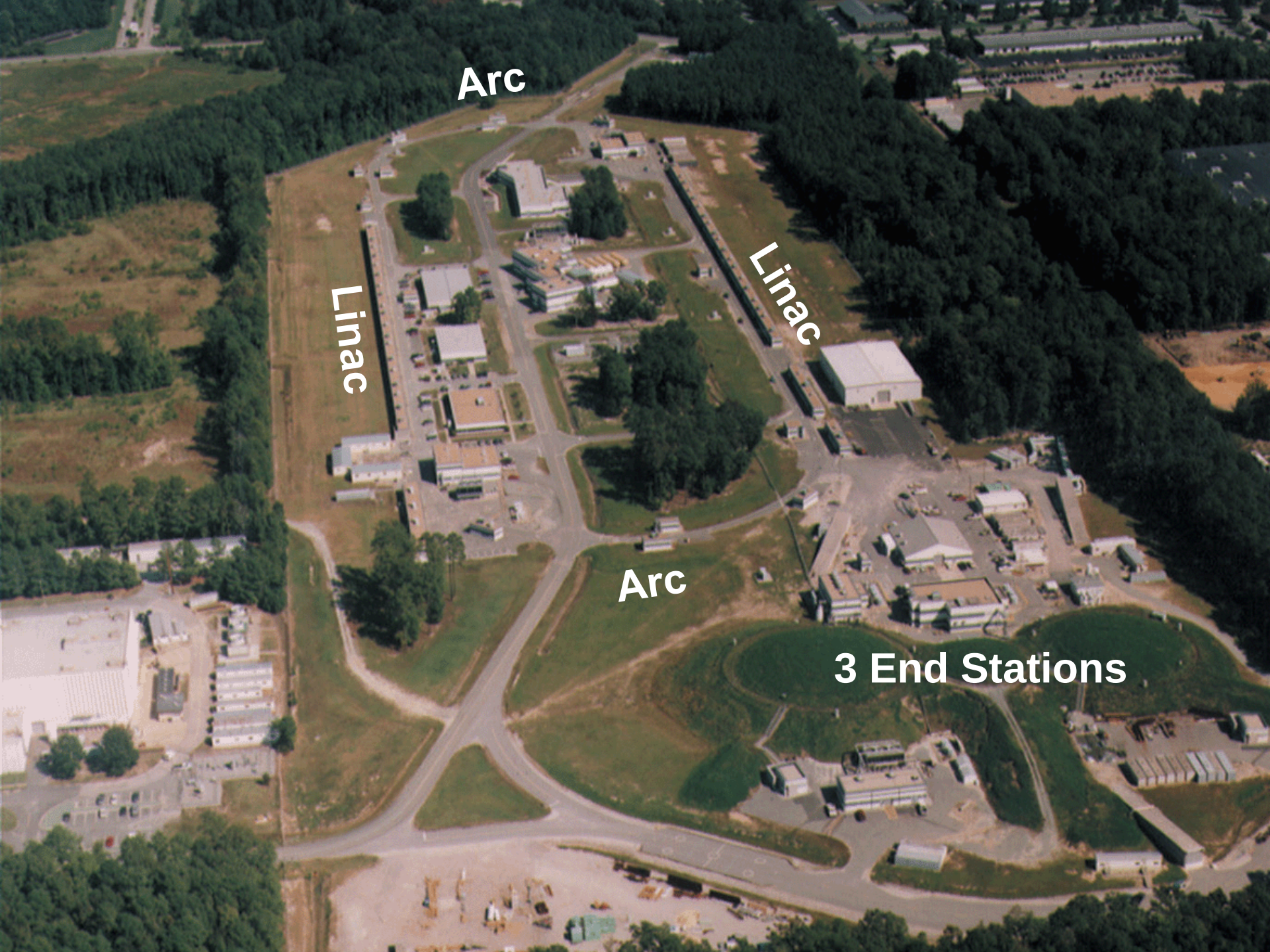
JLab@12 GeV

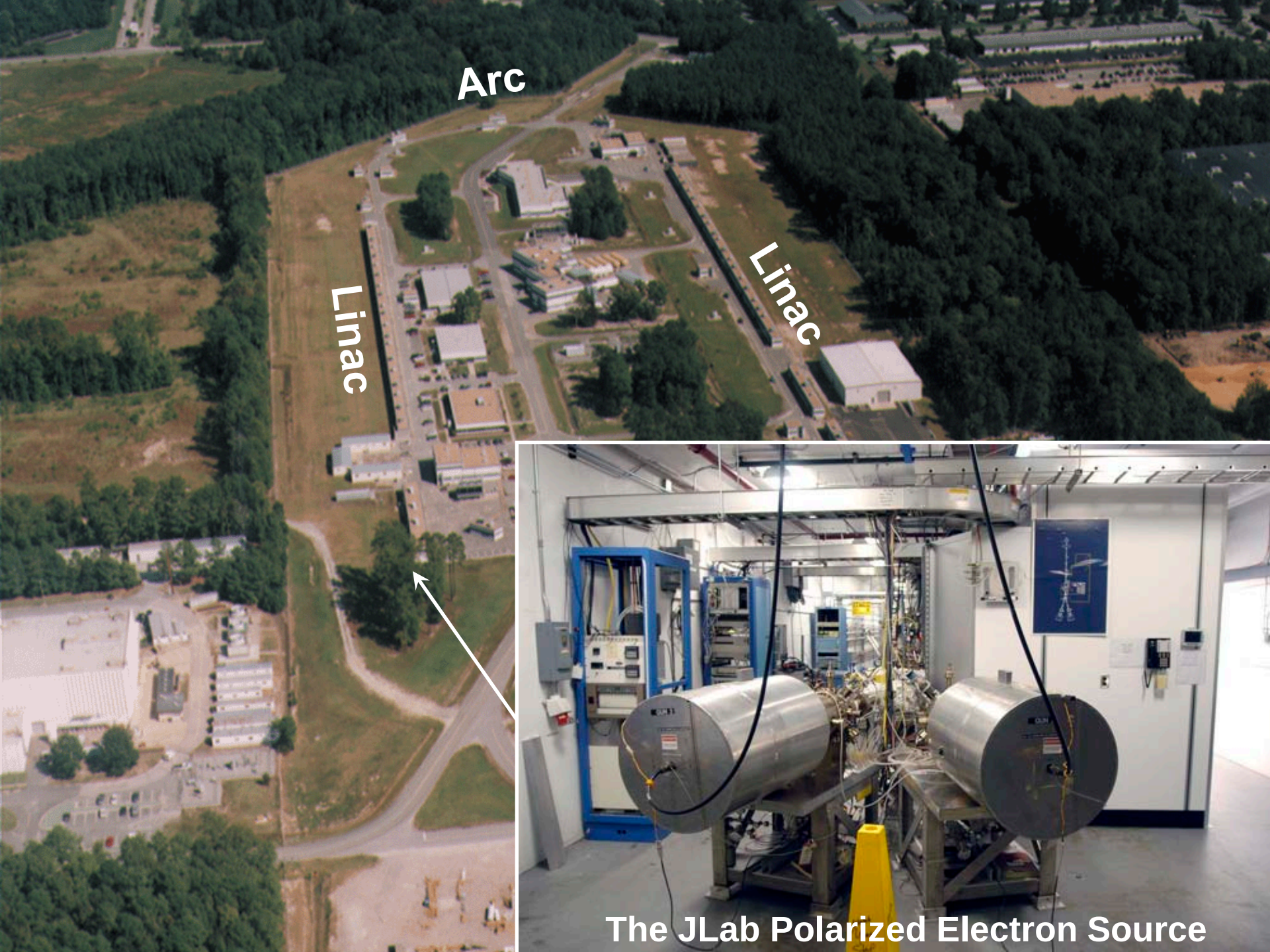
L. Cardman

Jefferson Lab and University of Virginia

EINN 2009

Μήλος, Ελλάδα


Arc
Linac
Linac
Arc
3 End Stations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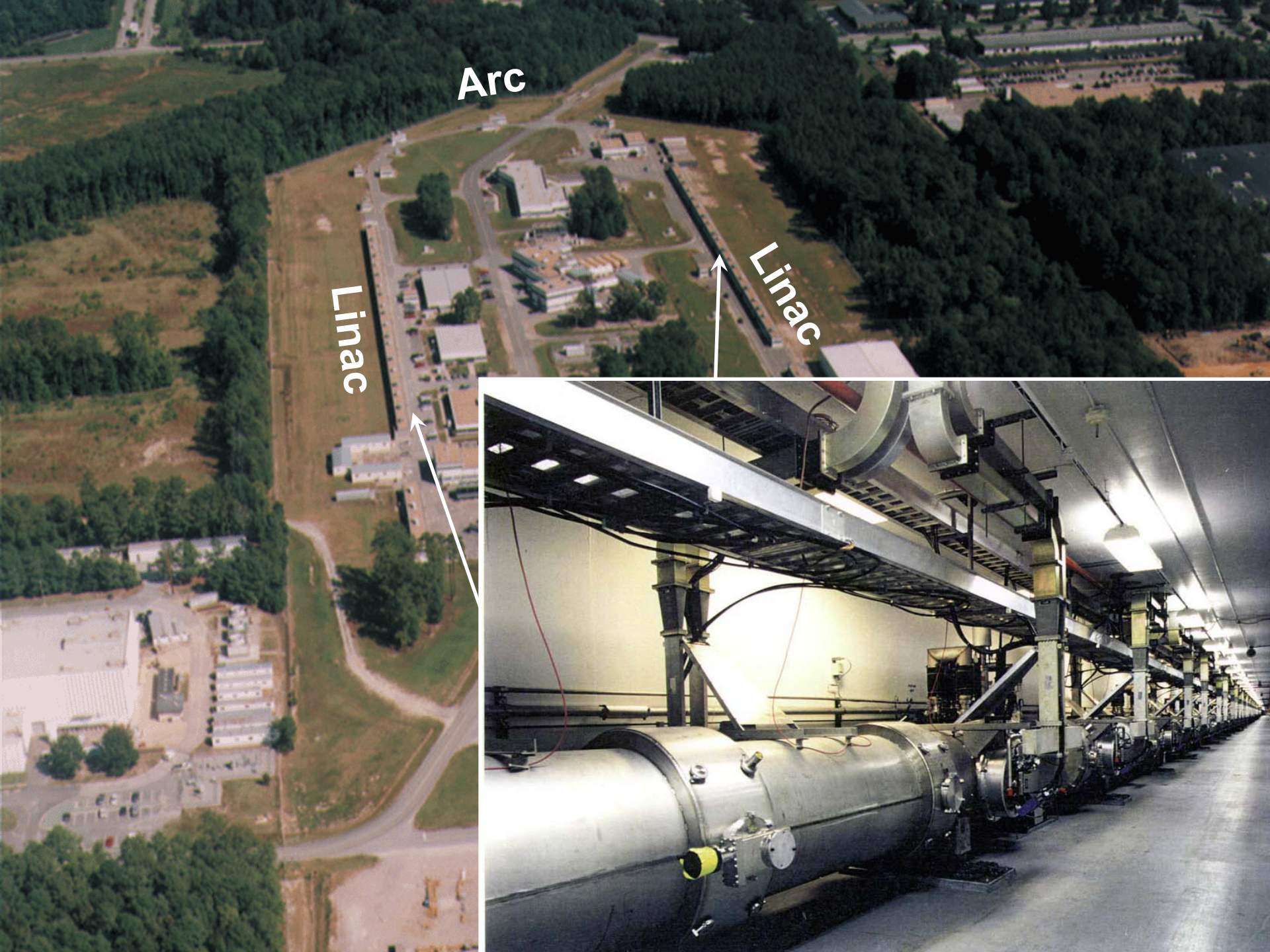
The JLab Polarized Electron Source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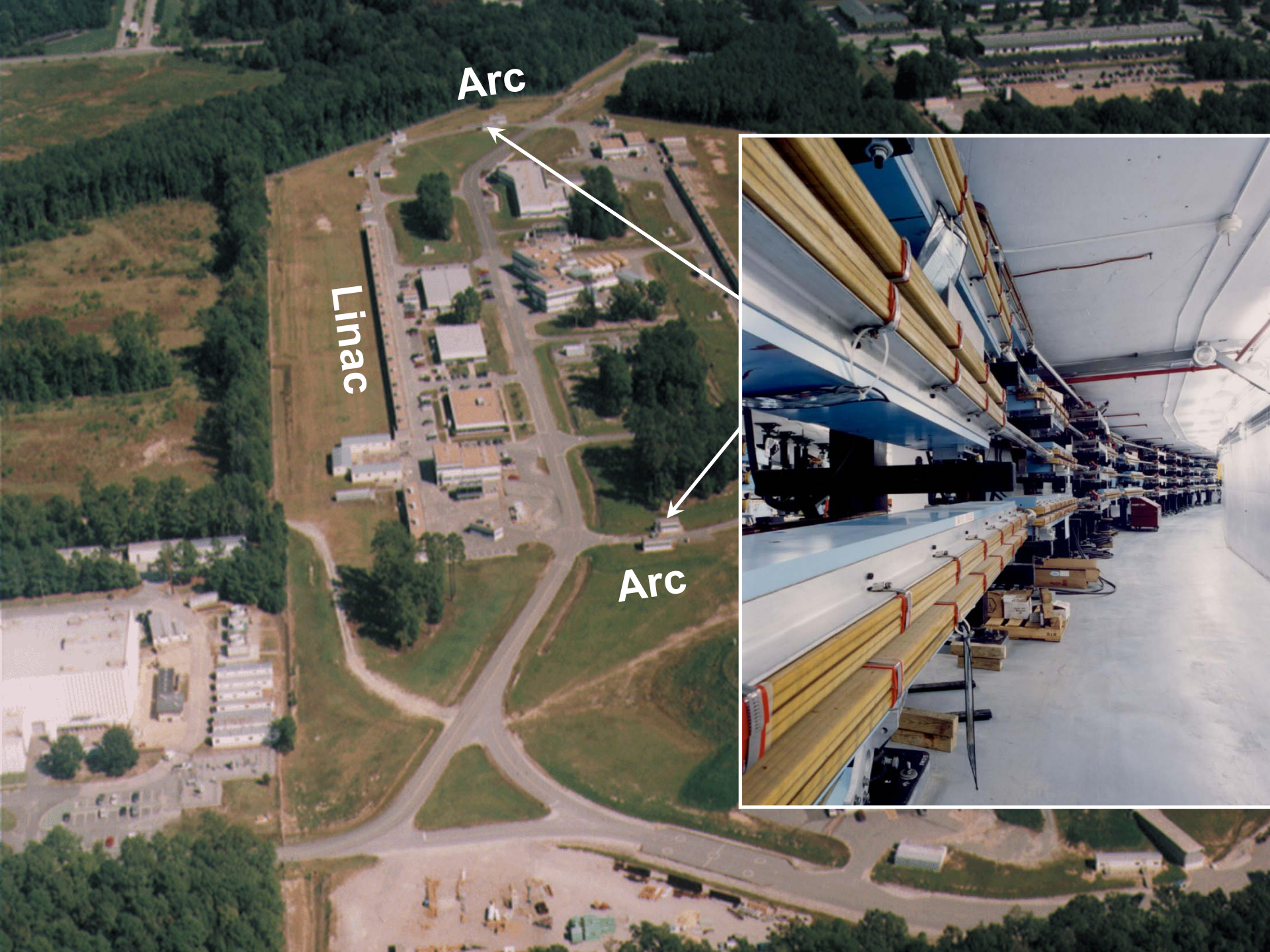
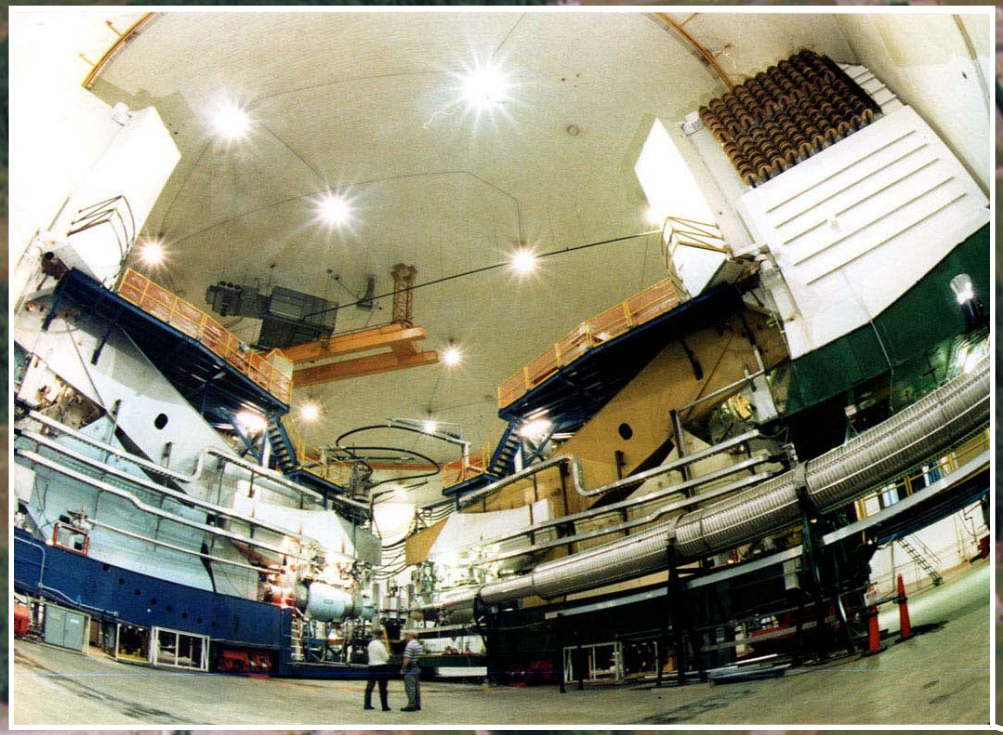
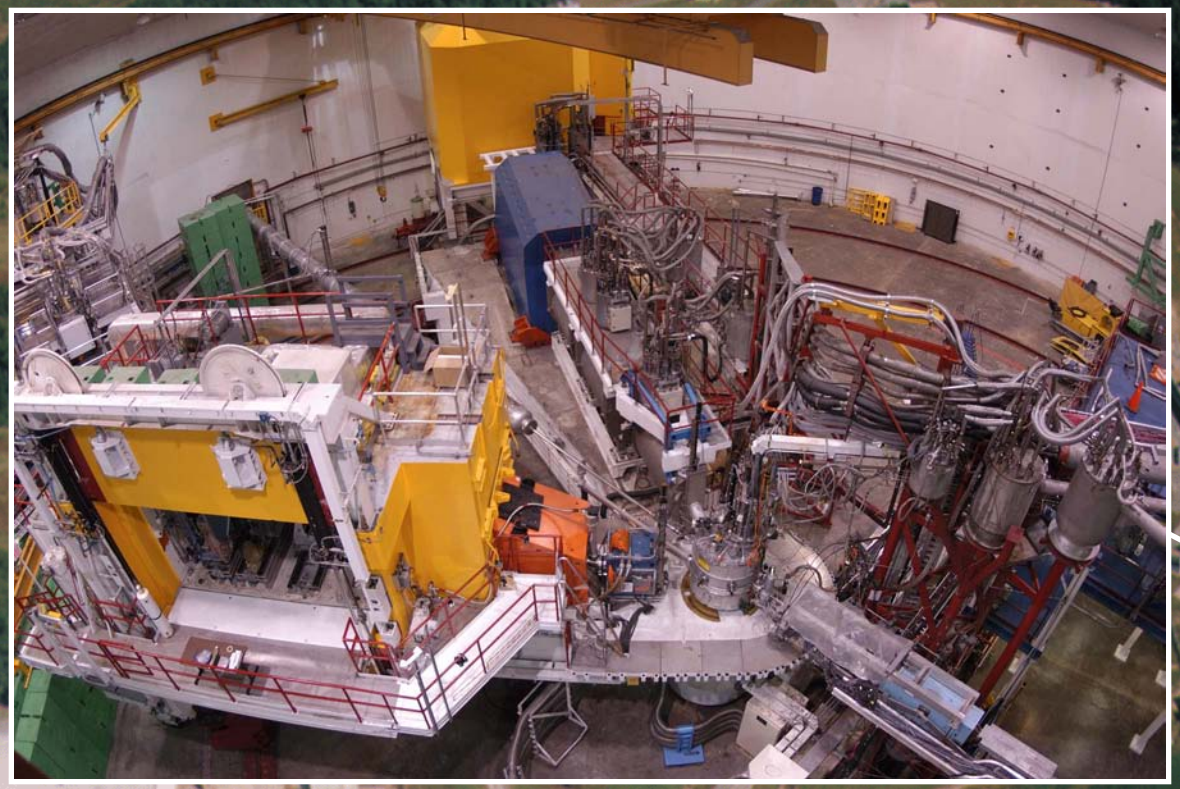

