Deeply Virtual Compton Scattering @ JLab

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For the Hall A and Hall B collaborations

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- Non-dedicated measurements
- E00-110 experiment in Hall A
- E03-106 experiment in Hall A
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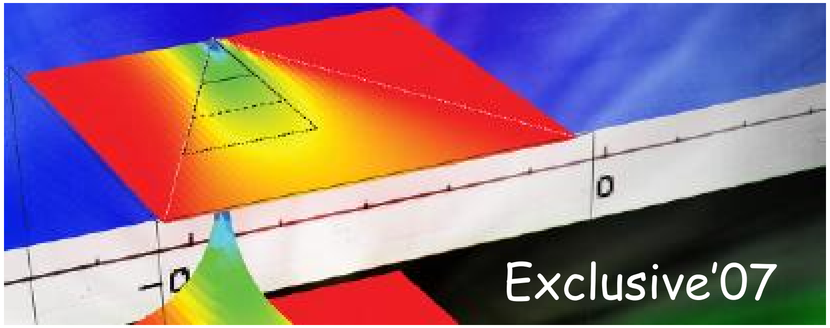
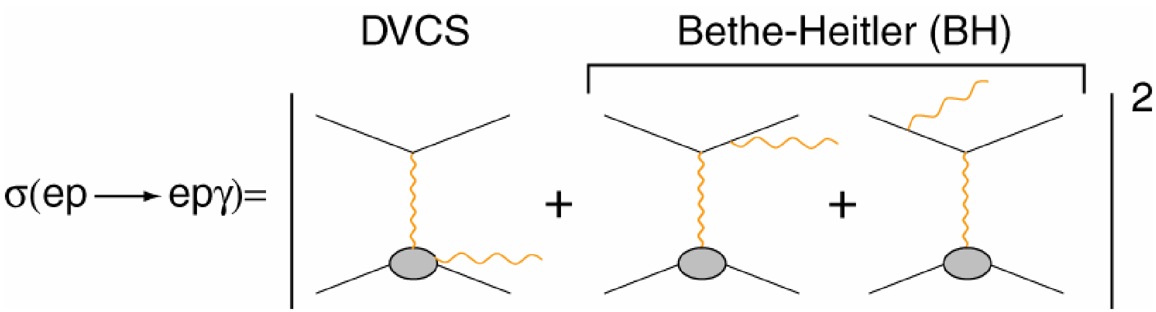
- Summary



Experimental observables linked to GPDs

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, $|T^{DVCS}|^2$ supposed small

Kroll, Guichon, Diehl, Pire, …

Into the harmonic structure of DVCS

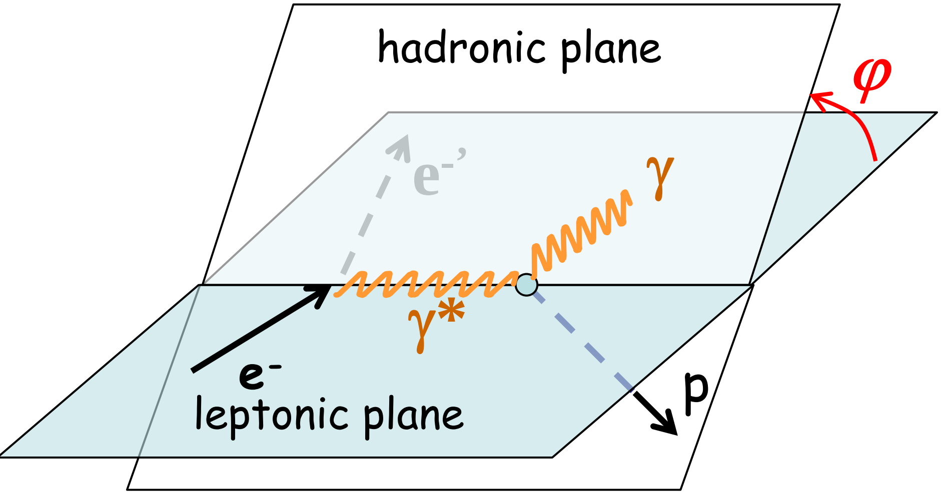
$$\frac{d^4\sigma}{dx_B dQ^2 dt d\varphi} = \frac{1}{P_1(\varphi)P_2(\varphi)}\Gamma_1(x_B,Q^2,t)\left\{c_0^{BH} + c_1^{BH}\cos\varphi + c_2^{BH}\cos 2\varphi\right\}$$

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

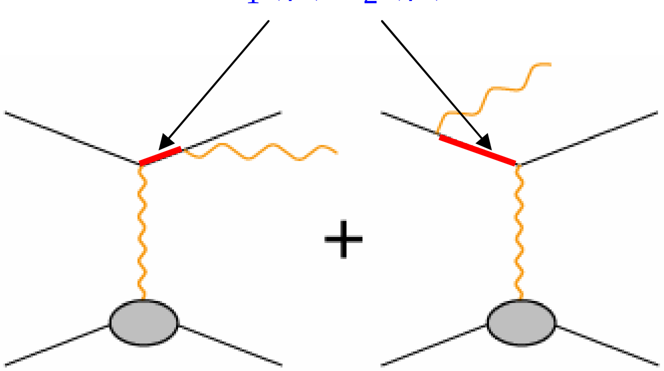
$|T^{BH}|^2$

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

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!

Special case of the asymmetry

The asymmetry can be written as:

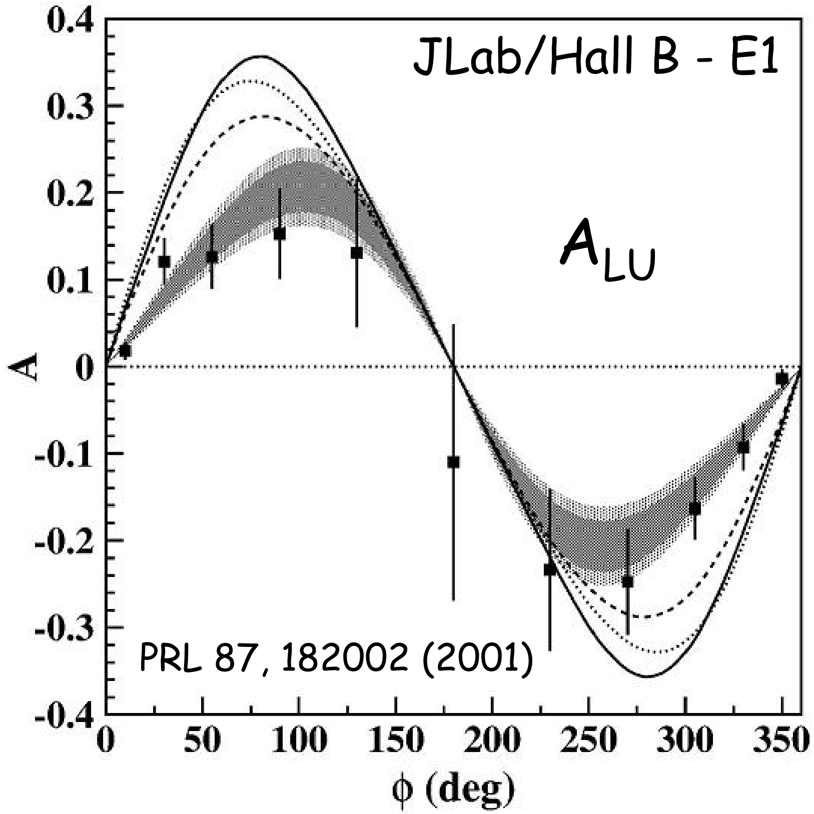
$$\frac{d^4\overrightarrow{\sigma}-d^4\overleftarrow{\sigma}}{d^4\overrightarrow{\sigma}+d^4\overleftarrow{\sigma}}=\Gamma_A(x_B,Q^2,t)\frac{s_1^I\sin\varphi+s_2^I\sin 2\varphi}{c_0^I+c_0^{BH}+(c_1^I+c_1^{BH})\cos\varphi+\ldots}$$

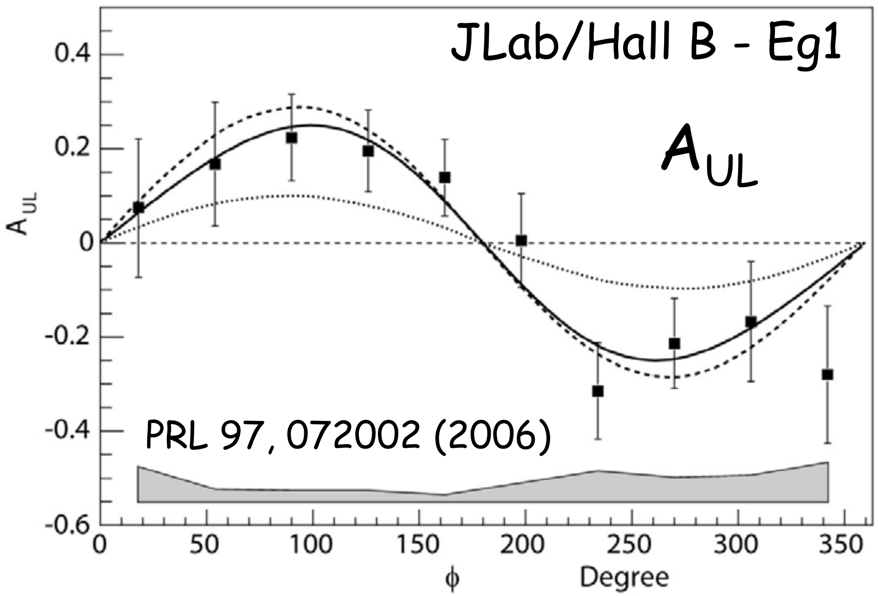
Pro: easier experimentally, smaller RC, smaller systematics

Con: direct extraction of GPDs is model- (or hypothesis-) dependent
(denominator complicated and unknown)

It was naturally the first observable extracted from non-dedicated experiments...

