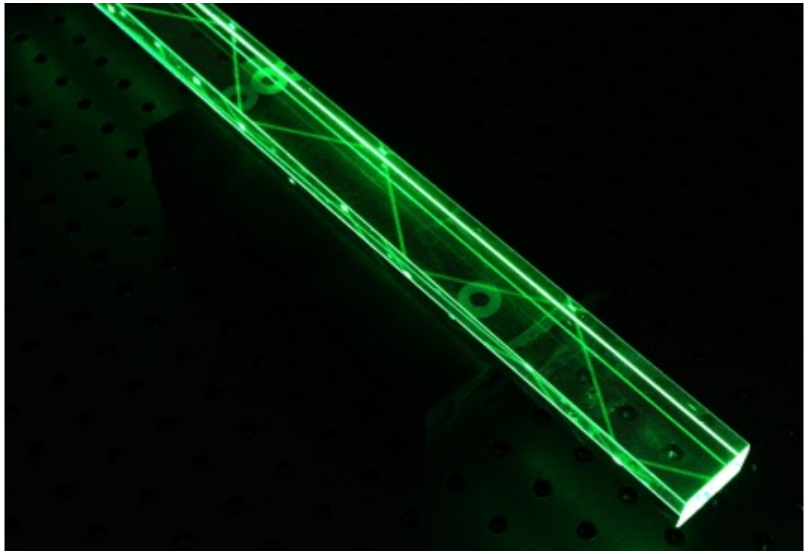
EIC DIRC

Greg Kalicy

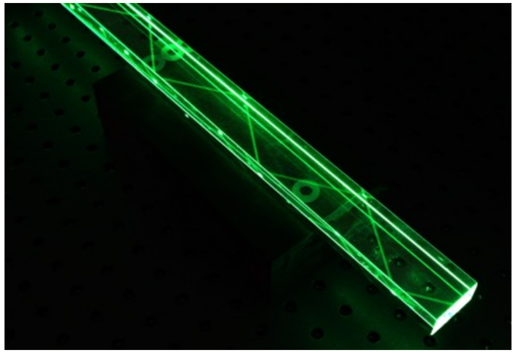


April 6, 2015

Outline

- **Basics**
  - DIRC concept
  - Reconstruction approach
- **Main Goals**
  - Investigate possibility of pushing state-of-the-art performance
  - Feasibility of using DIRC in EIC detector
  - Integration of DIRC with other systems
- **Ongoing activities**
  - Simulations with DrcProp and Geant
  - Prototype in particle beam
  - Component lab tests

Synthetic fused silica prototype bar



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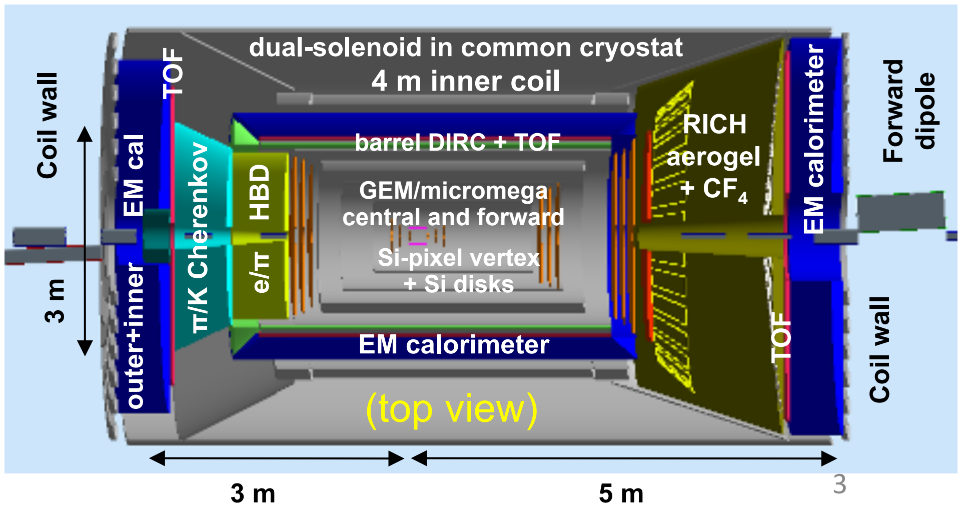
MEIC IP1detector



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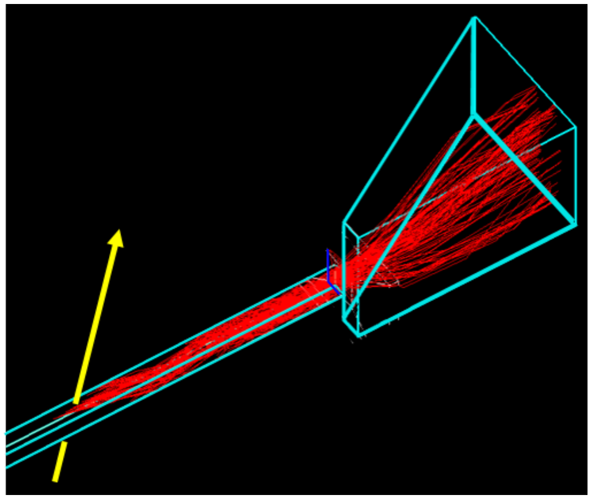
Simulation



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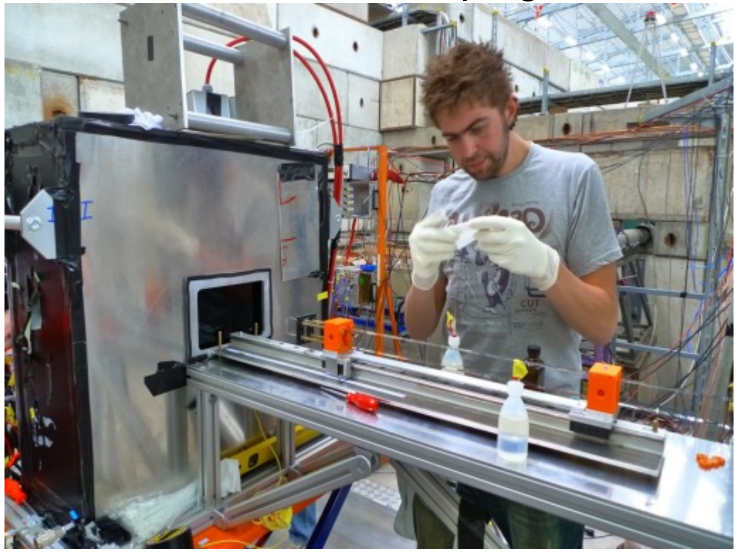
Full system prototype in CERN test beam campaign



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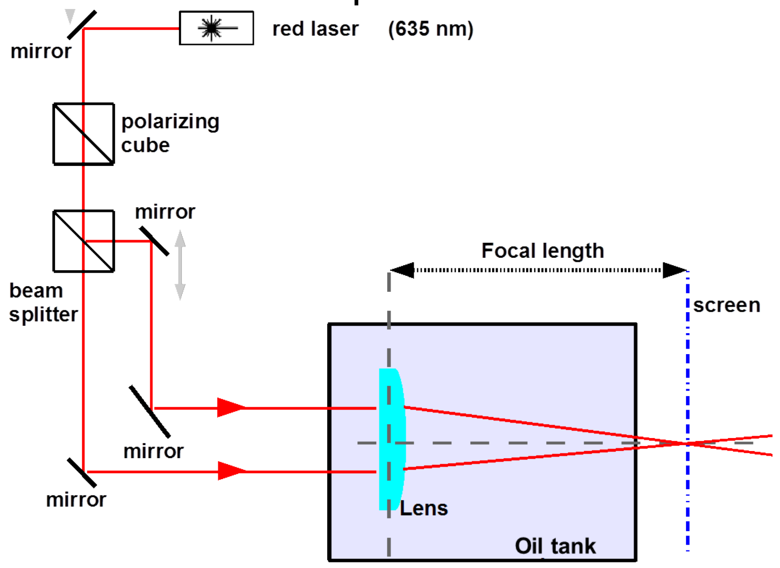
Setup to measure the shape of focal plane



