Overview of the Generalized Parton Distributions Program

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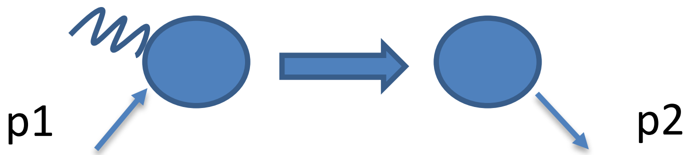
IMP Lanzhou University

Outline

- Nucleon structure : Form factors, partons distributions
- Generalized Parton Distribution
- Deeply Virtual Scattering
- Recent measurements
- Future measurements at Jlab
- Possible Double DVCS measurement with SoLID
- Conclusion

Nucleon structure

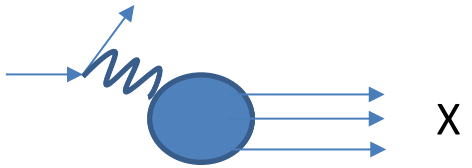
- Elastic scattering



- Form factor

- Give spatial distribution of the charge of nucleon but no information on nucleon content

- Deep Inelastic Scattering



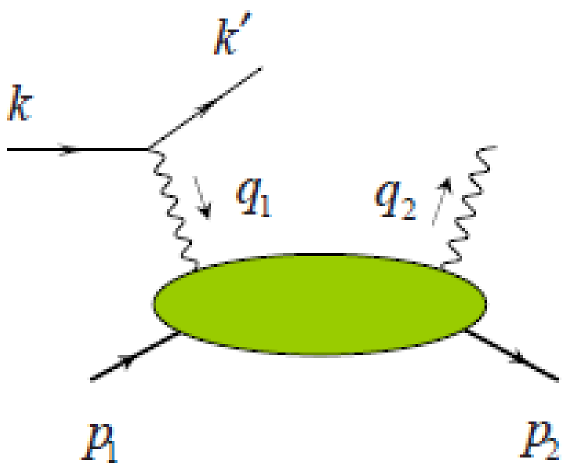
- Parton distributions

- Give the content of the nucleon and longitudinal momentum distribution but no transverse information

Generalized parton distributions

$$T_{\mu\nu} = i\int d^4z e^{i(q.z)} \left\langle N(p1,s1)\middle| T\left\{J^\mu\left(-\frac{z}{2}\right), J^\nu\left(\frac{z}{2}\right)\right\}\middle| N(p1,s1)\right\rangle$$

$$T_{\mu\nu} = i\int d^4z e^{i(q.z)} \left\langle N(p1,s1)\middle| T\left\{J^\mu\left(-\frac{z}{2}\right), J^\nu\left(\frac{z}{2}\right)\right\}\middle| N(p2,s2)\right\rangle$$



Δ = p1-p2 = q2-q1

$Q^2 = -q^2$

p = p1+p2

q = ½ (q1+q2)

$$\eta = \frac{\Delta.q}{p.q}$$

Q^2= -(k-k')^2

$$\xi = \frac{Q^2}{2p.q}$$

$$x_{bj} = \frac{Q^2}{2p_1q_1}$$

$$\langle p_2|\mathcal{O}^{qq}(-z^-,z^-)|p_1\rangle = \int_{-1}^{1} dx\, e^{-ixp^+z^-}\left\{h^+H^q(x,\eta,\Delta^2) + e^+E^q(x,\eta,\Delta^2)\right\},$$

$$\langle p_2|\widetilde{\mathcal{O}}^{qq}(-z^-,z^-)|p_1\rangle = \int_{-1}^{1} dx\, e^{-ixp^+z^-}\left\{\tilde{h}^+\widetilde{H}^q(x,\eta,\Delta^2) + \tilde{e}^+\widetilde{E}^q(x,\eta,\Delta^2)\right\},$$

$$\langle p_2|\mathcal{T}_\mu^{qq}(-z^-,z^-)|p_1\rangle = \int_{-1}^{1} dx\, e^{-ixp^+z^-}\left\{t^{+\perp}_{\ \mu}H_T^q(x,\eta,\Delta^2) + \frac{p^+e^\perp_\mu}{M_N}\widetilde{H}_T^q(x,\eta,\Delta^2)\right.$$
$$\left. - \frac{1}{2M_N}\left(\Delta^\perp_\mu h^+ - \Delta^+ h^\perp_\mu\right)E_T^q(x,\eta,\Delta^2) - \frac{p^+h^\perp_\mu}{2M_N}\widetilde{E}_T^q(x,\eta,\Delta^2)\right\}.$$

Unraveling nucleon structure with generalized parton distributions Belitsky, Radysuhkin

Arxiv:0504030

Properties of GPDs

- Forward limit p1=p1 Δ=0 and η = 0

$$H(x,0,0) = f^q(x) \qquad \widetilde{H}(x,0,0) = \Delta f^q(x)$$

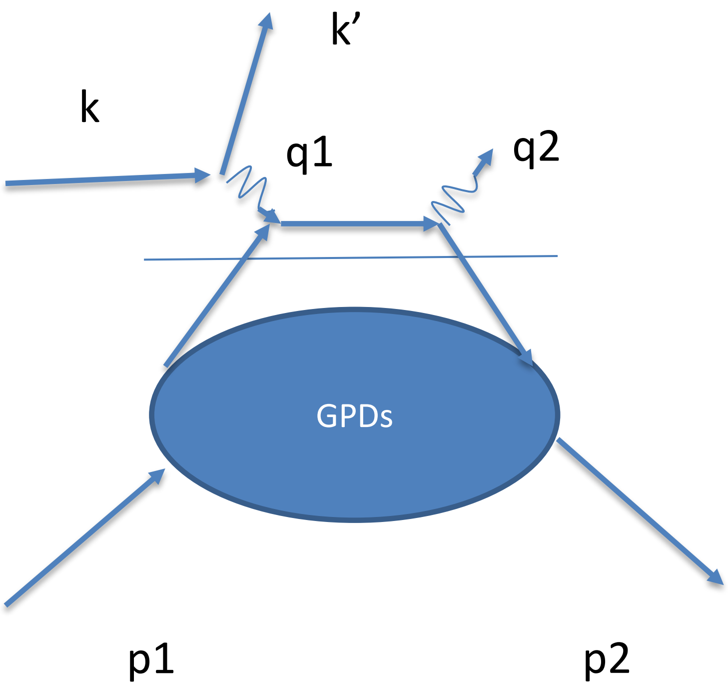
- First moment

$$\int_{-1}^{1} dx\, H^q(x,\eta,\Delta^2) = F_1^q(\Delta^2)\,, \qquad \int_{-1}^{1} dx\, E^q(x,\eta,\Delta^2) = F_2^q(\Delta^2)\,,$$
$$\int_{-1}^{1} dx\, \widetilde{H}^q(x,\eta,\Delta^2) = G_A^q(\Delta^2)\,, \qquad \int_{-1}^{1} dx\, \widetilde{E}^q(x,\eta,\Delta^2) = G_P^q(\Delta^2)$$

- Second moment can give access to quark orbital momentum (Ji’ s sum rule)

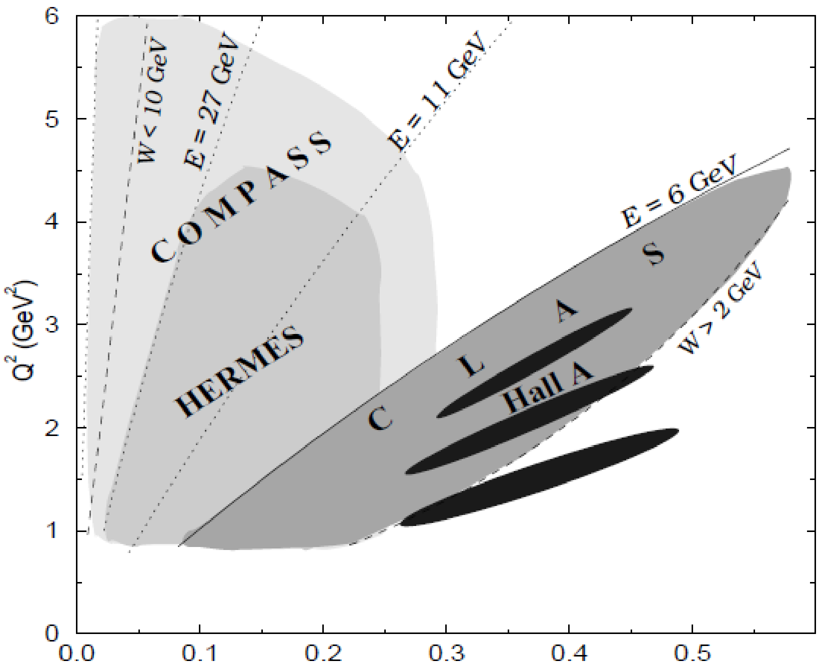
$$J^q = \frac{1}{2}\int dx\ x[H^q(x,\zeta,t=0) + E^q(x,\zeta,t=0)]$$

Deeply Virtual Compton Scattering



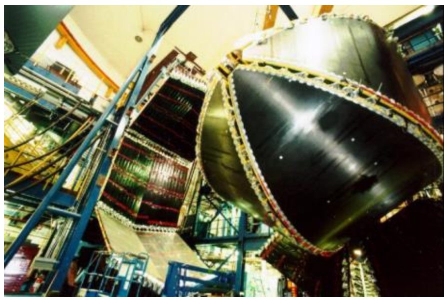
- Handbag diagram
- Factorization theorem need large Q^2, large s and small t
- Cross-section is product of hard scattering on quark computable with pQCD and the soft non perturbative GPD

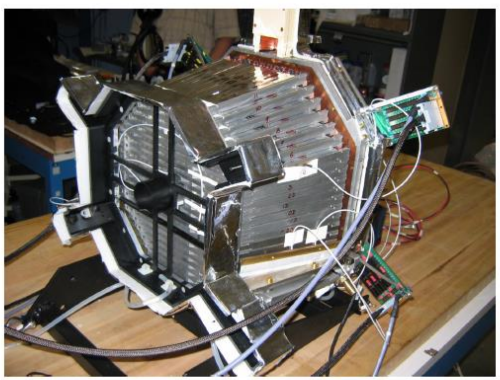
Scattering at 6 GeV at Jefferson Laboratory

