Deep Exclusive Processes

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Outline

- Some basics about the proton
- Generalized Parton Distributions (GPDs) and what they can tell us
- experiments to access GPDs
- CEBAF future experiments & JLab @ 12 GeV
- Imaging of the Proton’s Quark Structure
- Conclusions

Some well known facts about the proton

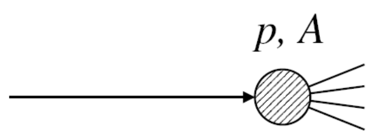
- Charge: $Q_p = +1$
  - It has a neutral partner, the neutron, $Q_n = 0$

- Spin: $s = ½\hbar$
  - Magnetic moment $\mu_p = 2.79\mu_N$
  - Anomalous magnetic moment $m_a = 1.79m_N$

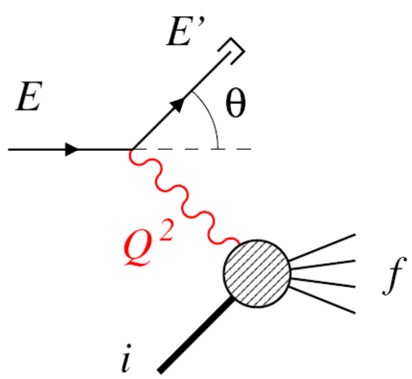
- Mass: $M_p \sim 940$ MeV/c^2
  - Protons + neutrons make up 99.9% of the mass of the visible universe

1950's: Does the proton have finite size?

Scattering Experiments in Nuclear Physics



$p, \pi, \ldots$	hadron
$e, \mu, \nu, \ldots$	lepton
γ	photon



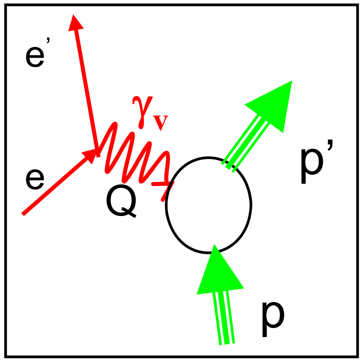
$$\langle f|\ J_\mu(x)\ |i\rangle$$

- Uses of scattering experiments
  - Structure target
  - Produced system (meson, resonances)

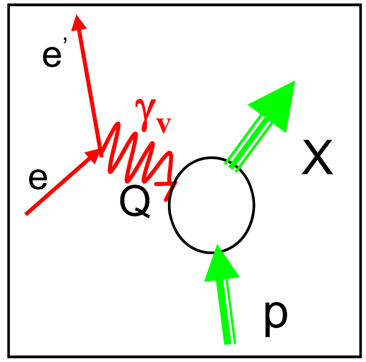
- Advantages of electron scattering
  - Structureless probe. "clean"
  - Controlled energy/momentum transfer, "microscope" with resolution Q^2
  - Interaction through well-known EM current operator

Electron Scattering a clean probe of the Proton Structure

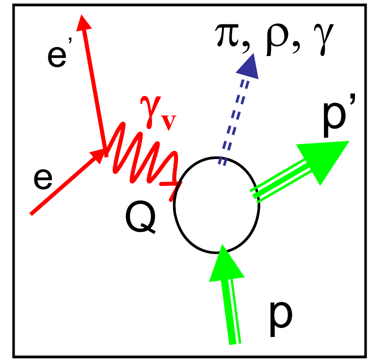
elastic



inclusive



exclusive



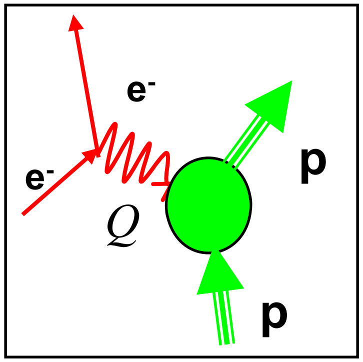
Interaction described by:

$Q^2 = -(e-e')^2$
$\nu = E_e - E_{e'}$
$x_B = Q^2/2M\nu$
$t = (p-p')^2$

$1/\sqrt{Q^2}$ is the space-time resolution of the virtual γ

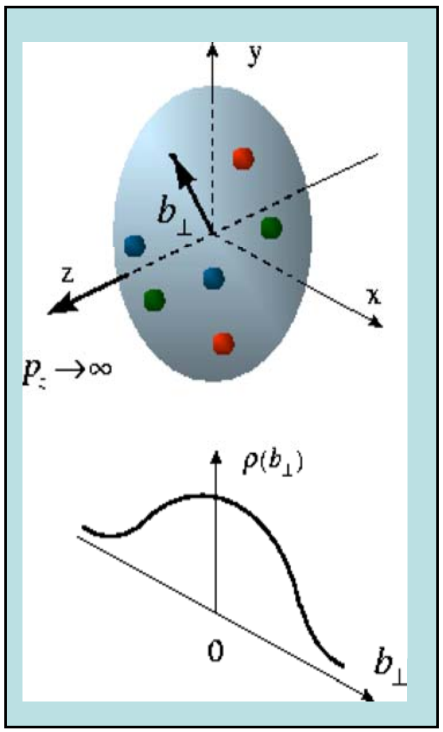
The exploration of the internal structure of the proton began in the 1950's with Hofstadter's experiments.

Does the Proton have finite size?



$$d\sigma/d\Omega = [d\sigma/d\Omega]_{n.s.} |F(\vec{q})|$$

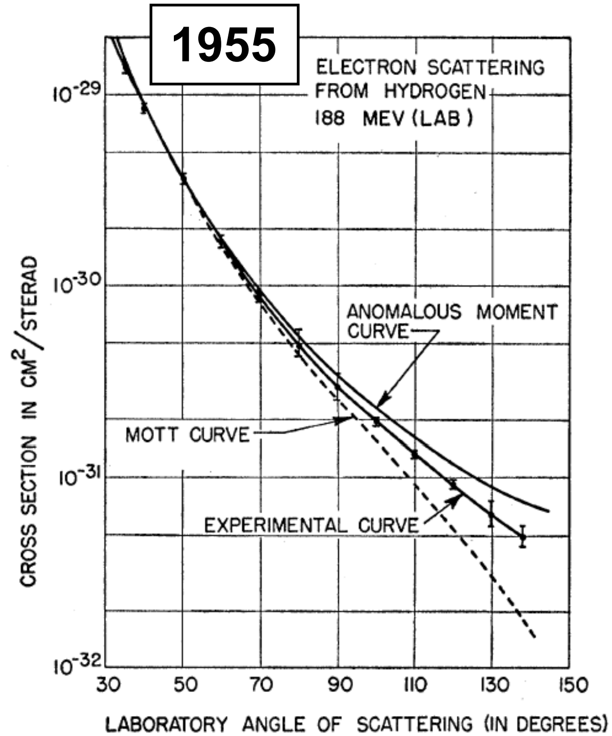
$$F(q) = \int dr\, e^{-iq\,r} \rho(r)$$



Proton form factors, transverse charge & current densities

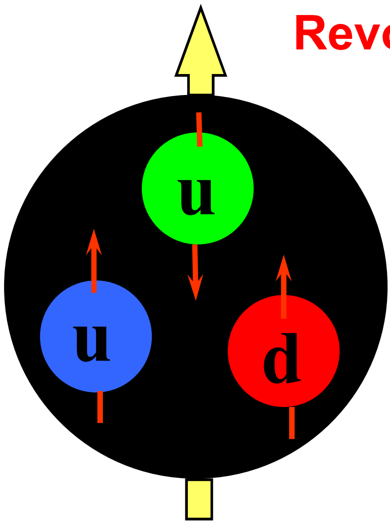
Nobel Prize for Physics. 1961

R. Hofstadter



- Elastic electron-proton scattering
  ⇨ the proton is not a point-like particle, it has finite size.

Constituent Quark Model



Revolutionized our way of thinking about proton structure

The proton is build from three quarks of spin s = 1/2 moving in the s-state (L = 0) and having masses m_q ~ 300 MeV.

M. Gell-Mann, 1964
G. Zweig, 1964

- Proton mass: $m_p \approx 3m_q$
- Proton spin: $S = \frac{1}{2} \oplus \frac{1}{2} \oplus \frac{1}{2}$

Solely built from the quark spins!

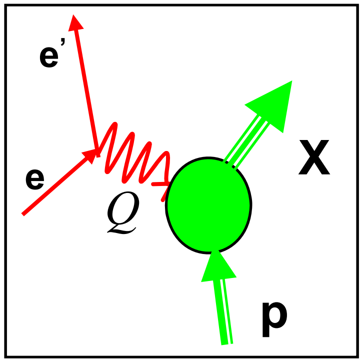
Tremendously successful model in description of

- Hadron mass spectra
- Magnetic moments

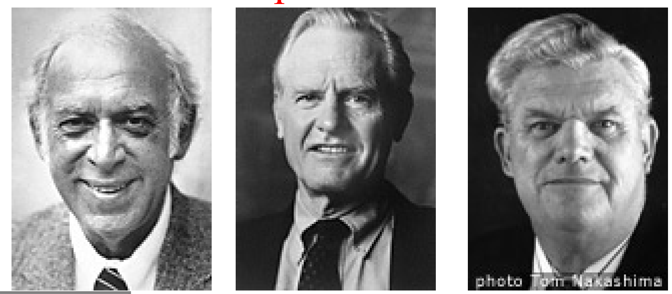
e.g. $\mu_p = 2.79 \dfrac{e}{2m_p c} \approx \dfrac{e}{2(m_p/3)c}$

What is the internal structure of the proton?

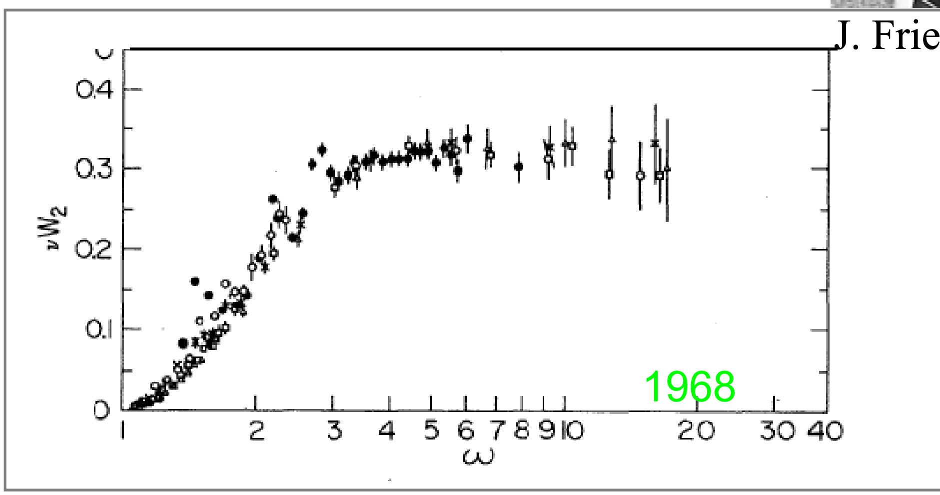
Deep inelastic electron-proton scattering   ep→e'X



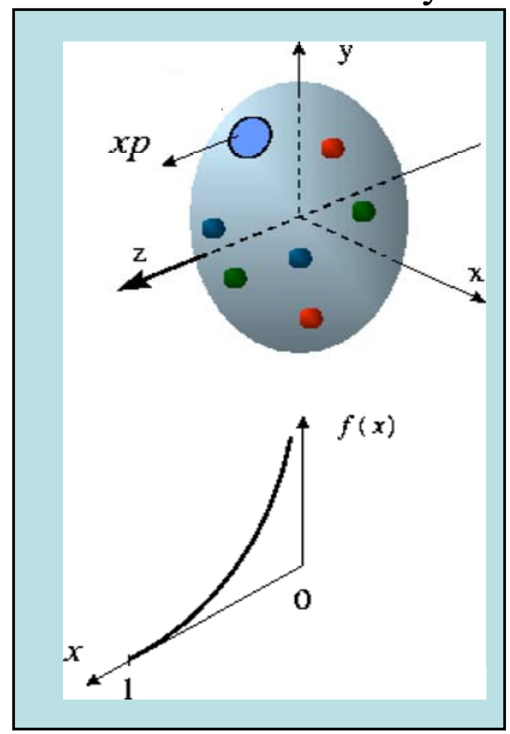
Nobel prize 1990



J. Friedman   H. Kendall   R. Taylor



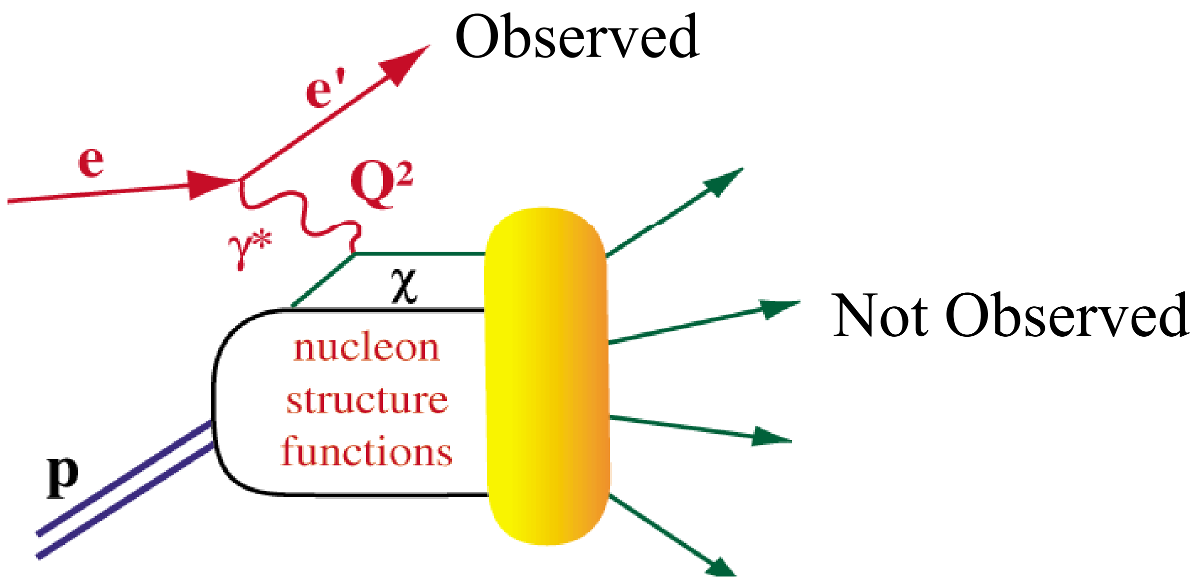
$= 1/x_B$



Scaling → Quarks are point-like objects!

Quarks carry ~ 50% of the proton momentum =>glue=>QCD
The quark spins contributes only 25% to the proton spin.

Deep Inclusive Scattering (DIS)



What have we learned?

- quarks-substructure of the nucleon
- 50% of the nucleon momentum is carried by quarks, the remainder by gluons
- quarks are spin ½ objects
- less than 25% of the nucleon spin is carried by quark helicity

Some Open Questions in Nucleon Physics in the Valence Quark Region

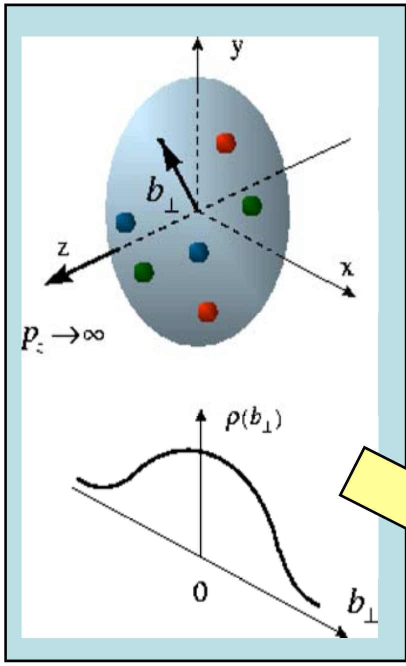
- Internal nucleon dynamics
- Transverse momentum distributions
- Quark-quark correlations
- Full (complex) quark wave functions
- Origin of the nucleon spin

⬇

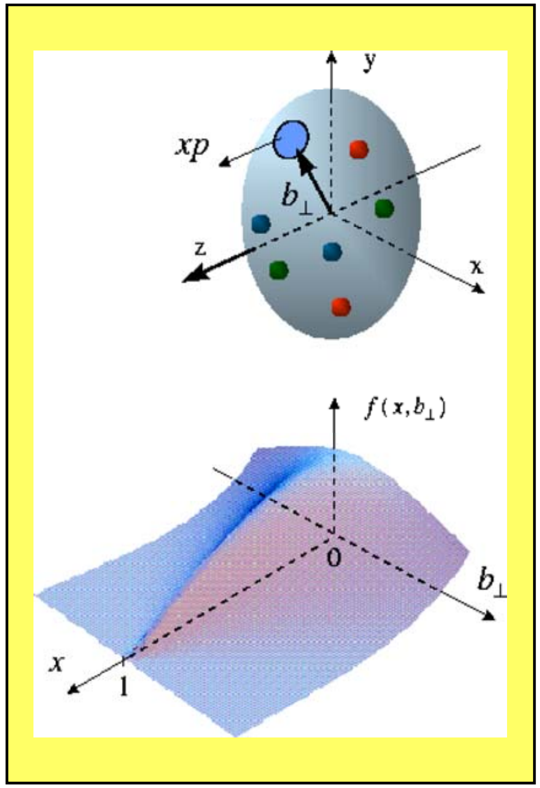
GPDs and Exclusive processes

How are the proton's charge/current densities related to its quark momentum/spin distribution?

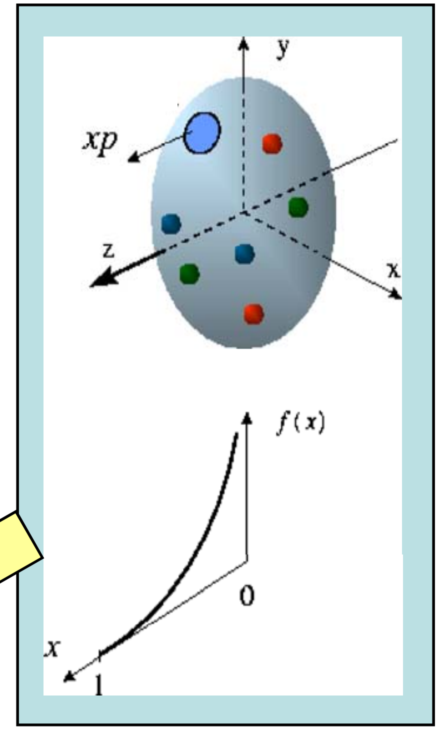
D. Mueller, X. Ji, A. Radyushkin, …1994 -1997
M. Burkardt, A. Belitsky… Interpretation in impact parameter space



Proton form factors, transverse charge & current densities

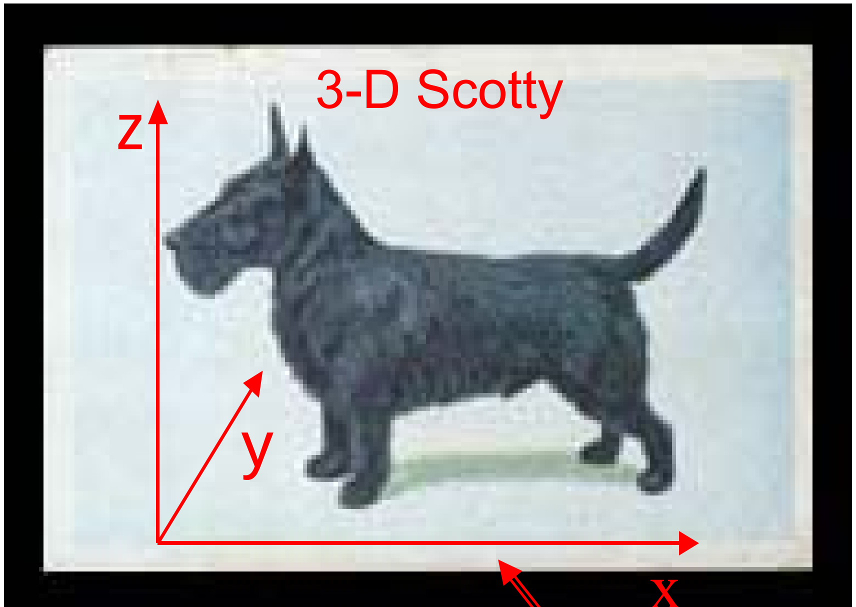


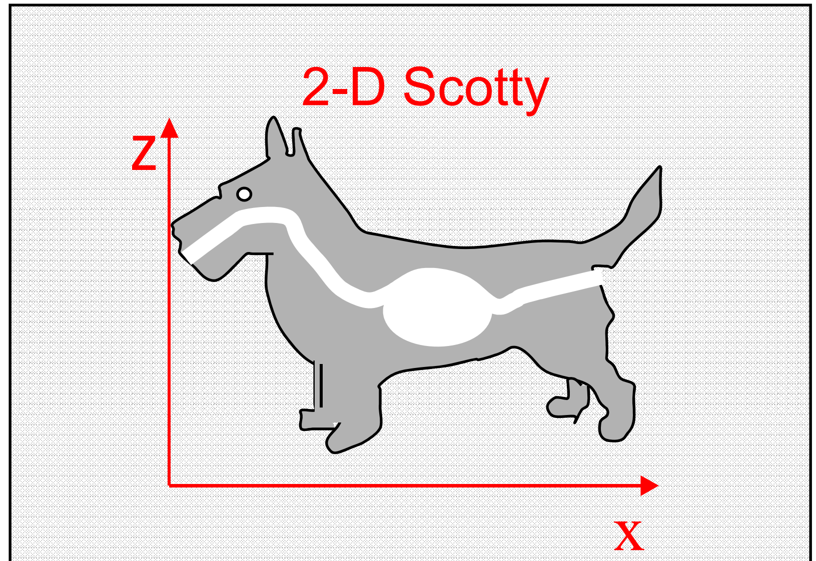
Correlated quark momentum and helicity distributions in transverse space - GPDs

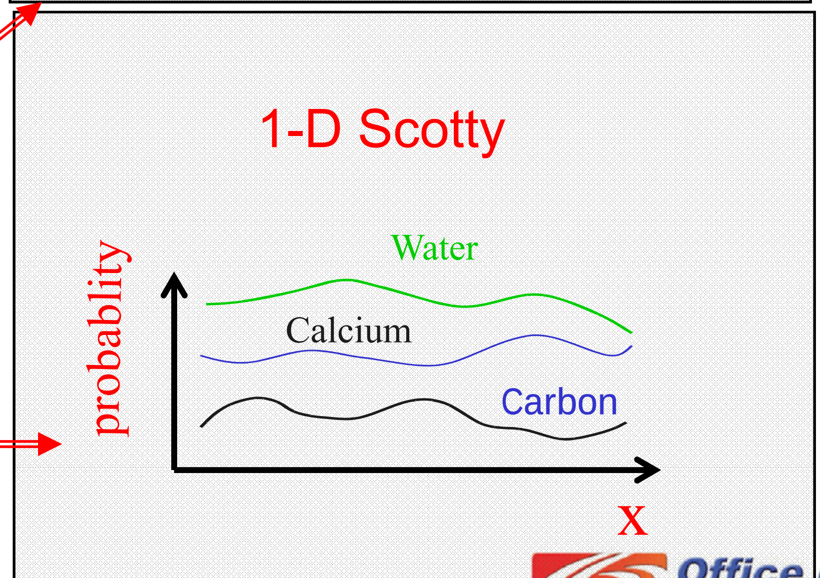


Structure functions, quark longitudinal momentum & spin distributions

GPDs & PDFs





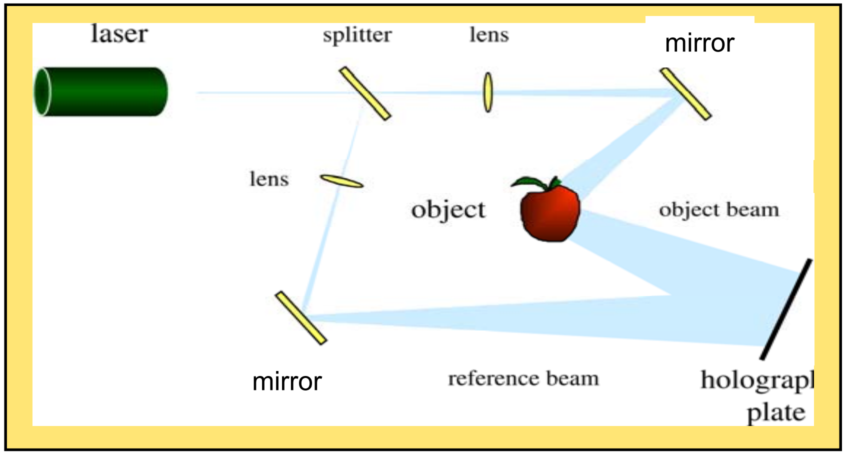


Deeply Virtual Exclusive Processes & GPDs

Deep Inelastic Scattering & Parton Distribution Functions.

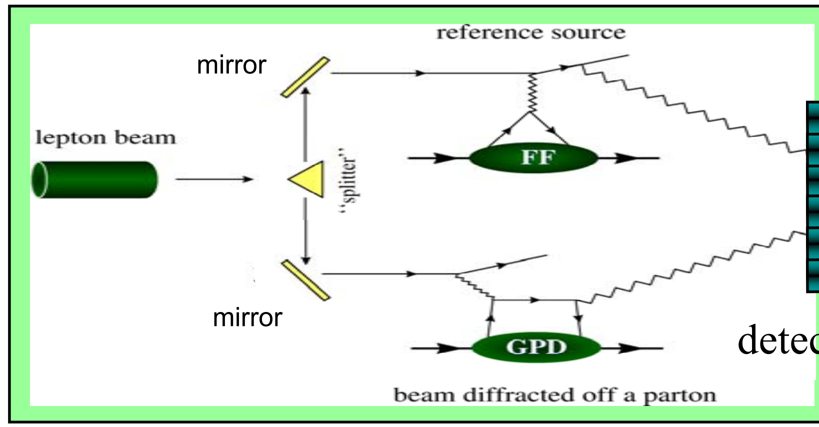
From Holography to Tomography

A. Belitsky, B. Mueller, NPA711 (2002) 118



An Apple

A Proton

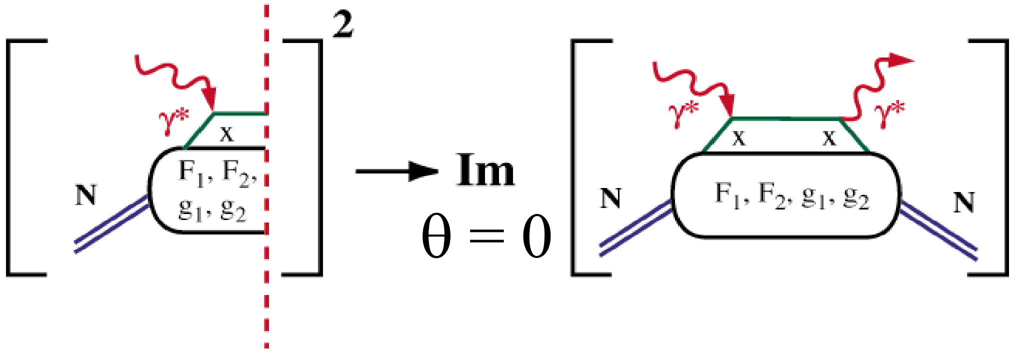


detector

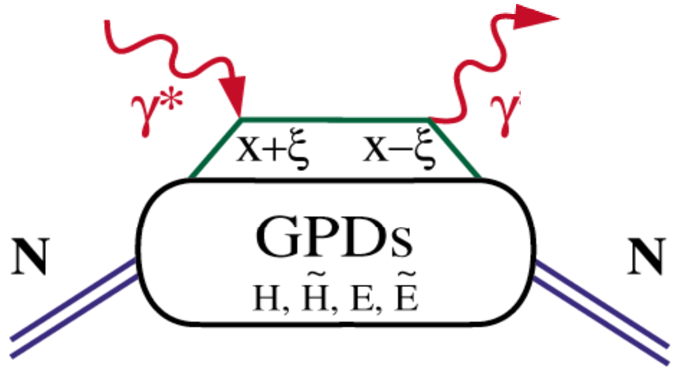
By varying the energy and momentum transfer to the proton we probe its interior and generate images of the proton's quark content.

