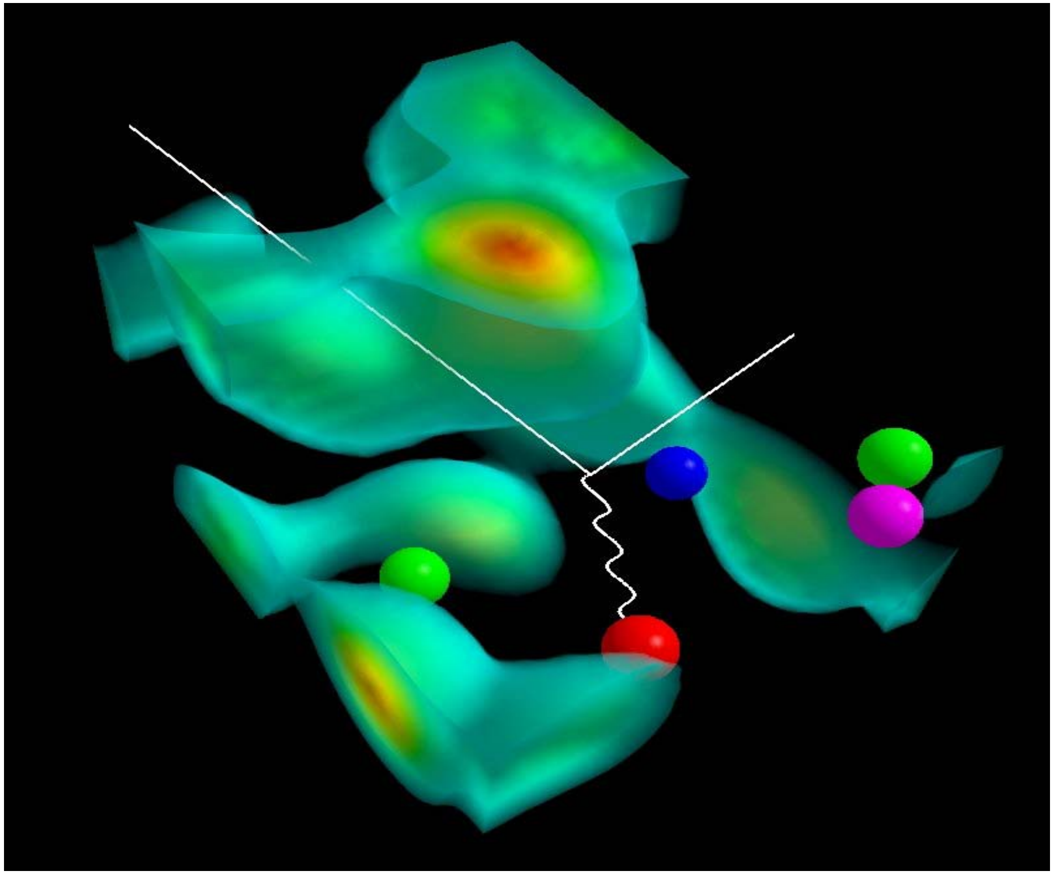
Scientific Overview



Anthony W. Thomas

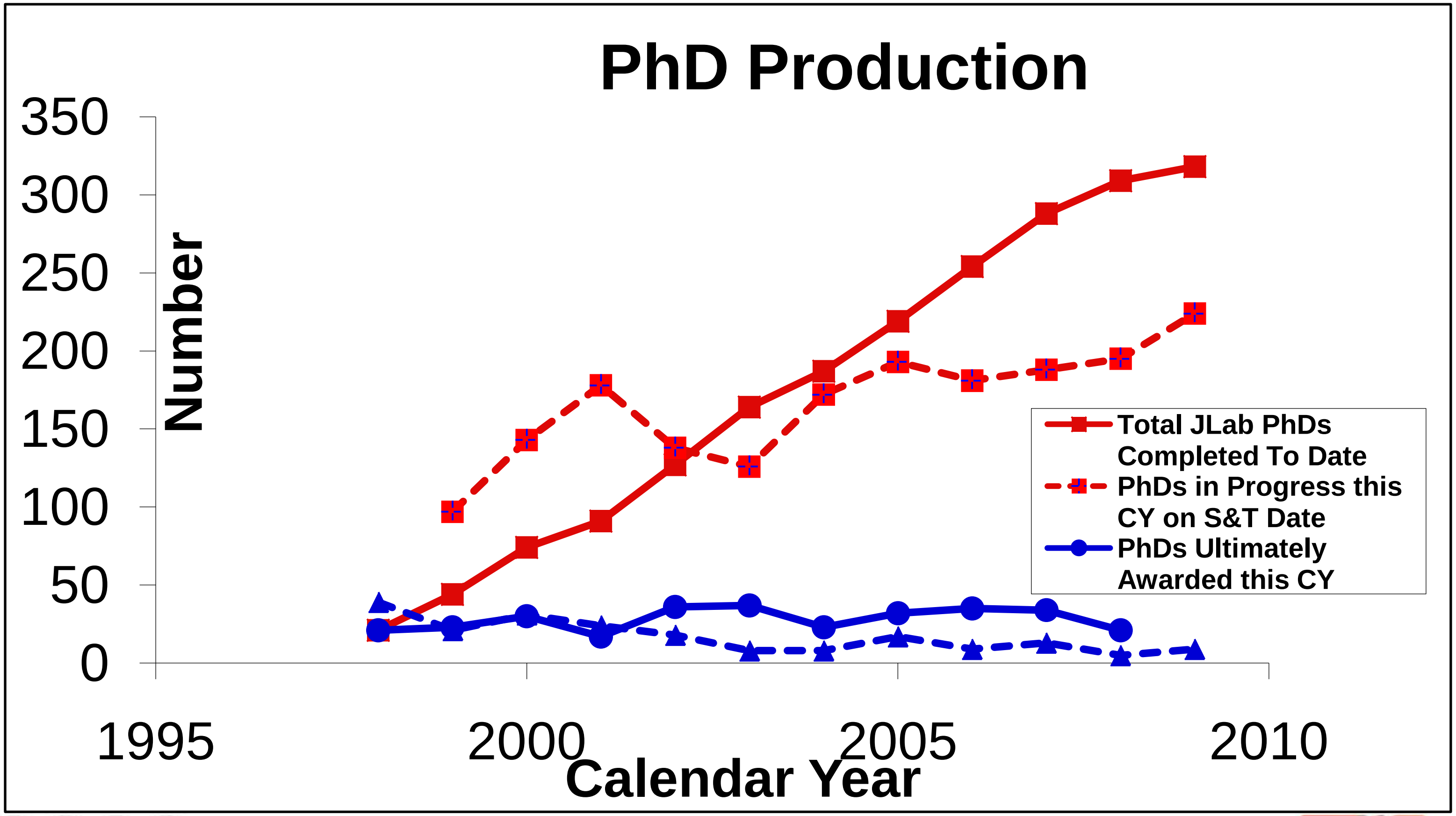
S&T Review: JLab July 14th 2009

Overview

- Past 12 years have yielded outstanding science
- Remaining years of 6 GeV operation promise more
- 12 GeV Upgrade offers "high probability for discoveries that may lead to significant paradigm shifts"
  - top rated NP project in the NSAC Long Range Plan
- Strong Theory Group focused on support for program
- Innovative design for staging a future (M)EIC
- World leader in SRF and ERL technology
- Opportunities for scientific discovery at the FEL
  - plans for a future 4th generation light source

Users / Students

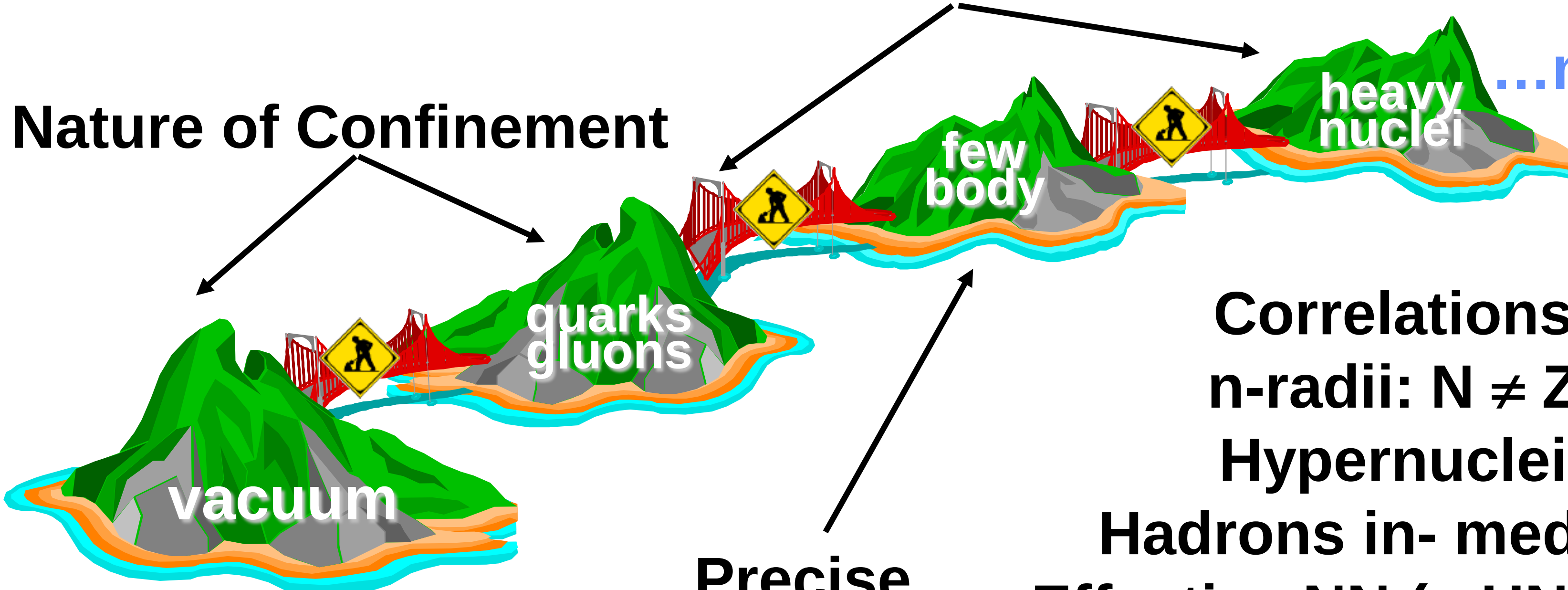
- **Active Users: 1,300**
  - **Largest nuclear physics user base at any laboratory worldwide**
- **Produce ~ 30% of US PhDs in Nuclear Physics annually**



JLab Central to Nuclear Science

Quark-Gluon Structure
Of Nucleons and Nuclei

Nature of Confinement



…n-stars

Correlations
n-radii: N $\neq$ Z
Hypernuclei
Hadrons in- medium
Effective NN (+ HN) force

Precise
few-nucleon
calculations

Exotic mesons
and baryons

Highlights of First Decade

- Discovery of unexpected behavior of G_E^p - **new result FY09**
- Superb program of studies in parity violation
  - strangeness content of the nucleon – **new result FY09**
  - factor 5 increase in precision of Standard Model couplings
- Study of deformation of Δ and transition form factors of nucleon excited states
- Major new results for structure functions – **new result FY09**
  - Bjorken & DHG sum rule; g_{1n}; $|\Delta G|$; **d/u ratio**

Highlights of First 10 years – cont.

- **New information on correlations in nuclei**

  - role of the tensor force

- **Studies of hypernuclei – better than 400keV resolution**

- **Exploration of duality, pQCD counting rules, color transparency**

- **Initial exploration of Generalized Parton Distributions (GPDs) – towards mapping of angular momentum in the proton**

Highlights of Remaining 6 GeV Program

Structure of nuclear building blocks

- **Precision measurements of electric and magnetic form factors and their quark flavor decompositions (OMB milestone)**
- **Understand nucleon excitation spectra, measuring transition form factors (OMB milestone)**
- **Determine nucleon structure at intermediate x; measure moments of unpolarized structure functions (OMB milestone)**
- **Develop tools for a program of "nuclear tomography" (OMB milestone)**

Highlights of Remaining 6 GeV Program (cont.)

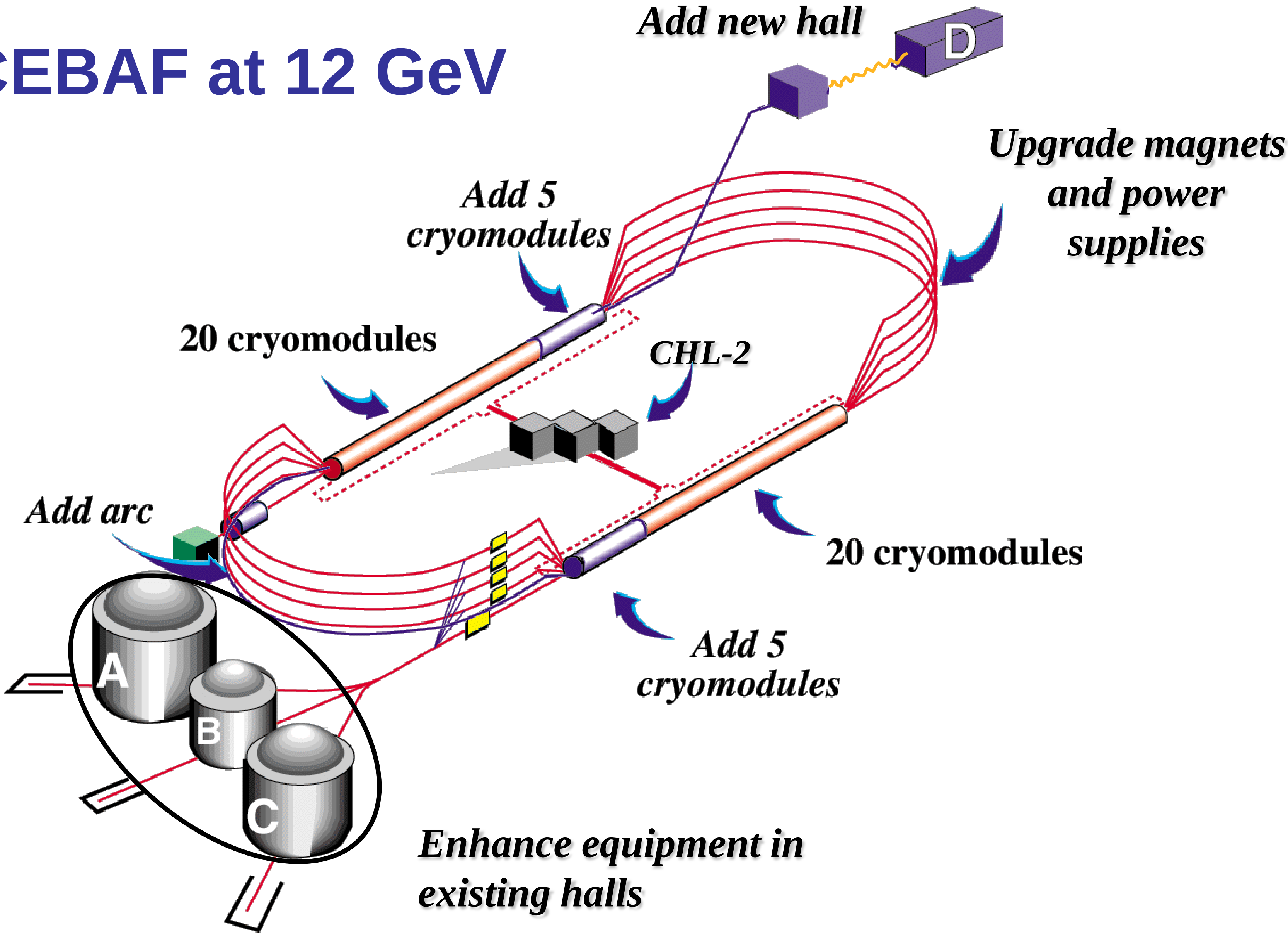
Structure of nuclei

- **Explore deeply-lying shell structure, QCD basis of N-N force via hypernuclear experiments**
- **Compare properties of nucleons bound in nuclei with those of free nucleons (OMB milestone)**
- **Measure the neutron radius of Pb^{208} providing essential information for a broad range of physics**
- **Explore underlying quark-gluon structure of light nuclei by measuring elastic form factors at high momentum transfer**

Symmetry Tests

- **Determine the weak charge of the proton**

CEBAF at 12 GeV



Highlights of the 12 GeV Program

- **Revolutionize Our Knowledge of Spin and Flavor Dependence of Valence PDFs**

- **Revolutionize Our Knowledge of Distribution of Charge and Current in the Nucleon**

- **Totally New View of Hadron (and Nuclear) Structure: GPDs**
  - **Determination of the quark angular momentum**

Highlights of the 12 GeV Program….2

- **Exploration of QCD in the Nonperturbative Regime:**
  - **Existence and properties of exotic mesons**

- **New Paradigm for Nuclear Physics:**
  Nuclear Structure in Terms of QCD
  - **Spin and flavor dependent EMC Effect**
  - **Study quark propagation through nuclear matter**

- **Precision Tests of the Standard Model**
  - **Parity Violating DIS & Möller**

12 GeV : Milestone Performance

Level and Number	Milestone Description	Baseline	Projected	Actual
1-1	CD-0 (Approve Mission Need)	Mar-04		Mar-04
1-2	CD-1 (Approve Preliminary Baseline Range)	Feb-06		Feb-06
1-3	CD-2 (Approve Performance Baseline)	Dec-07		Nov-07
1-4	CD-3 (Approve Start of Construction)	Sep-08		Sept-08
1-5	CD-4A (Approve *Accelerator* Project Completion and Start of Operations	Dec-14	Dec-14	
1-6	CD-4B (Approve *Experimental Equipment* Project Completion and Start of Operations)	Jun-15	Jun-15	
2-05	Design Review of Superconducting Magnets	Jul-08		May-08
2-14	Design of Conventional Facilities Completed	Sep-08		Sep-08
2-06	Award First Superconducting Magnet Contract	Jul-09		Jul-09
2-15	Ready for Equipment - CHL Addition (RFE)	Sep-10	Sep-10	
2-16	Ready for Equipment - Hall-D (RFE)	Oct-10	Oct-10	
2-10	Start Hall-D Installation	Nov-10	Nov-10	
2-01	Klystron Mass Production Authorization	Jun-11	Jun-11	

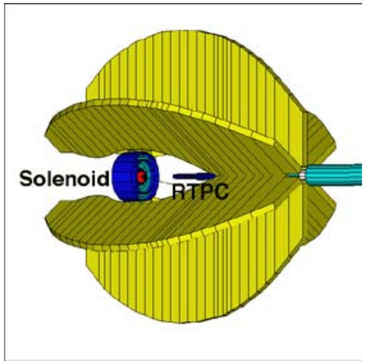
Talk of C. Rode

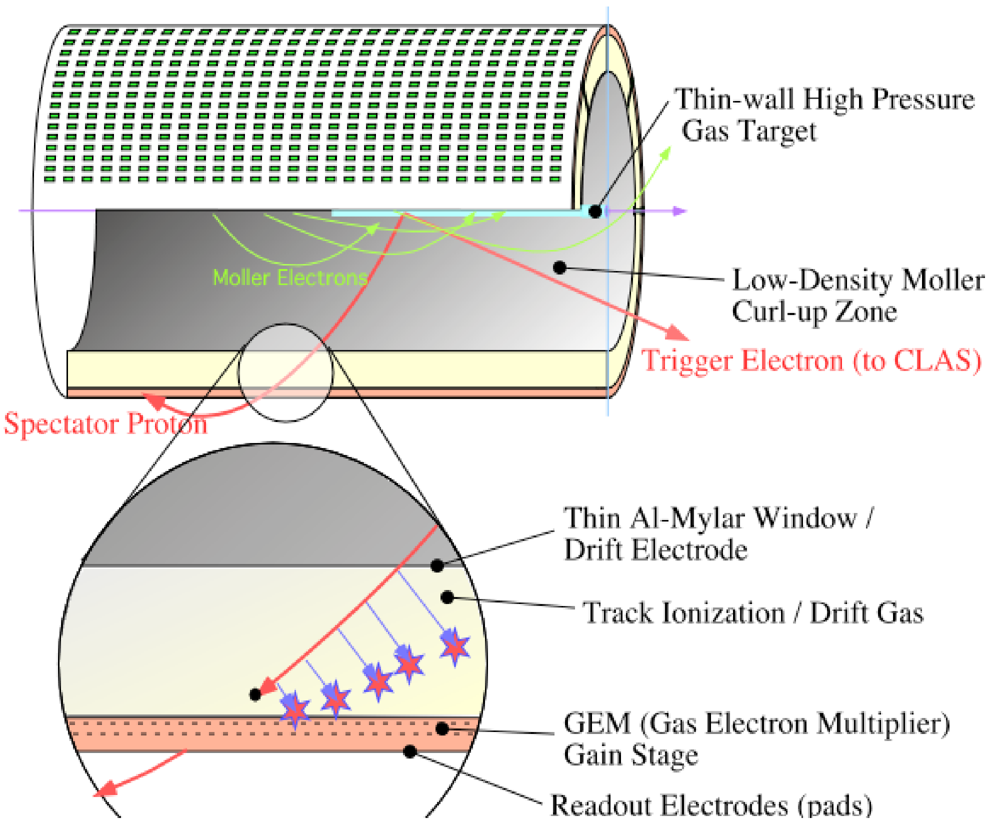
Scientific Highlights

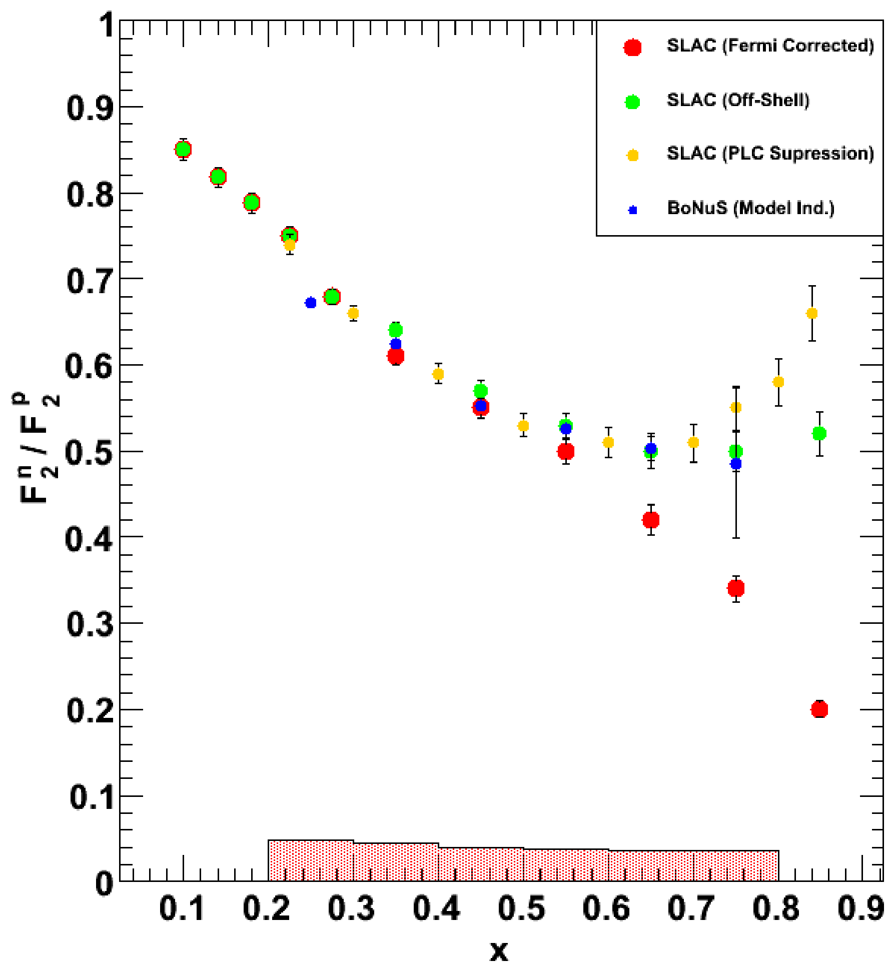
6 GeV Highlights Leading to the 12 GeV Upgrade

- **Parton Distribution Functions**
- **Form Factors**
- **Generalized Parton Distributions**
- **Exotic Meson Spectroscopy: Confinement and the QCD vacuum**
- **Nuclei at the level of quarks and gluons**
- **Tests of Physics Beyond the Standard Model**

Preliminary Result from Bonus Experiment







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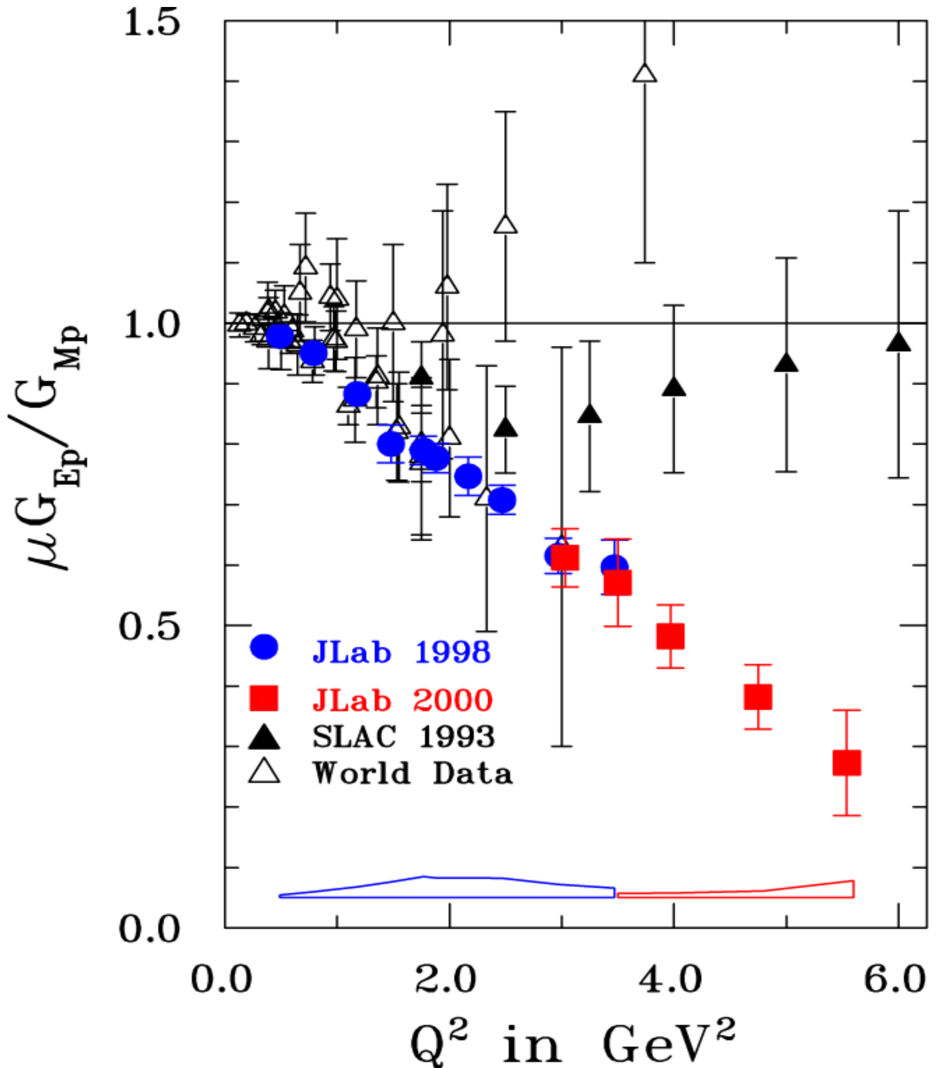
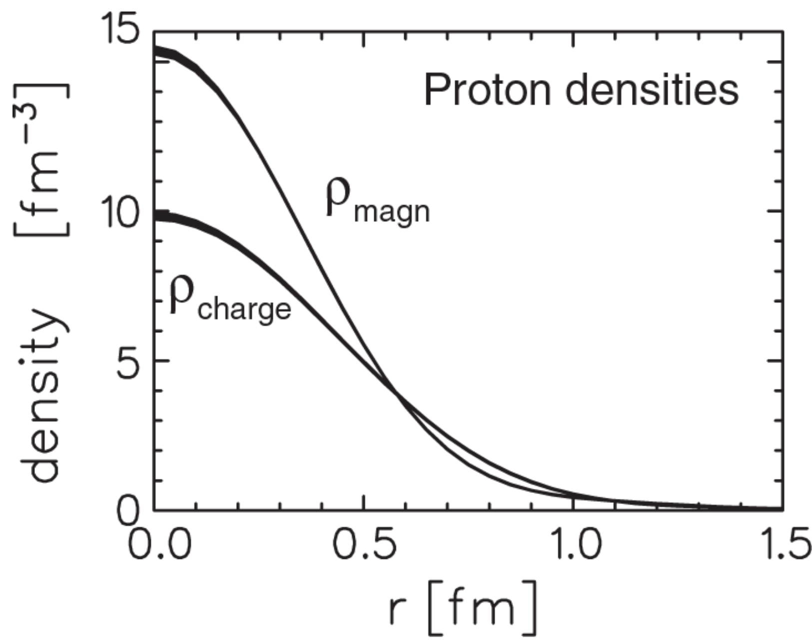
JLab Data Rewrote the Text Book on G_E^p



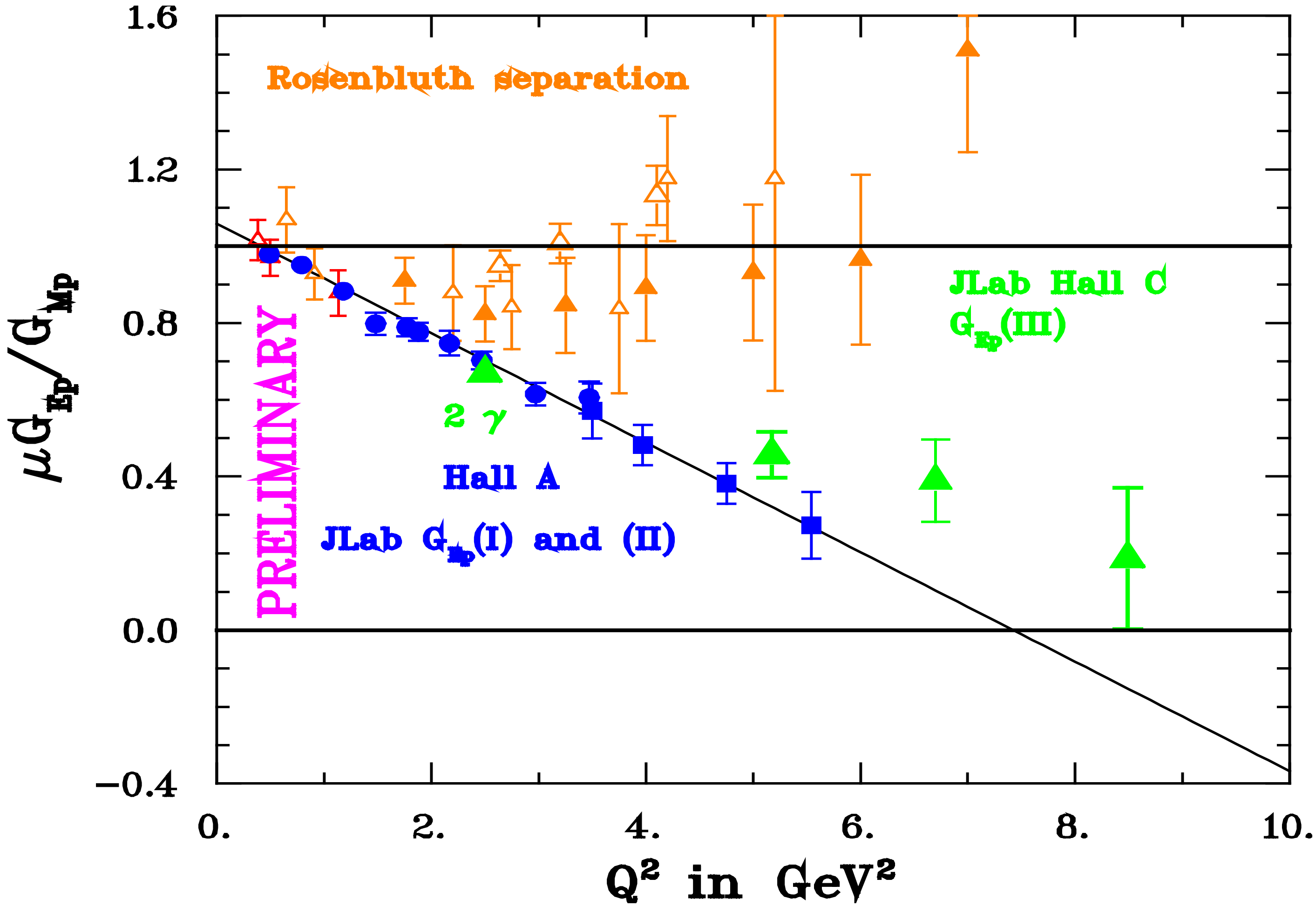
- High Intensity
- High Duty Factor
- High Polarization

⇒ Revolutionized our knowledge

⇒



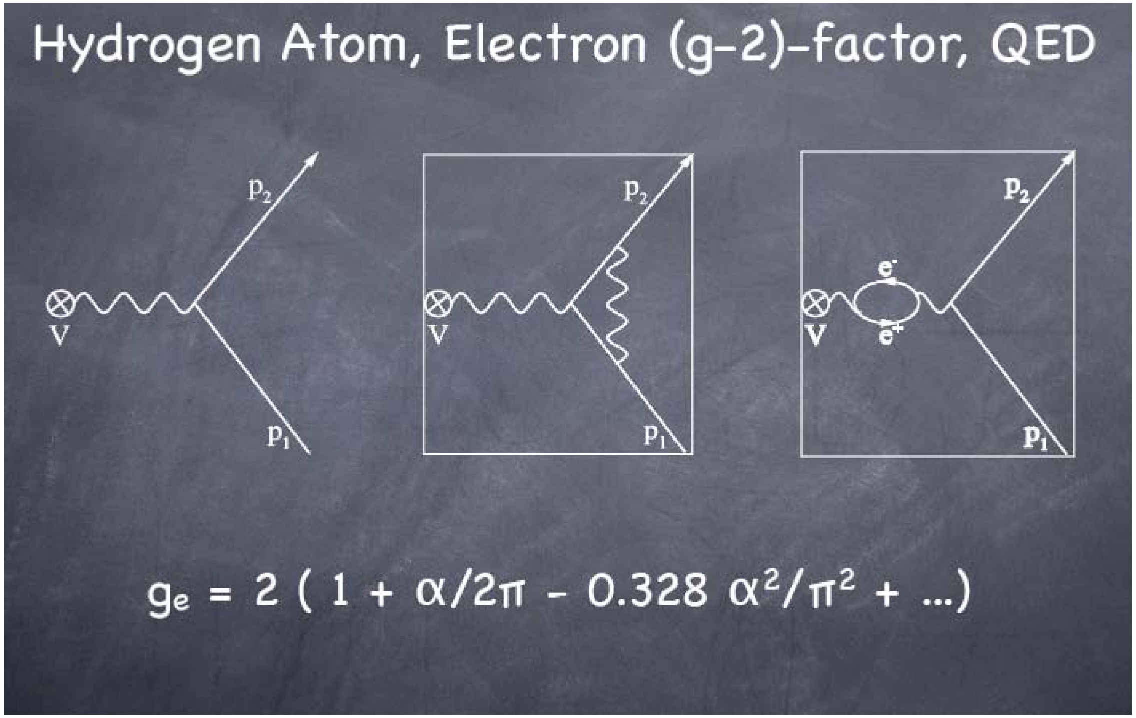
Further Measurements of G_E^p



- Perdrisat *et al*. E01-109 — increased range of Q^2 by 50% in FY08 (analysis nearing completion)
- 12 GeV and SHMS in Hall C will go to 14 GeV^2

Strangeness in the Nucleon

- Strangeness contribution is a vacuum polarization effect, analogous to Lamb shift in QED



- It is a fundamental test of non-perturbative QCD

Experimental Determination

- **Assuming charge symmetry:**

$$G_{E,M}^{u,p} = \left(3 - 4\sin^2\theta_W\right) G_{E,M}^{\gamma,p} - G_{E,M}^{Z,p}$$

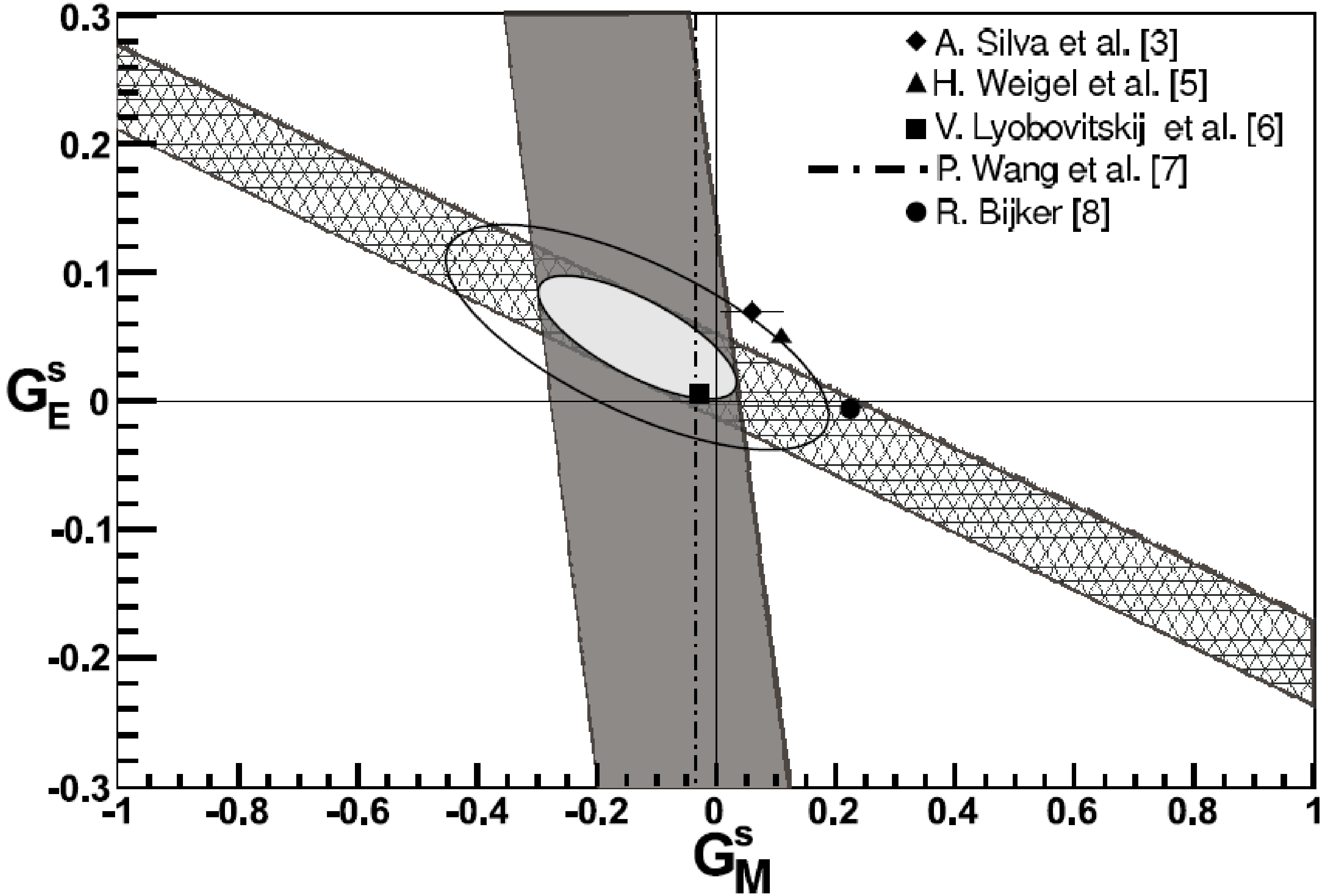
$$G_{E,M}^{d,p} = \left(2 - 4\sin^2\theta_W\right) G_{E,M}^{\gamma,p} - G_{E,M}^{\gamma,n} - G_{E,M}^{Z,p}$$

$$G_{E,M}^{s,p} = \left(1 - 4\sin^2\theta_W\right) G_{E,M}^{\gamma,p} - G_{E,M}^{\gamma,n} - G_{E,M}^{Z,p}$$

- **Need three independent observables to extract individual quark contributions to form factors**

PVA4 2009: $Q^2 = 0.22\ \text{GeV}^2$

arXiv: 0903.2733v1



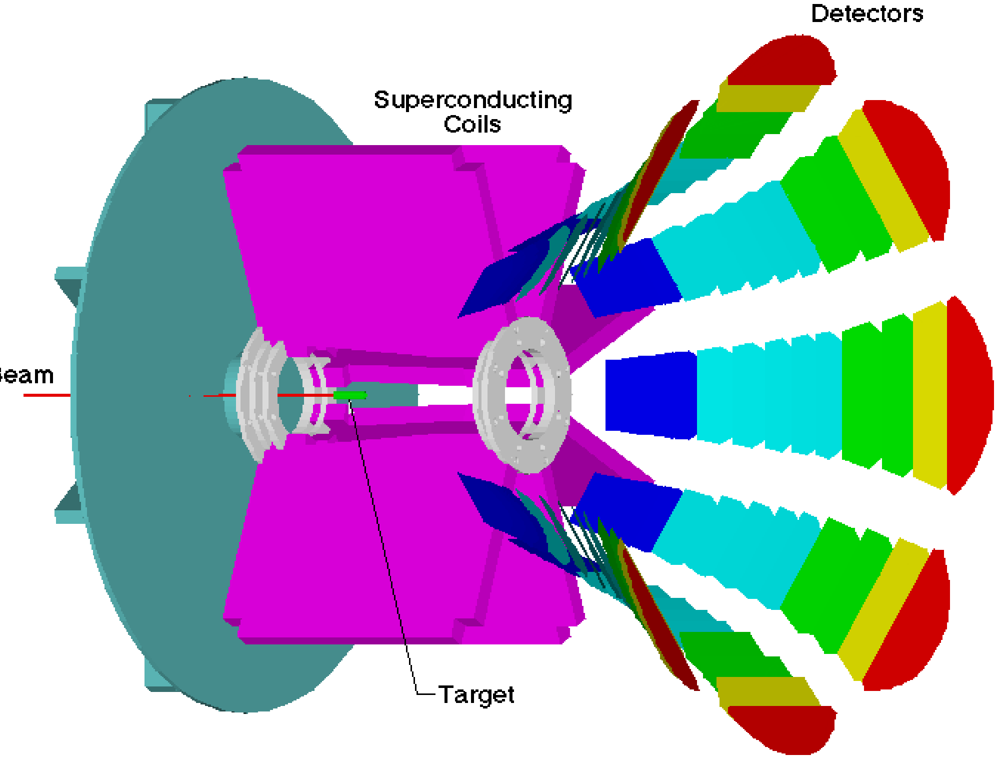
$G_M^s = -0.14 \pm 0.11 \pm 0.11\ \mu_N$; $G_E^s = 0.050 \pm 0.038 \pm 0.019$

The G0 experiment at JLAB

- **Forward and backward angle PV e-p elastic and e-d (quasielastic) in JLab Hall C**

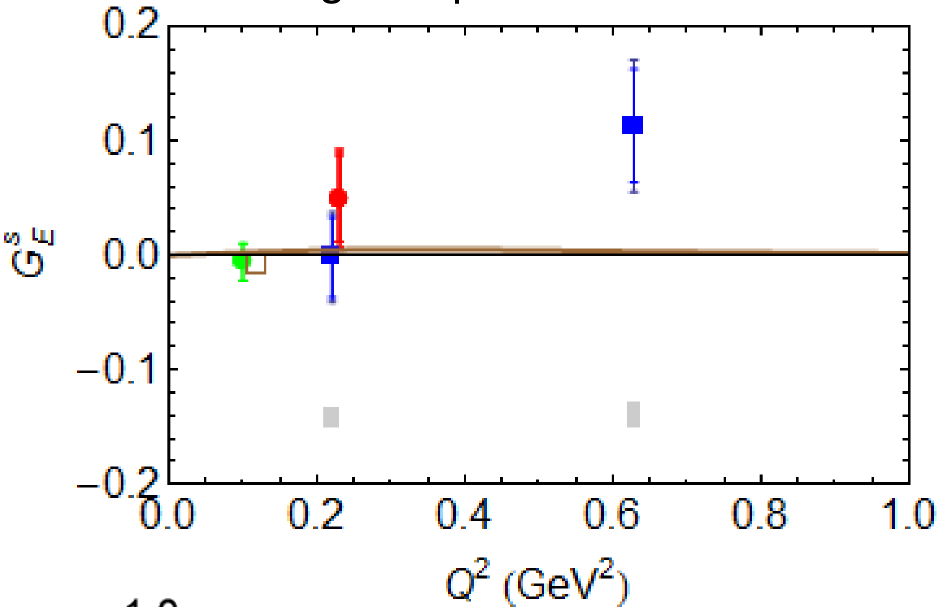
G_E^s , G_M^s and G_A^e separated over range $Q^2 \sim 0.1-1.0\ (\mathrm{GeV/c})^2$

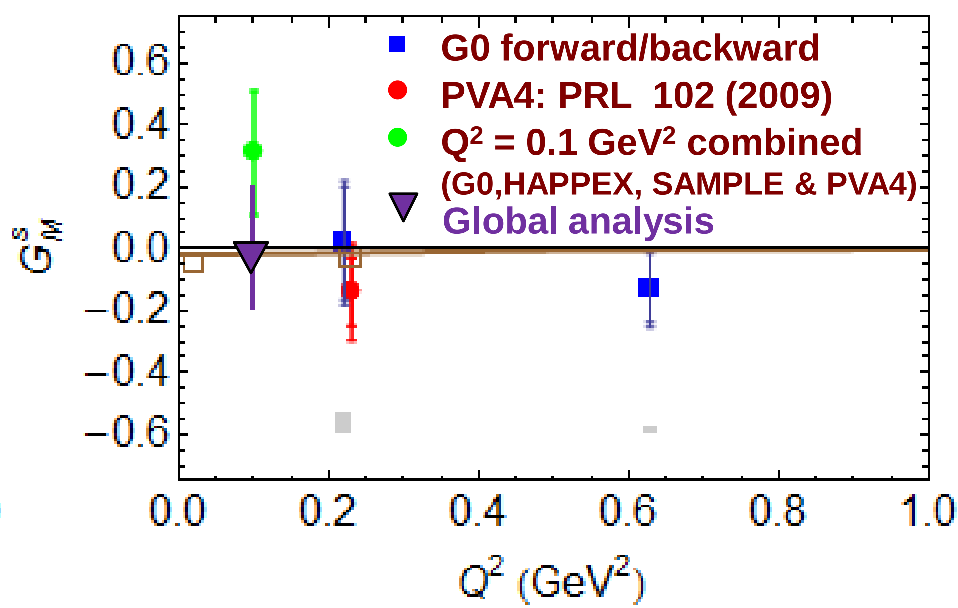
- **superconducting toroidal magnet**
  - **scattered particles detected in segmented scintillator arrays in spectrometer focal plane**
  - **custom electronics count and process scattered particles at > 1 MHz**
  - ***forward angle data published 2005***
  - ***backward angle data: 2006-2007***

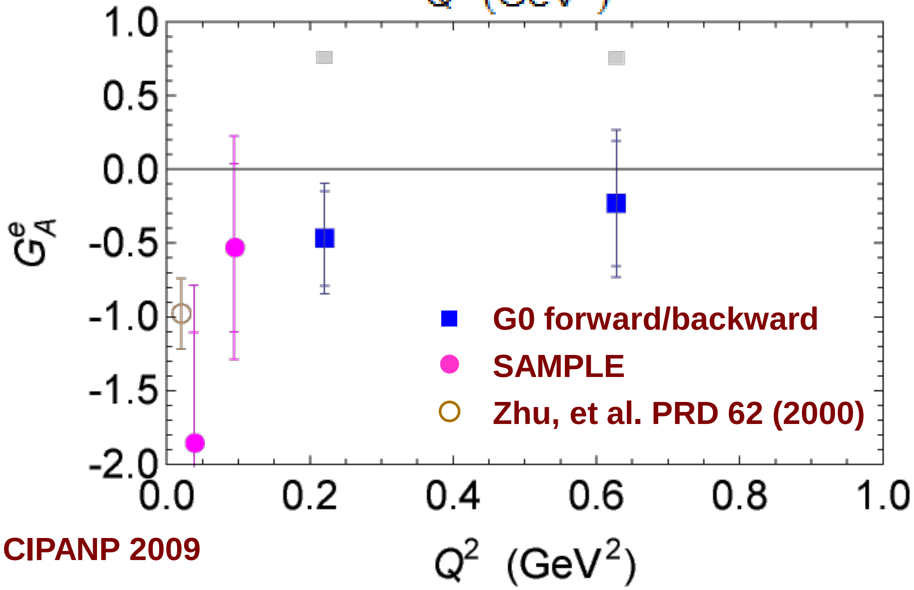


Form Factor Results

- Using interpolation of G0 forward measurements





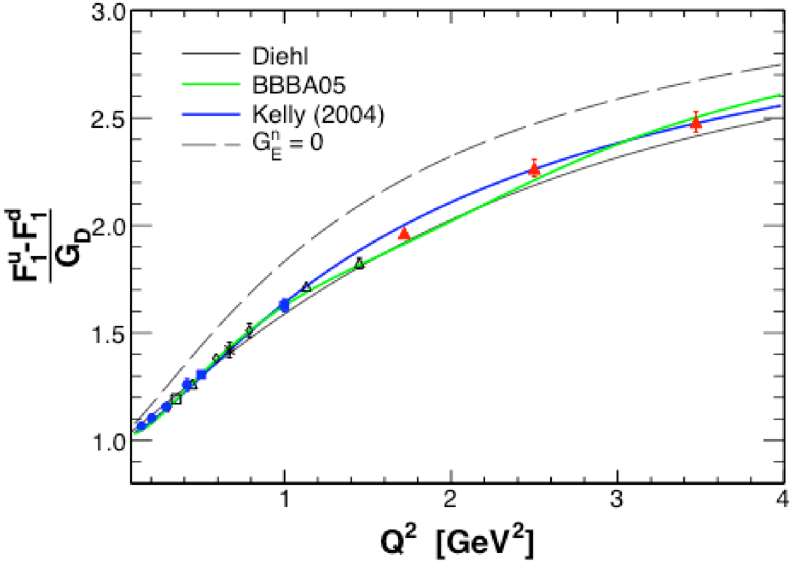


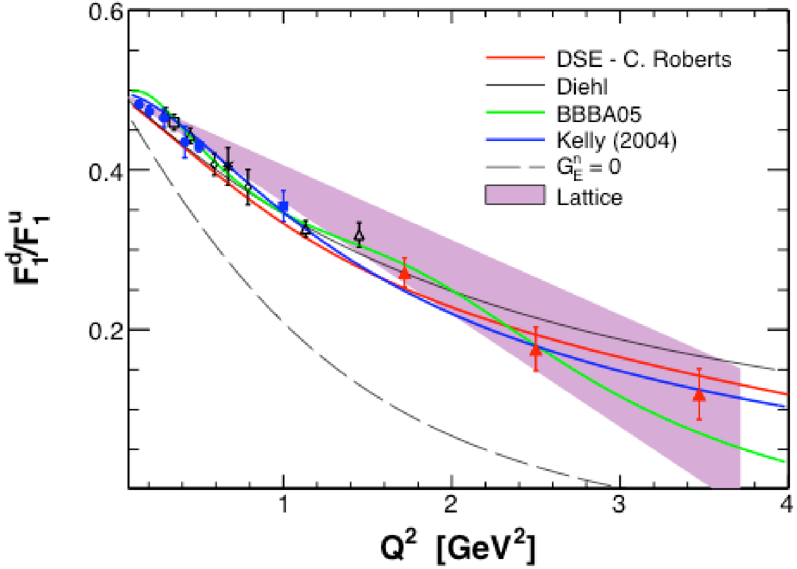
Global uncertainties

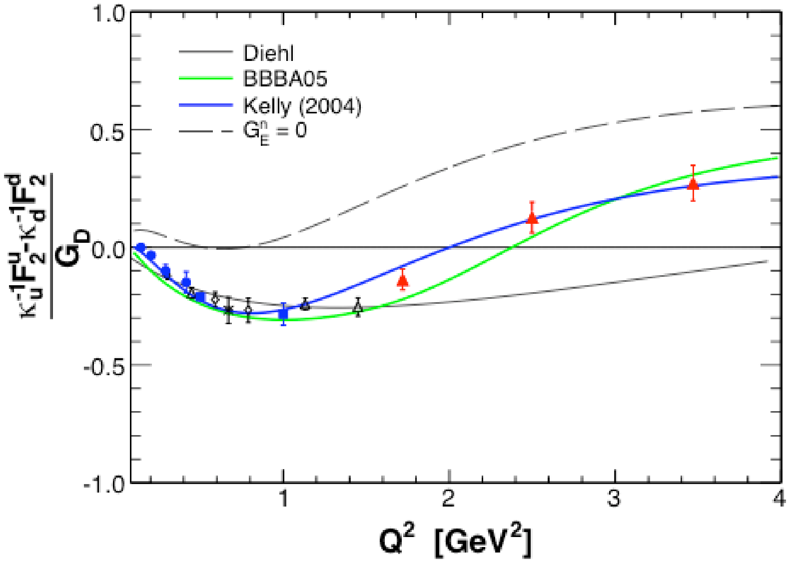
Some calculations:

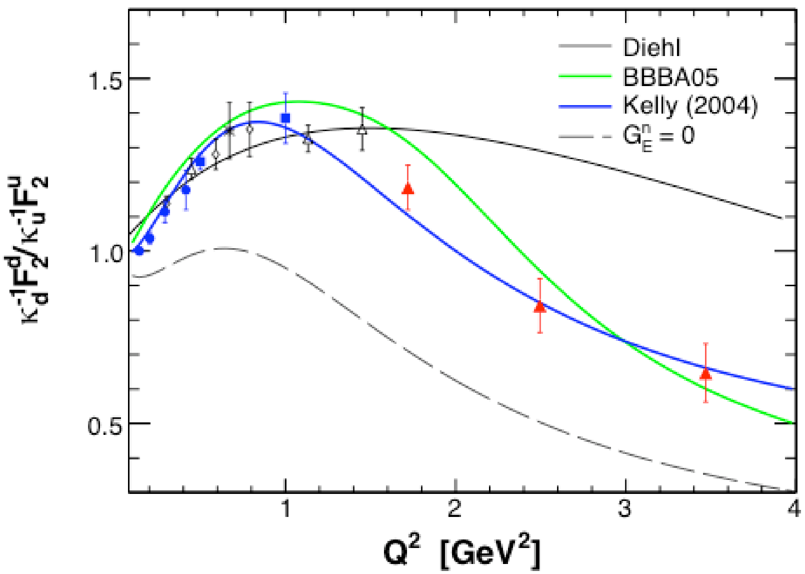
Leinweber, et al. PRL 97 (2006) 022001
Leinweber, et al. PRL 94 (2005) 152001
Wang, et al arXiv:0807.0944 (Q^2 = 0.23 GeV^2)
Doi, et al, arXiv:0903.3232

Flavor Separated Form Factors









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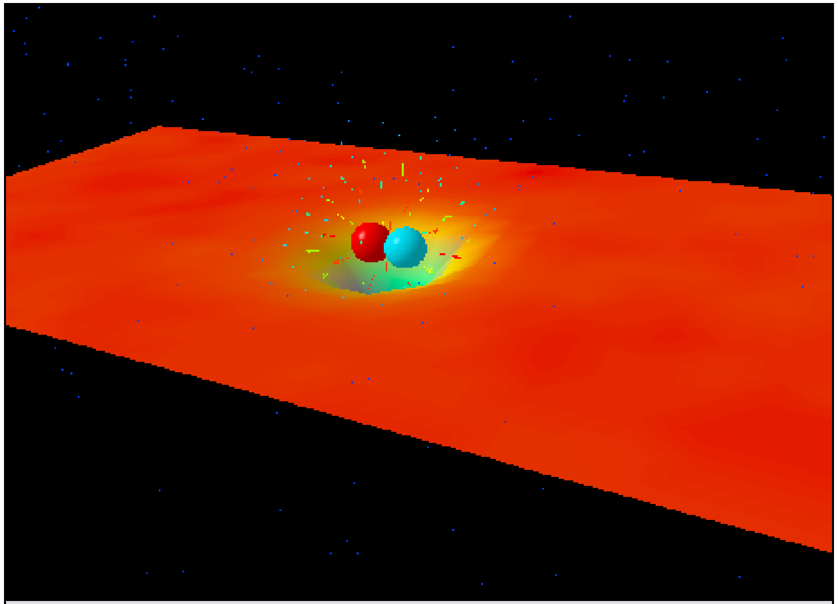
Gluonic Excitations and the Origin of Confinement



QCD predicts a rich spectrum of as yet to be discovered gluonic excitations - whose experimental verification is crucial for our understanding of QCD in the confinement regime.

With the upgraded CEBAF, a linearly polarized photon beam, and the GlueX detector, Jefferson Lab will be uniquely poised to:

- discover these states,

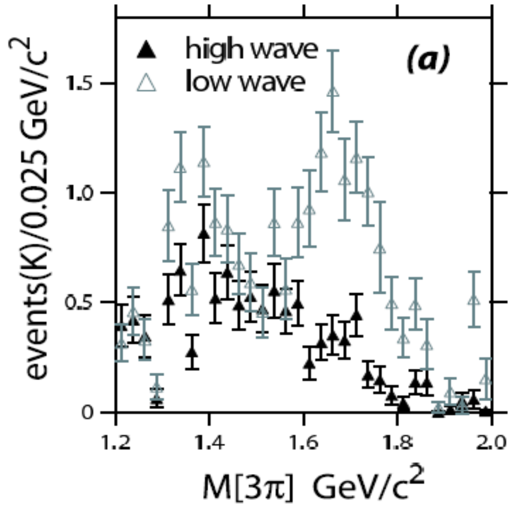
- map out their spectrum, and

- measure their properties

Search for hybrid $\pi_1(1600)$ meson

- **Possible evidence of exotic meson (hybrid) $\pi_1(1600)$ in $\pi p \to (3\pi) p$**
- **Not confirmed in a re-analysis of a higher statistic sample**

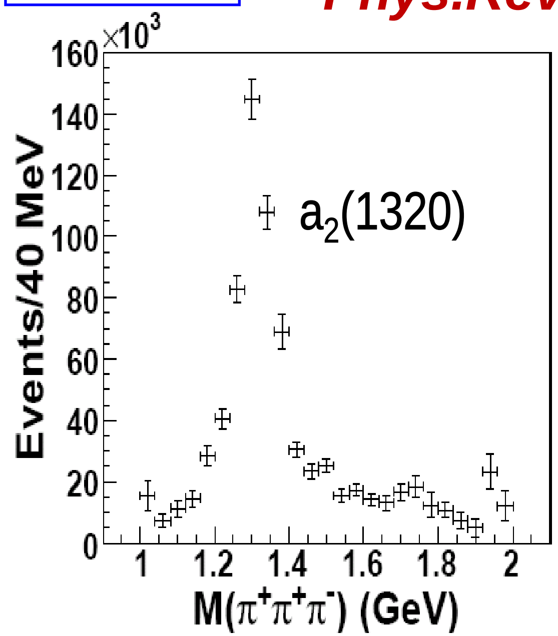
E852-Brookhaven

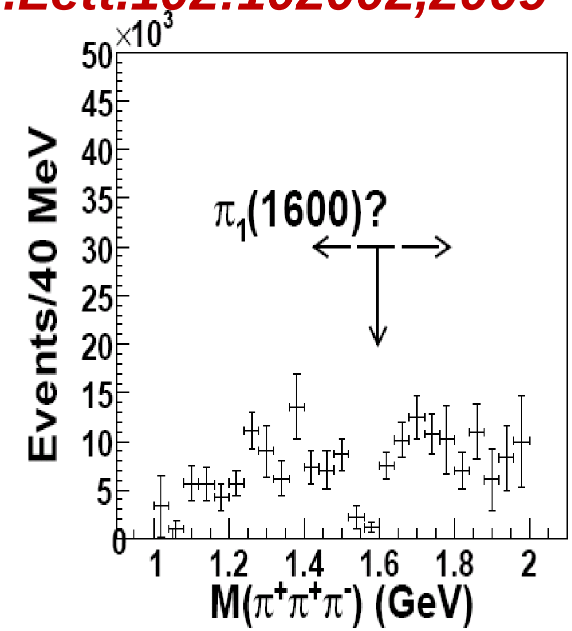


CLAS

E-01-017

Phys.Rev.Lett.102:102002,2009





- **Clear evidence of non-exotic 2^{++} state $a_2(1320)$**
- **No-evidence of exotic 1^{-+} state $\pi_1(1600)$**

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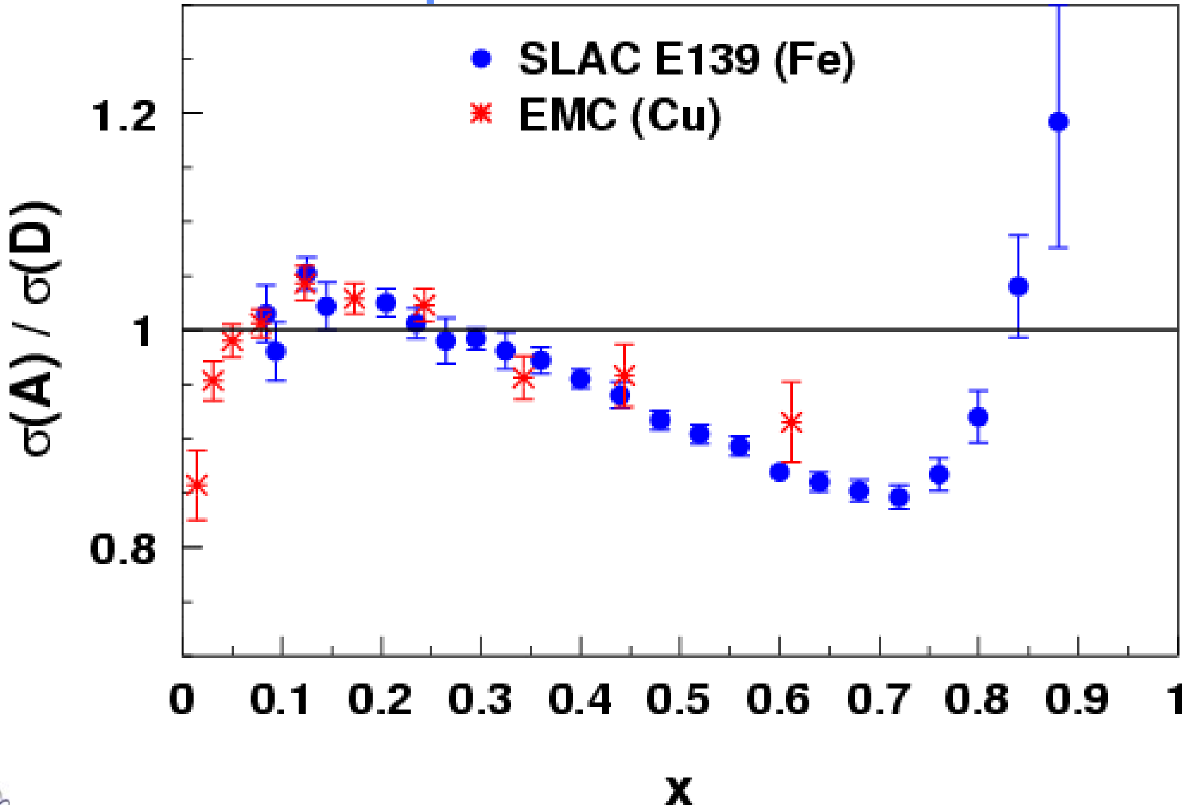
The EMC Effect: Nuclear PDFs

- Observation **stunned and electrified** the HEP and Nuclear communities 20 years ago
- Nearly 1,000 papers have been generated…..
- What is it that alters the quark momentum in the nucleus?

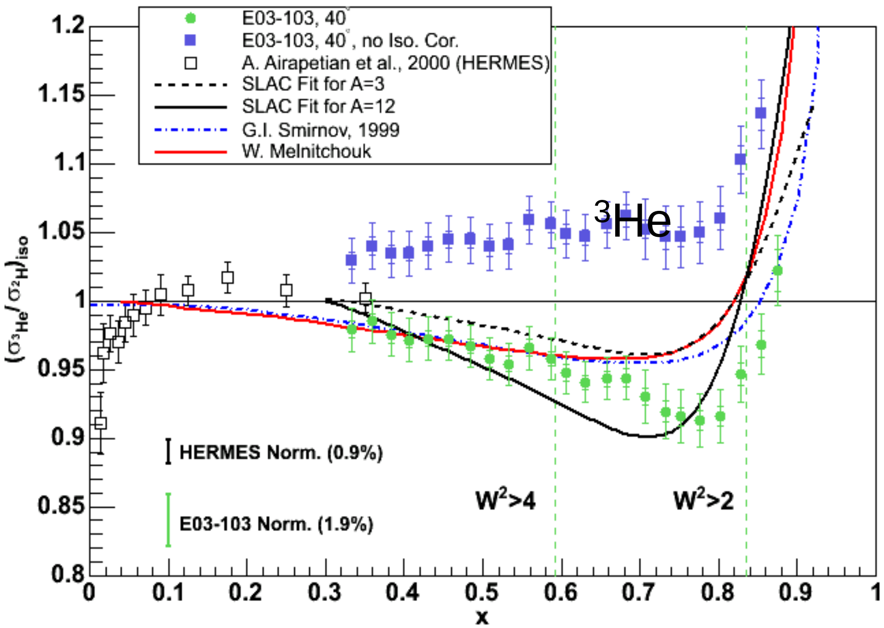


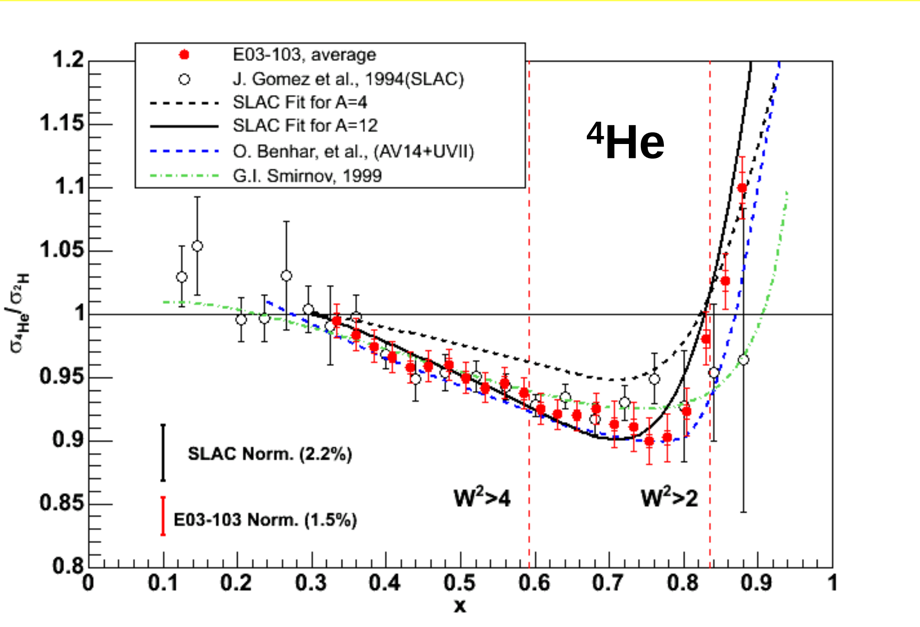
J. Ashman *et al.*, Z. Phys. C57, 211 (1993)

J. Gomez *et al.*, Phys. Rev. D49, 4348 (1994)

E03-103 Preliminary Results

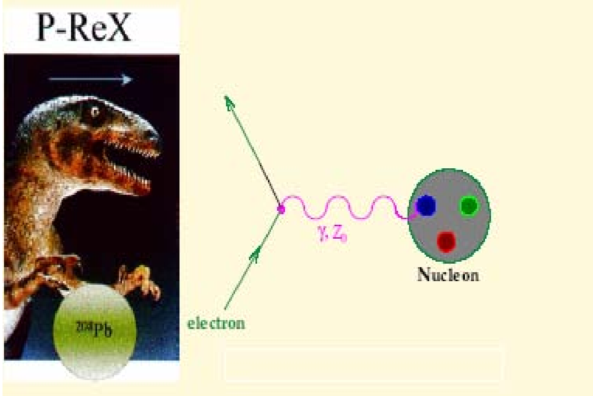
- **Analysis for ^{4}He and ^{3}He nearly complete → paper draft in progress (thesis of C. Seely, MIT)**





- **^{3}He ratio has significant correction due to "proton excess"**
- **Data show significant EMC effect, although somewhat smaller than ^{4}He**
- **Heavy target analysis in progress → A. Daniel (Houston) thesis**

PREX : ^{208}Pb Radius Experiment



Low Q^2 elastic e-nucleus scattering

(E = 850 MeV, $\Theta = 6^o$)

Z^0 **(Weak Interaction)** : **couples mainly to neutrons**

$$\frac{dA}{A} = 3\% \quad \rightarrow \quad \frac{dR_n}{R_n} = 1\%$$

Measure a Parity Violating Asymmetry

$$A = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}}\left[1 - 4\sin^2\theta_W - \frac{F_n(Q^2)}{F_P(Q^2)}\right]$$

Applications:

- **Fundamental check of Nuclear Theory**
- **Input to Atomic PV Expts**
- **Neutron Star Structure**

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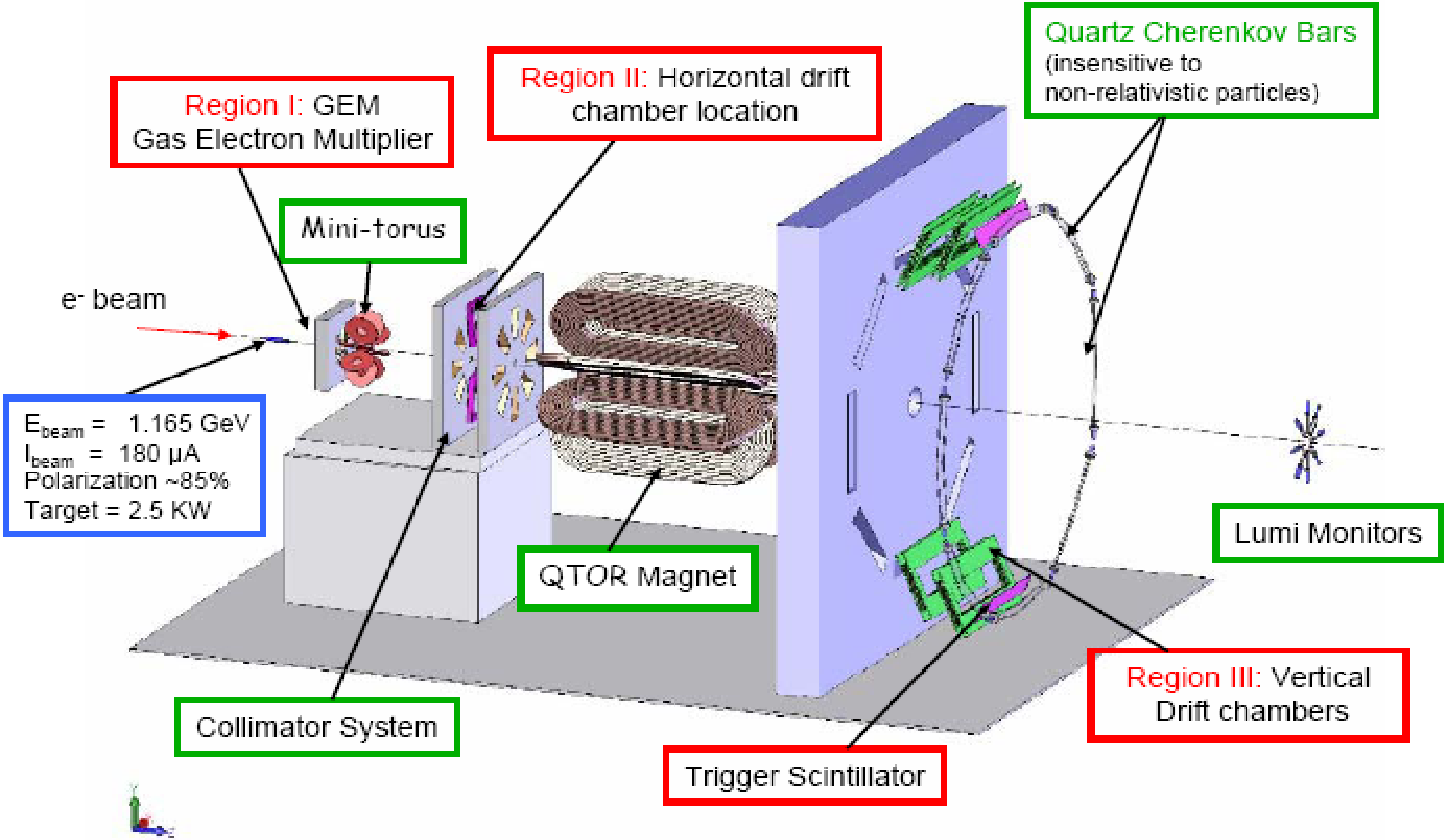
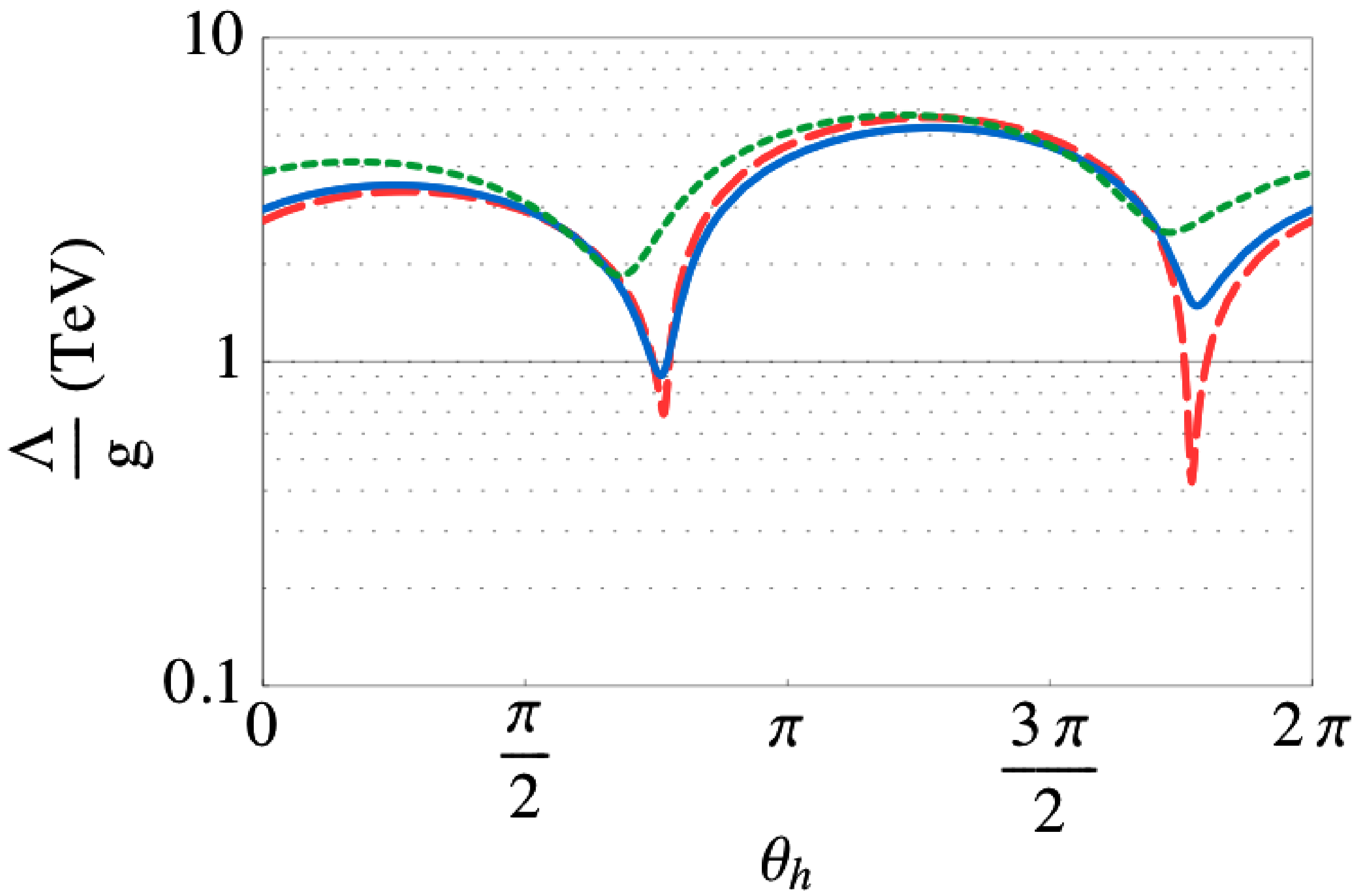
Q_{weak} Apparatus – to be installed late CY09



New Physics Limits
(if result consistent with Standard Model)



future Qweak

with PVES

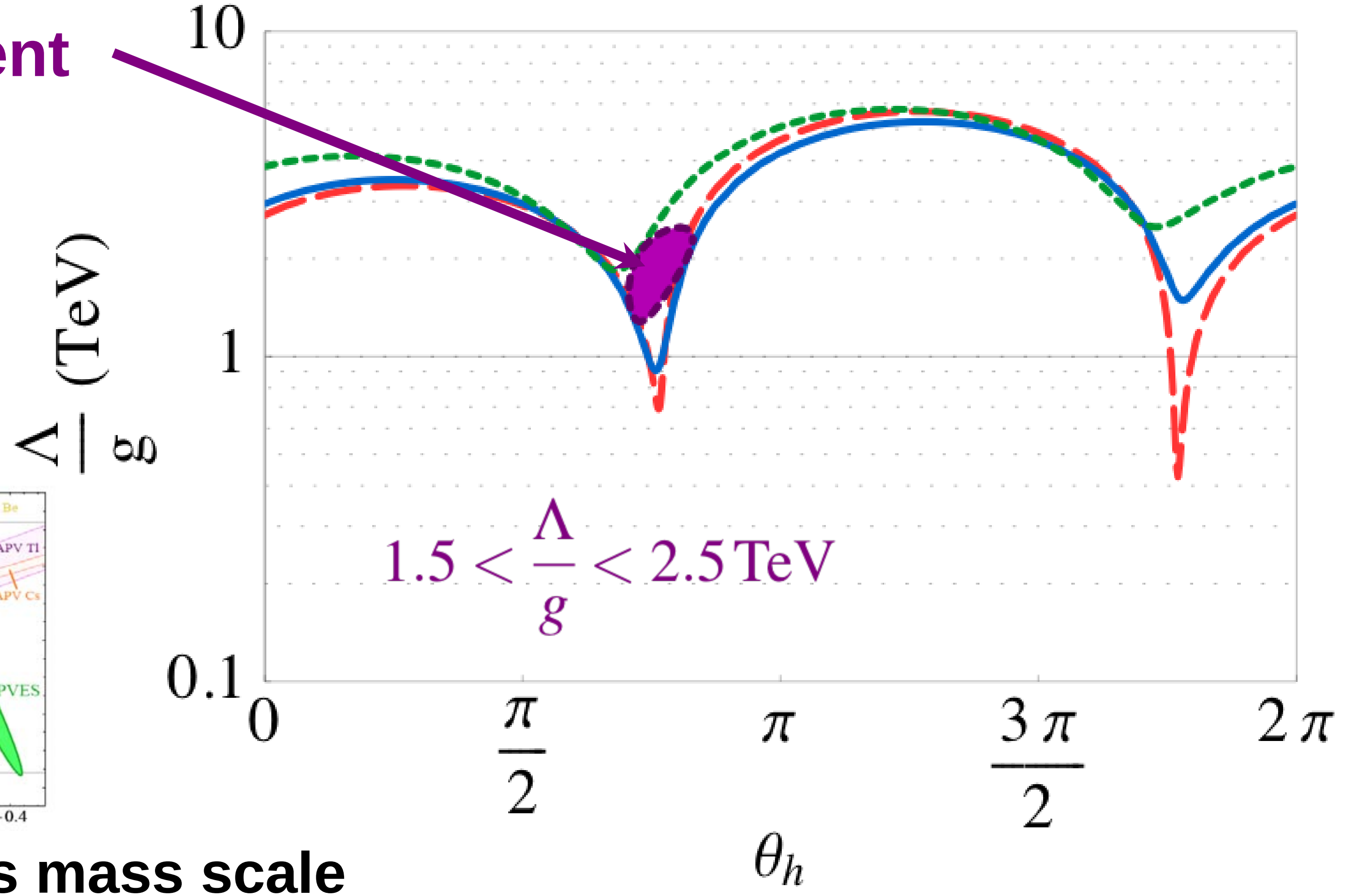
Atomic only

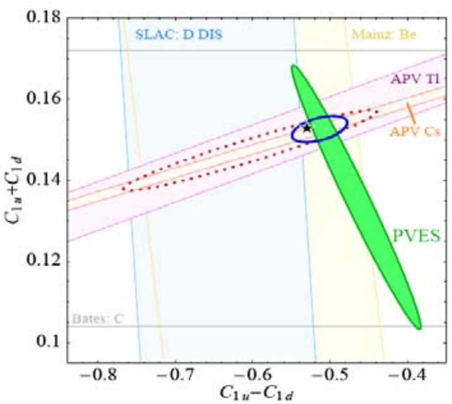
95% CL

Q_{weak} constrains new physics to beyond 2 TeV

Next Generation: Q_{weak} has real discovery potential!

IF: Q_{weak} takes central value of current PVES measurement



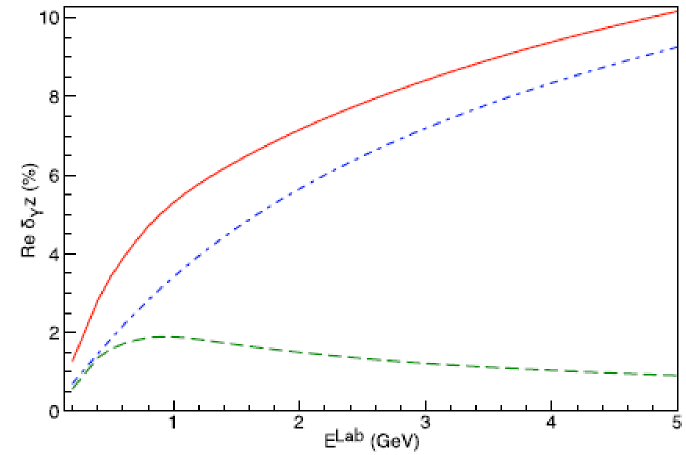


Q_{weak} yields mass scale and coupling of new Z'

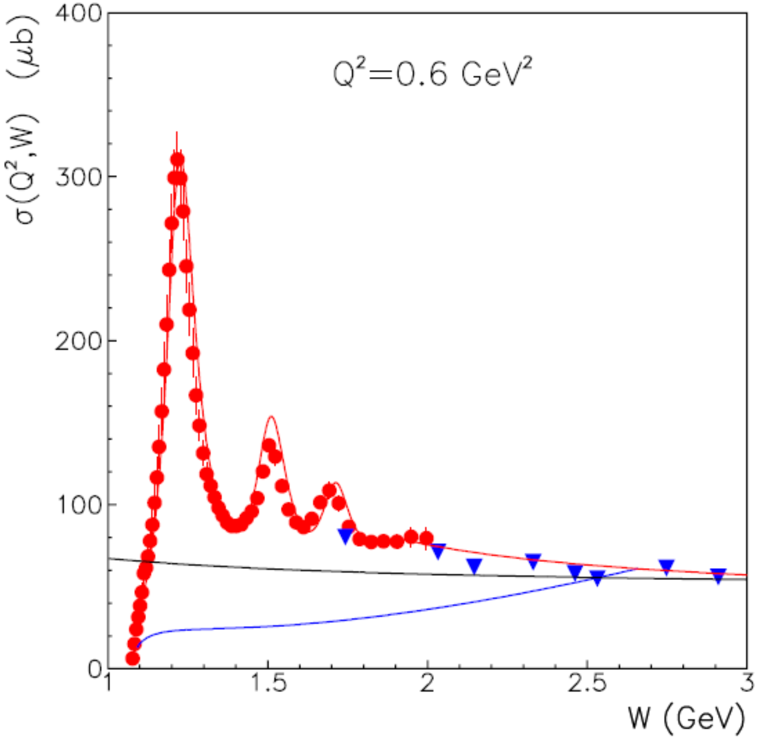
Young et al. (Dec 2006)

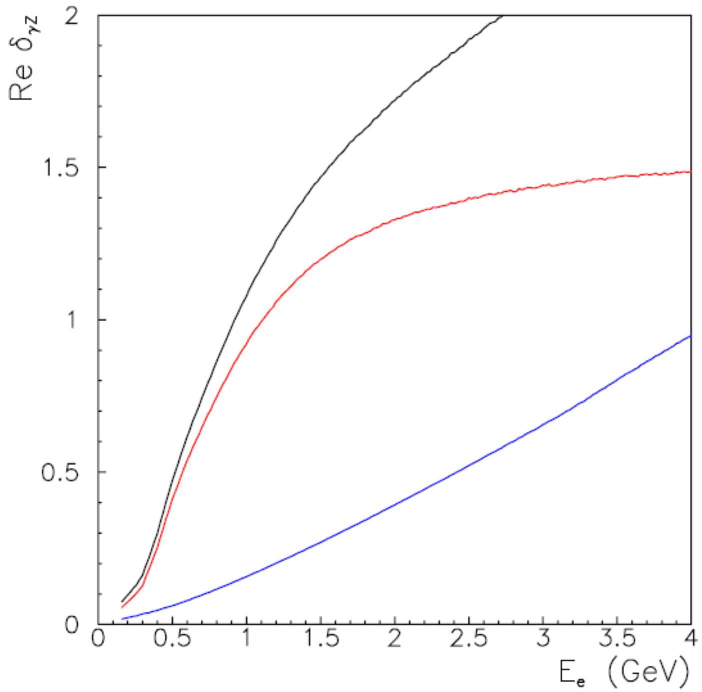
Qweak Radiative Corrections

Claim: Gorchtein &Horowitz : PRL March 2009
Radiative corrections big and large errors ⇒ Qweak problem!



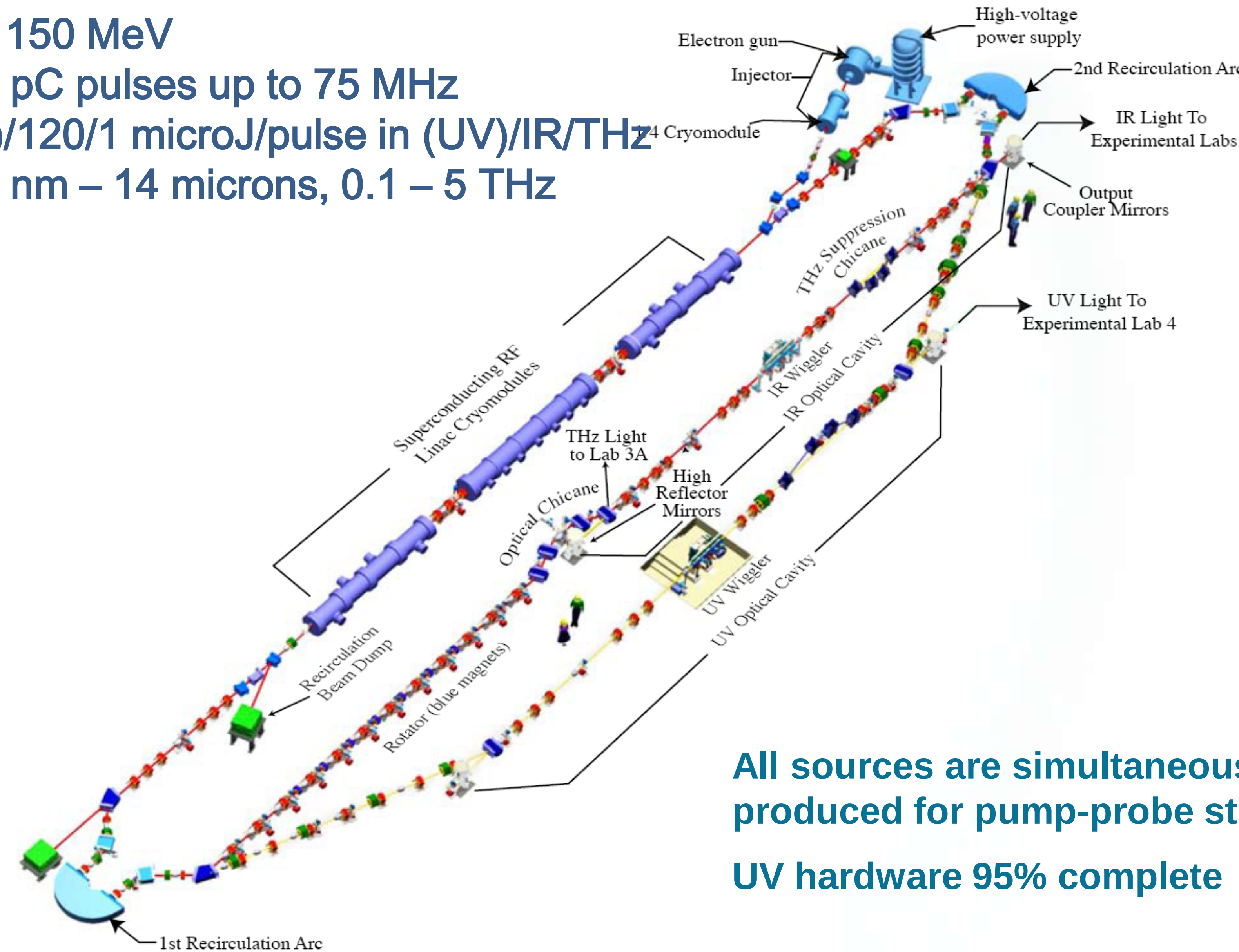
Melnitchouk, Sibirtsev AT: under control!





JLab Energy Recovered Linac / FEL

E = 150 MeV
135 pC pulses up to 75 MHz
(20)/120/1 microJ/pulse in (UV)/IR/THz
250 nm – 14 microns, 0.1 – 5 THz



All sources are simultaneously produced for pump-probe studies

UV hardware 95% complete

Jefferson Lab Light Source Plans

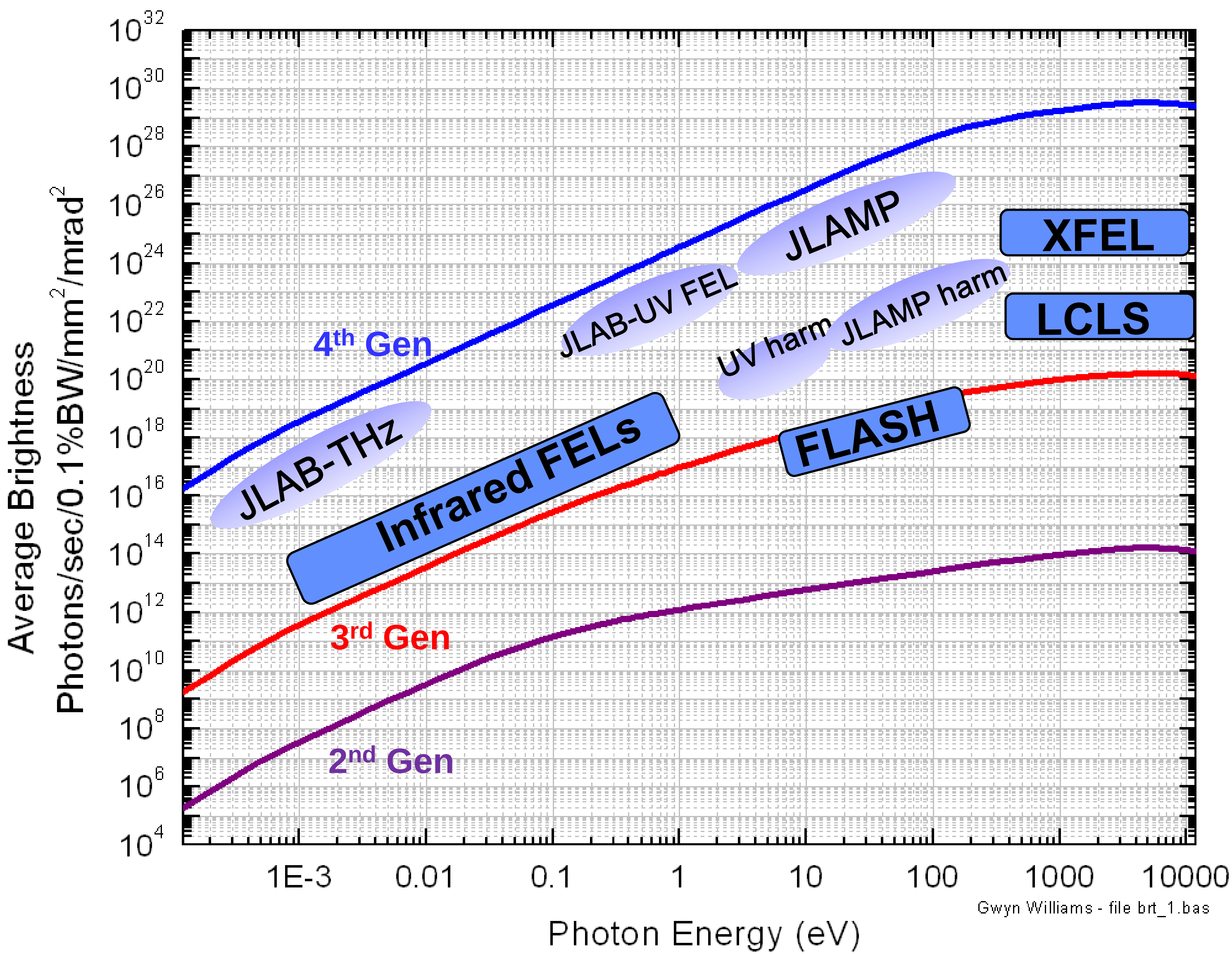
Talk of G. Neil

- **Immediate: Engage key users for scientific utilization of existing FEL, while extending our capability into the 100nm region using the 3rd harmonic of UV-FEL by increasing beam energy from 100 MeV to 150 MeV,**

- **Increase the machine energy to 600 MeV by recirculation. Install amplifier undulator and seed laser – JLab AMPlifier**
    - **JLAMP - Reach 10nm in fundamental**
    - **Two soft X-ray user stations**
    - **Validate CSR physics limitations to recirculation.**

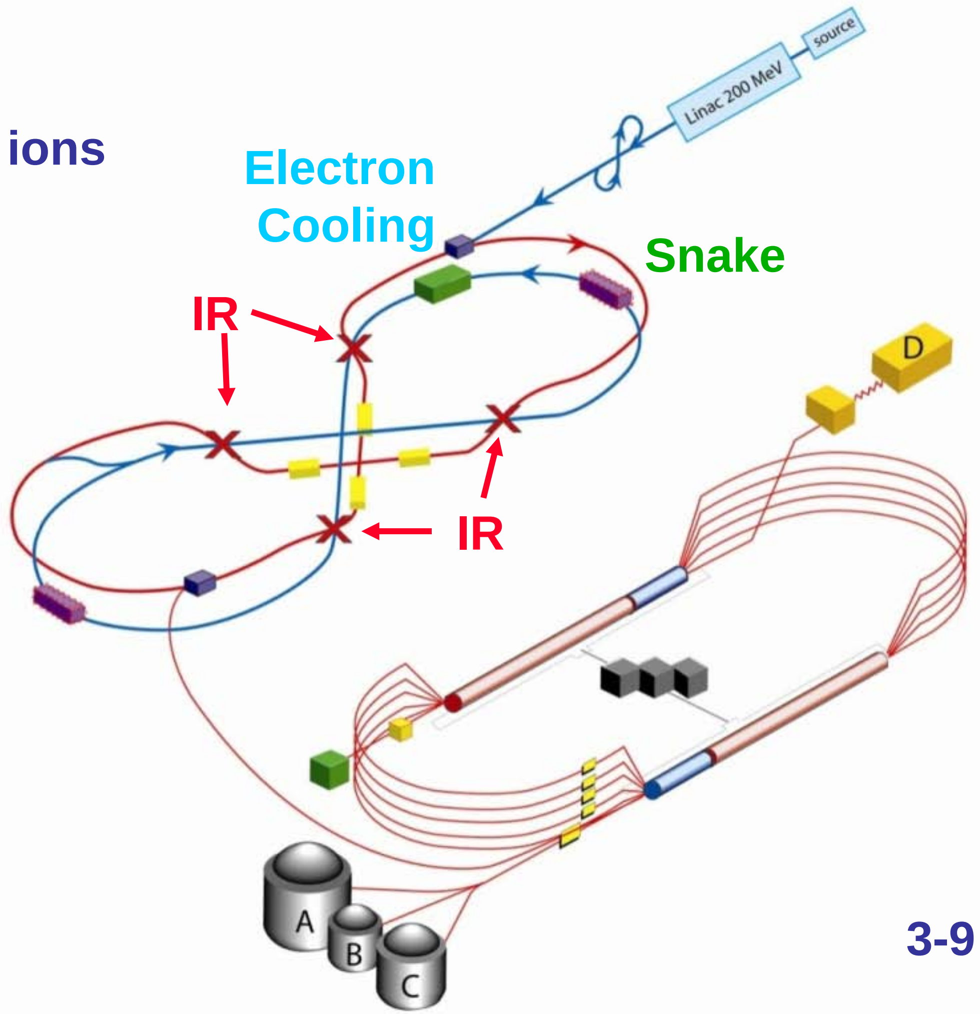
Parallel objectives of the approach are developing the technology for both the source and user while performing cutting edge science with a world class photon beam

JLAMP Performance



Long-term Landscape : ELIC

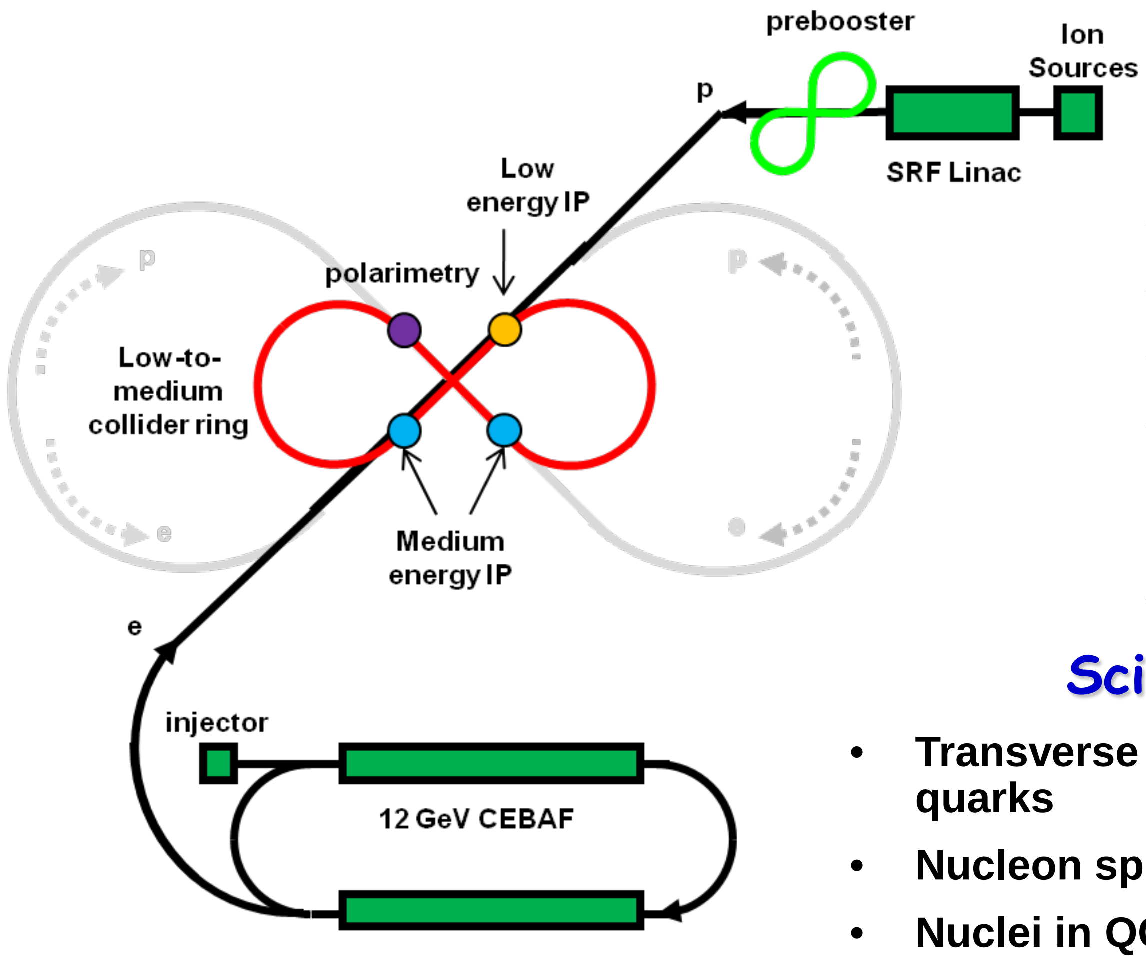
30-225 GeV p
30-100 GeV/A ions



3-9 GeV e^+ and e^-

BUT recently much work devoted to lower cost staging options

MEIC@JLab – an overview



Talk of G. Krafft

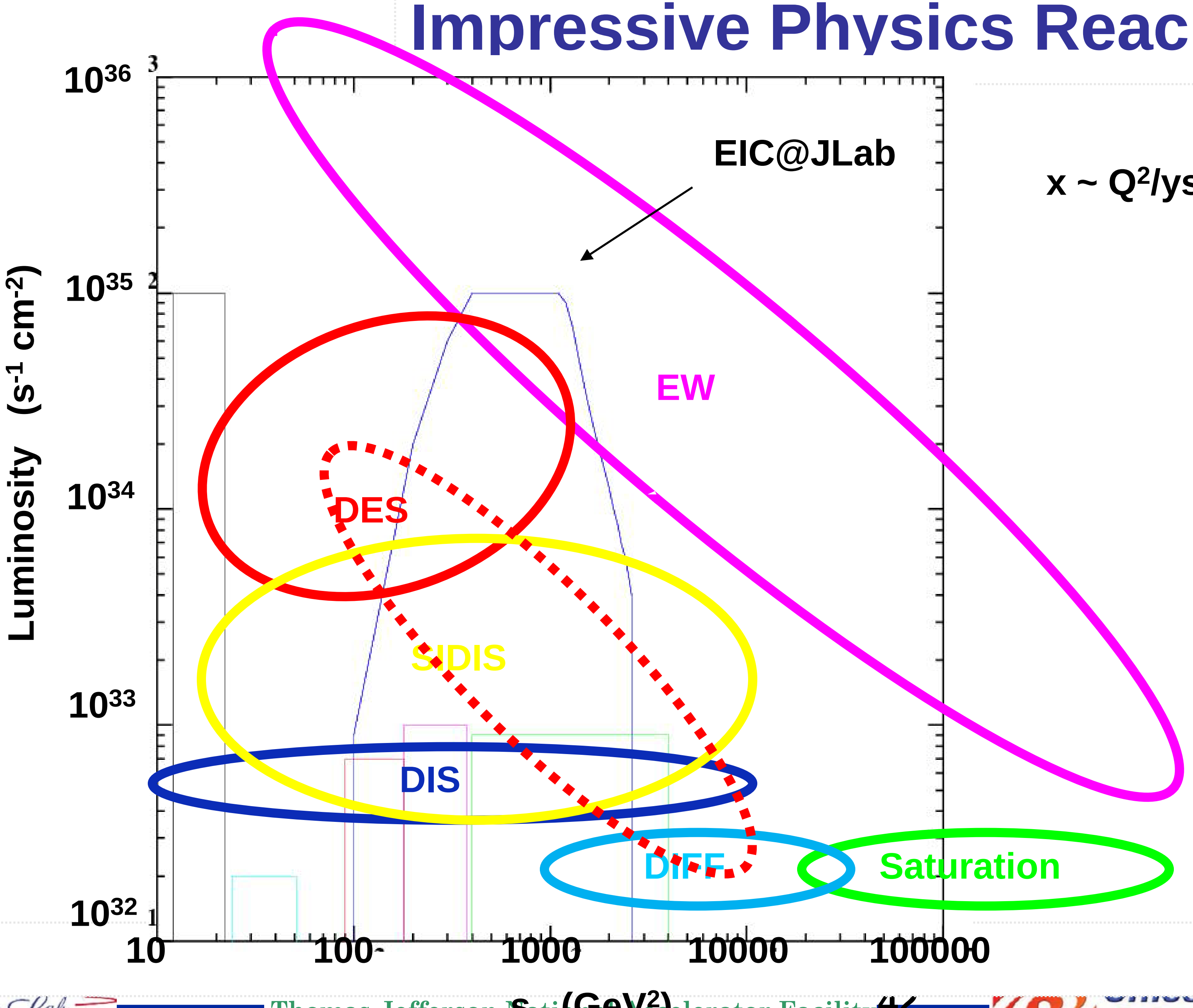
Main Features

- Electron energy: 3-11 GeV
- Proton energy: 12-60 GeV
- Luminosity: few x 10^{34} cm^{-2} s^{-1}
- Polarized electrons and light ions
  - longitudinal and transverse
- Limited R&D

Science highlights

- Transverse imaging of gluons and sea quarks
- Nucleon spin (quark/gluon orbital motion)
- Nuclei in QCD (quark/gluon structure)
- QCD vacuum in hadron structure and creation

Impressive Physics Reach



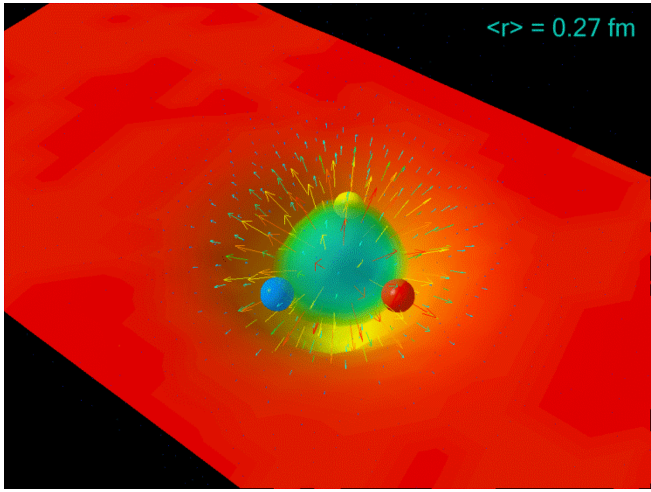
MEIC Accelerator R&D

- Key R&D for MEIC are
  - electron cooling for delivering low emittance/ultra short ion bunches
  - Traveling focusing for suppressing space charge effect & boosting luminosity
  - Crab cavity required for colliding high repetition beams
  - Forming high intensity low energy ion beam
  - Beam-beam effect
- There are other less critical/challenging R&D topics but required by ZDR

Level of R&D	MEIC	ELIC
Nearly impossible		
Very challenging		Electron cooling
Challenging	Electron cooling Traveling focusing	Crab crossing/crab cavity
Likely	Crab crossing/crab cavity High intensity low energy *i* beam Beam-beam	High intensity low energy *i* beam Beam-beam
Know-how	Spin tracking IP design/chromaticity	Spin tracking IP design/chromaticity

Talk of G. Krafft

Summary



- Jefferson Lab has a remarkable record of outstanding science
- It has a very strong program for the remaining 6 GeV operation
- The 12 GeV Upgrade is on track and will produce discovery class science

- There are maturing plans beyond 12 GeV
- JLab has a position of world leadership as the world's pre-eminent electron scattering facility for the next 20+ years