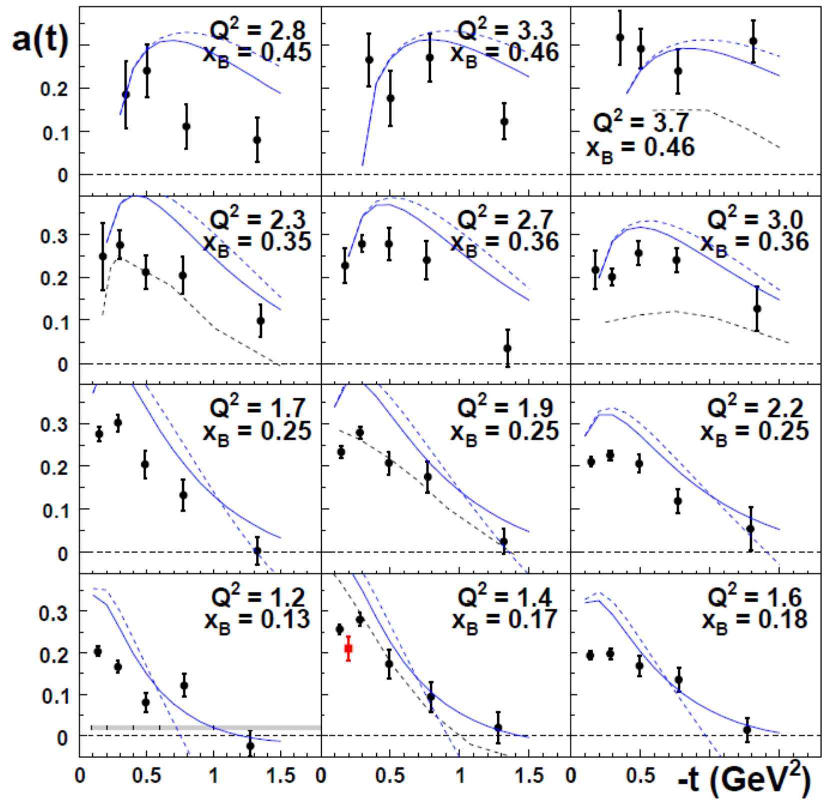


Large acceptance measurement Hall B

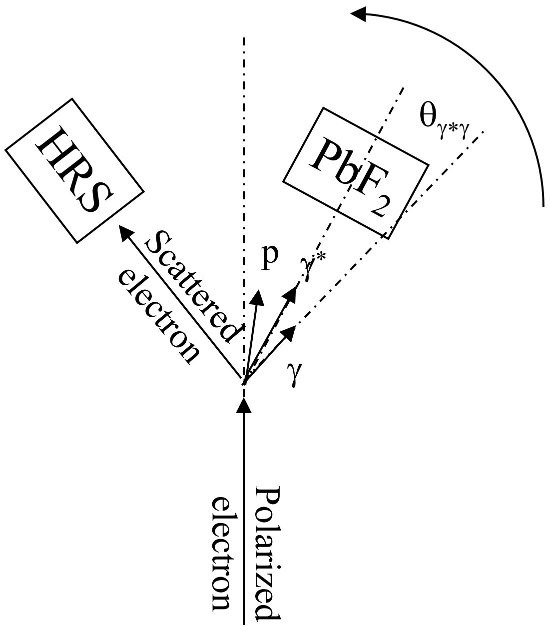
$$A = \frac{N^+ - N^-}{N^+ + N^-}$$

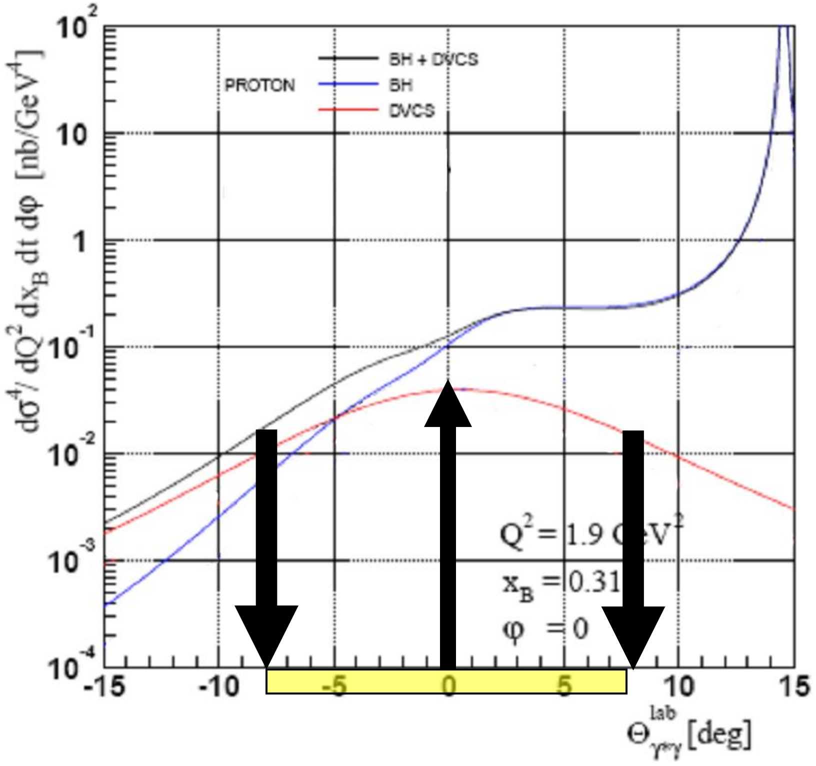






Hall A DVCS experiment





Cross sections measurement

Electron helicity dependent cross sections of photon electroproduction using Jefferson Laboratory polarized electron beam

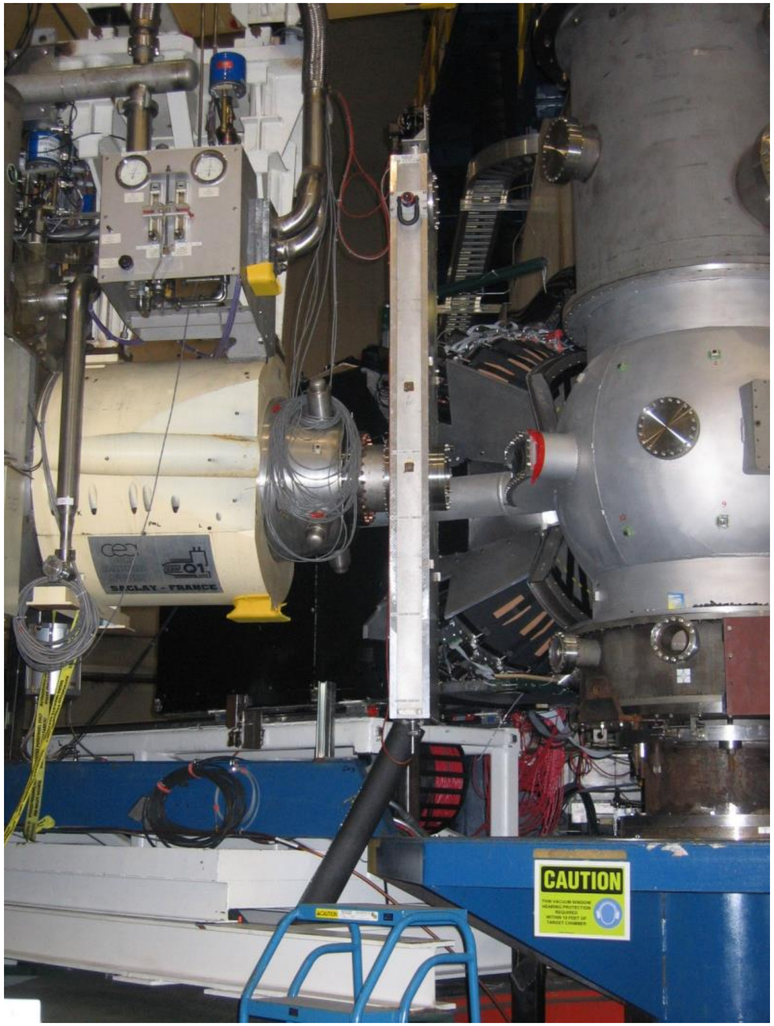
$$d^5\overrightarrow{\sigma} - d^5\overleftarrow{\sigma} \propto BH \cdot \mathrm{Im}(DVCS)$$

$$+ (\overrightarrow{DVCS}^2 - \overleftarrow{DVCS}^2)$$

$$d^5\overrightarrow{\sigma} + d^5\overleftarrow{\sigma} \propto BH^2 + \mathrm{Re}(BH \cdot DVCS)$$

$$+ DVCS^2$$

Setup in Hall A

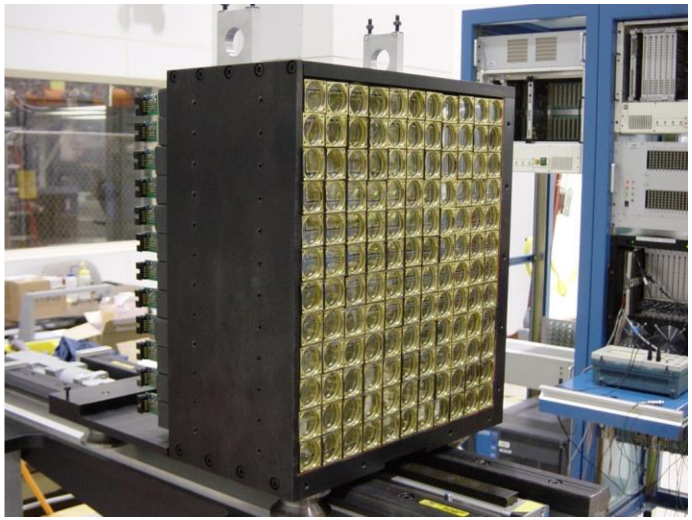


11x12 = 132 blocks

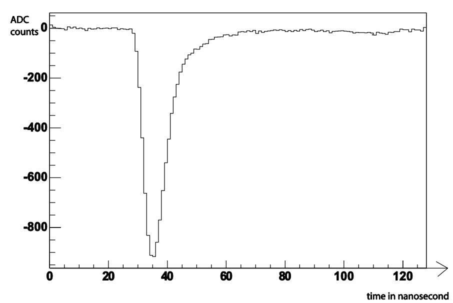
3cmx3cmx18.6cm

located at 110 cm from the target

1msrd per block



- PMT R7700 Hammamatsu
  - 8 stages
  - Typical gain : 10^4
  - Rise time 2 ns
  - width 6ns

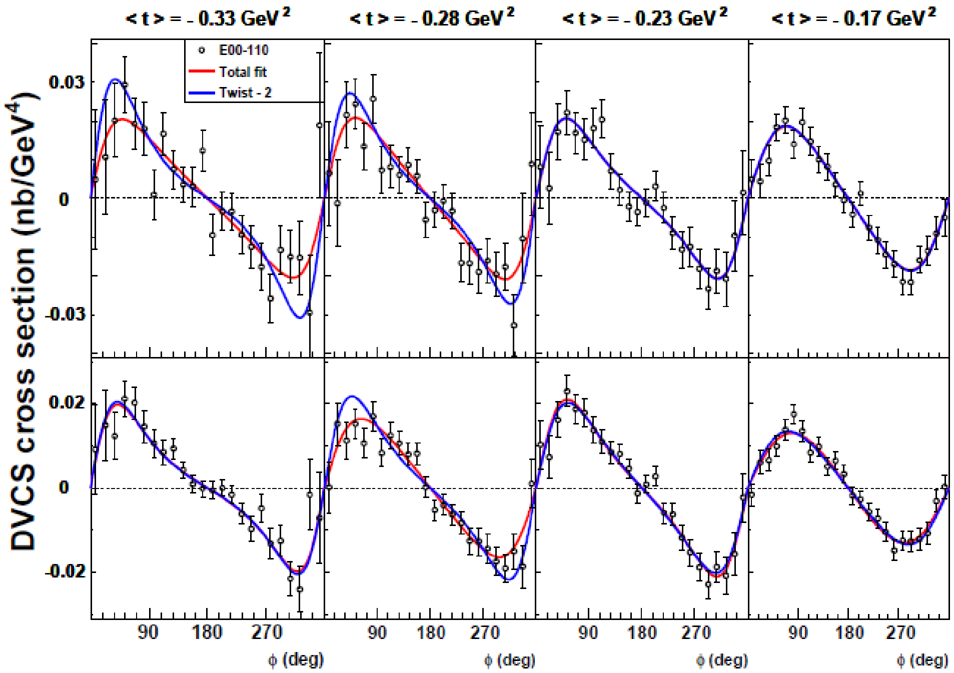


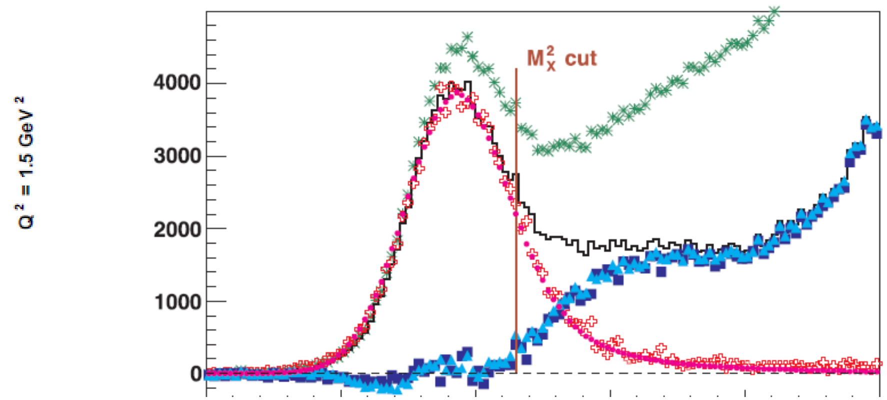
- Lead fluoride properties
  - density 7.77 $g.cm^3$
  - X_0=0.93 cm length=$20X_0$ Moliere radius = 2.2 cm
  - Pure Cerenkov : fast pulse, less sensitive to hadronic background
  - 1 Photoelectron per MeV,
  - Resolution 4 .2GeV : 2.7 %
  - Angular resolution :

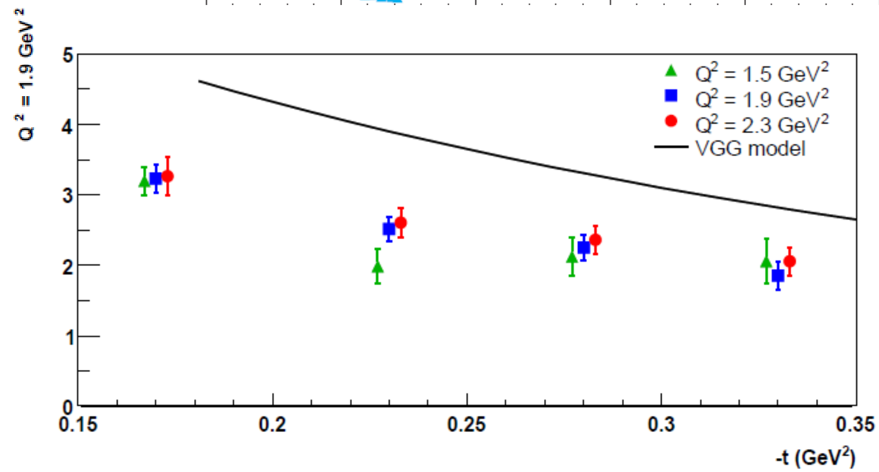
    Horizontal 1.3 mrad

    Vertical 1.8 mrad
  - Radiation hard

Hall A measurement

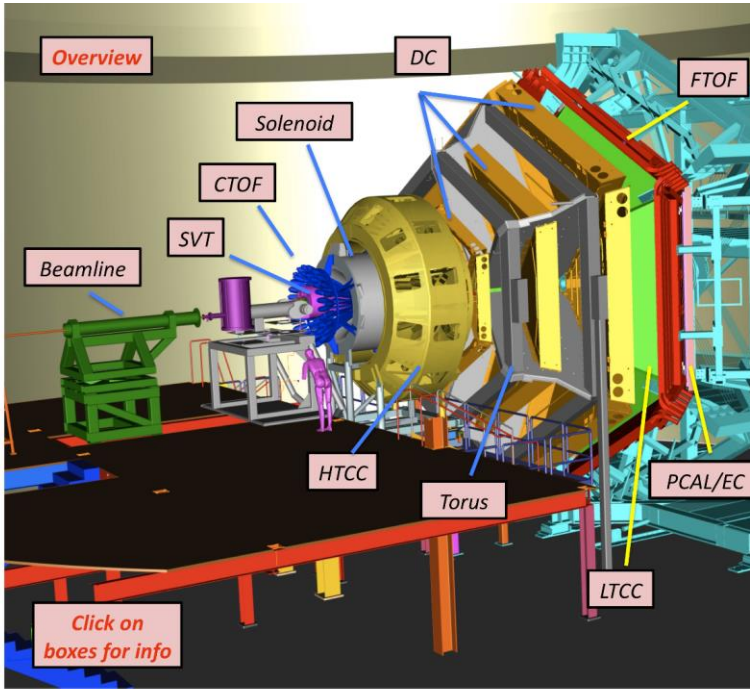


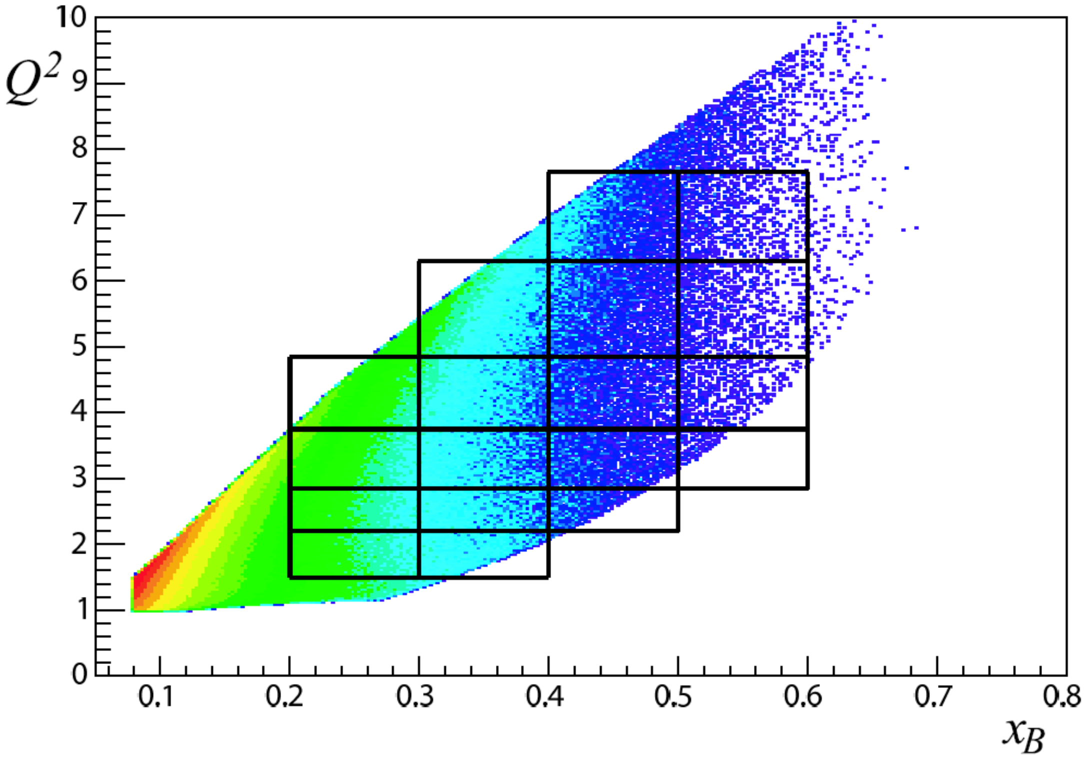




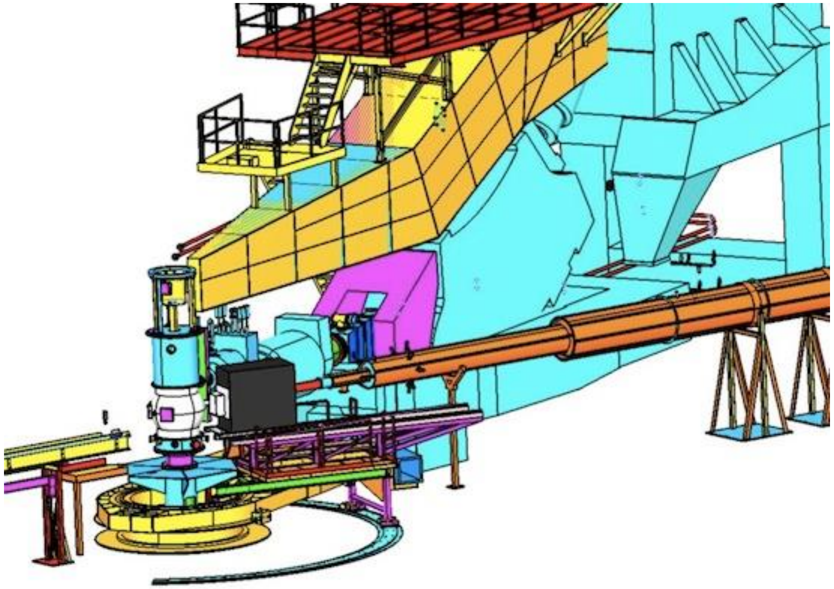
12 GEV EXPERIMENTS

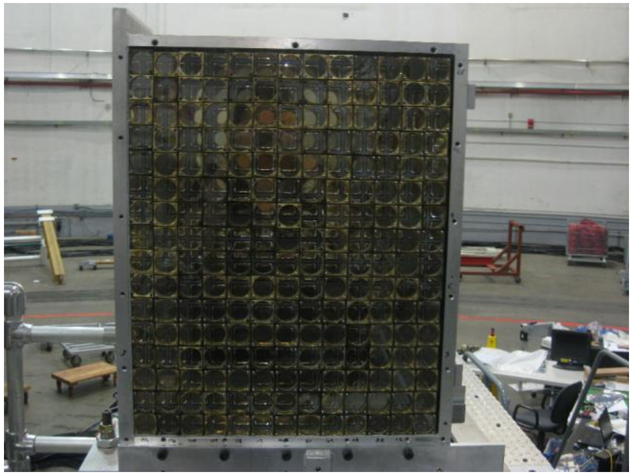
CLAS 12 Hall B



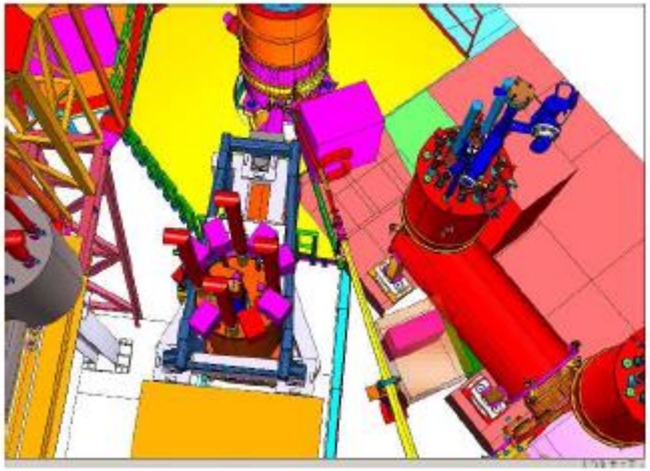


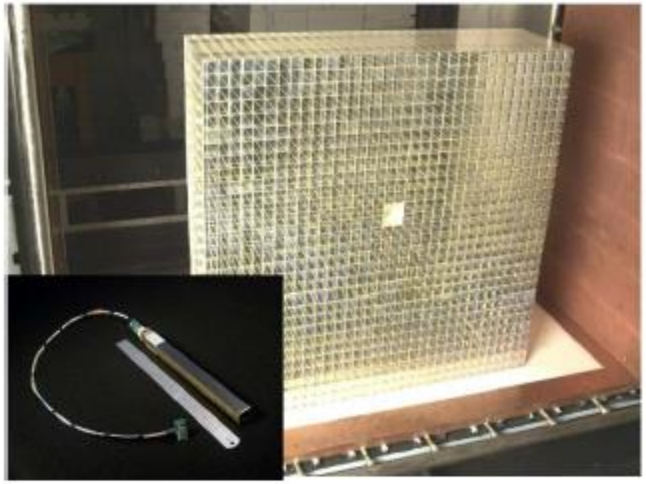
Hall A setup



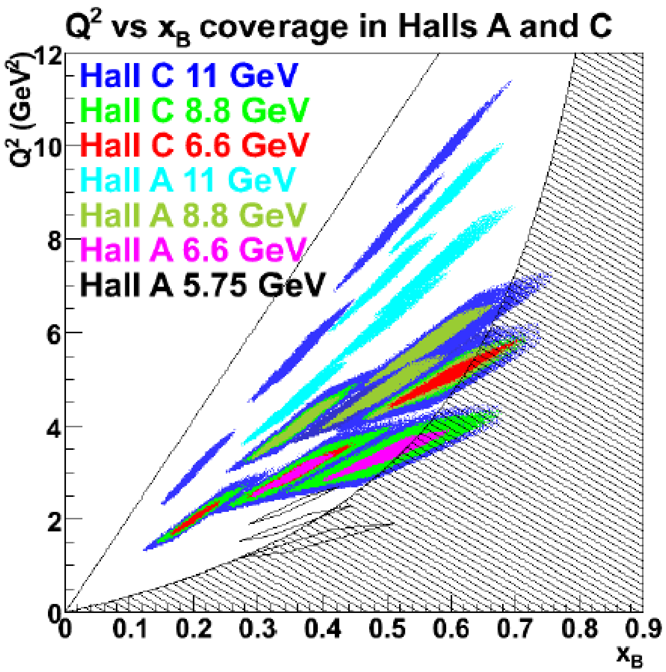


Hall C measurement using Neutral Photon Spectrometer





Hall A/C coverage



