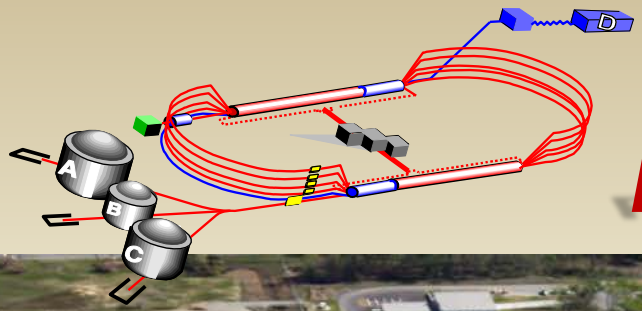
U.S. DEPARTMENT OF ENERGY | Office of Science | JSA




# Jefferson Lab
# *Future Science Program*

R. D. McKeown

NSAC Presentation
November 17, 2014

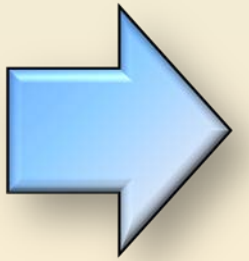
Jefferson Lab
Thomas Jefferson National Accelerator Facility

# Outline

- JLab context in Nuclear Physics
- 12 GeV CEBAF
  - Upgrade status
  - Science Program:

New

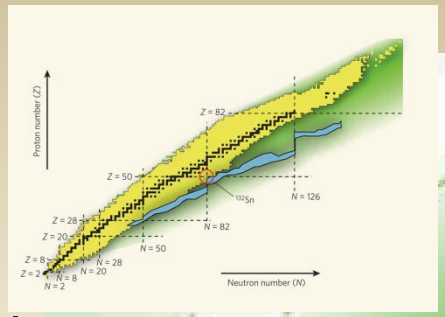
Phenomenology
Techniques (theory+exp)
Standard model tests



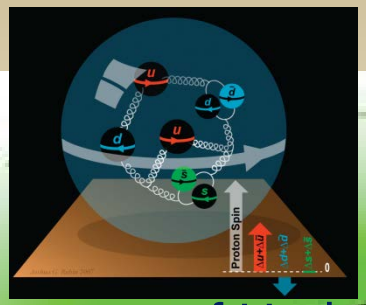
**Discovery Potential**

- Future new capability: MEIC
- Outlook

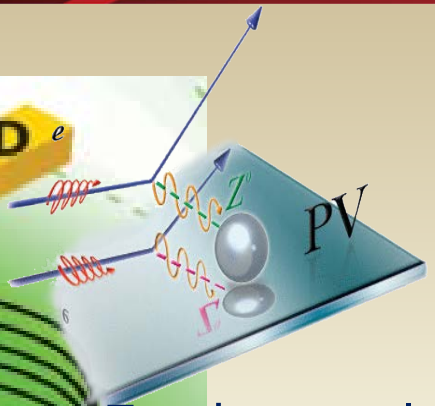
# A Laboratory for Nuclear Science




Nuclear Structure



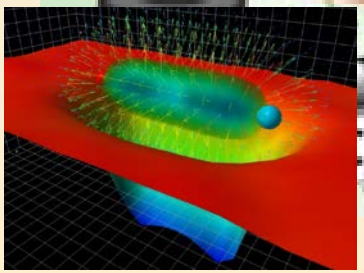

Structure of Hadrons



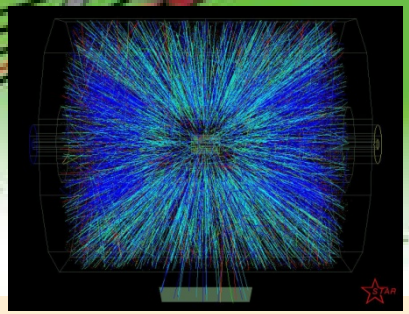

Fundamental
Forces & Symmetries

Medical Imaging

Accelerator S&T



Quark Confinement

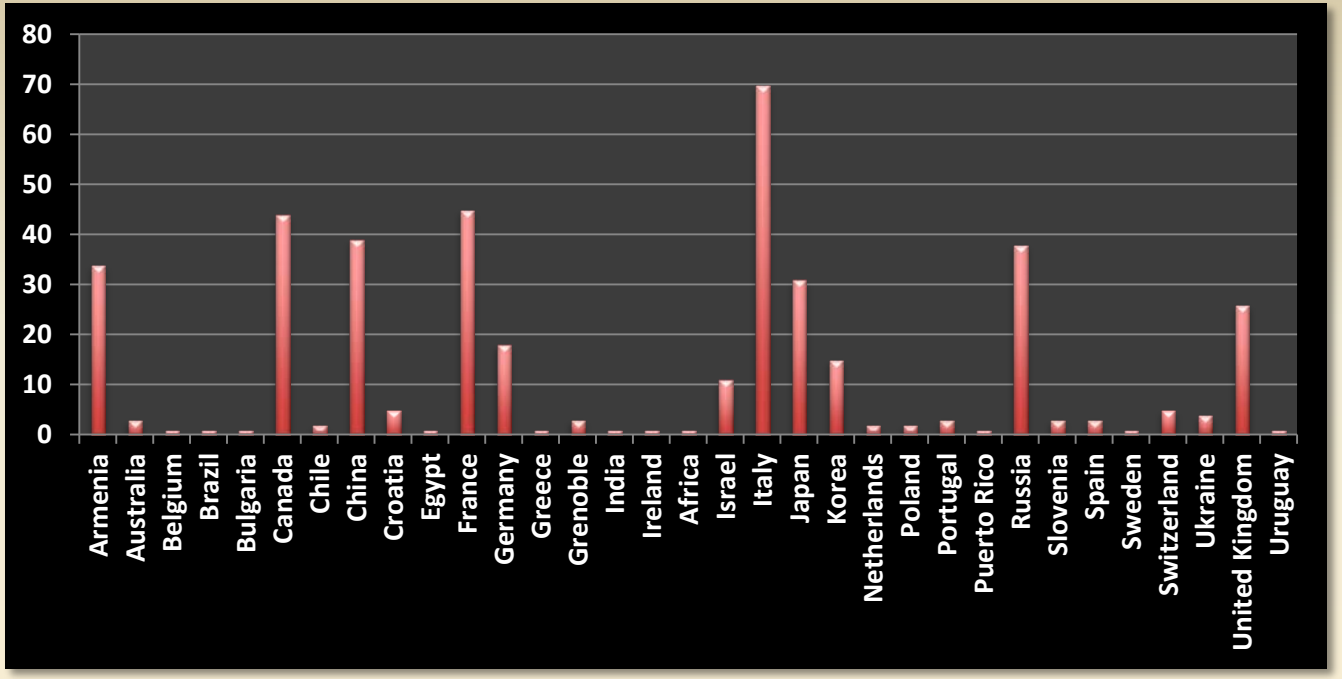


Hadrons from Quarks

Theory and Computation

# International Jefferson Lab

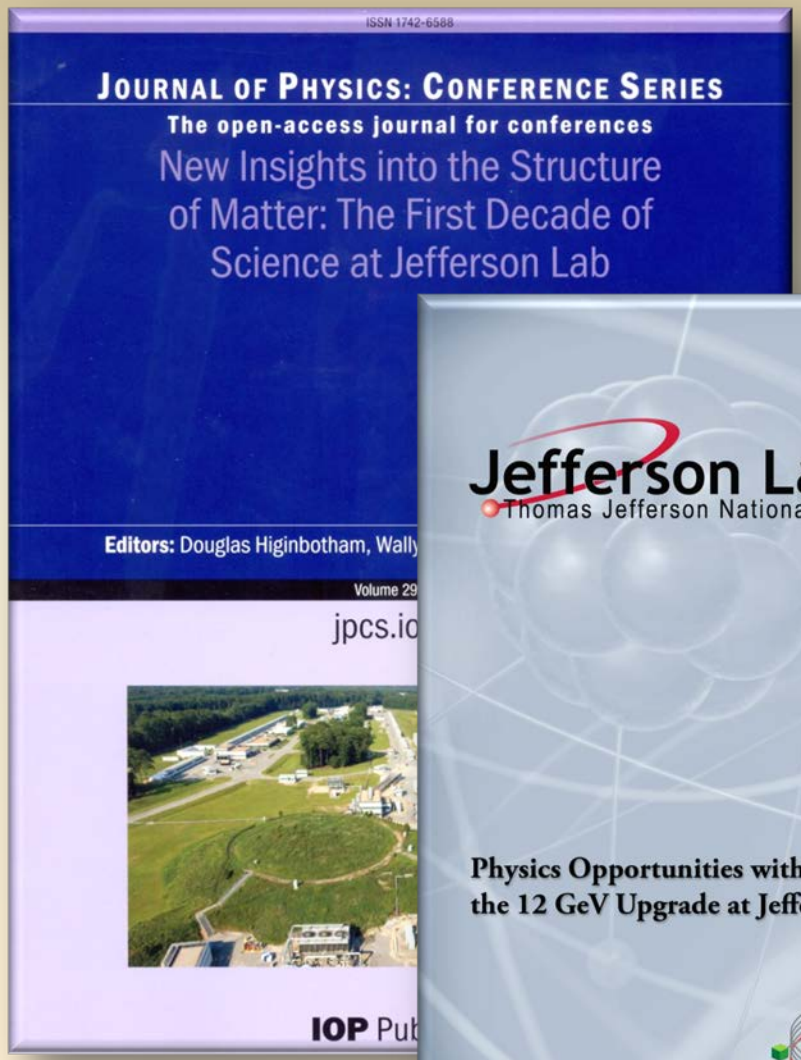
## ~1300 Users, 1/3 from 33 Foreign Countries




