Hall A DVCS Program

S. Lee Allison

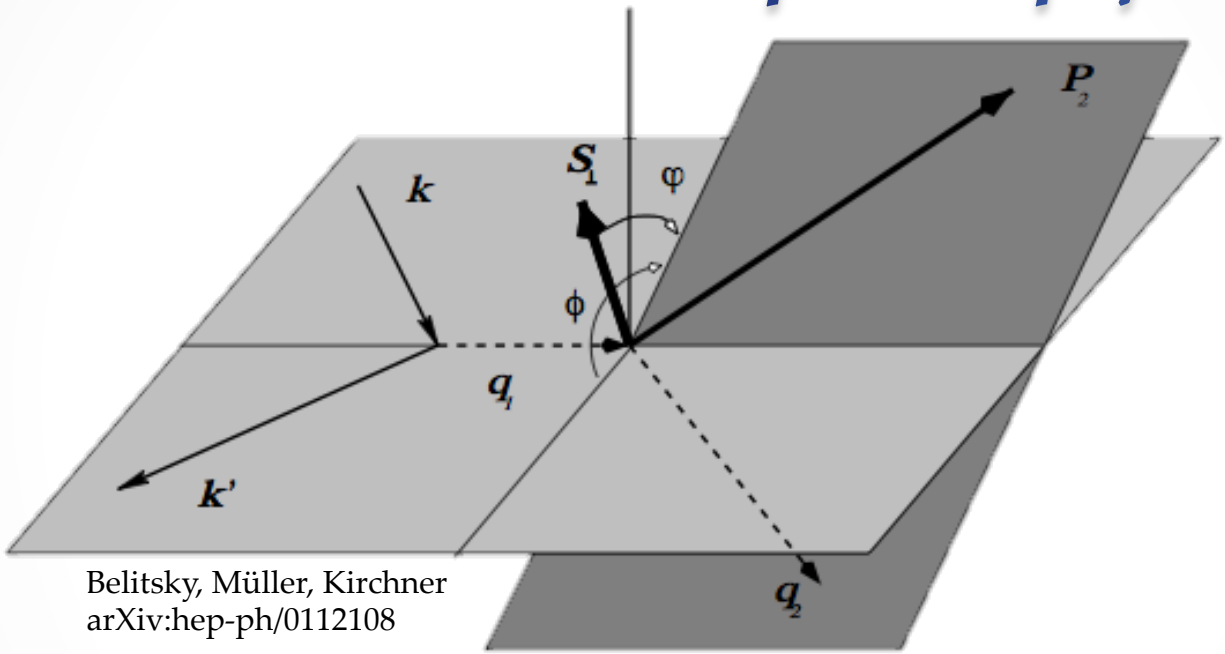
JLab Pizza Seminar, 2/25/2105

OLD DOMINION
UNIVERSITY

Outline

- DVCS Reaction
- Cross section and GPD dependence
- Simulation
- Experimental setup
- 2010 and 2014 runs

Reaction $ep \rightarrow ep\gamma$



Belitsky, Müller, Kirchner
arXiv:hep-ph/0112108

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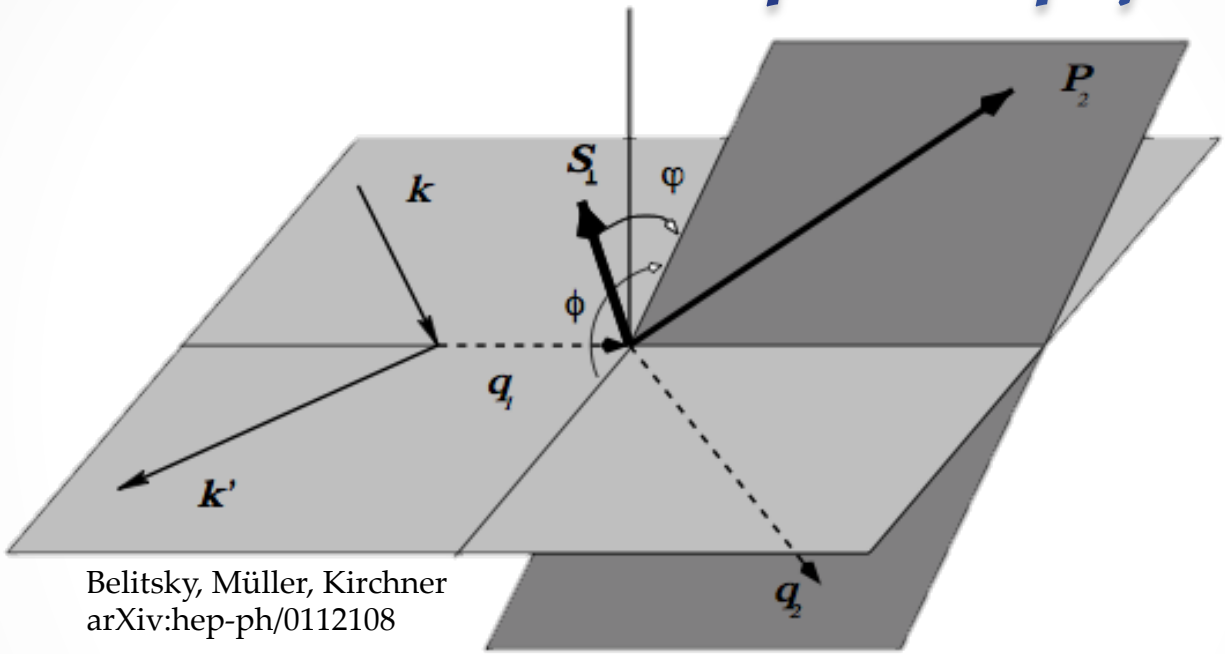

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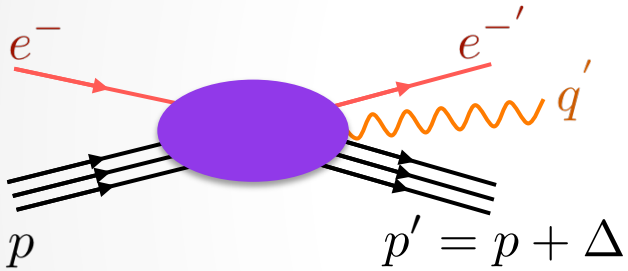
- 5 relevant variables
  - Q^2, x_{Bj}, $t = \Delta^2$, $\phi_{\gamma\gamma}$, ϕ_e

$$x_{Bj} = \frac{Q^2}{2p_\mu \cdot q^\mu}$$

$$\Delta = (q - q') = (p' - p)$$

Bethe-Heitler and VCS

$$ep \to ep\gamma$$



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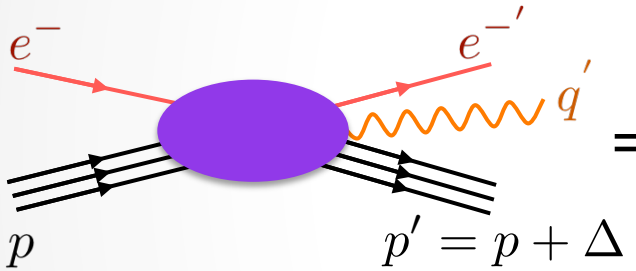

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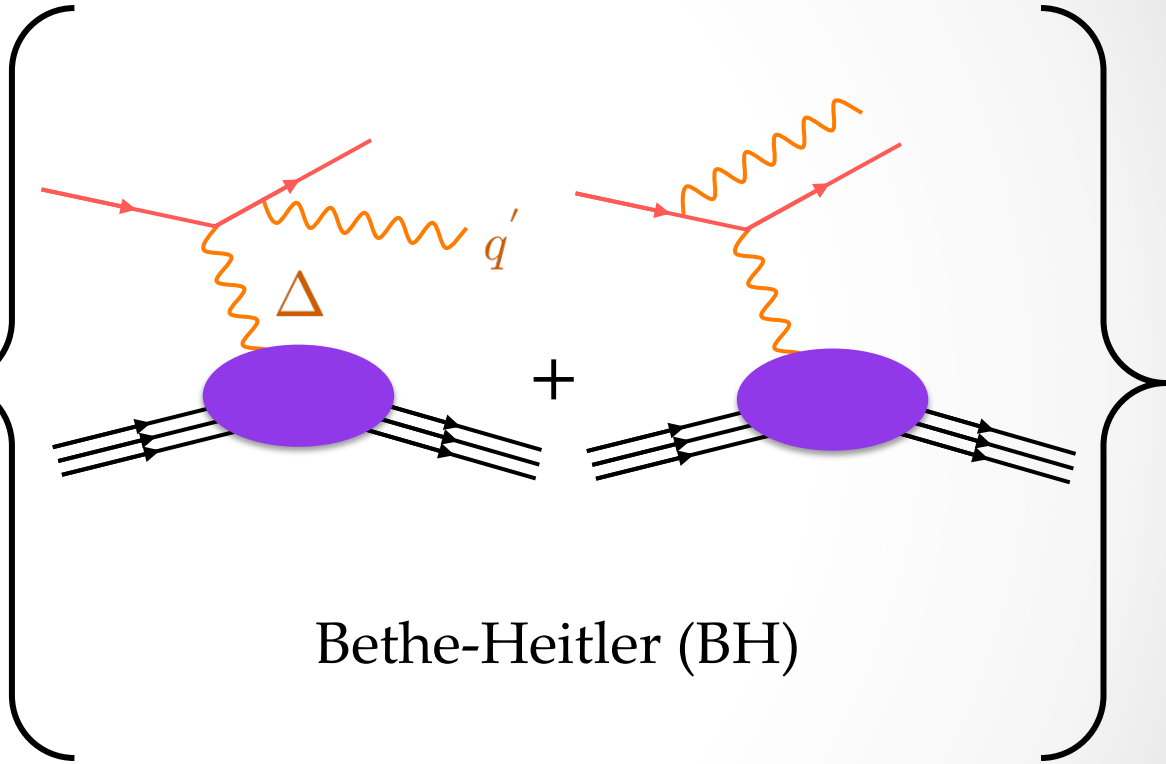

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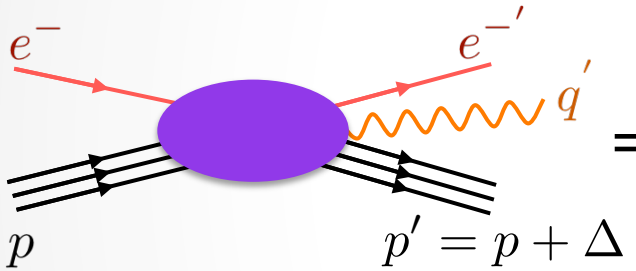

