Hall B Physics Program and Upgrade Plan

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- Introduction
- The Equipment Plan
- The 12 GeV Physics Program
- Conclusions

PAC23 Meeting on the 12 GeV Upgrade, January 20, 2003

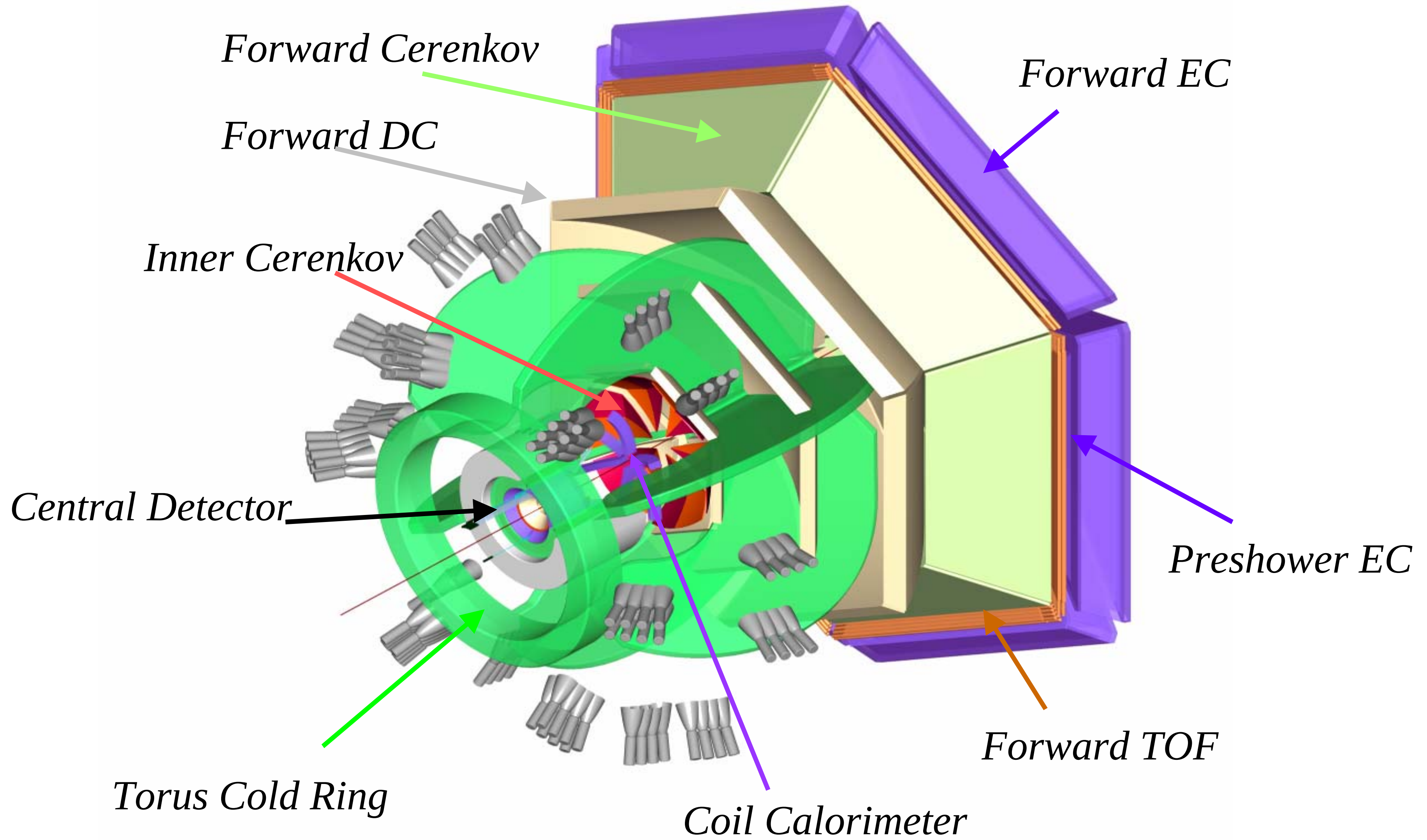
Physics Program with ***CLAS***$^{++}$ at 12 GeV

- **Quark-Gluon Dynamics and Nucleon Tomography**
  - Deeply Virtual Compton Scattering (DVCS)
  - Deeply Virtual Meson Production (DVMP)
  - High-t DVCS and π^0/η production
- **Valence Quark Distributions**
  - Proton and Neutron Spin Structure
  - Neutron Structure Function $F_{2n}(x,Q^2)$
  - Tagged Quark Distribution Functions
  - Novel Quark Distribution Functions (tranversity, e(x),..)
- **Form Factors and Resonance Excitations**
  - The Magnetic Structure of the Neutron
  - Resonance Excitation Dynamics
- **Hadrons in the Nuclear Medium**
  - Space-Time Characteristics of Hadronization
  - Color transparency
- **Physics with quasi-real Photons**

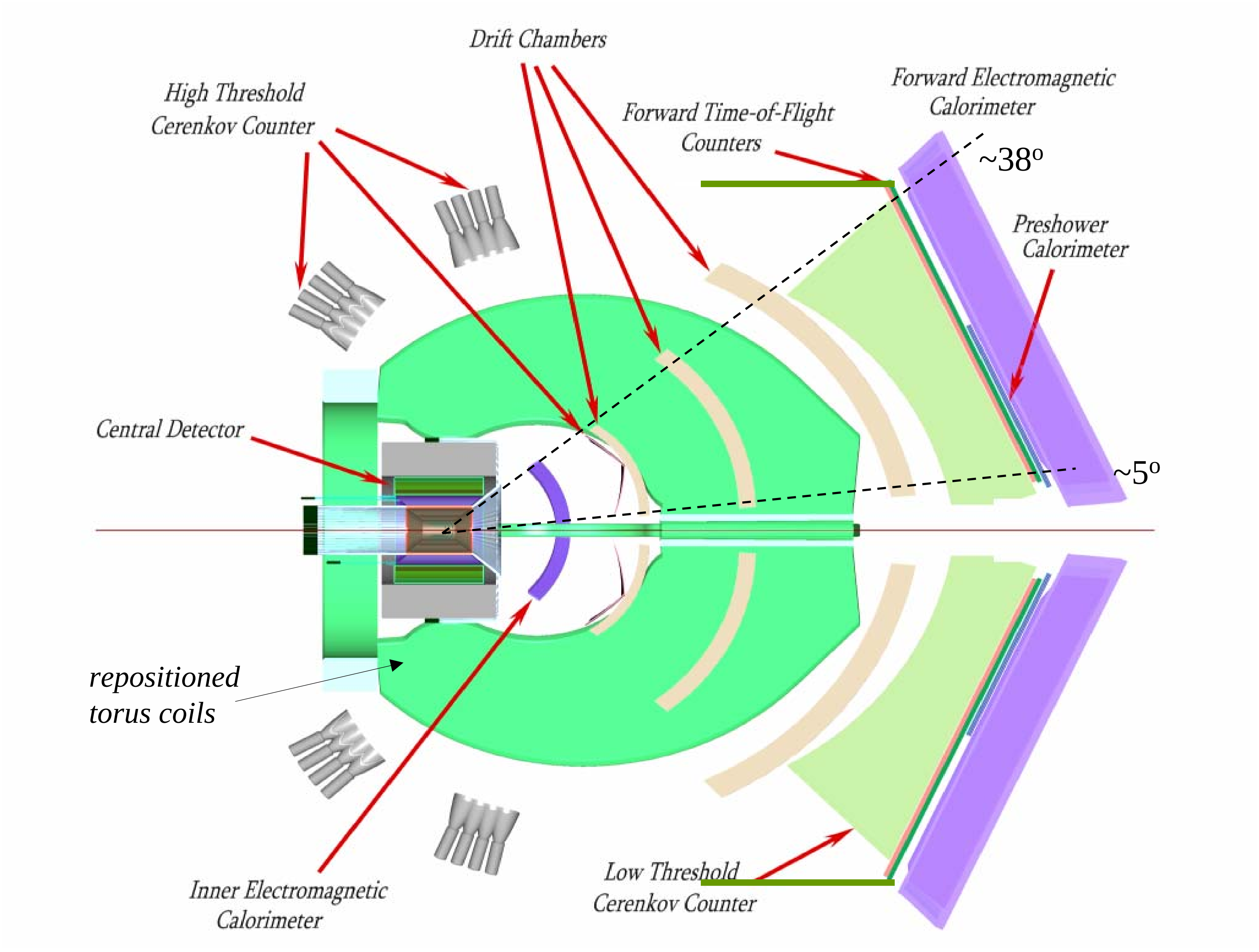
Requirements for the CLAS upgrade:

- Retain high statistics capabilities for exclusive processes at beam energies up to 12 GeV
  - Complement missing mass techniques by more complete detection of hadronic final state
  - Increase maximum luminosity to $10^{35}cm^{-2}sec^{-1}$
  - Extend particle ID to higher momenta (e^-/π^-, $\pi/K/p$, γ/π^o)
- Complement CLAS detection system with new Central Detector
  - tracking, magnetic analysis, and photon detection in angular range 5^o - 135^o
  - veto events with incomplete determination of final state
- Reduce DC occupancies to reach higher luminosities
  - reduce DC cell sizes
  - new magnetic shielding for Möller electrons
- Upgrade the CLAS Forward detection system
  - implement new threshold Cherenkov detector $p_\pi \sim 5$ GeV/c
  - improve time-of-flight resolution to ~ 60psec
  - increase calorimeter granularity for π^o/γ separation

The CLAS^{++} Detector

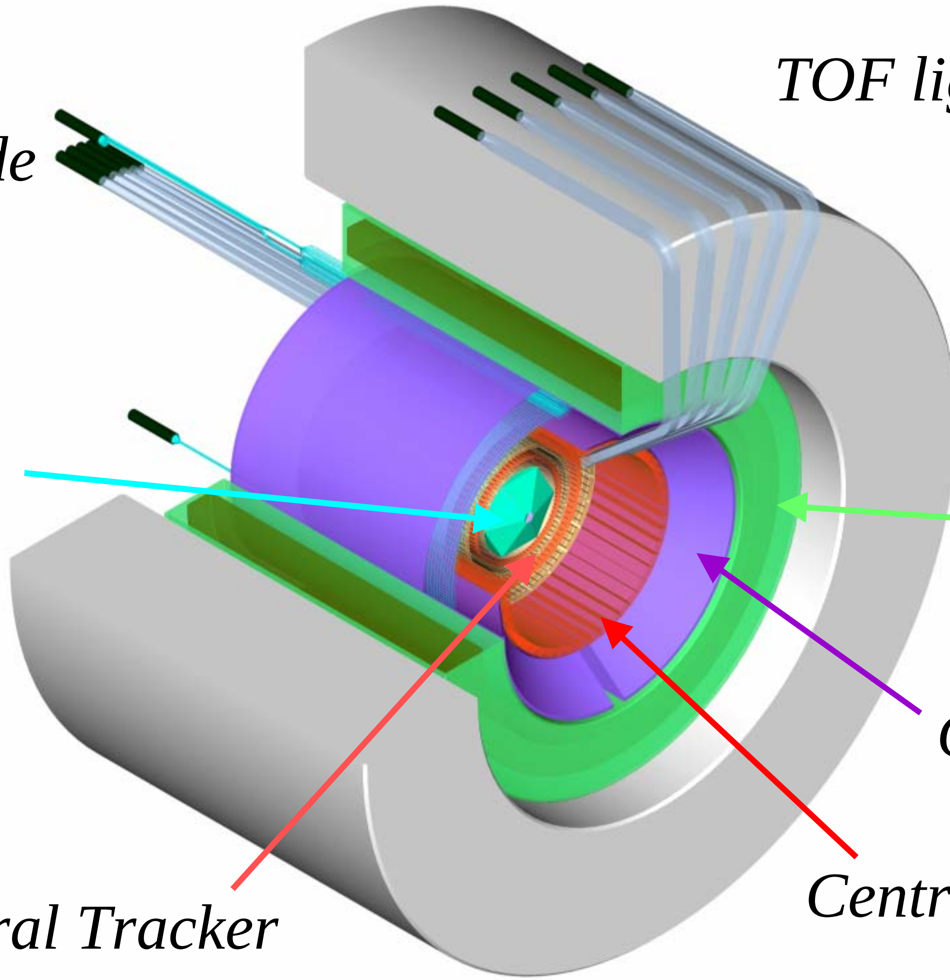


CLAS^{++} - 2D CUT



Drift Chambers
High Threshold
Cerenkov Counter
Forward Time-of-Flight
Counters
Forward Electromagnetic
Calorimeter
~38°
Preshower
Calorimeter
Central Detector
~5°
repositioned
torus coils
Inner Electromagnetic
Calorimeter
Low Threshold
Cerenkov Counter

