Deeply Virtual Compton Scattering from the Neutron with CLAS and CLAS12

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on behalf of the CLAS Collaboration

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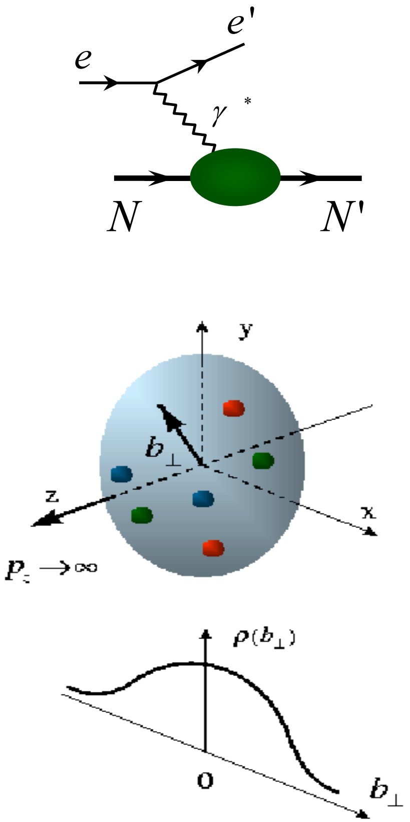
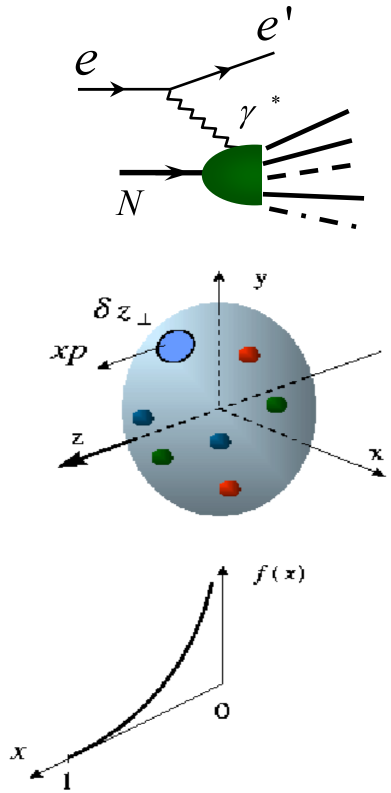
Nucleon Structure

Elastic Scattering



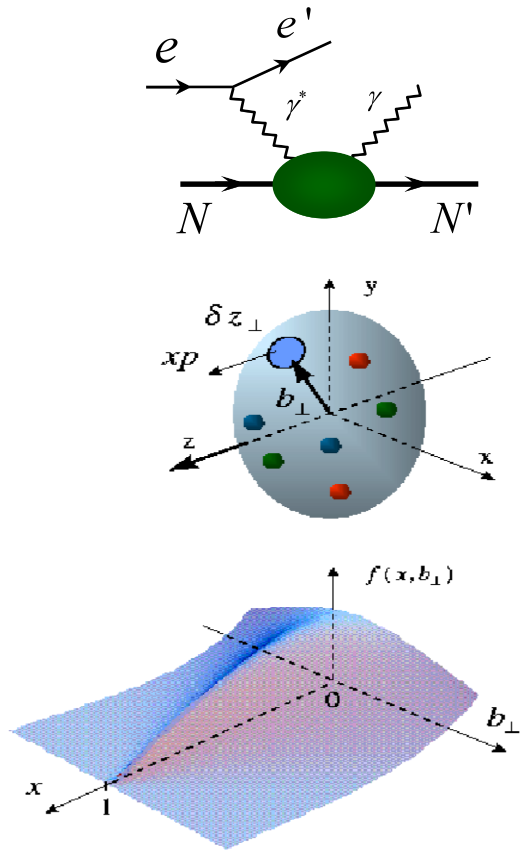
Transverse quark distributions

Deep Inelastic Scattering



Longitudinal momentum distributions of quarks

Deep Exclusive Reactions



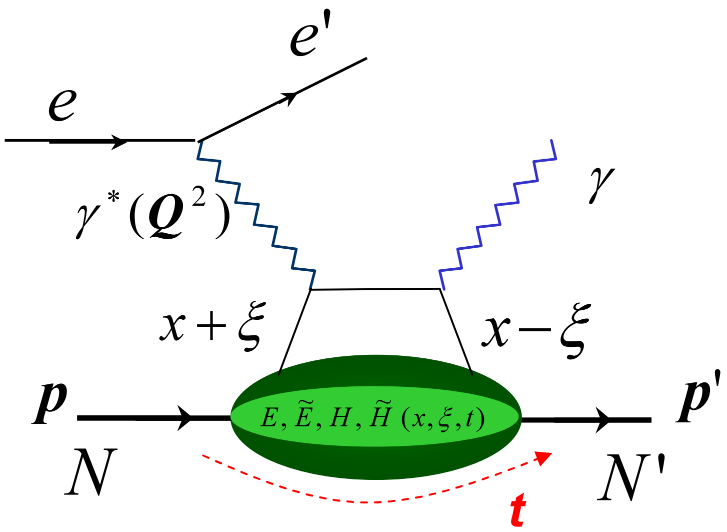
Generalised Parton Distributions (GPDs)

Deeply Virtual Compton Scattering

- GPDs relate transverse position of partons to longitudinal momentum.

  → contain information on angular momentum of quarks

- Can be accessed in measurements of cross-sections and asymmetries in, eg: **Deeply Virtual Compton Scattering** (DVCS).

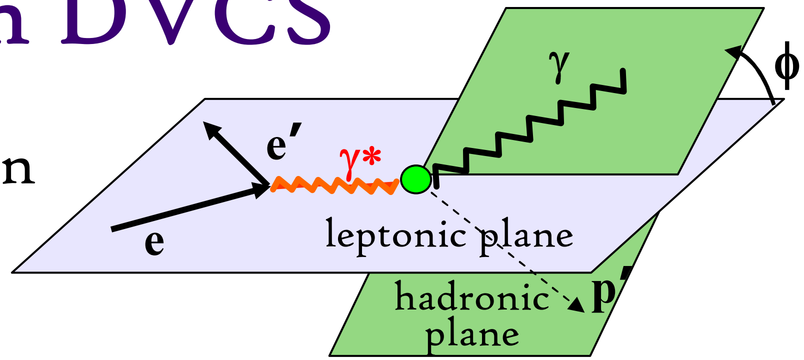


$Q^2 = -(e - e')^2 \qquad t^2 = -(p - p')^2$

$x \pm \xi$ *longitudinal momentum fractions of quarks* $\qquad \xi \cong \frac{x_B}{2 - x_B}$

- At high exchanged Q^2, access to four GPDs: $E_q, \tilde{E}_q, H_q, \tilde{H}_q\ (x,\xi,t)$

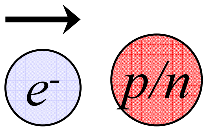
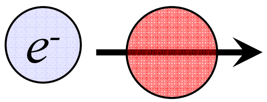
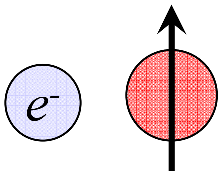
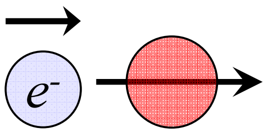
Extracting GPDs from DVCS



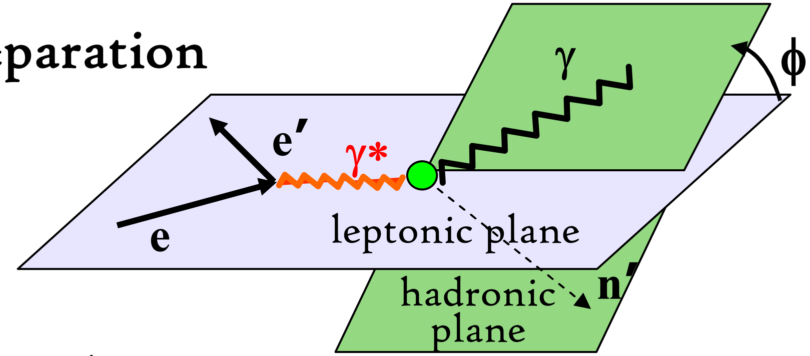
❖ Experimentally accessible in DVCS spin asymmetries, eg:

$$A_{LU} = \frac{d\vec{\sigma} - d\overleftarrow{\sigma}}{d\vec{\sigma} + d\overleftarrow{\sigma}} = \frac{\Delta\sigma_{LU}}{d\vec{\sigma} + d\overleftarrow{\sigma}}$$

