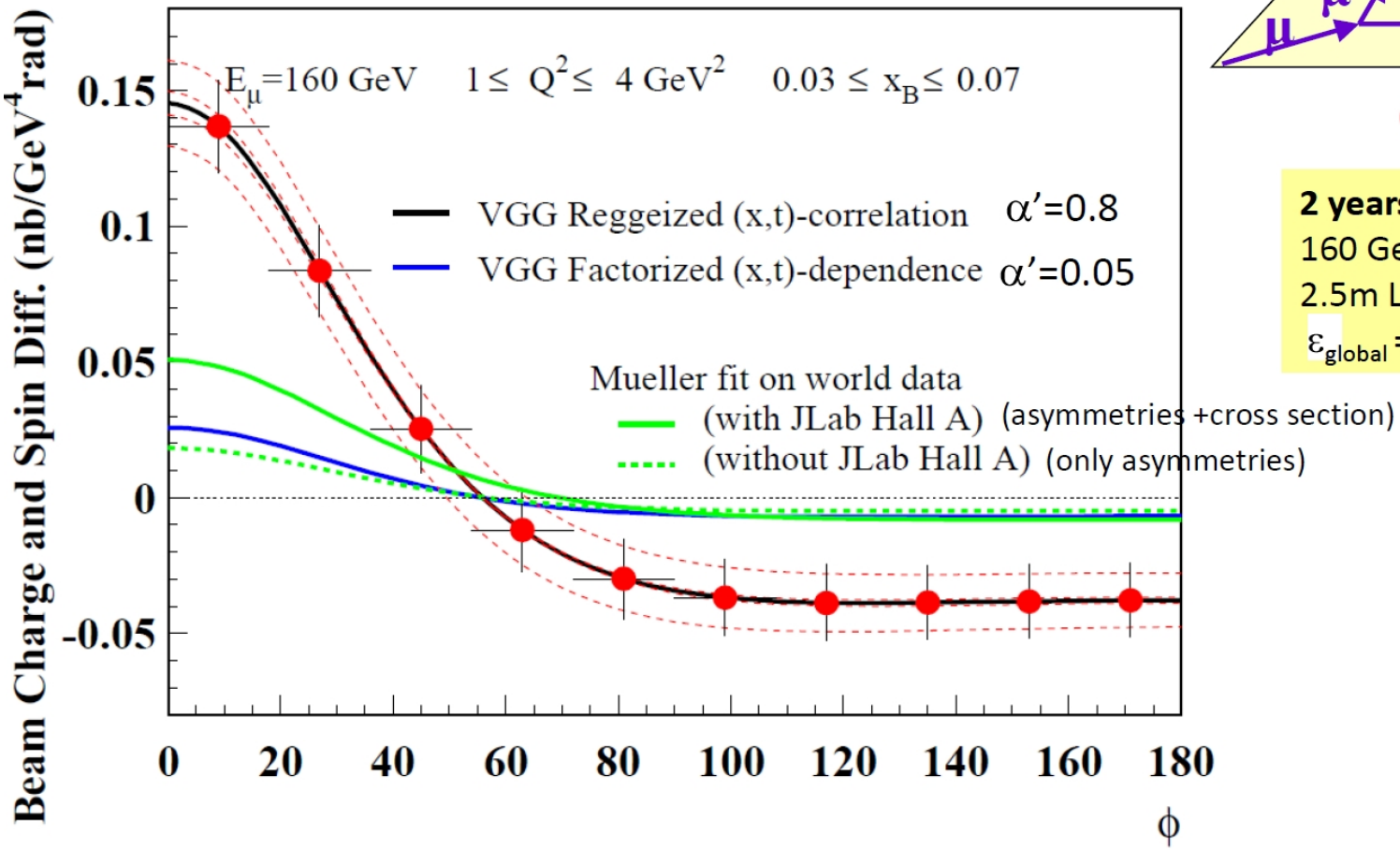
DVCS with Compass-II: transverse imaging of the nucleon

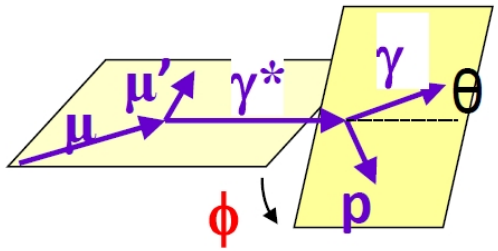
$$B(x_B) = \frac{1}{2}\langle r_\perp(x_B)\rangle$$



DVCS with Compass-II

Comparison to different models





2 years of data
160 GeV muon beam
2.5m LH_2 target
ε_{global} = 10%

Slide by N. d'Hose

Summary

- DVCS golden channel for GPDs, but also accessible in:
  - Time-like Compton Scattering (JLab proposal underway)
  - Deep meson production (but higher Q^2 are needed...)
- Large set of data (cross-sections and asymmetries) is now available from HERMES and JLab
- First contraints on GPDs coming out from global fits
- Compeling GPD program in the future at Jefferson Lab & COMPASS