Deeply Exclusive Scattering (DES)

Inclusive Scattering ⟹ Compton Scattering



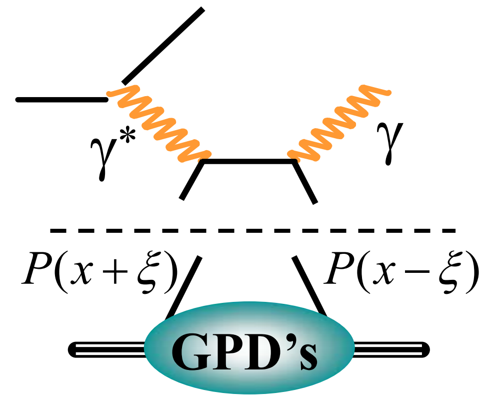
Deeply Virtual Compton Scattering (DVCS)



⟹ Probes the nucleon quark structure and correlations at the amplitude level

DVCS and Generalized Parton Distributions (GPDs)

GPDs: H, E unpolarized, $\tilde{H}$, $\tilde{E}$ polarized



e.g. $$\mathcal{H}(\xi, t, Q^2) = \int \frac{H^q(x, \xi, t, Q^2)dx}{x-\xi + i\varepsilon}$$

$$= \int \frac{H^q(x, \xi, t, Q^2)dx}{x-\xi} + i\pi H^q(\xi, \xi, t, Q^2)$$

real part　　imaginary part

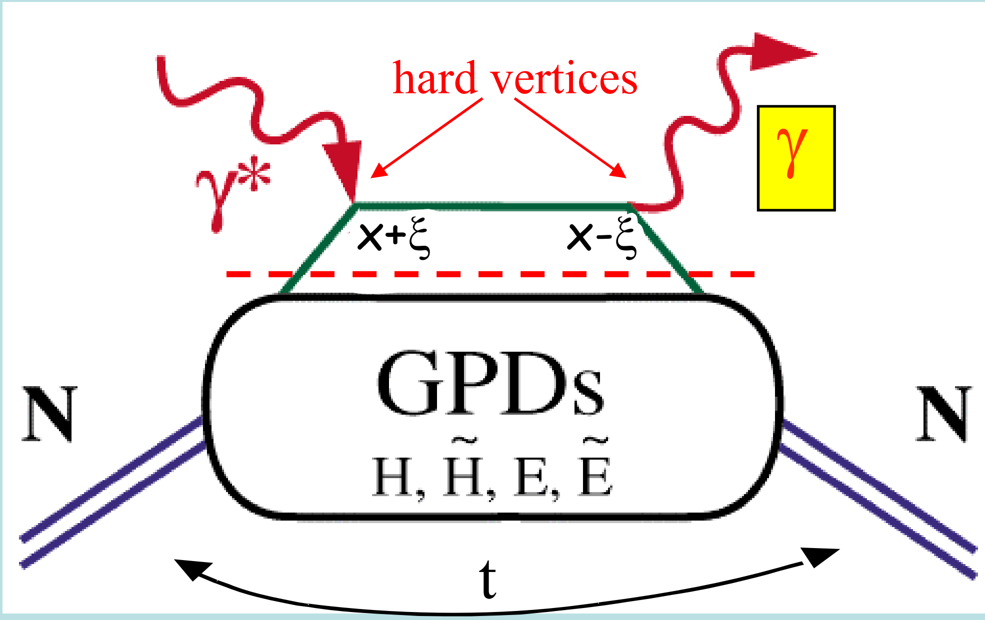
cross section difference

$$\frac{d^3\sigma}{dQ^2 dx_B dt} \sim [a\mathcal{H}(\xi, t, Q^2)+b\mathcal{E}(\xi, t, Q^2)+c\tilde{\mathcal{H}}(\xi, t, Q^2)+d\tilde{\mathcal{E}}(\xi, t, Q^2)]^2$$

H^q: Probability amplitude for N to emit a parton q with x+ξ and N' to absorb it with x- ξ.

Basic Process – Handbag Mechanism

Deeply Virtual Compton Scattering (DVCS)



x – longitudinal quark momentum fraction

2ξ – longitudinal momentum transfer

$\sqrt{-t}$ – Fourier conjugate to transverse impact parameter

GPDs depend on 3 variables, e.g. *H(x, ξ, t)*. They probe the quark structure at the amplitude level.

$$\xi = \frac{x_B}{2 - x_B}$$

Link to DIS and Elastic Form Factors

Form factors

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

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

$$\int_{-1}^{1} dx\, \widetilde{H}^q(x,\xi,t) = G_{A,q}(t), \quad \int_{-1}^{1} dx\, \widetilde{E}^q(x,\xi,t) = G_{P,q}(t)$$

DIS at $\xi = t = 0$

$$H^q(x,0,0) = q(x)$$

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

Forward limit

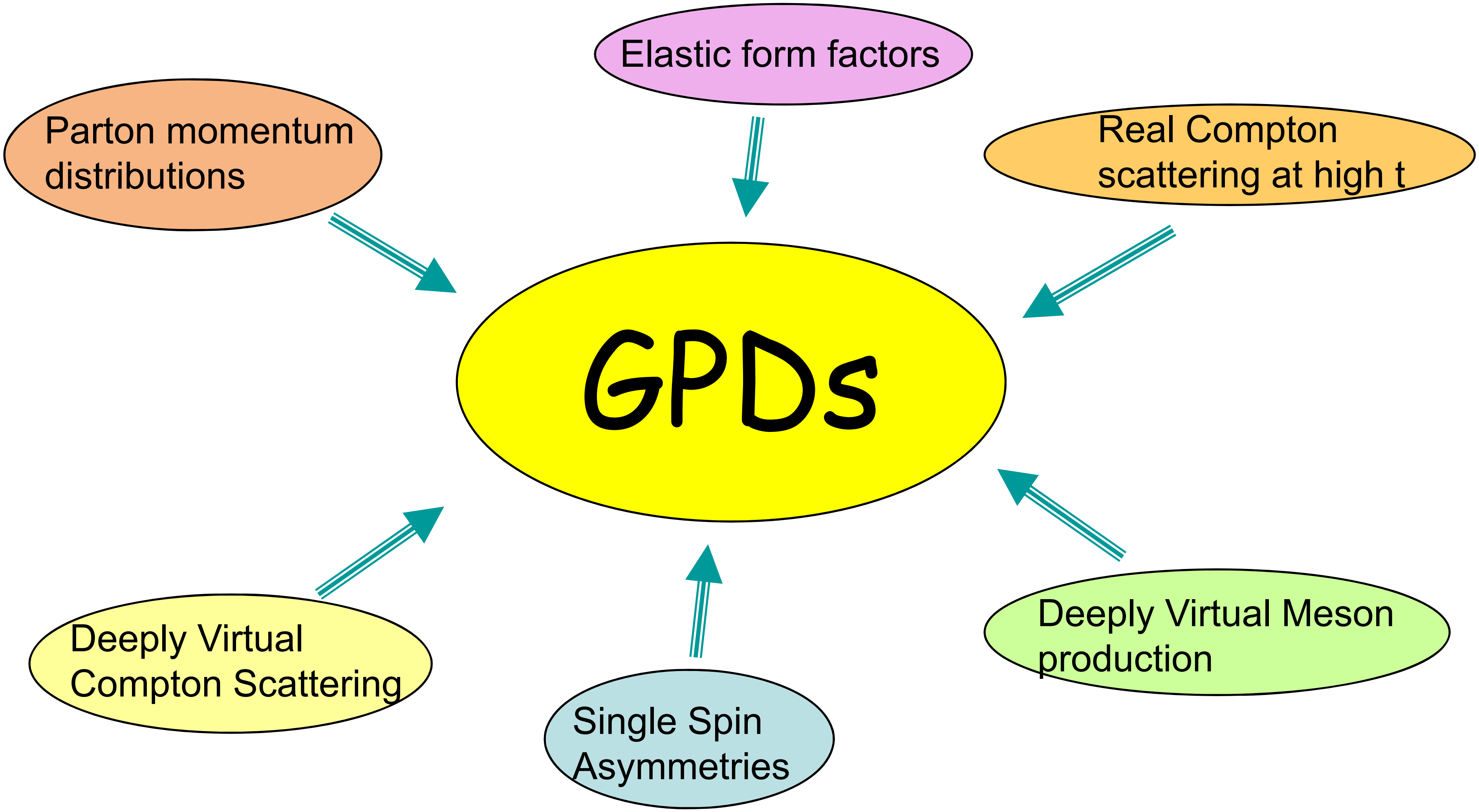
Sum rules

$$H^q, E^q, \widetilde{H}^q, \widetilde{E}^q(x,\xi,t)$$

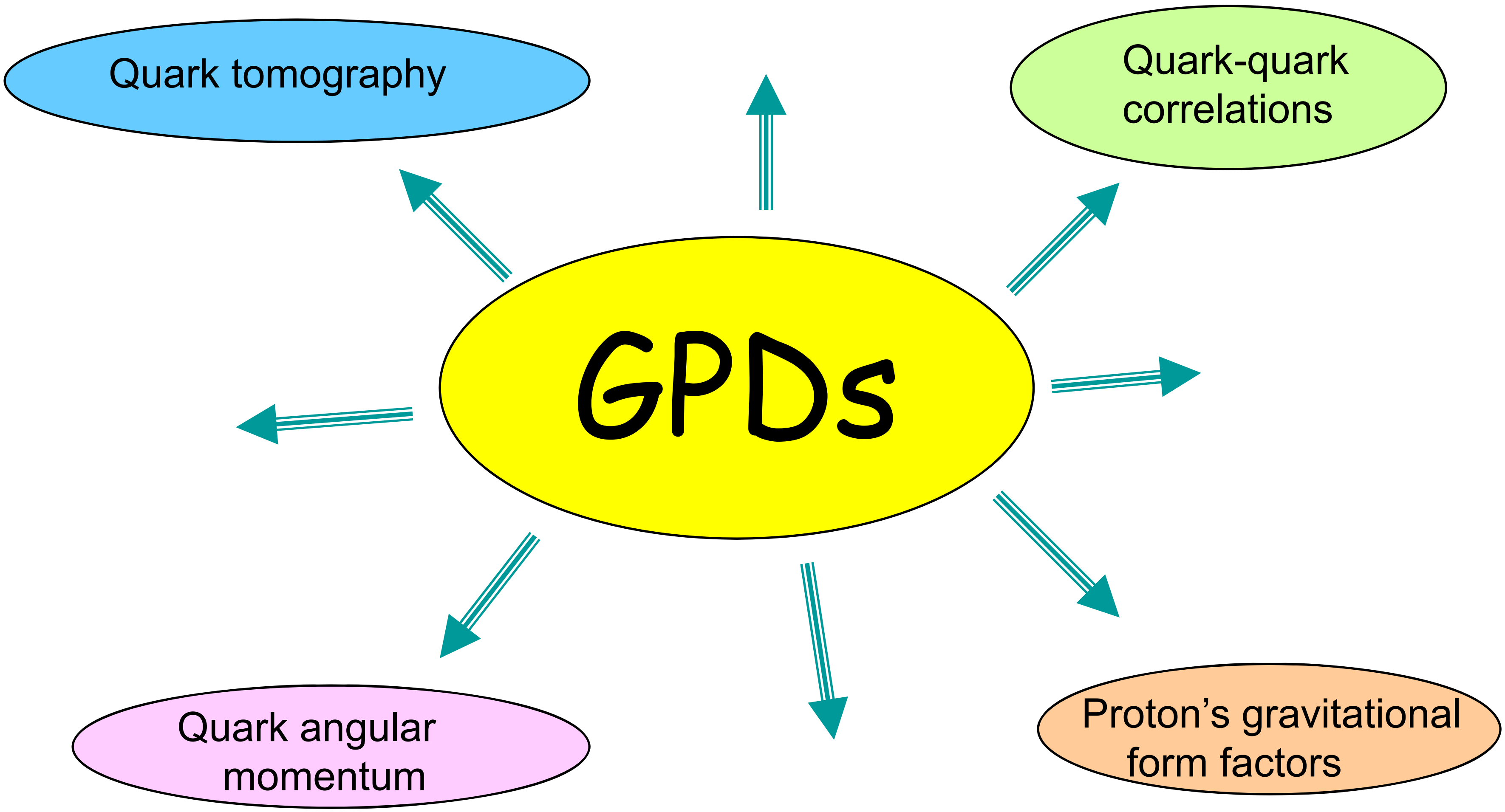
$$J^q = \frac{1}{2} - J^G = \frac{1}{2} \int_{-1}^{1} x dx \left[H^q(x,\xi,0) + E^q(x,\xi,0) \right]$$

Ji's Angular Momentum Sum Rule

Universality of GPDs



Universality of GPDs



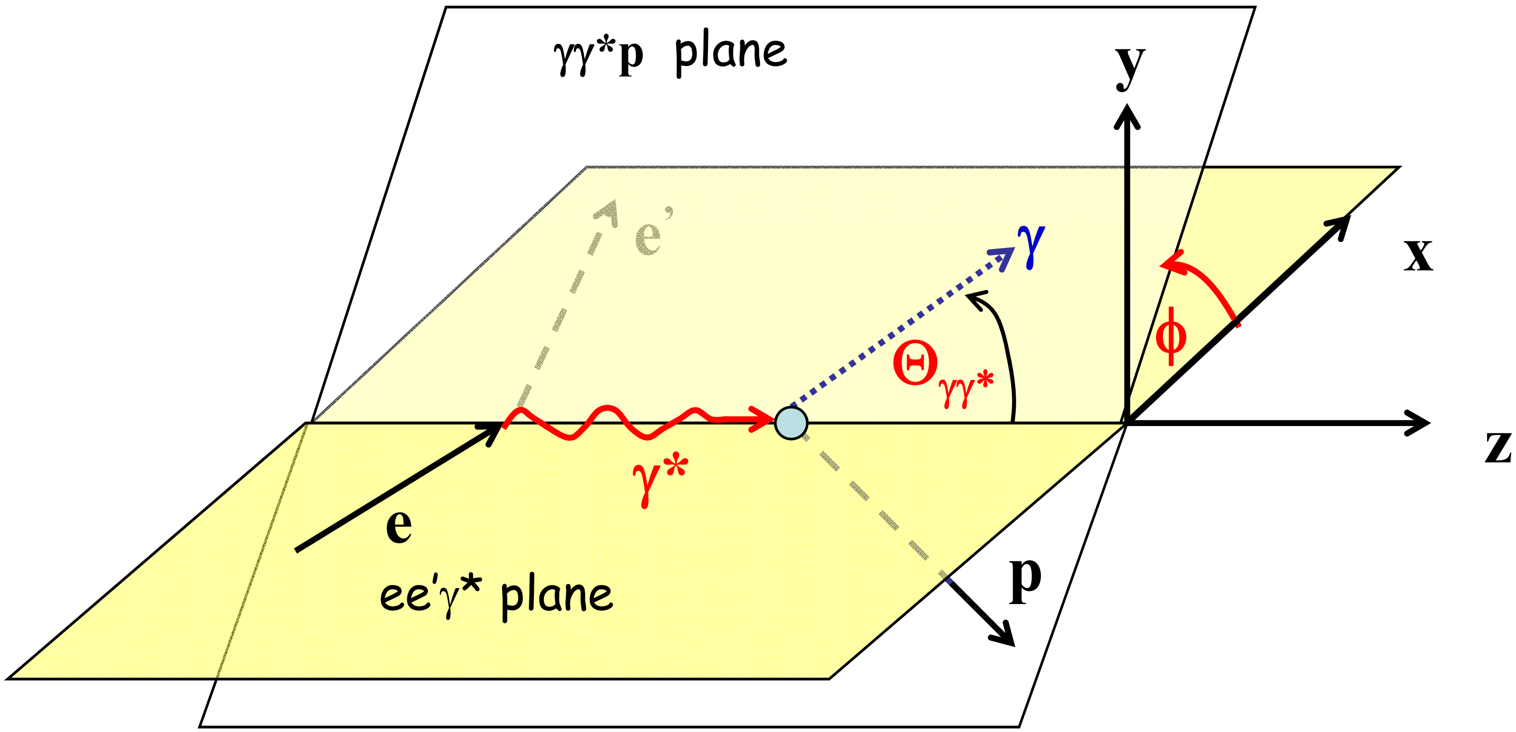
So, GPDs give access to complex Proton Structure, but …

How can be determine them?

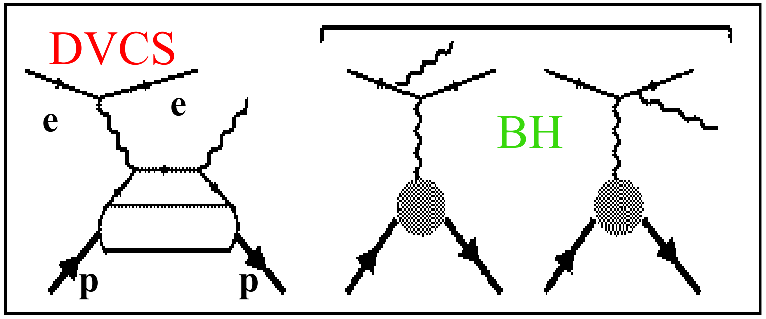
Deeply Virtual Compton Scattering

$ep \longrightarrow ep\gamma$

Kinematics



Access GPDs through Interference

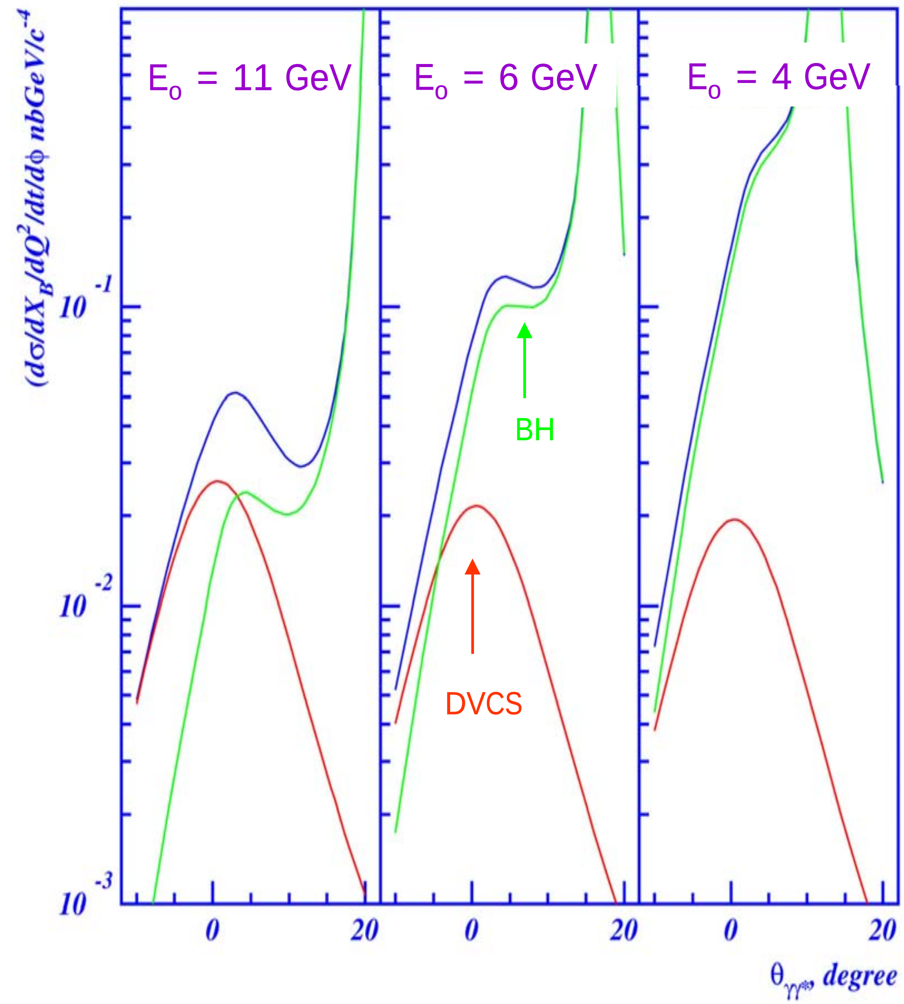


$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} \sim |T^{DVCS} + T^{BH}|^2$$

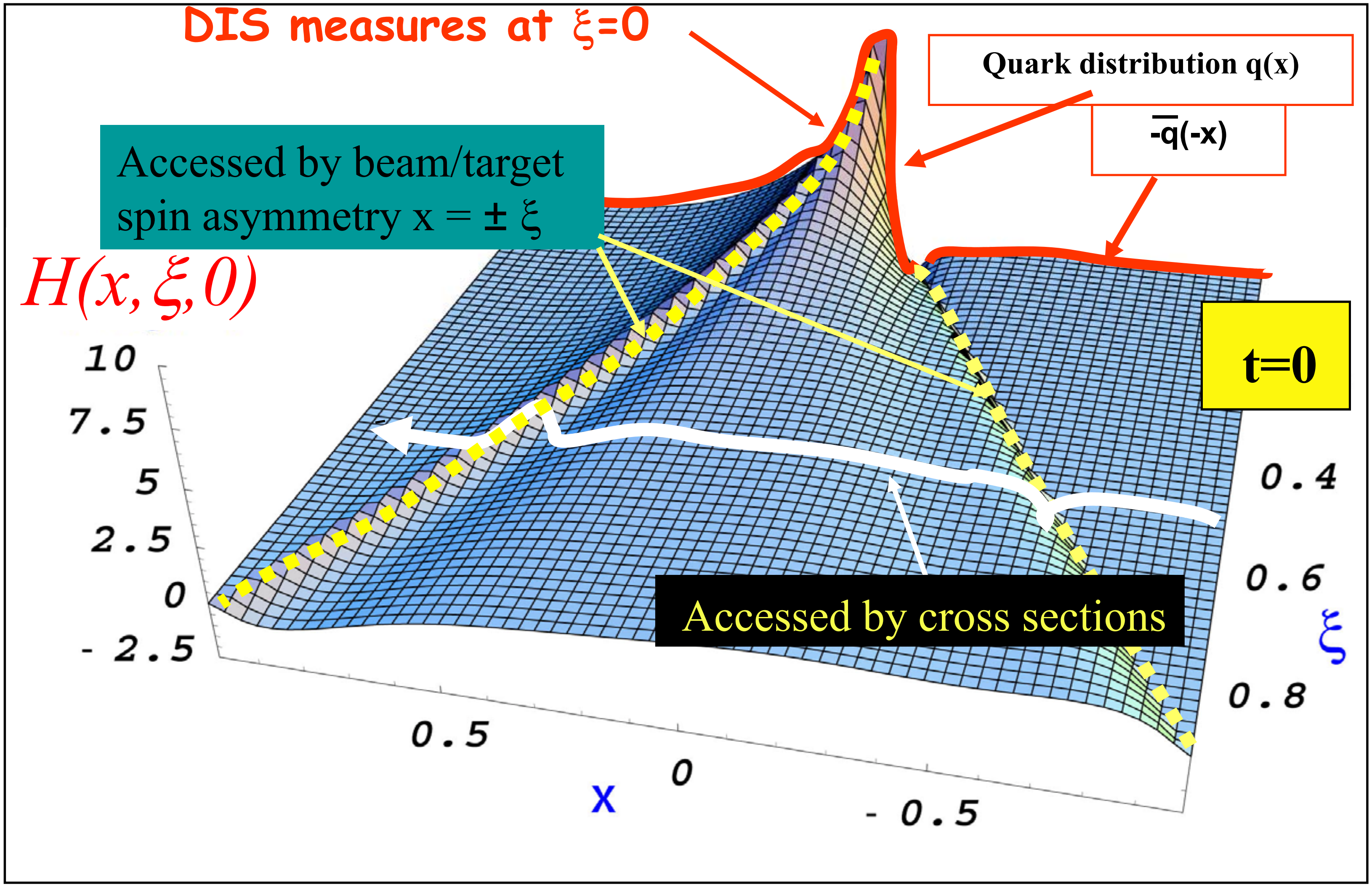
T^{BH}: given by elastic form factors F_1, F_2
T^{DVCS}: determined by GPDs

$$I \sim 2(T^{BH})\mathrm{Im}(T^{DVCS})$$

BH-DVCS interference generates *beam and target polarization asymmetries* that carry the proton structure information.



Model representation of GPD $H(x,\xi,0)$



Measuring GPDs through polarization

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta\sigma}{2\sigma}$$

Polarized beam, unpolarized target:

$$\Delta\sigma_{LU} \sim \sin\phi\{F_1 H + \xi(F_1+F_2)\tilde{H} + kF_2 E\}d\phi \Rightarrow H(\xi,t)$$

Kinematically suppressed

$\xi \approx x_B/(2-x_B)$

$k = t/4M^2$

Unpolarized beam, longitudinal target:

$$\Delta\sigma_{UL} \sim \sin\phi\{F_1\tilde{H} + \xi(F_1+F_2)(H + \xi/(1+\xi)E) - .. \}d\phi \Rightarrow \tilde{H}(\xi,t),\ H(\xi,t)$$

Kinematically suppressed

Unpolarized beam, transverse target:

$$\Delta\sigma_{UT} \sim \sin\phi\{k(F_2 H - F_1 E) + \ldots..\}d\phi \Rightarrow H(\xi,t),\ E(\xi,t)$$

Kinematically suppressed

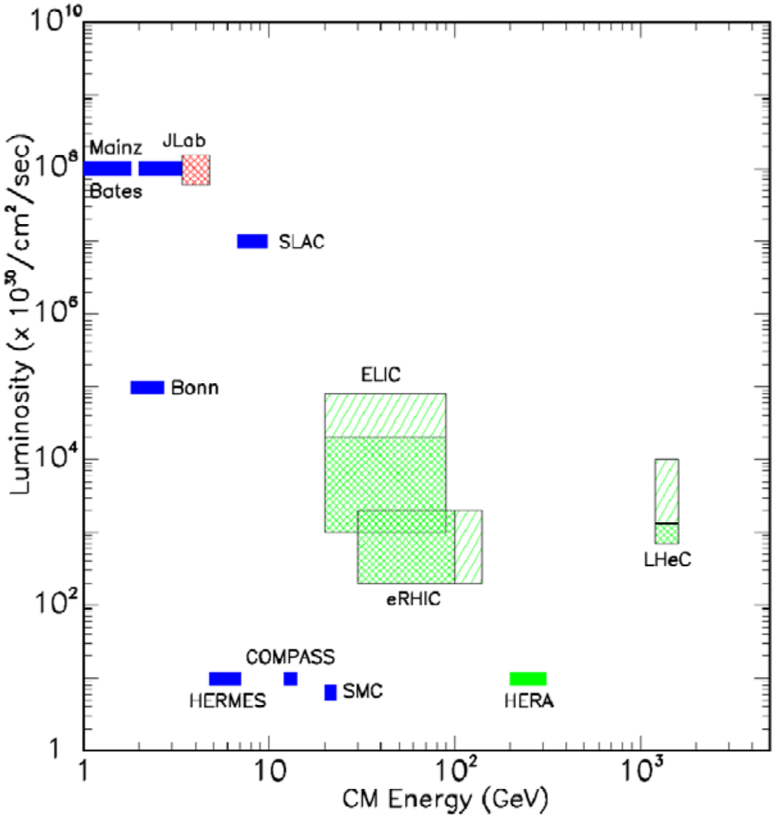
Typical cross sections and rates in eN/eA

Process		Cross section	Rate*,** (s^{-1})
$ep \to e'X$	inclusive DIS	$\sim$ few 10 nb	10^5
$ep \to e'\gamma p$	exclusive DVCS	$\sim$ 1 nb	10^4
$eA \to e'X$	nuclear DIS at $x > 1$	$\sim$ 1 pb	10
$eA \to e'A$	nuclear elastic FF at high t	$\sim$ 1 pb	10

* Luminosity $L = 10^{37}\text{cm}^{-2}\text{s}^{-1}$ [1 nb $= 10^{-33}$ cm^2]

** Does not include detector acceptance, kinematic cuts etc.

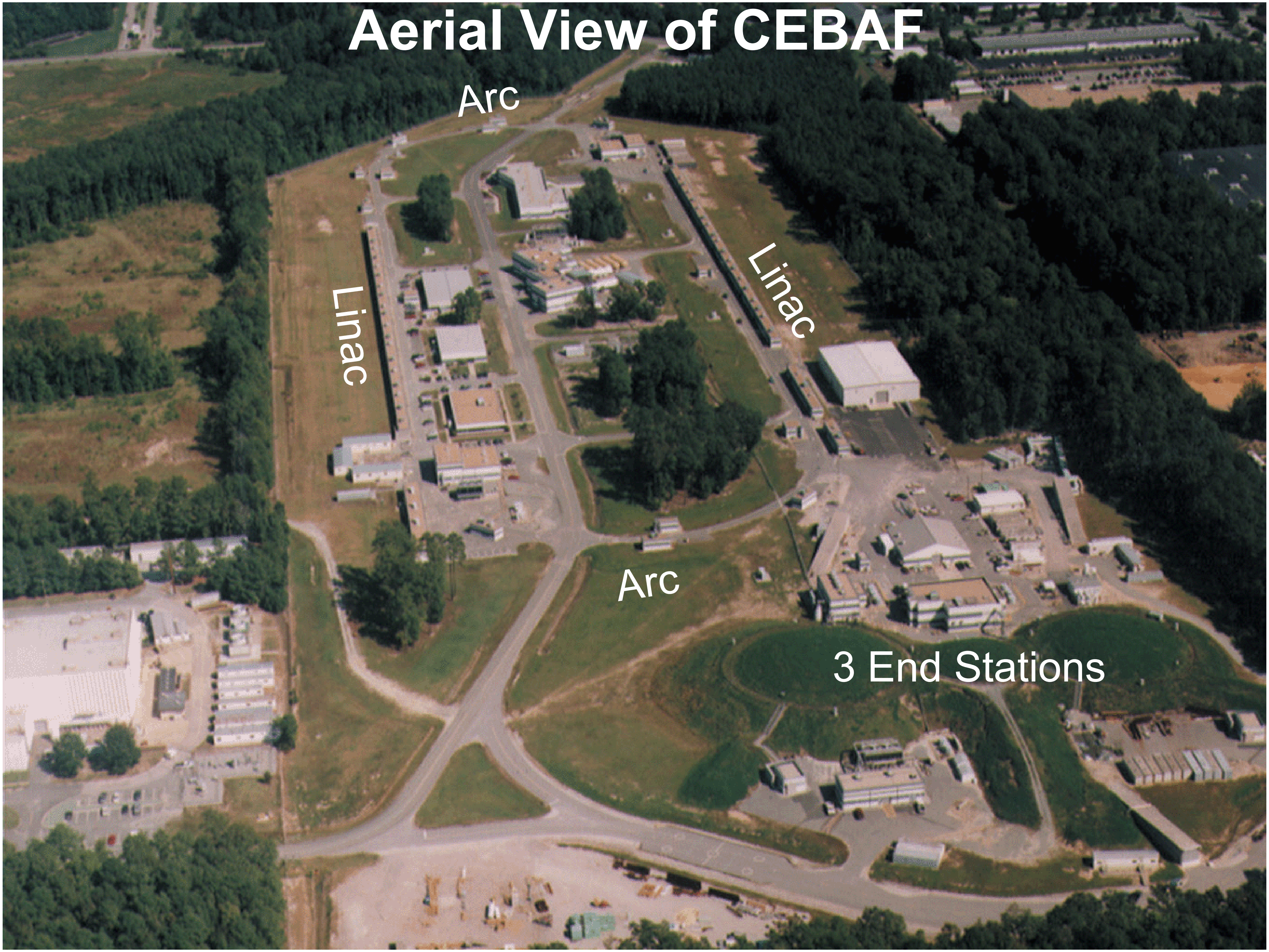
Characteristics of eN facilities



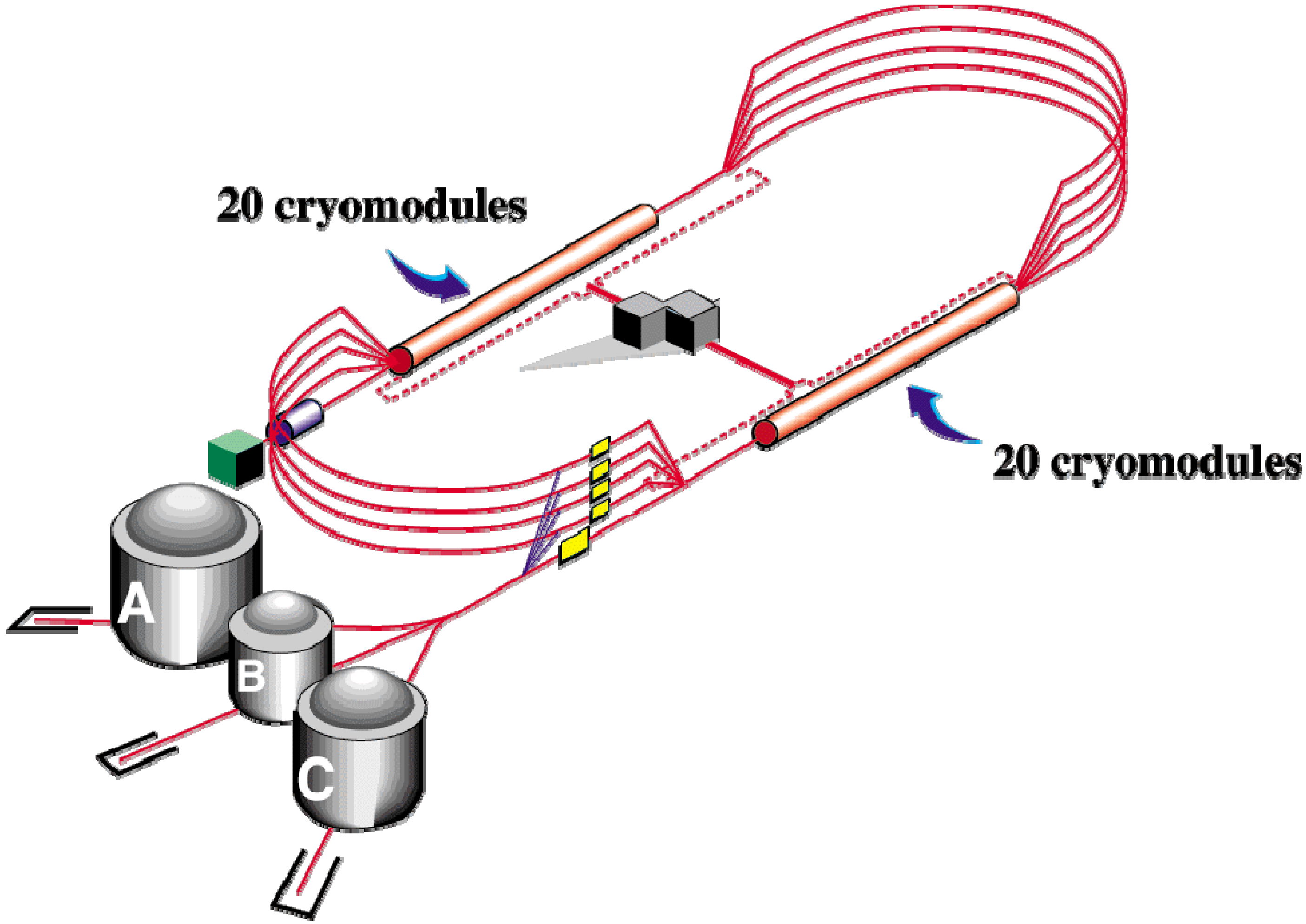
- Luminosity L: Number of possible eN collisions per time [$cm^{-2}S^{-1}$]
  $dN_{event} = L\sigma dt$

- Polarization (beam, target)

JLab: High –luminosity frontier


Aerial View of CEBAF
Arc
Linac
Linac
Arc
3 End Stations

6 GeV CEBAF



CEBAF Actual Parameters

- **Primary Beam: Electrons**
- **Beam Energy: 6 GeV**

nucleon → quark transition

baryon and meson excited states

- **100% Duty Factor (CW) Beam**

  •**coincidence experiments** ⇒ excite system with a known (q,ω) and observe its evolution

- **Three Simultaneous Beams with Independently Variable Energy and Intensity**

  •**complementary, long experiments**

- **Polarization (85% beam (!) and reaction products)**

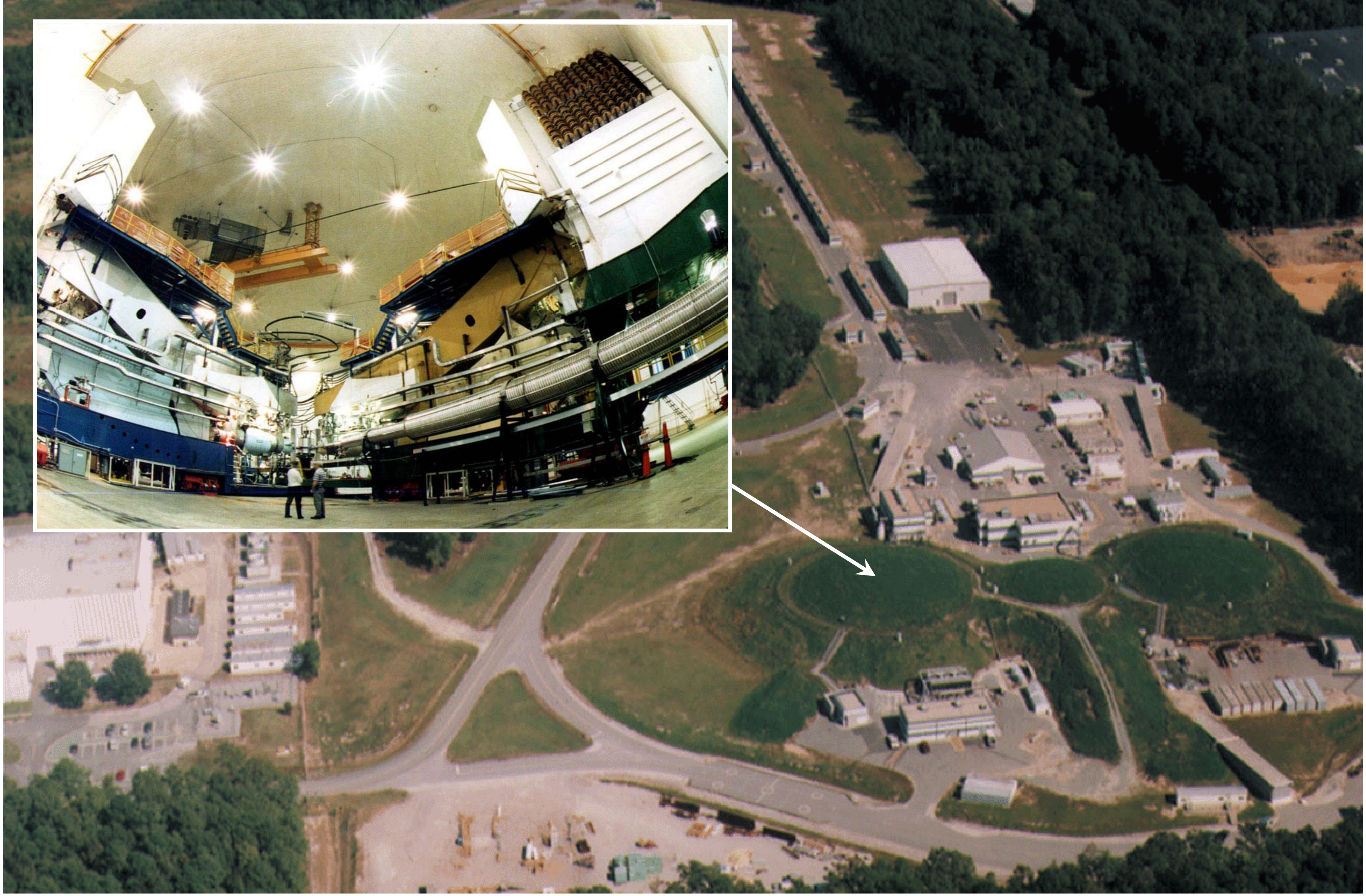
  •**spin degrees of freedom**

  weak neutral currents (extremely small helicity-correlated changes)

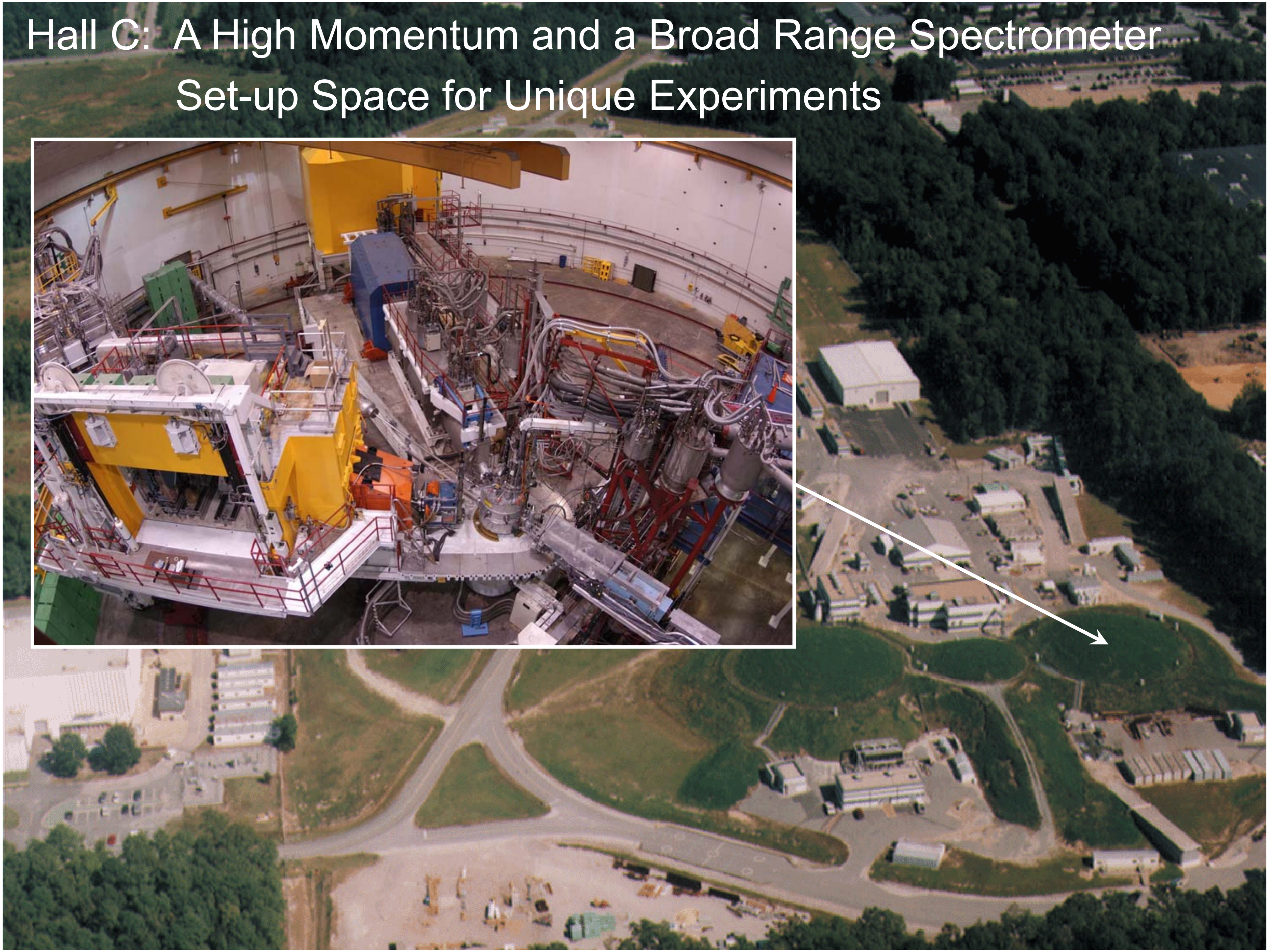
□ > 10^6 X SLAC at the time of the original DIS experiments

Hall A: Two High Resolution (10^{-4}) Spectrometers

Maximum luminosity 10^{38} $cm^{-2}s^{-1}$

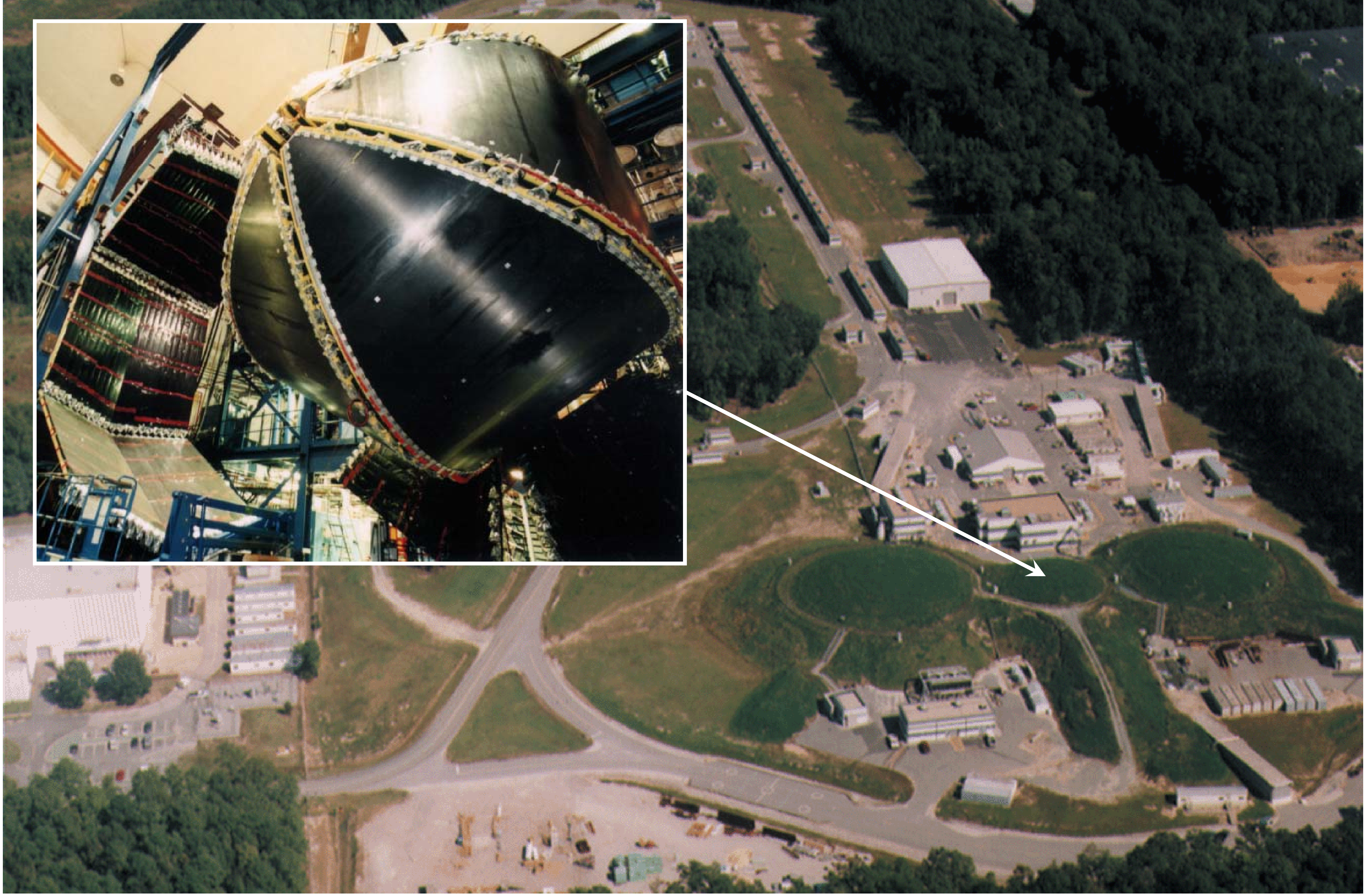


Hall C: A High Momentum and a Broad Range Spectrometer
Set-up Space for Unique Experiments

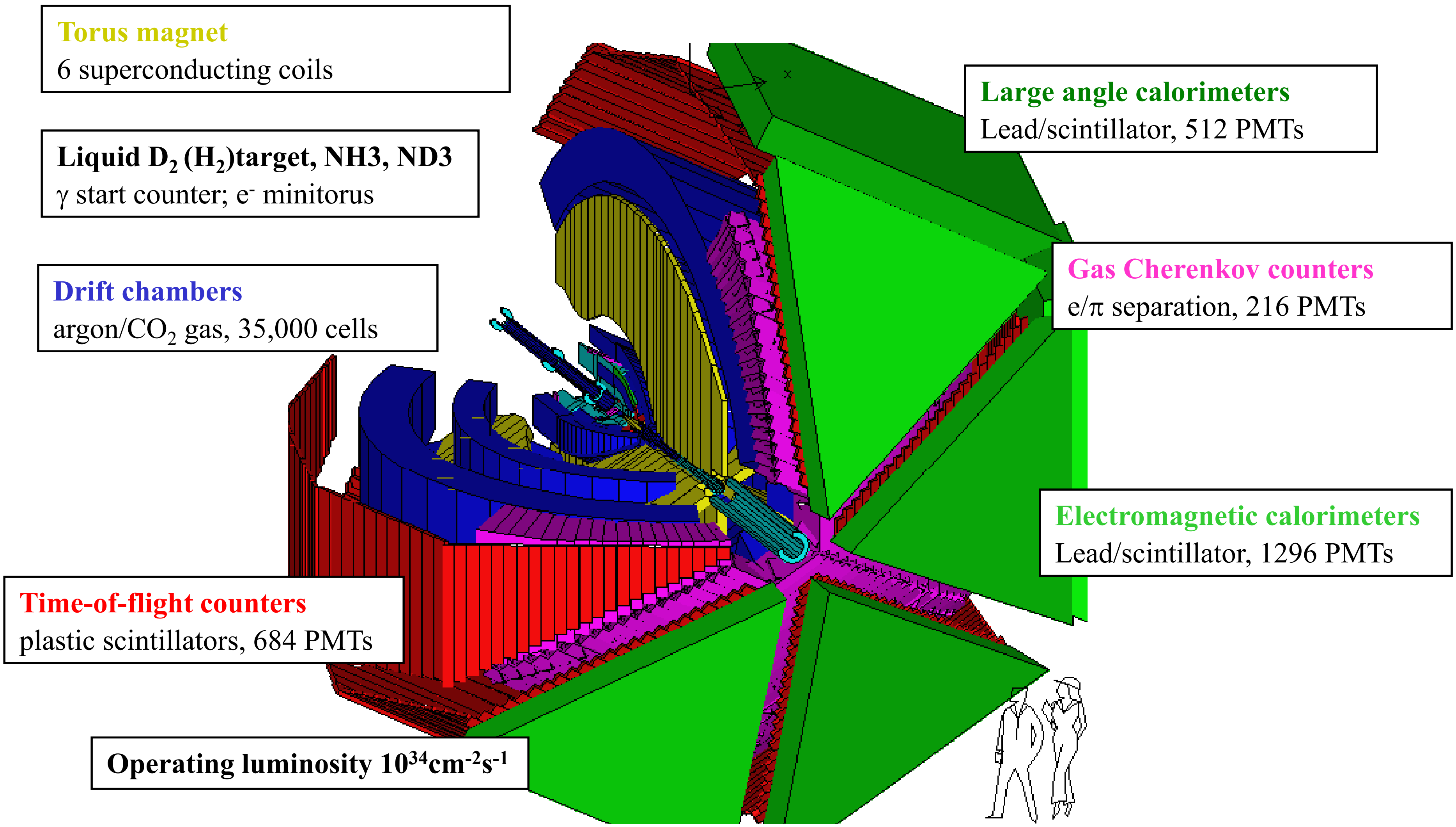


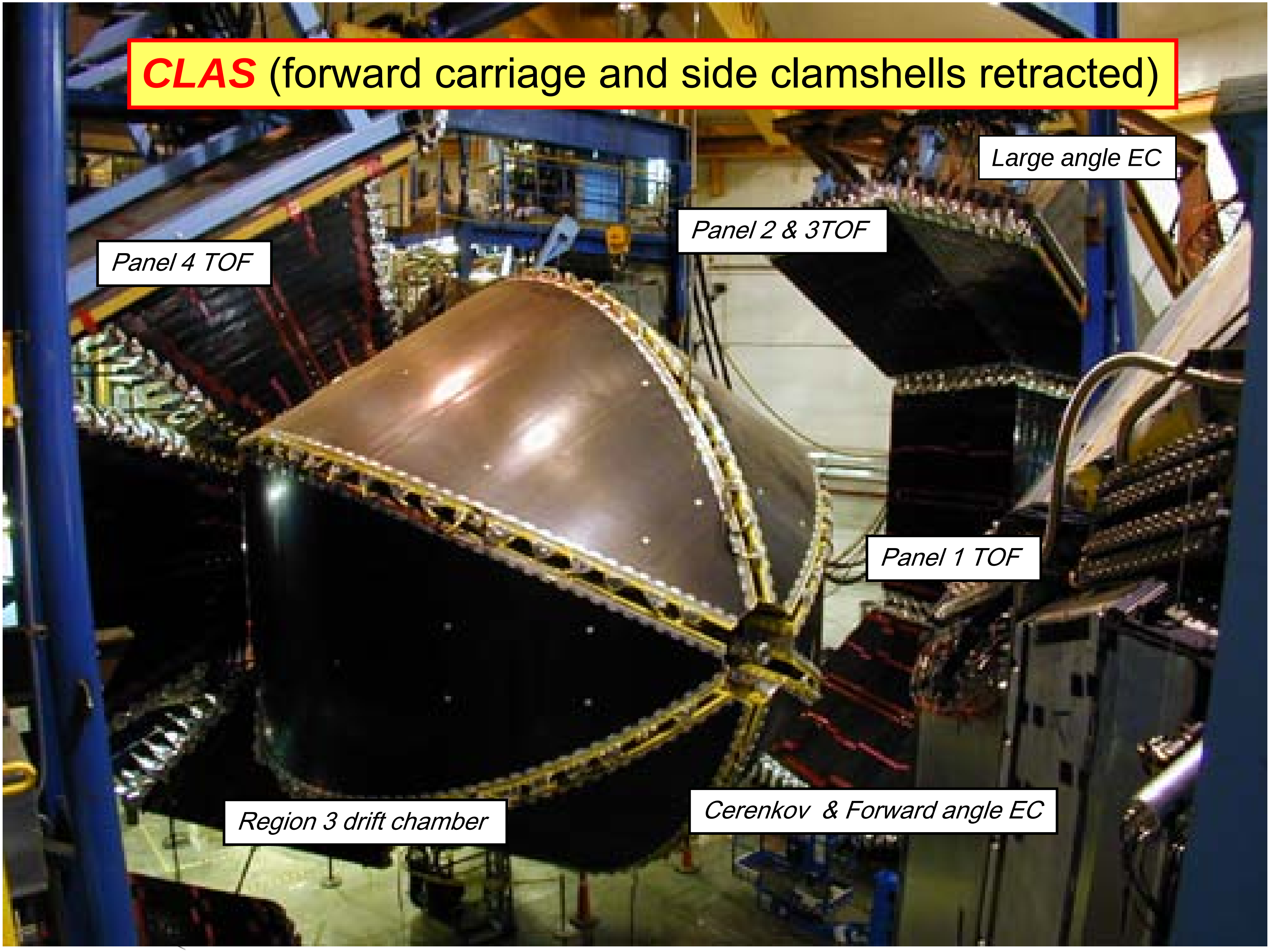
Hall B: The CEBAF Large Acceptance Spectrometer (CLAS)

Maximum luminosity 10^{34} cm^{-2}s^{-1}



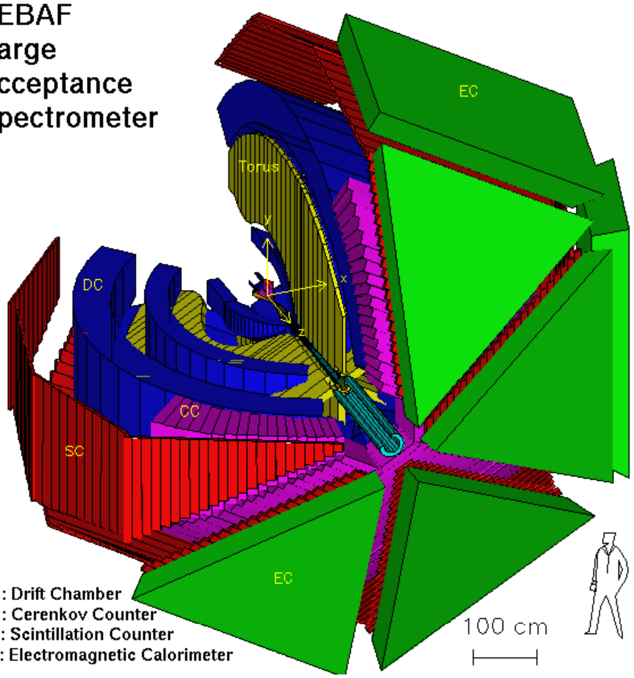
CEBAF Large Acceptance Spectrometer (CLAS)




CLAS (forward carriage and side clamshells retracted)
Large angle EC
Panel 2 & 3TOF
Panel 4 TOF
Panel 1 TOF
Region 3 drift chamber
Cerenkov & Forward angle EC

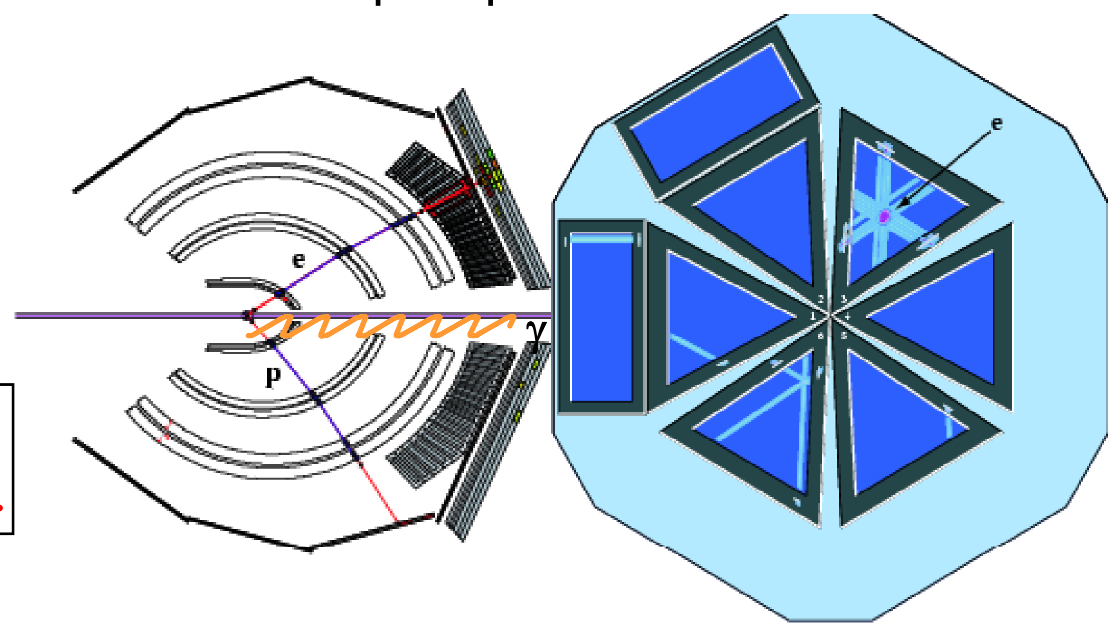
Analysis of CLAS 4.2 and 4.8 GeV data

CEBAF
Large
Acceptance
Spectrometer



Polarized electrons, E = 4.25 GeV and 4.8 GeV

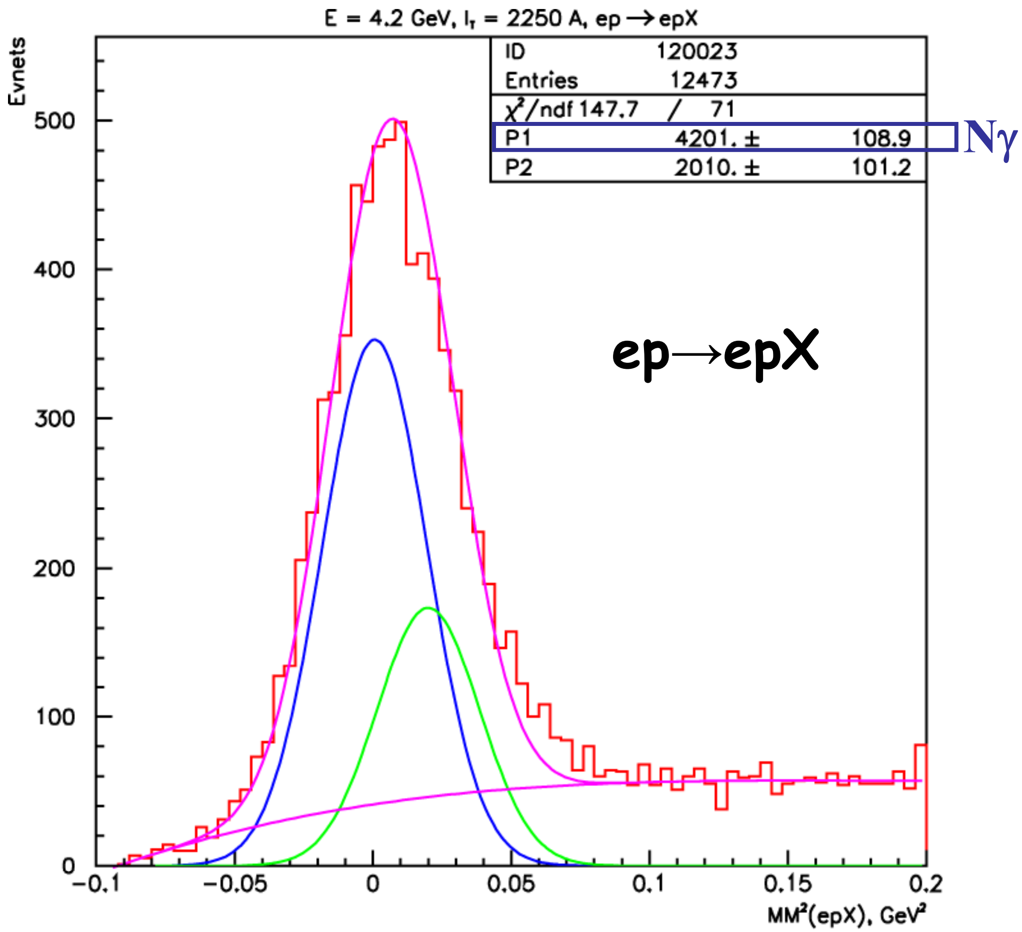
An $\vec{e}p \rightarrow epX$ event in CLAS



Separation of single γ from $\pi^0 \rightarrow \gamma\gamma$ using missing mass.

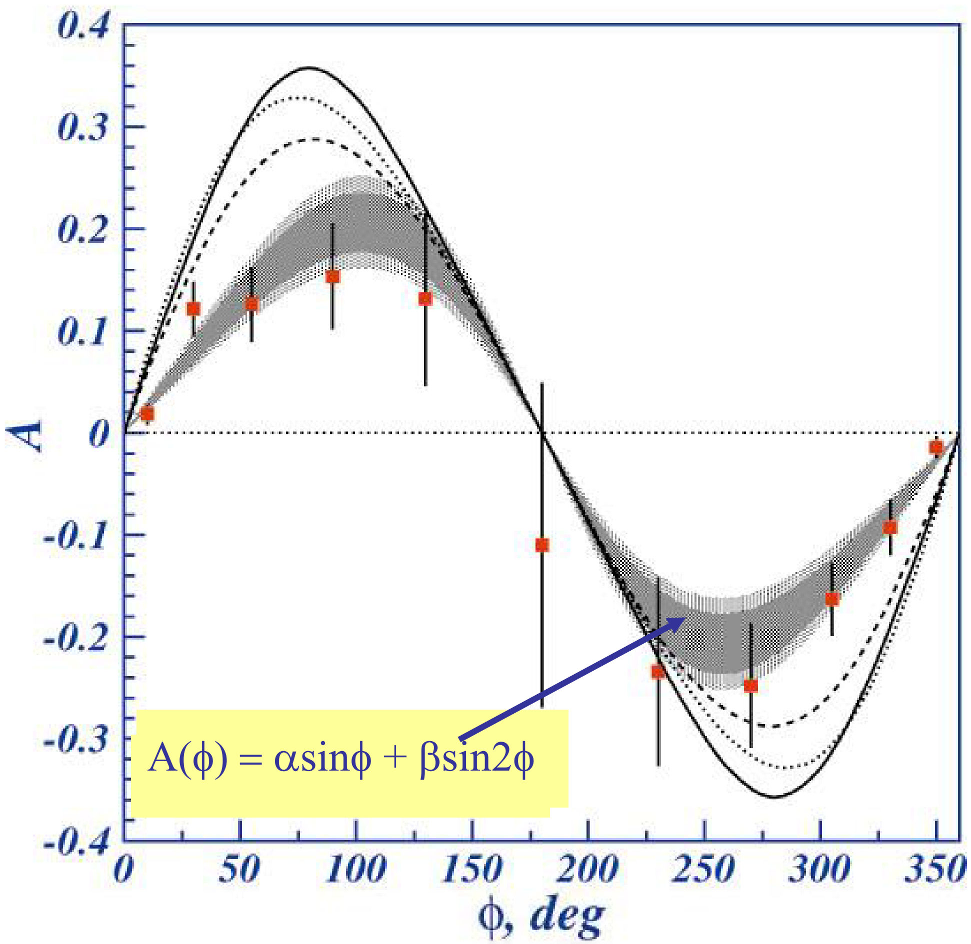
Background

Only 2-parameter fit: N_γ and N_{π^0}



Exclusive DVCS with CLAS

Beam Spin Asymmetry



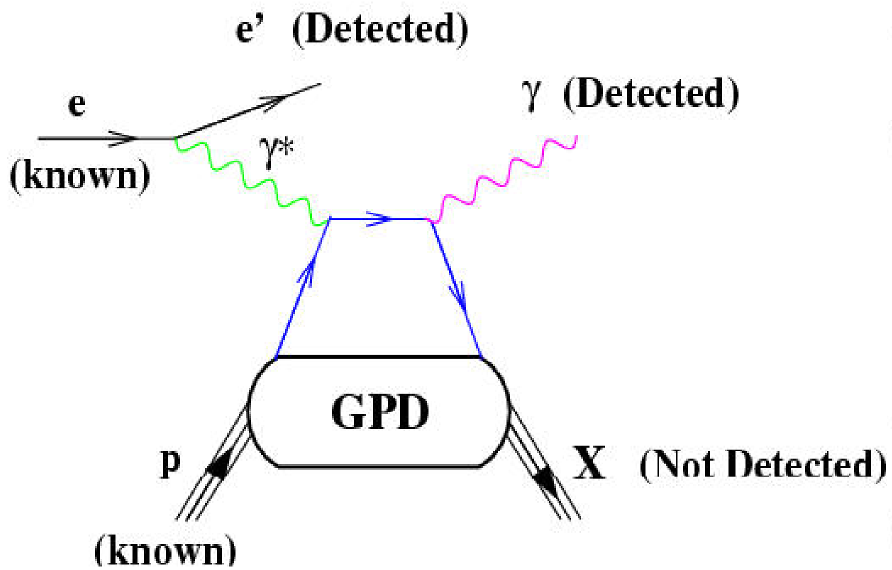
- Beam energy – 4.25 GeV
- ep→epγ identified by analyzing the missing mass distribution ep→epX

- W > 2 GeV
- $1 (GeV/c)^2 < Q^2 < 1.75 (GeV/c)^2$
- $0.1 (GeV/c)^2 < -t < 0.3 (GeV/c)^2$

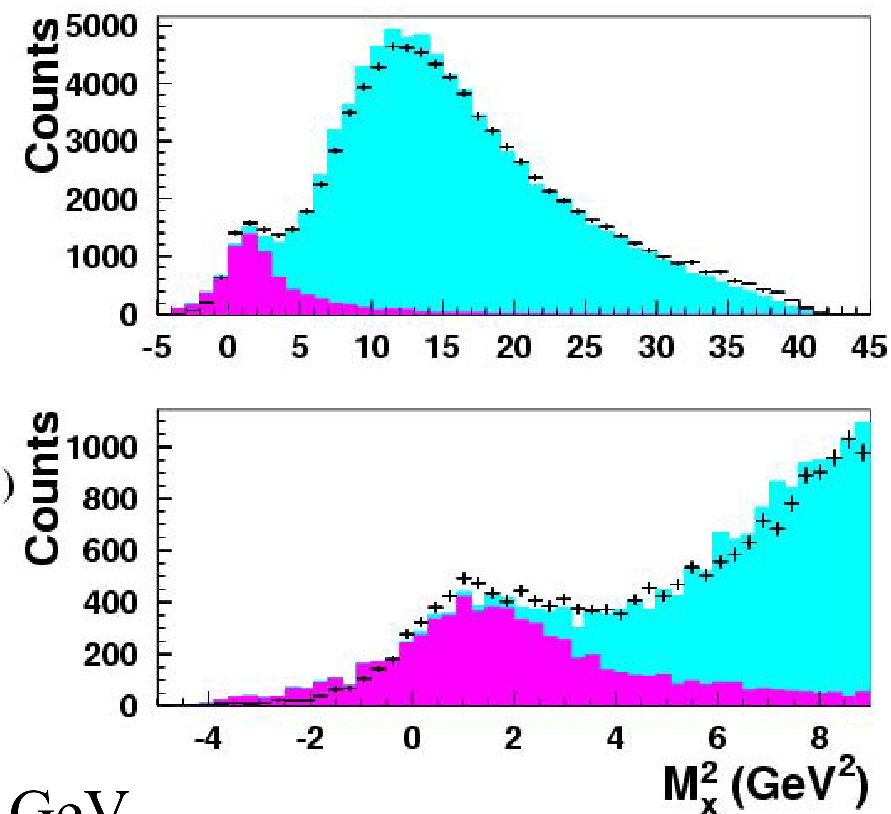
The measured asymmetry:

$$\alpha = 0.202 \pm 0.028^{stat} \pm 0.013^{sys}$$

Exclusivity for e p → e p γ



Missing Mass^2 = (p + γ* – γ)^2



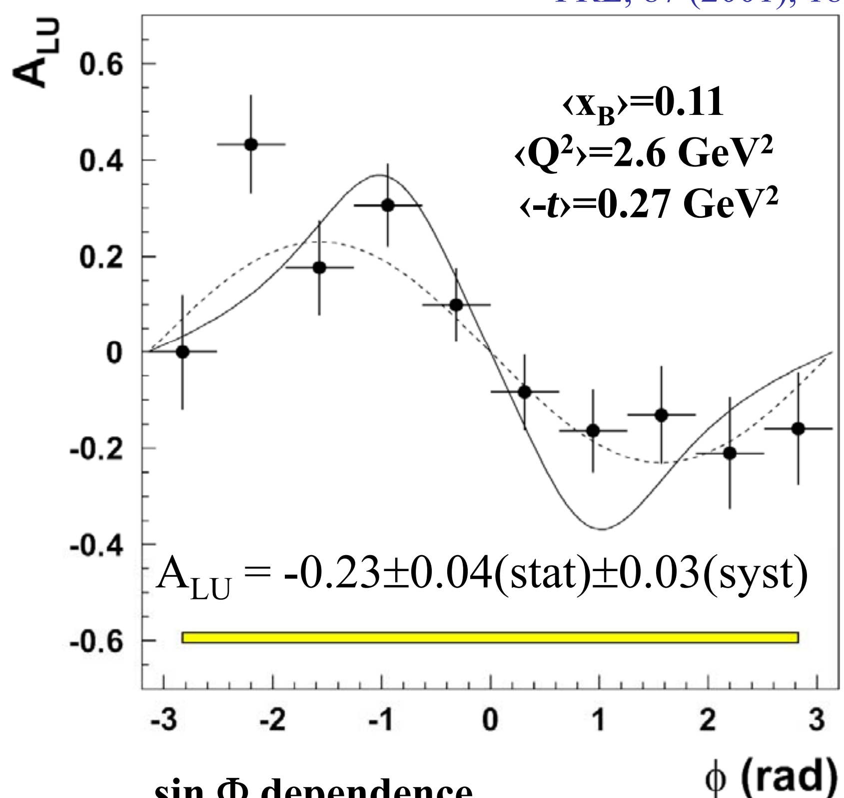
Missing Mass resolution : 0.8 GeV

Exclusive region: Missing Mass < 1.7 GeV

DVCS asymmetry measurement

$\vec{e}\, p \rightarrow e\, p\, \gamma$

PRL, 87 (2001), 182001



.... **sin Φ dependence**

―― *-Kivel, Polyakov & Vanderhaeghen* ***(2001)*** –

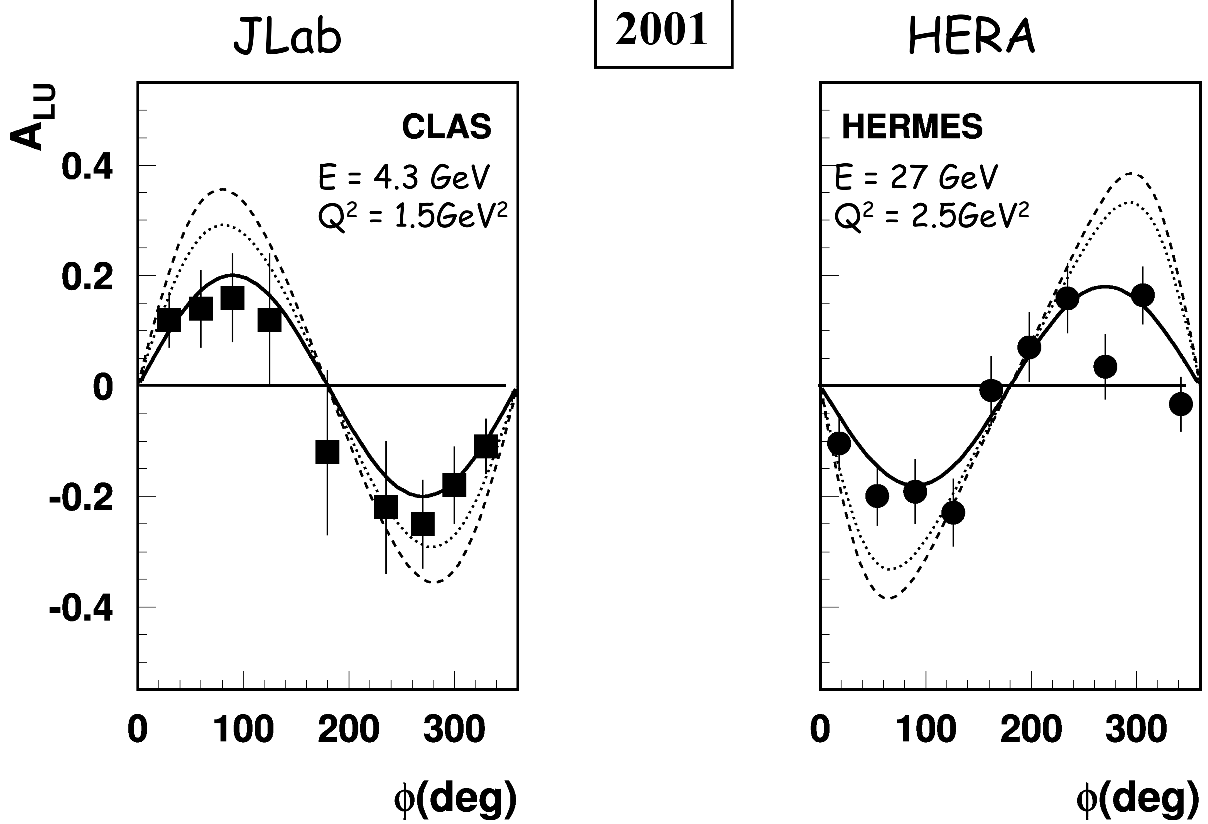
→ Signal of DVCS process

→ Can be described by GPD calculation

Pioneering experiments observe interference !

2001

$\vec{e}^{-}p \rightarrow e^{-}p\gamma$



$\vec{e}^{+}p \rightarrow e^{+}p\gamma$

$$A_{UL} = \alpha \sin\phi + \beta \sin 2\phi$$

Leading term (α) non-leading (β)

Non-leading contributions are small!

Measuring GPDs through polarization

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta\sigma}{2\sigma}$$

Polarized beam, unpolarized target:

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

Kinematically suppressed

→ $H(\xi,t)$

$\xi \approx x_B/(2-x_B)$

$k = t/4M^2$

Unpolarized beam, longitudinal target:

$$\Delta\sigma_{UL} \sim \sin\phi\{F_1\tilde{H} + \xi(F_1+F_2)(H + \xi/(1+\xi)E) - .. \}d\phi$$

Kinematically suppressed

→ $\tilde{H}(\xi,t)$, $H(\xi,t)$

Unpolarized beam, transverse target:

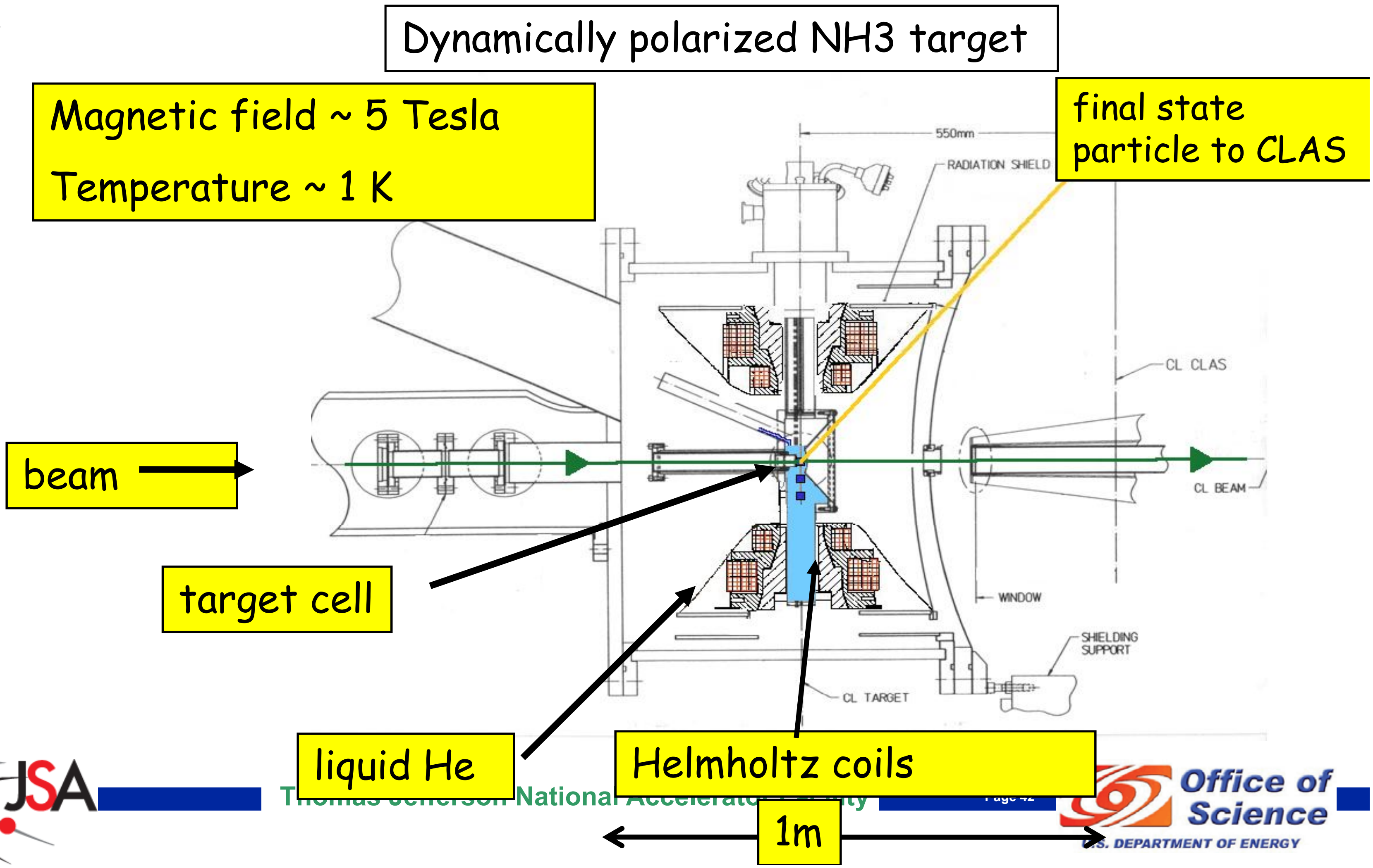
$$\Delta\sigma_{UT} \sim \sin\phi\{k(F_2 H - F_1 E) + ... \}d\phi$$

Kinematically suppressed

→ $H(\xi,t)$, $E(\xi,t)$

Spin polarized proton target

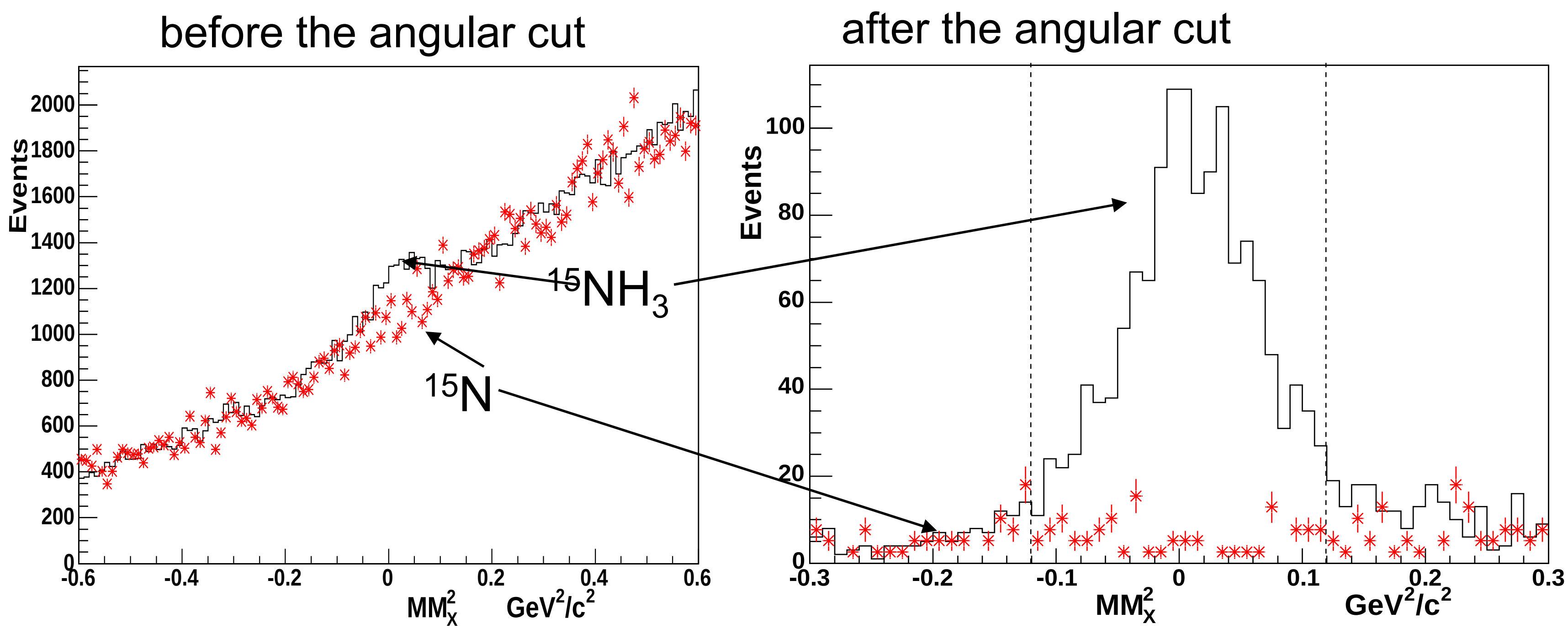
The separation of GPDs requires measurements on polarized hydrogen targets.
Measurements on such a target are more difficult than on unpolarized hydrogen.
A typical polarized target $\vec{NH_3}$ contains only 3 protons with spins aligned out of 17 nucleons.



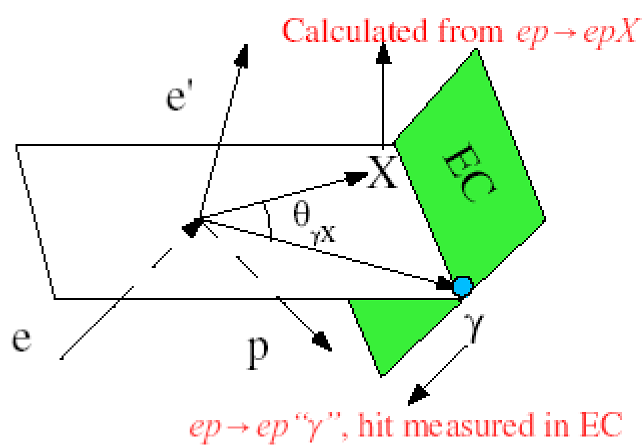
Hall B Longitudinally Polarized Target

- Dynamically polarized NH_3
- 5 Tesla magnetic field
- $\delta B/B \approx 10^{-4}$
- 1K LHe cooling bath
- NH_3 polarization:75%
- ^{12}C, ^{15}N, and ^{4}He targets to measure the dilution factor

DVCS eg1: Separating DVCS Photons from Polarized Protons in NH_3



Events from both π^0 and unpolarized target nucleons are suppressed



Geometry cut: $\theta_{\gamma X} < 1^o$

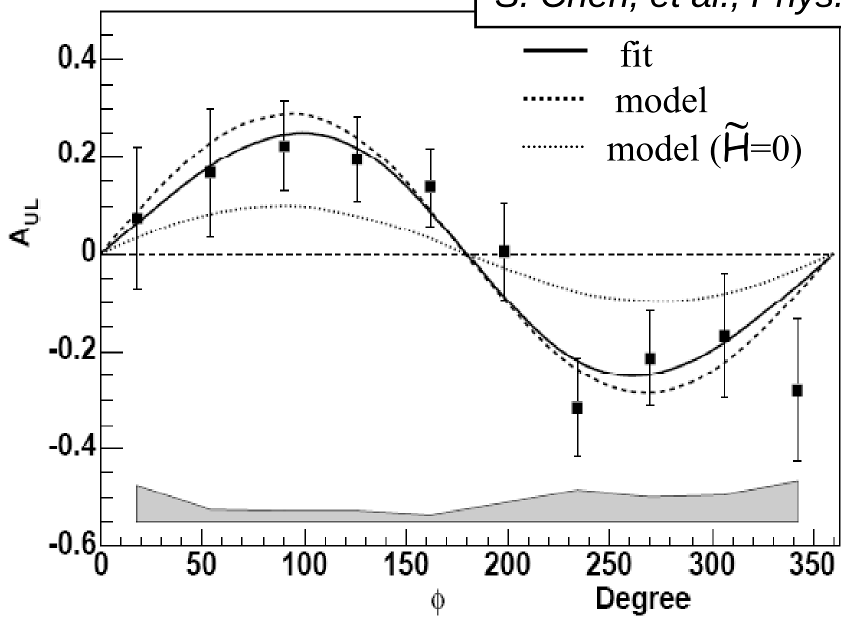
First DVCS measurement with spin-aligned target

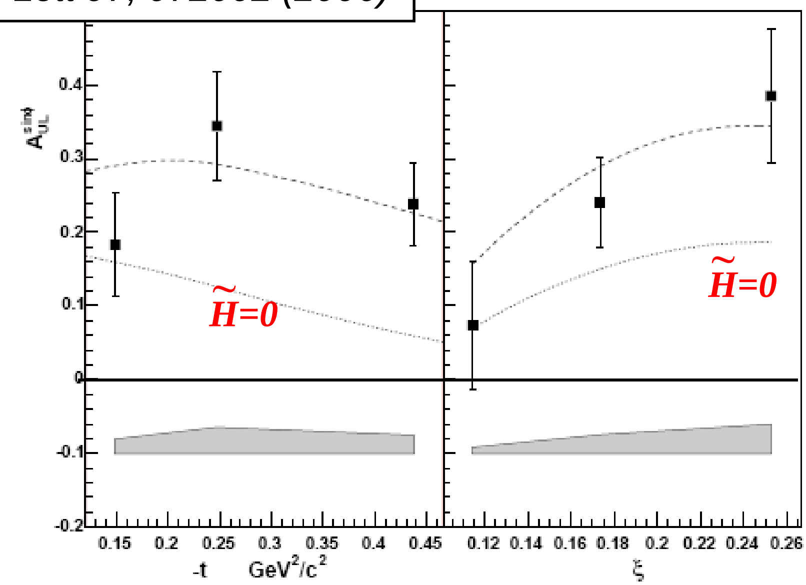
Unpolarized beam, longitudinally spin-aligned target:

$$\Delta\sigma_{UL} \sim \sin\phi\, \mathrm{Im}\{F_1\tilde{H} + \xi(F_1+F_2)H + \ldots\}d\phi$$

A_{UL} is dominated by H and $\tilde{H}$

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

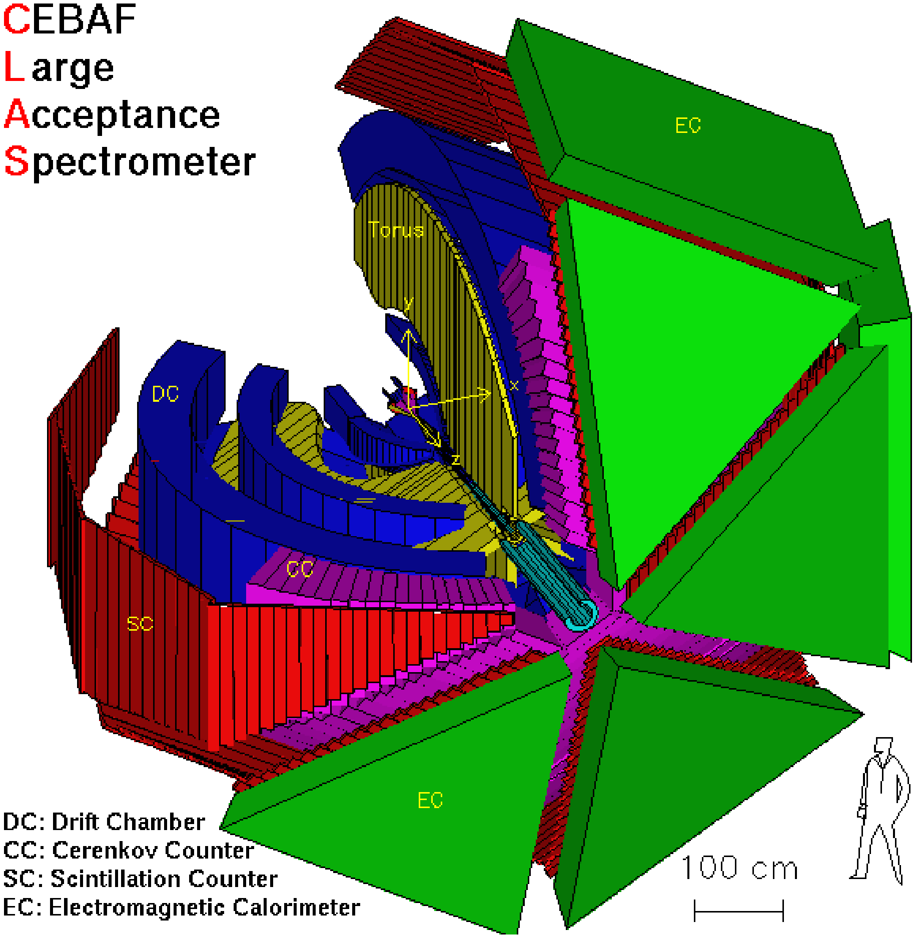




α = 0.252 ± 0.042
β = -0.022 ± 0.045

Planned experiment in 2008 will improve accuracy dramatically.

The CLAS detector



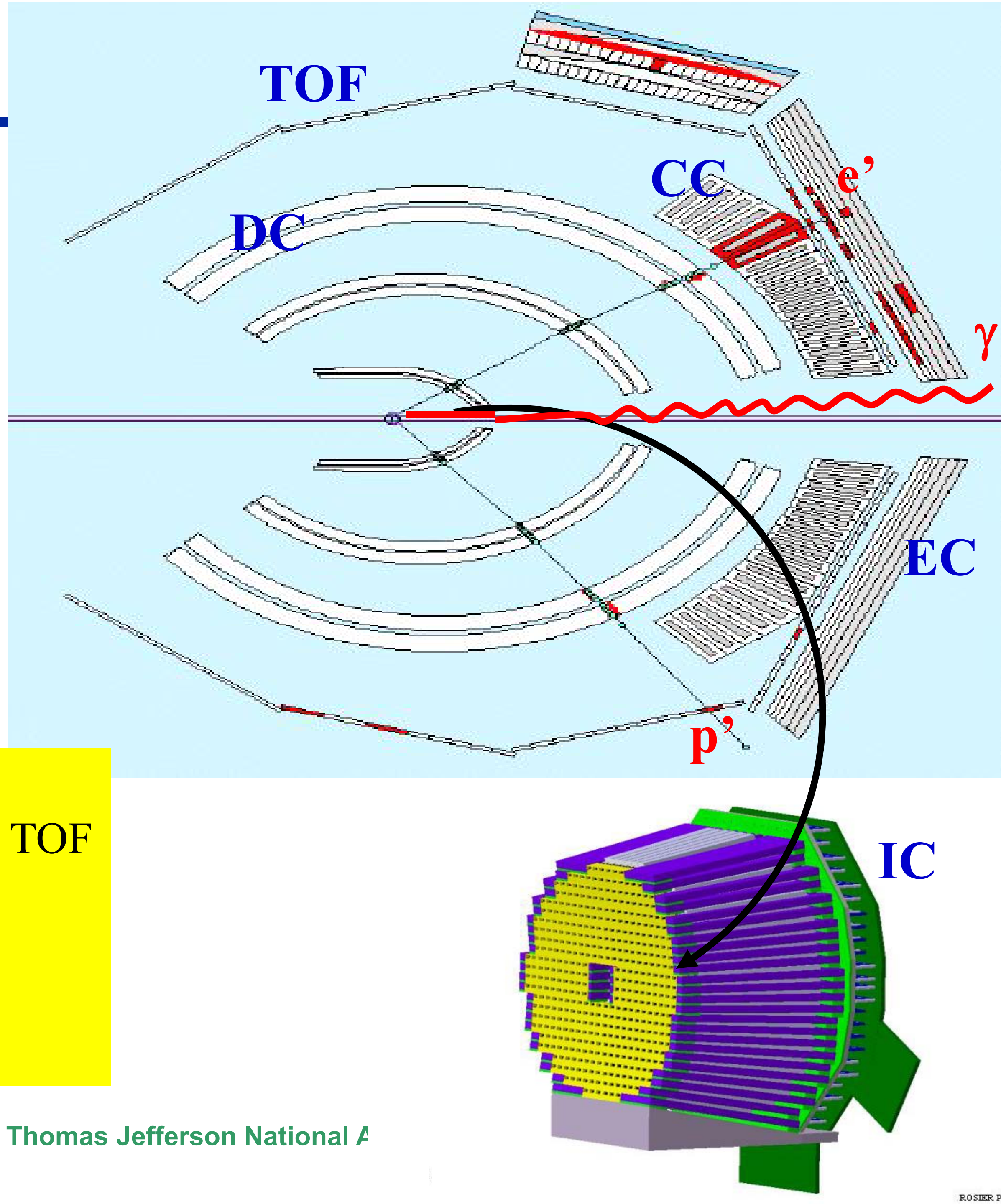
- Toroidal magnetic field (6 supercond. coils)
- **Drift chambers (argon/CO_2 gas, 35000 cells)**
- **Time-of-flight scintillators**
- **Electromagnetic calorimeters**
- **Cherenkov Counters (e/π separation)**

Performances:

- **large acceptance** for charged particles
  $8° < \theta < 142°$, $p_p > 0.3$ GeV/c, $p_\pi > 0.1$GeV/c
- **good momentum and angular resolution**
  $\Delta p/p \leq 0.5\%$- 1.5%, $\Delta\theta$, $\Delta\phi \leq 1$ mrad

ep→e'p'γ in CLAS

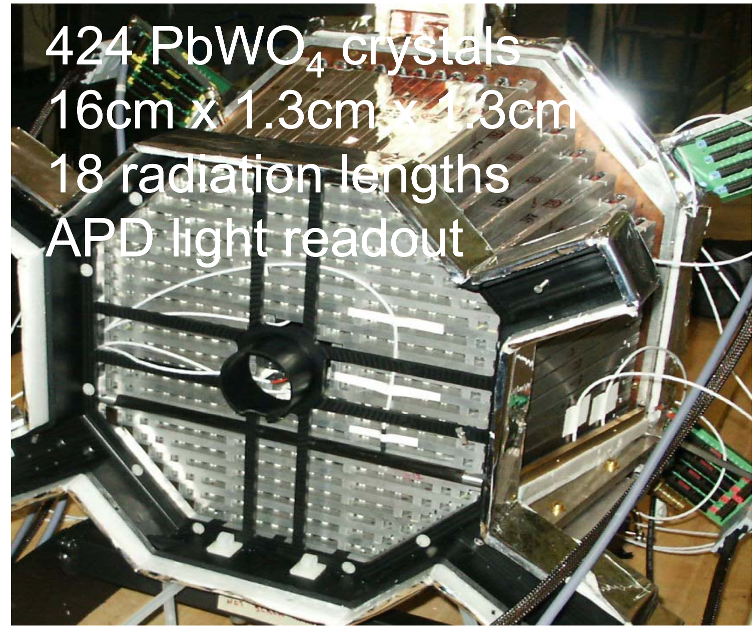
All 3 particles are detected

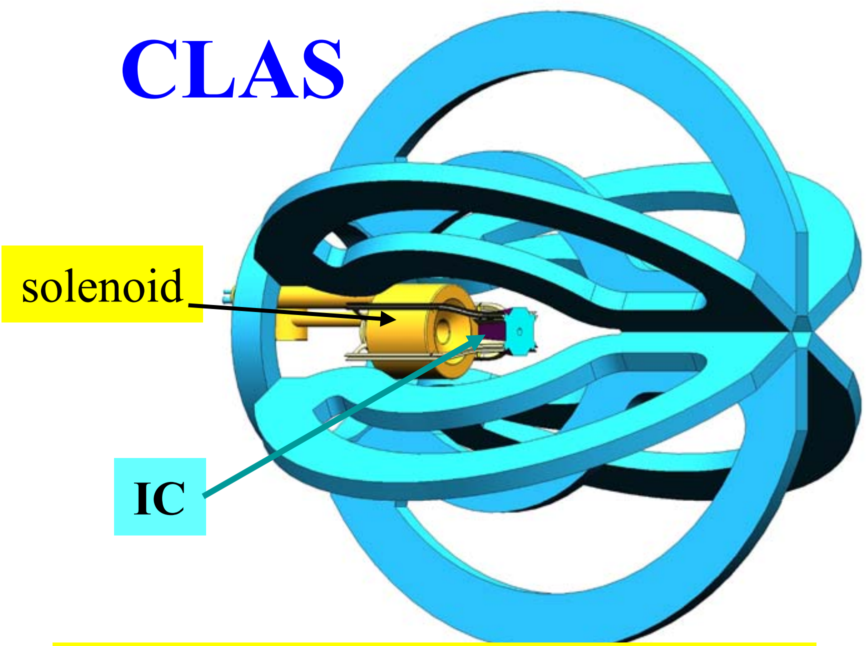


- **electron ID**:
  - ➢ EC, CC, DC and TOF
- **proton ID**:
  - ➢DC and TOF
- **photon ID**:
  - ➢IC or EC

The e1-dvcs experiment at CLAS

- Experiment: March - May 2005
- E_e = 5.77 GeV
- Polarization: 76% - 82%
- Current: 20-25 nA
- Integrated luminosity: $3.33 \cdot 10^{7}$ nb^{-1}



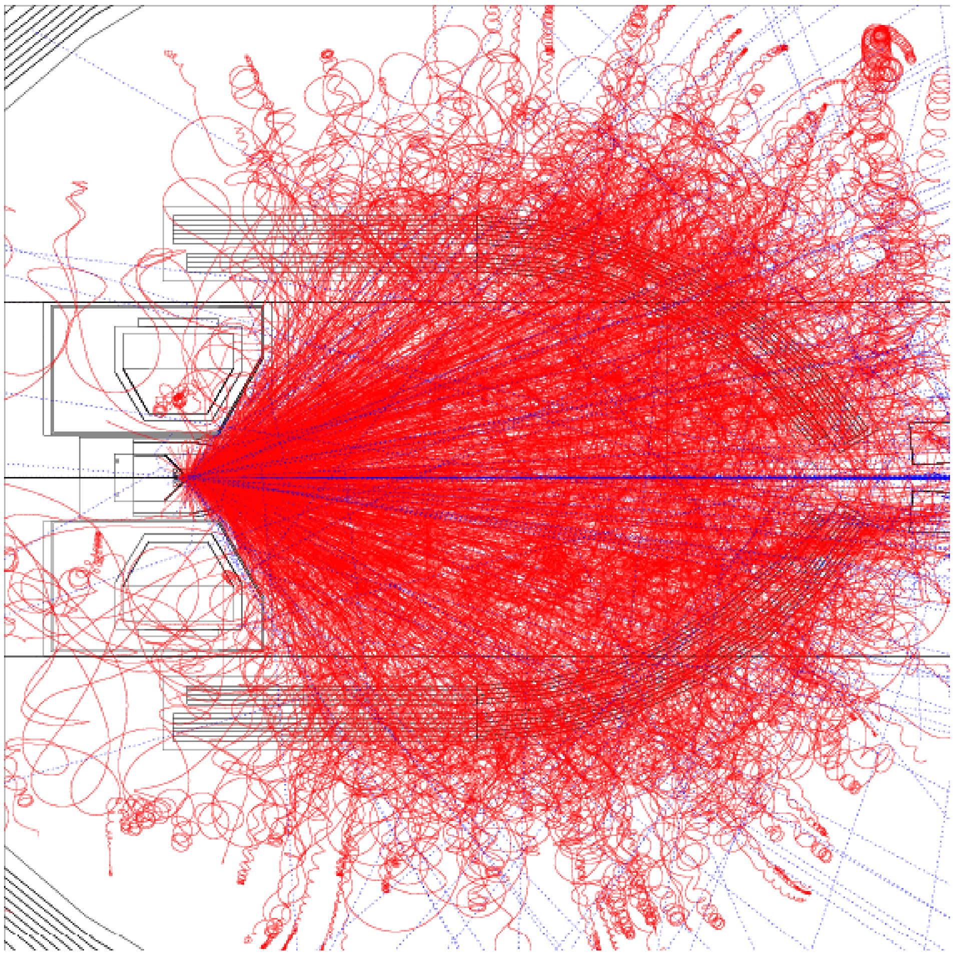


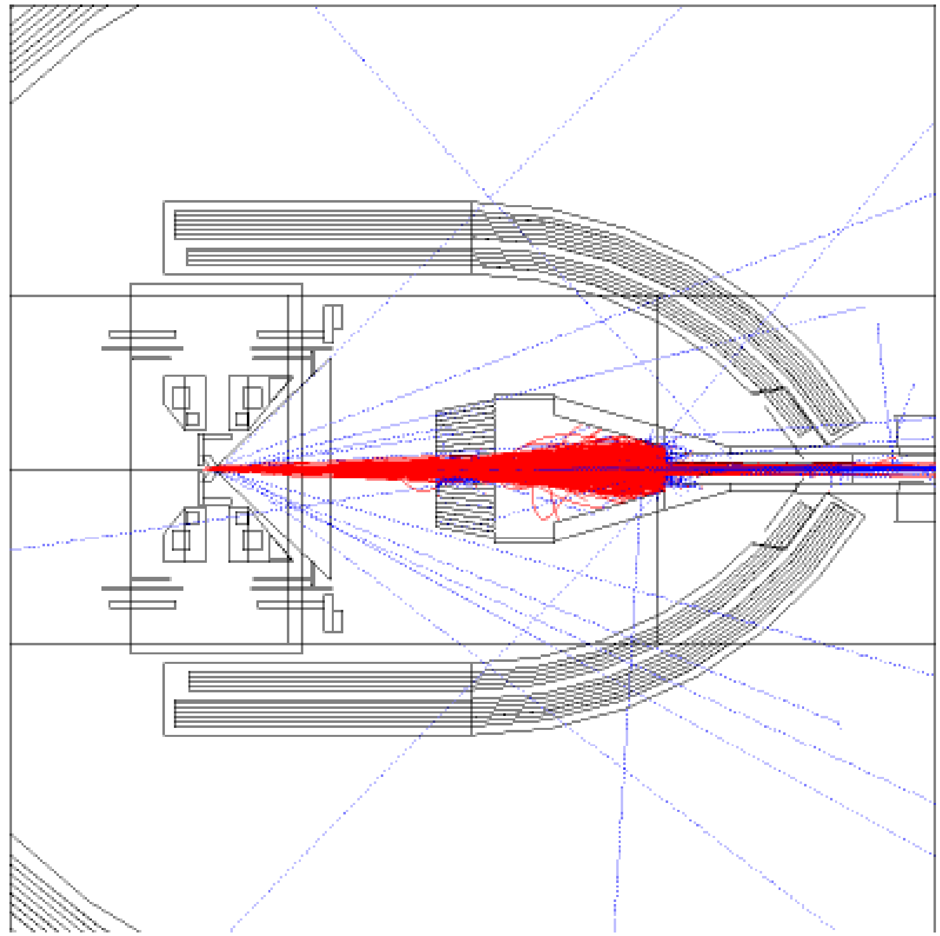
Superconducting solenoid magnet (shielding for Moeller electrons)

Standard CLAS acceptance for photons: $\theta \in [17^o;43^o]$

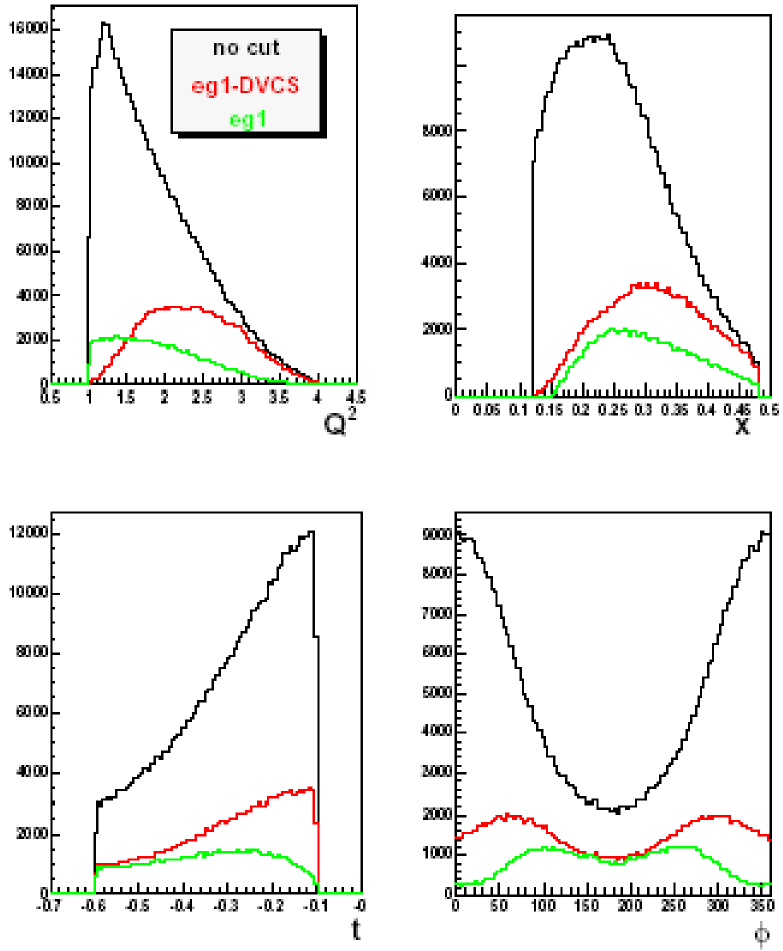
Inner calorimeter: $\theta \in [4^o;15^o]$

Magnetic Shielding for Møller Electrons


without magnetic field

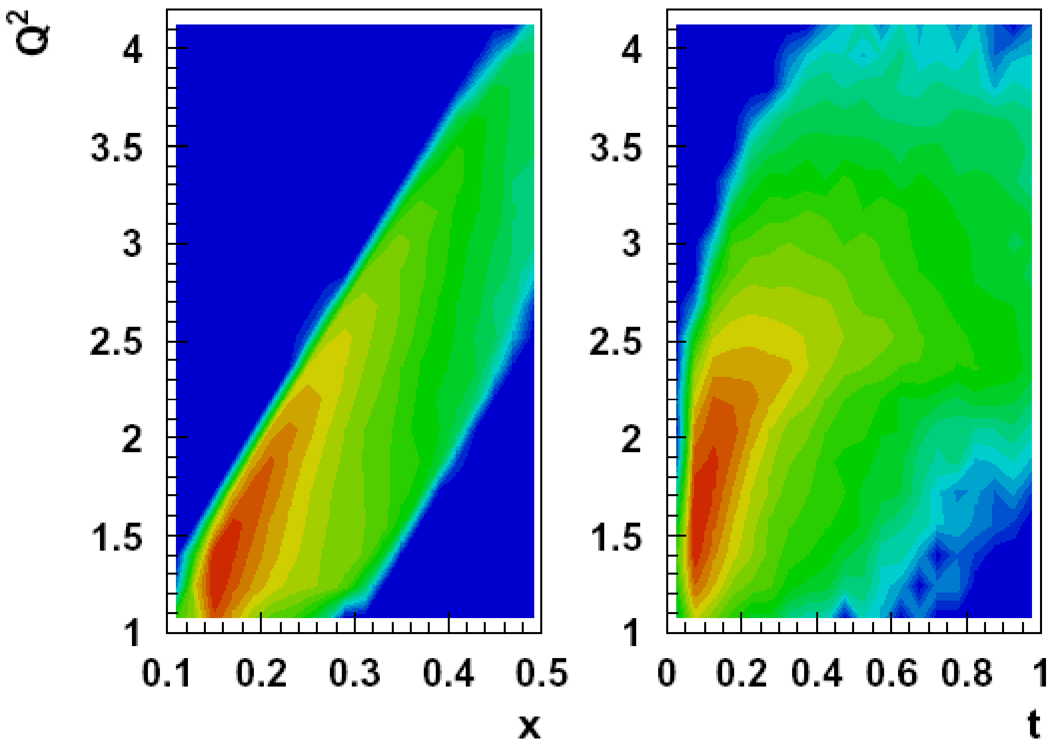

with magnetic field

Kinematics and Acceptance with CLAS + IC



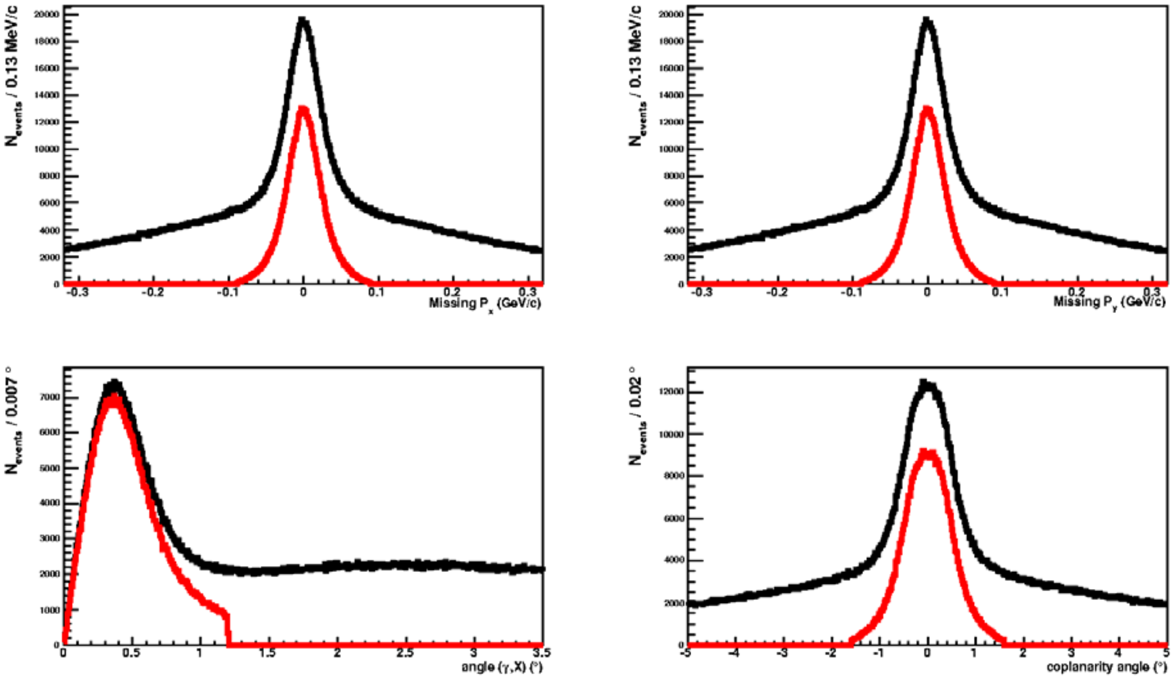
DVCS studies require:

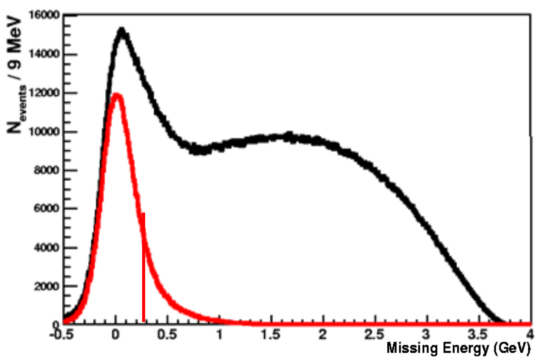
- high Q^2
- low t



The much improved acceptance for photon detection, and the longer running time will allow us to extend the kinematics range to higher Q^2, and to map out the x_B and t dependence in small bins

Selection of the DVCS final state





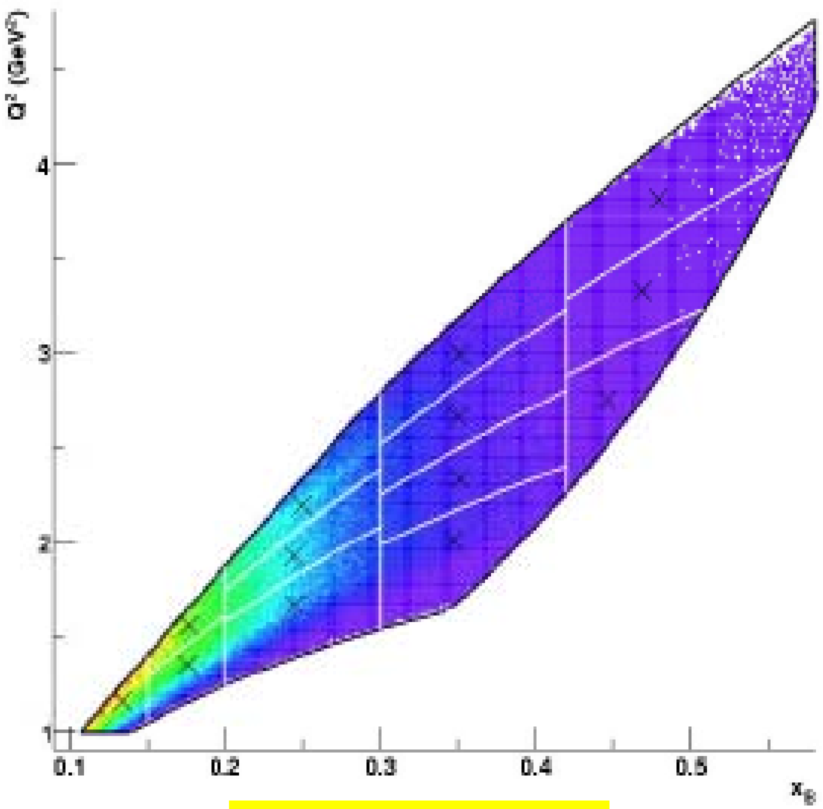
$ep\pi^0 \rightarrow ep\gamma(\gamma)$ background calculated with Monte Carlo simulation and experimental $ep\pi^0 \rightarrow ep\gamma\gamma$ data: 5% on average

Exclusivity cuts:

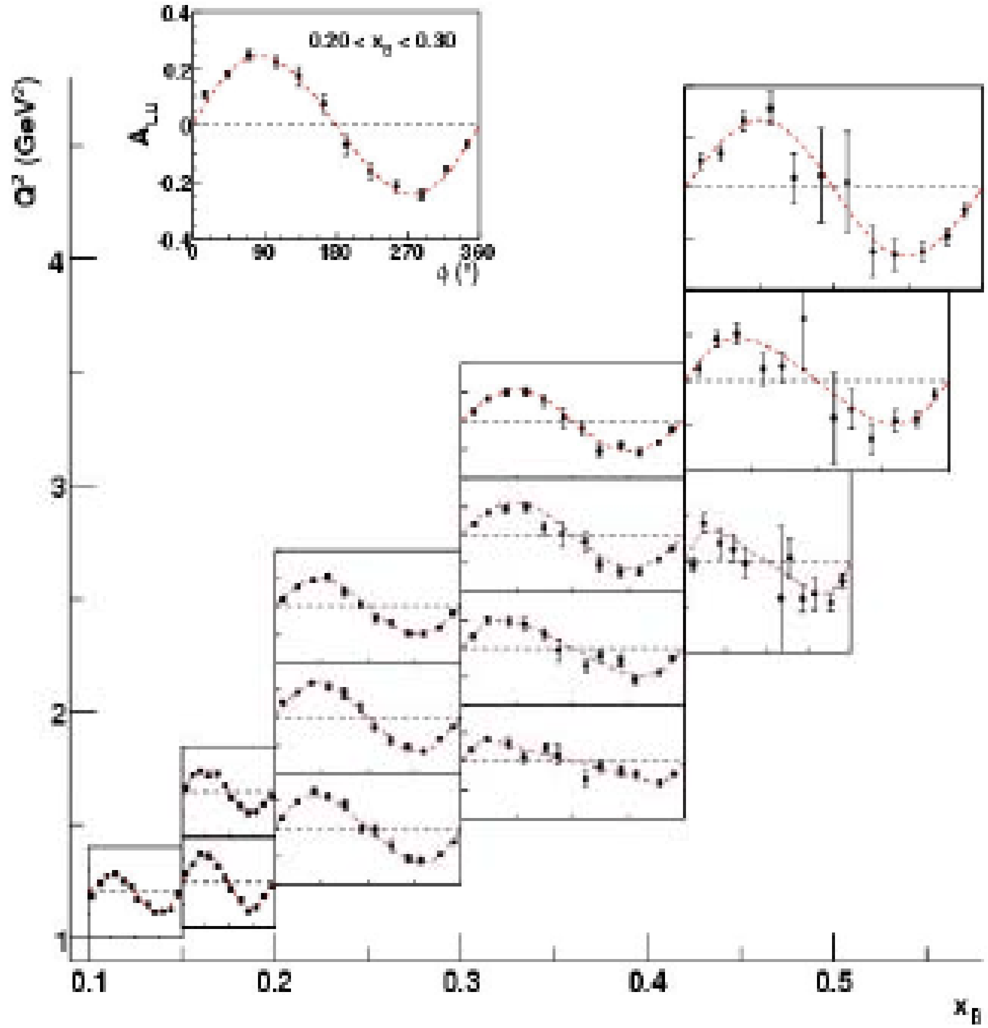
- P_X^T < 90 MeV/c (150 MeV/c) [ep→epgX]
- Cone angle $\alpha(\gamma X')$ <1.2° (2.7°) [ep→epX']
- Coplanarity angle between (γp) et (γ^*p)<±1.5° (±3°)
- E_X < 300 MeV (500 MeV)

BSA: coverage and f distributions

Data integrated over t



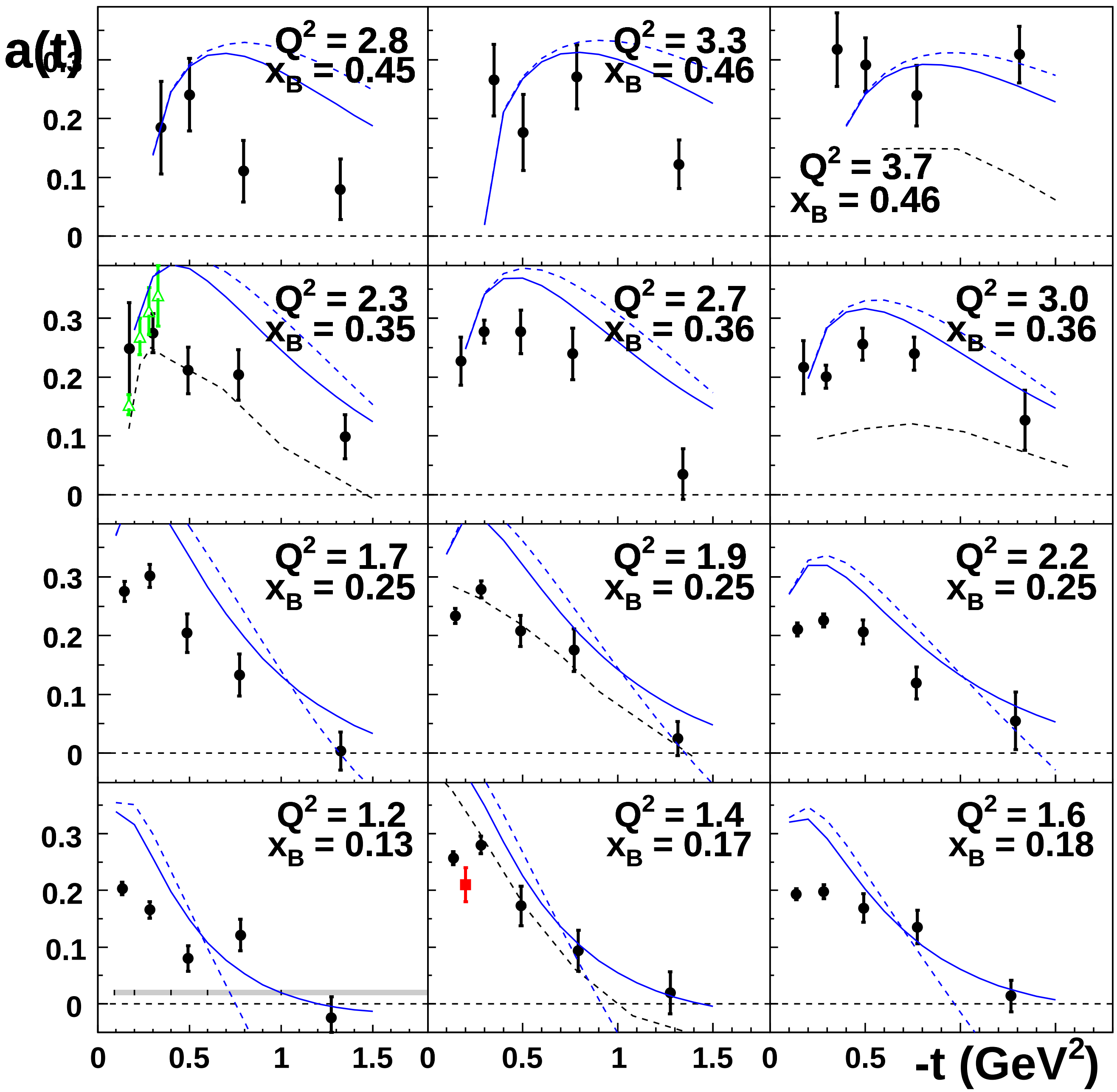
- 13 Q^2, x_B bins
- 5 t bins
- 12 ϕ bins



Fit = $\alpha \sin\phi/(1+\beta\cos\phi)$

Ph.D. Thesis of F.X. Girod

BSA: a vs. t



- CLAS e1-dvcs
- Hall A
- CLAS @ 4.3 GeV²
- VGG(*) twist-2 (DD)
- VGG(*) twist-2 and 3
- Regge model (**)

(*) Guidal, Polyakov, Radyushkin, Vanderhaegen, PRD 72 (2005)

(**) Cano and Laget, PL B551 (2003)

GPD model overestimates the data

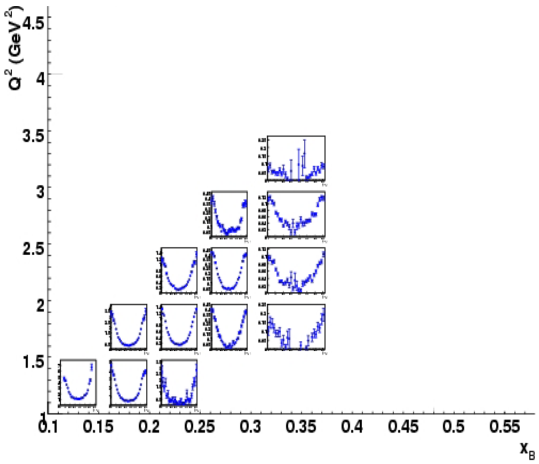
arXiv: 0711.4805 [hep-ex]
Submitted to PRL

Ph.D. Thesis of F.X. Girod

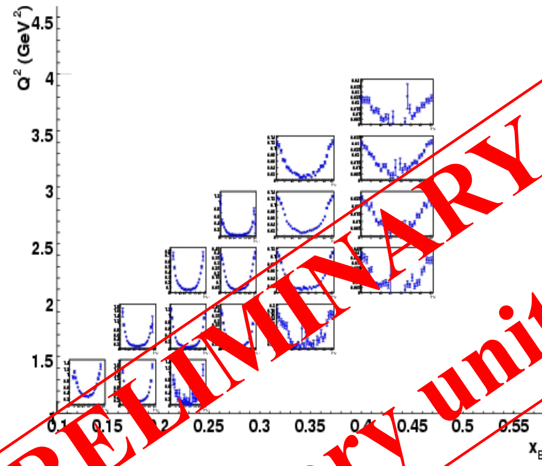
Unpolarized Cross Sections

$\frac{d^4\sigma_{ep\to ep\gamma}}{dQ^2 dx_B dt d\phi}$ as a function of ϕ

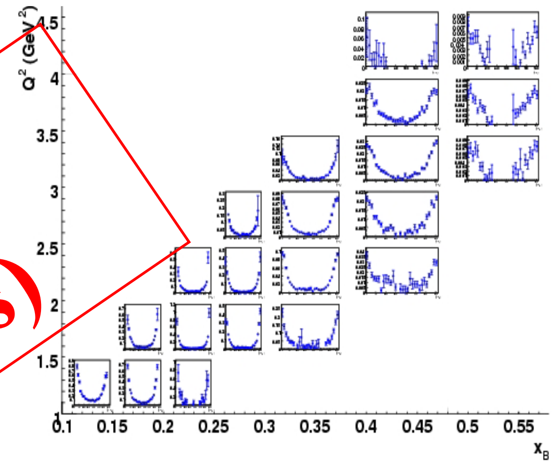
0.09<-t<0.2 GeV²



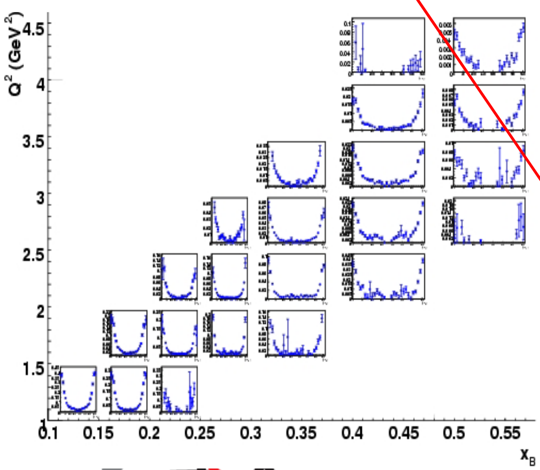
0.2<-t<0.4 GeV²



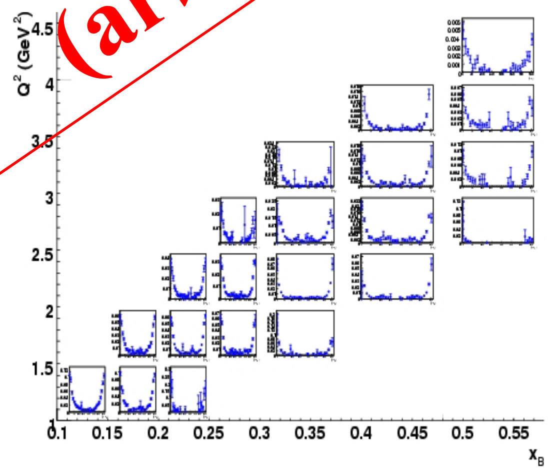
0.4<-t<0.6 GeV²



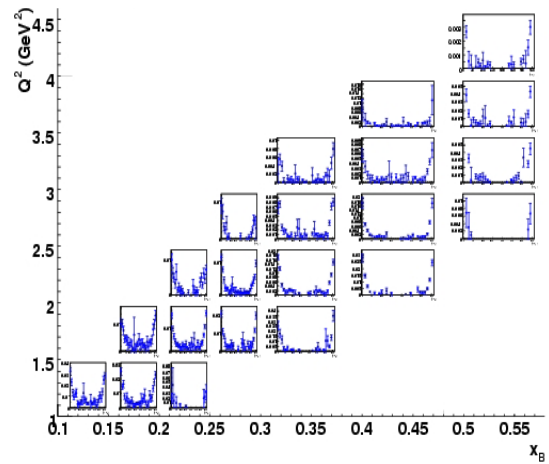
0.6<-t<1 GeV²



1<-t<1.5 GeV²



1.5<-t<2 GeV²

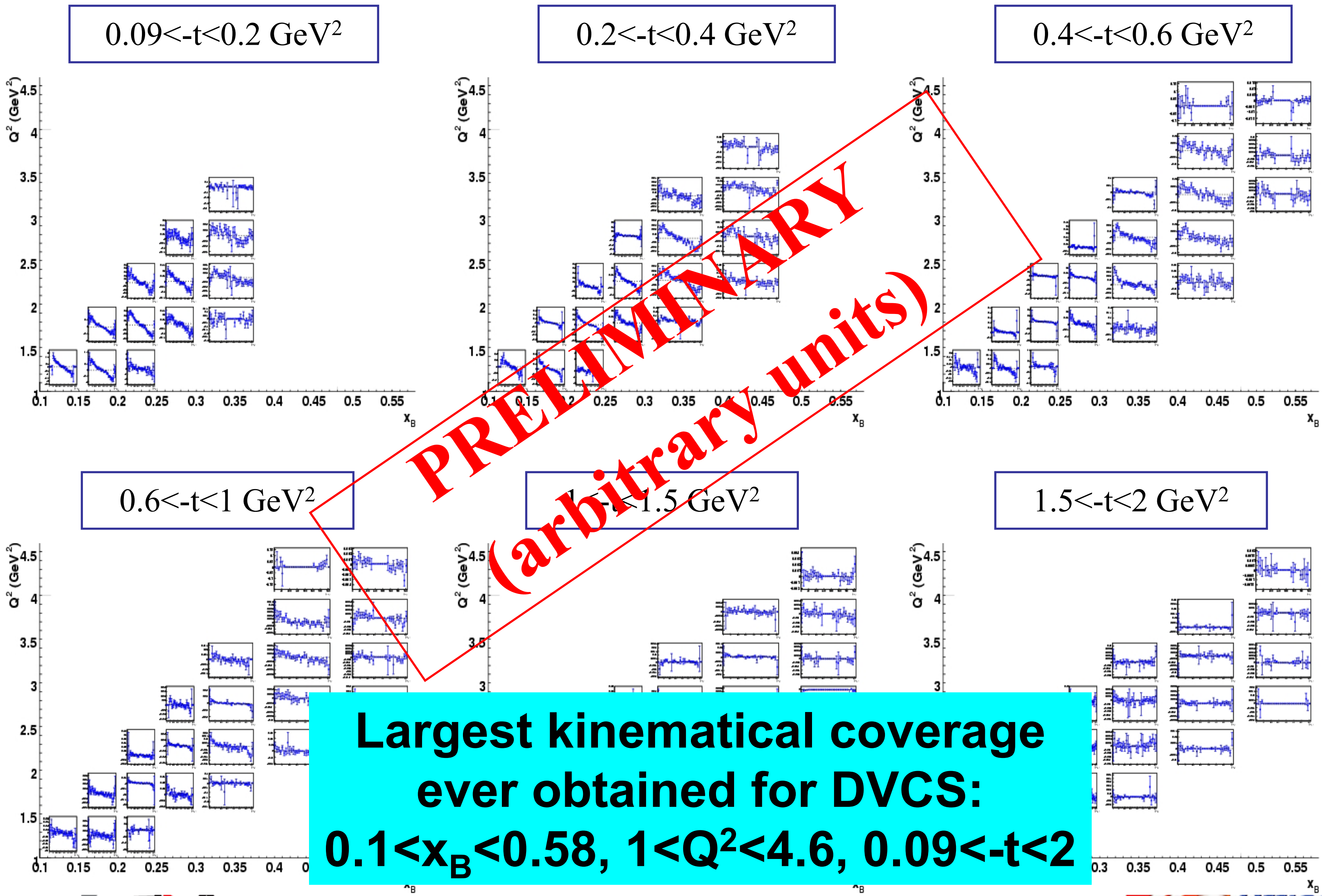


PRELIMINARY
(arbitrary units)

Ph.D. Thesis of H.S. Jo

Difference of Polarized Cross Sections

$$\frac{d^4\vec{\sigma}_{ep\to ep\gamma}}{dQ^2dx_Bdtd\phi} - \frac{d^4\overleftarrow{\sigma}_{ep\to ep\gamma}}{dQ^2dx_Bdtd\phi}$$ as a function of ϕ



Largest kinematical coverage ever obtained for DVCS: $0.1<x_B<0.58$, $1<Q^2<4.6$, $0.09<-t<2$

Ph.D. Thesis of H.S. Jo

Separating GPDs Through Polarization

$ep \longrightarrow ep\gamma$

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta\sigma}{2\sigma}$$

$\xi = x_B/(2-x_B)$

$k = -t/4M^2$

Polarized beam, unpolarized target:

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

Kinematically suppressed

$\Rightarrow$ H, $\tilde{H}$, E

Unpolarized beam, longitudinal target:

$$\Delta\sigma_{UL} \sim \sin\phi\{F_1\tilde{H} + \xi(F_1+F_2)(H + \ldots\}d\phi$$

$\Rightarrow$ H, $\tilde{H}$

Unpolarized beam, transverse target:

$$\Delta\sigma_{UT} \sim \sin\phi\{k(F_2 H - F_1 E) + \ldots\}d\phi$$

$\Rightarrow$ H, E

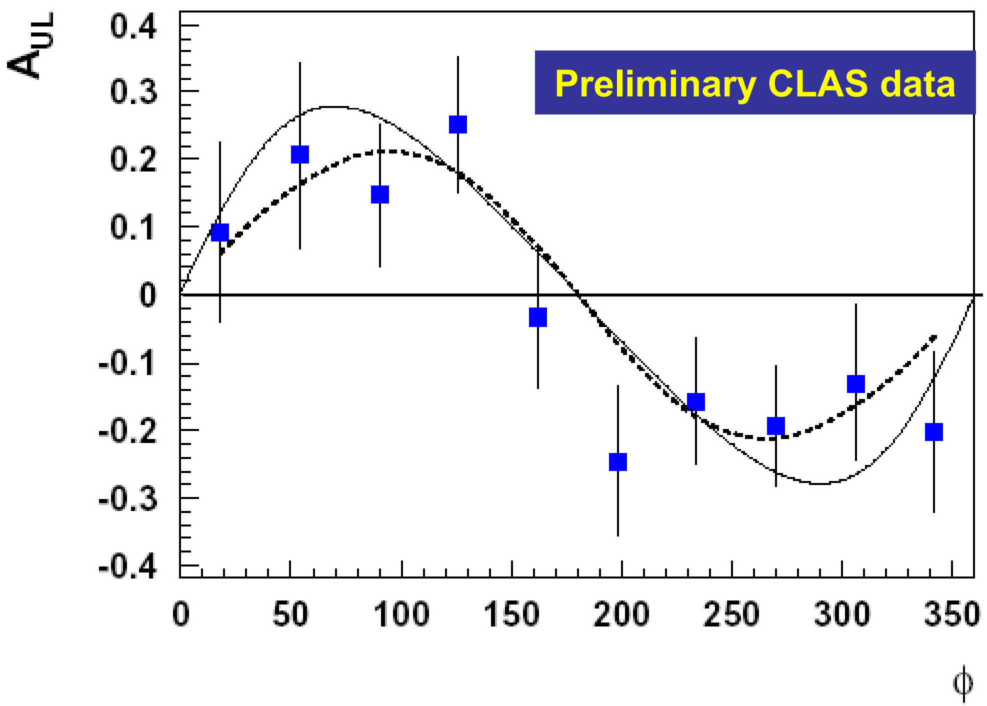
Global analysis of polarized and unpolarized data needed for GPD separation

Status of GPDs Studies at Jefferson Lab

GPD	Reaction	Obs.	Expt		Status	
$H(\pm\xi,\xi,t)$	ep→epγ (DVCS)	BSA	CLAS	4.2 GeV	Published PRL	*From* $ep \to epX$
			CLAS	4.8- 5.75 GeV	Preliminary	
		(+ σ)	**Hall A**	**5.75 GeV**	**Fall 04**	*Dedicated set-up*
			CLAS	**5.75 GeV**	**Spring 05**	
$\tilde{H}(\pm\xi,\xi,t)$	**ep→epγ (DVCS)**	TSA	CLAS	5.65 GeV	Preliminary	
$E(\pm\xi,\xi,t)$	**e(n)→enγ (DVCS)**	BSA	**Hall A**	**5.75 GeV**	**Fall 04**	*Dedicated set-up*
$(u+d)$	**ed→edγ (DVCS)**	BSA	CLAS	5.4 GeV	under analysis	
	ep→epe$^+$e$^-$ (DDVCS)	BSA	CLAS	5.75 GeV	under analysis	

No other proposals at Jefferson Lab are available for the study of the DVCS process with a polarized target.

DVCS with Polarized Target, Experimental Situation



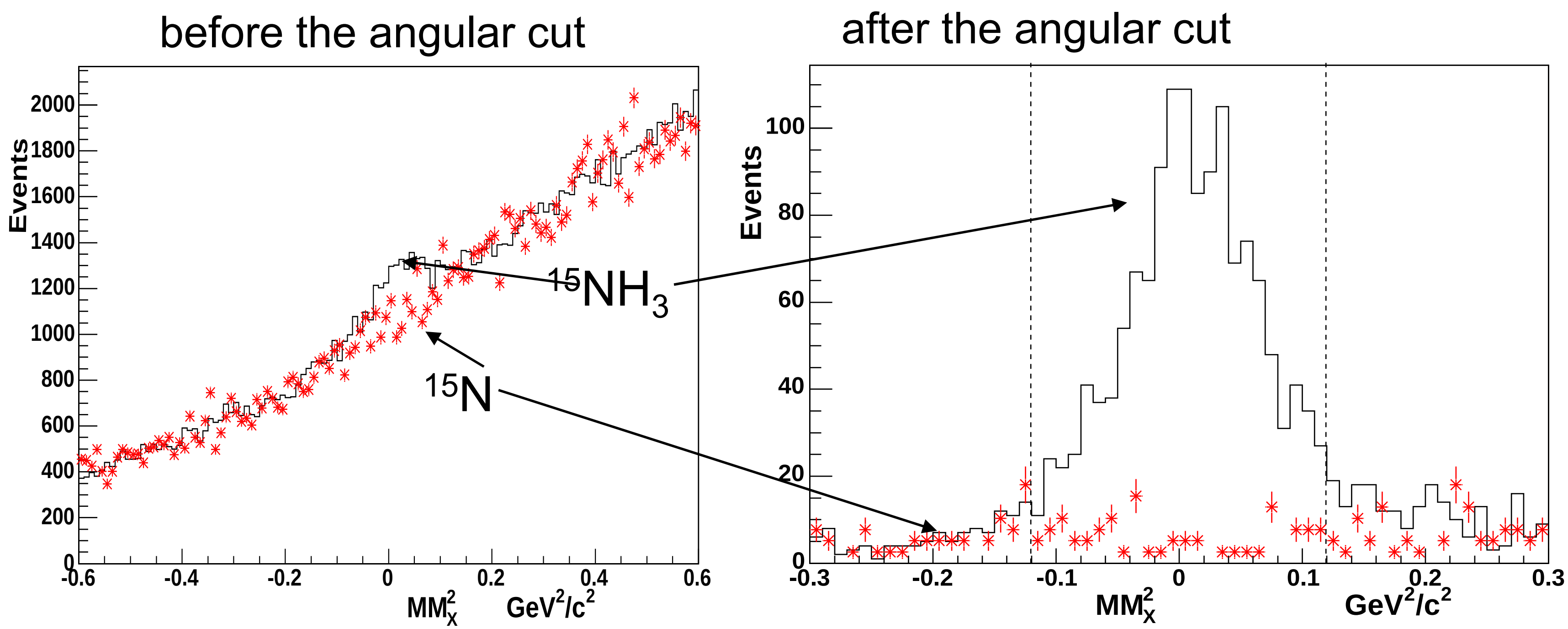
Experimental Studies with CLAS

Data were collected as a by-product during the **Eg1 2000** run: 5.75 GeV with **NH_3** longitudinally polarized target, <Q^2> ~ 1.8 GeV^2

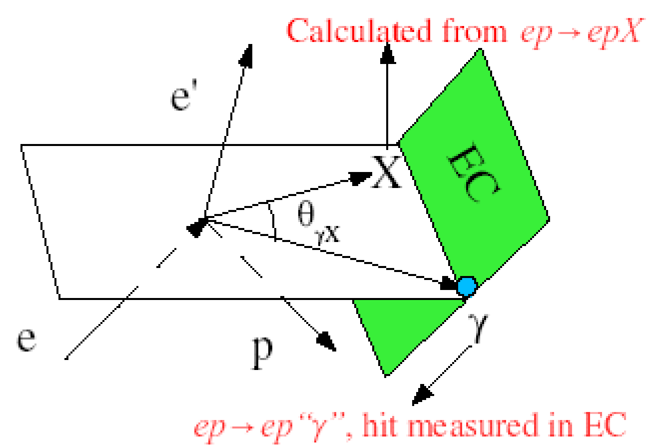
HERMES Experiment

Preliminary target spin asymmetries have been shown by HERMES Collaboration
DIS2005 Workshop, Madison (2005)

DVCS eg1: Separating DVCS Photons from Polarized Protons in NH_3



Events from both π^0 and unpolarized target nucleons are suppressed



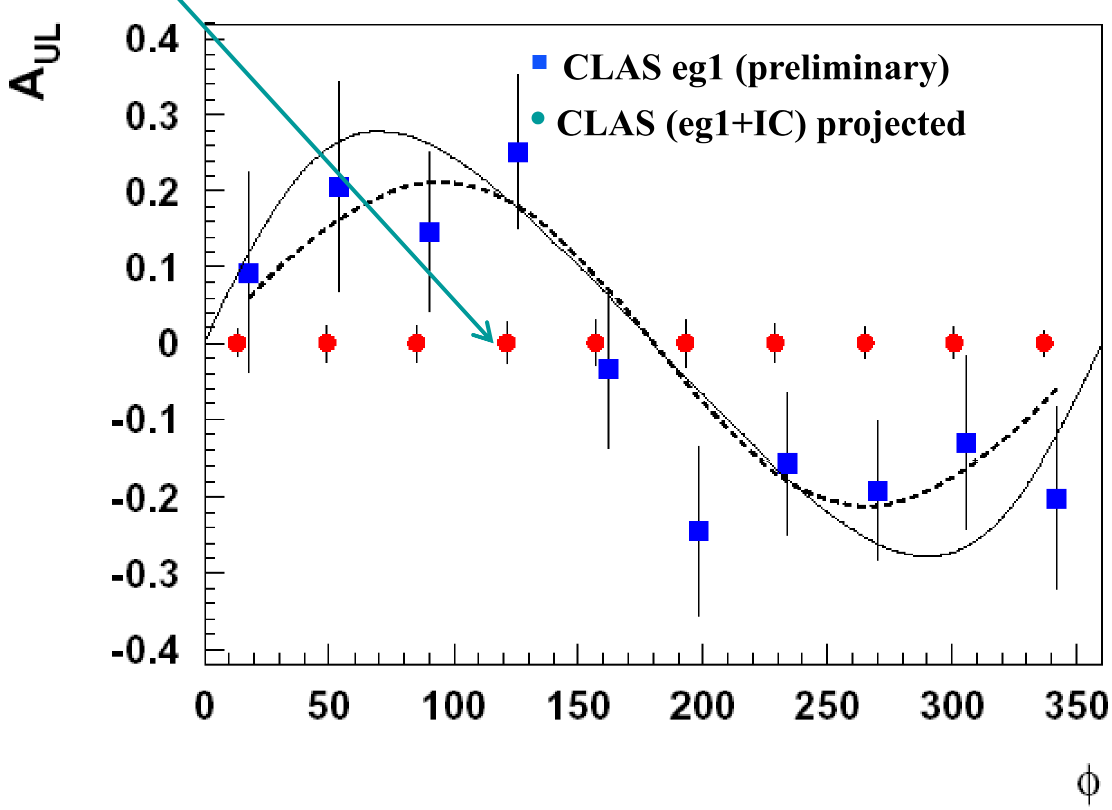
Geometry cut: $\theta_{\gamma X} < 1^o$

Hall B Longitudinally Polarized Target

- Dynamically polarized NH_3
- 5 Tesla magnetic field
- $\delta B/B \approx 10^{-4}$
- 1K LHe cooling bath
- NH_3 polarization:75%
- ^{12}C, ^{15}N, and ^{4}He targets to measure the dilution factor

Target Spin Asymmetry: ϕ Dependence

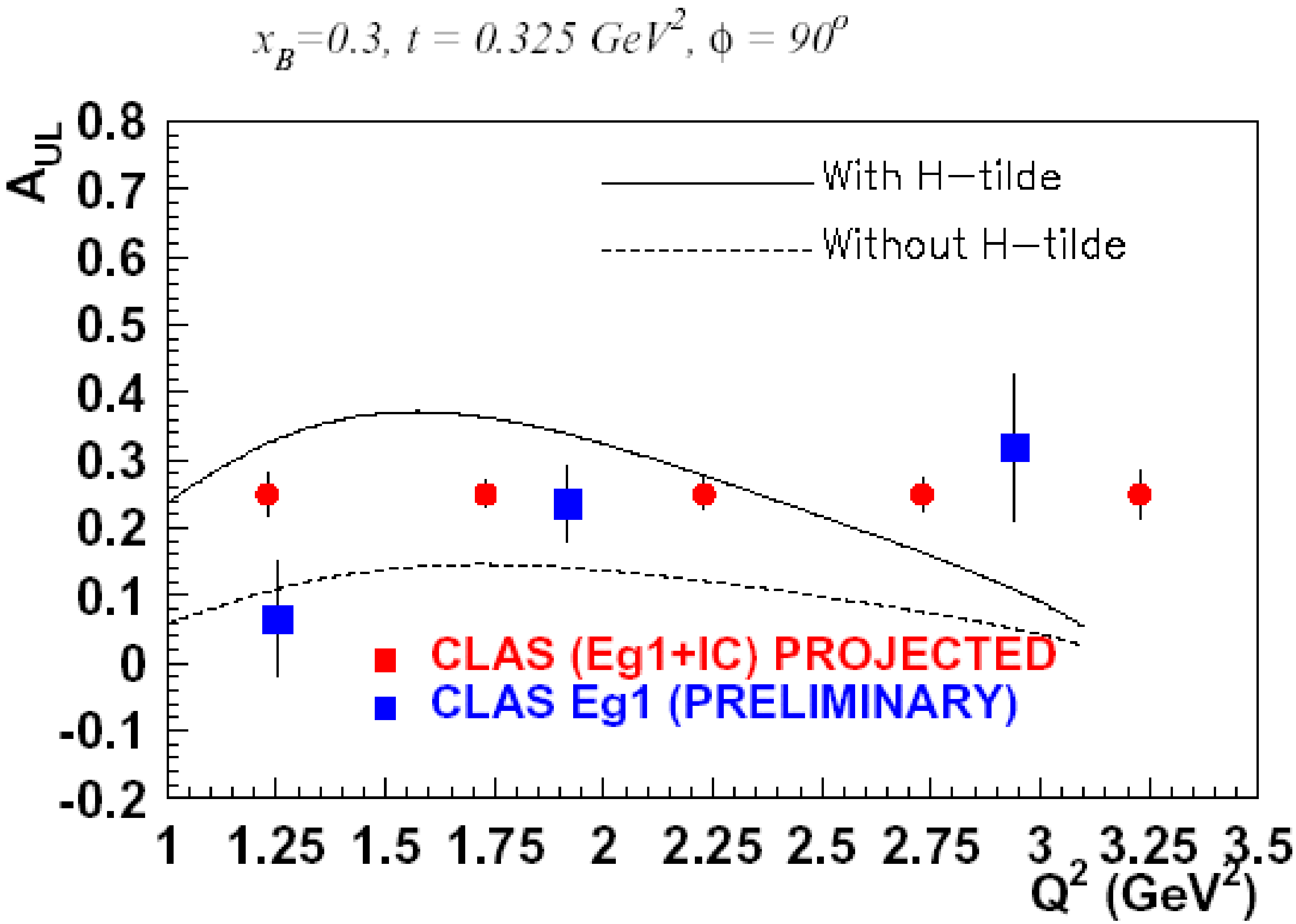
6 GeV run with NH_3 longitudinally polarized target (CLAS + IC) 60 days of beam time



A dedicated CLAS experiment with longitudinally polarized target will provide a statistically significant measurement of the kinematical dependences of the DVCS target SSA

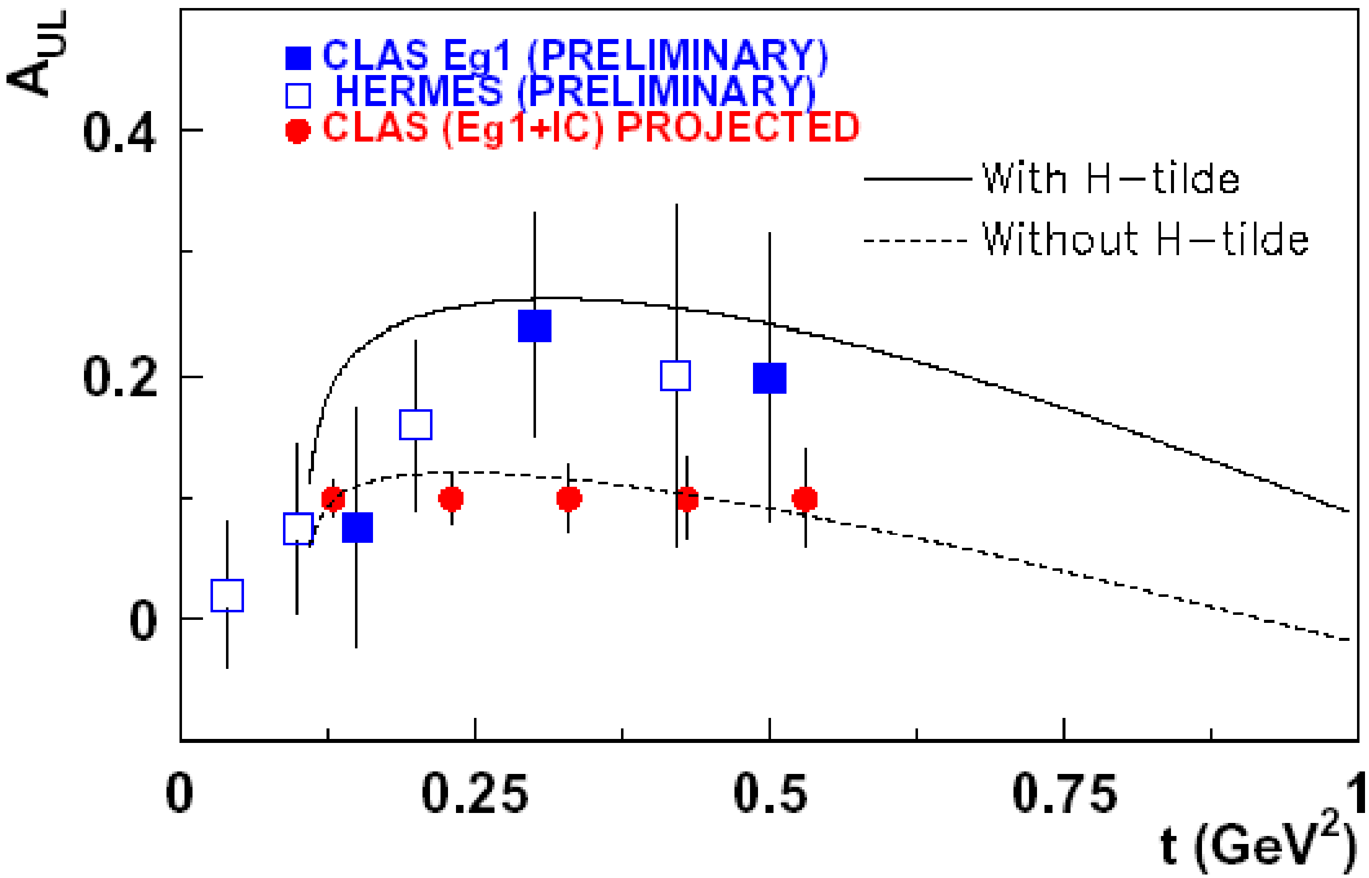
Office of Science
U.S. DEPARTMENT OF ENERGY

Target Spin Asymmetry: Q^2 Dependence



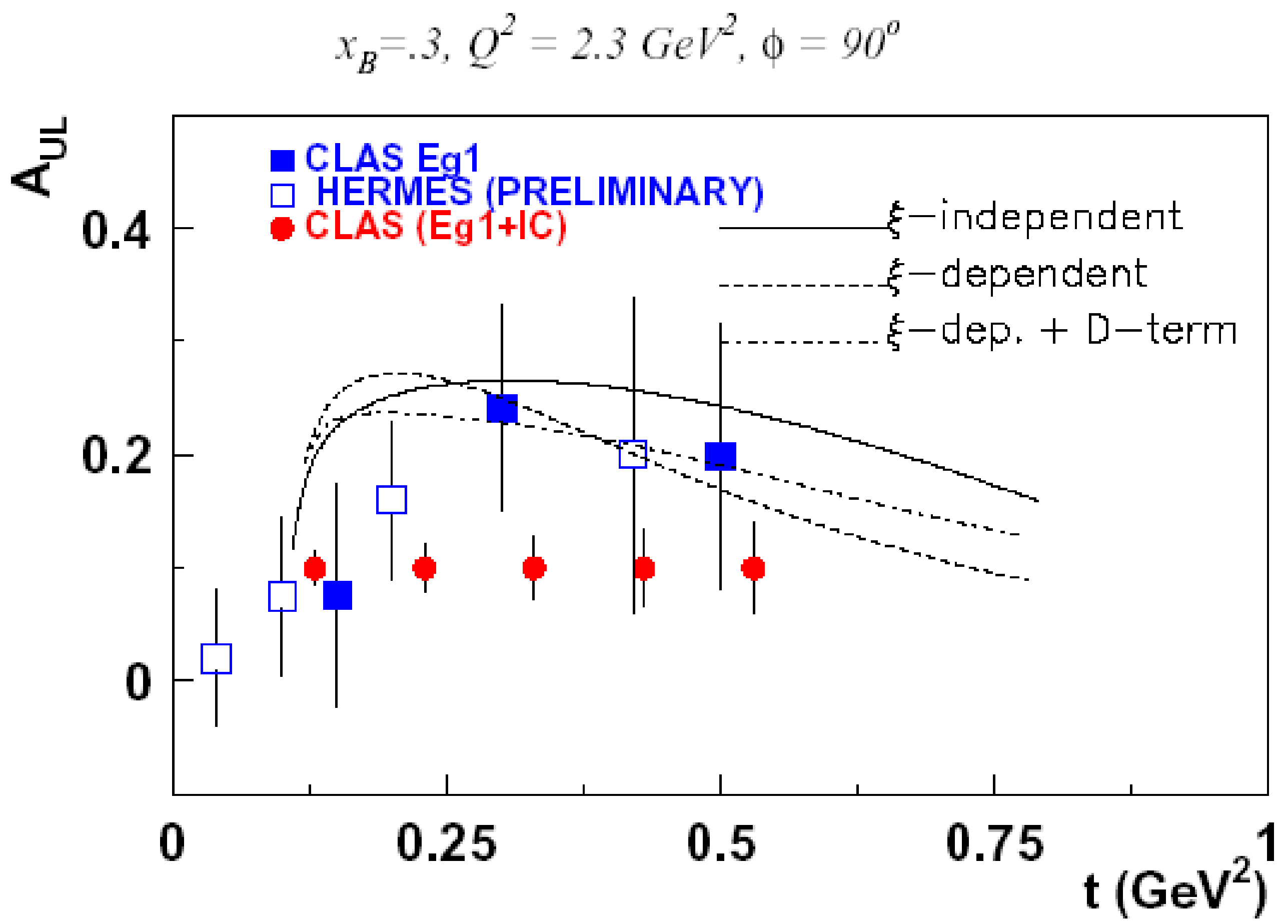
Target Spin Asymmetry: t- Dependence

$x_B = .3,\ Q^2 = 2.3\ GeV^2,\ \phi = 90^o$

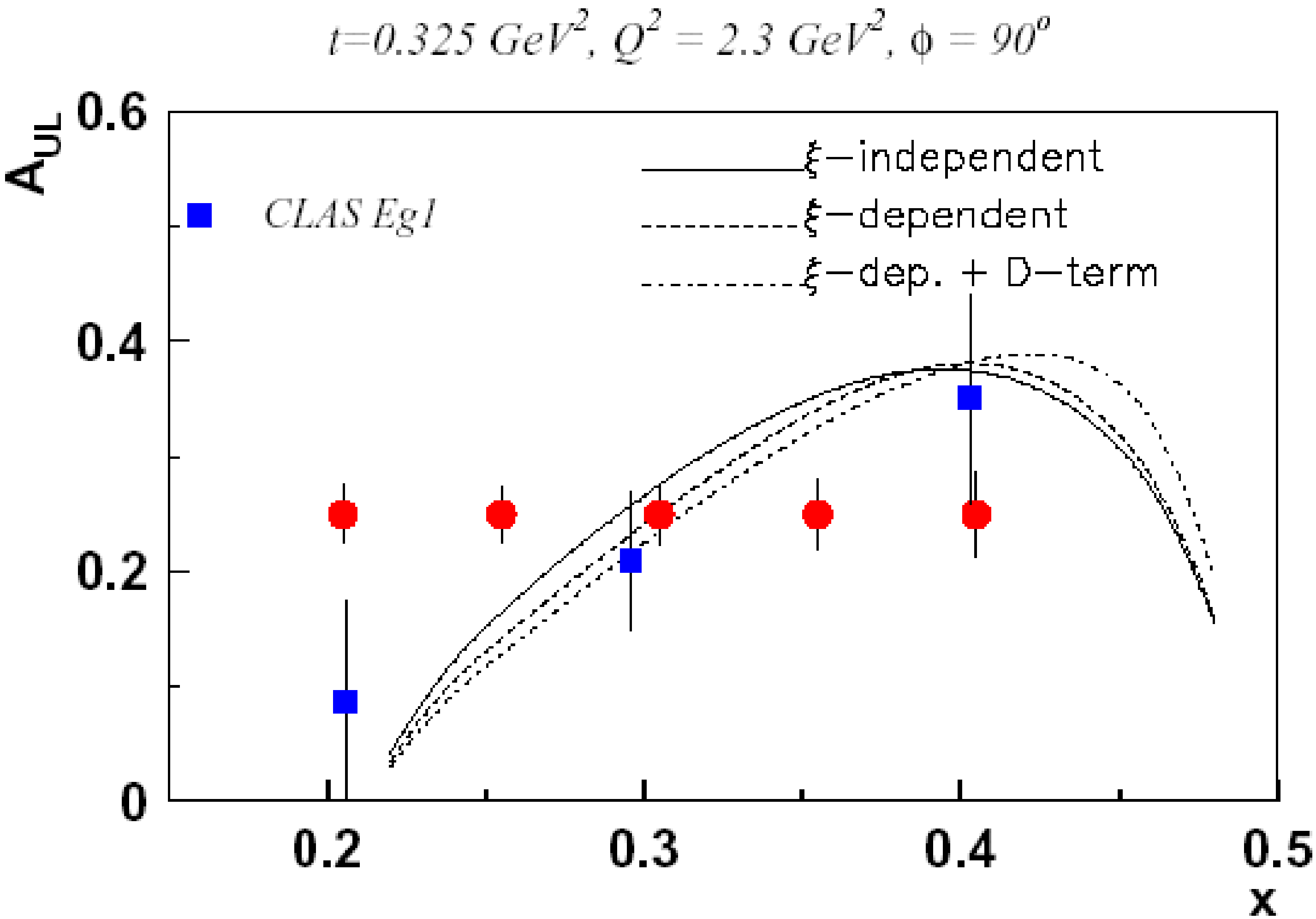


Higher t values will also be measured. The interpretation within the handbag formalism needs to be clarified.

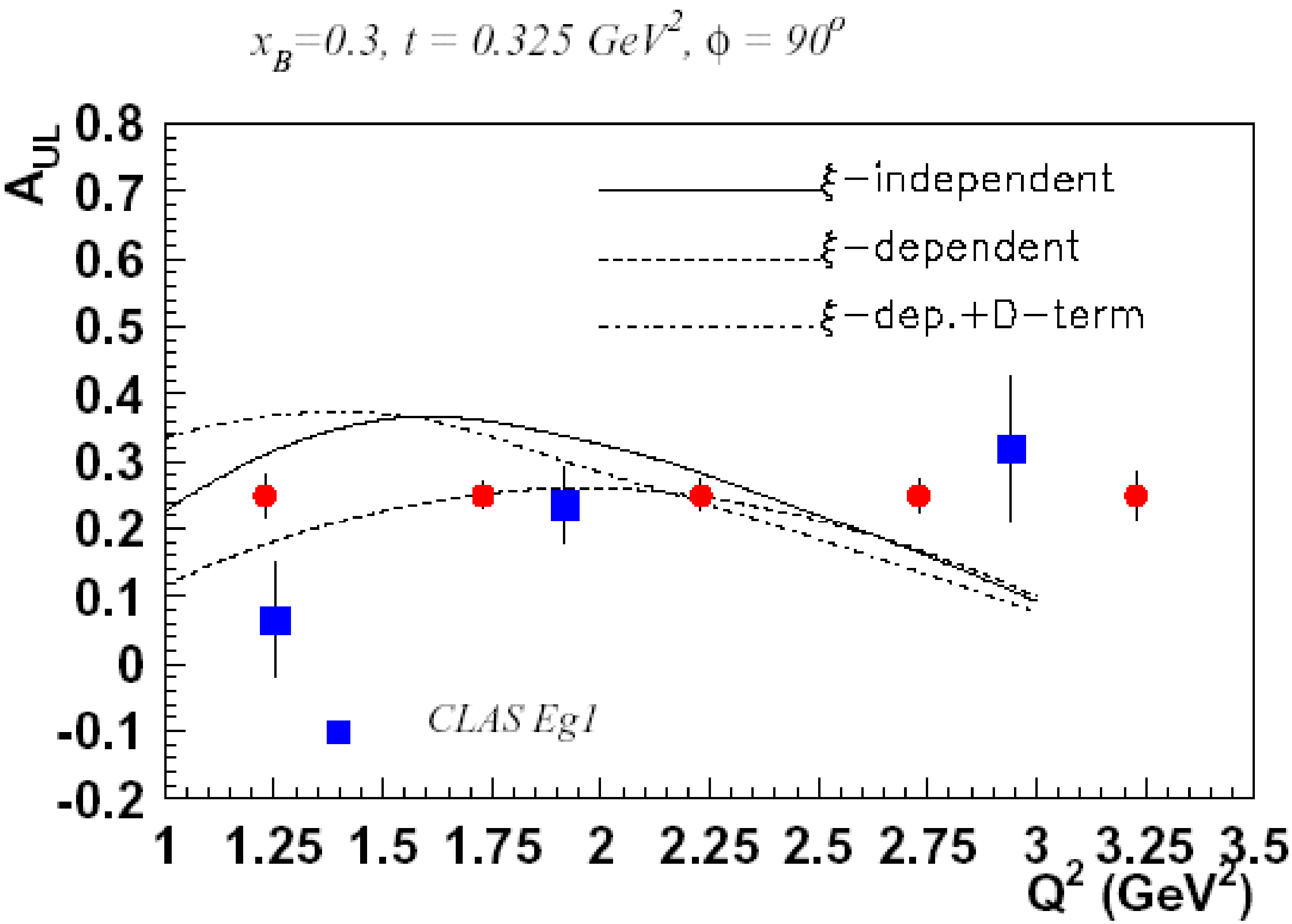
Target Spin Asymmetry: t- Dependence



Target Spin Asymmetry: x- Dependence

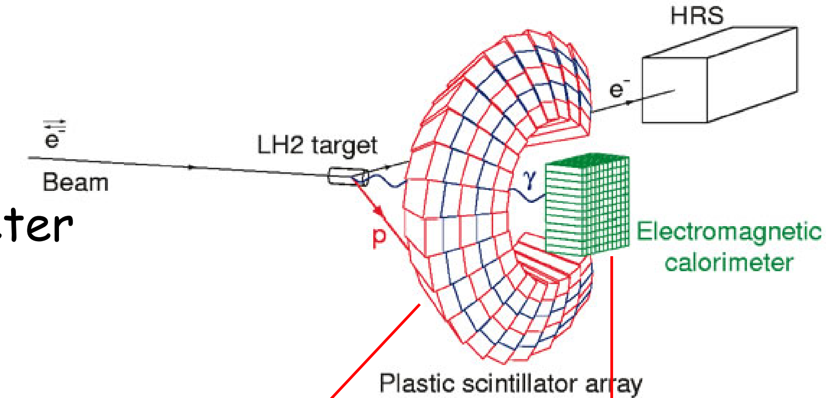


Target Spin Asymmetry: Q^2- Dependence

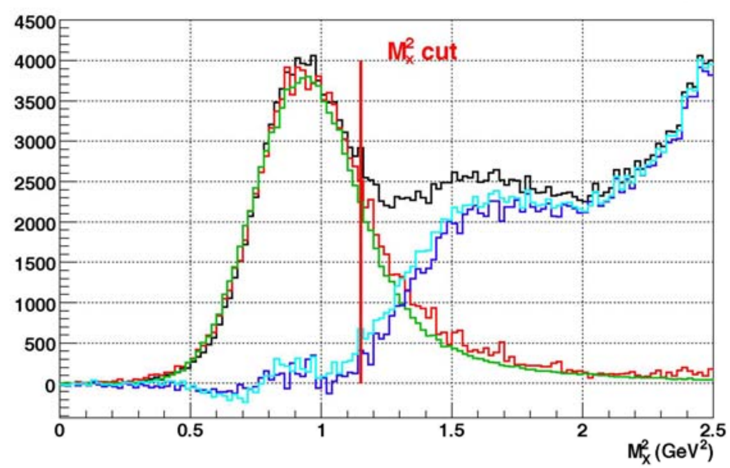


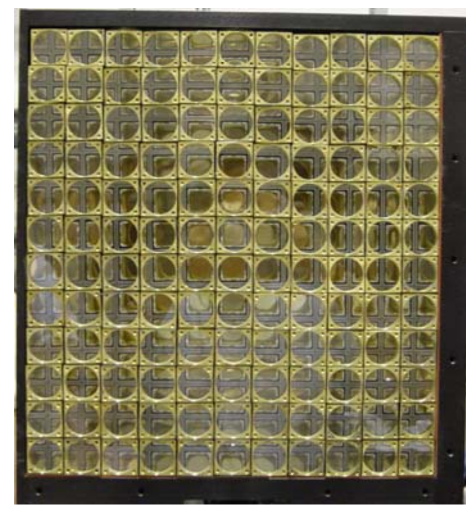
DVCS in Hall A (E00-110 and E03-106)

- 75% polarized 2.5 μA electron beam
- 15 cm LH2 target -> $L = 10^{37}$ cm^{-2}s^{-1}
- Left Hall A HRS with electron package
- 11x12 blocks PbF_2 electromagnetic calorimeter
- 5x20 blocks plastic scintillator array
- Digital sampling of PMT signals at 1 GHz