## Non-US Accelerator Collaborations, 14+ Institutions from 10+ Countries

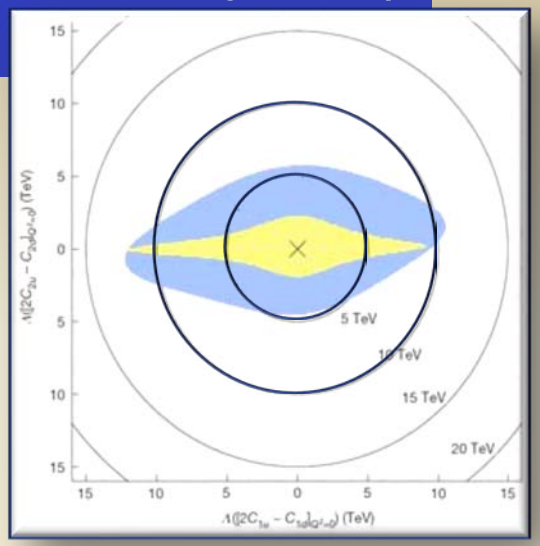
- Canada (1)
- China (1)
- France (1)
- India (1)
- Germany (3)
- Mexico (1)
- Multi-country (2)
- Russia (1)
- Sweden (1)
- Switzerland (1)
- UK (1)

# Scientific Results

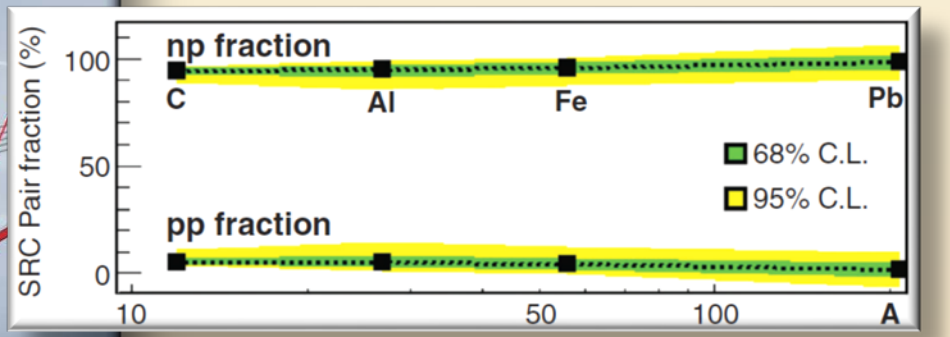




*Nature* 506, 67–70 (06 February 2014)
**Parity Violating DIS**



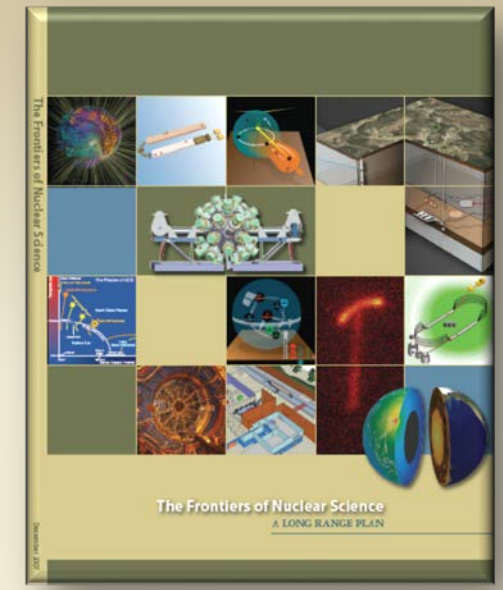

*Science* 346, 614 (October 2014)
**Short Range NN Correlations**



# *JLab:* 21st Century Science Questions

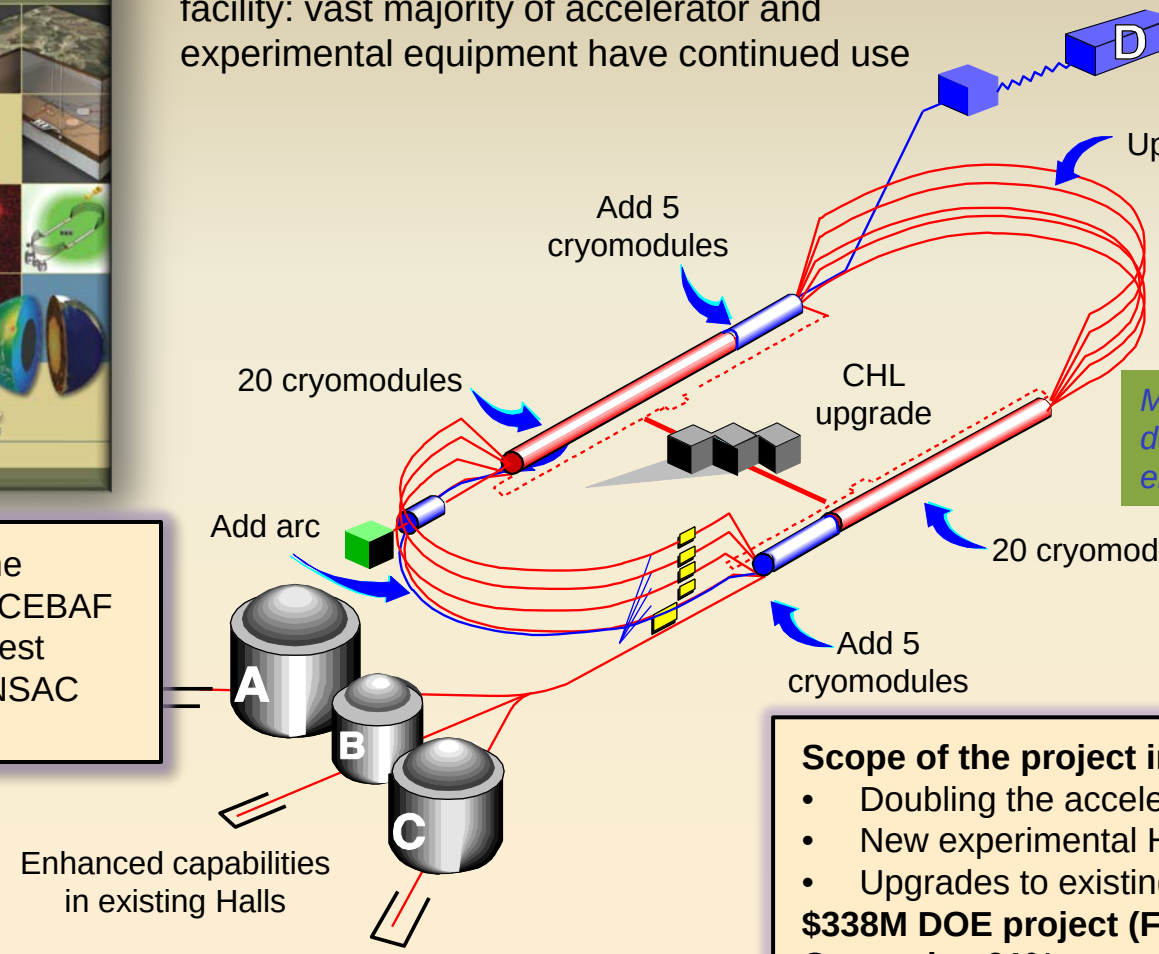
- What is the role of gluonic excitations in the spectroscopy of light mesons? Can these excitations elucidate the origin of quark confinement?
- Where is the missing spin in the nucleon? Is there a significant contribution from valence quark orbital angular momentum?
- Can we reveal a novel landscape of nucleon substructure through measurements of new multidimensional distribution functions?
- What is the relation between short-range N-N correlations , the partonic structure of nuclei, and the nature of the nuclear force?
- Can we discover evidence for physics beyond the standard model of particle physics?

# 12 GeV Upgrade Project




The completion of the 12 GeV Upgrade of CEBAF was ranked the highest priority in the 2007 NSAC Long Range Plan.

Upgrade is designed to build on existing facility: vast majority of accelerator and experimental equipment have continued use




*Maintain capability to deliver lower pass beam energies: **2.2, 4.4, 6.6….***

**Scope of the project includes:**

- Doubling the accelerator beam energy
- New experimental Hall and beamline
- Upgrades to existing Experimental Halls

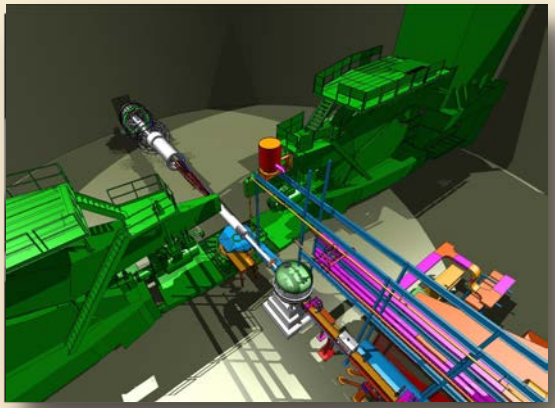
**$338M DOE project (FY09-17)**
**Currently ~91% complete**
**Beam Commissioning in progress**

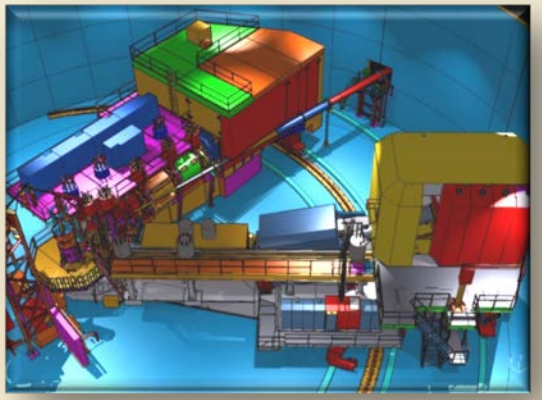
# 12 GeV Scientific Capabilities

*Hall D* – exploring origin of confinement by studying exotic mesons

*Hall B* – understanding nucleon structure via generalized parton distributions

*Hall C* – precision determination of valence quark properties in nucleons and nuclei

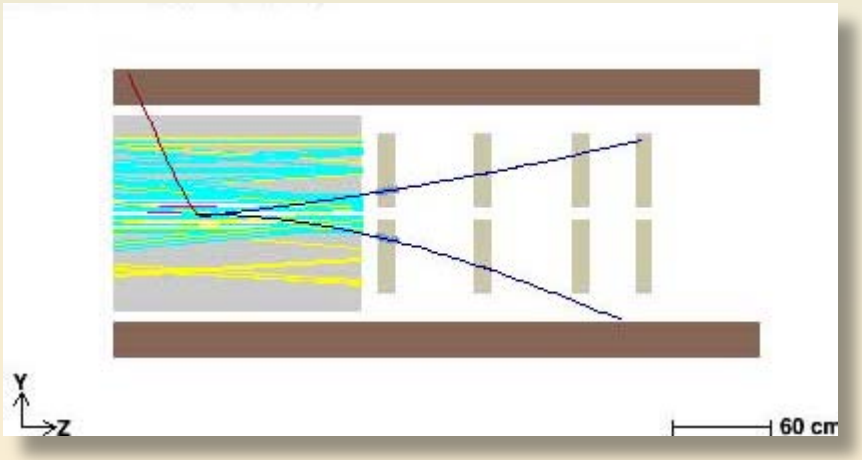


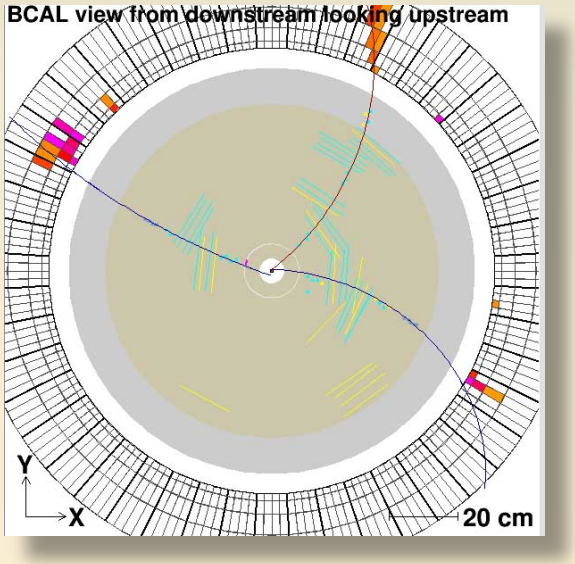


*Hall A* –form factors, future new experiments (e.g., SoLID and MOLLER)

# 12 GeV Commissioning Progress

- Achieved CD-4A milestone (accelerator commissioning) 5 months before scheduled
- Delivered 10.5 GeV beam to Hall D radiator, first photon induced events observed in GlueX!

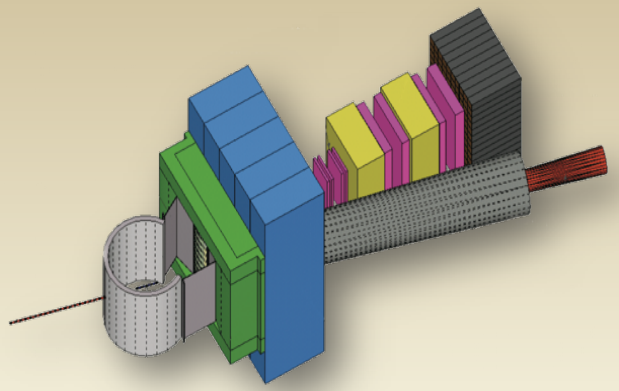


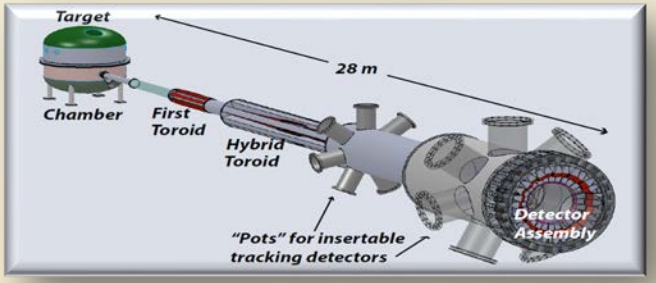

- Simultaneous beam to Hall A, B and D in progress
- Hope for FY15 physics production running in A,B and D (budget)

# Additional Experimental Equipment

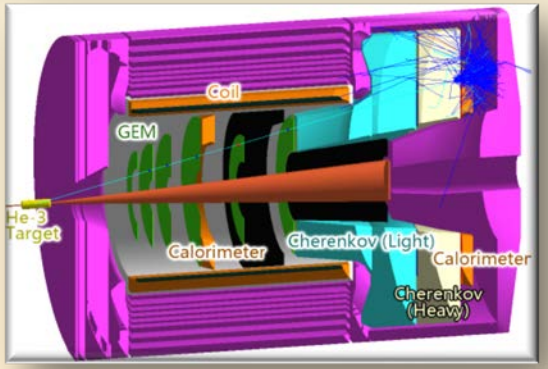
- Super BigBite Spectrometer (FY13-16 construction)
  - High $Q^2$ form factors
  - SIDIS



- MOLLER experiment (MIE – FY17-19?)
  - Standard Model Test
  - Successful Science Review




- SoLID
  - SIDIS and PVDIS
  - Chinese collaboration
  - CLEO Solenoid



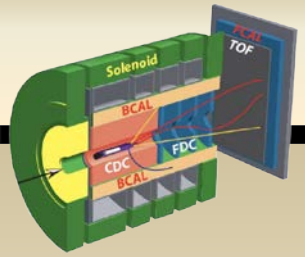
# 12 GeV Approved Experiments by Physics Topics

| Topic | Hall A | Hall B | Hall C | Hall D | Other | Total |
|---|---|---|---|---|---|---|
| The Hadron spectra as probes of QCD (GlueX and heavy baryon and meson spectroscopy) | | 1 | | 3 | | 4 |
| The transverse structure of the hadrons (Elastic and transition Form Factors) | 5 | 3 | 2 | 1 | | 11 |
| The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions) | 2 | 3 | 6 | | | 11 |
| The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions) | 5 | 9 | 7 | | | 21 |
| Hadrons and cold nuclear matter (Medium modification of the nucleons, quark hadronization, N-N correlations, hypernuclear spectroscopy, few-body experiments) | 6 | 3 | 7 | | 1 | 17 |
| Low-energy tests of the Standard Model and Fundamental Symmetries | 3 | 1 | | 1 | 1 | 6 |
| TOTAL | 21 | 20 | 22 | 5 | 2 | 70 |

**A Decade of Experiments**

# 12 GeV Approved Experiments by PAC Days

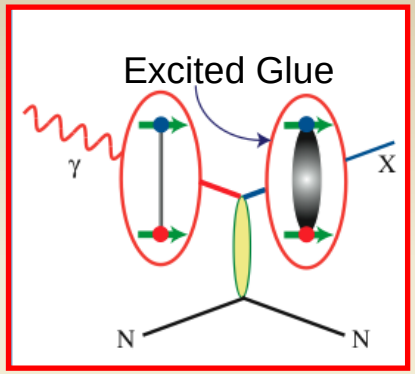
| Topic | Hall A | Hall B | Hall C | Hall D | Other | Total |
|---|---|---|---|---|---|---|
| The Hadron spectra as probes of QCD (GlueX and heavy baryon and meson spectroscopy) | | 119 | | 540 | | 695 |
| The transverse structure of the hadrons (Elastic and transition Form Factors) | 145.5 | 85 | 102 | 25 | | 357.5 |
| The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions) | 65 | 230 | 165 | | | 460 |
| The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions) | 409 | 872 | 212 | | | 1493 |
| Hadrons and cold nuclear matter (Medium modification of the nucleons, quark hadronization, N-N correlations, hypernuclear spectroscopy, few-body experiments) | 180 | 175 | 201 | | 14 | 570 |
| Low-energy tests of the Standard Model and Fundamental Symmetries | 547 | 205 | | 79 | 60 | 891 |
| TOTAL | 1346.5 | 1686 | 680 | 644 | 74 | 4430.5 |




# Hybrid Mesons

GlueX Experiment Citations
Hall D@JLab

**Quarks** ⊕ **Excited Gluon Field** → **Hybrid Meson**




$$S = 1$$
$$L = 0$$
$$J^{PC} = 1^{--}$$

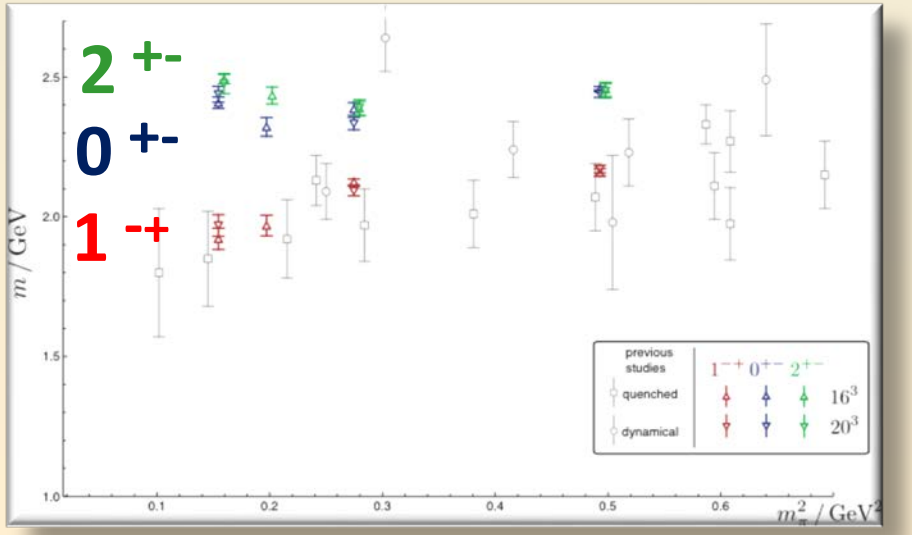
$$J^{PC} = \begin{cases} 1^{+-} \\ 1^{-+} \end{cases}$$

**Exotic**

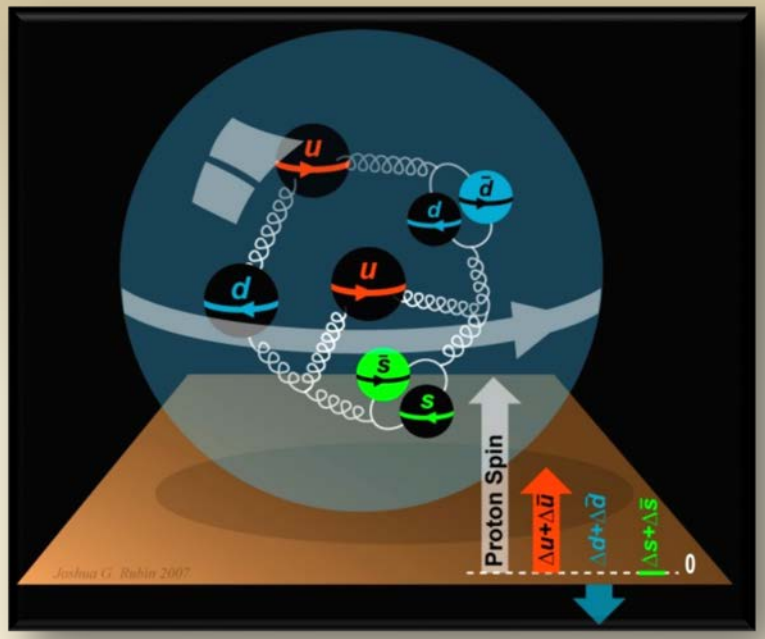
$$J^{PC} = \begin{cases} 0^{-+} & \mathbf{1^{-+}} & 2^{-+} \\ \mathbf{0^{+-}} & 1^{+-} & \mathbf{2^{+-}} \end{cases}$$

**Gluonic excitation (and parallel quark spins) lead to exotic $J^{PC}$**

**Recent LQCD results predict the existence and masses of these hybrid mesons**

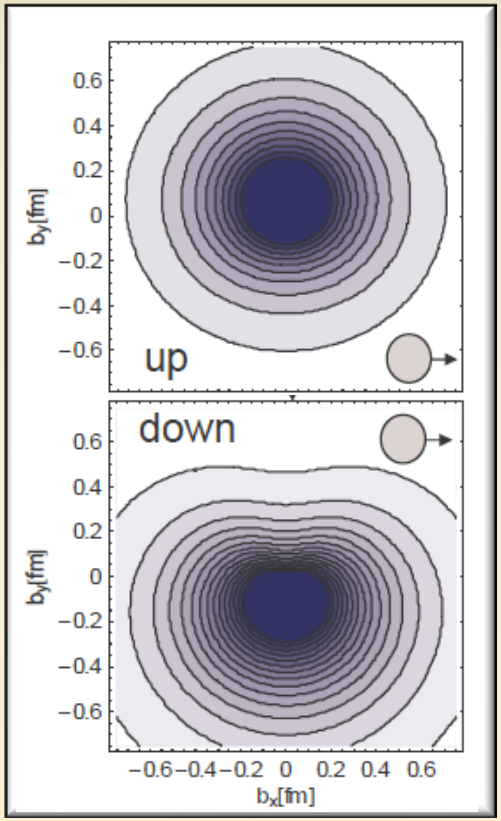


# The Incomplete Nucleon: Spin Puzzle



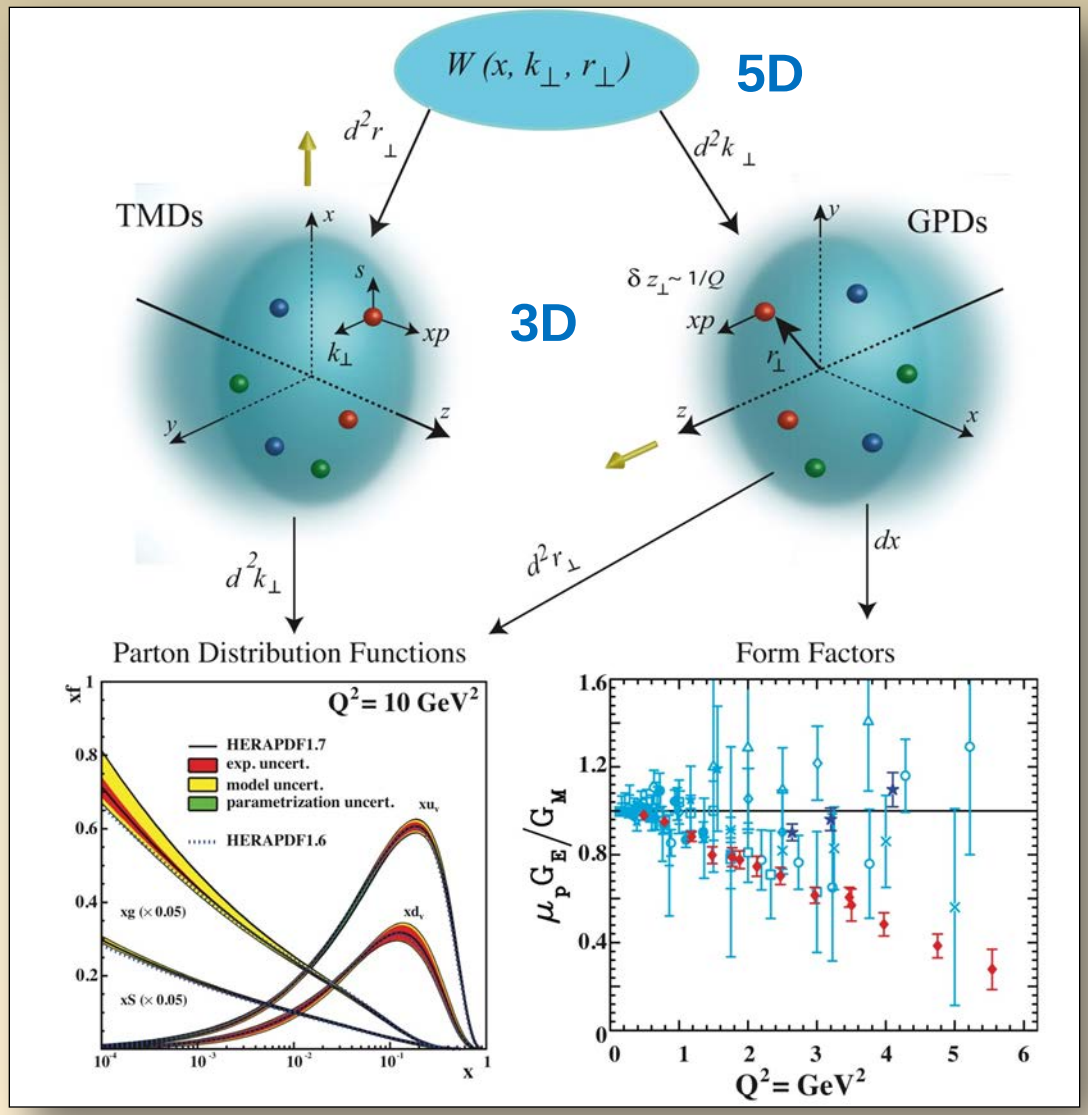

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g$$

[X. Ji, 1997]




- **DIS → $\Delta\Sigma \cong 0.25$**
- **RHIC + DIS → $\Delta G \sim 0.2$**
- **→ $L_q$**

# New Paradigm for Nucleon Structure




- TMDs
  - Confined motion in a nucleon (semi-inclusive DIS)
- GPDs
  - Spatial imaging (exclusive DIS)
- Requires
  - High luminosity
  - Polarized beams and targets

**Major new capability with JLab12**

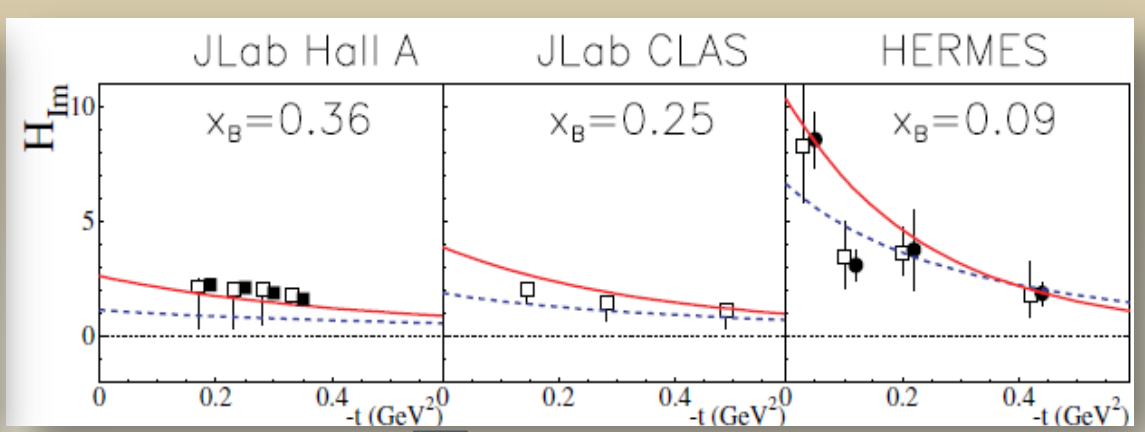
# The First Crude Images

## the GPD H in *Im* DVCS

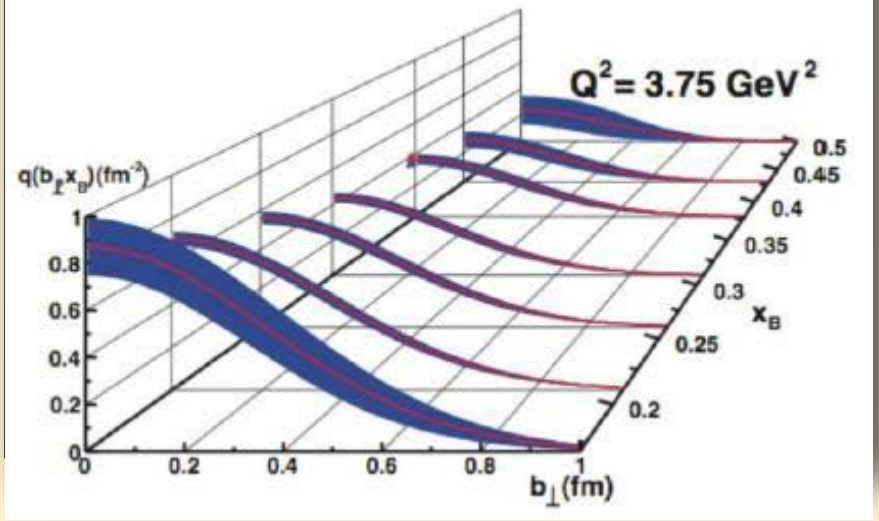
●○■□ Different local fits

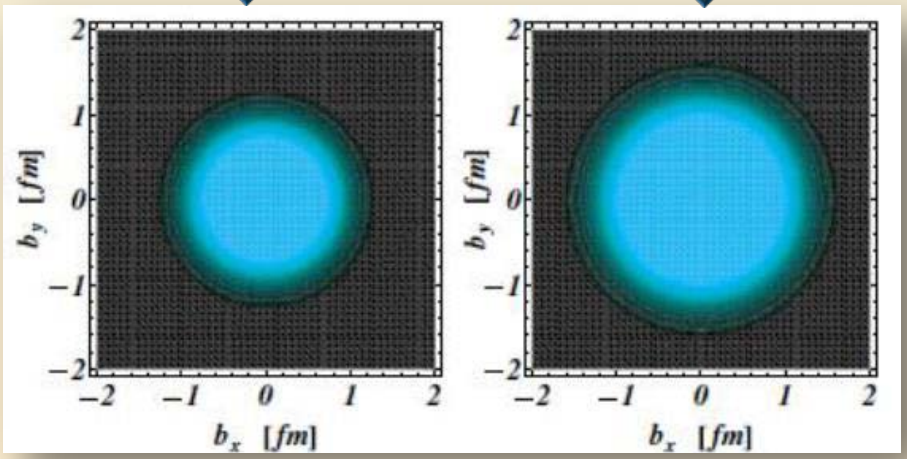
VGG model

KM10 global fit on the world data ranging from H1,ZEUS to HERMES, JLab



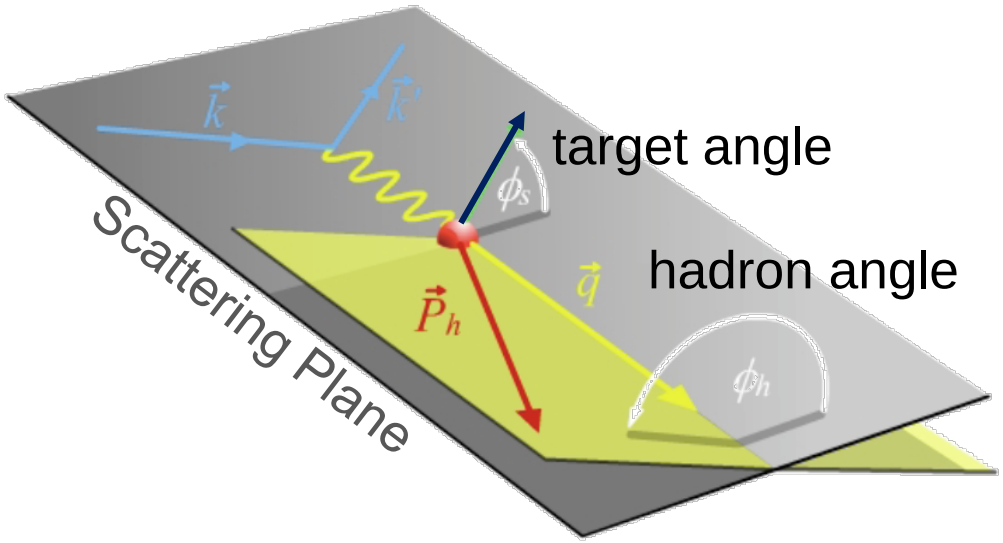

## Projection for JLab 12 GeV



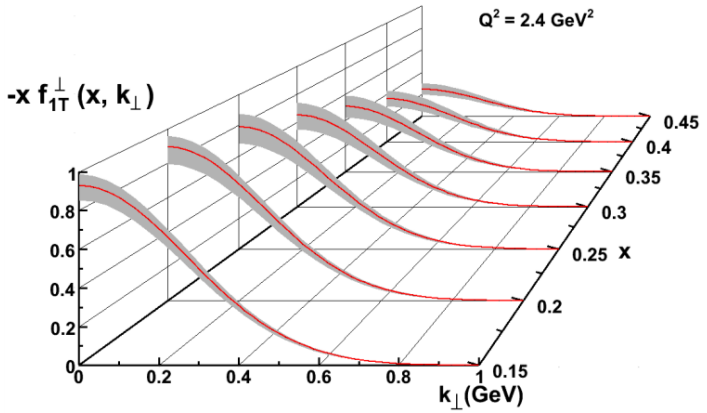



# SIDIS Electroproduction of Pions

- Separate Sivers and Collins effects



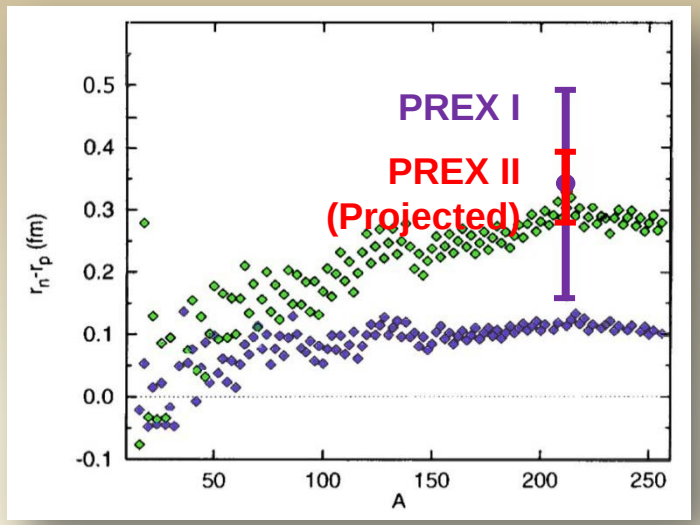

- Previous data from HERMES,COMPASS
- New landscape of TMD distributions
- Access to orbital angular momentum




- **Sivers** angle, effect in distribution function: $(\phi_h - \phi_s)$
- **Collins** angle, effect in fragmentation function: $(\phi_h + \phi_s)$

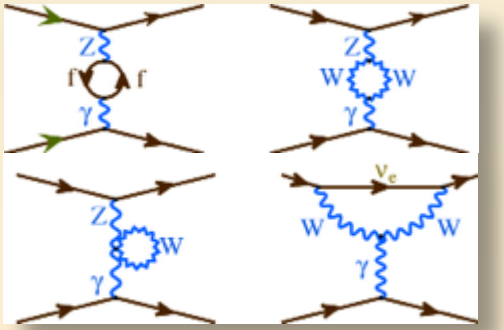
# Parity Violation at JLab

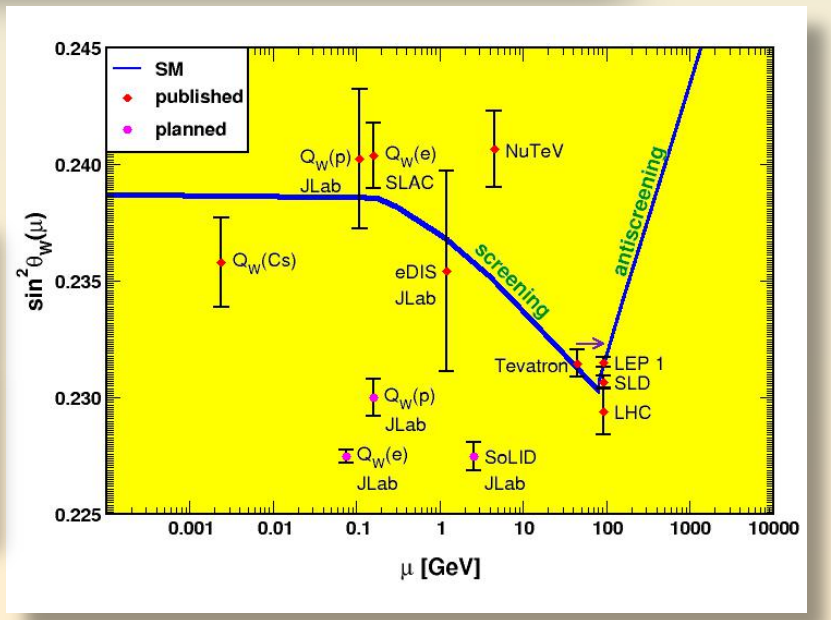
- Strangeness Form Factors (complete)
  - HAPPEX (Hall A)
  - G0 (Hall C)
- PREX, CREX
  neutron skin in Pb, Ca nuclei
- Qweak (under analysis)
- MOLLER
- SoLID




Relativistic mean field

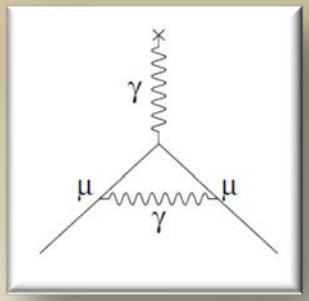
Nonrel. skyrme

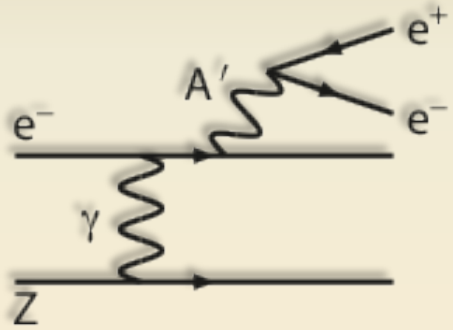


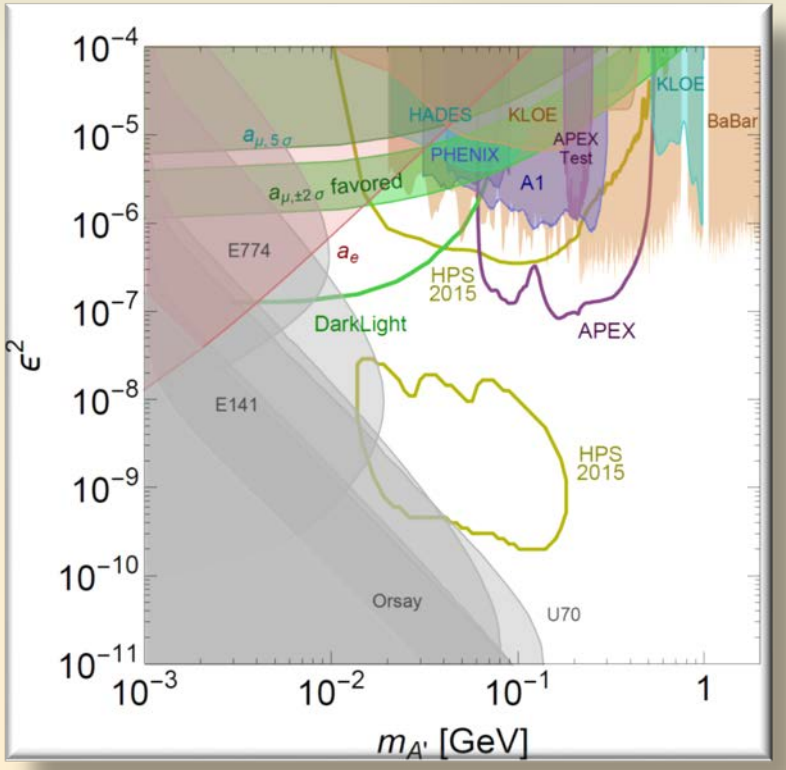
# New Opportunity: Search for A' at Jefferson Lab

- BNL "g-2" expt: $\Delta a_\mu$(expt-thy) = (295±88) x $10^{-11}$ (3.4 $\sigma$)
- No evidence for SUSY at LHC (yet)
- Another solution: A', a massive neutral vector boson




  - Also useful for dark matter models

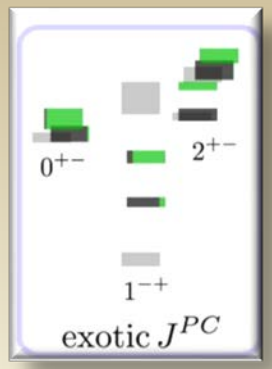


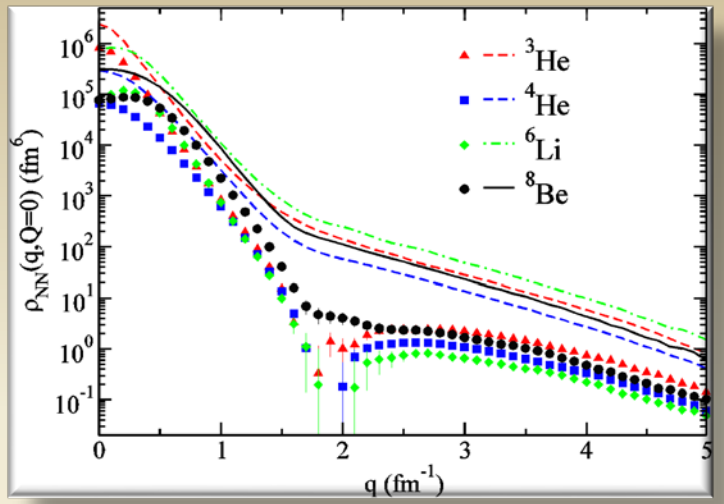

- 3 Jefferson Lab proposals:

- APEX test run (Hall A) – published PRL 107, 191804 (2011)
- HPS (Hall B) – installed for FY15 run
- DarkLight (FEL) – NSF-MRI funds

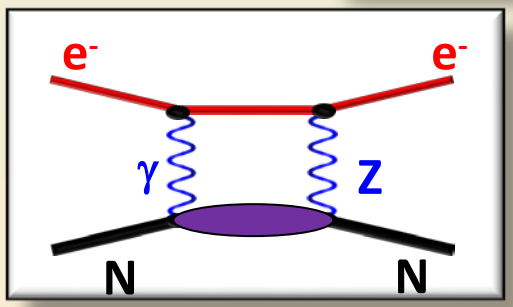
# Jefferson Lab Nuclear Theory

- Lattice QCD



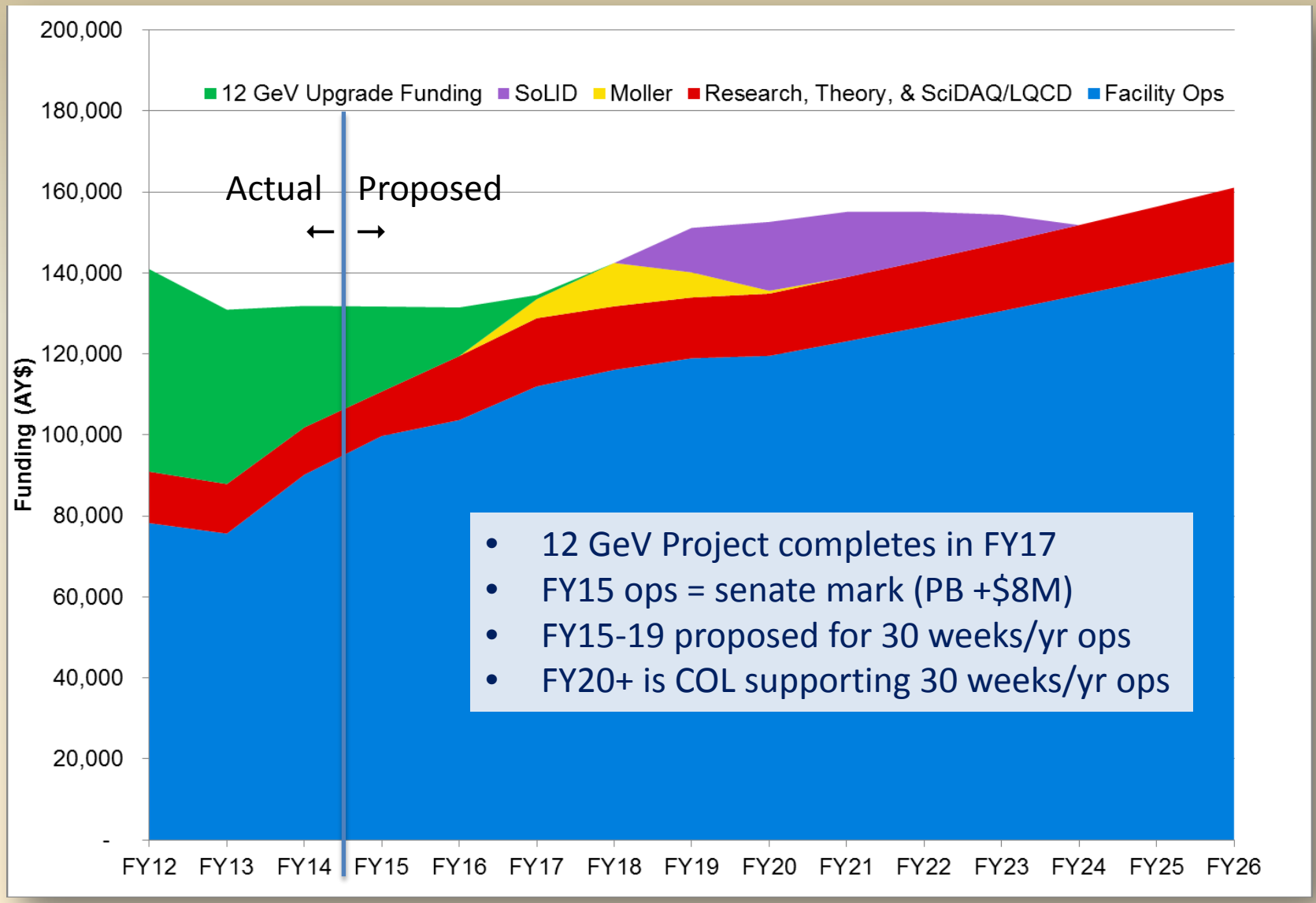

- Phenomenology
  - → Physics Analysis Center
- Nuclear Structure




- Electroweak

➢ **Strong support for experimental program**
➢ **An intellectual center for a global theory effort**

# Jefferson Lab NP Funding Projection (AY$)



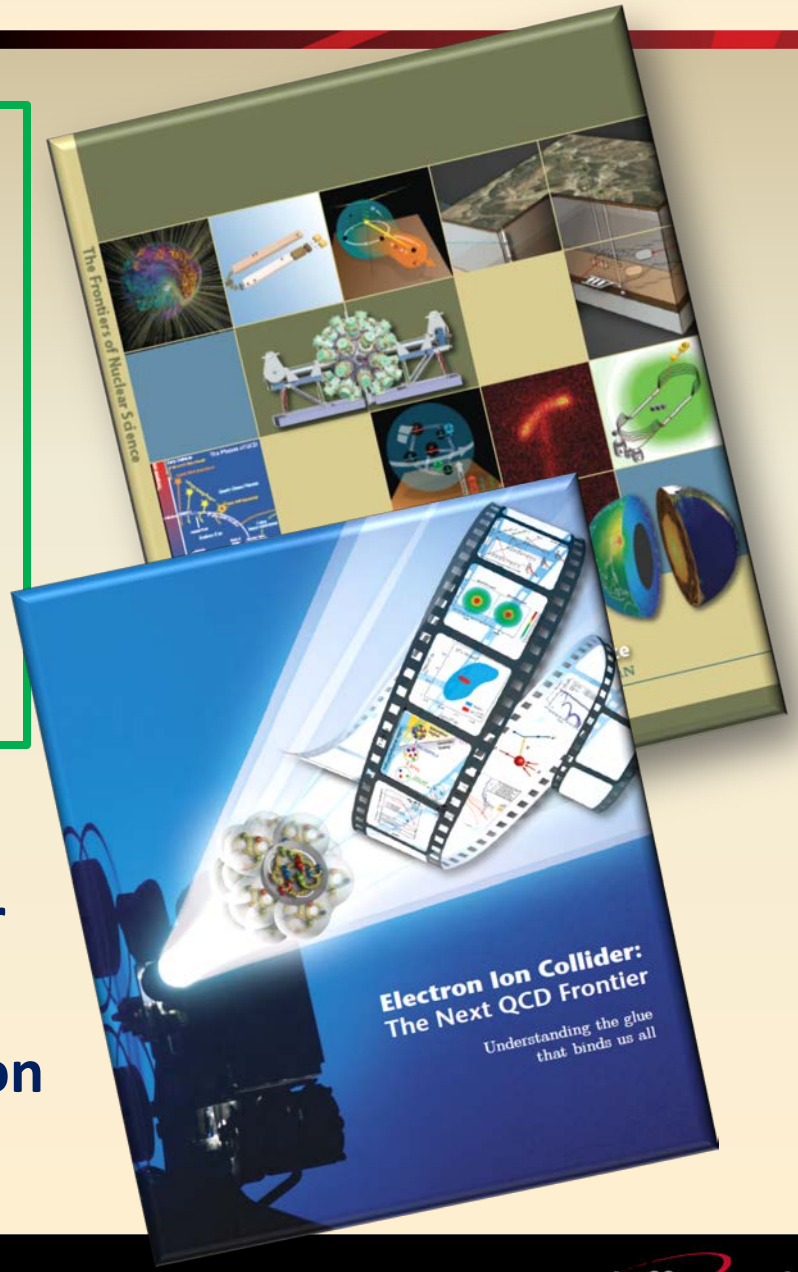
# 12 GeV JLab – The Potential

- Opportunity to discover and study new exotic mesons to elucidate the mechanism of confinement.
- Open a new landscape of nucleon tomography, with potential to identify the missing angular momentum.
- Establish the quantitative foundation for the short-distance behavior in nuclei, underpinning the development of precision nuclear structure studies.
- Provide stringent new tests of the standard model and extensions, complementing the information obtained at LHC.
- Establish a firm basis for higher energy studies with a future **Electron Ion Collider**

# Electron Ion Collider

**NSAC 2007 Long-Range Plan:**

"An **Electron-Ion Collider (EIC)** with **polarized** beams has been **embraced by the U.S. nuclear science community** as embodying the vision for **reaching the next QCD frontier**. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide and complementary to those planned for the next generation of accelerators in Europe and Asia."

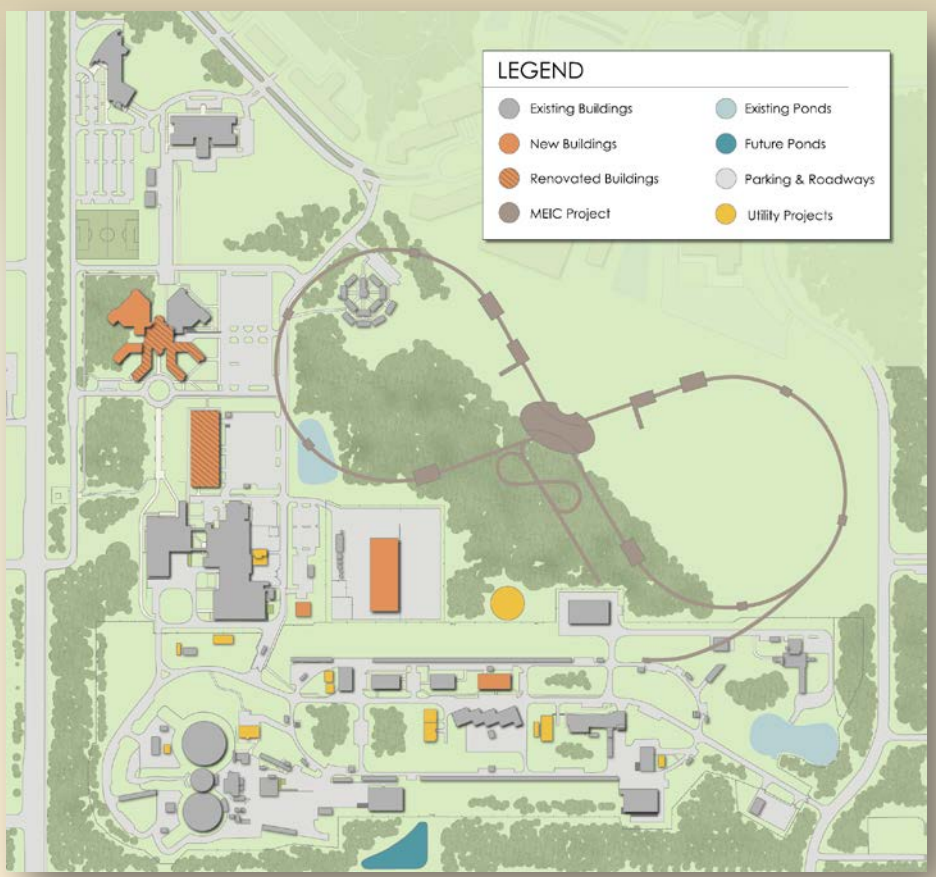



**EIC Community White Paper**
**arXiv:1212.1701**
**Updated version coming soon**

# Medium Energy EIC@JLab

## JLab Figure 8 Concept

- Initial configuration (MEIC):
  - 3-12 GeV on 20-100 GeV ep/eA collider
  - Fully-polarized, longitudinal and transverse
  - Luminosity:
    up to few x $10^{34}$ e-nucleons $cm^{-2}$ $s^{-1}$
- Upgradable to higher energies
  250 GeV protons + 20 GeV electrons
- Construction compatible with normal CEBAF operation
- Cost estimate in progress




→ **Fulfills White Paper Requirements**

# A Laboratory for Nuclear Science

- The Jefferson Lab electron accelerator is a unique world-leading facility for nuclear physics research

- These are exciting times at Jefferson Lab
  - Upgraded accelerator operational, commissioning underway
  - Ready to begin physics program
  - Construction of Halls B,C continue through FY17

- 12 GeV program ensures at least a decade of excellent opportunities for discovery
  - New vistas in QCD
  - Growing program Beyond the Standard Model
  - Budget for 30 weeks operation presented
  - Additional equipment: MOLLER, SoLID

- EIC moving forward:
  - JLab design well developed – time scale following 12 GeV program is “natural”