DIRC-based PID for the EIC

— Progress Report and funding request

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Generic Detector R&D for an Electron Ion Collider
Advisory Committee Meeting, BNL, June 5, 2013

Outline

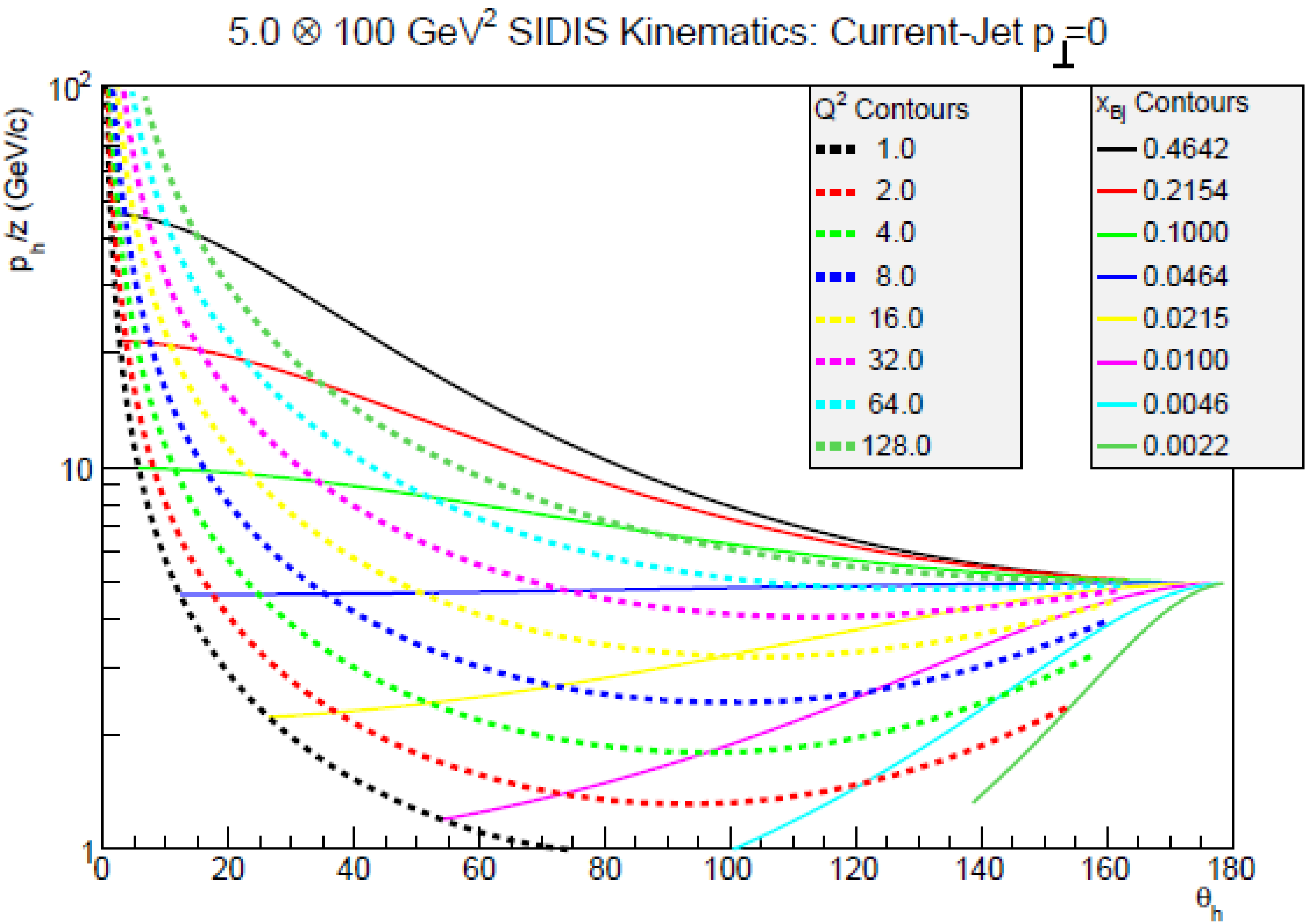
1. Introduction

2. Simulations

3. Hardware

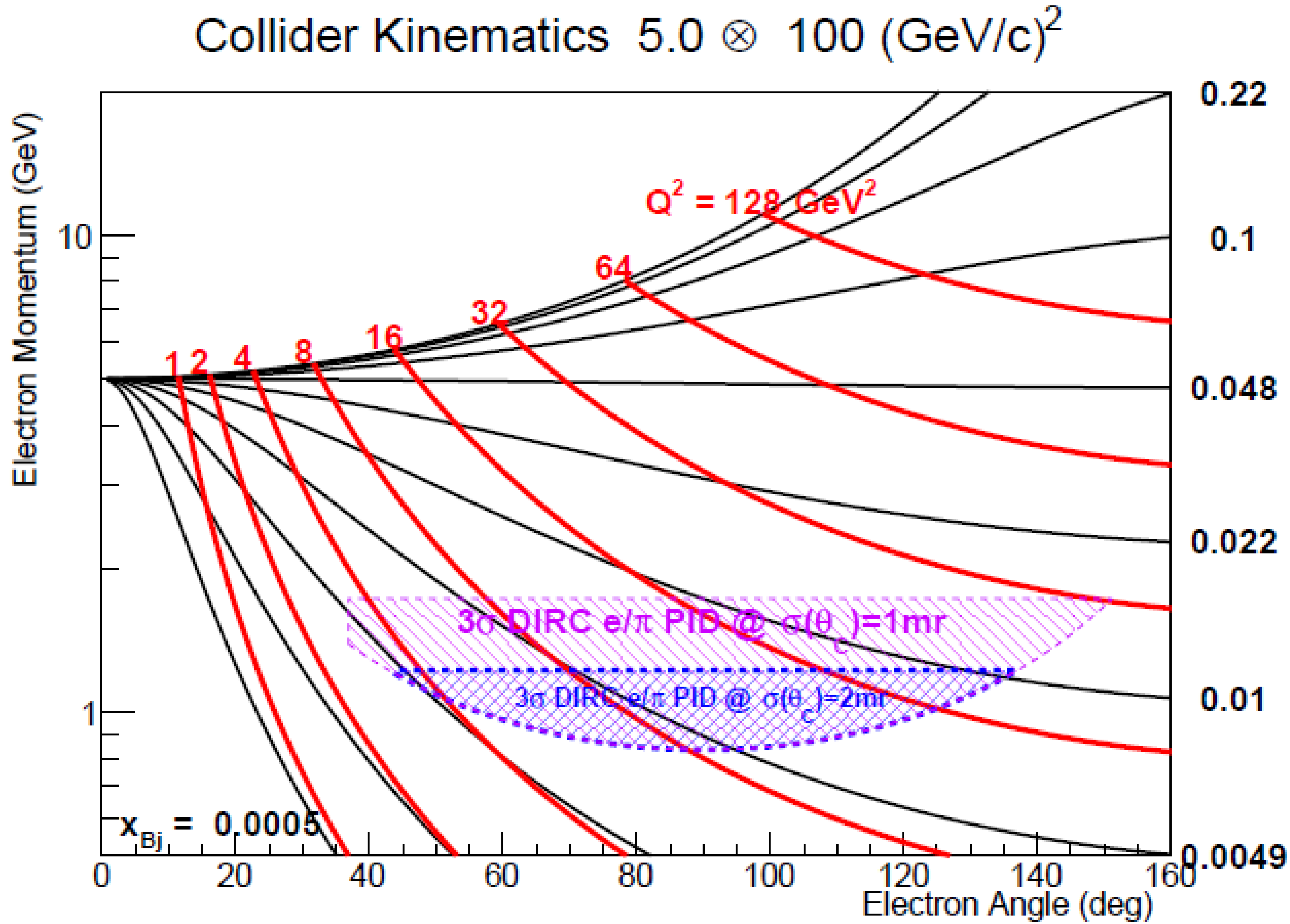
4. Funding request

Example: π/K identification in semi-inclusive DIS



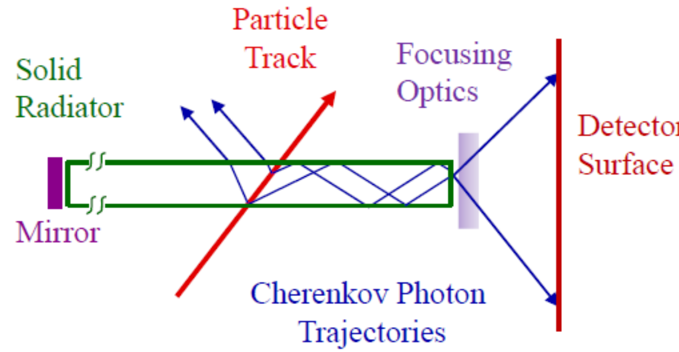
- Kinematic coverage in SIDIS is limited by hadron detection and identification.
- Momenta are large at forward angles and grow with z, x, and Q^2
- See proposal text for discussion of application to, for instance, TMDs.

Example: e/π identification in DIS at low x



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

DIRC principle



- Charged particle traversing radiator with refractive index n with $\beta = v/c > 1/n$ 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.

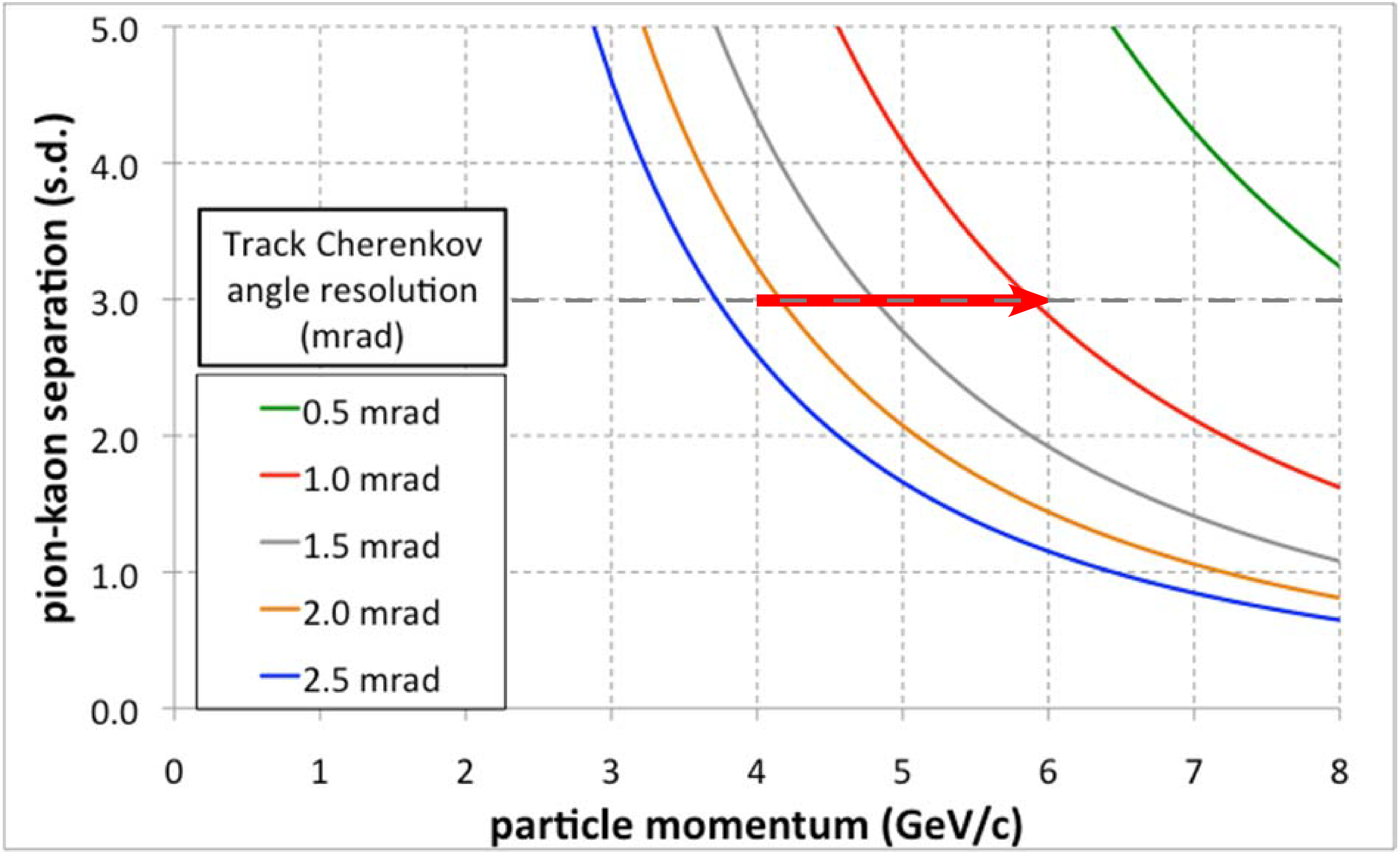
- Radiator and light guide: bar made from Synthetic Fused Silica

- 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.

π/K ID as a function of the θ_c resolution



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:
- 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

Could be improved via:
- focusing optics
- smaller pixel size
- better time resolution

topics for R&D proposal

9.6 mrad ----▸ 4-5 mrad (?) per photon

- number of photons 15-50 ----▸ photocathode/SiPM

- 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 goals

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

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 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**

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

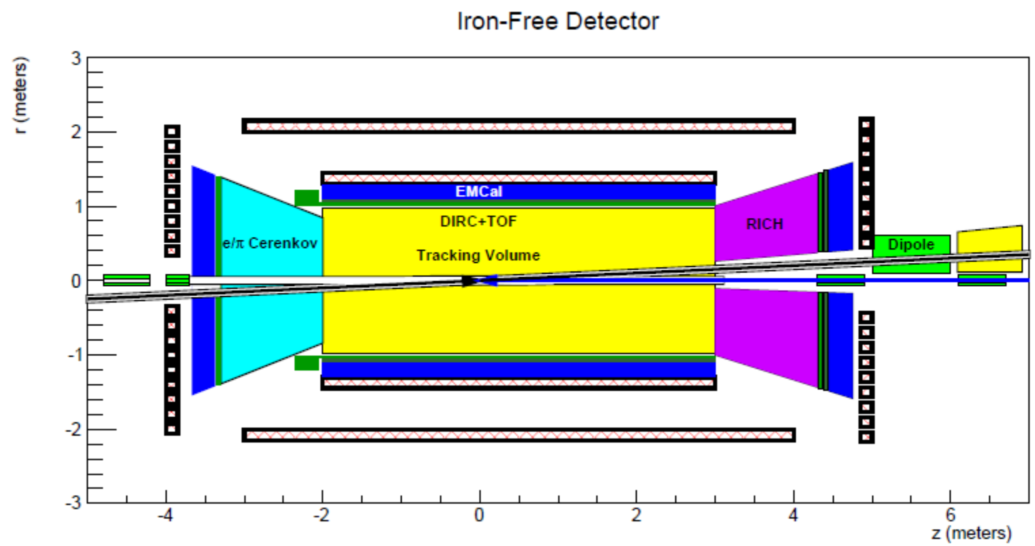
1. Expansion volume inside detector

- 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)

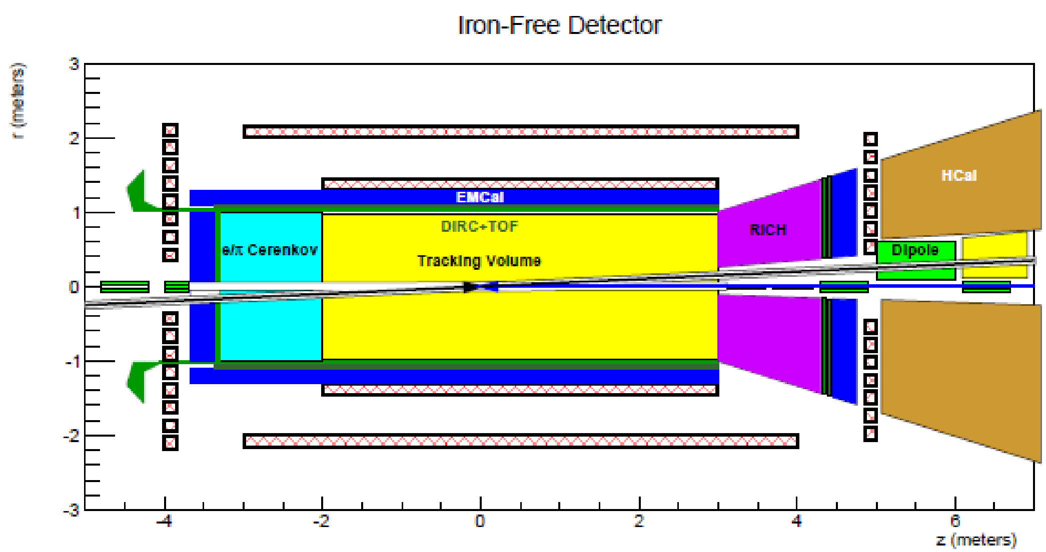
2. Expansion volume outside detector endcap and iron

- 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

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

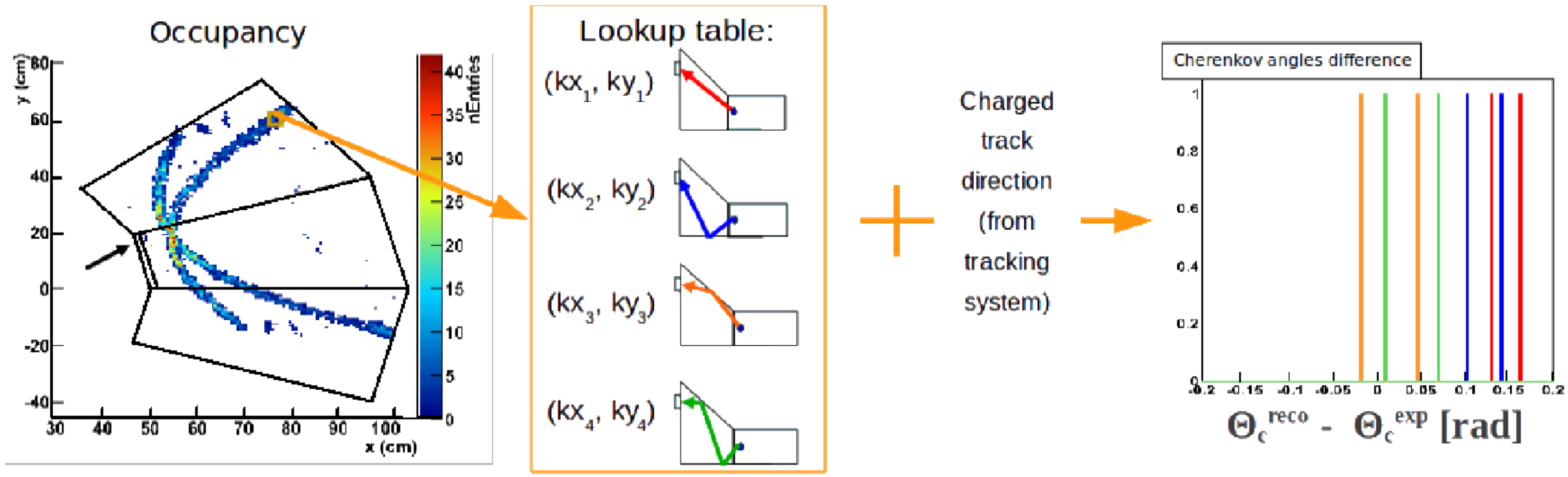
- Both internal (lens) and external (mirror) configurations will be investigated

3. Design and construction of lens and EV for prototype

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

Event reconstruction

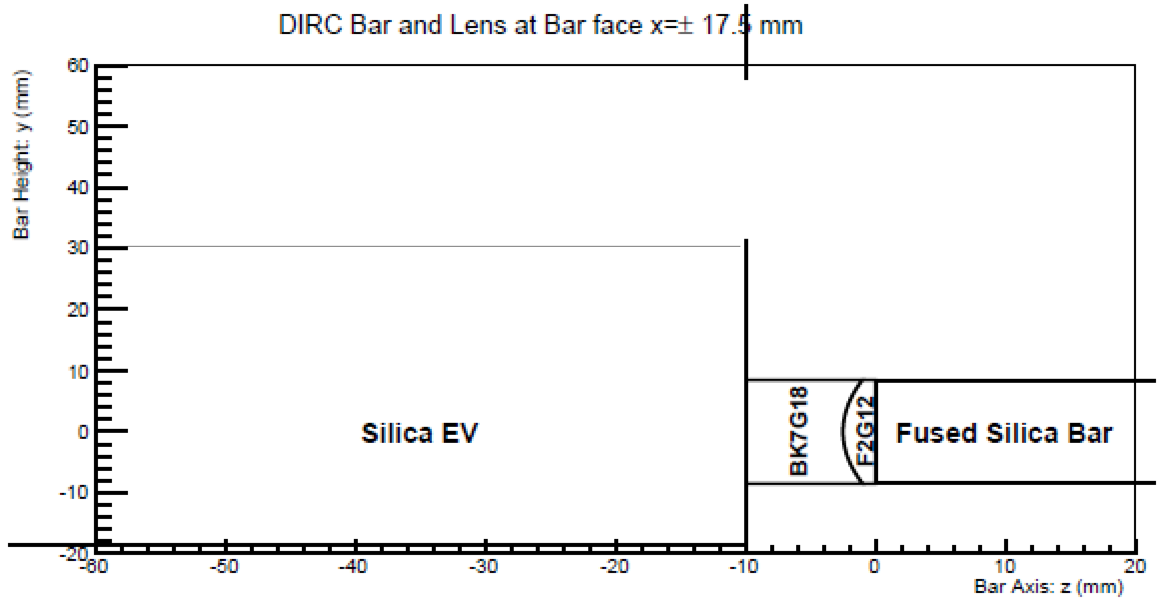


- For design purposes the main goal is to establish a figure of merit
- Explicitly reconstruct the single-photon θ_c resolution and photon yield
- Currently the algorithm uses a spatial lookup table (generated through simulation) combined with cuts on the time of propagation
  - Can be extended to include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

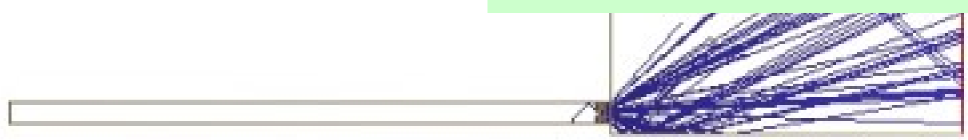
Benchmark expansion volume geometries

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

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



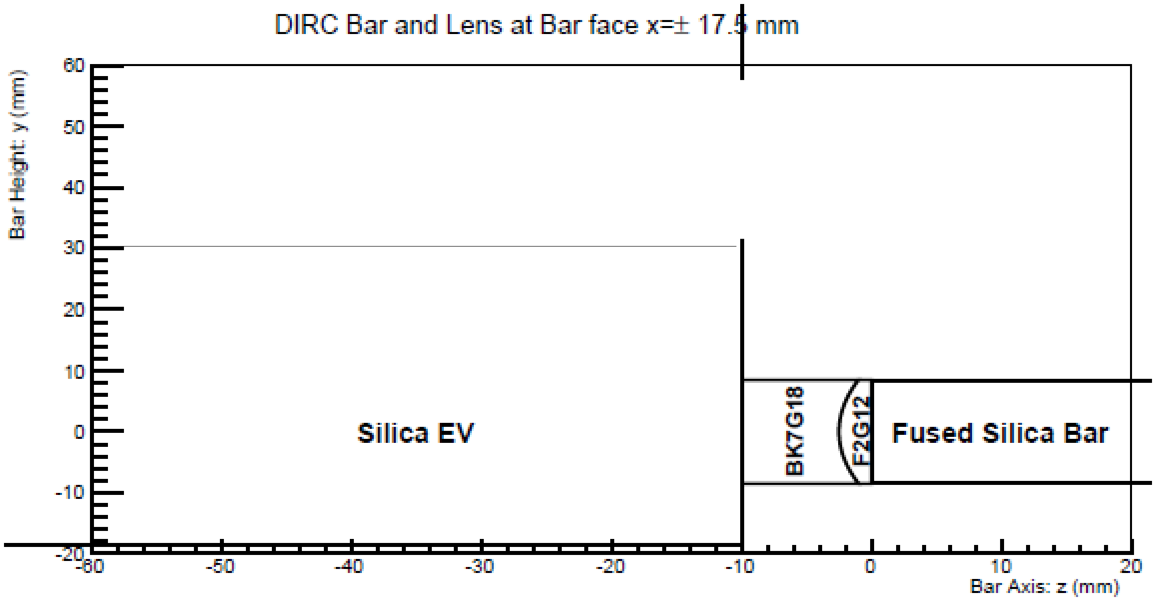
Benchmark EV (box) geometry
30 cm long, 15 cm high, 1 cm step

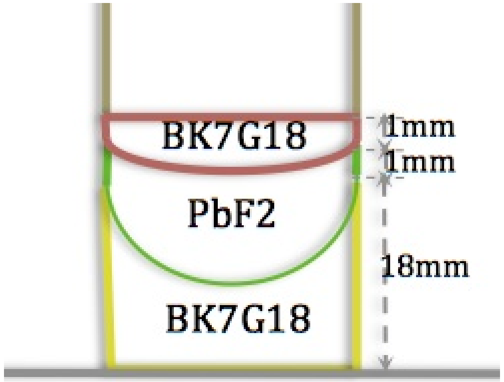


Trapezoid with 30 degree angle
Similar dimensions as for the box

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).



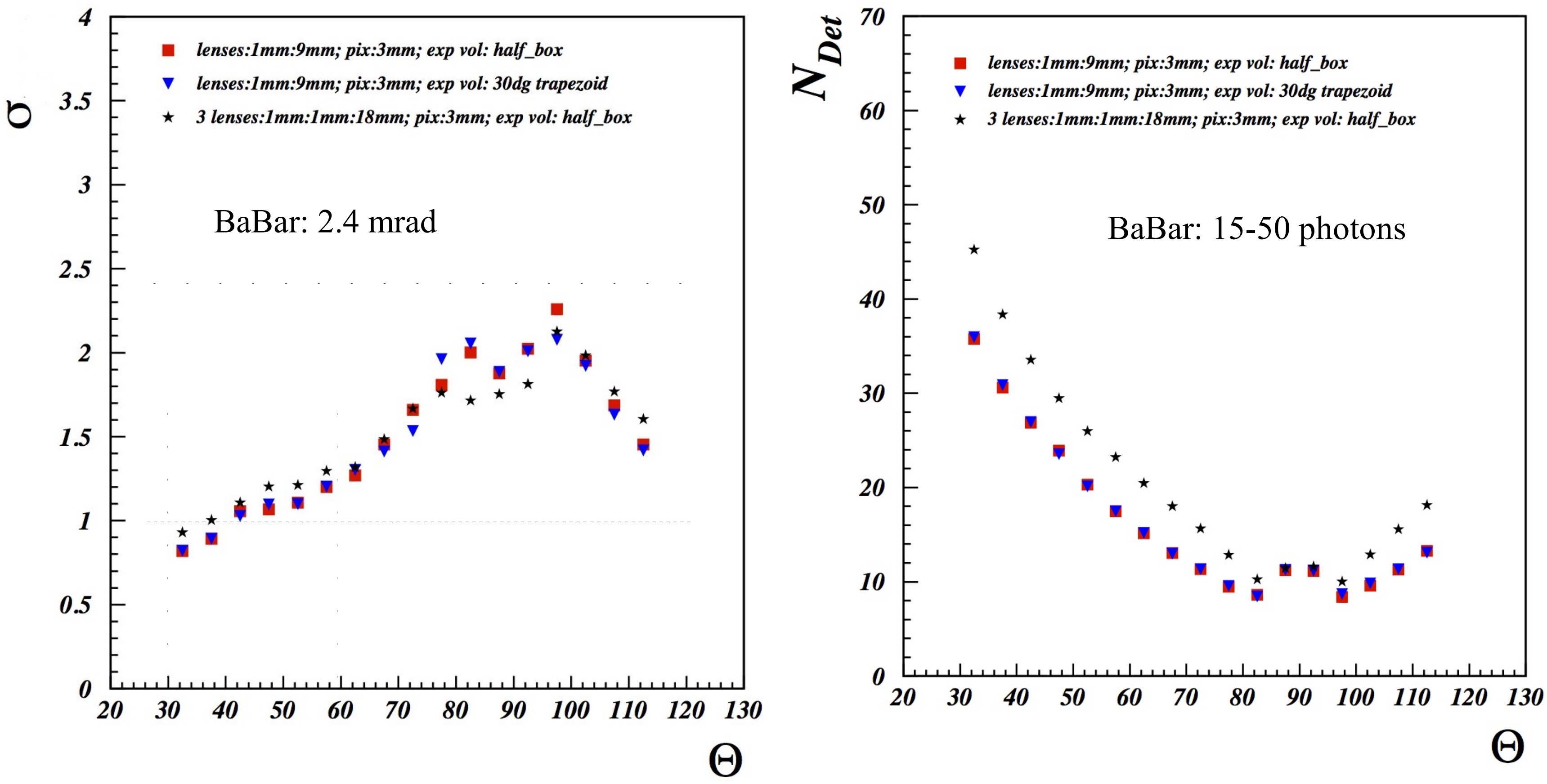


Triple lens
Midplane view

Double lens
Midplane view

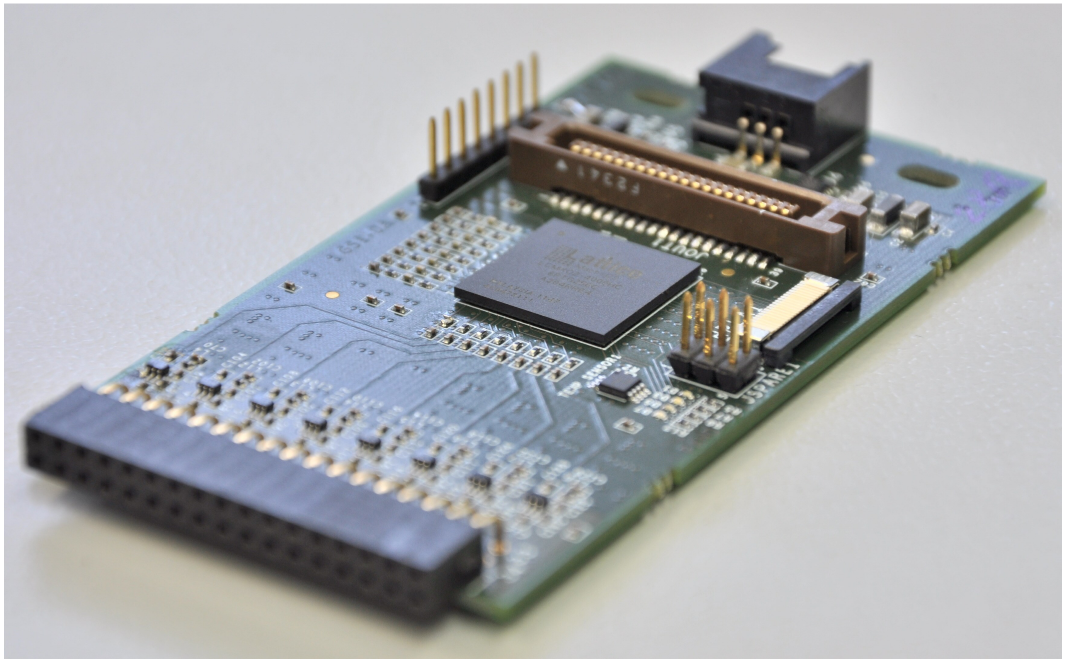
Achieved θ_c resolution

drcprop simulation with 2σ cuts on time of propagation

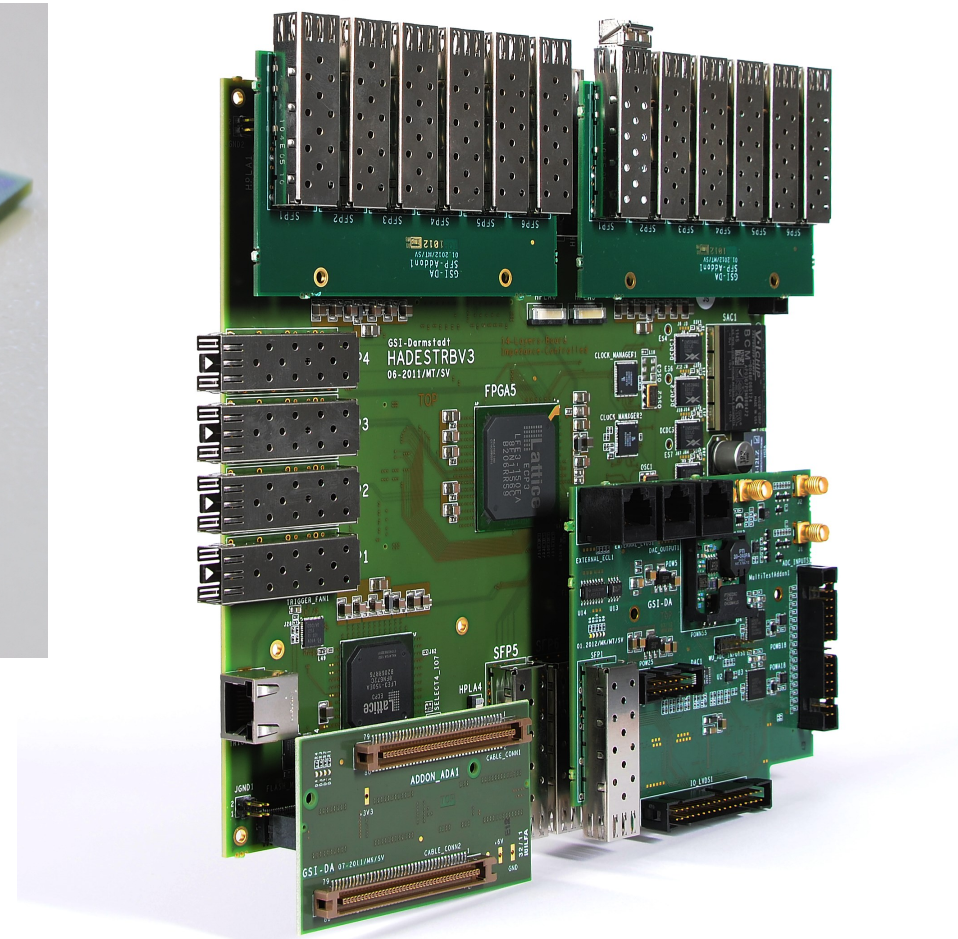


- Resolution per track includes photon number, focusing, pixel size, and chromaticity
- Resolution (σ) at forward angles is better than 1 mrad per track (*i.e.*, for all photons)
- New lenses with high refractive index improve performance, especially around 90°

Procurement: DAQ electronics (@GSI)



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



TRBv3 DAQ card with AddOns Procurement complete

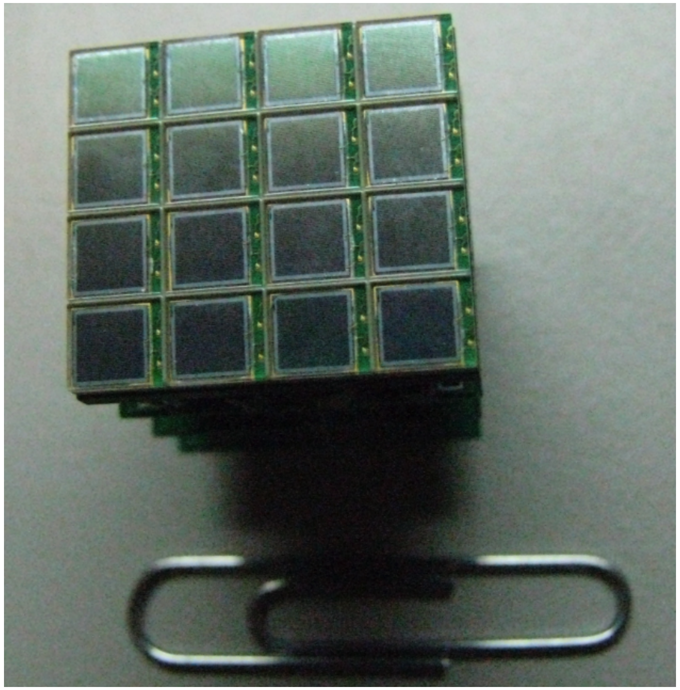
Procurement: PMTs

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

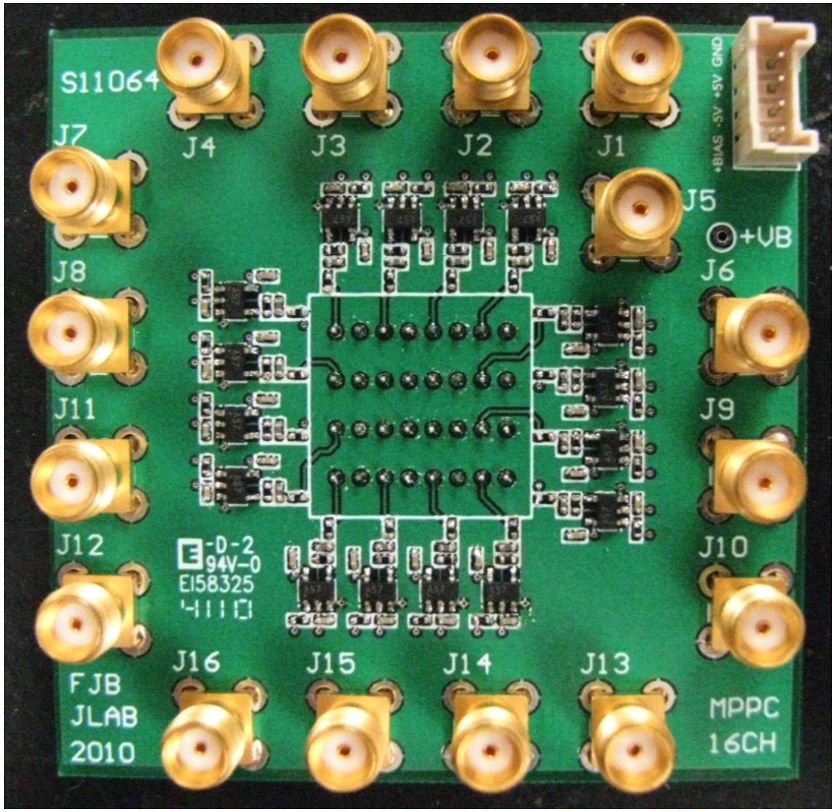
Tests in high magnetic fields will show if how far one could go with this type of sensor, which has a good single-photon capability

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

Procurement: SiPMs



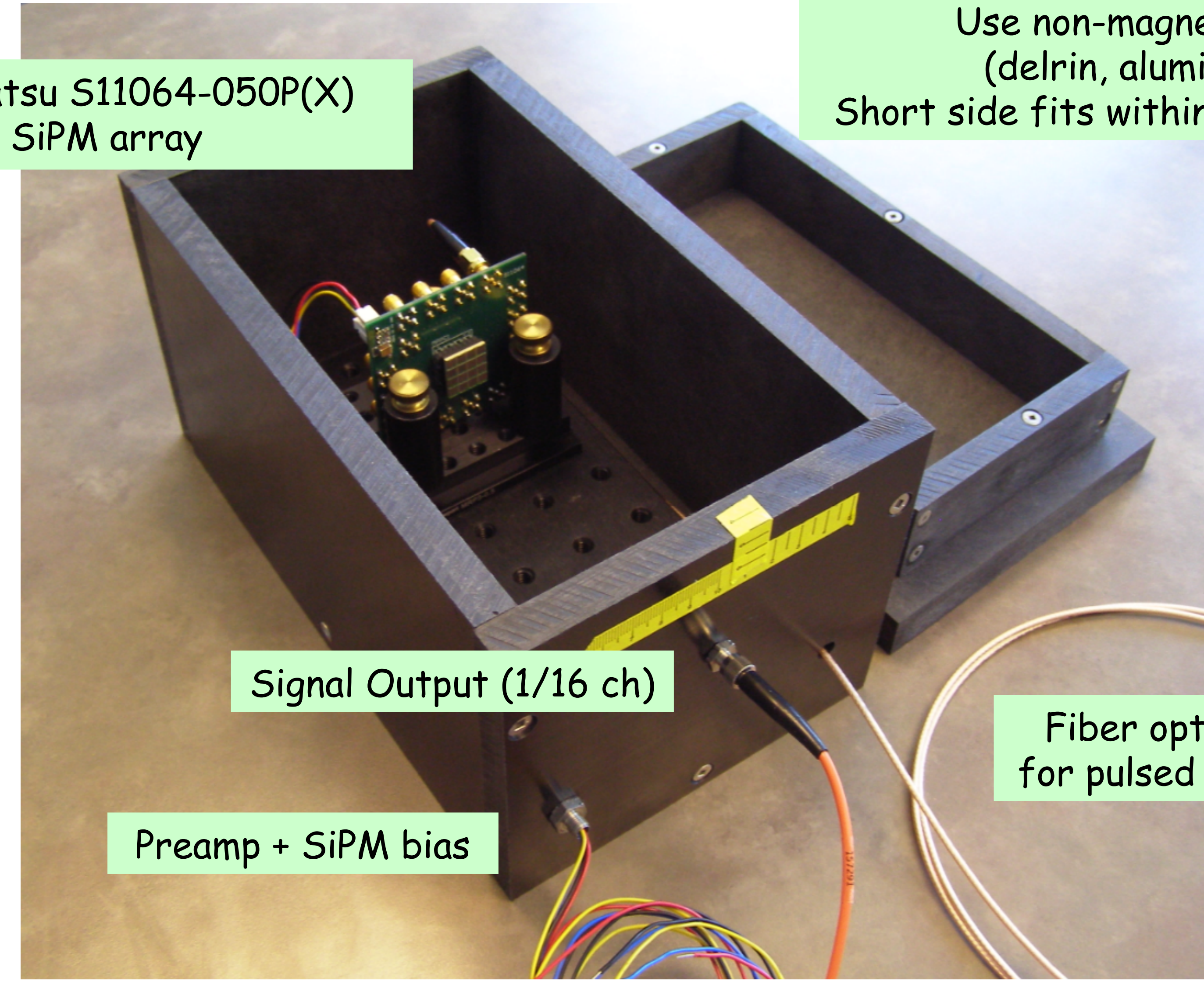
Hamamatsu S11064-050P(X) array
16 channels – 3x3 mm^2
50 μm microcells
400 microcells / mm^2



16 channel readout board (with preamp)

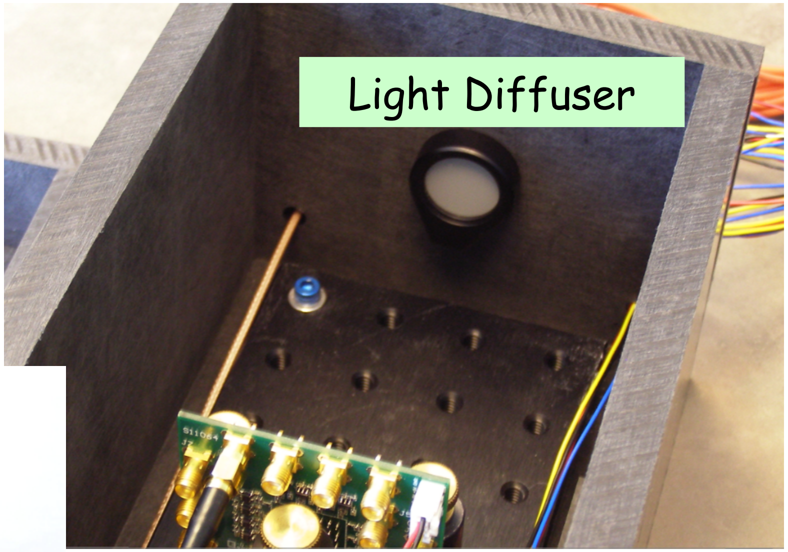
To be used for high B-field tests at JLab

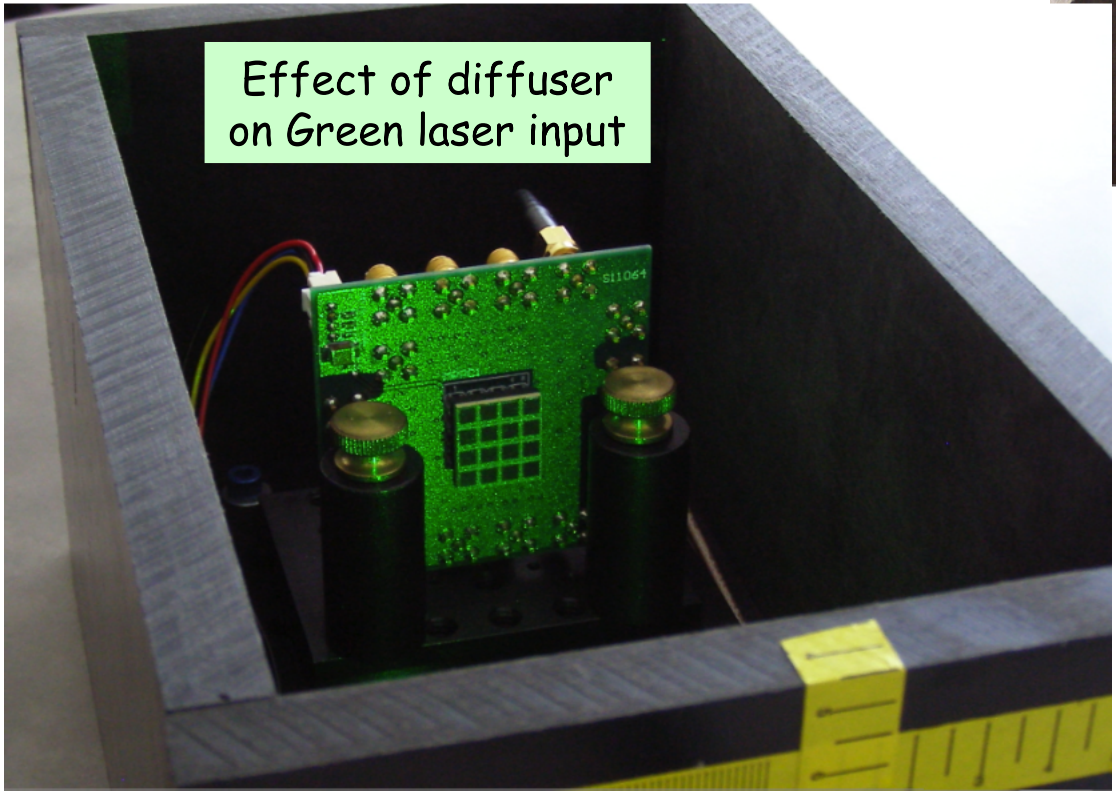
High-B sensor test facility – dark box



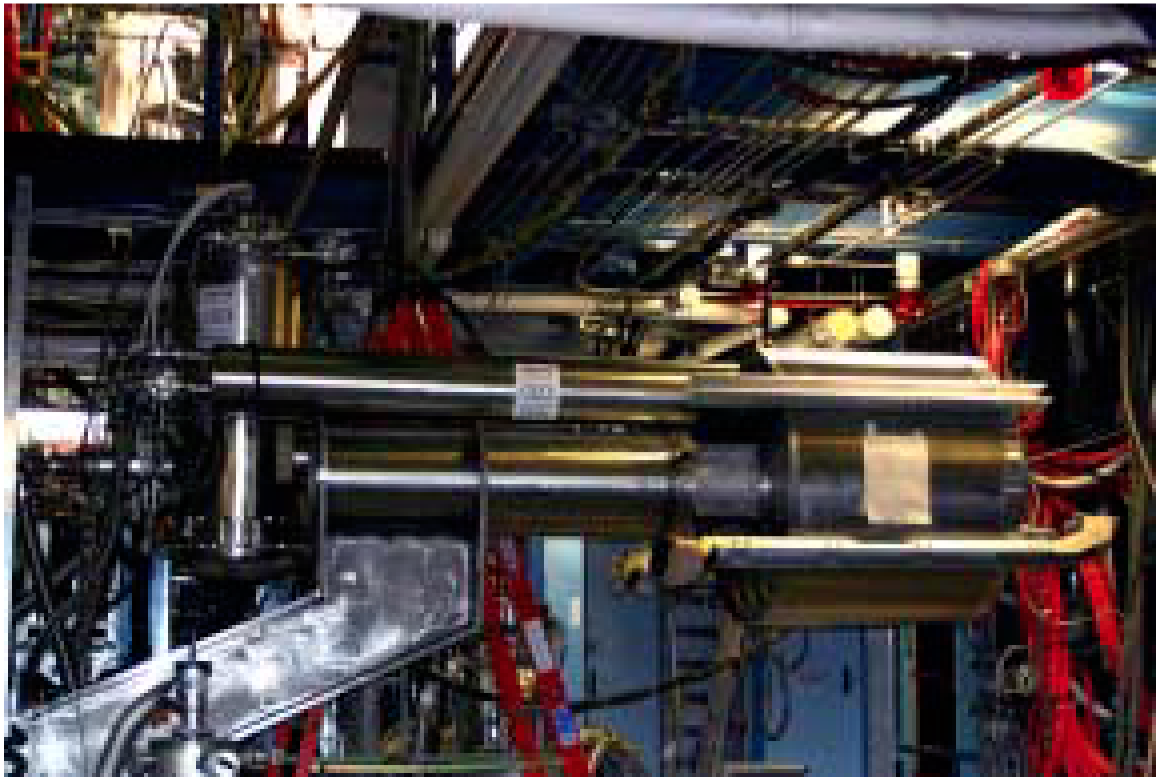
High-B sensor test facility – light diffuser

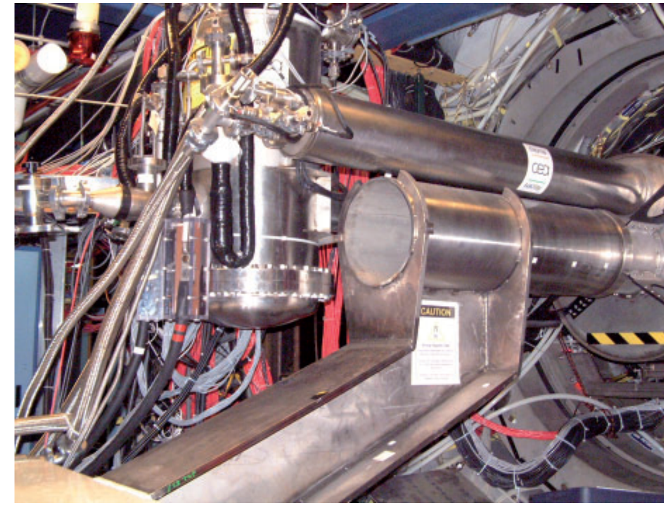
Need optical diffuser to uniformly illuminate photodetector



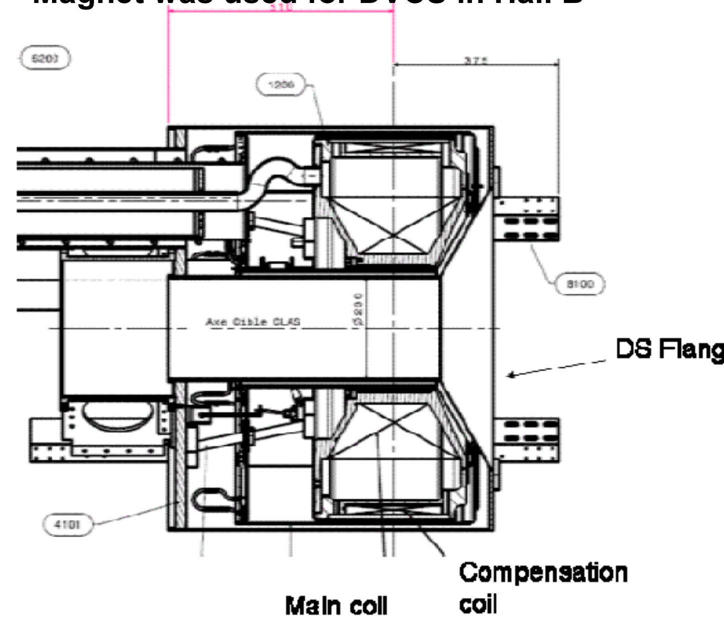


High-B sensor test facility - magnet



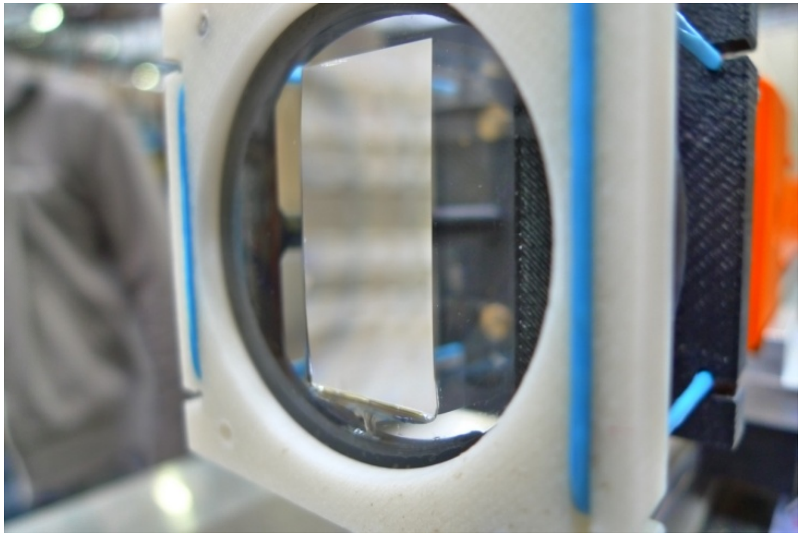


Magnet was used for DVCS in Hall B

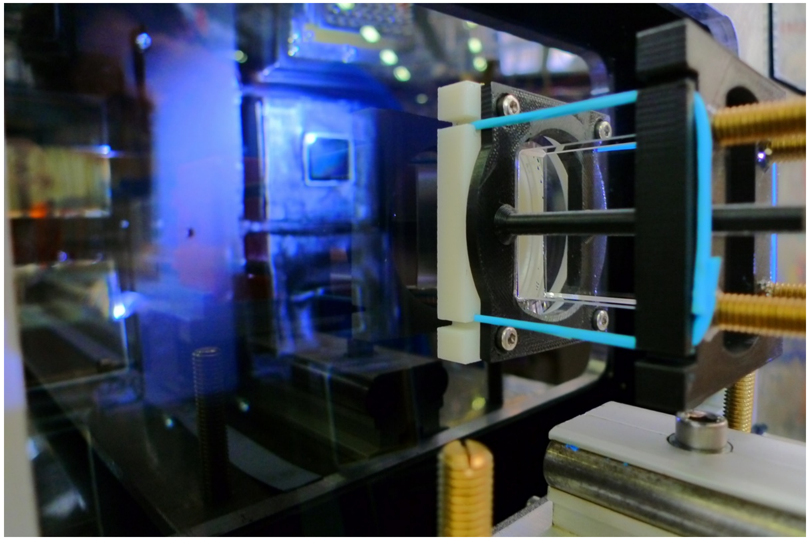


- Superconducting dual-solenoid
- Max. nominal field at center: 4.7 T
- Adjustable nominal field
- Bore diameter: 0.23 cm

PANDA: EV prototype tests at CERN

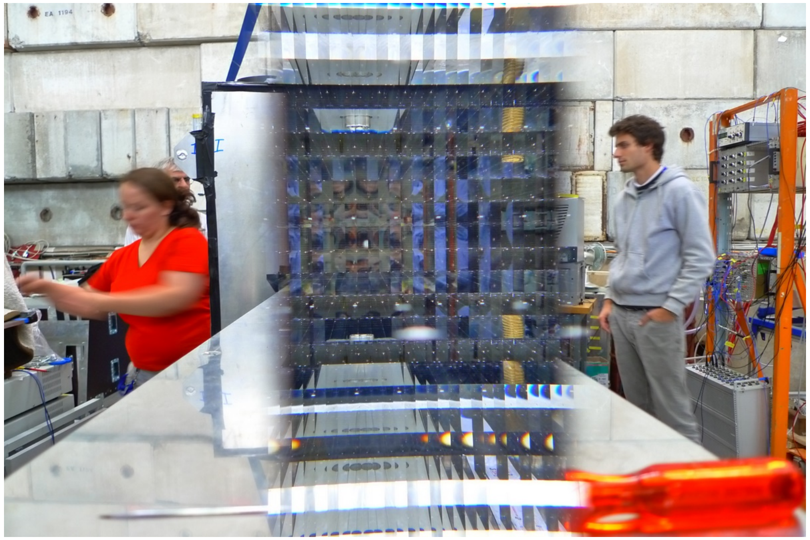


Simple plano-convex focusing lens attached to bar

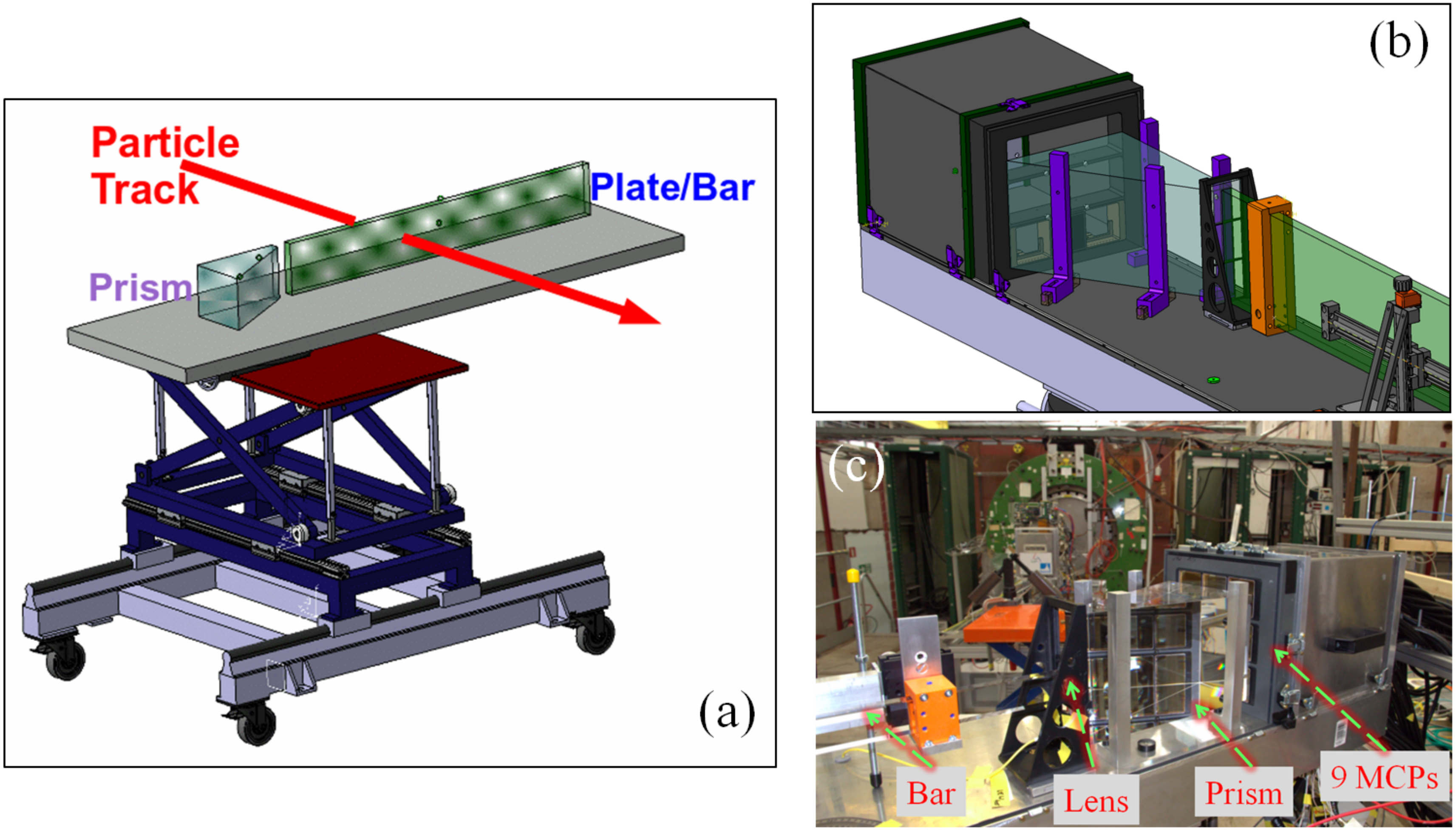


Looking into mineral-oil filled EV; MCPs in black

- Tests carried out in 2011 and 2012
  - Pictures are from 2011 run
- 2012 test were very comprehensive
  - Data analysis in progress
  - Will help to guide EIC prototype design



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
  - Next beam time at CERN will not be available until year 4.

Funding request

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*

Matching funds are available for the ODU postdoc, H. Seraydaryan, hired in November 2011.
Travel in Year 3 mostly driven by high B-field test facility. Tables include overhead.

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*

See sections 5 and 6 of the proposal for a detailed breakdown

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 will be presented at conferences this fall
- Simulations of mirror-based optics with external EV will begin in the fall

Hardware projects on track

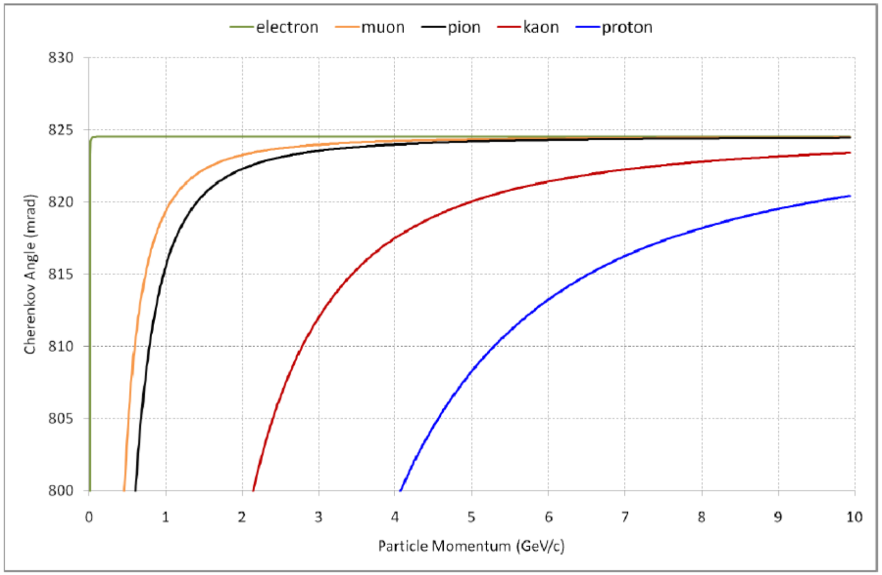
- Procurement of first round of sensors and DAQ components for GSI setup had been completed and second round is under way
- Components for the high B-field test facility are being procured and prepared
  - preparations for installation of magnet and infrastructure are ongoing

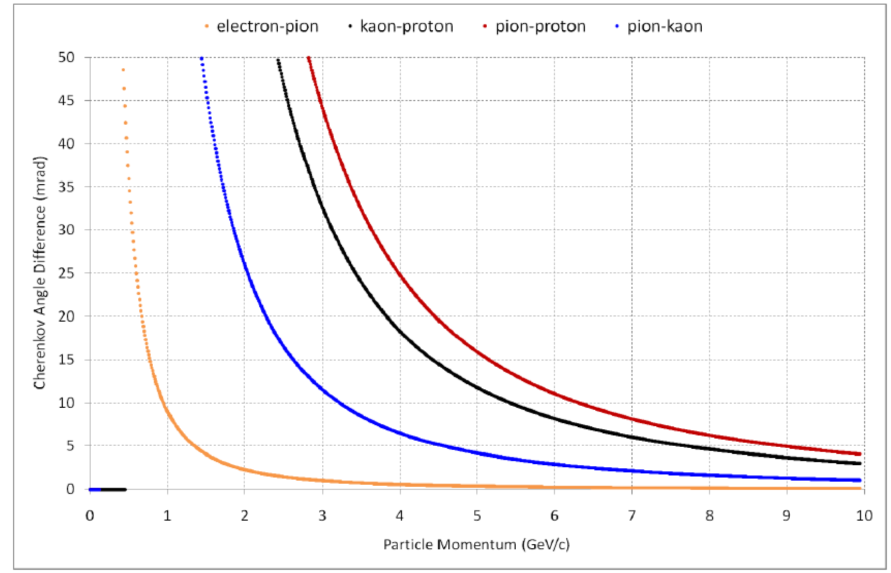
Adjusted funding profile

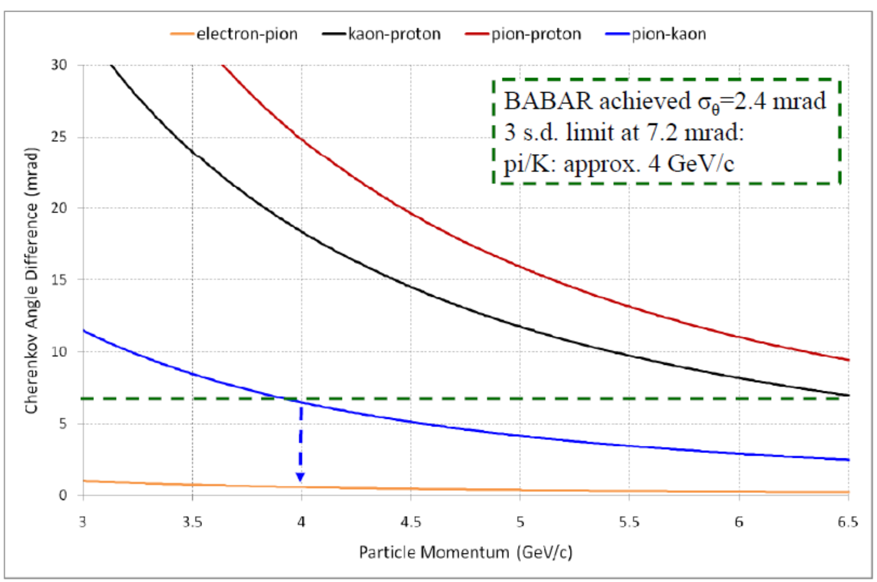
- Due to the success of our simulations, development of new lenses, and unavailability of test beams until Year 4, we ask to extend the time line of the proposal, but with a lower annual cost.

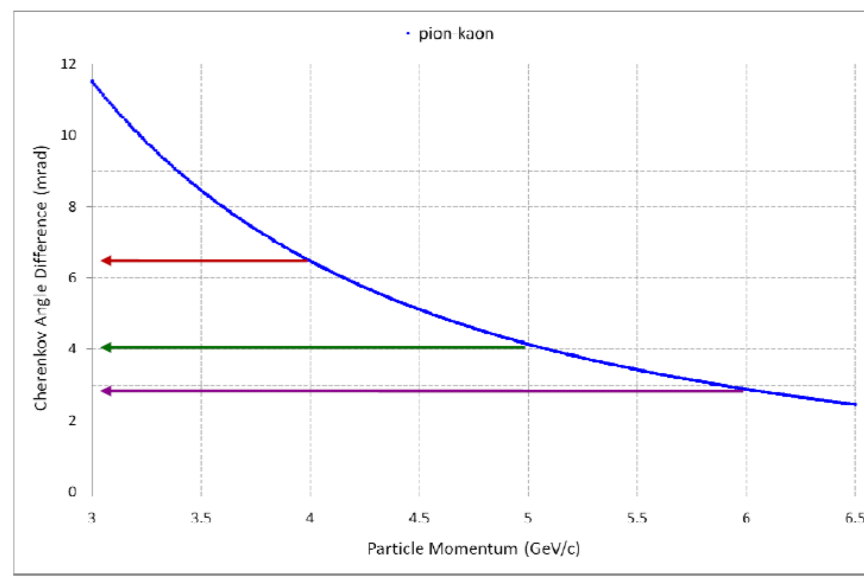
Backup

Momentum coverage and θ_c resolution





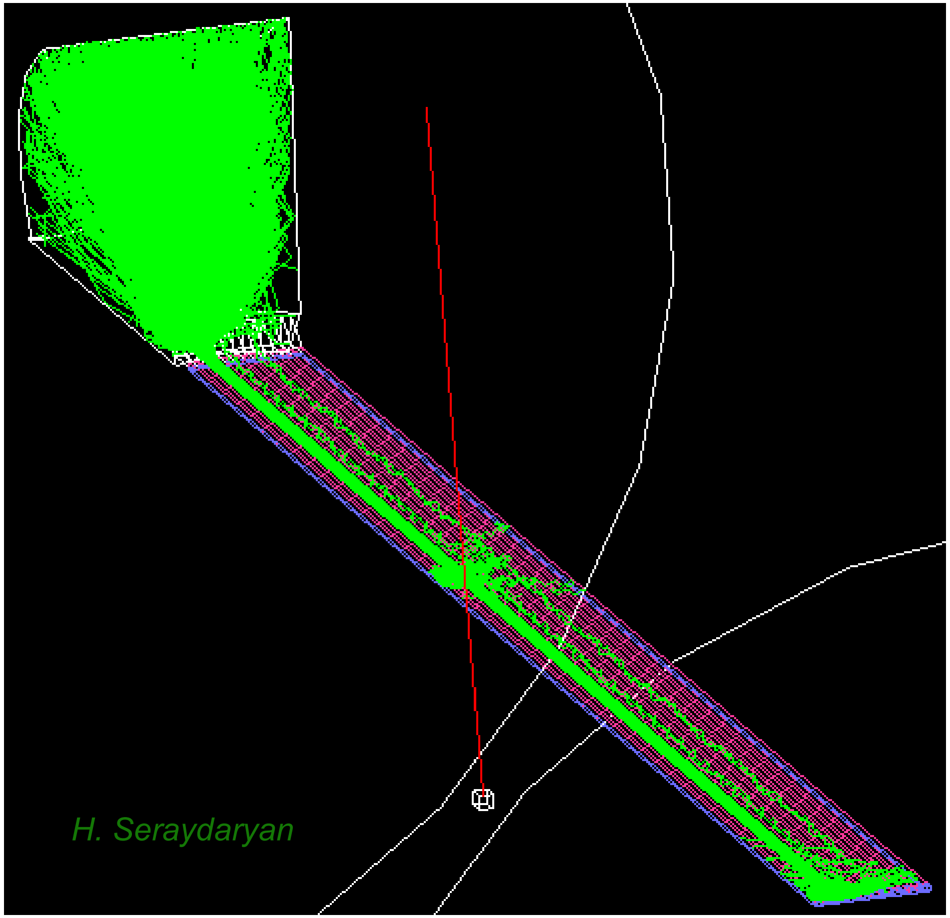




- Extending π/K separation from 4 to 6 GeV/c requires $\sigma_\theta \sim 1$ mrad (vs 2.4 in BaBar – a 58% reduction).

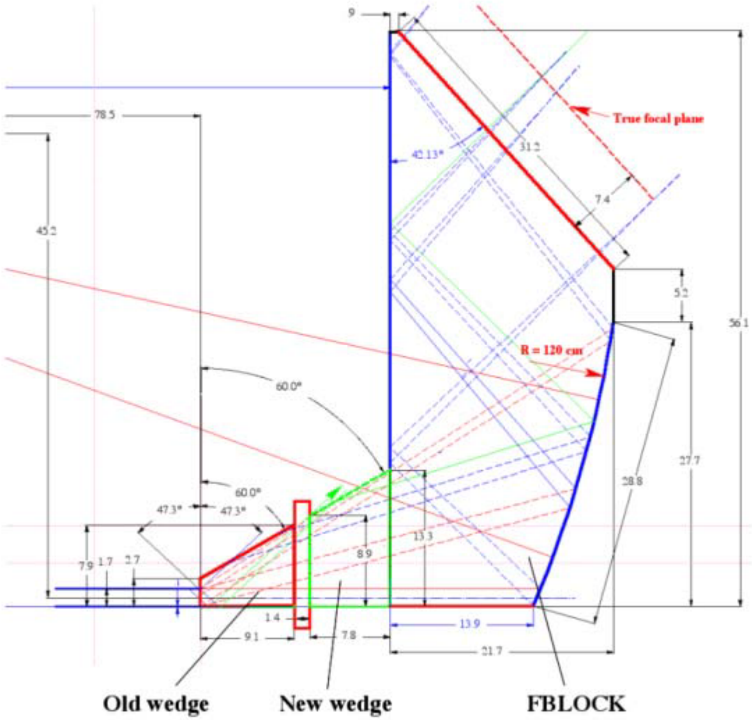
DIRC simulations and EV design

- Ray-tracing software (DRCPROP) will be used for parameter studies and the initial design of the EV
- Detailed studies of the selected EV design will be performed using GEANT4
- This can then be implemented into the GEANT4 (GEMC) framework used for the EIC detector
  - Integration studies

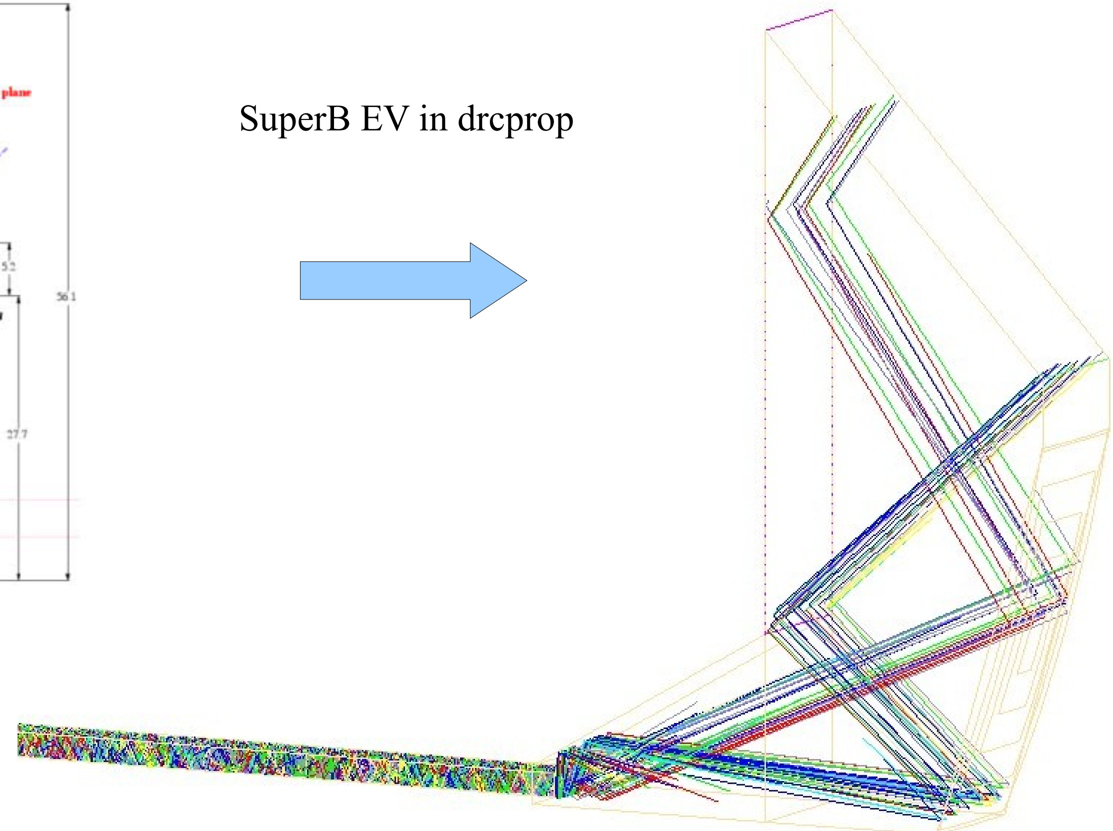


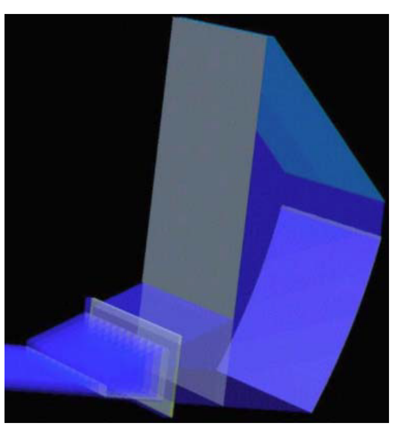
First tests of implementing a DIRC into GEANT4 at ODU/JLab using the BaBar geometry

Focusing-mirror optics implemented in drcprop



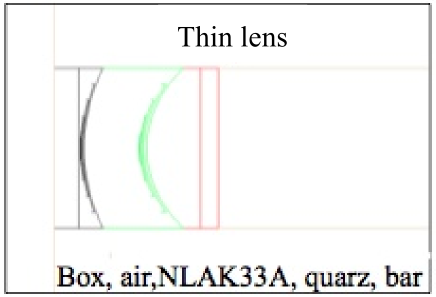
SuperB EV in drcprop

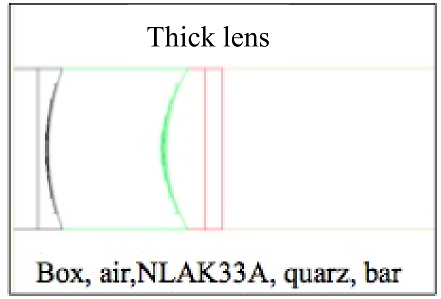


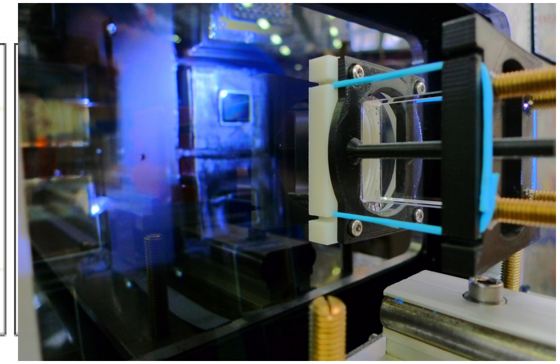


- SuperB mirror optics have been implemented in drcprop
- Will be modified to fit EIC requirements

Simulations using lenses with air gap



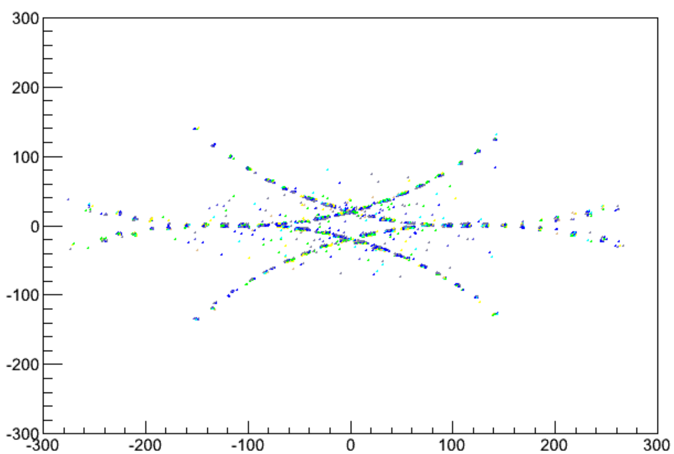




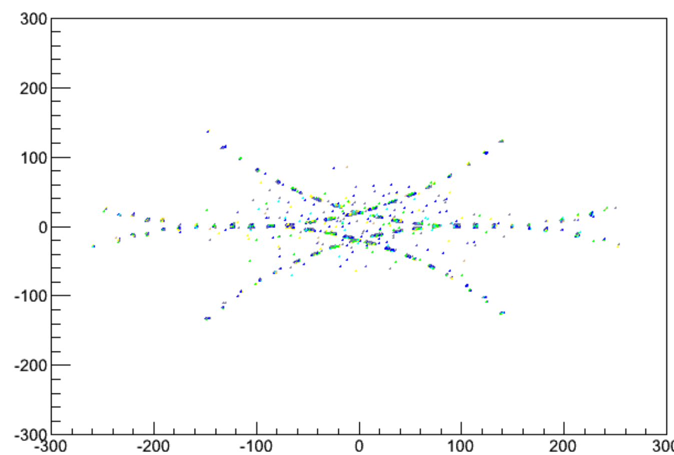
PANDA prototype with lens

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

Thin lens focussed



Thick lens focussed



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

Event reconstruction I

Calculate unbiased likelihood for signals to originate from e/μ/π/K/p track or from background:

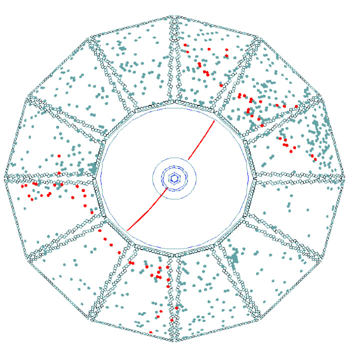
Likelihood: **Pdf(θ_c) × Pdf(δt) × Pdf(N_γ)**

Pdf = Probability distribution function

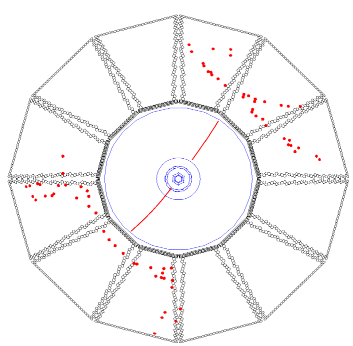
Example: comparison of real event to simulated response of BABAR DIRC to e/μ/π/K/p.

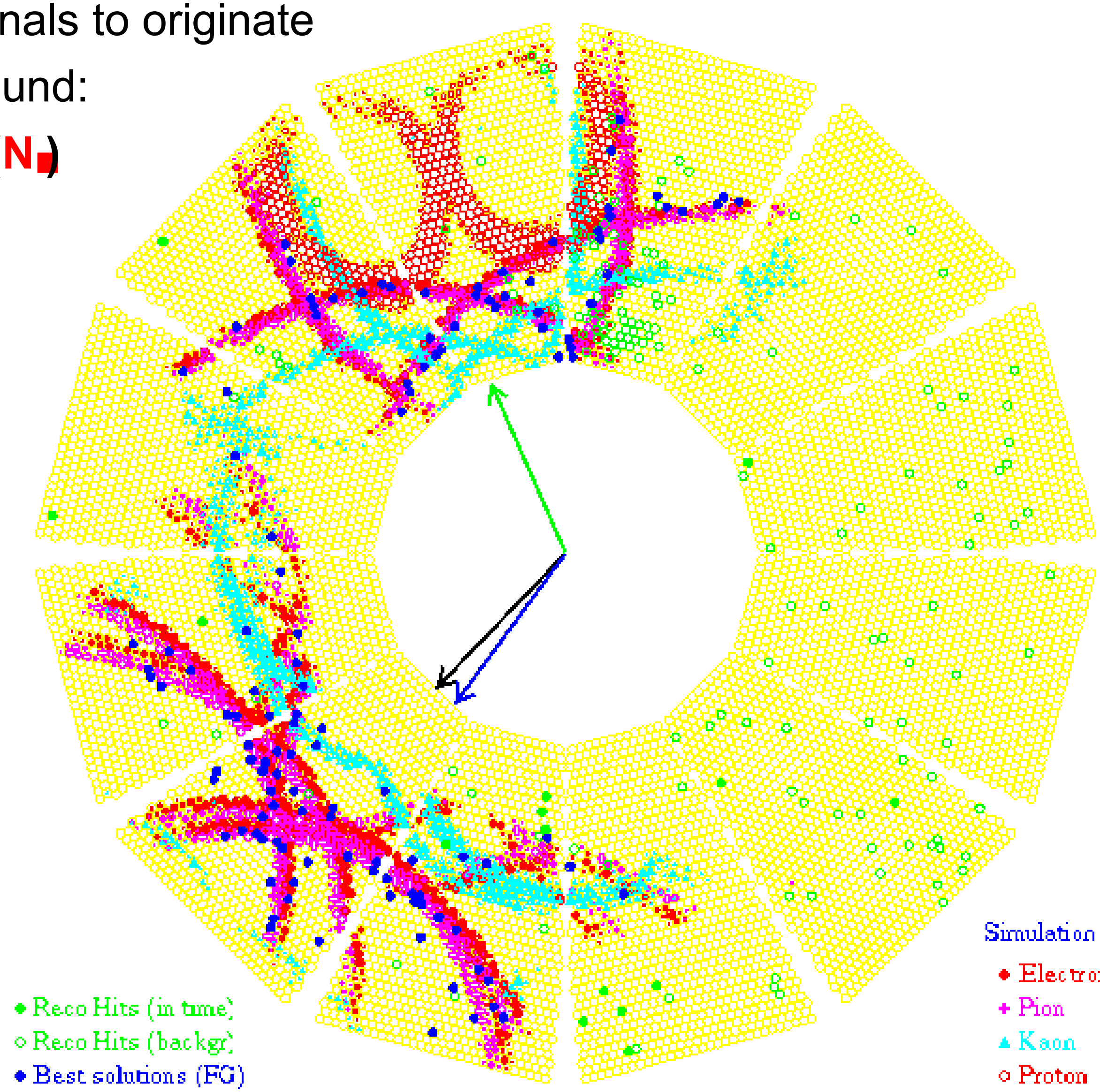
Time resolution important for background suppression

±300 nsec trigger window
(~500-1300 background hits/event)

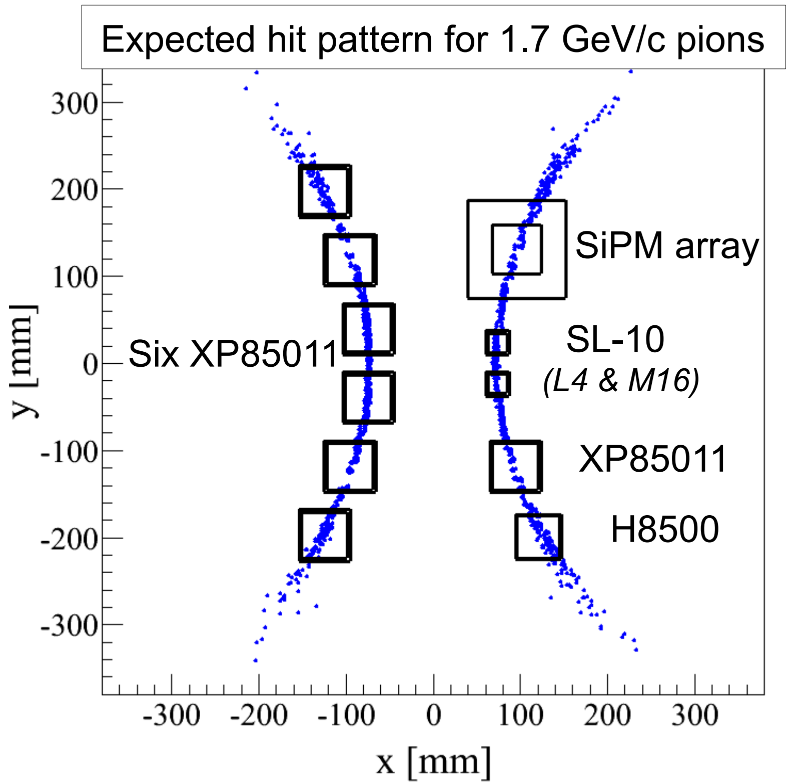


±8 nsec δt window
(1-2 background hits/sector/event)

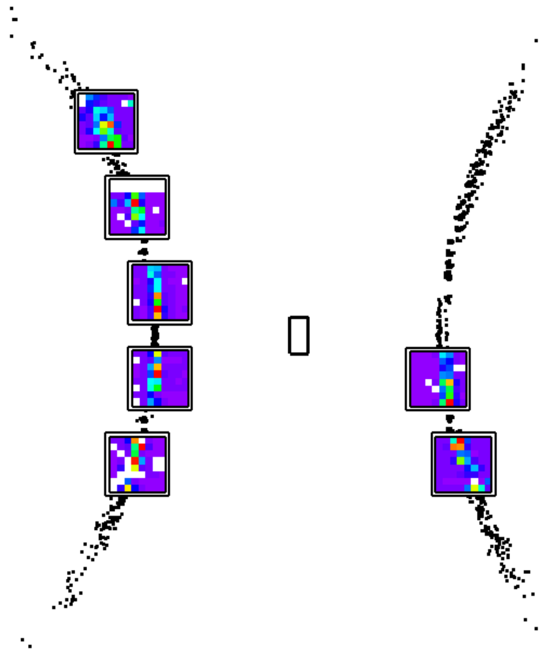




PANDA: results from 2011 tests at CERN

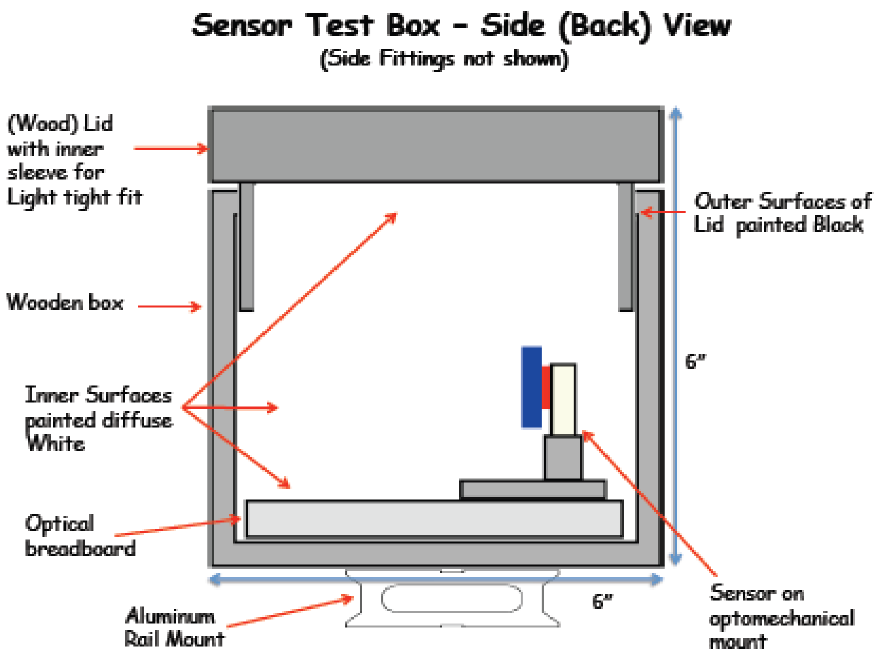


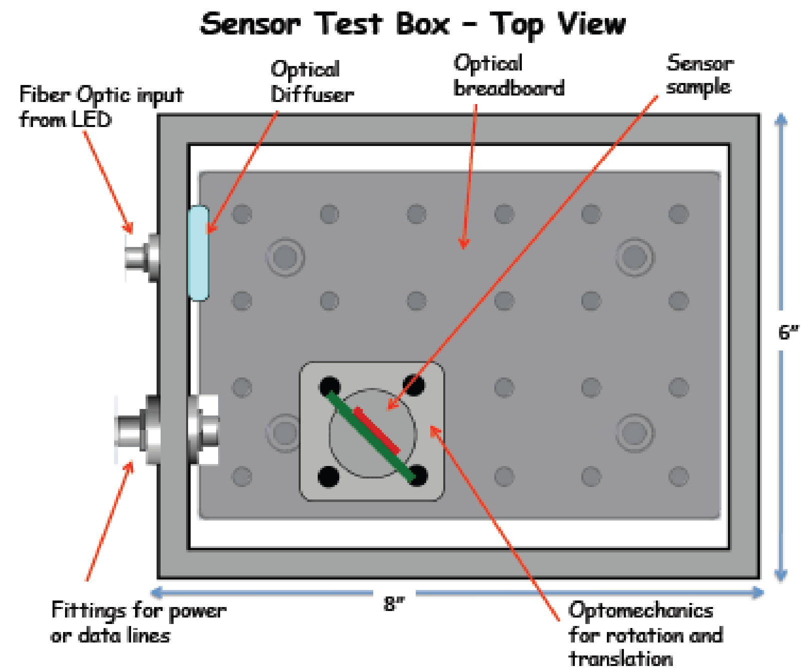
Simulation



Data

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