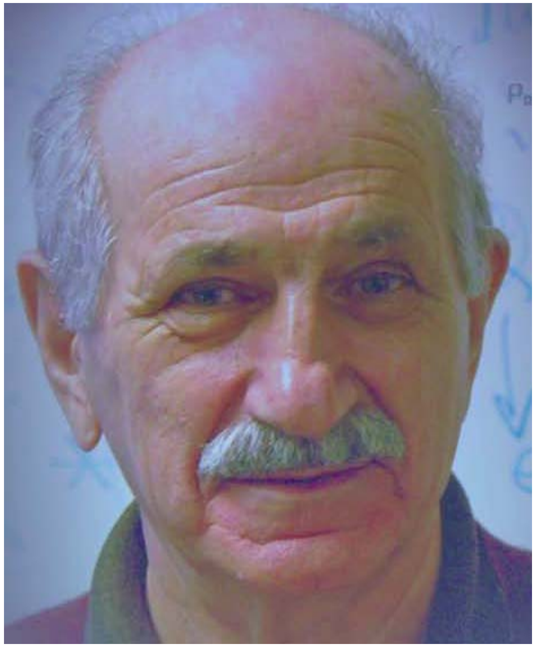
Unraveling the hidden structure of the deuteron with DVCS



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Kim Egiyan Memorial Workshop on SRC

JLAB , October 21, 2006

OUTLINE

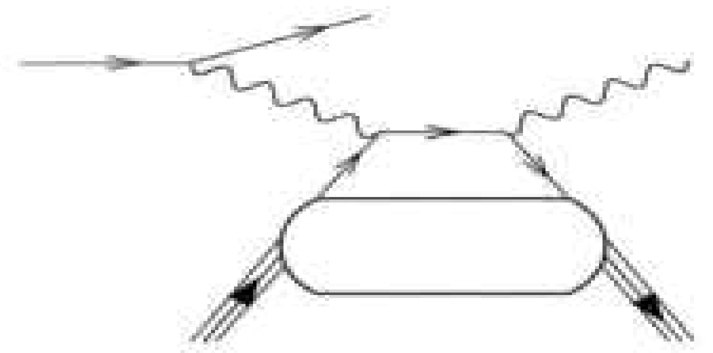
- Introduction
- DVCS on spin-1 target
- Beam-spin asymmetry
- Existing Data
- Experimental Setup
- Projected physics results
- Summary

Physics Motivation

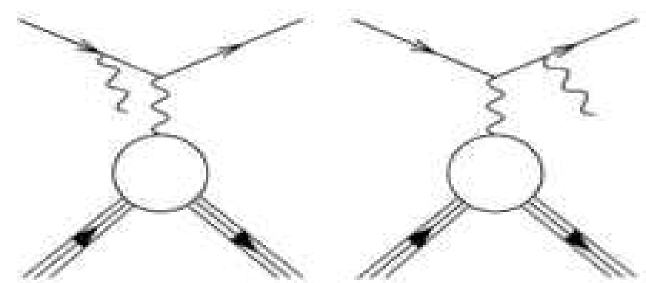
- DVCS combines features of both: elastic and deep-inelastic scattering
- Therefore it allows for the first time to investigate partonic structure of any nuclei as of a single hadron
- Depending on the spin of the target different GPDs contribute to DVCS
- Below we discuss mainly how to measure deuteron GPDs via coherent DVCS

Coherent electroproduction of real photons

- γ-quanta can be produced exclusively via two processes:
- **DVCS**
- **Bethe-Heitler**
- Both processes can occur on any nuclear target
- In spin-1 target new GPDs manifest themselves
- Some of them vanish in the forward limit



DVCS



Bethe-Heitler

GENERAL FORMALISM

Spin-1 target hadronic current J_μ is represented as:

$$J_\mu = -\varepsilon^*_2 \cdot \varepsilon_1 \cdot P_\mu G_1 + (\varepsilon_2 \cdot P \cdot \varepsilon_{1\mu} + \varepsilon \cdot P \cdot \varepsilon^*_{2\mu}) G_2$$
$$-[\varepsilon^*_2 \cdot P \cdot \varepsilon_1 \cdot P \cdot P_\mu/(2M^2)] G_3$$

$\varepsilon_{1\mu}(\varepsilon_{2\mu}) \rightarrow$ initial(final) hadron polarizations

and

$G_i(\Delta^2)$, (i=1,2,3) $\rightarrow$ EM form factors

DVCS hadronic tensor $T_{\mu\nu}$ is time-ordered product of hadronic currents $J_\nu J_\mu$

$$T_{\mu\nu}(x,\xi,\Delta) = (i/e^2) \int e^{ixq} \langle P_2 | T J_\mu J_\nu | P_1 \rangle dx =$$

$$-P_{\mu\sigma} g_{\sigma\tau} P_{\tau\nu}\; q \cdot V_1/P \cdot q - P_{\mu\sigma}\, i\varepsilon_{\sigma\tau q\rho}\, P_{\tau\nu} A_{1\rho}/P \cdot q$$

$P_{\mu\sigma}$ - projection operator
V - vector current
A - axial-vector current

Vector V_μ and Axial-Vector A_μ currents

$$V_\mu = \Sigma\, a_i \mathcal{H}_i$$
$$A_\mu = \Sigma\, b_i \tilde{\mathcal{H}}_i$$

Compton Form Factors

$\tilde{\mathcal{H}}_i$ (i =1…4) polarized

$\mathcal{H}_i$ (i =1…5) unpolarized

CFFs, GPDs and Deuteron Form Factors

Compton Form Factors $\mathcal{H}_k(\xi,t)$, $\tilde{\mathcal{H}}_k(\xi,t)$

- $\mathcal{H}_k(\xi,t) = \Sigma \int C_i^-(\xi,x) H_k(x,\eta,t) dx$ for $k = \{1,\ldots,5\}$
- $\tilde{\mathcal{H}}_k(\xi,t) = \Sigma \int C^+(\xi,x) \tilde{H}_k(x,\eta,t) dx$ for $k = \{1,\ldots,4\}$

Generalized Parton Distributions (GPDs)

$\tilde{H}_k$ ($k= 1,\ldots,4$) axial-vector

H_k ($k= 1,\ldots,5$) vector

General Parton Distribution Functions H_k, $\tilde{H}_k$ obey Sum Rules

- $\int dx\, \tilde{H}_i(x,\eta,t) = \tilde{G}_i(t)$ ($i=1,2$)
- $\int dx\, H_i(x,\eta,t) = G_i(t)$ ($i=1,2,3$)
- $\int dx\, H_4(x,\eta,t) = \int dx\, H_5(x,\eta,t) = 0$
- $\int dx\, \tilde{H}_3(x,\eta,t) = \int dx\, \tilde{H}_4(x,\eta,t) = 0$

$G_i(t)$ - deuteron FFs

Deuteron Form Factors

$G_i(t)$ - deuteron FFs are related to

G_C - charge monopole

G_M - magnetic dipole

G_Q - charge quadrupole

$$G_1(t) = G_C(t) - (2/3)\tau G_Q(t)$$

$$G_2(t) = G_M(t)$$

$$G_3(t) = (G_M(t) - G_C(t) + (1+2\tau/3)\, G_Q(t))/\,(1+\tau)$$

where $\tau = \Delta^2 / 4M_d^2$

NOTE:

In natural units:

$G_C(0) = 1$

$G_M(0) = \mu_d = 1.714$

$G_Q(0) = Q_d = 25.83$

Deuteron SFs, GPDs and Parton Densities

In the forward limit

Structure Functions (SFs)

$F_1 \sim H_1(x,0,0) = [q^+(x) + q^-(x) + q^0(x)]/3$ unpolarized

$g_1 \sim \tilde{H}_1(x,0,0) = q^+(x) - q^-(x)$ polarized

$b_1 \sim H_5(x,0,0) = q^0(x) - [q^+(x) + q^-(x)]/2$ tensor SF

Parton Densities for helicty states along z-axis

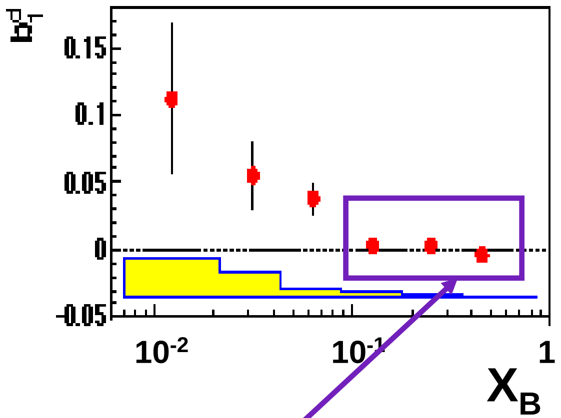
$q^+(x)$ - parallel

$q^-(x)$ - antiparallel

$q^0(x)$ - helicity -0 state

H_2, H_3, H_4 and $\tilde{H}_2$, $\tilde{H}_3$, $\tilde{H}_4$

are inaccessible in the forward limit



Phys.Rev.Lett.95:242001,2005
By HERMES Collaboration

b_1 is small

Beam Spin Asymmetry

- $A_{LU} = [d\sigma^{+}(\phi) - d\sigma^{-}(\phi)] / [d\sigma^{+}(\phi) + d\sigma^{-}(\phi)]$
- For spin-1 target

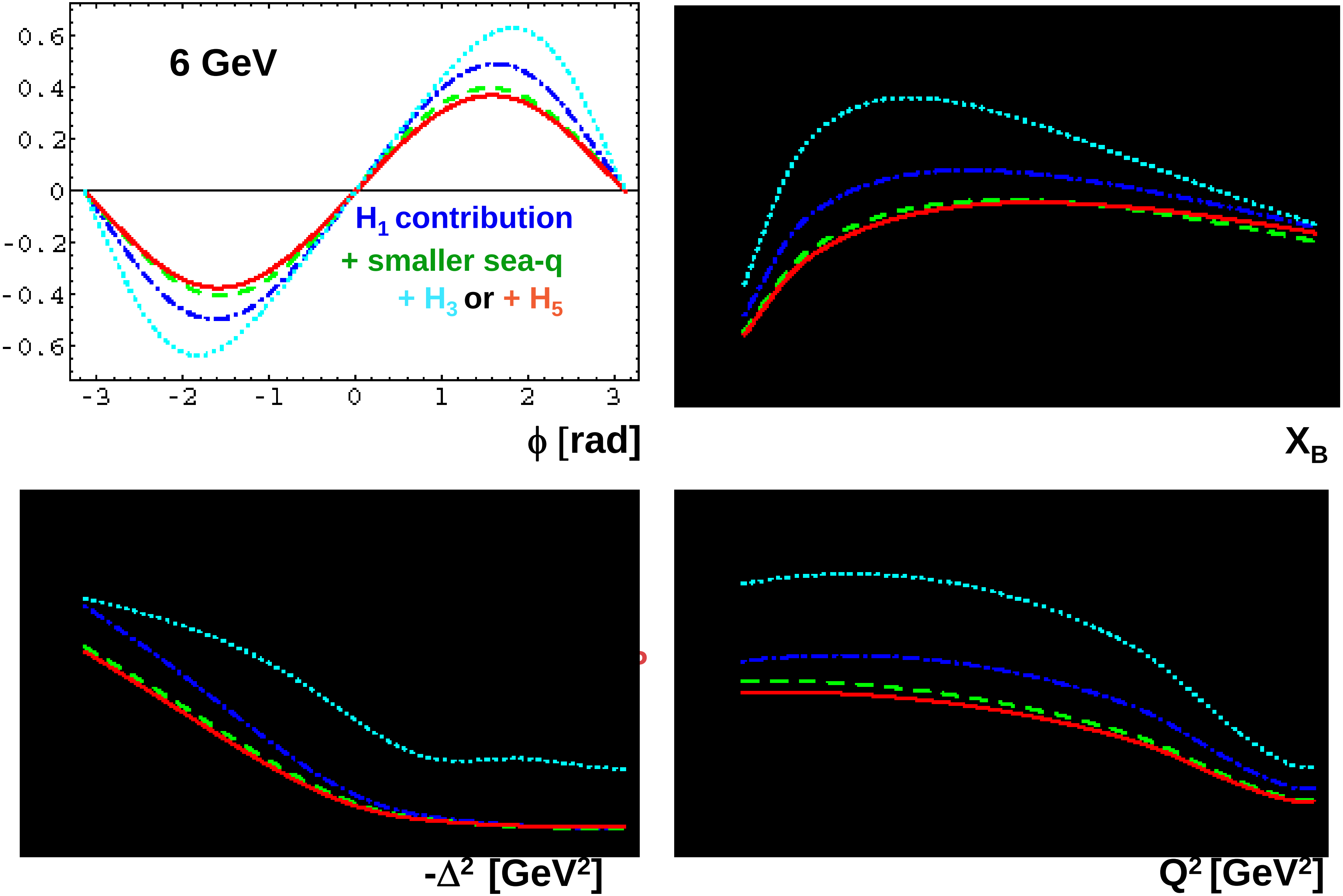
$$A_{LU} \sim \frac{\mathrm{Im}\,[2G_1\mathcal{H}_1 + (G_1 - 2\tau\, G_3)(\mathcal{H}_1 - 2\tau\,\mathcal{H}_3) + (2\tau/3)\, G_3\mathcal{H}_5]\ \sin(\phi)}{2G_1^2 + (G_1 - 2\tau\, G_3)^2}$$

$\tau = \Delta^2 / 4M_d^2$; ($\Delta^2 = t$ -Mandelstam)

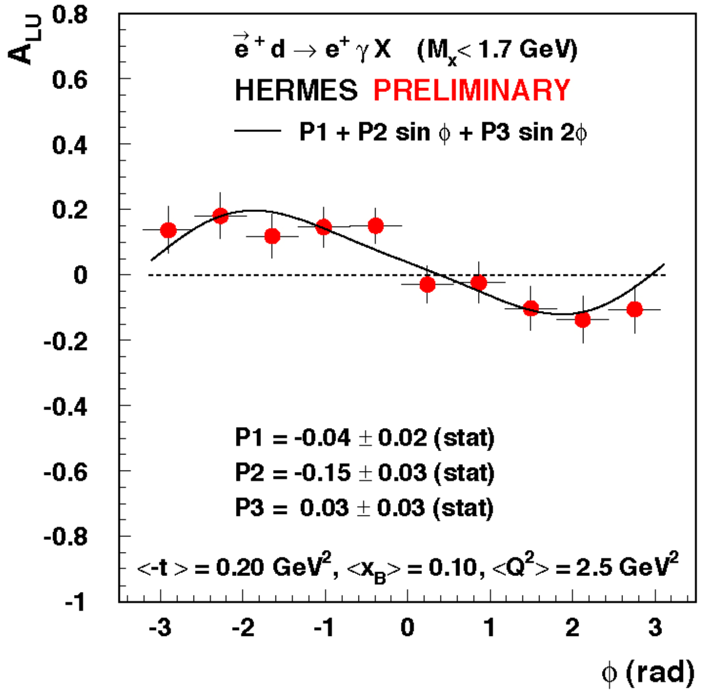
Theoretical Predictions

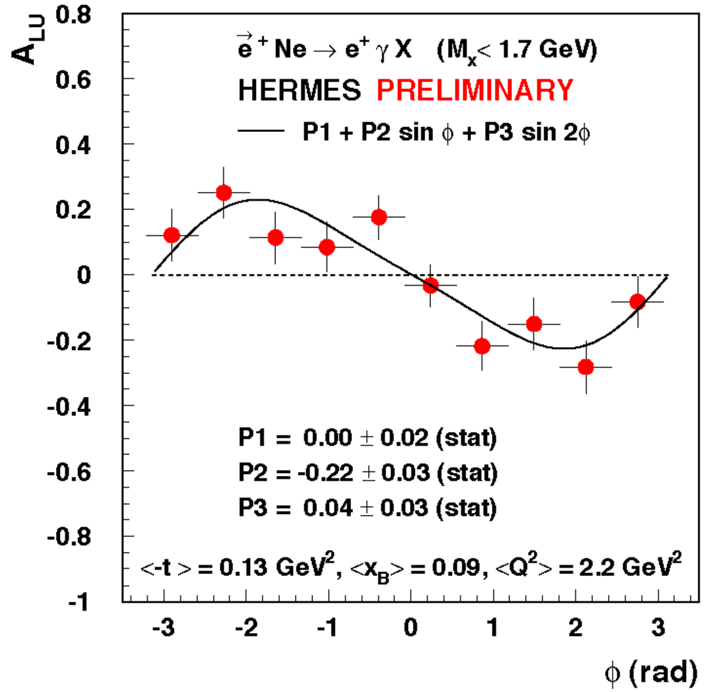
- Different models for contributions of
- $\mathcal{H}_1$, $\mathcal{H}_3$ and $\mathcal{H}_5$ to A_{LU}(following D.Mueller)
- Model **A** includes $\mathcal{H}_1$
- Model **B** same as **A**, but with smaller sea-quark contribution
- Model **B'** is **B** plus $\mathcal{H}_3$ contribution
- Model **B^** is **B** plus $\mathcal{H}_5$

A_{LU} Predictions



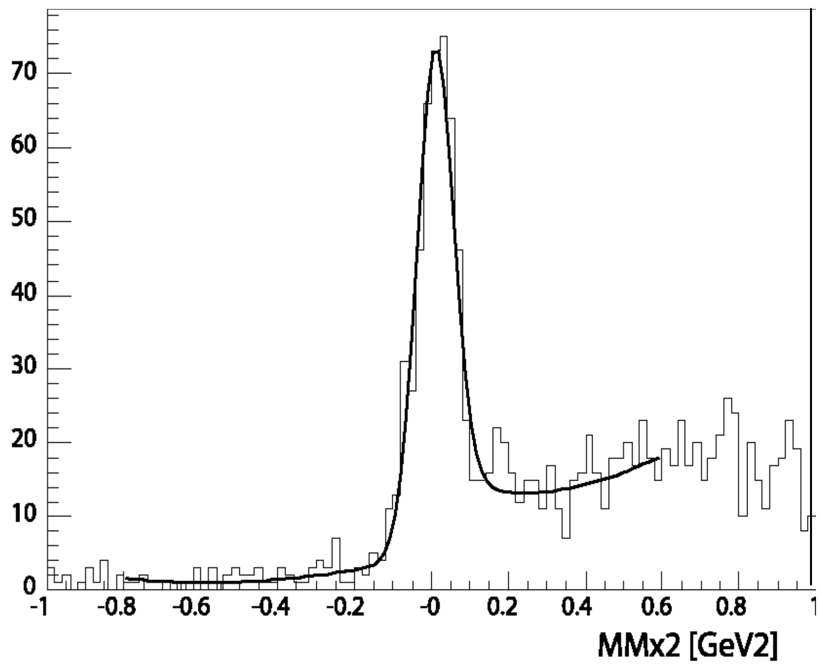
DVCS on Nuclei

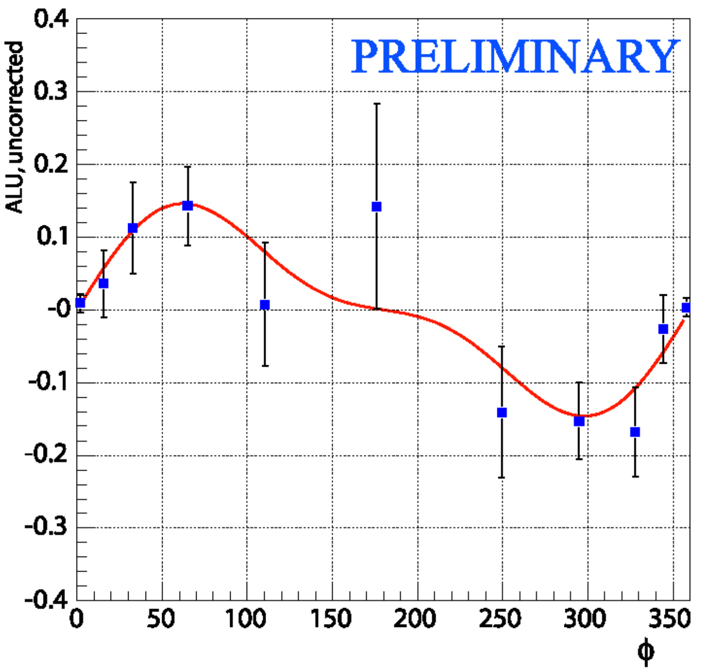




- The only existing data on DVCS on Nuclei are from HERMES on a deuteron and neon targets (now also on Kr and Xe)
- Data on a Neon are dominated by coherent scattering
- However data on a deuteron are dominated by incoherent scattering on a single nucleon

CLAS E6 analysis

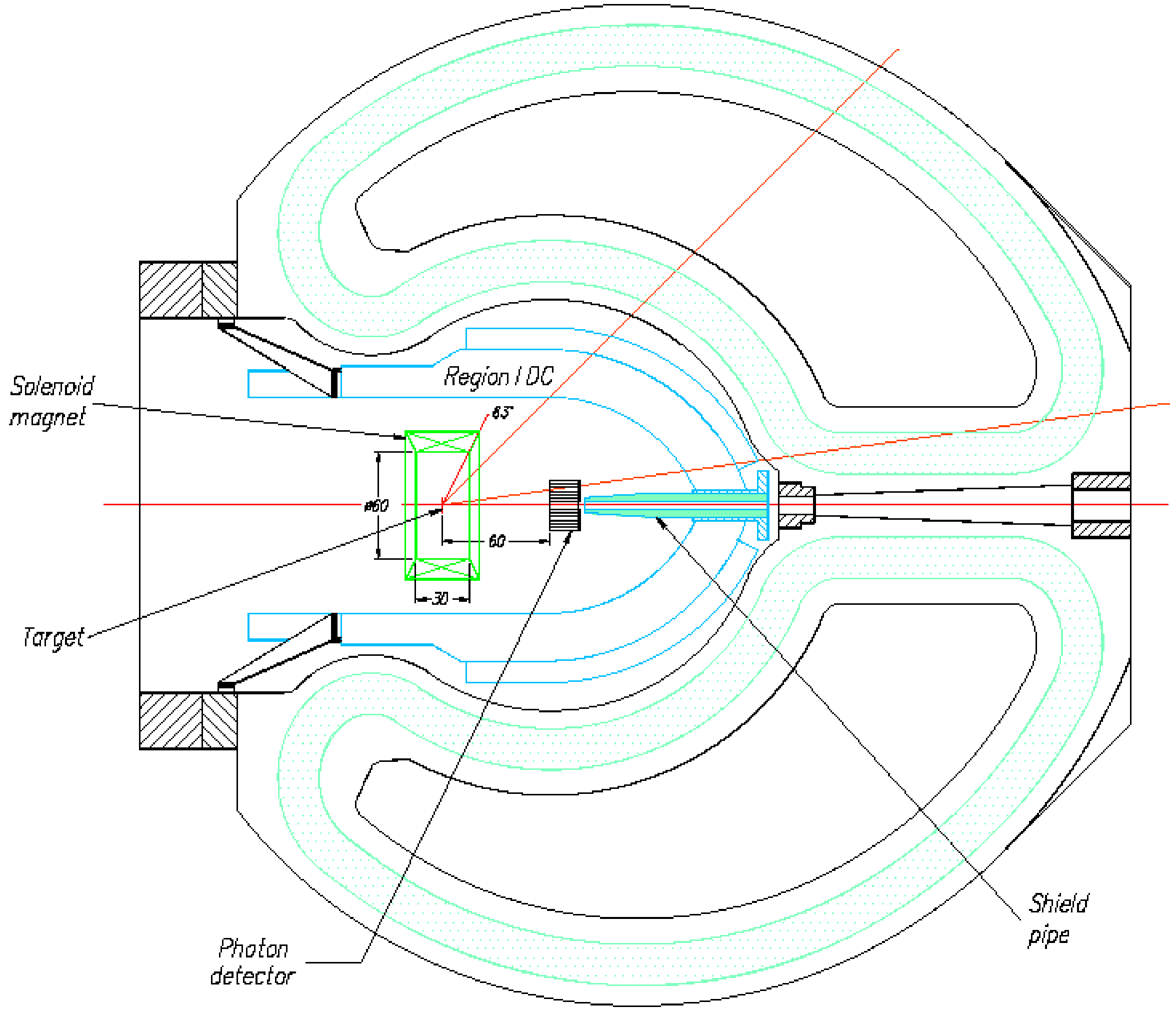




- From preliminary E6 data analysis →

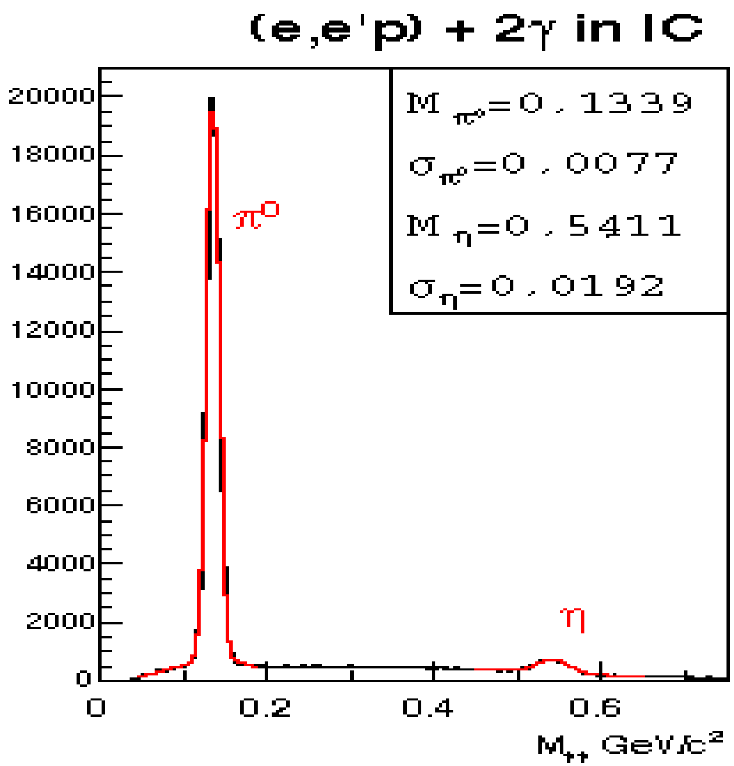
  sizeable beam-spin asymmetry in coherent DVCS on deuteron

CLAS DVCS Setup

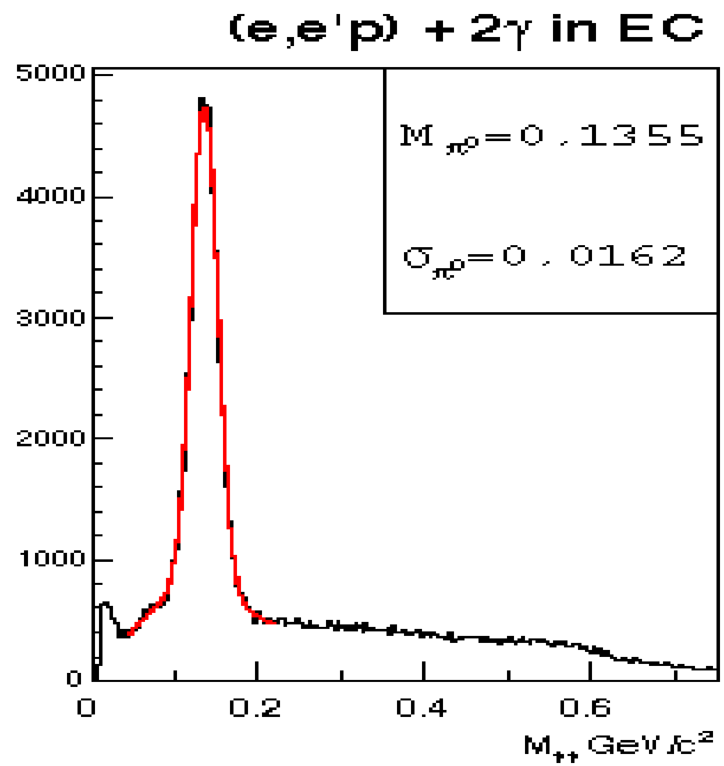


- Scattered electron and deuteron in standard CLAS acceptance
- Photon in Inner Calorimeter

Detection of Photons



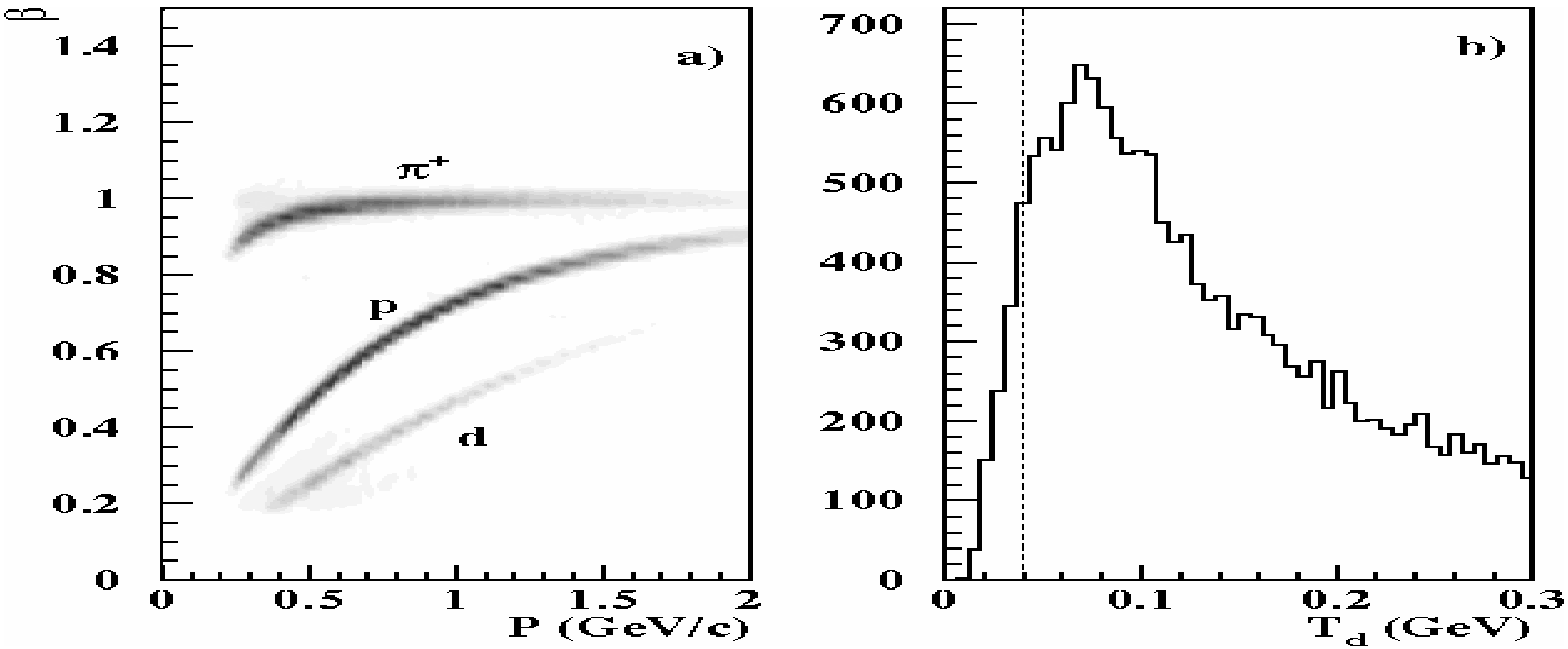
a)



b)

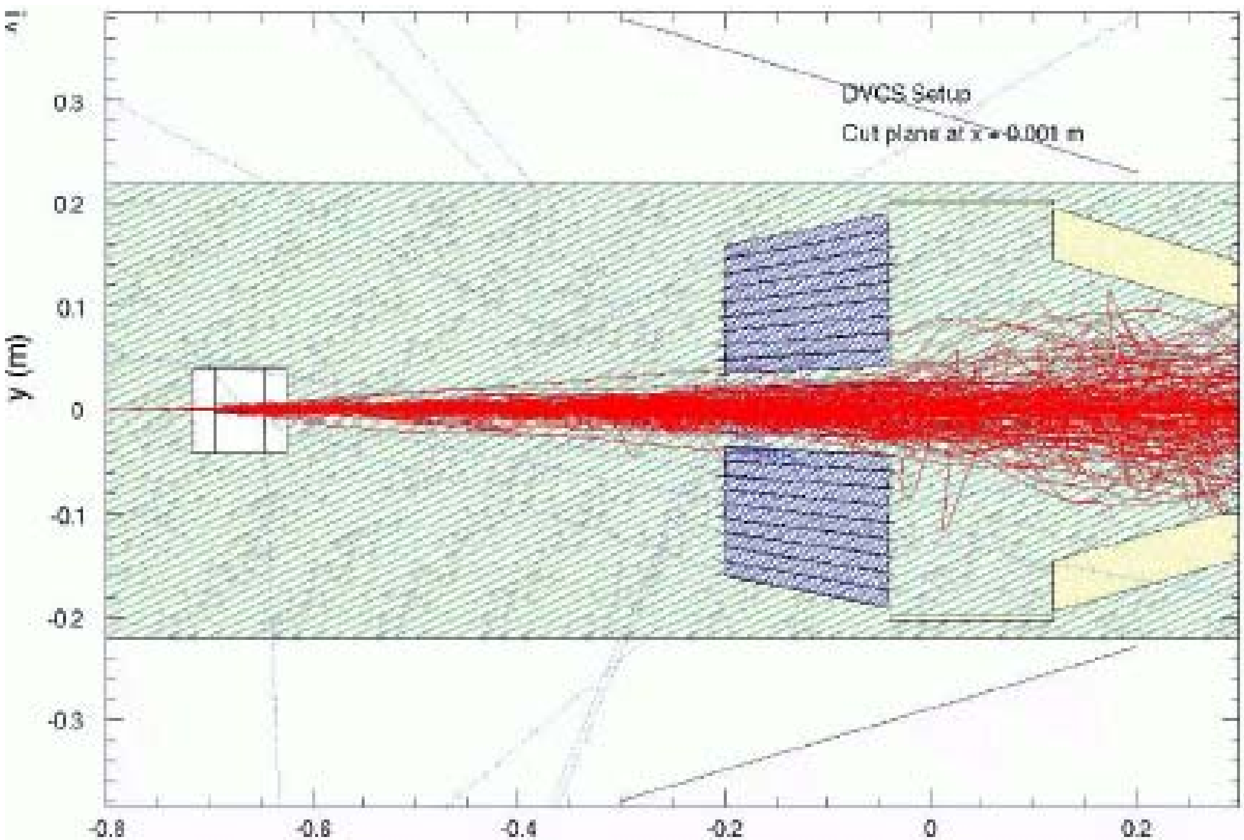
- Inner calorimeter provides excellent mass resolution

Detection of Deuterons



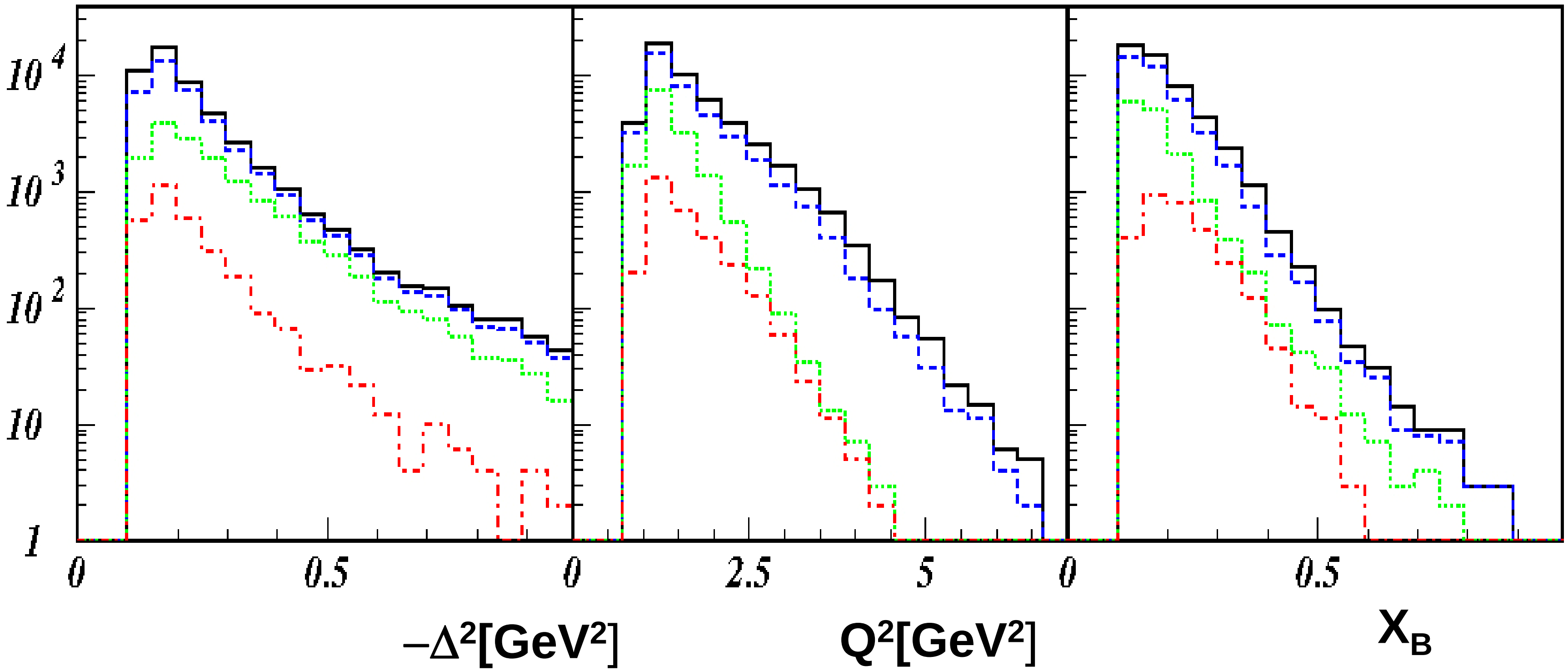
- Left panel shows TOF spectra
- Right panel shows minimum kinetic energy of the deuteron in CLAS to be detected
- Deuterons in the range of interest P<1 GeV/c are well separated

Moeller Electrons, Target and Solenoid



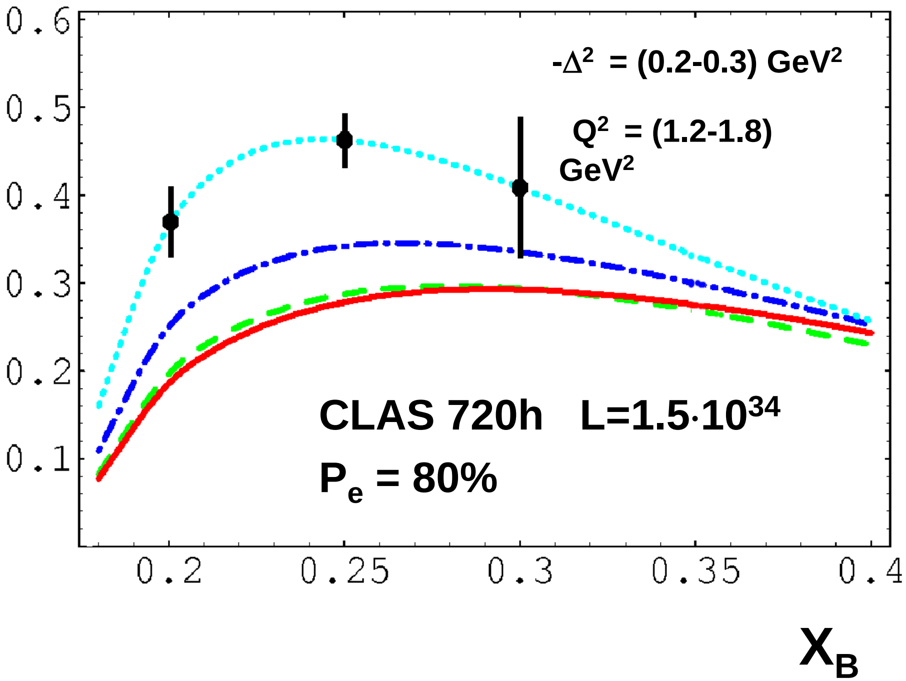
- Simulation of Moeller electrons with solenoid magnet installed
- Target area and IC are shown along the beam line
- The actual experiment will use liquid deuterium target
- With maximum luminosity of **$L=1.5 \cdot 10^{34}/cm^2 \cdot sec$**

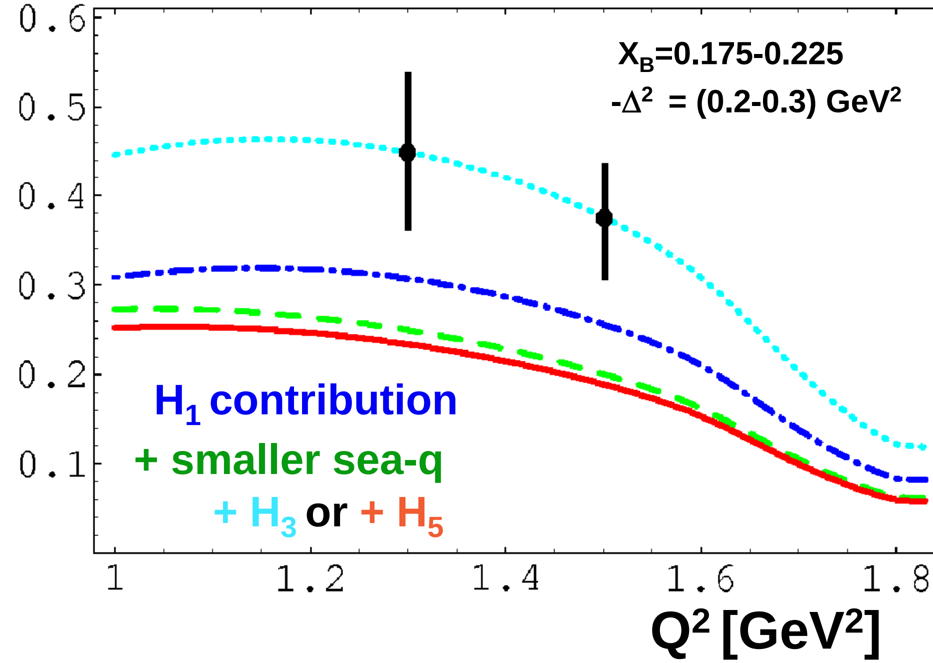
CLAS Acceptance for d-DVCS

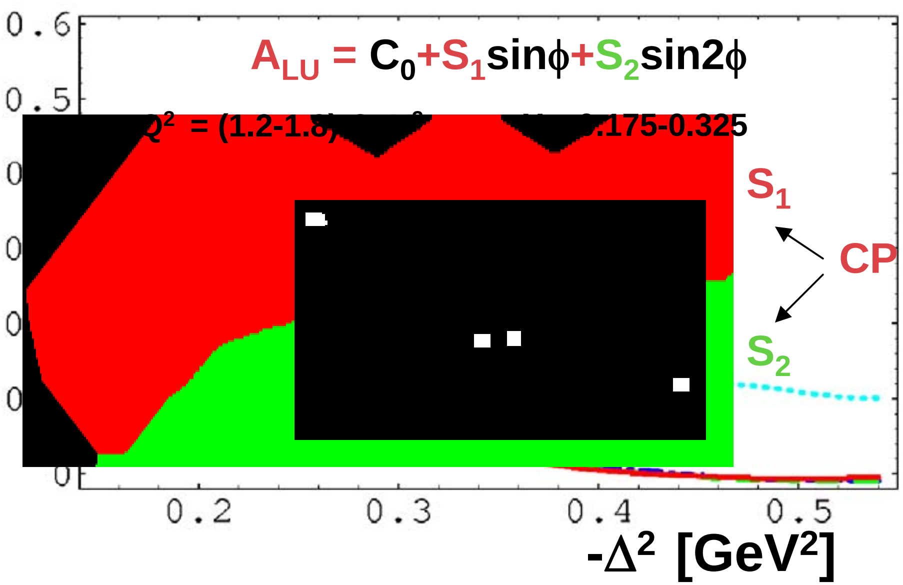


- CLAS acceptance for d-DVCS as a function of Δ^2,Q^2 and x_B
- Each plot shows (from top to bottom) the simulated distribution: **without CLAS**, **with detected electron**, **plus detected photon**, **plus detected deuteron**

A_{LU} Projected Errors







- First measurements of the Deuteron Partonic structure as of single hadron
- H_3 contribution dominates

→ Direct access to the partonic structure of the deuteron in D wave state

Summary

- This work is related to coherent DVCS on a deuteron
- Experiment will allow for the first time to get an access to partonic structure treating **deuteron as a single hadron**
- From model predictions beam-spin asymmetry is very sensitive to GPD H_3 related to quadrupole FF of the deuteron
- It is hidden in a forward limit and was never measured !
- In order to separate between different models it will require at least **720h of beam time**
- With minimum of **80% of beam polarization**
- At beam energy **E_e = 6 GeV**
- And luminosity **$L = 1.5 \cdot 10^{34}/cm^2 \cdot sec$**
- Experiment requires to run with CLAS + IC + SM
- Proposal was approved by CLAS Collaboration, found "interesting and feasible" by PAC29 and recommended for a future
- The future is running!