Hall B
CLAS12 Physics Program

Latifa Elouadrhiri
Jefferson Lab

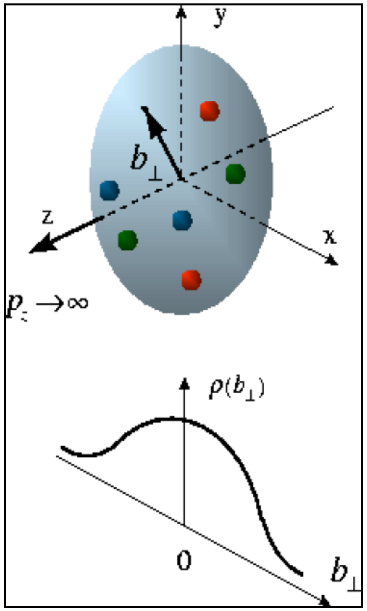
Outline

- Introduction to 12 GeV Upgrade
- CLAS12 Detector
- CLAS12 Science Program
- Summary

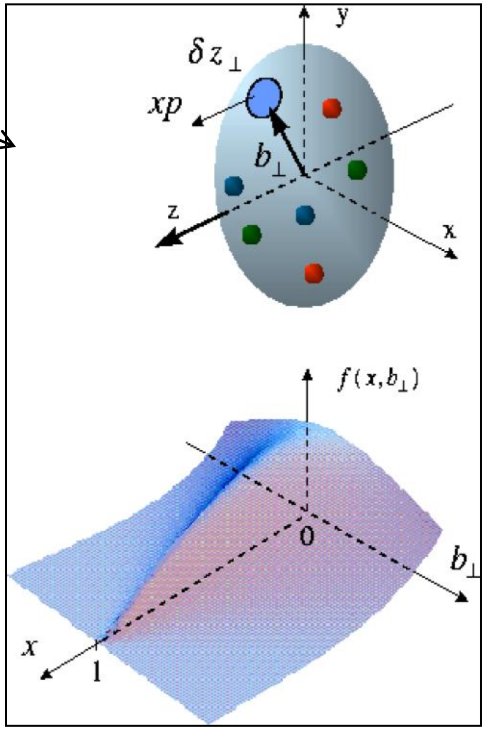
Generalized Parton Distributions (GPDs)

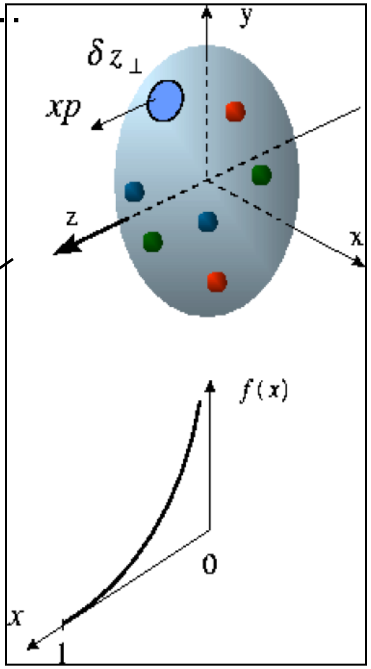
D. Mueller, X. Ji, A. Radyushkin, A. Belitsky, …

GPDs connect the charge and parton distribution



The size and structure of proton.
Proton form factors, **transverse** charge and current distributions
Nobel prize 1961- R. Hofstadter



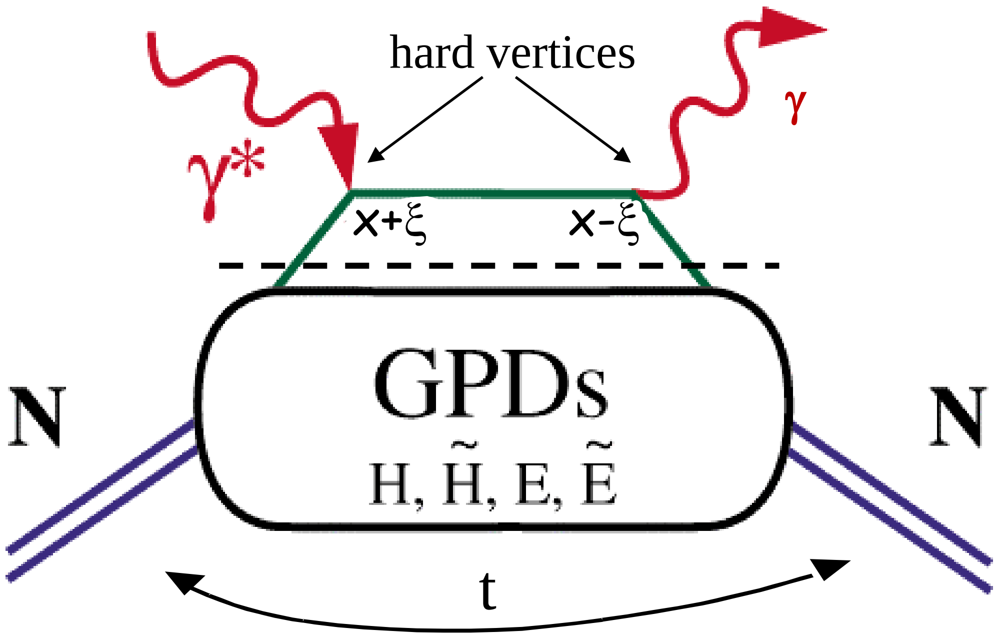


Internal constituents of the nucleon
Quark **longitudinal** momentum and helicity distributions
Nobel prize 1990 - J. Friedman, H. Kendall, R. Taylor

Extend longitudinal quark momentum & helicity distributions
to transverse momentum distributions - TMDs

3 dimensional imaging of the nucleon

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 describe the internal nucleon dynamics.

Link to DIS and Elastic Form Factors

Form factors (sum rules)

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

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

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

DIS at $\xi = t = 0$

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

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

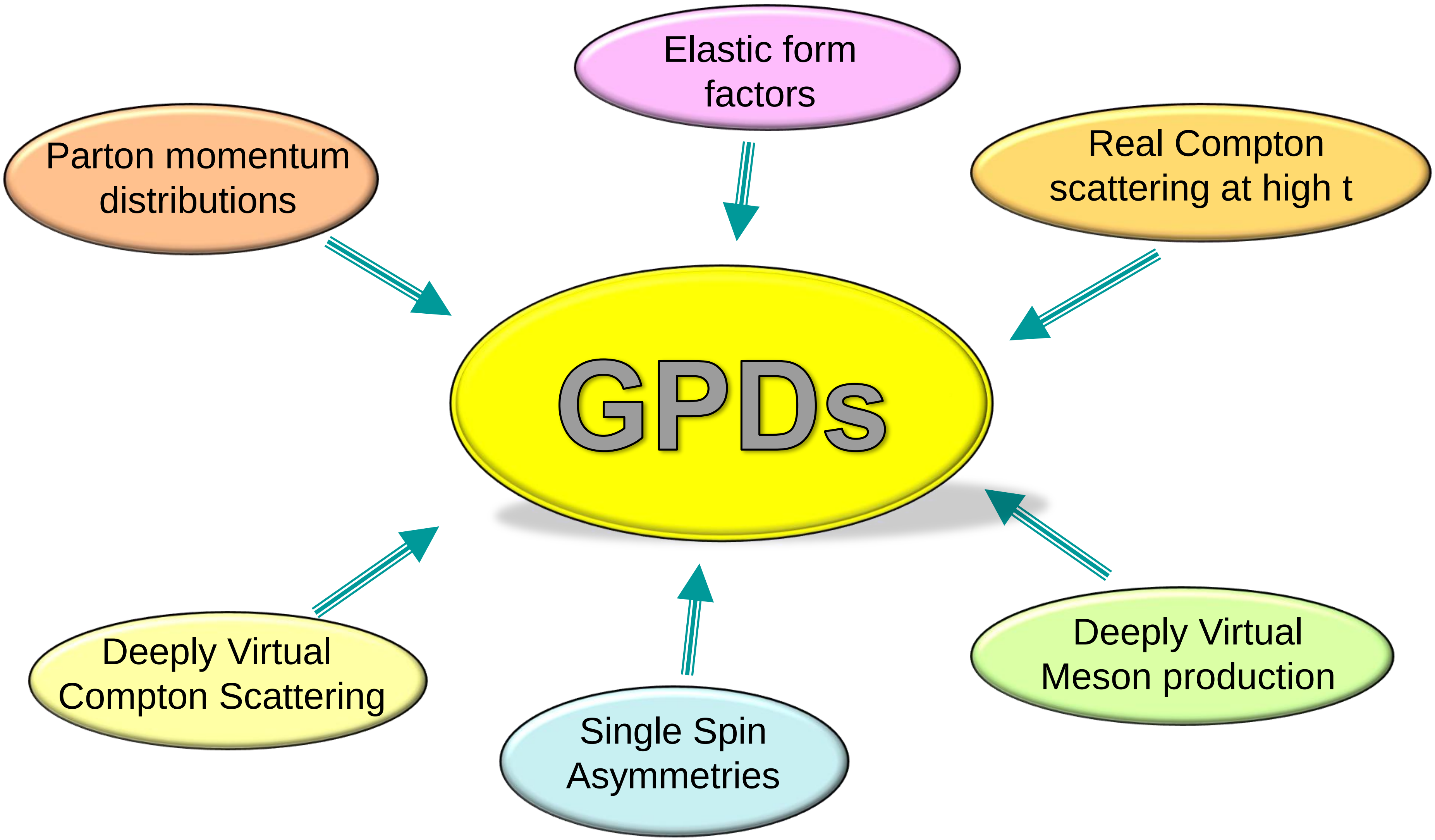
$$H^q, E^q, \tilde{H}^q, \tilde{E}^q(x,\xi,t)$$

Angular Momentum 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)

Universality of GPDs



How can we determine the GPDs?

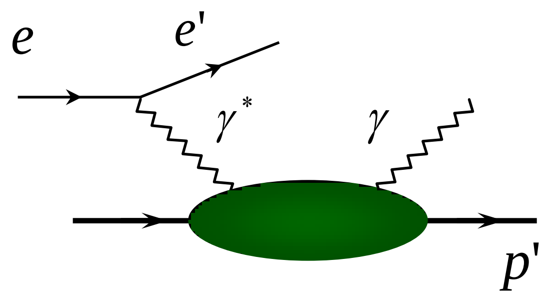
Accessing GPDs in Exclusive Processes

- Deeply virtual Compton scattering (clean probe, flavor blind)

$ep \to e'\,p'\,\gamma$ — *Sensitive to all GPDs.*

$ep \to e'\,p'\,L^+L^-$ — *Insensitive to quark flavor*

$\ldots$

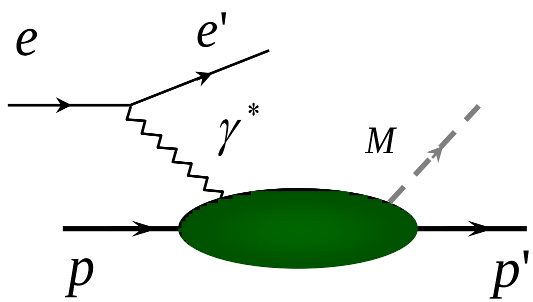


- Hard exclusive meson production (quark flavor filter)

$ep \to e'\,p'\,\pi$ — *Sensitive to* $\tilde{H}, \tilde{E}$

$ep \to e'\,p'\,\rho$
$ep \to e'\,p'\,\omega$ } *Sensitive to* H, E

$\ldots$



- 4 GPDs in leading order, 2 flavors (u, d) $\to$ 8 measurements

Measuring GPDs through polarization

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

Polarized beam, unpolarized target:

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

Kinematically suppressed

→ H

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

$k = t/4M^2$

Unpolarized beam, longitudinal target:

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

Kinematically suppressed

→ $\tilde{H}$

Unpolarized beam, transverse target:

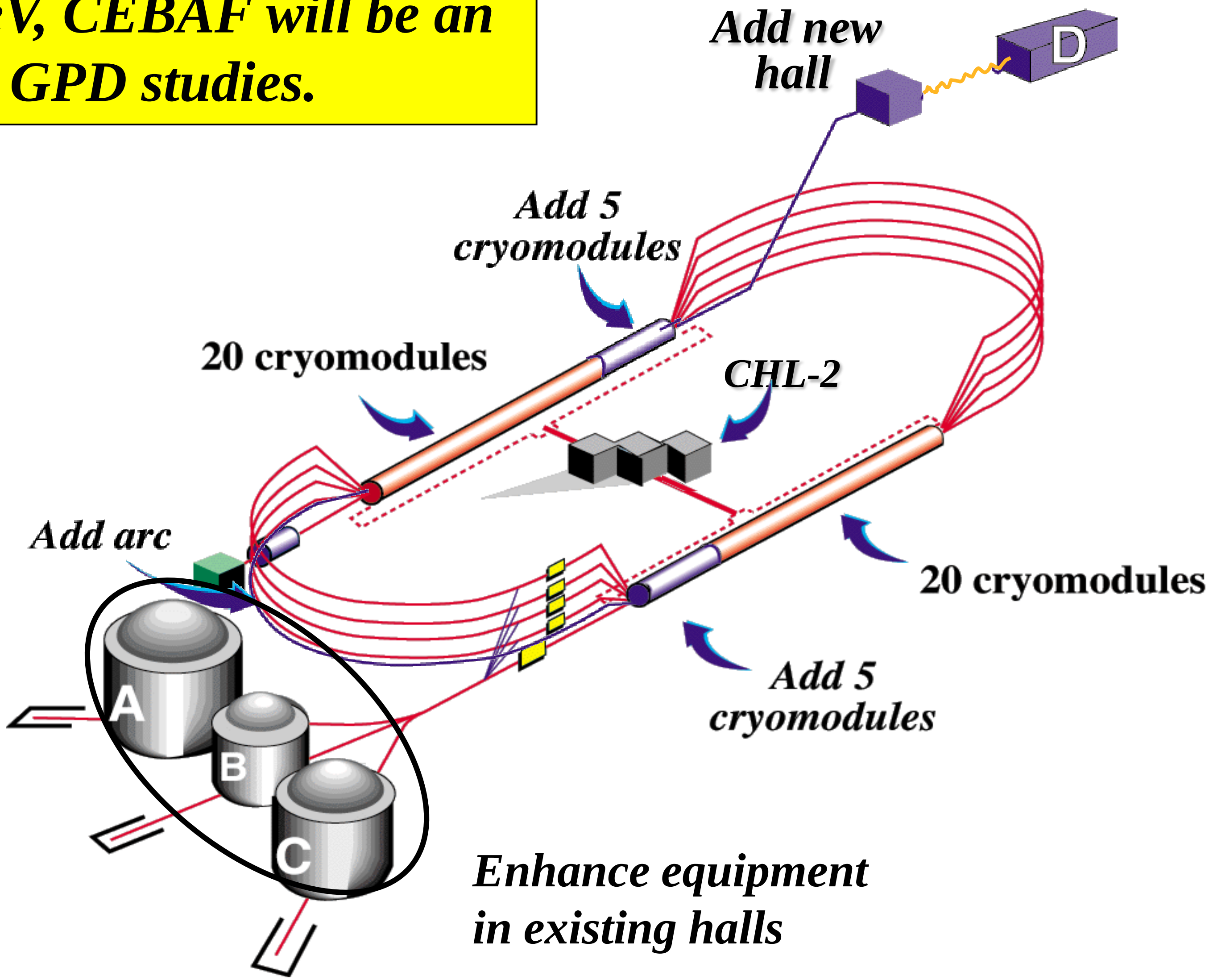
$$\Delta\sigma_{UT} \sim \sin\phi \, \mathrm{Im}\{k(F_2 H - F_1 E) + \ldots.. \} d\phi$$

Kinematically suppressed

→ H, E

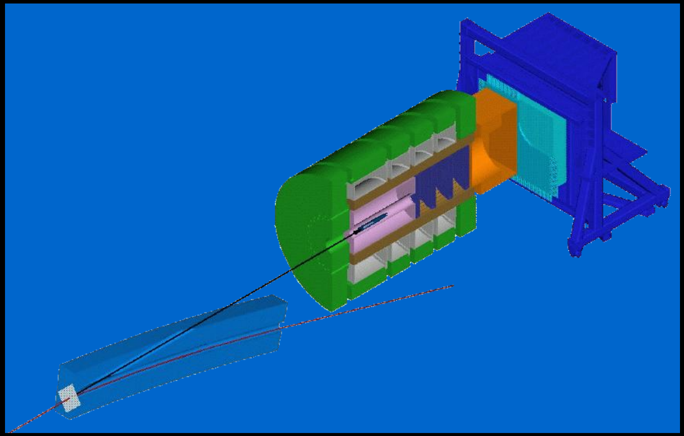
JLab Upgrade to 12 GeV

At 12 GeV, CEBAF will be an ideal for GPD studies.



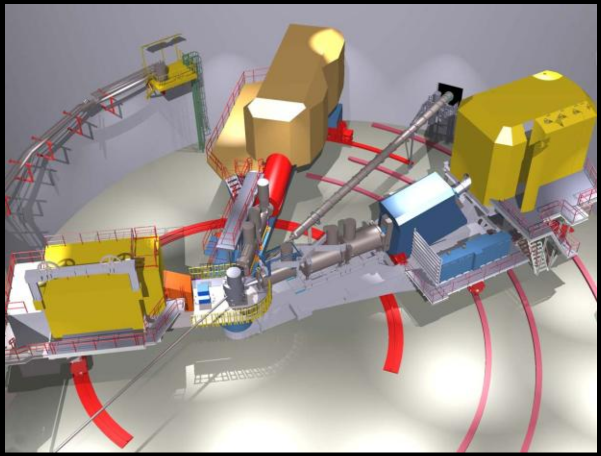
New Capabilities in Halls A, B, & C, and a New Hall D

D



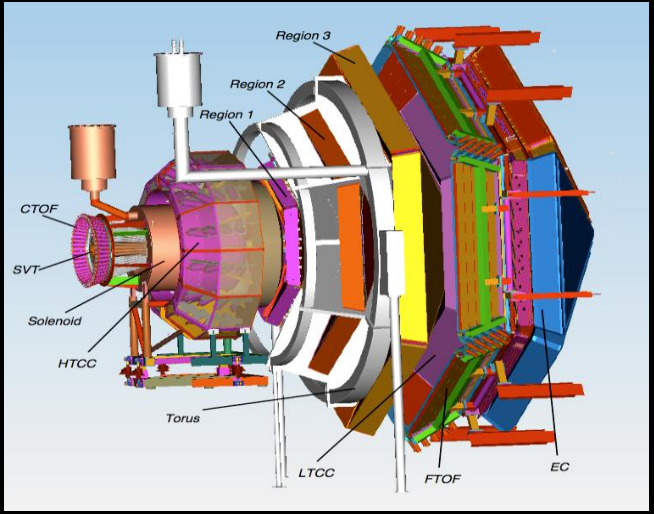
9 GeV tagged polarized photons and a 4π hermetic detector

C



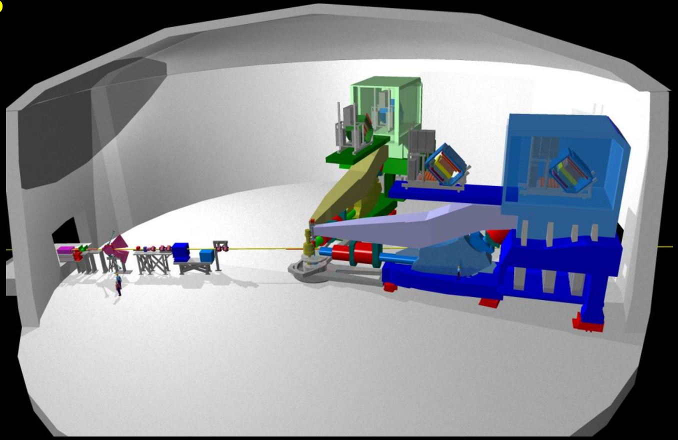
Super High Momentum Spectrometer (SHMS) at high luminosity and forward angles

B



CLAS12 high luminosity, large acceptance.

A



High Resolution Spectrometer (HRS) Pair, and specialized large installation experiments

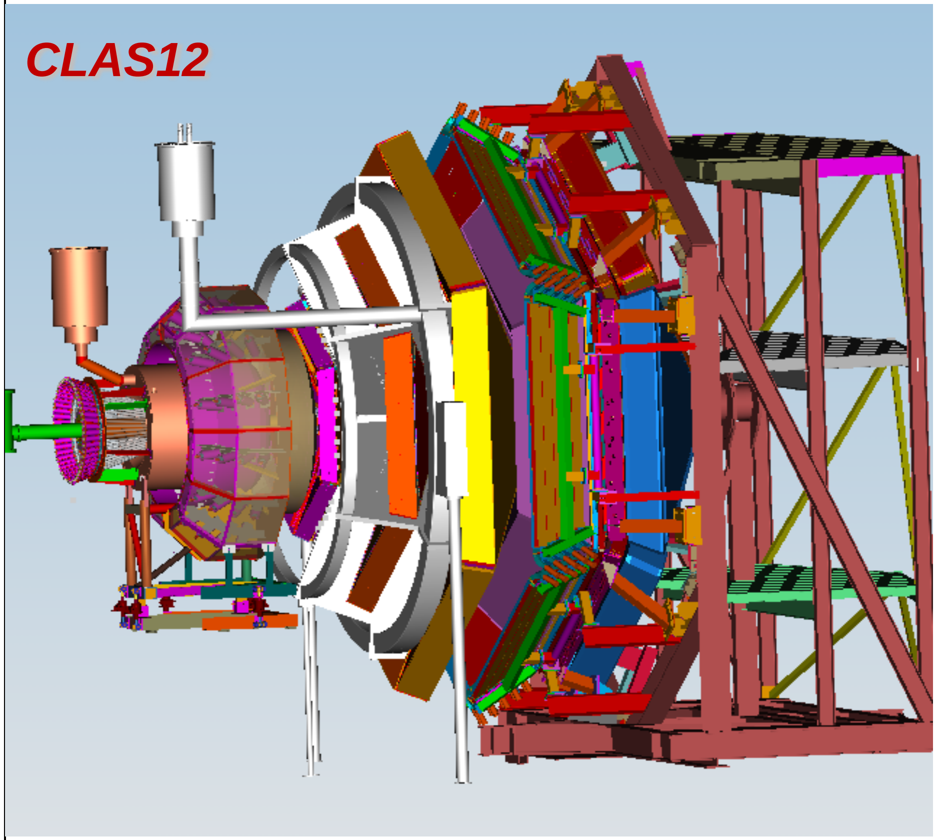
Hall B 12GeV upgrade overview

Hall B currently houses the **C**EBAF **L**arge **A**cceptance **S**pectrometer (**CLAS**) **L=10^{34} cm^{-2}s^{-1}**

CLAS will be replaced by ***CLAS12***

CLAS12 is designed to operate with an upgraded luminosity of **L=10^{35} cm^{-2}s^{-1}**

CLAS12 will be world wide the only **large acceptance high luminosity spectrometer** for fixed target electron scattering experiments



CLAS12

Forward Detector:

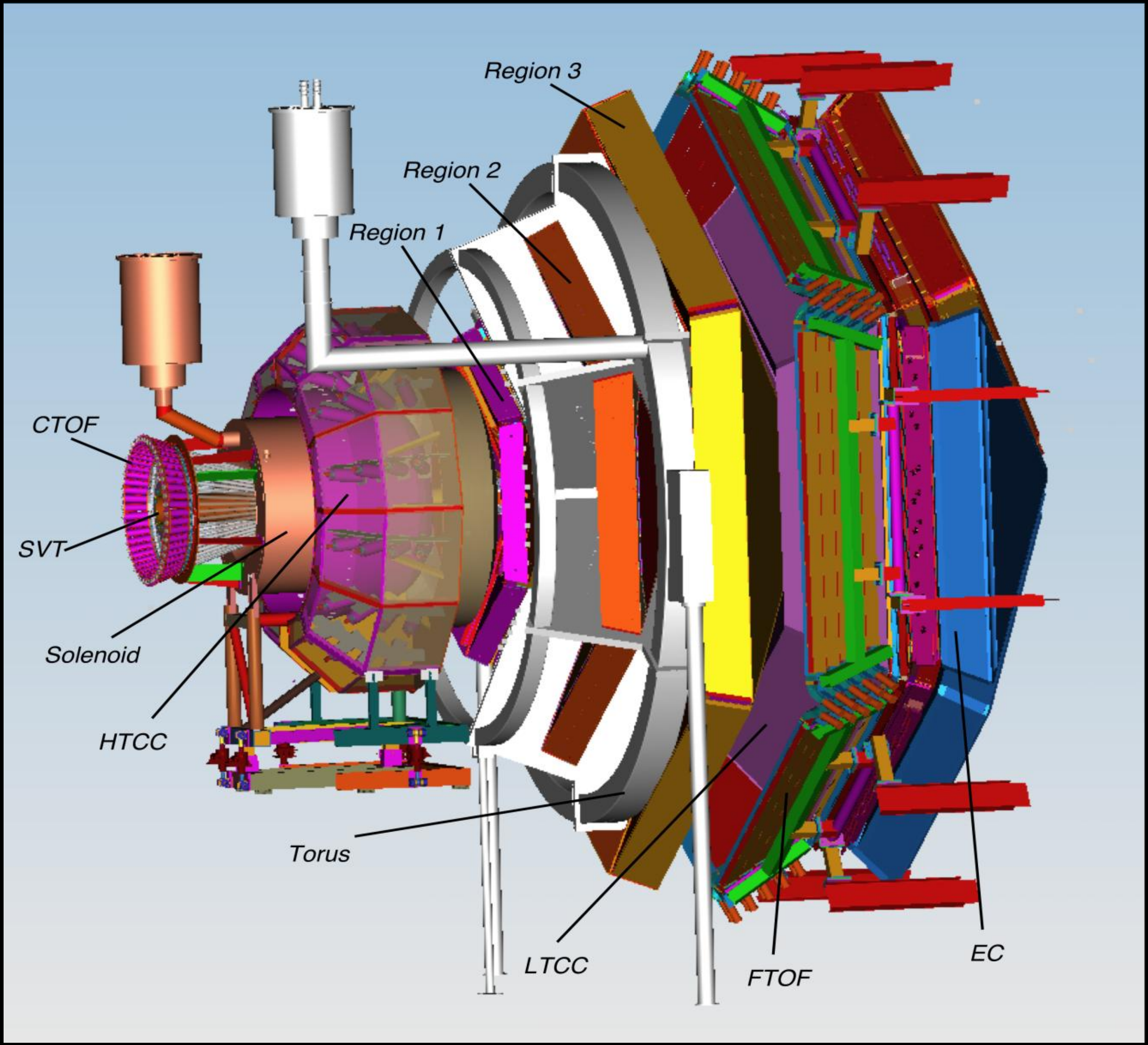
- *TORUS magnet*
- *Forward SVT tracker*
- *HT Cherenkov Counter*
- *Drift chamber system*
- *LT Cherenkov Counter*
- *Forward ToF System*
- *Preshower calorimeter*
- *E.M. calorimeter (EC)*

Central Detector:

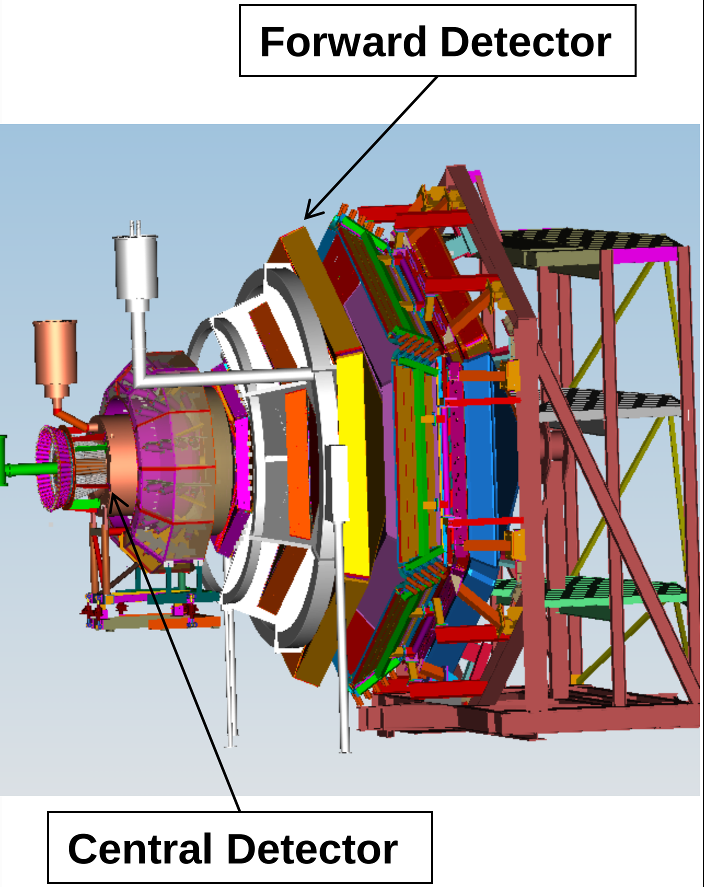
- *SOLENOID magnet*
- *Barrel Silicon Tracker*
- *Central Time-of-Flight*

Proposed upgrades:

- *Micromegas (CD)*
- *Neutron detector (CD)*
- *RICH detector (FD)*
- *Forward Tagger (FD)*

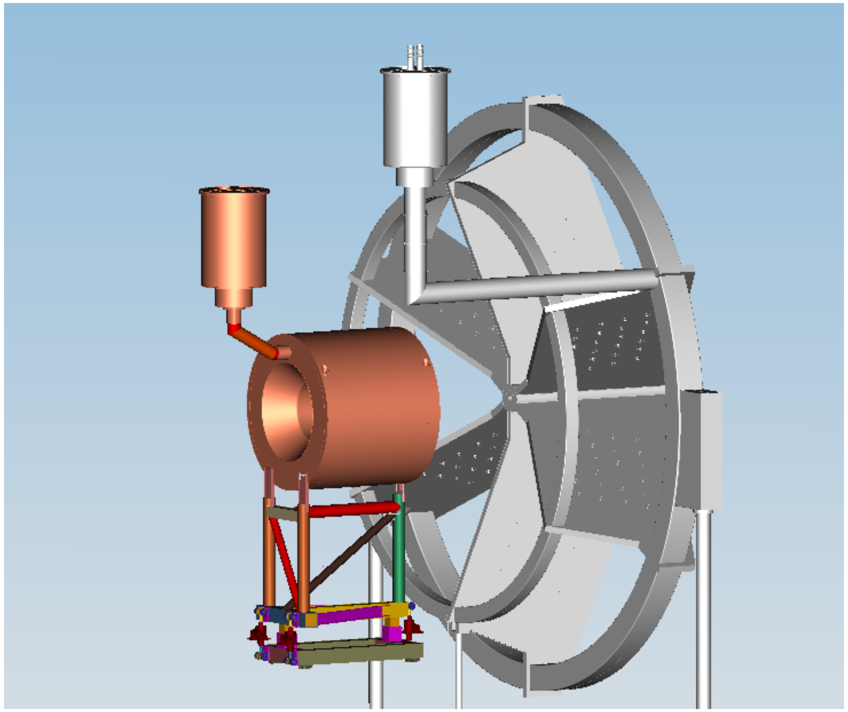


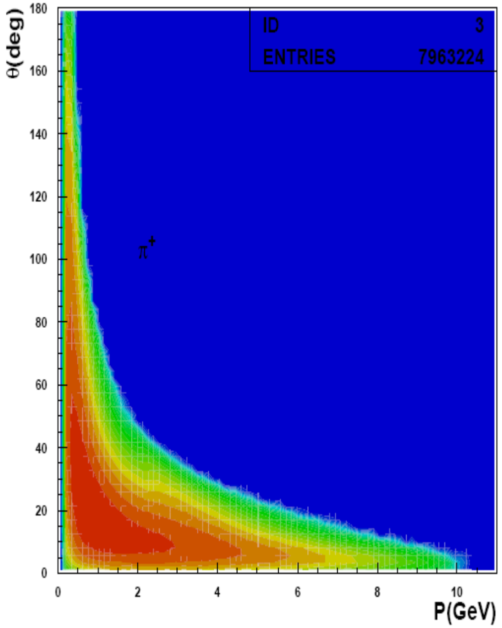
CLAS12 – Design parameters

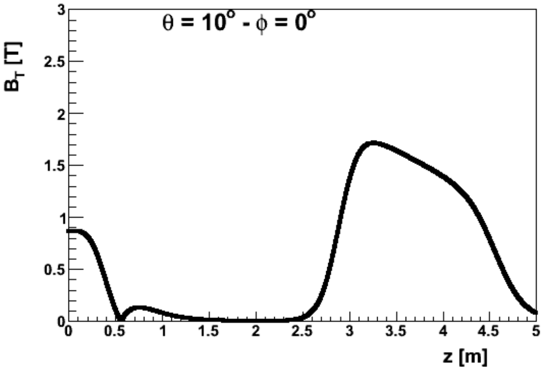


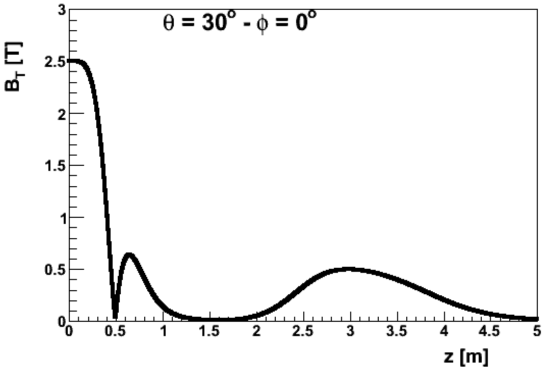
	Forward Detector	Central Detector
Angular range		
Tracks	$5^0 – 40^0$	$35^0 – 125^0$
Photons	$3^0 – 40^0$	n.a.
Resolution		
$\delta p/p$ (%)	< 1 @ 5 GeV/c	< 5 @ 1.5 GeV/c
$\delta\theta$ (mr)	< 1	< 10 - 20
$\Delta\phi$ (mr)	< 3	< 5
Photon detection		
Energy (MeV)	>150	n.a.
$\delta\theta$ (mr)	<4 @ 1 GeV	n.a.
Neutron detection efficiency	< 0.7 (EC+PCAL)	n.a.
Particle ID		
e/π	Full range	n.a.
π/p	Full range	< 1.25 GeV/c
π/K	Full range	< 0.65 GeV/c
K/p	< 4 GeV/c	< 1.0 GeV/c
$\pi^0 \to \gamma\gamma$	Full range	n.a.
$\eta \to \gamma\gamma$	Full range	n.a.

CLAS12 – Solenoid and Torus





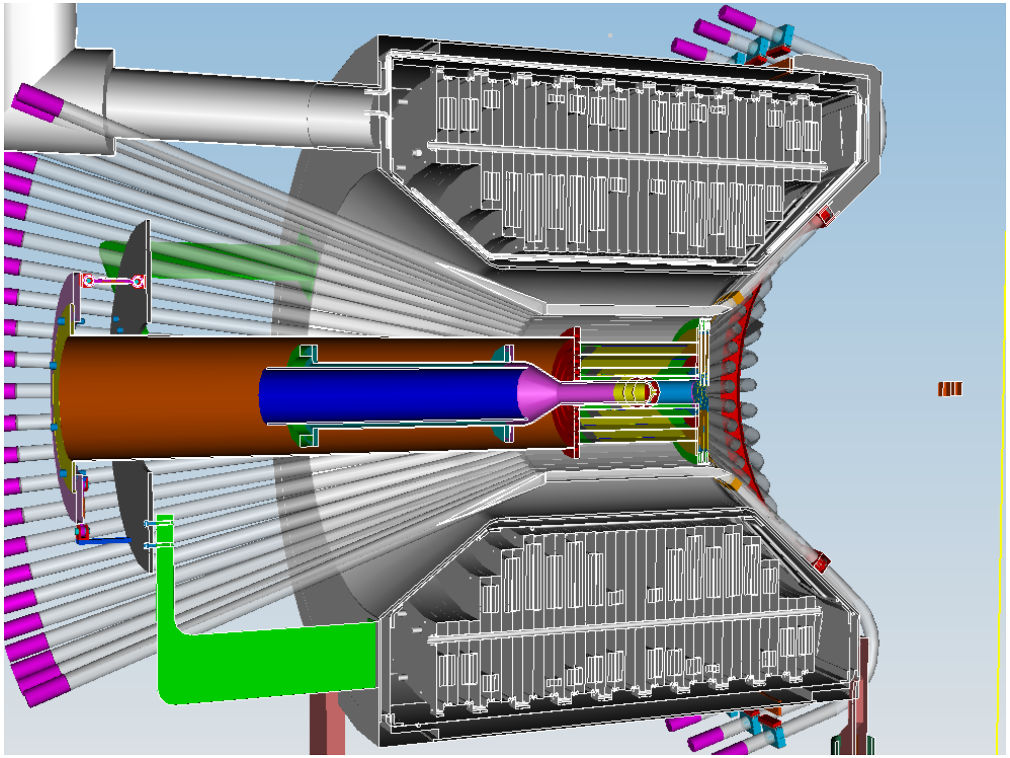


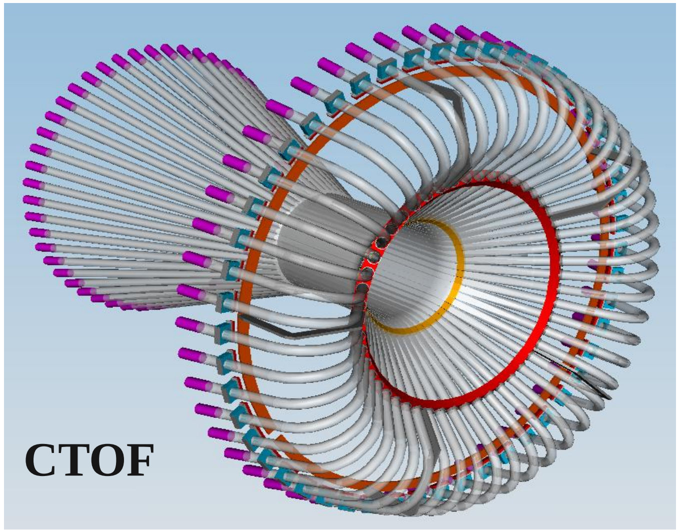


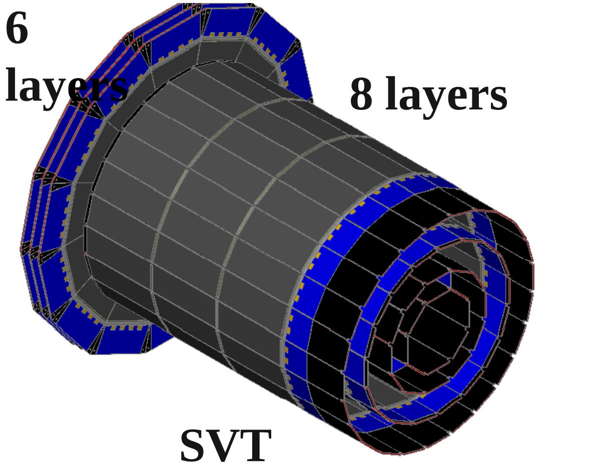
The B-field transverse to the particle trajectory is approximately matched to the average particle momentum.

CLAS12 – Central Detector SVT, CTOF

- SVT - Charged particle tracking in 5T field
- Vertex reconstruction
- $\Delta T < 60$psec in CTOF for particle id
- Moller electron shield
- Polarized target operation $\Delta B/B < 10^{-4}$ in 3x5 cm cylinder around center

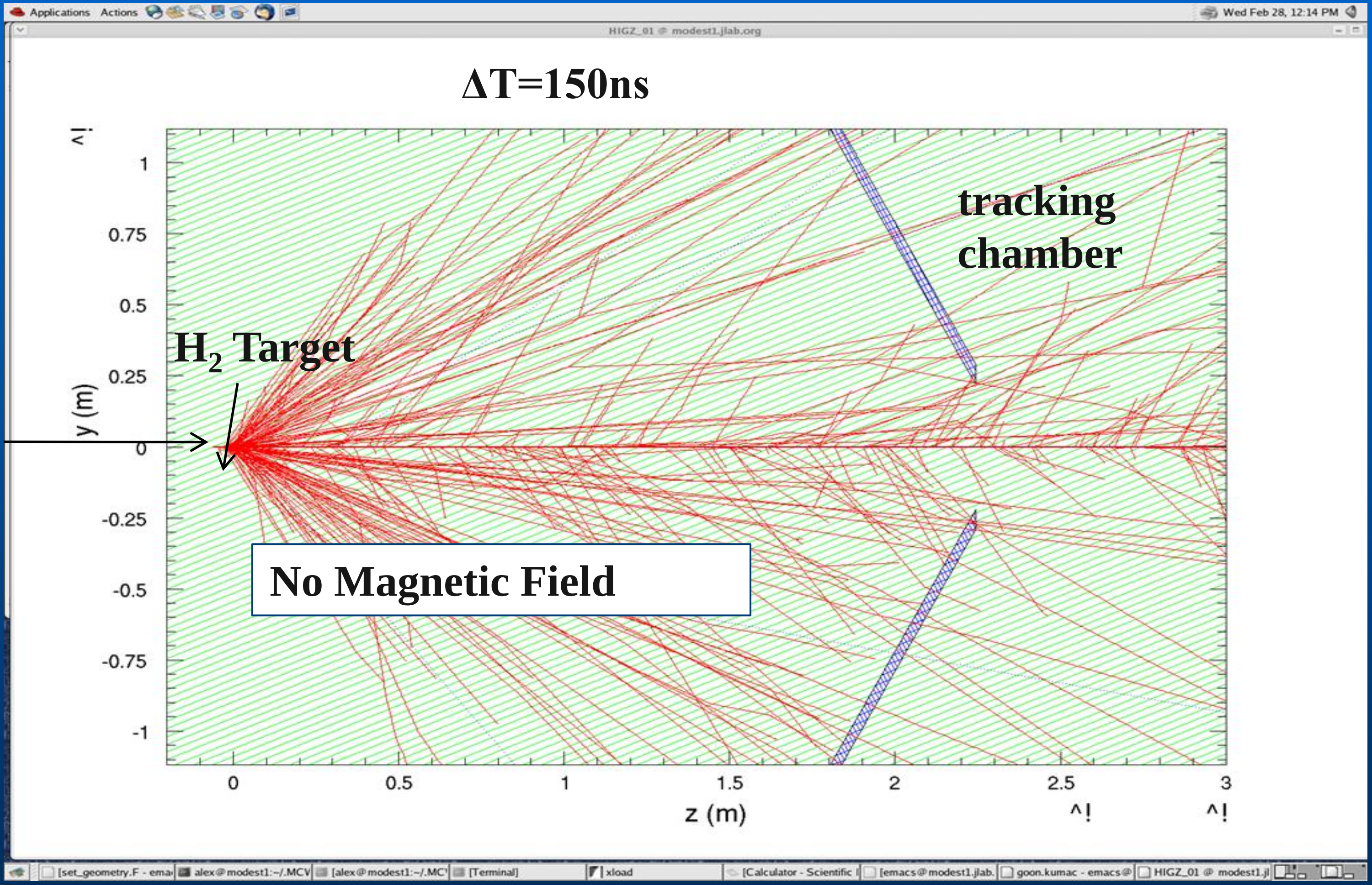






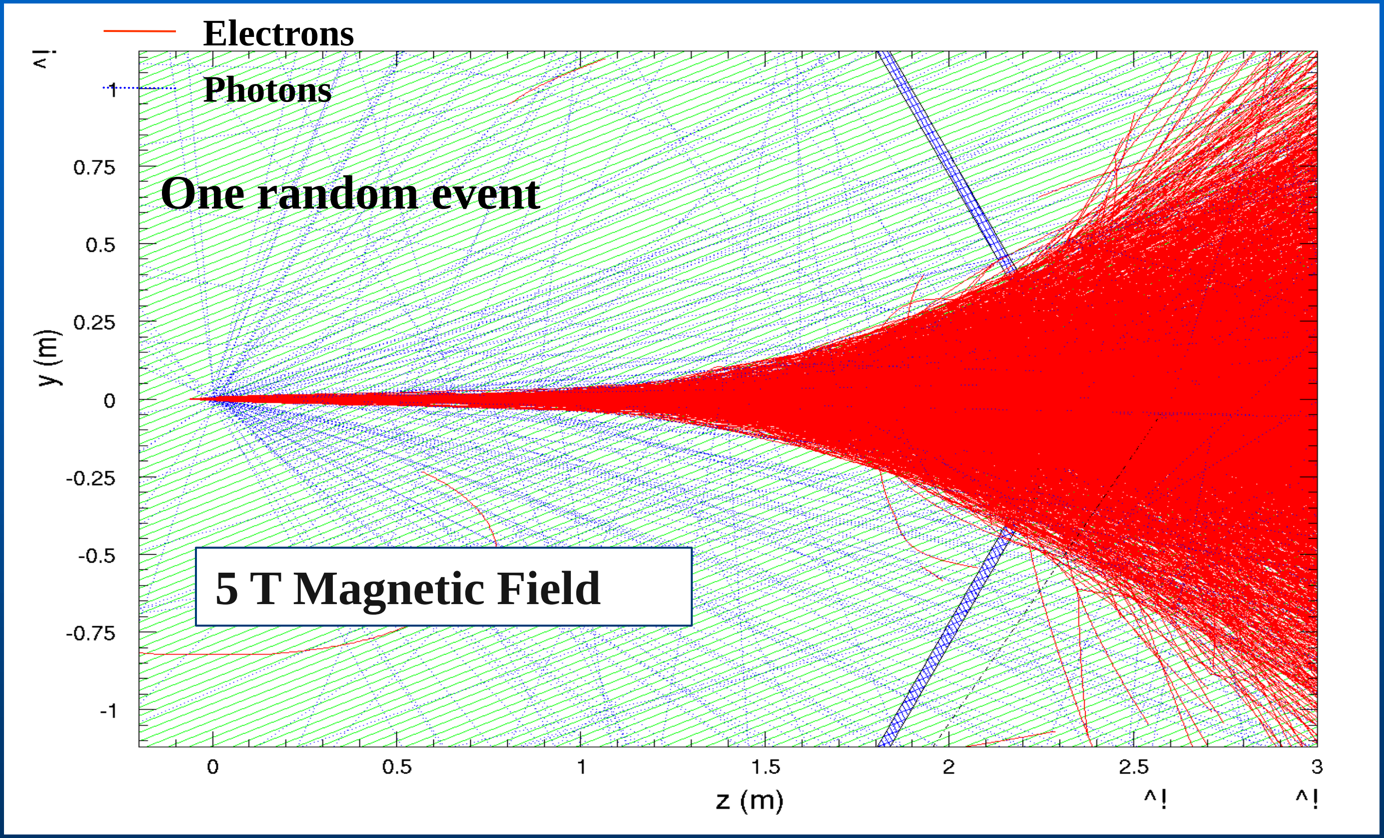
CLAS12 Background Shielding

Background at $L=10^{32}cm^{-2}s^{-1}$, ΔT = 150ns



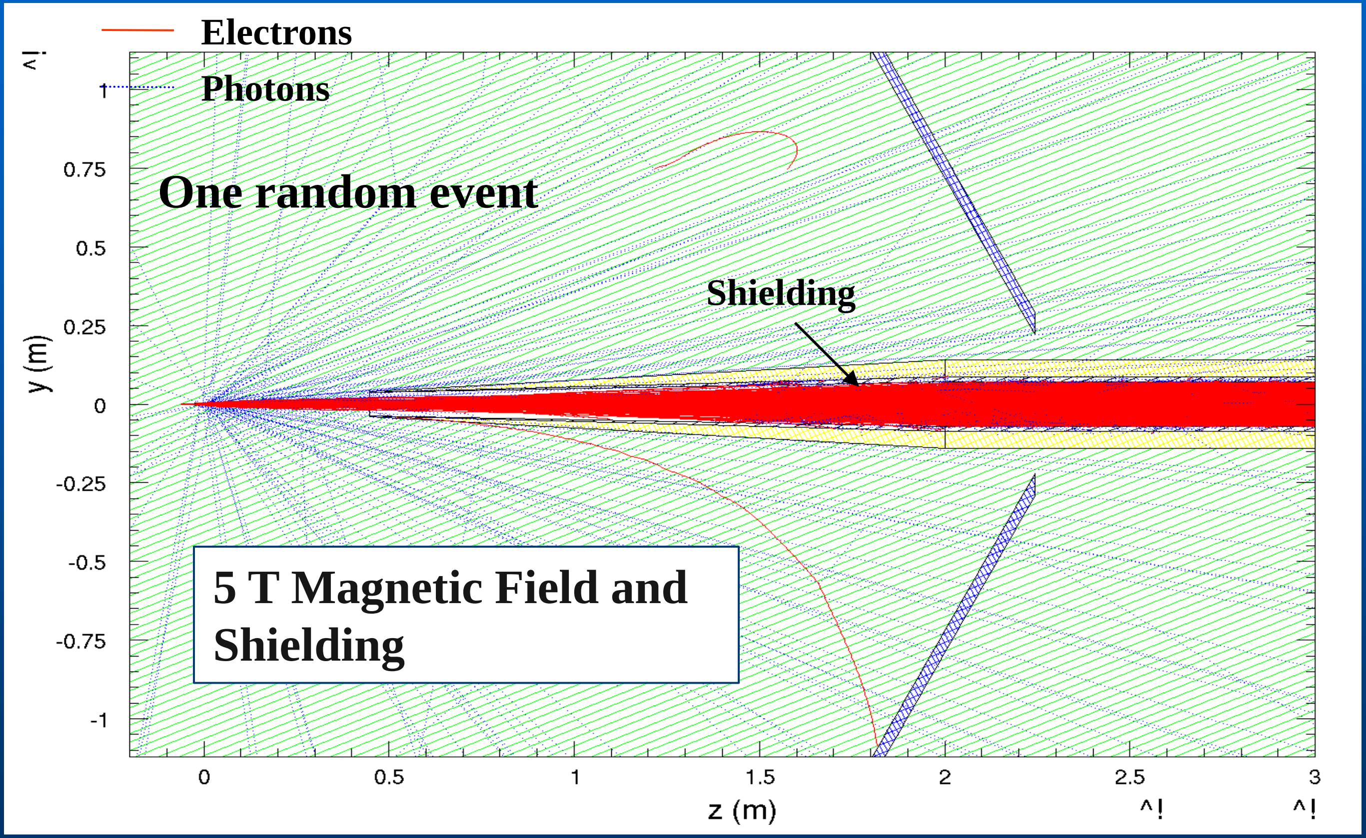
CLAS12 **Background Shielding**

Background at $L=10^{35} cm^{-2}s^{-1}$, ΔT = 150ns



CLAS12 Background Shielding

Background at $L=10^{35}cm^{-2}s^{-1}$, ΔT = 150ns



A Program at the Forefront of Hadron Physics

- 3D Structure of the Nucleon Structure - the new Frontier in Hadron Physics
- Nucleon GPDs and TMDs – exclusive and semi-inclusive processes with high precision
- Precision measurements of structure functions and forward parton distributions at high x_B
- Elastic & Transition Form Factors at high momentum transfer

CLAS12 Initial Science Program

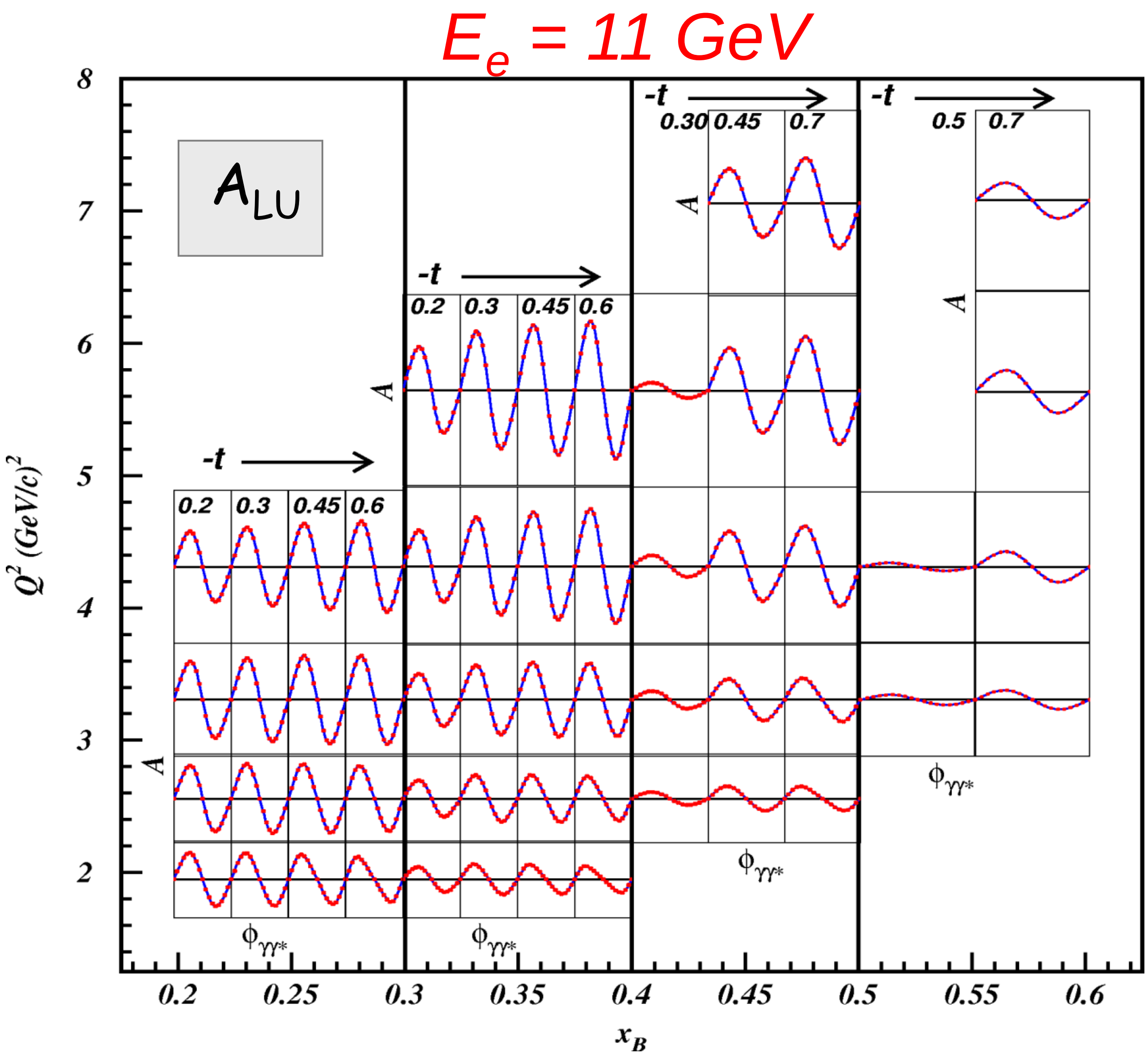
Physics Focus	Approved experiments	LOIs supported
GPD's & exclusive Processes	3	1
TMDs & SIDIS	4	4
Parton Distribution Function & DIS	2	1
Elastic & resonance form factors	2	
Hadronization & Color Transparency	2	
Baryon Spectroscopy		1
Total	13	7

Approved experiments correspond to about 5 years of scheduled beam operation .

CLAS12 Institutions

Institution	Focus Area
Argonne National Laboratory (US)	Cerenkov Counter
California State University (US)	Cerenkov Counters
Catholic University of America (US)	Software
College of William & Mary (US)	Calorimetry, Magnet Mapping
Edinburgh University (UK)	Software
Fairfield University (US)	Polarized Target
Florida International University, Miami (US)	Beamline/Moller polarimeter
Glasgow University (UK)	Central Detector, DAQ, Forward Tagger, RICH
Grenoble University/IN2P3 (France)	Central Detector
Idaho State University (US)	Drift chambers
INFN –University Bari (Italy)	tbd, interest in RICH
INFN –University Catania (Italy)	tbd
INFN – Frascati and Fermi Center (Italy)	Central Neutron Detector+ interest show in RICH
INFN –University Ferrara (Italy) (will join in 2010)	tbd, interest in RICH
INFN – University Genoa (Italy)	Central Neutron Detector+ interest in Forward Tagger
INFN – ISS/Rome 1 (Italy)	tbd, interest in RICH
INFN – University of Rome Tor Vergata (Italy)	Central Neutron Detector+ HD target
Institute of Theoretical and Experimental Physics (Russia)	SC. Magnets, Simulations
James Madison University (US)	Calorimetry
Kyungpook National University (Republic of Korea)	CD TOF
Los Alamos National Laboratory (US)	Silicon Tracker
Moscow State University, Skobeltsin Institute for Nuclear Physics (Russia)	Software, SVT
Moscow State University (High Energy Physics) (Russia)	Silicon Tracker
Norfolk State University (US)	Preshower Calorimeter
Ohio University (US)	Preshower Calorimeter
Orsay University/IN2P3 (France)	Central Neutron Detector
Old Dominion University (US)	Drift Chambers
Renselear Polytechnic Institute (US)	Cerenkov Counters
CEA Saclay (France)	Central Tracker, Reconstruction software
Temple University, Philadelphia (US)	Cerenkov Counters
Thomas Jefferson National Accelerator Facility (US)	Project coordination & oversight
University of Connecticut (US)	Cerenkov Counters
University of New Hampshire (US)	Central Tracker, Offline Software
University of Richmond (US)	Offline Software
University of South Carolina (US)	Forward TOF
University of Virginia (US)	Beamline/Polarized Targets
Yerevan Physics Institute (Armenia)	Calorimetry

DVCS/BH- Beam Asymmetry



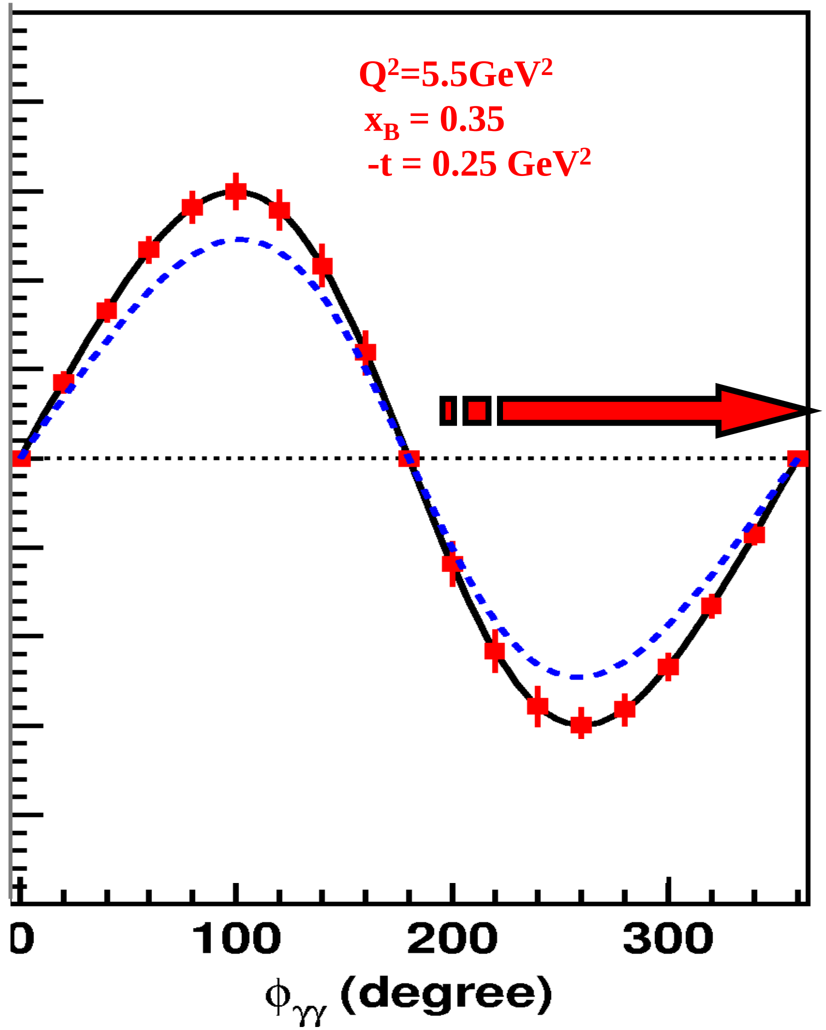
With large acceptance, measure large Q^2, x_B, t ranges simultaneously.

$A(Q^2,x_B,t)$
$\Delta\sigma(Q^2,x_B,t)$
$\sigma\ (Q^2,x_B,t)$

CLAS12 - DVCS/BH- Beam Asymmetry

E_e = 11 GeV

Luminosity = 720fb^{-1}



CLAS12 - DVCS/BH Beam Asymmetry

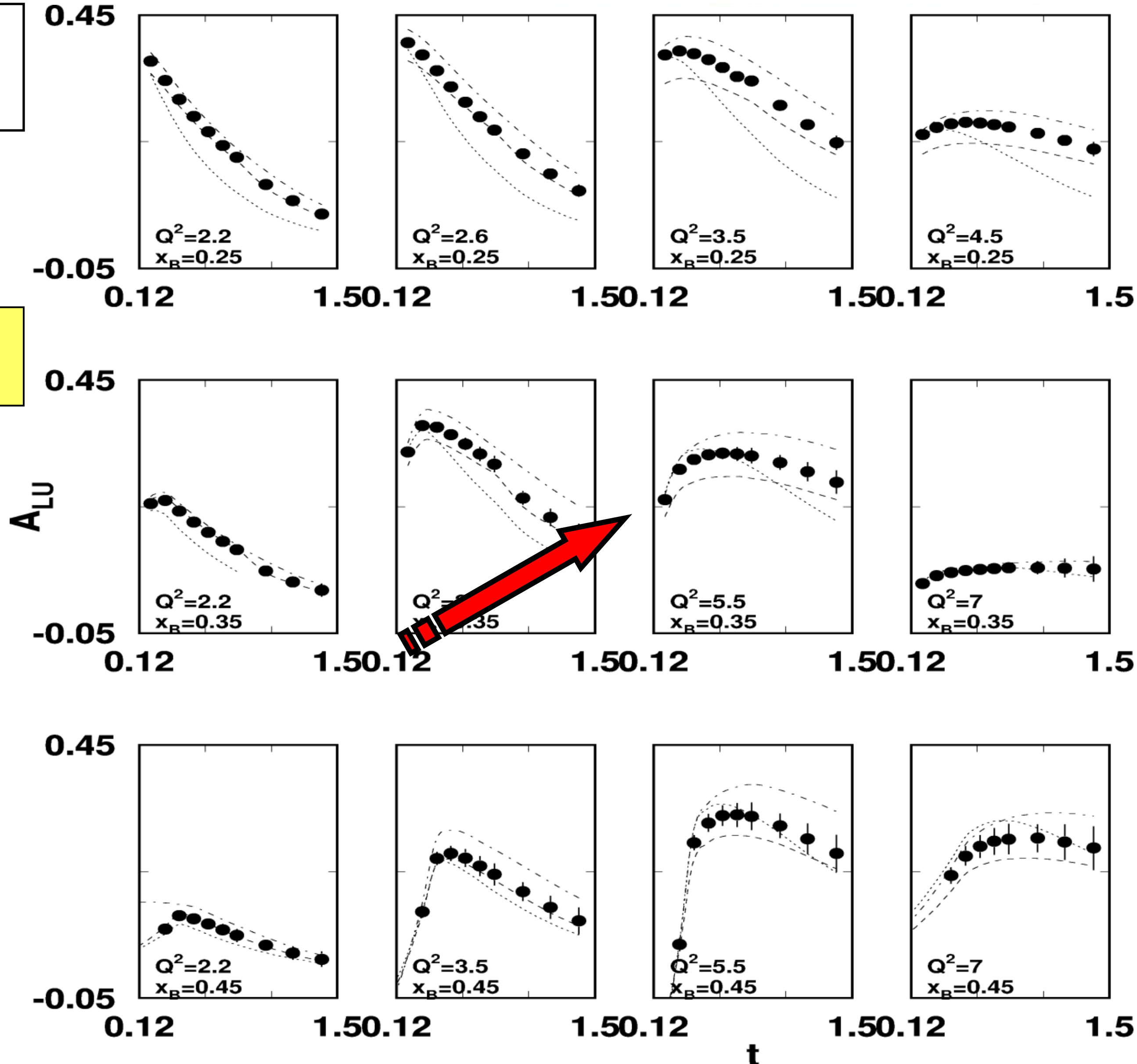
$\vec{e}p \longrightarrow ep\gamma$

E = 11 GeV

$\Delta\sigma_{LU} \sim \sin\phi \, \mathrm{Im}\{F_1 H + ..\} d\phi$

Selected Kinematics

L = 1x10^35
T = 2000 hrs
$\Delta Q^2 = 1\ GeV^2$
$\Delta x = 0.05$



CLAS12 - DVCS/BH Target Asymmetry

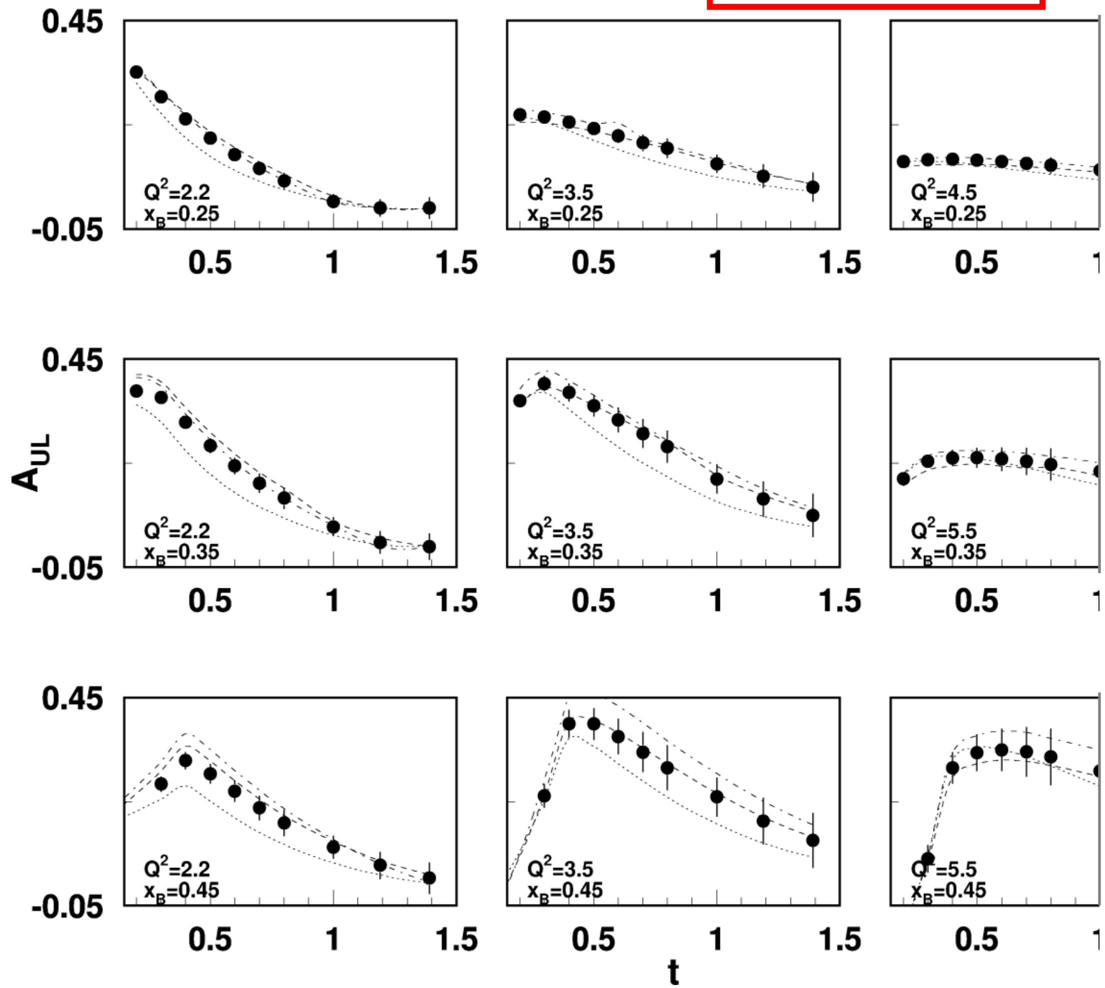
$e\,\vec{p} \longrightarrow e p \gamma$

Longitudinally polarized target

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

E = 11 GeV

$L = 2\times10^{35}\ cm^{-2}s^{-1}$
T = 1000 hrs
$\Delta Q^2 = 1 GeV^2$
$\Delta x = 0.05$



CLAS12 - DVCS/BH Target Asymmetry

$e\,p^{\uparrow} \longrightarrow e p \gamma$

E = 11 GeV

Sample kinematics

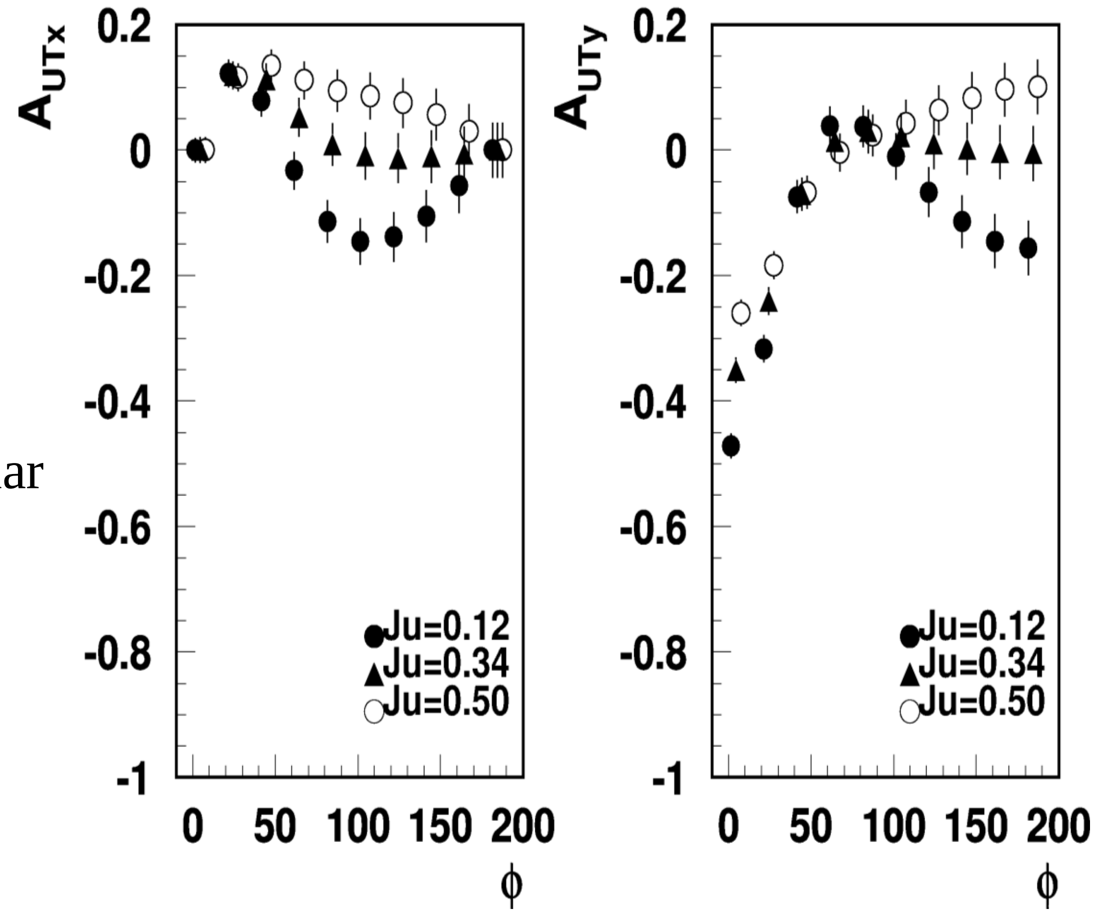
Q^2=2.2 GeV^2, x_B = 0.25, -t = 0.5GeV^2

Transverse polarized target

$\Delta\sigma \sim \sin\phi \mathrm{Im}\{k_1(F_2 H - F_1 E) + \ldots\}d\phi$

A_{UTx} Target polarization in the scattering plane

A_{UTy} Target polarization perpendicular to the scattering plane

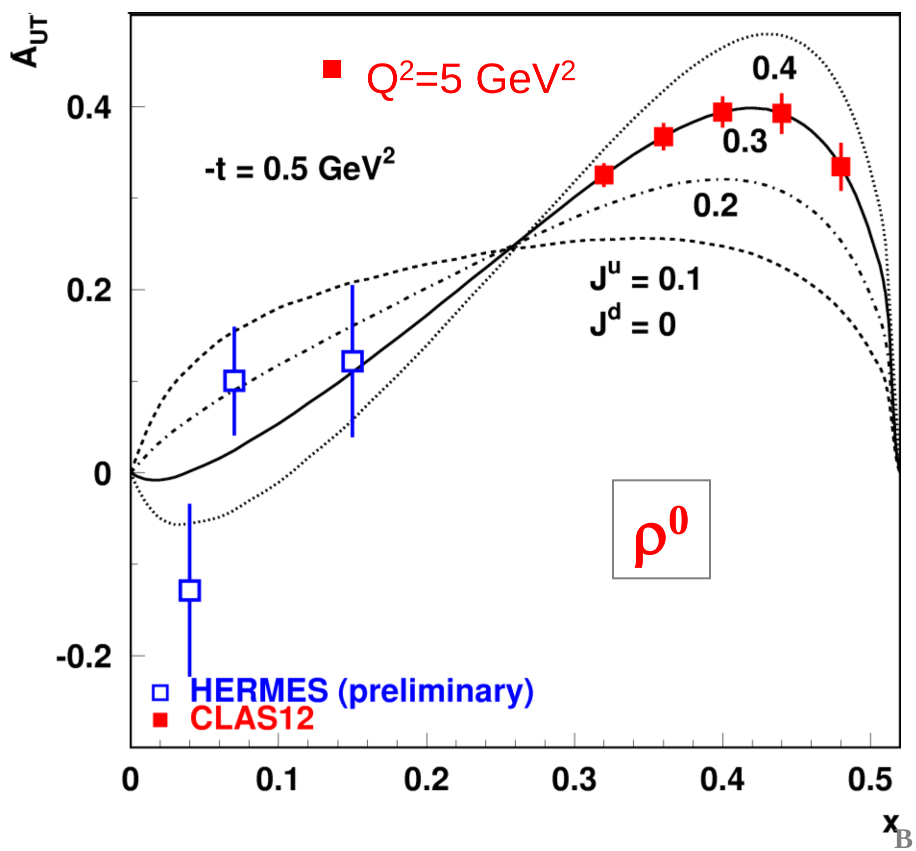


- Asymmetries highly sensitive to the u-quark contributions to the proton spin.

Jefferson Lab

Exclusive ρ^0 production on transverse target

$$A_{UT} \sim 2\Delta_{\perp}(\mathrm{Im}(AB^*))$$



K. Goeke, M.V. Polyakov, M. Vanderhaeghen, 2001

ρ^0

$A \sim 2H^u + H^d$

$B \sim 2E^u + E^d$

ρ^+

$A \sim H^u - H^d$

$B \sim E^u - E^d$

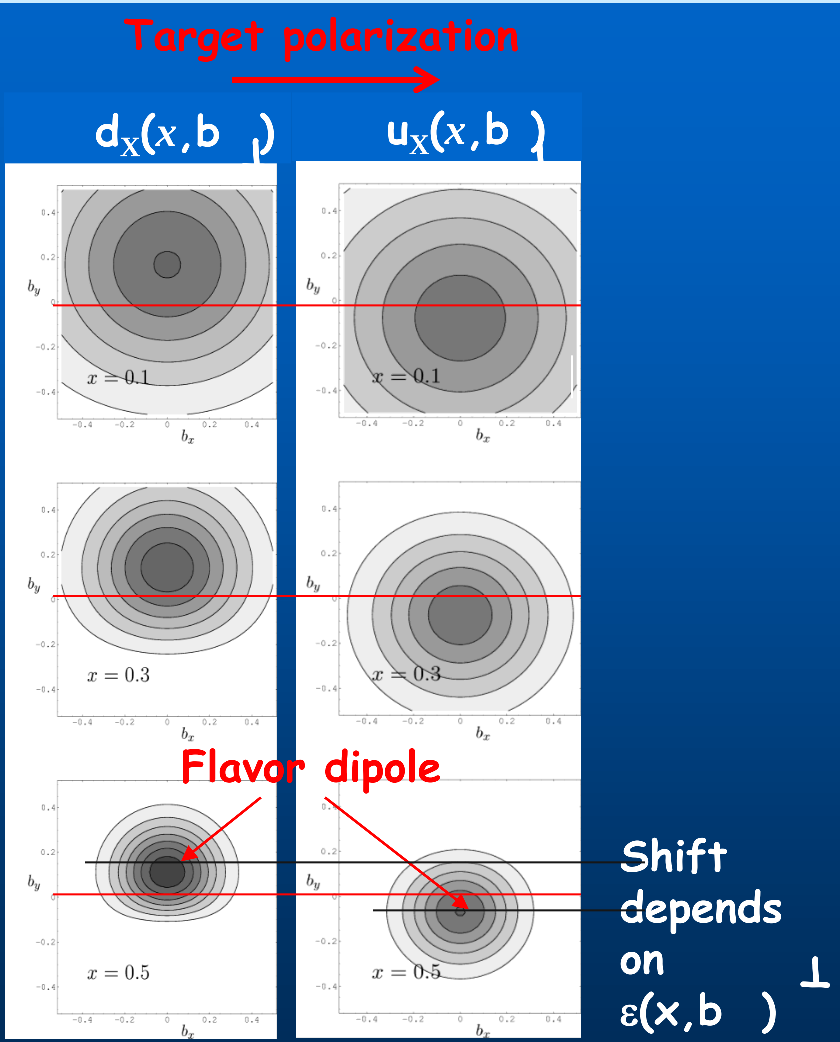
E^u, E^d allow to map the *orbital motion of quarks*.

The Promise of GPDs: 2-D & 3-D Images of the Proton

$$\mathcal{E}(x,b_\perp) = \int \frac{d^2\Delta_\perp}{(2\pi)^2} e^{i\Delta_\perp b_\perp} E_q(x,\Delta_\perp)$$

M. Burkardt

Cat scan of the human brain



CLAS12 Transverse Momentum Distributions

- TMDs are complementary to GPDs in that they allow to construct 3-D images of the nucleon in *momentum* space
- TMDs are connected to orbital angular momentum (OAM) in the nucleon wave function – for a TMD to be non-zero OAM must be present.
- TMDs can be studied in experiments measuring azimuthal asymmetries or moments.
- Several proposals have been accepted by PAC34 that propose to upgrade CLAS12 with Kaon id

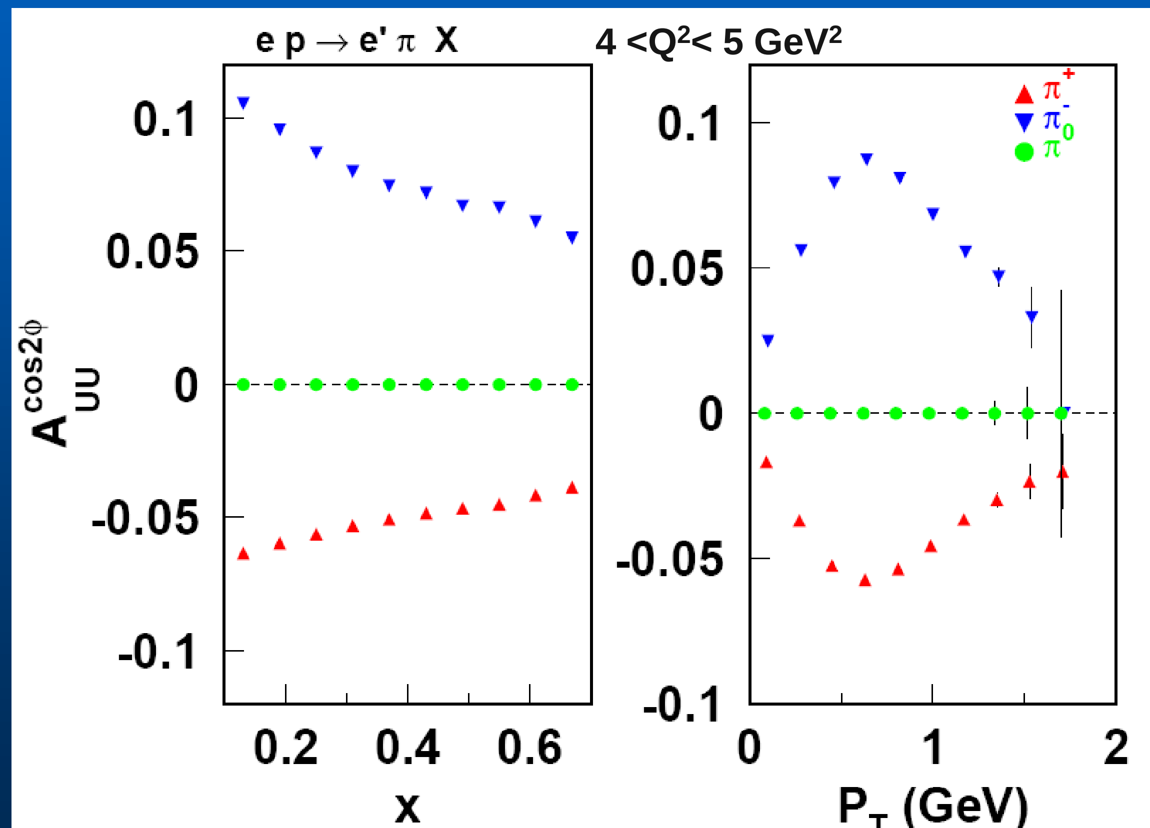
CLAS12 SIDIS on unpolarized protons.

N \ q	U	L	T
U	f_1		$h_1^{\perp}$
L		g_1	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	h_1 $h_{1T}^{\perp}$

In inclusive electroproduction of pions the diff. cross section has an azimuthal modulation.

$$d\sigma/d\Omega = \sigma_T + \varepsilon\sigma_L + \varepsilon\sigma_{TT}\cos 2\Phi + [\varepsilon(1+\varepsilon)]^{1/2}\sigma_{LT}\cos\Phi$$

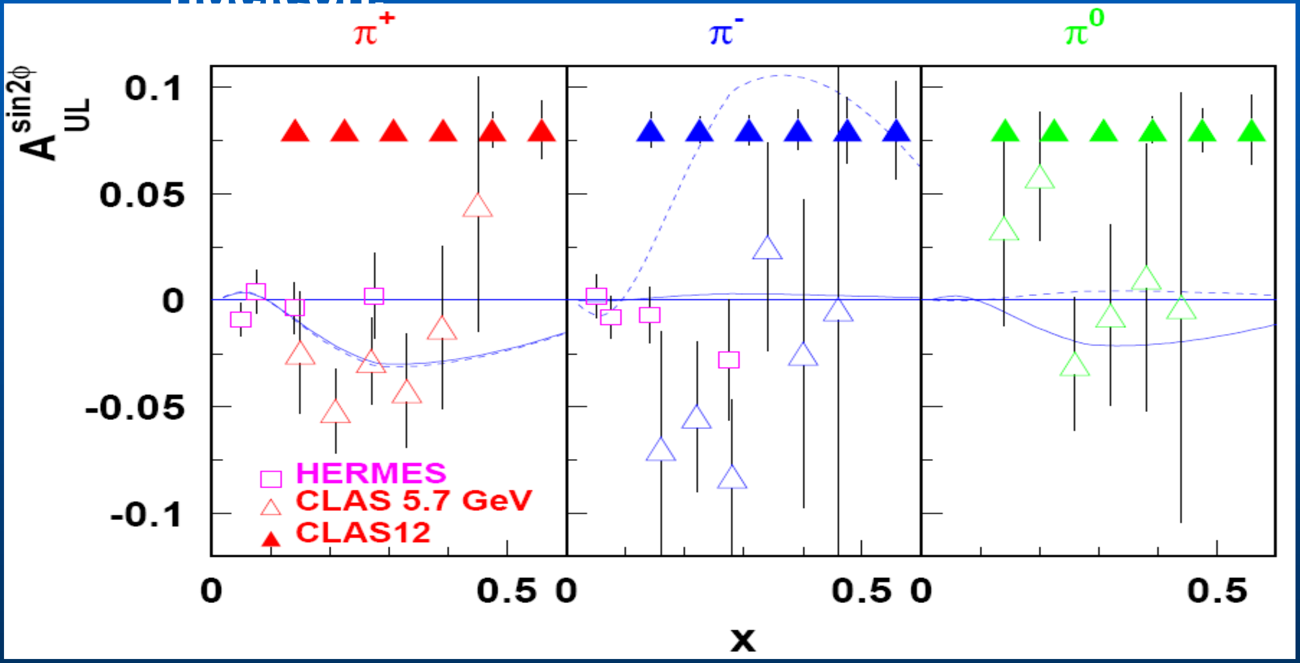
The cos2Φ moment of the azimuthal asymmetry gives access to the Boer-Mulders Function which measures the momentum distribution of transversely polarized quarks in unpolarized nucleons.



CLAS12 SIDIS on Long. Polarized Target

N \ q	U	L	T
U	f_1		$h_1^{\perp}$
L		g_1	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	h_1 $h_{1T}^{\perp}$

The sin2Φ moment gives access to the Kotzinian-Mulders function which measures the momentum distribution of transversely polarized quarks in the longitudinally polarized nucleon.

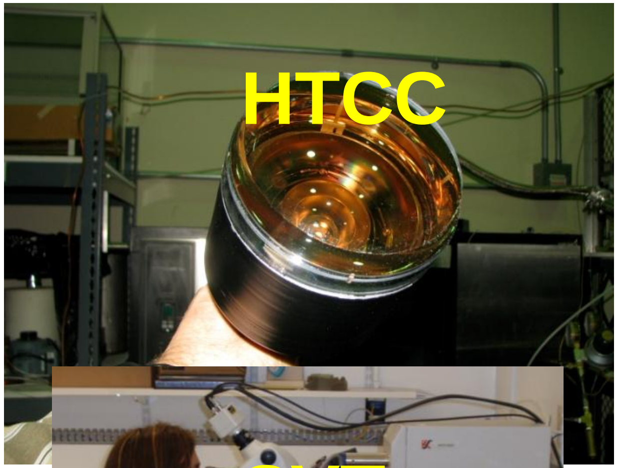


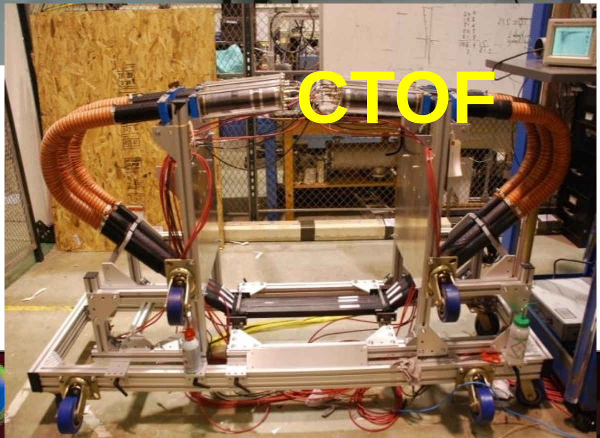
- **The sin2ϕ moment is sensitive to spin-orbit correlations: the only leading twist azimuthal moment for longitudinally polarized target.**

DOE Project Critical Decisions – 12 GeV Schedule

- CD-0 Approve Mission Need (Mar 2004)
- CD-1 Approve Alternative Selection and Cost Range (Feb 2006)
  - Permission to develop a Conceptual Design Report
  - Defines a range of cost, scope, and schedule options
- **CD-2 Approve Performance Baseline (Nov 2007)**
  - **Fixes "baseline" for scope, cost, and schedule**
  - **Now develop design to 100%**
  - **Begin monthly Earned Value progress reporting to DOE**
  - **Permission for DOE-NP to request construction funds**
- **CD-3 Approve Start of Construction**
  - **DOE Office of Science CD-3 Approval: September 15, 2008**
- CD-4 Approve Start of Operations or Project Close-out

CLAS12 In Construction





2007 NSAC Long Range Plan (4 recommendations)

Recommendation 1

We recommend the completion of the 12 GeV Upgrade at Jefferson Lab.

- It will enable **three-dimensional imaging of the nucleon**, revealing hidden aspects of its internal dynamics.

- It will complete our understanding of the transition between the hadronic and quark/gluon descriptions of nuclei.

- It will test definitively the existence of exotic hadrons, long-predicted by QCD as arising from quark confinement.

- It will provide low-energy probes of physics beyond the Standard Model complementing anticipated measurements at the highest accessible energy scales.

Summary

- The CLAS12 with the 12 GeV Upgrade has a well defined physics goals of fundamental importance for the future of hadron physics, addressing in new and revolutionary ways the quark and gluon structure of hadrons by
  - accessing GPDs & TMDs
  - mapping the valence quark structure of nucleons with high precision
  - understanding hadronization processes
  - extending nucleon form factors to short distances
- Construction started October 2008

This is a very exciting time for hadronic physics,

and the perfect time for new collaborators to make significant contributions to the physics and equipment of ***CLAS12***

Jefferson Laboratory
12 GeV Upgrade Science, Technology & Education Center Stage