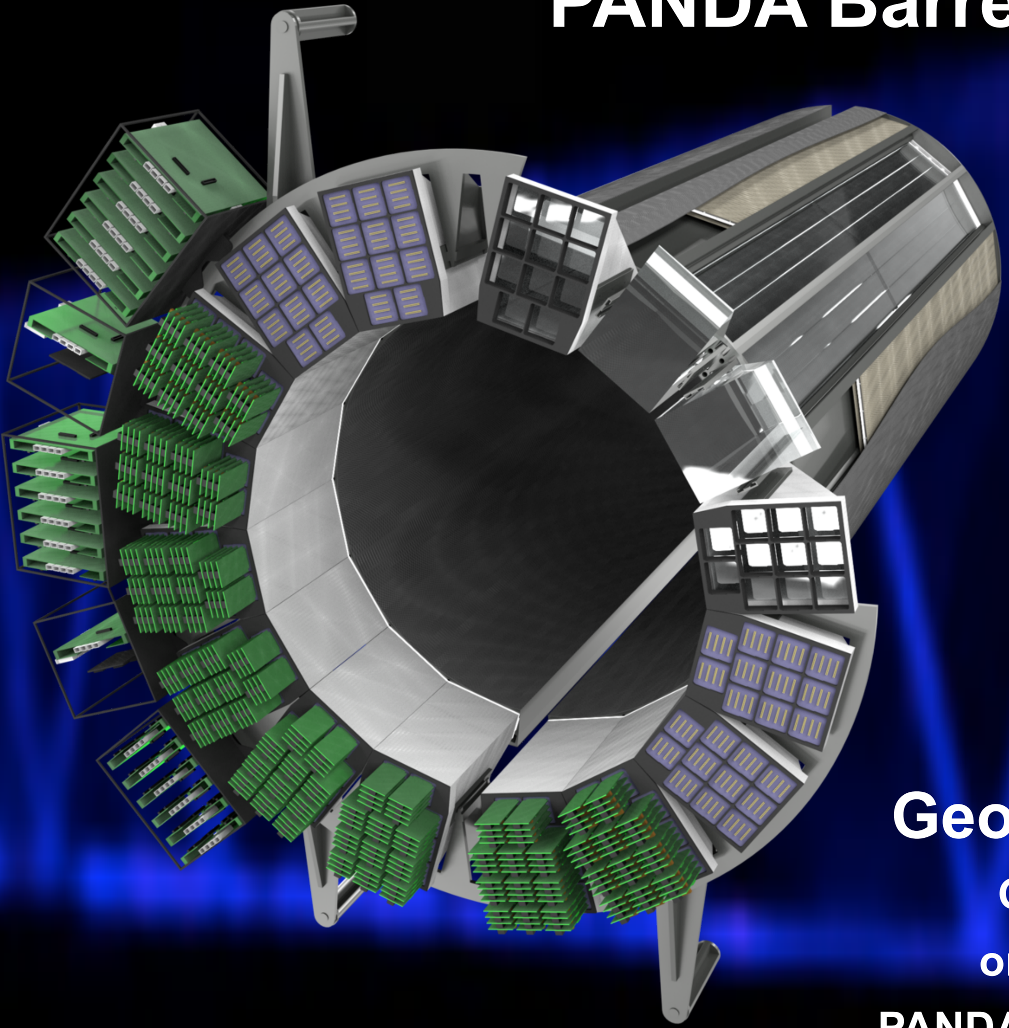
The innovative Design of the PANDA Barrel DIRC



EuNPC 2018
Bologna

Georg Schepers
GSI Damstadt
on behalf of the
PANDA Cherenkov Group

04.09.2018

FAIR

see Talk “Future facility FAIR”
P. Giubellino

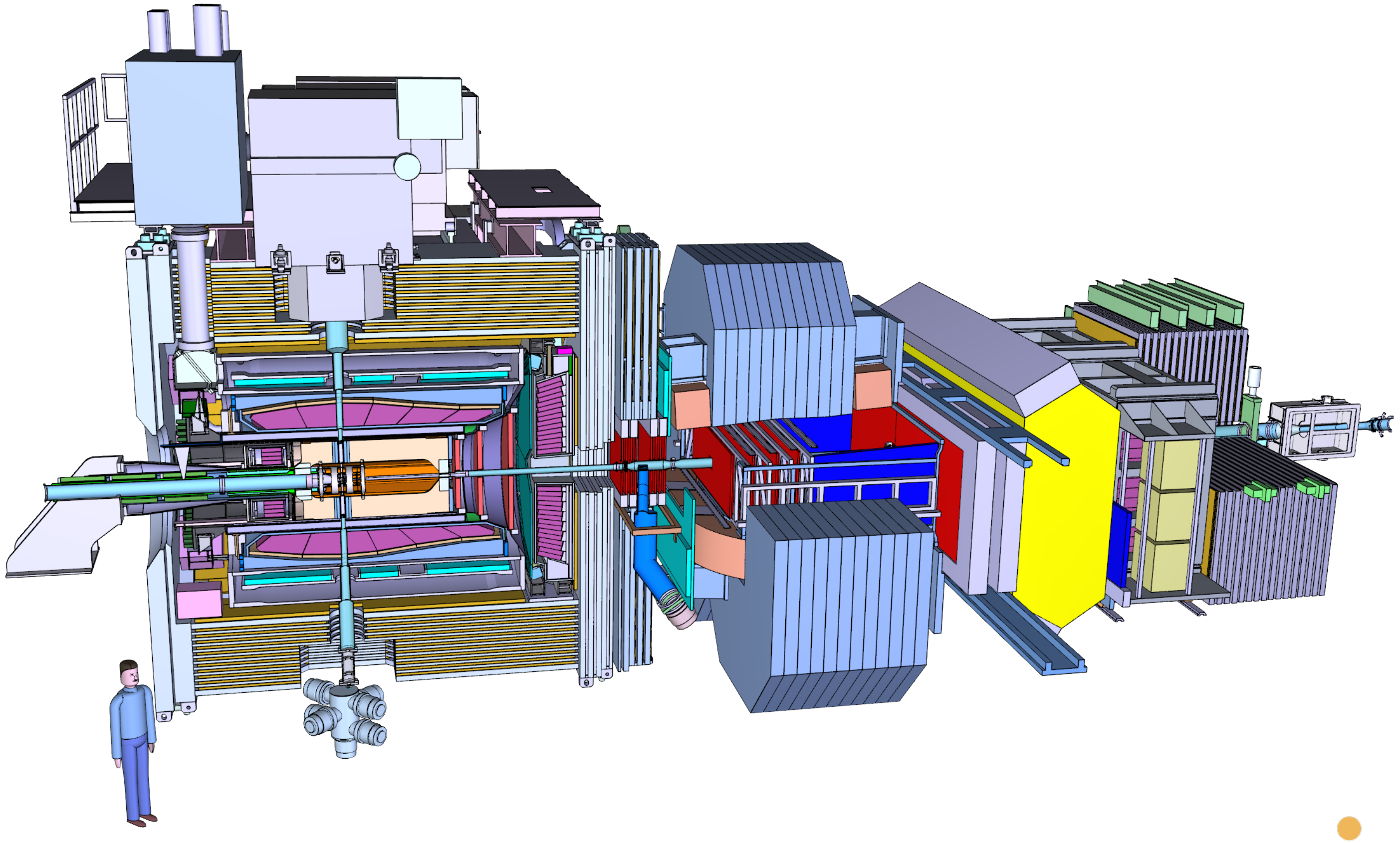
High Energy Storage Ring

- High intensity and high resolution antiproton beam
- 1.5 to 15 GeV/c momentum

PANDA physics program

- Charmonium and open charm spectroscopy
- Search for charmed hybrids and glueballs
- Modification of charmed mesons in nuclear matter
- Hypernuclei
- Nucleon structure

