

The Jefferson Lab 12 GeV Program

The Jefferson Lab facilities have undergone a substantial upgrade, both of accelerator, CEBAF, and of the experimental installations. We will discuss the progress to completion of these facilities, the status of accelerator commissioning, and the recent first operations for physics. We will then flesh out the anticipated exciting physics program of the next several years.

Hugh Montgomery
Jefferson Lab

International Nuclear Physics Conference 2016

Acknowledgements

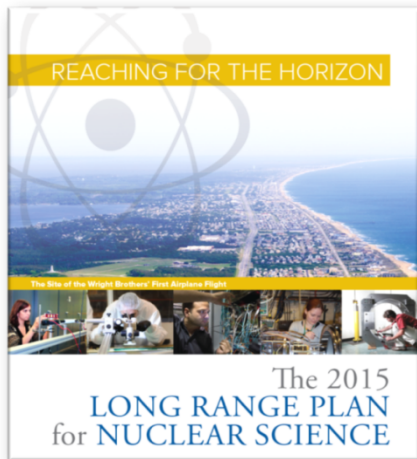
The 12 GeV Program at Jefferson Lab has taken many years from its inception in the previous millennium to its realization as an important pillar of the world nuclear physics program in the 21st Century.

I would like to acknowledge the input and contributions from the staff and users of Jefferson Lab who have made this exciting program possible. In particular, much of the material was shown by Bob McKeown at *Hadron Workshop 2016* in China, and some of the output from the GlueX experiment was presented by Curtis Meyer at *Meson 2016*.

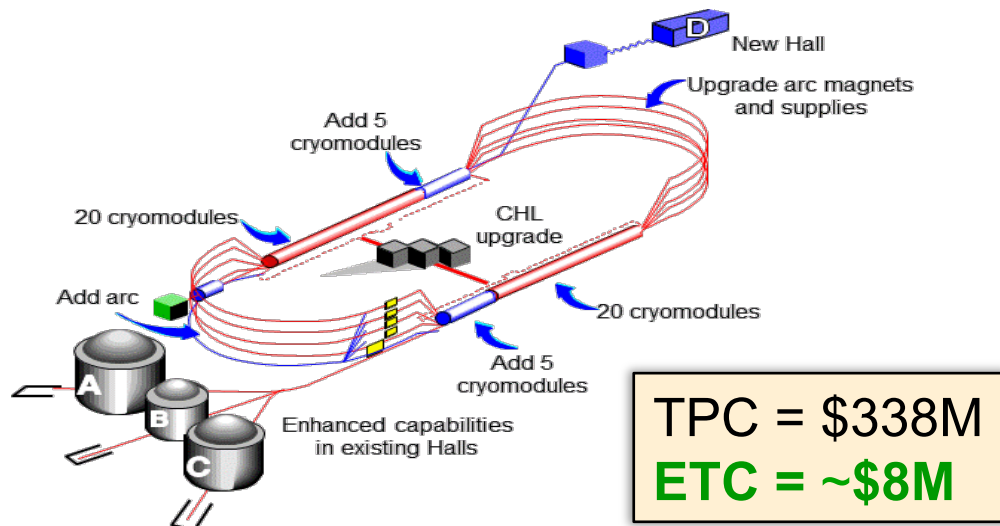
Outline

- 12 GeV CEBAF
- Status of the Experiments
- 12 GeV Physics Program
 - Meson Spectroscopy, Hybrid Mesons, and Confinement
 - Nucleon Tomography
 - Nuclei and Nuclear Structure
 - The Standard Model and Beyond
- Conclusions

CEBAF Upgrade



“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**

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

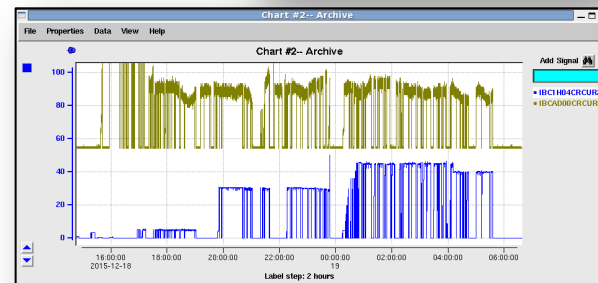
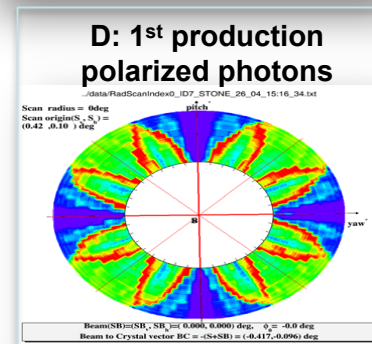
Spring 2016:

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

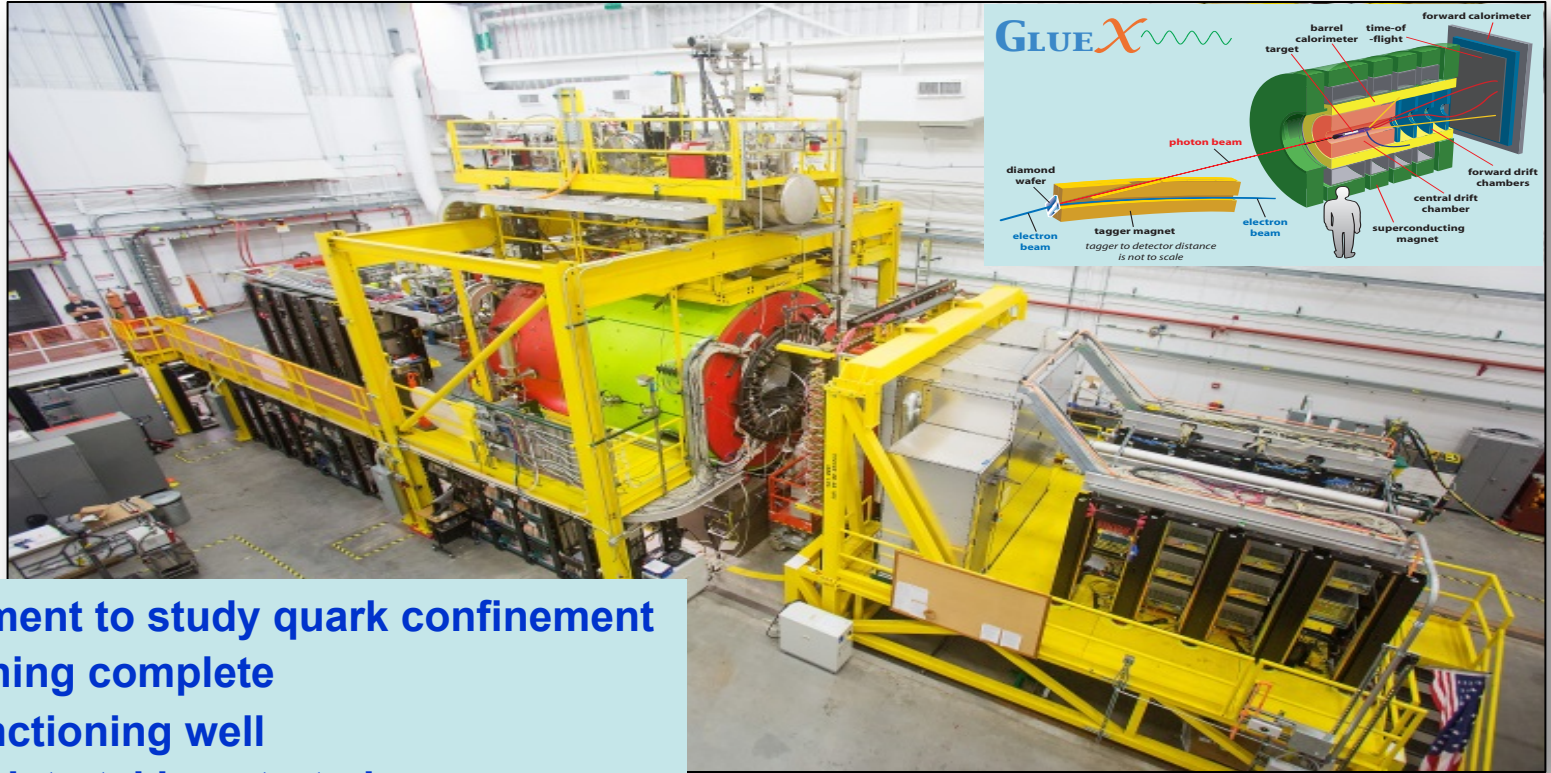
Summer 2016:

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

Accelerator ready for 12 GeV physics program



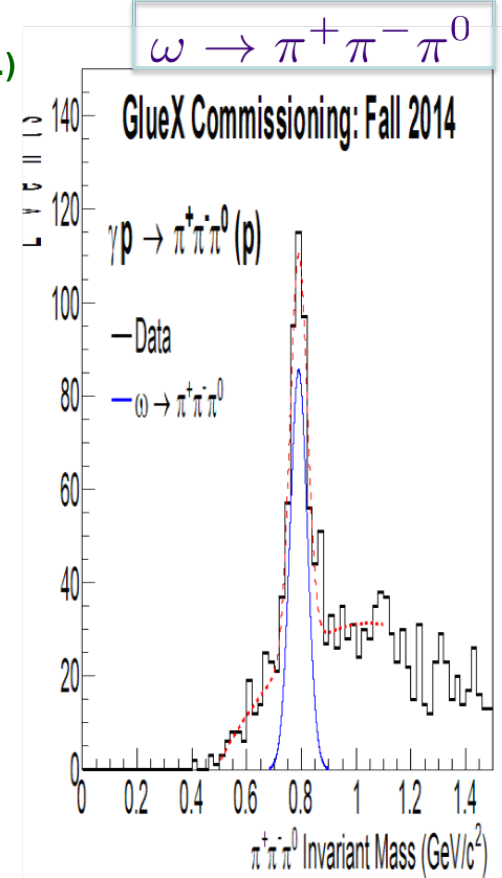
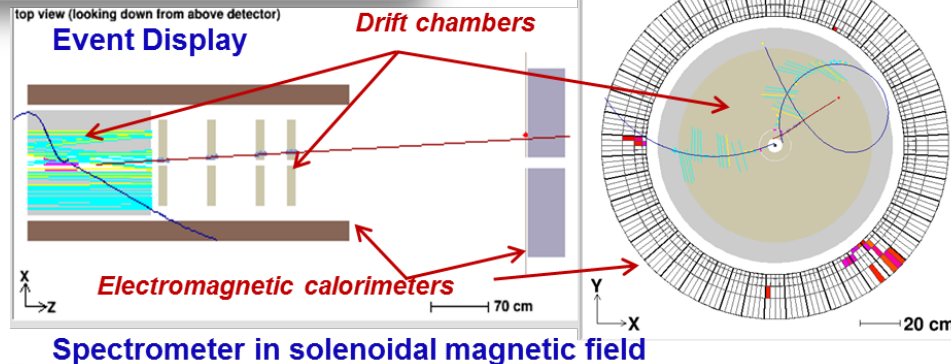
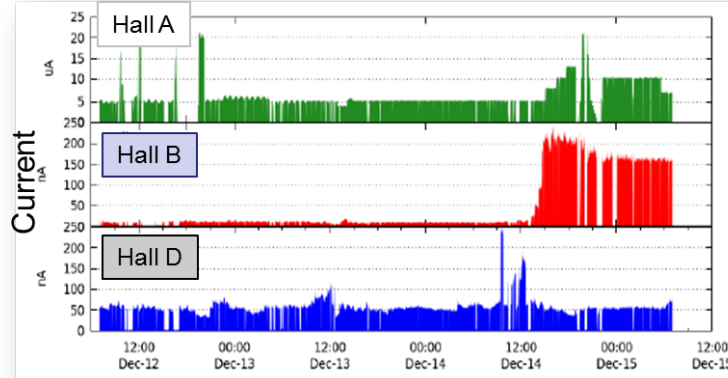
GlueX in Hall D



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

CEBAF 2014 Commissioning: Hall D

- Achieved 12 GeV Project Hall D performance parameters (December 2014)
- Delivered beam quality met the *initial years* user requirements (e, dp/p, polarization...)
- Beam delivered to 3 Halls simultaneously



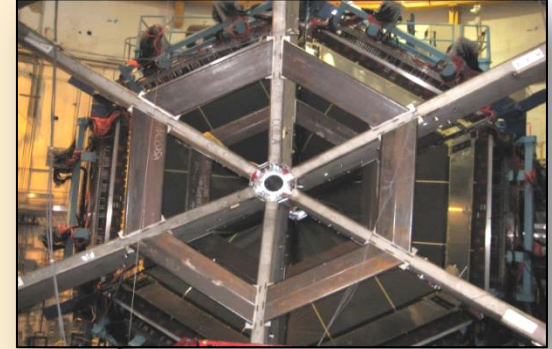
12 GeV Upgrade Project

Remaining scope & status:

- Hall C superconducting dipole, 2 quads
 - All magnets assembled, leak-checking & welding in progress
 - Q2 quadrupole left Vannes in late August
- Hall B superconducting torus, solenoid
 - Torus in cool-down
 - Solenoid: (coils 1 – 4, and coil 5 mated) cold mass assembled

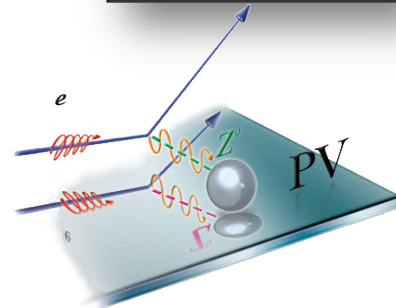
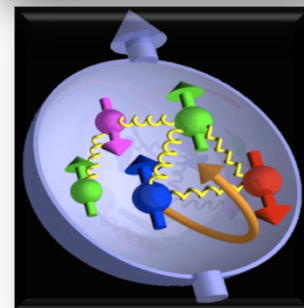
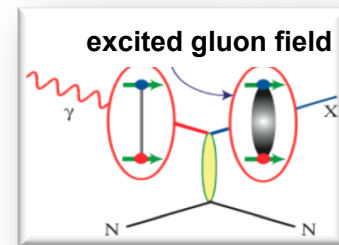
Most key technical risks retired.

Proactively managing work at vendors to minimize schedule delays.



