Hall B
CLAS12 Physics Program

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Jefferson Lab

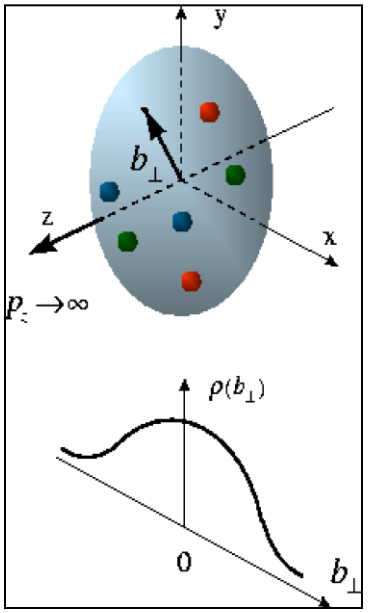
Outline

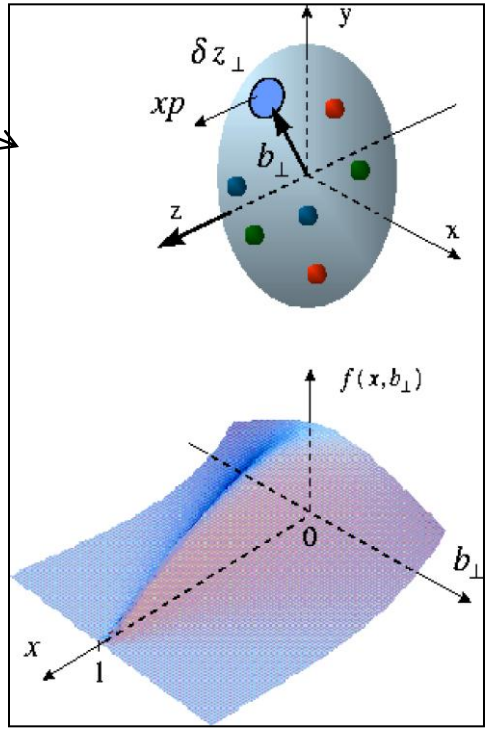
- Introduction to 12 GeV Upgrade
- CLAS12 Detector
- CLAS12 Science Program
- Summary

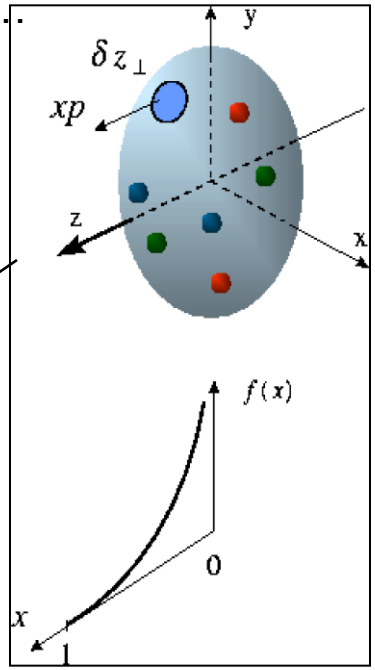
Generalized Parton Distributions (GPDs)

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

GPDs connect the charge and parton distribution







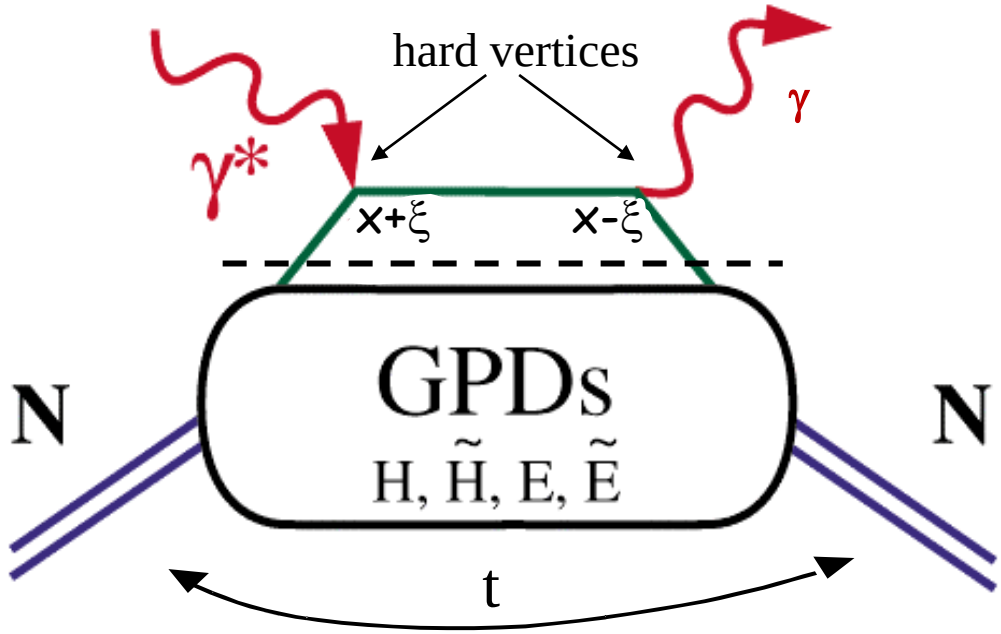
The size and structure of proton.
Proton form factors, **transverse** charge and current distributions
Nobel prize 1961- R. Hofstadter

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. $H(x, \xi, t)$. They describe the internal nucleon dynamics.

Link to DIS and Elastic Form Factors

DIS at $\xi = t = 0$

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

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

Form factors (sum rules)

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

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

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

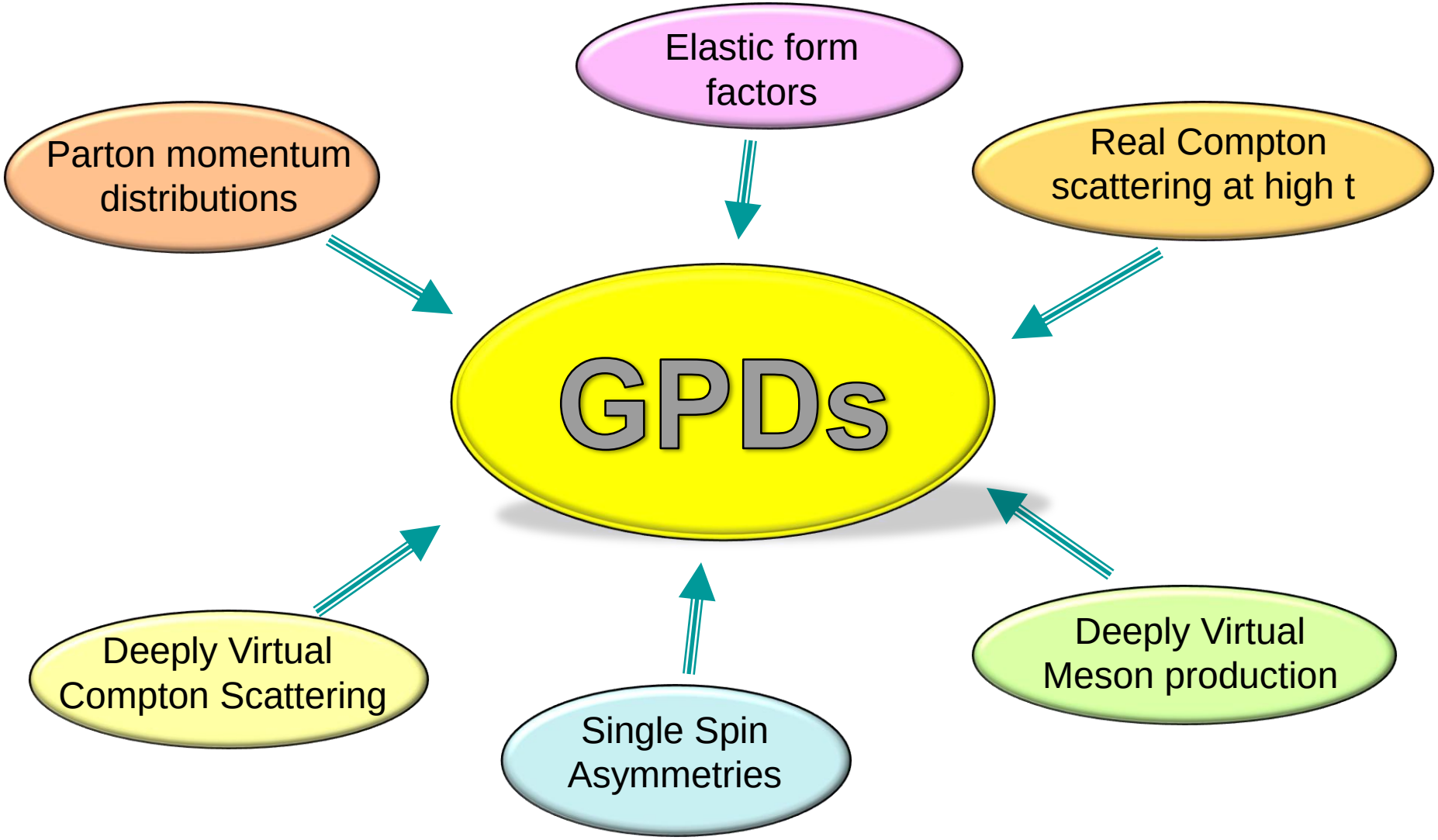
$$H^q, E^q, \tilde{H}^q, \tilde{E}^q(x,\xi,t)$$

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?

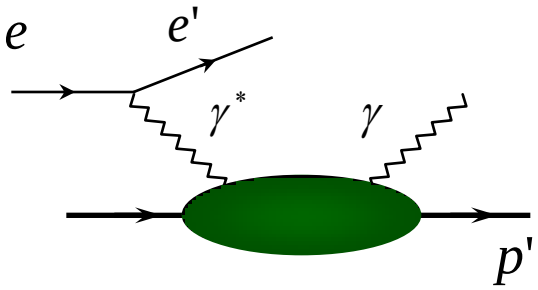
Accessing GPDs in Exclusive Processes

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

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

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

$\ldots$



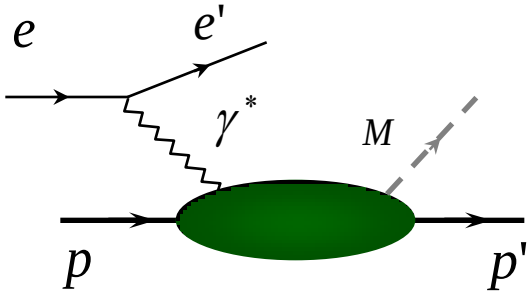
- Hard exclusive meson production (quark flavor filter)

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

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

$ep \rightarrow e' p' \omega$

$\ldots$



- 4 GPDs in leading order, 2 flavors (u, d) $\rightarrow$ 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

$\Rightarrow$ 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

$\Rightarrow$ $\tilde{H}$

Unpolarized beam, transverse target:

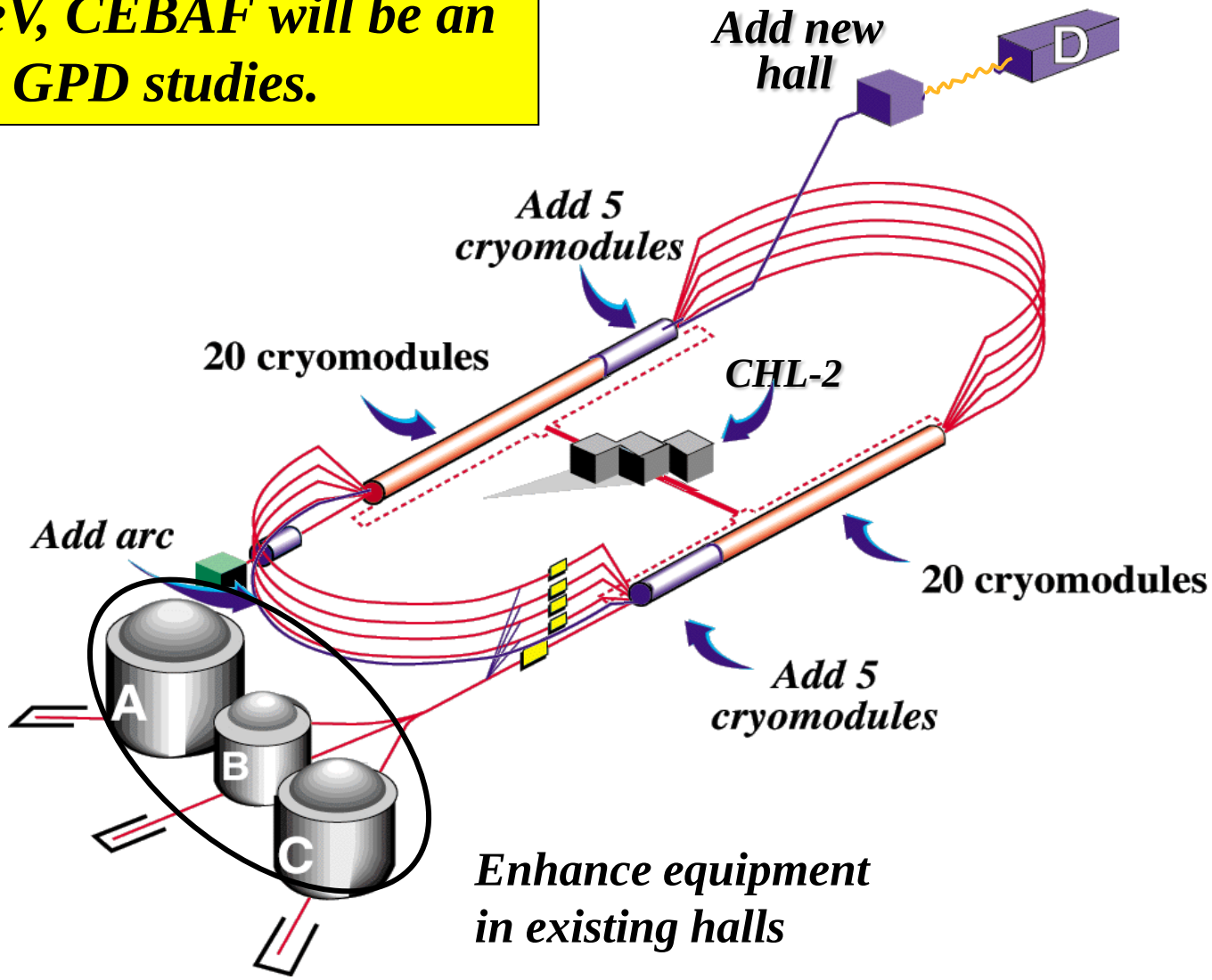
$$\Delta\sigma_{UT} \sim \sin\phi \, \mathrm{Im}\{k(F_2 H - F_1 E) + ... \}d\phi$$

Kinematically suppressed

$\Rightarrow$ H, E

JLab Upgrade to 12 GeV

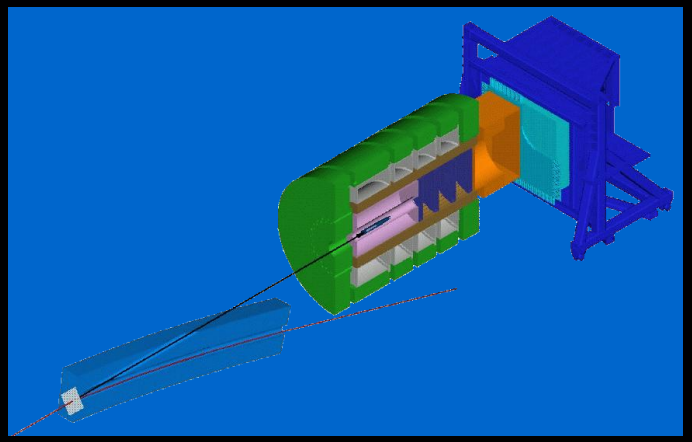
At 12 GeV, CEBAF will be an ideal for GPD studies.



Enhance equipment in existing halls

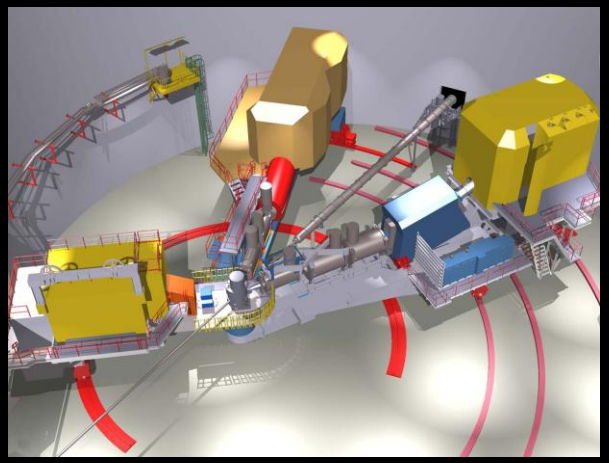
New Capabilities in Halls A, B, & C, and a New Hall D

D



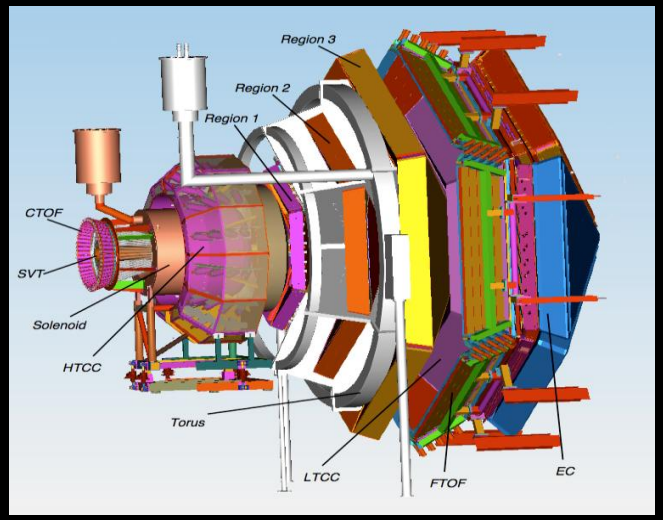
9 GeV tagged polarized photons and a 4π hermetic detector

C



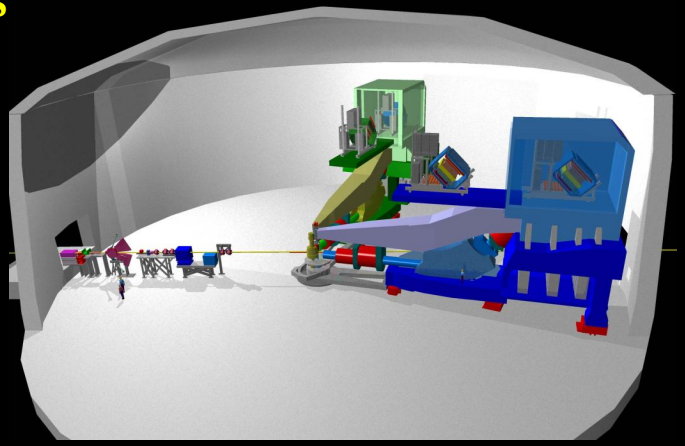
Super High Momentum Spectrometer (SHMS) at high luminosity and forward angles

B



CLAS12 high luminosity, large acceptance.

A



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

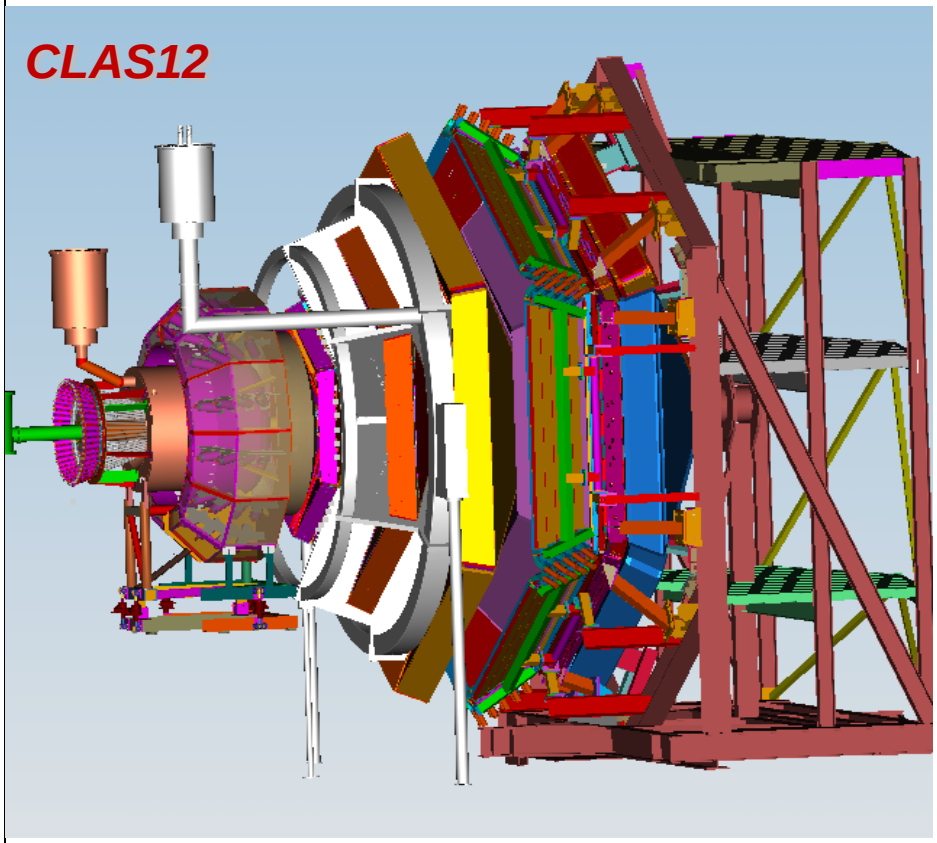
Hall B 12GeV upgrade overview

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:

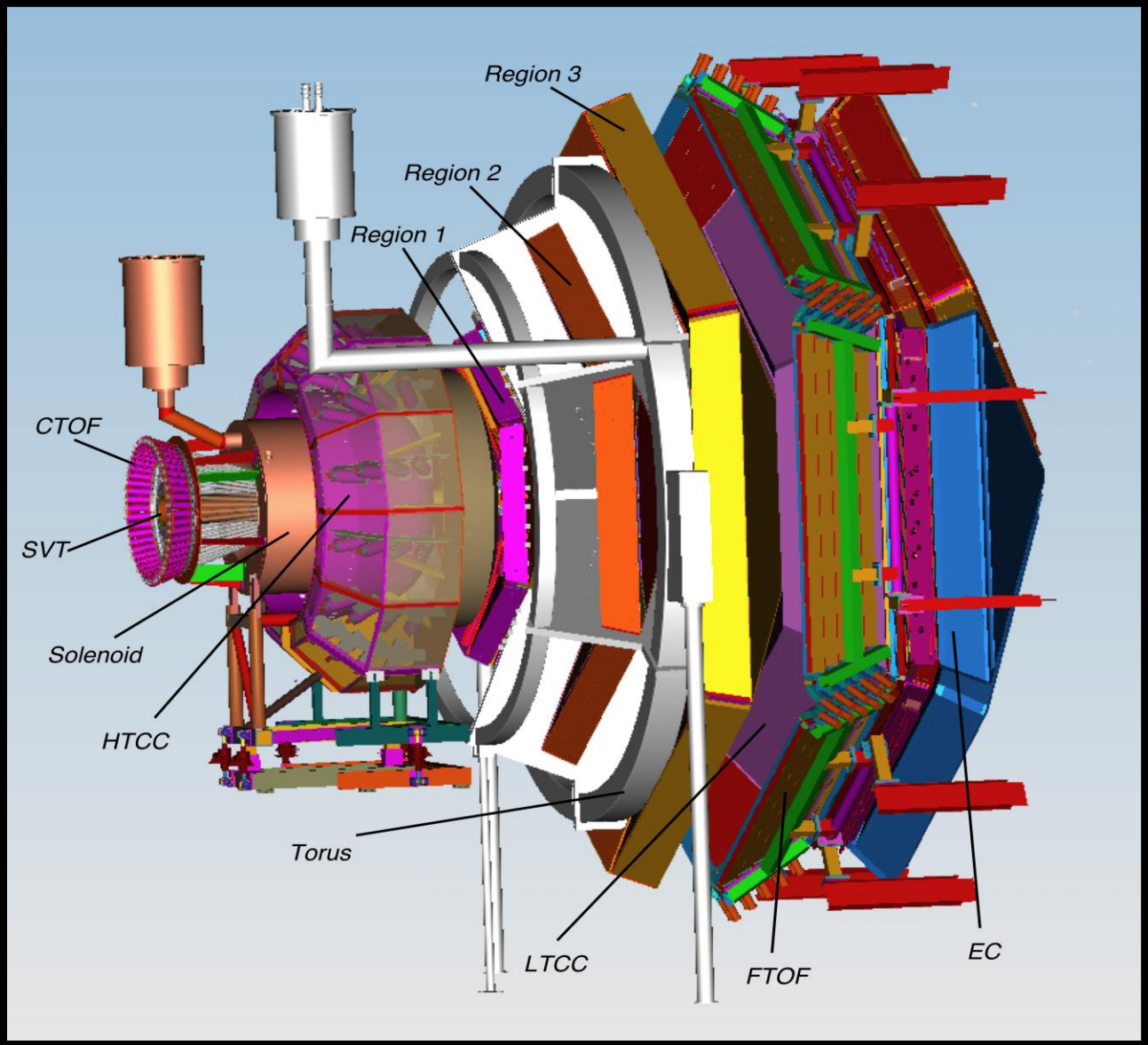
- *TORUS magnet*
- *Forward SVT tracker*
- *HT Cherenkov Counter*
- *Drift chamber system*
- *LT Cherenkov Counter*
- *Forward ToF System*
- *Preshower calorimeter*
- *E.M. calorimeter (EC)*

Central Detector:

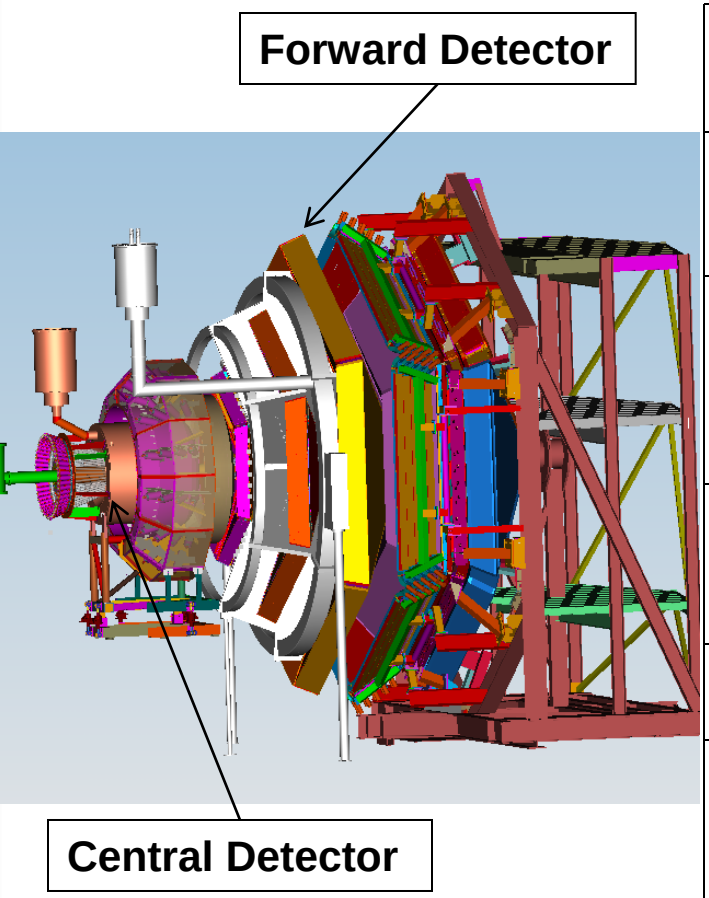
- *SOLENOID magnet*
- *Barrel Silicon Tracker*
- *Central Time-of-Flight*

Proposed upgrades:

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

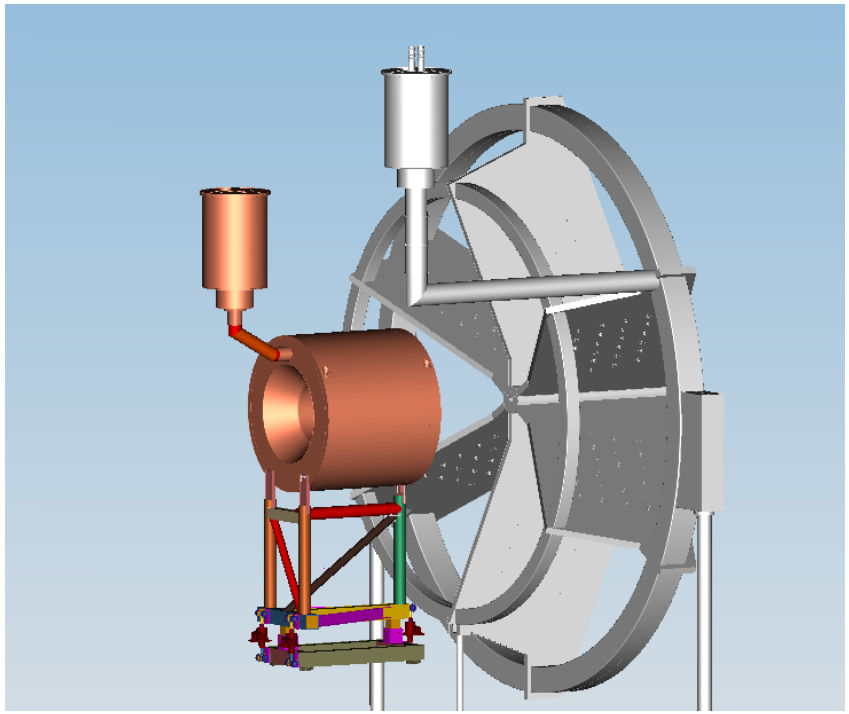


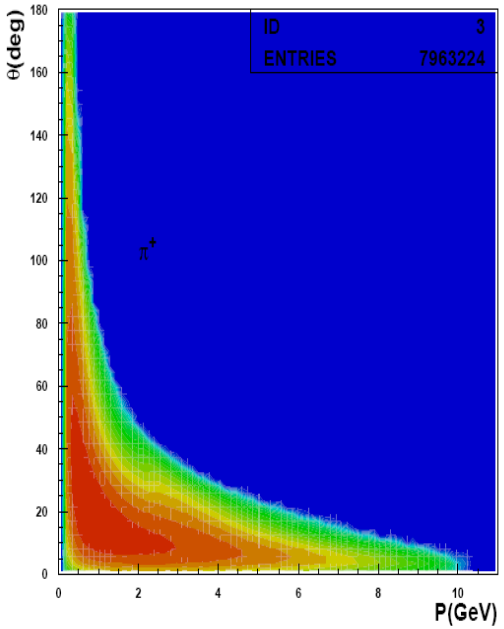
CLAS12 – Design parameters

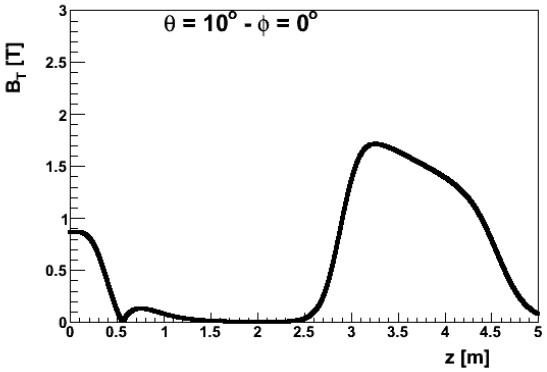


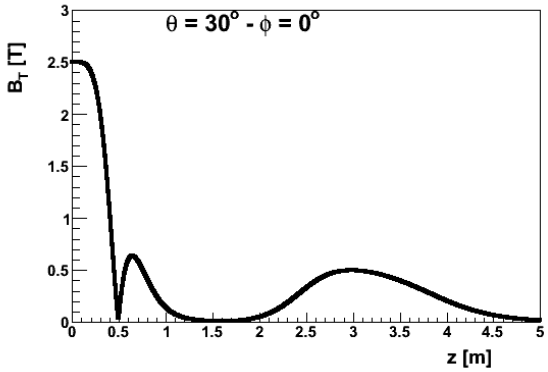
	Forward Detector	Central Detector
Angular range		
Tracks	$5^0 – 40^0$	$35^0 – 125^0$
Photons	$3^0 – 40^0$	n.a.
Resolution		
$\delta p/p$ (%)	< 1 @ 5 GeV/c	< 5 @ 1.5 GeV/c
$\delta\theta$ (mr)	< 1	< 10 - 20
$\Delta\phi$ (mr)	< 3	< 5
Photon detection		
Energy (MeV)	>150	n.a.
$\delta\theta$ (mr)	<4 @ 1 GeV	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
$\pi^0 \rightarrow \gamma\gamma$	Full range	n.a.
$\eta \rightarrow \gamma\gamma$	Full range	n.a.