The CLAS^{++} Detector
Central Detector

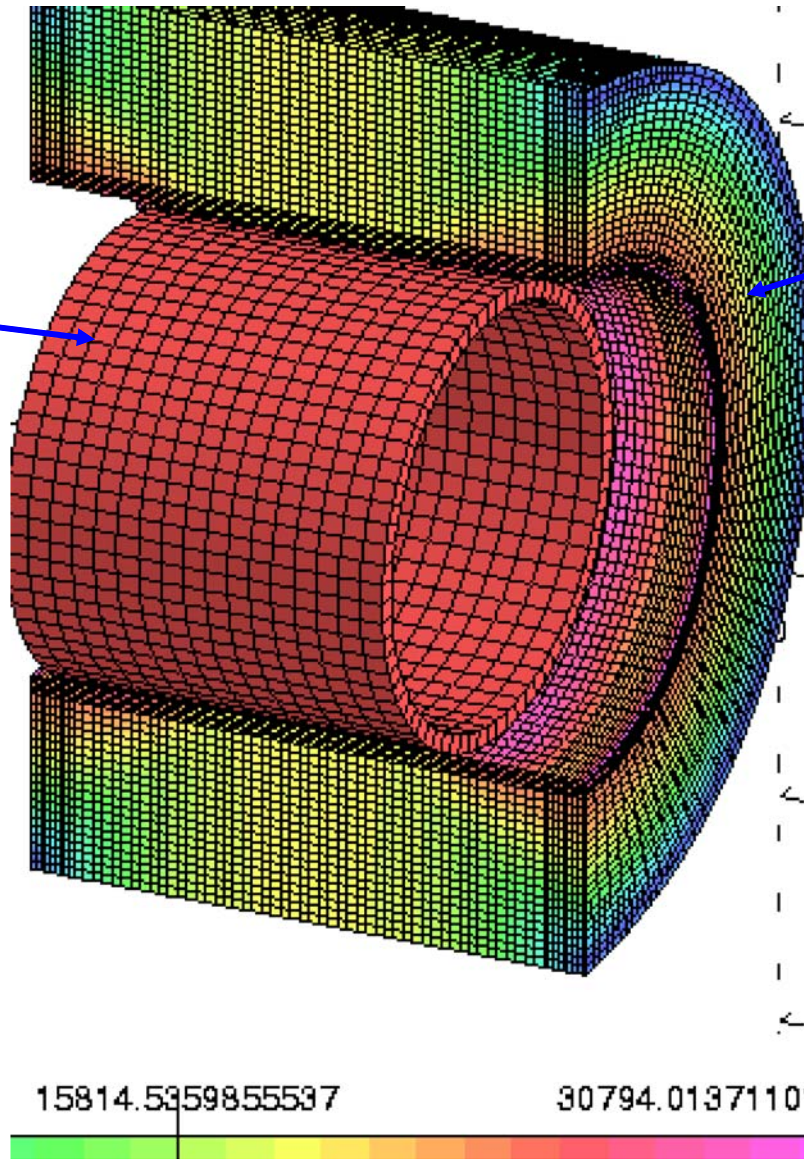


Magnetic Field Distribution in Flux Return Iron

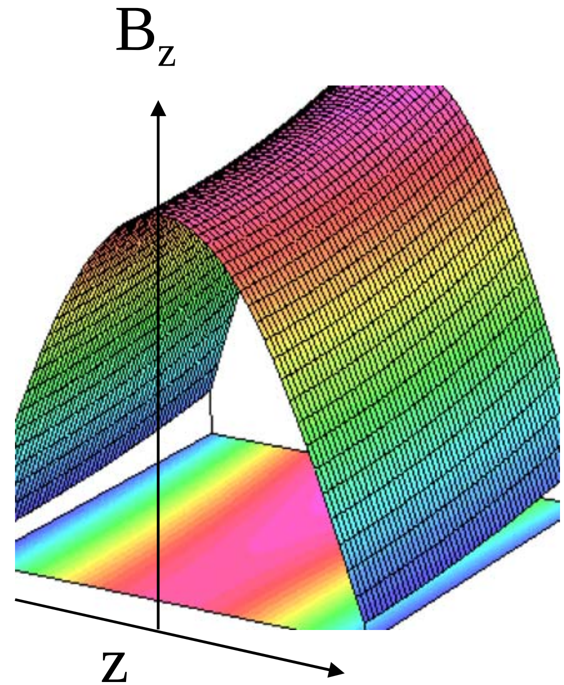
Solenoid Coil

Flux Return Iron

Central B-Field
5 Tesla

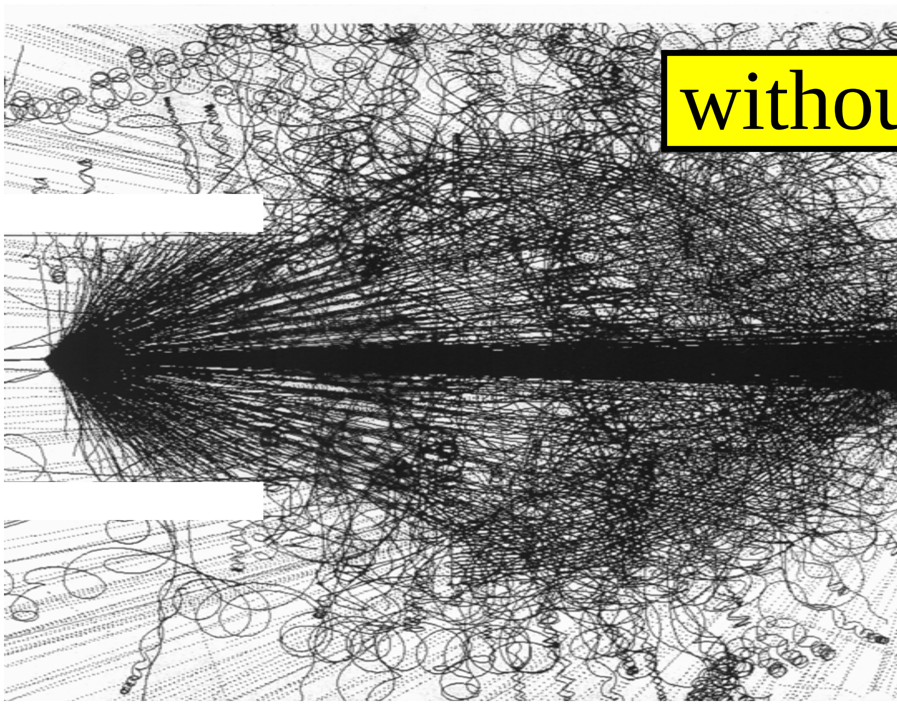


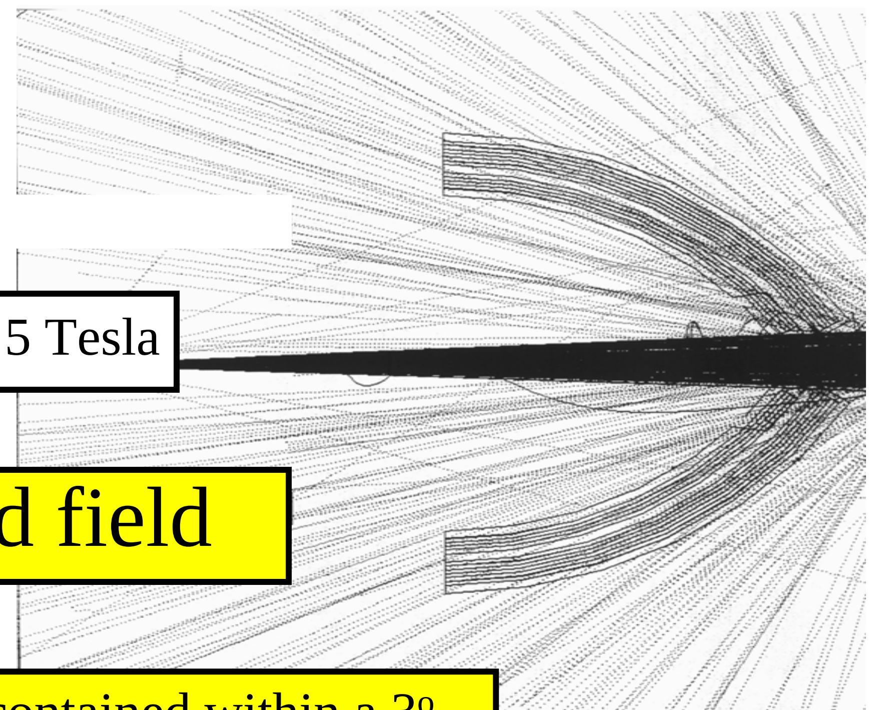
(Gauss)



Möller Electrons in Target Region

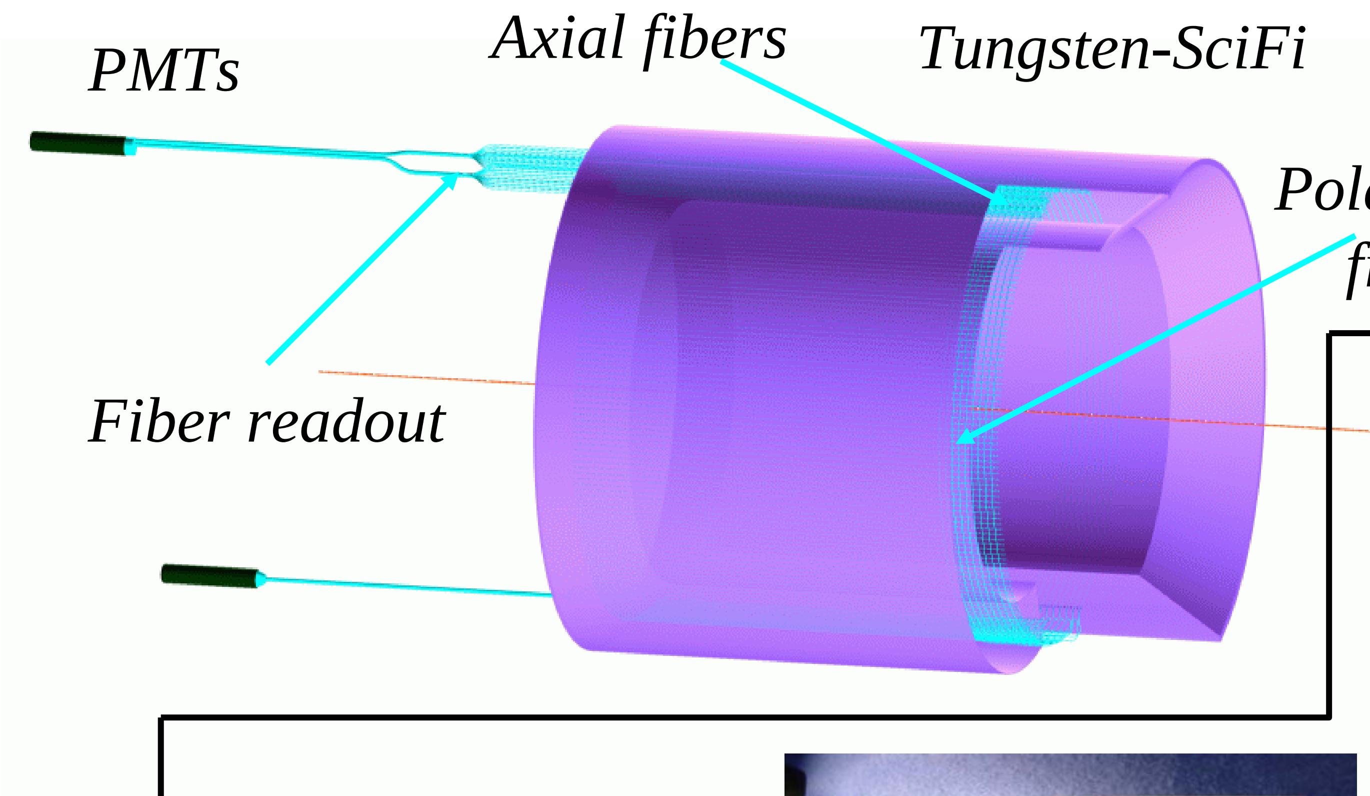
$L=10^{35}cm^{-2}s^{-1}$, $\Delta T = 250nsec$



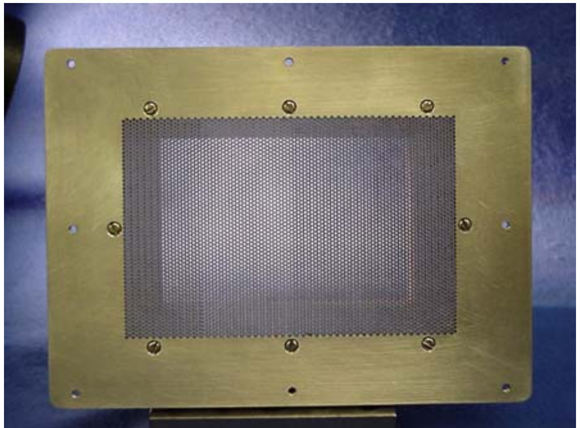


Möller electrons are contained within a 3^o cone around the beam.