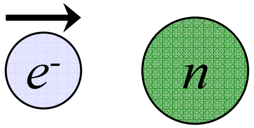
$\xi = x_B/(2-x_B) \quad k = t/4M^2$

Beam, target polarisation		Proton Neutron
	$\Delta\sigma_{LU} \sim \sin\phi\, \mathrm{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}d\phi$	$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \mathcal{E}_n\}$
	$\Delta\sigma_{UL} \sim \sin\phi\, \mathrm{Im}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E}) - \xi kF_2\tilde{\mathcal{E}} + \ldots\}d\phi$	$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Im\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$
	$\Delta\sigma_{UT} \sim \cos\phi\, \mathrm{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}d\phi$	$Im\{\mathcal{H}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n\}$
	$\Delta\sigma_{LL} \sim (A+B\cos\phi)\, \mathrm{Re}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E})\ldots\}d\phi$	$Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Re\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$

Neutron DVCS



- GPDs from proton and neutron: **flavour separation**
- **Neutron DVCS** extremely sensitive to *E*, least-known and least-constrained GPD



*Polarized beam, unpolarized **neutron** target:*

$$\Delta\sigma_{LU} \sim \sin\phi \; \mathbf{Im}\{F_1 H + \xi(F_1+F_2)\widetilde{H} - kF_2 E\}d\phi \longrightarrow H_n, \widetilde{H}_n, \mathbf{E_n}$$

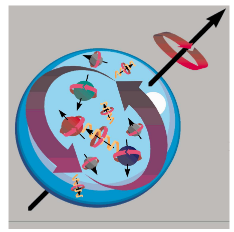
Suppressed because $F_1(t)$ is small

Suppressed because of cancellation between PDF's of u and d quarks

- **Ji's "Sum Rule":** $J^q = \frac{1}{2} - J^g = \frac{1}{2}\int_{-1}^{1} x dx \left\{ H^q(x,\xi,0) + E^q(x,\xi,0) \right\}$

$$J_N = \frac{1}{2} = \frac{1}{2}\Sigma_q + L_q + J_g$$

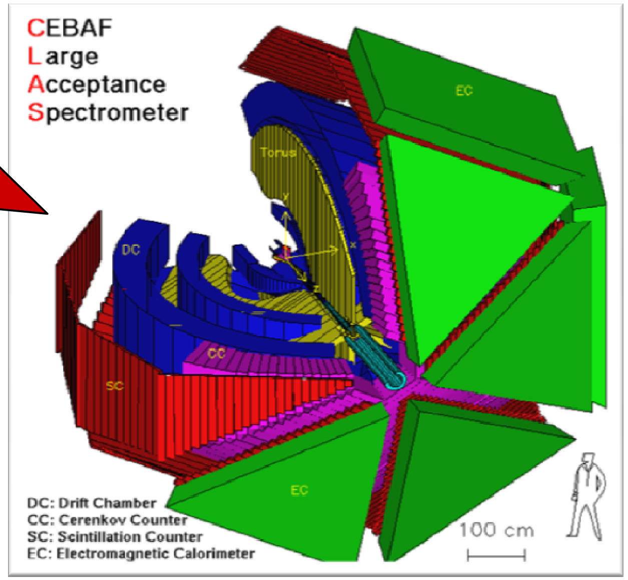
Important missing link in the **nucleon spin puzzle!**



CLAS @ Jefferson Lab (Virginia, USA)

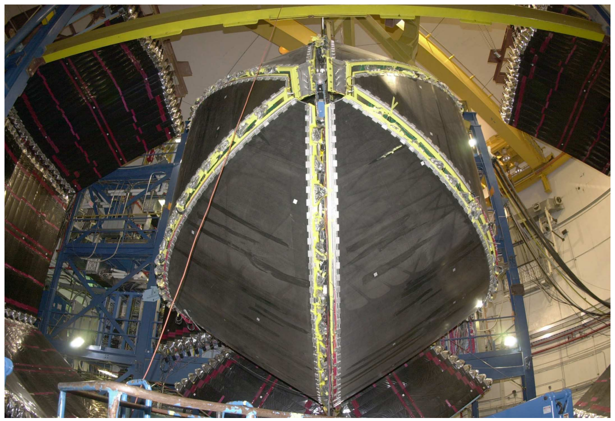
CEBAF: Continuous Electron Beam Accelerator Facility:

- Duty cycle: ~ 100%
- Energy up to ~6 GeV
- Electron polarisation up to ~85%



CLAS in Hall B:

- Drift chambers
- Toroidal magnetic field
- Cerenkov Counters
- Scintillator Time of Flight
- Electromagnetic Calorimeters



→ *Extremely large angular coverage*

Neutron DVCS: Eg1-dvcs experiment

Data taken: Feb – Sept 2009

Beam: polarised electrons
E_e = 4.7 to 6 GeV
polarisation ~ 85%

Longitudinally polarised targets:

NH_3 (95 days)
ND_3 (33 days)

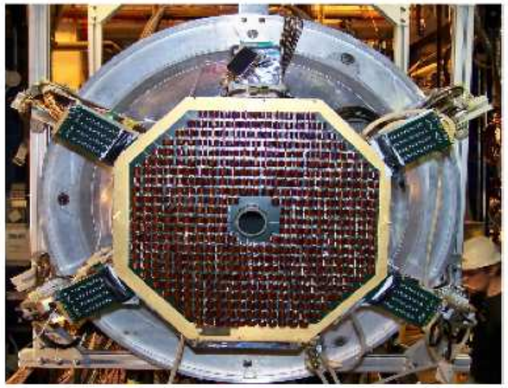
Proton / neutron pol. ~ 80 / 40 %

$$\vec{e} + \vec{d} \rightarrow e' + \gamma + n + (p_s)$$

CLAS → **Exclusive** reconstruction of e', N, and γ.
Spectator proton identified via missing mass.

plus

Inner Calorimeter (IC) → high-energy forward photon detection

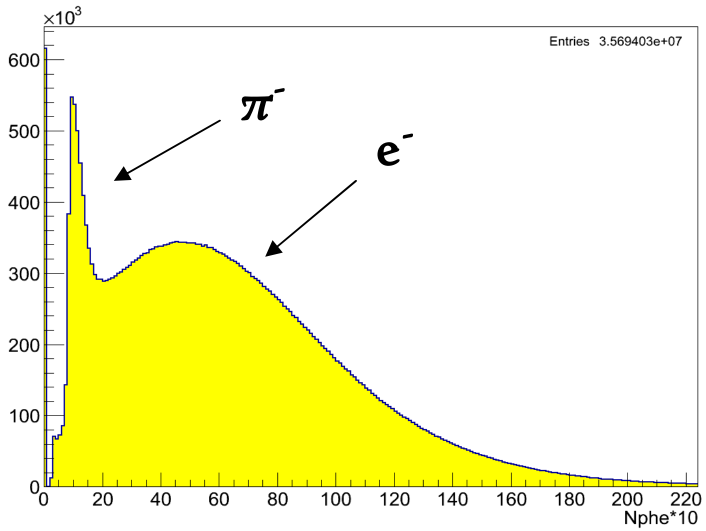


Particle ID – Electrons

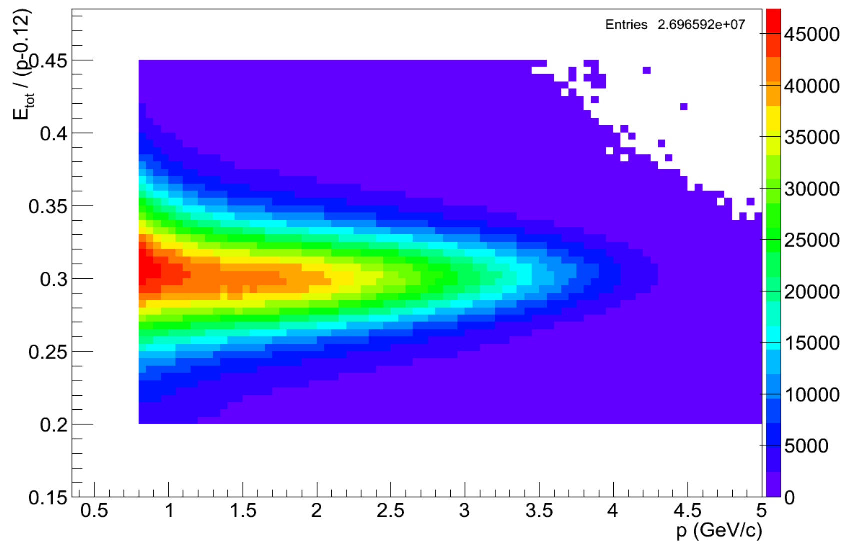
❖ *q* and *p* from track-curvature through drift chambers in magnetic field

❖ **Separation from π^-:** on basis of energy deposit in electromagnetic calorimeter (EC) and number of photoelectrons produced in Cerenkov counters (CC).

\# of photoelectrons (x10) in CC

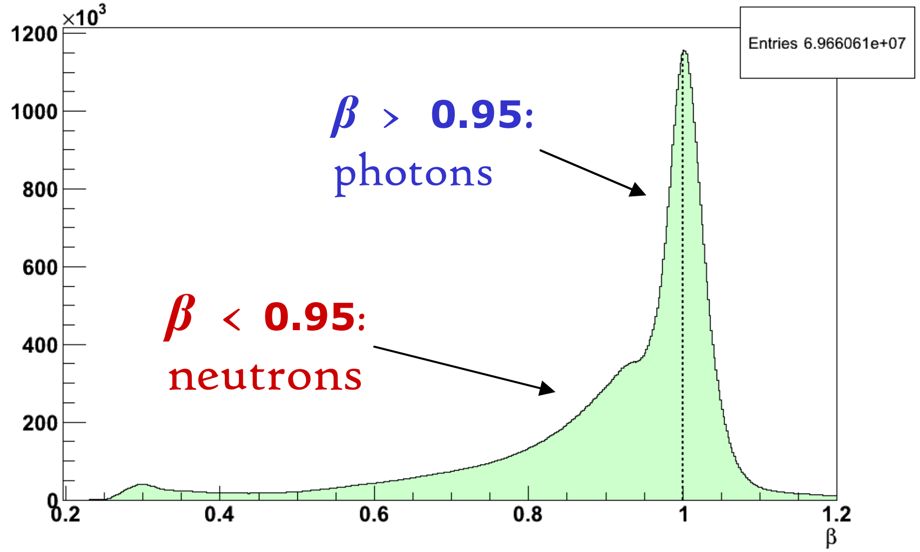


E deposit in EC / *p* vs. *p*



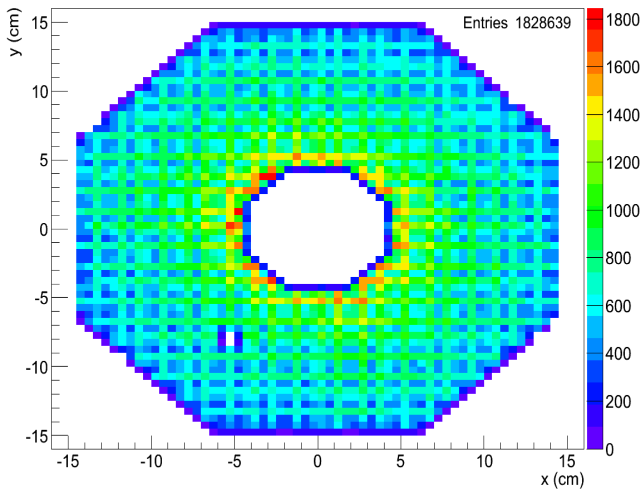
Particle ID – Photons and Neutrons

❖ β from neutral particles' time of flight to EC



❖ Forward, low-angle photons in additional Inner Calorimeter

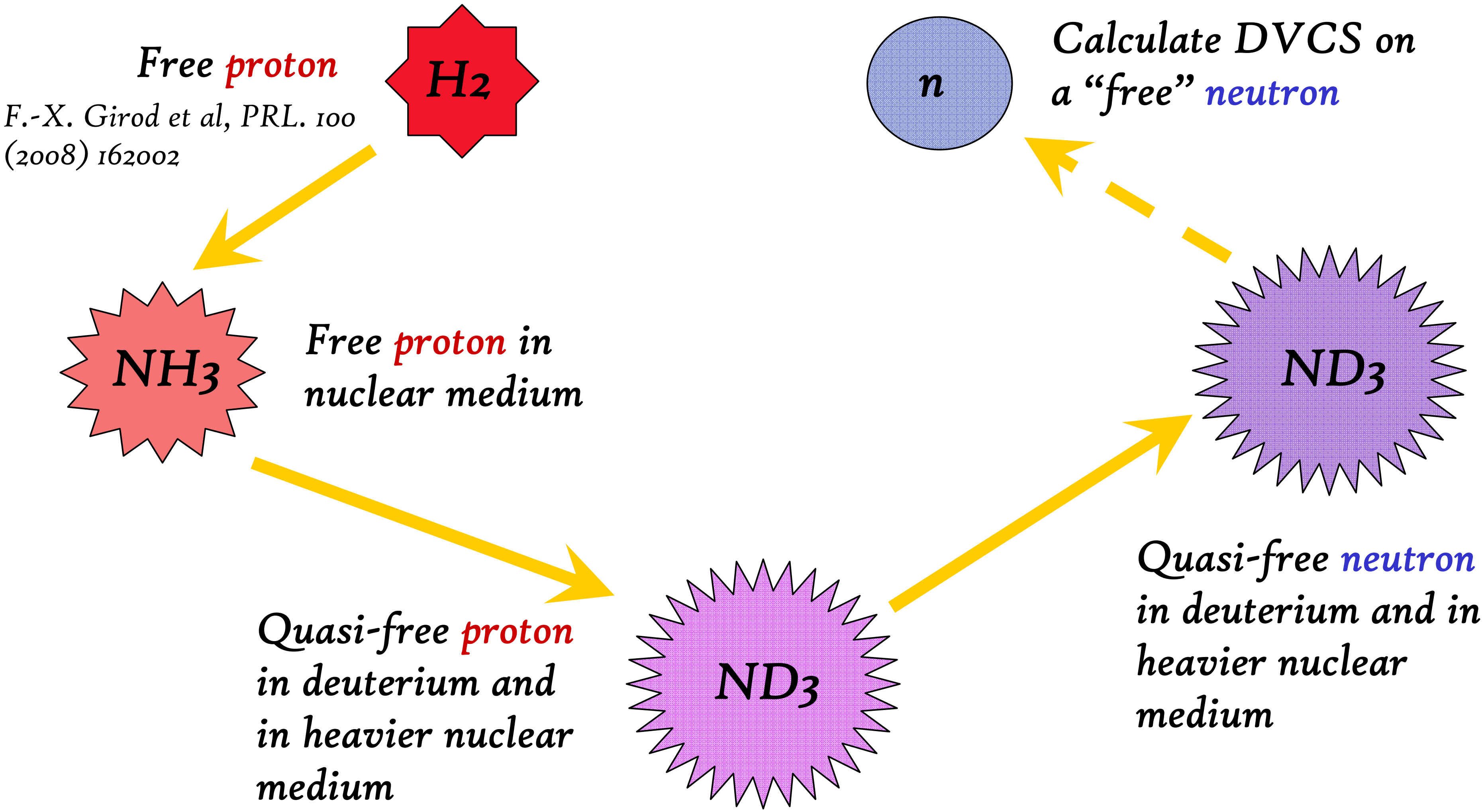
Hits in IC with E deposit > 1 GeV



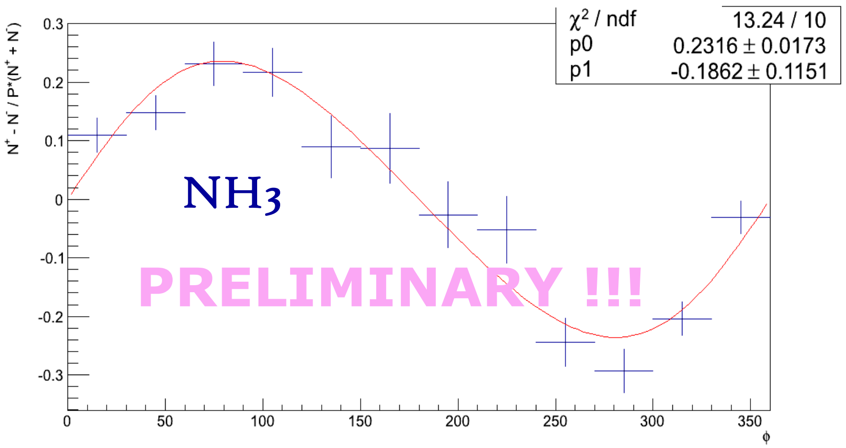
❖ Neutrons: $p_n = \frac{\beta m_n}{\sqrt{1-\beta^2}}$ $E_n = \sqrt{m_n^2 + p_n^2}$