CLAS12 – Solenoid and Torus





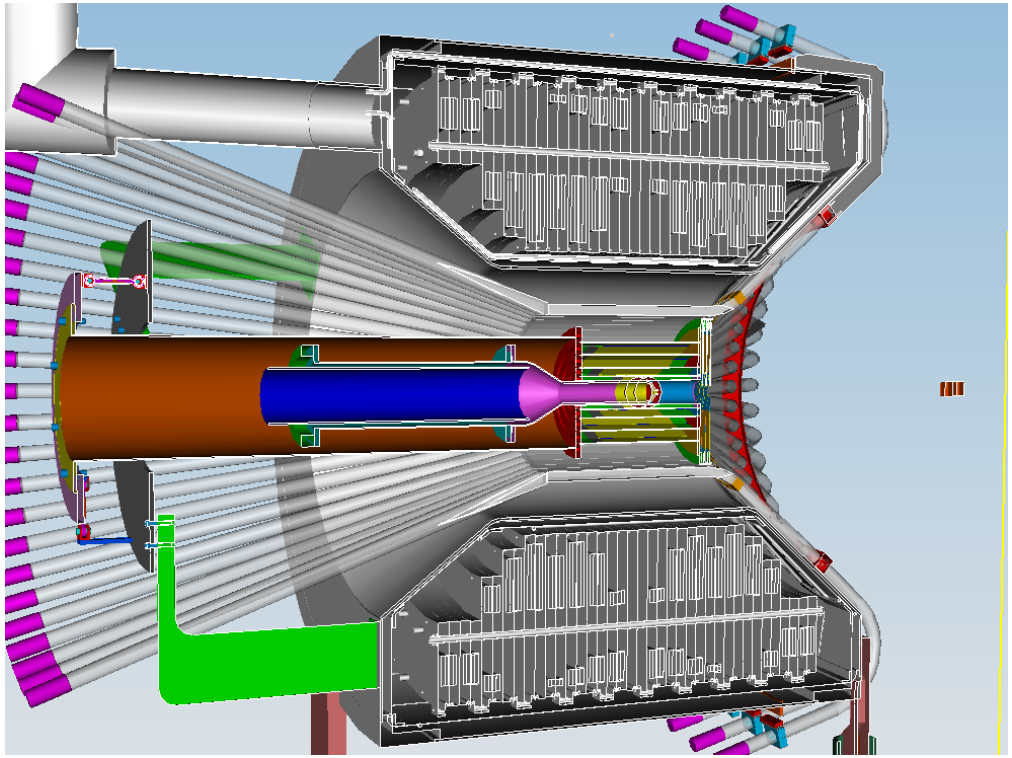


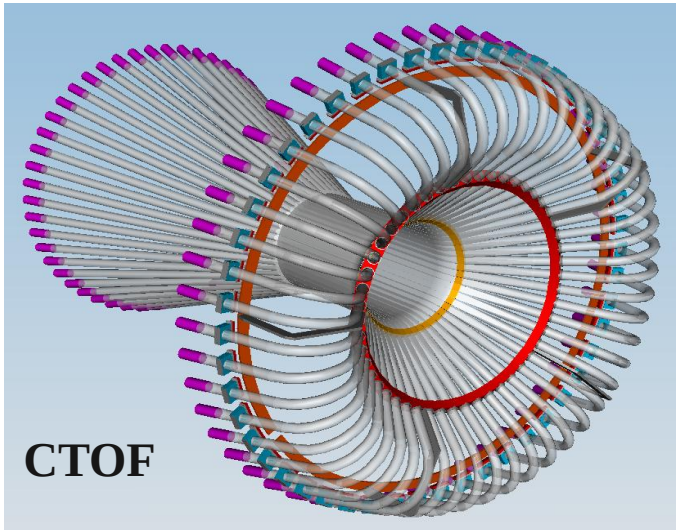


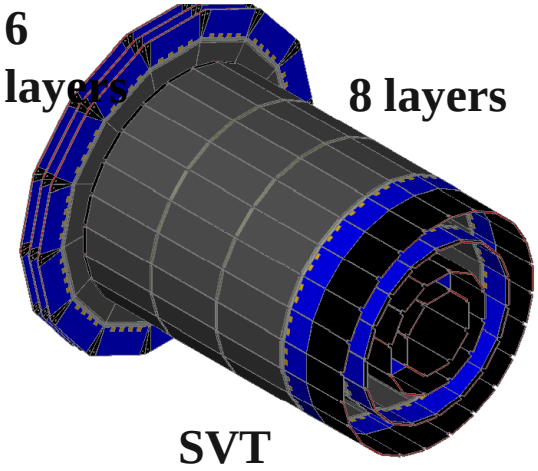
The B-field transverse to the particle trajectory is approximately matched to the average particle momentum.

CLAS12 – Central Detector SVT, CTOF

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

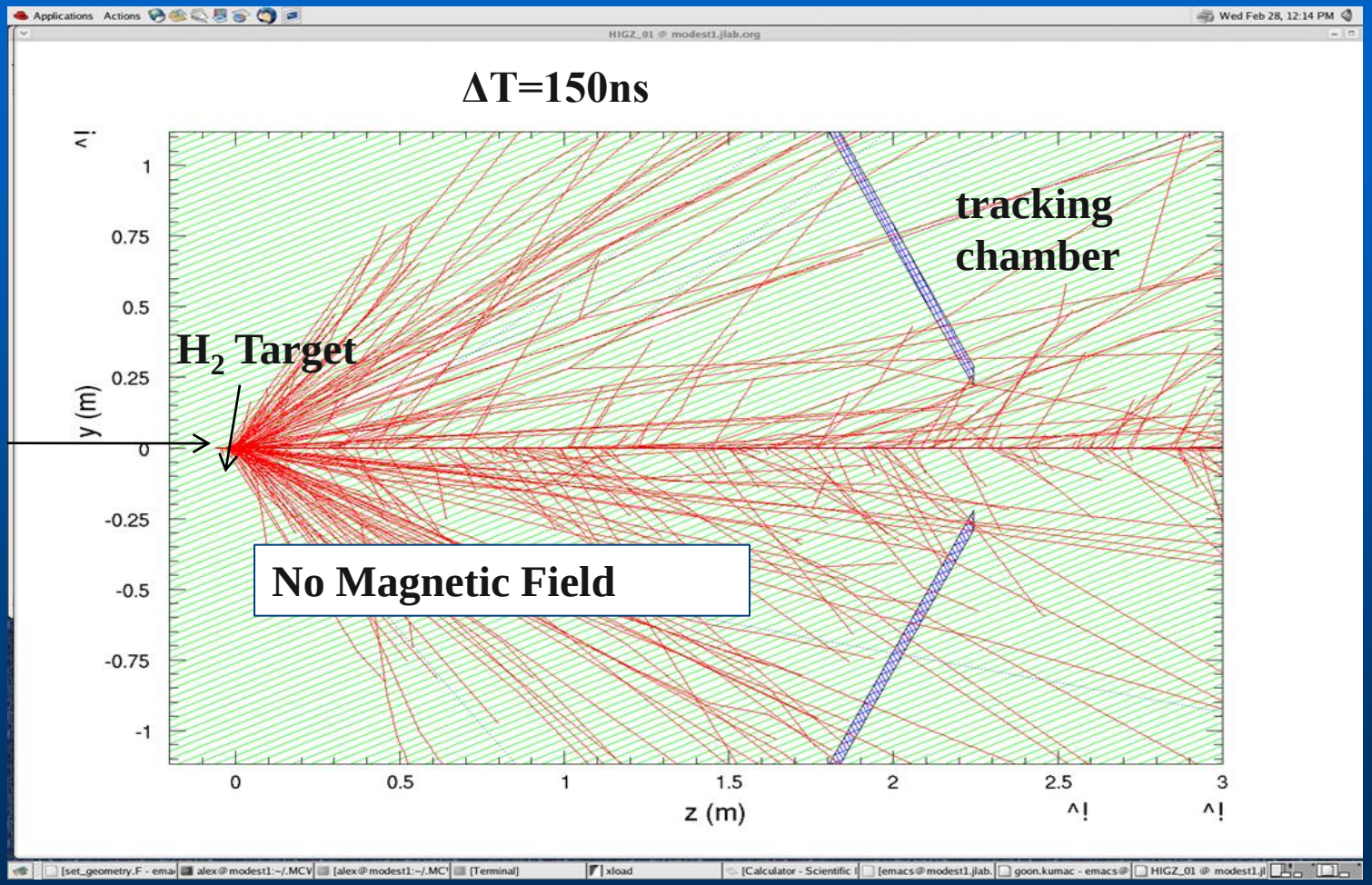






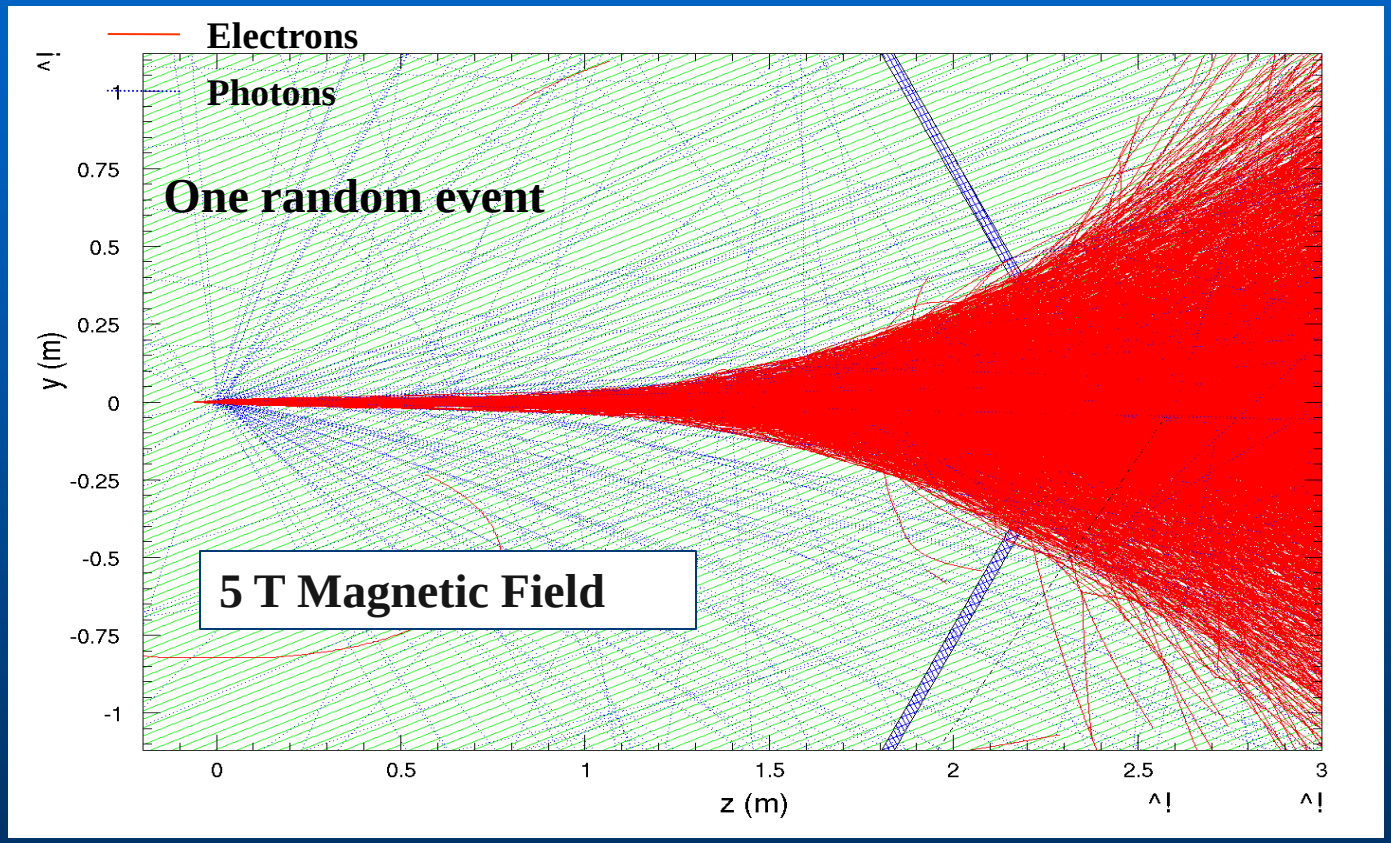
Background Shielding

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



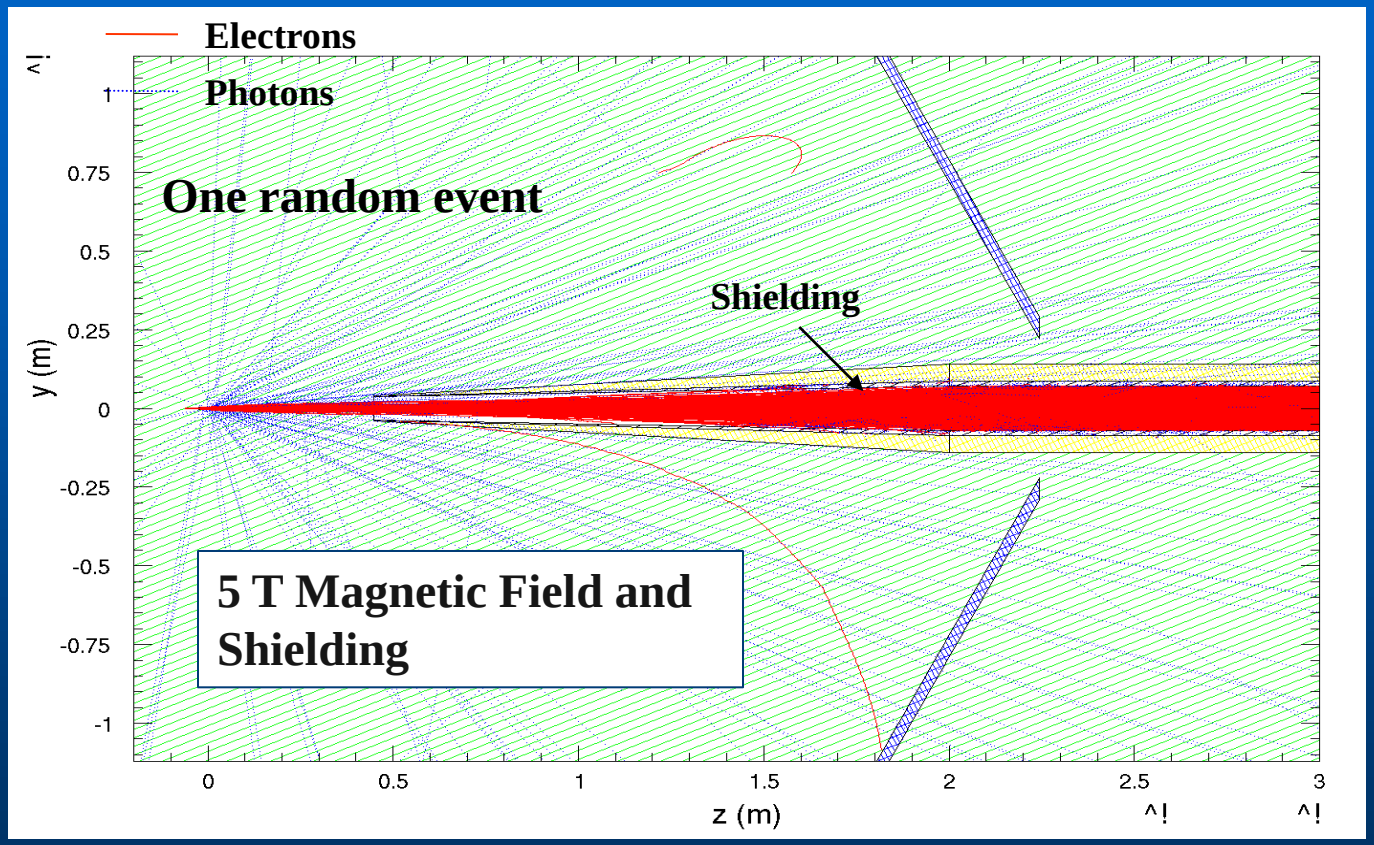
Background Shielding

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



Background Shielding

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



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

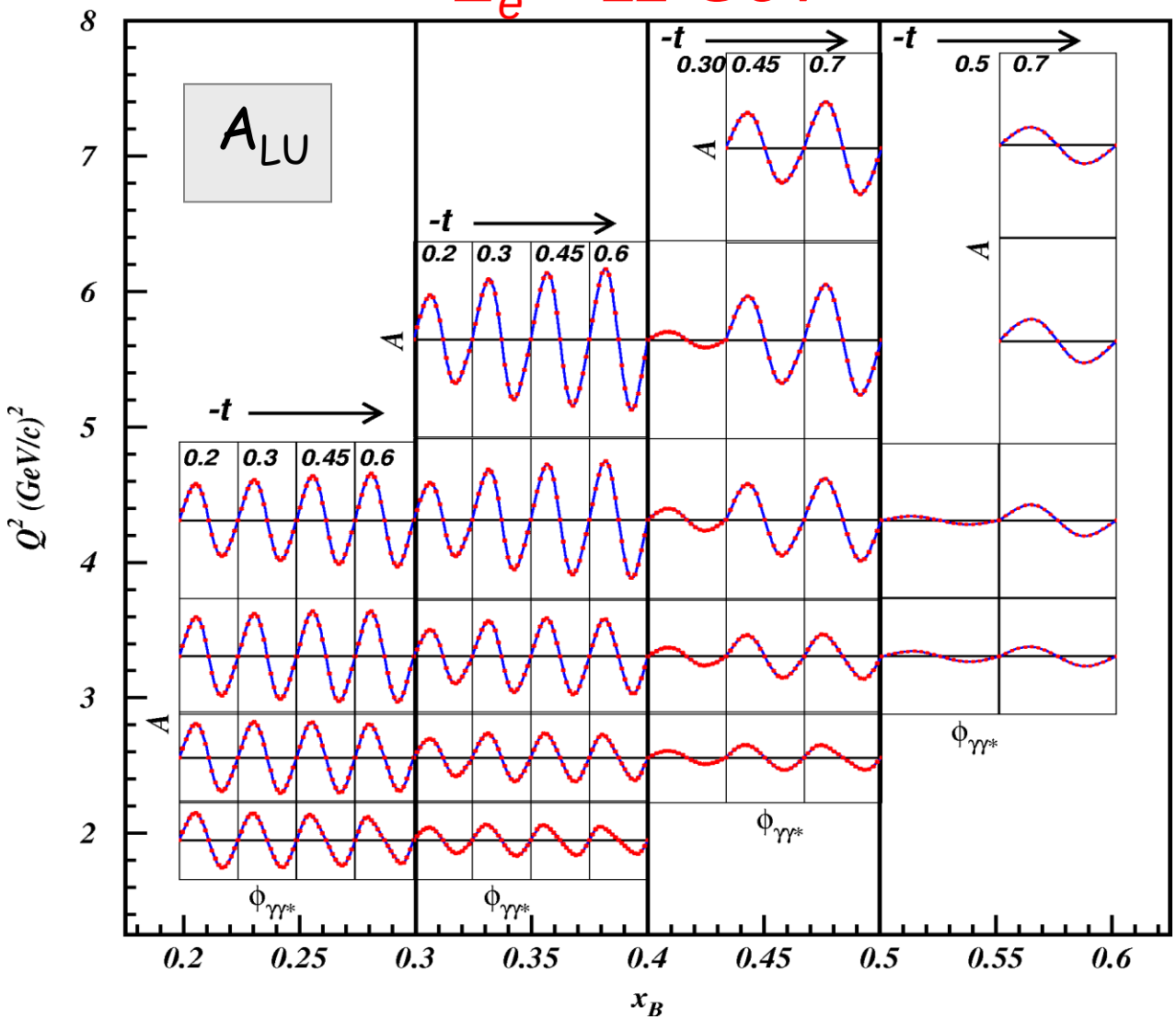
Approved experiments correspond to about 5 years of scheduled beam operation .

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

$E_e = 11$ GeV



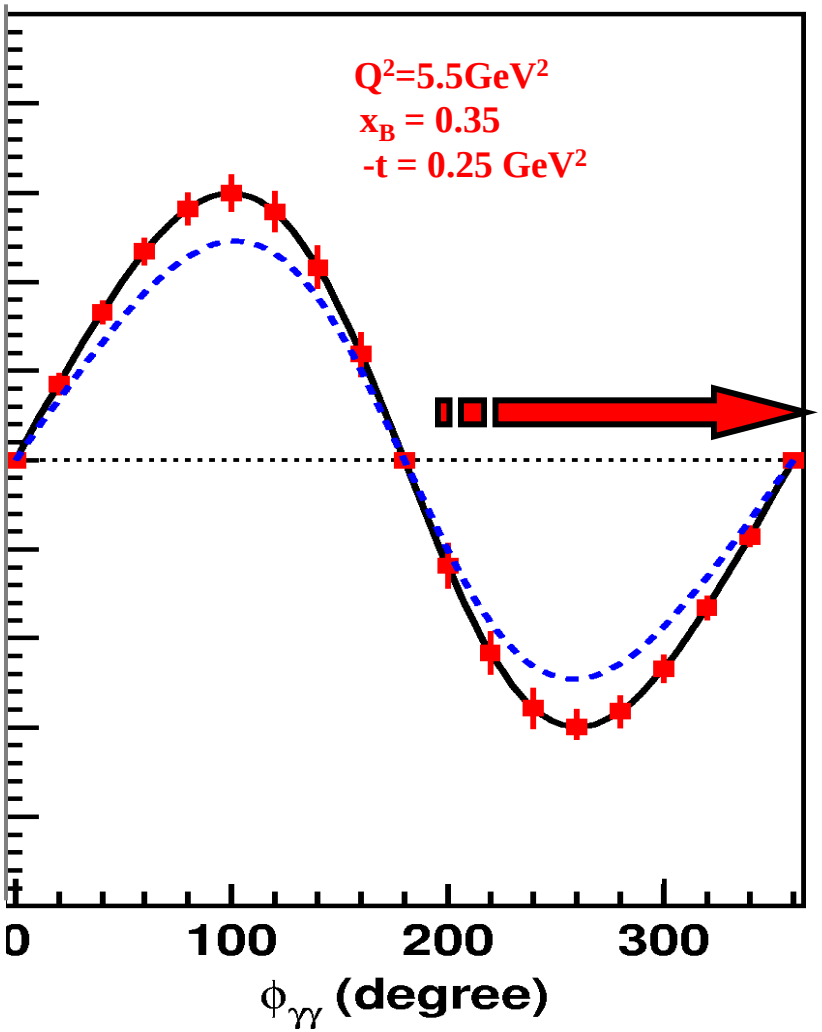
With large acceptance, measure large Q^2, x_B, t ranges simultaneously.

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

CLAS12 - DVCS/BH- Beam Asymmetry

$E_e = 11$ GeV

Luminosity = 720fb^{-1}



CLAS12 - DVCS/BH Beam Asymmetry

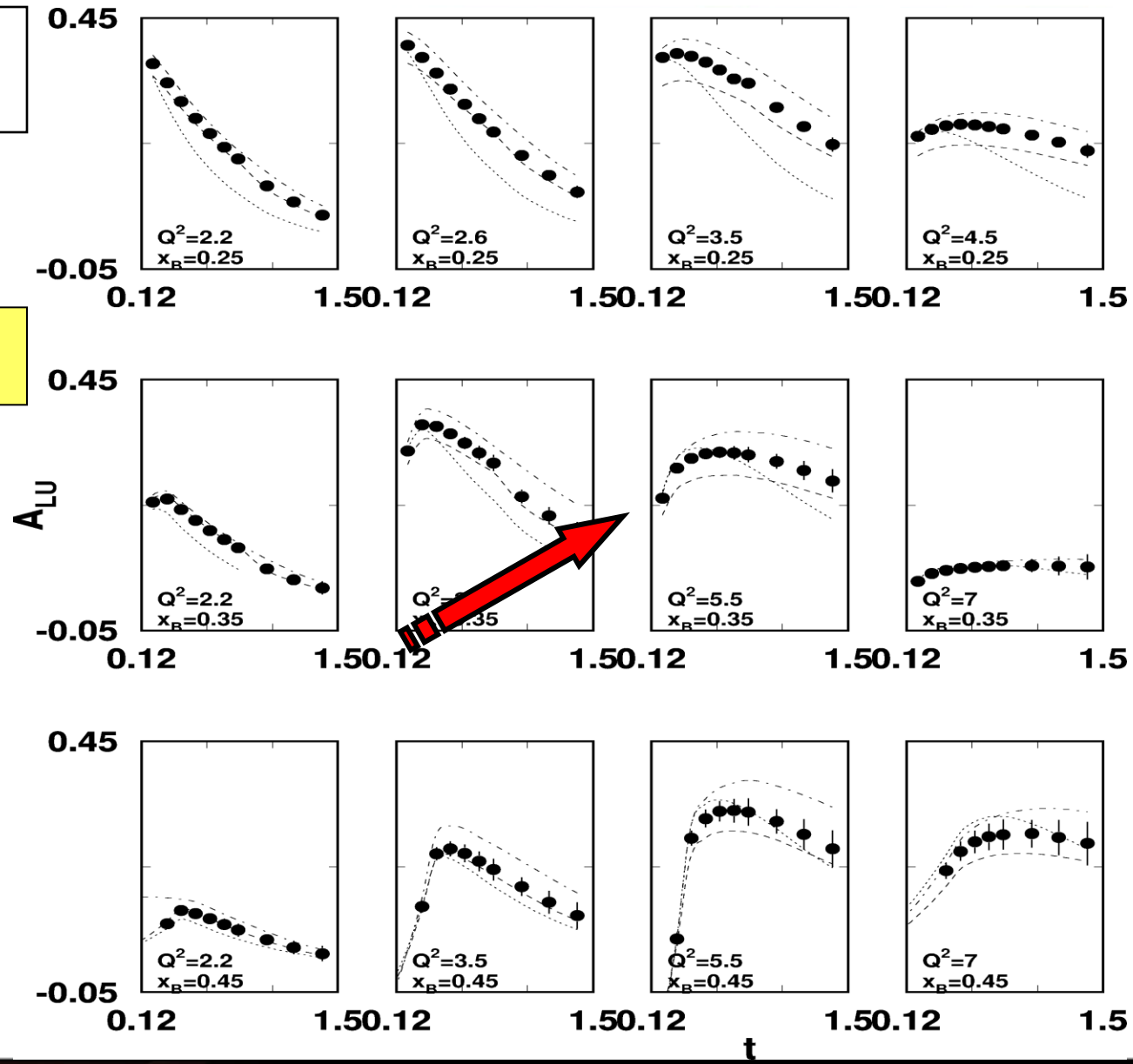
$\vec{e}p \longrightarrow ep\gamma$

E = 11 GeV

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

Selected Kinematics

$L = 1\times10^{35}$
$T = 2000$ hrs
$\Delta Q^2 = 1\ GeV^2$
$\Delta x = 0.05$



CLAS12 - DVCS/BH Target Asymmetry

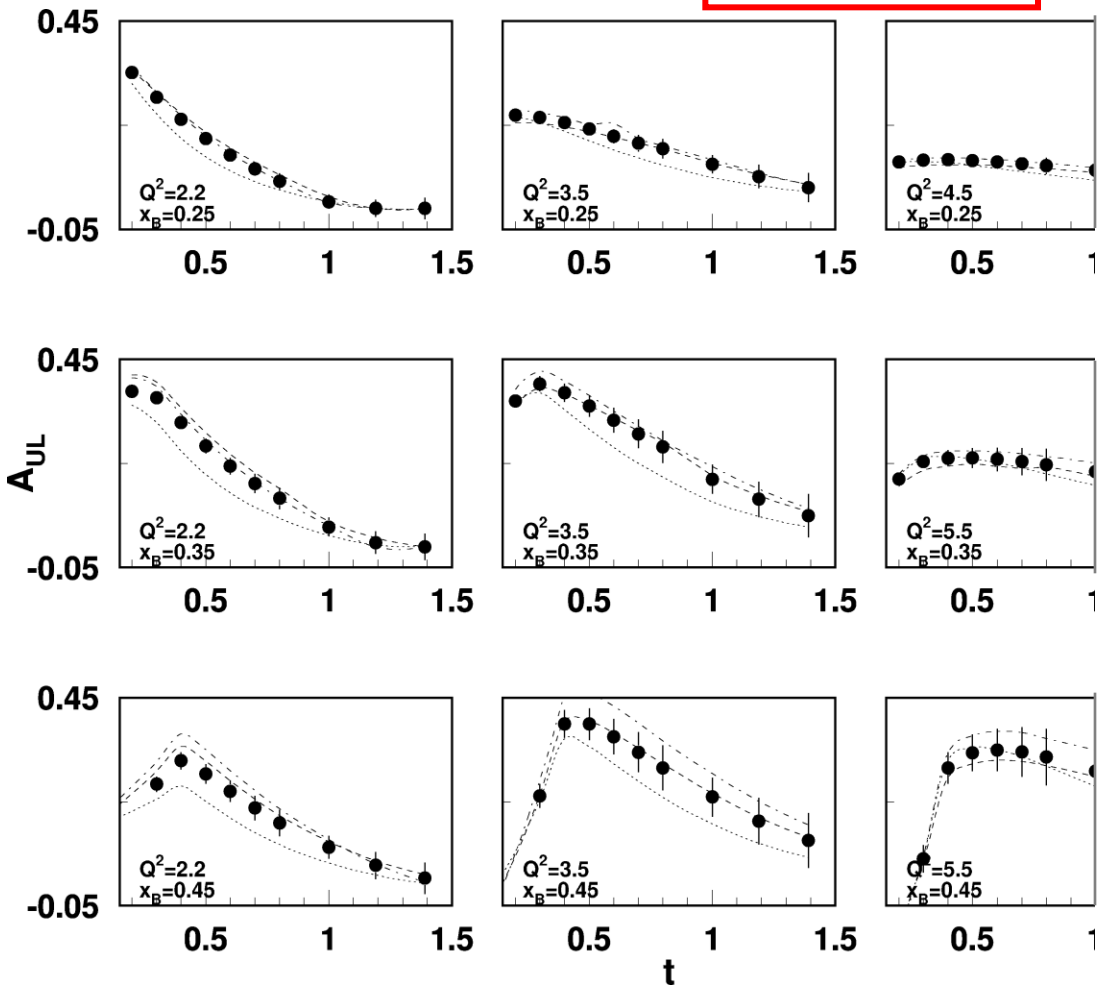
$$e\,\vec{p} \longrightarrow ep\gamma$$

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 = 2×10^{35} cm^{-2}s^{-1}
T = 1000 hrs
ΔQ^2 = 1GeV^2
Δx = 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

