Beam Characteristics and Experimental Equipment Needed to Achieve the Research Goals of the 12 GeV Upgrade

L. Cardman

The Science

- **Mapping Gluonic Excitations and Understanding Confinement** — **A. Dzierba**

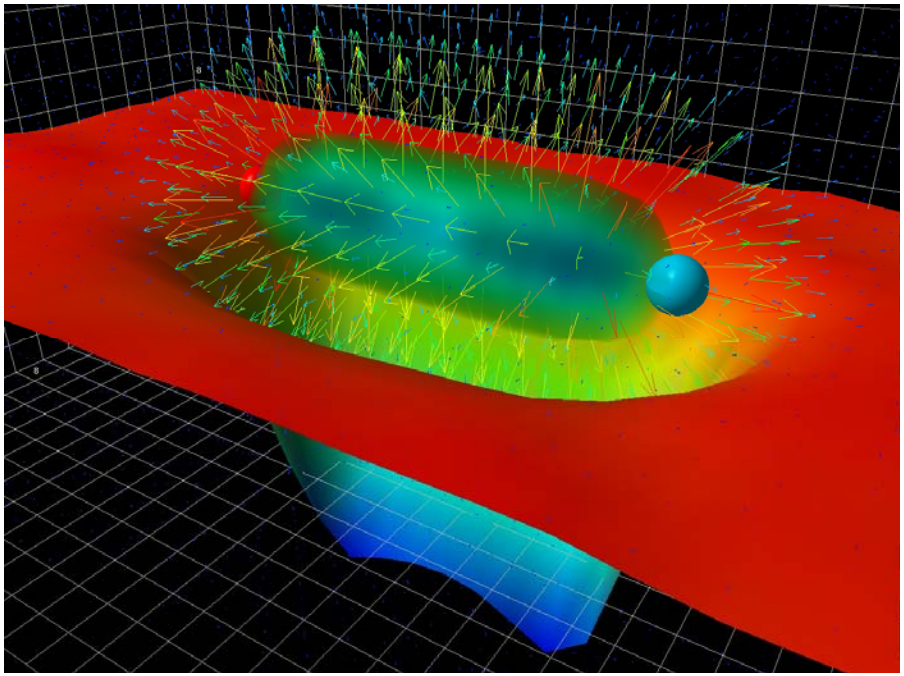
- **The Fundamental Structure of the Nuclear Building Blocks**
  - 3-D Quark/Gluon Imaging of the Nucleon — **V. Burkert**
  - Valence Quark Structure — **Z.-E. Meziani**
  - Spin Structure of the Nucleon
  - The Parton-hadron transition
  -

- **The Physics of Nuclei** — **W. Brooks**
  - The Emergence of Nuclei from QCD
  - Fundamental QCD processes in the Nuclear Arena

- **Symmetry Tests in Nuclear Physics** — **K. Kumar**
  - Standard Model Tests

The apparatus and beam requirements can be determined with great confidence based on previous experience and results from the 6 GeV Research Program

Gluonic Excitations and the Origin of Confinement



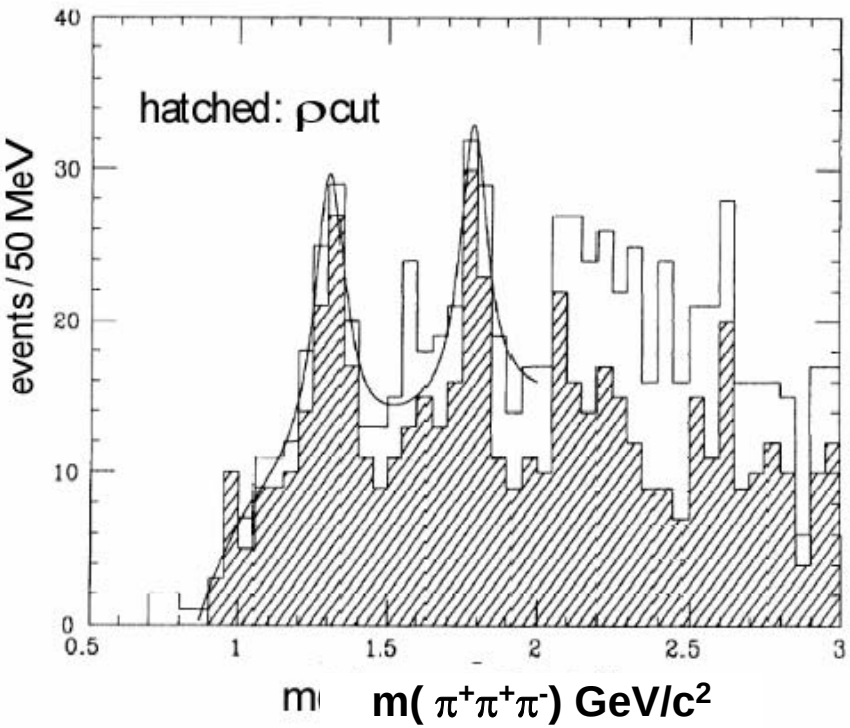
QCD predicts a rich spectrum of as yet to be discovered gluonic excitations - whose experimental verification is crucial for our understanding of QCD in the confinement regime.

With the upgraded CEBAF, a linearly polarized photon beam, and the GlueX detector, Jefferson Lab will be uniquely poised to:

- discover these states,
- map out their spectrum and
- measure their properties

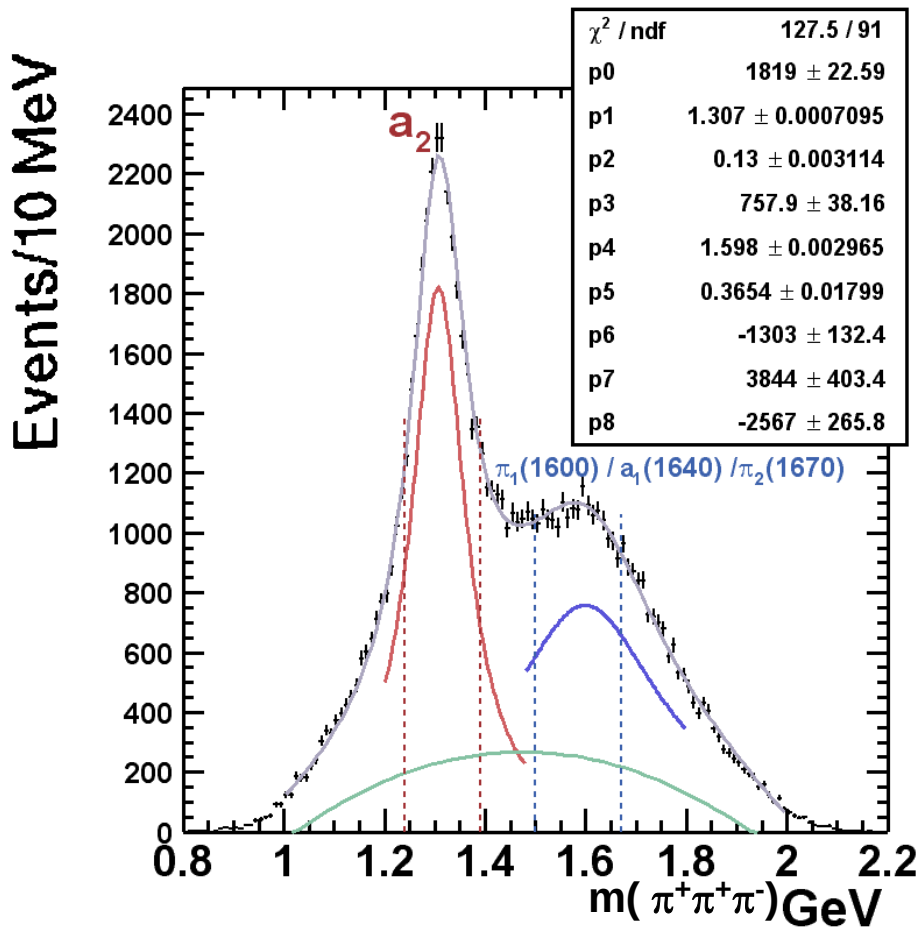
Ongoing Analysis of CLAS Data Demonstrates the Promise of Meson Photoproduction

SLAC Hybrid Facility Photon Collaboration

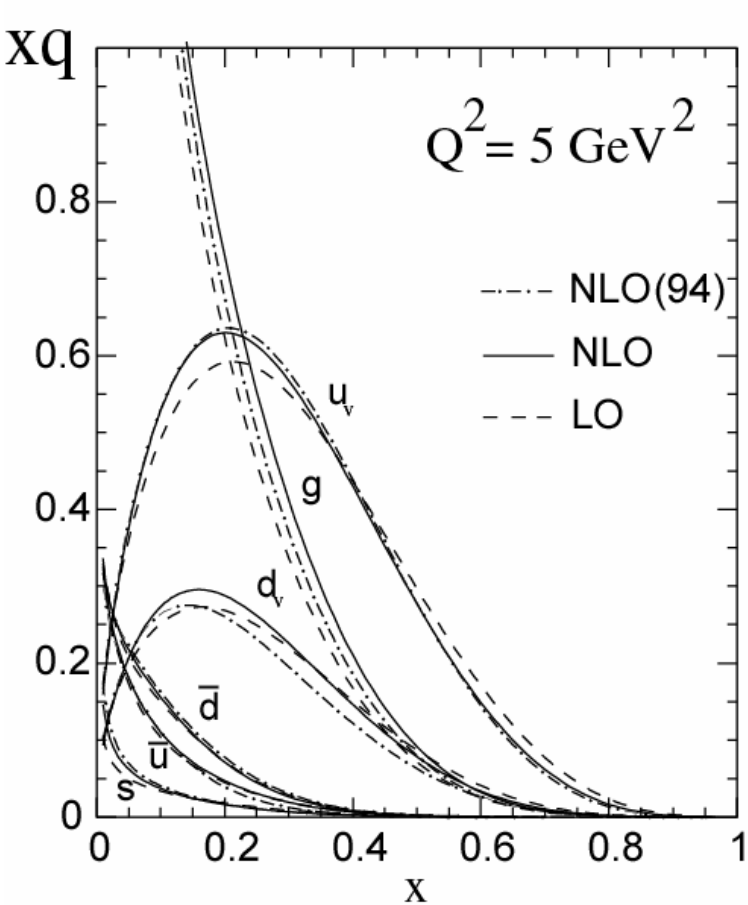


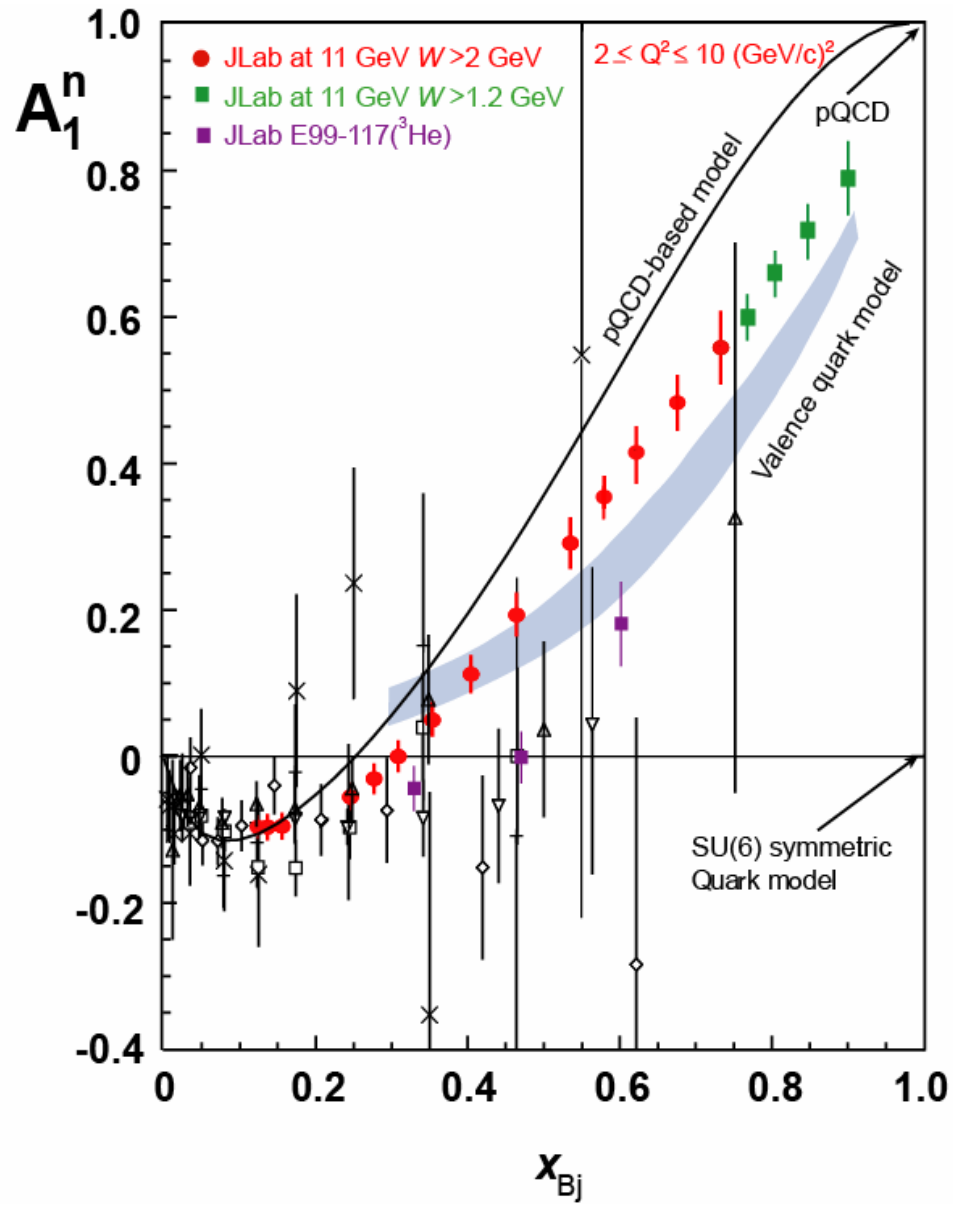
Phys. Rev. D 43, #9 2787 (1991)

