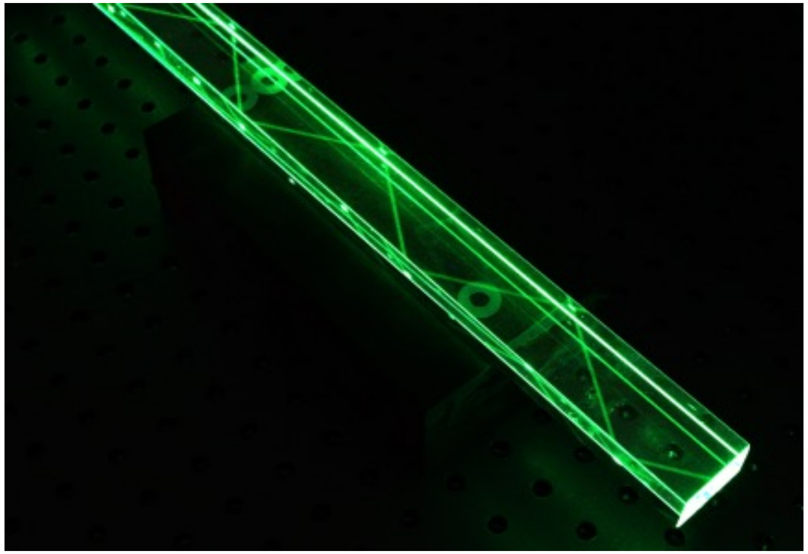
# EIC DIRC

**Greg Kalicy**

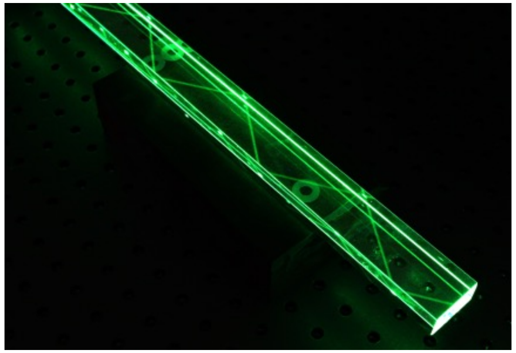


March 23, 2015

# 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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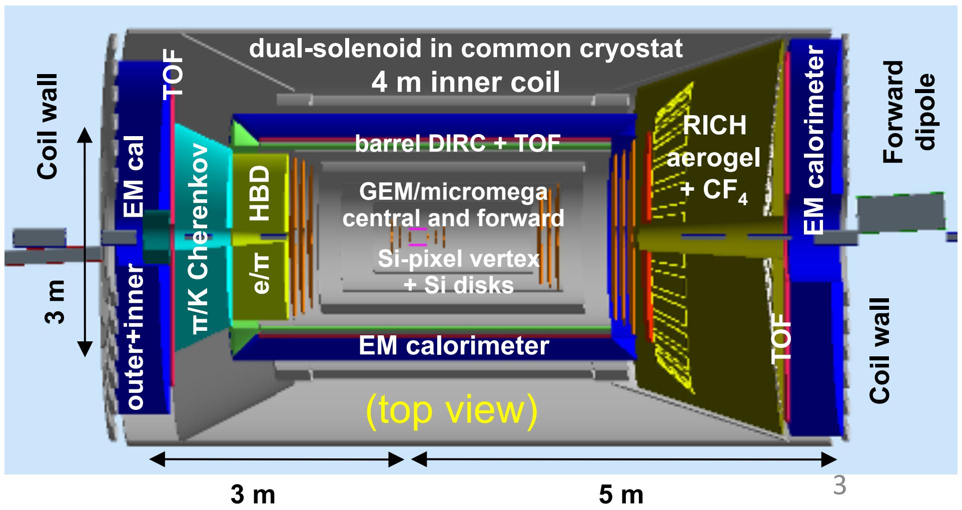
**MEIC IP1detector**



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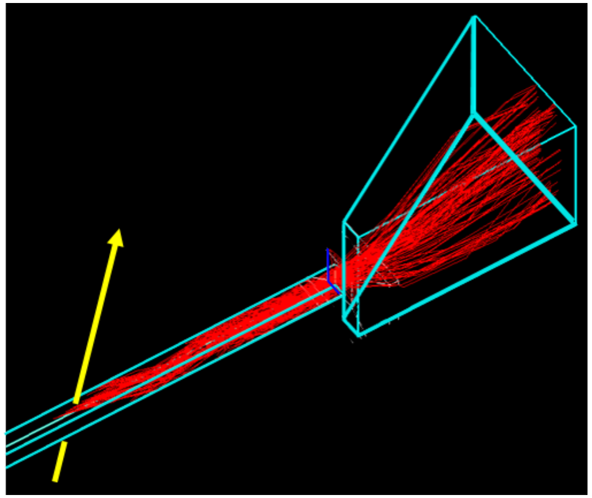
**Simulation**



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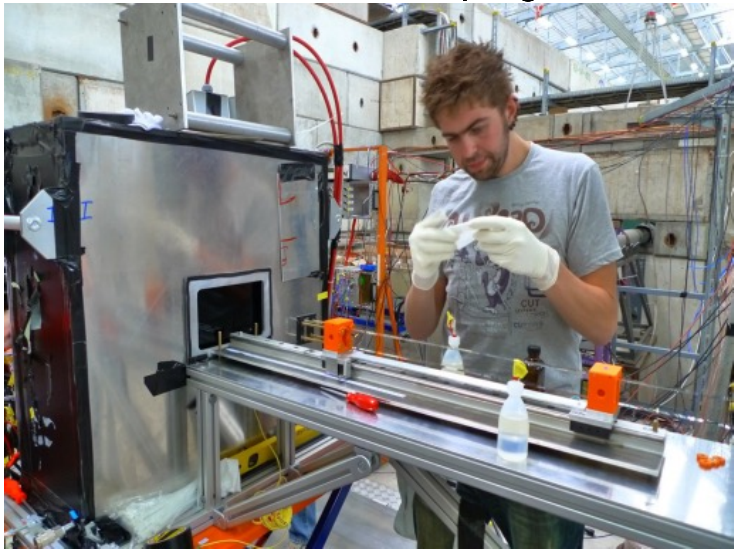
Full system prototype in CERN test beam campaign



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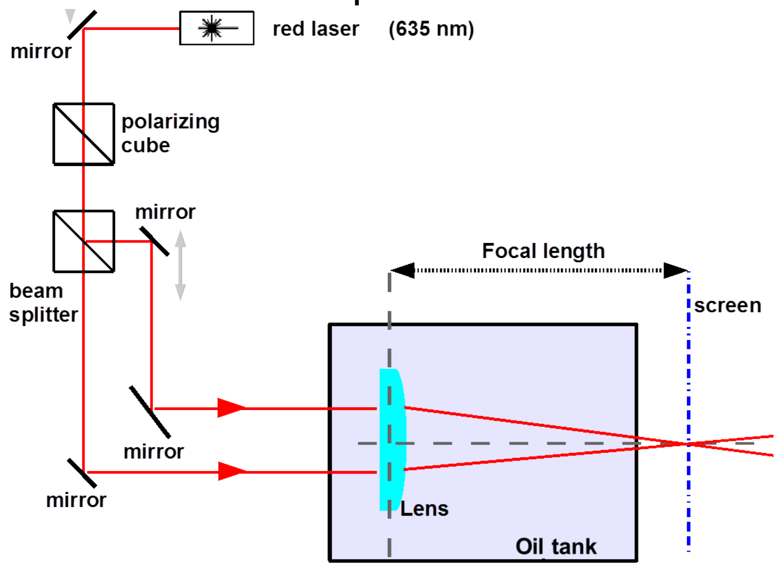
Setup to measure the shape of focal plane



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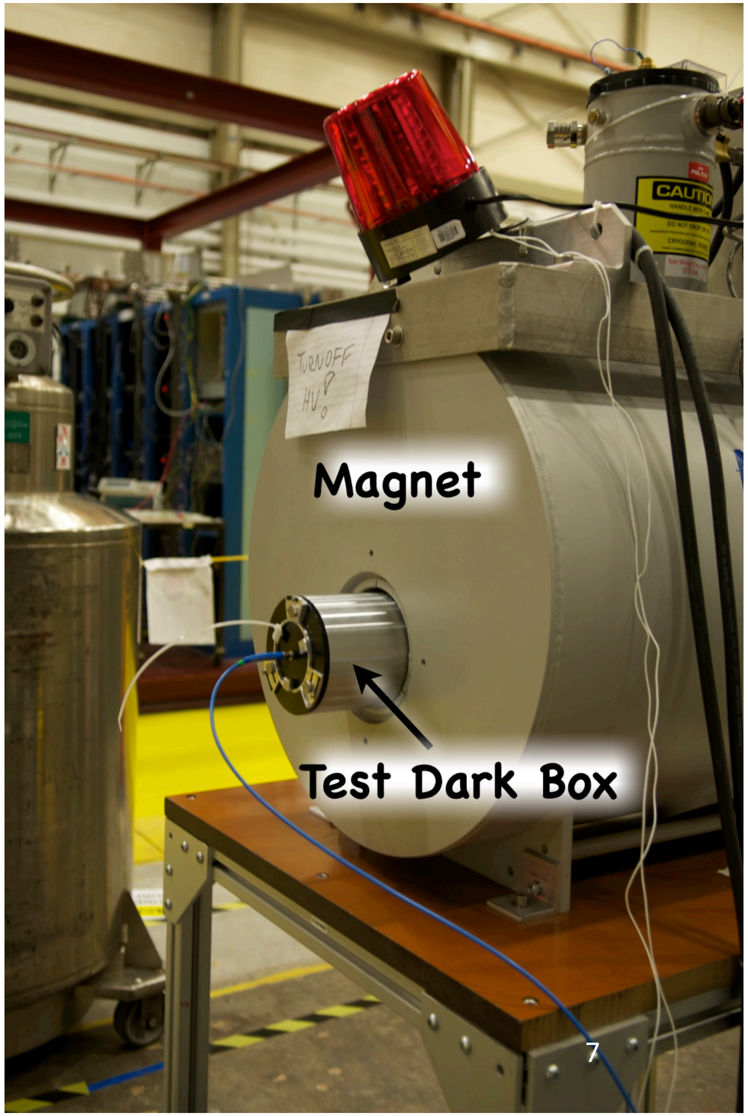
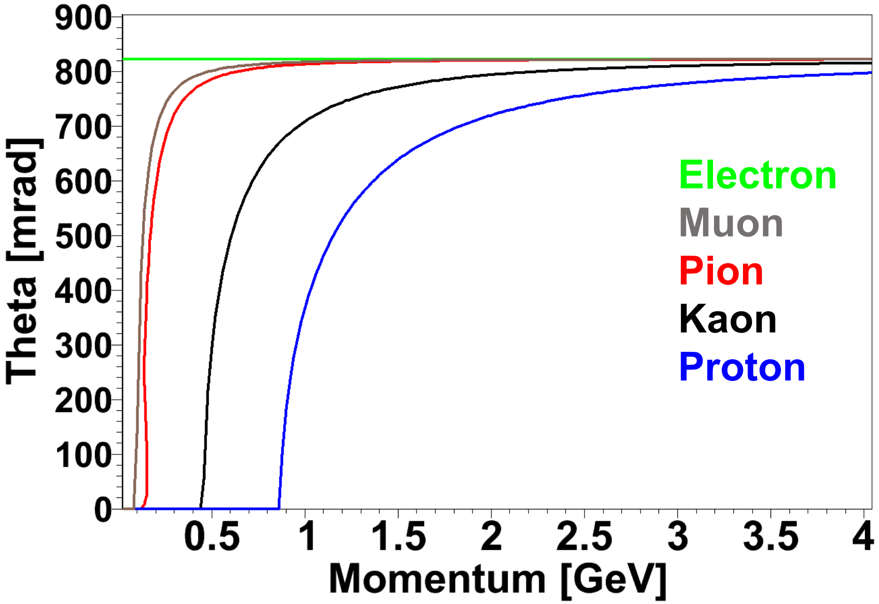
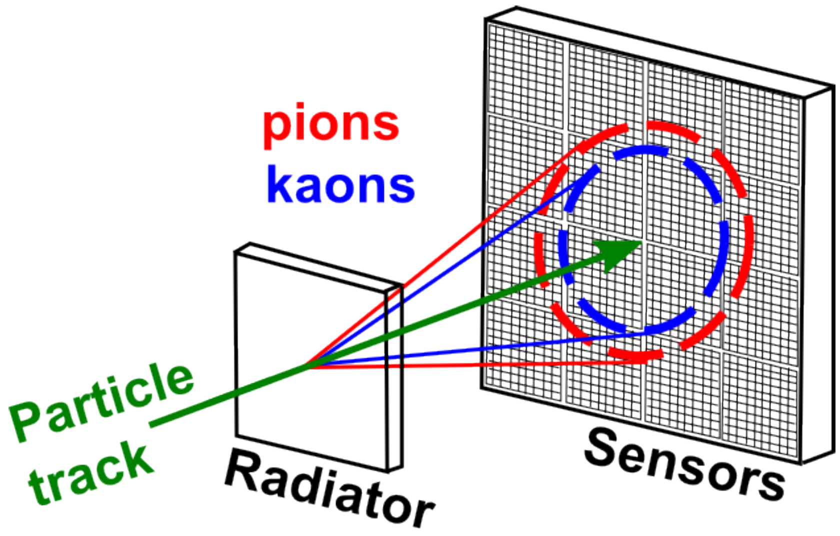
Setup to test photosensors in high magnetic field



# 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).

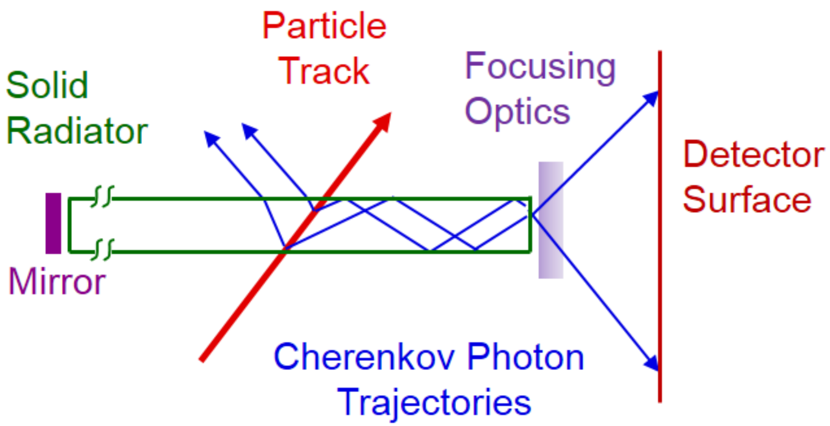
# DIRC Detection of Internally Reflected Cherenkov Light

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

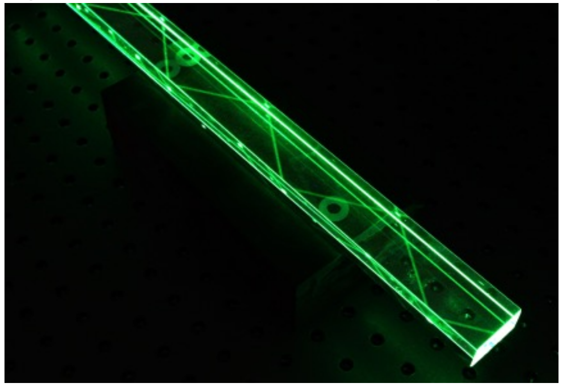
- Cherenkov angle conserved during internal reflections of propagating photons.

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

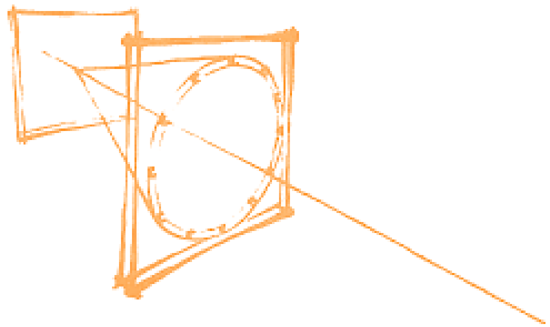
- Photon detector array measures **x, y and time** of photons that exit radiator and defines **$\theta_c$, $\varphi_c$ and time of propagation of individual Cherenkov photons.**




Synthetic fused silica prototype bar



# DIRC Example hit pattern



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

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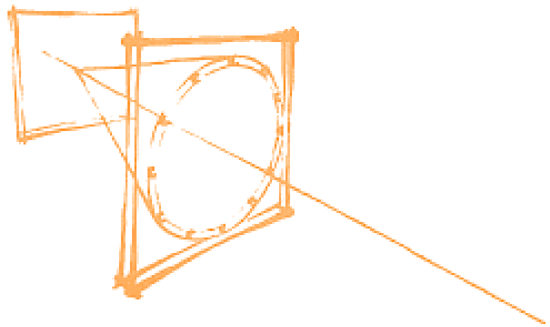

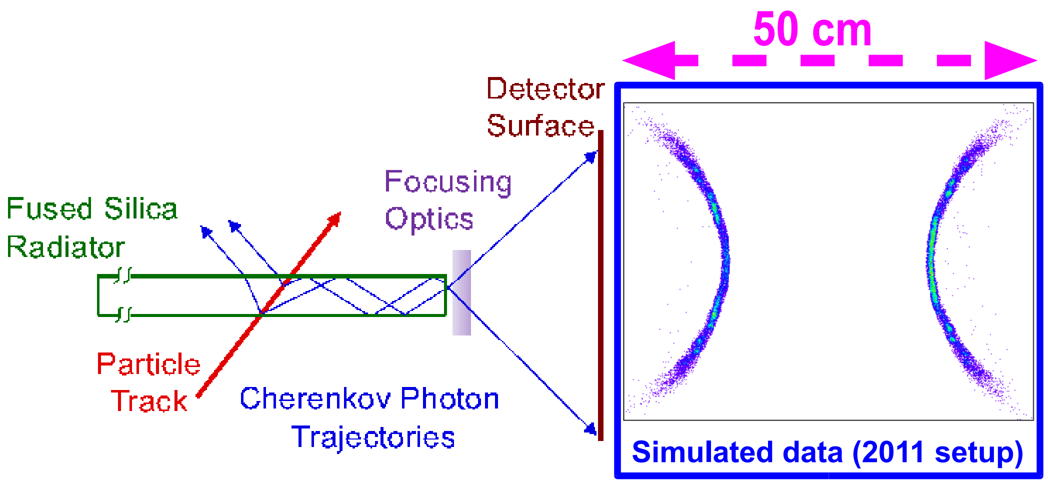


- DIRC hit patterns do not look like typical RICH detector.

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

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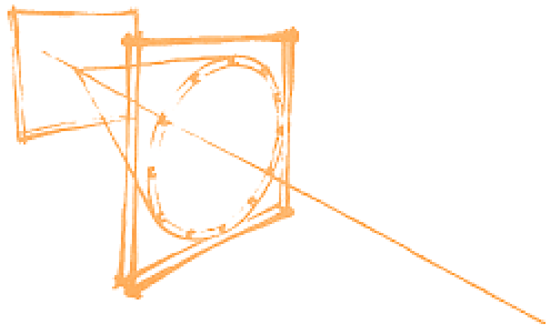

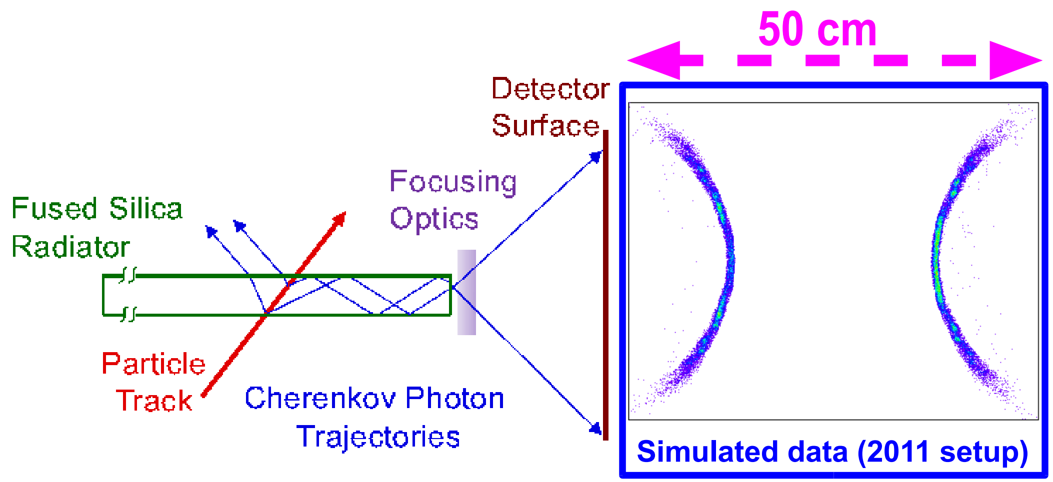


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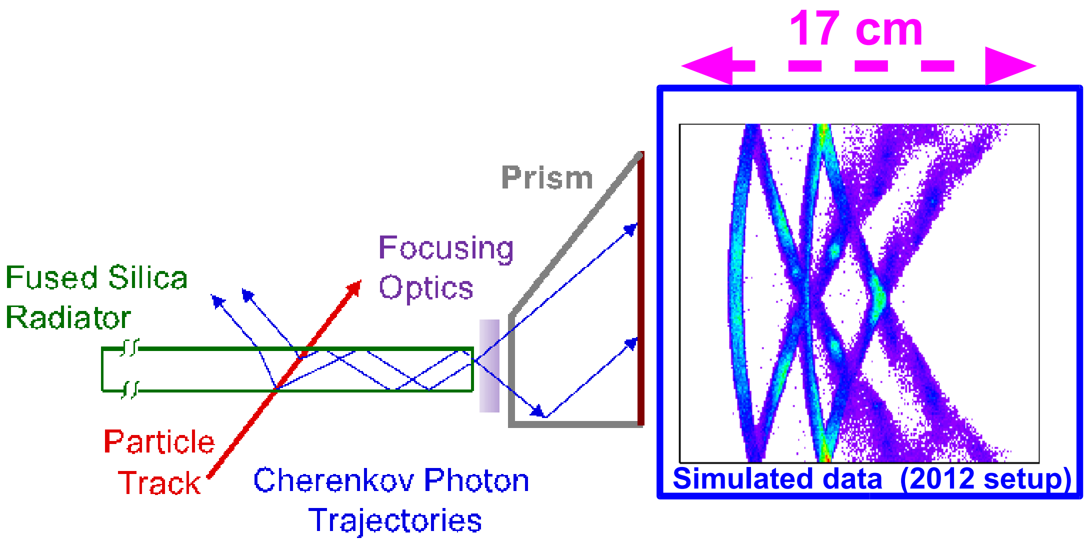
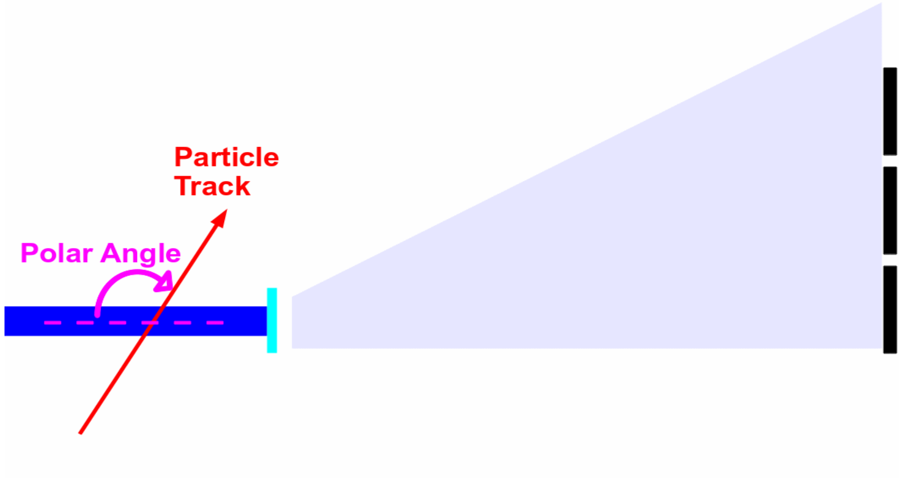
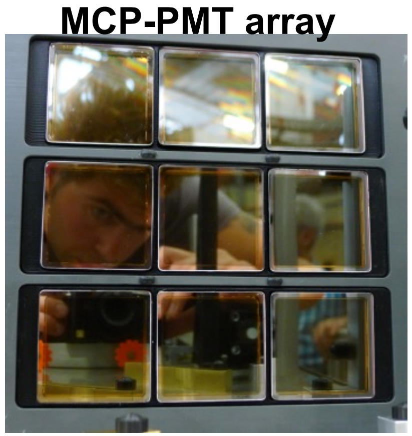



- Part of the ring escapes, not totally internally reflected.
- Ring image gets folded due to propagation in bar/plate.

- Additional folding in the prism expansion volume.

# DIRC Occupancy plot from experiment

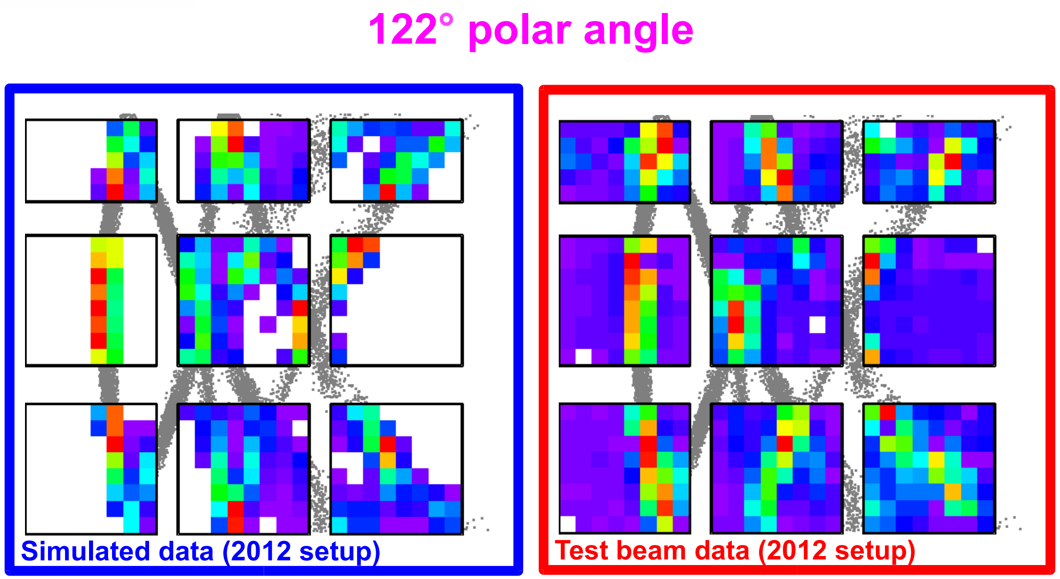




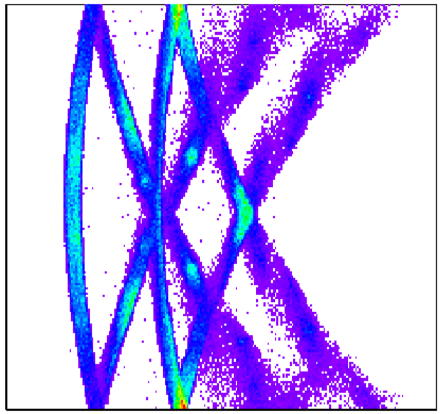
- Comparison of the **pixelized simulated data** to **test beam data.**

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

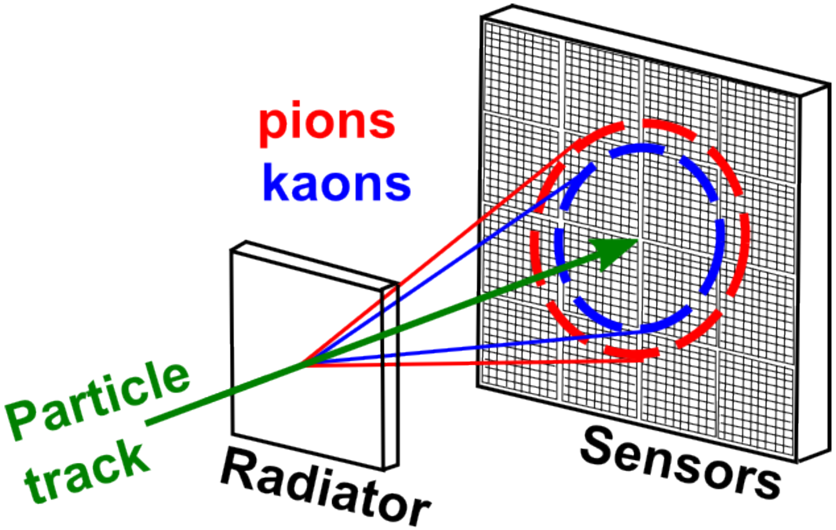


# DIRC Example hit pattern

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



Simulated data (2012 setup)



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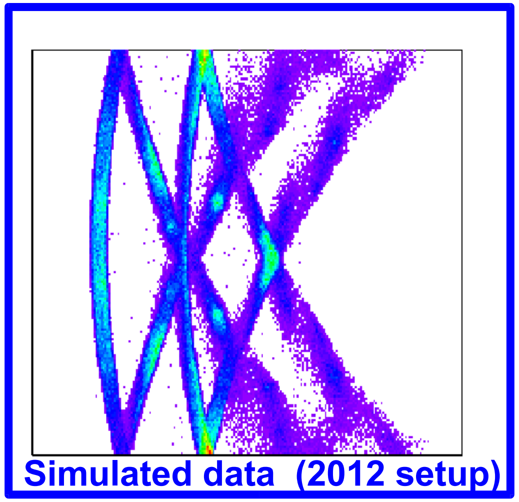
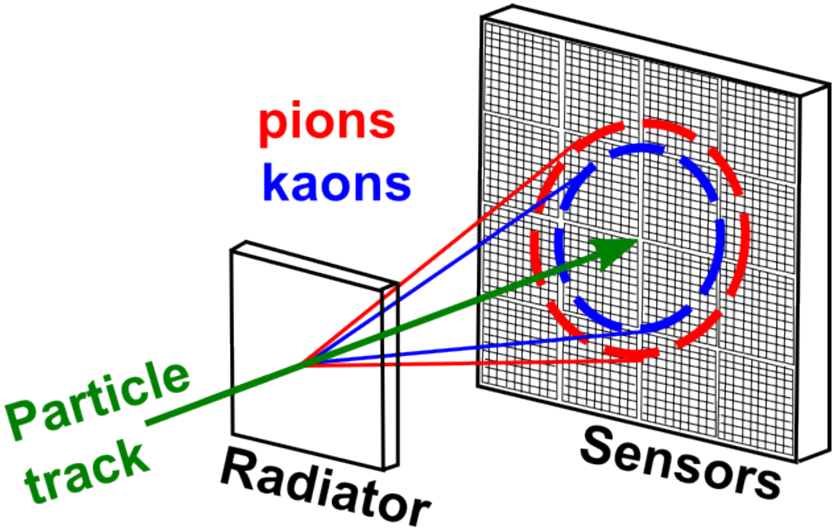
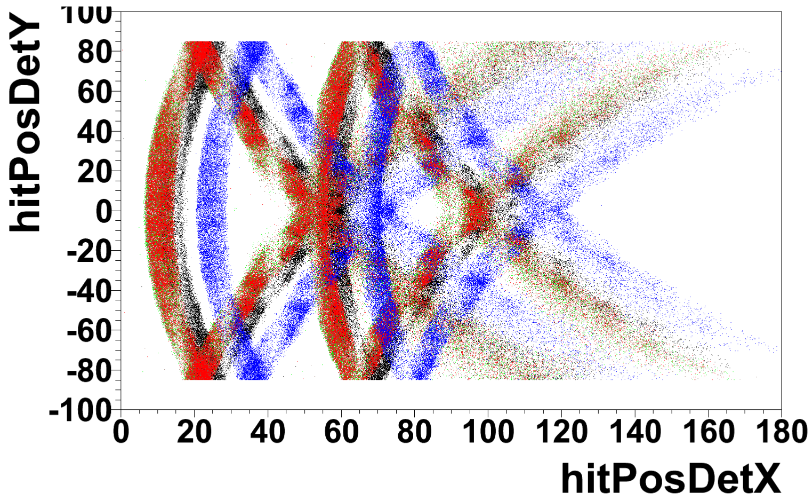



**Pions vs Protons at 3 GeV/c.**
**210k accumulated events.**
**(Hit pattern from simulation)**



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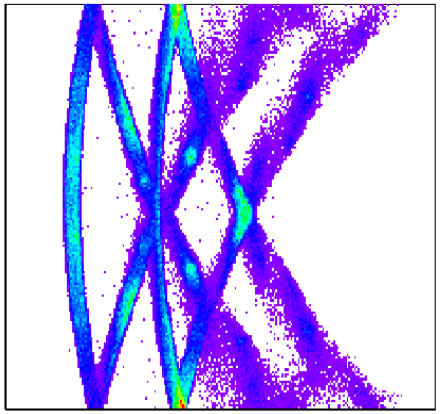
- **What is so challenging here?**
  - Ring segments corresponding to different particles are close and overlapping
  - Pixelated image (+ additional background)



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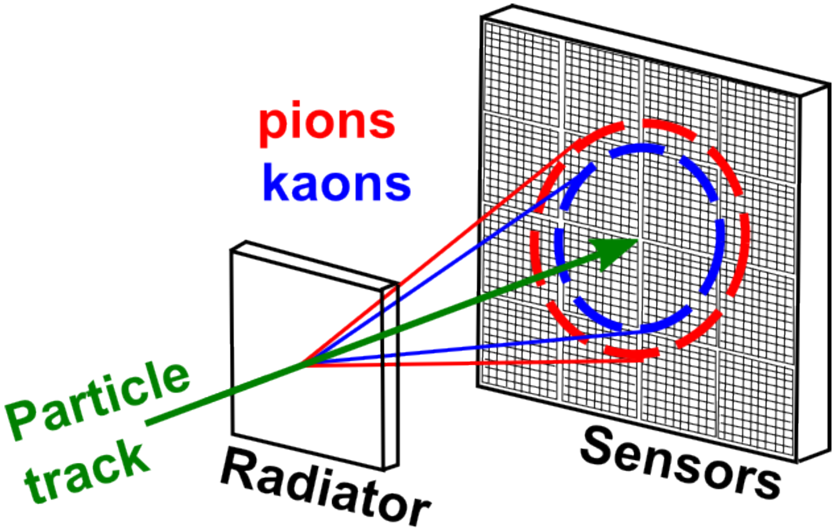


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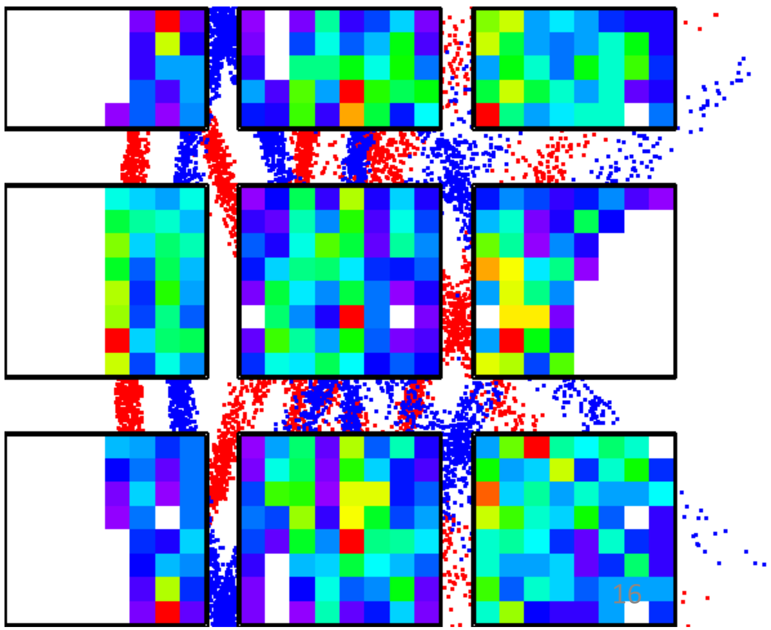
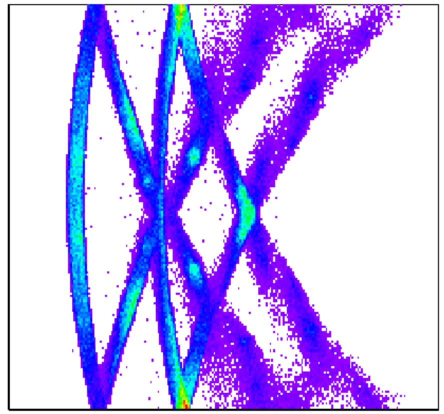


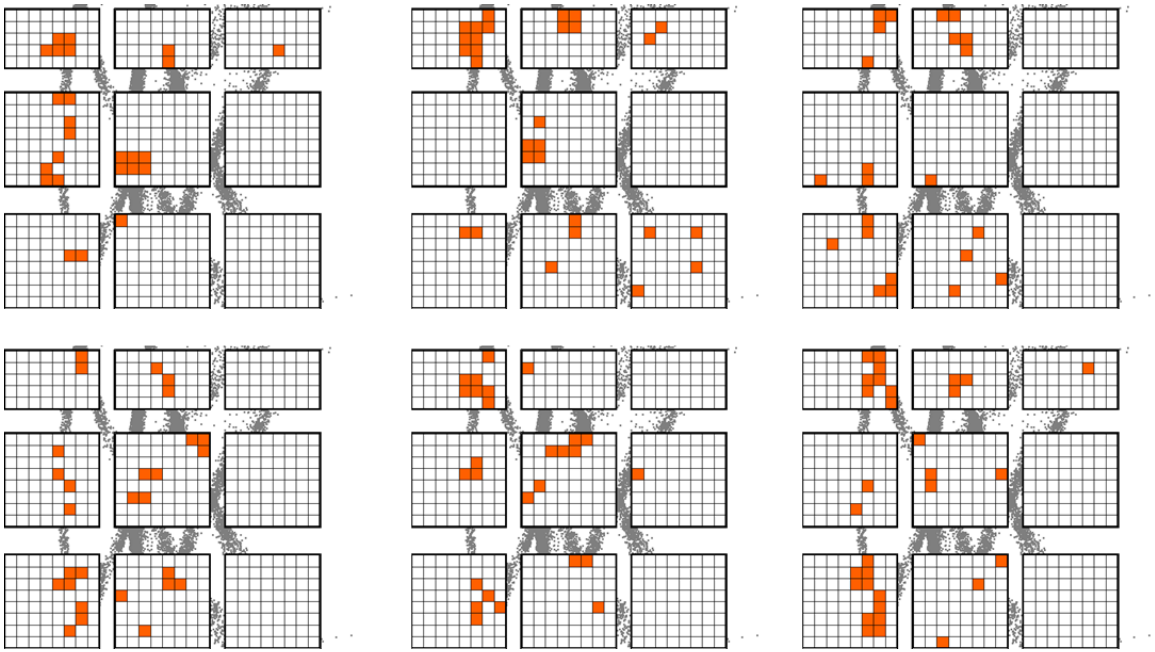
# DIRC Example hit pattern

- **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

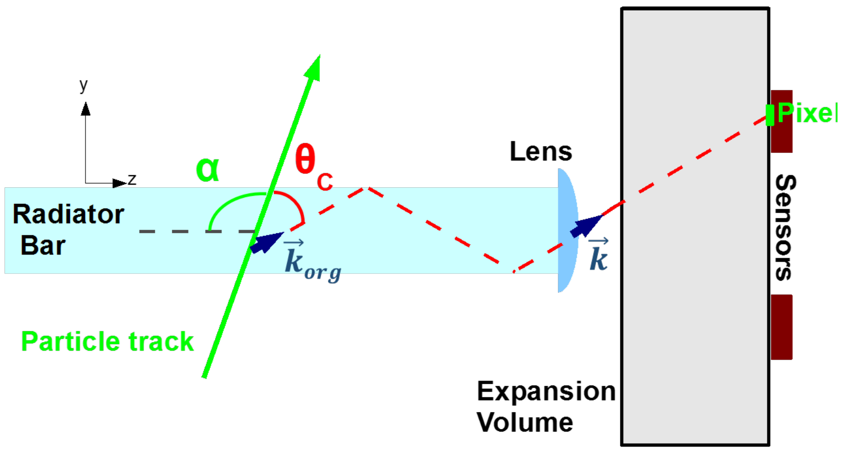
$$\sigma_{\Theta_C}^{track} = \sqrt{\left(\sigma^{corelated}\right)^2 + \left(\frac{\sigma_{\Theta_C}^{photon}}{\sqrt{N_{pe}}}\right)^2}$$

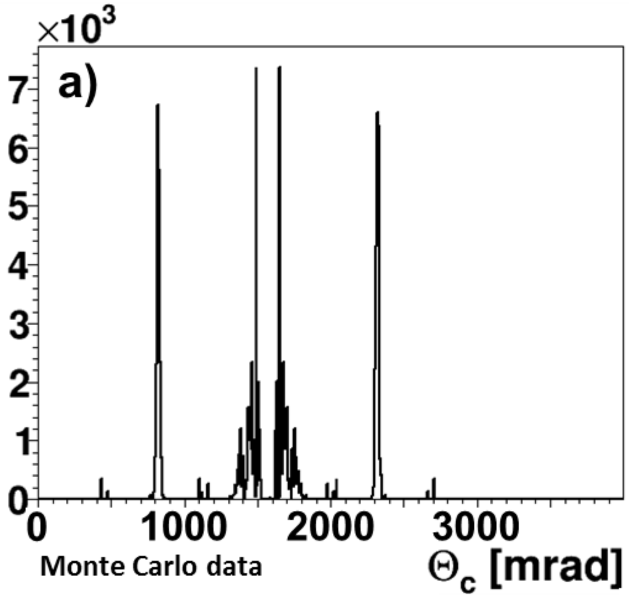
- $\sigma^{corelated} < 1.5 - 2 \ mrad$ **Correlated term:** tracking detectors, multiple scattering
- $\sigma_{\Theta_C}^{photon} < 8 - 9 \ mrad$ **Single photon Cherenkov angle resolution:** bar size, pixel size, chromatic, bar imperfections
- $N_{pe} > 20$ **Number of photons:** bar size, bar imperfections, photon detection efficiency of the detector

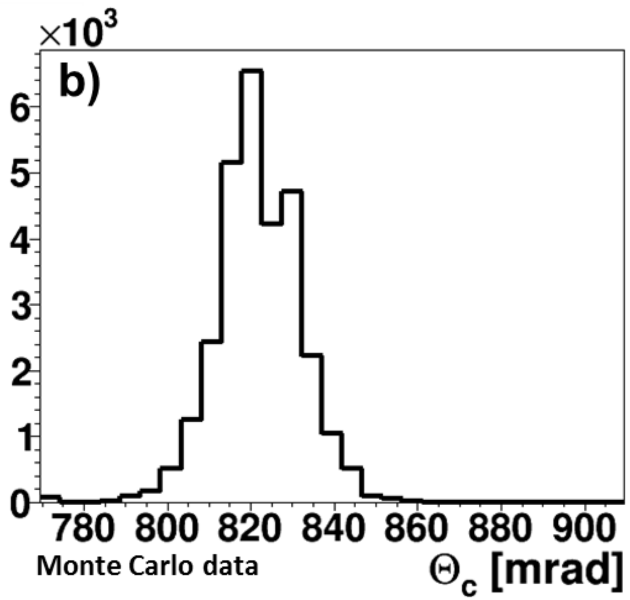
# DIRC Cherenkov angle reconstruction method

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

- **Photon path not unique**
  Additional combinatorial background in $\Theta_C$



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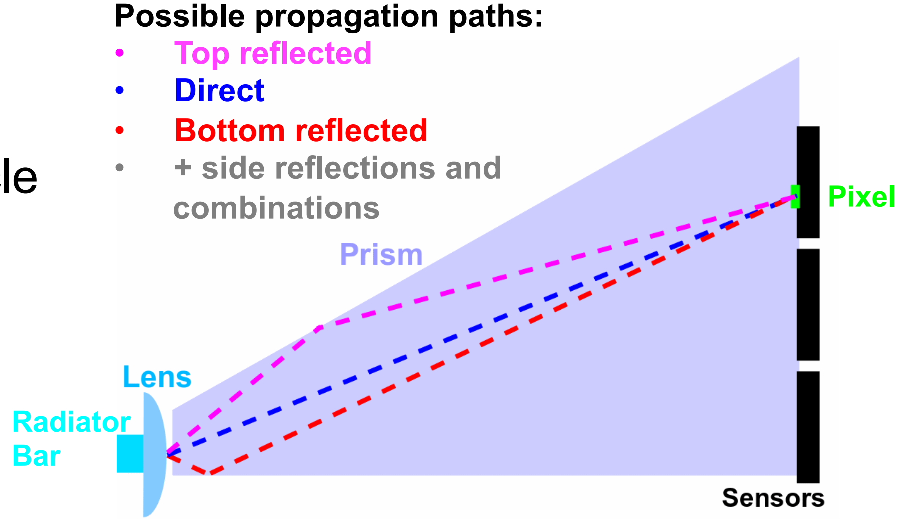
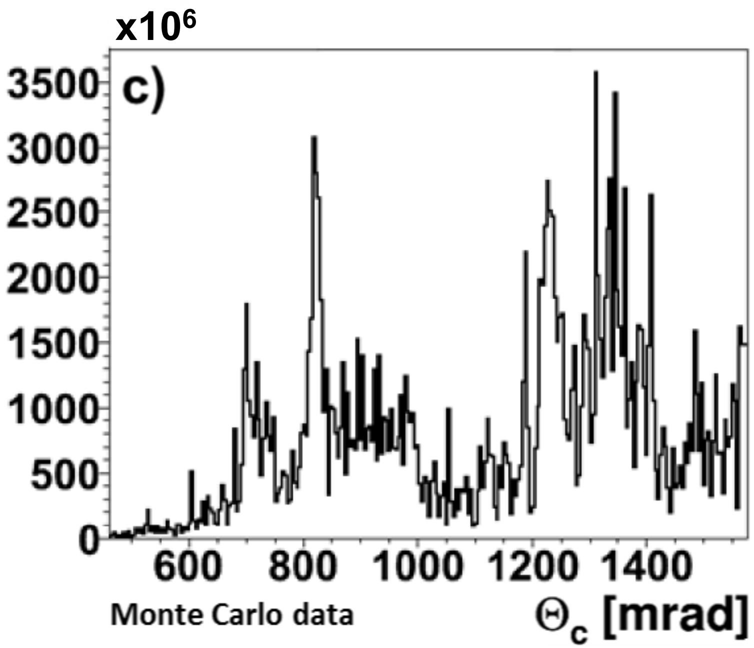
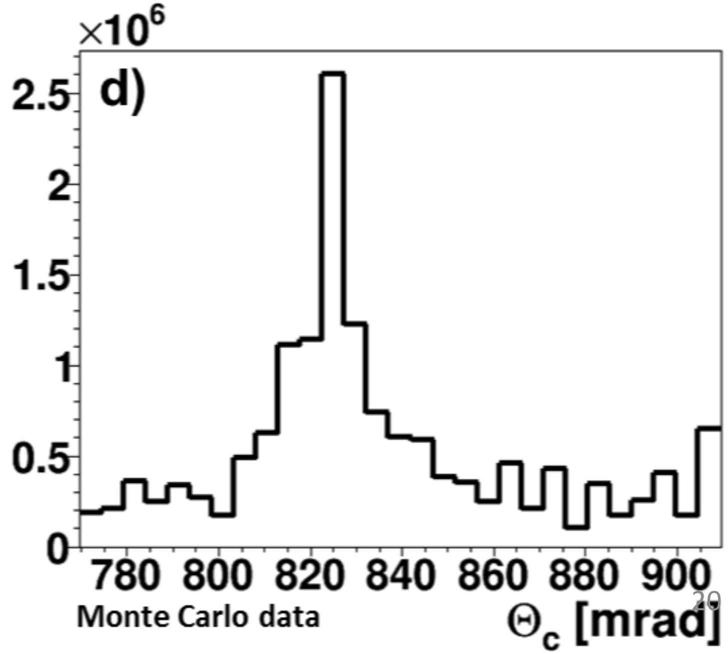


# Improving DIRC Performance

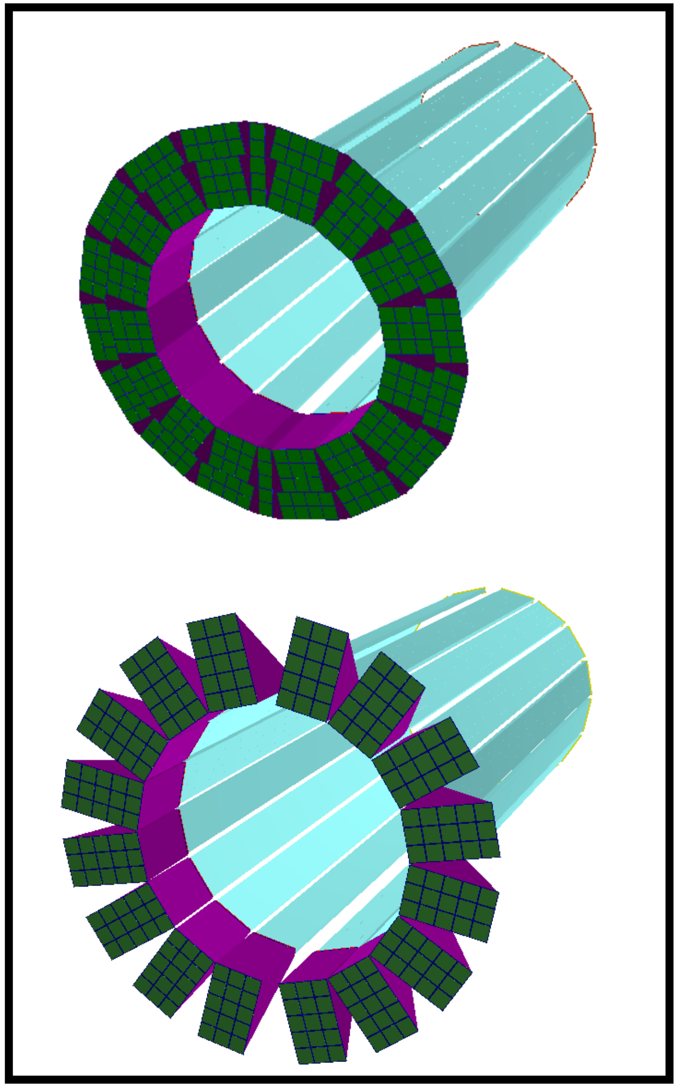
- **Make DIRC less sensitive to background**
  - decrease size of expansion volume
  - use photon detectors with smaller pixels and faster timing
  - place photon detector inside magnetic field
- **Investigate alternative radiator shapes** (plates, disks)
- **Push DIRC π/K separation by improving single-photon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

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

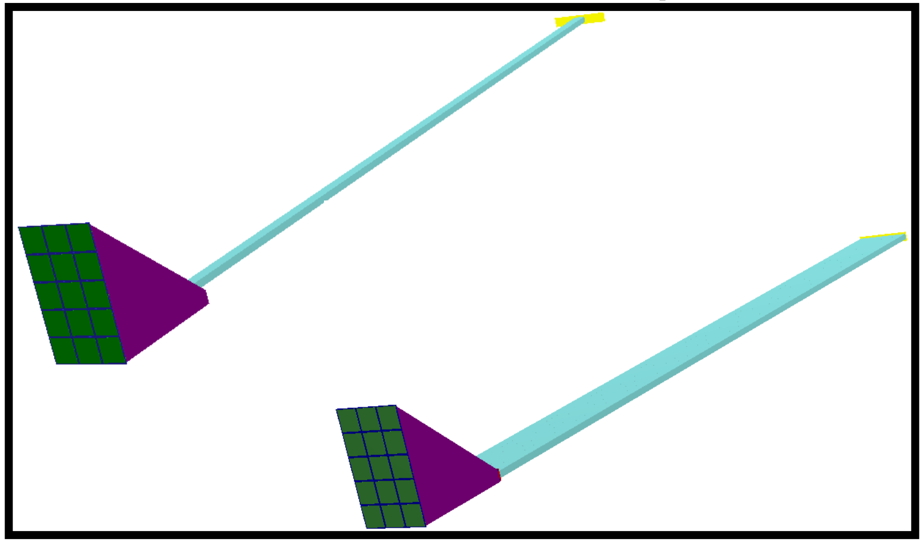
| **Limited in BABAR by:** | | | **Could be improved for new DIRCs via:** |
|---|---|---|---|
| ▪ size of bar image | ~4.1 mrad | → | ▪ focusing optics |
| ▪ size of PMT pixel | ~5.5 mrad | → | ▪ smaller pixel size |
| ▪ chromaticity ($n=n(\lambda)$) | ~5.4 mrad | → | ▪ better time resoluion |
| | **9.6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

# DIRC Design Options

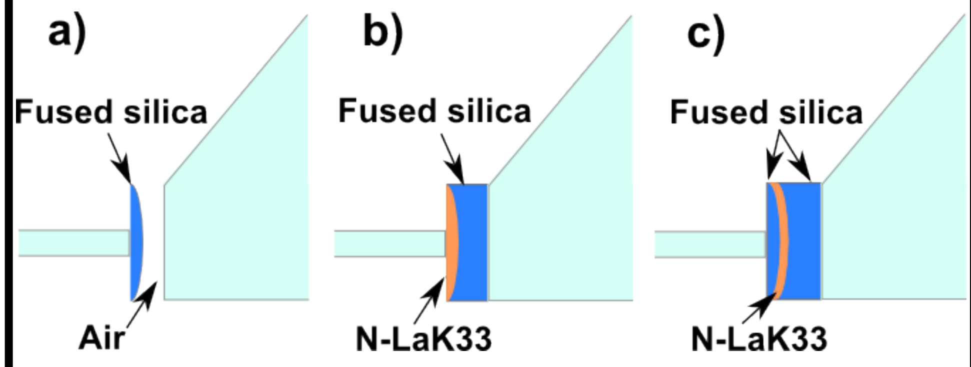
**Expansion volume: oil tank/prism**



**Radiator: narrow bar/wide plate**



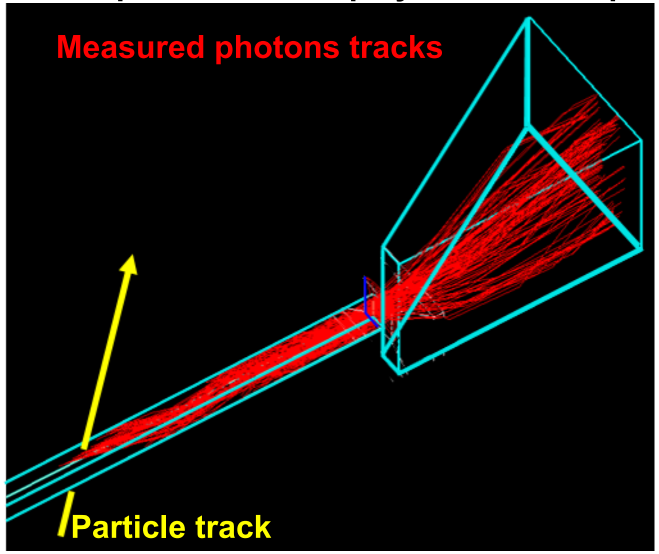
**Focusing system: different lenses**



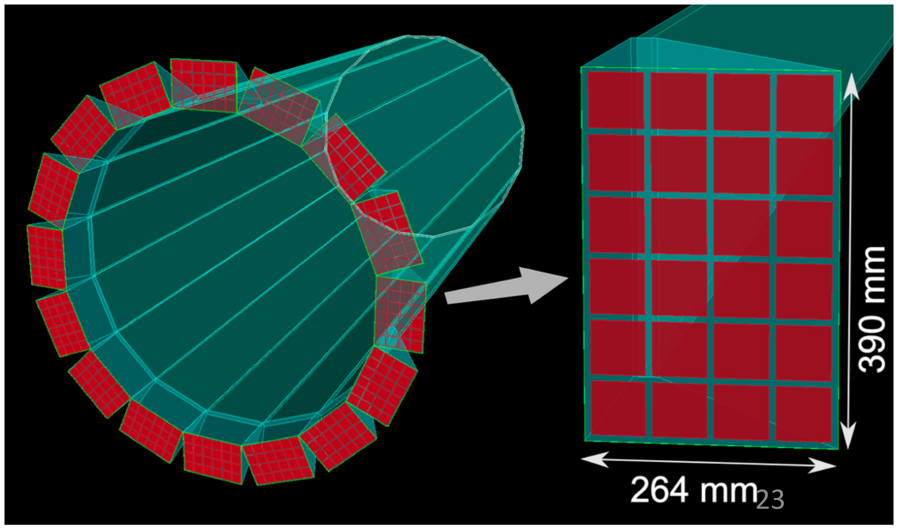
# Monte Carlo Studies

- **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**

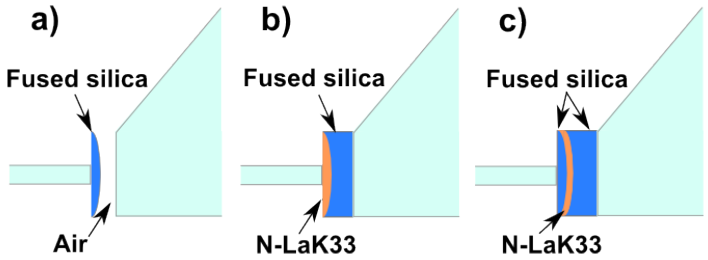


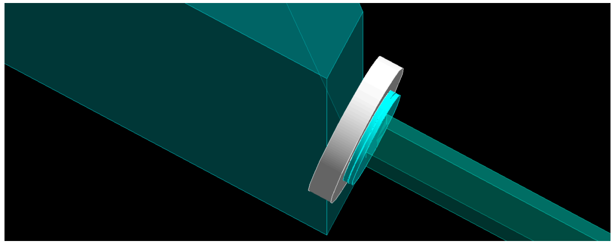

**Geant4 simulation of plate and prism geometry**

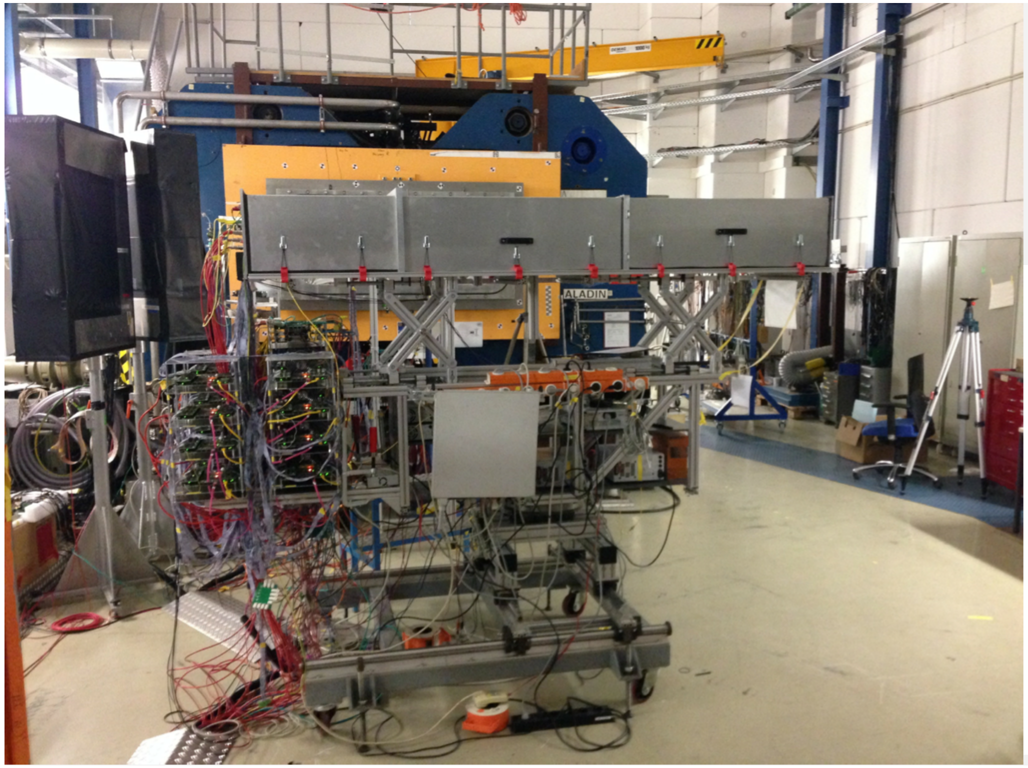


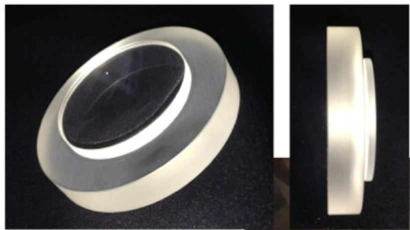
# Focusing Prototype of 3-component lens

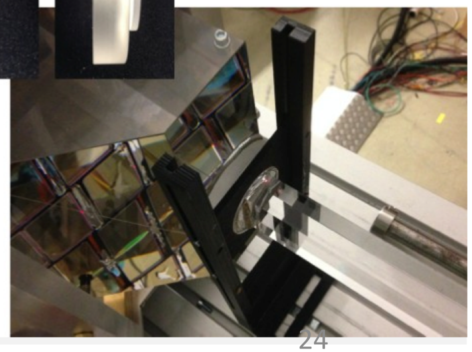
- Prototype of 3 component high refractive lens without air gap.
- Lens produced and already tested in particle beam with PANDA Barrel DIRC group



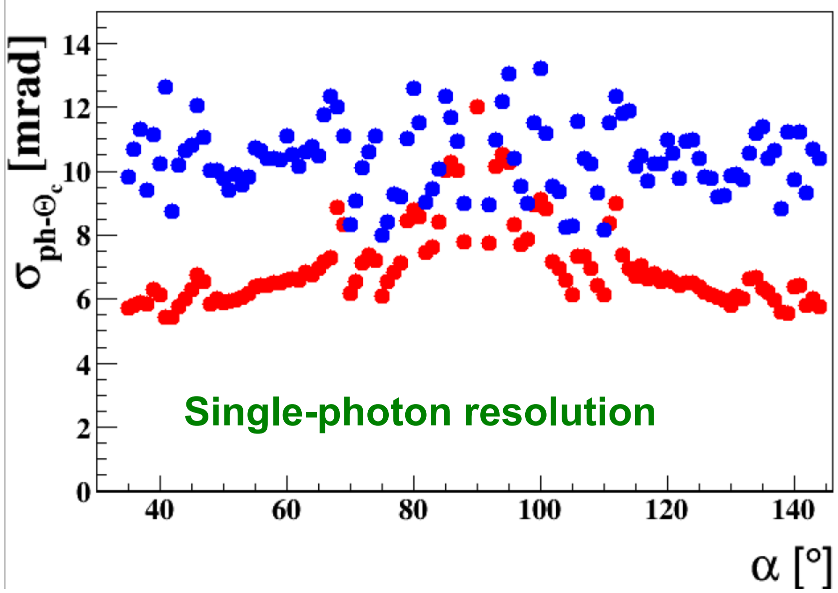



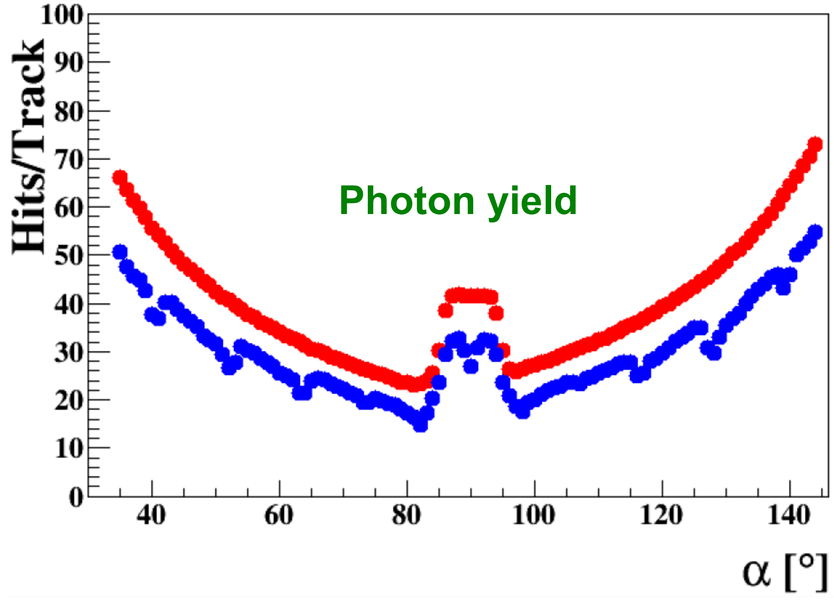


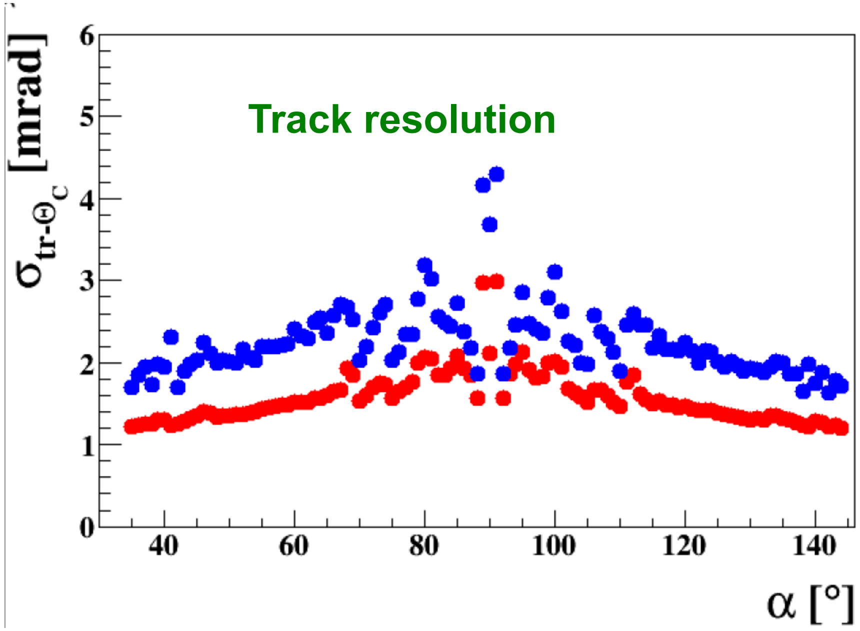




# Focusing Simulation of 3-component lens



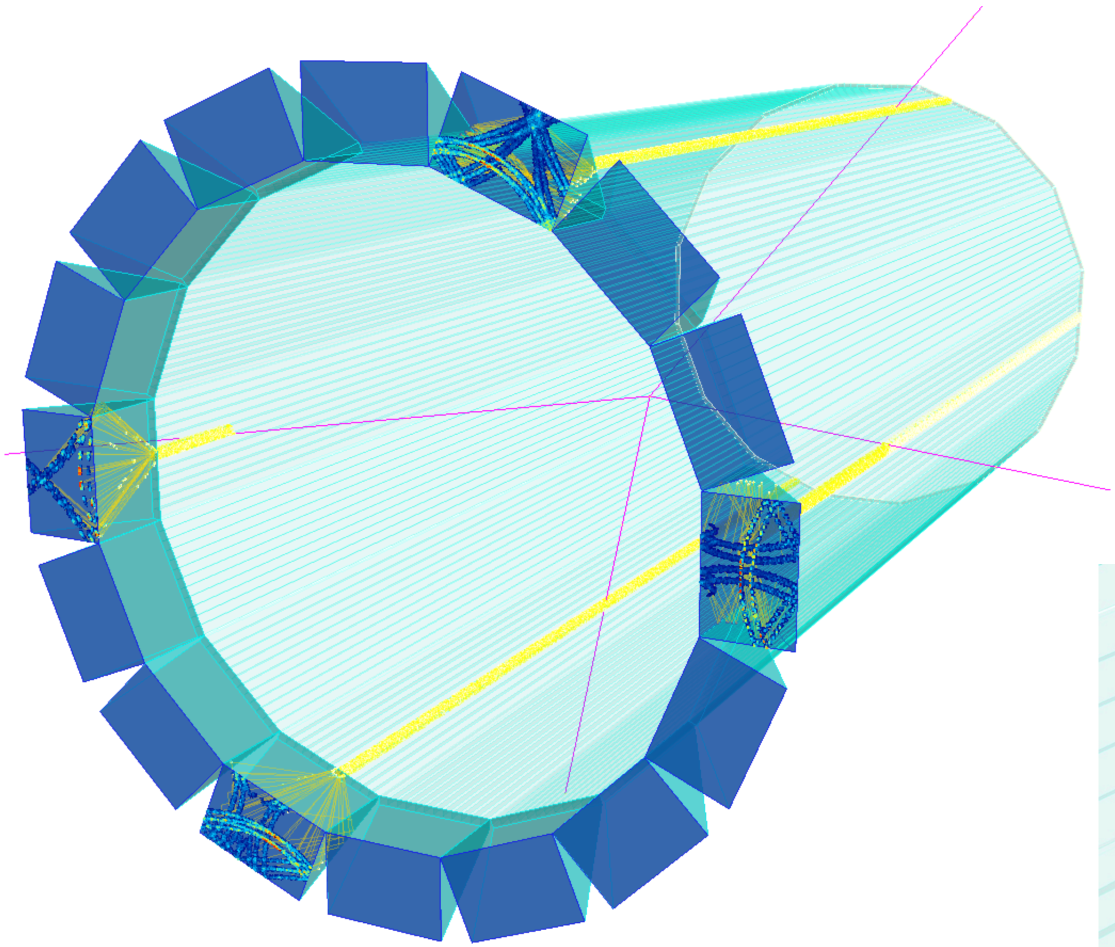



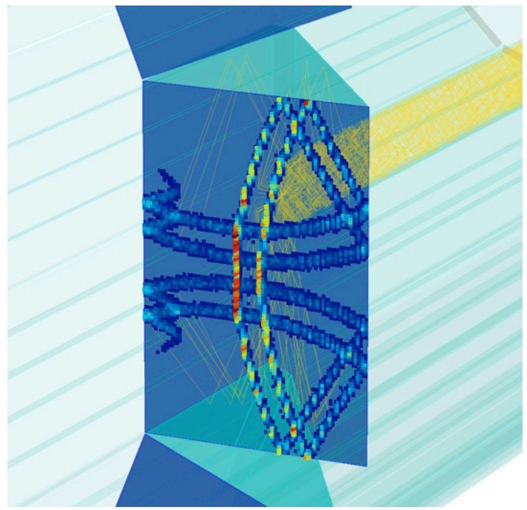




**Procured 3-component lens, Planacon MCP**
**Procured 3-component lens, 2x2 mm MCP**

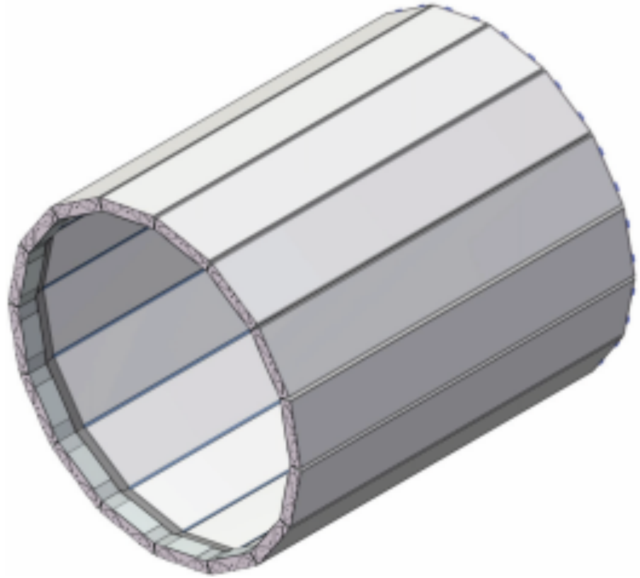
- A high-performance DIRC will require new small-pixel photosensors.
- The simulation confirms that a resolution close to 1 mrad (6 GeV/c) can be reached at forward (and backward) angles.

# To be continued…

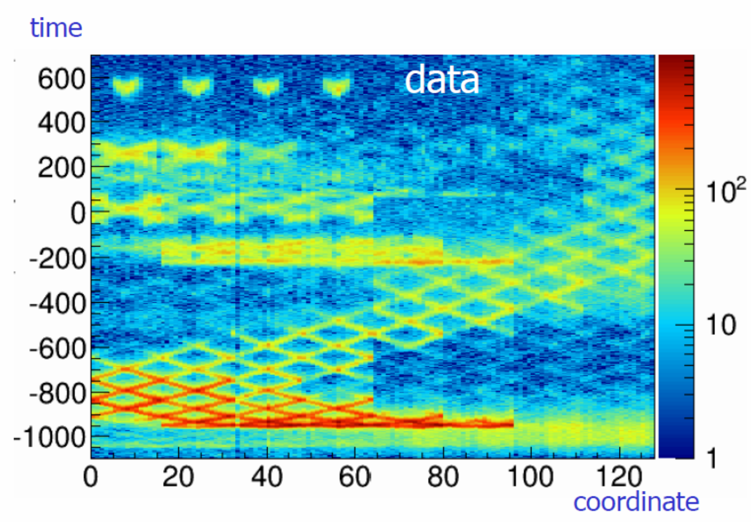


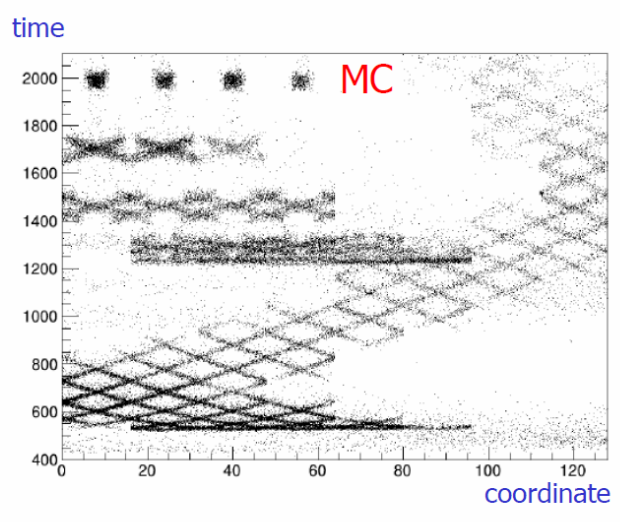


# Other DIRCs BELLE II TOP

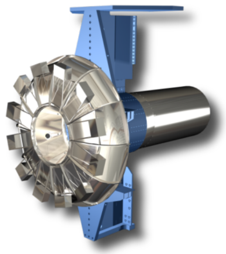


- **Belle II TOP** is barrel DIRC-type RICH with emphasis on fast timing
- **PID goal:** 3σ π/K separation for p < 4 GeV/c
- **Radiator:** fused silica plate 45cm wide, 2cm thick, 250cm long.
- TOP barrel formed by 16 plates
- Small expansion volume (10cm depth)
- **Photon detector:** array of 32 Hamamatsu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

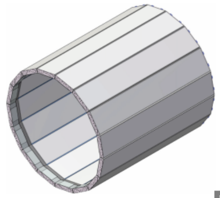


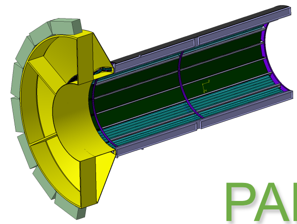
# Barrel DIRCs



BABAR DIRC



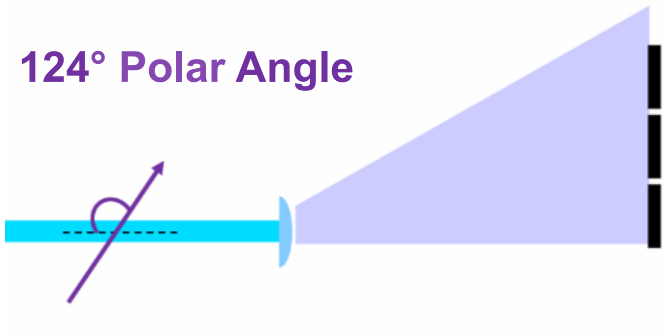
BELLE II TOP

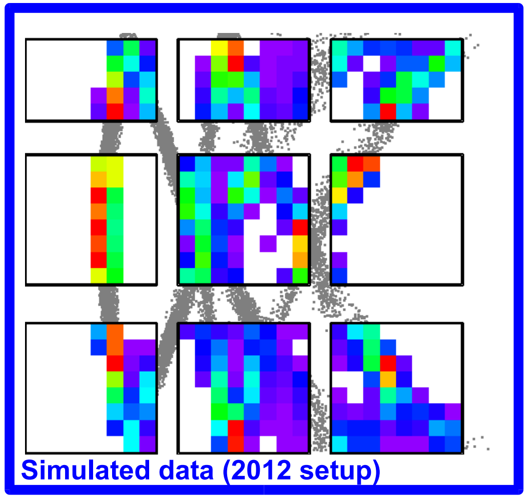


PANDA BARREL DIRC

| | | | |
|---|---|---|---|
| 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. $\pi/K$ to 4 GeV/c | 3 s.d. $\pi/K$ to 4 GeV/c | 3 s.d. $\pi/K$ to 3.5 GeV/c |
| Timeline | 1999 - 2008 | Installation 2015 | Installation 2017/18 |

# DIRC Example of number of hits per track

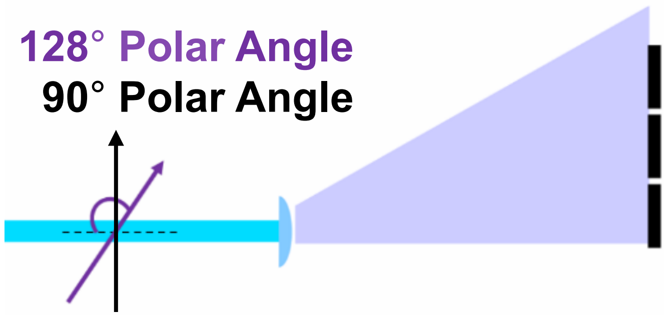



**~20 photons per track predicted by simulation at 124° polar angle, 10 GeV/c momentum beam.**

- 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.

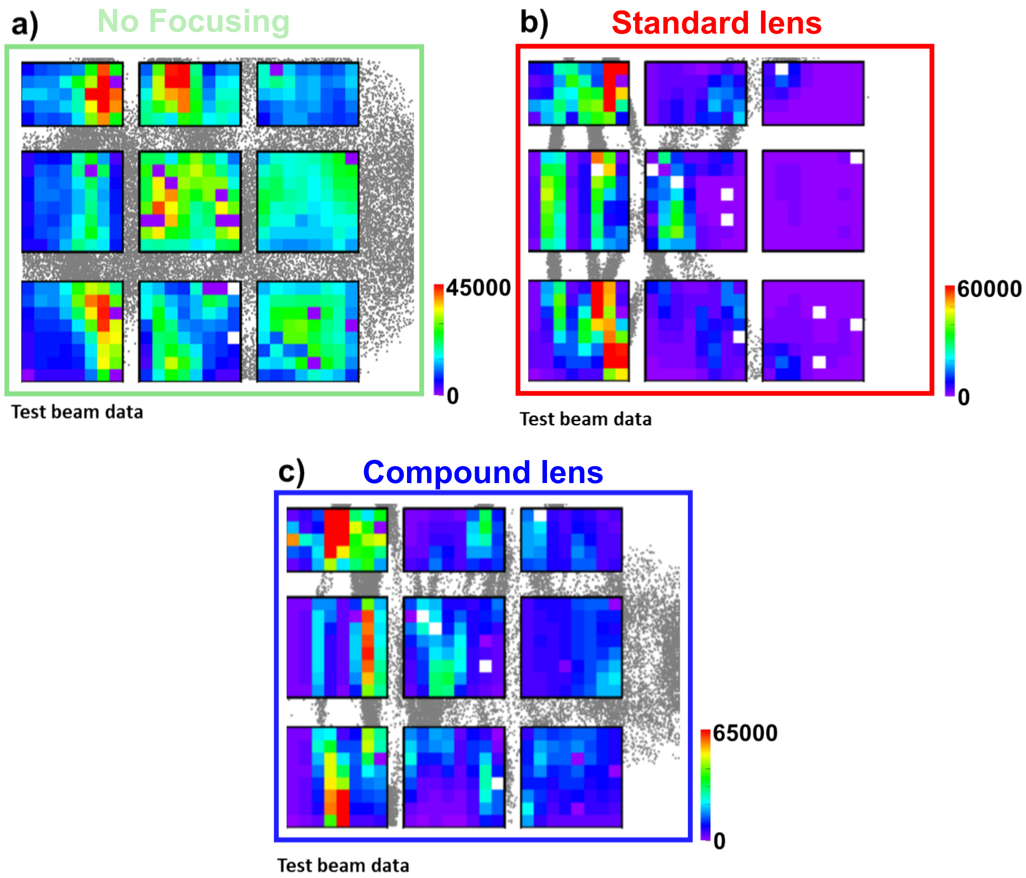
# DIRC Focusing options



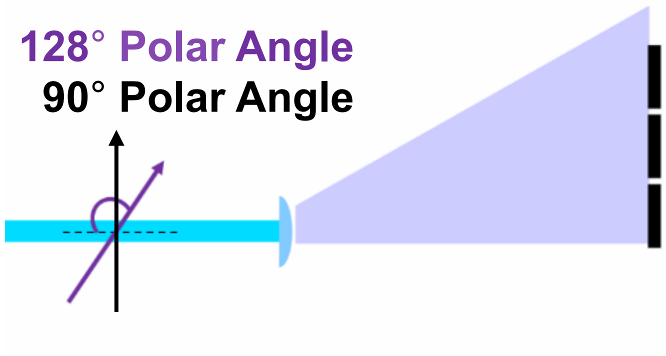

- No focusing, bar directly coupled to the prism

- 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:**