JLab Nuclear Physics at 12 GeV and Beyond

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Over the Past Two Years

For the 12 GeV Upgrade:

- The science case has expanded dramatically and been documented
- The science case has been strengthened by results from the 6 GeV program
- The hall equipment designs have matured and been documented
- There has been further progress on accelerator-related R&D
- Both the science and the equipment have been further reviewed by the PAC and NSAC

Now All that is Missing is CD-0!

For physics "beyond 12 GeV":

- The outlines of the science motivation are emerging
- Machine design studies reveal promising options for achieving high luminosity in a collider
- The basics have been presented to NSAC

Evolution of the Science Case for the Upgrade

Following the Long Range Plan:

- Hall collaborations prepared Hall-specific pCDRs with:
  - Physics motivating the equipment
  - Technical descriptions of the apparatus with many details
  - Examples of experiments that could be carried out using the equipment to address the motivating physics
- The User Group Formed an Executive Committee to write the pCDR for the overall project
- PAC23 Reviewed the Science as presented by working groups (mainly committee members) and the equipment
- The Executive Committee developed a Summary of the Physics Case (which was presented to the NSAC Facilities Subcommittee), then
- Wrote the pCDR (now available for community review)

The Science Driving CEBAF @ 12 GeV (As Presented to NSAC)

Key new physics:

- Understanding confinement (via meson spectroscopy)
  (defines E_{max} and requires the addition of "Hall D")
- Detailed mapping of the quark and gluon wave functions of the nucleons via measurements of:
  - Deep Exclusive Scattering, and
  - Deep Inelastic Scattering as $x \to 1$ for a large range of Q^2
  (MAD in Hall A, CLAS upgrade to $\mathcal{L} = 10^{35}$, SHMS in Hall C)

Enhancements to our present physics program

- Extension of the present program of spin, hadron and nuclear microscopy to higher Q^2
  (Higher energies also increase throughput for many experiments now run with 6 GeV beams)

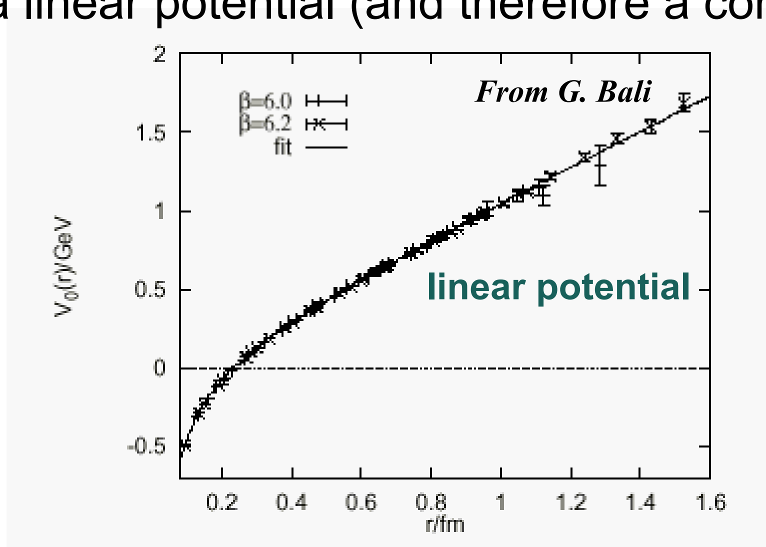
The Science Case Has Evolved Significantly Over the Past Year

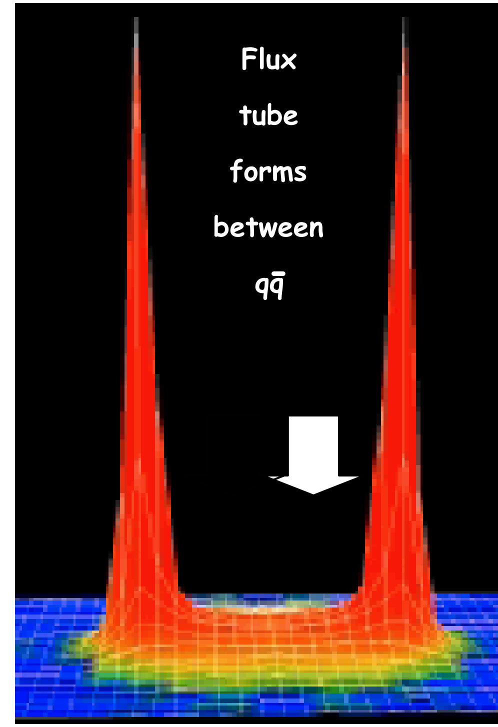
As presented to PAC23 (1/03) and NSAC: examples

- **Gluonic Excitations and the Origin of Confinement** ✓
- **Developing a Unified Description of Hadron Structure**
  - The GPDs as Accessed via Deep(ly) Exclusive Reactions ✓
  - Valence Quark Structure and Parton Distributions ✓
  - Form Factors – Constraints on the GPDs
  - Other Topics in Hadron Structure ✓
- **The Physics of Nuclei**
  - The Short-Range Behavior of the N-N Interaction and Its QCD Basis
  - Identifying and Exploring the Transition from the Nucleon/Meson Description of Nuclei to the Underlying Quark/Gluon Description ✓
- **Symmetry Tests in Nuclear Physics**
  - Standard Model Tests
  - Spontaneous Symmetry Breaking ✓

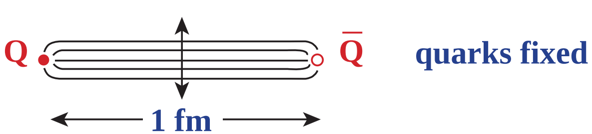
Gluonic Excitations and the Origin of Confinement

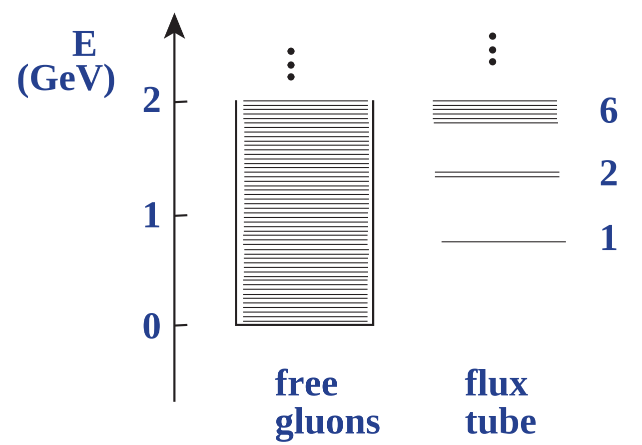
Theoretical studies of QCD suggest that confinement is due to the formation of "Flux tubes" arising from the self-interaction of the glue, leading to a linear potential (and therefore a constant force)





Experimentally, we want to "pluck" the flux tube and see how it responds

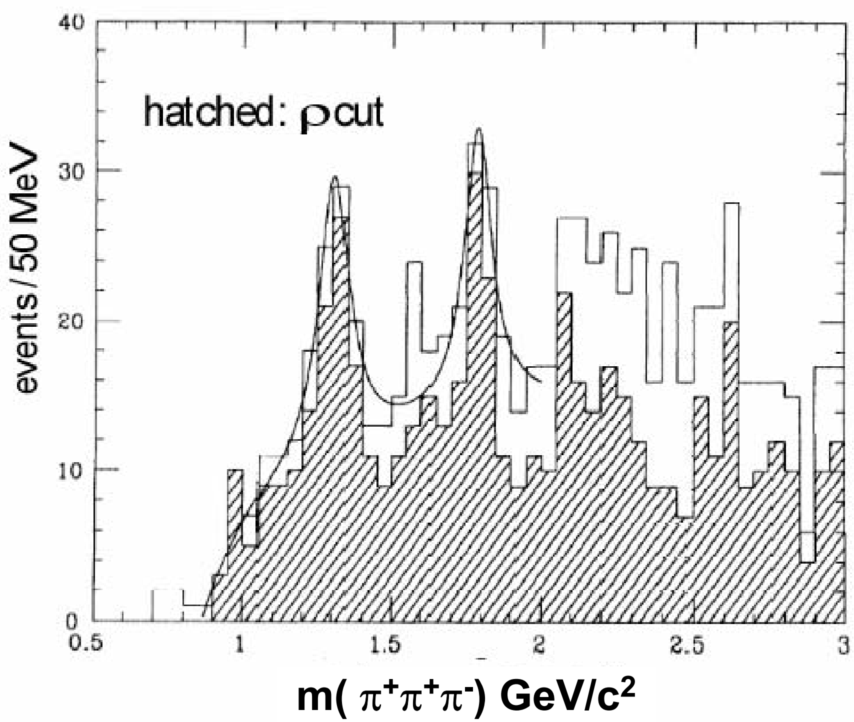




CLAS Data Demonstrates the Promise of Meson Photoproduction

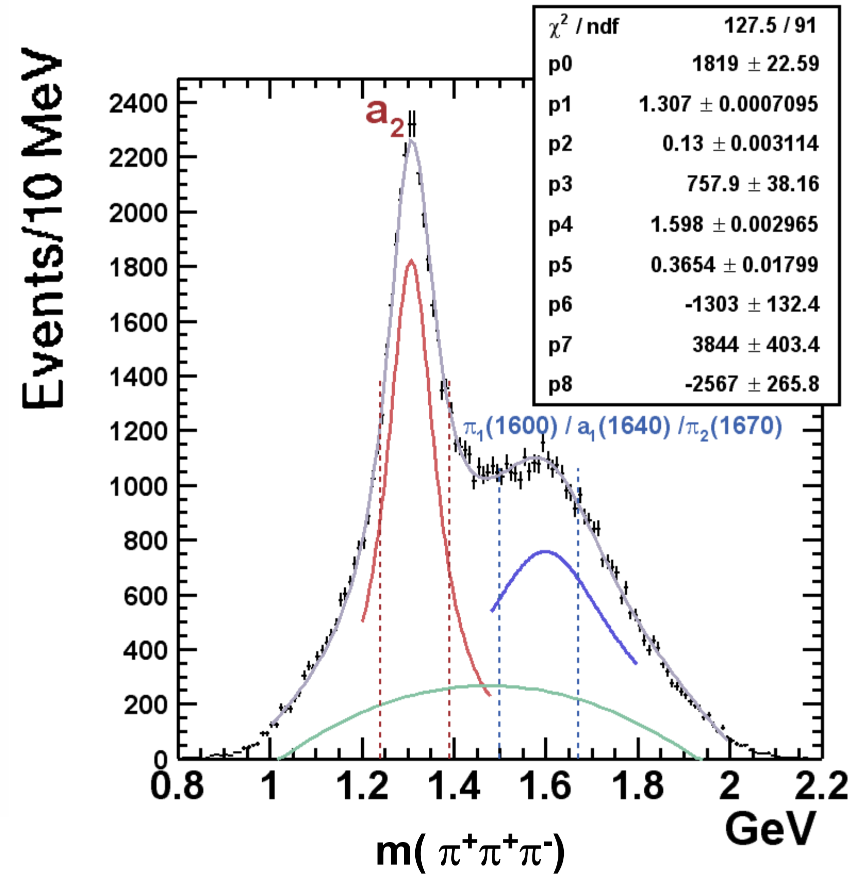
~500x existing data on photo-production from a 1 month run with CLAS

SLAC Hybrid Facility Photon Collaboration

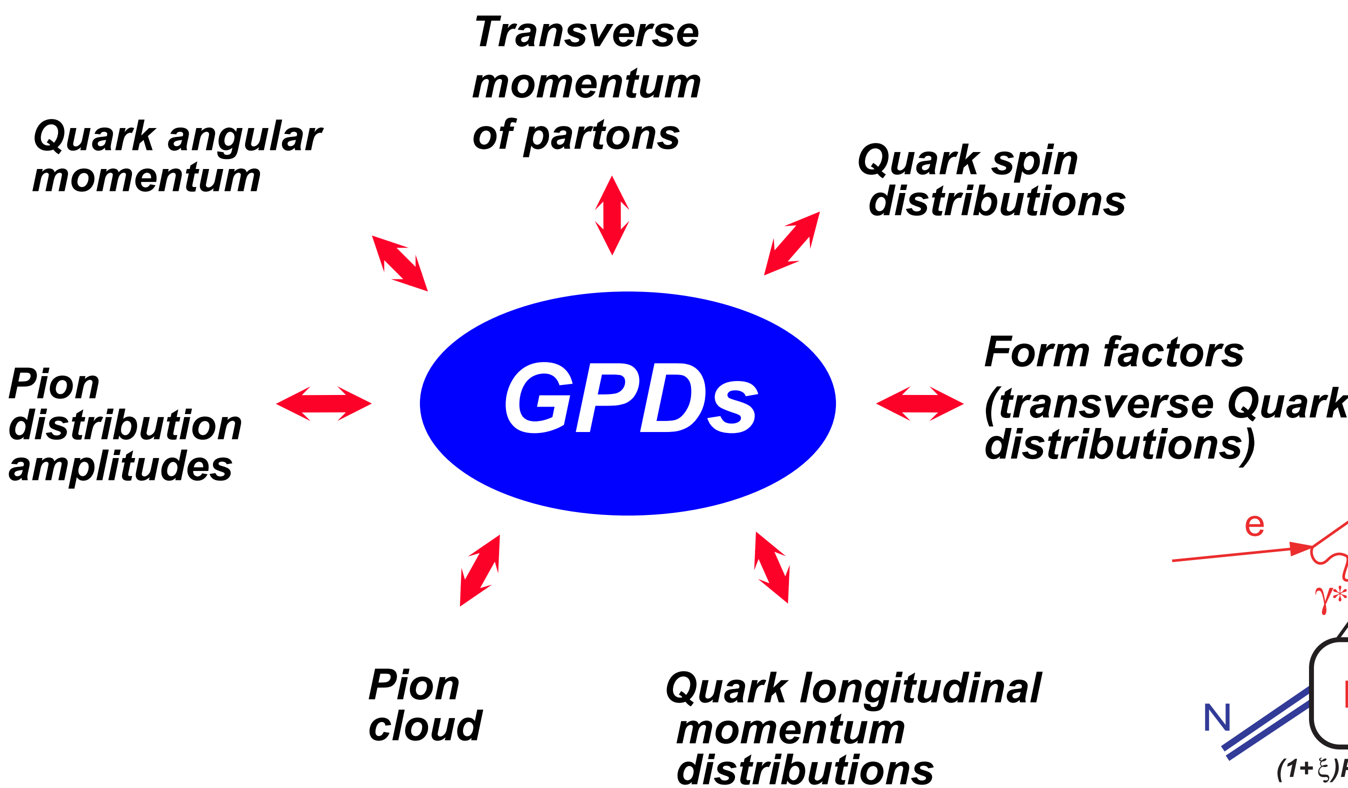


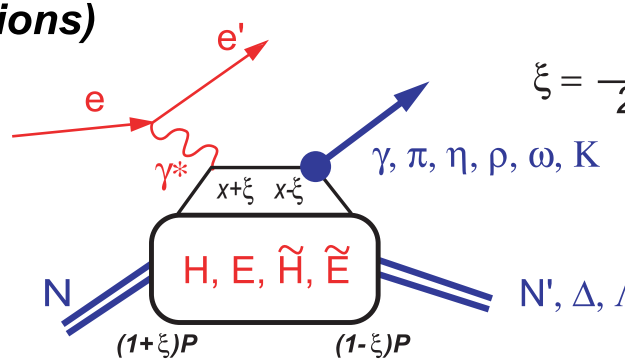
Phys. Rev. D 43, #9 2787 (1991)

g_{6c} CLAS Collaboration



Developing a Unified Description of Hadron Structure via the Recently Devised Generalized Parton Distributions