~500x existing data on photo-production from a 1 month run with CLAS



Extending DIS to High x
The Neutron Asymmetry A_1^n



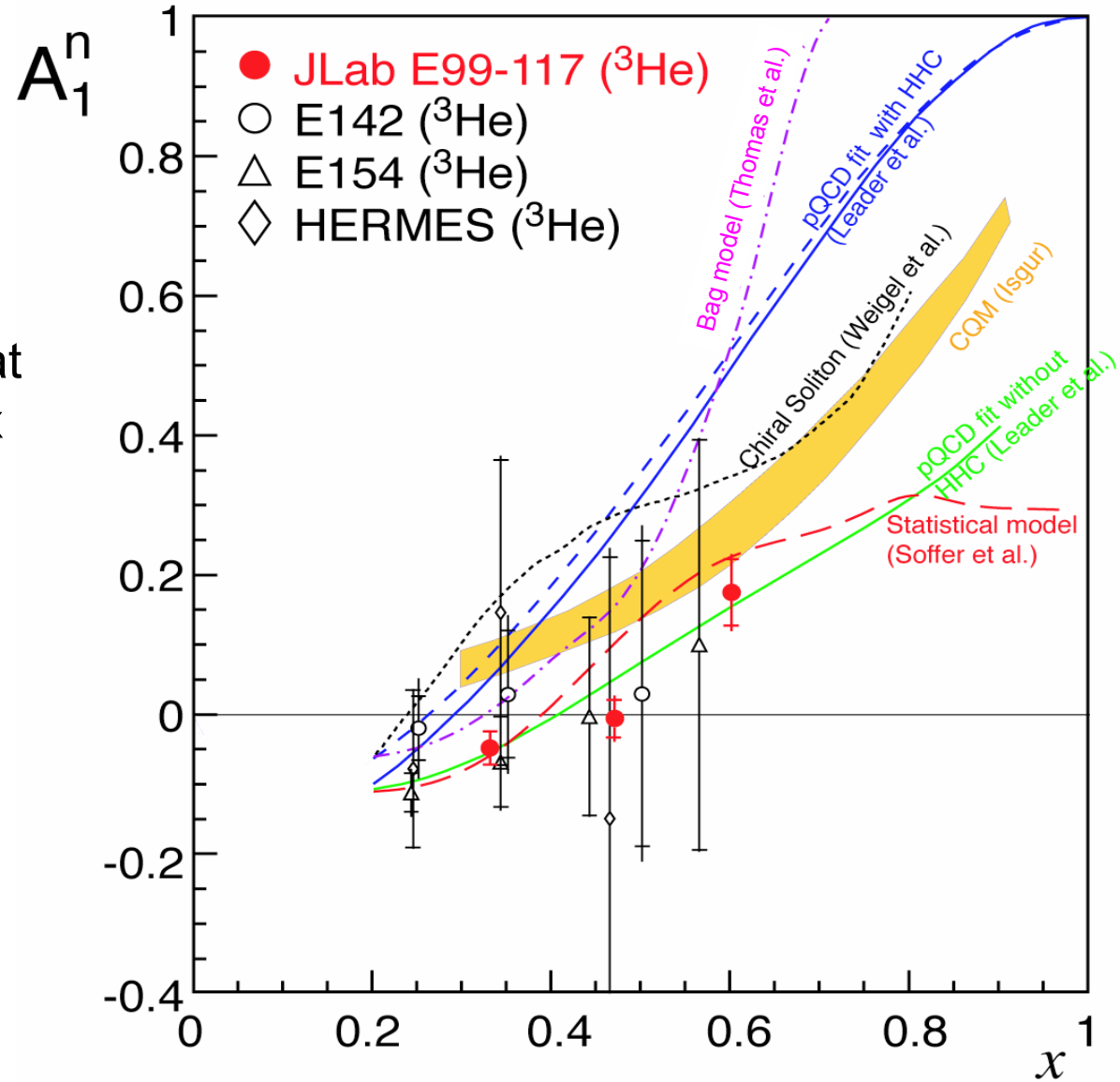


12 GeV will access the regime (x > 0.3), where valence quarks dominate

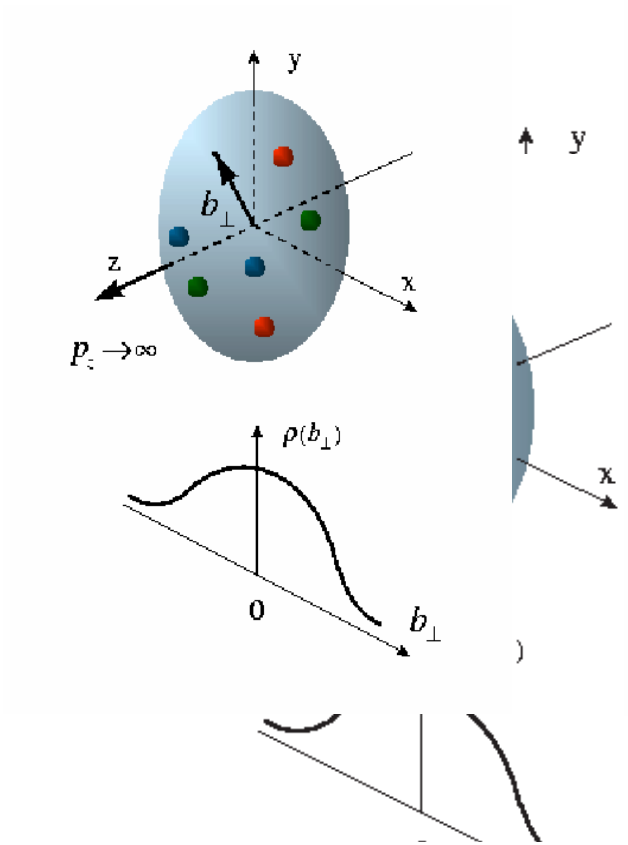
$\vec{^3He}$ Data Demonstrate the Feasibility of These Experiments

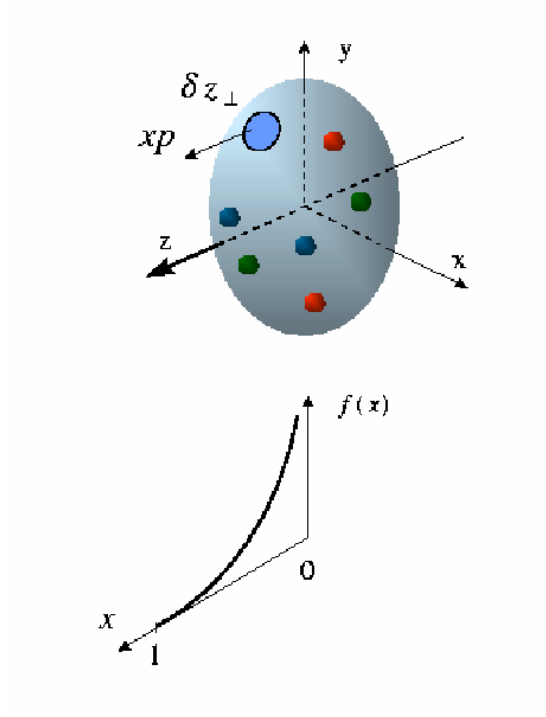
New E99-117 data

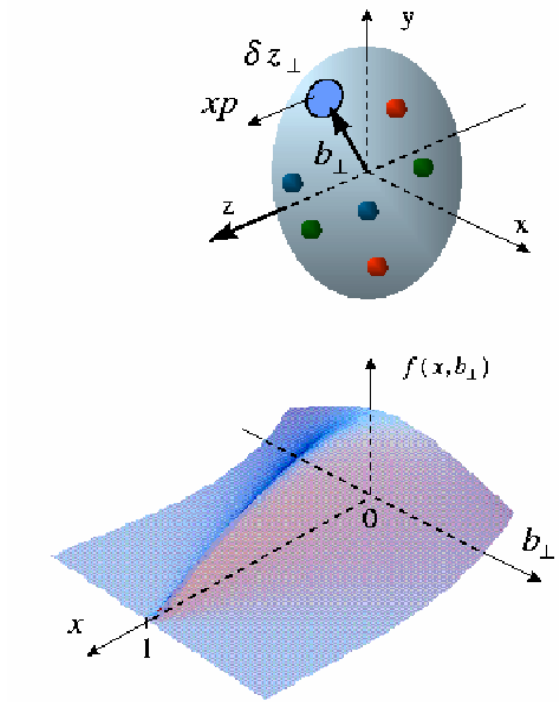
provide the first indication that A_1^n deviates from 0 at large x



Proton Properties Measured in Different Experiments







Elastic Scattering

transverse quark distribution in coordinate space

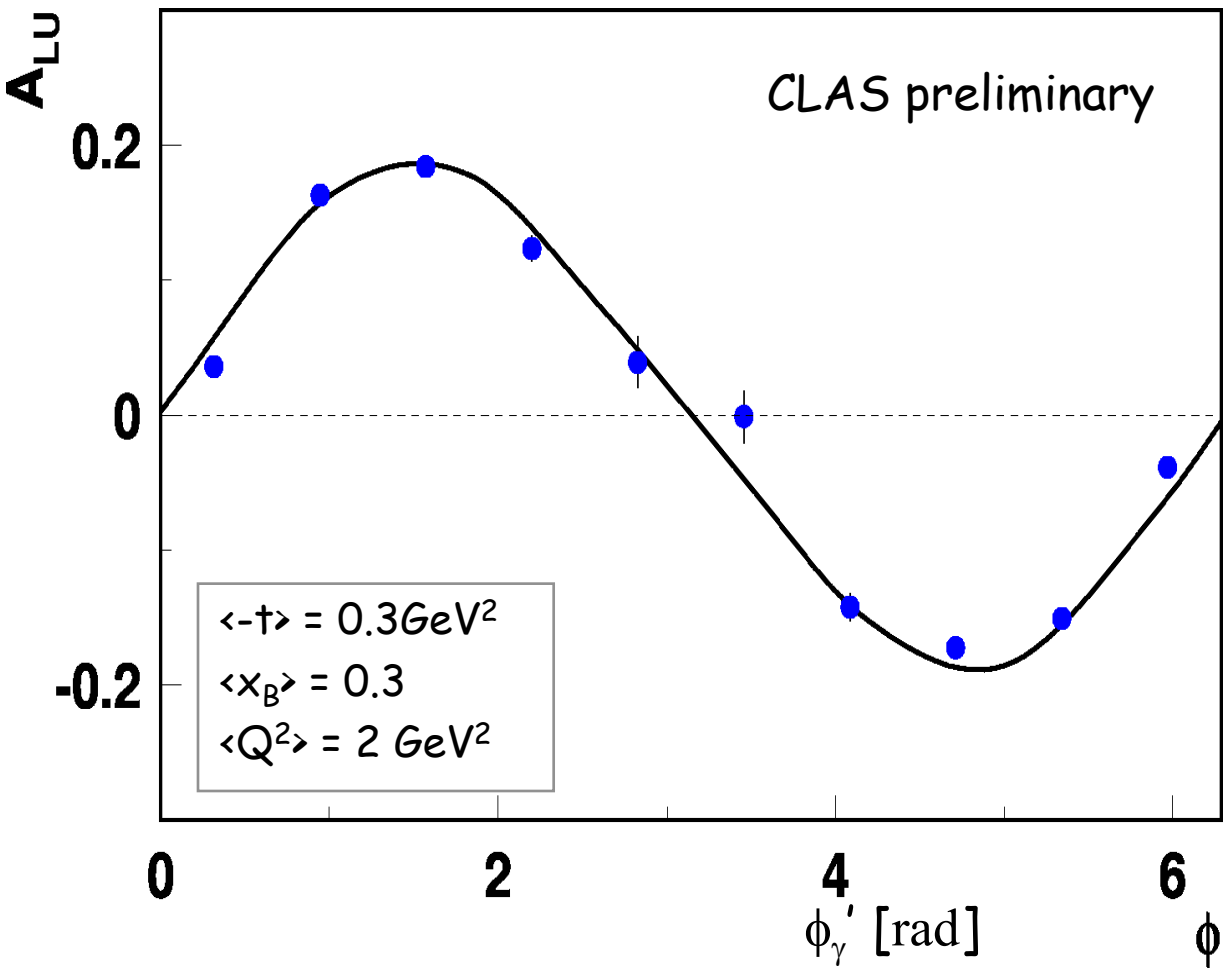
DIS

longitudinal quark distribution in momentum space

DES (GPDs)

fully-correlated quark distribution in both coordinate and momentum space

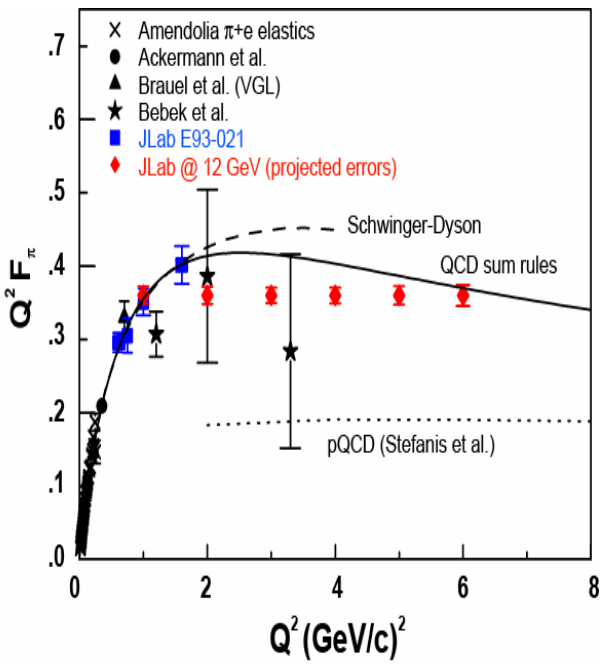
CLAS DVCS Data at E=5.75 GeV
Demonstrate Experimental Feasibility



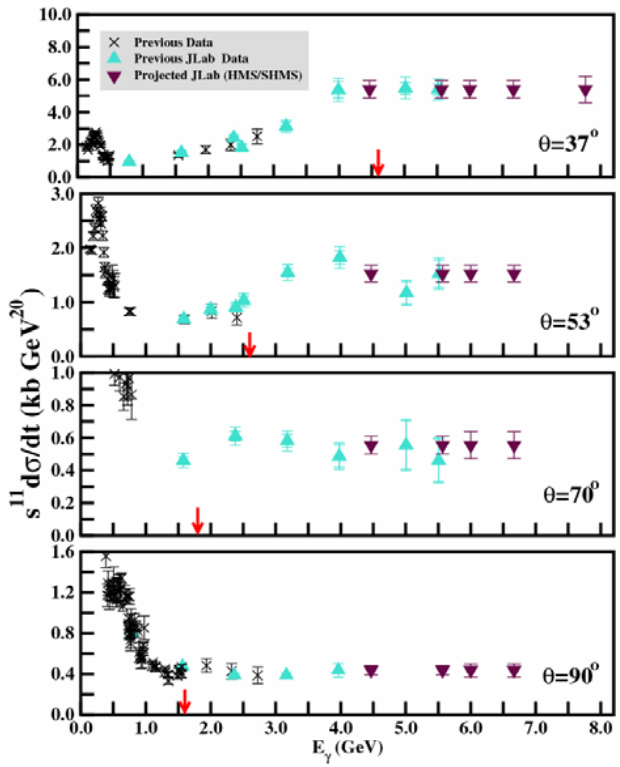
- Higher energy increases kinematics range
- Higher statistics allows binning in Q^2, t, ξ

Many Other Experiments Can be Modeled in Detail Based on Experience with CEBAF @ 6 GeV

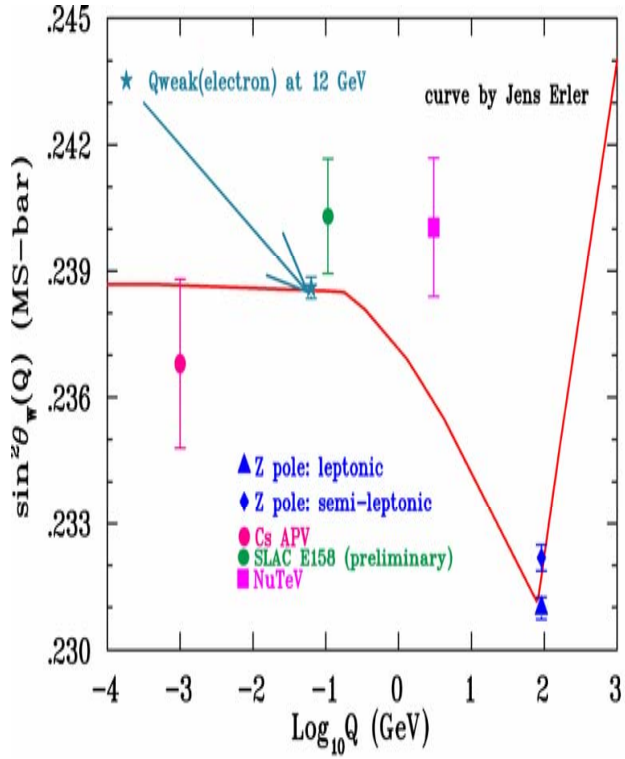
Pion Elastic Form Factor



Deuteron Photodisintegration



Parity Violation Experiments



,etc……

Beam Requirements Were Determined from:

- the mass reach and polarization requirements of GlueX

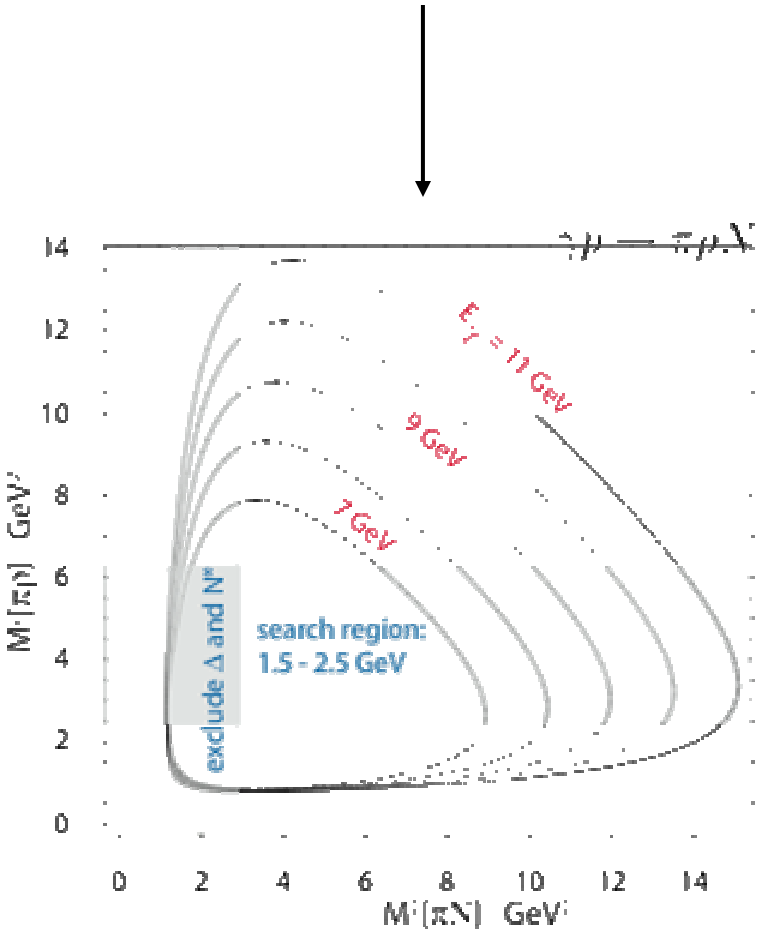
  and from

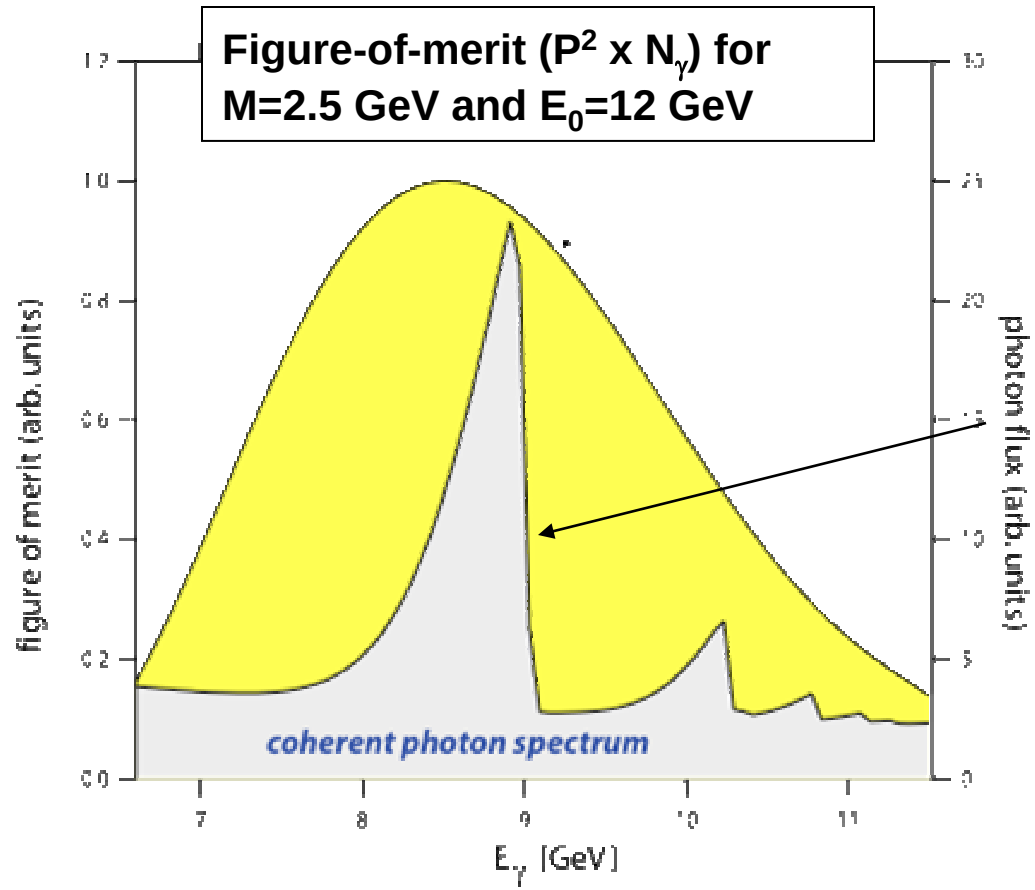
- the kinematics requirements for access to the valence quark regime in DIS

