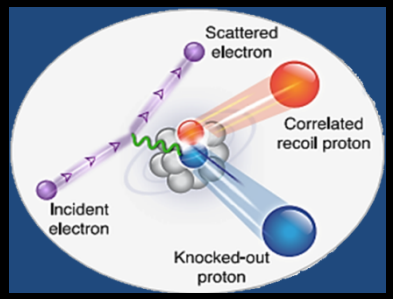
Overview/Future Program at JLab

Jian-ping Chen (陈剑平), Jefferson Lab, Virginia, USA

Hadron-China2017, Nanjing University University, July 24-28, 2017

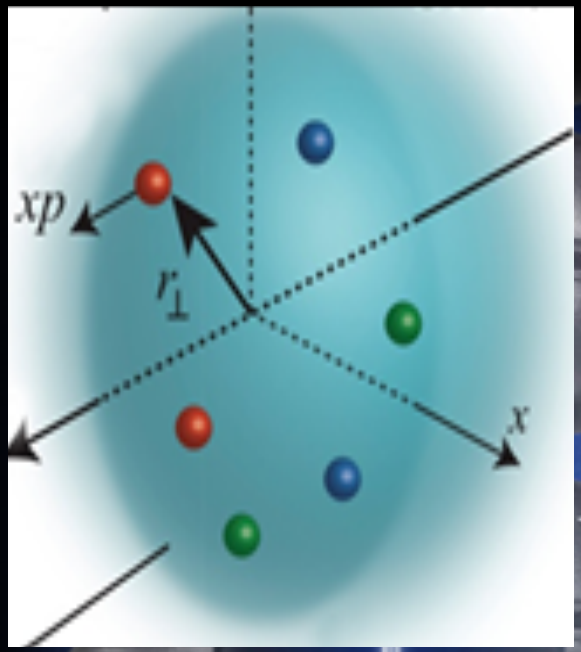
- JLab and 12 GeV Energy Upgrade, Detector Upgrade (SoLID, …)
- JLab12 Science Program Recent Highlights
- Future - Electron Ion Collider

JLab: A Laboratory for Nuclear Science

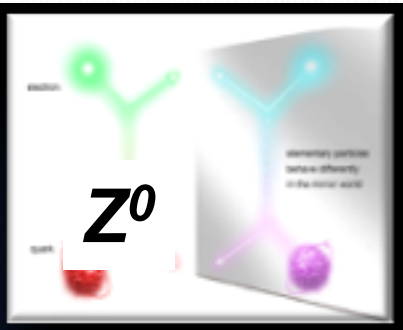


Nuclear Structure

Medical Imaging



Structure of Hadrons



Fundamental Forces & Symmetries

Nuclear Astrophysics

Cryogenics

Accelerator S&T

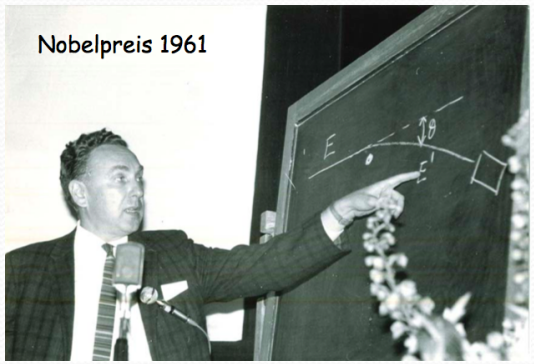
Theory &

Introduction

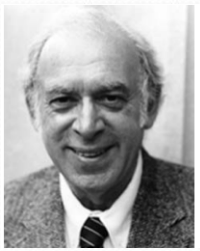
JLab and 12 GeV Energy Upgrade
Detector Upgrade (SoLID)

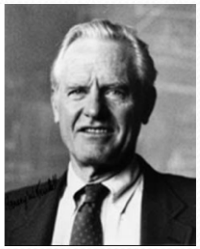
Electron Scattering and Nucleon Structure

- Clean probe to study nucleon structure
  only electro-weak interaction, well understood
- **Elastic Electron Scattering: Form Factors**
  → 60s: established nucleon has structure (Nobel Prize)
  electrical and magnetic distributions
- Resonance Excitations
  → internal structure, rich spectroscopy (new particle search)
  constituent quark models
- **Deep Inelastic Scattering (DIS)**
  → 70s: established quark-parton picture (Nobel Prize)
  parton distribution functions (PDFs)
  polarized PDFs : Spin Structure
- **Semi-inclusive DIS, Exclusive DIS**
  → 3D nucleon structure (TMDs, GPDs)



Robert Hofstadter,
Nobel Prize 1961





J.T. Friedman ***R. Taylor*** ***H.W. Kendall***

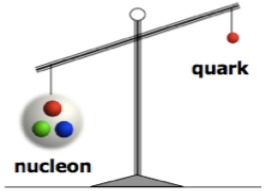
Nobel Prize 1990

Nucleon Structure: A Universe Inside

- Nucleon: proton =(uud) , neutron=(udd) ***+ sea quarks + gluons (QCD vacuum)***
- Nucleon: ***99% of the visible mass in universe***

➢ **Proton mass "puzzle":**

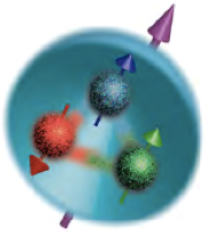
Quarks carry $\sim 1\%$? of proton's mass



m_q ~ 10 MeV

m_N ~ 1000 MeV

How does glue dynamics generate the energy for nucleon mass?

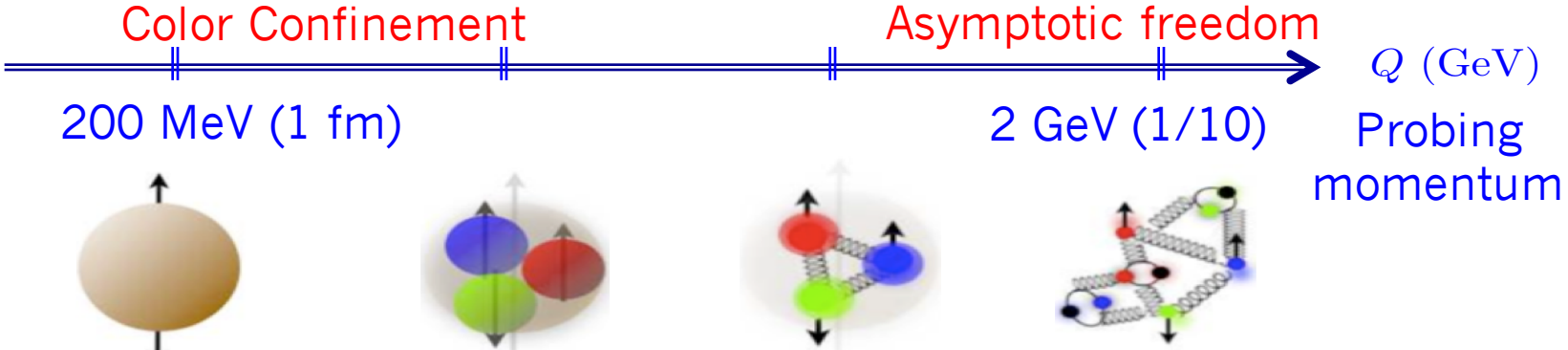


➢ **Proton spin "puzzle":**

Quarks carry $\sim 30\%$ of proton's spin

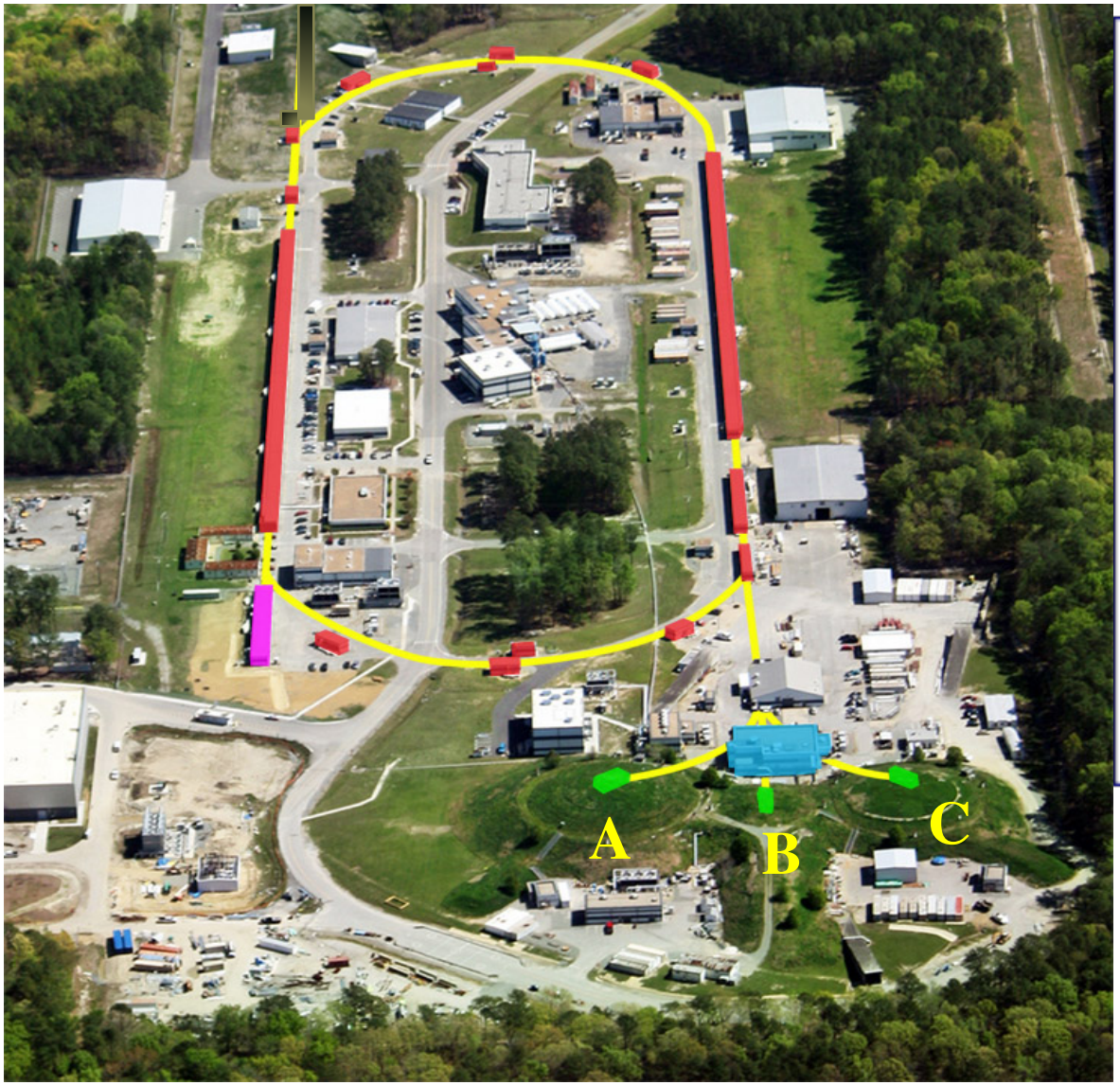
How does quark and gluon dynamics generate the rest of the proton spin?

➢ **3D structure of nucleon: 3D in momentum or (2D space +1 in momentum)**



How does the glue bind quarks and itself into a proton and nuclei?
Can we scan the nucleon to reveal its 3D structure?

Jefferson Lab Newport News, Virginia, USA



CEBAF

- **High-intensity** electron accelerator based on **CW SRF** technology
- I_{max} = 200 μA
- Pol_{max} = 90%
- E_{max} = 6 GeV: 1995-2012
- **Energy Upgrading to 12 GeV (2012-now)**
- **12 GeV data taking started**

- **~ 1400** Active Users
- Produces **~1/3** of US PhDs in Nuclear Physics

Jefferson Lab is an Integral Part of the 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.

- *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.* ***→ 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

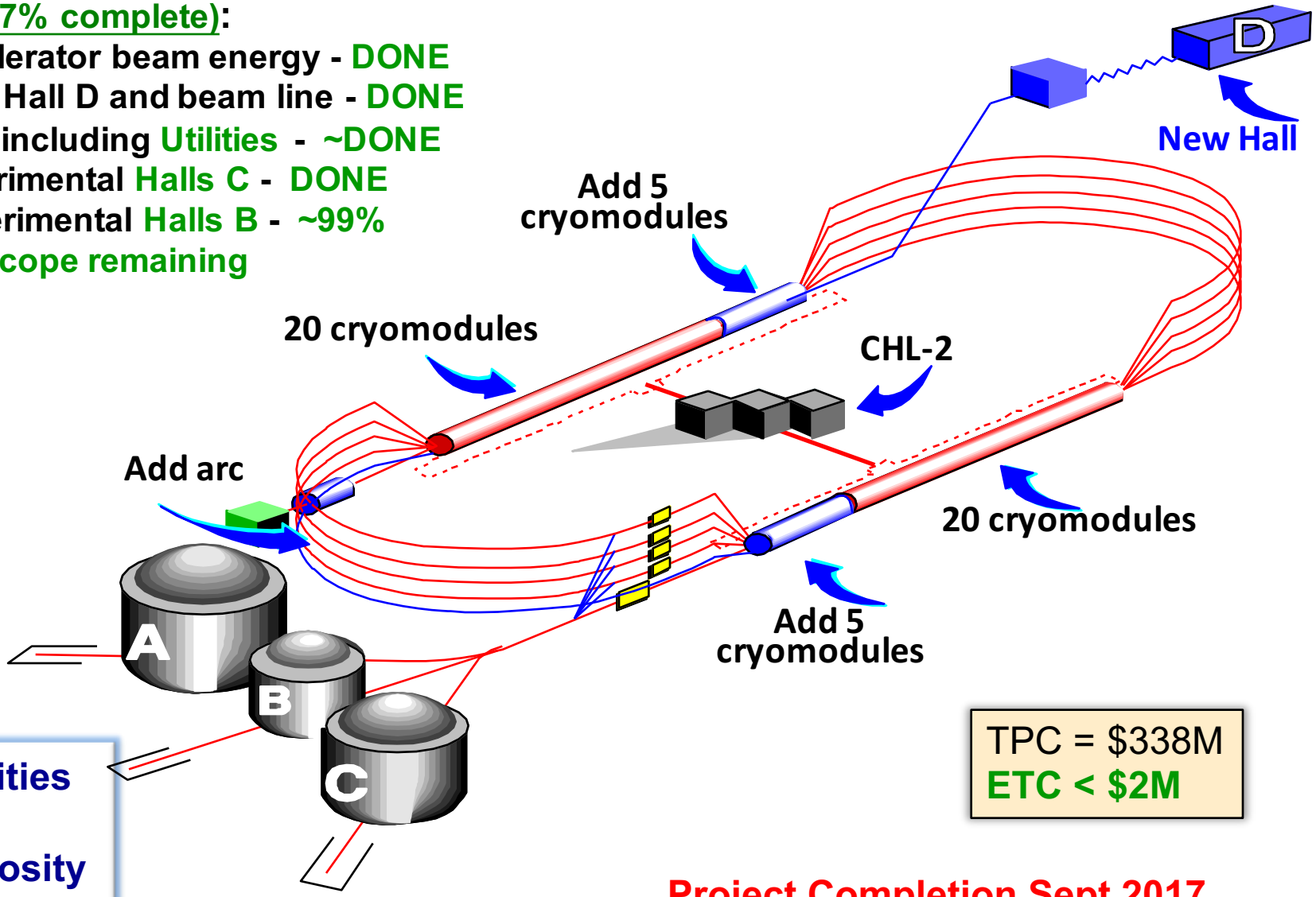
We recommend increasing investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.

→ MOLLER, SoLID

12 GeV Upgrade Project

Project Scope (~99.7% complete):

- Doubling the accelerator beam energy - DONE
- New experimental Hall D and beam line - DONE
- Civil construction including Utilities - ~DONE
- Upgrades to Experimental Halls C - DONE
- Upgrades to Experimental Halls B - ~99%
  - Solenoid only scope remaining



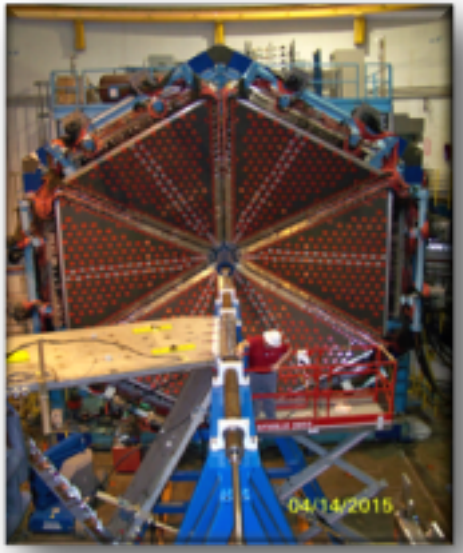
- Enhanced capabilities in existing Halls
- Increase of Luminosity 10^{35} - ~10^{39} $cm^{-2}s^{-1}$

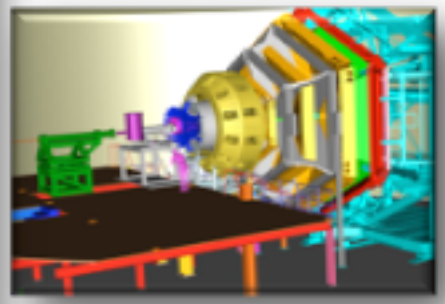
TPC = $338M
ETC < $2M

Project Completion Sept 2017

12 GeV Scientific Capabilities

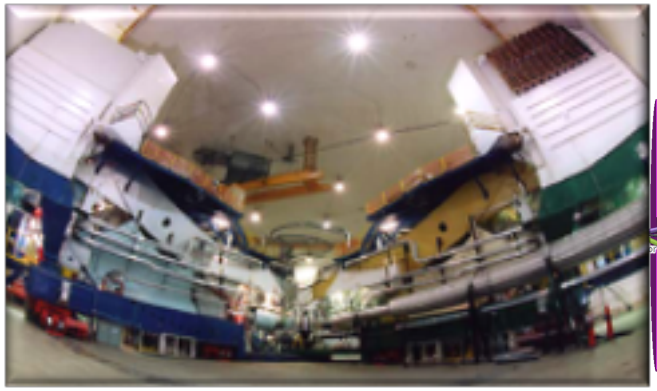
Hall B – understanding nucleon structure via generalized parton distributions

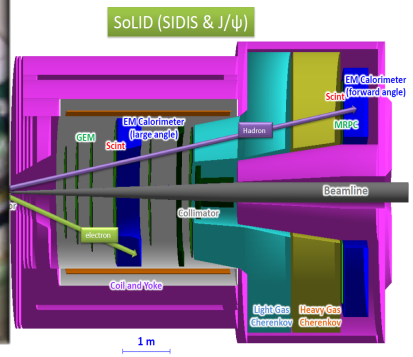




Hall D – exploring origin of confinement by studying exotic mesons

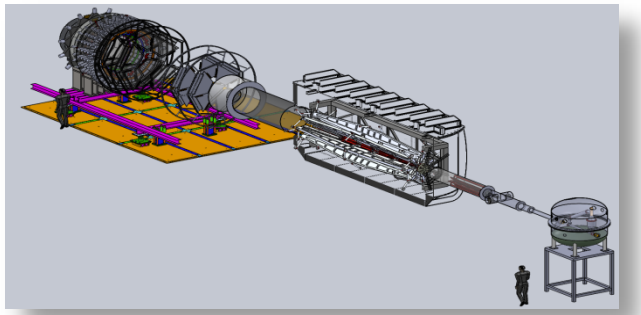
Hall A – form factors, future new experiments (e.g., SoLID and MOLLER)





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

Future Projects



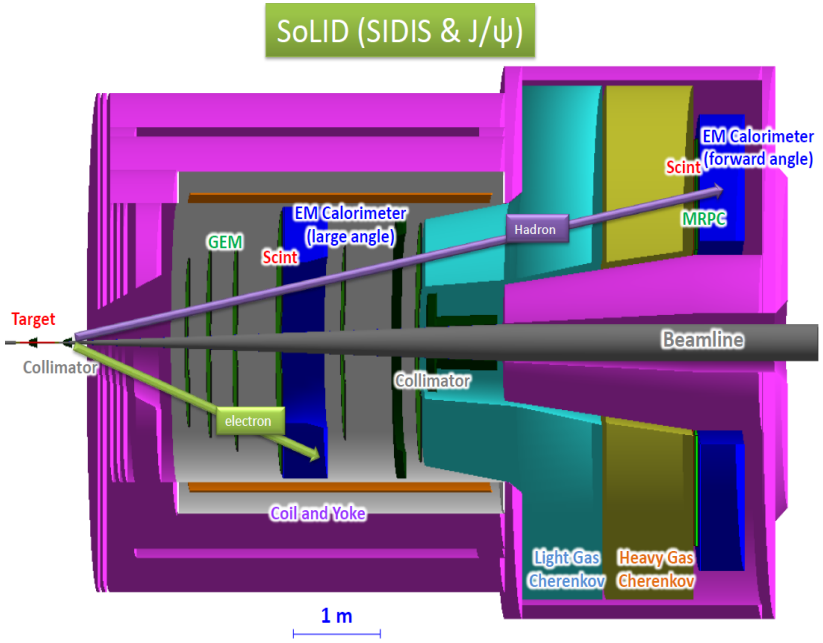
- *MOLLER experiment*
  (Possible MIE – FY19-23)
  - *CD-0 approved*
    (project paused due to budget uncertainty)
  - *Standard Model Test*
  - *DOE science review (September 2014) – strong endorsement*
  - *Director's review held December 15-16, 2016*
    Technical, cost & schedule

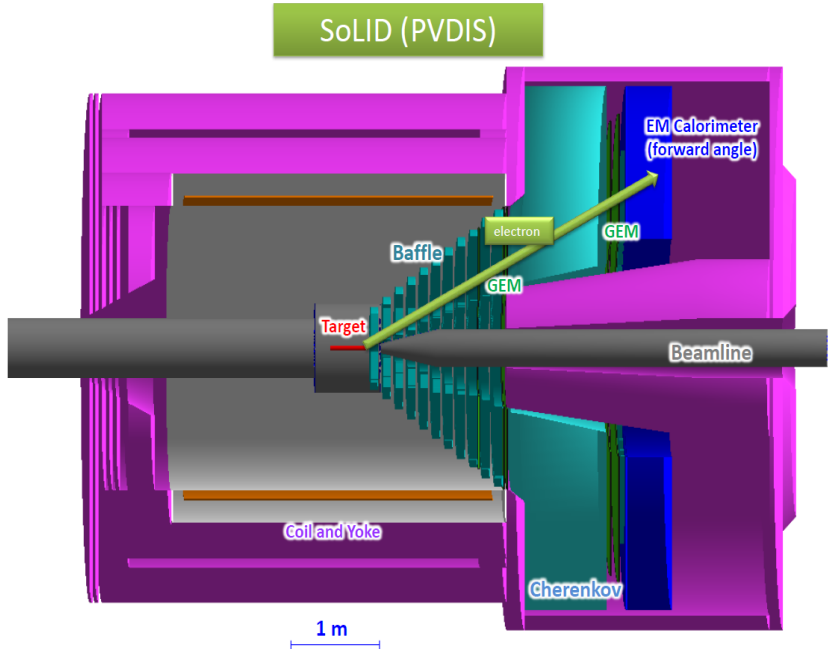
- *SoLID*
  - *SIDIS, PVDIS, J/ψ*
  - *CLEO Solenoid ✓*
  - *International collaboration*
  - *Director's review (Feb. 2015)*
    → new pre-CDR complete

Overview of SoLID

Solenoidal **L**arge **I**ntensity **D**evice

- **Full exploitation of JLab 12 GeV Upgrade**
  → A **Large Acceptance** Detector **AND** Can Handle **High Luminosity** (10^{37}-10^{39})
  Take advantage of latest development in detectors , data acquisitions and simulations
  Reach ultimate precision for SIDIS (TMDs), PVDIS in high-*x* region and threshold J/ψ
- **5 highly rated experiments approved**
  Three SIDIS experiments, one PVDIS, one J/ψ production (+ 4 run group experiments)
- **Strong collaboration** (250+ collaborators from 70+ institutes, 13 countries)
  International collaborations (significant Chinese contributions)





JLab12 Science Program

Gluonic Excitations
Spin and 3D Structure (TMDs, GPDs)
Parity Violation: Test Standard Model

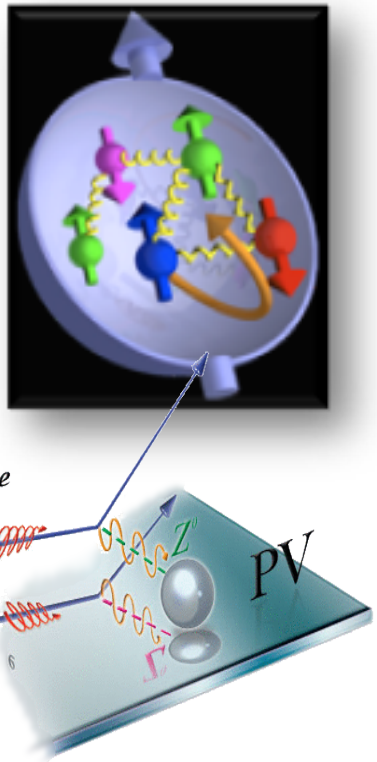
Jefferson Lab @ 12 GeV Science Questions

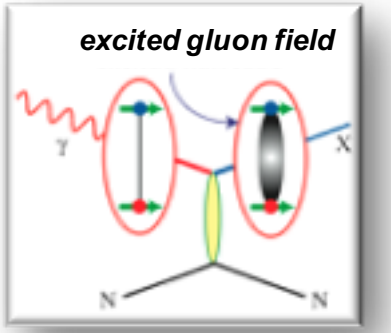
- How does the valence quark behave in the nucleon?
  Where is the missing spin in the nucleon?
  Role of orbital angular momentum?

- Can we reveal a novel landscape of nucleon substructure through 3D imaging at the femtometer scale?

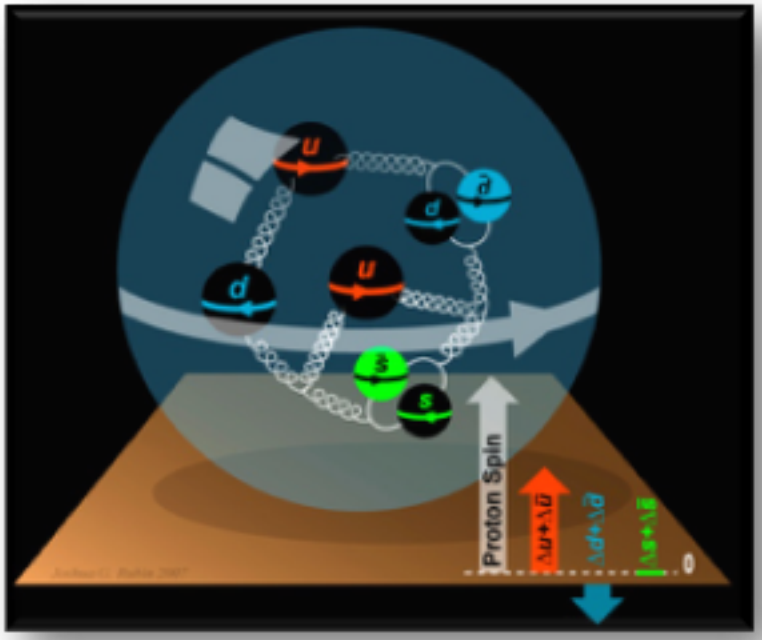
- Can we discover evidence for physics beyond the standard model of particle physics?

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





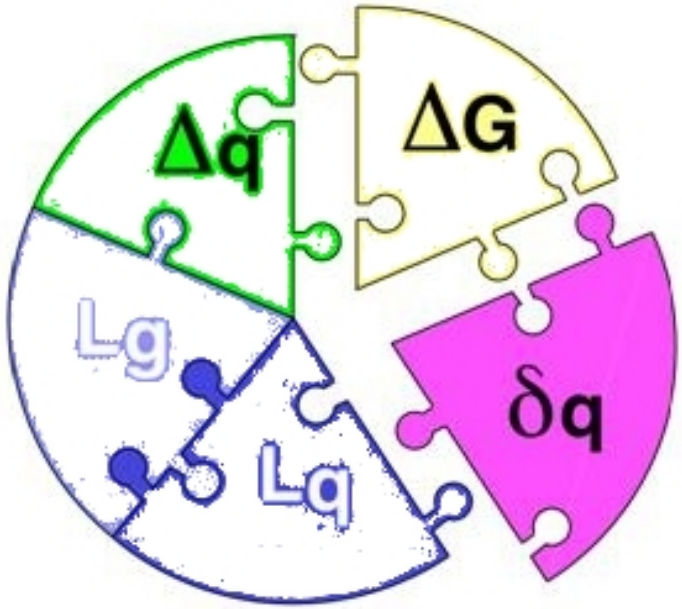
Spin Puzzle



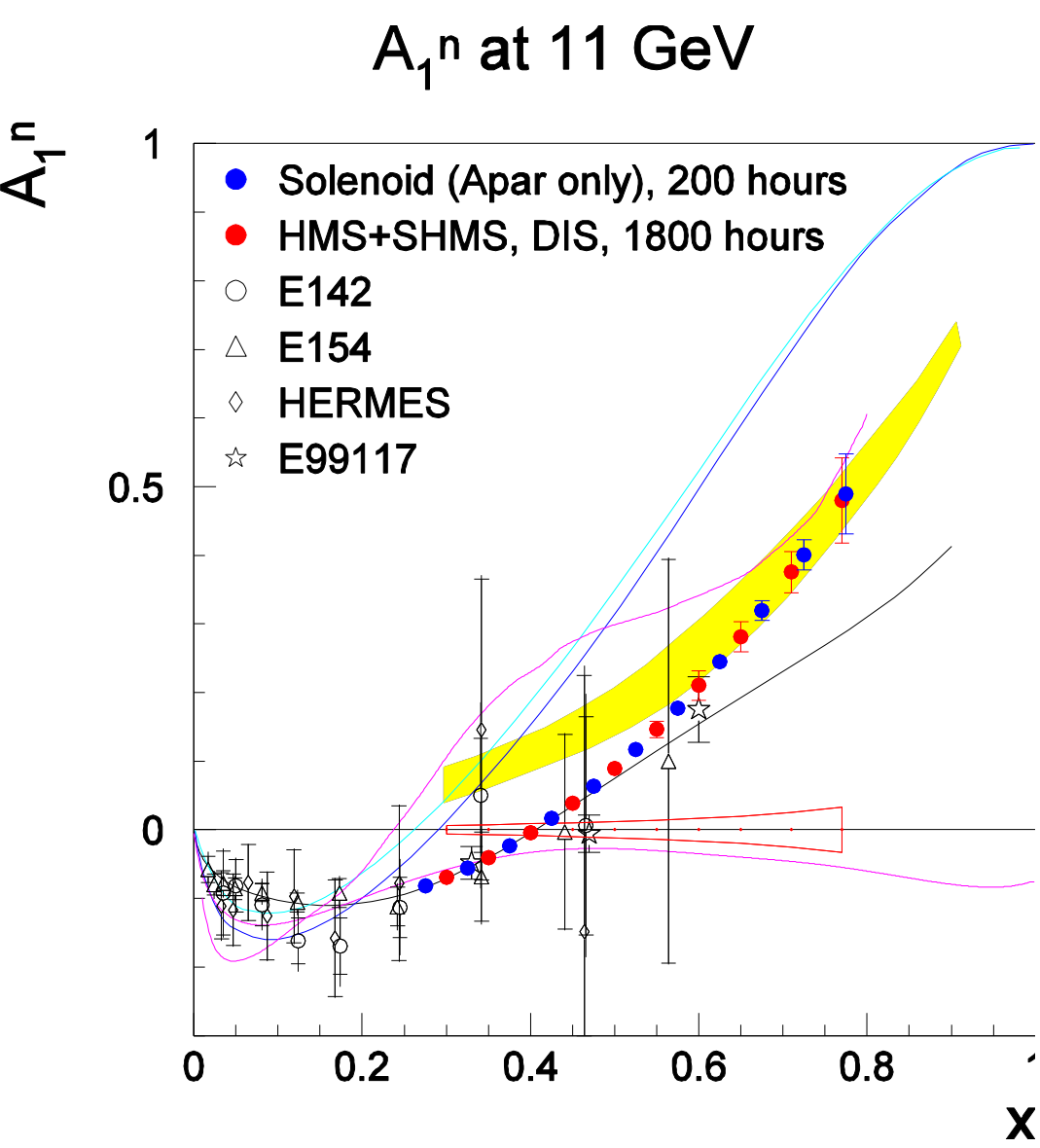
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g$$

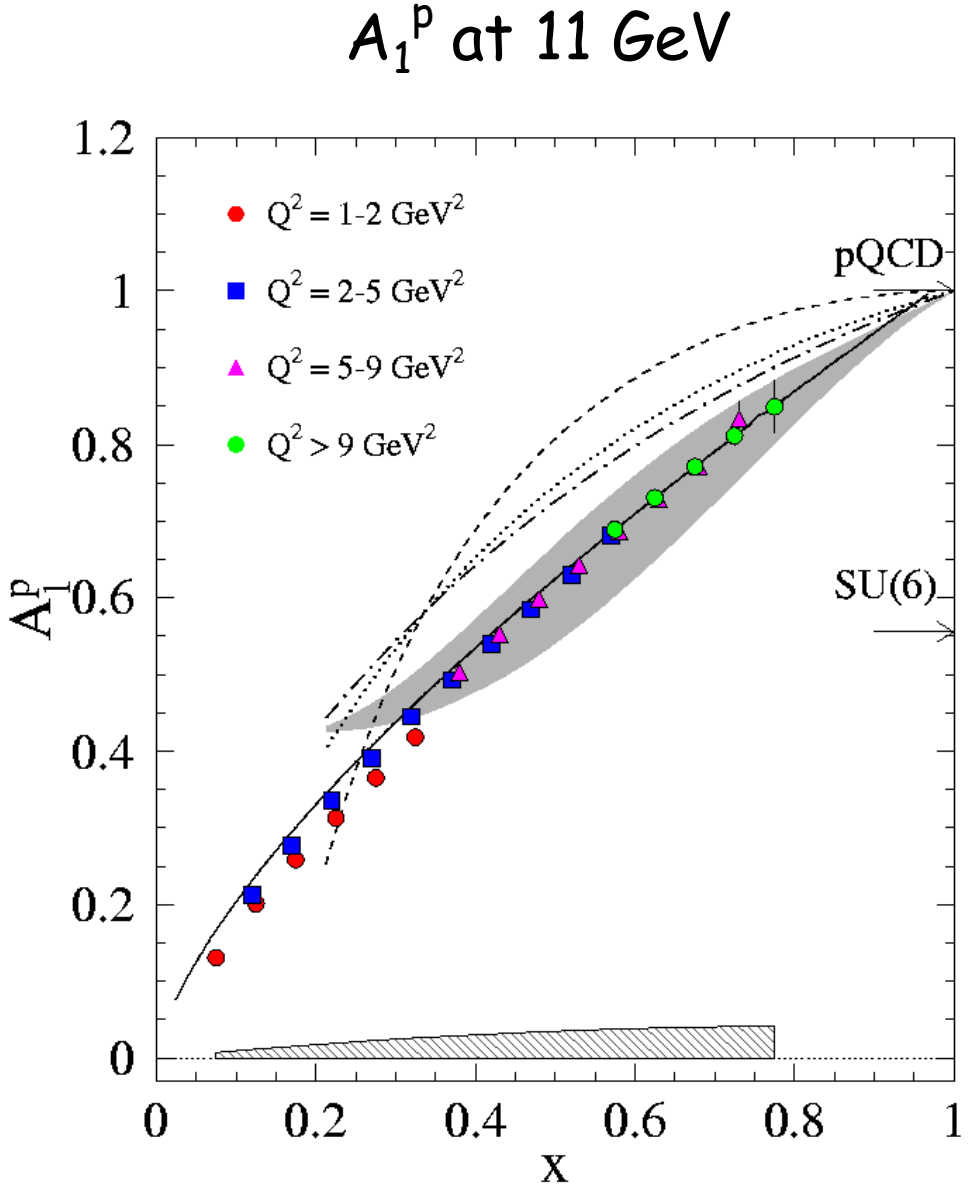
[X. Ji, 1997]

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

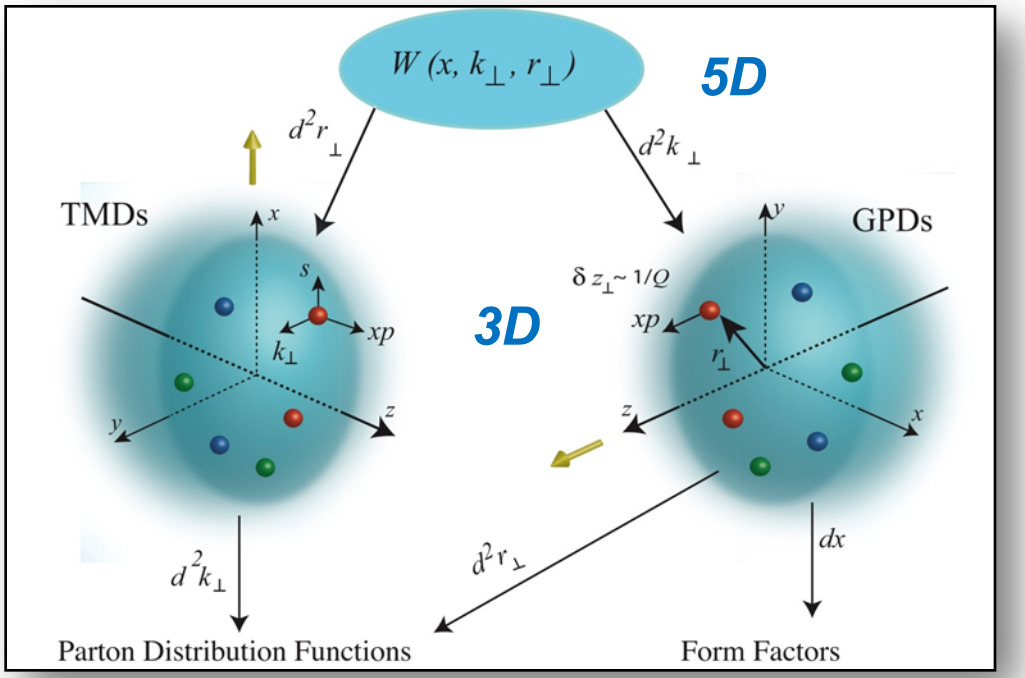


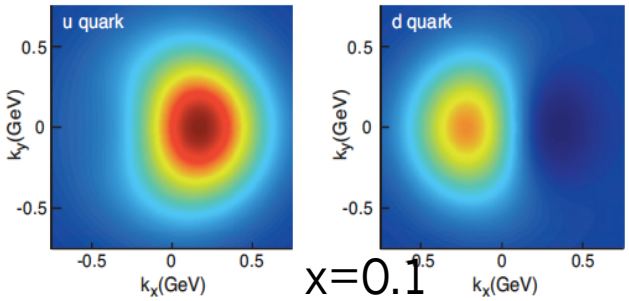
Polarized DIS: JLab12 Projections

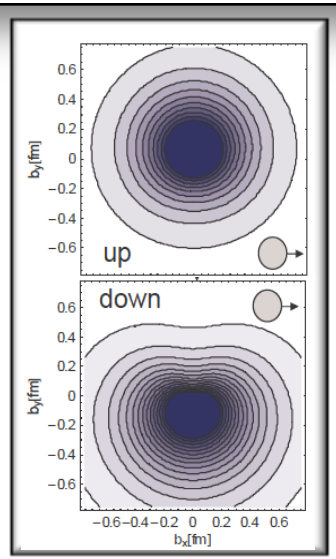




Imaging the Nucleon



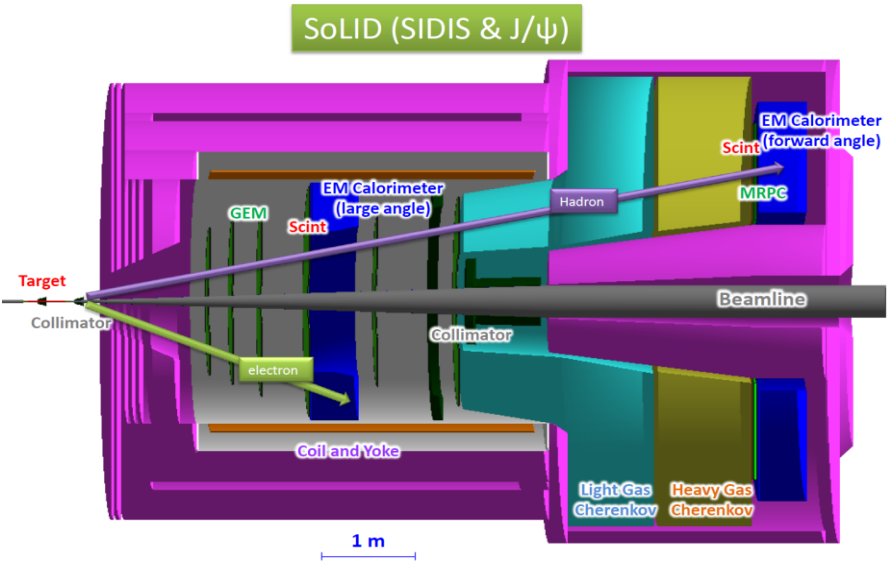




- *Transverse Momentum Dist. (TMD)*
  - *Confined motion in a nucleon (semi-inclusive DIS)*
- *Generalized Parton Dist. (GPD)*
  - *Spatial imaging (exclusive DIS)*
- *Requires*
  - *High luminosity*
  - *Polarized beams and targets*
  - *Sophisticated detector systems*

Major new capability with JLab @ 12 GeV

SoLID-Spin: SIDIS on ^{3}He/Proton @ 11 GeV



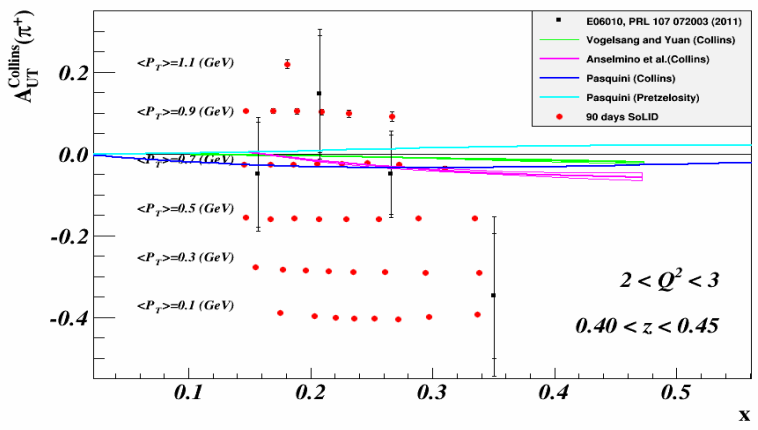
E12-10-006: Single Spin Asymmetry on Transverse ^{3}He, rating A

E12-11-007: Single and Double Spin Asymmetries on ^{3}He, rating A

E12-11-108: Single and Double Spin Asymmetries on Transverse Proton, rating A

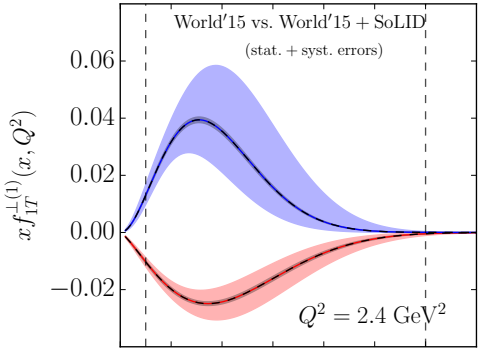
Two run group experiments
DiHadron and Ay

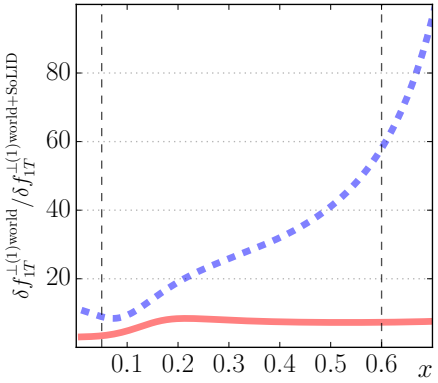
Sivers Asymmetries



P_T vs. x for one (Q^2, z) bin
Total > 1400 data points

Key of SoLID-Spin program:
Large Acceptance
+ High Luminosity
→ **4-D** mapping of asymmetries
→ Tensor charge, TMDs …
→Lattice QCD, QCD Dynamics,
Quark Orbital Angular Momentum,
Imaging in 3-D momentum space.

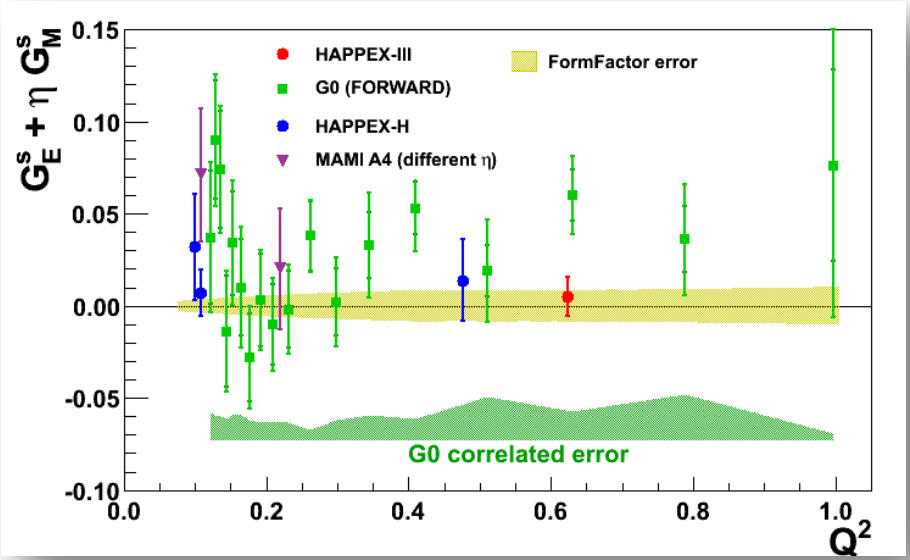




Parity Violation at JLab

X. Zheng'talk

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

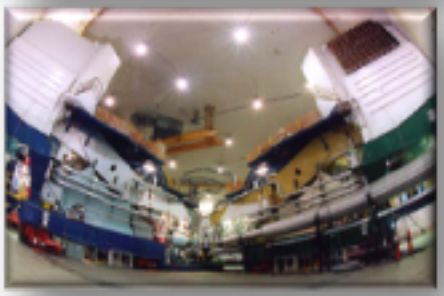


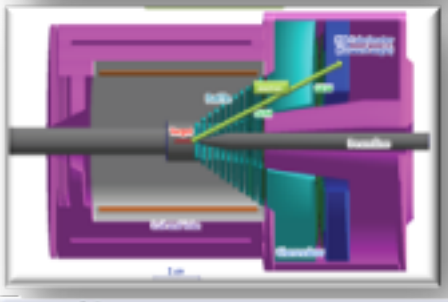
- Neutron Skin
  - PREX
  - CREX

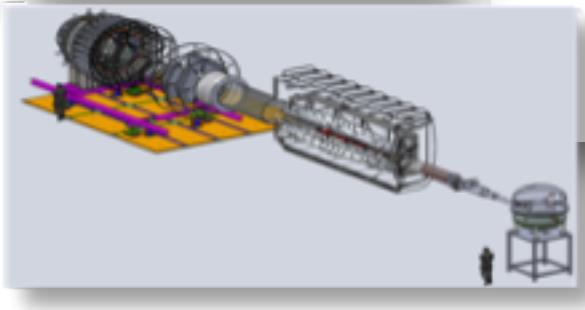
- Precision Tests of Standard Model
  - Qweak (Under analysis)
  - MOLLER
  - SoLID

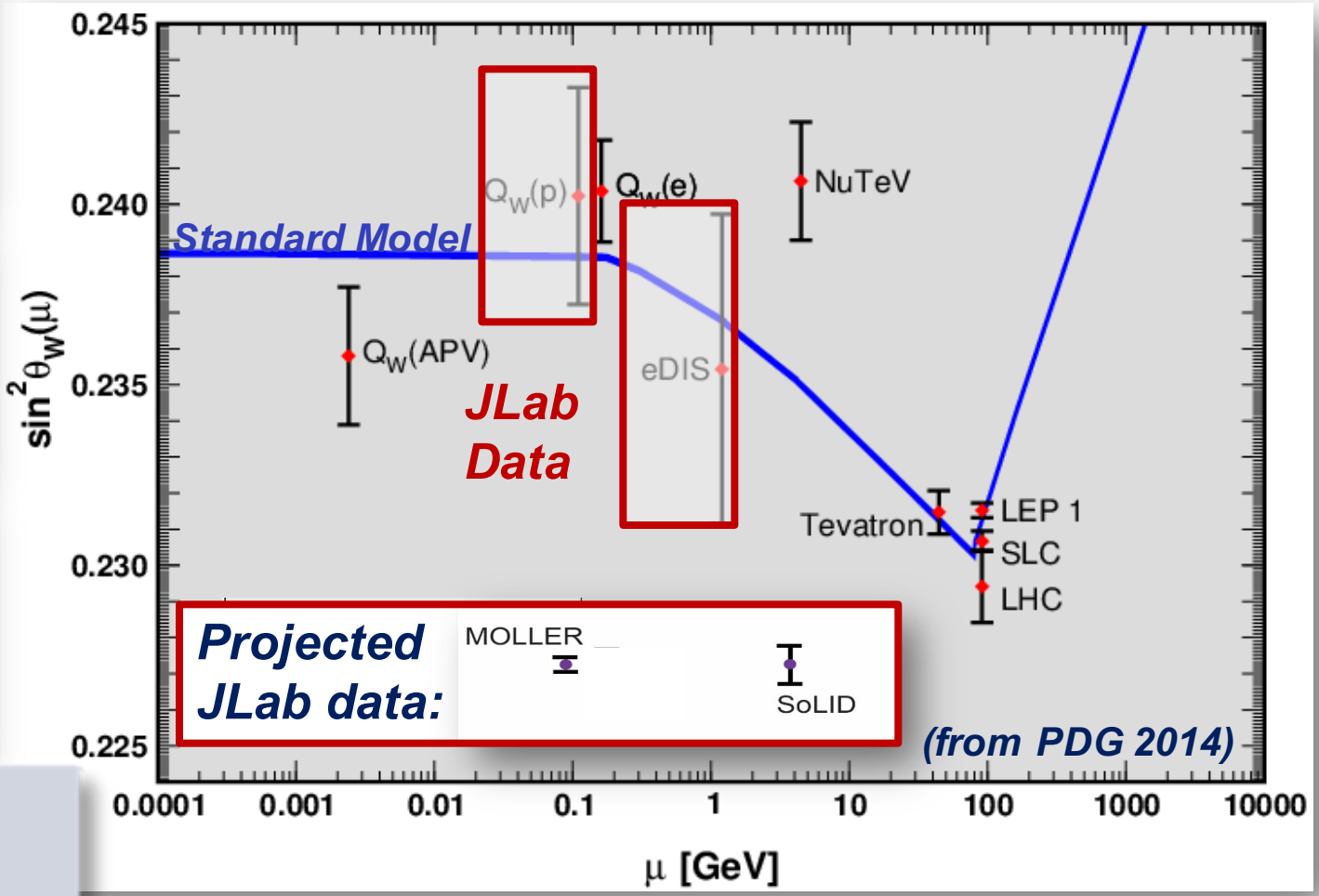
Testing the Standard Model at JLab

X. Zheng'talk



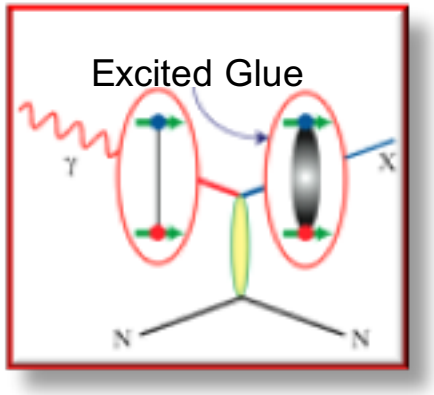


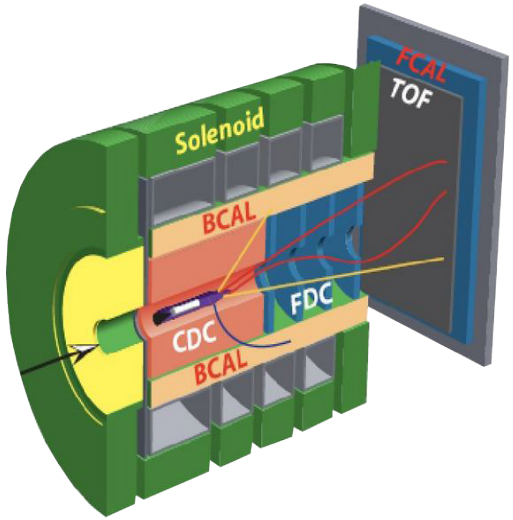




Gluonic Excitations and the Mechanism for Confinement

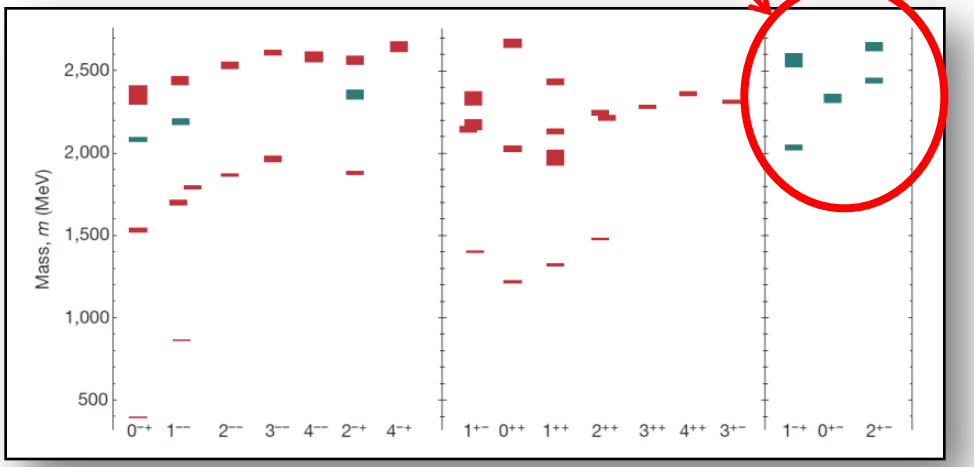
B.Zilhmann's talk





GLUEX CITATIONS PERIMENT
Hall D@JLab

States with Exotic

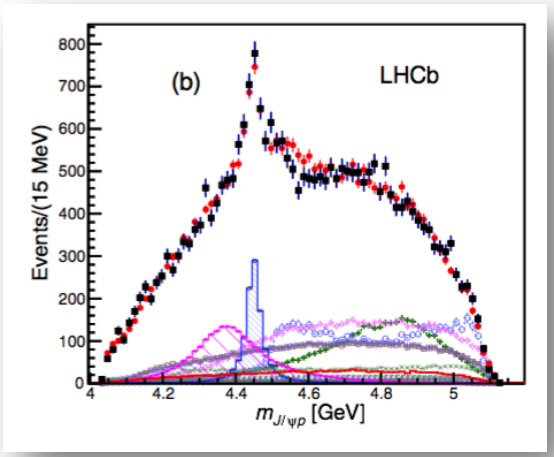


nature International weekly journal of science

Searching for the rules that govern hadron construction

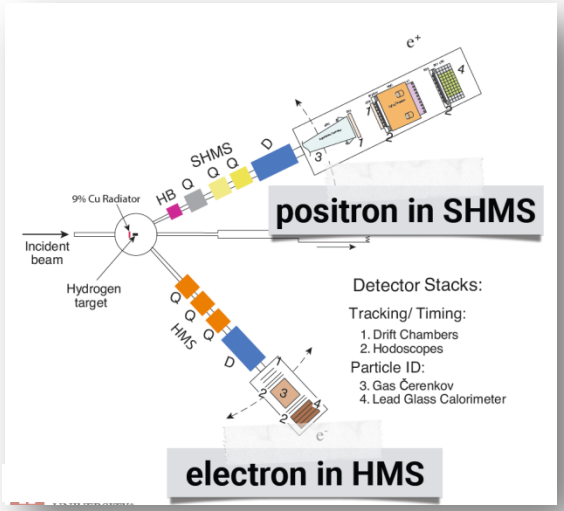
M. R. Sheperd, J. J. Dudek, R. E. Mitchell

Charmonium Pentaquark

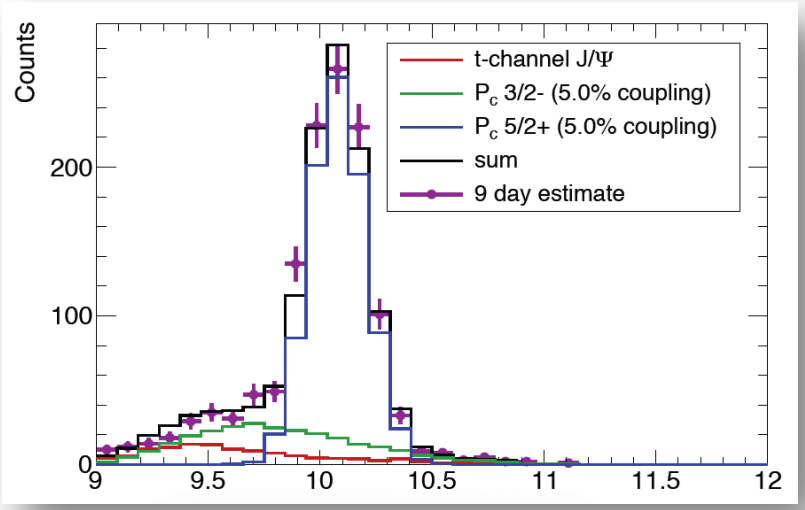


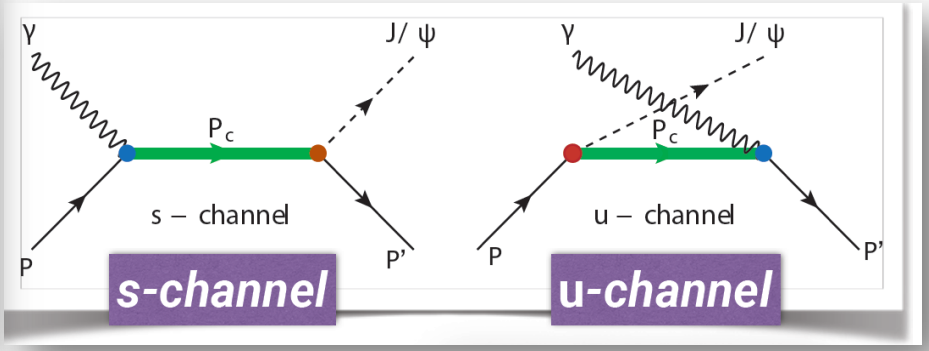
LHCb
2 P_c states needed to describe results:
narrow: $P_c(4450)$
wide: $P_c(4380)$

JLab E12-16-007



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





SoLID-J/ψ: Study Non-Perturbative Gluons

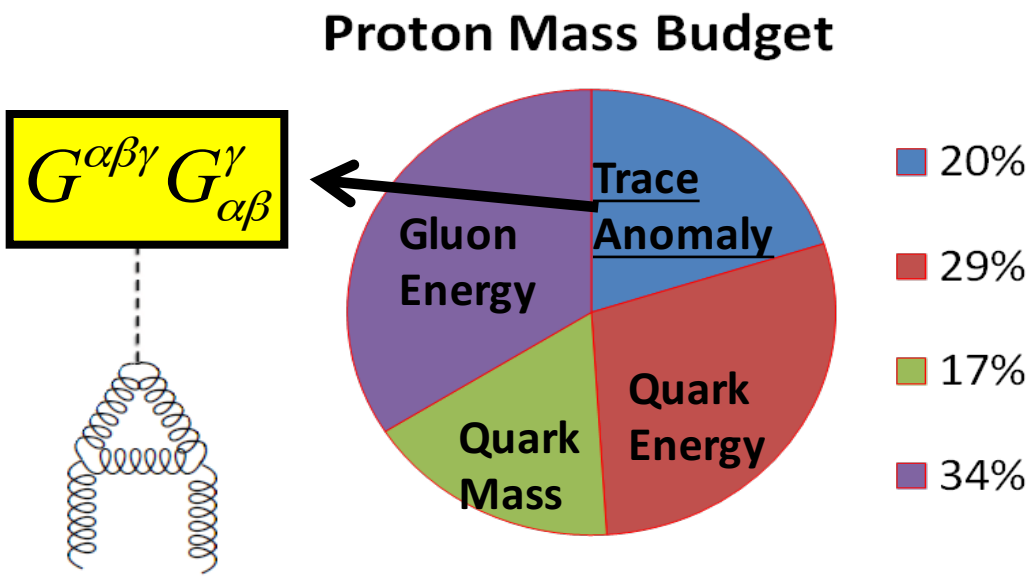
J/ψ: ideal probe of non-perturbative gluon

The high luminosity & large acceptance capability of SoLID enables a unique "precision" measurement near threshold

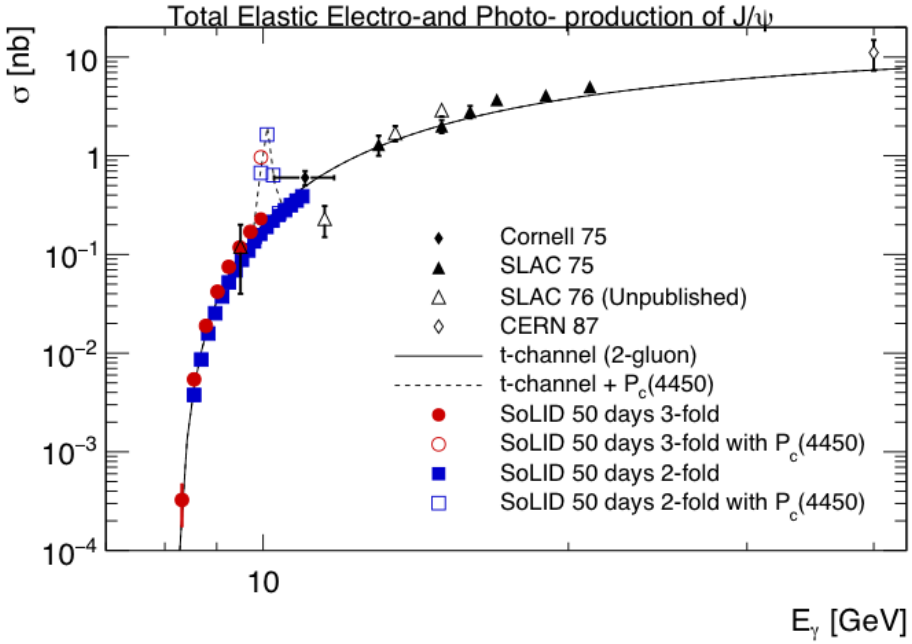
- **Shed light on the low energy J/ψ-nucleon interaction (color Van der Waals force)**
- **Shed light on the 'conformal anomaly' an important piece in the proton mass budget:**

Models relate J/ψ enhancement to trace anomaly

$$\gamma^* + N \rightarrow N + J/\psi$$



X. Ji PRL 74 1071 (1995)



Recent Highlights

First 12 GeV Experiment: DVCS
First Results from GlueX
Proton Radius (PRad)
Heavy Quark Search

12 GeV Science Era has Begun!

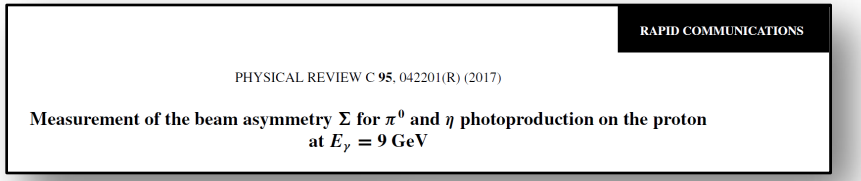
- ***Quark confinement:*** *Hall D (GlueX) started physics operations*
  - *Engineering Run Complete: Basis for > dozen papers at APS DNP Fall 2016 Meeting*
  - *First 12 GeV era publication: 24 April, 2017!*
  - *First physics run: 50 Billion events in Spring 2017*

- ***Nucleon Structure(I):*** *Hall A in physics operations*
  - *GMp experiment completed in Fall 2016*
  - *First phase of DVCS experiment completed*

- ***Nuclear Structure:*** *First experiment completed*
  - *Argon Spectral Function experiment completed in Hall A in Spring 2017*

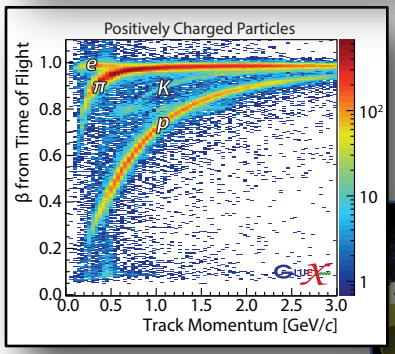
- ***Fundamental Symmetries:*** *Hall B Heavy Photon Search*
  - *First results of 2015 engineering run presented*

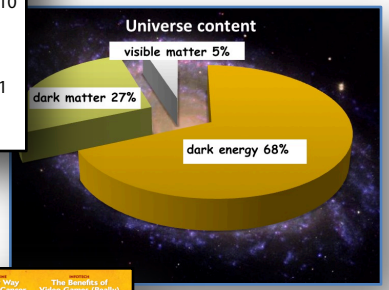
- ***Nucleon Structure (II):*** *Hall B Proton Radius (PRad)*
  - *Experiment run and completed Summer 2016*


RAPID COMMUNICATIONS

PHYSICAL REVIEW C **95**, 042201(R) (2017)

Measurement of the beam asymmetry Σ for π^0 and η photoproduction on the proton at $E_\gamma = 9$ GeV





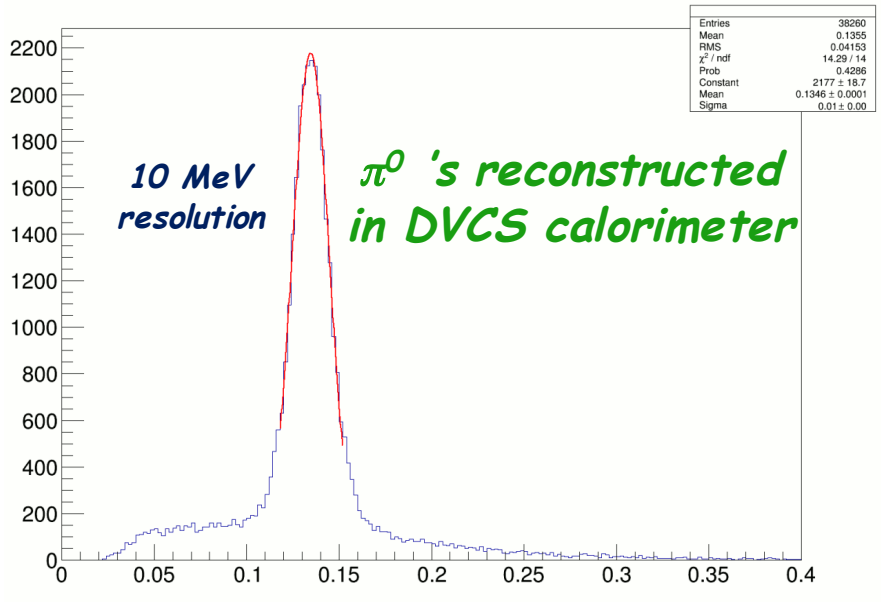
Starting to exploit the Upgrade for Physics

E12-06-114 DVCS in Hall A (first 12 GeV era experiment)

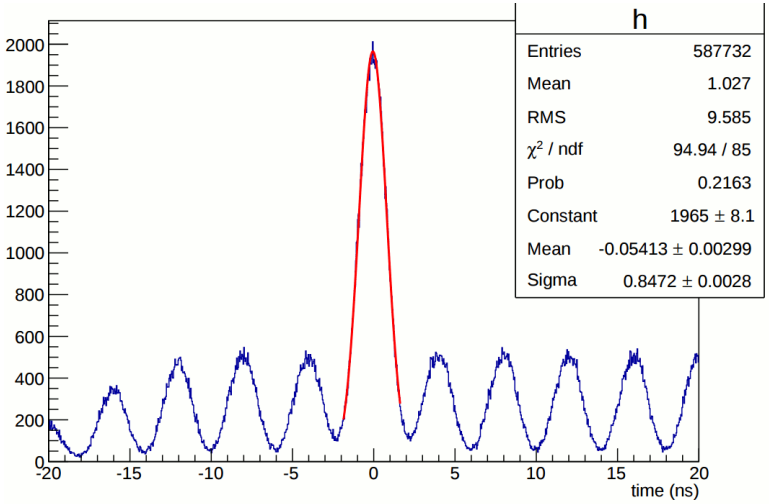
100 PAC days approved:

- ***High impact experiment for nucleon 3D imaging program***
- ***High precision scaling tests of the DVCS cross section at constant x_B***
- ***CEBAF12 will allow first time exploration of the high x_B region***

Planned 50% of experiment completed in 2014-2016



Excellent coincident time resolution: 250 MHz beam structure



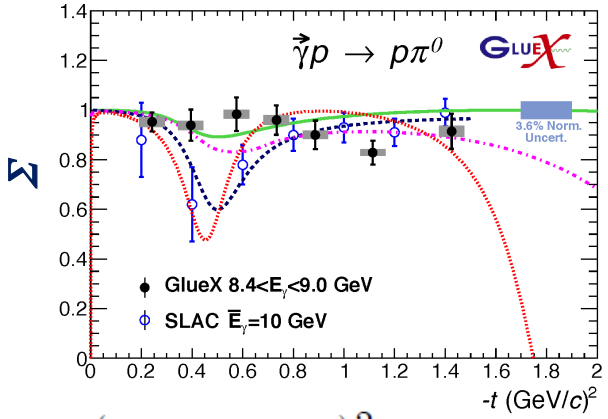
Analysis path:

- ***Jun'17: Report at JLab Summer Meeting.***
- ***Jan'18: Preliminary results on π^0 at x_B=0.36***
- ***Apr'18: Preliminary results on DVCS***
- ***Jul'18 : Short paper submitted to PRL on π^0***
- ***Jan'19: Letter to PRL on DVCS***
- ***Jul'19: Long paper to PRC (DVCS & pi0)***

First Published Results from 12 GeV CEBAF

B.Zilhmann's talk

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



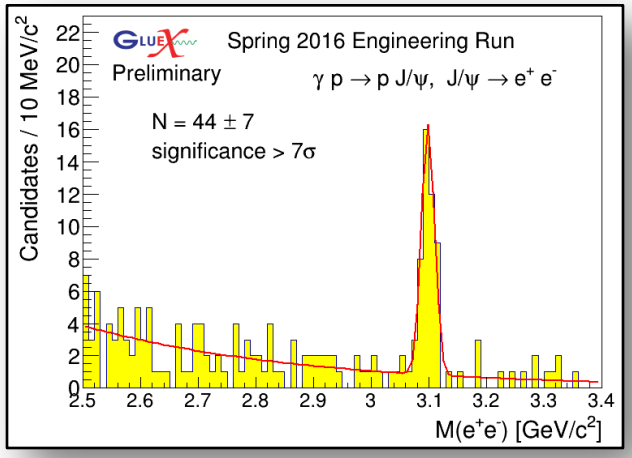
$$t = (p_{\text{target}} - p_{\text{p}})^2$$

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.

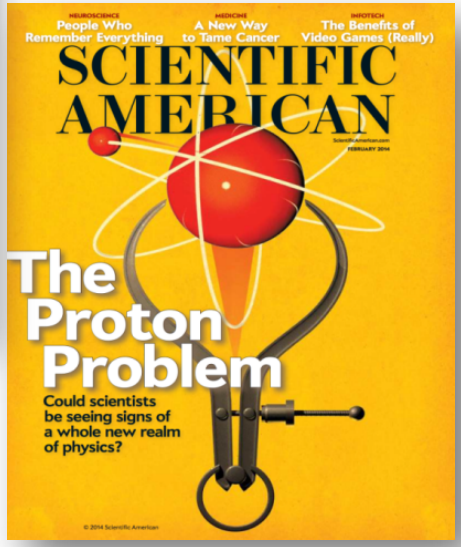
Bonus: First observation of charmonium at JLab!

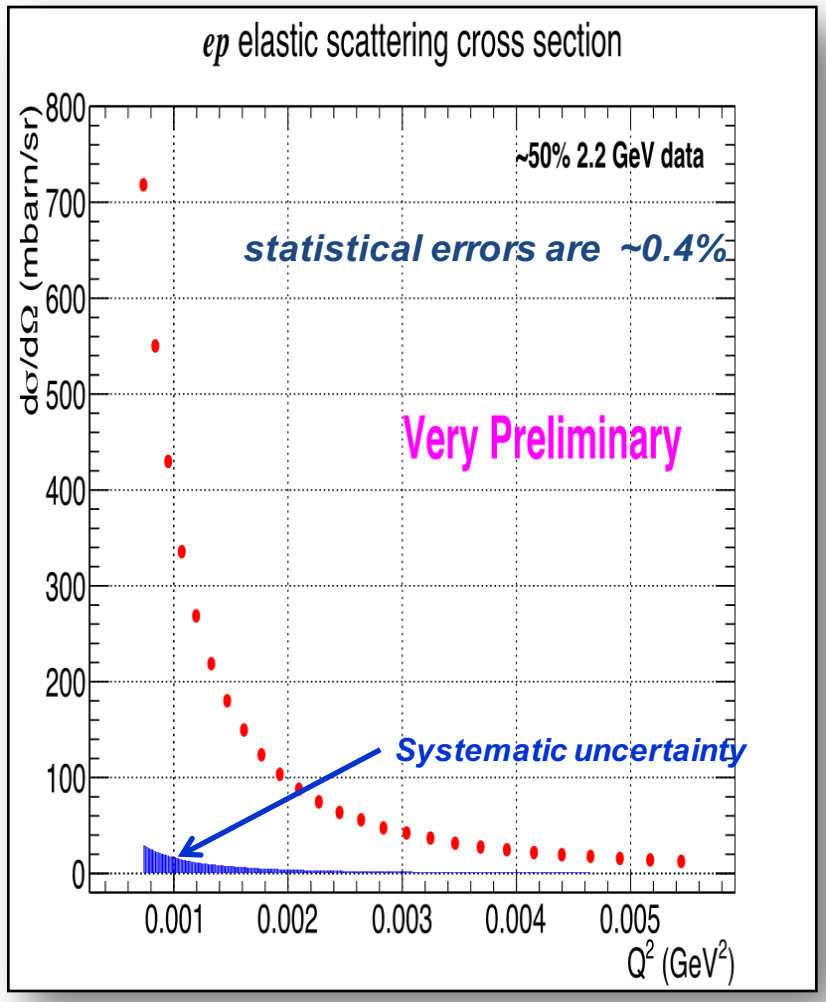


Proton Radius (PRad)

H. Gao'talk

- *PRad: new experiment to address proton radius @ JLab*
- *Successful run in summer 2016*

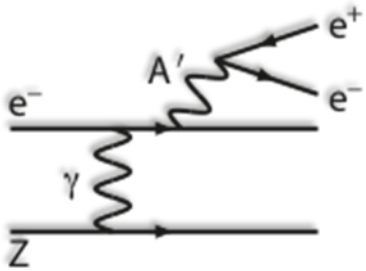


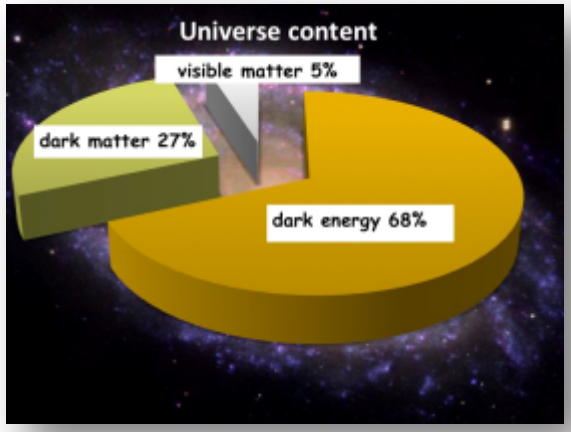


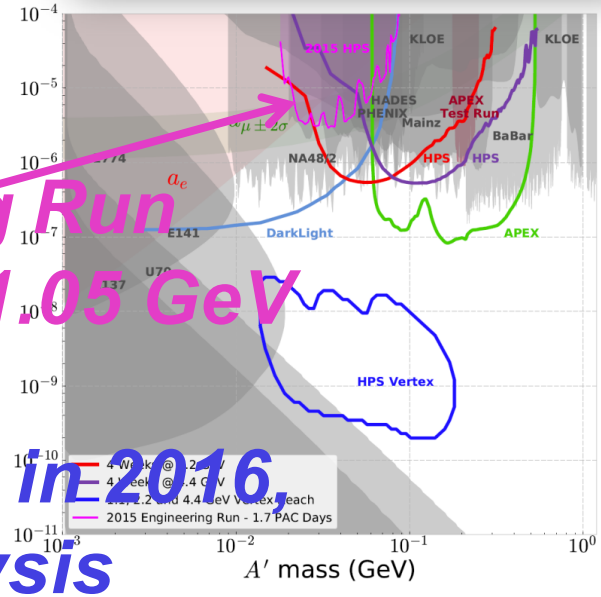
1 GeV data will extend to Q^2~2×10^{-4} GeV^2

Heavy Photon Search – First Results

- ***NP-HEP Collaboration***

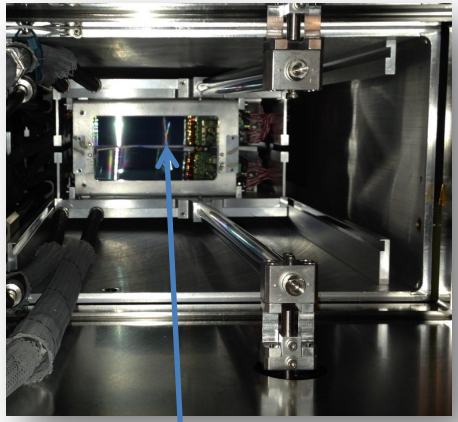






2015 Engineering Run
1.7 PAC days @ 1.05 GeV

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

Z. Meziani'talk

Futrue: Electron Ion Collider

EIC@JLab: JLEIC

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."

NSAC 2015 Long-Range Plan:

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

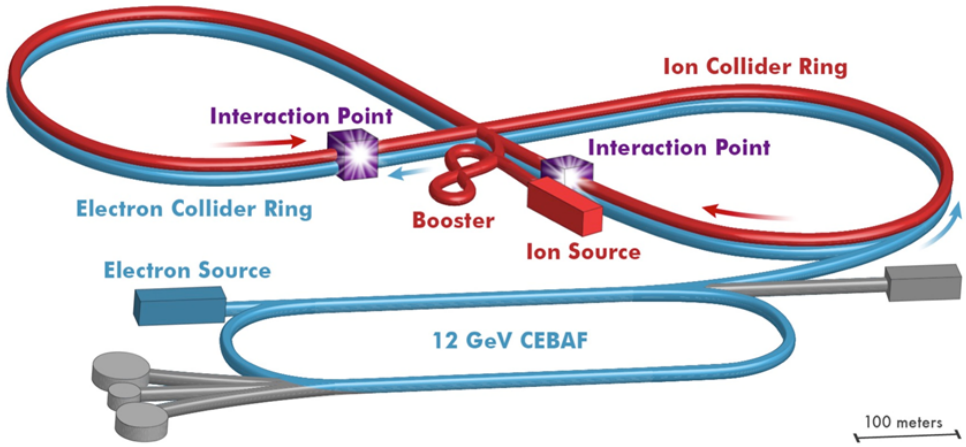
EIC Community White Paper arXiv:1212.1701v2

EIC at Jefferson Lab

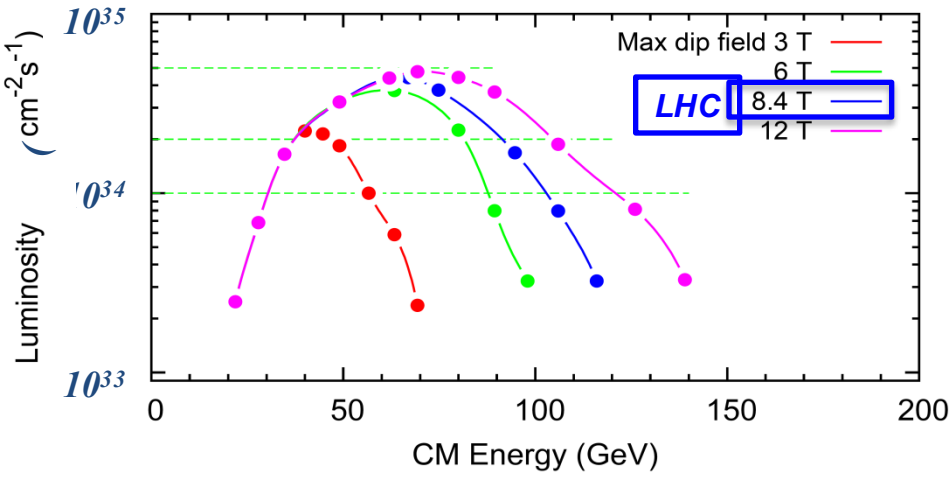
JLab EIC Figure 8 Concept

- *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

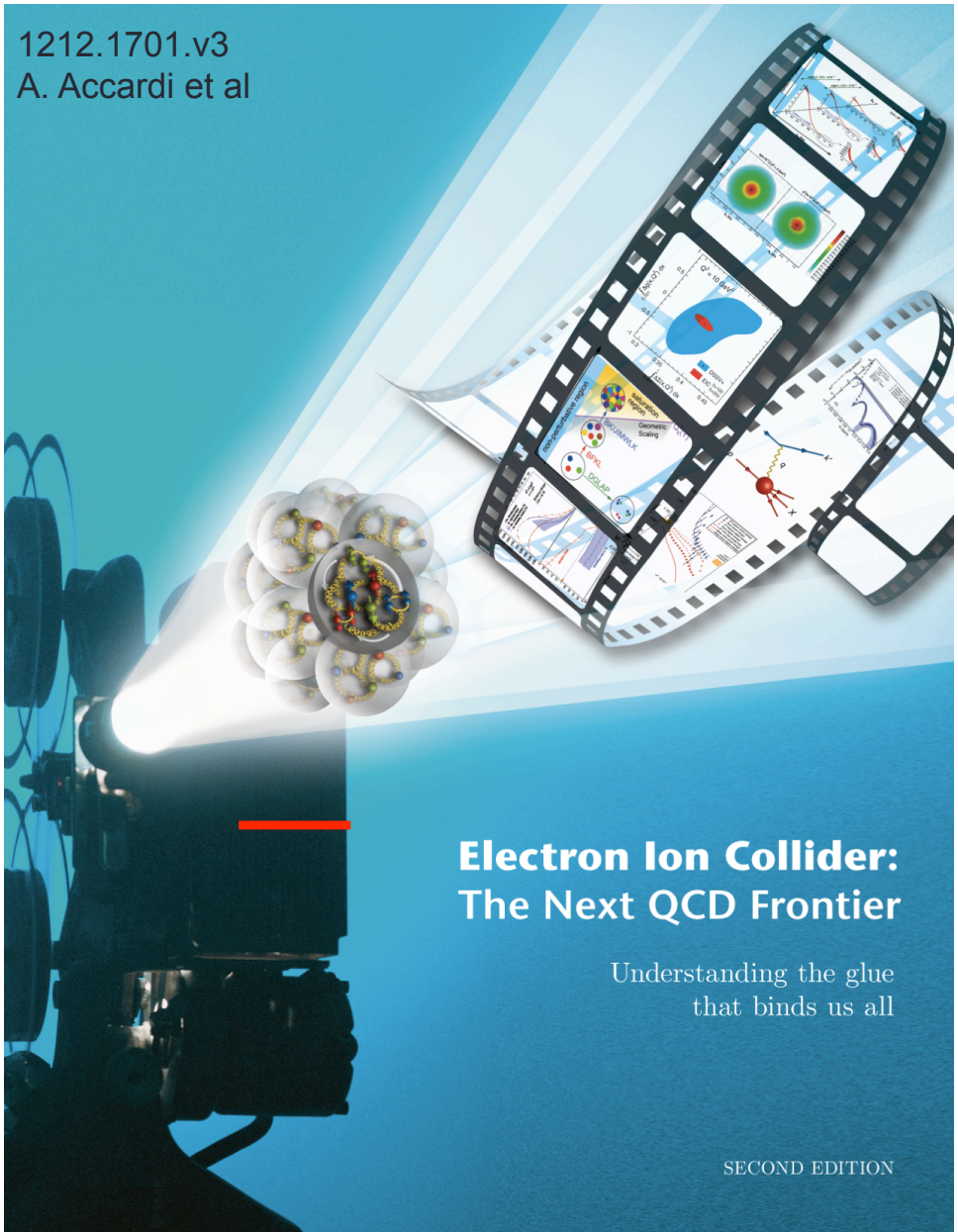
- 12 GeV upgrade ensures at least a decade of excellent opportunities for discovery
  - *New vistas in QCD*
  - Growing program Beyond the Standard Model
  - *Additional equipment: MOLLER, SoLID,* plus smaller projects

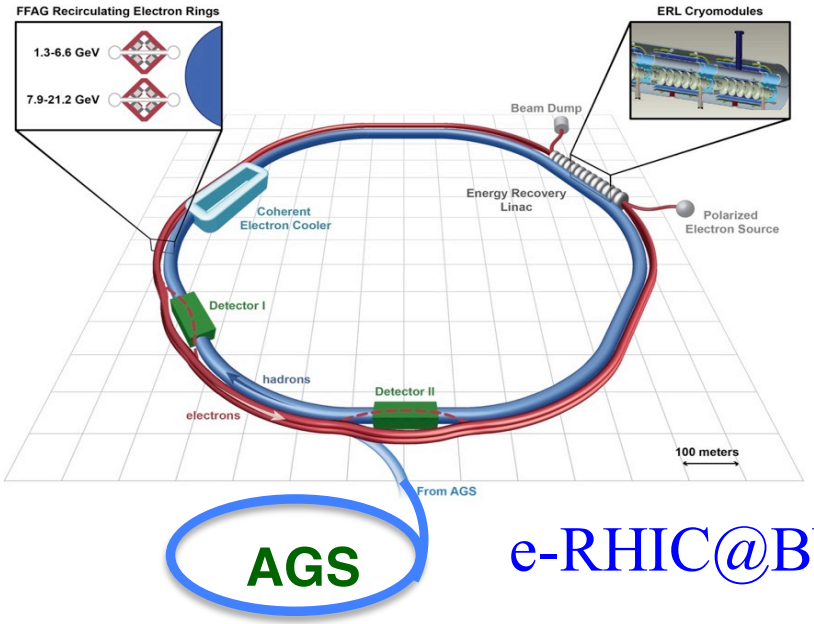
- EIC moving forward:
  - *Strong science case, much builds on JLab 12 GeV program*
  - JLEIC design well developed – time scale following 12 GeV program is "natural"
  - *NSAC 2015 Long Range Plan recommendation*

Backup

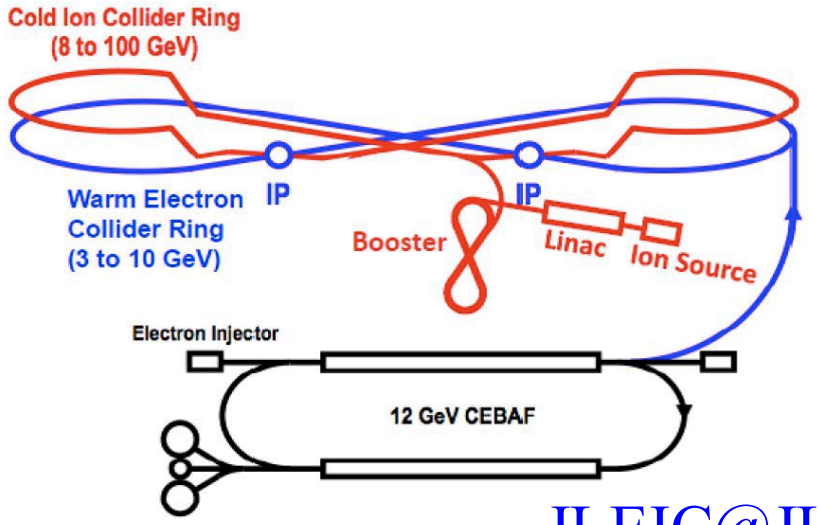
The Electron Ion Collider

Two proposals for realization of the Science Case





e-RHIC@BNL



JLEIC@JLab

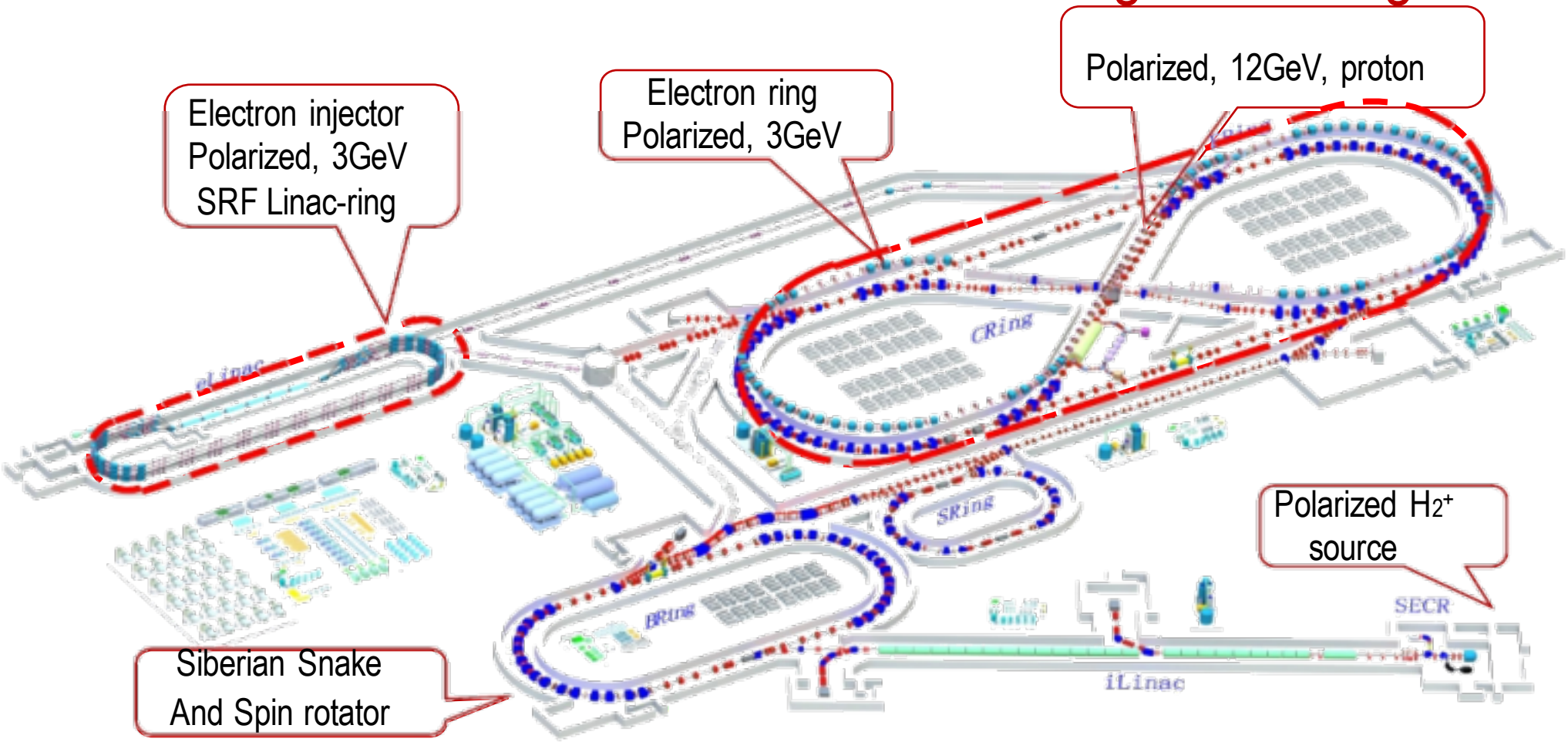
Second phase for HIAF: EIC (3 x 12 GeV) in China

- HIAF design maintains a well defined path for EIC
- **In HIAF I: EIC Ion pre-Booster $10^{14\sim15}$ ppp → Lower energy EIC (Update +ERL)**

See W. L. Zhan's talk@The 8th Workshop on Hadron Physics in China and Opportunities Worldwide (2016)

Luminosity : ~10^{33} cm^{-2} s^{-1}

figure-8 design



Overview of EIC Experiments

A Key Question for EIC:

"How are the sea quarks and gluons, and their spins distributed in space and momentum inside the nucleon?"

- Spin and Flavor Structure of the Nucleon
- 3-d Structure in Momentum Space and Confined Motion of Partons inside the Nucleon
- 3-d Structure in Coordinator Space and Tomography of the Nucleon

Other Important Questions:

"Where does the saturation of gluon densities set in?

How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?"

Opportunity for Low Energy Search of Physics Beyond SM

- Parity Violating e-N