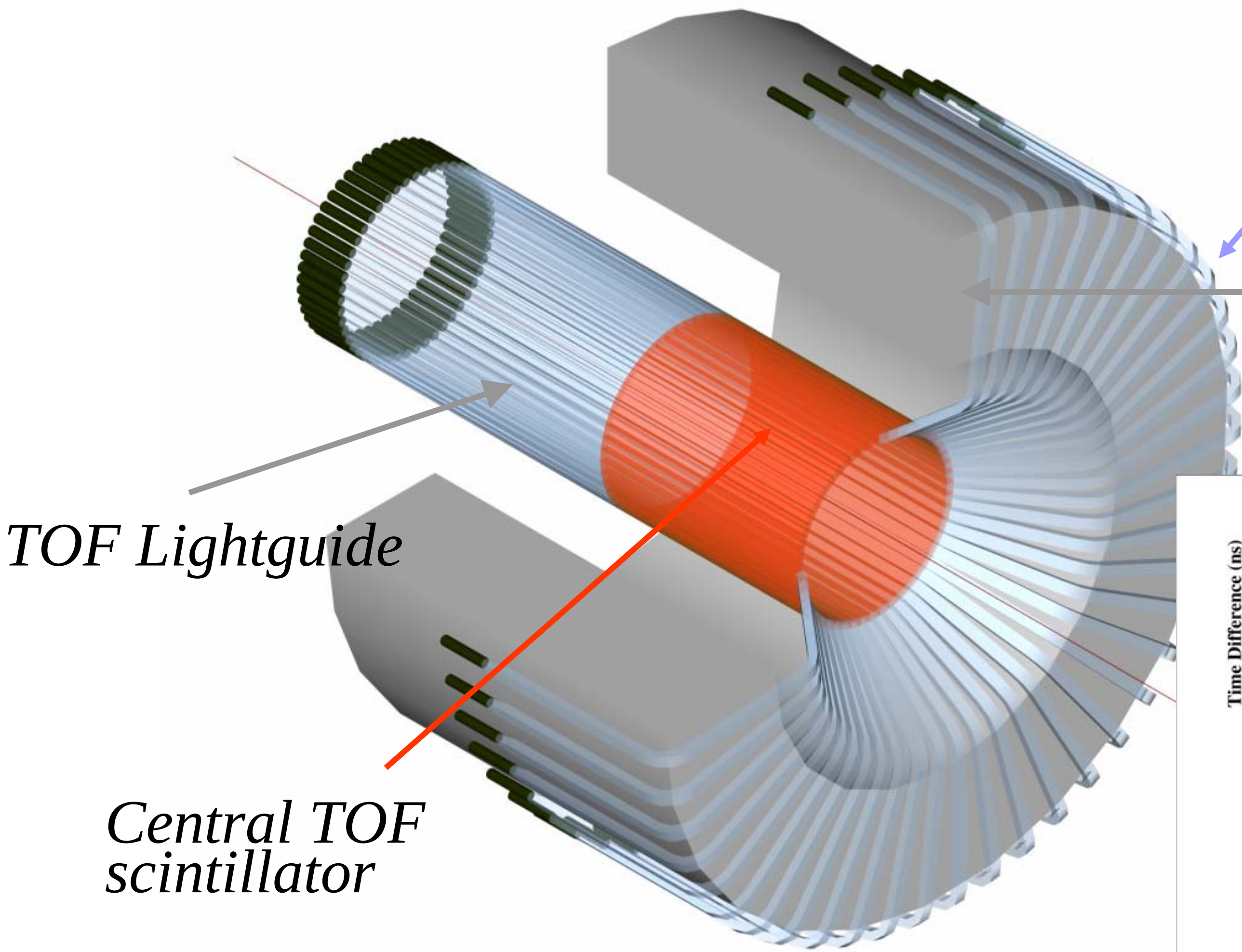
CLAS ++ Central Calorimeter

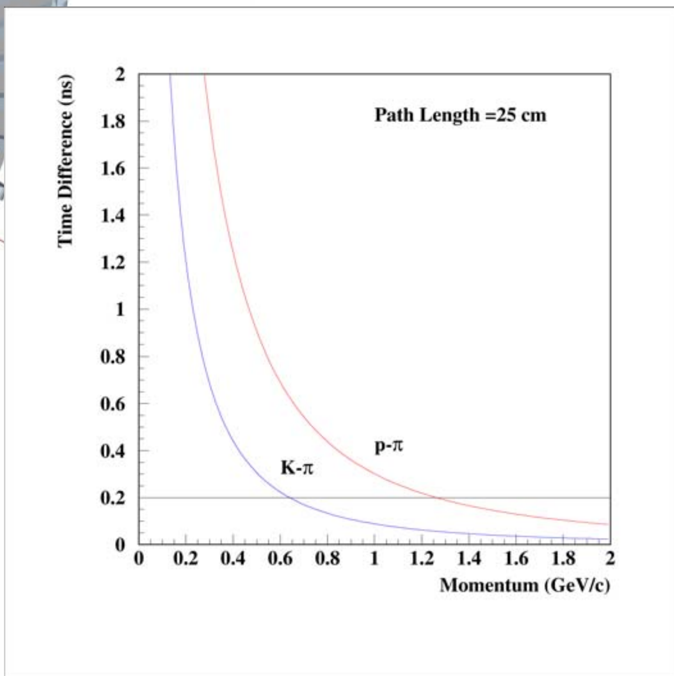


axial readout prototype under construction with 5,500 fibers



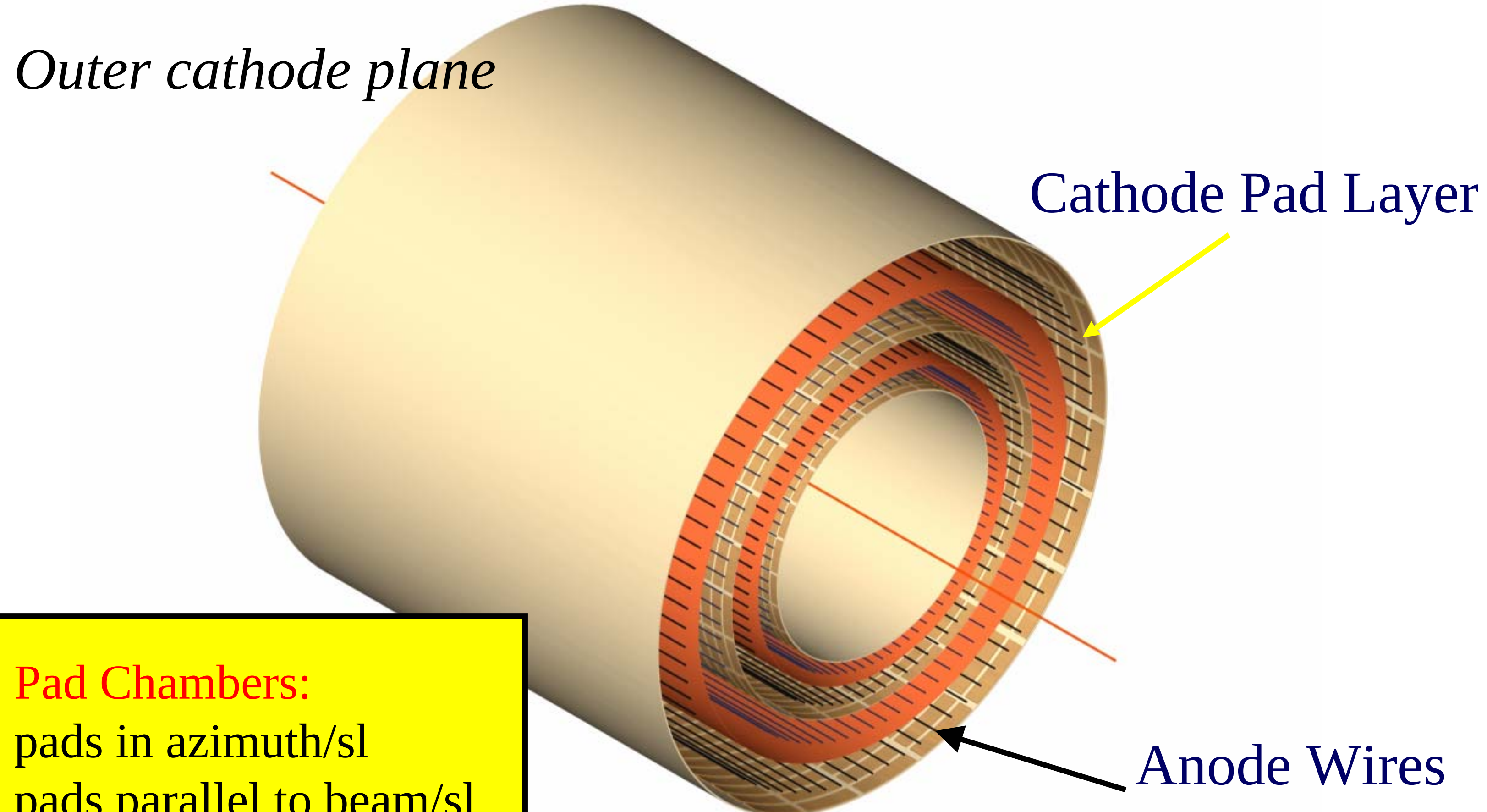
The CLAS^{++} Detector
Central Time-of-Flight Detector





additional particle id from ΔE_{scint}

The CLAS^{++} Detector
Central Drift Chamber - Cathode Pad Readout

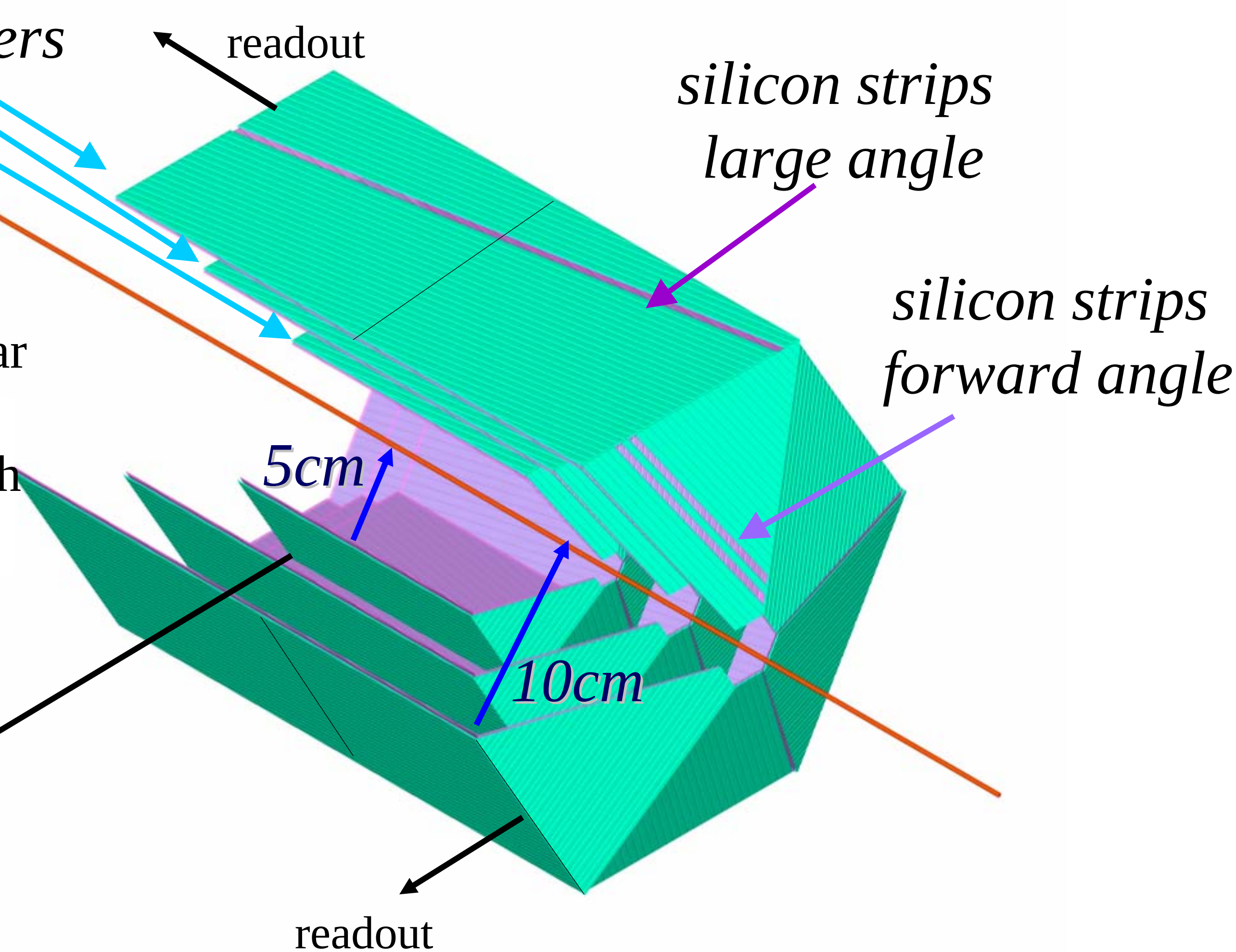


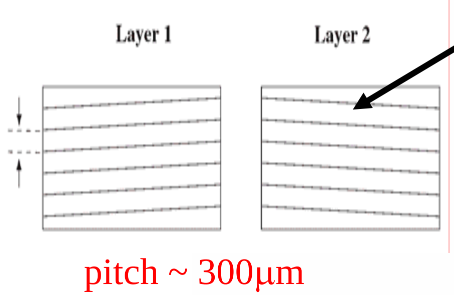
Cathode Pad Chambers:

- 20 pads in azimuth/sl
- 40 pads parallel to beam/sl
- 160 anode wires
- 1600 cathode pads read out

The CLAS++ Detector
Central Microstrip Detector

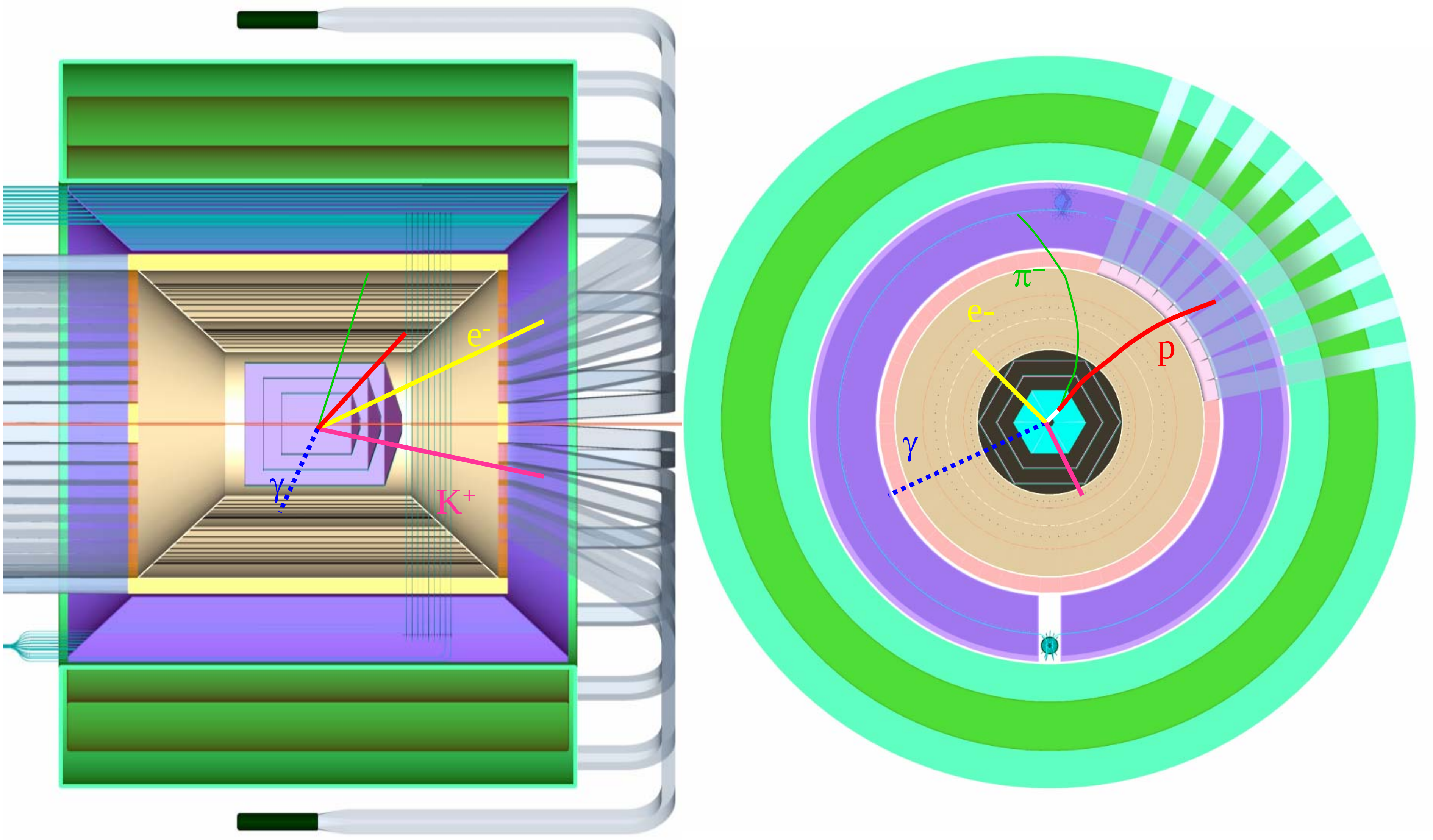
- vertex reconstruction
- high rate operation near target
- tracking in full azimuth





High Q^2, low t $ep \longrightarrow eK^+\Sigma^0(\gamma\Lambda(p\pi^-))$ event

Central Detector



Forward Detector System Upgrades

- Replace Region 1, Region 2, Region 3 drift chambers
  => similar design as current DCs, factor 2 smaller cell sizes

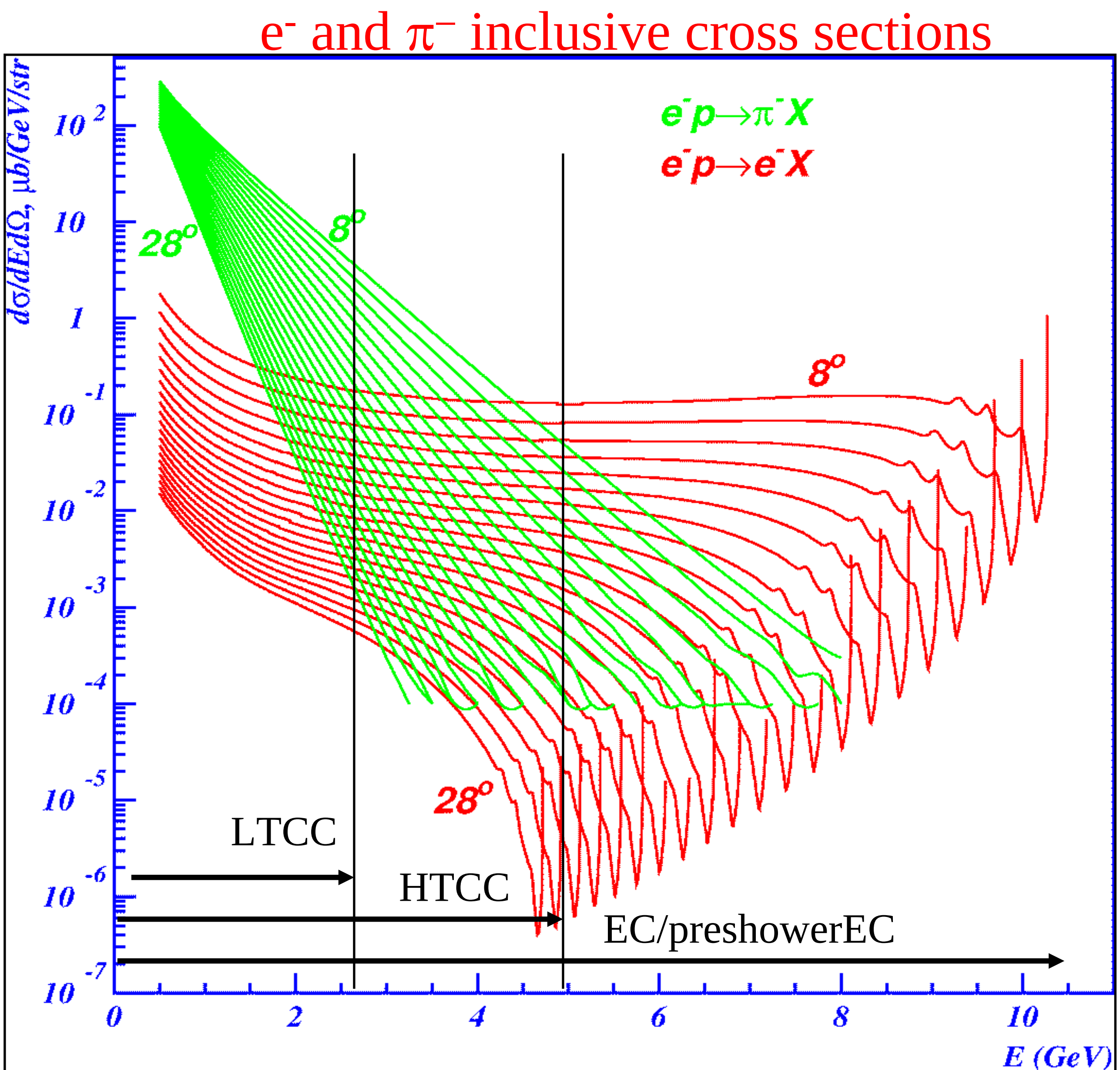
- Time-of-flight detector with improved timing resolution

- Forward calorimeter => extend γ/π^0 separation to higher momenta
  + instrument coil regions with calorimetry ($PbWO_4$ crystals)