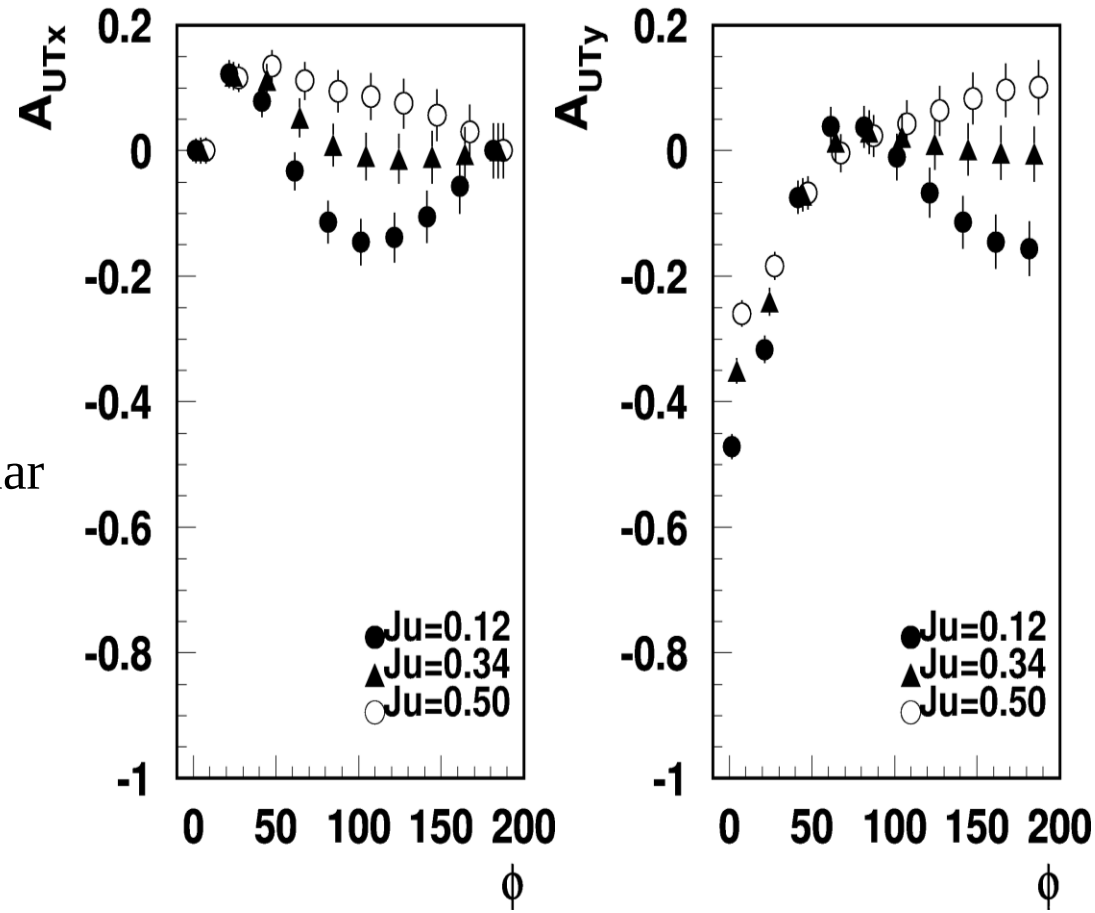
Transverse polarized target

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

A_{UTx} Target polarization in the scattering plane

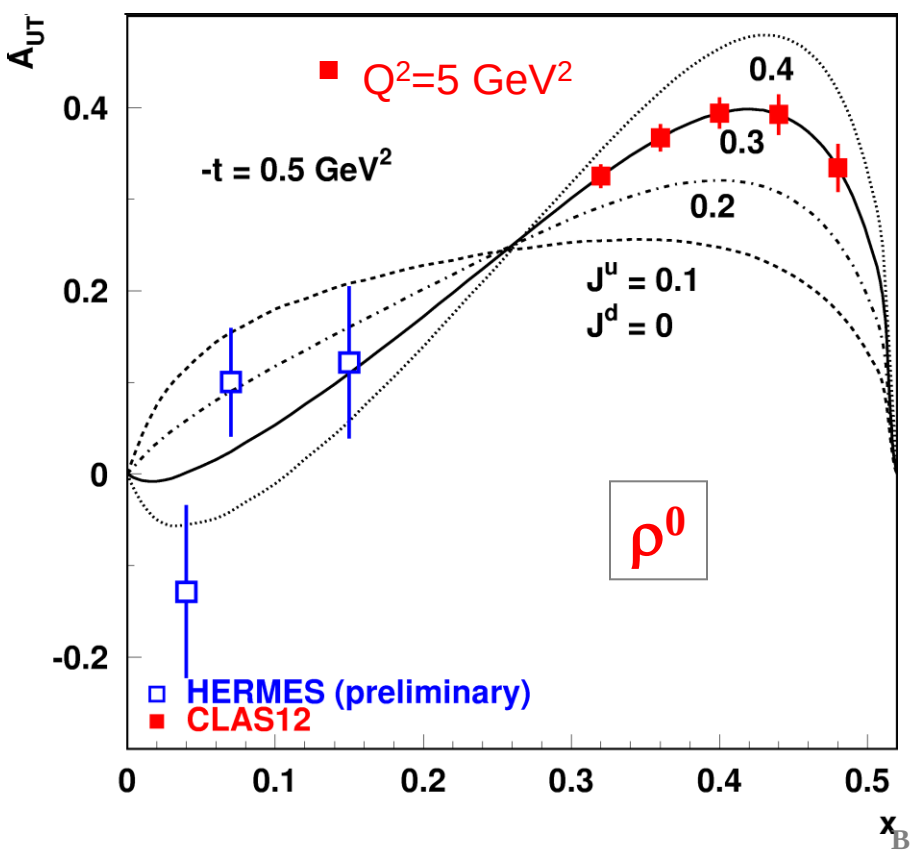
A_{UTy} Target polarization perpendicular to the scattering plane

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



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*.

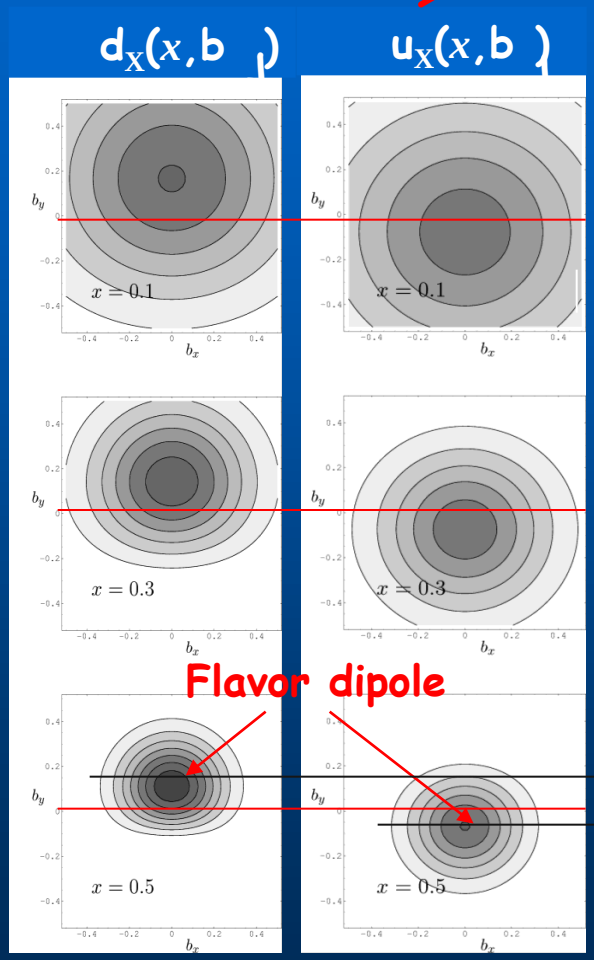
The Promise of GPDs: 2-D & 3-D Images of the Proton

$$\varepsilon(x,\mathbf{b}_\perp) = \int \frac{d^2\Delta_\perp}{(2\pi)^2} e^{i\Delta_\perp b_\perp} E_q(x,\Delta_\perp)$$

M. Burkardt

Cat scan of the human brain

Target polarization



Shift depends on $\varepsilon(x,b_\perp)$

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

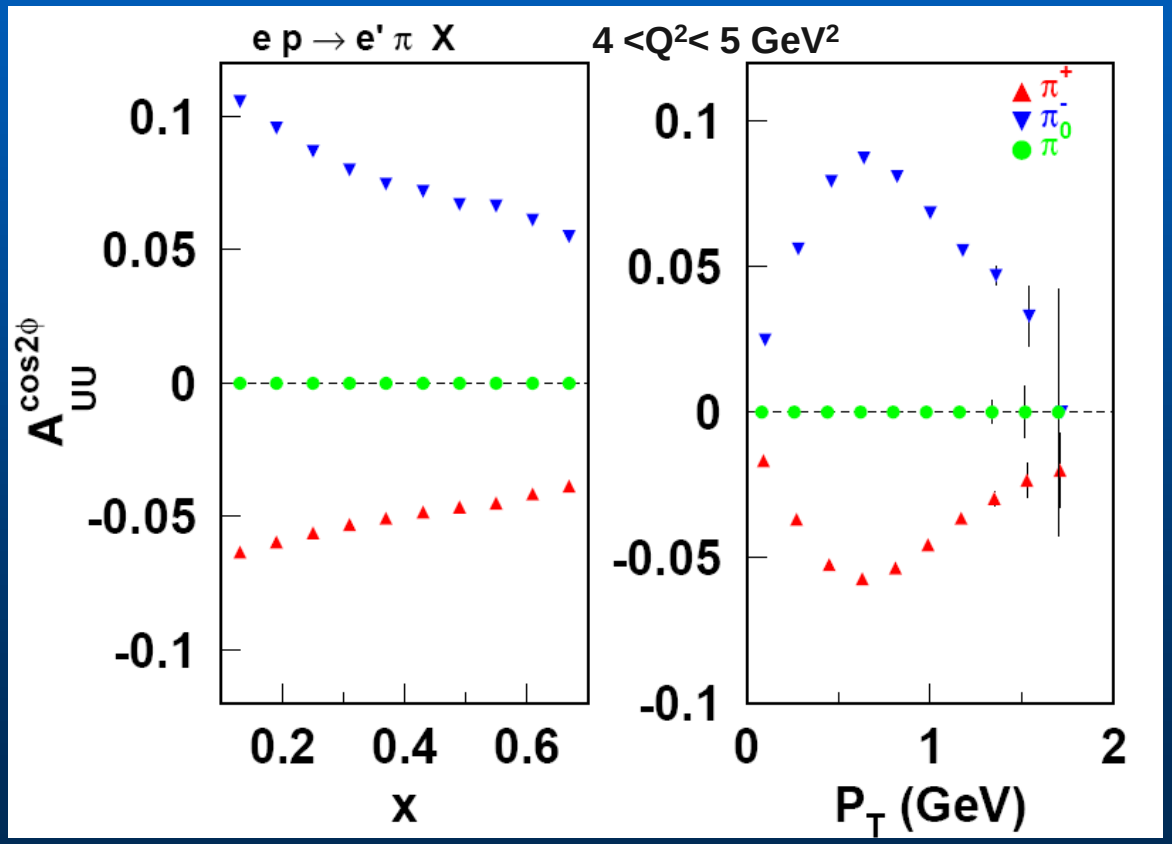
CLAS12 SIDIS on unpolarized protons.

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.

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

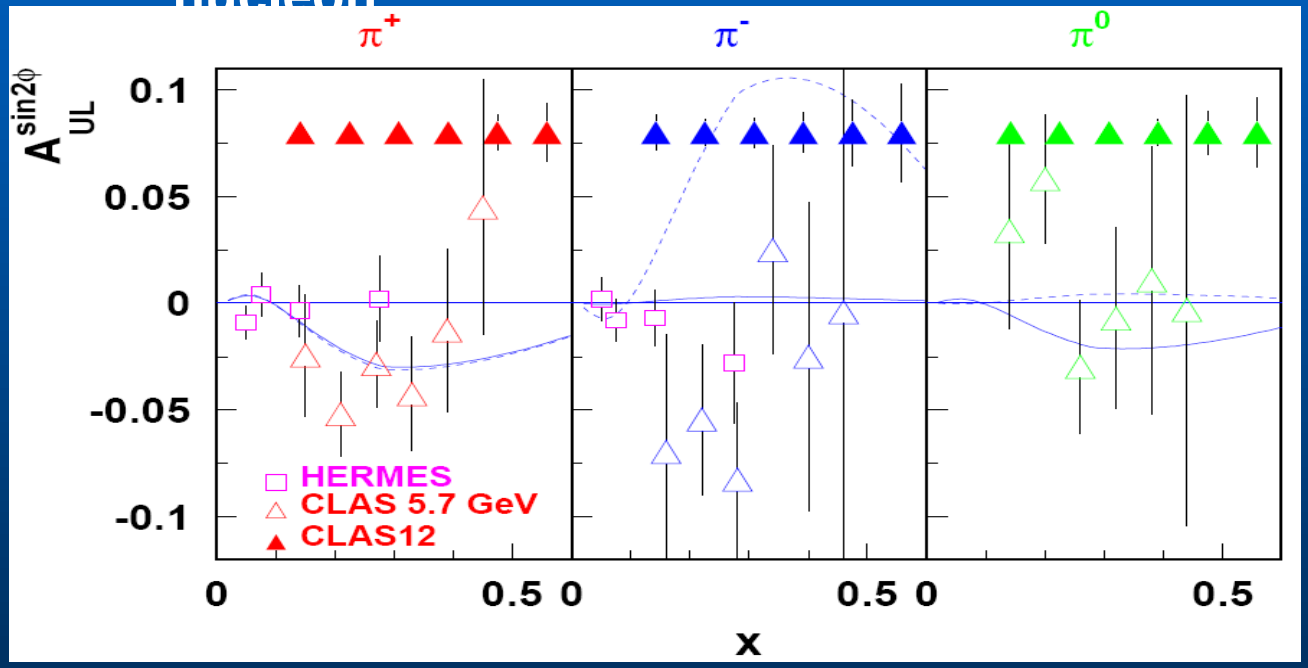
The cos2Φ moment of the azimuthal asymmetry gives access to the Boer-Mulders Function which measures the momentum distribution of transversely polarized quarks in unpolarized nucleons.



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

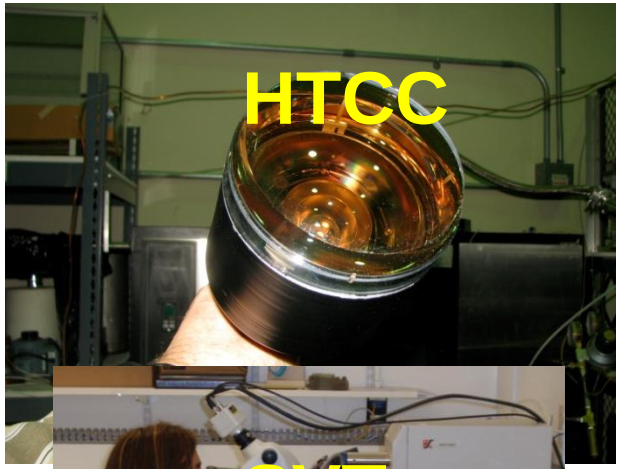


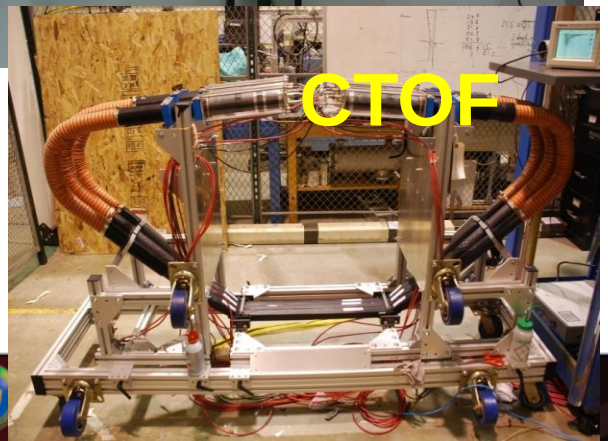
- **The sin2ϕ moment is sensitive to spin-orbit correlations: the only leading twist azimuthal moment for longitudinally polarized target.**

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

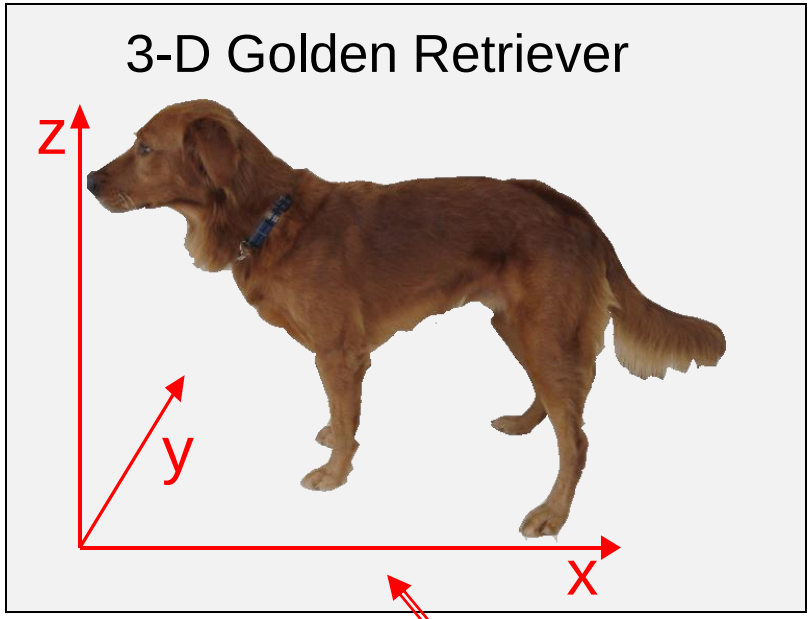
- The CLAS12 with the 12 GeV Upgrade has a well defined physics goals of fundamental importance for the future of hadron physics, addressing in new and revolutionary ways the quark and gluon structure of hadrons by
  - accessing GPDs & TMDs
  - mapping the valence quark structure of nucleons with high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

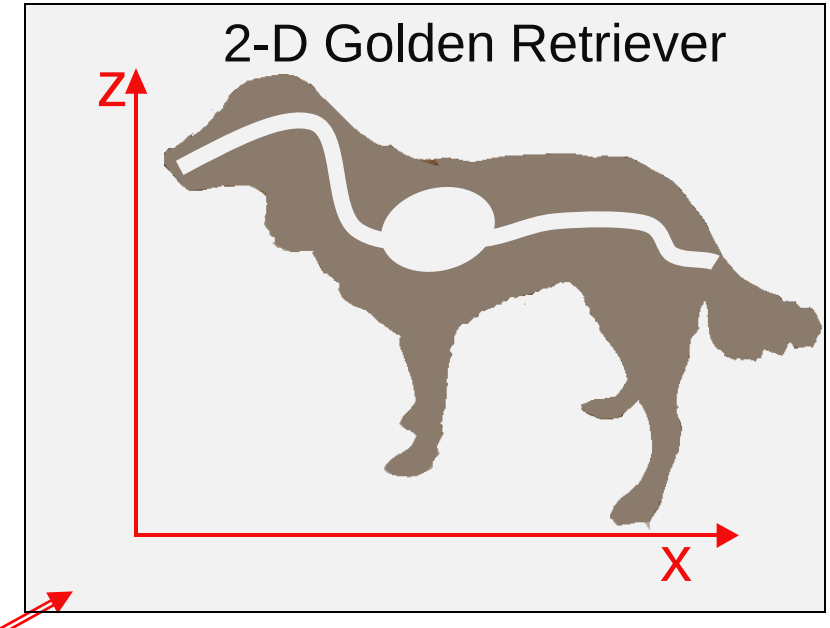
This is a very exciting time for hadronic physics,

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

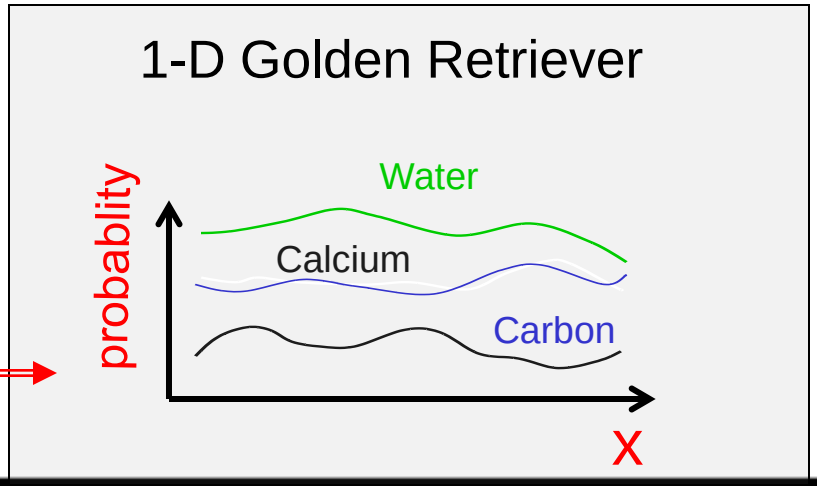
GPDs & PDFs





Deeply Virtual Exclusive Processes & GPDs

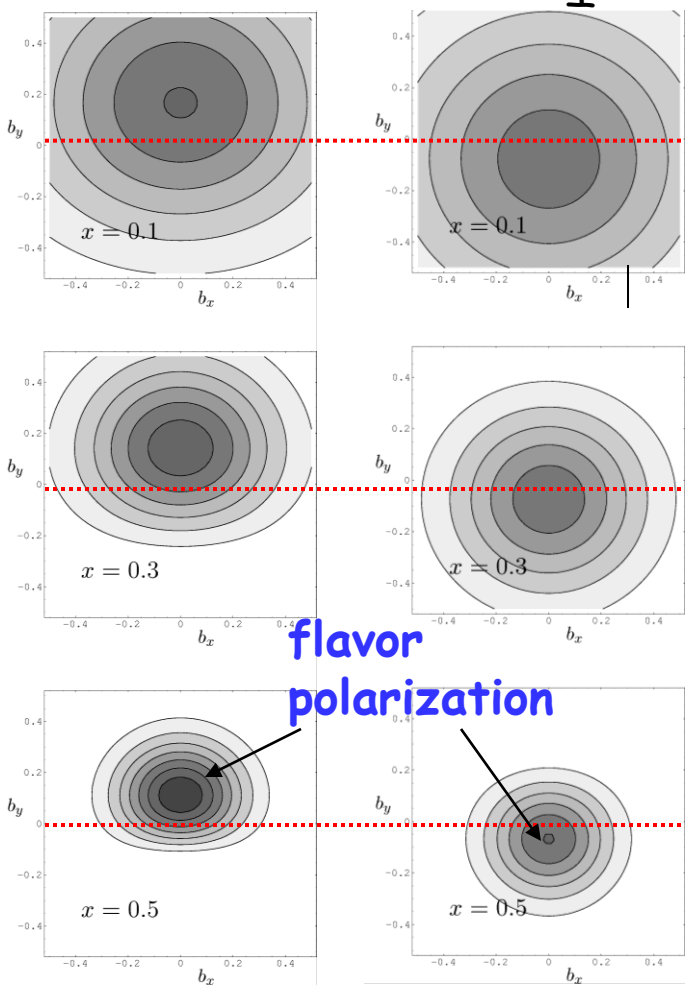
Deep Inelastic Scattering & PDFs



Tomographic Images of the Proton

Target polarization

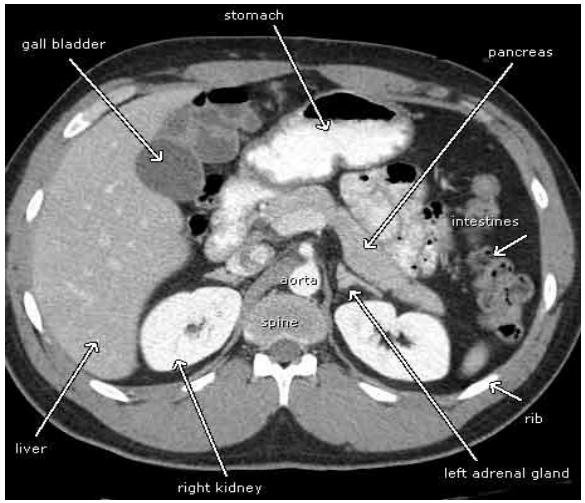
$d_x(x,b_\perp)$ $u_x(x,b_\perp)$



$E^d(x,t)$ $E^u(x,t)$

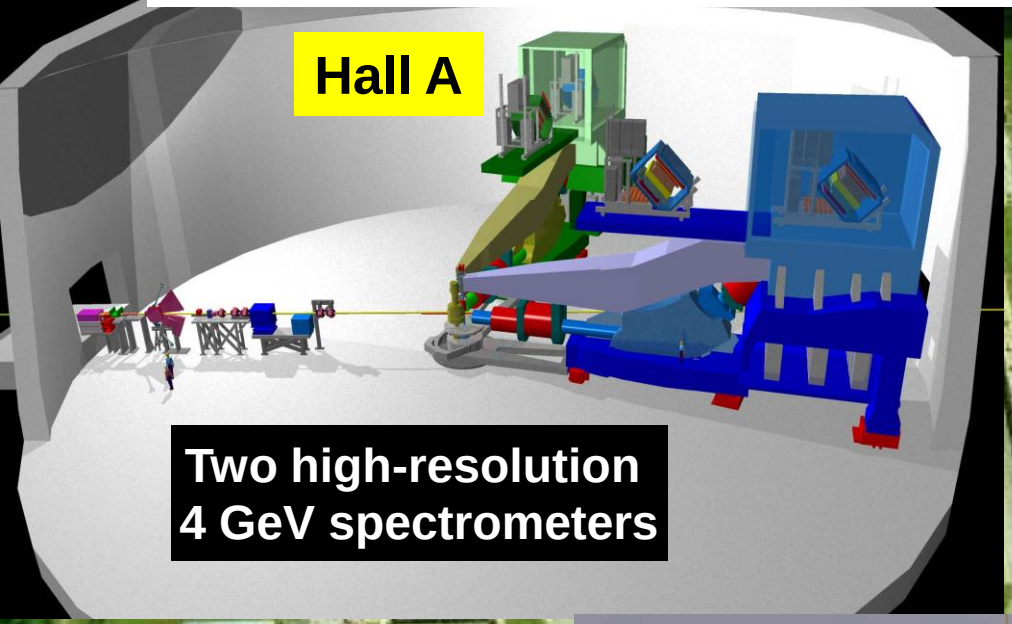
$$q(x,b_\perp) = \int \frac{d^2t}{(2\pi)^2}\, e^{-i\,t\,b_\perp} E(x,0,t)$$

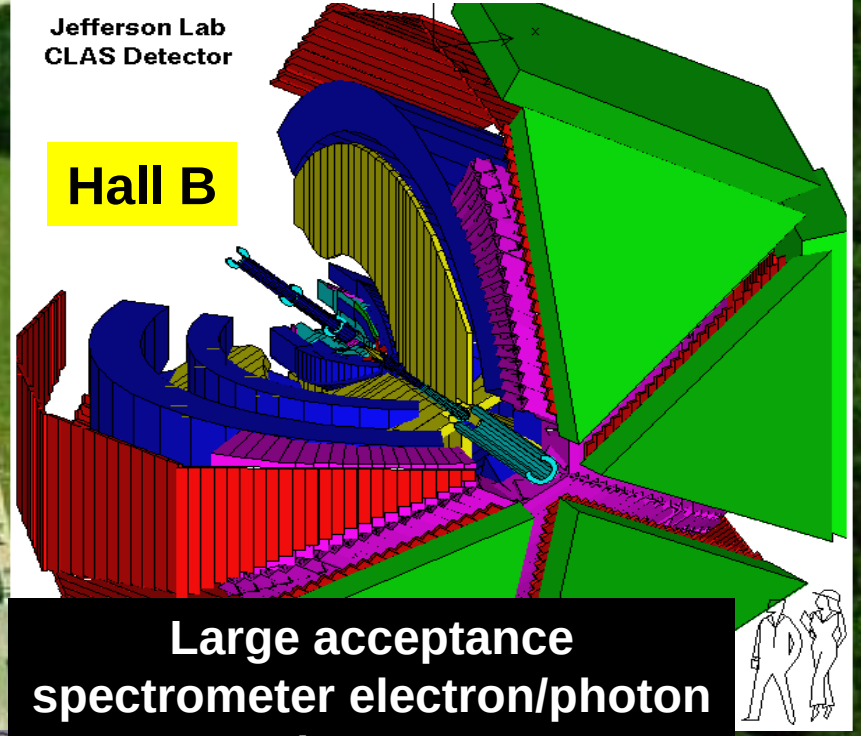
CAT scan slice
of human abdomen

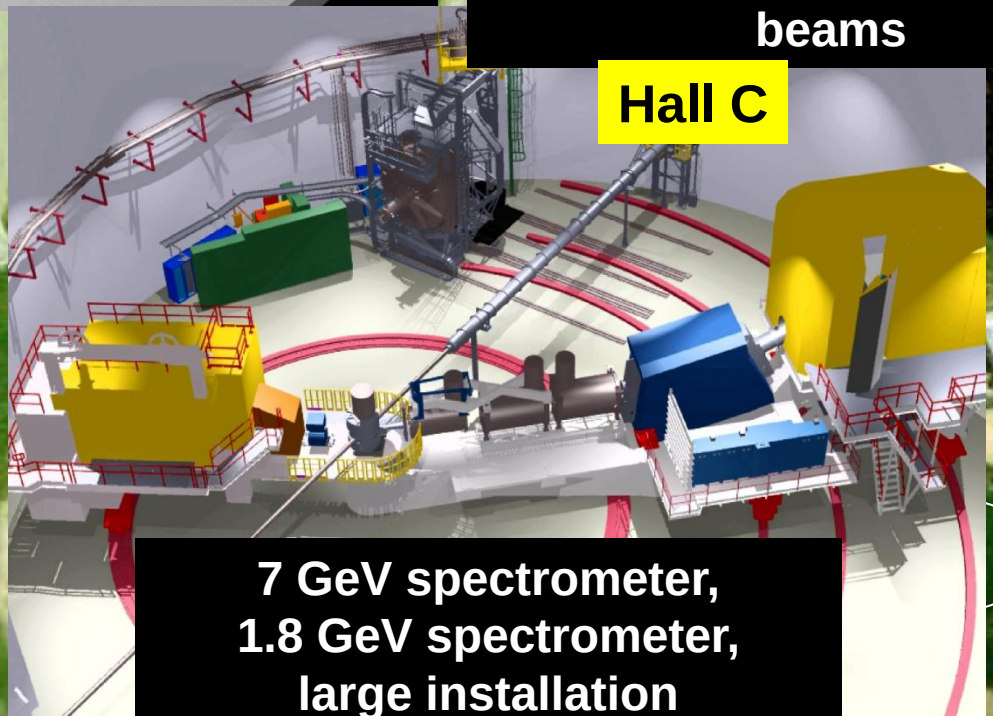


M. Burkardt

Jefferson Lab Today



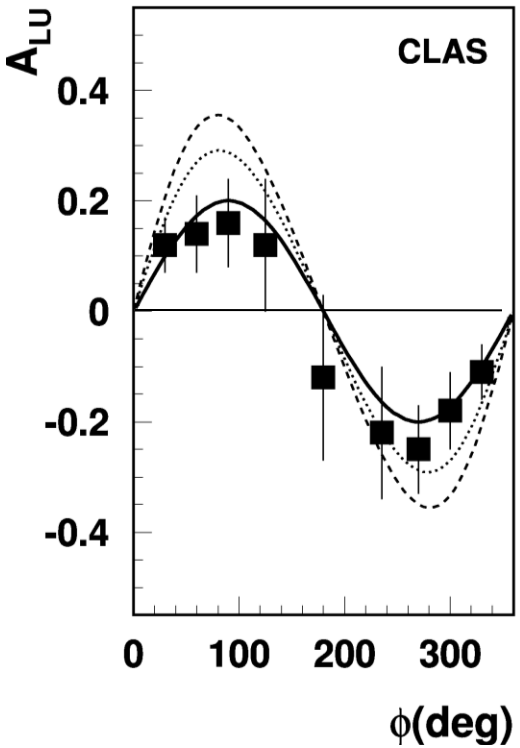


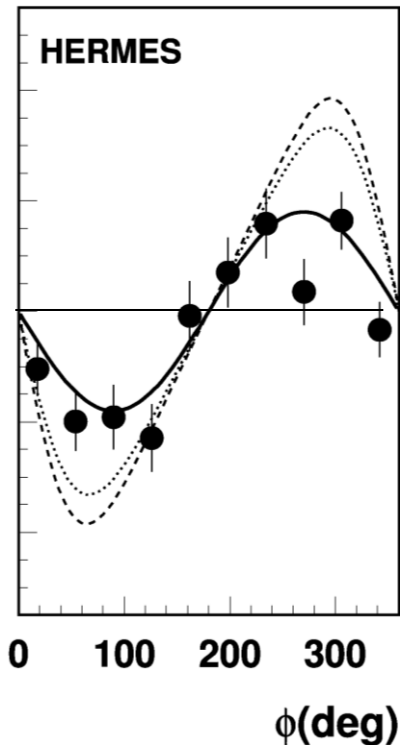


Pioneering Experiments Observe Interference

2001

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





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

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

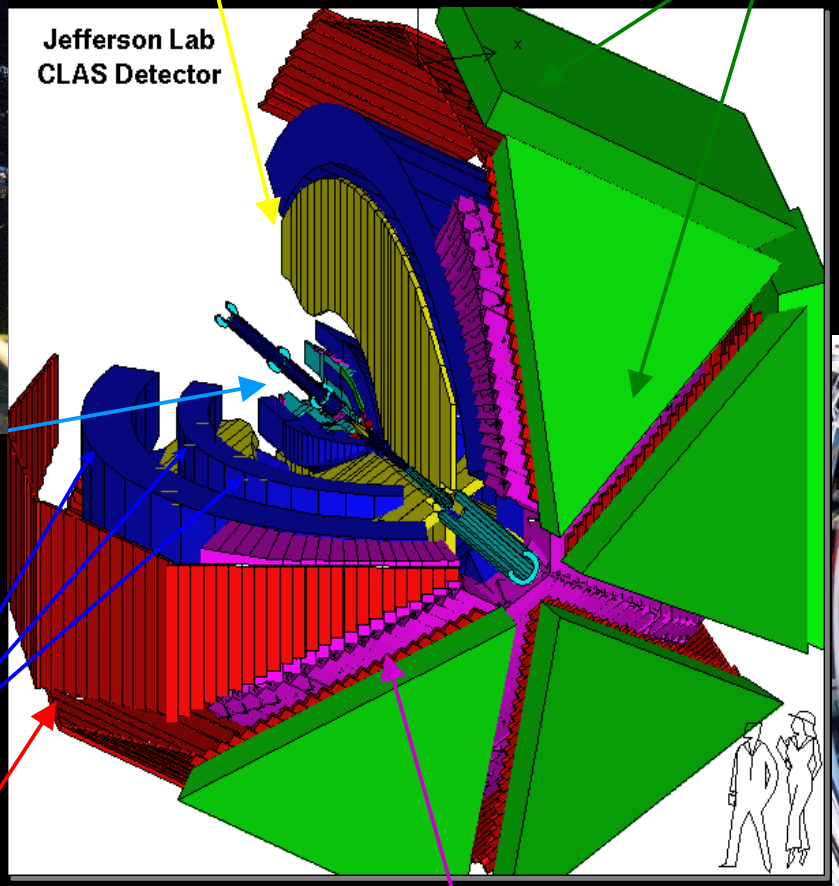
twist-2 twist-3

First GPD analyses of HERA/CLAS/HERMES data in LO/NLO consistent with **$\alpha \sim 0.20$.**
A. Freund (2003), A. Belitsky et al. (2003)

