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

Jefferson Lab Science Opportunities at 12 GeV

R. D. McKeown

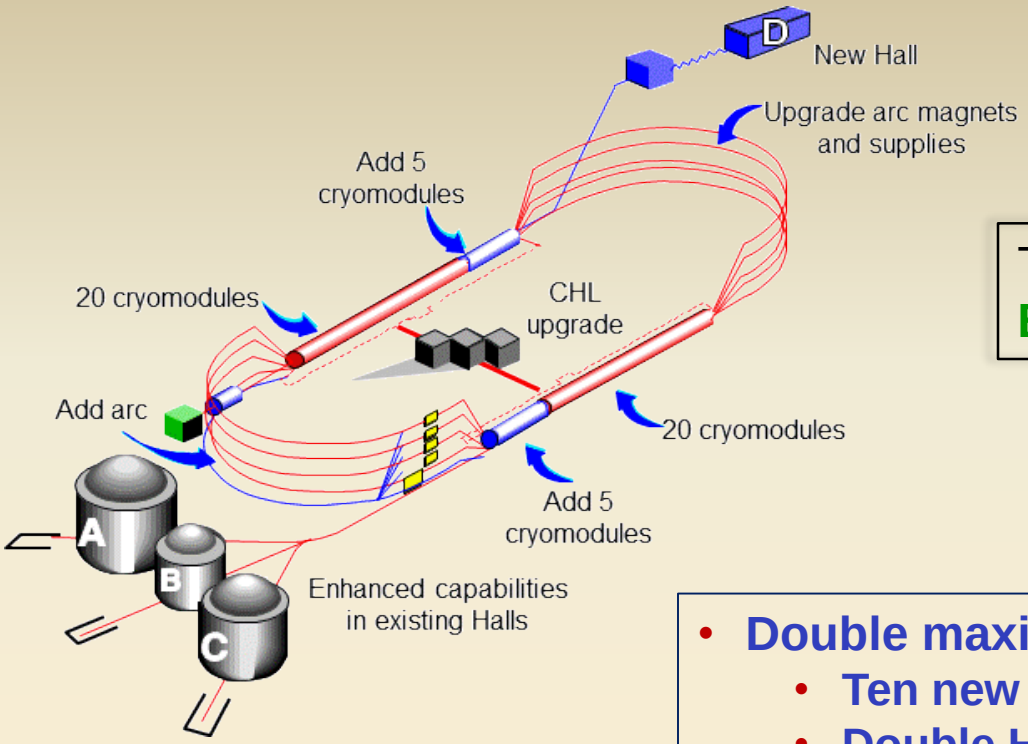
Light Cone 2017

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Outline

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

12 GeV CEBAF Upgrade

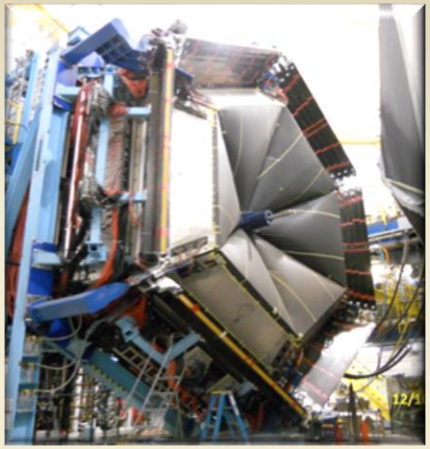


Total Project Cost = $338M
Estimate to Complete < $1M

- **Double maximum Accelerator energy to 12 GeV**
  - **Ten new high gradient cryomodules**
  - **Double Helium refrigerator plant capacity**
  - **Civil construction and upgraded utilities**
- **Add 10th arc of magnets for 5.5 pass machine**
- **Add 4th experimental Hall D**
- **New experimental equipment in Halls B, C, D**

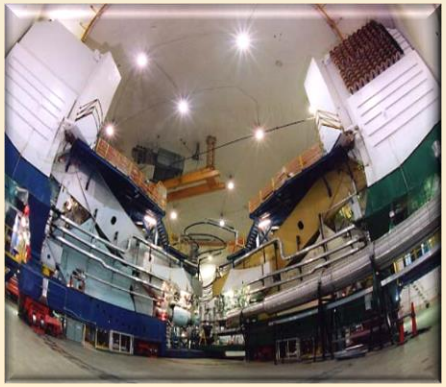
12 GeV Scientific Capabilities

Hall D – exploring origin of confinement by studying exotic mesons



Hall B – understanding nucleon structure via generalized parton distributions and transverse momentum distributions

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



Hall A – short range correlations, form factors (SBS), hyper-nuclear physics, future new experiments (e.g., SoLID and MOLLER)

12 GeV Project: University Detector Work

Hall	University	Activity	Status
B	**Idaho State U**	Drift Chamber	**Complete**
B	**Old Dominion U**	Drift Chamber	**Complete**
B	**U South Carolina**	TOF Counters	**Complete**
B	Moscow State U (RU)	SVT Testing	**Complete**
C	**Michigan State U**	HB Magnet	**Complete**
C	**U Virginia**	Noble Gas Cerenkov	**Complete**
D	U Athens (GR)	Monitoring BCAL, FCAL	**Complete**
D	**Carnegie Mellon U**	Central Drift Chamber	**Complete**
D	**Catholic U**	Tagger Hodoscope	**Complete**
D	**U Connecticut**	Tagger Microscope	**Complete**
D	**Florida Internat'l U**	Start Counter	**Complete**
D	**Florida State U**	TOF Counters	**Complete**
D	**Indiana U**	Forward Calorimeter	**Complete**
D	U Regina (CA)	Barrel Calorimeter	**Complete**
D	U Santa Maria (CH)	SiPM, Lightguides for BCAL	**Complete**
B, C, D	**U Massachusetts**	Electronics Testing	**Complete**

NSF-MRI funded (Hall B):
- **PCAL Detector**
- **Long. Polarized Target**

NSF-MRI funded (Hall C):
- **Drift Chambers**
- **Trigger Hodoscopes**
- **Aerogel**

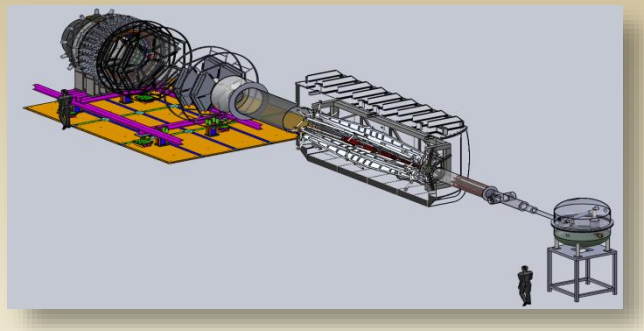
Internat'l contributions for detectors beyond base equipment.

12 GeV Upgrade – Path to Completion

- **Accelerator**
  - Full 12 GeV energy achieved
  - Full luminosity demonstrated
  - Simultaneous multi-hall beam delivery achieved
- **Hall C** – Key Performance Parameter demonstrated
  - SHMS installed, commissioned with beam
  - March 2017
- **Hall B** – Key Performance Parameter demonstrated
  - CLAS12 installed, commissioned with beam
  - February 2017
- **Remaining Scope** = Solenoid Magnet for Hall B
  - Final phase of assembly at vendor completed in June 2017
  - Delivered to Jefferson Lab June 27
  - Installation and acceptance tests underway

Project Completion September 2017

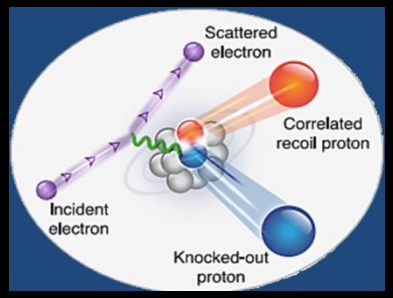
Future Projects



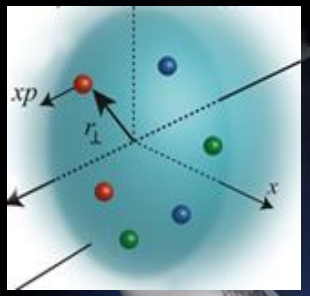
- MOLLER experiment
  (Possible MIE – FY19-23)
  - CD-0 approved
    (project paused due to budget uncertainty)
  - Standard Model Test
  - DOE science review (September 2014) – strong endorsement
  - Director's review held December 15-16, 2016
    Technical, cost & schedule