❖ Photons: $p_\gamma = E$ deposited in calorimeter

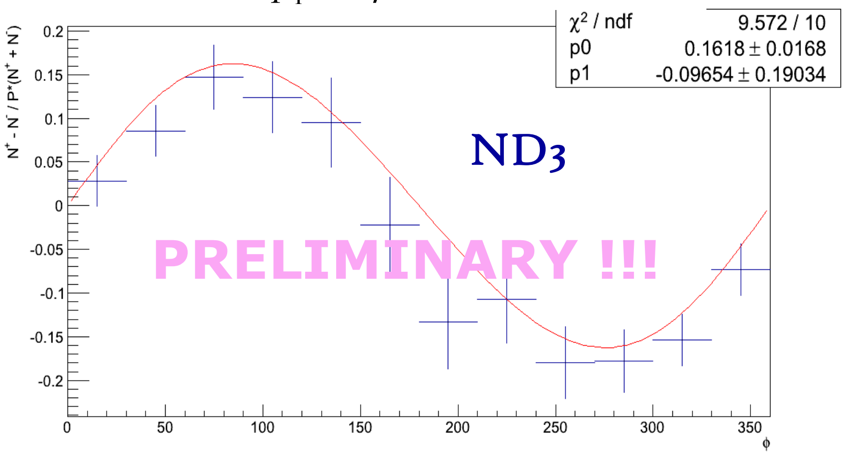
DVCS on different targets



A_{LU} – check on proton DVCS in NH_3 and ND_3



Fit: $A = \dfrac{p_0 \sin\varphi}{1 + p_1 \cos\varphi}$



Previously measured result on H_2 is in range 0.2 -0.3.

F.-X. Girod et al, PRL. 100 (2008) 162002

$$\frac{N^+ - N^-}{P(N^+ + N^-)} \approx 0.23 \pm 0.02$$

Uncorrected for π^o contamination

→ *actual A_{LU} larger!*

Deuterium target – smearing due to Fermi motion requires wider data cuts.

$$\frac{N^+ - N^-}{P(N^+ + N^-)} \approx 0.16 \pm 0.02$$

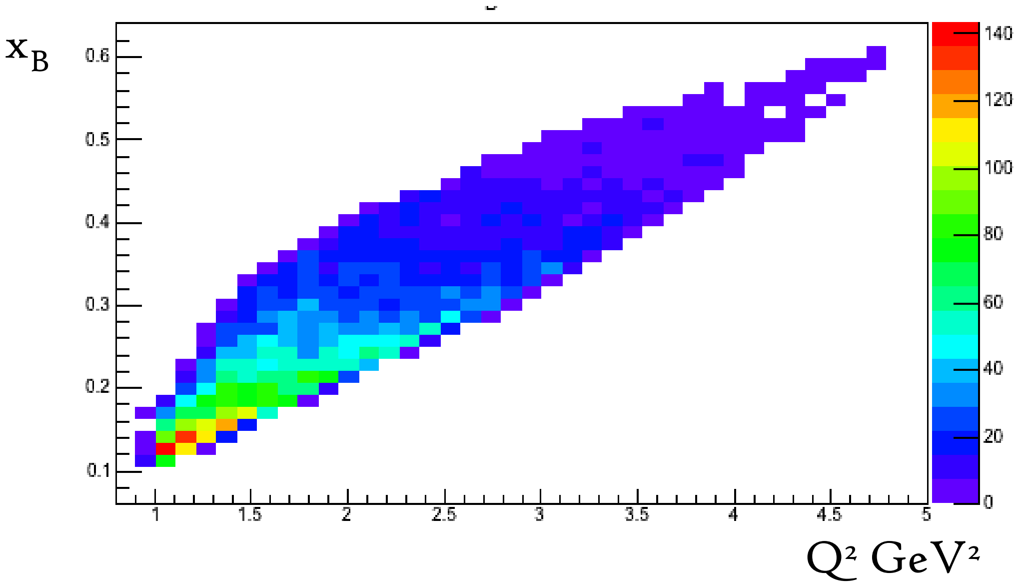
π^o contamination more significant

→ *measured A_{LU} lower than on NH_3.*

Neutron DVCS in ND_3 – data cuts I

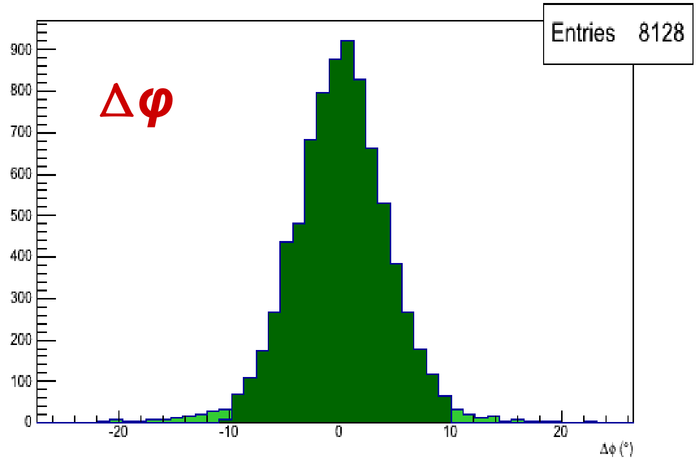
Deep Inelastic Scattering cuts:

- $Q^2 > 1$ GeV^2
- $E_\gamma > 1$ GeV
- $W > 2$ GeV/c^2 where W is the missing mass of $(eN \to e' X)$, isolate resonance region of remaining γN

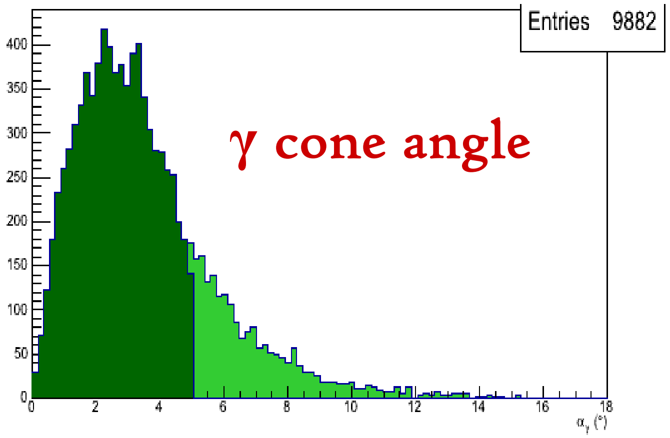


Neutron DVCS in ND_3 – data cuts II

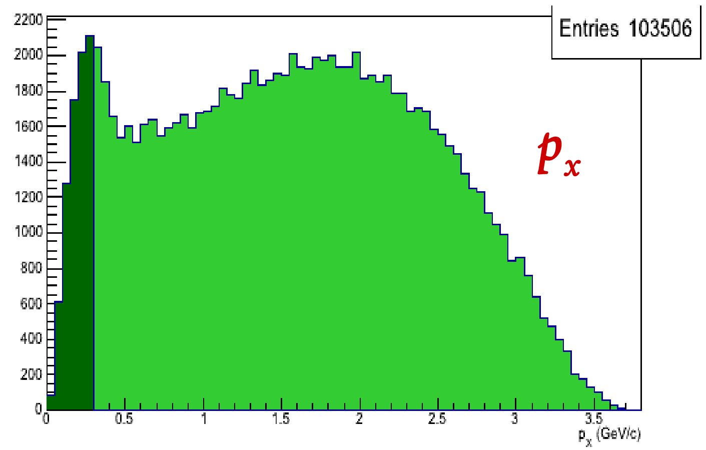
- ❖ $p_n > 0.4$ *GeV/c* Recoiling nucleon should not have a low *p*
- ❖ $|\Delta\varphi| < 10°$ Coplanarity between γ and *N*



- ❖ γ cone angle < 5° Difference between calculated and measured γ direction



- ❖ Missing momentum from $ed \rightarrow e'N'\gamma\ X$
Should be low for spectator nucleon in quasi-free reaction

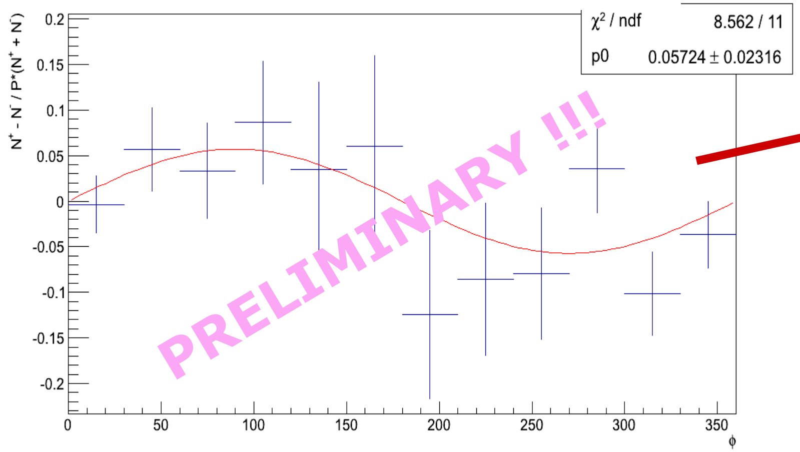


A_{LU} and A_{UL} in neutron DVCS on ND_3

❖ **Beam-spin asymmetry:**

One previous measurement from Hall A @ JLab, A_{LU} ~ 0. Big statistical and systematic uncertainties, slightly different kinematic region.

(M. Mazouz et al, PRL 99 (2007) 242501)



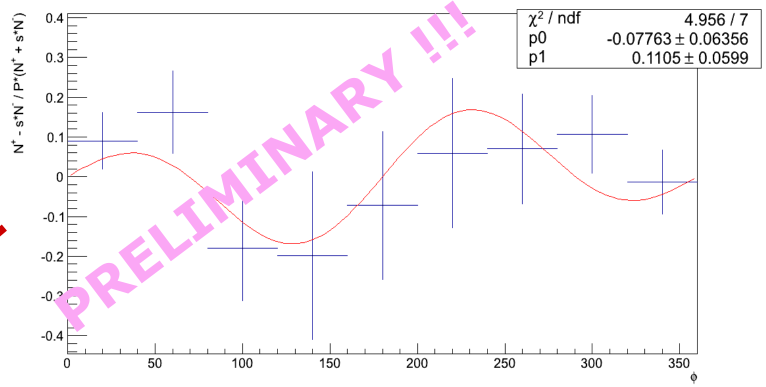
Fit: $A_{LU} = p_0 \sin\varphi$

$$\frac{N^+ - N^-}{P(N^+ + N^-)} \approx 0.06 \pm 0.02$$

Uncorrected for π^0 contamination, includes neutrons from N!

❖ **Target-spin asymmetry:**

First measurement!



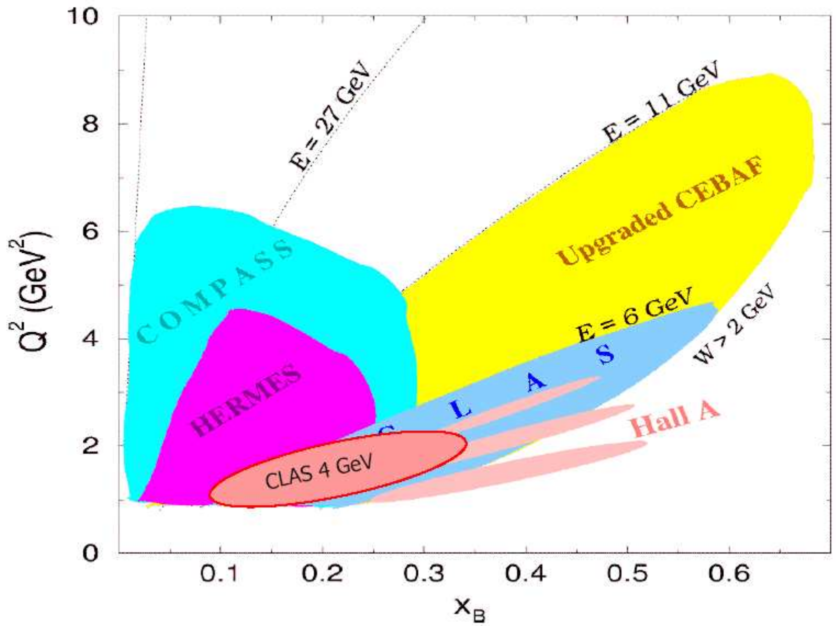
Fit: $A_{UL} = p_0 \sin\varphi + p_0 \sin 2\varphi$

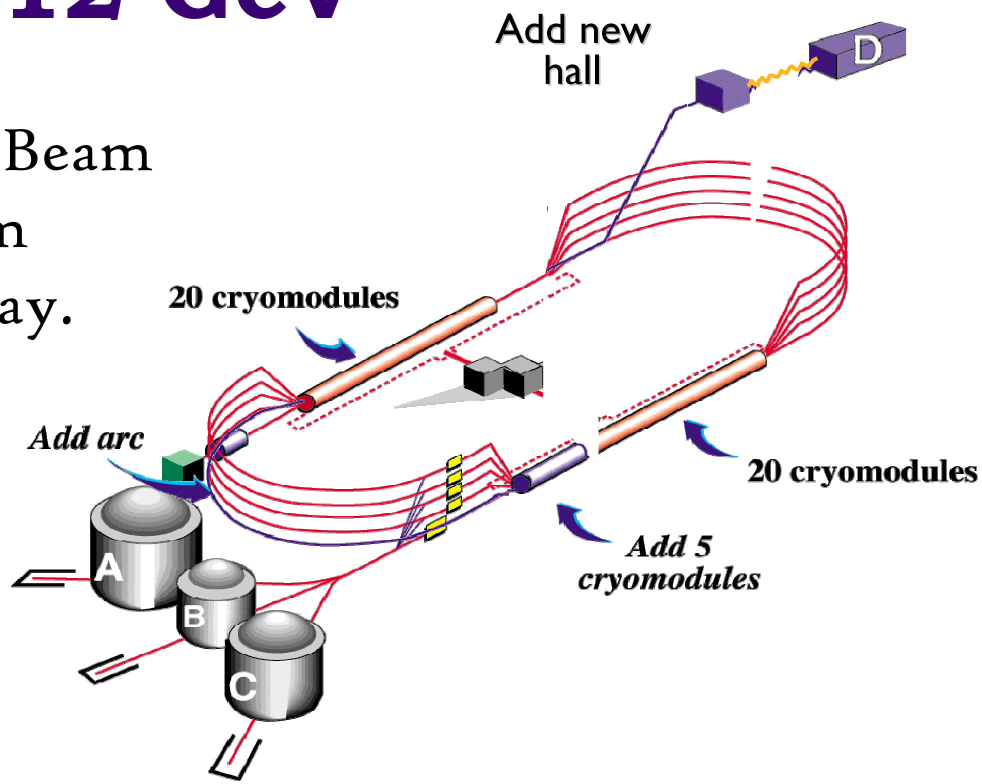
$$p_0 \approx 0.077 \pm 0.06 \qquad p_1 \approx 0.11 \pm 0.06$$

Jefferson Lab @ 12 GeV

❖ **CEBAF:** Continuous Electron Beam Accelerator Facility, upgrade from current 6 GeV to **12 GeV** underway.

