Deeply Virtual Compton Scattering @ JLab

Franck Sabatié
Saclay

On behalf of the Hall A and CLAS collaborations

SPIN'06 - Kyoto
October 6th 2006

From GPDs to DVCS, to GPDs back

Onto the DVCS harmonic structure

E00-110 experiment in Hall A

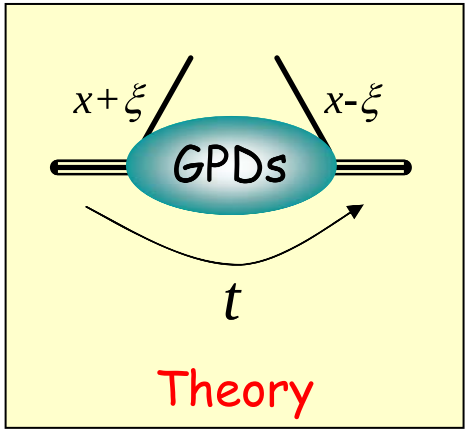
Scaling tests & GPD measurement

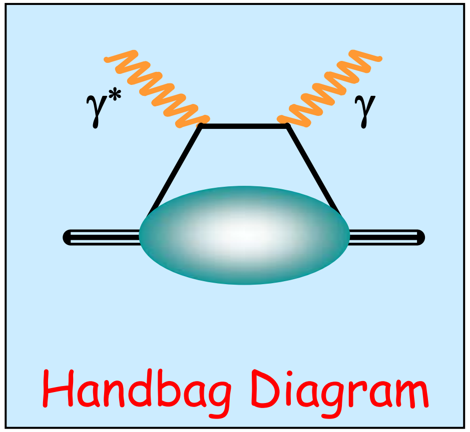
E1-DVCS experiment at CLAS in Hall B

Summary

SPIN 2006
The 17th International Spin Physics Symposium
Kyoto Japan Oct. 2-7 '06

GPDs from Theory to Experiment





2. The GPDs enter the DVCS amplitude as an integral over x:

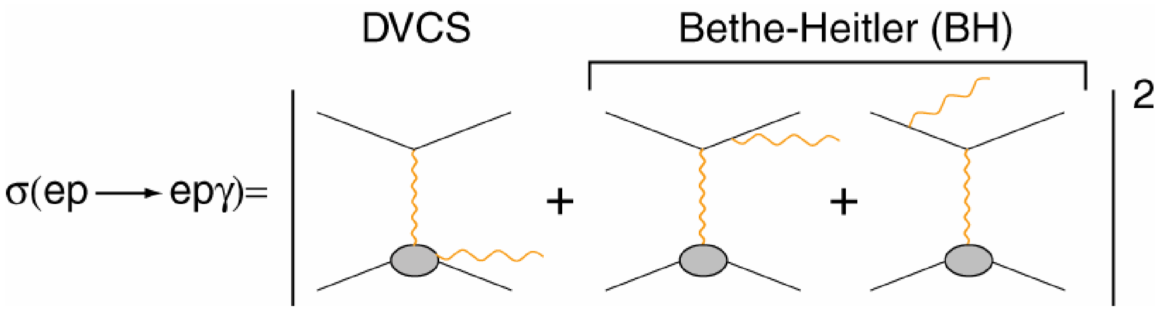
- GPDs appear in the real part through a PP integral over x
- GPDs appear in the imaginary part but at the line x=ξ

$$T^{DVCS} = \int_{-1}^{+1} \frac{GPD(x,\xi,t)}{x-\xi+i\varepsilon} dx \quad + \quad \cdots$$

$$= P\int_{-1}^{+1} \frac{GPD(x,\xi,t)}{x-\xi} dx \quad - \quad i\pi GPD(x=\xi,\xi,t) \quad + \quad \cdots$$

Experimental observables linked to GPDs

3. Experimentally, DVCS is undistinguishable with Bethe-Heitler



However, we know FF at low t and BH is fully calculable

Using a polarized beam on an unpolarized target, 2 observables can be measured:

$$\frac{d^4\sigma}{dx_B dQ^2 dt d\varphi} \approx \left|T^{BH}\right|^2 + 2T^{BH} \cdot \mathrm{Re}\left(T^{DVCS}\right) + \left|T^{DVCS}\right|^2$$

$$\frac{d^4\overrightarrow{\sigma} - d^4\overleftarrow{\sigma}}{dx_B dQ^2 dt d\varphi} \approx 2T^{BH} \cdot \mathrm{Im}\left(T^{DVCS}\right) + \left[\left|\overrightarrow{T^{DVCS}}\right|^2 - \left|\overleftarrow{T^{DVCS}}\right|^2\right]$$

At JLab energies, $|T^{DVCS}|^2$ should be small

Kroll, Guichon, Diehl, Pire, …

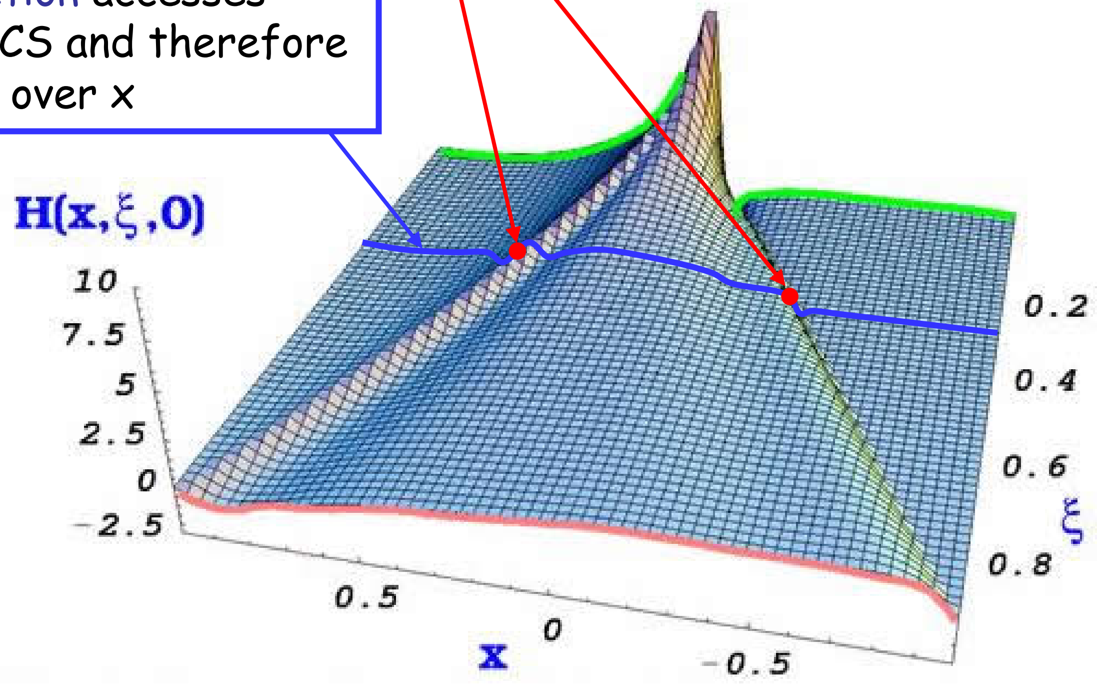
Observables and their relationship to GPDs

$$T^{DVCS} = \int_{-1}^{+1} \frac{GPD(x,\xi,t)}{x-\xi+i\varepsilon}dx \quad + \quad \cdots$$

The cross-section difference accesses the imaginary part of DVCS and therefore GPDs at $x = \xi$

$$= P\int_{-1}^{+1} \frac{GPD(x,\xi,t)}{x-\xi}dx \quad - \quad i\pi GPD(x=\xi,\xi,t) \quad + \quad \cdots$$

The total cross-section accesses the real part of DVCS and therefore an integral of GPDs over x



