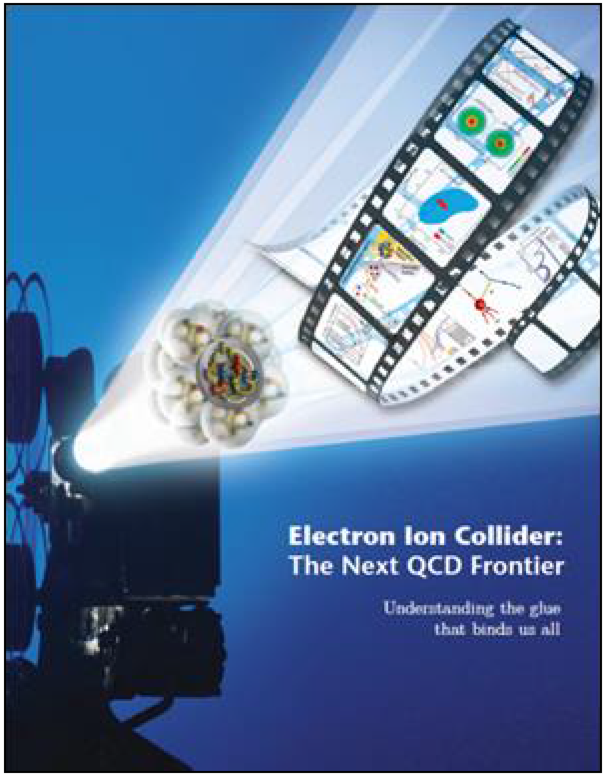
The EIC Barrel DIRC



Pawel Nadel-Turonski

Jefferson Lab

DIRC 2013, Castle Rauischholzhausen, Germany, September 4-6, 2013

Outline

1. The Electron-Ion Collider

- Some highlights from the physics program
- Implementation ideas at JLab and BNL
- Quick look at detector ideas

2. The Generic EIC Detector R&D Program

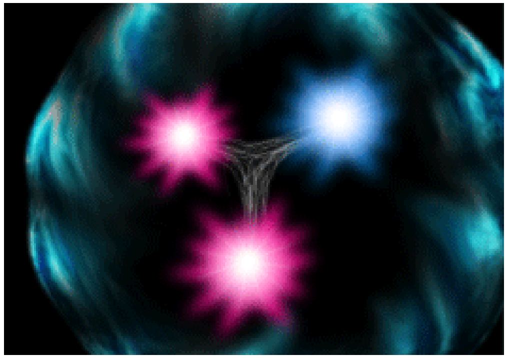
3. The DIRC R&D proposal

- Scope and goals
- Examples of lens development, simulations, sensor tests, etc

Some physics questions addressed by the EIC

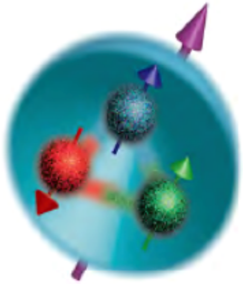
- 3D structure of the nucleon is non-trivial
  - Far more than the simple valence quark structure
  - Need to understand confinement to know how proton properties arise from constituents

How do gluons and quarks bind into 3D hadrons?



- Gluon dynamics plays a large role in proton spin
  - Spin = intrinsic (parton spin) + motion (orbital angular momentum)

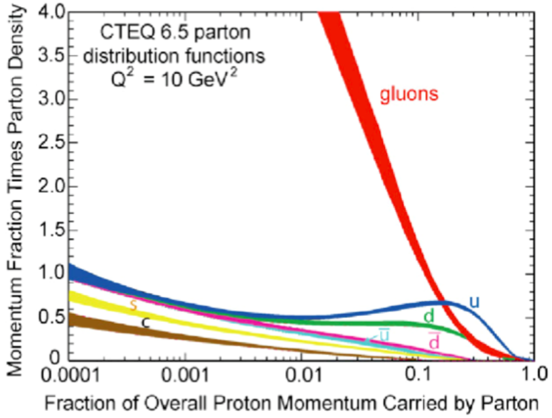
Why do quarks contribute so little (~30%) to proton spin?



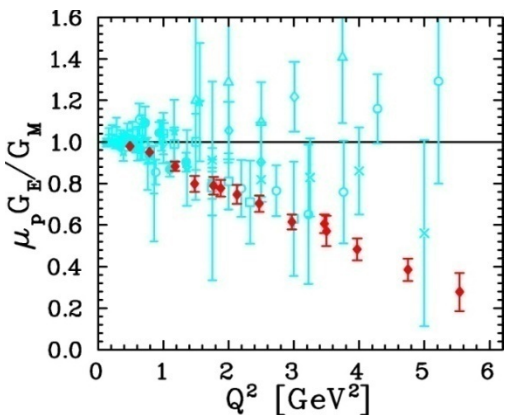
- Dynamical balance between gluon radiation and recombination
  - How does the unitarity bound of the hadronic cross section survive if soft gluons in a proton or nucleus continue to grow in numbers?

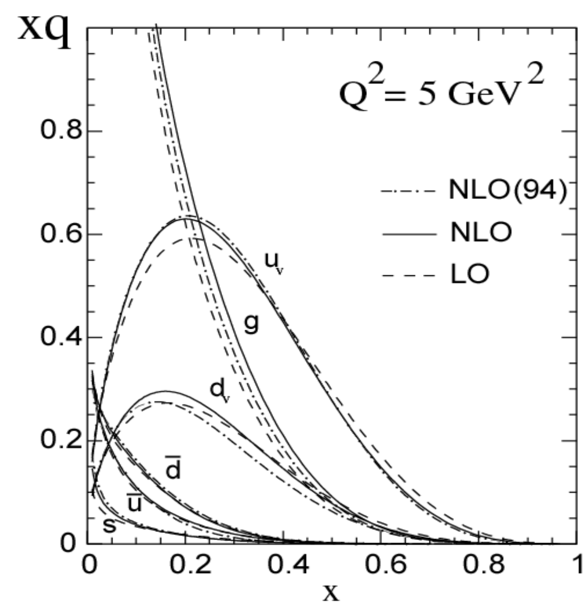
Does the gluon density saturate at small x?

EIC stage II measurement



3D structure of the nucleon



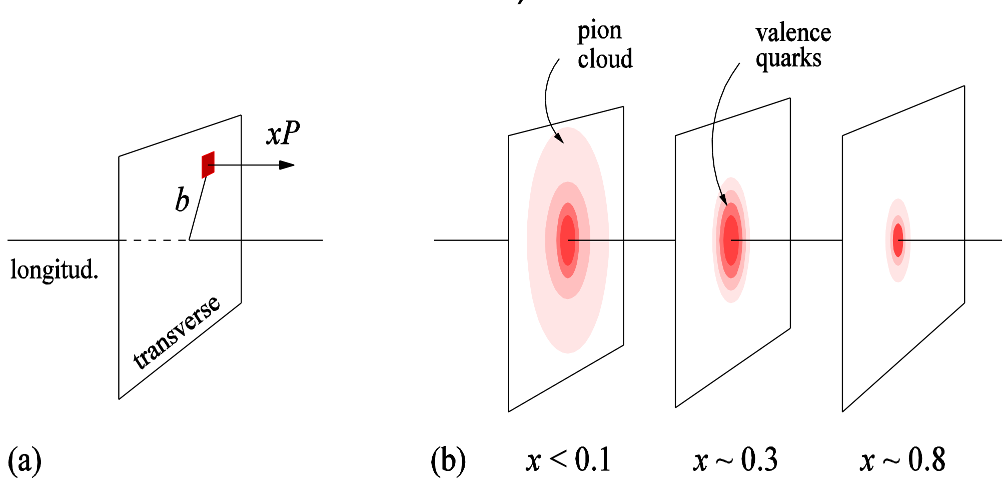


Elastic form factors

Transverse spatial distributions
(Naively Fourier transform of Q^2 or t)

Parton Distribution Functions

Longitudinal momentum distributions



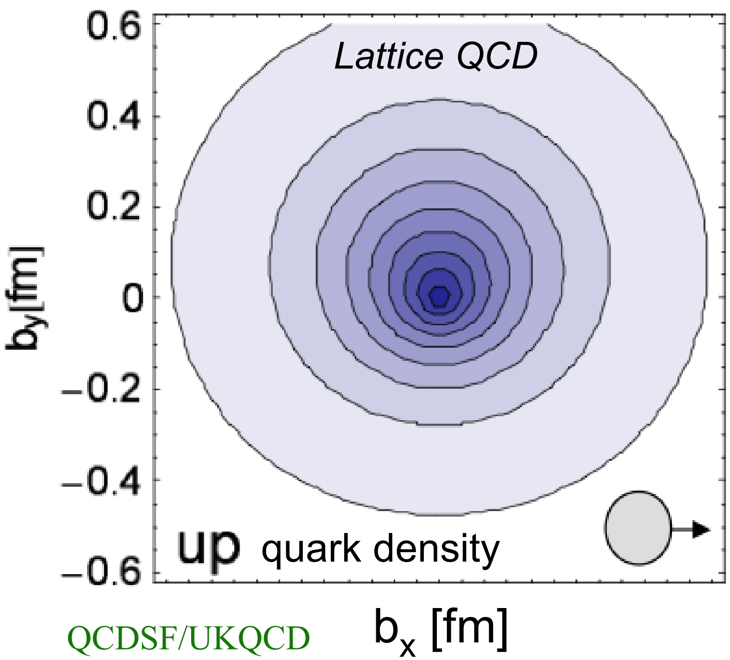
Generalized Parton Distributions

A unified descriptions of partons (quarks and gluons) in momentum and impact parameter space

Imaging in coordinate and momentum space

<u>GPDs</u>

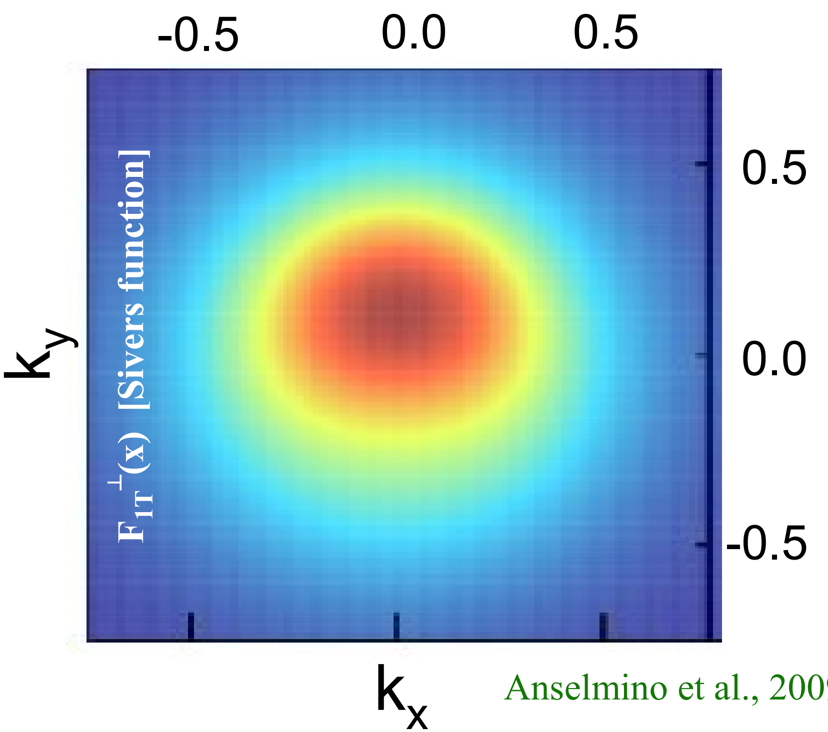
2+1 D picture in **impact-parameter space**



QCDSF/UKQCD Coll., 2006

<u>TMDs</u>

2+1 D picture in **momentum space**



Anselmino et al., 2009

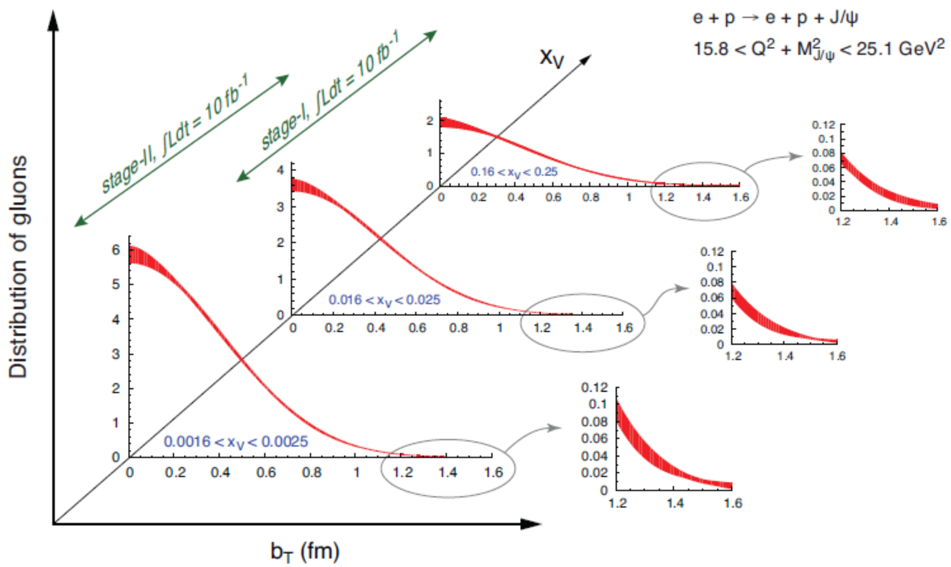
- Accessed through *exclusive* processes
- Ji sum rule for nucleon spin

- Accessed through *Semi-Inclusive* DIS
- OAM through spin-orbit correlations?

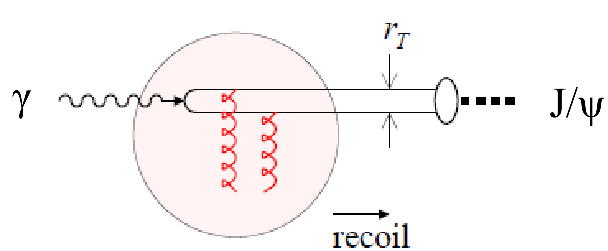
Imaging in coordinate and momentum space

GPDs

2+1 D picture in **impact-parameter space**

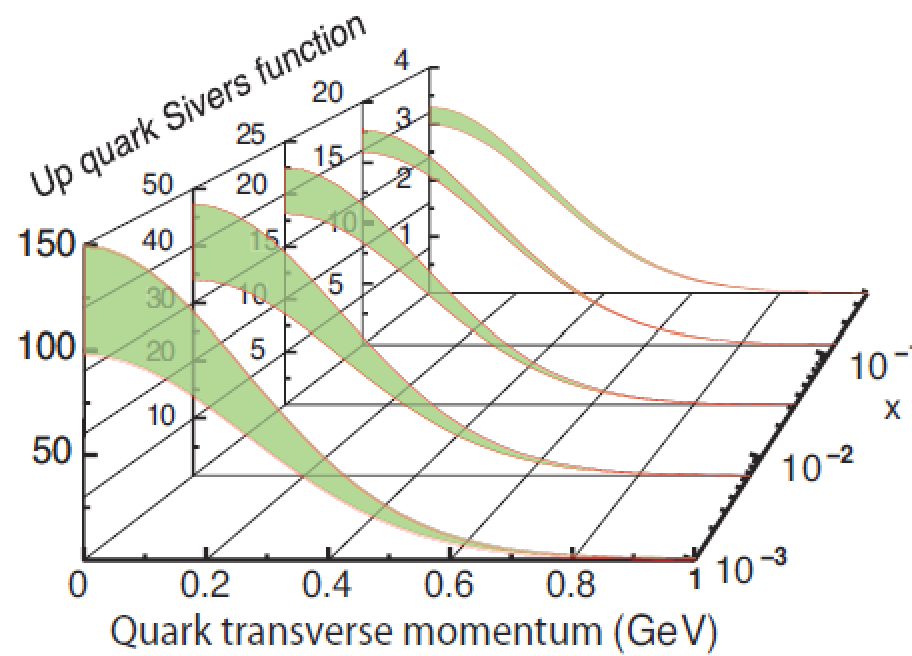


Transverse gluon distribution from J/ψ production

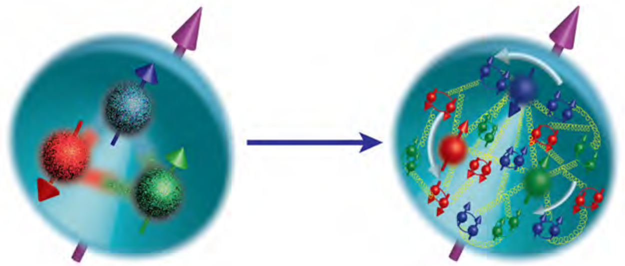


TMDs

2+1 D picture in **momentum space**



The spin of the proton



The number ½ turns out to be a complicated interplay between the intrinsic properties and interactions of quarks and gluons

$$\frac{1}{2} = \underbrace{\overbrace{\frac{1}{2}\Delta\Sigma(\mu)}^{\sim 0.35}_{\text{polarization}} + \overbrace{L_q(\mu)}^{?}_{\text{orbit}}}_{\text{quarks}} + \underbrace{\overbrace{\Delta G(\mu)}^{\text{small ?}}_{\text{polarization}} + \overbrace{L_g(\mu)}^{?}_{\text{orbit}}}_{\text{gluons}}$$

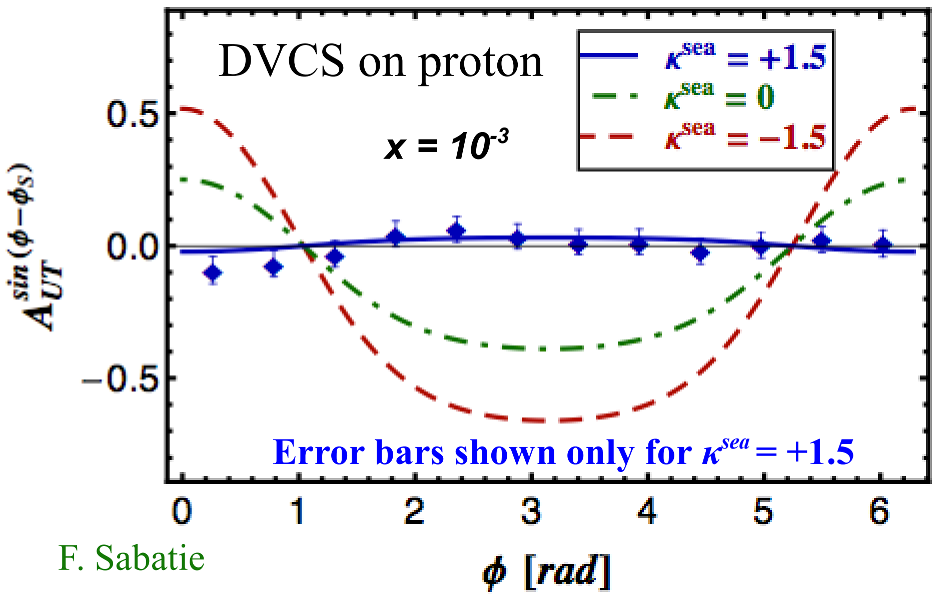
Two complementary approaches to resolve proton spin puzzle

Measure ΔG - gluon polarization

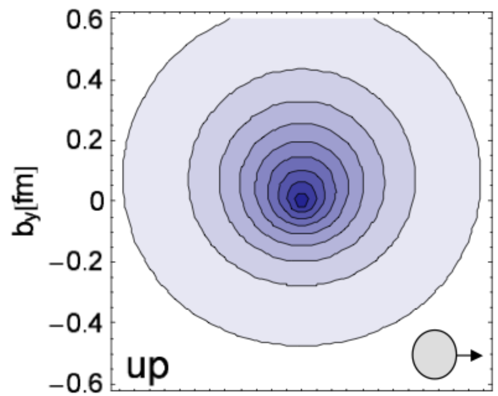
Measure TMD and GPDs - orbital motion

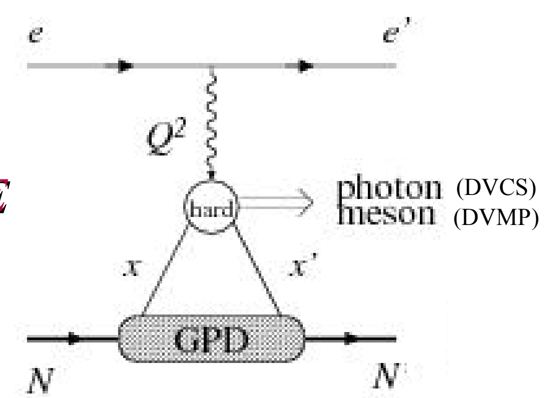
GPDs and angular momentum

Model: $E^i(x, \xi, t) = \kappa^i(t)\, H^i(x, \xi, t)$



F. Sabatie

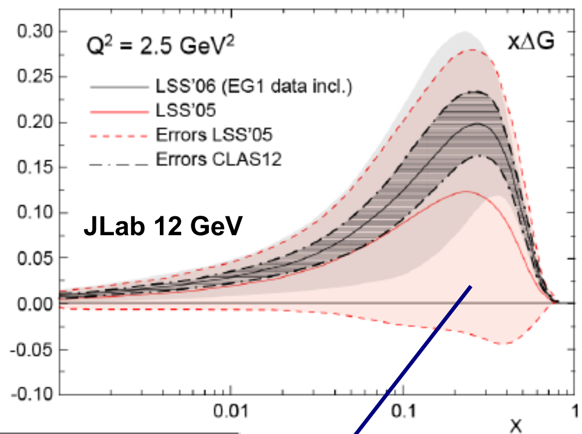


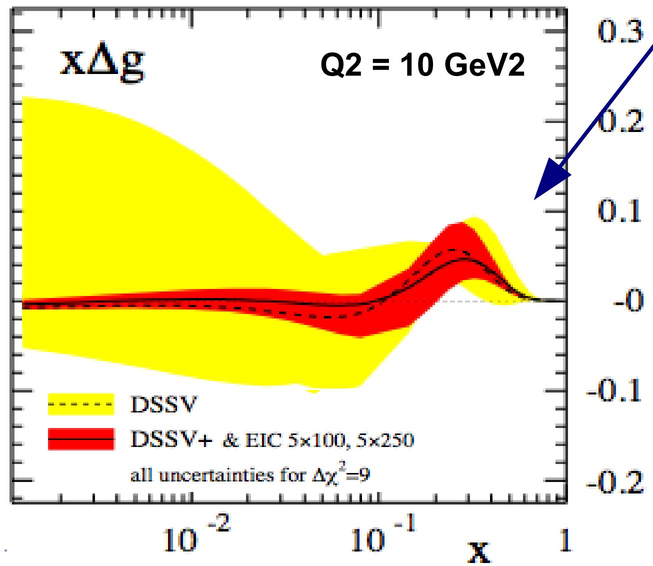


- DVCS on a transversely polarized target is sensitive to the ***GPD E***
  - Opens up opportunity to study spin-orbit correlations
  - GPD H can be measured through the beam spin asymmetry

$$J^q = \frac{1}{2}\int_{-1}^{+1} dx\, x\left[H^q(x,\xi,t) + E^q(x,\xi,t)\right]$$

Longitudinal spin – ΔG (gluon polarization)



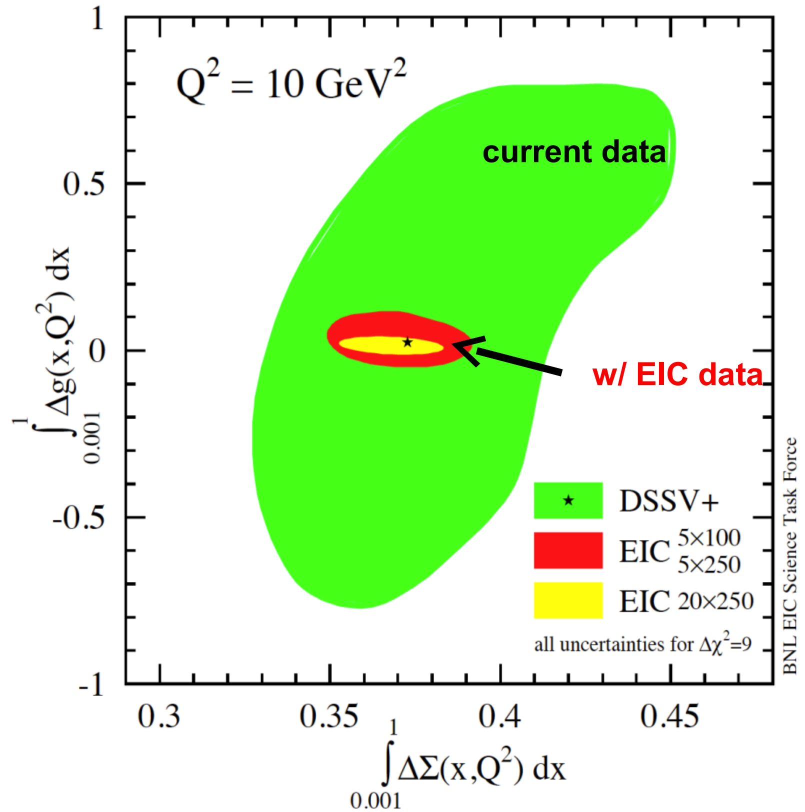


M. Stratmann

Green: RHIC spin, etc

Red: EIC Stage I (MEIC or eRHIC)

Yellow: EIC Stage II



- EIC stage I will greatly improve our understanding of ΔG
  - Stage II will further reduce the uncertainty

The physics program of an EIC

Map the spin and spatial structure of quarks and gluons in nucleons

- How much spin is carried by gluons?
- Does orbital motion of sea quarks contribute to spin?
  - Generalized Parton Distribution (GPDs)
  - Transverse Momentum Distributions (TMDs)
- What do the partons reveal in transverse momentum and coordinate space

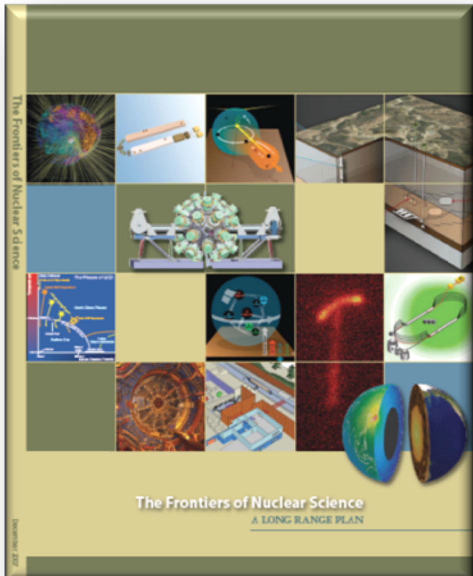
Discover the collective effects of gluons in atomic nuclei

- What is the distribution of glue in nuclei?
- Are there modifications as for quarks?
- Can we observe gluon saturation effects?

Understand the emergence of hadronic matter from color charge

- How do color charges evolve in space and time?
- How do partons propagate in nuclear matter?
- Can nuclei help reveal the dynamics of fragmentation?

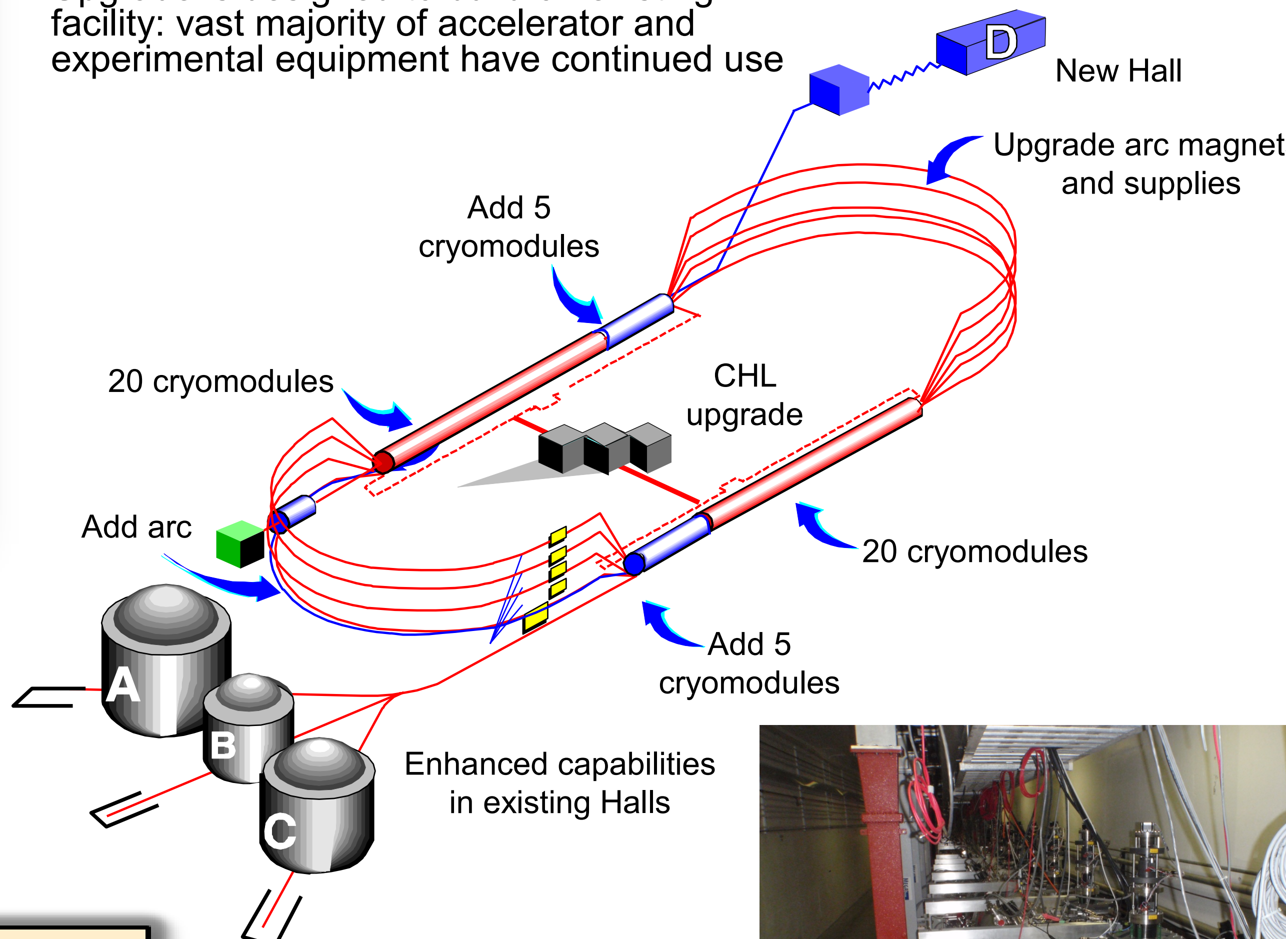
JLab 12 GeV upgrade – probing the valence quarks



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



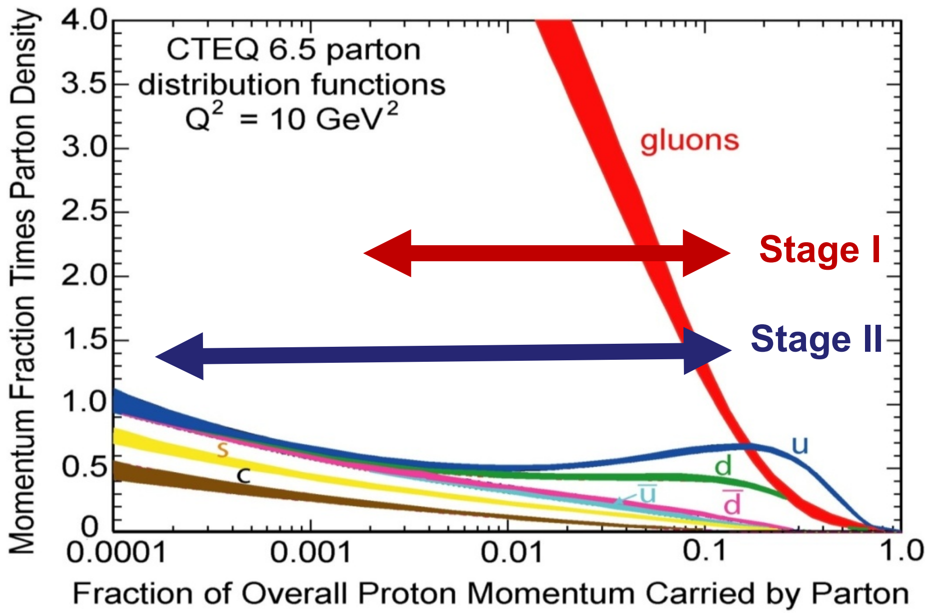
New C100 cryomodules in linac tunnel

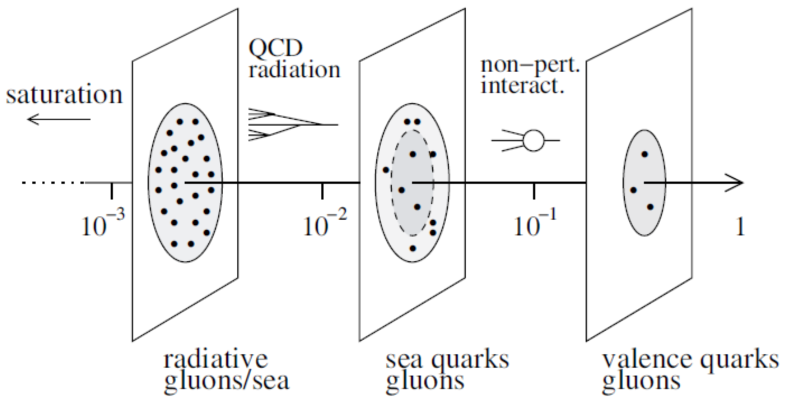
EIC stage I – probing the sea

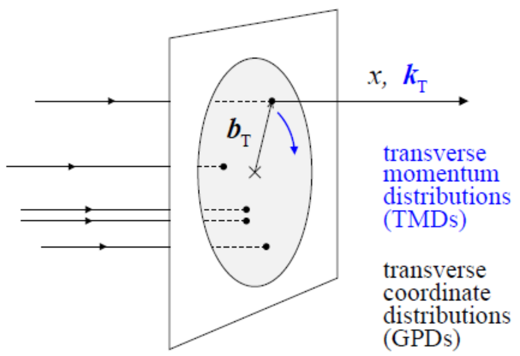
Already the first stage of an EIC gives access to sea quarks and gluons

Need polarization and good acceptance to detect spectators & fragments

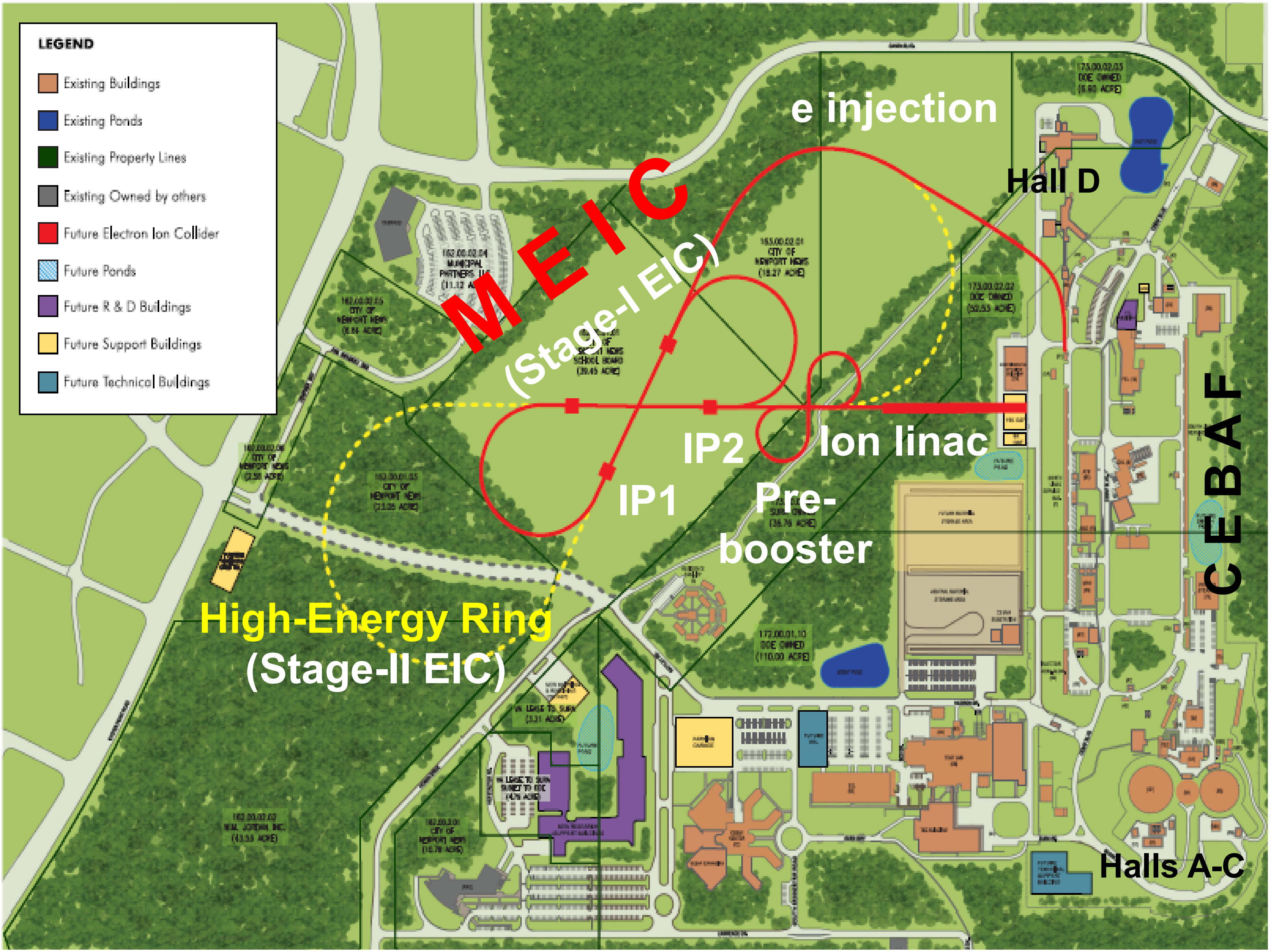
An EIC aims to study the sea quarks and gluon-dominated matter.





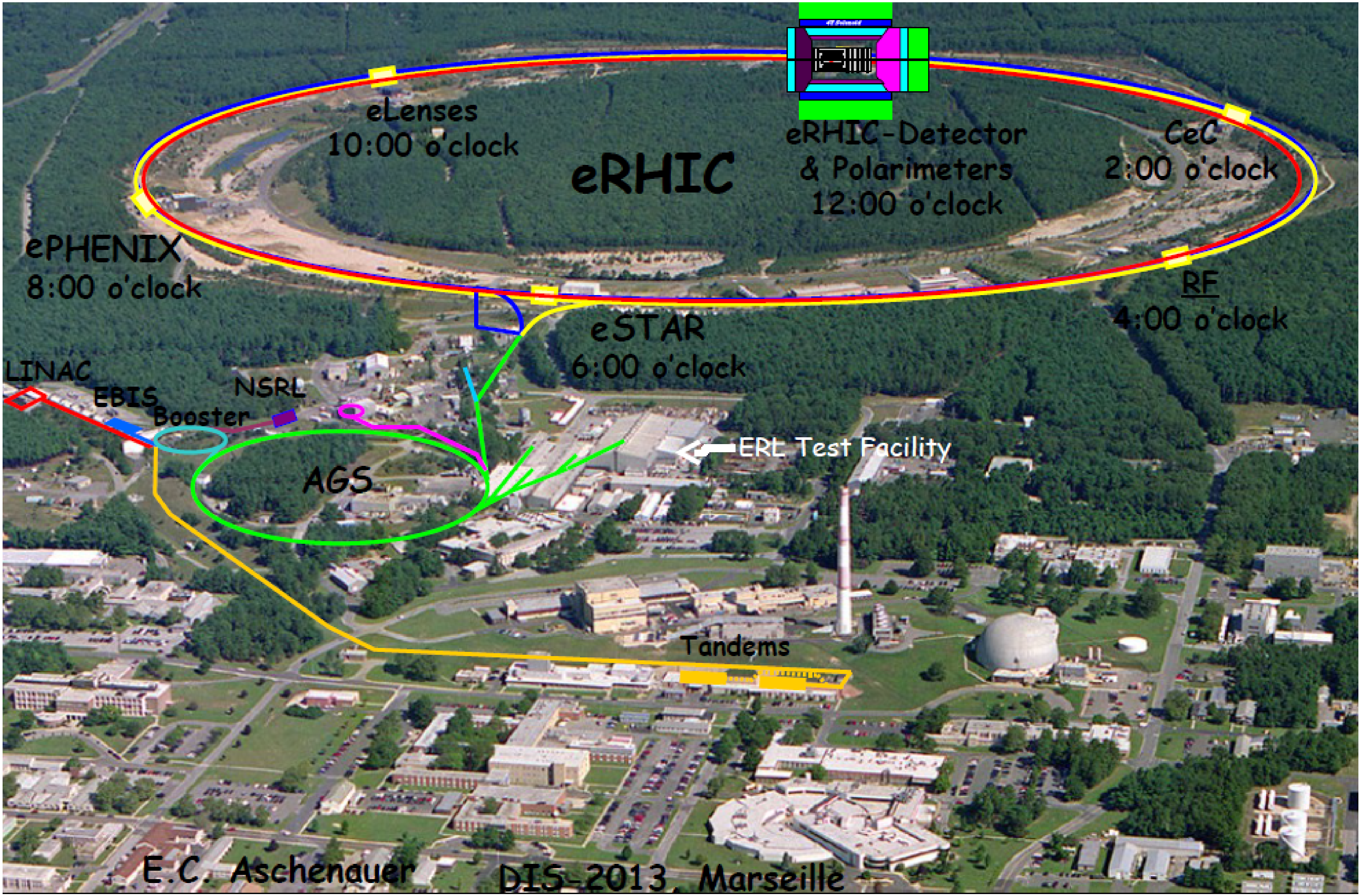


The EIC at Jefferson Lab, VA

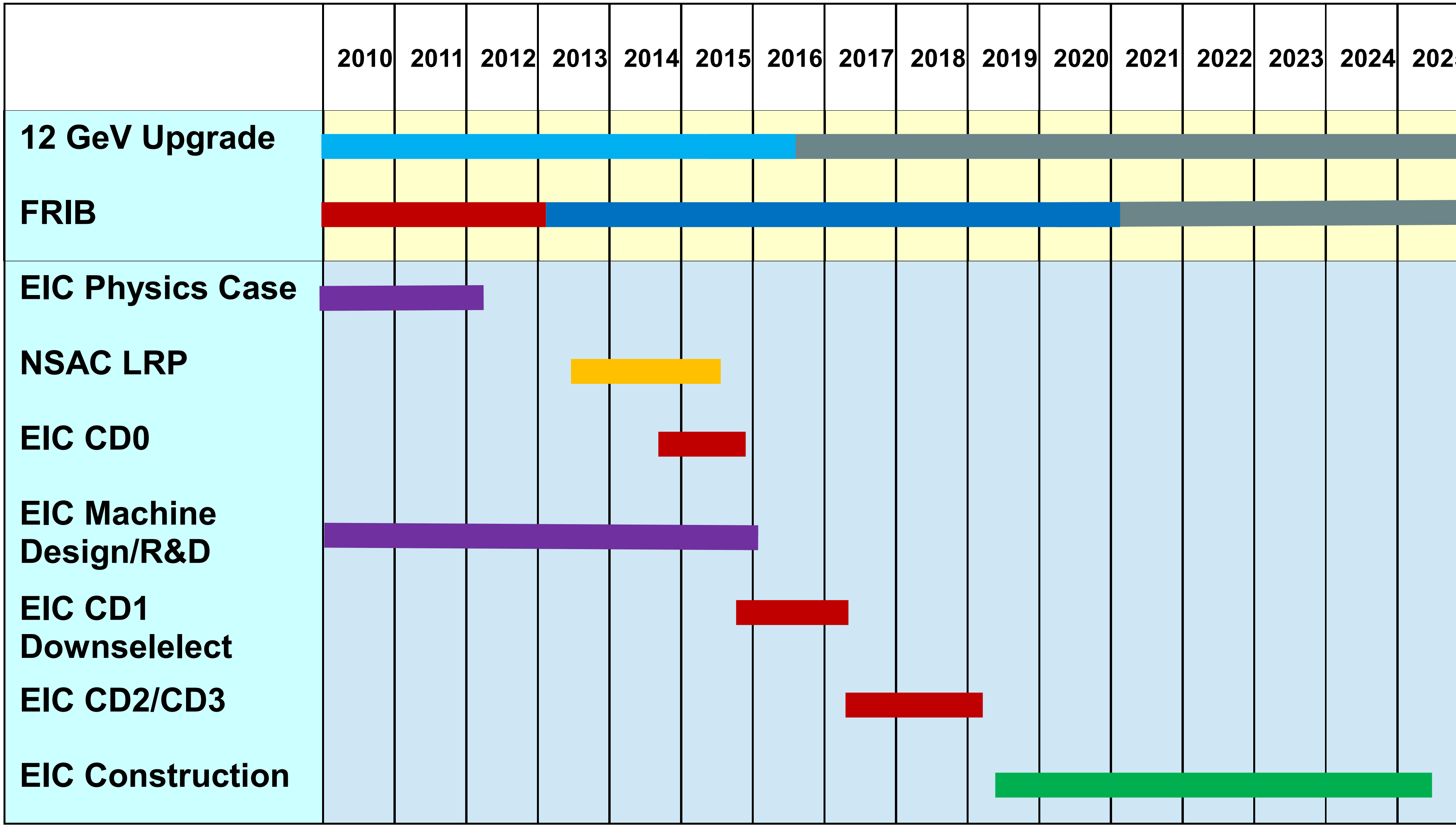


- The MEIC has a circumference similar to CEBAF (1.4 km)

eRHIC at Brookhaven National Lab, NY



EIC timeline



Assumes endorsement for an EIC at the next NSAC Long Range Plan
Assumes relevant accelerator R&D for down-select process done around 2016

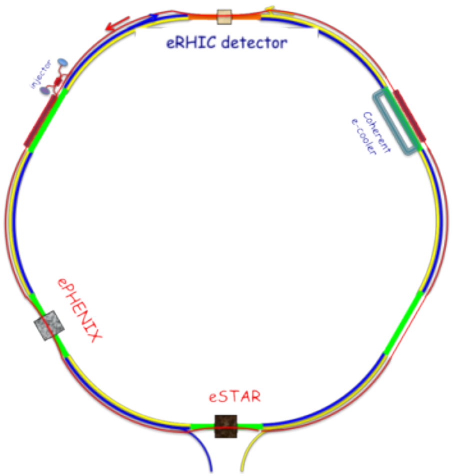
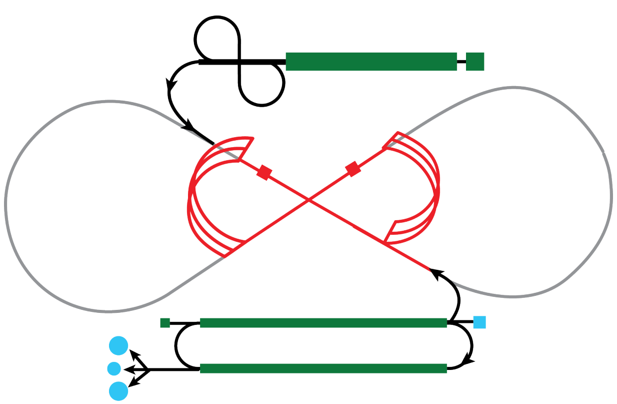
EIC – consensus on many global requirements

The EIC project is pursued jointly by BNL and JLab, and both labs work towards implementing a common set of goals

From base EIC requirements in the INT report

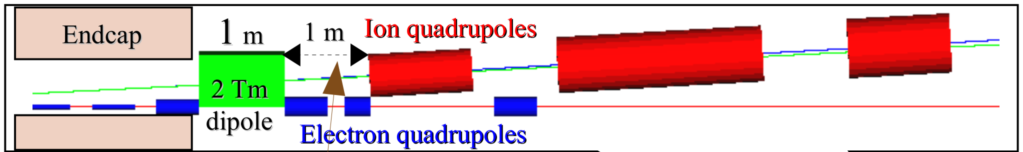
- Polarized electron, nucleon, and light ion beams
  - Electron and nucleon polarization > 70%
  - Transverse polarization at least for nucleons
- Ions from hydrogen to A > 200
- Luminosity reaching 10^{34} $cm^{-2}s^{-1}$
- Stage I energy: $\sqrt{s}$ = 20 – 70 GeV (variable) (MEIC)
- Stage II energy: $\sqrt{s}$ up to about 150 GeV (EIC)

EIC – staging at BNL and JLab

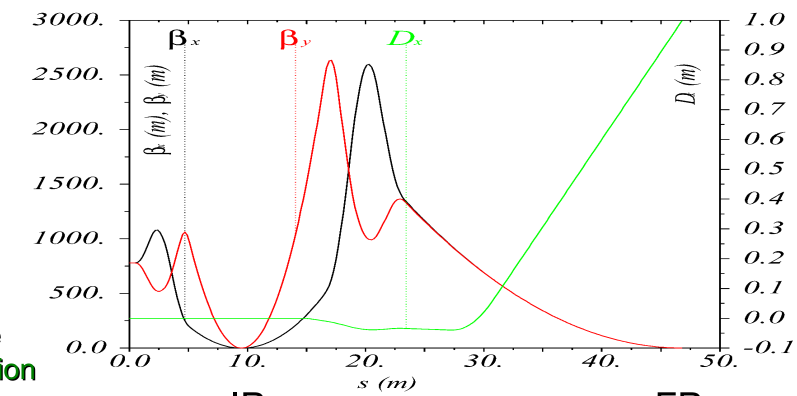
	Stage I	Stage II
eRHIC @ BNL 	$\sqrt{s}$ = 34 – 71 GeV E_e = 3 – 5 (10 ?) GeV E_p = 100 – 255 GeV E_{Pb} = up to 100 GeV/A	$\sqrt{s}$ = up to ~180 GeV E_e = up to ~30 GeV E_p = up to 275 GeV E_{Pb} = up to 110 GeV/A
MEIC / EIC @ JLab 	$\sqrt{s}$ = 13 – 70 GeV E_e = 3 – 12 GeV E_p = 15 – 100 GeV E_{Pb} = up to 40 GeV/A (MEIC)	$\sqrt{s}$ = up to ~140 GeV E_e = up to 20 GeV E_p = up to at least 250 GeV E_{Pb} = up to at least 100 GeV/A (EIC)

The JLab full-acceptance detector concept

No other magnets or apertures between IP and FP!



Trackers and “donut” calorimeter

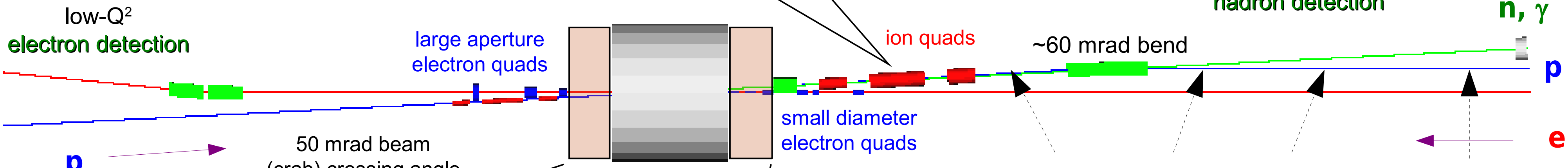


IP FP

small angle hadron detection

(from GEANT4)

ultra forward hadron detection

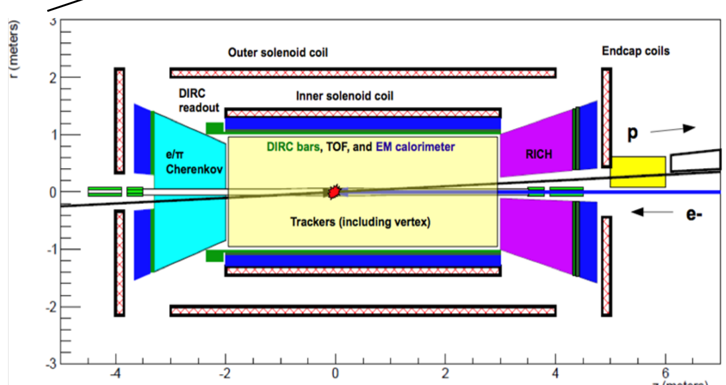


Thin exit windows

Fixed trackers in vacuum?

Roman pots

central detector with endcaps

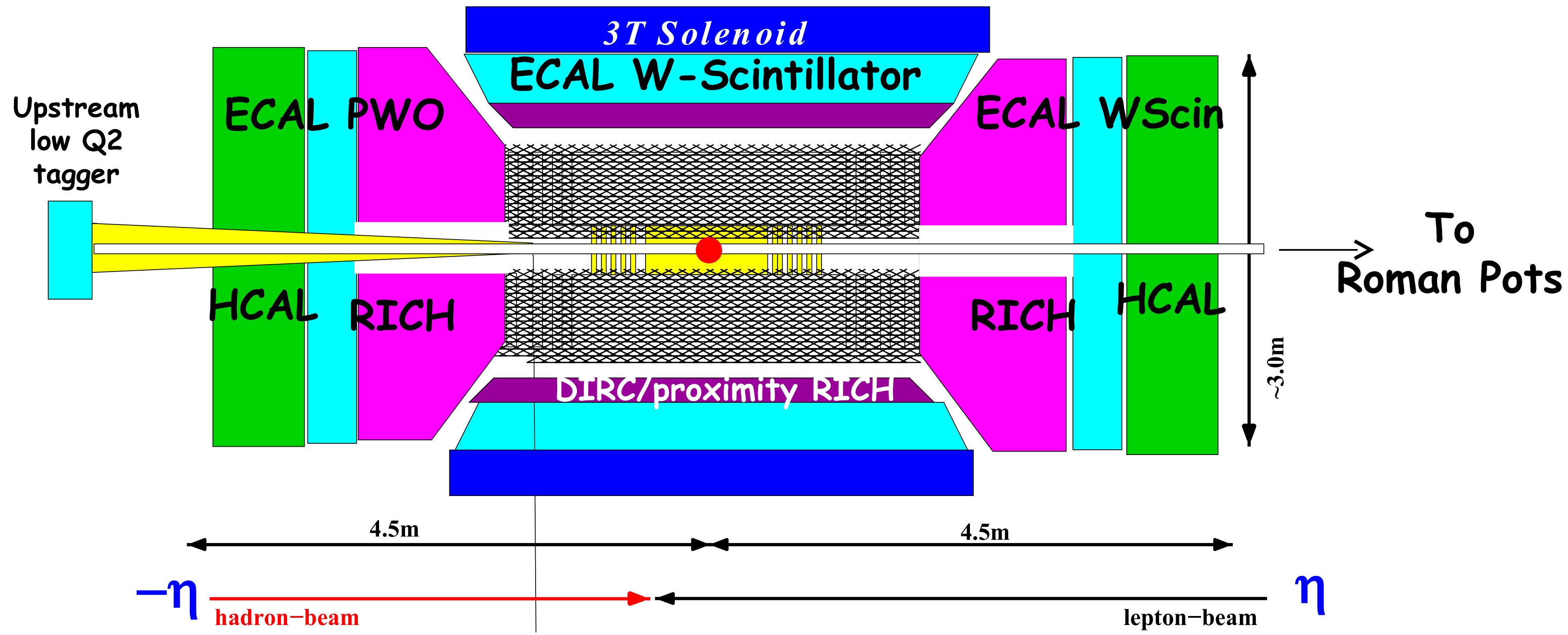


Cartoon based on previous iteration IR design

Forward hadron detection in three stages:

1. Encap with 50 mrad crossing angle
2. Small dipole covering angles up to a few degrees
3. Ultra-forward, up to one degree, for particles passing the accelerator quads

BNL: 1st Detector Design Concept



PID:

-1<η<1: DIRC or proximity focusing Aerogel-RICH
1<|η|<3: RICH

Lepton-ID:

-3 <η< 3: e/p
1<|η|<3: in addition Hcal response & γ suppression via tracking
|η|>3: ECal+Hcal response & γ suppression via tracking
-5<η<5: Tracking (TPC+GEM+MAPS)

The Generic Detector R&D for an EIC program

https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

In January 2011 Brookhaven National Laboratory, in association with Jefferson Lab and the DOE Office of Nuclear Physics, announced a generic detector R&D program to address the scientific requirements for measurements at a future Electron Ion Collider (EIC). The **primary goals of this program are to develop detector concepts and technologies that have particular importance for experiments in an EIC environment**, and to help ensure that the techniques and resources for implementing these technologies are well established within the EIC user community.

This program is supported through R&D funds provided to BNL by the DOE Office of Nuclear Physics. It is **not intended to be specific to any proposed EIC site, and is open to all segments of the EIC community**. Proposals should be aimed at optimizing detection capability to enhance the scientific reach of polarized electron-proton and electron-ion collisions up to center-of-mass energies of 50-200 GeV and e-p equivalent luminosities up to a few times 10^{34} $cm^{-2}s^{-1}$. Funded proposals will be selected on the basis of peer review by a standing EIC Detector Advisory Committee consisting of internationally recognized experts in detector technology and collider physics. This committee meets approximately twice per year, to hear and evaluate new proposals, and to monitor progress of ongoing projects. The program will be administered by the BNL Physics Department. This program is **funded at an annual level of $1.0M - $1.5M**, subject to availability of funds from DOE NP.

The RD-3 „DIRC" proposal

DIRC-based PID for the EIC Central Detector

T. Cao[3], T. Horn[1] (co-PI), C. Hyde[2] (co-PI), Y. Ilieva[3] (co-PI), P. Nadel-Turonski[4,*] (co-PI), K. Peters[5], C. Schwarz[5], J. Schwiening[5] (co-PI), H. Seraydaryan[2], W. Xi[4], C. Zorn[4].

[1)] The Catholic University of America, Washington, DC 20064

[2)] Old Dominion University, Norfolk, VA 23529

[3)] University of South Carolina, Columbia, SC 29208

[4)] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606

[5)] GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

[*)] turonski@jlab.org

- Funding approved for four years

R&D goals presented to the advisory committee

1. Investigate possibility of pushing state-of-the-art performamce

- Extend 3σ π/K separation beyond 4 GeV/c, maybe as high as 6 GeV/c
  - also improving e/π and K/p separation

2. Demonstrate feasibility of using a DIRC in the EIC detector

- Compact readout "camera" (expansion volume + sensors)
- Operation in high magnetic fields (up to 3 T)

3. Study integration of the DIRC with other detector systems

- Long bars (plates) penetrating endcap?

Primary responsibilities

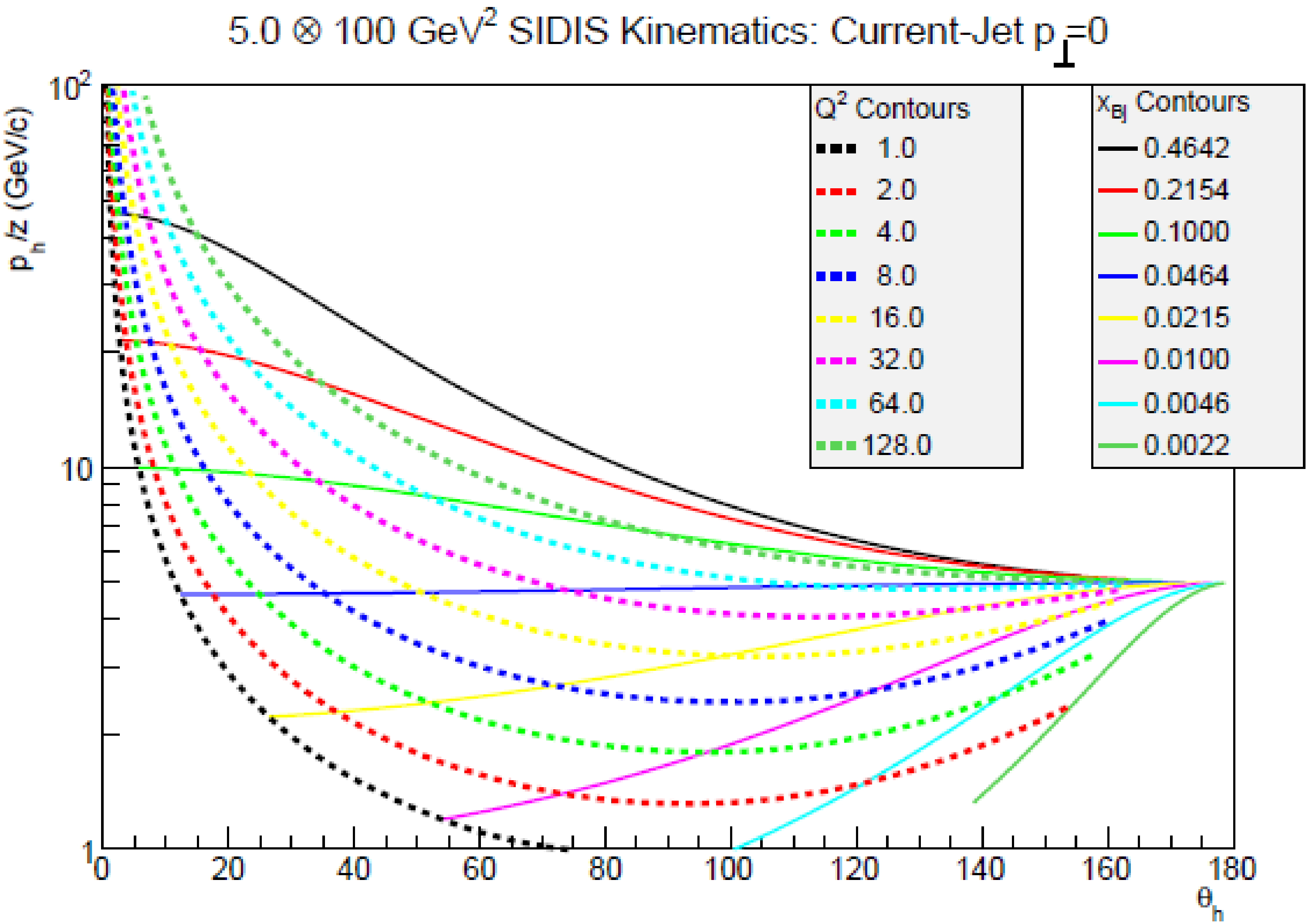
1. **Simulations of DIRC performance and design of EV prototype**
   - Old Dominion University

2. **Lens and EV prototype construction and testing**
   - GSI Helmholtzzentrum für Schwerionenforschung

3. **Sensor tests in high magnetic fields**
   - University of South Carolina and Jefferson Lab

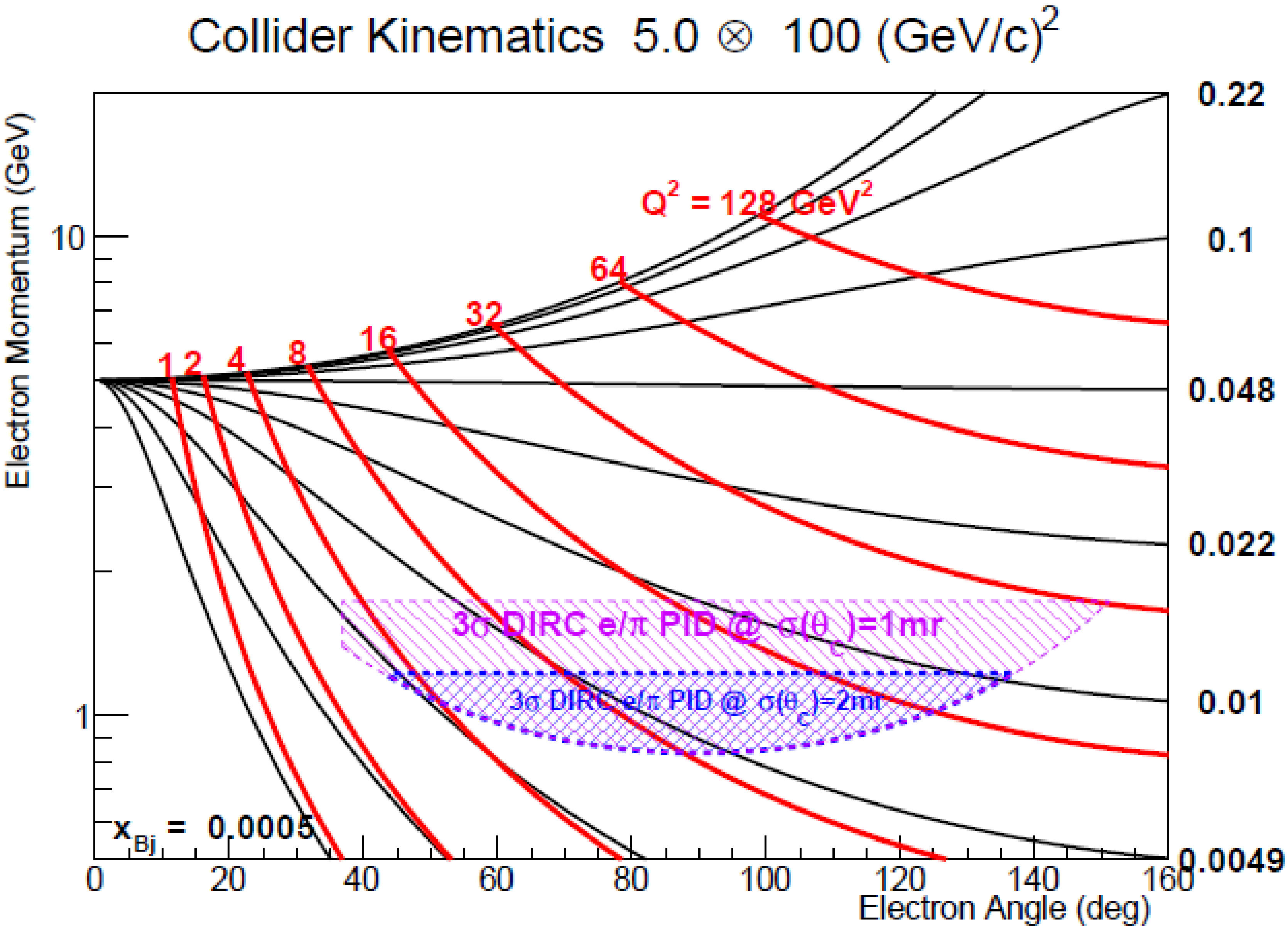
4. **Detector integration**
   - Catholic University of America

Example: π/K identification in semi-inclusive DIS



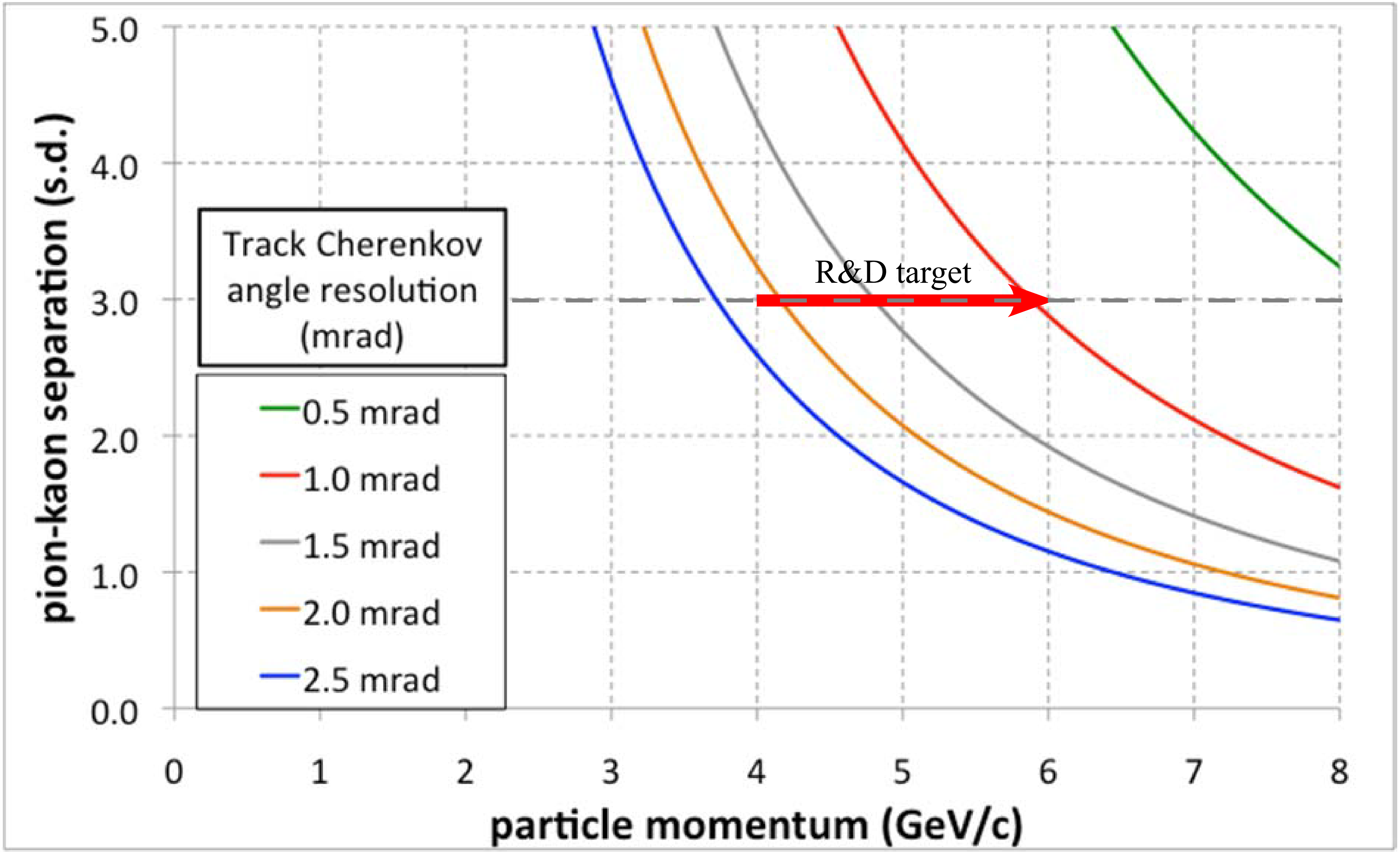
- Kinematic coverage in SIDIS is limited by hadron detection and identification.
- **Momenta are large at forward angles** and grow with z, x, and Q^2

Example: e/π identification in DIS at low *x*



- High-Q^2, low-x electrons have low momenta and require good pion suppression

π/K ID as a function of the θ_c resolution



Design choices

1. Focusing

- Proximity focusing (BaBar)
- Mirror on the side opposite of readout (Belle)
- Mirror on the side of the readout (SuperB)
- Lenses (PANDA)

2. Expansion volume and sensors

- Inside detector volume
- Outside of endcap (and iron or equivalent)

3. Radiator bars

- Boxes of narrow bars (BaBar)
- Plates = wide bars (Belle)

Design strategies

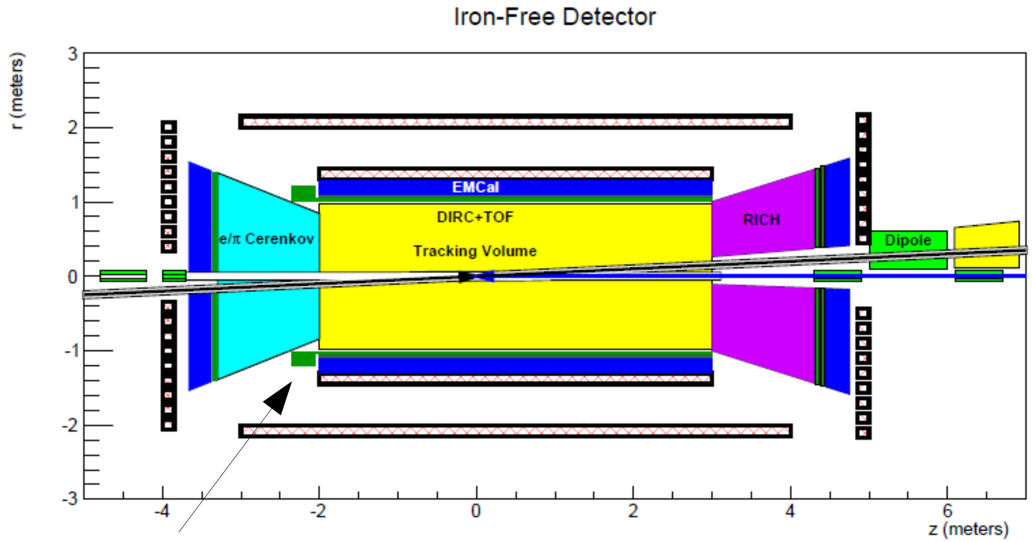
1. Expansion volume inside detector

- Narrow bars of moderate length (4 m)
  - Reconstruction well understood
  - Good azimuthal segmentation - can handle high multiplicity events
- Compact expansion volume important (fused silica)
  - Lens focusing primary choice – benefits from PANDA R&D
- Sensor challenges
  - High magnetic fields (1.5 – 3 T)
  - Radiation hardness

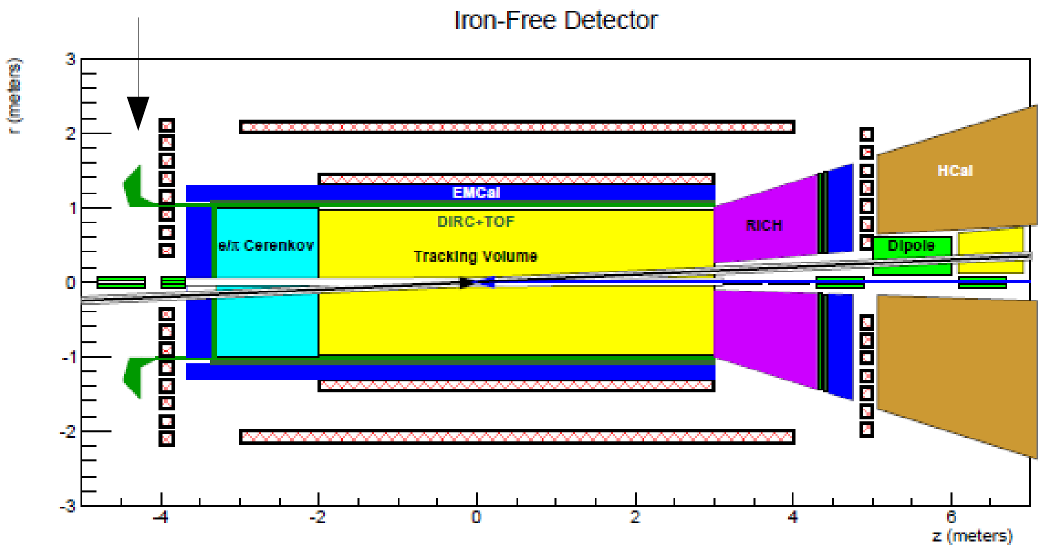
2. Expansion volume outside detector endcap (and iron)

- Long bars – wide plates preferable in order to reduce number of reflections
  - Lower tolerances and potentially lower total cost
  - Requires new reconstruction methods – synergies with PANDA R&D
  - Azimuthal segmentation requirements need to be studied
- Fewer constraints on EVsize and orientation
  - Mirror focusing similar to FDIRC for SuperB?
- Sensors – easier access and moderate magnetic fields
- Major impact on endcap detectors – needs to be studied!

Example layouts with internal and external EV



DIRC readout

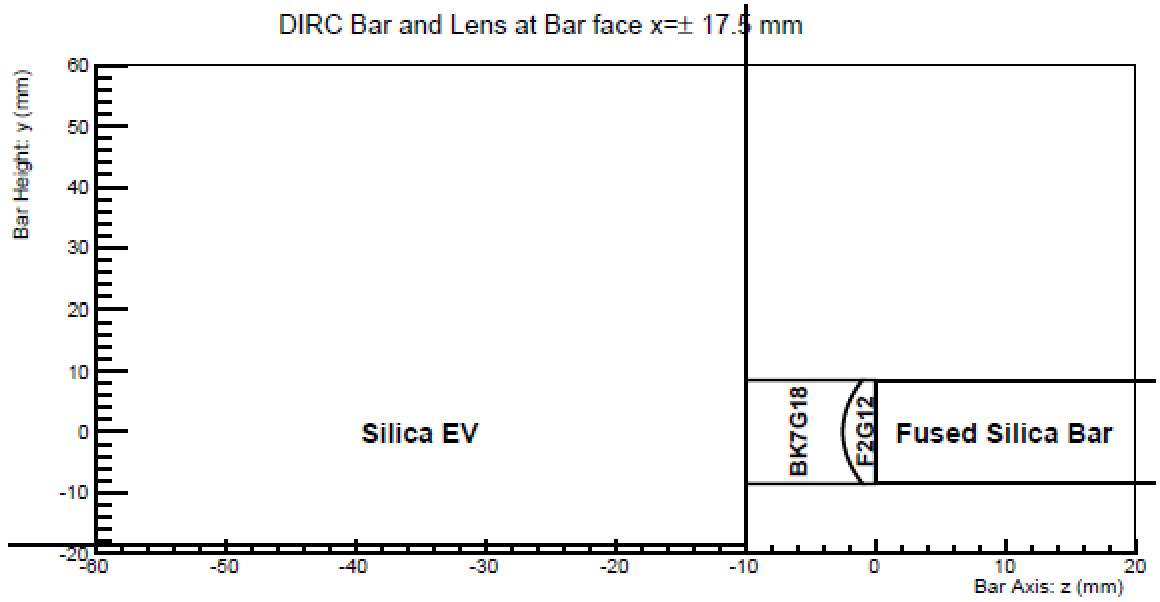


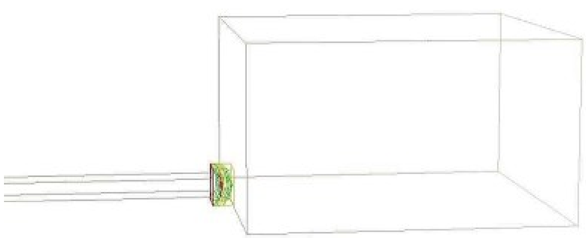
- An internal readout requires a compact EV and sensors that can operate in high magnetic fields
- An external readout requires very long bars (plates).
  - Significant impact on endcap design

Benchmark expansion volume geometries

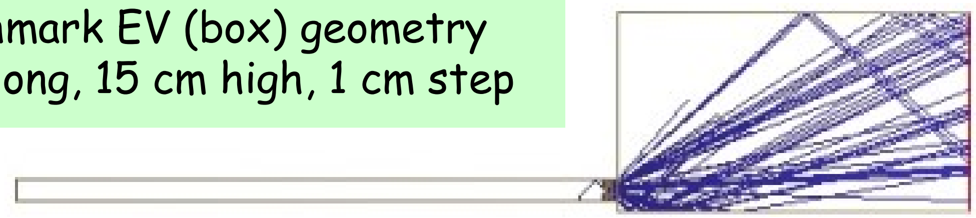
- Simulations were performed for two benchmark geometries: box and trapezoid

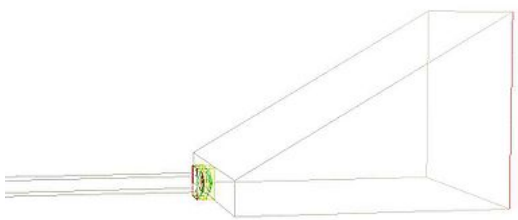
- No matching of the focal plane and EV image plane has yet been performed



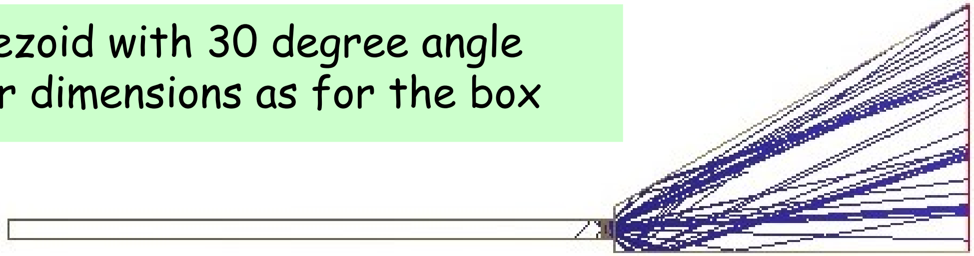


Benchmark EV (box) geometry
30 cm long, 15 cm high, 1 cm step



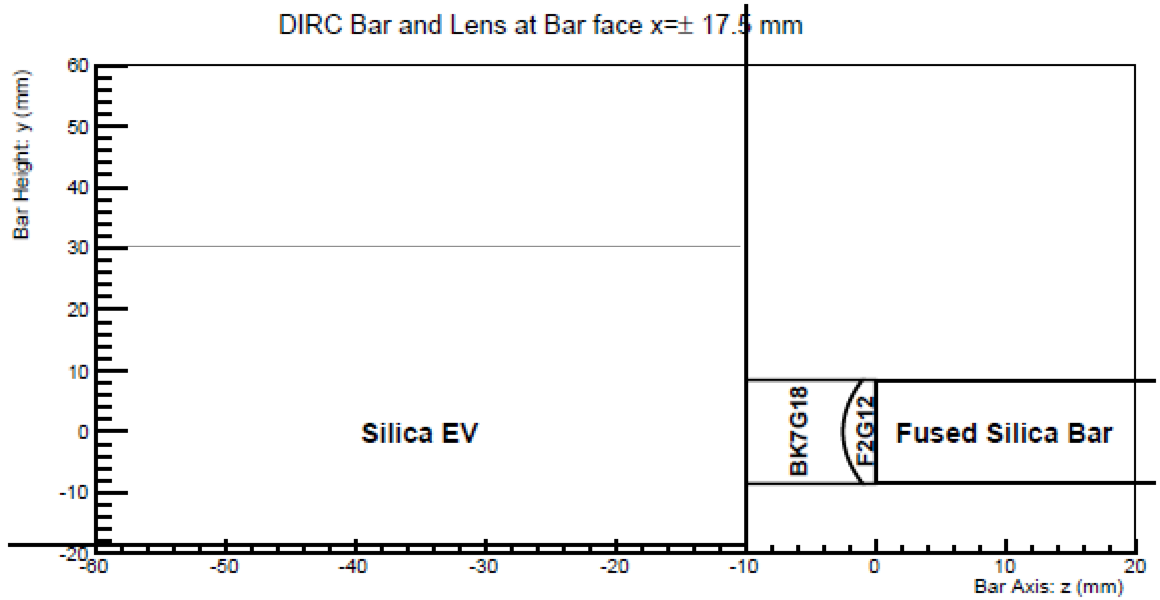


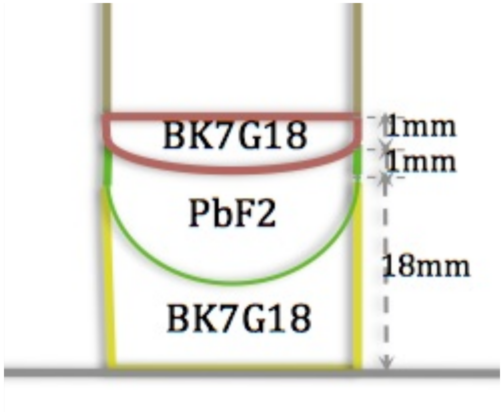
Trapezoid with 30 degree angle
Similar dimensions as for the box



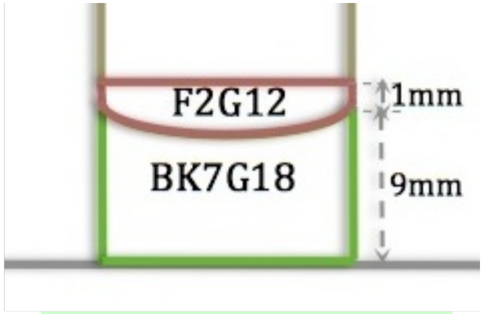
Lenses with high refractive index

- Lenses with air gaps cause photon losses around 90 degrees.
- Novel lenses with high refractive index have been designed to address this
- So far the focus has been on photon yield, not single photon resolution (and matching of focal plane with EV geometry)
- New triple lens is very promising.



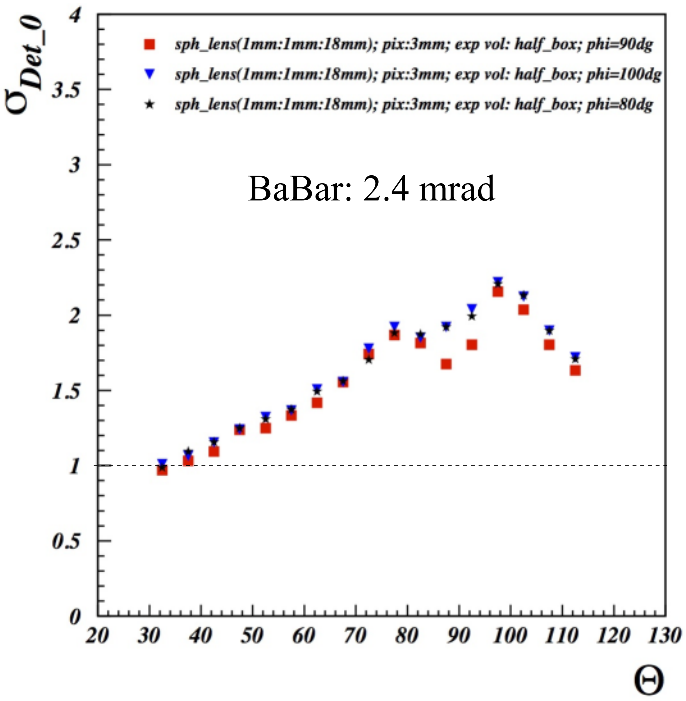


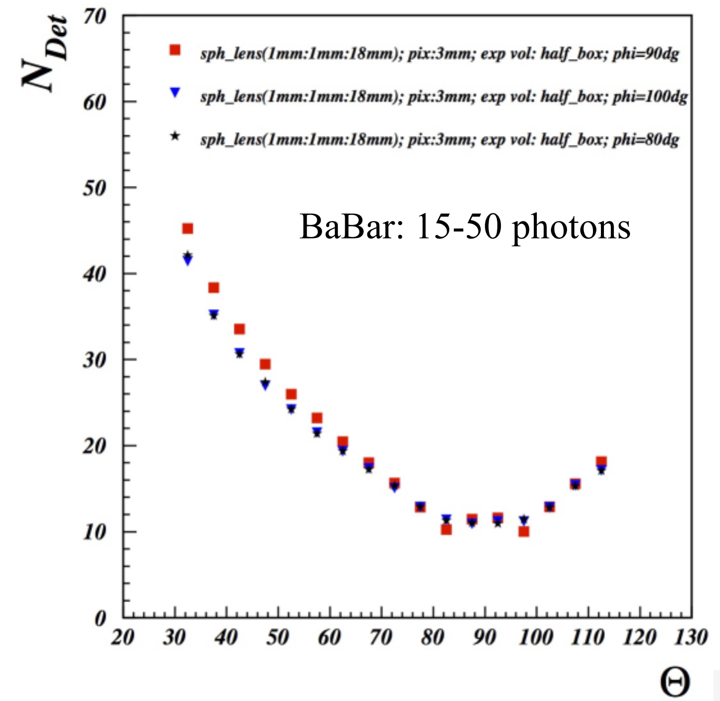
Triple lens
Midplane view



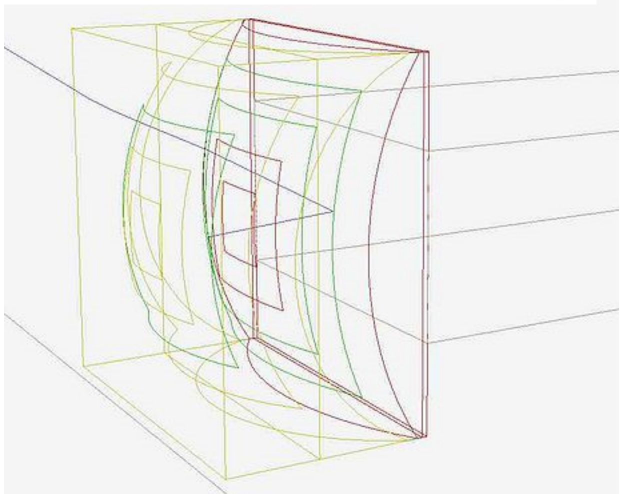
Double lens
Midplane view

θ_c resolution for spherical triple lens

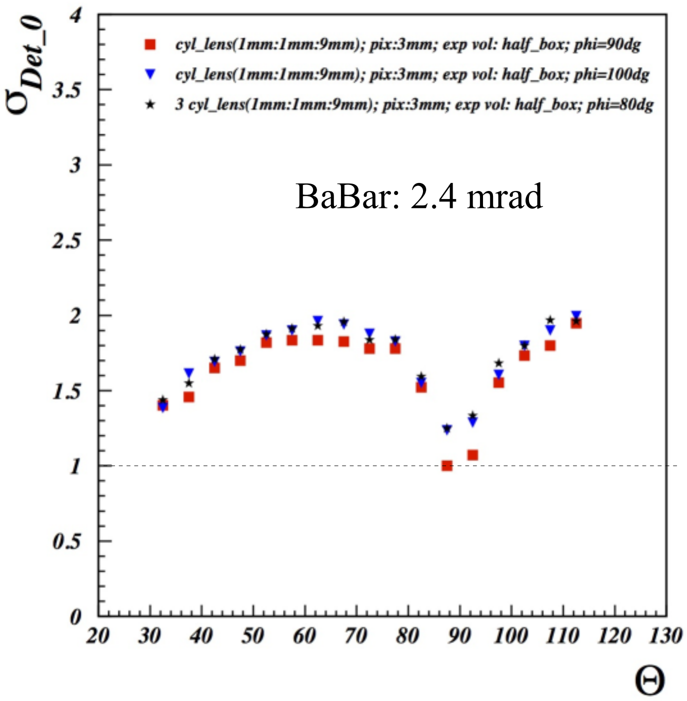


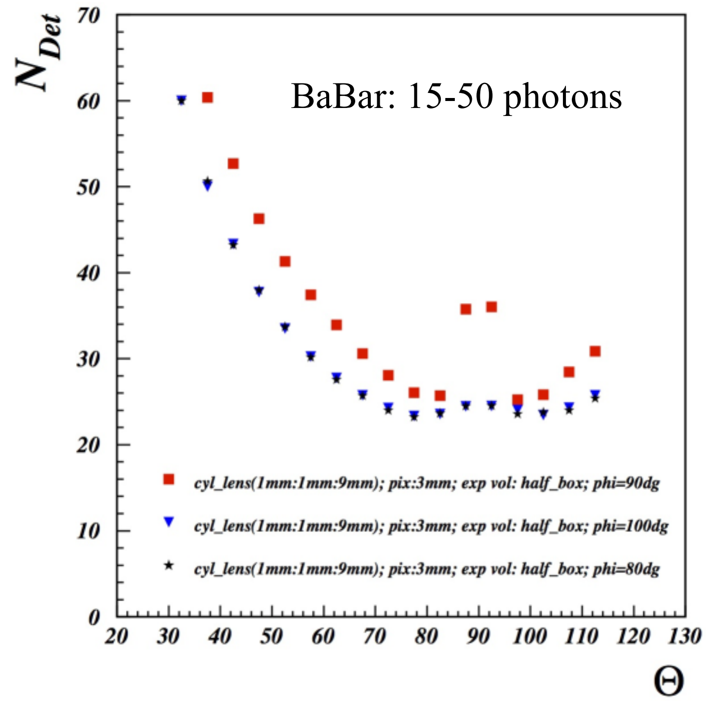


- Reaches goal of 1 mrad at forward angles, and performance at 90° comparable to BaBar
  - Lens improves photon yield
- Optimization of focal plane and EV shape possible to further improve single-photon resolution?

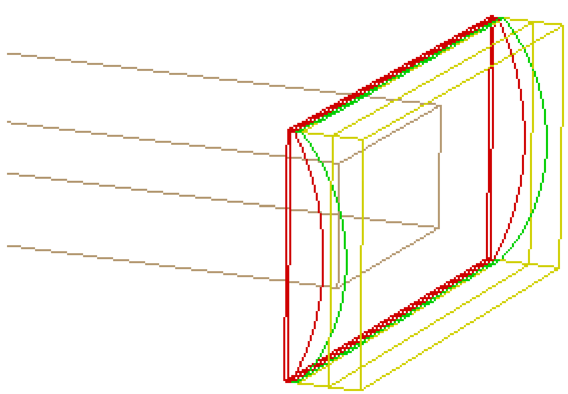

Bar and lens in drcprop

θ_c resolution for cylindrical triple lens



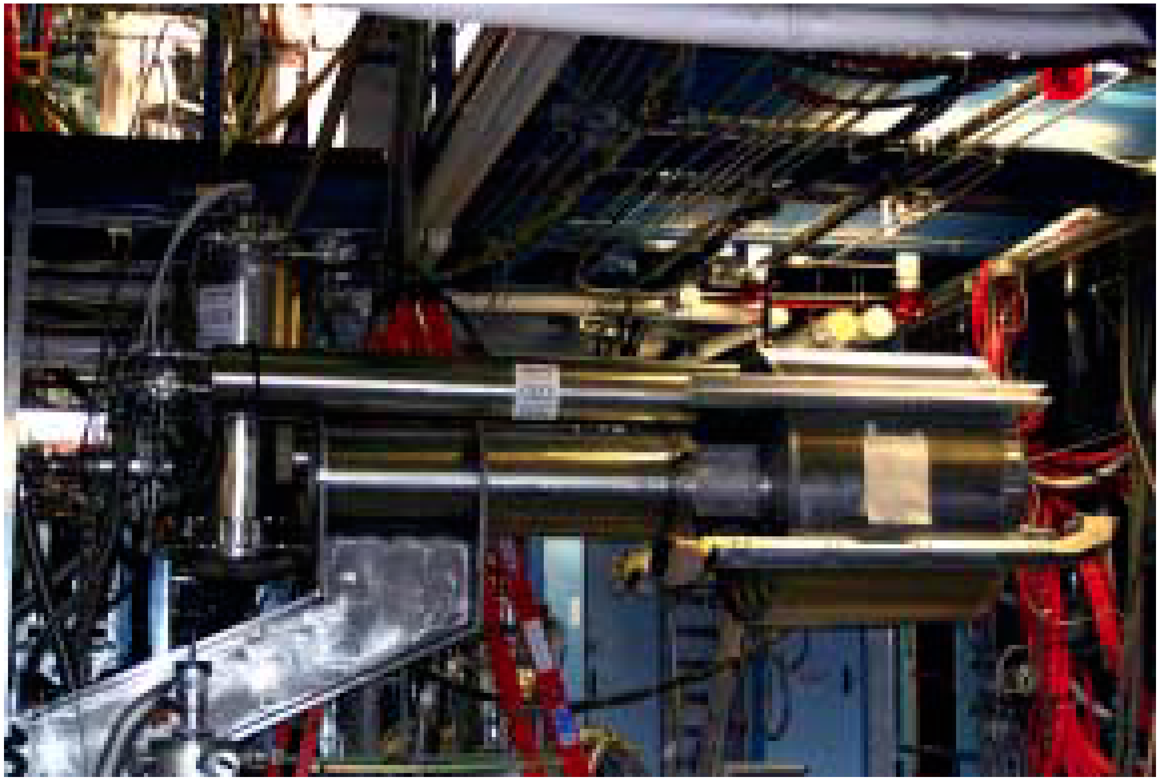


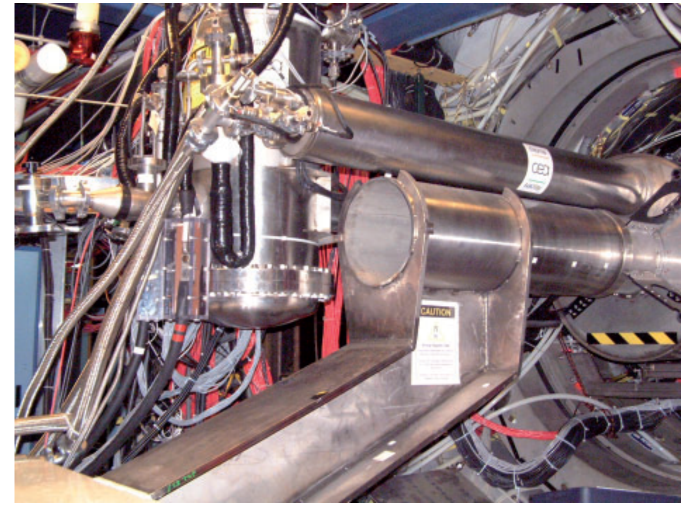
- Cylindrical lens also improves photon yield at 90°.
  - Details not yet well understood
- Resolution does not match EIC kinematics as well as spherical lens
- Further optimization possible?



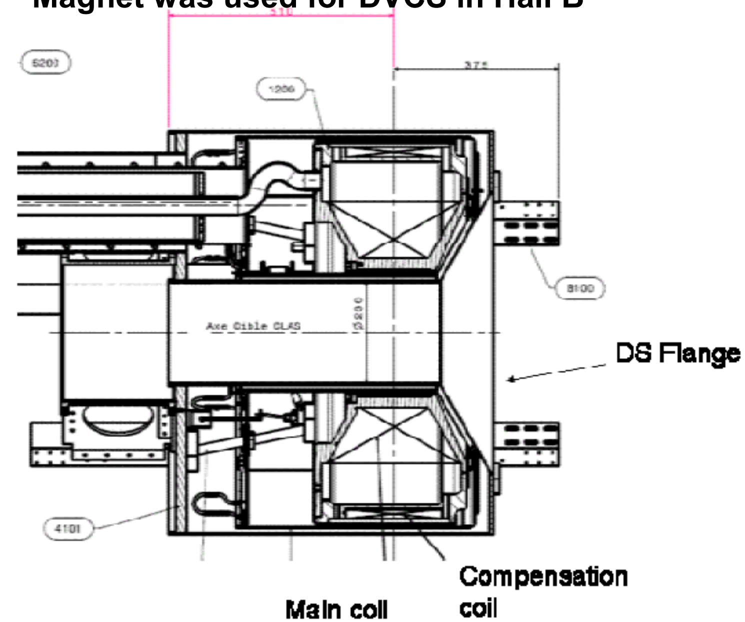
Bar and lens in drcprop

Magnet for High-B sensor test facility





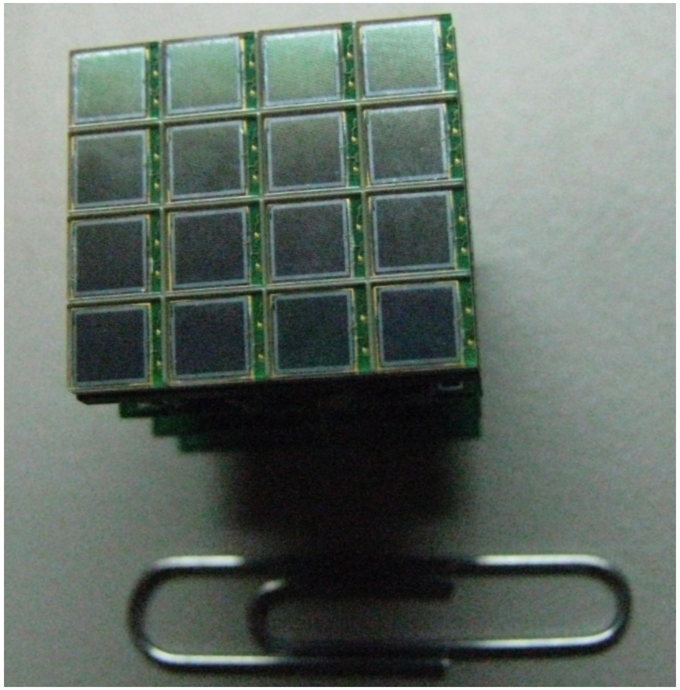
Magnet was used for DVCS in Hall B



- Superconducting dual-solenoid
- Max. nominal field at center: 4.7 T
- Adjustable nominal field
- Bore diameter: 0.23 cm

First sensors for high-B field tests at JLab

Katod single-anode MCP-PMTs
Two ordered, with 3 and 5 μm pore size, respectively.

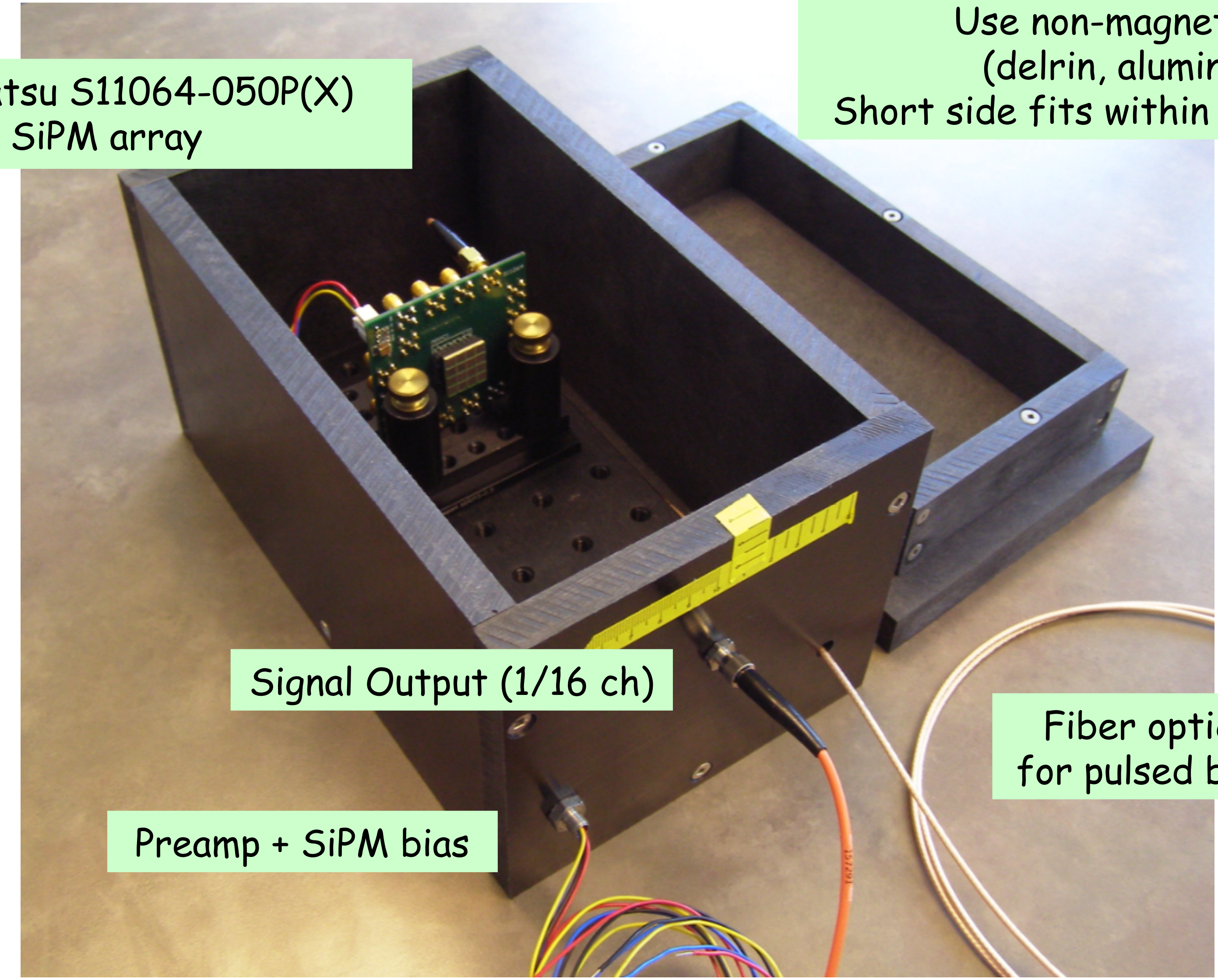


Hamamatsu S11064-050P(X) array
16 channels – 3x3 mm^2
50 μm microcells
400 microcells / mm^2

Used for GlueX in Hall D

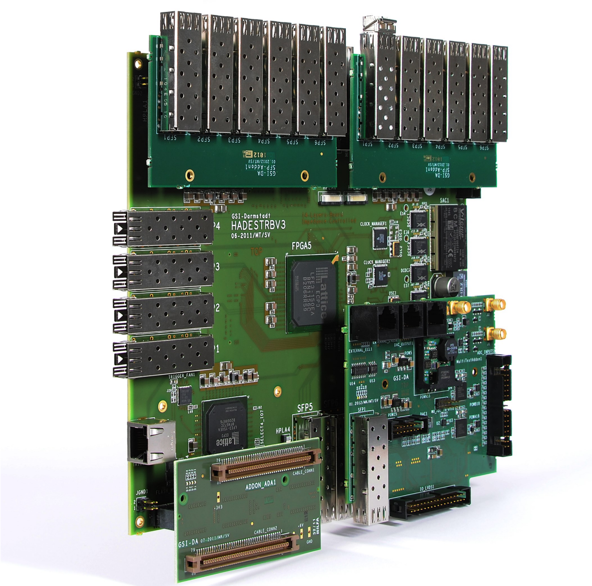
Dark box for High-B sensor test facility

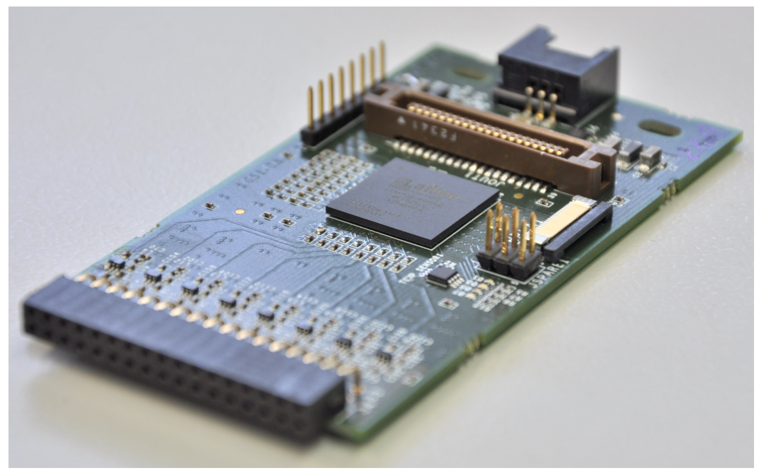
1st version of dark box
Use non-magnetic materials
(delrin, aluminum, brass)
Short side fits within 22 cm magnet bore



Readout for new EV prototype at GSI

PADIWA interface card for MaPMTs (via Hamamatsu E11906 sockets) to the TRBv3 DAQ card.





TRBv3 DAQ card with AddOns

Hamamatsu R11265-103-64 MaPMTs
256 channels (4 MaPMTs) procured.
Photo taken in transit at JLab

Summary

The Electron-Ion Collider (EIC) is a next-generation US facility for the study of the strong interaction (QCD).

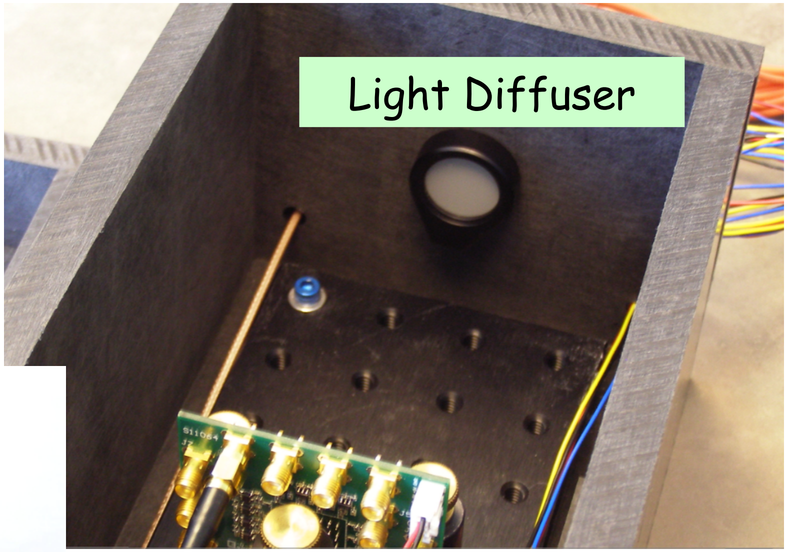
An R&D program exists to develop technologies for the future EIC detector(s)

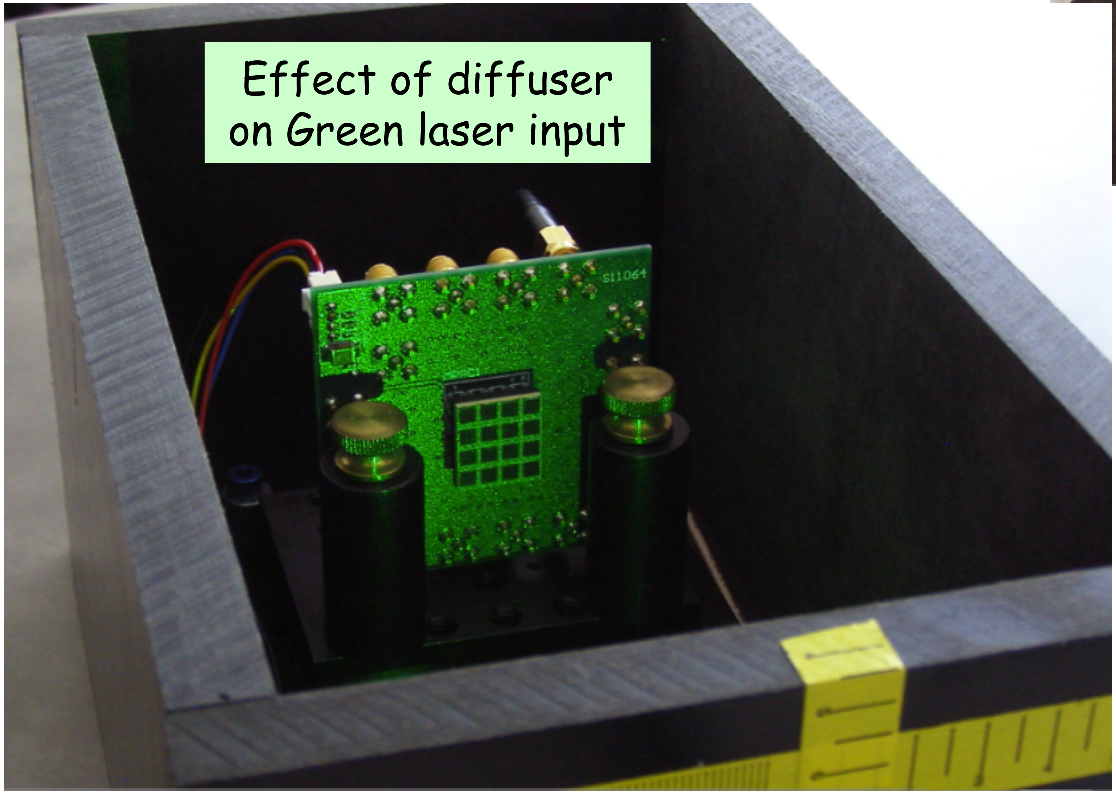
The DIRC R&D carried out in collaboration with GSI has shown very promising results, suggesting that a DIRC would be a good PID system for the EIC central detector.

Backup

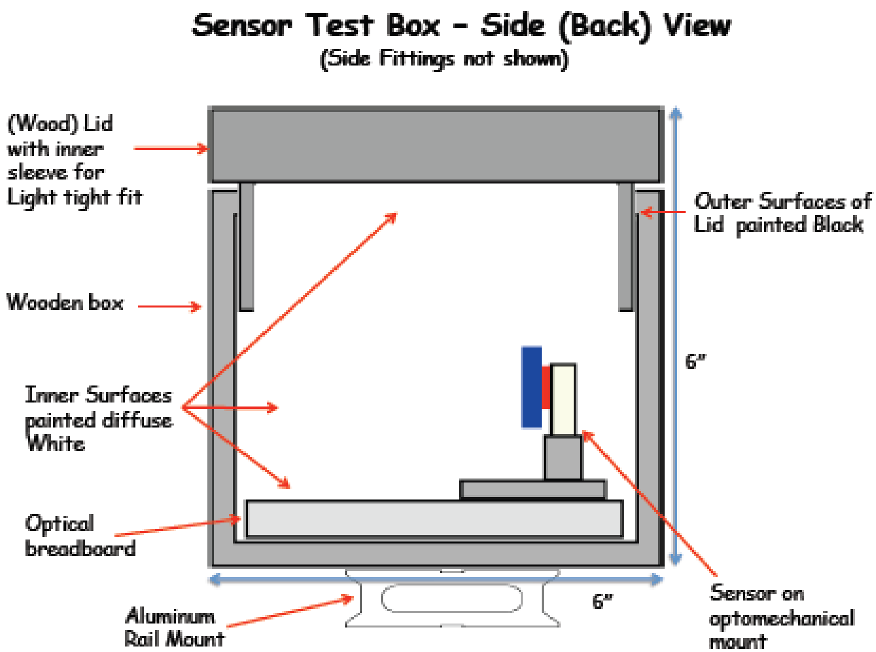
Light diffuser for High-B sensor test facility

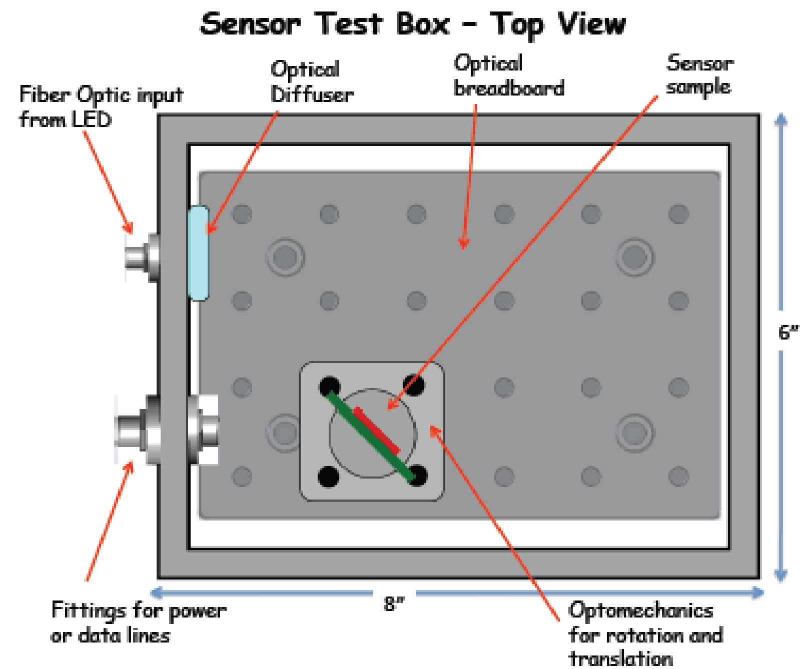
Need optical diffuser to uniformly illuminate photodetector





High-B sensor test facility – the test box

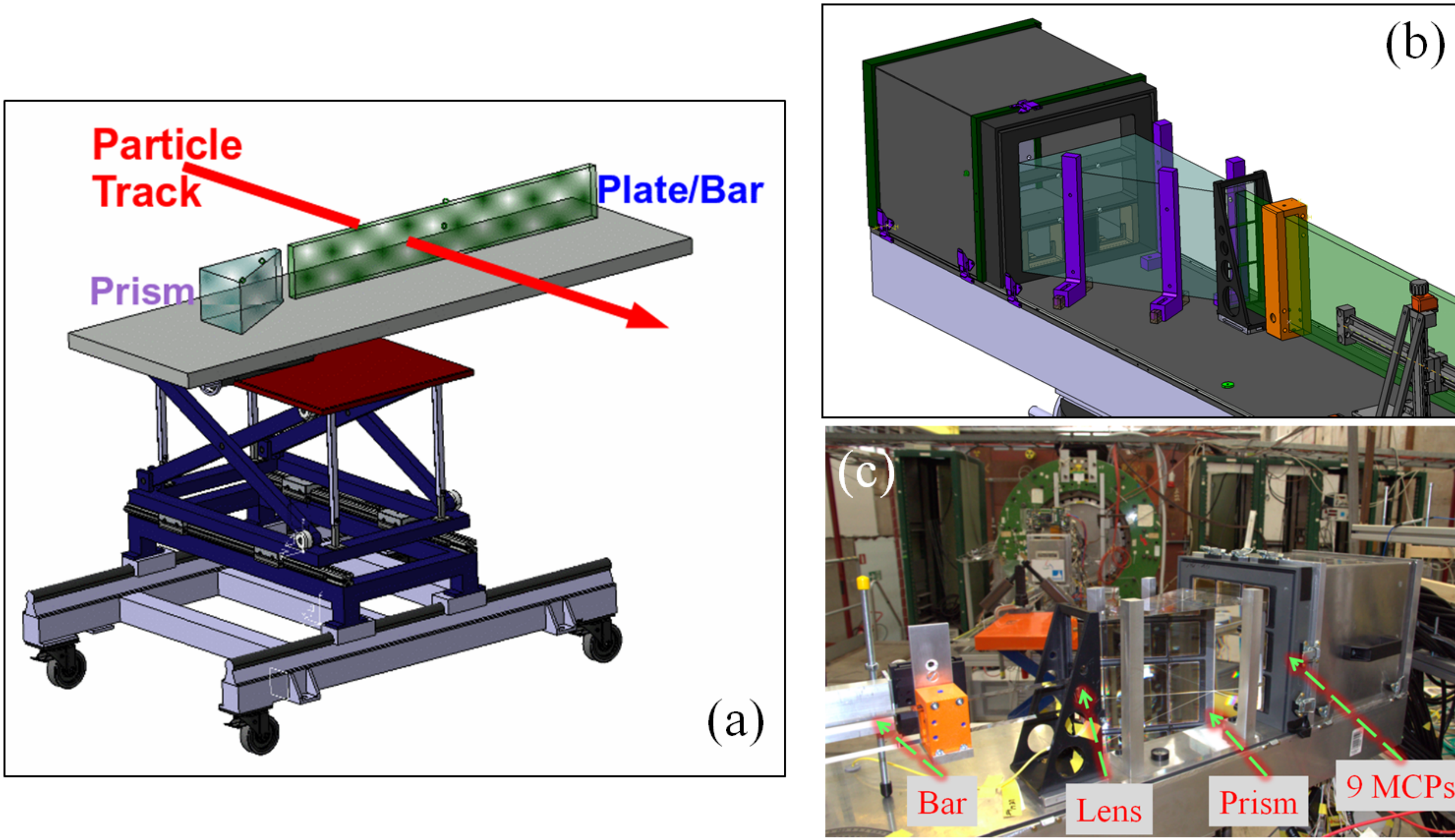




Figures, courtesy of C. Zorn

- Box features
  - Light tight
  - Non-magnetic
  - Cool
  - Temperature controlled
- Suitable for testing
  - SiPMs
  - MCP-PMTs

General layout of EIC prototype



- The EIC prototype will an infrastructure and layout generally similar to those that were used for the PANDA beam tests at CERN in 2012
  - It will, however, feature new lenses, sensors, and EV geometry

Improving the 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

R&D strategy – simulations and design

1. Proof of Concept

- Configuration with lens focusing and EV inside detector
- New lenses with high index of refraction
- Reconstruction package (needed for figure of merit)
- Ray tracing (drcprop) simulations show 1 mrad resolution!
- Next steps: lens and EV optimization

2. Design optimization for EIC detector

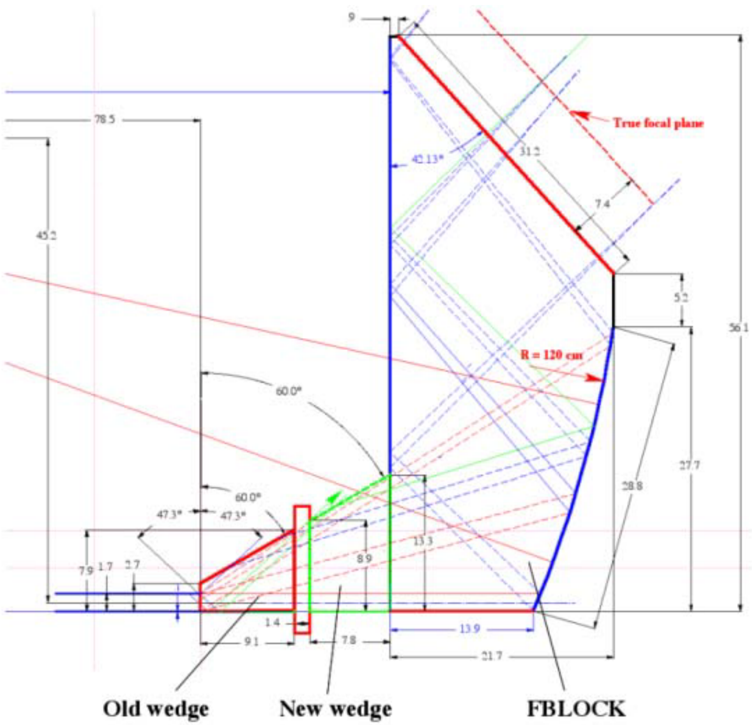
- Both internal (lens) and external (mirror) configurations will be investigated

3. Design and construction of lens and EV for prototype

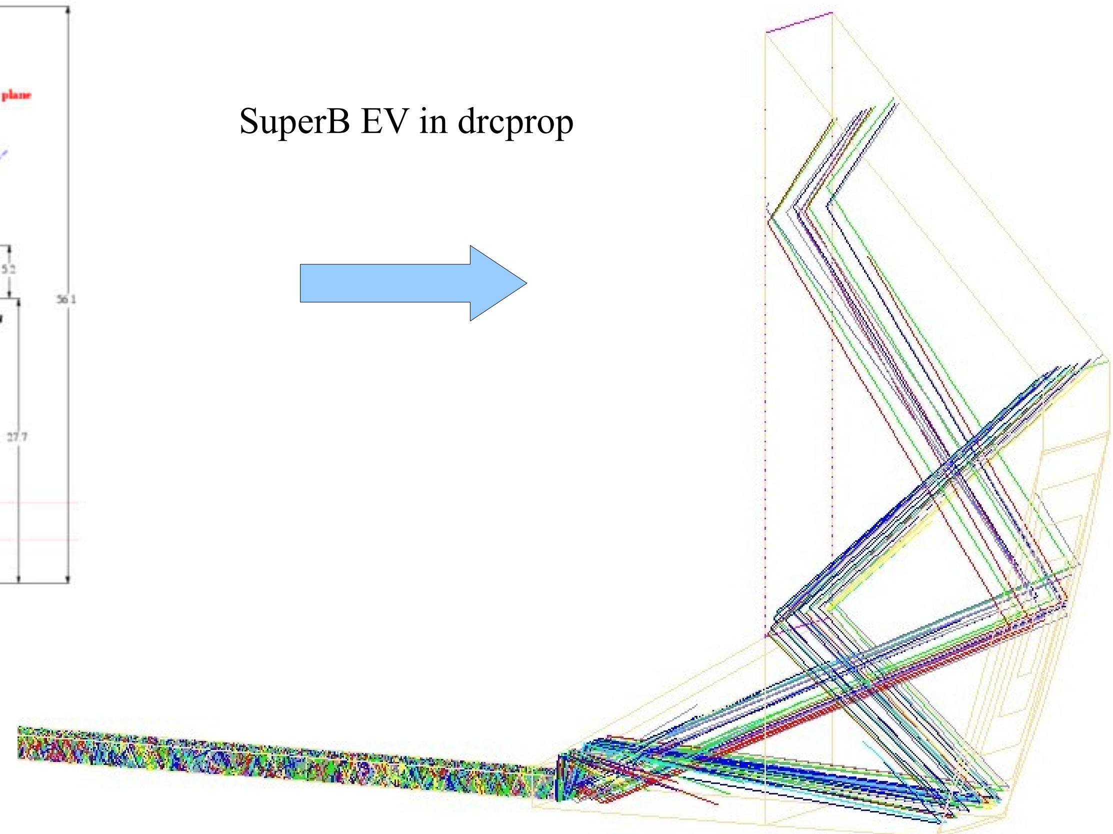
4. Studies of other configurations

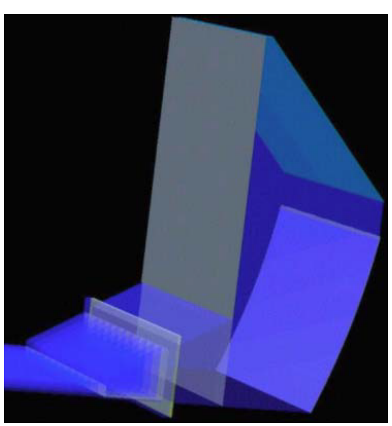
- Bar with mirror on the opposite side of EV (a la Belle) has been studied in drcprop
  - Results were not promising and this approach has not been pursued further
- Bar with Babar geometry EV has been implemented in GEANT4
  - Intended as a benchmark for GEANT4 simulations of prototype

Focusing-mirror optics implemented in drcprop



SuperB EV in drcprop





- SuperB mirror optics have been implemented in drcprop
- Will be modified to fit EIC requirements