The Jefferson Laboratory

12 GeV upgrade

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Jefferson Lab

EINN-2007

Milos

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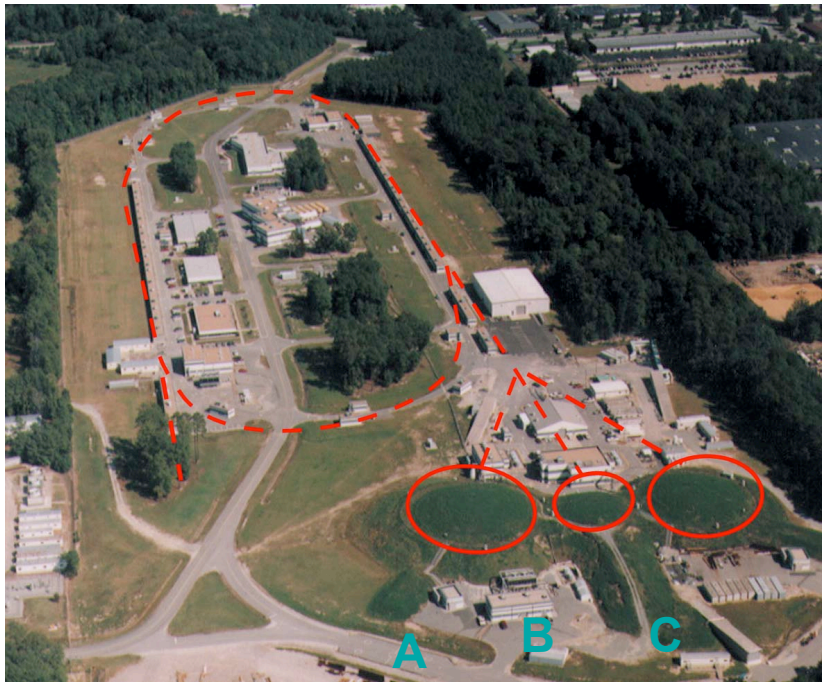
Outline of this talk

- JLab today
- Physics plans with 12 GeV
- Status of 12-GeV upgrade
- Time line of construction
- Tool for hadron community

Jefferson Lab Today

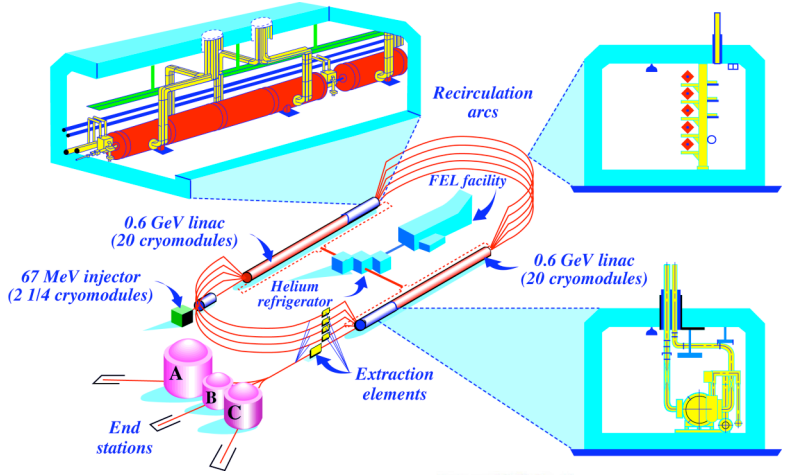
- ~1200 active users worldwide engaged in exploring and understanding the quark-gluon structure of matter

- The SRF electron accelerator provides CW beams of unprecedented quality (polarization of up to 85%) with a maximum beam energy of 6 GeV

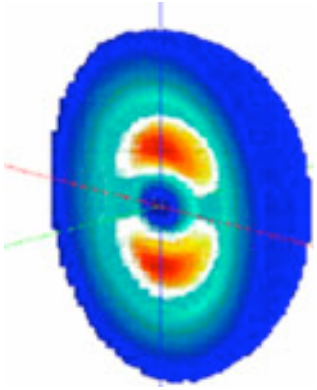


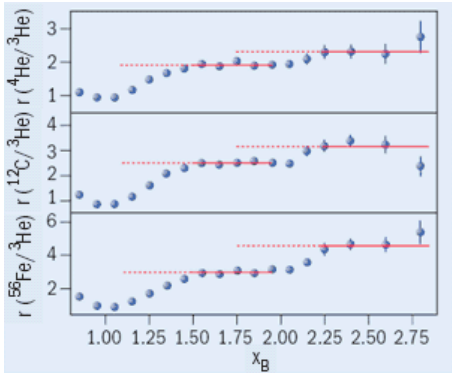
Luminosity is a key element of discovery potential

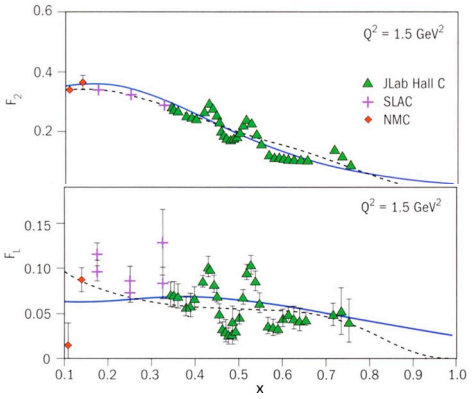
- CEBAF's innovative design allows delivery of beam with unique properties to three experimental halls simultaneously
- Each of the three halls offers complementary experimental capabilities and allows for large equipment installations

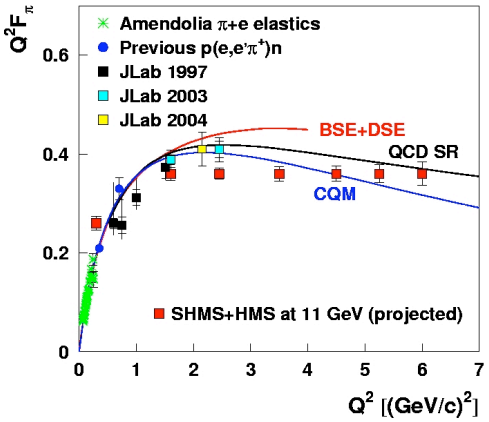


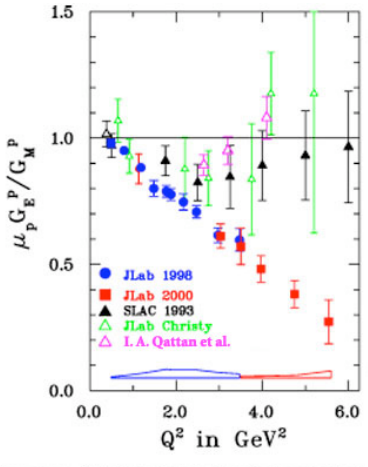
Jefferson Lab Today

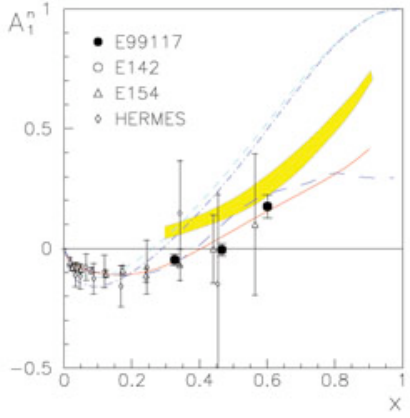


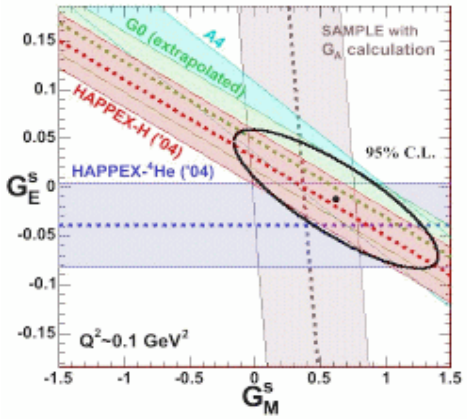


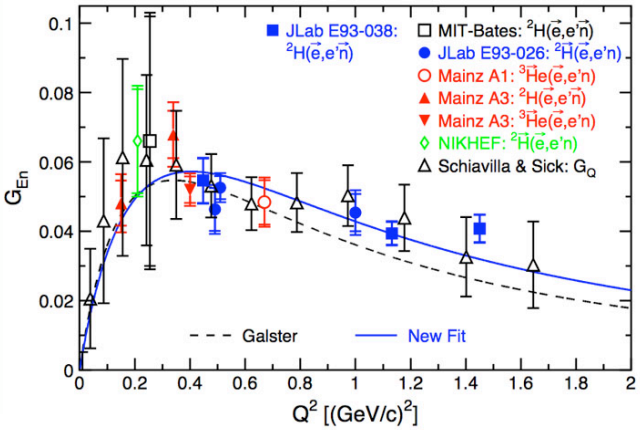






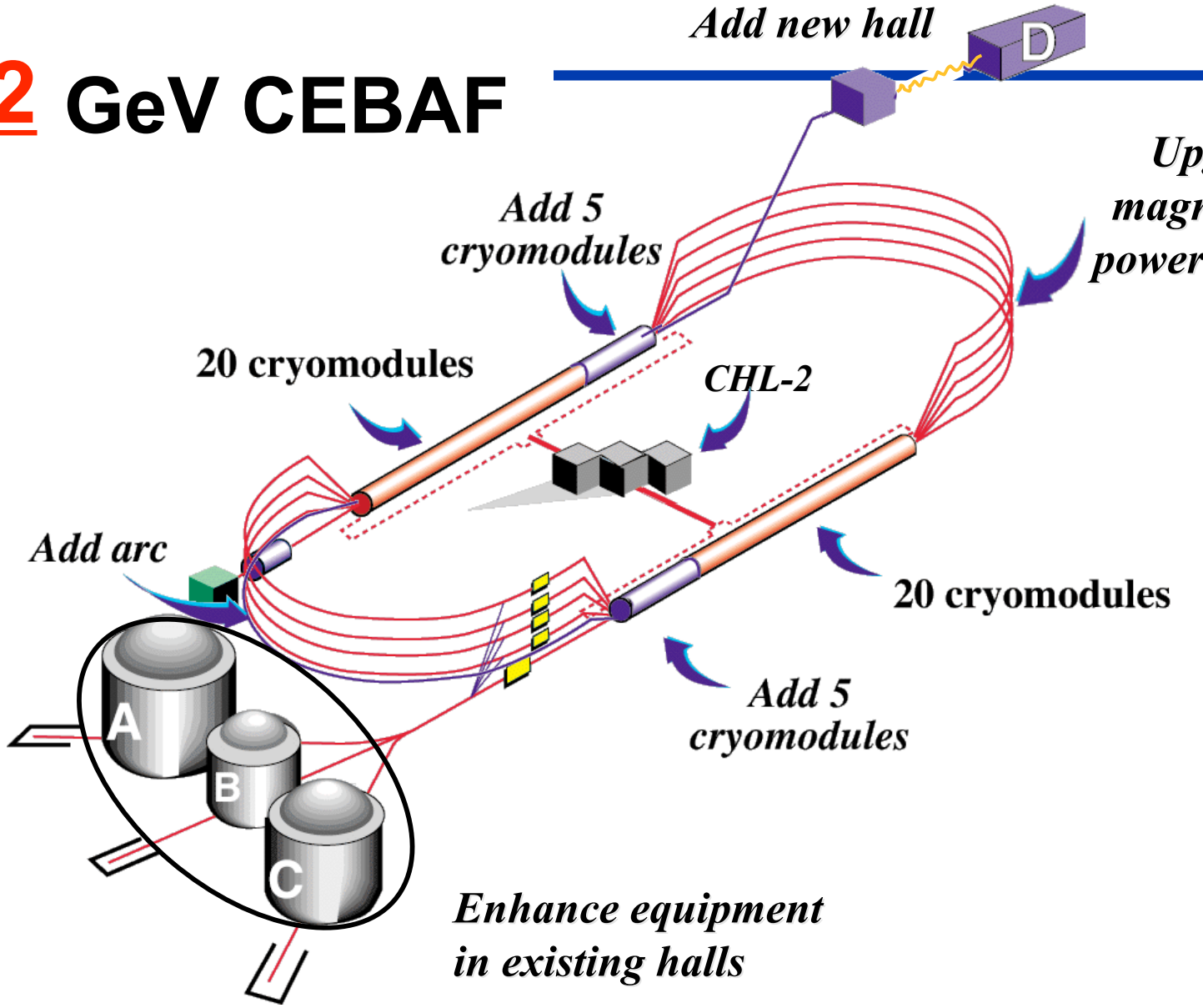






Recent and next four years: DVCS-A/B; GEN-3.4;GEP-8.6;QWEAK; Lead-parity, …

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

High-level Parameters

• Beam energy	12 GeV
• Beam power	1 MW
• Beam current (Hall A/D)	85/5 μA
• Emittance @ 12 GeV	10 nm-rad
• Energy spread @ 12 GeV	0.02%
• Simultaneous beam delivery	Up to 3 halls

LRP Recommendation #1

We recommend the completion of the 12 GeV Upgrade at Jefferson Lab. The Upgrade will enable new insights into the structure of the nucleon, the transition between the hadronic and quark/gluon descriptions of nuclei, and the nature of confinement.

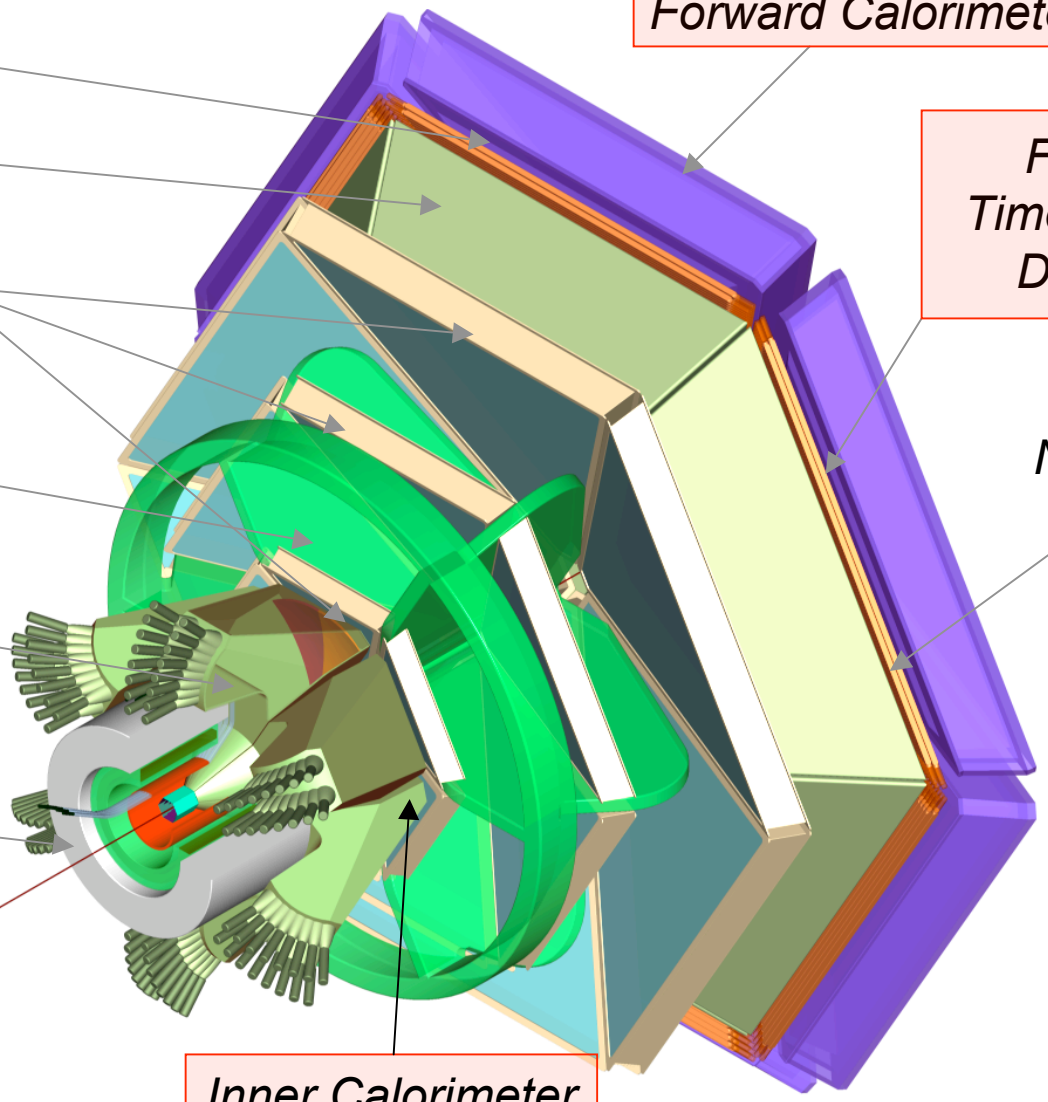
A fundamental challenge for modern nuclear physics is to understand the structure and interactions of nucleons and nuclei in terms of quantum chromodynamics. Jefferson Lab's unique electron microscope has given the US leadership in addressing this challenge. Its first decade of research has already provided key insights into the structure of nucleons and the dynamics of finite nuclei.

Doubling the energy of this microscope will enable three-dimensional imaging of the nucleon, revealing hidden aspects of its internal dynamics. It will complete our understanding of the transition between the hadronic and quark/gluon descriptions of nuclei, and test definitively the existence of exotic hadrons, long-predicted by QCD as arising from quark confinement. Through the use of parity violation, it will provide low-energy probes of physics beyond the Standard Model, complementing anticipated measurements at the highest accessible energy scales.

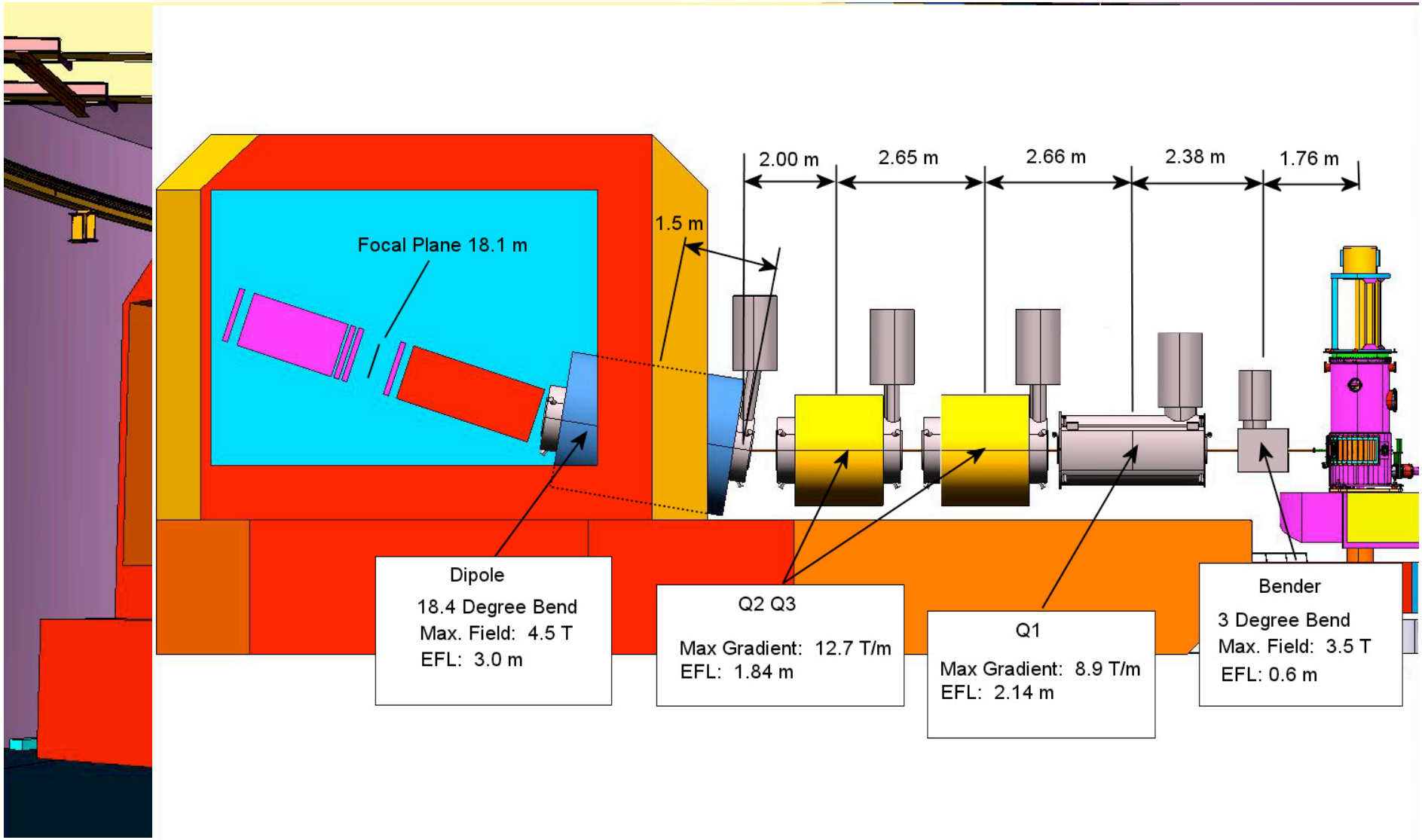
Highlights of the 12 GeV Program

- Revolutionize Our Knowledge of Spin and Flavor Dependence of PDFS in the Valence Region
- Totally New View of Hadron (and Nuclear) Structure: GPDs
  - ➔ Determination of the quark angular momentum
- Exploration of QCD in the Nonperturbative Regime:
  - ➔ Existence and properties of QCD flux-tube excitations
- New Paradigm for Nuclear Physics: Nuclear Structure in Terms of QCD
  - ➔ Spin- and flavor-dependent EMC Effect
  - ➔ Quark propagation through nuclear matter
- Precision Tests of the Standard Model
  - ➔ Factor 20 improvement in $(2C_{2u}-C_{2d})$ axial-vector quark couplings
  - ➔ Determination of $\sin^2\theta_w$ to within 0.00025

Hall B - CLAS12

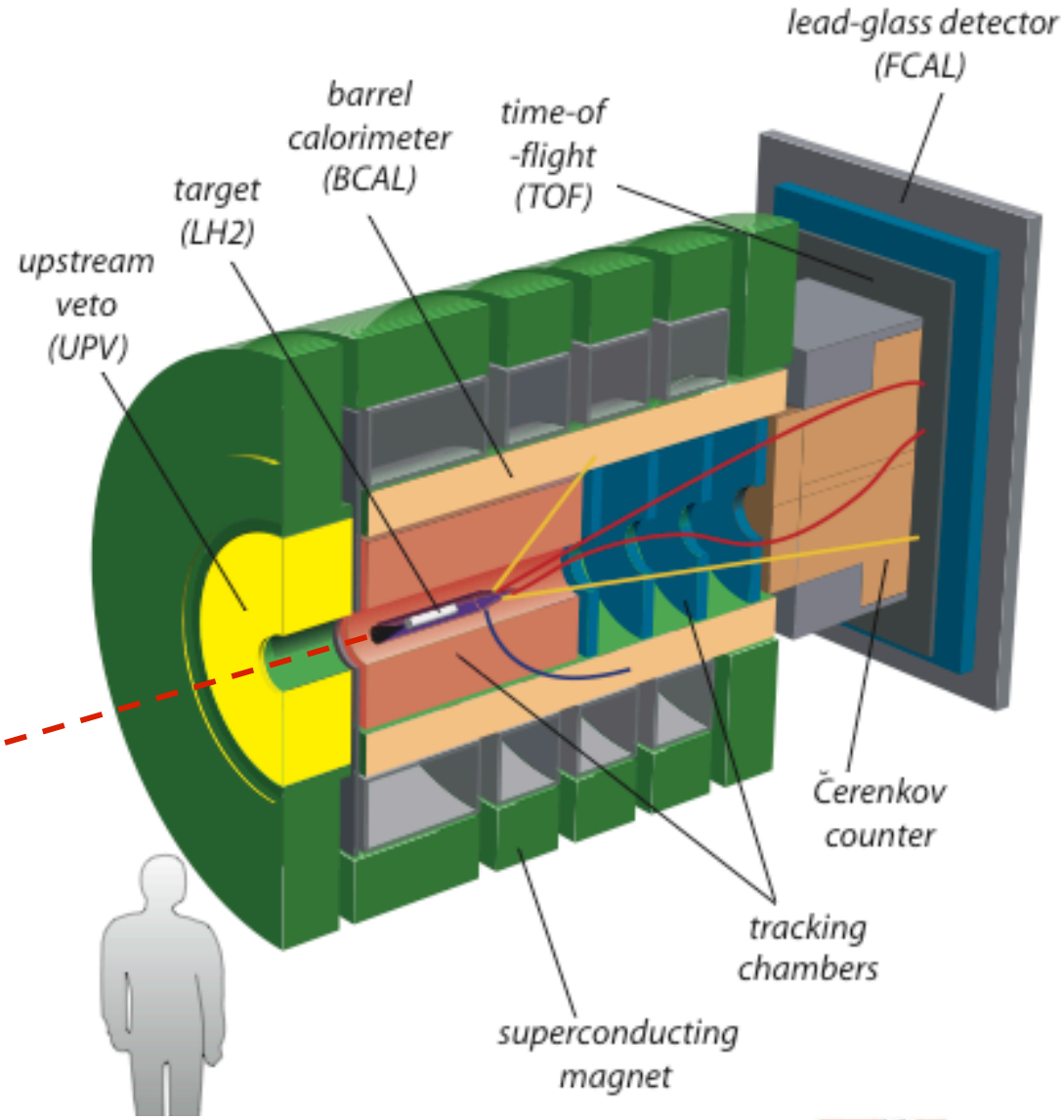


Hall C - Side View of SHMS Design



Hall D - GluEx Detector

Hermetic detection of charged and neutral particles



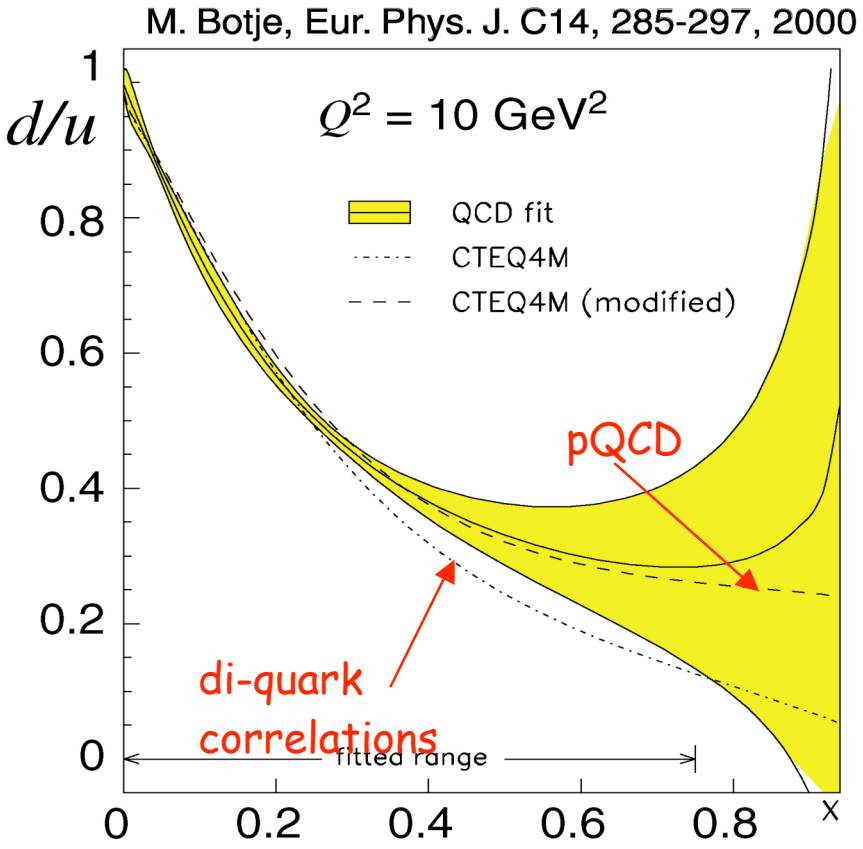
Tagger Spectrometer (Upstream)

Examples of the 12 GeV Upgrade Research

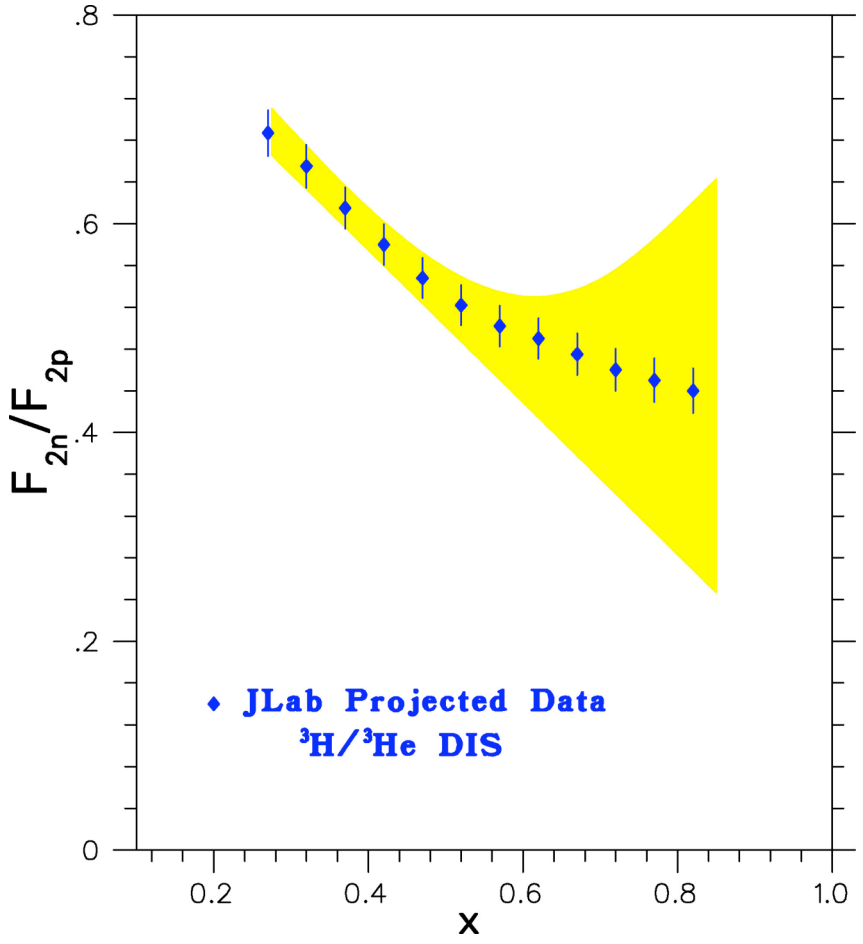
- **Parton Distribution Functions**
- Generalized Parton Distributions and Form Factors
- Exotic Meson Spectroscopy:
  Confinement and the QCD vacuum
- Nuclei at the level of quarks and gluons
- Tests of Physics Beyond the Standard Model

12 GeV : Unambiguous Flavor Structure x —> 1

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



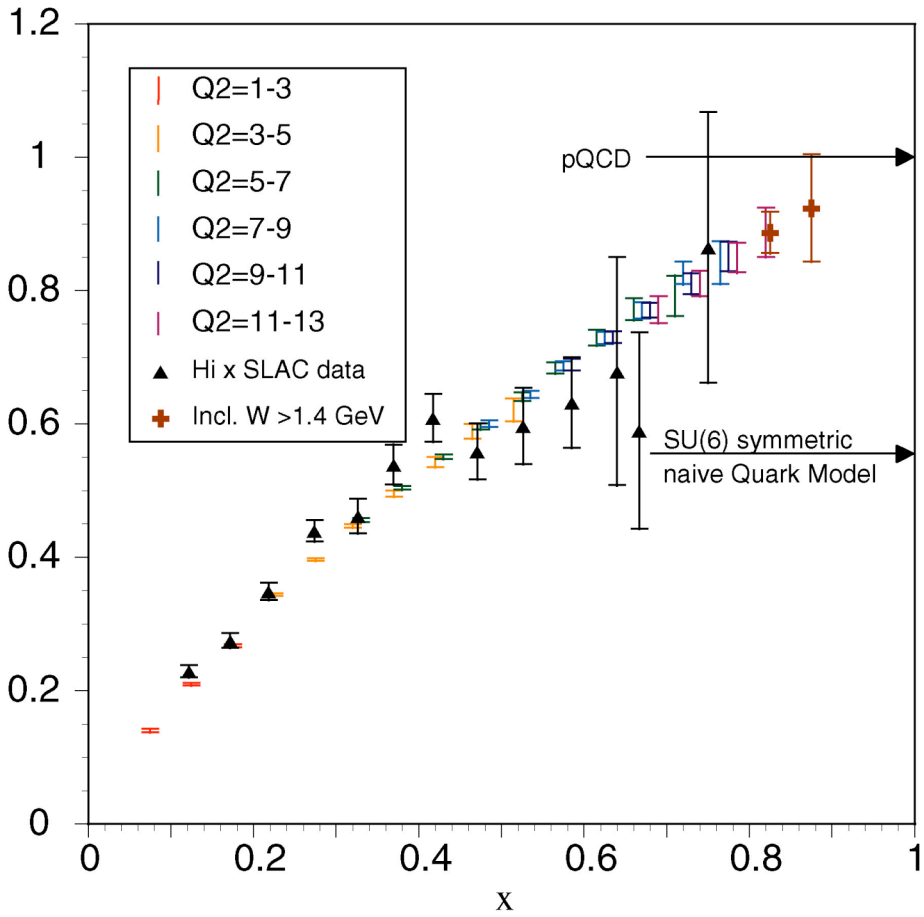
Hall A at 11 GeV with HRS



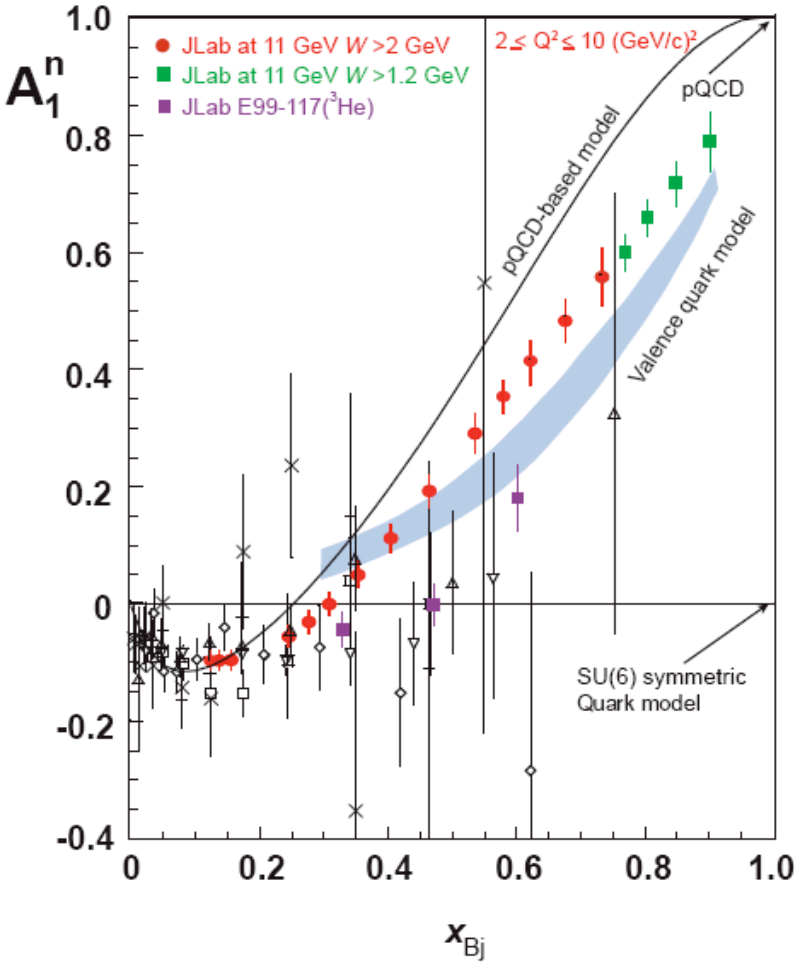
Unambiguous Resolution of Valence Spin

Hall A at 11 GeV with BigBite

A_1^p at 11 GeV



A_1^n at 11 GeV



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- Exotic Meson Spectroscopy:
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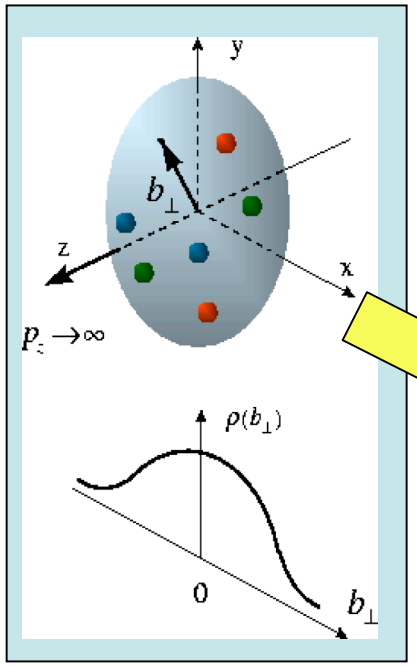
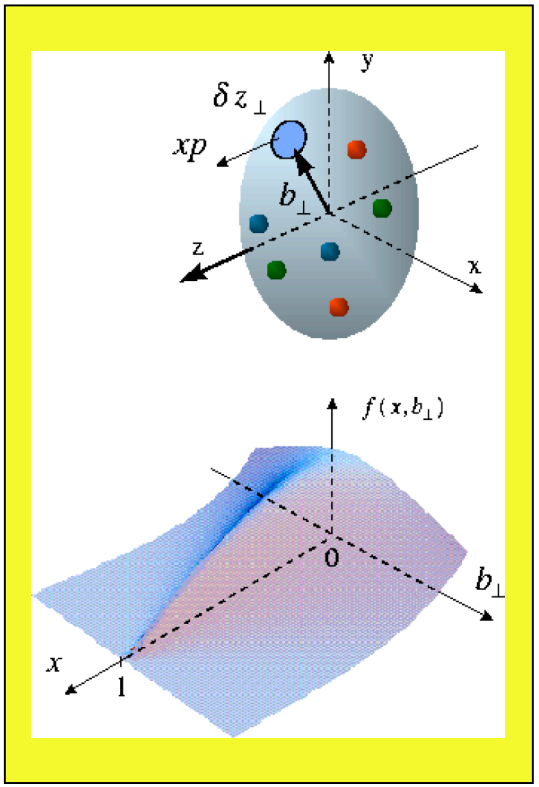
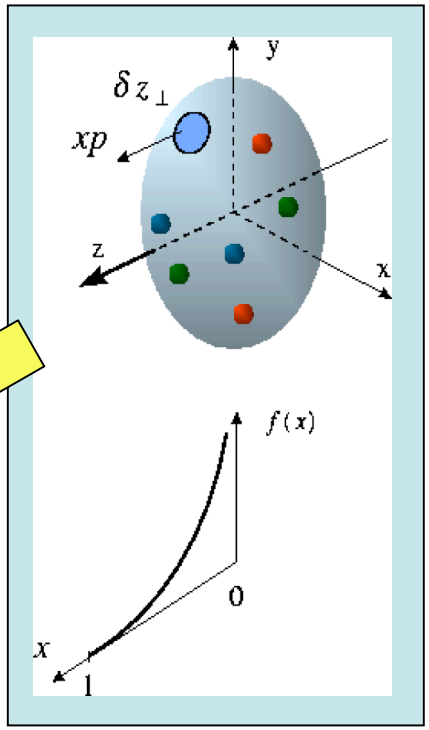
Generalized Parton Distributions (GPDs)

X. Ji, D. Mueller, A. Radyushkin (1994-1997)







Proton form factors, transverse charge & current densities

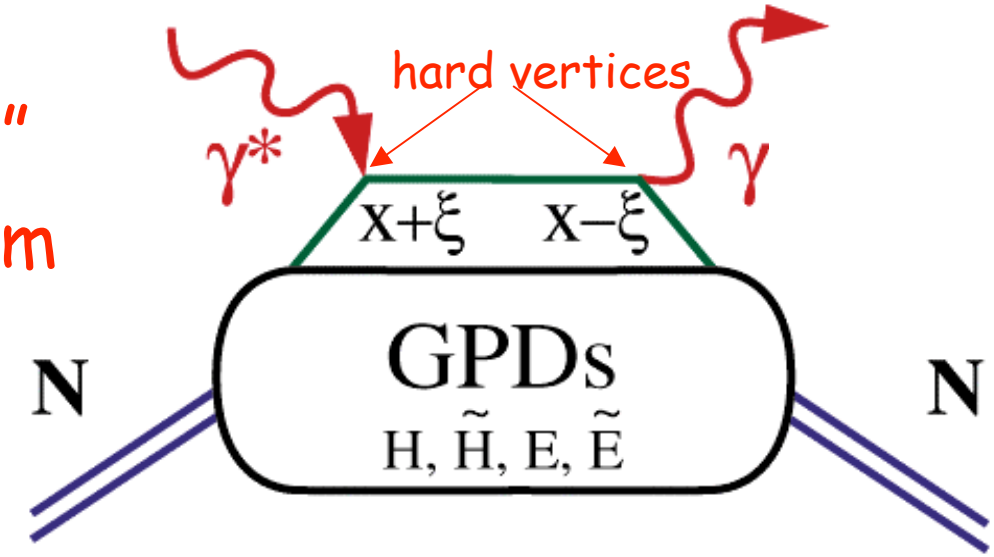
Correlated quark momentum and helicity distributions in transverse space - GPDs

Structure functions, quark longitudinal momentum & helicity distributions

Generalized Parton Distributions (GPDs):

Deeply Virtual Compton Scattering (DVCS)

"handbag" mechanism



x – quark momentum fraction
ξ – longitudinal momentum transfer
√-t – Fourier conjugate to transverse impact parameter

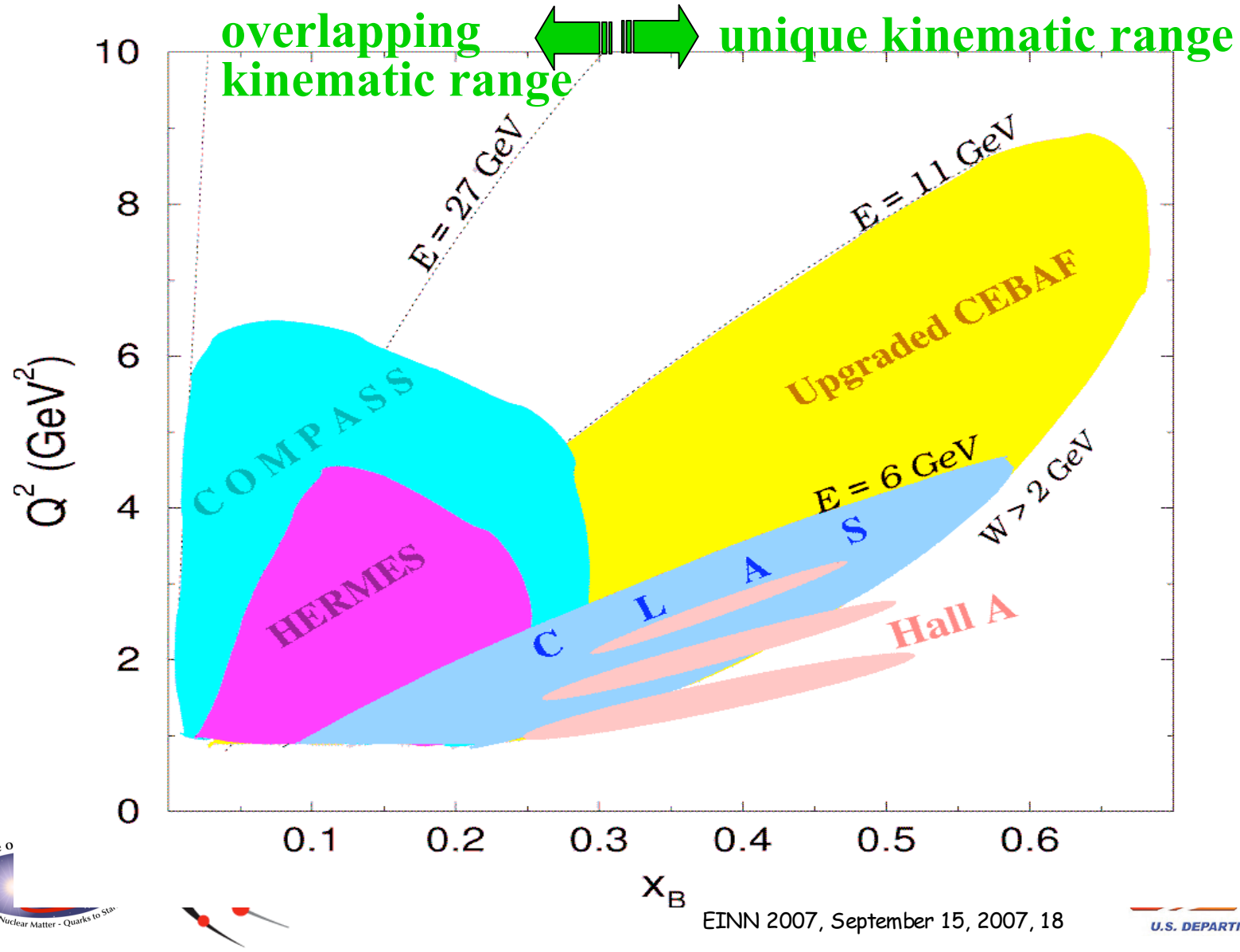
e.g.

Quark angular momentum (Ji's sum rule)

$$J^q = \frac{1}{2} - J^G = \frac{1}{2}\int_{-1}^{1} x dx \left[H^q(x,\xi,0) + E^q(x,\xi,0) \right]$$

X. Ji, Phy.Rev.Lett.78,610(1997)

Kinematics for deeply exclusive experiments

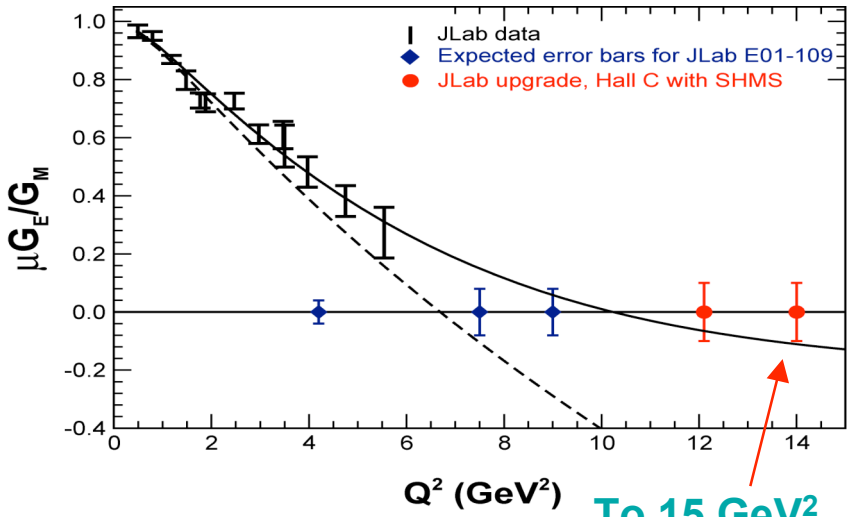


Experiments at 11 GeV will extend EMFF data

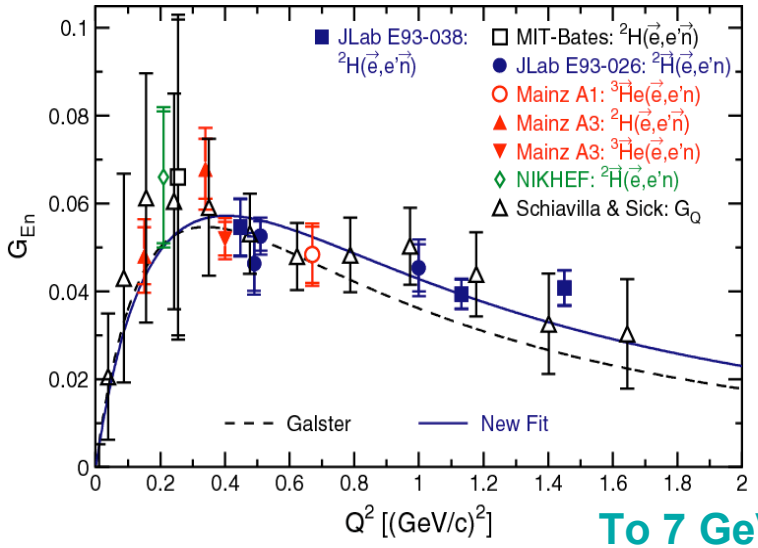
Proton

Neutron

Electric

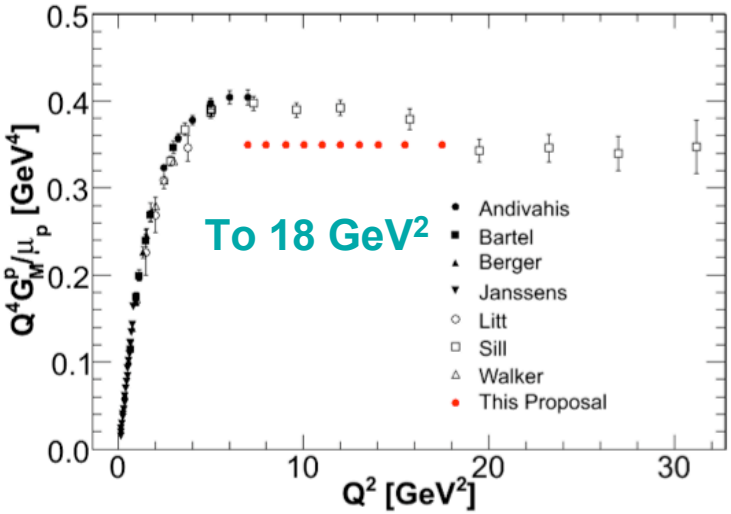


To 15 GeV^2



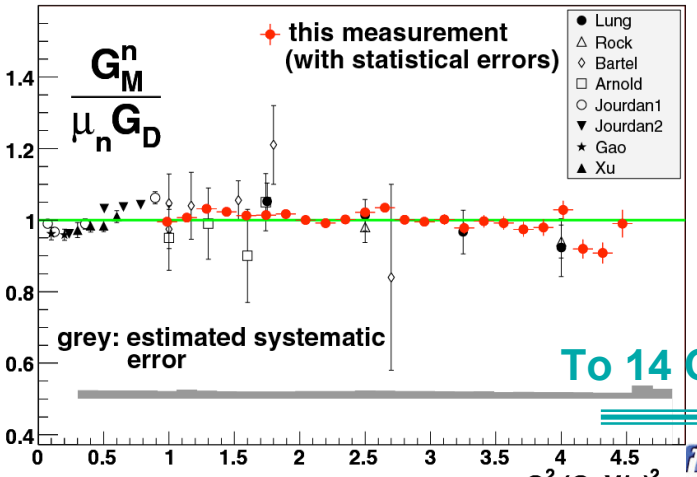
To 7 GeV^2

Magnetic



To 18 GeV^2

Selected World Data



To 14 GeV^2

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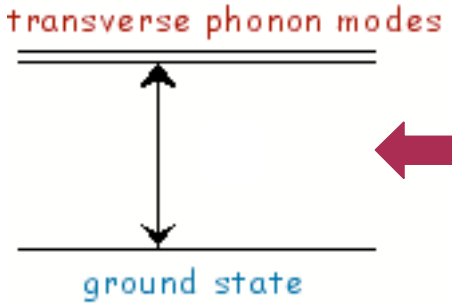
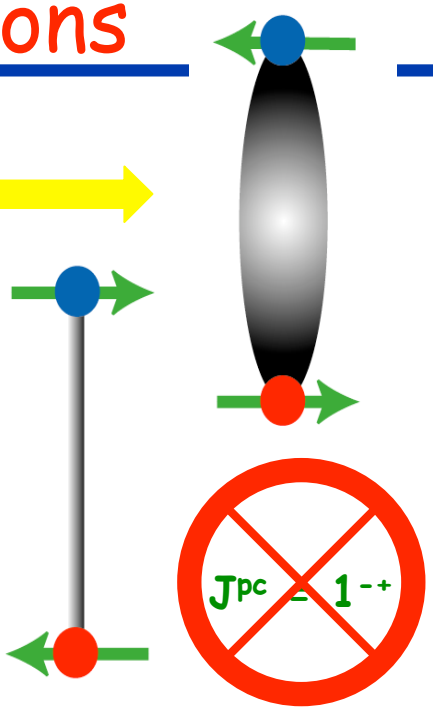
Hybrid mesons and mass predictions

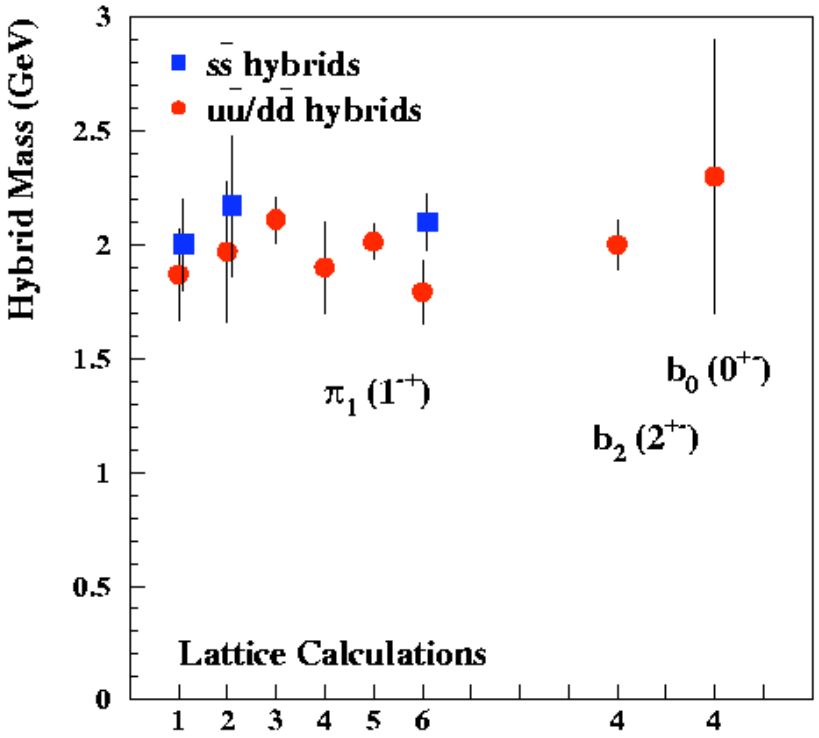


Hybrid mesons

1 GeV mass difference

Normal mesons





Lattice

1^{-+} 1.9 GeV

2^{+-} 2.1 GeV

0^{+-} 2.3 GeV

Lowest mass expected to be $\pi_1(1^{-+})$ at 1.9±0.2 GeV

Physics goals and key features

The physics goal of GlueX is to map the spectrum of hybrid mesons starting with those with the unique signature of exotic J^{PC}

Identifying J^{PC} requires an amplitude analysis which in turn requires

- ➔ linearly polarized photons
- ➔ detector with excellent acceptance and resolution
- ➔ sensitivity to a wide variety of decay modes

Final states include photons and charged particles and require particle identification

⇨ Hermetic detector with large acceptance for charged and neutral particles

In addition, sensitivity to hybrid masses up to 2.5 GeV requires 9 GeV photons which will be produced using coherent bremsstrahlung from 12 GeV electrons

Examples of the 12 GeV Upgrade Research

- Parton Distribution Functions
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- Exotic Meson Spectroscopy:
  Confinement and the QCD vacuum
- **Nuclei at the level of quarks and gluons**
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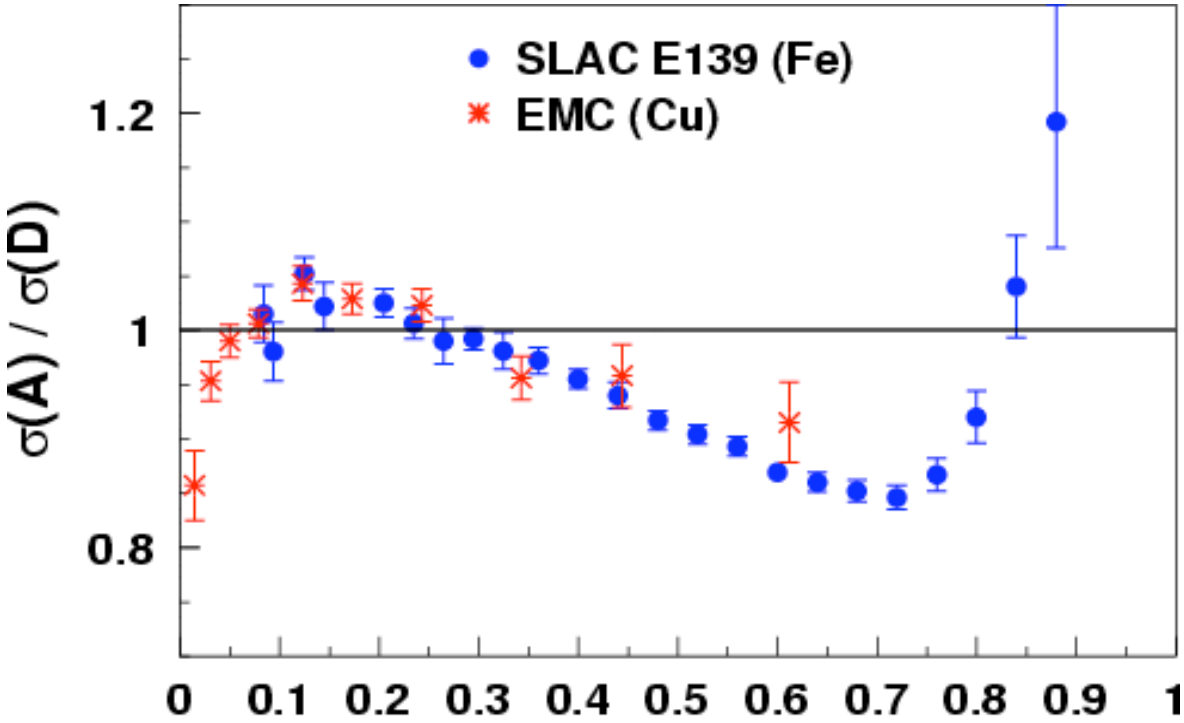
The EMC Effect: Nuclear PDFs

- Observation stunned and electrified the HEP and Nuclear communities 20 years ago
- Nearly 1,000 papers have been generated…..
- What is it that alters the quark momentum in the nucleus?



J. Ashman *et al.*, Z. Phys. C57, 211 (1993)

J. Gomez *et al.*, Phys. Rev. D49, 4348 (1994)

Unpacking the EMC effect

- With 12 GeV, we have a variety of tools to unravel the EMC effect:
  - → Parton model ideas are valid over fairly wide kinematic range
  - → High luminosity
  - → High polarization

- New experiments, including several major programs:
  - → Precision study of A-dependence; $x>1$; valence vs. sea
  - → $g_{1A}(x)$ "Polarized EMC effect" – influence of nucleus on spin
  - → Flavor-tagged polarized structure functions $\Delta u_A(x_A)$ and $\Delta d_A(x_A)$
  - → x dependence of axial-vector current in nuclei (can study via parity violation)
  - → Nucleon-tagged structure functions from ^{2}H and ^{3}He
  - → Study x-dependence of exclusive channels on light nuclei, sum up to EMC

12 GeV Upgrade: Phases and Schedule

- 2004-2005 Conceptual Design (CDR) - ***finished***
- 2004-2008 Research and Development (R&D) - ***ongoing***
- 2006 Advanced Conceptual Design (ACD) - ***finished***
- 2006-2008 Project Engineering & Design (PED) - ***ongoing***
- 2009-2013 Construction – ***starts in ~14 months!***
  - ***Accelerator shutdown start mid 2012***
  - ***Accelerator commissioning mid 2013***
- ***2013-2015 Pre-Ops (beam commissioning)***
  - ***Hall commissioning start late 2013***

DOE Generic Project Timeline

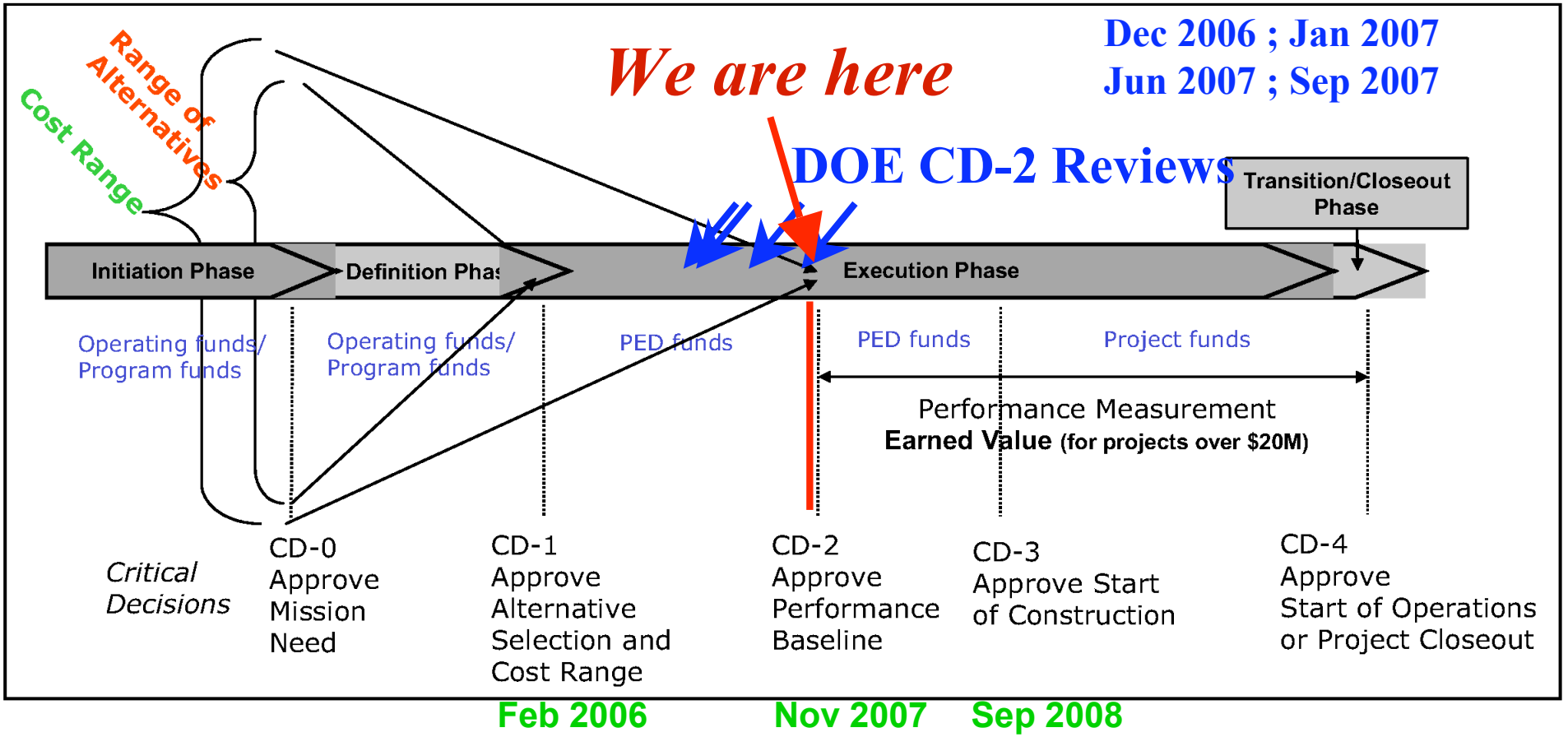
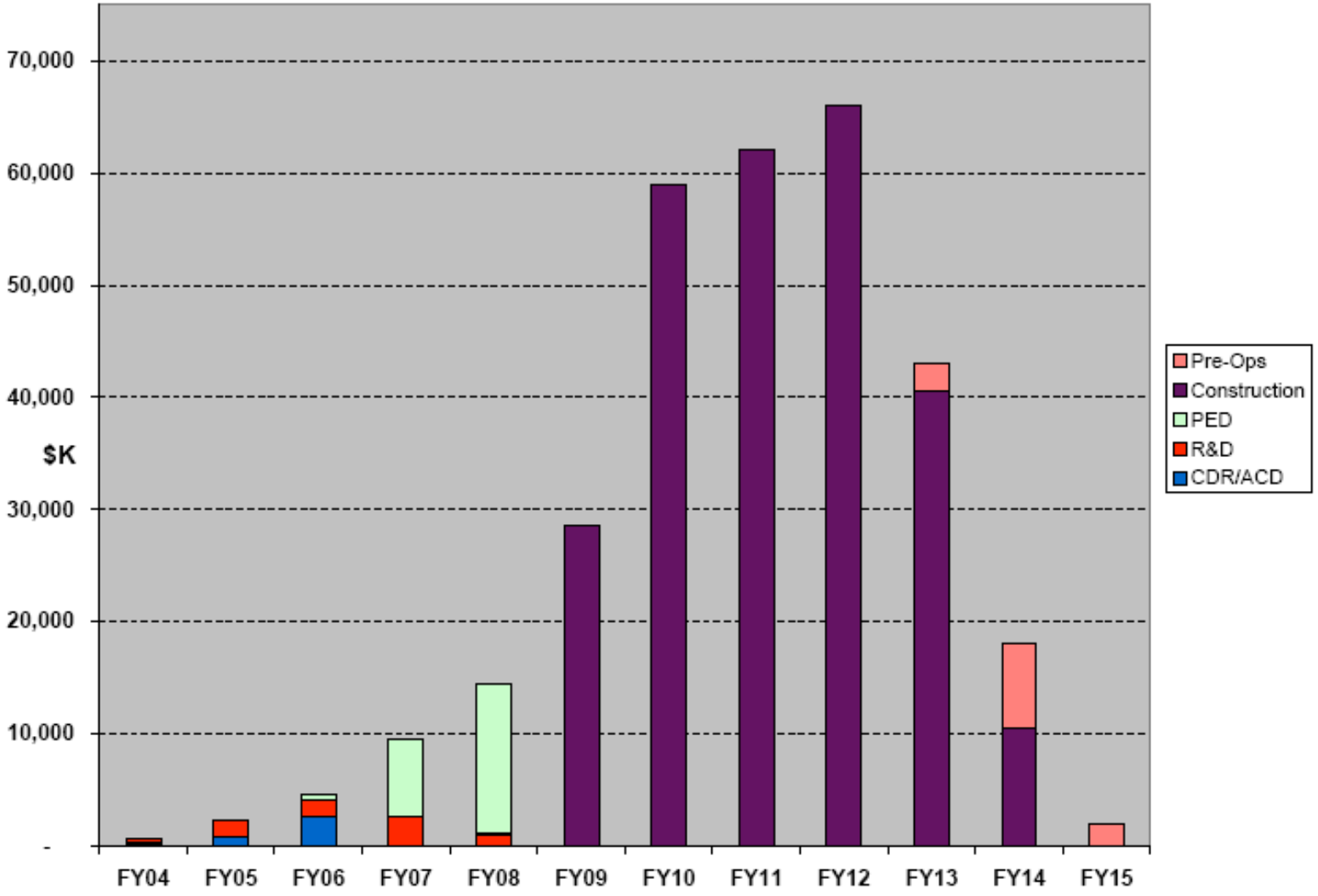


Figure 1-1. DOE Acquisition Management System.

12 GeV Funding Profile



Future tools for hadron physics

- ✓ JLab-12
- ✓ PANDA
- ✓ J-PARC

Each presents an important part of the same hadron world

User communities, which run experiments at these facilities, could benefit from larger overlap, collaborations, extended trips

12-GeV JLab and PANDA

- ✓ **Complement in physics, e.g.**

$$p\gamma \rightarrow p\gamma \text{ and } p\bar{p} \rightarrow \gamma\gamma$$

- ✓ **Complement in theory - GPDs**

- ✓ **We can/should extend joint efforts into detector/target technology and experimental proposals/analysis, e.g.**

GEM based tracking, large size polarized NH_3 target.

Summary

- The Upgrade to 12 GeV at JLab is well underway (preparing for CD-2 review this month!) with strong support from the Nuclear Physics LRP

- It will allow ground-breaking studies of
  - → the structure of the nucleon
  - → exotic mesons and the origin of confinement
  - → the QCD basis of nuclear structure
  - → the Standard Model at the multi-TeV scale

- The world-wide hadron physics community will have a great tool

Many thanks to
Greece and
EINN-2007