Jefferson Lab – The Next Ten Years and Beyond

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Nuclear Sciences Division Colloquium
Lawrence Berkeley National Laboratory
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Abstract

Jefferson Lab had its 25th anniversary a year ago. After successful operation of its 6 GeV continuous wave superconducting radiofrequency accelerator for a decade, the laboratory is constructing an upgrade to double the energy of the accelerator to 12 GeV, and to extend its experimental capabilities. The result will be an exciting physics program, which will extend well beyond 2020. The beautiful superconducting radio-frequency technology also offers other opportunities, for example, in photon physics.

Acknowledgements

This talk is derived from a number of talks prepared by my colleagues at Jefferson Lab over the past months.

I am especially grateful for the input from Larry Cardman, Rolf Ent, Joe Grames, Doug Higinbotham, Andrew Hutton, Allison Lung, Bob McKeown, George Neil, and Gwyn Williams.

The Talk

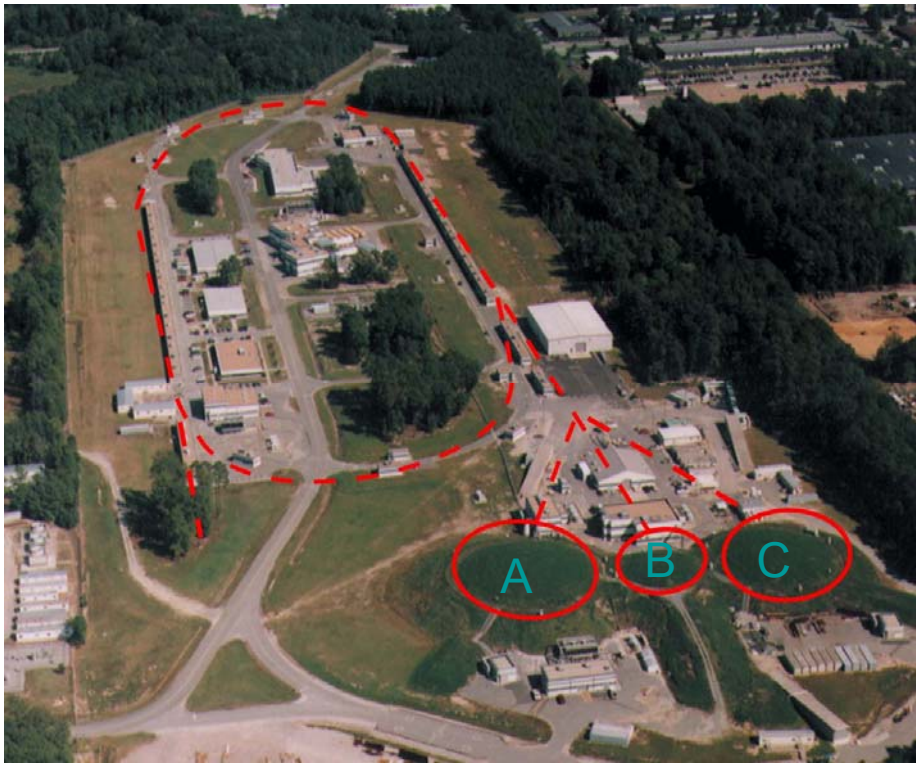
- Jefferson Lab today
- 12 GeV; The Physics Opportunities
- 12 GeV; The Project Status
- Other Initiatives
- Conclusions

JEFFERSON LAB TODAY

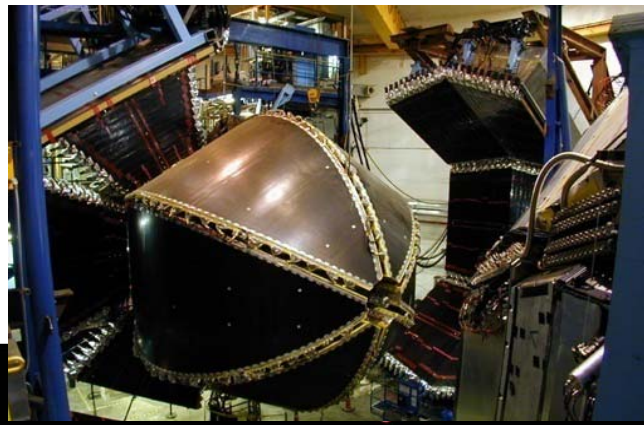
>1200 active member international user community engaged in exploring quark-gluon structure of matter.

Superconducting electron accelerator provides 100% duty factor beams of unprecedented quality, with high polarization at energies up to 6 GeV.

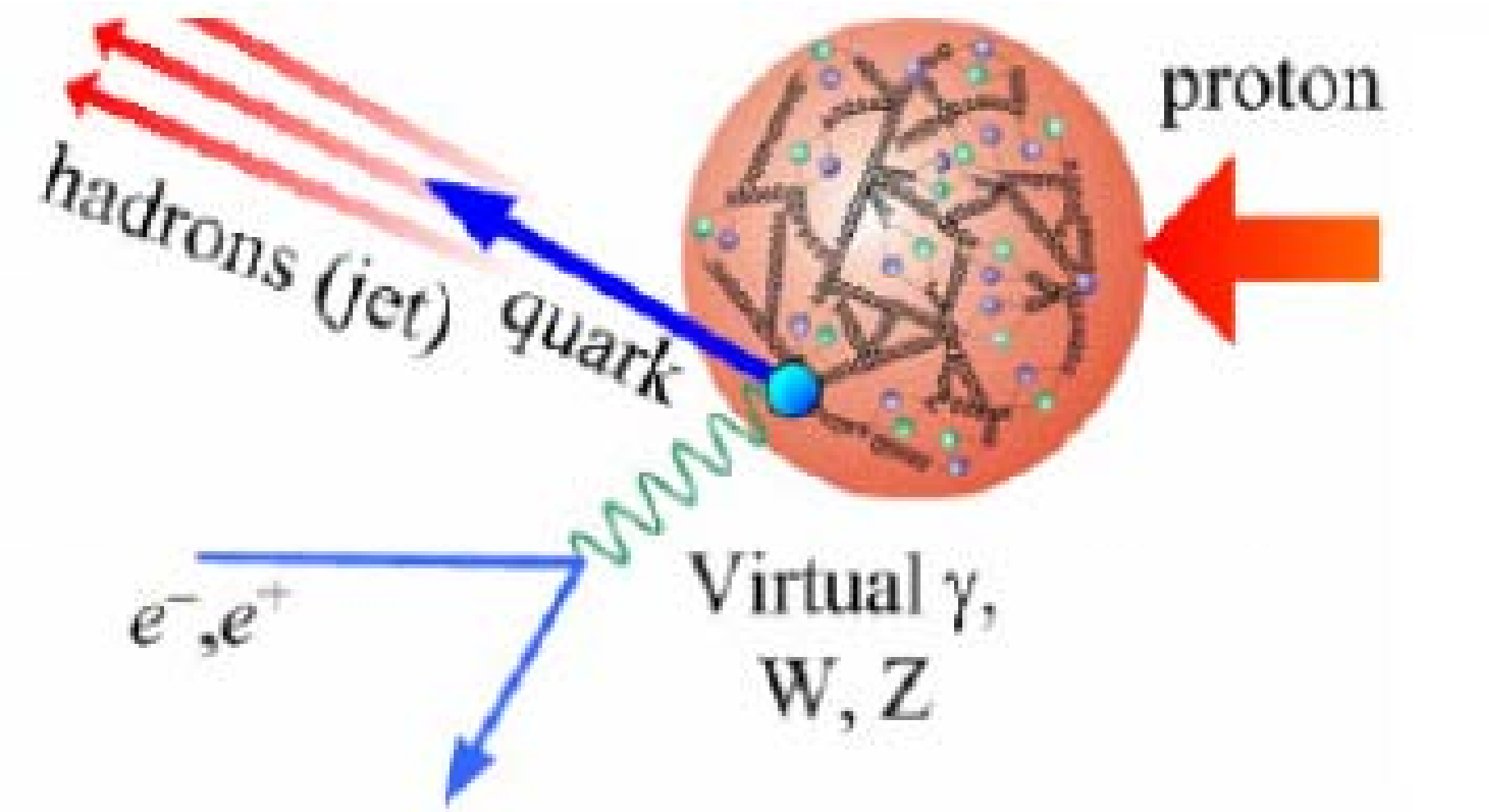
Newport News, VA



CEBAF's delivery of beam with unique properties to three experimental halls simultaneously. Each hall offers different capabilities.



Electron Scattering: A picture

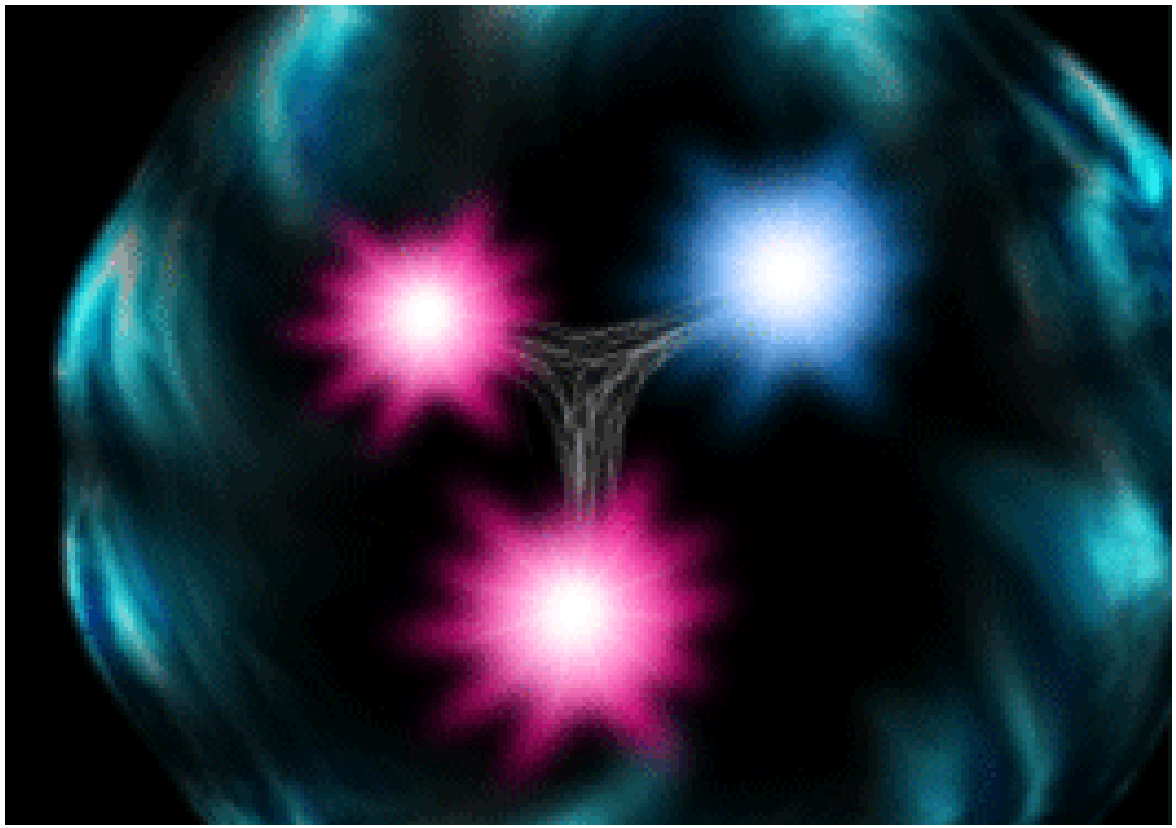


The Structure of the Proton

Naïve Quark Model: proton = uud (valence quarks)

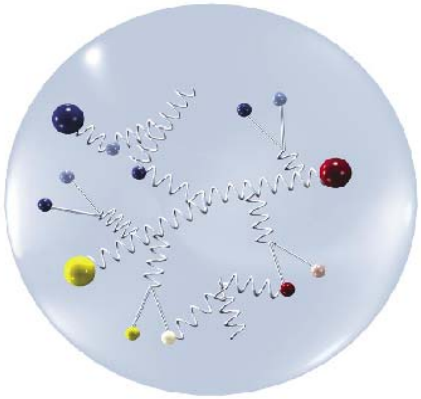
QCD: proton = uud + $u\bar{u}$ + $d\bar{d}$ + $s\bar{s}$ +

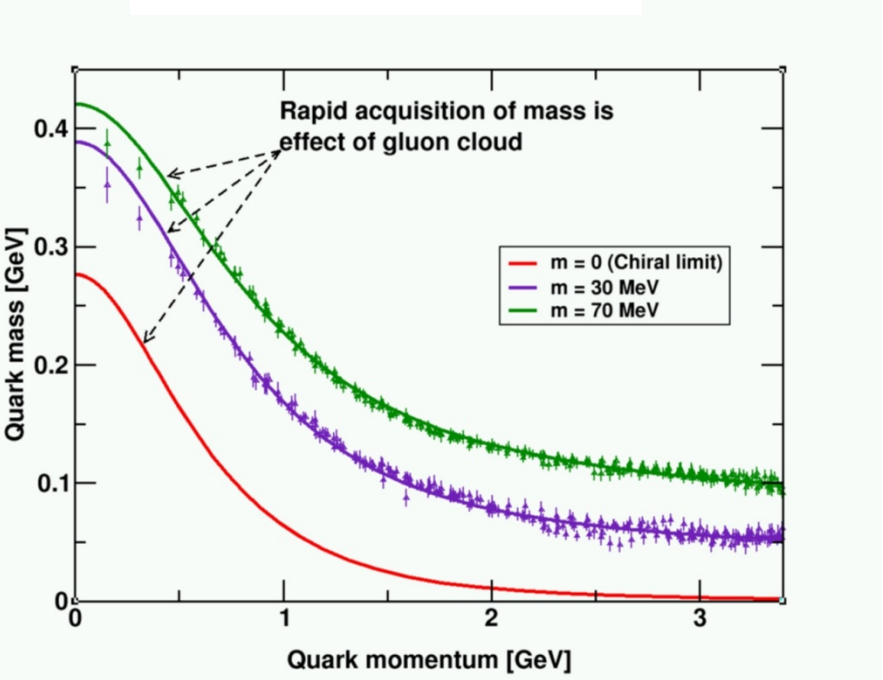
The proton sea has a non-trivial structure: $\bar{u} \neq \bar{d}$



The proton is **far more** than just its up + up + down (valence) quark structure

QCD and the Origin of Mass

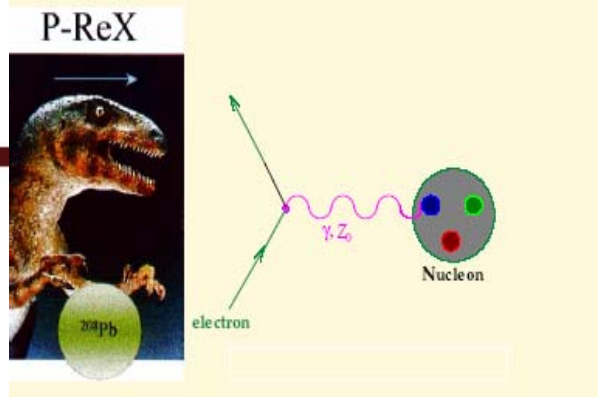




- 99% of the proton's mass/energy is due to the self-generating gluon field
  - Higgs mechanism has almost no role.

- The similarity of mass between the proton and neutron arises from the fact that the gluon dynamics are the same
  - Quarks contribute almost nothing.

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

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

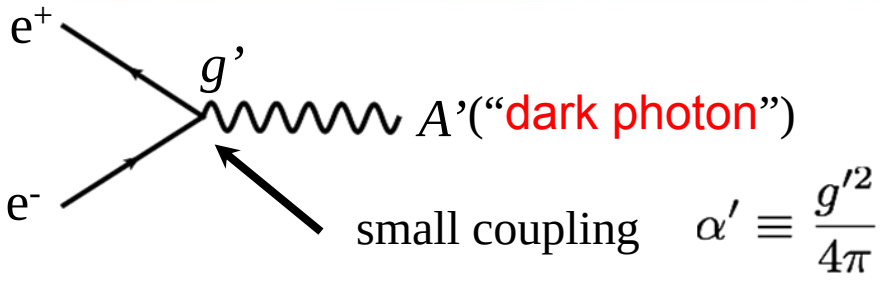
Measure a Parity Violating Asymmetry

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

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

New Opportunity: Search for A'

Search for new forces mediated by ~100 MeV vector boson A' with weak coupling to electrons



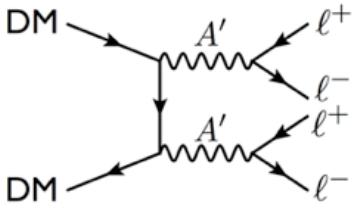
Motivated by **dark matter anomalies**:

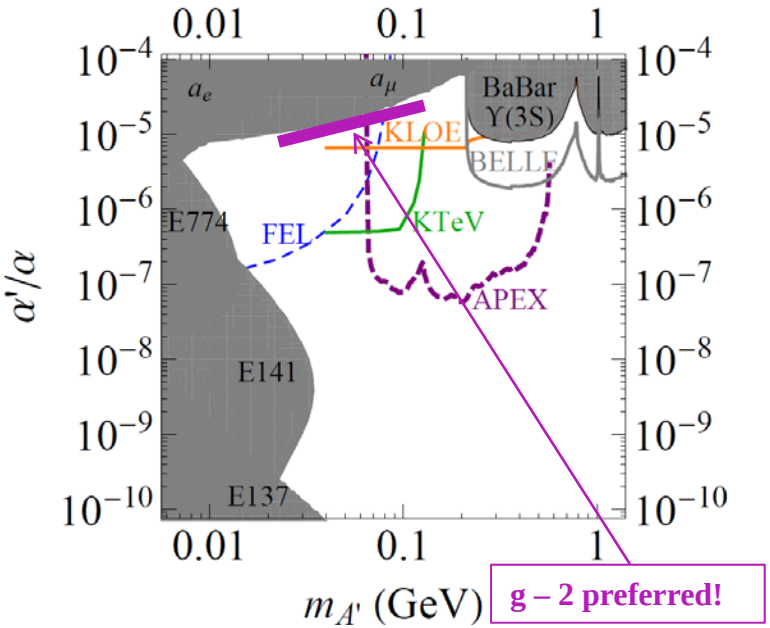
- excess of 10-100 GeV e^+ flux found by PAMELA satellite (Nature 2009, 1 citation/day)
- excess of few-100 GeV $e^+ + e^-$ flux by Fermi satellite/HESS

But - no excess of anti-protons observed!
- observed annihilation rate is large!

→ Suggests $M_{A'} < 1$ GeV

→ decay to protons kinematically forbidden

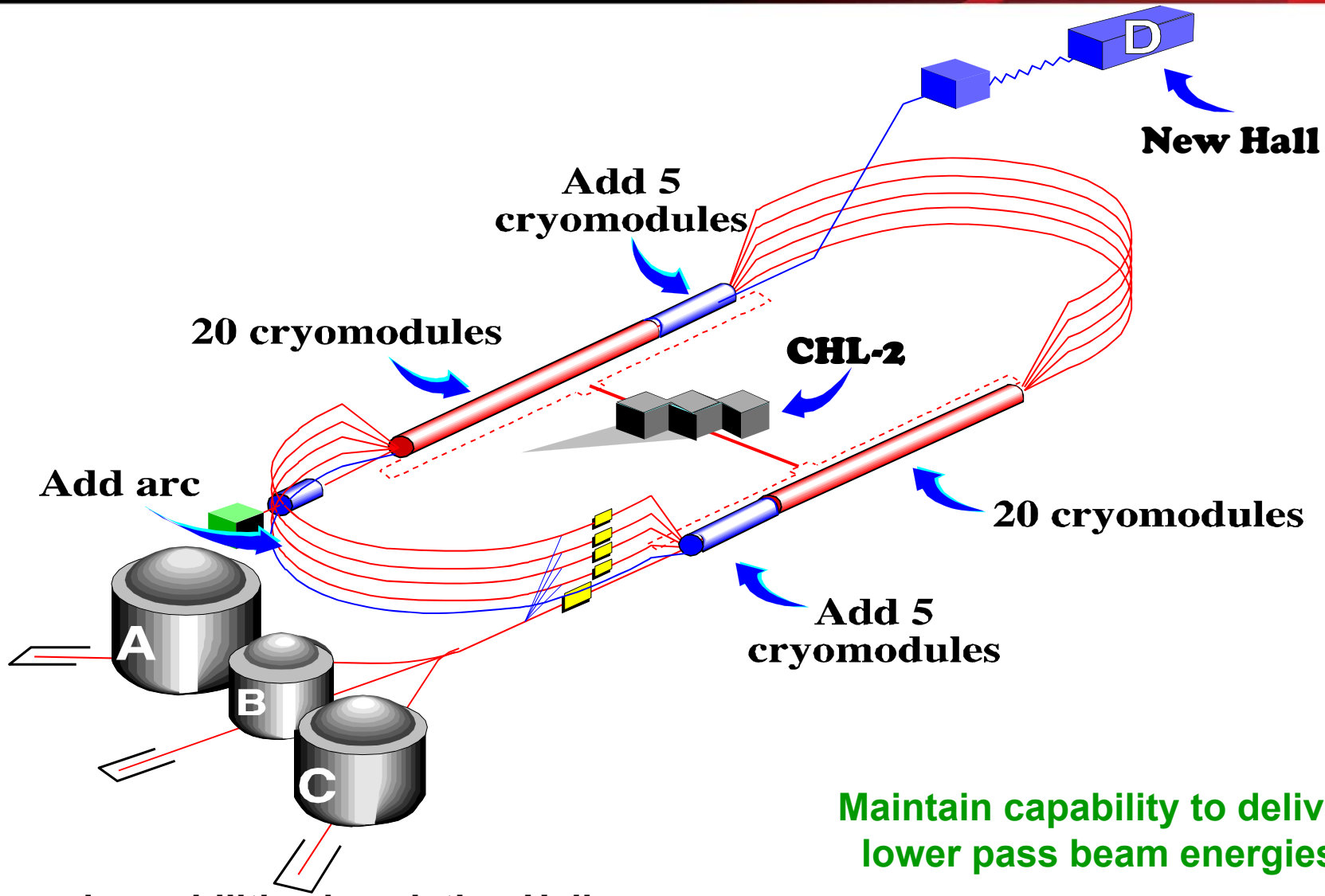




Irrespective of anomalies:

- New ~GeV–scale force carriers are important category of physics beyond the SM
- Fixed-target experiments @JLab (FEL + CEBAF) have unique capability to explore this!

12 GeV Upgrade

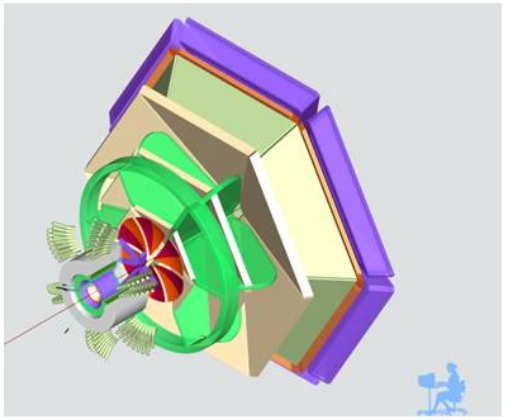


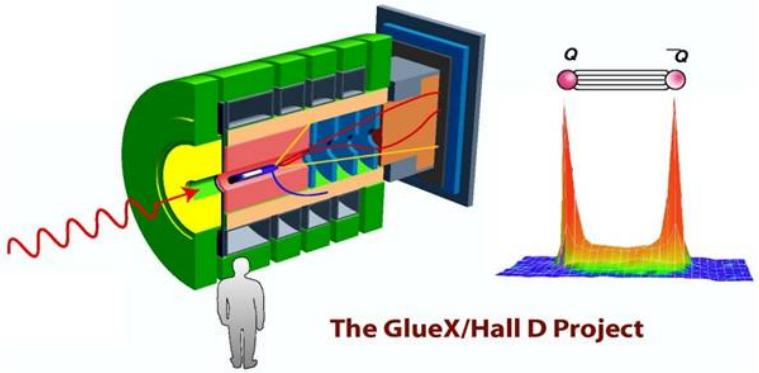
Maintain capability to deliver lower pass beam energies

Enhanced capabilities in existing Halls

Four Halls

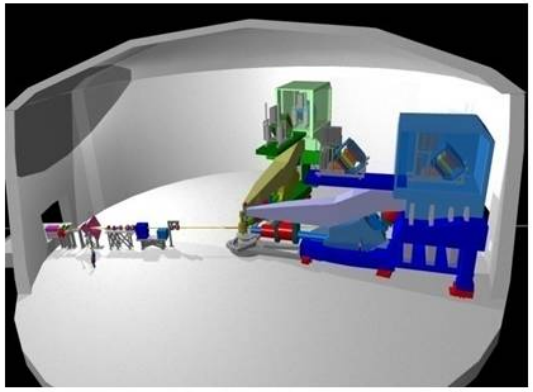
Hall D – exploring origin of confinement by studying exotic mesons

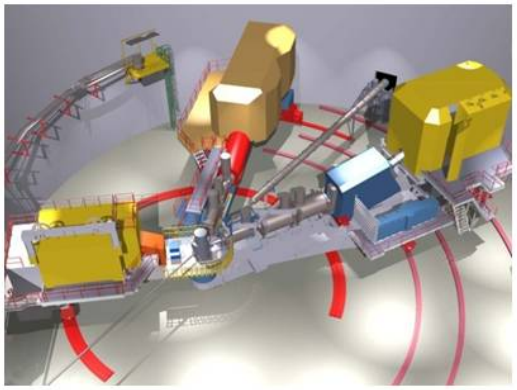




Hall B – understanding nucleon structure via generalized parton distributions

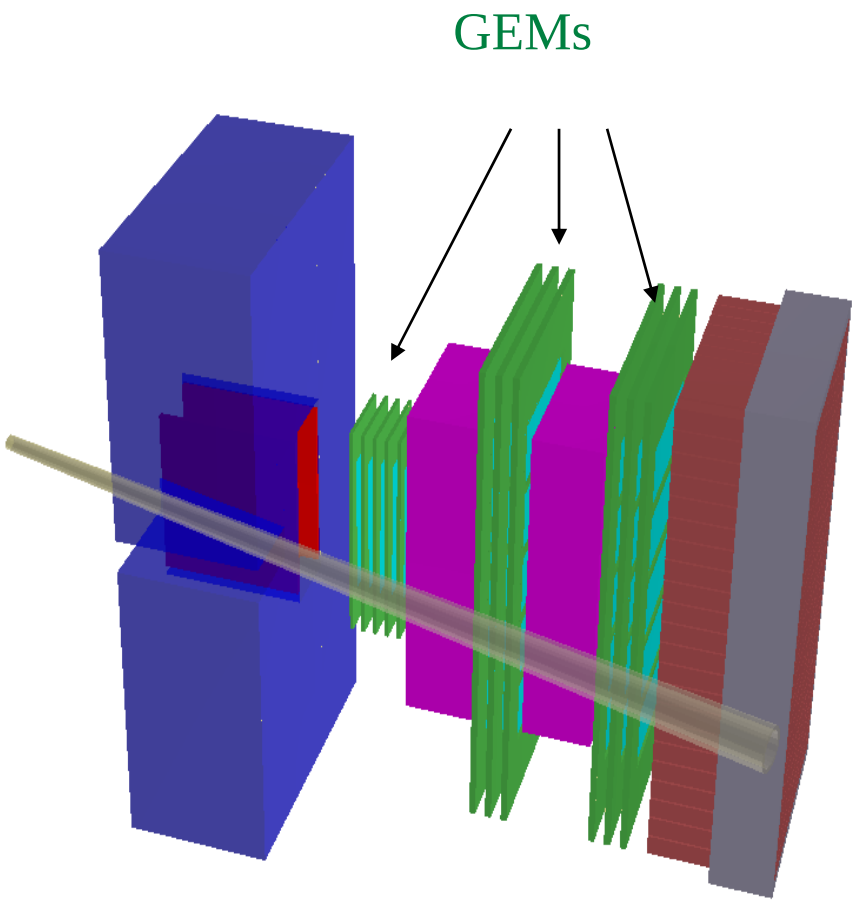
Hall C – precision determination of valence quark properties in nucleons and nuclei





Hall A – short range correlations, form factors, hyper-nuclear physics, future new experiments

Hall A (equipment beyond project)



Super Bigbite Spectrometer:

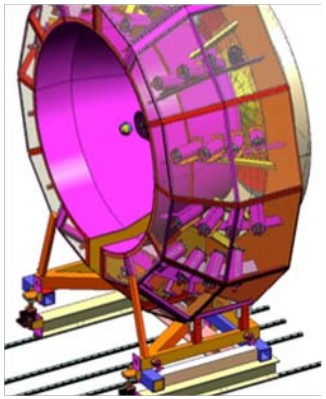
- large dipole magnet
- GEM trackers (~100,000 channels)
- hadron and EM calorimeter
- Trigger and DAQ

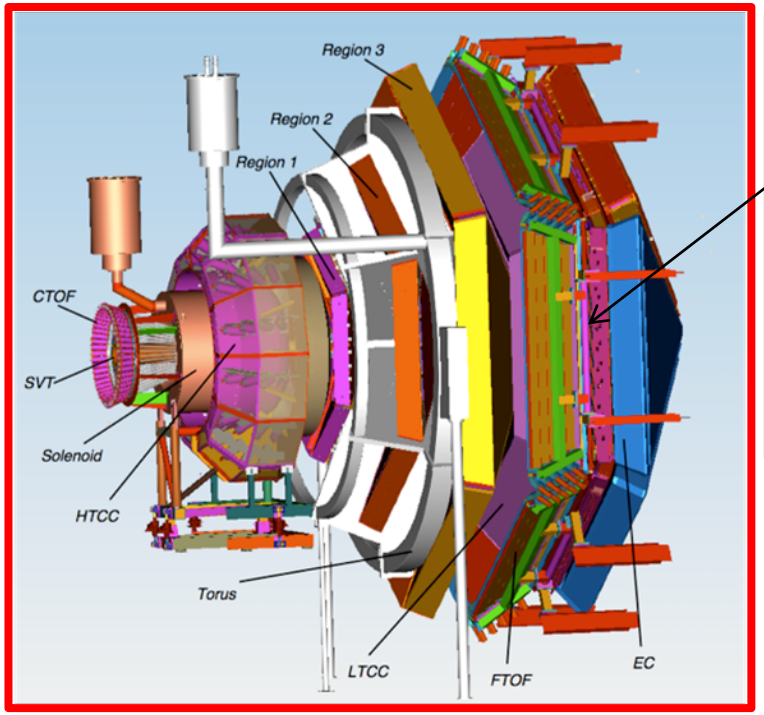
operating in open geometry at a luminosity of 10^{38} $cm^{-2}s^{-1}$

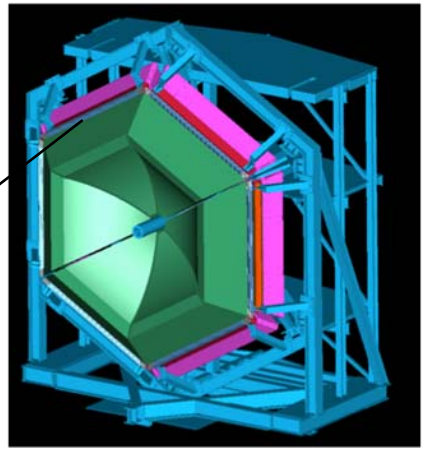
Hall B

CLAS12

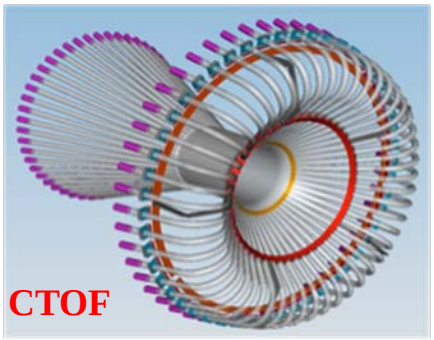
HTCC



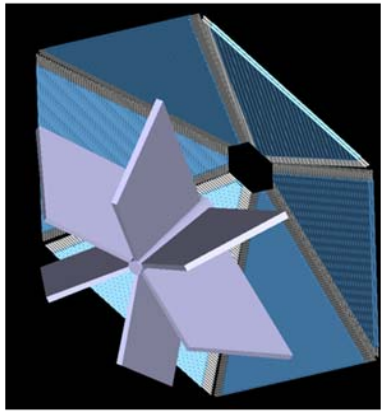




PCAL

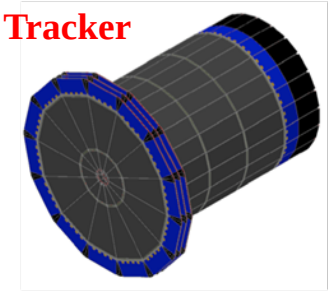


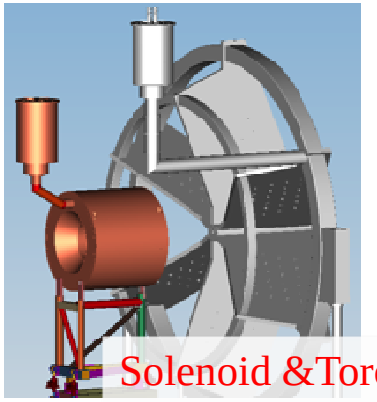
CTOF



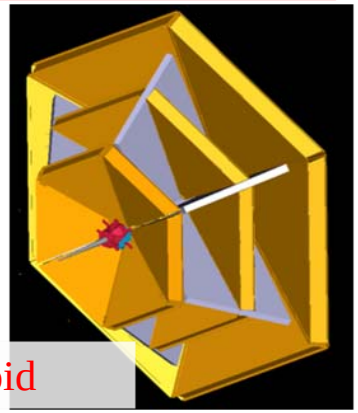
FTOF

Silicon Tracker





Solenoid &Toroid



Drift Chambers R1, R2, R3

Hall C

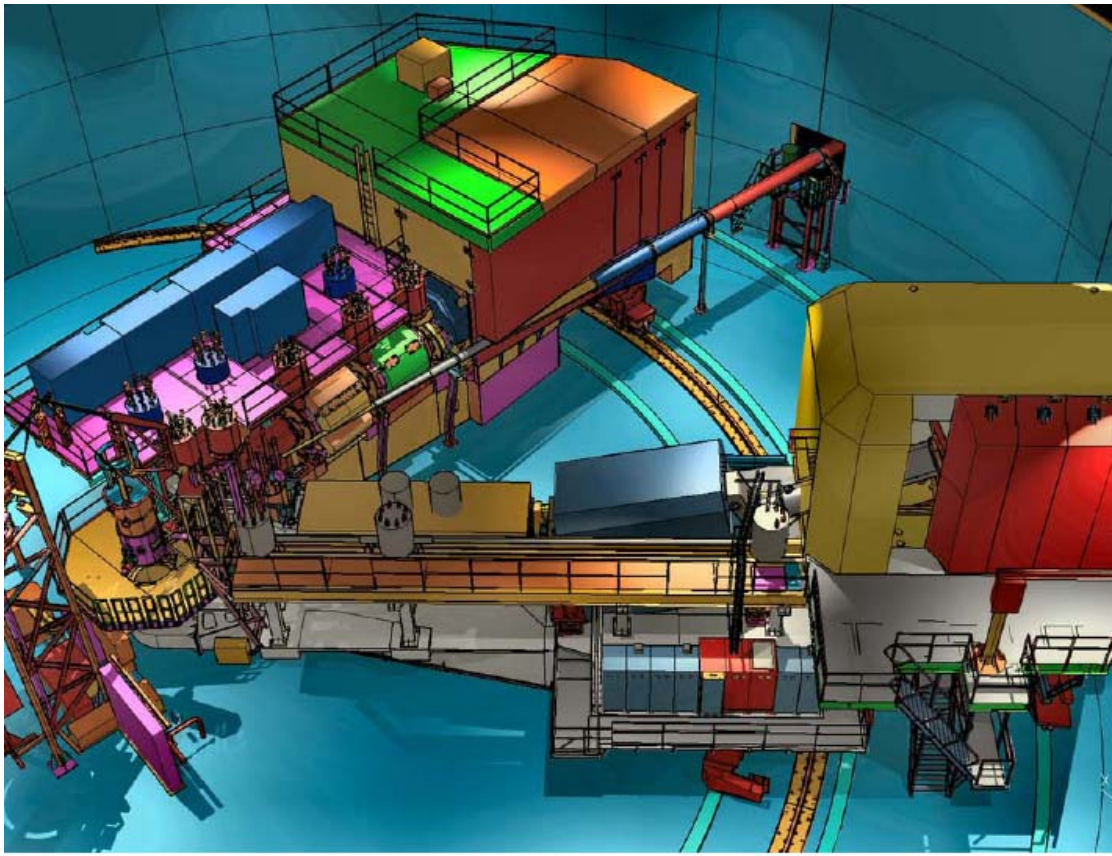
- **New Super High Momentum Spectrometer (SHMS)** Horiz. Bender, 3 Quads + Dipole

P →11 GeV/c
dP/P 0.5 –1.0x10^{-3}
Acceptance: 5msr, 30%
5.5°< θ< 40°

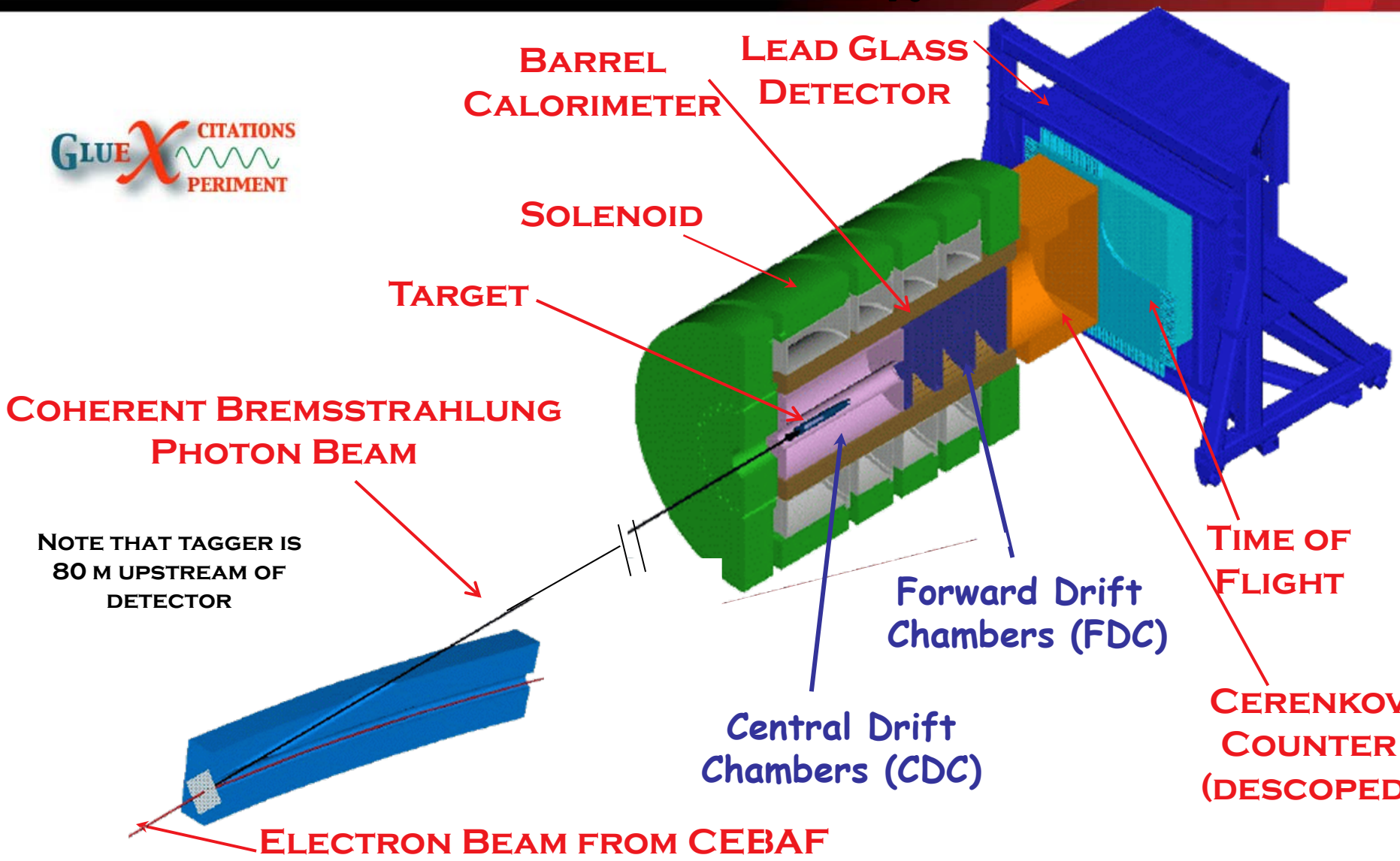
- **High Momentum Spectrometer (HMS)**

P →7.5 GeV/c
ΔP/P = 0.5 –1.0x10^{-3}
Acceptance: 6.5msr, 18%
10.5°< θ< 90°

- **Minimum opening angle: 17°**



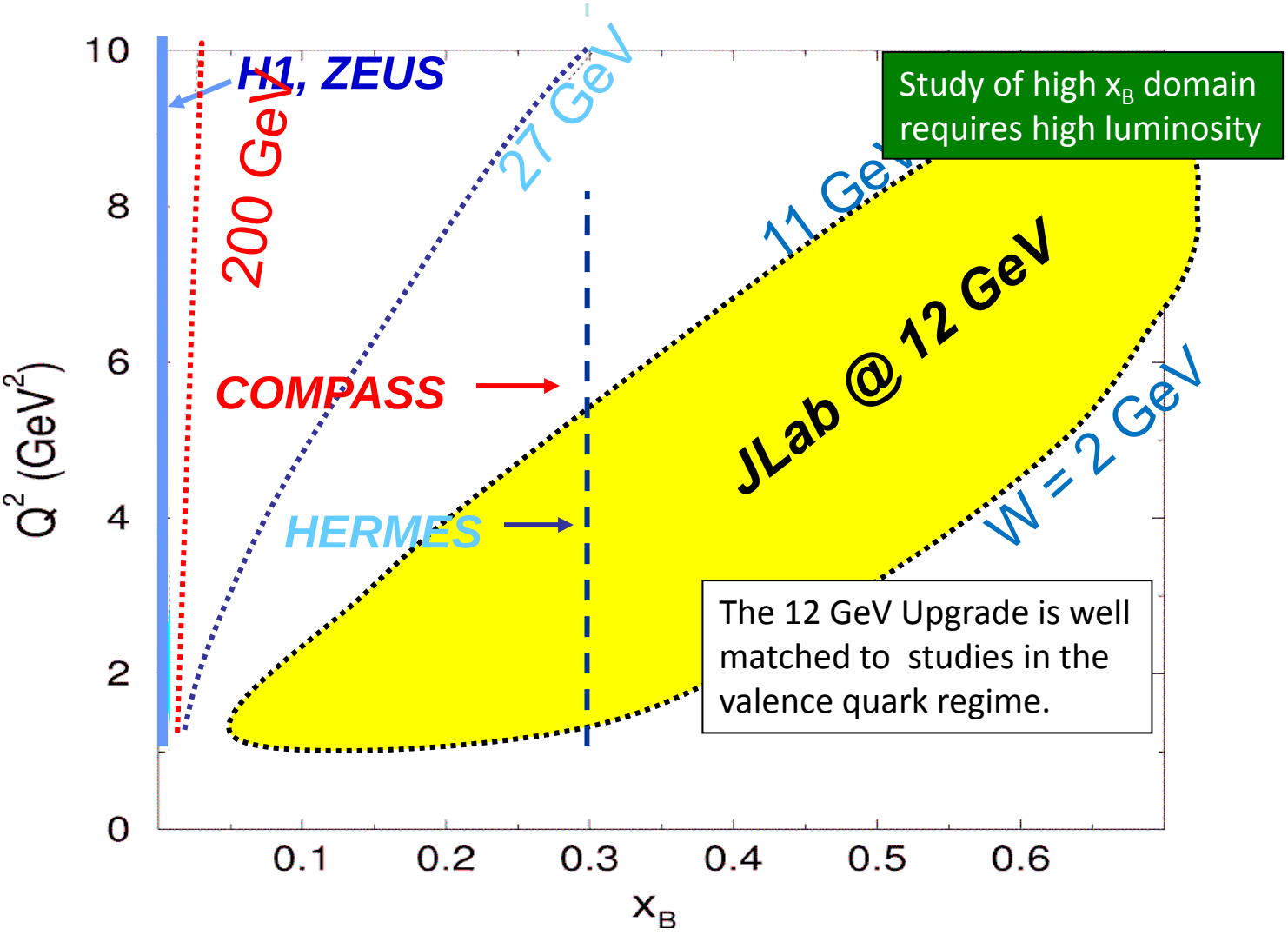
Hall D Gluex


Barrel Calorimeter
Lead Glass Detector
Solenoid
Target
Coherent Bremsstrahlung Photon Beam
Note that tagger is 80 m upstream of detector
Time of Flight
Forward Drift Chambers (FDC)
Cerenkov Counter (descoped)
Central Drift Chambers (CDC)
Electron Beam from CEBAF

12 GeV Physics seen by the Physics Advisory Committee

- **The Hadron spectra as probes of QCD**
  (GlueX and heavy baryon and meson spectroscopy)
- **The transverse structure of the hadrons**
  (Elastic and transition Form Factors)
- **The longitudinal structure of the hadrons**
  (Unpolarized and polarized parton distribution functions)
- **The 3-D structure of the hadrons**
  (Generalized Parton Distributions and Transverse Momentum Distributions)
- **Hadrons and cold nuclear matter**
  (Medium modification of the nucleons, quark hadronization, N-N correlations, hypernuclear spectroscopy, few-body experiments)
- **Low-energy tests of the Standard Model and Fundamental Symmetries**
  (Møller, PVDIS, PRIMEX, …..)

Kinematic Coverage of the 12 GeV Upgrade



Asymptotic Freedom

Small Distance
High Energy

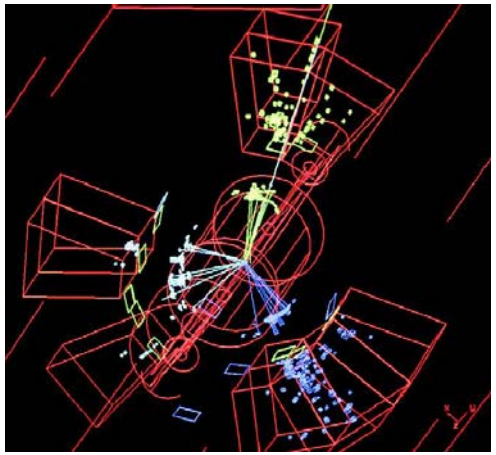
Confinement

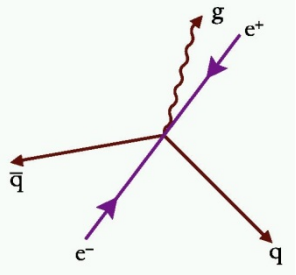
Large Distance
Low Energy

Perturbative QCD

Strong QCD

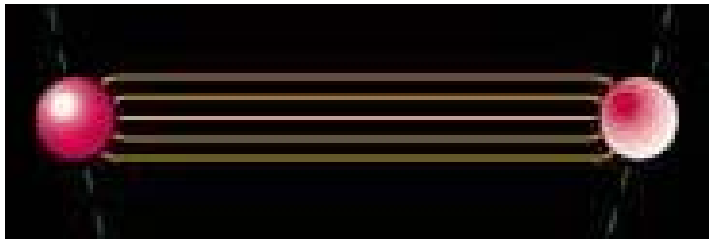
High Energy Scattering





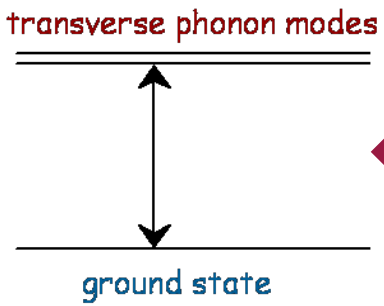
Gluon
Jets
Observed

Spectroscopy



Gluonic
Degrees of Freedom
Missing

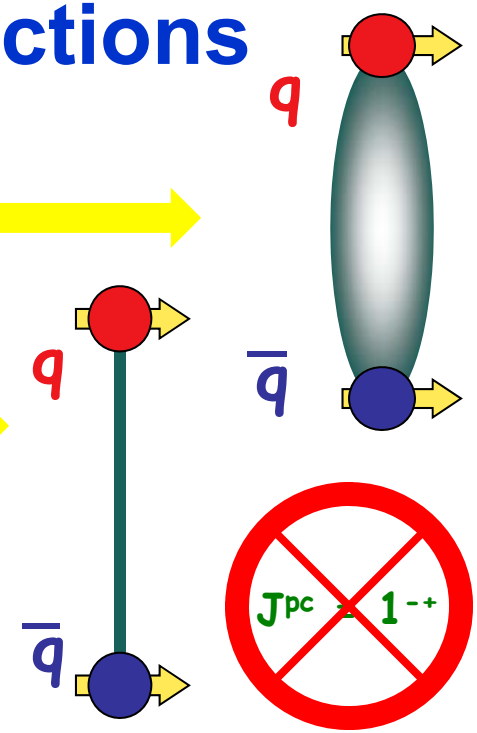
Hybrid mesons and mass predictions

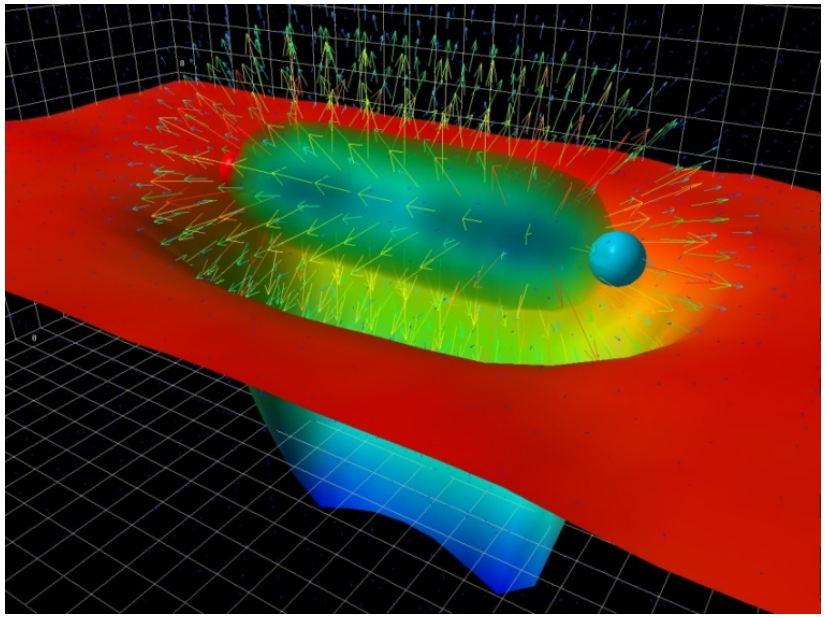


Hybrid mesons

1 GeV mass difference

Normal mesons





Lattice

1^{-+} 1.9 GeV

2^{+-} 2.1 GeV

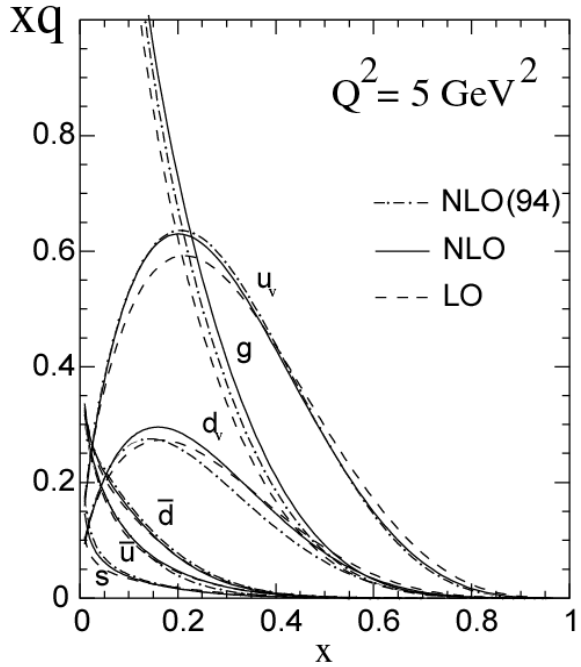
0^{+-} 2.3 GeV

Lowest mass expected to be $p_1(1^{-+})$ at 1.9±0.2 GeV

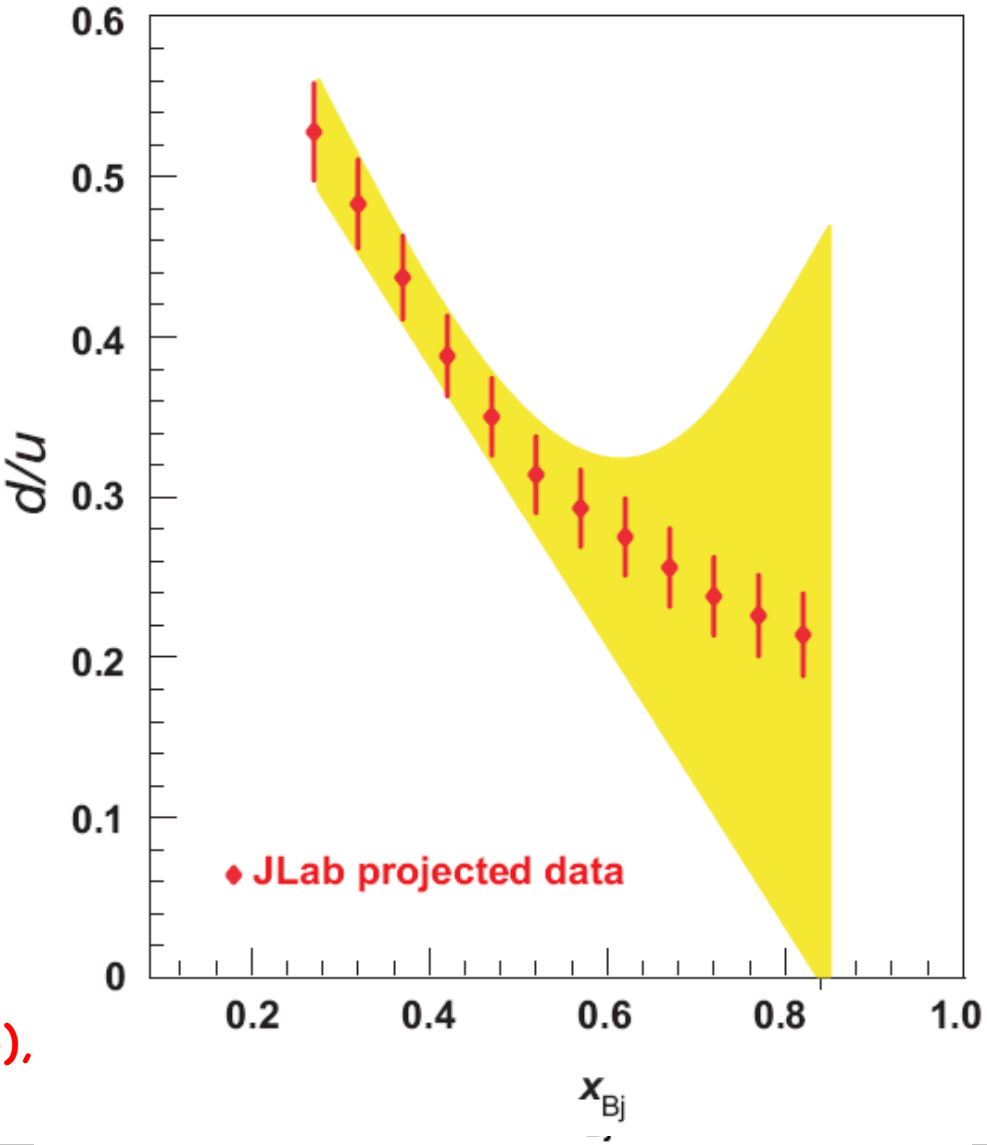
Measuring High-x Structure Functions

REQUIRES:

- High beam polarization
- High electron current
- High target polarization
- Large solid angle spectrometers

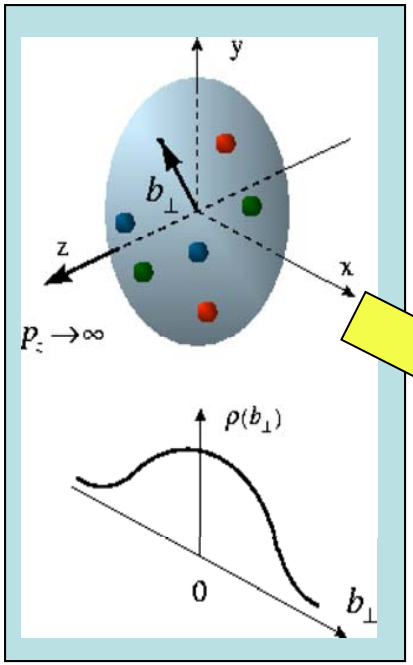


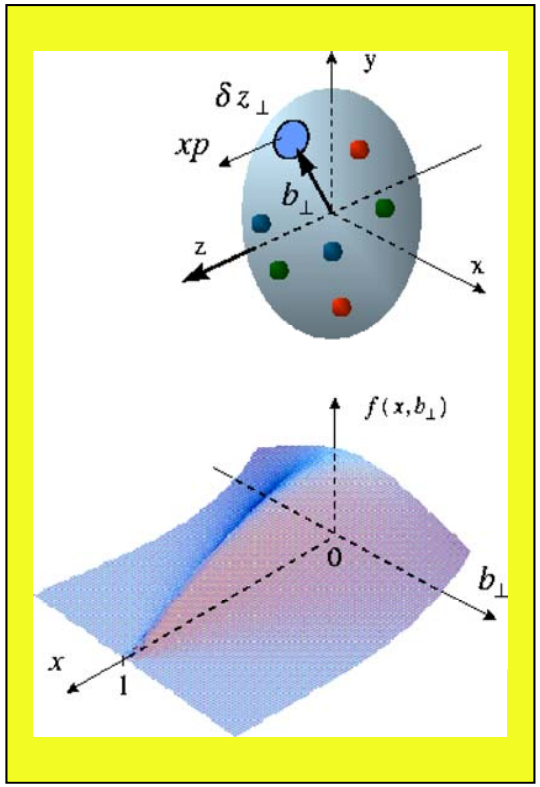
12 GeV will access the regime (x > 0.3), where valence quarks dominate

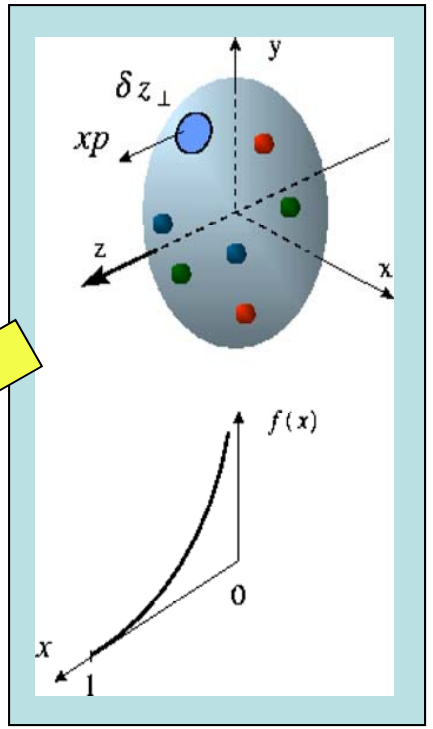


Generalized Parton Distributions (GPDs)

X. Ji, D. Mueller, A. Radyushkin (1994-1997)







Proton form factors, transverse charge & current densities

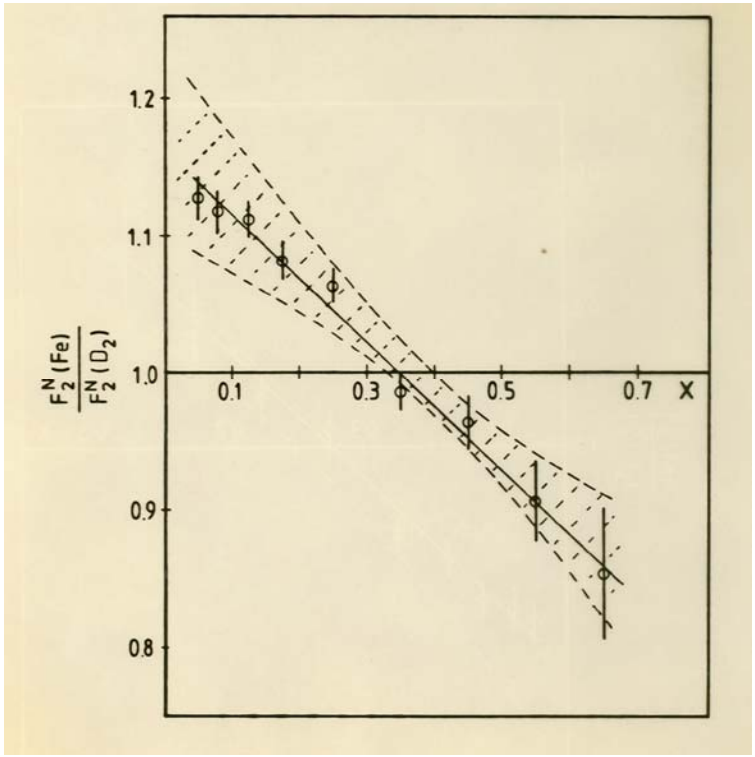
Correlated quark momentum and helicity distributions in transverse space – GPDs, TMDs

Structure functions, quark longitudinal momentum & helicity distributions

The Nucleus : The EMC Effect

1982

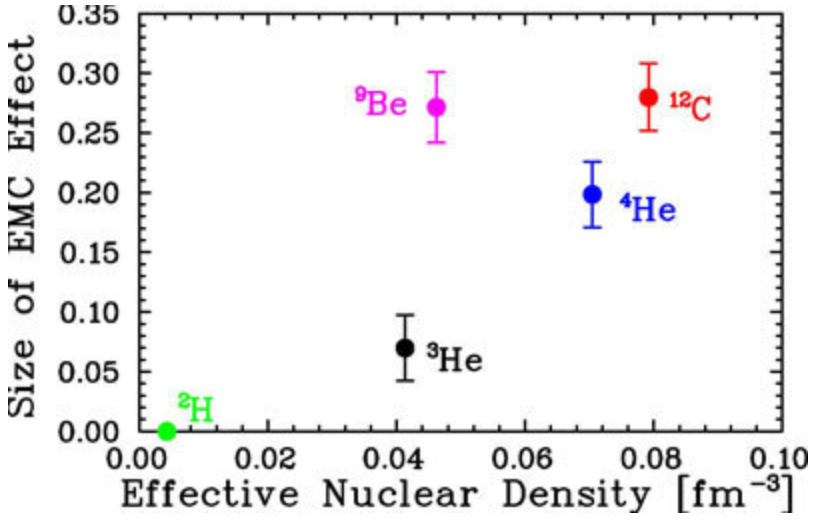
EMC Effect Observed

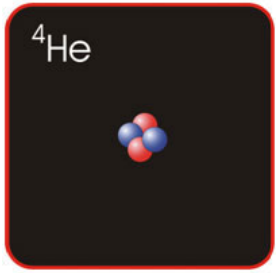


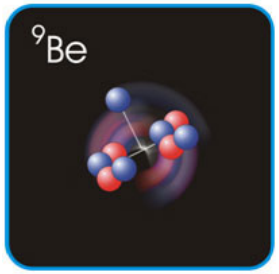
2009

Origins Still Obscure

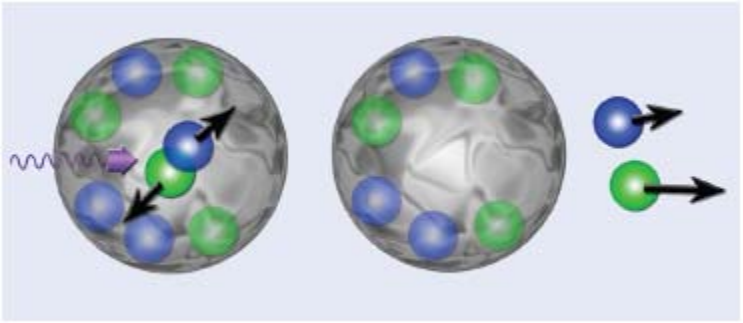
Local Density Effect?

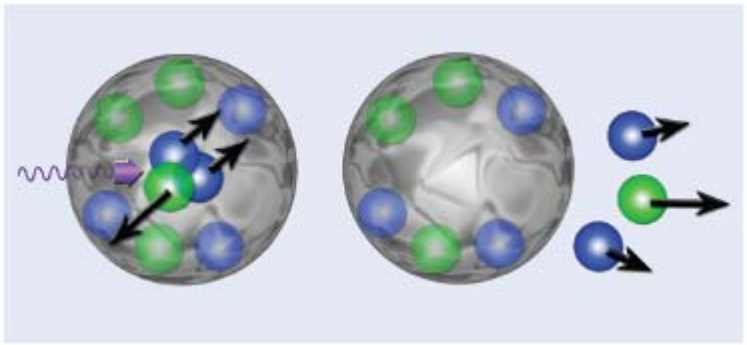




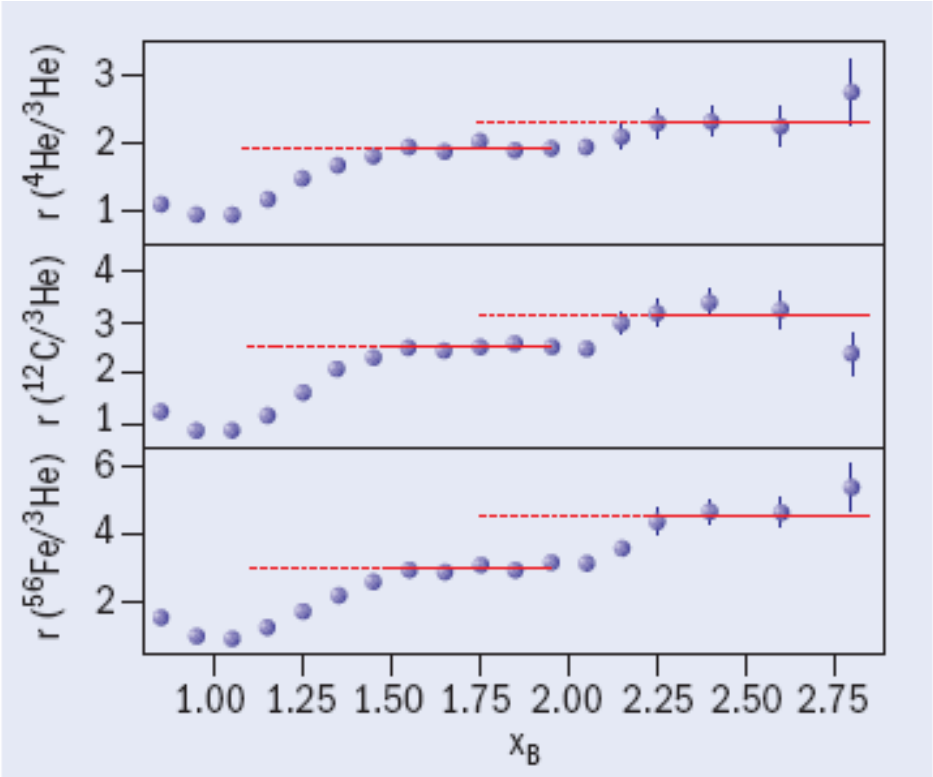


Nucleon-Nucleon Short Range Correlations





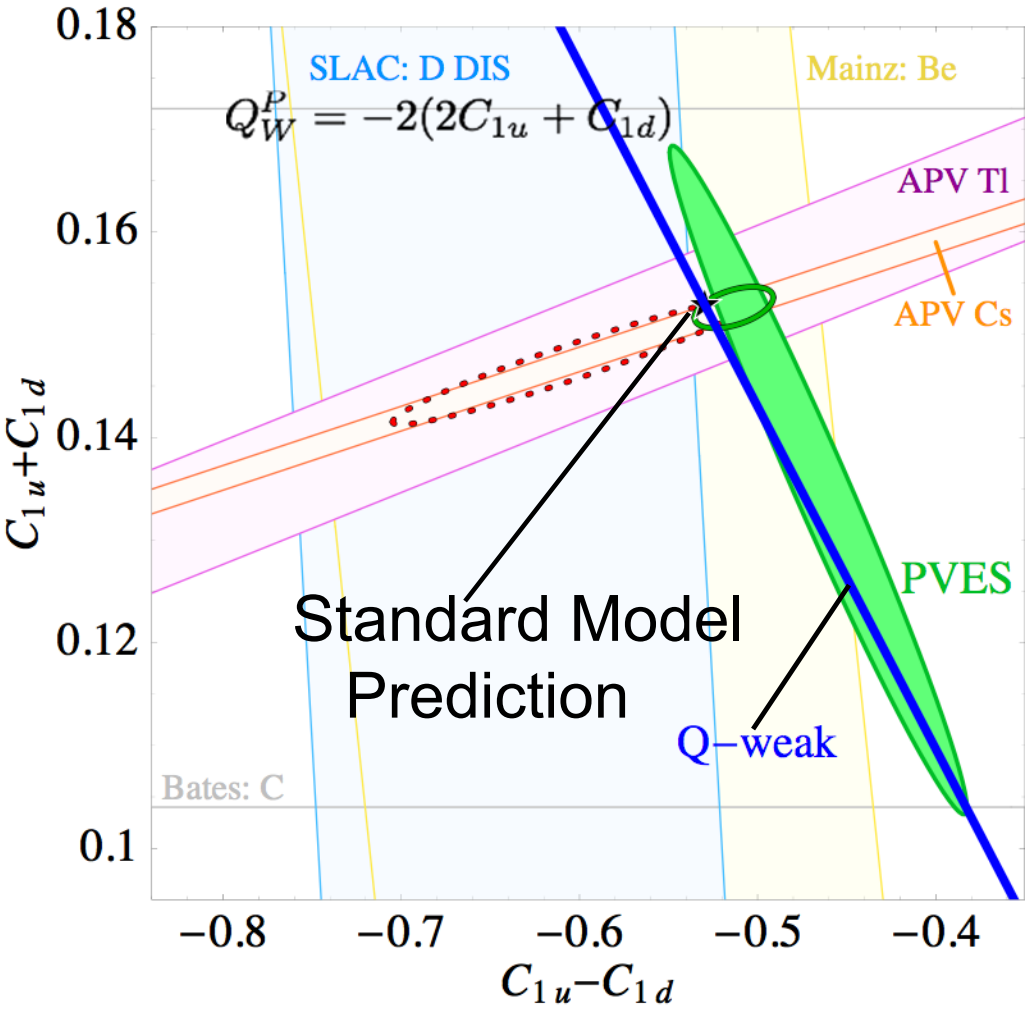
- Strong multi-nucleon component indicating short range correlations
- p-n dominates
- Plateaux x>1 scale with EMC slope $0.35<x_{Bj}<0.7$??



Experiment from Jefferson Lab
Graphics from CERN Courier

Short Range Correlations and EMC Effect have common origin???

Weak Couplings



Isoscalar weak charge

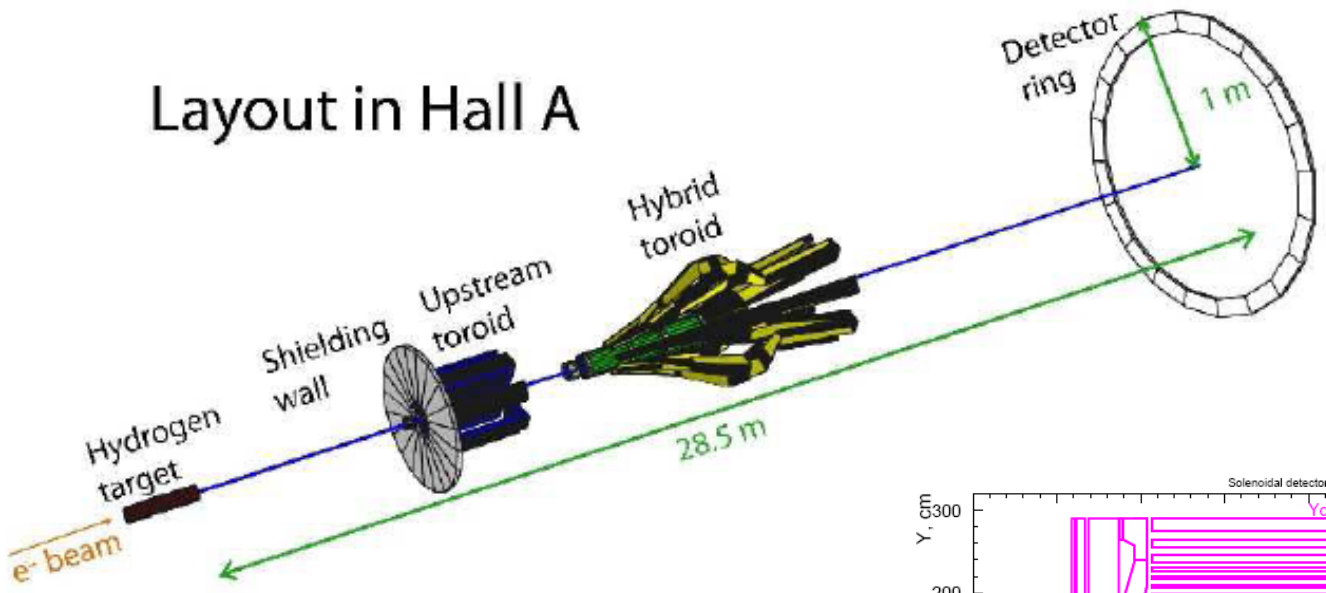
Isovector weak charge

All Data & Fits Plotted at 1 σ

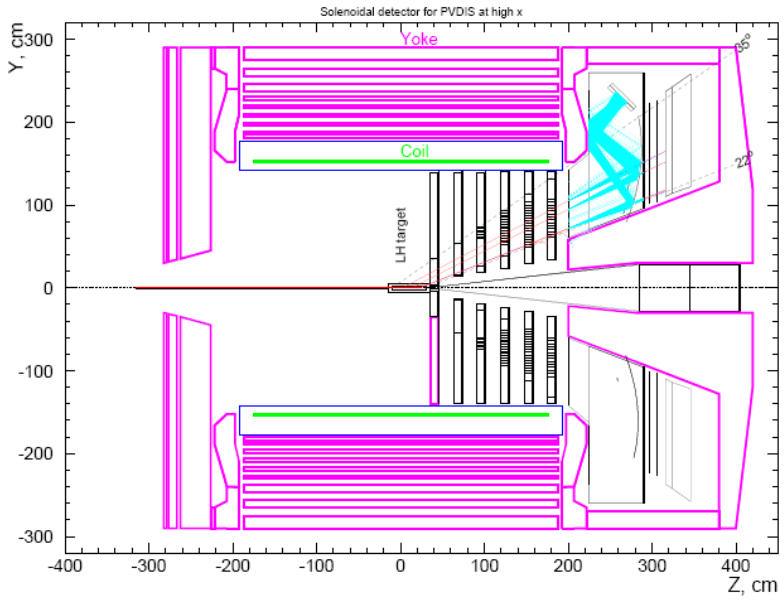
HAPPEx: H, He
G^0: H,
PVA4: H
SAMPLE: H, D

Q-weak expected precision

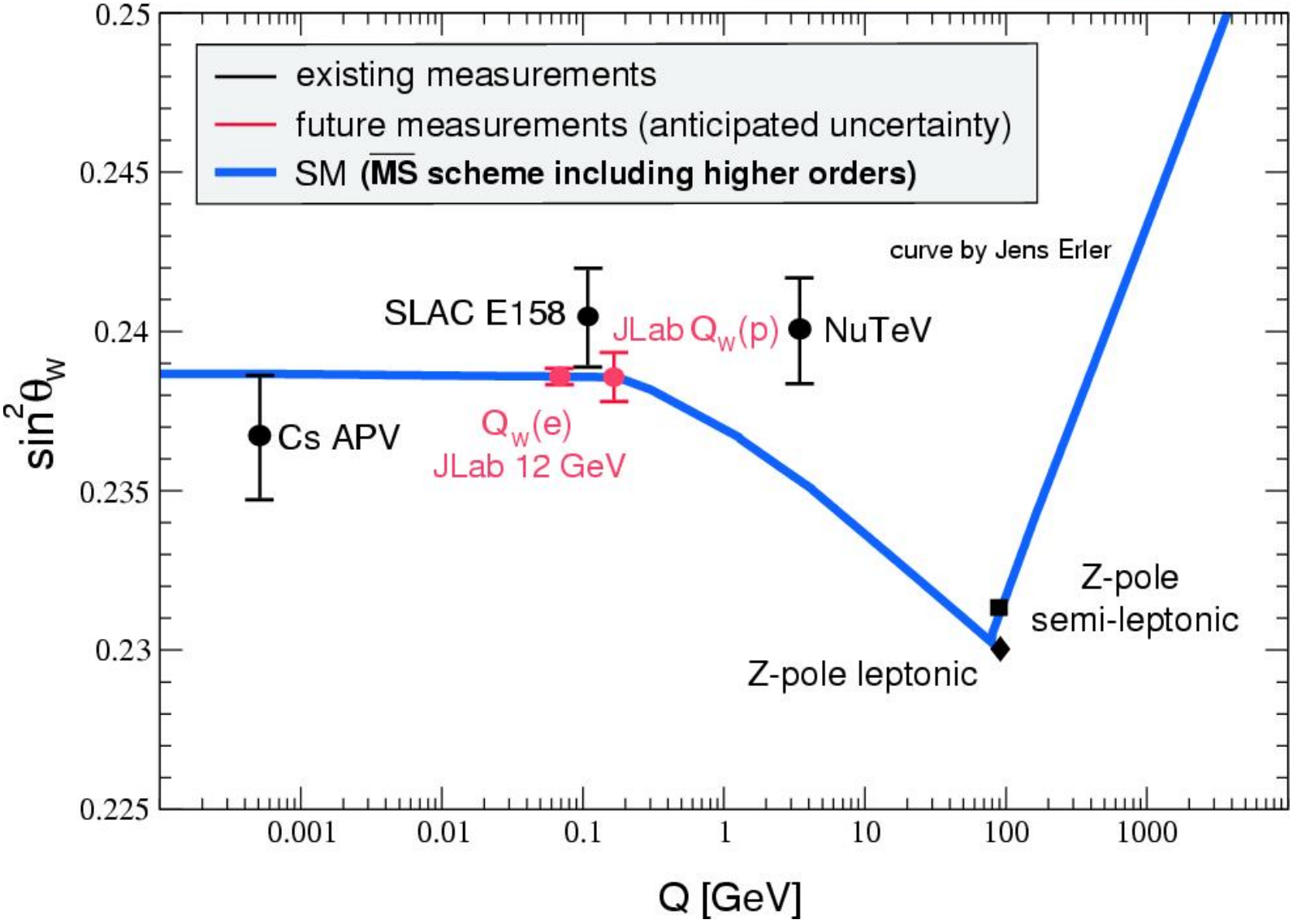
Møller & Deep Inelastic Scattering Parity Violation



- Dedicated Møller Experiment with toroids
- SoLID general purpose deep inelastic parity violating experiment with solenoid
  - Semi-Inclusive Program



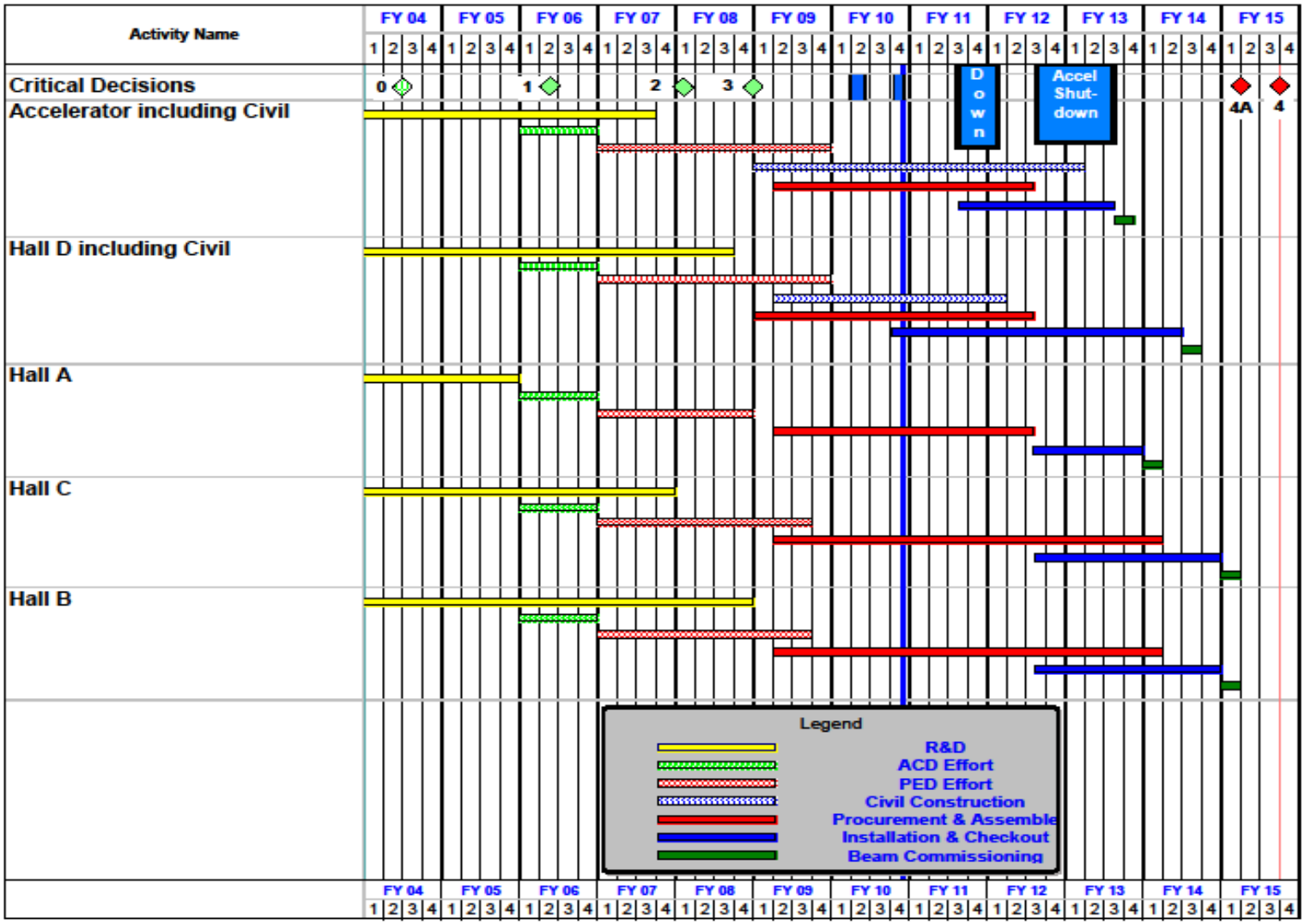
$\sin^2\theta_W$


existing measurements
future measurements (anticipated uncertainty)
SM (MS scheme including higher orders)
curve by Jens Erler
SLAC E158
JLab $Q_W(p)$
NuTeV
Cs APV
$Q_W(e)$
JLab 12 GeV
Z-pole
semi-leptonic
Z-pole leptonic
$\sin^2\theta_W$
Q [GeV]
0.25
0.245
0.24
0.235
0.23
0.225
0.001
0.01
0.1
1
10
100
1000

Upgrade Project Status

- Overall Project (End of July 2010)
  - Funding $145M
  - Cost Performance Index 0.95
  - Schedule Performance Index 1.00
    - On average less than a month behind schedule
    - Contingencies maintained
  - Contingency ~$53M,
    - ~43% of Est. To Complete.
    - FY11 is very constrained
    - Availability projected for FY12 and FY13
  - Effort on Project exceeds 120FTE
- Lehman Review (September 2010)
  - Satisfactory Review
    - Manpower management , appeared satisfactory
    - Schedule holding, civil schedule recovered
  - Concerns
    - Hall D Solenoid, Hall B Silicon

12 GeV UPGRADE SCHEDULE



CIVIL CONSTRUCTION - Hall D Complex

Hall D

June-July 2010

Counting House
Basement Walls/Stairwell

Hall D – NW Corner
Last wall lift

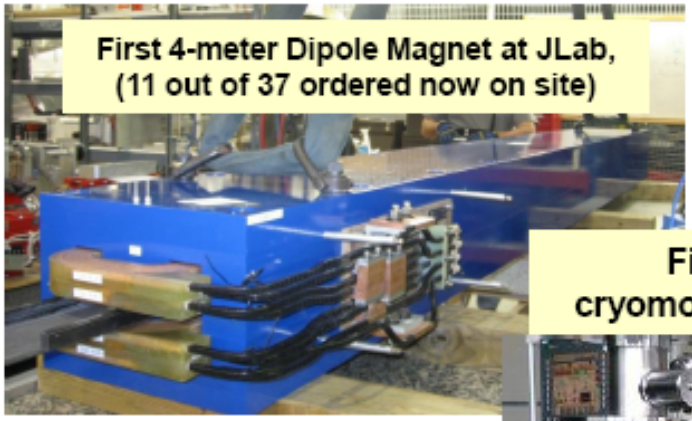
CIVIL CONSTRUCTION – Central Helium Liquefier (CHL) #2

- Ready for Equipment – May 5th
- *five months ahead of Level 2 Milestone Date*

- *Cryogenics equipment installation underway*

Accelerator Construction Highlights

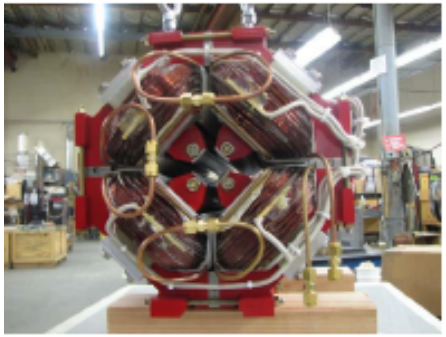
- **Major Procurements (> $500K) nearly complete:**
  - cryomodule cavities
  - beam transport magnets
  - cryogenics coldbox
  - vacuum valves
  - cold tuner
  - etc. etc. etc.



First 4-meter Dipole Magnet at JLab,
(11 out of 37 ordered now on site)

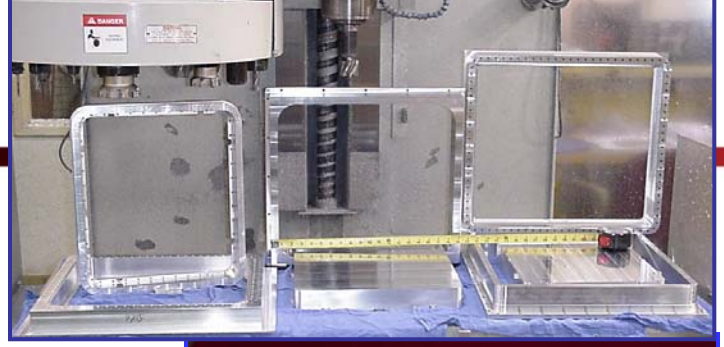
First two 12 GeV
cryomodule cavities on site

Beam Transport
Quadrupole Magnets at JLab
(114 - total order - now on site)

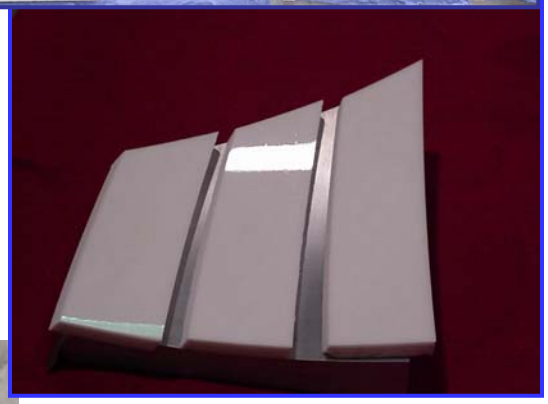


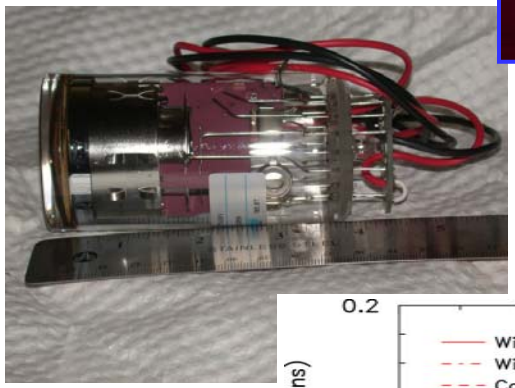
Hall B Detectors

SVT sensor bonding and probe testing (UNH and Moscow State)

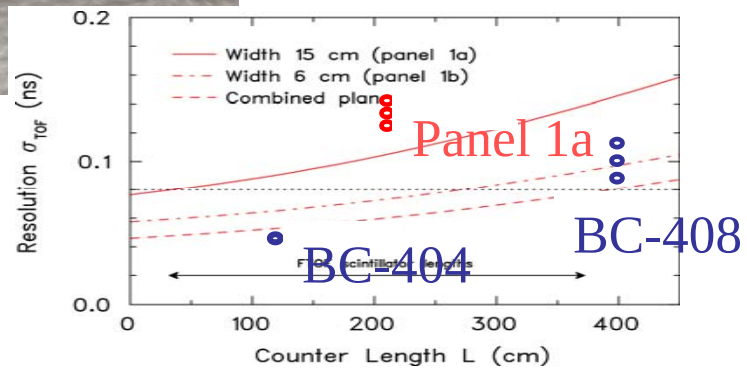


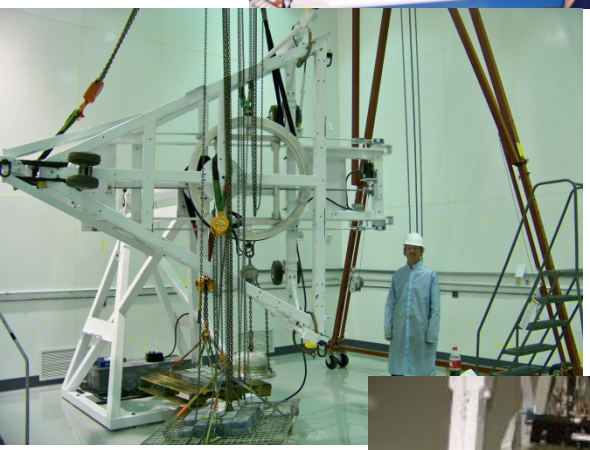
HTCC prototype molds and mirrors (JLab)





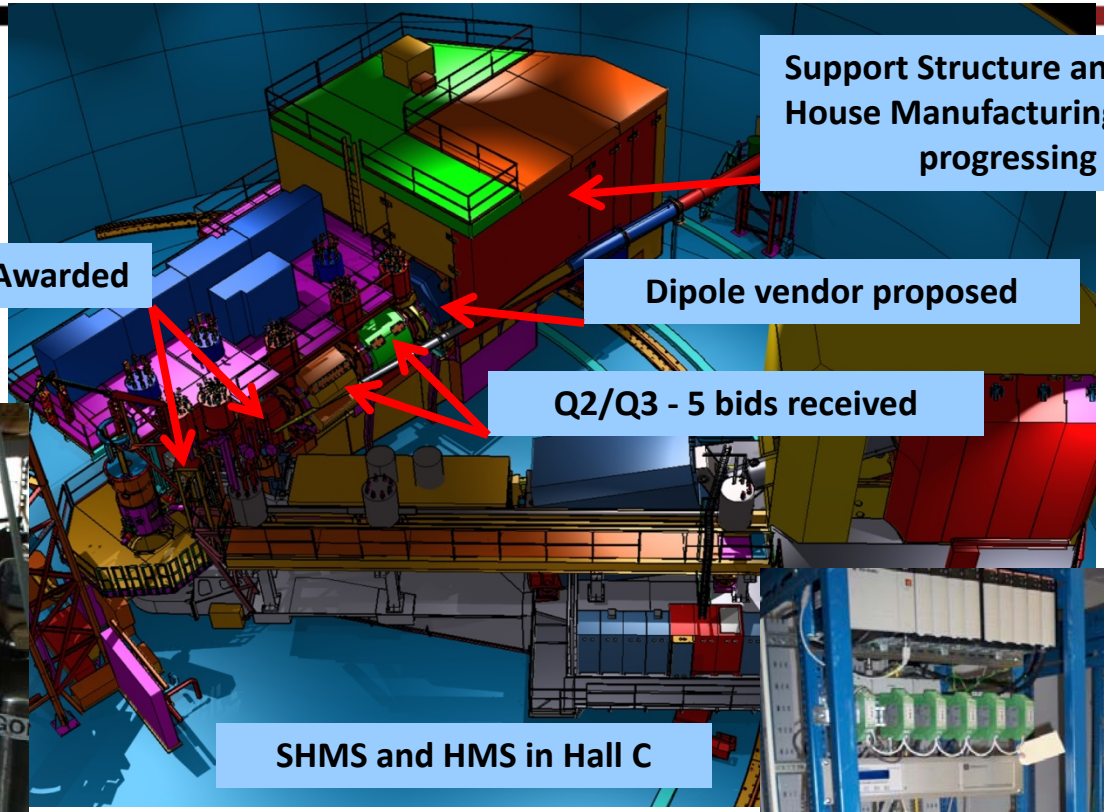
FTOF PMTs and timing test results (US Carolina, JLab)





Drift Chamber R2 wire stringing (ODU, and Idaho State)

Hall C - SHMS Infrastructure



Support Structure and Shield House Manufacturing Design progressing

HB and Q1 Contracts Awarded

Dipole vendor proposed

Q2/Q3 - 5 bids received

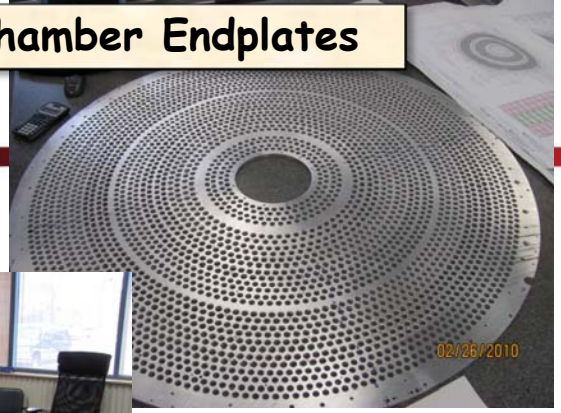
SHMS and HMS in Hall C

1st Cryogenic Control Reservoir

Magnet Control Racks

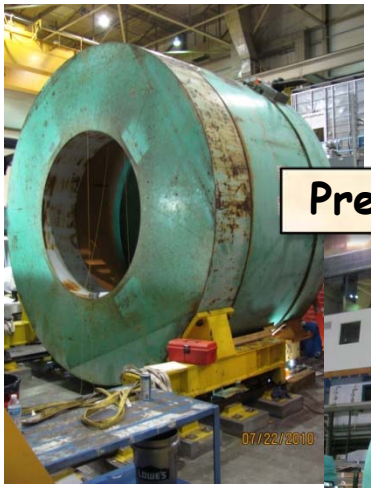
Hall D Detectors

Central Drift Chamber Endplates



Barrel Calorimeter Sixteenth Production Module

The Mighty BCAL Press



Preparing Solenoid Test

First BCAL Modules Arrive!

Jefferson lab 12 GeV Upgrade

An exciting scientific opportunity

- Explore the physical origins of quark confinement (GlueX)
- New access to the spin and flavor structure of the proton and neutron
- Reveal the quark/gluon structure of nuclei
- Potential new physics through high precision tests of the Standard Model

Strong User community involvement

- NSF MRI and NSERC funding to universities for detector elements
- Strong international collaborations and contributions
- > 32 PAC-approved experiments – ranking in progress

Accel-Civil-Physics scope leverages the existing facility

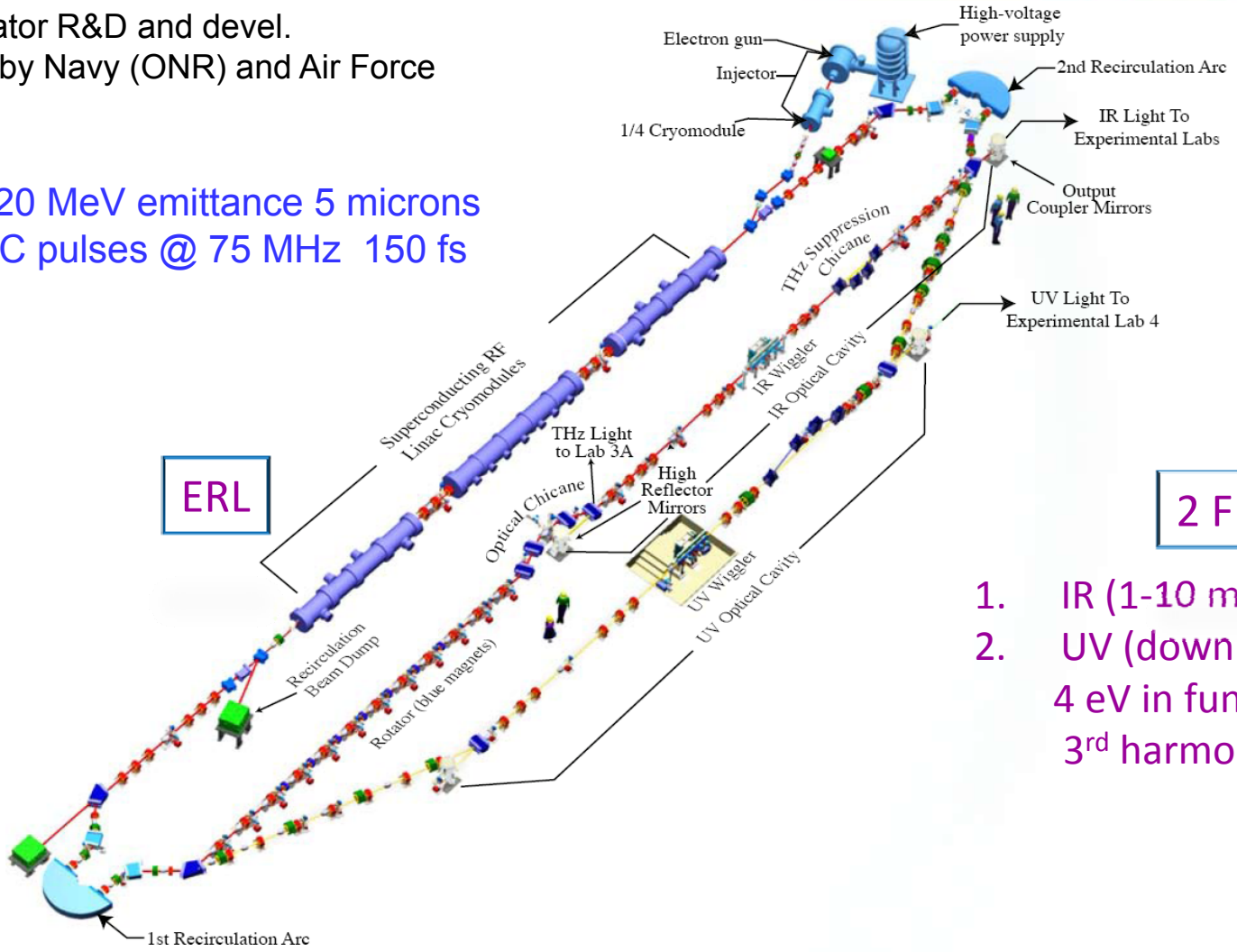
Construction is well underway !

New Proposals and collaborations are welcome

Jefferson Lab Light Source

Accelerator R&D and devel.
funded by Navy (ONR) and Air Force

E = 120 MeV emittance 5 microns
135 pC pulses @ 75 MHz 150 fs



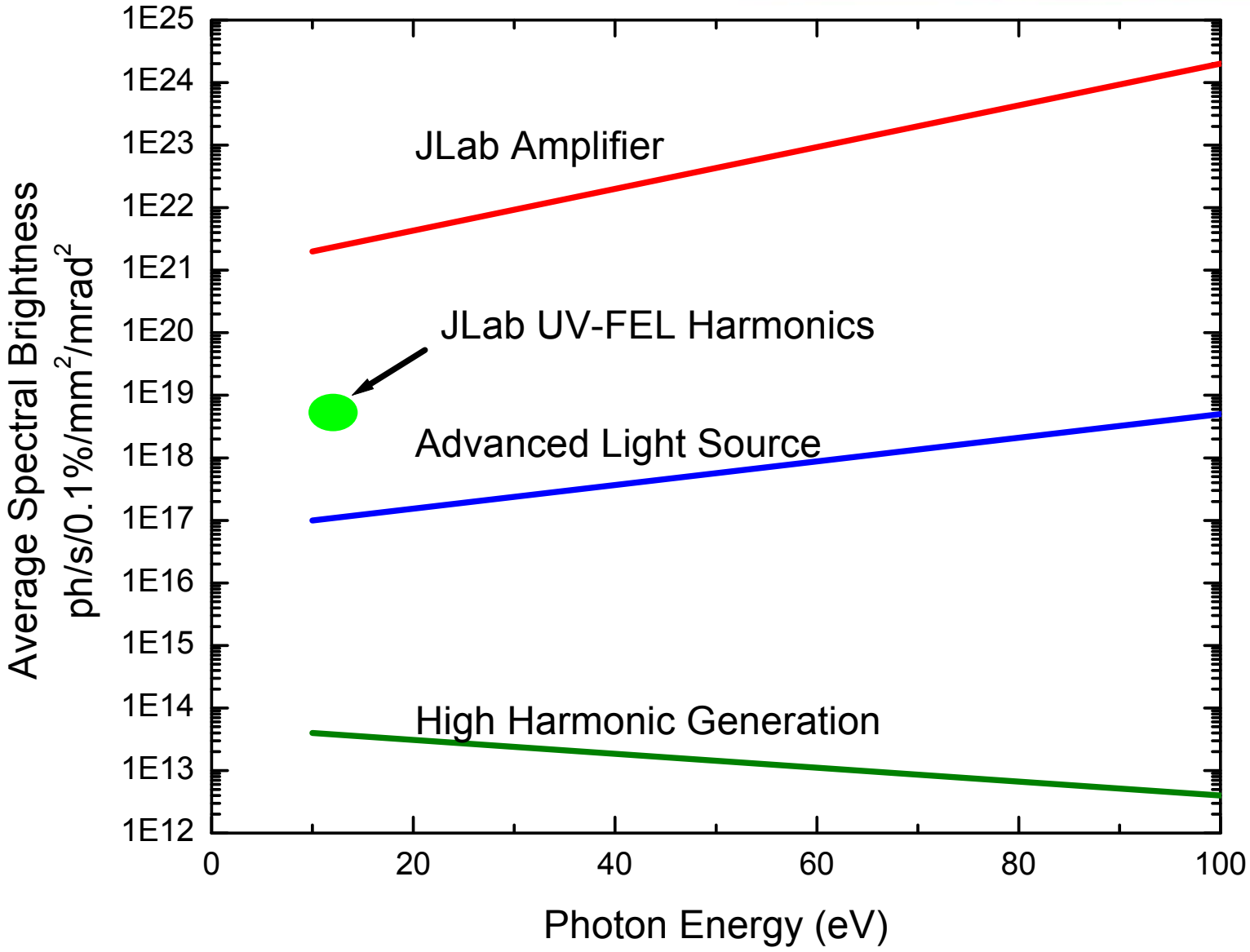
ERL

2 FELs

1. IR (1-10 microns), 14 kW
2. UV (down to 300nm)
   4 eV in fund. 12eV in 3rd harmonic

A VUV/IR/THz 4th Generation Light Source

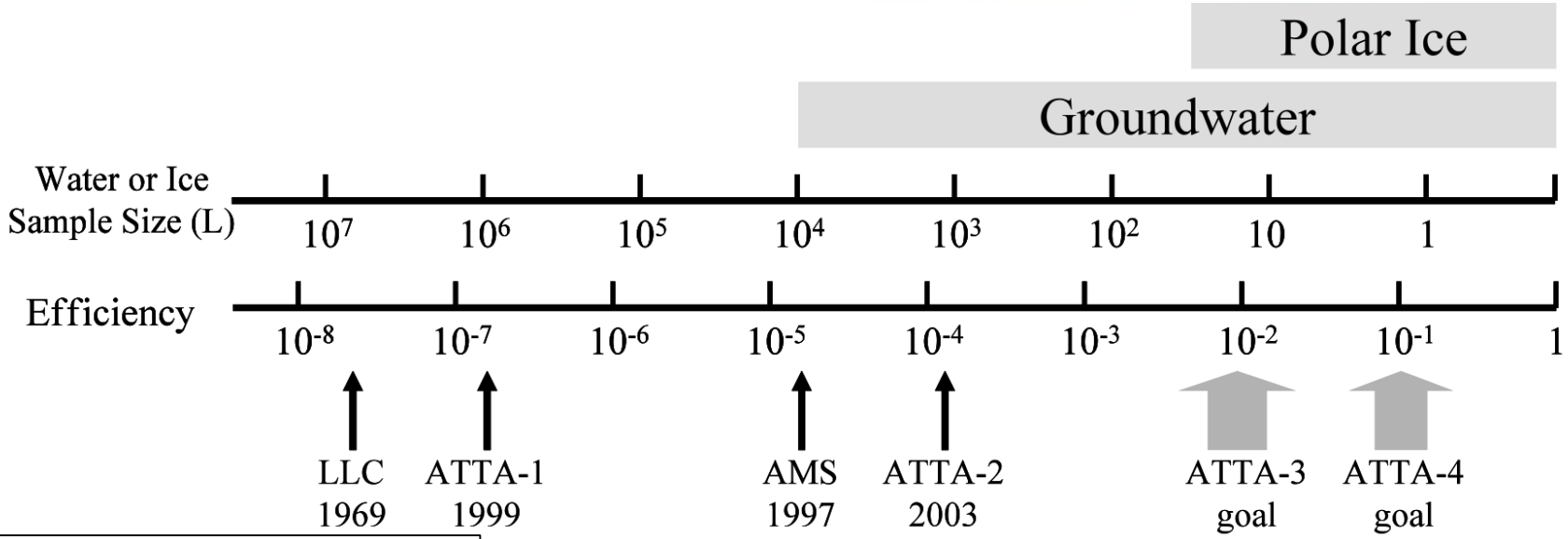
Jefferson Lab UV Source

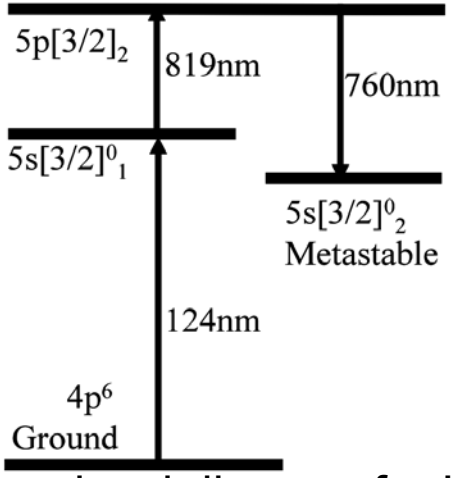


Potential New Science with JLab VUV FEL

- **Electronic structure of correlated materials. Johnson (BNL), Shen (Stanford)**
- **Combustion dynamics. Osborn (Sandia)**
- **Atom Trap Trace Analysis (ATTA). Zheng-Tian (ANL)**

Atom Trap Trace Analysis (ATTA)





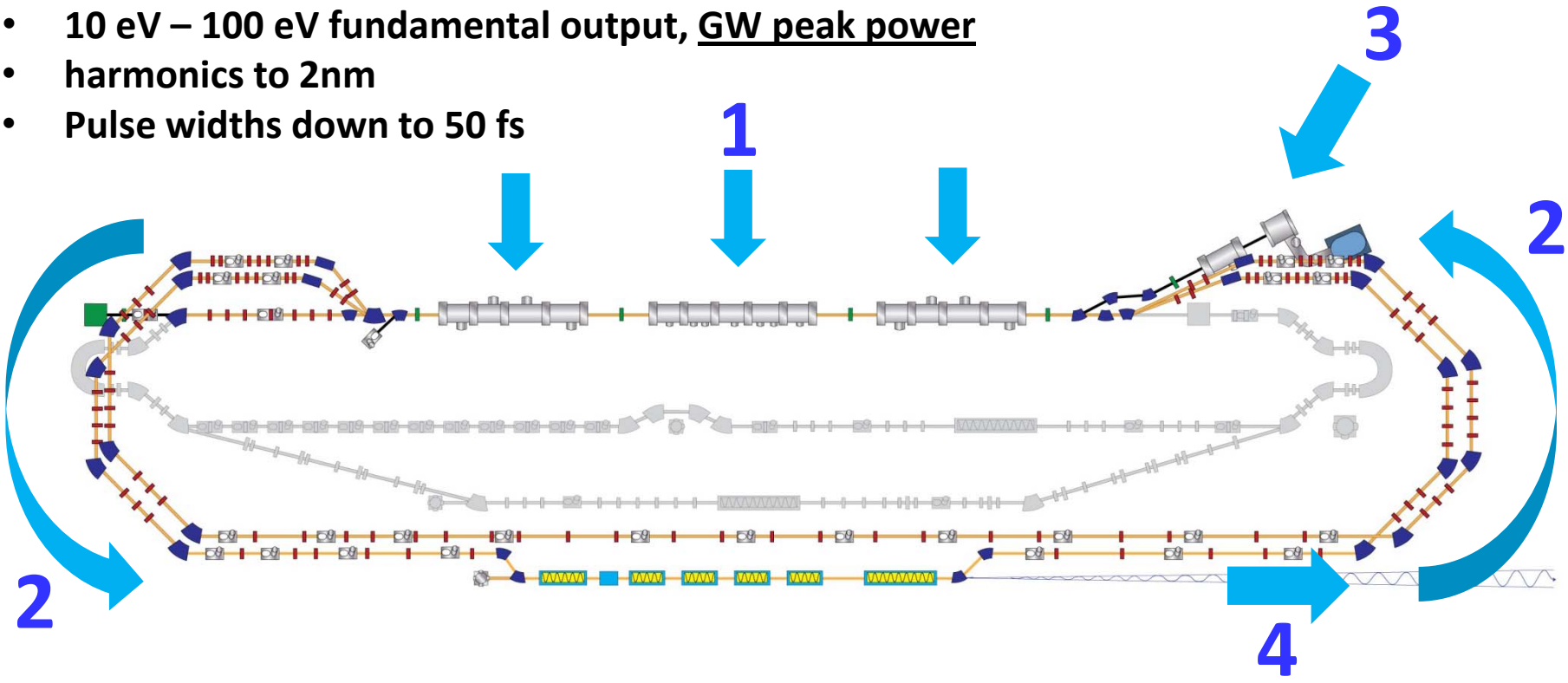
Energy level diagram for Kr

^{81}Kr half-life 229,000 years – ideal for water/ice in the 10^5 – 10^6 year range.
^{14}C half-life is 5,730 years

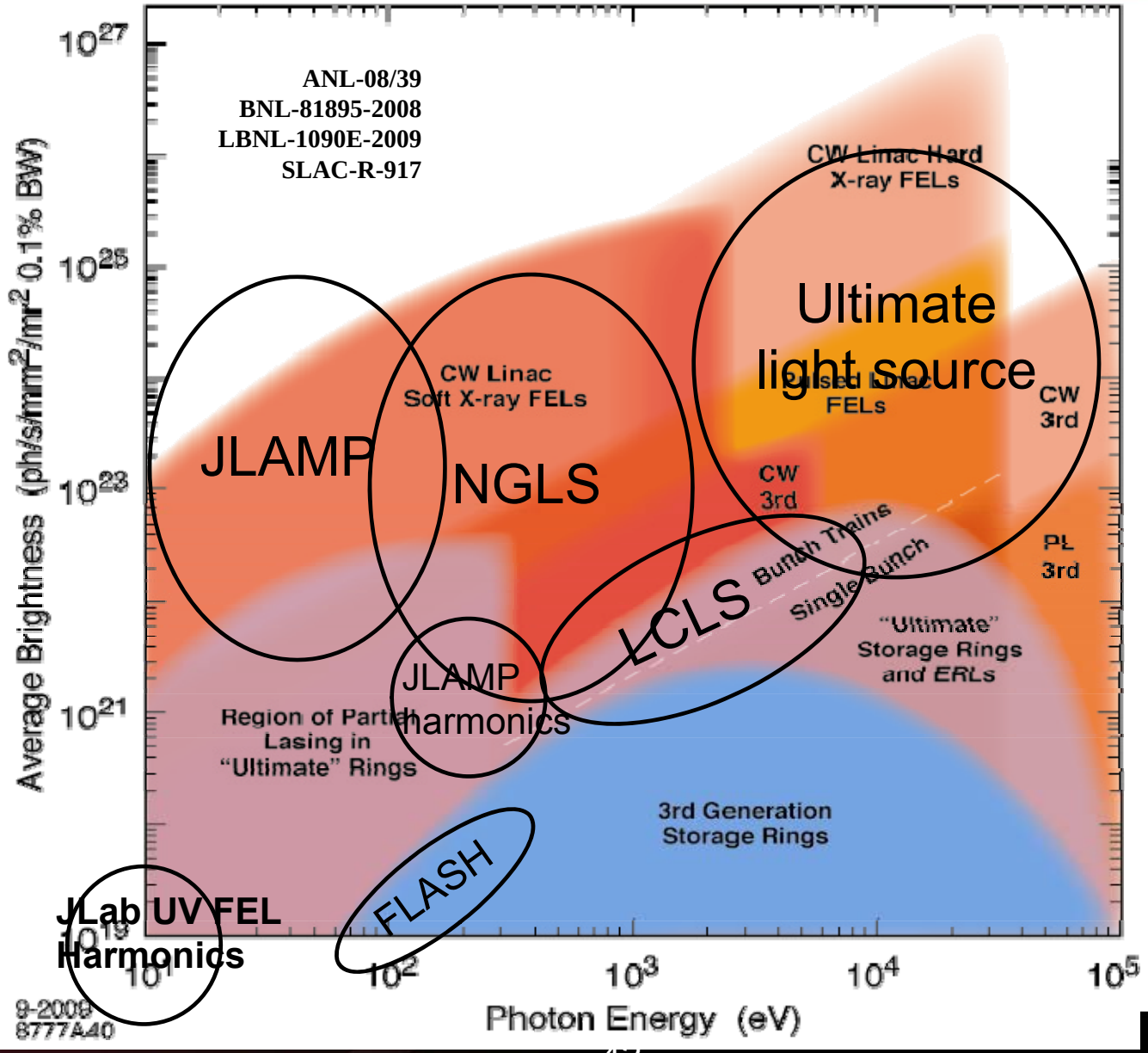
Courtesy Lu Zheng-Tian ANL

Jefferson Lab: Potential 100 eV Source

- 4 steps
- 600 MeV, 2 pass acceleration
- 200 pC, 1 mm mrad injector
- Up to 4.68 MHz CW repetition rate
- Recirculation and energy recovery
- 10 eV – 100 eV fundamental output, GW peak power
- harmonics to 2nm
- Pulse widths down to 50 fs



Average Brightness Plot for Light Sources



Potential 100 eV Physics Program: (from JLAMP Proposal)

- Condensed Matter Physics

- Chemical Physics and Atomic, Molecular, Optical Physics (AMO) and Laser-like VUV Pulses

- Imaging Biological and Soft Condensed Matter Systems

Accelerators and Nuclear Power

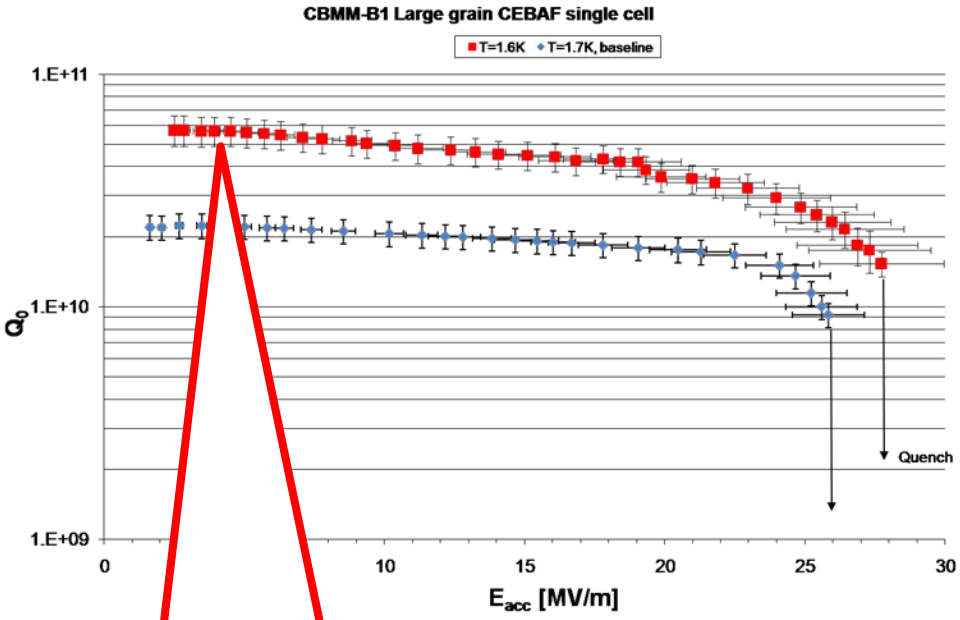
- Long history of proposals for using accelerators in the nuclear power industry
  - 1950 – Lawrence, High power accelerators for producing fissile materials
  - 1952 – Lewis, proposed use of thorium with intense neutron generator
  - 1992 – Bowman, Energy generation with ATW
    - *Accelerator Transmutation of Waste*
  - 1993 – Rubbia, Energy amplifier
- Concept
  - Enable Sustainability
    - Avoid criticality
    - Enable waste disposal
    - Enable alternative fuel cycles
- Require
  - High Power (10, 20 Megawatt), Reliable Accelerator

Accelerators and Nuclear Power

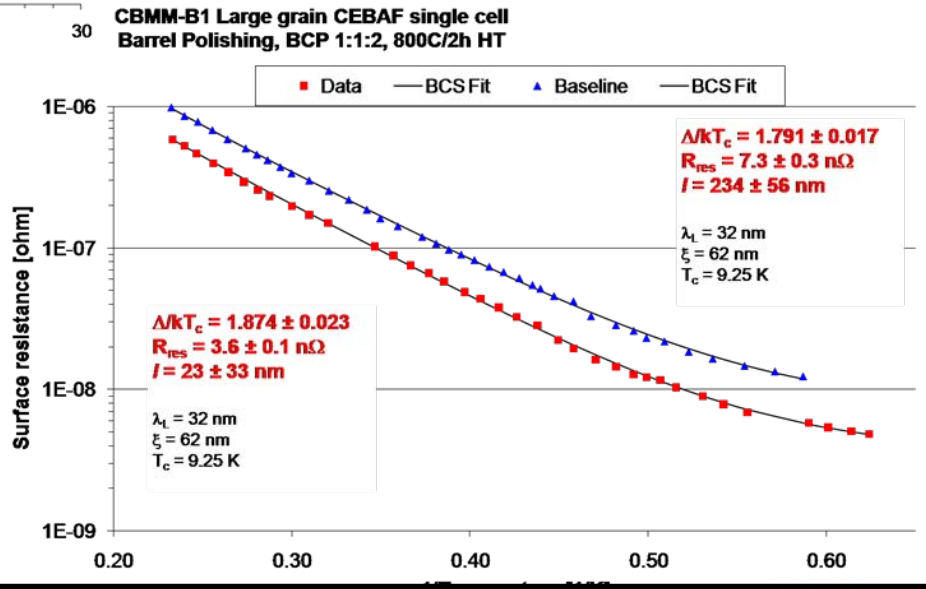
- EEU Projects
  - Eurotrans
  - MYRRHA – ADS demo at Mol, Belgium; CNRS/IN2P3 involved
- India
  - No Uranium
  - Foresee Thorium Cycle
  - Power from U-233
- China
  - Lots of discussions
- UK Thorea - Full Proposal for ADS demo
- United States
  - Discussions TJNAF with Brinkman about SRF progress
  - Possible Project X interest
  - Henderson Panel

It depends on SRF progress

800C, 2hrs (G.Ciovati):Large grain CBMM"B1"



Record Q Values
First results from DOE-NP
ARRA-funded Program



Electron Ion Colliders

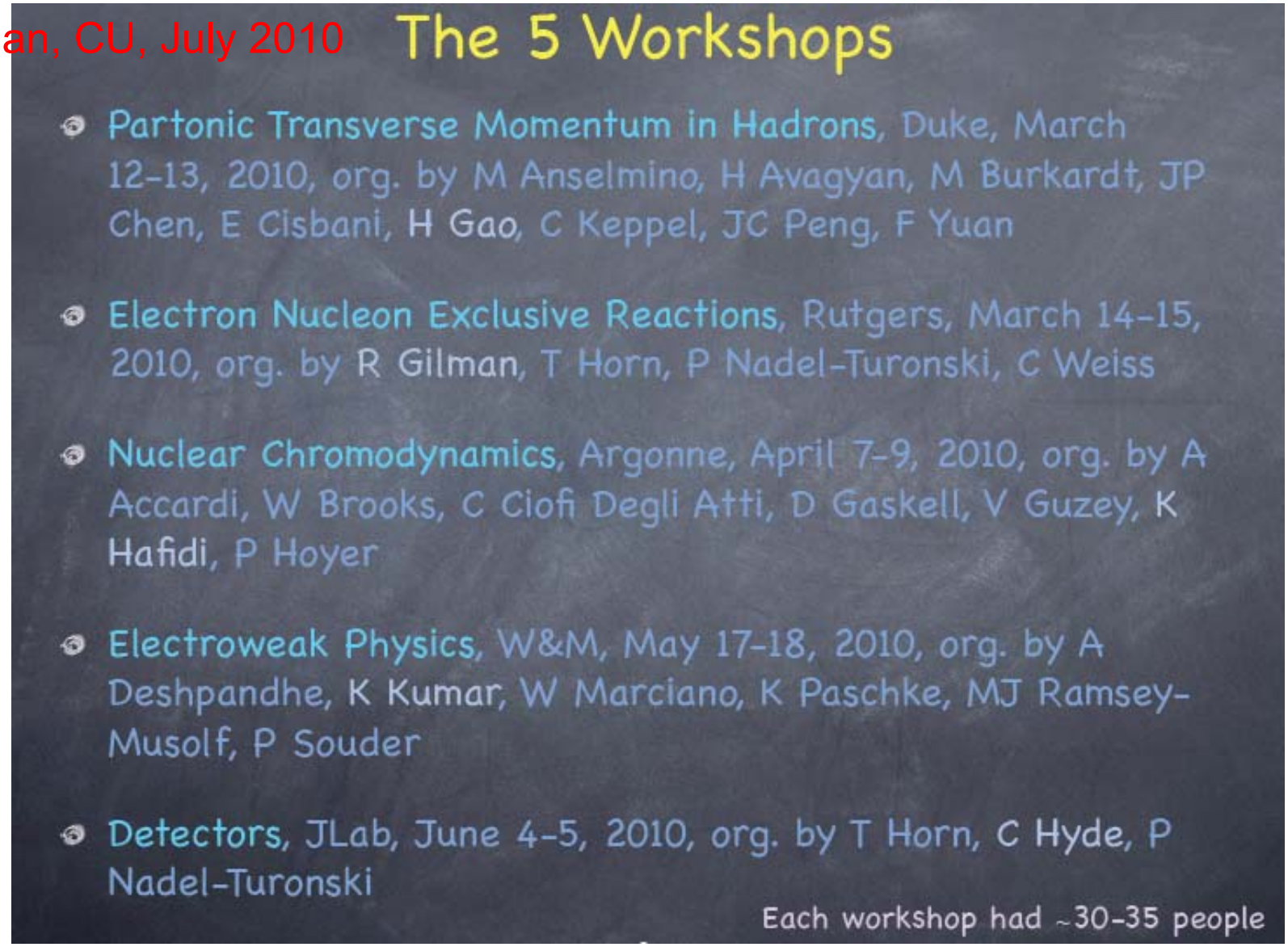
Design Goals for Colliders Under Consideration World-wide

	Energies	s	Design Luminosity
(M)EIC@JLab	**Up to 11 x 60+**	**240-3000**	**Close to 10^{34}**
Future ELIC@JLab	**Up to 11 x 250 (20? x 250)**	**11000 (20000?)**	**Close to 10^{35}**
Staged MeRHIC@BNL	Up to 5 x 250	600-5000	Close to 10^{34}
eRHIC@BNL	Up to 20 x 325 (30 x 325)	26000 (39000)	Close to 10^{34}
ENC@GSI	Up to 3 x 15	180	Few x 10^{32}
LHeC@CERN	Up to 150 x 7000	4200000	Close to 10^{33}

Present focus of interest (in the US) are the (M)EIC and Staged MeRHIC versions, with s up to ~3000 and 5000, resp.

Physics Workshops

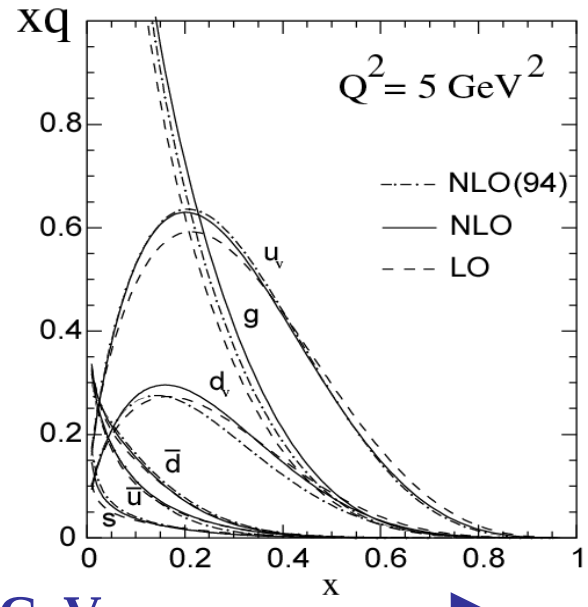
R. Gilman, CU, July 2010



EIC Science

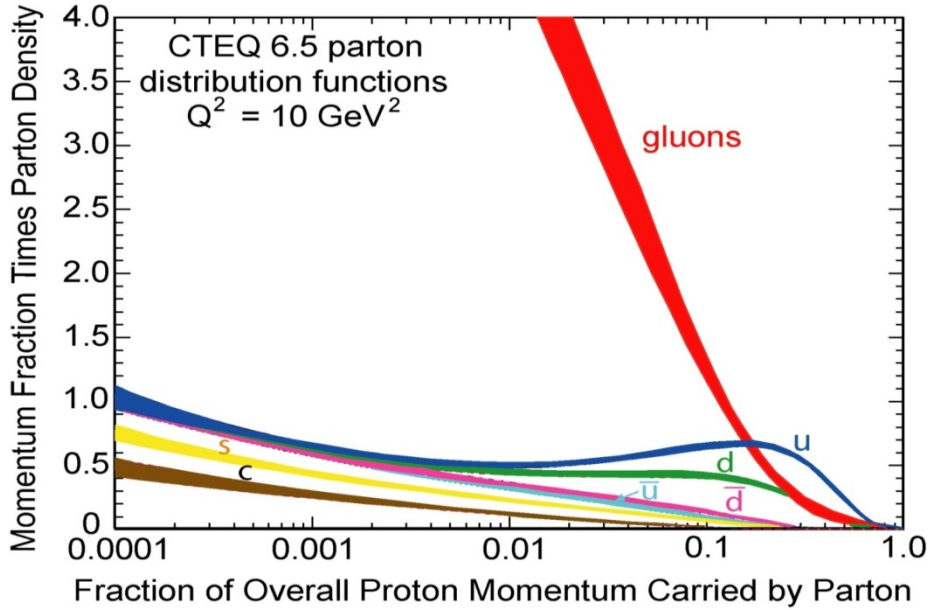
• Hadrons in QCD are relativistic many-body systems, with a fluctuating number of elementary quark/gluon constituents and a very rich structure of the wave function.

• With 12 GeV we study mostly the valence quark component, which can be described with methods of nuclear physics (fixed number of particles).

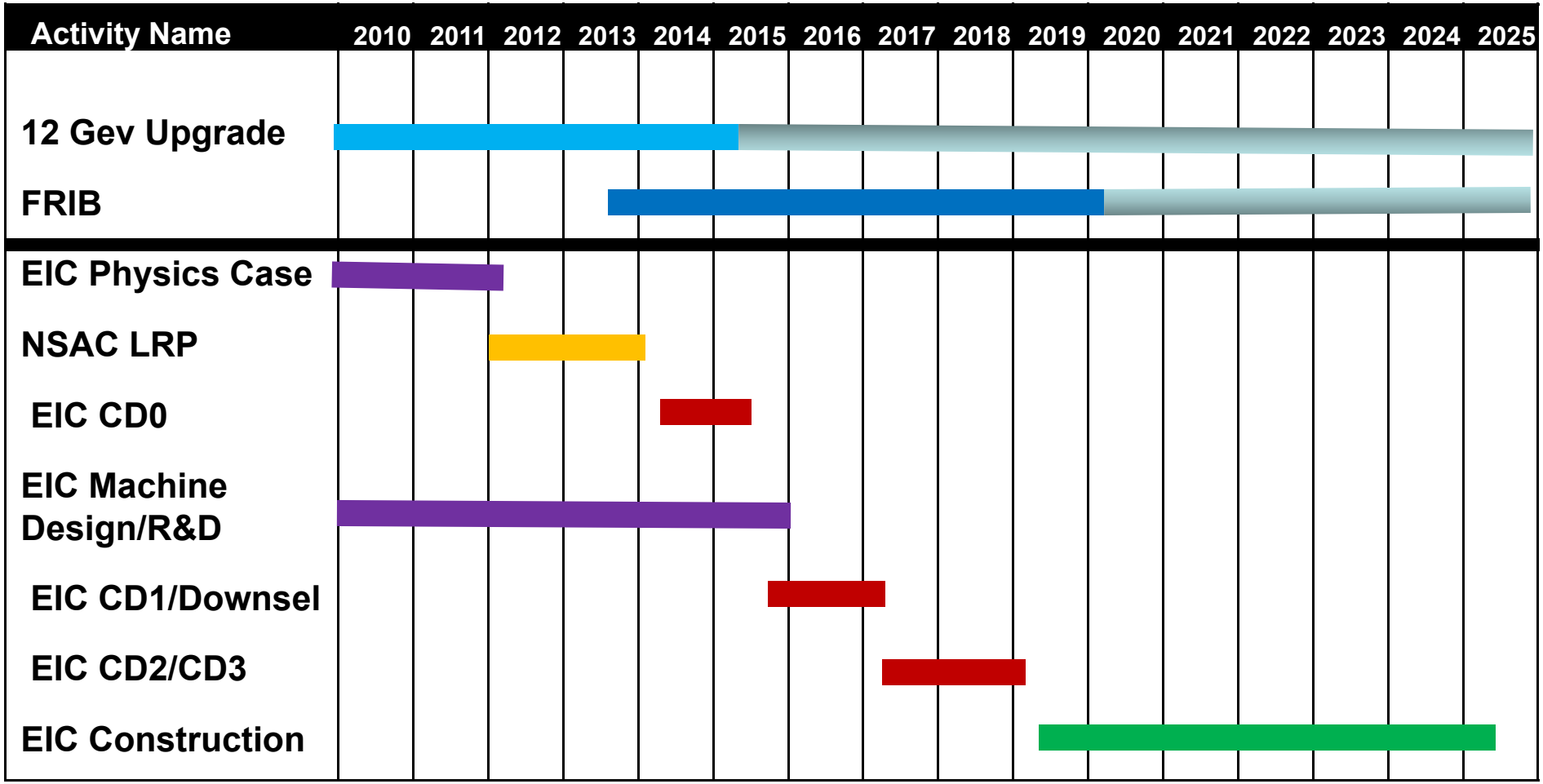


12 GeV →

• With an (M)EIC we enter the region where the many-body nature of hadrons, coupling to vacuum excitations, etc., become manifest and the theoretical methods are those of quantum field theory. An EIC aims to study the sea quarks, gluons, and scale (Q^2) dependence.



EIC Realization Imagined



Summary

- The 6 GeV nuclear physics program is pushing through to 2012 Completion
- The 12 GeV Upgrade Project is making excellent progress
- Exciting future nuclear physics program
- Future Directions
  - Photon Physics Opportunities: Immediate and longer term
  - Accelerator Driven Systems- R&D
  - Electron Ion Collider
- **Jefferson Lab: The Next Decade and Beyond**
- Life is great