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

Meson & Baryon Spectroscopy

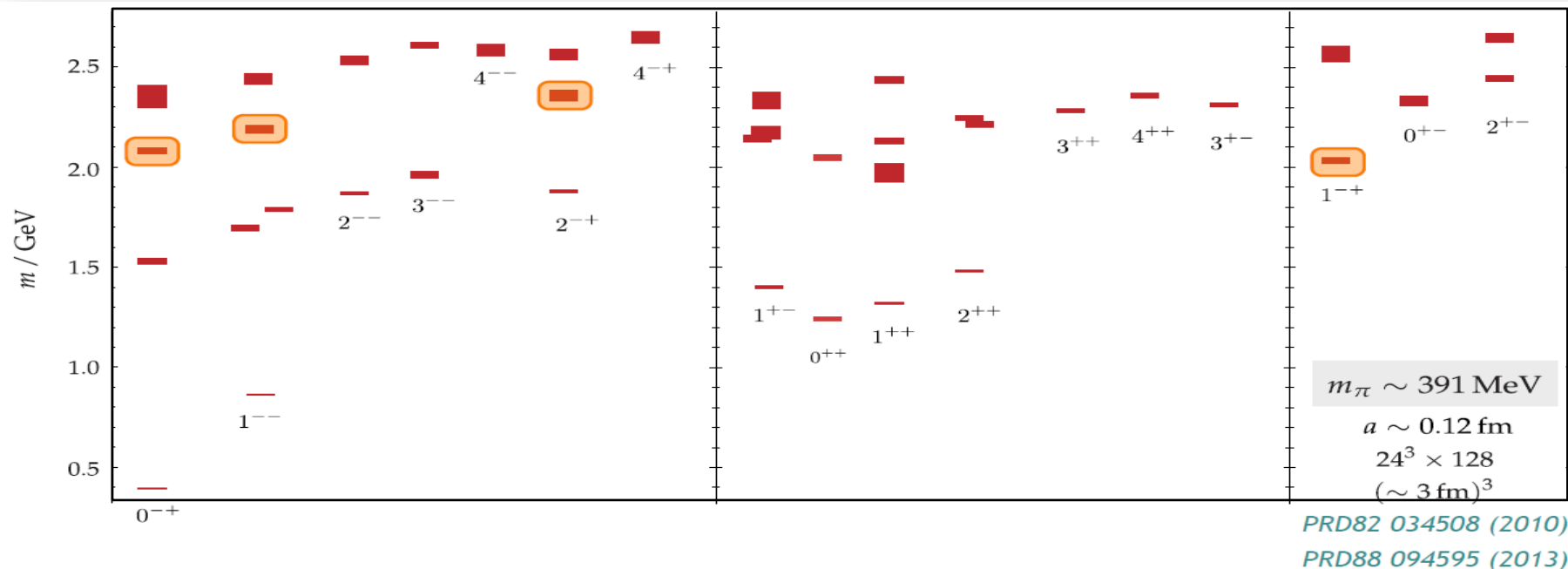
Hybrid Mesons

Confinement

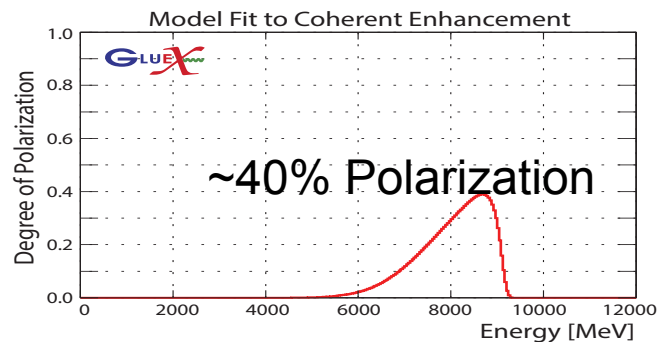
Isospin 1 Meson Spectrum

- ‘super’-multiplet of **hybrid mesons** roughly 1.2 GeV above the ρ

$(0, 1, 2)^{-+}, 1^{--}$

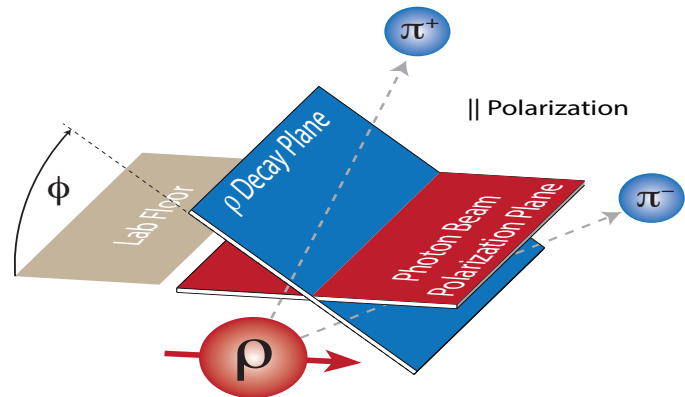


Beam Asymmetry in ρ Photoproduction



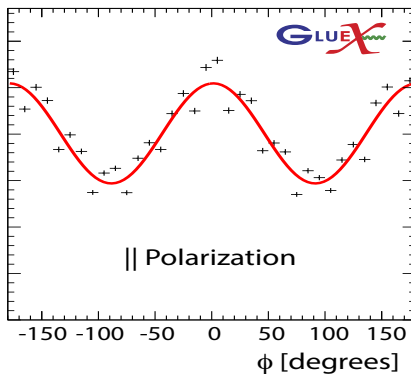
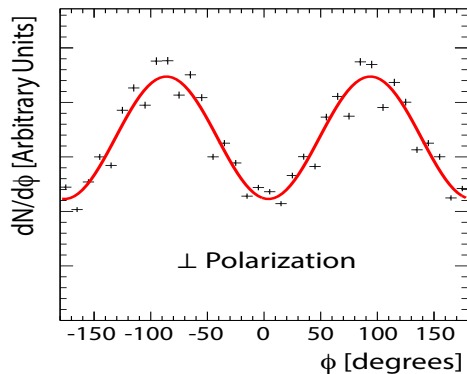
Between 100 and 1000 times the 3000 existing events from SLAC.

Working with JPAC on models for analysis

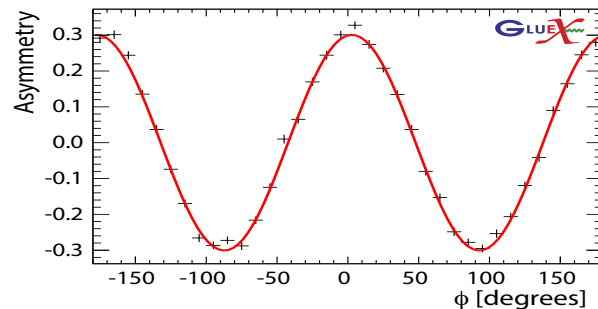


$$d\sigma_{\perp} \propto 1 - P_{\perp} \Sigma \cos 2\phi$$

$$d\sigma_{\parallel} \propto 1 + P_{\parallel} \Sigma \cos 2\phi$$



$$P \Sigma \cos 2\phi = \frac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}}$$



Acceptance errors not included

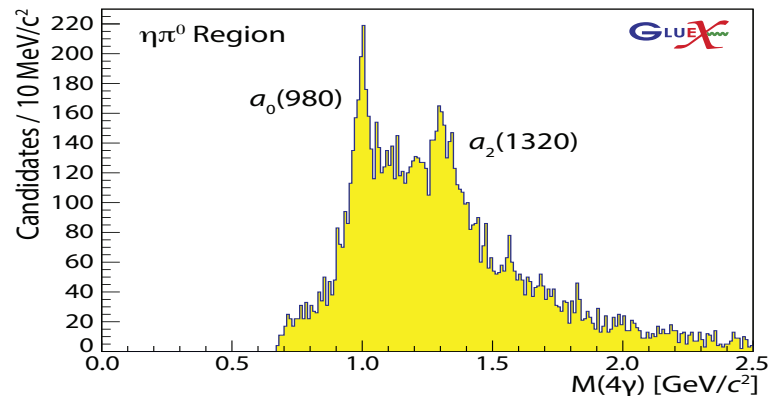
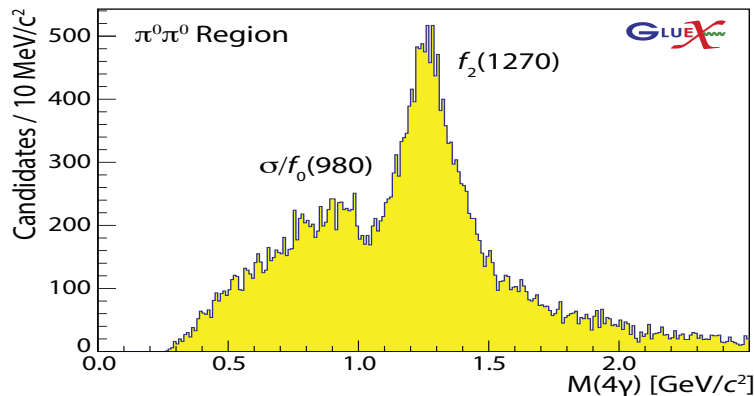
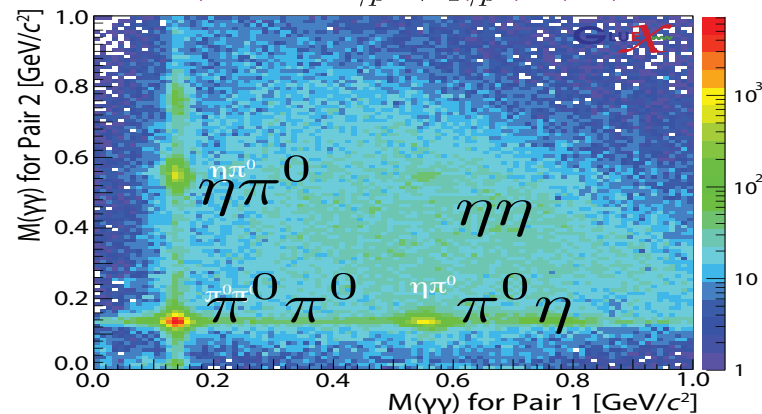
Large polarization transfer to the r

Four Photon Final States

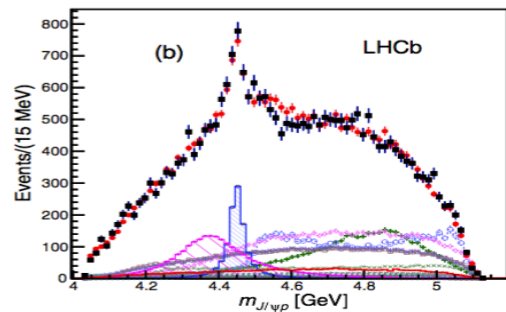
About 6% of the spring 2016 statistics from early in the run and using a very preliminary production run.