Into the harmonic structure of DVCS

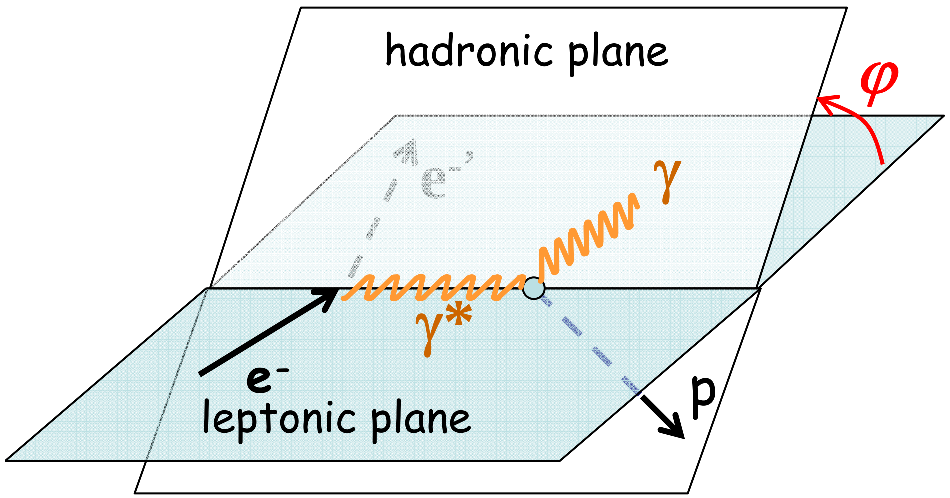
$$\frac{d^4\sigma}{dx_B dQ^2 dt d\varphi} = \frac{1}{P_1(\varphi)P_2(\varphi)}\Gamma_1(x_B,Q^2,t)\left\{c_0^{BH} + c_1^{BH}\cos\varphi + c_2^{BH}\cos 2\varphi\right\}$$

$|T^{BH}|^2$

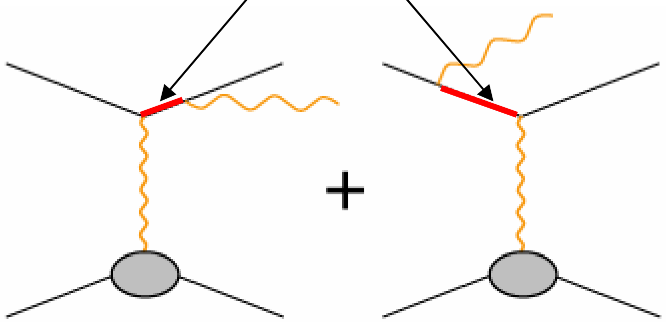
$$+\frac{1}{P_1(\varphi)P_2(\varphi)}\Gamma_2(x_B,Q^2,t)\left\{c_0^I + c_1^I\cos\varphi + c_2^I\cos 2\varphi + c_3^I\cos 3\varphi\right\}$$

$$\frac{d^4\overrightarrow{\sigma} - d^4\overleftarrow{\sigma}}{dx_B dQ^2 dt d\varphi} = \frac{\Gamma(x_B,Q^2,t)}{P_1(\varphi)P_2(\varphi)}\left\{s_1^I \sin\varphi + s_2^I \sin 2\varphi\right\}$$

Interference term



$$\frac{1}{P_1(\varphi)P_2(\varphi)}$$



BH propagators φ dependence

Belitsky, Mueller, Kirchner

Tests of scaling

$$\frac{d^4\sigma}{dx_B dQ^2 dt d\varphi} = \frac{1}{\mathrm{P}_1(\varphi)\mathrm{P}_2(\varphi)}\Gamma_1(x_B, Q^2, t)\left\{c_0^{BH} + c_1^{BH}\cos\varphi + c_2^{BH}\cos 2\varphi\right\}$$

$$+\frac{1}{\mathrm{P}_1(\varphi)\mathrm{P}_2(\varphi)}\Gamma_2(x_B, Q^2, t)\left\{\boxed{c_0^I + c_1^I\cos\varphi} + c_2^I\cos 2\varphi + c_3^I\cos 3\varphi\right\}$$

$$\frac{d^4\overrightarrow{\sigma} - d^4\overleftarrow{\sigma}}{dx_B dQ^2 dt d\varphi} = \frac{\Gamma(x_B, Q^2, t)}{\mathrm{P}_1(\varphi)\mathrm{P}_2(\varphi)}\left\{\boxed{s_1^I\sin\varphi} + s_2^I\sin 2\varphi\right\}$$

1. Twist-2 terms should dominate σ and $\Delta\sigma$
2. All coefficients have Q^2 dependence which can be tested!

Analysis – Extraction of observables

Re-stating the problem (difference of cross-section):

$$\frac{d^4\overrightarrow{\sigma} - d^4\overleftarrow{\sigma}}{dx_B dQ^2 dt d\varphi} = \frac{\Gamma(x_B, Q^2, t)}{\mathrm{P}_1(\varphi)\mathrm{P}_2(\varphi)}\left\{s_1^I \sin\varphi + s_2^I \sin 2\varphi\right\}$$

$$s_1^I = 8Ky(2-y)\,\mathrm{Im}\,C^I(F)$$

What we measure

$$C^I(F) = F_1\mathrm{H} + \frac{x_B}{2-x_B}(F_1+F_2)\tilde{\mathrm{H}} - \frac{t}{4M^2}F_2\mathrm{E}$$

$$\mathrm{Im}\,\mathrm{H} = \pi\sum_q e_q^2\left\{H^q(\xi,\xi,t) - H^q(-\xi,\xi,t)\right\}$$

GPD !!!

Special case of the asymmetry

The asymmetry can be written as:

$$\frac{d^4\overset{\rightarrow}{\sigma} - d^4\overset{\leftarrow}{\sigma}}{d^4\overset{\rightarrow}{\sigma} + d^4\overset{\leftarrow}{\sigma}} = \Gamma_A(x_B, Q^2, t)\frac{s_1^I \sin\varphi + s_2^I \sin 2\varphi}{c_0^I + c_0^{BH} + (c_1^I + c_1^{BH})\cos\varphi + \ldots}$$