Ideal Photon Beam Energy for GlueX

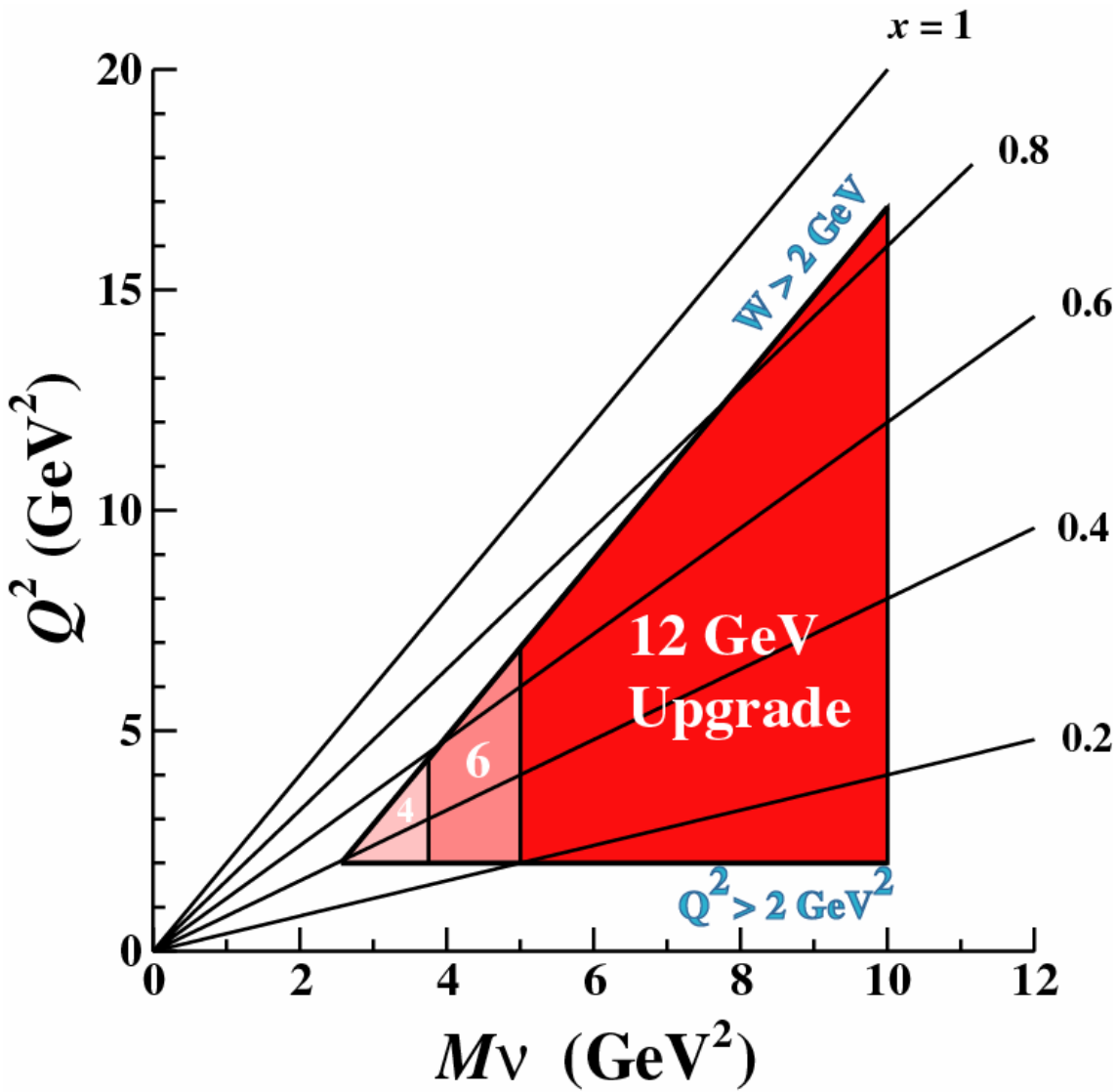
Based on:

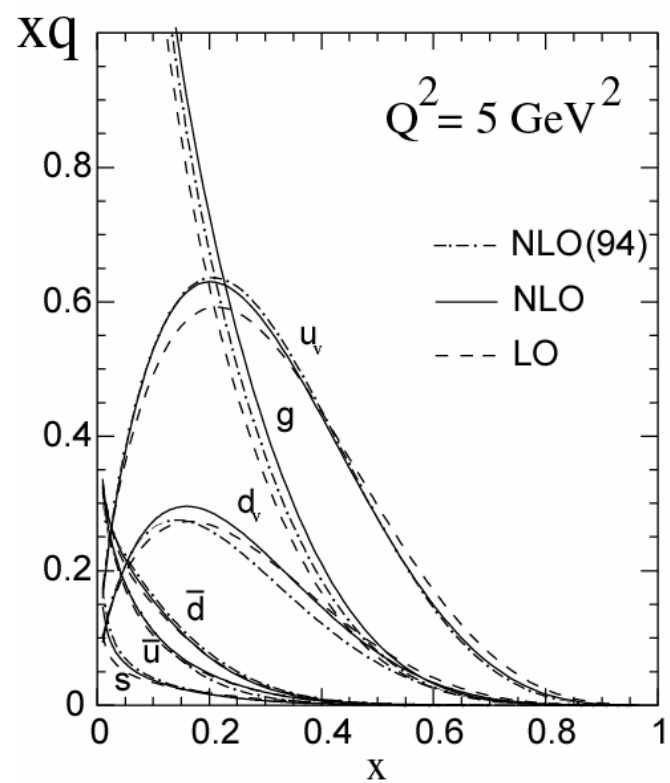
- maintain sufficient photon flux/polarization (via coherent bremsstrahlung)
- maintain sufficient meson yield for high mass (2.5 GeV) region
- separate baryon from meson resonances





The 12 GeV Upgrade Provides Substantially Enhanced Access to the DIS Regime

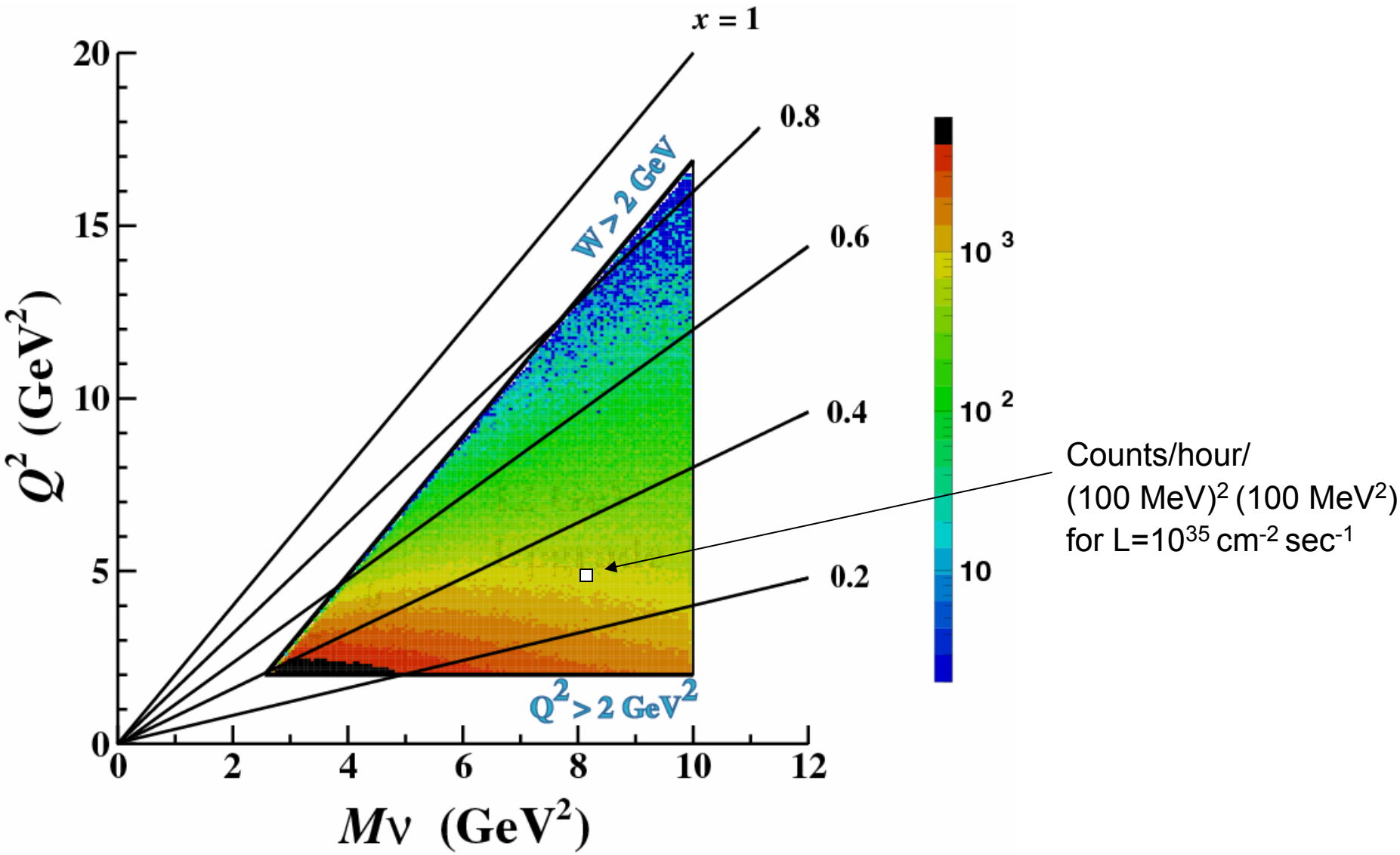




12 GeV will access the regime (x > 0.3), where valence quarks dominate

The 12 GeV Upgrade Provides Substantially Enhanced Access to the DIS Regime

with enough luminosity to reach the high-Q^2, high-x region!



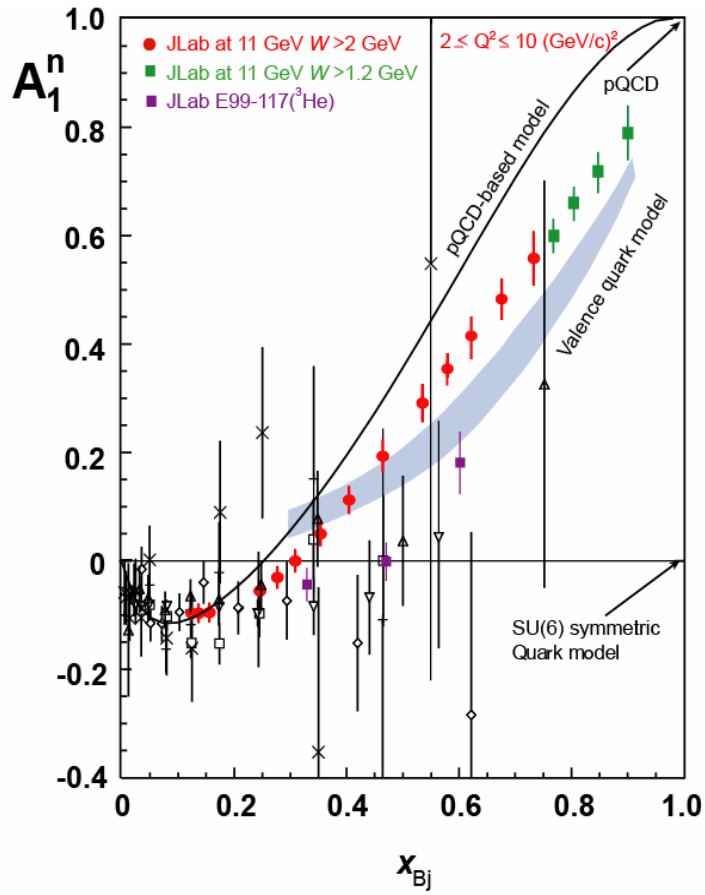
Measuring High-x Structure Functions

Measuring high-x structure functions requires:

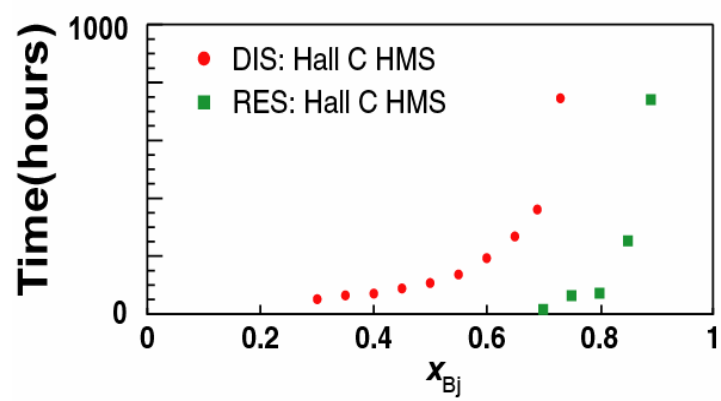
- high beam polarization
- high electron current
- High target polarization
- Large solid angle spectrometers

For A_1^n:

- 15 μA, 85% polarized beam
- target polarization is 40%
- luminosity is 10^{36}



- JLab rates are a factor of 25 or more higher than would have been possible in End Station A at SLAC



Beam Energy Determined by the Requirements of GlueX and High-x Measurements

Gluex

- 12 GeV needed to get 9 GeV polarized photons required for 2.5 GeV mass reach

DIS

- 11 GeV gets to x=0.8 in DIS regime; luminosity and polarization essential

DVCS

- with 10^{35} cm^{-2} sec^{-1} luminosity limit (set by CLAS12 detector), 11 GeV accesses broad range of x and Q^2

DVMP

- Ideal for initial exploration of the flavor structure of the GPDs

Nuclear Physics

- Ideal for exploration of EMC effect
- Full kinematic coverage for envisaged “traditional” nuclear physics studies
- Provides good access to hadronization regime