Published non-dedicated JLab/Hall B results on A_{LU} and A_{UL}



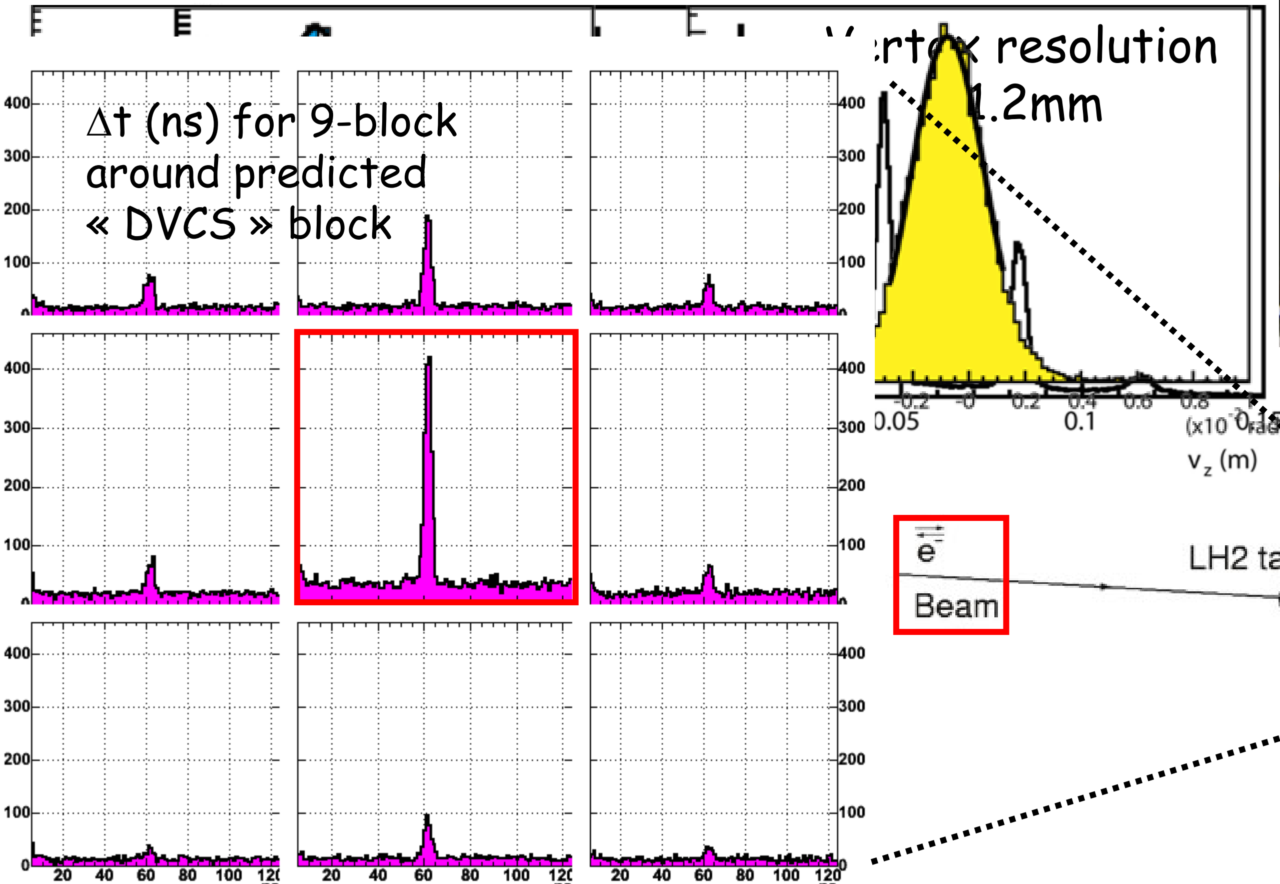


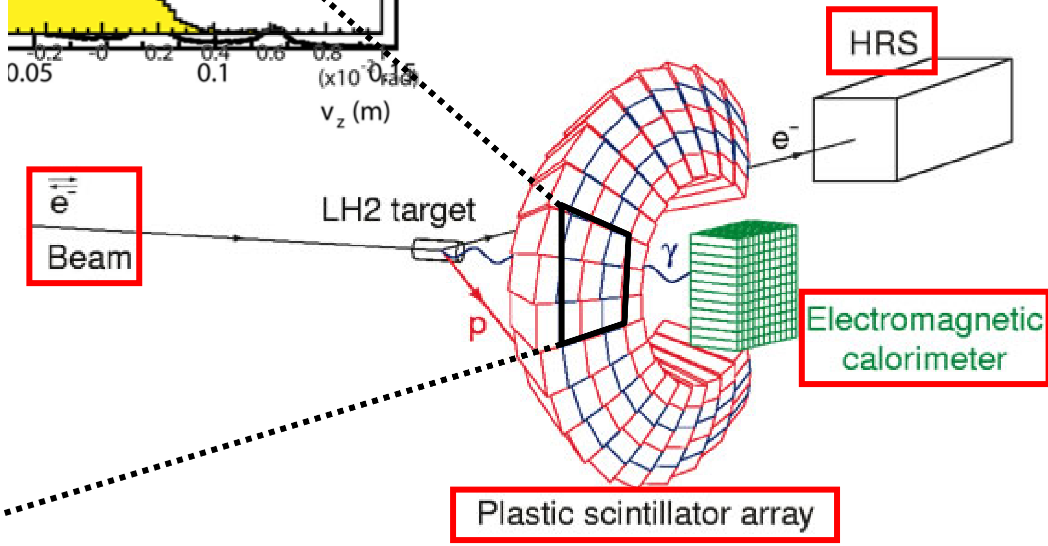
Both results show, with a limited statistics, a sin φ behavior (necessary condition for handbag dominance)

In the A_{LU} result, models (VGG) tend to over-estimate the data

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

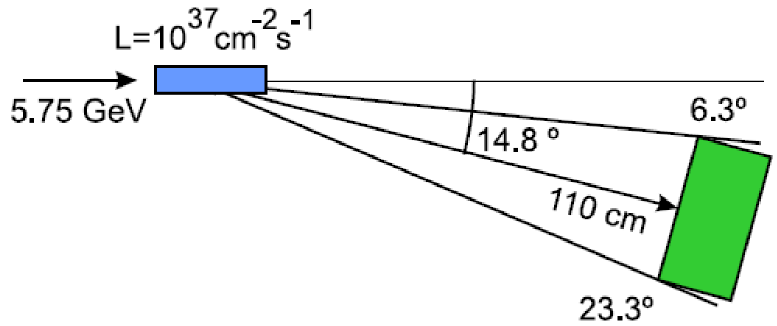




E00-110 kinematics

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

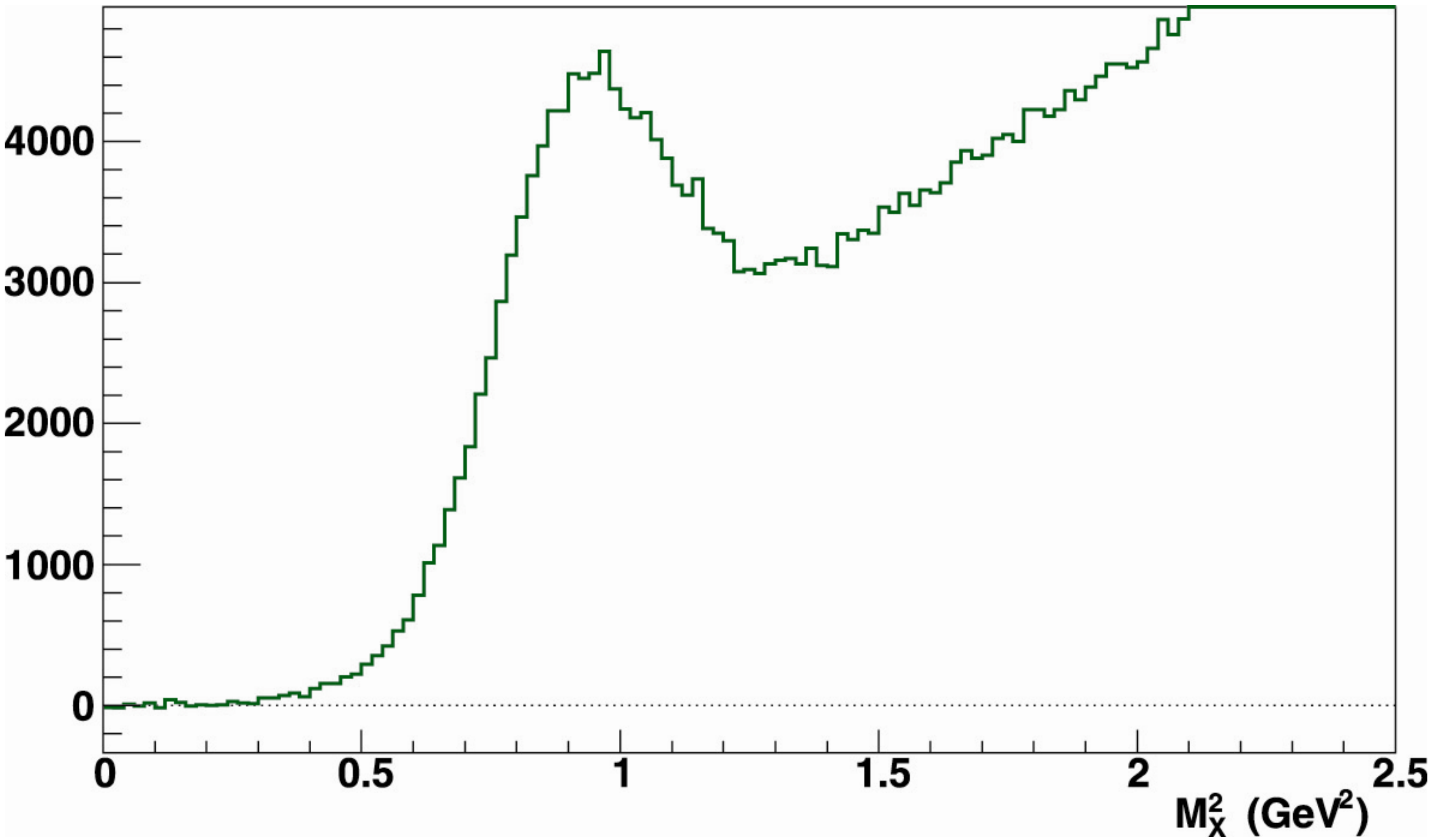
$$\int Lu \cdot dt = 13294 \text{ fb}^{-1}$$