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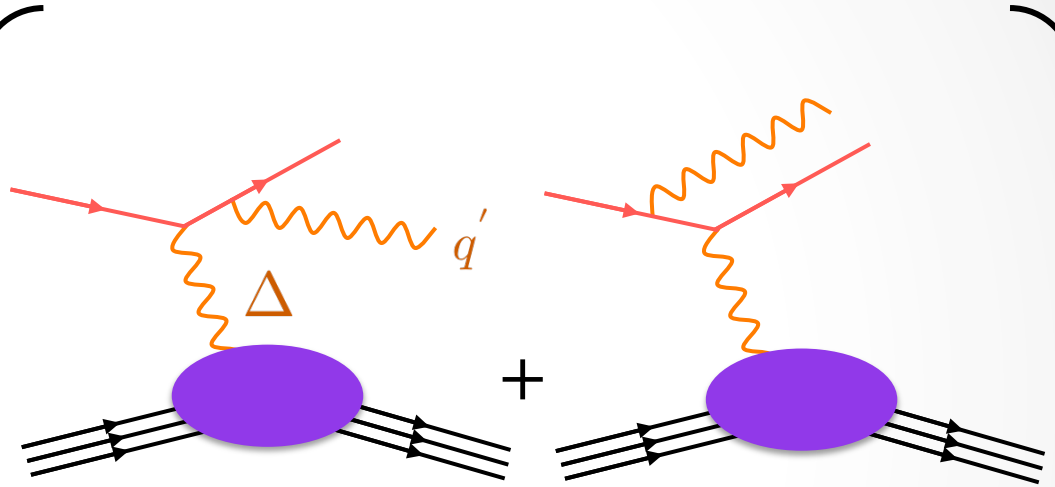
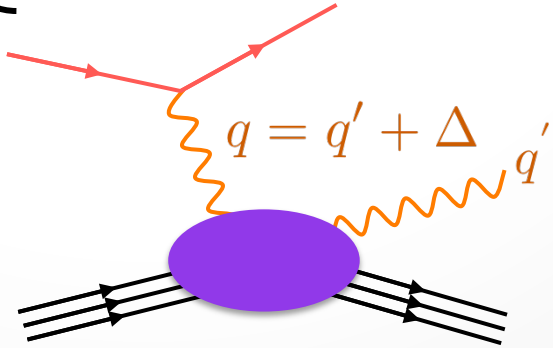


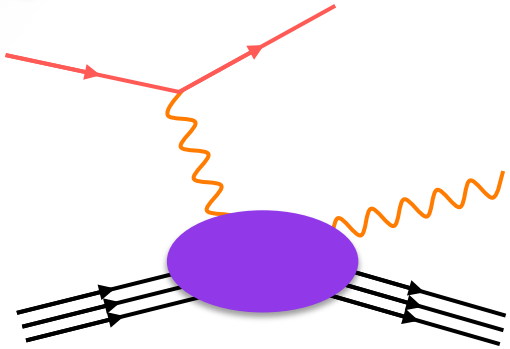
Bethe-Heitler (BH)

+

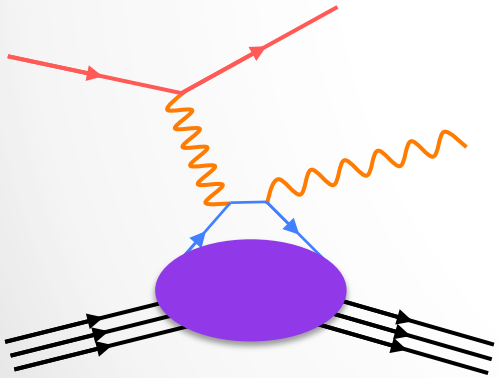


Virtual Compton Scattering (VCS)

QCD Limit of VCS



$Q^2 \to \text{large}$



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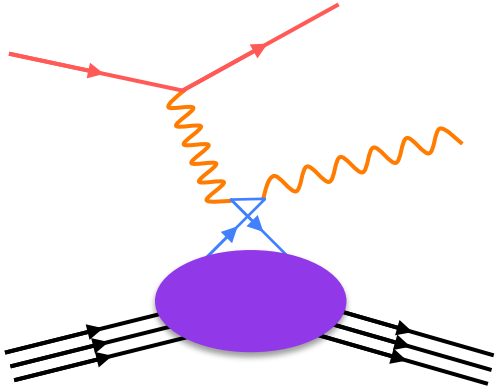

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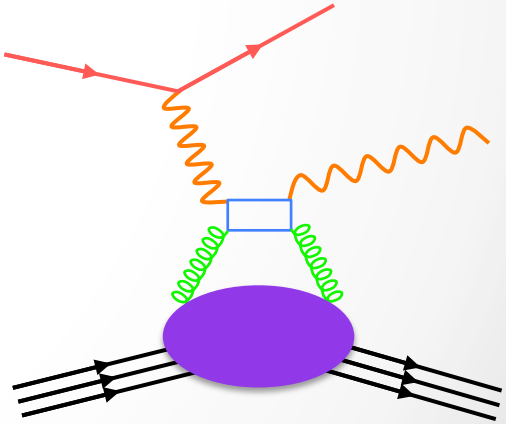

Deeply Virtual
Compton Scattering
(DVCS)

$ep \rightarrow ep\gamma$ cross section and Elastic Form Factors

- Total $ep \rightarrow ep\gamma$ cross section

$$d^4\sigma = |BH + DVCS|^2$$

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- Total $ep \rightarrow ep\gamma$ cross section

$$d^4\sigma = |BH + DVCS|^2$$

- Bethe-Heitler dependence on Dirac and Pauli Form Factors (F_1, F_2) well-known

$$BH \equiv BH\,(F_1, F_2)$$

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$$BH \equiv BH\,(F_1, F_2)$$

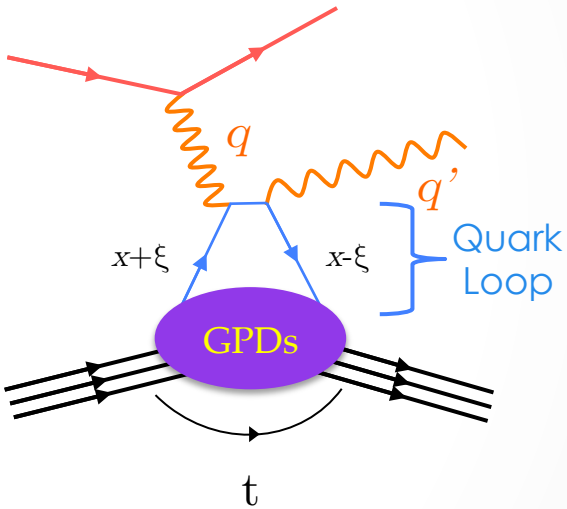
- F_1 and F_2 describe 2D spatial distribution of charge and magnetization of nucleon after integration over longitudinal space coordinates

Compton Form Factors (CFFs) and Generalized Parton Distributions (GPDs)

- GPDs describe the transverse spatial distribution of quarks as a function of longitudinal momentum fraction $x \pm \xi$

$$P = \frac{p + p'}{2}$$

$$\xi = \frac{-(q+q')^2}{2(q+q')\cdot P} \xrightarrow[-t<<Q^2]{} \frac{x_B}{2 - x_B}$$



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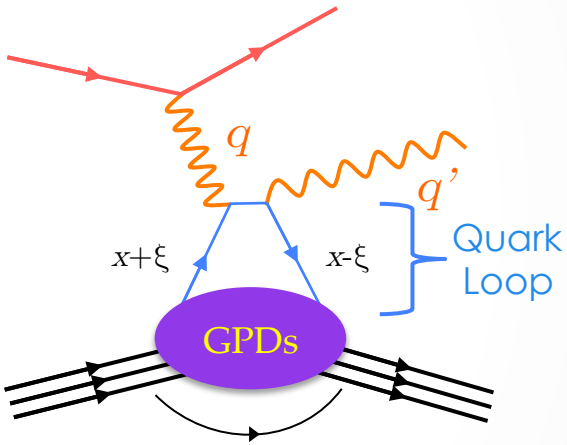

- DVCS amplitude depends directly on CFFs ($\mathcal{H}$, $\mathcal{E}$, …) which are integrals of GPDs (H, E, …)

$$DVCS \equiv DVCS\left(\mathcal{H}, \tilde{\mathcal{H}}, \mathcal{E}, \tilde{\mathcal{E}}\right)$$

Compton Form Factors (CFFs) and Generalized Parton Distributions (GPDs)

- Belitsky, Müller, and Kirchner's definitions of CFFs
  - Similar definitions for higher twist terms

$$\{\mathcal{H}, \mathcal{E}\} = \int_{-1}^{1} dx \frac{\{H, E\}(x, -\xi, t)}{x \pm \xi}$$

$$\{\tilde{\mathcal{H}}, \tilde{\mathcal{E}}\} = \int_{-1}^{1} dx \frac{\{\tilde{H}, \tilde{E}\}(x, -\xi, t)}{x \pm \xi}$$

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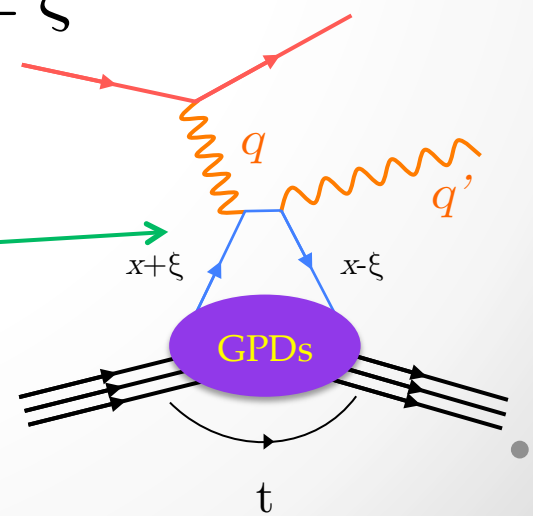
Integrate because of loop in diagram