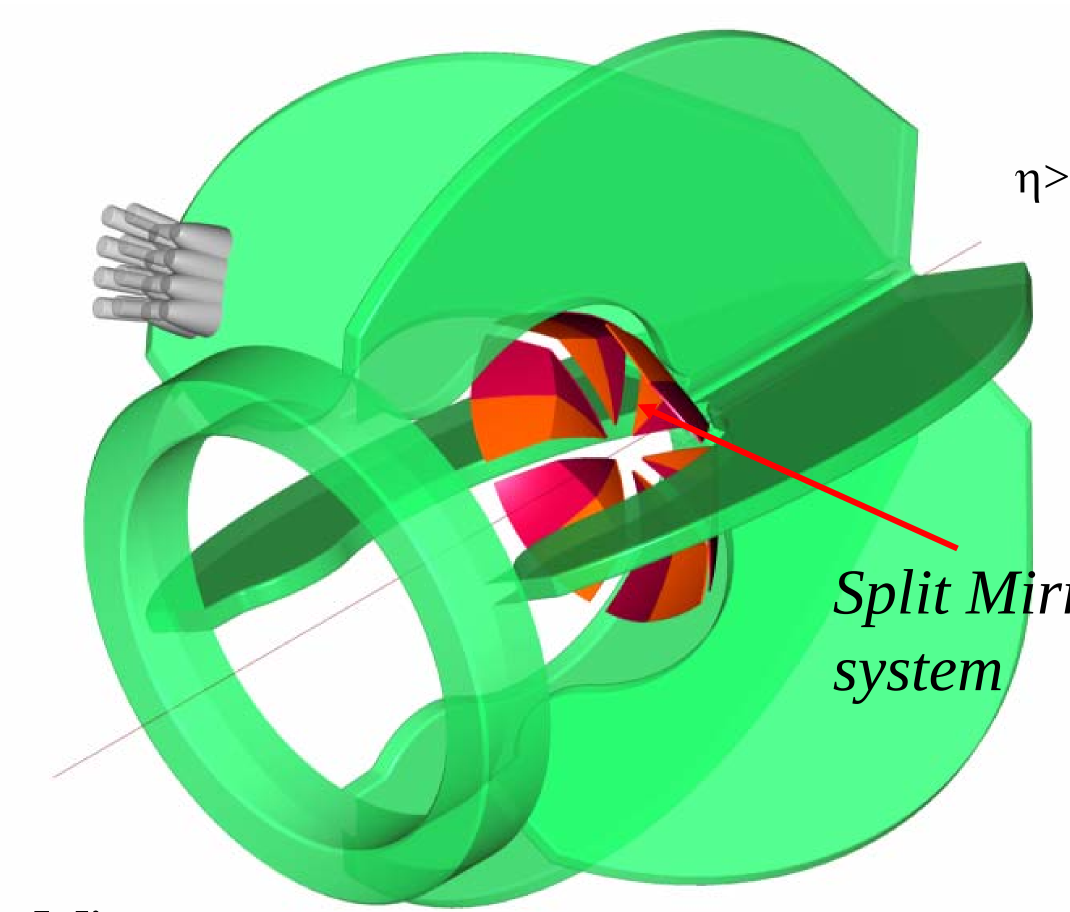
- New Cherenkov Detector with pion threshold ~ 5GeV

- Microstrip detector (forward angle portion)

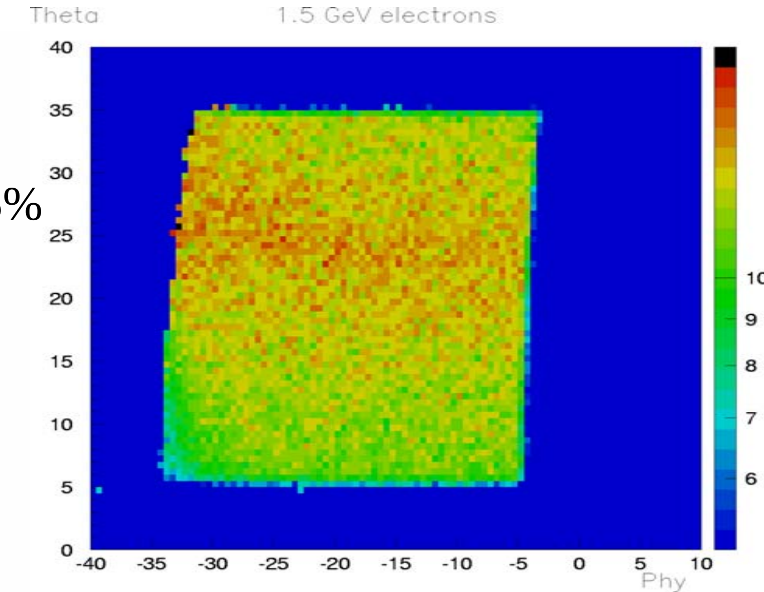
CLAS++ - Electron/pion separation



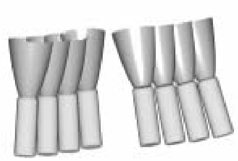
The CLAS^{++} Detector
Inner Cerenkov Detector



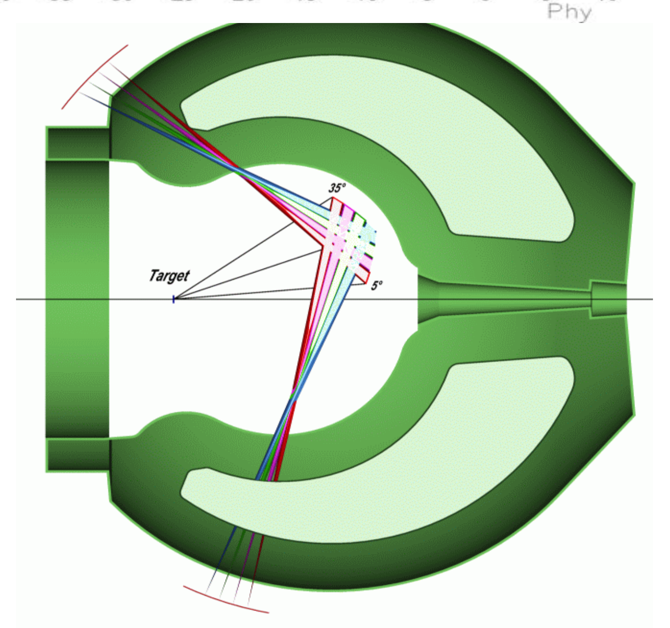
$\eta > 99.5\%$



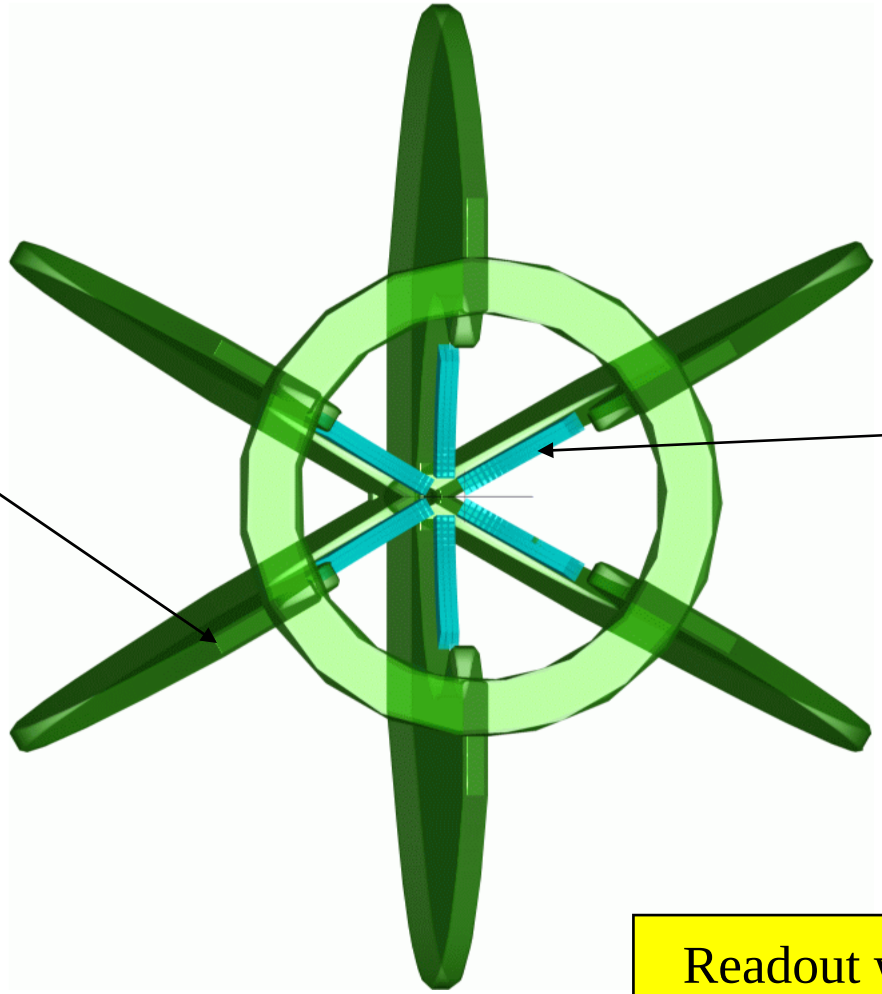
Winston cones,
PMTs



Radiator Gas
CO_2



Coil Calorimeter in Torus coil region

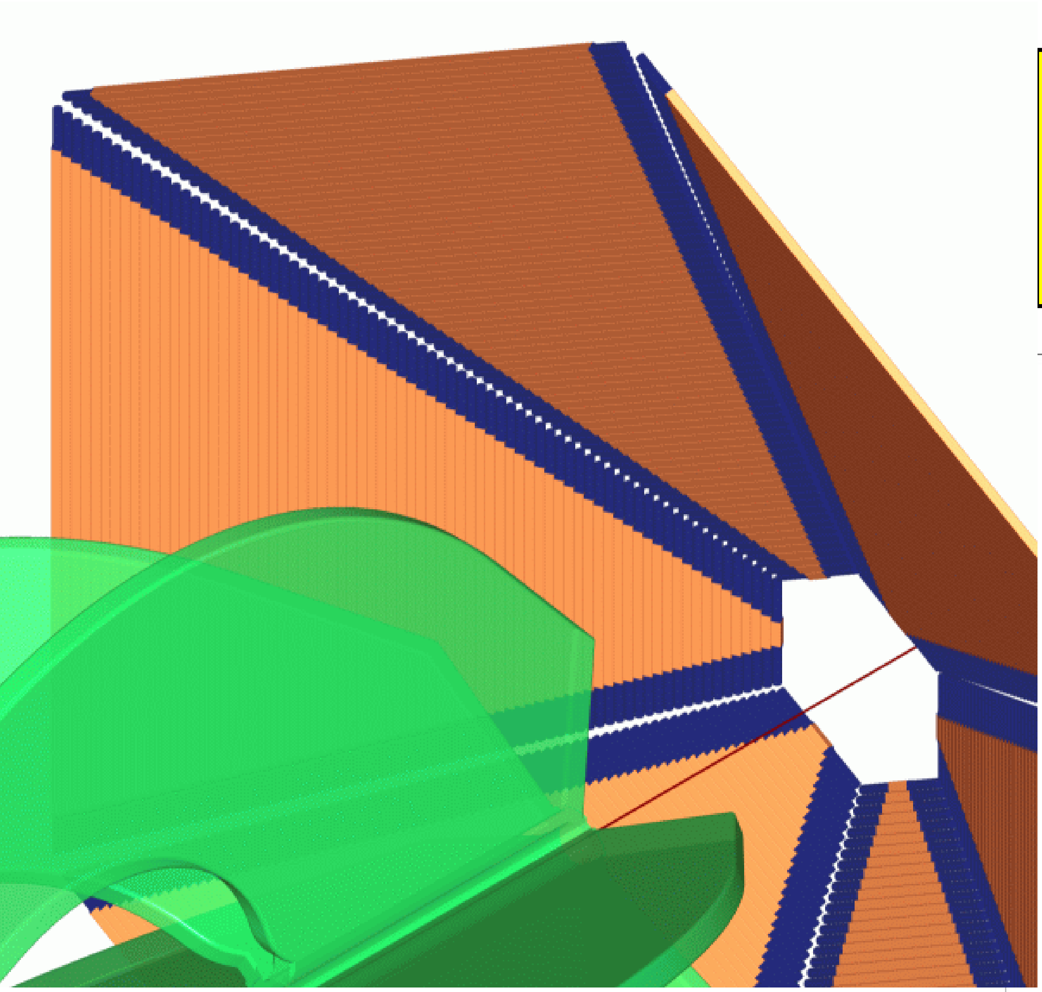


Torus coils

Inner Calorimeter
e.g. $PbWO_4$ crystals

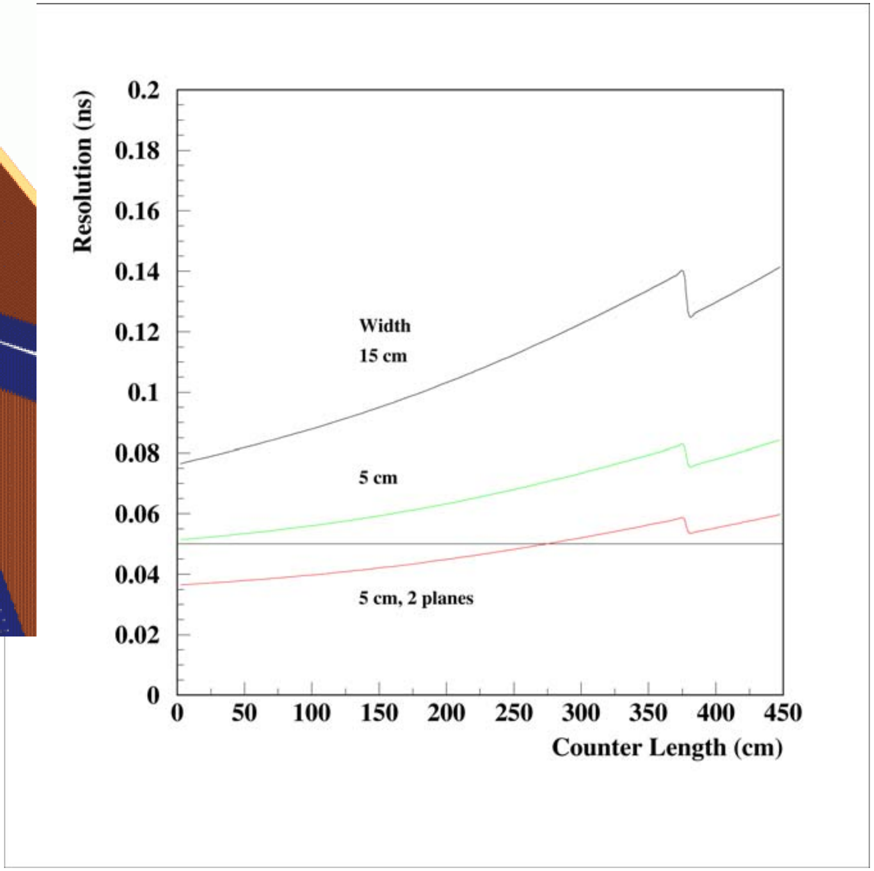
Readout with APD or magnetic field insensitive PMTs.