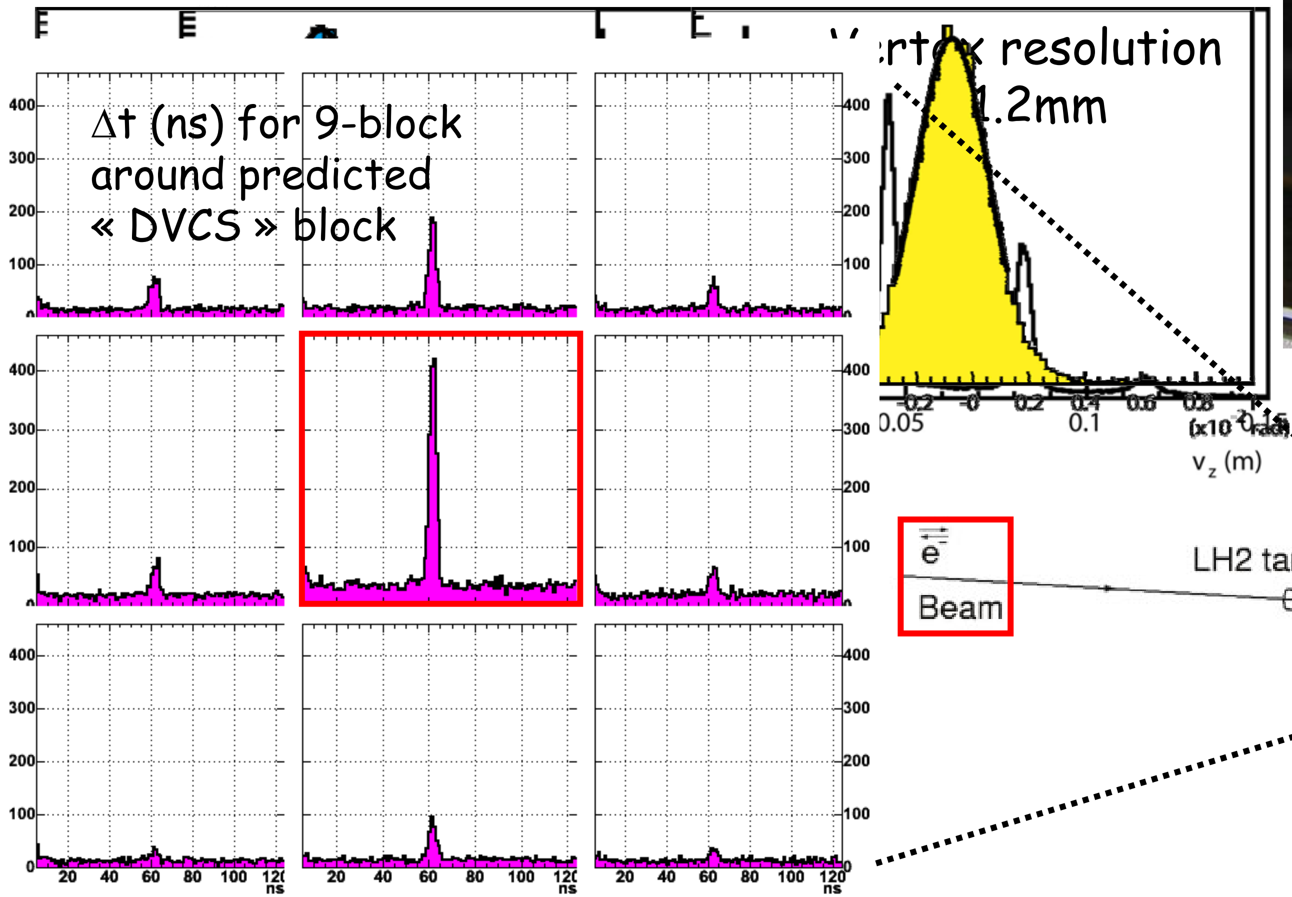
Pros: easier experimentally, smaller RC

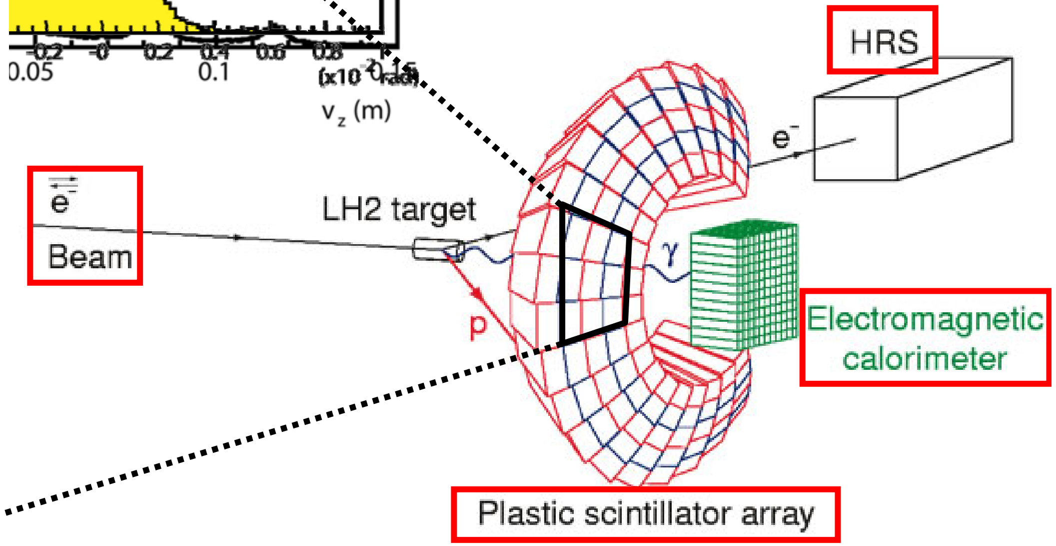
Cons: - extraction of GPDs model-dependent
(denominator complicated and not well known)
- Large effects of the BH propagators in the denominator

Asymmetries are largely used in CLAS and HERMES measurements, where acceptance and systematics are more difficult to estimate.

E00-110 experimental setup and performances

- 75% polarized 2.5uA electron beam
- 15cm LH2 target
- Left Hall A HRS with electron package
- 11x12 block PbF2 electromagnetic calorimeter
- 5x20 block plastic scintillator array

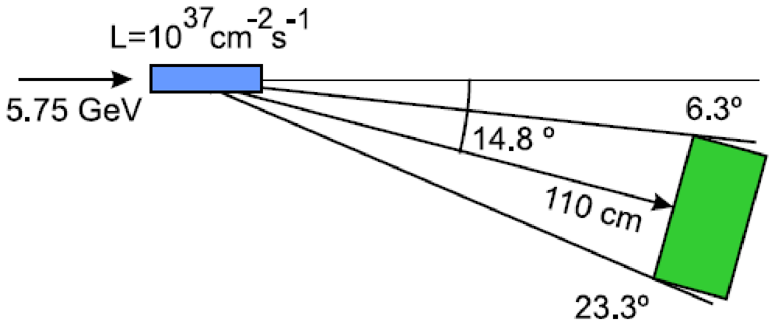




E00-110 kinematics

Kin	Q^2 (GeV^2)	x_B	θ_{γ^*} (deg.)	W (GeV)
1	**1.5**	0.36	**22.3**	1.9
2	**1.9**	0.36	**18.3**	2.0
3	**2.3**	0.36	**14.8**	2.2

The calorimeter is centered on the virtual photon direction



50 days of beam time in the fall 2004, at 2.5μA intensity

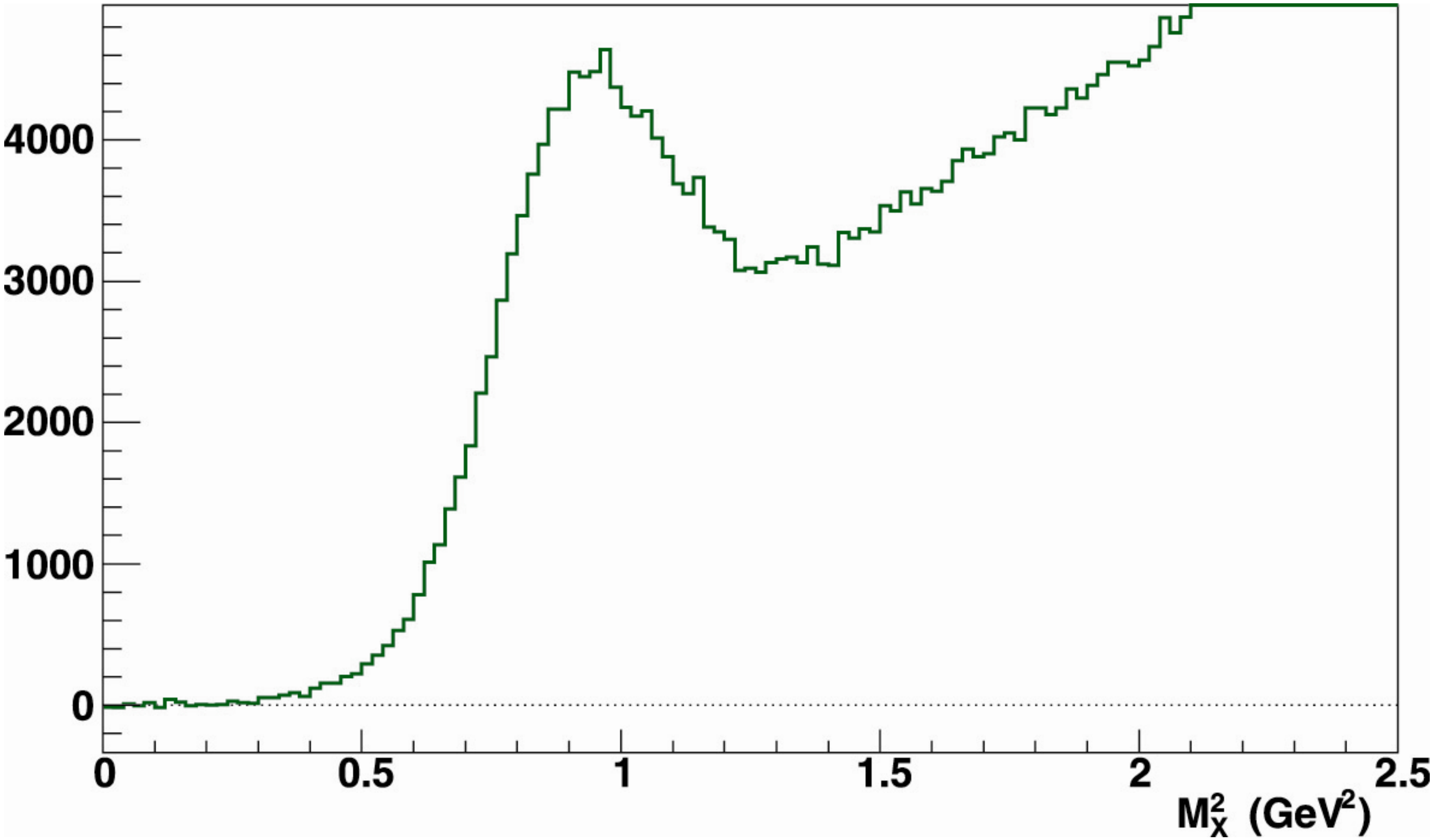
$$\int Lu \cdot dt = 13294 \text{ fb}^{-1}$$

Analysis – Looking for DVCS events

<u>HRS</u>: Cerenkov, vertex, flat-acceptance cut with R-functions

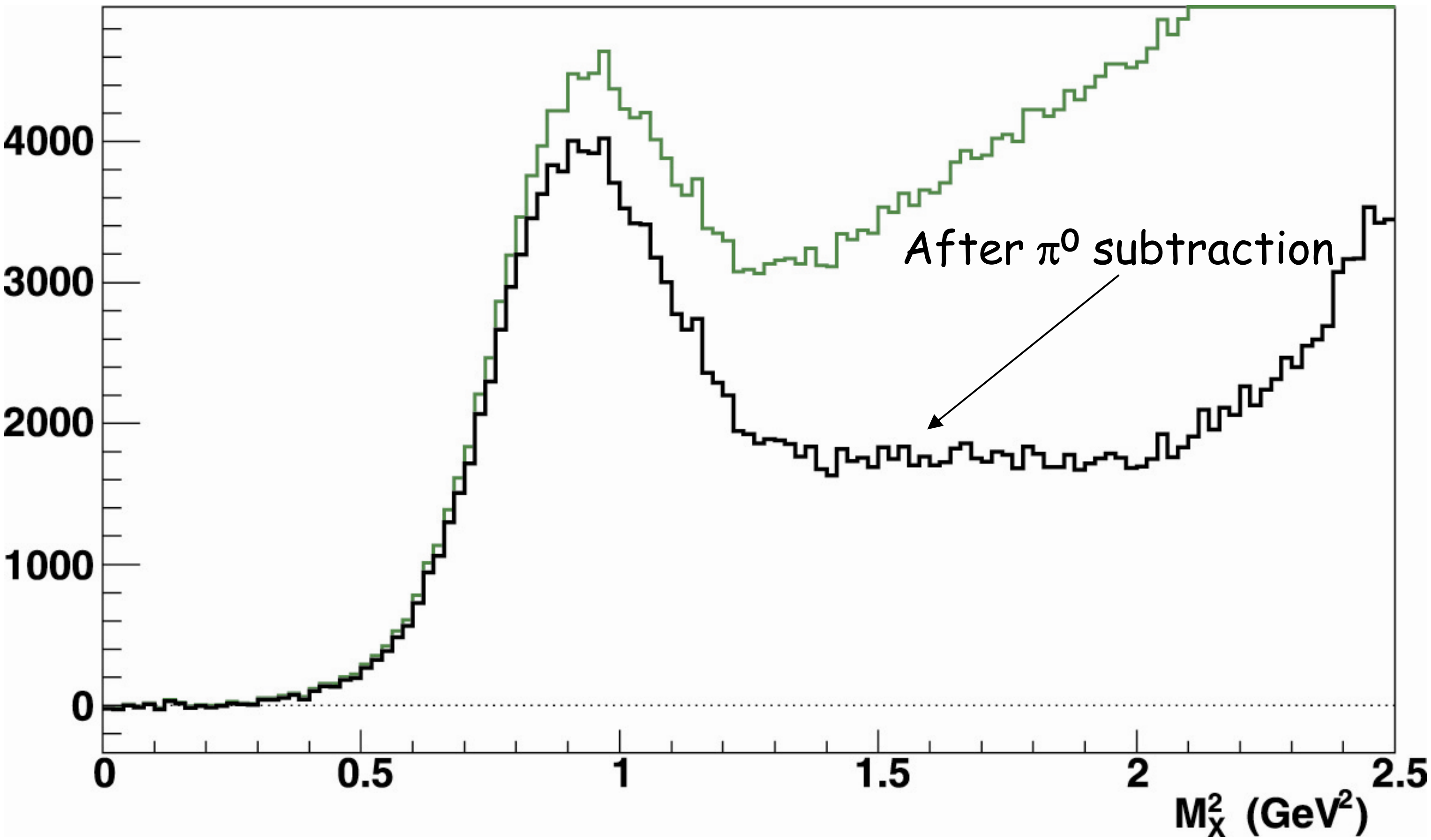
<u>Calo</u>: 1 cluster in coincidence in the calorimeter above 1 GeV

<u>With both</u>: subtract accidentals, build missing mass of (e,γ) system



Analysis – π^o subtraction effect on missing mass spectrum

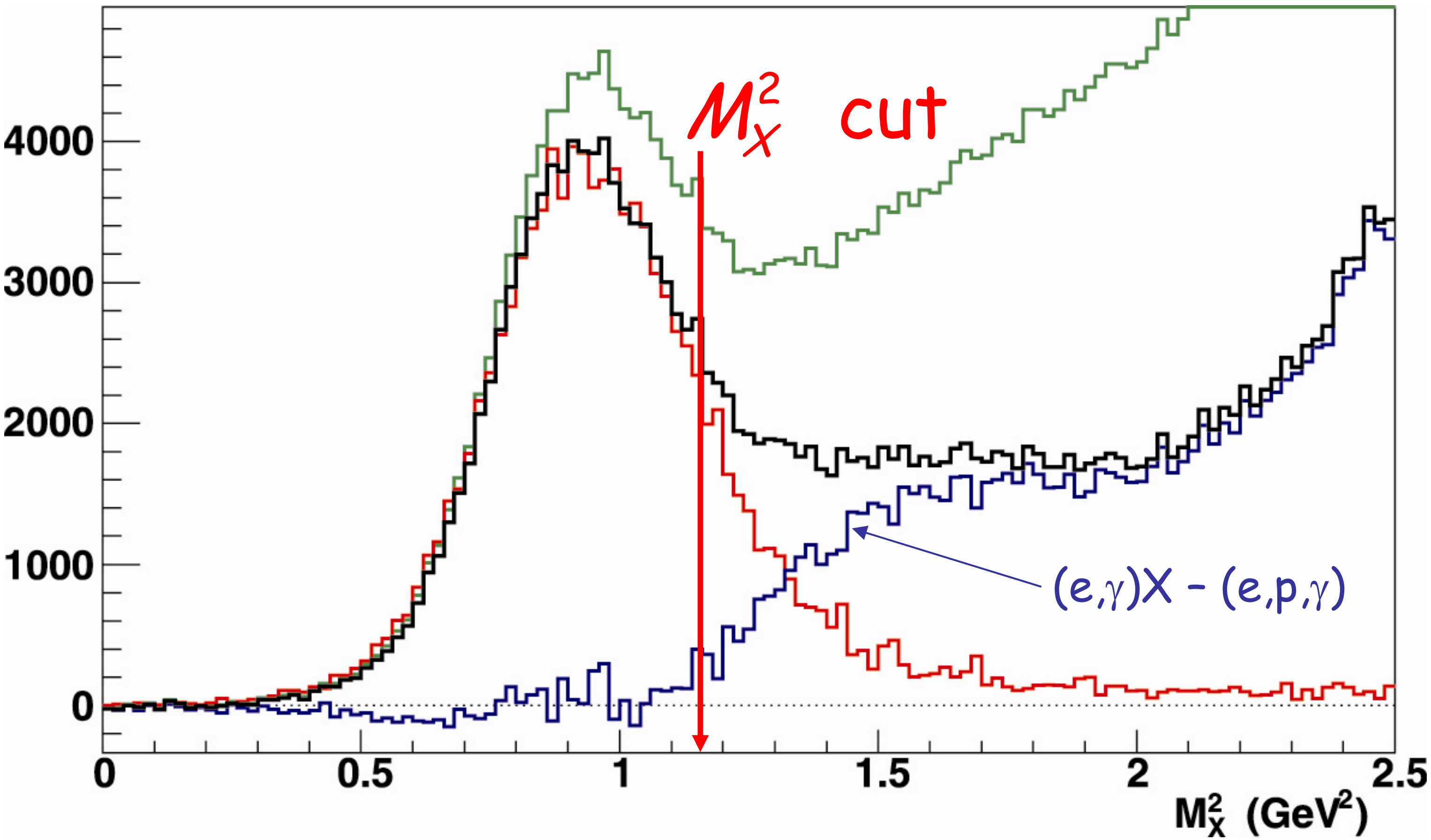
Using $\pi^0 \rightarrow 2\gamma$ events in the calorimeter, the π^0 contribution is subtracted bin by bin



Analysis – Exclusivity check using Proton Array and MC

Using Proton-Array, we compare the missing mass spectrum of the triple and double-coincidence events.

The missing mass spectrum using the Monte-Carlo gives the same position and width. Using the cut shown on the Fig.,the contamination from inelastic channels is estimated to be under 3%.



Analysis – Extraction of observables

$$\sigma^{\rightarrow} - \sigma^{\leftarrow} = \Gamma_1^{\Im}(x_B, Q^2, t, \varphi)\ \Im\mathrm{m}[\mathcal{C}^{\mathcal{I}}(\xi, t)]\ \sin\varphi +$$
$$\Gamma_2^{\Im}(x_B, Q^2, t, \varphi)\ \Im\mathrm{m}[\mathcal{C}^{\mathcal{I}}_{eff}(\xi, t)]\ \sin 2\varphi$$

$$\xi = \frac{x_B}{2 - x_B}$$ (Up to twist-3)

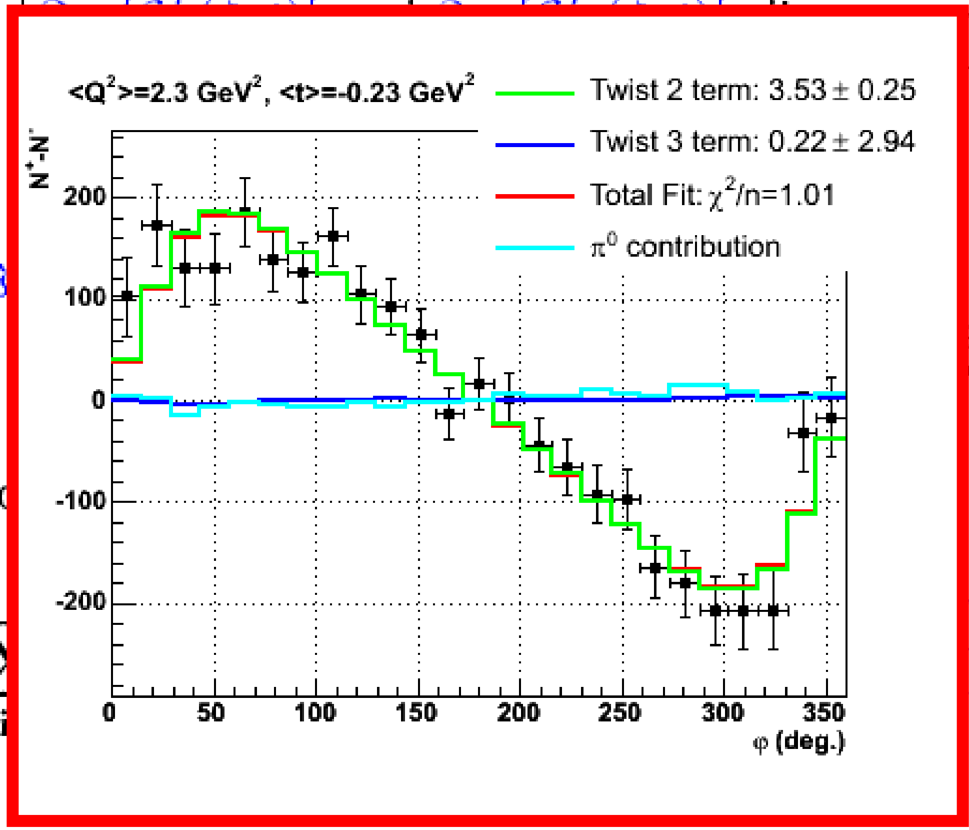
mbinations of GPDs

$$N^{\mathrm{Exp}}(\mathbf{i}_e) = N^{+}_{\mathbf{i}_e}$$

$$N^{\mathrm{MC}}(\mathbf{i}_e) = \mathcal{L}\Big[\ \Im \quad \underbrace{\in \mathbf{i}_e \quad \Gamma_2^{\Im} \cdot \sin 2\varphi \otimes \mathrm{Acc.}}_{\text{MC sampling}}\Big]$$

- MC incluc and internal).

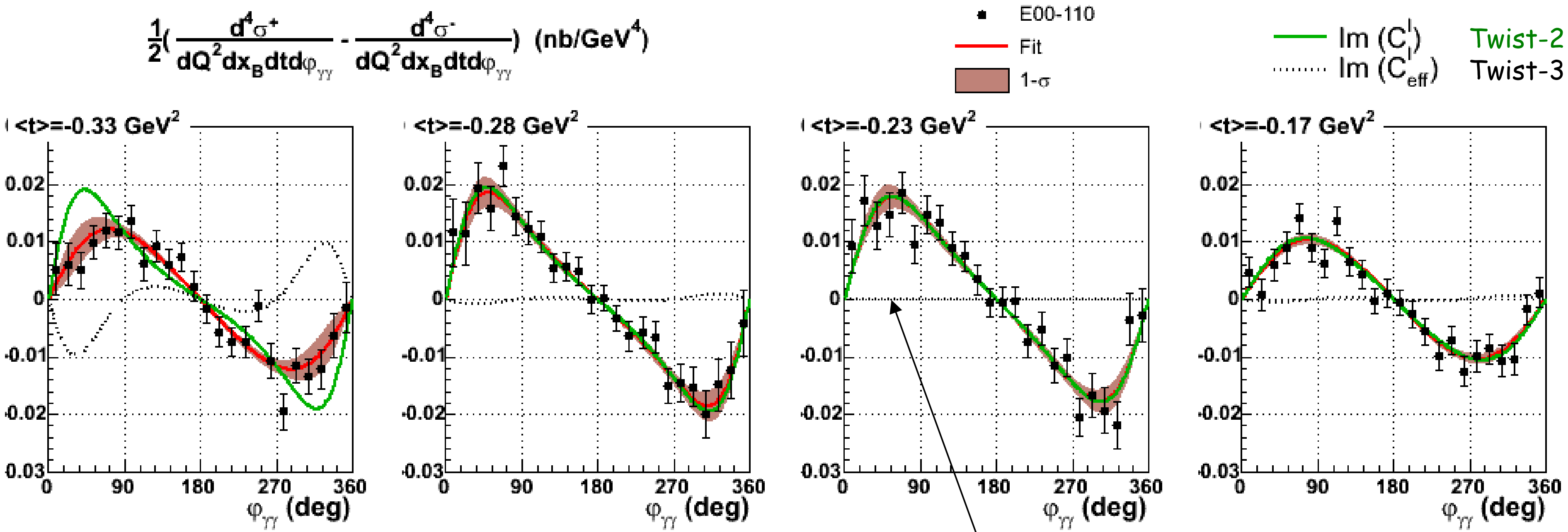
$$\chi^2 = \sum_{\mathbf{i}} \quad (\xi, t)]\rangle \quad (\xi, t)]\rangle$$



