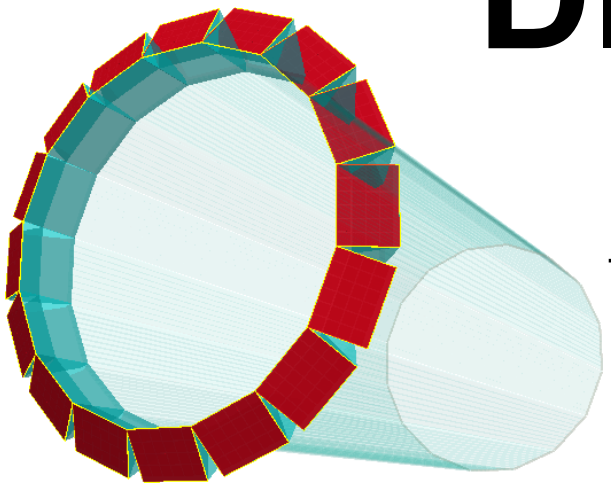
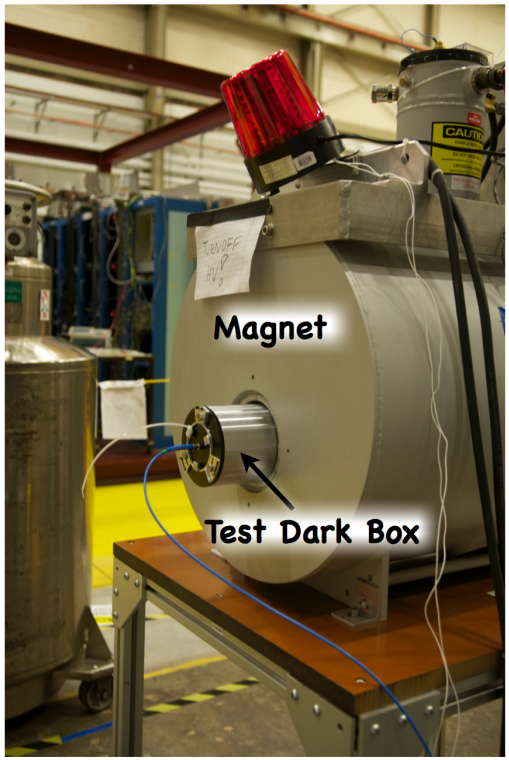
DIRC@EIC



Greg Kalicy
for the EIC DIRC group



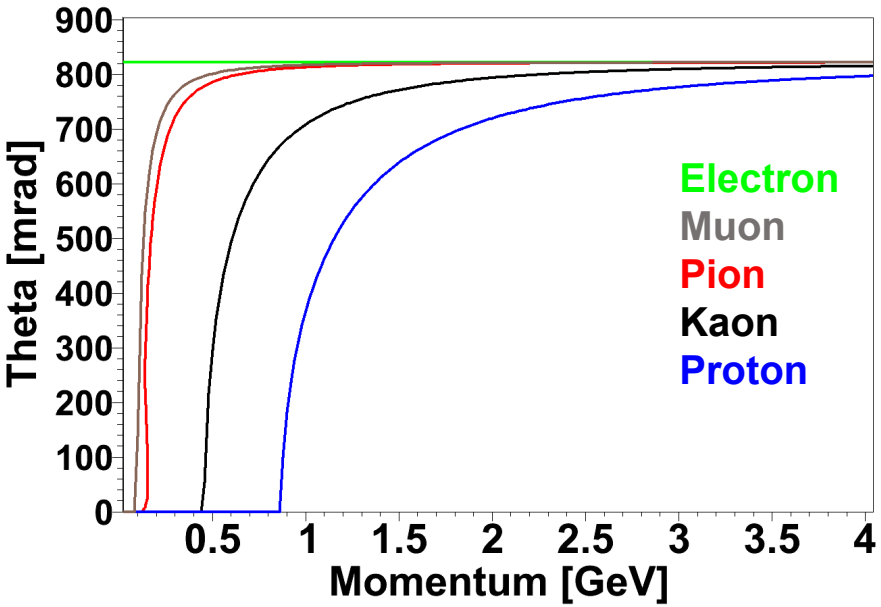
- **DIRC – Novel type of RICH detector**
- **DIRC@EIC – New generation DIRC**
- **Photosensors tests in magnetic field**

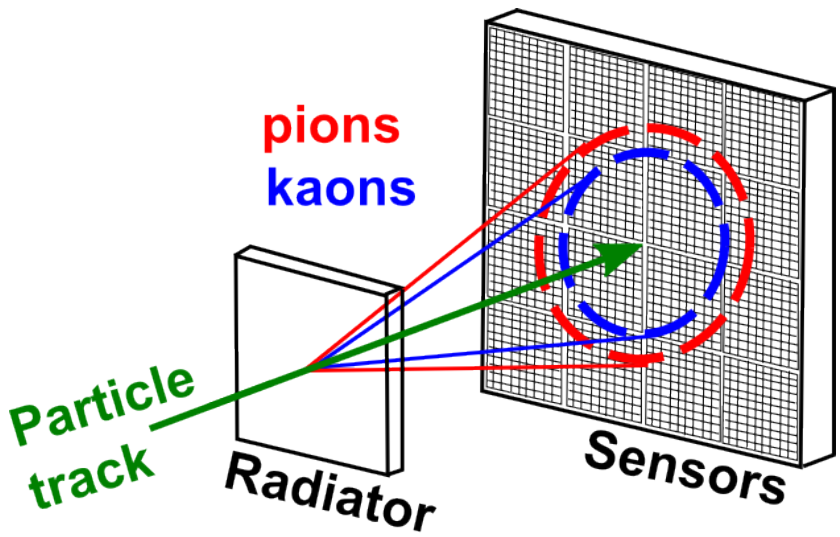
Old Dominion University

Jefferson Lab

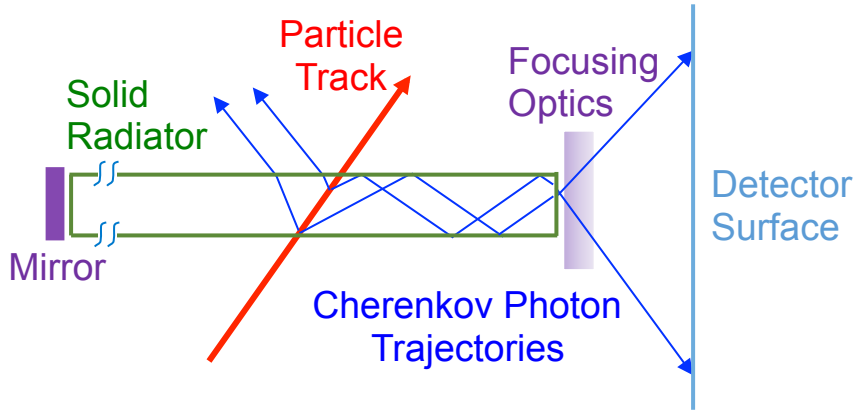
Ring Imaging Cherenkov Detectors

Compare ring image with expected image for e/μ/π/K/p (likelihood test) or **calculate mass from track β** using independent momentum measurement (B field, tracking).



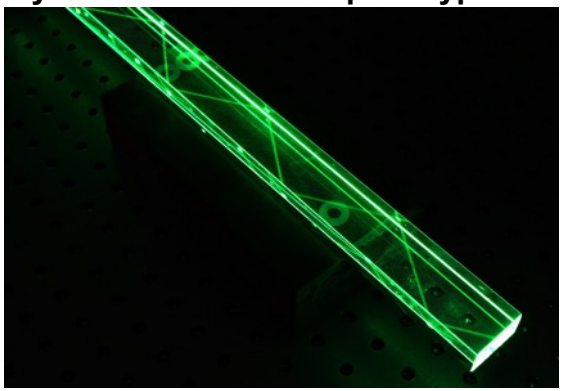


DIRC Detection of Internally Reflected Cherenkov Light

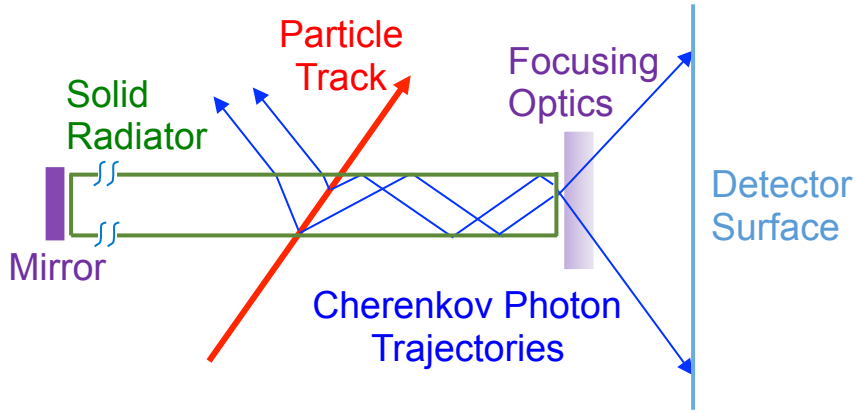


- **Charged particle** traversing radiator with refractive index n with β=**v/c> 1/n** emits **Cherenkov photons** on cone with half opening angle **cos θ_c = 1/βn(λ)**.
- **Radiator and light guide**: bar, plate, or disk made from **Synthetic Fused Silica**.
- For n>√2 some photons are always **totally internally reflected** for $\beta\approx1$ tracks.
- Magnitude of Cherenkov angle conserved during internal reflections.

Synthetic fused silica prototype bar

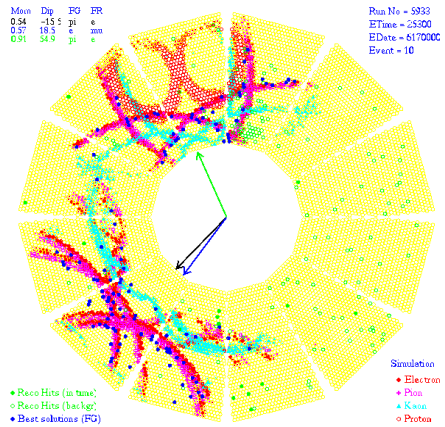


DIRC Detection of Internally Reflected Cherenkov Light

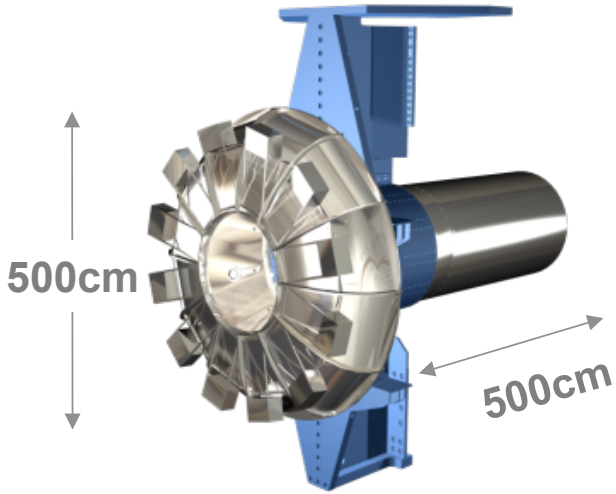


- Photons exit radiator via (optional) focusing optics into **expansion volume**, detected on **photon detector array**.
- Measured **x, y, and time** of Cherenkov photons are used to reconstruct θ_c, ϕ_c, $t_{propagation}$.
- **Ultimate deliverable for DIRC: PID likelihoods.**
  Calculate likelihood for observed hit pattern
  to be produced by e/μ/π/K/p plus event/track background.

Example: Comparison of real event to simulated response of BABAR DIRC to e/p/K/p.



DIRC First DIRC Detector

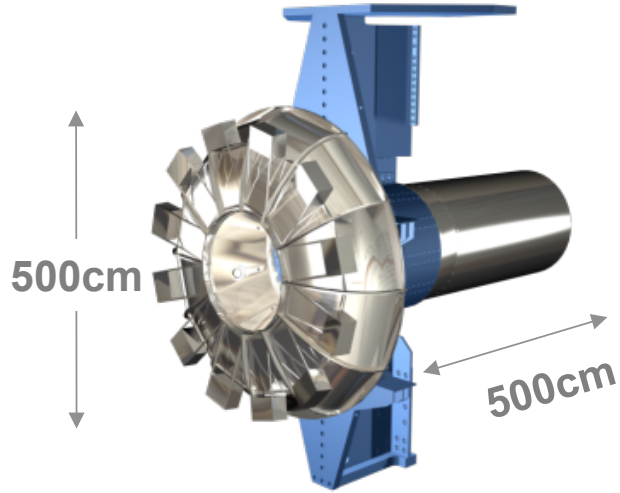


courtesy of the BaBar collaboration

BaBar-DIRC (1998-2008):

- Reliable, robust, easy to operate
- Reached excellent performance.

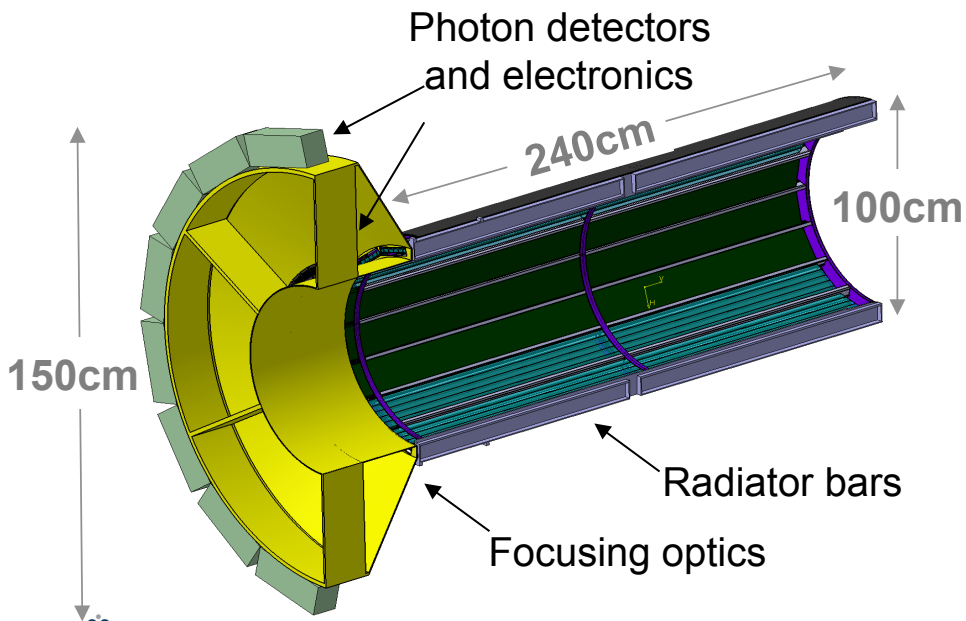
DIRC Focusing DIRC for PANDA



courtesy of the BaBar collaboration

BaBar-DIRC (1998-2008):

- Reliable, robust, easy to operate
- Reached excellent performance.



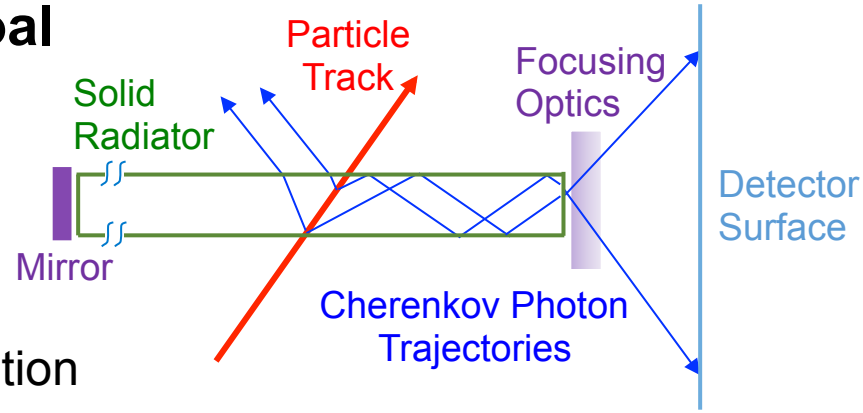
Needed modifications for PANDA detector at future FAIR facility in Germany:

- Compact expansion volume
- Focusing
- New compact single photon detectors operating in 2T magnetic field.