Forward TOF Detector - Improved Time Resolution



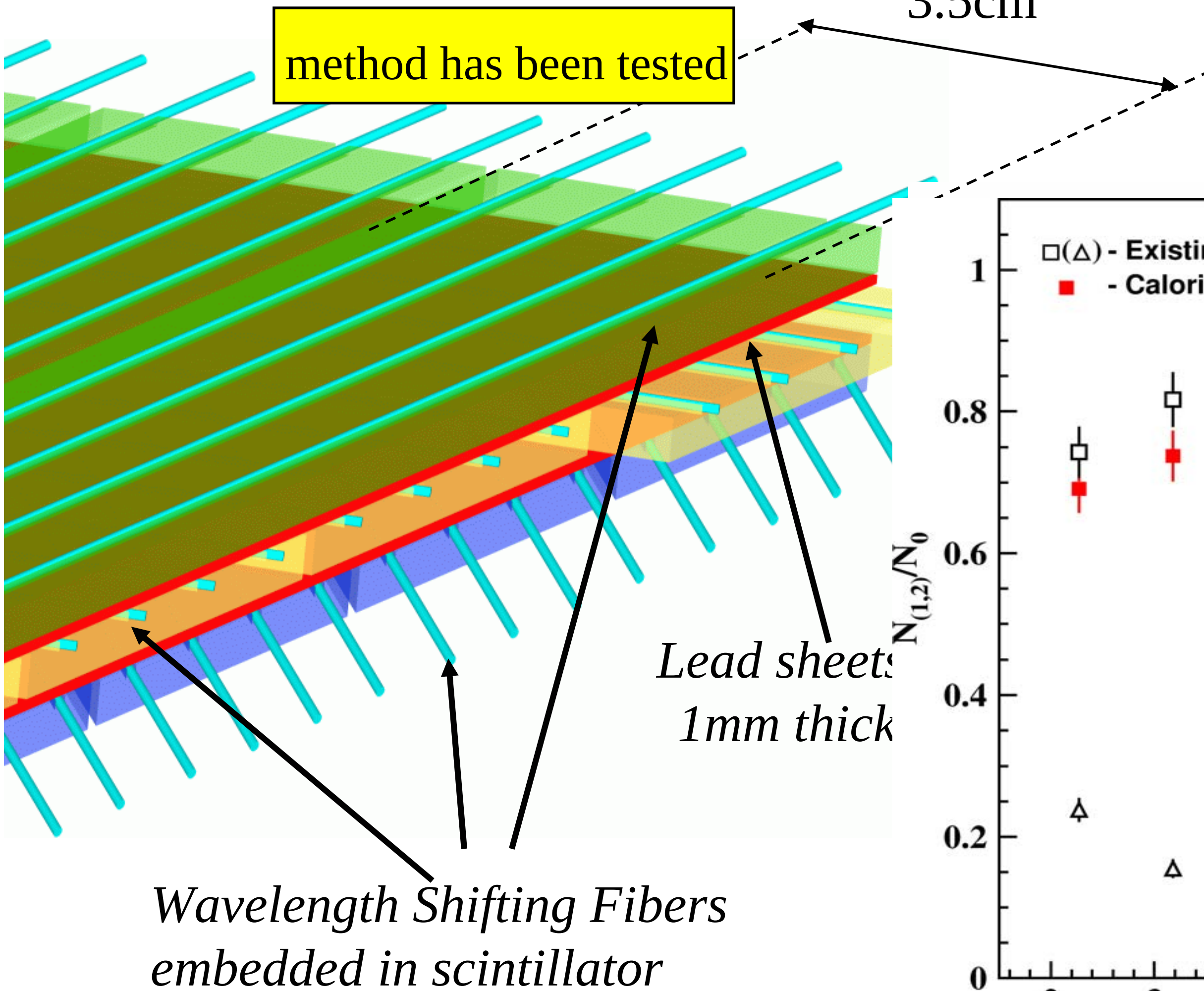
- reduce scintillator width to 5cm
- add second scintillator layer

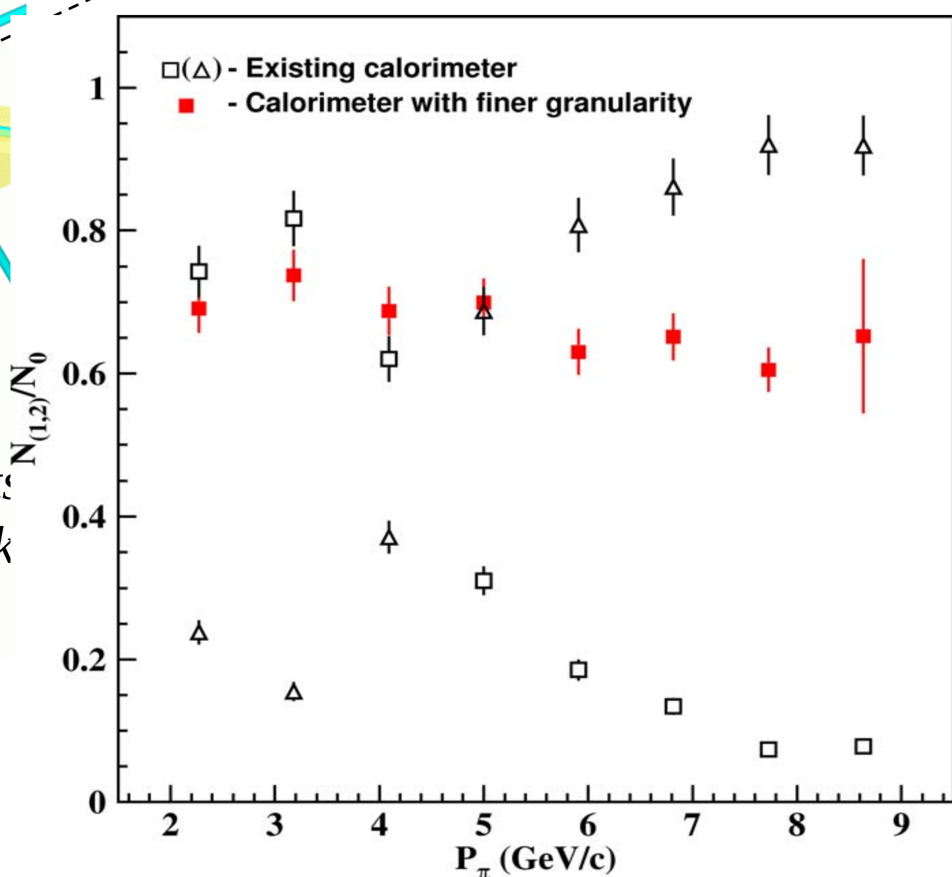
  => δT ~ 50-60psec



Pre-shower Calorimeter

Scintillator/lead sandwich, with wavelength shifting fiber readout, ~ 4 rad. length.





CLAS ++ - Expected Performance

	Forward Detector	Central Detector
Angular coverage:		
Tracks (inbending)	8^o - 37^o	40^o - 135^o
Tracks (outbending)	5^o - 37^o	40^o - 135^o
Photons	3^o - 37^o	40^o - 135^o
Track resolution:		
δp (GeV/c)	$0.003p + 0.001p^2$	$\delta p_T = 0.02 p_T$
$\delta\theta$ (mr)	1	5
$\delta\phi$ (mr)	2 - 5	2
Photon detection:		
Energy range	> 150 MeV	> 60 MeV
$\delta E/E$	0.09 (1 GeV)	0.06 (1 GeV)
$\delta\theta$ (mr)	3 (1 GeV)	15 (1 GeV)
Neutron detection:		
η_{eff}	0.5 (p > 1.5 GeV/c)	
Particle id:		
e/π	>>1000 (< 5 GeV/c) >100 (> 5 GeV/c)	
π/K (4σ)	< 3 GeV/c	0.6 GeV/c
π/p (4σ)	< 5 GeV/c	1.3 GeV/c

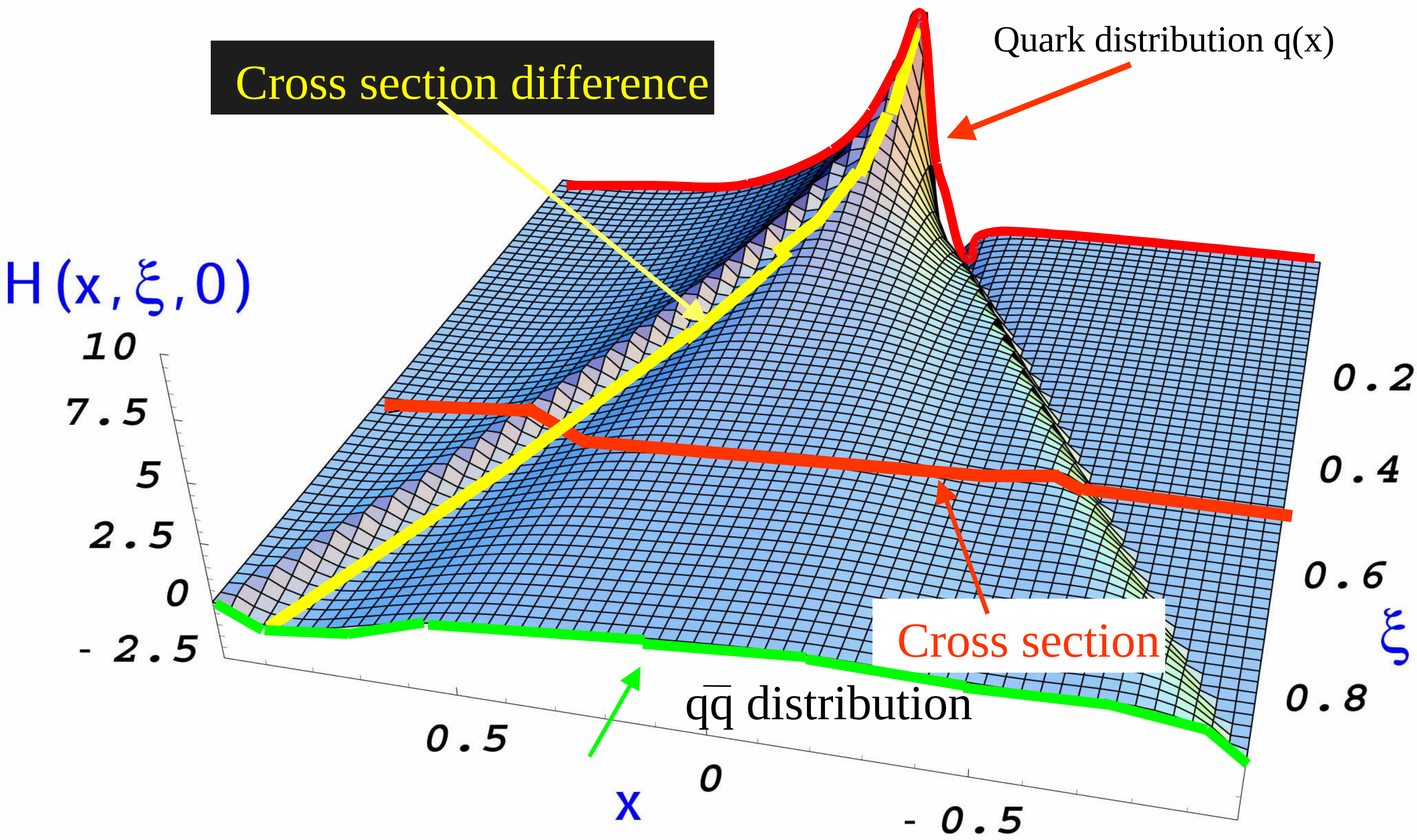
Physics processes measured concurrently - I

Target: H_2
Beam: E = 11 GeV, $P_e > 0.70$
L = $10^{35} cm^{-2} s^{-1}$, 2000 hours

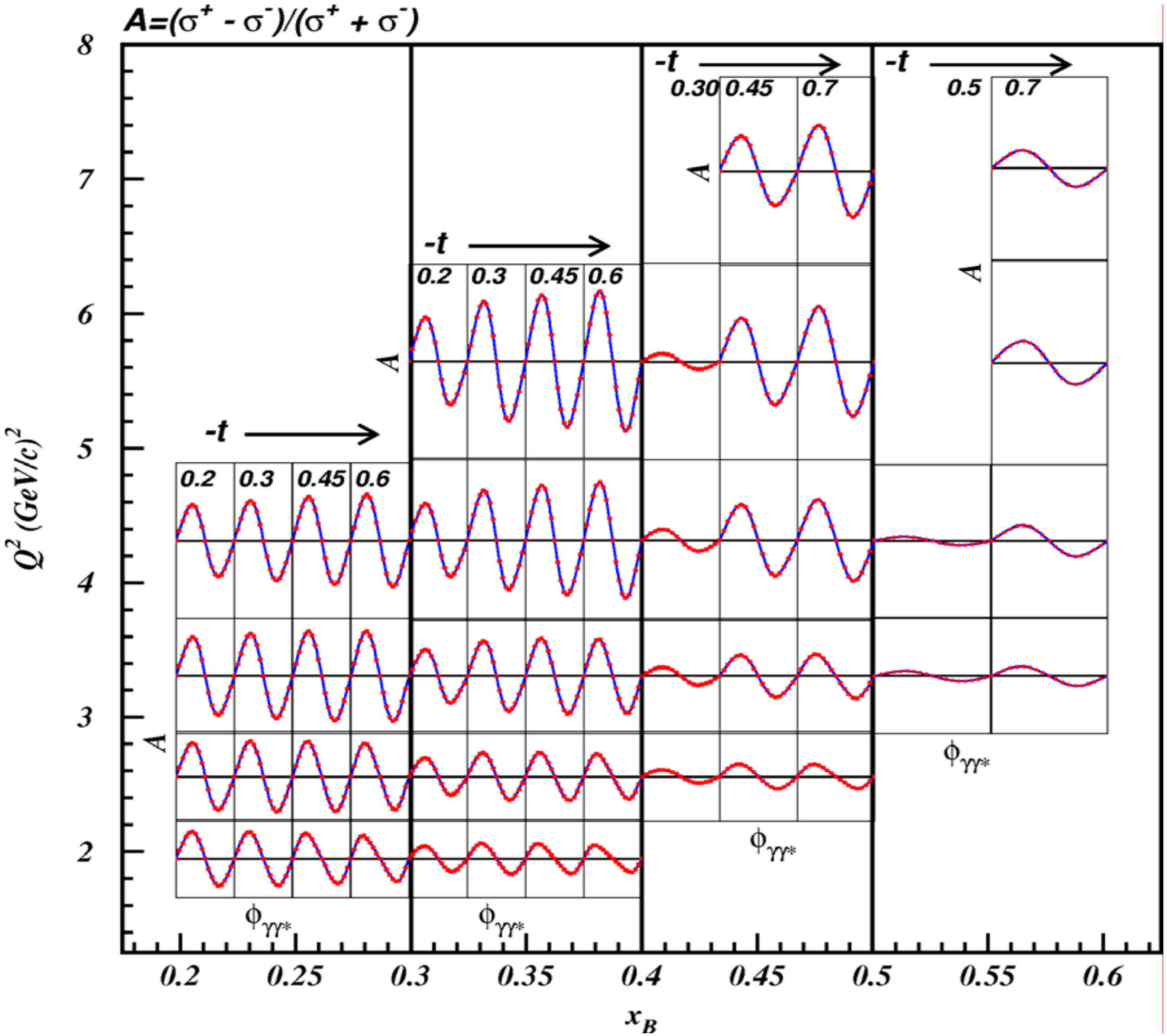
All reactions require:
Forward tracking, HTCC, Forward TOF, Central solenoid

Reaction	Description	Physics quantity	Equipment
$ep \to ep\gamma$ $ep \to epe^+e^-$ $ep \to e(\Delta,N^*)\gamma$ $ep \to ep(\rho,\omega,\phi)$ $ep \to eN(\pi^0,\eta,\pi^+)$	DVCS, DVMP, internal qq (twist-2), qGq (twist-3), spin dynamics, proton tomography	GPDs, **H,** $x=\xi$ GPDs, $-\xi<x<\xi$ N* transition GPDs GPDs spin/flavor separation	central tracker, central TOF, pre-shower EC, inner EC, central EC
$ep \to eN(\pi^0,\eta,\pi^+)$	hard meson production short distance dynamics	GPDs @ high t	central tracker, central TOF, central EC
$ep \to e(\pi^+,\pi^0,\eta,K^+)X$	quark transverse momentum-dependent distributions (TMD)	e(x) twist-3 distribution function, twist-3 sum rule	central tracker central TOF
$ep \to eN(\pi^0,\pi^+)$ $ep \to eN(\eta,\pi^+\pi^-,\omega)$	$N\Delta$ - R_{EM}, R_{SM} high mass N^*, pQCD	approach to scaling spectroscopy of high mass N*	central tracker, central TOF, central EC