GPDs, the Ji Sum Rule and the Proton Spin Puzzle

- J_q is the total angular momentum contribution from quarks and anti-quarks of flavor q in the nucleon
  - Involves integrals of H_q and E_q in the limit that $t \rightarrow 0$

$$J_q = \frac{1}{2}\int_{-1}^{1} dx x \left[H_q\left(x,0,0\right) + E_q\left(x,0,0\right)\right]$$

$$S_p = \frac{1}{2} = \sum_q J_q + J_g$$

Total Cross Section

$$d^4\sigma = |BH|^2 + |DVCS|^2 + I\,(BH \cdot DVCS)$$

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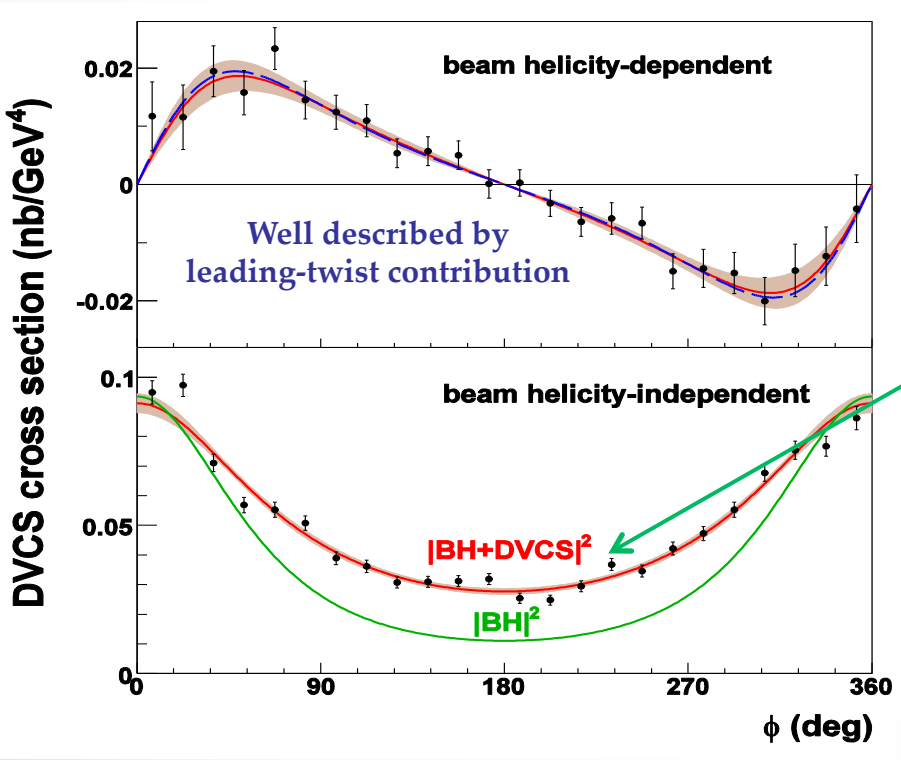

Significant deviation from Bethe-Heitler.

Both Interference and $|DVCS|^2$ contribute

Results from E00-110
C. Munoz-Camacho et. al.
PRL 97, 262002 (2006)

Total Cross Section

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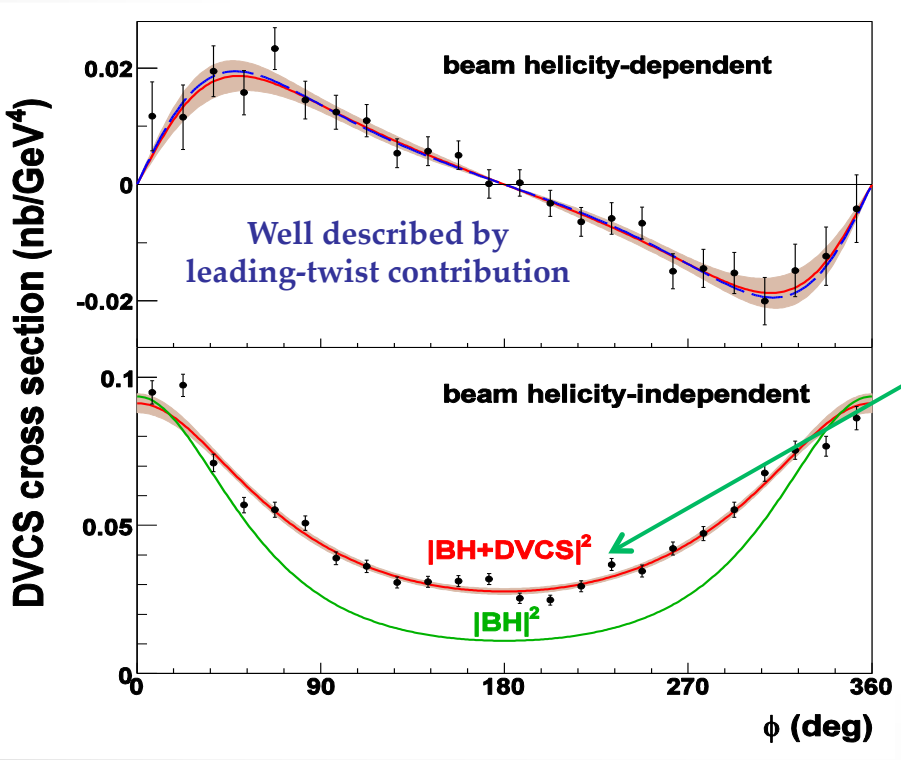

$(d^4\sigma^+ - d^4\sigma^-)/2 \rightarrow$
$\mathcal{I}m(\text{BH*DVCS}) \;\alpha\; \sin(\phi_{\gamma\gamma})$

$(d^4\sigma^+ + d^4\sigma^-)/2 \rightarrow$
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Total Cross Section

Known

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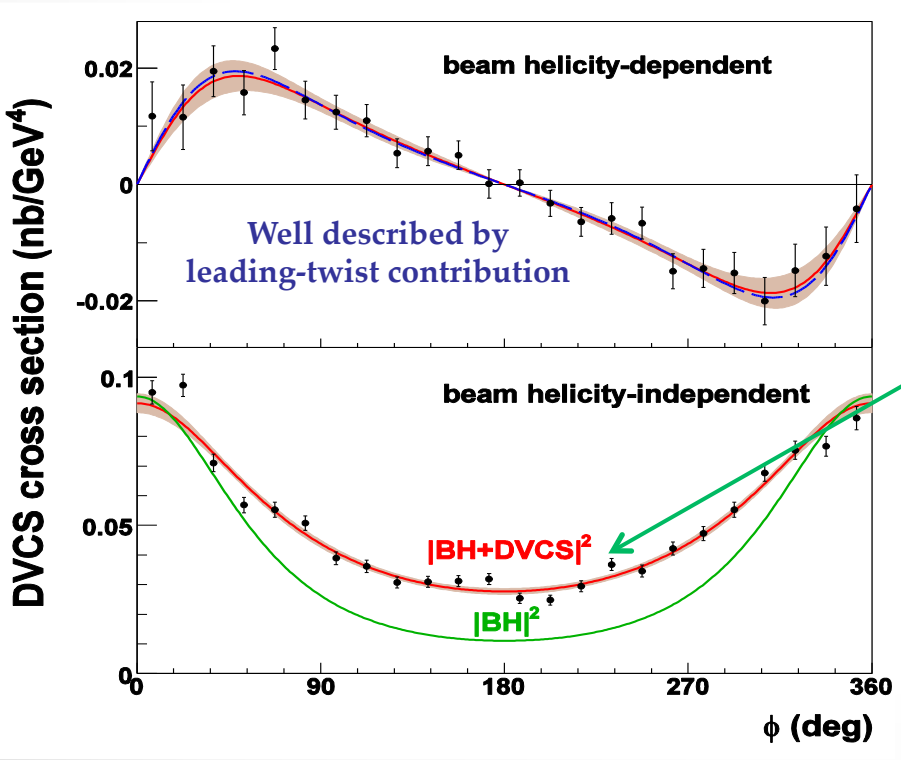

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Measured Known

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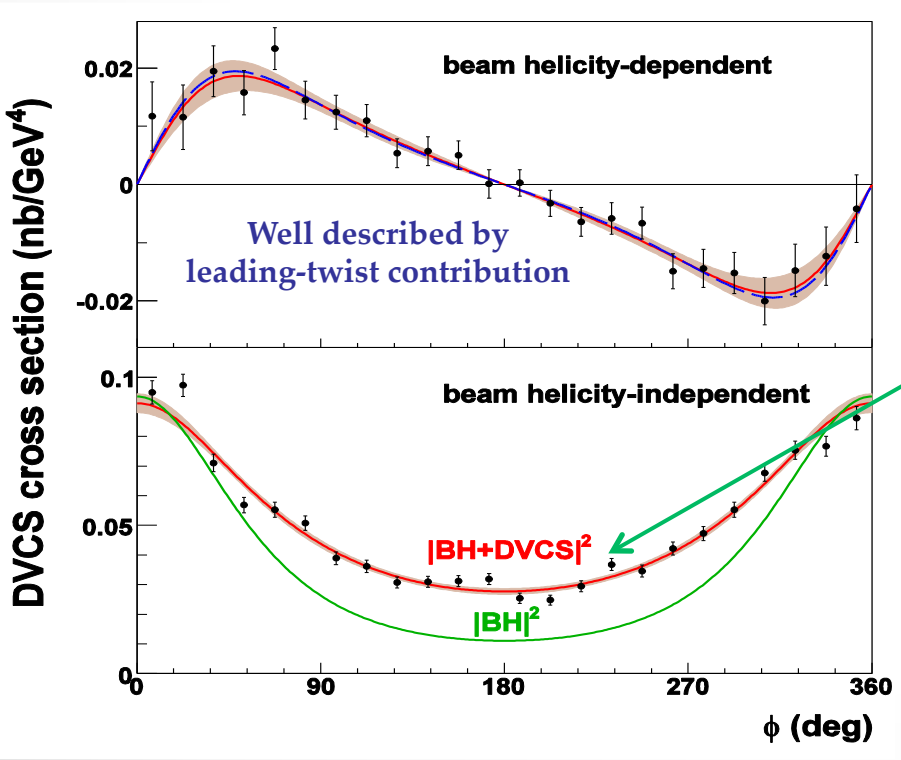

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Total Cross Section

Measured Known Fit with Data

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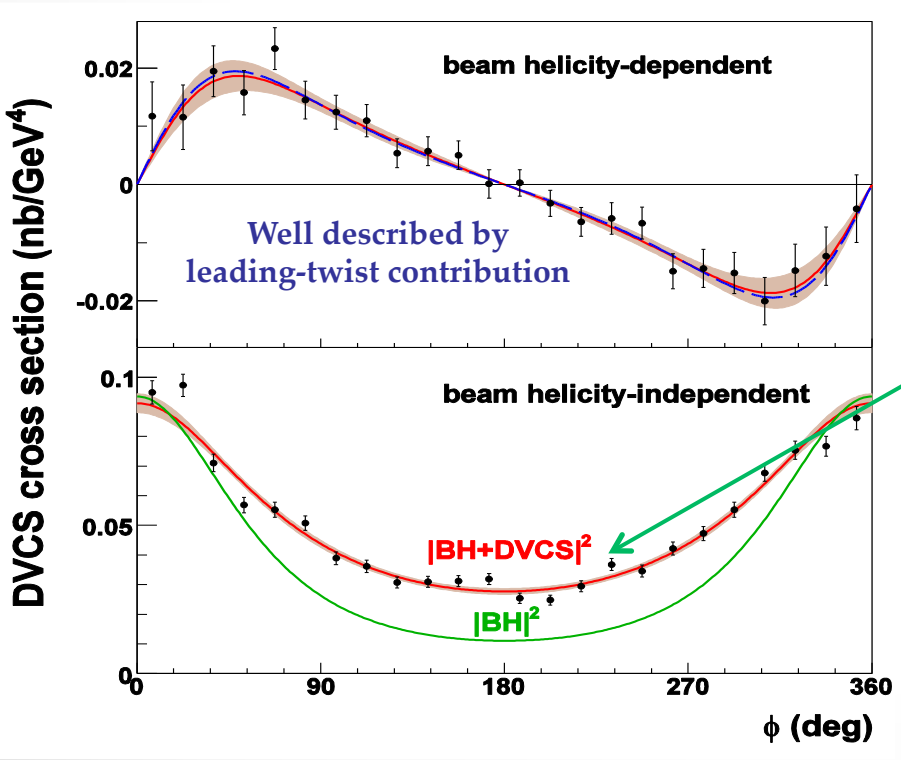

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Total Cross Section

Measured — Known — Fit with Data — Fit with Data

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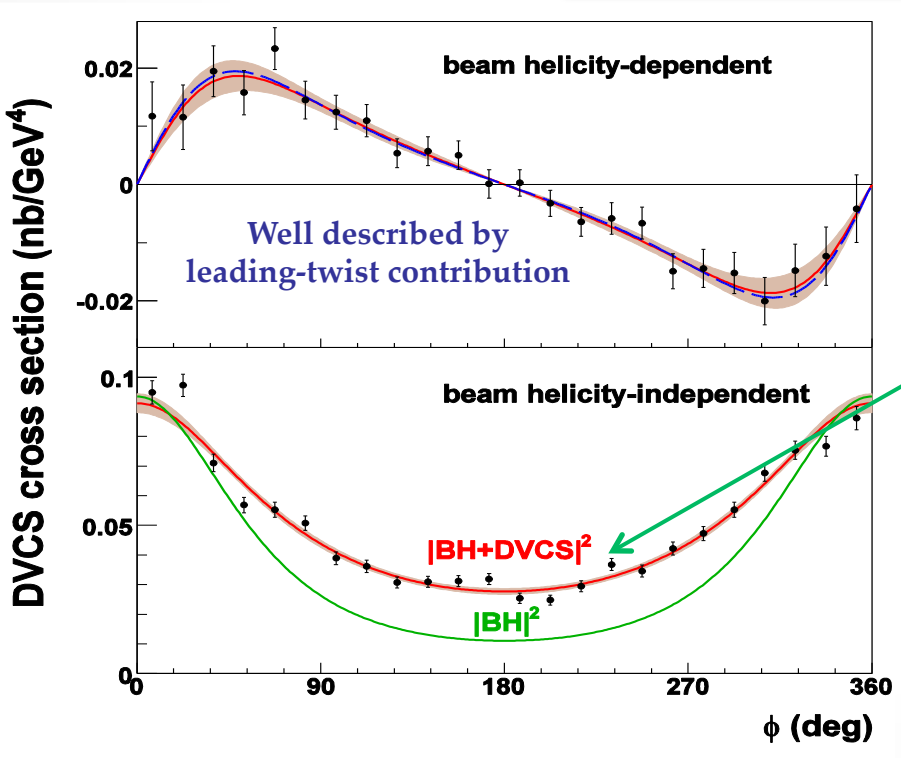

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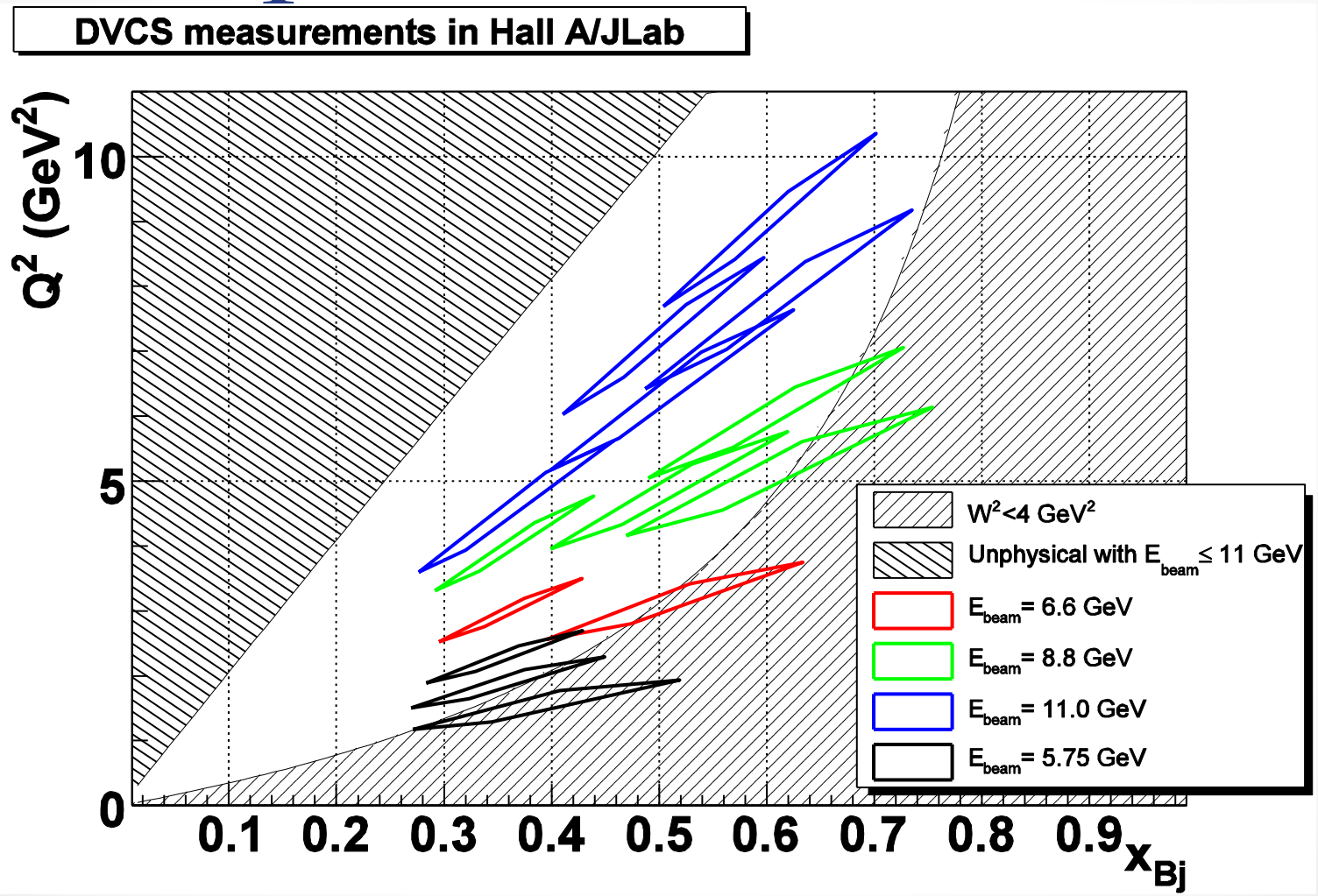
Proposed Kinematics

- Measuring at 3 fixed values of x_{Bj} and varying Q^2 for high precision measurement DVCS cross section dependence
  - Study possible influence of higher-order diagrams suppressed by powers of $1/Q^2$

- Want to utilize higher beam energy to explore higher Q^2 and x_{Bj} region

Proposed Kinematics



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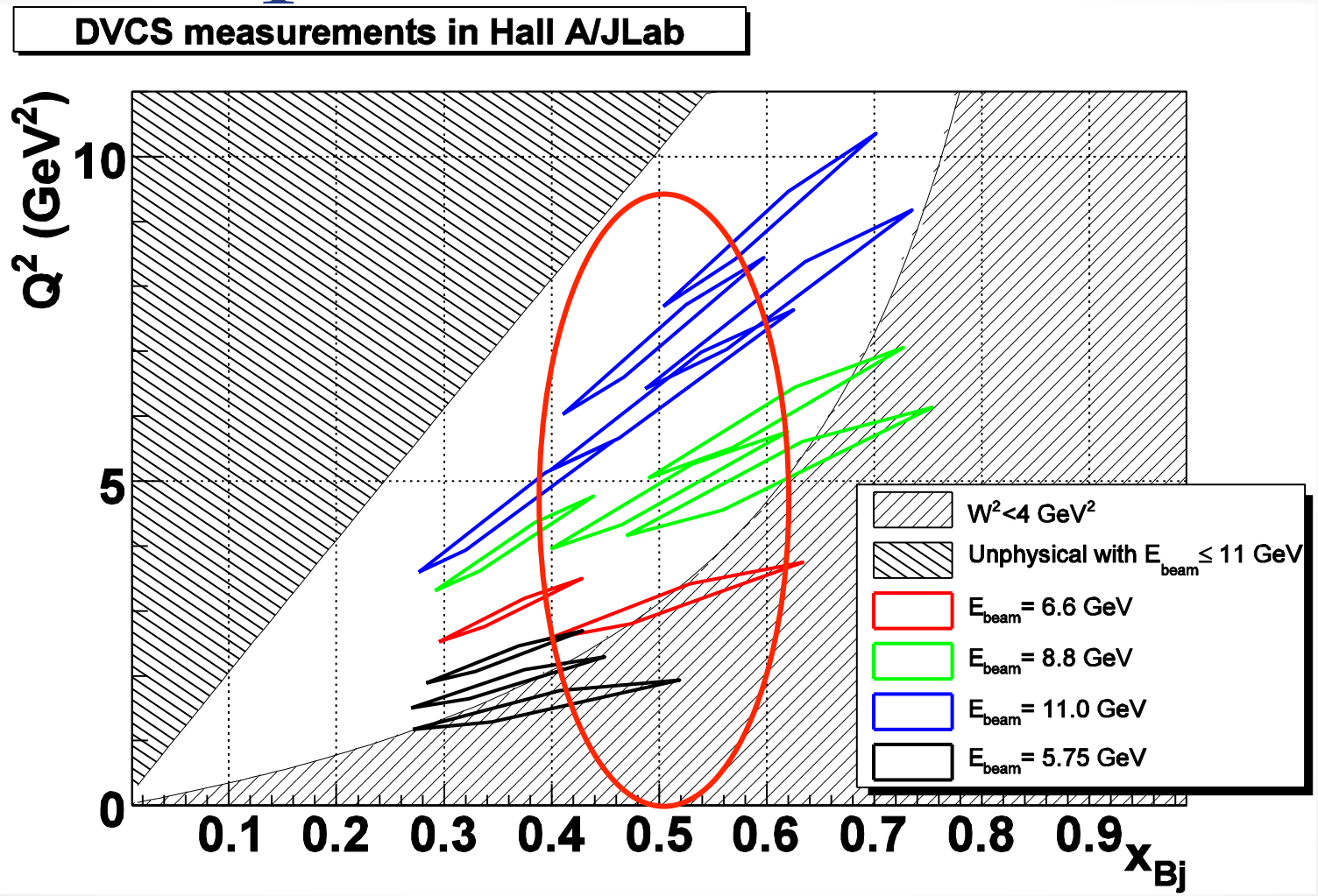