Standard Model tests

- 11 GeV more than sufficient for high precision tests foreseen

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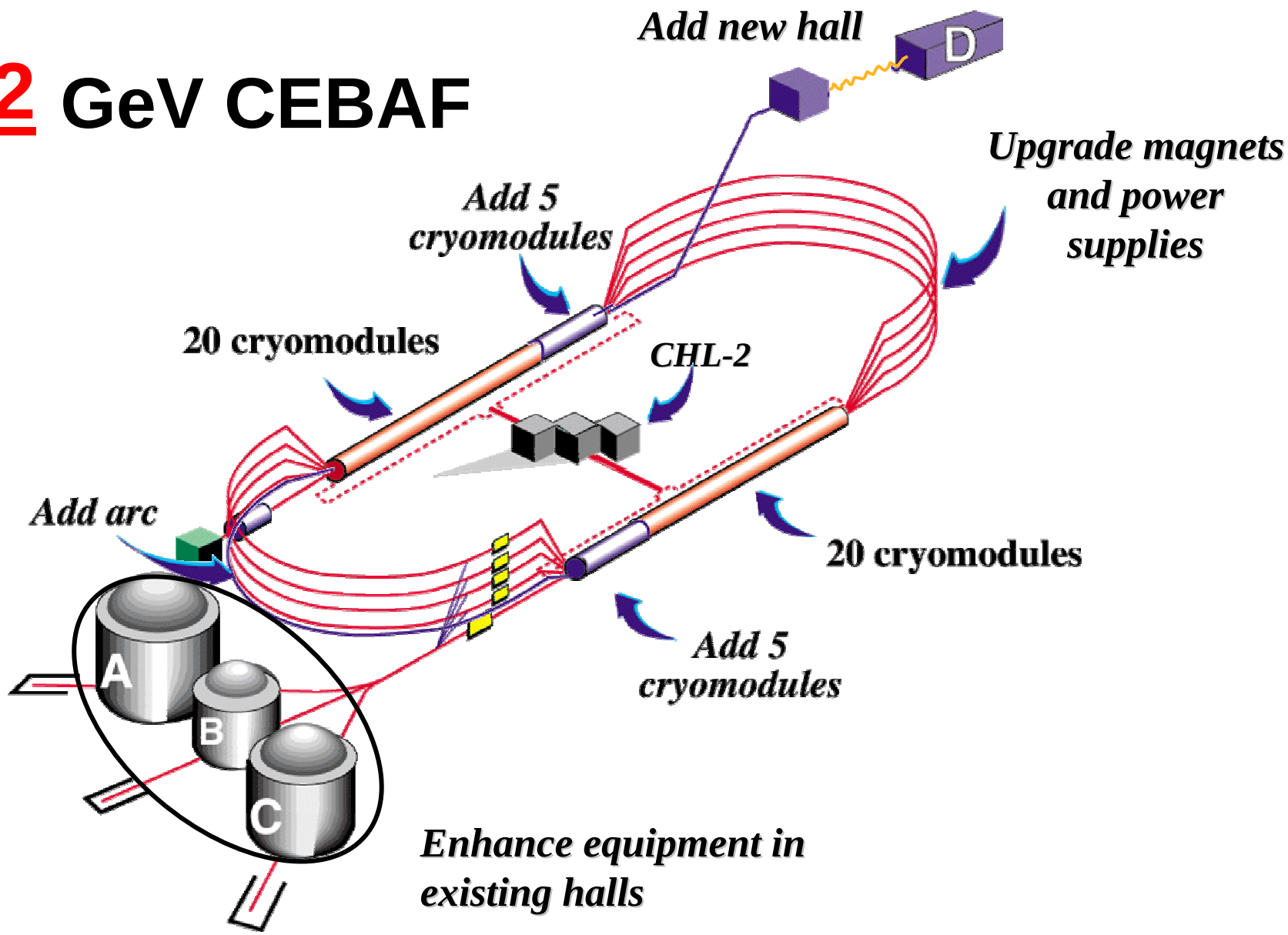
For most experiments: 100% duty cycle essential

For many experiments: Polarization essential

Upgrade Beam Properties

Number of passes for Hall D max. energy for Hall D	5.5 12 GeV
Number of passes for Halls A, B, C max. energy for Halls A, B, C	5 (4, 3, 2, 1) 11 GeV (8.8, 6.6, 4.4, 2.2)
max. current to Halls A, B, C max. current to Hall D	85 μA 5 μA ***All polarized !***
Max. beam power Duty-cycle	1 MW 100%

12 GeV CEBAF


Add new hall
D
Upgrade magnets and power supplies
Add 5 cryomodules
20 cryomodules
CHL-2
Add arc
20 cryomodules
Add 5 cryomodules
A
B
C
Enhance equipment in existing halls

The Experimental Halls Today

- Hall C (operational since mid '95) $\mathbf{L} \sim 10^{38}\ cm^{-2}s^{-1}$
  - Two medium-resolution spectrometers HMS and SOS
  - High-Momentum Spectrometer / Short-Orbit Spectrometer

	High-Momentum Spectrometer	Short-Orbit Spectrometer
$\delta p/p$	$\sim 10^{-3}$	$\sim 10^{-3}$
p_{max}	~ 7 GeV/c	~ 1.5 GeV/c
$\Delta\Omega$	~ 7 msr	~ 9 msr

- Hall A (operational since May '97) $\mathbf{L} \sim 10^{38}\ cm^{-2}s^{-1}$
  - Two identical high-resolution spectrometers (HRS)

$\delta p/p$	$\sim 10^{-4}$
p_{max}	~ 4 GeV/c
$\Delta\Omega$	~ 6 msr

- Hall B (operational since December '97) $\mathbf{L} \sim 10^{34}\ cm^{-2}s^{-1}$
  - CEBAF Large Acceptance Spectrometer (CLAS)
  - Based on six-sector superconducting toroidal magnetic field

Experiment Instrumentation

We have reviewed the key experiments motivating the 12 GeV Upgrade and considered the equipment necessary to carry out those experiments.

Experiments and Hall equipment best suited to carry them out were matched in a matrix (see the following example).

This review concluded that a complement of equipment that will support a very large fraction of the broad range of physics research accessible with 11-12 GeV electron beams included:

- The GlueX experiment
- A high luminosity hall with a well-matched pair of magnetic spectrometers (the SHMS/HMS combination proposed for Hall C)
- A large solid angle detector (CLAS12)
- Space and facilities for mounting “one-of-a-kind” experiments that require specialized apparatus

This broad strategy was presented to and supported by PAC27

Example

(remainder in Appendix)

Matrix 1: Valence Quark Structure and Parton Distributions

Physics Subject	Beam Pol	Target Pol	FPP	L/T Sep	Hall A	Hall B	Hall C
d/u ratio						D(e, e'p_s) n-tagging	
A_1^{3He}	L	L					^{3}He(e, e')
A_1^d	L	L				D(e, e')	
A_1^p	L	L				H(e, e')	
$A_{//}$,$A_{\perp}^{p,d}$	L	//+⊥				H/D(e, e')	
g_2^p,d_2^p	L	T				H(e, e')	
g_2^n,d_2^n	L	T				D(e, e')	^{3}He(e, e')
R at high Q^2				Y			H(e, e')
Moments of F2/FL	L	L		Y			H,D,A(e, e')
Moments of g_{1p}, g_{1n}	L	L				H,D(e, e')	
π structure function					H(e, e'π)		
Bjorken sum (Q^2) , $\alpha_s(Q^2)$	L	L				H,D(e, e')	
Δu, Δd	L	L				H/D(e, e'$\pi^{+/-}$/$K^{+/-}$)	
$\Delta\bar{u}$, $\Delta\bar{d}$	L	L					H/D(e, e'$\pi^{+/-}$)

Corresponds to experiments presented during this review

Experiment Instrumentation (cont'd)

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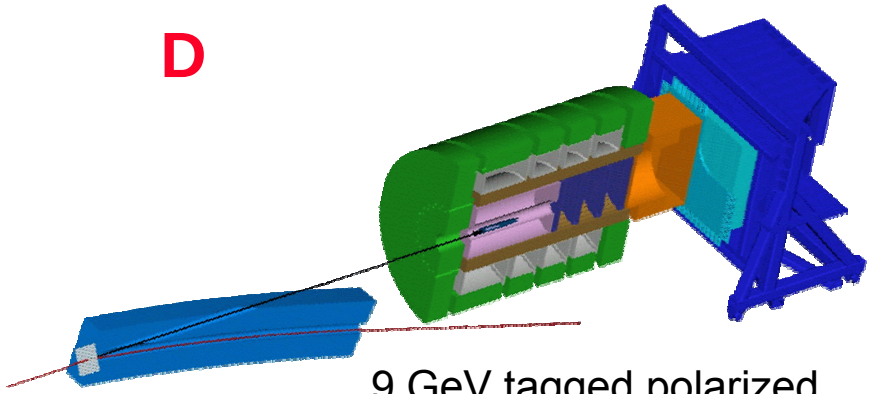
CEBAF Upgrade: Experimental Equipment

Hall	Major Physics Goal	Measurement Technique	Instrumentation (new and upgraded)
A	Traditional Nuclear Physics issues and unique experiments	(e,e'), (e,e'p), polarized variants and specialized, one-of-a-kind experiments	**Keep the HRS spectrometers pair** Add new, single-purpose apparatus as needed
B	Determine the Generalized Parton Distributions	Multi-particle final states in exclusive electron scattering	CLAS upgraded to higher (10^{35}) luminosity and coverage **(reuse major detector elements)**
C	Understand form factors and structure functions of simple quark systems	Exclusive and inclusive reactions (including L/T separations) at large momentum transfer (one arm at full beam momentum)	Super High Momentum Spectrometer (SHMS) at high luminosity and forward angles **(keep HMS)**
D	Understand confinement	Photo-production of mesons with exotic quantum numbers	9 GeV tagged polarized photons and 4π hermetic detector **(refurbish SC solenoid, lead glass array)**

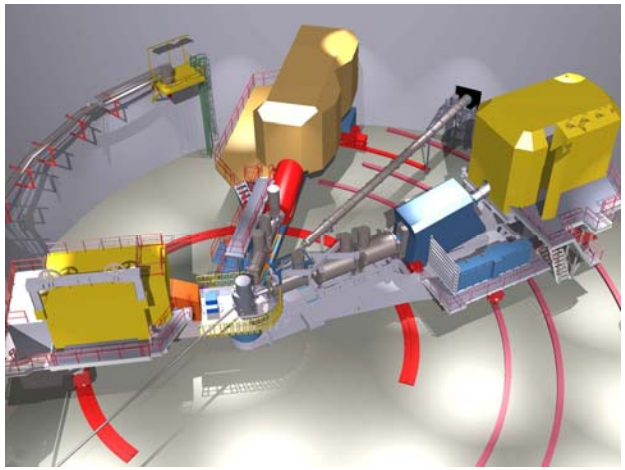
The 12 GeV Upgrade as Presented in the pCDR has Enhanced Complementary Equipment in Halls B & C, and a New Hall D

D



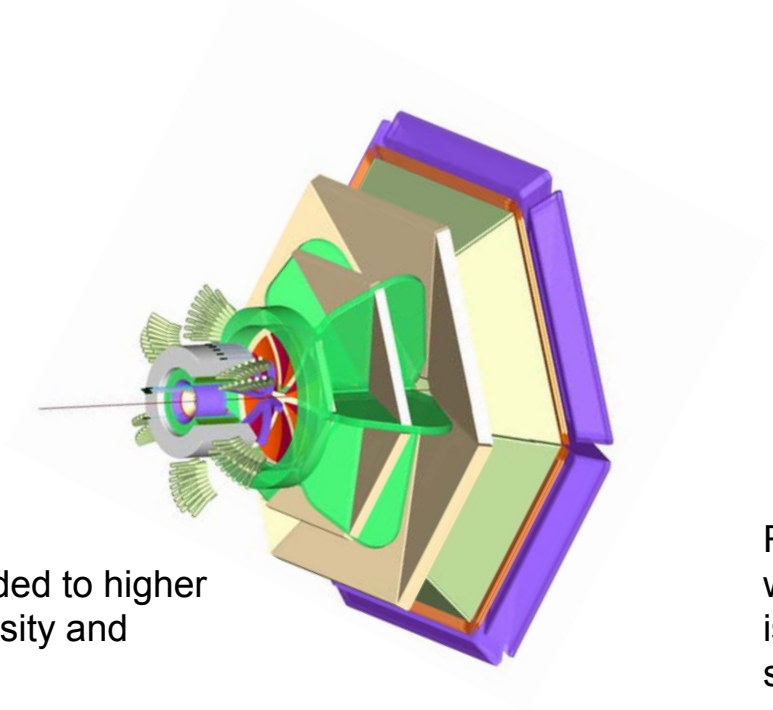
9 GeV tagged polarized photons and a 4π hermetic detector

C



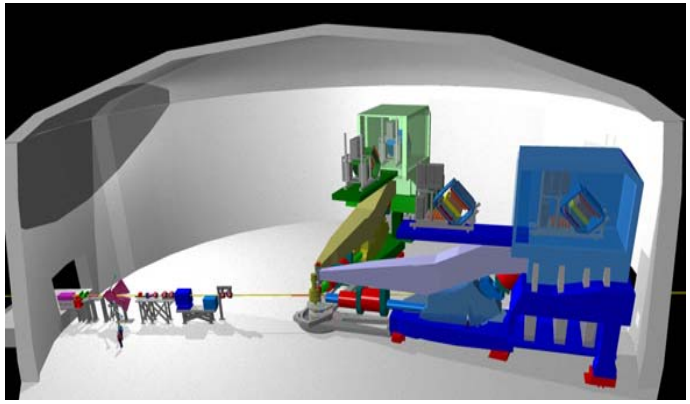
Super High Momentum Spectrometer (SHMS) at high luminosity and forward angles

B



CLAS upgraded to higher (10^{35}) luminosity and coverage

A



Retain HRS Pair for continuation of research in which resolution comparable to nuclear level spacing is essential. Use Hall to stage “one-of-a-kind” specialized experiments requiring unique apparatus.