- Clear DVCS identification from HRS+calo



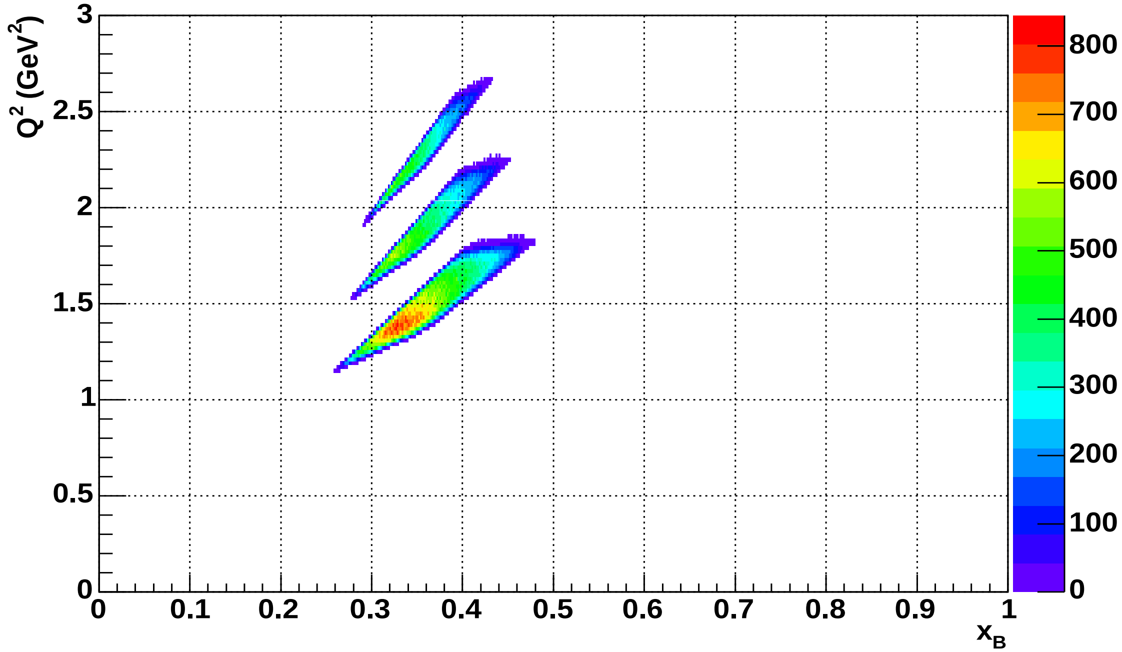


Clermont-Ferrand, Saclay, Grenoble, ODU, Rutgers

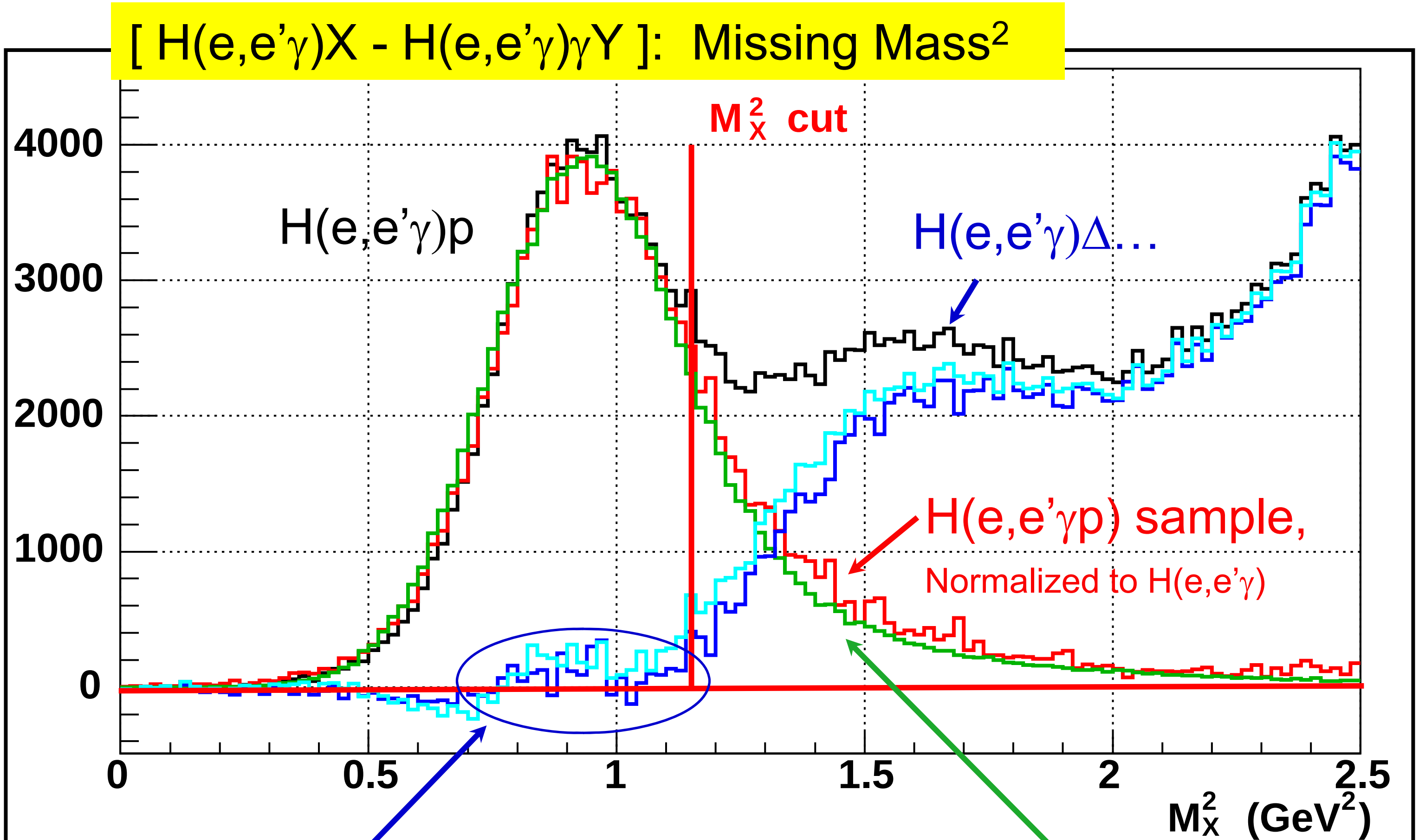
E00-110 kinematics

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

The calorimeter is centered on the virtual photon direction.
Acceptance: $\theta_{\gamma\gamma} < 150$ mrad



H(e,e'γ) Exclusivity



<2% in estimate of H(e,eγ)Nπ… below threshold $M_X^2<(M+m)^2$

H(e,e'γp) simulation, Normalized to data

Difference of cross sections

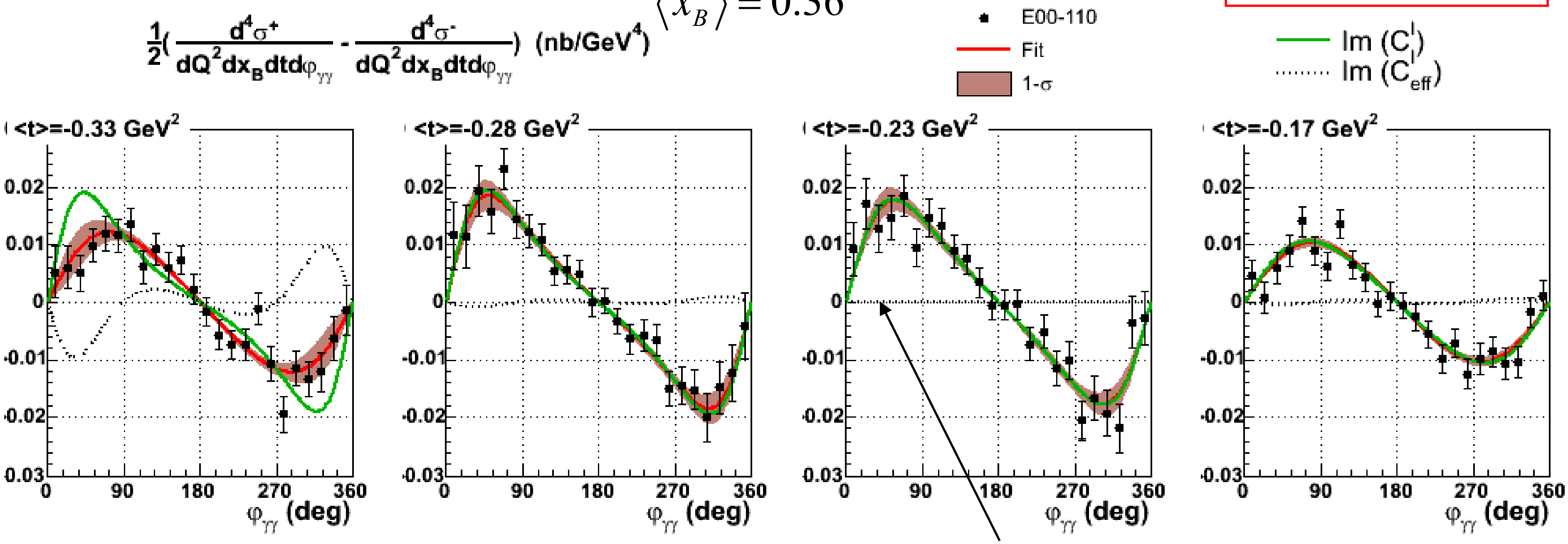
PRL97, 262002 (2006)

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

$$\langle x_B \rangle = 0.36$$

Im(C_I^I) ∝ s_1^I Twist-2

Im(C_I^I) ∝ s_2^I Twist-3



Extracted twist-3 contribution small !

Corrected for real+virtual RadCor
Corrected for efficiency
Corrected for acceptance
Corrected for resolution effects
Checked elastic cross section @ ~1%

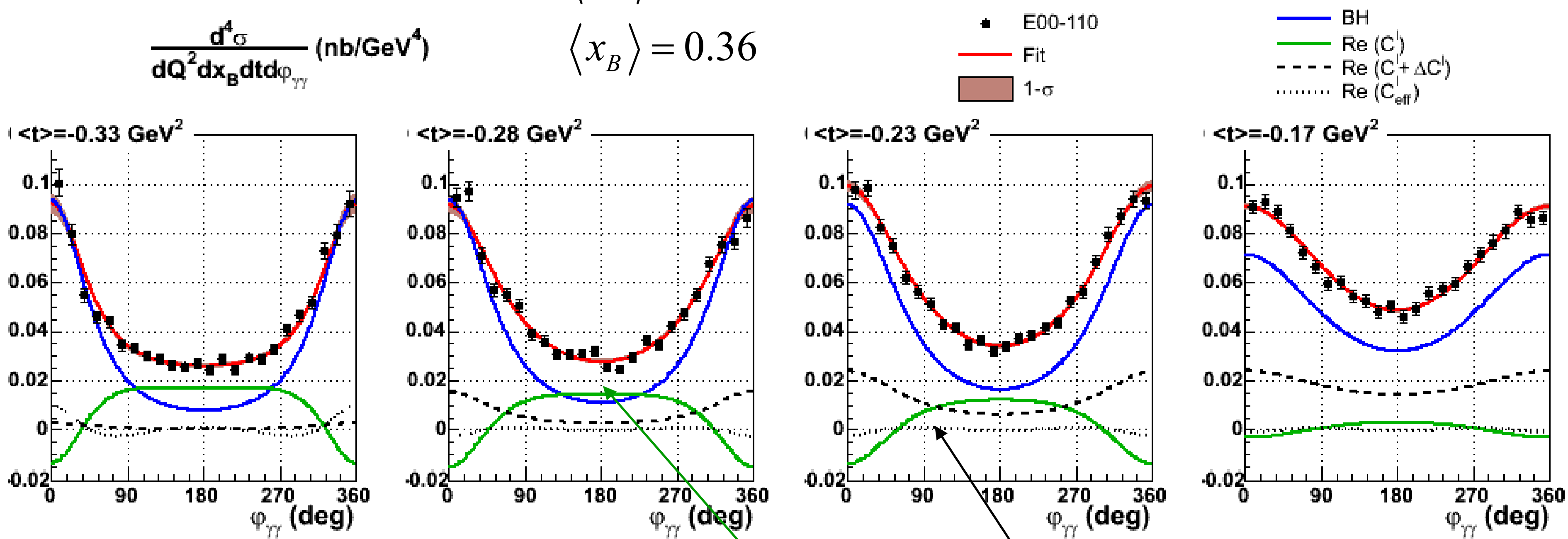
New work by P. Guichon

Total cross section

PRL97, 262002 (2006)

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

$$\langle x_B \rangle = 0.36$$



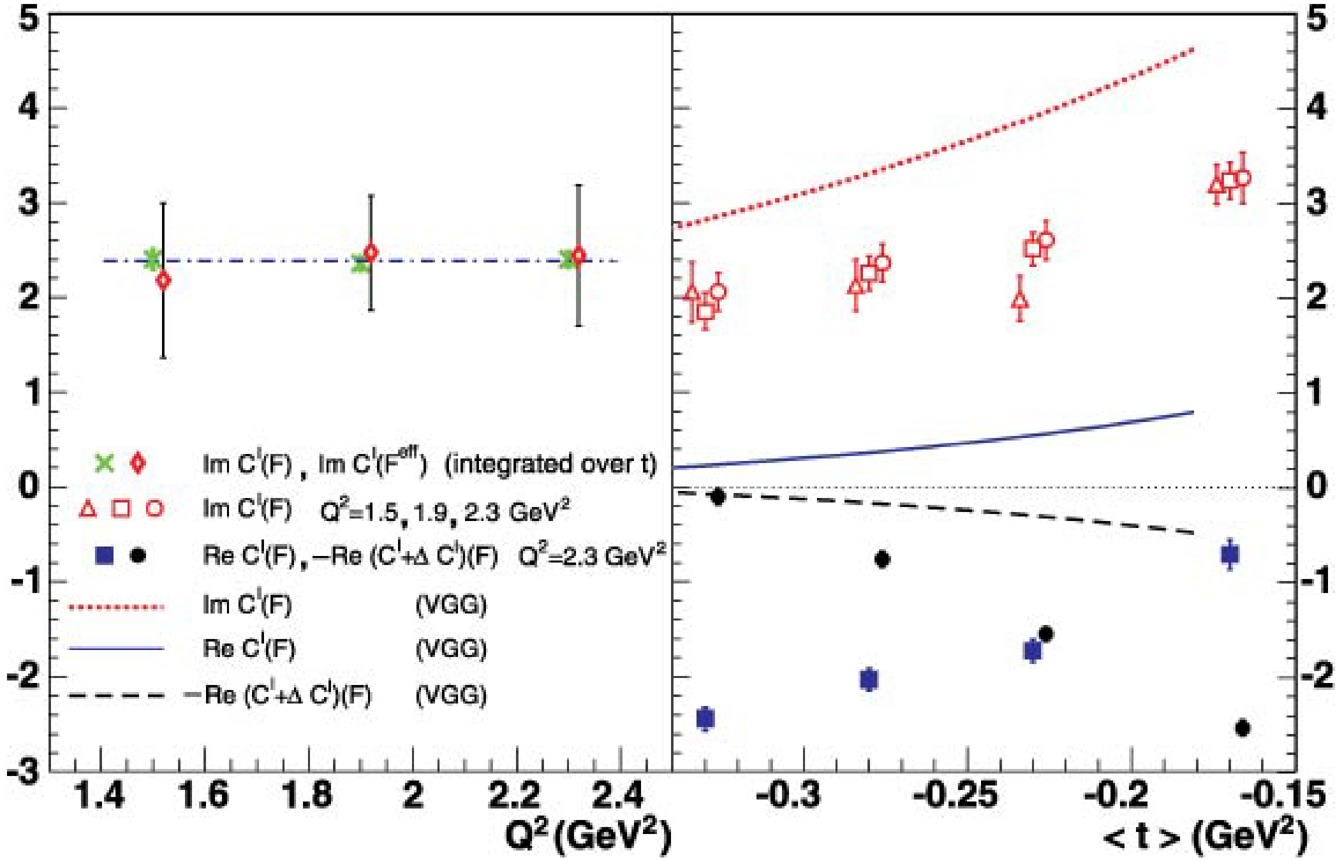
Again, extracted twist-3 contribution small !

Corrected for real+virtual RC
Corrected for efficiency
Corrected for acceptance
Corrected for resolution effects

BH*DVCS + DVCS² is large, comparable to BH²

Q^2 dependence and test of scaling

Twist-2
Twist-3

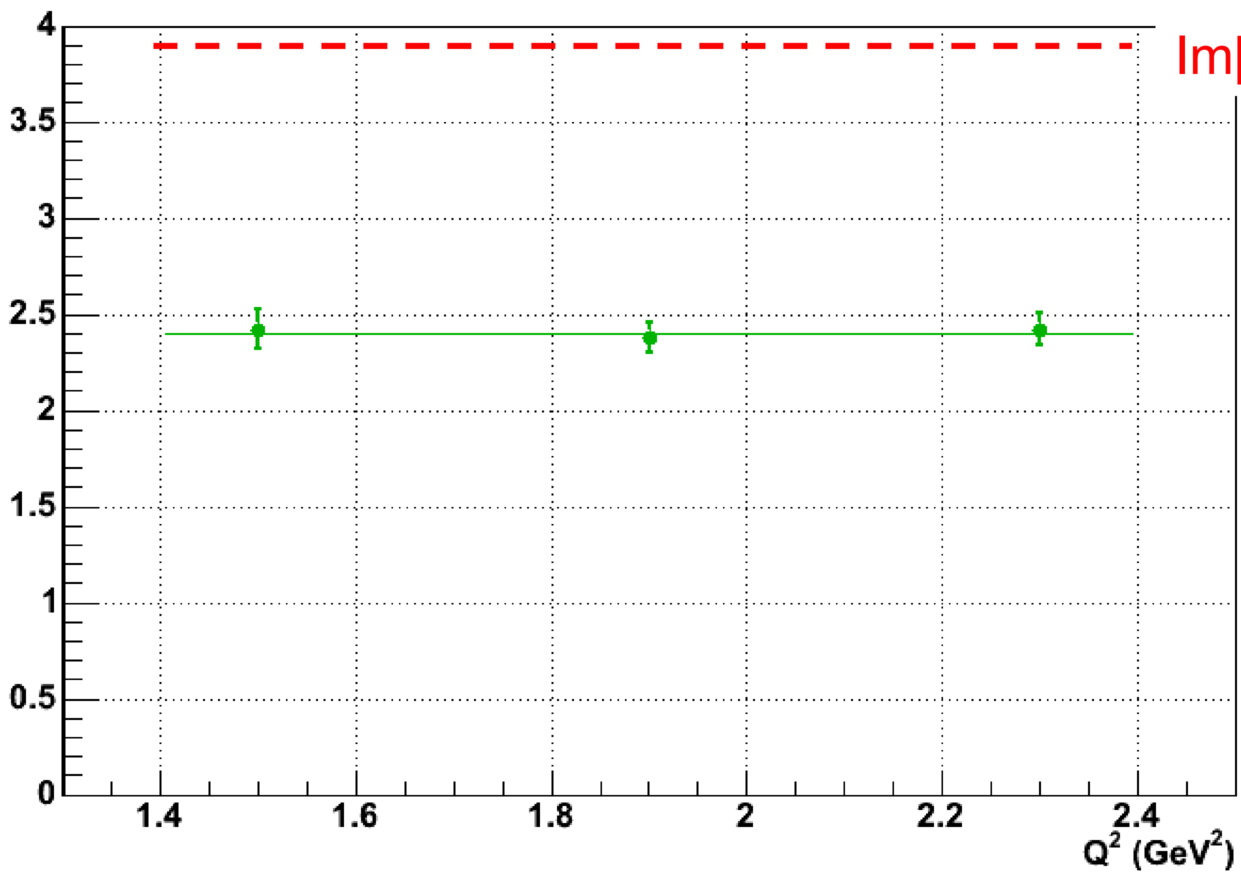


No Q^2 dependence: strong indication for scaling behavior and handbag dominance

Cross-section coefficients much larger than VGG

Q^2-dependence: averaged over t: <t>=-0.23 GeV^2

$Im[C^I(\mathcal{F})]$: 'sinφ term'



$H_q(x,0,t) = x^{-\alpha' t} q(x)$
ξ-dependence:
DD, b=1
$E_q = 0$

Average of three Q^2 points.

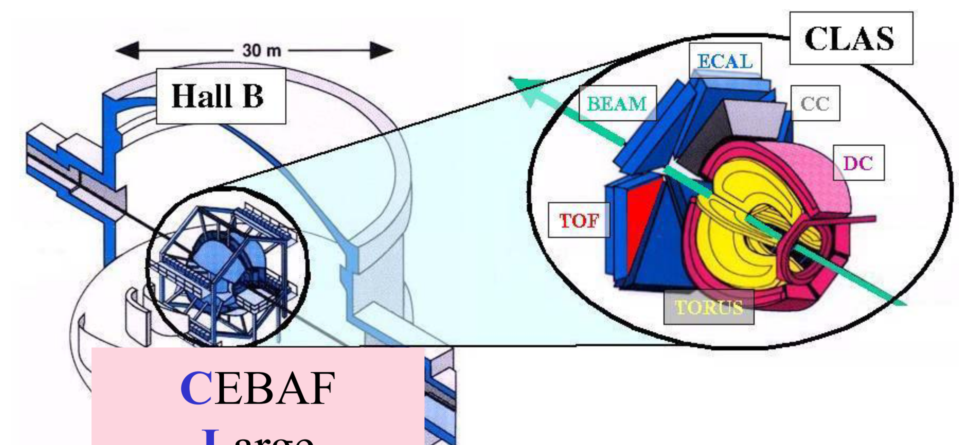
$Im[C^I]$: 10% bound on [Twist-4 + $d\sigma_{LT'}(DVCS^2)$] terms

Twist-3

Jefferson Laboratory
Newport News, USA

I_{max} ~ 200 μA
Duty Factor ~ 100%
σ_E/E ~ 2.5 10^{-5}
Beam Pol ~ 80%

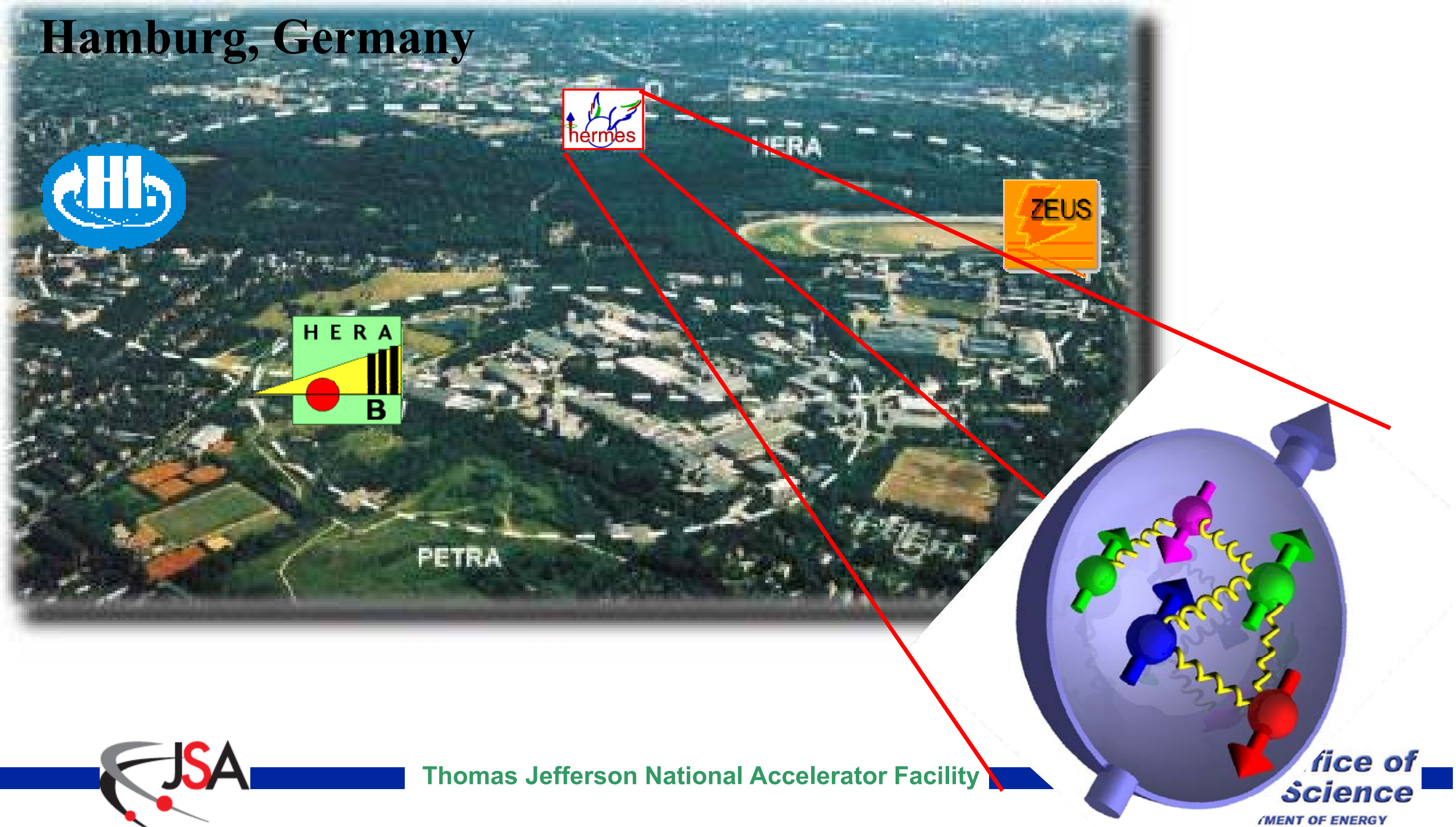
Continuous
Electron
Beam
Accelerator
Facility



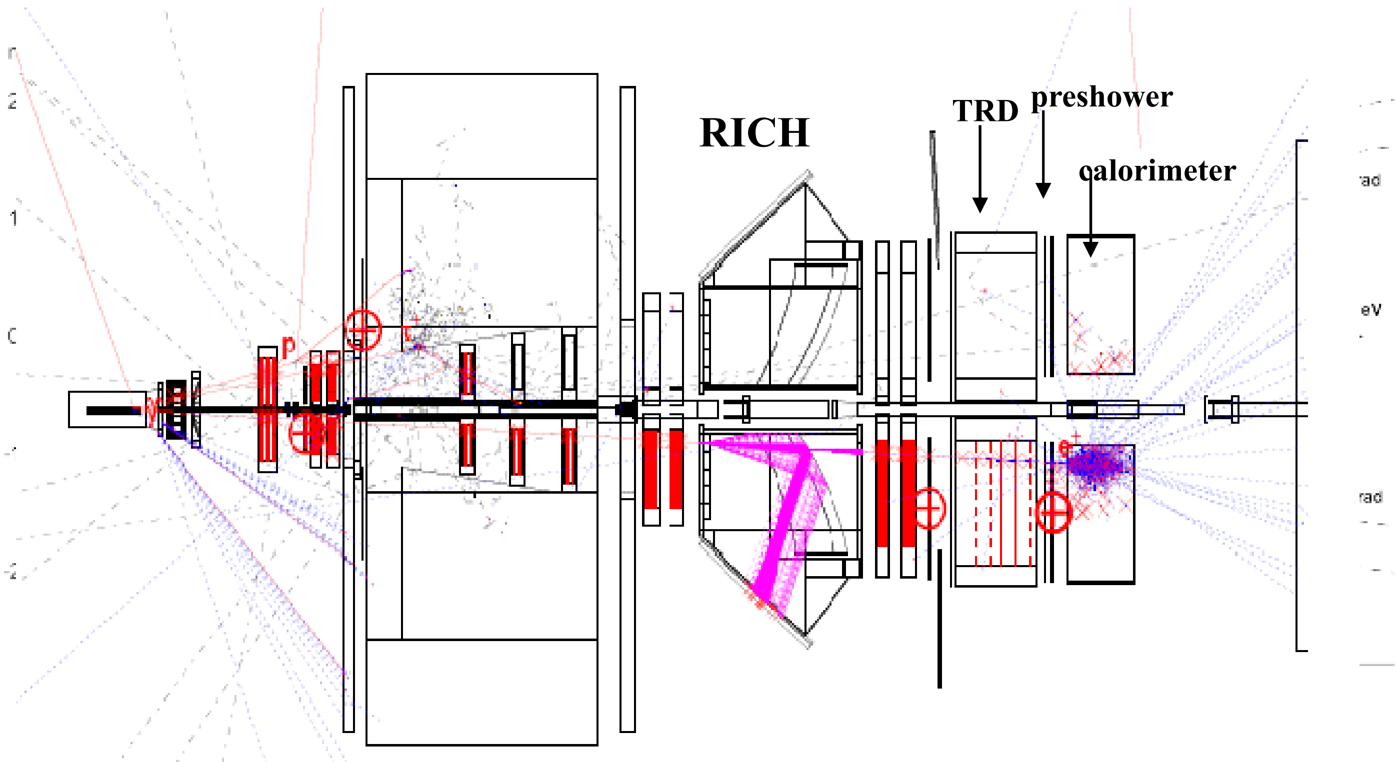
CEBAF
Large
Acceptance
Spectrometer

- **Add the upgrade**

HERA experiments



Hermes @ DESY



10 countries
30 institutions

- resolution: $\delta p/p \sim 2\%$, $\delta\theta < 1$ mrad
- particle ID: lepton ID with $\varepsilon \sim 98\%$, hadron contamination <1%

RICH: π, K, p ID within $2 < E_h < 15$ GeV

Lumi $\sim 10^{32} cm^{-2} sec^{-1}$

pure nuclear-polarised atomic gas target