Monte Carlo Simulation

- Based on Geant4 simulation written by Carlos Munoz Camacho and Rafayel Paremuzyan
  - Simulation of interactions inside calorimeter not included
- CFF model taken from Kroll *et. al.* http://arxiv.org/pdf/1210.6975v3.pdf
- Total cross section (DVCS+BH) computed analytically using produced CFFs given initial kinematic settings
  - Beam energy
  - Calorimeter and HRS positions
  - HRS momentum acceptance
- Focused on count rate and cross section evaluation for future run plans

Monte Carlo Simulation

- Set target parameters, detector geometries, and detector acceptances
- Generate initial vertex and initial Bremsstrahlung
- Generate uniformly in phase space
  x_{Bj}, Q^2, φ_e, t, and $\phi_{\gamma\gamma}$
  - Reject unphysical points
  - Phase Space Factor (PSF) = $\Delta x_{Bj} \Delta Q^2 \Delta t \Delta \phi_{\gamma\gamma}$
- Use generated kinematics along with model values of CFFs to calculate cross section

Monte Carlo Integration

- Integrate over experimental bin#n to find expected yield

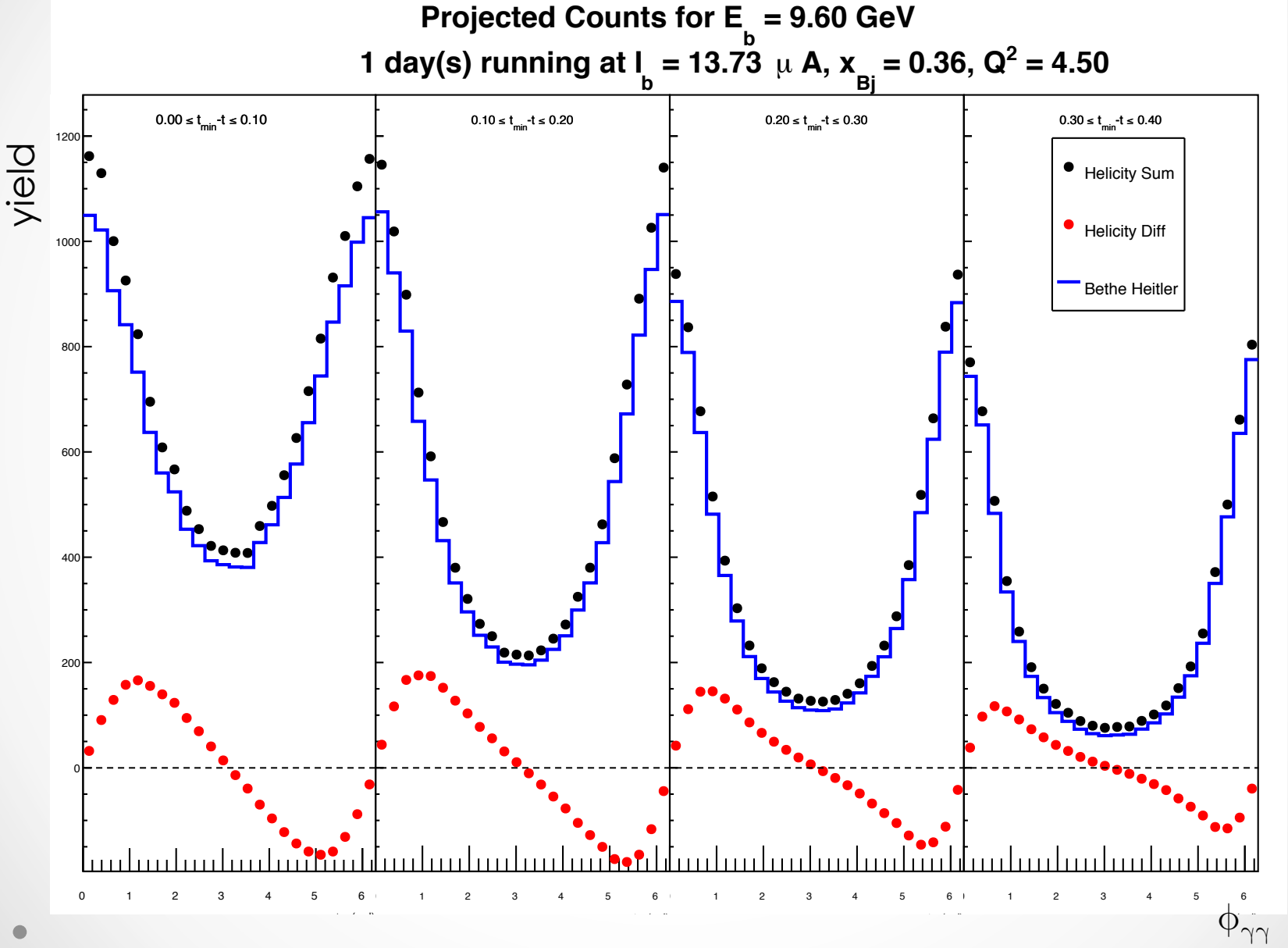
$$L = \frac{X \rho I}{e} \frac{N_0}{A}$$

$$PSF = \Delta x_{Bj} \Delta Q^2 \Delta t \Delta \phi_{\gamma\gamma}$$

$$Y(n) = \frac{L \cdot T}{N_{MC}} \sum_{\text{event } i} d^4\sigma_i \cdot PSF_i \cdot \chi_n \left(t_{min,i} - t_i\right)$$

- χ_n = Cut on bin#*n* in *t* increments of 0.1 GeV^2

Results – Count Yield



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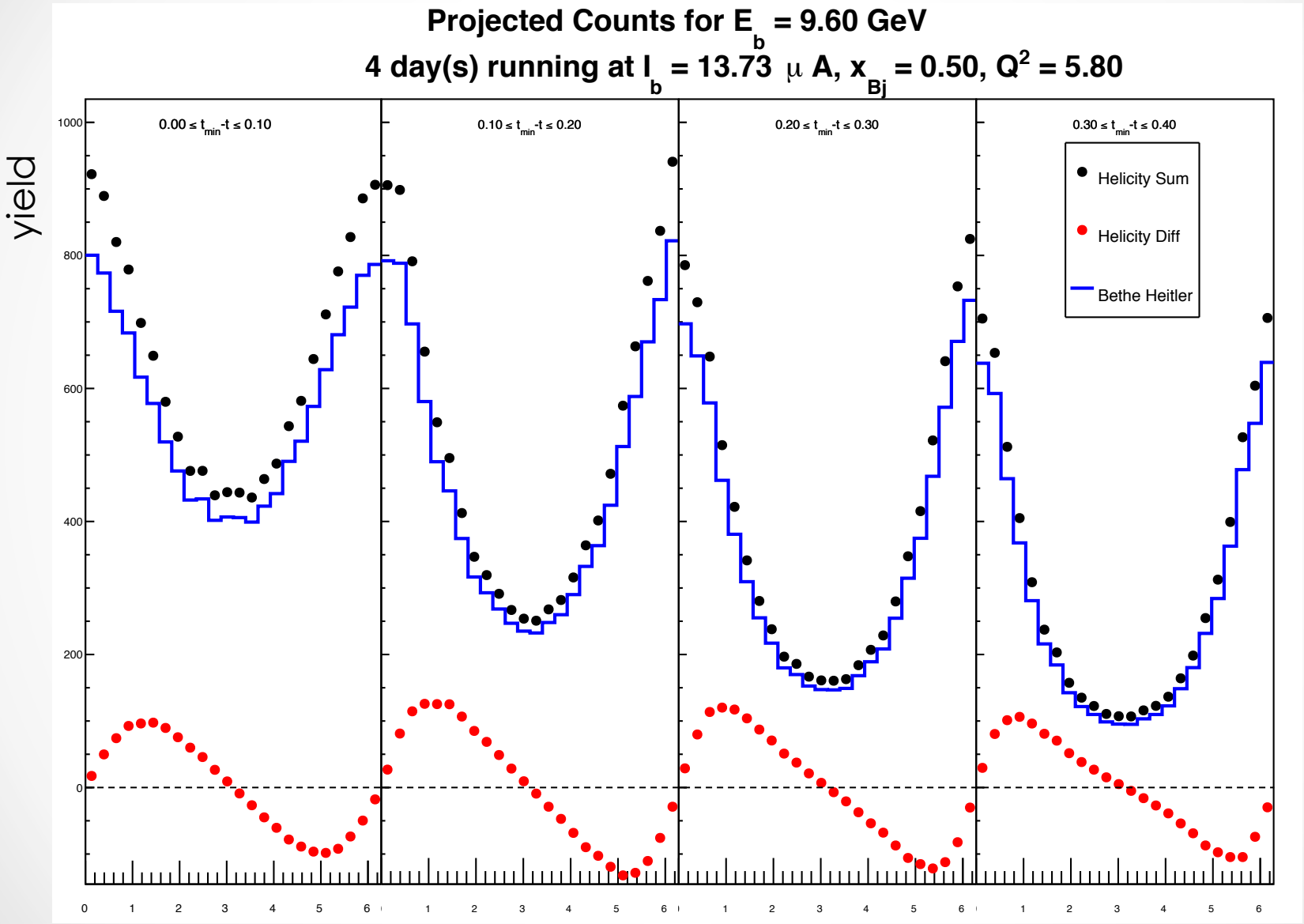