Hall D (GlueX): Research Program

- Search for Gluonic Excitations
  - Hybrid ($q\bar{q}g$) spectrum expected between 1.5 and 2.5 GeV/c^2
  - Exotics do not mix with normal $q\bar{q}$ mesons

ALSO:

- $s\bar{s}$ spectroscopy
  - Only five states established
  - Photon has a large virtual ($s\bar{s}$) component
- Other physics
  - $K\bar{K}$ threshold
  - Radiative decays of excited vector mesons

Strategy for Exotic Meson Search

- Use photons to produce meson final states
  - tagged photon beam with 8 – 9 GeV
  - linear polarization to constrain production mechanism

- Use large acceptance detector
  - hermetic coverage for charged and neutral particles
  - typical hadronic final states:

    $f_1\eta \longrightarrow K\bar{K}\eta \longrightarrow K\bar{K}\pi\pi\pi$

    $b_1\pi \longrightarrow \omega\pi \longrightarrow \pi\pi\pi\pi$

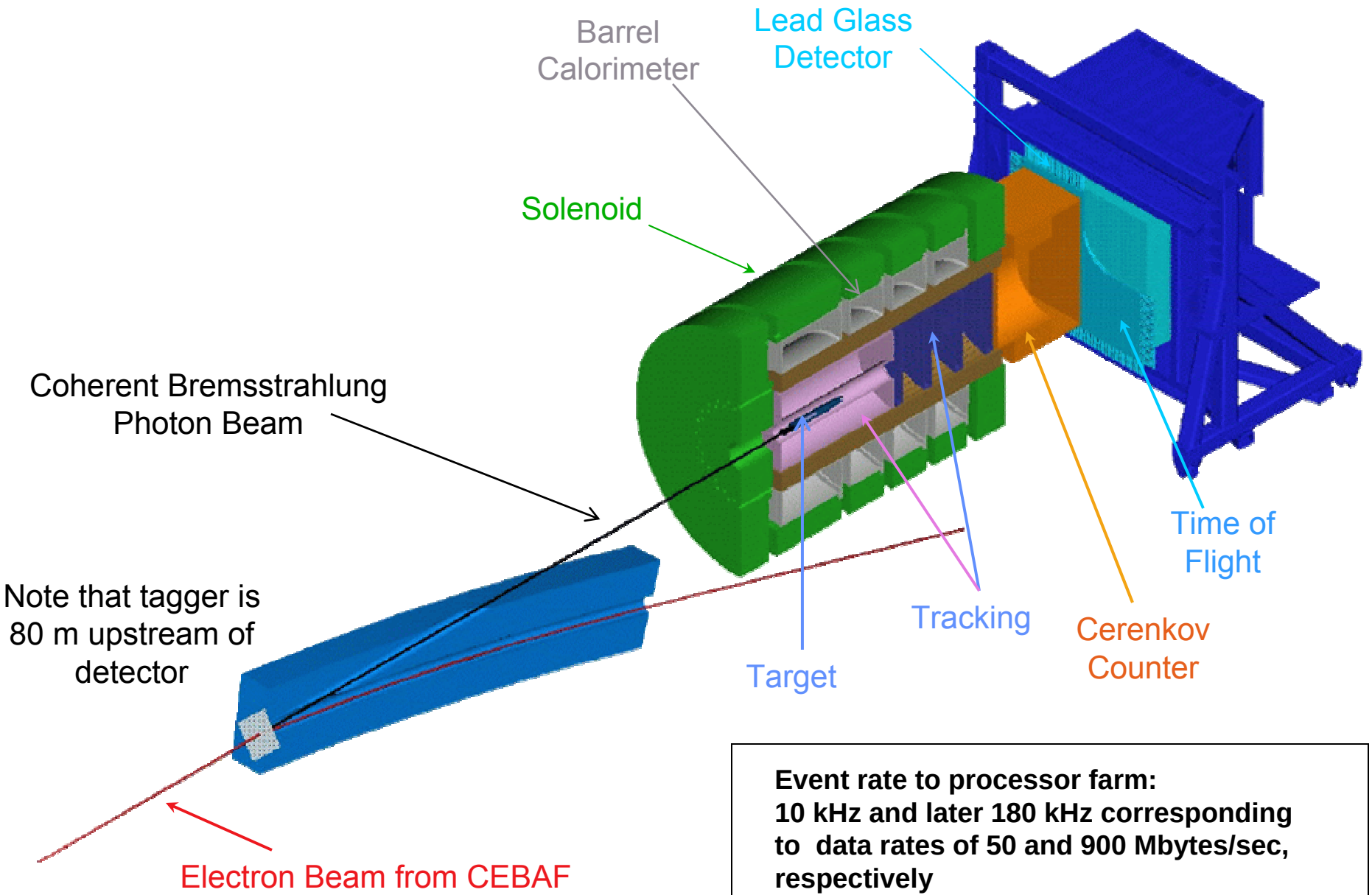
    $\rho\pi \longrightarrow \pi\pi\pi$
  - high data acquisition rate

- Perform partial-wave analysis
  - identify quantum numbers as a function of mass
  - check consistency of results in different decay modes

Physics Requirements for GlueX Detector

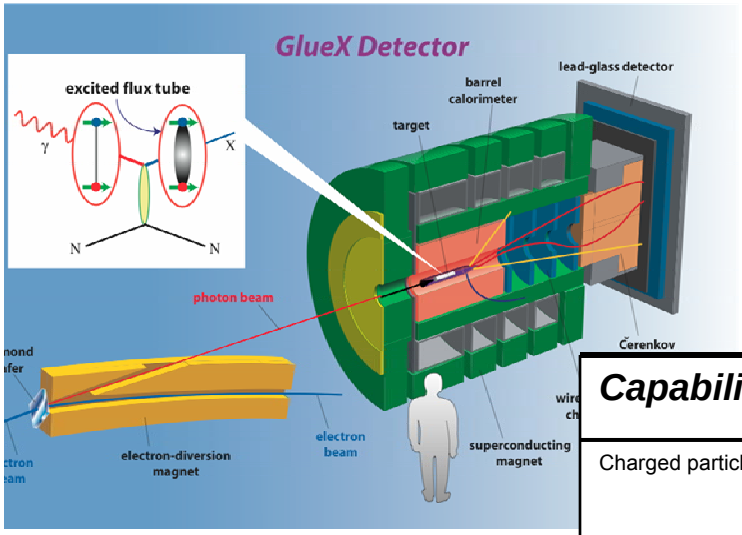
- Acceptance between 1º and 130º to allow reconstruction of exclusive final states with multiple charged and neutral particles
- Momentum resolution ~ 1% (MEGA magnet)
- Calorimeter energy resolution $\sigma/E \sim 5\%/\sqrt{E}$
- Particle identification using TOF and Cerenkov counters
- High DAQ rate with a software Level 3 trigger

GlueX Detector



Event rate to processor farm:
10 kHz and later 180 kHz corresponding to data rates of 50 and 900 Mbytes/sec, respectively

Hall D: the GlueX Detector



Capability	*Quantity*	*Range*
Charged particles	Coverage	$2^o < \theta < 170^o$
	Momentum Resolution (5°-140°)	$\sigma_p/p = 1 - 2\%$
	Position resolution	$\sigma \sim 150\ \mu m$
	dE/dx measurements	$20 < \theta < 140^o$
	Time-of-flight measurements	$\sigma_t < 60$ ps
	Cerenkov and π/K separation	$\theta < 12^o$
	Barrel time resolution	$\sigma_t < (150 + 50/\sqrt{E})$ ps
Photon detection	Energy measurements	$2 < \theta < 138^o$
	Veto capability	$135^o < \theta < 170^o$
	Lead glass energy resolution (E > 100 MeV)	$\sigma_E/E = (3.6 + 7.3/\sqrt{E})\%$
	Barrel energy resolution (E > 20 MeV)	$\sigma_E/E = (2 + 5/\sqrt{E})\%$
	Barrel position resolution	$\sigma_z \sim 1$ cm
DAQ/trigger	Level 1	200 kHz
	Level 3 event rate	15 kHz to tape
	Data rate	100 MB/s
Electronics	Fully pipeline	Flash ADCs, multi-hit TDCs
Photon Flux	Tagged rate	$10^8\ \gamma$/s

GlueX Reviews

December 1999: PAC Requested Review of the GlueX Project
D. Cassel (chair), J. Domingo, W. Dunwoodie, D. Hitlin, G. Young.

April 2001: NSAC Long Range Plan Committee.

July 2003: Electronics Review of the GlueX Project
J. Domingo, A. Lankford, G. Young (chair)

October 2004: Detector Review
M. Albrow, J. Alexander (Chair), W. Dunwoodie, B. Mecking.

December 2004: Solenoid Assessment
J. Alcorn, B. Kephart (Chair), C. Rode.

PAC16 and 23

All of these review committees have made excellent suggestions for improvements which are being implemented.

Hall C Physics Program for 12 GeV

HMS-SHMS: Spectrometer pair capable of exploiting full 11 GeV energy & luminosity

- Pion form factor up to $Q^2 = 6\ GeV^2$
- Nucleon elastic and transition form factors up to $Q^2 \sim 15\ GeV^2$
- Real Compton scattering up to $s \sim 20\ GeV^2$
- Exclusive π and K electroproduction up to $Q^2 \sim 10\ GeV^2$
- Precise L/T separations up to $Q^2 \sim 10\ GeV^2$
- SIDIS reactions requiring precision measurements
- Smallest cross sections at large x (spin structure & $x > 1$)
- Precision EMC-type measurements
- Color Transparency measurements up to $Q^2 = 18\ GeV^2$

This program will provide the highest Q^2 for exclusive reactions, and the highest Q^2 for L/T separations for the foreseeable future.

Requirements for Hall C

- Charged particle detection with momentum up to the beam energy

  $z = E_h/\nu = 1$

- Small angle capability essential to measure charged particle along momentum transfer

  θ_h // q (± a few $^{o)}$

- High Luminosity to measure small cross sections

  $L = 10^{38}\ cm^{-2}\ sec^{-1}$

- Precision L/T separations

  reproducible, well understood system

$$\sigma = \Gamma\left(\sigma_T + \varepsilon\sigma_L + \varepsilon\cos(2\phi)\sigma_{TT} + [\varepsilon(\varepsilon+1)/2]^{1/2}\cos(\phi)\sigma_{LT}\right)$$

HMS + SHMS Pair

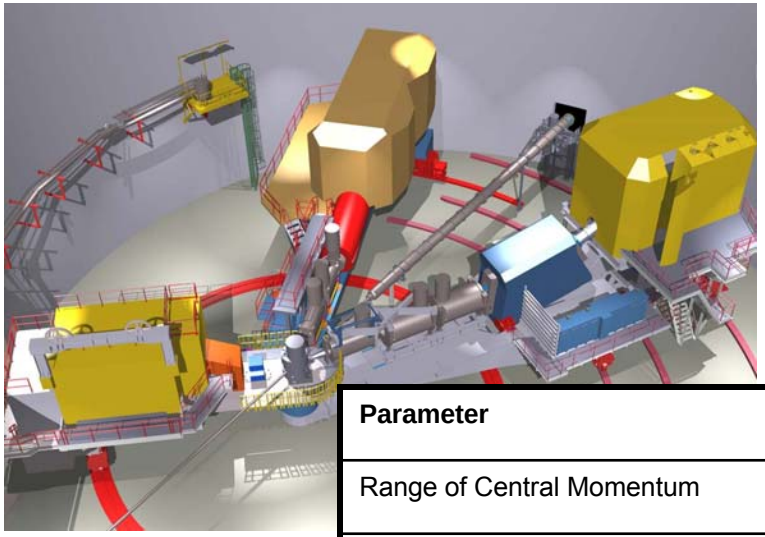
HMS has been characterized extensively between 0.5 and 5 GeV, and is extremely well understood, e.g. as highlighted by >200 Rosenbluth separations (close to 1,000 kinematics) performed to date in Hall C.

