



U.S. DEPARTMENT OF
ENERGY

Office of
Science



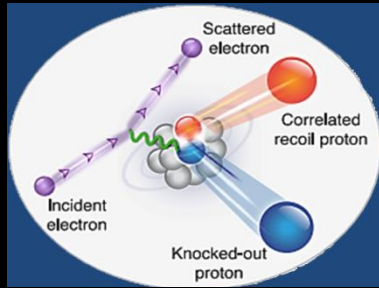
Jefferson Lab Science



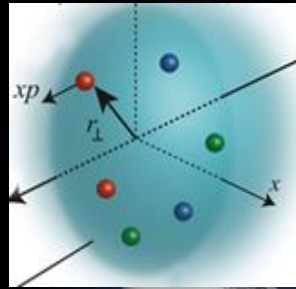
R. D. McKeown
August 8, 2016

Jefferson Lab
Thomas Jefferson National Accelerator Facility

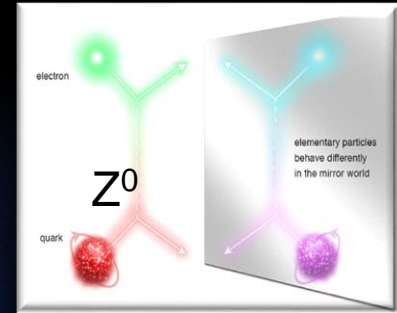
JLab: A Laboratory for Nuclear Science



Nuclear Structure



Structure of Hadrons



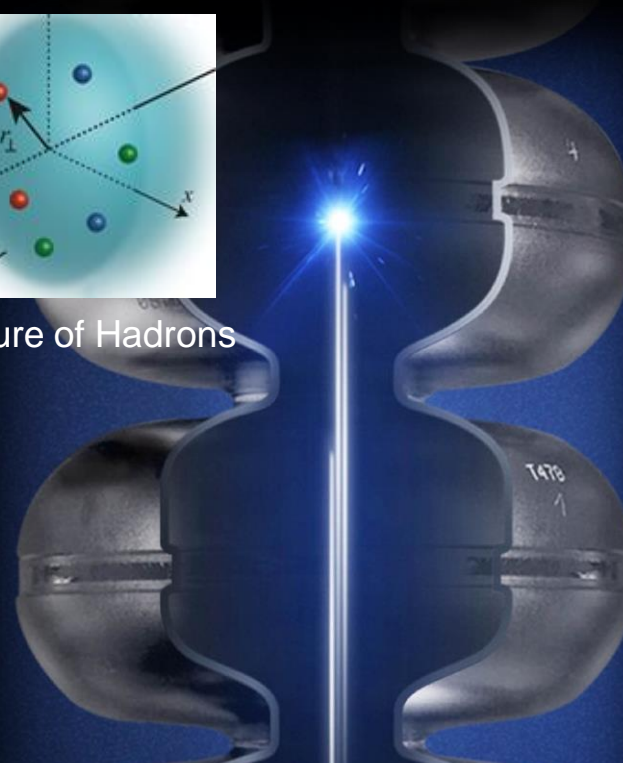
Fundamental Forces & Symmetries



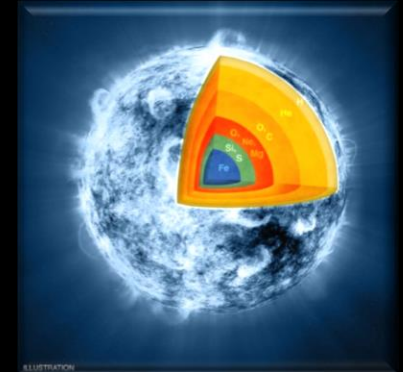
Medical Imaging



Cryogenics



Accelerator S&T



Nuclear Astrophysics

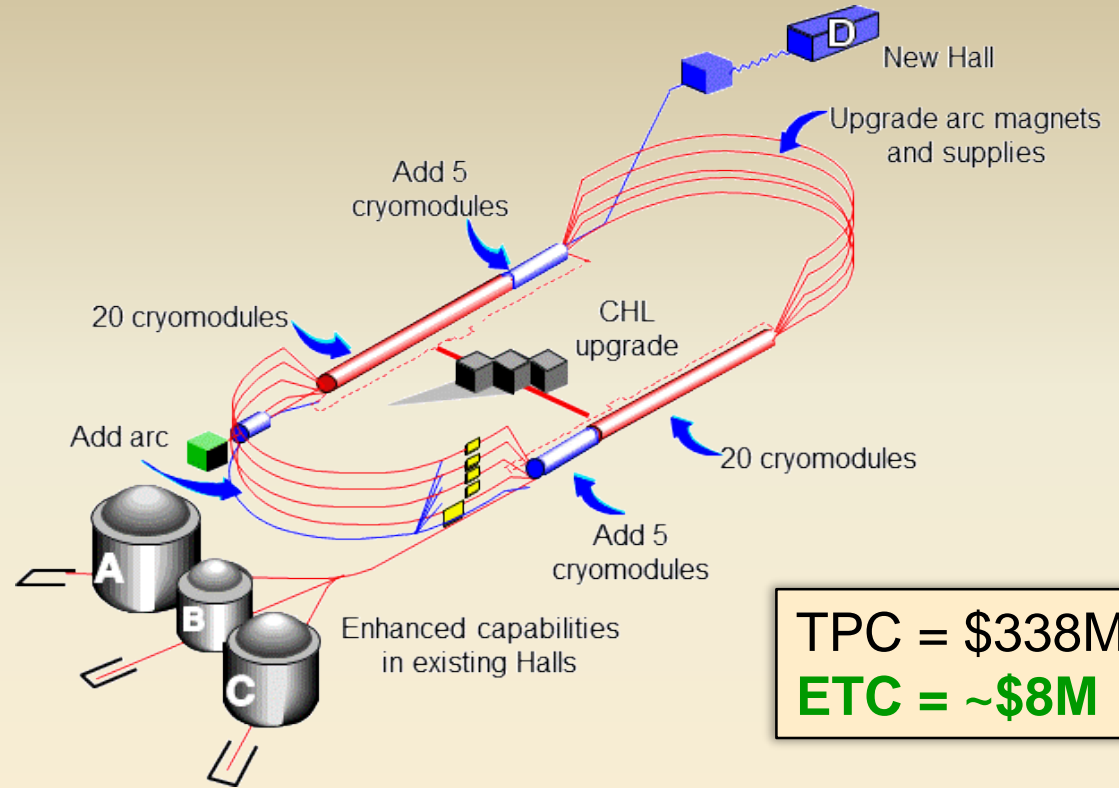
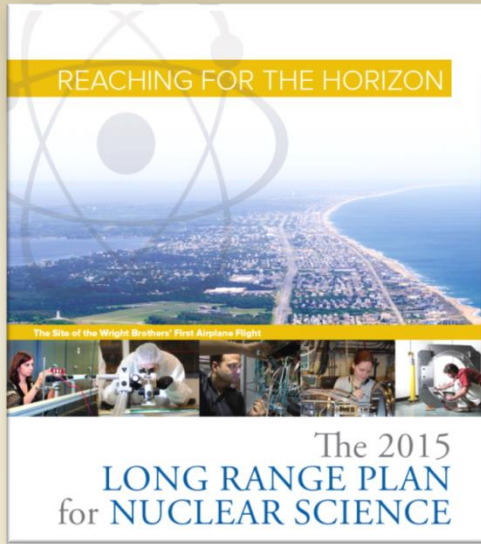


Theory & Computation

Outline

- Upgrade status
- Recent highlights
- 12 GeV Research Program
- Future EIC

CEBAF Upgrade



TPC = \$338M
ETC = ~\$8M

“With the imminent completion of the CEBAF 12-GeV Upgrade, its forefront program of using electrons to unfold the quark and gluon structure of hadrons and nuclei and to probe the Standard Model **must** be realized”

Project Scope (~98% complete):

- Doubling the accelerator beam energy - **DONE**
- New experimental Hall D and beam line - **DONE**
- Civil construction including utilities - **DONE**
- Upgrades to Experimental Halls B & C - **~96%**
 - Halls B & C Detectors – **DONE**

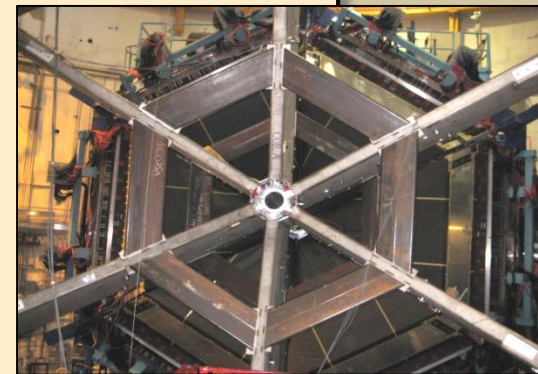
12 GeV Upgrade Project

Remaining scope & status:

- Hall C superconducting dipole, 2 quads
 - All magnets in cryostats, leak-checking & welding in progress
 - Next magnet delivery in mid-September
- Hall B superconducting torus, solenoid
 - Torus ready to start cool-down
 - Solenoid: all coils wound & potted; coils 1 through 4 shrink-fitted

Most key technical risks retired.

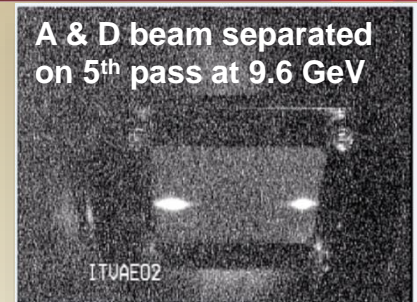
Proactively managing work at vendors to minimize schedule delays.