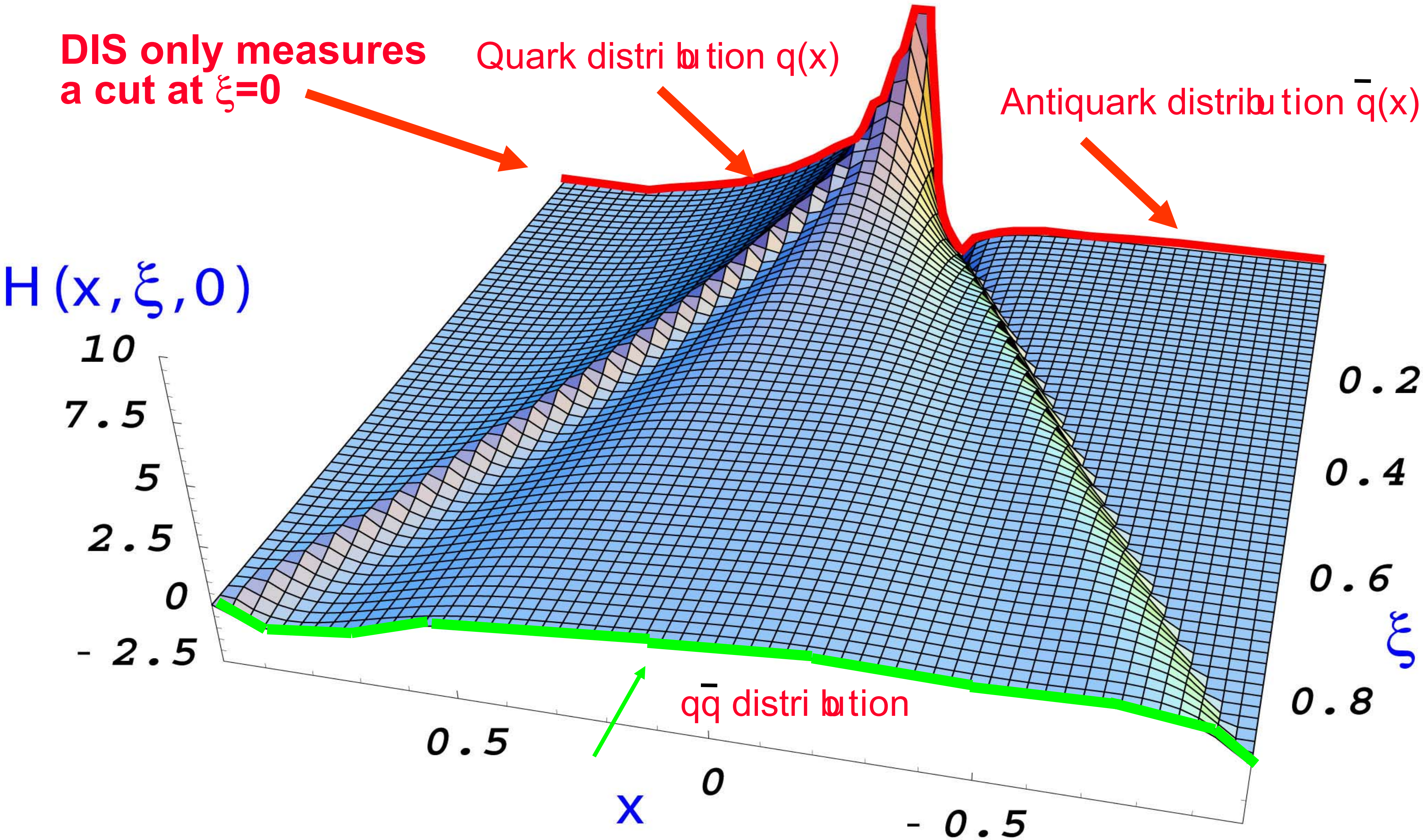


$$\xi = \frac{x_B}{2 - x_B}$$

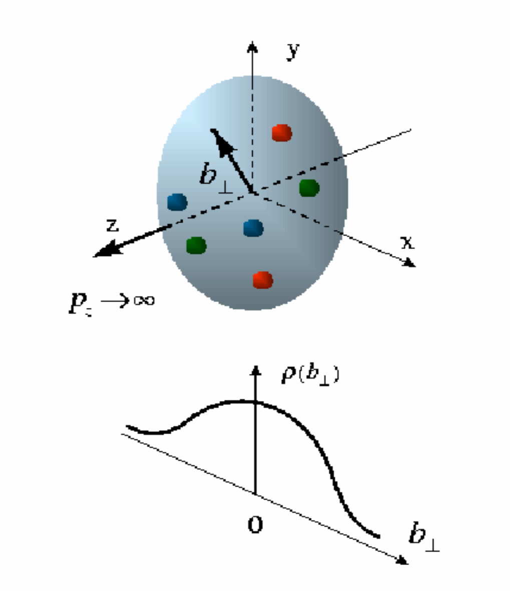
H, E - unpolarized, $\tilde{H}$, $\tilde{E}$ - polarized GPD

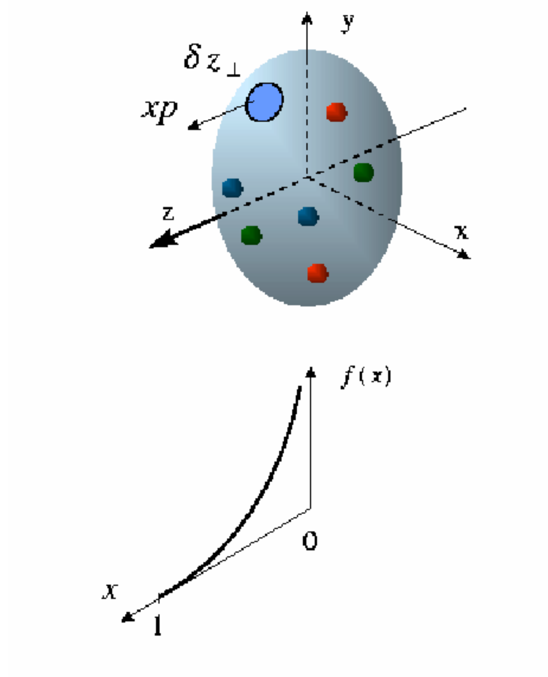
The GPDs Define Nucleon Structure

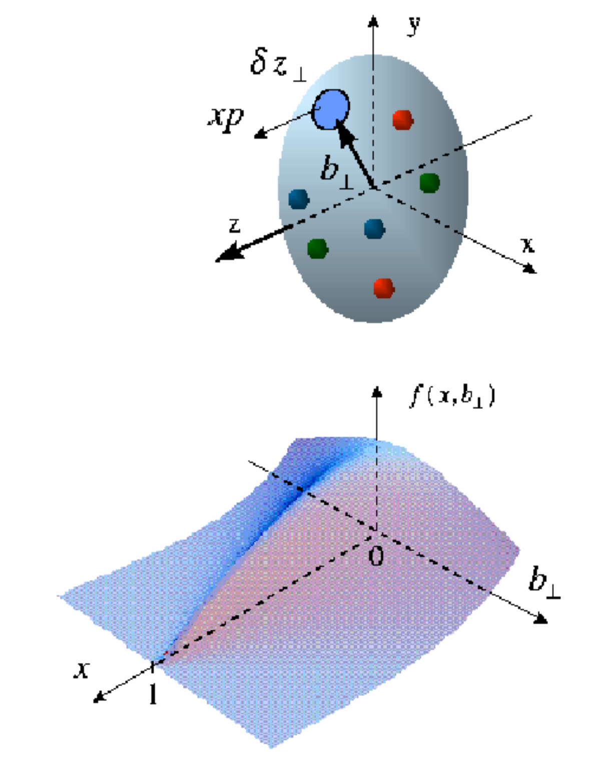
Generalized Parton Distributions Contain Much More Information than DIS



Proton Properties Measured in Different Experiments







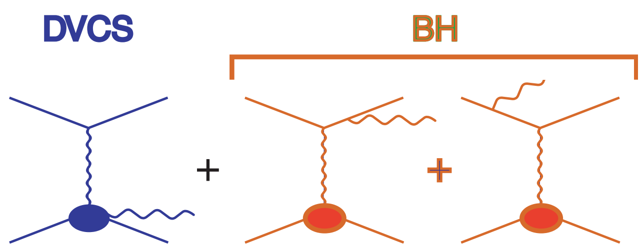
Elastic Scattering
transverse quark distribution in Coordinate space

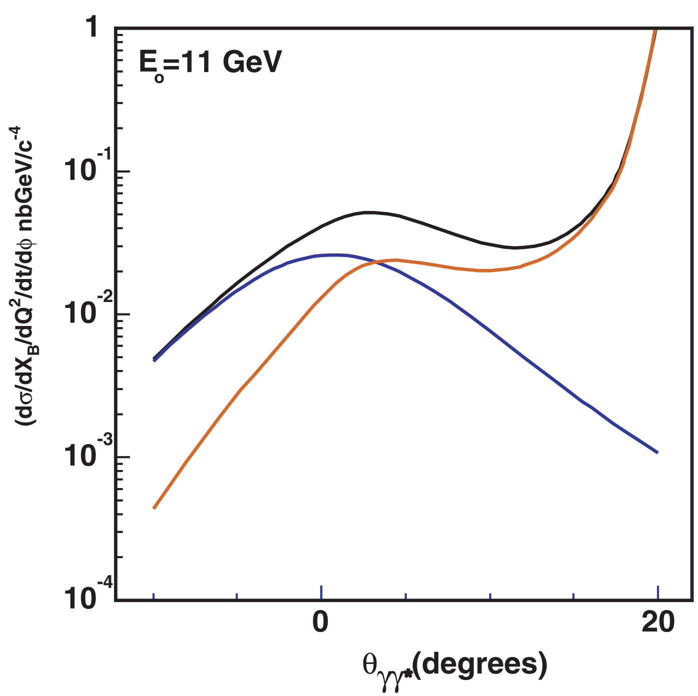
DIS
longitudinal quark distribution in momentum space

DES (GPDs)
The fully-correlated Quark distribution in both coordinate and momentum space

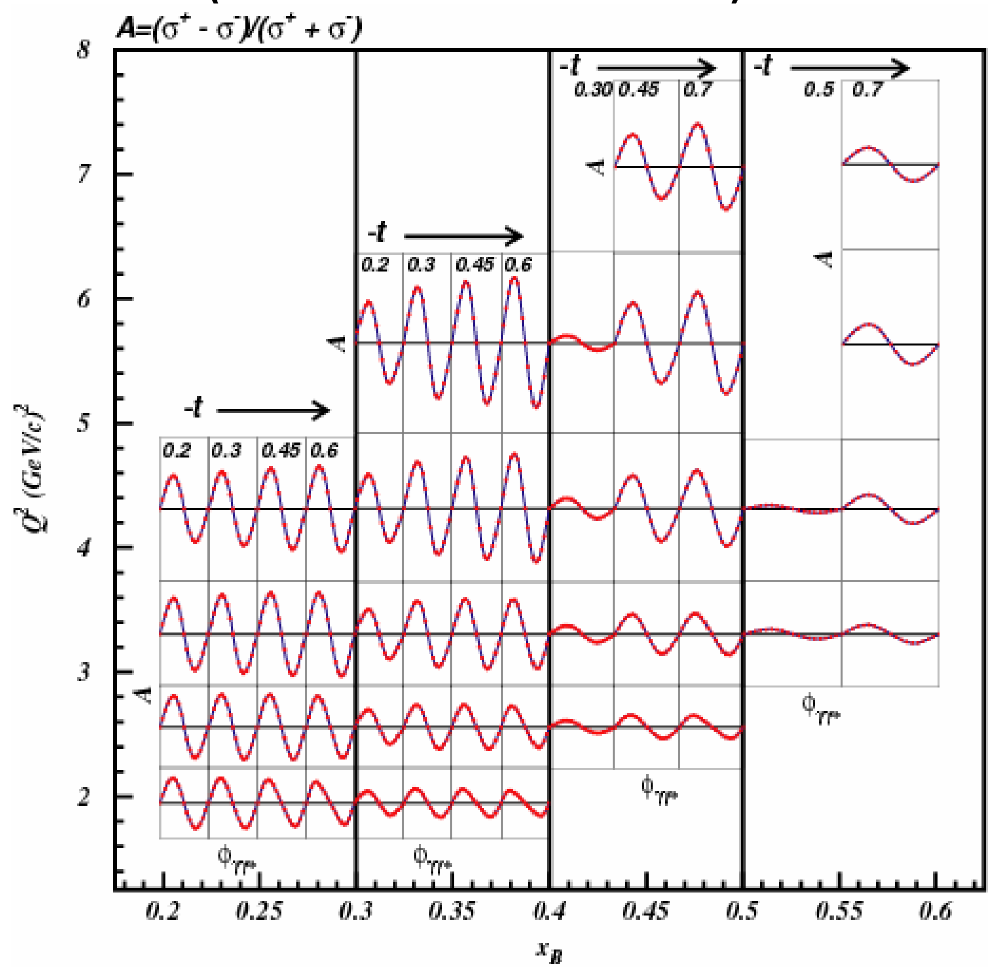
DVCS: Single-Spin Asymmetry in $\vec{e}p \rightarrow ep\gamma$ Measures phase and amplitude directly

DVCS and **Bethe-Heitler** are coherent
$\Rightarrow$ can measure amplitude AND phase

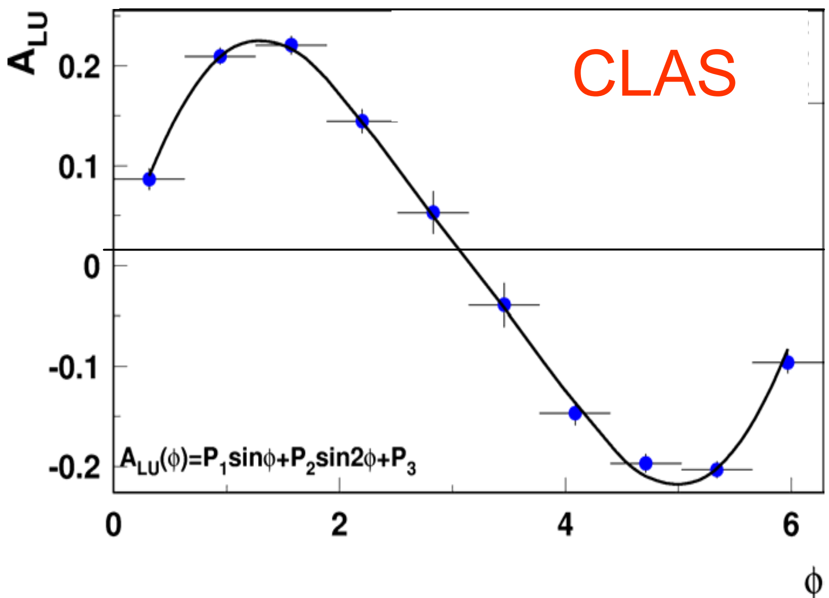




DVCS at 11 GeV can cleanly test correlations in nucleon structure (data shown – 2000 hours)

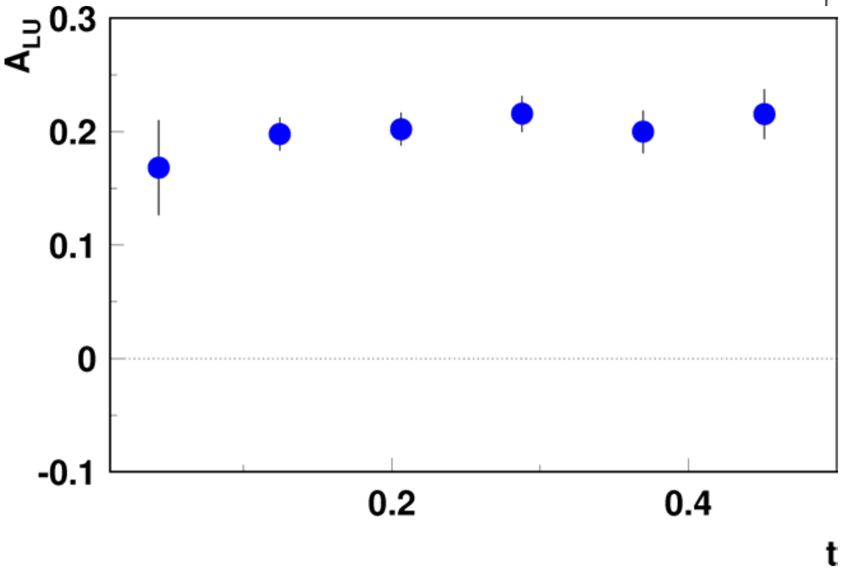


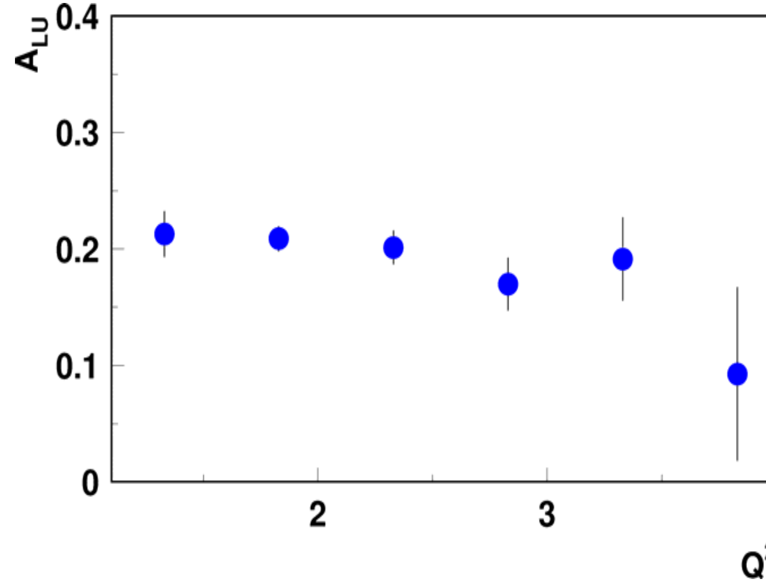
CLAS Data Demonstrate The Feasibility of These Experiments: DVCS/BH Beam Spin Asymmetry



not for distribution

- **5.8 GeV energy increases kinematics range.**
- **Higher statistics allows binning in Q^2, t, x**