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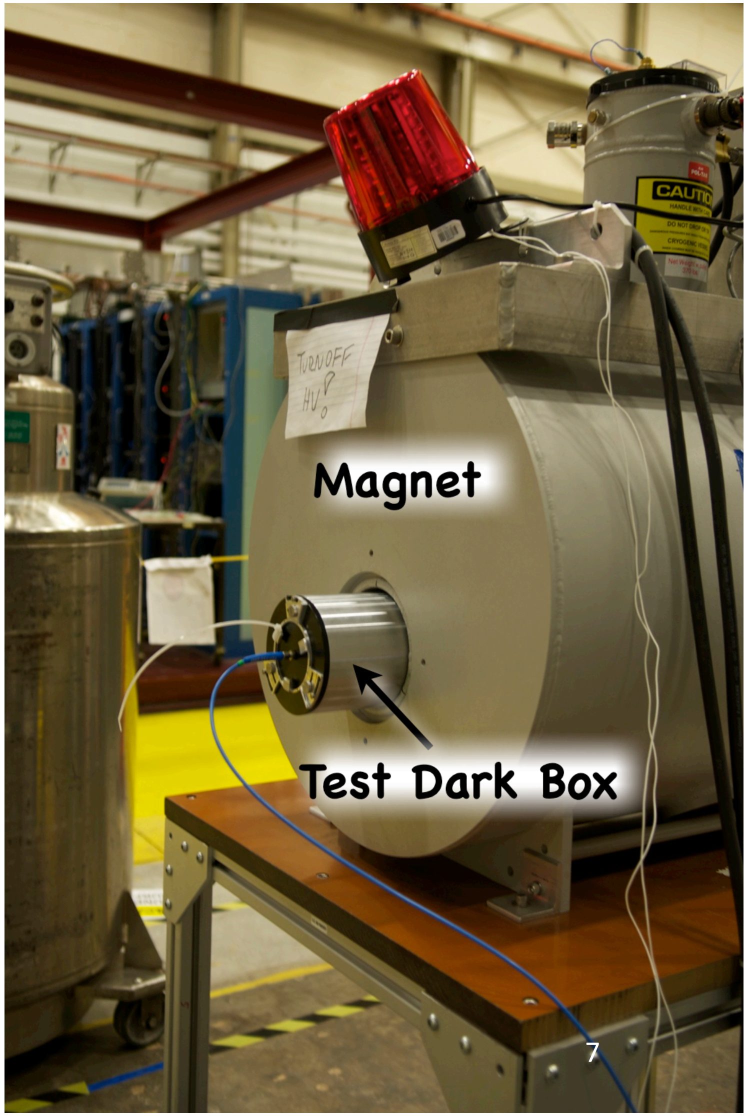
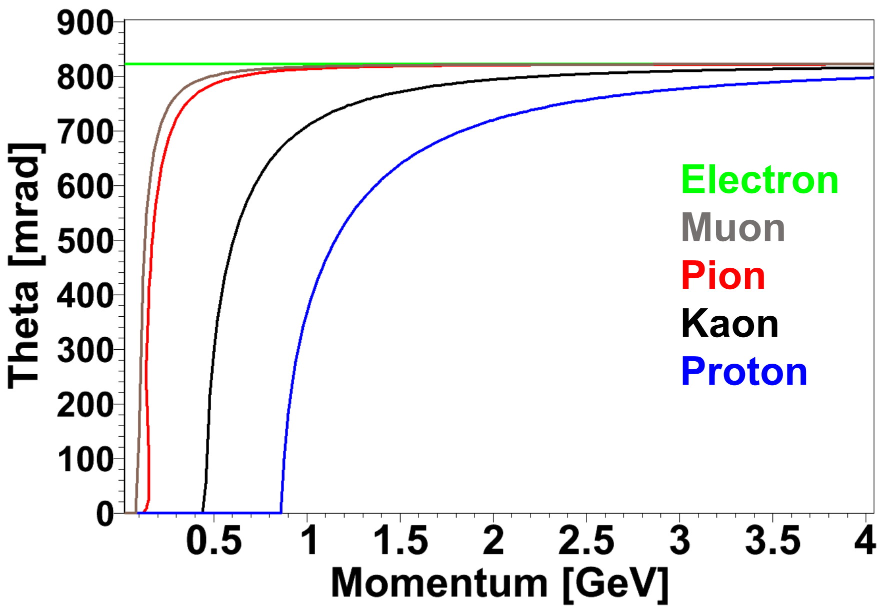
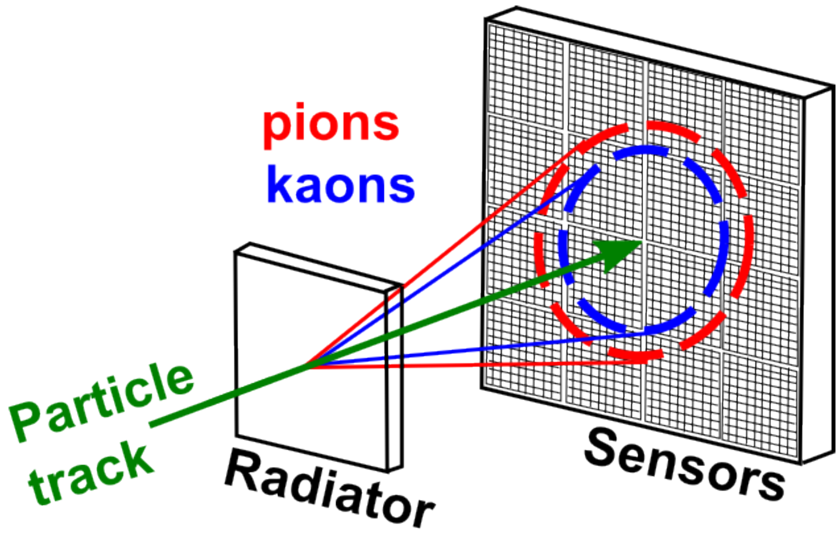
Setup to test photosensors in high magnetic field



Cherenkov Detectors

- **Main Cherenkov detector concepts in particle physics:**





➢ 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).

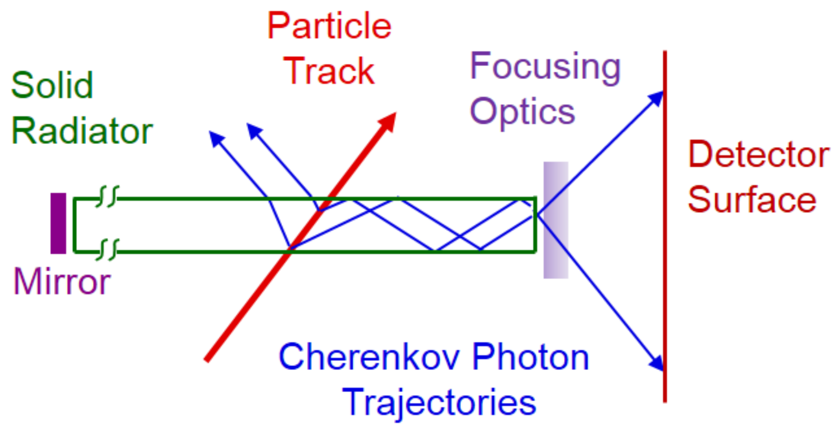
DIRC Detection of Internally Reflected Cherenkov Light

- Charged particle traversing radiator (with refractive index n) with velocity $\beta = \frac{v}{c}$ emits Cherenkov photons on cone with half opening angle: $cos\theta = \frac{1}{\beta n}$

- Cherenkov angle conserved during internal reflections of propagating photons.

- Photons exit radiator bars through focusing elements into expansion volume and are imaged on photon detector array.

- Photon detector array measures **x, y and time** of photons that exit radiator and defines **θ_c, φ_c and time of propagation of individual Cherenkov photons.**



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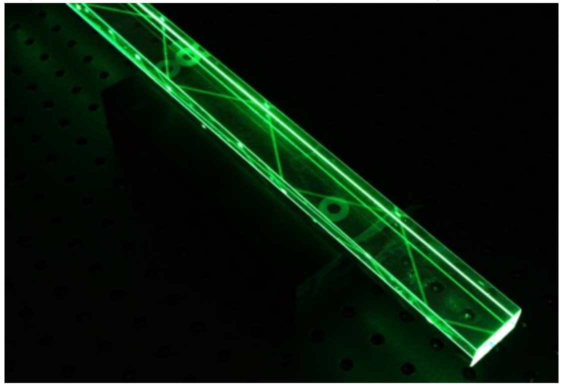
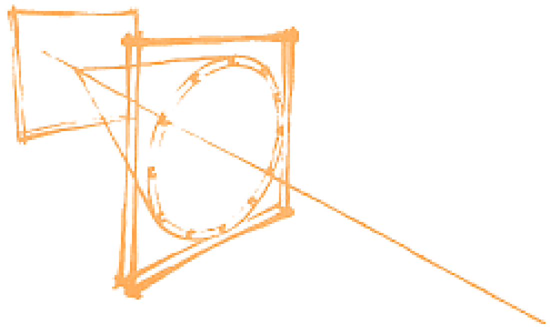
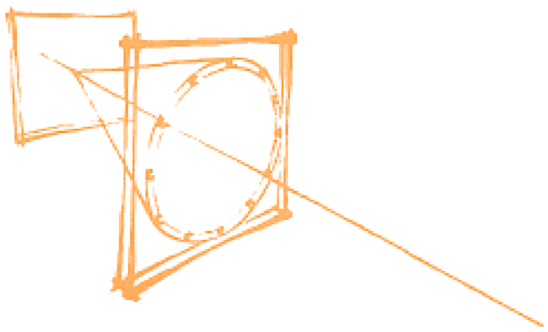


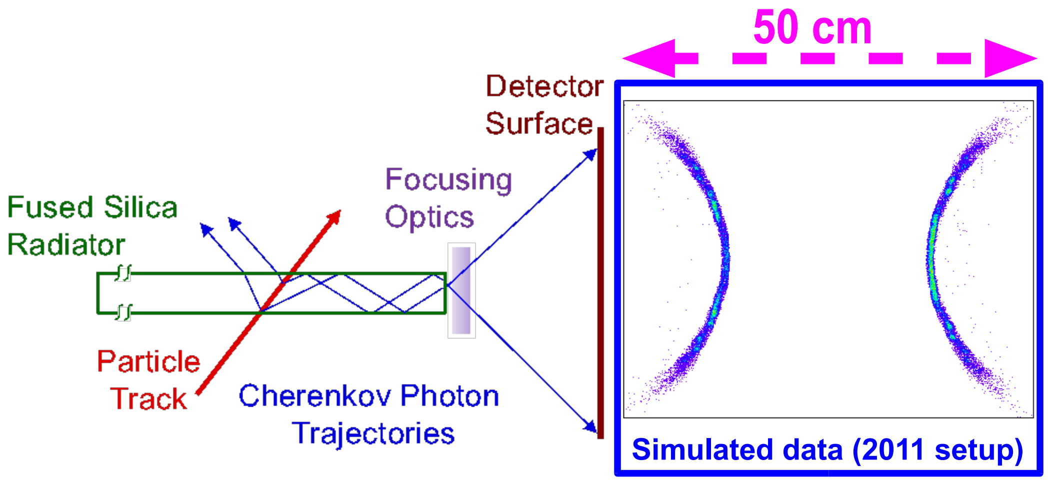
DIRC Example hit pattern



→ DIRC hit patterns do not look like typical RICH detector.

DIRC Example hit pattern

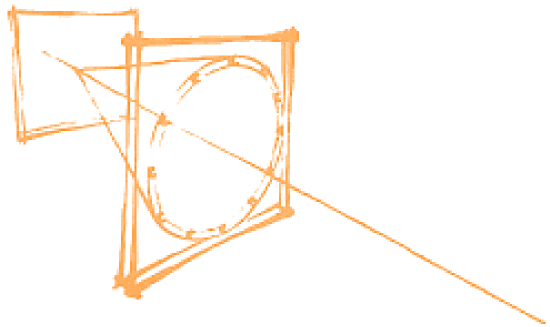


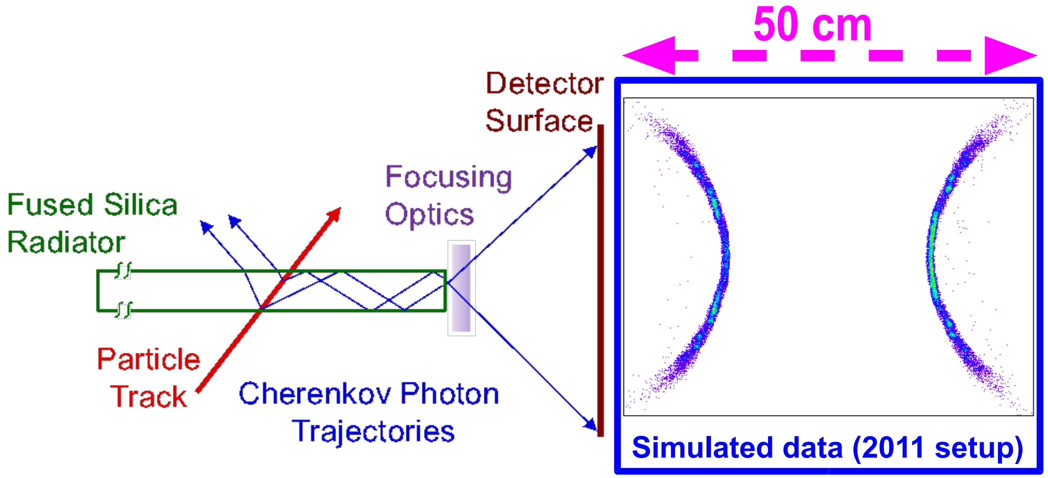


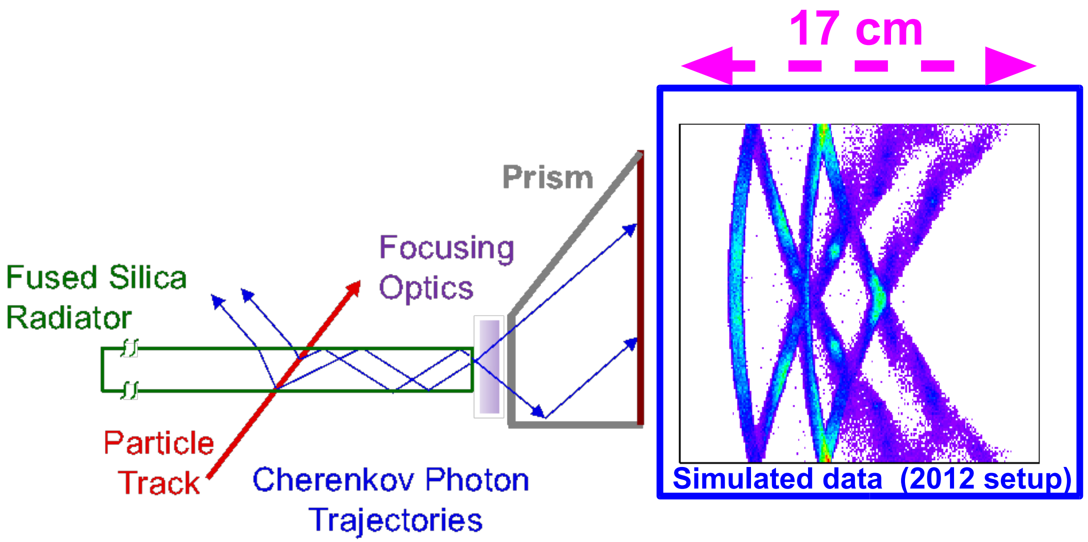
- DIRC hit patterns do not look like typical RICH detector.

- Part of the ring escapes, not totally internally reflected.
- Ring image gets folded due to propagation in bar/plate.

DIRC Example hit pattern

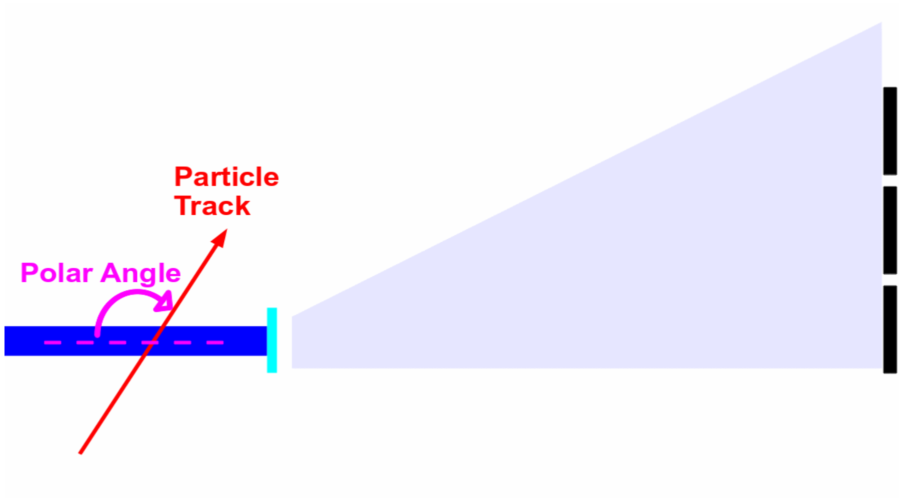






- DIRC hit patterns do not look like typical RICH detector.
- Part of the ring escapes, not totally internally reflected.
- Ring image gets folded due to propagation in bar/plate.
- Additional folding in the prism expansion volume.

DIRC Occupancy plot from experiment



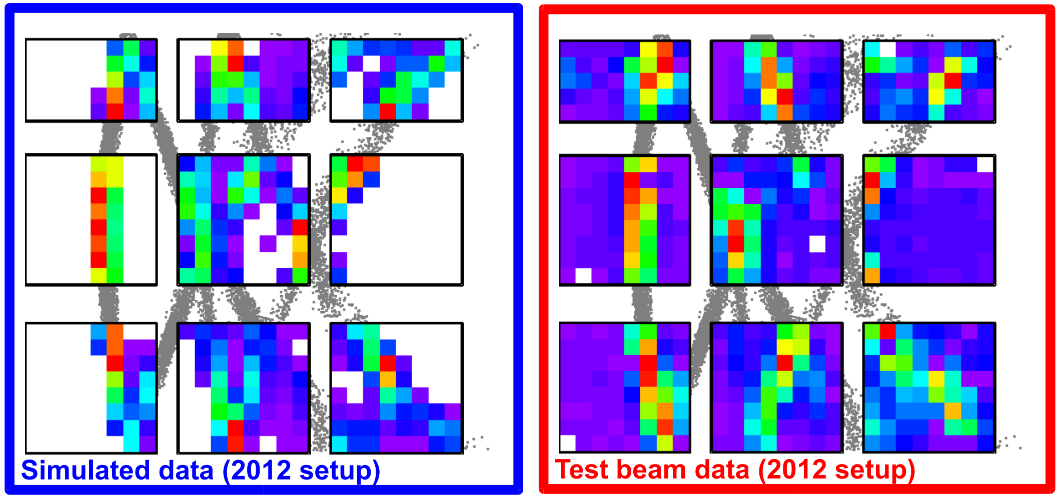
MCP-PMT array

Photonis Planacon
XP85012 (8 x 8 pixels)

122° polar angle

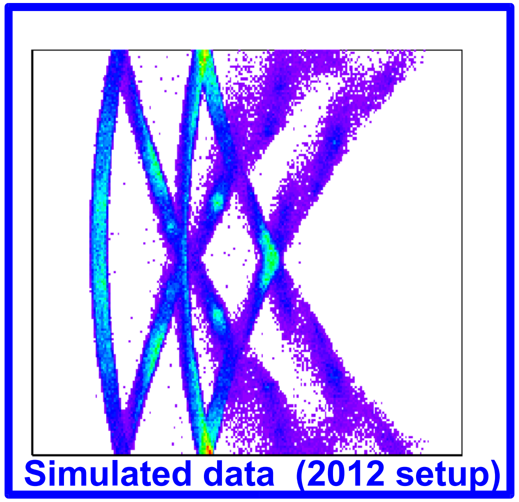
- Comparison of the **pixelized simulated data** to **test beam data.**

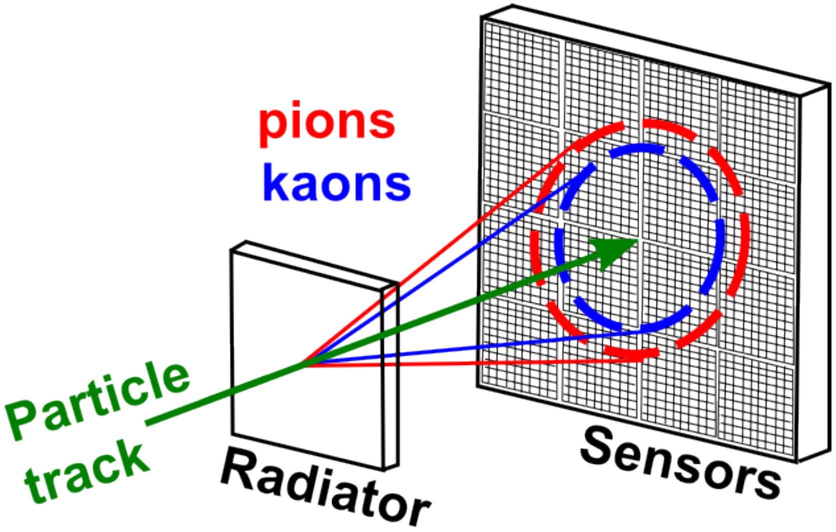
- Grey dots in the background are true hit positions from the simulation.



DIRC Example hit pattern

- **What is so challenging here?**
  - Ring segments corresponding to different particles are close and overlapping





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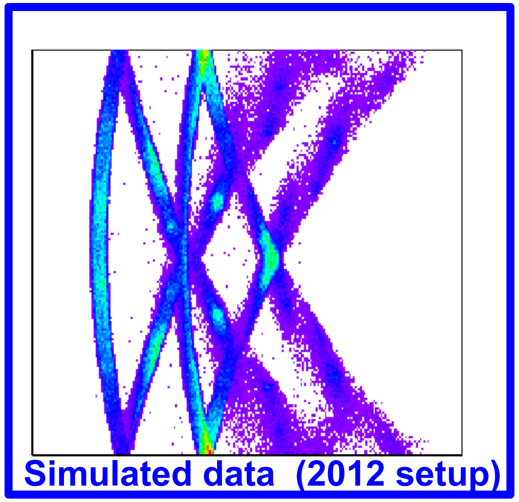
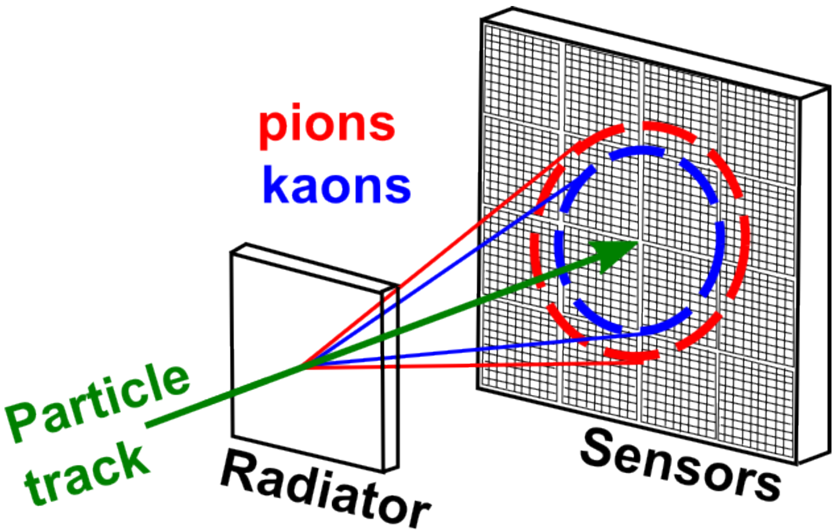
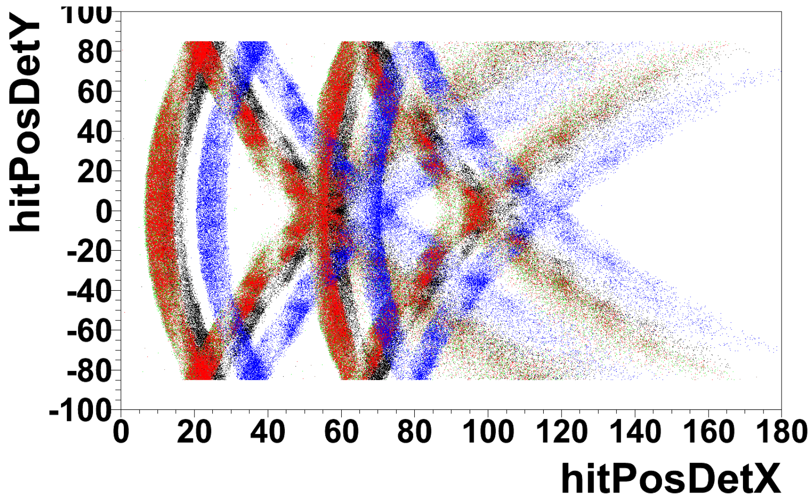