Modeling of the Generalized Parton Distributions



DVCS/BH projected for CLAS++ at 11 GeV



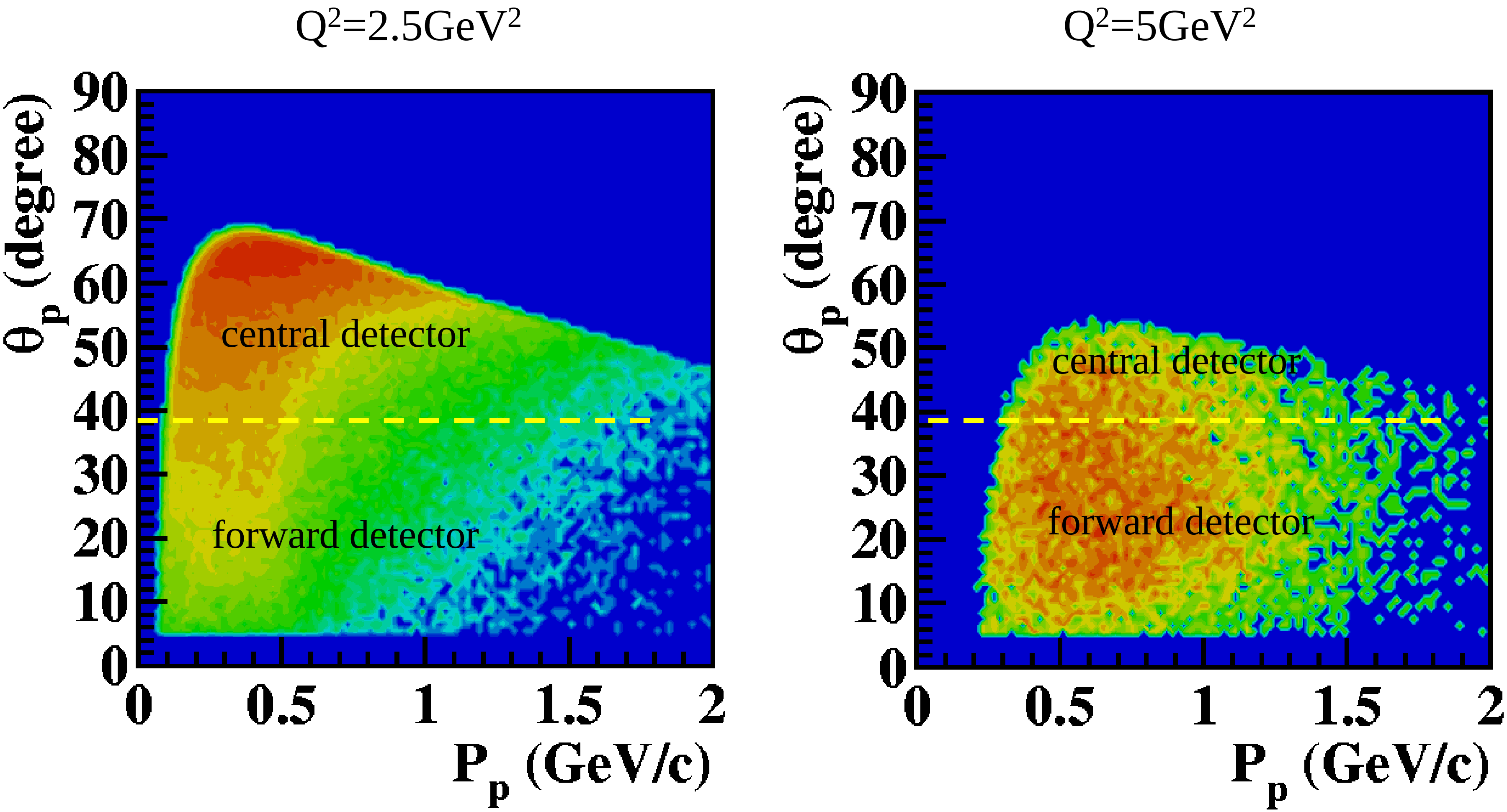
972 data points measured simultaneously + high t (not shown)

Q^2, x_B, t ranges measured simultaneously.

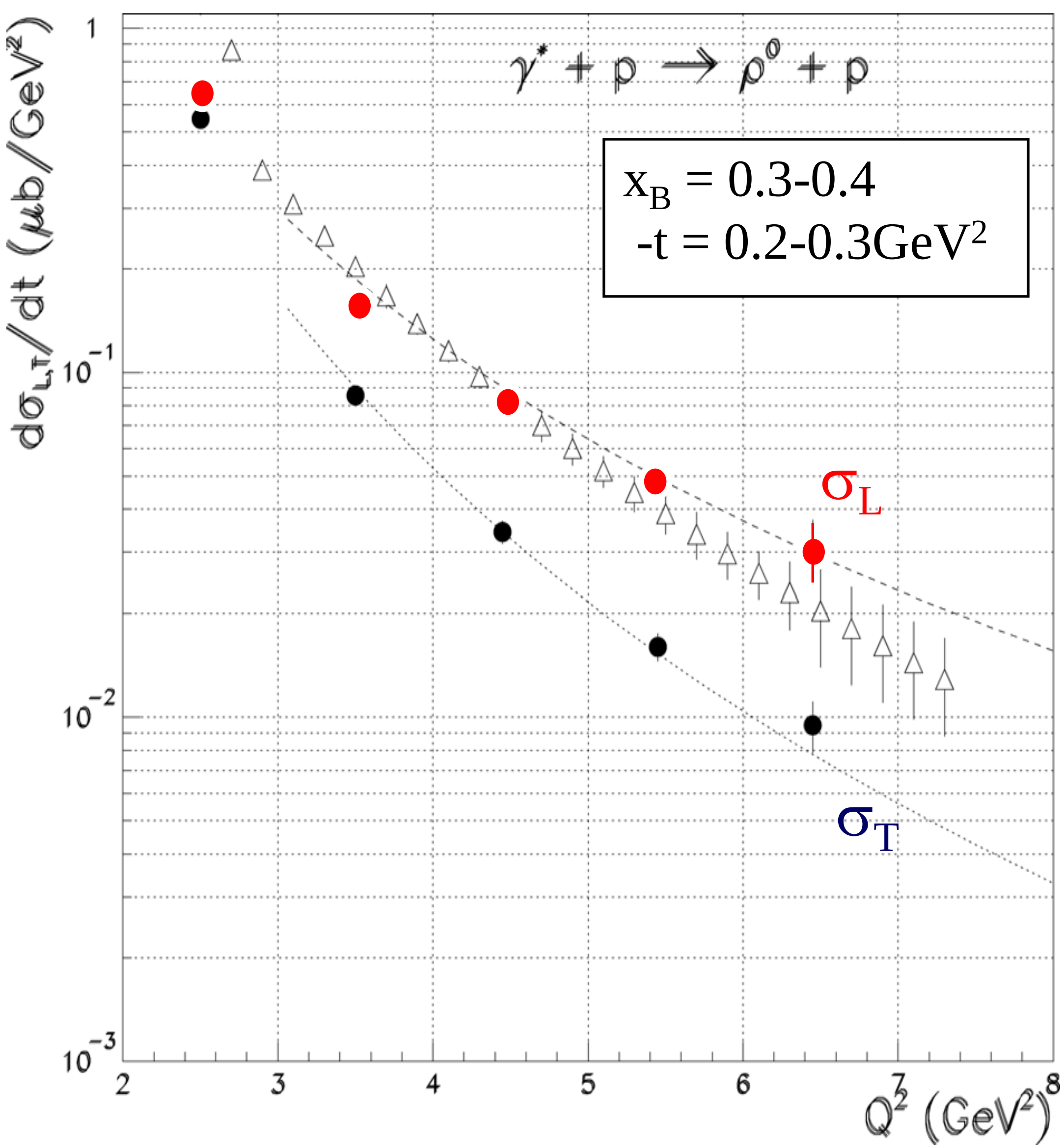
$A(Q^2,x_B,t)$
$\Delta\sigma\ (Q^2,x_B,t)$
$\sigma\ (Q^2,x_B,t)$

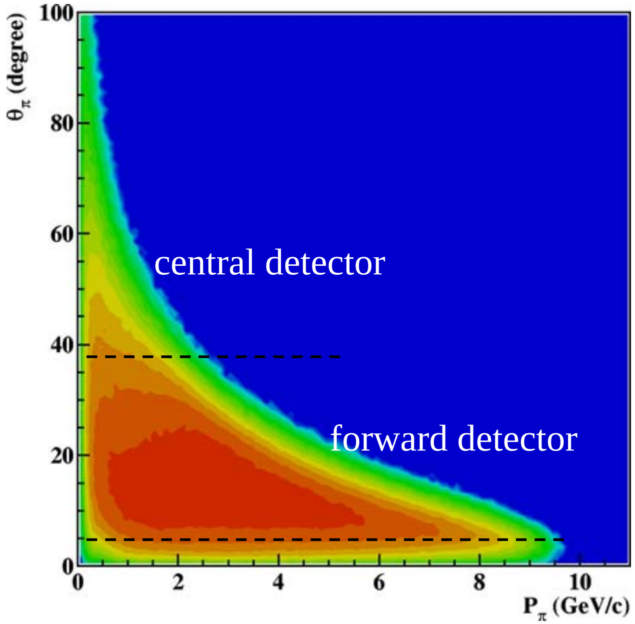
CLAS^{++}: Kinematics for ep $\longrightarrow$ epγ (DVCS)

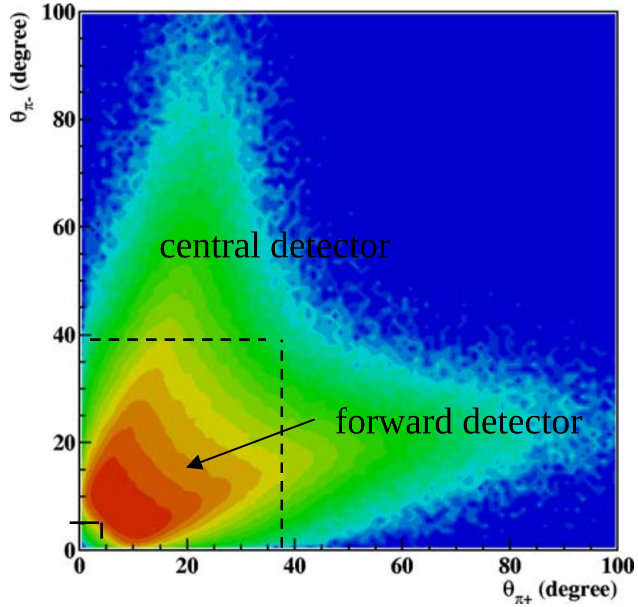
E = 11 GeV



Separated Cross Section for ep ⟶ epρ° ($\pi^+\pi^-$)

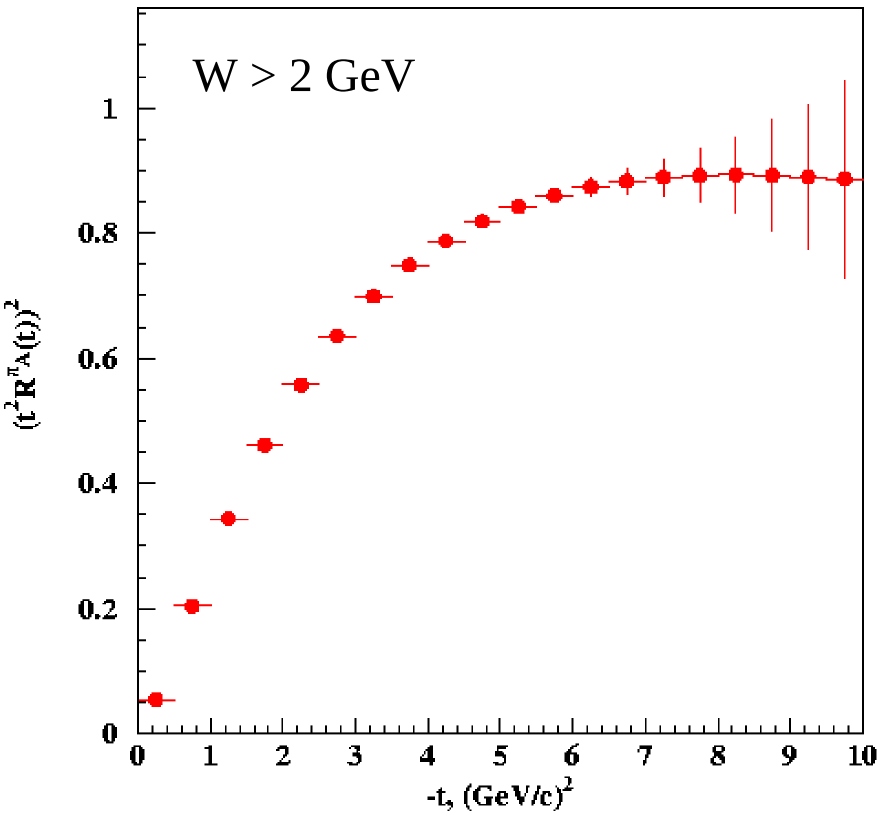




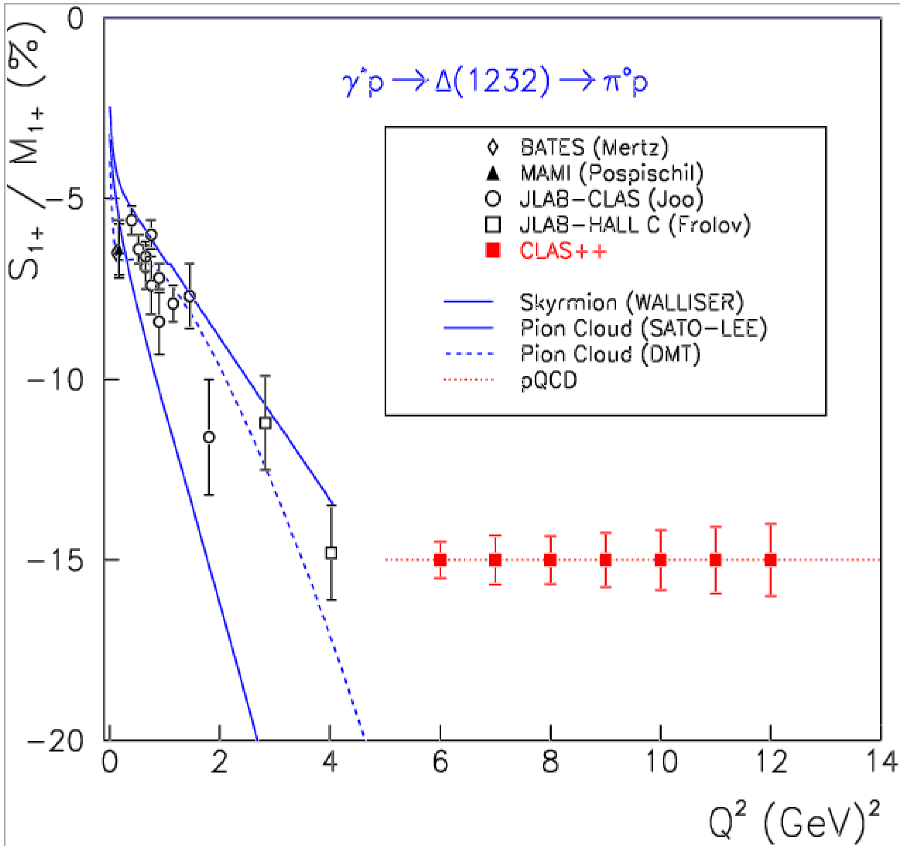


Axial Compton Formfactor and NΔ(1232) Transition

$\gamma^* p \longrightarrow p\pi^o$



$\gamma^* p \longrightarrow p\pi^o(\gamma\gamma)$



also: E_{1+}/M_{1+}

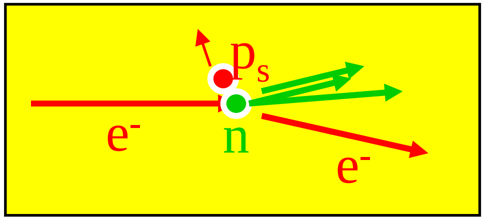
Physics processes measured concurrently - II

Target: D_2
Beam: E = 11 GeV, $P_e > 0.70$
L = $10^{35} cm^{-2} s^{-1}$, 2000 hours

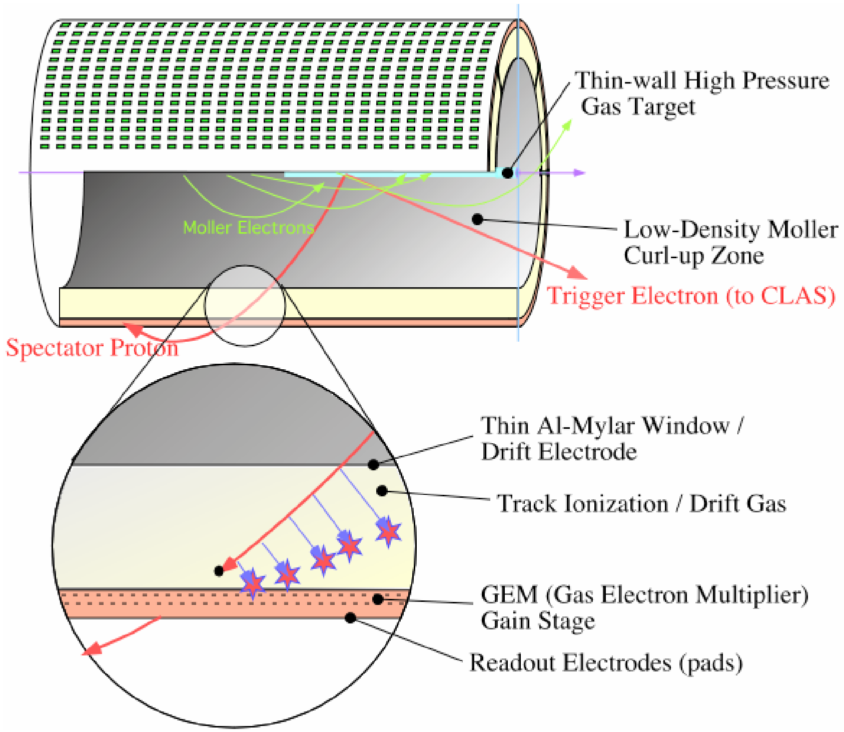
All reactions require:
Forward tracking, HTCC, Forward TOF, Central solenoid

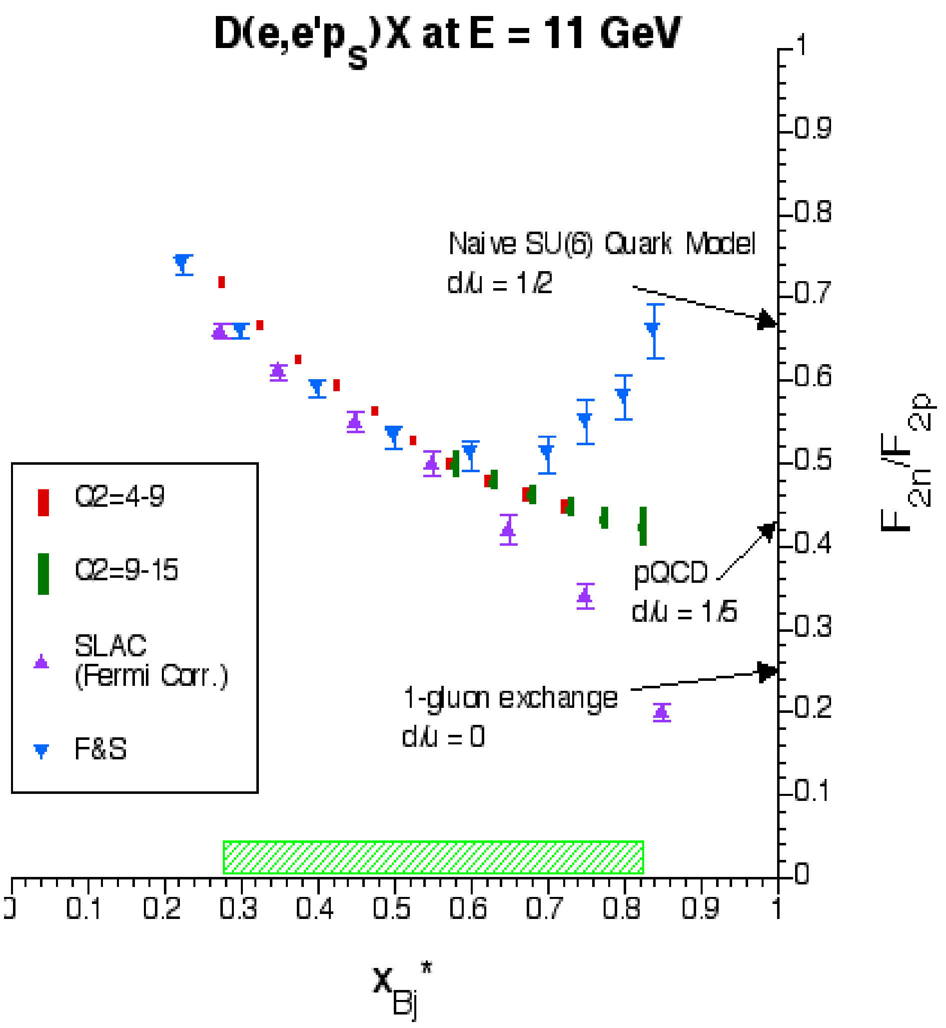
Reaction	Description	Physics quantity	Equipment
$eD \rightarrow ep_sX$ $eD \rightarrow ep_s(\pi^-p),\Delta^+\pi^-$	S.F. of "free" neutron neutron resonances	$F_{2n}(x,Q^2)$ $A^o_{1/2},A^o_{3/2}\ (Q^2)$	central tracker central TOF central EC
$eD \rightarrow eD\gamma$ $eD \rightarrow ep_s(\Delta^0,N^*)\gamma$	DVCS, N*VCS	GPD $H(\xi,\xi,t)$ $G_{N^*}(t)$	central tracker, central TOF, pre- shower EC, inner EC
$eD \rightarrow e(M,\gamma)X$	twist-3 distribution functions	$e(x)$	central tracker central TOF, pre- shower EC
$eD \rightarrow e(n,p)$ $ep \rightarrow e\pi^+n$	neutron magnetic form factor	$G_{Mn}(Q^2)$	central tracker central TOF
$eD \rightarrow eD(\rho,\omega,\phi)$	color transparency in coherent VM production	$d\sigma(t1)/d\sigma(t2)$ vs Q^2	central tracker central TOF
$eD \rightarrow e(\rho,\omega,\phi)X$	color transparency at fixed coherence length	$\sigma_A/A\sigma_N$	central tracker central TOF

Structure of "Free" Neutrons - e.g. F_{2n}



Requires detection of a slow recoil proton at backward angles and with momenta ~60-150MeV/c

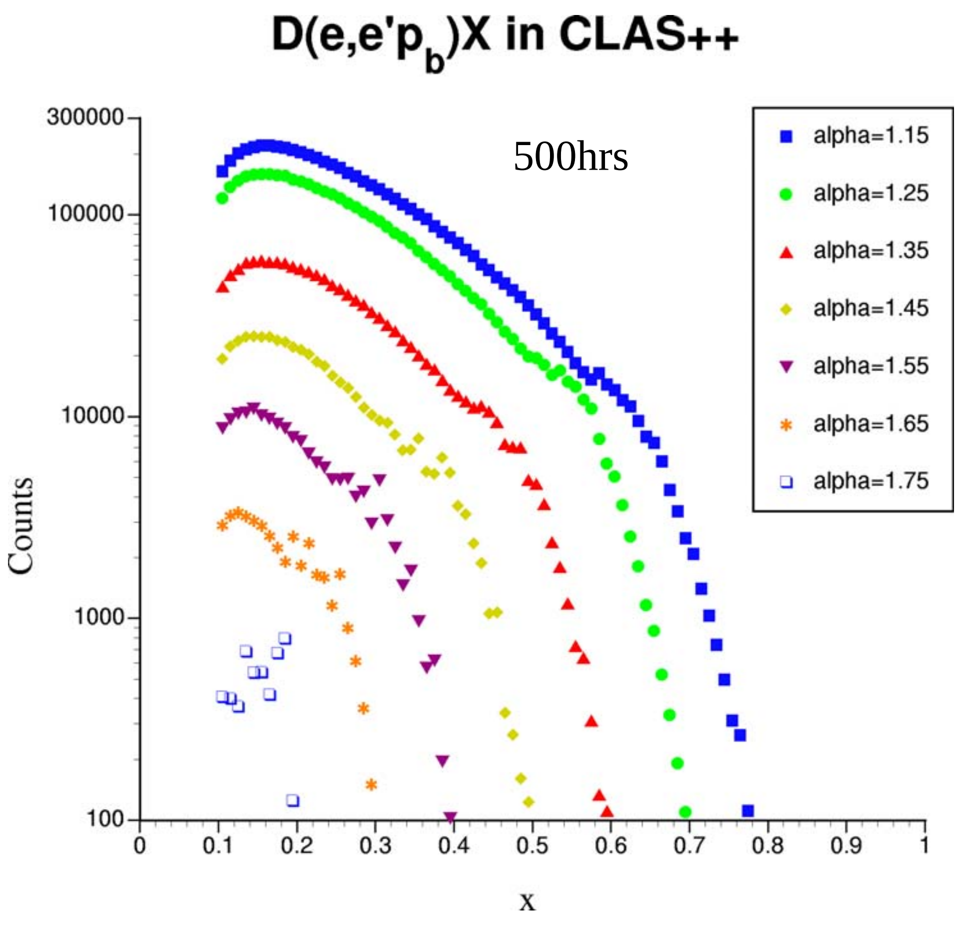




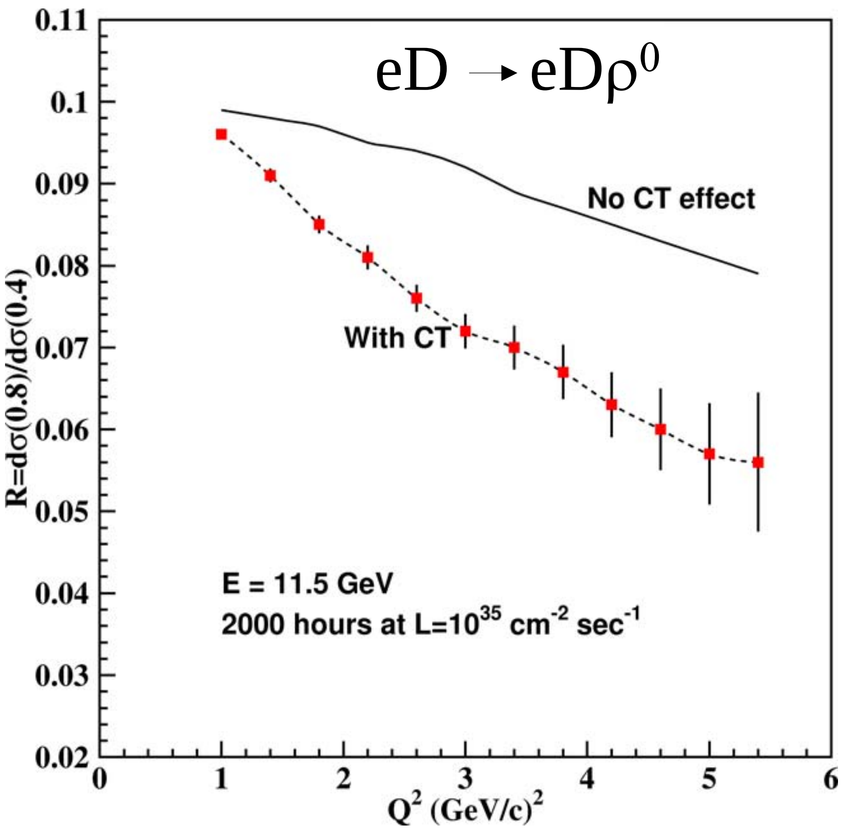
Measure Q^2 dependence simultaneously

Structure of bound Neutrons & Color Transparency

Bound Neutron

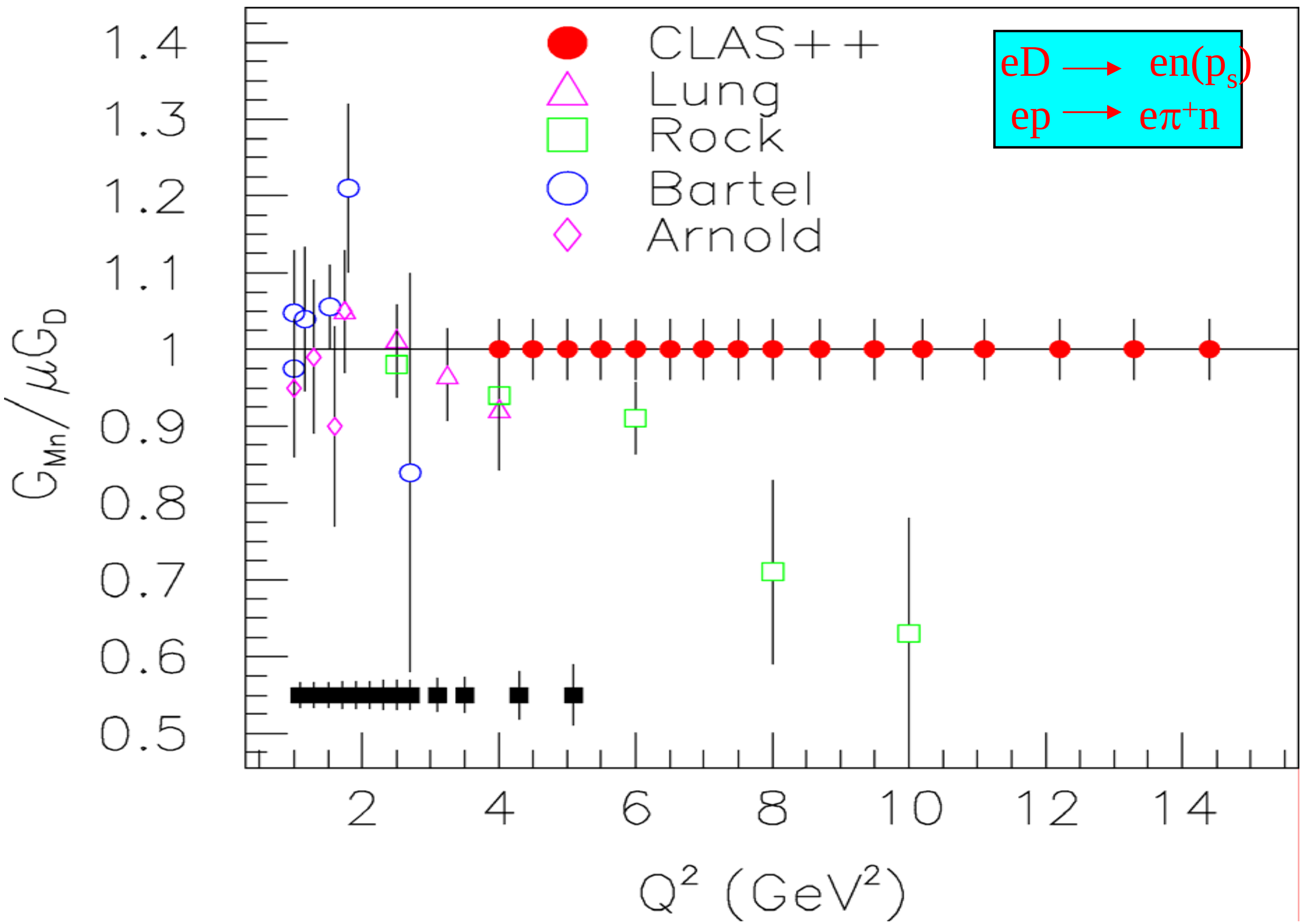


Color Transparency



CLAS^{++} : Neutron G_{Mn}

E = 11 GeV



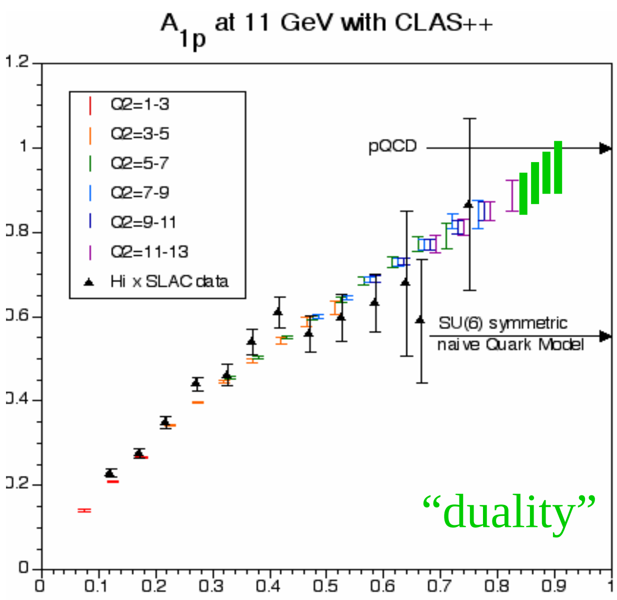
Physics processes measured concurrently - III

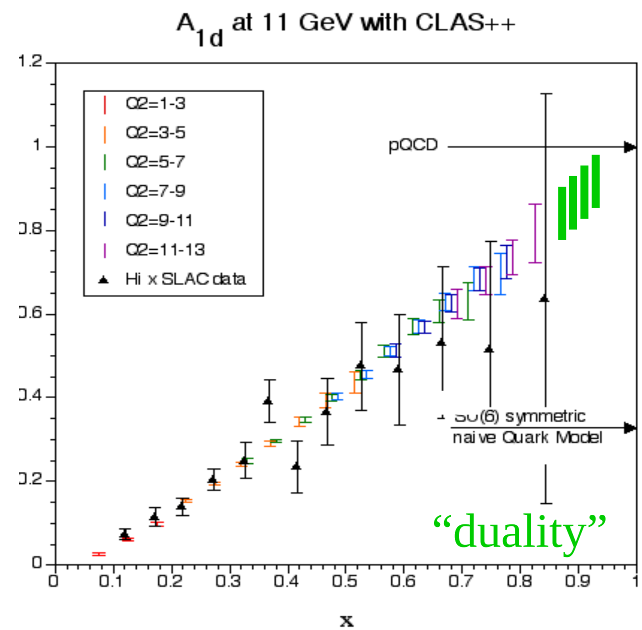
Target: Polarized H/D
Beam: E = 11 GeV, $P_e > 0.70$, $Pp=0.75, P_D=0.35$
$L = 10^{35} cm^{-2}s^{-1}$, 1000 hrs NH_3, 1000 hrs ND_3

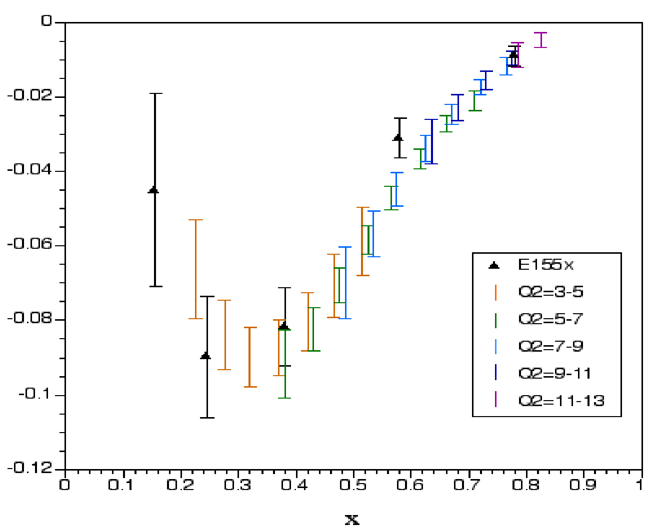
All reactions require:
Forward tracking, HTCC, Forward TOF

Reaction	Physics description	Physics quantity	Equipment
$\vec{e}\,\vec{p} \rightarrow eX$, $ep^T \rightarrow eX$ $\vec{e}\,\vec{D} \rightarrow eX$, $eD^T \rightarrow eX$	proton spin structure neutron spin structure	$A_{1p}, g_{1p}, g_{2p}, \Gamma_{1p}$ $A_{1n}, g_{1n}, g_{2n}, \Gamma_{1n}$	transverse target
$e\vec{p} \rightarrow ep\gamma$ $\vec{e}\,\vec{p} \rightarrow ep\gamma$	DVCS/BH target SSA DVCS/BH double asym.	GPDs $\tilde{H}$ $H, E, \tilde{H}, \tilde{E}$	central tracker, central TOF, preshower EC
$e\vec{p} \rightarrow eN(\pi^0,\eta,\pi^+)$ $\vec{e}\,\vec{p} \rightarrow eN(\pi^0,\eta,\pi^+)$	DVMP target SSA DVMP/BH double asym.	GPDs $\tilde{H}, \tilde{E}$	central tracker, central TOF preshower EC
$\vec{e}\,\vec{p} \rightarrow e(\pi^+,\pi^0,\eta,K^+)X$ $\vec{e}\,\vec{D} \rightarrow e(\pi^-,\pi^0,\eta)X$	quark flavor tagging	$A_{UL}^{\sin\phi}$ $\Delta d_v/d_v$	preshower EC central tracker central TOF
$ep^T \rightarrow e(\pi^+,\pi^0,\eta,K^+)X$	quark transversity	$A_{UT}^{\sin\phi}$ $\delta u/u$	transverse target preshower EC

CLAS^{++}: $A_{1p}(x,Q^2)$, $g_{2p}(x,Q^2)$ $A_{1d}(x,Q^2)$, $A_{1n}(x,Q^2)$





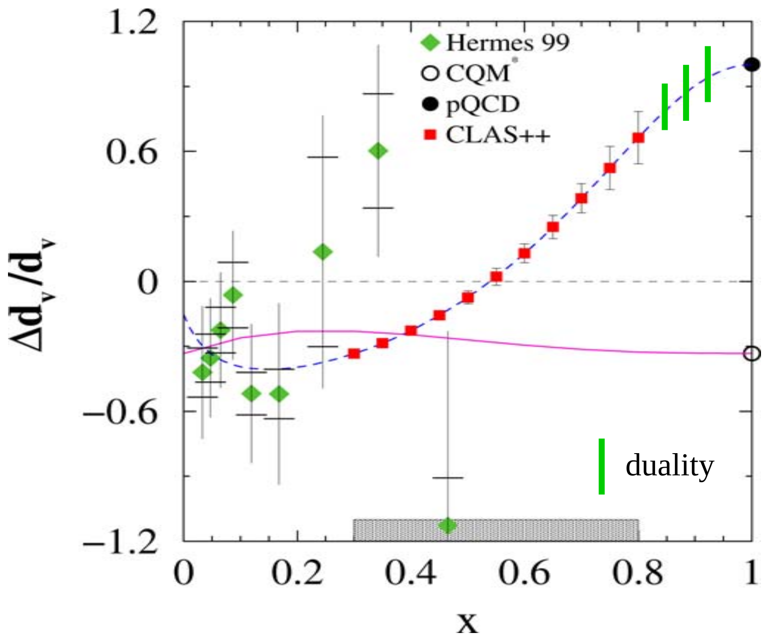


$g_{2p}(x,Q^2)$ at 11 GeV with transverse target

1000 hrs @ $10^{35}cm^{-2}s^{-1}$ /target

Measure Q^2 dependence simultaneously

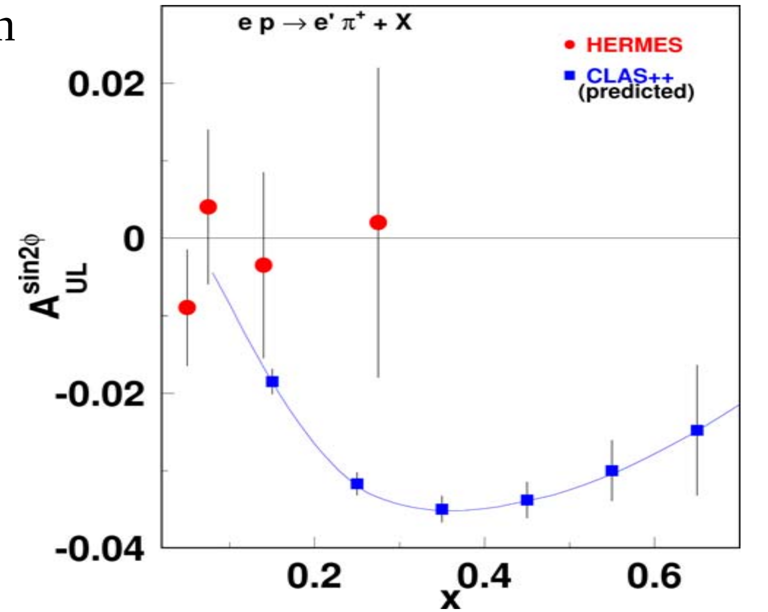
Semi-Inclusive Deeply Inelastic Scattering



Flavor separation

$\vec{e}\vec{p} \to e\pi^+X$

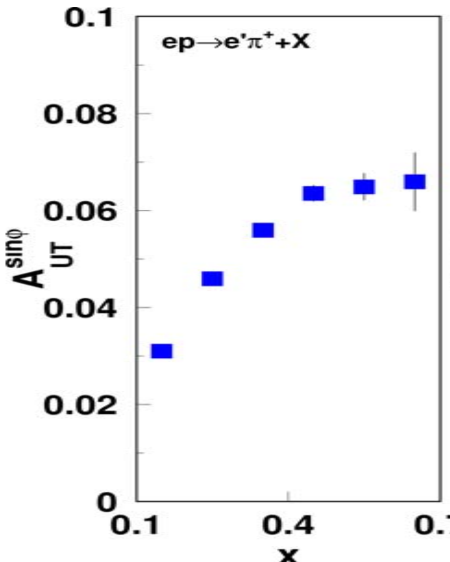
$\vec{e}\vec{d} \to e\pi^- X$

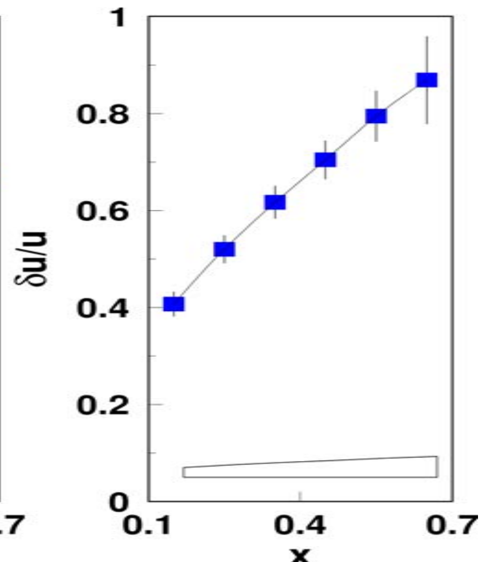


$\vec{e}p \to e\pi^+X$

twist-3

Quark transversity





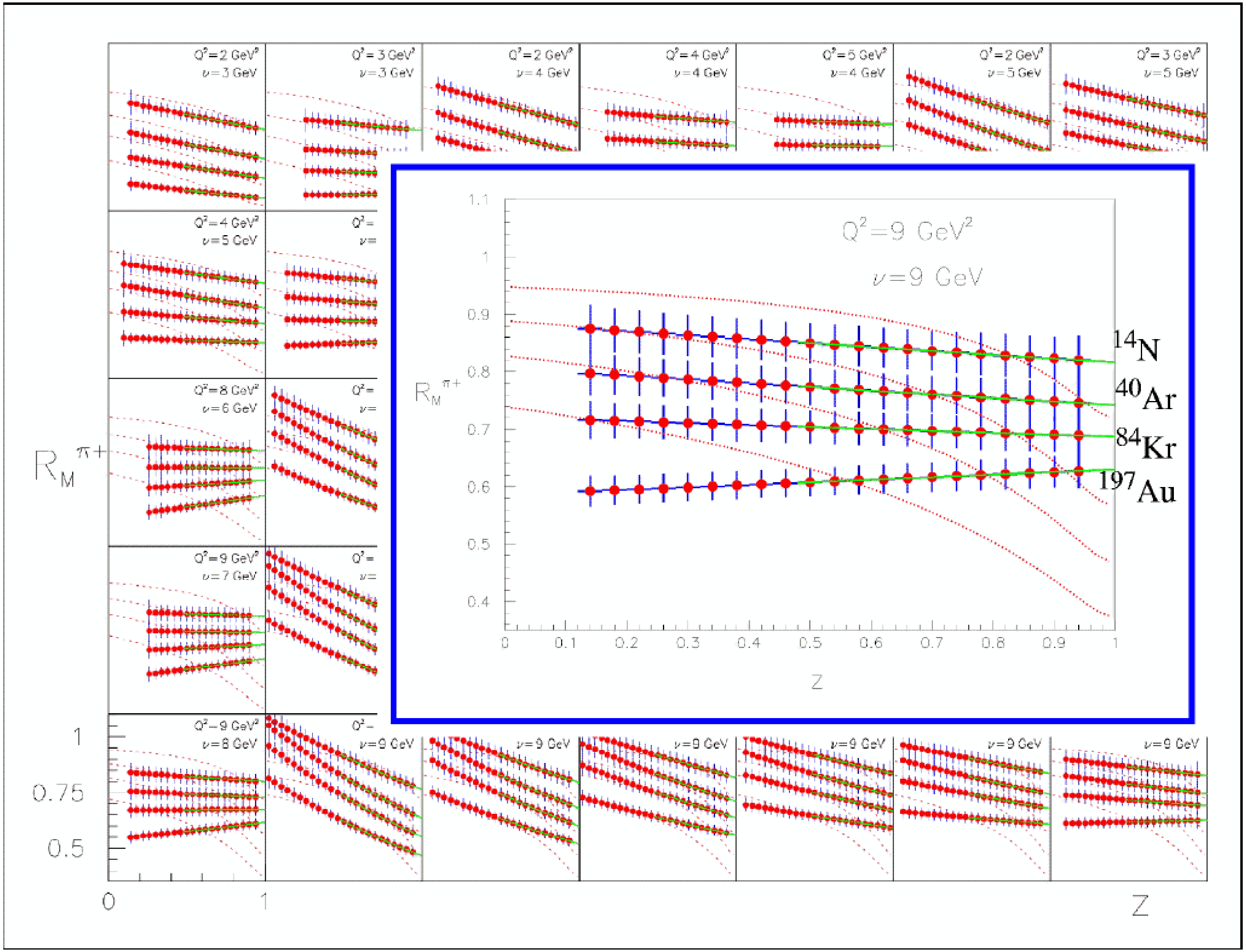
Physics processes measured concurrently - IV

Target: Nuclear
Beam: E = 11 GeV, $P_e > 0.70$
L = $10^{35} cm^{-2} s^{-1}$, 2000 hrs

All reactions require:
Forward tracking, HTCC, Forward TOF

Reaction	Physics description	Physics quantity	Equipment
$e^2H \rightarrow$ e hadrons X $e^{14}N \rightarrow$ e hadrons X $e^{56}Fe \rightarrow$ e hadrons X $e^{84}Kr \rightarrow$ e hadrons X $e^{197}Au \rightarrow$ e hadrons X hadrons = π^0, π^+, π^-, η, ω, η', ϕ, K^+, K^-, K^0, p, $\bar{p}$, Λ, $\Lambda(1520)$, Σ^+, Σ^0, Σ^0, Ξ^0, Ξ^-	space-time characteristics of hadronization (DIS kinematics)	Hadronization length vs. Q^2, ν, p_T, z, hadron mass and size, and quark flavor; quark energy loss, gluon emission properties, quark-gluon correlations	central tracker central TOF central EC, preshower EC
$e^{14}N \rightarrow e\rho X$ $e^{56}Fe \rightarrow e\rho X$	color transparency in ρ production from complex nuclei	color transparency at fixed coherence length	central tracker central TOF

Space-Time Characteristics of Nuclear Hadronisation



Physics potentials with forward electron facility

Meson spectroscopy, e.g. with ^{4}He - gas targets

Heavy baryon spectroscopy, e.g Ξ^*

Time-like virtual-Compton-scattering "γ"p -> pe^+e^-

Structure functions at very low Q^2

J/ψ production

others...

Physics goals with ***CLAS***$^{++}$ and ***Hall B***

The primary goal of experiments using the ***CLAS*** $^{++}$ detector at energies up to 12 GeV is the study of the internal nucleon dynamics in terms of elementary degrees of freedom, and the QCD structure of hadrons in the nuclear medium. Towards this end, the detector has been optimized for studies of ***exclusive*** and ***semi-inclusive*** reactions in a wide kinematic range. ***Inclusive*** processes, for which the unique properties of the ***Hall B*** instrumentation are essential (e.g. polarized NH_3(ND_3), neutron tagger, forward electron tagger), will be measured as well.