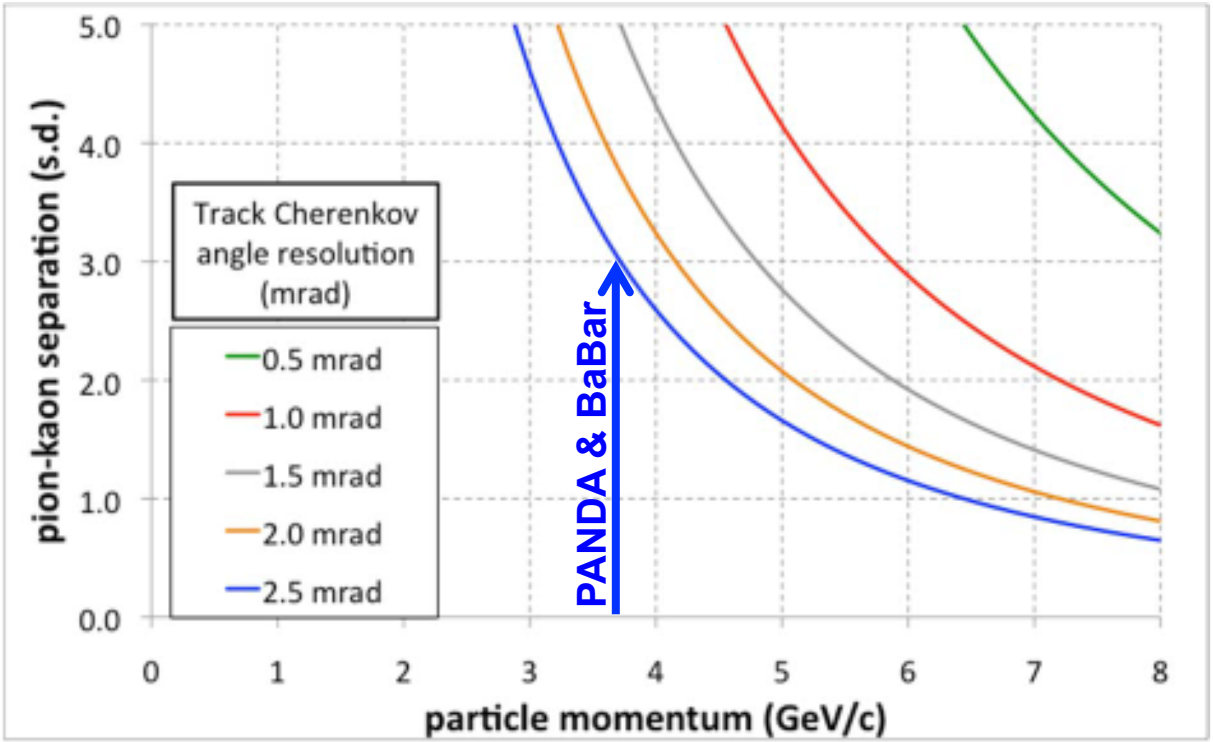
DIRC@EIC Performance Goal

Contributions to performance:

- Correlated term
- Photon Yield
- Single photon Cherenkov angle resolution



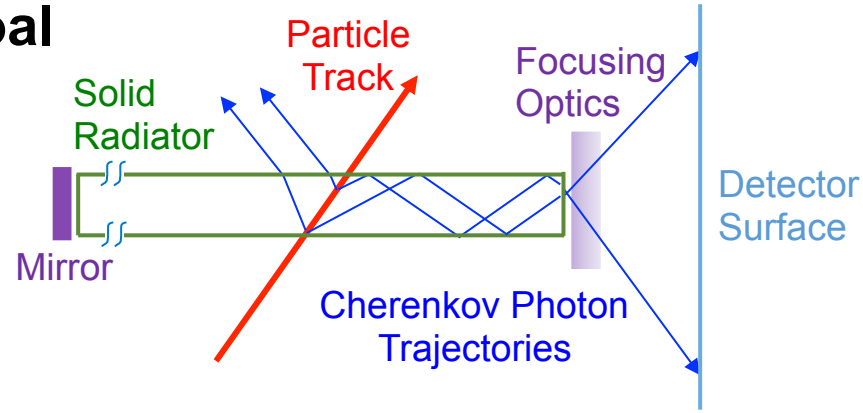
π/K identification as a function of the θ_c resolution



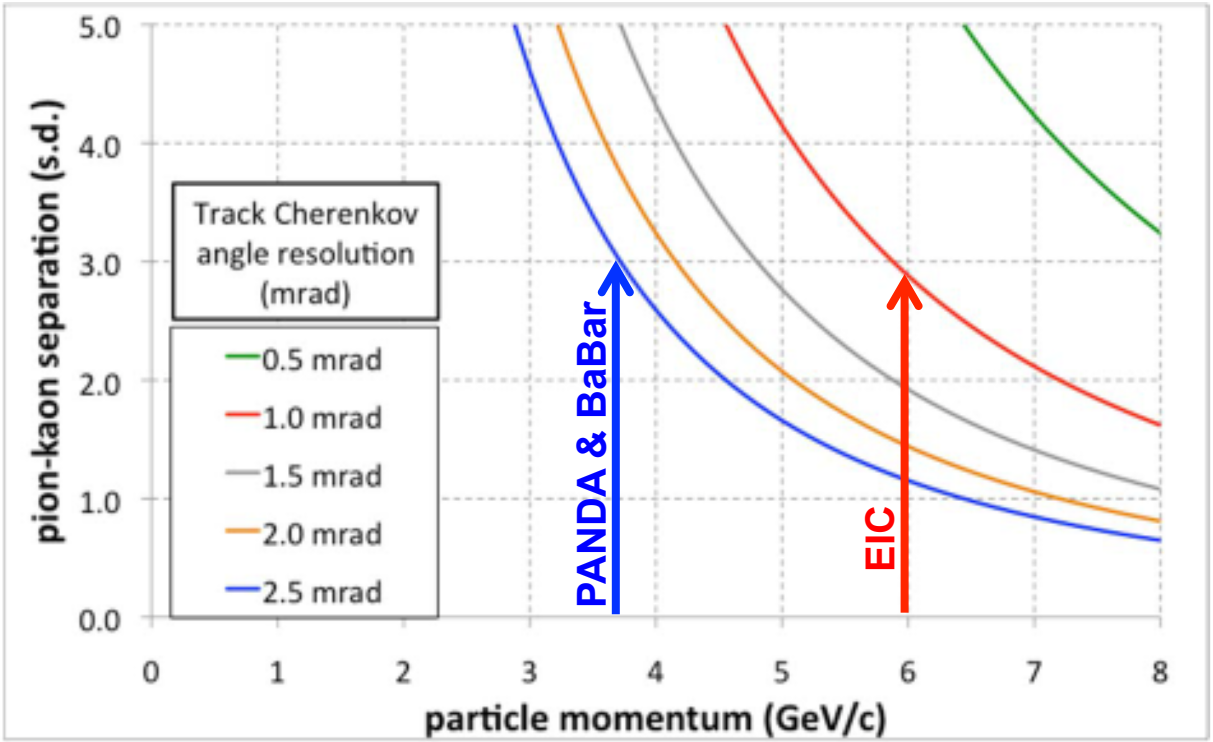
DIRC@EIC Performance Goal

DIRC@EIC PID capability:

- **p/K up to 10 GeV/c**
- **π/K up to 6 GeV/c**
- **e/π up to 1.8 GeV/c**



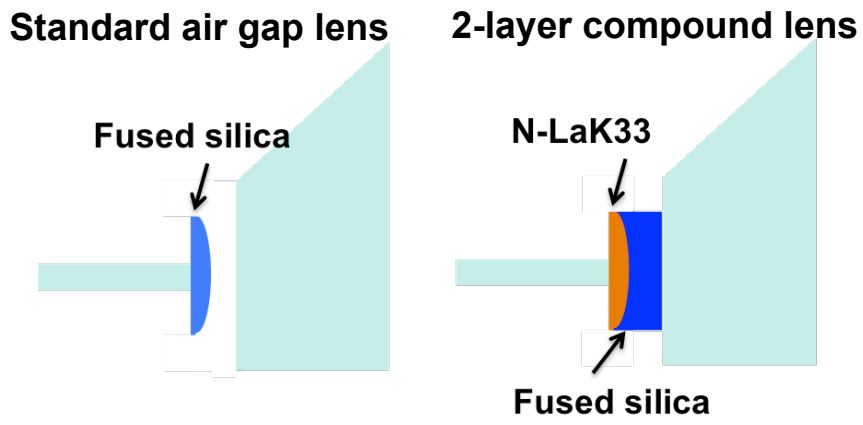
π/K identification as a function of the θ_c resolution



DIRC@EIC Improving Performance

Limitations of standard focusing lenses:

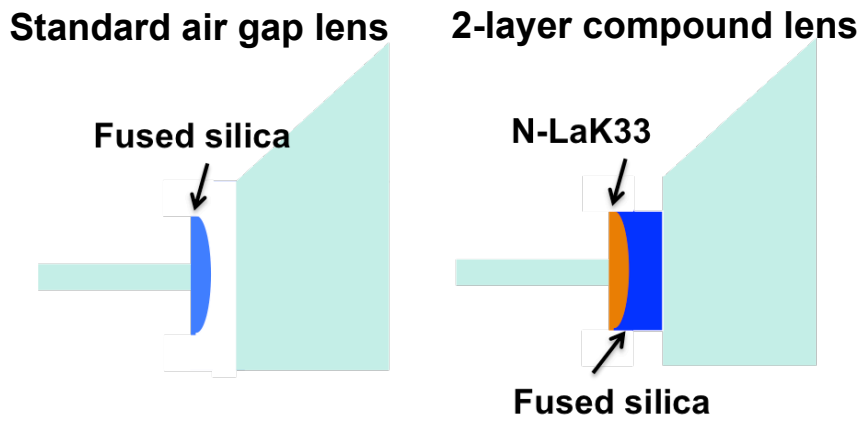
- Significant photon yield loss around 90° particle track



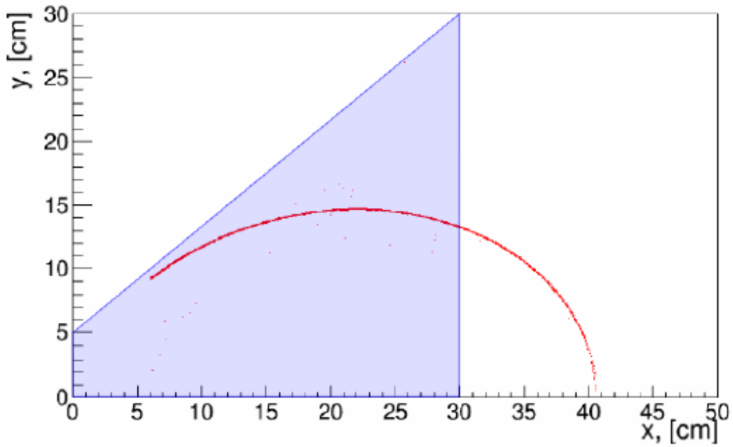
DIRC@EIC Improving Performance

Limitations of standard focusing lenses:

- Significant photon yield loss around 90° particle track
- Aberration for photons with steeper angles



Geant4 simulation of focal plane: Standard air gap lens



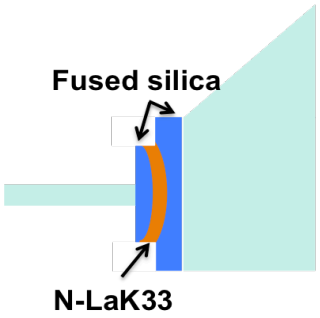
R. Dzhygadlo, G. Kalicy, C. Schwarz

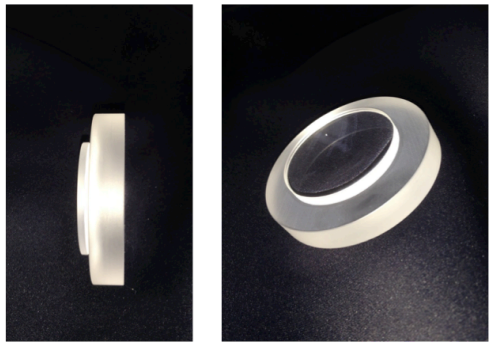
DIRC@EIC Prototype 3-layer lens

Prototype 3-layer lens:

- Flat focal plane
- Higher photon yield

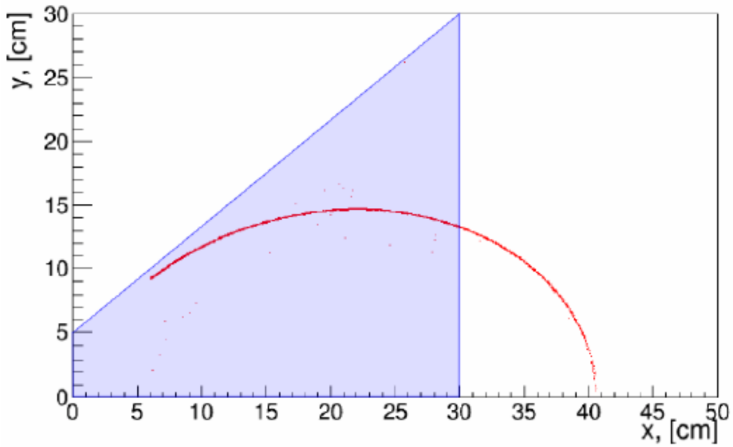
3-layer compound lens



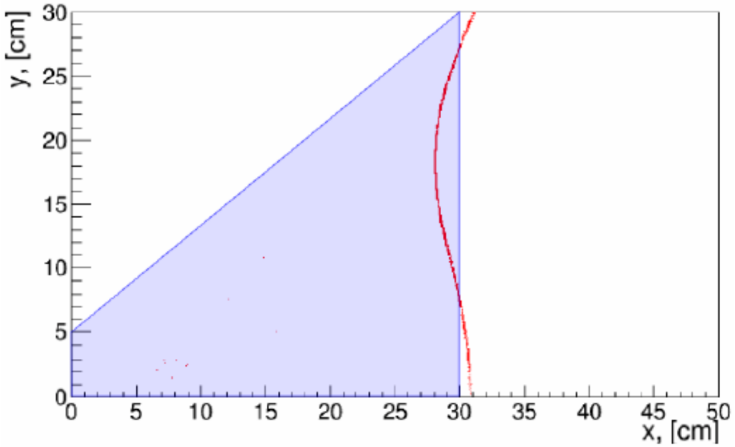


Geant4 simulation of focal plane:

Standard air gap lens



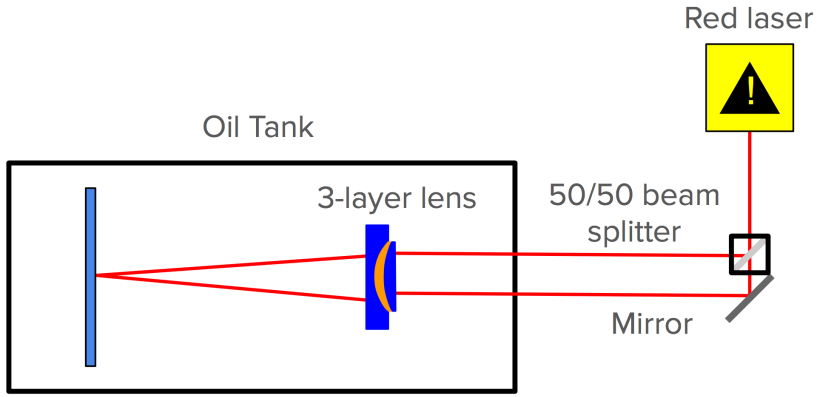
3-layer compound lens



DIRC@EIC Prototype 3-layer lens

Experimental tests of the prototype 3-layer lens:

- Test benches
  (focal plane, radiation hardness)

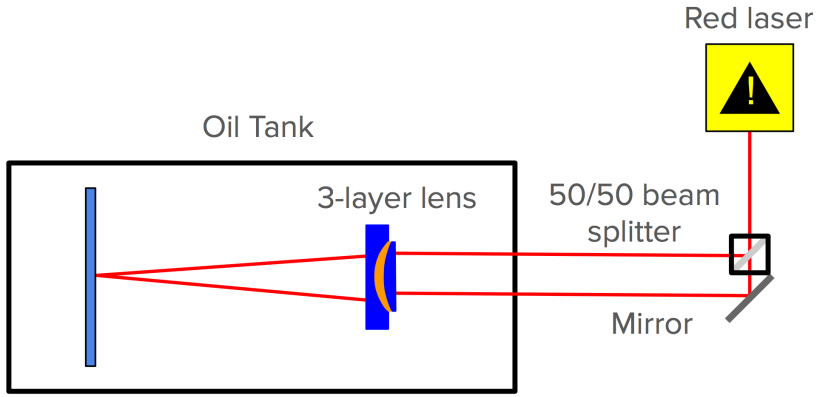


L. Allison, G. Kalicy

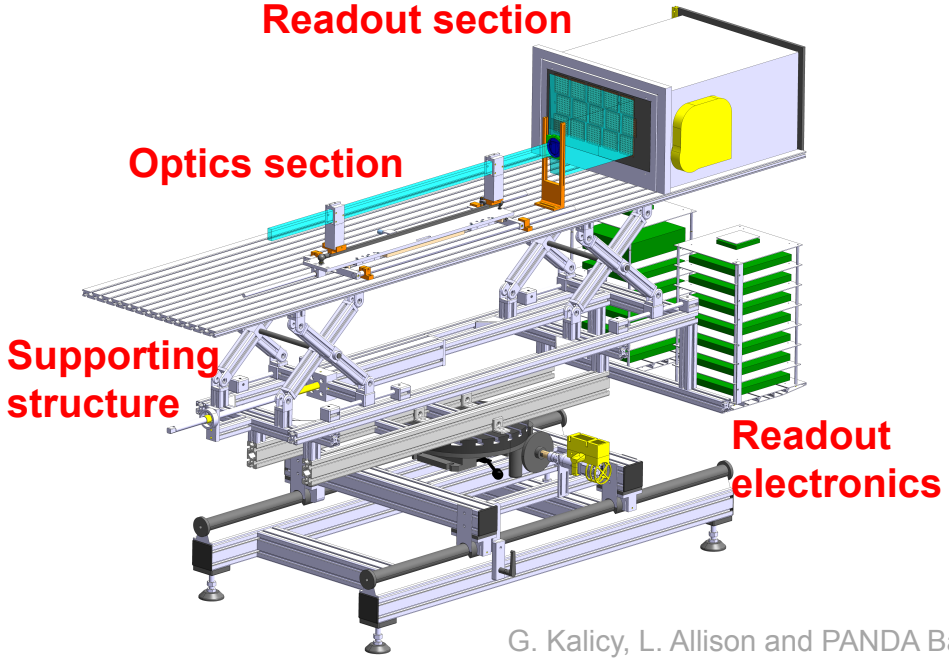
DIRC@EIC Prototype 3-layer lens

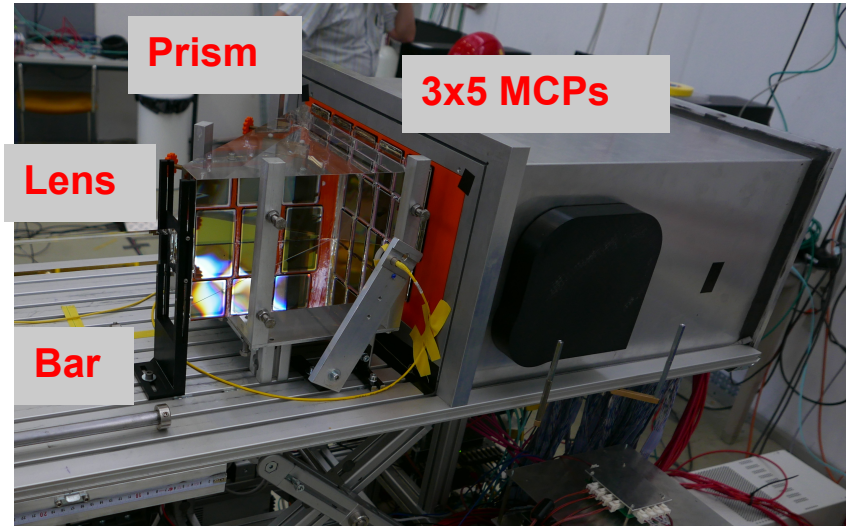
Experimental tests of the prototype 3-layer lens:

- Test benches (focal plane, radiation hardness)
- Full system prototype at particle beam



L. Allison, G. Kalicy



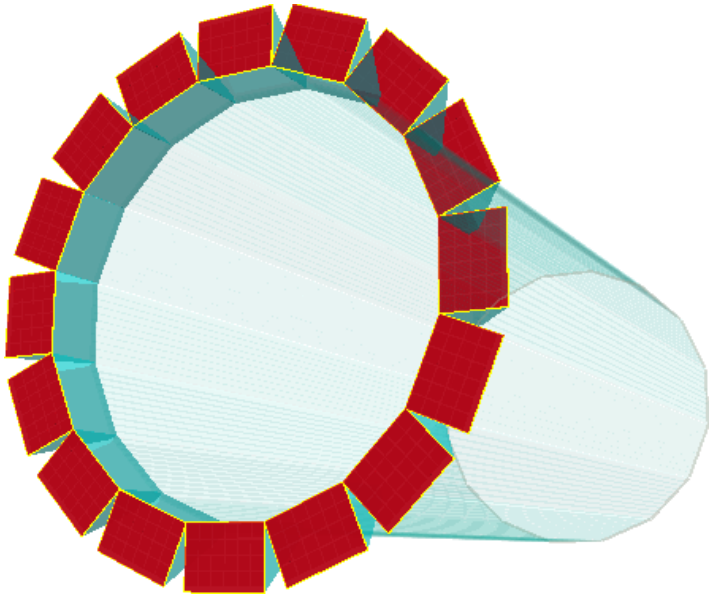


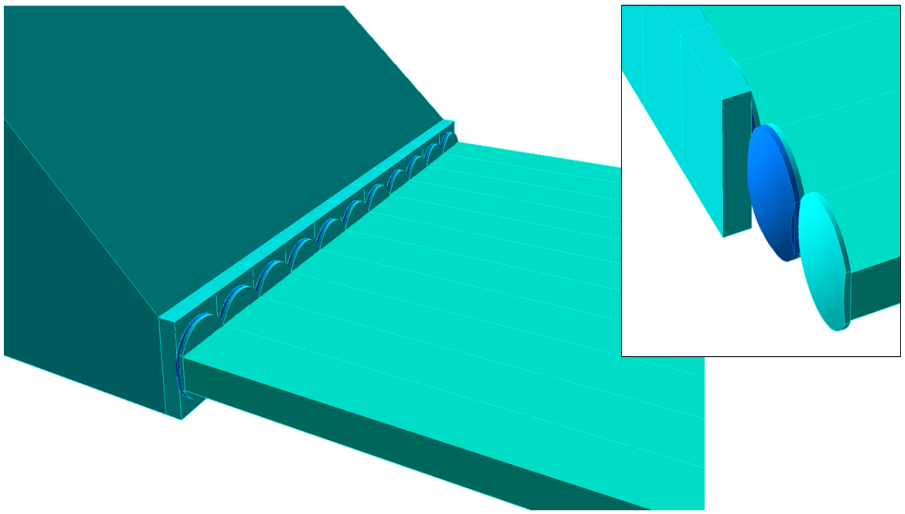
G. Kalicy, L. Allison and PANDA Barrel DIRC group

DIRC@EIC High Performance DIRC

High Performance DIRC

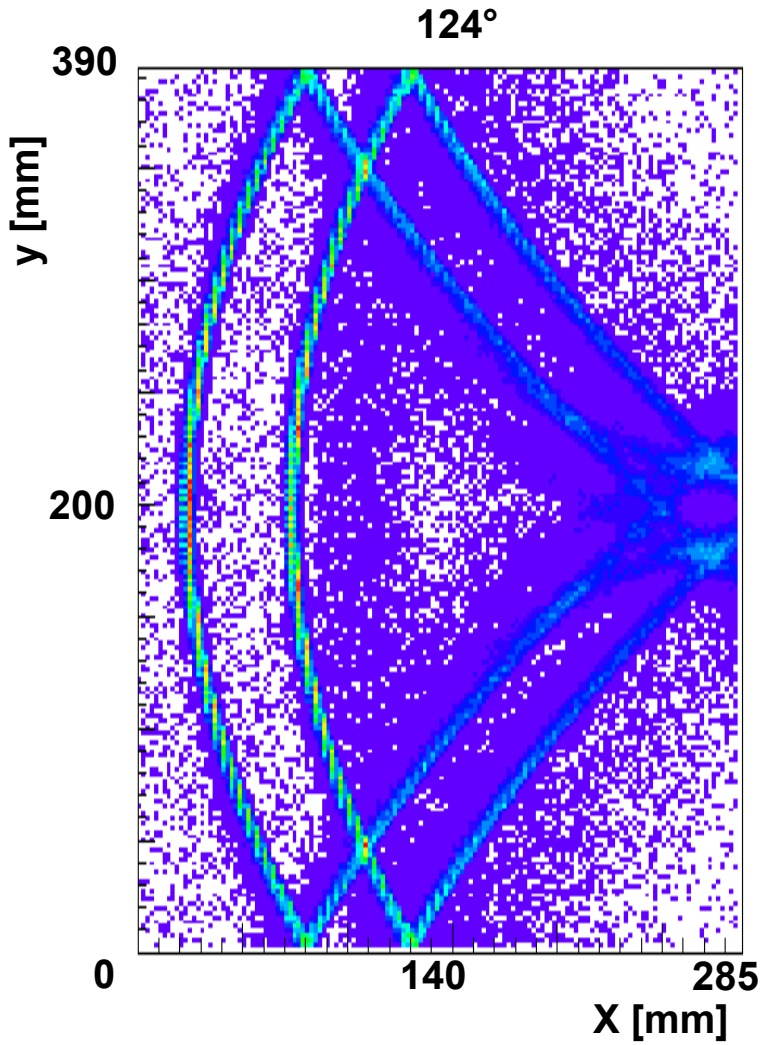
- 3-layer lens based baseline design
- 16 bar boxes, at 1m radius
- 11 radially thin bars
  (each 17 x 35 x 4200 mm) per box
- Fused silica prism expansion volume
- 208k pixels, each 2 mm^2
- **Geant4 simulations shows capability of reaching 1 mrad Cherenkov track resolution!**



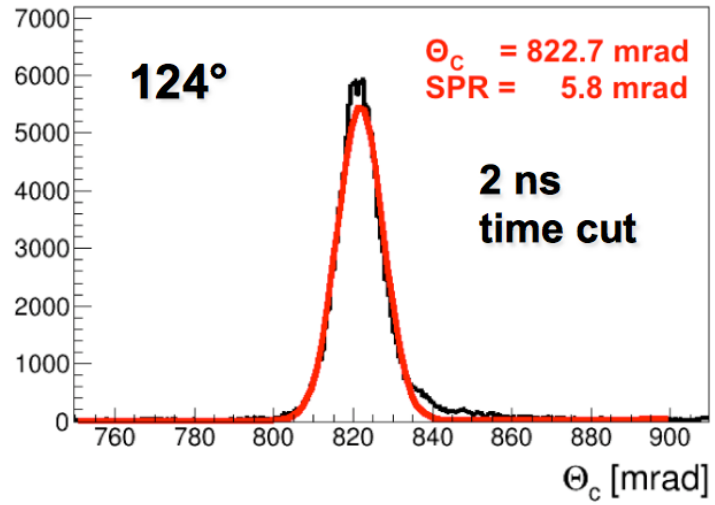


DIRC@EIC High Performance DIRC

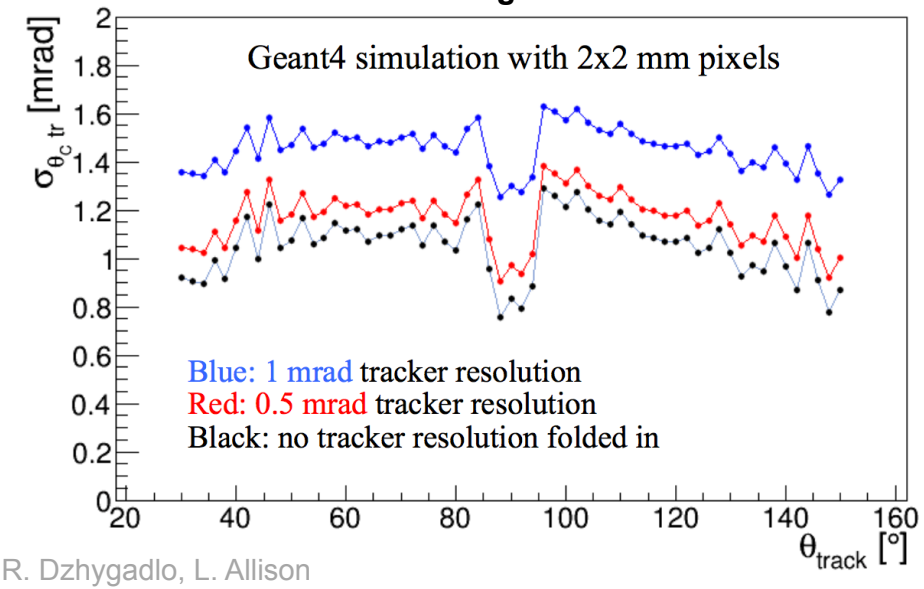
Hit pattern digitalized with 2mm pixels



Single Photon Cherenkov angle resolution (SPR)



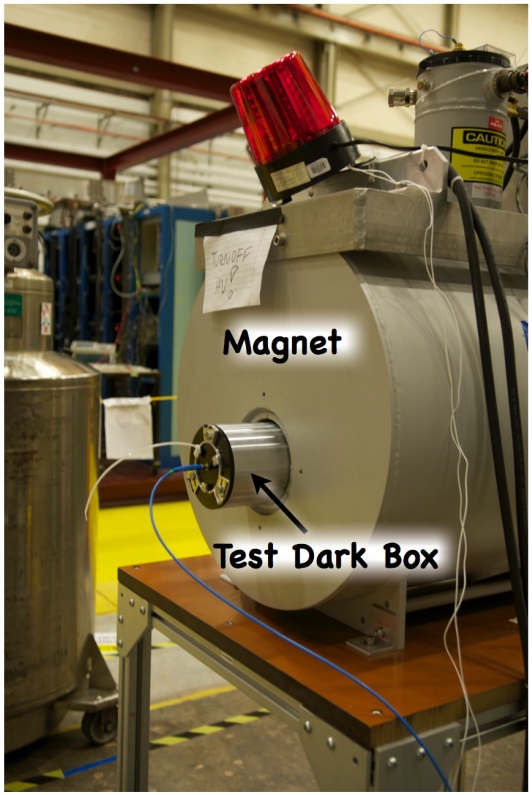
Track Cherenkov angle resolution

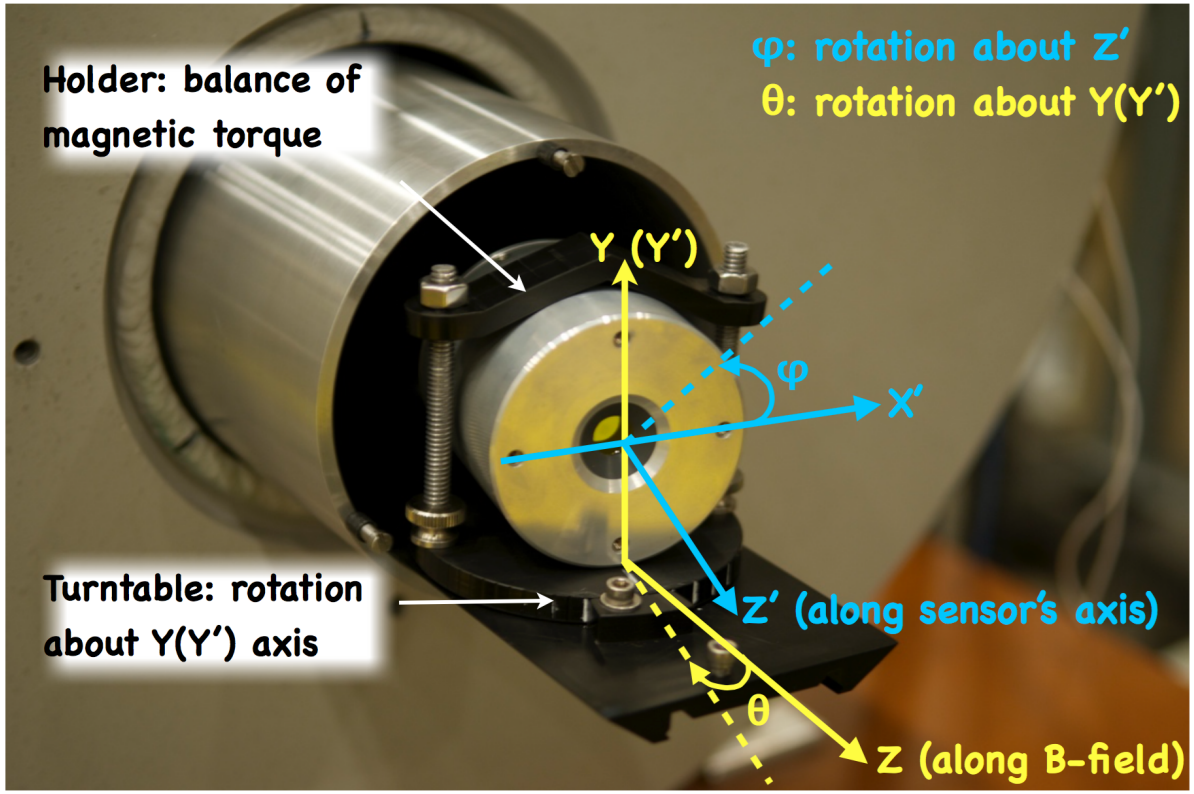


G. Kalicy, R. Dzhygadlo, L. Allison

High B field test facility Measurements of photosensors

Measurements in 2014 and 2015 with several sensors at multiple positions in B field up to 5T



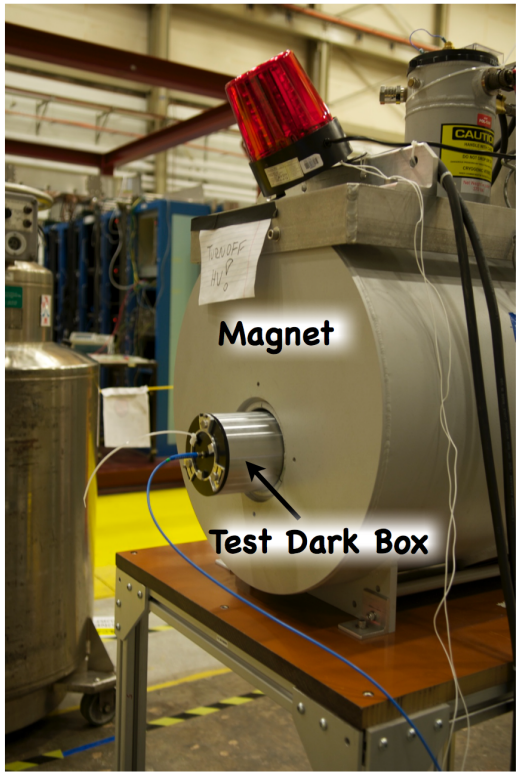


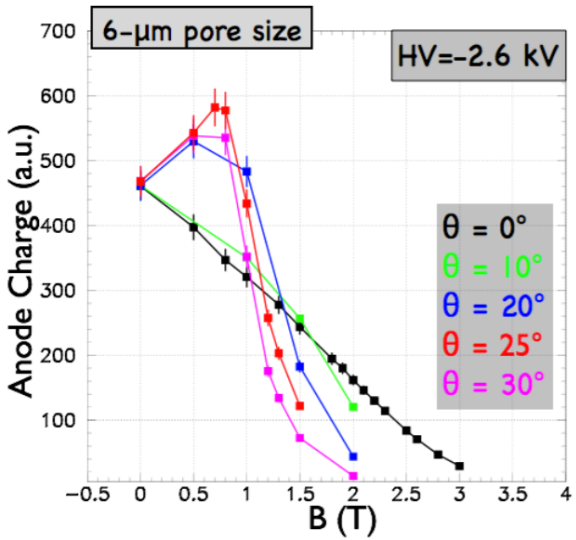
Y. Ilieva, L. Allison, T. Cao, G. Kalicy, P. Nadel-Turonski, K. Park, C. Schwarz, J. Schwiening, and C. Zorn

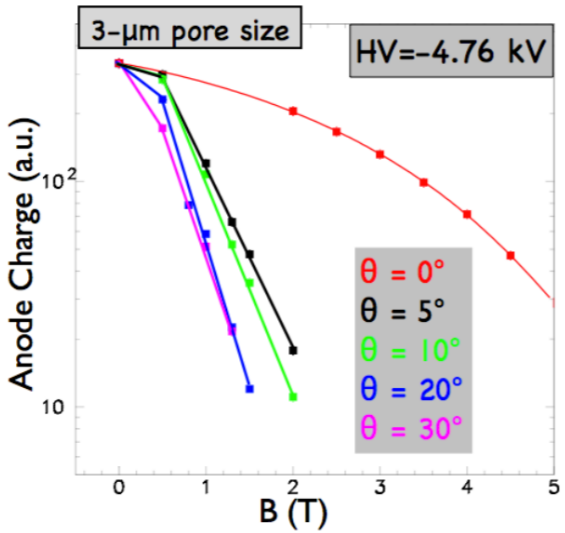
High B field test facility Measurements of photosensors

Measurements in 2014 and 2015 with several sensors at multiple positions in B field up to 5T

- Smaller Pore size - better performance
- Above 0.5 T the signal amplitude continuously decreases
- Very strong correlation between sensor orientation (both θ and φ) and averaged charge collected on anode
- **Change of the voltages across MCPs allows to recover part of the signal! (especially for θ = 0°)**





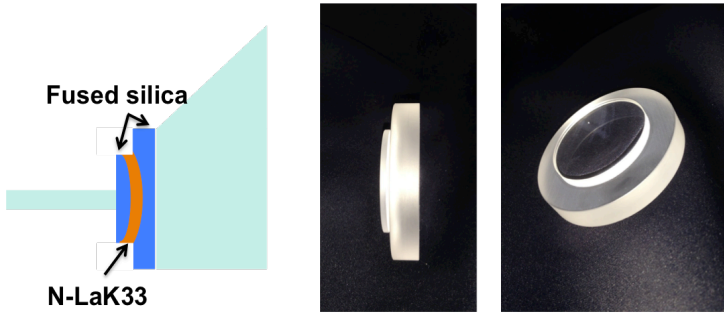


Y. Ilieva, L. Allison, T. Cao, G. Kalicy, P. Nadel-Turonski, K. Park, C. Schwarz, J. Schwiening, and C. Zorn

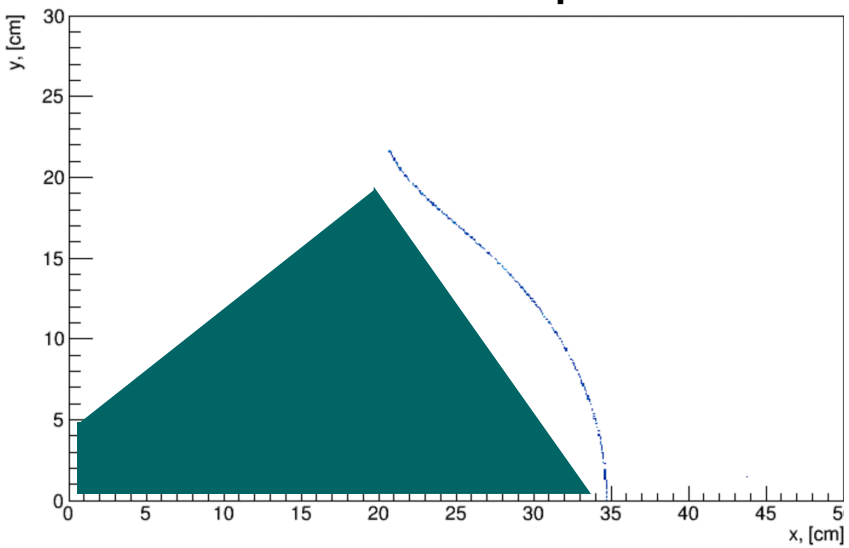
High-performance DIRC Tilted detector plane

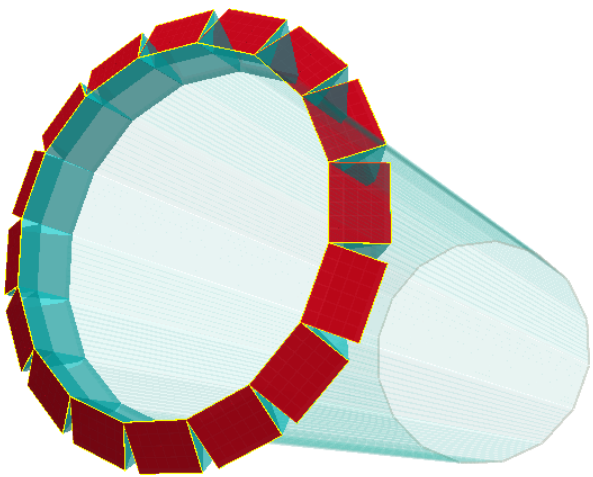
Modification of 3-layer lens

- Selecting different (larger) radiuses of lens layers allows to tilt the focal plane
- Tilted detector plane allows to locate sensors perpendicular to the B field lines
- Larger radiuses means smaller curvatures and allows to produce thinner lens that will improve photon yield.



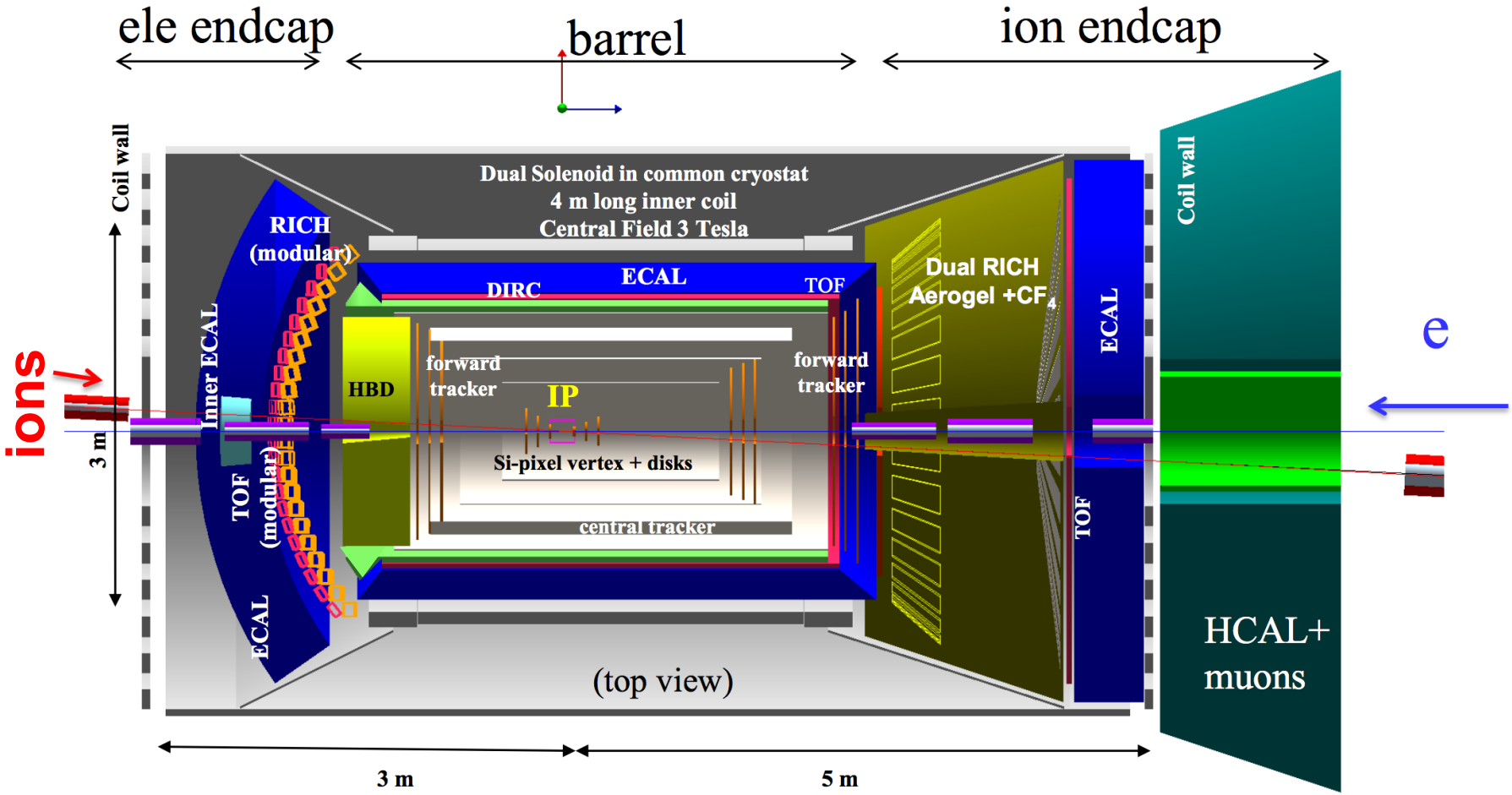
Geant4 simulation of 3-layer lens with tilted focal plane





G. Kalicy, R. Dzhygadlo, L. Allison

DIRC Integration in JLab EIC detector



Summary

Fundamental milestone achieved:
Simulation shows that 1 mrad Cherenkov angular resolution is reachable.

High Performance DIRC

- **DIRC@EIC with 3-layer is capable of separating: p/K @10GeV/c, π/K @ 6GeV/c and e/π @ 1.8GeV/c**
- Properties of 3-layer lens evaluated in simulation
- Experimental tests of 3-layer lens in beam and on test benches (ongoing)

High B test facility

- Tested several sensors from different vendors
- Observed strong dependence on sensor orientation in the field and pore size
- **Recovery of part of the signal is possible**

Tilted Detector Plane

- Optimized lens design allows to tilt the focal plane and place sensors perpendicular to the B field

Improving DIRC Performance

- **Make DIRC less sensitive to background**
  - decrease size of expansion volume
  - use photon detectors with smaller pixels and faster timing
  - place photon detector inside magnetic field
- **Investigate alternative radiator shapes** (plates, disks)
- **Push DIRC π/K separation by improving single-photon θ_C resolution**

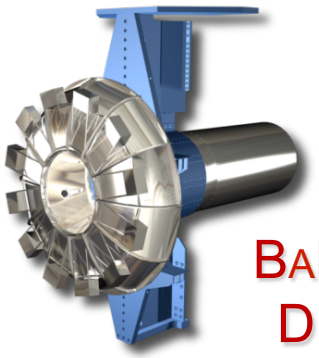
BABAR-DIRC Cherenkov angle res.: 9.6 mrad per photon → 2.4 mrad/track

Limited in BABAR by:			**Could be improved for future DIRCs 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 res.

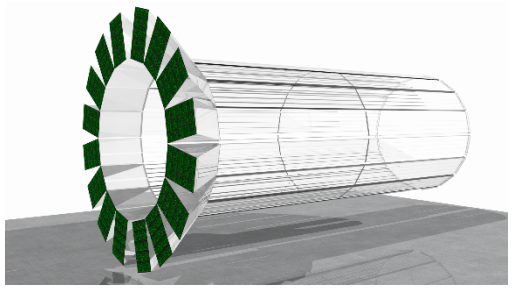
SUPERB, BELLE II & PANDA

9.6 mrad → 4-5 mrad per photon → < 1.5–2 mrad/tr.

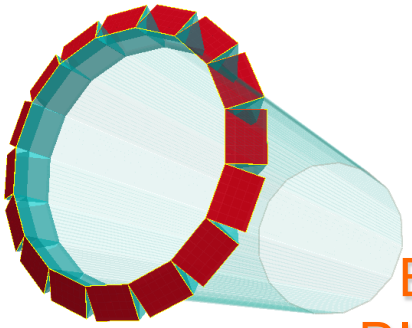
DIRC Family



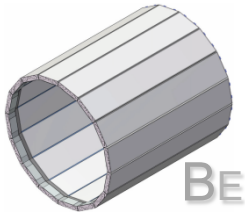
BaBar DIRC



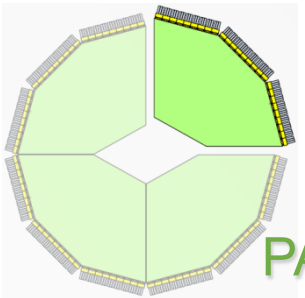
PANDA Barrel DIRC



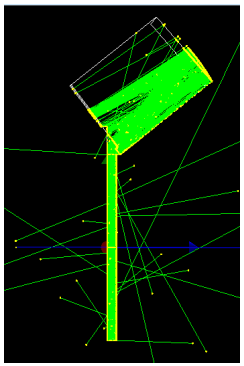
EIC DIRC



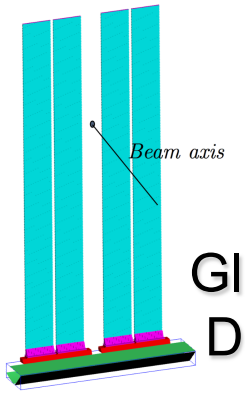
Belle II TOP



PANDA Disc DIRC

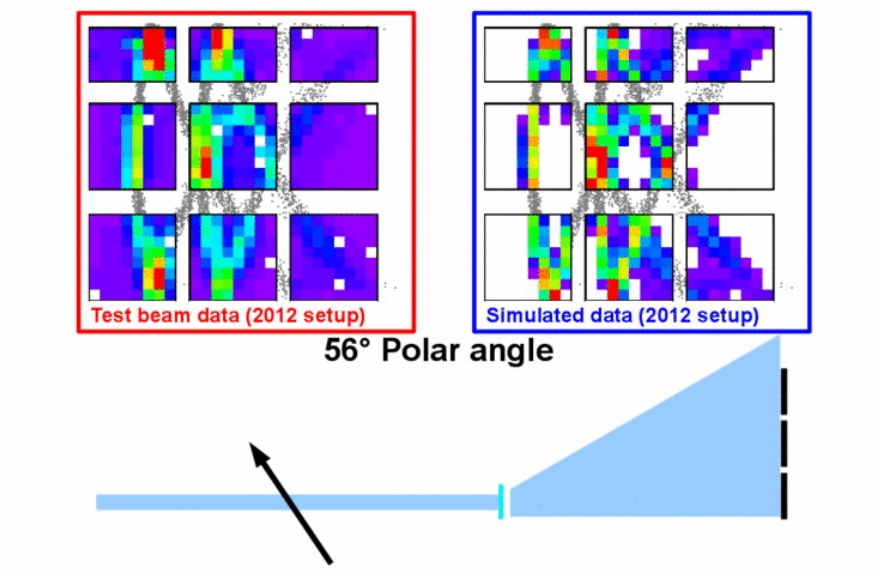


LHCb TORCH



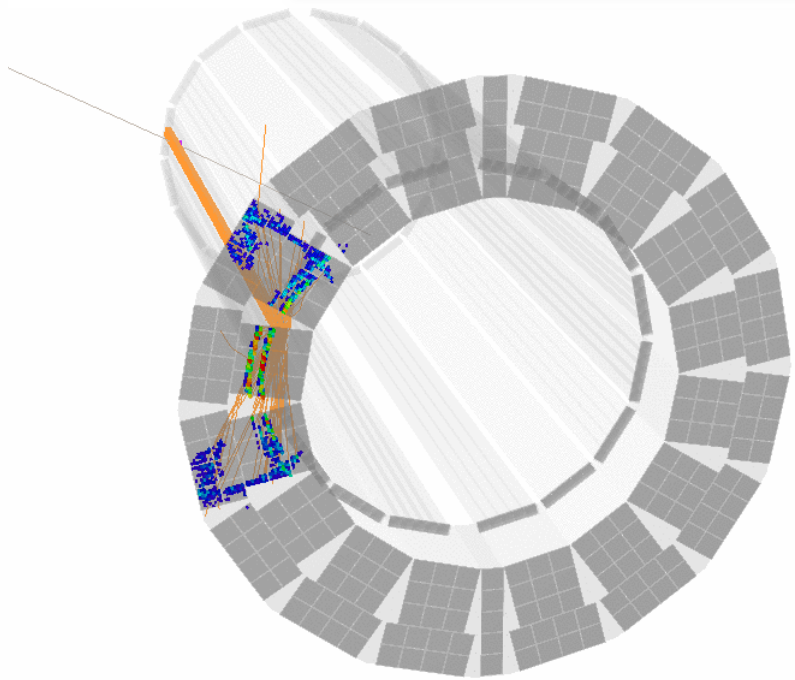
GlueX DIRC

Thank you



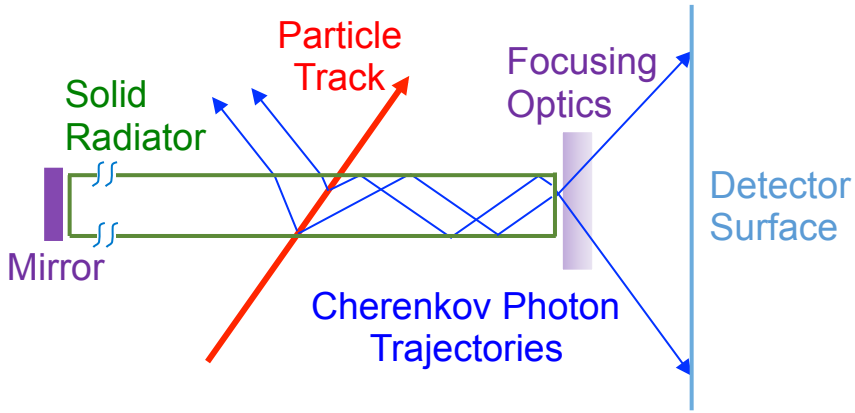
Hit patterns for 2012 prototype with narrow bars and fused silica prism

Geant simulation of hit pattern for narrow bars and oil tank geometry



DIRC Performance

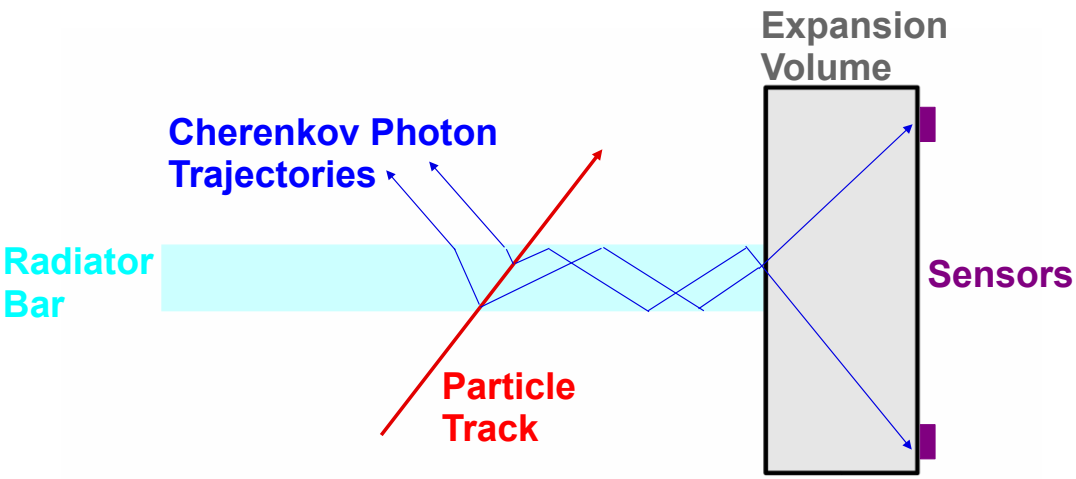
- Expected PID performance defined by **Cherenkov angle resolution** $\sigma_{\Theta_c}^{track}$.

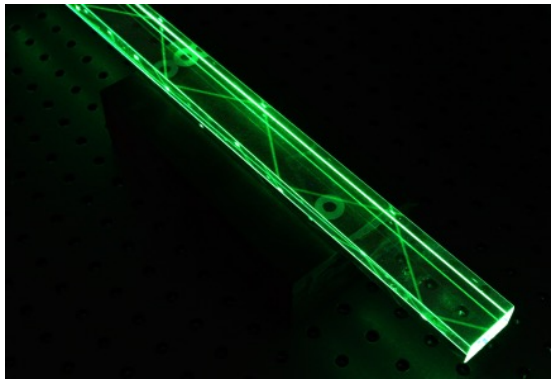


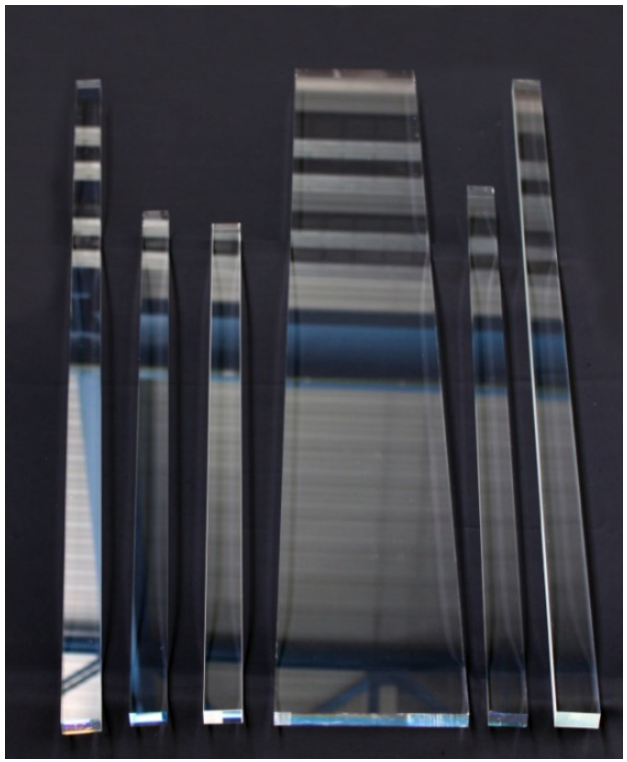
- $$\sigma_{\Theta_c}^{track} = \sqrt{\left(\frac{\sigma_{\Theta_c}^{photon}}{\sqrt{N_{pe}}}\right)^2 + (\sigma^{correlated})^2}$$

  - $\sigma^{correlated}$ (**Correlated term:** tracking detectors, multiple scattering)
  - $\sigma_{\Theta_c}^{photon}$ (**Single photon Cherenkov angle resolution:** bar size, pixel size, chromatic, bar imperfections)
  - N_{pe} (**Number of photons:** bar size, bar imperfections, Photon Detection Efficiency of the detector.