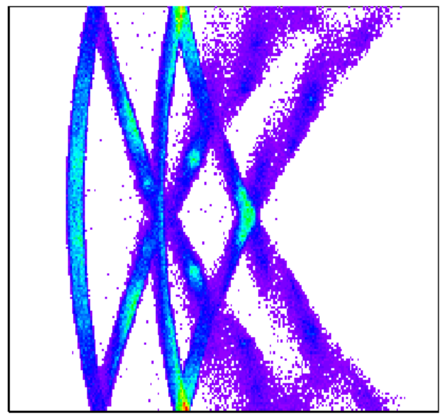


Pions vs Protons at 3 GeV/c.
210k accumulated events.
(Hit pattern from simulation)

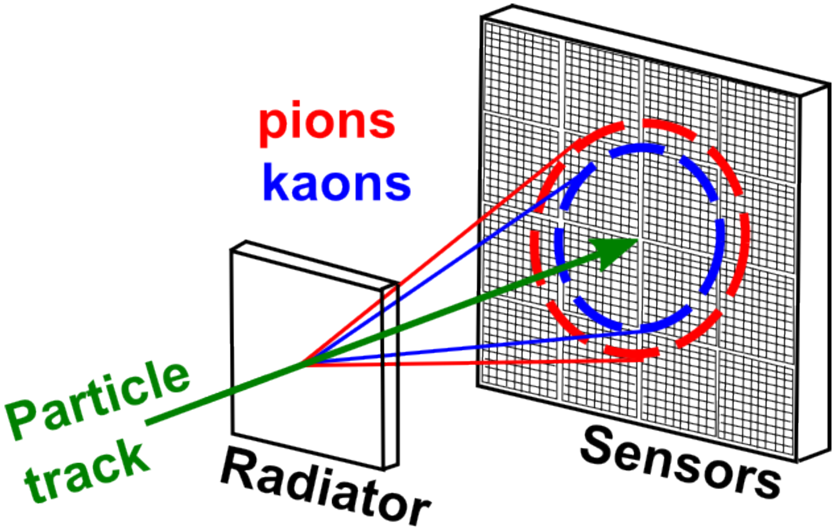


DIRC Example hit pattern

- **What is so challenging here?**
  - Ring segments corresponding to different particles are close and overlapping
  - Pixelated image (+ additional background)



Simulated data (2012 setup)



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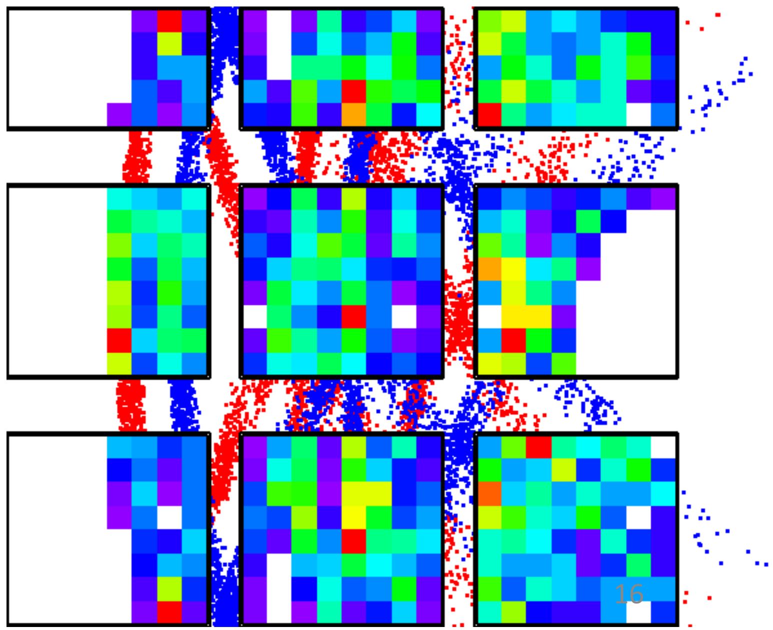
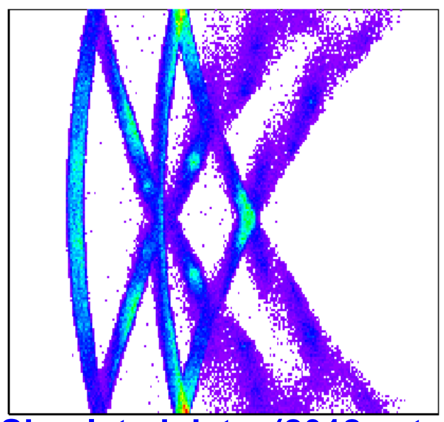


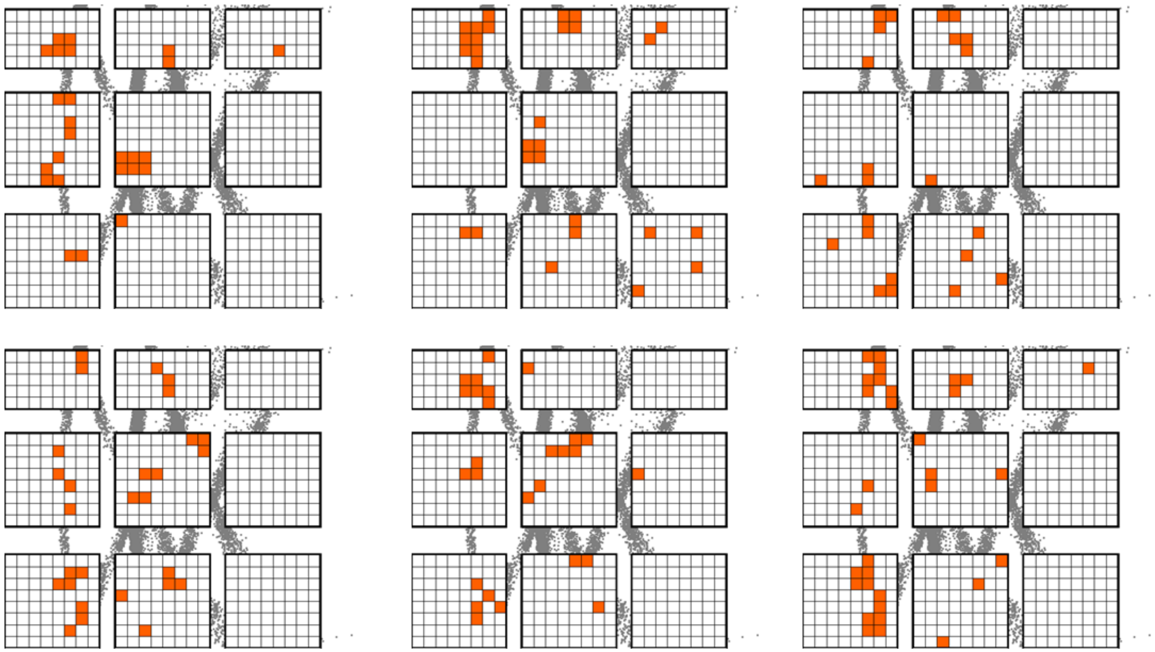
DIRC Example hit pattern

- **What is so challenging here?**
  - Ring segments corresponding to different particles are close and overlapping
  - Pixelated image (+ additional background)
  - Reconstruction from 20-50 photons per event



Simulated data (2012 setup)

Pions at 10 GeV/c. Example of 6 single events.
(Pixelated Hit pattern from simulation)



Barrel DIRC Expected performance

- Difference in Cherenkov angle between π and K at 4 GeV/c is 6.5 mrad

- Required per track resolution has to be 2 mrad or better

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

- $\sigma^{corelated} < 1.5 - 2\ mrad$ **Correlated term:**
  tracking detectors, multiple scattering

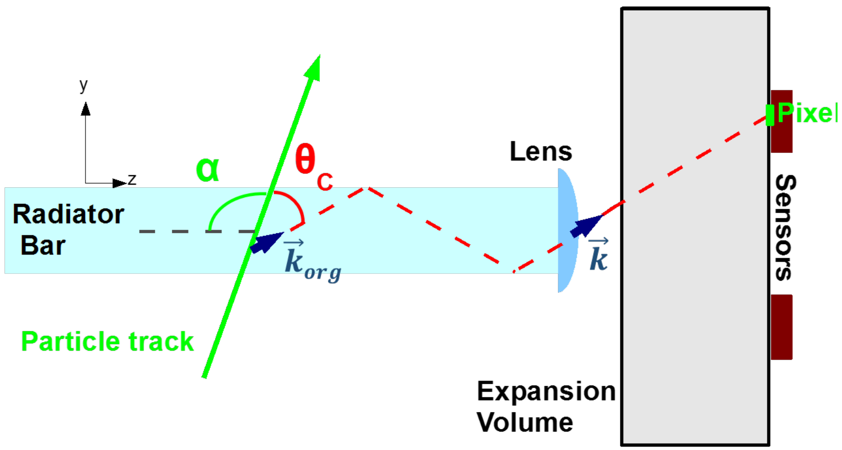
- $\sigma_{\Theta_C}^{photon} < 8 - 9\ mrad$ **Single photon Cherenkov angle resolution:**
  bar size, pixel size, chromatic, bar imperfections

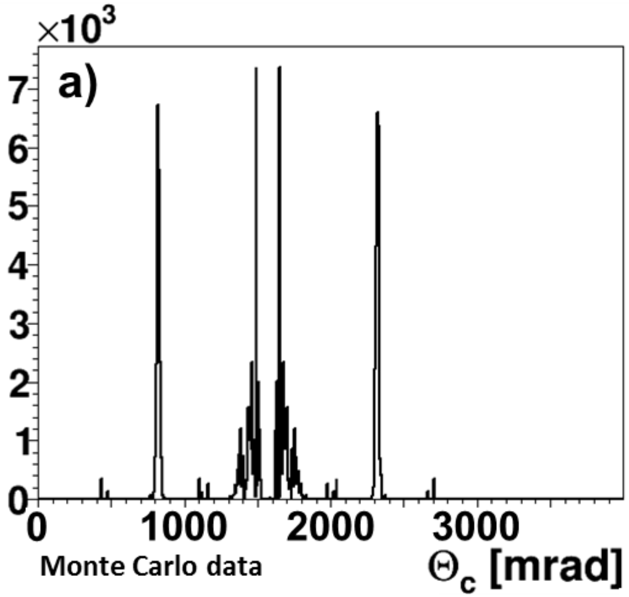
- $N_{pe} > 20$ **Number of photons:**
  bar size, bar imperfections, photon detection efficiency of the detector

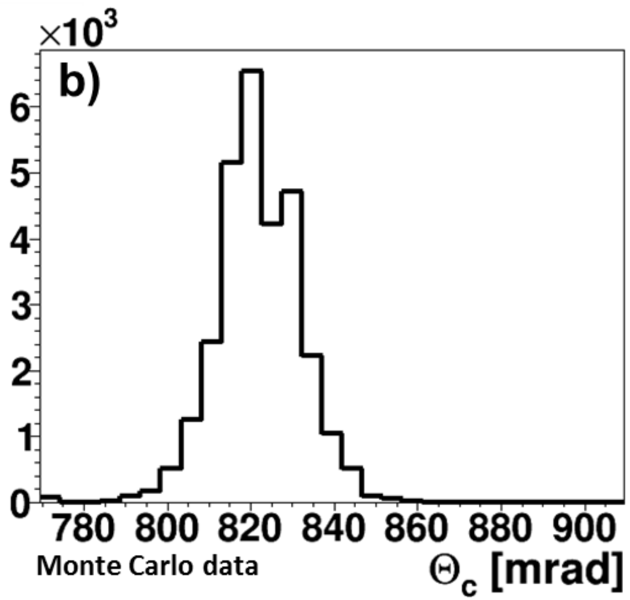
DIRC Cherenkov angle reconstruction method

- **Reconstruction method**
  Pixel position + bar location define photon direction at bar end, stored in Look-up table, combined with particle track to calculate Θ_C.

- **Photon path not unique**
  Additional combinatorial background in Θ_C







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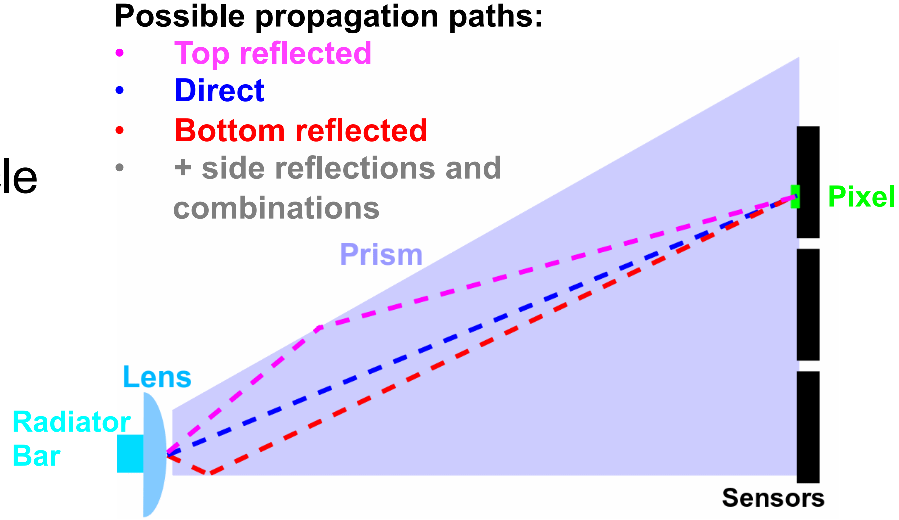
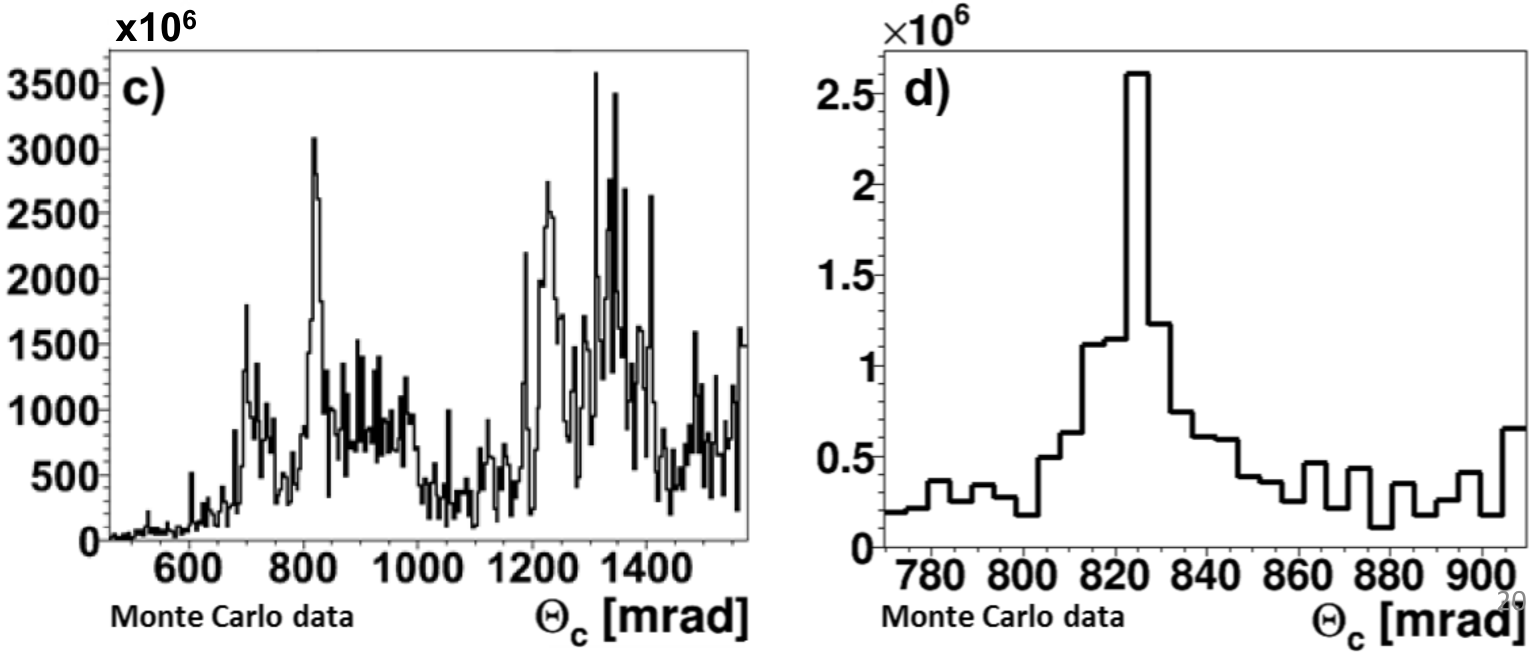




Improving DIRC Performance

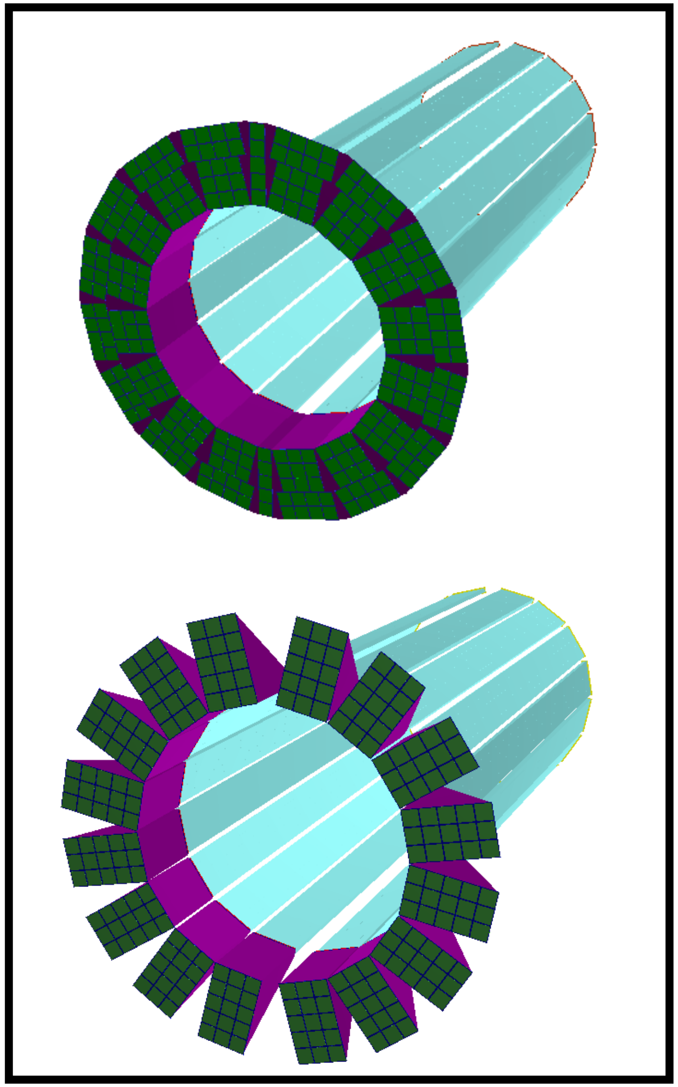
- **Make DIRC less sensitive to background**
  - decrease size of expansion volume
  - use photon detectors with smaller pixels and faster timing
  - place photon detector inside magnetic field
- **Investigate alternative radiator shapes** (plates, disks)
- **Push DIRC π/K separation by improving single-photon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

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

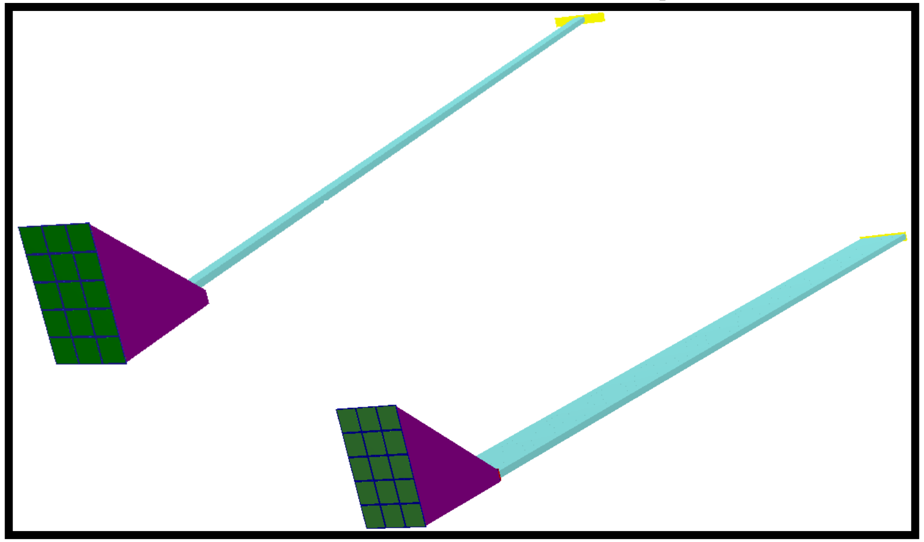
Limited in BABAR by:			Could be improved for new DIRCs via:
▪ size of bar image	~4.1 mrad	→	▪ focusing optics
▪ size of PMT pixel	~5.5 mrad	→	▪ smaller pixel size
▪ chromaticity ($n=n(\lambda)$)	~5.4 mrad	→	▪ better time resoluion
	9.6 mrad	→	**4-5 mrad** per photon → **< 1.5–2 mrad/tr.**

DIRC Design Options

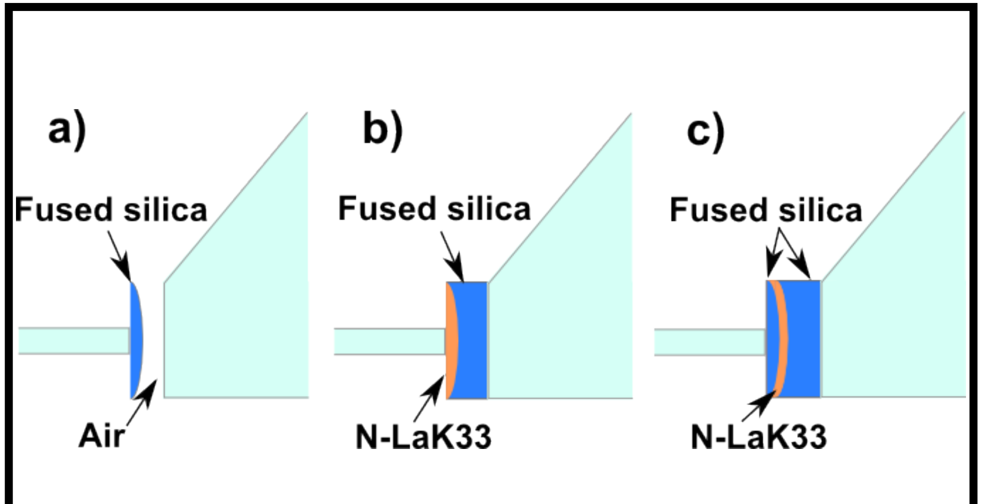
Expansion volume: oil tank/prism



Radiator: narrow bar/wide plate



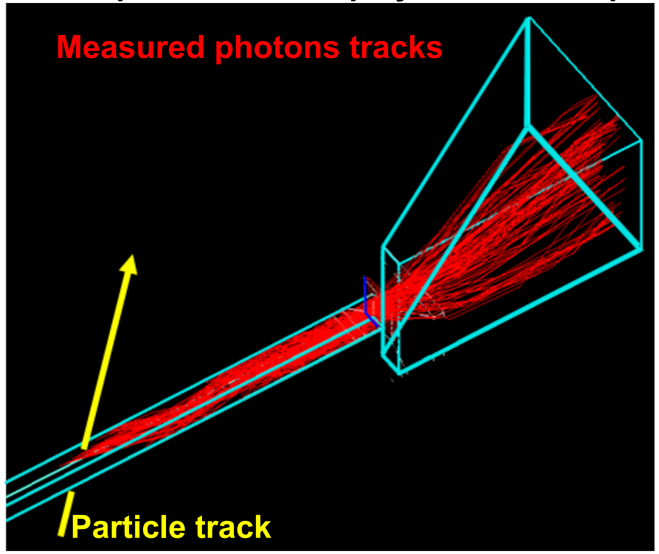
Focusing system: different lenses



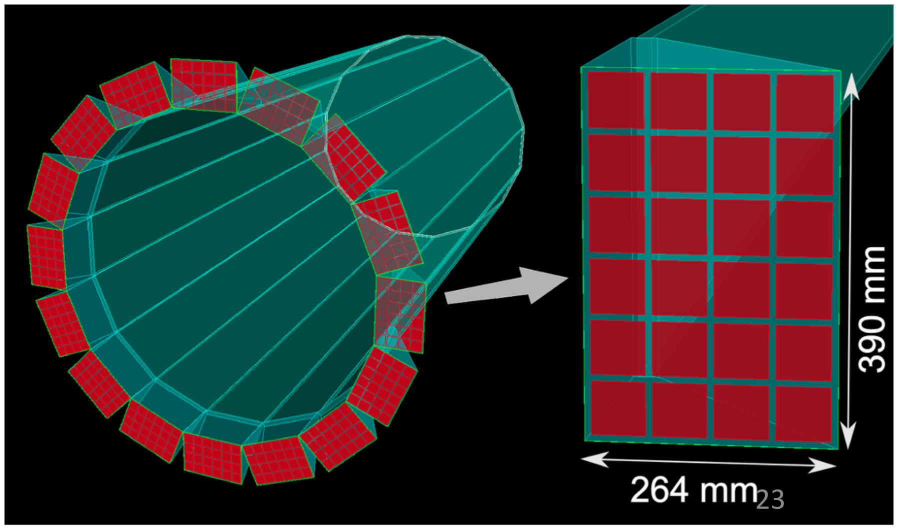
Monte Carlo Studies

- **DrcProp: stand-alone package for ray tracing simulations includes:**
  - Detector geometries
  - Beam properties
- **Stand alone Geant4 simulation package**
  - Physical processes
  - Will be integrated with MEIC
- **MEIC simulation**
  - EIC environment

Example of event display from DrcProp



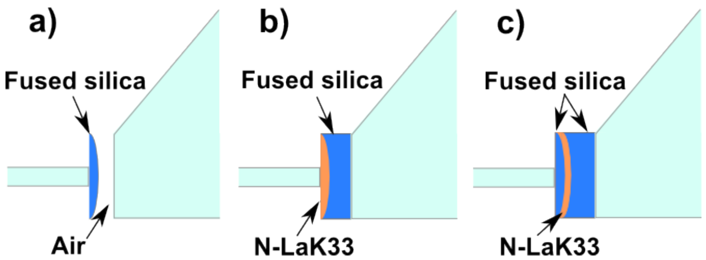
Geant4 simulation of plate and prism geometry

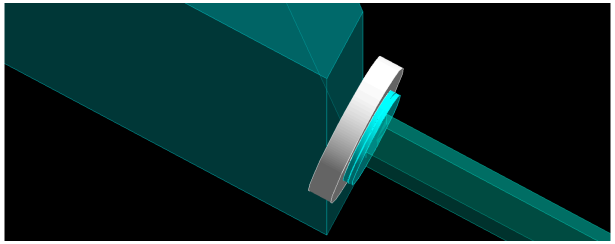


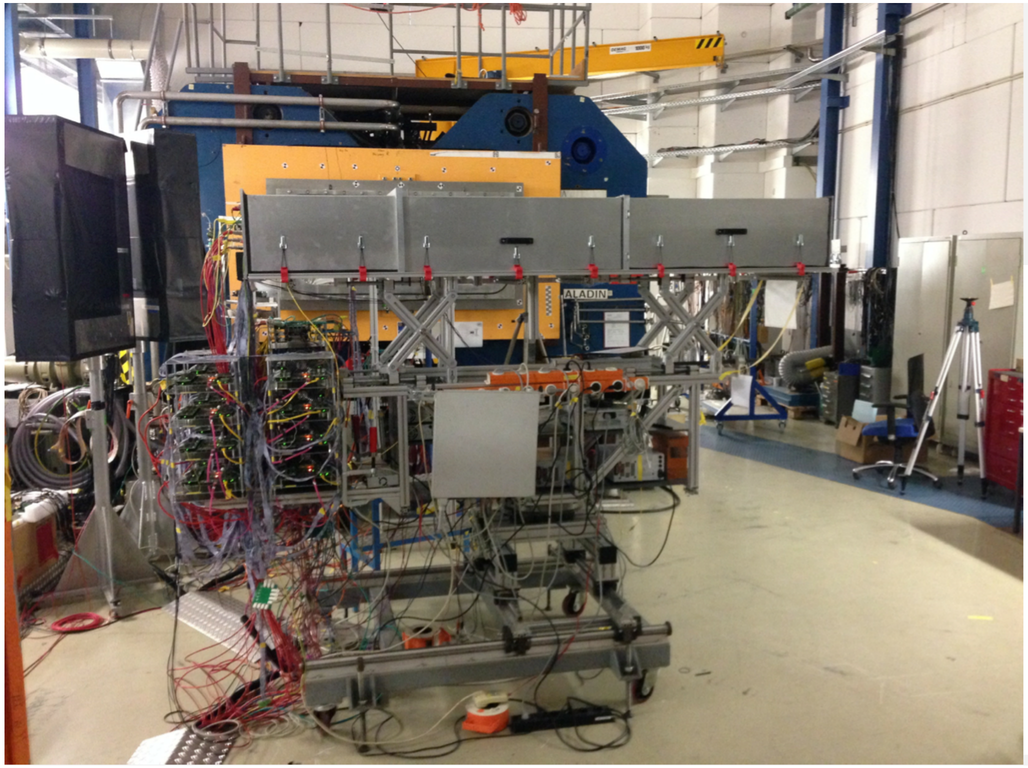
Focusing Prototype of 3-component lens

- Prototype of 3 component high refractive lens without air gap.

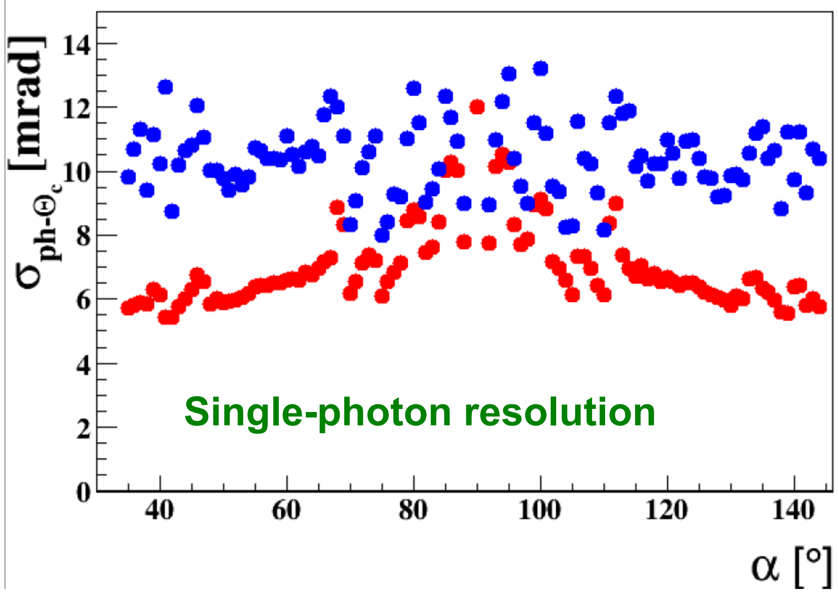
- Lens produced and already tested in particle beam with PANDA Barrel DIRC group

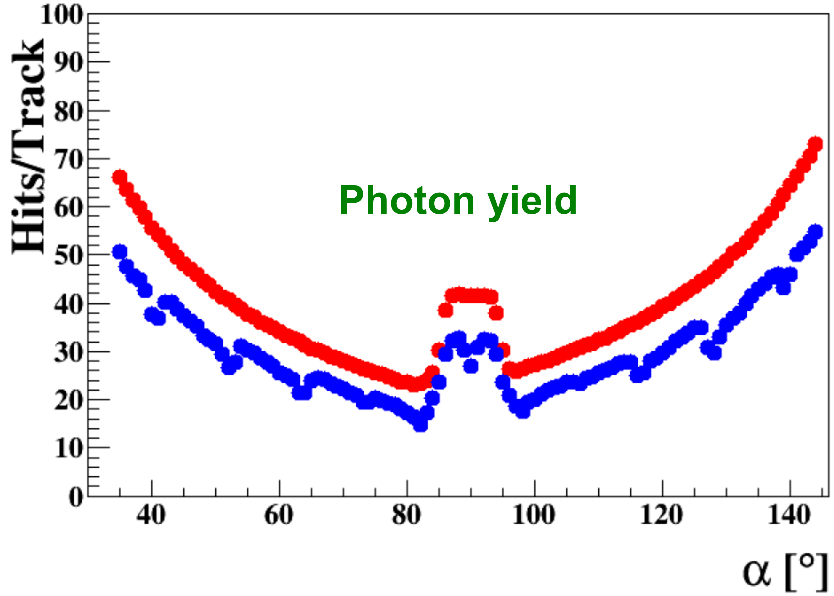


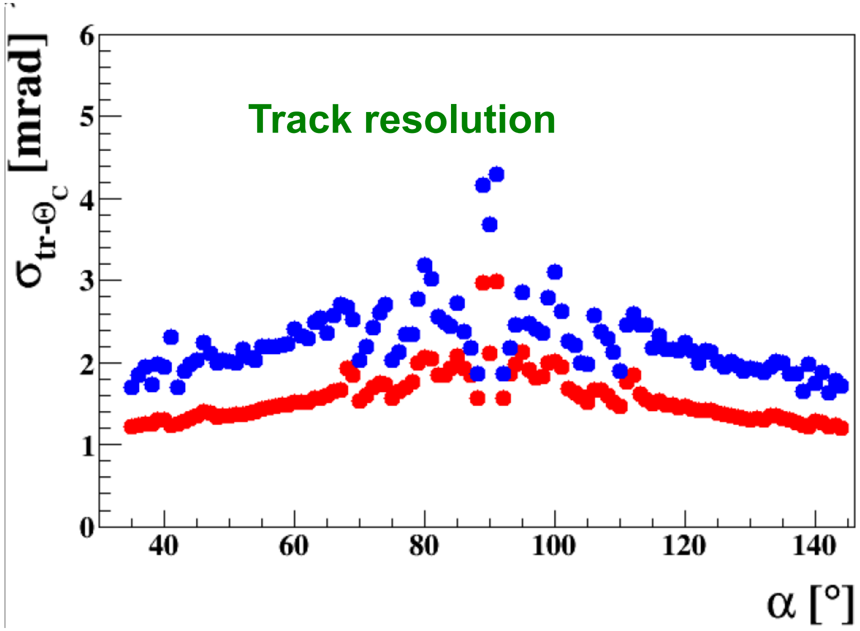




Focusing Simulation of 3-component lens



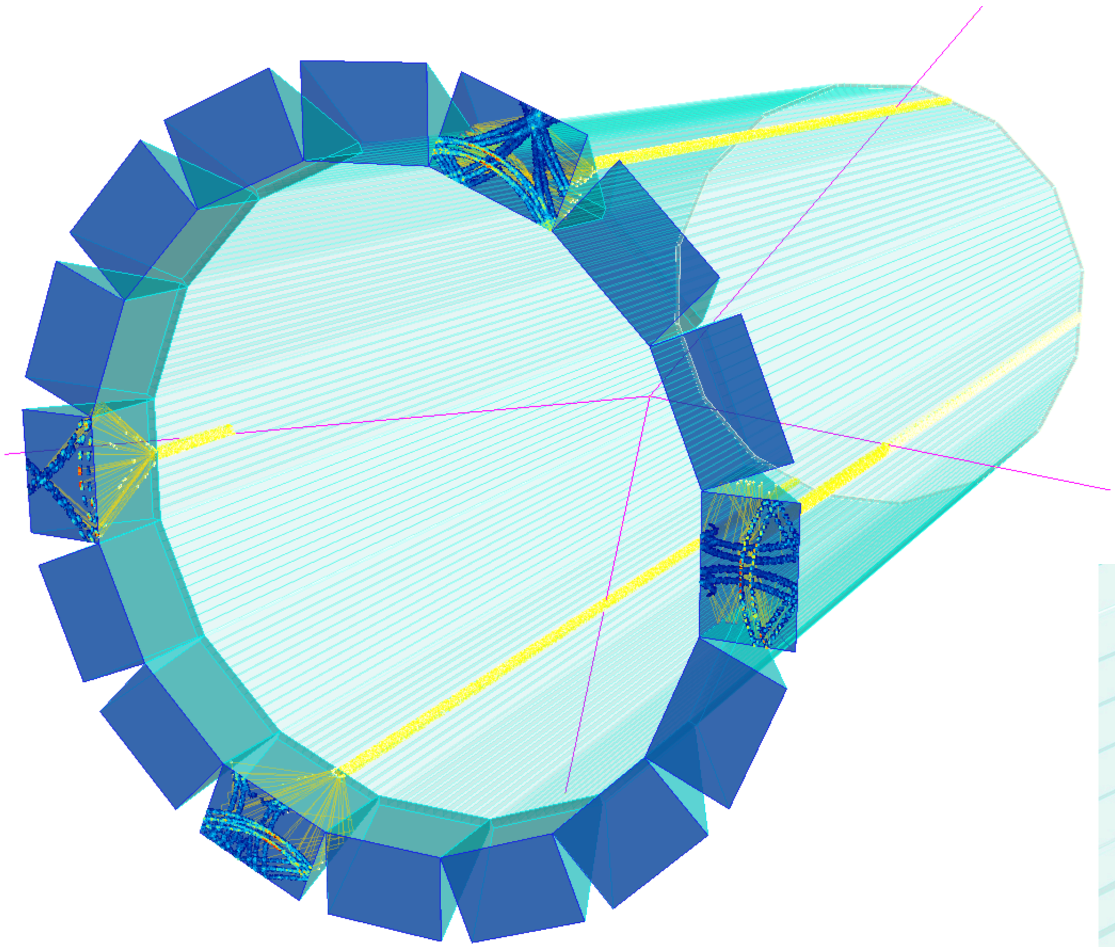


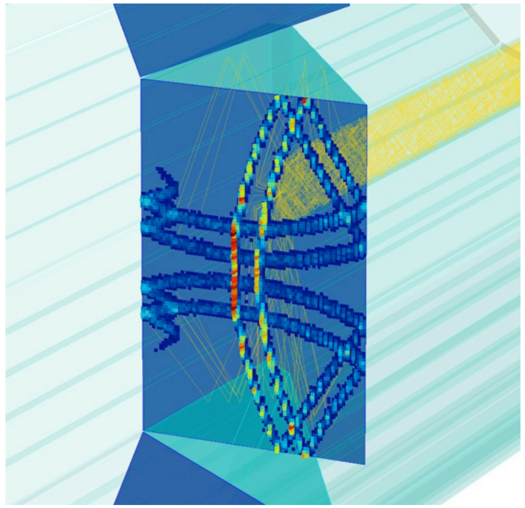


Procured 3-component lens, Planacon MCP
Procured 3-component lens, 2x2 mm MCP

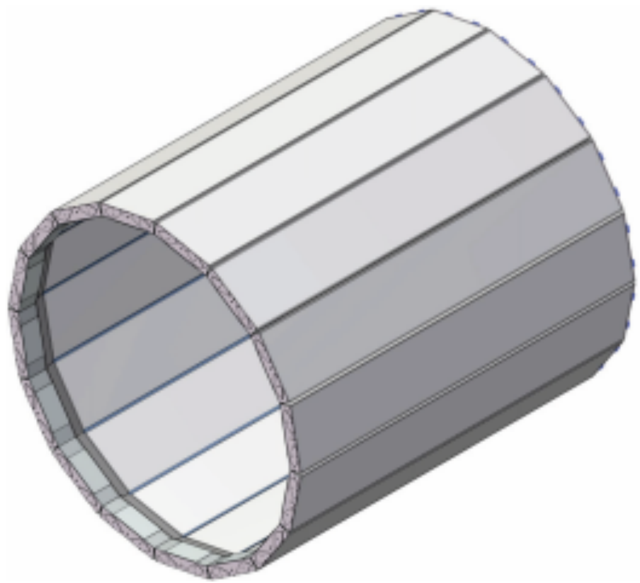
- A high-performance DIRC will require new small-pixel photosensors.
- The simulation confirms that a resolution close to 1 mrad (6 GeV/c) can be reached at forward (and backward) angles.

To be continued…

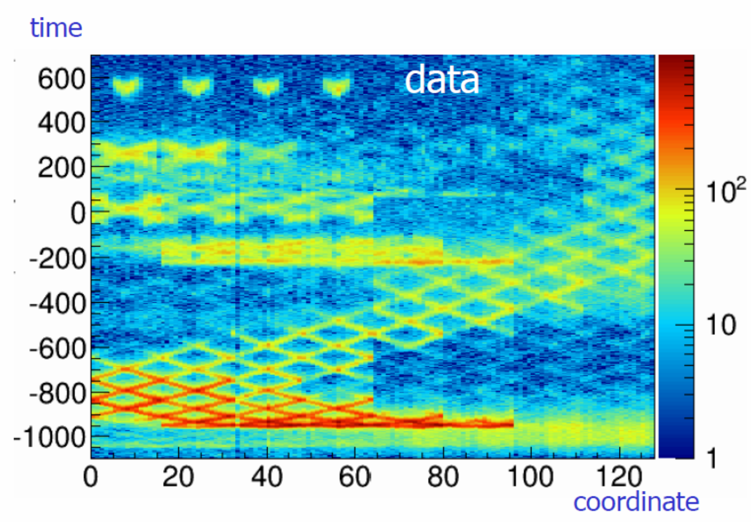


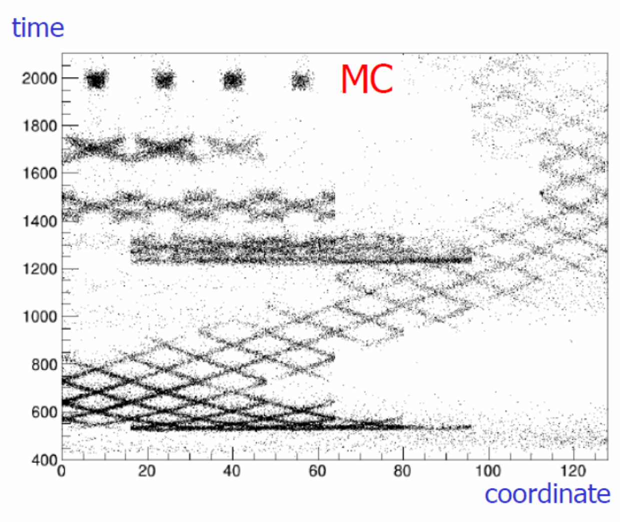


Other DIRCs BELLE II TOP

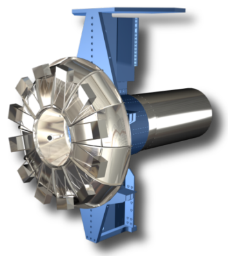


- **Belle II TOP** is barrel DIRC-type RICH with emphasis on fast timing
- **PID goal:** 3σ π/K separation for p < 4 GeV/c
- **Radiator:** fused silica plate 45cm wide, 2cm thick, 250cm long.
- TOP barrel formed by 16 plates
- Small expansion volume (10cm depth)
- **Photon detector:** array of 32 Hamamatsu SL-10 MCP-PMTs per sector, 512 in total

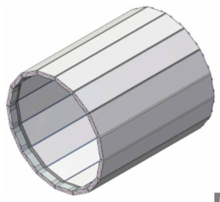




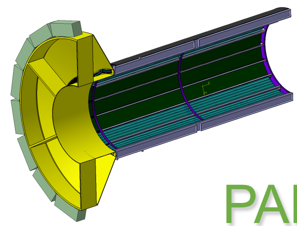
Barrel DIRCs



BABAR DIRC



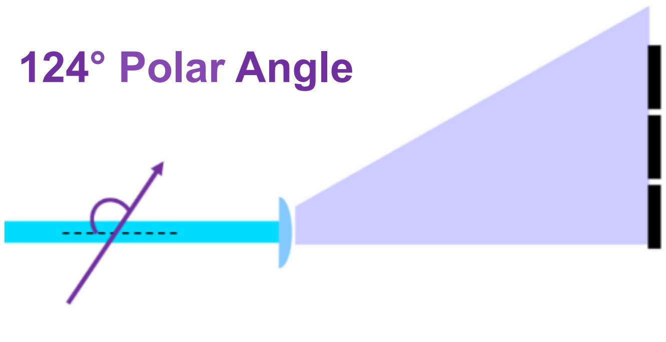
BELLE II TOP

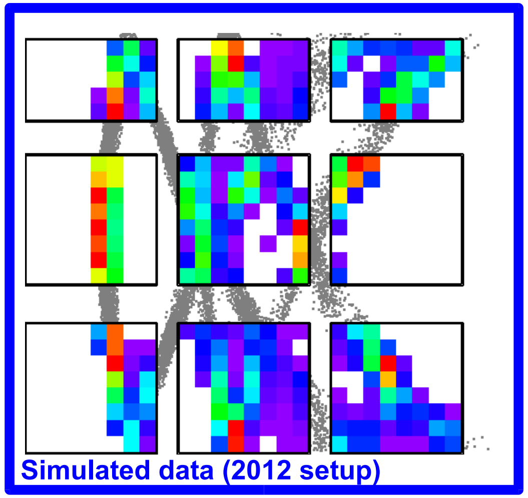


PANDA BARREL DIRC

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

DIRC Example of number of hits per track

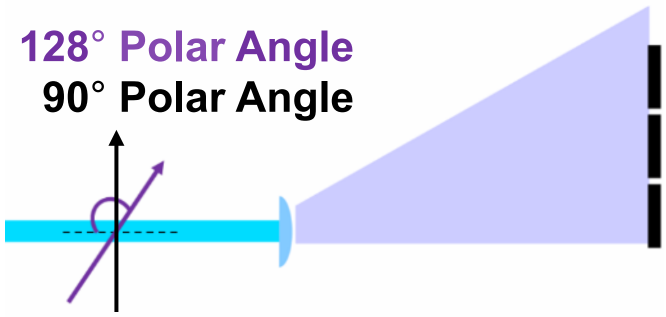




~20 photons per track predicted by simulation at 124° polar angle, 10 GeV/c momentum beam.

- 908 photons generated per track
- ~59% of photons propagate to the end of the bar.
- ~25% enter expansion volume.
- ~19% reach photo cathode of MCP-PMTs.
- ~2.2% detected.

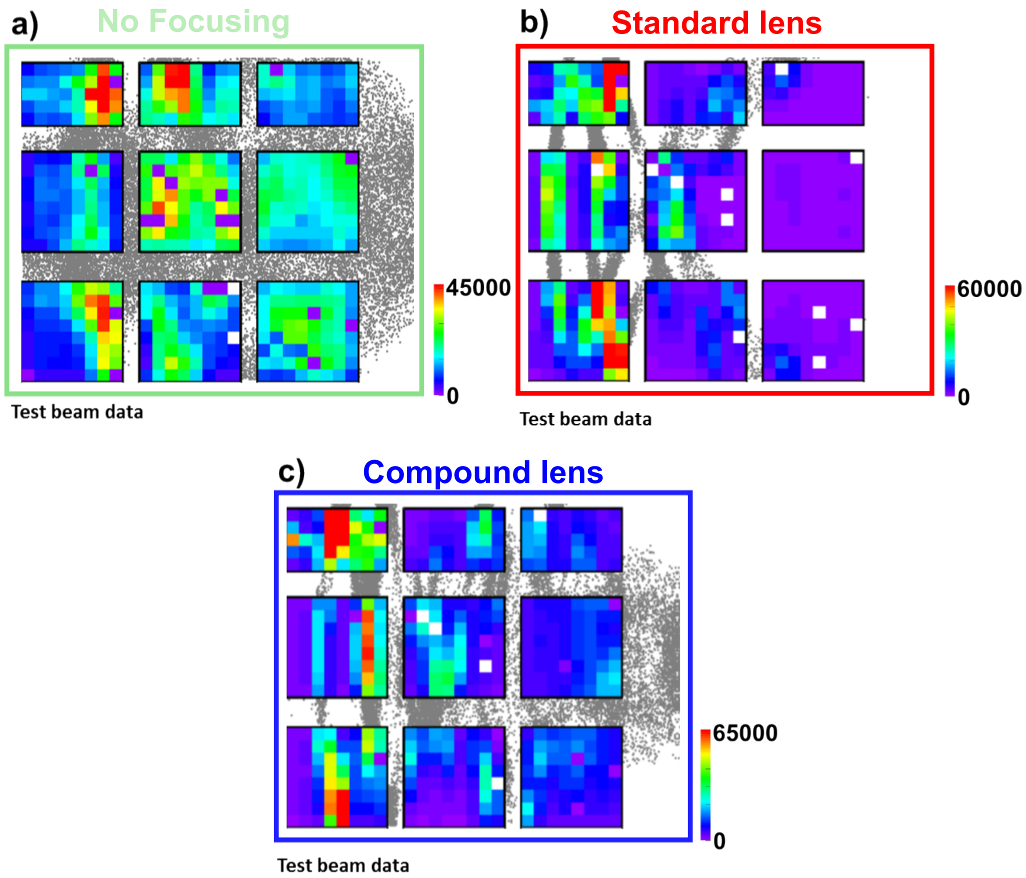
DIRC Focusing options



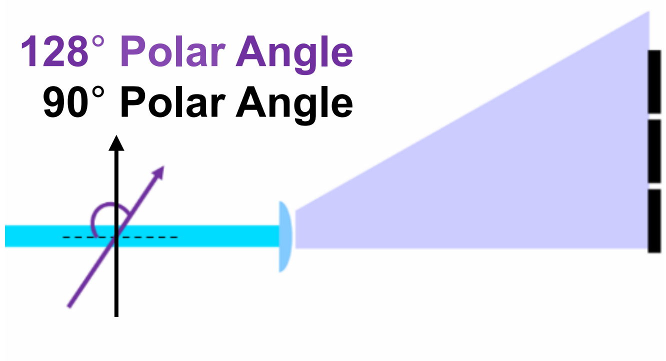
- No focusing, bar directly coupled to the prism

- Standard UV coated lens with 2 mm air gap between bar and prism.

- Compound lens Fused silica/NLaK without air gap.



DIRC Focusing options



- In this configuration 10% improvement of photon yield, consistent with simulations.

- **For particle polar angle close to 90° difference much more dramatic.**

Number of hits per track: