DIRC-based PID for the EIC

— Mid-year progress Report

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Generic Detector R&D for an Electron Ion Collider

Advisory Committee Meeting, BNL, January 13, 2014

Outline

This update focuses on the current year.
The plans for next year remain as outlined in the proposal

1. Introduction

2. DIRC simulations

3. High-B field test facility

R&D goals and progress summary

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 improves e/π and K/p separation

Accomplished. Proof of concept simulations done!

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

- Compact readout "camera" (focusing + expansion volume + sensors)
  - simulations, lens and EV design, prototyping, test beams
- Operation in high magnetic fields (up to 3 T)
  - sensor tests

In progress. High-B facility being set up.

3. Study integration of the DIRC with other detector systems

- Internal or external readout? Bars or plates?
- Impact on endcap design and barrel calorimeter?

Remains to be done

Primary responsibilities

1. Simulations of DIRC performance and design of EV prototype

- Old Dominon 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

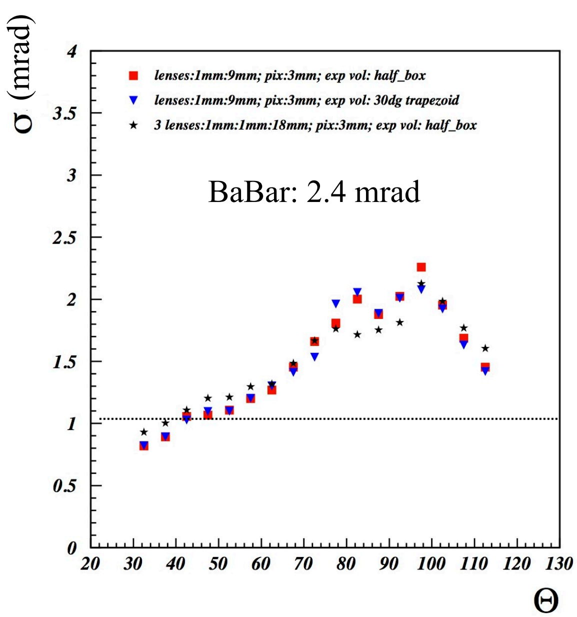
4. Detector integration

- Catholic University of America

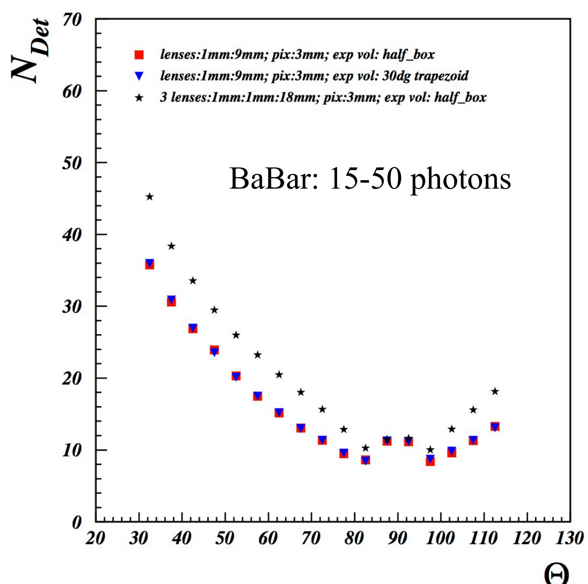
Note: **The proposal is a collaborative effort and most institutions will contribute to more than one of the areas above regardless of their primary responsibility**

DIRC summary

- A DIRC can provide a radially compact particle identification solution for the EIC central detector
- The goals of the R&D are to adapt DIRC to the EIC requirements (performance and integration)
- Simulations show that using novel lenses and a compact expansion volume one could improve the resolution at forward angles below 1 mrad, corresponding to a 3σ K/π separation at 6 GeV/c (and greater at lower momenta)

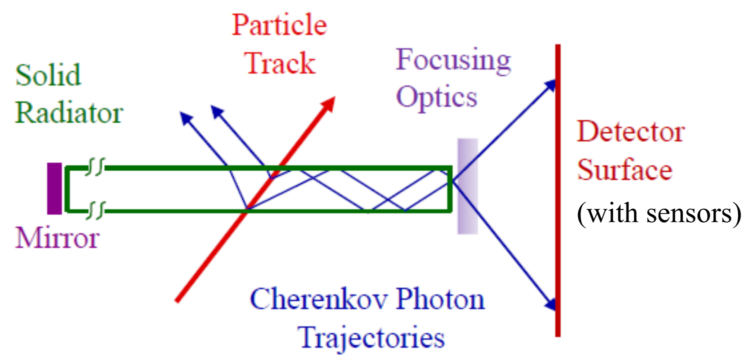


Cherenkov angle resolution
(for each track)

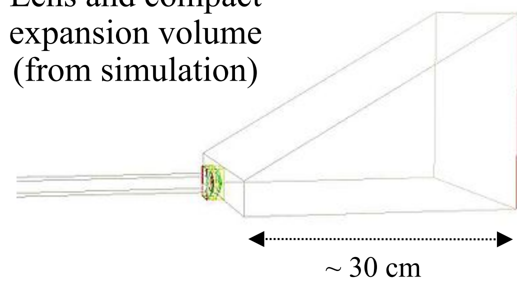


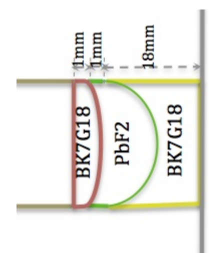
Cherenkov photons

General layout of a DIRC with lens focusing

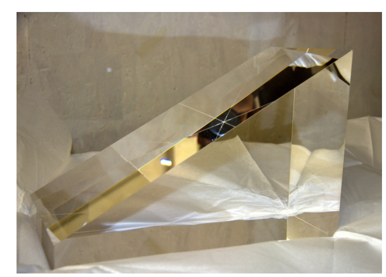


Lens and compact expansion volume (from simulation)



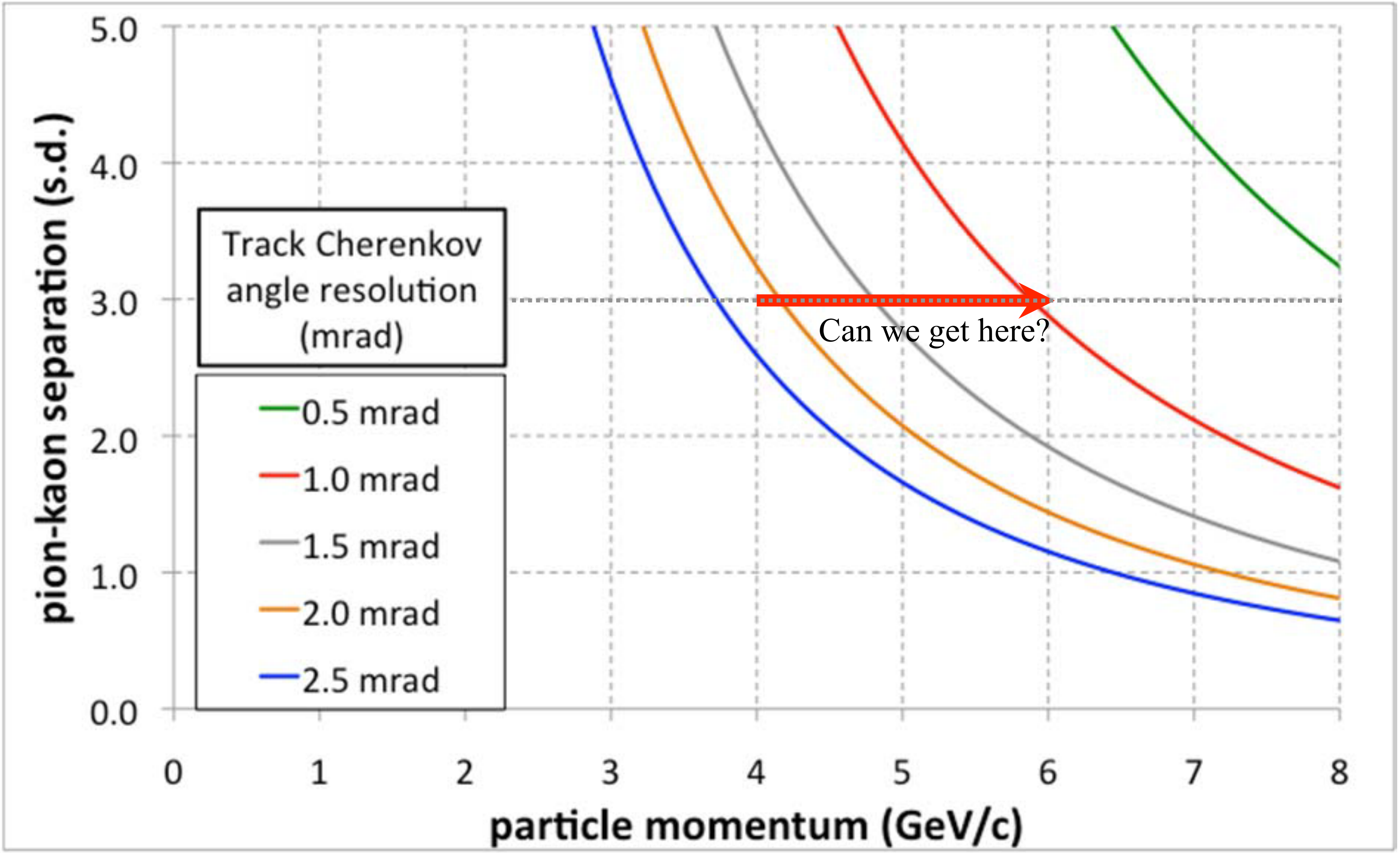


Novel high index of refraction lens (no air gaps)



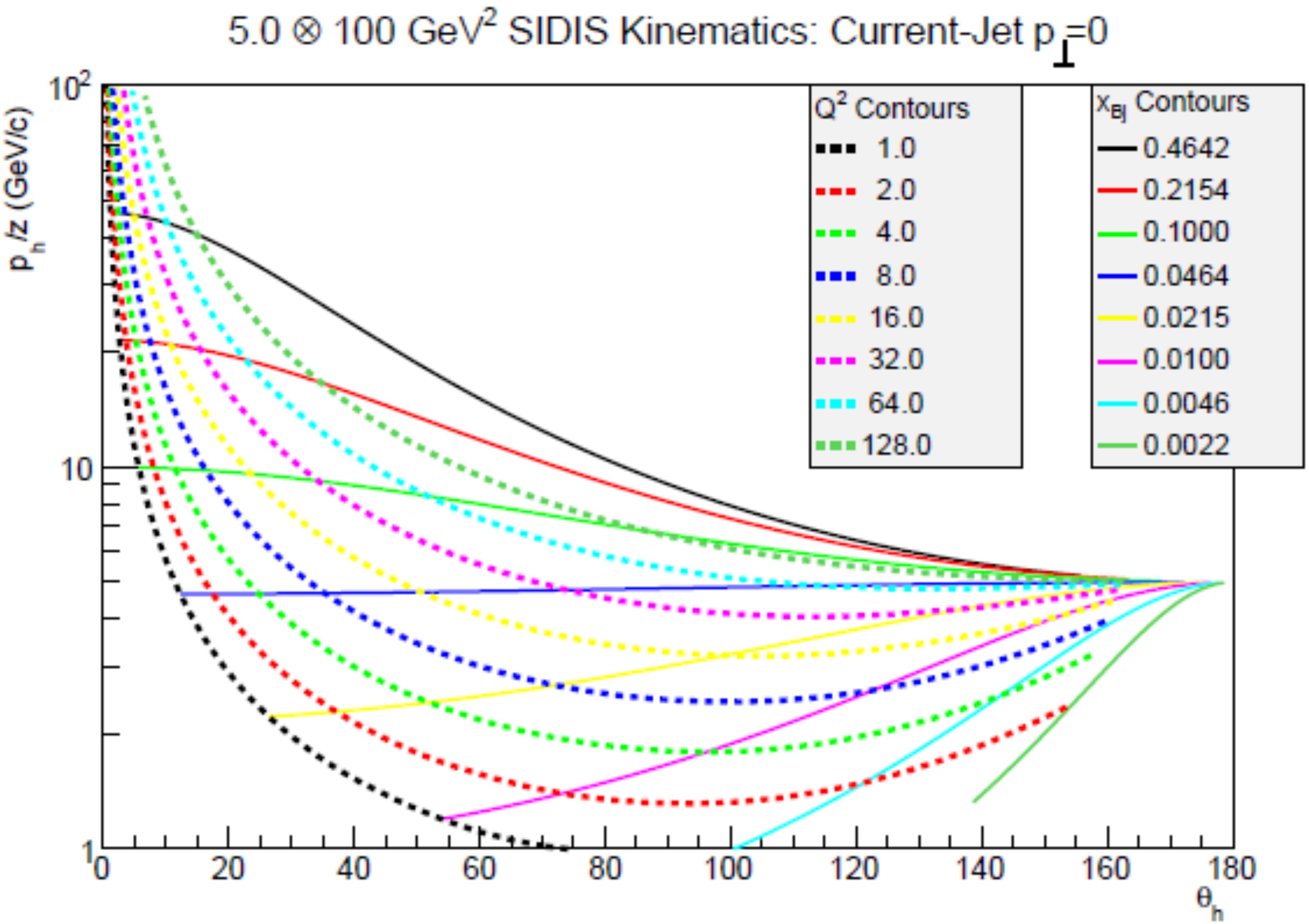
Compact expansion volume of fuzed silica (quartz)

π/K ID as a function of the θ_c resolution



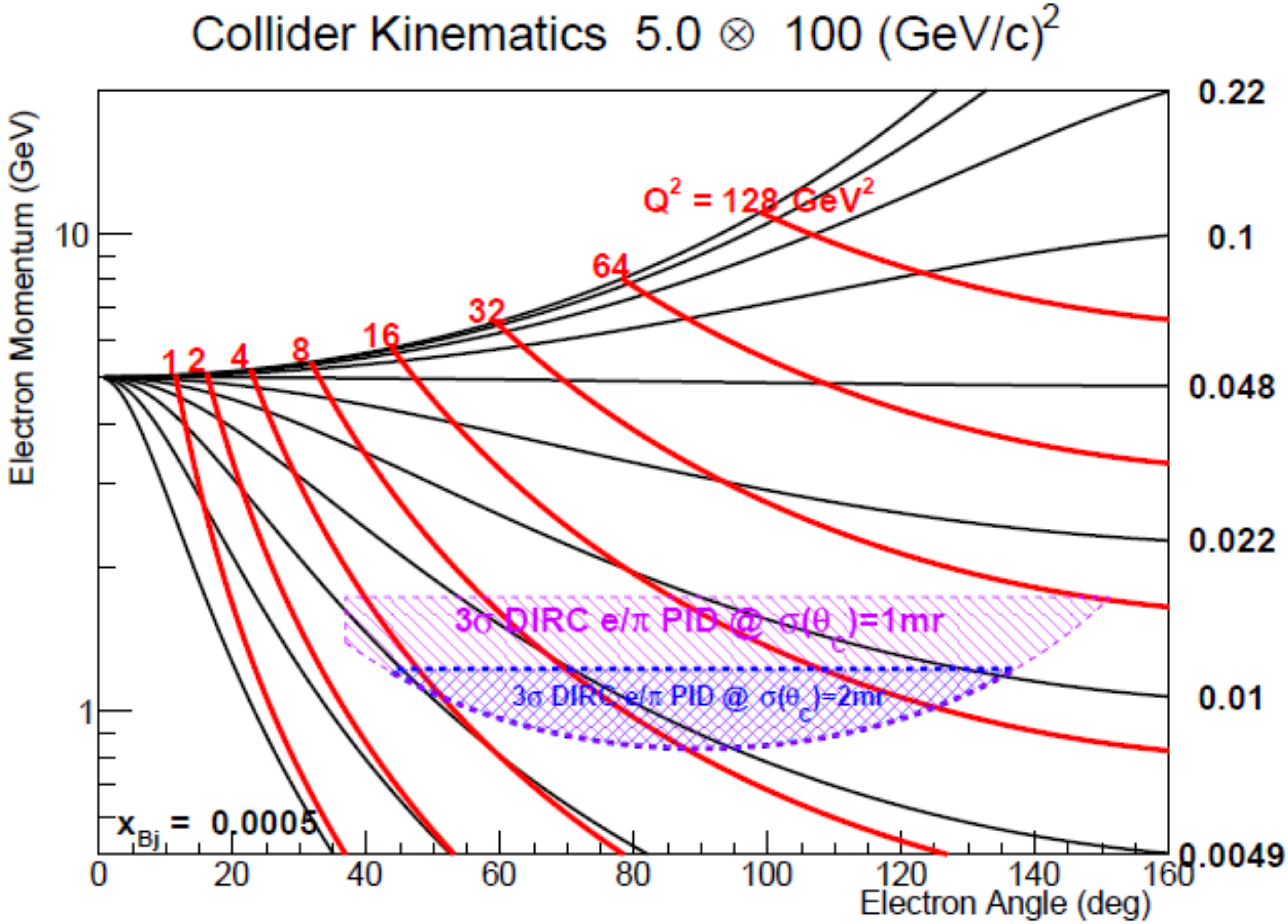
- Proof-of-concept simulations suggest possible to reach 6 GeV/c at forward angles

Example: π/K identification in semi-inclusive DIS



- Need high momentum coverage – especially at forward barrel angles!

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



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

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 ($n=n(\lambda)$)	~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

- DIRC bar thickness can in principle also be increased beyond the 17 mm (19% r.l.) used in Babar
- Excellent 3D imaging (2 spatial + time) essential for pushing performance beyond state-of-the-art

R&D strategy – simulations and design

1. Proof of Concept

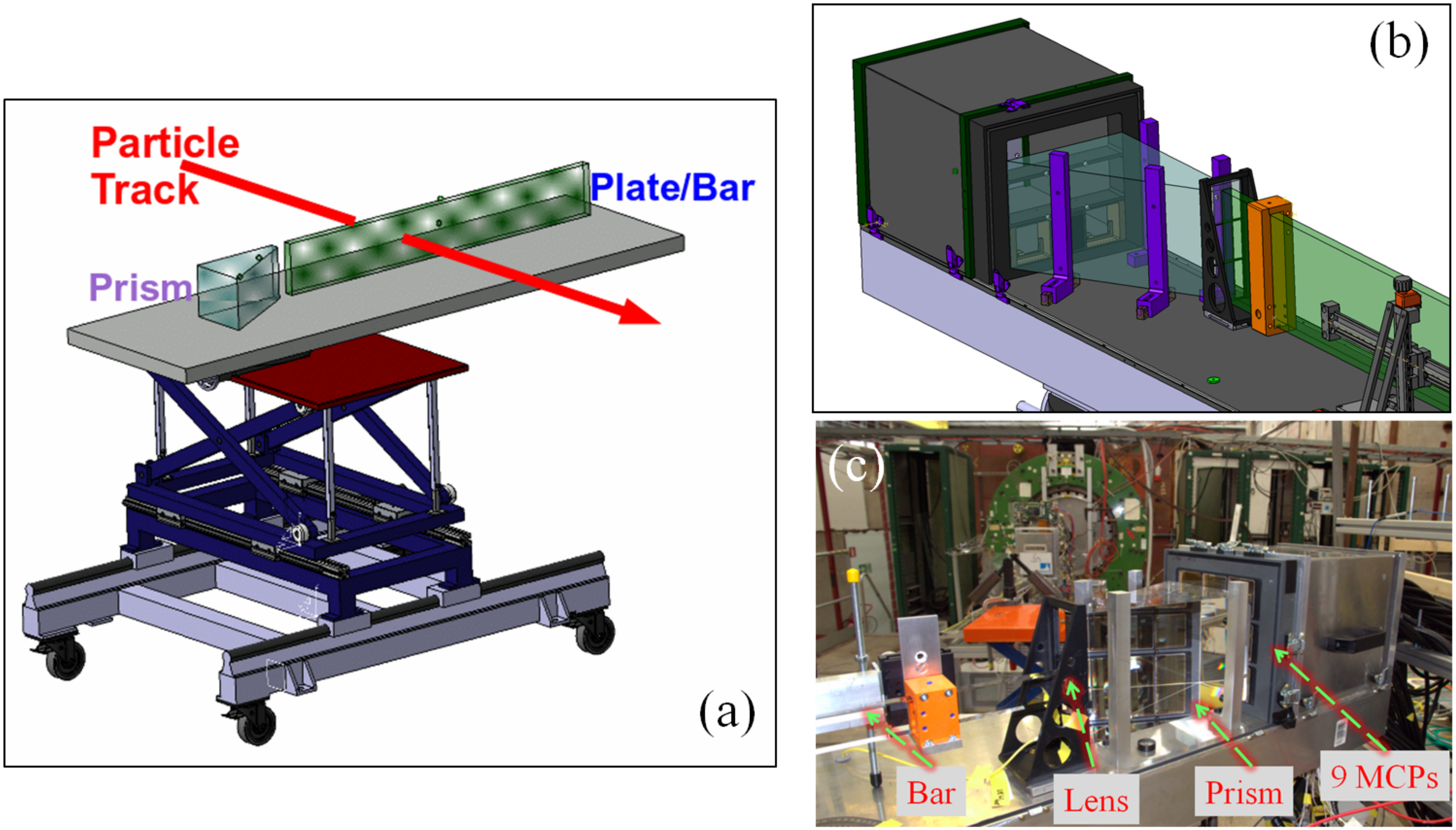
- Configuration with lens focusing and EV inside detector
- New lenses with high index of refraction have been developed
- Reconstruction package developed (needed for figure of merit)
- Ray tracing (drcprop) simulations show 1 mrad resolution!
- Next steps: lens and EV optimization

2. Design optimiziation for EIC detector

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

3. Design and construction of lens and EV for prototype

General layout of the future EIC prototype

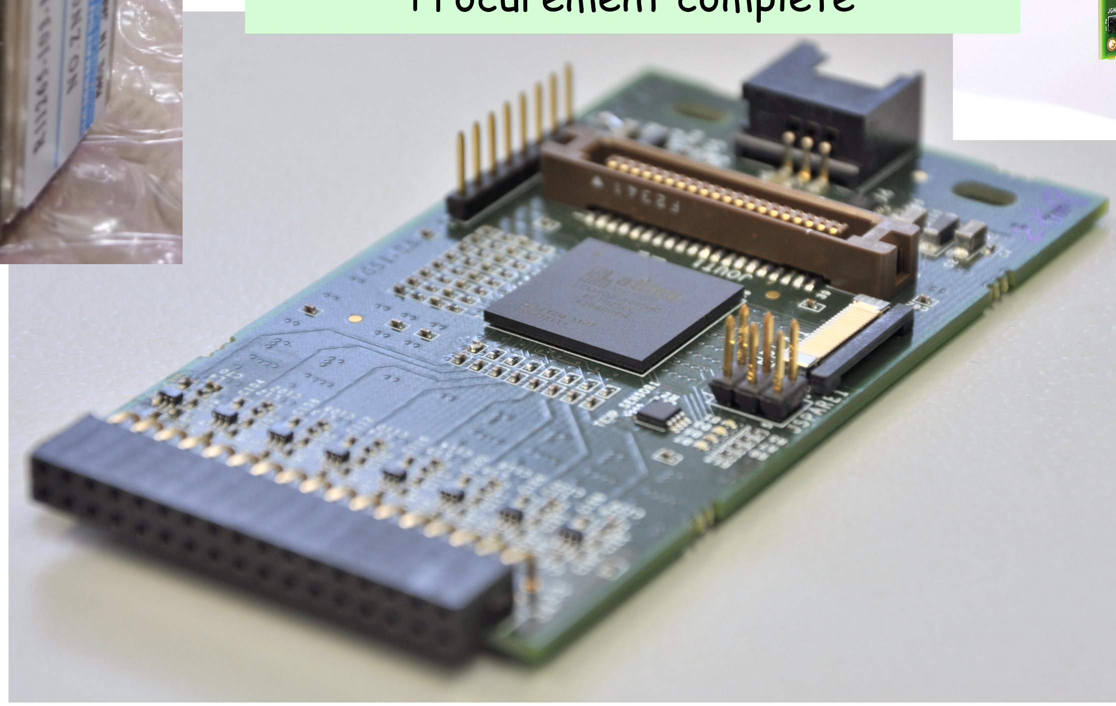


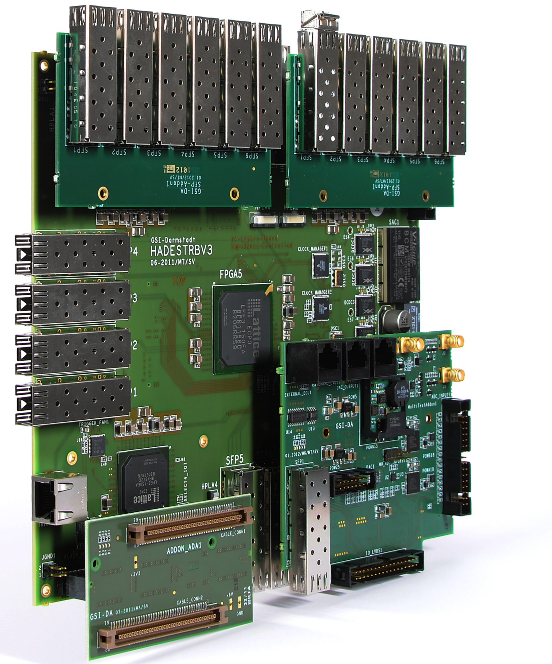
- The EIC prototype will have an layout generally similar to that used for the PANDA beam test at CERN in 2012
- It will, however, be functionally different, testing new lenses, EV geometry and sensors (already procured and now being integrated with the readout).

Procured sensors and DAQ electronics (at GSI)

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

PADIWA interface card for connecting the procured MaPMTs (via Hamamatsu E11906 sockets) to the TRBv3 DAQ card (right).
Procurement complete





TRBv3 DAQ card with AddOns
Procurement complete

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Remains to be done

ODU postdoc status

1. Proof-of-principle simulations completed by H. Seraydaryan

- Milestone completed, but HS left ODU for personal reasons at the end of year 2 (September 2013) to join her husband in DC

2. New search completed

- Four excellent candidates interviewed – last late entry today!
- Decision expected this week, with a *target start date of April 1*

3. Temporary boost for high-B field sensor testing effort

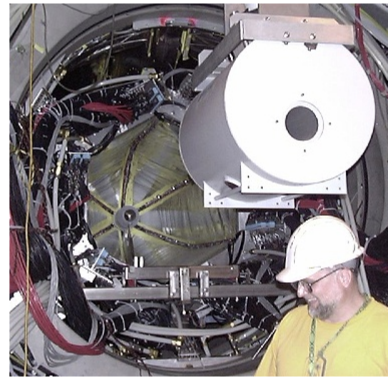
- A new ODU, K. Park, was reassigned to the DIRC project for December – February to help in setting up the test facility

4. Impact on timeline and funding

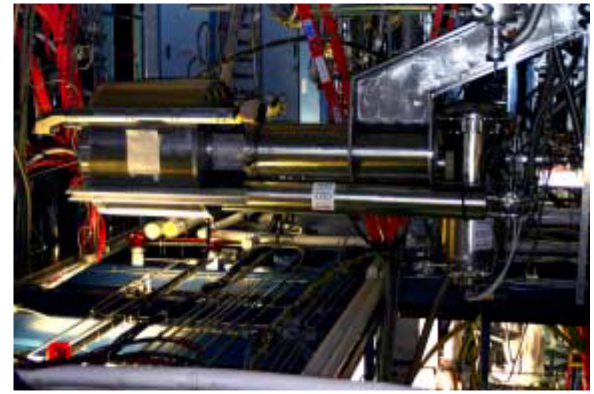
- We expect that 3 months of postdoc salary will be rolled over to the next year
- Given the quality and experience of the candidates, we do not expect a major delay in completing the simulations, but an assessment will be made once the hiring process is complete and a progress report submitted
- An updated budget will be presented at the next meeting

Tests of photosensors in high magnetic fields

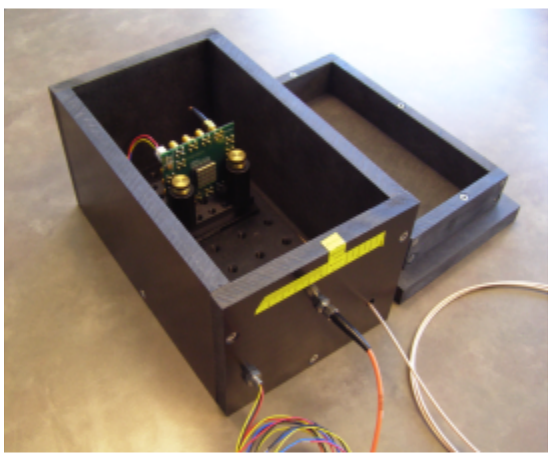
- A compact DIRC readout inside the EIC central detector will require sensors that can operate in high magnetic fields (1-3T)
  - Also a requirement for other systems!
- A new, permanent EIC sensor test facility is set up at JLab as part of the DIRC R&D
  - Two 5T magnets provided by JLab
- Tests will include MCP-PMTs with small pore size (2-6 μm), SiPMs and LAPPDs



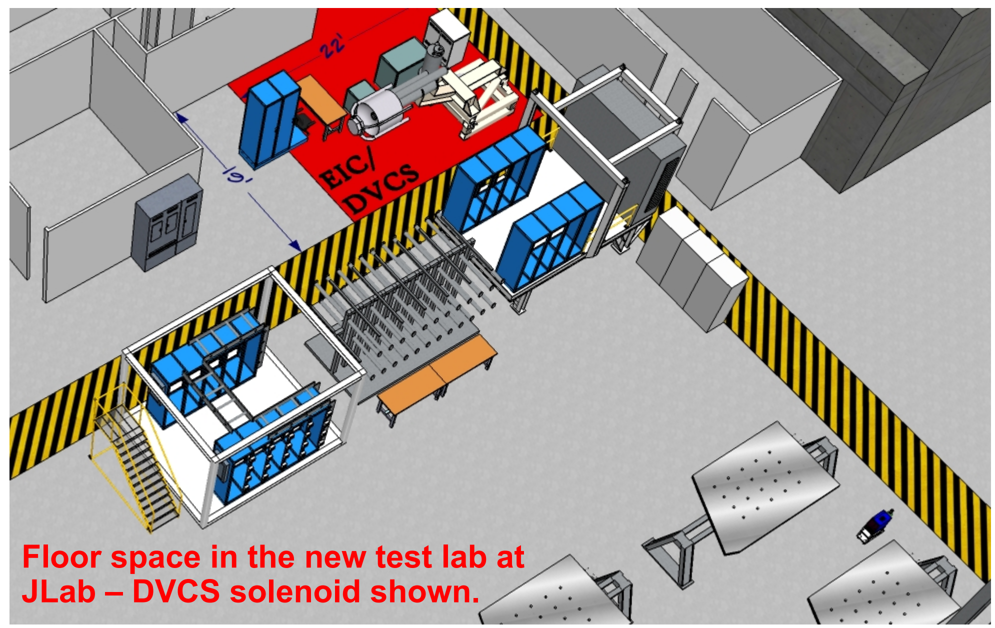
CLAS FROST solenoid with 5 inch bore



CLAS DVCS solenoid with 9 inch bore



Non-magnetic dark box with pulsed LED for the DVCS solenoid – note the GlueX SiPM (Hamamatsu S11064-050P(X))

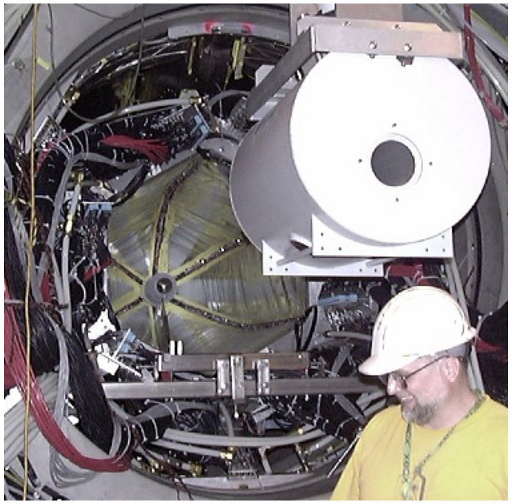


Floor space in the new test lab at JLab – DVCS solenoid shown.

High-B field – new magnet

FROST magnet available

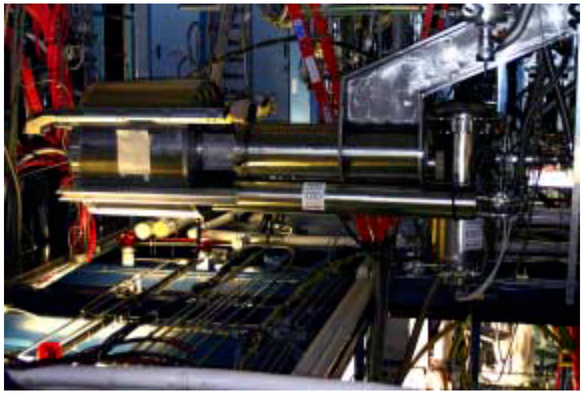
- In addition to the CLAS DVCS solenoid, the smaller FROST magnet has also become available
- Both magnets can reach 5 T, but the FROST one is cheaper to set up and operate (requires less LHe)



CLAS FROST solenoid
with 5 inch bore

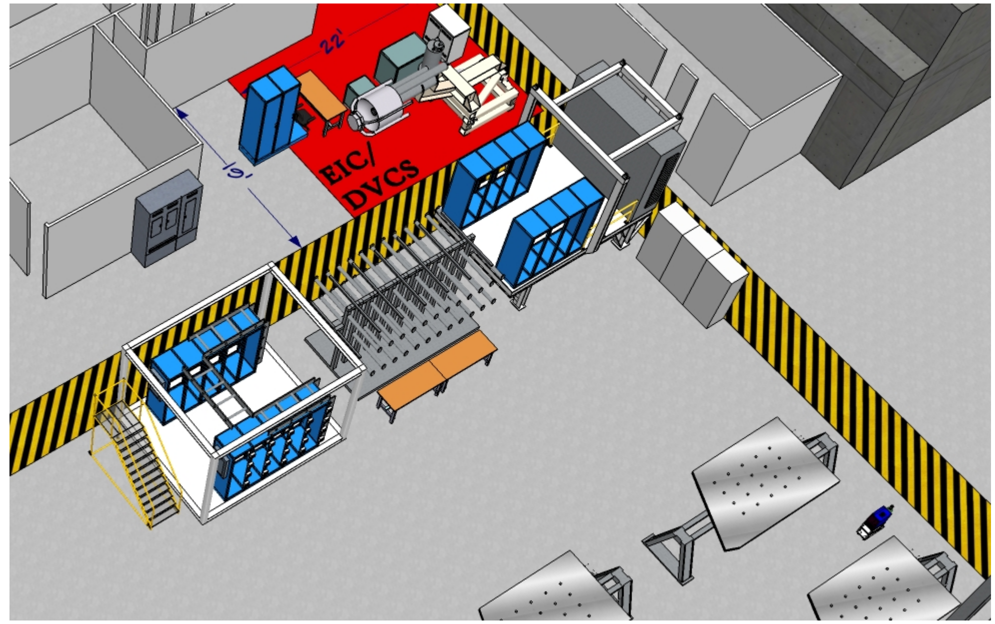
New, staged approach

- Perform first series of tests using smaller magnet.
- Will save funds in this year's budget (up to $10k), which could be used for sensor procurement
- Depending on sensor size, both magnets can be used for future tests as needed
- Test boxes will be built for both magnets (C. Zorn)



CLAS DVCS solenoid with 9 inch bore

High-B field – test facility status



Permanent floor space in new test lab building at JLab

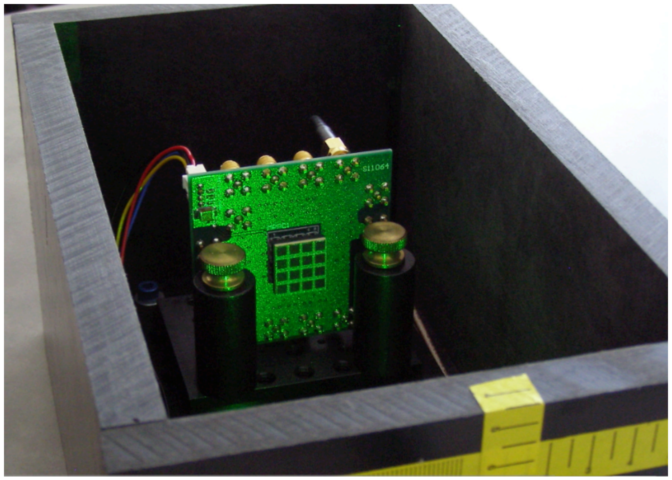
- Support equipment for both magnets, the FROST solenoid, and lab equipment is being moved in
  - The DVCS magnet will initially remain in storage

Personnel working on setup and test box (excluding undergrads)

- Y. Ilieva (co-PI, USC), lead
- K. Park (postdoc, ODU): working at JLab 50% Dec 2013 – Feb 2014
- T. Cao (grad student, USC): first visit to JLab Jan 2014 – Feb 2014
- C. Zorn and other JLab staff: on site

Commissioning of facility expected this spring

High-B field – planned sensor tests



Hamamatsu S11064-050P(X) SiPM for GlueX in non-magnetic dark box

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

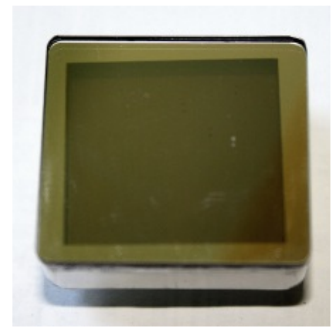
1st measurement this year: small pore size MCP-PMTs

- MCP-PMTs offer good single-photon resolution and radiation hardness (next slide)
  - could become a baseline photosensor for the EIC if high-B field performance is ok
  - SiPMs have to catch up in both areas, but progress is quick (will also be measured)
- We are currently looking at small-pore MCP-PMTs form Katod, Photek, Photonis, and Hamamatsu. Reducing cost by borrowing some MCP-PMTs may be possible!
- We would also want to test a small LAPPD if one would be available!

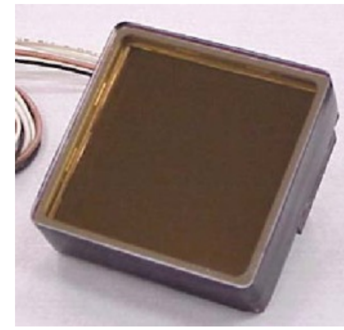
Radiation hardness of MCP-PMTs

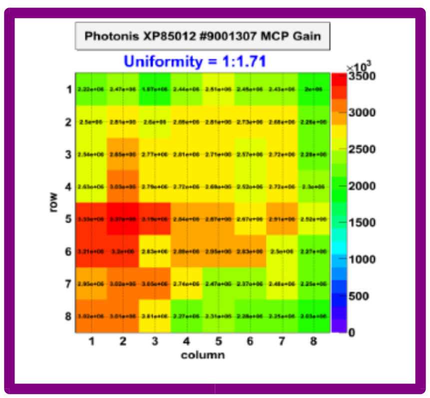
- Setup to study sensors in Erlangen
  - Gain scans
  - Quantum efficiency scans
  - Lifetime measurements.
- Recent significant improvement in lifetime of MCP-PMTs
  - Photonis Planacon MCP-PMTs (2 inches)
  - New Hamamatsu SL-10 (1 inch)

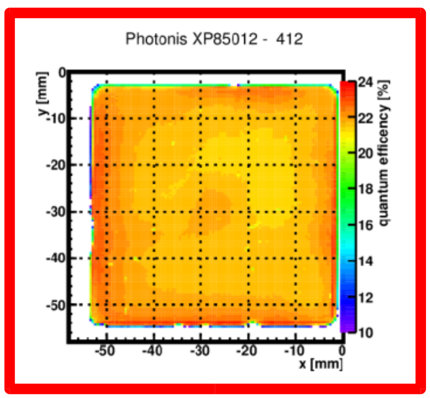
Hamamatsu SL-10 (4 x 4 pixels)

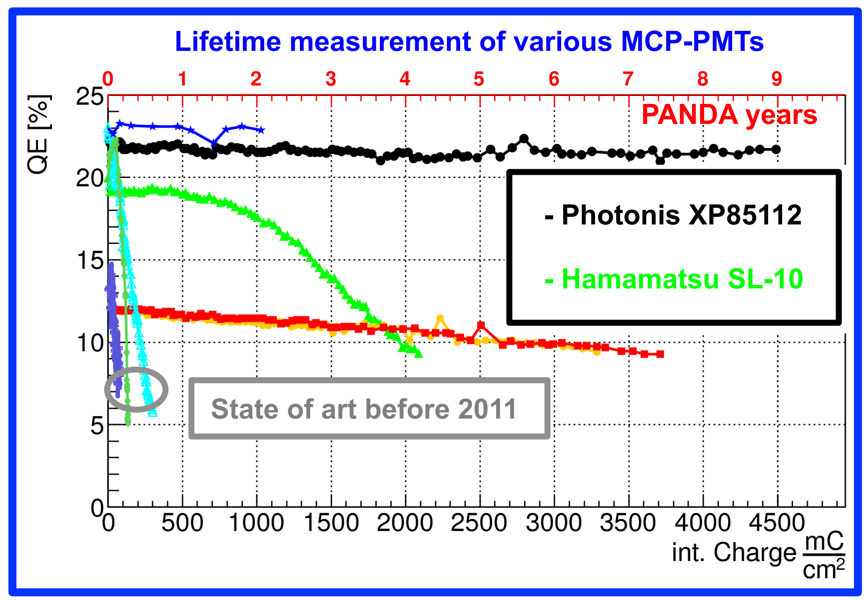


Photonis Planacon XP85012 (8 x 8 pixels)









A.Lehmann, DIRC2013, Giessen

From Greg Kalicy's postdoc interview talk

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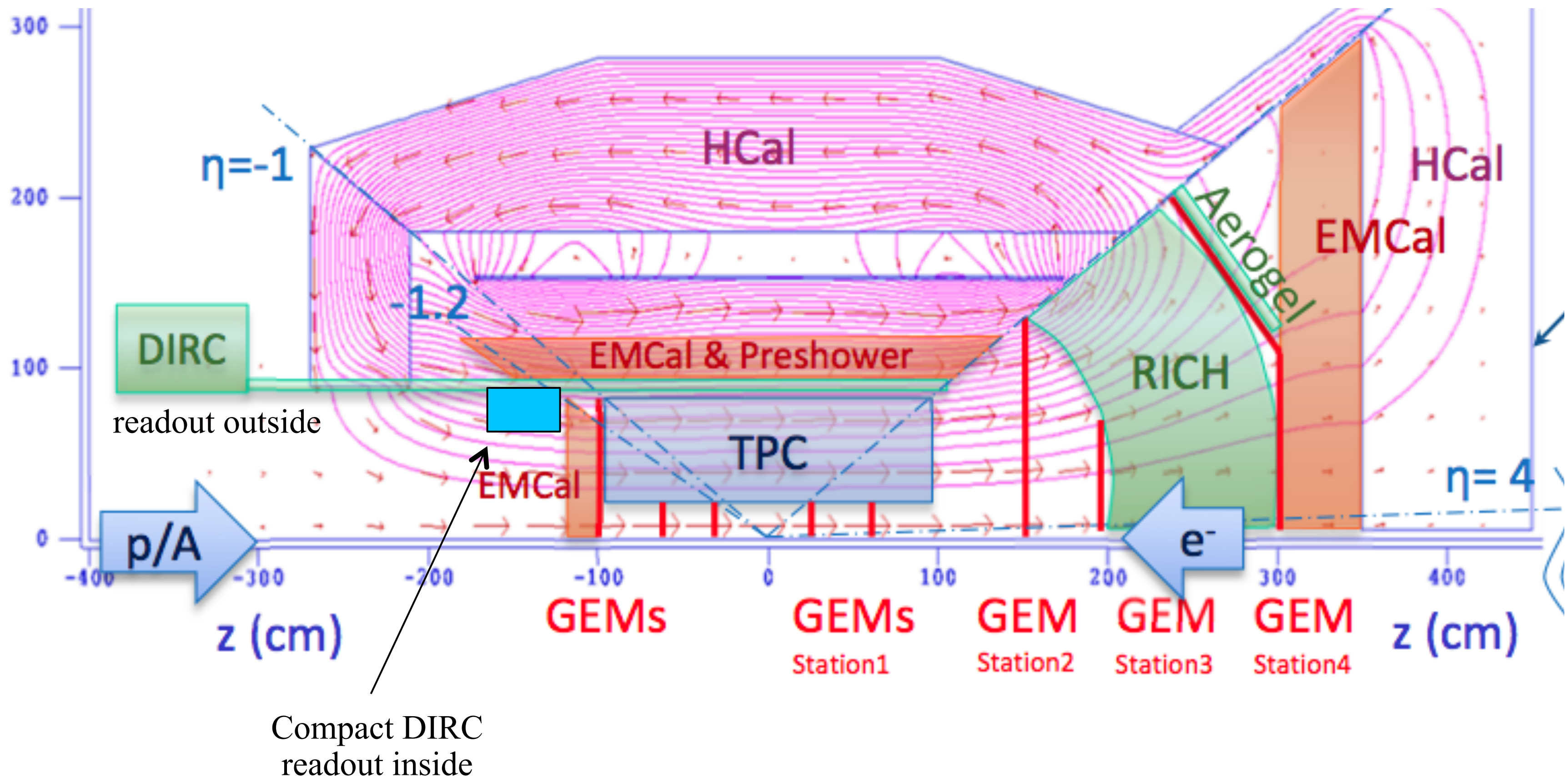
Remains to be done

Layouts with internal and external EV



- Options with internal and external expansion volume were previously shown for a dual solenoid, but apply also to, e.g., the ePHENIX upgrade

Meetings and travel funded by the grant

Yearly collaboration meeting at JLab planned for March 25-31, 2014

- Full participation expected – maybe even including new ODU postdoc

Invited talk at DIRC 2013 specifically on this DIRC R&D project

- Also mentioned at many conferences not funded by grant

Travel to BNL for two meetings with the advisory committee

Travel for University of South Carolina for setting up test facility

- Was initially intended to be covered through USC travel funds, but will be paid through JLab due to delays with the transfer to USC. Some adjustments may be needed in the upcoming proposal update to reflect this.

Budget

Budget	Year 1	Year 2	Year 3	Year 4	*Total*
Postdoc (50%)	$53,290	$54,000	$55,200	$56,300	*$218,790*
Students	$8,300	$13,764	$13,764	$13,784	*$49,592*
Hardware	$41,970	$58,630	$27,000	$30,000	*$157,600*
Travel	$11,440	$13,606	$19,036	$14,936	*$59,018*
Total	*$115,000*	*$140,000*	*$115,000*	*$115,000*	*$485,000*

Budget	Year 1	Year 2	Year 3	Year 4	*Total*
Old Dominon Univesity (ODU)	$53,290	$54,000	$55,200	$56,300	*$218,790*
Catholic University of America (CUA)	$9,800	$8,300	$8,300	$8,300	*$34,700*
University of South Carolina (USC)		$7,606	$12,646	$7,606	*$27,858*
JLab and GSI (through MoU)	$51,910	$70,094	$38,854	$42,794	*$203,652*
Total	*$115,000*	*$140,000*	*$115,000*	*$115,000*	*$485,000*

- Year 3 budget already contains a $10k rollover from Year 2.
- Additional savings could increase this by up to $20-30k

Summary

Very promising simulation results

- New lenses with high refractive index developed – improved photon yield
- Proof of concept for high-performance DIRC
  - Resolutions better than 1 mrad obtained at forward angles
- Results of the R&D presented at DIRC 2013 and other conferences
- Simulations of mirror-based optics with external EV will begin this fall

Hardware projects on track

- Procurement of first round of sensors and DAQ components for GSI setup had been completed and second round is under way
- Components for the high B-field test facility are being procured and prepared
  - preparations for installation of magnet and infrastructure are ongoing

Adjustments to funding request will be presented at next meting

Backup

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

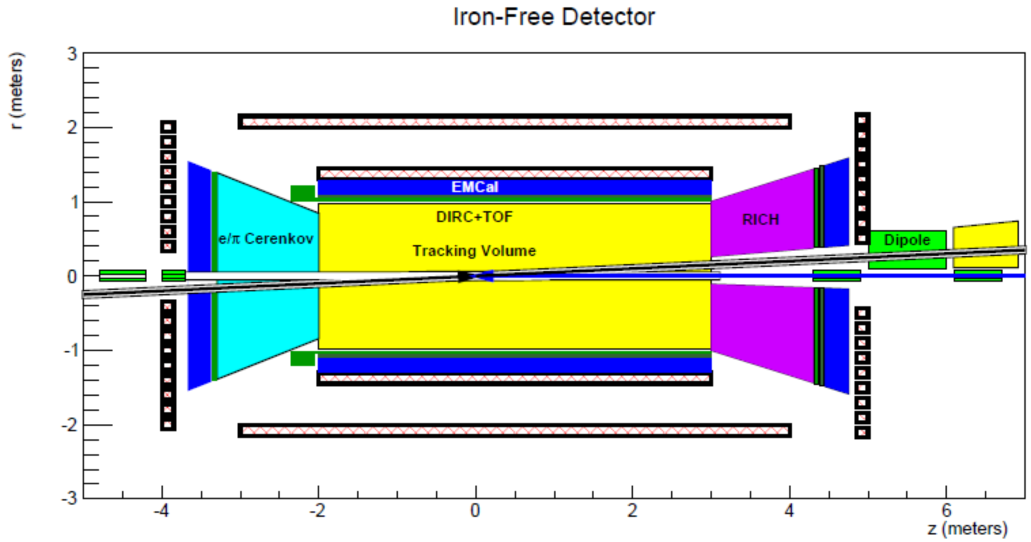
1. Expansion volume inside detector

- Narrow bars of moderate length (4-5 m)
  - Reconstruction well understood
  - Good azimuthal segmentation - can handle high multiplicity events
- Compact expansion volume important (fused silica)
  - Lens focusing primary choice – concept benefits from PANDA R&D
- Sensor challenges
  - High magnetic fields (low-noise SiPMs or MCP-PMTs with small pore size?)
  - Radiation? (EV in „quiet" corner)

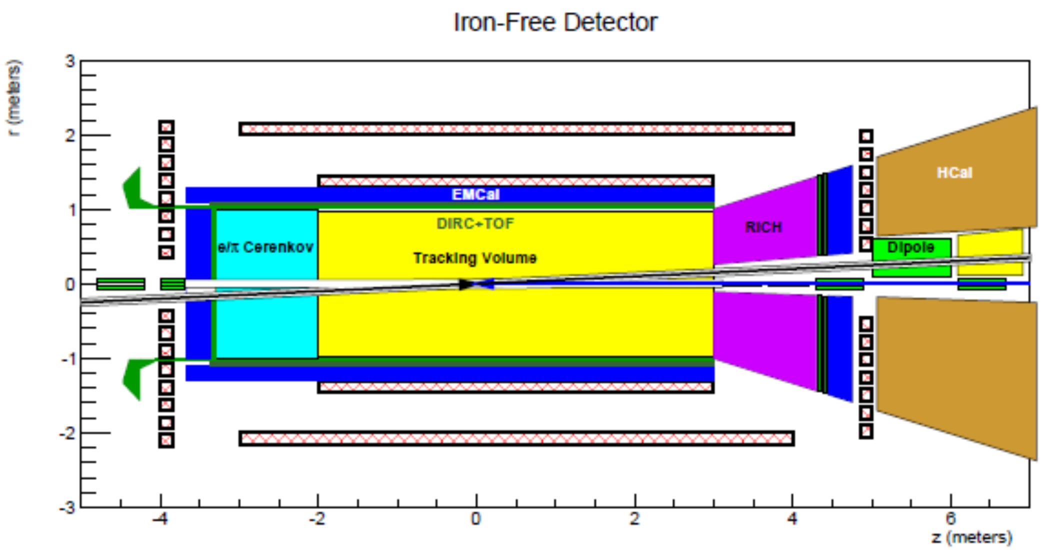
2. Expansion volume outside detector endcap and iron

- 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 – can be radially large
  - Mirror focusing similar to FDIRC for SuperB?
- Sensors – easier access and moderate magnetic fields (MCP-PMTs?)
- Major impact on endcap detectors – needs to be studied!

Possible layouts with internal and external EV

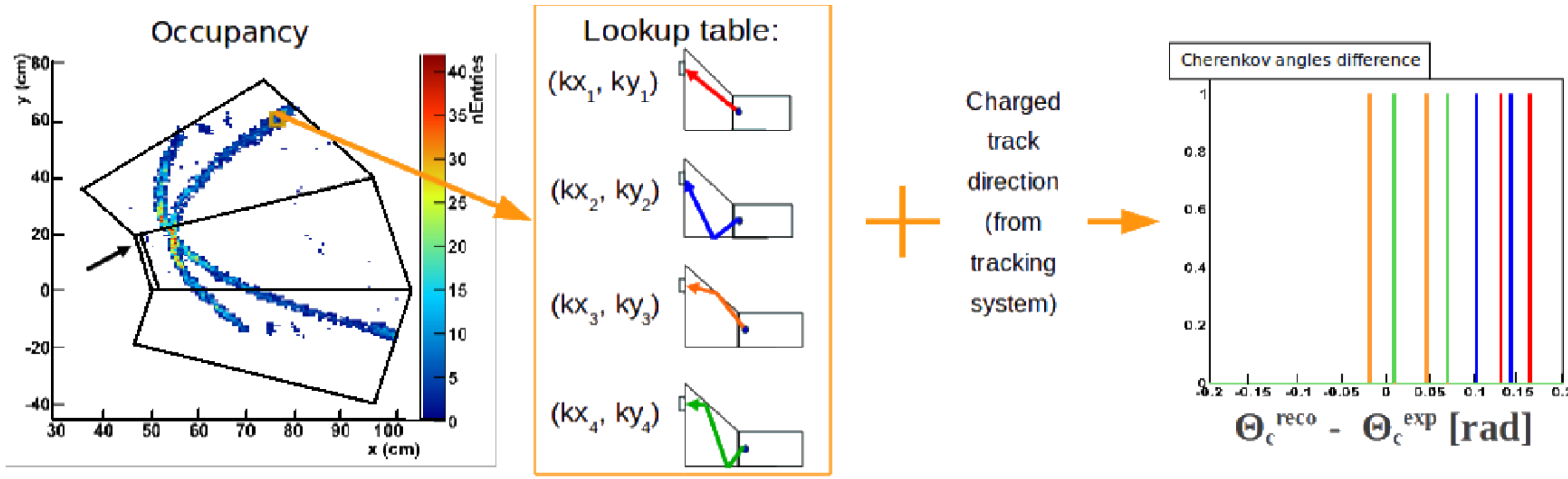


- A DIRC-based PID solution for the central detector can have the EV placed inside or outside of the detector.
- An internal solution requires a compact EV



- The DIRC bars/plates would be quite long if the EV was outside.
- Need to evaluate the impact of long bars/plates on endcap design

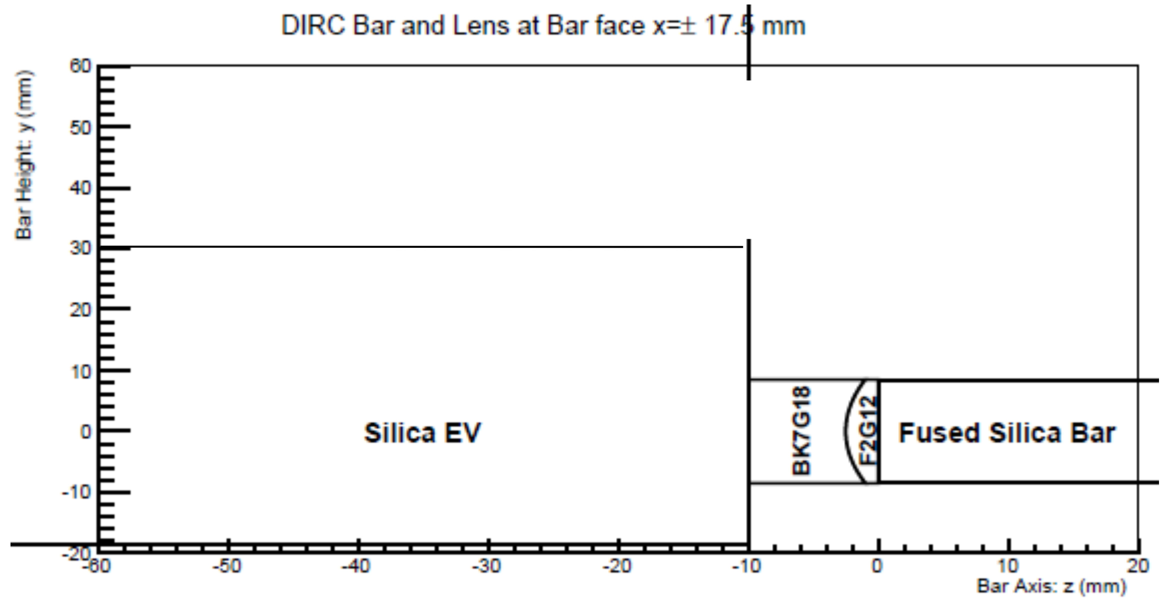
Event reconstruction

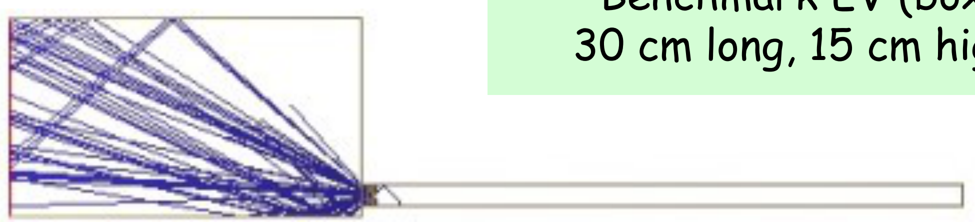


- For design purposes the main goal is to establish a figure of merit
- Explicitly reconstruct the single-photon θ_c resolution and photon yield
- Currently the algorithm uses a spatial lookup table (generated through simulation) combined with cuts on the time of propagation
  - Can be extended to include time explicitly in lookup table

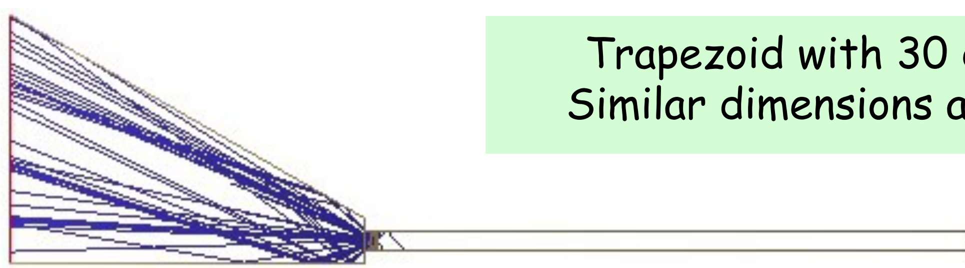
Benchmark expansion volume geometries

- Simulations were performed for two benchmark geometries: box and trapezoid
- No matching of the focal plane and EV image plane has yet been performed





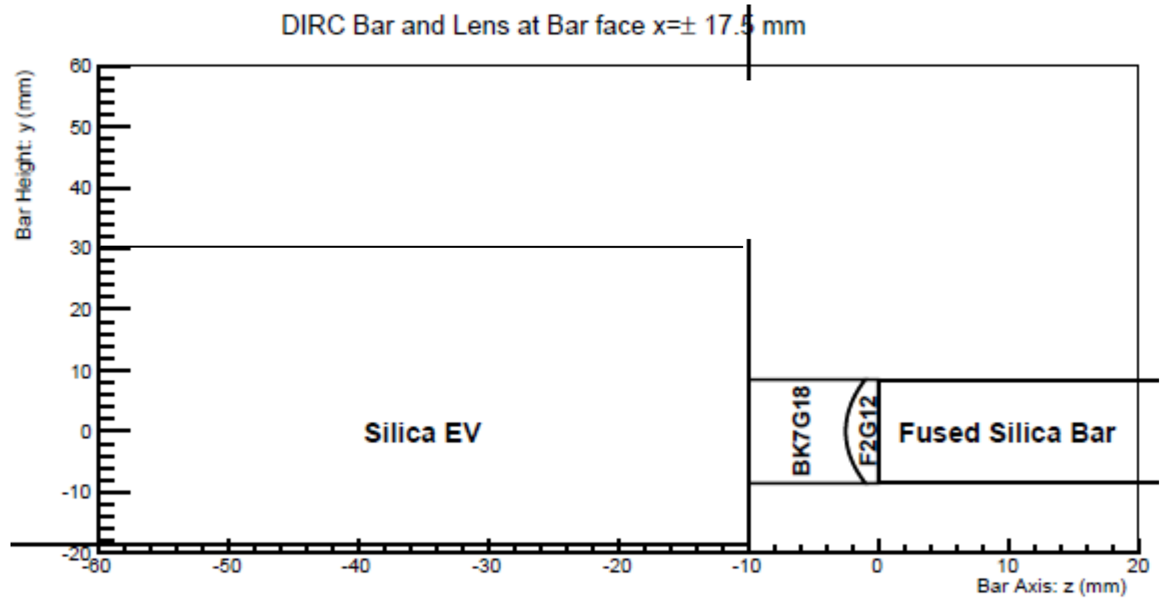
Benchmark EV (box) geometry
30 cm long, 15 cm high, 1 cm step

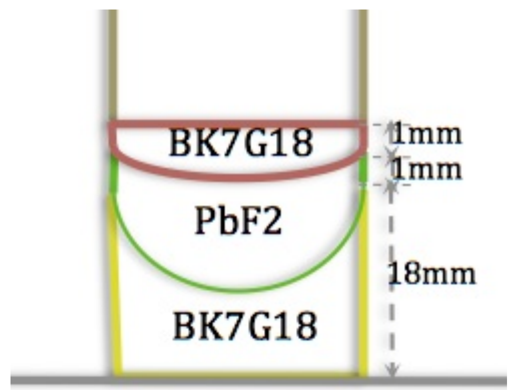


Trapezoid with 30 degree angle
Similar dimensions as for the box

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. Cylindrical lenses will also be investigated (for plates).

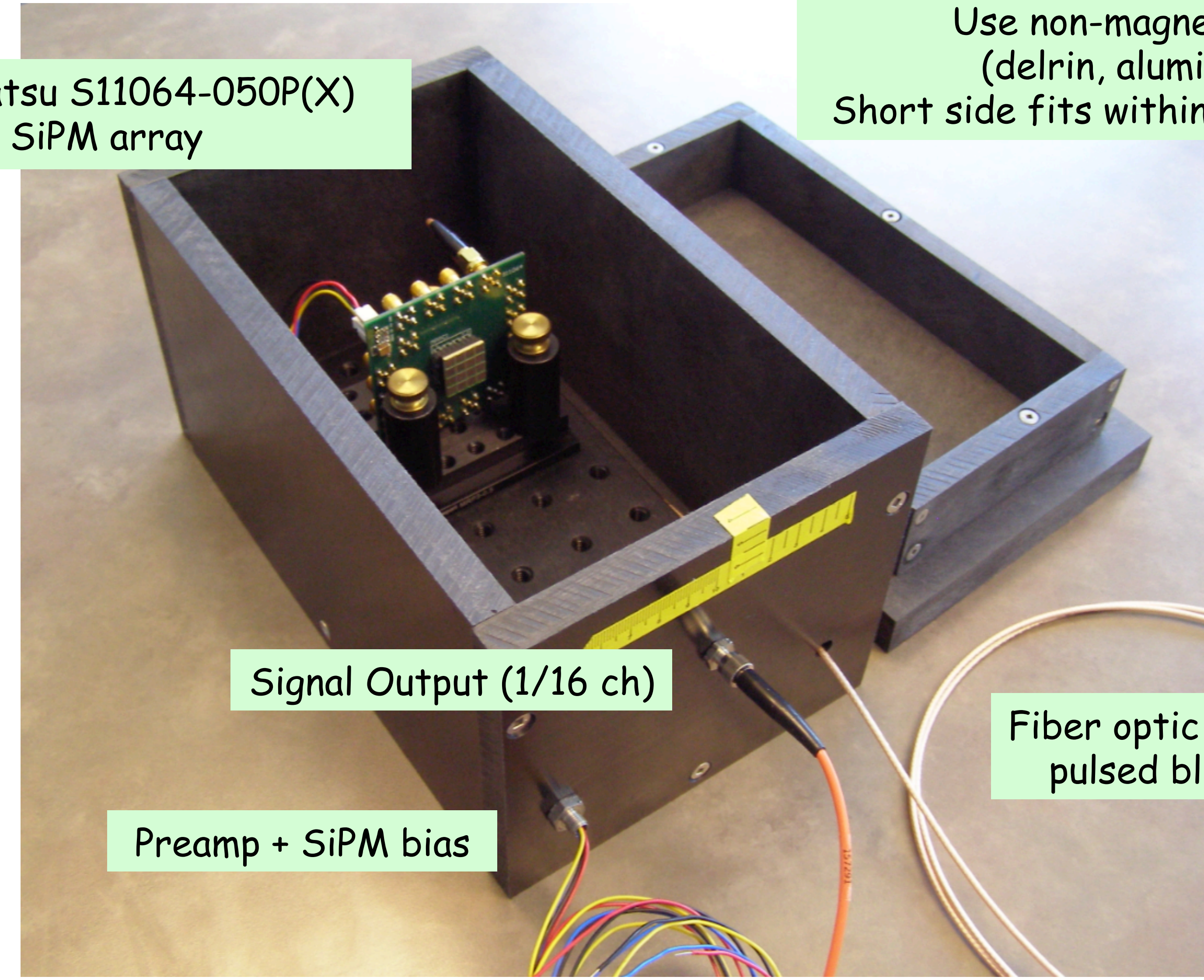




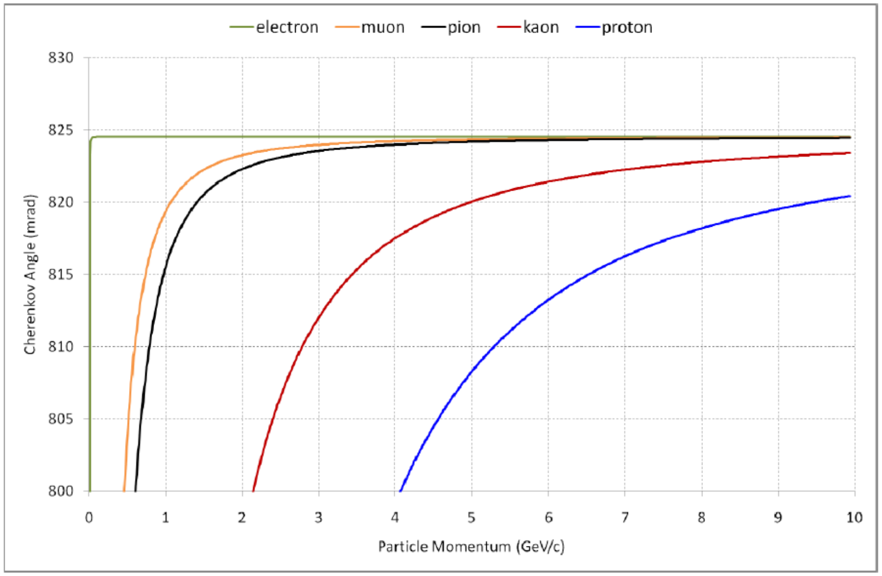
Triple lens
Midplane view

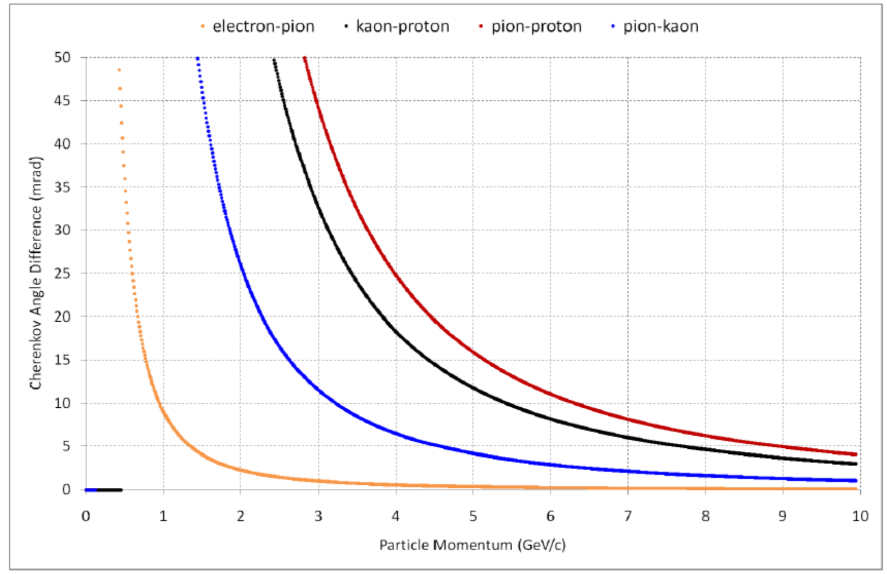
Double lens
Midplane view

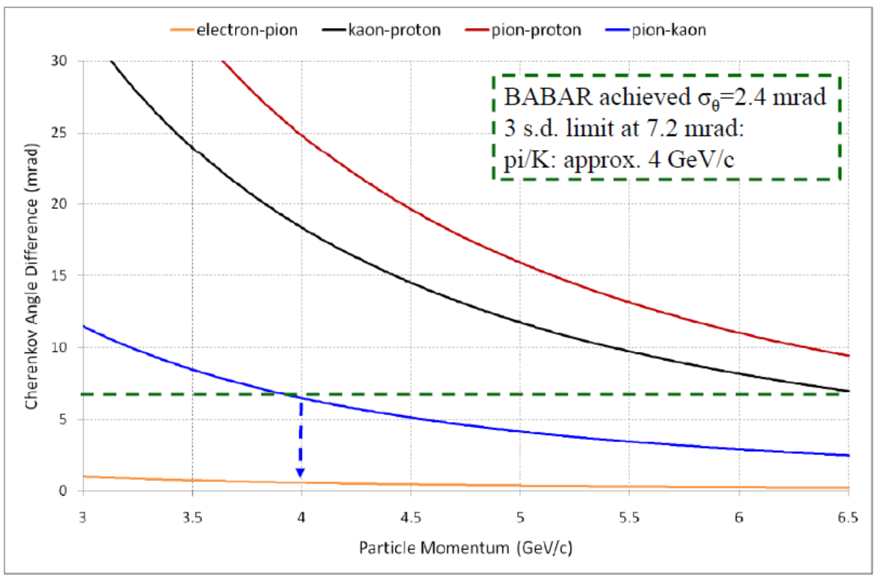
High-B sensor test facility – dark box

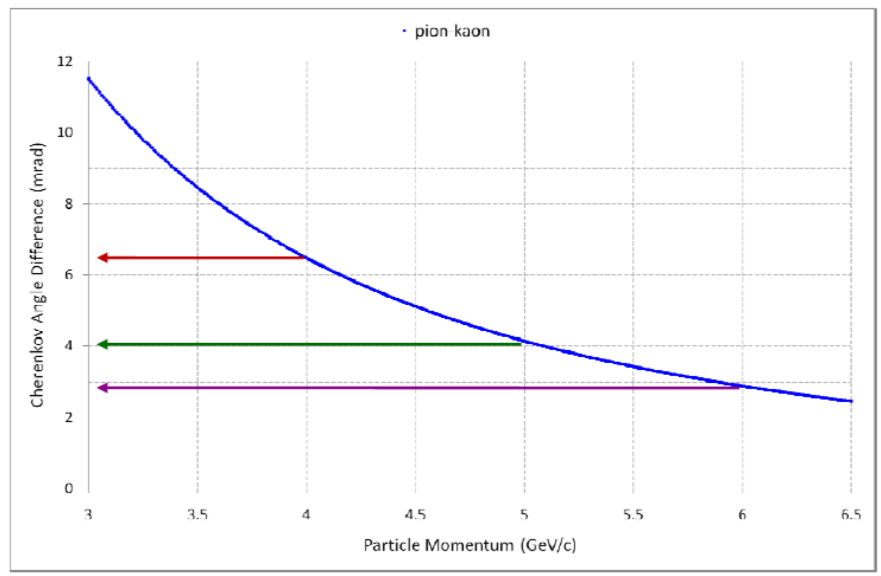


Momentum coverage and θ_c resolution



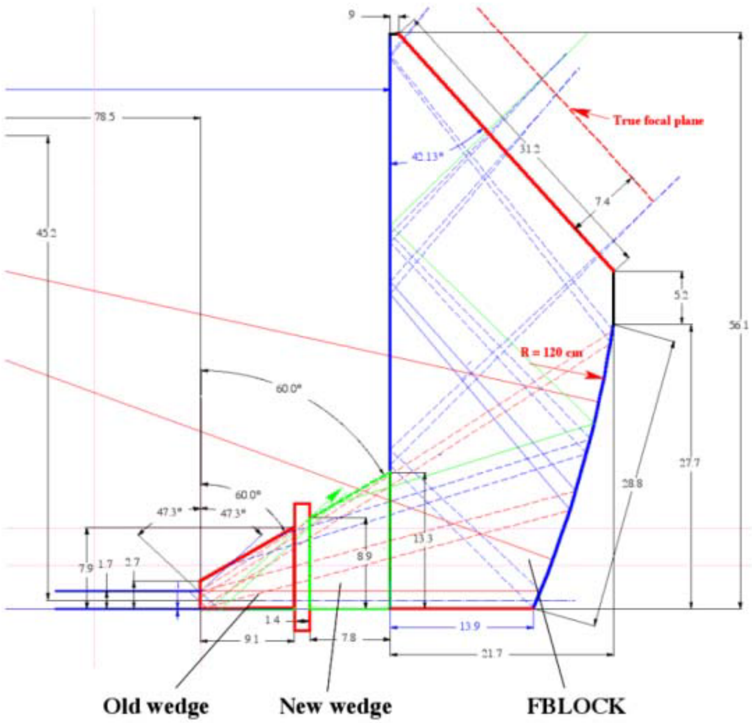




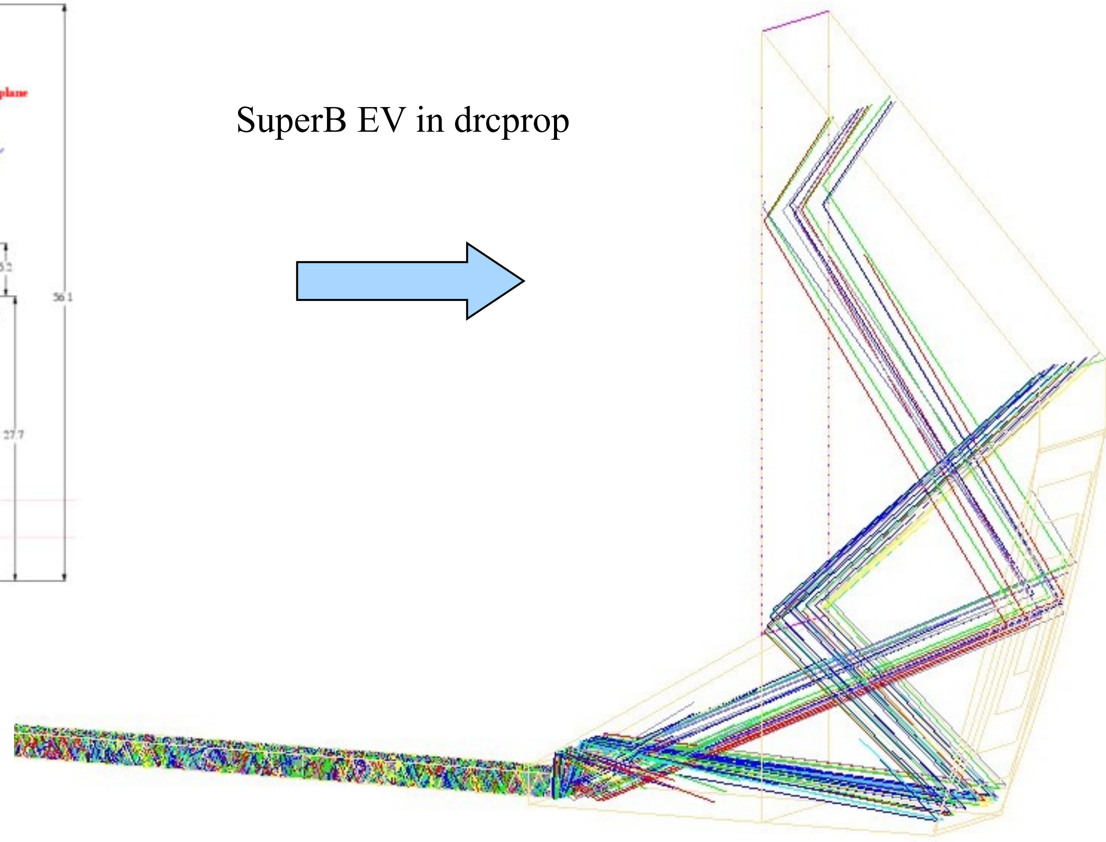


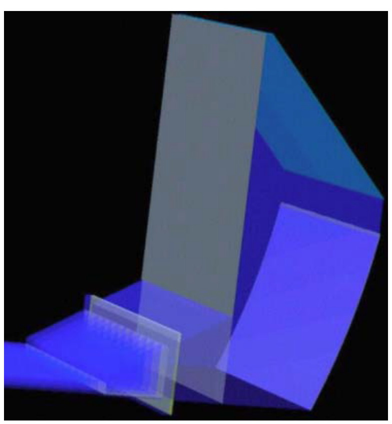
- Extending π/K separation from 4 to 6 GeV/c requires $\sigma_\theta \sim 1$ mrad (vs 2.4 in BaBar – a 58% reduction).

Focusing-mirror optics implemented in drcprop



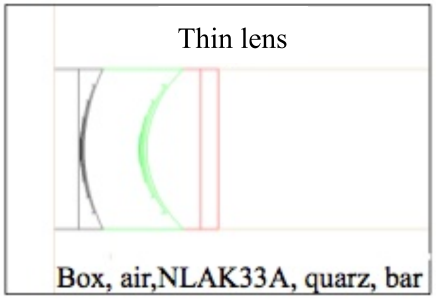
SuperB EV in drcprop

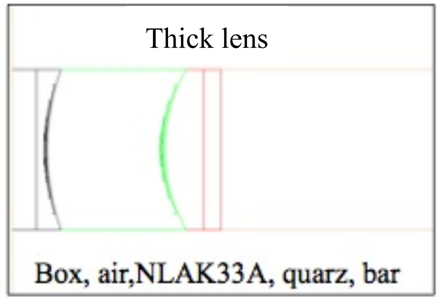


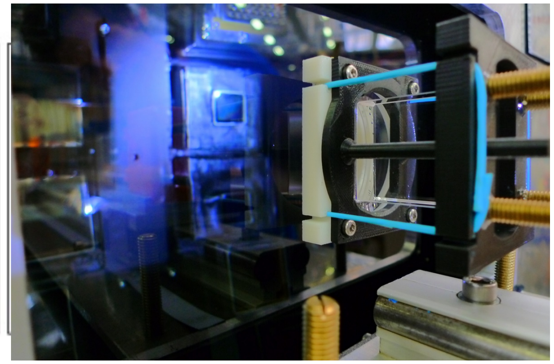


- SuperB mirror optics have been implemented in drcprop
- Will be modified to fit EIC requirements

Simulations using lenses with air gap

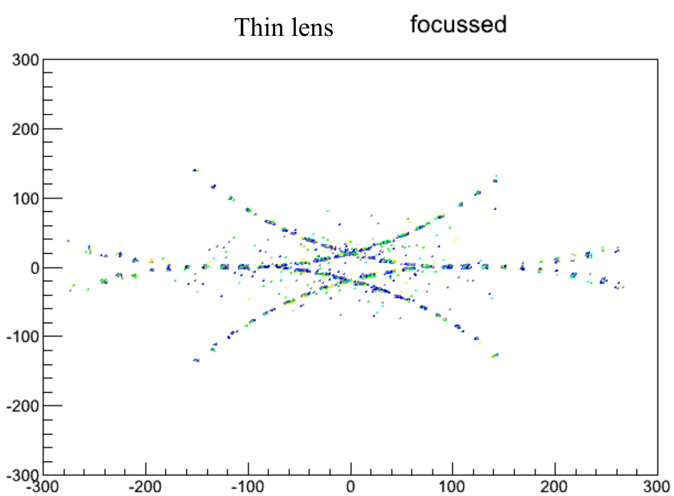


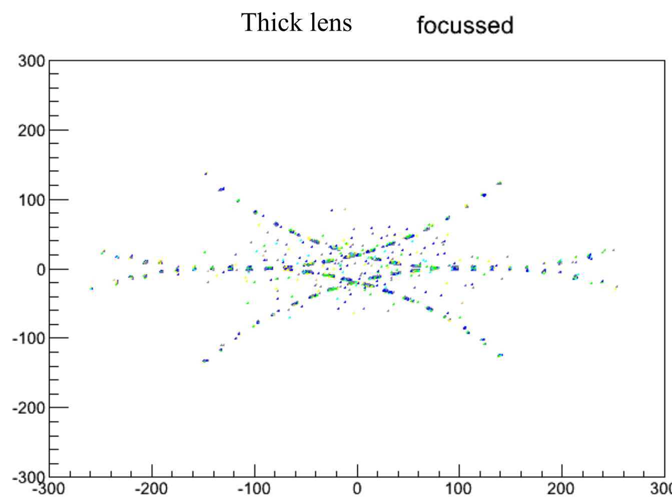




PANDA prototype with lens

$\beta = 0.99$, $\theta = 50°$, $\varphi = 70°$





- Lenses with an air gap provide a sharp image
- Photon losses due to internal reflection for track angles around 90 degrees