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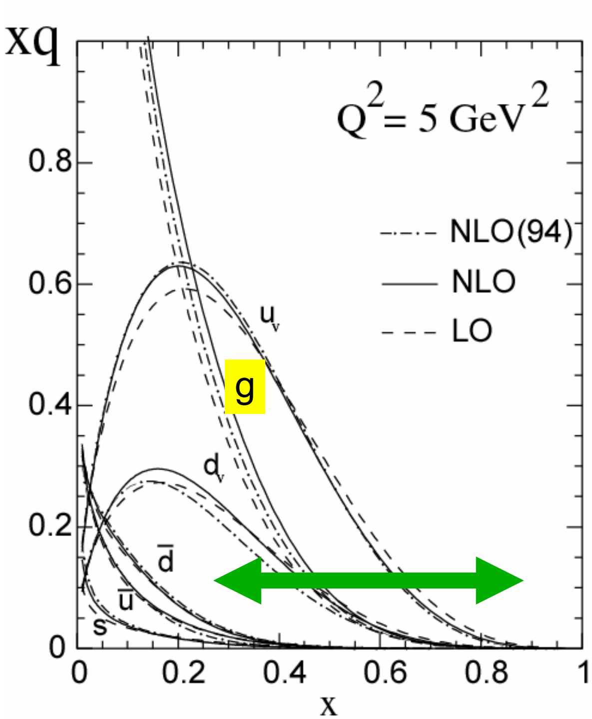
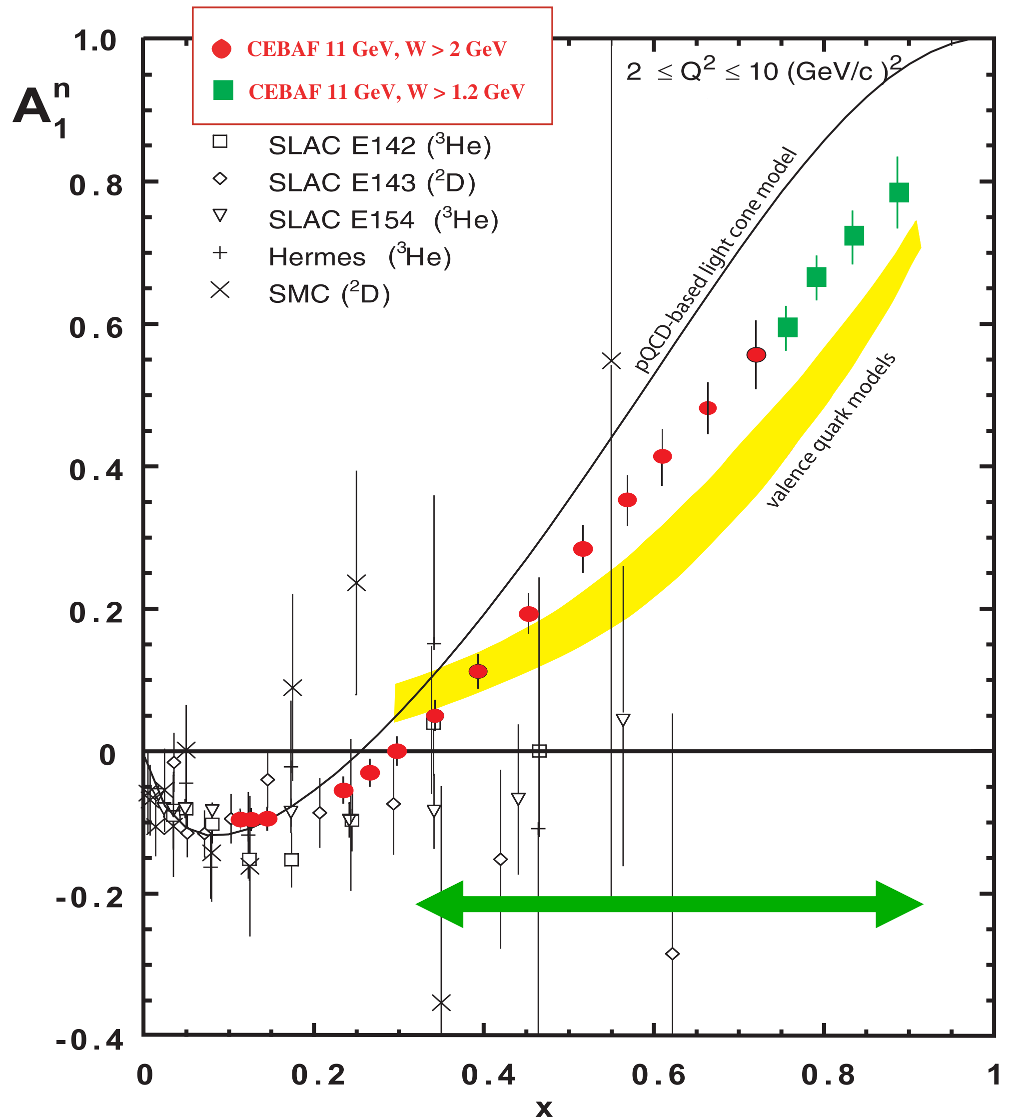
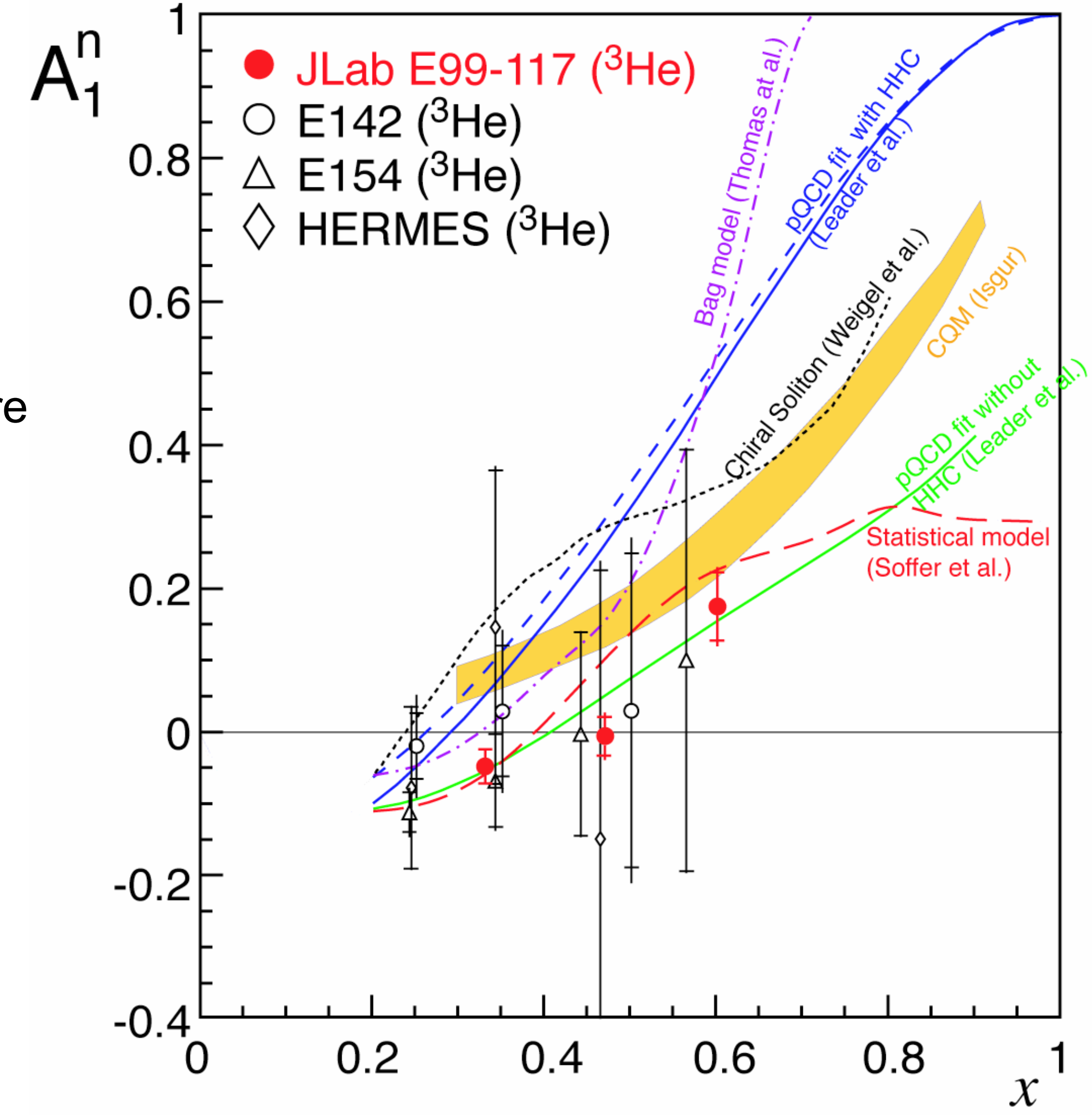
Extending DIS to High x
The Neutron Asymmetry A_1^n





12 GeV will access the valence quark regime (x > 0.3), where constituent quark properties are not masked by the sea quarks and glue

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

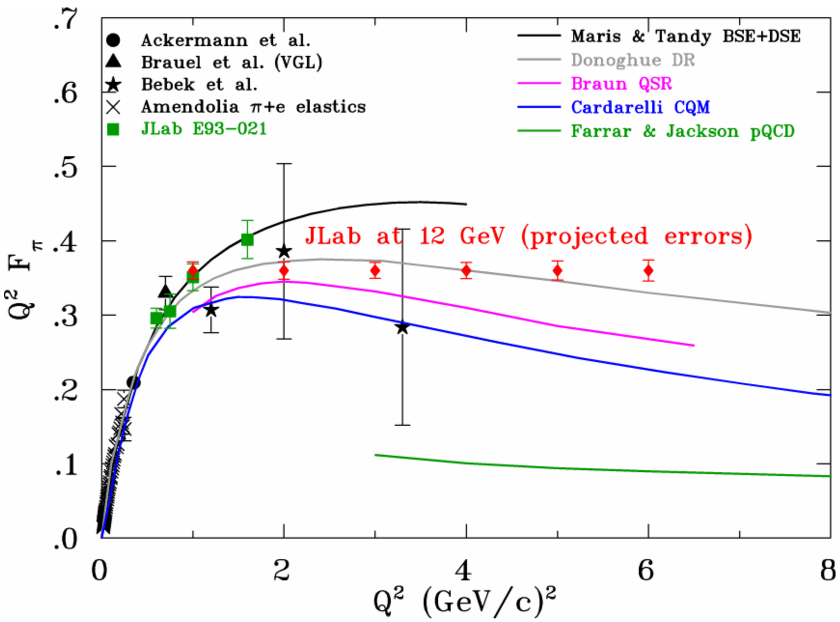


New E99-117 data

provide first indication that A_1^n deviates from 0 at large x, but are clearly at variance with pQCD prediction assuming Hadron Helicity Conservation

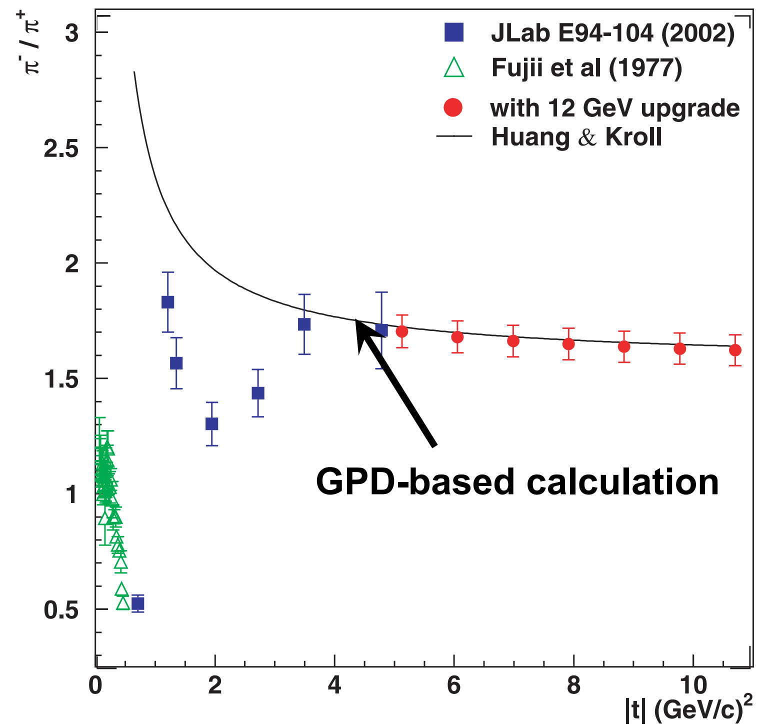
Determine the Distance Scale for the Transition from 'Strong' to pQCD

Pion Elastic Form Factor



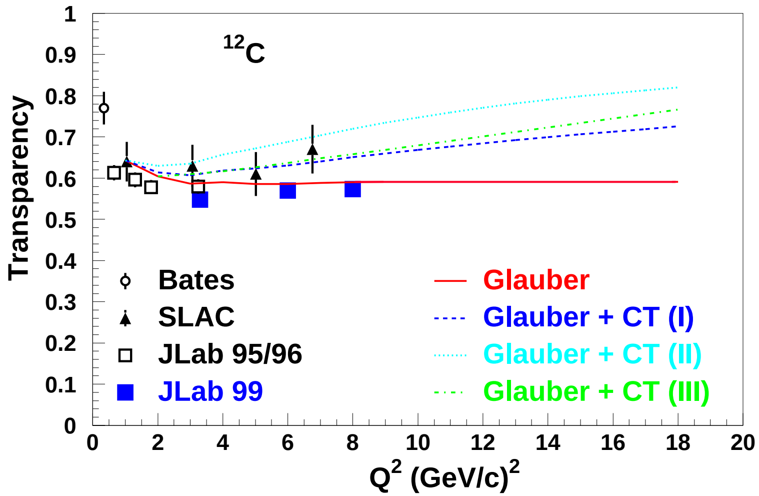
Complementary Approach:

Corrections cancel in π^-/π^+ Ratio
(but theoretical interpretation is more ambiguous)



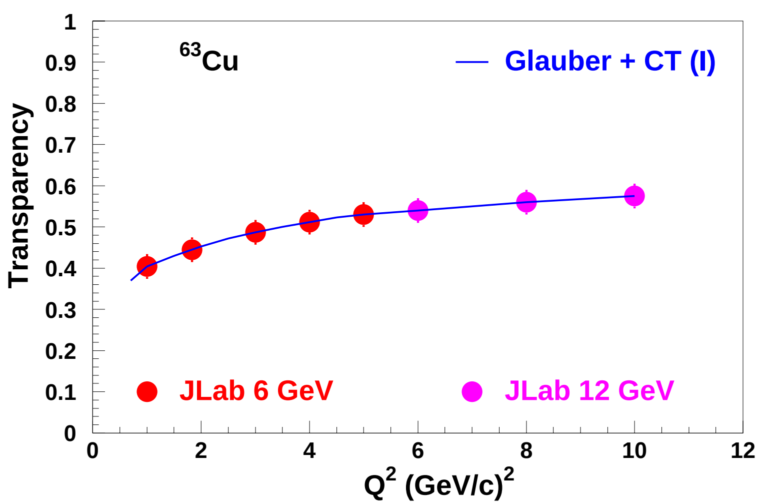
- Simplest valence quark structure
- pQCD is expected to manifest at low momentum transfer
- pQCD and non-pQCD calculations exist
- The asymptotic pion form factor: $f_\pi(Q^2) = \dfrac{12 f_\pi^2 \pi C_F \alpha_s(Q^2)}{Q^2}$

Color Transparency – Now and at 12 GeV



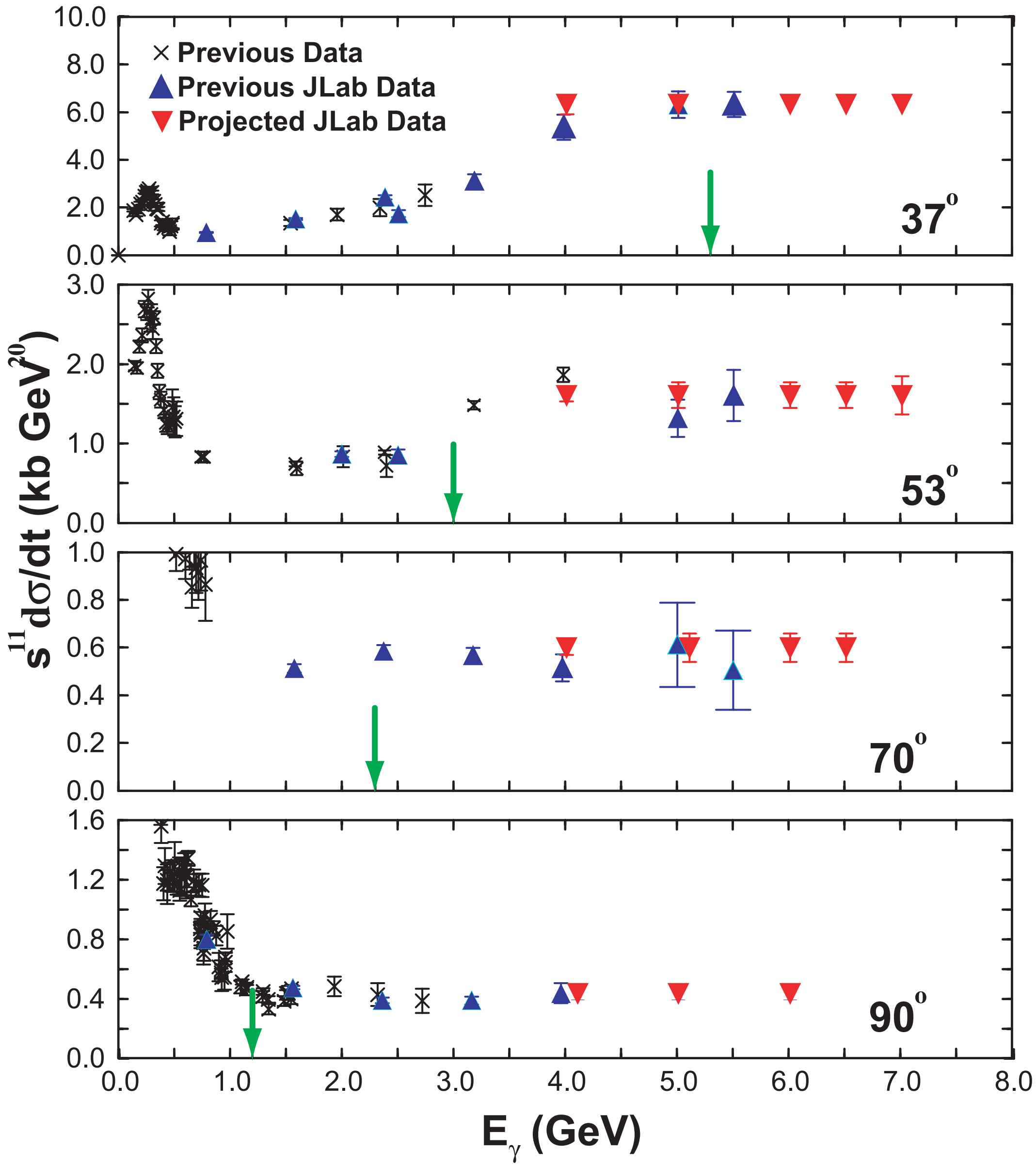
Hall C (e,e'p) experiments at 4 and 5.5 GeV show no evidence for color transparency

Extending these data to 12 GeV will either reveal color transparency or force us to rethink our understanding of quark- based models of the nucleus



12 GeV will also permit similar measurements using the (e,e'π) reaction, which is expected to show color transparency at lower Q^2

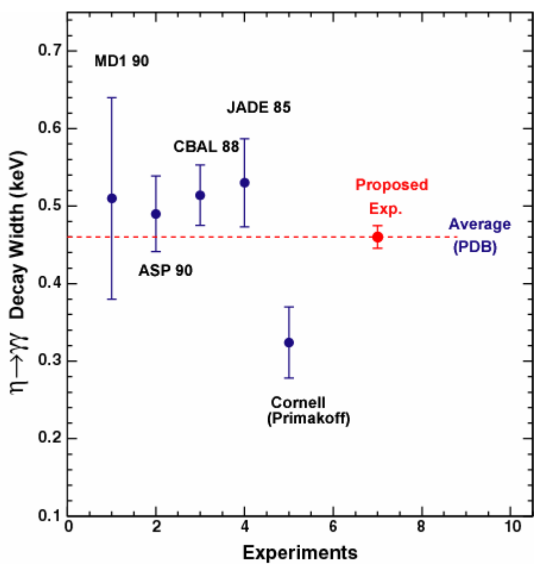
Identifying and Exploring the Transition from the Meson/Nucleon to the Quark/Gluon Description of Nuclei

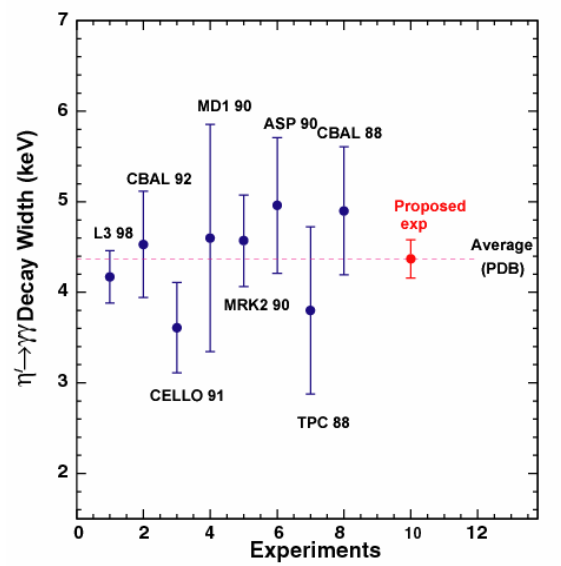


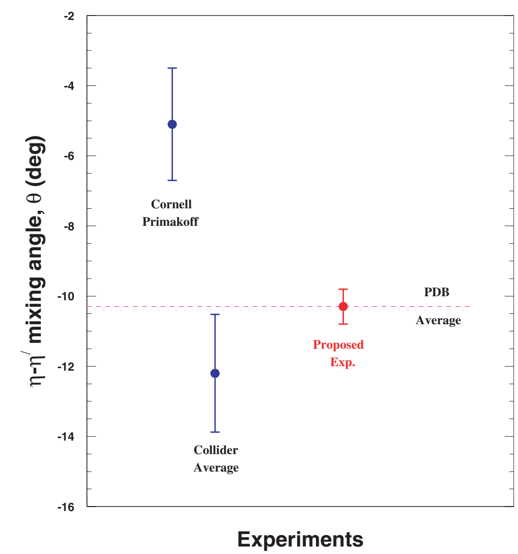
Extend the deuteron photodisintegration data to higher energy, confirming the onset of scaling behavior at constant p_t

Determine Fundamental Parameters of the Standard Model

Primakoff Effect Measurements:







$\Gamma(\eta\rightarrow\gamma\gamma)$ **and** $\Gamma(\eta'\rightarrow\gamma\gamma)$ $\Rightarrow$ **$\eta\eta'$ mixing and**

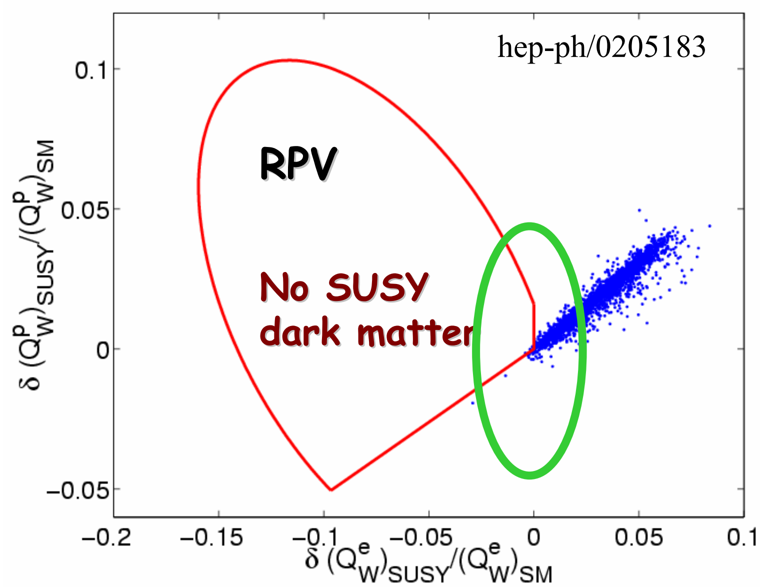
quark mass ratio

SM Tests

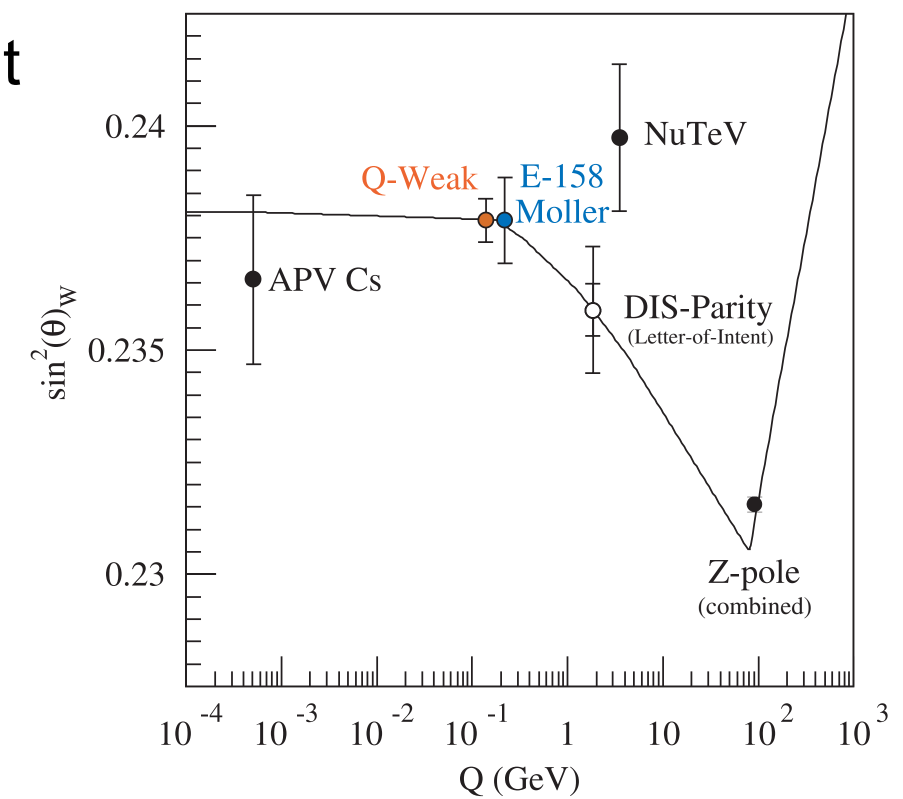
χPT to $\mathcal{O}(p^6)$.....

And Test Its Predictions

- Measurements of $\sin^2(\theta_W)$ below M_Z provide strict tests of the SM.
- Measurements in different systems provide **complementary** information.
- Møller Parity Violation can be measured at JLab at a level which will impact the Standard Model.
- **DIS-Parity** violation measurement is *easily* carried out at JLab.



Weak Mixing Angle MS-bar scheme
Jens Erler



PAC Conclusions about the Science (from Review Summary)

- Gluonic excitations of mesons and the origin of confinement, and the unified description of the quark-gluon structure of the nucleon, primarily through the determination of Generalized Parton Distributions continue to represent the main driving motivations for the 12 GeV upgrade. The physics is well motivated and JLab has a unique opportunity to have strong impact in these areas.
- Two additional areas have outstanding potential to develop into major components of the physics program.
  - a coherent experimental and theoretical physics program to develop a unified description of high-density cold nuclear matter as it can be explored at the 12 GeV facility,
  - measurements that test the Standard Model: in the electro-weak sector as they relate to parity violation in deep-inelastic scattering, and the weak charge of the proton and the electron, as well as in the strong sector as they test the strong interaction Lagrangian through investigation of the radiative decay of π^o, η, and η' mesons.

PAC Overall Conclusion (from Review Summary)

Overall it is the judgment of the PAC that the envisioned JLab Upgrade offers an outstanding opportunity for exploring new and fundamental physics issues of wide spread interest to the community of nuclear and particle physicists. In many respects the new experimental facilities will be unique in the world. They will also impact issues raised at other facilities. Therefore the PAC enthusiastically endorses the JLab 12 GeV Upgrade in view of the timeliness and high impact it can have on physics issues of concern to a broad spectrum of the nuclear and particle physics community.

NSAC Facilities Subcommittee Conclusions

SCIENCE (Category 1 – Absolutely Central)

The 2002 NSAC Long Range Plan *"strongly recommend[s] the upgrade of CEBAF at Jefferson Laboratory to 12 GeV as soon as possible. [It] is critical for our continued leadership in the experimental study of hadronic matter…"* This was one of the four major recommendations of the LRP. The Upgrade has the support of a large and active user community (~1100 scientists from 29 countries); it has been enthusiastically reviewed by numerous outside peer groups and will be unique worldwide. The realization of the Upgrade will create synergies with other fields of research, most notably with large-scale computing, high-energy physics, and astrophysics.

The 12 GeV Upgrade will provide answers to questions of fundamental importance, probing issues that are absolutely central to nuclear science in four main areas:

- The experimental study of gluonic excitations in order to understand the confinement of quarks. …….
- The determination of the quark and gluon wavefunctions of the nuclear building blocks…..
- Exploring the basis of our understanding of nuclei. …..
- Tests of the Standard Model of electro-weak interactions and the determination of fundamental parameters of QCD. …..

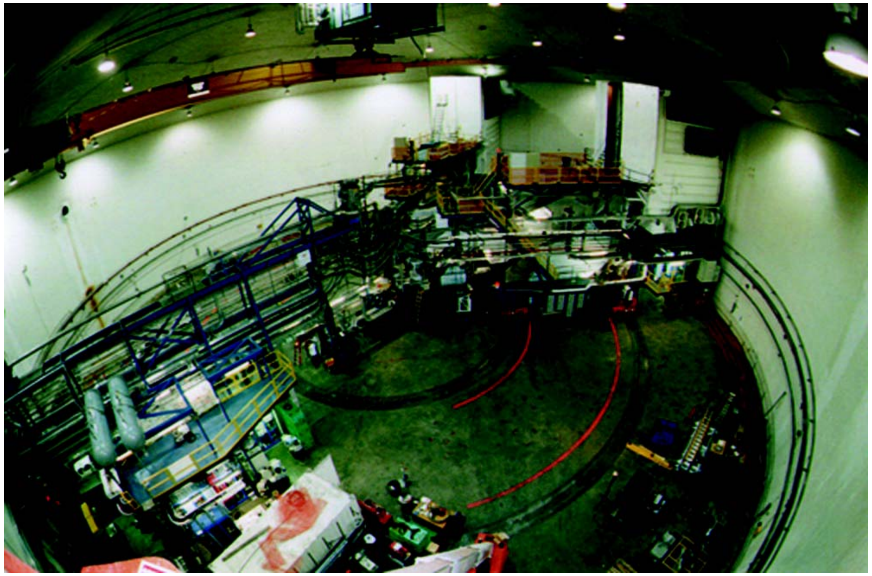
The Development of This Outstanding Science Case Took Place as Part of a Detailed Study of the Experimental Apparatus Needed

In Sum:

- Four major user community workshops (4/94, 6/98, 1/00, and 7/02)
- Extensive physics experiment designs and equipment designs carried out by the existing hall collaborations and the new GlueX collaboration
- PAC review of science and equipment (7/00) prior to completion of the 2/01 “White Paper” that defines the science and the equipment requirements
- Two-year effort (post NSAC) to refine equipment designs and expand science program, including writing of hall-specific pCDRs
- Second PAC review of science and equipment (1/03)
- pCDR for the science and equipment (in final review)

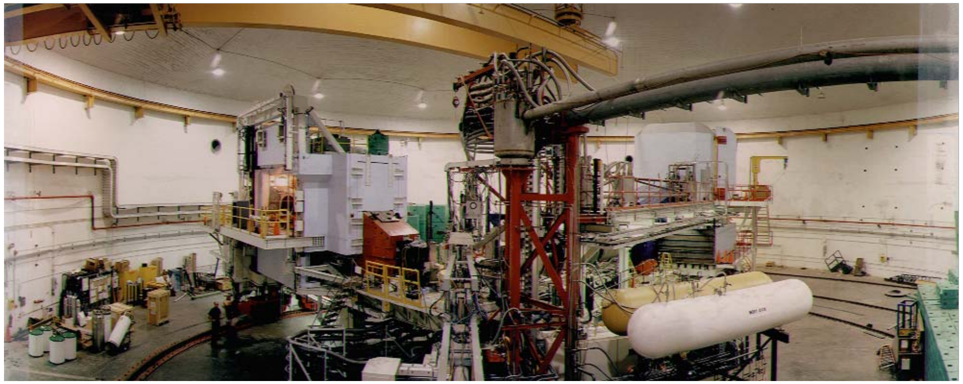
Plans for 12 GeV Began With The Equipment in the Existing Experimental Halls

Hall A (2 HRS)



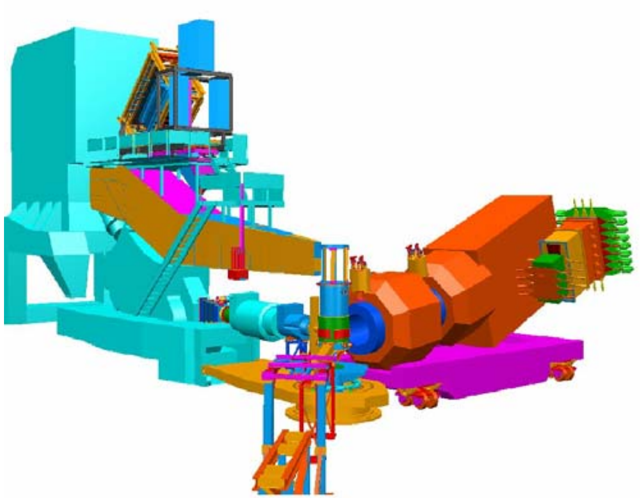
Hall B (CLAS)

Hall C (SOS/HMS)



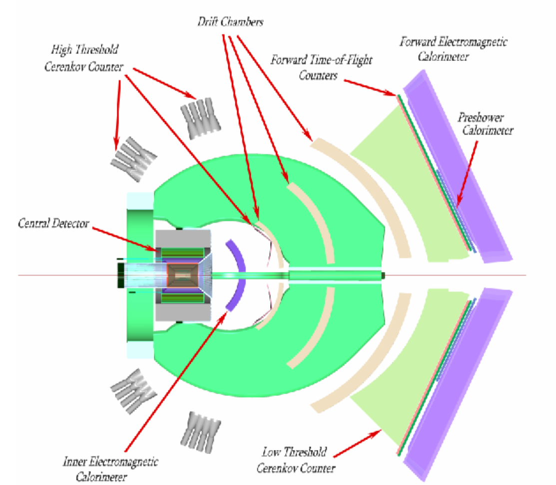
And Ended With Enhanced and/or Complementary Equipment in Halls A, B, & C and a New Hall D

A



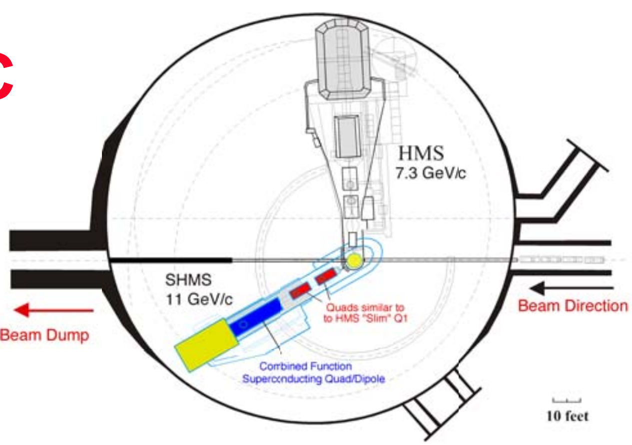
Medium Acceptance Detector (MAD) at high luminosity and intermediate angles

B



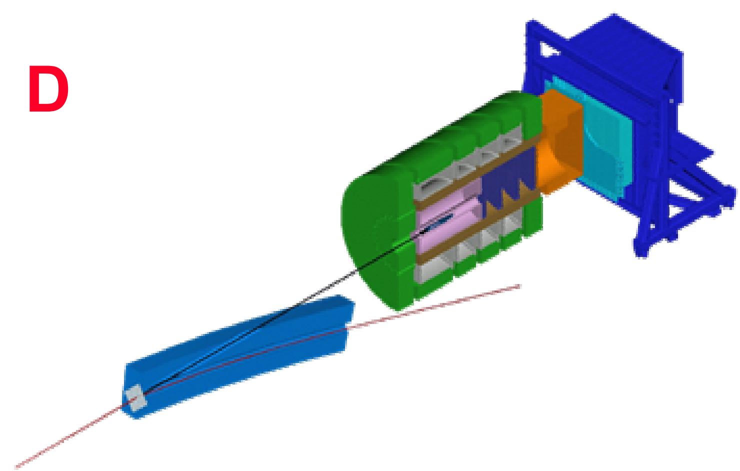
CLAS upgraded to higher (10^{35}) luminosity and coverage

C



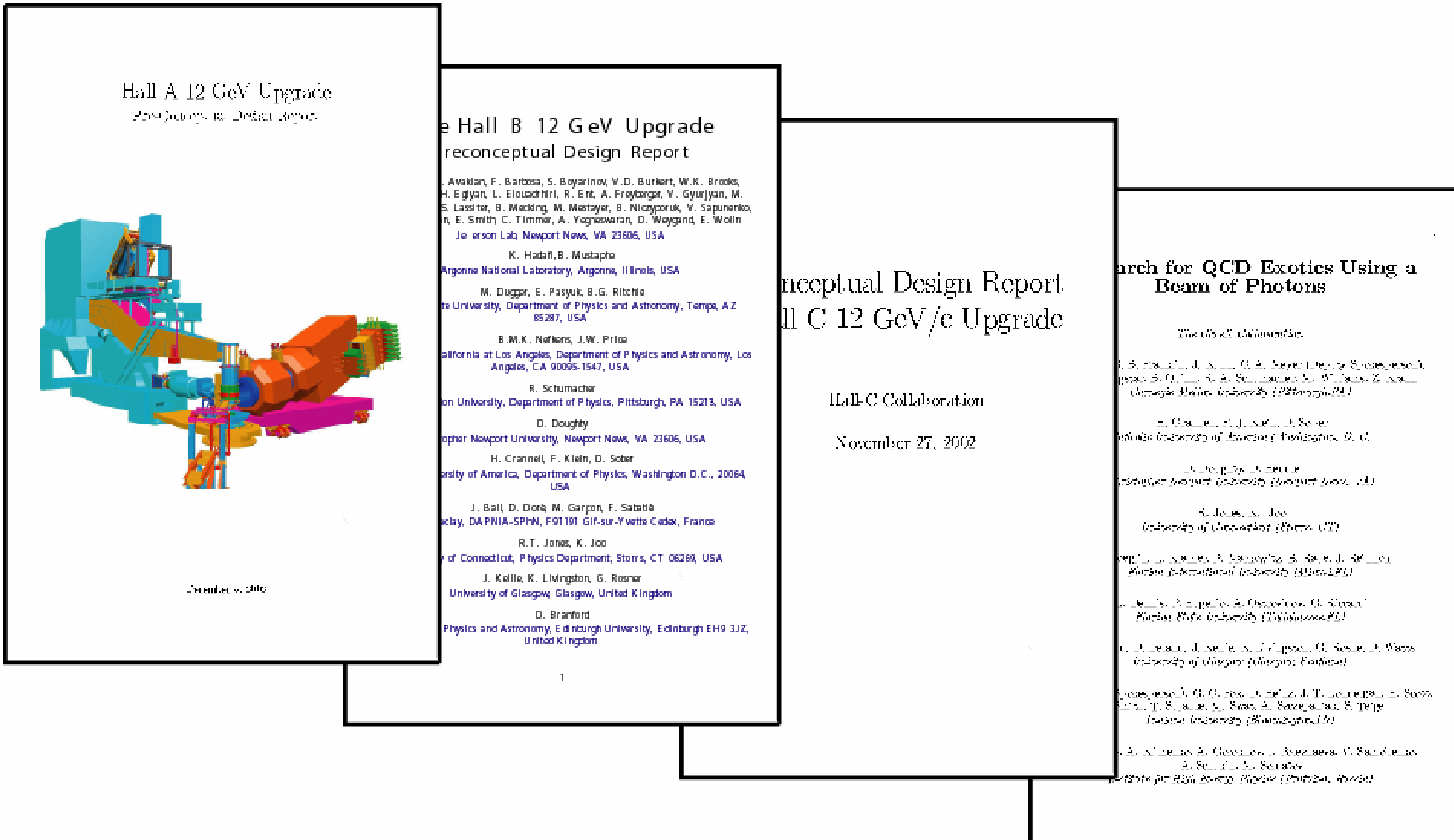
Super High Momentum Spectrometer (SHMS) at high luminosity and forward angles

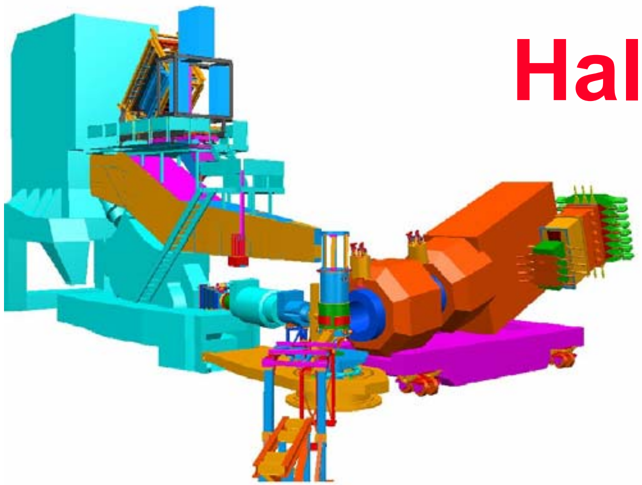
D



9 GeV tagged polarized photons and a 4π hermetic detector

Four Hall-Specific pCDRs Have Been Written

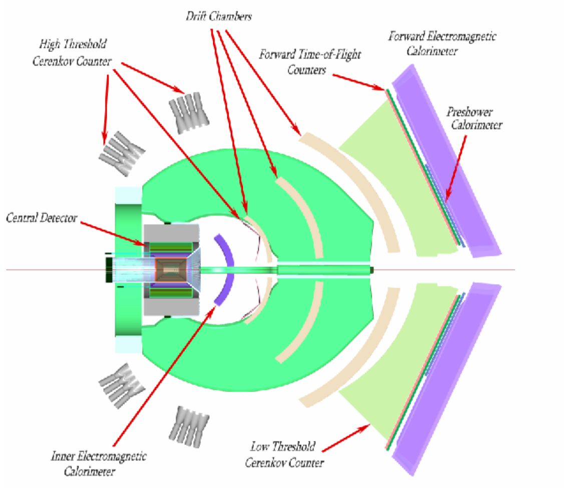




Hall A: MAD and the HRS

Parameter	MAD design	HRS performance
Central momentum range	0.4 - 6.0 GeV/c	0.2 - 4.3 GeV/c
Scattering angle range	6° - 130°	6° - 150
Momentum acceptance	$\pm$ 15%	$\pm$ 5%
Momentum resolution	0.1%	0.02%
Angular acceptance	28 msr ($\geq 35^\circ$)	6 msr (standard)
	6 msr (6°– 12°)	12 msr (forward)
Angular resolution (hor)	1 mrad	0.5 mrad
Angular resolution (ver)	1 mrad	1 mrad
Target length acceptance (90°)	50 cm	10 cm
Vertex resolution	0.5 cm	0.1 cm
Maximum DAQ rate	20 kHz	5 kHz
e/h Discrimination	0.5×10^5 at 98%	2×10^5 at 99%
π/K Discrimination	100 at 95%	100 at 95%

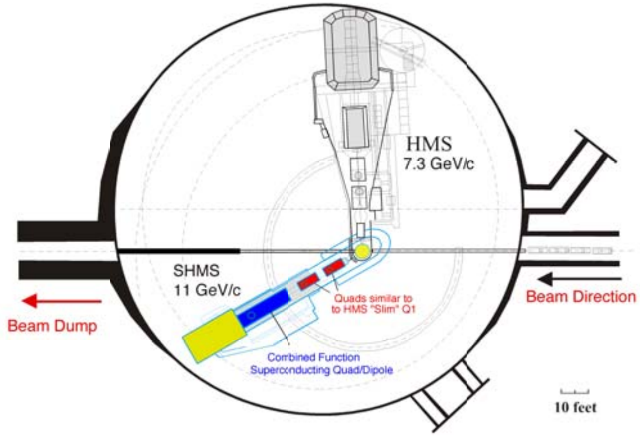
Hall B: CLAS++



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

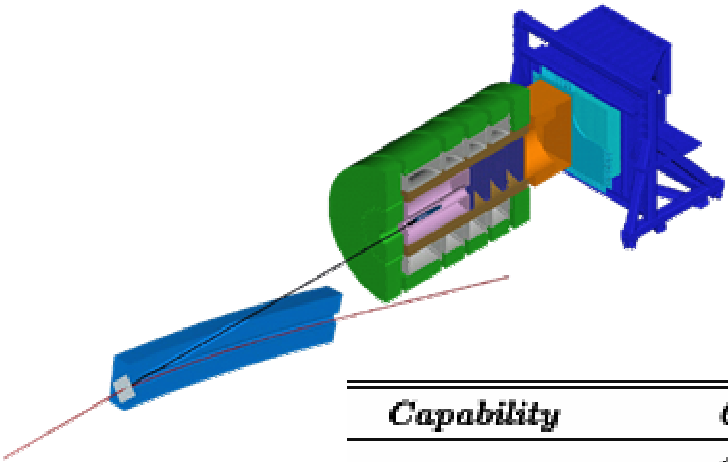
	Forward detector	Central Detector
Angular coverage		
Tracks (inbending)	8° – 37°	40° – 135°
Tracks (outbending)	5° – 37°	40° – 135°
Photons	3° – 37°	40° – 135°
Track resolution		
$\delta p/p$	$0.003 - 0.001p$	$\delta p_T/p_T = 0.02$
$\delta\theta(mr)$	1	8
$\delta\phi(mr)$	2 – 5	2
Photon detection		
Energy range (MeV)	> 150	> 60
$\delta\theta$(mr)	4 (1 GeV)	15 (1 GeV)
Neutron detection		
η_{eff}	0.5 ($p > 1.5 GeV/c$)	NA
Particle id		
Electron/pion	> 1000 (p < 4.8GeV/c)	NA
	> 100 (p > 4.8GeV/c	NA
π^+/π^-	full range	<0.65 GeV/c
K/ π	full range	<0.65 GeV/c
K^+/p, K^-/p	<4.5 GeV/c	<0.90 GeV/c
$\pi^0 \rightarrow \gamma\gamma$	full range	full range
$\eta \rightarrow \gamma\gamma$	full range	full range

Hall C: The SHMS



Parameter	*HMS Performance*	*SHMS Specification*
Range of Central Momentum	0.4 to 7.3 GeV/c	2.5 to 11 GeV/c
Momentum Acceptance	± 10%	-15% to +25%
Momentum Resolution	0.1% – 0.15%	< 0.2%
Scattering Angle Range	10.5 to 90 degrees	5.5 to 25 degrees
Target Length Accepted at 90	10 cm	50 cm
Horizontal Angle Acceptance	± 32 mrad	± 18 mrad
Vertical Angle Acceptance	± 85 mrad	± 50 mrad
Solid Angle Acceptance	8.1 msr	4 msr (LSA tune) 2 msr (SSA tune)
Horizontal Angle Resolution (yptar)	0.8 mrad	2-4 mrad
Vertical Angle Resolution (xptar)	1.0 mrad	1-2 mrad
Vertex Reconstruction Resolution (ytar)	0.3 cm	0.2 - 0.6 cm
Maximum DAQ Event Rate	2,000 events/second	10,000 events/second
Maximum Flux within Acceptance	5 MHz	5 MHz
e/h Discrimination	>1000:1 at 98% efficiency	1000:1 at 98% efficiency
π/K Discrimination	100:1 at 95% efficiency	100:1 at 95% efficiency

Hall D: The GlueX Detector



Capability	*Quantity*	*Range*
Charged particles	Coverage	$1 \leq \theta \leq 170^\circ$
	Momentum resolution (5° - 140°)	$\sigma_p/p \approx$ 1-2%
	Position resoultion	$\sigma \approx$ 150 - 200 μm
	dE/dx measurements	$20 \leq \theta \leq 140^\circ$
	Vertex detector	$\sigma \approx$ 500 μm
	Time-of-flight scintillator	$\sigma_t \approx$ 50 ps
	Cerenkov for π/K separation	$\theta \leq 14^\circ$
	Barrel time resolution	$\sigma_t \approx$ 250 ps
Photon detection	Energy measurements	$1 \leq \theta \leq 120^\circ$
	Veto capability	$\theta \geq 120^\circ$
	Lead glass energy resolution (Æ 150 MeV)	$\sigma_E/E \approx 2 + 5\%/\sqrt{E}$
	Barrel energy resolution (Æ 20 MeV)	$\sigma_E/E \approx 4.4\%/\sqrt{E}$
	Barrel position resolution	$\sigma_z \approx$ 1 cm
DAQ / trigger	Level 1	20 kHz
	Event Rate	15 kHz to tape
	Data Rate	100 MB/s
Electronics	fully pipeline	Flash ADCs, TDCs
Photon Flux	Tagged rate	$10^8 \gamma/s$

There is a Detailed WBS for the Project

e.g., for Hall D

Title: HallD roll-up

Description:

	Total	Contingency		CDR		R&D		PED		Construction		Pre-Ops	
	k$ or m-w	%	k$ or m-w	%	k$ or m-w	%	k$ or m-w	%	k$ or m-w	%	k$ or m-w	%	k$ or m-w
Identified WBS				1.0.2		1.1.2.1		1.2.2.1.1		1.4.1.1.1		1.8.4	
Procurements (FY02 $)													
Supplies & Materials	$991k	30%	$297k	1%	$14k	4%	$44k	15%	$152k	79%	$780k	0%	$0k
Travel	$0k		$0k		$0k		$0k		$0k		$0k		$0k
Machine Shop Labor	$462k	30%	$139k	0%	$0k	0%	$0k	0%	$0k	100%	$462k	0%	$0k
Major Components/A&E < $50K	$3,264k	30%	$979k	0%	$4k	0%	$8k	1%	$28k	99%	$3,223k	0%	$0k
Major Components/A&E > $50K	$7,286k	30%	$2,186k	0%	$29k	1%	$47k	2%	$134k	97%	$7,076k	0%	$0k
Total	$12,002k		$3,601k		$48k		$99k		$315k		$11,541k		$0k
JLab Labor (man-weeks)													
Plant Eng	0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w
Plant Dsgn	0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w
Plant Tech	0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w
Skilled Trades, Electrician	104 m-w	30%	31 m-w	0%	0 m-w	1%	1 m-w	3%	3 m-w	96%	100 m-w	0%	0 m-w
Mech Eng	452 m-w	30%	136 m-w	4%	18 m-w	8%	34 m-w	25%	113 m-w	63%	287 m-w	0%	0 m-w
Mech Dsgn	1008 m-w	30%	302 m-w	1%	5 m-w	3%	35 m-w	12%	123 m-w	84%	845 m-w	0%	0 m-w
Mech Tech	5107 m-w	30%	1532 m-w	1%	62 m-w	3%	164 m-w	7%	353 m-w	89%	4529 m-w	0%	0 m-w
Elect Engr	94 m-w	30%	28 m-w	3%	3 m-w	34%	32 m-w	50%	47 m-w	13%	13 m-w	0%	0 m-w
Elect Dsgn	572 m-w	30%	172 m-w	5%	27 m-w	9%	54 m-w	14%	82 m-w	72%	409 m-w	0%	0 m-w
Elect Tech	228 m-w	30%	68 m-w	2%	4 m-w	4%	10 m-w	6%	14 m-w	88%	200 m-w	0%	0 m-w
Proj Admin	0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w
Scientists-Existing	0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w
Scientists-Additional	1892 m-w	30%	568 m-w	3%	48 m-w	9%	170 m-w	18%	348 m-w	70%	1326 m-w	0%	0 m-w
Comp Spt	440 m-w	30%	132 m-w	0%	0 m-w	5%	21 m-w	6%	27 m-w	89%	392 m-w	0%	0 m-w
Office	0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w
Total	9897 m-w	30%	2969 m-w	2%	167 m-w	5%	520 m-w	11%	1110 m-w	82%	8099 m-w	0%	0 m-w
University Labor (man-weeks)													
Faculty	1835 m-w	30%	551 m-w	3%	47 m-w	16%	293 m-w	14%	262 m-w	67%	1233 m-w	0%	0 m-w
Staff	1856 m-w	30%	557 m-w	2%	41 m-w	14%	261 m-w	19%	348 m-w	65%	1205 m-w	0%	0 m-w
Undergrad stud.	938 m-w	30%	281 m-w	7%	63 m-w	24%	221 m-w	16%	149 m-w	54%	504 m-w	0%	0 m-w
Grad stud.	1026 m-w	30%	308 m-w	2%	17 m-w	14%	139 m-w	26%	265 m-w	59%	605 m-w	0%	0 m-w
Total	5655 m-w	30%	1697 m-w	3%	168 m-w	16%	915 m-w	18%	1025 m-w	63%	3547 m-w	0%	0 m-w
Purchased labor (man-weeks)													
Mech Dsgn	0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w
Mech Tech	44 m-w	30%	13 m-w	0%	0 m-w	0%	0 m-w	0%	0 m-w	100%	44 m-w	0%	0 m-w
Elect Dsgn/Engr	0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w
Elect Tech	345 m-w	30%	104 m-w	0%	0 m-w	10%	35 m-w	10%	35 m-w	80%	276 m-w	0%	0 m-w
Electrician	0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w		0 m-w
Plumb/Weld	8 m-w	30%	2 m-w	0%	0 m-w	0%	0 m-w	0%	0 m-w	100%	8 m-w	0%	0 m-w
Rig&Oper	1950 m-w	30%	585 m-w	0%	0 m-w	0%	0 m-w	0%	0 m-w	100%	1950 m-w	0%	0 m-w
Laborer	132 m-w	30%	40 m-w	0%	0 m-w	0%	0 m-w	0%	0 m-w	100%	132 m-w	0%	0 m-w
Total	2479 m-w	30%	744 m-w	0%	0 m-w	1%	35 m-w	1%	35 m-w	97%	2410 m-w	0%	0 m-w
Consultant (FY02 k$)	$0k		$0k		$0k		$0k		$0k		$0k		$0k

PAC Conclusions about the Equipment (from Review Summary)

- The PAC endorses the overall plan for the major new instrumentation as being required to implement the new physics program and therefore recommends that the major components in all four halls be implemented.

This Effort Formed the Basis for Our Current Plan for the Upgrade, as Outlined in the pCDR

The Hall-Specific pCDRs Included:

- Physics motivating the equipment;
- Technical descriptions of the apparatus with many details; and
- Examples of experiments that could be carried out using the equipment to address the motivating physics.

They have been combined into a coherent physics case, together with a detailed presentation of the apparatus in the pCDR for the Science and Experimental Equipment

Through the PAC23 Upgrade Meeting this plan has received its first serious peer review

The pCDR Draft is Now Posted for Review by the Entire JLab Community

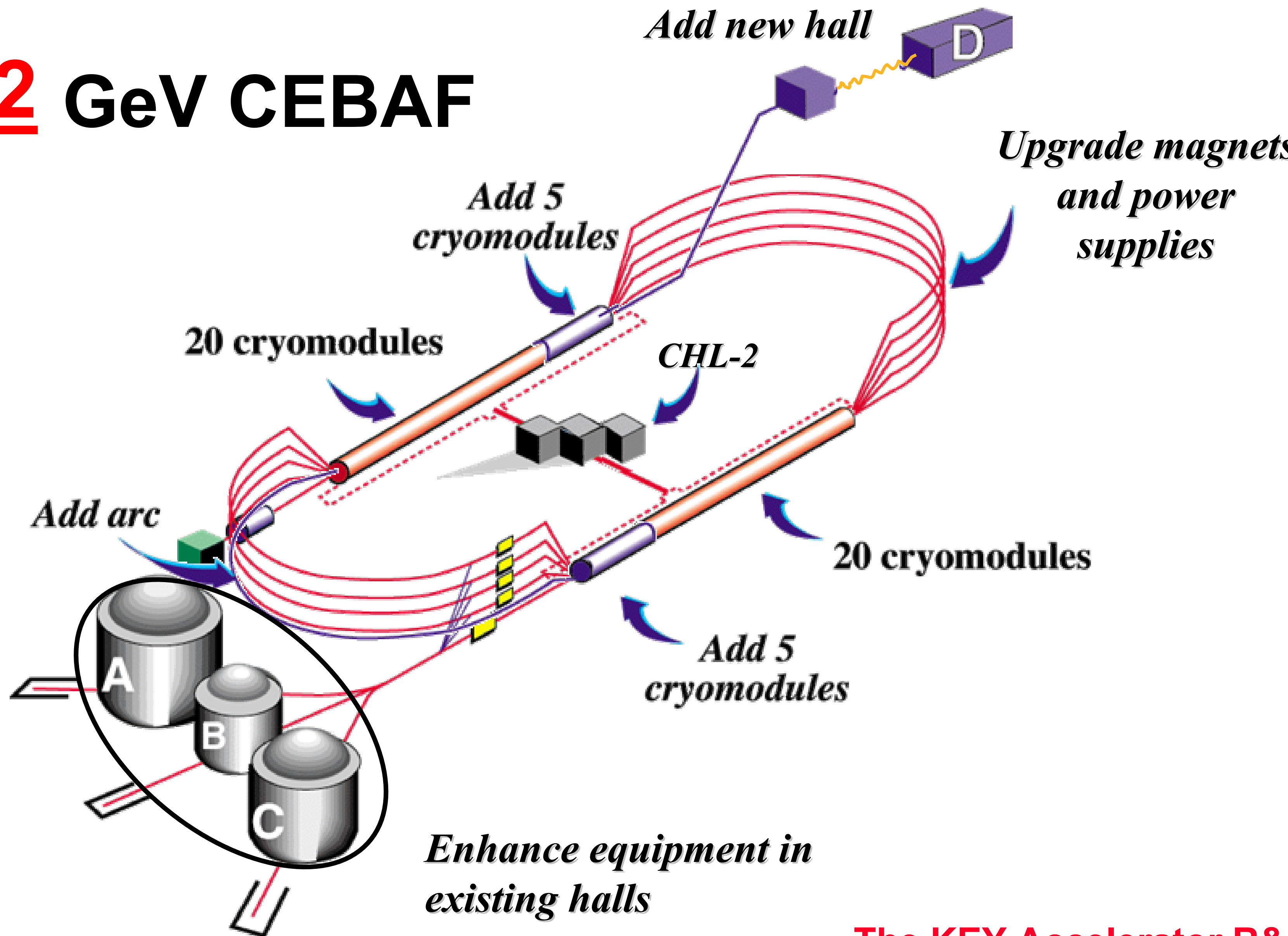
Contents

• • • • • •

We expect to complete that review and finalize the pCDR by late summer

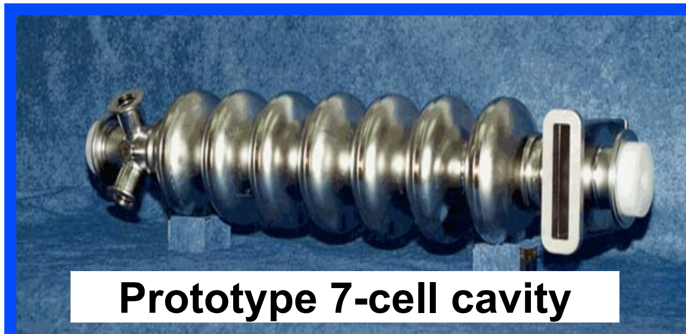
There Has Also Been Significant Progress on Accelerator Issues Relevant to the Upgrade

12 GeV CEBAF



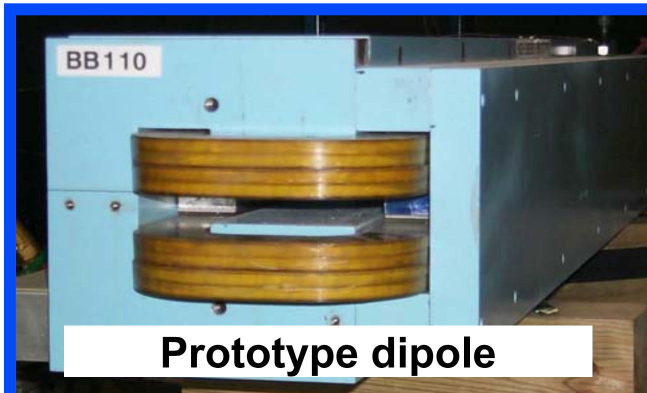
The KEY Accelerator R&D Issues are the SRF and the Magnets

Key R&D Issues Have Been Addressed

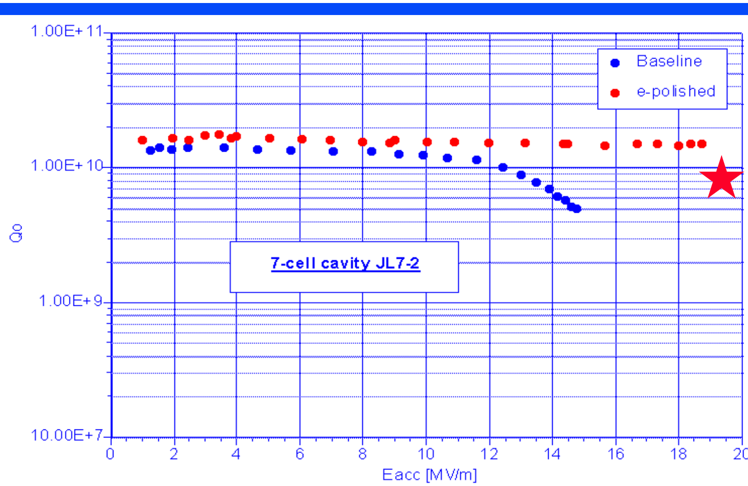


Prototype 7-cell cavity

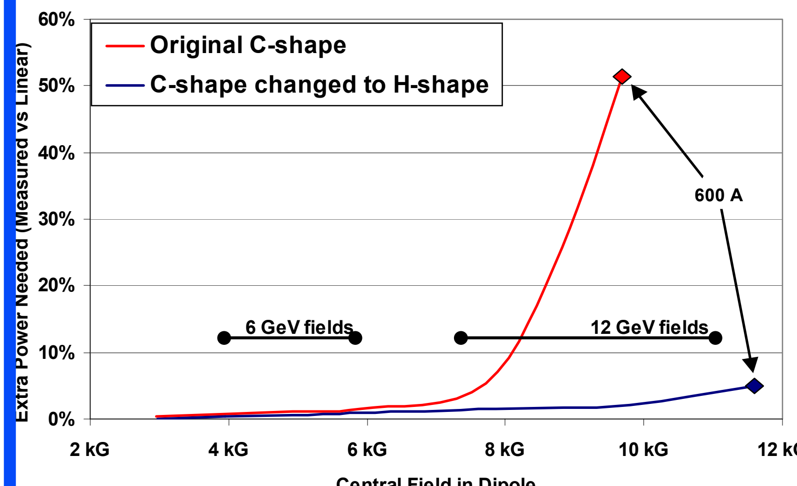
Prototype tuner



Prototype dipole

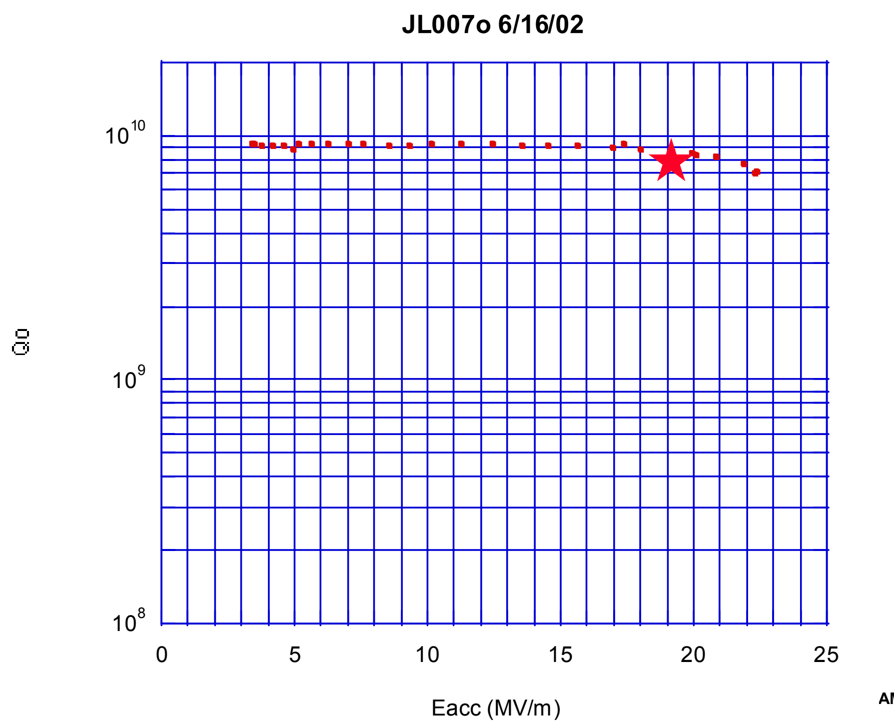


Performance of 7-cell electropolished cavity (red) exceeds design specs.



Conversion fro `C' to `H' configuration Eliminates saturation to 12 GeV

The First "New Style" Cryomodule (SL21) Was Just Under Test at the Time of the Facility Review



The new cryomodule meets its design goals

SL21 Is Now In CEBAF

- Our Experience With It Has Been Invaluable (see Warren Funk's talk)
- The Lessons Learned Will Improve the Final Upgrade Cryomodule Design and Smooth the Upgrade Commissioning

NSAC Facilities Subcommittee Conclusions

READINESS (Category 1) "Ready to initiate construction", with no significant scientific/engineering challenges to resolve prior to construction.

The Upgrade project is a proposal to double the maximum energy of the CEBAF accelerator at Jefferson Lab, to build a fourth experimental facility dedicated to the study of gluonic excitations, and to upgrade the existing experimental facilities. **The accelerator portion of the upgrade is straightforward**; CEBAF was designed with such an upgrade in mind. **The key issues** were increasing the performance of the superconducting RF cavities and cost-effectively increasing the bending power of the recirculation arcs; both **have been addressed successfully**. The major equipment in the new end station is a refurbished large superconducting solenoid previously used at LAMPF and SLAC. All aspects of the project, as well as a detailed budget, have been described in reports. **The scientific goals and proposed design of the Upgrade have been positively evaluated by internal and peer review committees,** including the 2001 Institutional Plan Review and the 2002 DOE S&T Review of JLab, which noted that "*It appeared that the 12 GeV upgrade project is technically ready to proceed.*" The 2002 LRP considered the project "*ready to initiate construction*". **All remaining R&D is focused on cost reduction and/or improved technical contingency; no R&D is needed to demonstrate feasibility.** ***The project is fully ready to initiate construction. A CD-0 package has been generated and is awaiting approval.***

There Has Also Been Progress in Planning for Science "Post-12 GeV"

- Further design work on an electron, light-ion collider
- Development of the basics of the science case

Both presented to NSAC at the 2/03 Facilities Subcommittee meeting

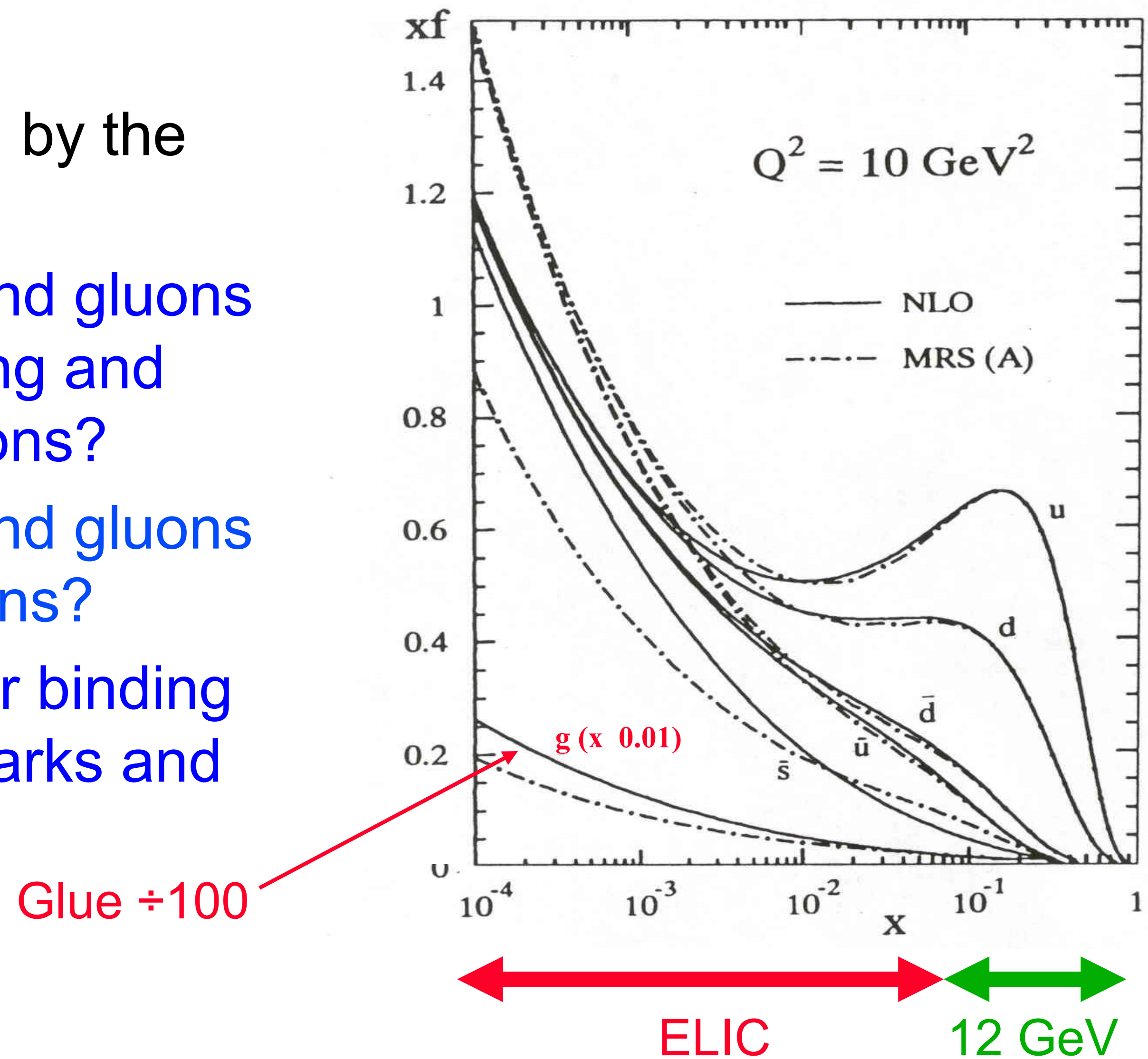
CEBAF Beyond 12 GeV

- There is a clear scientific case for the 12-GeV JLab Upgrade, addressing outstanding issues in Hadron Physics:
  - Unprecedented measurements to region in x (> 0.1) where basic three-quark structure of nucleons dominates.
  - Measurements of correlations between quarks, mainly through Deep-Virtual Compton Scattering (DVCS) and constraints by nucleon form factors, in pursuit of the Generalized Parton Distributions.
  - Finishing the job on the transition from hadronic to quark-gluon degrees of freedom.
- In Addition, over the next 5-10 years, data from facilities worldwide concurrent with vigorous accelerator R&D and design will clarify the key physics and machine issues, revealing the relative advantages and technical feasibility of alternate “next generation” accelerator designs and permitting an informed choice for the next facility:
  - A 25 GeV Fixed-Target Facility? Or
  - An Electron-Light Ion Collider, center-of-mass energy of 20-65 GeV?

CEBAF II/ELIC Upgrade - Science

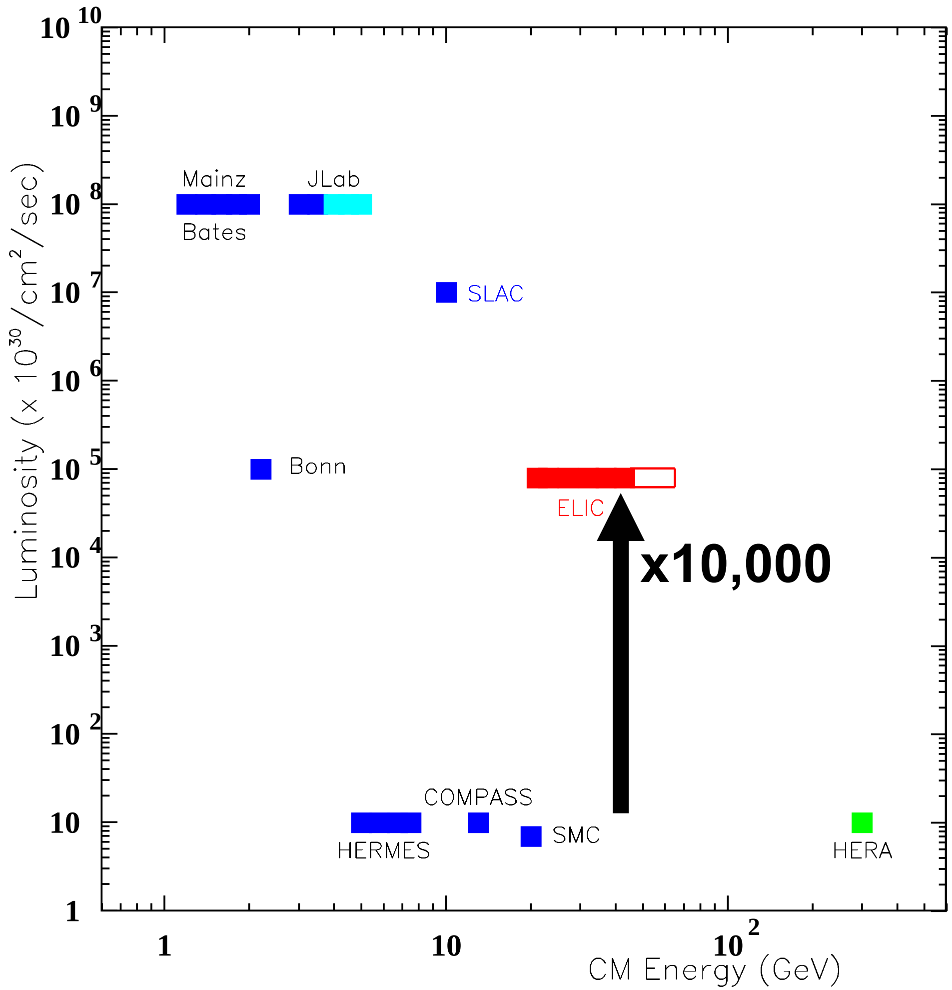
Science addressed by the second Upgrade:

- How do quarks and gluons provide the binding and spin of the nucleons?
- How do quarks and gluons evolve into hadrons?
- How does nuclear binding originate from quarks and gluons?



Luminosity Potential with ELIC

Parameter	Units	Design	
		e^-	Ions
Energy	GeV	5	50/100
Electron Cooling	-	-	Yes
Circulator Ring	-	Yes	-
Luminosity	cm^{-2} sec^{-1}	$6x10^{34}$ / $1x10^{35}$	
I_{ave}	A	2.5	2.5
f_c	MHz	1500	



NSAC Facilities Subcommittee Conclusions

- **SCIENCE (Category 1 – Absolutely Central)** The research program of this type of facility at JLab, similar in many ways to the electron-ion collider EIC that received a preliminary endorsement in LRP 2002, will be absolutely central to nuclear physics

- **READINESS (Category 3 - mission and/or technical requirements not yet fully defined)** This project is still in an early stage of development. A number of technical challenges must be resolved, and several R&D projects have been started. These include development of a polarized electron source with a high average current and high bunch charge, electron cooling of protons/ions, and energy recovery at high current and high energy. The design of an interaction region and detector that support the combination of high luminosity and high detector acceptance and resolution is also underway. Construction would not begin until after the completion of the 12 GeV upgrade of CEBAF; the final design will be influenced by evolving physics

Summary and Perspectives

- CEBAF research is producing outstanding science, modest incremental investments will make it even better!
- The 12 GeV Upgrade, a formal recommendation of the NSAC Long Range Plan, is *essential* to address identified key questions and maintain our world leadership in hadronic physics
- The Upgrade project was judged of the highest scientific importance and "ready for construction"

  OUR KEY PROBLEM IS GETTING IT STARTED

  CD-0 in FY03 and R&D $$$ in FY05
- ELIC and 25 GeV fixed target opportunities were judged "central to the science" but there are "mission and/or technical requirements to be defined". Developing these ideas (both the science and the machine) over the next 5 years will be important

There has been Extensive Community Review for and Support of the 12 GeV Upgrade

- From the entire community, as represented by NSAC and the Long Range Planning Process:
  - NSAC "Barnes Panel" (4/82)
  - NSAC "Bromley Panel" (4/83)
  - NSAC 1996 Long Range Plan

  Foresaw the need for higher energies in the planning for the initial facility

  - NSAC Intermediate Energy Review (9/98)
  - **NSAC 2002 Long Range Plan**
  - **NSAC Facilities Review (**/**)**

  Supported, then recommended the energy upgrade

The Energy Upgrade was a Formal Construction Recommendation of the 2002 Long Range Plan

NSAC 2002 Long Range Plan:

> **"We *strongly recommend* the upgrade of CEBAF at Jefferson Laboratory to 12 GeV as soon as possible."**
>
> "The 12 GeV upgrade of the unique CEBAF facility is critical for our continued leadership in the experimental study of hadronic matter. This upgrade will provide new insights into the structure of the nucleon, the transition between the hadronic and quark/gluon description of matter, and the nature of quark confinement."

- **This is the only major construction initiative that is feasible within a constant effort budget:**
  "We should emphasize that smaller initiatives – even medium size initiatives such as the Jefferson Lab Upgrade – should be accommodated within a constant effort budget"

The Charge for the PAC23 Review of the pCDR In Progress

- **Comment on the intellectual framework presented for the 12 GeV pCDR.**

  Is this the best way to present the science case to DOE and to the larger nuclear physics community? Are there flaws or omissions in the framework?

- **Review the new research programs that are under consideration for being highlighted in the executive summary of the pCDR**

  Do they represent compelling science that must be done to advance our understanding of nuclear physics? At what level should they be included in the executive summary?

- **Have we omitted any key science initiatives that could be supported by a 12 GeV electron beam?**

- **Is the experimental equipment proposed well matched to the key physics experiments motivating the upgrade?**

  In cases where an experiment or program is proposed for more than one set of equipment, are the differences in capability and physics reach of the equipment essential for getting all of the physics, important for getting as much physics as possible, or simply useful in that, for example, an experiment could be done somewhat faster with one hall equipment compared to another?

Presentations by Editorial Board Members

- **Executive Summary**

  Larry Cardman and Frank Close

- **The Science Motivating the 12 GeV Upgrade**
  - **Confinement**

    Curtis Meyer, Alex Dzierba, Ted Barnes, and David Richards

  - **Hadron Structure**

    Valence Quark Structure and Parton Distributions

    Zein-Eddine Meziani, Sebastian Kuhn, Oscar Rondon, Wally Melnitchouk

    The GPDs as Accessed via Deep(ly) Exclusive Reactions

    Volker Burkert, Charles Hyde-Wright, Xiangdong Ji

    Form Factors and Polarizabilities – Constraints on the GPDs

    Paul Stoler, Mark Jones, Bogdan Wojtsekhowski, Anatoly Radyushkin

    Other Topics in Hadron Structure

    Gordon Cates, Latifa Elouadrhiri, Thia Keppel, Sabine Jeschonnek

Presentations by Editorial Board Members (cont.)

- **The Science Motivating the 12 GeV Upgrade (cont.)**
  - **Nuclear Structure**

    The Parton-Hadron Transition in Nuclear Physics

    Haiyan Gao, Roy Holt, Carl Carlson

    Hadrons in the Nuclear Medium

    John Arrington, Doug Higinbotham, Jean-Marc Laget, Will Brooks

    Probing the Limits of the Nucleon-Based Description of Nuclei

    Rocco Schiavilla, Larry Weinstein, Paul Ulmer

  - **Additional Topics that Will be Addressed by the 12 GeV Upgrade**

    Standard Model Tests

    Paul Reimer, Mike Ramsey-Musolf, Paul Souder, and Dave Mack

    Other Topics in Meson Spectroscopy

    Curtis Meyer, Alex Dzierba, Carlos Salgado, Ted Barnes and David Richards

    Spontaneous Symmetry Breaking

    Aron Bernstein, Ashot Gasparian, Jose Goity

    Space-time Characteristics of Nuclear Hadronization

    Will Brooks

Presentations by the Editorial Board and Others

- The Experimental Equipment (hardware and capabilities):
  - Hall A: *J.-P. Chen, Kees de Jager*
  - Hall B: *Volker Burkert*
  - Hall C: *Howard Fenker* *(Rolf Ent)*
  - Hall D: *Curtis Meyer and Alex Dzierba* *(Elton Smith)*
  - Other Equipment for Specialized Experiments: *Ashot Gasparian and Paul Reimer*

pCDR Posted on JLab Web for Comments from the Entire JLab Community

- Comments will be welcome until July 4 when we'll "close the books"
- Please send your remarks (ideally with proposed "fixes") to the head of the writing group responsible for the material with a copy to me
- Suggested changes will be reviewed by the subgroup and added with their approval and/or recommended modifications
- You can appeal to the larger editorial board (through me) if you are unhappy with the result
- The finished pCDR will be the basis for the next round of discussion on the experimental equipment (hopefully in the context of a real budget!)

Summary and Perspectives

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- The 12 GeV Upgrade, a formal recommendation of the NSAC Long Range Plan, is *essential* to address identified key questions and maintain our world leadership in hadronic physics
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Upgrade Readiness Reviews

- 12 GeV Design is a straightforward extension of the present accelerator and experimental equipment
- There have been no formal technical reviews yet (they are not allowed before CD-0!), but…
- Technical aspects of the Upgrade have been considered by:
  - **the 2002 DOE S&T Review**: ``It appeared that the 12 GeV upgrade project is technically ready to proceed."
  - **NSAC (2002) LRP**: considered the project ``ready to initiate construction" two years ago; in its funding scenarios it noted that ``The Jefferson Lab Upgrade is included as a construction project starting in fiscal year 2005, leading into a modest increase for Jefferson Lab operations later in the decade."
  - **2001 Institutional Plan review concluded**: ``The Laboratory also made a compelling argument that there are no major technological risks inherent in the upgrade, and that the Laboratory could complete the upgrade without compromising the current science program."
  - **NSAC Facilities Review (2003) concluded: (The Upgrade is clearly**get quote**) Ready to initiate construction"**

There Has Been Major Progress Refining the 12 GeV Upgrade Science and Plans CD-0 Is Needed Soon!!!

Since the NSAC LRP:

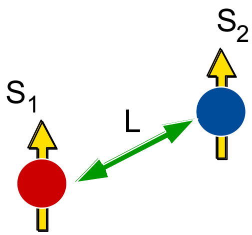
- Two-year effort to refine equipment designs and expand science program
- Individual, Hall-specific pCDRs written summarizing science and equipment needs
- Second PAC review of science and equipment (1/03)
- Defended before NSAC Facilities Subcommittee (2/03)
  - Science absolutely central
  - Ready for Construction
- pCDR summarizing all science and experimental equipment now in editorial review by the community

CD-0 is the next essential step:

- Work on the CDR can begin in earnest as soon as we have CD-0 authorization to carry out the remaining needed R&D
- It will permit serious exploration of non-DOE/NP funding sources

Photons are the Preferred Beam for Producing Flux Tube Excitiations

Normal mesons: $J^{PC} = 0^{-+} \quad 1^{+-} \quad 2^{-+}$



$S = S_1 + S_2$

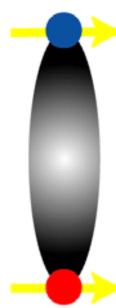
$J = L + S$

$P = (-1)^{L+1}$

$C = (-1)^{L+S}$

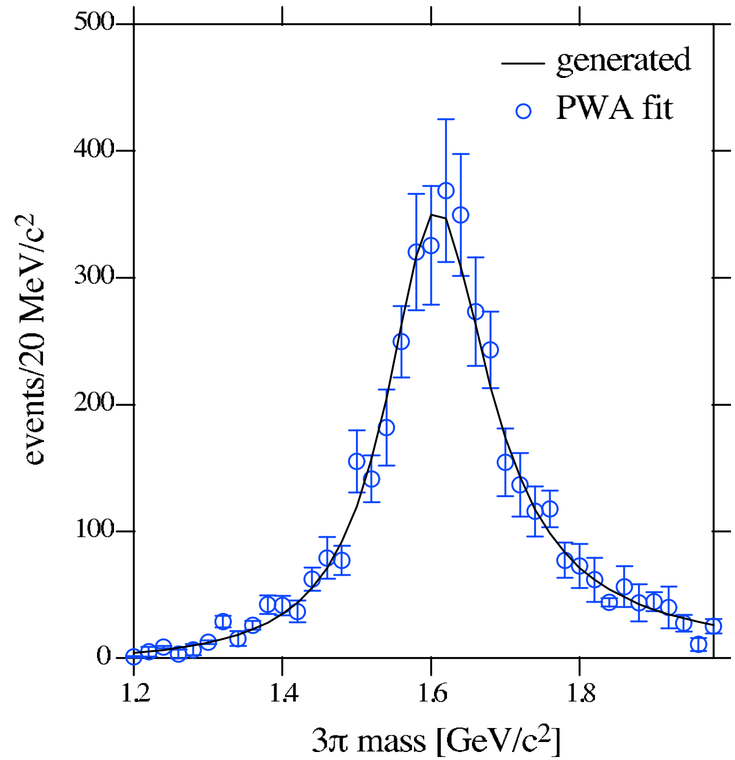
First excited state of flux tube has J=1
combined with S=1 for quarks

$J^{PC} = 0^{-+} \quad 0^{+-} \quad 1^{+-} \quad 1^{-+} \quad 2^{-+} \quad 2^{+-}$



exotic
(mass ~ 1.7 – 2.3 GeV)

Photons couple to exotic mesons via $\gamma \rightarrow$ VM transition (same spin configuration)

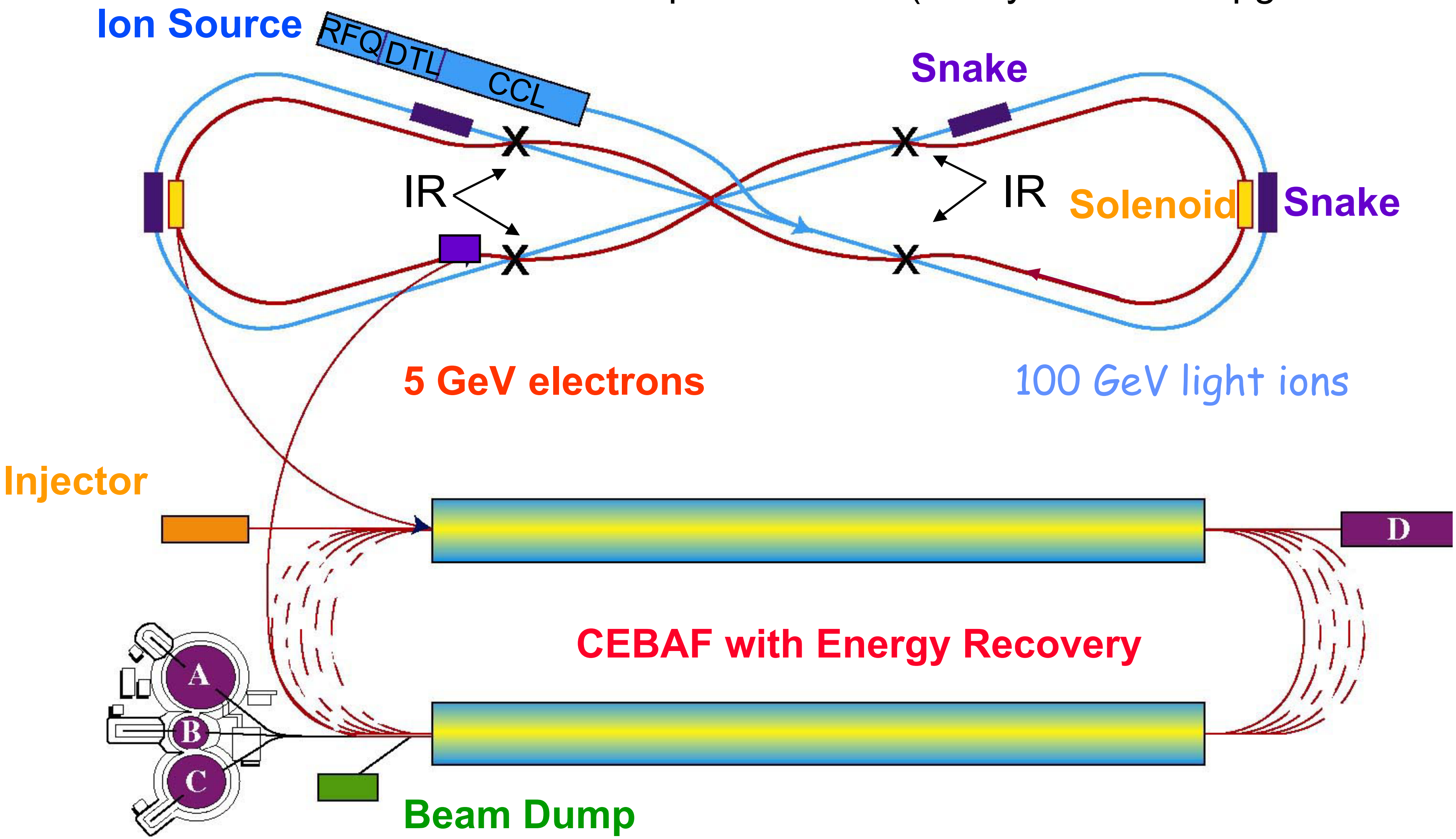


Double-blind Monte Carlo Simulation:

2½% exotic signal clearly visible

ELIC Layout

One accelerating & one decelerating pass through a 5 GeV pass CEBAF (all cryomodules upgrade-class)

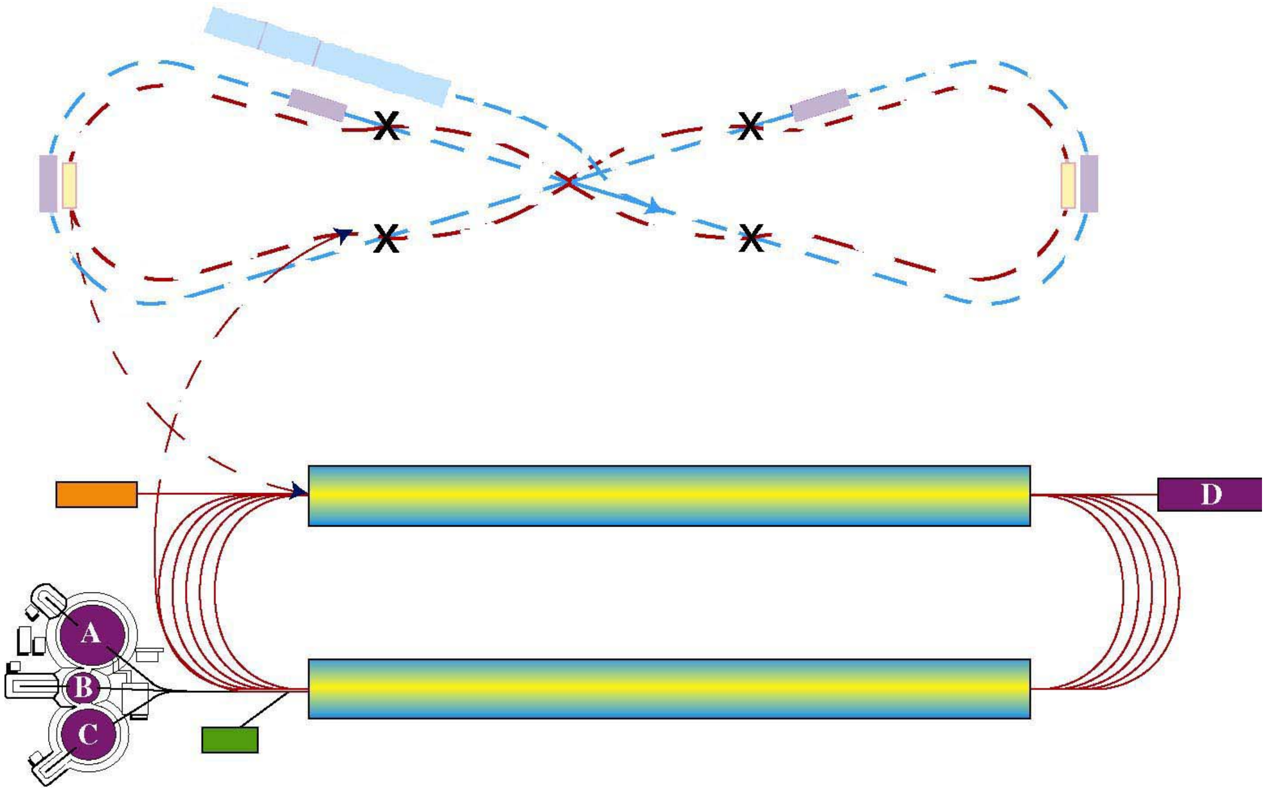


The same electron accelerator can also provide 25 GeV electrons for fixed target experiments

- Implement 5-pass recirculator, at 5 GeV/pass, as in present CEBAF

  (straightforward upgrade, no accelerator R&D needed)

- Exploring whether collider and fixed target modes can run simultaneously (can certainly run in alternating-use mode)



CEBAF II/ELIC Upgrade – Design Issues

Electron-Light Ion Collider (ELIC)

- R&D needed on
  - High Charge per Bunch and High Average Current Polarized Electron Source
  - High Energy Electron Cooling of Protons/Ions
  - High Current and High Energy demonstration of Energy Recovery
  - Integration of Interaction Region design with Detector Geometry
- NSAC Report: “Strong consensus among nuclear scientists to pursue R&D over the next three years to address a number of design issues”

25-GeV Fixed-Target Facility Straightforward

- Use existing CEBAF footprint
- Upgrade ALL Cryo modules to 12-GeV design (7-cell design, 18 MV/m)
- Change ARC magnets, Switchyard, Hall Equipment

R&D Strategy

- Several important R&D topics have been identified
- Our R&D strategy is multi-pronged:
  - Conceptual development
    - "Circulator Ring" concept promises to ease high current polarized photoinjector and ERL requirements significantly
    - Additional concepts for luminosity improvements are being explored
  - Analysis/Simulations
    - Electron cooling and short bunches
    - Beam-beam physics
    - ERL physics
  - Experiments
    - CEBAF-ER: The Energy Recovery experiment at CEBAF to address ERL issues in large scale systems (First run: March 2003)
    - JLab FEL (10mA), Cornell/JLab ERL Prototype (100mA), BNL Cooling Prototype (100mA) to address high current ERL issues