Deeply Virtual Compton Scattering : Experimental Review

Franck Sabatié
CEA Saclay

EINN 07 - Milos
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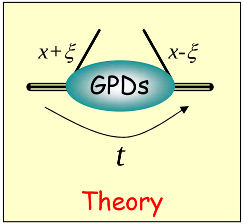
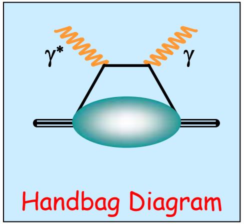
- Introduction
- How it all began
- New(er) HERMES results
- Experiments in JLab/Hall A
- Experiment in JLab/Hall B
- Short term experimental efforts:

  HERMES-recoil JLab

  COMPASS GPD
- [Longer term: JLab12]

GPDs from Theory to Experiment





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

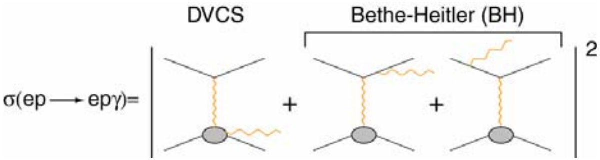
- GPDs appear in the real part through a PP integral over x
- GPDs appear in the imaginary part but at the line x=ξ

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

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

Experimental observables linked to GPDs

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

Ji, Kroll, Guichon, Diehl, Pire, …

Into the harmonic structure of DVCS

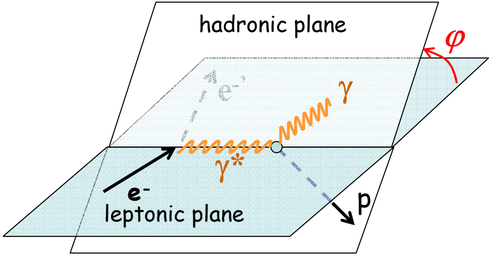
$$\frac{d^4\sigma}{dx_B dQ^2 dt d\varphi} = \frac{1}{P_1(\varphi)P_2(\varphi)}\Gamma_1(x_B,Q^2,t)\left\{c_0^{BH}+c_1^{BH}\cos\varphi+c_2^{BH}\cos 2\varphi\right\}$$

$|T^{BH}|^2$

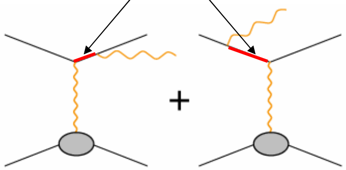
$$+\frac{1}{P_1(\varphi)P_2(\varphi)}\Gamma_2(x_B,Q^2,t)\left\{c_0^{I}+c_1^{I}\cos\varphi+c_2^{I}\cos 2\varphi+c_3^{I}\cos 3\varphi\right\}$$

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

Interference term



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



BH propagators φ dependence

Belitsky, Mueller, Kirchner

Deep Exclusive experiments

Published or Finalized 2001			Published or close to be		Analysis in progress	2008 – 2009	2010?	2013?
HERMES *27 GeV*	**CLAS** *4-5 GeV*	**CLAS** *5.75 GeV*	**Hall A** *6 GeV*	**CLAS** *6 GeV*	**HERMES**	**JLab**	**COMPASS**	**JLab@ 12GeV**
DVCS – BSA + BCA + nuclei BSA d-BCA + Polarized target DVCS ep→epρ σ_L + DSA	DVCS BSA	DVCS DDVCS ΔDVCS D2VCS Polarized DVCS ep→epρ$_L$ ep→epω$_L$ ep→epπ^0/η ep→enπ$^+$ ep→epΦ	DVCS proton neutron ep→epπ^o	DVCS Proton ep→epπ^o/η	DVCS BSA+BCA *With recoil detector*	Hall A DVCS² CLAS BSA+TSA	DVCS σ+BCA *With recoil detector*	EVERYTHING, **with more statistics** than ever before

More information for underlined items by: A. Camsonne, W. Dieter Nowak, A. Sandacz

Special case of the asymmetry

The asymmetry can be written as:

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

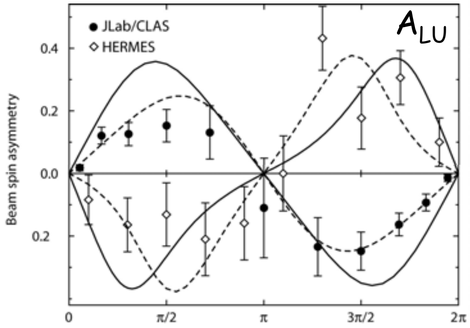
Pro: easier experimentally, smaller RC, smaller systematics