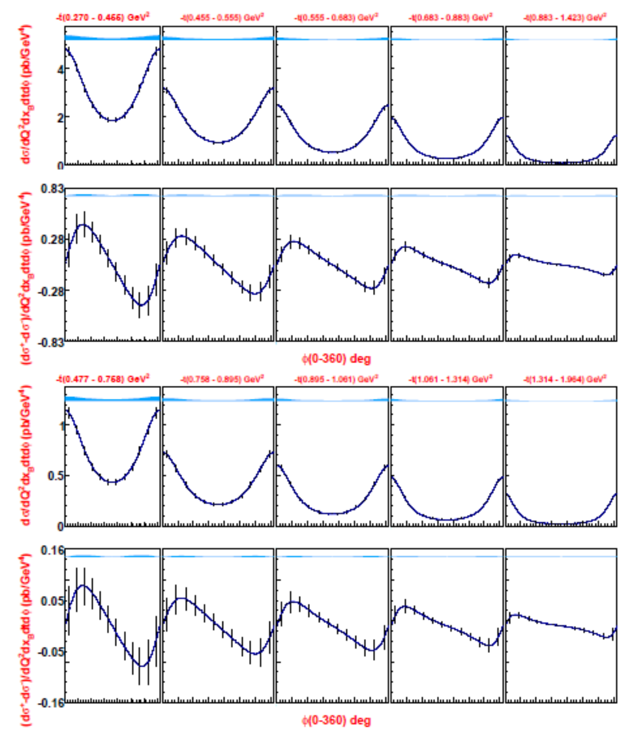


FIG. 12: Projections for the highest Q^2 settings: $Q^2 = 8$ GeV^2 (top, $x_B = 0.5$) and $Q^2 = 10$ GeV^2 (bottom, $x_B = 0.6$).

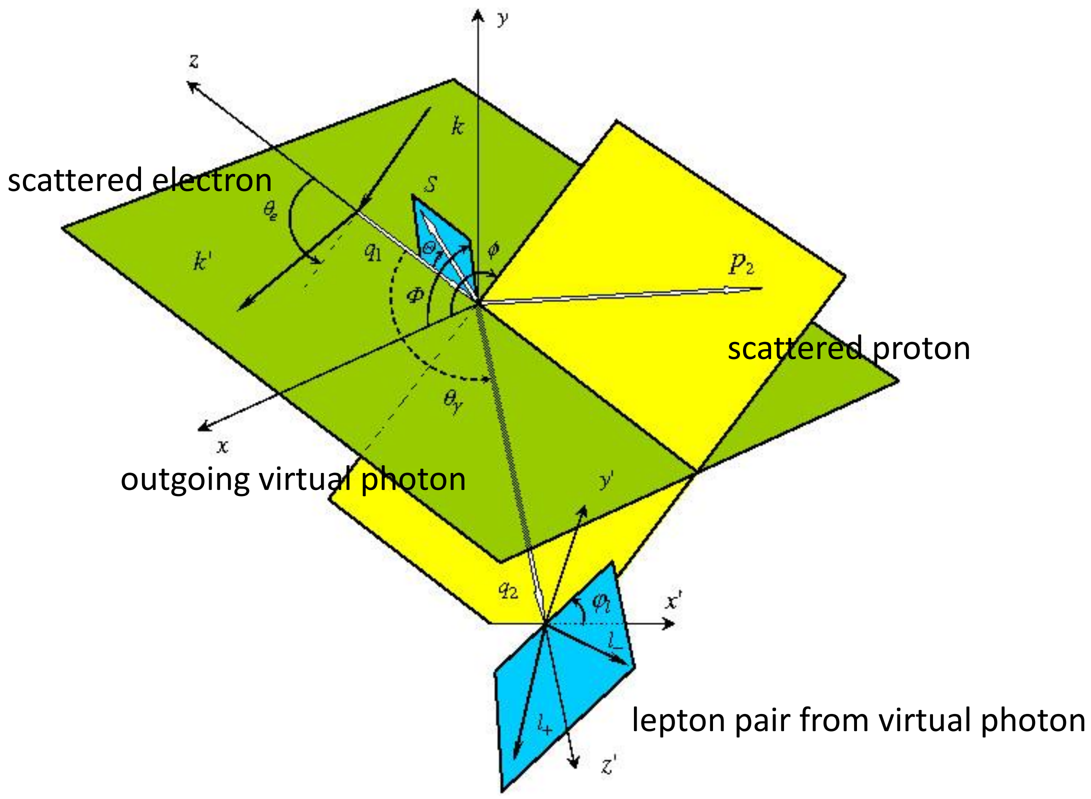
Double DVCS

$$\gamma^{*} + p \longrightarrow \gamma'^{*} + p'$$

$$\gamma'^{*} \longrightarrow l^{+} + l^{-}$$

Guidal and Vanderhaegen : Double deeply virtual Compton scattering off the nucleon (arXiv:hep-ph/0208275v1 30 Aug 2002)
Belitsky Radyushkin : Unraveling hadron structure with generalized parton distributions (arXiv:hep-ph/0504030v3 27 Jun 2005)

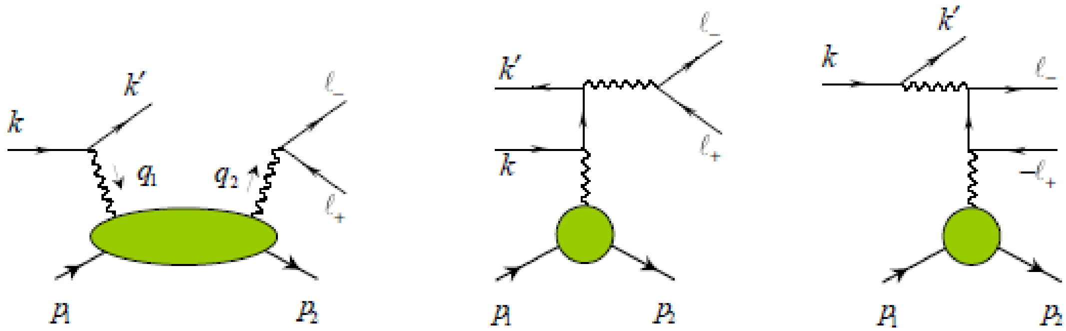
Double Deeply Virtual Compton Scattering



Double DVCS

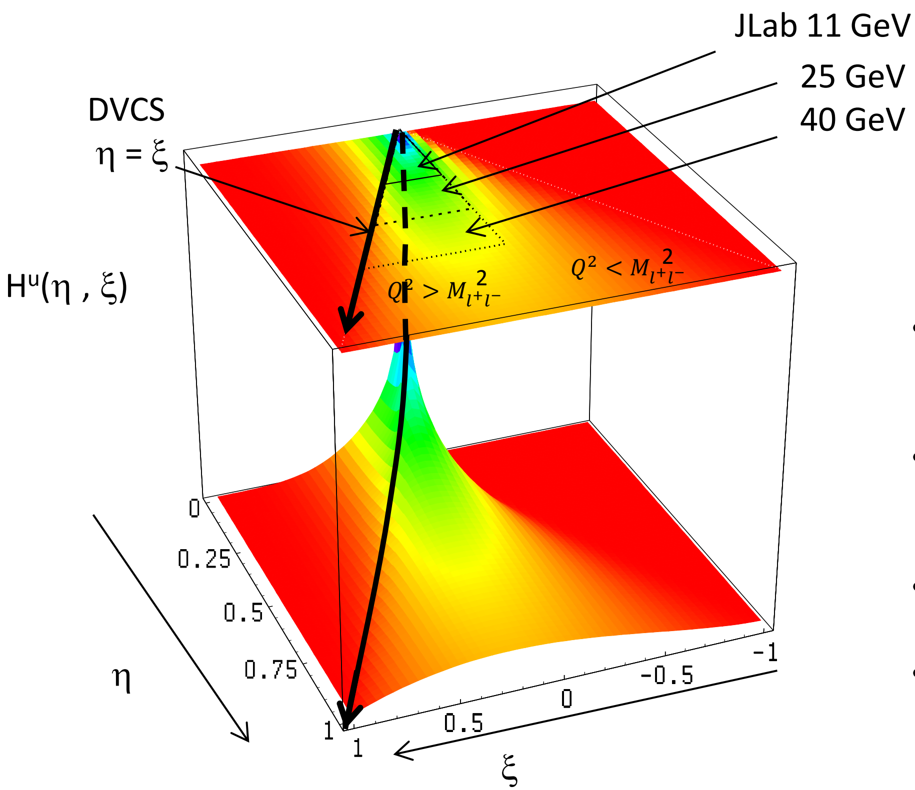
- Detect dilepton pair instead of real photon
- Allow to vary skewness η of the reaction
- Charged particle in final state can use spectrometer to measure momentum (less requirement on calorimeter energy resolution)
- Muon channel can go through large amount of material, possibly clean trigger with coincidence

Double DVCS and Virtual Bethe Heitler



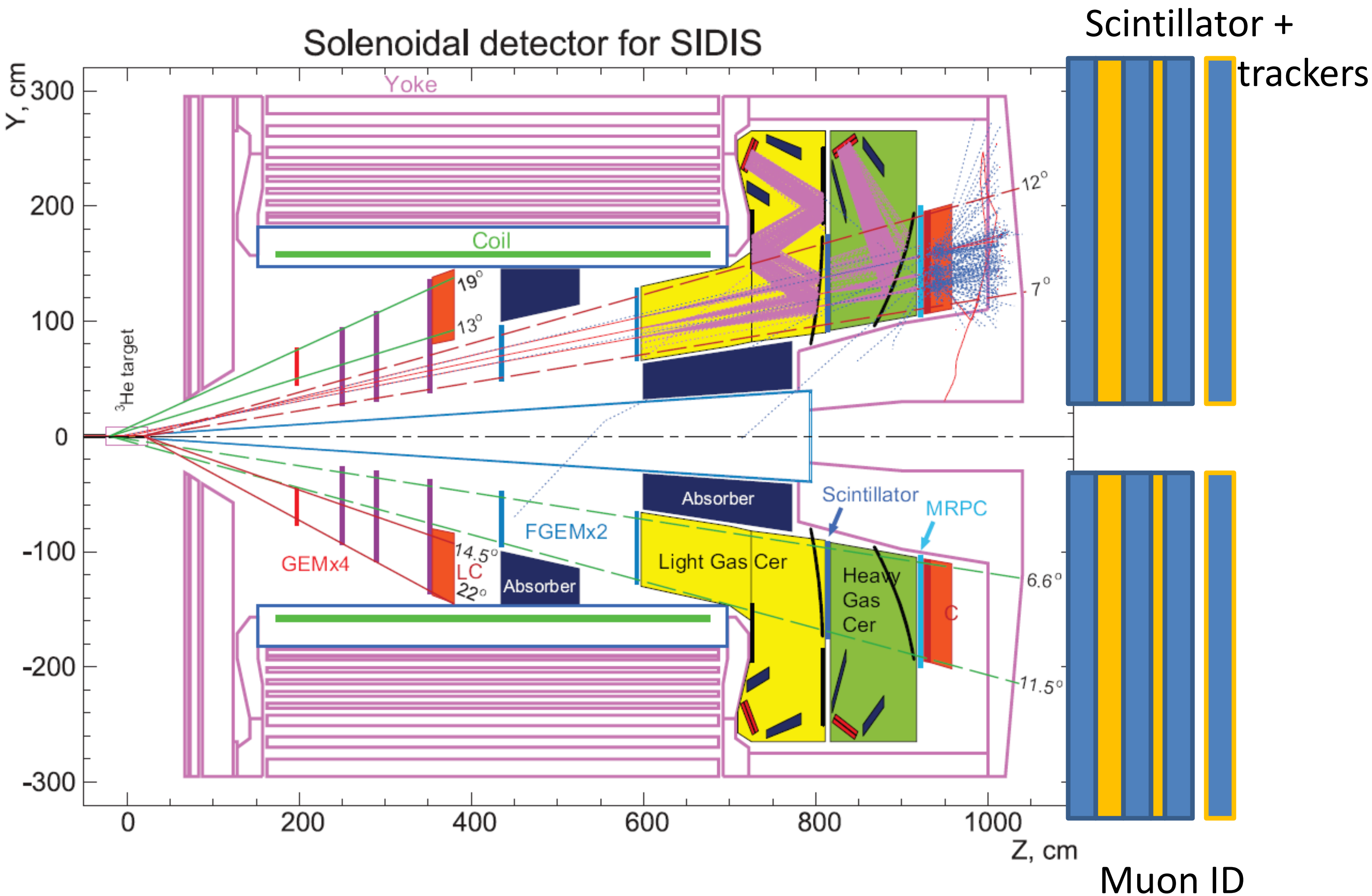
- Interference of Double DVCS and virtual Bethe Heitler

