Particle ID at Jefferson Lab

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Jefferson Lab

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Outline

1. The 12 GeV Upgrade at Jefferson Lab

- Short Overview

2. JLab experimental Halls and detectors

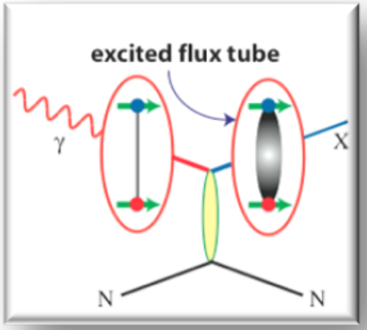
- Halls A-D
- Beyond 12 GeV

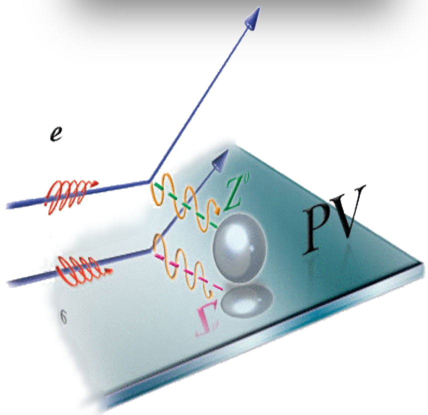
3. Generic detector R&D for an Electron-Ion Collider

- DIRC-based PID for the EIC central detector

Questions in medium-energy nuclear physics

- What is the role of gluonic excitations in hadrons?
  – spectroscopy of light mesons
- Where is the missing spin in the nucleon?
  What is the role of orbital angular momentum?
- Can we reveal a novel landscape of nucleon substructure through measurements of new multidimensional distribution functions?
- What is the relation of short-range nuclear structure and parton dynamics?
- Physics beyond the standard model?
  – precision measurements



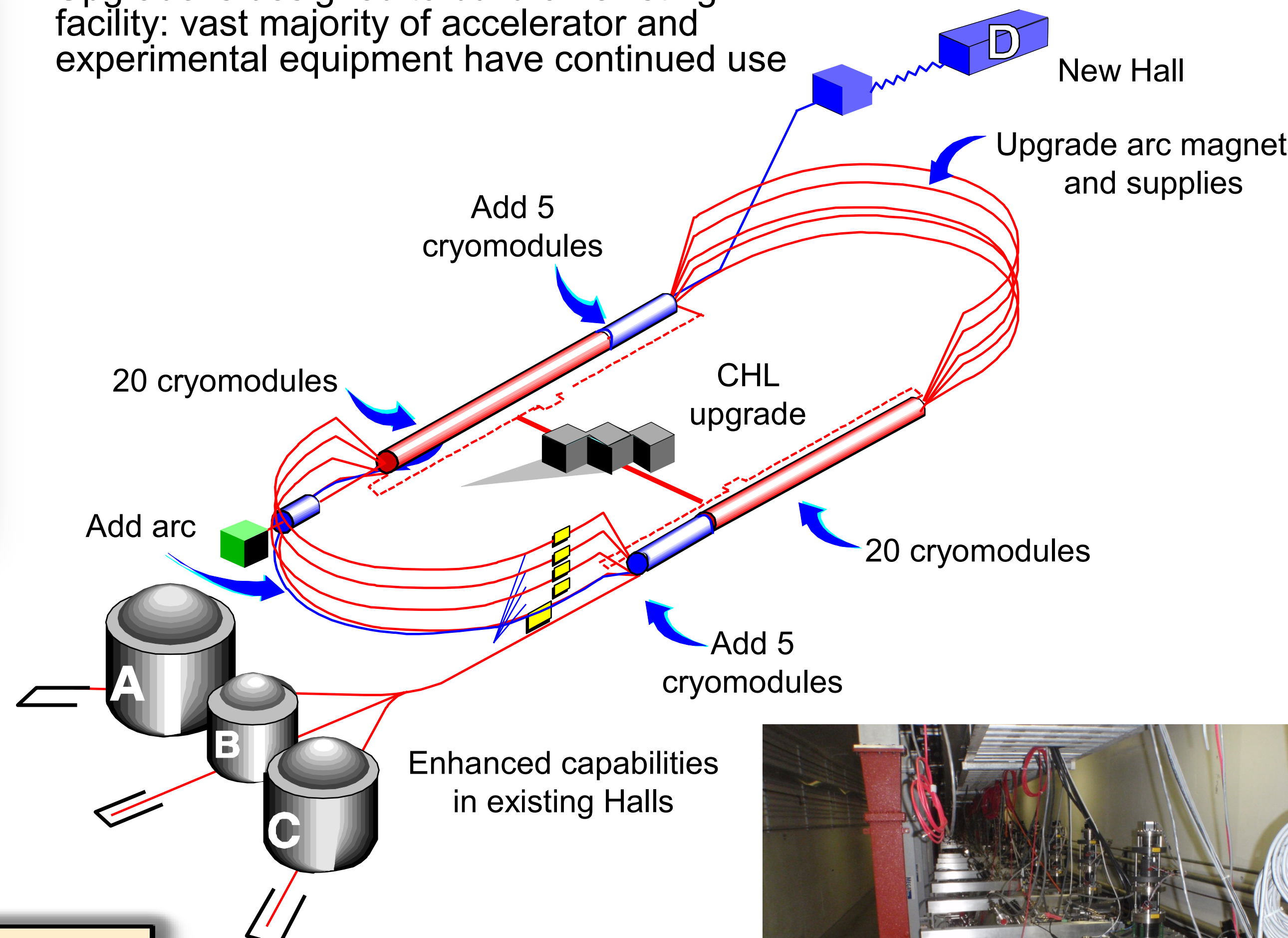


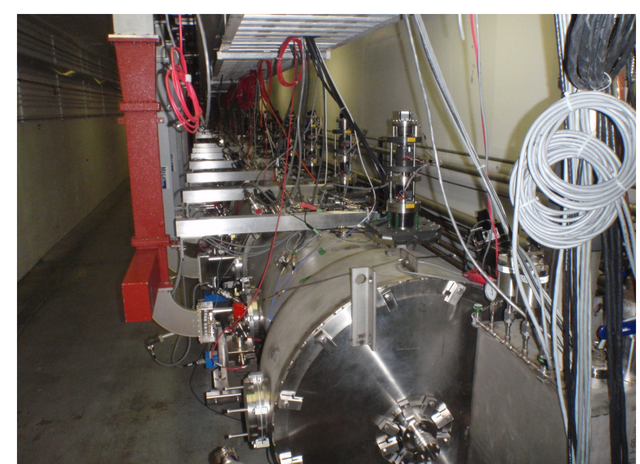
Jefferson Lab 12 GeV upgrade

The completion of the 12 GeV Upgrade of CEBAF was ranked the highest priority in the 2007 NSAC Long Range Plan.

Scope of the project includes:
- Doubling the accelerator beam energy
- New experimental Hall and beamline
- Upgrades to existing Experimental Halls

Upgrade is designed to build on existing facility: vast majority of accelerator and experimental equipment have continued use





New C100 cryomodules in linac tunnel

Civil construction essentially complete

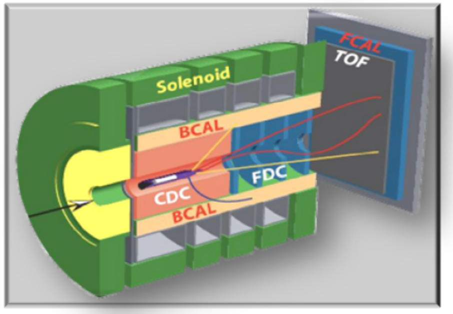
HL-2 Refrigeration system
installed and commissioned

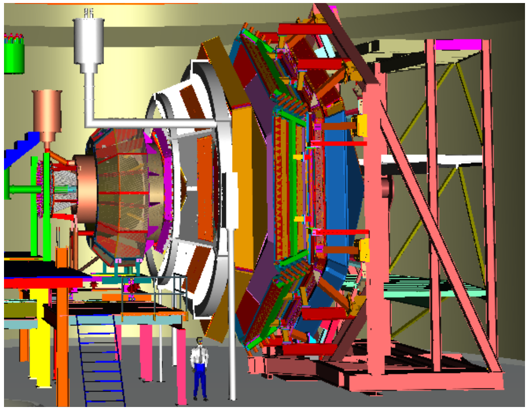
Central Helium Liquefier
building addition

New Hall D
counting house

12 GeV Upgrade Physics Instrumentation

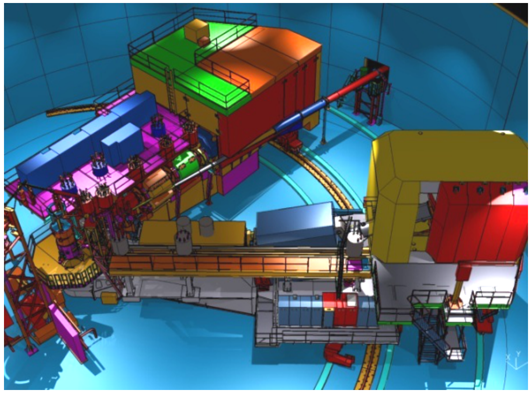
GLUEx (Hall D): **exploring origin of confinement by studying hybrid mesons**

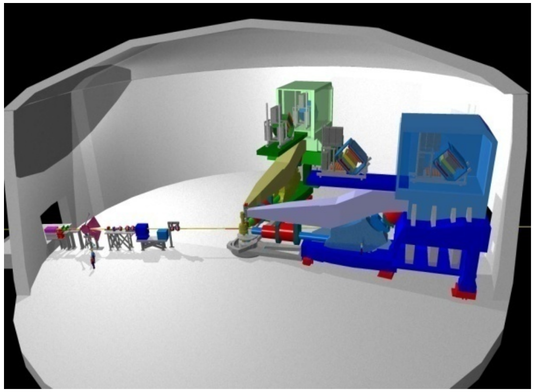




CLAS12 (Hall B): **understanding nucleon structure via generalized parton distributions**

SHMS (Hall C): **precision determination of valence quark properties in nucleons and nuclei**





Hall A: **nucleon form factors,**
& future new experiments like Moller & SOLID

Experiments and instrumentation

1. Instrumentation at JLab is constantly evolving

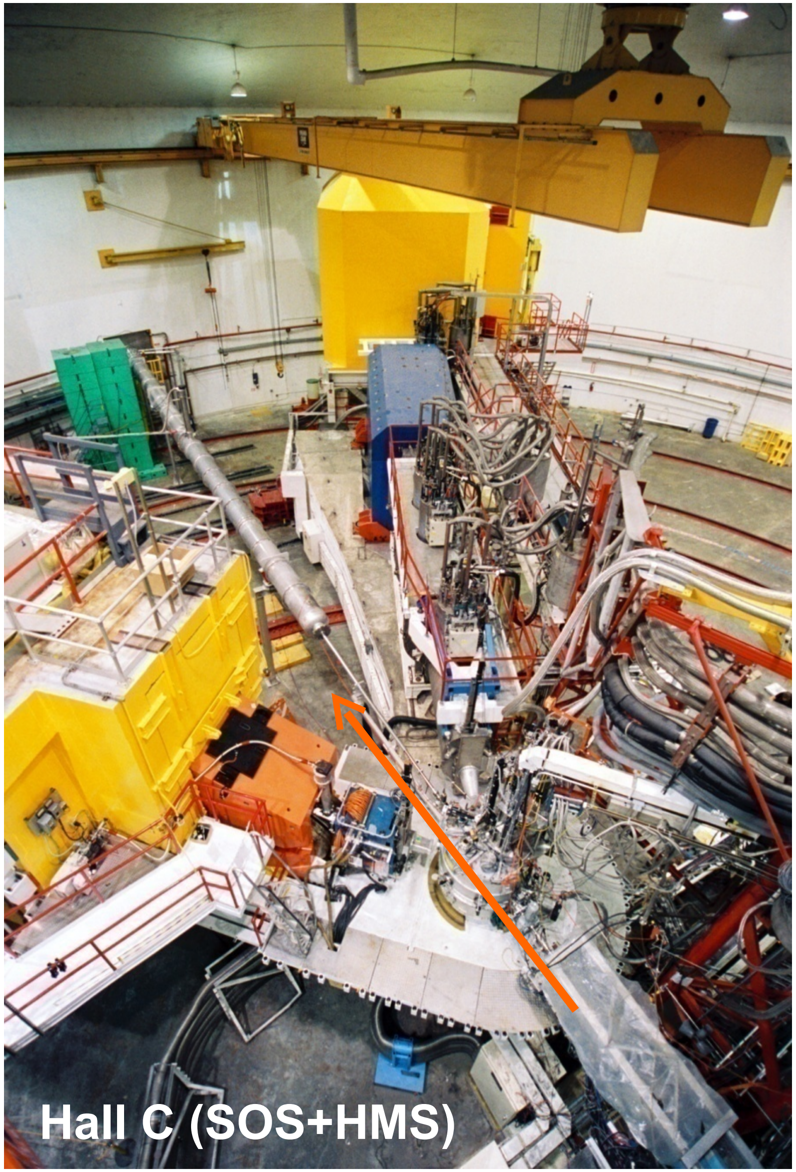
- Typical JLab experimental runs are short (typically less than a year)
- New experiments usually add hardware to the base equipment
  - Can be targets or detectors

2. Installation experiments

- Halls sometimes run experiments that do not use the base equipment
  - Examples include G0 and Qweak in Hall C
- At 12 GeV there will for instance be several such dark matter searches
  - HPS in Hall B, Dark Light at the Free Electron Laser, etc

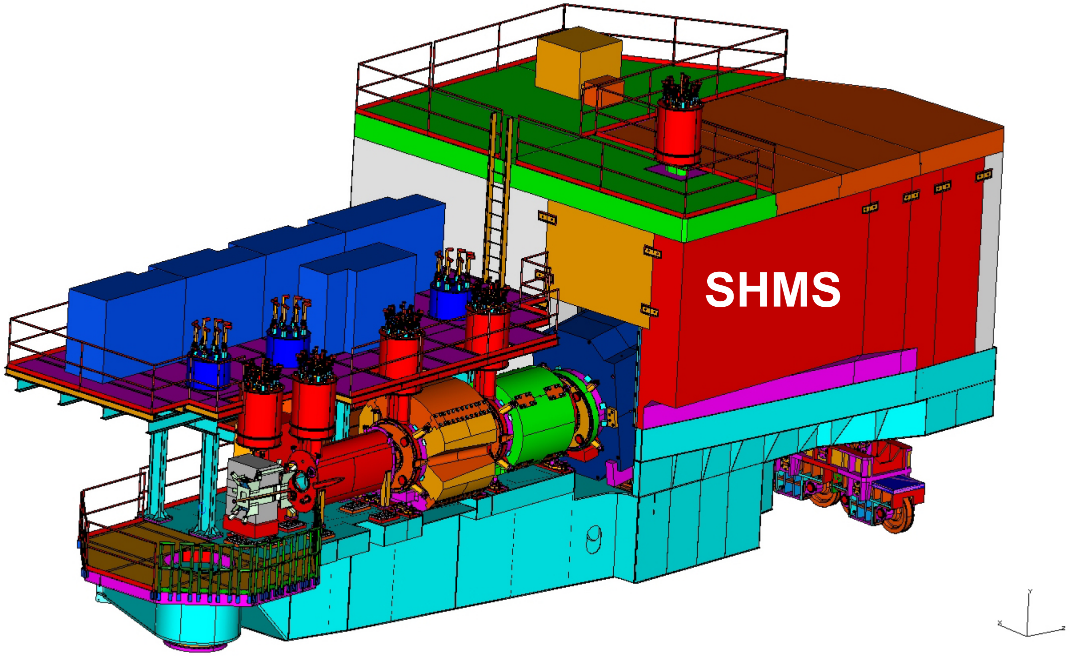
3. The next few slides will show an overview of the main detectors

Hall C: focusing spectrometers



- Retain the High-Momentum Spectrometer (HMS)
- Replace SOS spectrometer with new Super-HMS

- Luminosities reaching at least 10^{38} $cm^{-2}s^{-1}$
- PID and momentum analysis up to 11 GeV/c

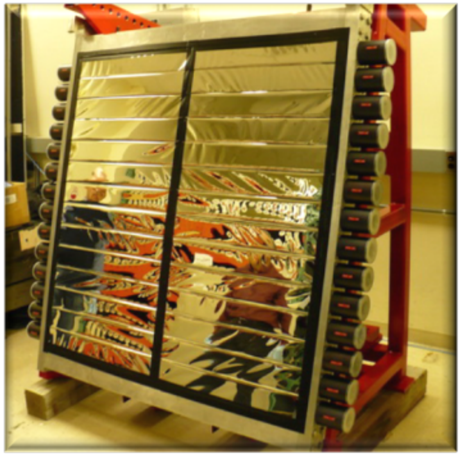


Hall C: SHMS detectors

Dipole Magnet Prototype Coil (SigmaPhi, France)

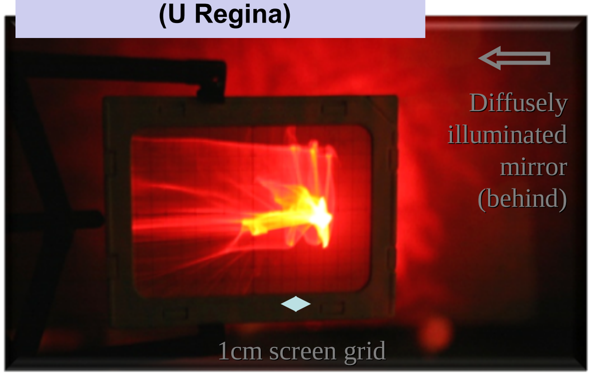
Wire Chambers (Hampton U)

PreShower (Yerevan/NSL)



All detectors but one from user contributions

Heavy-gas Cherenkov Mirror (U Regina)

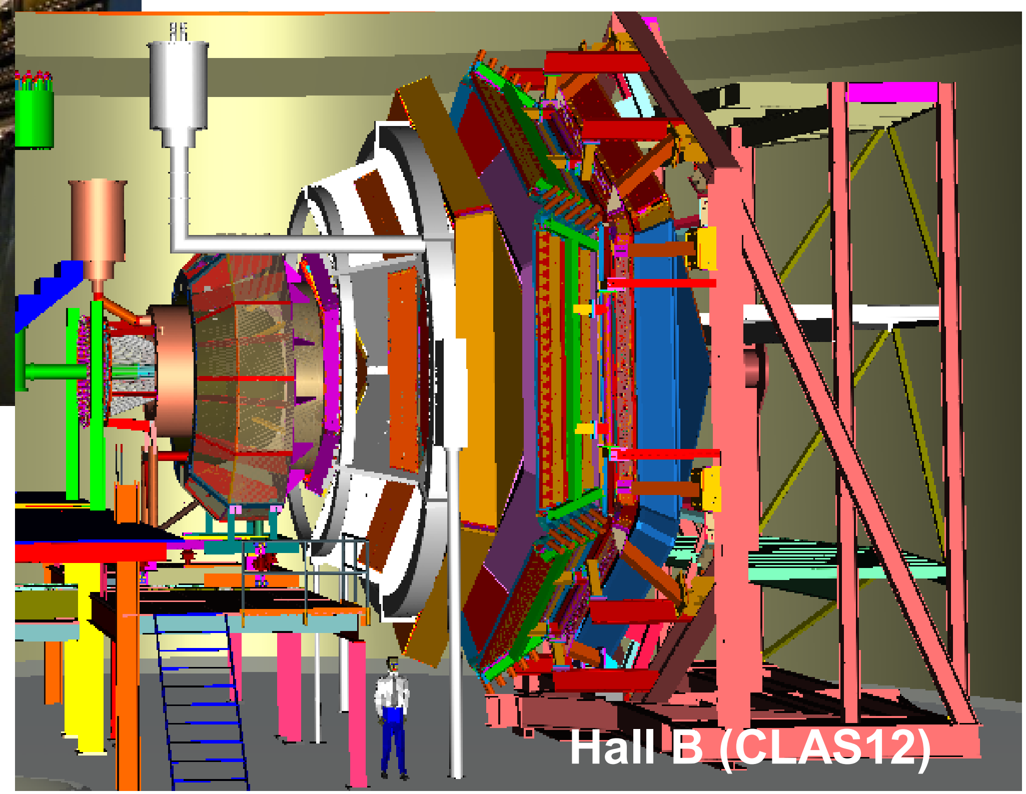


Quartz Hodoscope (NC A&T)

Aerogel Cherenkov Box (CUA)

Hall B: CEBAF Large Acceptance Spectrometer (CLAS)

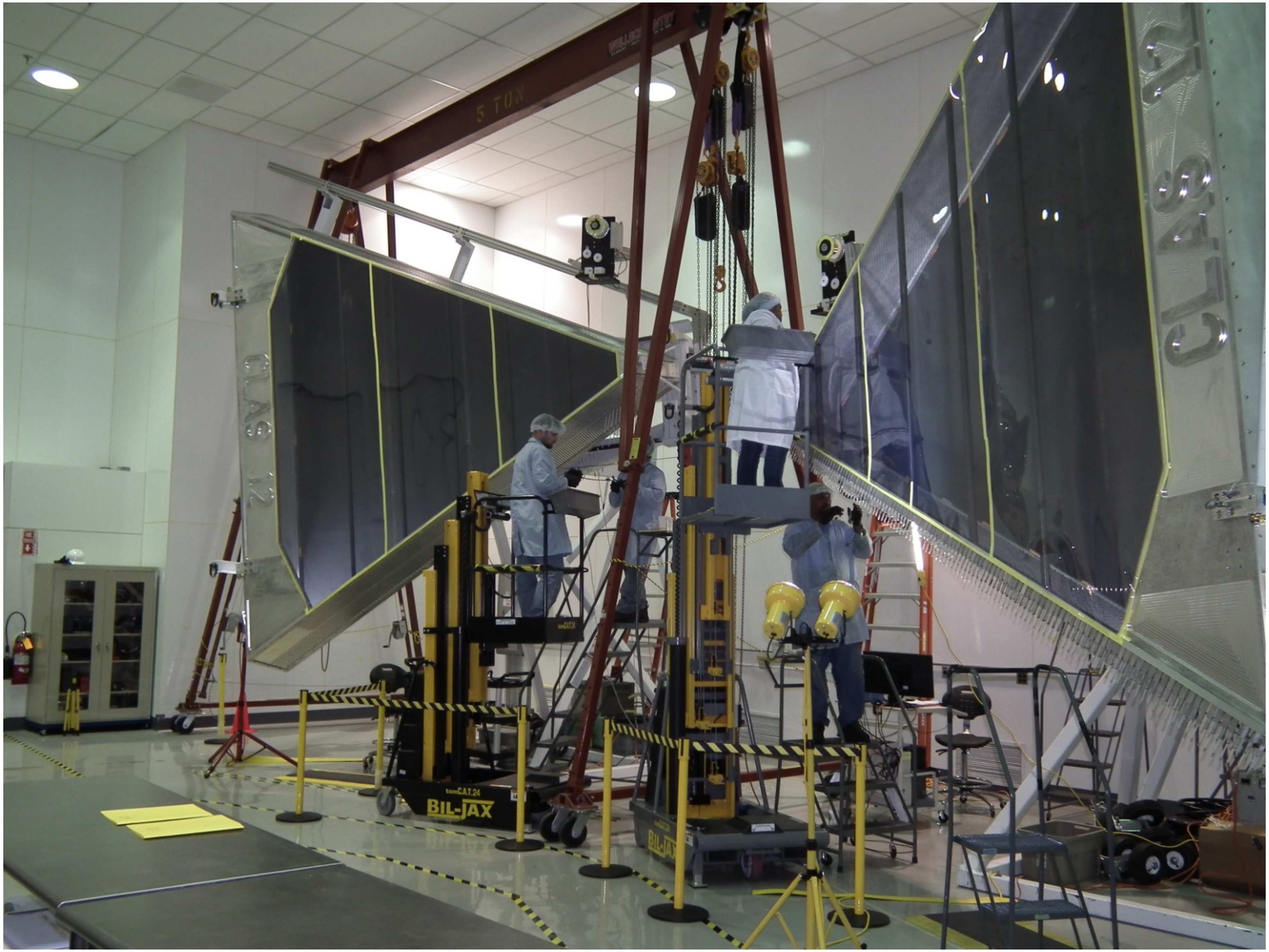
- CLAS replaced by CLAS12
  - Optimized for forward detection
- New magnets and detectors
- Old components reused when possible



PID includes:

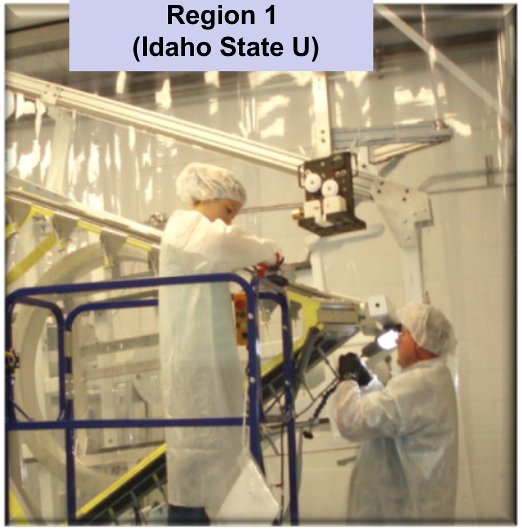
- Two sets of threshold gas Cherenkovs and sampling EM calorimeter with preshower for e/π identification
- TOF detectors with 80 ps resolution
- RICH detector for π/K identification

Hall B: Stringing new drift chambers for CLAS12



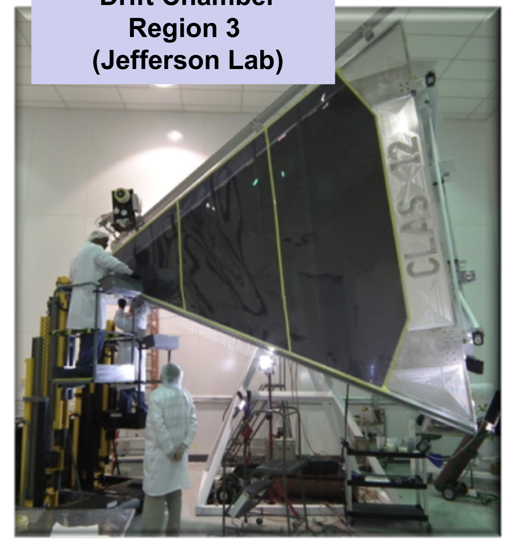
Hall B: CLAS12 detector components

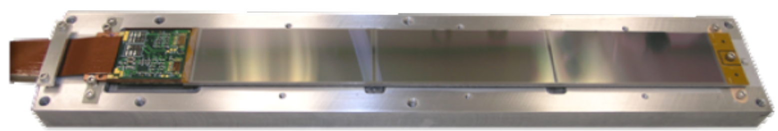
Drift Chamber
Region 1
(Idaho State U)



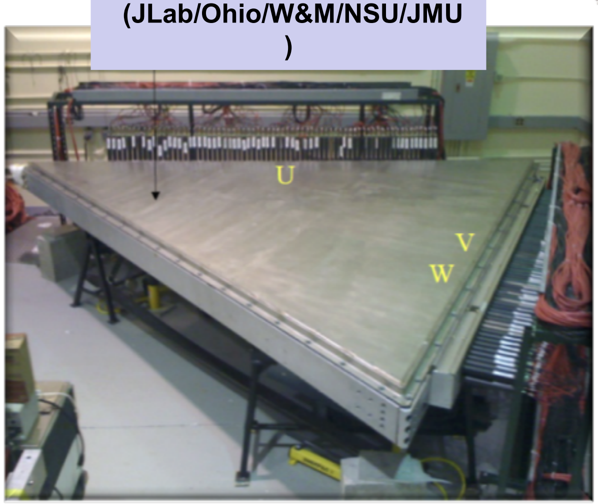
Drift Chamber
Region 2
(Old Dominion U)

Drift Chamber
Region 3
(Jefferson Lab)

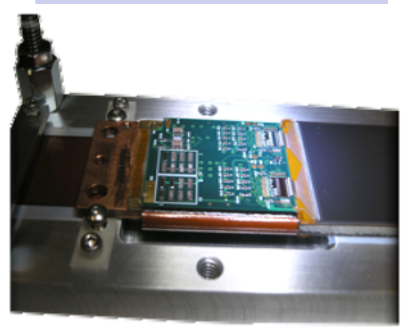




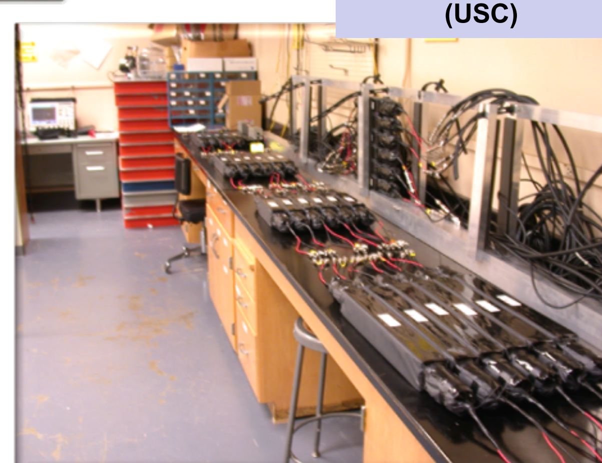
PCAL
(JLab/Ohio/W&M/NSU/JMU
)



Silicon Vertex Tracker
(JLab/FNAL/UNH)

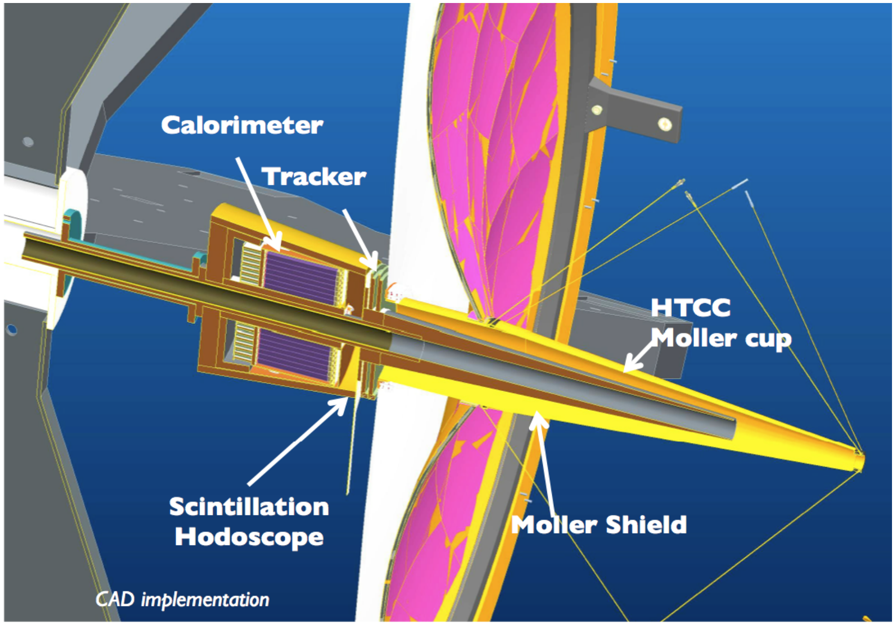


FTOF
(USC)



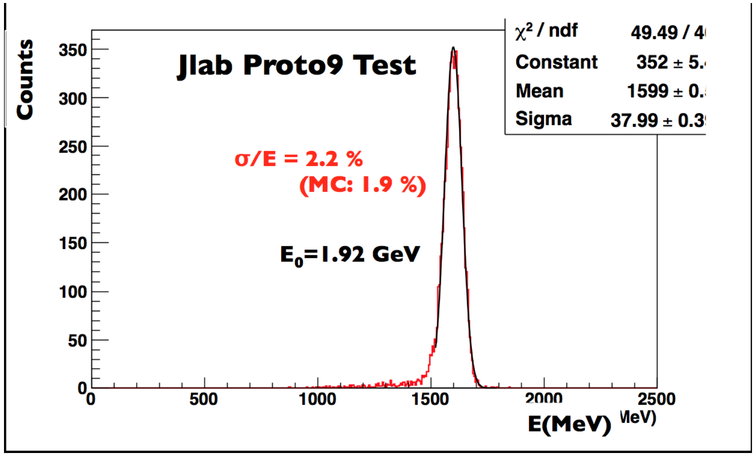
The Forward Tagger for CLAS12

GOAL:
• New system to detect electrons at small angle and perform **quasi-real photo-production** expts
CURRENT DESIGN
• **FT-Cal:** PbWO4 calorimeter (electron E/p)
• **FT-Hodo:** Scintillator tiles (veto for photons)
• **FT-Trck:** MicroMegas detectors (electron angles and polarization plane)



FT-Cal prototypes

• Test Proto9 (3x3 matrix) at JLab (Dec.'11-Feb.'12)
• First test Proto16 (4x4 matrix) at LNF(May '12)
• Final test Proto16 at LNF (Oct 2012)



TIME SCHEDULE
2010: detector design, end of R&D
2011: test of components, end of R&D
2012/2013: prototyping, procurement
2013: procurement and detector construction
2014/2015: detector test and installation in CLAS12

FT project JLab review
December 11-12, 2012

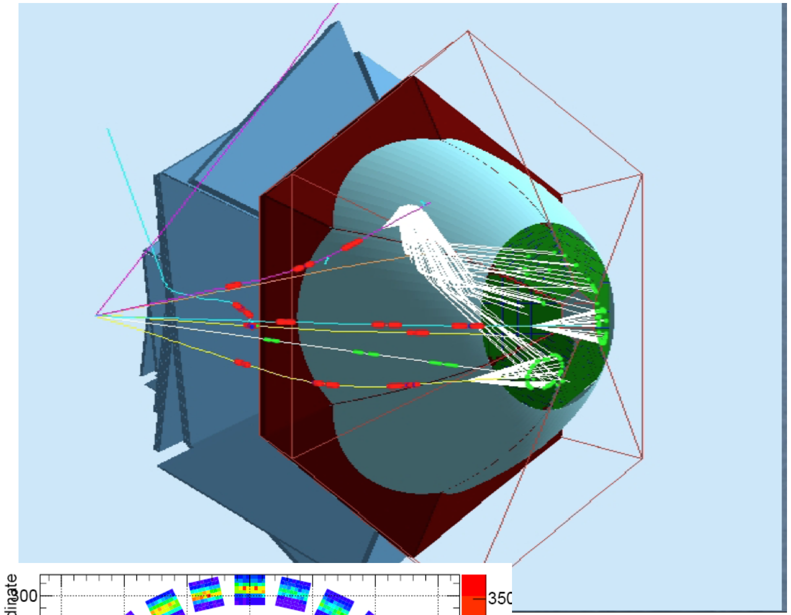
The RICH detector for CLAS12

GOAL:

- identification of K in the 2-8 GeV/c momentum region
- π/K separation with rejection factor ~1000

CURRENT DESIGN

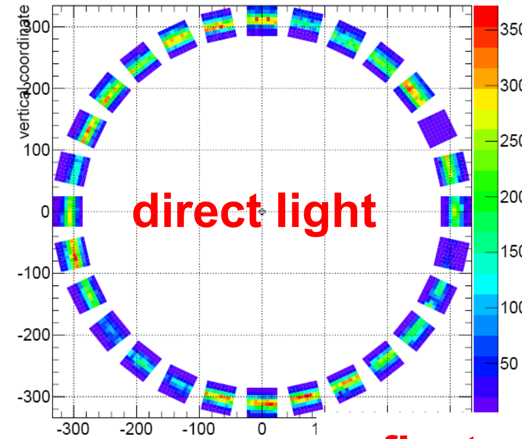
- replace the LTCC
- aerogel radiator to match the momentum range
- multi-anode PMT for photon detection
- mirrors to focalize the photons in a smaller area



STATUS OF THE PROJECT

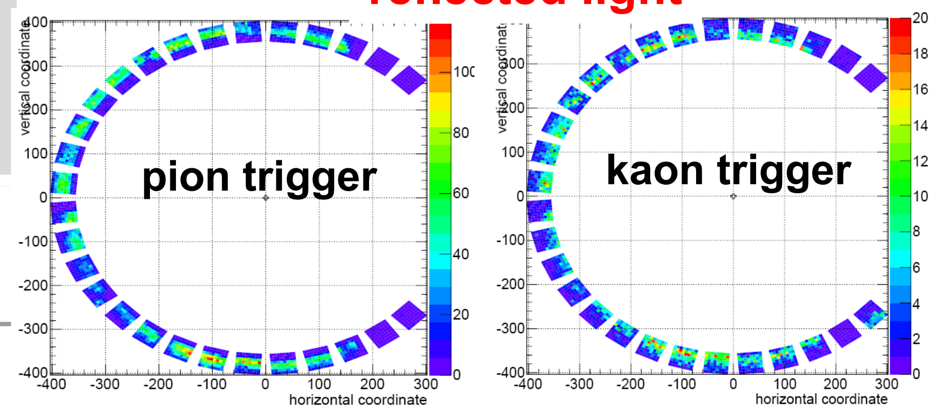
- in-beam test at CERN of a simplified detector **Done**
  - test of MAPMT as single photon detectors
  - pion ring reconstruction
- Monte Carlo simulations **Done**
  - simulations calibrated with CERN data
  - first realistic estimate of resolution and efficiency
- in-beam test at LNF-BTF (July 2012) **Done**
  - test of DAQ system
- in-beam test at CERN of a new prototype **Done + Underway**
  - direct and reflected light setup
  - π/K separation
  - Multiple crossing through aerogel

2012: detector geometry definition&prototyping
2013/2014: end of R&D, procurement

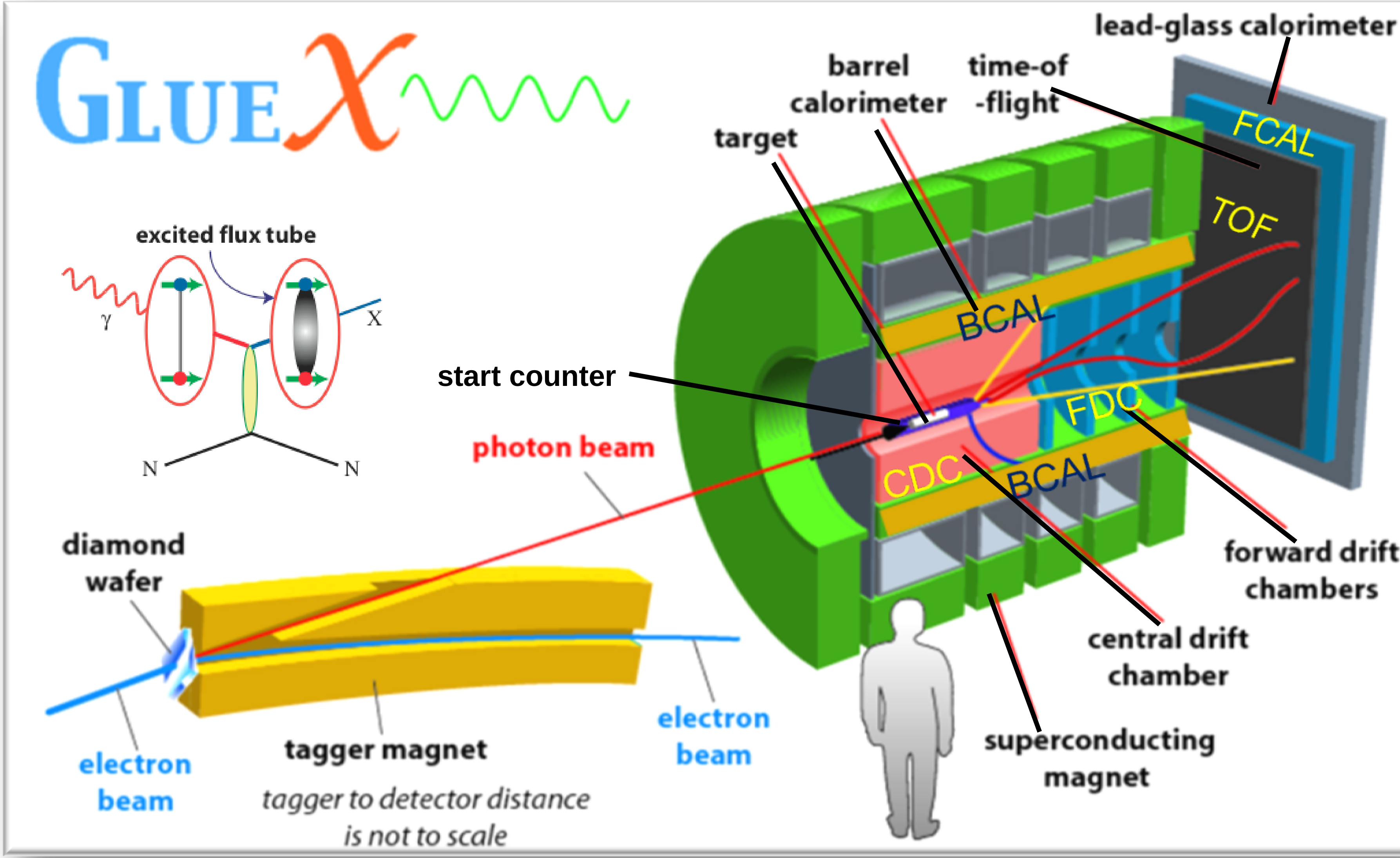


CERN test results Aug 2012

reflected light



Hall D: GlueX with tagged, polarized real photons

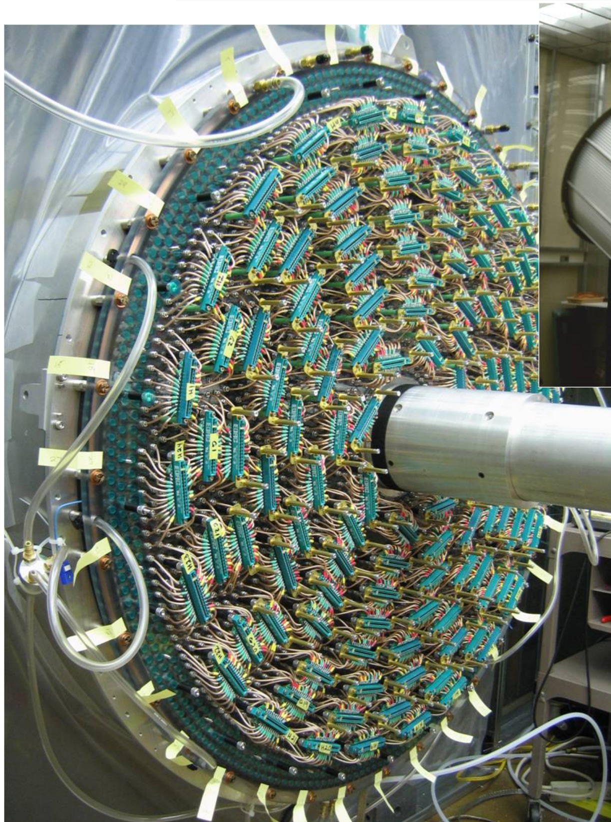


New Hall, new detector (only solenoid reused)

Hall D: GlueX detector components

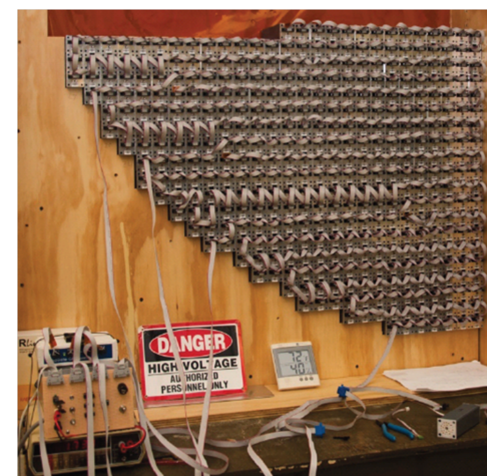
Barrel Calorimeter (BCAL) module (U Regina)

Hall D interior, Oct 2012



Central DC (CDC)
(Carnegie Mellon)

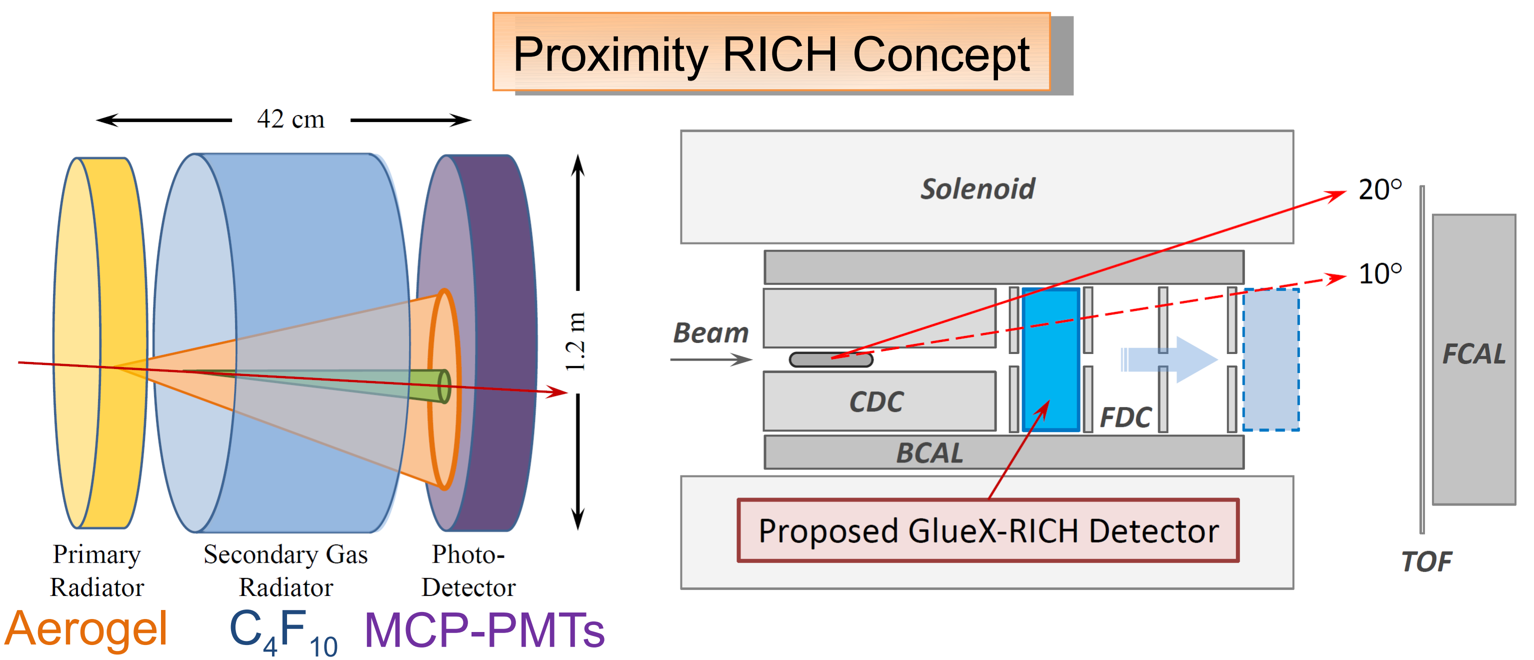
Forward DC (FDC) (JLab)



Forward Calorimeter (FCAL)
(Indiana U)

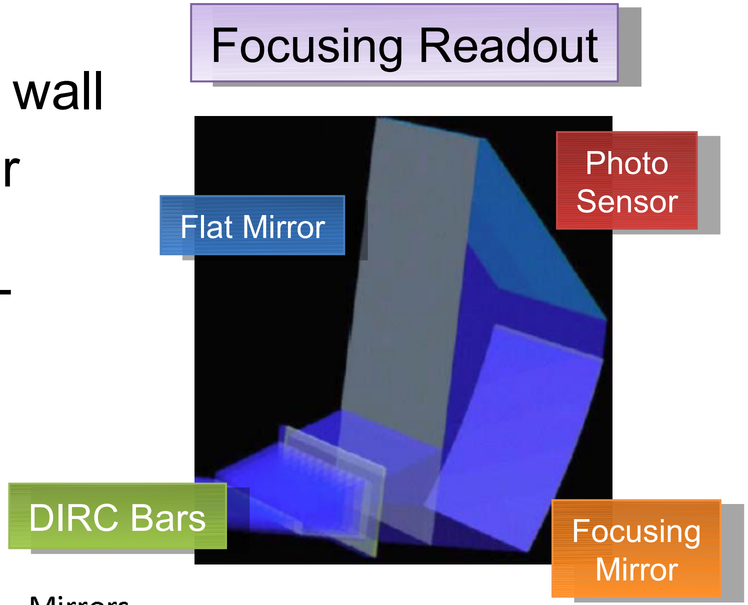
Hall D: GlueX PID upgrade – option 1

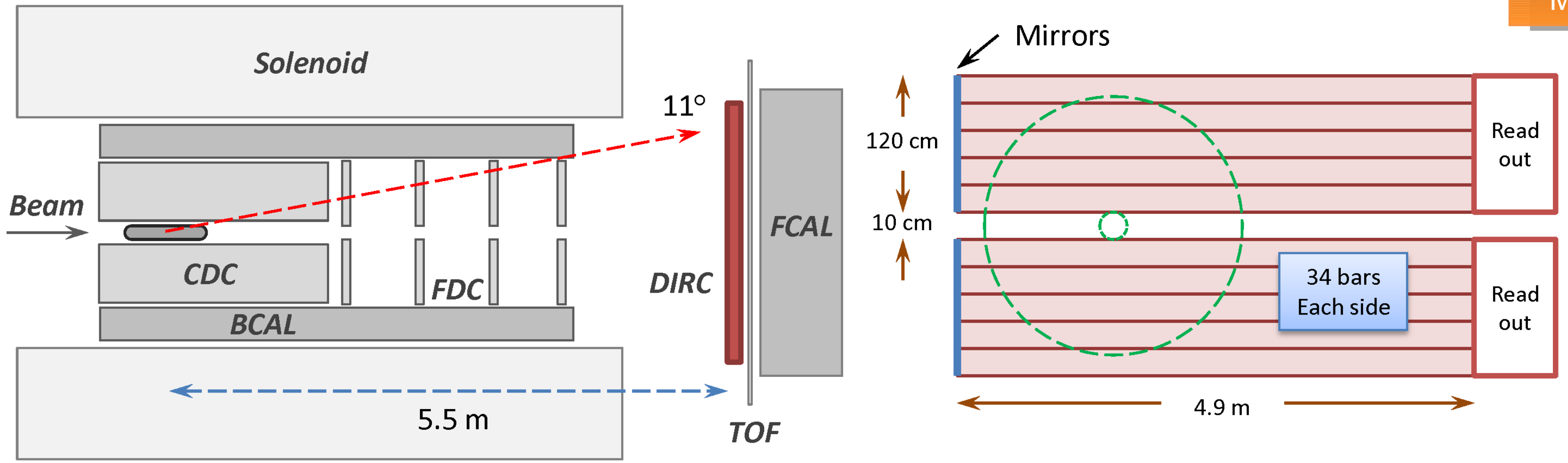
- Baseline GlueX setup has limited kaon identification
- Upgrade option 1: Dual-radiator RICH similar to LHCb
  - limited to forward region
  - well-developed technology



Hall D: GlueX PID upgrade – option 2

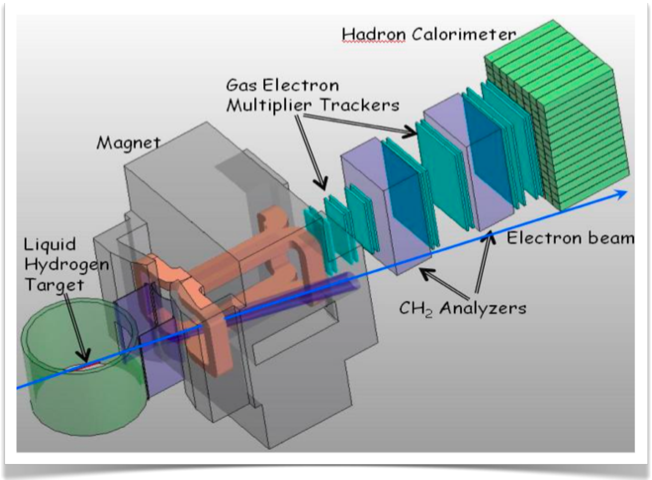
- DIRC in GlueX detector
  - Use half of SLAC DIRC bars to form a wall
  - Focusing readout: compact size, better resolution
  - Photon sensors: MCP-PMT or MaPMT
  - Can be combined with a threshold Cherenkov to cover higher momenta



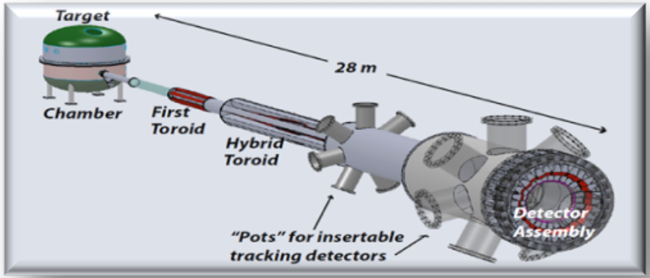


Hall A: Beyond the 12 GeV upgrade

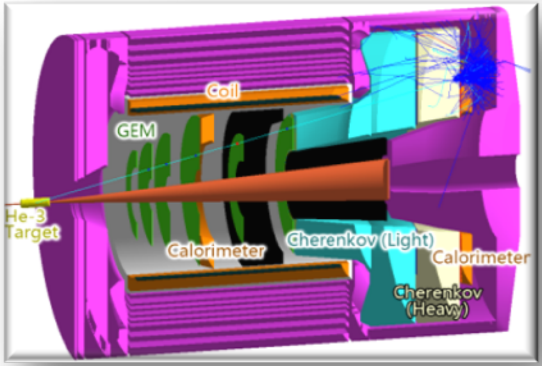
Hall A will run early, with only modest initial upgrades. Later, several major installations are planned:



- **Super BigBite Spectrometer**
  (Approved for FY13-16 construction)
  - **high Q^2 form factors**
  - **SIDIS**

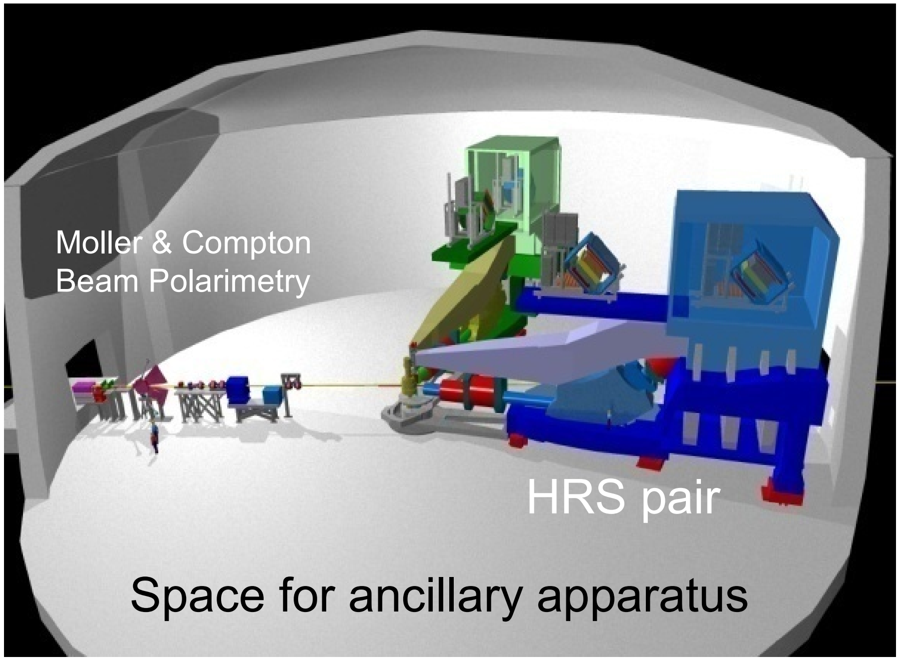


- **MOLLER experiment**
  (MIE – FY14-18?)
  - Standard Model Test



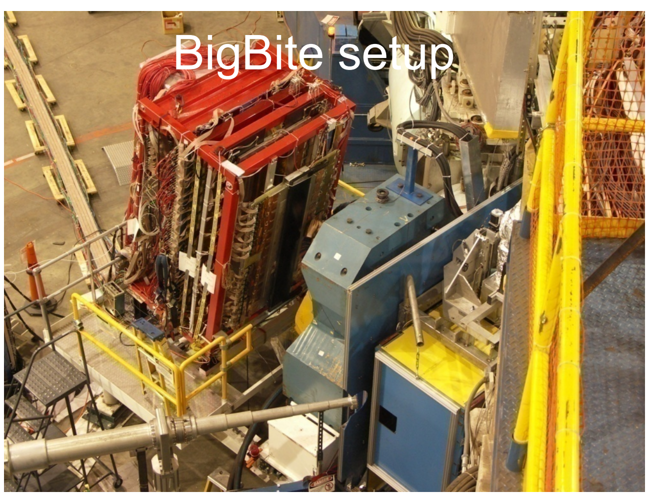
- **SoLID**
  Chinese collaboration
  CLEO Solenoid

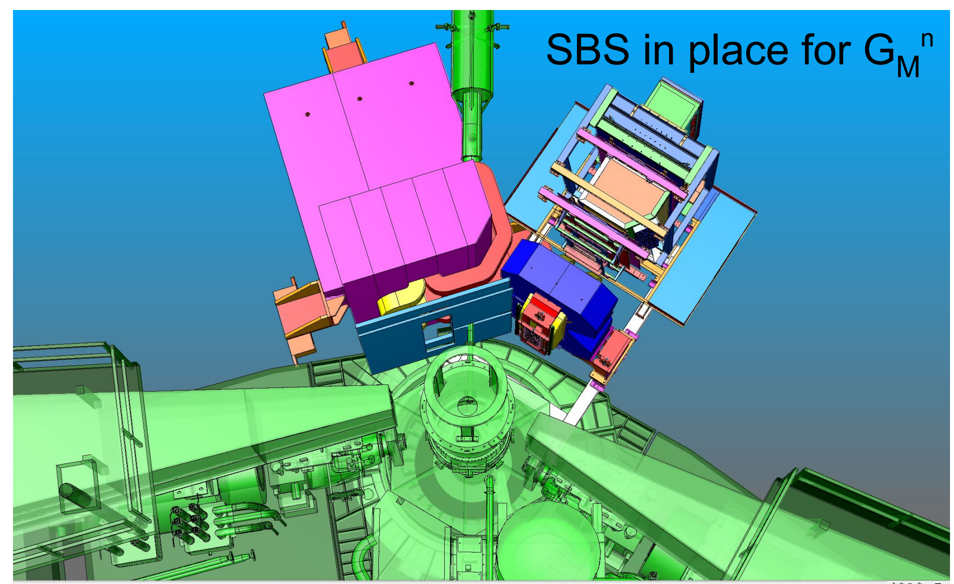
Hall A: HRS and (Super) Bigbite Spectrometers



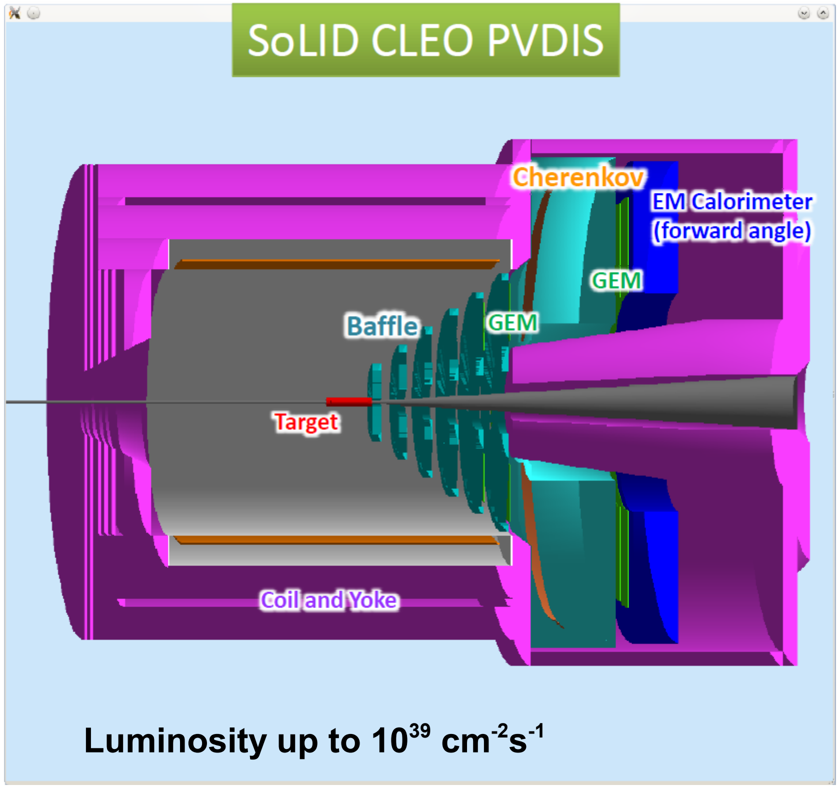
- Retain High-Resolution Spectrometers (HRS)
- Upgrade Bigbite to SuperBigbite (SBS)

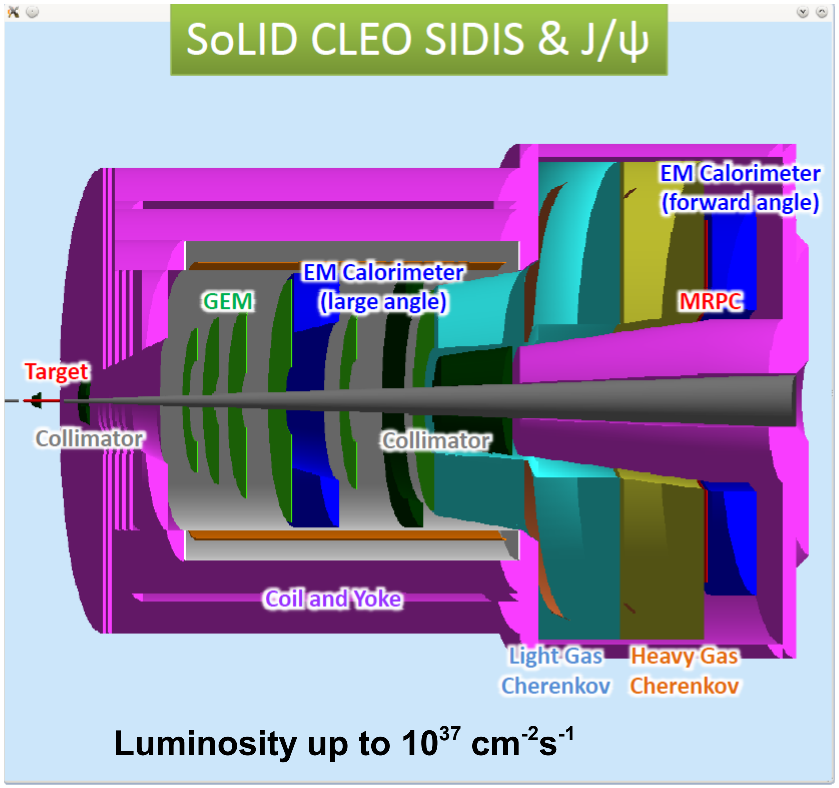
- SBS approved by DOE/NP in April 2012
- PID options include refurbished dual-radiator RICH from HERMES





Hall A: Solenoidal Large Intensity Device (SoLID)



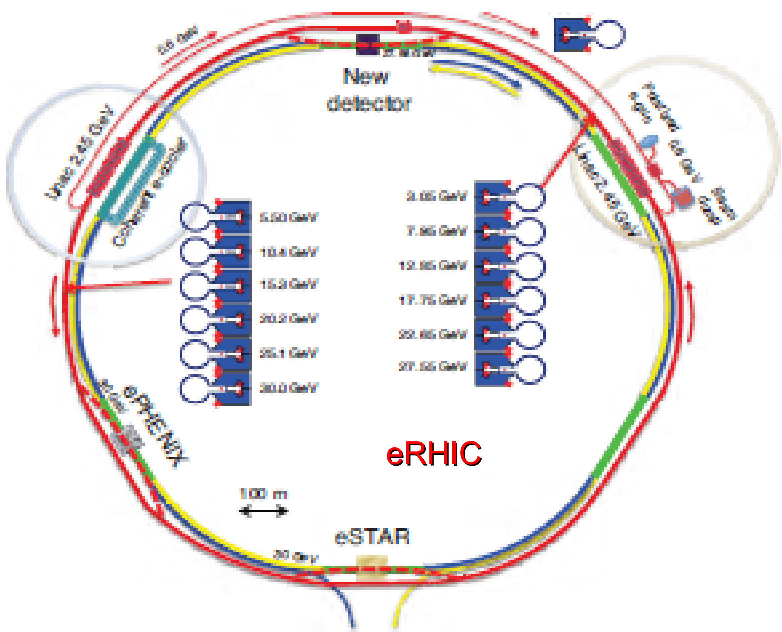


- Large acceptance detector based on CLEO solenoid
- GEM-based tracking will allow reaching very high luminosities
- Envisioned to run in two configurations

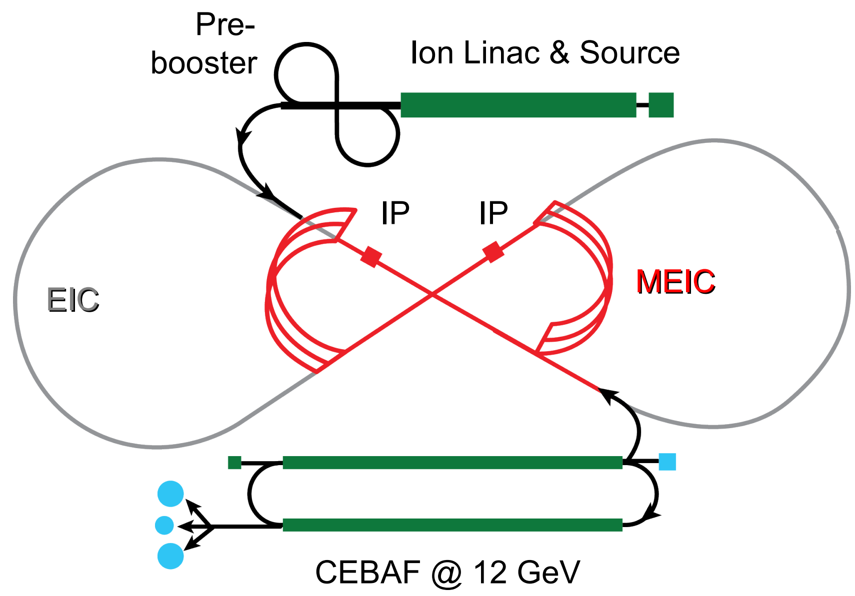
- PID includes two threshold Cherenkovs, a Shashlyk-type EM calorimeter, and high-resolution time-of-flight detectors

Generic detector R&D for an Electron-Ion Collider

BNL

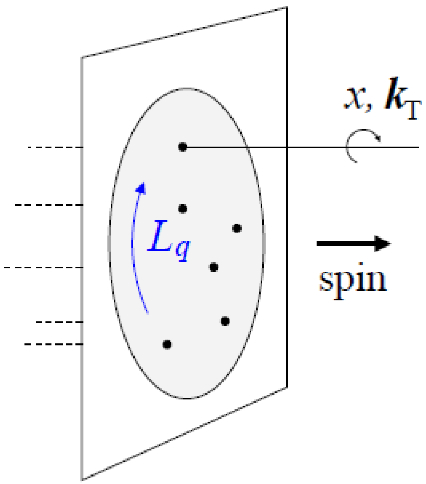


JLab

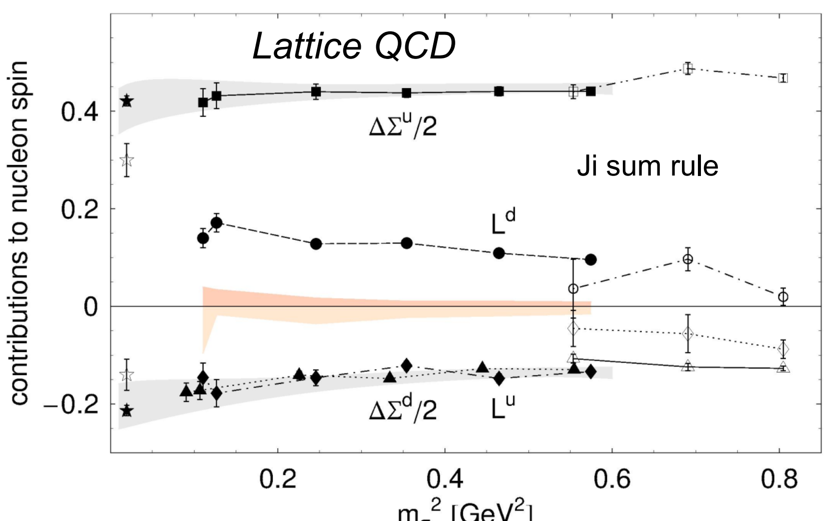


- The generic detector R&D program is site-independent
  - Addresses common R&D challenges in developing an EIC detector.
  - Coordinated by Tom Ludlam (BNL)
  - Significant HEP representation on the advisory committee

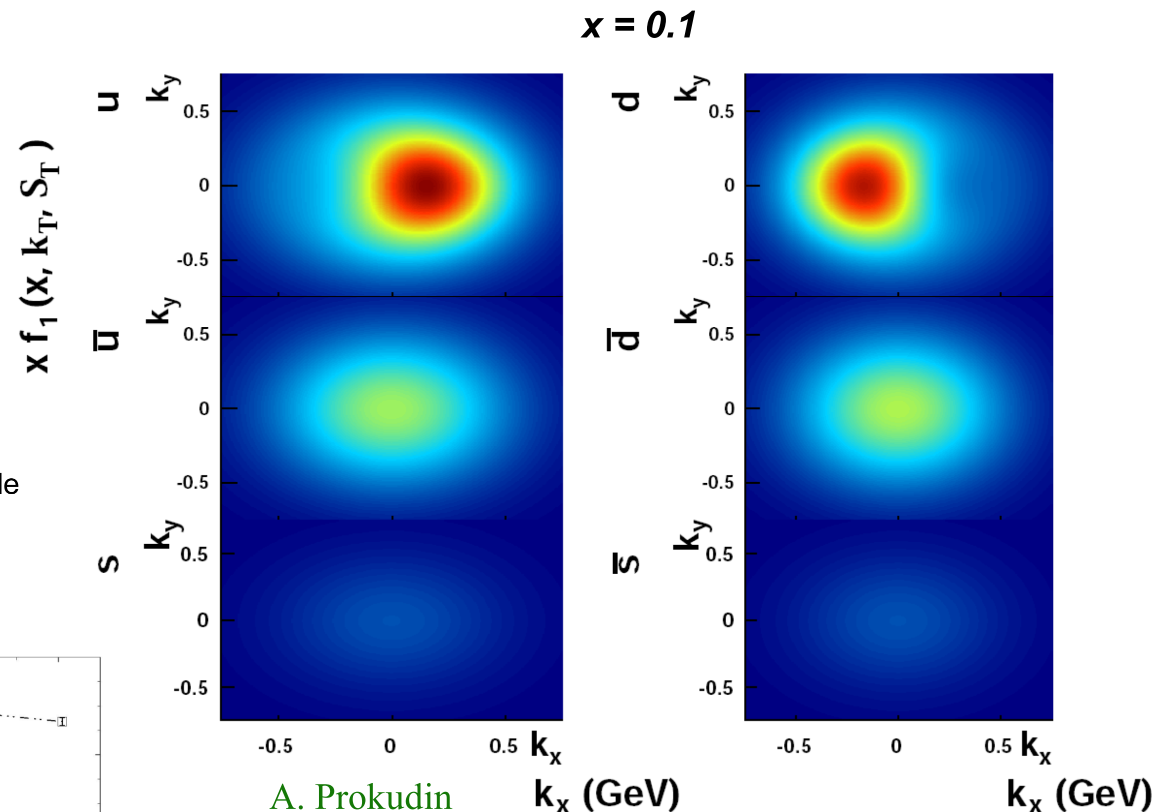
Quark Orbital Angular Momentum (OAM) with flavor



Jaffe sum rule



LHPC Collaboration

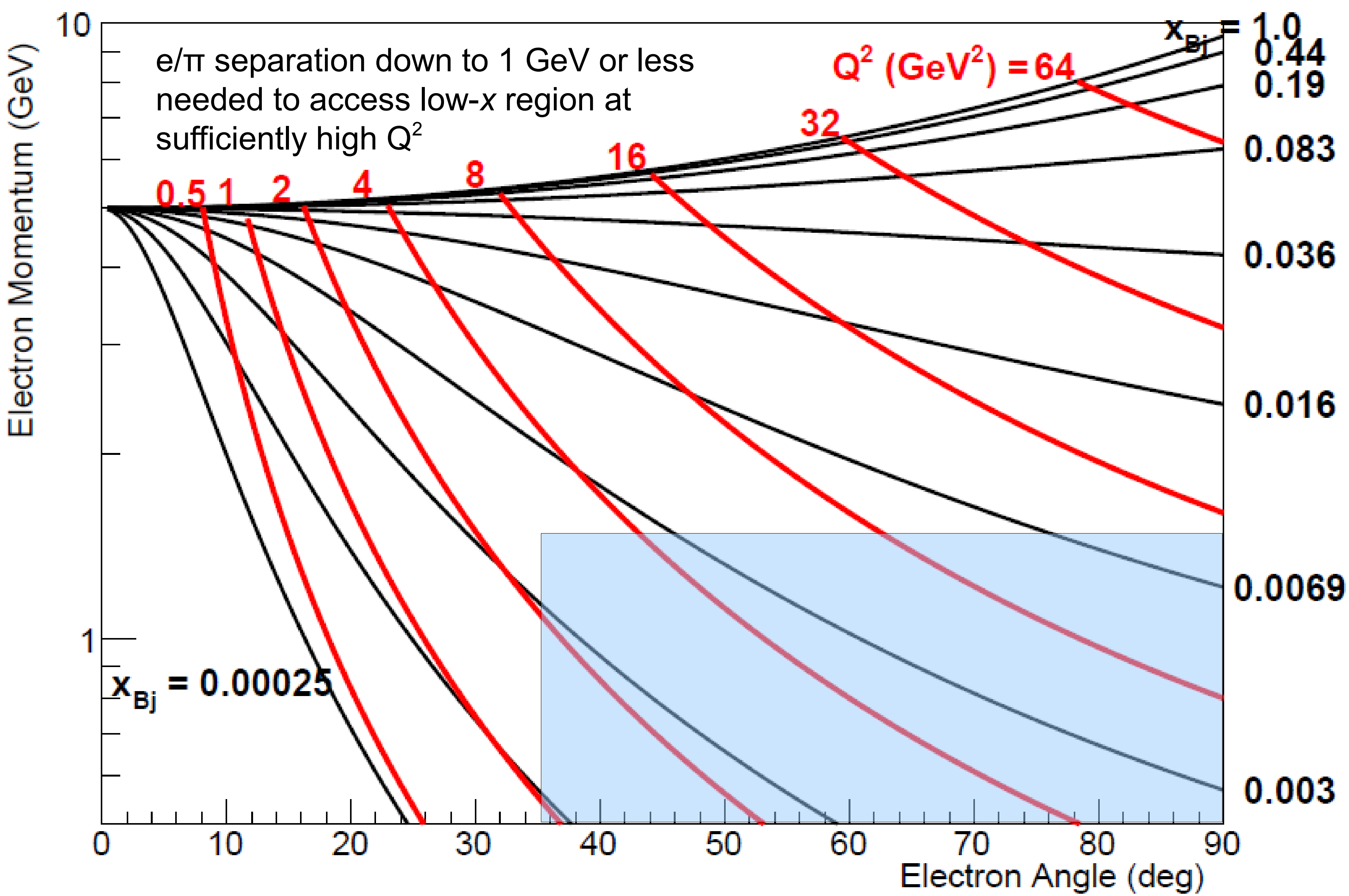


A. Prokudin

- 3D mapping of quarks in momentum space through Transverse Momentum Distributions
- JLab 12 GeV: Do valence u and d quarks have opposite signs of their OAM?
- EIC: OAM of sea quarks (with flavor)?

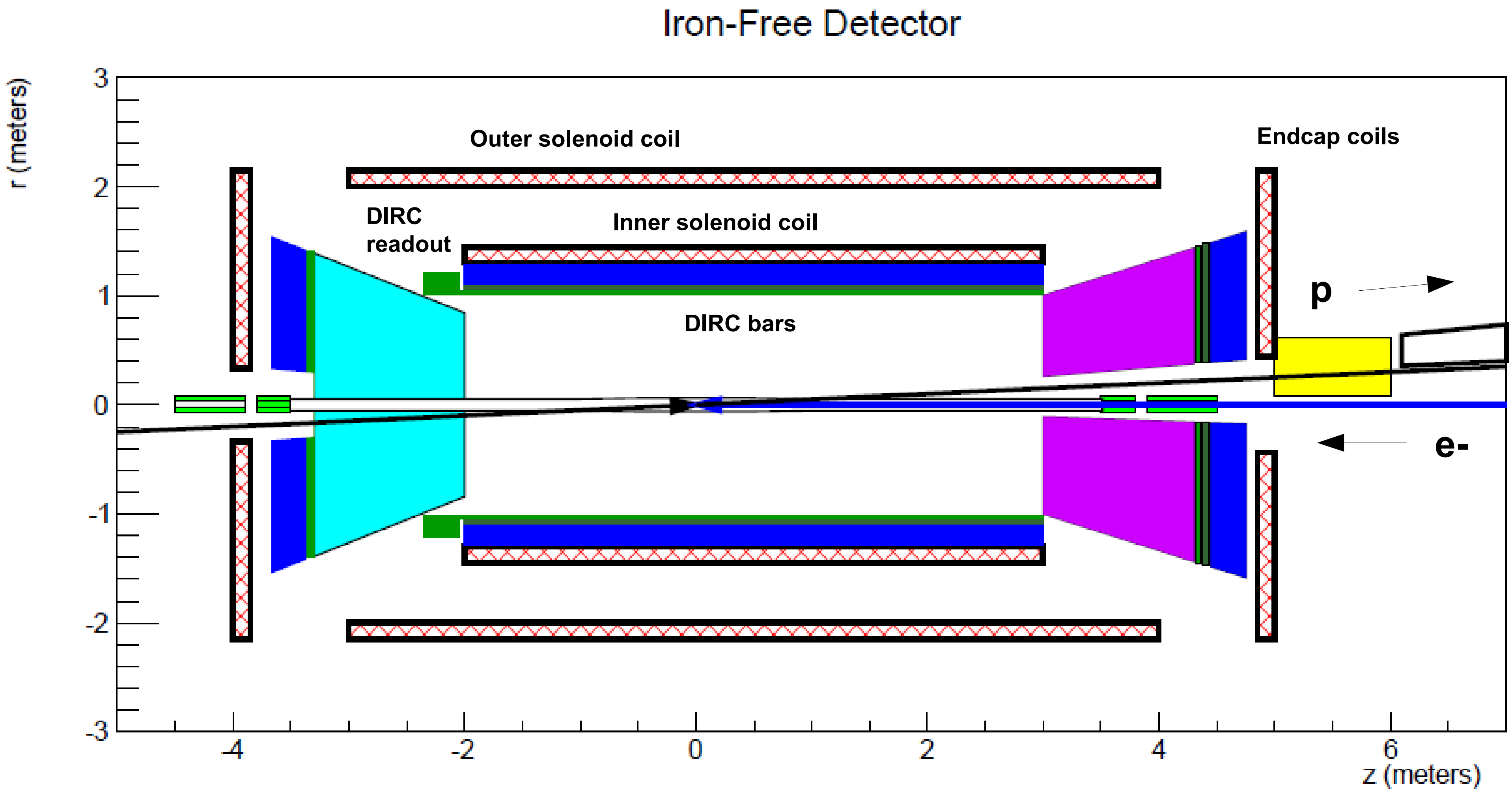
EIC electron identification at low *x*

Collider Kinematics 5.0 ⊗ 100 (GeV/c)^2



• Shaded area could be covered by a DIRC

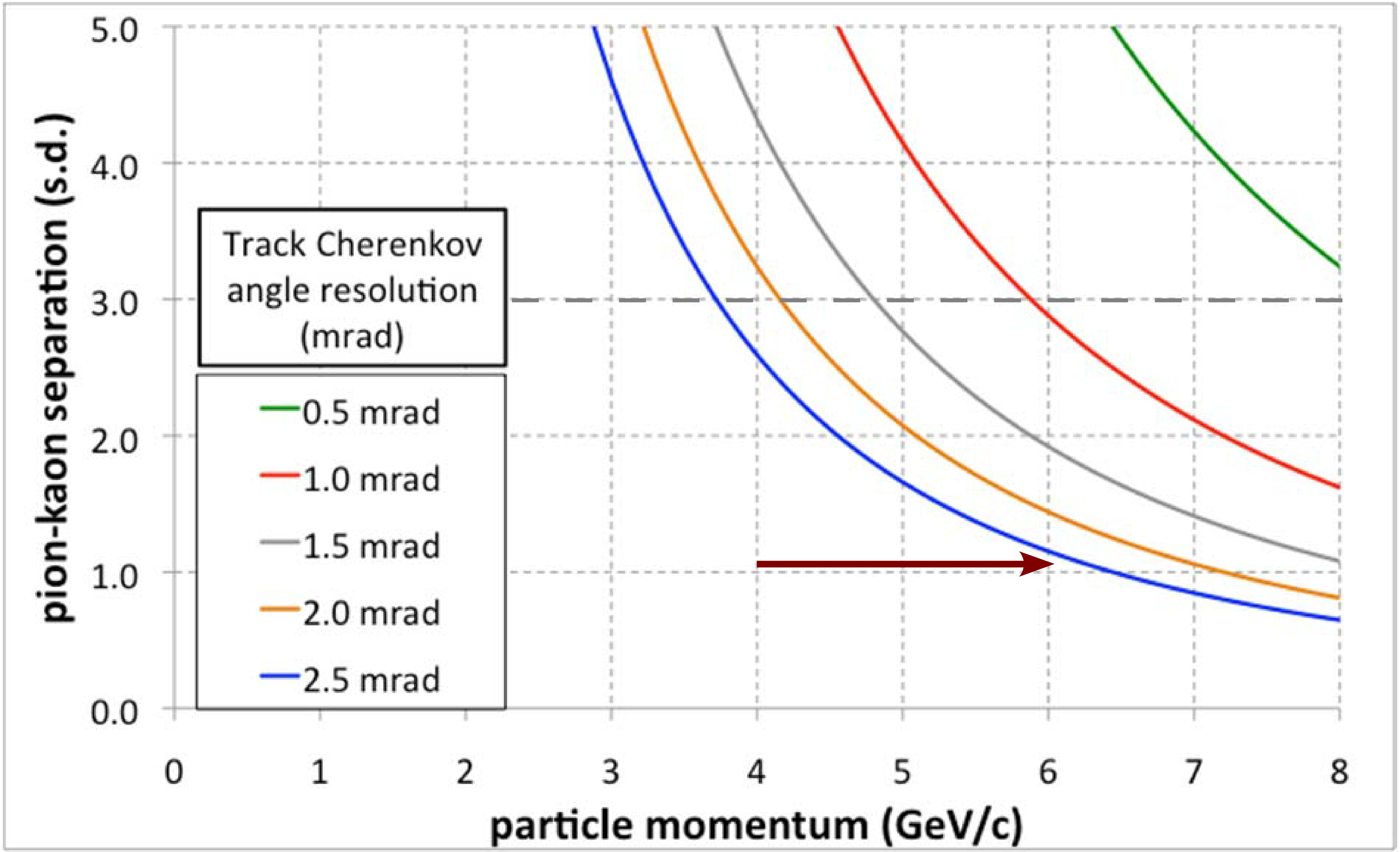
EIC: Iron-free detector layout with DIRC



• One possible detector layout incorporating a DIRC with readout inside of the detector volume.

• An iron-free solenoid for the EIC would be about half the size (1/8 the volume) of the 4th detector concept for the ILC.

DIRC π/K separation as a function of Θ_c resolution



- Better Cherenkov angle resolution allows pushing the p_T coverage

Improving DIRC Θ_c resolution

$$\sigma_{\theta_c}^{track} = \frac{\sigma_{\theta_c}^{photon}}{\sqrt{N_{p.e.}}} \otimes \sigma^{correlated}$$

Correlated term:
tracking detectors, multiple scattering, etc

$$\sigma_{\theta_c}^{photon} = \sqrt{\sigma_{bar-size}^2 + \sigma_{pixel-size}^2 + \sigma_{chromatic}^2 + \sigma_{bar-imperfection}^2}$$

BABAR-DIRC Cherenkov angle resolution: 9.6 mrad per photon → 2.4 mrad per track

Limited in BABAR by:			Could be improved via:
· size of bar image	~4.1 mrad	→	· focusing optics
· size of PMT pixel	~5.5 mrad	→	· smaller pixel size
· chromaticity (n=n(λ))	~5.4 mrad	→	· better time resolution
	9.6 mrad	→	4-5 mrad (?) per photon
· number of photons	15-50	→	· photocathode/SiPM

topics for R&D proposal (focusing optics, smaller pixel size, better time resolution; 4-5 mrad (?) per photon)

Summary

1. The JLab 12 GeV upgrade is well underway

- Halls A and D will come online first, B and C a little later.
- Experiments should be running by 2015
- Fixed-target program will run for at least 10-15 years.

2. Opportunities for early use of HEP detectors in real experiments?

- Replacing existing detector components
- Building ancillary detectors systems
- Collaborating on new experiments

3. Detector R&D for an Electron-Ion Collider

- HEP experience could provide important input

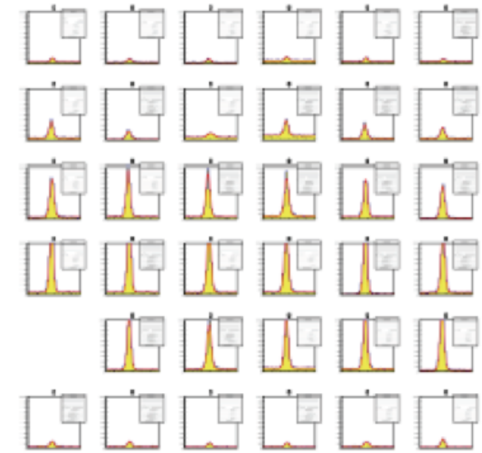
Backup

RICH Detector

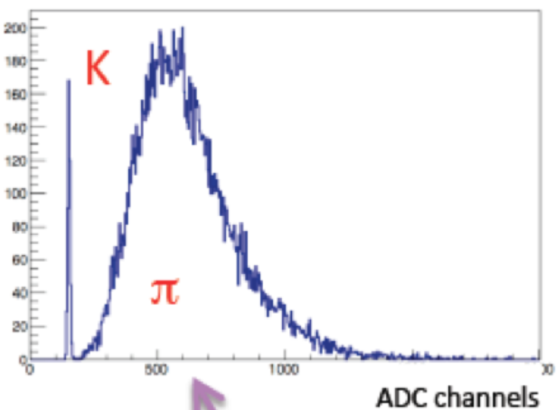
December 2012:

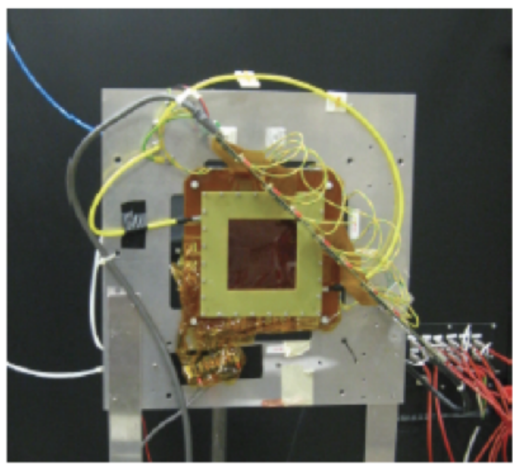
Extensive prototype tests at CERN hadron beam facility w/ pion and kaon beams.

Cherenkov Ring Profile

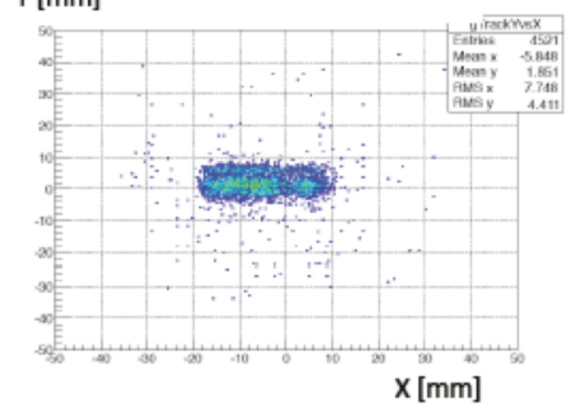


Beam ID

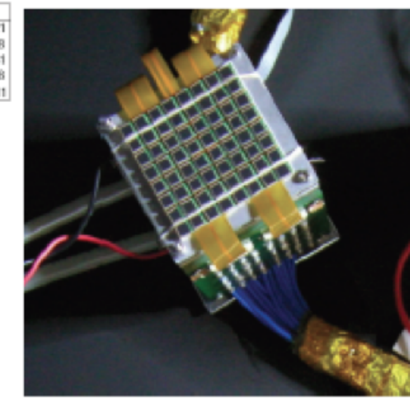




Beam Profile

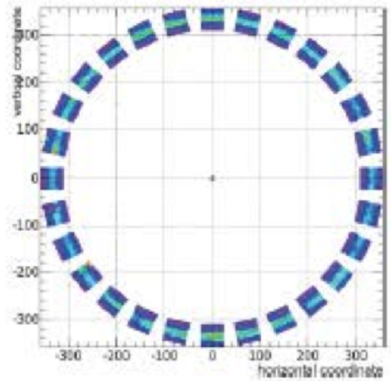


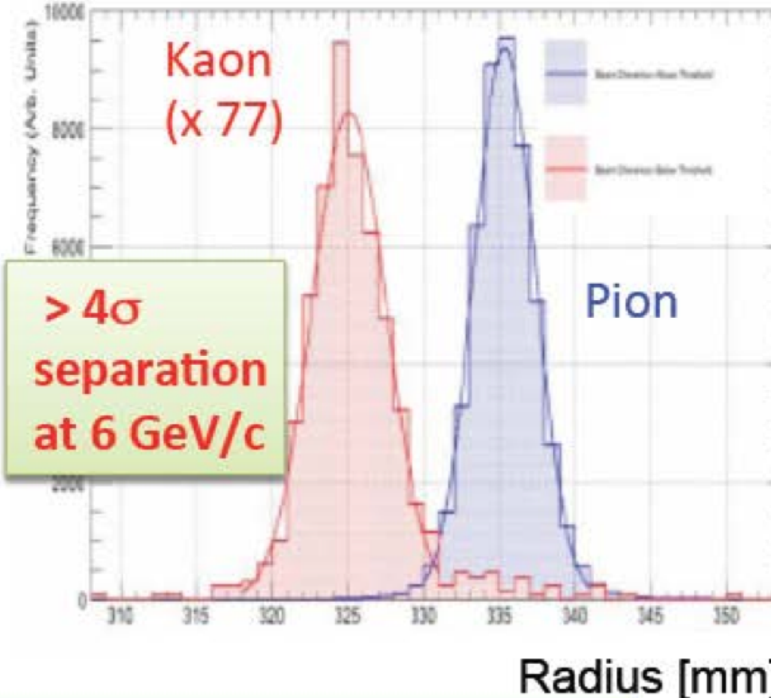
Δt with trigger



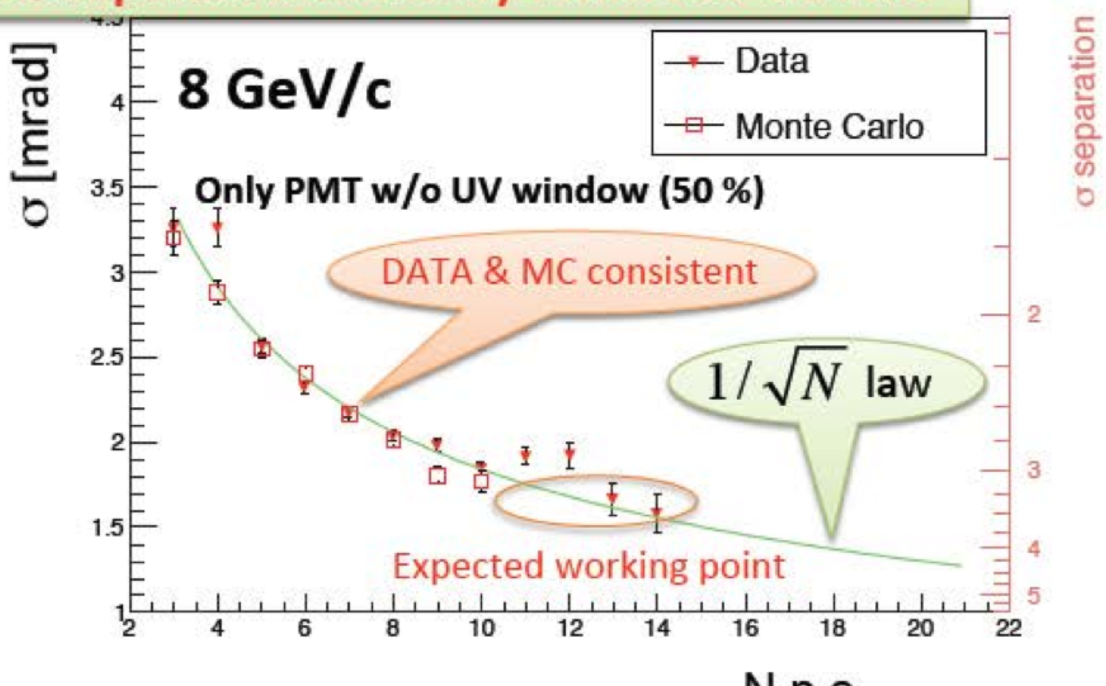
RICH Prototype: Direct Light

Aerogel n=1.05, Beam P = 6 and 8 GeV/c



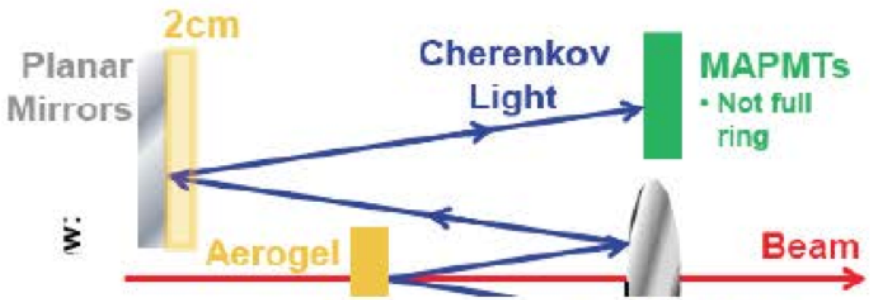


> 3σ separation at 8 GeV/c with not-UV PMT

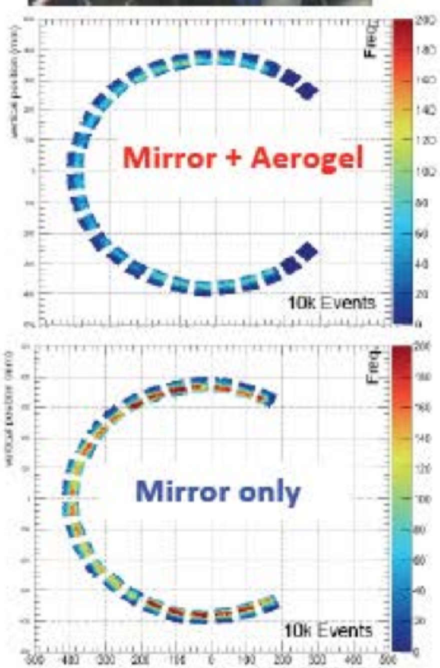


RICH Prototype: Reflected Light

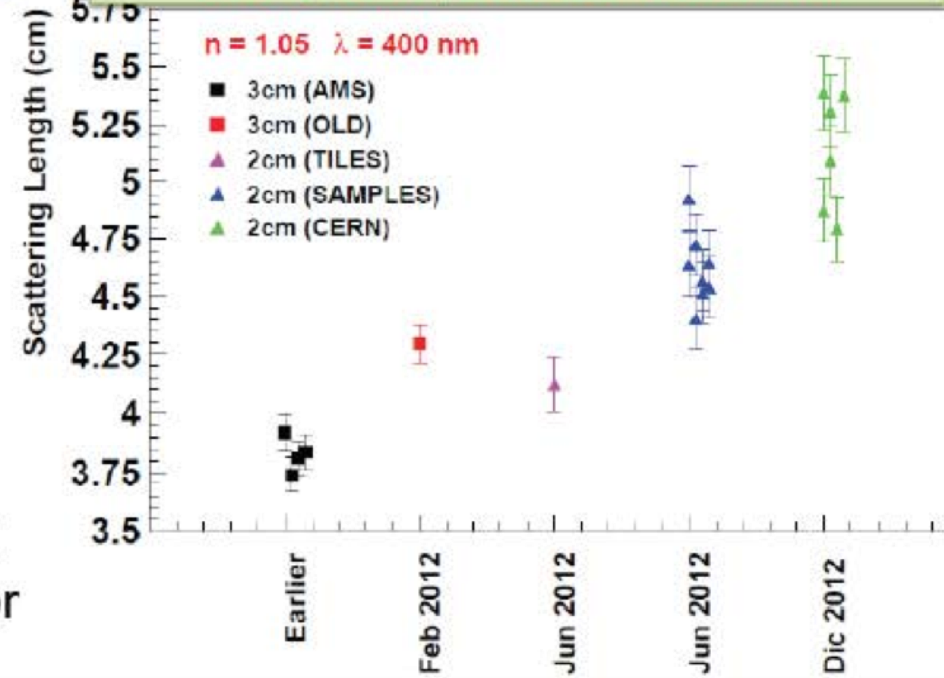
Aerogel n=1.05, Beam P = 6 GeV/c



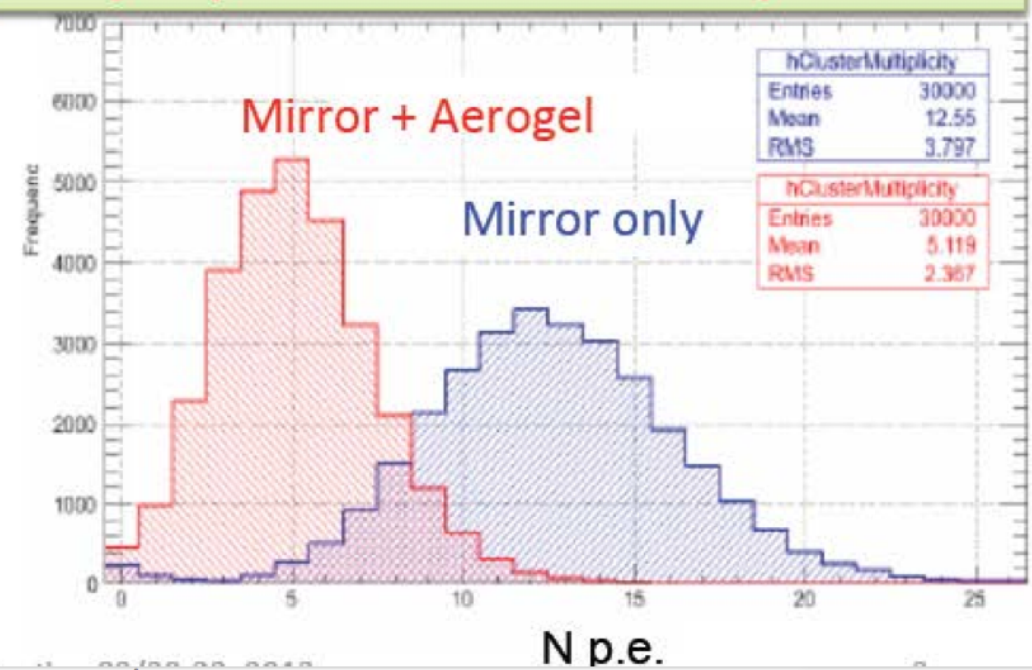
HTCC mirror



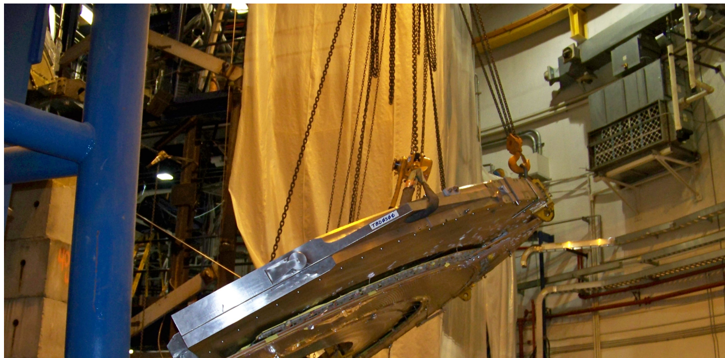
Aerogel improvement in Time

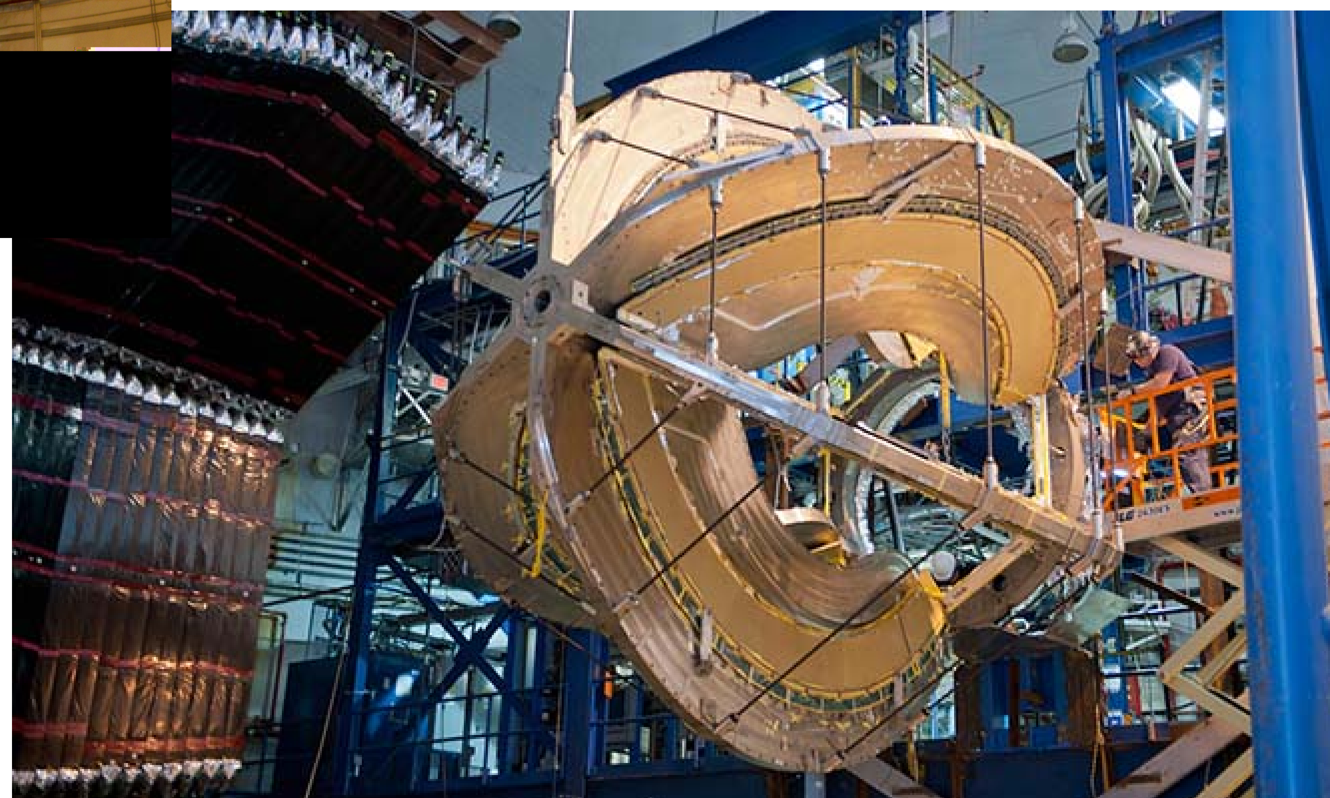


60% p.e. yield loss matches the requirements

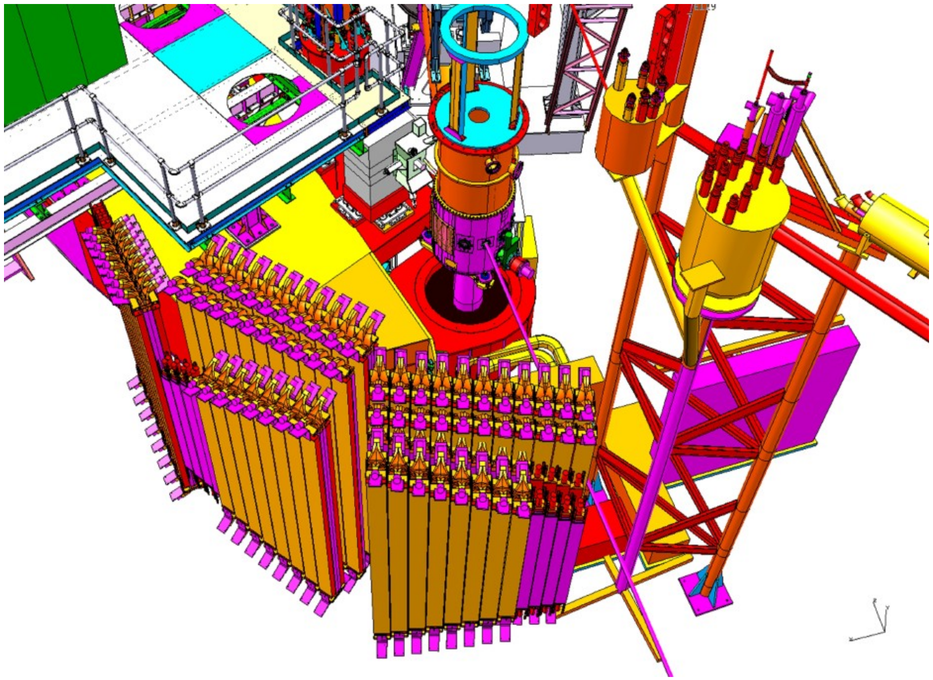


Hall B: Removal of old torus magnet



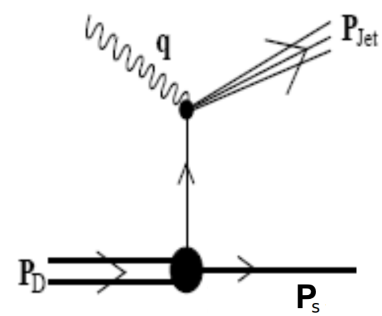


Re-using CLAS detectors for Hall C experiment

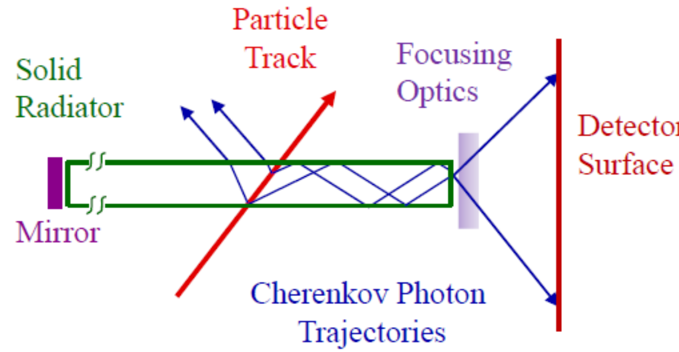


Recycled CLAS (Hall B) TOF detectors not used for CLAS12

$d(e, e' N_{backward})$
Detect spectator proton or neutron to tag in-medium structure function on off-shell nucleon (EMC effect).



DIRC principle



- Charged particle traversing radiator with refractive index n with $\beta \equiv v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos\theta_c = 1/\beta n(\lambda)$.

- For $n>\sqrt{2}$ some photons are always totally internally reflected for $\beta \approx 1$ tracks.

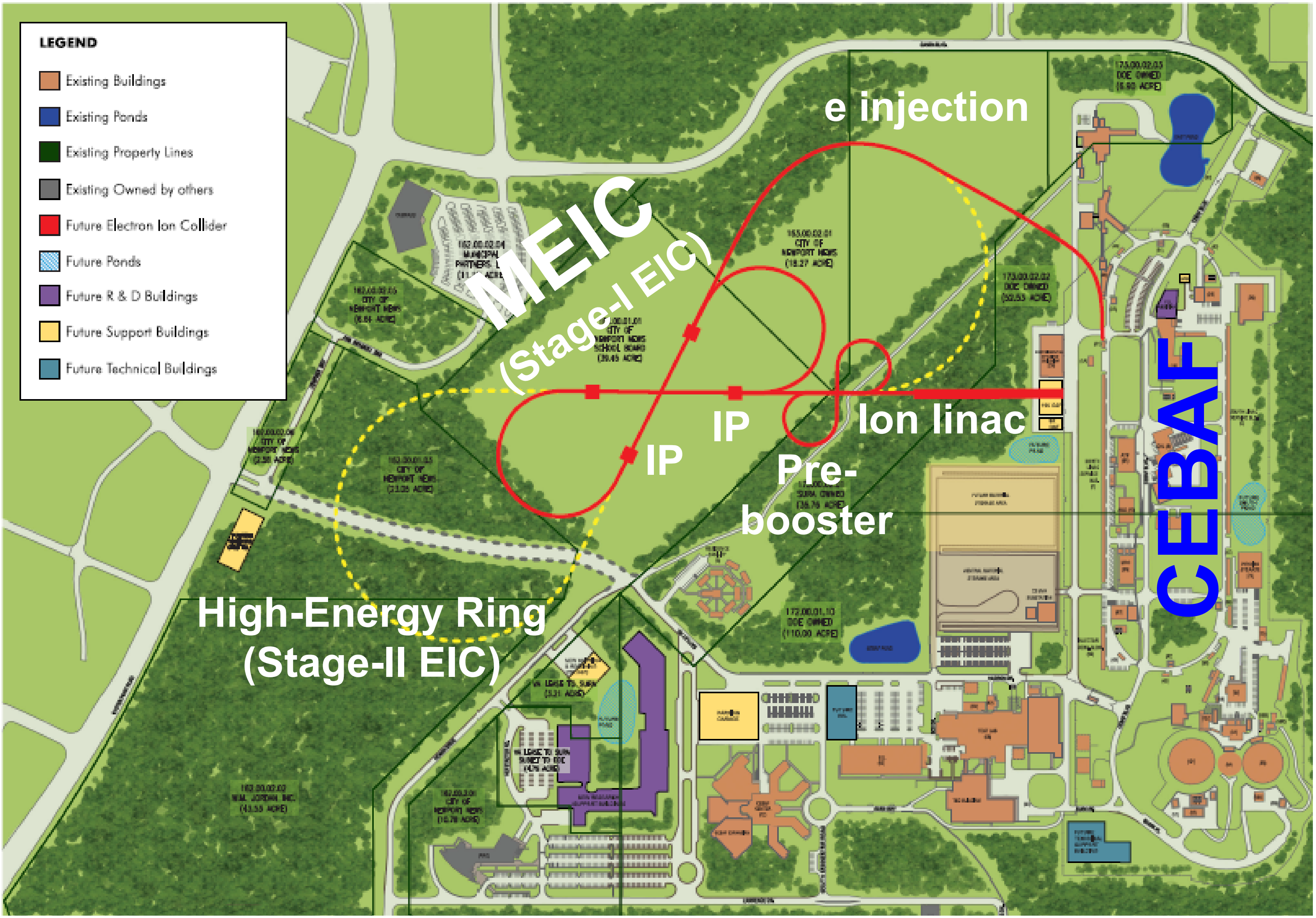
- Radiator and light guide: bar made from Synthetic Fused Silica

- Magnitude of Cherenkov angle conserved during internal reflections (provided optical surfaces are square, parallel, highly polished)

- Photons exit radiator into expansion region,
  detected on photon detector array.
  (pinhole imaging/camera obscura or focusing optics)

- DIRC is intrinsically a 3-D device, measuring: x, y, and time of Cherenkov photons, defining θ_c, ϕ_c, $\Delta t_{propagation}$ of each photon.

EIC: Layout on the JLab site



- The MEIC has the same circumference as the CEBAF accelerator