- SoLID
  - SIDIS and PVDIS
  - CLEO Solenoid ✓
  - International collaboration
  - Director's review (Feb. 2015)
    → new pre-CDR almost complete

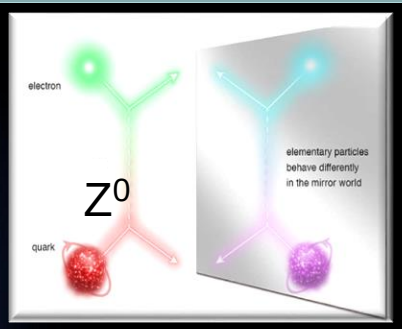
JLab: A Laboratory for Nuclear Science



Nuclear Structure

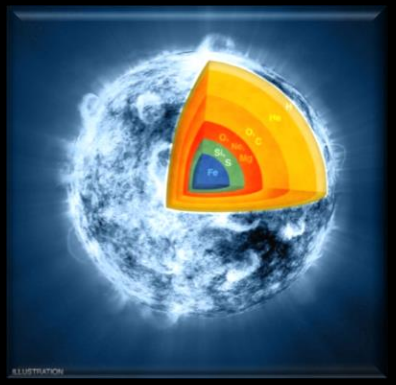


Structure of Hadrons

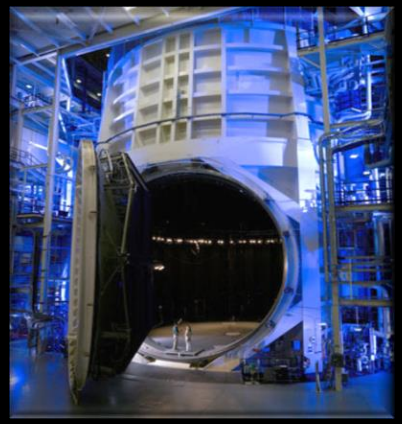


Fundamental Forces & Symmetries

Medical Imaging



Nuclear Astrophysics



Cryogenics

Accelerator S&T

Theory & Computation

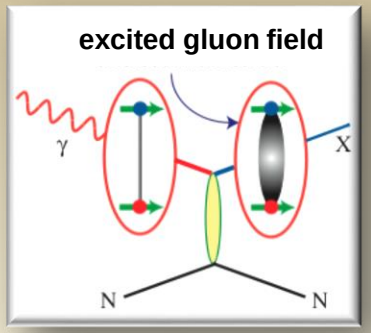
Jefferson Lab @ 12 GeV Science Questions

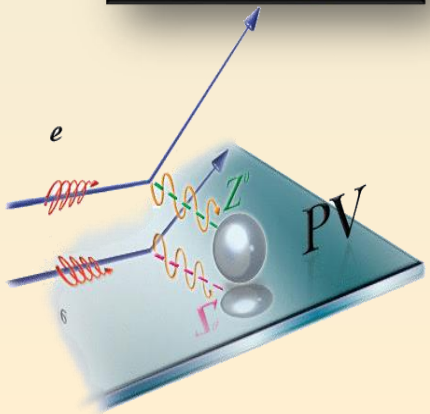
- What is the role of gluonic excitations in the spectroscopy of light mesons?

- 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?



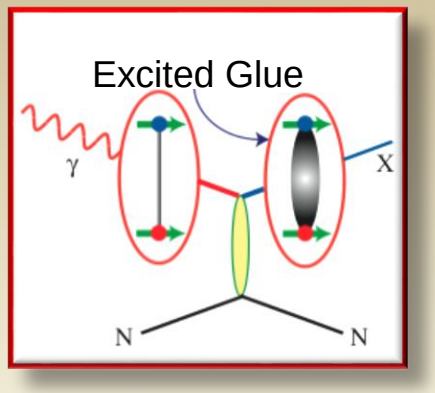


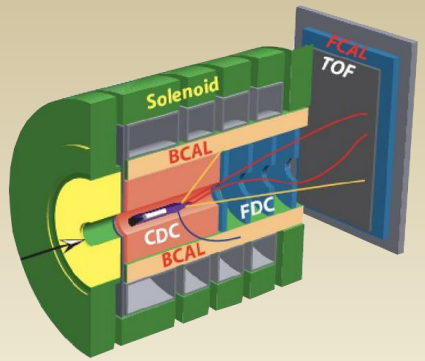
12 GeV Approved Experiments by Physics Topics

Topic	Hall A	Hall B	Hall C	Hall D	Other	Total
The Hadron spectra as probes of QCD	0	3	1	3	0	**7**
The transverse structure of the hadrons	6	4	3	1	0	**14**
The longitudinal structure of the hadrons	2	3	6	0	0	**11**
The 3D structure of the hadrons	5	9	6	0	0	**20**
Hadrons and cold nuclear matter	8	4	7	0	1	**20**
Low-energy tests of the Standard Model and Fundamental Symmetries	3	1	0	1	1	**6**
Total	**24**	**24**	**23**	**5**	**2**	**78**
Total Experiments Completed	**2.5**	**1.1**	**0**	**0.4**	**0**	**4.0**
Total Experiments Remaining	**21.5**	**22.9**	**23.0**	**4.6**	**2.0**	**74.0**

A Decade of Experiments

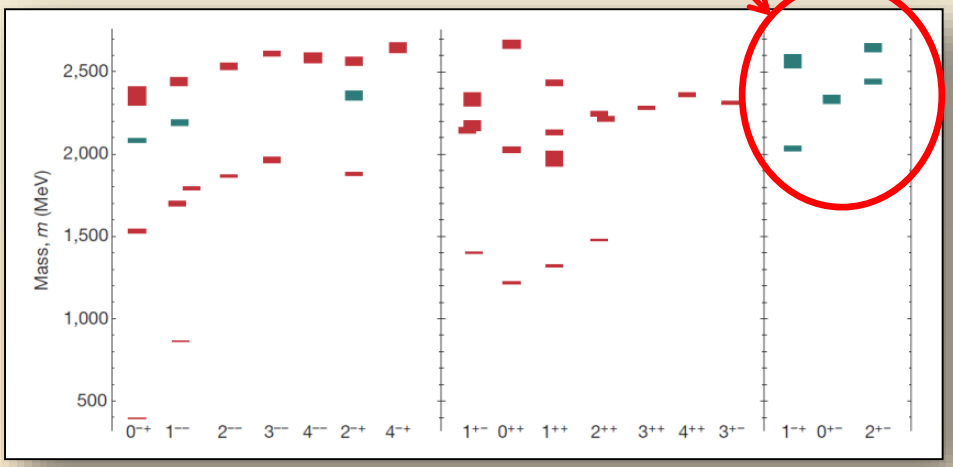
Gluonic Excitations and the Mechanism for Confinement





