Results and Achievements at CLAS

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DIS2011 - Newport News, April 14°, 2011.

Overview

- Generalized Parton Distributions (GPDs)
  - Introduction
  - Accessing GPDs: Deeply Virtual Compton Scattering (DVCS) & Deeply Virtual Meson Production (DVMP)
  - Asymmetries
- GPDs with the CLAS experiment
  - The Cebaf Large Acceptance Spectrometer
  - Selected results
    - e1-dvcs: polarized beam, unpolarized target
    - eg1-dvcs: polarized beam, polarized target
    - DVMP
- CLAS12

Beyond Form Factors and quark distributions - Generalized Parton Distributions

Proton form factors, transverse charge & current densities

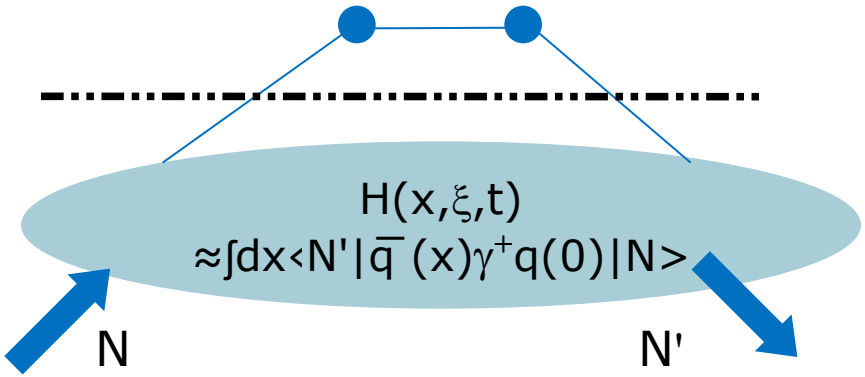
+

Structure functions, quark longitudinal momentum & helicity distributions

→

Correlated quark momentum and helicity distributions in transverse space - GPDs

Electromagnetic vertices



In a scattering process, they describe the hadronic bound state dynamics

GPDs are matrix elements of quark and gluons operators at a light-like separation. They depend on 3 variables:

- x
- t
- ξ

There are 4 GPD for each quark flavour: H, E, $\tilde{H}$, $\tilde{E}$

Link to known quantities:

DIS quantities@ξ=t=0:
H(x,0,0)=q(x), -q(-x)
$\tilde{H}$(x,0,0)=Δq(x), Δq(-x)

$$\int_0^1 dx \sum_q \left[H^q(x,\xi,t)\right] = \quad F_1(t) \text{ Dirac FF}$$

$$\int_0^1 dx \sum_q \left[E^q(x,\xi,t)\right] = \quad F_2(t) \text{ Pauli FF}$$

GPDs are also related to the quark angular momentum *via* the Ji's sum rule:

$$J^q = \frac{1}{2} - J^G = \frac{1}{2}\int_{-1}^{1} x dx \left[H^q(x,\xi,0) + E^q(x,\xi,0)\right]$$

X. Ji, Phy.Rev.Lett. 78,610(1997)

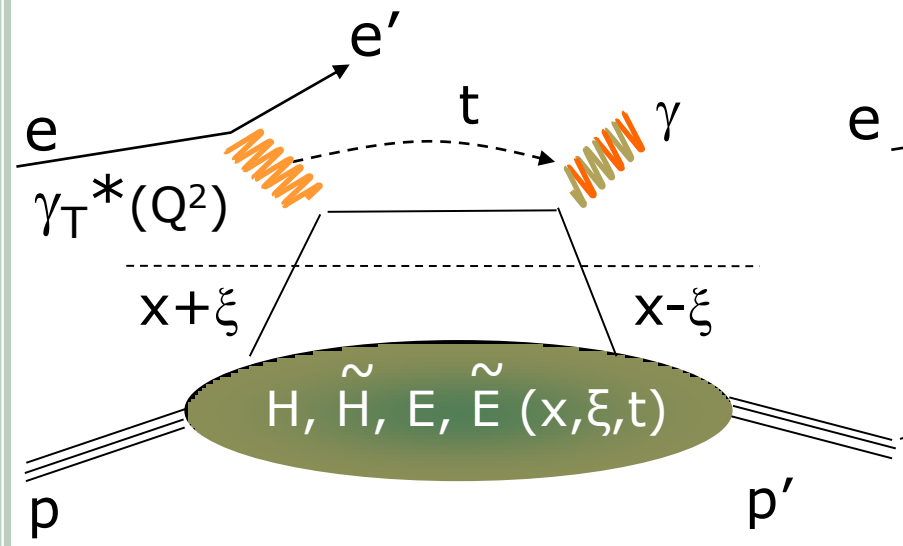
By using electromagnetic probes...

...one can test the relevant degrees of freedom inside the hadron, with a resolution depending on the exchanged four-momentum Q^2.

Two main processes can be used to access GPDs experimentally: **Deeply Virtual Compton Scattering** and **Deeply Virtual Meson Production**.

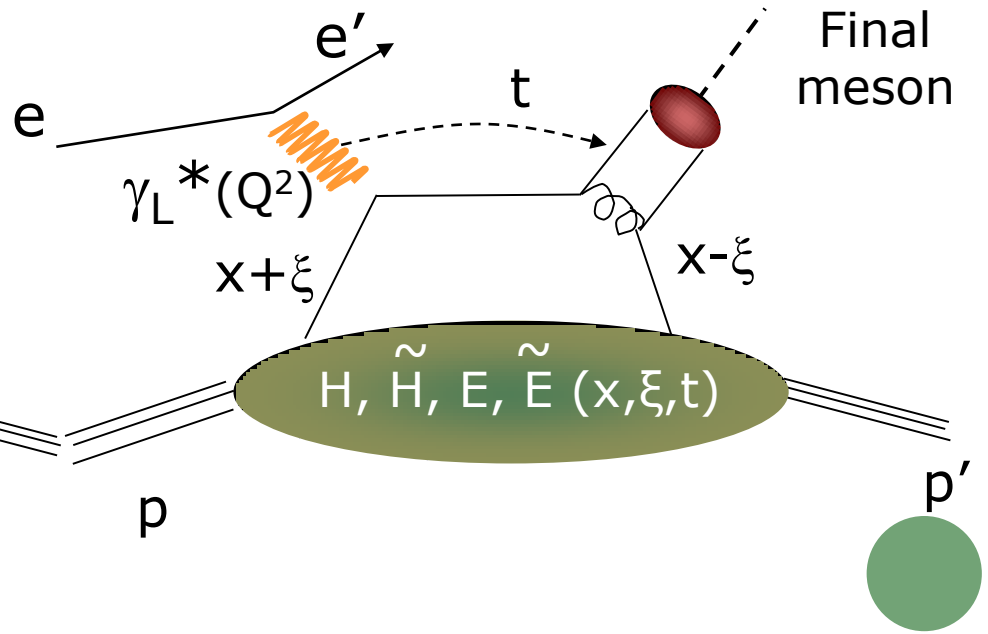
DVCS

$e\ p \rightarrow e'\ p'\ \gamma$



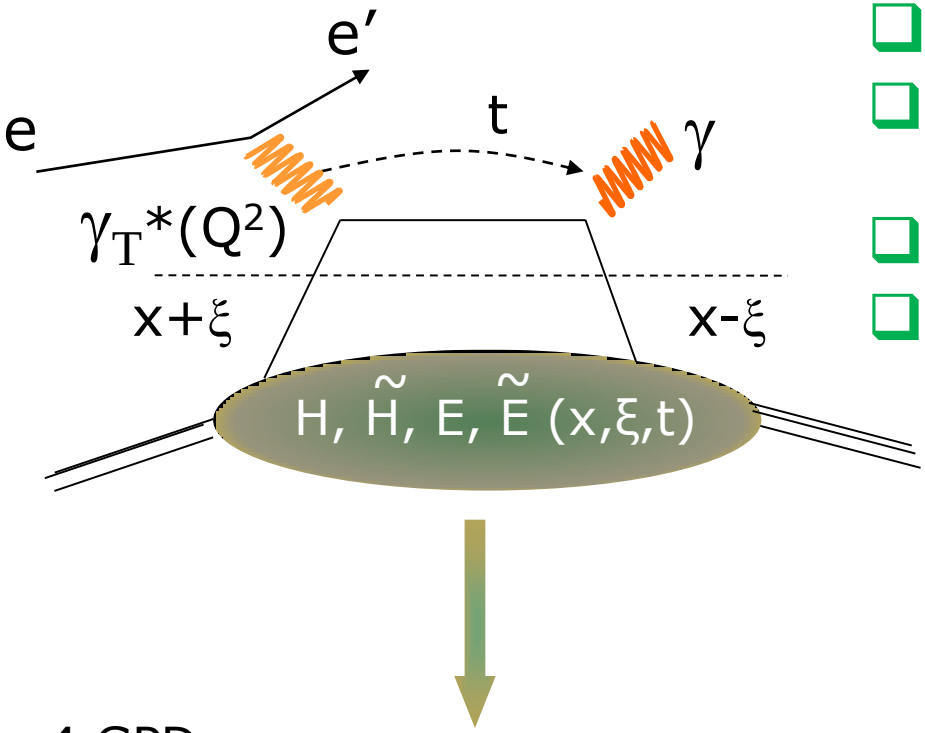
DVMP

$e\ p \rightarrow e'p'\pi, \rho, \omega...$



Deeply Virtual Compton Scattering

The most suitable process to extract GPDs is DVCS: it is described by the "Handbag" mechanism



- $Q^2 = -(e-e')^2$
- $x_B = Q^2/2M\nu$, $\nu = E_e - E_{e'}$
- $x+\xi$, $x-\xi$ longitudinal momentum fractions
- $t = (p-p')^2$
- $\xi \cong x_B/(2-x_B)$

handbag factorization valid at high Q^2 (fixed x_B) and small t

4 GPD:

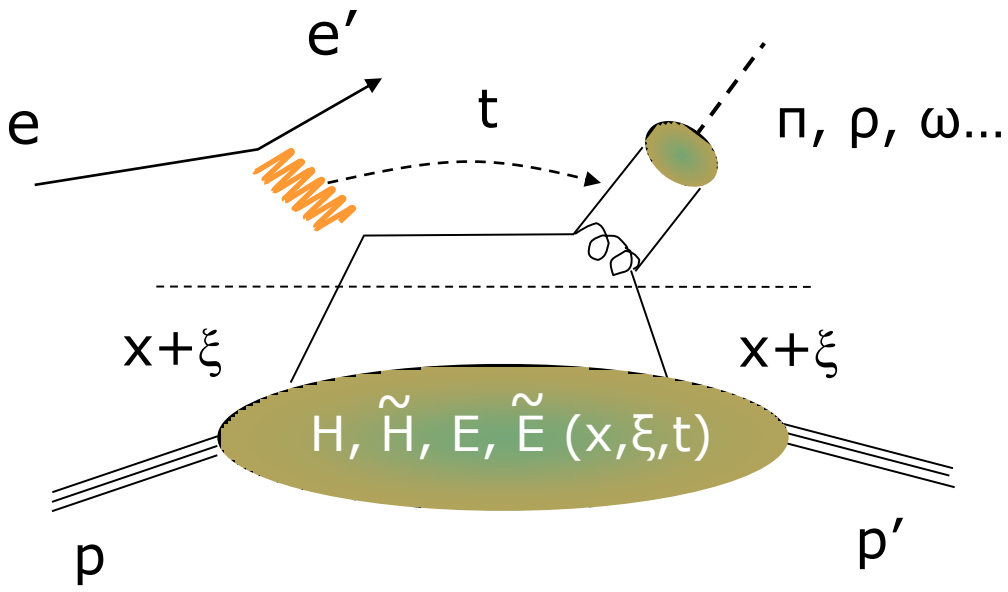
- Nucleon spin conserving: Vector $H(x,\xi,t)$ and Axial-Vector $\tilde{H}(x,\xi,t)$
- Nucleon spin non-conserving: Tensor: $\tilde{E}(x,\xi,t)$ and Pseudoscalar $E(x,\xi,t)$

Extraction of GPDs through DVMP

Depending on the nature of the meson produced, different GPDs will be accessed:

- E, H with vector mesons
- $\tilde{E}$, $\tilde{H}$ with pseudoscalar mesons

Quark flavour decomposition accessible *via* meson production



It is important to analyze the various channels

e p → e' p' ρ, ω, ϕ ...

in order to operate the decomposition!

π^0	$2\Delta u+\Delta d$
η	$2\Delta u-\Delta d$
ρ^0	$2u+d$
ω	$2u-d$
ρ^+	$u-d$

Physical observables: Asymmetries

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

Depending on the polarization degrees of freedom acting in the process different combinations of GPDs can be accessed.

- Polarized beam, unpolarized target
  - $\Delta\sigma_{LU} \sim \sin\phi\, \mathrm{Im}\{F_1 H + \xi(F_1 + F_2)\tilde{H} + kF_2 E\}d\phi$ → $\tilde{H}$
- Unpolarized beam, longitudinally polarizet target
  - $\Delta\sigma_{UL} \sim \sin\phi\, \mathrm{Im}\{F_1 \tilde{H} + \xi(F_1 + F_2)H + kF_2 E\}d\phi$ → H

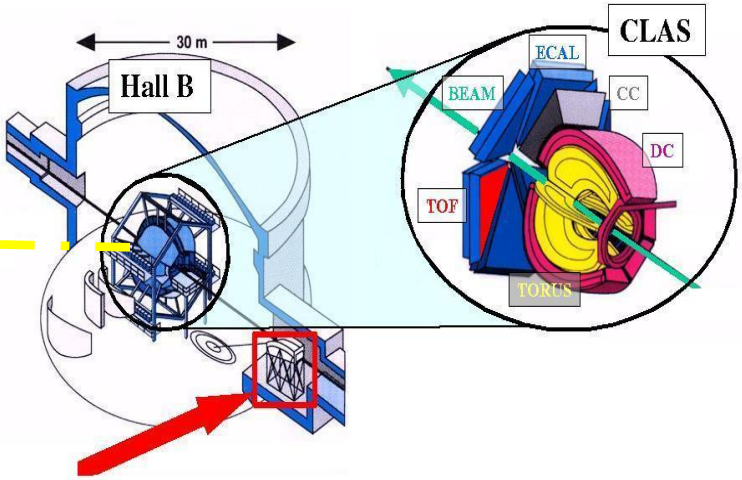
Kinematically suppressed terms

- Polarized beam, polarized target
  - $\Delta\sigma_{LL} \sim \cos\phi\, \mathrm{Re}\{F_1 \tilde{H} + \xi(F_1 + F_2)(H + \ldots\}d\phi$
- ..and other combinations are available.

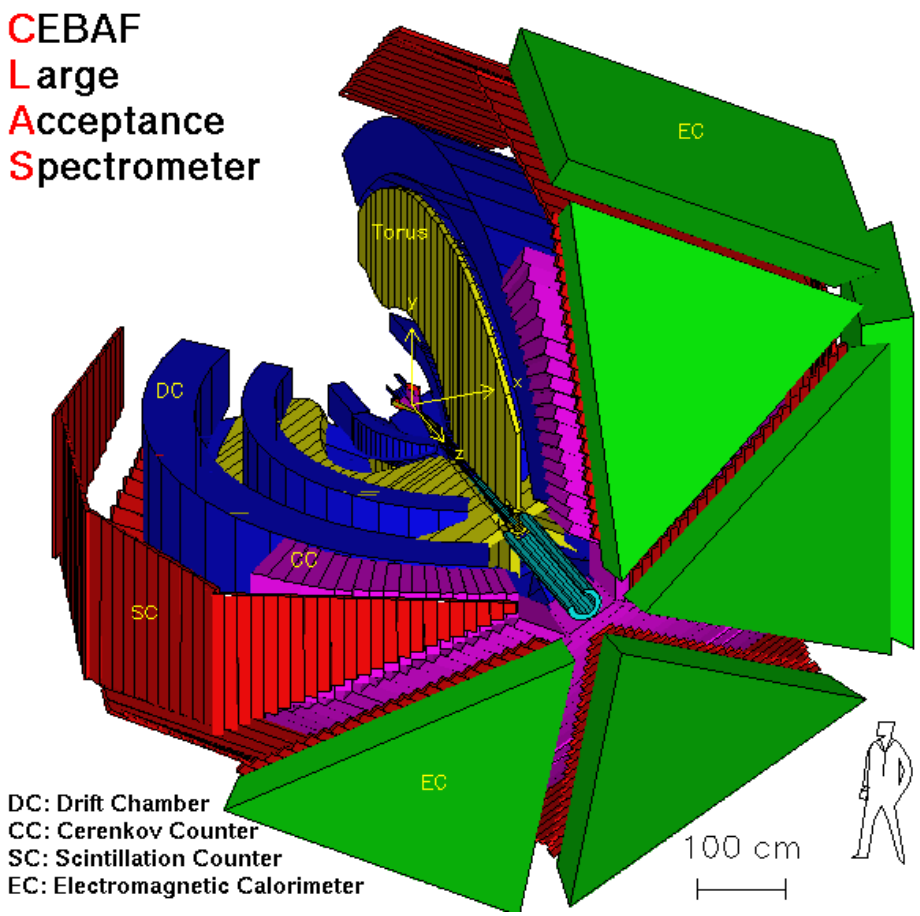
H, $\tilde{H}$, E: Compton Form Factors

CEBAF LARGE ACCEPTANCE SPECTROMETER @JLAB

- Duty Factor ~ 100%
- $\sigma_E/E \sim 2.5\ 10^{-5}$
- Beam Pol ~ 85%



The CLAS detector



- Toroidal magnetic field (6 supercondicting coils)
- Drift chambers (argon/CO2 Gas, 35000 cells)
- Time-of-flight scintillators
- Electromagnetic calorimeters
- Cherenkov counters (e/π separation)

- Performances:
- Nearly 4π acceptance
- Large kinematical coverage
- Detection of charged and neutral particles

CLAS selected results on GPDs

DVCS:

- **e1-dvcs** experiment: polarized beam, unpolarized target
  - Beam Spin Asymmetry
- **eg1-dvcs** experiment: polarized beam, polarized target
  - Target Spin Asymmetry
  - Double Spin Asymmetry

DVMP:

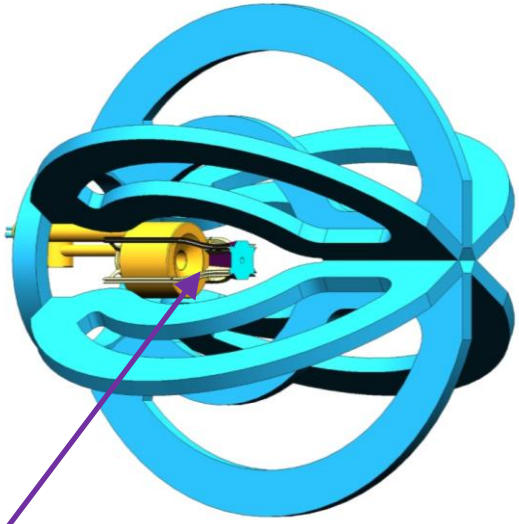
- **e1-6** experiment: e p $\rightarrow$ e p ρ^0
  - cross section
  - interpretations
- Other DVMP channels

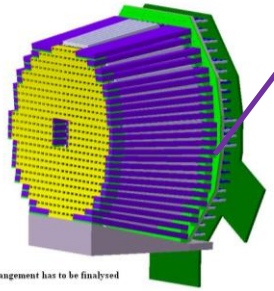
e1-dvcs: FIRST CLAS DVCS-DEDICATED EXPERIMENT

The final state to be detected is

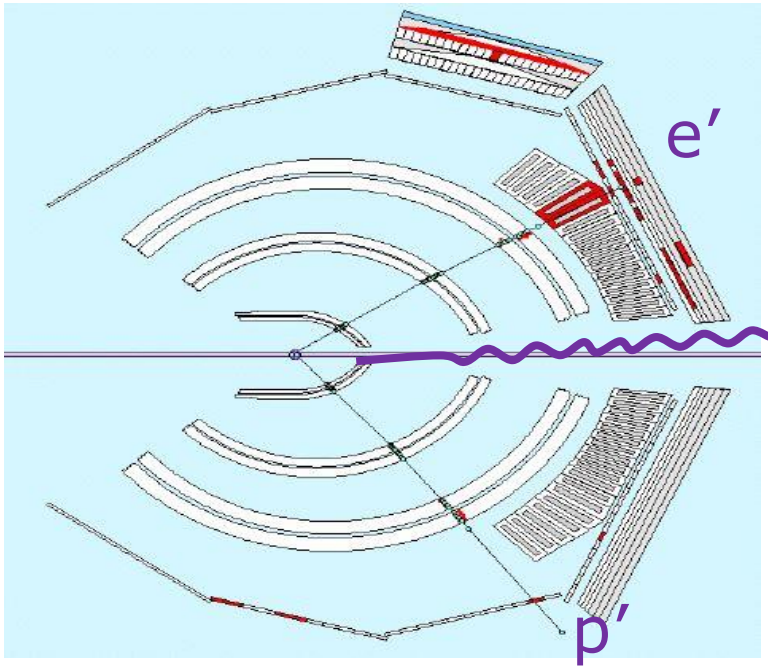
$$e\,p \rightarrow e'\,p'\,\gamma$$

An exclusive reconstruction of the final state is essential: in order not to lose high energetic (*forward*) dvcs photons, a new, forward electromagnetic calorimeter (IC) has been added





new acceptance with IC: θ [4°, 43°] (old: θ [17°,43°])

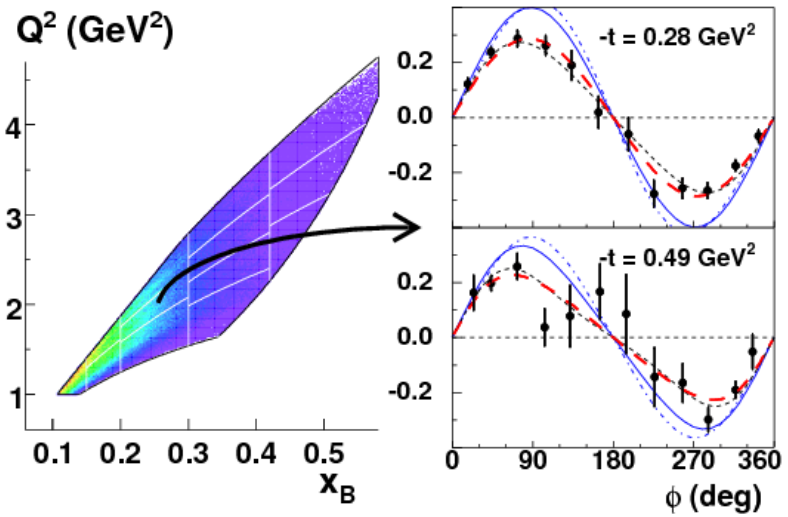


- Experiment: March - May 2005
- E_e = 5.75 GeV
- Beam polarization: 76% - 82%
- Current: 20-25 nA
- Integrated luminosity: 33.3 fb^{-1}

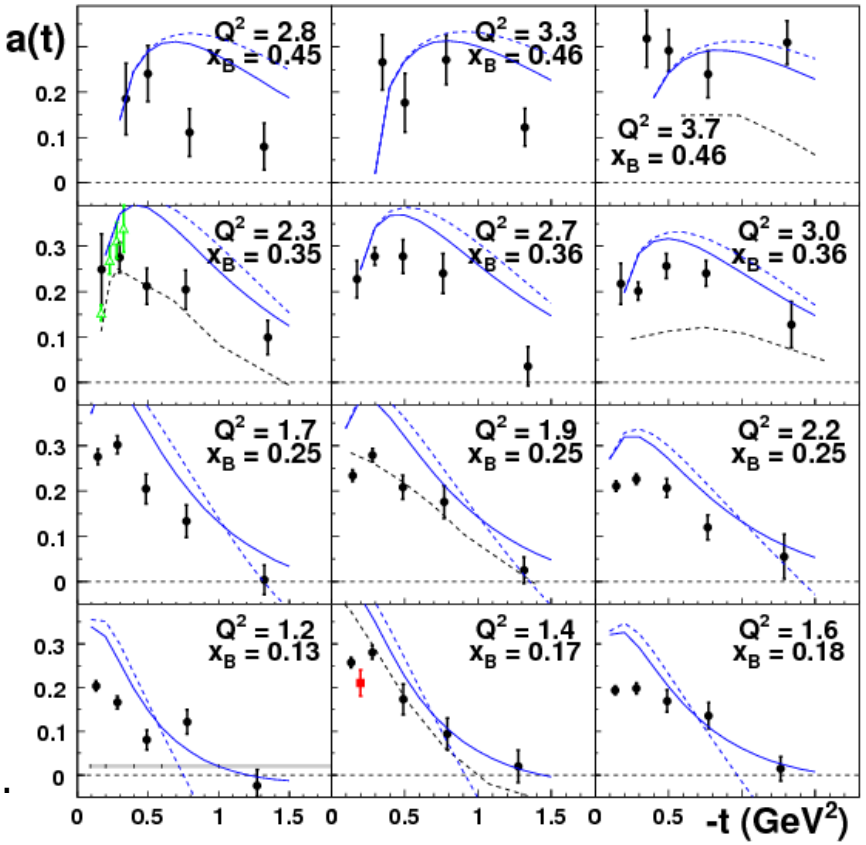
E1-DVCS: KINEMATICS AND BEAM-SPIN ASYMMETRY

F.X. Girod et al; Phys. Rev. Lett.100:162002,2008

x_B = 0.249,
Q^2 = 1.95 GeV^2



a = A(90◦) as a function of −t.



A ~ a *sin*ϕ/(1+c *cos*ϕ).

Black dashed curves: Regge calculation [*].
Blue curves: GPD calculation[**] at twist-2 (solid) and twist-3 (dot-dashed) levels, with H contribution only.

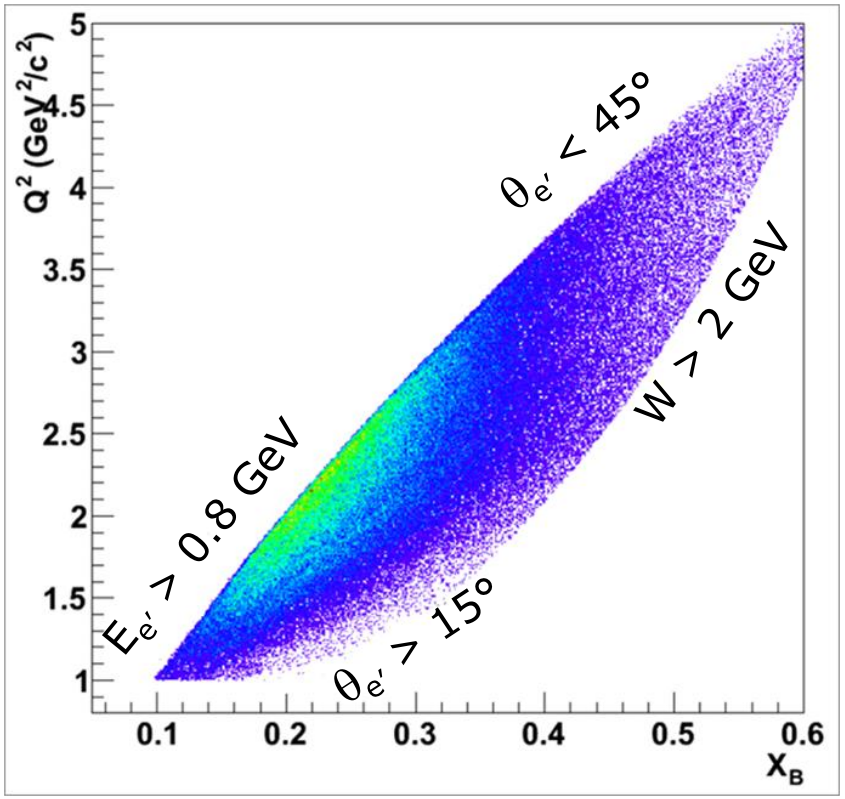
*J. M. Laget, Phys. Rev. C 76 (2007) 052201.

**M. Guidal, M.V. Polyakov, A.V. Radyushkin and M. Vanderhaeghen, Phys. Rev. D72 (2005) 054013.

DVCS WITH A LONGITUDINALLY POLARIZED TARGET: THE EG1-DVCS EXPERIMENT

In the period **February - September 2009** a new DVCS-dedicated experiment run.

- NH3 and ND3 polarized targets
- Thanks to the polarized target, two new asymmetries are accessible: a ***Target Spin Asymmetry*** (TSA) and a ***Double Spin Asymmetry*** (DSA)
- As in the e1-dvcs case, the inner calorimeter is added to detect the dvcs photons



See Andrey Kim's talk for more details on dvcs with the eg1-dvcs experiment!

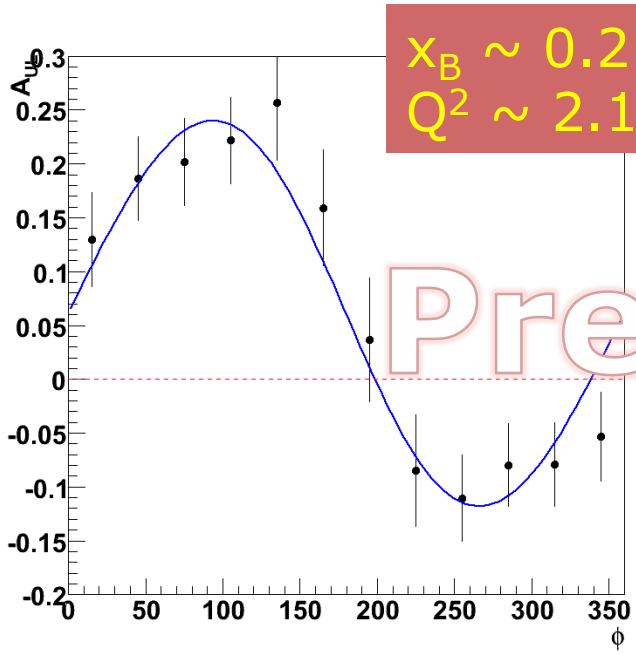
DVCS Target Spin Asymmetry

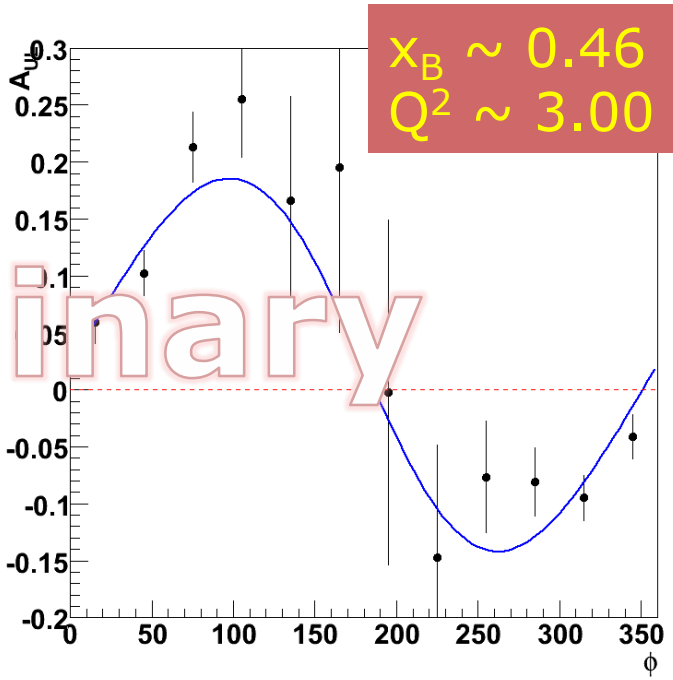
$$A_{UL} = \frac{1}{f P_T} \frac{(N^+ - N^-)}{(N^+ + N^-)}$$

- $N^{+(-)}$: number of DVCS events with a positive (negative) target polarization
- $P^{+(-)}$: target polarization
- f: dilution factor

Fitting function:

$$A_{UL} \sim \alpha \sin\Phi + \beta \sin 2\Phi$$





Preliminary

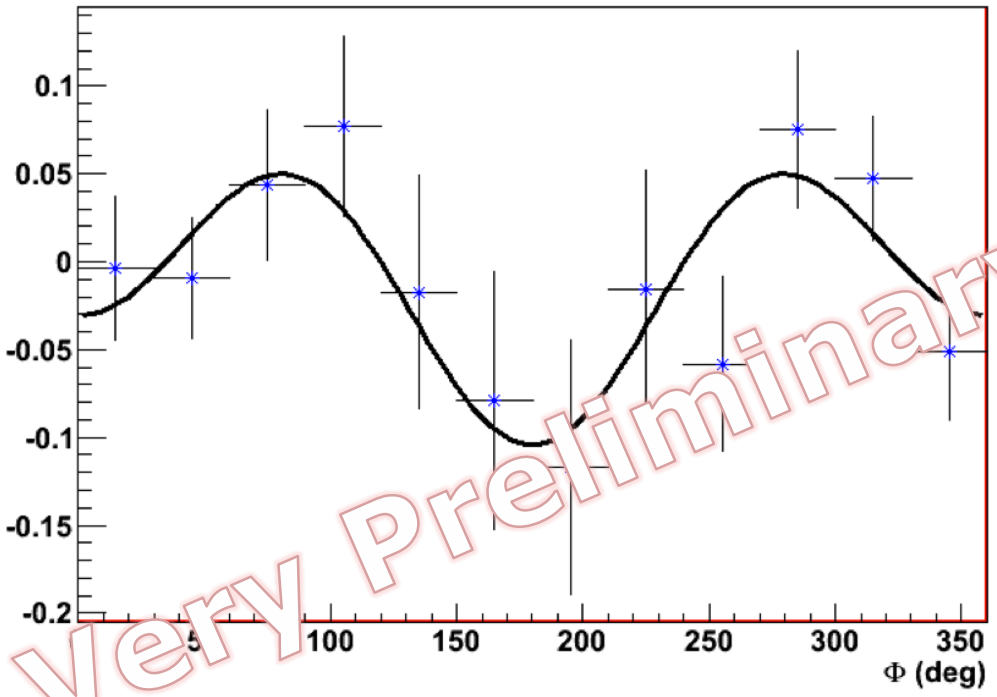
Plots and analysis done by Erin Seder

DVCS Double Spin Asymmetry

$$A_{LL} = \frac{1}{f P_{beam} P_T} \frac{(N^{++}+N^{--}) - (N^{+-}+N^{-+})}{(N^{++}+N^{--}) + (N^{+-}+N^{-+})}$$

Fitting function:

$$A_{LL} \sim \alpha + \beta \cos\varphi + \gamma (\cos\varphi)^2 + \delta (\sin\varphi)^2$$



- $N^{++(+/-)}$: number of DVCS events with a positive (negative) target polarization & a positive (negative) beam helicity
- $P_{beam/T}$: beam/target polarization
- f: dilution factor

EG1-DVCS: NEXT IMPROVEMENTS

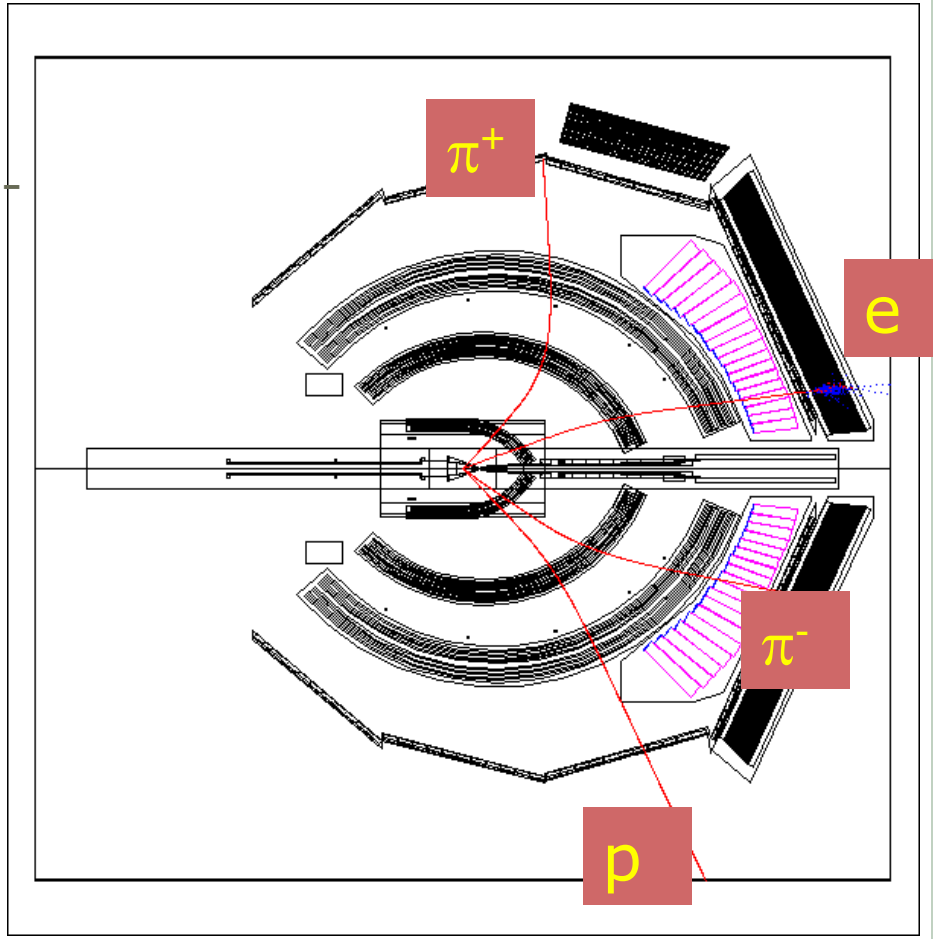
Eg1-dvcs analyses are still on-going. Further improvements are expected, as:

- Nitrogen background evaluation
- Improvements in the calibration
- Subtraction of the π^0 contribution to the DVCS channel
- MC studies for a better background subtraction

Furthermore, other analyses are ongoing with eg1-dvcs data, as e p -> e p π^0 and nDVCS

E1-6 EXPERIMENT@CLAS

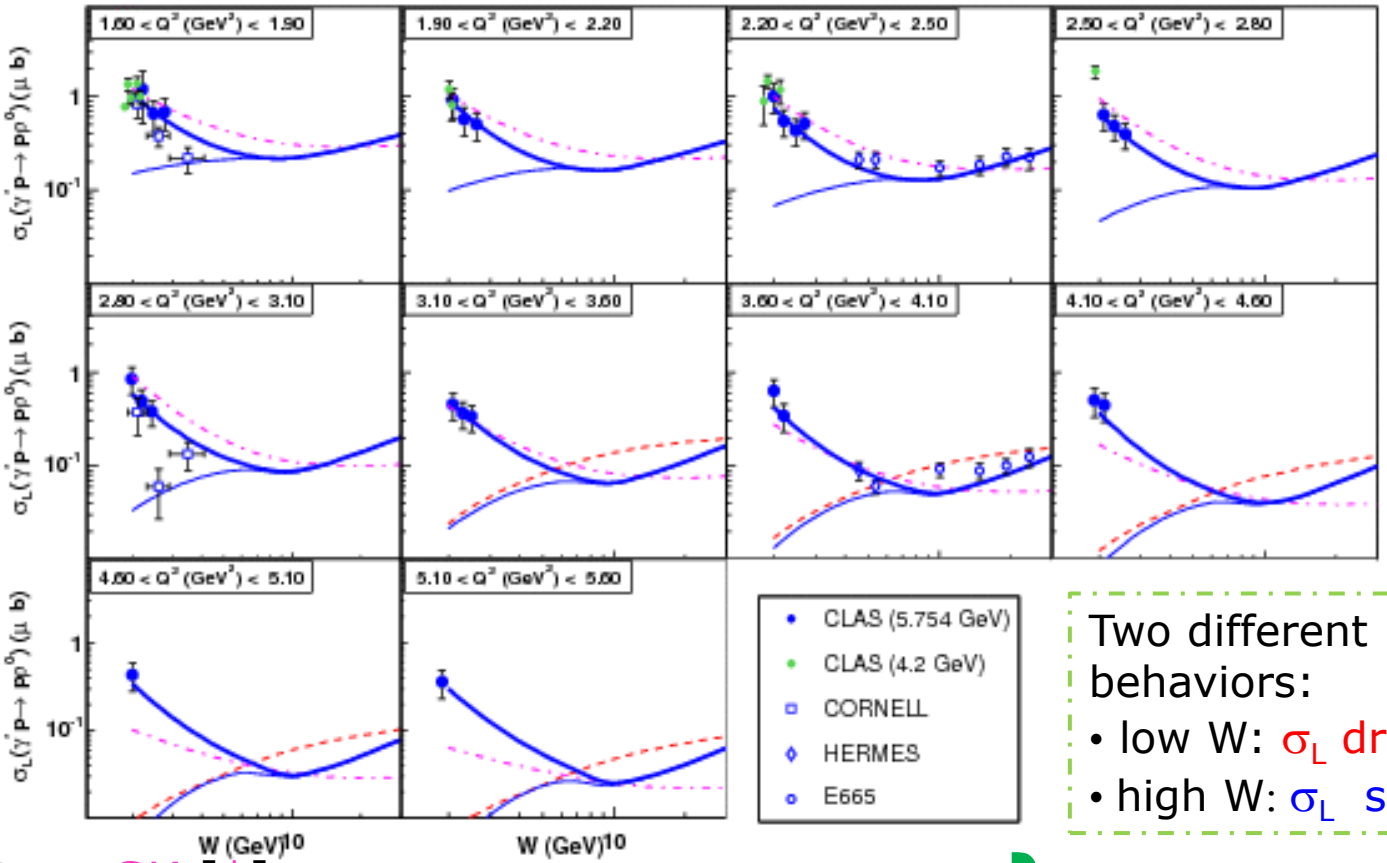
$e\ p \rightarrow e\ p\ \rho^0 \rightarrow e\ p\ \pi^+\ \pi^-$



- E_e = 5.754 GeV
- 5-cm-long liquid H target
- 1.8 < W (GeV) < 2.8
- L = 28.5 fb^{-1}

Since the factorization theorems for the meson electroproduction have been proven only for the longitudinal component of the cross-section, a transverse-longitudinal separation is needed for $\sigma_{(\gamma p \rightarrow p \rho 0)}$. Such a separation is realized by analyzing the decay-pion angular distribution in the ρ^0 center of-mass frame and relying on the s-channel helicity conservation.

Longitudinal cross section σ_L ($\gamma^*_L P \to P\rho_L^0$)



S. Morrow et al., Eur. Phys. J. A 39 (2009) 5.

Two different behaviors:
- low W: σ_L drops
- high W: σ_L slowly rises

- --- GK [*]
- - thin blue VGG [*]
- - thick blue VGG + strong D-term [*]

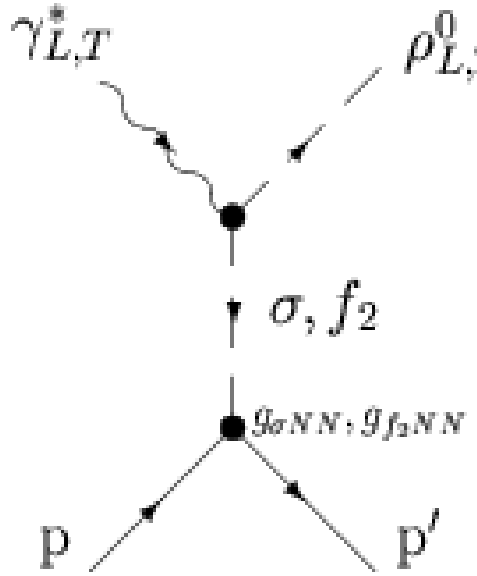
} GPD approaches based on Double-Distributions

- -.-.- dash-dotted JLM calculation *à la* Regge [*] } Hadronic approach

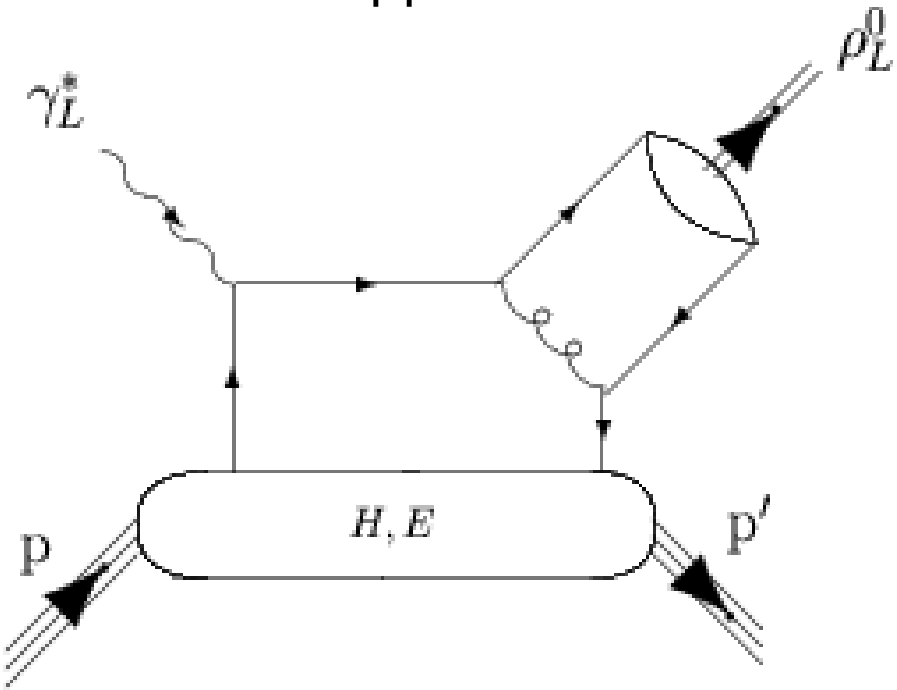
* K. Goeke *et al.*, Prog. Part. Nucl. Phys. 47 (2001) 401.
* M. Guidal, M.V. Polyakov, A.V. Radyushkin and M. Vanderhaeghen, Phys. Rev. D72 (2005) 054013.
* F. Cano and J.-M. Laget, Phys. Rev. D 65 (2002) 074022

Interpretations

Reggeized meson Exchange approach



"handbag" diagram approach



partonic descriptions are expected to be valid at large Q^2, while hadronic descriptions dominate in low-Q^2 electroproduction

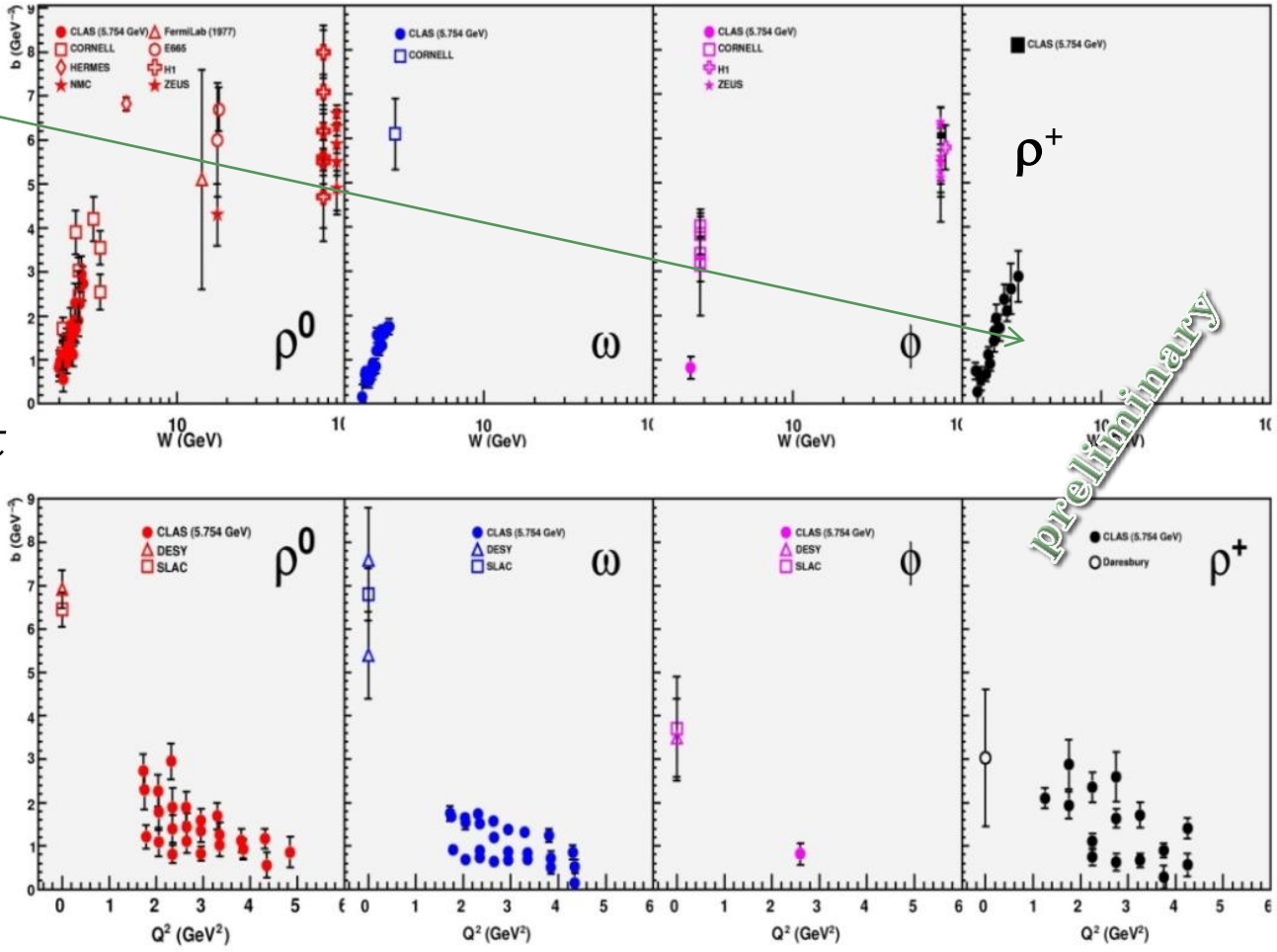
DVMP: OTHER CHANNELS

- *C. Hadjidakis et al., Phys.Lett.B605:256-264, 2005:* e p -> e p ρ^0 *@4.2 GeV*
- *L. Morand et al., Eur.Phys.J.A24:445-458, 2005:* e p -> e p ω *@5.75 GeV*
- *K. Lukashin, Phys.Rev.C63:065205, 2001: ϕ@4.2 GeV):* e p -> e p ϕ *@4.2 GeV*
- *J. Santoro et al., Phys.Rev.C78:025210, 2008:* e p -> e p ϕ *@5.75 GeV*

Ongoing analyses:

- e p -> e p π^0
- e p -> e p ρ^+

$$\frac{d\sigma}{dt} \sim \sqrt{-t} e^{bt}$$

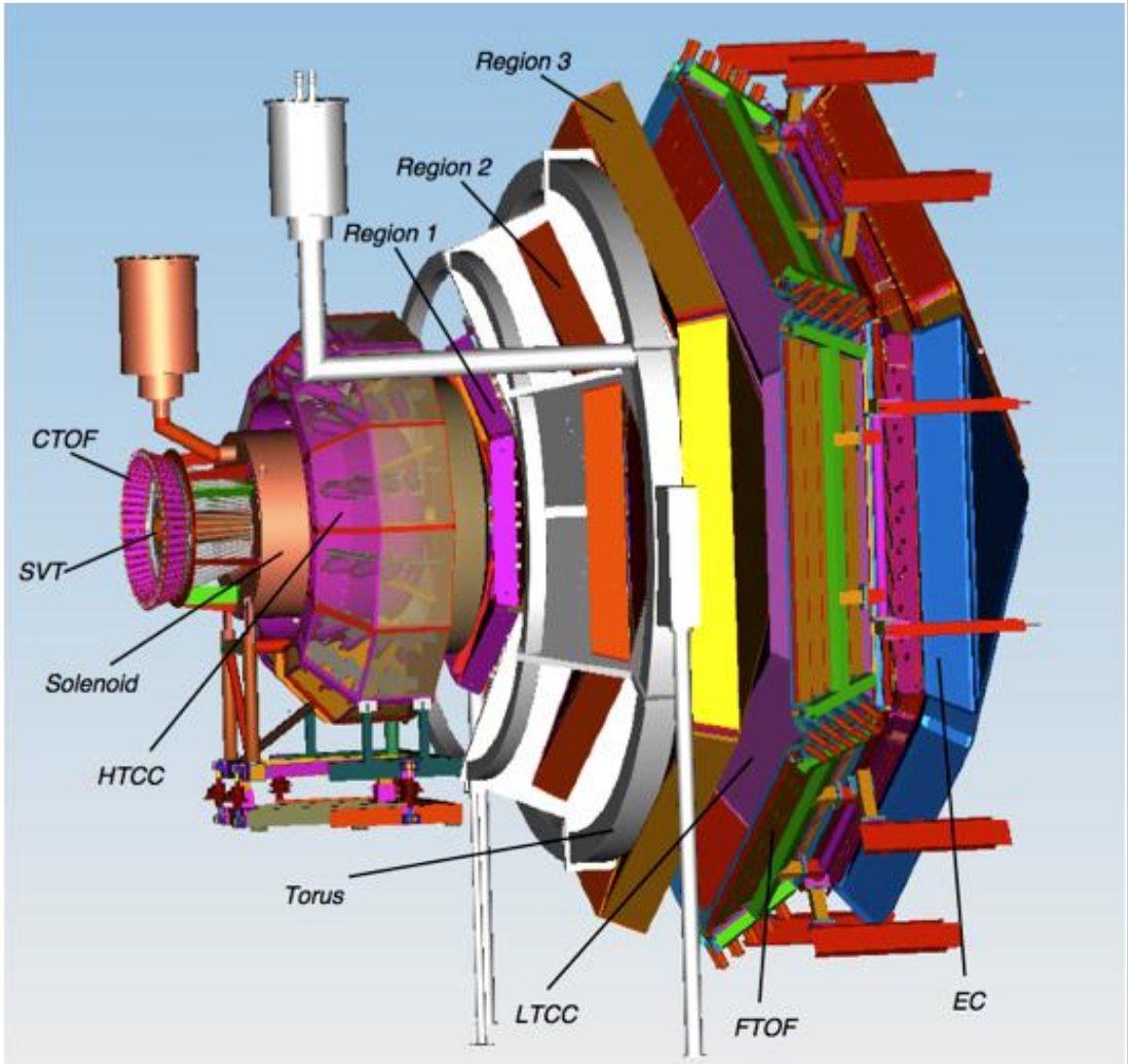


GPDs@CLAS12

GPD is one of the main subjects of the 12 GeV Hall-B physics program

Broadened kinematic coverage

Energy upgrade and higher luminosity: *beam energy up to 11 GeV for Hall-B*

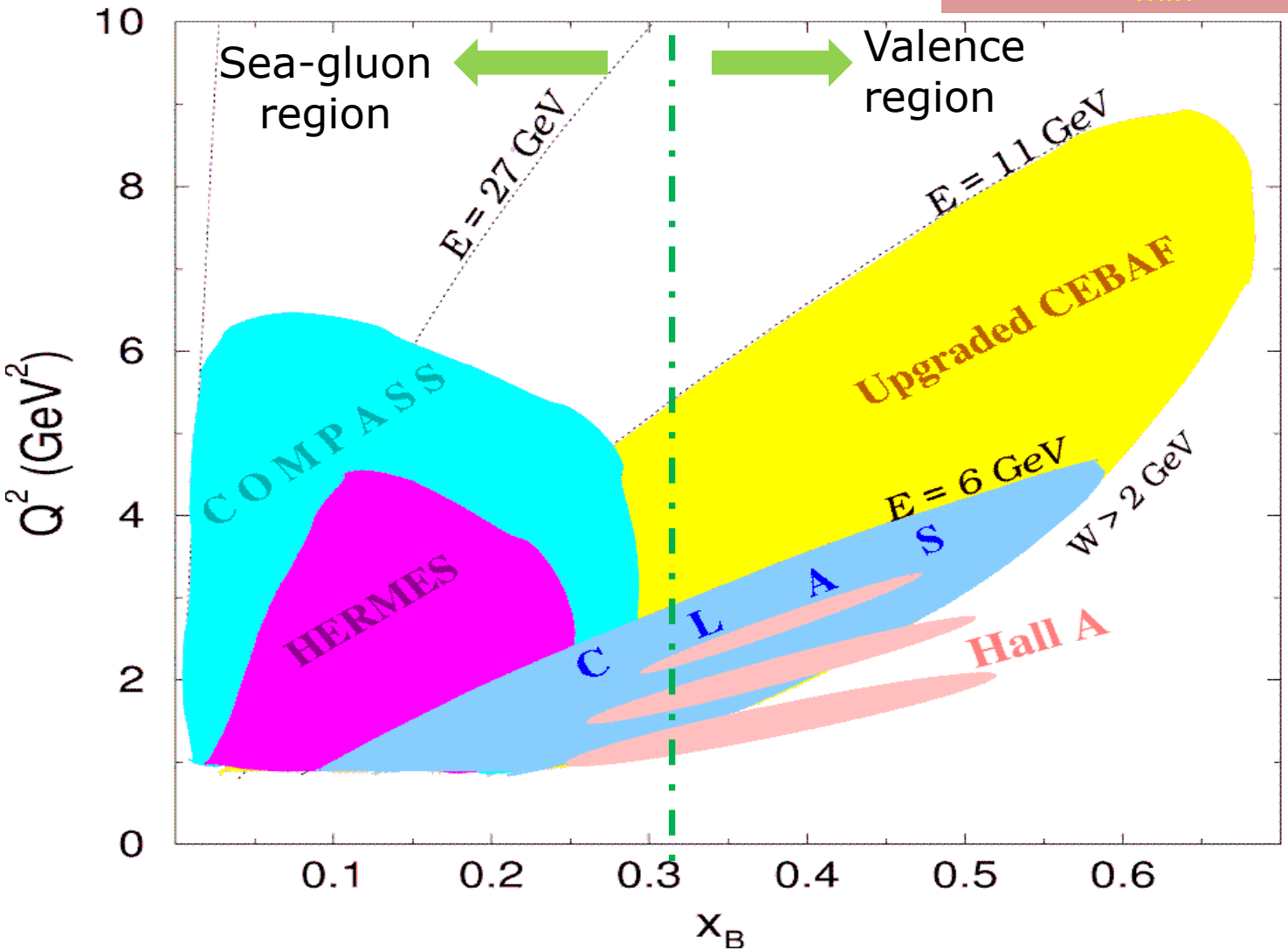


GPDs@CLAS12: KINEMATICS

Deeply virtual exclusive processes kinematics@CLAS12

High precision DVCS data for:

- $Q^2 = 1.0 \div 7.5\ GeV^2$
- $X_B = 0.1 \div 0.65$
- $-(t-t_{min}) < 1.5\ GeV^2$



Broad DVCS program@CLAS12!

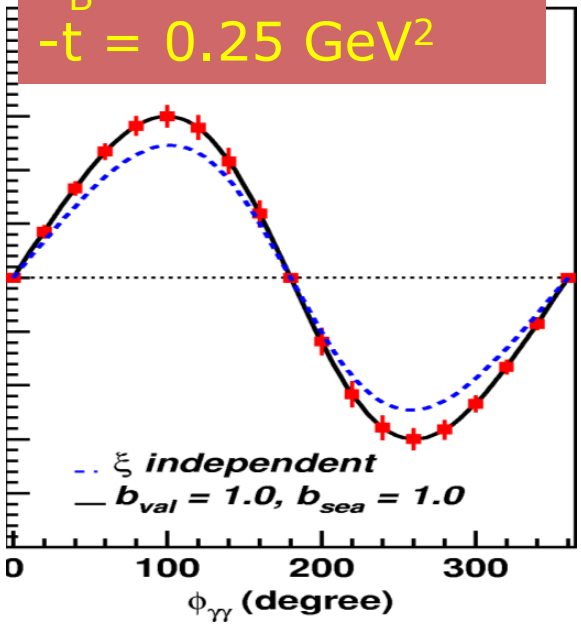
Various DVCS related measurements will be available in the wider kinematic range of CLAS12:

- Beam Spin Asymmetry
- Target Spin Asymmetry with a **longitudinally** polarized target @11 GeV
- nDVCS: DVCS on the neutron will be studied with CLAS12
  - access to the GPD E
- Target Spin Asymmetry with a **transversely** polarized target @11 GeV. It gives access to the GPD E&H
- $e\, p^{\uparrow} \rightarrow e\, p\, \rho 0$
- Furthermore, CLAS12 will allow us to measure DVCS polarized and unpolarized cross sections, vector and pseudo-scalar meson electroproduction…

R&D underway

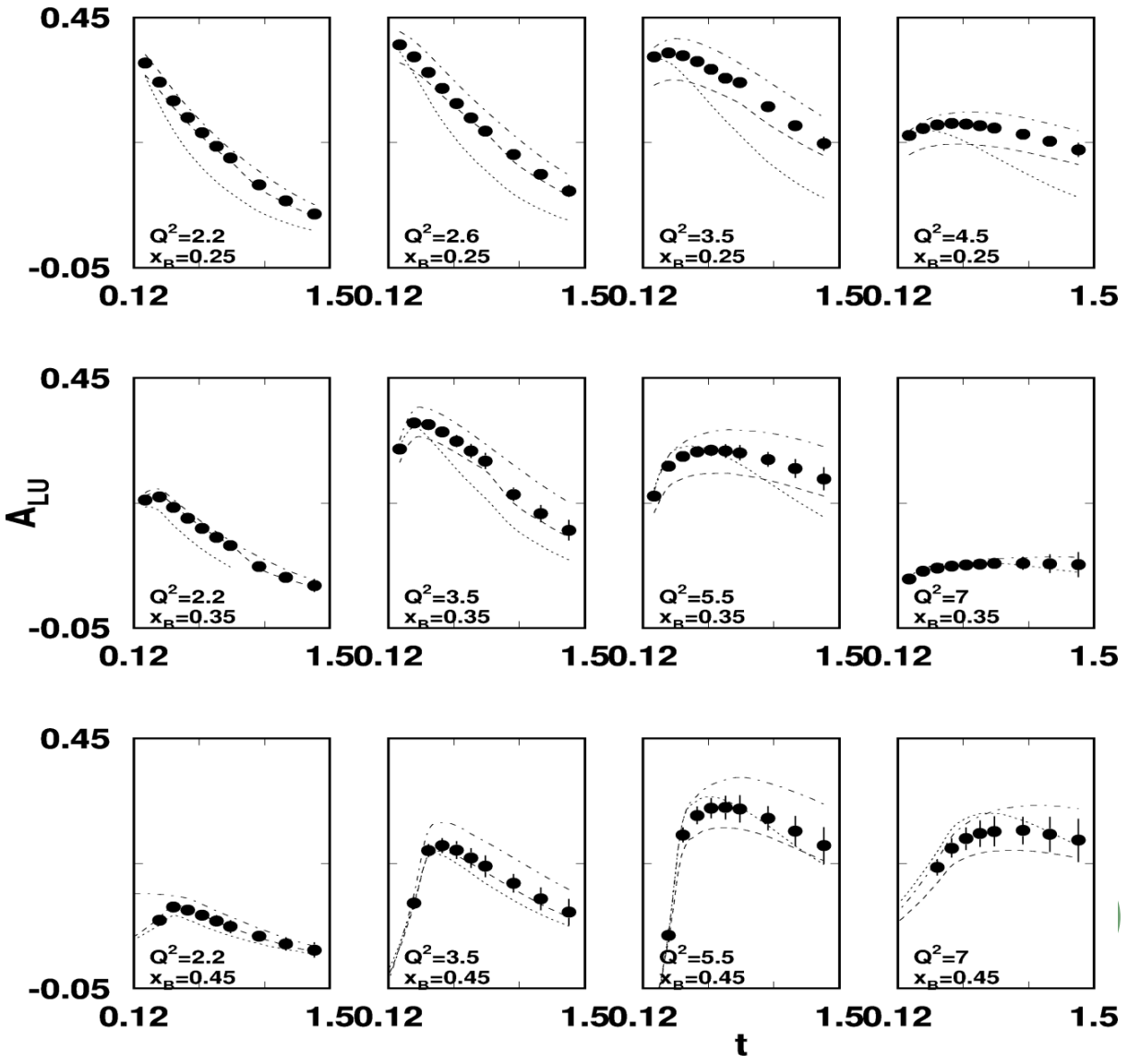
DVCS BSA @11GeV

Q^2 = 5.5 GeV^2
x_B = 0.35
-t = 0.25 GeV^2



- L = 1 x 10^{35}
- T= 2000 hrs

Projected BSA at 11GeV



CLAS12: Neutron DVCS

nDVCS is a strategic process to complete the information of the nucleon structure in terms of GPDs

It plays a role complementary to the proton DVCS, giving access at the less known and constrained GPD, ***E***

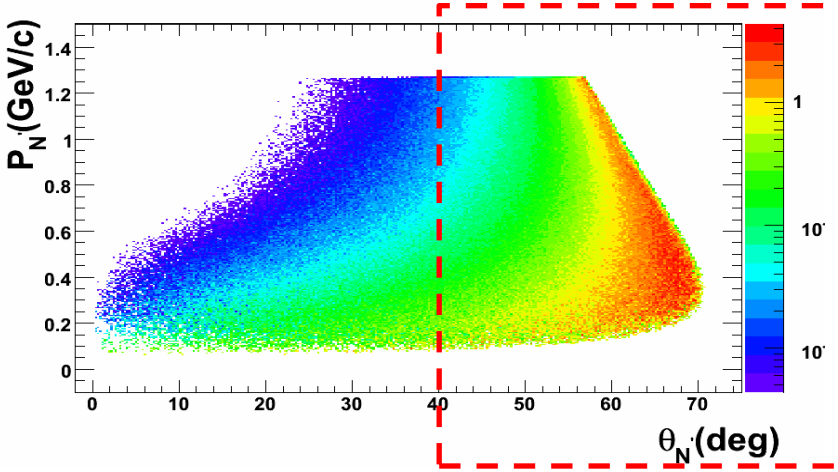
It allows, e.g., flavour decomposition:

$$H^p(\xi,\xi,t)=\frac{4}{9}H^u(\xi,\xi,t)+\frac{1}{9}H^d(\xi,\xi,t)$$

$$H^n(\xi,\xi,t)=\frac{1}{9}H^u(\xi,\xi,t)+\frac{4}{9}H^d(\xi,\xi,t)$$

E enters in the Ji's sum rule!

$$J^q=\frac{1}{2}-J^G=\frac{1}{2}\int_{-1}^{1}xdx\left[H^q(x,\xi,0)+E^q(x,\xi,0)\right]$$



more than 80% of them will have a $\theta > 40°$, that is it will be on the region covered by Central Detector

SUMMARY&CONCLUSIONS

- DVCS is the cleanest reaction giving access to GPDs
- e1-dvcs@CLAS → first extraction of BSA and polarized and unpolarized cross sections (analysis in progress)→ strong constraint for GPD models -> evidence for handbag dominance at modest Q^2
- $e\,p \rightarrow e'p'\rho^0$: at low W a hadronic approach seems to describe better the data, while at higher W the GPD approach starts to be effective
- DVMP cross-sections analysis are underway using e1-dvcs data → the aim is the flavour decomposition of GPD through the different channels: $ep\pi^0$, $ep\eta$, $ep\rho^+$
- TSA&DSA analyses in progress with polarized target data (eg1-dvcs)
- The JLab 12 GeV upgrade is essential for the study of **3-D nucleon structure** in the **valence region** with high precision, allowing the measurement of **deeply virtual exclusive processes** with polarized beam and polarized targets
- **CLAS12** will be world wide **the only full acceptance**, general purpose detector for **high luminosity** electron scattering experiments
- The experimental program of CLAS12 will provide new insight into 3D structure of the nucleon's interior and correlations
- The first 11 GeV electron beam is expected to hit the CLAS12 target at the **end of 2014**

Backup

GPD-RELATED EXPERIMENTS

Various experiment have been performed with the CLAS detector, that produced/are going to produce GPD-related results.

Unpolarized target

- e1-6
  - Data taking in 2001
  - Unpolarized H2 target
  - Measurement of the DVMP process e p -> e p ρ^0

  S. Morrow et al., Eur. Phys. J. A 39 (2009) 5.

- e1-dvcs
  - Data taking in 2005
  - Unpolarized H2 target
  - Measurements of the DVCS Beam Spin Asymmetry

  F.X. Girod et al; Phys. Rev. Lett.100:162002,2008

Polarized target

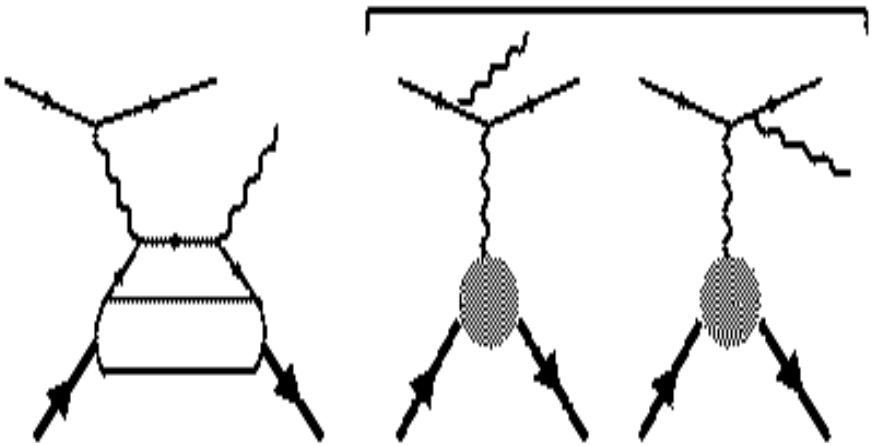
- eg1
  - Data taking in 2001
  - ^{3}NH & ^{3}ND target
  - First measurements of the DVCS Target Spin Asymmetry

  S. Chen et al., Phys. Rev. Lett. 97, 072002 (2006).

- eg1-dvcs
  - Data taking in 2009
  - $^{14}NH_3$ & ^{14}ND target
  - Measurements of the DVCS Target Spin Asymmetry

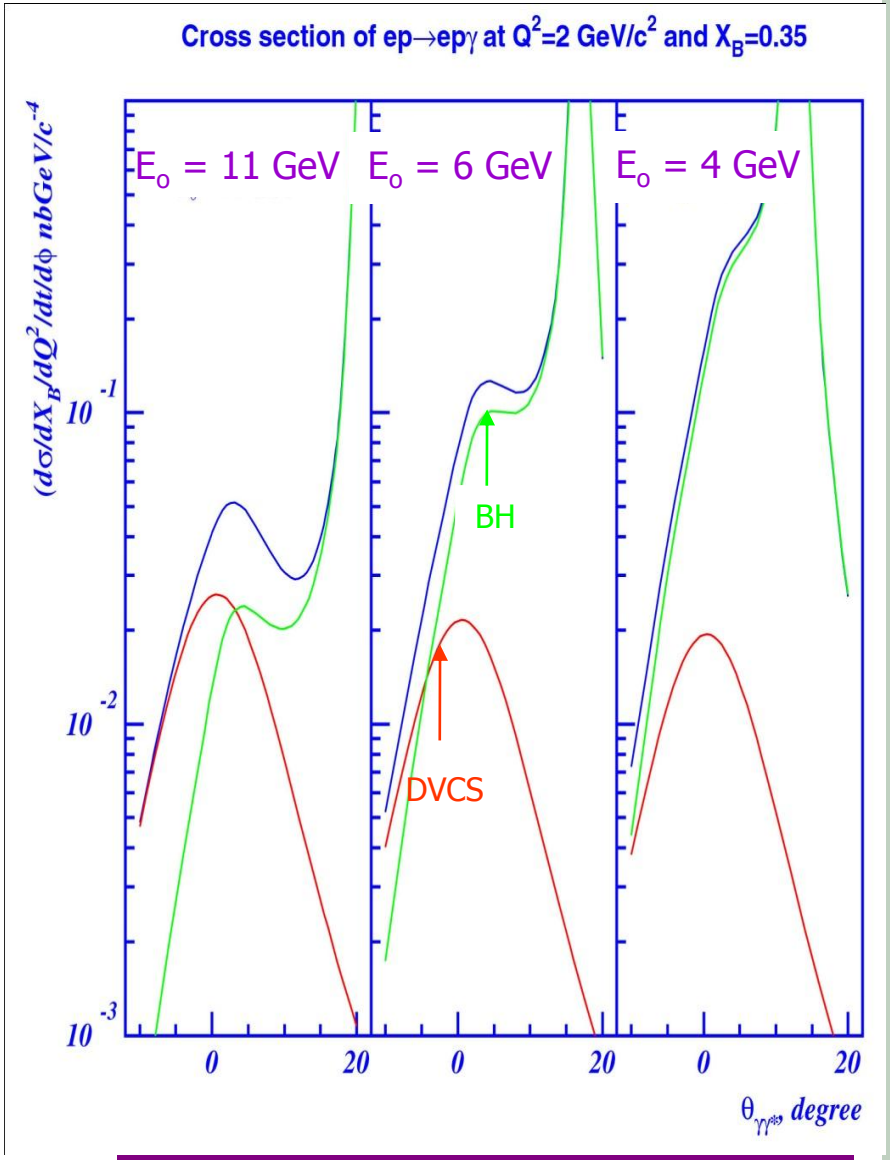
ACCESSING GPDS THROUGH DVCS

Two main mechanisms contribute to the process
e p → e' p' γ:
DVCS and Bethe-Heitler



DVCS

Bethe-Heitler

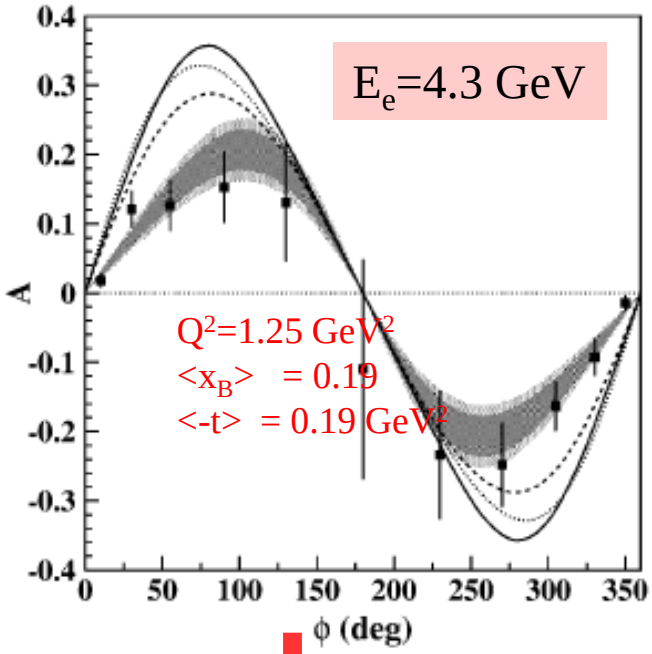


BH dominates at low energy

DVCS@CLAS: FIRST ASYMMETRIES

$e\,p \rightarrow e\,p\,X$

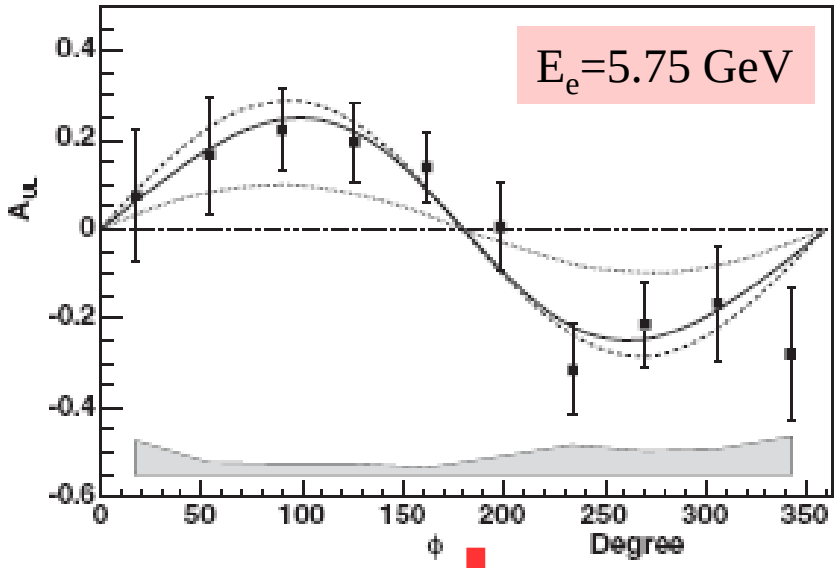
S. Stepanyan et al., PRL 87 (2001)



Beam Spin Asymmetry → H

$e\,p \rightarrow e\,p\,\gamma$

S. Chen et al., PRL 97 (2006)

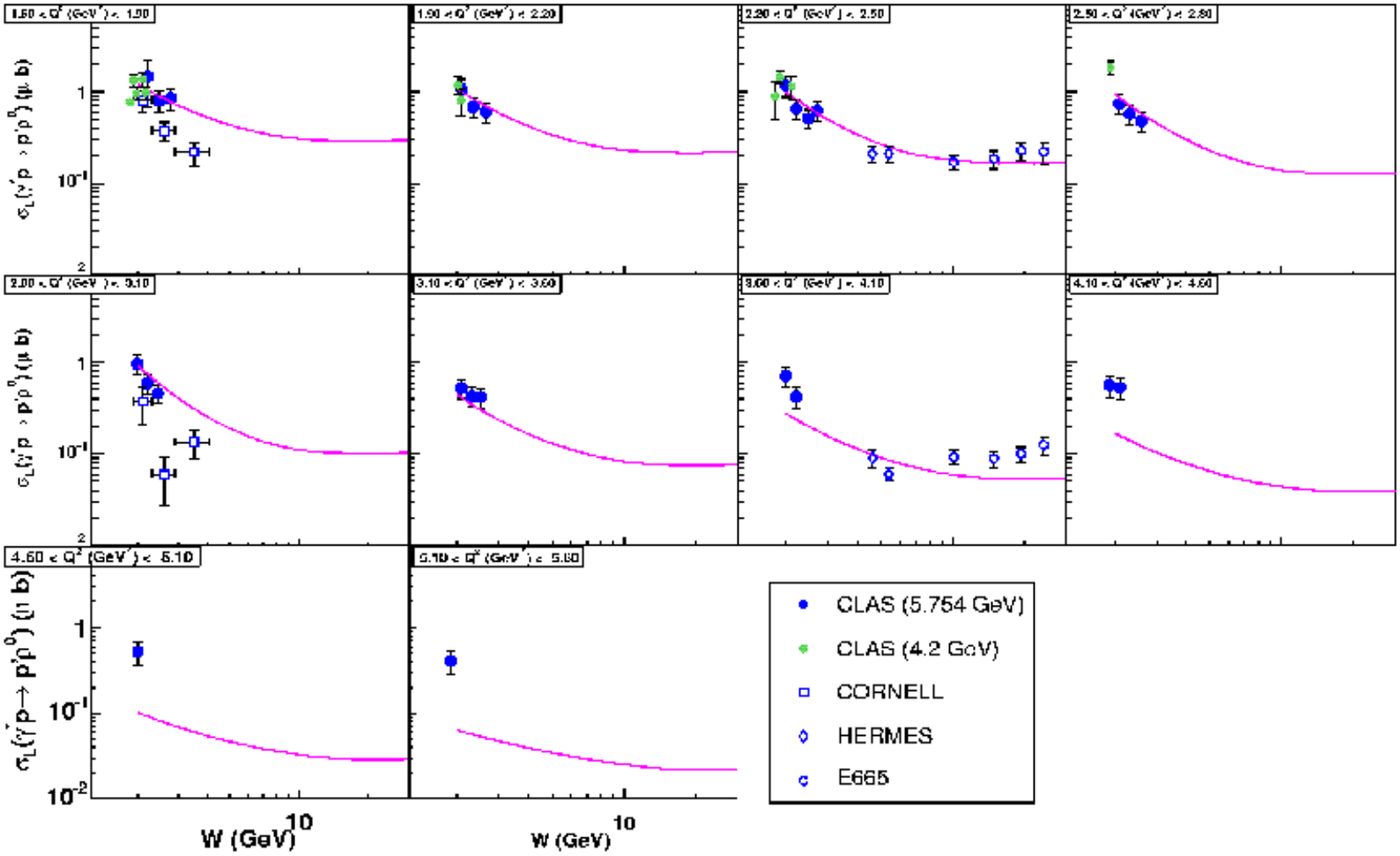


Target-Spin Asymmetry → H, H

$A \sim \alpha \sin\phi + \beta \sin 2\phi$ ➡ $\beta \sim 0$ confirms twist-2 dominance

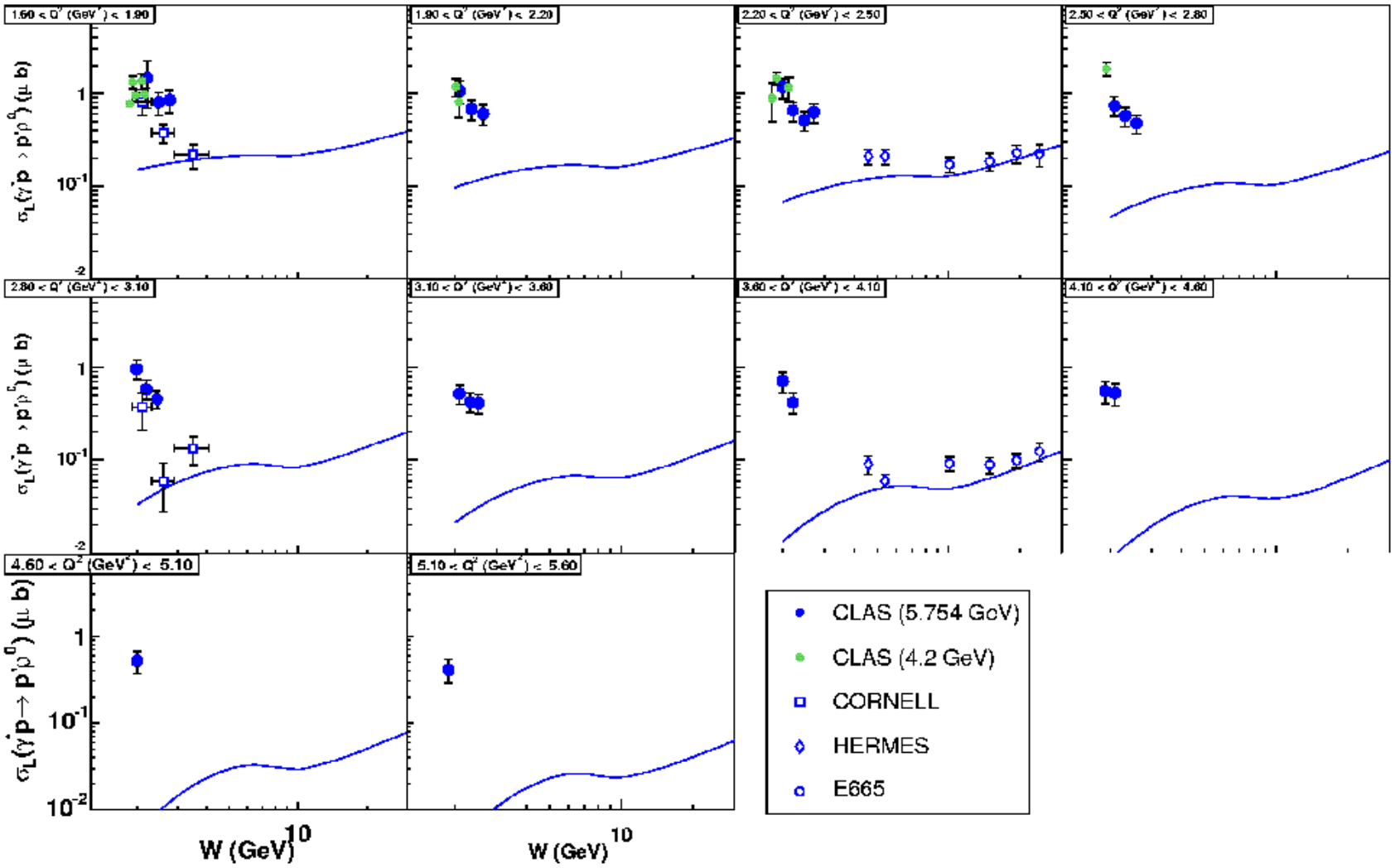
E1-6 Backup

"Hadron" Interpretation



F. Cano and J.-M. Laget, Phys. Rev. D 65 (2002) 074022

GPD Interpretation



M. Vanderhaeghen, P.A.M. Guichon, and M. Guidal, Phys. Rev. Lett. 80 (1998) 5064; Phys. Rev. D 60 (1999) 094017;

E1-DVCS Backup

Eg1-dvcs Backup

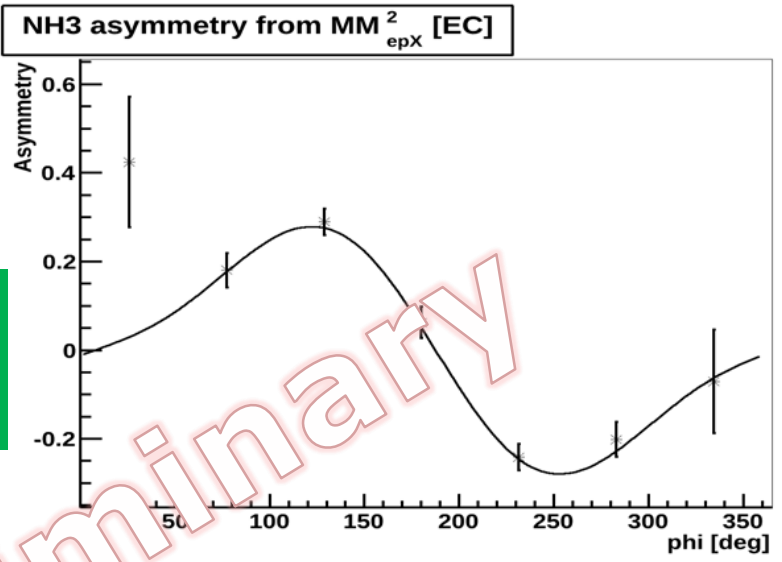
DVMP@EG1-DVCS: $e\ p \rightarrow e\ p\ \pi^0$

Target spin asymmetry for the channel

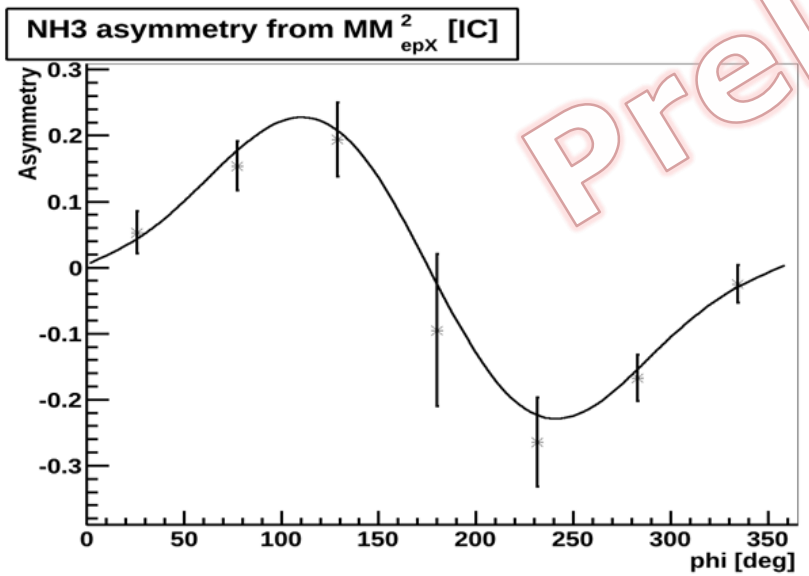
$e\ p \rightarrow e\ p\ \pi^0$

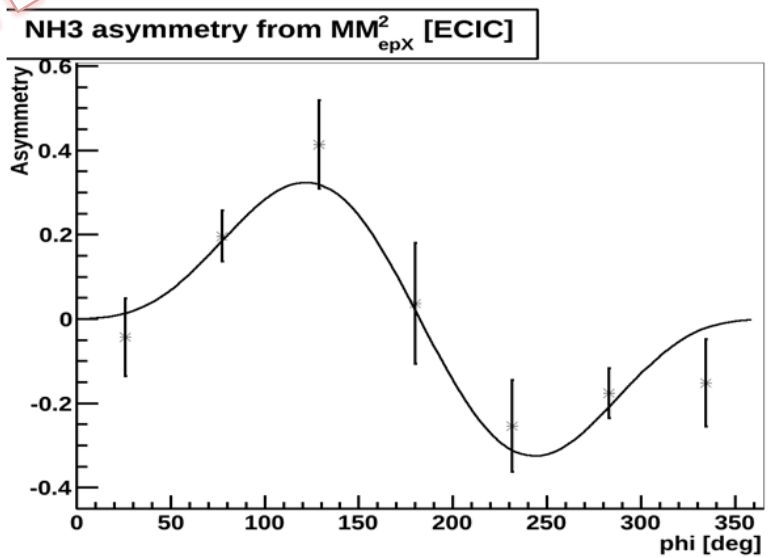
The superimposed fitting function is

$A = a \sin\phi + b \sin 2\phi$



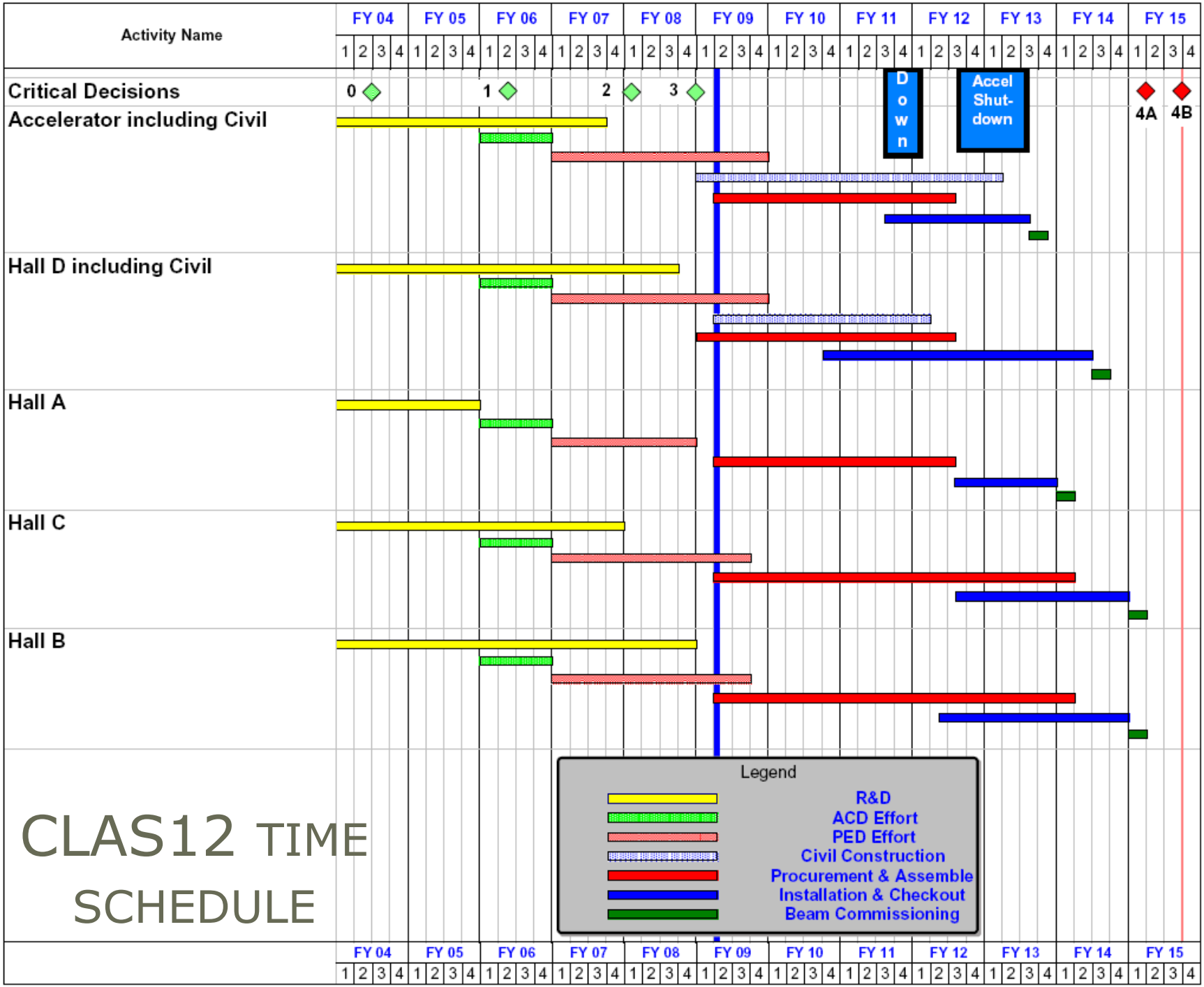
Preliminary



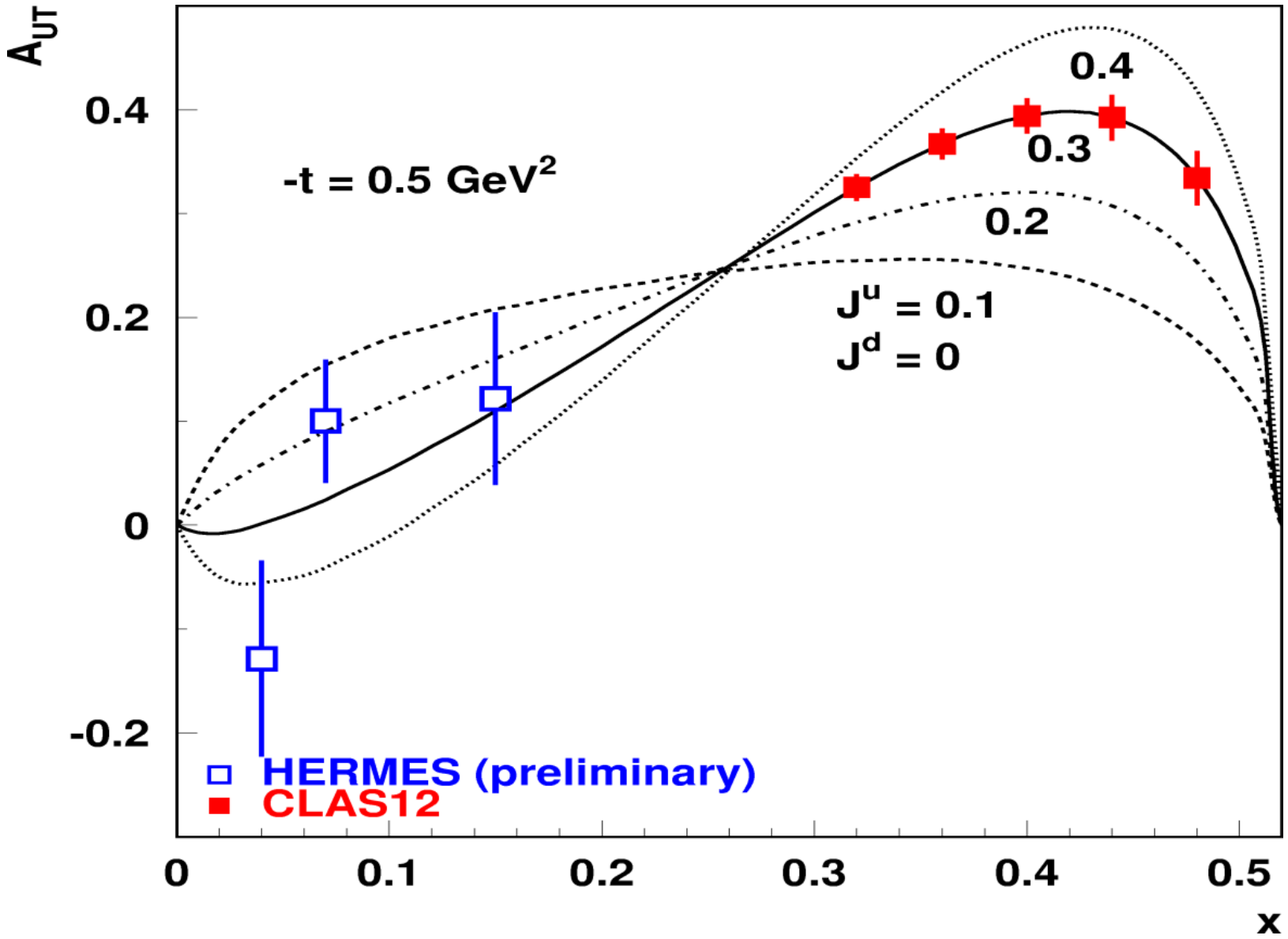


Plots and analysis done by Andrey Kim

CLAS12 Backup


Activity Name
FY 04
FY 05
FY 06
FY 07
FY 08
FY 09
FY 10
FY 11
FY 12
FY 13
FY 14
FY 15
1 2 3 4
Critical Decisions
0
1
2
3
Down
Accel Shut-down
4A
4B
Accelerator including Civil
Hall D including Civil
Hall A
Hall C
Hall B
Legend
R&D
ACD Effort
PED Effort
Civil Construction
Procurement & Assemble
Installation & Checkout
Beam Commissioning
CLAS12 TIME SCHEDULE

E P_TR -> E P RHO0


A_{UT}
0.4
0.2
0
-0.2
$-t = 0.5\ GeV^2$
0.4
0.3
0.2
$J^u = 0.1$
$J^d = 0$
HERMES (preliminary)
CLAS12
0
0.1
0.2
0.3
0.4
0.5
x