Arc
Linac
Arc

Hall A: Two High Resolution (10^{-4}) Spectrometers

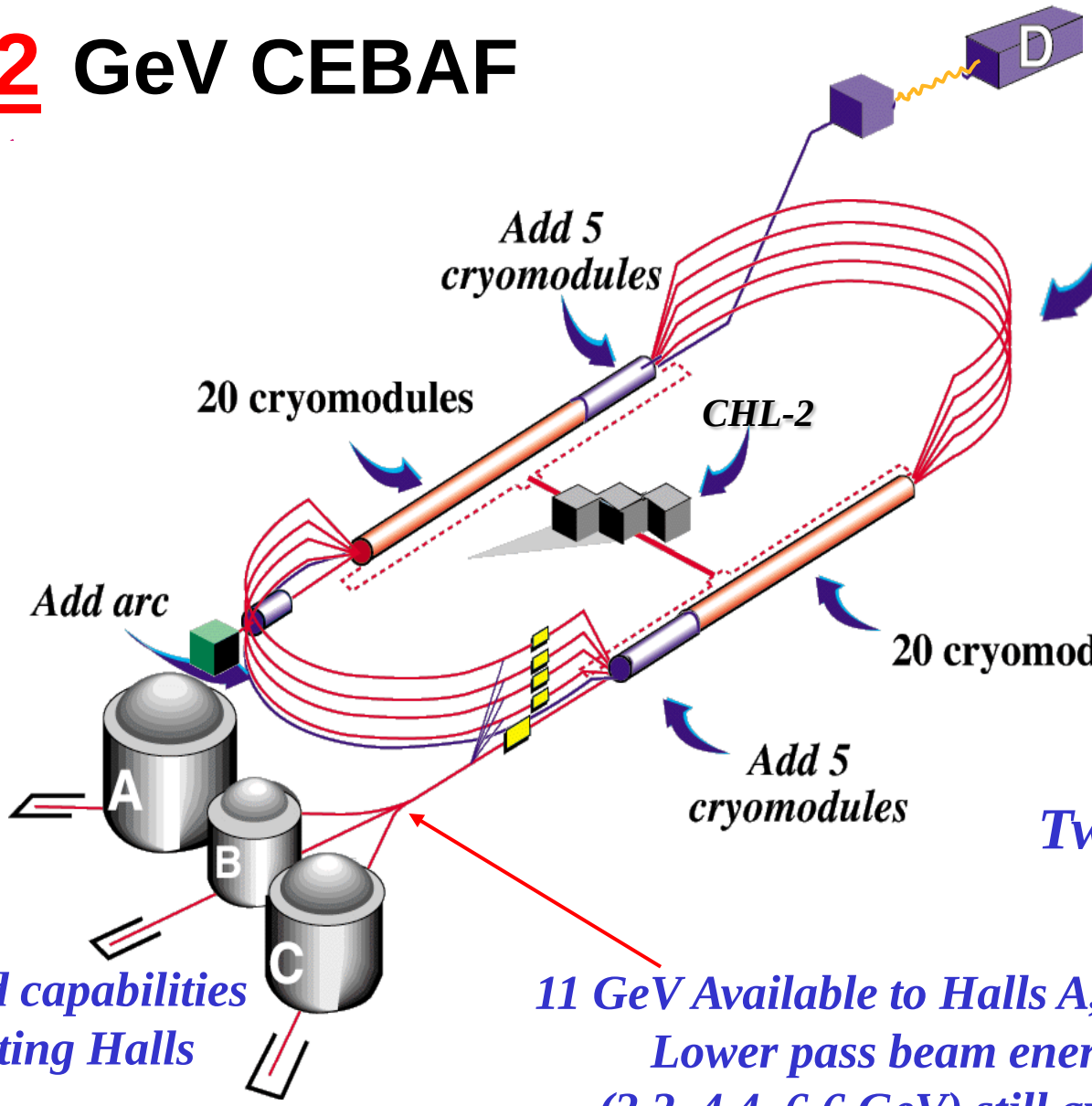


Hall B: The CEBAF Large Acceptance Spectrometer (CLAS)

Hall C: A High Momentum and a Broad Range Spectrometer Setup Space for Unique Experiments

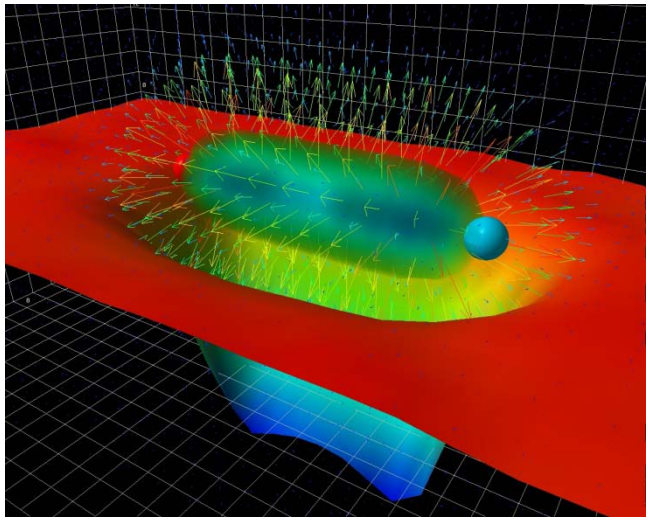


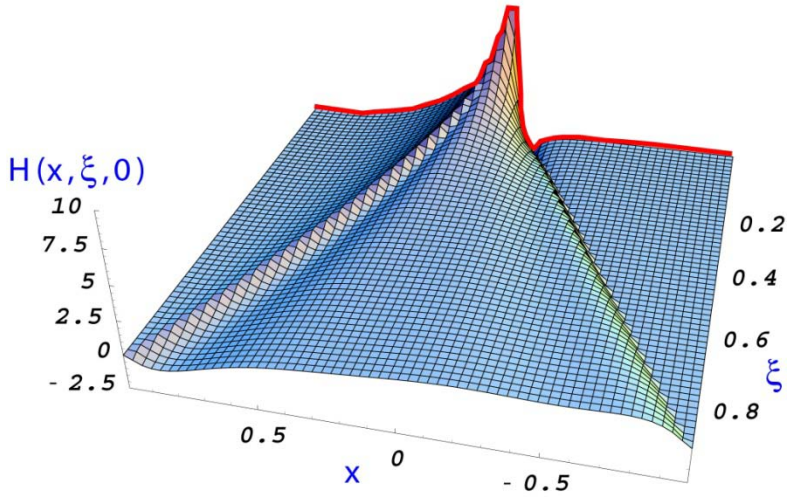
12 GeV CEBAF


D
12 GeV to Hall D
Upgrade magnets and power supplies
Add 5 cryomodules
20 cryomodules
CHL-2
Add arc
20 cryomodules
Add 5 cryomodules
A
B
C
Two 1.1 GeV linacs
Enhanced capabilities in existing Halls
11 GeV Available to Halls A, B, and C
Lower pass beam energies
(2.2, 4.4, 6.6 GeV) still available

The Science Motivating the 12 GeV Upgrade

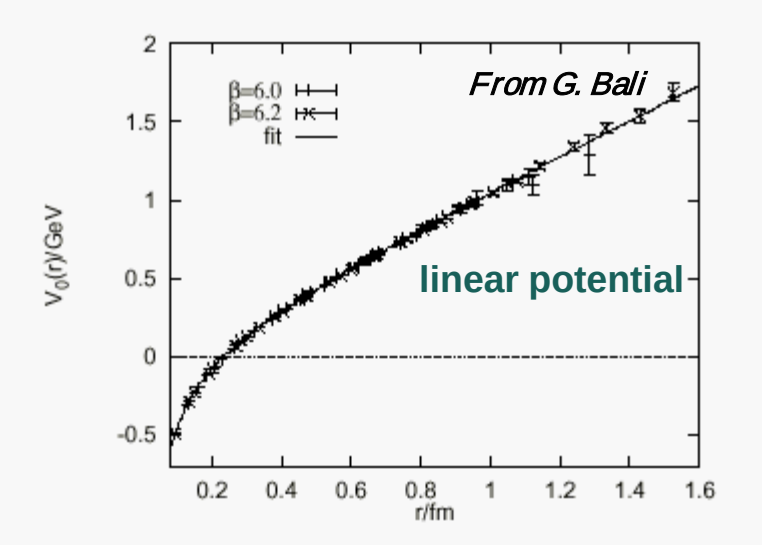
- **The experimental study of the confinement of quarks – one of the outstanding questions of the 21st century physics (Hybrid Meson Program)**
- **Dramatic improvements in our knowledge of the fundamental quark-gluon structure of the nuclear building blocks (GPDs and Valence PDFs)**
- **Further exploration of the limits of our understanding of nuclei in terms of nucleons and the *N-N* force**
- **Precision experiments with sensitivity to TeV scale physics beyond the Standard Model**
- **And other science we can't foresee**

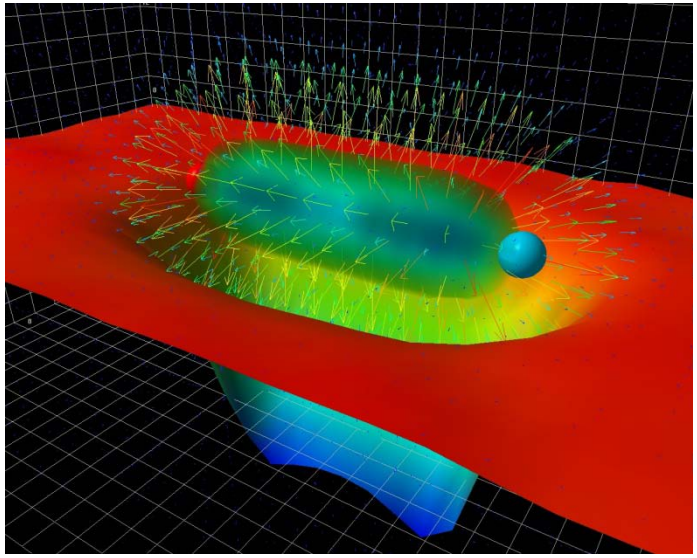




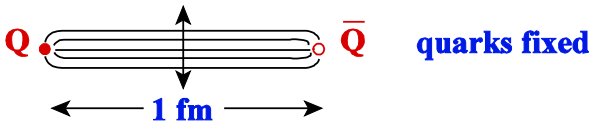
Gluonic Excitations and the Origin of Confinement

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)

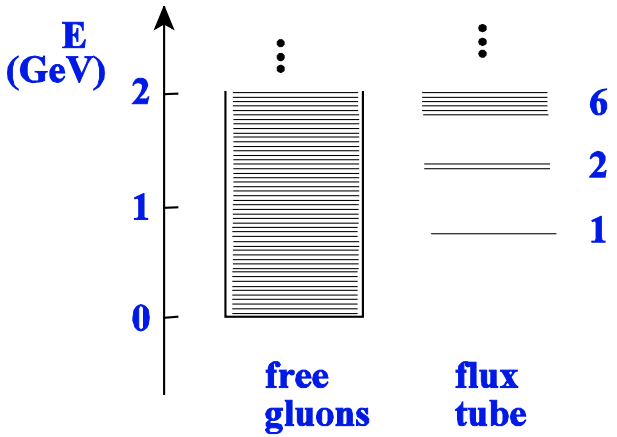




Experimentally, we want to "pluck" the flux tube (wiggle the hot dog?) and see how it responds

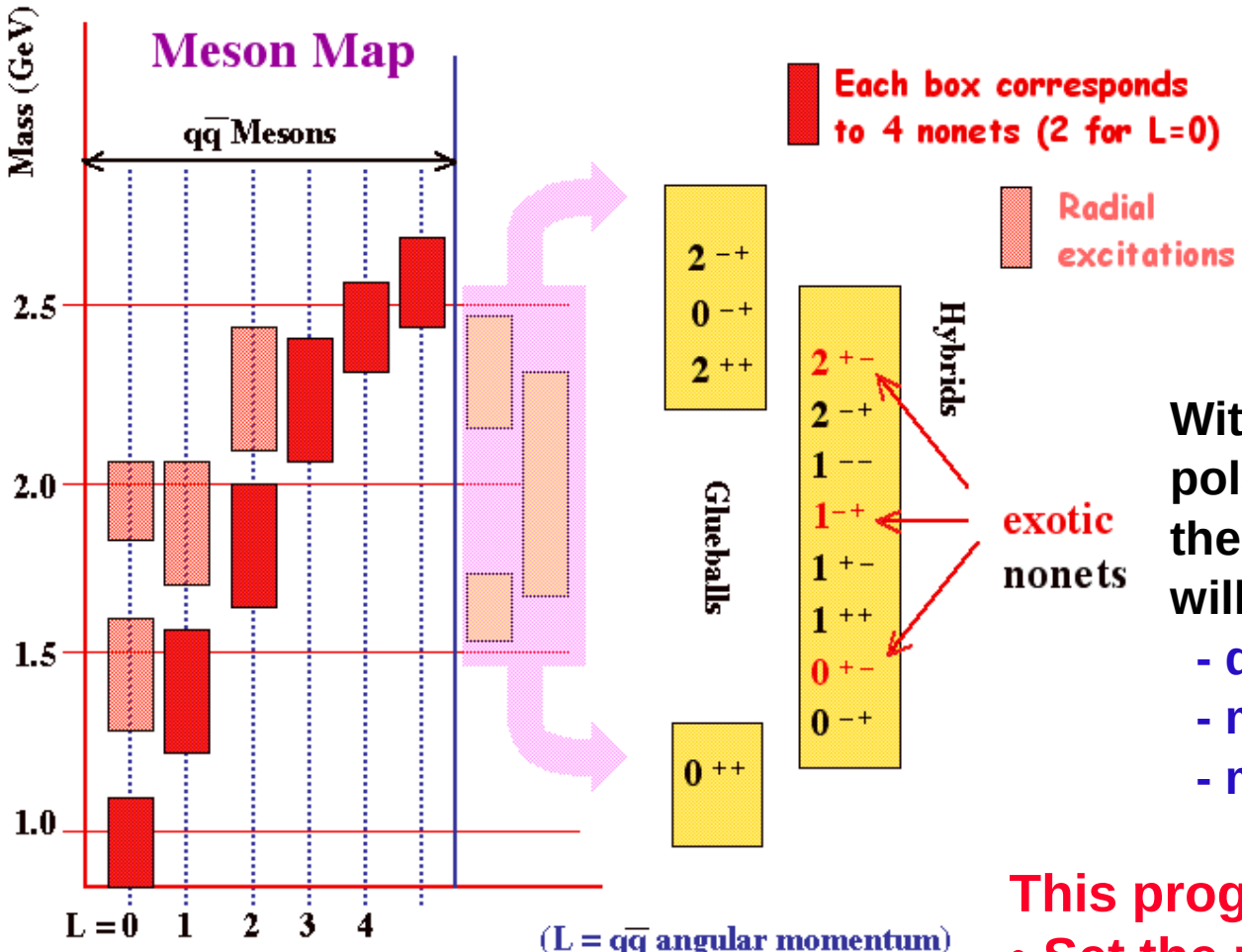


quarks fixed



Glueballs and Hybrid Mesons

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.



Colin Morningstar:
Gluonic Excitations workshop, 2003 (Jlab)

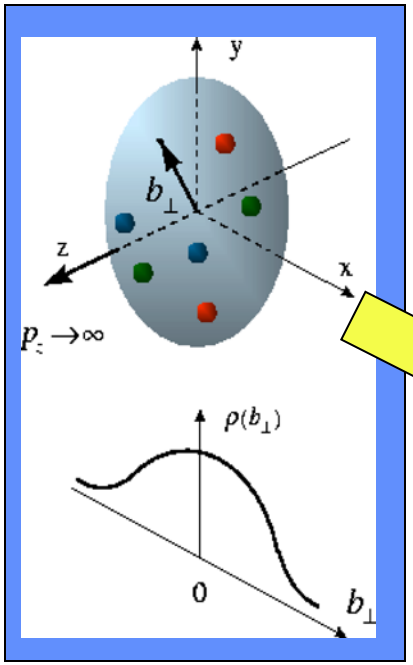
With 12 GeV, a linearly polarized photon beam, and the GlueX detector, Jlab will be uniquely poised to:

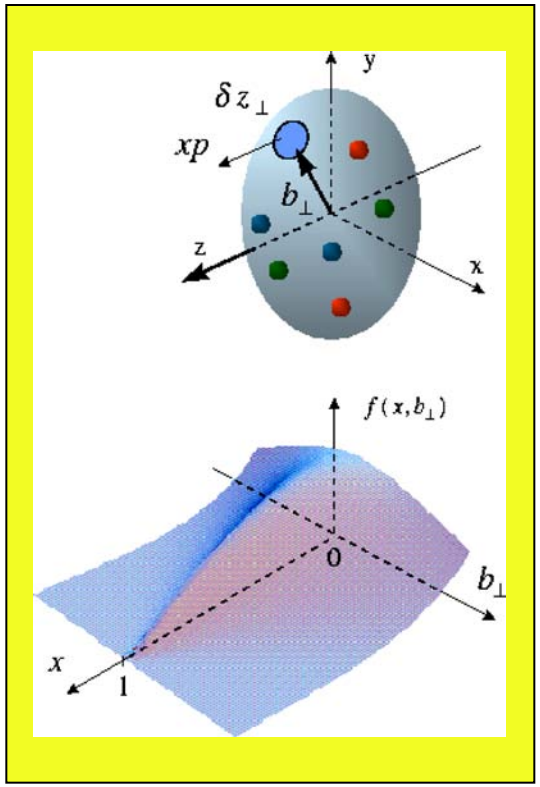
- **discover these states,**
- **map out their spectra, and**
- **measure their properties**

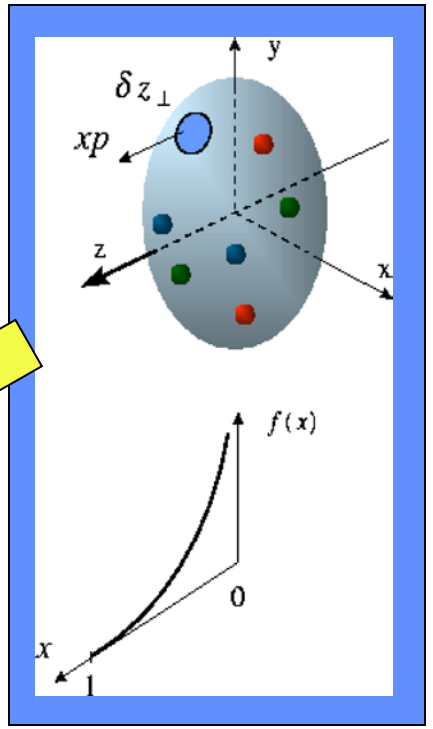
This program:

- **Set the maximum beam energy**
- **Drove the need for a 4th Hall**

Understanding Nucleon Structure: Form Factors PDFs, and Generalized Parton Distributions (GPDs)





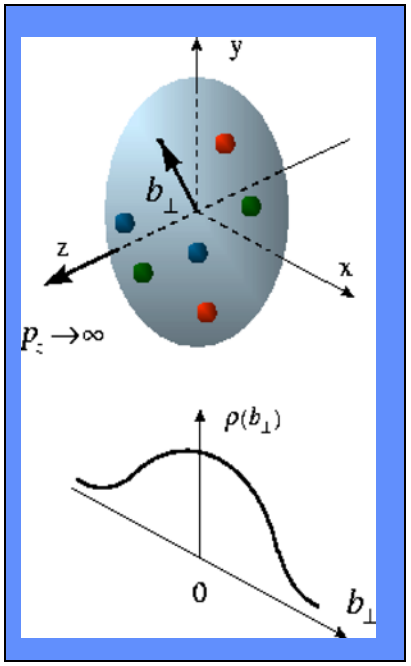


Elastic Scattering & Form Factors:
Transverse charge & current densities in coordinate space

DES & GPDs:
Correlated quark distributions In transverse coordinate and longitudinal momentum space

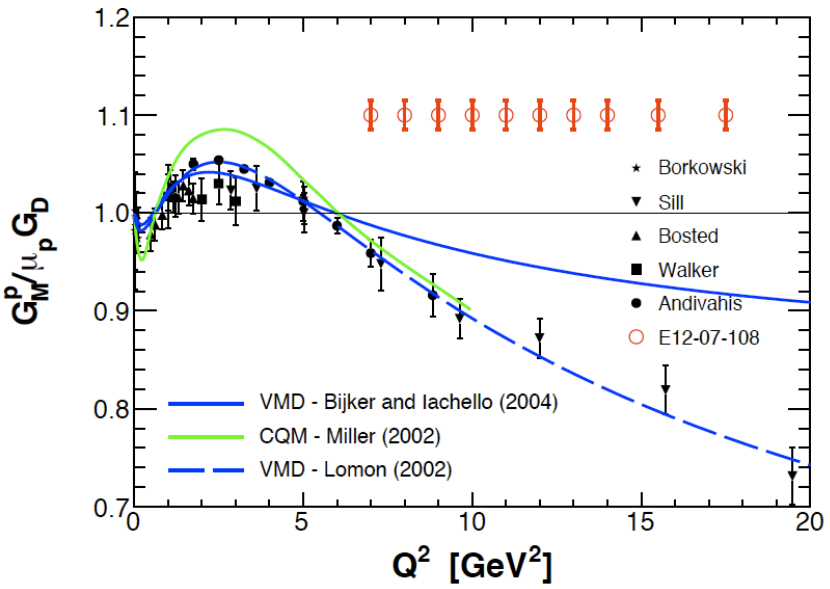
DIS & Structure Functions:
Quark longitudinal & helicity distributions in momentum space

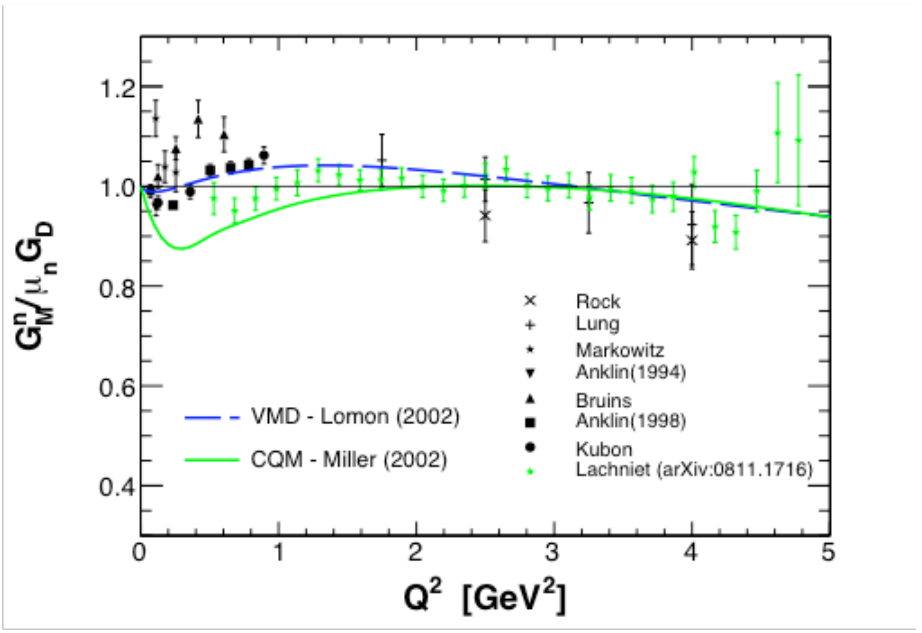
Understanding Nucleon Structure: Form Factors PDFs, and Generalized Parton Distributions (GPDs)

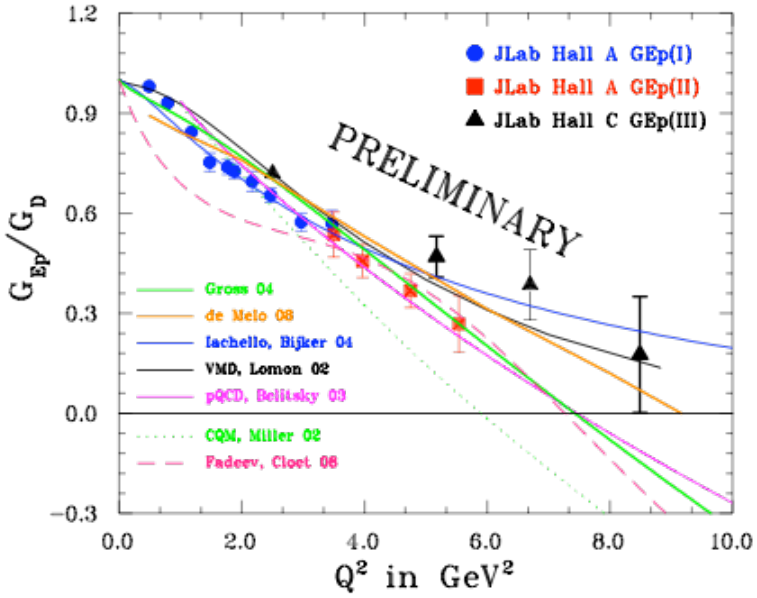


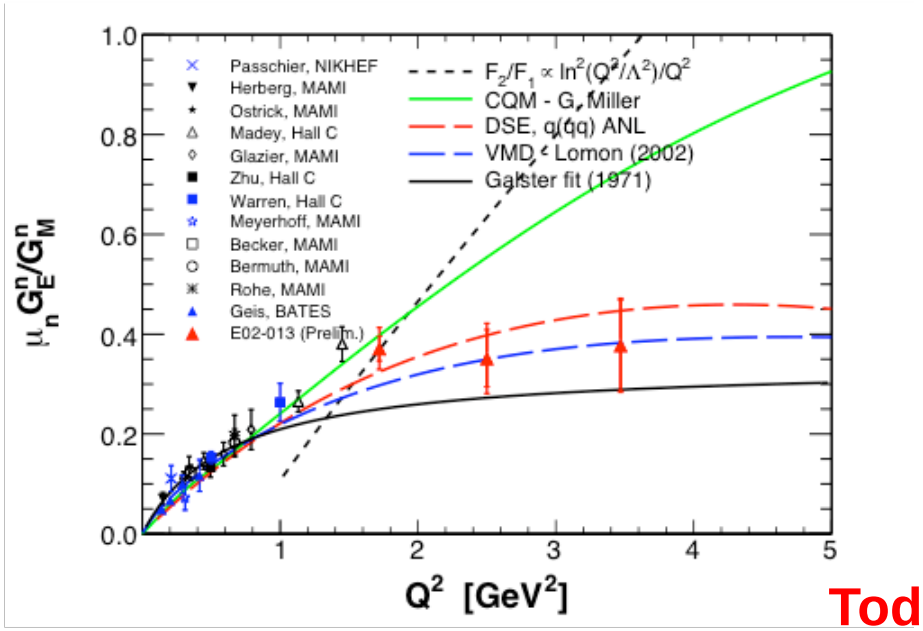
Elastic Scattering & Form Factors:
Transverse charge & current densities in coordinate space

Form Factors – Constraints on the GPDs



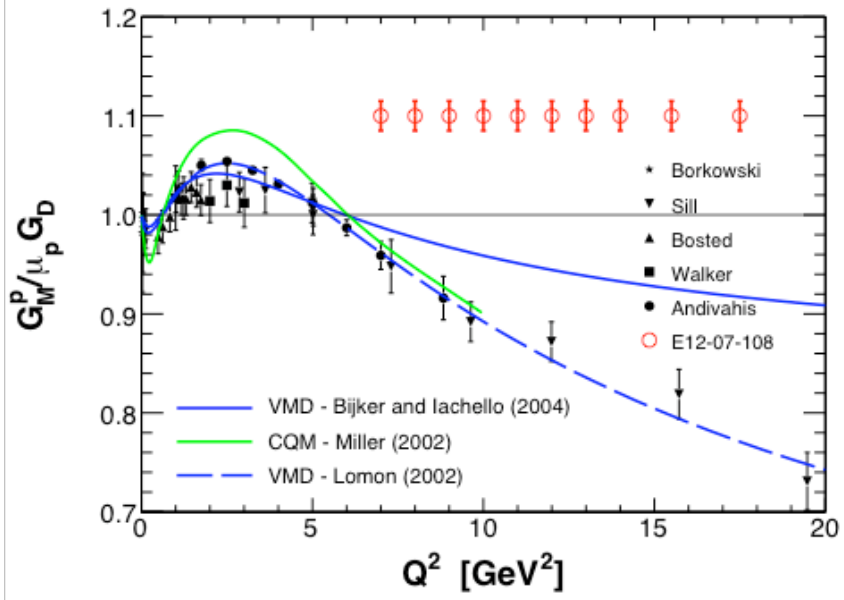


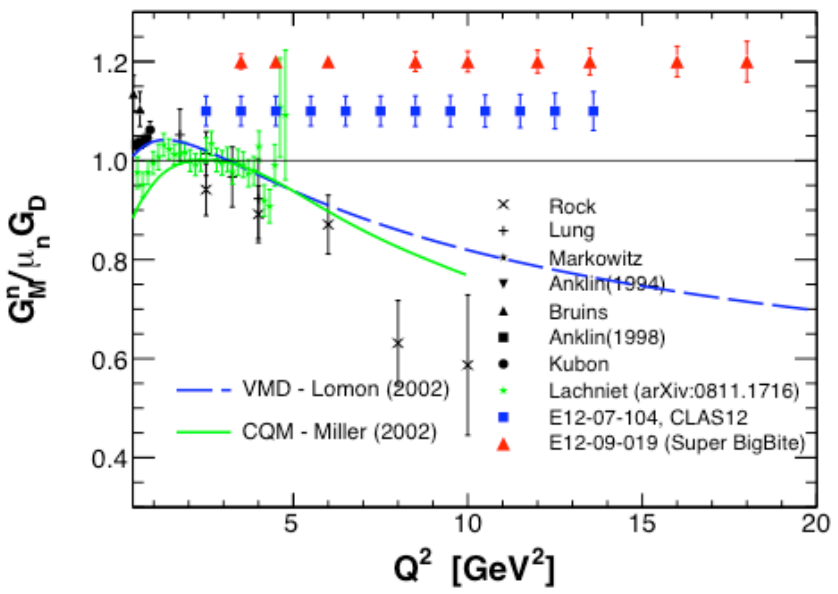


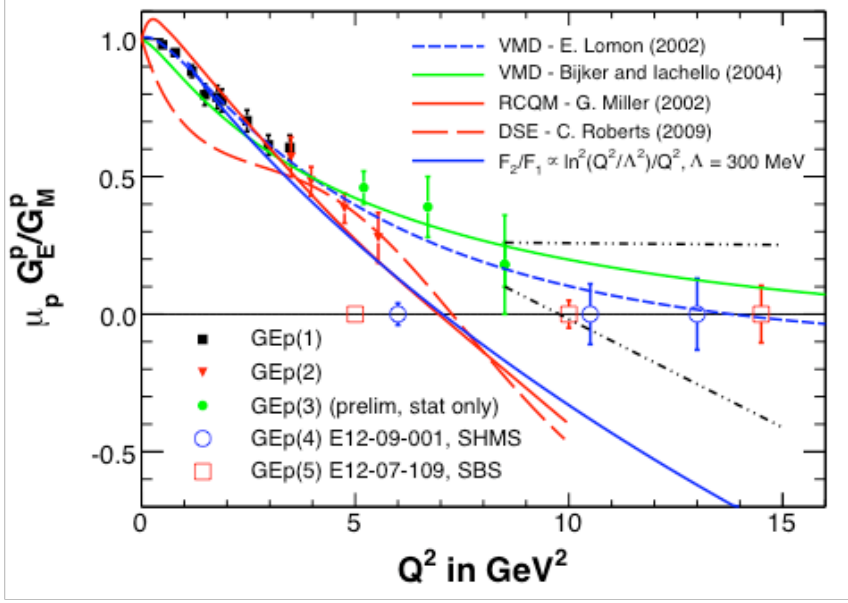


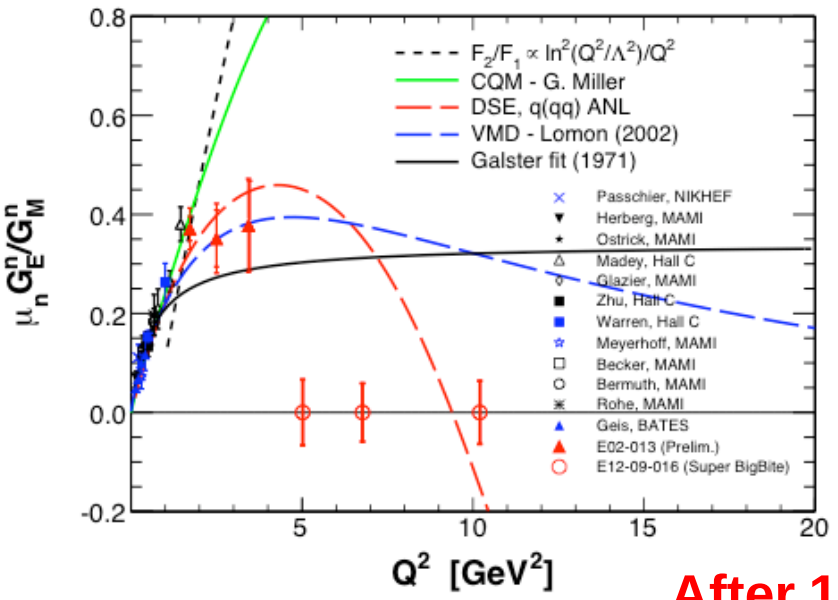
Today

Form Factors – Constraints on the GPDs



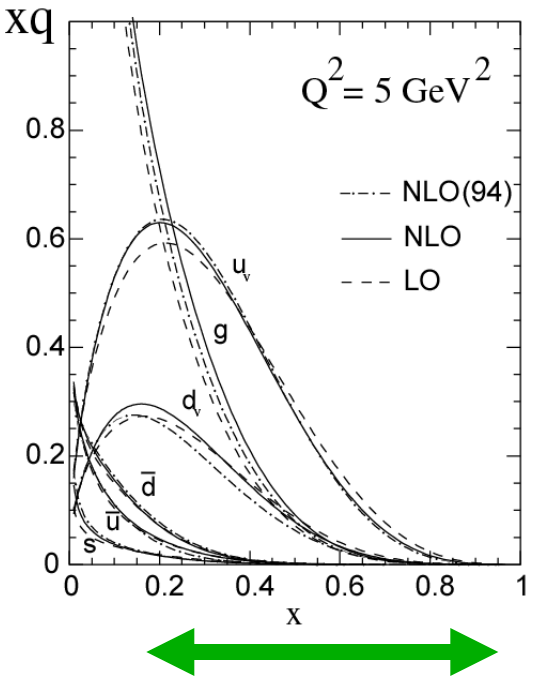


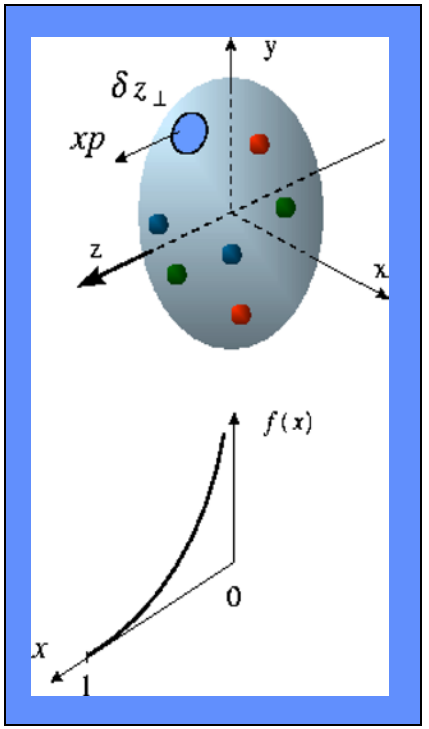




After 12 GeV

Understanding Nucleon Structure: Form Factors PDFs, and Generalized Parton Distributions (GPDs)

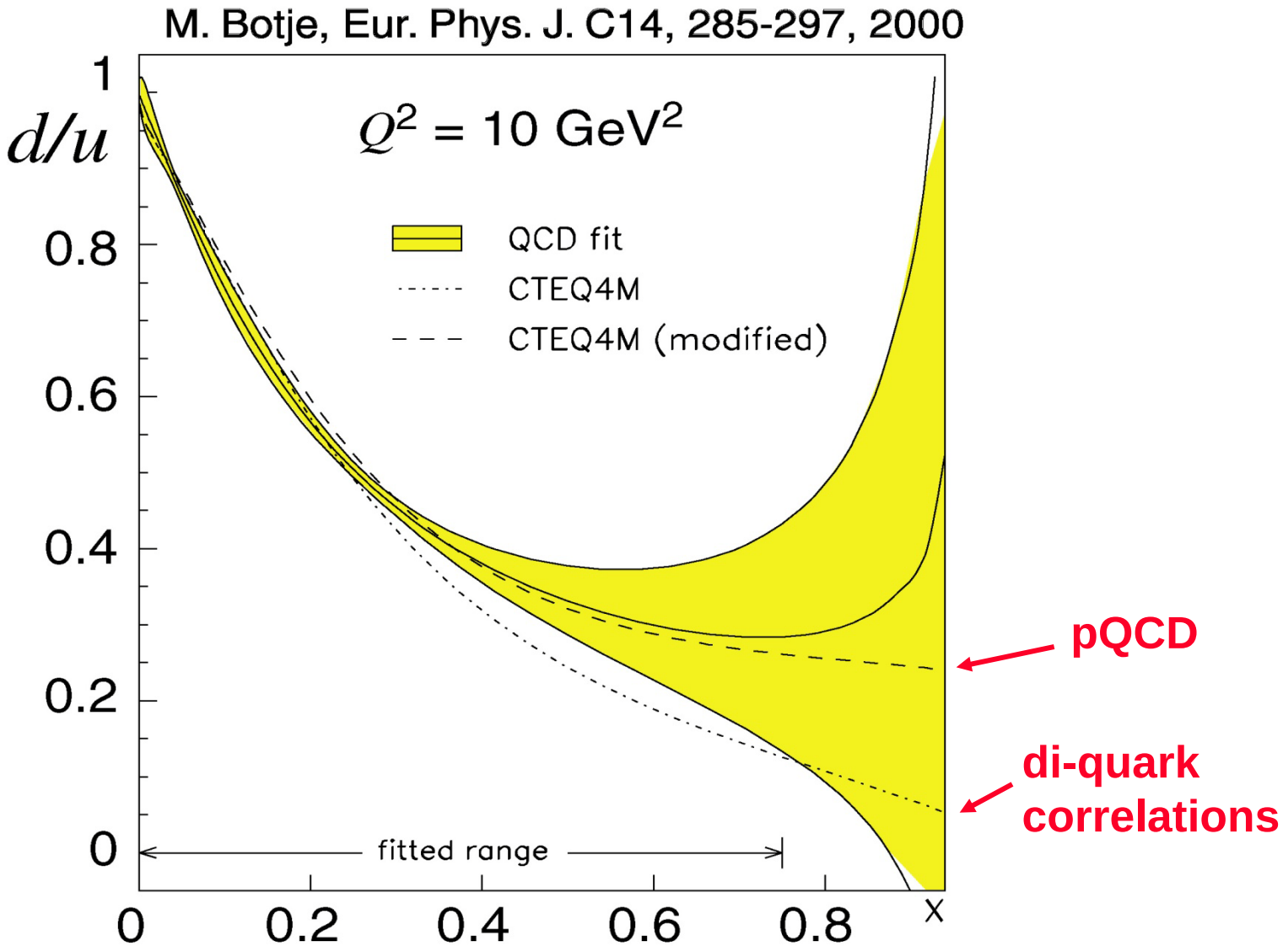




12 GeV will access the regime (x > 0.3), where valence quarks dominate

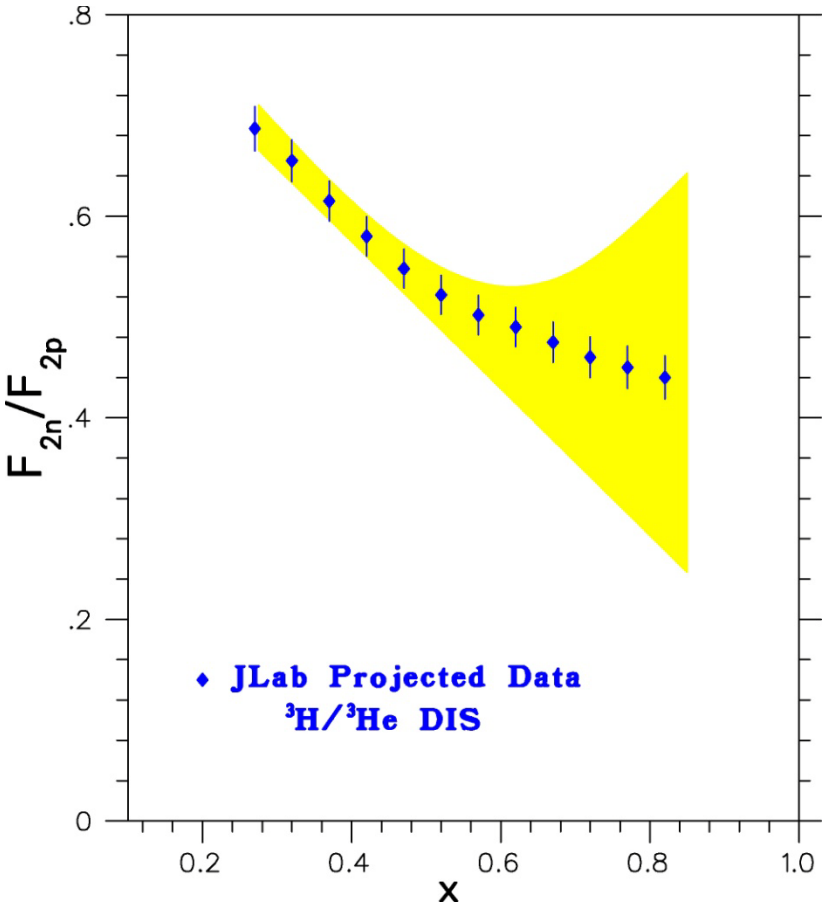
DIS & Structure Functions:
Quark longitudinal & helicity distributions in momentum space

After 35 years:
Miserable Lack of Knowledge of Valence d-Quarks

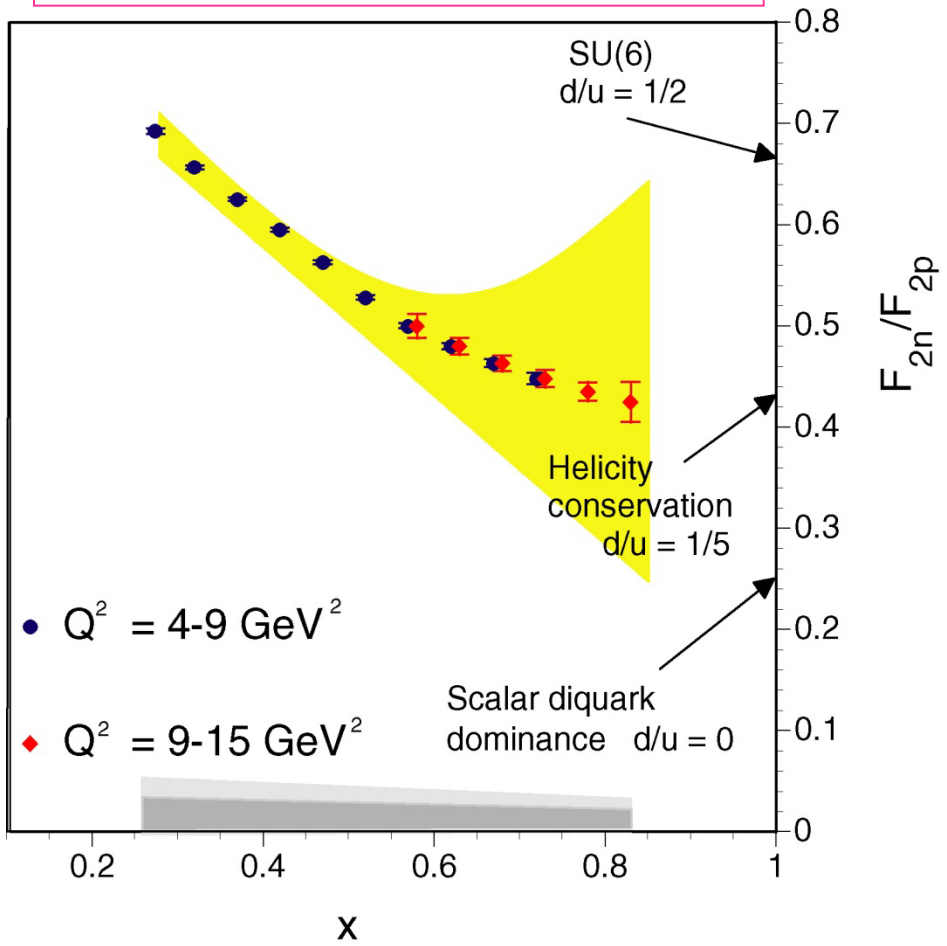


12 GeV : Unambiguous Flavor Structure x → 1

Hall C 11 GeV with HMS
^{3}H/^{3}He DIS

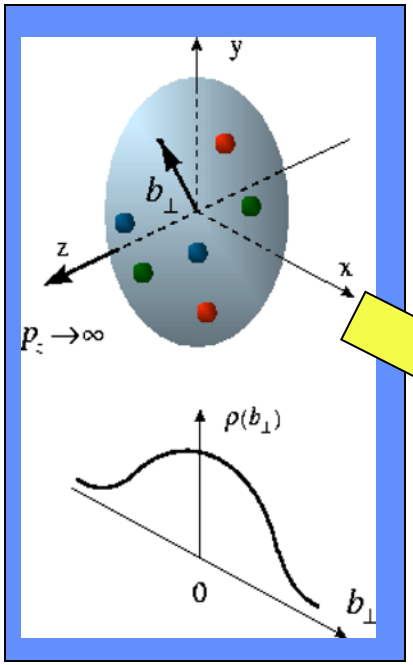


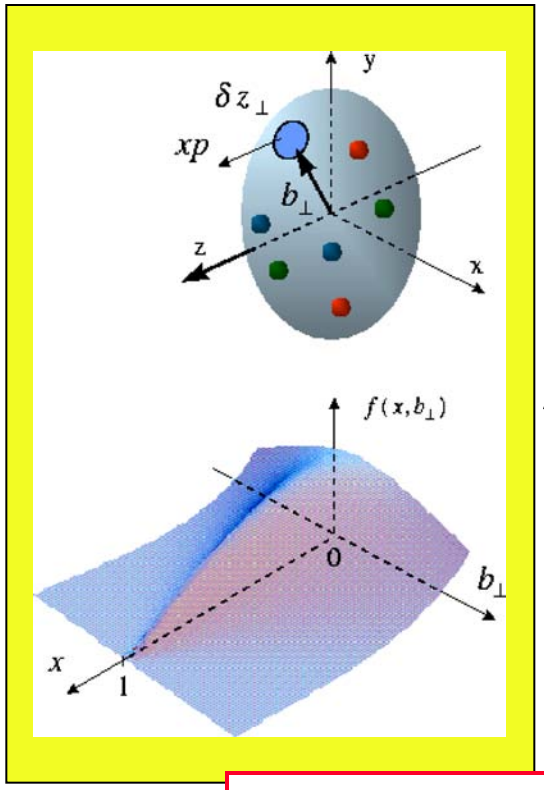
Hall B 11 GeV with CLAS12
^{2}H w/ recoil detection

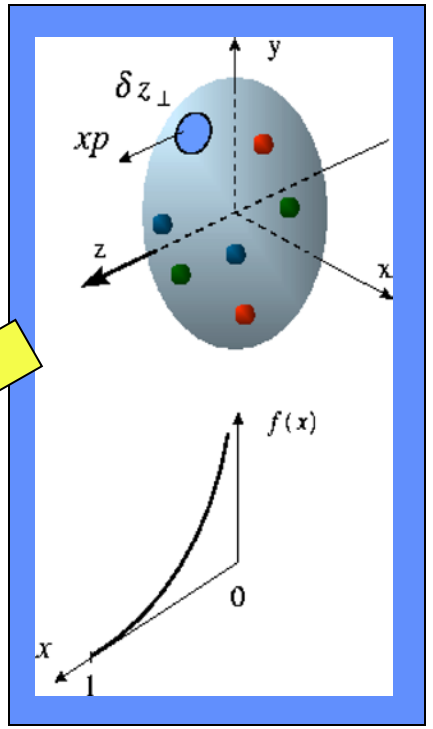


Initial experiment with recoil detection technique (BONUS radial TPC) was highly successful

Understanding Nucleon Structure: Form Factors PDFs, and Generalized Parton Distributions (GPDs)





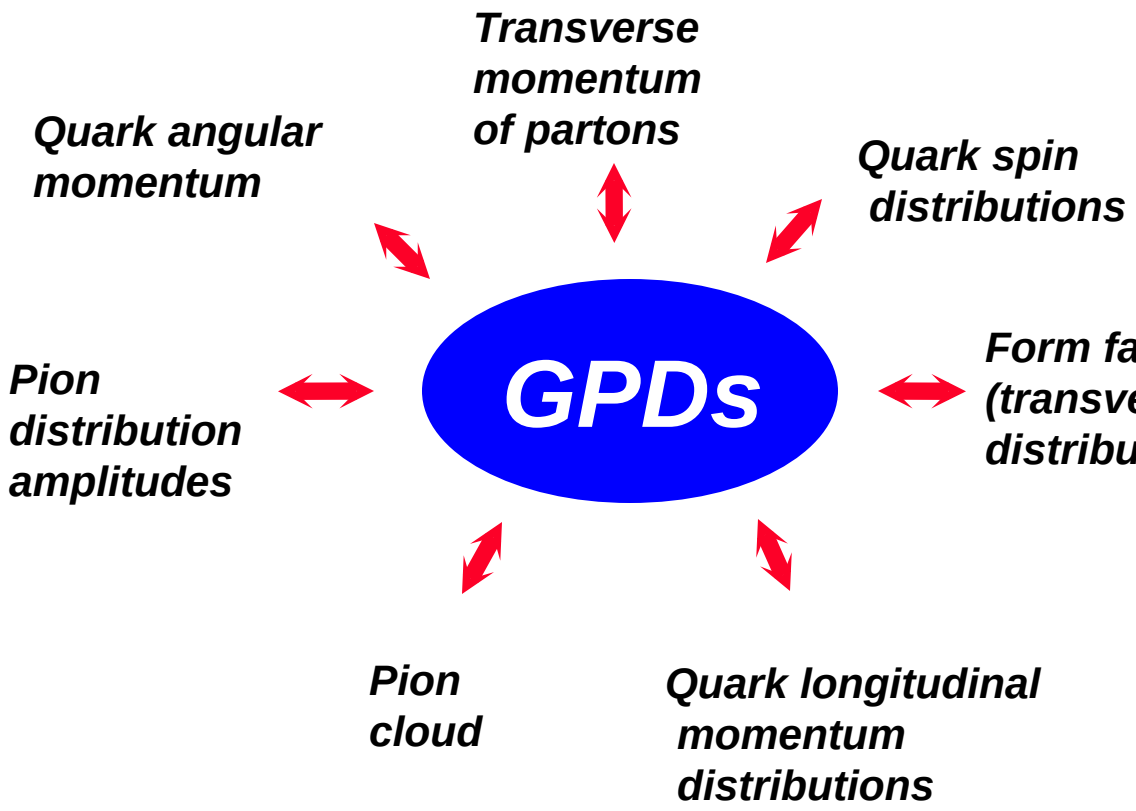


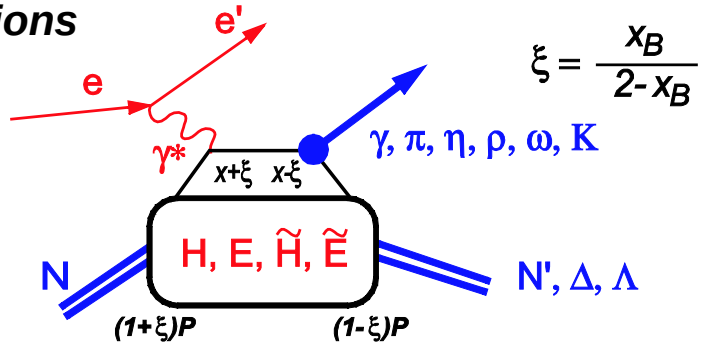
Elastic Scattering & Form Factors:
Transverse charge & current densities in coordinate space

DES
Correlated q
In transverse
and longitudi
space

This program:
- **Drove spectrometer requirements for CLAS12 & the SHMS**
- **Sets beam power goal**

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

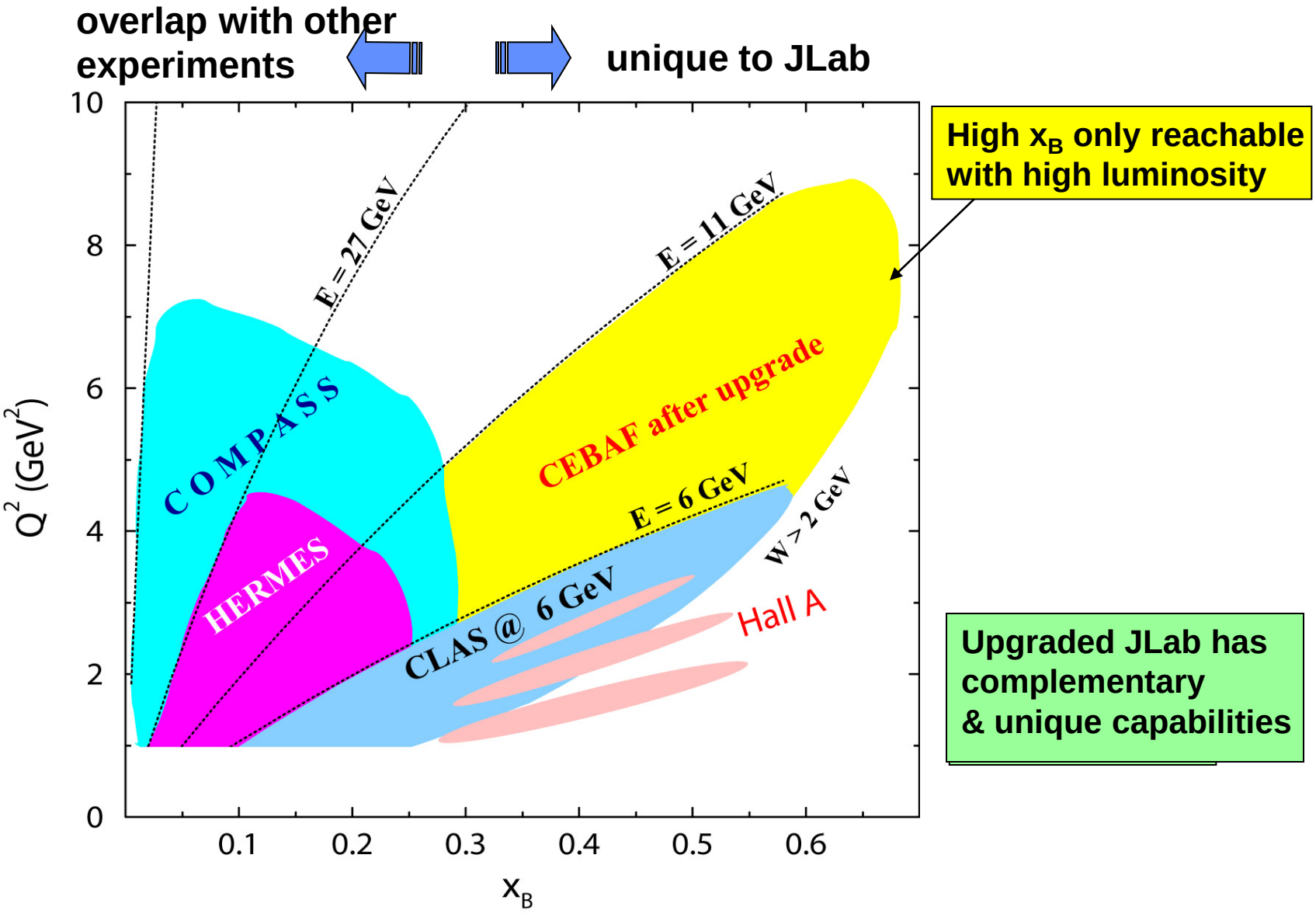




H, E - unpolarized, $\widetilde{H}$, $\widetilde{E}$ - polarized GPD

The GPDs Define Nucleon Structure

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



Projected Path: the Extraction of GPDs

Use polarization!