SHMS emulates the essential features of HMS:

A rigid connection to the pivot, a precision rail system, vacuum, a simple and reproducible point-to-point optics design, a flat and easily understood acceptance, and a heavily shielded hut with redundant detectors allowing for detailed cross checks.

HMS and SHMS will provide a flexible and reproducible spectrometer pair that can handle the full energy and luminosity capabilities of the 12 GeV Upgrade with low reconfiguration overhead and high physics throughput.

(Approach recommended by Spectrometer Mini-Review of January 2005)



Hall C: The SHMS and HMS

Parameter	HMS Performance	SHMS Projections (@ 7 GeV/c)
Range of Central Momentum	0.4 to 7.3 GeV/c	2 to 11 GeV/c (9 GeV/c for LSA tune)
Momentum Acceptance	-10% to 10%	-15% to 25%
Momentum Resolution	0.1%-0.15%	0.02-0.12%
Scattering Angle Range	10.5 to 90 degrees	5.5 to 25 degrees
Vertex Length (as viewed at 90 degrees)	10 cm	50 cm (35 cm "flat")
Horizontal Angle Acceptance	+/- 32 mrad	+/- 24 mrad (LSA tune) +/- 18 mrad (SSA tune)
Vertical Angle Acceptance	+/- 85 mrad	+/- 55 mrad (LSA tune) +/- 40 mrad (SSA tune)
Solid Angle Acceptance	8.1 msr	4.4 msr (LSA tune) 2.1 msr (SSA tune)
Horizontal Angle Resolution (yptar)	0.8 mrad	0.6-1.2 mrad (between -10% and +20%)
Vertical Angle Resolution (xptar)	1.0 mrad	0.7-1.3 mrad (between -10% and +20%)
Vertex Length Resolution (ytar)	0.3 cm	0.1-0.3 cm (between -10% and +20%)

Hall B Physics Program for 12 GeV

- GPD's and 3D-imaging of the nucleon
- Valence quark distributions
- Form factors and resonance excitations
- Hadrons in the nuclear medium
- Hadron spectroscopy with quasi-real photons

Requirements for Hall B Upgrade

High statistics capabilities for exclusive/semi-inclusive processes at electron energies up to 12 GeV

- Complement missing mass techniques by more complete detection of hadronic final state
- Increase operating luminosity to $L > 10^{35}$ $cm^{-2}sec^{-1}$
- Extend particle ID to higher momenta (e^-/π^-, $\pi/K/p$, γ/π^o)

➢ Upgrade the existing Forward Detection system

- replace DC's by smaller chambers with reduced cell sizes
- implement high-threshold Cerenkov detector $p_\pi > 5$ GeV/c
- improve TOF resolution to ~ 60psec
- increase calorimeter granularity for π^o/γ separation

➢ Complement CLAS detection system with new Central Detector

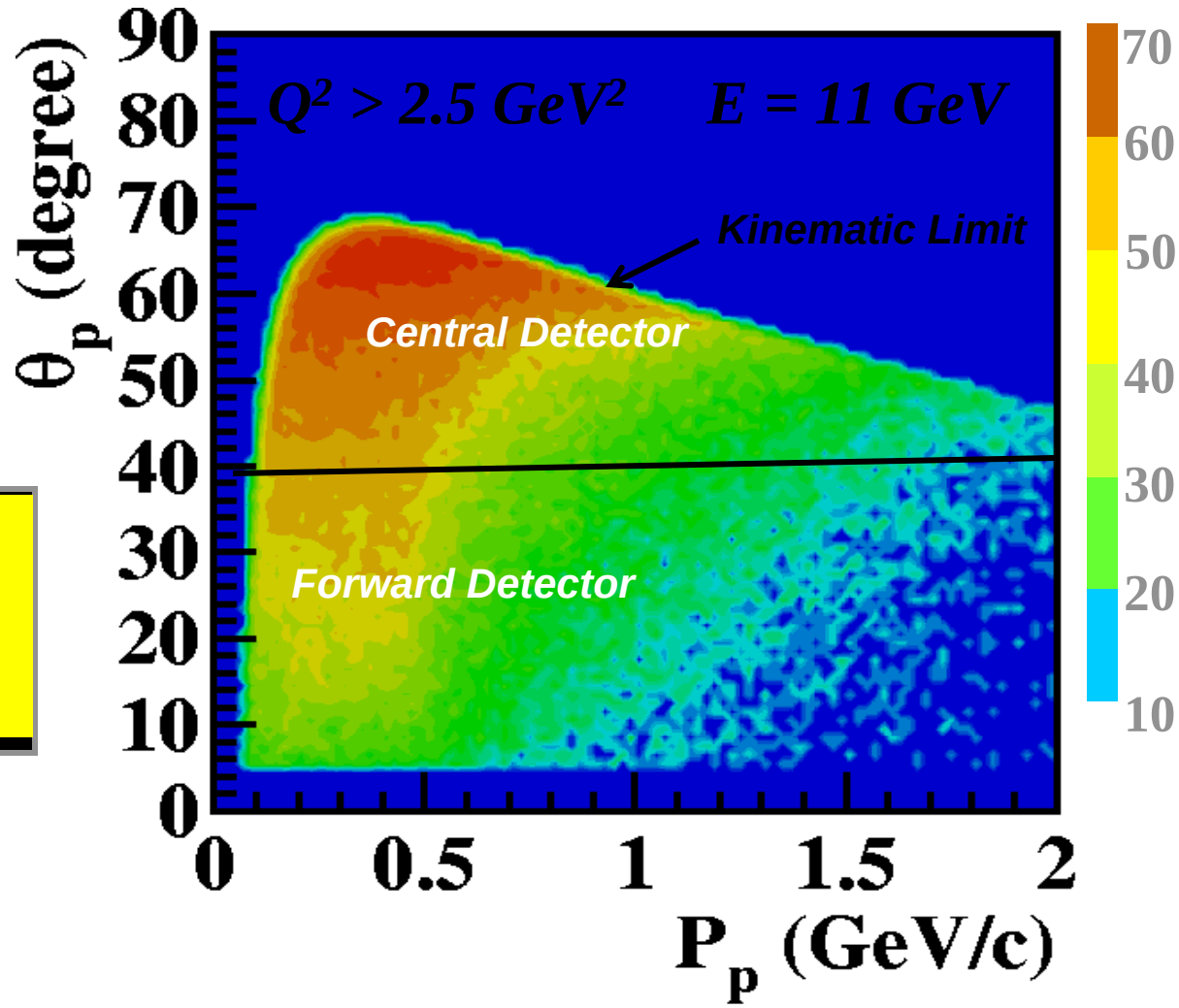
- momentum analysis & photon detection in angular range 40° - 135°, particle id for $p < 1.2$ GeV/c.
- allow polarized target operation in solenoid field
- improved Moller shielding
- veto events with incomplete determination of final state

CLAS12 - Acceptance for DVCS

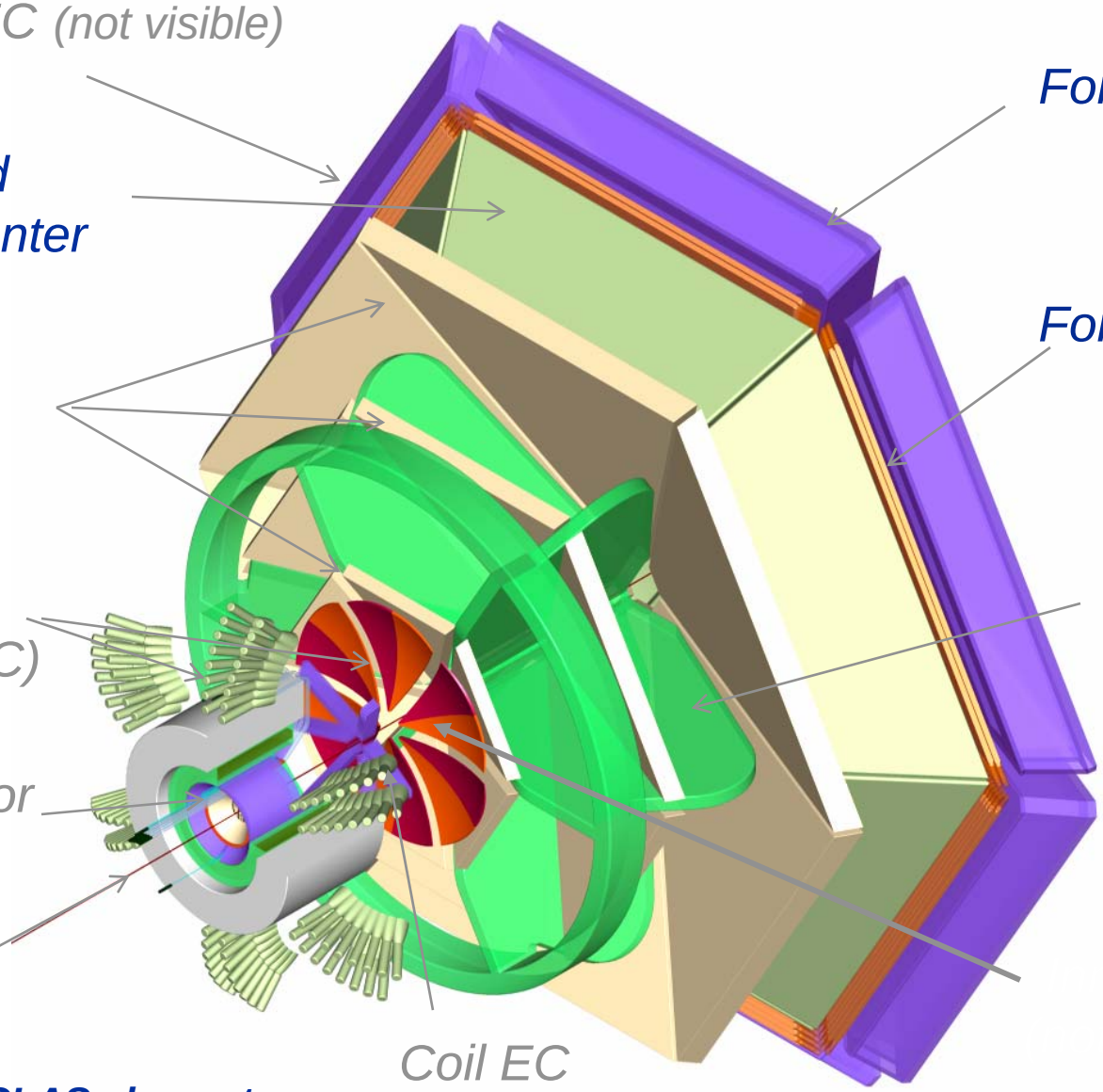
$ep \longrightarrow ep\gamma$

For small t, protons recoil at large polar angles.

Occupancy of DVCS events



CLAS12



Blue ⇒ Reused CLAS element

Utilization of Existing Hall B Equipment

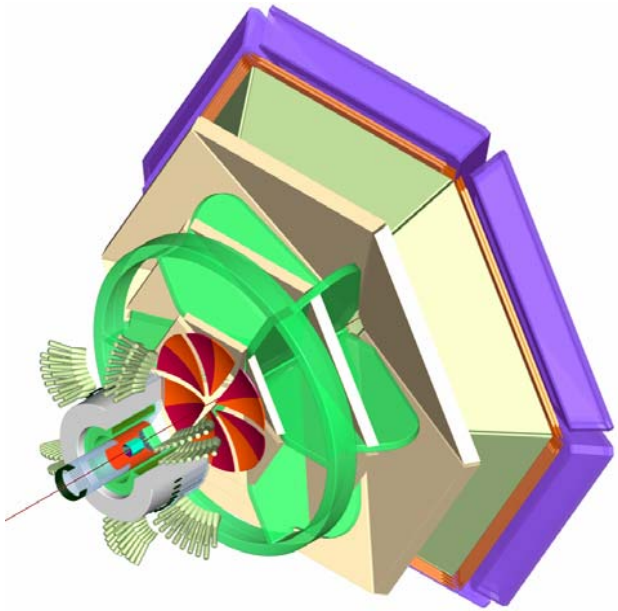
Re-use many existing components from CLAS:

- Forward electromagnetic calorimeters
- Low threshold gas Cerenkov counters
- Time-of-flight scintillators
- Drift chamber electronics and gas system
- Lead-tungstate DVCS small angle calorimeter
- DAQ and readout electronics

Re-use other Hall B components:

- Photon energy tagging system (limited energy range)
- Coherent bremsstrahlung/goniometer
- Cryogenic target
- Frozen spin polarized target
- Dynamically polarized target
- Moller polarimeter
- Faraday cup
- Beam diagnostics
- Pair spectrometer

Hall B: CLAS12



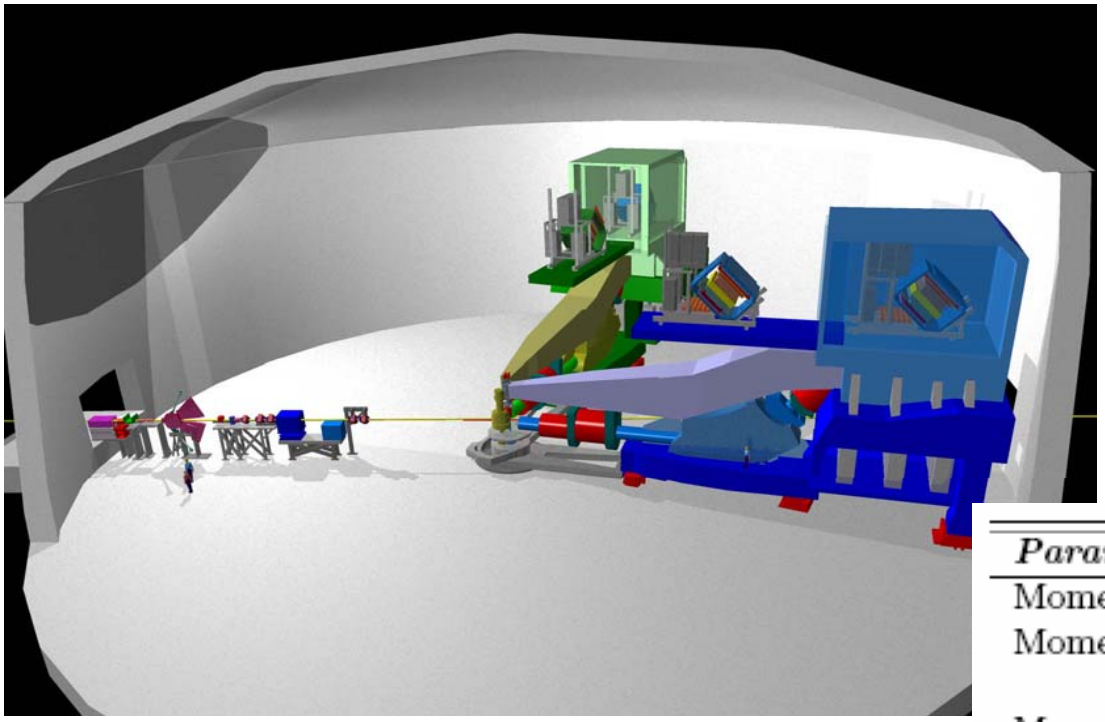
Target	Luminosity ($10^{34} cm^{-2} s^{-1}$)
H_2	10
^3He	15
^2H, ^4He, ^{12}C, ^{16}O,..,Pb	20
NH_3, ND_3 (long. polarization)	20
NH_3, ND_3 (trans. polarization)	2

	Forward detector	Central Detector
Angular coverage		
Tracks (inbending)	$8^{\circ} \leftarrow 37^{\circ}$	$40^{\circ} \leftarrow 135^{\circ}$
Tracks (outbending)	$5^{\circ} \leftarrow 37^{\circ}$	$40^{\circ} \leftarrow 135^{\circ}$
Photons	$3^{\circ} \leftarrow 37^{\circ}$	$40^{\circ} \leftarrow 135^{\circ}$
Track resolution		
$\psi p/p$	$0.003 + 0.001p$	$\psi p_T/p_T = 0.03$
$\psi\psi(mr)$	< 1 ($p > 2.5 GeV/c$)	8 p = 1GeV/c
$\psi\psi(mr)$	< 3 ($p > 2.5 GeV/c$)	2 p = 1GeV/c
Photon detection		
Energy range (MeV)	> 150	> 60
$\psi\psi$ (mr)	4 (1 GeV)	15 (1 GeV)
Neutron detection		
ψ_{eff}	0.5 ($p > 1.5 GeV/c$)	NA
Particle id		
Electron/pion	> 1000 ($p < 5$GeV/c)	NA
	> 100 ($p > 5$GeV/c	NA
ψ^+/P	full range	<1.2 GeV/c
K/ψ	full range	<0.65 GeV/c
K^+/p	<4.5 GeV/c	<0.90 GeV/c
$\psi^{-} \rightarrow$	full range	full range
$\psi \rightarrow$	full range	full range

Advantages of the Energy Upgrade for the Continuation of the Present Program (Mainly Hall A)

- Higher energies permit better experiments addressing the current physics problems:
  - Enhanced counting rates ($\sigma \propto E^2$ at fixed Q^2)
  - Dramatically improved experiment design flexibility and signal-to-noise ratio
- Note: 5½ pass recirculator design naturally provides 2.2, 4.4, and 6.6 GeV beams to support experiments best done at the present machine energies

Hall A w/ 2.2, 4.4, 6.6, 8.8 and 11 GeV Beam



Parameter	*HRS*
Momentum Resolution	1×10^{-4} FWHM
Momentum Range	0.3 to 4.3 GeV/c (left)
	0.3 to 3.3 GeV/c (right)
Momentum Acceptance	$\pm$ 5%
Horizontal Acceptance	$\pm$ 30 mrad
Vertical Acceptance	$\pm$ 60 mrad
Angle Range	6° to 150° (left)
	6° to 130° (right)
Solid Angle	6 msr (standard)
	12 msr (forward)
Vertical Resolution	$\pm$ 1.0 mrad
Horizontal Resolution	$\pm$ 0.5 mrad
Length Acceptance (90°)	10 cm
Vertex Resolution	0.1 cm
Maximum DAQ Rate	5 kHz

- **Retain High Resolution Spectrometer (HRS) pair for the continuation of research in which energy resolution comparable to nuclear level spacing is essential**
- **Use the hall infrastructure to support specialized large installation experiments**

Summary

- The 12 GeV Upgrade is essential to address key questions in the field and to maintain our world leadership in hadronic physics.

- The beam capabilities and experimental apparatus are optimized to carry out the research program.

Matrix 2: GPDs Accessed via Deep(ly) Exclusive Reactions

Physics Subject	Beam Pol	Target Pol	FPP	L/T Sep	Hall A	Hall B	Hall C
Deep Virtual Compton Scattering	L					H(e, e'γp)	
DVCS in Δ	L					H(e, e'γΔ/N*)	
nDVCS	L					D(e, e'γp_s)	
Long. Polarized DVCS - proton		L				H(e, e'γp)	
Polarized DVCS – neutron		L				D(e, e'γn)	
Trans. Polarized DVCS - proton		T				H(e, e'γp)	
DDVCS	L					H(e, e'pe^+e^-)	
Deep Virtual ρ/ω Productions				'Y'		H(e, e'$\rho^{0,+,-}$)	
Deep Virtual π/K Productions				Y			H(e, e'$\pi^{+/-}$)
Transverse Target Asymmetry		T				H(e, e'$\rho^{0,+,-}$)	

Matrix 3: Form Factors and Polarizabilities

Physics Subject	Beam Pol	Target Pol	FPP	L/T Sep	Hall A	Hall B	Hall C
π Form Factor				Y			H(e, e'π^+)
Proton Electric Form Factor	L		Y				H(e, e'p)
Neutron Electric Form Factor	L		Y				D(e, e'n)
Neutron Magnetic Form Factor						D(e, e'n/p)	
N-Delta Form Factor G_M^*						H(e, e'π^+)n,H(e, e'p)π^0	
E2/M1, S2/M1						H(e, e'π^+)n,H(e,e'pπ^0)	
N-S_{11} Form Factor						H(e, e'p)η H(e, e'ηp)	
N-N* Form Factor						H(e, e'π)p,n , H(e, e'p$\pi^+\pi^-$)	
Wide-angle Compton Scattering							H(γ, γp)

Matrix 4: Other Topics in Hadron Structure Transverse Mom.-Dependent PDFs and SSAs

Physics Subject	Beam Pol	Target Pol	FPP	L/T Sep	Hall A	Hall B	Hall C
Target Single Spin Asymmetry (Sivers)		T				H/D(e, e'$\pi^{+/-/0}$,K^{-0})	
Beam SSA and Higher Twist	L					H/D(e, e'$\pi^{+/-/0}$,K^{-0})	
Transversity		T				H/D(e, e'$\pi^{+/-/0}$,K^{-0})	
Transversity in 2-pion production		L,T				H,D(e, e'$\pi^{+}\pi^{-}/\pi^{0}$)X	
TMDs from azimuthal asymmetries A_{UL},A_{LT}	L	L, T				H/D(e, e'$\pi^{+/-/0}$,K^{-0})	
TMDs from unpolarized azimuthal asymmetries Auu ($\cos\phi$,$\cos 2\phi$)						H/D(e, e'$\pi^{+/-/0}$,K^{-0})	
Factorization Tests (DES)		L,T					H/D(e, e'$\pi^{+/-}$,$K^{+/-}$)

Matrix 5: Other Topics in Hadron Structure Duality and GDH Sum Rule

Physics Subject	**Beam Pol**	**Target Pol**	**FPP**	**L/T Sep**	**Hall A**	**Hall B**	**Hall C**
GDH at High Energy	L	L				H/D(e, e')	
d/u ratio through duality						D(e, e'p_{back}) BoNuS	
F_2,R at low Q^2				Y			H/D(e, e')
A_1^n through duality	L	L					H/D(e, e')
A_1^p through duality	L	L				H(e, e')	
Duality in Meson Production							H/D(e, e'$\pi^{+/-}$,$K^{+/-}$)
Factorization Tests (SIDIS)							H/D(e, e'$\pi^{+/-}$,$K^{+/-}$)

Matrix 6: Nuclear Structure

Physics Subject	Beam Pol	Target Pol	FPP	L/T Sep	Hall A	Hall B	Hall C
The Parton-Hadron Transition in Nuclear Physics							
QCD Oscillations							$H(\gamma,p)\pi^0$, $H(\gamma,\pi^+)$, $D(\gamma,\pi^-p)$
π^+/π^- ratio in photoproduction							$D(\gamma,\pi^{+/-}p)$
Deuteron Photo-disintegration			(Y)				$D(\gamma,p)n$
Probing the Limits of the Nucleon-Based Description of Nuclei							
Few-Body Form Factors							$^2H/^3He(e, e')$
A(e,e')SRC						A(e, e'NN)	
A(e,e'p) at high p_m and Q^2							A(e, e'p)

Matrix 7: Nuclear Structure (cont.)

Physics Subject	Beam Pol	Target Pol	FPP	L/T Sep	Hall A	Hall B	Hall C
Hadrons in the Nuclear Medium							
Superfast Quarks							A(e, e')
DIS off nuclei (EMC effect)							A(e,e ')
DIS off nuclei (tagged EMC effect)						A(e,e'X)	
DIS off polarized nuclei	L	L					A(e,e ')
DIS off polarized nuclei	L	L				A(e,e'X)	
Proton Color Transparency							A(e, e'p), D(e, e'p)
π Color Transparency				Y			A(e, e'$\pi^{+/-}$)
π Color transparency in deuterium						D(e, e'pp)π^- , D(γ,pp)π^-	
ρ Color Transparency				'Y'		A(e, e'ρ), D(e, e'ρ)	
Vector Meson Color Transparency				'Y'		A(e, e'ρ), D(e, e'D'V)	
Charm Production					A(γ, J/ψ)		

Matrix 8: Other Topics

Physics Subject	Beam Pol	Target Pol	FPP	L/T Sep	Hall A	Hall B	Hall C
1) Standard Model Tests							
DISParity	L						D(e, e')
DISParity – proton	L				H(e, e')		
Moller Parity	L				H(e, e')		
2) Other Topics in Spectroscopy							
Search for High Mass N* and Δ's						γ*-H (pππ, pω)	
3) Spontaneous Symmetry Breaking							
Primakoff production of η, η'					γ-A with tagger and HyCal		
4) Space-time Characteristics of Nuclear Hadronization							
Hadronization mesons						A(e, e'$\pi^{+/-/0}$, η, ω, $K^{-/0/+}$, ϕ)	
Correlated meson pairs						A(e, e'meson1,meson2)	
Hadronization baryons						A(e, e'p, pbar, Λ, Λ*, Σ^{+0}, Ξ^{-})	
Correlated meson-baryon pairs						A(e, e'meson, baryon)	
Nuclear Broadening	L					A(e, e'$\pi^{+/-}$, $K^{-/+/0}$)	

Matrix 0: Hybrid Meson Search

Physics Subject	**Beam Pol**	**Hall D & GlueX**
A) Confinement		
Meson Spectroscopy*	T	γ-N

* Note that this program includes a broad program in light quark spectroscopy