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

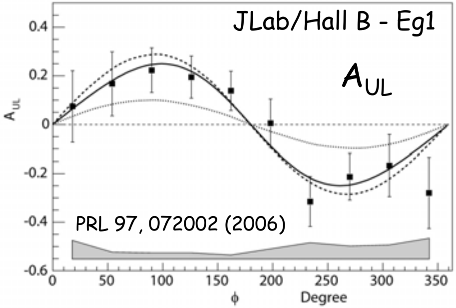
It was naturally the first observable extracted from non-dedicated experiments…

Published non-dedicated results on A_{LU} and A_{UL}

JLab/Hall B - E1 & HERMES



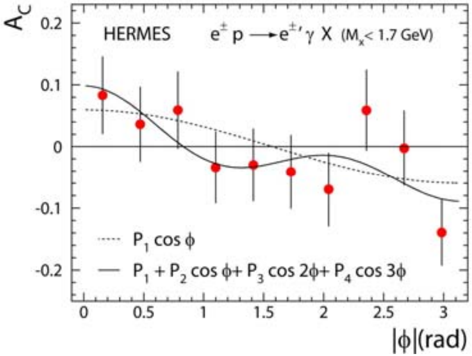
CLAS: PRL 87, 182002 (2001)
HERMES: PRL 87, 182001 (2001)



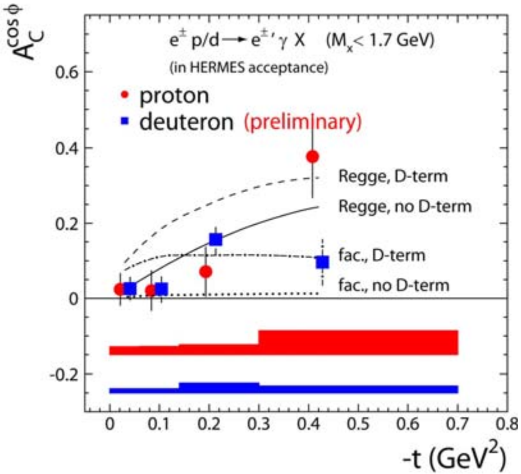
Both results show, with a limited statistics, a sin φ behavior (necessary condition for handbag dominance)

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

HERMES published (p) or unpublished (d) results on the BCA

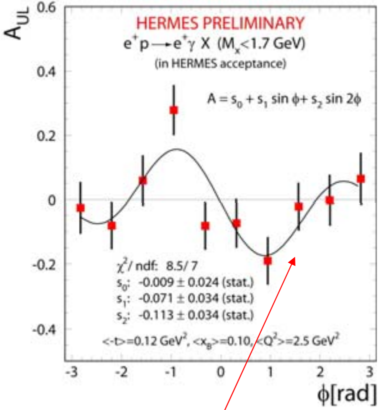


Sensitive to the real part of the DVCS.BH interference



Low statistics but a cosine wave is observed.
Still hard to compare to models

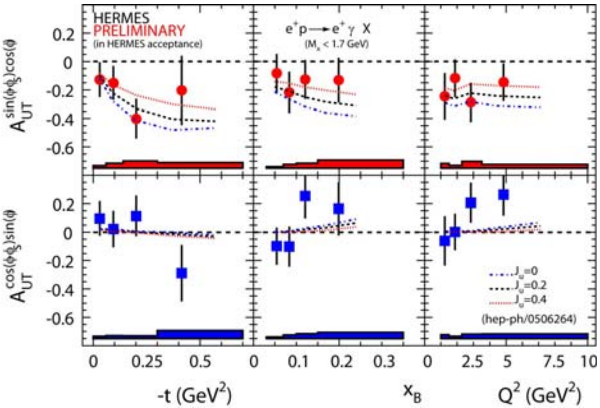
HERMES preliminary results for A_{UL} and A_{UT}



Strong sin2φ is observed, unlike in the CLAS data

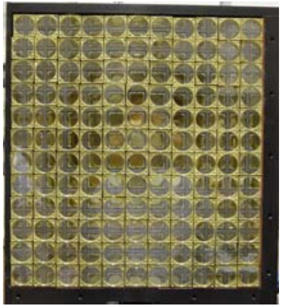
More in W. Dieter Nowak's talk

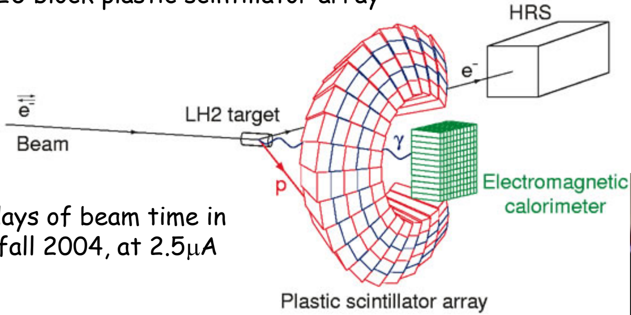
Model-dependent constraint on Ju-Jd (more on this later)



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





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

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

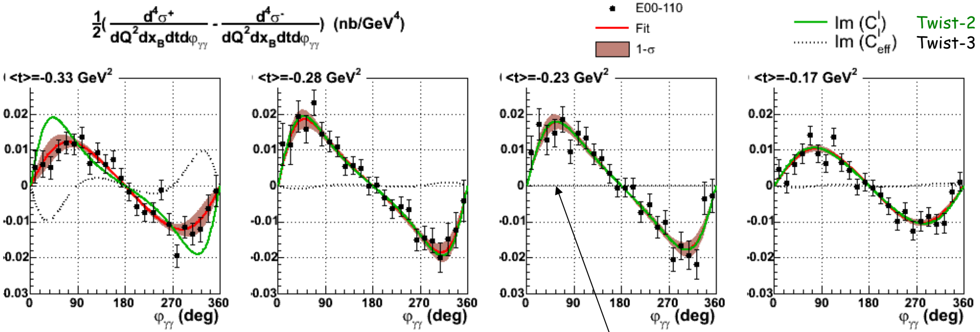
Kin	Q^2 (GeV^2)	x_B	θ_{γ^*} (deg.)	W (GeV)
1	**1.5**	0.36	**22.3**	1.9
2	**1.9**	0.36	**18.3**	2.0
3	**2.3**	0.36	**14.8**	2.2

Difference of cross-sections

PRL97, 262002 (2006)

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

$$\langle x_B \rangle = 0.36$$



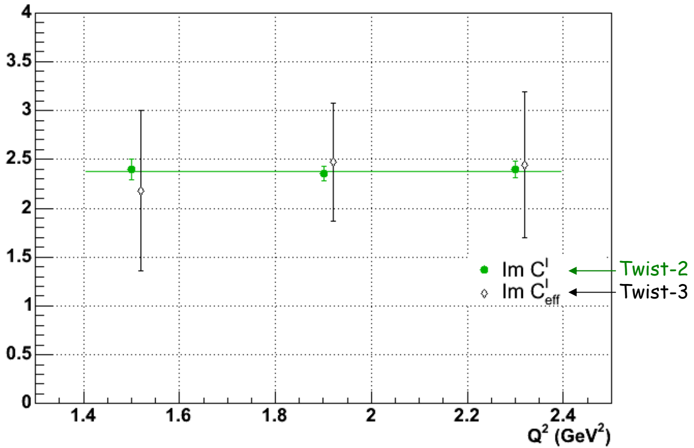
Extracted Twist-3 contribution small !

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 using BMK separation:
strong indication for scaling behavior and handbag dominance

Twist 4+ contributions are smaller than 10%

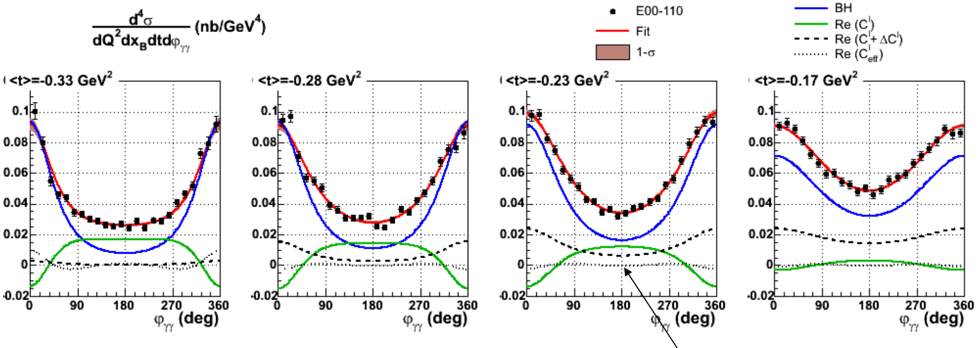
Total cross-section

PRL97, 262002 (2006)

See also A. Camsonne's talk

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

$$\langle x_B \rangle = 0.36$$

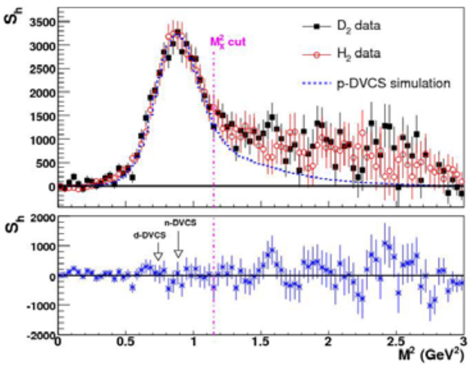


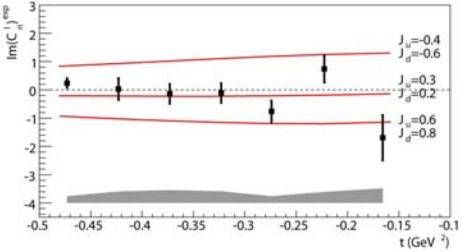
Extracted Twist-3 contribution small !

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 !

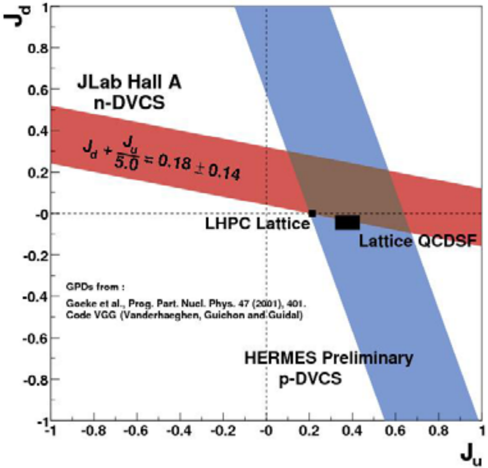
DVCS on the neutron in JLab/Hall A: E03-106





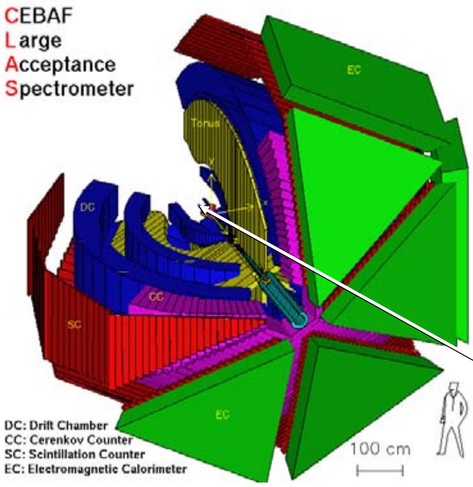
LD_2 target
24000 fb-1
x_B=0.36, Q^2=1.9 GeV^2

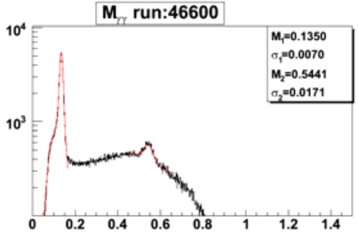
MODEL-DEPENDENT
Ju-Jd extraction



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

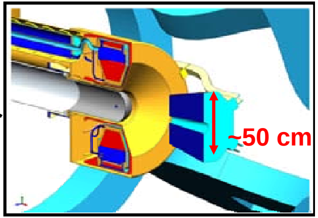
Beam energy:	~5.8 GeV
Beam Polarization:	75-85%
Integ. Luminosity:	45 fb^{-1}



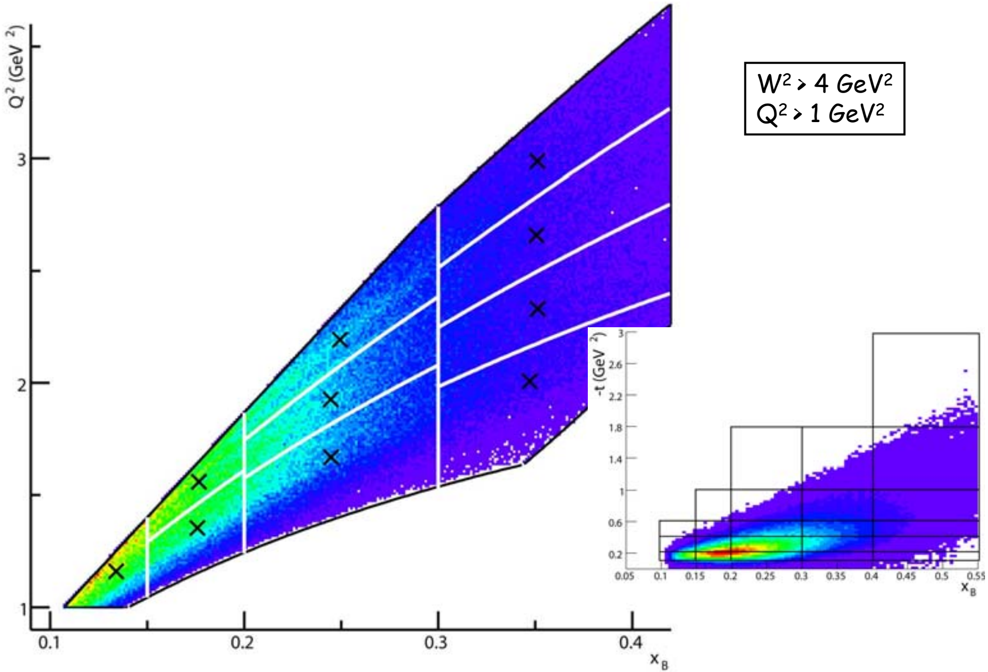


$M_{\gamma\gamma}$ (GeV^2)

Inner Calorimeter
+ Moller shielding solenoid

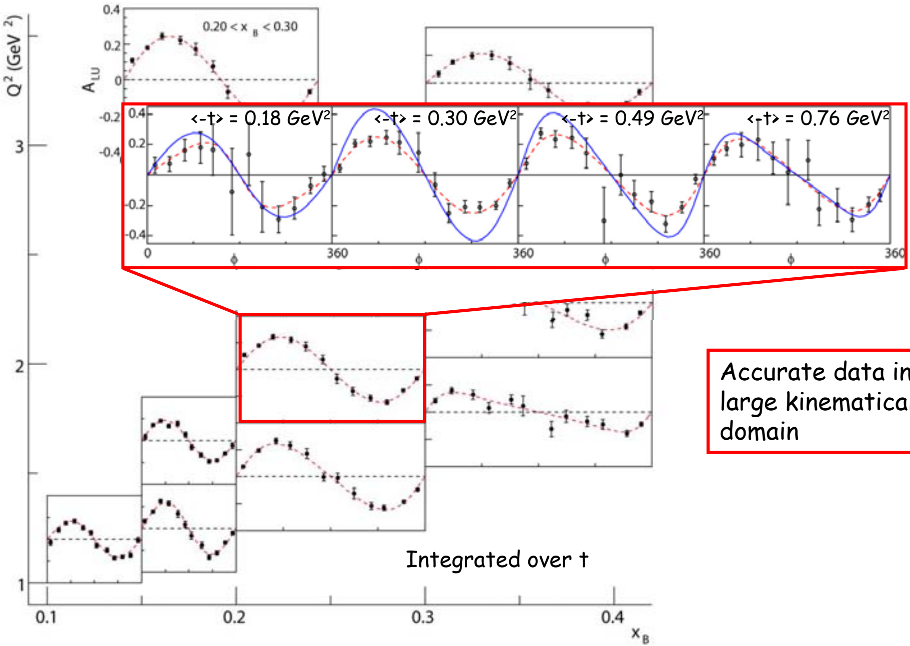


E1-DVCS kinematical coverage and binning



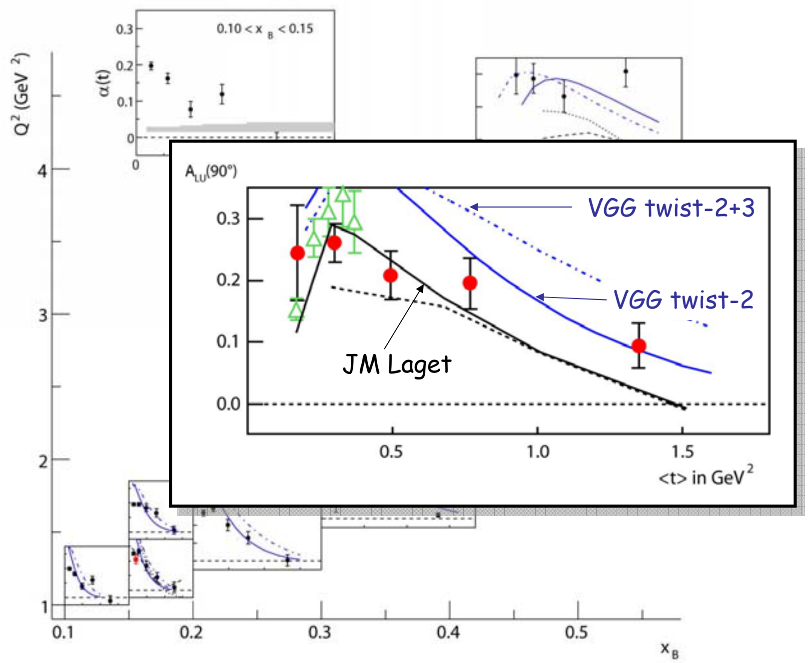
$W^2 > 4$ GeV^2
$Q^2 > 1$ GeV^2

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



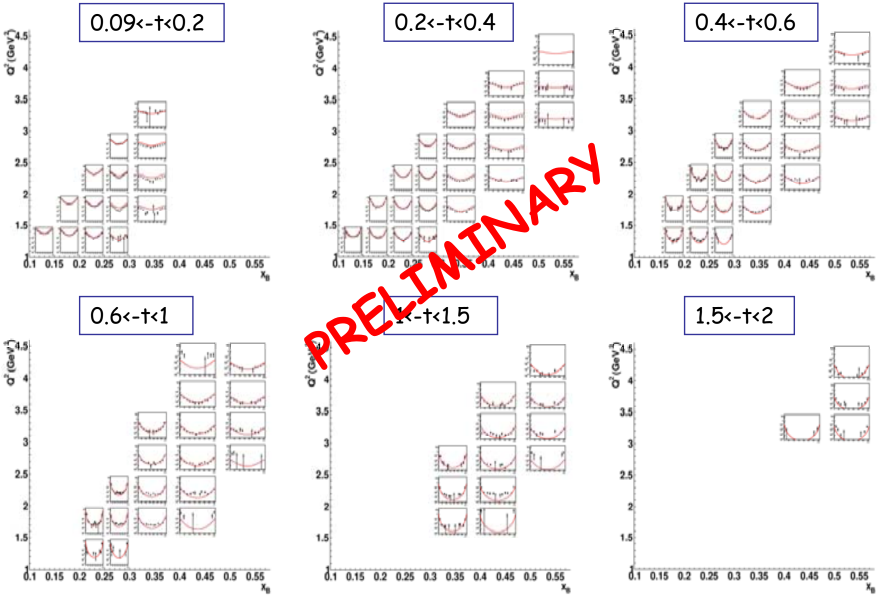
Accurate data in a large kinematical domain

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

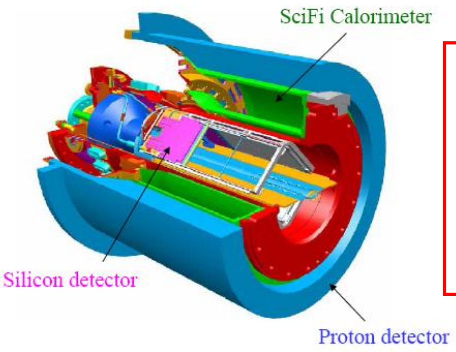


E1-DVCS : Cross-sections over a wide kinematical range

PhD Thesis H.S. Jo



The HERMES recoil detector: towards « true » exclusivity

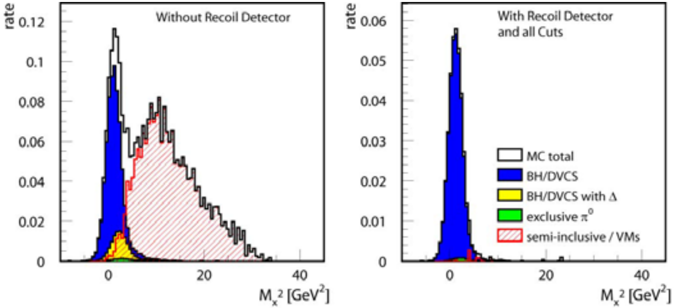


- Inside a 1T superconducting solenoid
- Detection of the recoil proton: momentum measurement and PID (p/π)

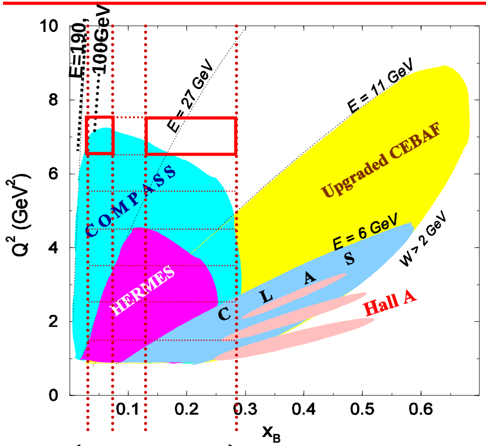
=> improves t resolution, enhances signal & π^0 background rejection

- Collected statistics:

e- 2006: H_2 5k DVCS, D_2 1k DVCS
e-/+ 2007: H_2 42k DVCS, D_2 10k DVCS



COMPASS at the horizon 2010



COMPASS at CERN-SPS

High energy muon beam
100/190 GeV

μ+ or μ-
change once per day
polar(μ+)=-0.80
polar(μ-)=+0.80

2.10^8 μ per SPS cycle

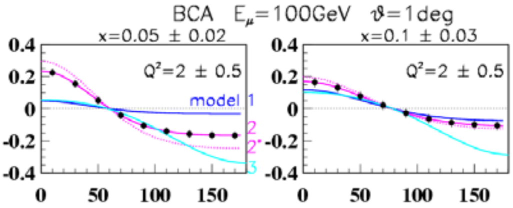
valence quarks
and sea quarks
and gluons

COMPASS
2010?

valence quarks

JLab 12 GeV
2013?

2 bins, for 6 months of data at 25% efficiency



Summary

After 7 years of worldwide experimental efforts on DVCS:

-It is rather firmly established that leading twist contribution seems to dominate unlike in the meson case, and very similarily to DIS.

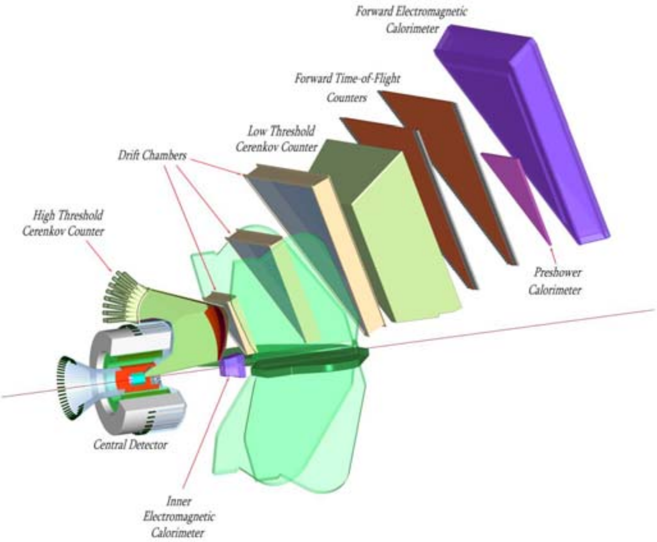
-GPD models such as VGG do not reproduce well most observables and it is now the ideal time to get the theory/phenomenology up to speed with the experimental side.

-It is only by a strong and common effort between theorists (modelists) and experimentalists that we will gain information about the GPDs themselves : disentangling GPDs from observables is a considerable challenge.

-The future 6 GeV and 12 GeV data from JLab, along with data coming from the analysis of recoil-detector-enabled data from HERMES and COMPASS will bring an amazing quantity of clean data in the next 8 years. We need to refine our analysis tools in preparation for this challenge !

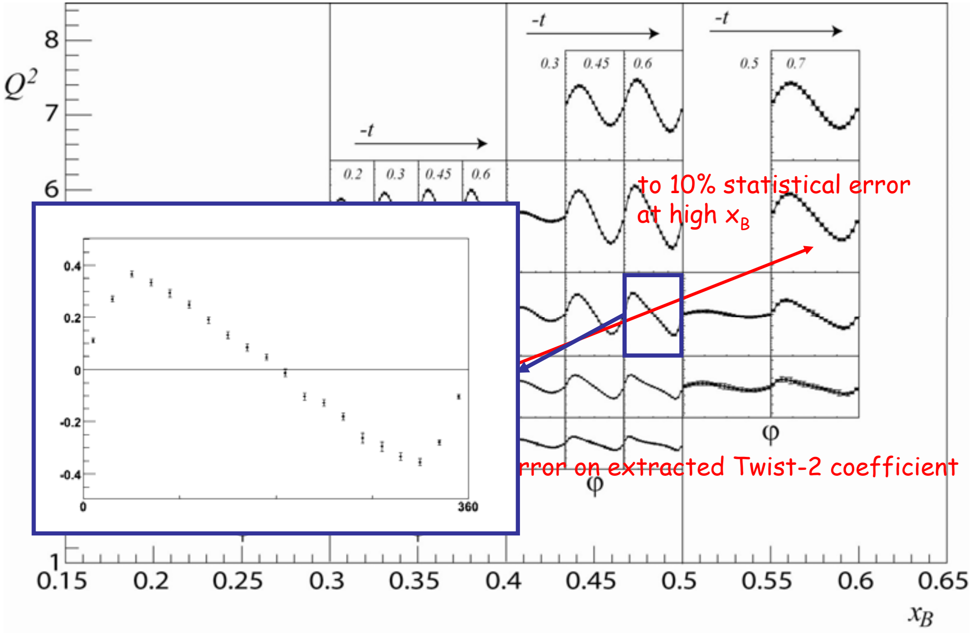
Experimental Setup and proposed experiments at 11 GeV

Use of base CLAS12 equipment, including Inner Calorimeter (IC)



Beam Spin Asymmetry

*IC in standard position – **80 days** – 10^35 Lum – VGG model*



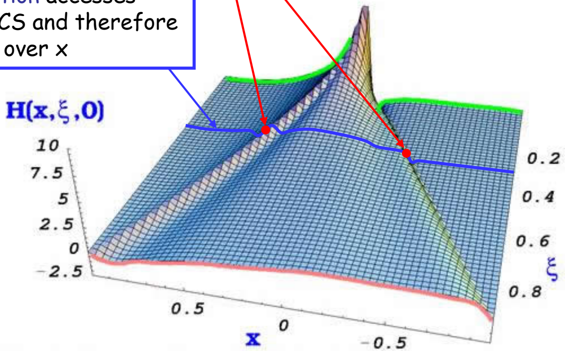
Observables and their relationship to GPDs

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

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

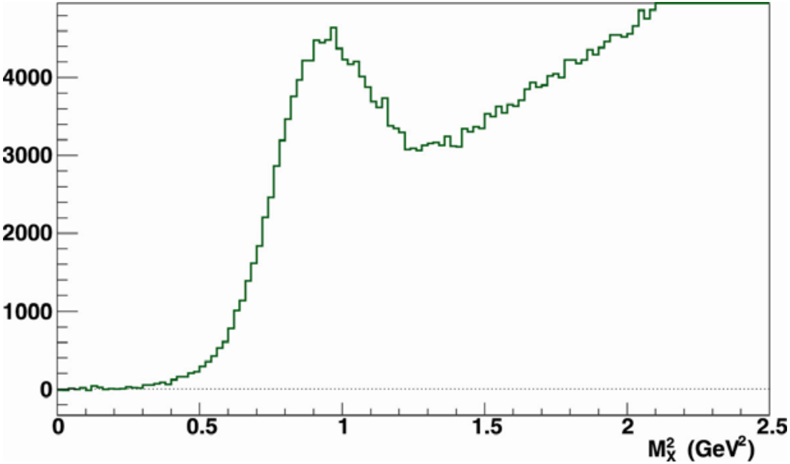


Analysis – Looking for DVCS events

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

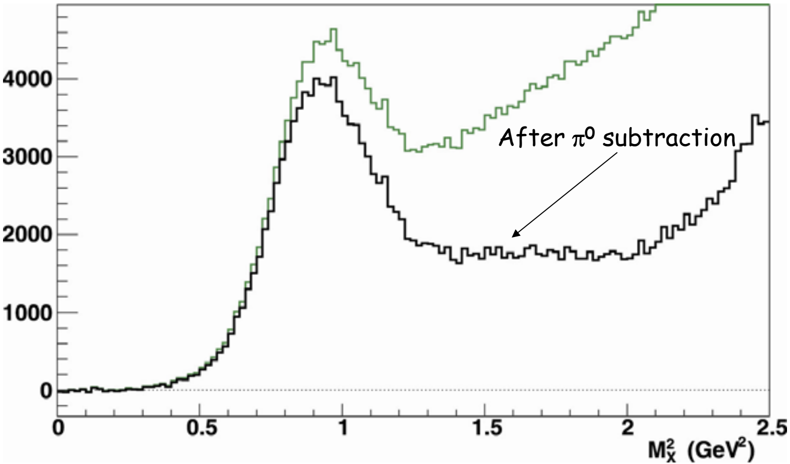
Calo: 1 cluster in coincidence in the calorimeter above 1 GeV

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



Analysis – π^0 subtraction effect on missing mass spectrum

Using $\pi^0 \to 2\gamma$ 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%.