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

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

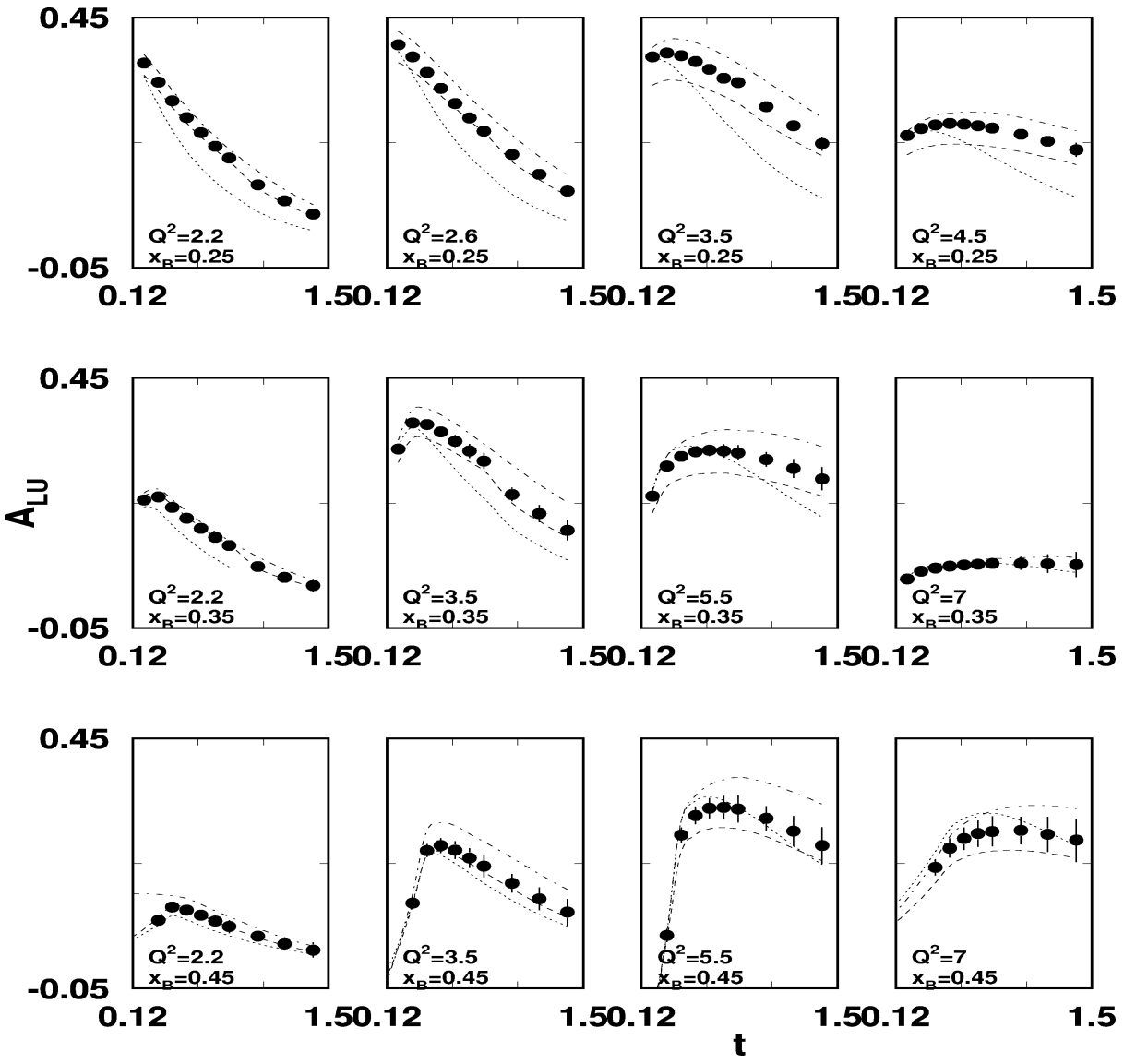
$$\Delta\sigma_{LU} \sim \sin\phi\, \mathrm{Im}\{F_1 H + \ldots\} d\phi$$

Kinematically suppressed

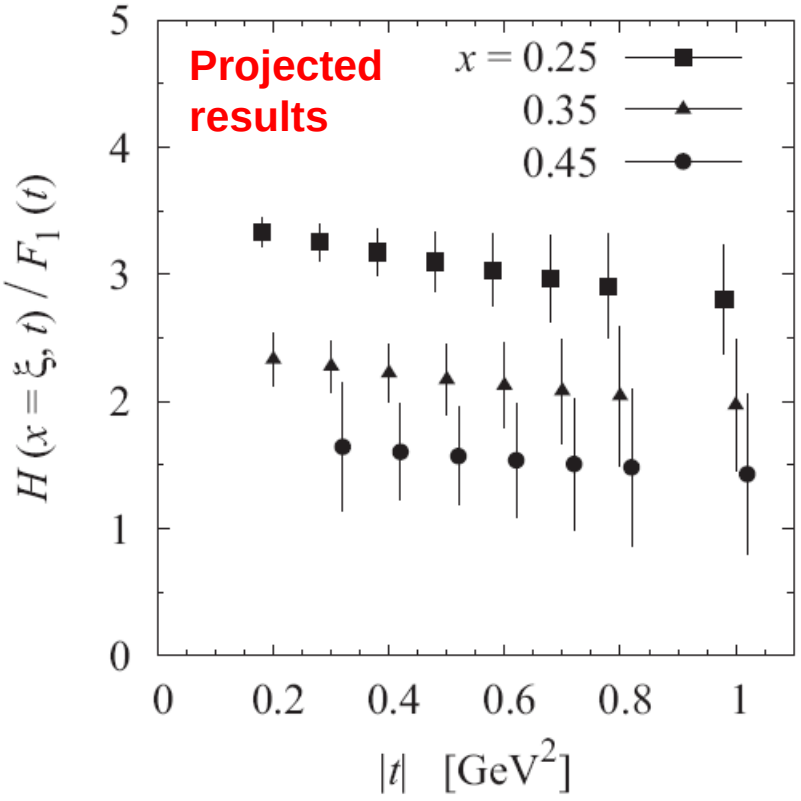
$$\Rightarrow H(\xi,t)$$

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

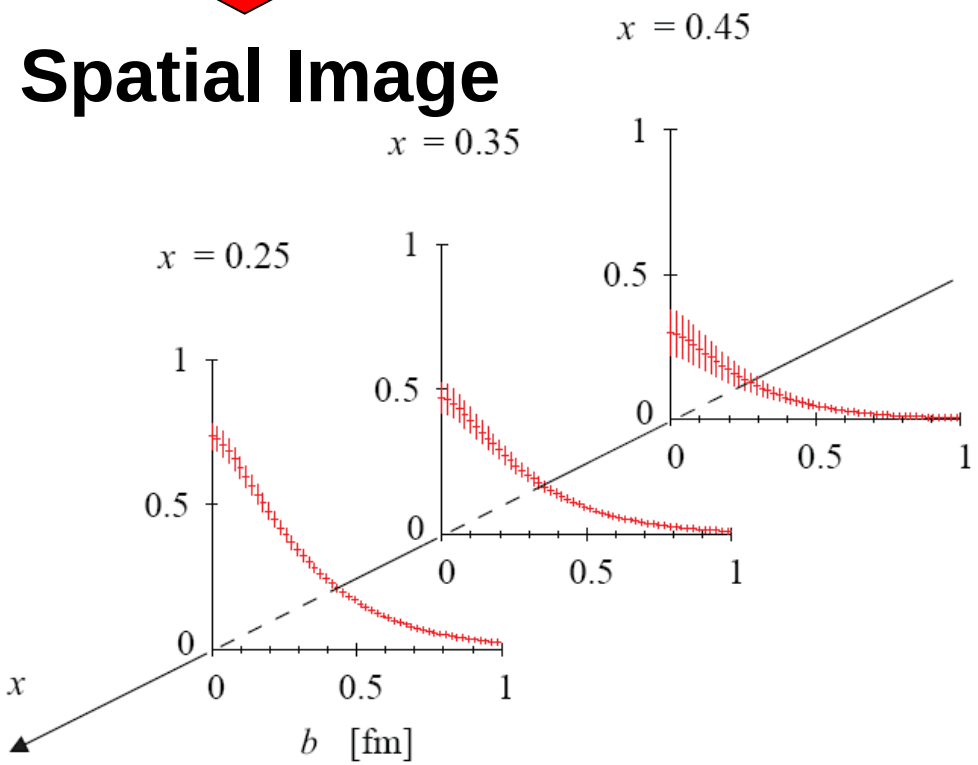
Subset of projected results



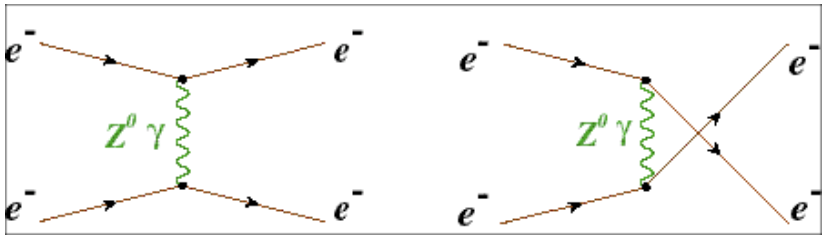
Projected precision in extraction of GPD H at x = ξ



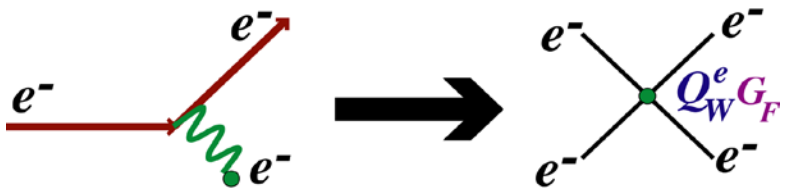
Spatial Image



A Major New Initiative for 12 GeV: Møller Scattering



Purely leptonic reaction

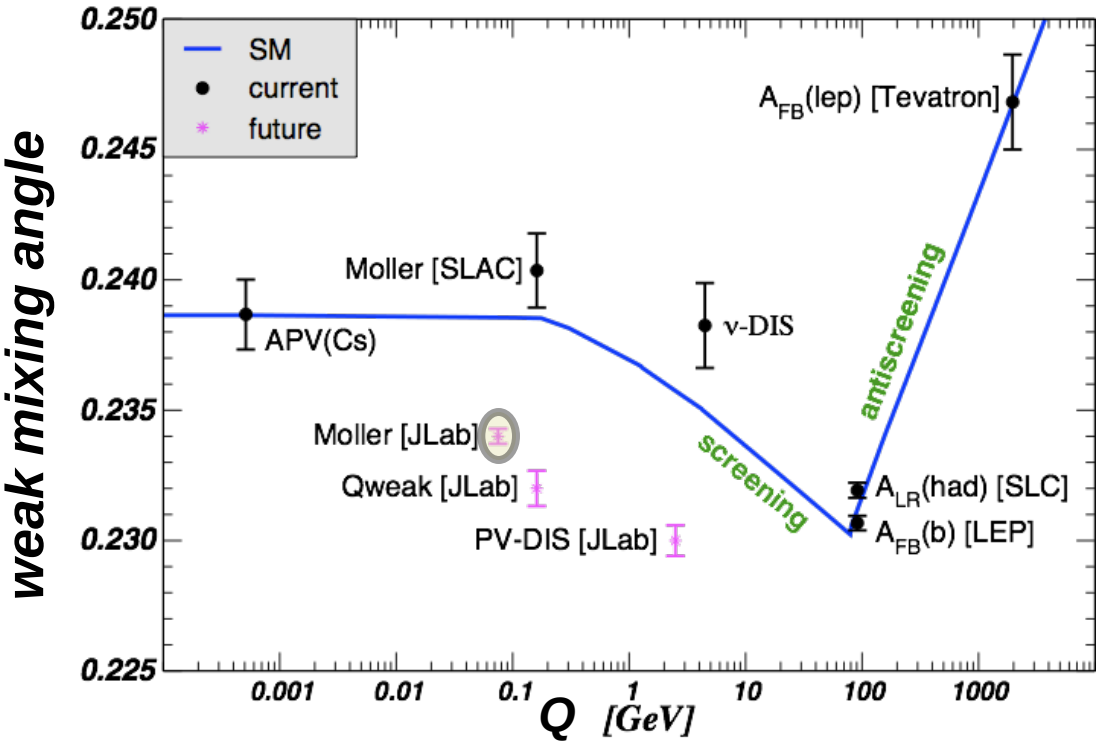


$$A_{PV} \propto m_e E_{lab} (1 - 4\sin^2 \vartheta_W)$$

Derman and Marciano (1978)

$$A_{PV} = -mE \frac{G_F}{\sqrt{2}\pi\alpha} \frac{16\sin^2\Theta}{(3+\cos^2\Theta)^2} Q_W^e$$

$$\frac{\delta(\sin^2\vartheta_W)}{\sin^2\vartheta_W} \cong 0.05 \frac{\delta(A_{PV})}{A_{PV}}$$



Measurement Of Lepton-Lepton Electroweak Reaction

MØLLER at JLab

E_{beam} = 11 GeV 75 μA 80% polarized → ~ 38 weeks (~ 2 yrs) → $\delta(A_{PV})$ = 0.73 ppb

A_{PV} = 35.6 ppb → $\delta(Q^e_W)$ = 2.1 (stat.) 1.0 (syst.) %

Compelling opportunity with the Jefferson Lab Energy Upgrade:

- Comparable to the two best measurements at colliders
- Unmatched by any other project in the foreseeable future

$$\mathcal{L}_{e_1e_2} = \sum_{i,j=L,R} \frac{g_{ij}^2}{2\Lambda^2} \bar{e}_i \gamma_\mu e_i \bar{e}_j \gamma^\mu e_j$$

A_{PV} →

$$\frac{\Lambda}{\sqrt{|g_{RR}^2 - g_{LL}^2|}} = 7.5 \text{ TeV}$$

New TeV Physics: Better sensitivity than LEP200 & complementary to LHC

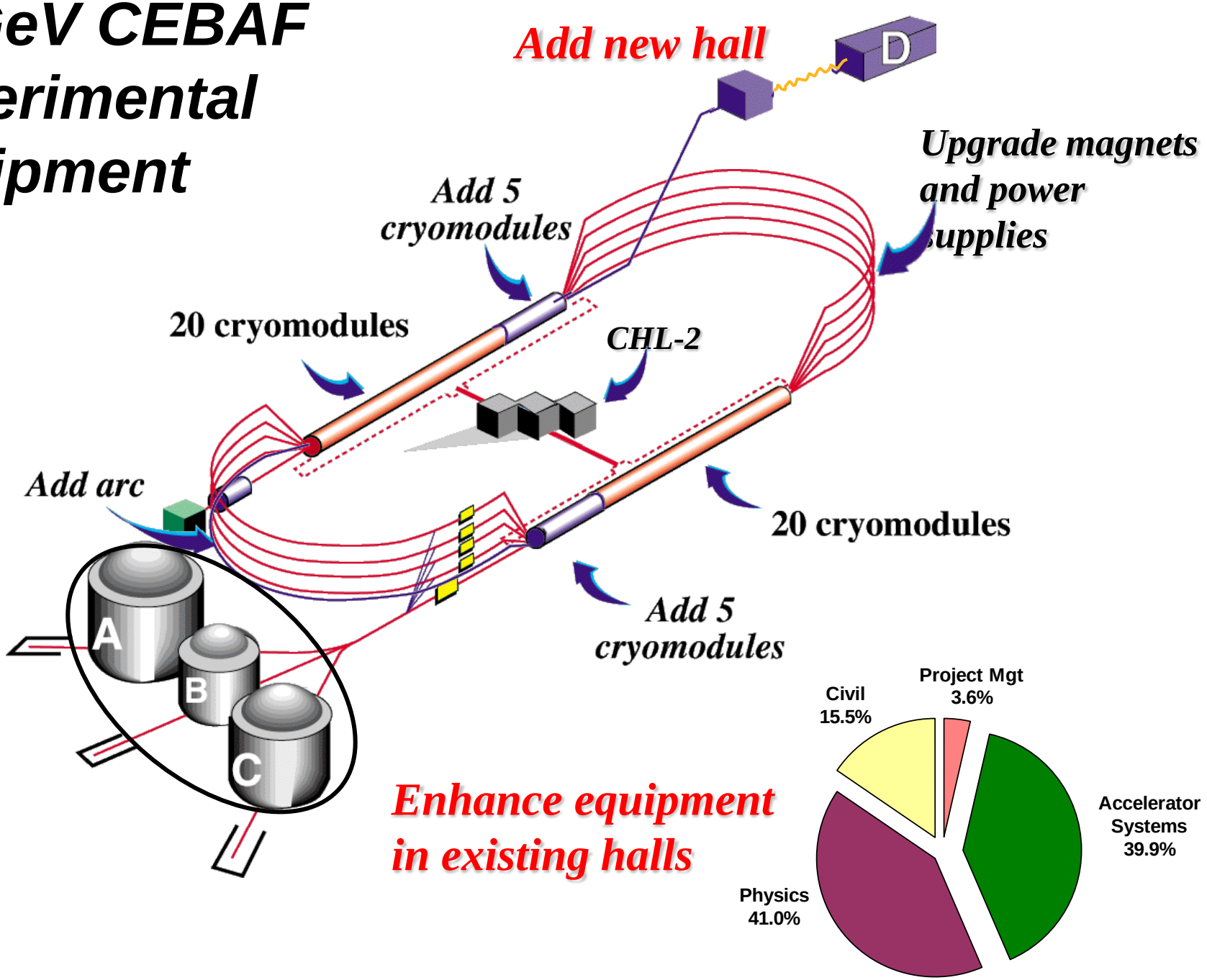
- ~ 100 authors from ~ 30 institutions: experienced personnel from III generation experiments PREX & Qweak
- Approved by 12 GeV JLab PAC in January 2009
- Collaboration working on pre-conceptual design
- Director's review in Jan '10: DoE CD0 request soon thereafter

Formal Science Program for the 12 GeV Upgrade is Developing Nicely Through the PAC Review Process

The PAC-Approved Science Program includes:

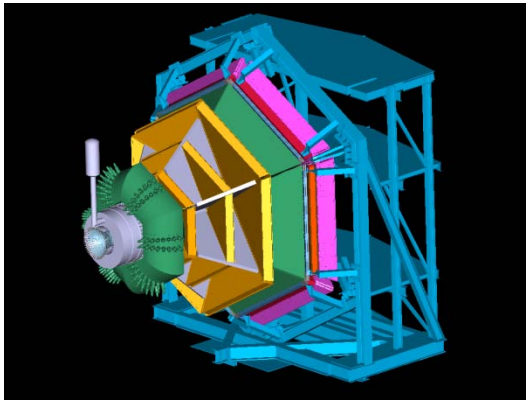
- **The Origin of Quark Confinement**
  - 1 major experiment (GLUEx)
- **Form Factors – Constraints on the GPDs**
  - 8 experiments (and 1 Cond. Approved)
- **Valence Quark Structure and Parton Distributions**
  - 9 experiments (and 5 Cond. Approved)
- **Deep Exclusive Scattering and GPDs**
  - 5 experiments
- **Hadron Structure in the Nuclear Medium**
  - 3 experiments (and 3 Cond. Approved)
- **Symmetry Tests in Nuclear Physics**
  - 1 experiment (and 3 Cond. Approved)

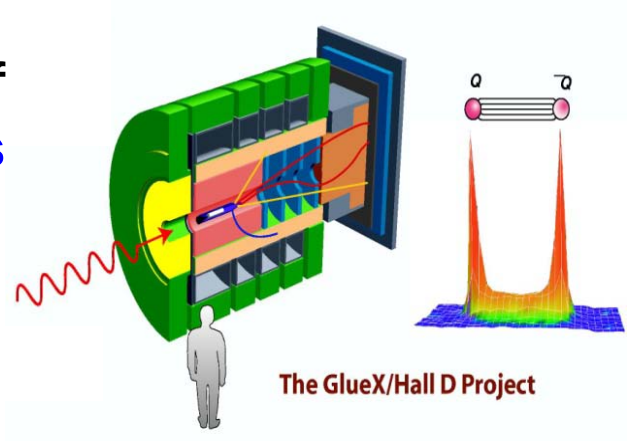
12 GeV CEBAF Experimental Equipment



12 GeV Upgrade Physics Instrumentation

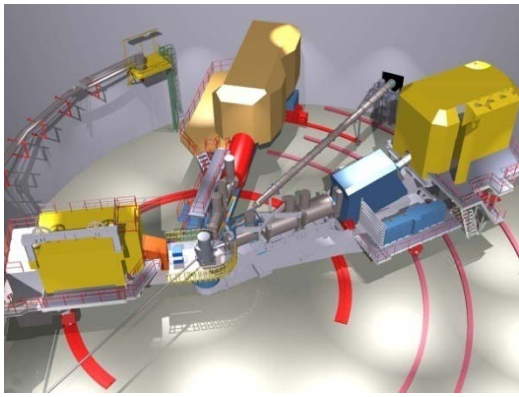
GLUEx (Hall D): **exploring origin of confinement by studying hybrid mesons**

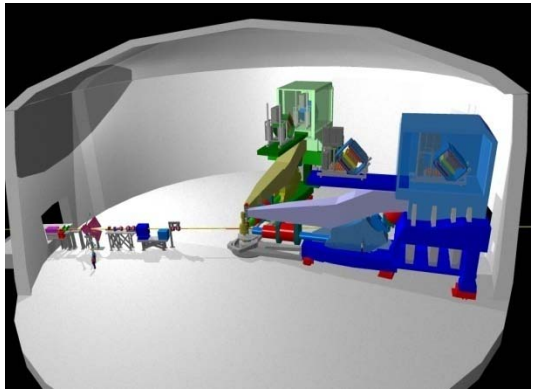




CLAS12 (Hall B): **understanding nucleon structure via generalized parton distributions**

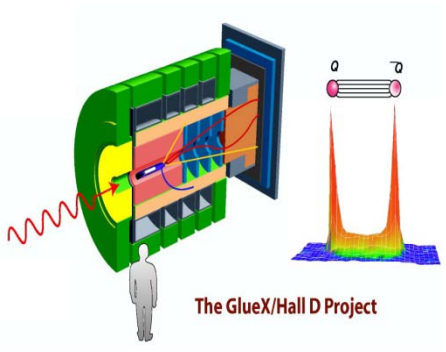
SHMS (Hall C): **precision determination of valence quark properties in nucleons and nuclei**

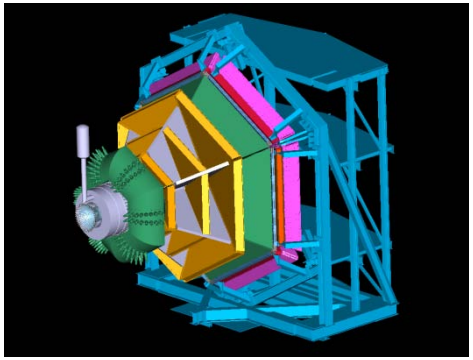


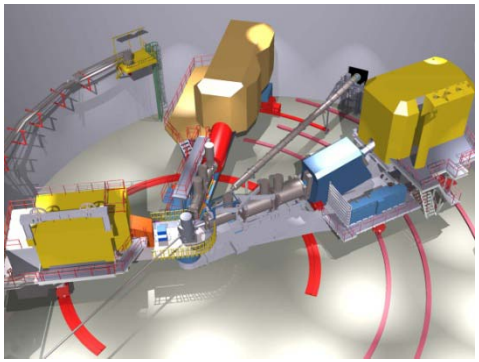


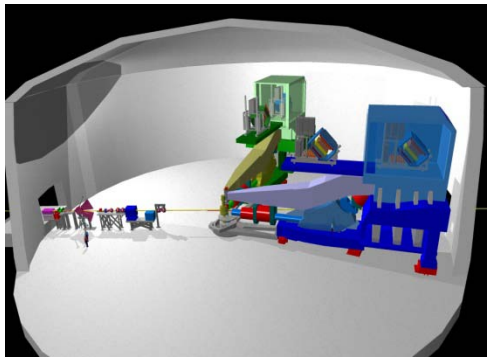
Hall A: **short range correlations, form factors, hypernuclear physics, *& future new experiments***

The 12 GeV Upgrade Physics Instrumentation Technical Performance Requirements



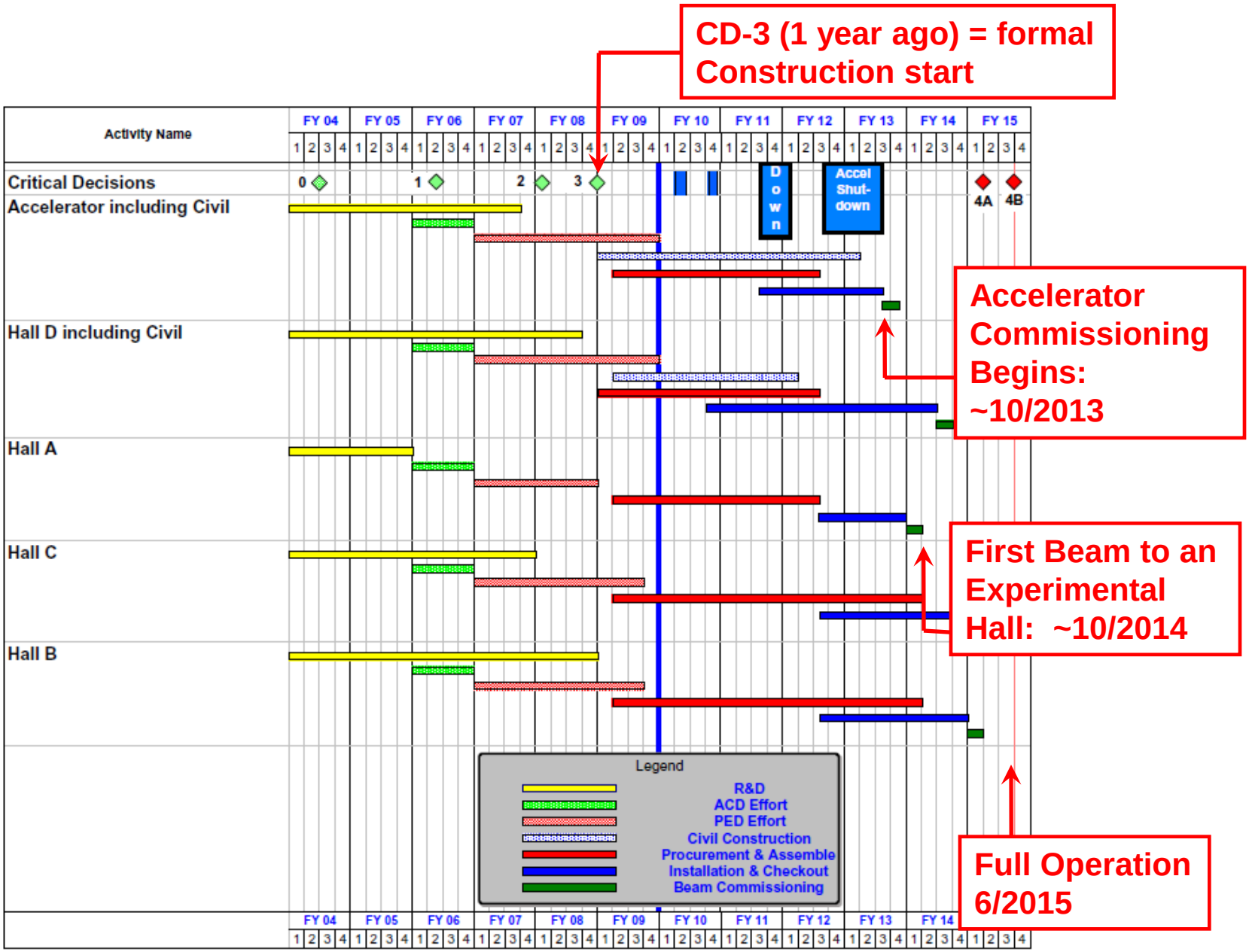




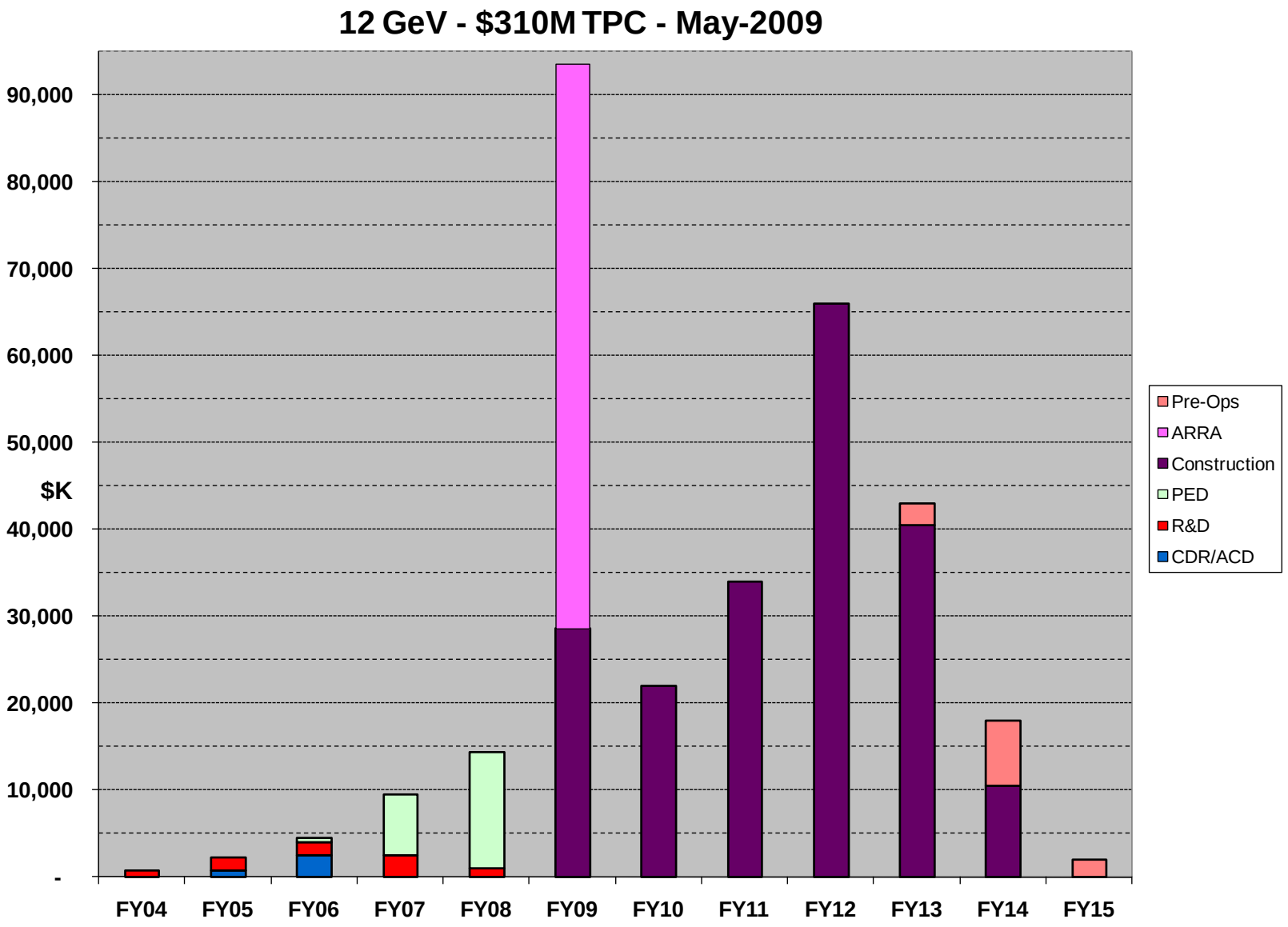


Hall D	Hall B	Hall C	Hall A
excellent hermeticity	luminosity 10^{35}	energy reach	installation space
polarized photons	hermeticity	precision	
E_γ~8.5–9 GeV	11 GeV beamline		
10^8 photons/s	target flexibility		
good momentum/angle resolution	excellent momentum resolution		
high multiplicity reconstruction	luminosity up to 10^{38}		
particle ID			

12 GeV UPGRADE SCHEDULE



12 GeV - $310M TPC – MAY-2009



CONSTRUCTION IS WELL UNDERWAY!!


Hall D Groundbreaking

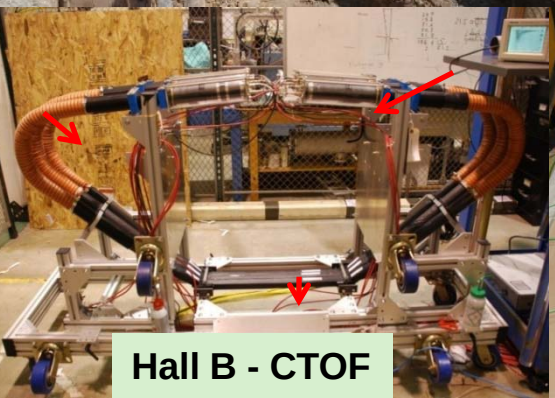
Hall D Tree Clearing

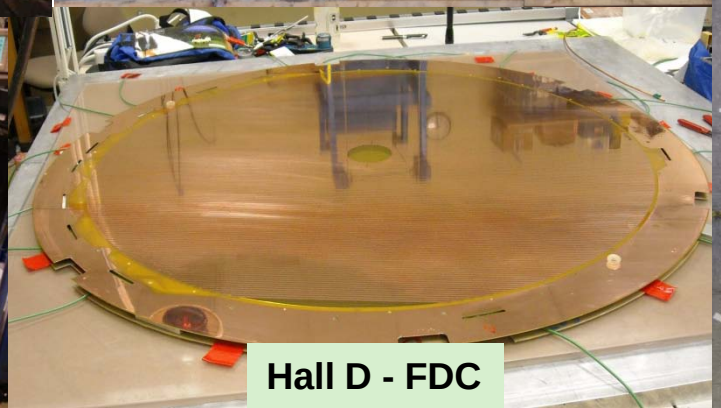

Hall D Excavation


CHL – Trench

CHL – Concrete Slab


CHL - Steel


Hall B - CTOF


Hall D - FDC


Hall C Magnet Coil

Defining the 12 GeV Science Program in Detail

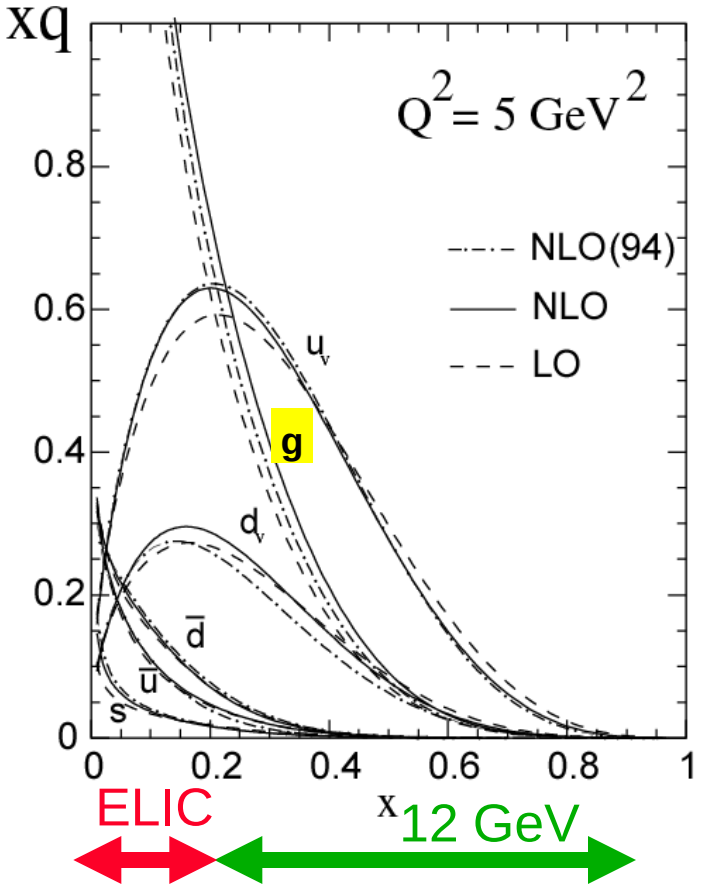
- PACs 30, 32, and 34 have approved a total of 27 proposals for 12 GeV science and conditionally approved 11 more. There are also a number of Letters of Intent that have been encouraged
- The process will continue with PAC35 (this January), and your participation is encouraged
- In 1-2 years there will be a PAC to prioritize the science that has been accepted
- ~1 year before the start of physics, hall-by-hall, there will be a PAC review of the Hall “commissioning year” of startup physics

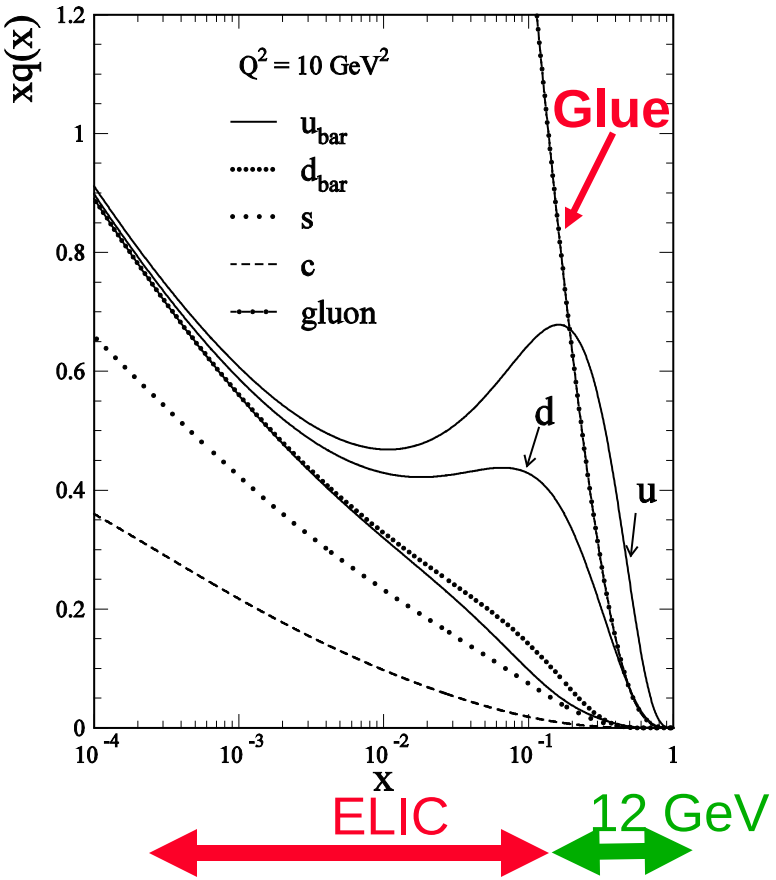
Longer Term Prospects at JLab (2015 and Beyond)

- ***Carry out the planned research program using CEBAF@12 GeV***

- **We are also developing plans developing for a new electron-ion collider and/or an external beam facility that would be constructed during this period, focused on the next generation of Electromagnetic Interaction experiments in Nucleons and Nuclei, much of which was discussed at this conference and in the preceding workshops**

After 12 GeV: CEBAF@25 GeV or a High-Luminosity Electron Light Ion Collider Would Provide Complementary Access to Nucleon Structure

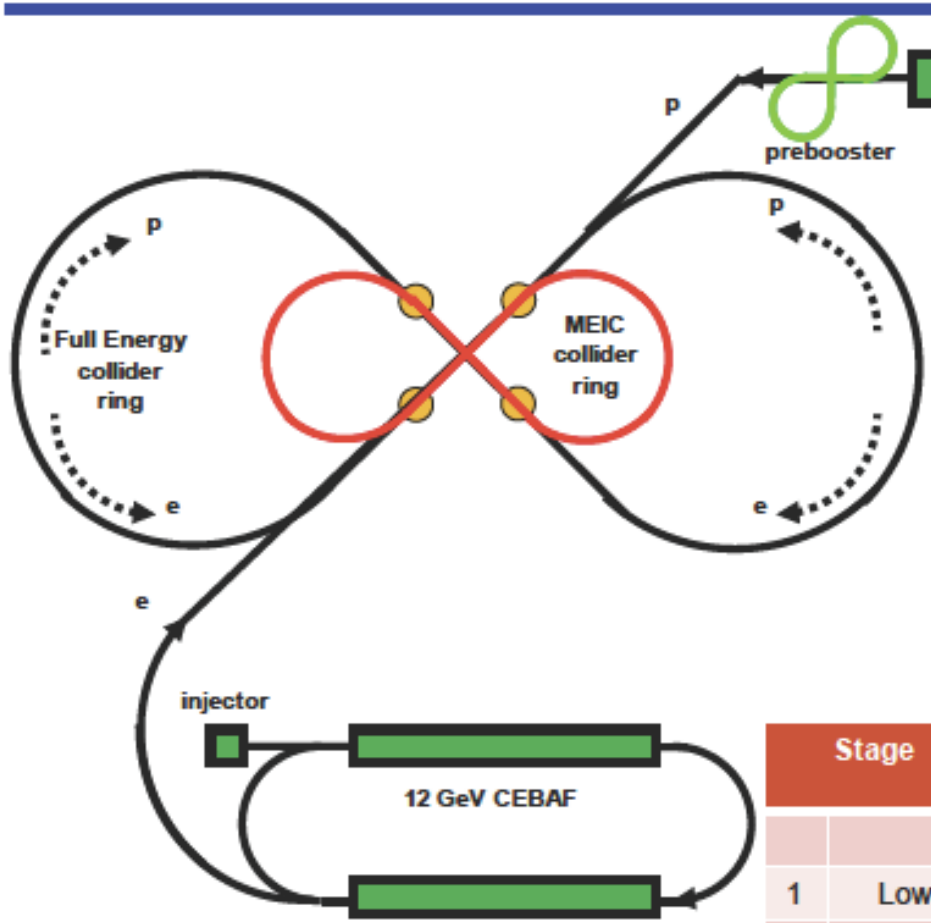




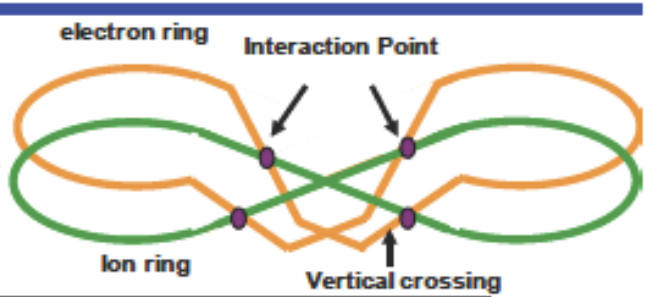
12 GeV will access the valence quark regime (x > 0.3), where the quark properties are not masked by the sea quarks and glue

ELIC will focus on the "sea" (x < 0.1) where the glue and q-q pairs dominate

Going to Higher Energy at JLab



Courtesy of G. Krafft



HE Ring Dimensions	m
Circumference	1800
Radius	140
Width	280
Length	695
Straight	306

Stage		Max. Energy (GeV/c)		Ring Size (m)		Ring Type		IP #
		p	e	p	e	p	e	
1	Low	12	5 (11)	630	630	Warm	Warm	1
	Medium	60	5 (11)	630	630	Cold	Warm	2
2	Medium	60	10	600	1800	Cold	Warm	4
3	High	250	10	1800	1800	Cold	Warm	4

EIC Parameters

Beam Energy	GeV	12/3	60/5	60/3	250/10
Collision freq.	MHz		499		
Particles/bunch	10^{10}	0.47/2.3	0.74/2.9	1.1/6	1.1/3.1
Beam current	A	0.37/2.7	0.59/2.3	0.86/4.8	0.9/2.5
Energy spread	10^{-4}		~ 3		
RMS bunch length	mm	50	5	5	5
Horz. emit., norm.	μm	0.18/80	0.56/85	0.8/75	0.7/51
Vert. emit. Norm.	μm	0.18/80	0.11/17	0.8/75	0.03/2
Horizontal β^*	mm	5	25	25	125
Vertical β^*	mm		5		
Vert. b-b tuneshift/IP		.015/.013	0.01/0.03	.015/.08	0.01/0.1
Laslett tune shift	p-beam	0.1	0.1	0.054	0.1
Peak Luminosity/IP, 10^{34}	$cm^{-2}s^{-1}$	0.59	1.9	4.0	11
		Low energy	MEIC		High energy

Courtesy of G. Krafft

Summary

An exciting science program investigating the nature of quark confinement and other aspects of "strong" QCD motivates the Upgrade of CEBAF from 6 to 12 GeV and the addition of major experimental equipment

Construction of the 12 GeV Upgrade is well underway, with first beams for commissioning the first experiments expected in late 2014, and full operation in 2015

The combination of advances driven by theoretical insights and tools (the formulation of the GPDs, TMDs, LQCD….) and the capabilities of high luminosity, high energy cw electron beams and modern experimental apparatus provides confidence that this effort will yield important new advances for our field

For the longer-range future, an electron-hadron/nucleus collider offers tantalizing possibilites that are being explored on both sides of the Atlantic