Analysis – Looking for DVCS events

HRS: Cerenkov, vertex, flat-acceptance cut with R-functions

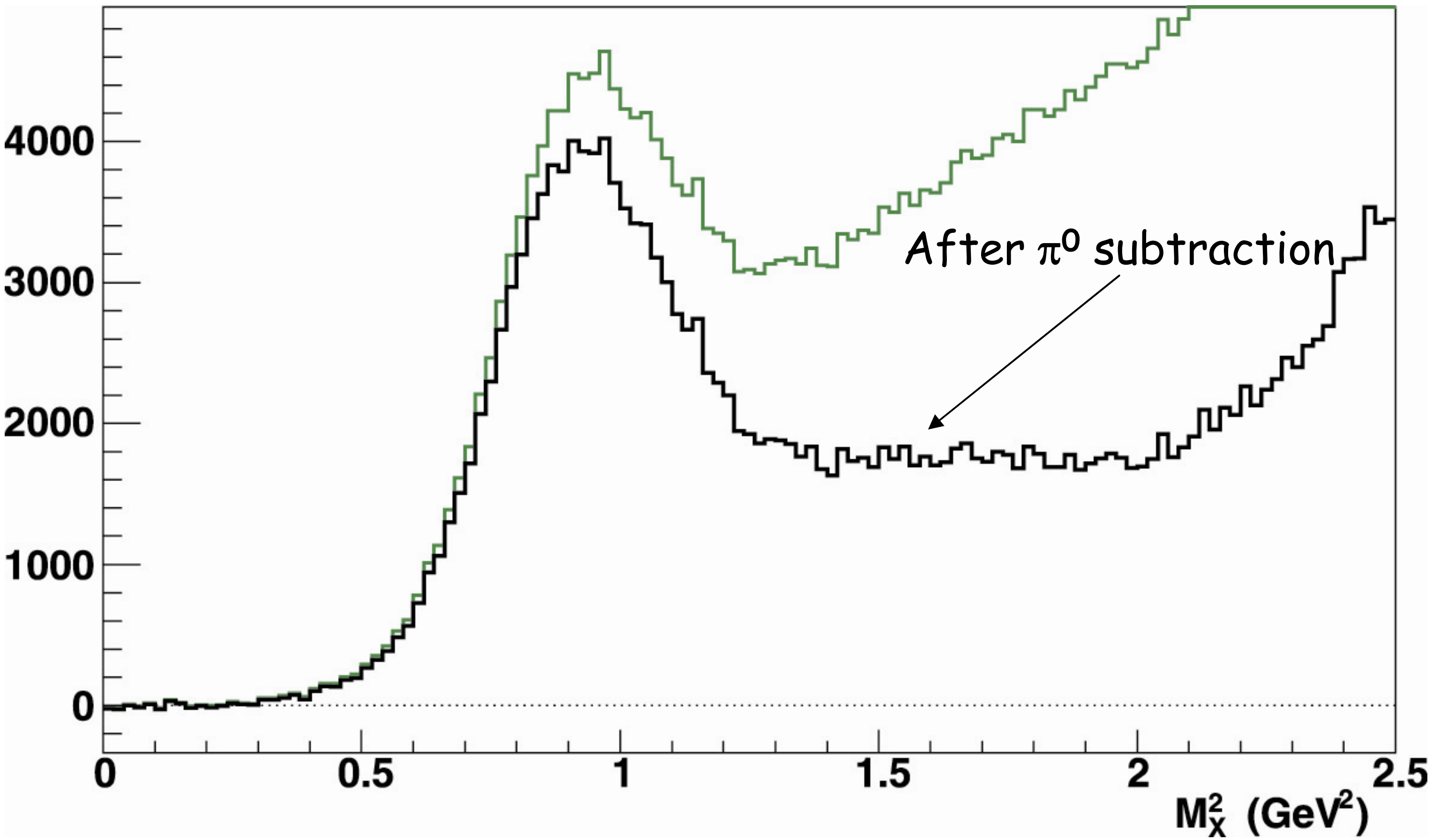
Calo: 1 cluster in coincidence in the calorimeter above 1 GeV

With both: subtract accidentals, build missing mass of (e,γ) system



Analysis – π^0 subtraction effect on missing mass spectrum

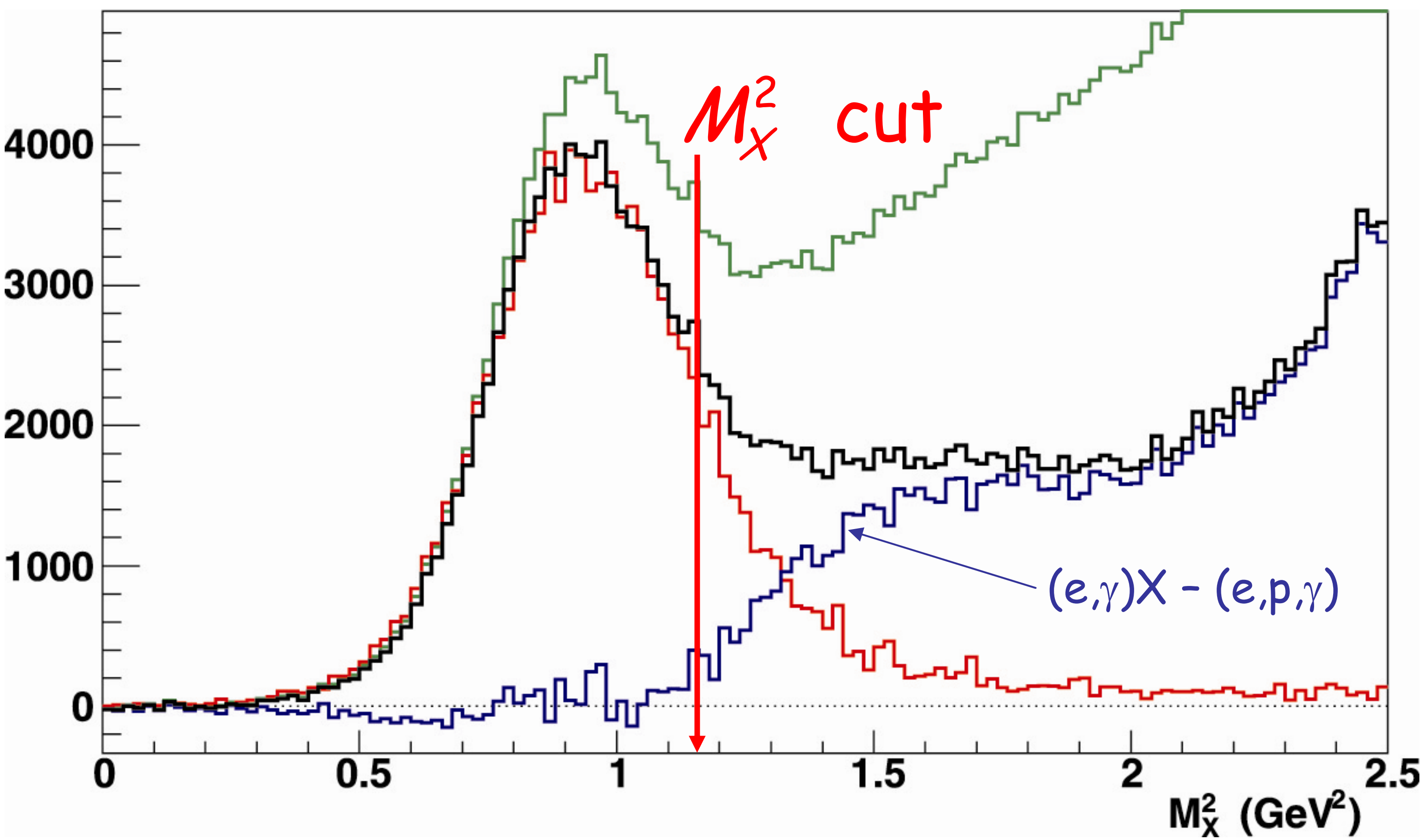
Using $\pi^0 \rightarrow 2\gamma$ events in the calorimeter, the π^0 contribution is subtracted bin by bin



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%.

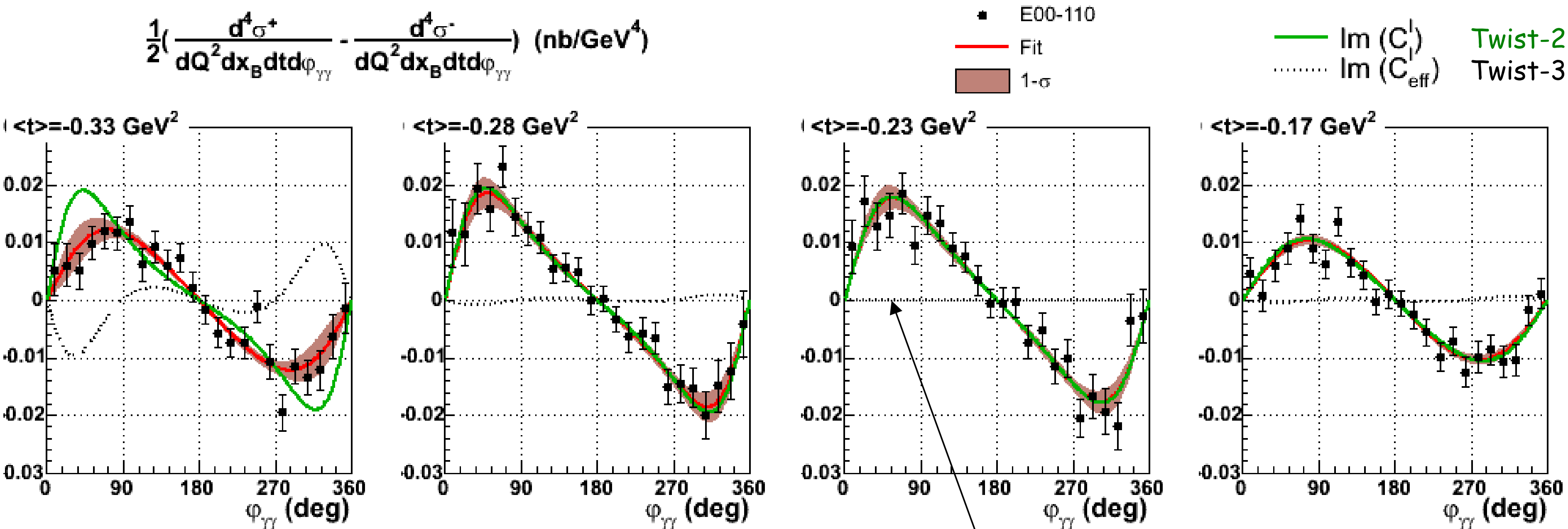


Difference of cross-sections

PRL97, 262002 (2006)

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

$$\langle x_B \rangle = 0.36$$



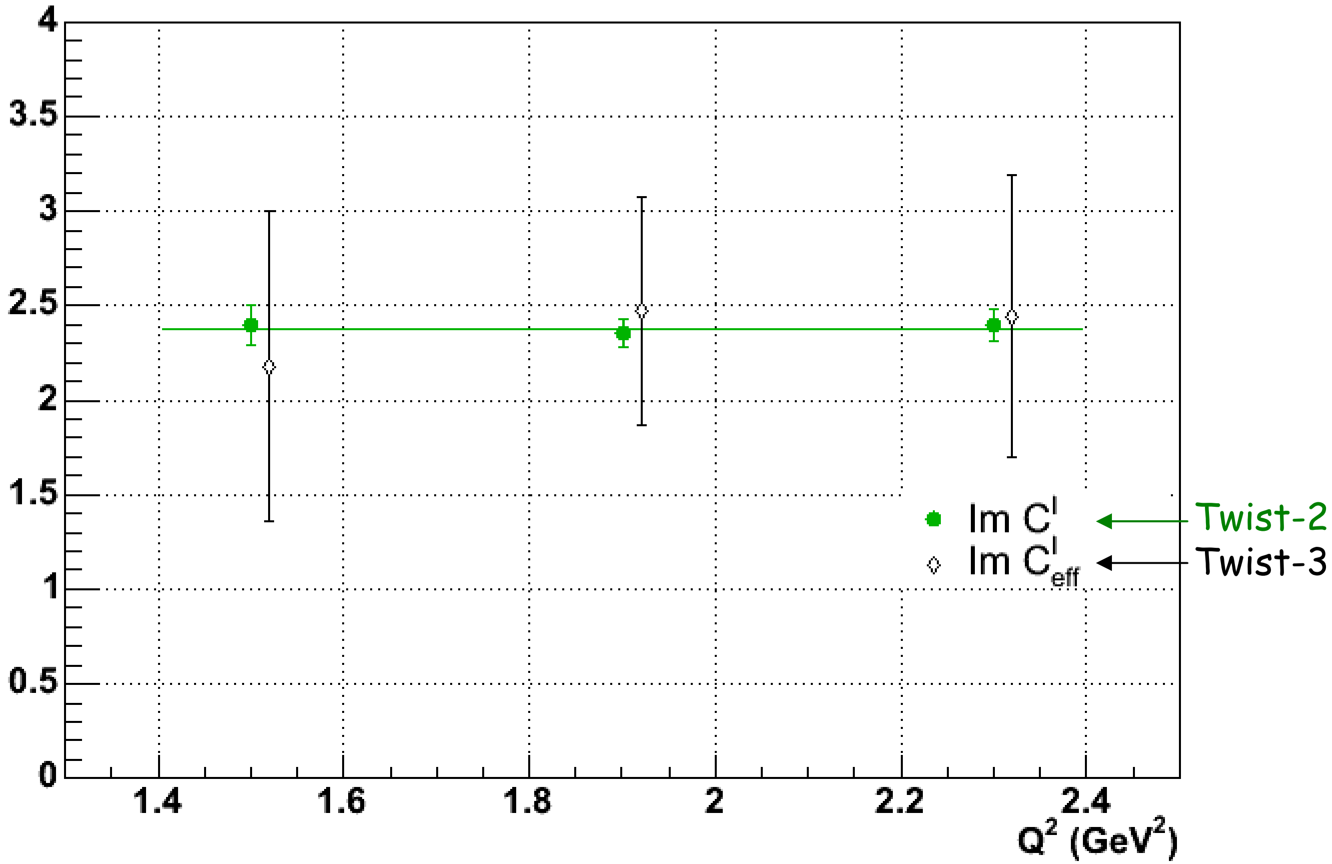
Extracted Twist-3 contribution small !

Corrected for real+virtual RC
Corrected for efficiency
Corrected for acceptance
Corrected for resolution effects
Checked elastic cross-section @ ~1%

New work by P. Guichon !

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

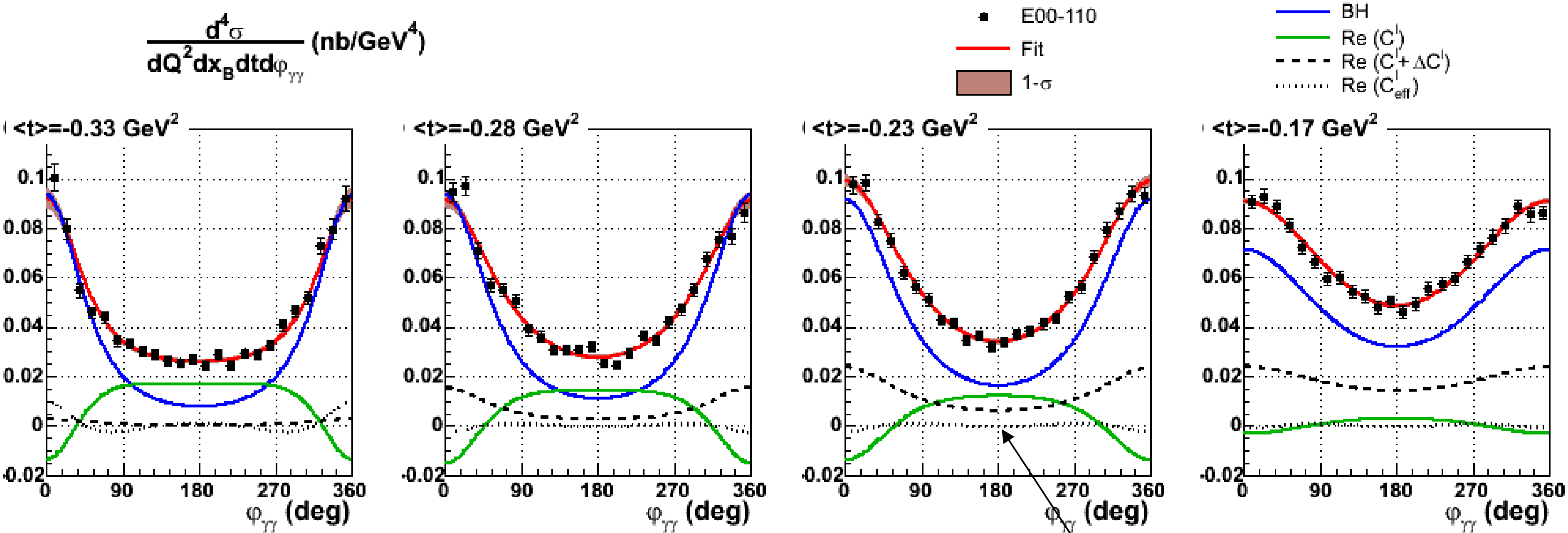
Twist 4+ contributions are smaller than 10%

Total cross-section

PRL97, 262002 (2006)

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

$$\langle x_B \rangle = 0.36$$



Extracted Twist-3 contribution small !