Kinematical coverage



- DVCS only probes η = ξ line
- Example with model of GPD H for up quark
- Jlab : $Q^2>0$
- Kinematical range increases with beam energy (larger dilepton mass)

SoLID SIDIS layout

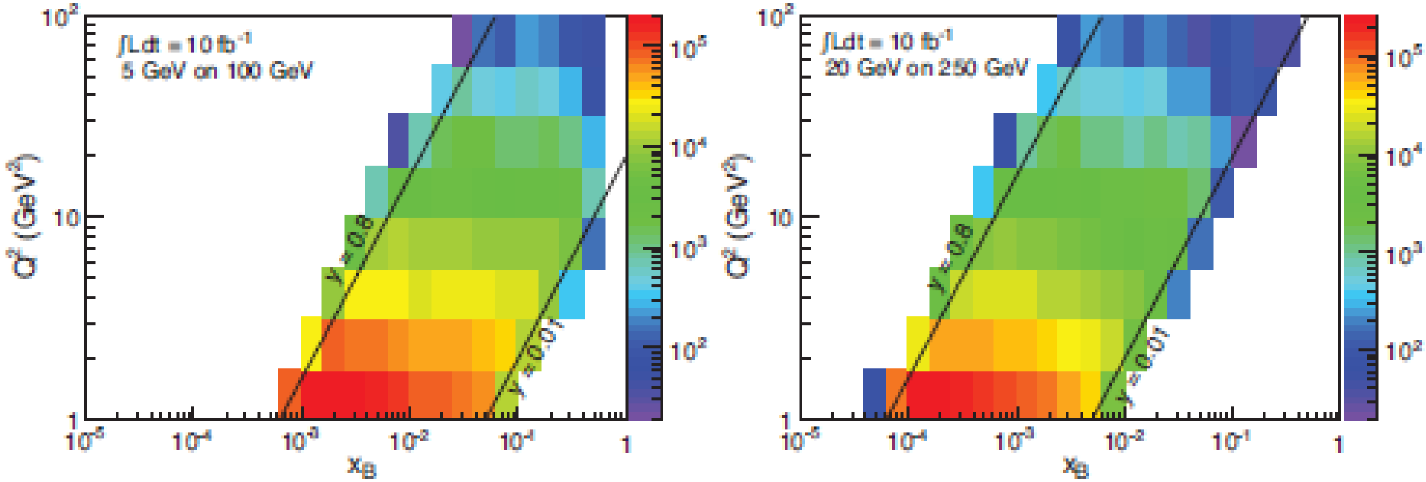


Electron Ion Collider

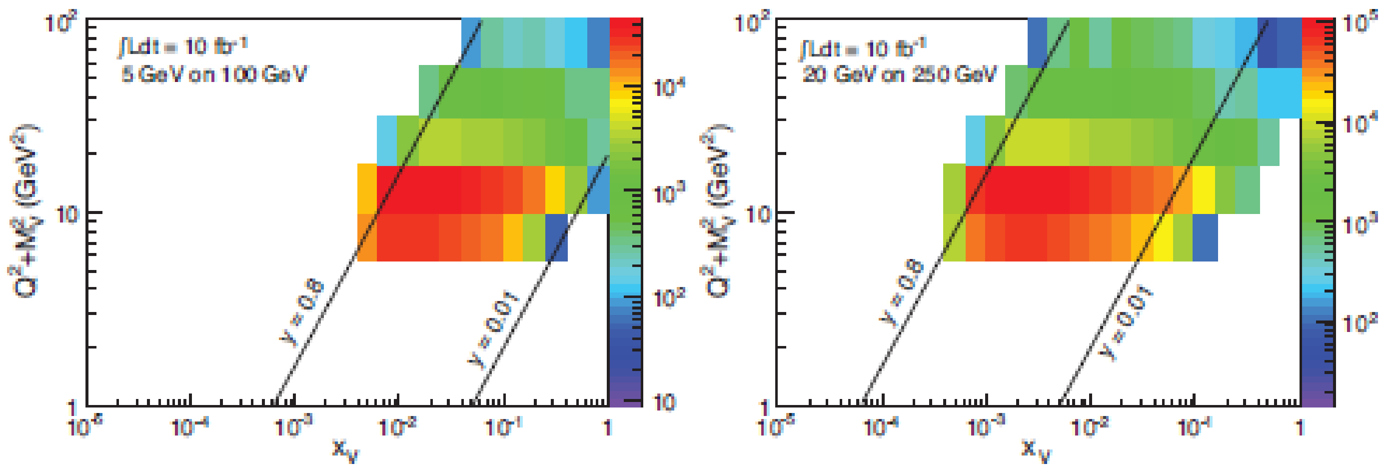
- Luminosity 10^35
- Polarized electron and proton (longitudinal and transverse)
- Low x for gluons GPDs, large range of

Deliverables	Observables	What we learn	Requirements
GPDs of sea quarks and gluons	DVCS and $J/\Psi, \rho^0, \phi$ production cross-section and polarization asymmetries	transverse spatial distrib. of sea quarks and gluons; total angular momentum and spin-orbit correlations	$\int dt\, L \sim 10$ to $100\,\mathrm{fb}^{-1}$; leading proton detection; polarized e^- and p beams; wide range of x and Q^2; range of beam energies; e^+ beam valuable for DVCS
GPDs of valence and sea quarks	electro-production of π^+, K and ρ^+, K^*	dependence on quark flavor and polarization	

EIC



Kinematical
Coverage
For DVCS
At EIC



Kinematical
Coverage
For J/y
At EIC

Conclusions

- On going GPDs program, can give additional information on the nucleon structure
- Still need many measurements to measure the GPDs
- Jlab 12 GeV will have a major contribution
- EIC can complete the coverage especially for gluons
- Investigating feasibility of DDVCS with SoLID for muons pairs to further constrain GPDs