see Poster "Hadron Physics at PANDA"
G. Schepers



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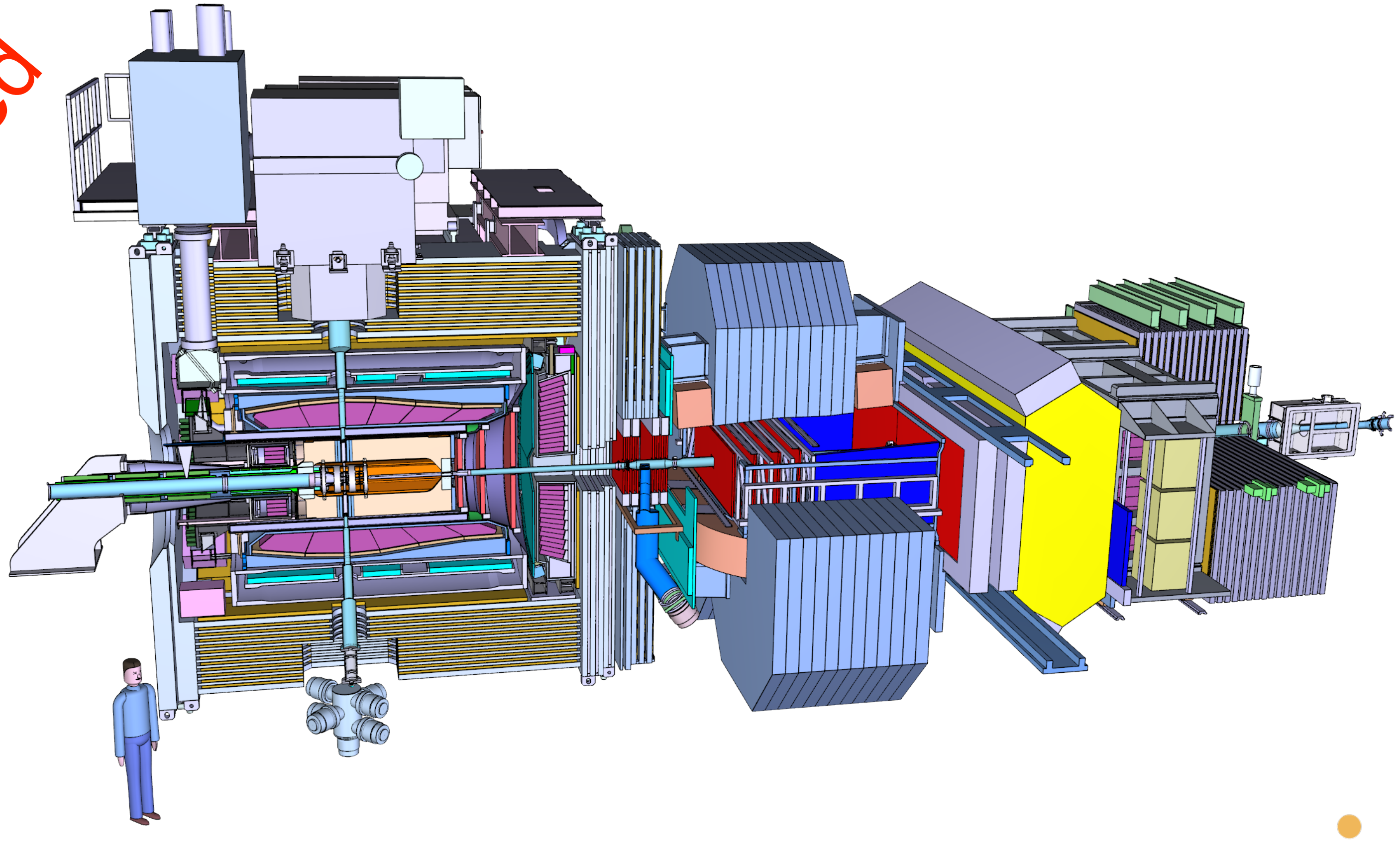
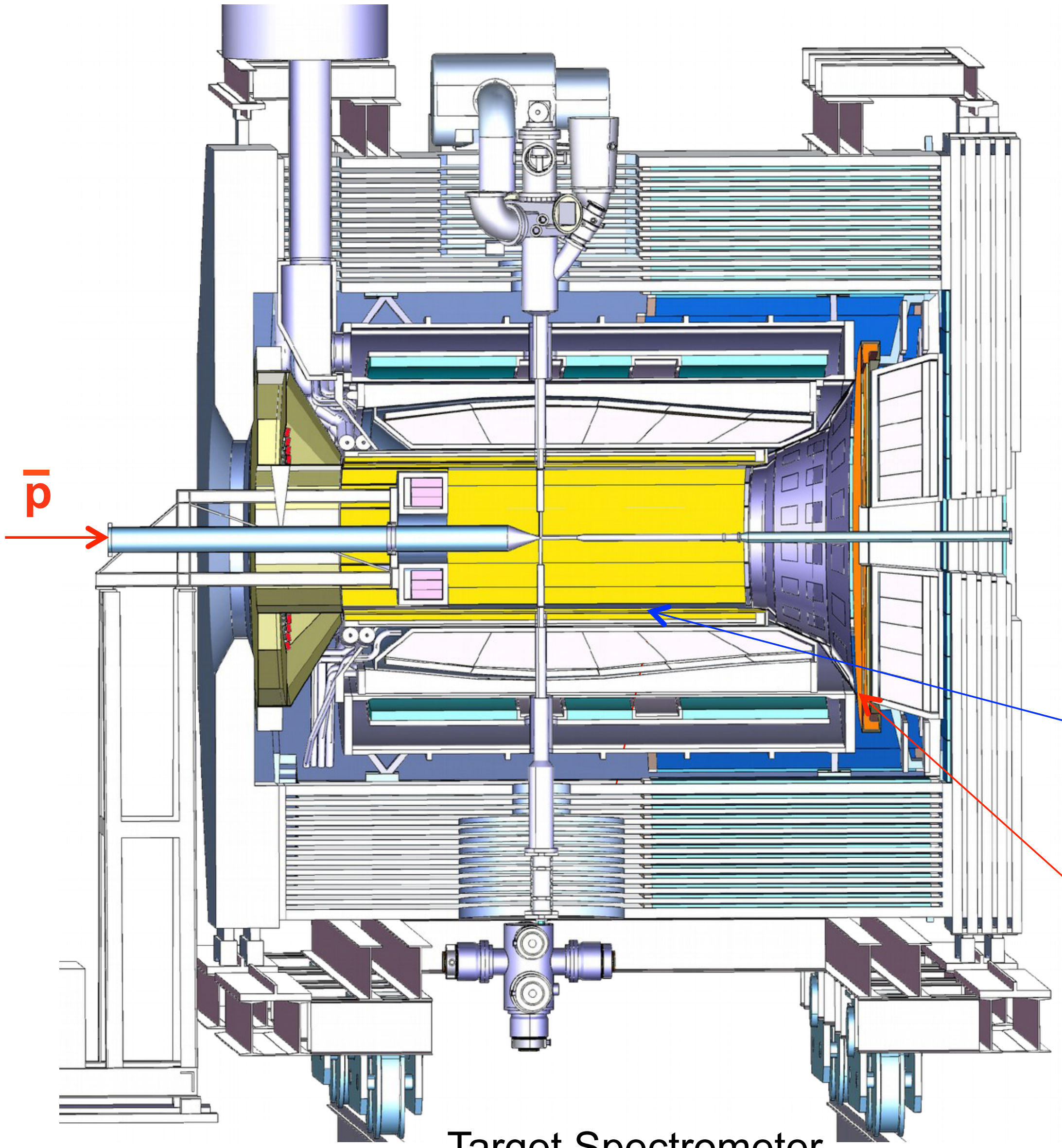
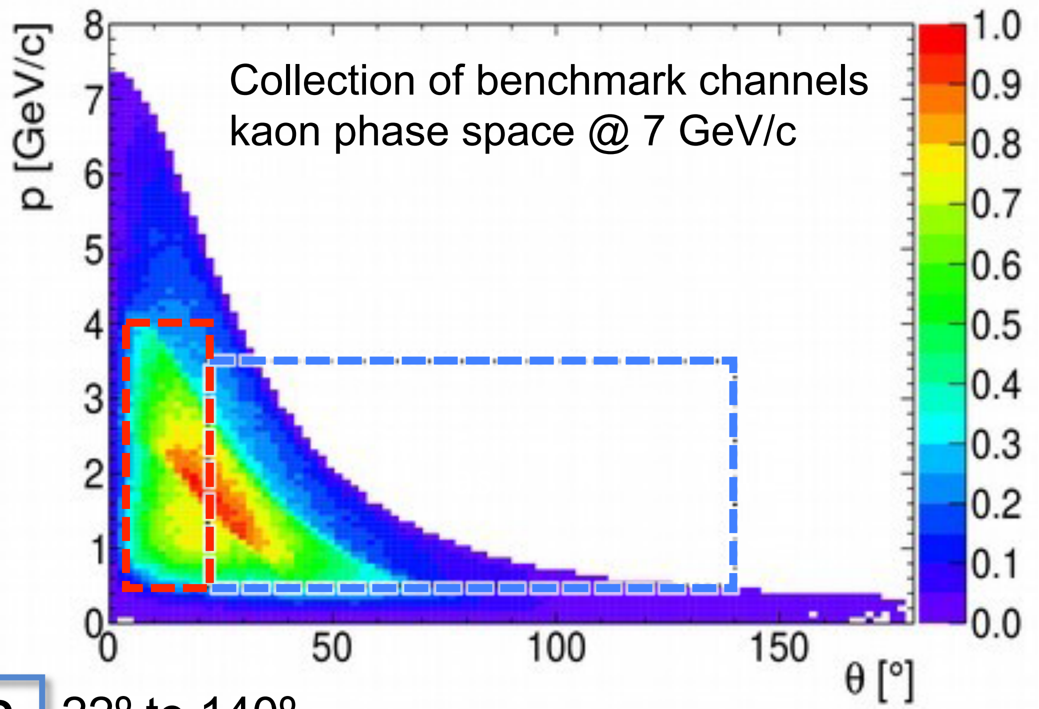
excellent PID is needed



The DIRCs in PANDA



Target Spectrometer



Barrel DIRC 22º to 140º

Goal: 3 s.d. π/K separation up to 3.5 GeV/c

Endcap Disc DIRC 22º to 5º

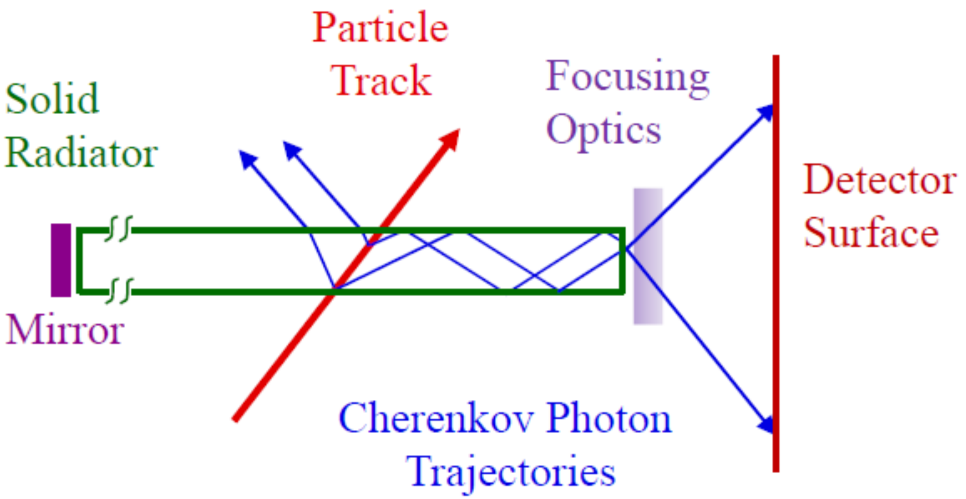
Goal: 3 s.d. π/K separation up to 4 GeV/c

see Talk Mustafa Schmidt, this session

Detection of Internally Reflected Cherenkov light

B.N. Ratcliff, SLAC-PUB-6047 (Jan. 1993)

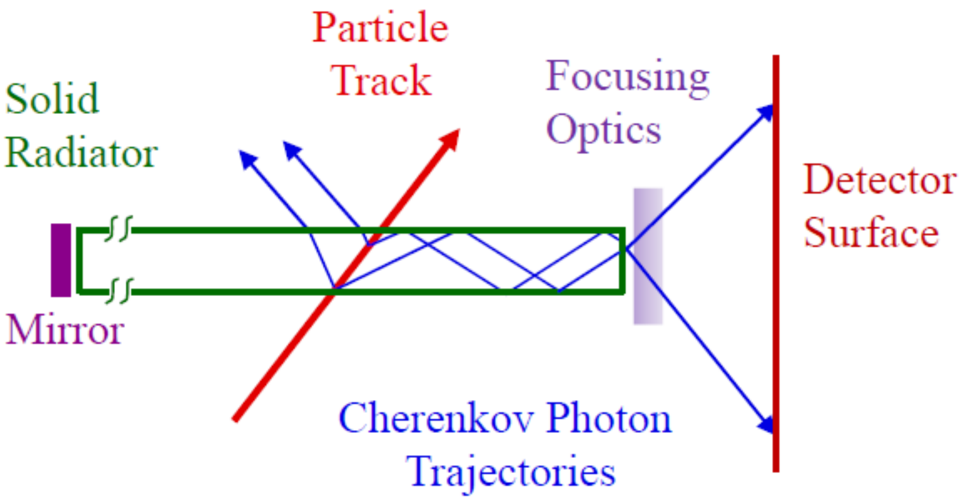
- Charged particle traversing radiator with refractive index n with $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos\theta_c = 1/\beta n(\lambda)$.



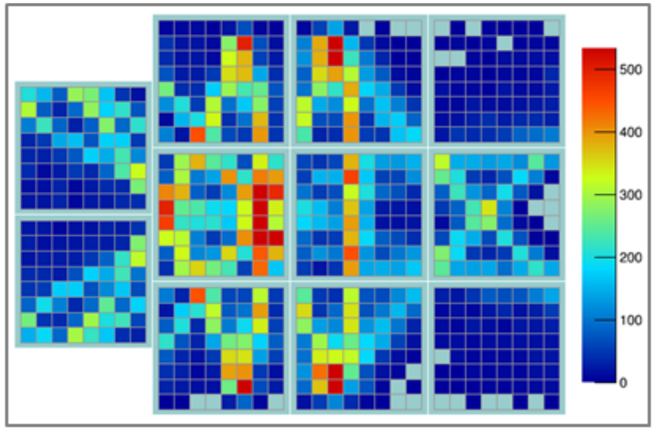
- For $n>\sqrt{2}$ some photons are always totally internally reflected for $\beta\approx1$ tracks.
- Radiator and light guide: bar, plate, or disk made from Synthetic Fused Silica ("Quartz") or fused quartz or acrylic glass or …
- Magnitude of Cherenkov angle conserved during internal reflections (provided optical surfaces are square, parallel, highly polished)

DIRC Concept

- Mirror attached to one bar end, reflects photon back to readout end.
- Photons exit radiator via optional focusing optics into expansion region, detected on photon detector array.
- DIRC is intrinsically a 3-D device, measuring: x, y, and time of Cherenkov photons, defining θ_c, φ_c, $t_{propagation}$.
- Ultimate deliverable for DIRC: PID likelihoods.



Accumulated hit pattern
PANDA Barrel DIRC (Geant)



Initial Studies

Successful BaBar DIRC had the performance required for PANDA

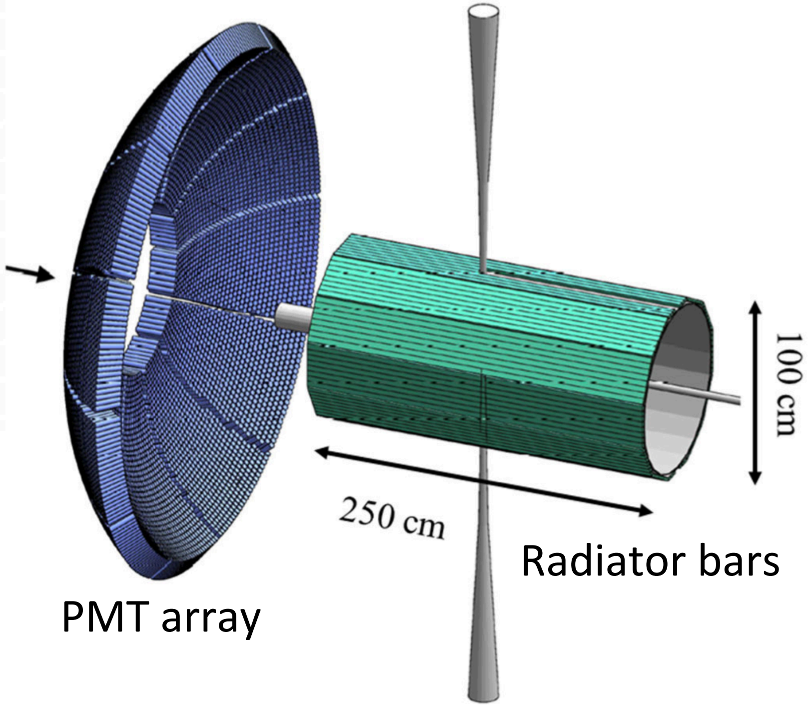
⇒ scaled version of BaBar DIRC

- Radiators: 96 narrow fused silica bars, 2.5m length
- Expansion volume: large water tank
- Sensors: ~ 7,000 conventional PMTs

Fast simulation: design meets PANDA PID goals.

But: increasingly complex PANDA detector design required compact imaging region inside magnet yoke

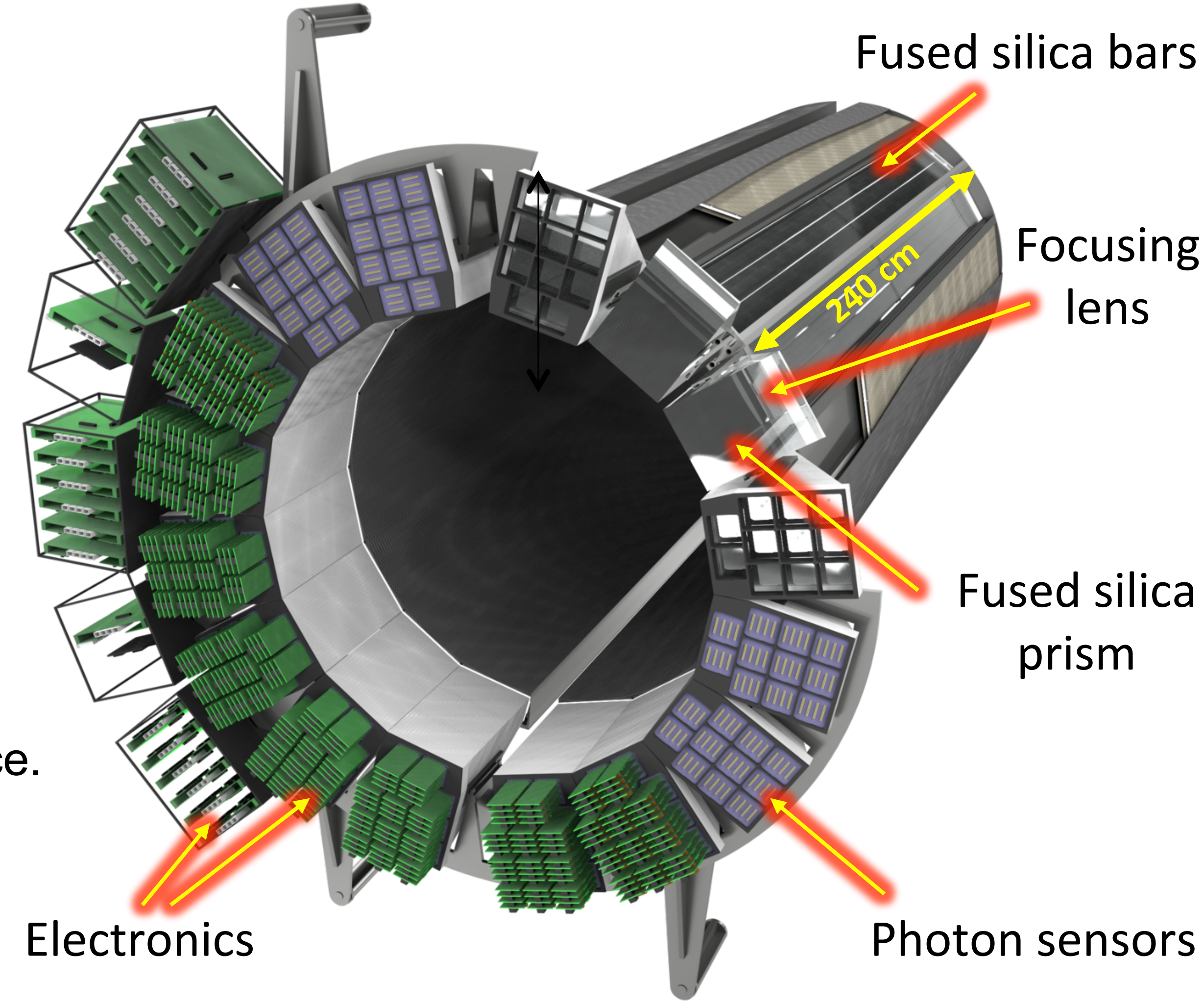
⇒ no large expansion volume, no conventional PMTs



Design

Compact fused silica prisms, 3 bars per bar box, 3-layer spherical lenses.

- 48 radiator bars (16 sectors), synthetic fused silica,
  17mm (T), 53mm (W), 2400mm (L).
- Focusing optics: 3-layer spherical lens
- Compact expansion volume:
  30cm-deep solid fused silica prisms
  ~11,000 channels of lifetime-enhanced MCP-PMTs
- Fast FPGA-based readout.
  ~100ps per photon timing resolution
- Expected performance (simulation and particle beams):
  better than 3 s.d. π/K separation for entire acceptance.



PANDA Barrel DIRC TDR, arXiv:1710.00684

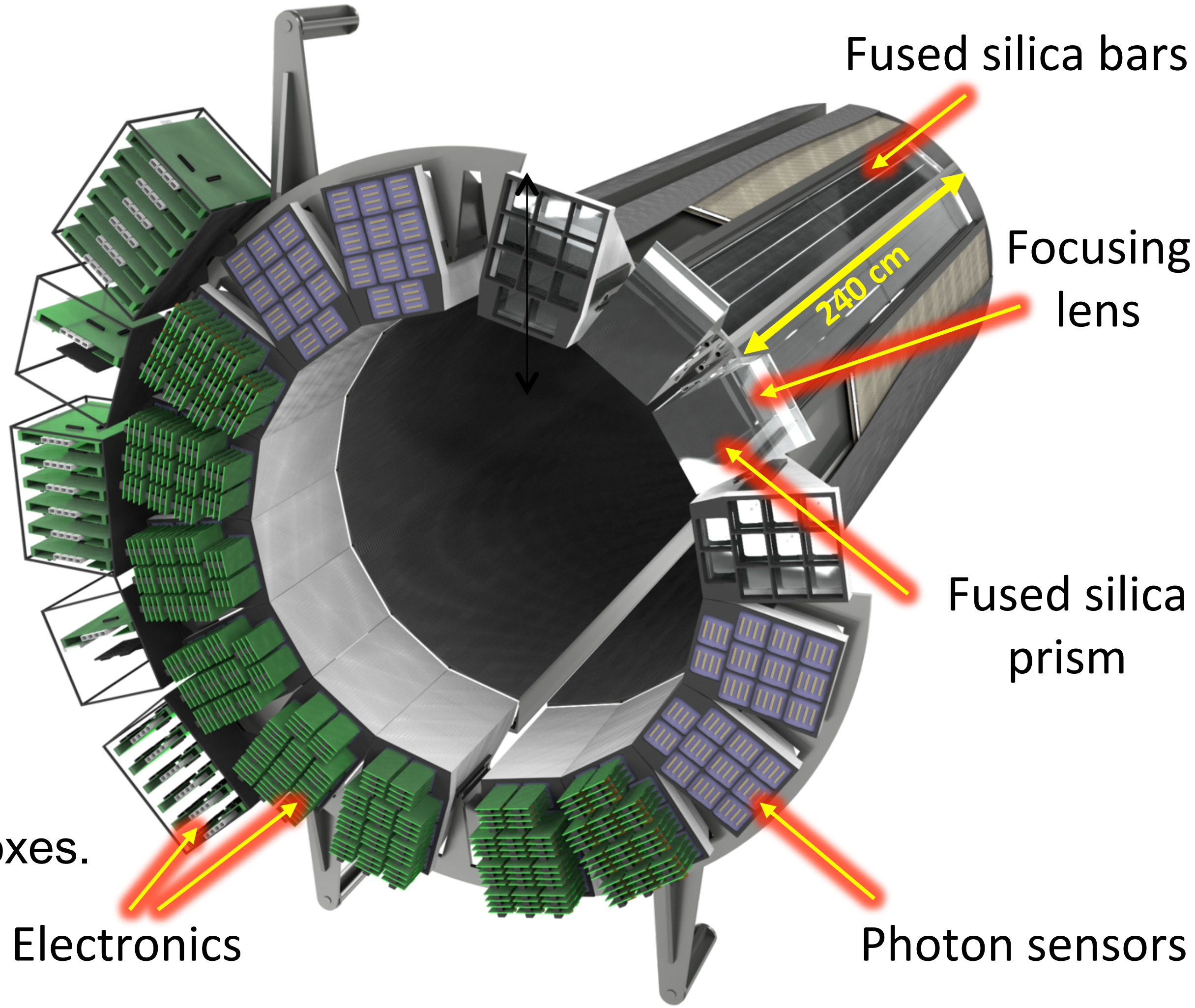
Design

Compact fused silica prisms, 3 bars per bar box, 3-layer spherical lenses.

Conservative design – similar to proven BaBar DIRC – with key innovations: validated in particle beams in 2015.

- Excellent performance
  robust, little sensitivity to backgrounds and timing deterioration.

- Modular design
  easy access and optional staged installation of bar boxes.

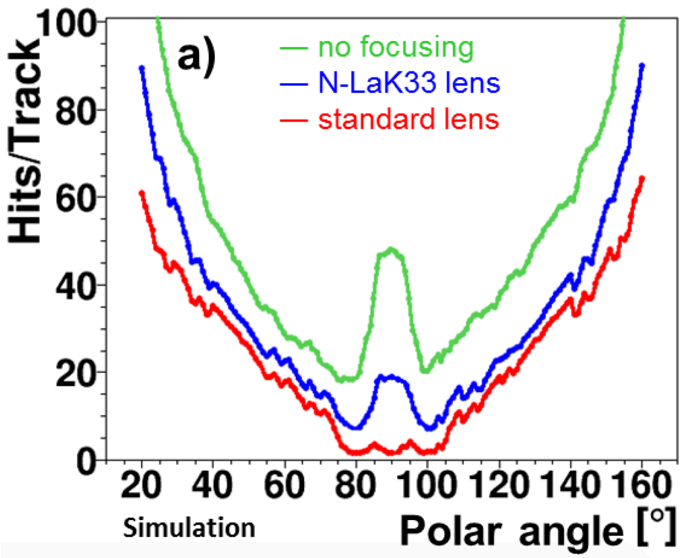


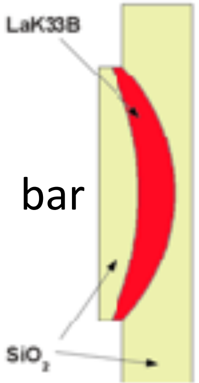
PANDA Barrel DIRC TDR, arXiv:1710.00684

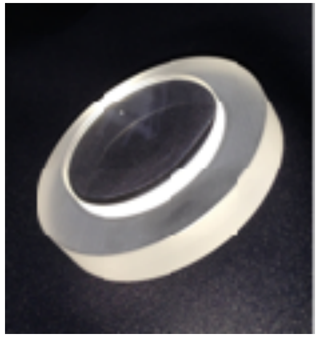
Multi-layer spherical lens

- Standard fused silica lens with air gap would create large hole in DIRC acceptance due to reflection at lens-prism air gap
- Innovative design: refraction between higher-refractive index material and fused silica.
- Solution for PANDA Barrel DIRC:
  lanthanum crown glass (LaK33B) as middle layer in 3-layer lens,
  focusing/defocusing inside lens
  (fused silica: n≈1.473, LaK33B: n≈1.786)
- Photon yield, resolution, and shape of focal plane agree with simulation, hole in acceptance closed.

