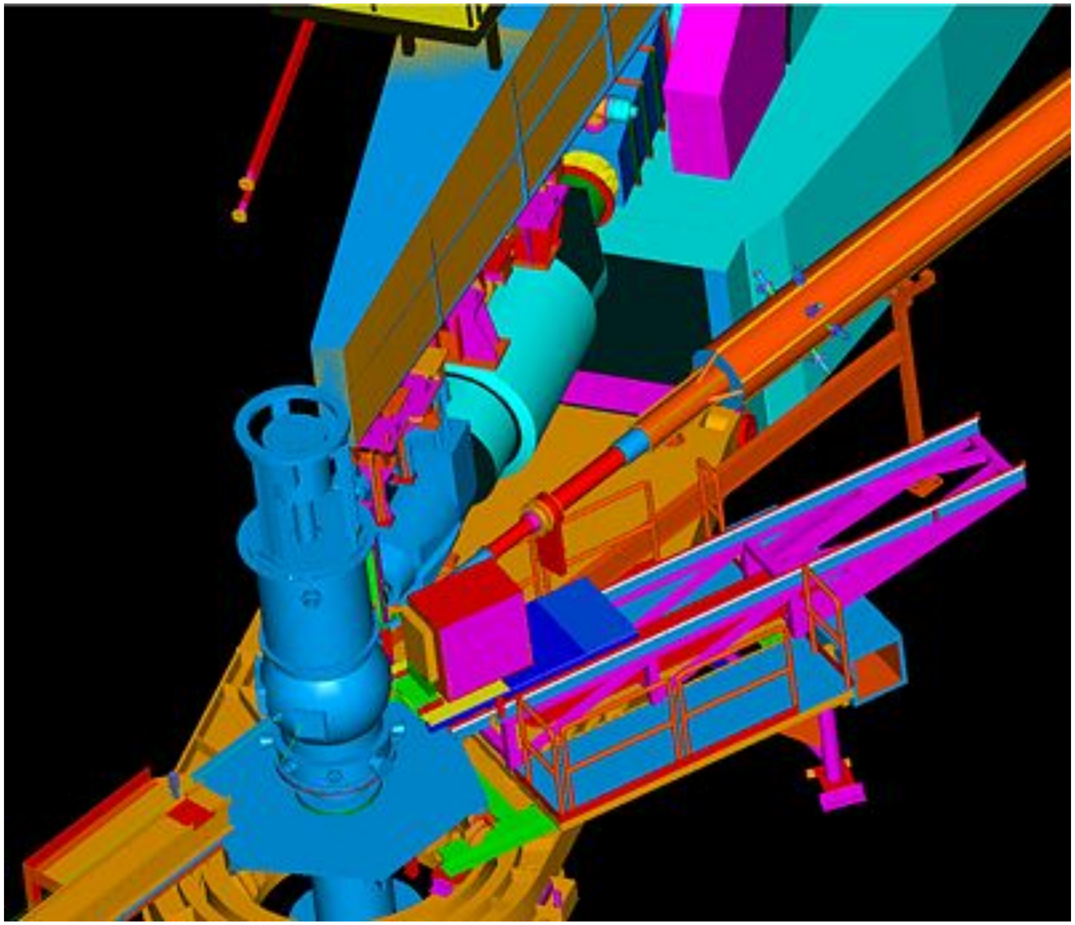
Hall C Collaboration Meeting
24—25 Jan 2013, Jefferson Lab

Deeply Virtual Compton Scattering in Hall C at 11 GeV

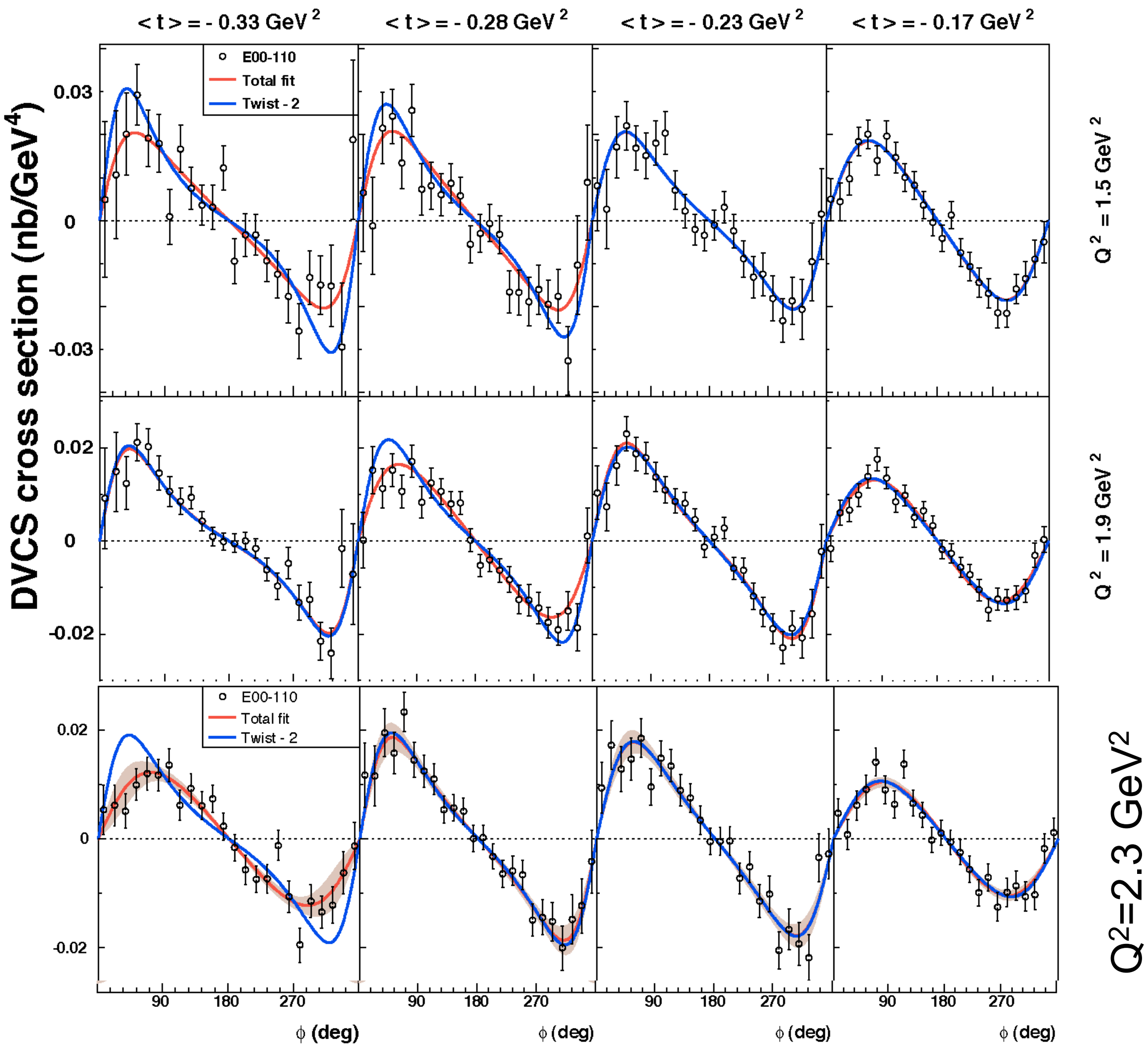


Charles Hyde
Old Dominion University

Why Use Spectrometers for DVCS?

- Precision cross sections are key to extracting physics
- $d\sigma(ep \rightarrow ep\gamma)$ = twist-2 (GPD) terms + Σ_n [twist-n]/Q^{n-2}
  - Isolate twist-2 terms → cross sections *vs* Q^2 at fixed (x_{Bj}, t);
  - Multiple beam energies at fixed (Q^2, x_{Bj}, t)
    - Two beam energies at fixed (Q^2, x_{Bj}, t) to isolate $[DVCS^{\dagger}BH]$ from $|DVCS|^2$
    - **Three** beam energies at fixed (Q^2, x_{Bj}, t) to isolate all twist-2 and twist-3 terms in unpolarized cross section.
- H$(e,e'\gamma)p$ at low Δ^2
  - Electron and photon are highly correlated
  - For a single kinematic setting, Luminosity×Acceptance (spectrometers) roughly 10×CLAS12
    - CLAS12 has greater reach to larger values of $-t$ and smaller x_{Bj}
    - Spectrometers yield high precision in highest Q^2 bins.

Hall A Helicity Dependent Cross Sections E00-110



PRL**97**:262002 (2006)
C. MUNOZ CAMACHO,
et al.,

Twist-2(GPD)+…

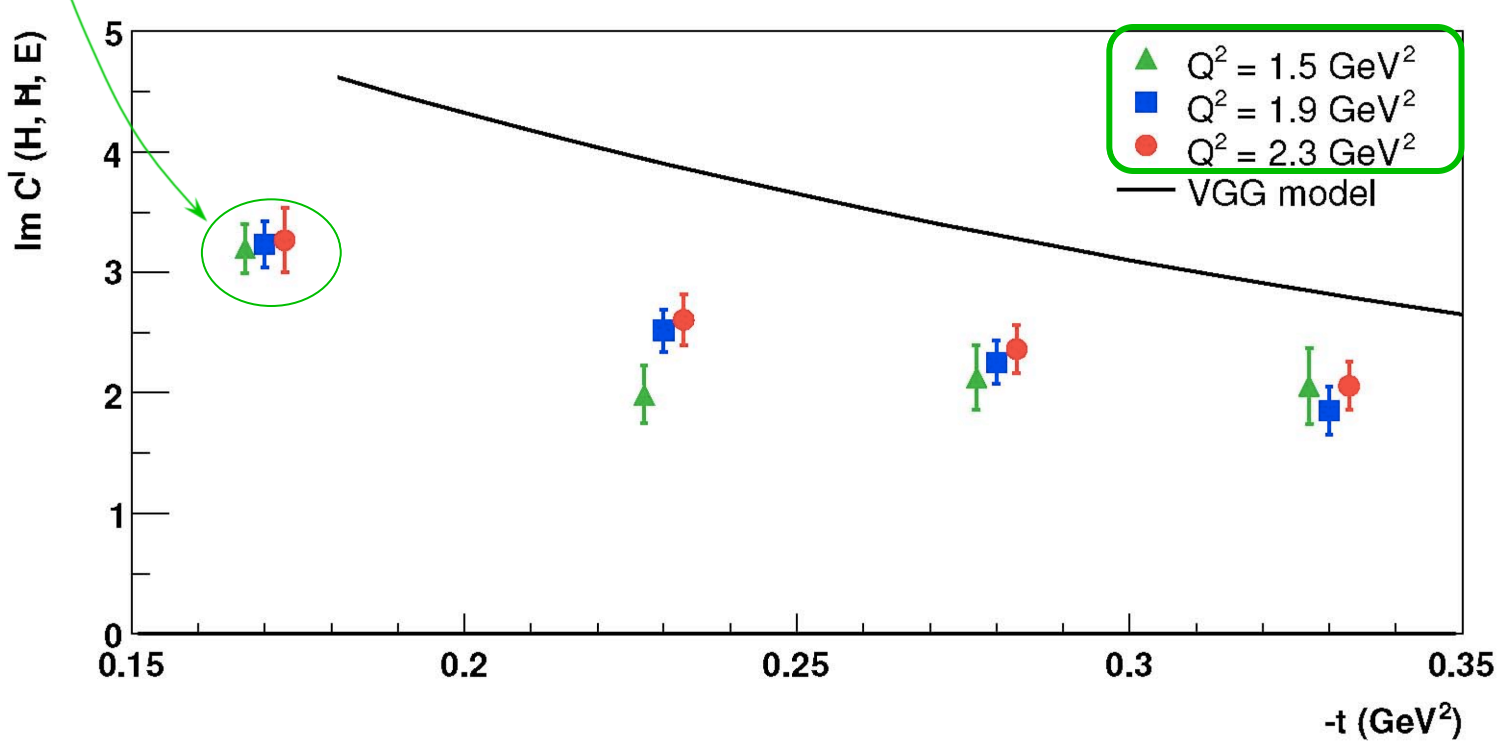
Twist-3(qGq)+…

$$\sum h d\sigma(h) = \frac{s_1 \sin(\phi_{\gamma\gamma})\Gamma_{s1} + s_2 \sin(2\phi_{\gamma\gamma})\Gamma_{s2}}{P_1(\phi_{\gamma\gamma})P_1(\phi_{\gamma\gamma})}$$

$\Gamma_{s1,2}$ = kinematic factors

GPD results from JLab Hall A (E00-110) (C.MUNOZ CAMACHO et al *PRL* **97**:262002)

- Q^2-independance of Im[DVCS*BH]
  - Twist-2 Dominance (GPD)
  - Model « Vanderhaeghen-Guichon-Guidal(VGG) » (based on Double Dist. of A.Radyushkin) accurate to ≈30%



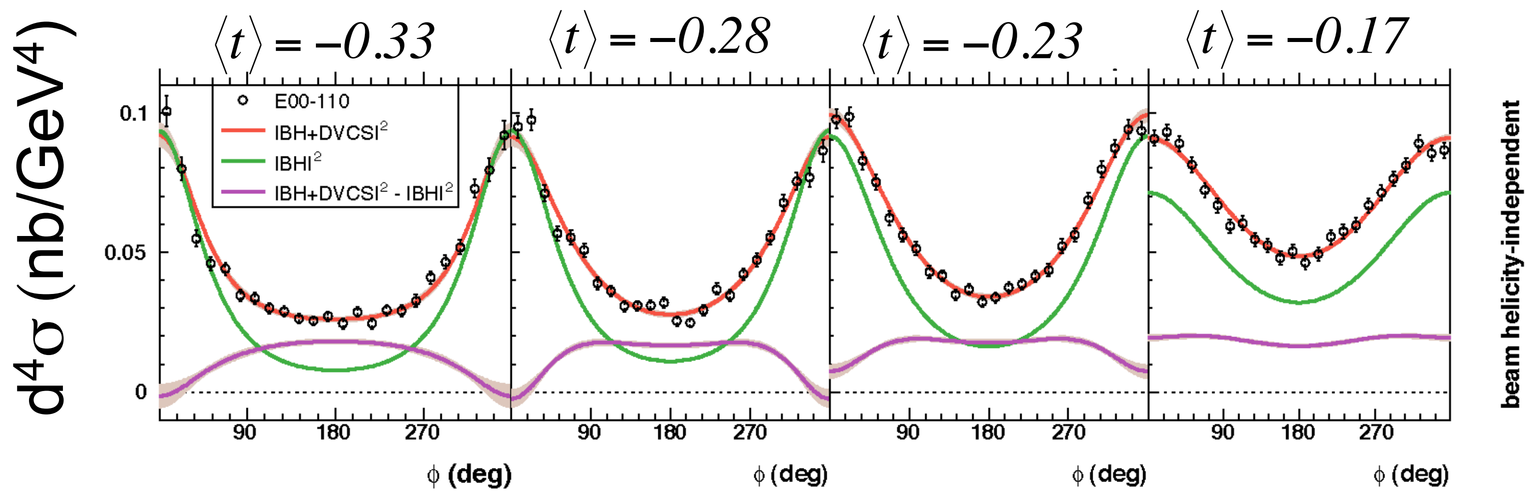
Extend to
$Q^2 = 4.5$ GeV^2
@11GeV

Compensate the small lever-arm in Q^2 with precision in dσ.

Beam helicity-independent cross sections at Q^2=2.3 GeV^2, x_B=0.36

- Contribution of Re[DVCS*BH] + |DVCS|^2 large.
- Positron beam or measurements at multiple incident energies to separate these two terms and isolate Twist 2 from Twist-3 contributions

PRL**97**:262002 (2006) C. MUNOZ CAMACHO, *et al.*,



$$d\sigma = d\sigma(|BH|^2) + 2\,\mathrm{Re}[DVCS^* BH] + |DVCS|^2$$

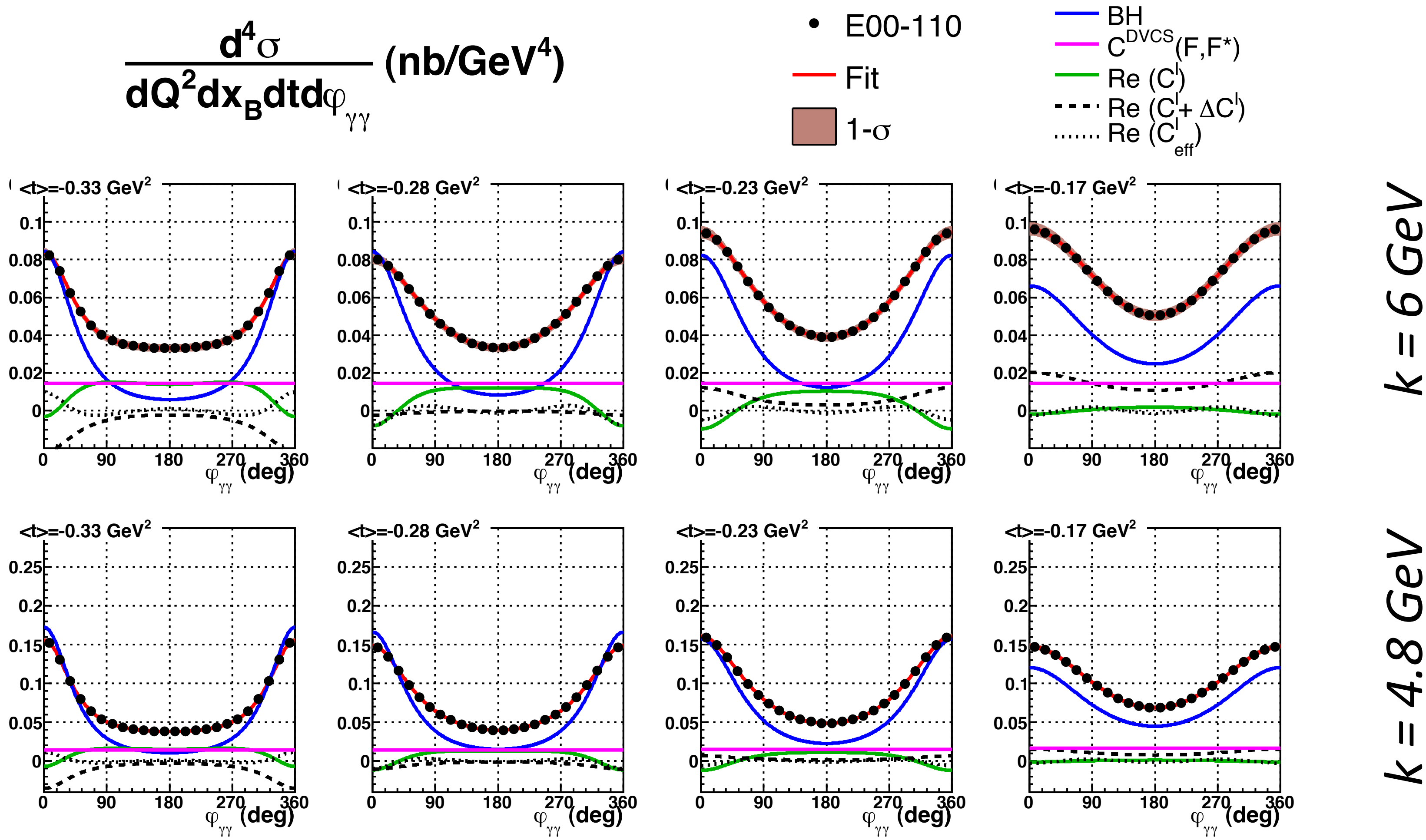
$$= d\sigma(|BH|^2) + \frac{c_0\Gamma_0 + c_1\cos(\phi_{\gamma\gamma})\Gamma_1 + c_2\cos(2\phi_{\gamma\gamma})\Gamma_2 + \ldots}{P_1(\phi_{\gamma\gamma})P_1(\phi_{\gamma\gamma})}$$

$$c_{0,1}(t) \approx \mathrm{Re}[C^I(GPD)] \pm C^{DVCS}\left(GPD^2\right) \ldots + \mathrm{Re}\left[\Delta C^I(GPD)\right]$$

$$c_2(t) = \mathrm{Twist}-3 = (qGq)$$

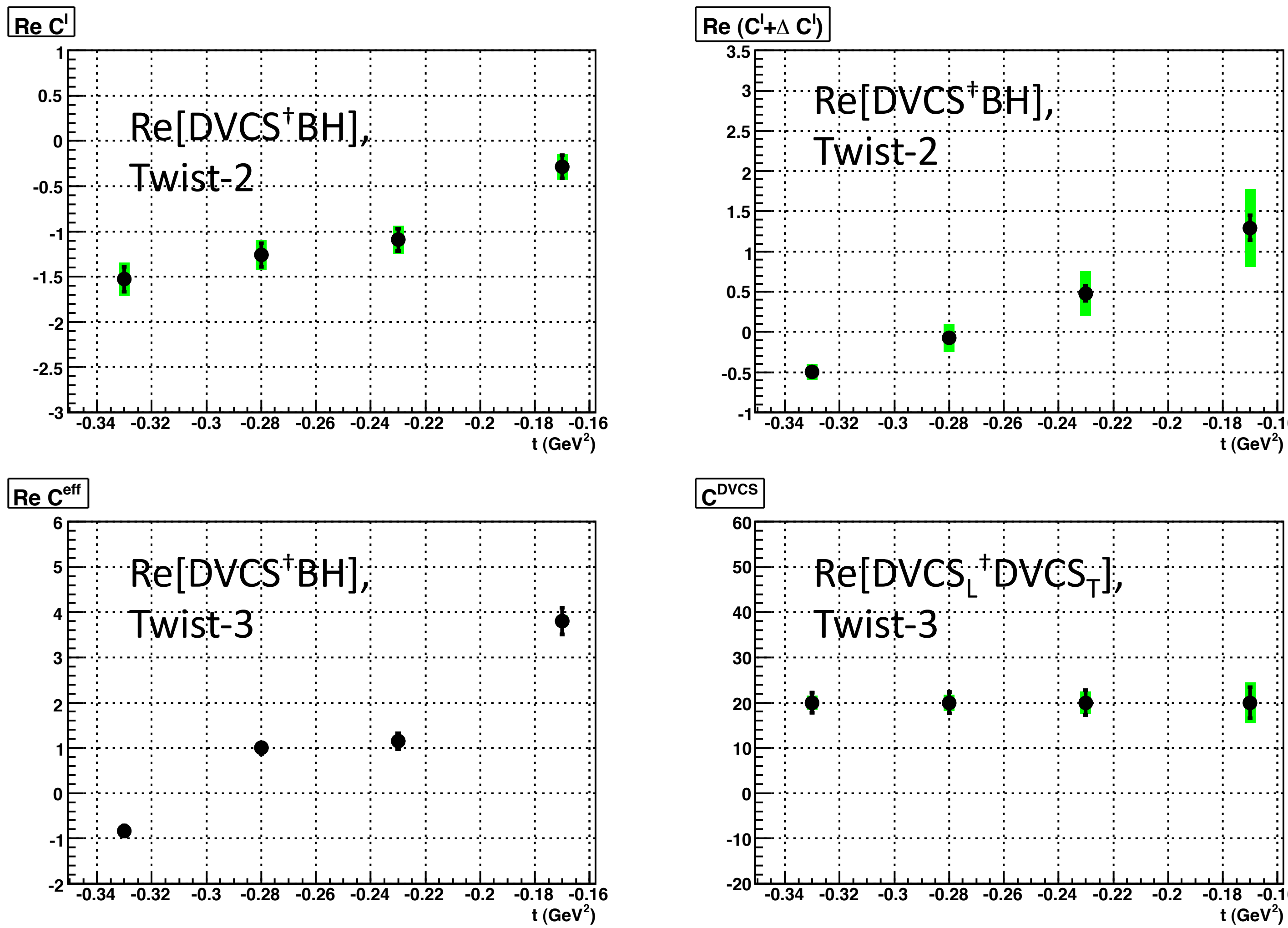
Projections for E07-007 (2010), Q^2=*1.9 GeV^2*

- Different dependence on incident energy for $|BH|^2$, *[DVCS†BH] (C^I twist-2)*, and $|DVCS|^2$*(C^{DVCS} twist-3)* terms



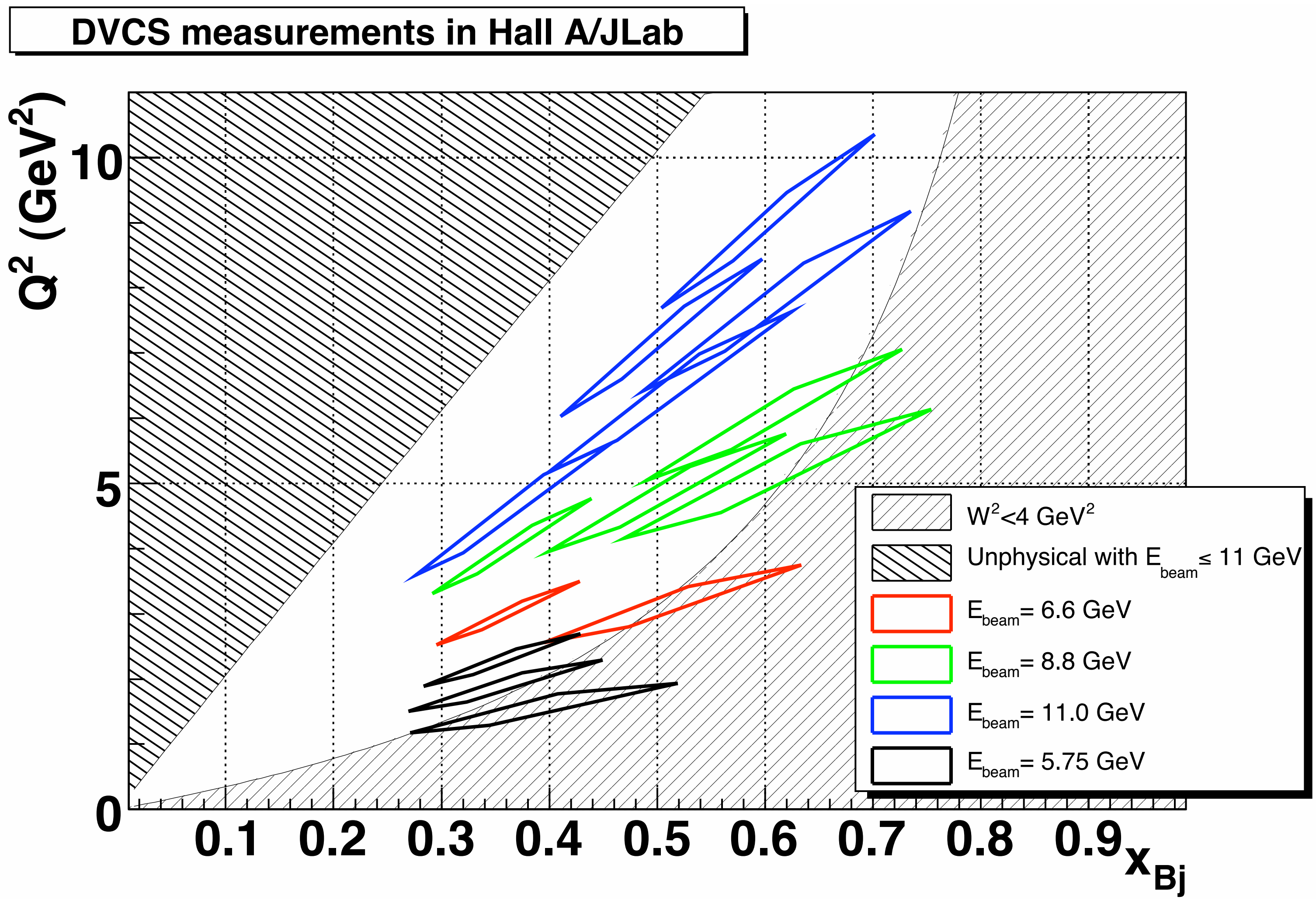
E07-007 Projected Extractions:

- green bands are systematic errors.
- Four different contributions to unpolarized cross sections
  - constant terms
  - $\cos\phi_{\gamma\gamma}$ terms
  - $\cos 2\phi_{\gamma\gamma}$ terms



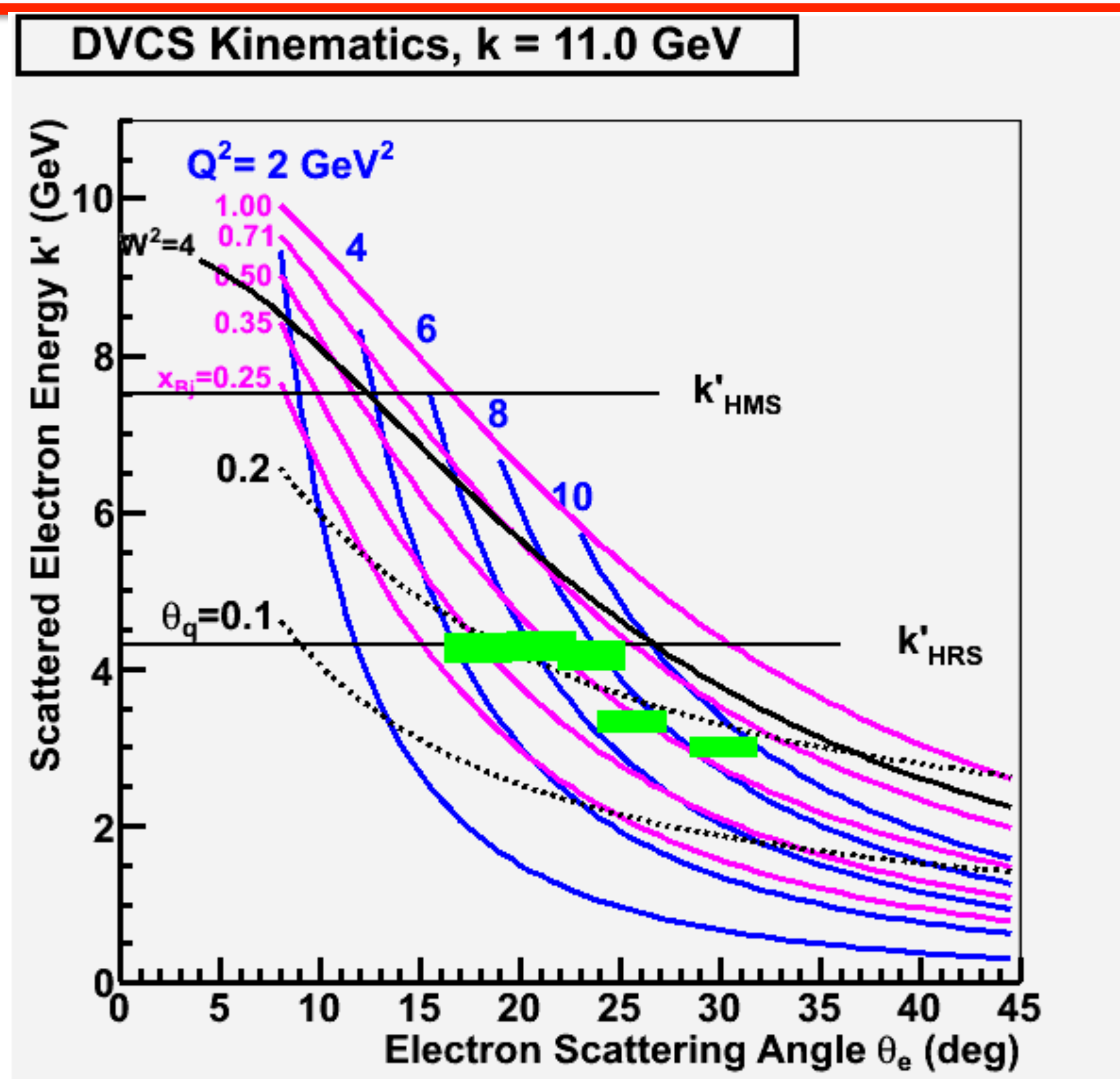
Hall A E12-06-116, approved for 100 days

- Multiple beam energies at fixed Q^2, x_{Bj} requires spectrometer momenta > k_{HRS}=4.3 GeV/c



DVCS Kinematics, Hall A & C

- Green rectangles are Hall A kinematics.
- Calorimeter centered at θ_q.
  - Require $\theta_q \geq 0.2$ rad to avoid small-angle background.



Kinematics Table Hall A E12-06-114

		Hall A E12-06-114			Hall C complement at fixed (Q^2, x_{Bj})								
Q^2	x_{Bj}	k	k'	θ_q	k	k'	θ_e	θ_q	k	k'	θ_e	θ_q	Days
3.00	0.36	6.60	2.16	11.7	8.80	4.36	16.08	14.7	11.00	6.56	11.70	16.2	6
4.00	0.36	8.80	2.88	10.3					11.00	5.08	15.38	12.4	3
4.55	0.36	11.00	4.26	10.7									
3.10	0.50	6.60	3.30	19.0	8.80	5.50	14.55	21.6	11.00	7.70	10.98	23.0	10
4.80	0.50	8.80	3.68	14.5					11.00	5.88	15.65	16.6	4
6.30	0.50	11.00	4.28	12.4									
7.20	0.50	11.00	3.32	10.2									
5.10	0.60	8.80	4.27	17.8					11.00	6.47	15.38	19.8	13
6.00	0.60	8.80	3.47	14.8					11.00	5.67	17.84	17.2	16
7.70	0.60	11.00	4.16	13.0									
9.00	0.60	11.00	3.00	10.2									
Total Days Hall A				**88**	**Total Days, Hall C Complement**								**52**

Kinematics Hall C Extensions

(Requires sweep magnet to reach lower θ_q)

		Hall C kinematics at fixed (Q^2, x_{Bj})									
		k = 6.6 GeV			k=8.8 GeV			k=11 GeV			Days
Q^2	x_{Bj}	k'	θ_e	θ_q	k'	θ_e	θ_q	k'	θ_e	θ_q	
		Lower x_{Bj}									
2.00	0.20	1.27	28.3	6.3	3.47	14.70	9.2	5.67	10.3	10.6	1
3.00	0.20							3.00	17.3	6.3	1
		Higher Q^2									
5.50	0.36							2.86	24.2	7.9	5
8.10	0.50							2.36	32.4	8.0	10
10.0	0.60							2.11	38.3	8.0	20
					Total Days						37

Calorimeter Issues

- Distance from target is dictated by $\pi^0 \rightarrow \gamma\gamma$ opening angle and Calorimeter Moliere radius (transverse shower profile).
  - Optimum to be able to vary Target to Calo distance in range 2-4 m for DVCS data, and to ≥ 5 m for calibration
- Angular size is dictated by:
  - $t_{Min} - t$ acceptance desired
  - $t_{Min} - t$ acceptance must be convoluted with $\pi^0 \rightarrow \gamma\gamma$
- High backgrounds require
  - Fast response
  - Radiation hard
  - Sweep magnet to get to central Calorimeter angles < 10°

Longitudinal and Transverse Polarized Targets
for DVCS at 11 GeV:

Required for separation of
H, E, $\tilde{H}$, $\tilde{E}$ GPDs
on $x=\xi$ line.

Polarized Protons, Neutrons in CLAS12

- Longitudinally polarized NH_3 target
  - 100 days approved
  - polarized proton luminosity ~ 10^{34} ?
  - Extensive data taken already at 6 GeV
- Transversely polarized protons in HDice
  - C2 approval from PAC, pending luminosity and polarization milestones
- Longitudinal ND_3 or LiD likely (proposals?)
  - Unpolarized D_2 program with Orsay neutron detector in central barrel
- No active program for transversely polarized neutrons

High Luminosity Polarized ^{3}He Target

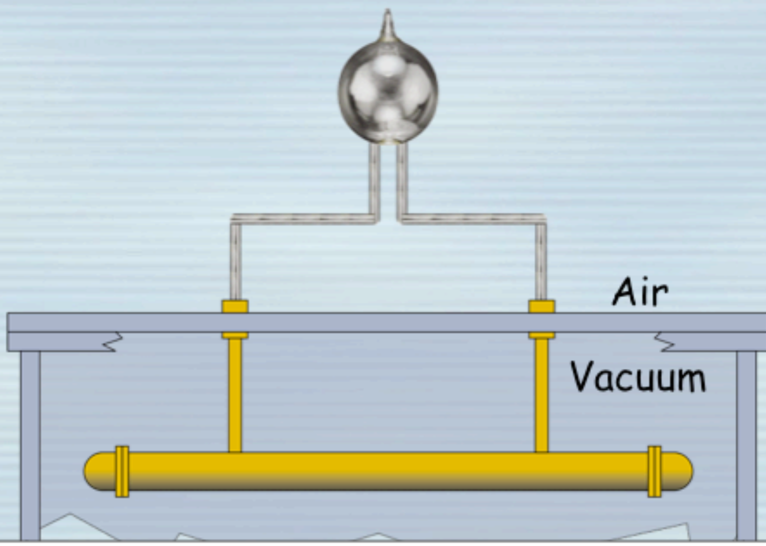
The requirements:

60% with 60 μA on a ~~60 cm~~ target at 11-12 atm

30 cm

Neutron
$\mathcal{L} = 3 \bullet 10^{36}$

- Convection-based cell to avoid polarization gradients at high current.
- Expanded vertical dimension will allow radiation shielding.
- Larger volume of polarized gas will enable target to tolerate higher beam depolarization.
- Metal target cell to better tolerate high beam (or at least metal endcaps).



Need thin metal walls, or 6 cm ϕ cell, to eliminate secondary background in DVCS Calorimeter

Neutron DVCS in ^{3}He Target:

$\vec{n}(\vec{e},e'\gamma)n$ via $^3\vec{H}e(\vec{e},e\gamma)X$

- Target spin-dependent cross sections
  - 0.86"n"-0.028"p" from ^{3}He wave-function
- Fermi-motion of neutron in ^{3}He
  - Smearing of QF neutron contribution with pion-production channels N(e,e'γ)Nπ
  - H(e,e'γ)X: M_X^2 resolution $\sigma(M_X^2) \approx 0.22$ GeV^2.
  - For $-t < 0.4$ GeV^2 and p_N <250 MeV/c, QF smearing contributes ≤0.1 GeV^2 to $\sigma(M_X^2)$.

Benhar, Day, Sick, RMP**80** (2008)

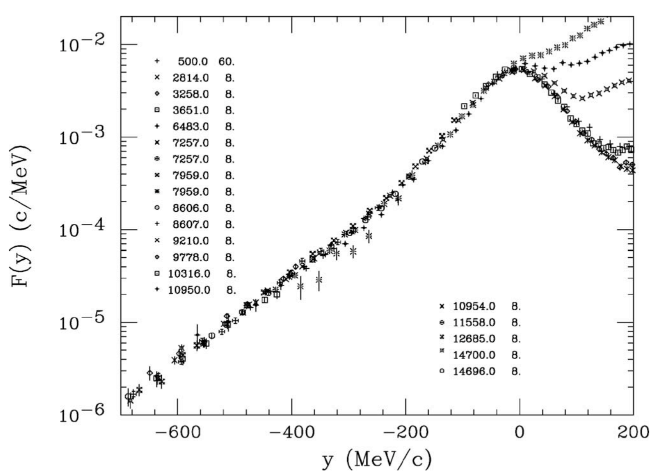
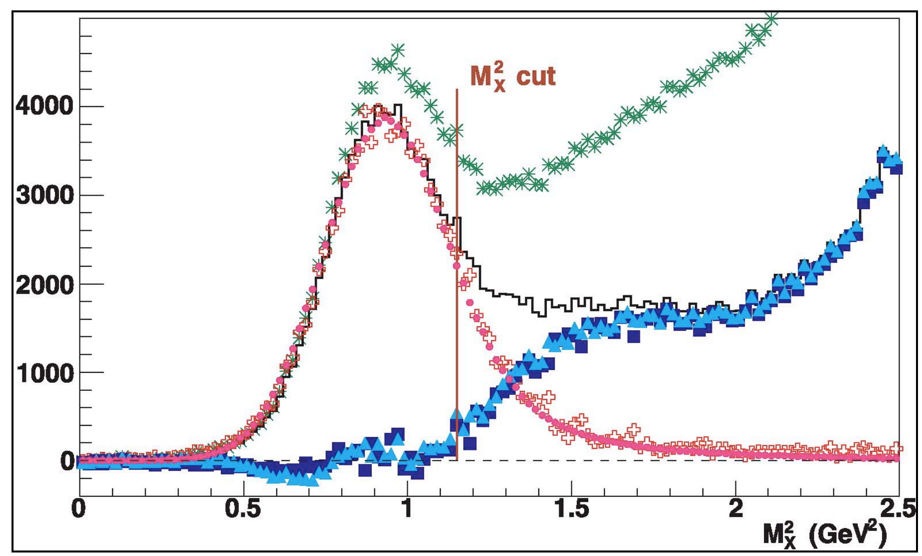


FIG. 19. Scaling function for ^{3}He(e,e'). The various data sets are labeled by electron energy (MeV) and angle (deg).



Neutron DVCS Observables

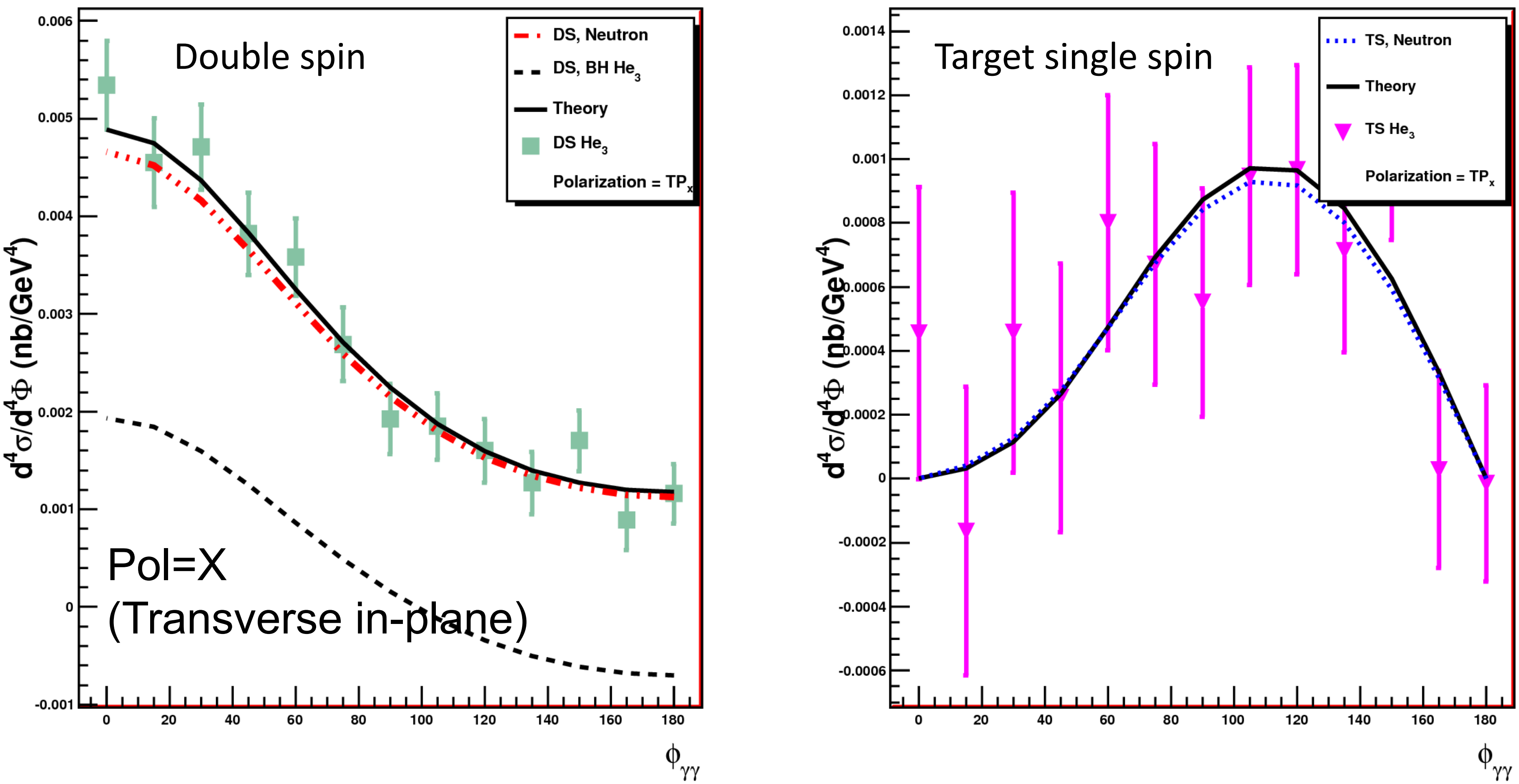
$$d\sigma(\lambda,\Lambda) \text{ for } \vec{n}(\vec{e},e'\gamma)n \text{ via } {}^3\vec{H}e(\vec{e},e\gamma)X$$

λ, Λ = electron, ^{3}He Polarization

- Long or Transverse Normal Polarization
- Target Single Spin Cross Sections
  - $d\sigma_{LSS} = \Sigma_{\lambda\Lambda}\,\Lambda d\sigma(\lambda,\Lambda)/4 \sim \sin\phi_{\gamma\gamma}$
    Im[BH*DVCS] (Twist-2)
    Unpolarized Protons in ^{3}He cancel
- Target Double Spin
  - $d\sigma_{LDS} = \Sigma_{\lambda\Lambda}\,\Lambda\lambda d\sigma(\lambda,\Lambda)/4 \sim c_0 + c_1\cos\phi_{\gamma\gamma}$
    Re[BH^2 + (BH*DVCS) + DVCS^2]
    Unpolarized protons cancel
- Transverse Sideways: $\sin\phi_{\gamma\gamma} \Leftrightarrow \cos\phi_{\gamma\gamma}$
- All other “neutron” observables ($d\sigma$, Beam-spin) have large incoherent proton contributions

$Q^2 = 3.05\ GeV^2$, $x_{Bj}=0.36$, $t_{Min}-t=0.05\ GeV^2$

$\Delta t=0.10 GeV^2$, 16 days @ $3 \bullet 10^{36} \times 60\% \times 80\%$



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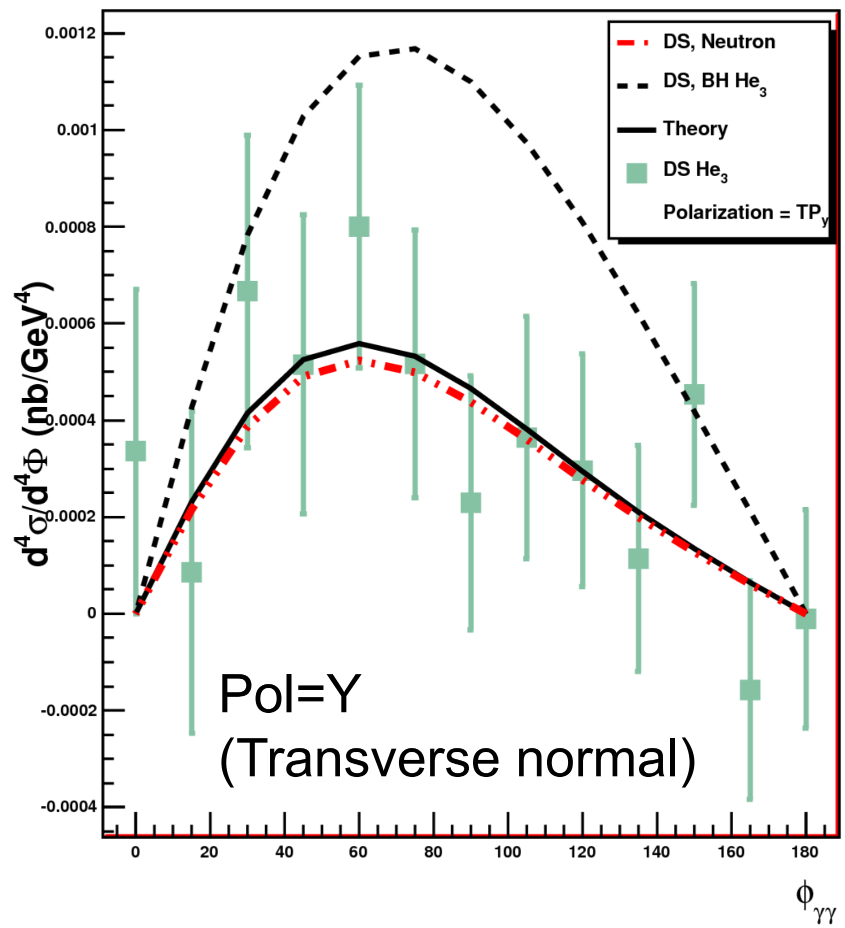
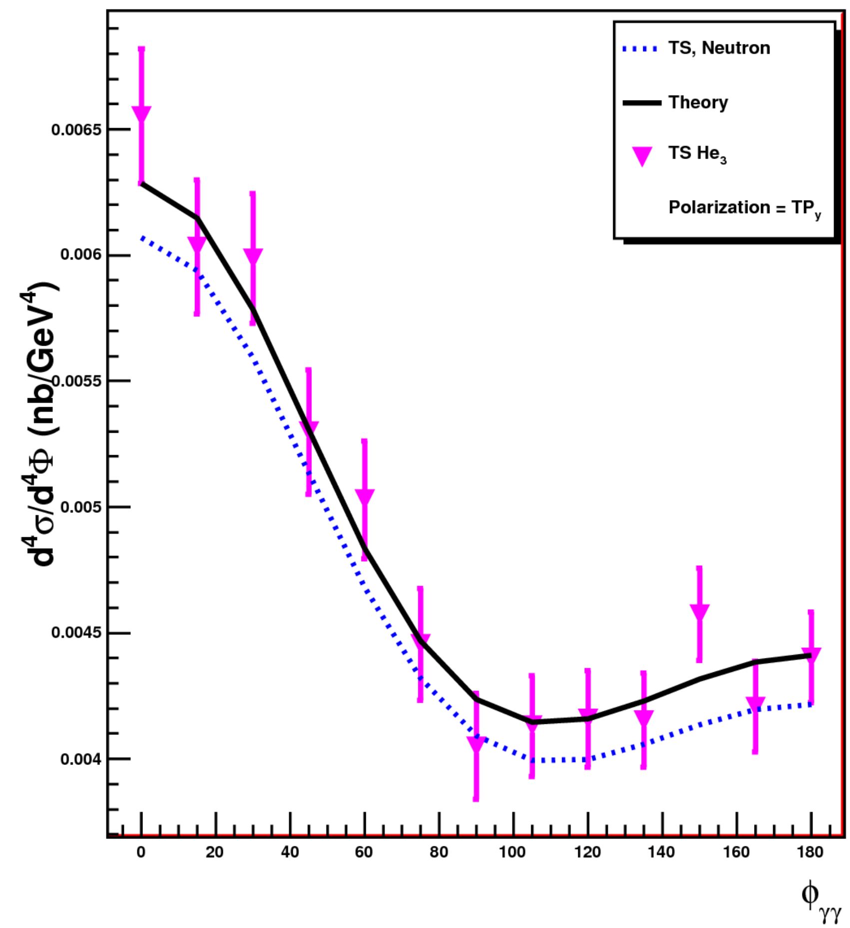
$\Delta t=0.10 GeV^2$, 16 days @ $3\bullet10^{36}\times60\%\times80\%$

Double spin



Target single spin



$Q^2 = 3.05\ GeV^2,\ x_{Bj}=0.36,\ t_{Min}-t=0.05\ GeV^2$

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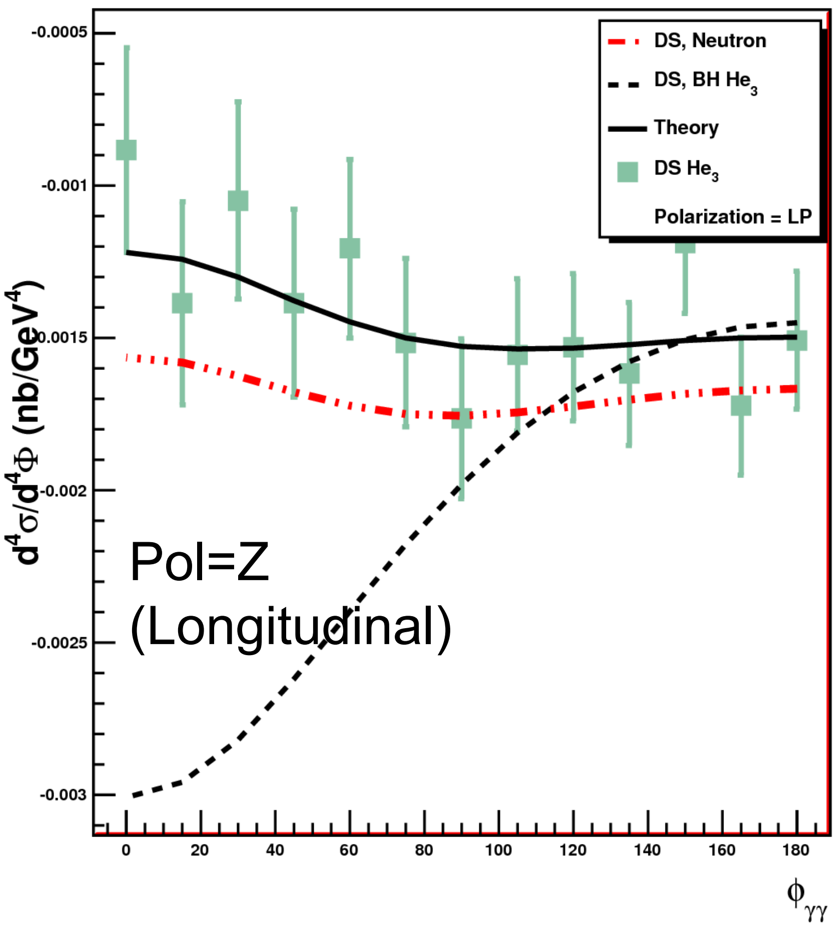
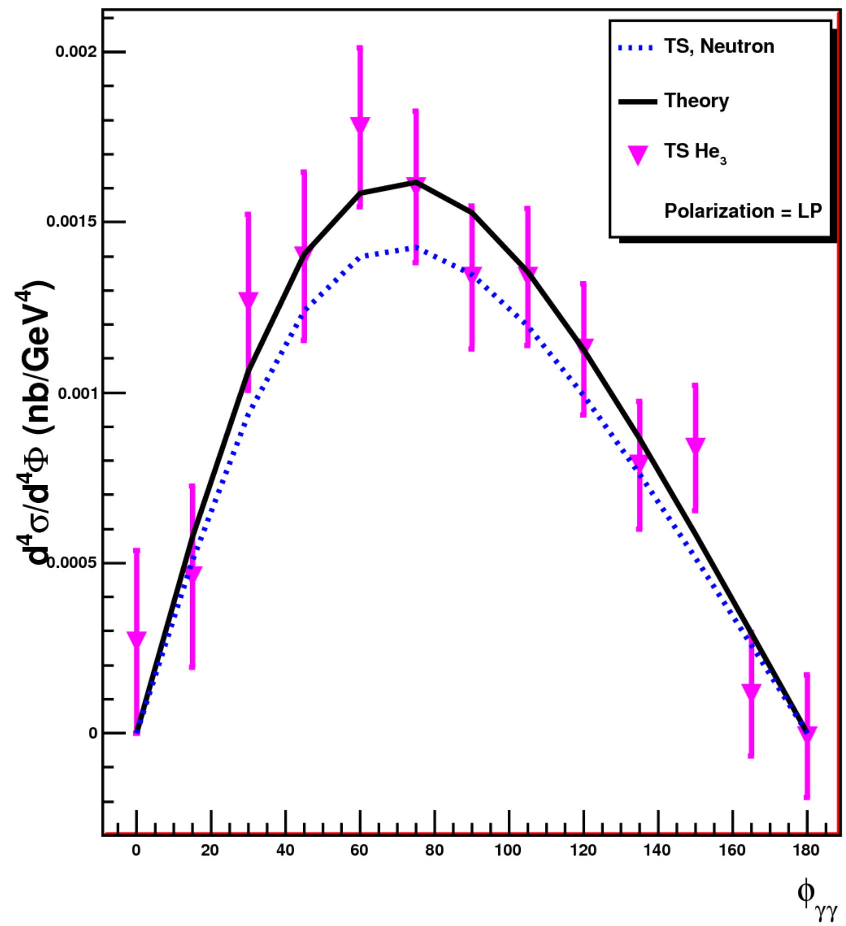
Double spin



Target single spin



Conclusions

- Precision cross section measurements with spectrometers are essential to extracting leading twist amplitudes from the ep→epγ cross section
- The Hall C HMS paired with the DVCS PbF_2 calorimeter (or alternate $PbWO_4$) will allow an extension to measure additional energy points for each x_{Bj} value (at one or two Q^2 values)
  - Separation of all twist-2 and twist-3 contributions to unpolarized cross sections, without positrons.
- A new sweep magnet, and a rad-hard calo will allow extensions to lower x_{Bj} and higher Q^2 (closer to kinematic limits)
- Polarized ^{3}He targets are only present option for transversely polarized 'neutron' target.
  - Measeurment of *$E_n(\xi,\xi,t)$ at 10—15% precision for 16 days per (Q^2,ξ) point.*

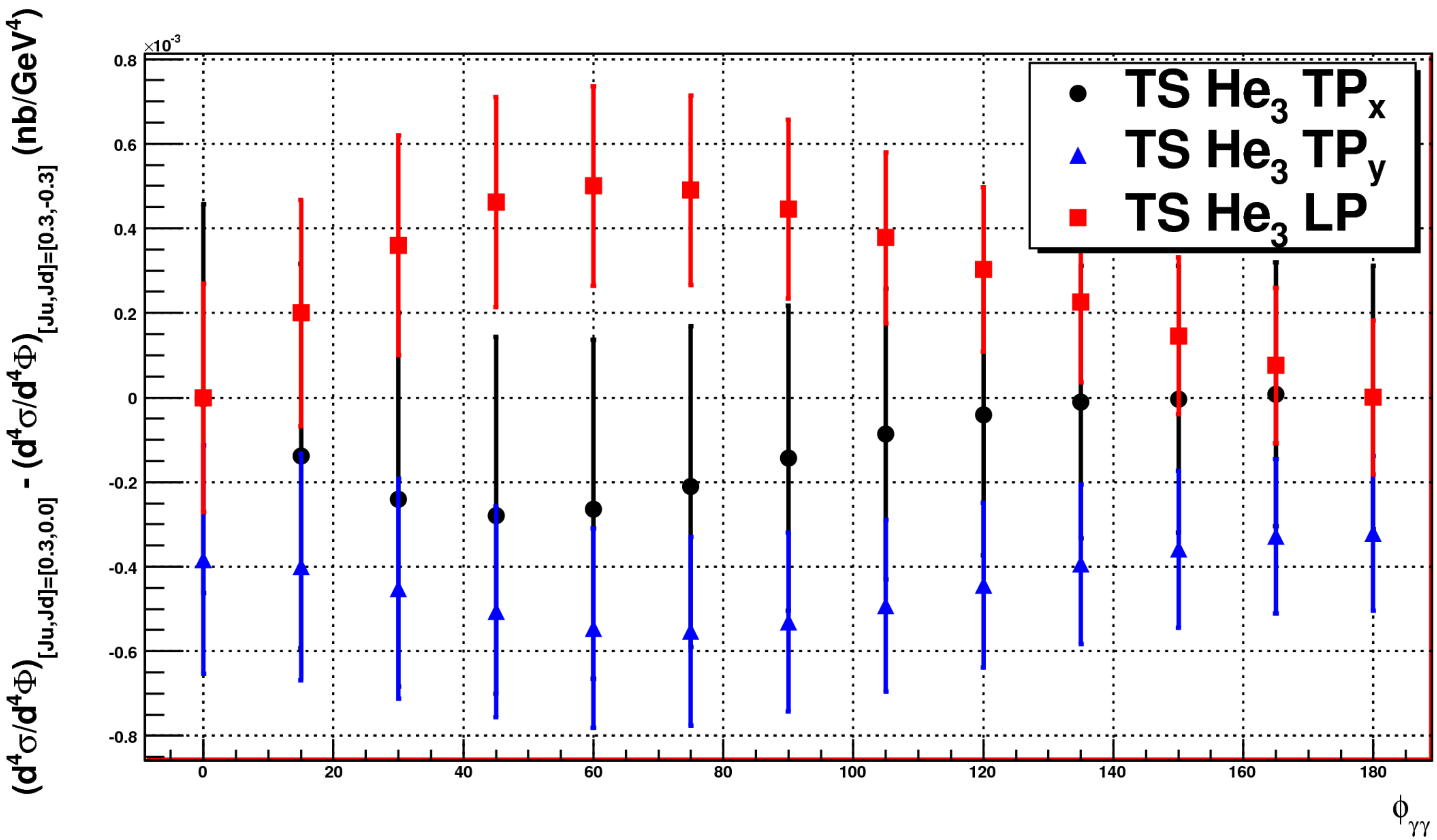
Deep Virtual η-Production

- H*(e,e'η)p*
  - *Detect via* $\eta \rightarrow \gamma\gamma$
  - *Strangeness?*
  - *Axial anomaly?*
- Requires a much larger calorimeter
  - $\gamma\gamma$ cone half-angle ≈ 4× larger for η than π^0
  - Roughly ± 100 mrad at $Q^2=4.0$ GeV^2, $x_{Bj} = 0.36$

Q^2 = 3.05 GeV^2, x_{Bj}=0.36, t_{Min}–t=0.05 GeV^2

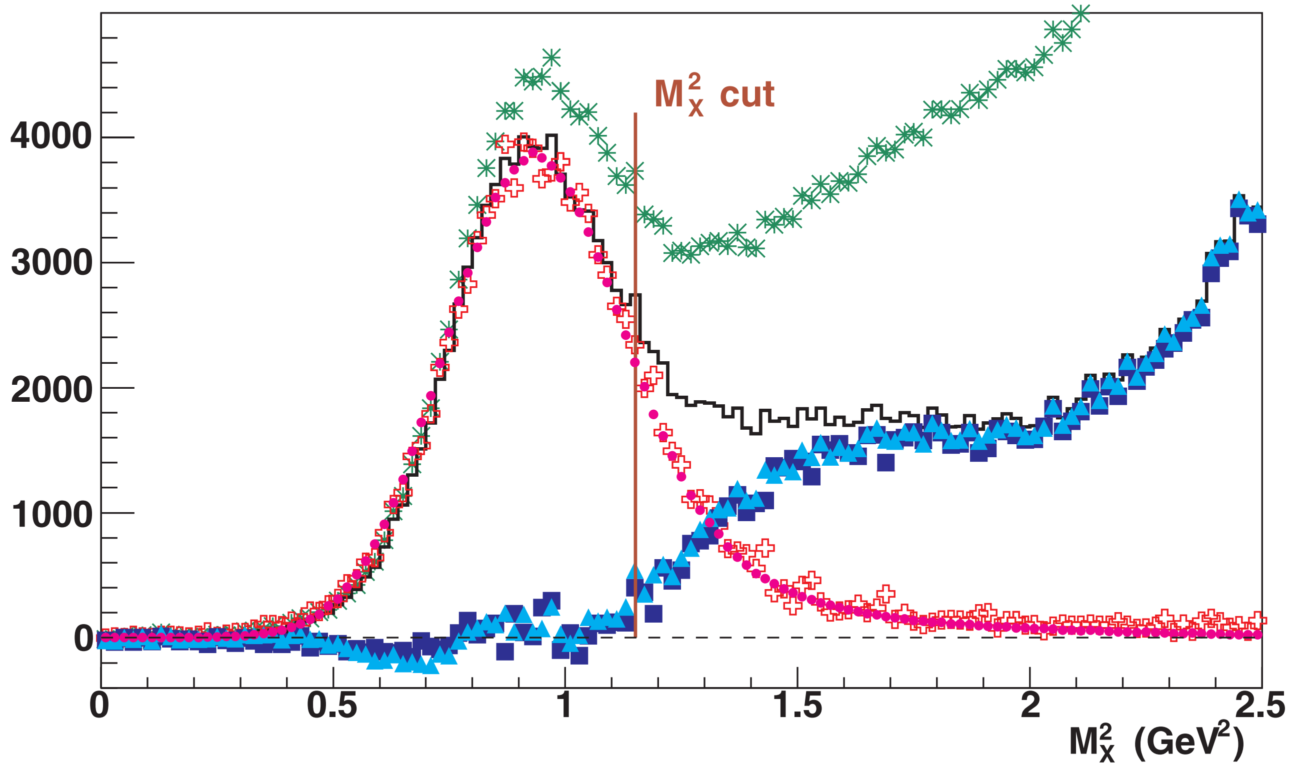
Δt=0.10GeV^2, 16 days @ 3•10^{36}×60%×80%

One-σ sensitivity $\Delta(J_u,J_d)$ = 0.06 (parameters of *E* in VGG model)

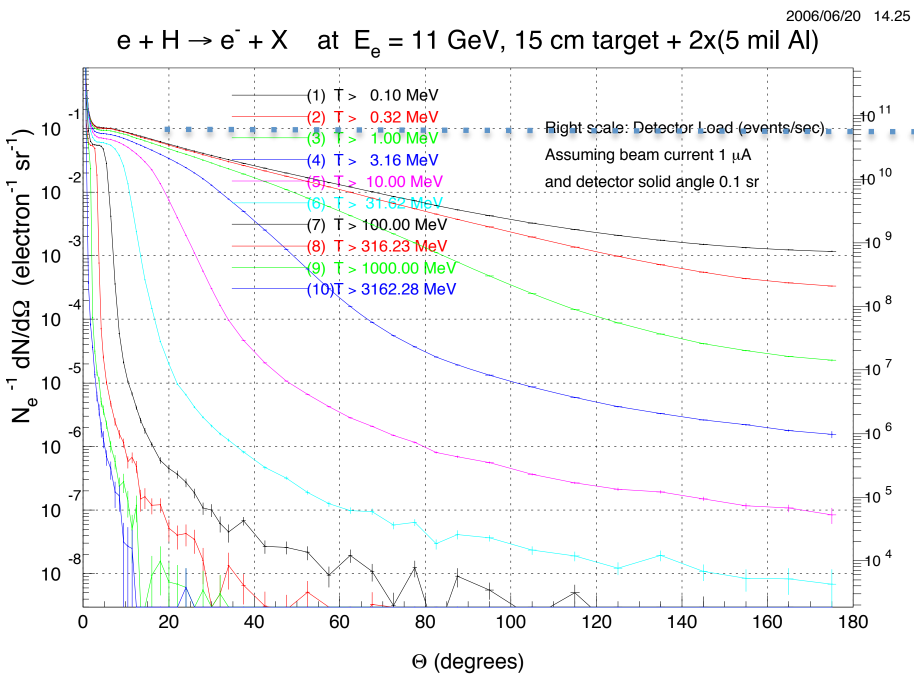


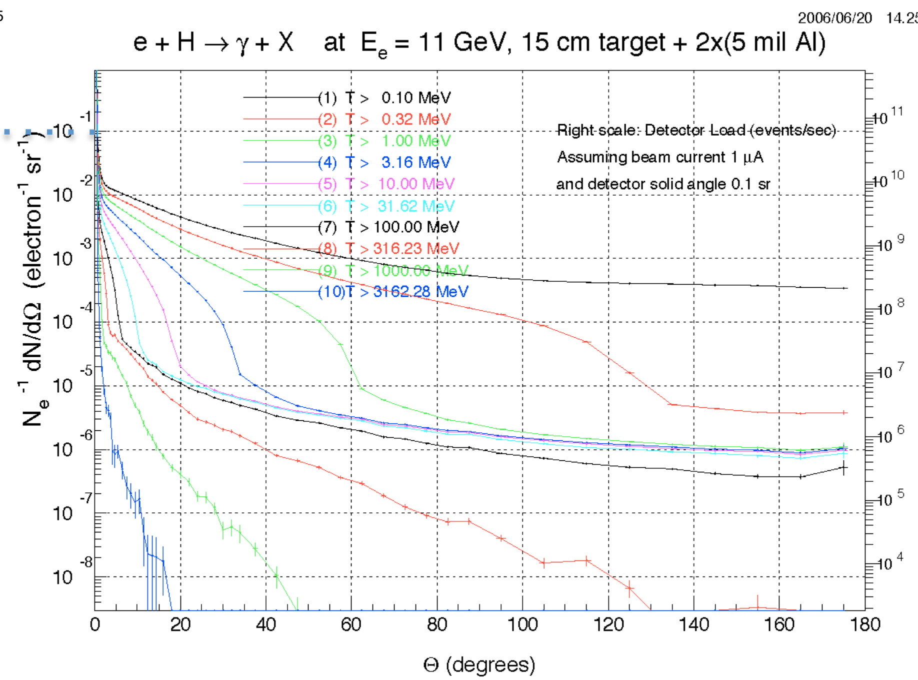
Missing Mass Resolution

- Spectrometer resolution required
  - $\delta p/p \leq 10^{-3}$
  - $\delta\theta \sim 10^{-3}$



Electron and Gamma-ray Backgrounds dominate





- Target dominates background
- Sweeping magnet ➔ Background/10

DVCS Kinematics, Hall A & C

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- Calorimeter centered at θ_q.
  - Require $\theta_q \geq 0.2$ rad to avoid small-angle background