CEBAF Commissioning Highlights

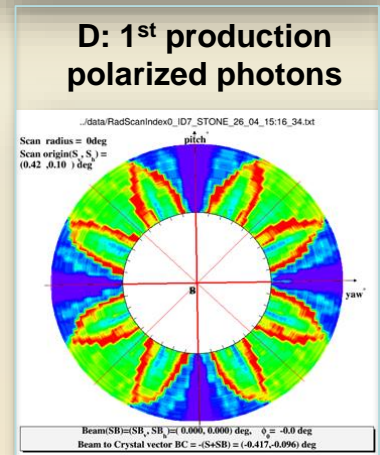
Spring 2015:

- First simultaneous Hall A/D operations
- Successful commissioning runs:
Hall B (Heavy Photon Search) and Hall D (GlueX)



Fall 2015:

- First operation of CEBAF at design energy



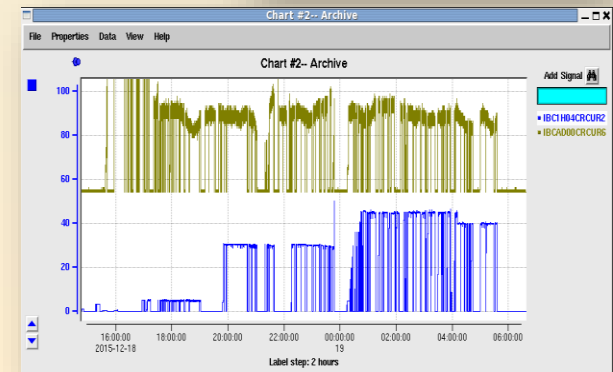
Spring 2016:

- Hall D engineering run complete
- Hall A commissioning and early physics run
- Hall B HPS on weekends, extended run

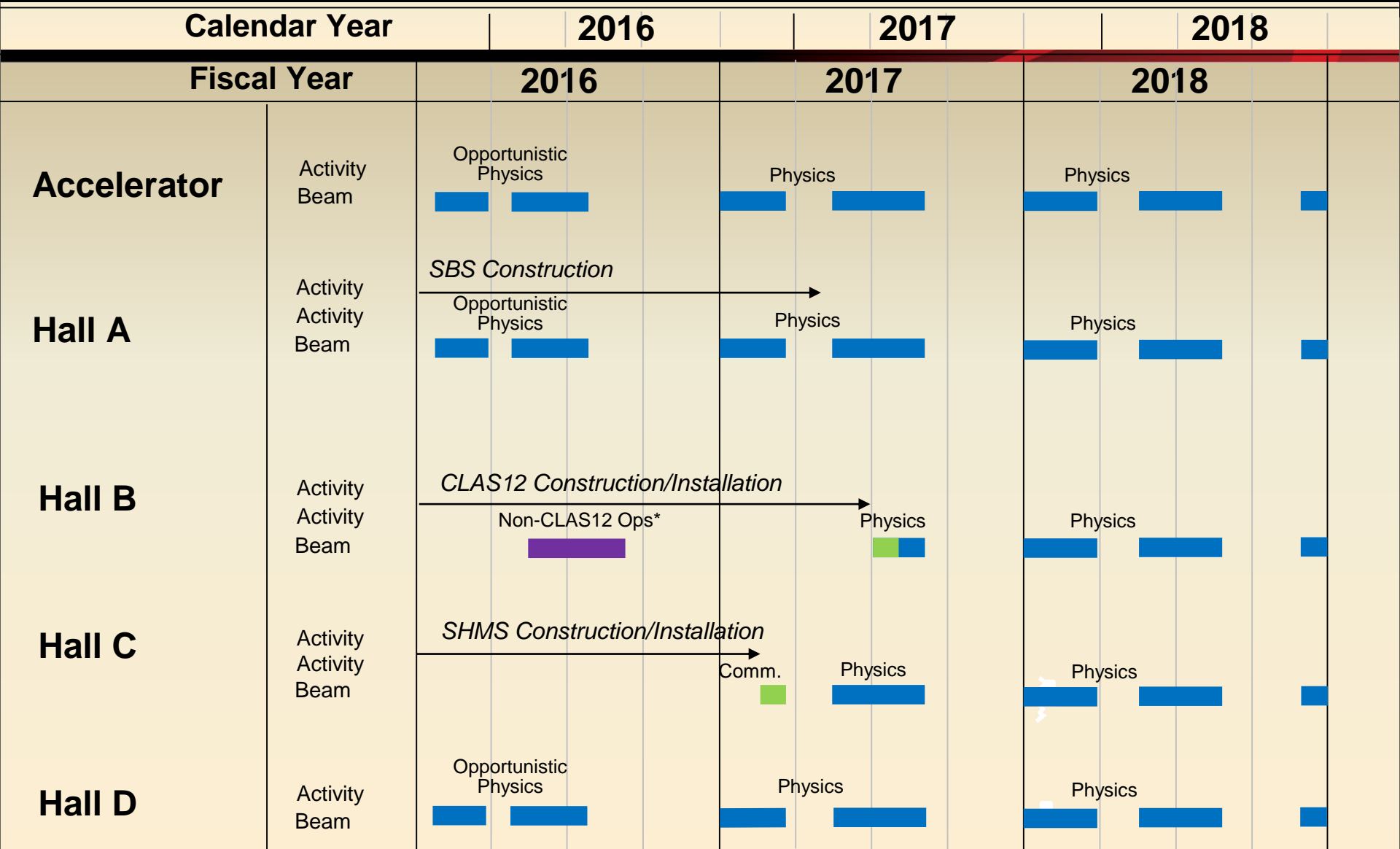
Summer 2016:

- Proton Radius Experiment (PRad)
- First completed experiment in 12 GeV era!

Accelerator ready for 12 GeV physics program



CEBAF Three-Year Schedule



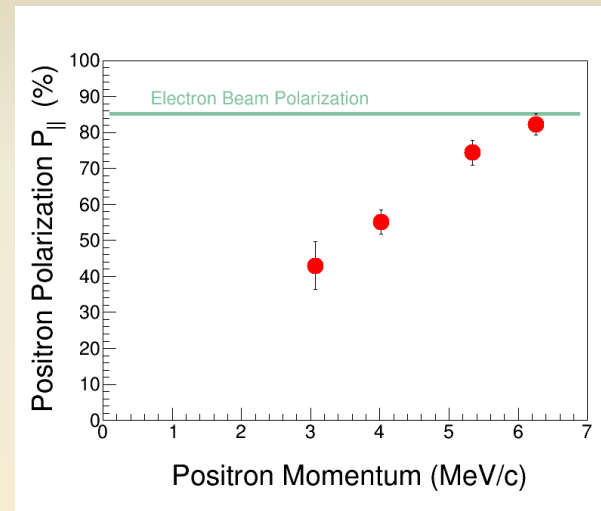
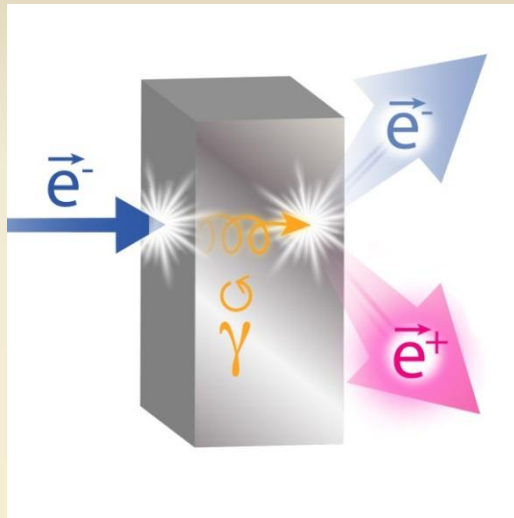
* PRad Summer 2016 run

■ Beam for Commissioning
 ■ Beam for Physics
 ■ Non-CLAS12 Ops

Polarized Positrons for Research

Positrons – the electron’s antiparticle offers new opportunities for research in

- Nuclear Physics
- Materials Science



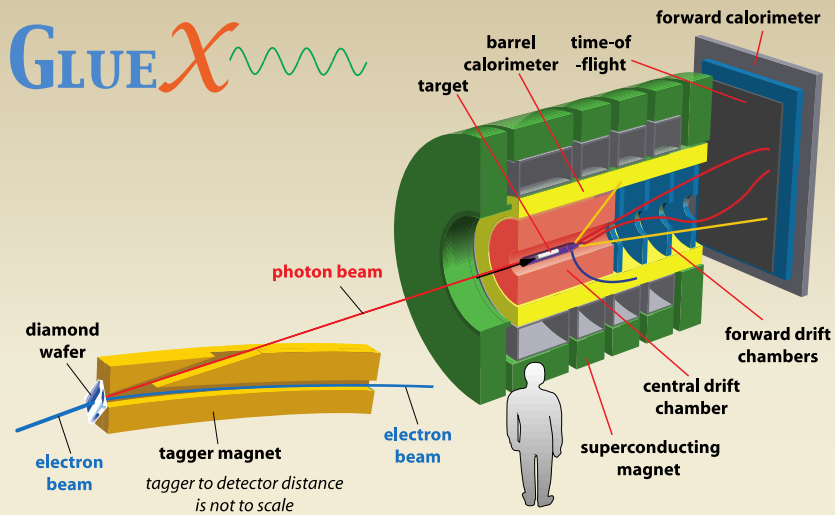
The **Polarized Electrons for Polarized Positrons (PEPPo)** experiment in Jefferson Lab’s CEBAF injector demonstrated a new technique for production of polarized positrons.

D. Abbott *et al.* (PEPPo Collaboration). “Production of highly polarized positrons using polarized electrons at MeV energies.”

Phys. Rev. Lett. **116**, 214801 (2016).

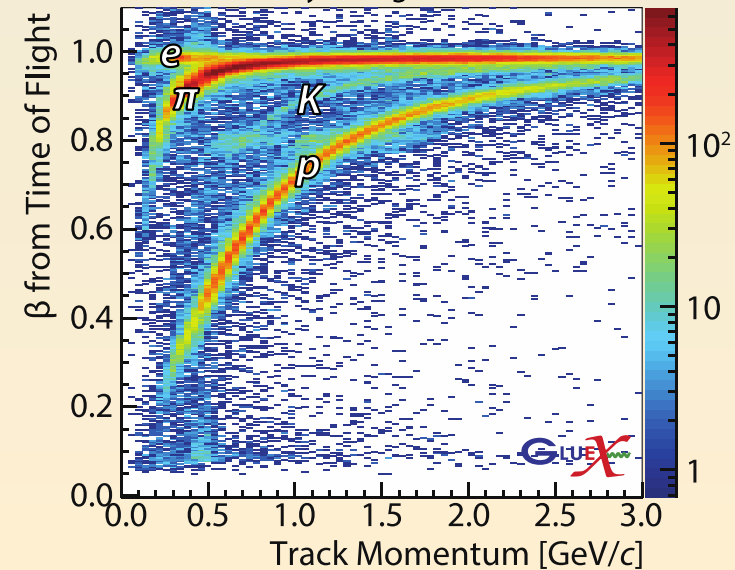
doi: [10.1103/PhysRevLett.116.214801](https://doi.org/10.1103/PhysRevLett.116.214801)

GlueX in Hall D

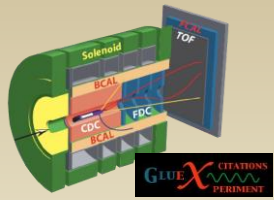


- New experiment to study quark confinement
- Commissioning complete
- Detector functioning well
- Production data-taking started
- Poised to discover exotic hybrid mesons

Positively Charged Particles

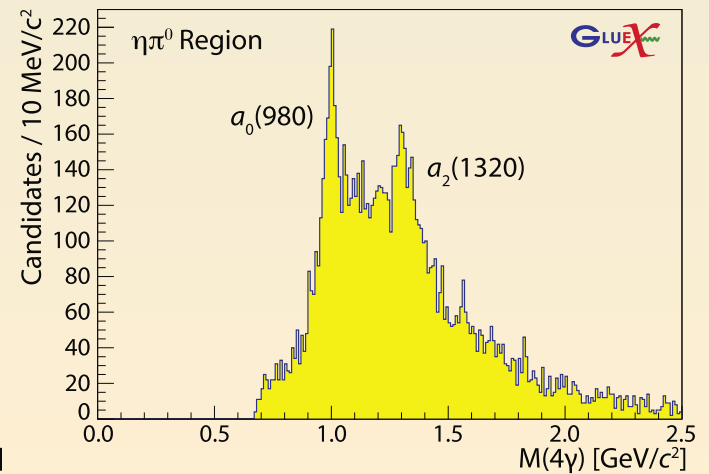
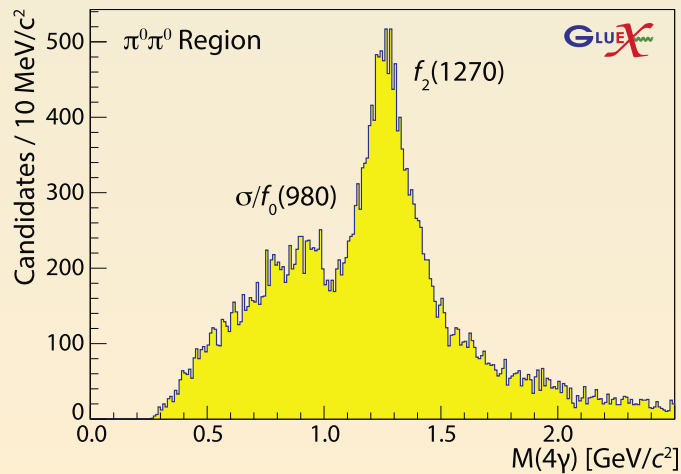
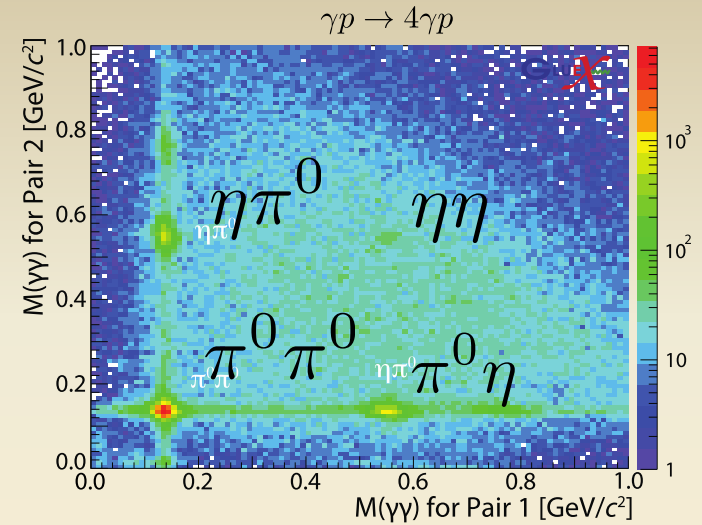


GlueX



Photoproduced mesons decay into:
complex photon final states

$$\gamma p \rightarrow p \gamma \gamma \gamma \gamma$$



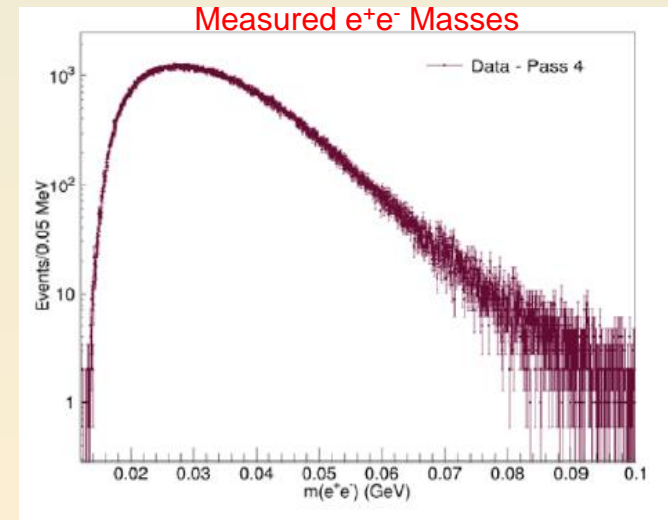
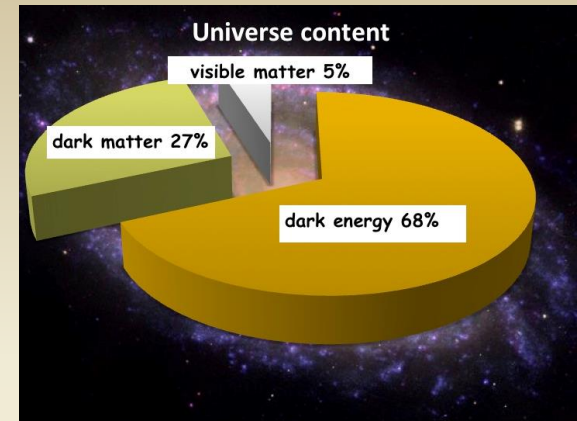


Heavy Photon Search

- HPS searches for an electro-produced hidden sector photon (A') which decays to e^+e^- pairs
- A' 's could mediate dark matter annihilations and interactions with *our* matter
- HPS identifies A' 's with invariant mass and separated vertices

Status:

- 1 GeV data under analysis
 - first results this summer
- 2 GeV data acquired in spring 2016
 - results next year
- More running in the future
- NP-HEP Collaboration

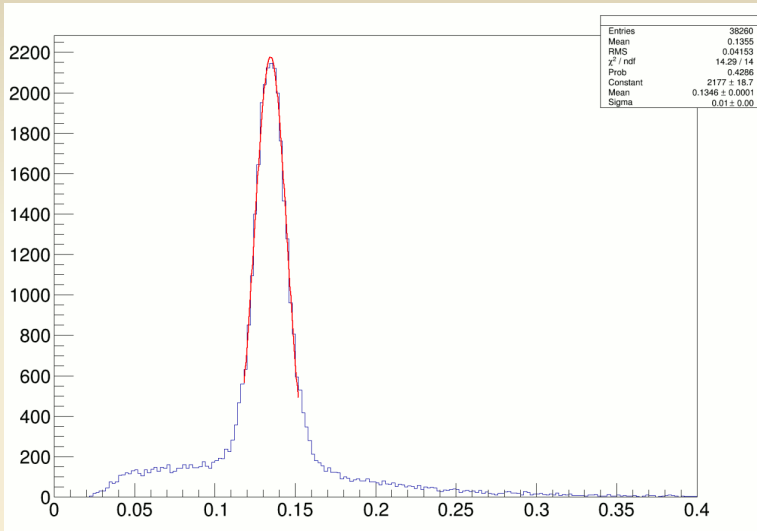


Future Program: more HPS, APEX, DarkLIGHT

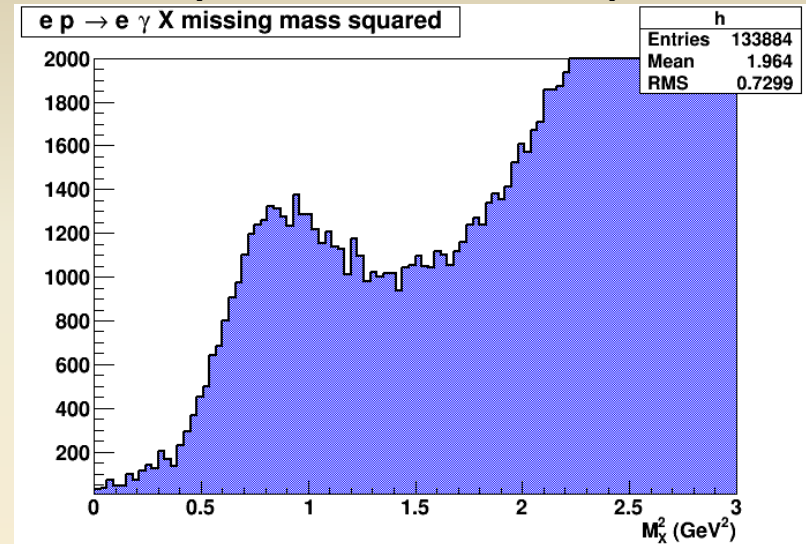
3D Imaging Program at 11 GeV

Hall A

Data reconstructed in calorimeter

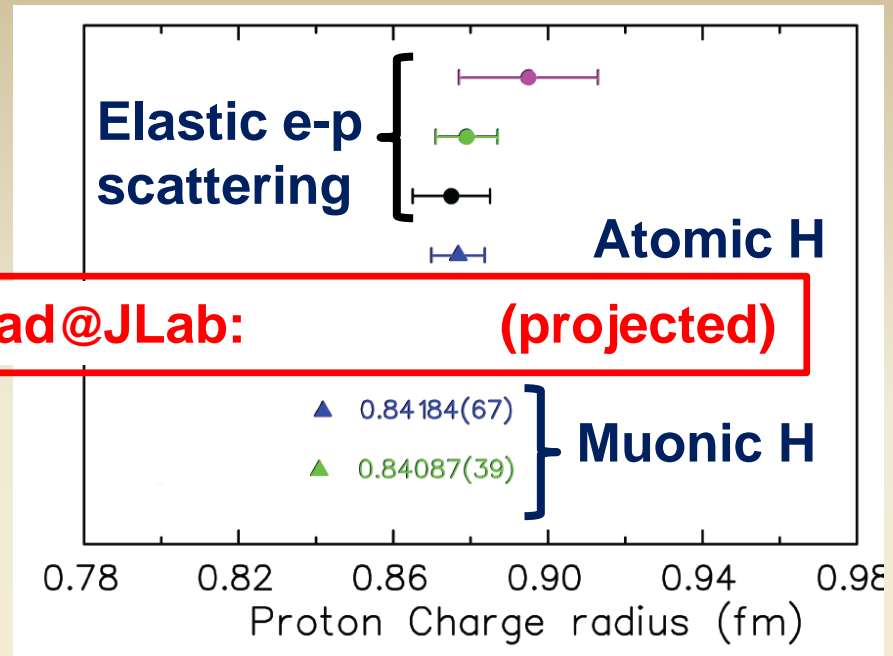
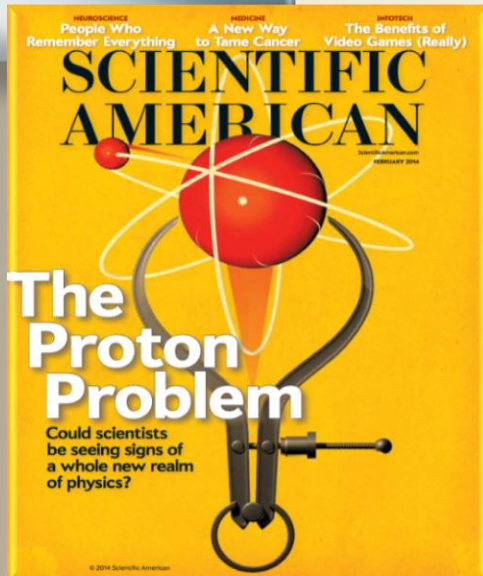


Missing Mass Reconstruction (1.5 h of beamtime)



- High impact experiment for nucleon 3D imaging program
- 16% of experiment completed in 2014-2016

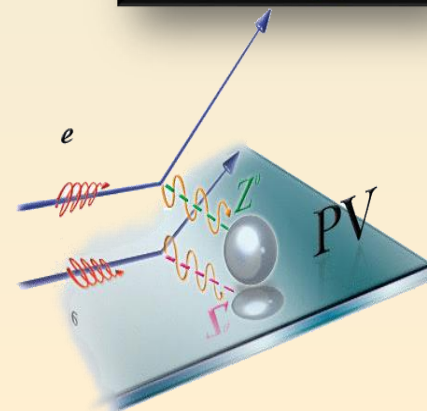
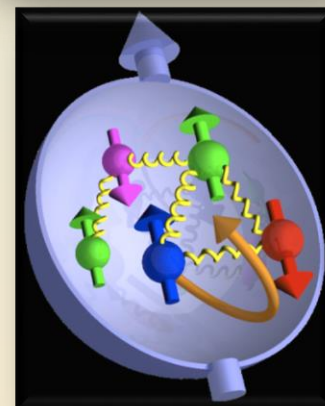
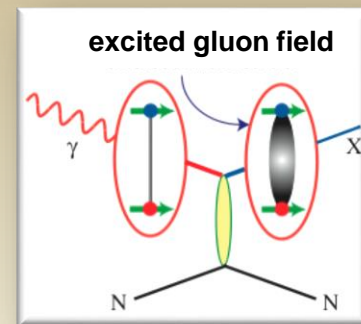
Solving the Proton Radius Puzzle



- **PRad: new experiment to address proton radius @ JLab**
- **NSF MRI: H₂ gas target**
- **DOE GEM tracking detectors**
- **Successful run in summer 2016!**

Jefferson Lab @ 12 GeV Science Questions

- What is the role of gluonic excitations in the spectroscopy of light mesons?
- Where is the missing spin in the nucleon? Role of orbital angular momentum?
- Can we reveal a novel landscape of nucleon substructure through 3D imaging at the femtometer scale?
- Can we discover evidence for physics beyond the standard model of particle physics?



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)		2	1	3		6
The transverse structure of the hadrons (Elastic and transition Form Factors)	5	3	3	1		12
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)	7	3	7		1	18
Low-energy tests of the Standard Model and Fundamental Symmetries	3	1		1	1	6
TOTAL	22	21	24	5	2	74

12 GeV Approved Experiments by PAC Days

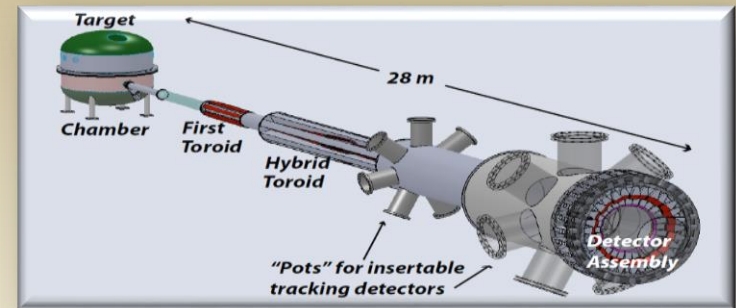
Topic	Hall A	Hall B	Hall C	Hall D	Other	Total
The Hadron spectra as probes of QCD		119		540		659
The transverse structure of the hadrons	145.5	85	102	25		357.5
The longitudinal structure of the hadrons	65	230	165			460
The 3D structure of the hadrons	409	872	212			1493
Hadrons and cold nuclear matter	180	175	201		14	570
Low-energy tests of the Standard Model and Fundamental Symmetries	547	180		79	60	866
Total Days	1346.5	1661	680	644	74	4405.5
Total Days – Without MIE Days	697.5	1661	680	644	28	3710.5
Total Approved Run Group Days (includes MIE)	1346.5	826	637	424	74	3307.5
Total Approved Run Group Days (without MIE)	528.5	826	637	424	28	2443.5
Total Days Completed	20	30 15	0	25	0	75 60
Total Days Remaining	508.5	796 811	637	399	28	2368.5 2383.5

Future Projects

- MOLLER

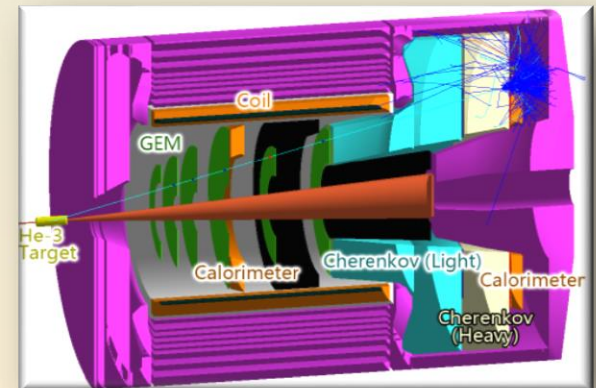
(Possible MIE – FY17-20)

- Standard Model Test
- DOE science review (September 2014): strong endorsement
- JLab technical, cost & schedule review this fall
- Now hope for FY18 construction start

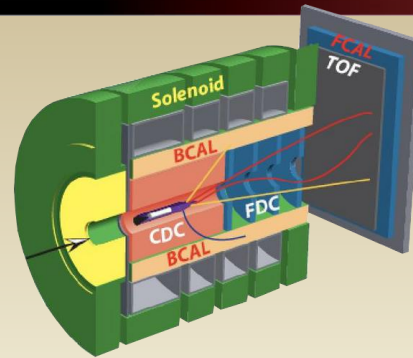
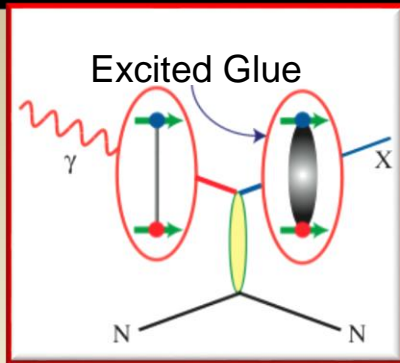


- SoLID

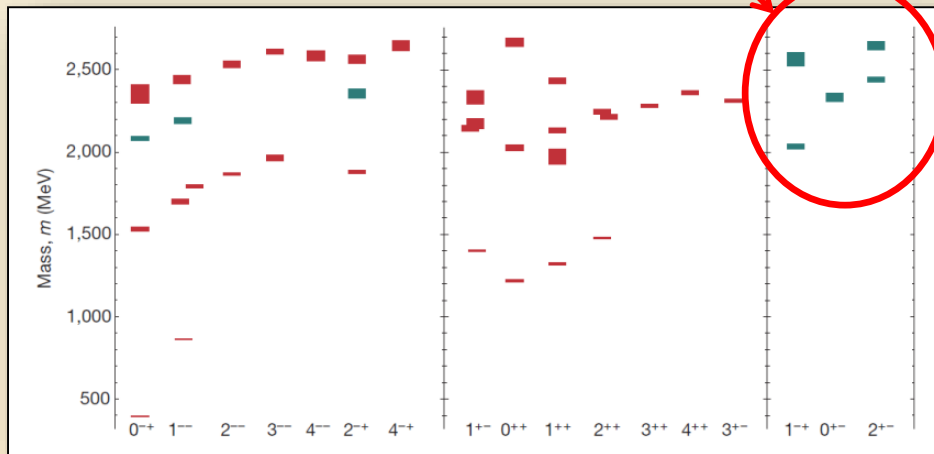
- CLEO Solenoid secured
- Strong collaboration with Chinese institutions
- Director's review (Feb. 2015)
 - good feedback being incorporated
- Collaboration briefing to DOE-NP (Nov. 2015)



Gluonic Excitations and the mechanism for confinement



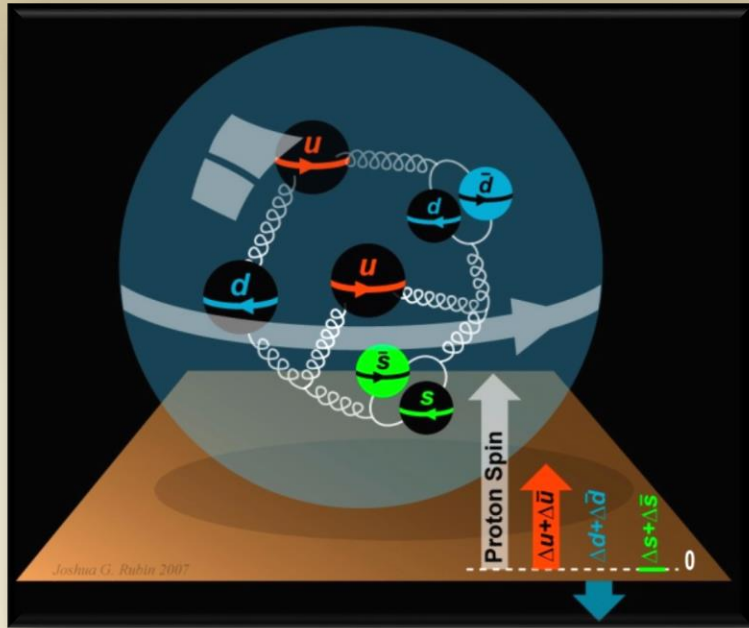
States with Exotic Quantum Numbers



nature International weekly journal of science

Searching for the rules that govern hadron construction
 M. R. Sheperd, J. J. Dudek, R. E. Mitchell

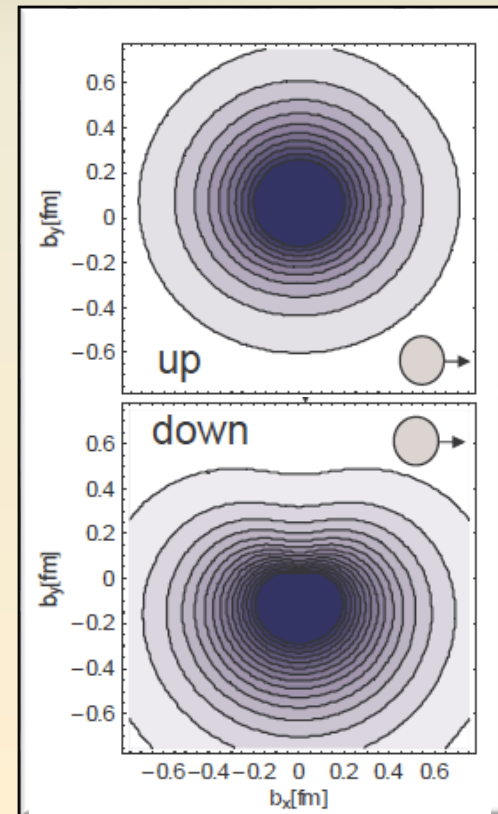
The Incomplete Nucleon: Spin Puzzle



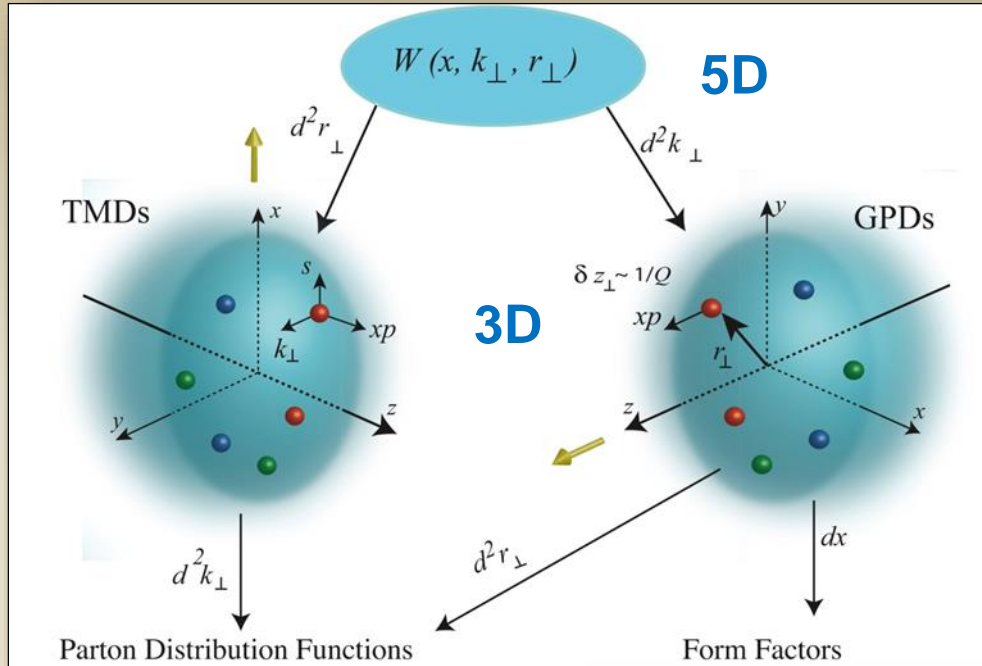
$$\frac{1}{2} = \frac{1}{2} \Delta\Sigma + L_q + J_g$$

[X. Ji, 1997]

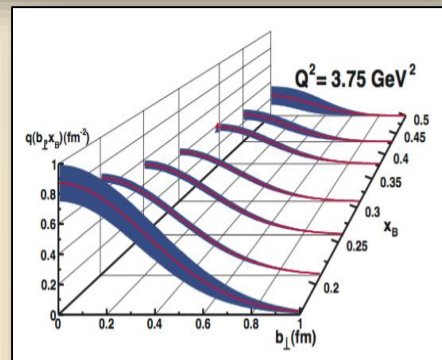
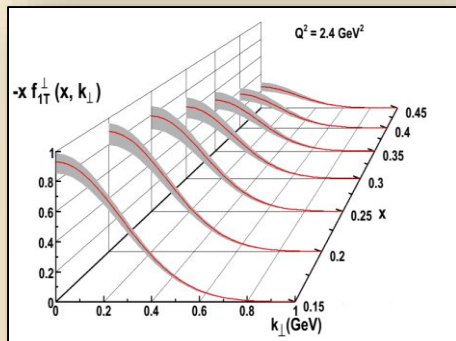
- DIS $\rightarrow \Delta\Sigma \cong 0.25$
- RHIC + DIS $\rightarrow \Delta G \sim 0.2$
- $\rightarrow L_q$



Imaging the Nucleon



- Transverse Momentum Dist. (TMD)
 - Confined motion in a nucleon (semi-inclusive DIS)
- Generalized Parton Dist. (GPD)
 - Spatial imaging (exclusive DIS)
- Requires
 - High luminosity
 - Polarized beams and targets
 - Sophisticated detector systems

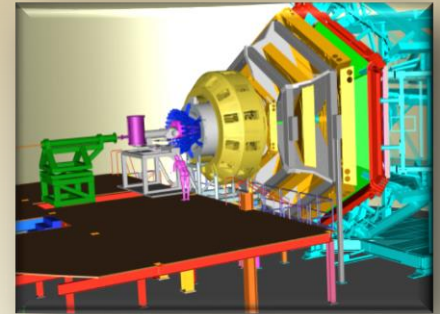


Major new capability with JLab @ 12 GeV

Imaging with JLab @ 12 GeV

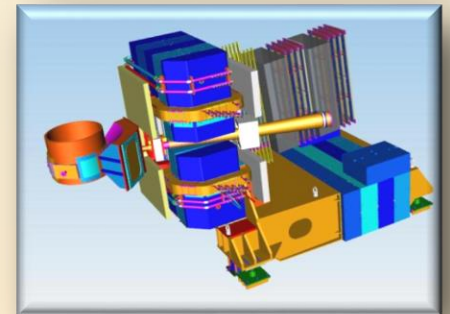
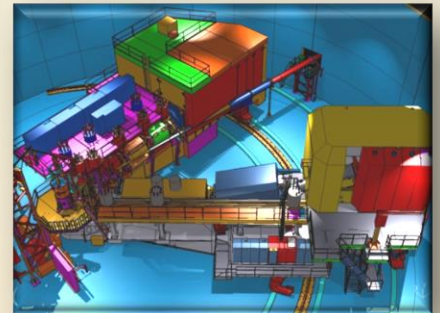
Generalized Parton Distributions (GPDs)

- CEBAF Large Acceptance Spectrometer (CLAS12) in Hall B



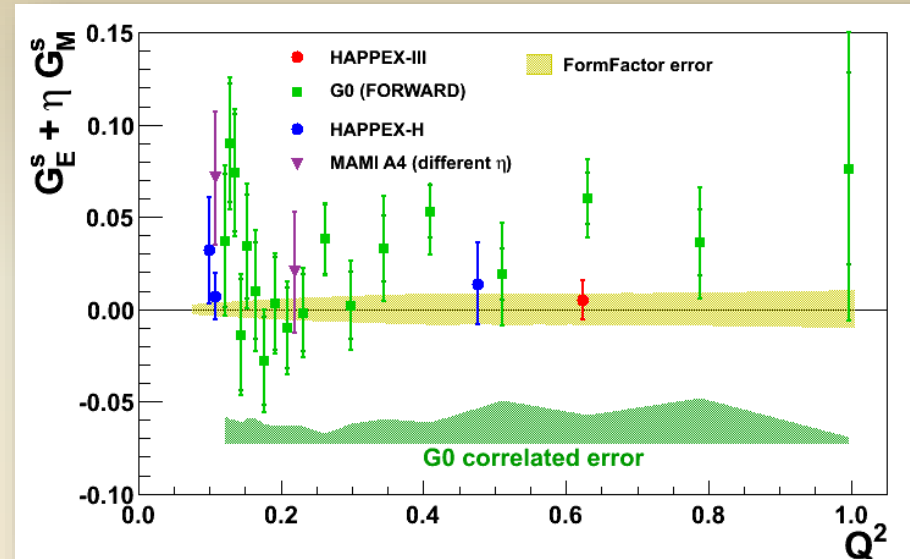
Transverse Momentum Distributions (TMDs)

- Super Bigbite Spectrometer (SBS) in Hall A
- SHMS, High Momentum Spectrometer (HMS), Neutral Particle Spectrometer (NPS) in Hall C
- Future: Solenoidal Large Intensity Device (SoLID) in Hall A



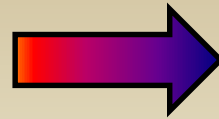
Parity Violation at JLab

- Nucleon Strangeness Form Factors (complete)
 - HAPPEX (Hall A)
 - G0 (Hall C)
- Neutron Skin
 - PREX
 - CREX
- Precision Tests of Standard Model
 - Qweak (Under analysis)
 - MOLLER
 - SoLID



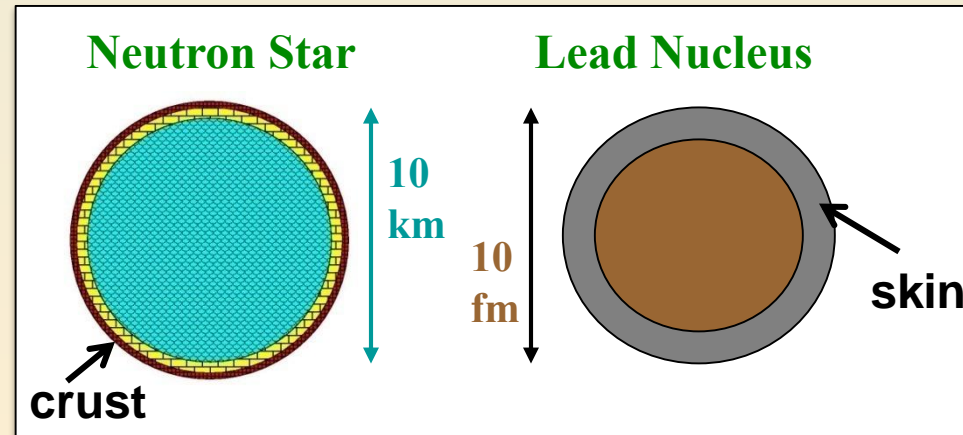
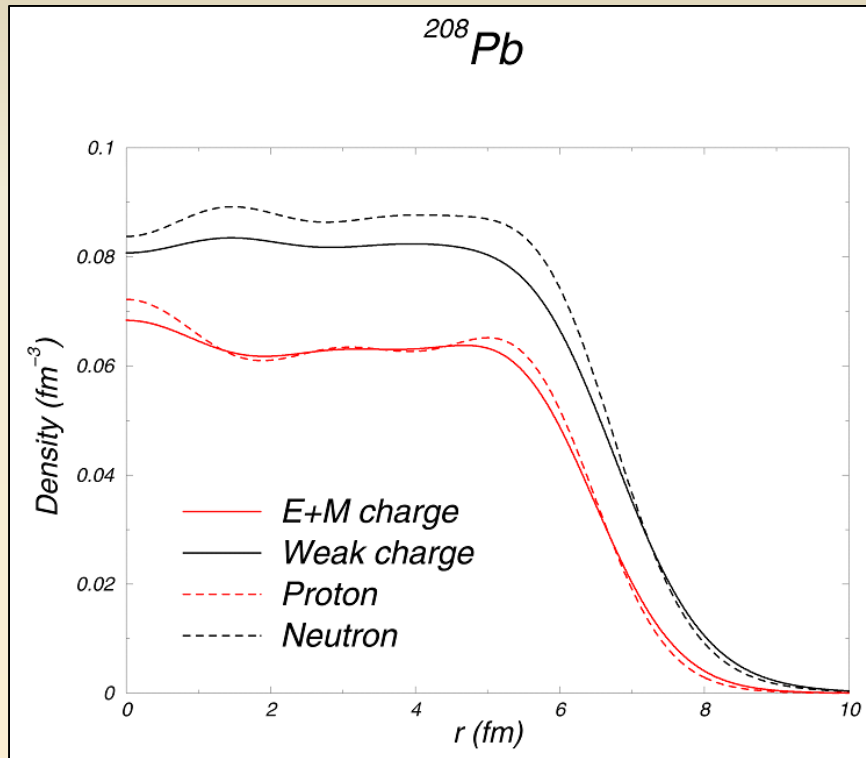
Measuring the Neutron “Skin” in the Pb Nucleus

$$Q_W^p = (1 - 4 \sin^2 \theta_W)$$
$$Q_W^n = -1$$



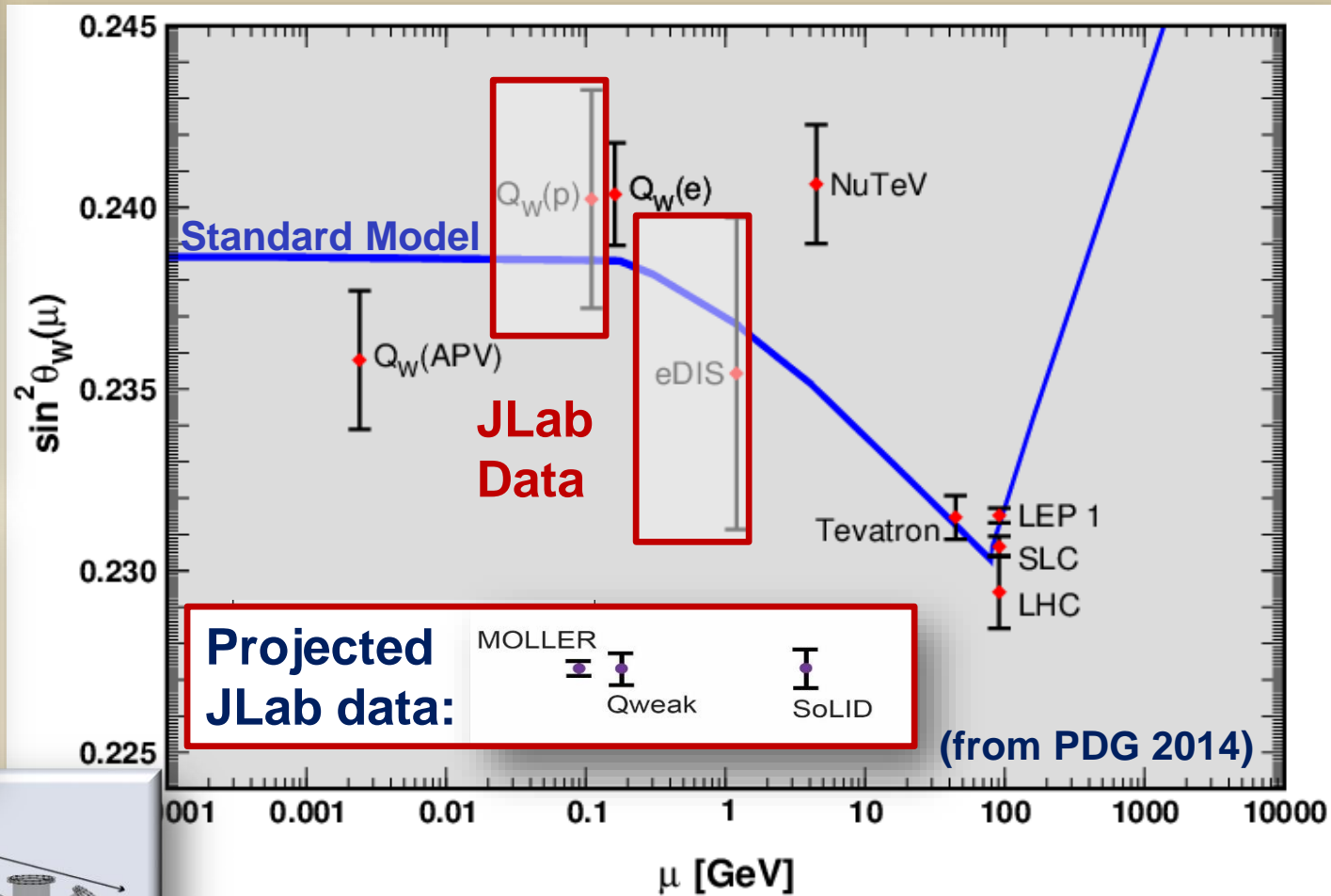
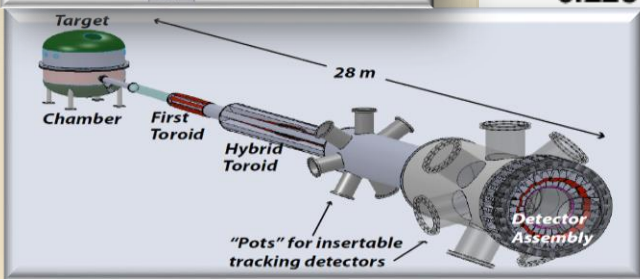
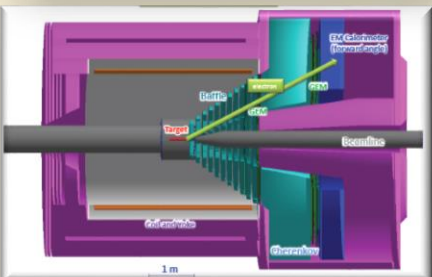
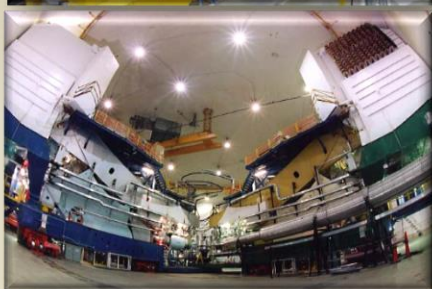
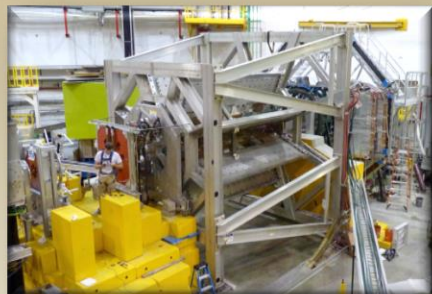
Weak interaction selects neutrons

- Parity violating electron scattering
- Sensitive to neutron distribution



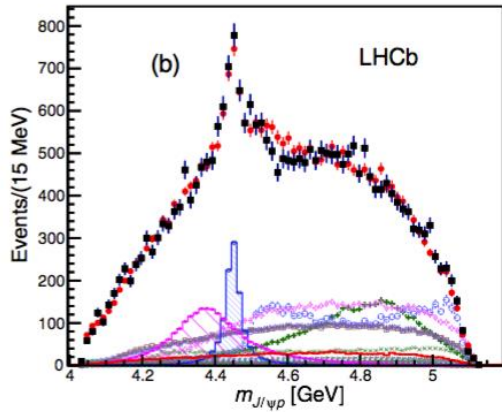
Applications: Nuclear Physics, Neutron Stars,
Atomic Parity, Heavy Ion Collisions

Testing the Standard Model at JLab



(from PDG 2014)

Charmonium Pentaquark

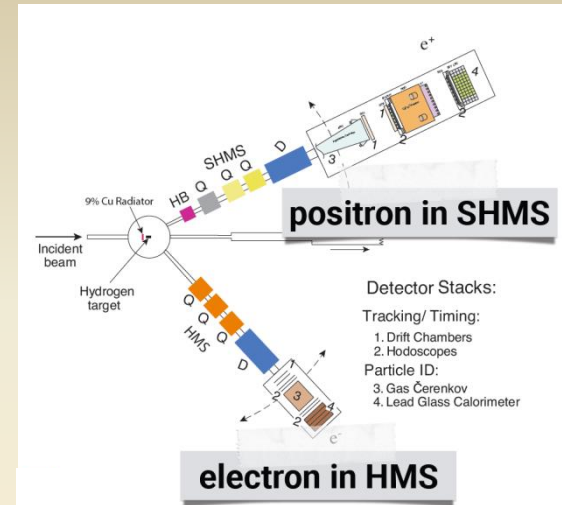


LHCb

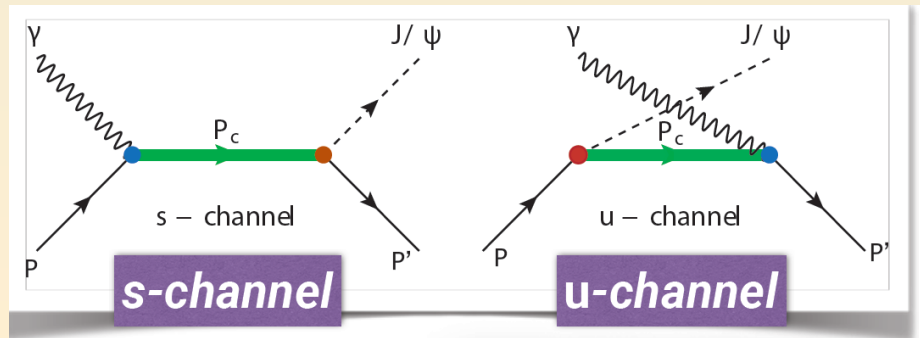
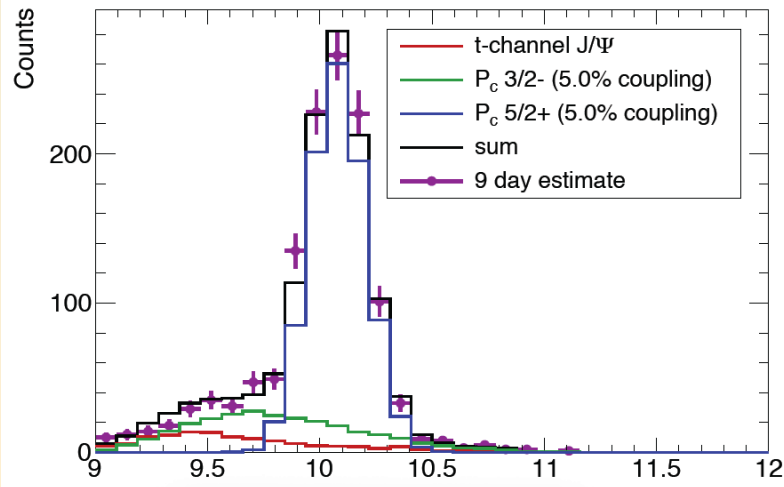
2 P_c states needed to describe results:

narrow: $P_c(4450)$
wide: $P_c(4380)$

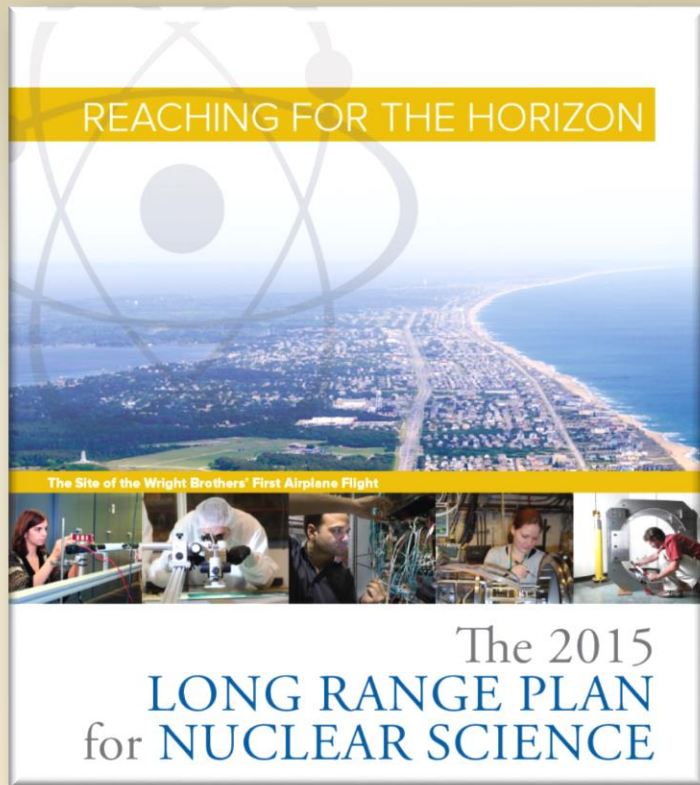
JLab E12-16-007



$$\gamma p \rightarrow P_c \rightarrow J/\psi p$$



2015 NSAC Long Range Plan



RECOMMENDATION I

The progress achieved under the guidance of the 2007 Long Range Plan has reinforced U.S. world leadership in nuclear science. The highest priority in this 2015 Plan is to capitalize on the investments made.

→ **Operate 12 GeV CEBAF**

RECOMMENDATION II

We recommend the timely development and deployment of a U.S.-led ton-scale neutrinoless double beta decay experiment.

RECOMMENDATION III

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

→ **Jefferson Lab EIC (JLEIC) development**

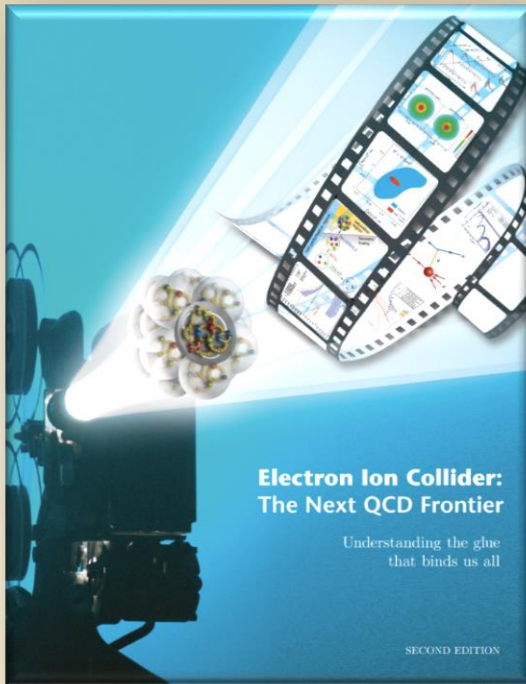
RECOMMENDATION IV

We recommend increasing investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.

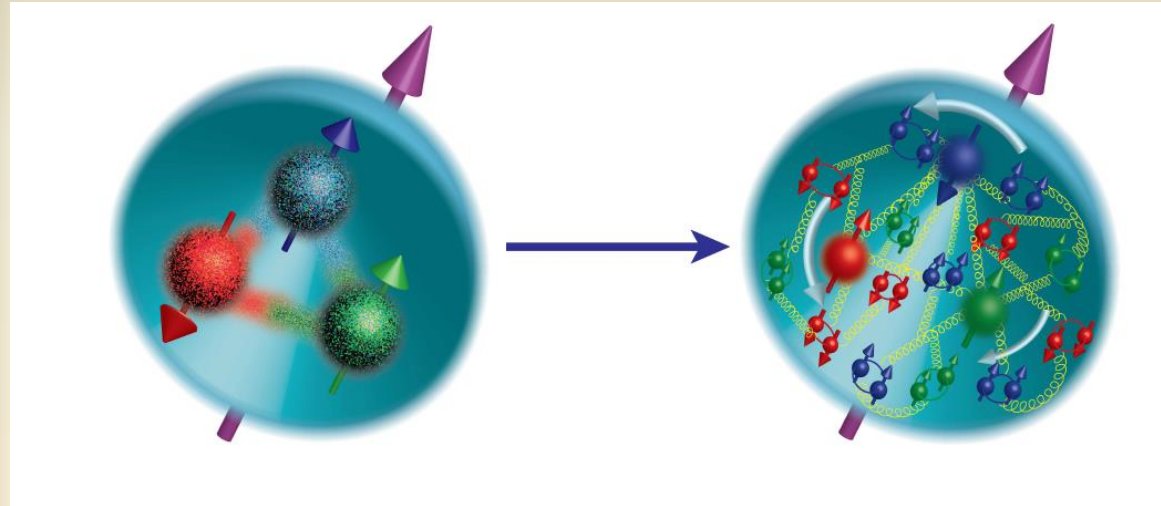
→ **MOLLER, SoLID**

Electron Ion Collider

LRP Recommendation III

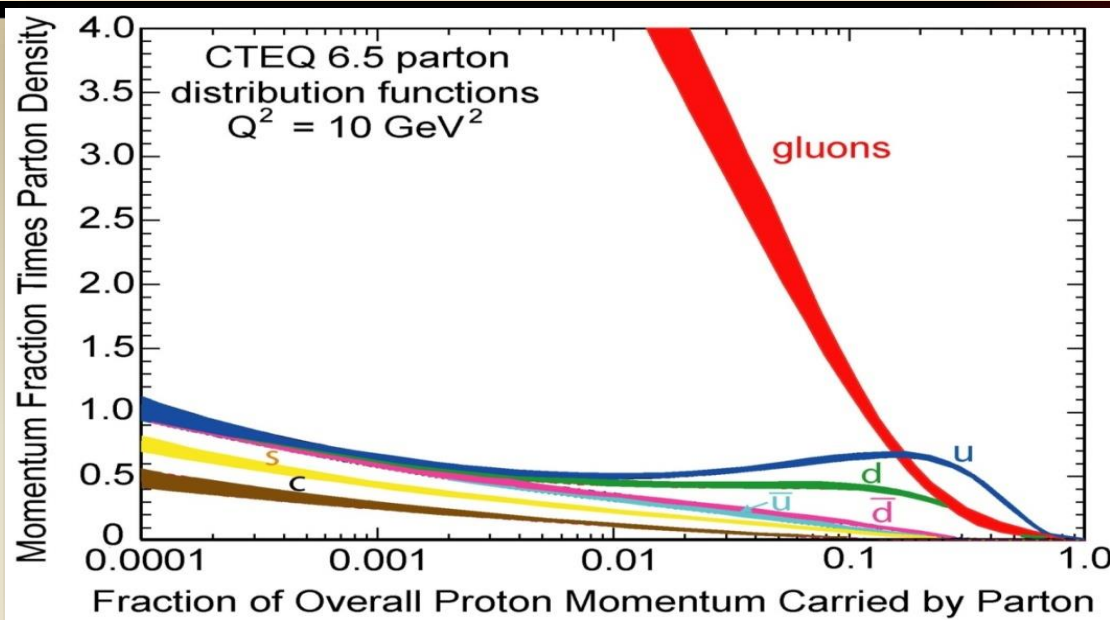


EIC Community
White Paper

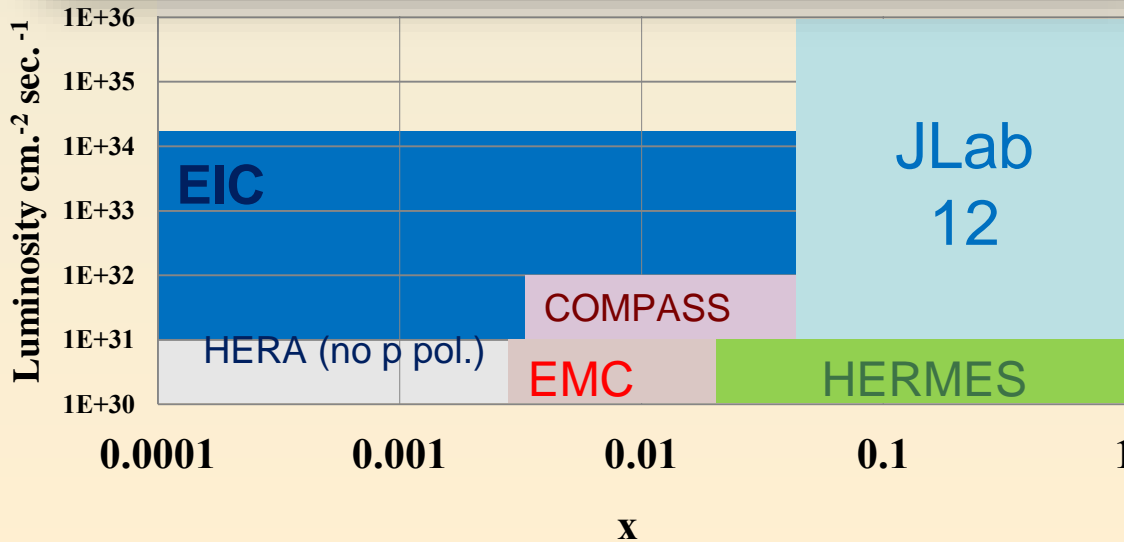


Exploring the Glue that Binds Us All

The New Landscape Enabled by EIC

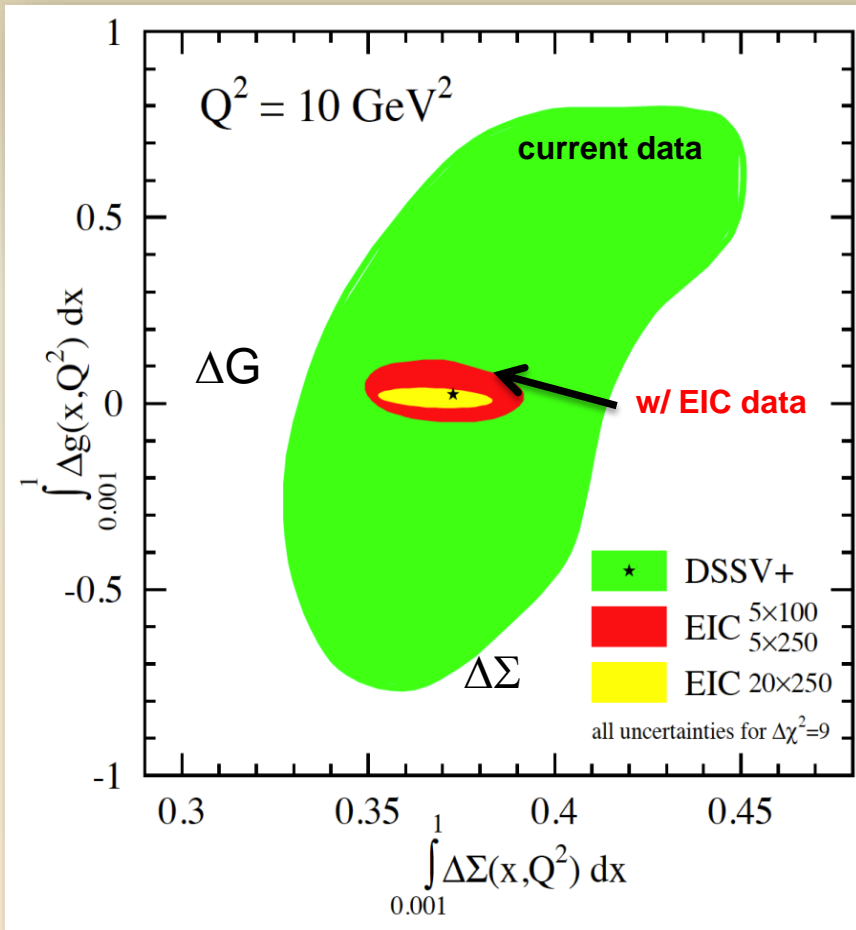


- High Luminosity
 $\rightarrow 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- Low x regime
 $x \rightarrow 0.0001$
- High Polarization
 $\rightarrow 70\%$



Discovery Potential!

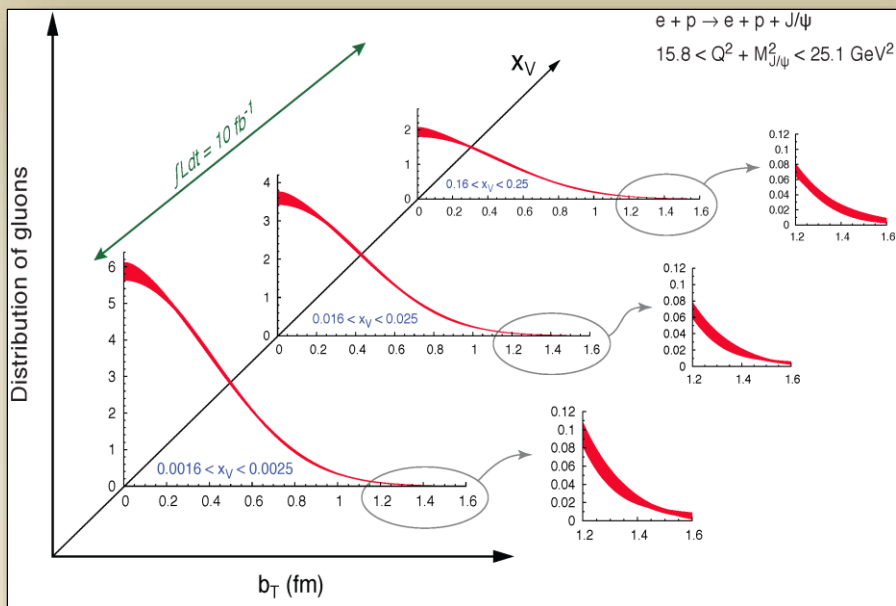
EIC: Are the Gluons Polarized?



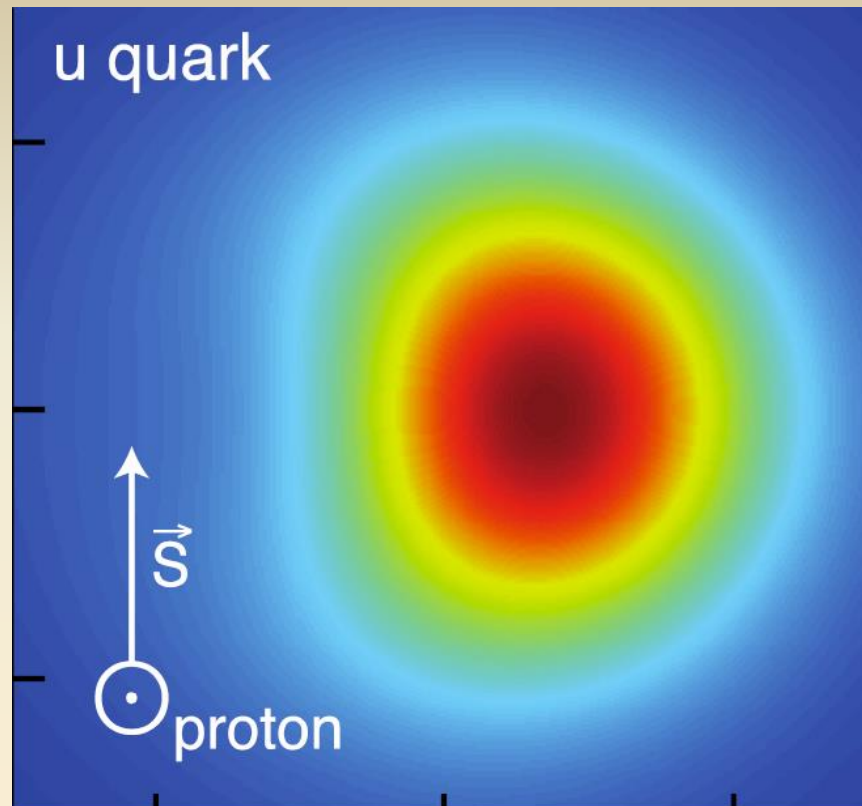
A Polarized EIC:

- Tremendous improvement on ΔG
- Also improvement in $\Delta \Sigma$
- Spin Flavor decomposition of the Light Quark Sea

Spatial Imaging at EIC



Images of gluons
from exclusive
 J/ψ production

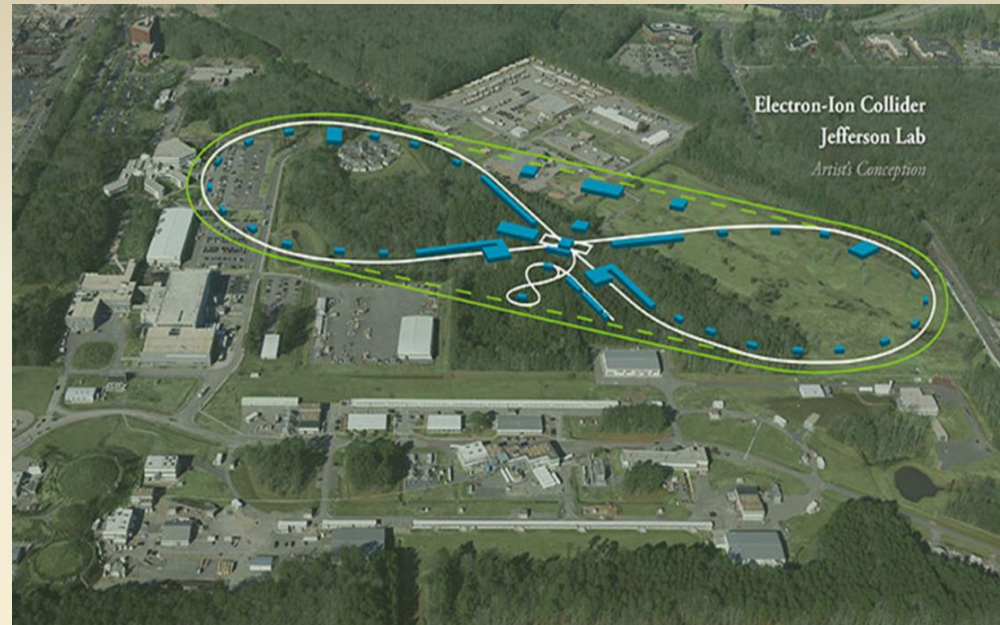


Transverse motion preferences of
an up sea quark for a proton
moving out of the page, with its
spin pointing upward.

JLEIC: EIC at Jefferson Lab

JLab EIC Figure 8 Concept

- High Polarization
- High Luminosity
- Low technical risk
- Flexible timeframe for construction consistent w/running 12 GeV CEBAF
- Cost effective operations
- Upgradable to higher energies
250 GeV protons + 20 GeV electrons
- Fulfills White Paper Requirements
- Collaboration with SLAC, LBNL, ANL
- Site evaluation (Virginia funds)

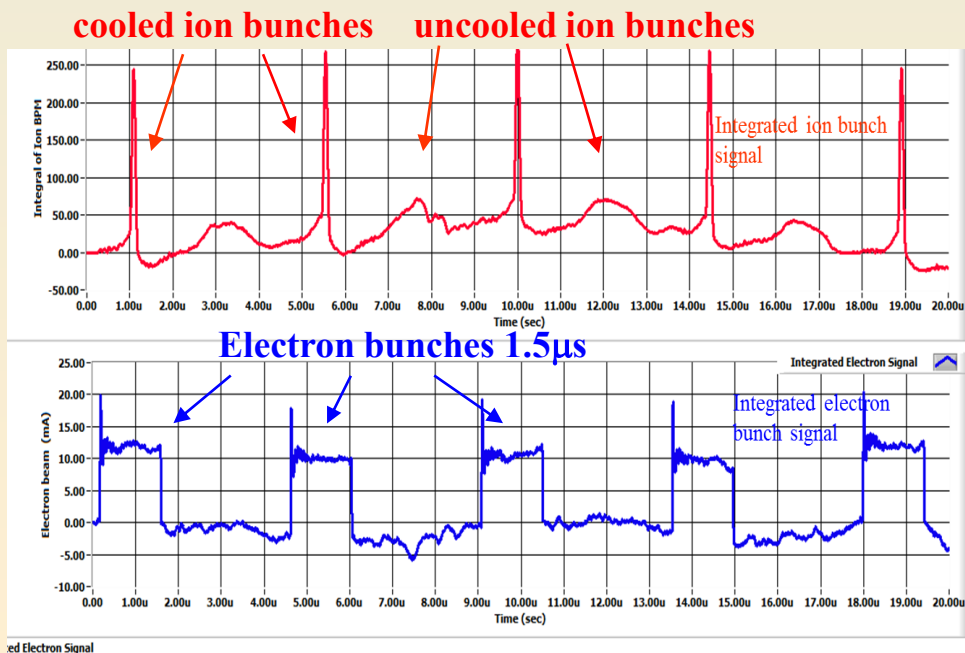


- User group organizing (charter, meetings)
- NAS study underway
- DOE-NP accelerator R&D program (FY17)

Bunched Ion Beam Cooling – preliminary results

- A collaboration of **JLAB** and Institute of Modern Physics (**IMP**), China
- The 1st experiment was carried out on **May 17-22**, 2016, at Lanzhou, China
- A 7MeV/u **$^{12}\text{C}^{6+}$ ion beam** stored in the IMP CSRm ring, either coasting or captured by 450kHz RF system (two long bunches)
- **Cooling of both coasting and bunched ion by a pulsed electron beam are observed: first successful step of experimental demonstration of bunched beam cooling**
- **Data analysis** both at IMP and JLAB is in progress
- Initial 1D **modeling** with RF capture and bunching shows the ion cooling and synchrotron sideband effects, agree with experimental observations

Experiment data observation on BPMs



Jefferson Lab: Today and Tomorrow

- The Jefferson Lab electron accelerator is a unique world-leading facility for hadron and nuclear physics research
- 12 GeV upgrade ensures at least a decade of excellent opportunities for discovery
 - New vistas in QCD
 - Growing program Beyond the Standard Model
 - Additional equipment: MOLLER, SoLID, plus smaller projects
- EIC moving forward:
 - Strong science case, much builds on JLab 12 GeV program
 - JLEIC design well developed – time scale following 12 GeV program is “natural”
 - NSAC 2015 Long Range Plan recommendation