❖ Open up much larger phase space in Q^2 and x_B

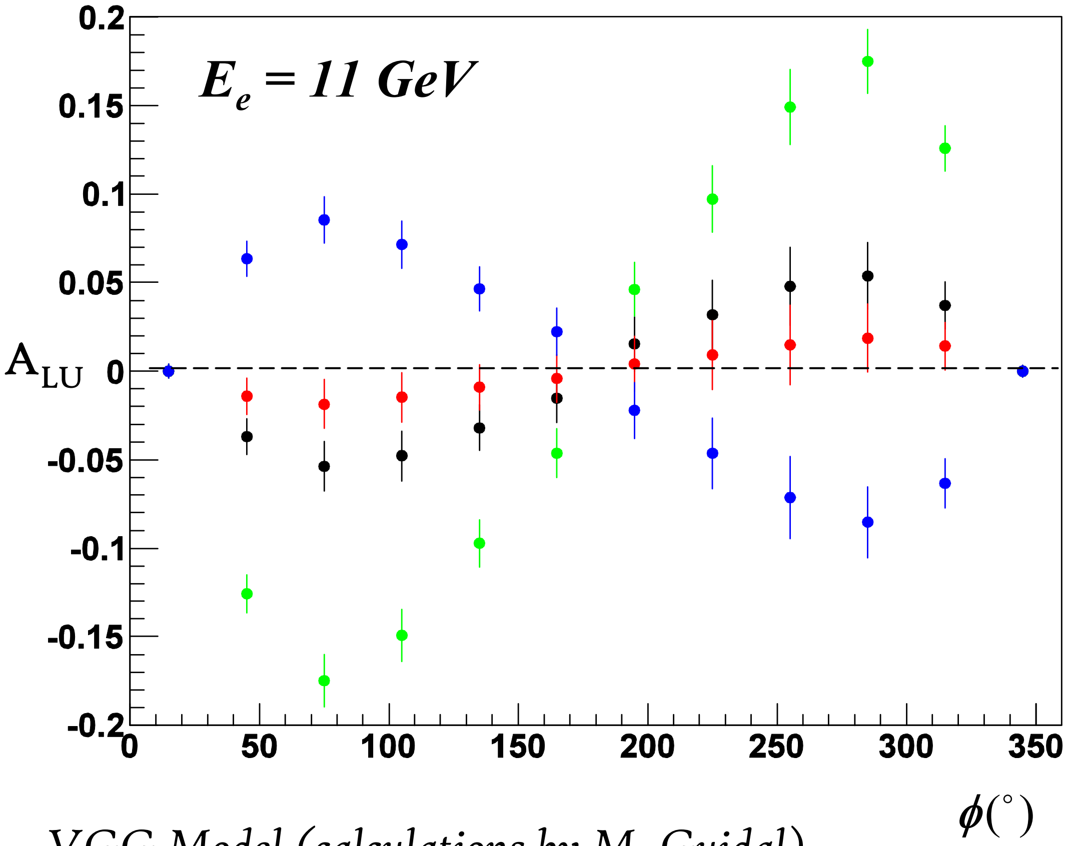




❖ Hall B – 11 GeV to the upgraded detector system **CLAS12**

❖ Scheduled completion ~ 2014

A_{LU} in Neutron DVCS @ 11 GeV



$J_u = 0.3, J_d = -0.1$ $J_u = 0.3, J_d = 0.1$

$J_u = 0.1, J_d = 0.1$ $J_u = 0.3, J_d = 0.3$

VGG Model (calculations by M. Guidal)

- At 11 GeV, beam spin asymmetry (A_{LU}) in neutron DVCS *is* very sensitive to J_u, J_d
- Wide coverage needed!

Fixed kinematics: $x_B = 0.17 \quad Q^2 = 2\ \mathrm{GeV}^2 \quad t = -0.4\ \mathrm{GeV}^2$

CLAS12

Design luminosity
$L \sim 10^{35}$ cm^{-2} s^{-1}

Acceptance for **charged particles**:

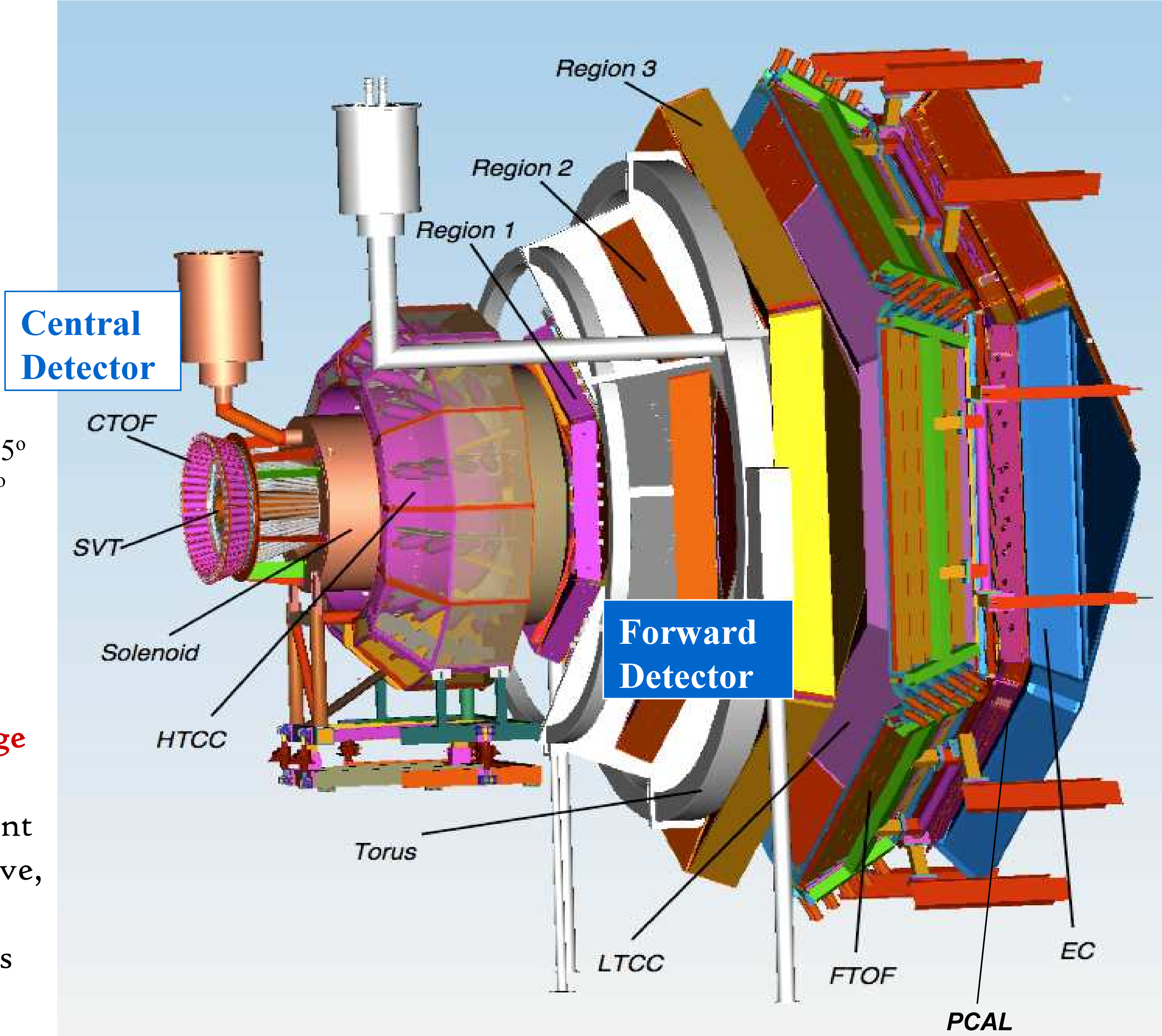
- Central (CD) $40^o < \theta < 135^o$
- Forward (FD) $5^o < \theta < 40^o$

Acceptance for **photons**:

- IC $2^o < \theta < 5^o$
- EC $5^o < \theta < 40^o$

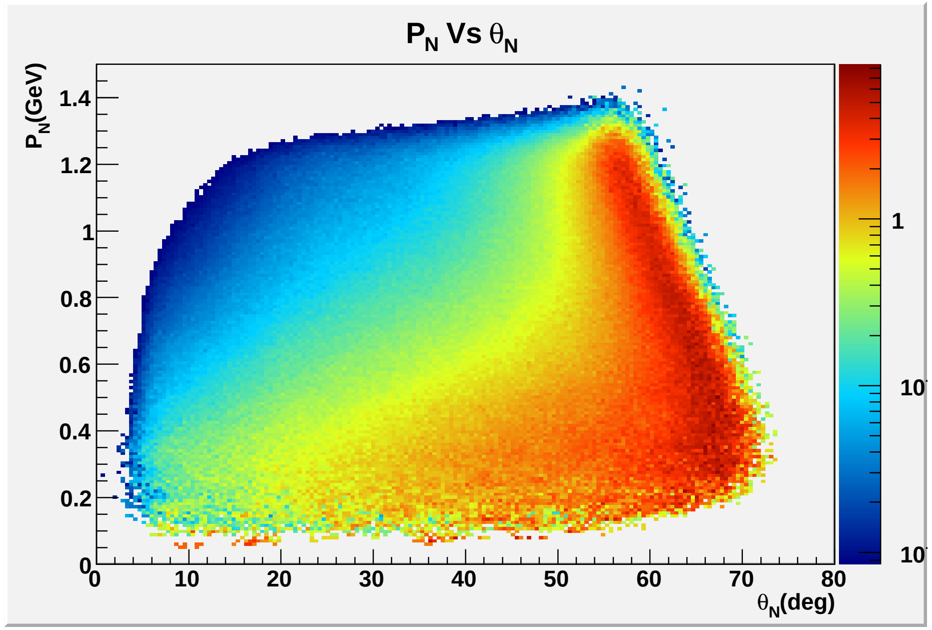
High luminosity & large acceptance:

Concurrent measurement of deeply virtual exclusive, semi-inclusive, and inclusive processes



Recoil DVCS neutrons in CLAS12

- Beam-spin asymmetry in neutron DVCS at 11 GeV – extremely sensitive to J_q
- Exclusive reconstruction of the DVCS process $en \rightarrow e'n'\gamma$ require detection and measurement of all three final state particles.

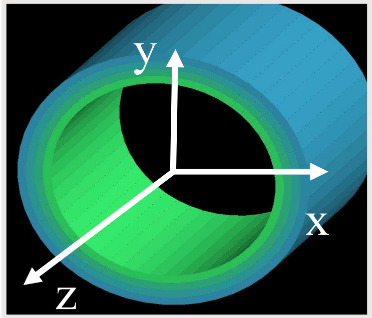


Simulation at E_e= 11 GeV

Over **80%** of neutrons recoil at θ_{lab} **> 40°** with peak momentum at **~ 0.4 GeV/c**.

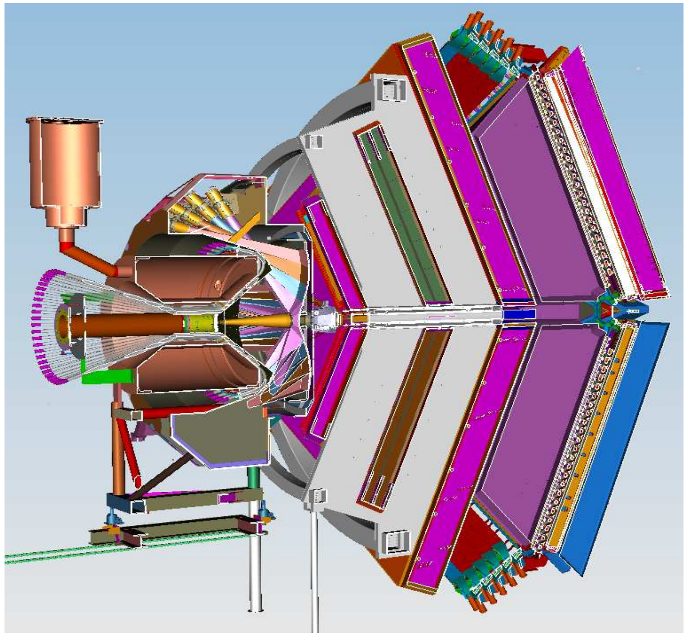
Requires central neutron detector sensitive to **$0.2 < p_n < 1.2$ GeV/c.**

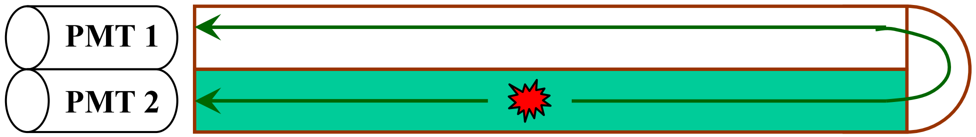
Neutron Detector for CLAS12



Available:

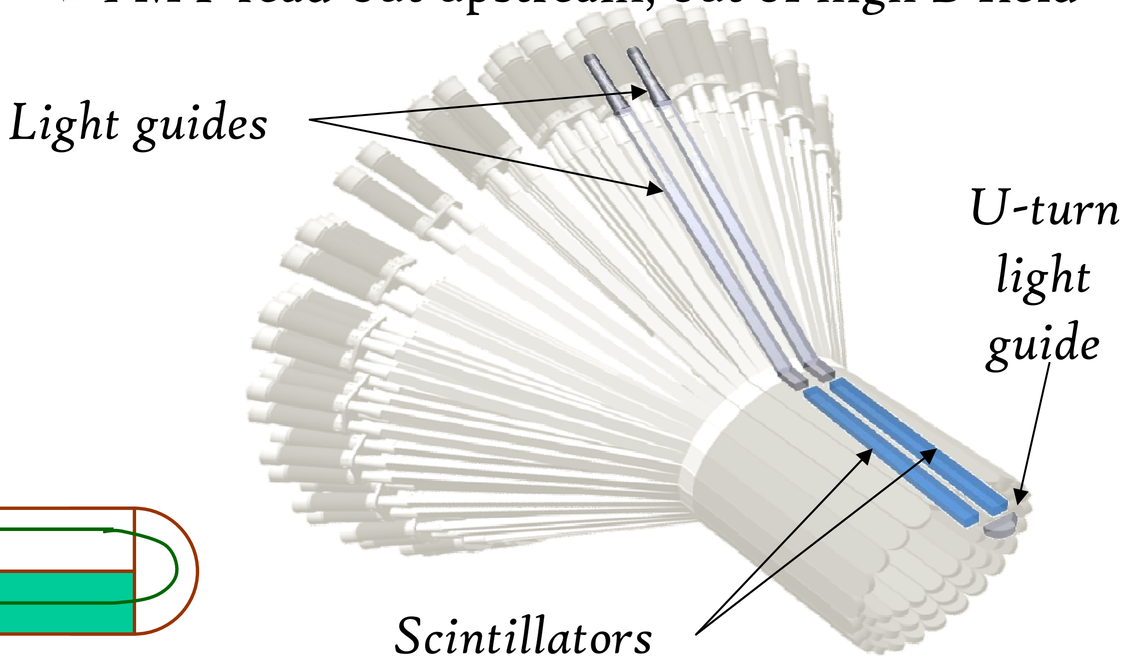
- 10 cm of radial space
- in a high magnetic field (~ 5T)





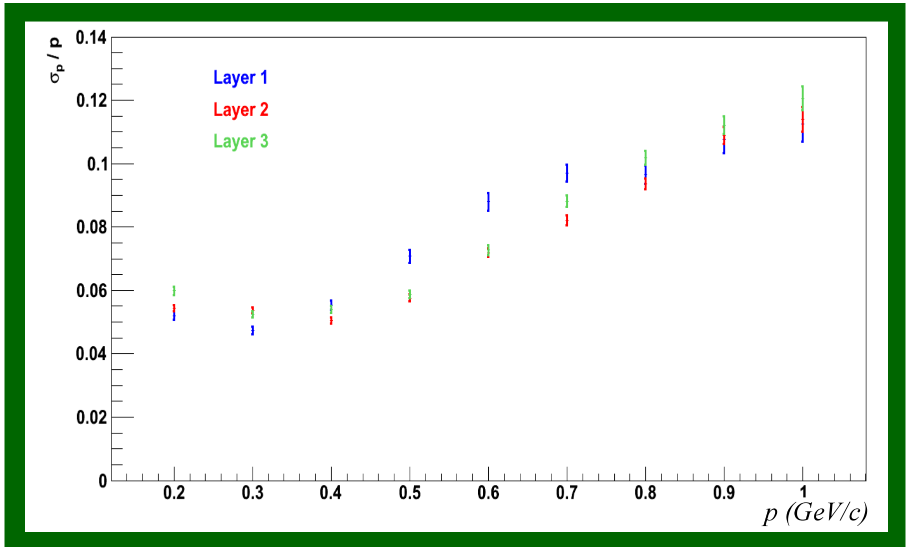
Detector proposal **approved:**

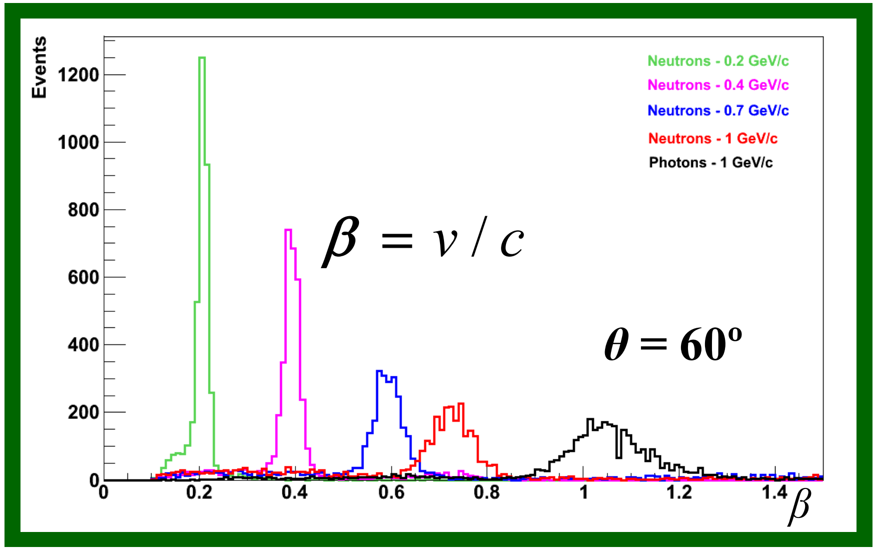
- Plastic scintillator barrel: 3 layers, 48 paddles in each
- Length ~ 70 cm, inner radius 28.5 cm
- Long (~ 1.5 m) light-guides
- PMT read-out upstream, out of high B field



CND Simulation (Geant 4)

- Neutron **efficiency** ~ 8-9 %
- Good **separation of neutrons and** γ up to ~ 1 GeV/c
- $\frac{\sigma_p}{p} \approx 5-12\ \%$ $\quad \sigma_\theta \approx 2-3^\circ$
- 1 – 3% contamination from mis-reconstructed hits





Proposal Accepted in 2011 – detector under construction at Orsay for 2014.

Summary and Conclusions

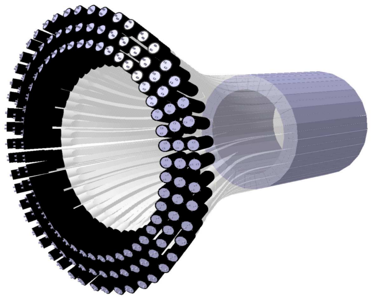
- **GPDs** provide a 3D image of the internal dynamics of the nucleon and are experimentally accessible in exclusive reactions such as DVCS.

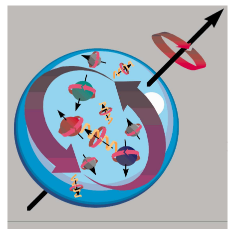
- A measurement of the **beam-spin asymmetry in DVCS** on the **neutron**, particularly in the kinematic range opening up with CLAS12, will offer important information on the composition of nucleon spin.

- The **Central Neutron Detector** is under construction – to allow exclusive reconstruction of **neutron** DVCS with **CLAS12.**

- A preliminary extraction of DVCS on **deuterium** @ 6GeV is underway – indications of a low measurable beam-spin and target-spin asymmetry on the neutron.

Thank you!

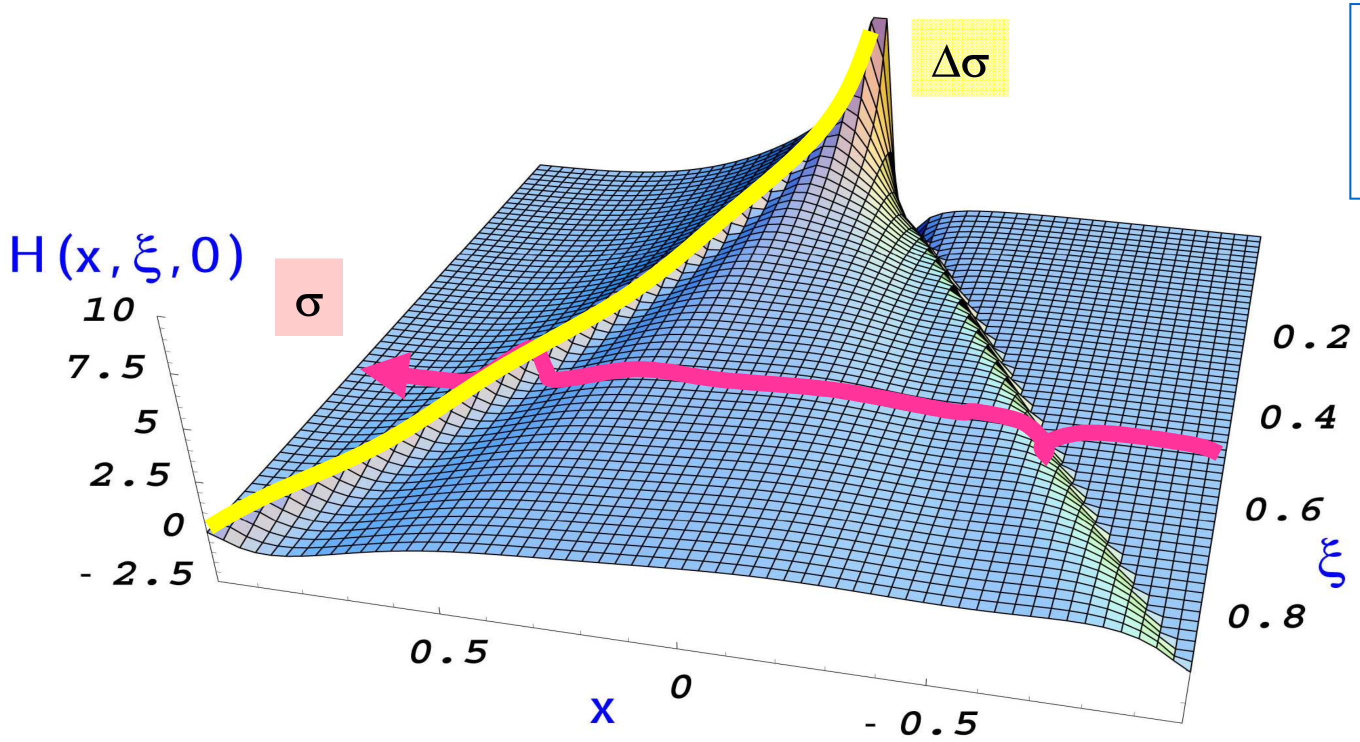




Back-up slides

Accessing GPDs through DVCS

$$T^{DVCS} \sim \int_{-1}^{+1} \frac{GPDs\,(x,\xi,t)}{x \pm \xi + i\varepsilon}\,dx \;+ \ldots \sim \quad P\int_{-1}^{+1} \frac{GPDs\,(x,\xi,t)}{x \pm \xi}\,dx \pm i\pi\, GPDs\,(\pm\xi,\xi,t) + \ldots$$



Only ξ and t are accessible experimentally

A_{LU} from *neutron DVCS* with CLAS12

$$\vec{e} + d \rightarrow e' + n + \gamma + (p_s)$$

$\Delta\sigma_{LU} \sim \sin\phi\ \mathbf{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}d\phi$

The **most sensitive** observable to the GPD **E**

80 days of data taking

L = 10^{35} cm^{-2}s^{-1}/nucleon

CLAS12 +
Forward Calorimeter +
Neutron Detector

Model predictions (VGG)
for different values of
quarks' angular momentum: