The Jefferson Lab – 12 GeV Upgrade

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Electron Ion Collider Workshop
Institute of Nuclear Theory

September 14, 2010

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, Allison Lung and Bob McKeown.

The Talk

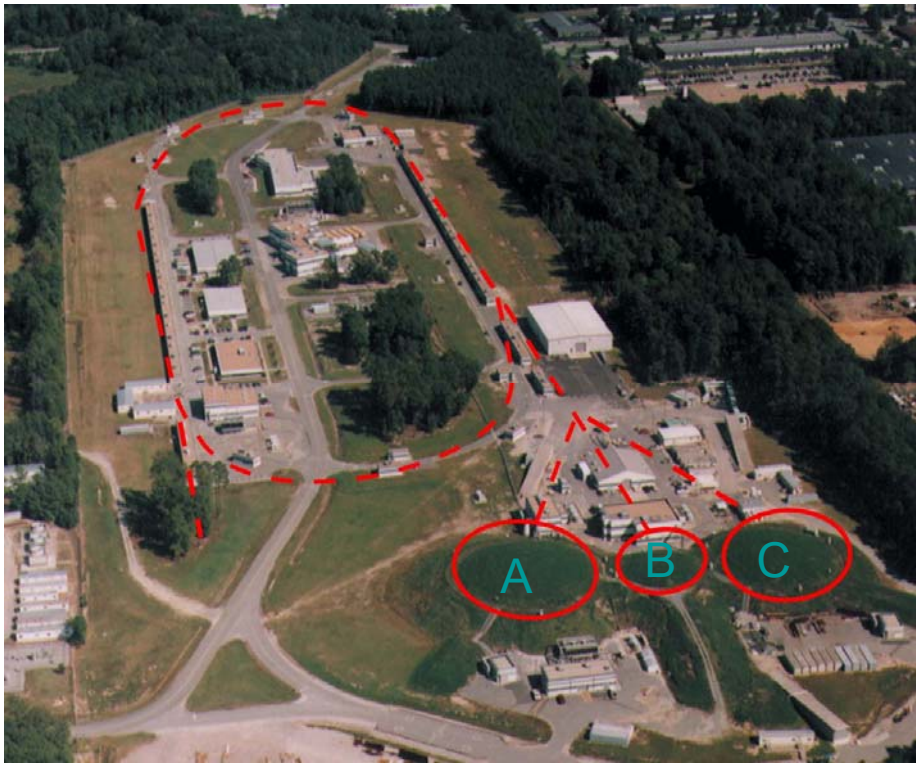
- Jefferson Lab today
- 12 GeV; The Physics Opportunities
- 12 GeV; The Project Status
- Conclusions

JEFFERSON LAB TODAY

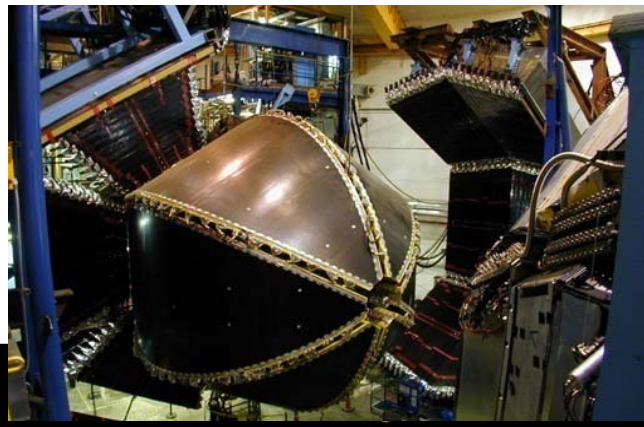
>1200 active member international user community engaged in exploring quark-gluon structure of matter.

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.

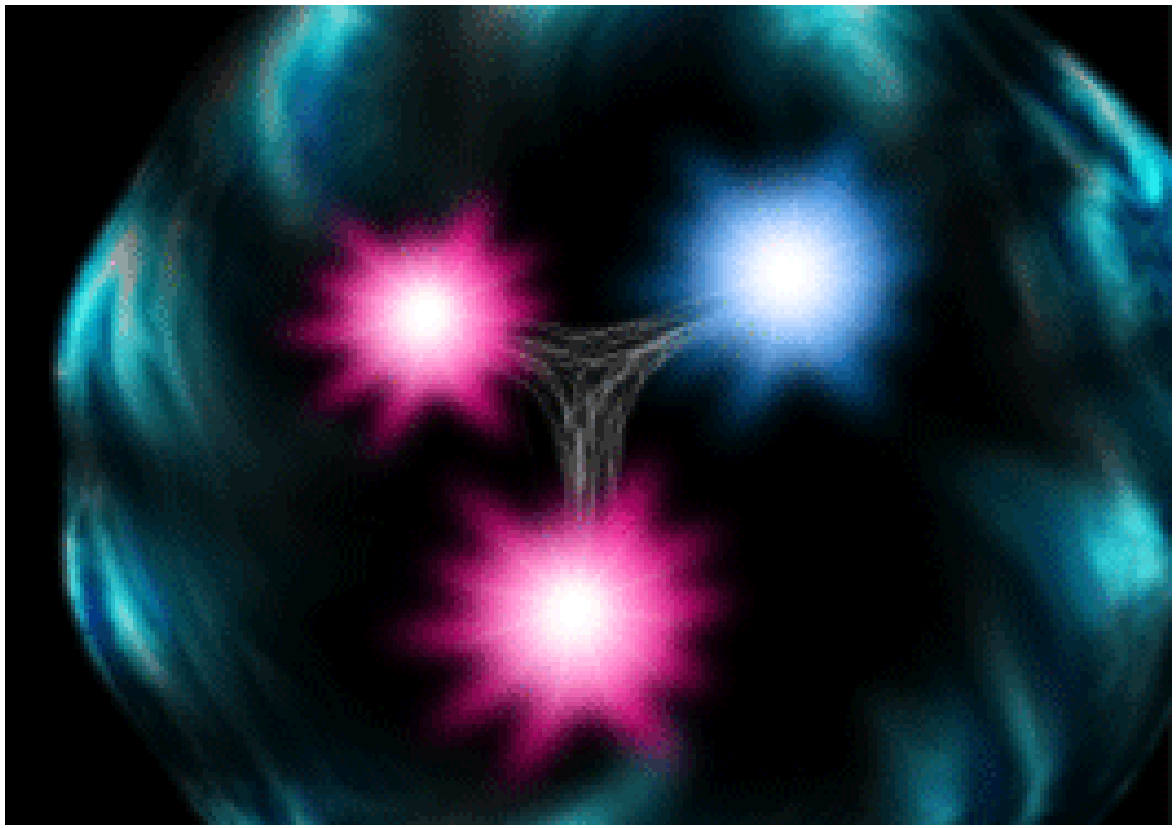


The Structure of the Proton

Naïve Quark Model: proton = uud (valence quarks)

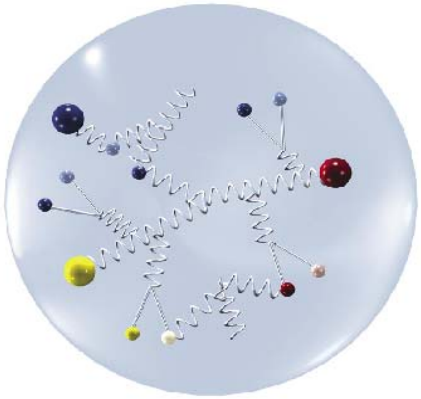
QCD: proton = uud + $u\bar{u}$ + $d\bar{d}$ + $s\bar{s}$ +

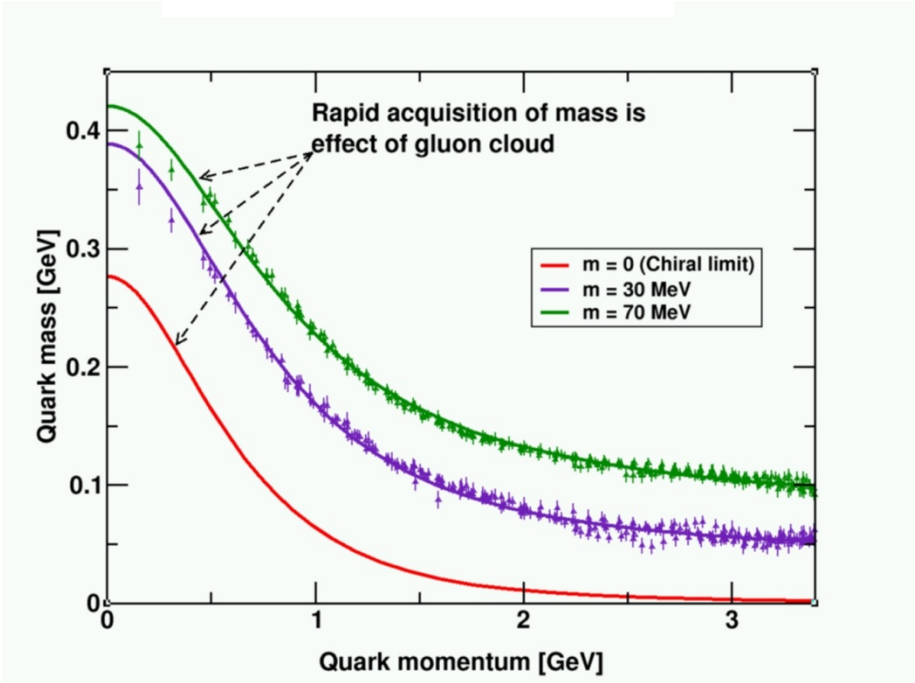
The proton sea has a non-trivial structure: $\bar{u} \neq \bar{d}$



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

QCD and the Origin of Mass

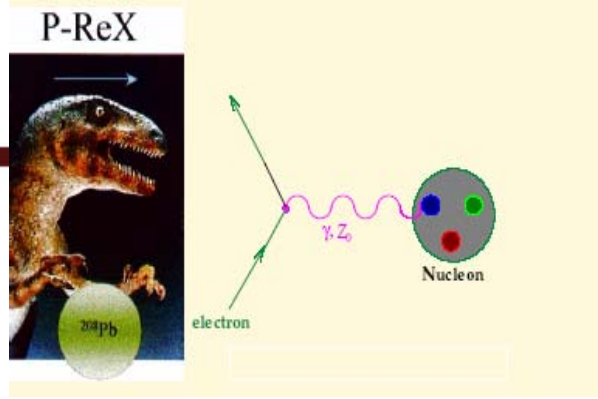




- 99% of the proton's mass/energy is due to the self-generating gluon field
  - Higgs mechanism has almost no role.

- 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

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

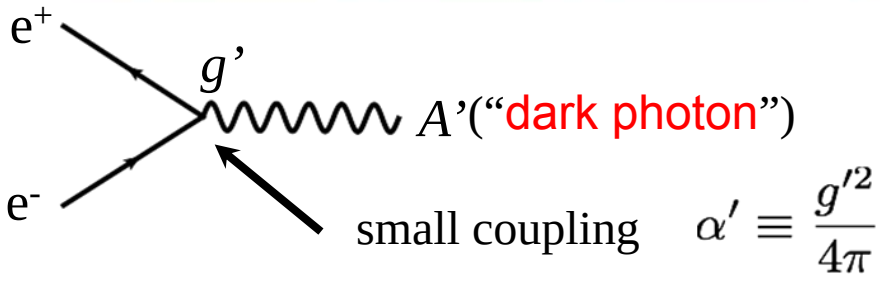
Measure a Parity Violating Asymmetry

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

- 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



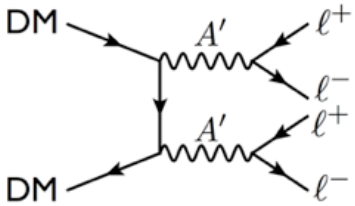
Motivated by **dark matter anomalies**:

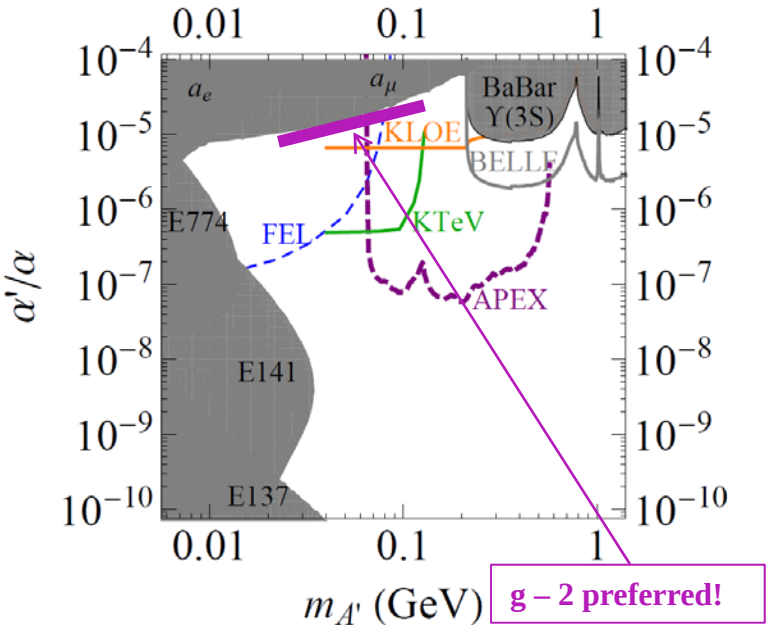
- excess of 10-100 GeV e^+ flux found by PAMELA satellite (Nature 2009, 1 citation/day)
- excess of few-100 GeV $e^+ + e^-$ flux by Fermi satellite/HESS

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

→ Suggests $M_{A'} < 1$ GeV

→ decay to protons kinematically forbidden

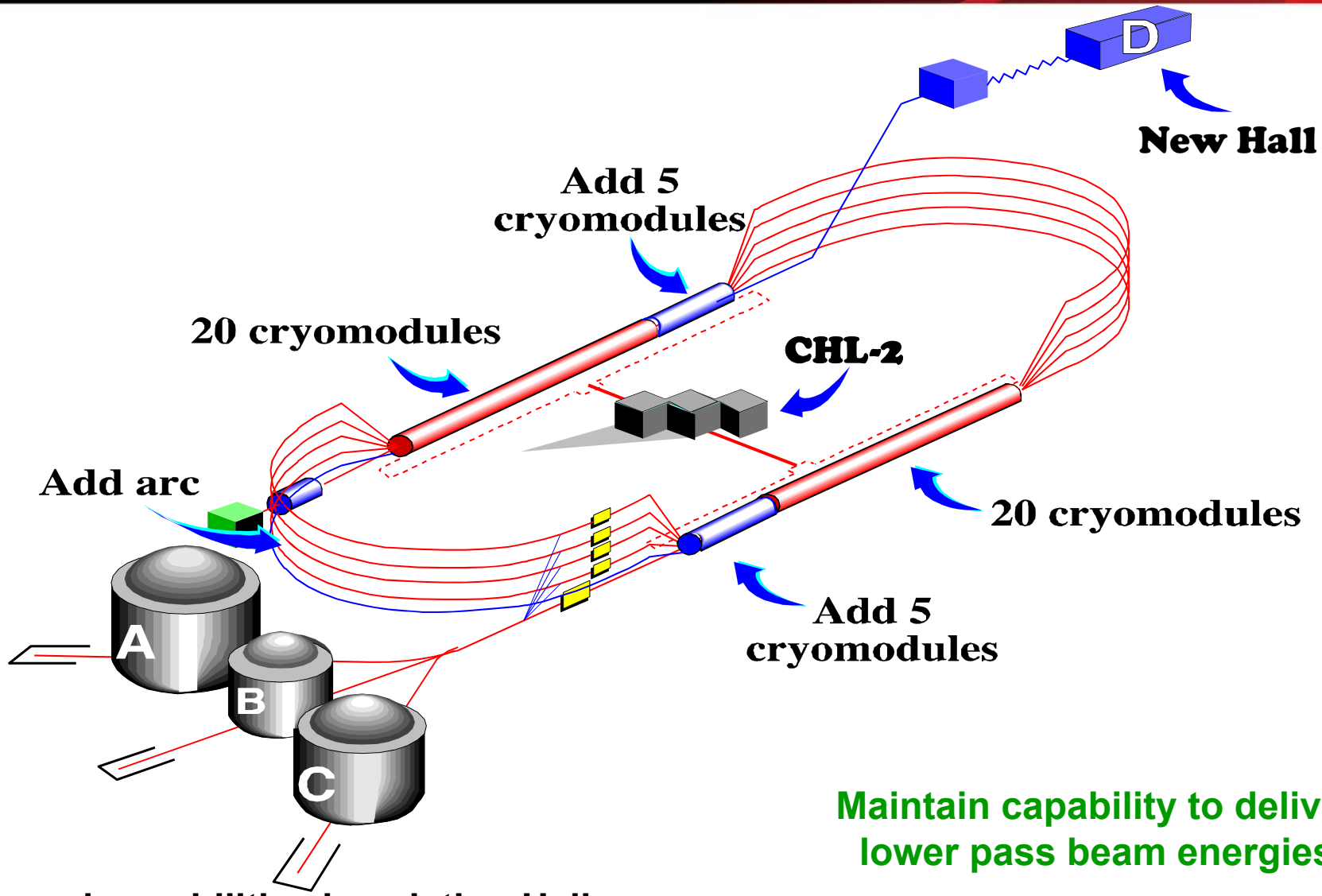




Irrespective of anomalies:

- 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

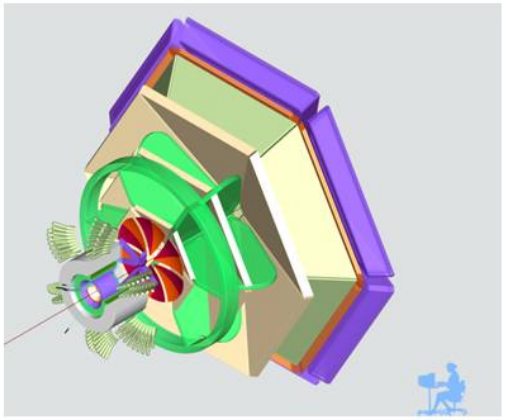


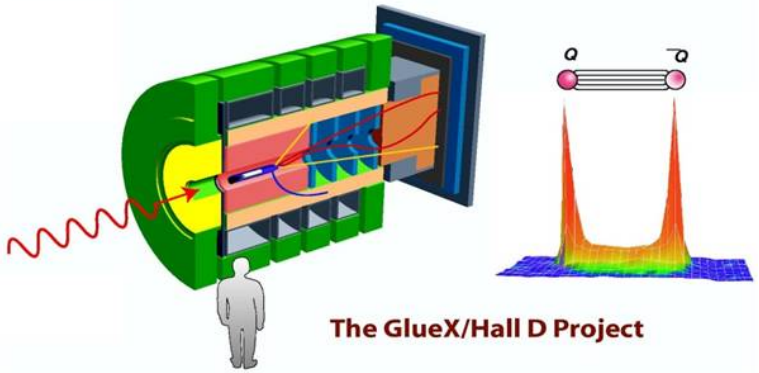
Maintain capability to deliver lower pass beam energies

Enhanced capabilities in existing Halls

Four Halls

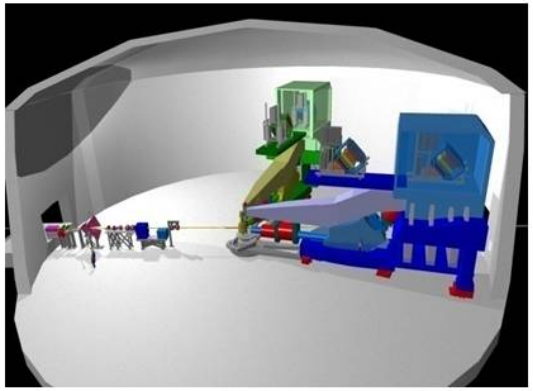
Hall D – exploring origin of confinement by studying exotic mesons

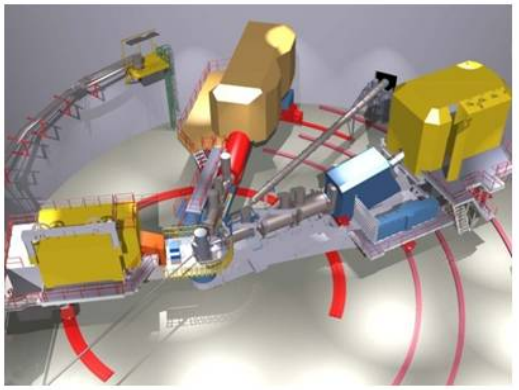




Hall B – understanding nucleon structure via generalized parton distributions

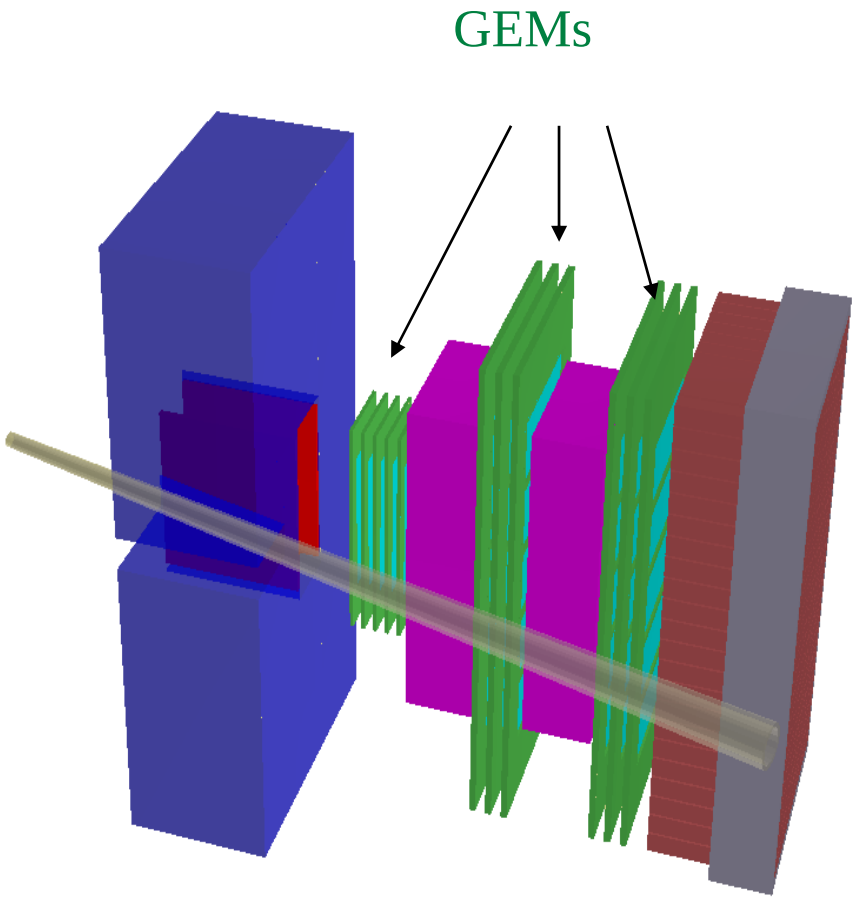
Hall C – precision determination of valence quark properties in nucleons and nuclei





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

Hall A (equipment beyond project)



Super Bigbite Spectrometer:

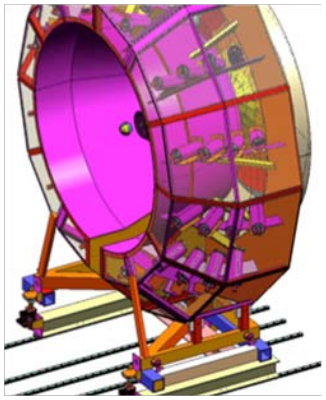
- large dipole magnet
- GEM trackers (~100,000 channels)
- hadron and EM calorimeter
- Trigger and DAQ

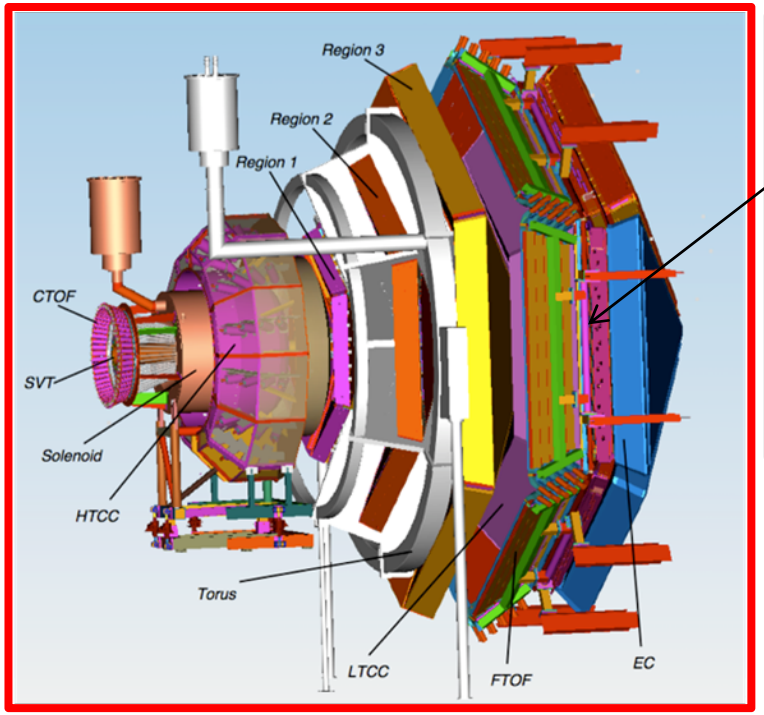
operating in open geometry at a luminosity of 10^{38} $cm^{-2}s^{-1}$

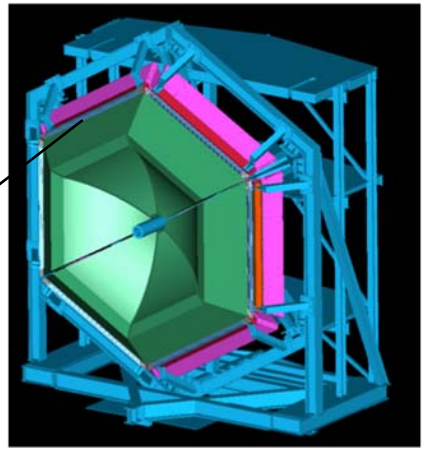
Hall B

CLAS12

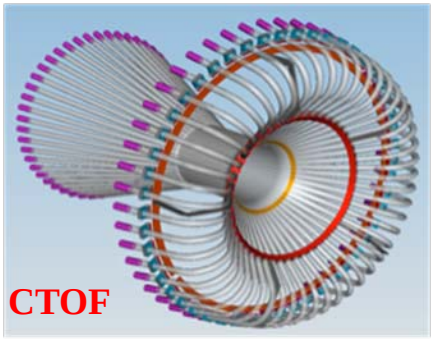
HTCC



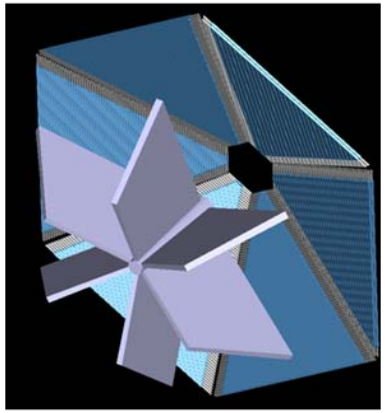




PCAL

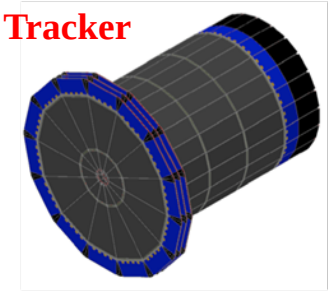


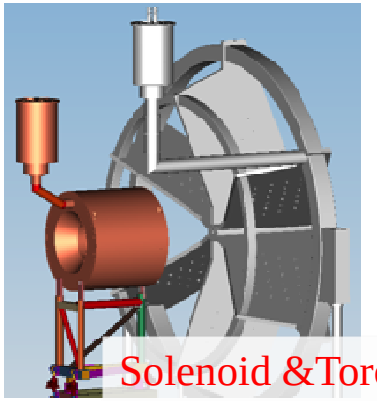
CTOF



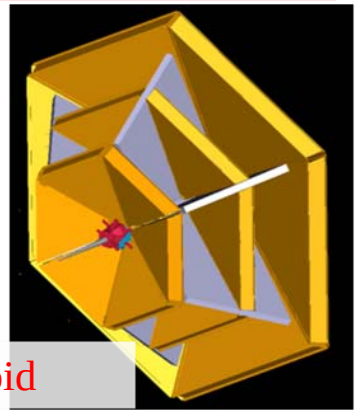
FTOF

Silicon Tracker





Solenoid &Toroid



Drift Chambers R1, R2, R3

Hall C

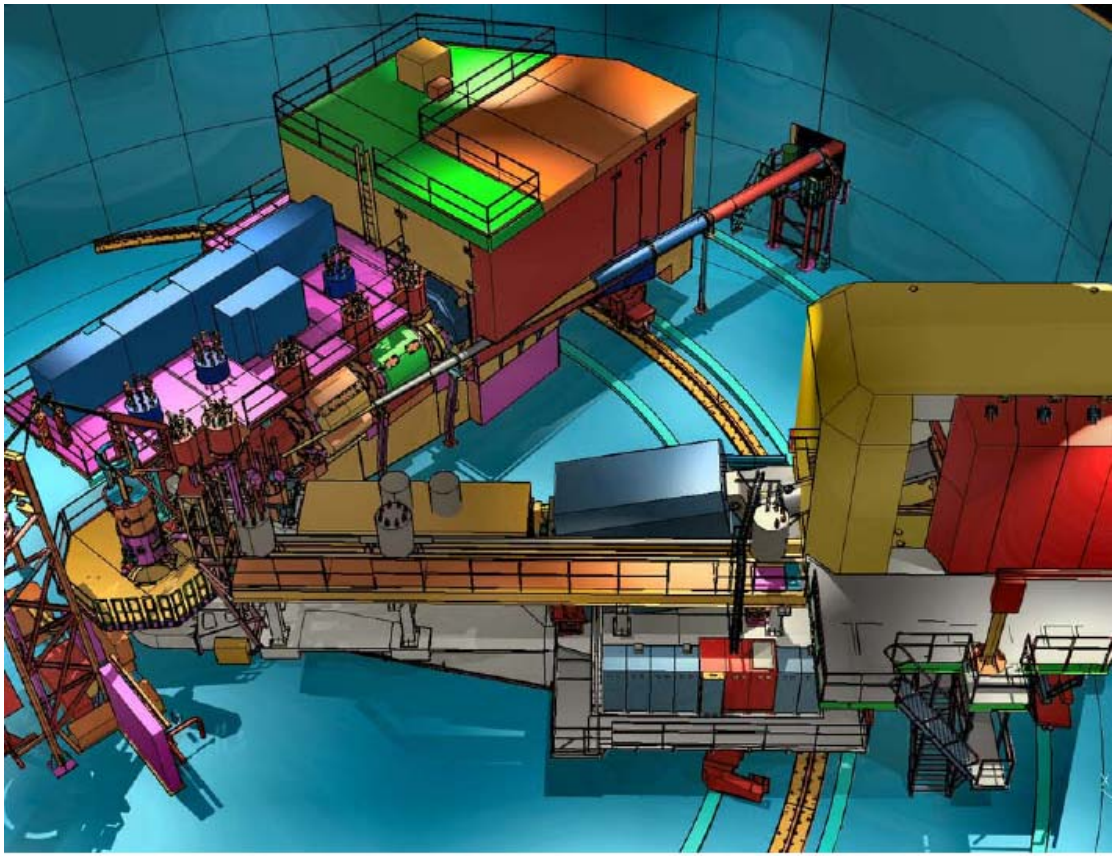
- **New Super High Momentum Spectrometer (SHMS)** Horiz. Bender, 3 Quads + Dipole

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

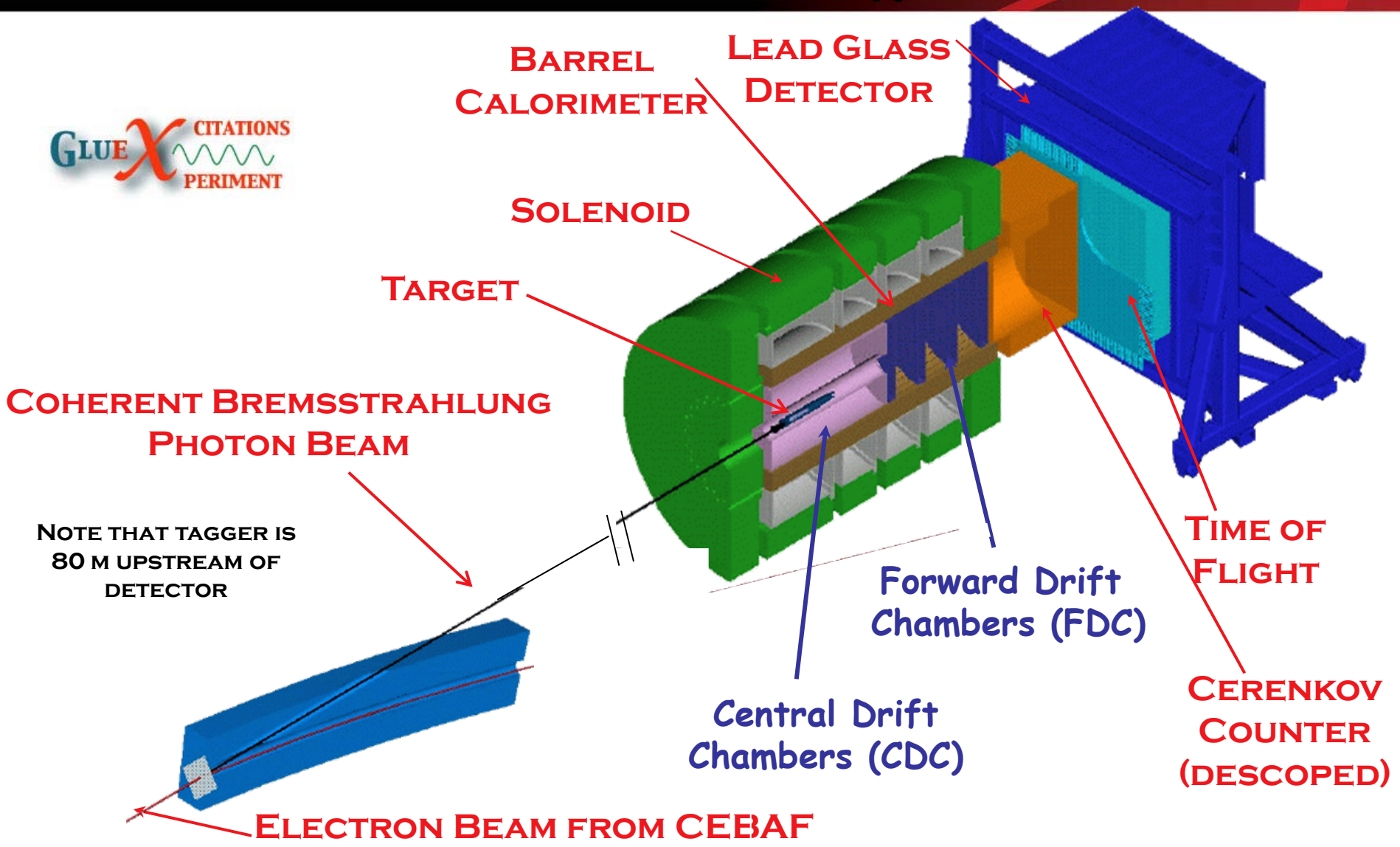
- **High Momentum Spectrometer (HMS)**

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

- **Minimum opening angle: 17°**



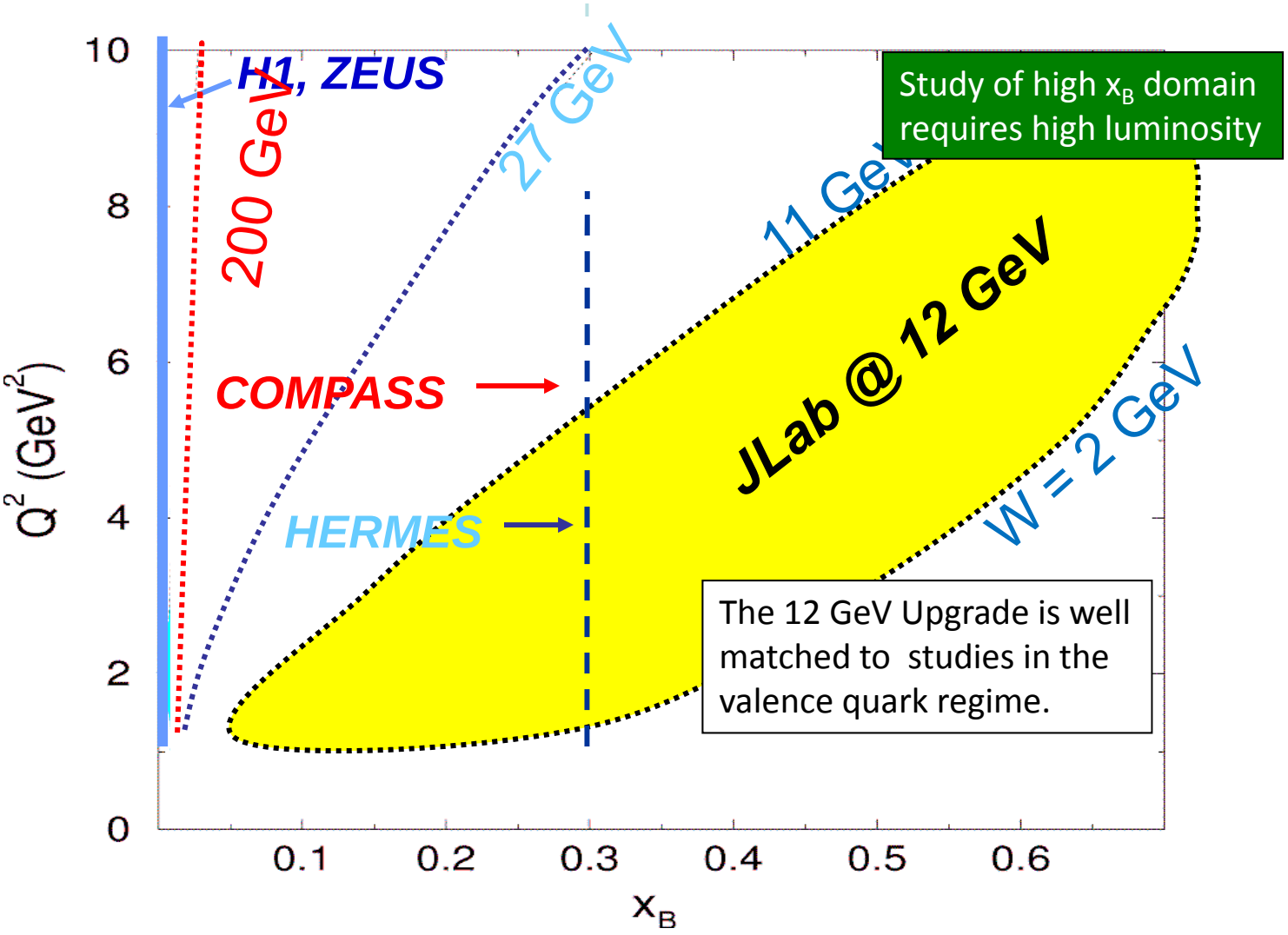
Hall D Gluex


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

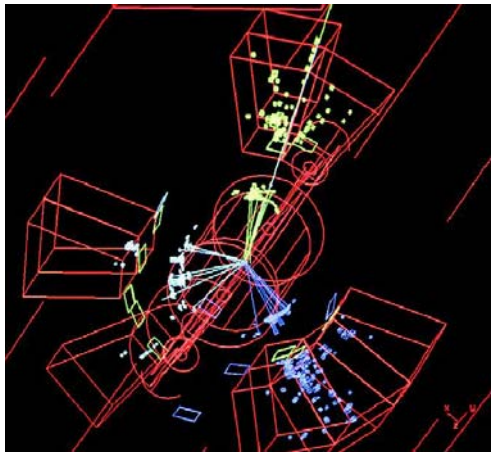
Confinement

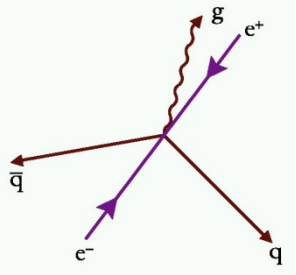
Large Distance
Low Energy

Perturbative QCD

Strong QCD

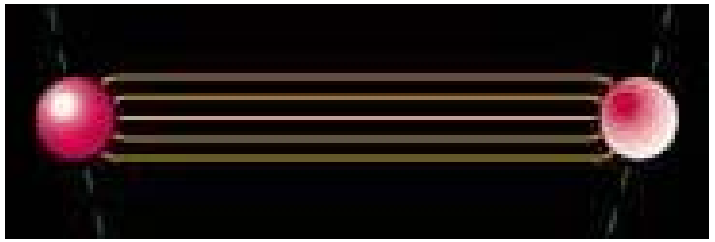
High Energy Scattering





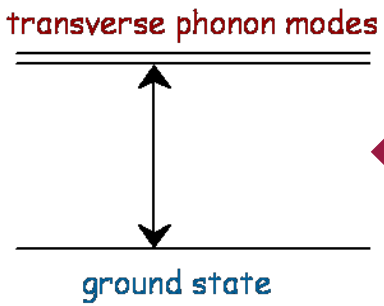
Gluon
Jets
Observed

Spectroscopy



Gluonic
Degrees of Freedom
Missing

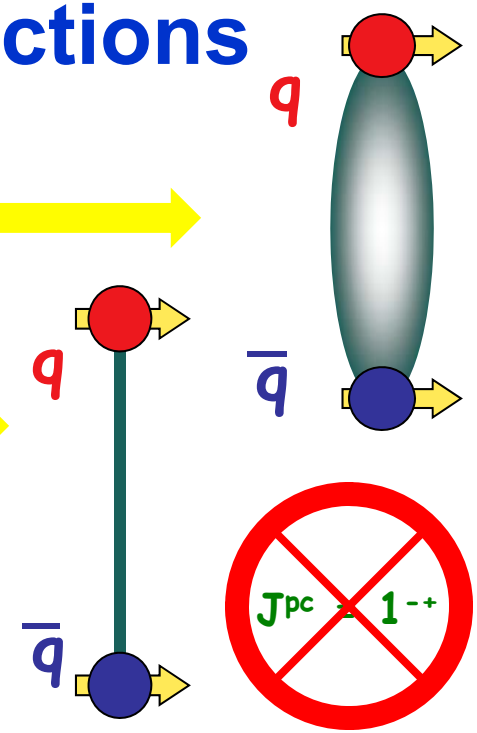
Hybrid mesons and mass predictions

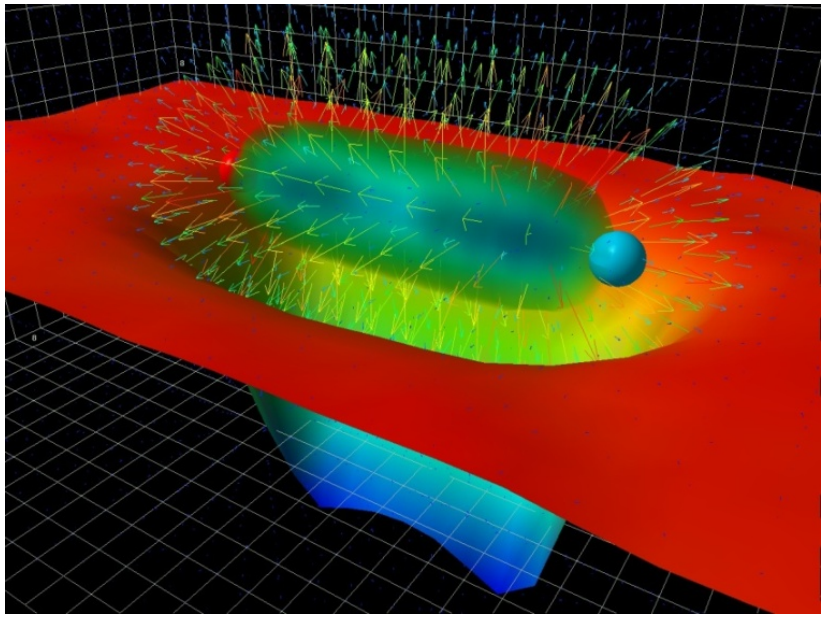


Hybrid mesons

1 GeV mass difference

Normal mesons





Lattice

1^{-+} 1.9 GeV

2^{+-} 2.1 GeV

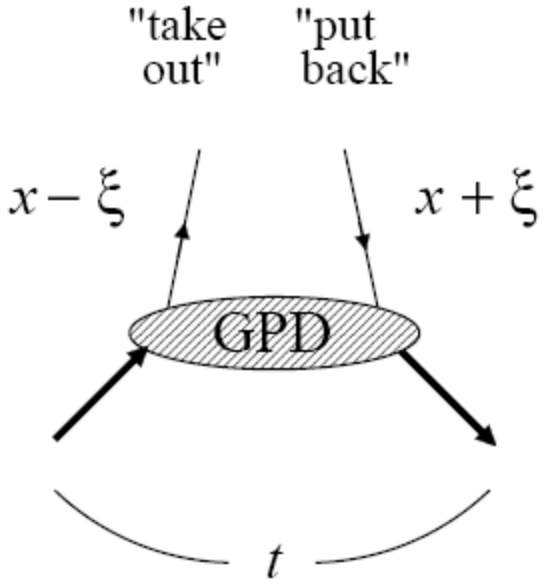
0^{+-} 2.3 GeV

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

Transverse Quark & Gluon Imaging

Deep exclusive measurements in ep/eA :

diffractive:	transverse gluon imaging	J/y, f, r^o, γ (DVCS)
non-diffractive:	quark spin/flavor structure	p, K, r^+, …

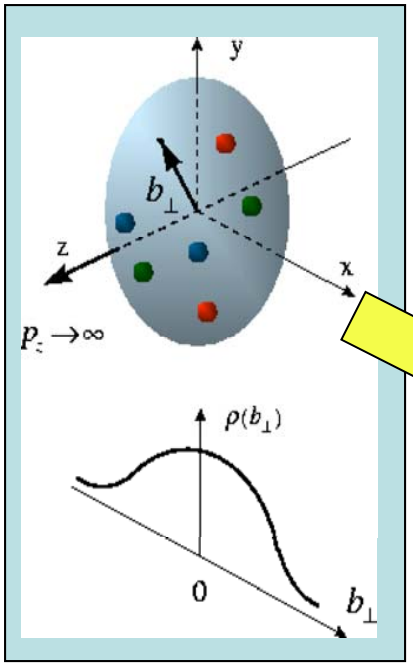


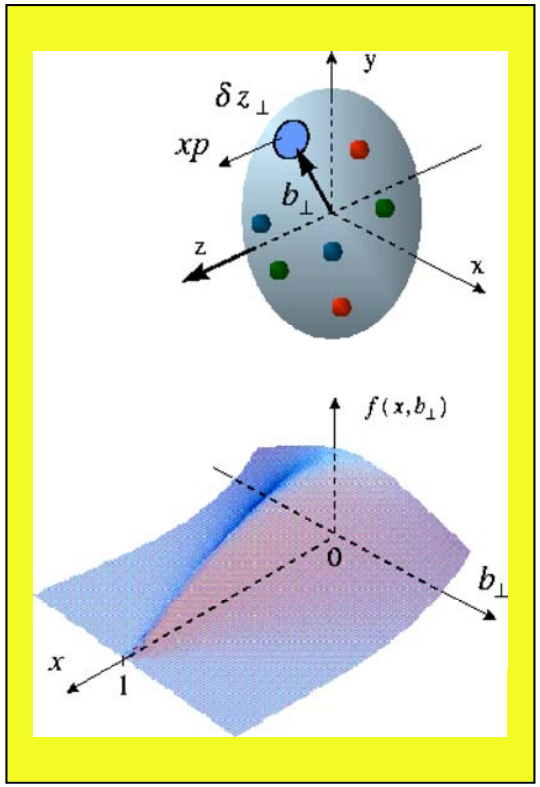
Describe correlation of longitudinal momentum and transverse position of quarks/gluons →

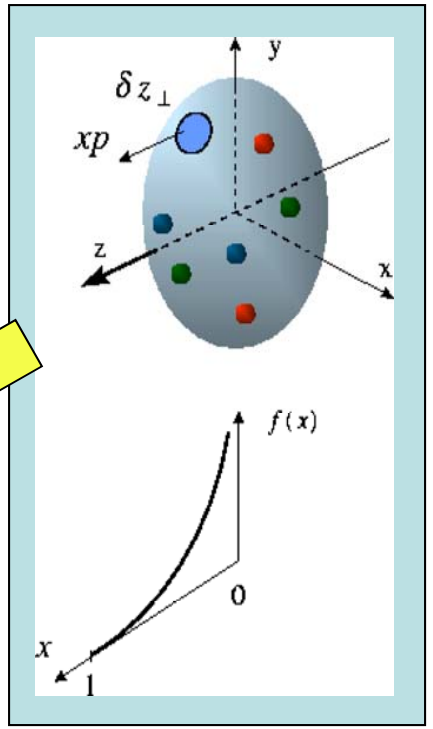
Transverse quark/gluon imaging of nucleon ("tomography")

Generalized Parton Distributions (GPDs)

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





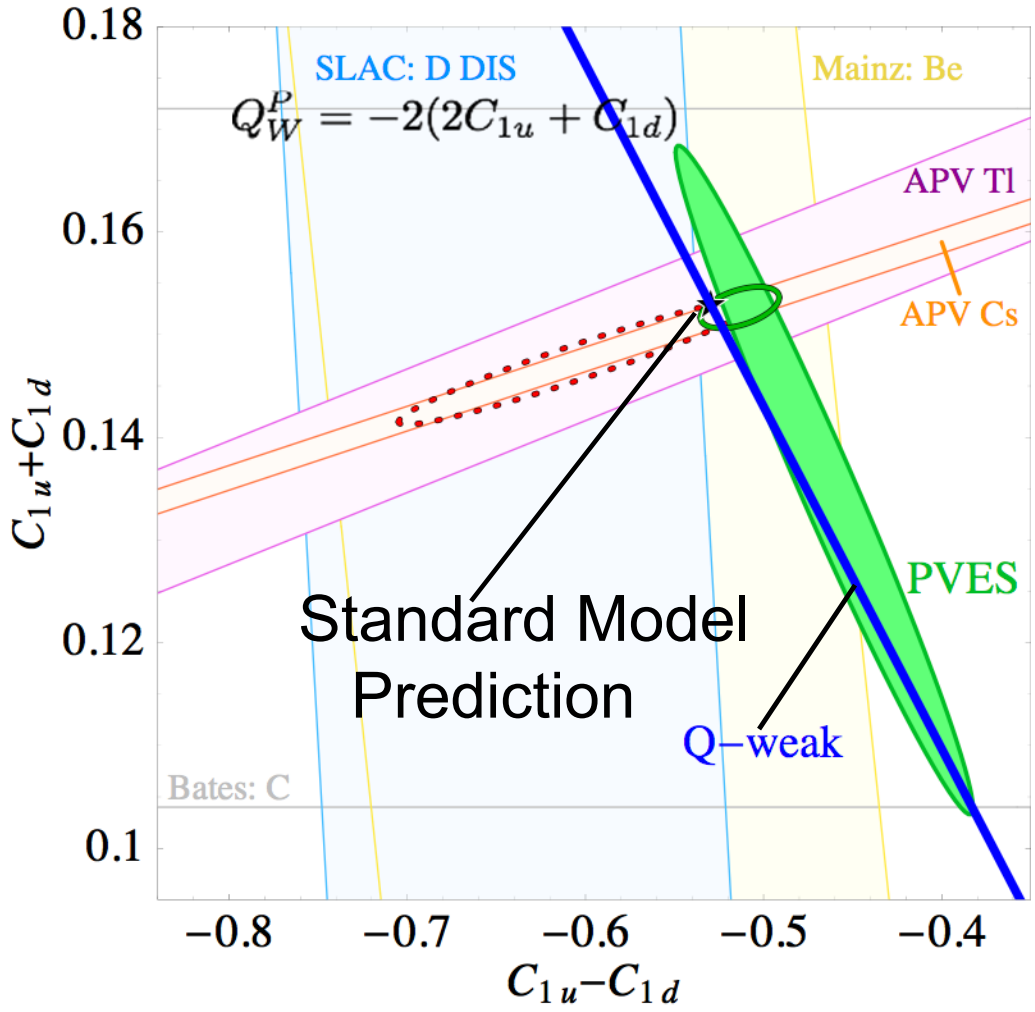


Proton form factors, transverse charge & current densities

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

Structure functions, quark longitudinal momentum & helicity distributions

Weak Couplings



Isoscalar weak charge

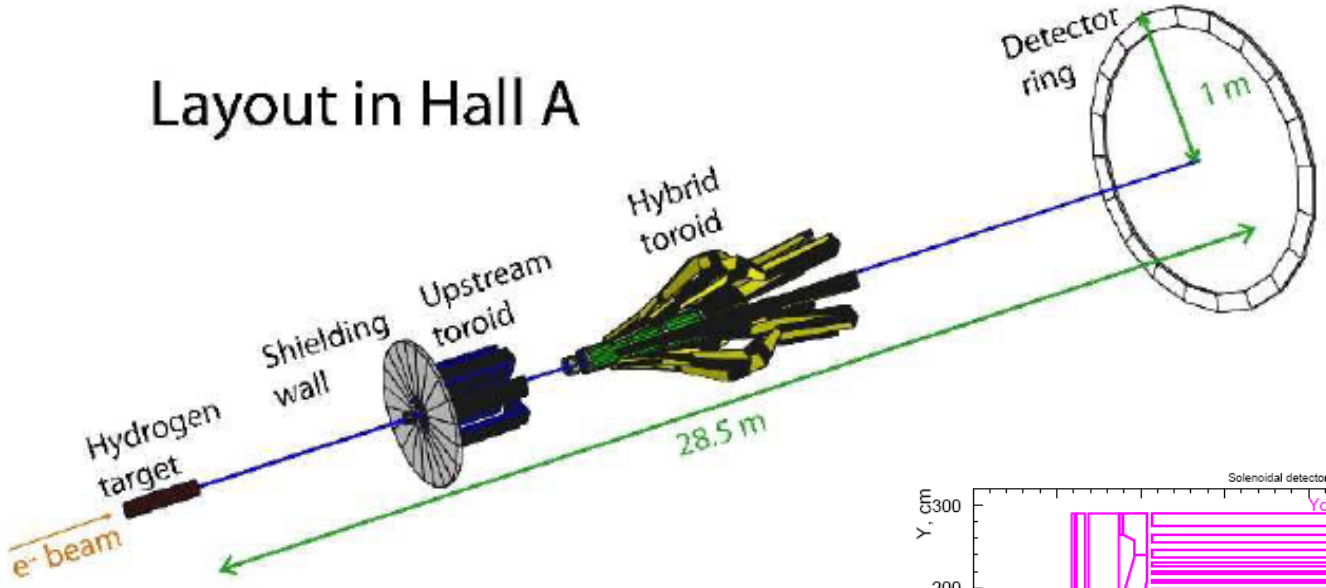
Isovector weak charge

All Data & Fits Plotted at 1 σ

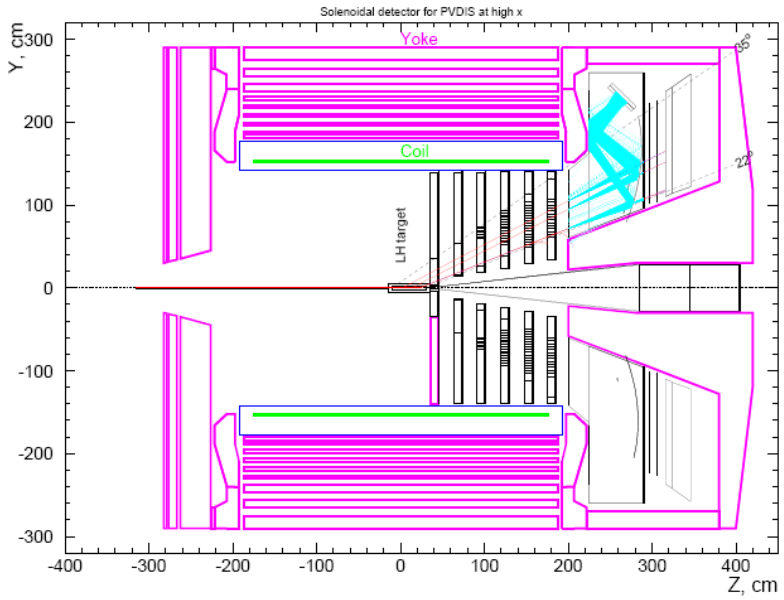
HAPPEx: H, He
G^0: H,
PVA4: H
SAMPLE: H, D

Q-weak expected precision

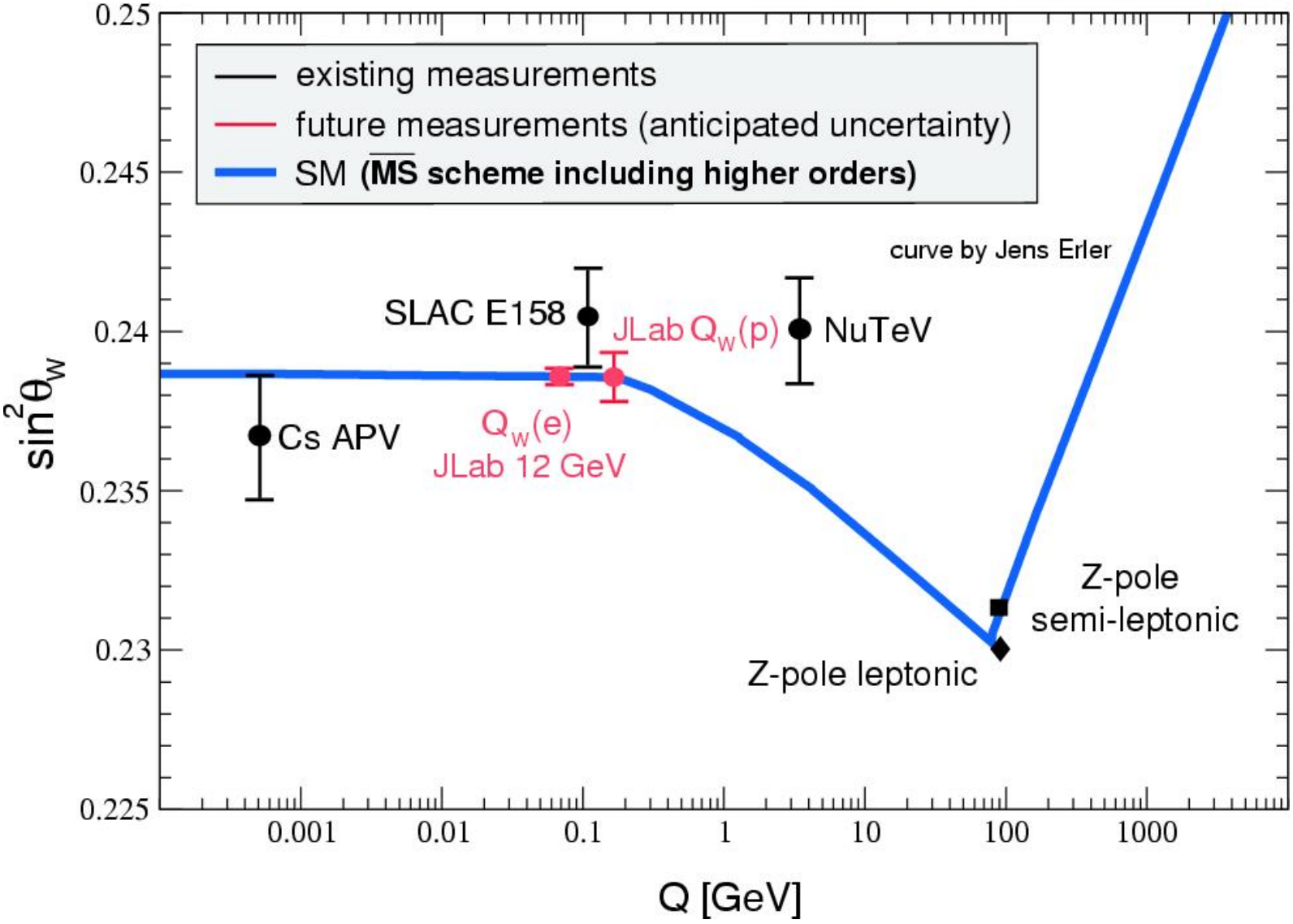
Møller & Deep Inelastic Scattering Parity Violation



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



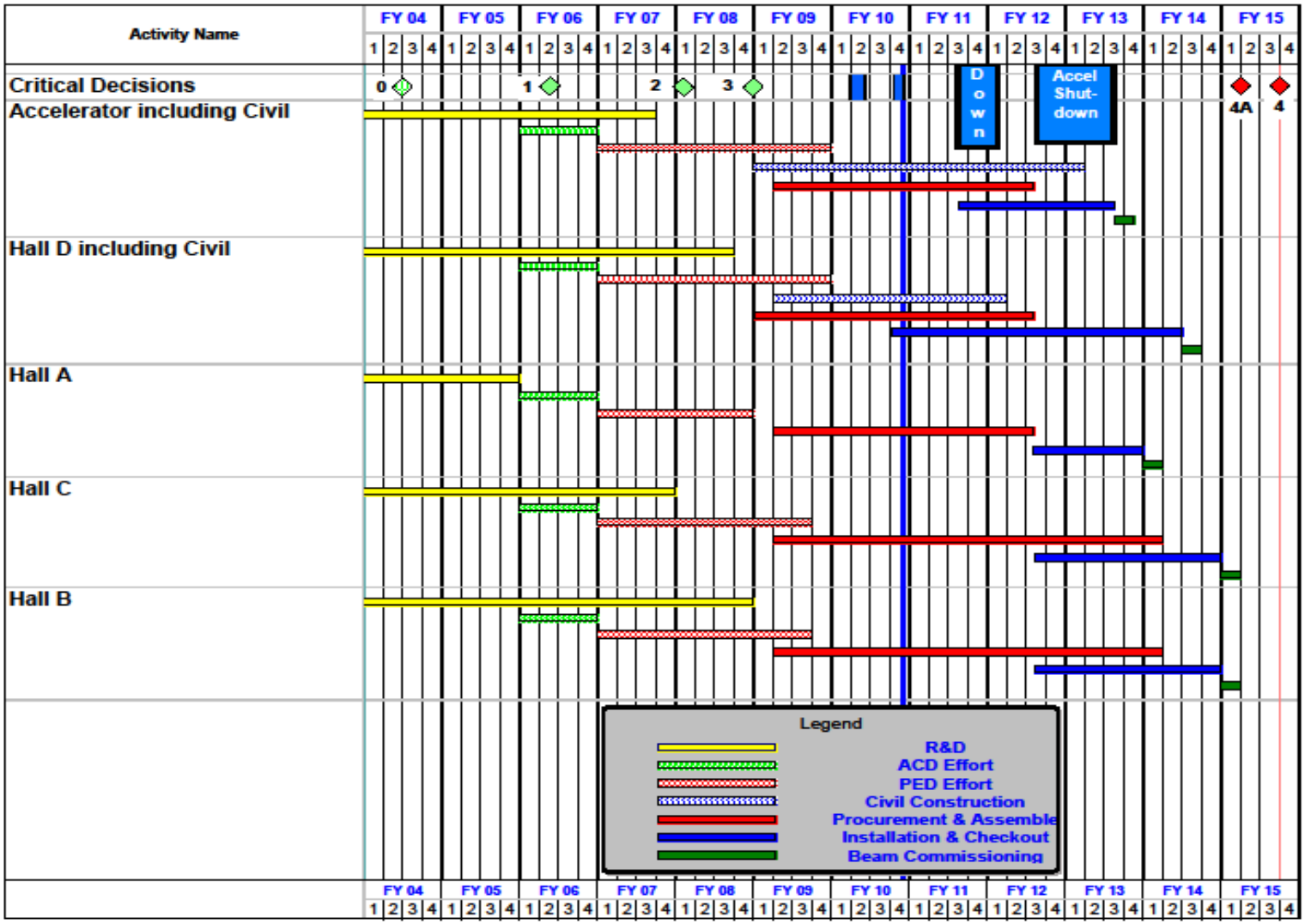
$\sin^2\theta_W$


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 (April 2010)
  - Very Satisfactory Review
    - Manpower management , appeared satisfactory
    - Schedule holding, civil schedule recovering
  - Concerns
    - Hall D Solenoid

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

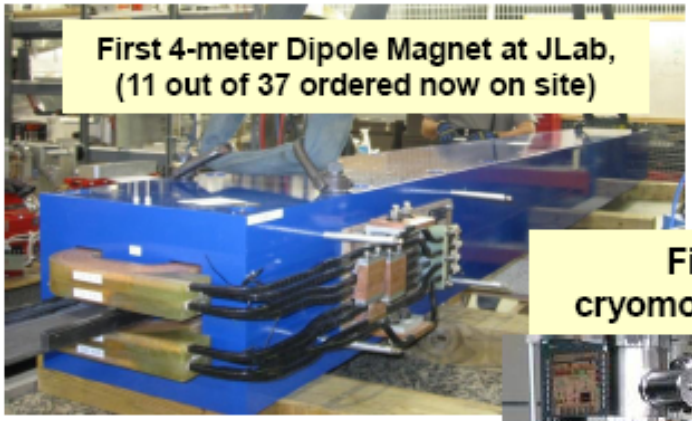
CIVIL CONSTRUCTION – Central Helium Liquefier (CHL) #2

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

- *Cryogenics equipment installation underway*

Accelerator Construction Highlights

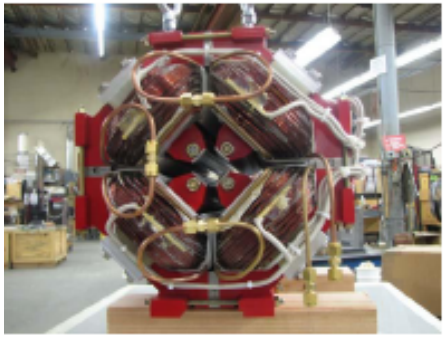
- **Major Procurements (> $500K) nearly complete:**
  - cryomodule cavities
  - beam transport magnets
  - cryogenics coldbox
  - vacuum valves
  - cold tuner
  - etc. etc. etc.



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

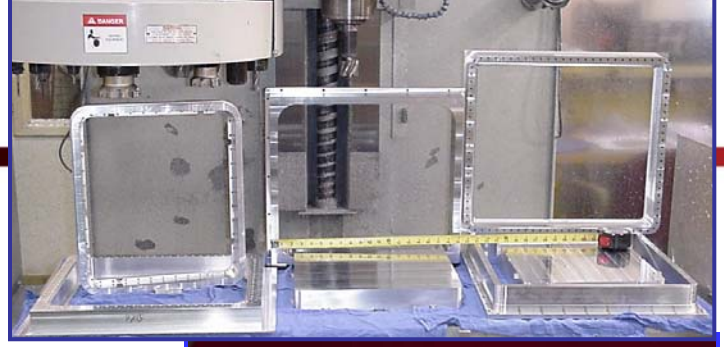
First two 12 GeV
cryomodule cavities on site

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

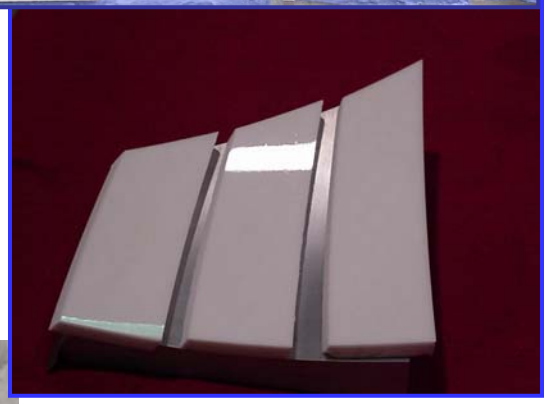


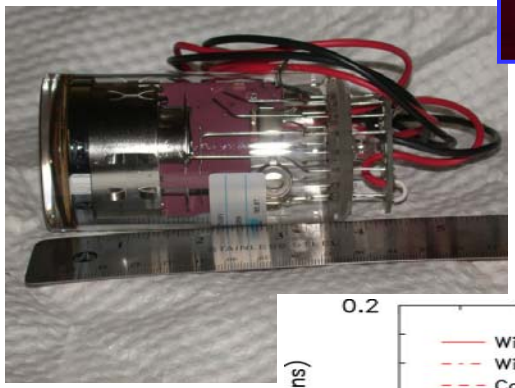
Hall B Detectors

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

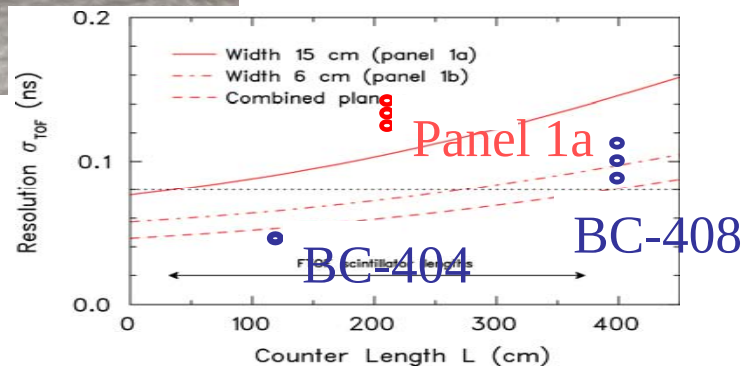


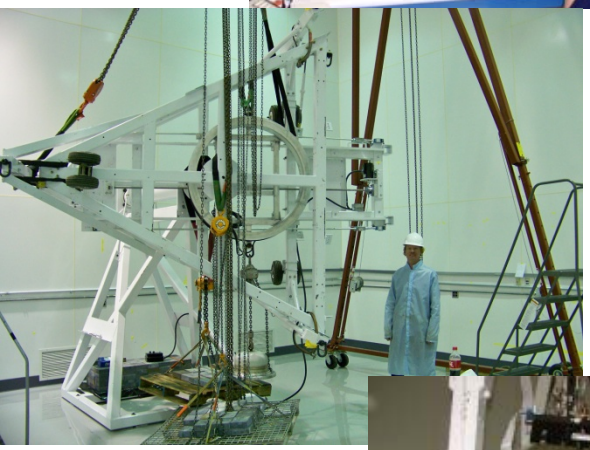
HTCC prototype molds and mirrors (JLab)





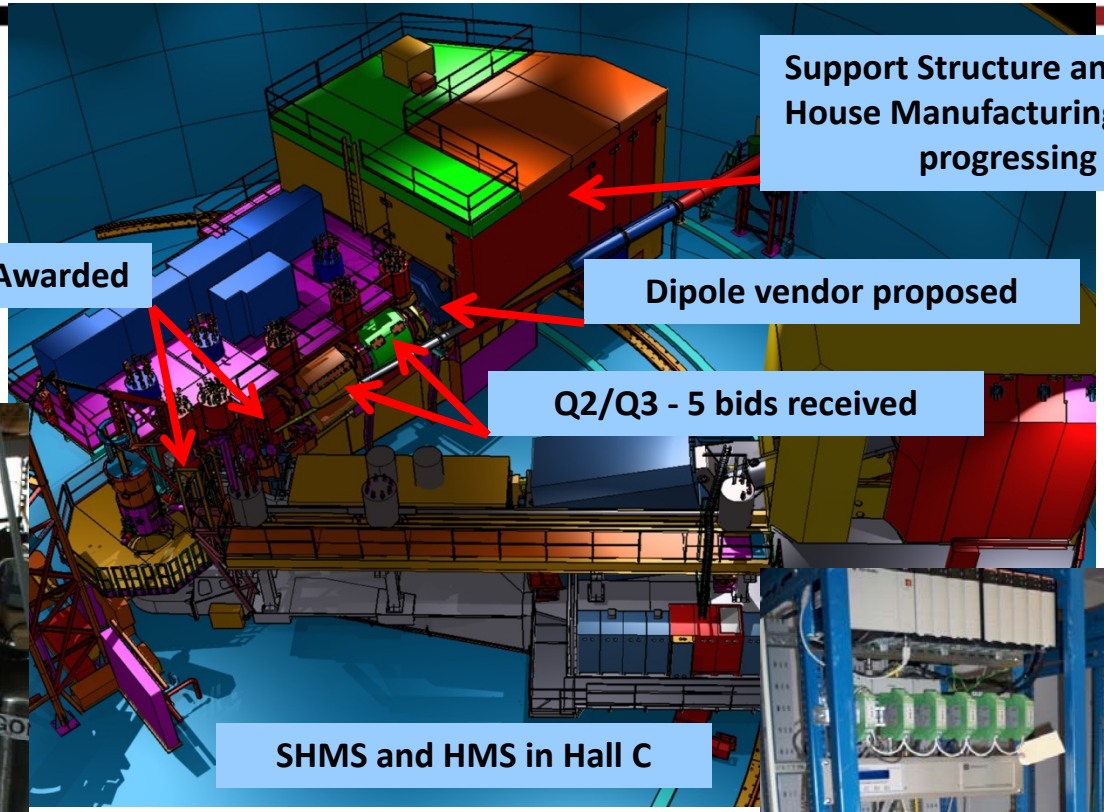
FTOF PMTs and timing test results (US Carolina, JLab)





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

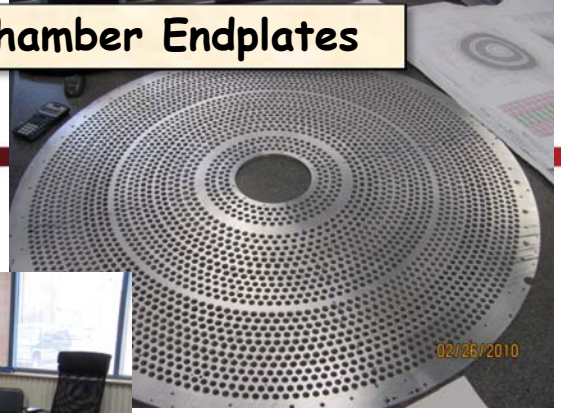
SHMS and HMS in Hall C

1st Cryogenic Control Reservoir

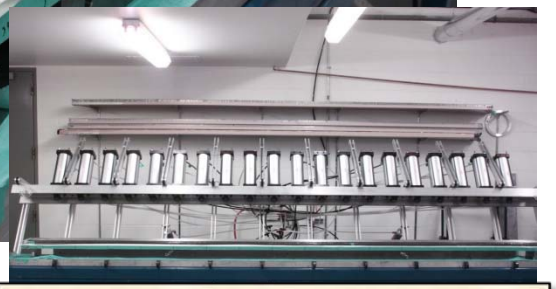
Magnet Control Racks

Hall D Detectors

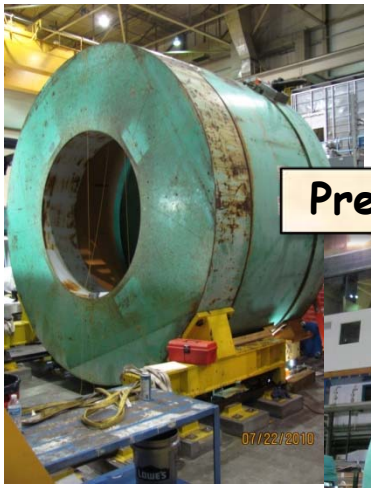
Central Drift Chamber Endplates



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