DIRC Components Radiator Bars



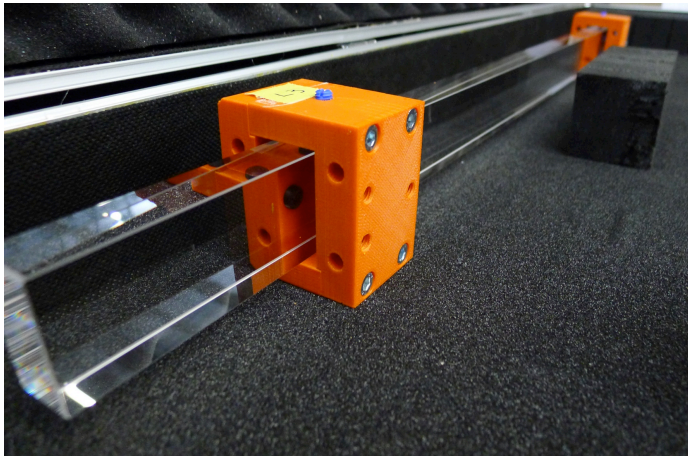


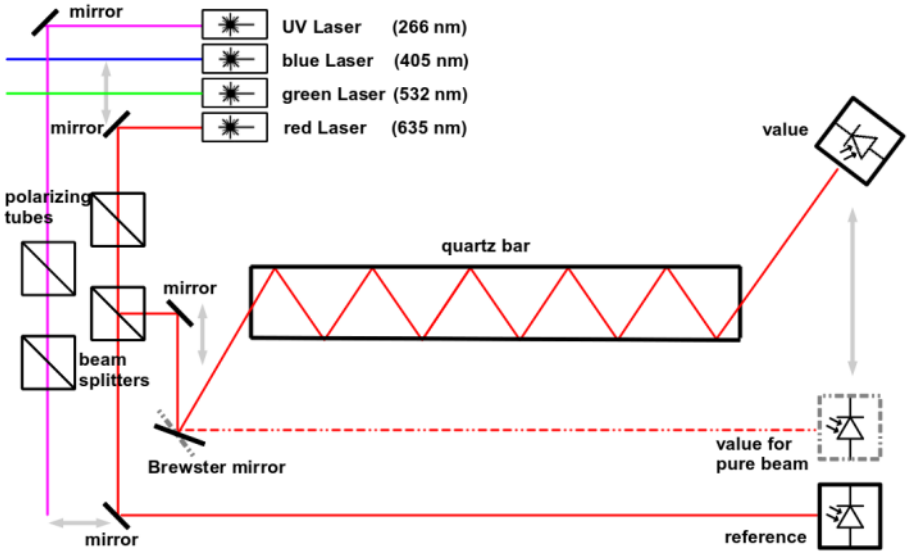


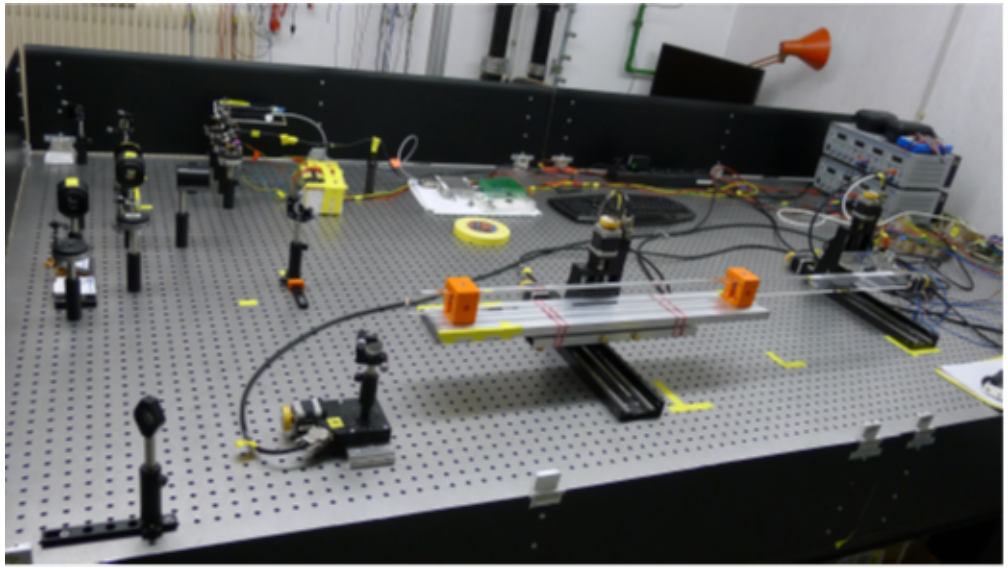
- Large fused silica bars and plates polished to ~10 Å rms with non-squareness < 0.25 mrad.
- 1Å = 10^{-10} m. 0.5Å is radius of hydrogen atom.
- 1 mrad ≈ 0.06°

DIRC Components Radiator Bars

- Measurement of surface roughness with 1-2Å precision.

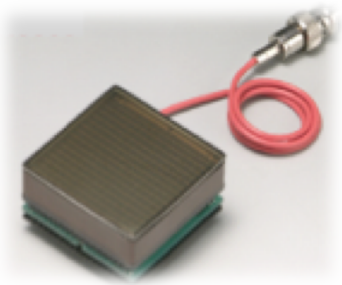




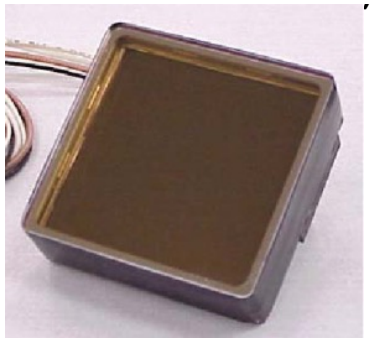


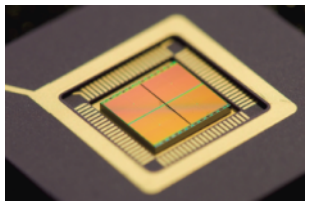
DIRC Components Photo Detectors

DIRCs need fast compact multi-pixel photon detectors



- Single photon sensitivity, low dark count rate;
- Reasonably high photo detection efficiency;
- Fast timing: $\sigma_{TTS} \approx$ 50-150 ps;
- Few mm position resolution (2-6 mm);
- Operation in magnetic field (up to 3T);
- Tolerate high rates (2 MHz/cm^2 for PANDA);
- Long lifetime (4-10 C/cm^2 per year at 10^6 gain for PANDA).

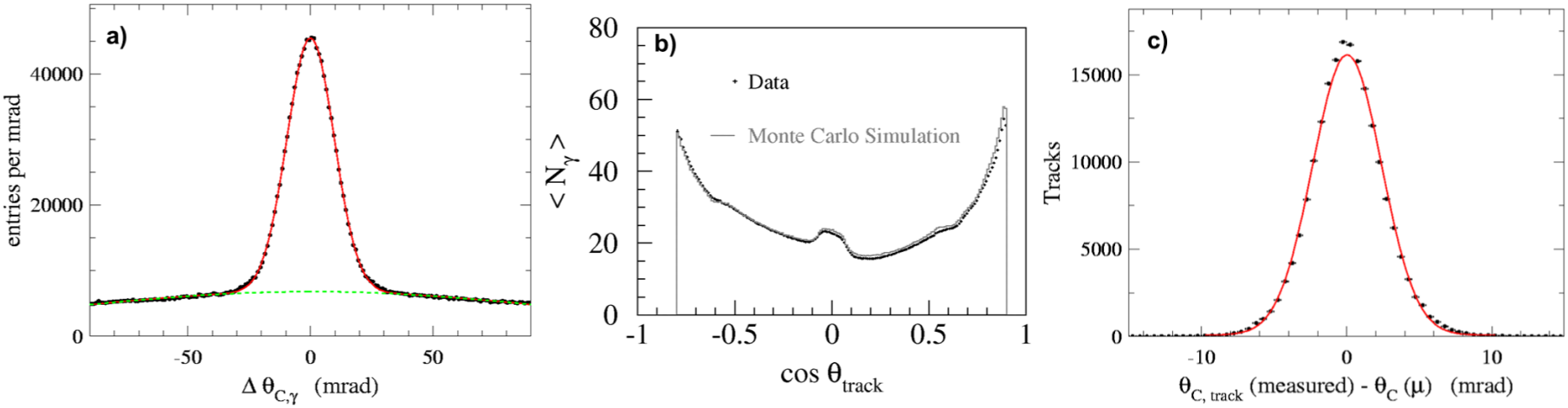




BaBar DIRC

Excellent performance:

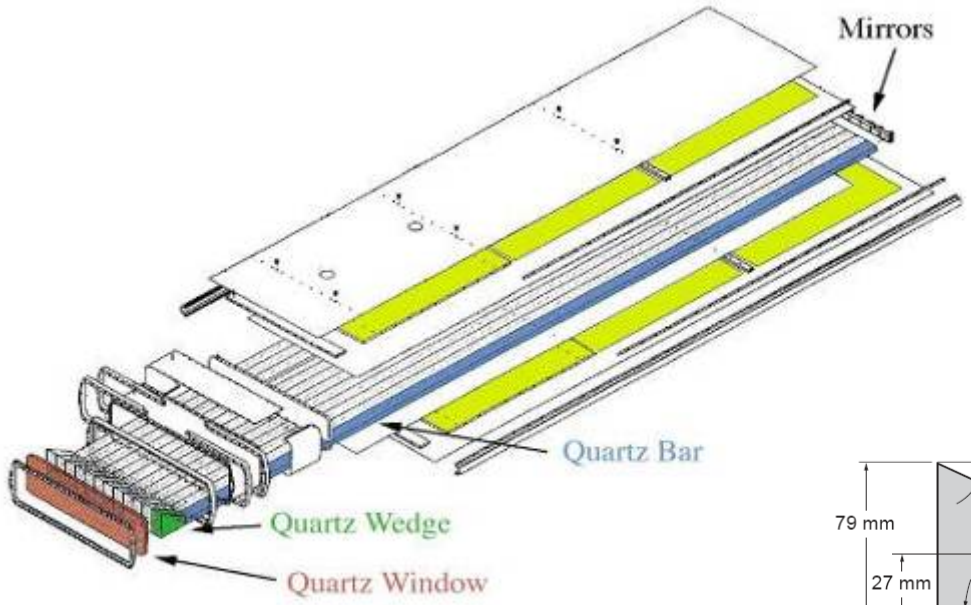
very reliable, robust, easy to operate, significant in almost all BABAR physics results.

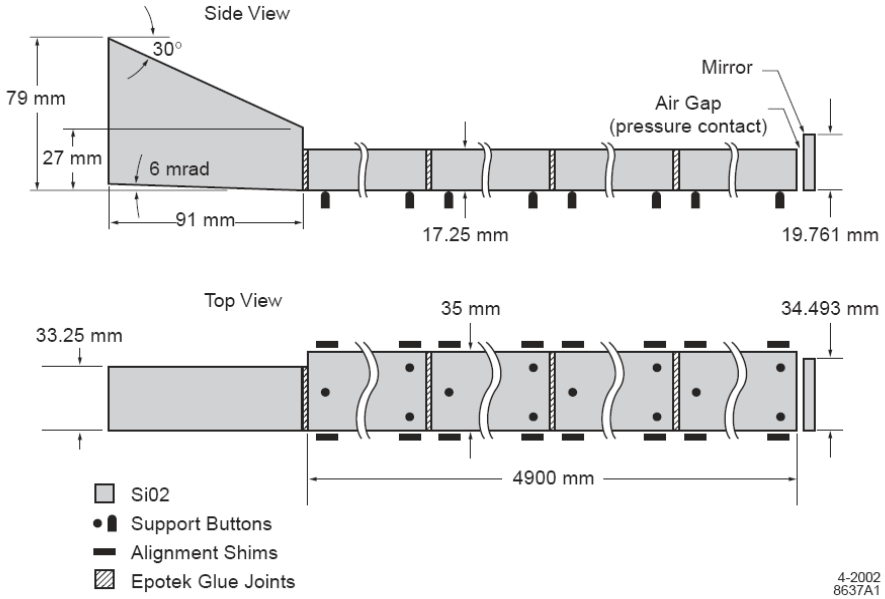


Single photon timing resolution	1.7ns
Single photon Cherenkov angle resolution	~10mrad
Photon yield	20-60 photons per track
Track Cherenkov angle resolution	2.4mrad
π/K separation power	4.3σ @ 3GeV/c, ~3σ @ 4GeV/c

BaBar DIRC

Bar box: 12 bar boxes in BABAR
12 long (4.9m) bars per box
150μm air gap between bars
dry nitrogen flow





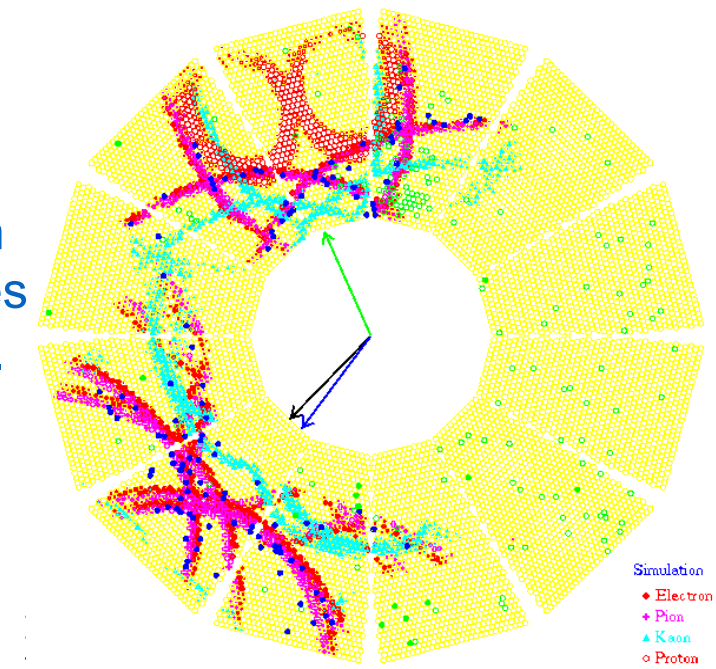
Long bar: 4 short (1.225m) bars
Mirror on forward end
Wedge on readout end

BaBar DIRC

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

(Likelihood: **Pdf(θ_c) ⊗ Pdf(Δt) ⊗ Pdf(N_γ)**)

Particle ID is based on log likelihood differences of the five hypotheses.



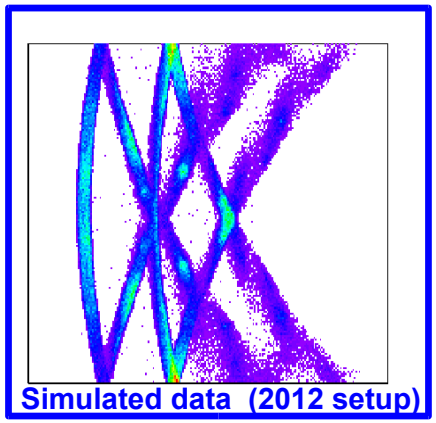
Example: Comparison of real event to simulated response of BABAR DIRC to e/π/K/p.

DIRC Components Photo Detectors

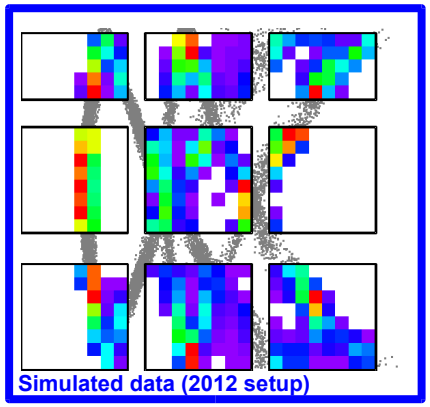
Photonis Planacon XP85012 (8 x 8 pixels)

MCP-PMT array

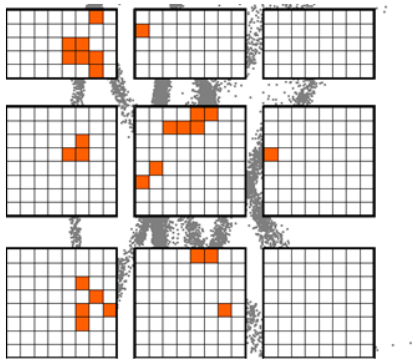
True hit positions from 180k pions.



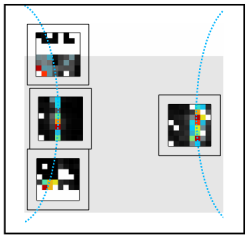
Pixelated hit positions from 180k pions.

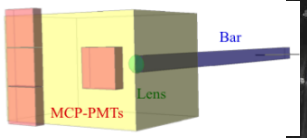


Pixelated hit positions from 1 pion.

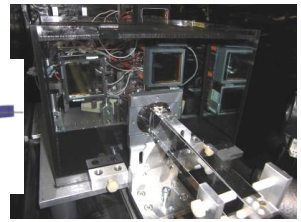


DIRC Prototype Test Beam Program

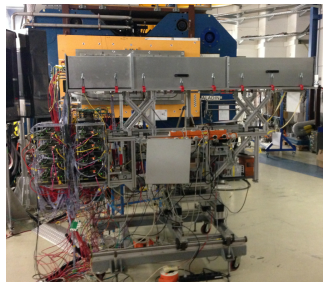


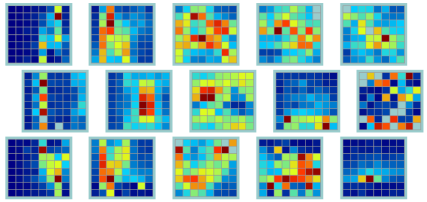


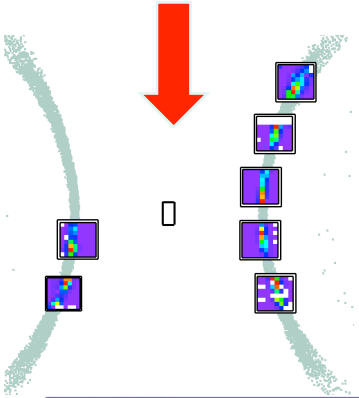
GSI
2008/2009



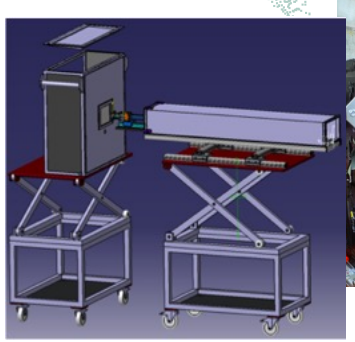
GSI 2014

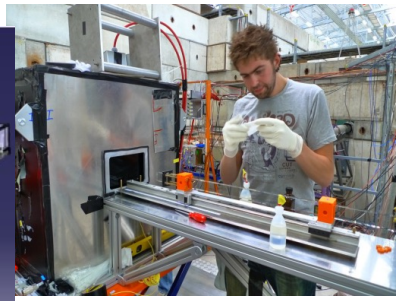




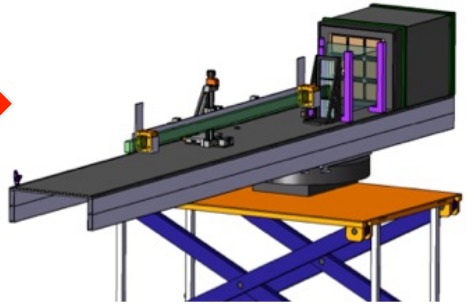


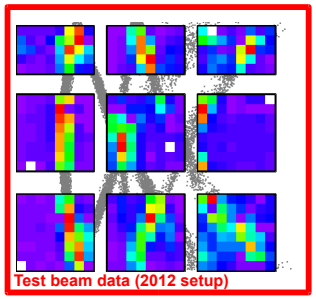
GSI, CERN
2011

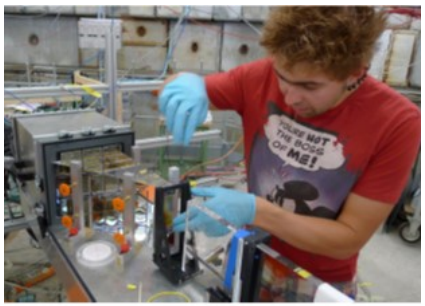




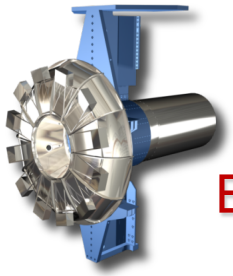
CERN
2012



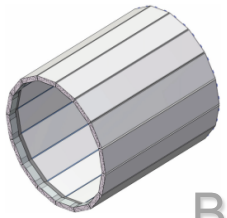




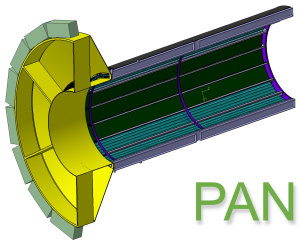
DIRC Landscape



BaBar DIRC



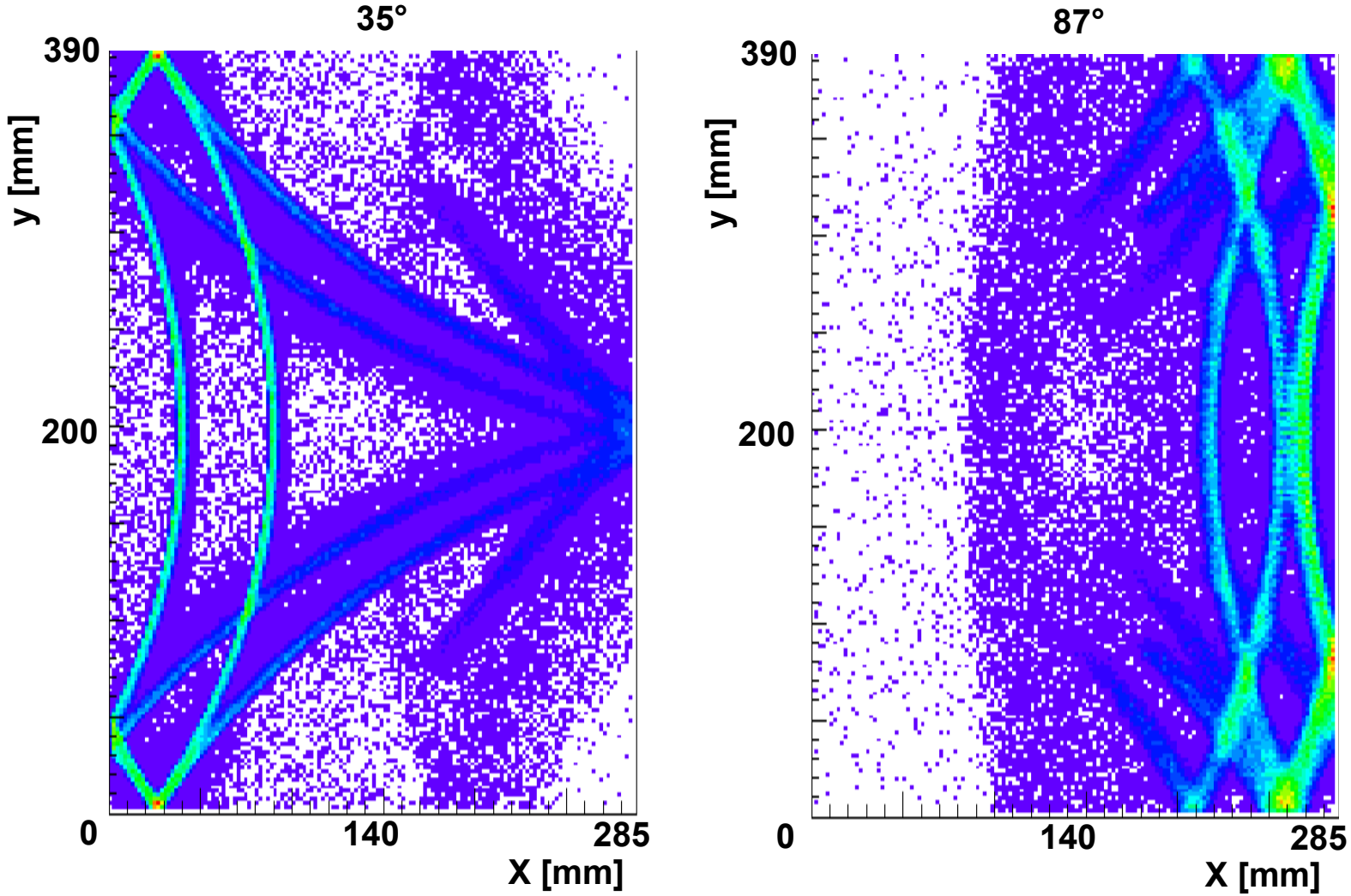
Belle II TOP



PANDA Barrel DIRC

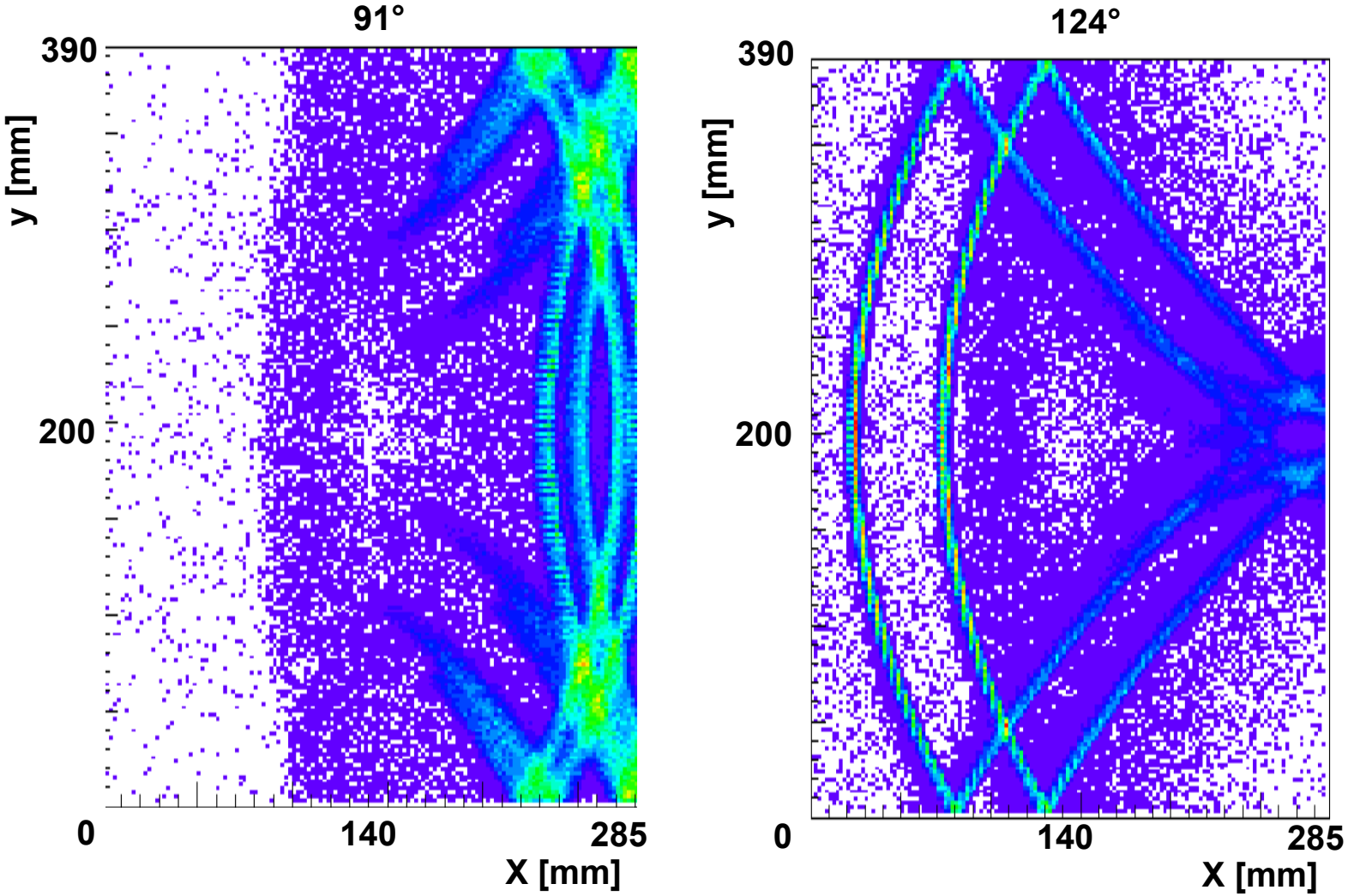
Radiator geometry	Narrow bars *(35mm)*	Wide plates *(450mm)*	Narrow bars *(32mm)*
Barrel radius	85cm	115cm	48cm
Bar length	490cm *(4×122.5cm)*	250cm *(2×125cm)*	240cm *(2×120cm)*
Number of long bars	144 *(12×12 bars)*	16 *(16×1 plates)*	80 *(16×5 bars)*
Expansion volume	110cm, ultrapure water	10cm, fused silica	30cm, mineral oil
Focusing	None (pinhole)	Mirror	Lens system
Photon detector	~11k PMTs	~8k MCP-PMT pixels	~15k MCP-PMT pixels
Timing resolution	~1.7ns	<0.1ns	~0.1ns
Pixel size	25mm diameter	5.5mm×5.5mm	6.5mm×6.5mm
PID goal	3 s.d. π/K to 4 GeV/c	3 s.d. π/K to 4 GeV/c	3 s.d. π/K to 3.5 GeV/c
Timeline	1999 - 2008	Installation 2015	Installation 2017/18

High-performance DIRC Hit Patterns



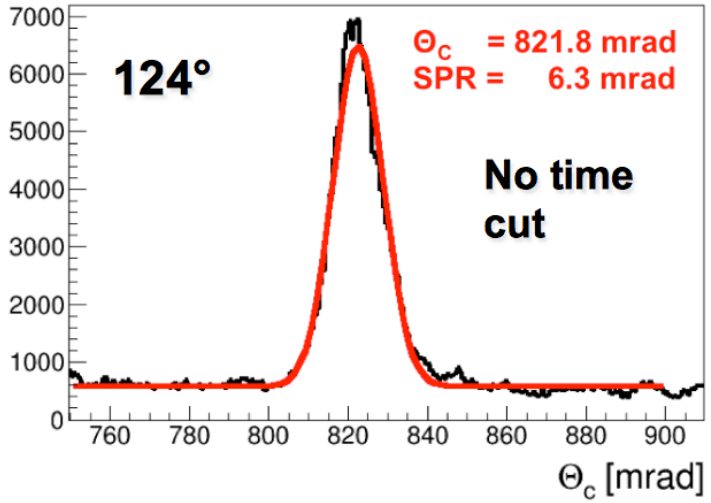
Simulated data

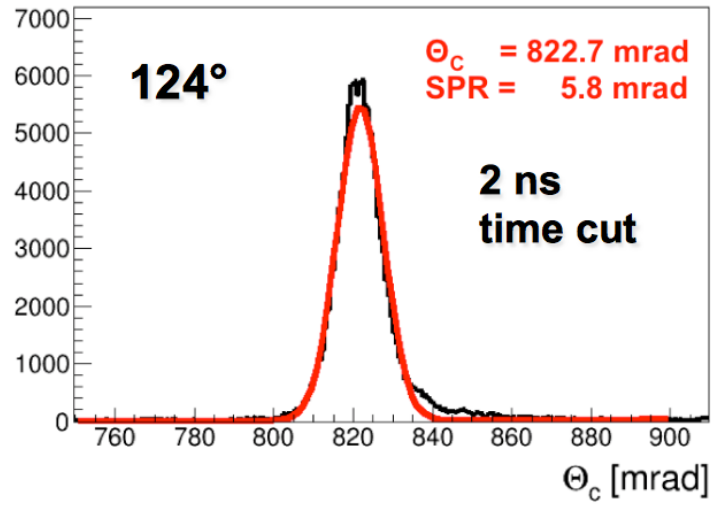
High-performance DIRC Hit Patterns

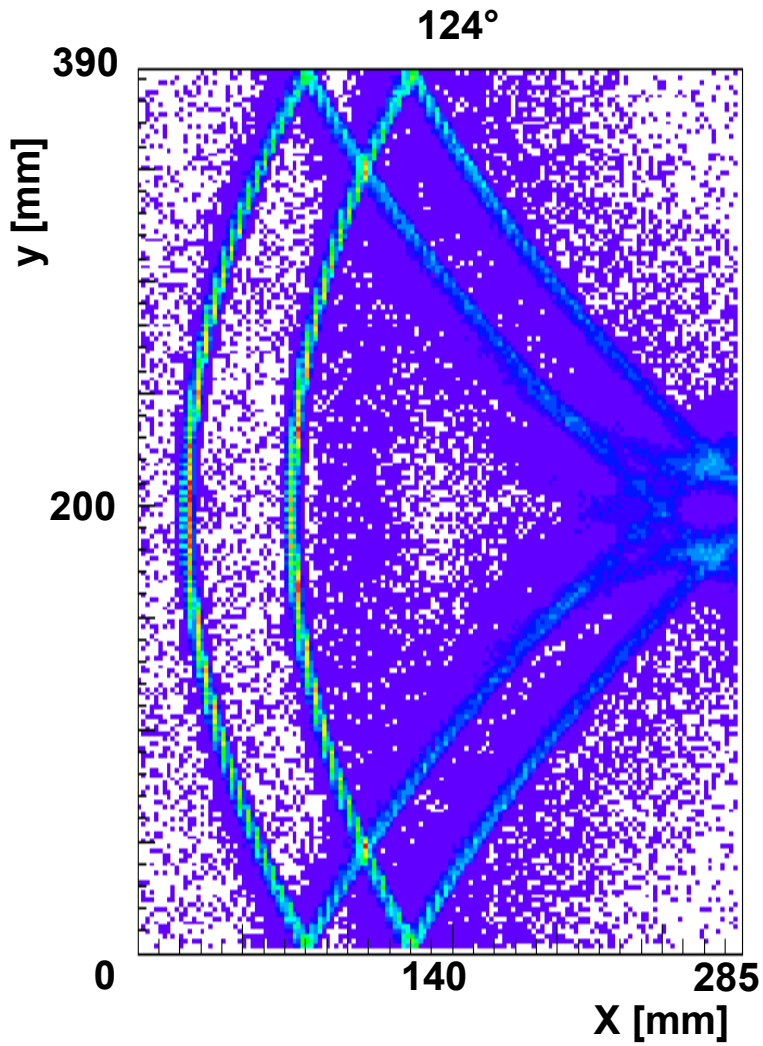


Simulated data

High-performance DIRC Single Photon Resolution



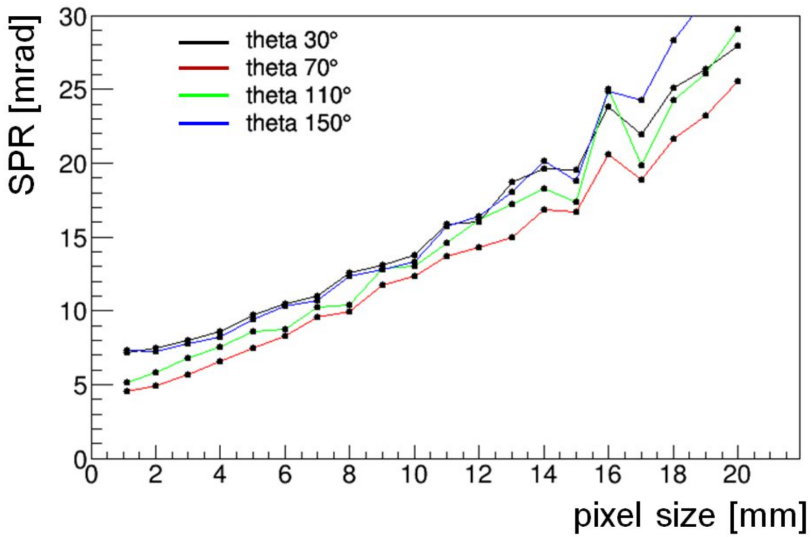


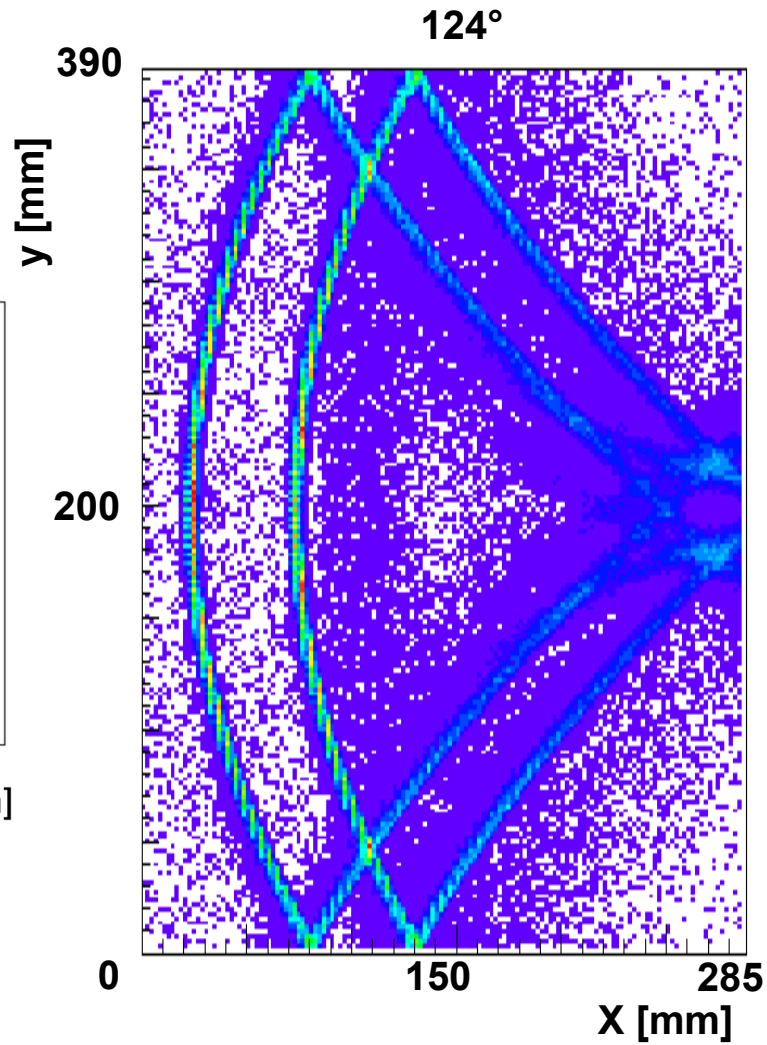


Simulated data

High-performance DIRC Single Photon Resolution (SPR)

Influence of the pixel size on SPR for selected track polar angles

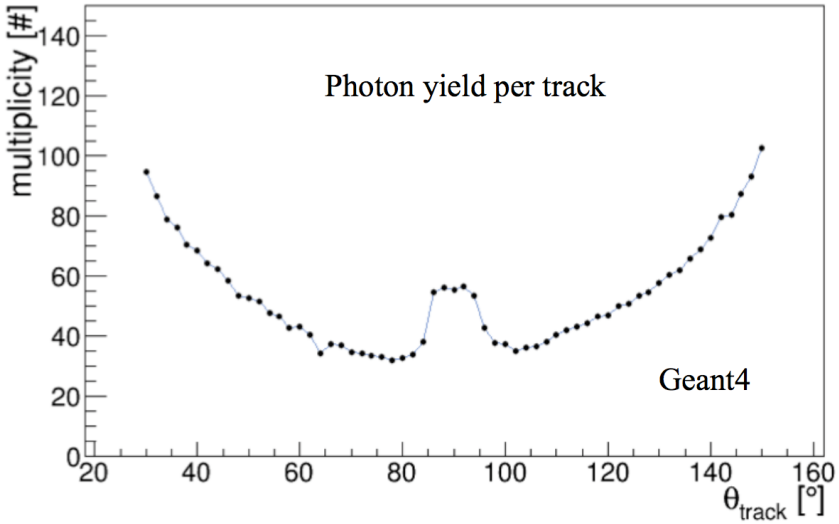


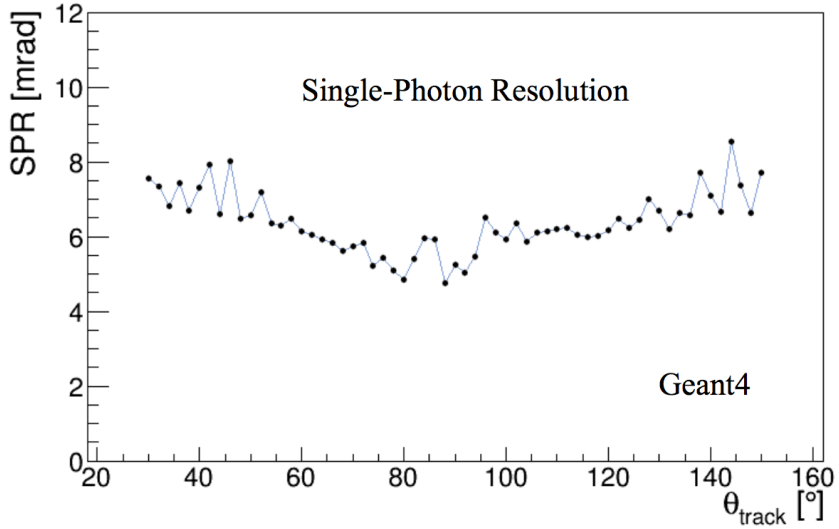


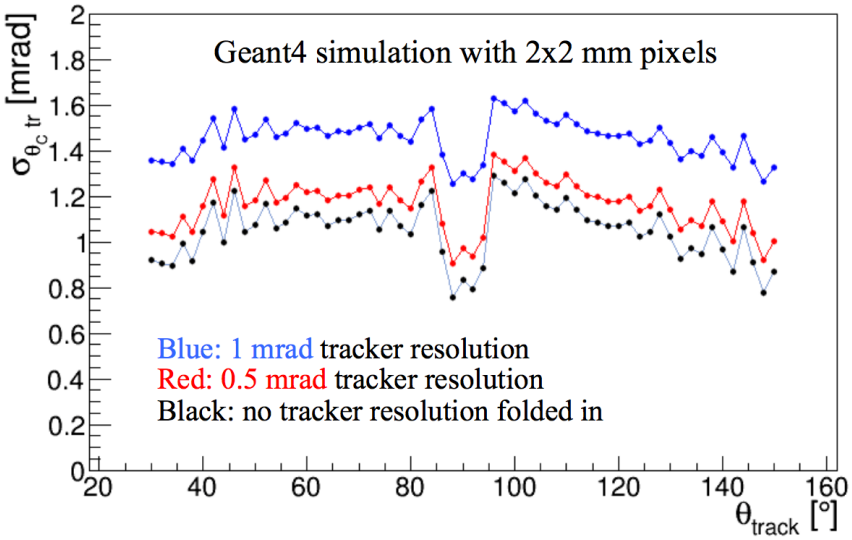
Simulated data

High-performance DIRC Track Resolution

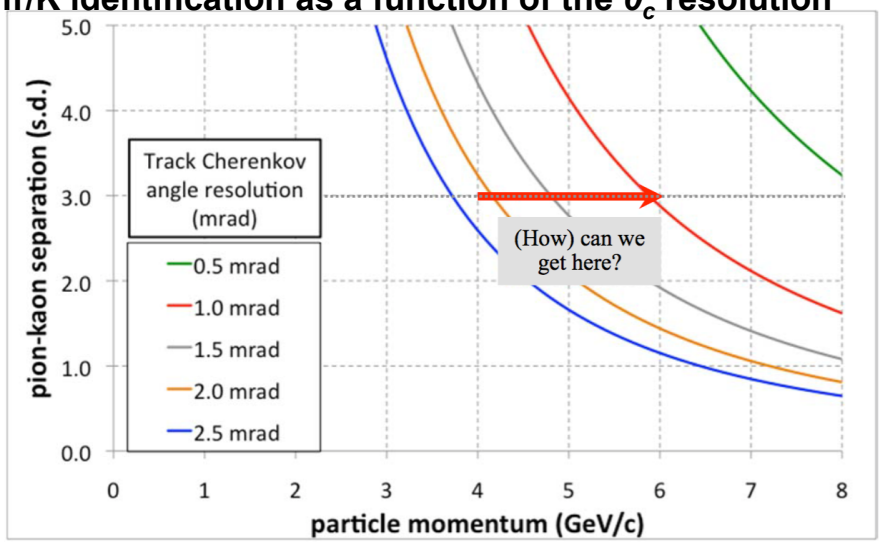
Simulated data







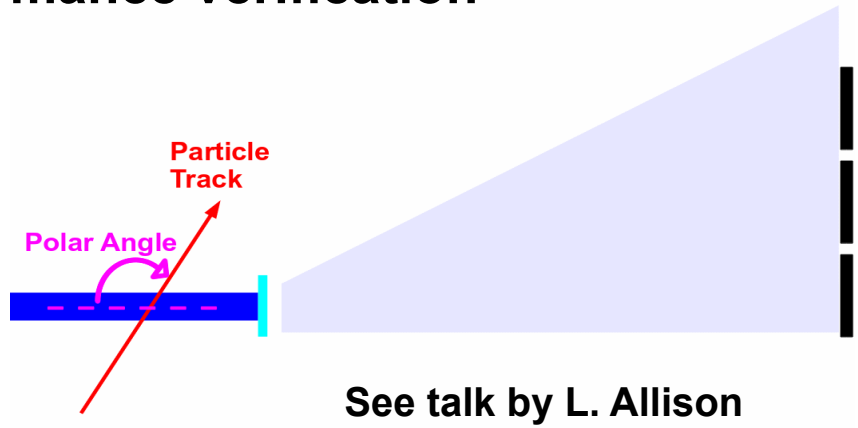
π/K identification as a function of the θ_c resolution



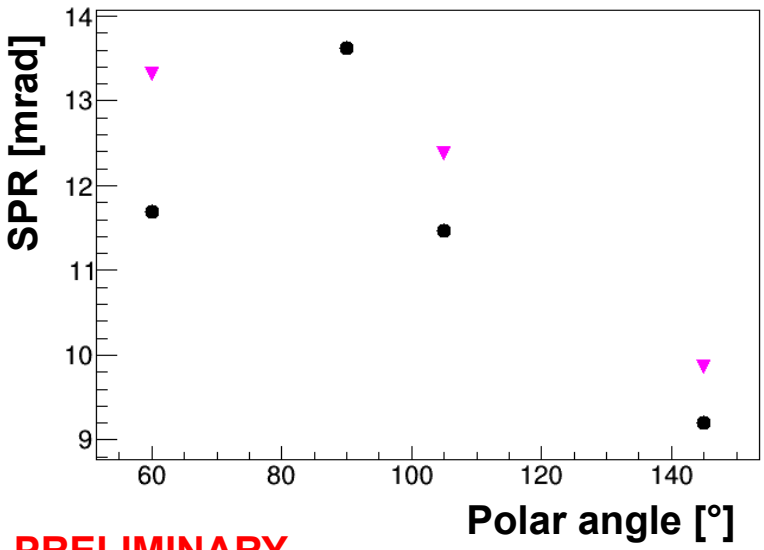
3-component Lens Performance verification

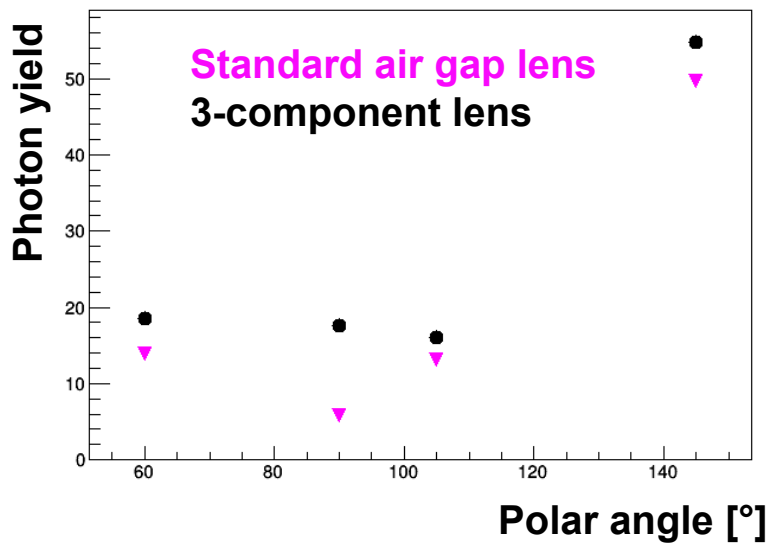
Comparison between standard air gap lens and 3 component lens

- 3CL improves both photon yield and resolution.



See talk by L. Allison





PRELIMINARY

Test beam data