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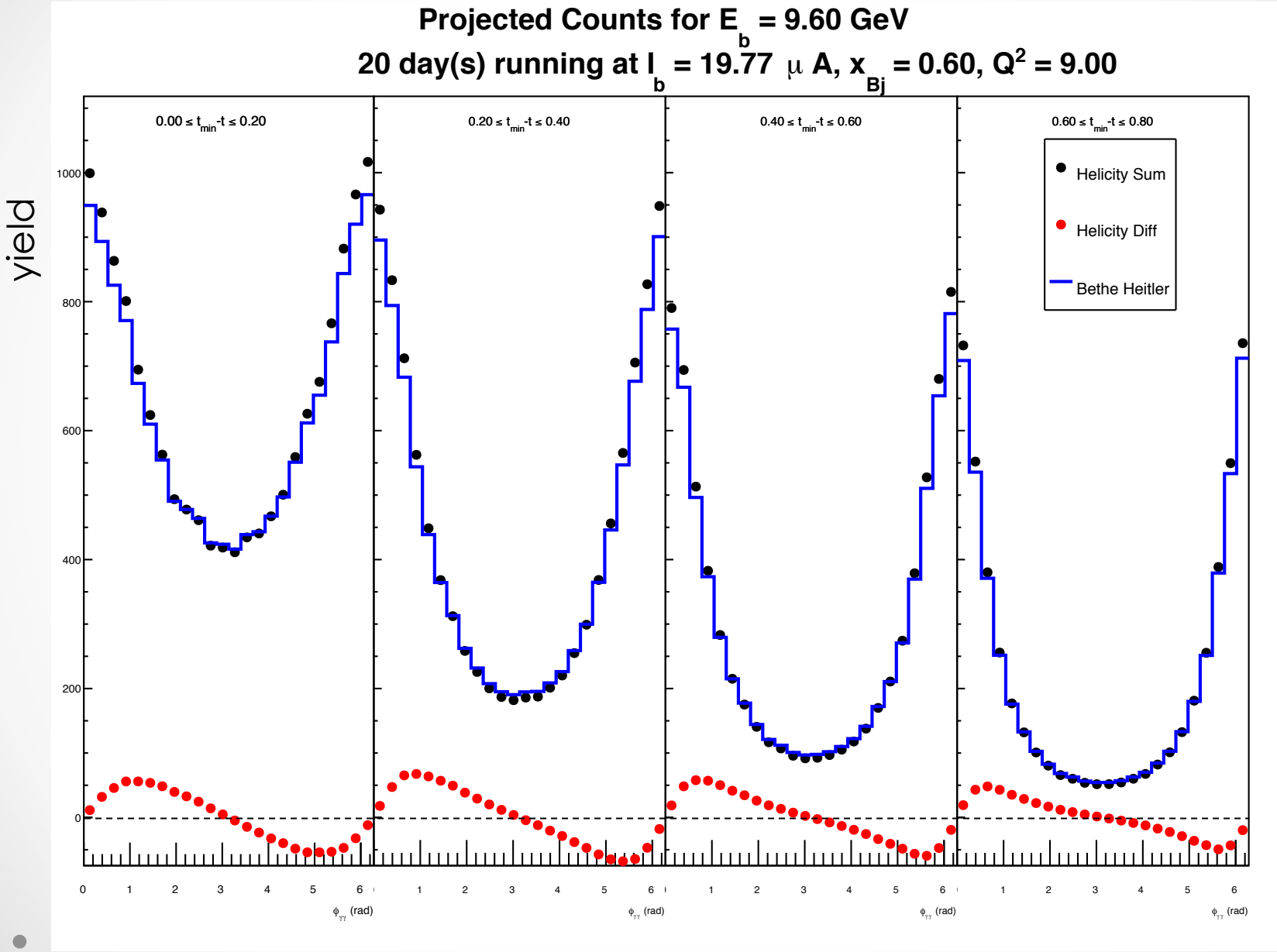
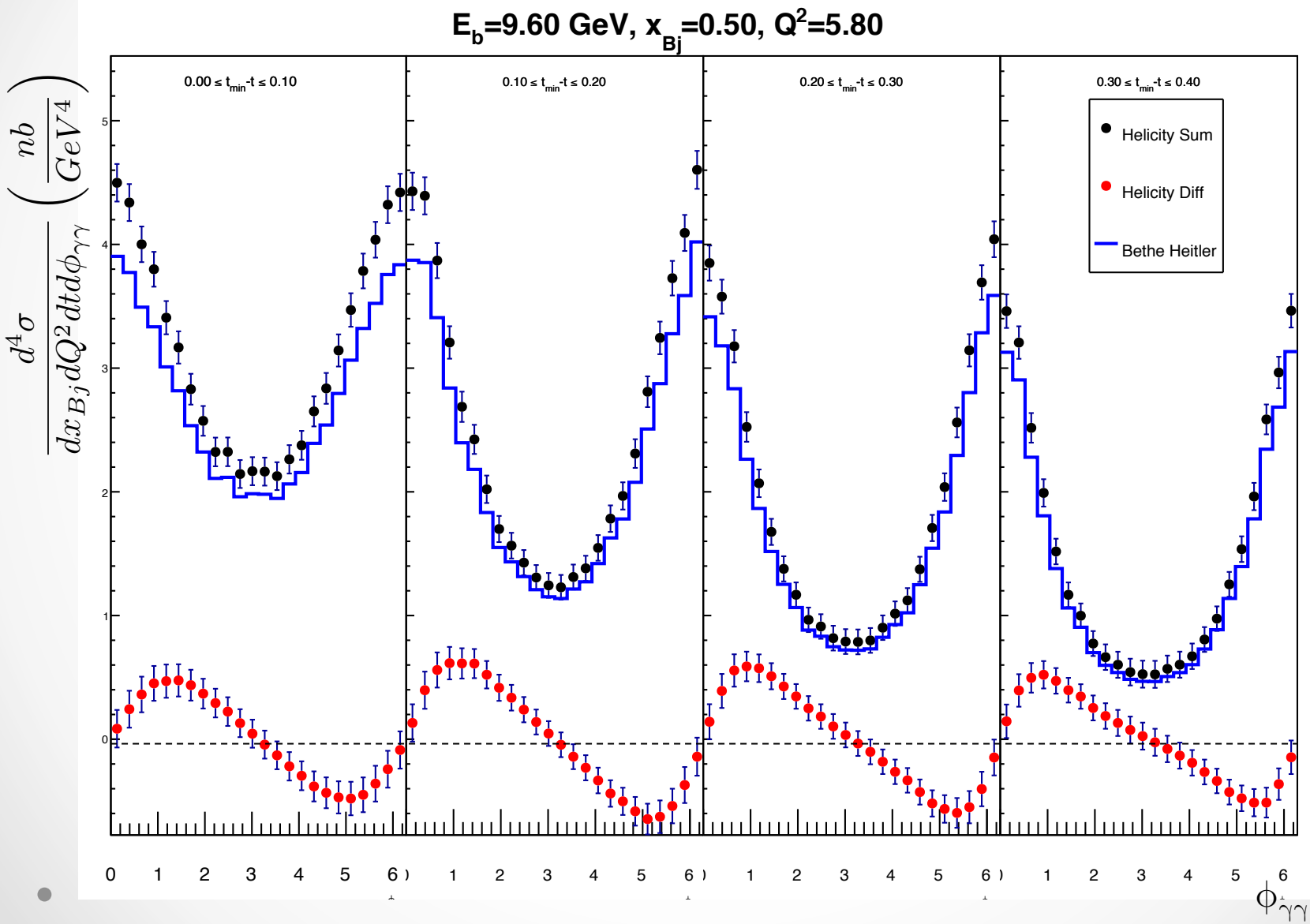
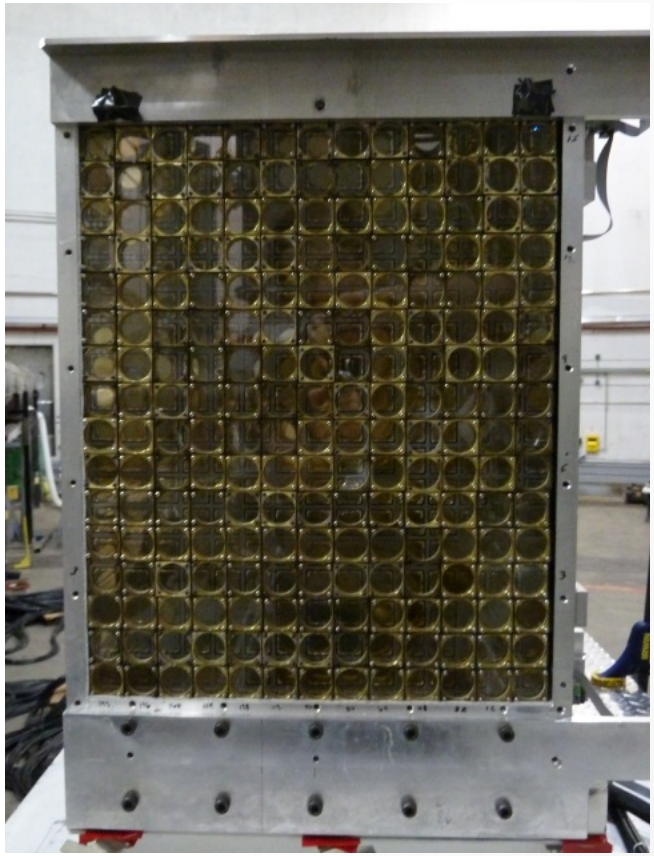


Results – Cross Section



Experimental Setup

- LH_2 Target
- 13 x16 PbF_2 EM calorimeter
  - Tags emitted photon
  - 3 x 3 x 18 cm^3
  - ρ = 7.77 g/cm^3
  - X_0 = 0.93 cm
  - Cerenkov only
- Left HRS
  - Tags scattered electron



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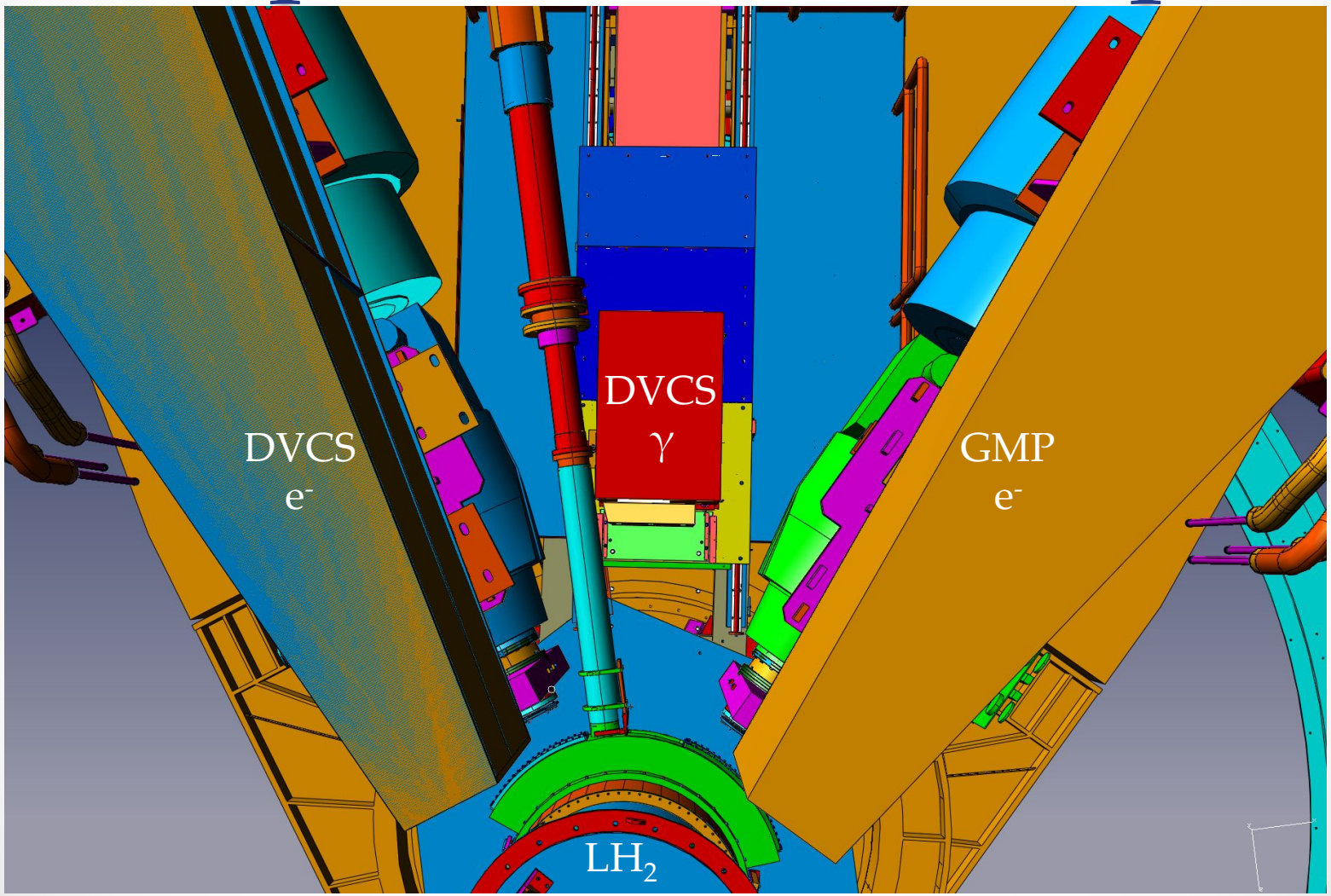
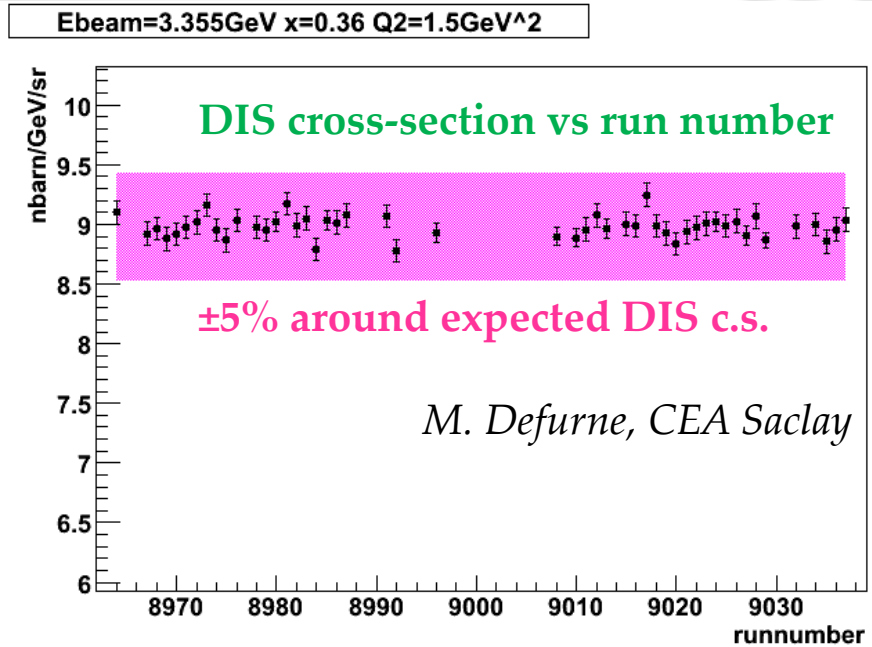


E07-007: Rosenbluth-like separation of DVCS

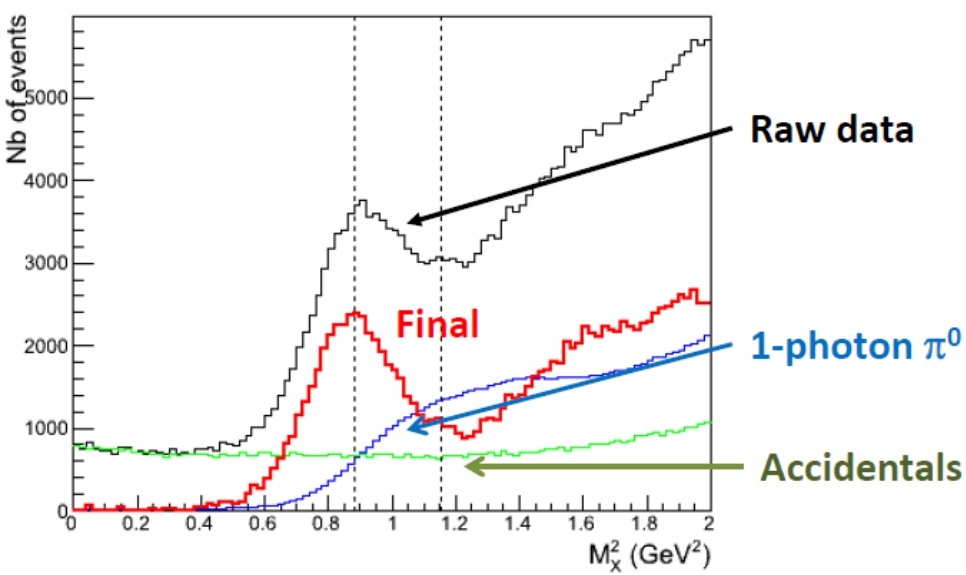


- Electron acceptance checks using DIS data
- Working on final global normalizations (multi-tracks, dead-time, radiative corrections)

- Data taken in late 2010
- Preliminary results expected in 2-3 months

3 kinematic points:
x_B=0.36, Q^2=1.5, 1.75, 2.0 GeV^2
5 bins in t
2 beam energies per point

$ep \rightarrow e\gamma X$ missing mass squared



Analysis underway (A. Marti, IPNO & Valencia U)

E08-025: DVCS on the neutron

- Beam energy separation off the neutron using an LD2 target
- Important contribution of $|DVCS|^2$ term expected in unpolarized cross section

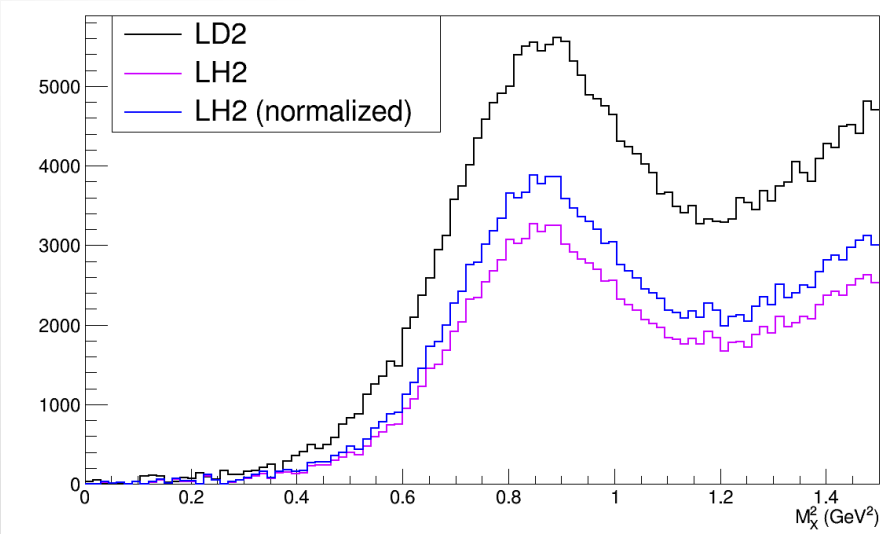
Data taken in Fall 2010 concurrently with E07-007

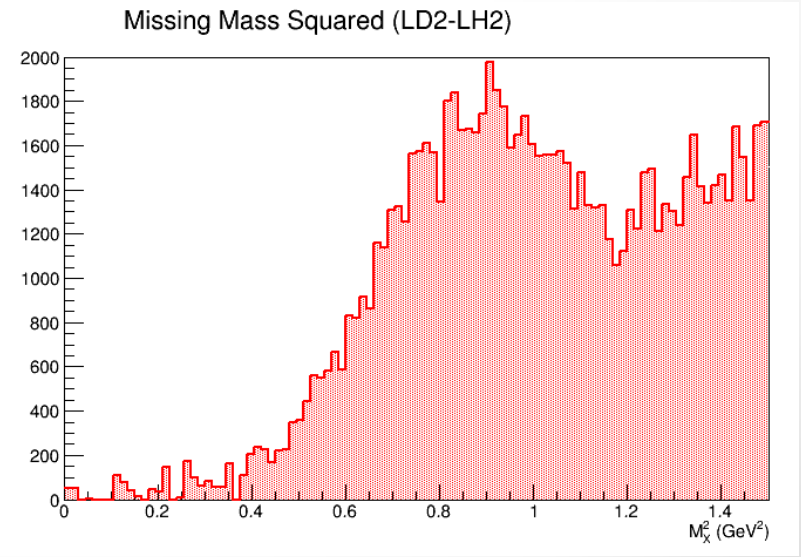
Analysis ongoing:

- Calibrations completed
- Exclusive data isolated
- Cross section extraction underway

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

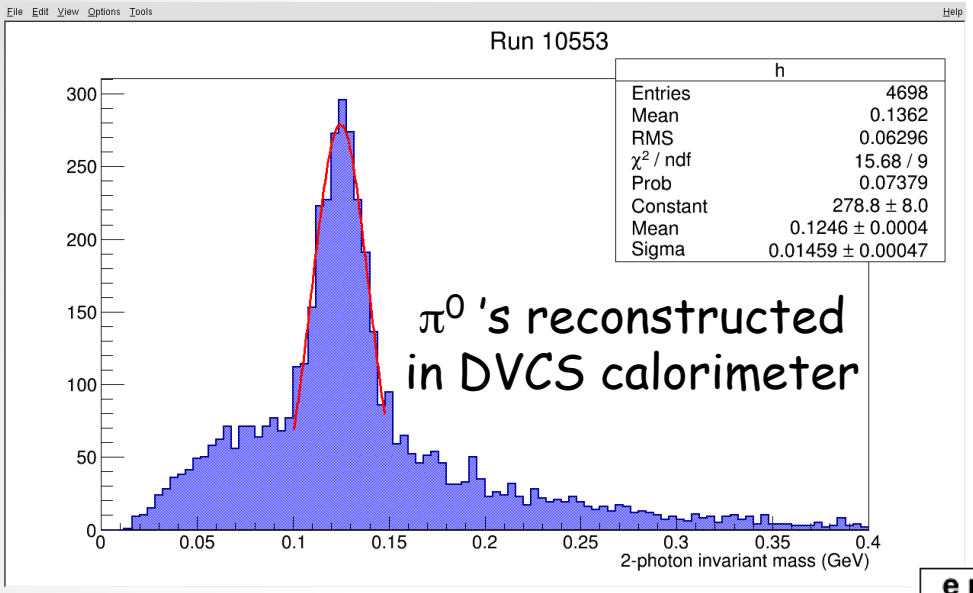
$eN \rightarrow e\gamma X$





C. Desnault

E12-06-114: Fall 2014 Run

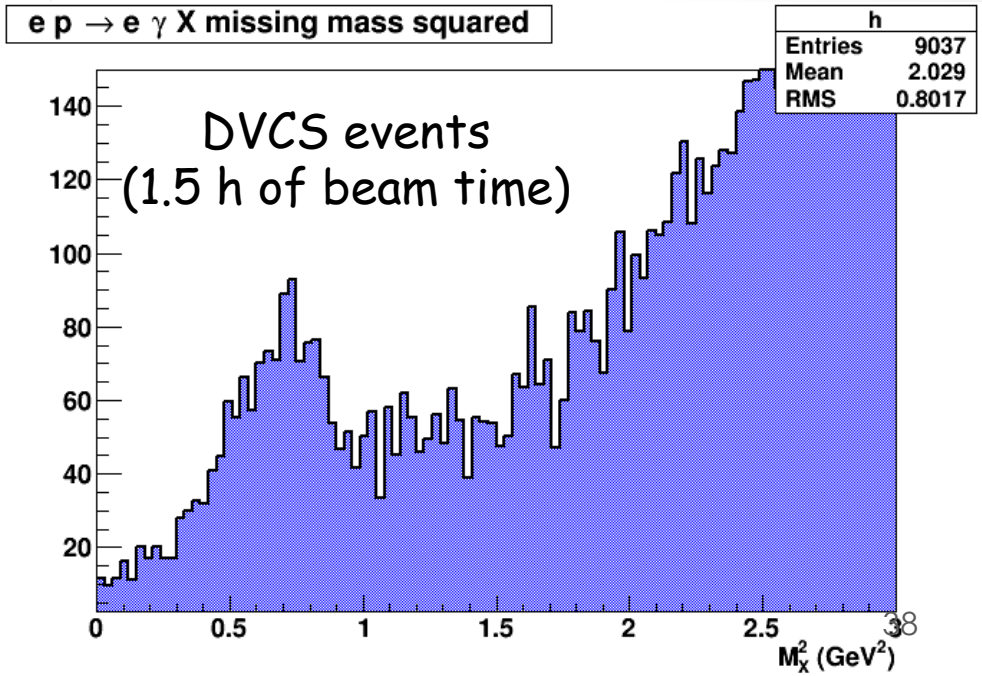


Beam line commissioning:

- ✓ Moller measurement (88% polarization)
- ✓ BPM calibration (+ harps operational)
- ✓ BCM calibration
- ✓ New raster commissioning

DVCS experiment commissioning:

- ✓ Coincidence (e + g) trigger
- ✓ 1 GHz sampling electronics
- ✓ *ep* → *ep* calorimeter elastic calibration
- ✓ (Almost) completed the 1st DVCS kinematic setting

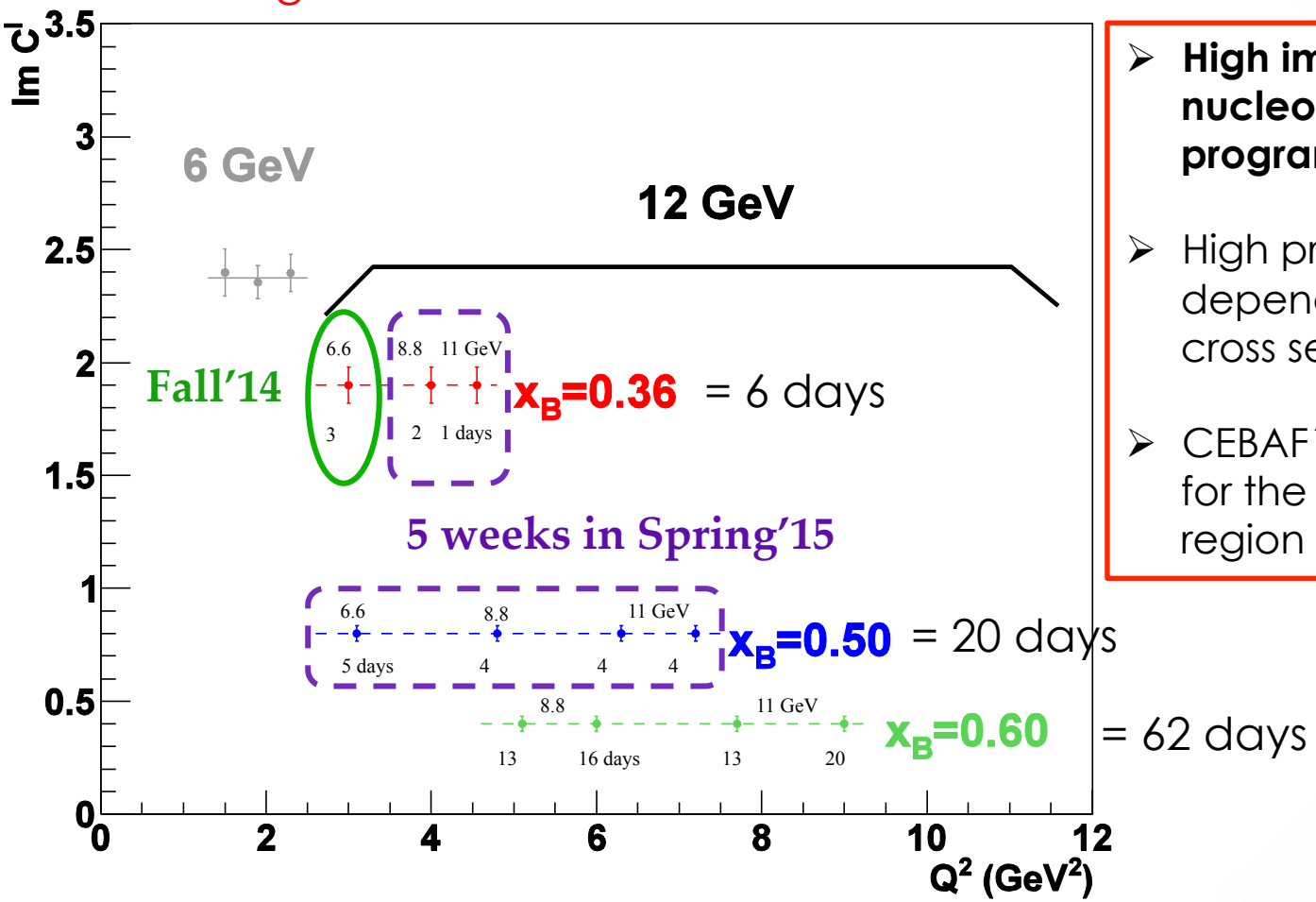


Summary

- Measuring total ep→ep γ cross section over full 12 GeV range in x_{Bj}, Q^2, t, $\phi_{\gamma\gamma}$ allows us to isolate GPD terms from DVCS amplitude
- GPD variation with t ➔ Traverse spatial distributions of quarks
- GPD variation with x_{Bj} ➔ Longitudinal momentum distribution of quarks
- A better understanding of GPDs leads to a better understanding of the inner structure of the proton and the distribution of quarks within it
  - Can also lead to a better understanding of (and possible resolution to) the proton spin puzzle

E12-06-114: DVCS at 11 GeV

Scaling tests of the DVCS cross section



- **High impact experiment for nucleon 3D imaging program**
- High precision Q^2 dependence of the DVCS cross section at constant x_{Bj} .
- CEBAF12 will allow to explore for the first time the high x_{Bj} region

Total = 100 days (88+12 days calibration) approved