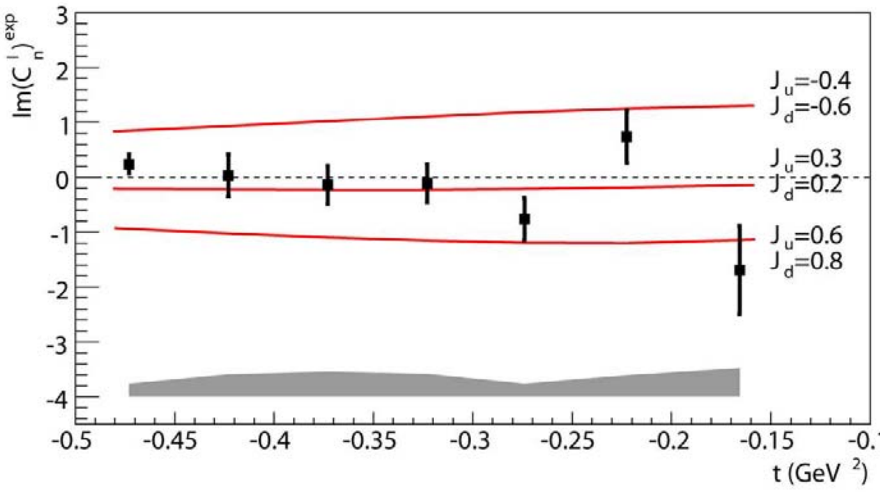
Corrected for real+virtual RC
Corrected for efficiency
Corrected for acceptance
Corrected for resolution effects

but impossible to disentangle DVCS^2 from the interference term (more on this in J. Roche talk)

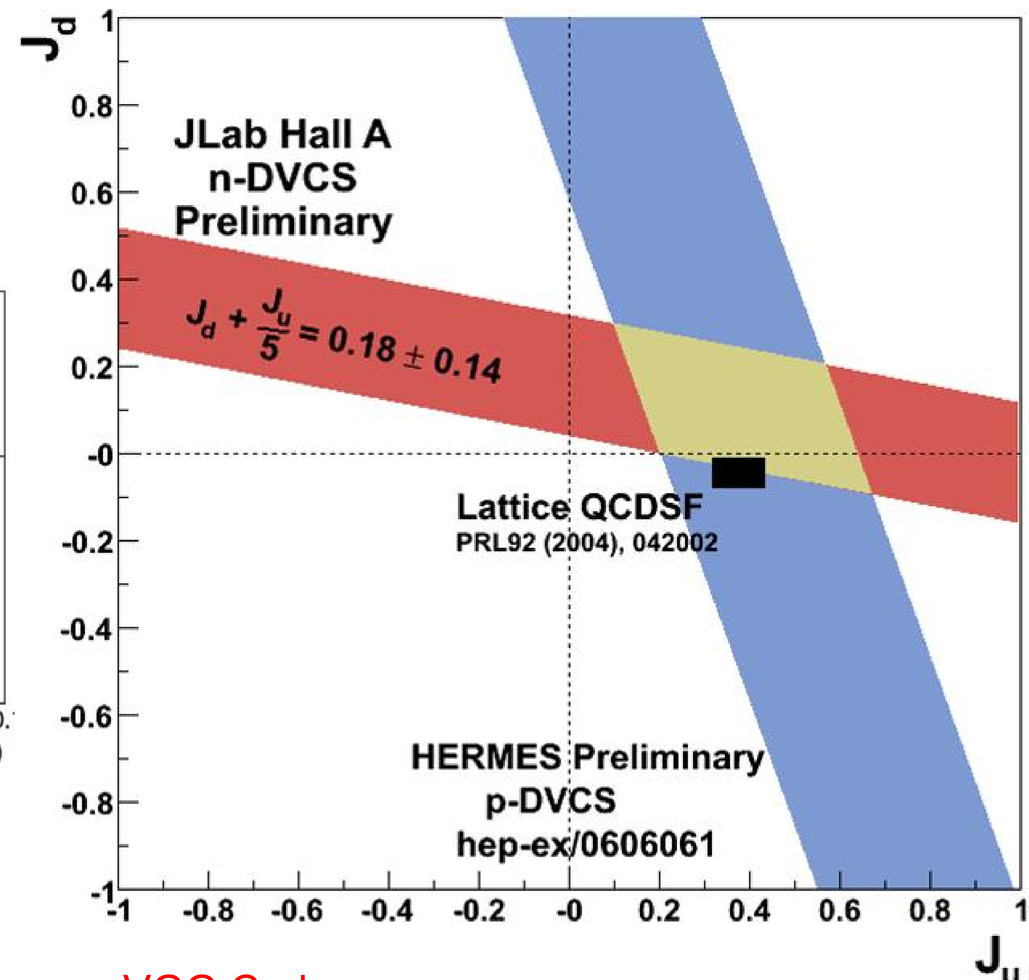
DVCS on the neutron in JLab/Hall A: E03-106

See talk from M. Mazouz

LD_2 target
24000 fb-1
x_B=0.36, Q^2=1.9 GeV^2



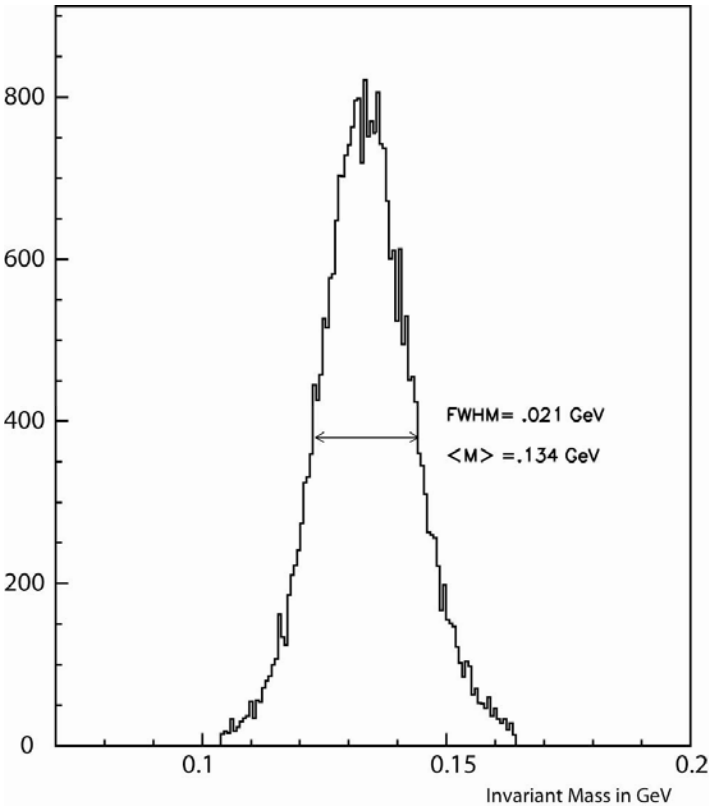
MODEL-DEPENDENT
Ju-Jd extraction

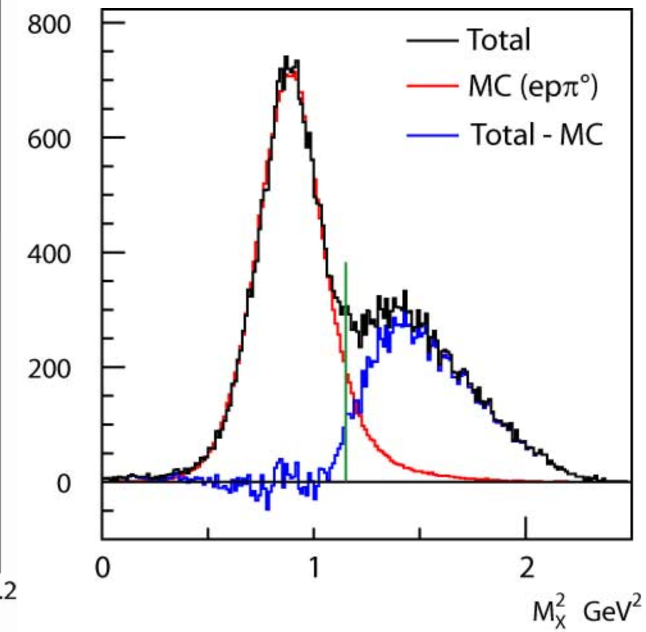


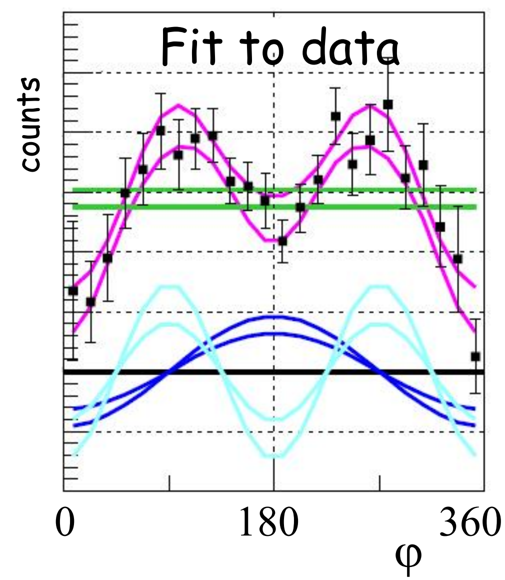
VGG Code
GPD model : LO/Regge/D-term=0
Goeke et al., Prog. Part. Nucl. Phys 47 (2001), 401.

Deep-π^0 electroproduction in JLab/Hall A

Same data as E00-110, but:
- 2γ requirement in the calorimeter at π^0 mass,
- $e\pi^0X$ at proton mass.







$$\frac{d\sigma}{dt} = \frac{d\sigma_T}{dt} + \varepsilon \frac{d\sigma_L}{dt} + \sqrt{2\varepsilon(1+\varepsilon)}\,\frac{d\sigma_{LT}}{dt}\cos\phi + \varepsilon \frac{d\sigma_{TT}}{dt}\cos 2\phi$$

Cross-sections for deep-π^0 production in JLab/Hall A

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

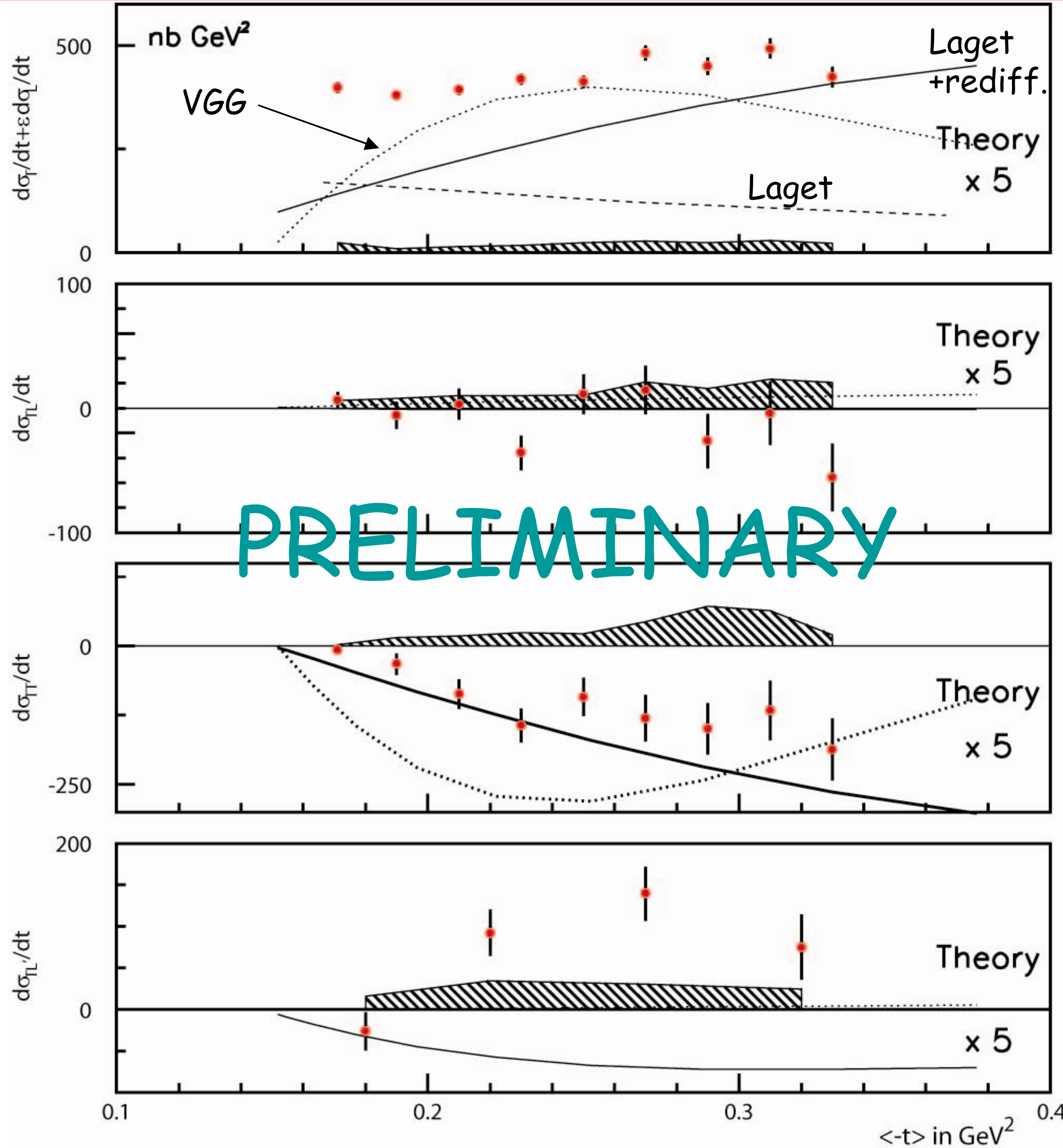
$$\langle x_B \rangle = 0.36$$

-Low-t cross-section largely overshoots GPD & JML models.

-TT term is large, suggesting a large transverse component.

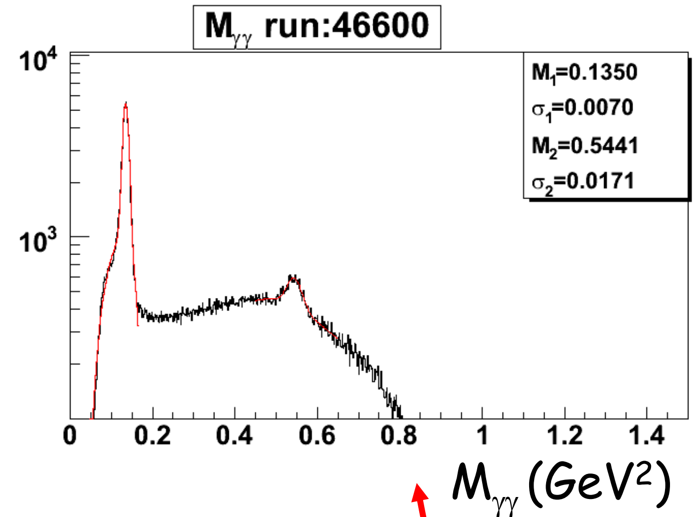
-But π^0 cross-section ratio for proton and deuteron targets is found 0.95...

More data needed !
(J. Roche talk)

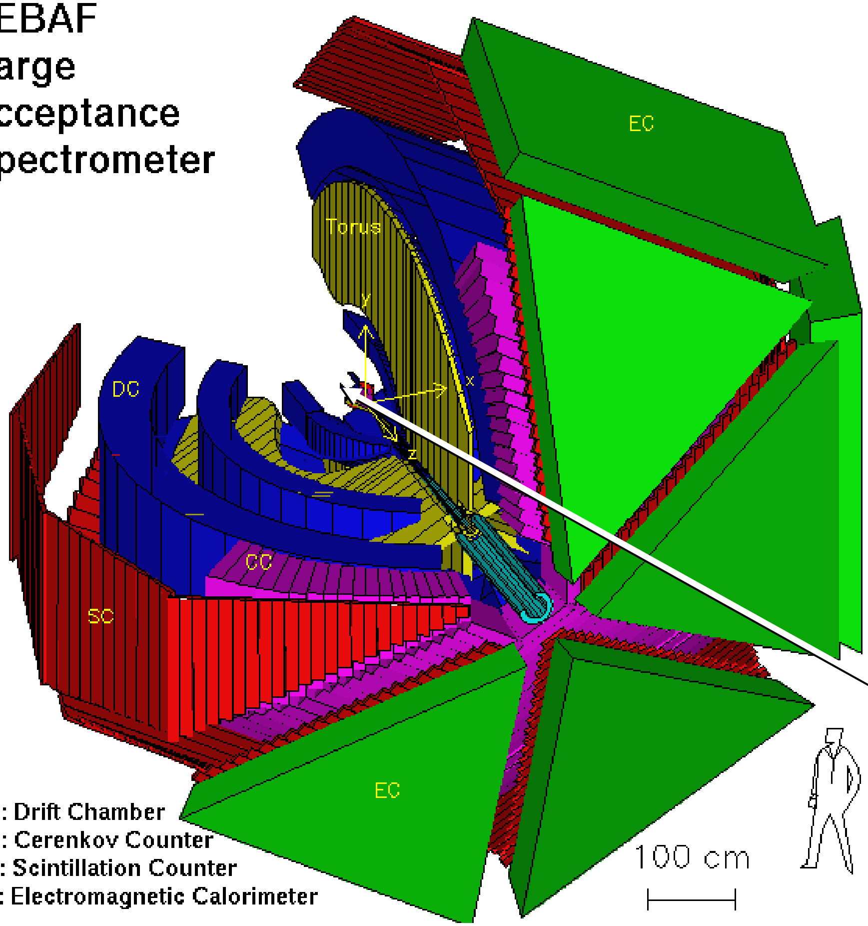


E1-DVCS with CLAS : a dedicated DVCS experiment in Hall B

Beam energy:	~5.8 GeV
Beam Polarization:	75-85%
Integ. Luminosity:	45 fb^{-1}

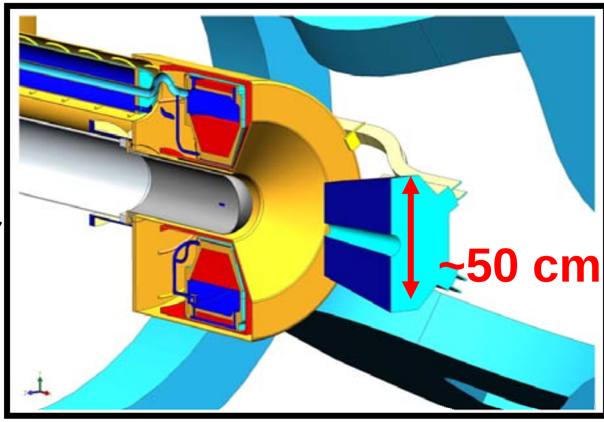


CEBAF
Large
Acceptance
Spectrometer



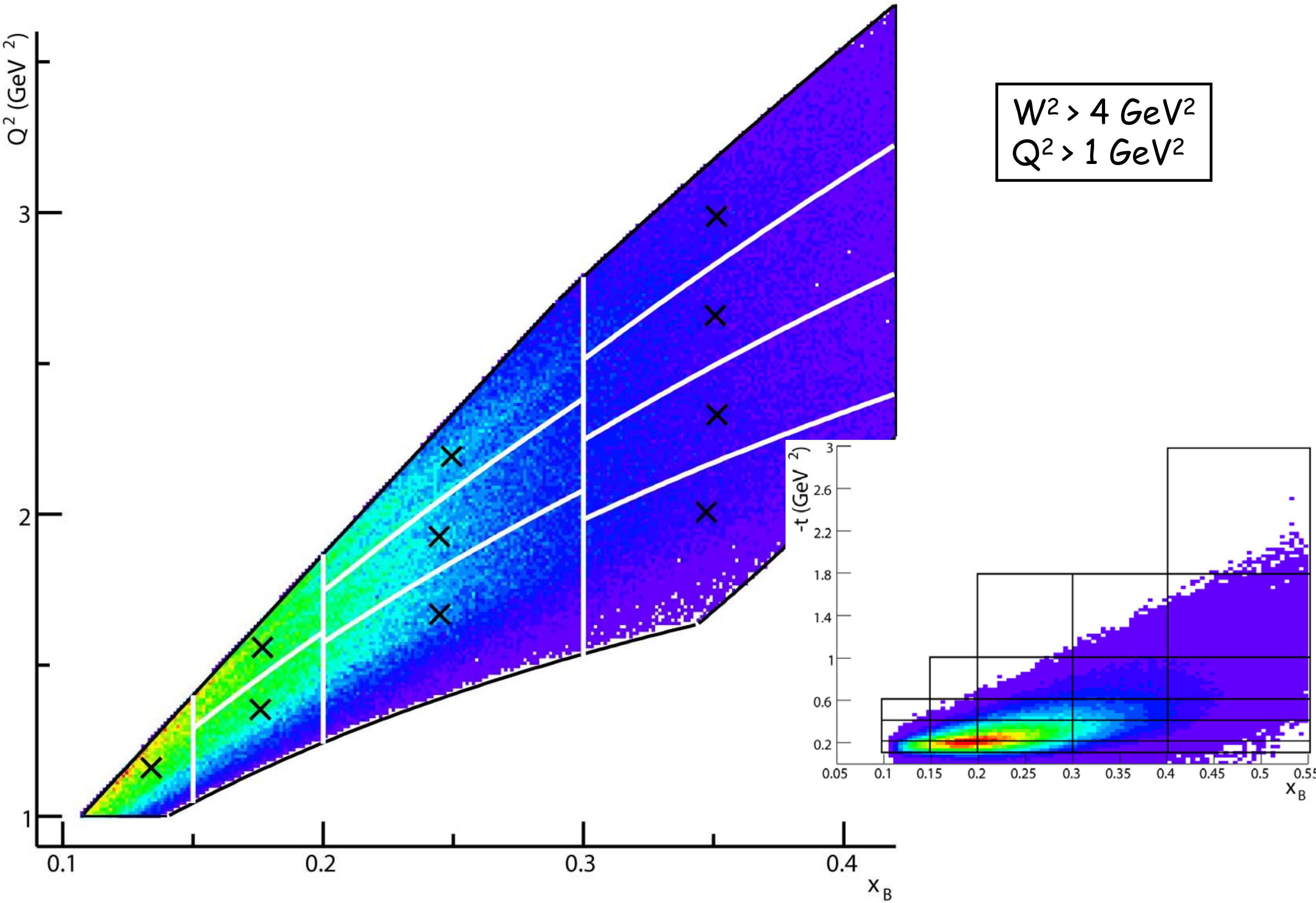
DC: Drift Chamber
CC: Cerenkov Counter
SC: Scintillation Counter
EC: Electromagnetic Calorimeter

Inner Calorimeter
+ Moller shielding solenoid

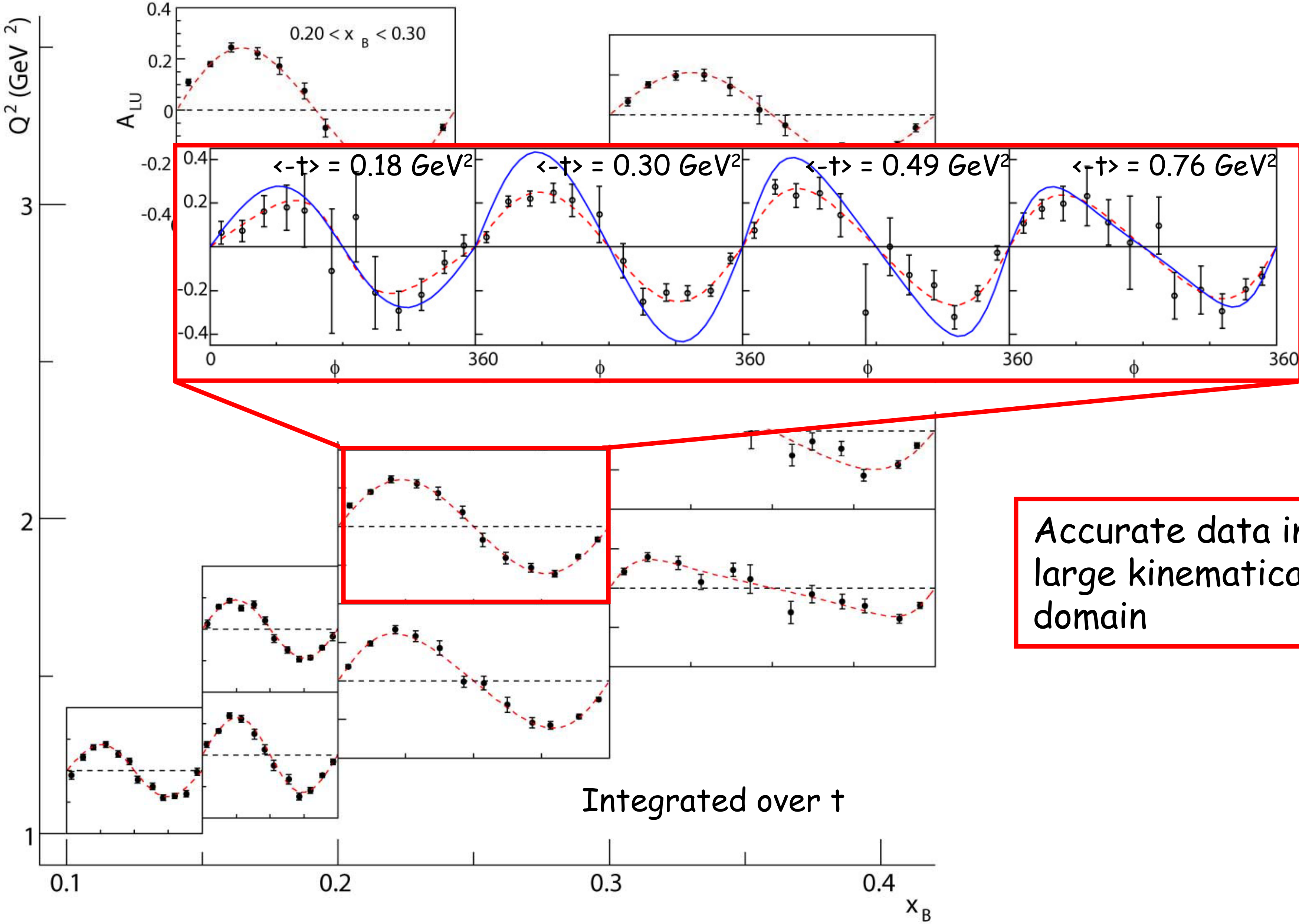


More details in FX Girod's talk

E1-DVCS kinematical coverage and binning

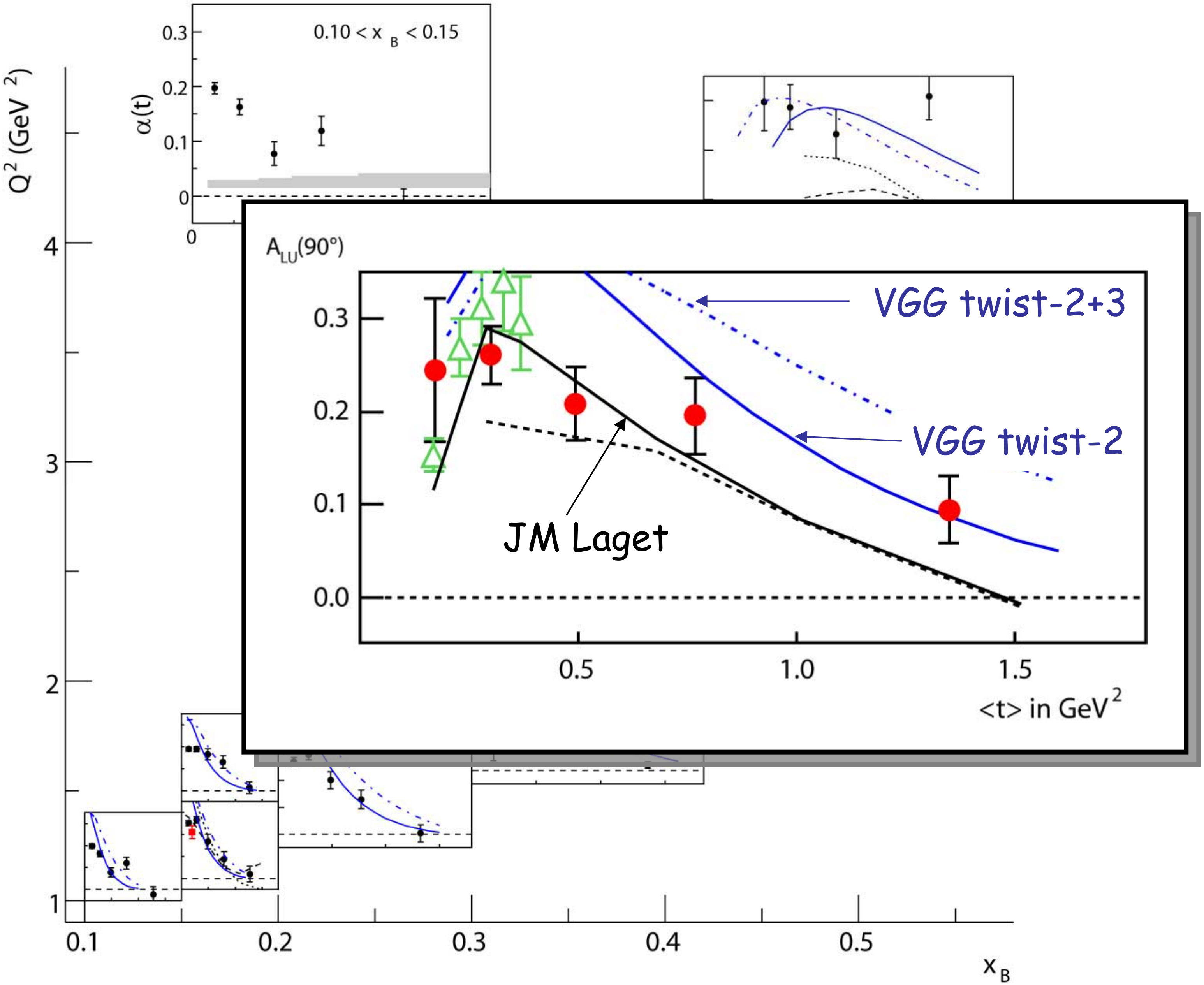


E1-DVCS : Asymmetry as a function of x_B and Q^2



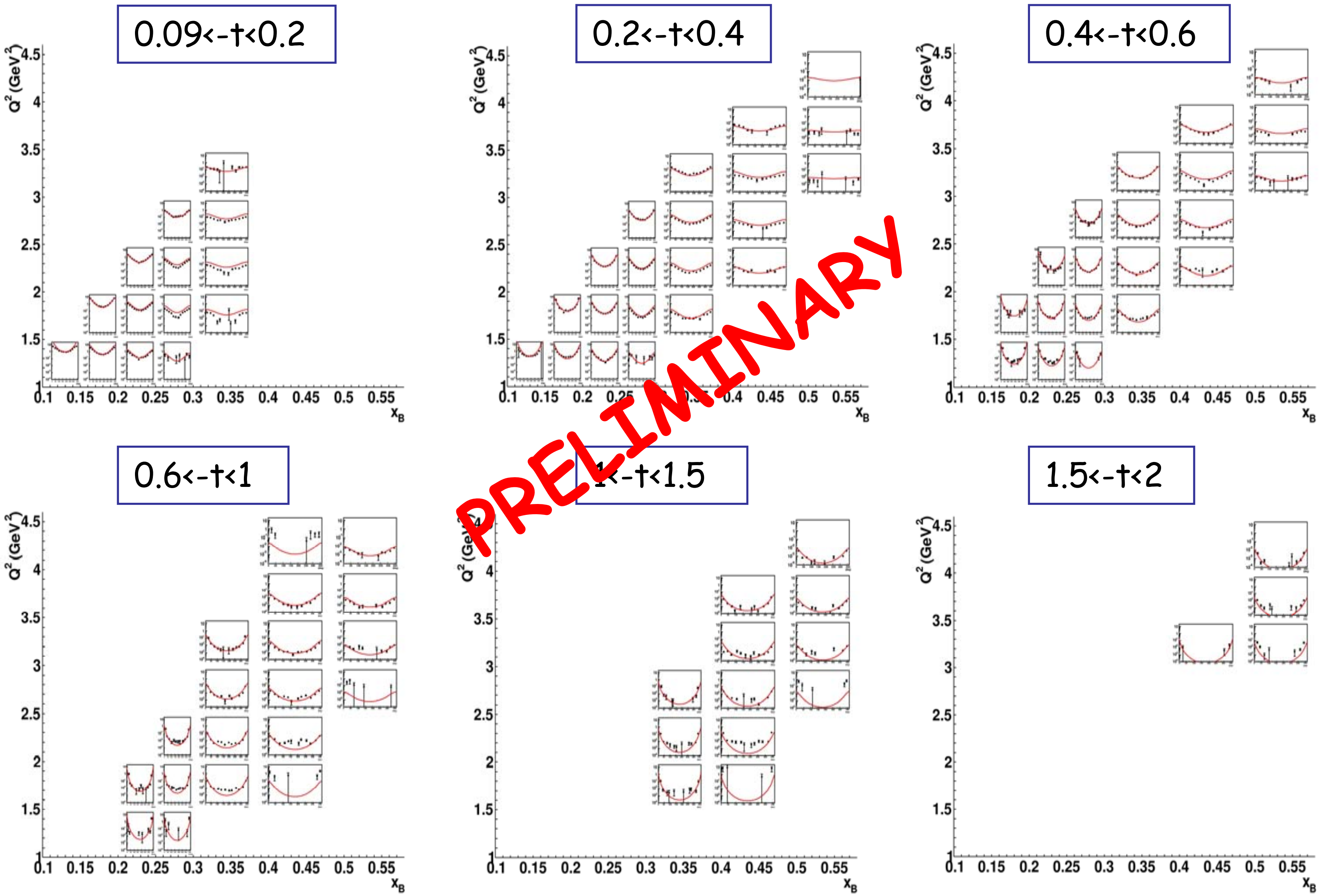
Accurate data in a large kinematical domain

E1-DVCS : $A_{LU}(90°)$ as a function of |t| + models



E1-DVCS : Cross-sections over a wide kinematical range

PhD Thesis H.S. Jo (IPNO)



What I did not have time to talk about

- Unpublished non-dedicated data from CLAS (G. Gavalian, H. Avakian, …)

- More details about E1-dvcs in Hall B (FX Girod talk)

- More details about E03-106 in Hall A (M. Mazouz talk)

- Plans for the short and long term studies of DVCS at JLab in both Hall A (J. Roche talk) and B (L. Elouadrhiri talk)

Summary

DVCS BSA (Hall B/CLAS):

- Data in a large kinematical range and good statistics. It will give a very hard time to models, to fit the whole range in Q^2, x_B and t.

- Data seem to favor JM Laget model at low-t and VGG model at high t.

DVCS Cross-section difference (Hall A):

- 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

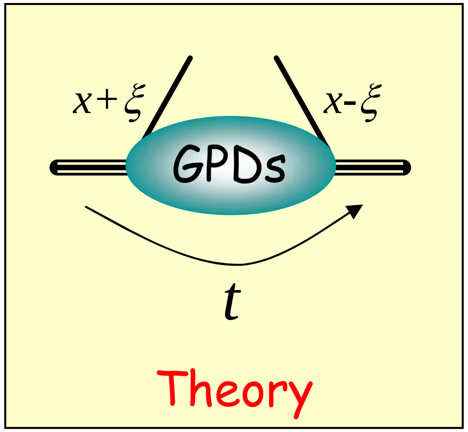
- Upper limit set on twist-4+ effects in the cross-section difference: twist>3 contribution is smaller than 10%

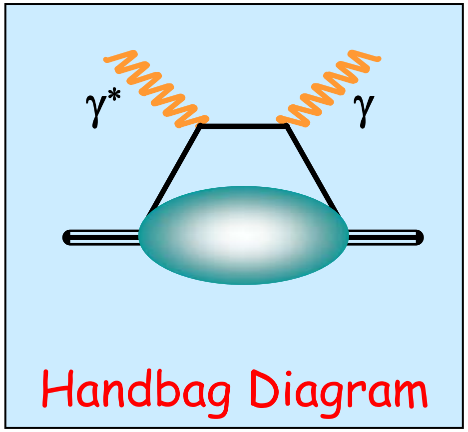
DVCS Total cross-section (Hall A):

- Bethe-Heitler is not dominant everywhere

- $|DVCS|^2$ terms might be sizeable (more on this in J. Roche's talk)

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

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

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

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