Clear signals for σ , $f_0(980)$, $f_2(1270)$, $a_0(980)$ and $a_2(1320)$.

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



Charmonium Pentaquark



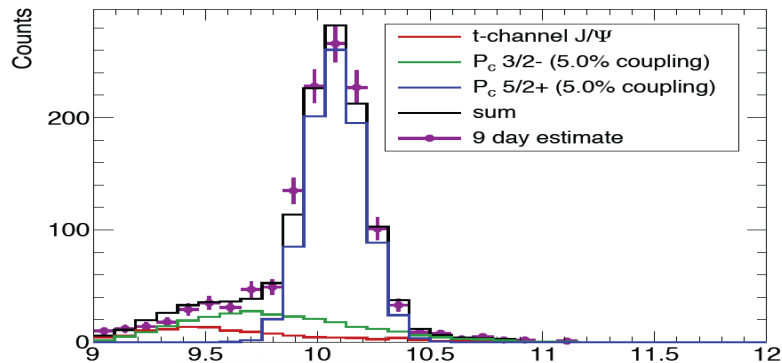
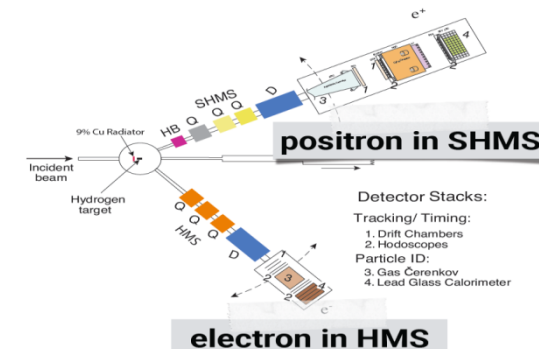
LHCb

2 P_c states needed to describe results:

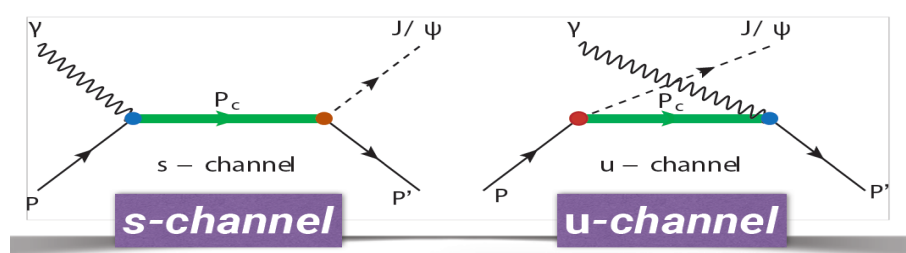
narrow: $P_c(4450)$

wide: $P_c(4380)$

JLab E12-16-007

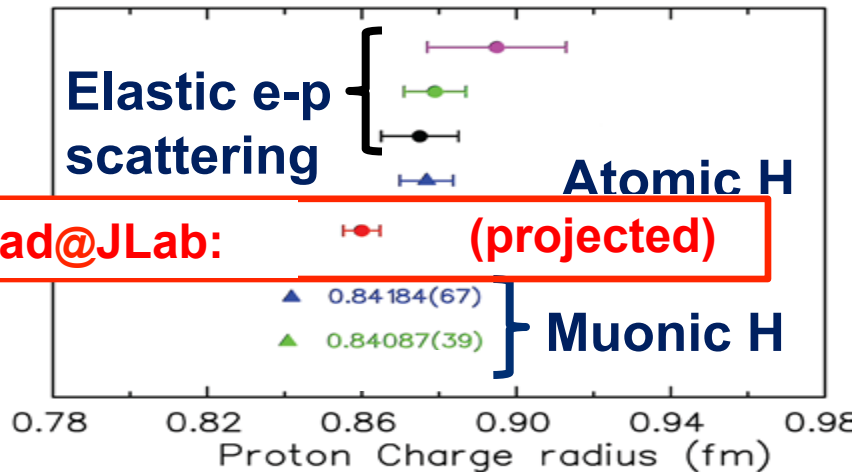


$$\gamma p \rightarrow P_c \rightarrow J/\psi p$$



Nucleon Tomography

Solving the Proton Radius Puzzle



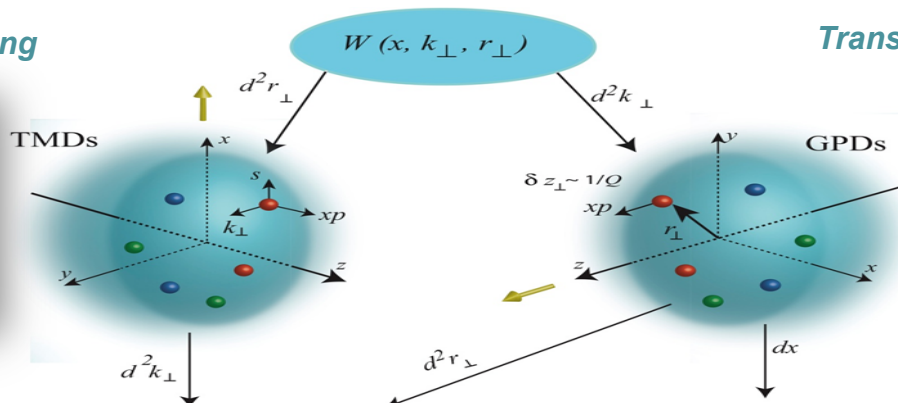
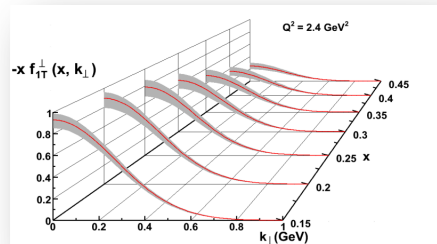
- PRad: new experiment to address proton radius @ JLab
- NSF MRI: H₂ gas target
- DOE GEM tracking detectors
- Successful run in summer 2016!

3D Mapping of the Nucleon

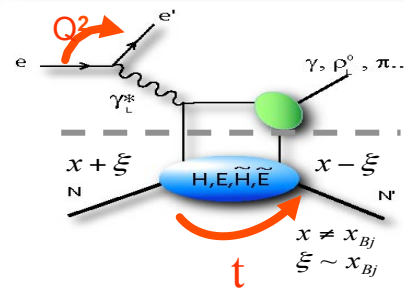
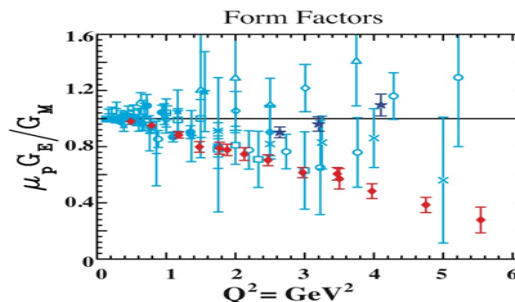
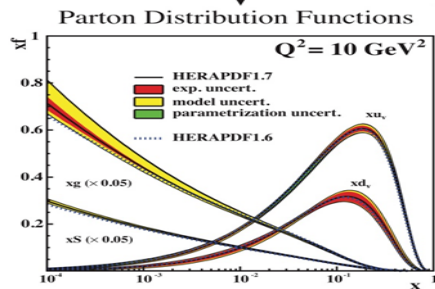
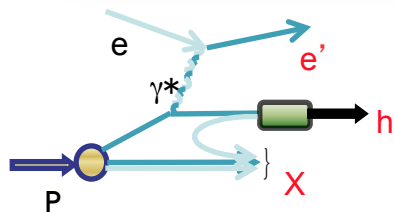
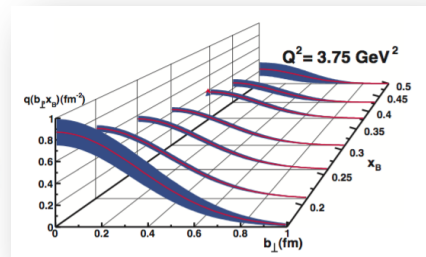
TMDs: Longitudinal momentum fraction x and transverse momentum k

GPDs: Longitudinal momentum fraction x at transverse location b

Transverse Momentum Imaging



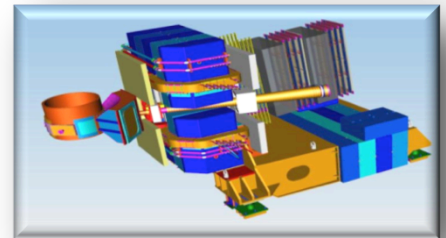
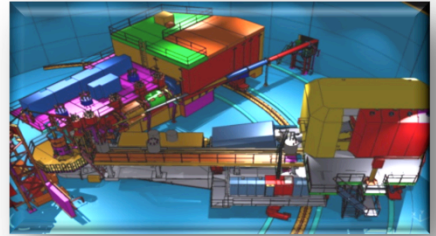
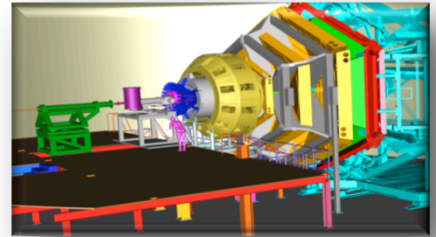
Transverse Spatial Imaging



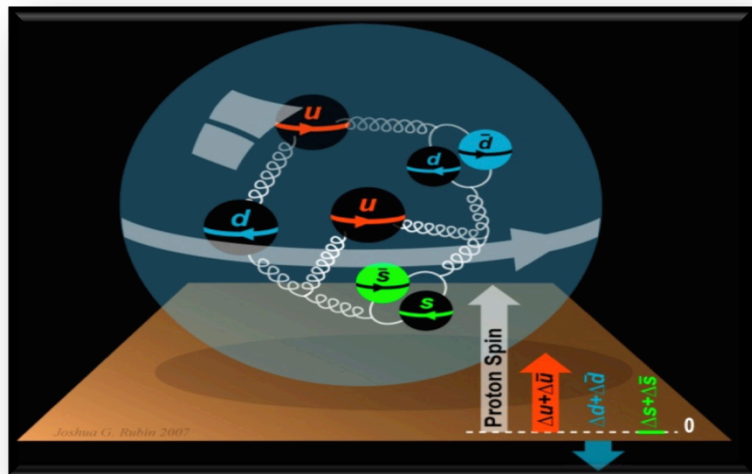
Imaging with JLab @ 12 GeV

Generalized Parton Distributions (GPDs) and Transverse Momentum Distributions (TMDs)

- CLAS12 in Hall B: general survey experiments, large acceptance and medium luminosity
- SHMS, (HMS) and Neutral-Particle Spectrometer (NPS) in Hall C: precision cross sections for L-T studies and ratios, small acceptance and high luminosity
- SBS in Hall A : dedicated large-x TMD study medium acceptance and high luminosity
- Future: SoLID in Hall A: large acceptance and high luminosity



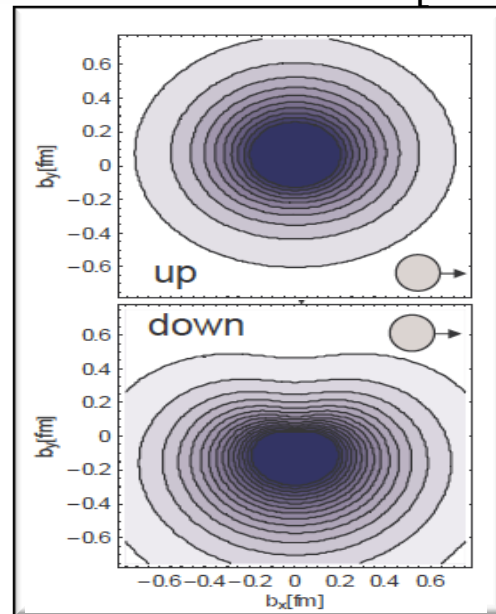
The Incomplete Nucleon: Spin Puzzle



- DIS $\rightarrow \Delta\Sigma \approx 0.25$
- RHIC + DIS $\rightarrow \Delta G \sim 0.2$
- $\rightarrow L_q$ CEBAF 12 GeV

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

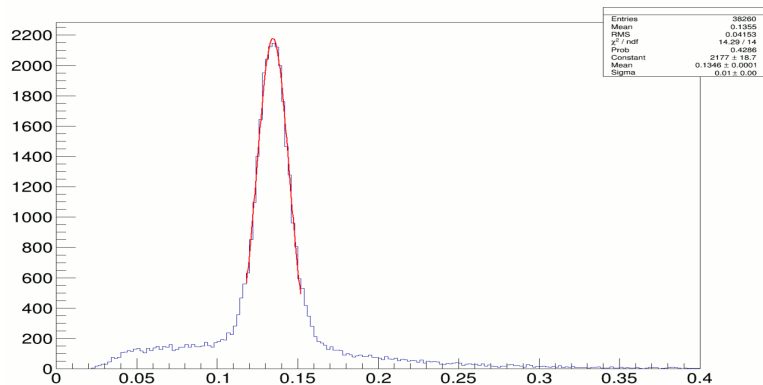
[X. Ji, 1997]



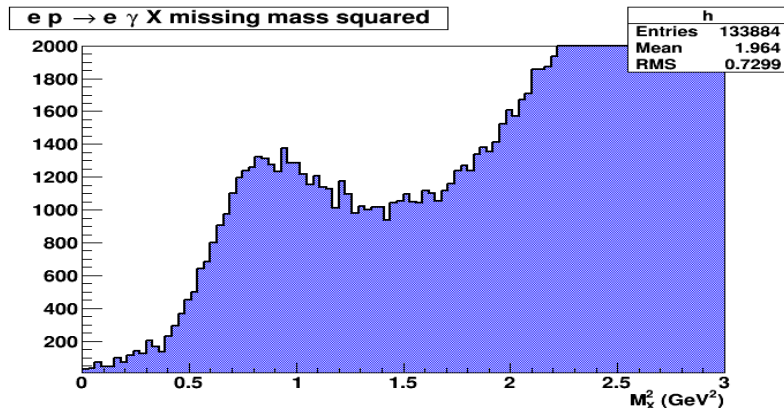
3D Imaging Program at Data at 11 GeV

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

Nuclei and Nuclear Structure

Measuring the Neutron “Skin” in the Pb Nucleus

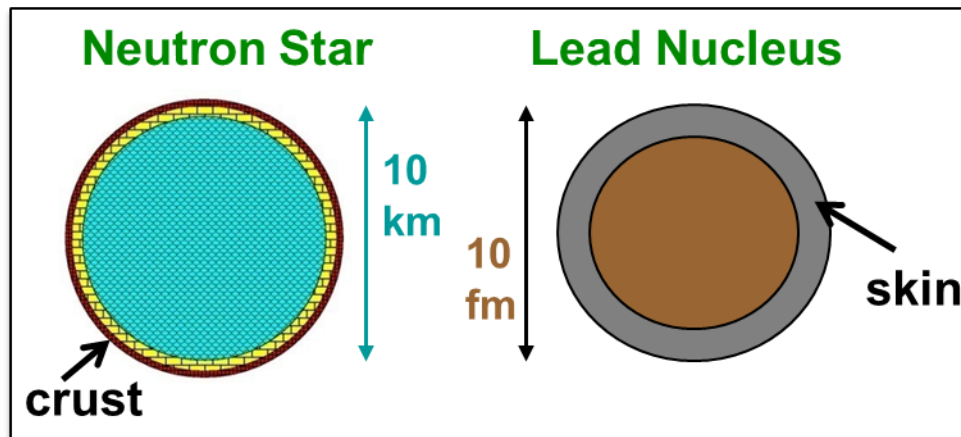
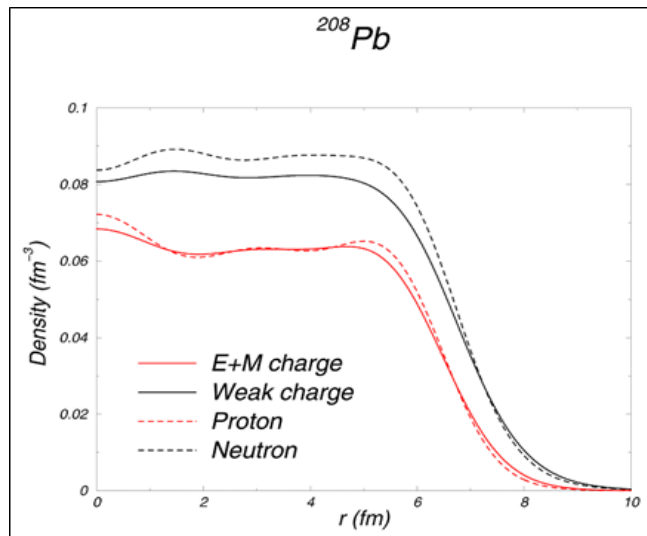
$$Q_w^p = (1 - 4 \sin^2 \theta_w)$$

$$Q_w^n = -1$$



Weak interaction selects neutrons

- Parity violating electron scattering
- Sensitive to neutron distribution



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

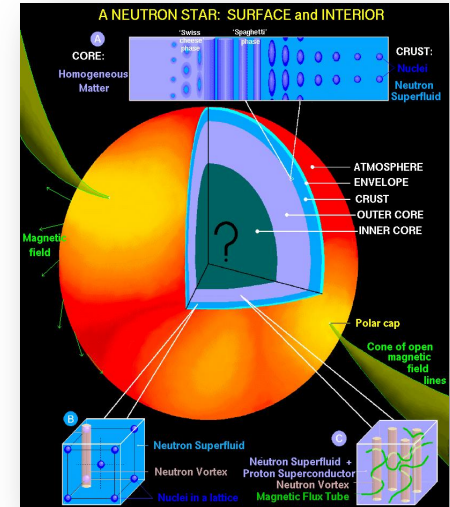
Beyond QCD

Nuclear Structure and Reactions

- Future CEBAF data will determine the thickness of the neutron skins in a Pb, ^{40}Ca , ^{48}Ca nucleus which is related to the radius of a neutron star.
- Future CEBAF data on hypernuclei should test explanations of why neutron stars with masses twice that of our sun exist.

Nuclear Astrophysics

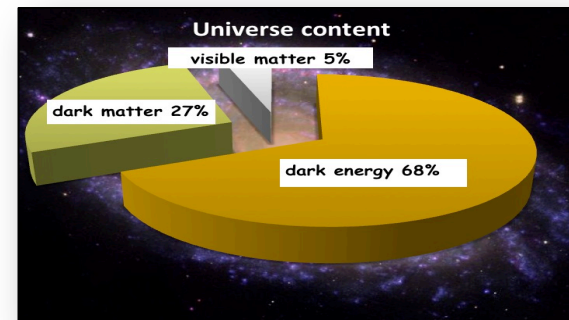
- Future CEBAF injector data on $\gamma + ^{16}\text{O} \rightarrow ^{12}\text{C} + \alpha$ will provide new information constraining the Carbon/Oxygen ratio in our universe.



The Standard Model and Beyond

Heavy Photon Search

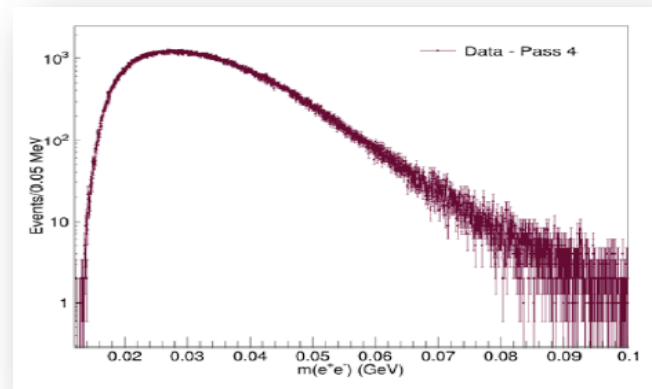
- HPS searches for an electro-produced hidden sector photon (A') which decays to e^+e^- pairs
- A' 's could mediate dark matter annihilations and interactions with *our* matter
- HPS identifies A' 's with invariant mass and separated vertices



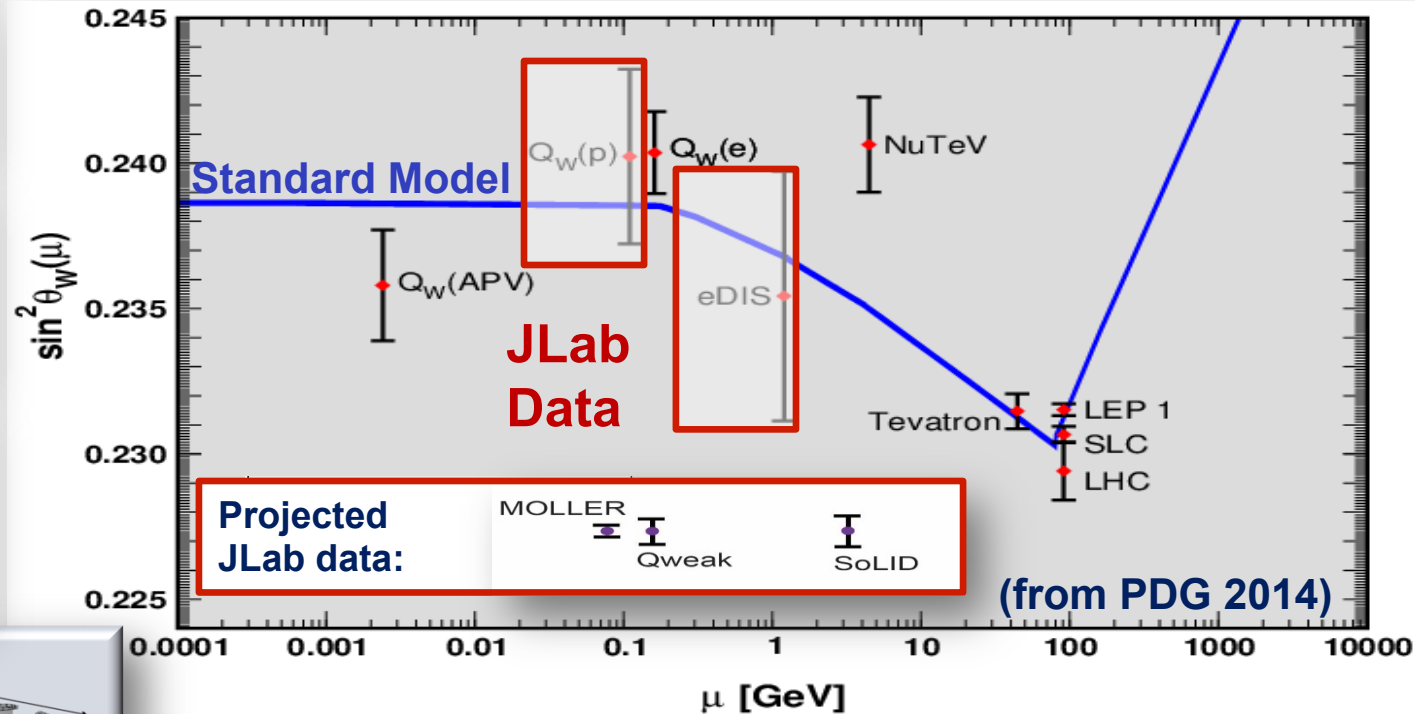
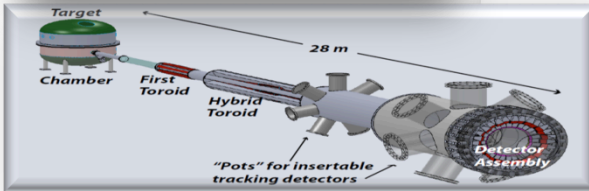
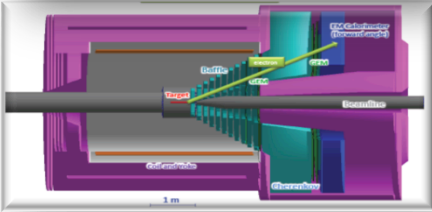
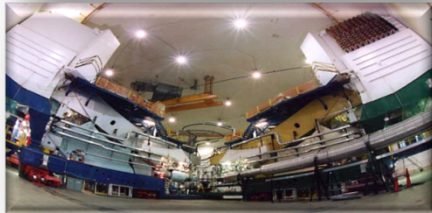
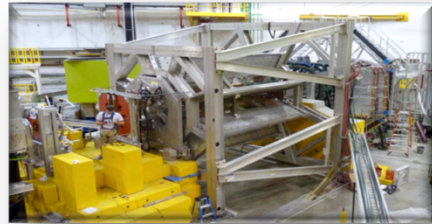
Status:

- 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

Measured e^+e^- Mass



Testing the Standard Model at JLab



Summary

- The 12 GeV Project is near to completion
- Elements of the 12 GeV Physics Program are established and operational in Halls A and D
- The detectors for Halls B and C are in their final phases of construction and will be commissioned during 2017
- The Physics program will be an exciting and perhaps dominant component of the Medium Energy Physics worldwide during the next decade.

It is a very exciting time at Jefferson Lab!!!