Difference of cross-sections

$$\langle Q^2 \rangle = 2.3\ \mathrm{GeV}^2$$

$$\langle x_B \rangle = 0.36$$

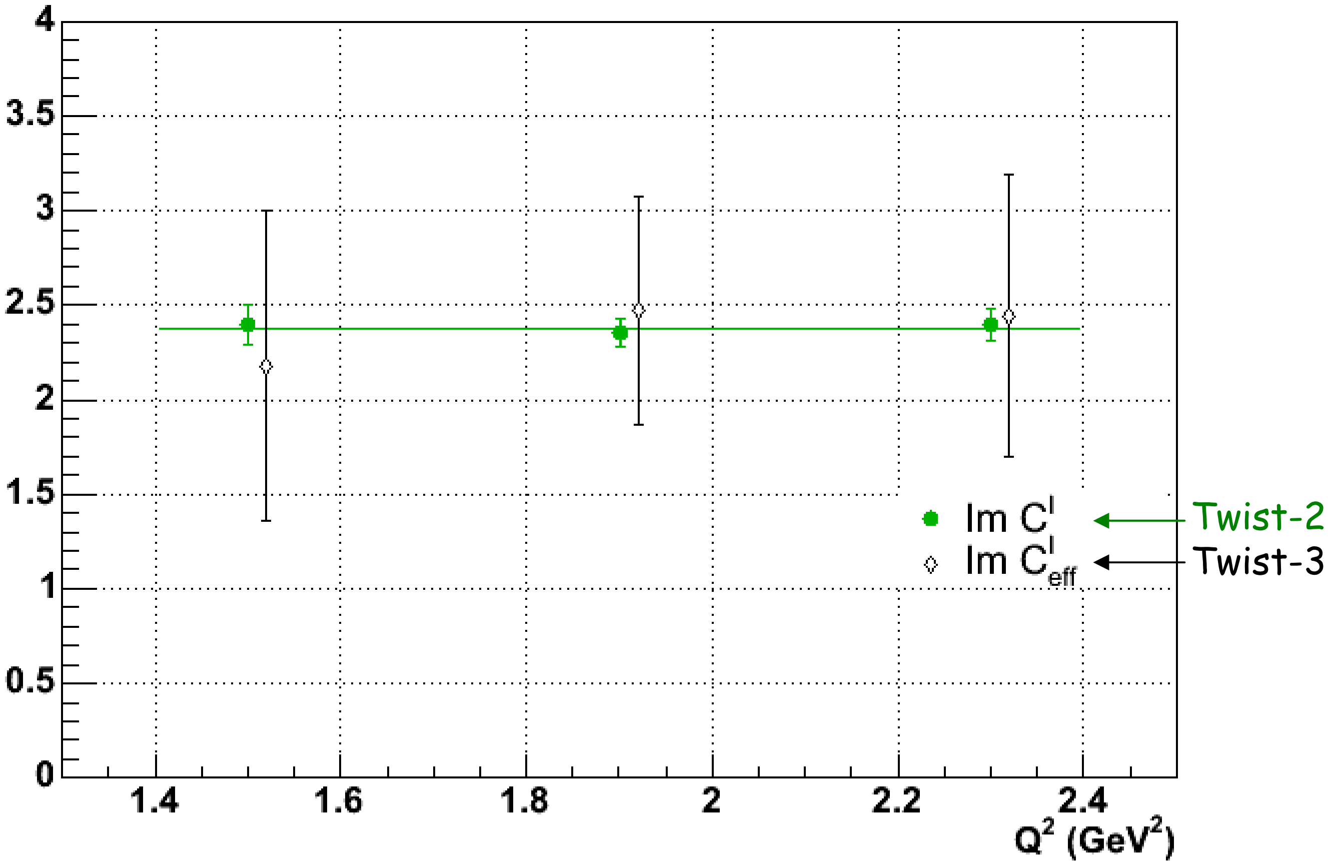


Corrected for real+virtual RC
Corrected for efficiency
Corrected for acceptance
Corrected for resolution effects

Extracted Twist-3
contribution small !

Q^2 dependence and test of scaling

$\langle -t \rangle = 0.26$ GeV^2, $\langle x_B \rangle = 0.36$



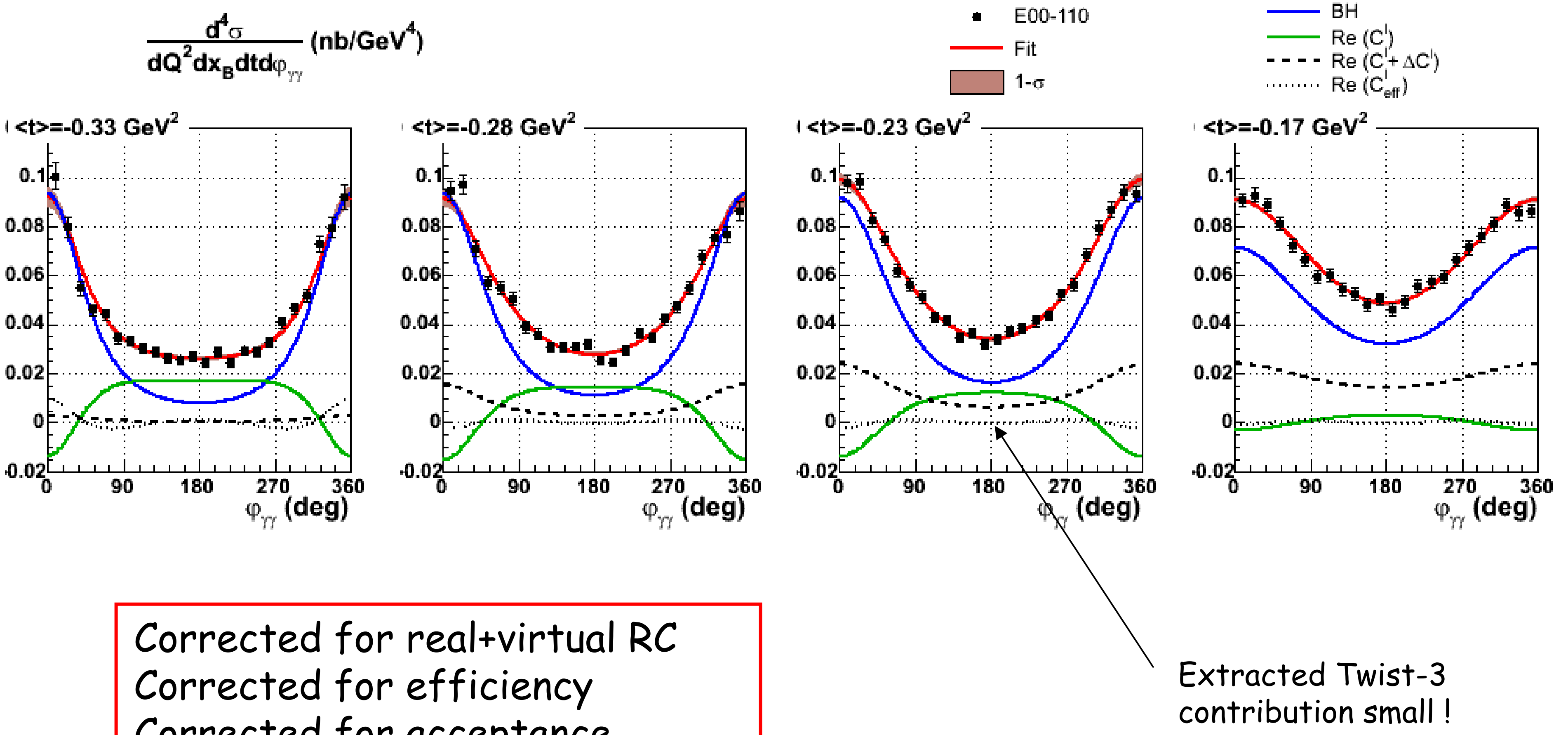
No Q^2 dependence: strong indication for scaling behavior and handbag dominance

Twist 4+ contributions are smaller than 10%

Total cross-section

$$\langle Q^2 \rangle = 2.3\ \mathrm{GeV}^2$$

$$\langle x_B \rangle = 0.36$$

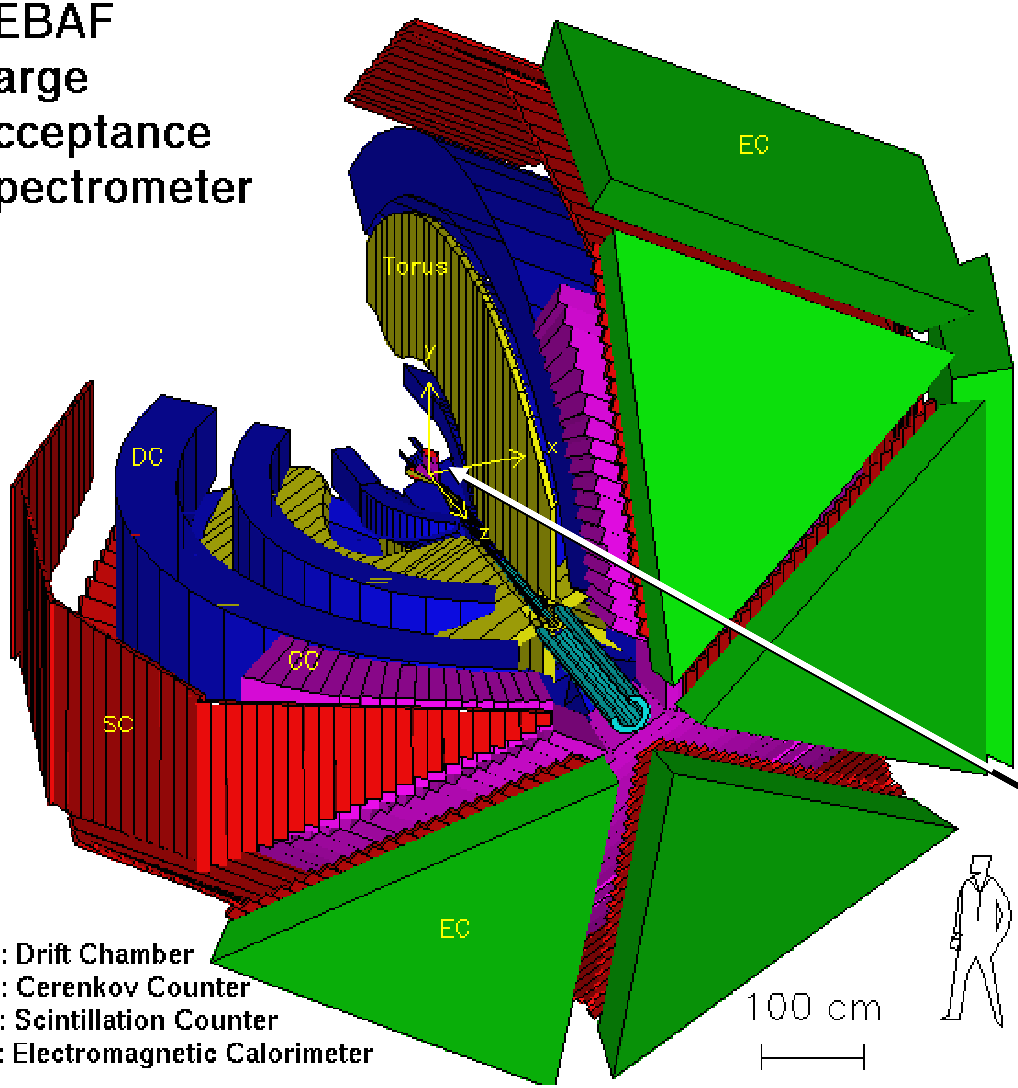


Corrected for real+virtual RC
Corrected for efficiency
Corrected for acceptance
Corrected for resolution effects

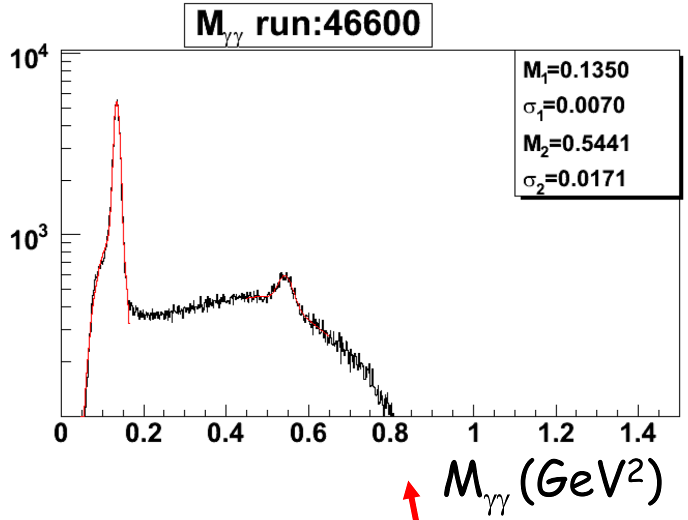
E1-DVCS @ CLAS : a dedicated DVCS experiment

Beam Polarization: 75-85%
Integ. Luminosity: 45 fb^{-1}

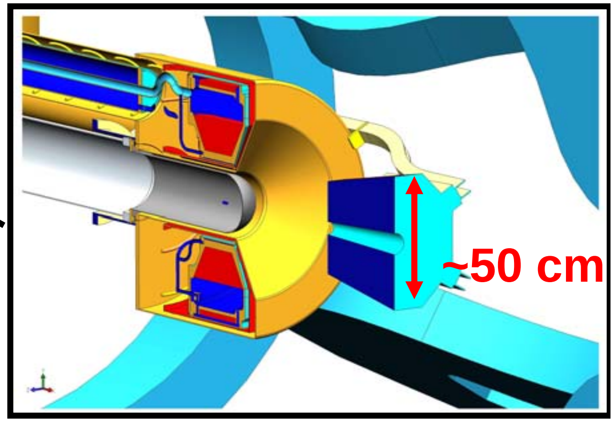
CEBAF
Large
Acceptance
Spectrometer



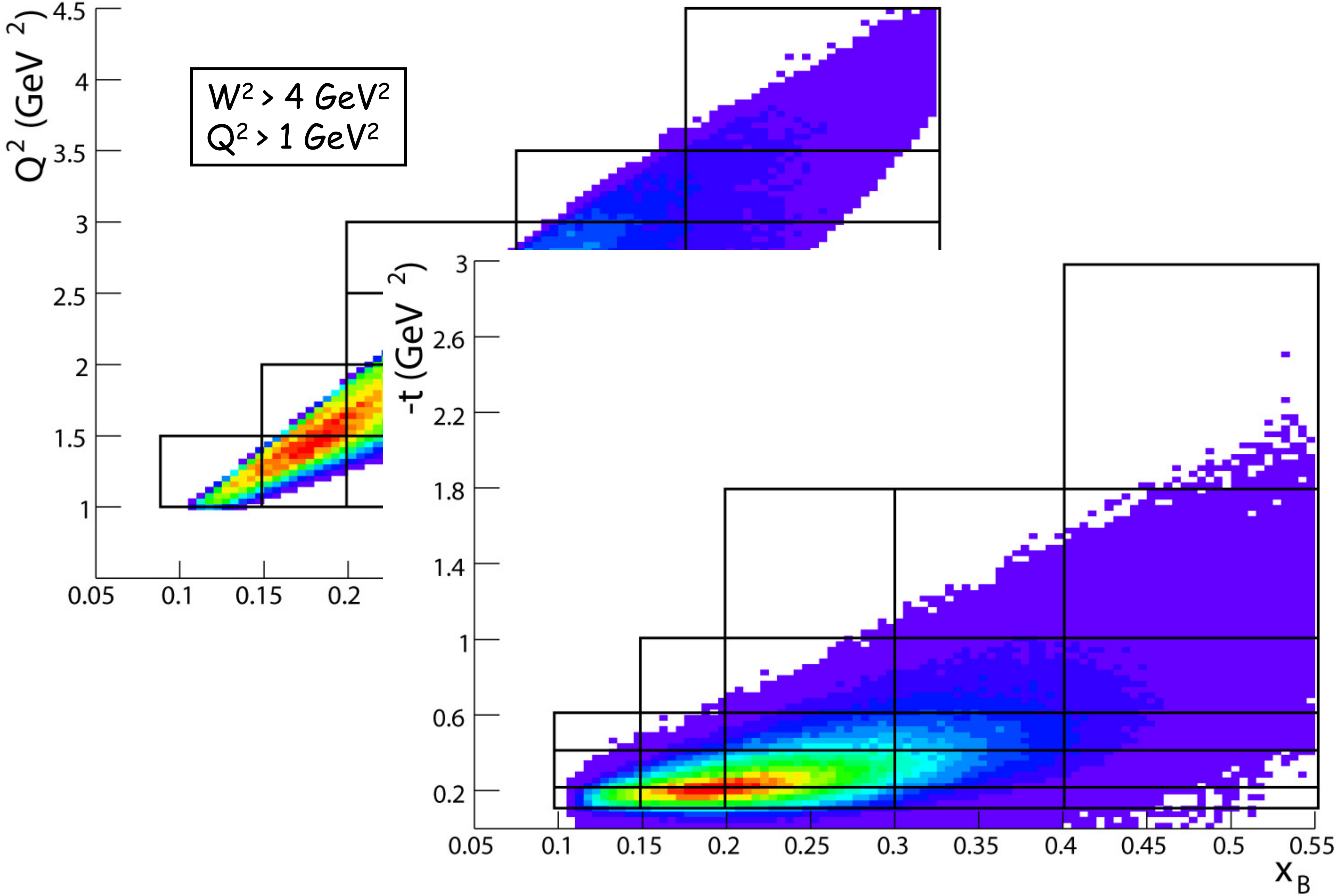
DC: Drift Chamber
CC: Cerenkov Counter
SC: Scintillation Counter
EC: Electromagnetic Calorimeter



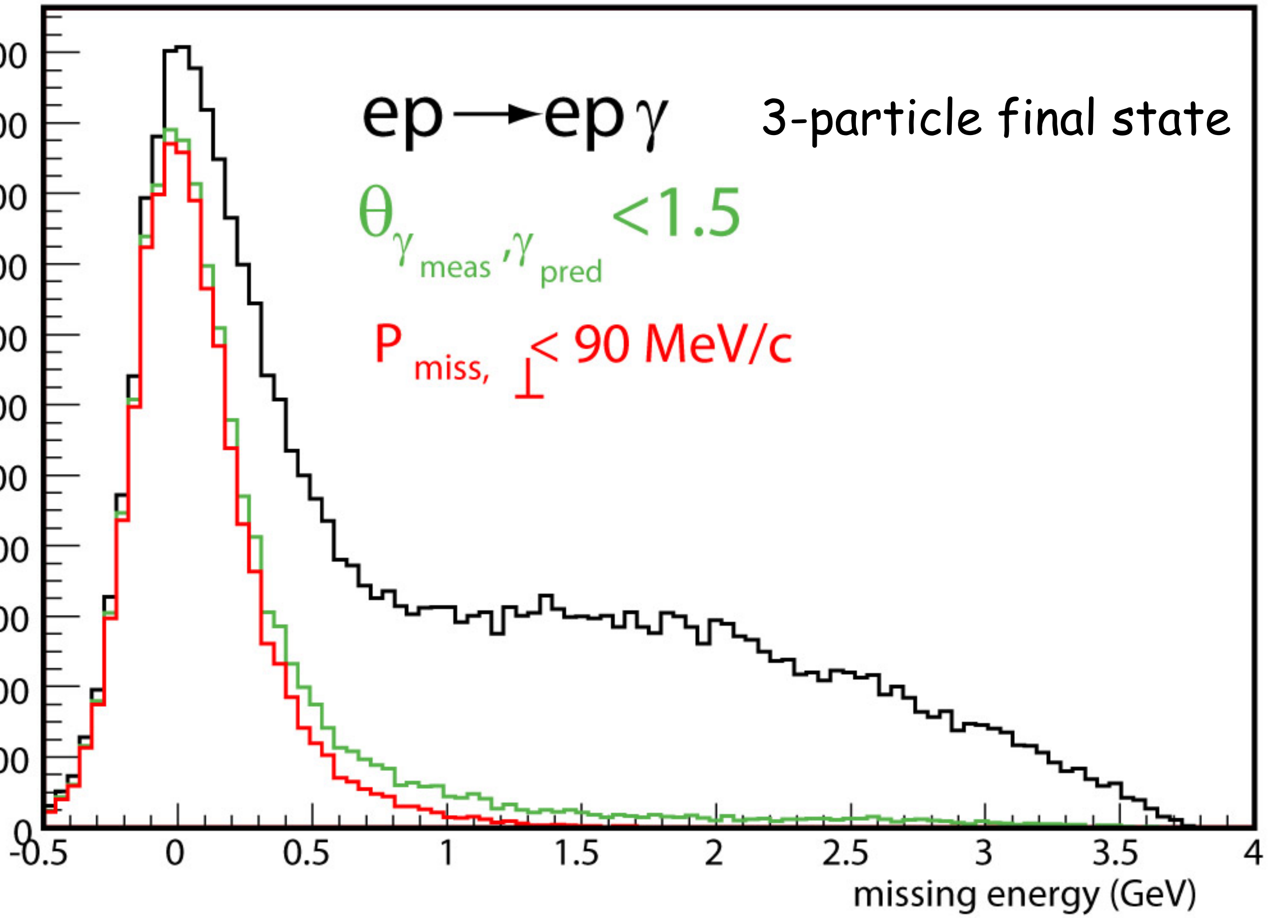
Inner Calorimeter
+ Moller shielding solenoid



E1-DVCS kinematical coverage and binning



E1-DVCS exclusive DVCS selection



Remaining π^0 contamination up to 20%, subtracted bin by bin
using p0 events and MC estimation of $\pi^0(1\gamma)$ to $\pi^0\ (2\gamma)$ acceptance ratio

CLAS results were very preliminary
and cannot be put on the web.

Summary

<u>Cross-section difference (Hall A):</u>

- High statistics test of scaling: Strong support for twist-2 dominance

- First model-independent extraction of GPD linear combination from DVCS data in the twist-3 approximation

- Upper limit set on twist-4+ effects in the cross-section difference: twist>3 contribution is smaller than 10%

<u>Total cross-section (Hall A):</u>

- Bethe-Heitler is not dominant everywhere

- $|DVCS|^2$ terms might be sizeable but almost impossible to extract using only total cross-section: e^+/e^- or μ^+/μ^- beams seem necessary

- Despite this, we performed a measurement of 2 different GPD integrals

<u>BSA (CLAS):</u>

- Preliminary data in large kinematic range and good statistics !