GlueX CITATIONS PERIMENT
Hall D@JLab

States with Exotic Quantum Numbers

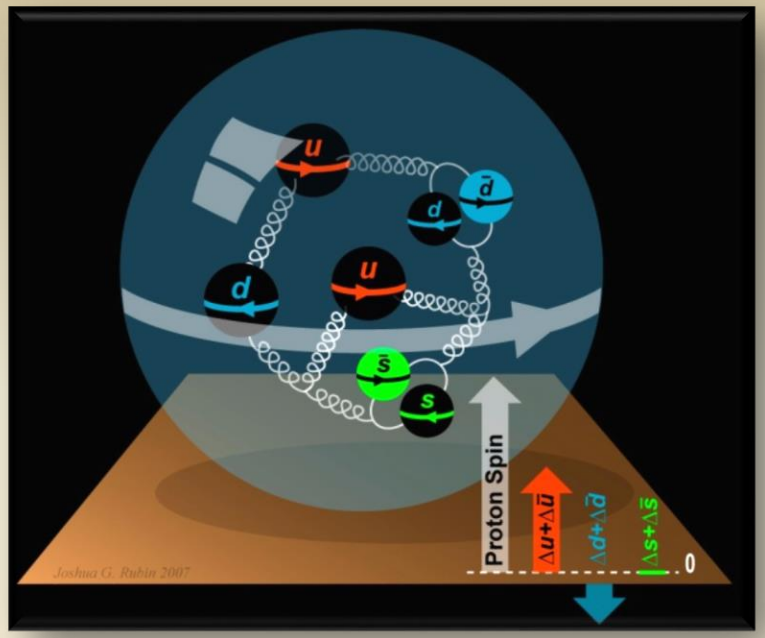


nature International weekly journal of science

Searching for the rules that govern hadron construction

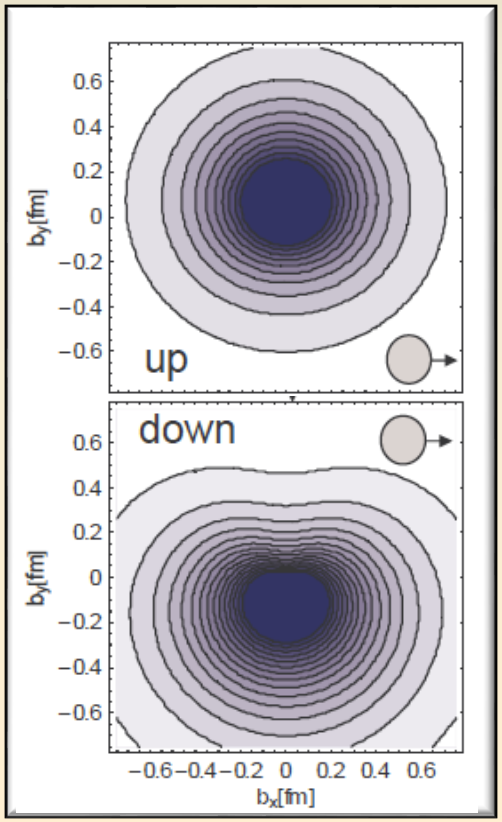
M. R. Sheperd, J. J. Dudek, R. E. Mitchell

The Incomplete Nucleon: Spin Puzzle



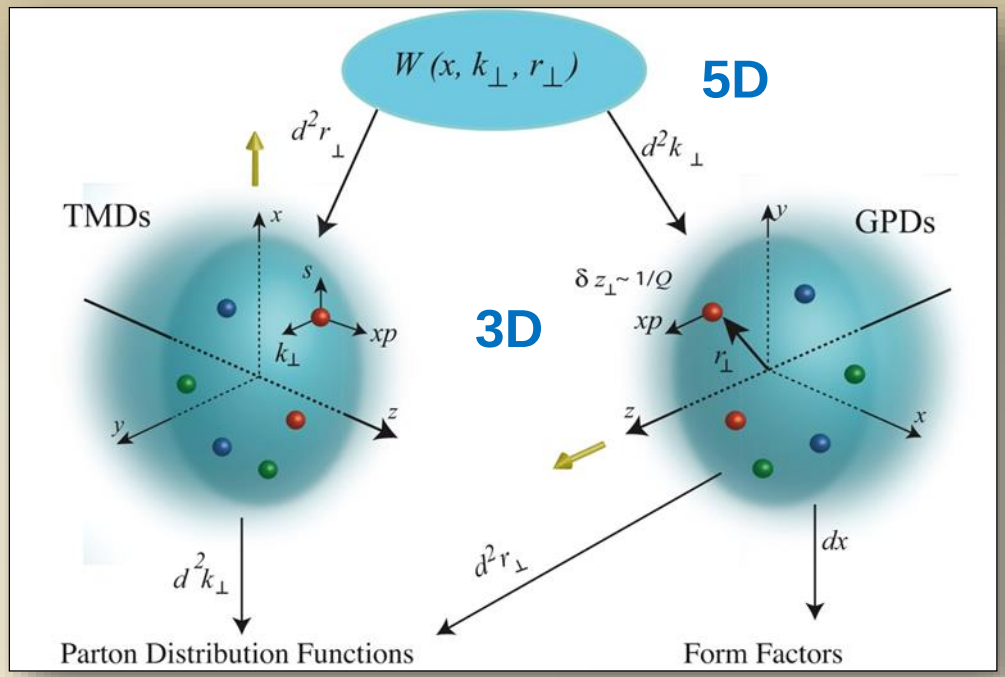
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g$$

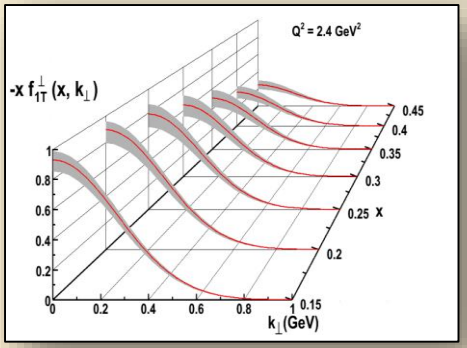
[X. Ji, 1997]

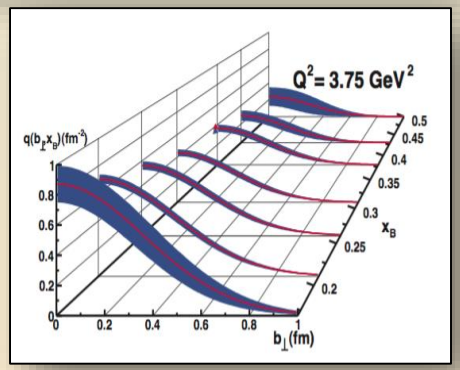


- DIS → $\Delta\Sigma \cong 0.25$
- RHIC + DIS → $\Delta G \sim 0.2$
- → L_q

Nuclear Femtography





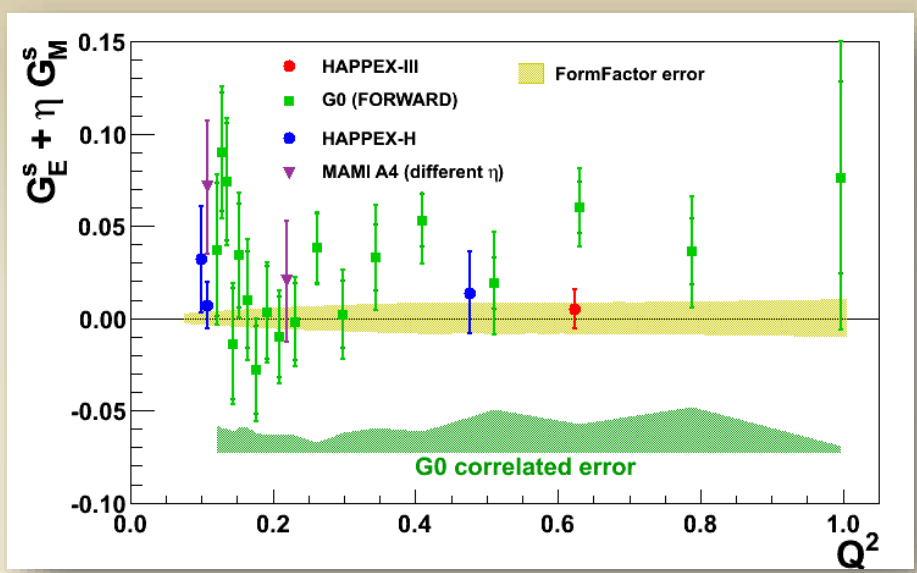


- Transverse Momentum Dist. (TMD)
  - Confined motion in a nucleon (semi-inclusive DIS)
- Generalized Parton Dist. (GPD)
  - Spatial imaging (exclusive DIS)
- Requires
  - High luminosity
  - Polarized beams and targets
  - Sophisticated detector systems

Major new capability with JLab @ 12 GeV

Parity Violation at JLab

- Nucleon Strangeness Form Factors (complete)
  - HAPPEX (Hall A)
  - G0 (Hall C)



- Neutron Skin
  - PREX
  - CREX

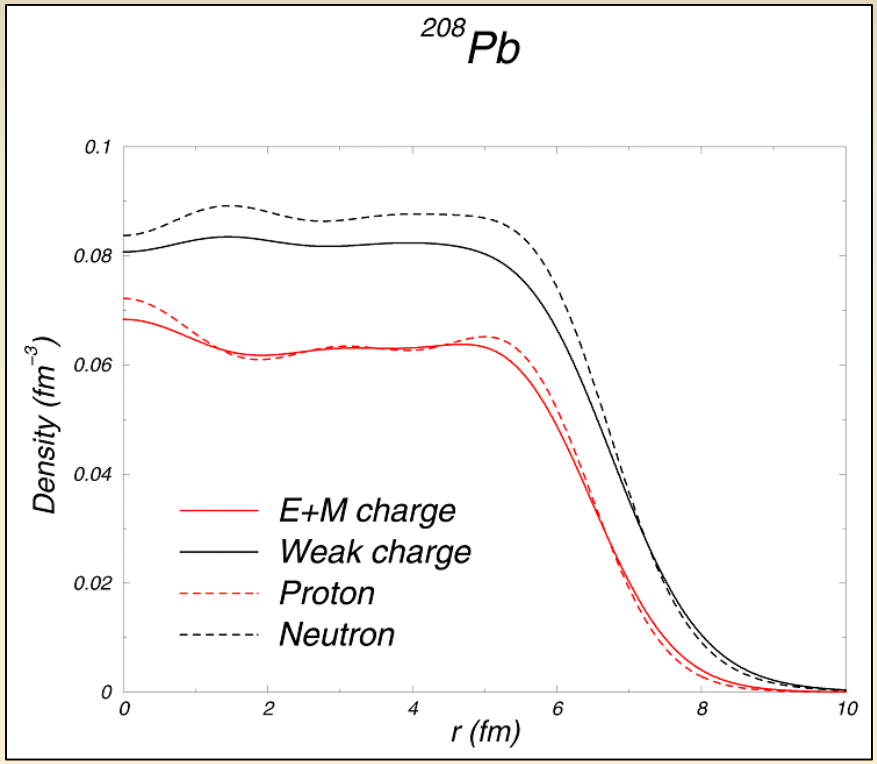
- Precision Tests of Standard Model
  - Qweak (Under analysis)
  - MOLLER
  - SoLID

Measuring the Neutron "Skin" in the Pb Nucleus

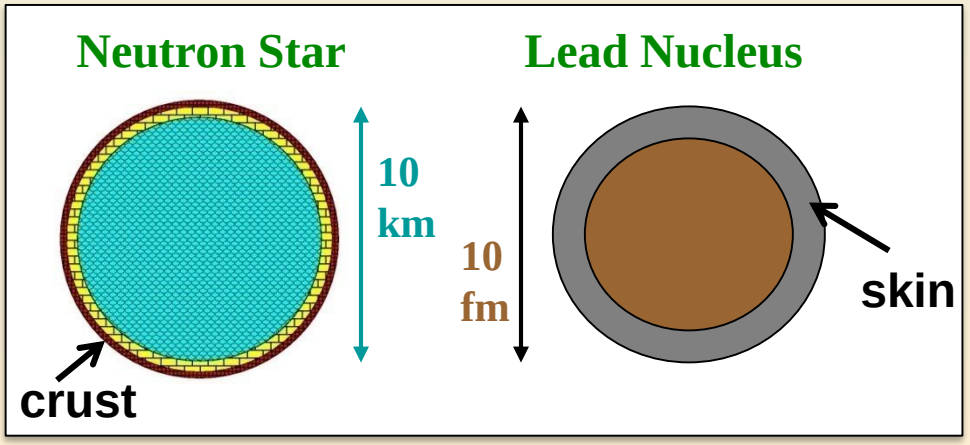
$Q_w^p = (1 - 4 \sin^2 \theta_W)$

$Q_w^n = -1$

Weak interaction selects neutrons

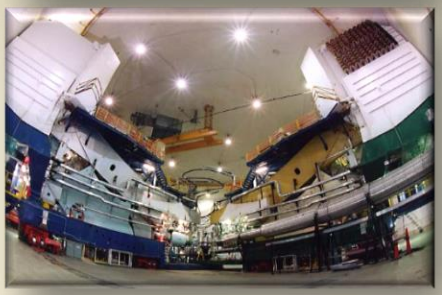


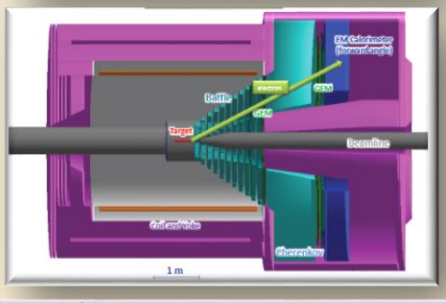
- Parity violating electron scattering
- Sensitive to neutron distribution

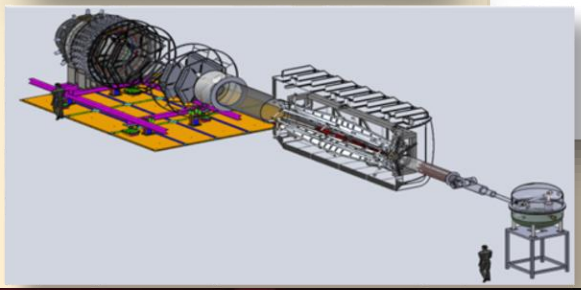


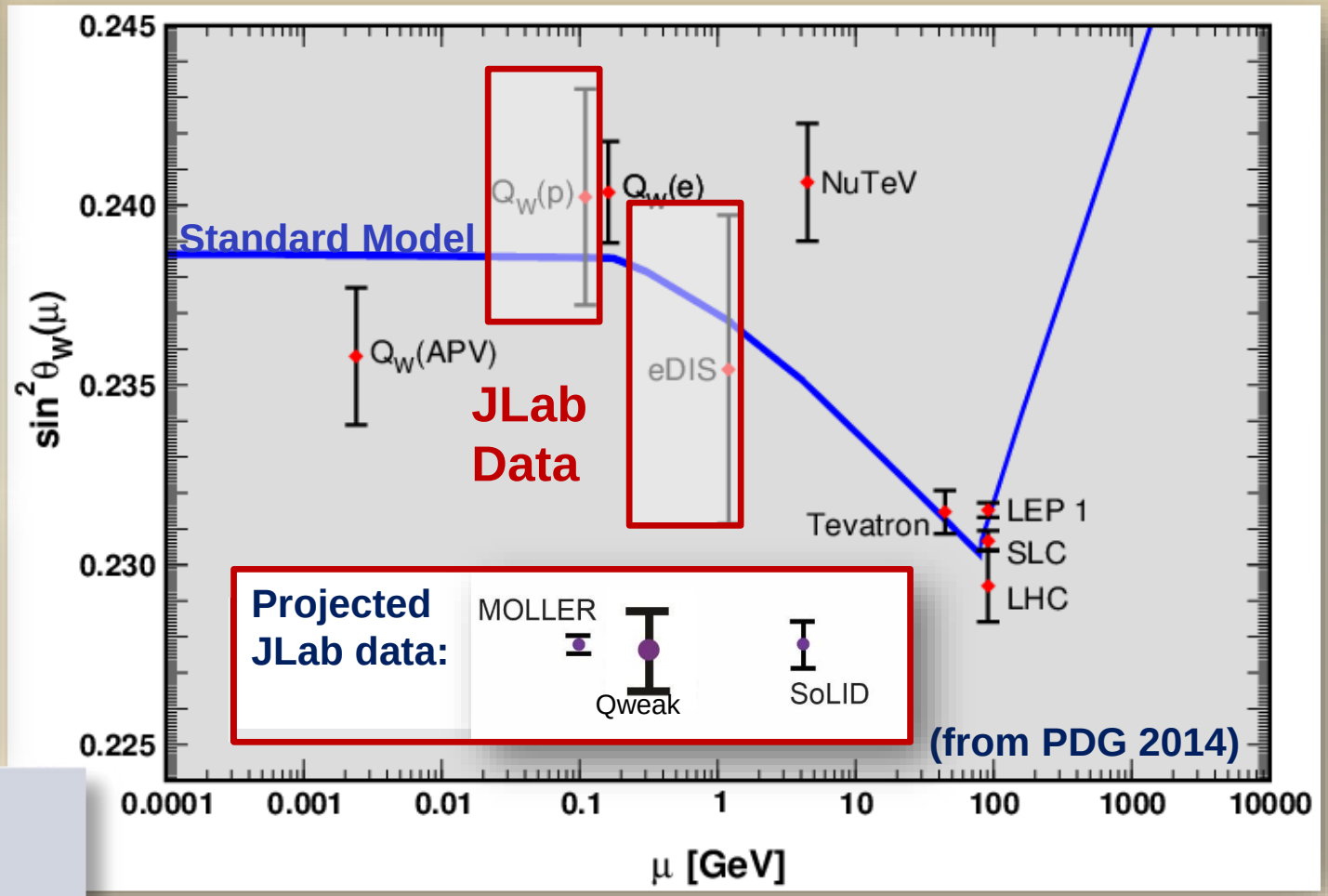
Applications: Nuclear Physics, Neutron Stars,
Atomic Parity, Heavy Ion Collisions

Testing the Standard Model at JLab







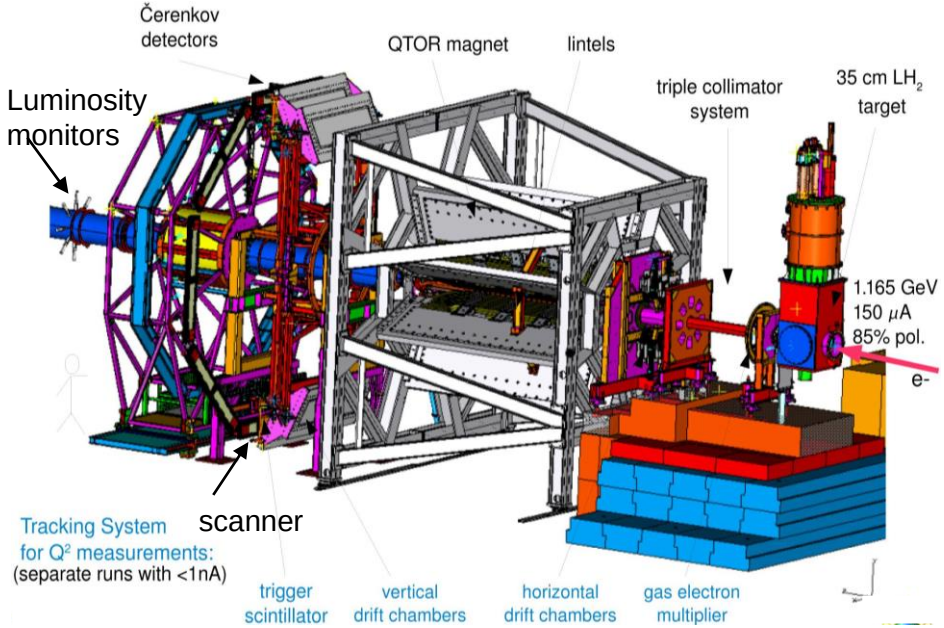


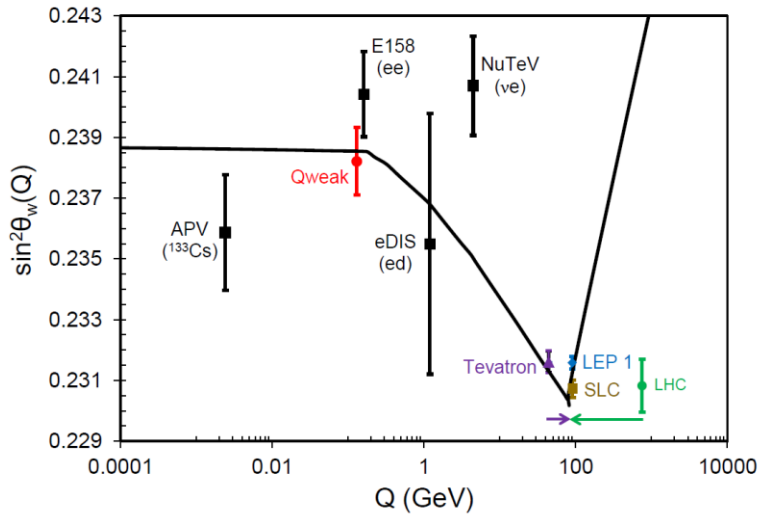
New Qweak Result

Precise determination of the weak charge of the proton

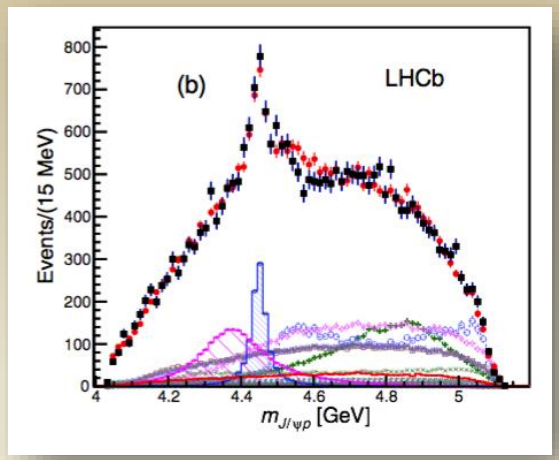
$$Q_W = -2(2C_{1u}+C_{1d})$$
$$=(1 - 4 \sin^2 \theta_W)$$

- Result unblinded March 2017
- In preparation for submission to Nature





Charmonium Pentaquark



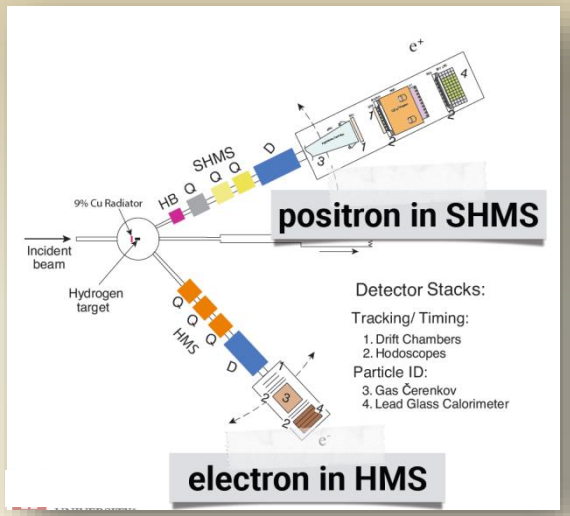
LHCb

2 P_c states needed to describe results:

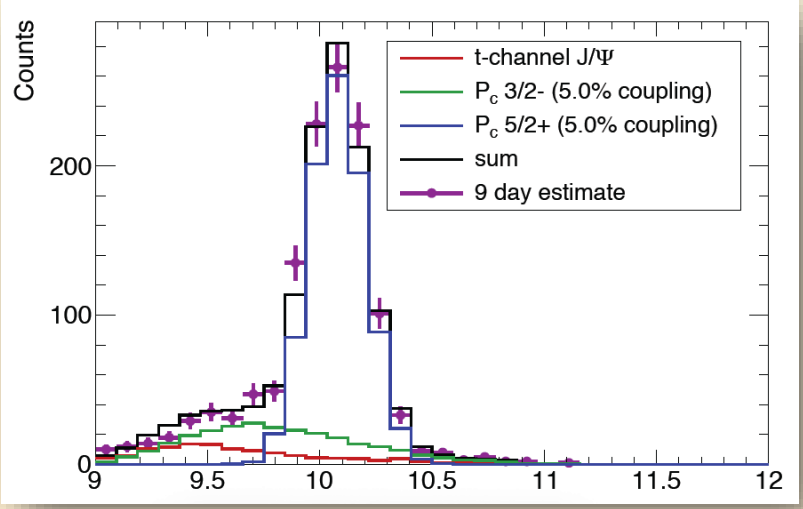
narrow: $P_c(4450)$

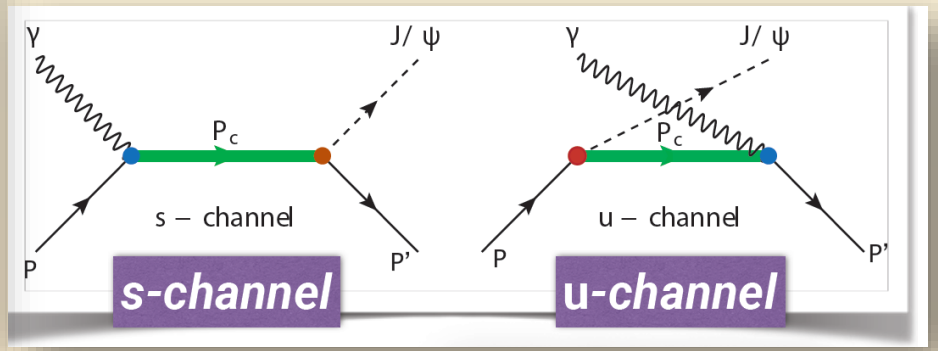
wide: $P_c(4380)$

JLab E12-16-007

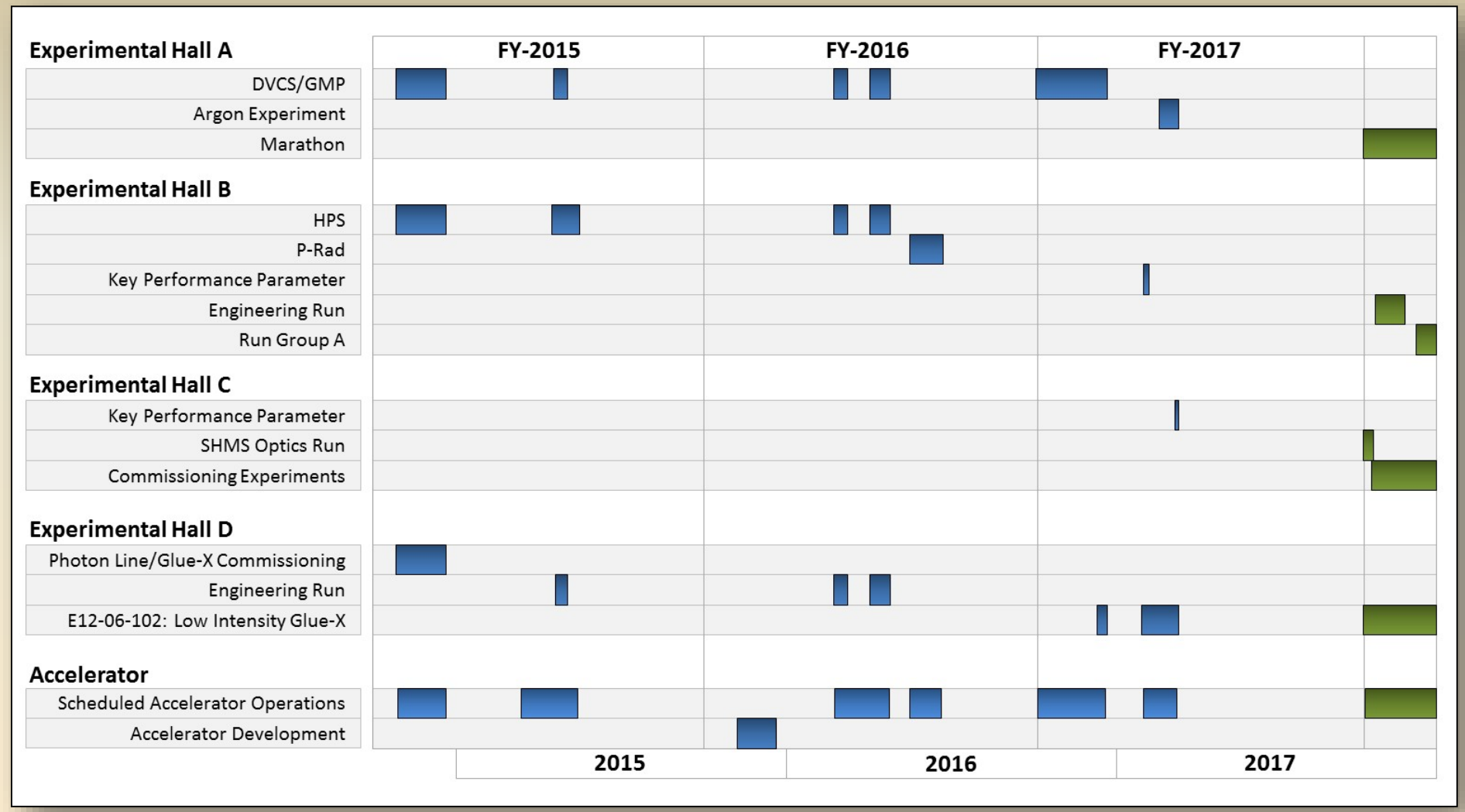


$$\gamma p \rightarrow P_c \rightarrow J/\psi p$$



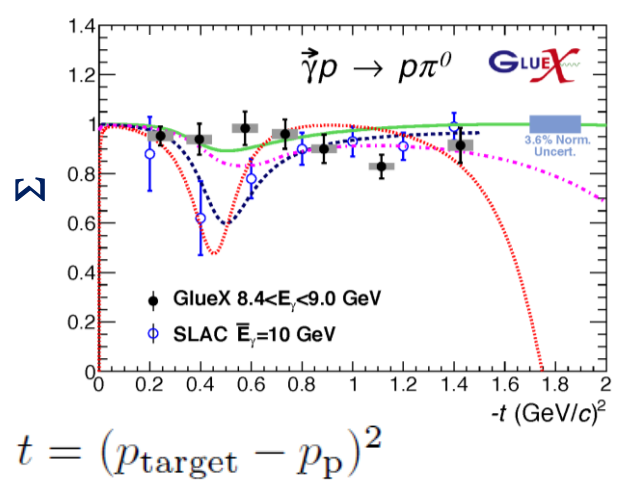


CEBAF Program FY15-17



First Published Results from 12 GeV CEBAF

The first experimental results, from data collected in the GlueX engineering run, have been published in Phys. Rev. C.

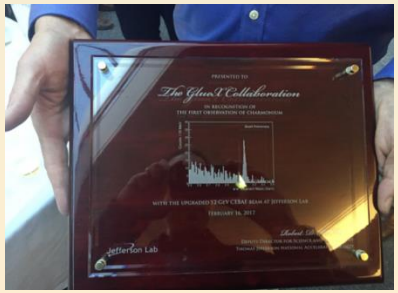


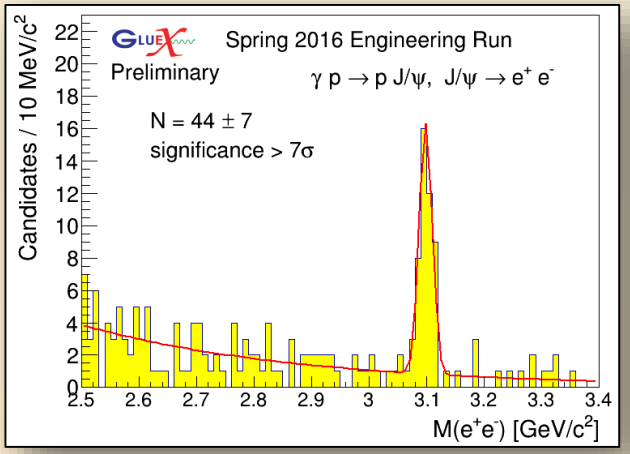
The new GlueX results show:

- For neutral pions, the reaction mechanism is dominated by pure vector coupling.
- The first data for beam asymmetry for η production >3 GeV.
- **The GlueX experiment in Hall D can produce timely results.**

GlueX will search for hybrid mesons, particles in which the strong gluonic field contributes directly to their properties. From the spectrum of these particles, we can learn about the gluonic field in QCD.

Bonus:

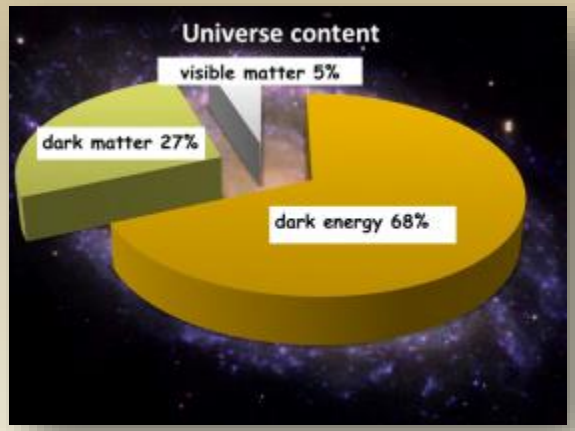


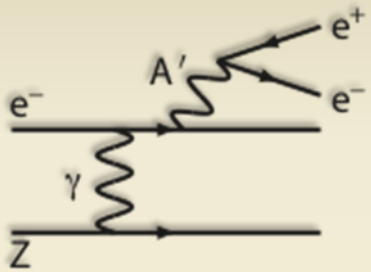


First observation of charmonium at JLab!

Heavy Photon Search – First Results

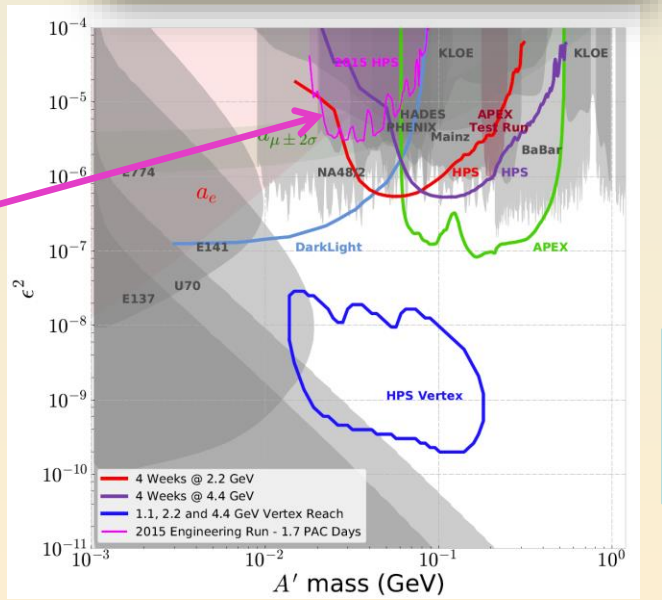
- NP-HEP Collaboration

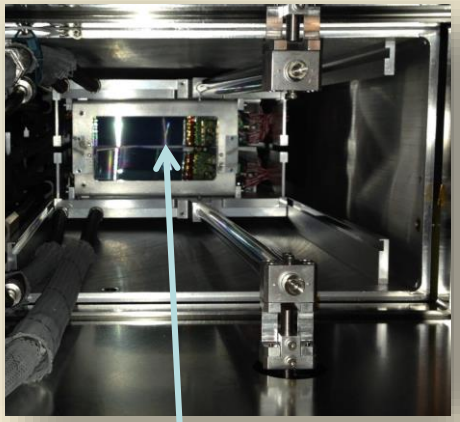




2015 Engineering Run
1.7 PAC days @ 1.05 GeV

2 GeV data taken in 2016, under analysis

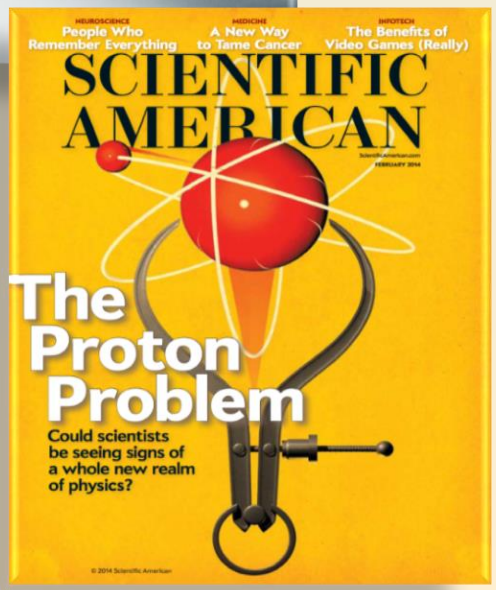


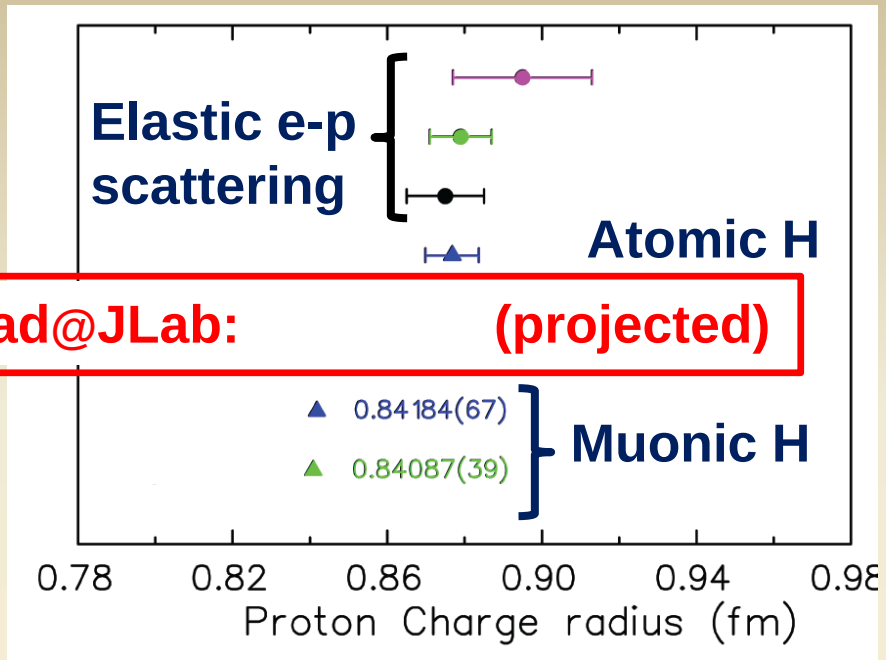


1 mm gap between Si tracker detectors for passage of electron beam

Future Program: more HPS, APEX, DarkLIGHT

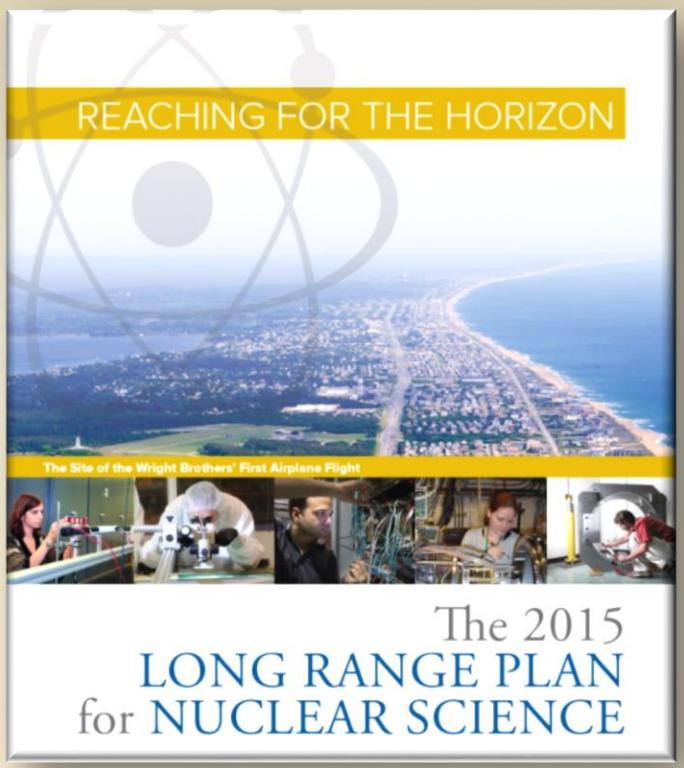
Solving the Proton Radius Puzzle





- PRad: new experiment to address proton radius @ JLab
- NSF MRI: H_2 gas target
- DOE GEM tracking detectors
- Successful run in summer 2016!

2015 NSAC Long Range Plan

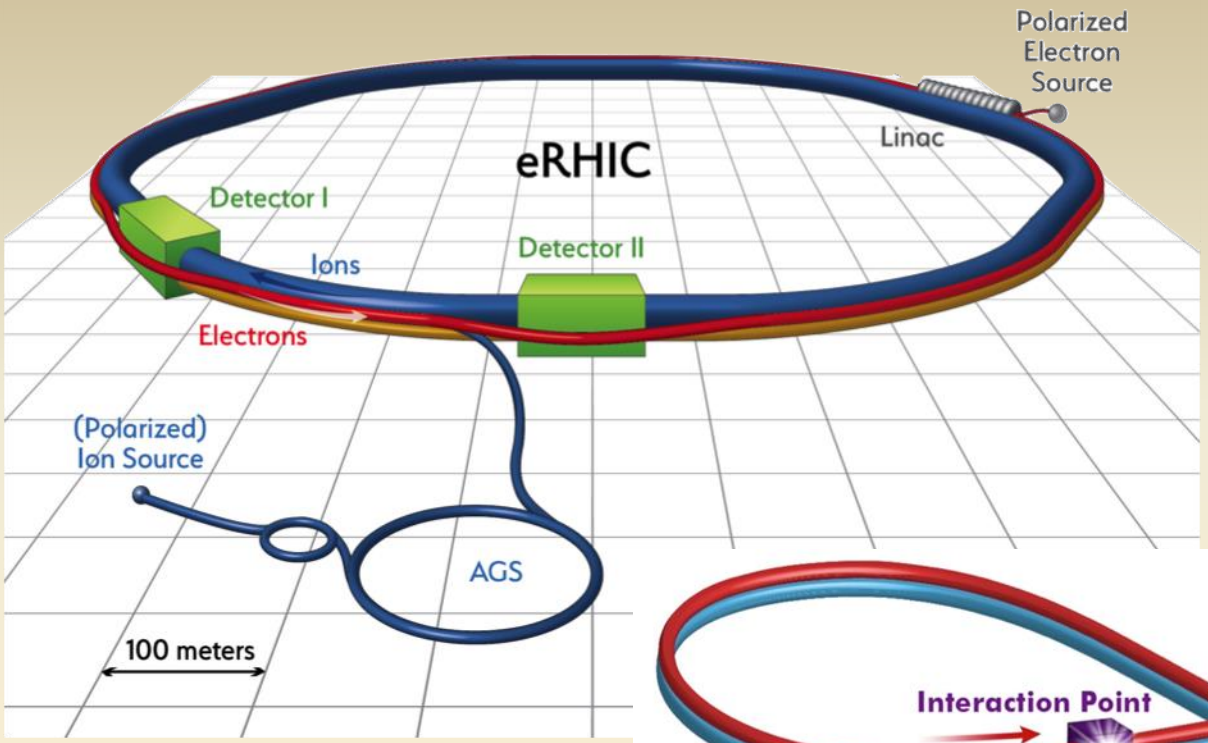


RECOMMENDATION III

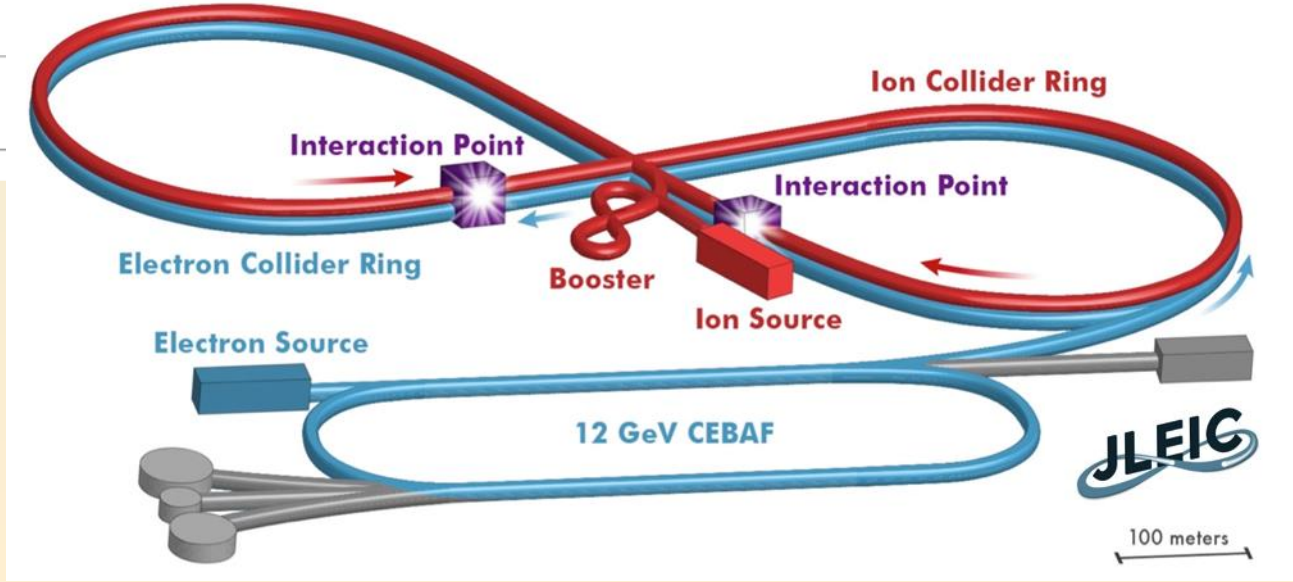
Gluons, the carriers of the strong force, bind the quarks together inside nucleons and nuclei and generate nearly all of the visible mass in the universe. Despite their importance, fundamental questions remain about the role of gluons in nucleons and nuclei. These questions can only be answered with a powerful new electron ion collider (EIC), providing unprecedented precision and versatility. The realization of this instrument is enabled by recent advances in accelerator technology.

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

US-Based EIC Proposals



Brookhaven Lab
Long Island, NY



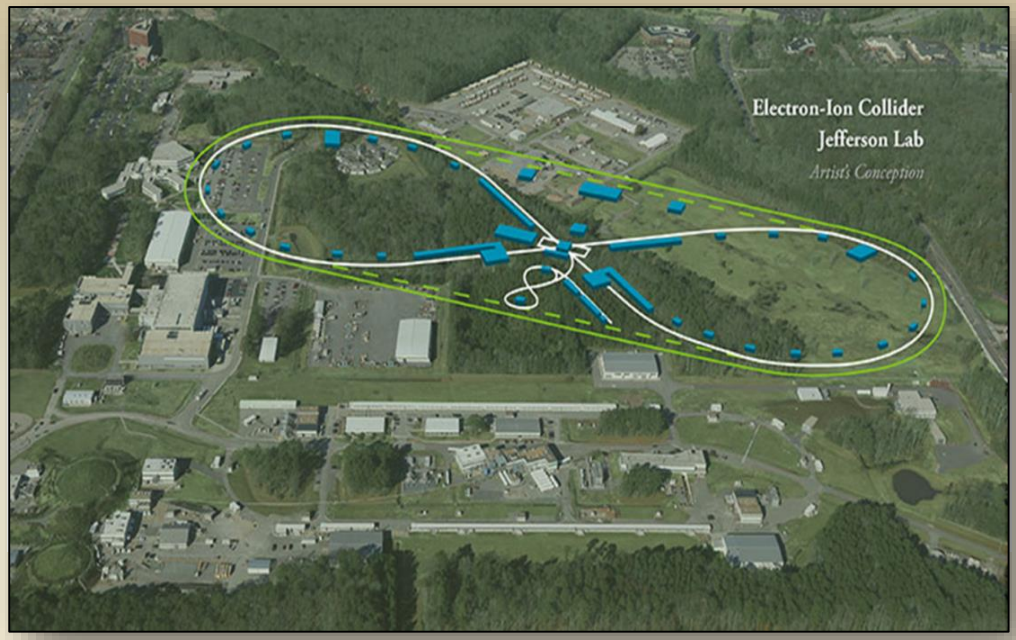
Jefferson Lab
Newport News, VA

EIC at Jefferson Lab

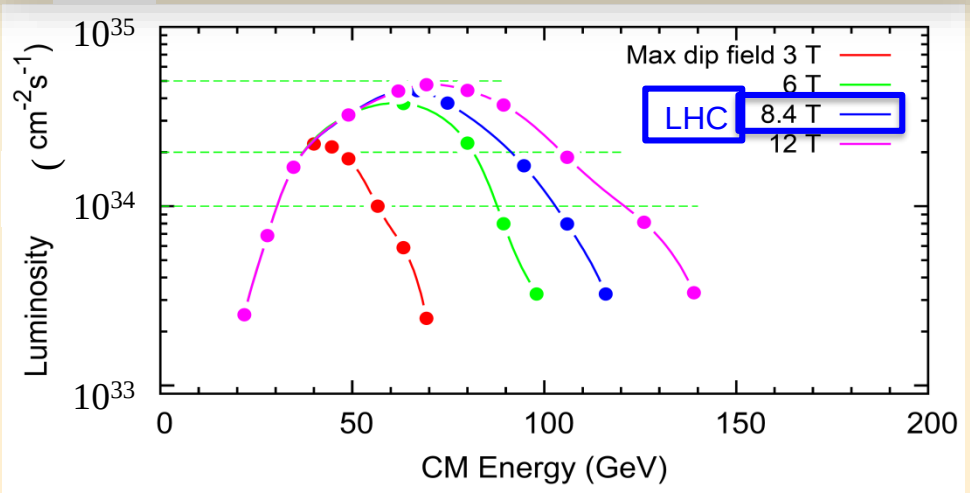
JLab EIC Figure 8 Concept

- High Polarization
- High Luminosity
- Low technical risk
- Flexible timeframe for construction consistent w/running 12 GeV CEBAF
- Cost effective operations

➢ Fulfills White Paper Requirements



- Collaboration with SLAC, LBNL, ANL, BNL
- Site evaluation (Virginia funds)
- User group organizing (charter, meetings)
- NAS study underway
- DOE-NP accelerator R&D program (FY17-18)



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