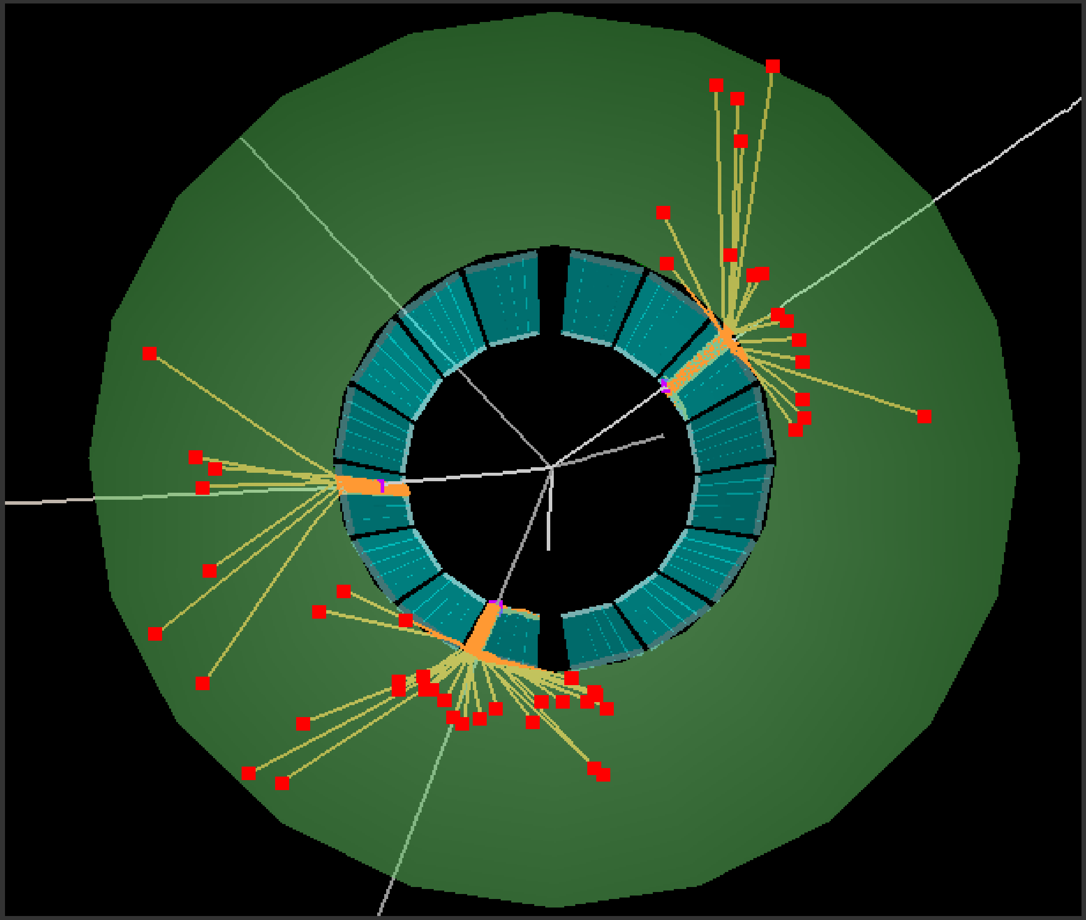

R & D for the PANDA Barrel DIRC

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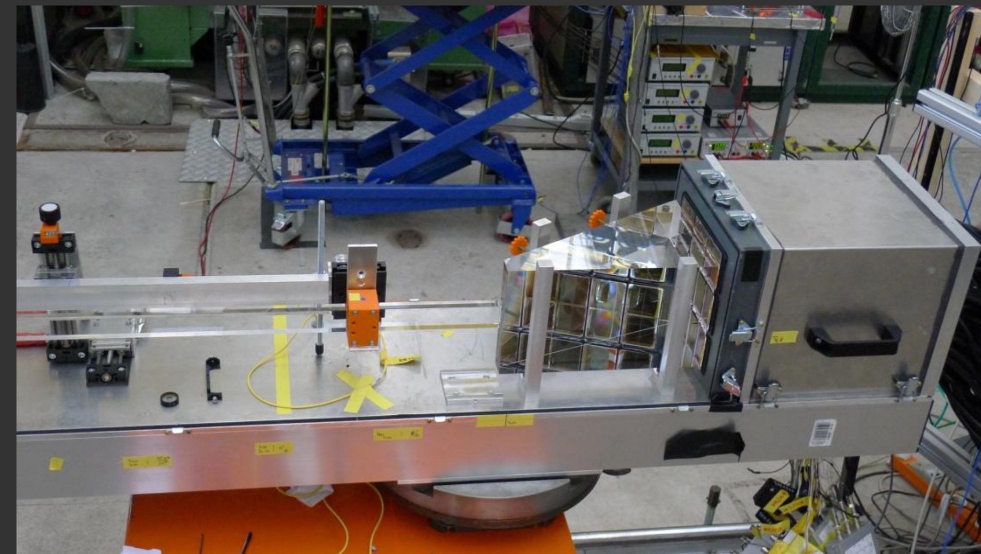
On behalf of the PANDA Cherenkov Group

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

Overview



1. PANDA @ FAIR

2. PID for PANDA

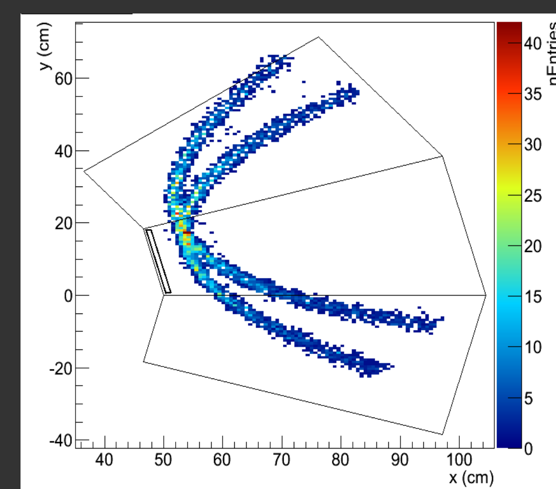
3. PANDA Barrel DIRC challenges

4. PANDA Barrel DIRC design - baseline and options

5. Simulation and reconstruction

6. Test beam results

7. Outlook and summary



PANDA Experiment at FAIR

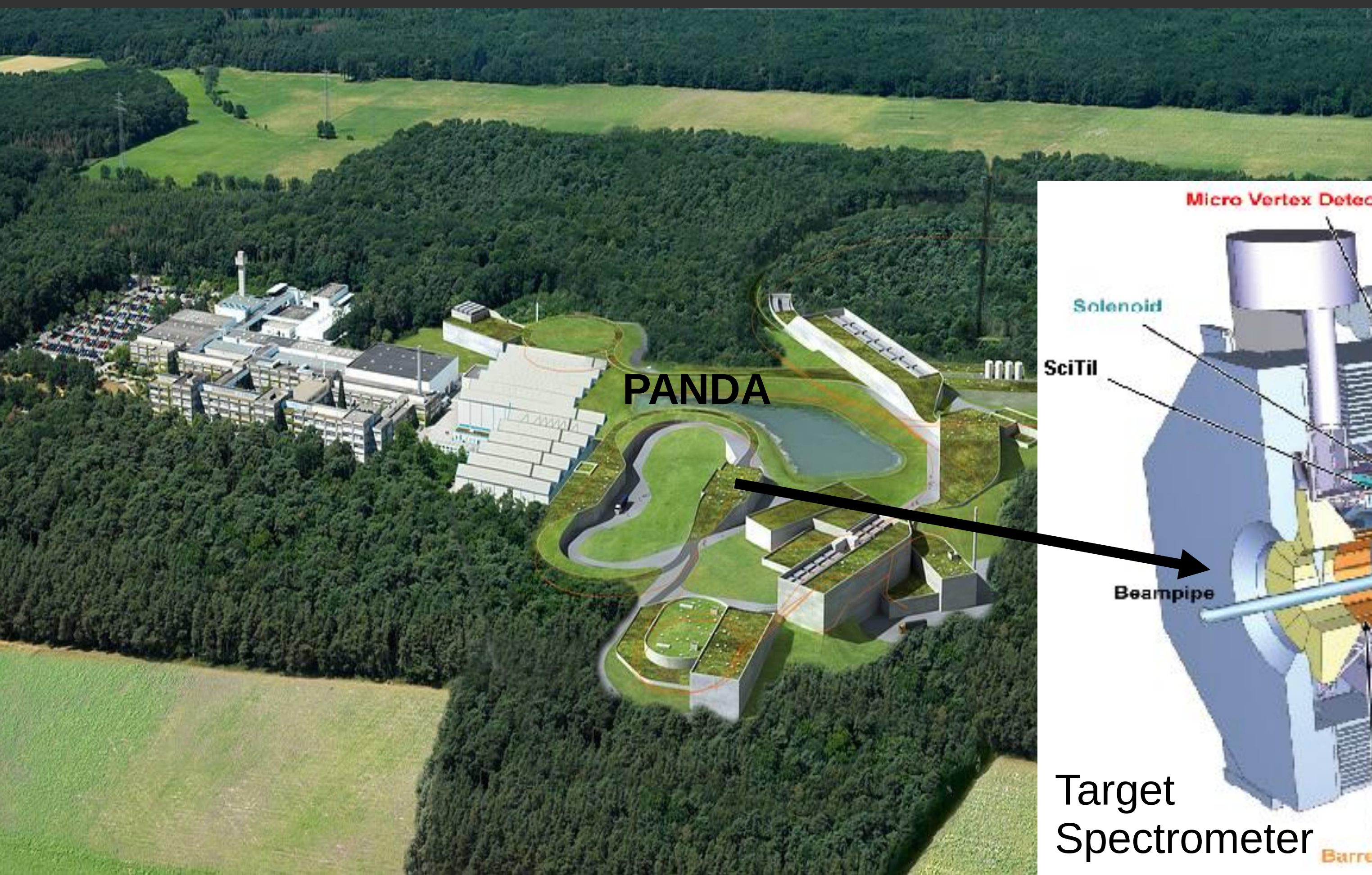
- German National Lab for Heavy Ion Study (Darmstadt), FAIR – future facility
- $\bar{p}p$ annihilation at up to 15 GeV/c
- cooled beams $L = 10^{31}\ cm^{-2}\ s^{-1}$, $\delta p/p \sim 10^{-5}$;

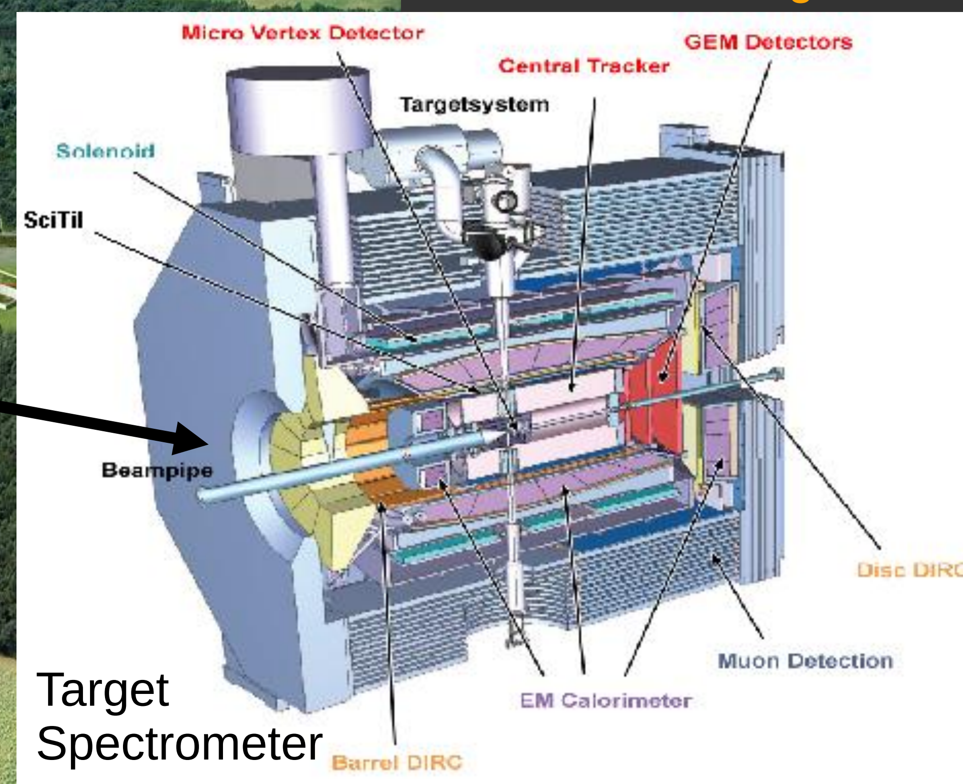
  $L = 2*10^{32}\ cm^{-2}\ s^{-1}$, $\delta p/p < 10^{-4}$
- PANDA – fixed target experiment, consists of Target Spectrometer and Forward Spectrometer

Physics highlights:

- hadron spectroscopy
- hadron structure
- nuclear physics

Installation and commissioning ~2017





Physics @ PANDA

Main physics topics:

- Charmonium spectroscopy
- Hybrids and glueballs
- In medium modifications of mesons
- Open charm physics

Some benchmark channels:

$$\bar{p}p \to \psi(3770) \to D^+ D^- \to K^- \pi^+ \pi^+ + c.c.$$

$$\bar{p}p \to \psi(4040) \to D^{*+} D^{*-} \to D^0 \pi^+ \overline{D}^0 \pi^-,$$

$$\mapsto D^0 \to K^- \pi^+ \quad or \quad K^- \pi^+ \pi^- \pi^+$$

$$\bar{p}p \to D^*_{sJ}(2317)^+ D^*_{sJ}(2317)^- \to D_s^+ \pi^0 D_s^- \pi^0 \to K^- K^+ \pi^+ \gamma\gamma + c.c.$$

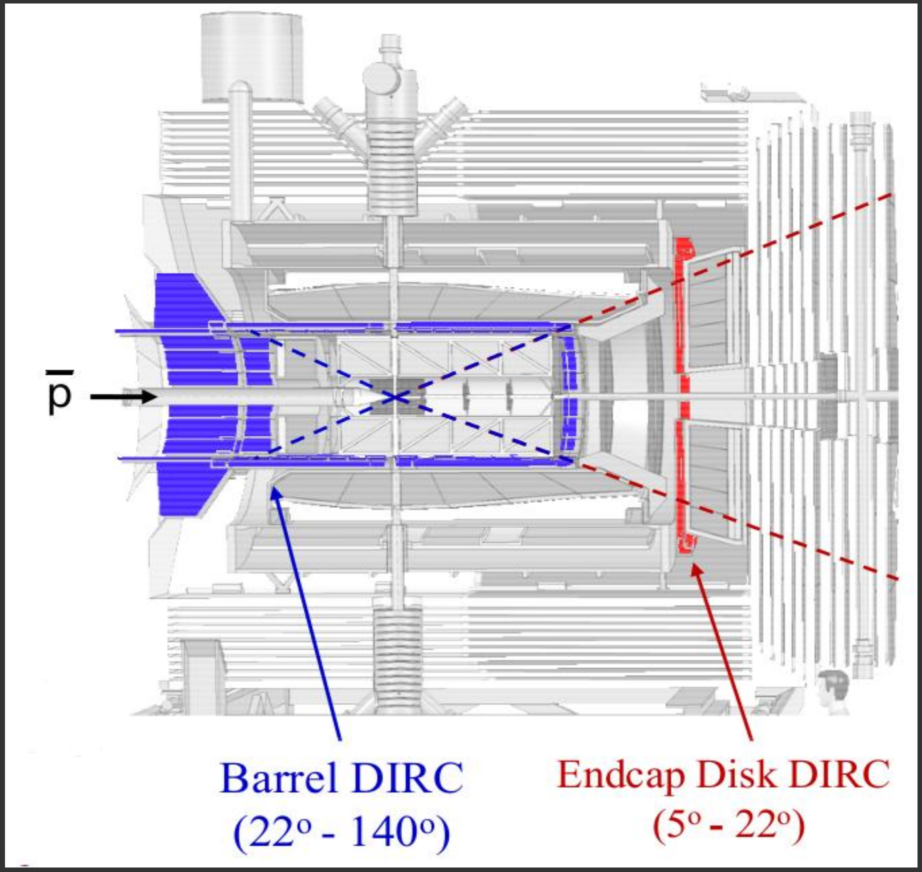
$$\bar{p}p \to D_{sJ}(2460)^+ D_{sJ}(2460)^- \to D_s^+ \gamma D_s^- \gamma \to K^- K^+ \pi^+ \gamma + c.c.$$

Important detector requirement:
good hadron PID – π/K separation

Hadron PID @ PANDA

Based on a number of elements: dE/dx, time-of-flight, **DIRC**

1. DIRC (Detection of Internally Reflected Cherenkov light) based on BABAR experience
   - first DIRC detector, excellent PID performance
   - 8+ years of stable and reliable operation
2. Advantages of DIRC detectors:
   - thin in radial direction and in radiation length → more compact EM calorimeter with less material in front
   - fast and tolerant to background
   - robust and stable detector operation
3. PANDA: two DIRC detectors
   - Barrel DIRC – similar to BABAR DIRC with several improvements
   - endcap Disk DIRC
   - Institutions involved: Dubna, Edinburgh, Glasgow, Erlangen, Gießen, GSI, Mainz, Vienna



Basics of DIRC Detectors

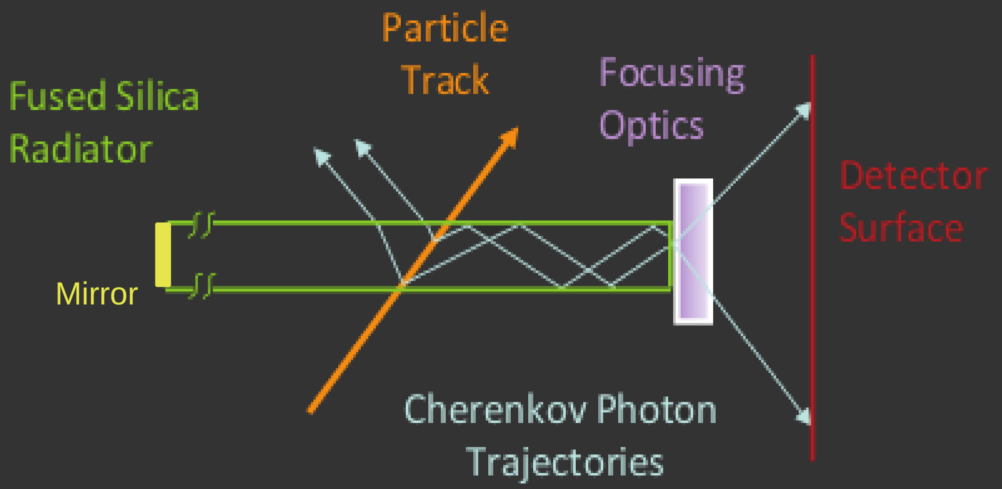
- Charged particle with $\beta = v/c > 1/n$ propagating in a medium with refractive index n emits Cherenkov photons on a cone with opening angle

$$\cos\theta_C = \frac{1}{\beta n(\lambda)}$$

- For media with n > √2 there are always some totally internal reflected photons

- High quality rectangular radiator shape is required to conserve the magnitude of the Cherenkov angle during the total internal reflections of propagating photons

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



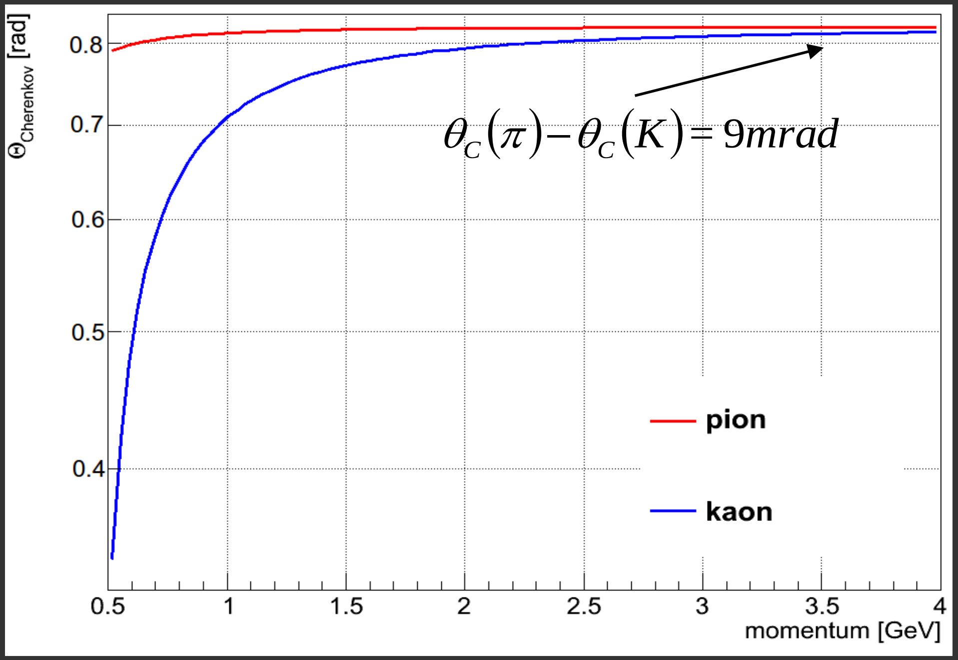
Observed hit patterns of Cherenkov photons (x,y,t) determine PID likelihoods for e/μ/π/K/p

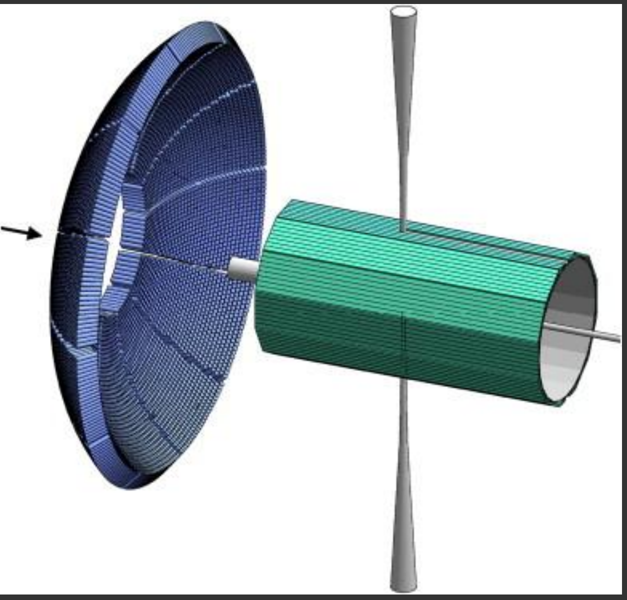
Basics of the PANDA Barrel DIRC

- Radiator bars are made of Synthetic Fused Silica with n ≈ 1.47

- PANDA particle identification requirement: ≥ 3 standard deviations π/K separation in the momentum range 0.5 GeV/c – 3.5 GeV/c

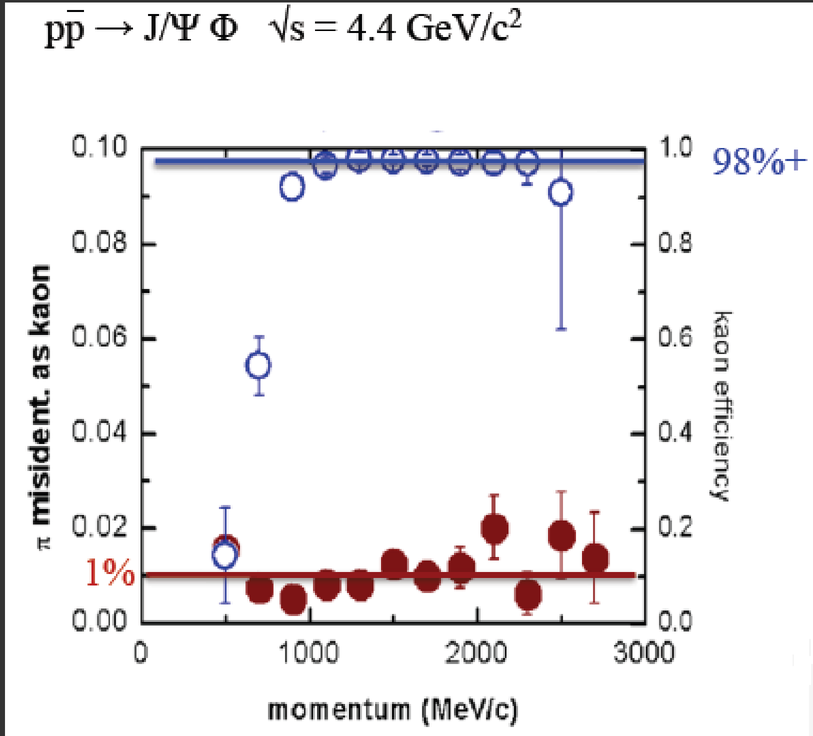
- 3 σ π/K separation at 3.5 GeV/c means ≤ 3 mrad Cherenkov angle resolution





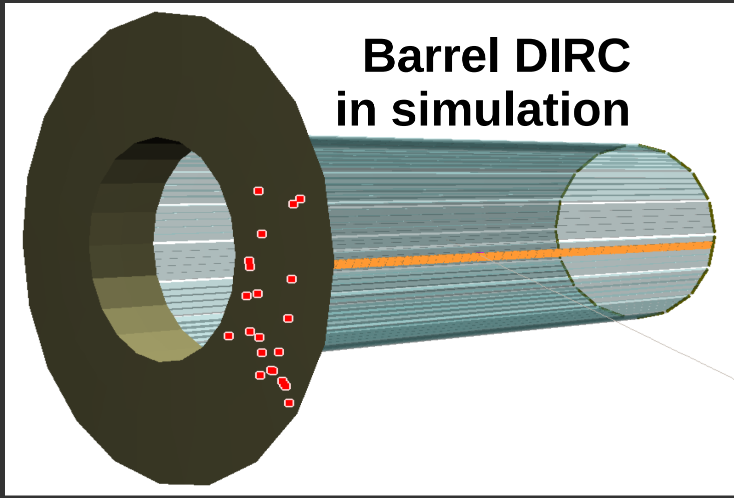
Initial design, close to BABAR DIRC

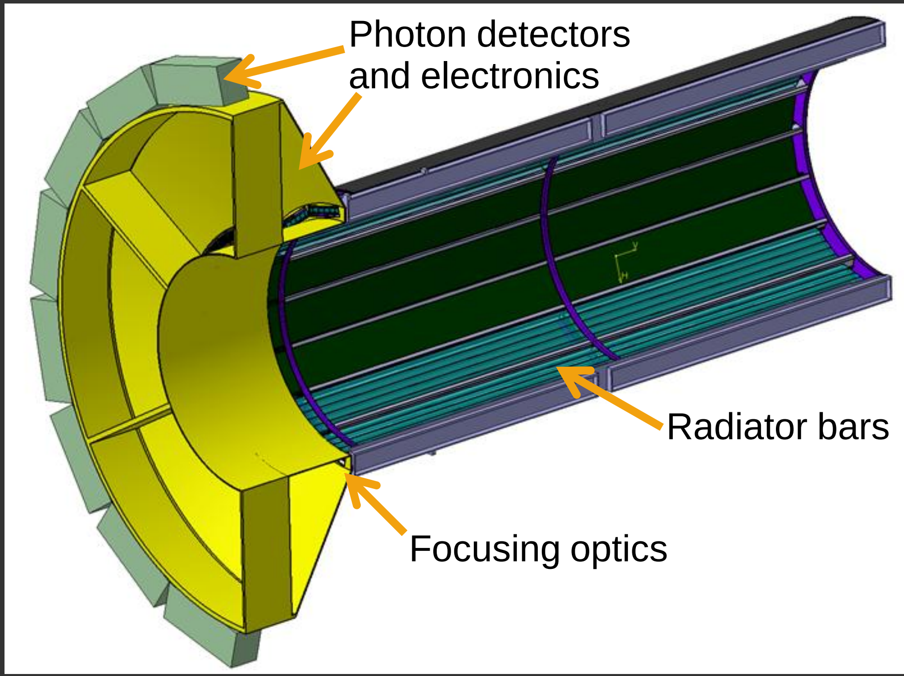
Expected PID performance example, based on the initial design and simplified fast simulation



PANDA Barrel DIRC

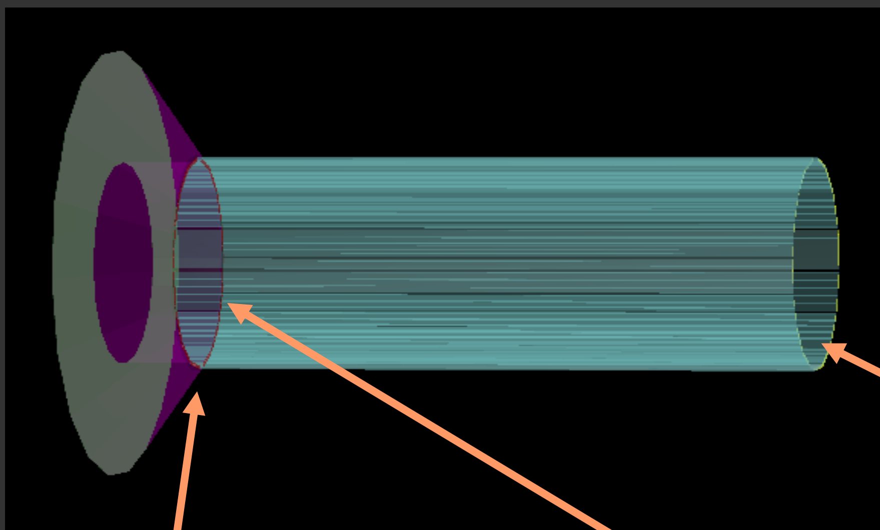
- PANDA Barrel DIRC is based on BABAR DIRC with several important improvements:
  - compact expansion volume (EV)
  - focusing system
  - fast photon timing
- 80 radiator bars (synthetic fused silica) in 16 bar boxes, each bar 17 mm x 33 mm x 2500 mm
- Barrel radius 46 cm
- 30 cm deep expansion volume filled with oil
- 10-15 k channels of MCP-PMTs, time resolution ~100 ps
- To improve the performance and reduce the detector cost, many parameters are being optimized and a number of design options are being studied:
  1. Simulation
  2. Particle beams





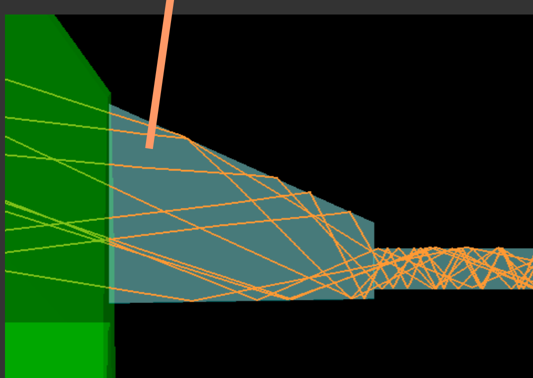
Performance Study: Simulation

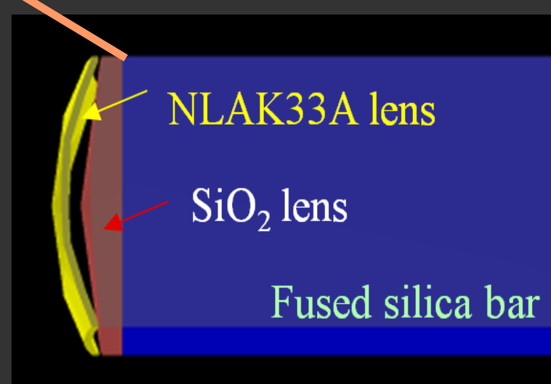
- detailed detector simulation using Geant
- the baseline design as well as a number of design options are implemented

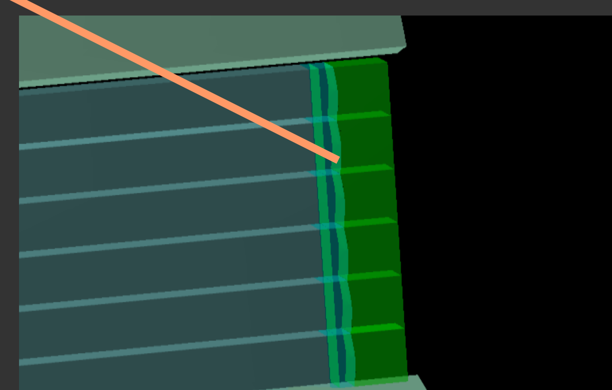


Some critical parameters:

1. width and thickness of the radiator
2. focusing system: lens or mirror
3. shape of the expansion volume



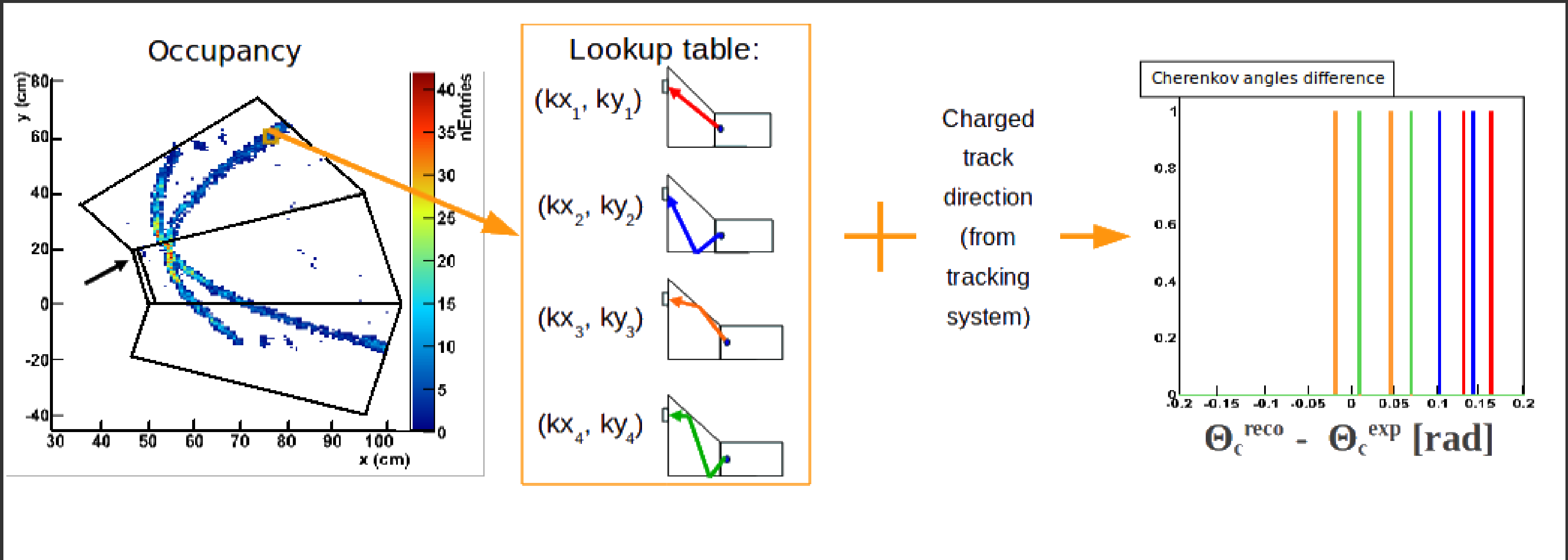




The prism, the lens and the focusing mirrors in the simulation

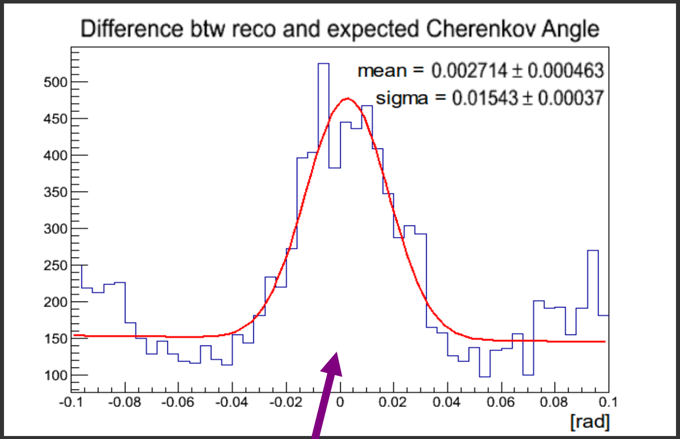
Performance Study: Reconstruction

To evaluate the performance of different designs a proven BABAR-type reconstruction was used. The Cherenkov angle is determined for each detected photon by comparing the direction of the particle track (taken from other detector systems) and the direction of the detected photon, approximated using the pixel and the bar positions (taken from the look-up table).



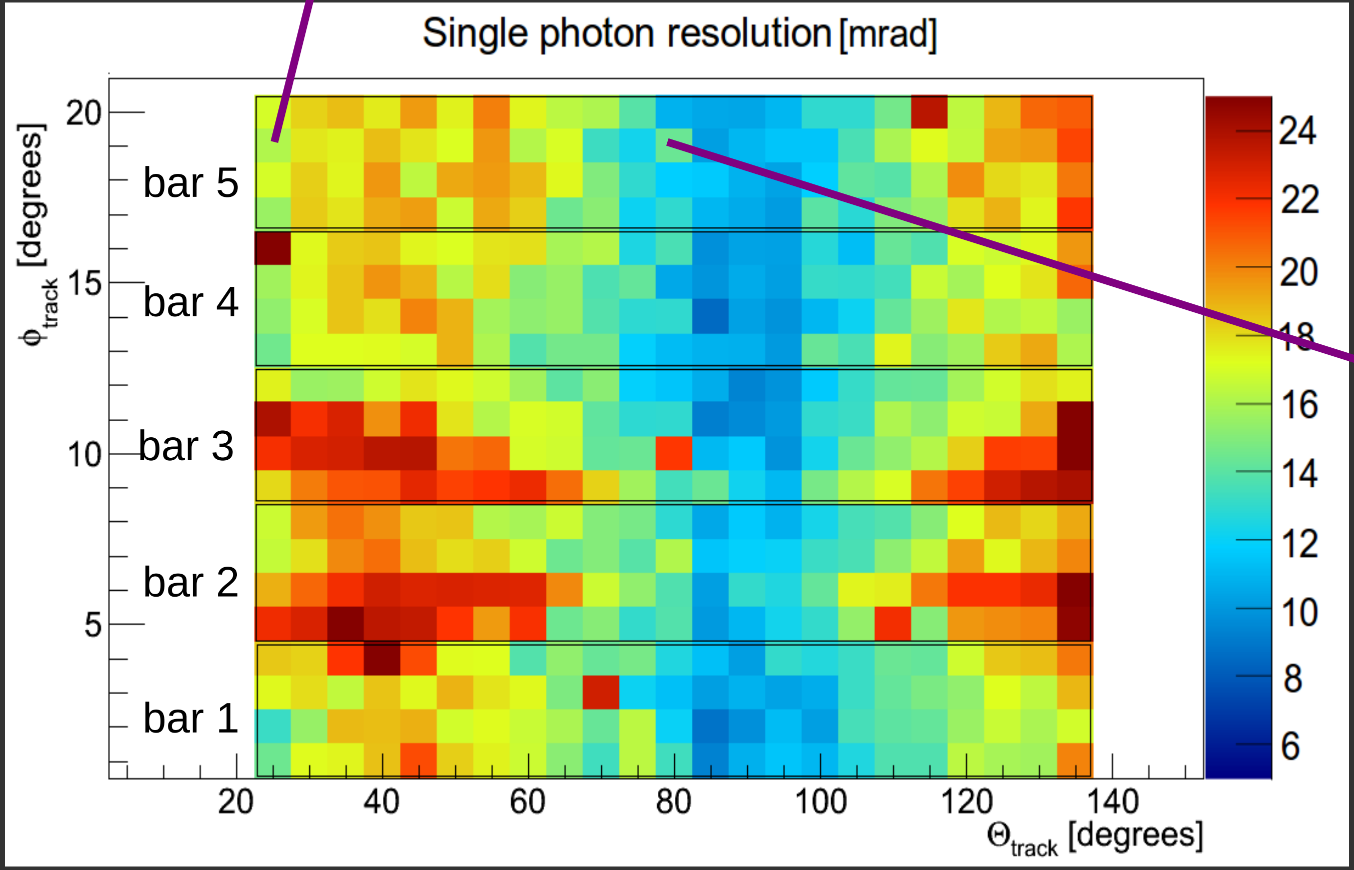
Apply this procedure to all photons from the same track → peak at the right $\Delta\theta_C$ value + combinatoric background.

Performance study: Example

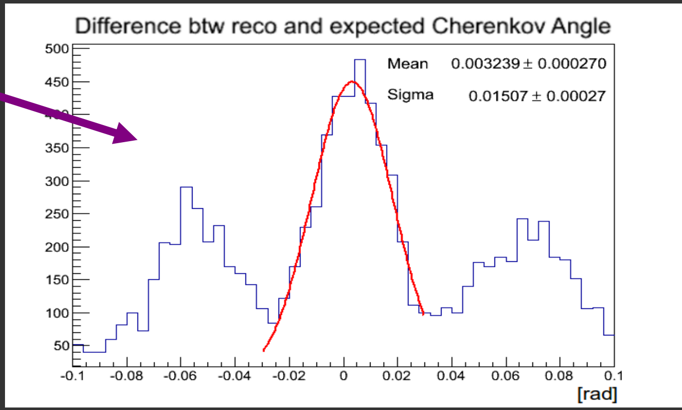


The width of the Gaussian fit for the distribution $<\theta_c^{reco}-\theta_c^{exp}>$ is shown on the map representing the whole bar box. The simulation was done using 3 GeV/c muons.

No focusing, fused silica bars are directly attached to the expansion volume (EV)

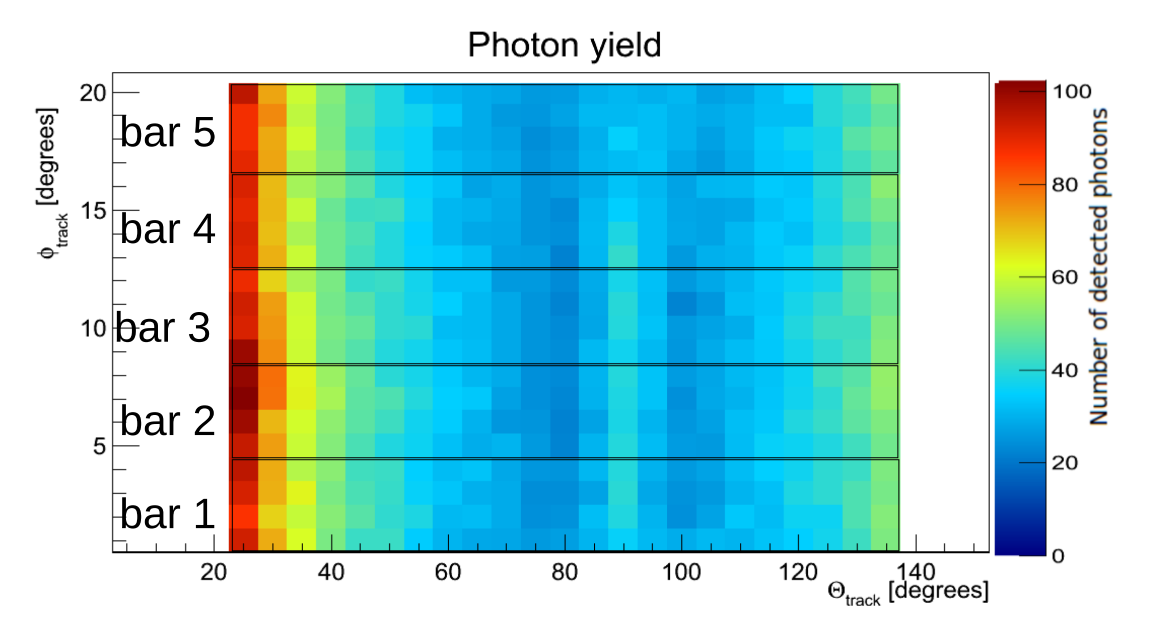


Simple estimation of single photon Cherenkov angle resolution - 18-19 mrad



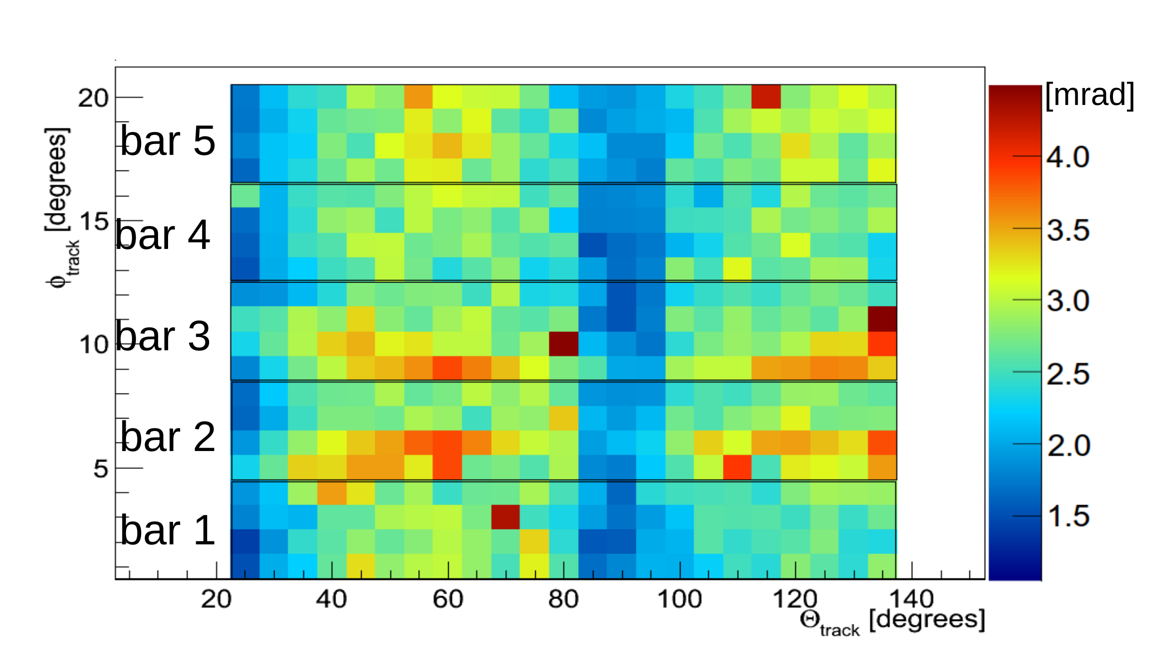
Background shape is due to the reconstruction ambiguities

Performance Study: Example



A map of number of detected photons per charged track, simulated with 3 GeV/c muons

The longer the photon path inside the radiator bar, the larger the photon yield.

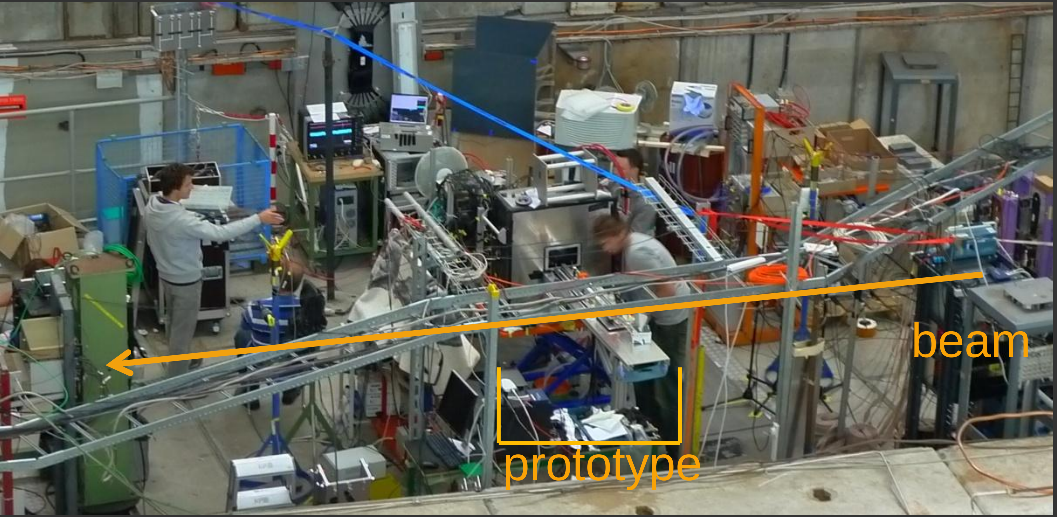


A map of Cherenkov angle resolution per track assuming ideal tracking and perfect bar shape

$$\sigma_{\theta_C^{track}} = \sigma_{\theta_C^{photon}} / \sqrt{N_{photons}}$$

Performance Study: Test Beam

CERN T9 beam line, East Area



2011 prototype setup

2011, 2012 @ T9 beam line, CERN East area

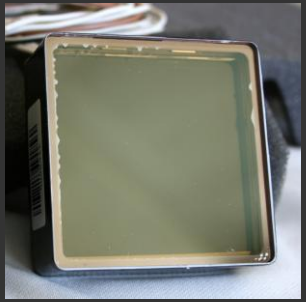
Goal: verify design concepts in terms of
- different expansion volumes
- optics
- bar vs plate

Obtain:
- hit patterns
- photon yield
- single photon resolution
- ultimately – PID performance

Vary:
- track angle and position
- beam momentum (1.5 – 10GeV/c)

2012
High quality tracks
were chosen with
two fiber trackers
(27 x 27 mm)

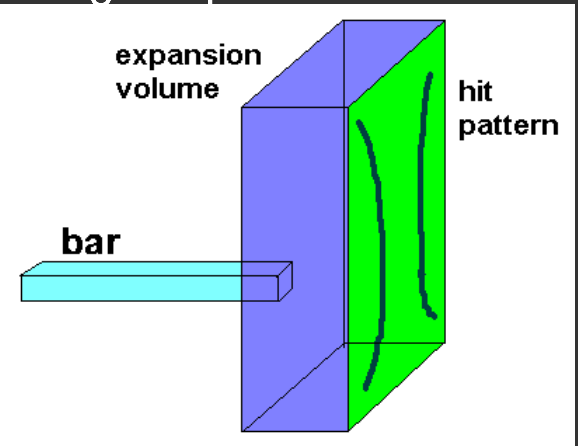
MCP-PMT
photon detector



Performance Study: Test Beam

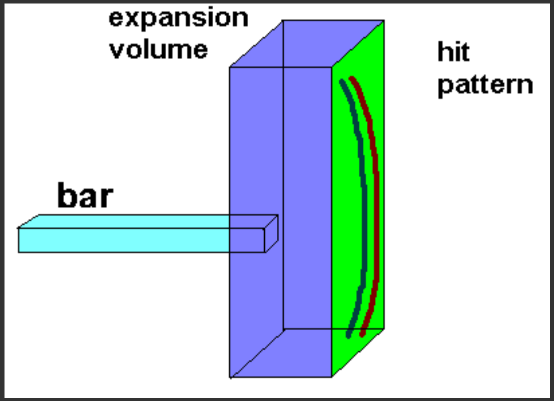
Transformation of the hit pattern with modifications in the expansion volume shape

Large expansion volume



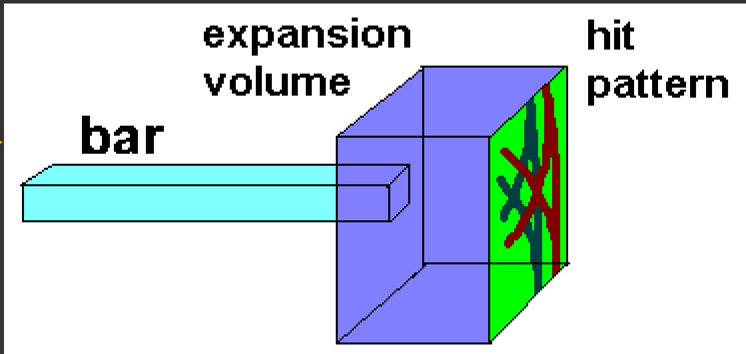
Two arches of Cherenkov ring

Expansion volume is cut vertically close to the bar

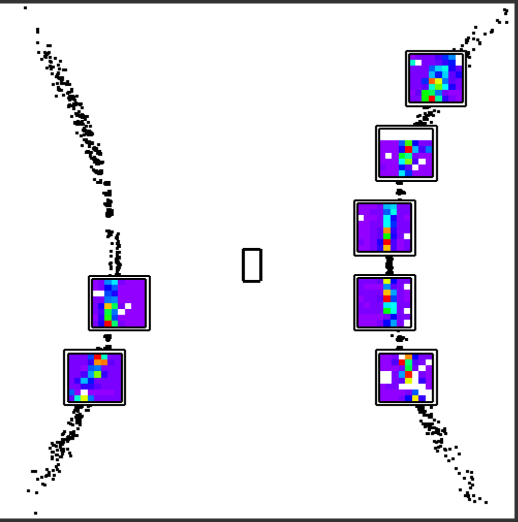


Two arches of Cherenkov ring parallel to each other

Expansion volume is cut horizontally so the bar is ~ in the middle of height



Two arches of Cherenkov ring parallel to each other with overlapping tails

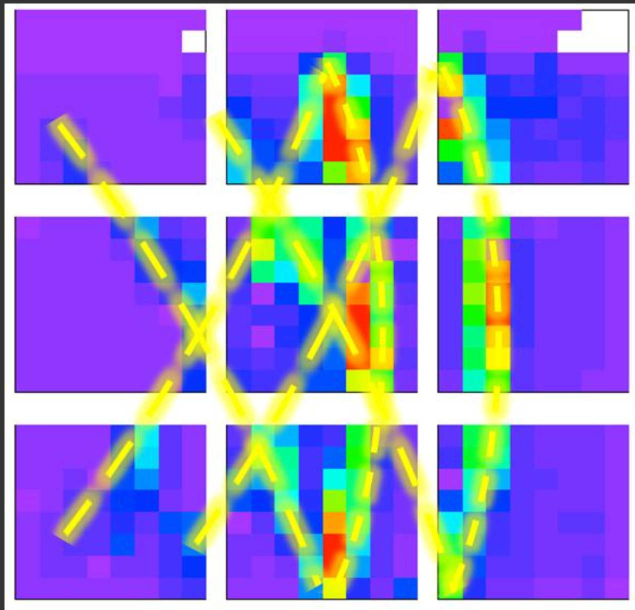


2011

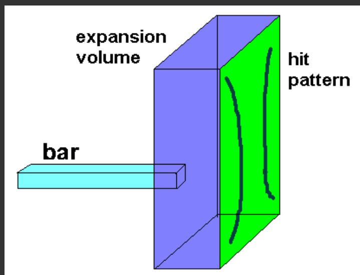
Simulated hit pattern overlaid with the observed hit pattern on the MCPs

2012

Observed hit pattern on the MCPs



Performance Study: Test Beam



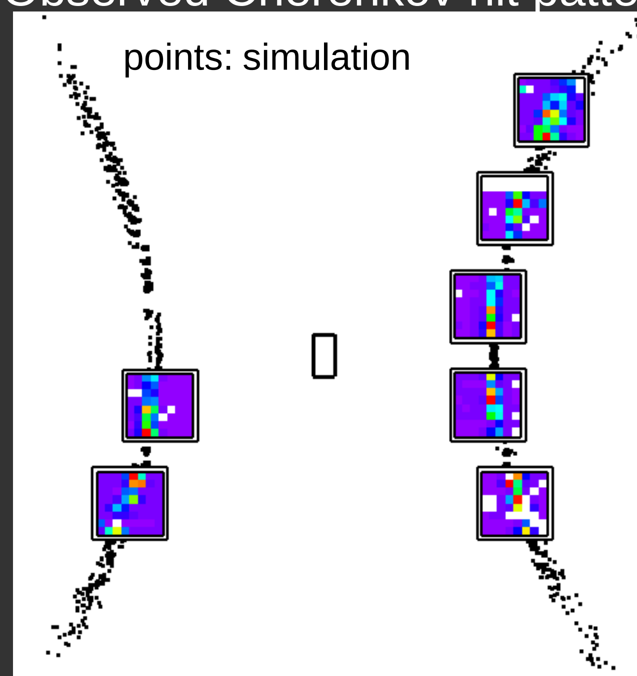
2011

Large expansion volume (80cm x 80cm x 30cm) filled with mineral oil

Two arches of Cherenkov ring on the photo detector plane

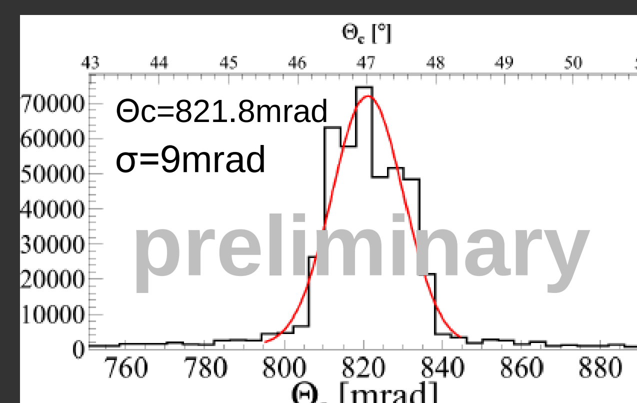
MCPs on the back side of the expansion volume

Observed Cherenkov hit pattern

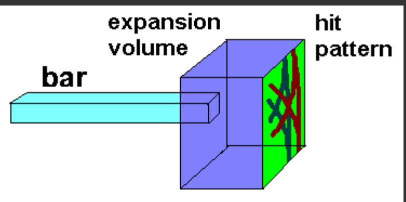


Number of detected photons: 3 photons/track detected, agrees with expectation

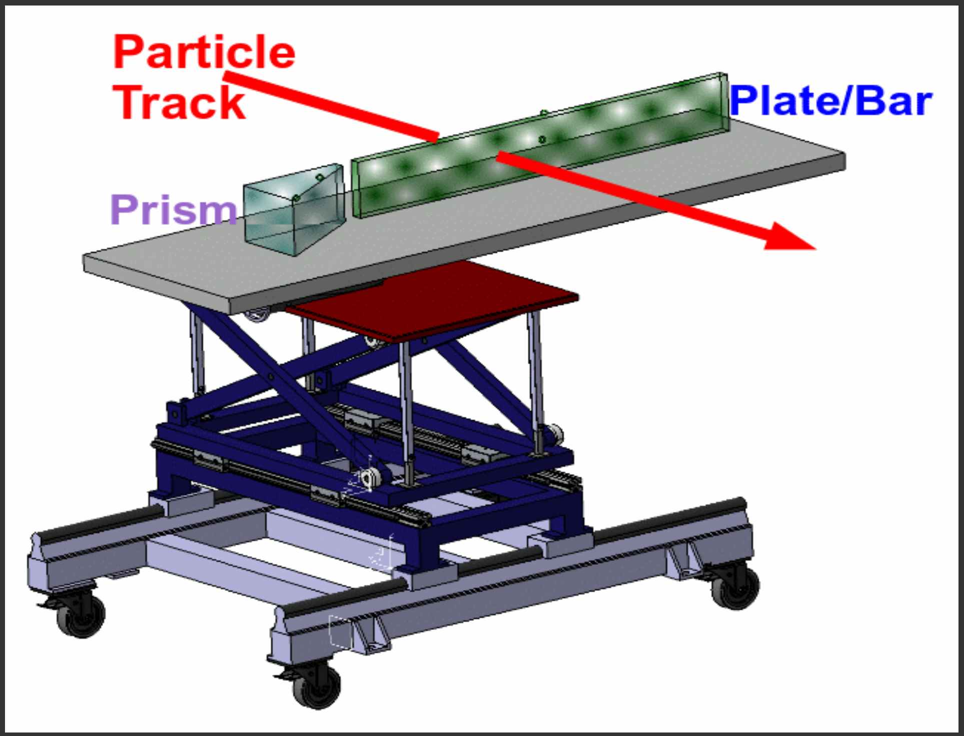
10 GeV/c pions, expected Θ_c=822 mrad, $\sigma_{\theta c}$ = 8.5 mrad



Performance Study: Test Beam



August/ September 2012



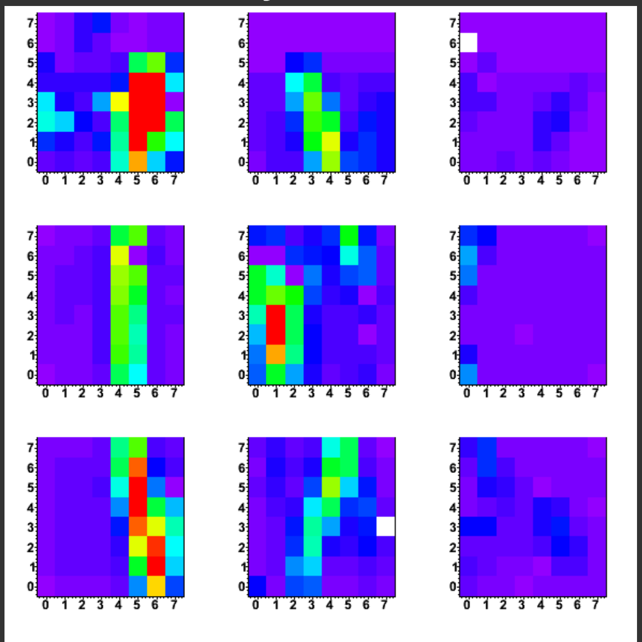
→ much more complex and ambitious test:

- wide range of polar angles, similar to PANDA acceptance
- different types of lenses
- bars from different manufacturers
- plate
- compact expansion volume (prism)
- different azimuth angles

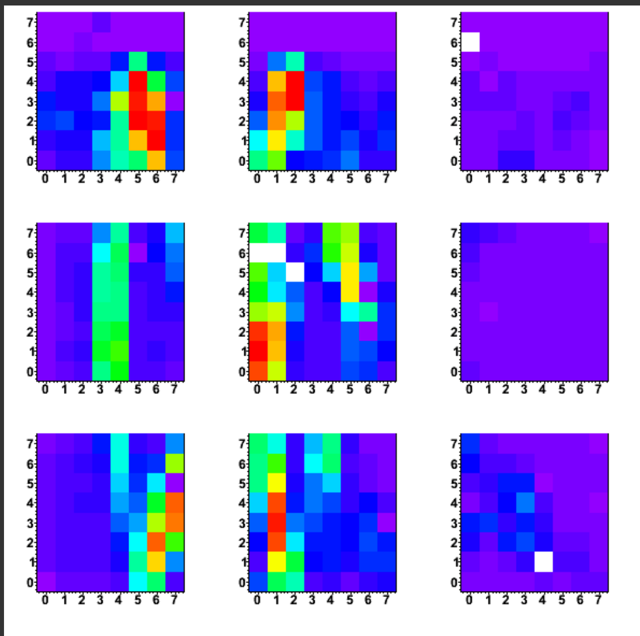
Small expansion volume – fused silica prism (17cm width, 30 cm depth, 30◦ opening angle)

Folded Cherenkov pattern on the photon detector plane

InSync bar



LZOS (Lytkarino) bar



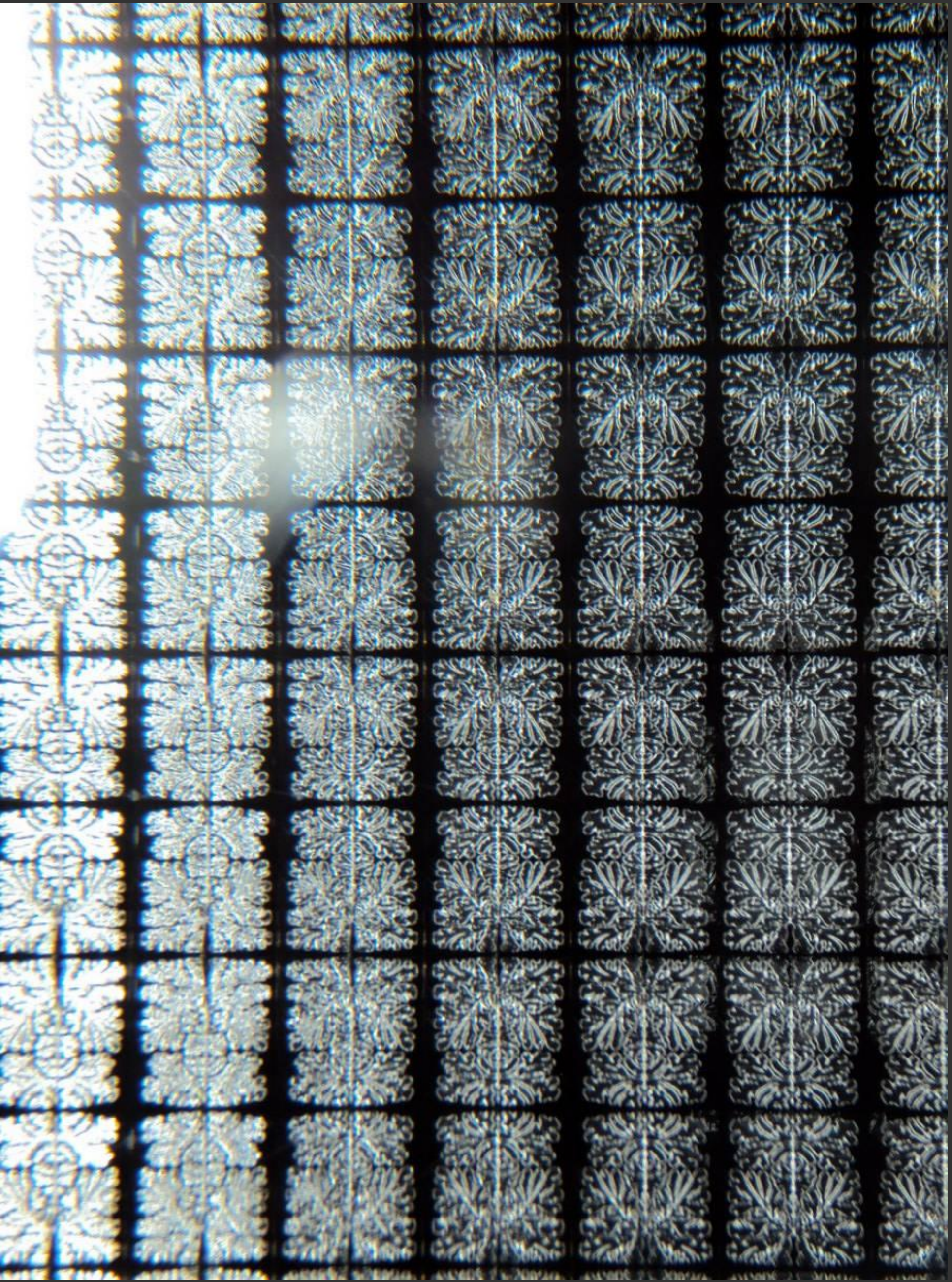
Summary & Outlook

- *Hadron PID for PANDA in the Barrel region → Cherenkov detector of the novel DIRC-type*

- *PANDA Barrel DIRC is based on the BABAR DIRC with important improvements: fast photon timing, compact expansion volume and focusing system*

- *Detailed detector simulation and prototypes in test beams to improve detector performance and cost*

Snowflakes



A pretty kaleidoscope effect typical for DIRC optics.

Looking into the bar from the end towards the front where optical grease was used to couple bar to the window, after the bar was pulled back from the window, some grease residue left on the bar