CEBAF Large Acceptance Spectrometer

Torus Magnet
6 Superconductive Coils

Electromagnetic Calorimeter
lead/plastic scintillator, 1296 PMTs

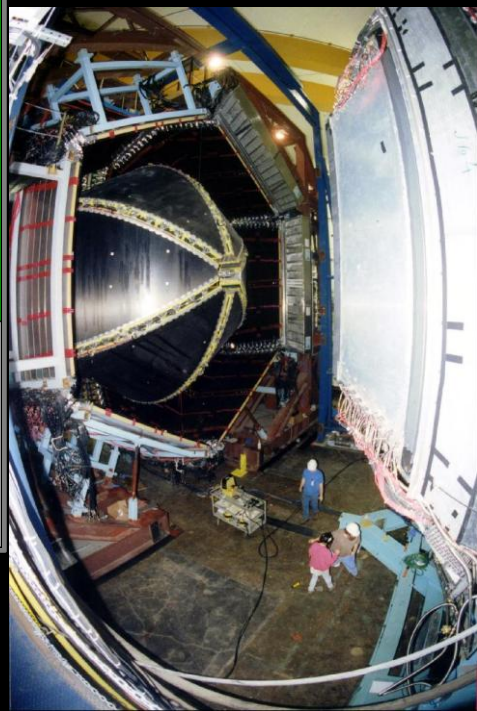


Target + γ
start counter
e mini-torus

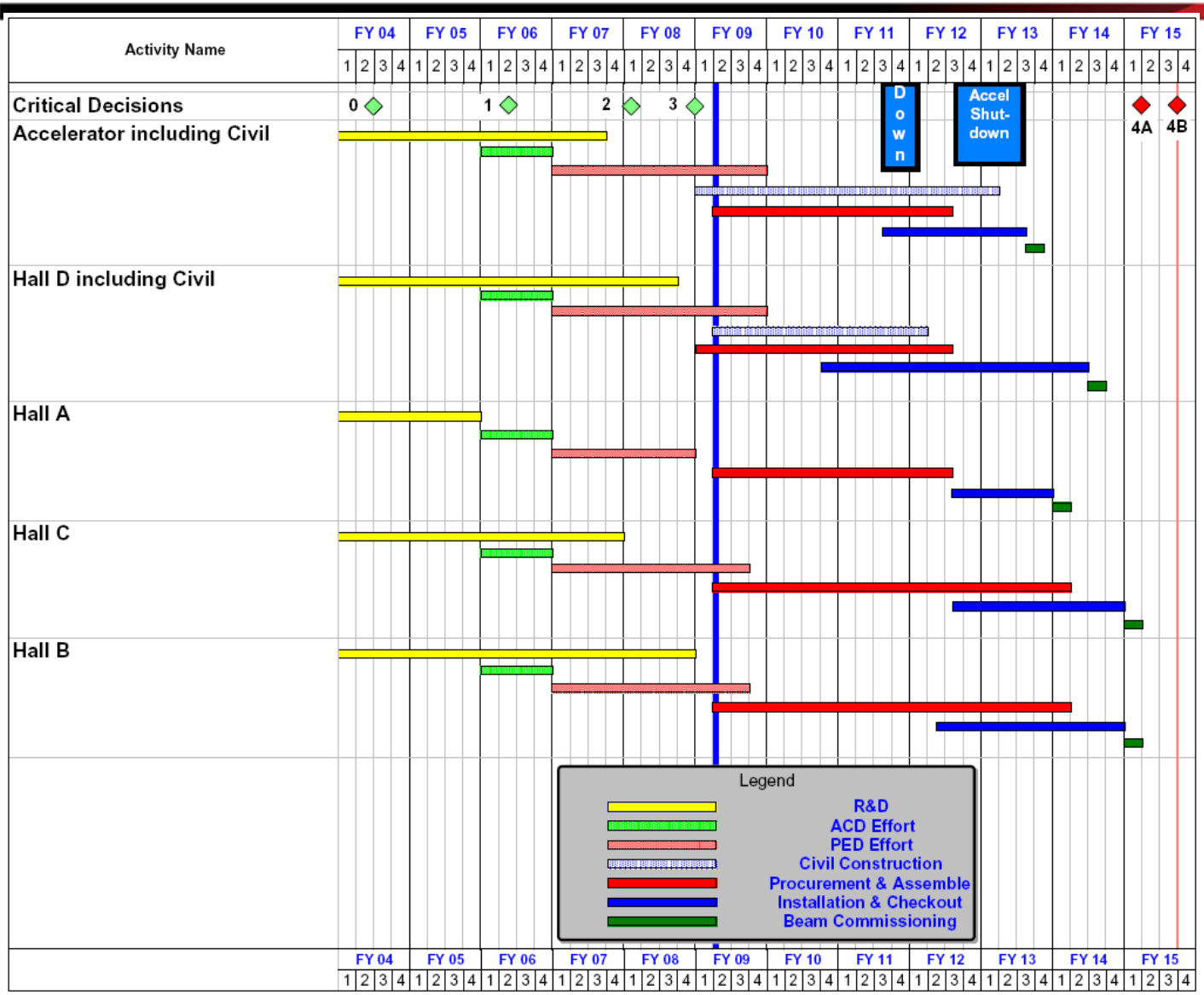
Drift Chamber
35,000 cells

Time of Flight
Plastic Scintillator,
684 PMTs

Cherenkov Counter
e/π separation, 256
PMTs

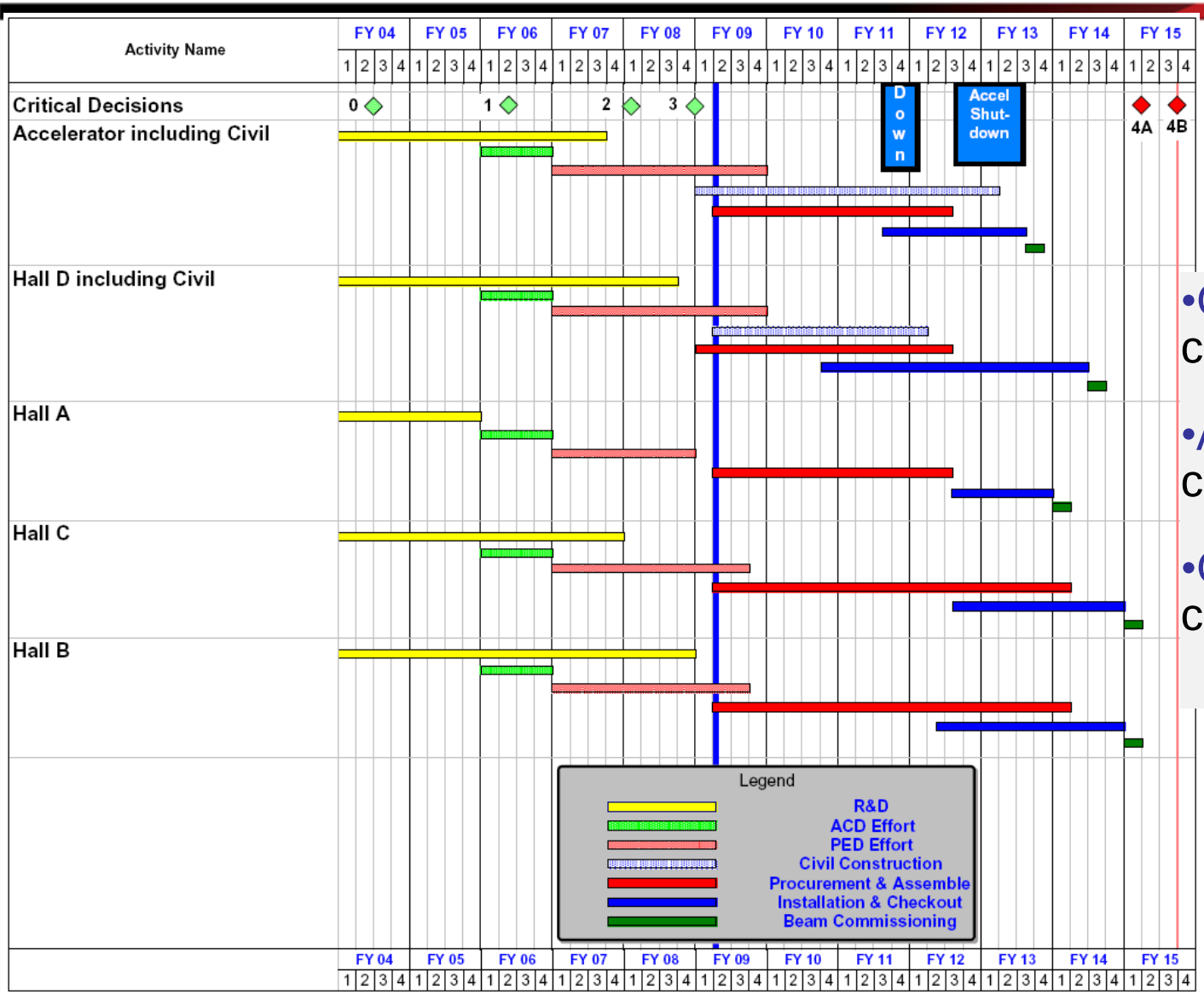


12 GeV Schedule



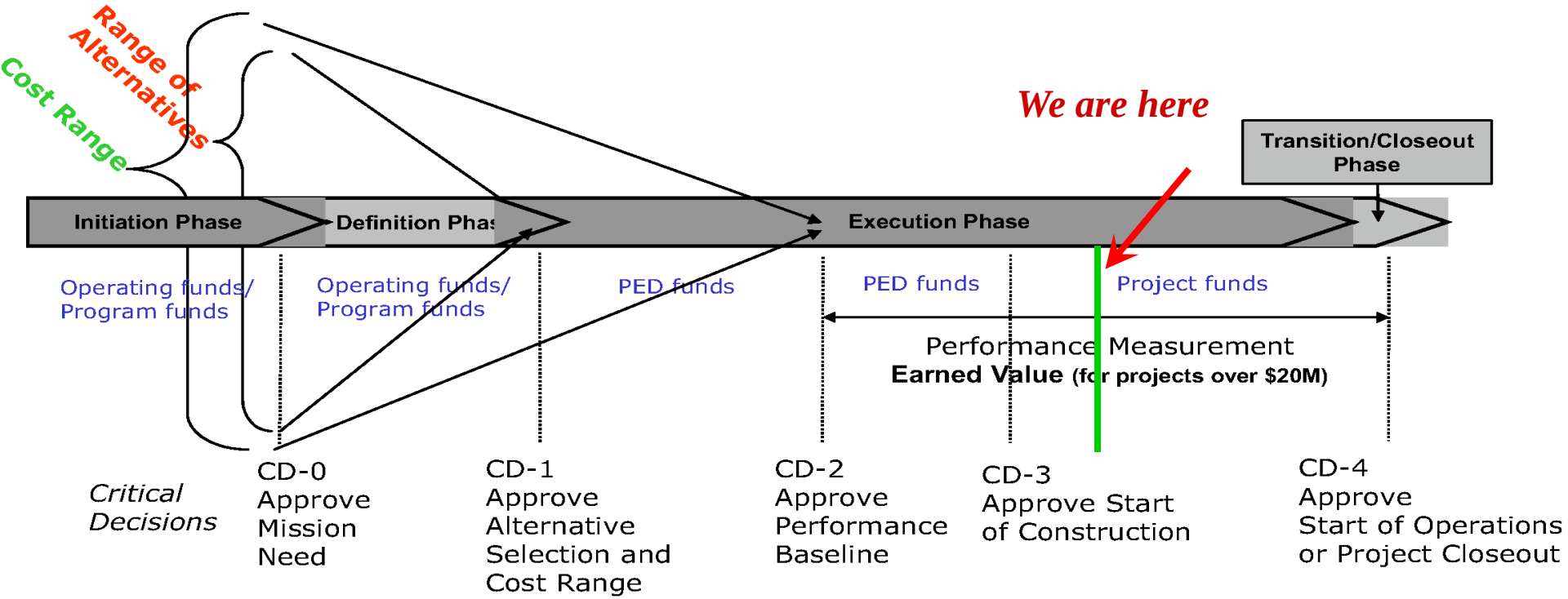
- May '11 - Oct '11
  6-month "down" for initial installations
- Nov '11 - May '12
  6-month run 6GeV
- Jun '12 - May '13:
  1-year "down" for major installation
- June '13 - Sep '13:
  Accelerator commissioning

12 GeV Schedule

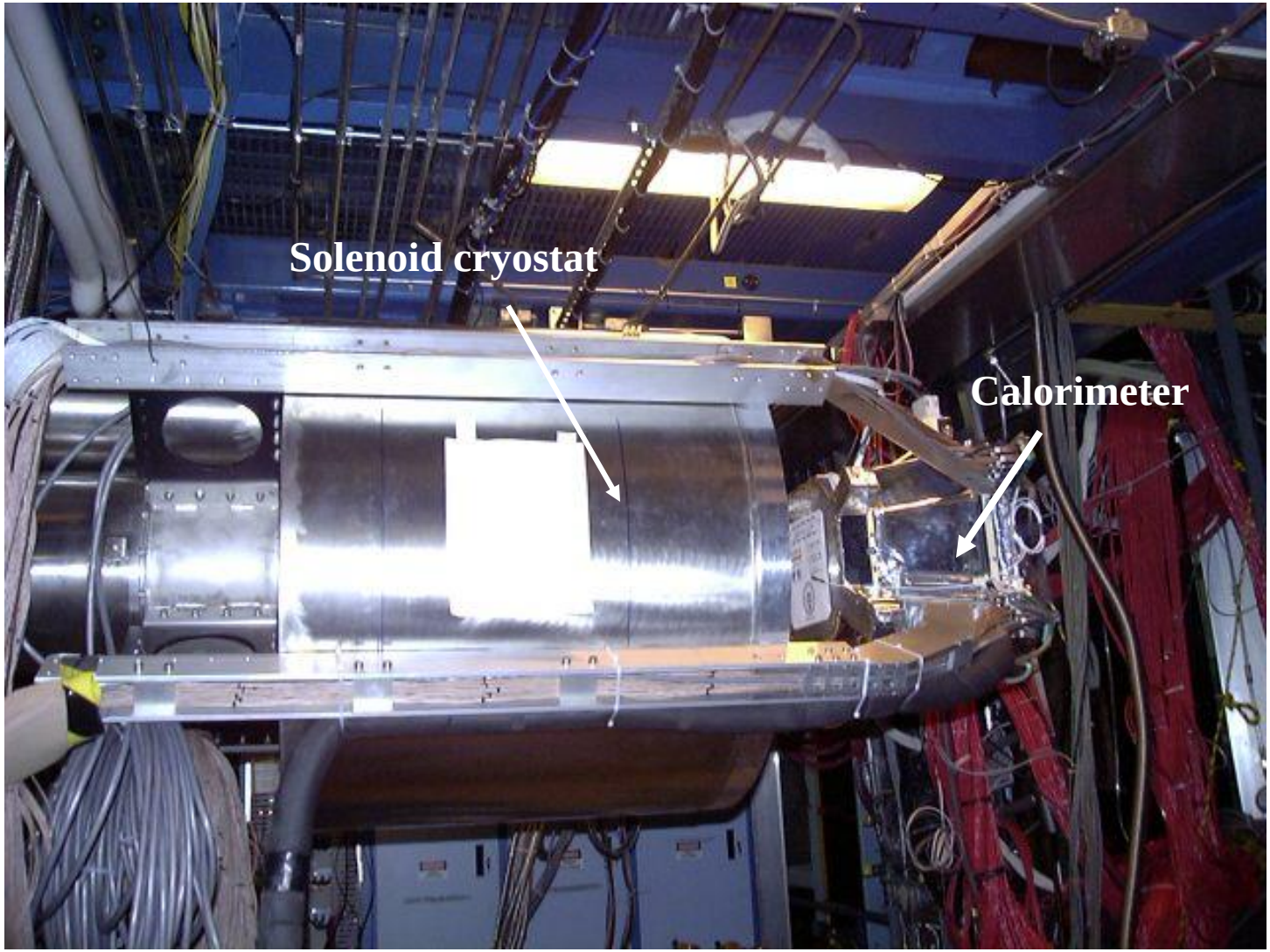


- Oct '13: Hall A commissioning start
- Apr '14: Hall D commissioning start
- Oct '14: Hall B & C commissioning start

DOE Generic Project Timeline



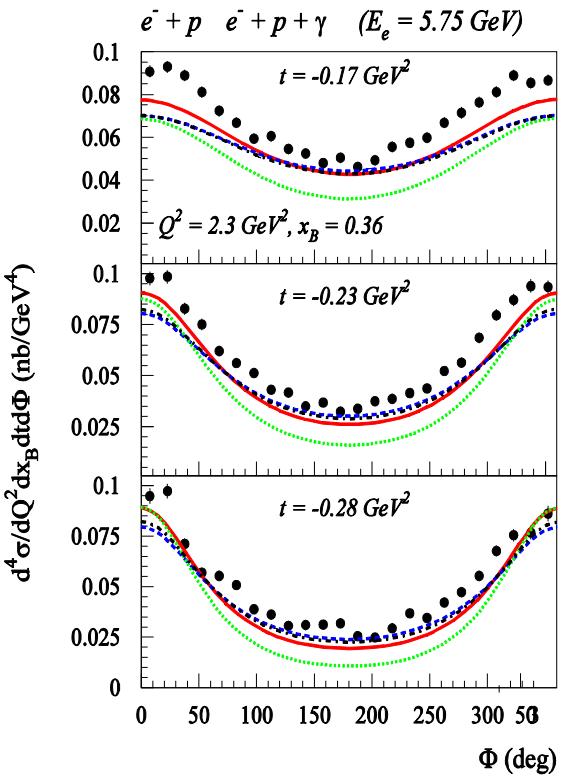
Hall B - DVCS Solenoid and Calorimeter



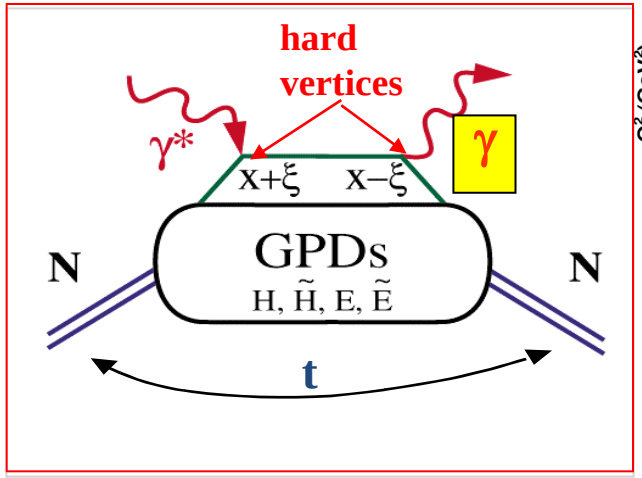
Deeply Virtual Compton Scattering & GPDs

Unprecedented set of Deeply Virtual Compton Scattering data accumulated in Hall A and with *CLAS*

Hall A



Phys.Rev.Lett.97:262002,2006



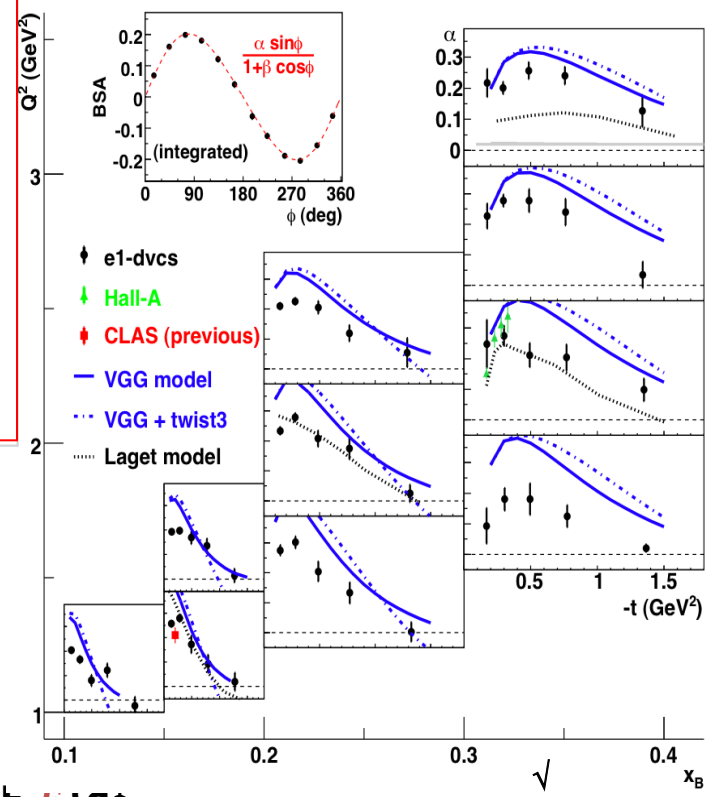
$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta\sigma_{LU}}{2\sigma}$$

Polarized beam, unpolarized target:

Kinematically suppressed

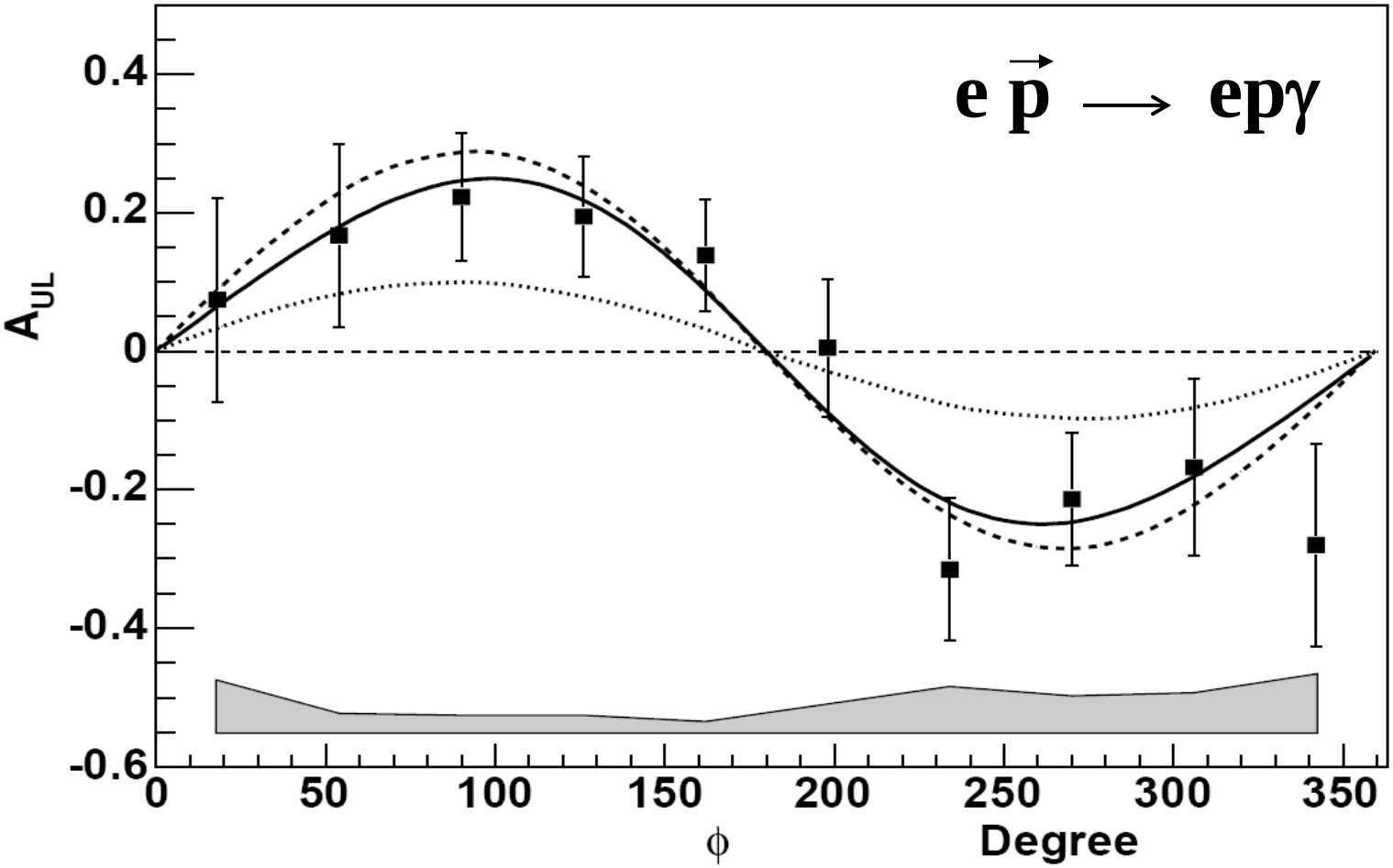
$$\Delta\sigma_{LU} \sim \sin\phi\{F_1 H + \xi(F_1 + F_2)\tilde{H} + kF_2 E\}d\phi$$

CLAS



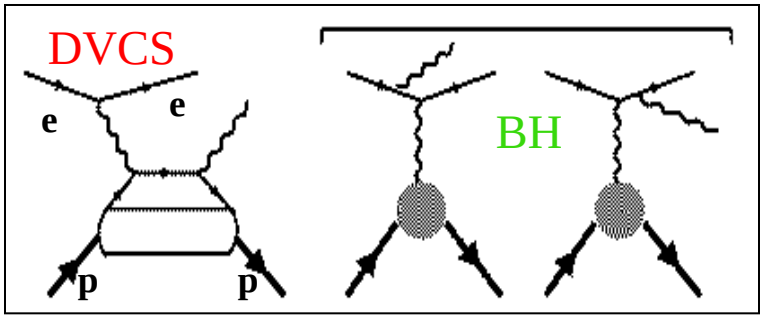
Phys.Rev.Lett.100:162002,2008

First measurement with CLAS



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

Accessing GPDs through DVCS

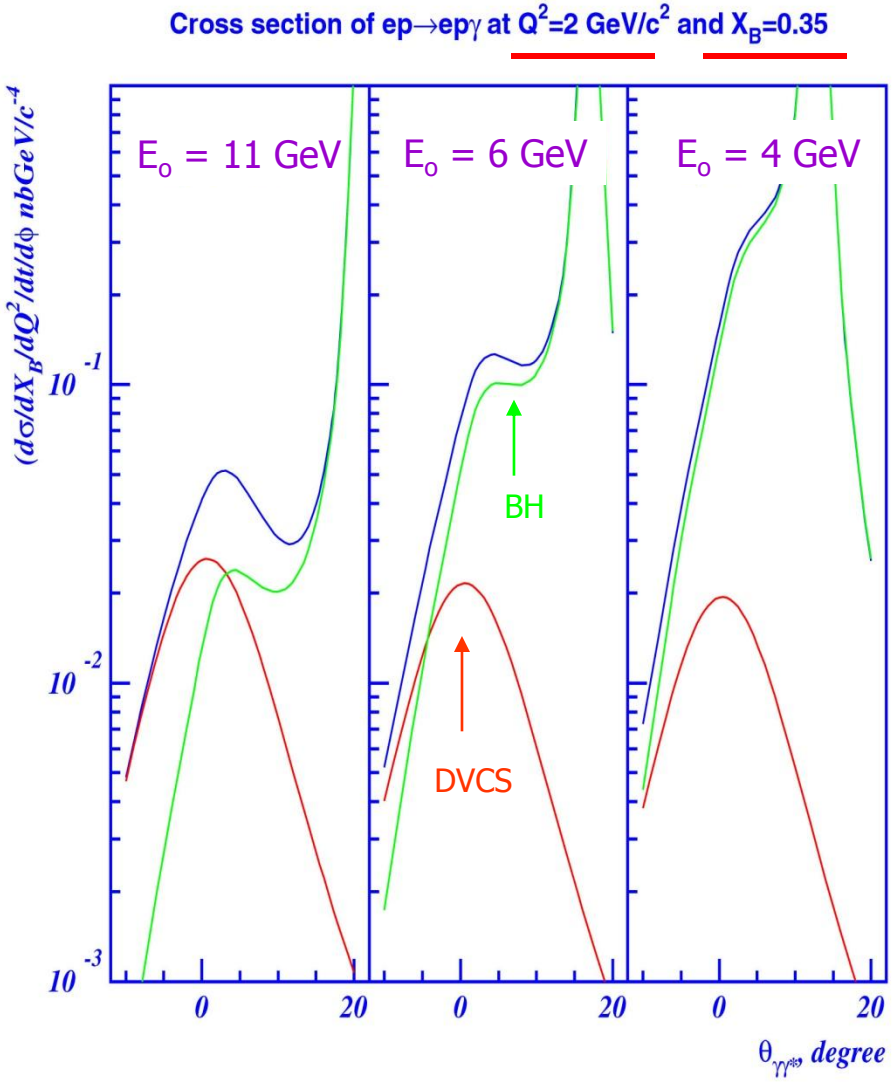


$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} \sim |T^{DVCS} + T^{BH}|^2$$

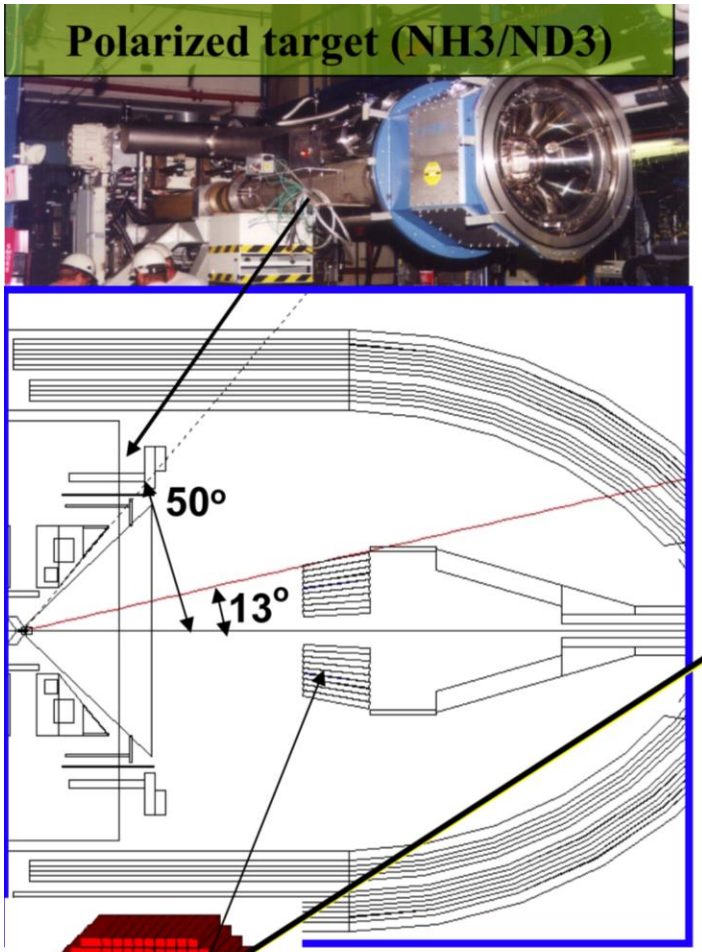
T^{BH}: given by elastic form factors F_1, F_2
T^{DVCS}: determined by GPDs

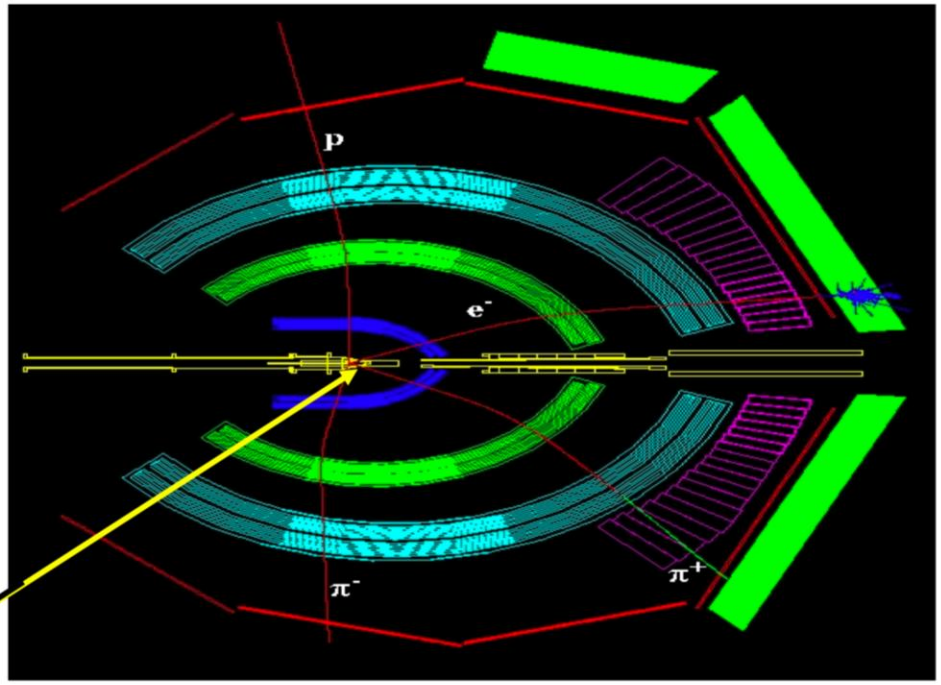
$$I \sim (T^{BH})\mathrm{Im}(T^{DVCS})$$

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

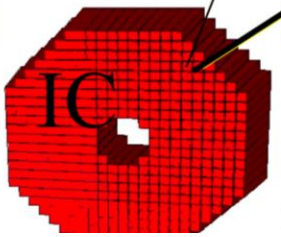


eg1-dvcs setup



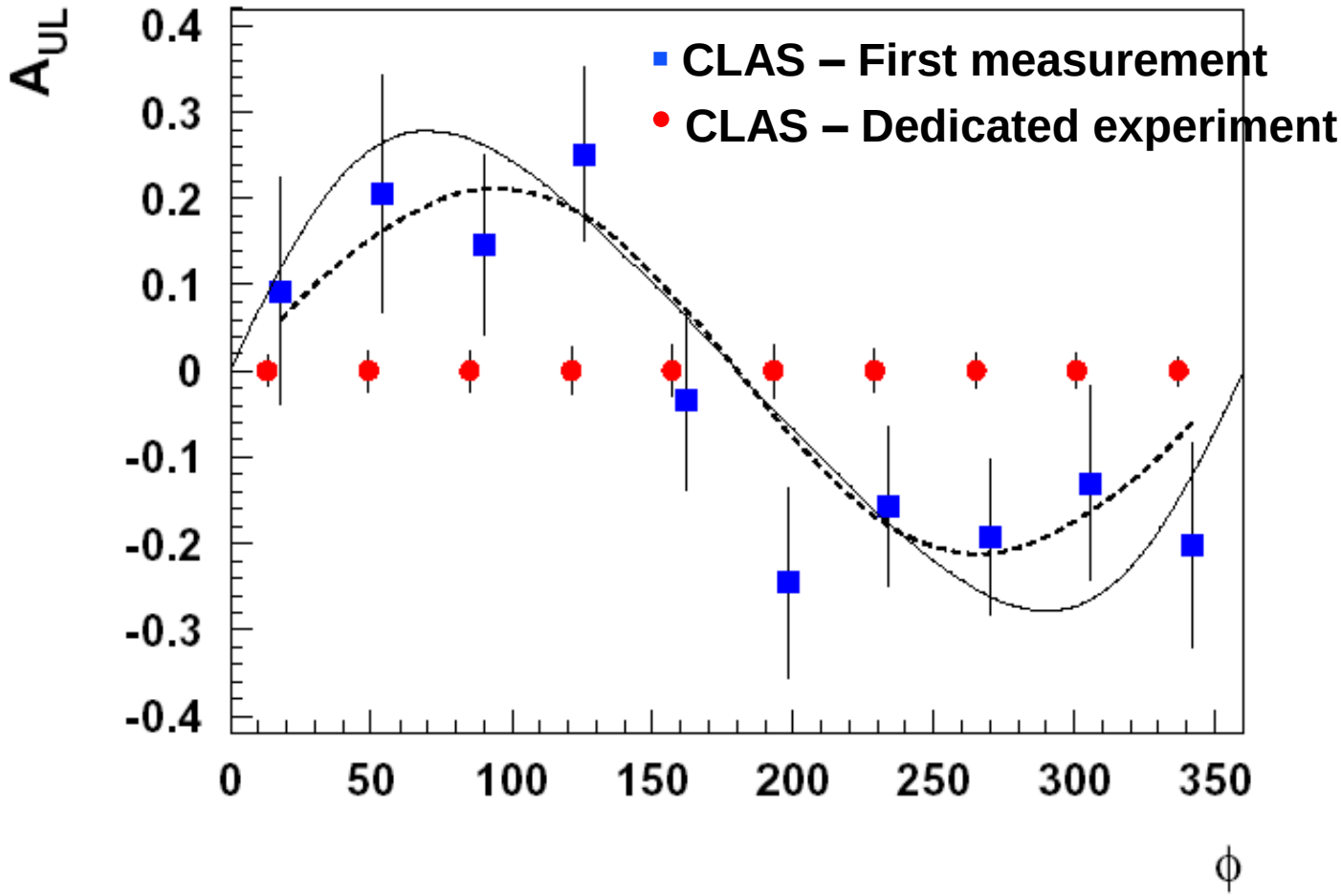


1) Polarized NH3 (2000, 5 days)
2) Polarized NH3/ND3 (2009 30+30 days)



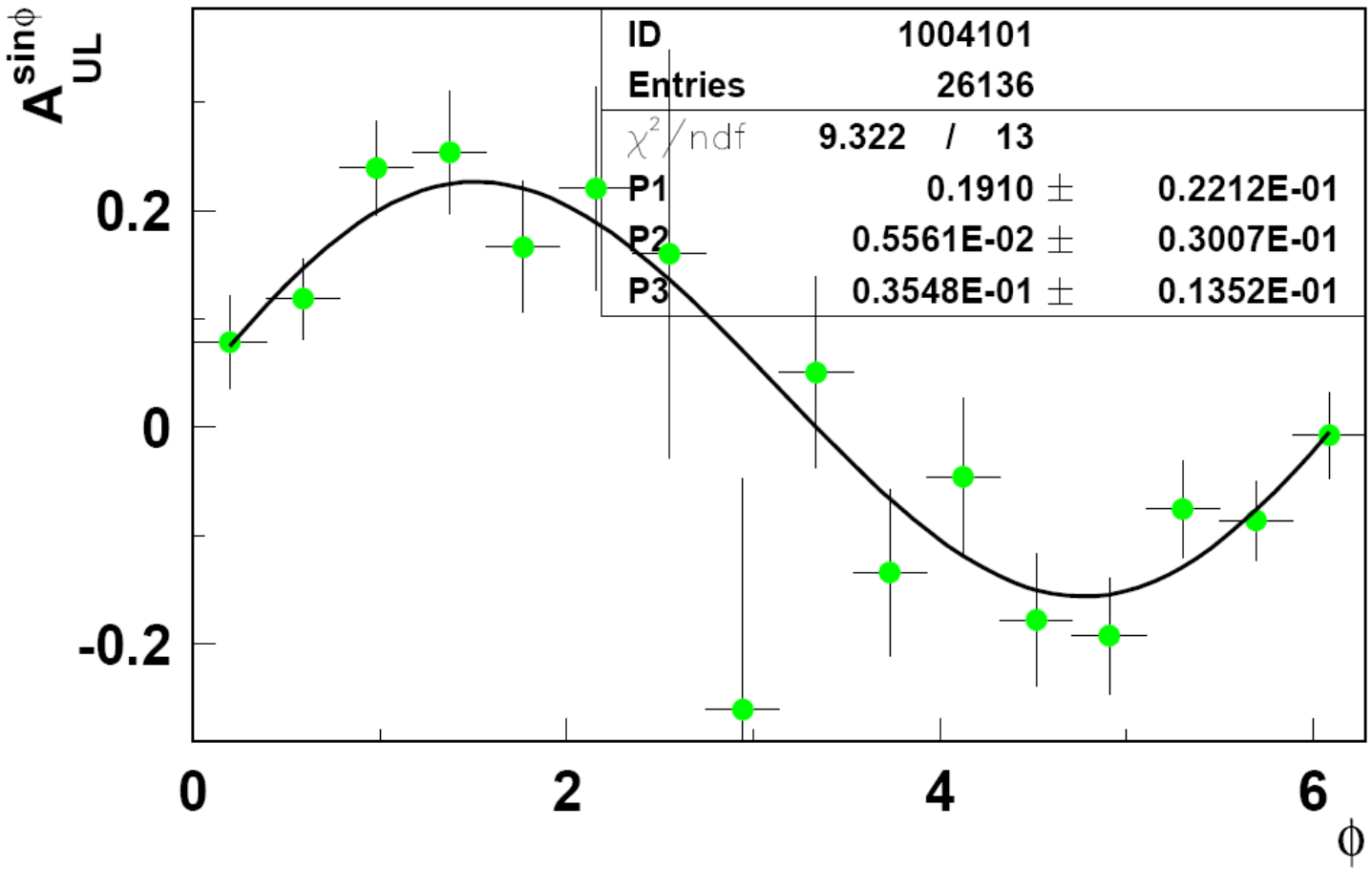
Inner Calorimeter (424 $PbWO_4$ crystals) to detect high energy photons at forward lab angles.

Target Spin Asymmetry: ϕ Dependence



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

Target Spin Asymmetry in DVCS – Preliminary Results



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

CLAS12

- 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

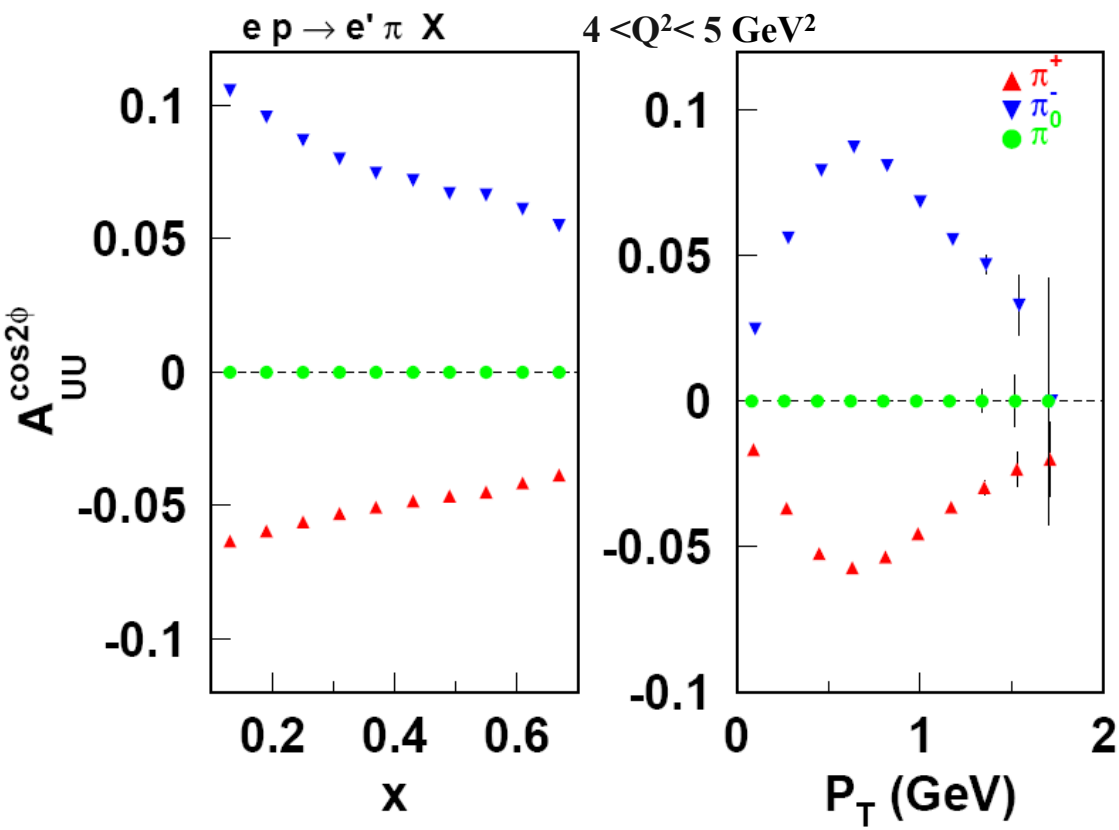
CLAS12

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.

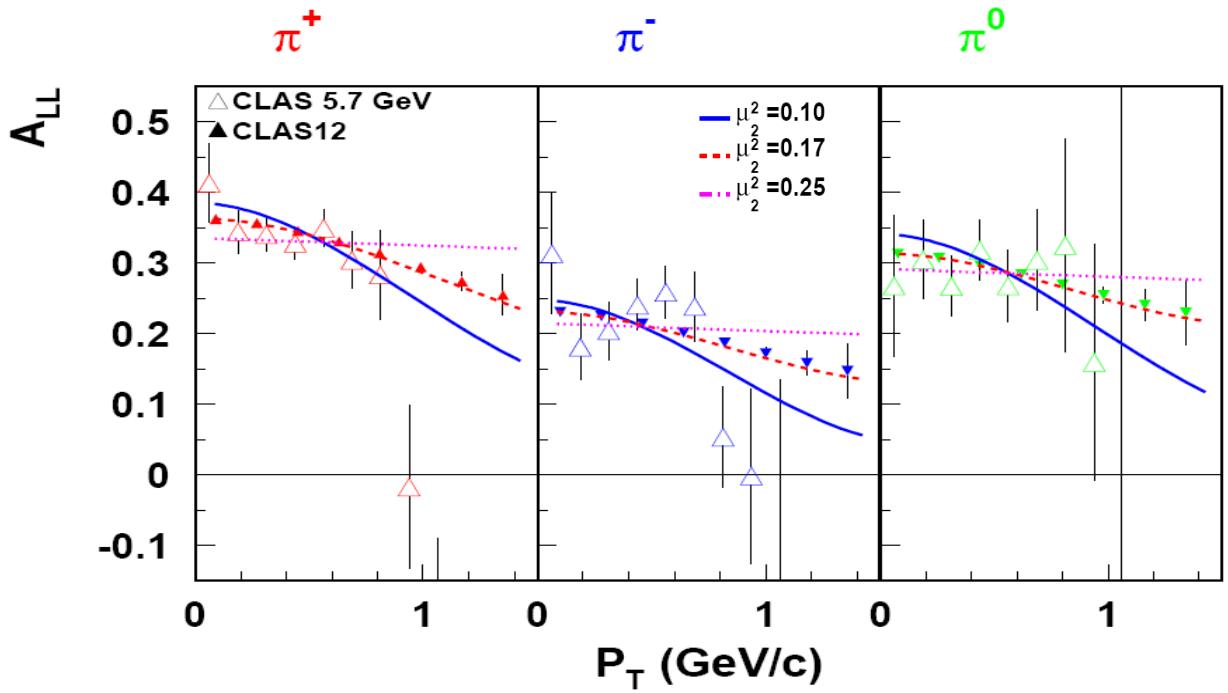


CLAS12

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 $h_{1T}^\perp$

Transverse momentum dependence of longitudinally polarized quarks in longitudinally polarized protons.

M.Anselmino et al
Phys Rev D74:074015 2006



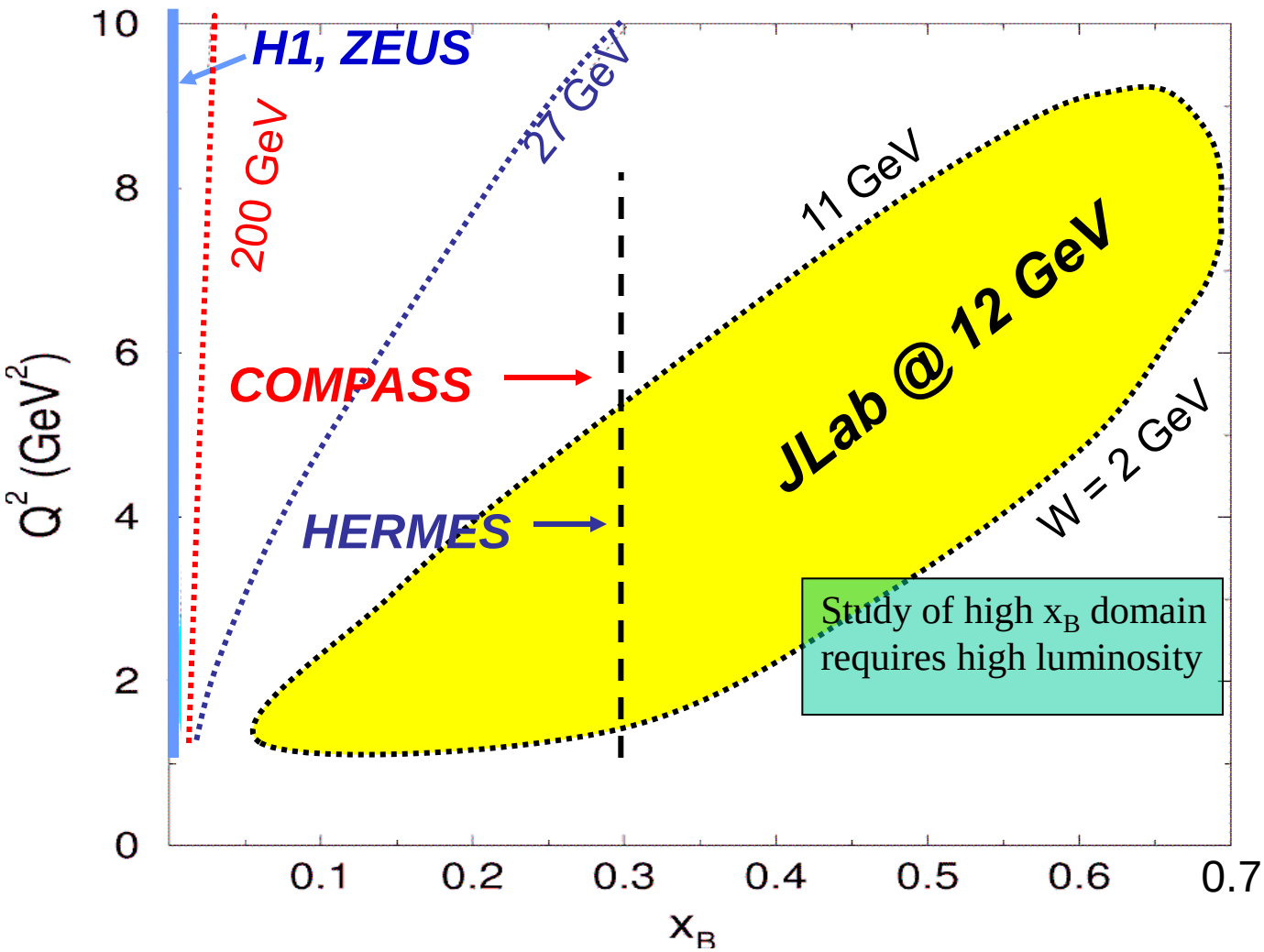
The double polarization asymmetry is sensitive to difference in the K_T distribution of quarks with spin orientation parallel and anti-parallel to proton spin.

- **Current data not sensitive enough to clearly identify the effect. CLAS12 has much more sensitivity and reaches higher P_T**

Scope of the 12 GeV Upgrade

Parameter	Present JLab	Upgraded JLab
Number of Halls	3	4
Number of passes Halls A/B/C	5 (for max energy)	5 (for max energy)
Max Energy to Halls A/B/C	up to ~6 GeV	up to ~11 GeV
Number of passes to Hall D	New Hall	5.5
Energy to Hall D	New Hall	12 GeV
Current – Hall A & C	max ~180 μA combined	max ~85 μA combined (higher at lower energy)
Current – Hall B & D	(B) Up to 5 μA max	(B, D) Up to ~5 μA max each
Central Helium Liquefier (CHL)	4.5 kW	9 kW
# of cryomodules in LINACS	40	50
Accelerator energy per pass	1.2 GeV	2.2 GeV

Deeply Virtual Exclusive Processes - Kinematics Coverage of the 12 GeV Upgrade



Hall B Overview

- **Hall B currently houses the CLAS detector. CLAS is a large acceptance detector and will be modified and upgraded to *CLAS12*, which will be worldwide the only large acceptance, multi-purpose detector for fixed target electron scattering experiments.**

- ***CLAS12* is expected to operate with an upgraded luminosity of $L=10^{35}cm^{-2}s^{-1}$, more than an order of magnitude increase over CLAS, and with improved particle identification.**

- **With these capabilities *CLAS12* will support a broad experimental program in fundamental nuclear physics.**

Present-day CLAS

CLAS12 - Initial 12 GeV Physics Program

- **GPD's and 3D-Imaging of the Nucleon**
  - **Deeply Virtual Compton Scattering - DVCS**
  - **Deeply Virtual Meson Production at low/high t**
- **Valence Quark Distributions**
  - **u- and d-Quark Spin Distributions in Proton and Neutron**
  - **Neutron Structure Function $F_{2n}(x,Q^2)$, d/u**
  - **TMD Quark Distribution Functions in SIDIS**
- **Form Factors and Resonance Excitations**
  - **The Magnetic Structure of the Neutron – G_{Mn}**
  - **N* Transition Form Factors at high Q^2**
- **Hadrons in the Nuclear Medium**
  - **Space-Time Characteristics of Quark Hadronization**
  - **Color Transparency**
  - **Short Distance Dynamics of Light Nuclei**
- **Spectroscopy of Strange Baryons**

CLAS12 - PAC approved proposals

Proposal	Physics	Experiment days
E12-06-119a	DVCS with polarized beam	80
E12-06-112	$ep \rightarrow e\pi^{+/-/0} X$	60
E12-06-108	DVMP in π^0,η production and L/T separation	120
E12-06-119b	DVCS on polarized target	120
E12-06- 109	Nucleon Spin Structure Functions	80
E12-07-107	Single Spin Asymmetries	103
E12-06-106	Color Transparency ρ^0	40
E12-06-117	Quark Hadronization	60
E12-07-104	Neutron magnetic form factor	56
Total		719

CLAS12 – Upgrade Goals

Capabilities to measure exclusive processes at 12 GeV

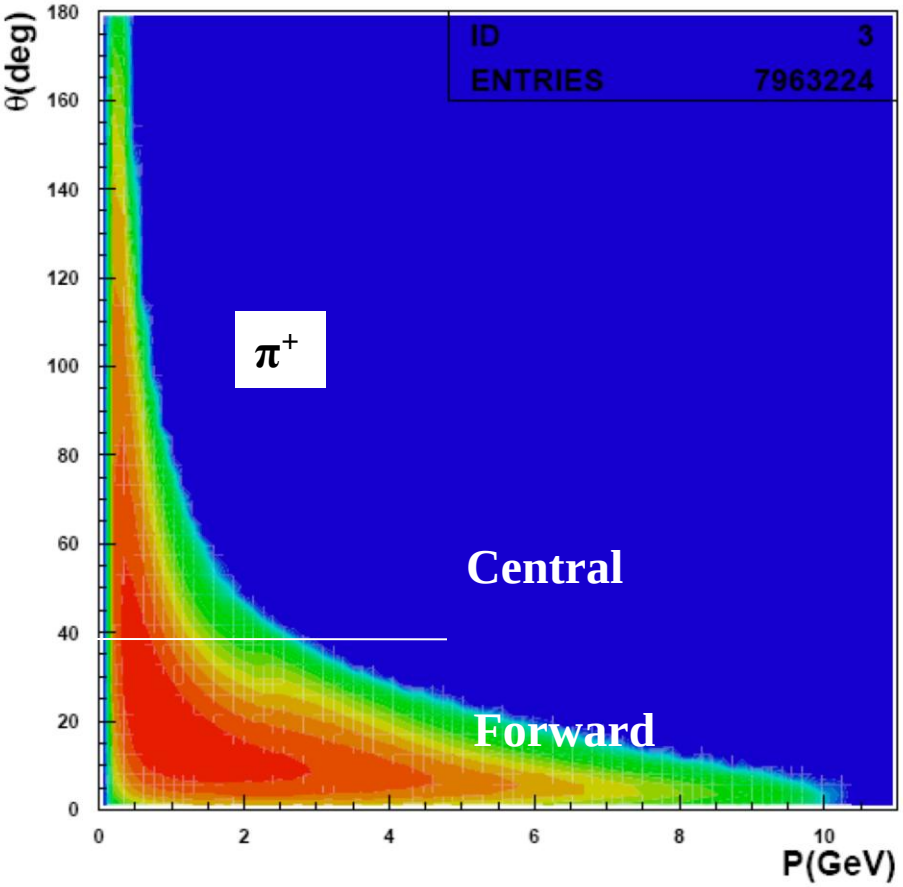
- **Operating luminosity up to 10^{35} $cm^{-2}sec^{-1}$**
- **Particle ID to higher momentum (e^-/π^-, π/K-p, γ/π^o)**
- **Momentum & angle resolution for use of missing mass techniques**
- **Coverage of large range in polar and azimuth angle**
- **Identify detached vertices**

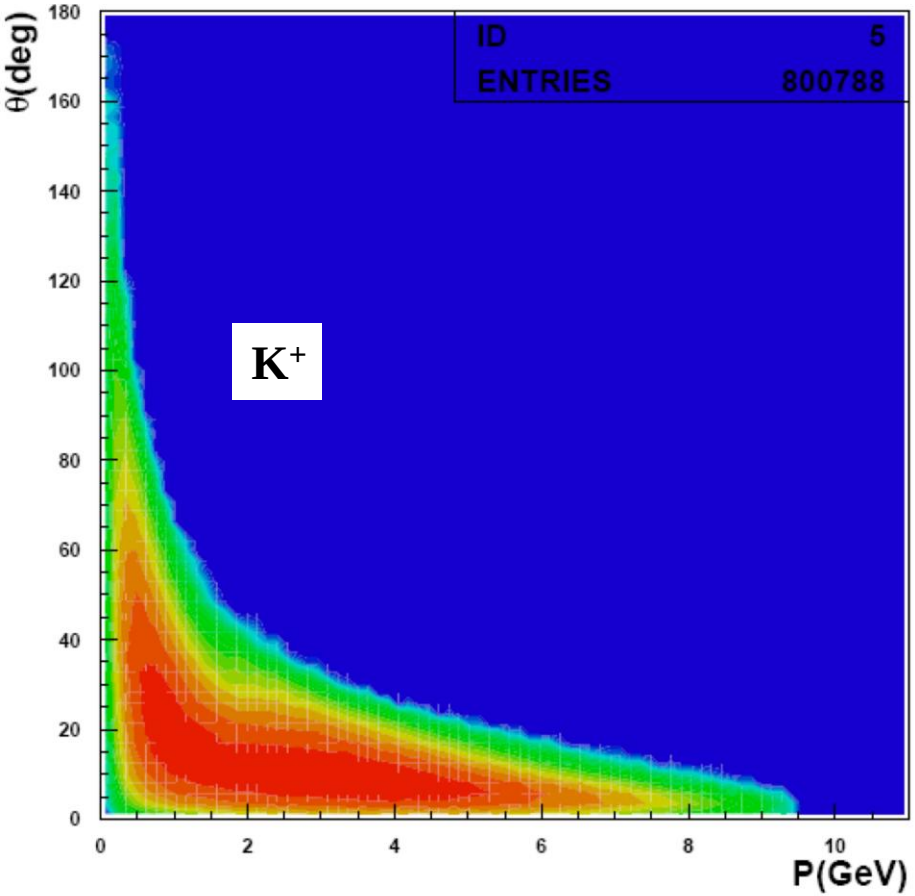
Solution:

- **Reduce DC occupancies to reach higher luminosities**
  - **Move DC's further downstream reducing solid angle seen by each cell**
  - **Improved magnetic shielding for Møller background electrons**
- **Upgrade the forward PID system**
  - **Additional threshold Cherenkov detector**
  - **Timing resolution of the Time-of-Flight detectors**
  - **Calorimeter granularity for π^o/γ separation**
  - **Add tracking capabilities for improved vertex resolution**
- **Complement the forward detection system with central detector**
  - **Tracking and magnetic analysis at large angles**
  - **Particle identification capabilities**
  - **Operation of a dynamically polarized target**

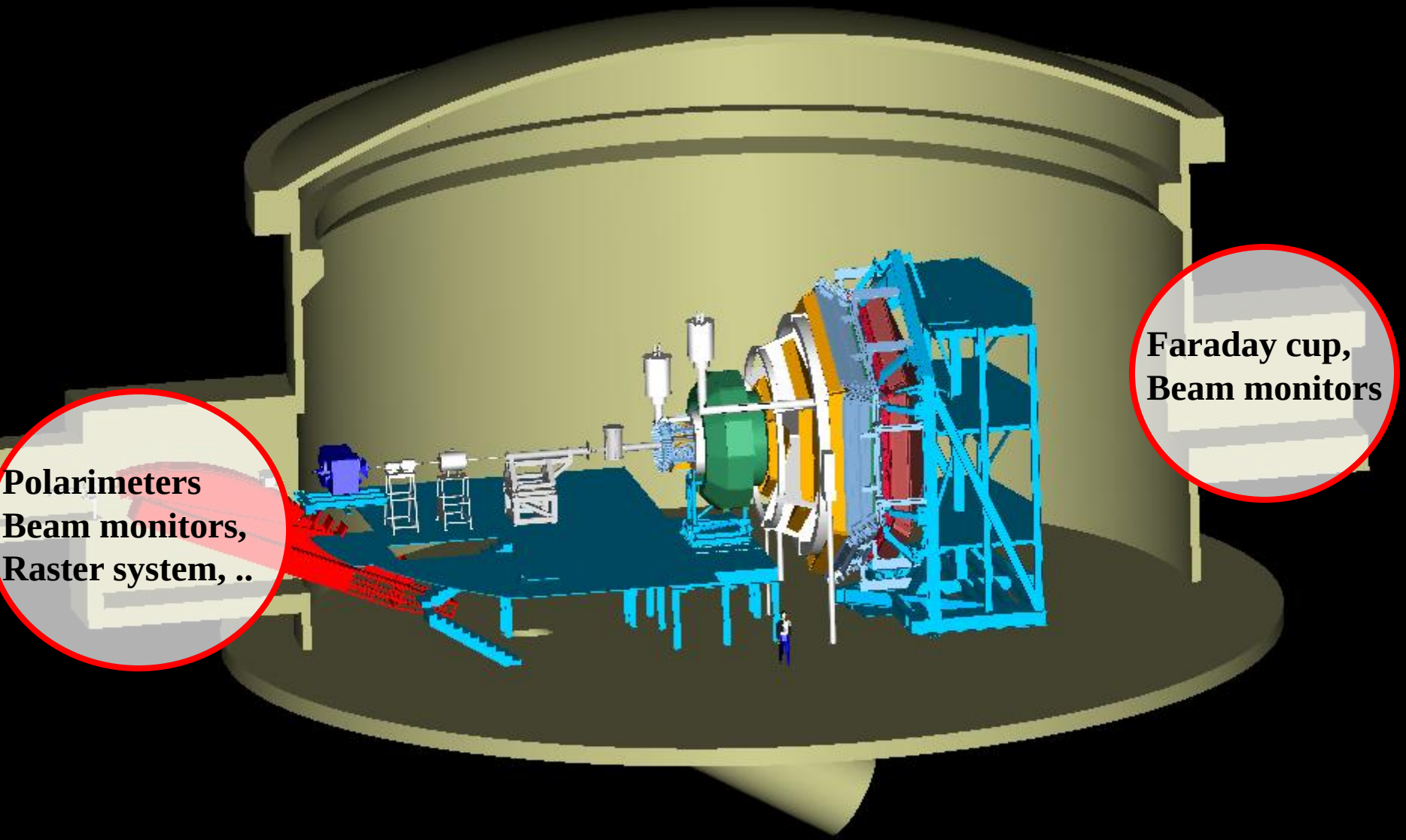
Distribution of π^+, K^+ in DIS Kinematics

$$e^-p \rightarrow e^-hX,\ h=\pi^+, K^+$$





CLAS12 in Hall B



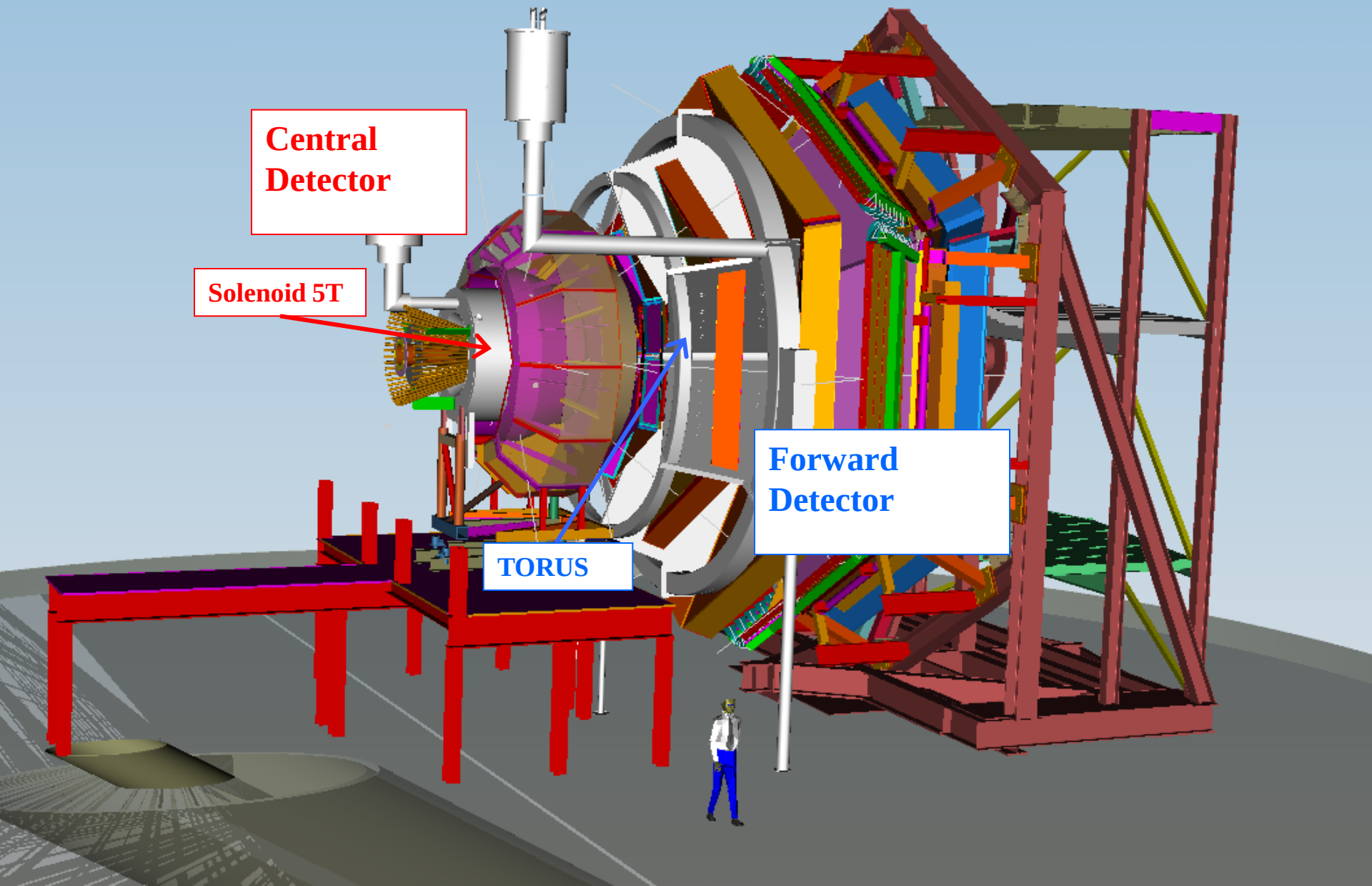
Utilization of existing Hall B Equipment

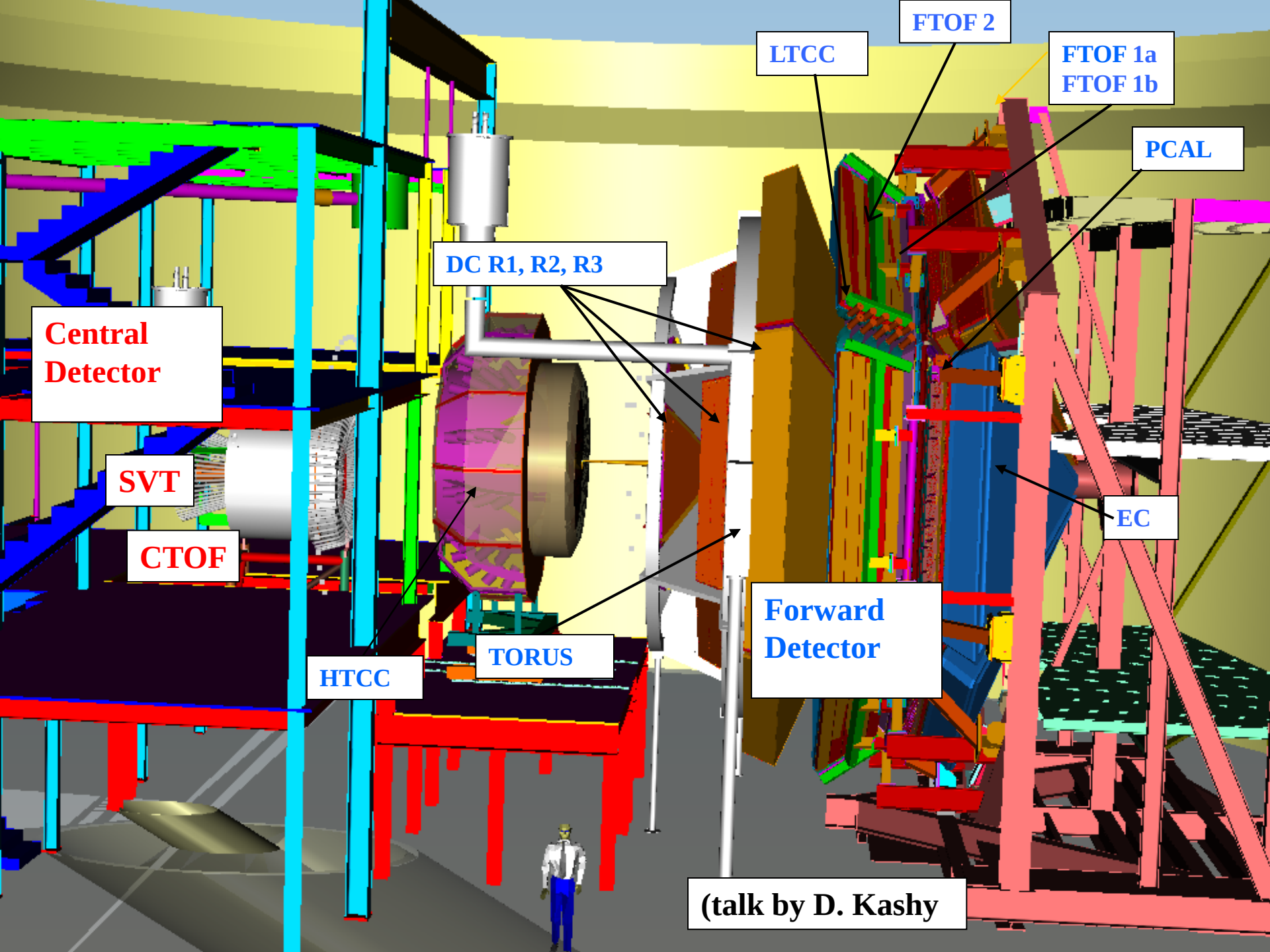
- **Re-use existing CLAS detector components**
  - **Forward electromagnetic calorimeters**
  - **Low threshold gas Cherenkov counters**
  - **Time-of-flight scintillators**
  - **Drift chamber electronics and gas system**
  - **Inner $PbW0_4$ small-angle calorimeter**
  - **DAQ and readout electronics**

- **Re-use other Hall B components**
  - **Cryogenic targets**
  - **Møller polarimeter**
  - **Raster magnets & power supplies**
  - **Faraday cup**
  - **Beam diagnostics**
  - **Photon energy tagging system**
  - **Coherent bremsstrahlung/goniometer**
  - **Frozen spin polarized target**
  - **Pair spectrometer magnet & power supplies**
  - **Utility distribution & space frames**

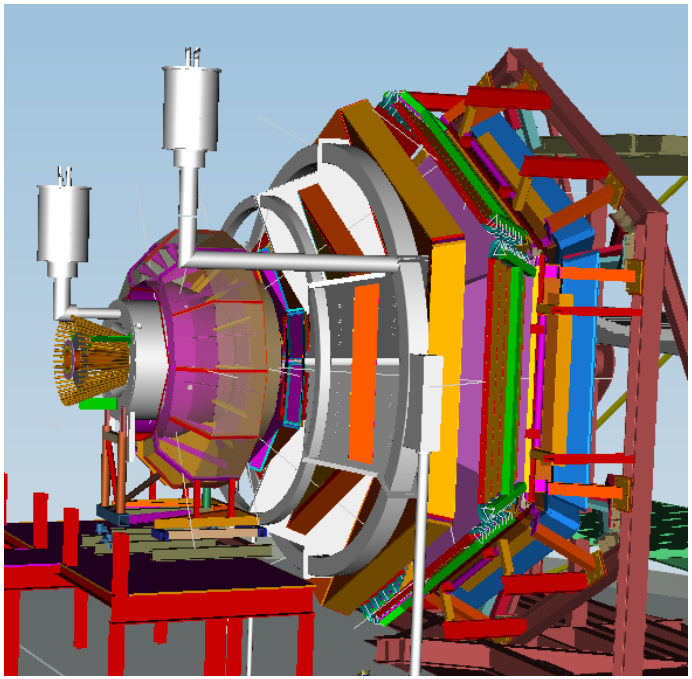
Equivalent to $26.5M assuming 2.3% escalation rate

CLAS12 - Detector




FTOF 2
LTCC
FTOF 1a
FTOF 1b
PCAL
DC R1, R2, R3
Central Detector
SVT
CTOF
EC
Forward Detector
TORUS
HTCC
(talk by D. Kashy

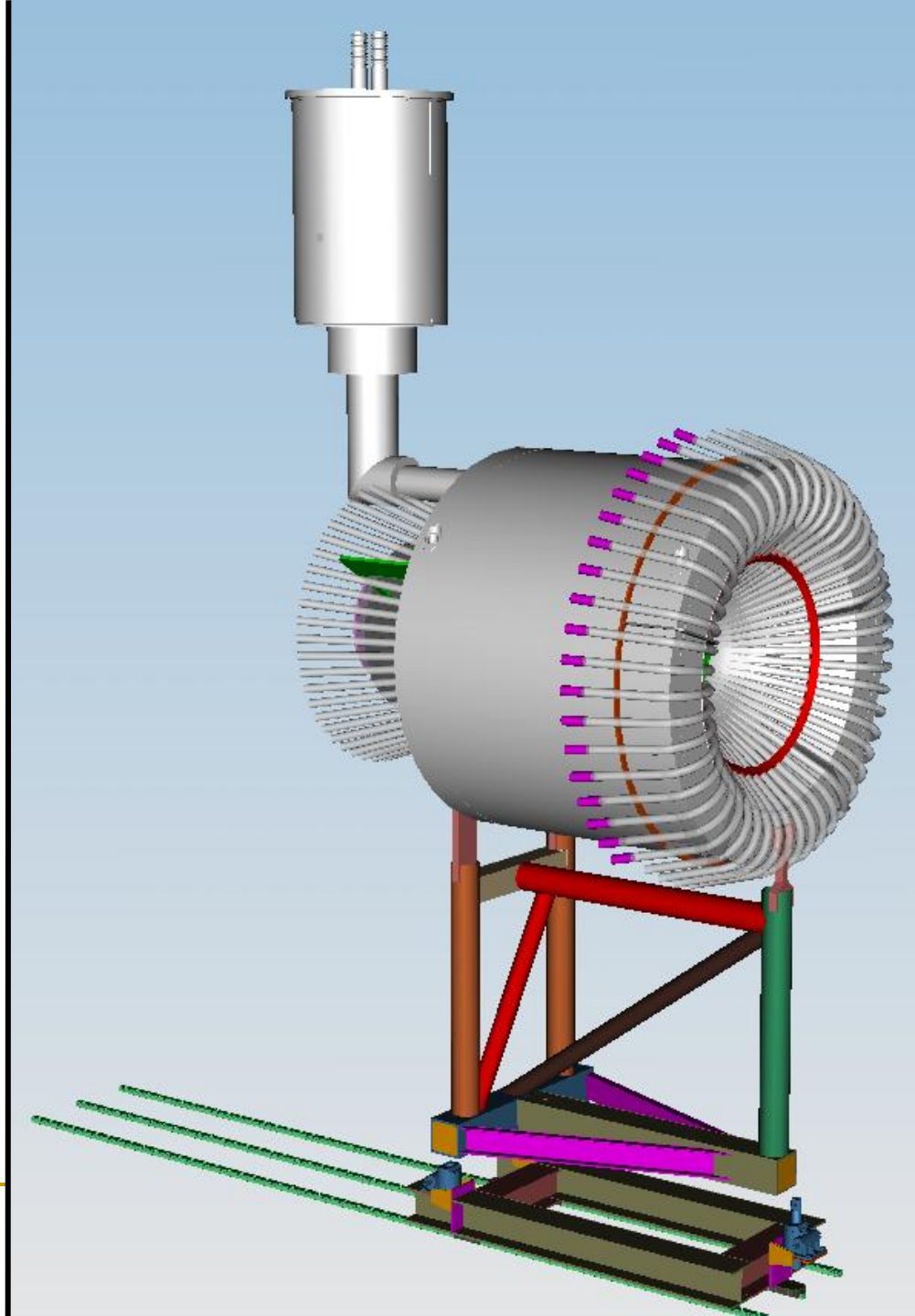
CLAS12 – Design Parameters



	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		
N_{eff}	< 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
$\pi^0 \rightarrow \gamma\gamma$	Full range	n.a.
$\eta \rightarrow \gamma\gamma$	Full range	n.a.

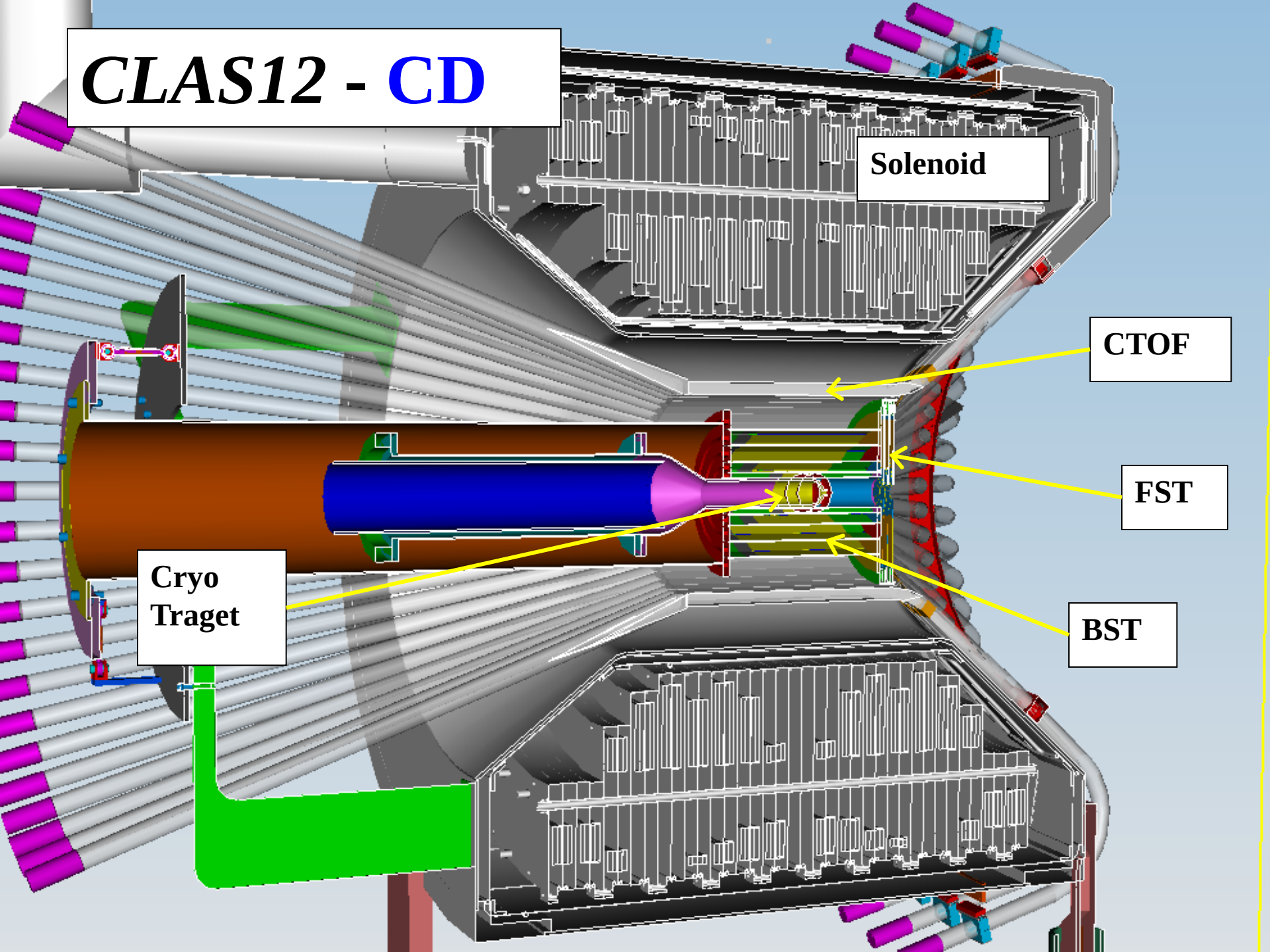
CLAS12
Central Detector

- Superconducting 5T Solenoid Magnet, w/ 78cm ø warm bore.
- Central scintillator array (CTOF).
- Silicon Vertex Tracker, barrel part (BST), forward part (FST).
- Space for cryogenic target.



OFFICE OF SCIENCE

CLAS12 - CD

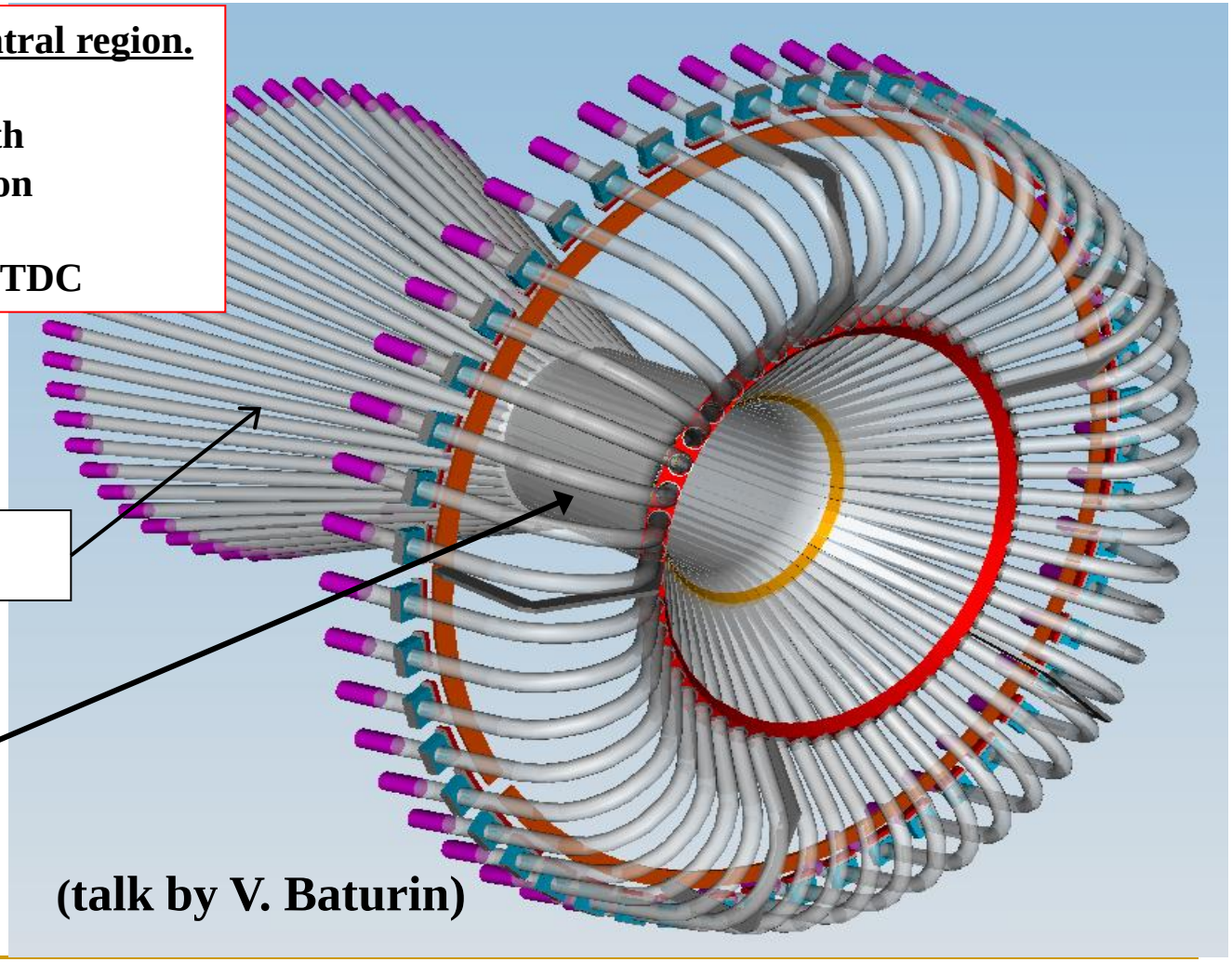


CLAS12 - Central Time-of-Flight Counter

Charged Particle ID in central region.

50 plastic scintillators with trapezoidal cross section

100 channels PMT, fADC, TDC



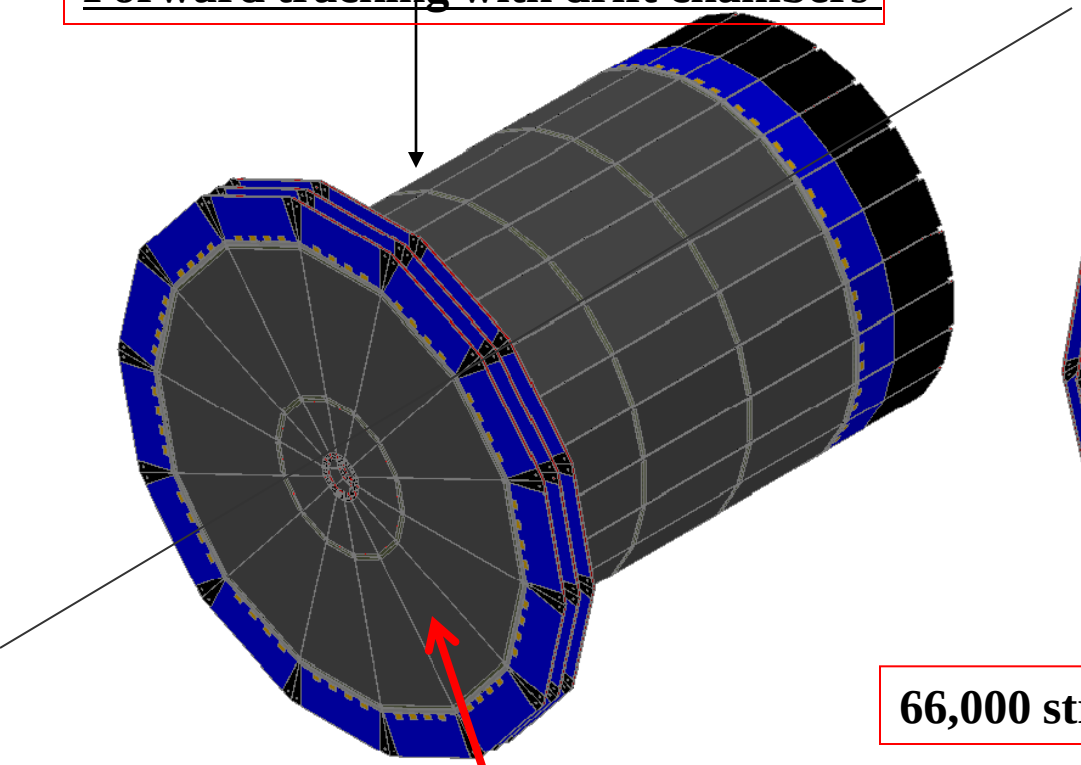
Light guides

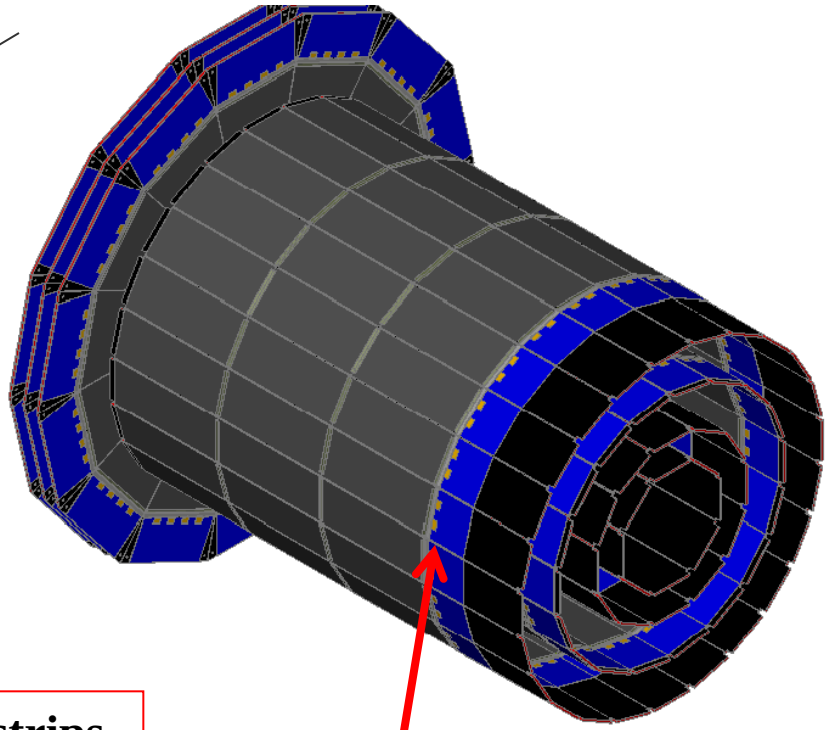
Scintillator

(talk by V. Baturin)

CLAS12 – Silicon Vertex Tracker

Central tracking in solenoid magnet
Forward tracking with drift chambers



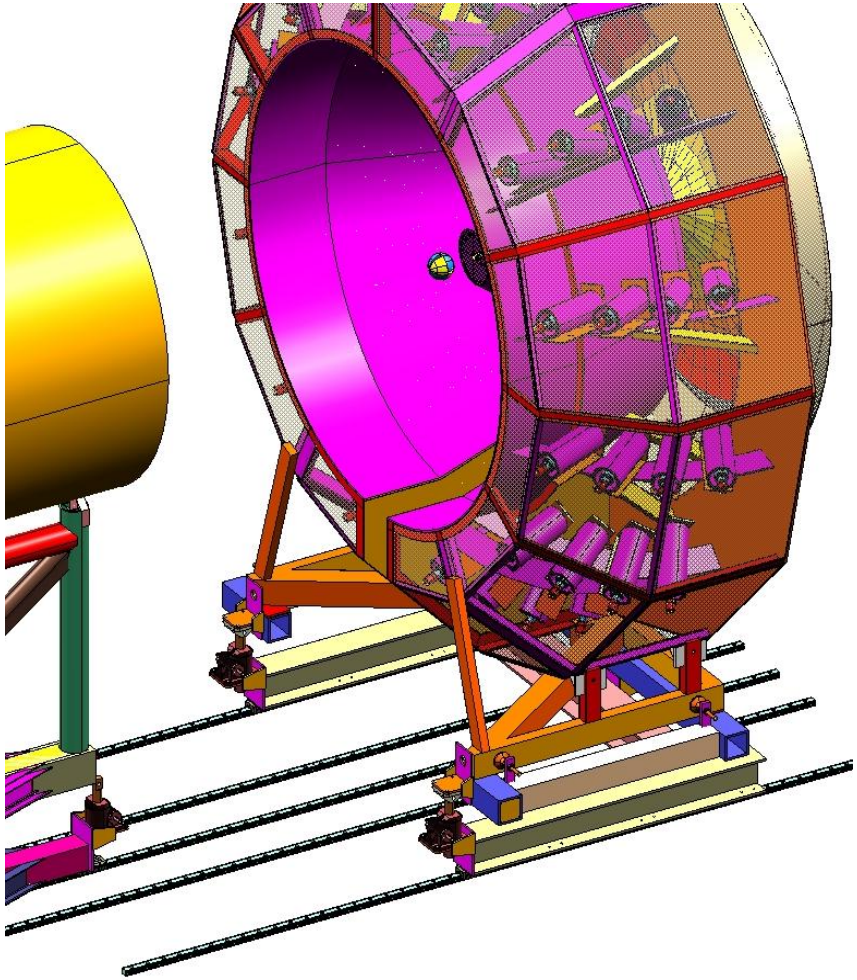


66,000 strips

Forward part, 6 stereo layers ±12°
With forward DC systems provide vertex

Barrel part, 8 stereo layers w/ 3°
Standalone Tracking in 5T magnetic field

CLAS12 - High Threshold Cerenkov Counter (HTCC)

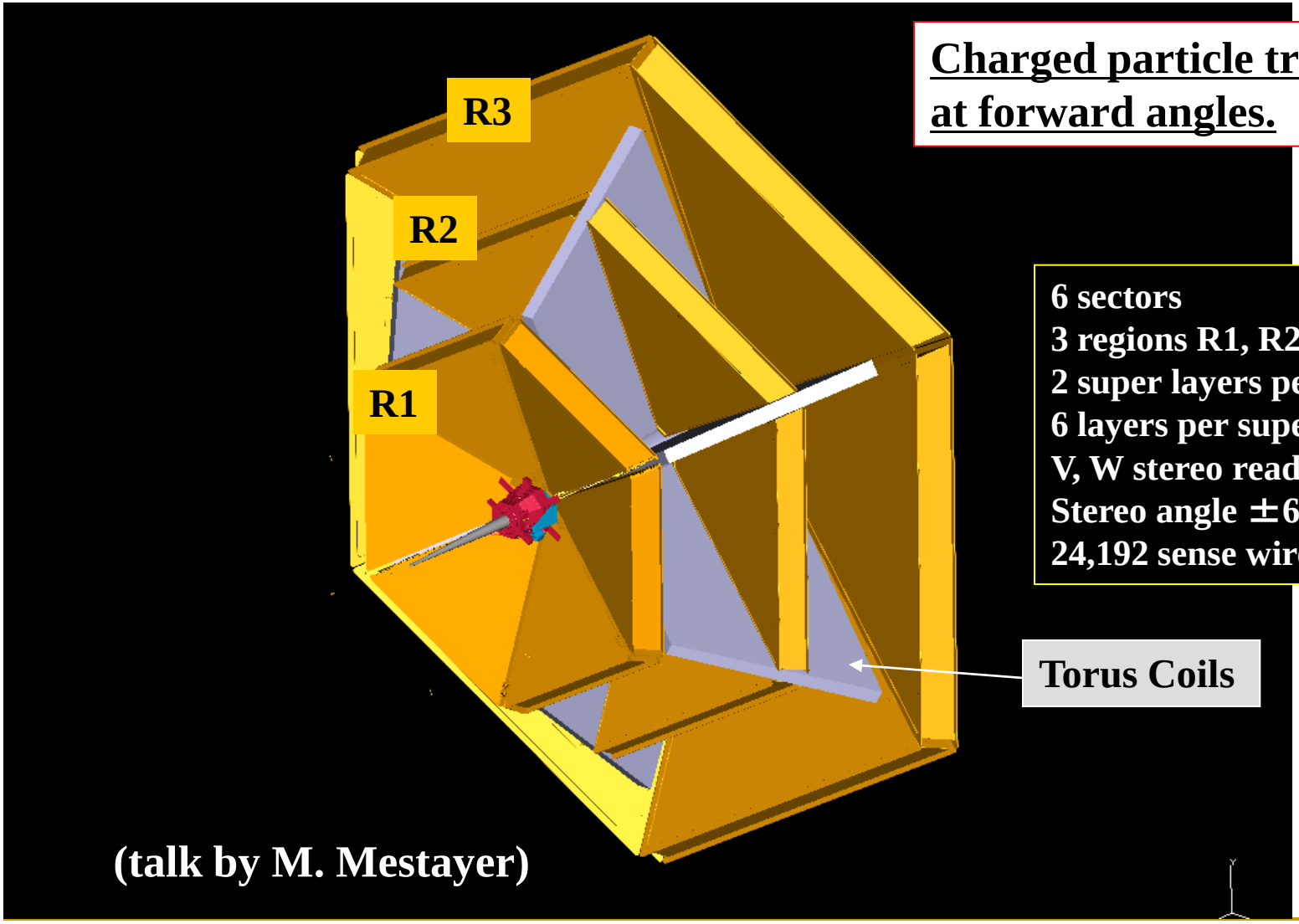


<u>Electron identification up to 5GeV/c</u>
<u>π/K.p separation > 5 GeV/c</u>
<u>Level 1 Trigger</u>

Radiator gas:	**CO_2 @ 1 atm**
π threshold:	**4.9 GeV/c**
π rejection:	**200**
# of PMTs (5”):	**48**
# sectors:	**12**
Mirror weight:	**< 200mg/cm^2**

(talk by S. Stepanyan)

CLAS12 - Forward Drift Chambers

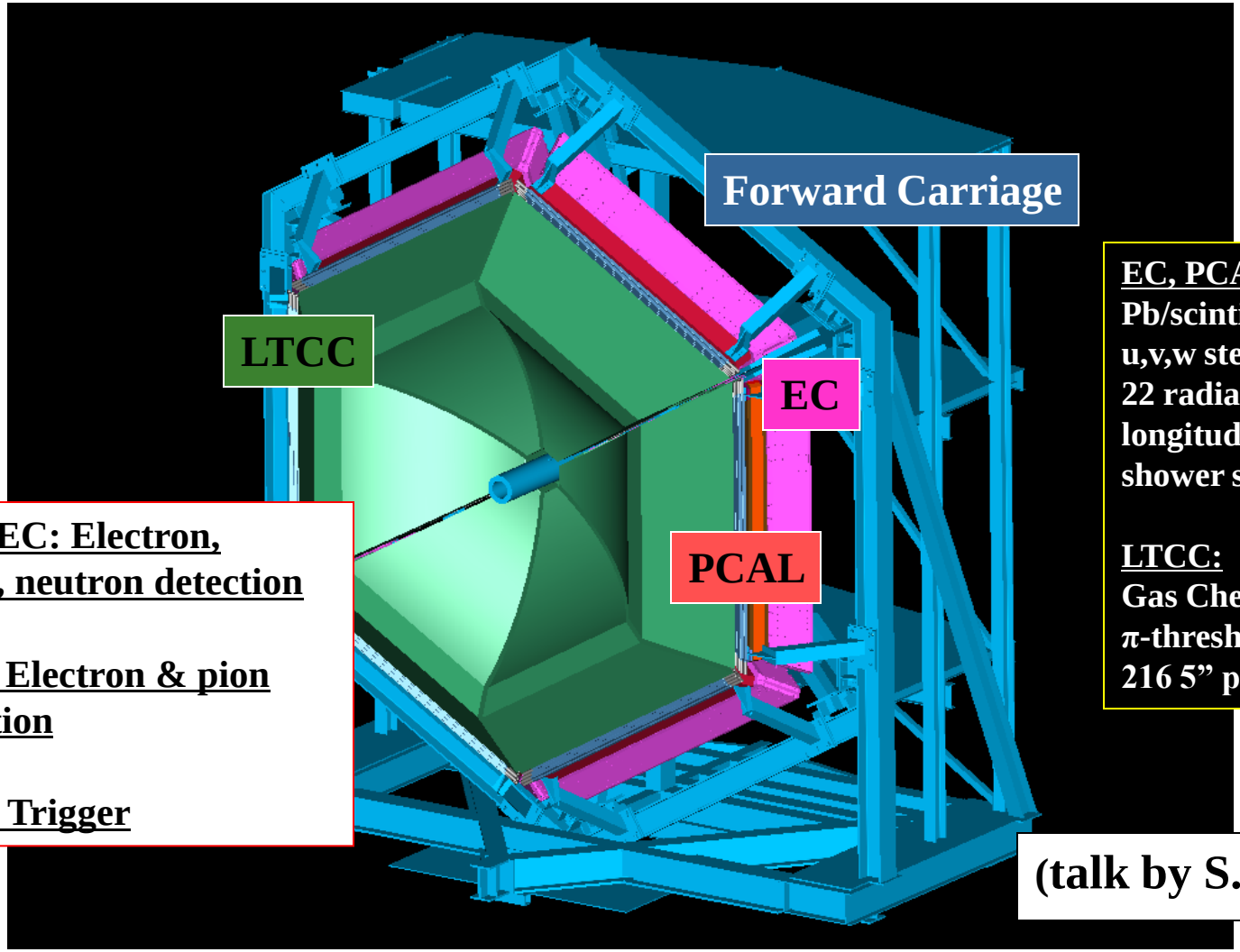


Charged particle tracking at forward angles.

6 sectors
3 regions R1, R2, R3
2 super layers per region
6 layers per super layer
V, W stereo readout
Stereo angle ±6 degrees
24,192 sense wires

(talk by M. Mestayer)

CLAS12 - Forward Carriage



EC, PCAL:
Pb/scintillators sandwich
u,v,w stereo readout
22 radiation lengths
longitudinal/transverse shower sampling

LTCC:
Gas Cherenkov counter
π-threshold: 2.7 GeV/c
216 5" photomultipliers

PCAL/EC: Electron, photon, neutron detection

LTCC: Electron & pion separation

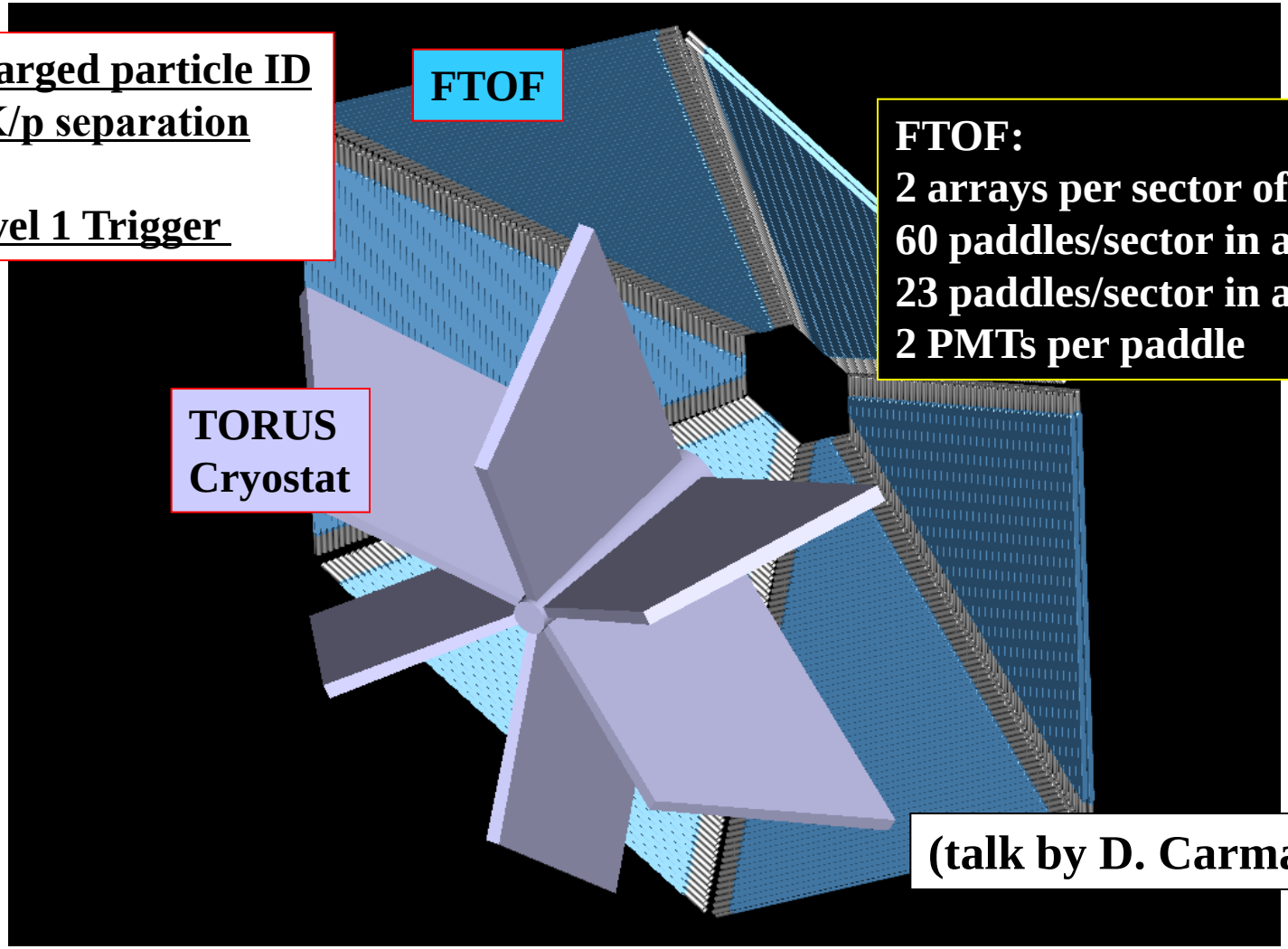
Level 1 Trigger

(talk by S. Stepanyan)

CLAS12 - Forward TOF Counters

Charged particle ID
π/K/p separation

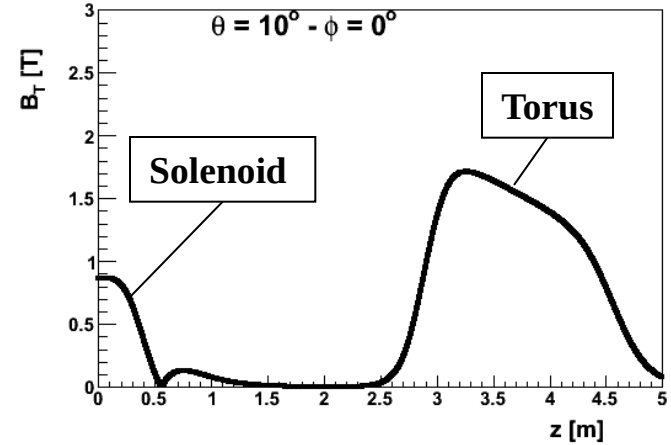
Level 1 Trigger

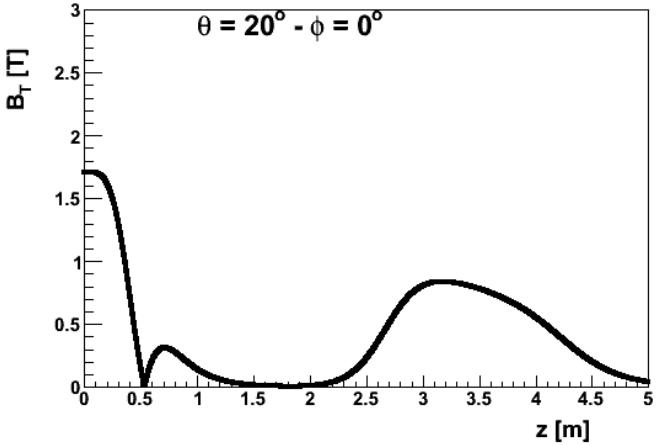


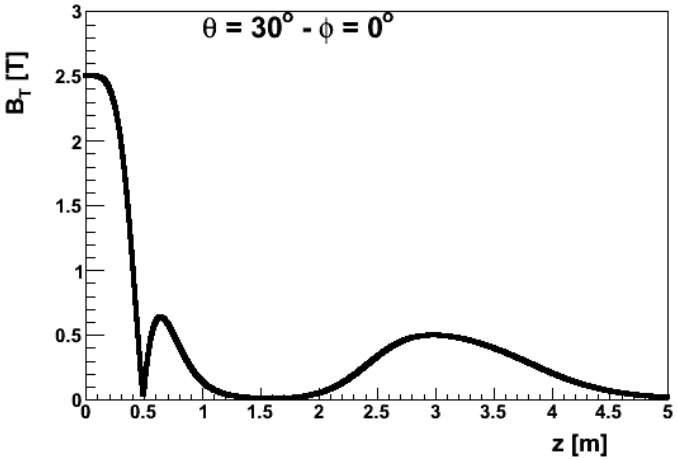
FTOF:
2 arrays per sector of scintillators
60 paddles/sector in array 1b (new)
23 paddles/sector in array 1a (existing)
2 PMTs per paddle

(talk by D. Carman)

CLAS12 - Magnetic Field

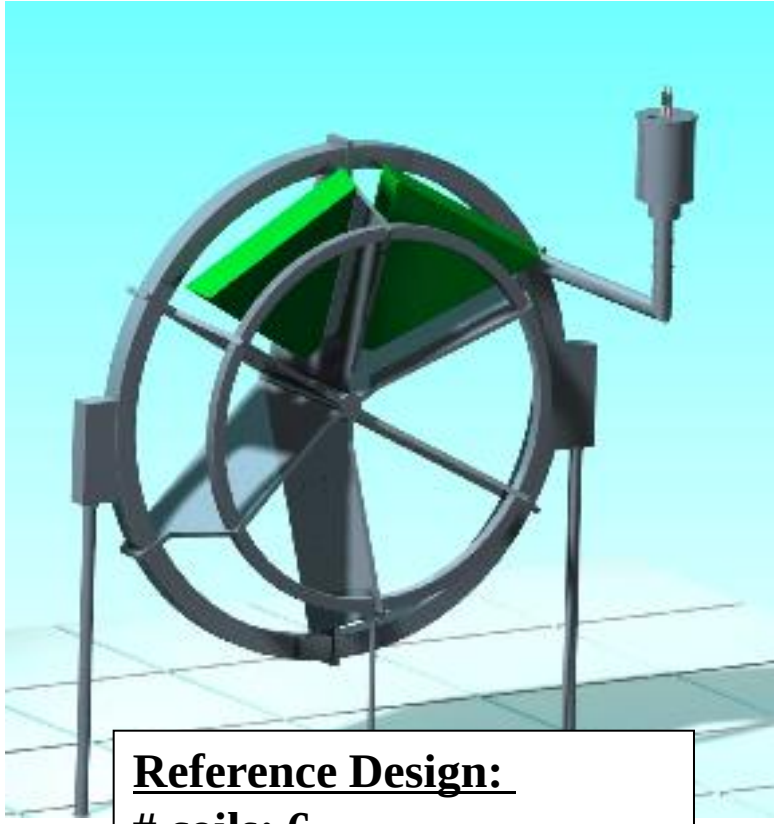




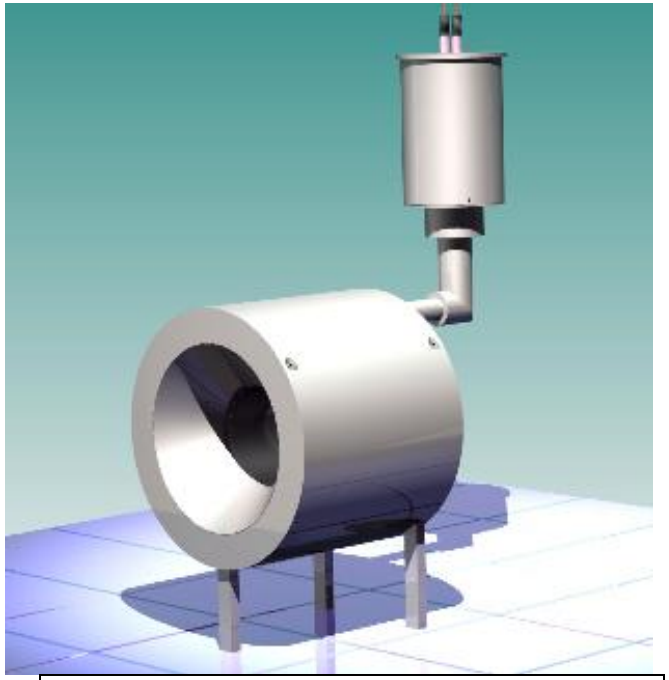


The Torus *transverse* field becomes weaker with increasing angle while the Solenoid *transverse* field component increases in strength.

Torus and Solenoid Magnets



Reference Design:
 # coils: 6
Radial thickness: 294mm
Width: 100mm
Stored energy: 14MJ



Reference Design:
Max. field: B=5 Tesla
Homogeneity: $\Delta B/B<10^{-4}$
Main coil windings: 4000
Shielding coil: 1880
Stored energy: 25 MJ

Examples of Physics Reactions

- **Deeply Virtual Compton Scattering**

- **Excited nucleon states**

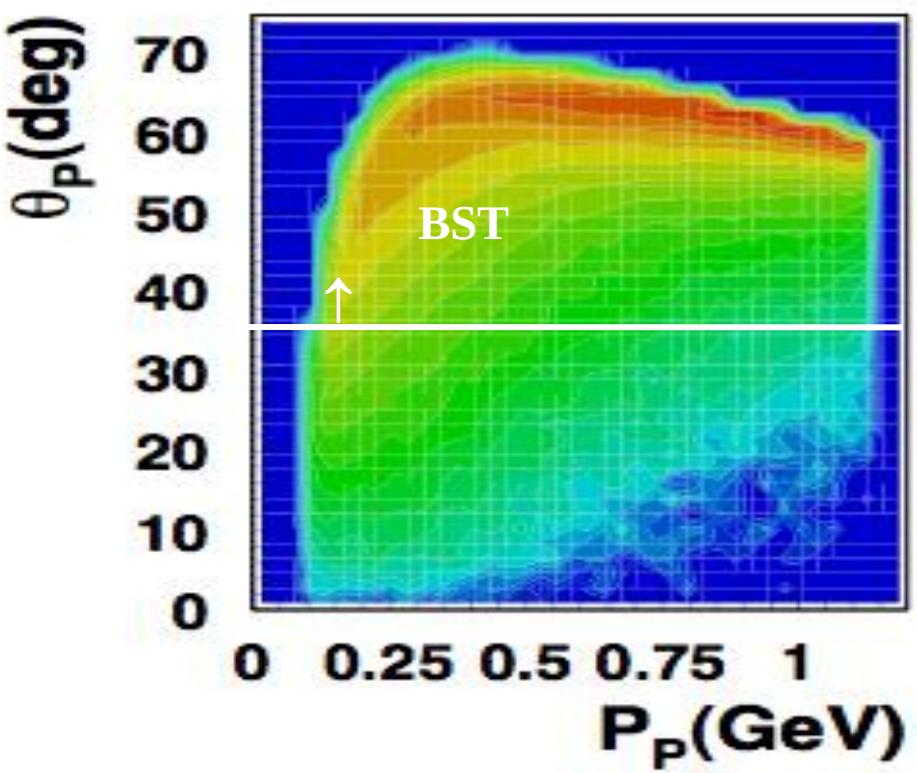
- **Cascade spectroscopy**

- **Use of missing mass techniques**

CLAS12 - DVCS protons in BST

ep→epγ

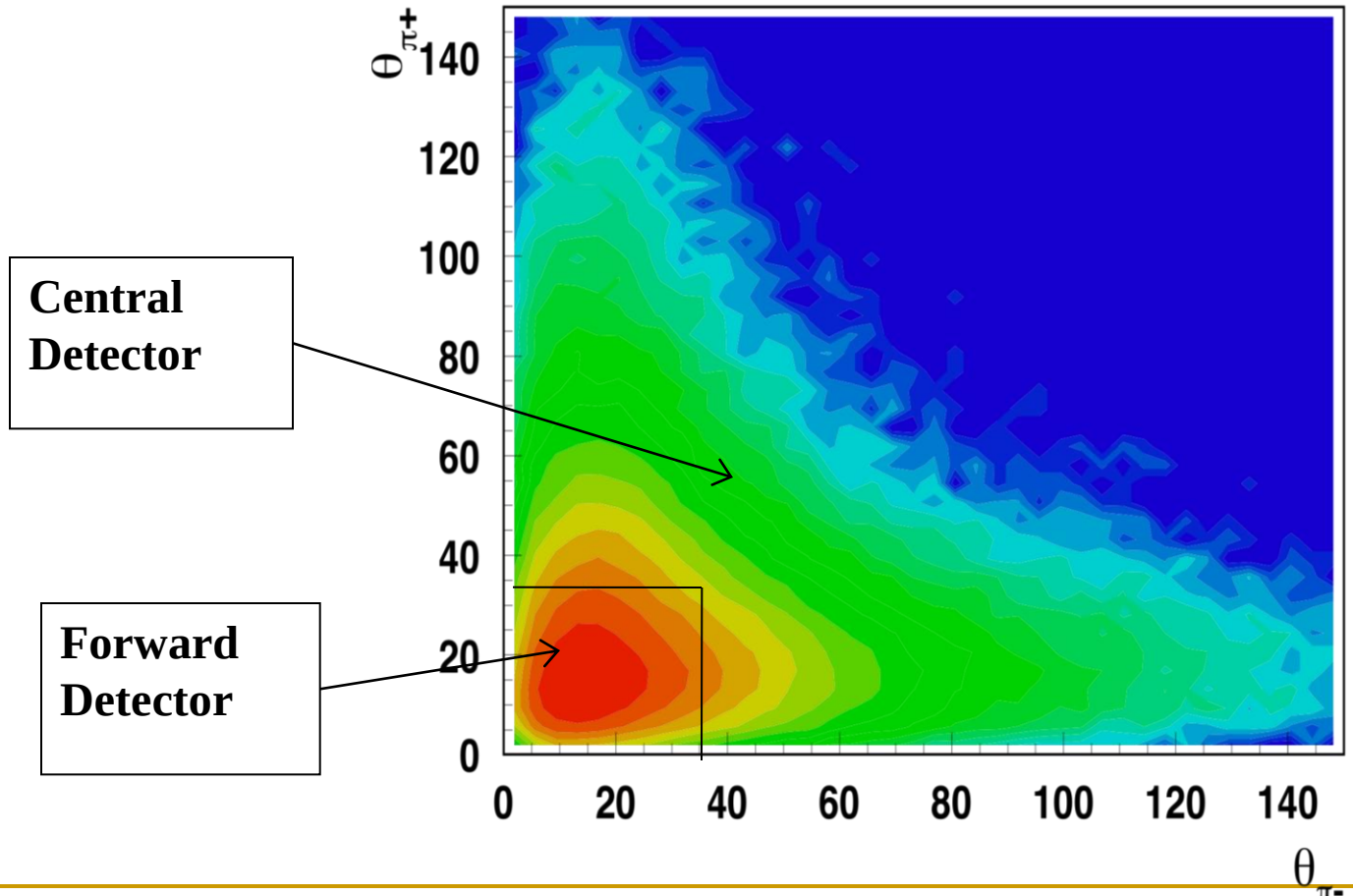
Measurement of Generalized Parton Distributions



Critical for tracking of recoil protons that occupy phase space at Lab angles greater than 35 degrees.

Kinematics for $ep \rightarrow eN^*(N^* \rightarrow p\pi^+\pi^-)$

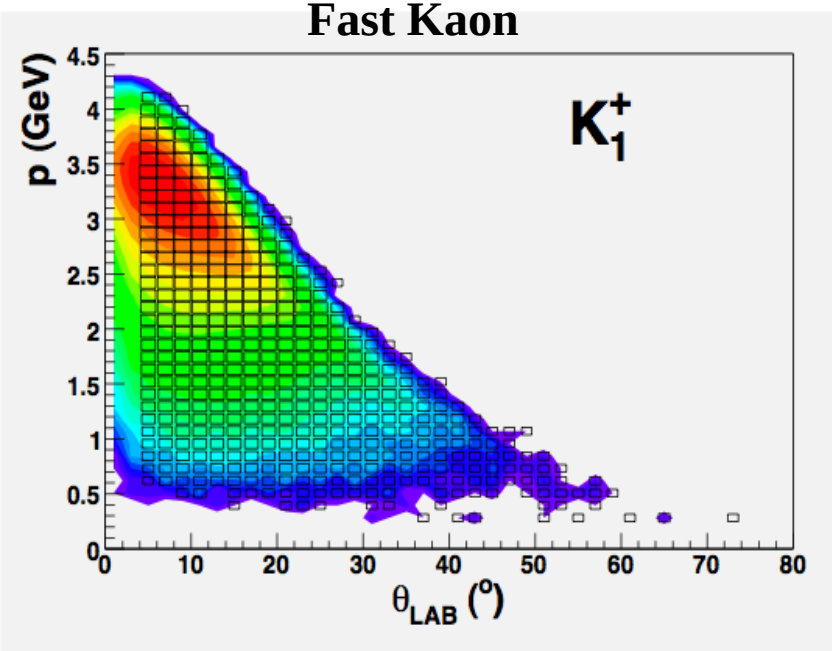
Measurement in full angular range needed for N* spectroscopy and partial wave analysis of final state hadrons.



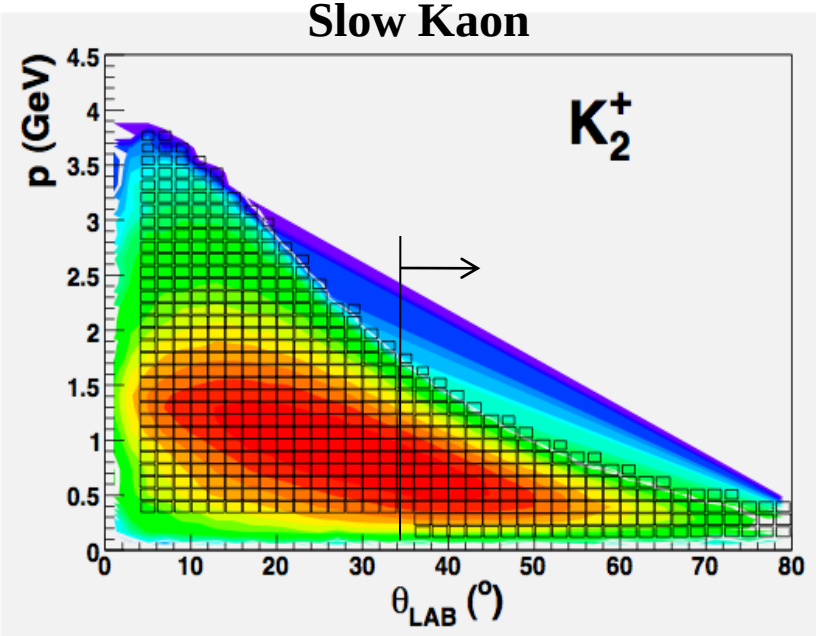
Kinematics for $\gamma p \rightarrow K_1^+ K_2^+ \Xi^{-*}$ ($\Xi^{-*} \rightarrow \Lambda\pi^-$, $\Lambda \rightarrow p\pi^-$)

Strange baryon spectroscopy – Search for cascade states

Fast Kaon



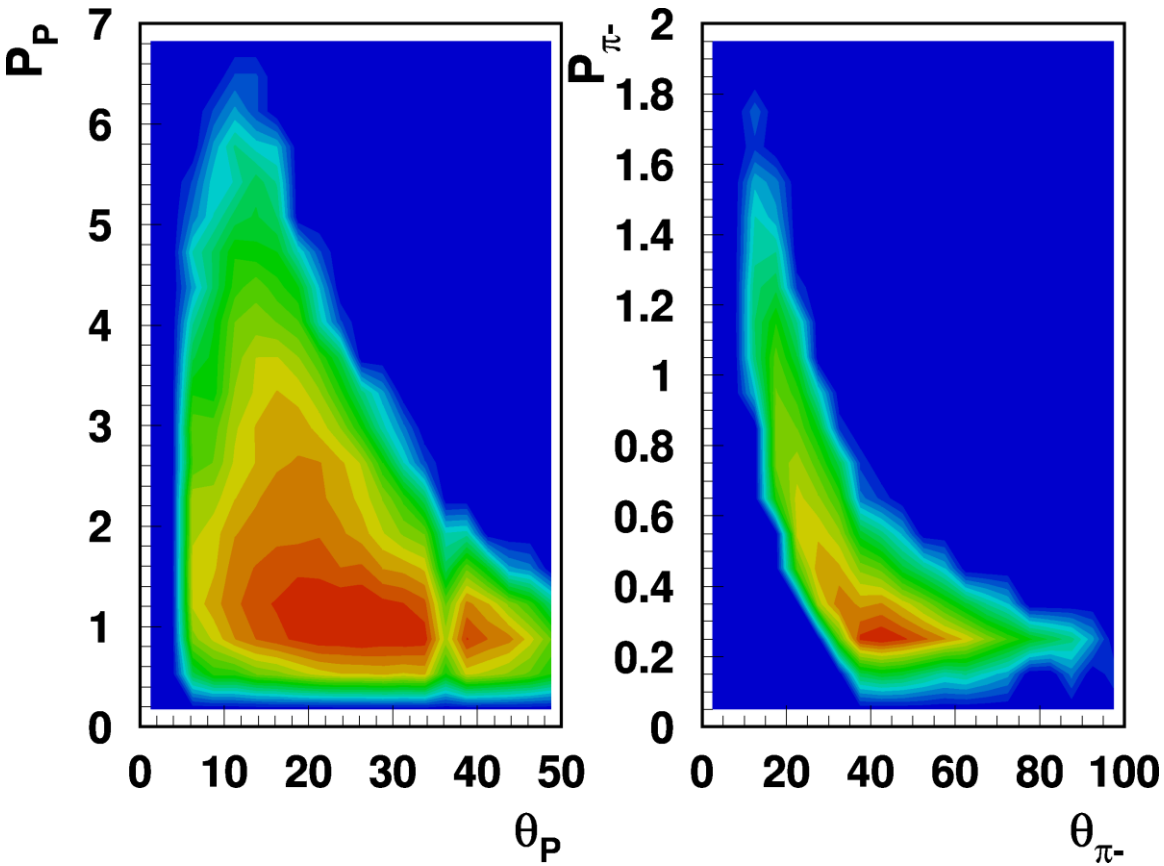
Slow Kaon

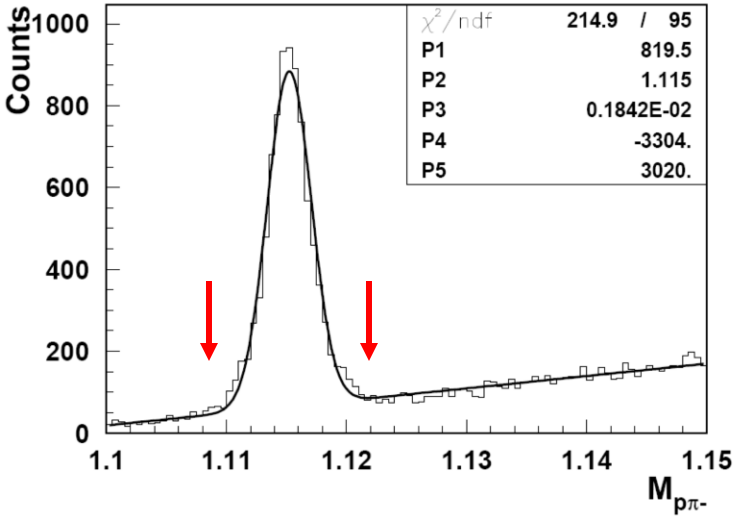


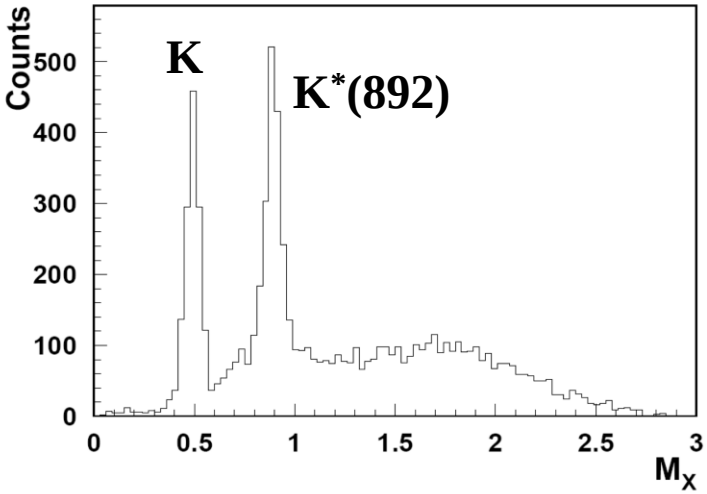
Direct reconstruction of Ξ^{+*} with tracking in FST/BST of detached vertices, e.g $\Xi^{-*} \rightarrow \Lambda\pi^-$, $\Lambda \rightarrow p\pi^-$

CLAS12 - Missing Mass Techniques

$$ep \rightarrow e\Lambda(p\pi^-)X$$







Rates & Background

CLAS12 - Electromagnetic Background

Low energy electromagnetic processes, especially Møller scattering of beam electrons off atomic electrons are the main contributor to the background load in an open large acceptance spectrometer such as *CLAS12*.

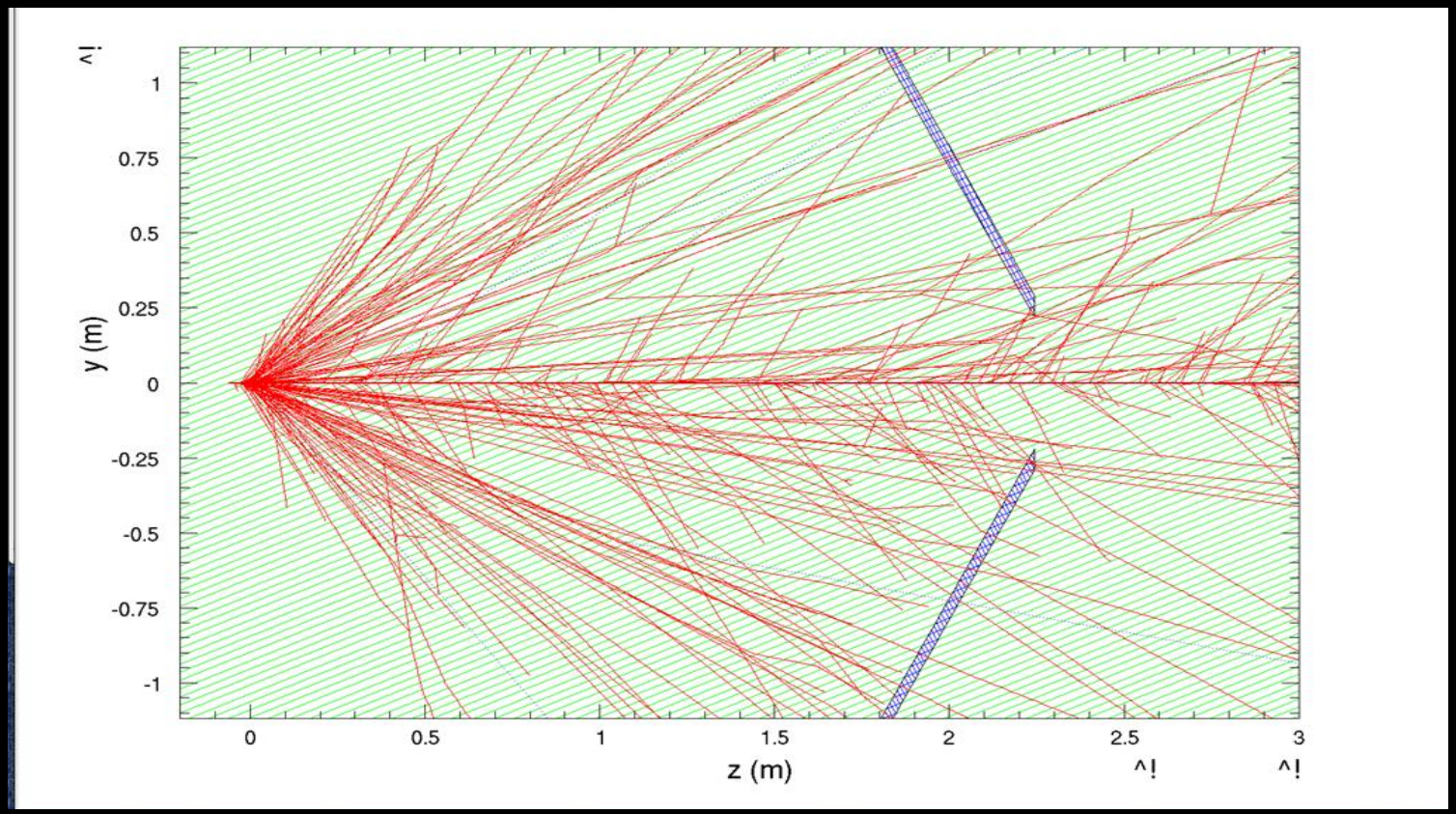
The full event and background load has been measured with CLAS, e.g. for DVCS process at 5.7 GeV. The GEANT simulation reproduces hit occupancy on tracking chambers.

We used the calibrated simulation code to extrapolate to 11 GeV and simulate the same process at higher luminosity for CLAS12 situation.

This background was also studied in a full Geant4 simulation.

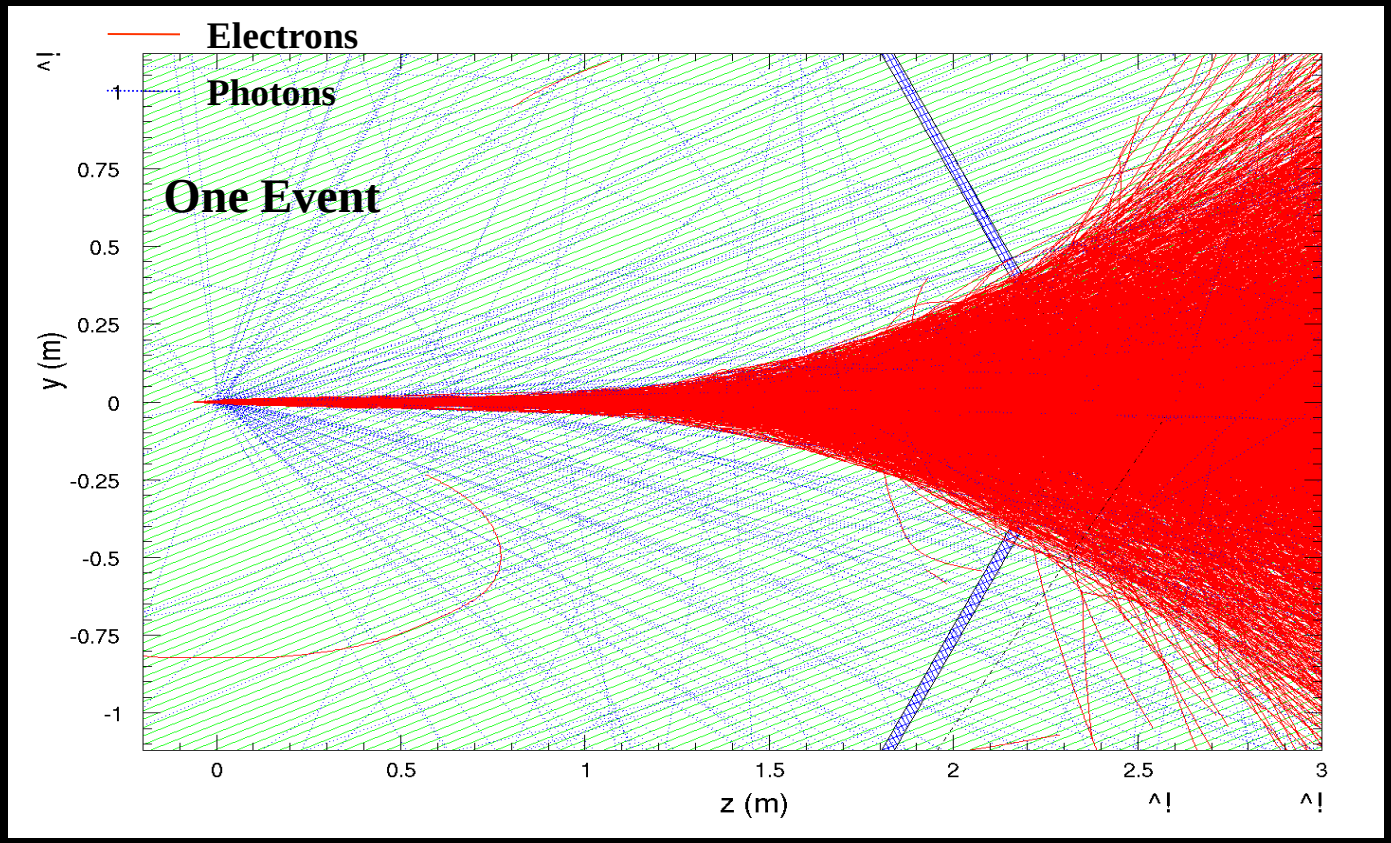
CLAS12

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



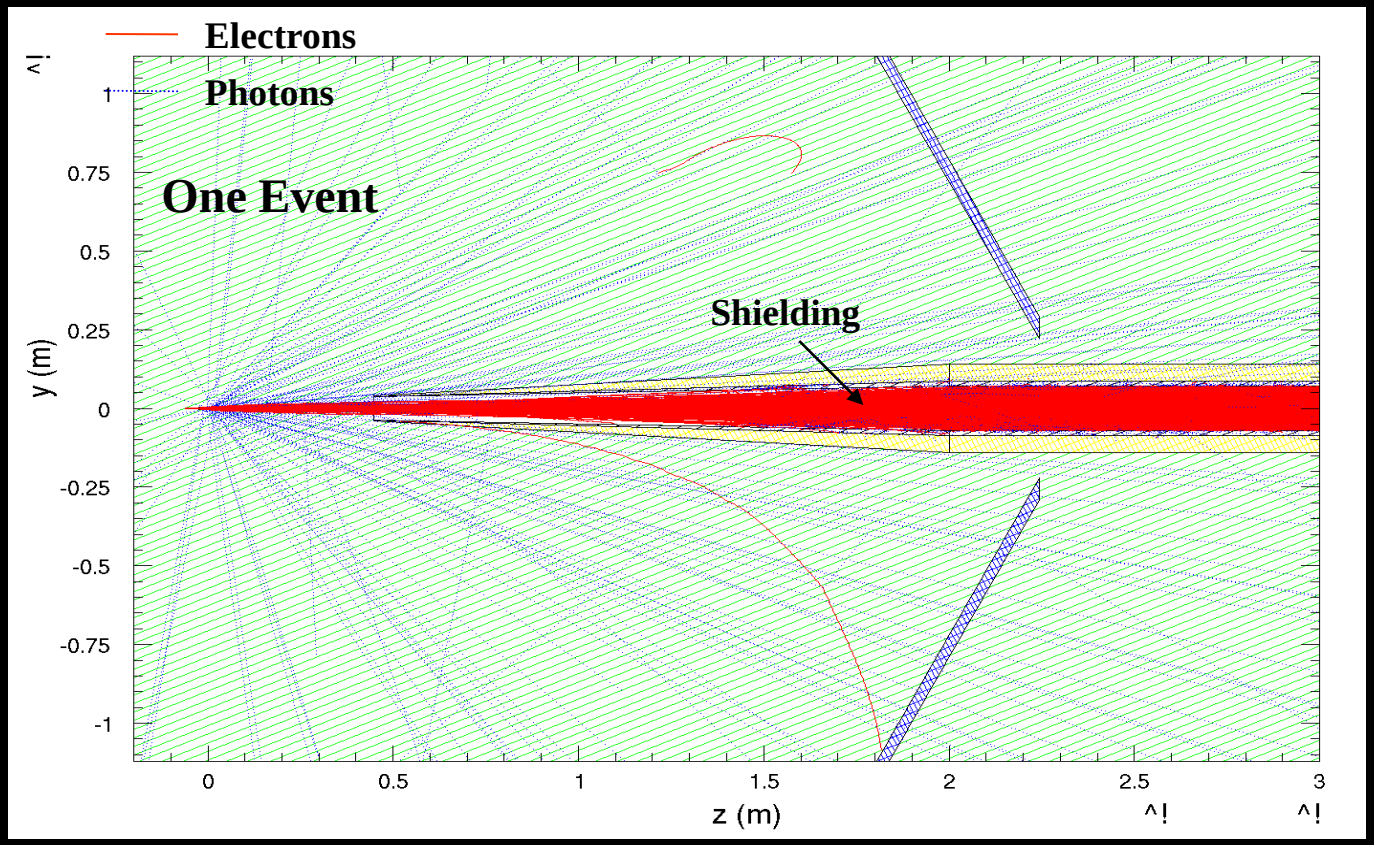
No magnetic field

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



5 T Magnetic Field

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



5 T Magnetic Field and Shielding

CLAS12 – Expected Rates in DC R1

	CLAS	CLAS12
Energy	5.75	11
Luminosity ($cm^{-2}s^{-1}$)	$2x10^{34}$	10^{35}
Total rate	**5.94**	**5.76**
Electrons from γ's	0.74	1.7
Scattered electrons	4.65	1.0
Hadrons	0.55	3.06

CLAS12 - Event rates & multiplicities

- Simulations show that typical deep inelastic events contain
  - 3.5 charged particles per event at $\theta < 35^o$ (Forward Detector)
  - 0.75 charged particles at $\theta > 35^o$ (Central Detector)
- The total hadronic interaction rate is ~$5x10^6$ sec^{-1}
- Expected level 1 trigger rate is up to 10KHz (inclusive electron rate ~4KHz, non-electron triggers ~5KHz), (talk by Boiarinov)
- Expected data rate is 50-80$Mbsec^{-1}$ for beam energies from 6.6 to 11 GeV.

CLAS12 - Event reconstruction

- A full event reconstruction is available for CLAS detectors that has been used to aid the R&D and design effort for ***CLAS12.***

- The collaboration is developing new simulation and reconstruction software packages making use of modern tools.

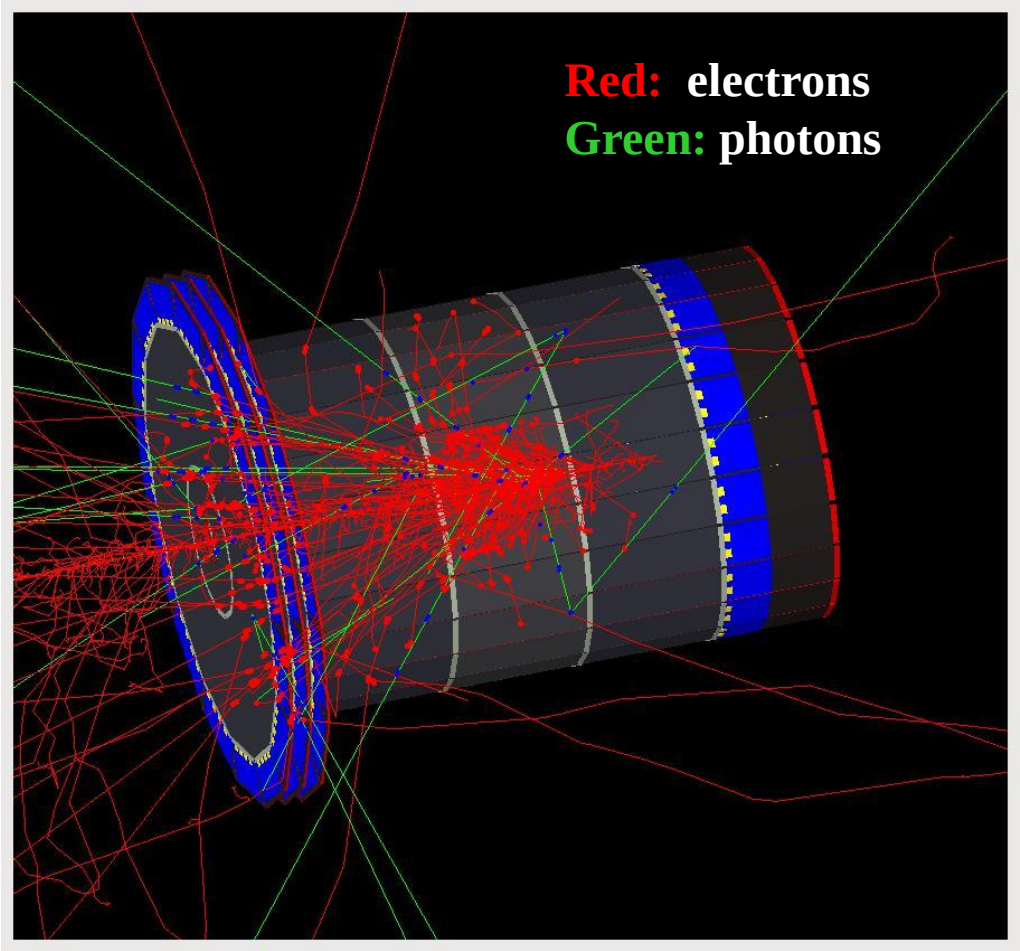
- The current effort is focused on Geant4 as simulation package (talk by Ungaro), and track reconstruction using the Kalman Filter approach (talk by Procureur).

Hall B Upgrade Summary

- The physics program allows to firmly establish requirements for the ***CLAS12*** performance in terms of rate capability, particle ID, and resolution.
- At 12 GeV typical events contain high momentum tracks at forward angles. The toroidal magnetic field of ***CLAS12*** and the forward tracking system provide excellent angle and momentum reconstruction.
- Essential parts of the physics program require tracking of low momentum at large angles. This is achieved by the Silicon Tracker.
- The increase in luminosity is achieved by improved background shielding and high rate capability of the tracking devices.
- The new Cerenkov and Scintillation counters in ***CLAS12*** are designed to improve particle separation at higher momentum.
- An experienced team is in place that built, installed, commissioned and operates CLAS, and collaboration members have taken on responsibilities for the construction of new detector components, and for state-of-the art event simulation and reconstruction.

Backup Slides

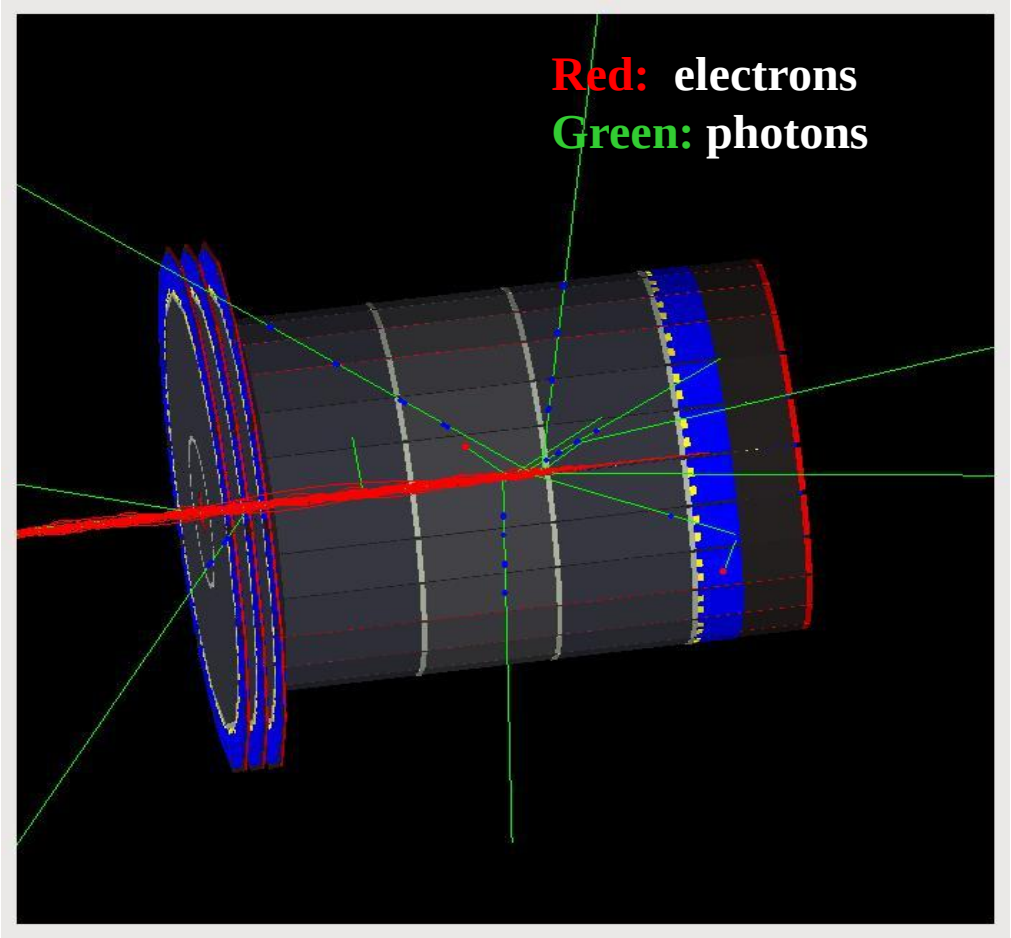
SVT - Møller electron background



Rate of Møller electrons in SVT during 125nsec at 1/50 of full luminosity.

Solenoid B-field - OFF

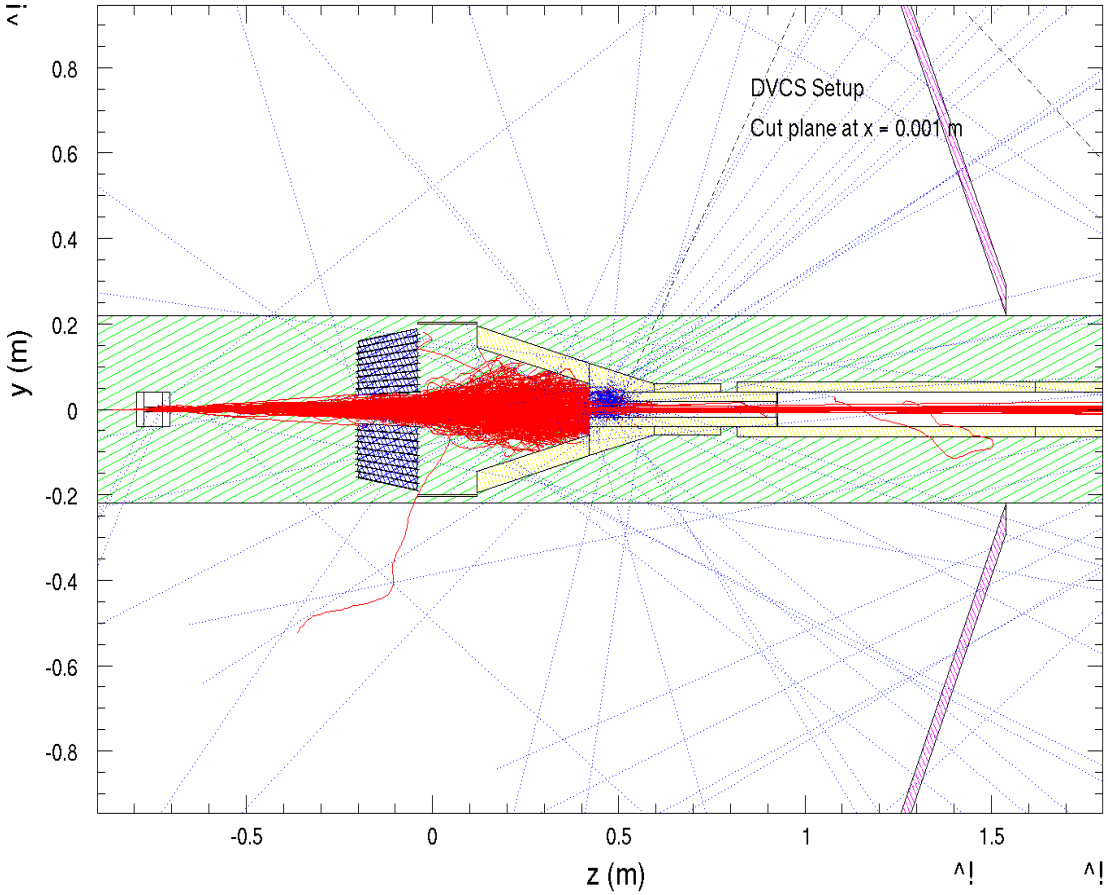
SVT - Møller electron background



Rate of Møller electrons in SVT during 125nsec at 1/50 of full luminosity.

Solenoid B-field - ON

CLAS Drift chamber R1 occupancy



- DVCS experiment.
- E=5.7 GeV, $L=2*10^{34}cm^{-2}s^{-1}$
- DVCS solenoid

Electromagnetic and Hadronic Rates

(in MHz)

SVT (5º-35º)

	Photons	Hadrons
L1	31.3	2.5
L2	31.1	2.2
L3	24.6	2.2

Deposited Energy > 20 KeV

SVT (35º-125º)

	Photons	Hadrons
L1	57.7	2.6
L2	50.8	3.7
L3	44.6	4.8
L4	32.7	3.4
CTOF	93.3	6.0