Hadron Physics with Electron Scattering

陈剑平 J. P. Chen, Jefferson Lab, Virginia, USA

Hadron Physics Workshop, Beijing, China, July 27-30, 2010

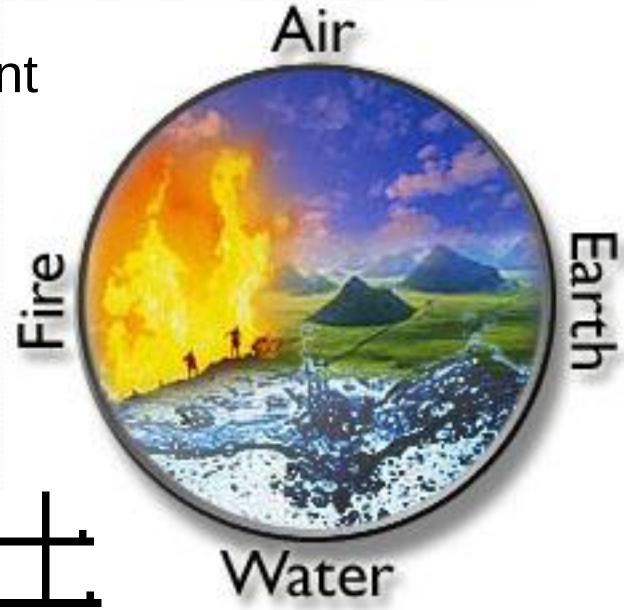
- Introduction
- Electron Scattering Experiments:
  - JLab 6 GeV Facility and Instrumentation
  - JLab 12 GeV Upgrade and Beyond (EIC)
- Elastic Scattering: Form Factors
- Nucleon Properties in Nuclear Medium

- Deep-inelastic Scattering: Parton Distributions
- Longitudinal Spin Structure
- Transverse Spin and Transverse Structure
- Parity Violation Electron Scattering

Eternal Questions:
(What is fundamental?)

- People have long asked the questions

Ancient west:



Ancient China:

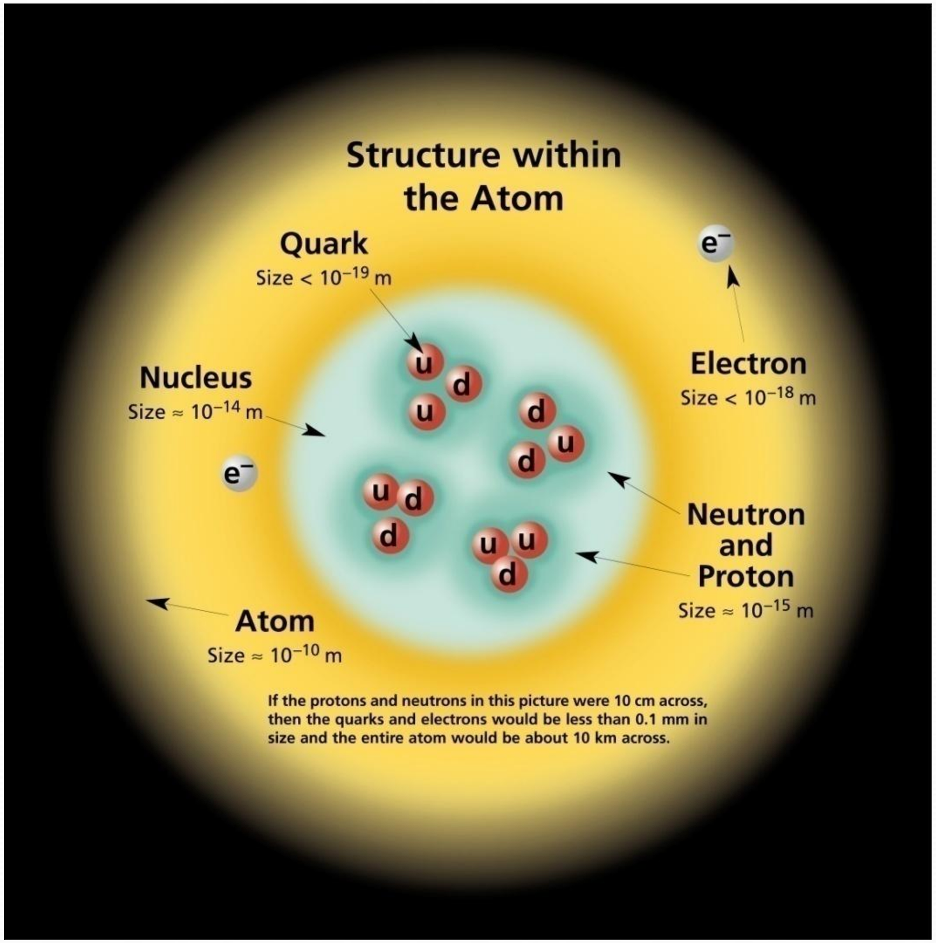
金木水火土

- **By convention there is color,**
  By convention sweetness,
  By convention bitterness,
  But in reality there are atoms and space.
  -Democritus (c. 400 BC)

What is the world made of?

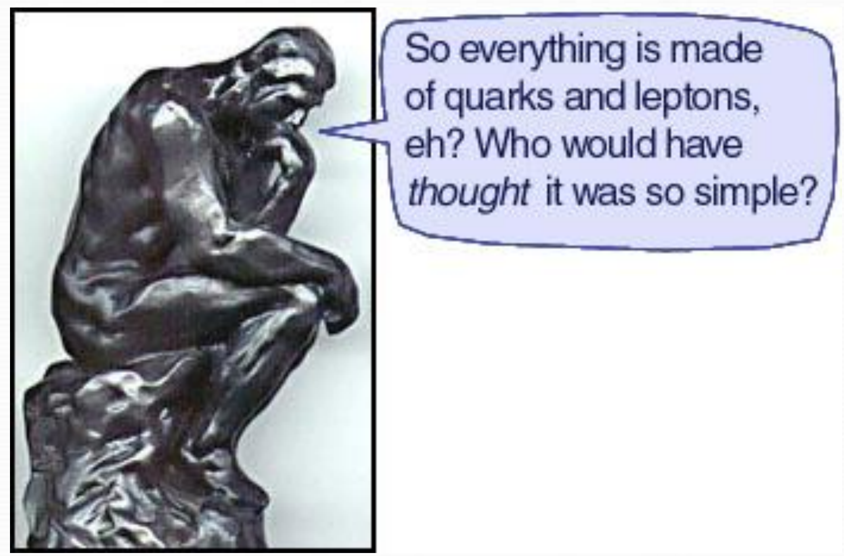
Visible Matter → Atom → Electrons + Nucleus

Nucleus → Nucleons(proton,neutron) → Quarks



FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c^2	Electric charge	Flavor	Approx. Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0	**u** up	0.003	2/3
e electron	0.000511	−1	**d** down	0.006	−1/3
ν_μ muon neutrino	<0.0002	0	**c** charm	1.3	2/3
μ muon	0.106	−1	**s** strange	0.1	−1/3
ν_τ tau neutrino	<0.02	0	**t** top	175	2/3
τ tau	1.7771	−1	**b** bottom	4.3	−1/3



Standard Model

FERMIONS
matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
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τ tau	1.7771	–1

Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
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c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

BOSONS
force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	–1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

What are the challenges?

- Success of the Standard Model

  Electro-Weak theory tested to very good level of precision

  QCD tested in the high energy (short distance) region

- Major challenges:

  Test QCD in the strong interaction region (distance of the nucleon size)

  Understand the nucleon structure

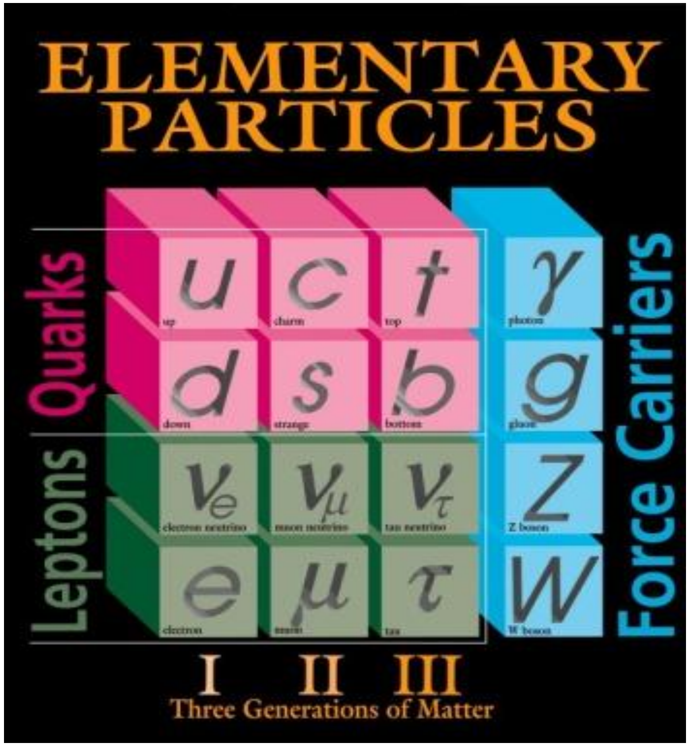
- Beyond Standard Model

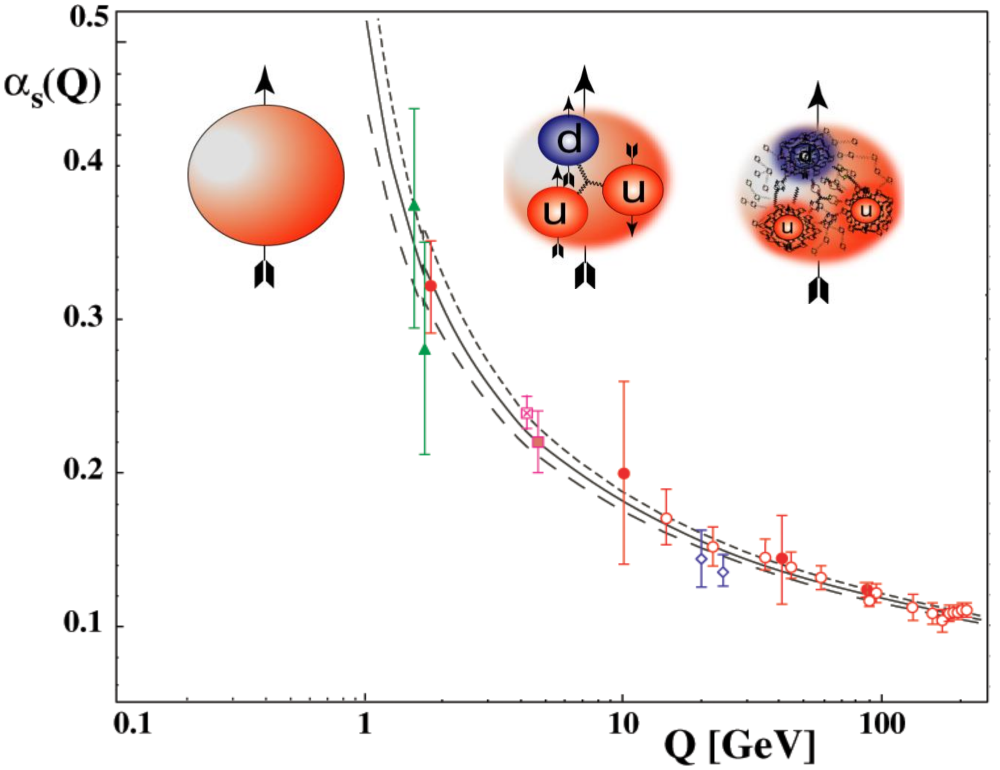
  Grand Unified Theories? Supersymmetry? String Theory? …

  Search for dark matter, dark energy, …

  Test standard model at low energy

QCD: still unsolved in non-perturbative region





- *2004 Nobel prize for ``asymptotic freedom''*
- *non-perturbative regime QCD ?????*
- *One of the top 10 challenges for physics!*
- *QCD: Important for discovering new physics beyond SM*
- *Nucleon structure is one of the most active areas*

Nucleon Structure and QCD

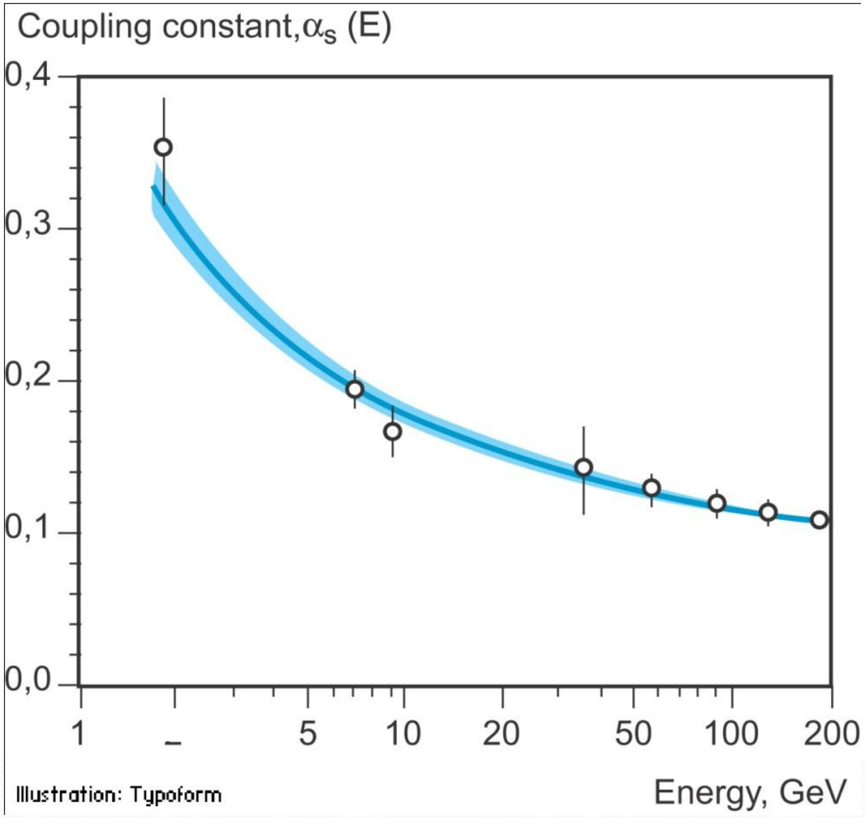
- Nucleon: quarks and gluons with strong interaction (QCD)
- Strong interaction, running coupling ~1

  -- asymptotic freedom (2004 Nobel)
  perturbation calculation works only at high energy
  interaction negligible

  -- interaction significant
  at intermediate energy
  quark-gluon correlations

  -- confinement
  interaction strong at low energy
  coherent hadron

  -- Chiral symmetry



Nucleon Structure

- Simple Picture (Naïve Quark Model):

  proton = u u d,   neutron = u d d

- Parton Model:

  valence quarks + sea (quark-antiquark pairs) + gluons

- Parton (Momentum) Distribution Functions

  quark: $q(x)$, antiquark: $\bar{q}(x)$, gluon: $g(x)$

- Parton (Longitudinal) Spin Distributions

  $\Delta q(x)$, $\Delta \bar{q}(x)$, $\Delta g(x)$, $\mathcal{L}(x)$ (orbital angular momentum)

- Transverse Spin Distributions (Transversity) and TMDs

  $\delta q(x, k_T)$, $d\bar{q}(x, k_T)$, …

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)

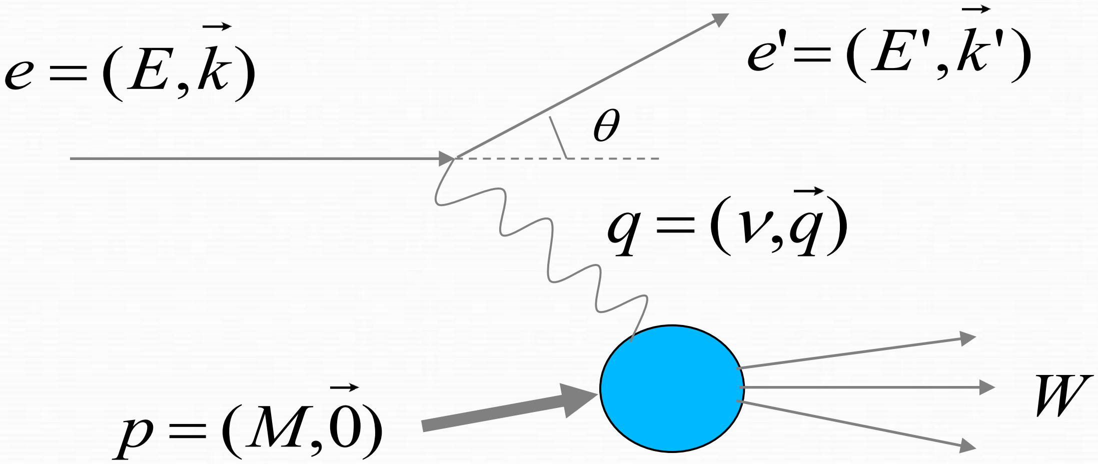
constituent quark models

- Deep Inelastic Scattering

  → 70s: established quark-parton picture (Nobel Prize)

  parton distribution functions

Inclusive Electron Scattering



4-momentum transfer squared

$$Q^2 = -q^2 = 4EE'\sin^2\tfrac{\theta}{2}$$

Invariant mass squared

$$W^2 = M^2 + 2M\nu - Q^2$$

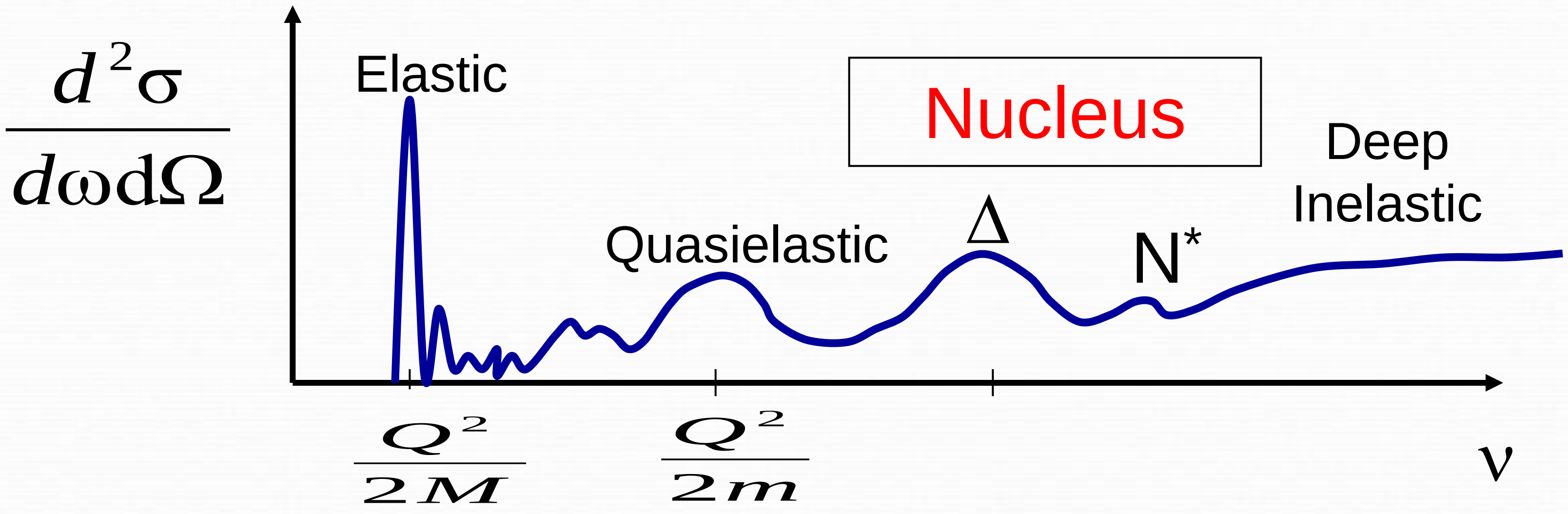
Unpolarized:

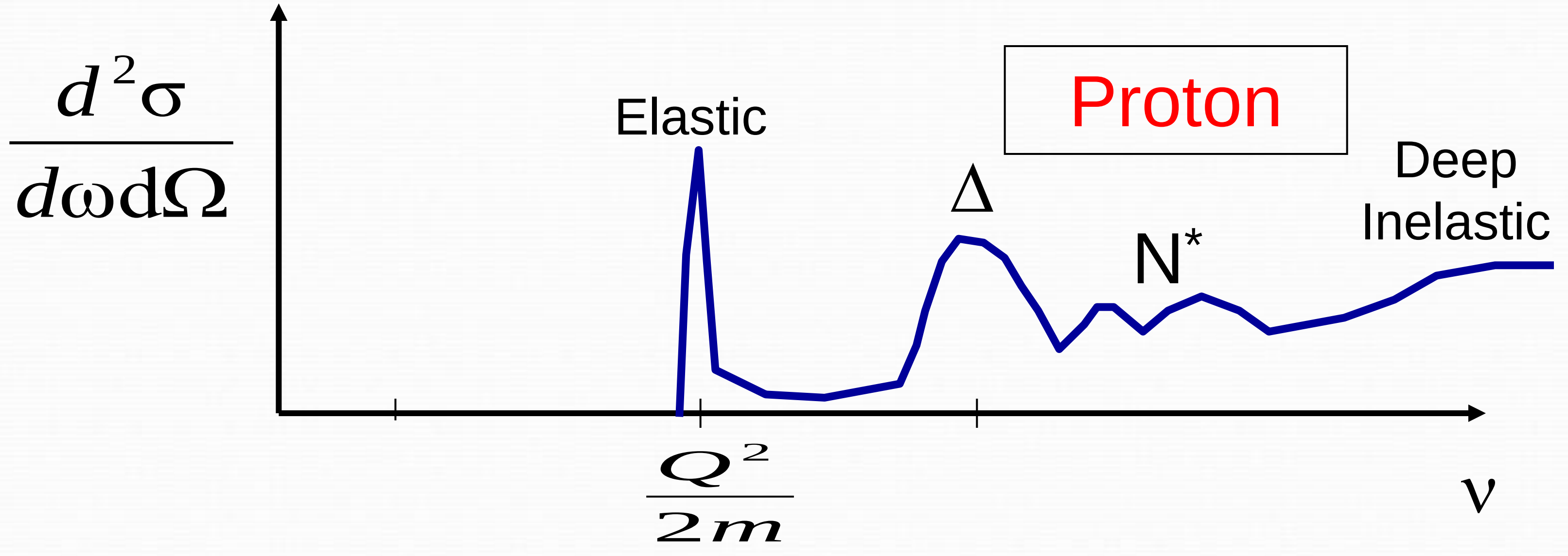
$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_M \left[\frac{1}{\nu} F_2(\nu, Q^2) + \frac{2}{M} F_1(\nu, Q^2) \tan^2\tfrac{\theta}{2} \right]$$

$$\sigma_M = \frac{\alpha^2 E' \cos^2(\theta/2)}{4E^3 \sin^4(\theta/2)}$$

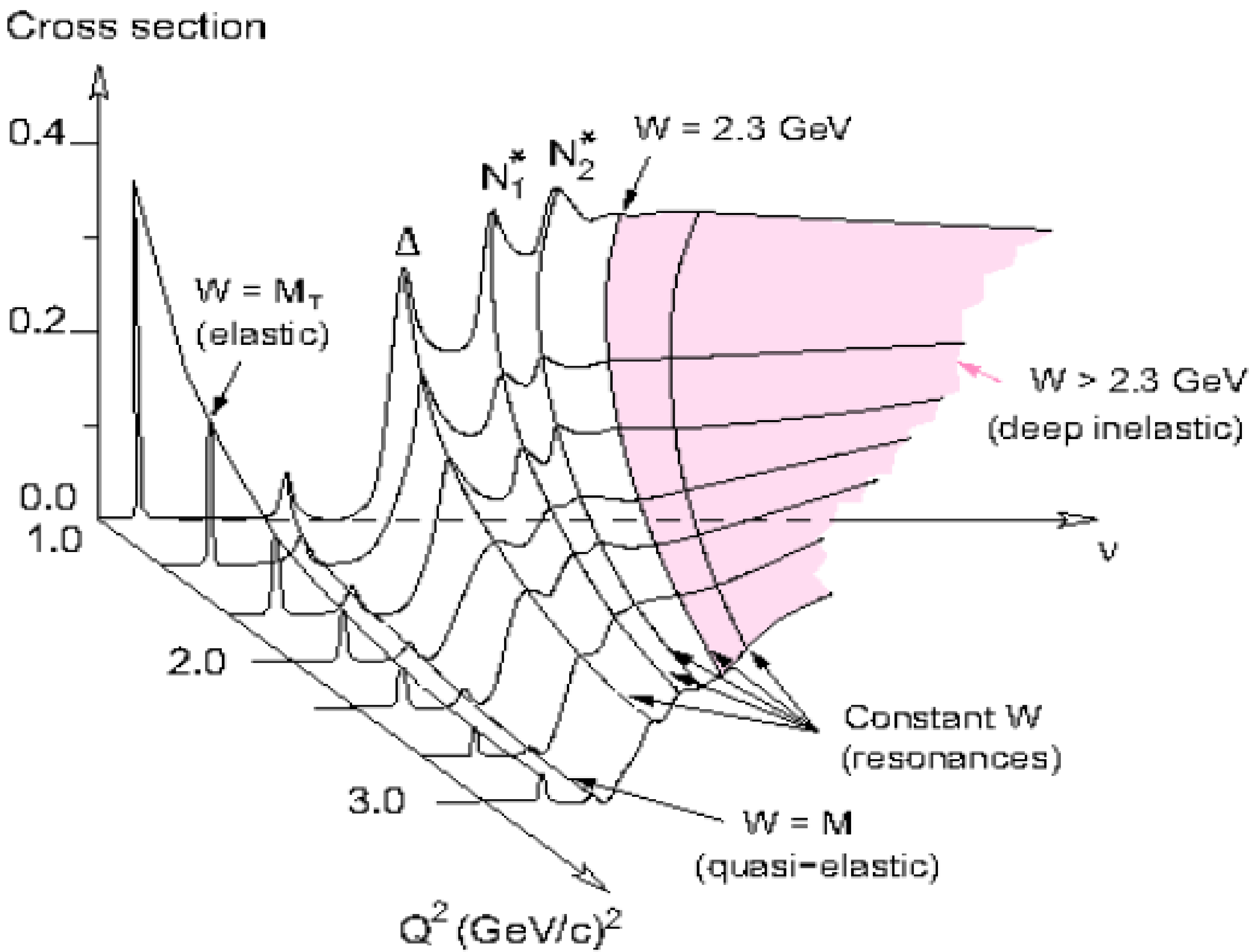
F_1 and F_2: information on the nucleon/nuclear structure

Typical Electron Scattering Spectra at Fixed Q^2





Electron Scattering ----- *A powerful tool*



JLab Facility

6 GeV CEBAF, 3 Experimental Halls

Thomas Jefferson National Accelerator Facility

Newport News, Virginia, USA

One of two primary DOE nuclear/hadronic physics laboratories

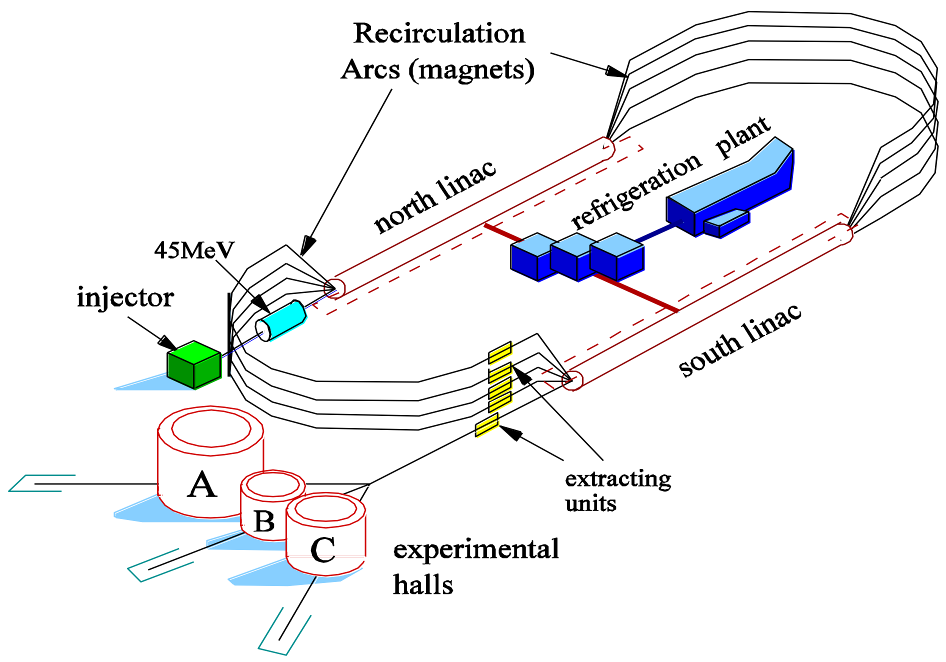
6 GeV polarized CW electron beam
(P = 85%, I = 180 μA)

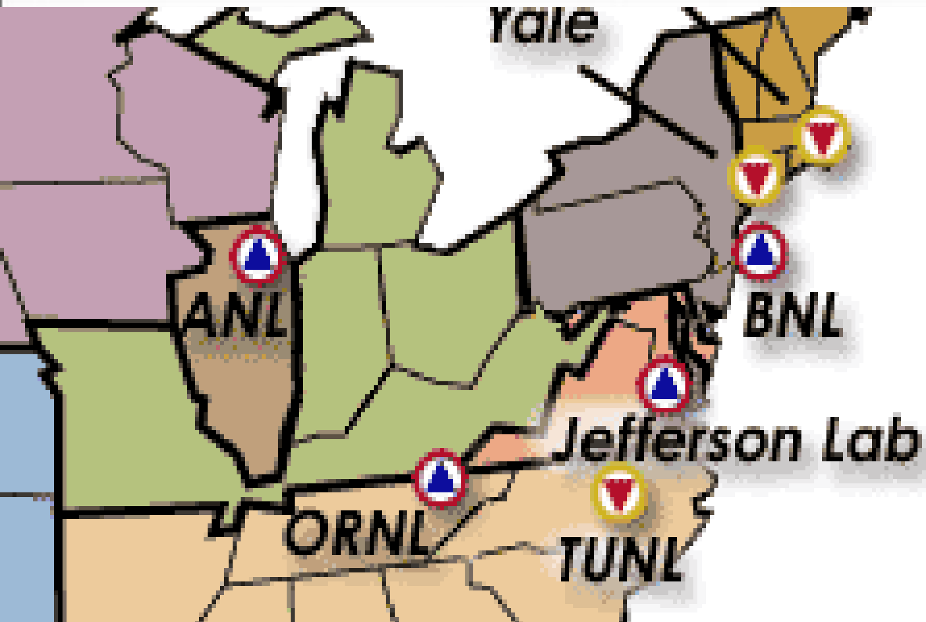
3 halls for fixed-target experiments

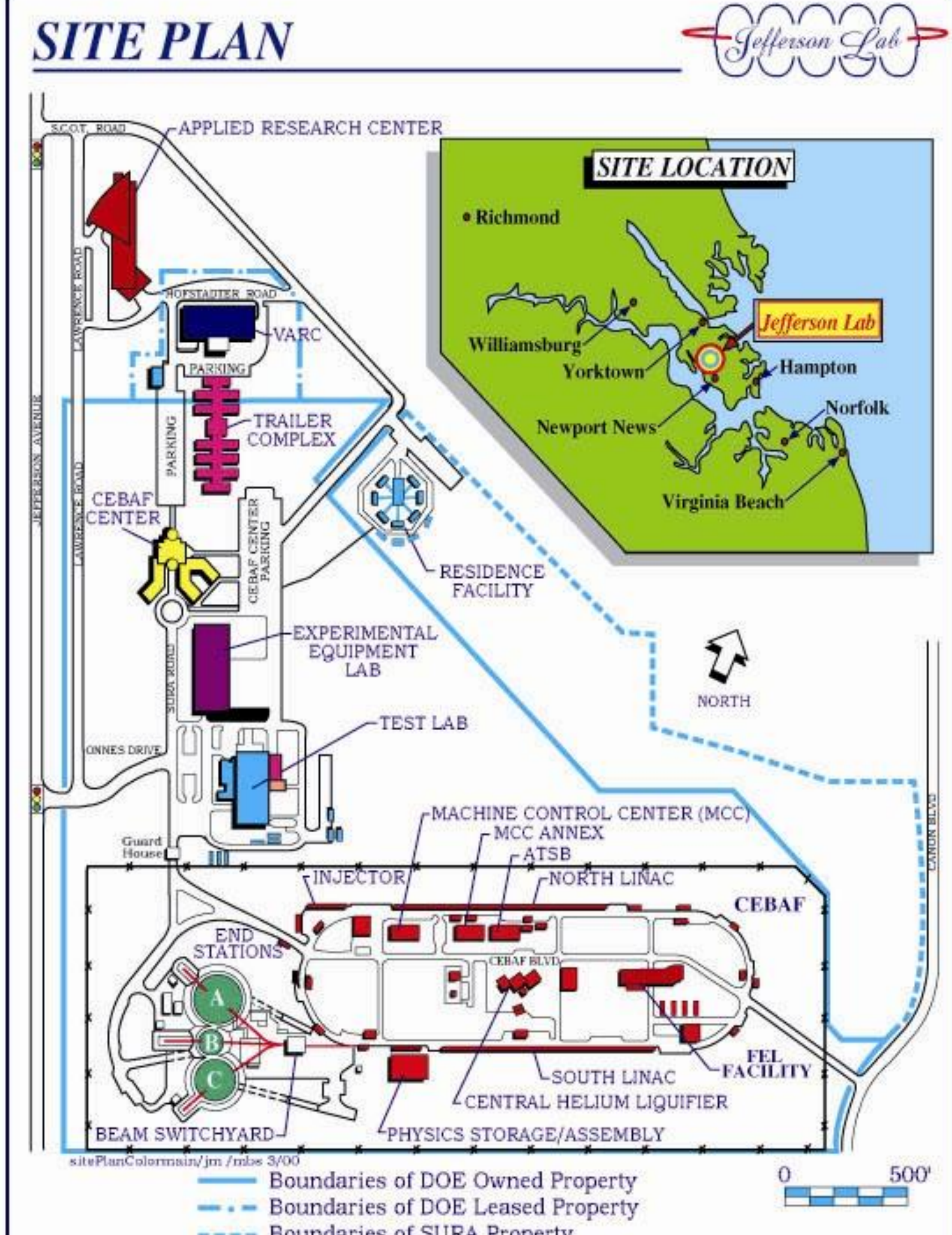
Hall A: 2 high resolution spectrometers
Unpolarized, $L=10^{39}\ cm^{-2}s^{-1}$
Polarized ^3He, $L=10^{36}\ cm^{-2}s^{-1}$

Hall B: large acceptance spectrometer
Polarized p/d, $L=10^{34}\ cm^{-2}s^{-1}$

Hall C: 2 spectrometers
Unpolarized, $L=10^{39}\ cm^{-2}s^{-1}$
Polarized p/d, $L=10^{35}\ cm^{-2}s^{-1}$



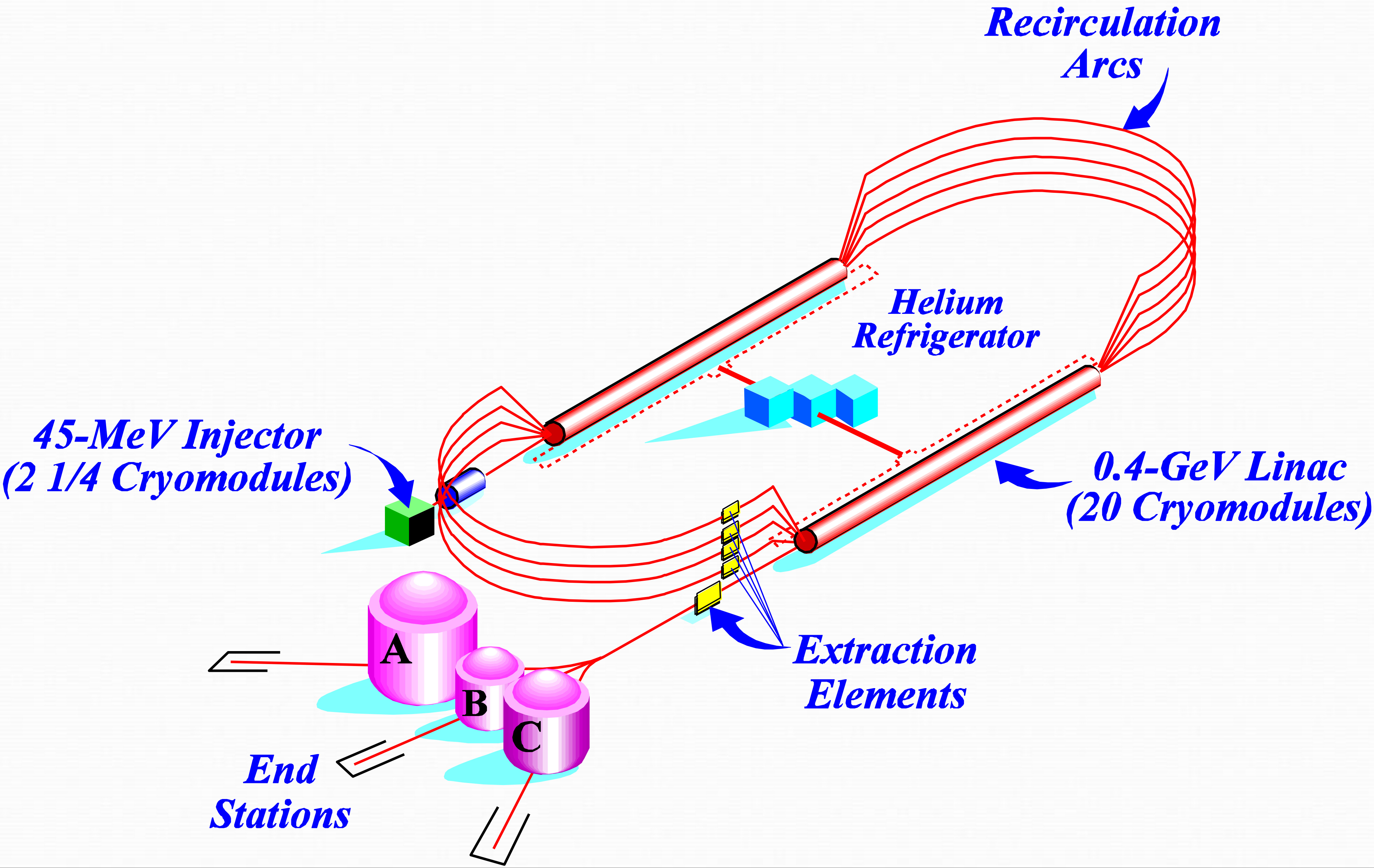

Yale
ANL
BNL
Jefferson Lab
ORNL
TUNL


SITE PLAN
Jefferson Lab
S.C.O.T. ROAD
APPLIED RESEARCH CENTER
SITE LOCATION
Richmond
Williamsburg
Yorktown
Jefferson Lab
Hampton
Norfolk
Newport News
Virginia Beach
HOFSTADTER ROAD
VARC
PARKING
TRAILER COMPLEX
PARKING
CEBAF CENTER
CEBAF CENTER PARKING
RESIDENCE FACILITY
EXPERIMENTAL EQUIPMENT LAB
NORTH
TEST LAB
ONNES DRIVE
JEFFERSON AVENUE
LAWRENCE ROAD
SURA ROAD
MACHINE CONTROL CENTER (MCC)
MCC ANNEX
ATSB
Guard House
INJECTOR
NORTH LINAC
CEBAF
END STATIONS
CEBAF BLVD
A
B
C
SOUTH LINAC
FEL FACILITY
CENTRAL HELIUM LIQUIFIER
BEAM SWITCHYARD
PHYSICS STORAGE/ASSEMBLY
CANON BLVD
sitePlanColormain/jm /mbs 3/00
Boundaries of DOE Owned Property
Boundaries of DOE Leased Property
Boundaries of SURA Property
0
500'

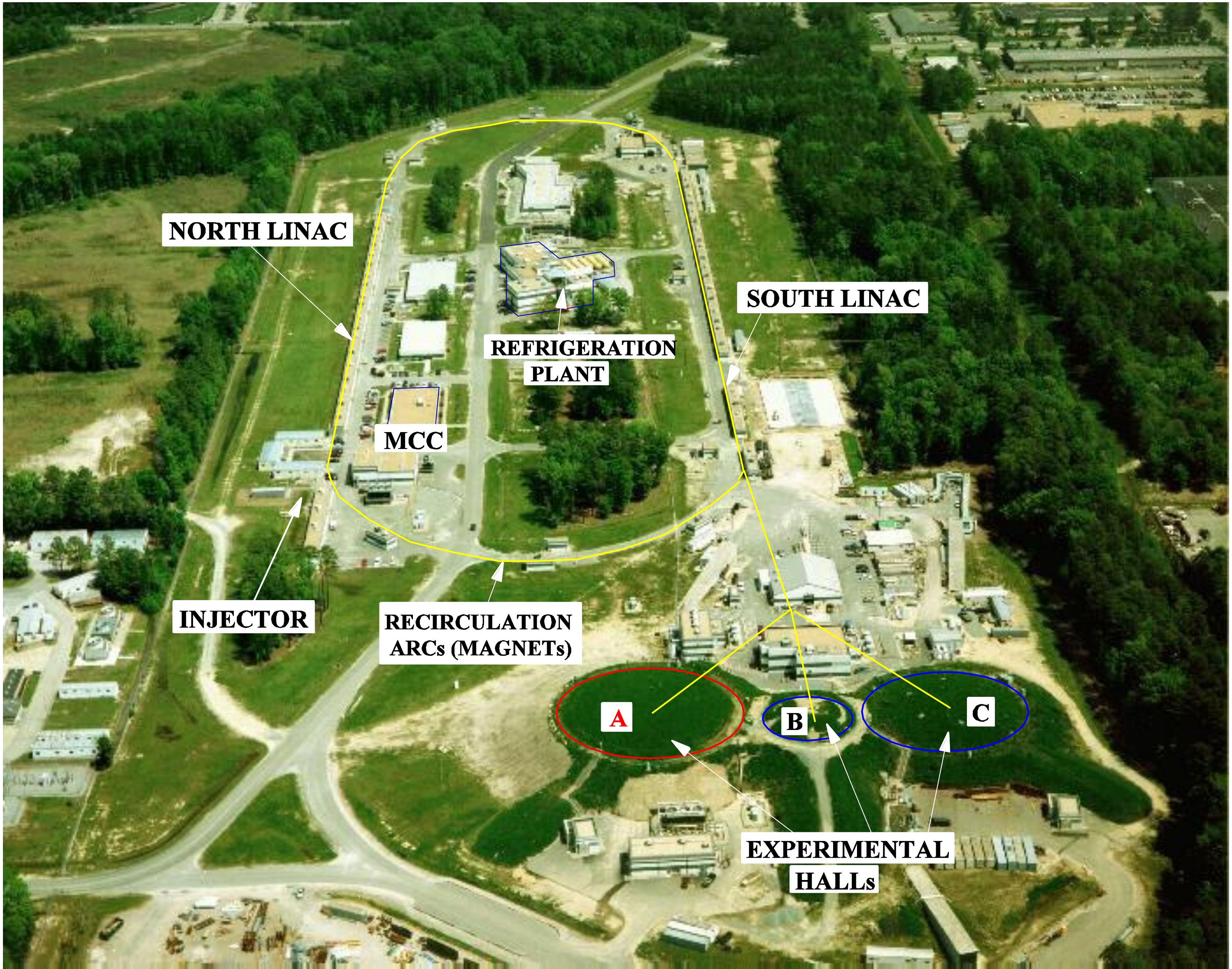
CEBAF @ JLab Today

- Superconducting recirculating electron accelerator
  - maximum energy 6 GeV
  - maximum current 200 μA
  - electron polarization 85%
- Equipment in 3 halls (simultaneous operation) $L[cm^{-2}s^{-1}]$
  - 2 High Resolution Spectrometers (p_{max}=4 GeV/c) 10^{39}
  - 2 spectrometers (p_{max}=7 and 1.8 GeV/c) 10^{39}
  - Large Acceptance Spectrometer 10^{34}
- JLab Personnel and User Community
  - ~600 JLab employees
  - ~1700 users from ~300 institutions, ~40 countries

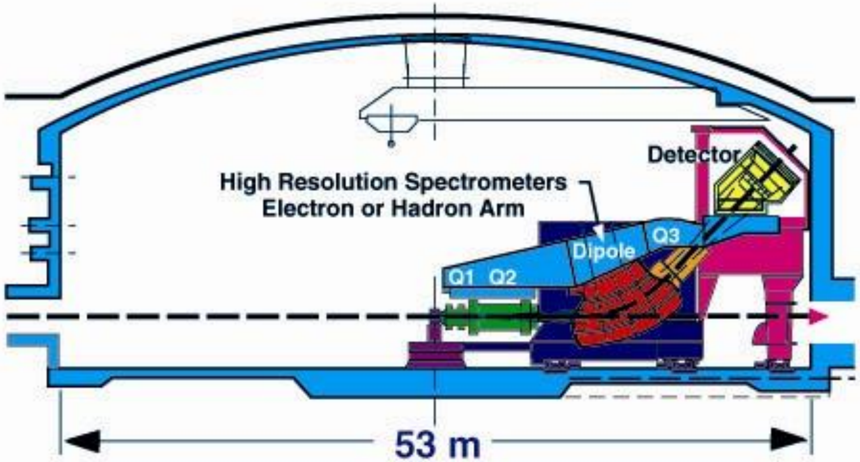
JLab Accelerator Site



JLab Accelerator Site

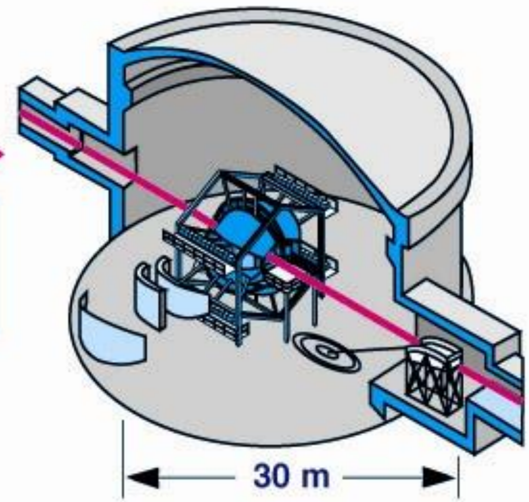


SIMULTANEOUS COMPLEMENTARY EXPERIMENTS



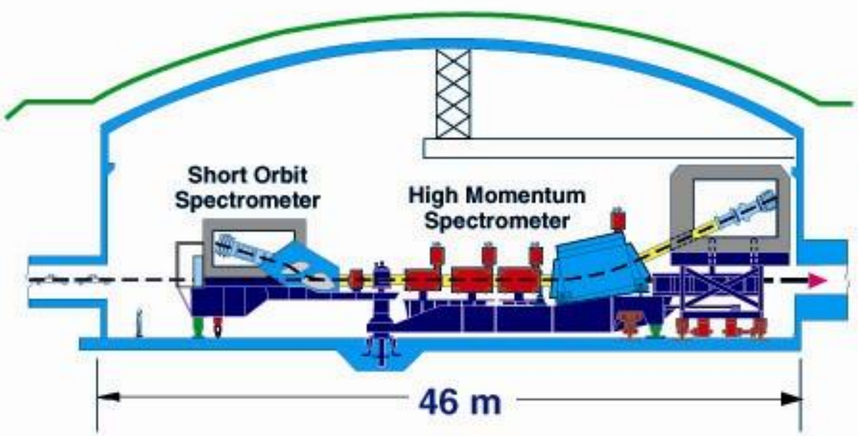
HALL A

Pair of identical High Resolution Spectrometers (HRS^2)



HALL B

CEBAF's Large Acceptance Spectrometer (CLAS) and Bremsstrahlung Photon Tagger

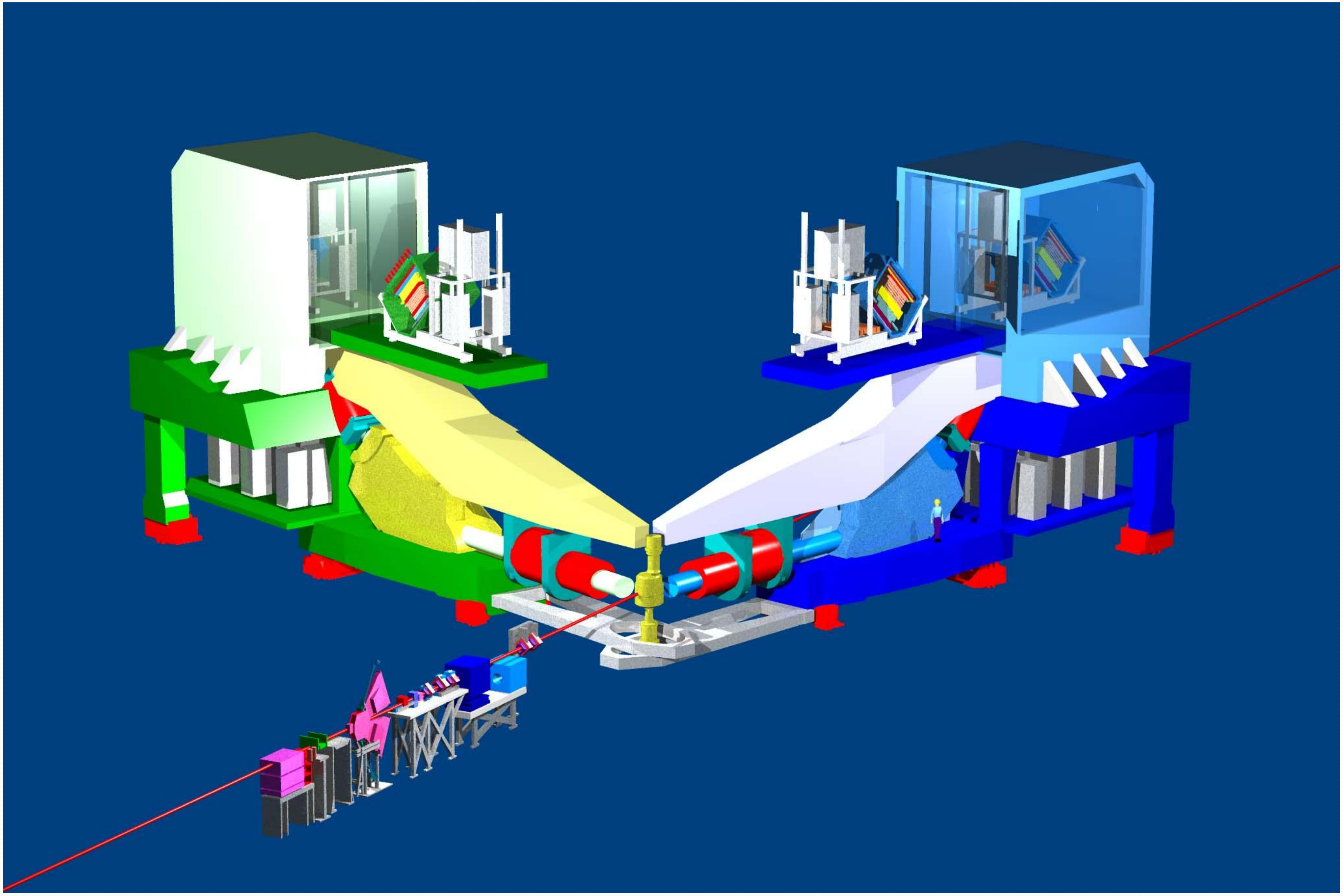


HALL C

High Momentum Spectrometer (HMS) and Short Orbit Spectrometer (SOS)

Jefferson Lab

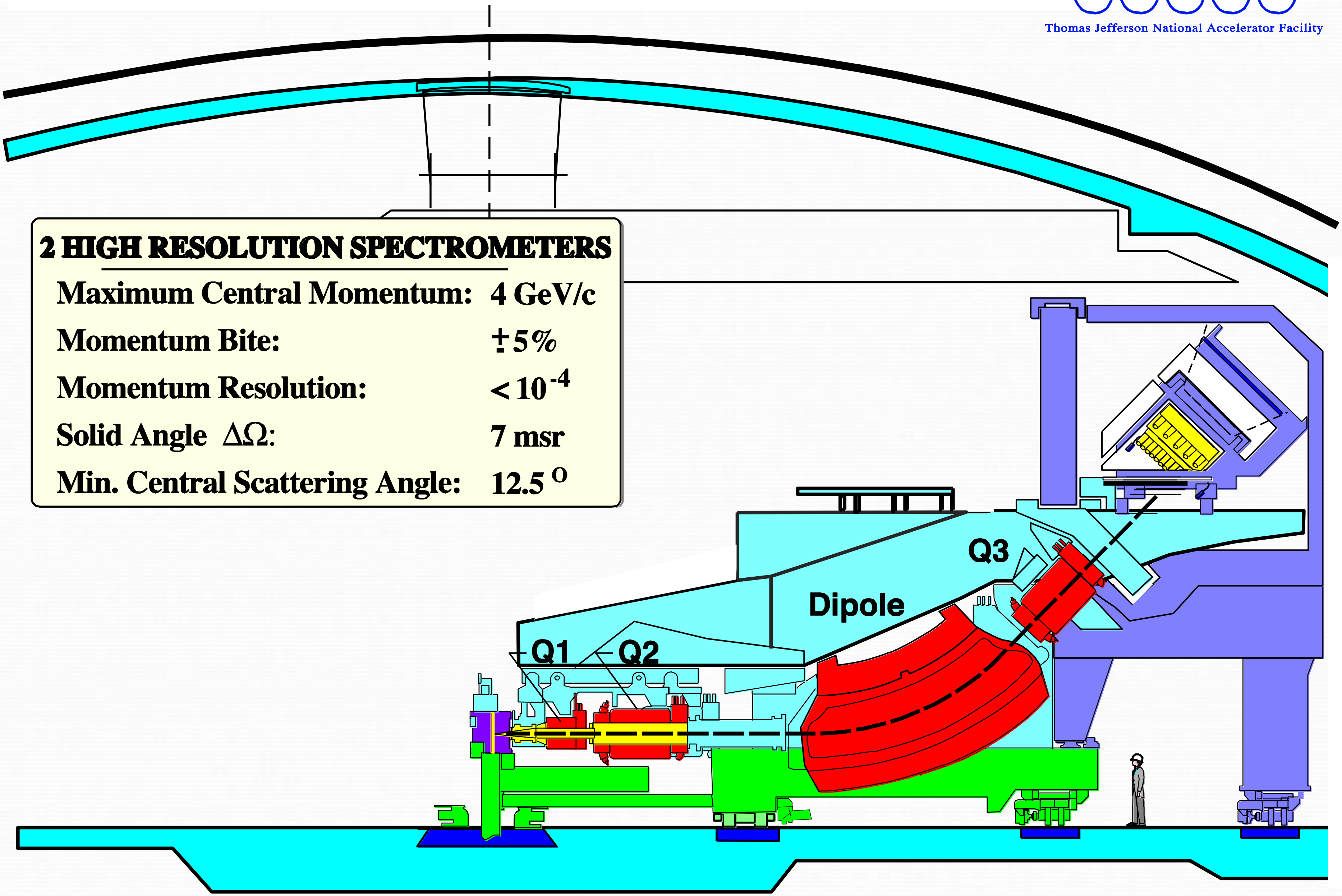
Hall A Beamline and Spectrometers



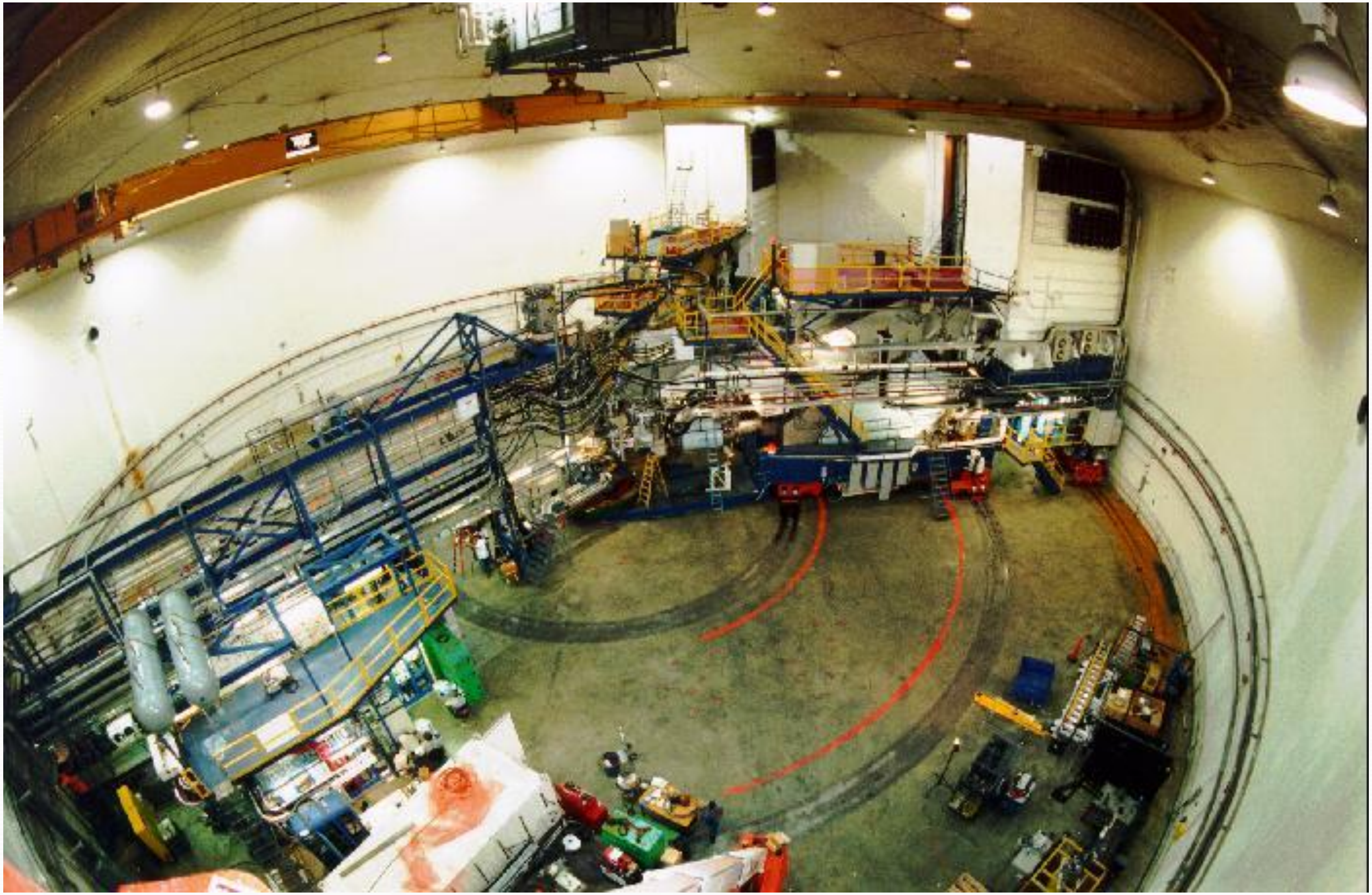
EXPERIMENTAL HALL A

2 HIGH RESOLUTION SPECTROMETERS

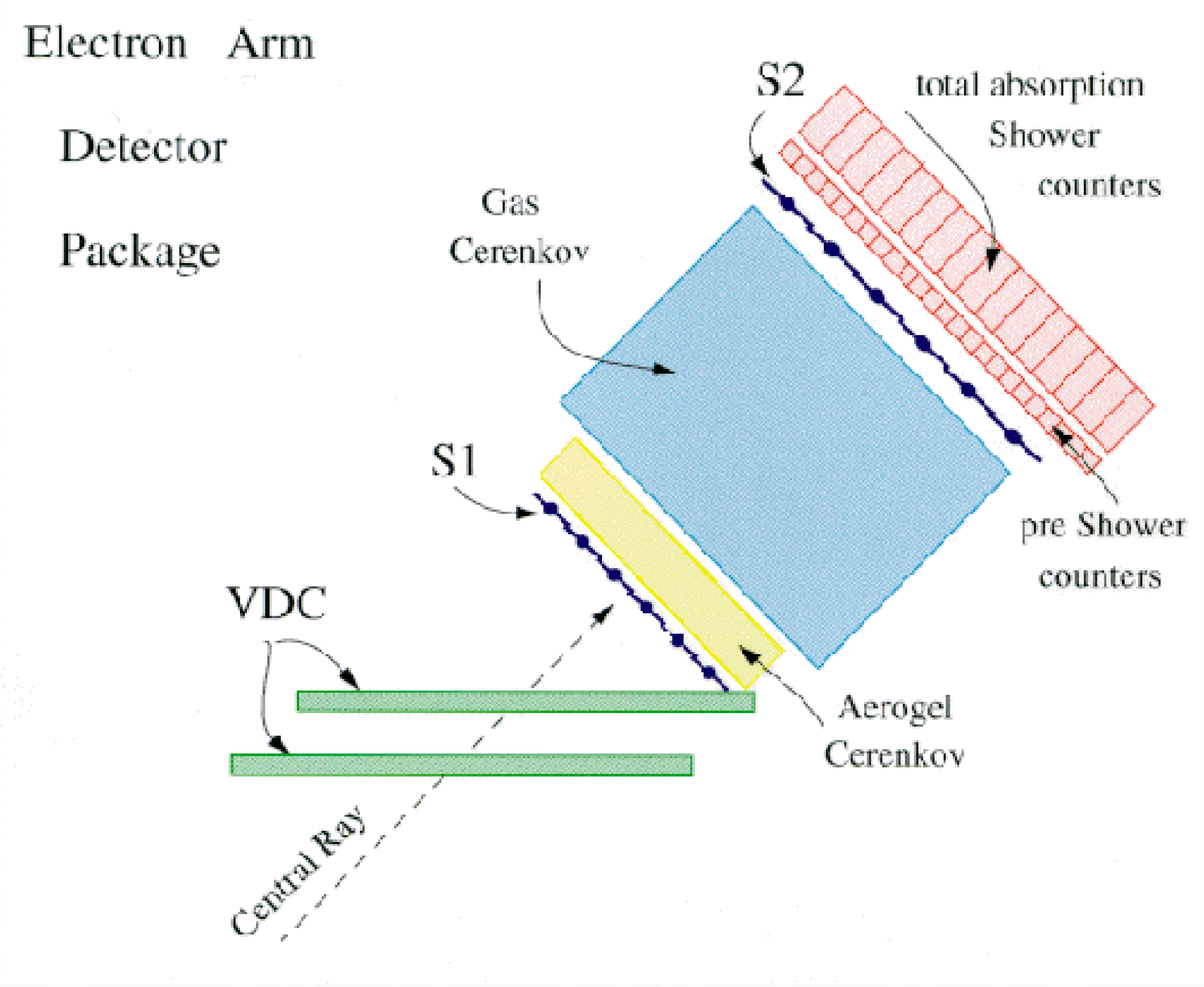
Maximum Central Momentum:	4 GeV/c
Momentum Bite:	$\pm 5\%$
Momentum Resolution:	$< 10^{-4}$
Solid Angle $\Delta\Omega$:	7 msr
Min. Central Scattering Angle:	12.5°



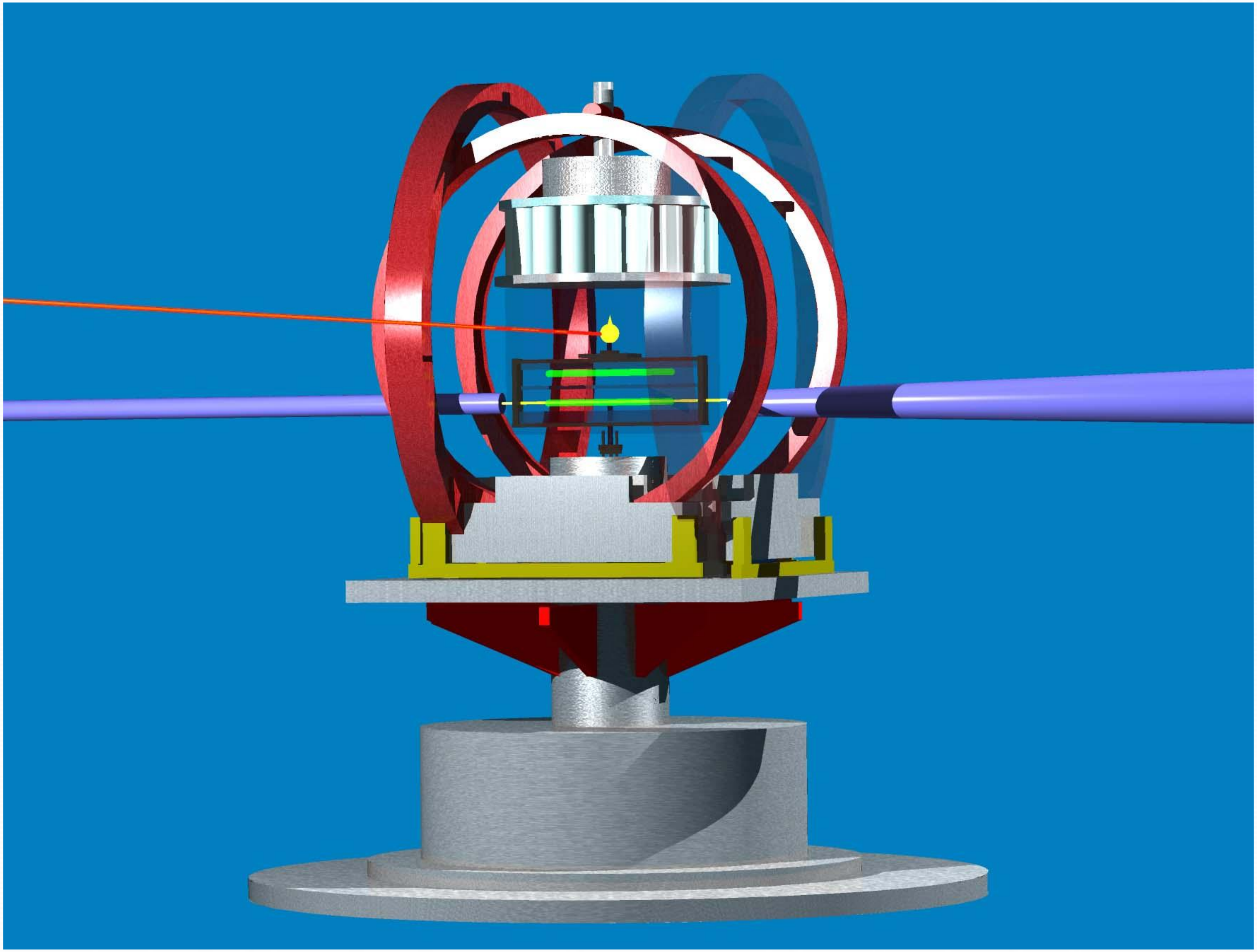
JLab Hall A



Electron Spectrometer Detector Package



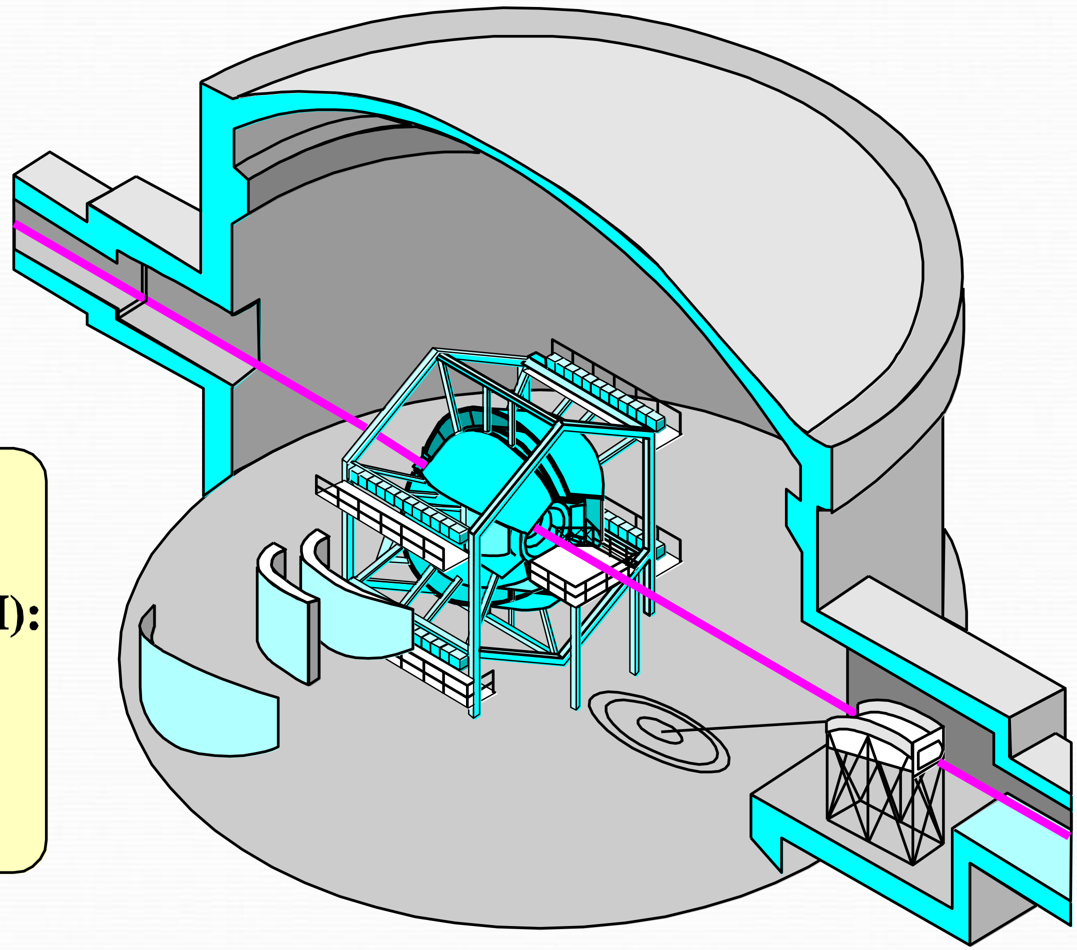
Polarized ^{3}He Target



Experimental Hall B

CEBAF Large Acceptance Spectrometer

Jefferson Lab
Thomas Jefferson National Accelerator Facility



- Six segment toroidal field
- Angular coverage: 8° - 140°
- Momentum resolution (FWHM):
  - Small angle, 0.5%
  - Large angle, 1.0%
- Maximum luminosity:
  - $\sim 10^{34} cm^{-2} sec^{-1}$

Hall B CLAS

CEBAF Large Acceptance Spectrometer

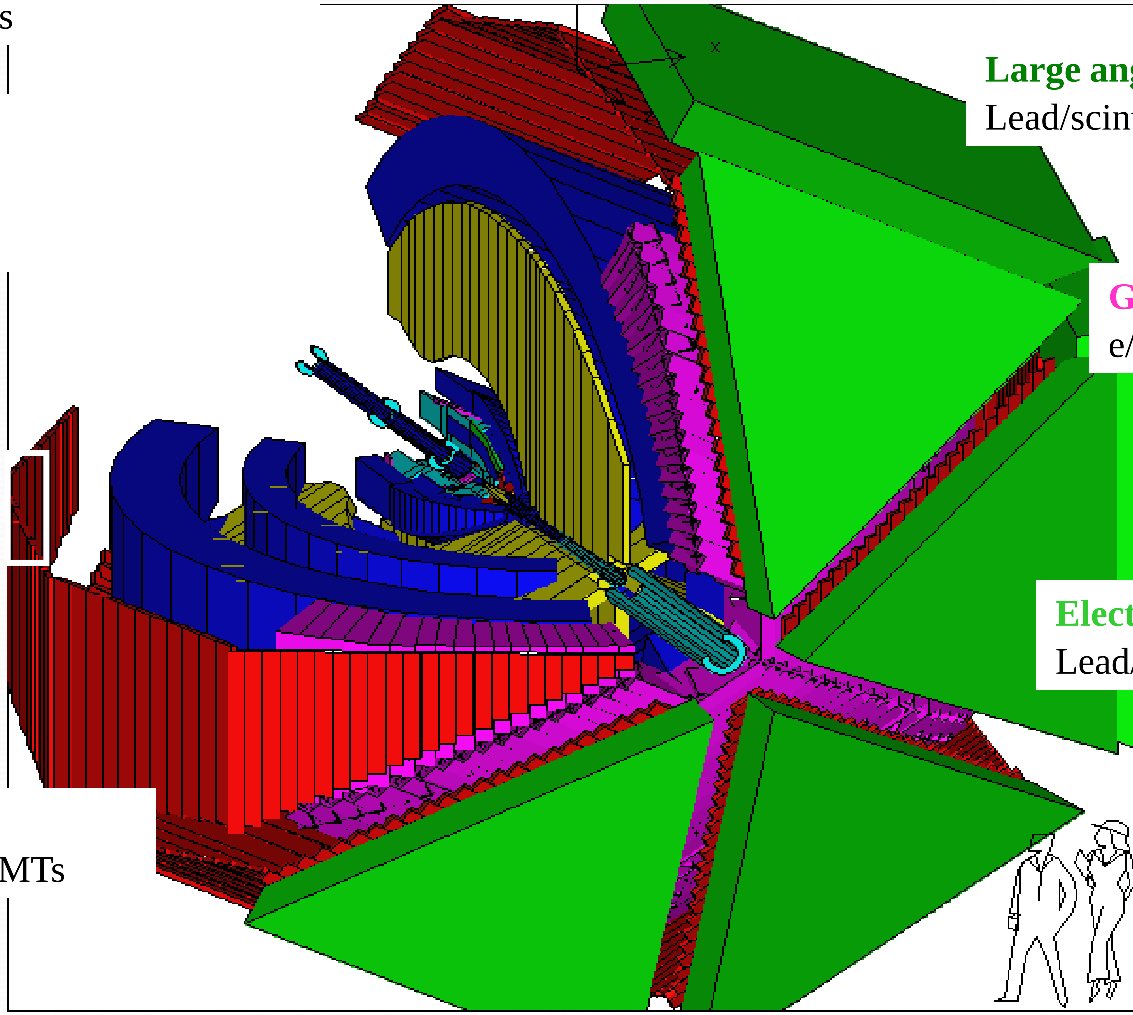
Torus magnet
6 superconducting coils

Pol. NH3/ND3 target or

Liquid H/D/He targets +
γ start counter; e minitorus

Drift chambers
3 regions, 35000 cells

Time-of-flight counters
plastic scintillators, 684 PMTs

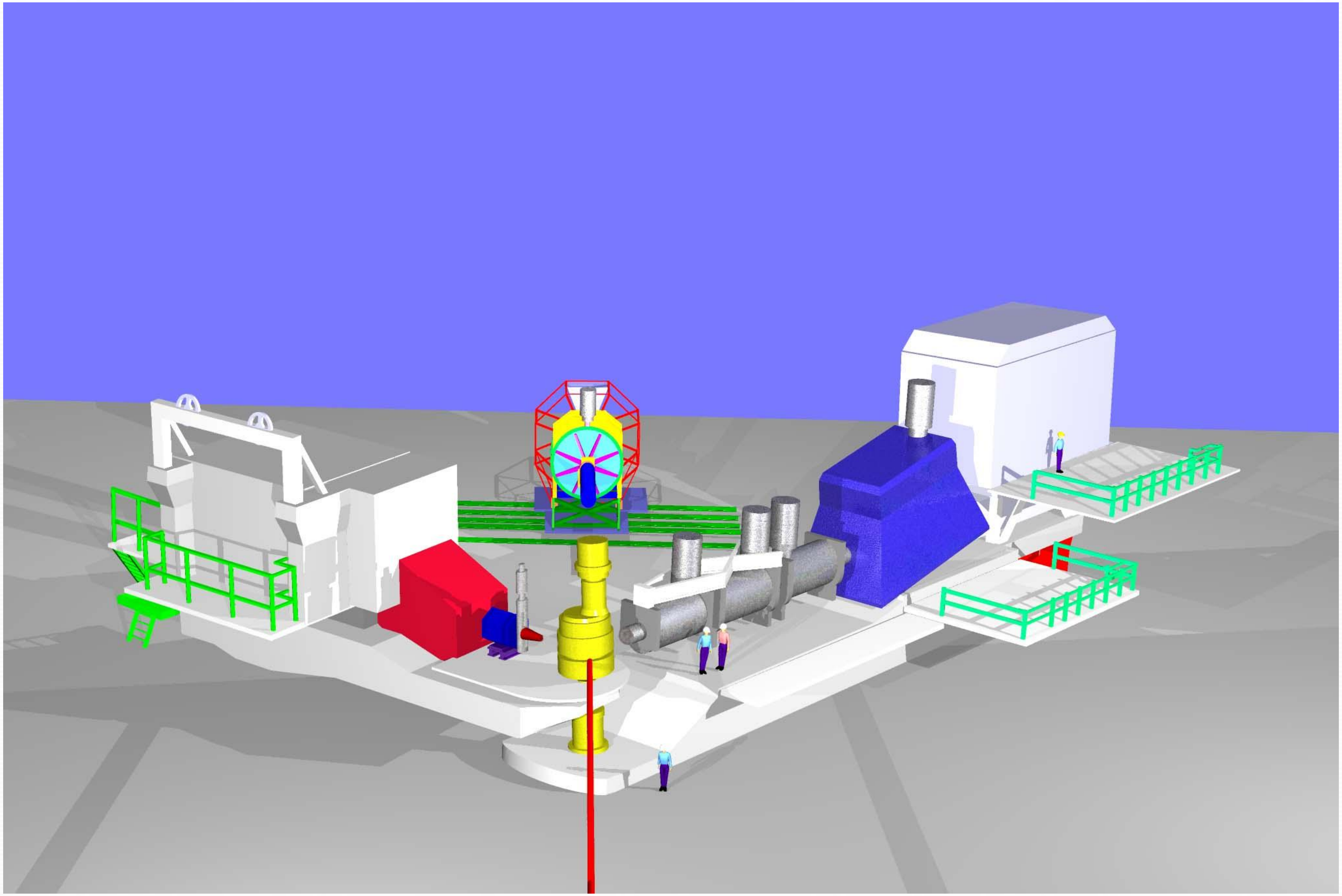


Large angle calorimeters
Lead/scintillator, 512 PMTs

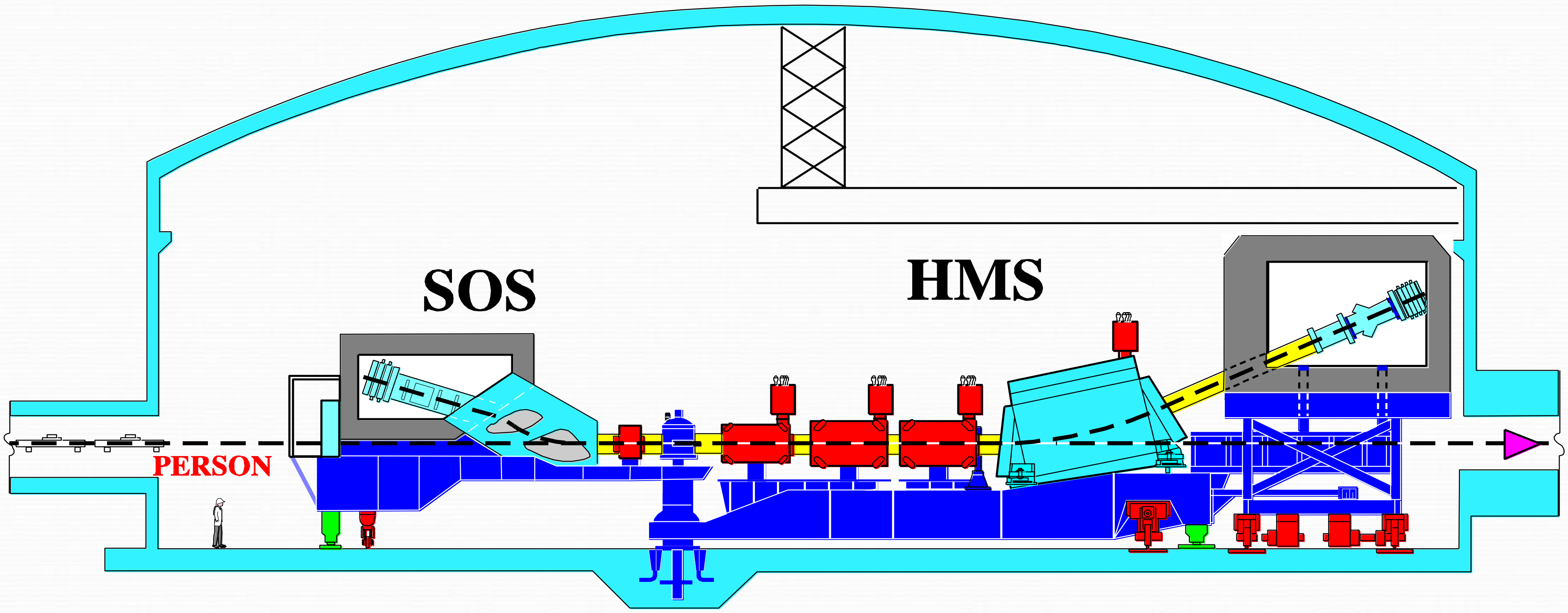
Gas Cherenkov counters
e/π separation, 216 PMTs

Electromagnetic calorimeters
Lead/scintillator, 1296 PMTs

Hall C Schematic Drawing

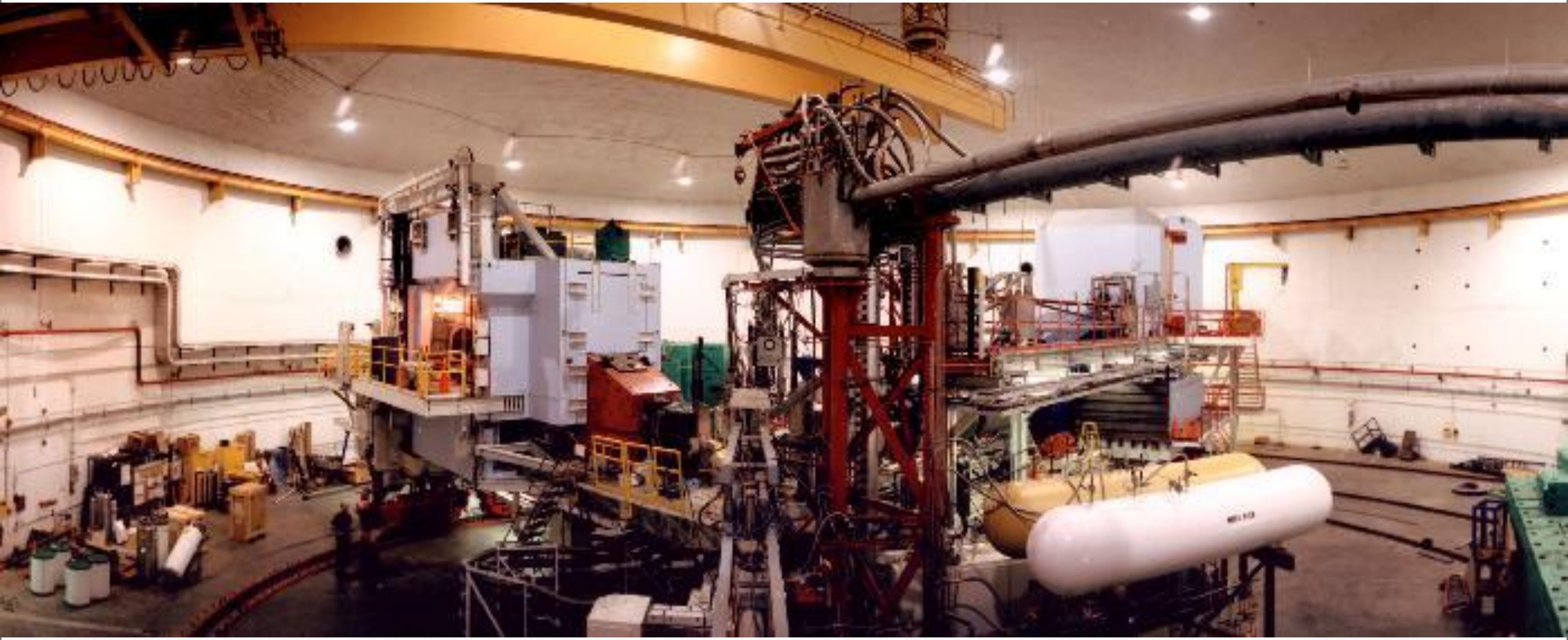


Hall C Elevation View



	SOS	HMS
Maximum Central Momentum	1.8 GeV/c	7.5 GeV/c
Momentum Resolution $\delta p/p$ [FWHM]	0.1%	0.05% - 0.1%
Solid Angle $\Delta\Omega$	9 msr	6.7 msr
Angular Range	12^0 - 165^0	12^0 - 90^0

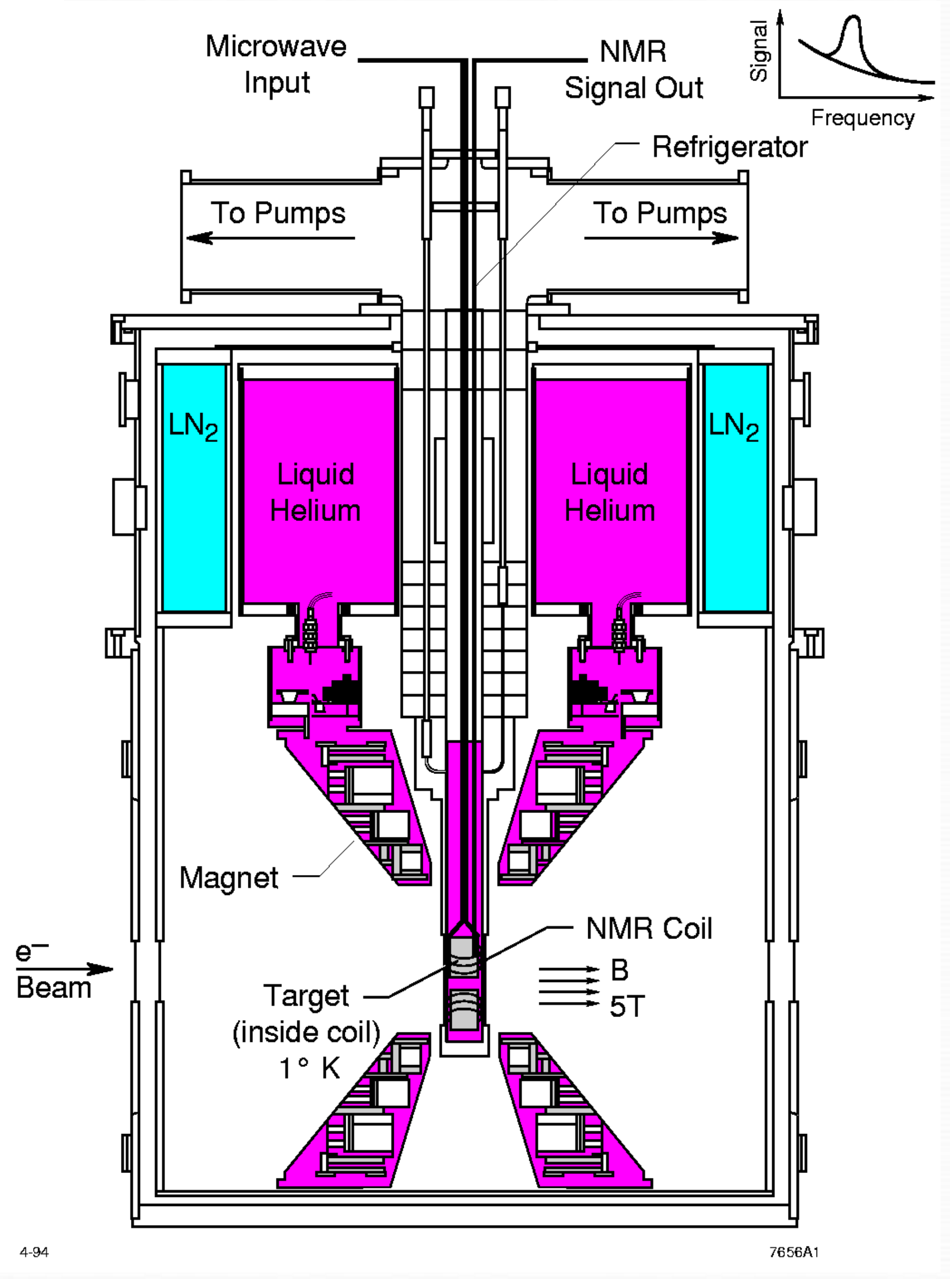
Hall C View



Polarized proton/deuteron target

- Polarized NH_3/ND_3 targets
- Used in Hall B and Hall C (also at SLAC)
- Dynamical Nuclear Polarization

- ~ 90% for p
  ~ 40% for d
- Luminosity ~ 10^{35}



JLab Physics Program

JLab's Scientific Mission

- How are the hadrons constructed from the quarks and gluons of QCD?
- What is the QCD basis for the nucleon-nucleon force?
- Where are the limits of our understanding of nuclear structure?
- Is the "Standard Model" complete?

Critical issues in "strong QCD":

- What is the mechanism of confinement?
- How and where does the dynamics of the q-g and q-q interactions make a transition from the strong (confinement) to the perturbative QCD regime?
- How does Chiral symmetry breaking occur?
- What is the multi-dimensional structure of the nucleon?

JLab 6 GeV Program

- Main physics programs
  - nucleon electromagnetic form factors
  - N $\rightarrow$ N* electromagnetic transition form factors
  - longitunidal spin structure of the nucleon
  - Transverse spin and transverse structure
  - exclusive reactions
  - parity violation
  - form factors and structure of light nuclei
  - nuclear medium effects
  - hypernuclear physics
  - exotic states search

  ……

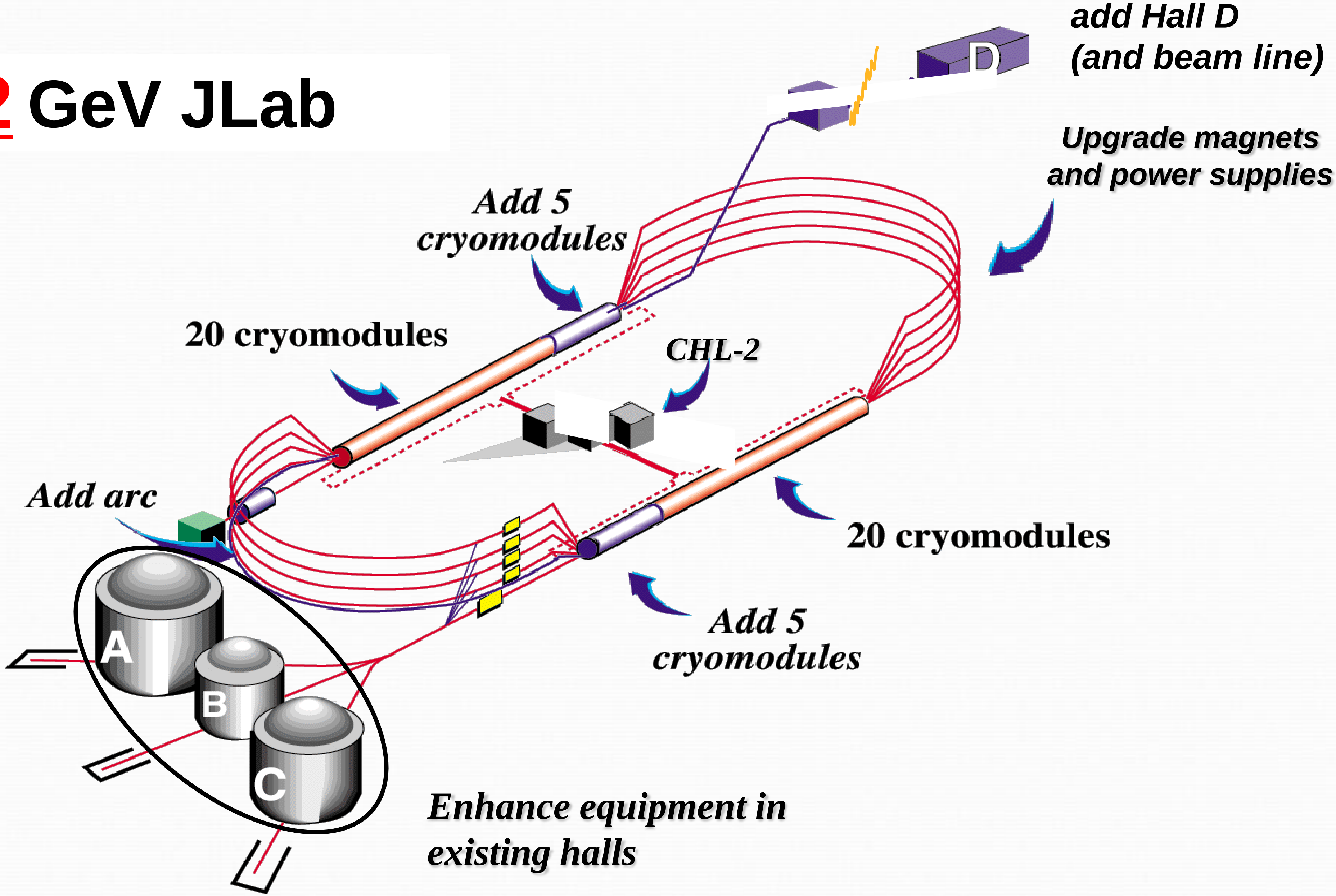
JLab 12 GeV Upgrade

and beyond

Physics Drivers for JLab Upgrade

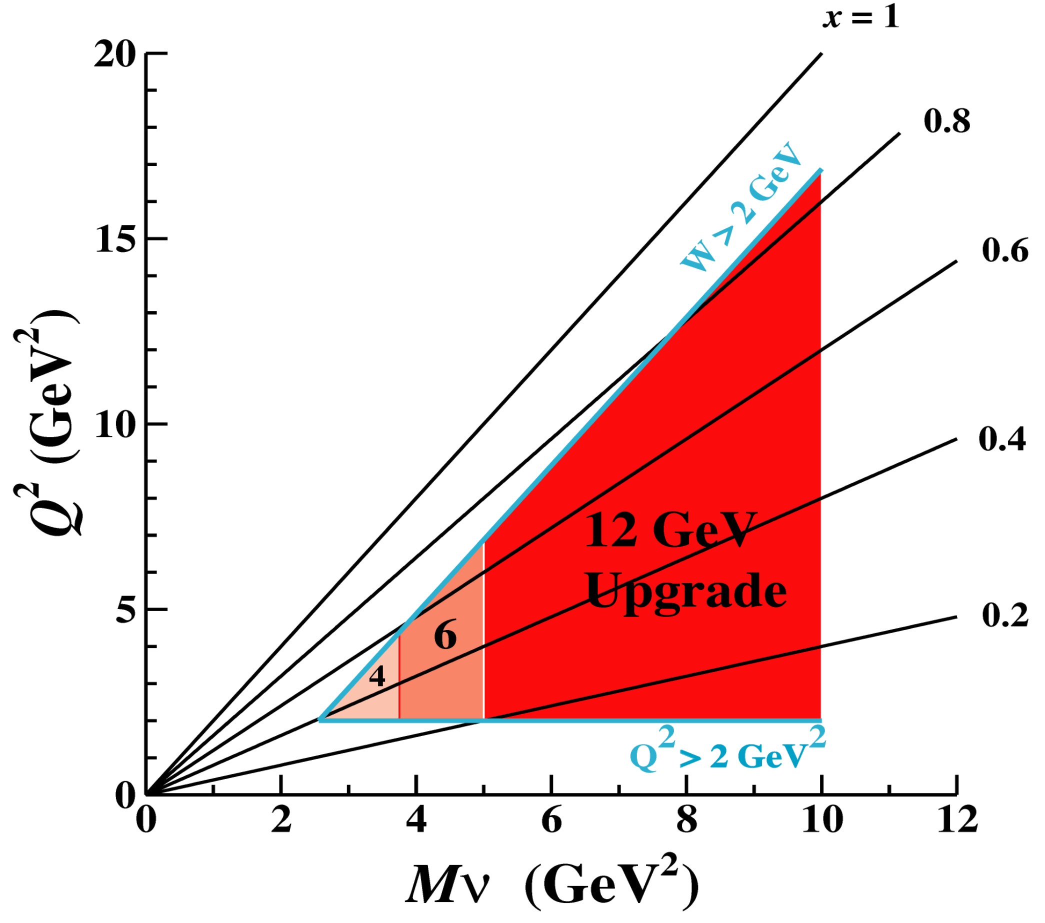
- New capabilities
  - search for origin of confinement (J^{PC} exotic mesons)
  - determine quark-gluon structure of the nucleon and nuclear matter via
    - parton distributions in valence region
    - transverse spin and transverse structure (TMDs)
    - exclusive processes (DVCS, meson production) to study GPDs
- Expand present program to higher Q^2
  - form factors of mesons, nucleons, and light nuclei
  - ……
- Low energy test of standard models

12 GeV JLab

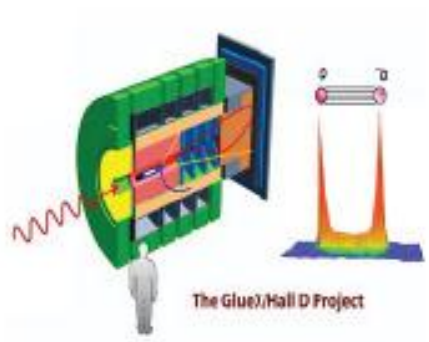

add Hall D
(and beam line)
D
Upgrade magnets
and power supplies
Add 5
cryomodules
20 cryomodules
CHL-2
Add arc
20 cryomodules
Add 5
cryomodules
A
B
C
Enhance equipment in
existing halls

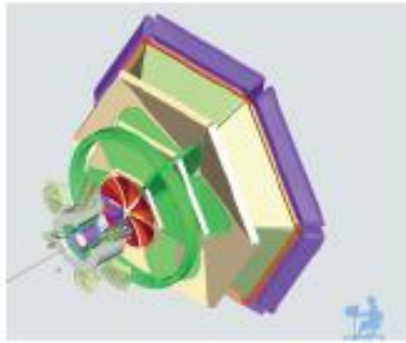
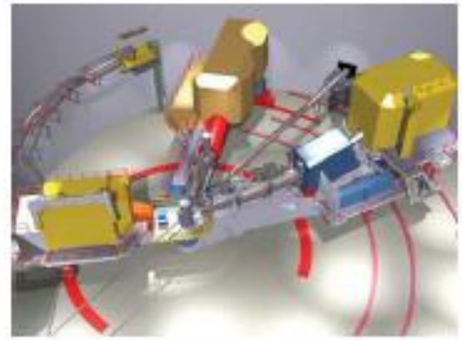
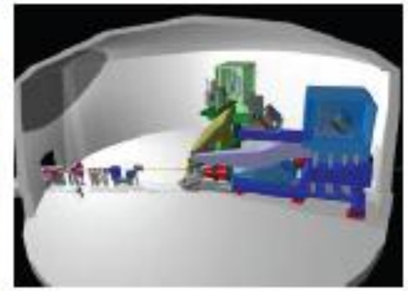
12 GeV Upgrade Kinematical Reach

- Reach a broad DIS region
- Precision SIDIS for transversity and TMDs
- Experimental study/test of factorization
- Decisive inclusive DIS measurements at high-x
- Study GPDs



Experimental Halls

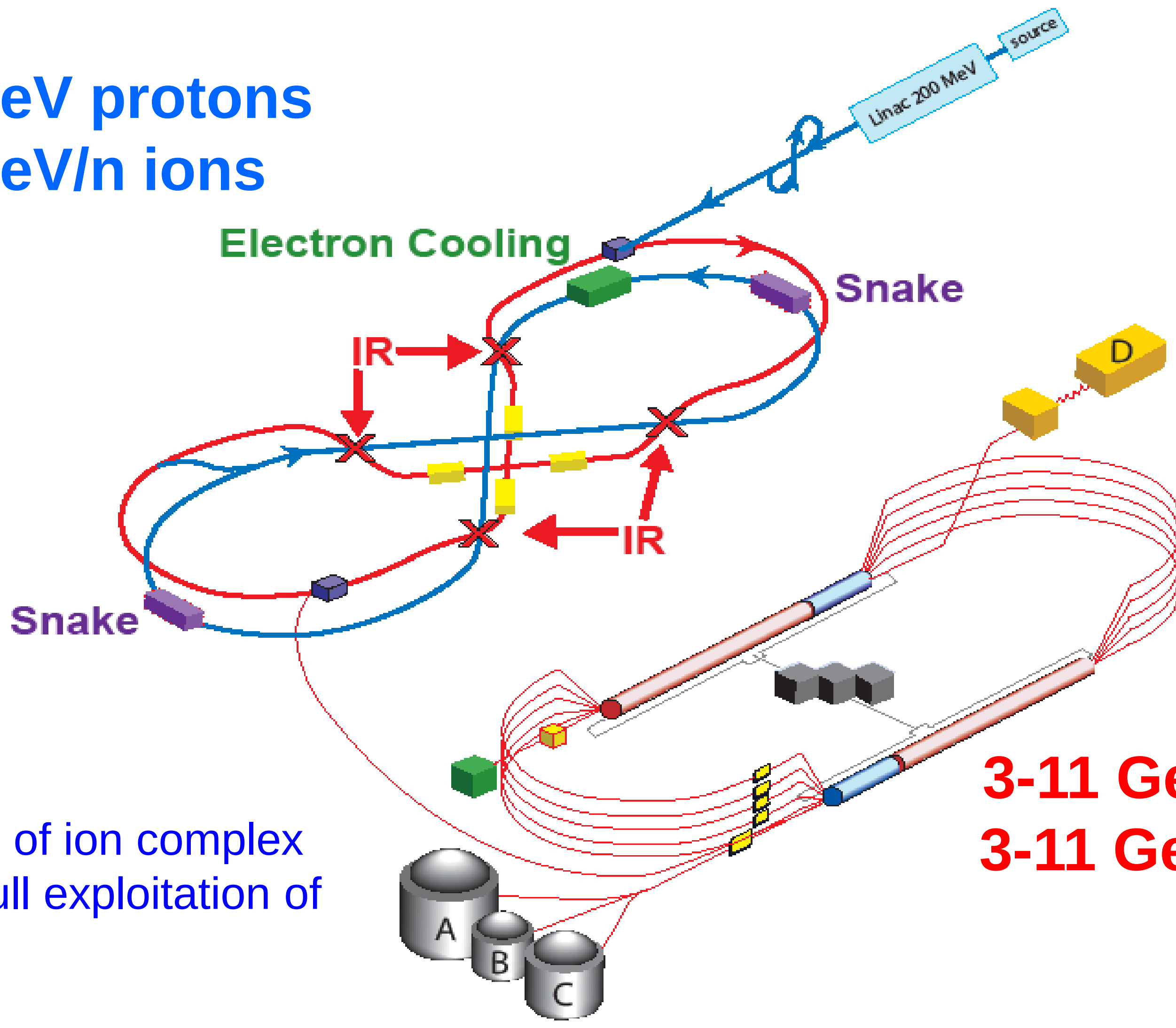


- **(new) Hall D: linear polarized photon beam, Selonoid detetcor**
  - *GluoX* collaboration: exotic meson spectroscopy
    gluon-quark hybrid, confinement
- Hall B: CLAS12
  - GPDs, TMDs, …
- Hall C: Super HMS + existing HMS
  - Form factors, structure functions, …
- Hall A: Dedicated devices + existing spectrometers
  - Super BigBite, Solenoid, Moller Spectrometer
  - SIDIS, PVDIS, …

ELIC at $L \sim 10^{35}$ cm^{-2}s^{-1}

30-225 GeV protons
30-100 GeV/n ions



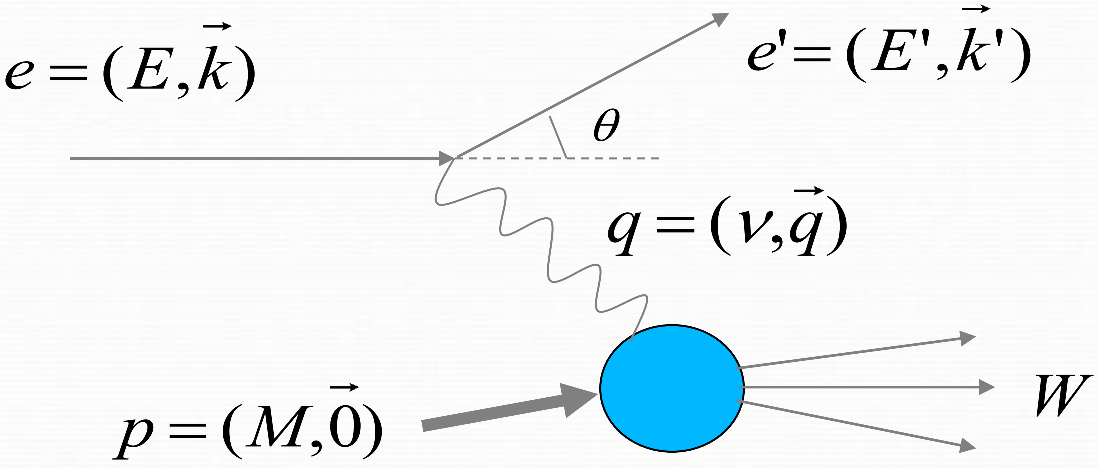
3-11 GeV electrons
3-11 GeV positrons

Green-field design of ion complex directly aimed at full exploitation of science program.

Electromagnetic Form Factors

$\mathbf{G_E^n, G_M^n, G_E^p, G_M^p}$

Elastic Electron Scattering



4-momentum transfer squared

$$Q^2 = -q^2 = 4EE'\sin^2\frac{\theta}{2}$$

Invariant mass squared

$$W^2 = M^2 + 2M\nu - Q^2$$

Elastic Scattering: *W*=*M*, no change of internal property, only recoil.

Nucleon Electro-Magnetic Form Factors

The Sachs Electric (charge) G_E and Magnetic G_M Form Factors

$$\frac{d\sigma}{d\Omega}(E,\theta) = \sigma_M \left[\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2(\theta/2) \right]$$

can be alternatively expressed as F_1 and F_2

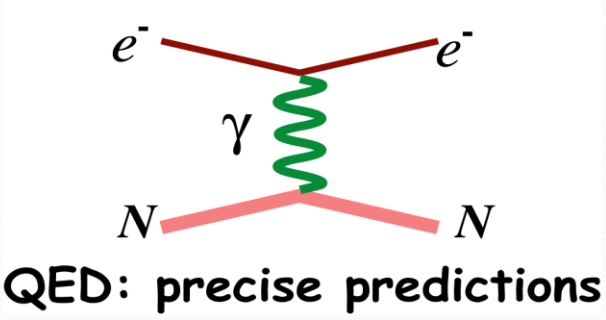
$$F_1 = G_E + \tau G_M \qquad F_2 = \frac{G_M - G_E}{\kappa(1+\tau)} \qquad \tau = \frac{Q^2}{4M^2}$$

with κ anomalous magnetic moment

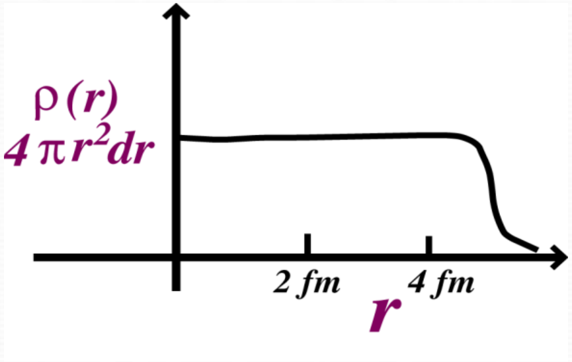
F_1 and F_2 are the Dirac (non-spin-flip) and Pauli (spin-flip) Form Factors

In the Breit (centre-of-mass) frame the Sachs Form Factors are the Fourier transforms of the charge and magnetization distributions

Nucleon E-M Form Factors



Fourier transform of charge distribution



Nucleon charge and magnetization distributions:

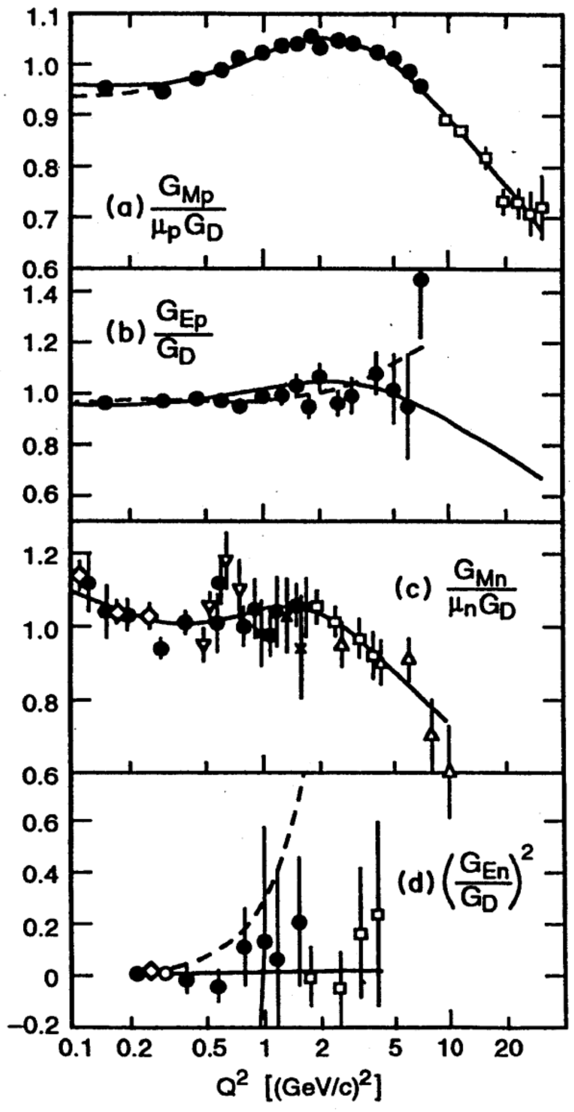
$G_E(Q^2)$, $G_M(Q^2)$

electric and magnetic form factors

$G_E^p(0) = 1$ $\quad$ $G_M^p(0) = +2.79 \equiv \mu_p = 1 + \kappa_p$

$G_E^n(0) = 0$ $\quad$ $G_M^n(0) = -1.91 \equiv \mu_n = \kappa_n$

Early Measurements of EM Form Factors



- Stern (1932) measured the proton magnetic moment $\mu_p \sim 2.5\ \mu_{Dirac,}$ →proton was not a point-like particle (Nobel Price)
- Hofstadter (1950's) provided the first measurement of the proton's radius through elastic electron scattering (Nobel Price)
- Good description with Dipole form factor

$$G_D = \left\{ \frac{\Lambda^2}{\Lambda^2 + Q^2} \right\}^2 \quad \textbf{with} \;\; \Lambda = 0.84\, GeV$$

- Bosted Fit: PRC 51, 409 (1995)

Polarization Improves Precision

Double polarization → interference term $G_E G_M$
Greatly improve the accuracy of form-factor measurements

Progress in polarized beam, polarized target and recoil polarimeters made it possible:

- Polarized beam with high intensity (~100 µA) and high polarization (up to 85%)
- Beam polarimeters with 1-3 % absolute accuracy
- Polarized targets with high polarization and high density or
- Recoil polarimeters with large analyzing power

JLab Polarization-Transfer Data

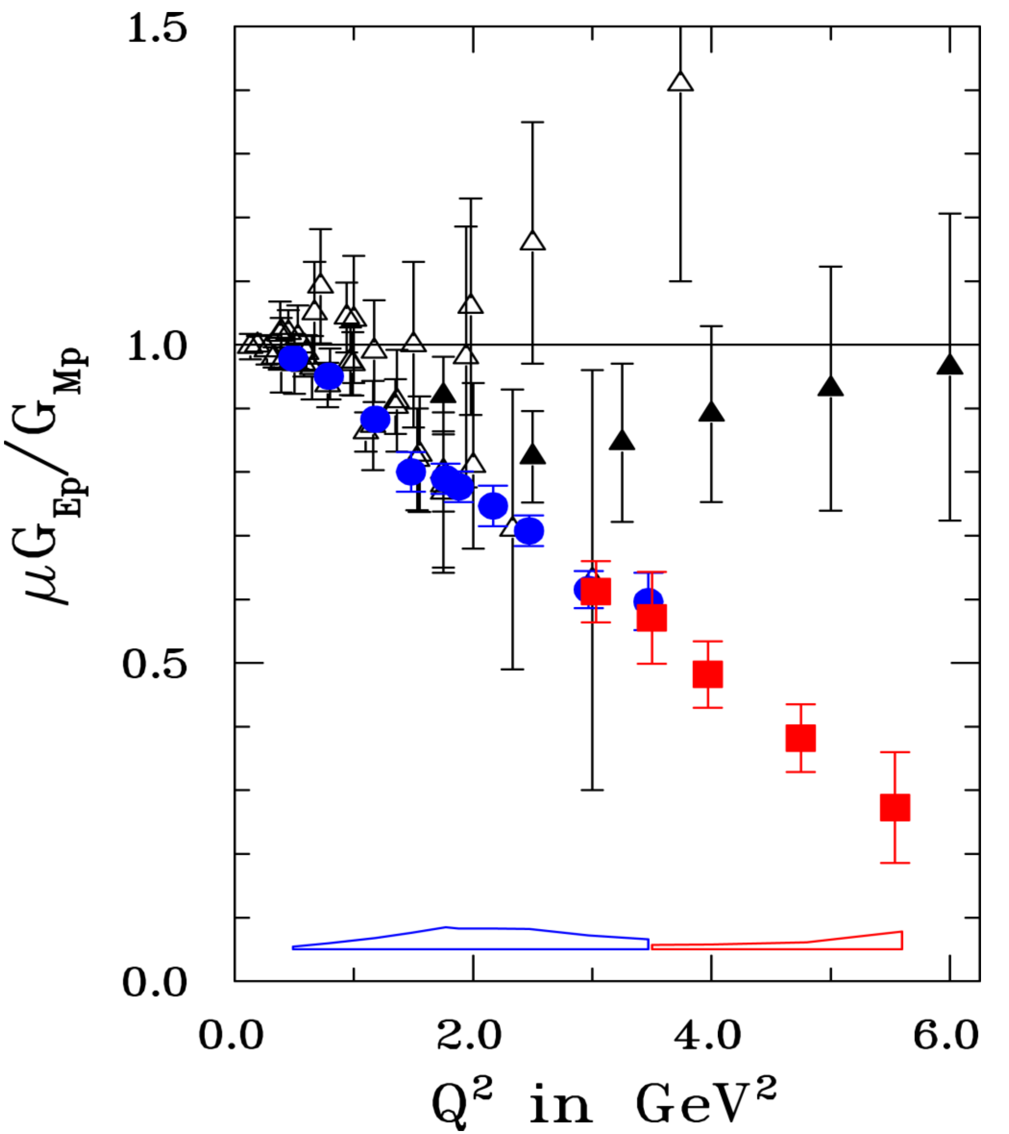
Using Focal Plane Polarimeter in Hall A

- E93-027 PRL 84, 1398 (2000)
- E99-007 PRL 88, 092301 (2002)

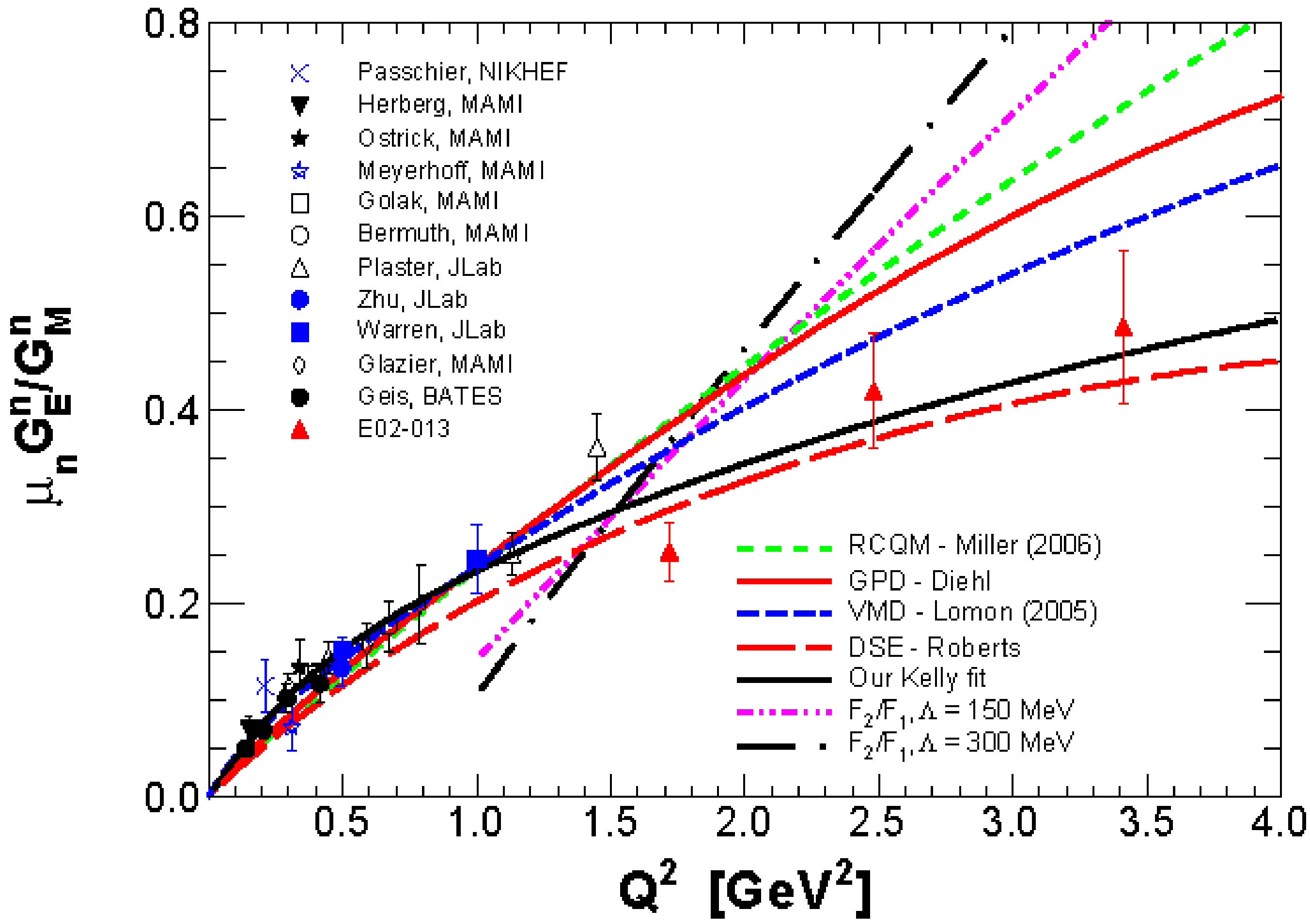
Clear discrepancy between polarization transfer and Rosenbluth data

- Investigate possible experimental sources for discrepancy:
  optimized Rosenbluth experiment
  confirmed SLAC results
- Investigate possible theoretical sources for discrepancy
  → two-photon contributions

New 6 GeV results (Vina Punjabi's talk)
12 GeV plan (Charles Perdrisat'talk)



JLab Polarization-Transfer Data (G_{En})

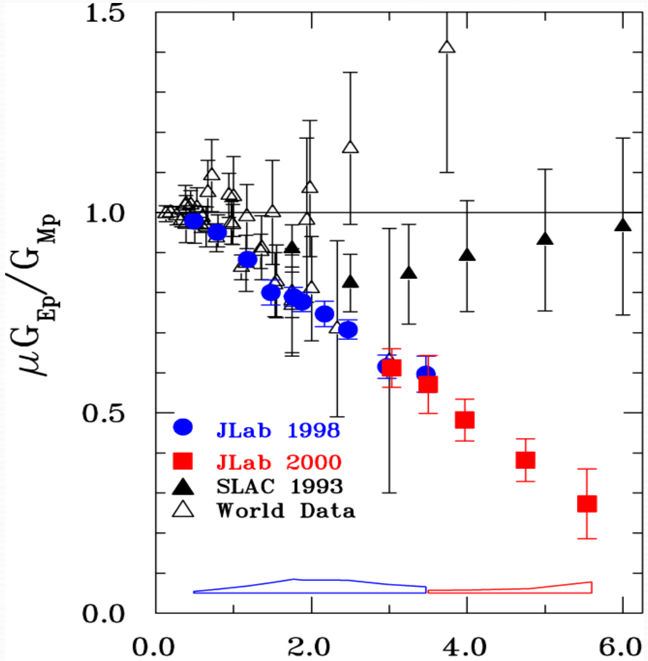
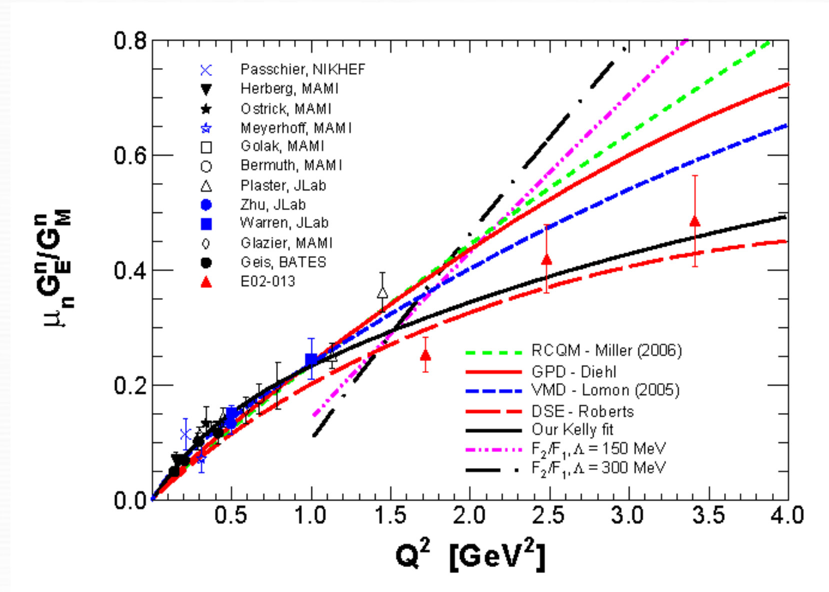
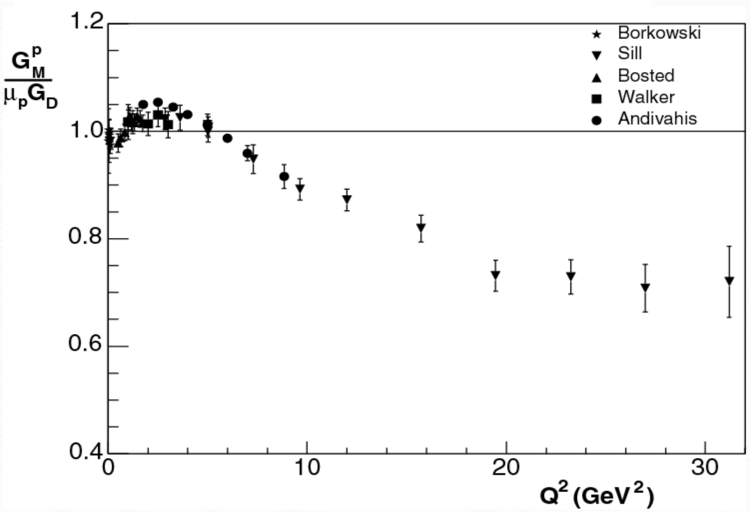
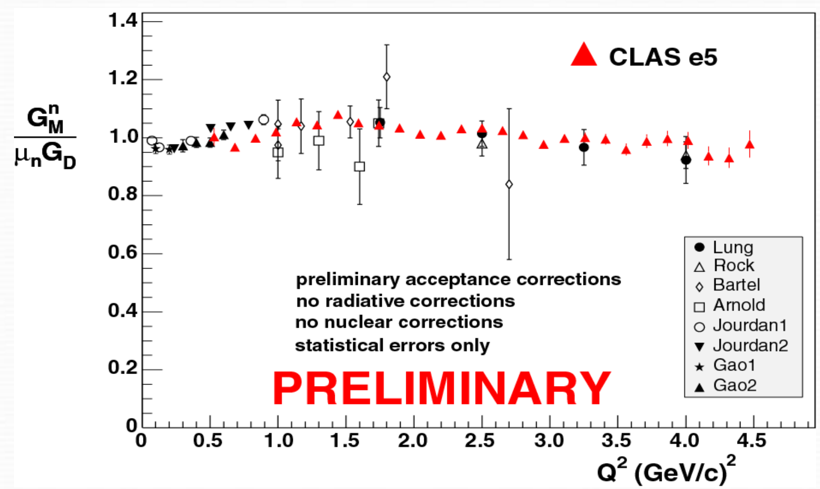


E02-012 Using polarized 3He target in Hall A, submitted to PRL

Earlier data using recoil polarization and polarized deuteron target, Hall C

JLab Data on EM Form Factors

Testing Ground for Theories of Nucleon Structure

	Proton	Neutron
Electric		
Magnetic		

Summary on Form Factor Experiments

- Very successful experimental program at JLab on nucleon form factors thanks to development of polarized beam (> 100 μA, ~80 %), polarized targets and polarimeters with large analyzing powers

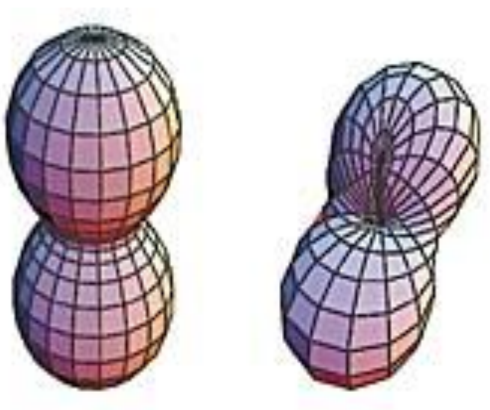
- G_E^p Precise polarization-transfer data set up to $Q^2 = 5.6$ GeV^2
  New Rosenbluth data from Halls A and C confirm SLAC data
  Discrepancy due to 2-photon effects
  New Hall C measurement up to $Q^2 = 9$ GeV^2 (Vina Punjabi'talk)
- G_E^n Hall C experiments on deuteron, precise data up to $Q^2 = 1.5$ GeV^2
  New Hall A ^{3}He experiment, extend to $Q^2 = 3.4$ GeV^2
- G_M^n $Q^2 < 1$ GeV^2 data from ^{3}He(e,e') in Hall A
  $Q^2 < 5$ GeV^2 data from ^{2}H(e,e'n)/^{2}H(e,e'p) in CLAS

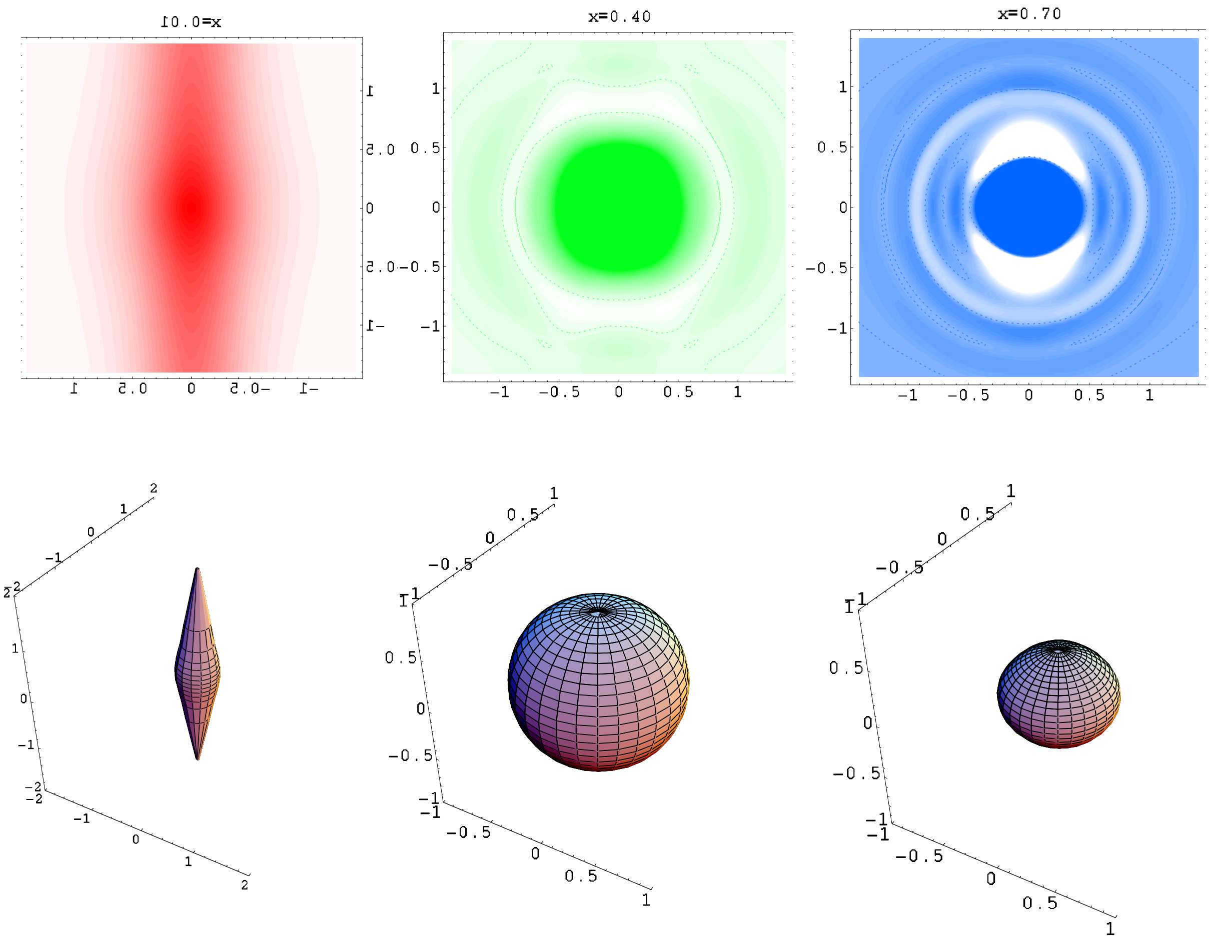
- JLab at 12 GeV will extend to higher Q^2 (Charles Perdrisat's talk)

The Proton's Shape

It's a Ball. No, It's a Pretzel.
Must Be a Proton.
(K. Chang, NYT, May 6, 2003)

Belitsky, Ji and Yuan: PRD 69, 074014(04)





quark spin parallel to that of the proton (left), quark spin perpendicular to the proton spin (right).

G. Miller, PRC 68, 022201 (03)

Nucleon in nuclear medium

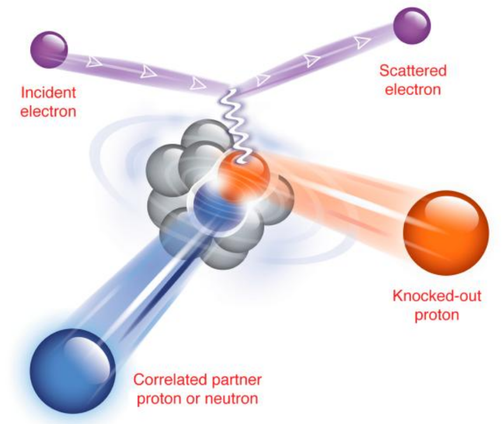
EMC Effects, Coulomb Sum Rule, Hadronization, …

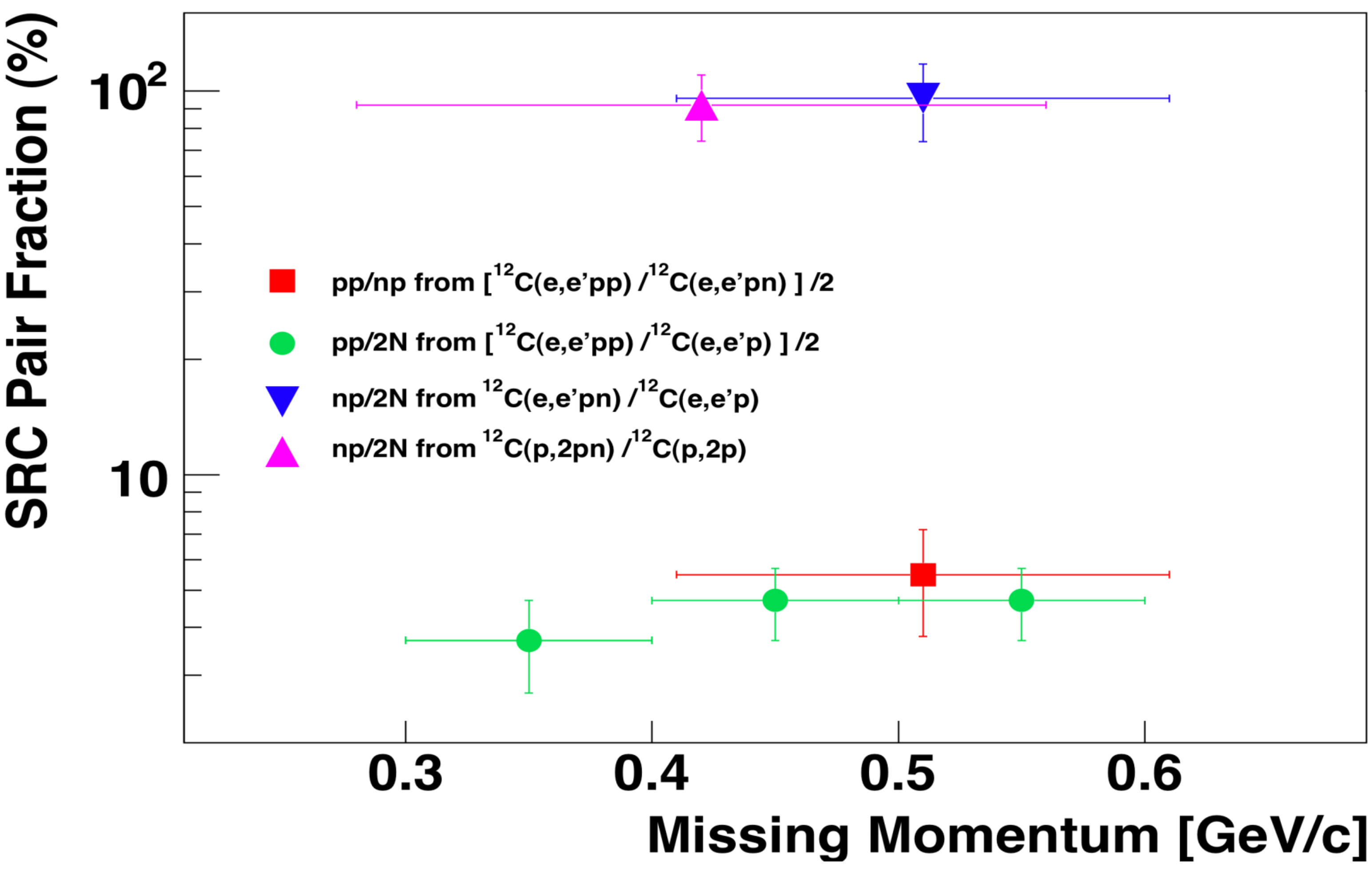
QCD and Nuclei

- **Most of the strong interaction confined in nucleon, only residual strong interaction remains among nucleons in a nucleus (exponential tail?)**
  - **Effective N-N interaction with meson exchange**
- **Study QCD with nuclei**
  - **Short range not well understood: Short range correlations**
  - **Nuclear medium effects**
    - **EMC effect**
    - **Coulomb Sum Rule quenching(?)**
    - **Form Factor Modification(?) in ^{4}He**
    - **Color Transparency**
    - **Quark propagation in cold and hot nuclear matter**

Short-Range Correlation Pair Factions

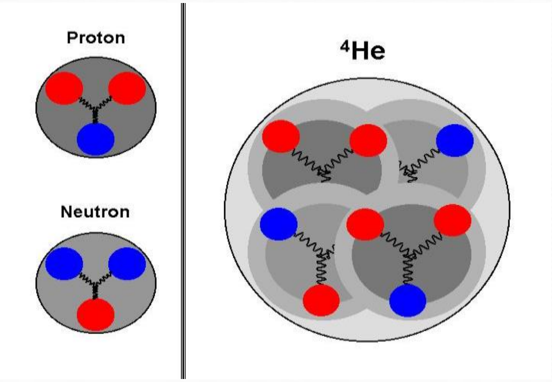
R. Subedi *et al.*, Science **320** (2008) 1476).





Hadrons in the Nuclear Medium

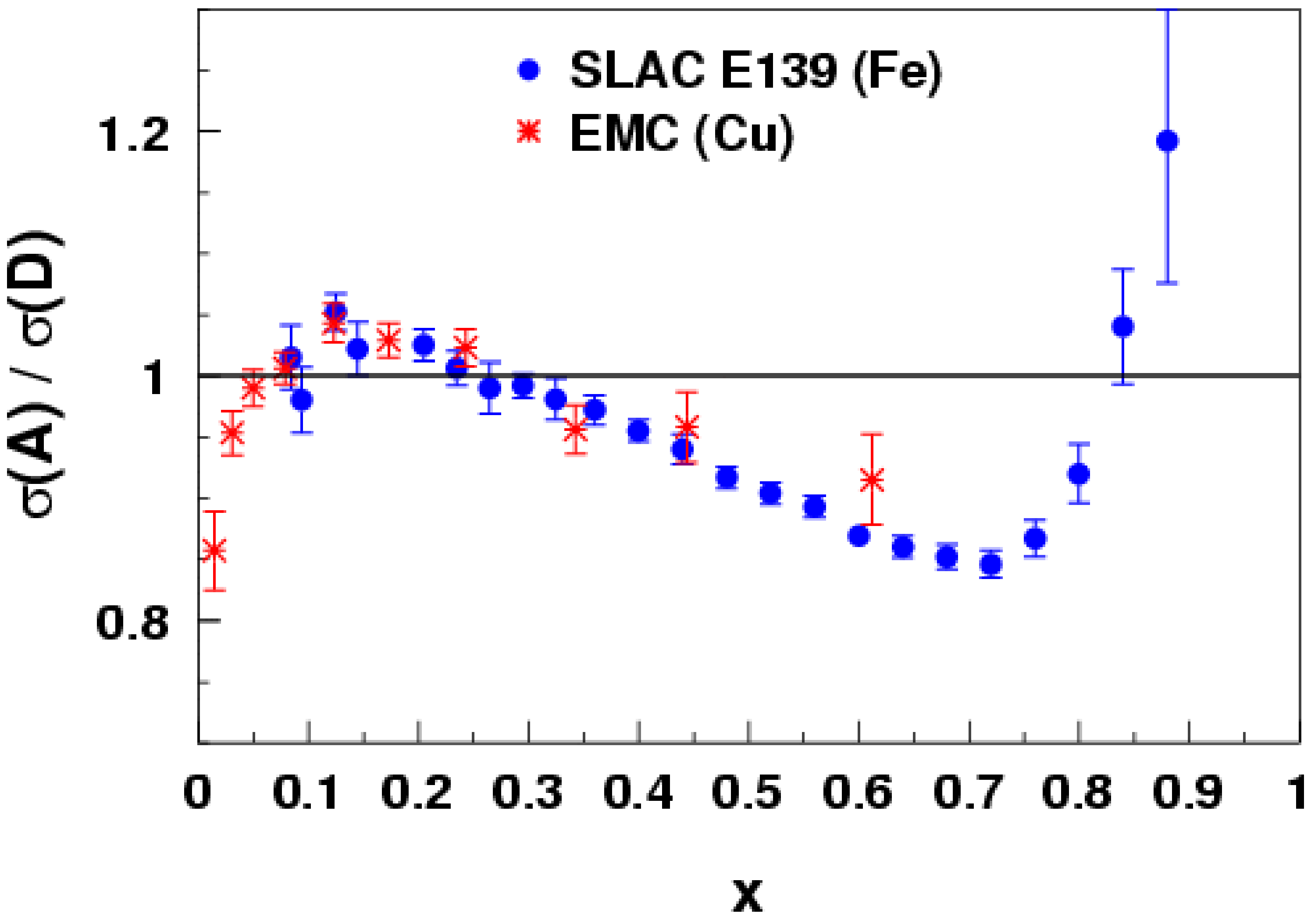
- Nucleons and Mesons are not the fundamental entities of the underlying theory.
- At nuclear matter densities of 0.17 nucleons/fm^3, nucleon wave functions overlap considerably.



- EMC effect: Change in the inclusive deep-inelastic structure function of a nucleus relative to that of a free nucleon.

Nuclear Medium Effects (I)

- **EMC effect, shielding and anti-shielding**



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

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

A dependence of ρ dependence?

Magnitude of the EMC effect for C and ^{4}He very similar, and

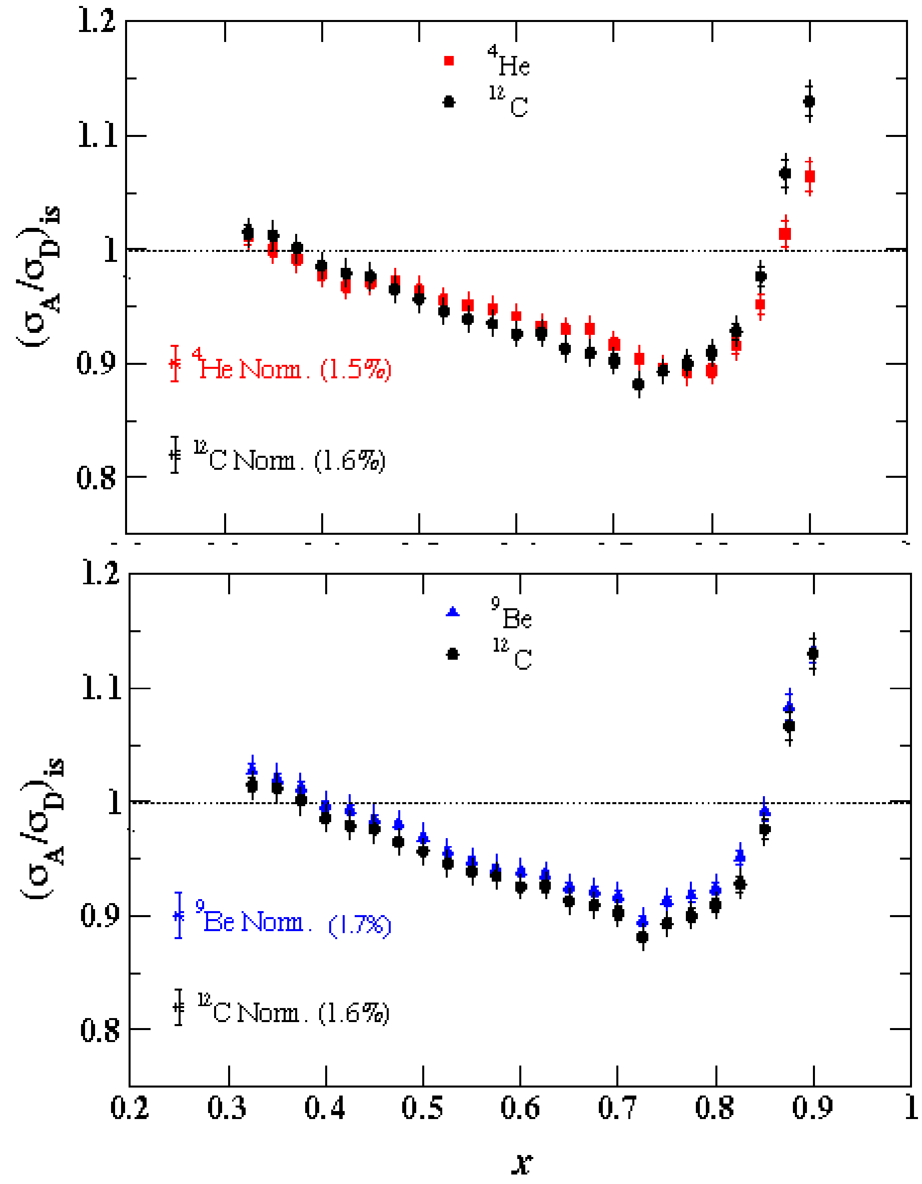
$\rho(^4He) \sim \rho(^{12}C)$

^{4}He suggests ρ−dependent

Magnitude of the EMC effect for C and ^{9}Be very similar, but

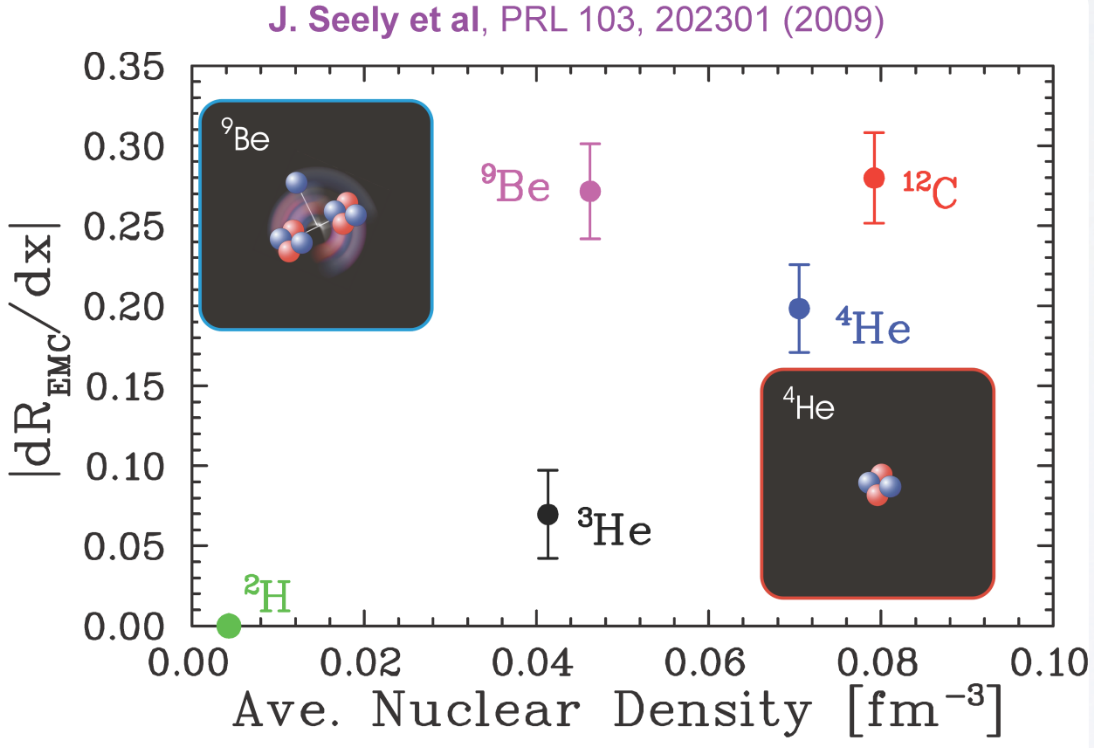
$\rho(^9Be) << \rho(^{12}C)$

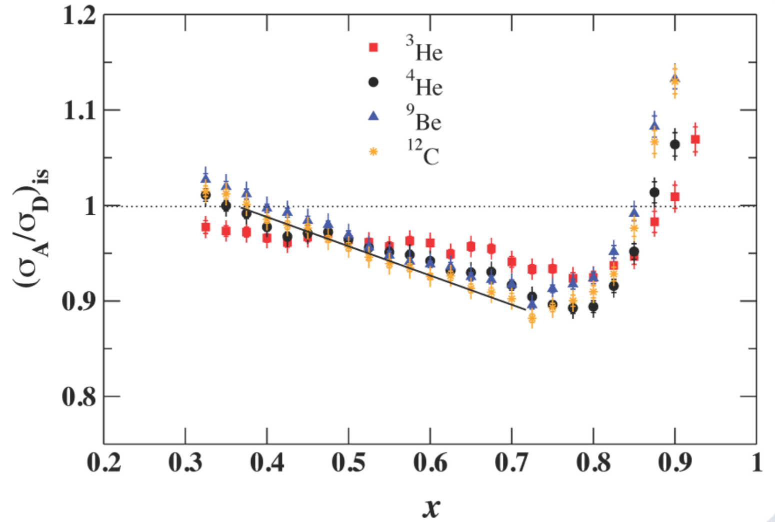
^{9}Be suggests A-dependent



A dependence of ρ dependence?

Fit of the EMC ratio for 0.35<x<0.7 and look at A- and density dependence of the slope





Density determined from ab initio few-body calculation

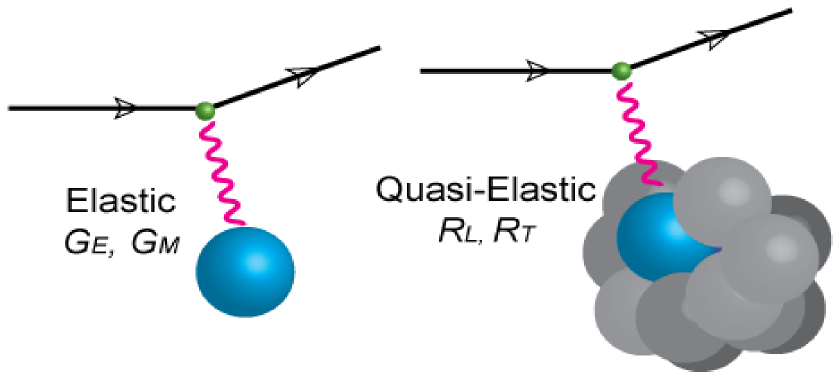
S.C. Pieper and R.B. Wiringa, Ann. Rev. Nucl. Part. Sci 51, 53 (2001)

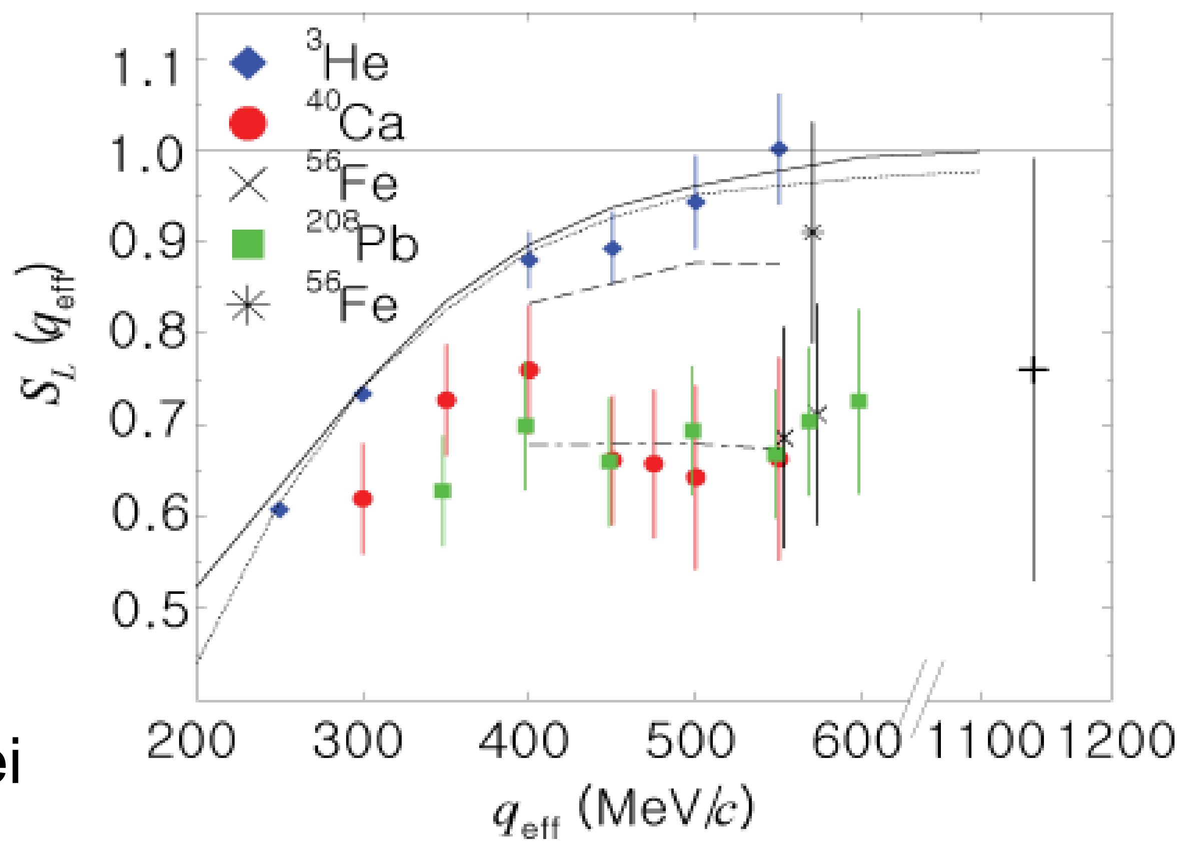
^{9}Be has low average density, but large component of structure is 2α+n most nucleons in tight, α-like configurations

Nuclear Medium Effects (II)

Coulome Sum Rule

$$S_L(q) = \frac{1}{Z}\int_{0+}^{\infty} \frac{R_L(q,\omega)}{[(G_E^p + N/ZG_E^n)\zeta]^2} d\omega \;=\; 1\;?$$





Probing a nucleon inside a nucleus

Possible modification of the nucleons' property inside nuclei

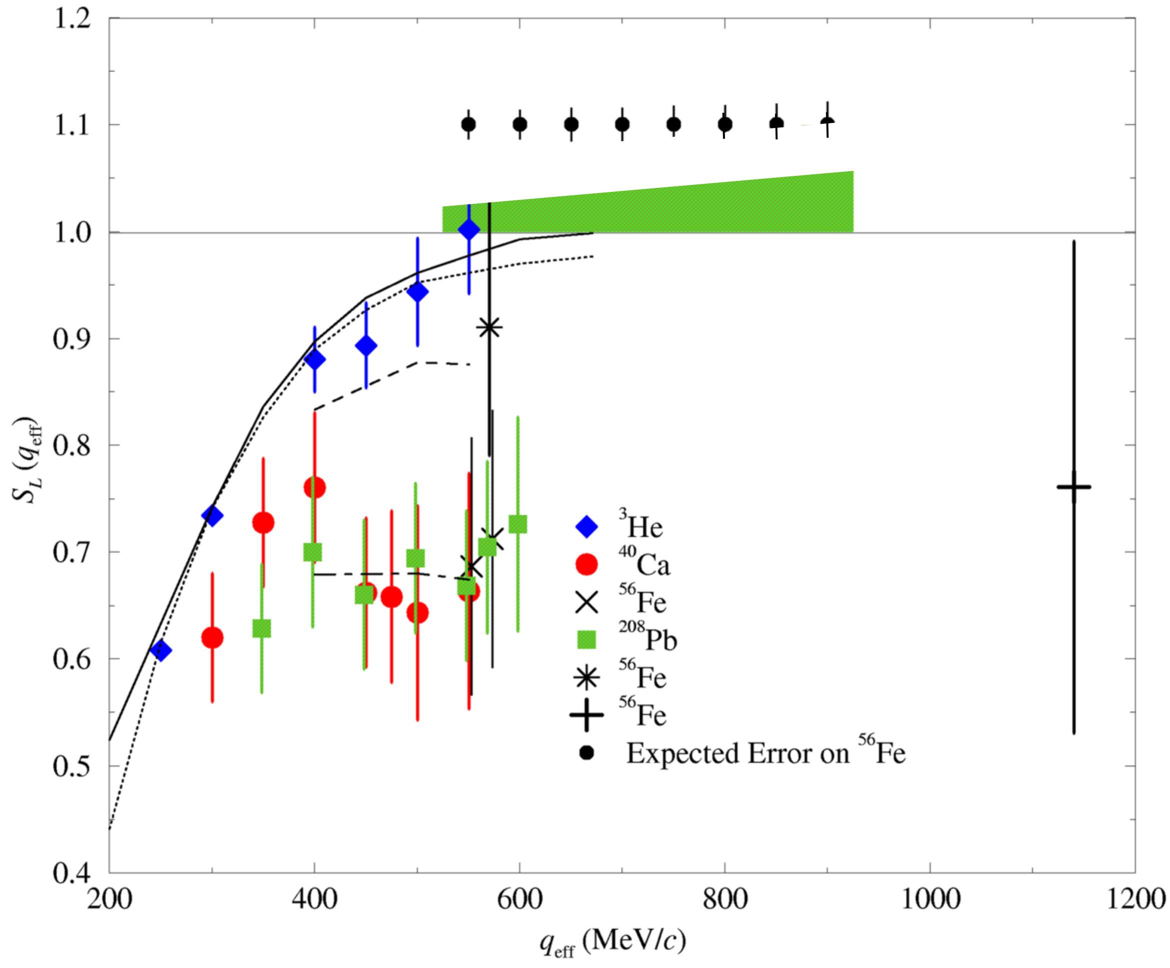
E01-015

Precision Measurement of Coulomb Sum at q=0.5-1 GeV/c

Spokespersons: J. P. Chen, S. Choi and Z. E. Meziani

PhD students: Y. Oh (Seoul), X. Yan (USTC), H. Yao (Temple),

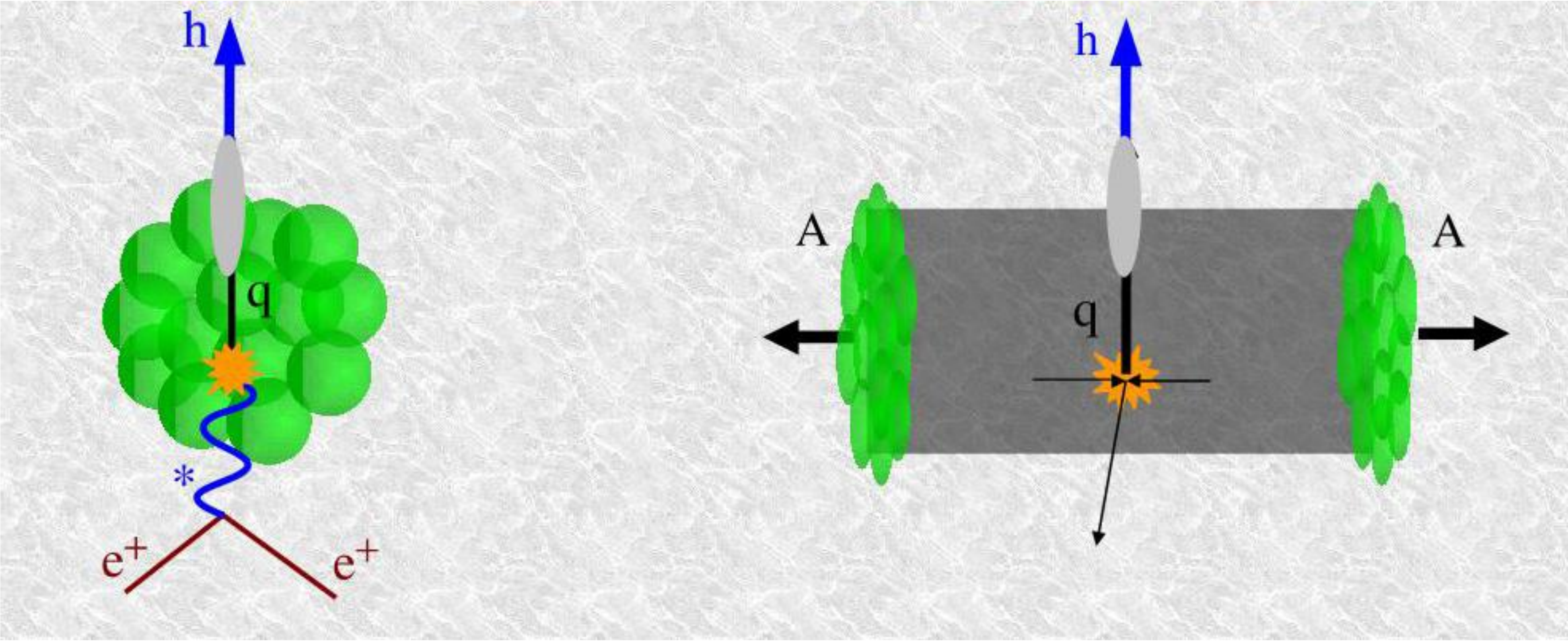
- New NaI detector for background control
- Precision data at 4 angles, for 4 targets (^{4}He, ^{12}C, ^{56}Fe and ^{208}Pb)
- Analysis well underway
- Expect preliminary results in a few months



Nuclear Medium Effects (III)

- **Quark propagation in cold and hot matter**

SIDIS **A-A Collision**

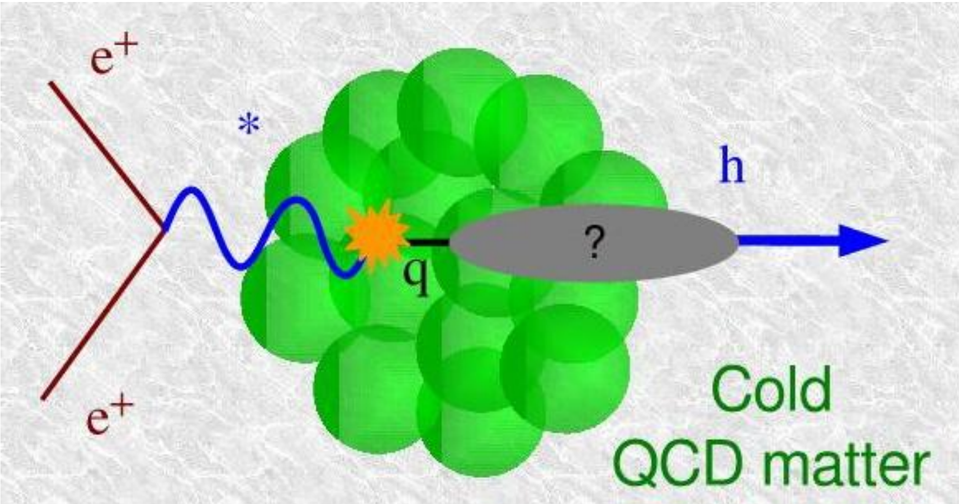


E_h = $z\nu \sim 2$ - 20 GeV (HERMES/JLab)

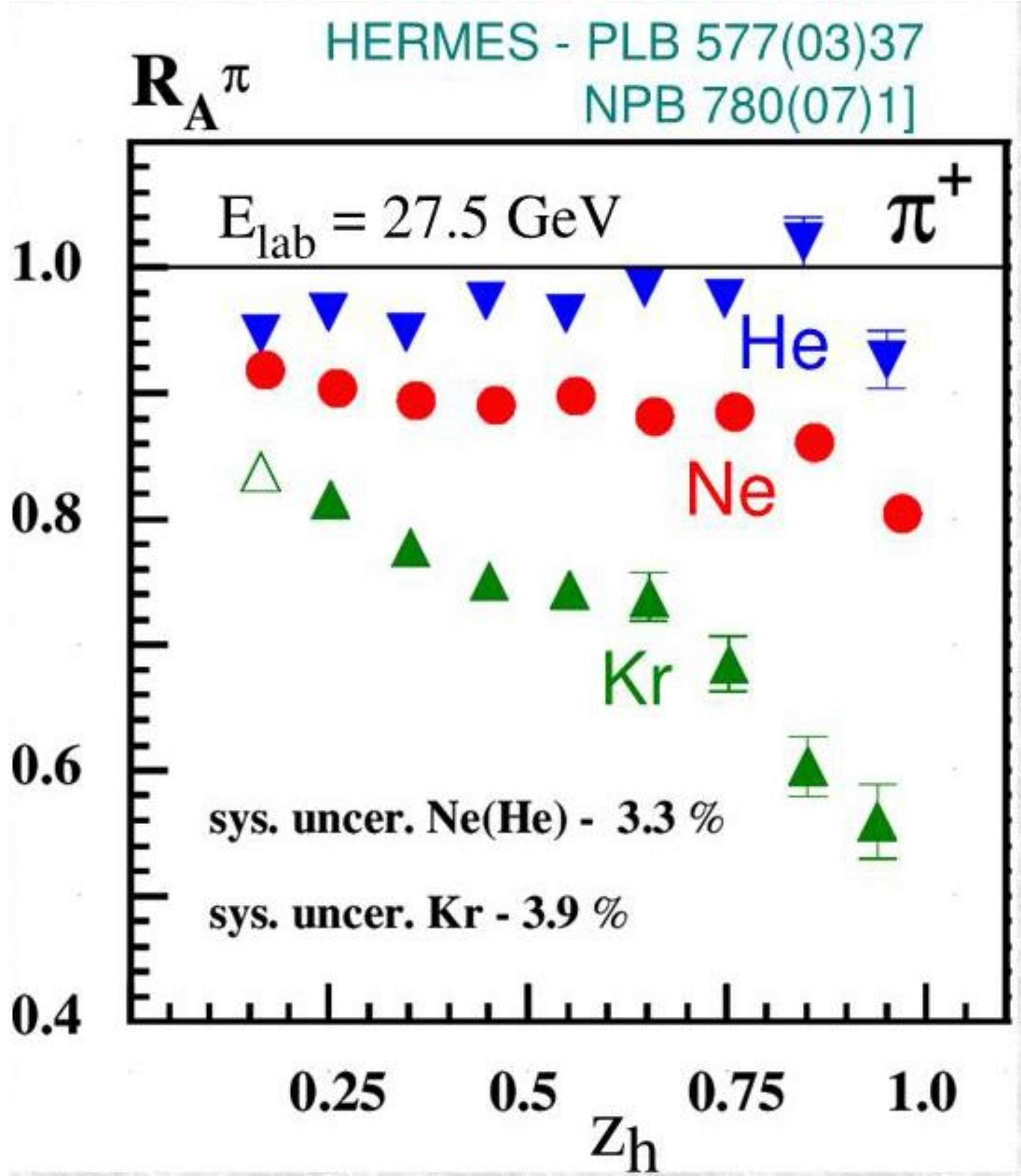
$E_h = p_T \sim 2$ – 20 GeV (RHIC)

SIDIS to study hadronization

- **Quark propagation**



$$R_M^h(z_h) = \frac{\frac{1}{N_A^{\mathrm{DIS}}}\frac{dN_A^h(z_h)}{dz_h}}{\frac{1}{N_D^{\mathrm{DIS}}}\frac{dN_D^h(z_h)}{dz_h}} \approx \frac{D_A(z)}{D_D(z)}$$

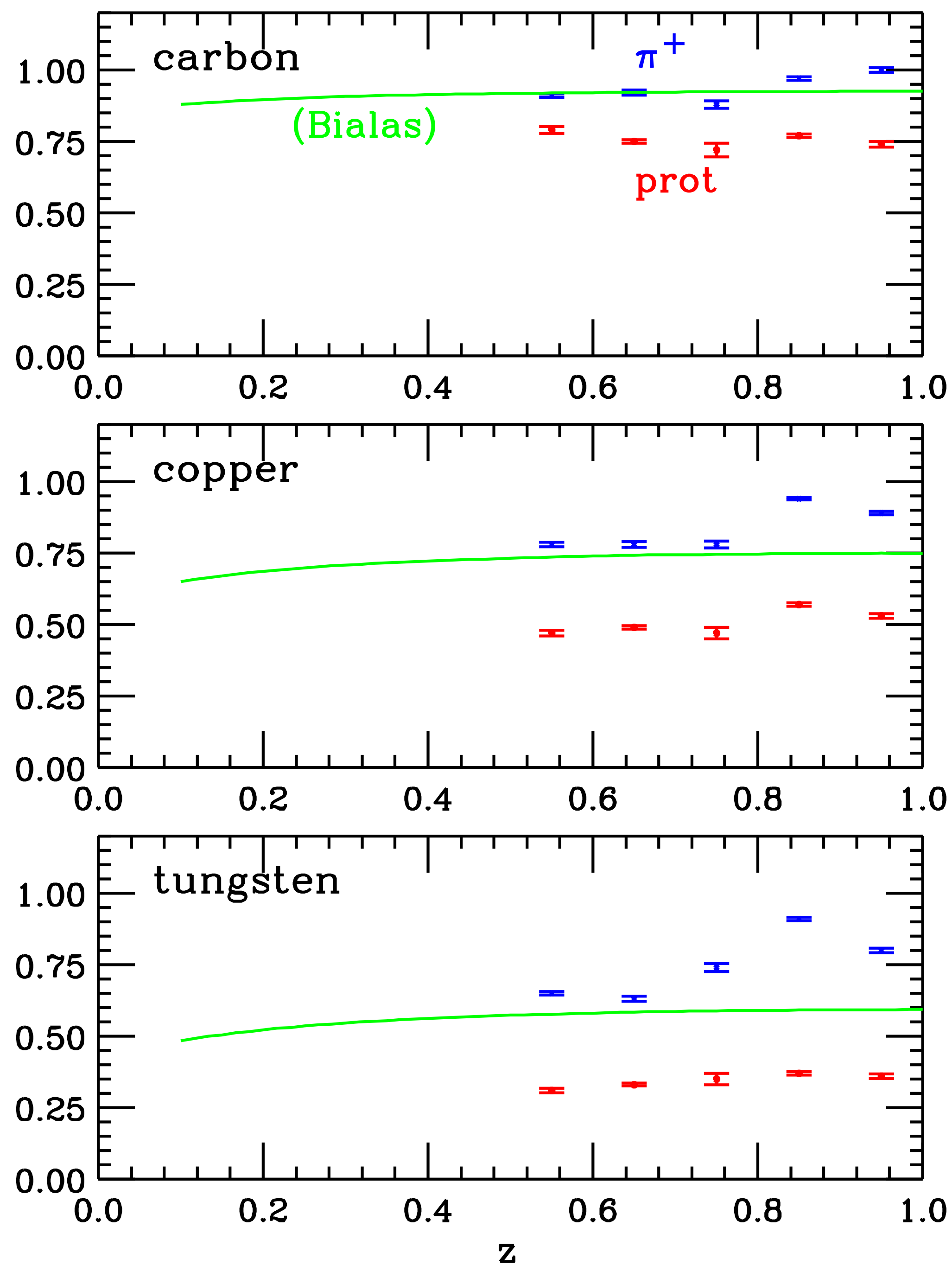


E12-07-101

Spokespersons: J.P. Chen, H. Lv, B. Norum, K. Wang

- **Projected R_M vs. z for π+ and proton on 3 targets**

^{12}C, ^{64}Cu, ^{184}W



Summary

- Electron Scattering: A clean tool to study nucleon/nuclear structure and QCD
- JLab facility: 6 GeV beam, 3 halls
- JLab 6 GeV program
- 12 GeV upgrade and beyond
- Precision EM form factors with polarization
- Nucleon property inside nuclear medium

  EMF effects

  Coulomb Sum Rule

  Hadronization