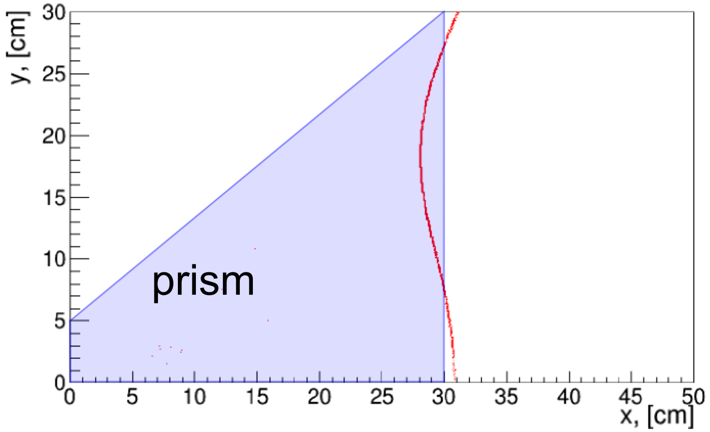
G. Kalicy, DIRC 2013







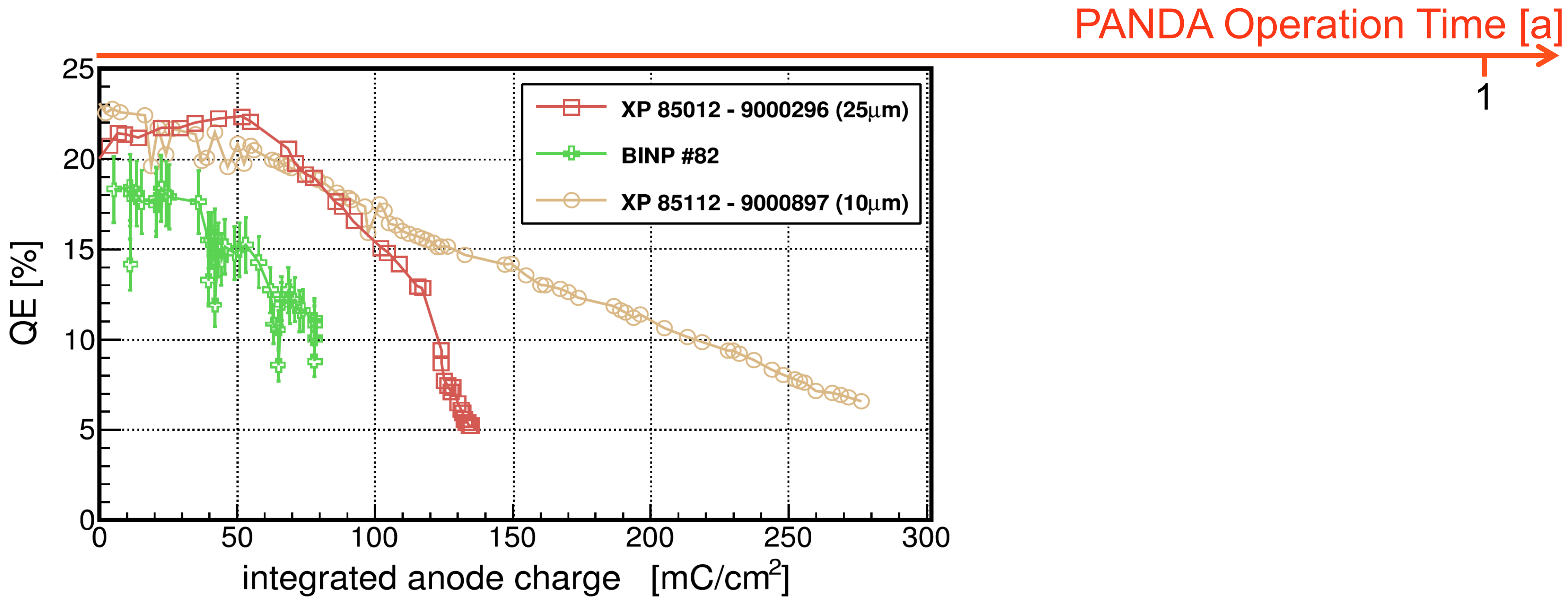
X. He, RICH 2018



Simulation: focal plane of 3-layer lens

Sensor of choice : MCP-PMTs (due to 1T magnetic field, high rate, low noise, timing precision)

Lifetime of MCP-PMTs was potential showstopper for Belle II and PANDA until a few years ago.



Situation in 2011

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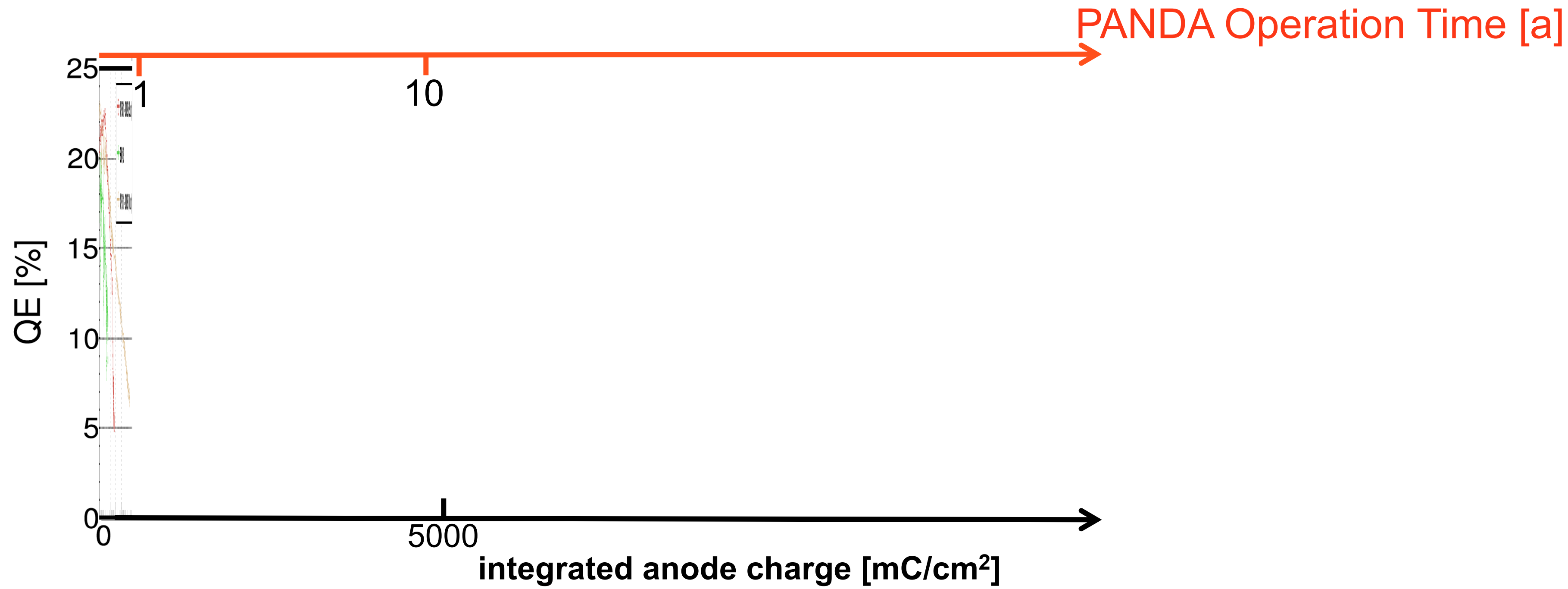

Situation in 2011

Recent MCP-PMTs with atomic layer deposition technique exceed requirements for the PANDA DIRC counters.

Photo Sensors

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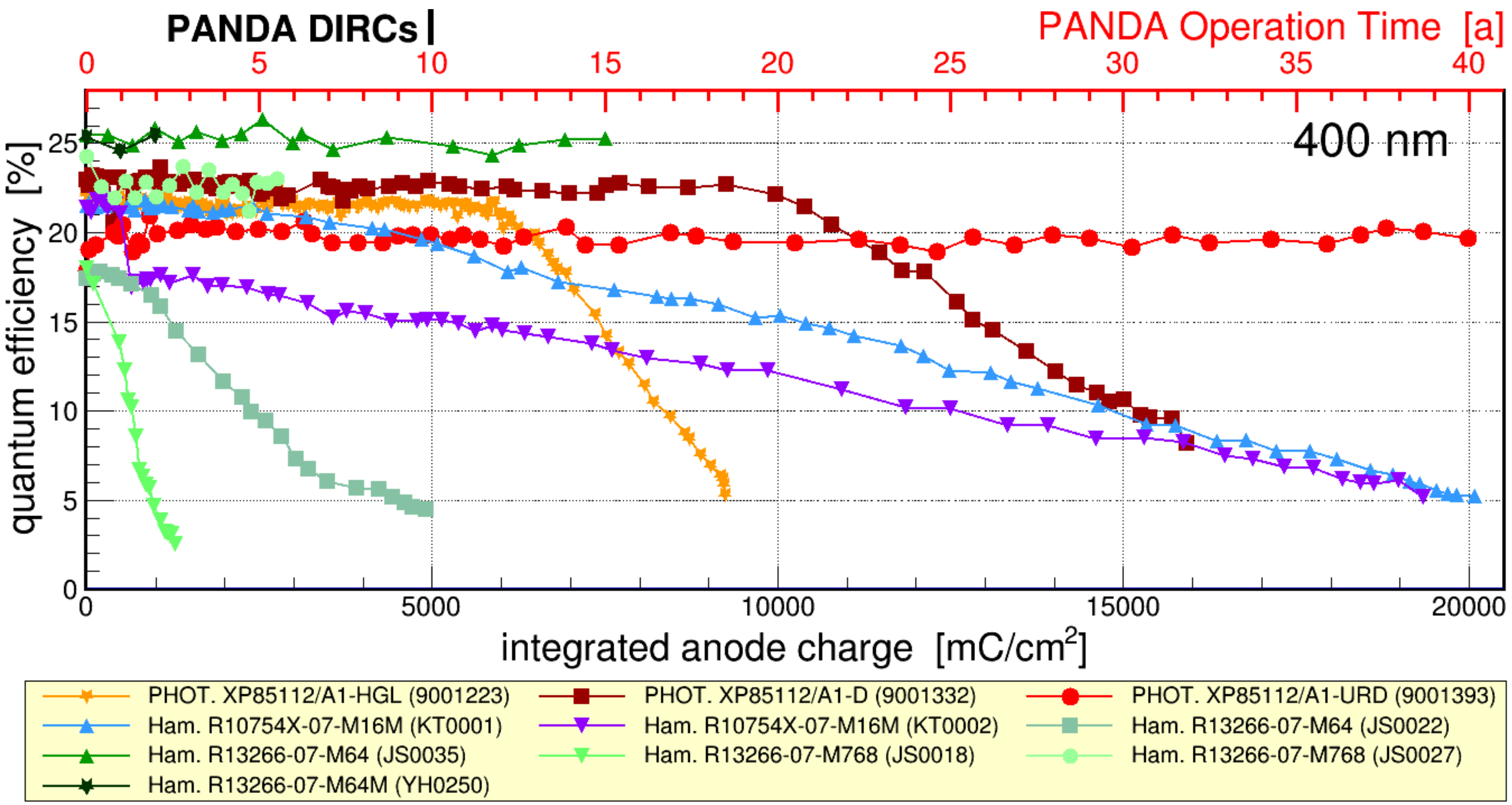


A. Lehmann, RICH2018

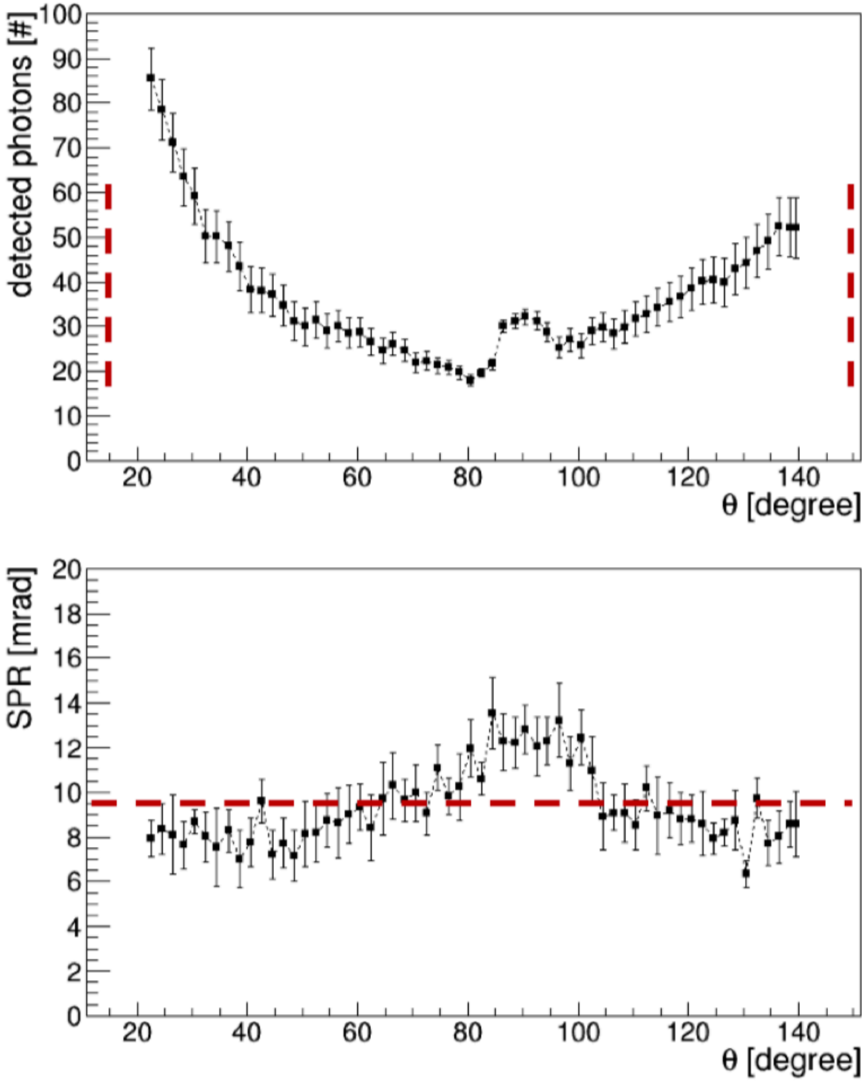
Factor >50 improvement since 2011

Recent MCP-PMTs with atomic layer deposition technique exceed requirements for the PANDA DIRC counters.

Final design, 3 bars per bar box, 3-layer spherical lens, prism

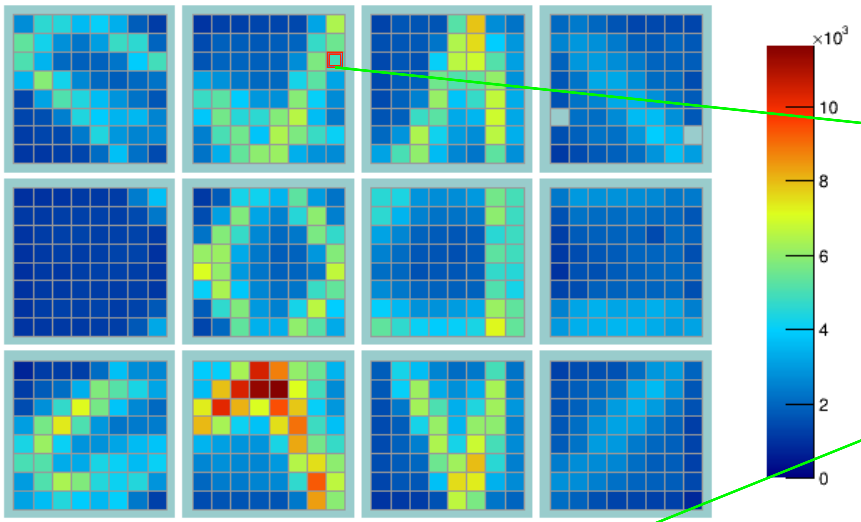
- Used **geometrical reconstruction (BaBar-like)** to determine photon yield and single photon Cherenkov angle resolution (SPR).
- Latest generation of MCP-PMTs expected to further increase photon yield by up to 50%.
- Yield and SPR reach performance goal.
- BaBar DIRC figures of merit reached or exceeded, in particular for most demanding high-momentum forward region.

Geant simulation

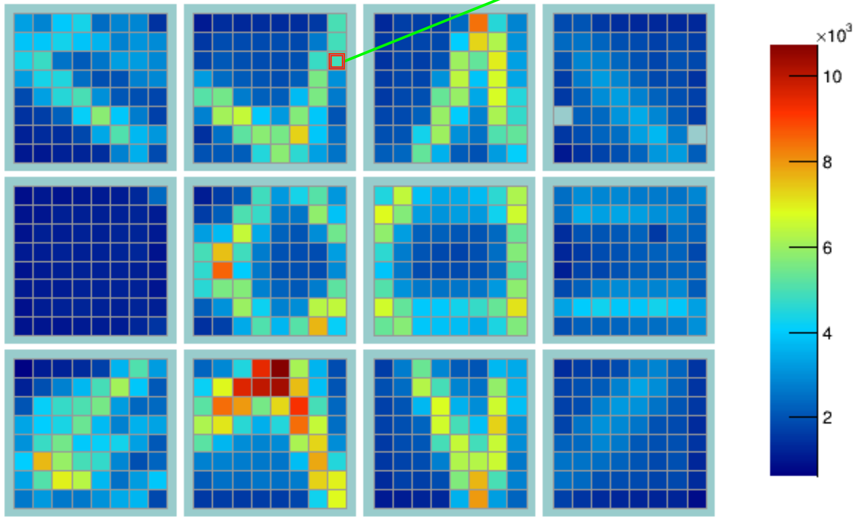


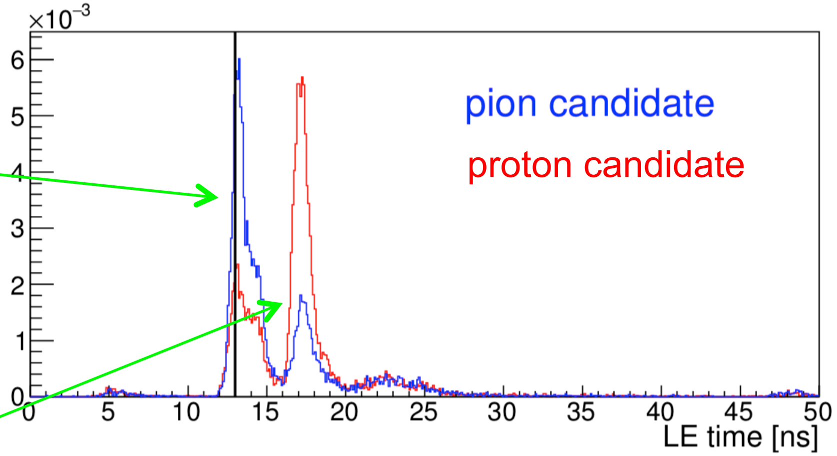
Expected Performance: Time based Imaging

Geant simulation for pions



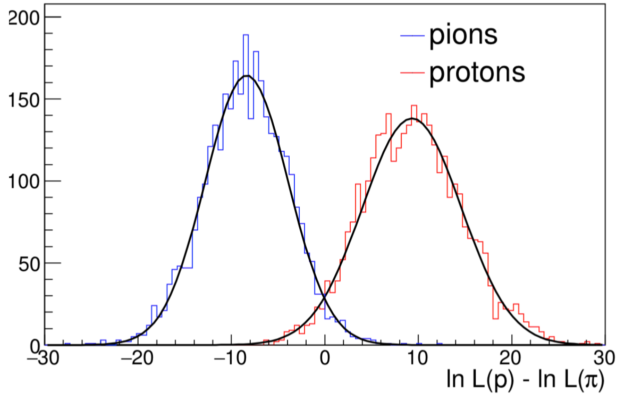
Geant simulation for protons





- **Probability Density Functions per pixel**

- Propagation time of the Cherenkov photons



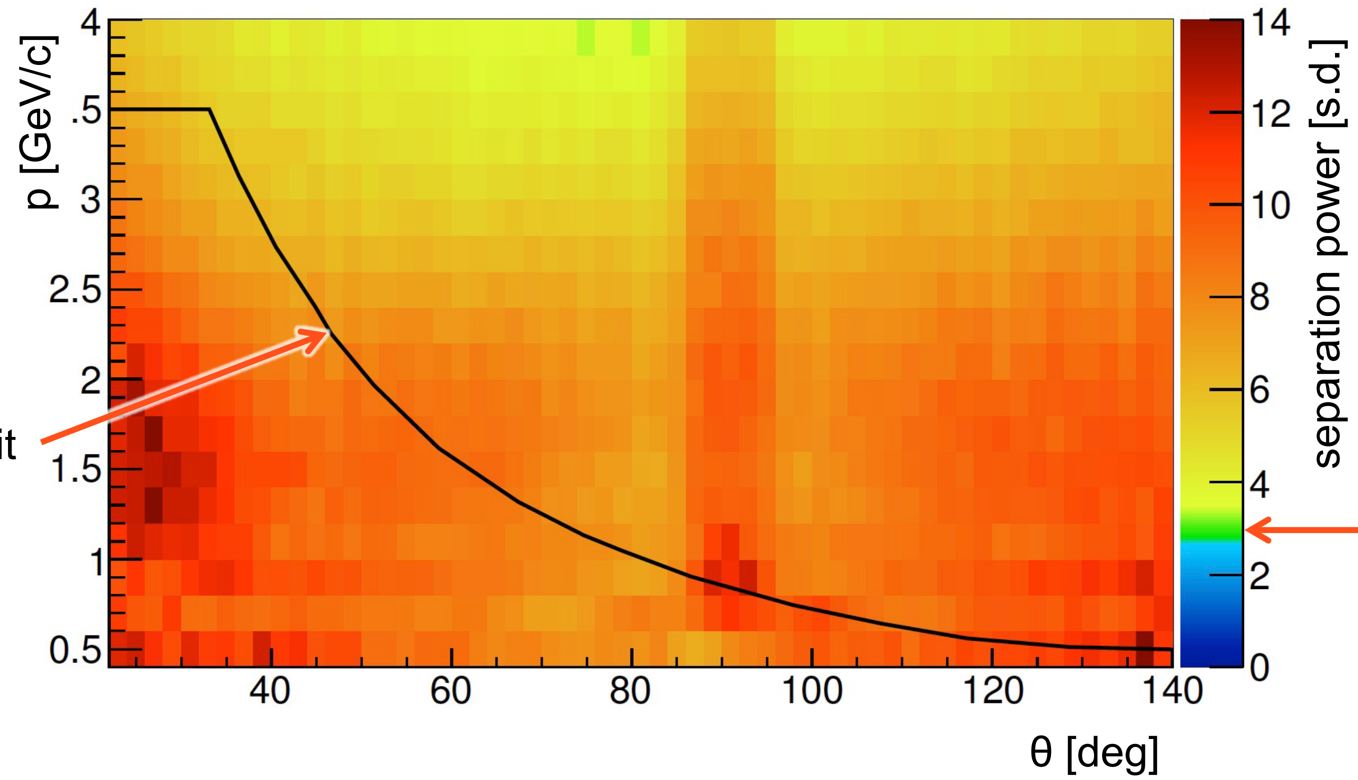
Log-likelihood difference from time-based imaging
(method similar to Belle II TOP)

$$N_{\mathrm{sep}} = \frac{|\mu_1 - \mu_2|}{0.5(\sigma_1 + \sigma_2)}$$

Expected PID Performance: Time based Imaging

Geant simulation, σ_t=100ps

PANDA kaon final state limit



Goal

$$N_{\rm sep} = \frac{|\mu_1 - \mu_2|}{0.5(\sigma_1 + \sigma_2)}$$

Design with 3 bars per bar box, 3-layer spherical lens and prism meets PID requirements

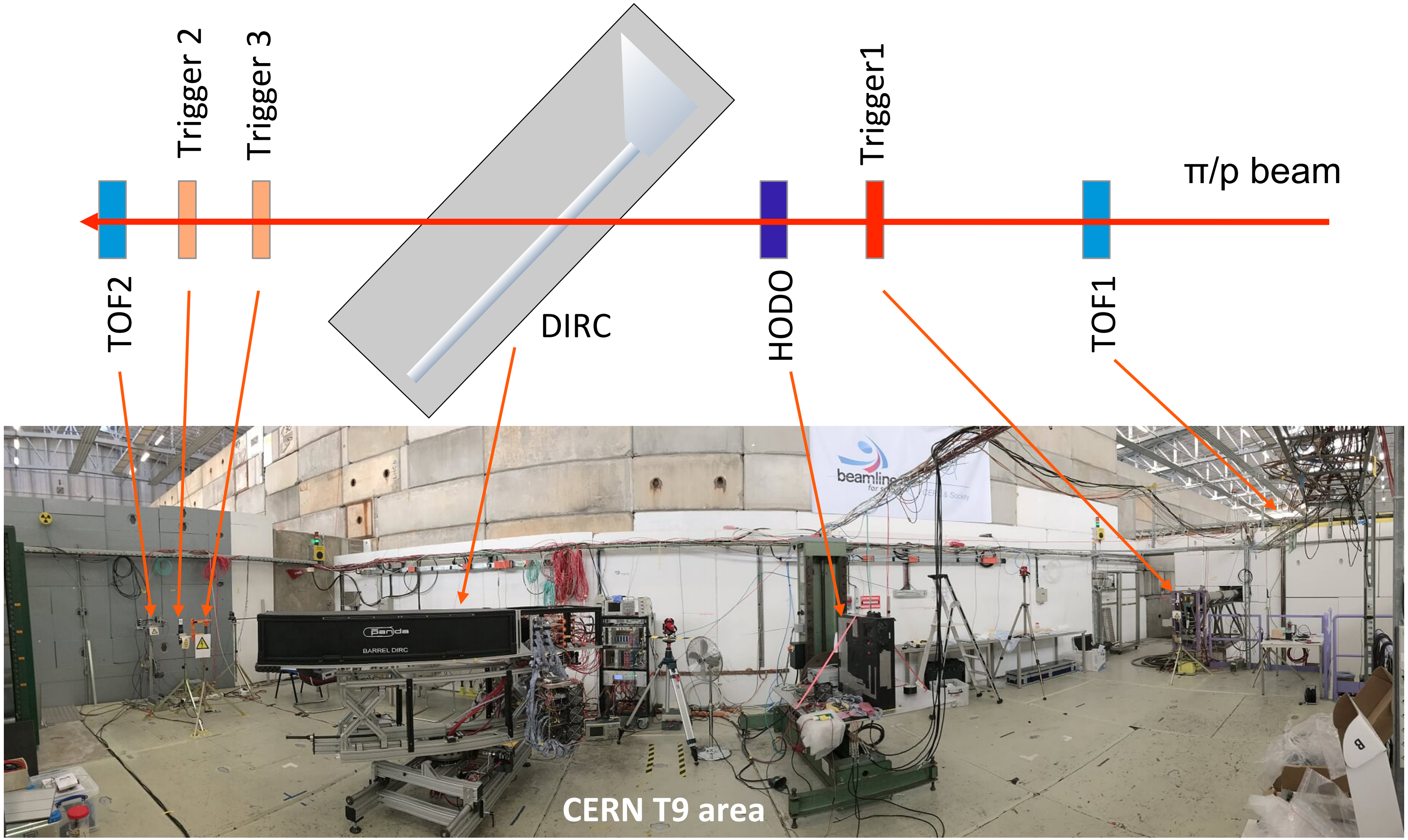
Beam Tests from 2008 GSI to 2018 CERN

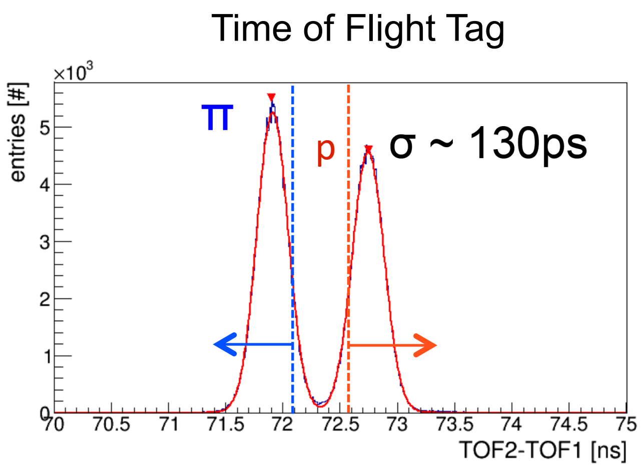

PANDA DIRC and MVD teams@T9 in 2012

PANDA DIRC team@T9 in July/August 2018


DIRC team during 2014 GSI beam test

2017 Test Beam at CERN PS/T9





- Time of Flight path of 29m
- Clean particle type tagging

Cherenkov angle difference

π/p @ 7 GeV/c

π/K @ 3.5 GeV/c

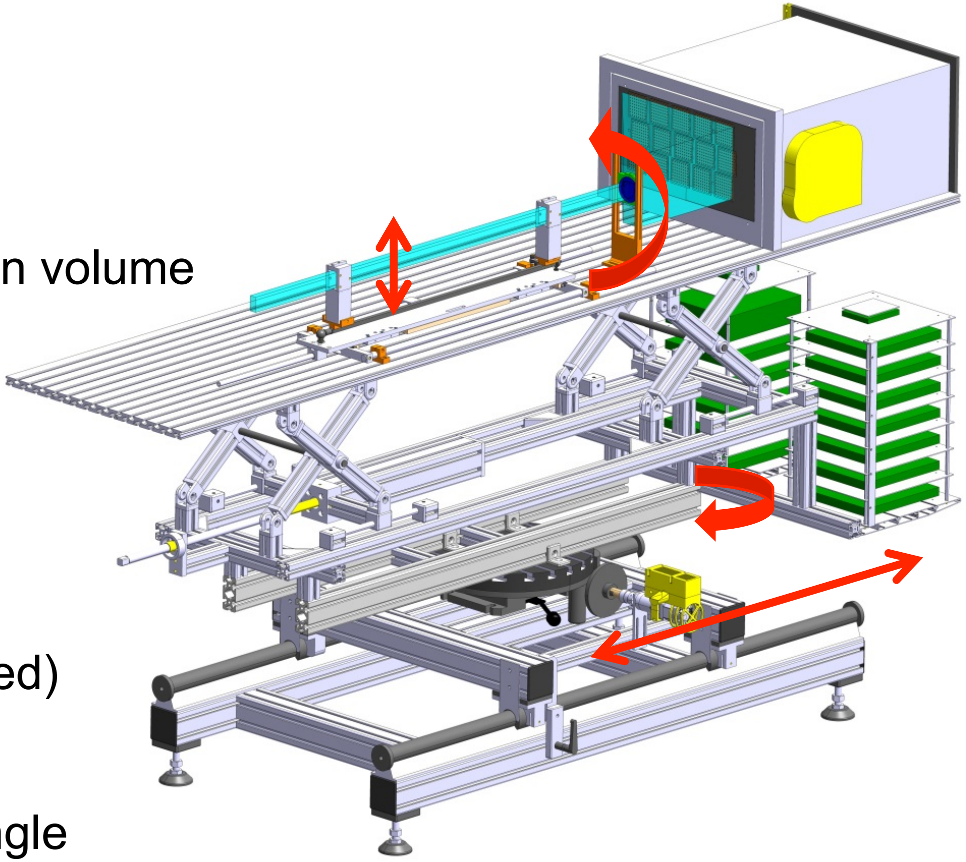
Goals

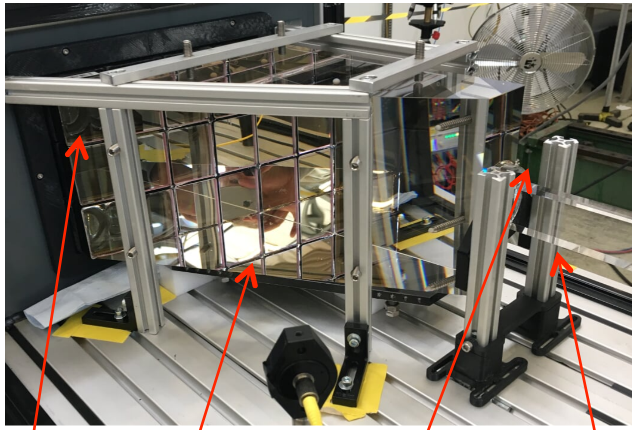
- validate the PID performance of near-final configuration of the PANDA Barrel DIRC

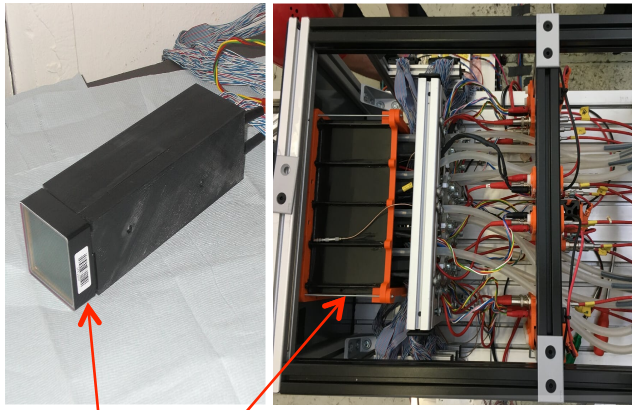
Highlight of the geometry

- 33 degree prism as expansion volume
- Photonis MCP-PMT array
- three layer spherical lens
- new readout modules
- narrow bar
- frontend electronics (air-cooled)
- updated mechanics:

  azimuthal as well as polar angle

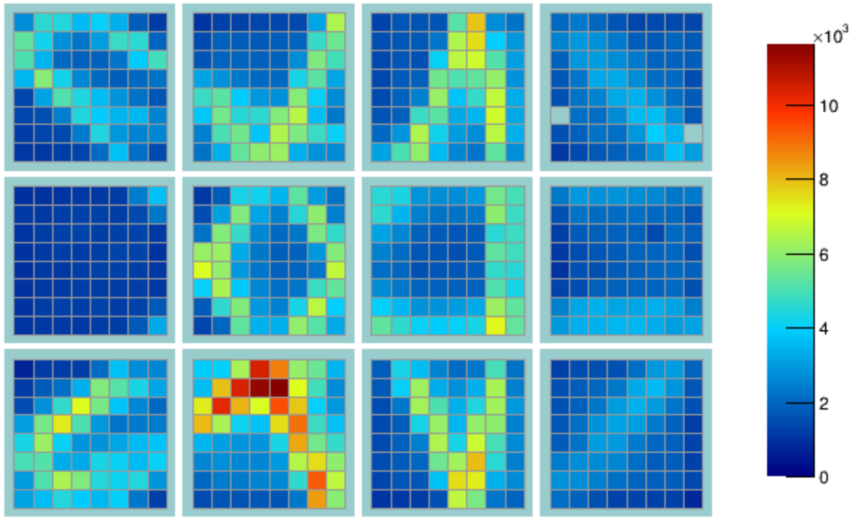




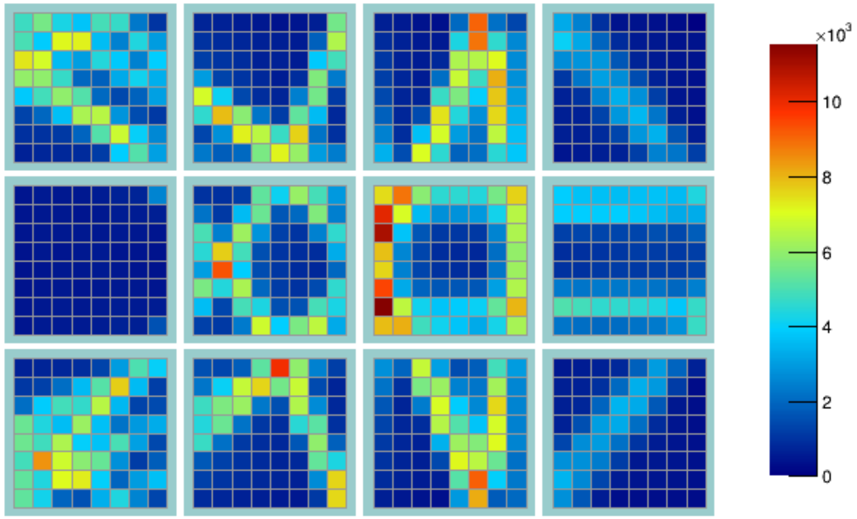


- 20 degree polar angle
- beam @ 7 GeV/c
- bar + 3 layer spherical lens

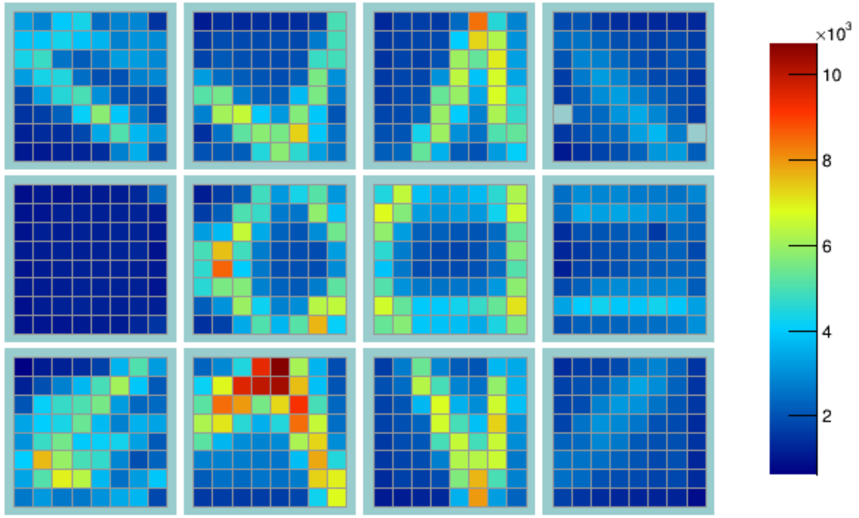
beam data with proton tag



Geant simulation for pions



beam data with pion tag

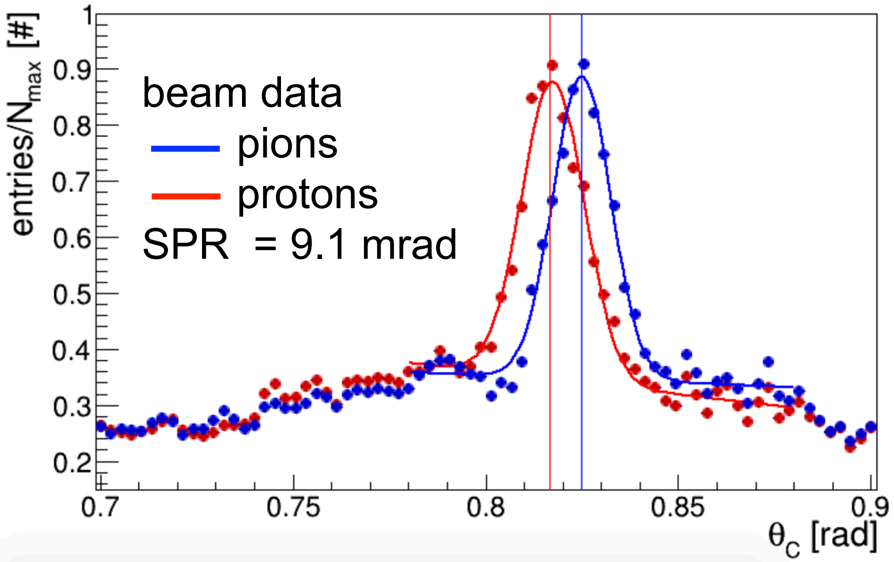


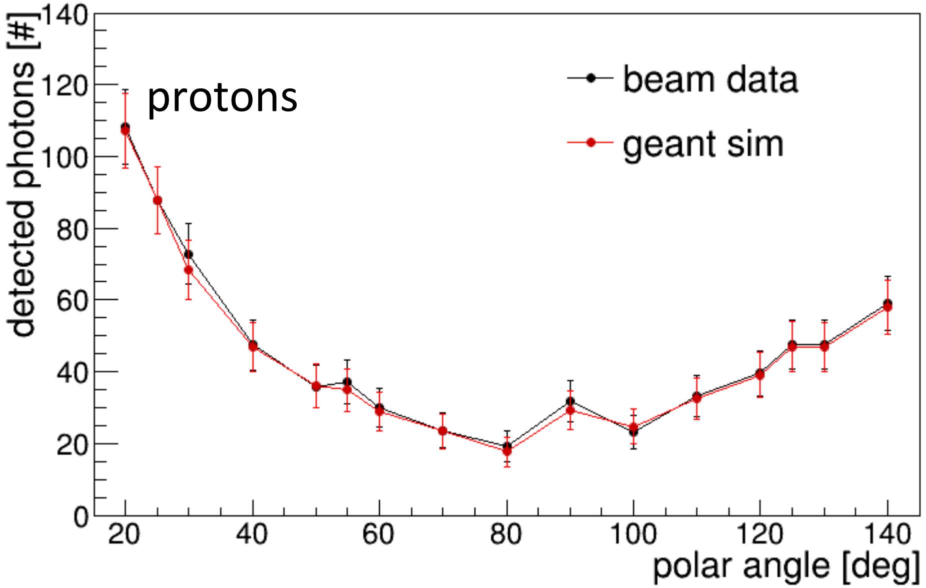
2017 Test Beam Results

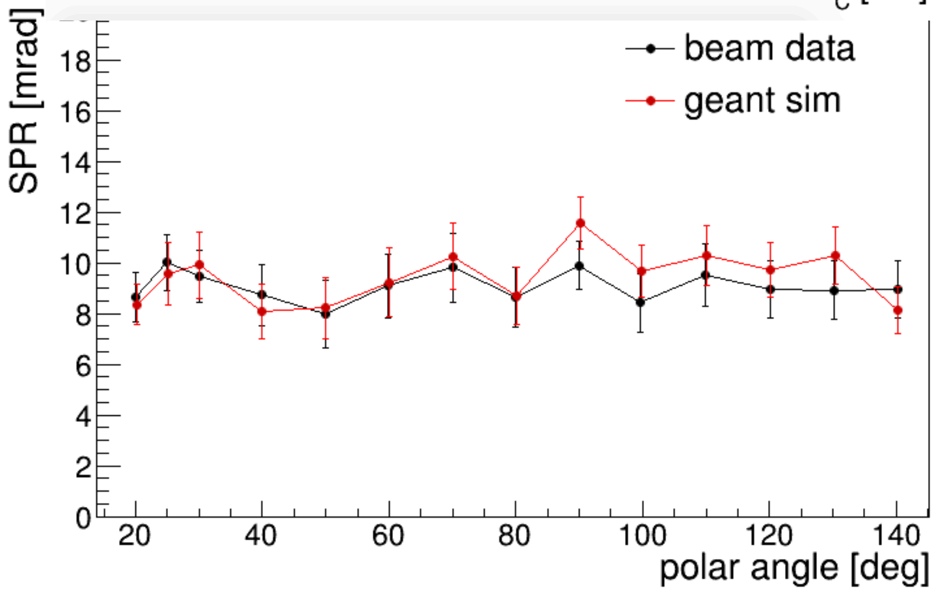
Photon yield and single photon Cherenkov angle resolution (SPR) at 7 GeV/c (equivalent to 3.5 GeV/c π/K).

Geometric reconstruction method.

Excellent agreement with detailed prototype Geant simulation.



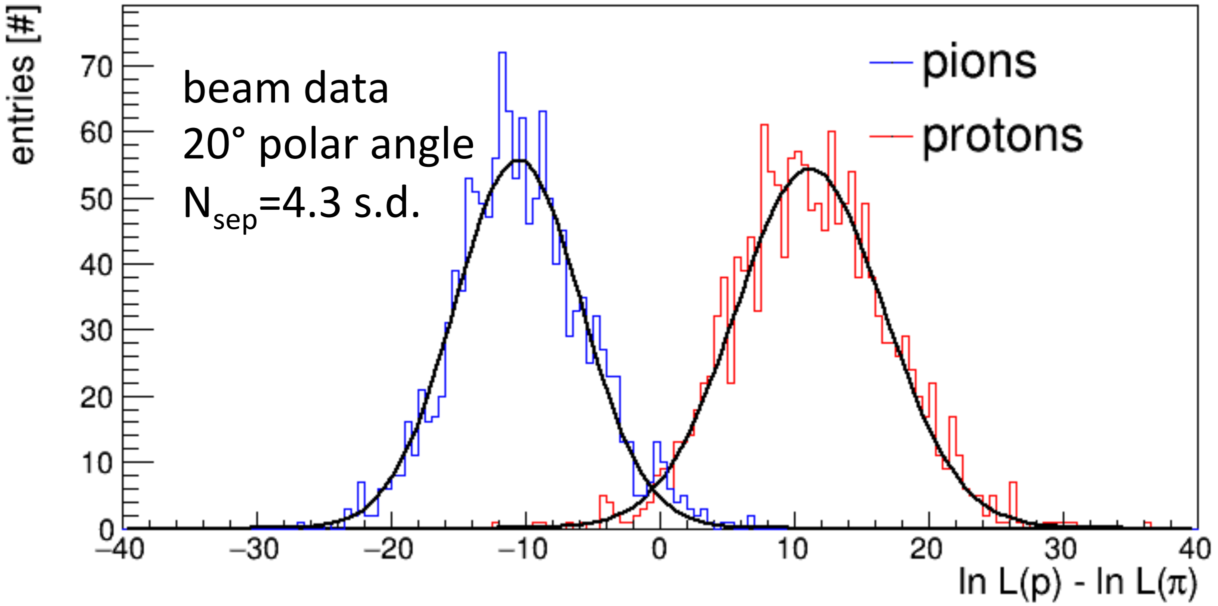




Separation power (N_{sep}) for TOF-tagged pions and protons at 7 GeV/c (equivalent to 3.5 GeV/c π/K).

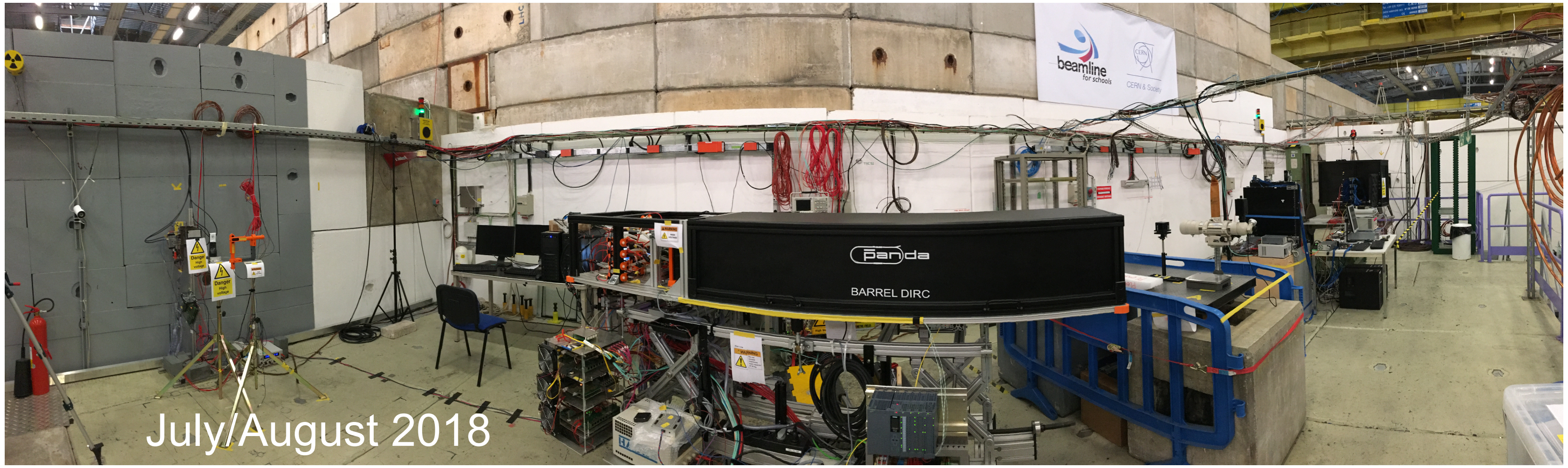
Time-based imaging reconstruction method, PDFs from beam data (250ps average timing precision).

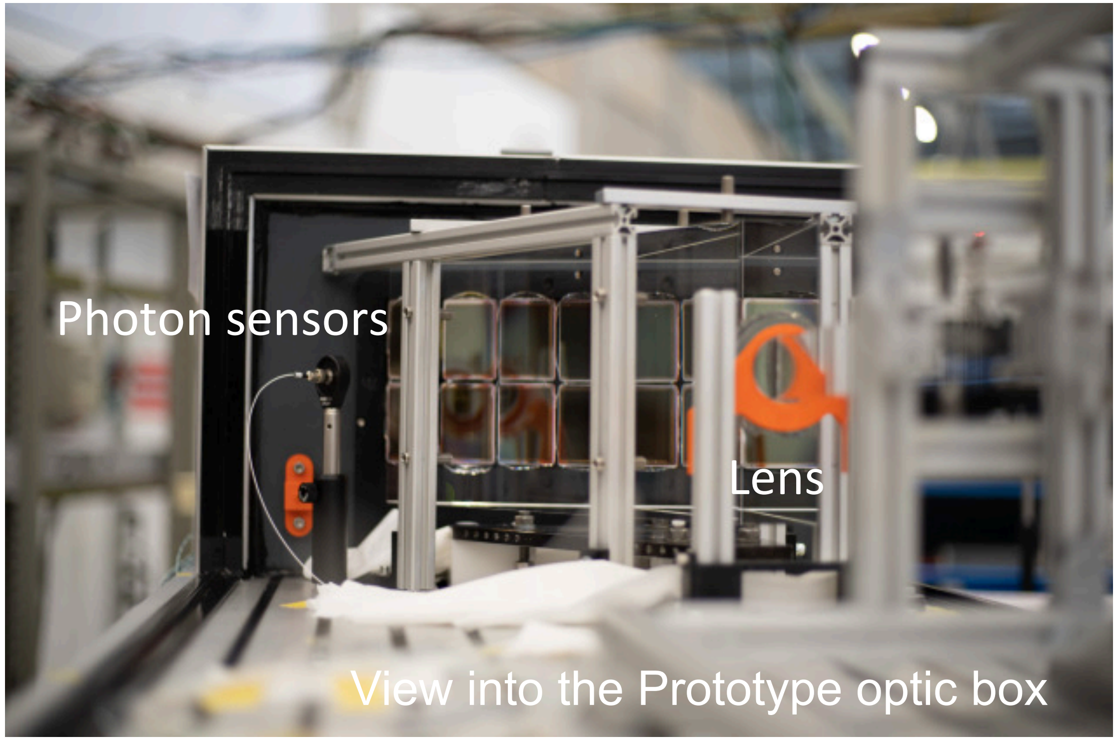
PID performance exceeds PANDA requirements, validates narrow bar/spherical lens design.

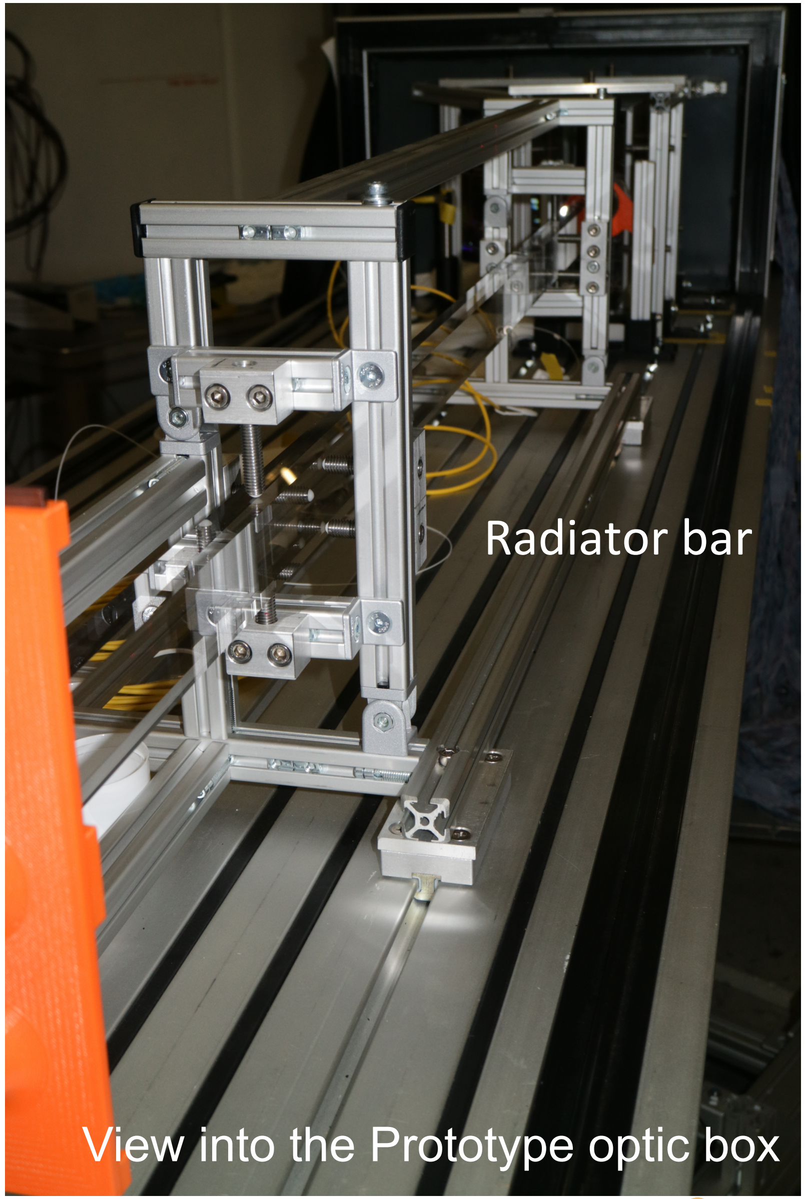


Result extrapolates to 6.6 s.d. π/K at 3.5 GeV/c, 22º for fully equipped PANDA Barrel DIRC (simulation with 100 ps timing).

2018 Test Beam at CERN PS/T9

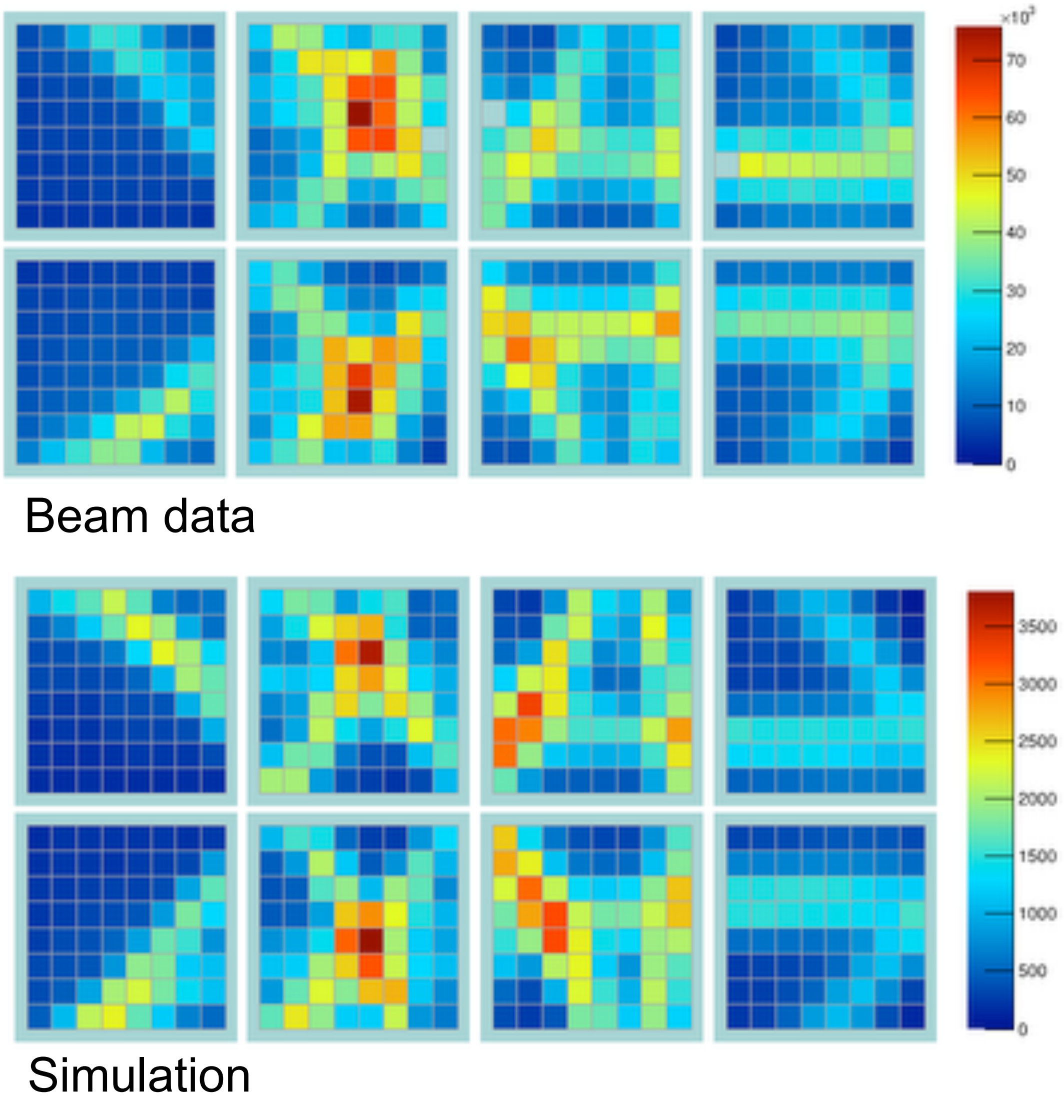






2018 Test Beam Results

Narrow bar, spherical lens



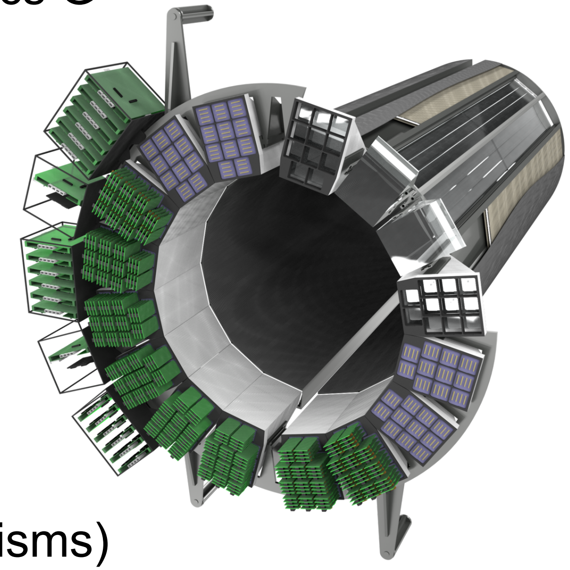
- “Quasi-live” monitoring of DIRC hit patterns for different optics configurations
- Geometry with reduced MCP-PMT coverage performs remarkably well.
- hit patterns in excellent agreement with expectation for pions and protons (tagged by our external TOF system).

- **preliminary** results show that the setup with fewer MCP-PMTs reaches design goals as well

Summary and Outlook

The PANDA Barrel DIRC is a Key Component for the PANDA Physics Program

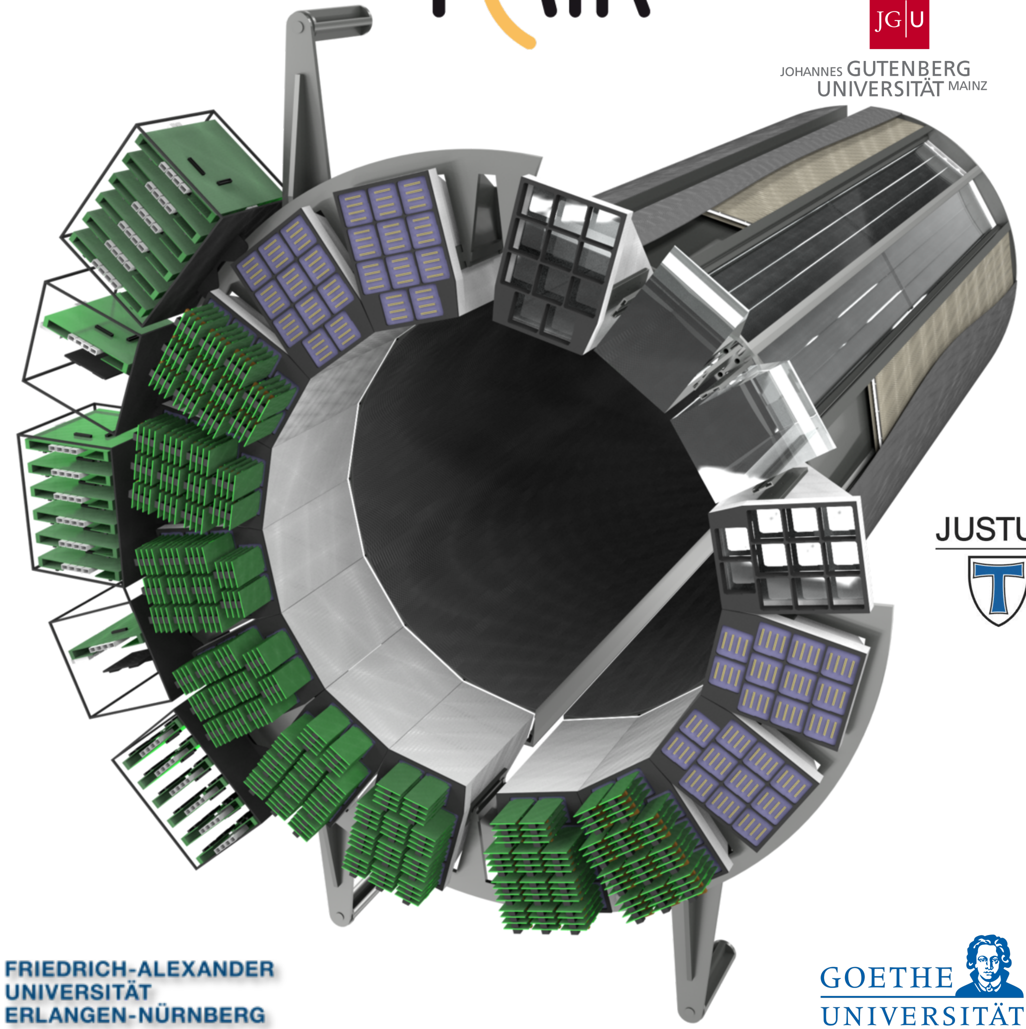
- Innovative cost-optimized design completed, performance validated in particle beams
- TDR available at arXiv:1710.00684, accepted for publication by Journal of Physics G
- Optimizing simulation and reconstruction code with experimental data at GlueX DIRC (“FAIR Phase 0”)
- Starting construction phase, first round of call for tenders end of this summer.



2018-2023: Component Fabrication, Assembly, Installation

- 2018/2019: Finalize specifications, call for tenders and contracts
- 2019-2021: Industrial fabrication of main components (sensors, bars, lenses, prisms)
- 2019-2020: Production and QA of readout electronics
- 2019-2022: Industrial fabrication of bar boxes and mechanical support frame;
  QA of all components; gluing of long bars, assembly of complete sectors
- 2023/2024: Installation in PANDA, commissioning

Thank you for your attention



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