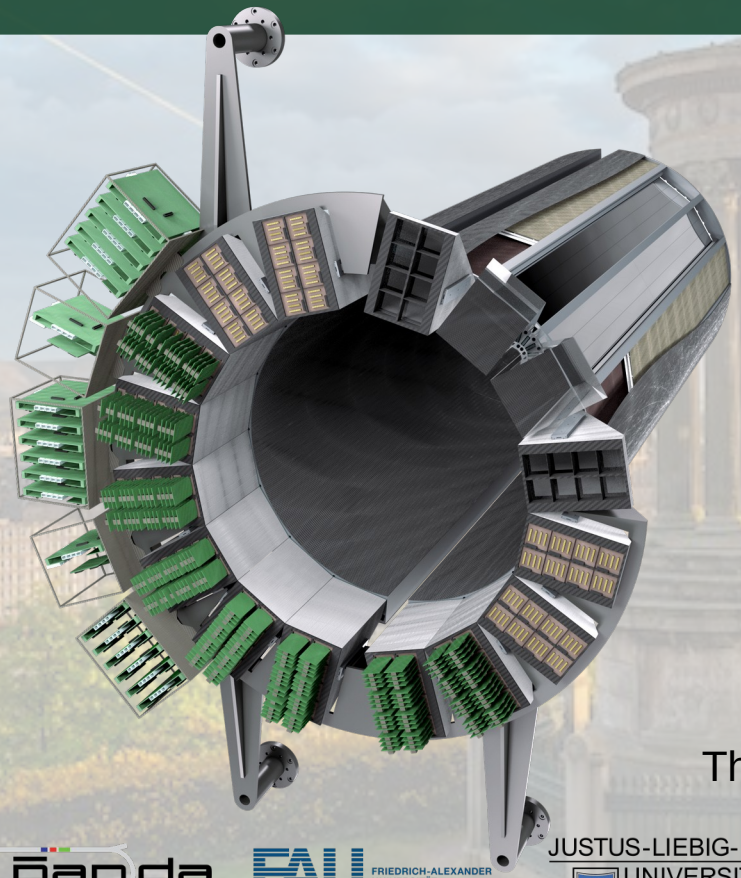
The PANDA Barrel DIRC



RICH2022

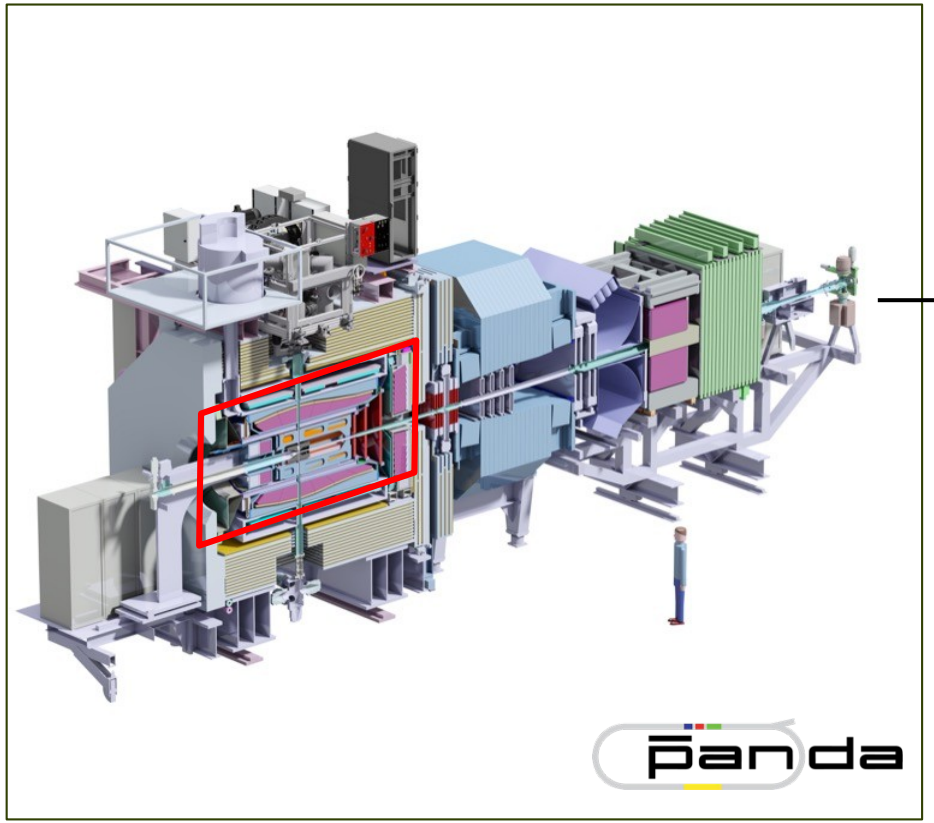
Roman Dzhygadlo (GSI)
for the PANDA Cherenkov Group

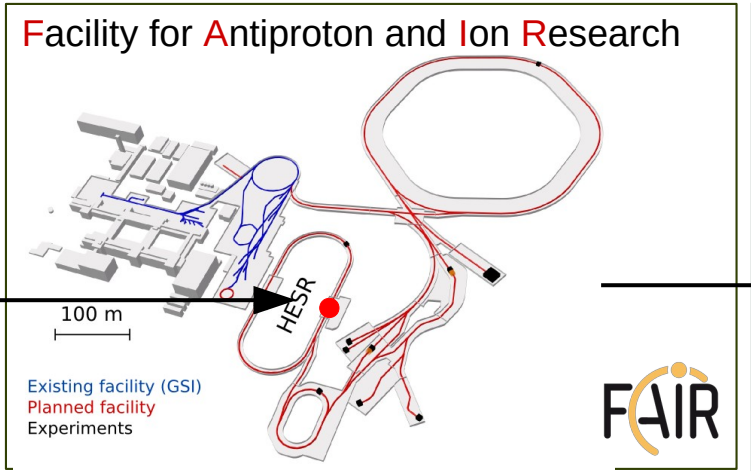
- PANDA experiment
- Barrel DIRC design
- Expected performance
- Validation in beam tests
- Component production

The PANDA Cherenkov Group:

panda · FAU Friedrich-Alexander Universität Erlangen-Nürnberg · Justus-Liebig-Universität Giessen · Goethe Universität Frankfurt am Main · HIM Helmholtz Helmholtz-Institut Mainz · JGU Johannes Gutenberg Universität Mainz · GSI · FAIR

The PANDA Experiment at FAIR





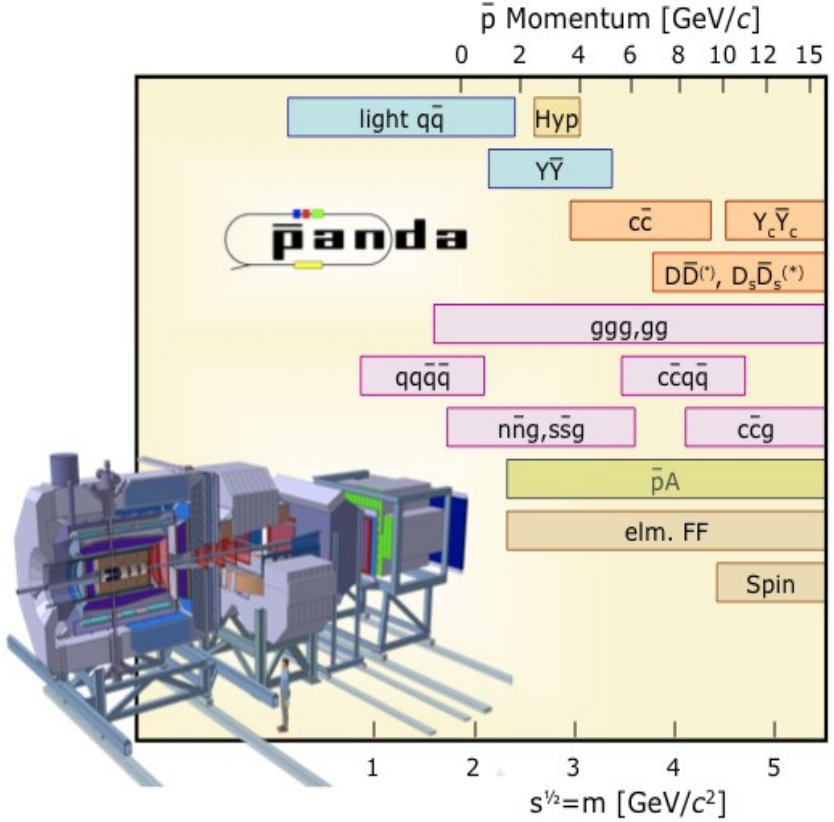
High Energy Storage Ring

- 5 x 10^{10} stored cooled antiprotons
- 1.5 to 15 GeV/c momentum
- Cluster jet / pellet target
- High luminosity mode $\Delta p/p \approx 10^{-4}$ $L = 1.6 \times 10^{32}$ cm^{-2}s^{-1}
- High resolution mode $\Delta p/p \approx 5 \times 10^{-5}$ $L = 1.6 \times 10^{31}$ cm^{-2}s^{-1}

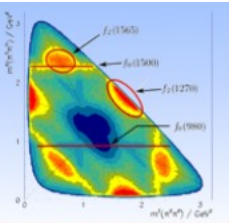
The PANDA Experiment at FAIR

PANDA Physics Program

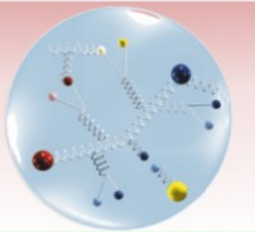
Study of QCD with Antiprotons



Hadron Spectroscopy
- Charmonium / Charmed hadrons
- Exotic QCD states
- Spectroscopy



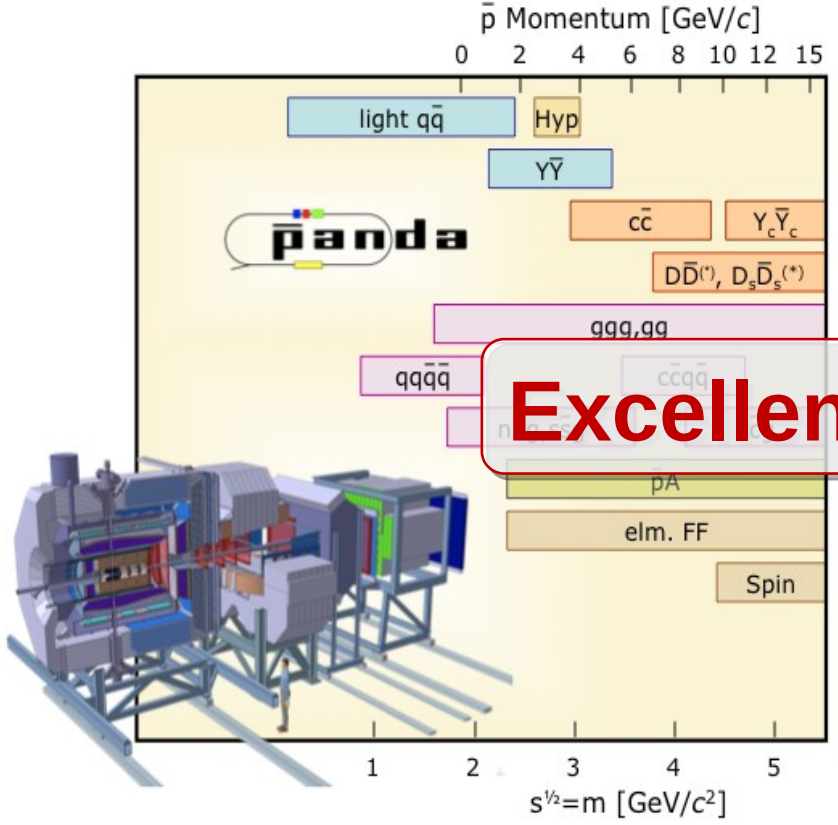
Hadron Structure
- Time-like Nucleon Form Factors
- Generalized Parton Distributions
- Drell-Yan Process



Nuclear Physics
- Production of Λ-Hypernuclei
- Hadrons in Nuclear Medium

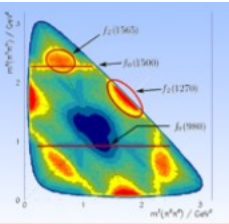
PANDA Physics Program

Study of QCD with Antiprotons



Excellent PID required

Hadron Spectroscopy
- Charmonium / Charmed hadrons
- Exotic QCD states
- Spectroscopy



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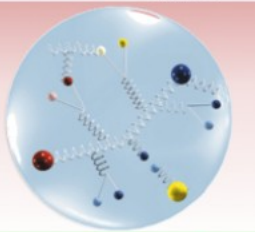
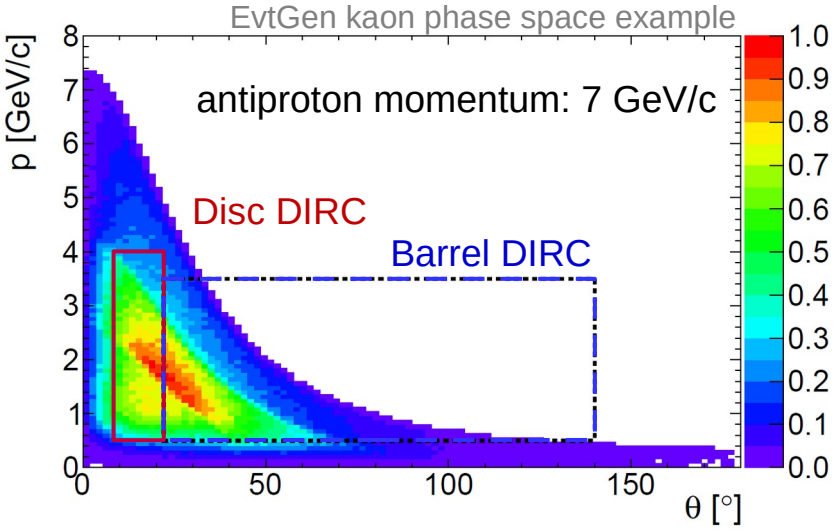


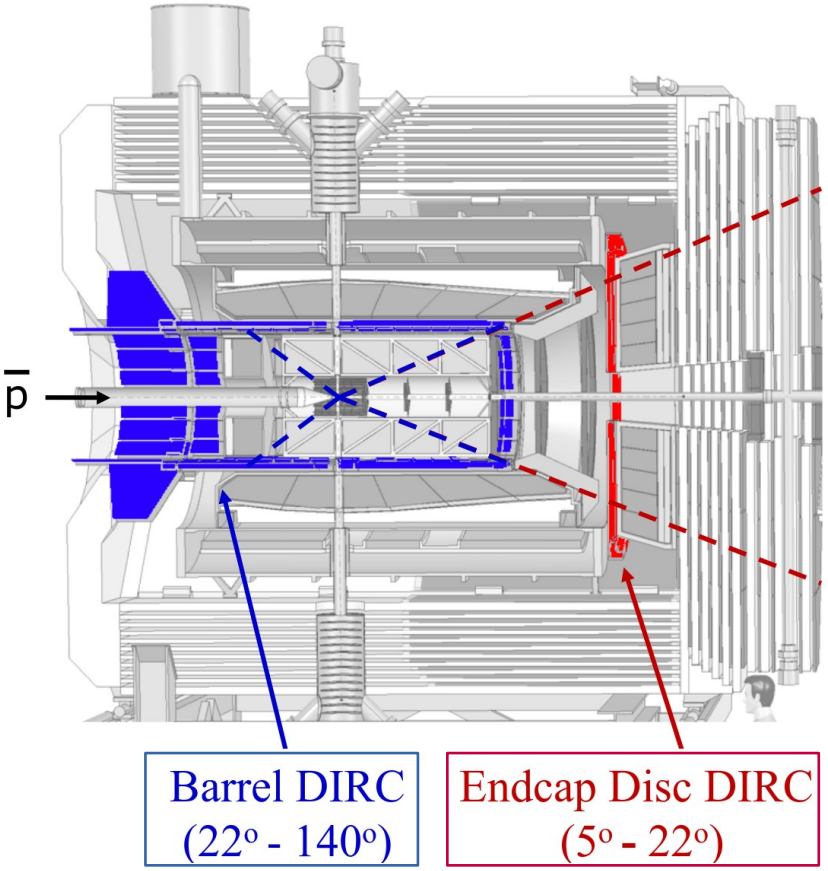
Nuclear Physics
- Production of Λ-Hypernuclei
- Hadrons in Nuclear Medium

DIRCs in PANDA

Two DIRC detectors for hadronic PID:

- Barrel DIRC
  Goal: 3 s.d. π/K separation up to 3.5 GeV/c
- Endcap Disc DIRC
  Goal: 3 s.d. π/K separation up to 4 GeV/c





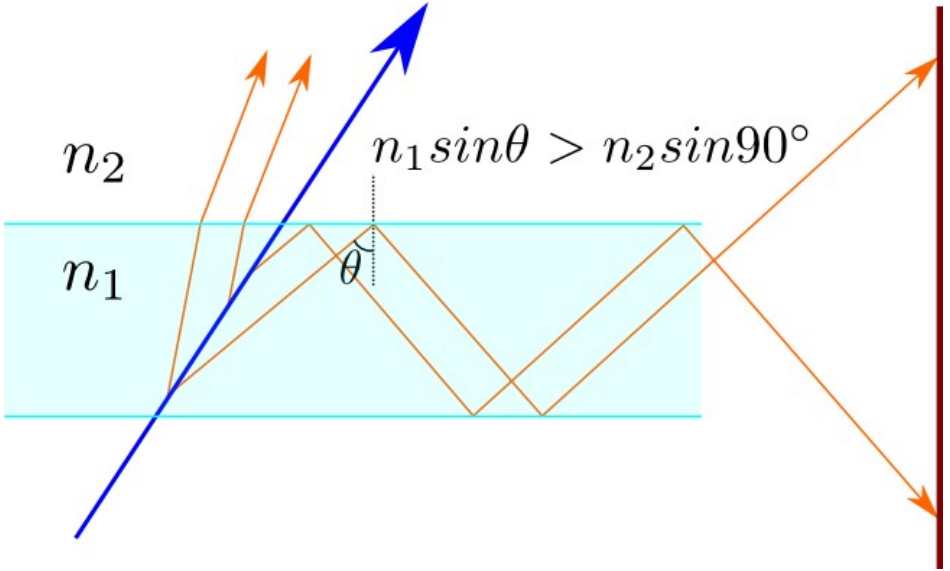
DIRC Principle

Detection of **I**nternally **R**eflected **C**herenkov Light

DIRC Principle

Detection of **I**nternally **R**eflected **C**herenkov Light

- Charged particle traversing radiator with refractive index ($n_1 \approx 1.47$) and $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos\theta_c = 1/\beta n(\lambda)$
- Some photons are always totally internally reflected for $\beta \approx 1$ tracks



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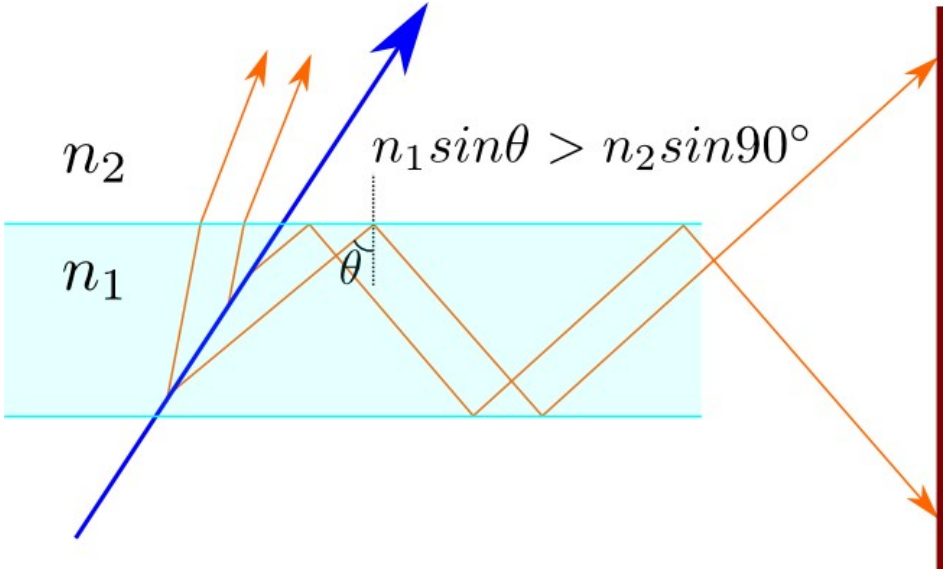

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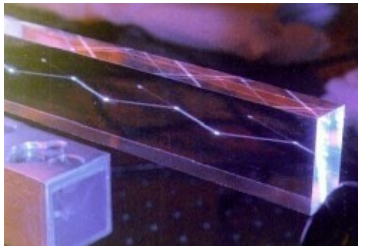
- Radiator and light guide: polished, long rectangular bar made from Synthetic Fused Silica ("Quartz")



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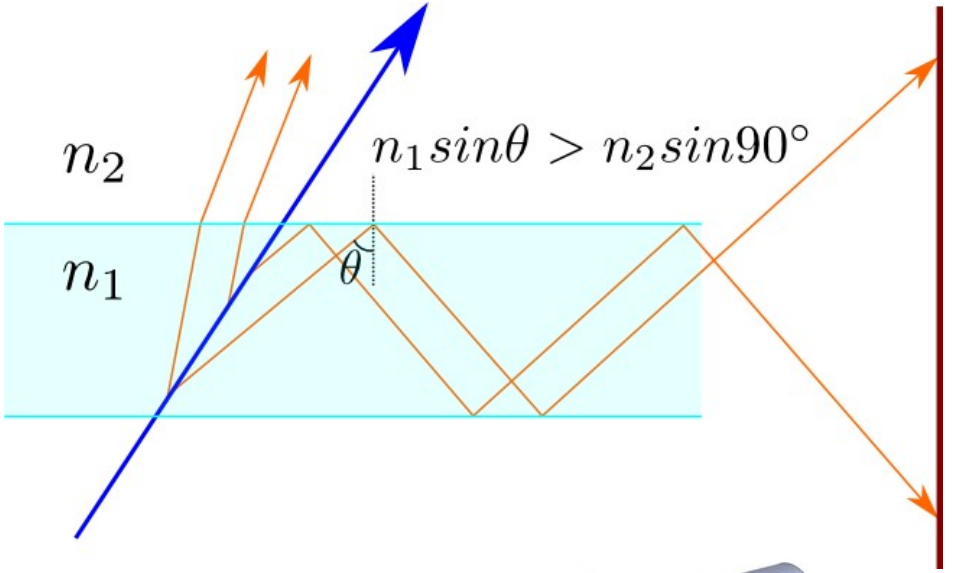

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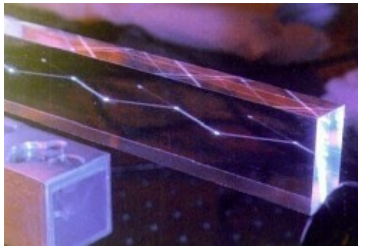
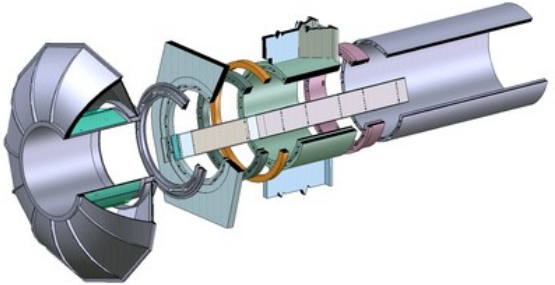
- Proven to work (BABAR-DIRC)

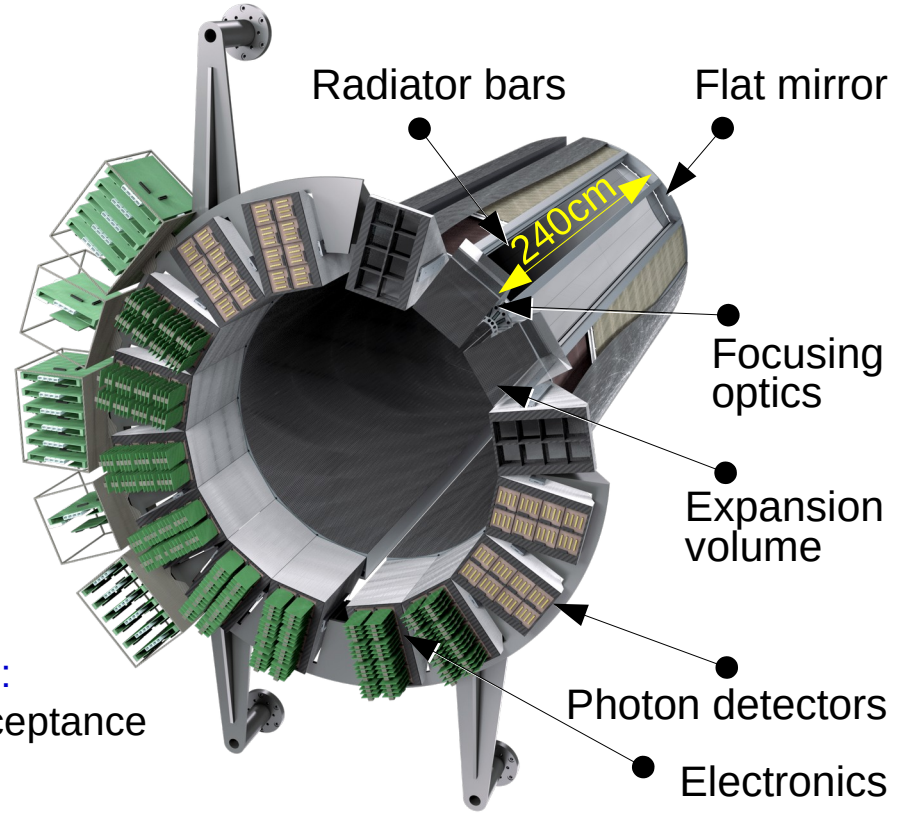




Barrel DIRC Design

Based on BABAR DIRC with key improvements
(compact fused silica prisms, spherical lenses)

- 48 radiator bars (16 sectors), synthetic fused silica
  17mm (T) x 53mm (W) x 2400mm (L)
- Focusing optics: triplet spherical lens system
- Compact expansion volume:
  30cm-deep solid fused silical prisms
- Photon detectors:
  Micro-Channel Photo Multipliers, 8192 channels
- Fast FPGA-based photon detection
  ~100ps per photon timing precision
- Expected performance (simulation and particle beams):
  better than 3 s.d. π/K separation for entire physical acceptance



TDR: JINST 13 C03004, DOI:10.1088/1748-0221/13/03/C03004

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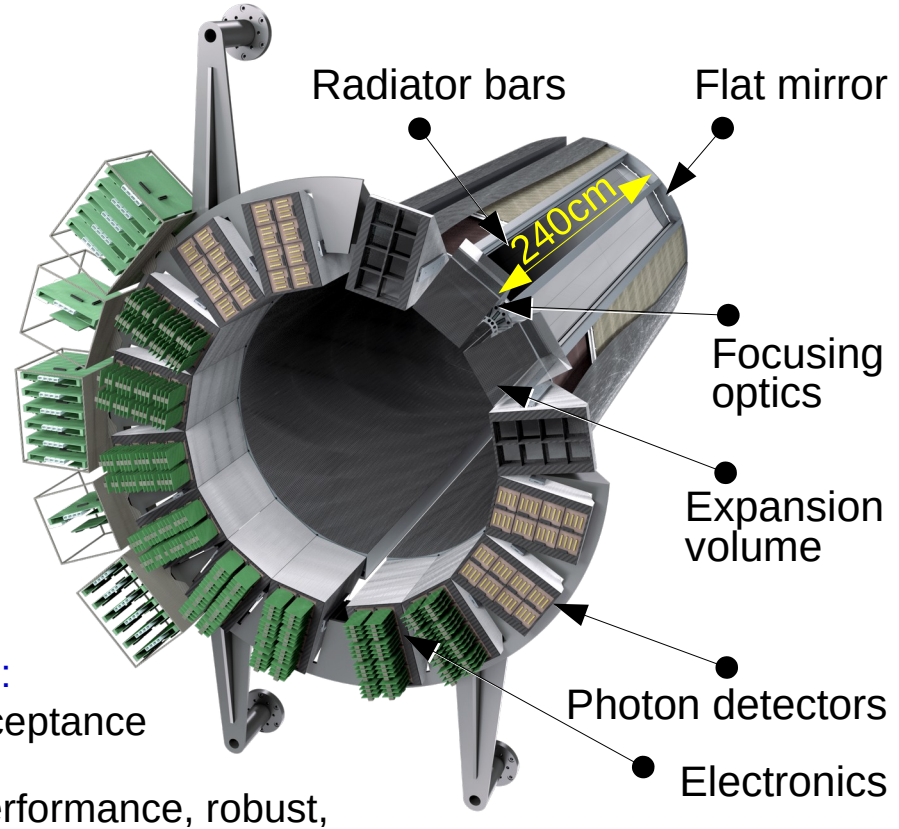


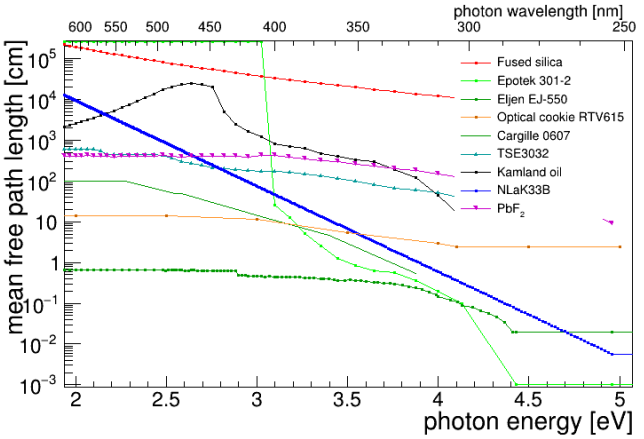
Conservative design: similar to BABAR DIRC, excellent performance, robust, little sensitivity to backgrounds and timing deterioration

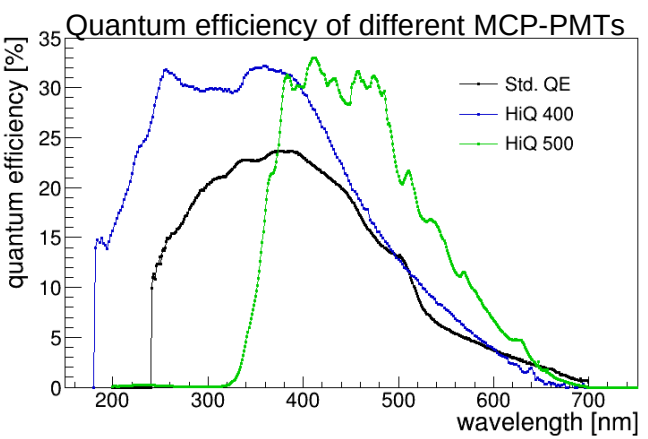
TDR: JINST 13 C03004, DOI:10.1088/1748-0221/13/03/C03004

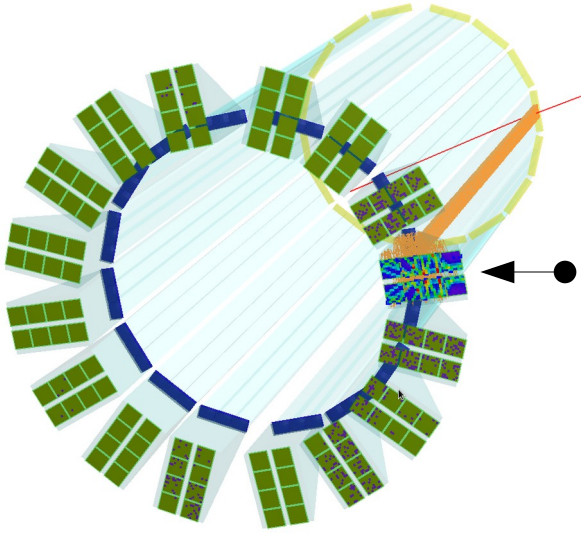
Simulation

Geant4 simulations includes:

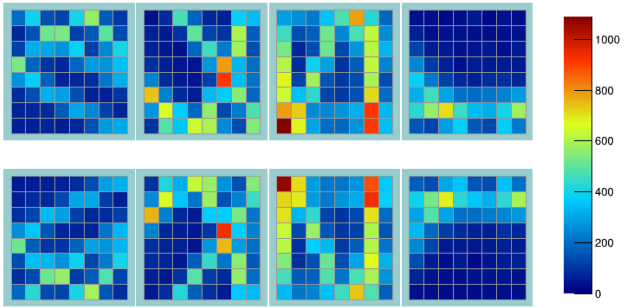
- Realistic materials properties
- Photons transport efficiency
- Single photon time resolution
- Quantum and collection efficiency
- Dark counts







Accumulated hit pattern from 1000 K^+ at 3.5 GeV/c and 25° polar angle

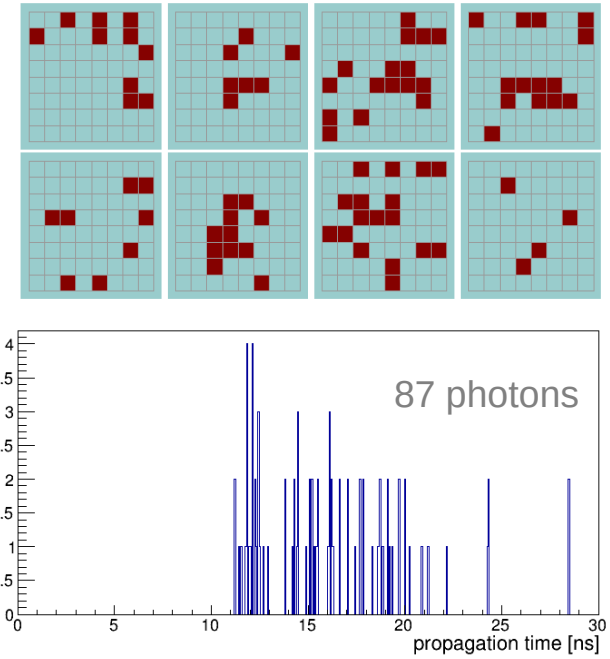


Observables

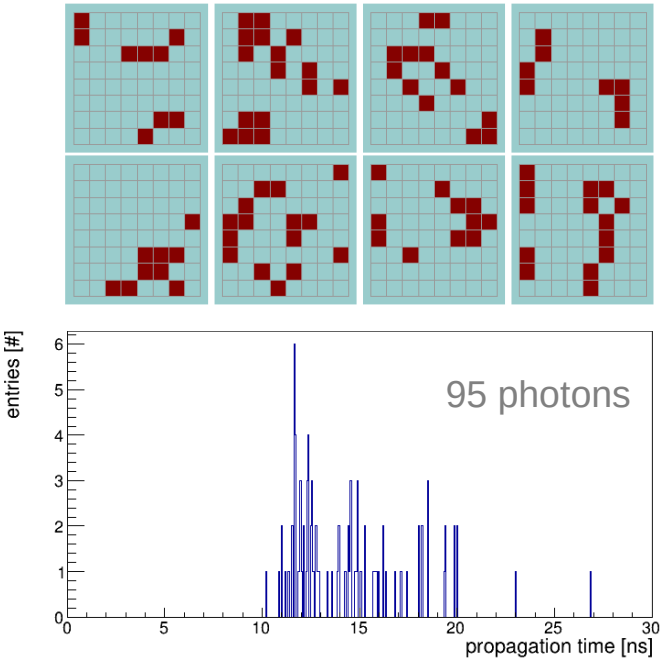
- Number of detected photons
- Photons hit position (6x6 mm^2 pixels)
- Photons propagation time (~100 ps precision)

Examples for p = 3.5 GeV and θ = 22°:

one pion



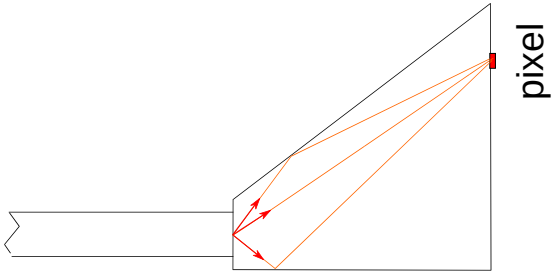
one kaon



Reconstruction Methods

Geometrical

- BABAR-like
- Needs Look-Up Tables



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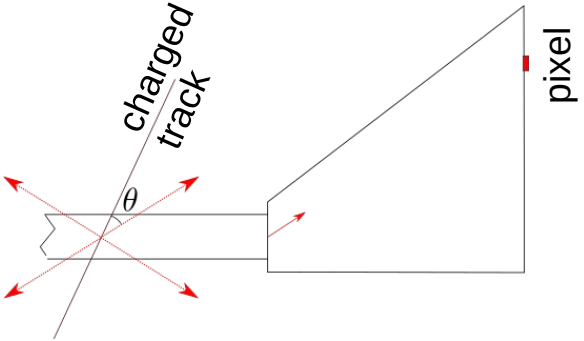

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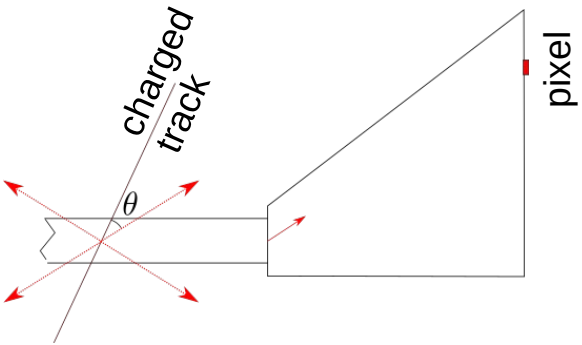

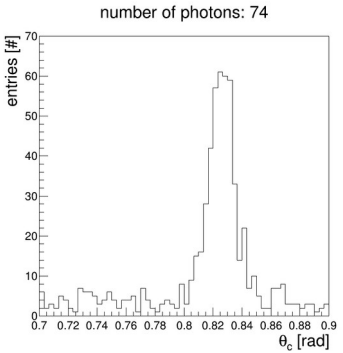

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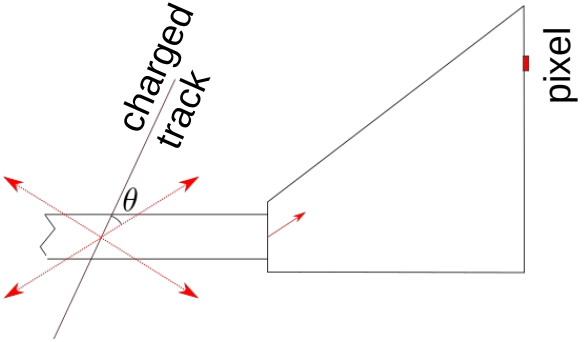

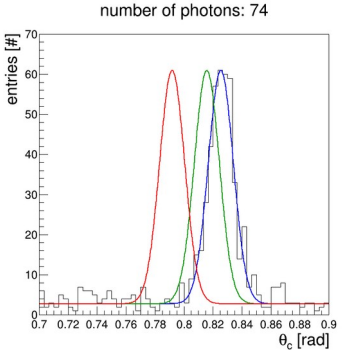

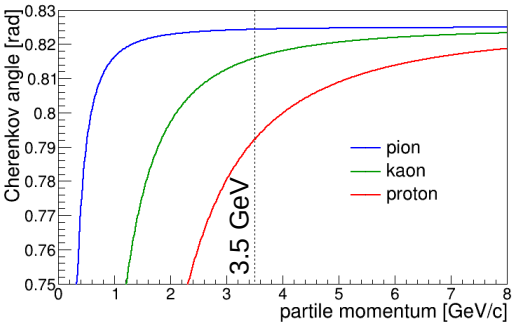

$$\log\mathcal{L}_h = \sum_{i=1}^{N} \log(S_h(c_i) + B_h(c_i)) + \log P_h(N)$$

Reconstruction Methods

Geometrical

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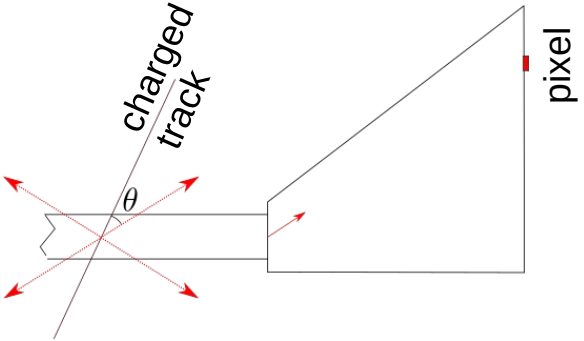

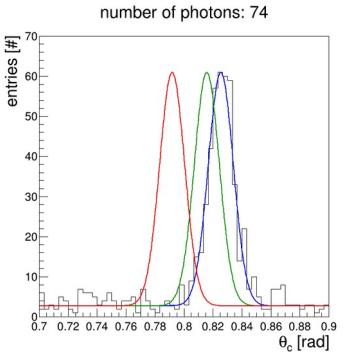

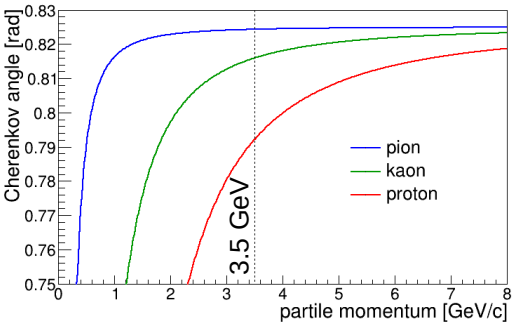

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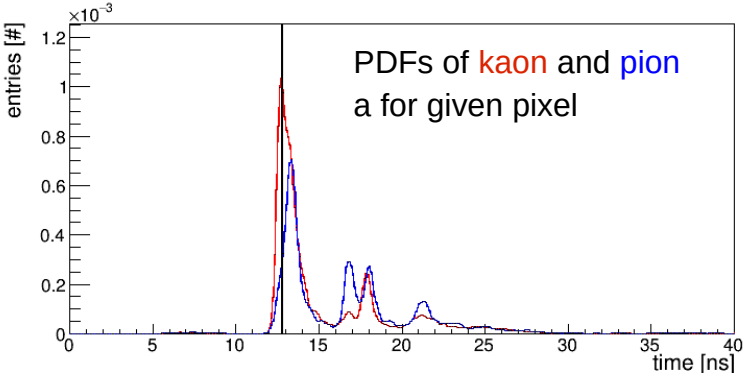
Time imaging

- Belle II TOP-like
- Needs Probability Density Functions of the propagation time
  - analytical
  - from data

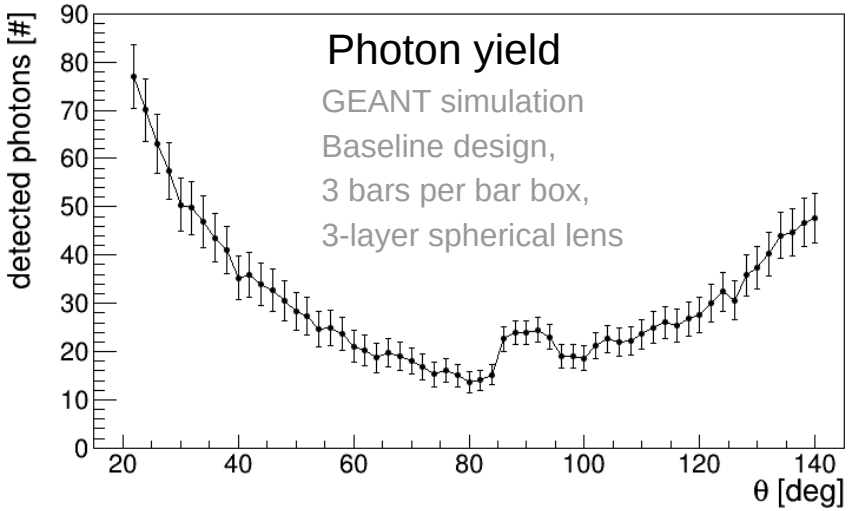


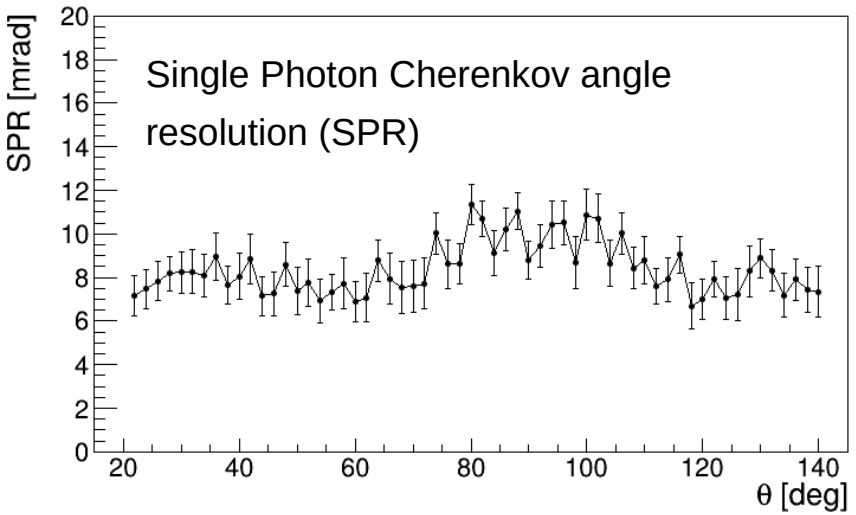
Expected Performance

Cherenkov track resolution:
(using geometrical reconstruction)

$$\sigma_{\theta_C}^{\text{track}} = \sqrt{\left(\frac{\sigma_{\theta_C}^{\text{photon}}}{\sqrt{N_{\text{photons}}}}\right)^2 + (\sigma^{\text{correlated}})^2}$$

tracking resolution 2-3 mrad





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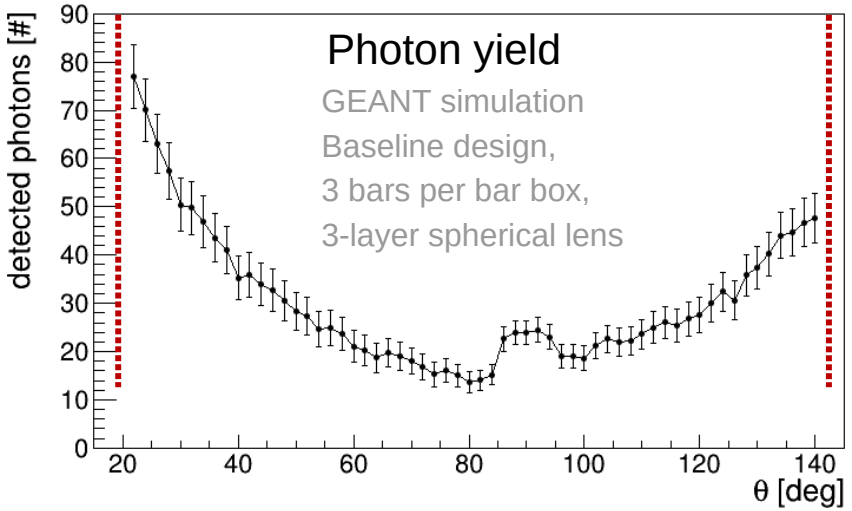
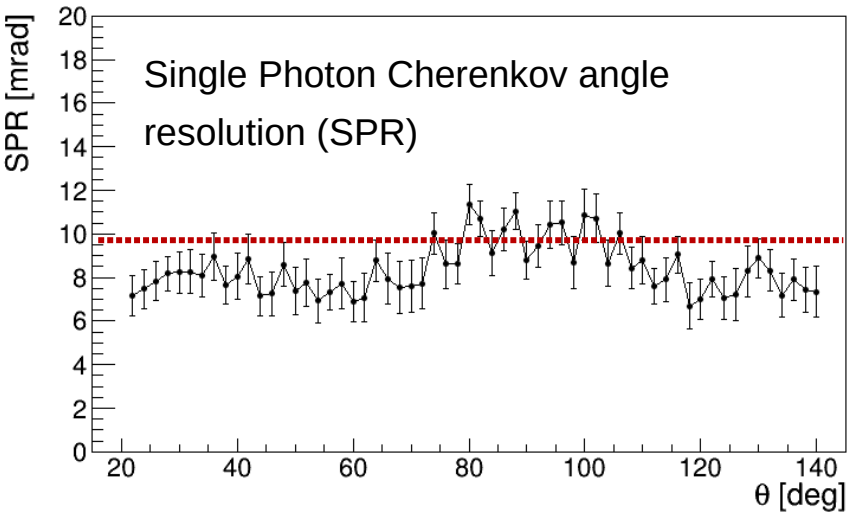
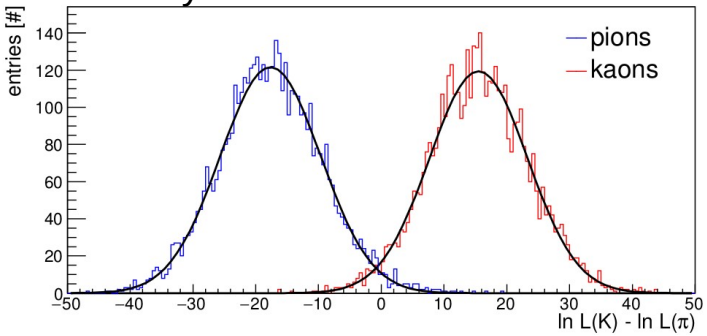




➡ Yield and SPR reach performance goal

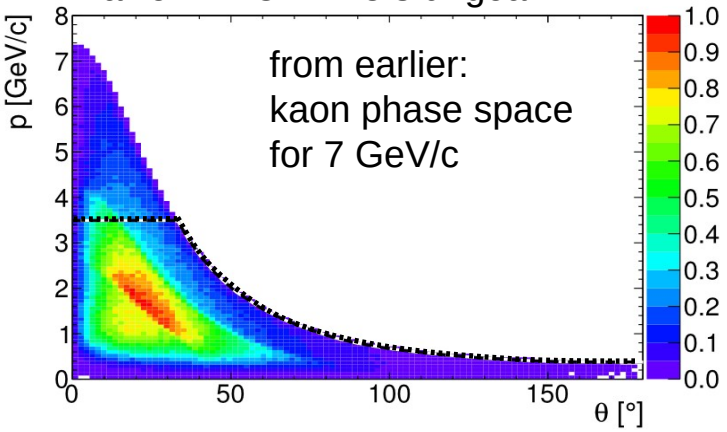
Expected Performance

track-by-track max. likelihood fit

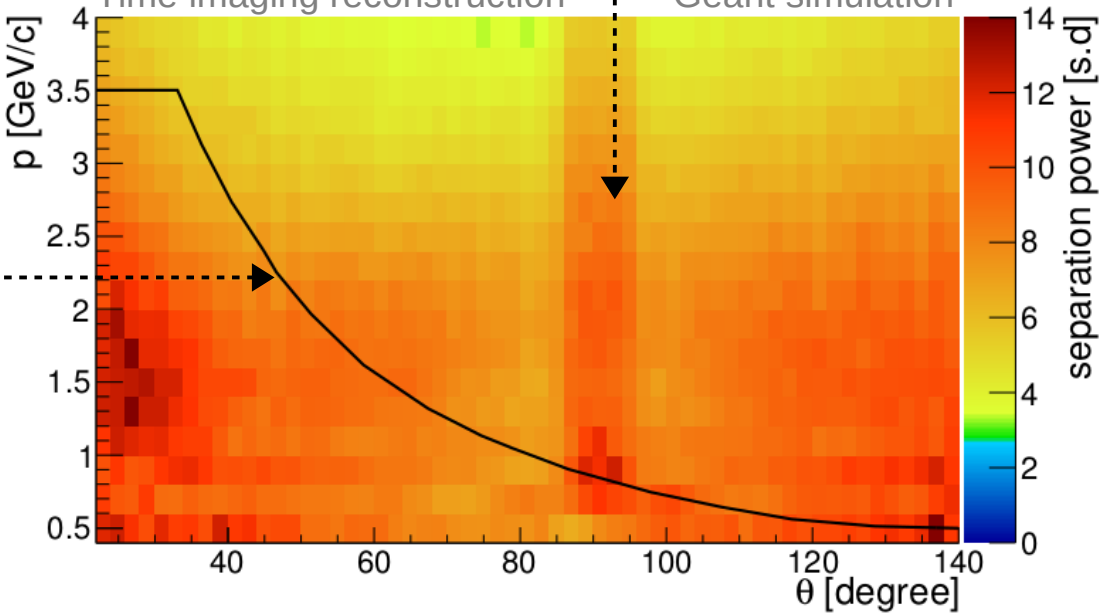


$$N_{\mathrm{sep}} = \frac{|\mu_1 - \mu_2|}{0.5(\sigma_1 + \sigma_2)}$$

Barrel DIRC PID 3 s.d. goal

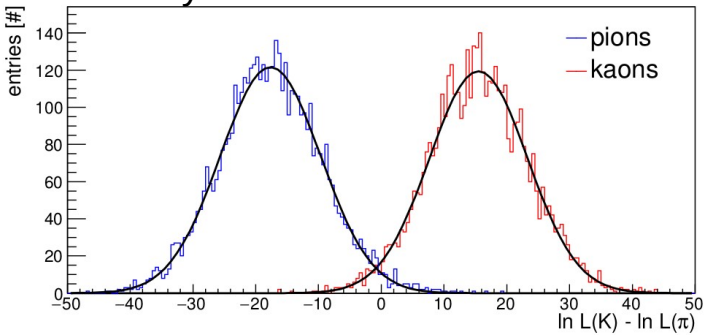


Time imaging reconstruction Geant simulation



Expected Performance

track-by-track max. likelihood fit



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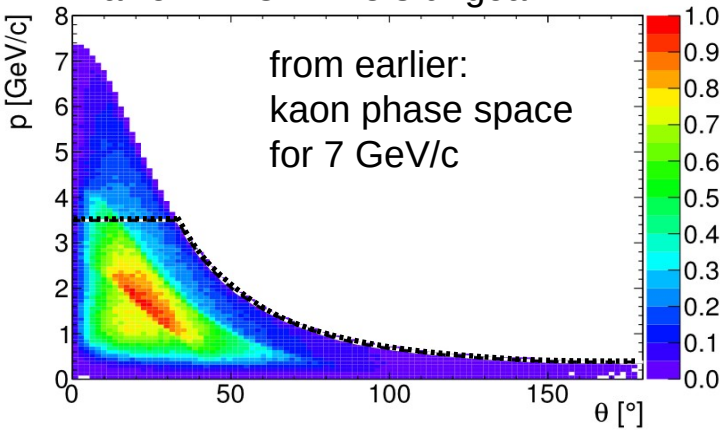
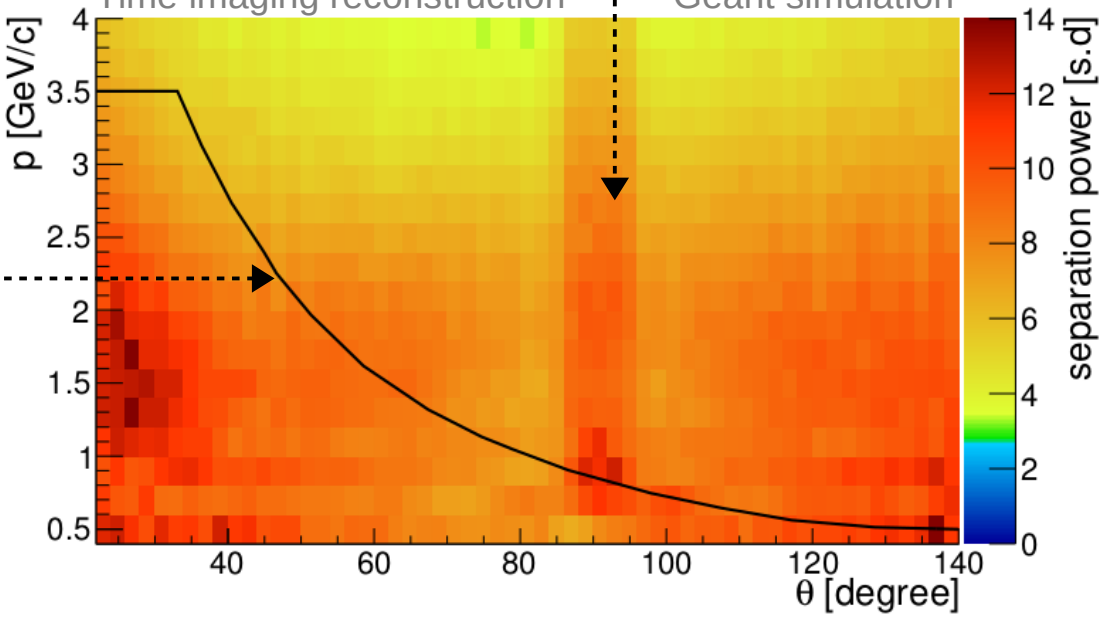
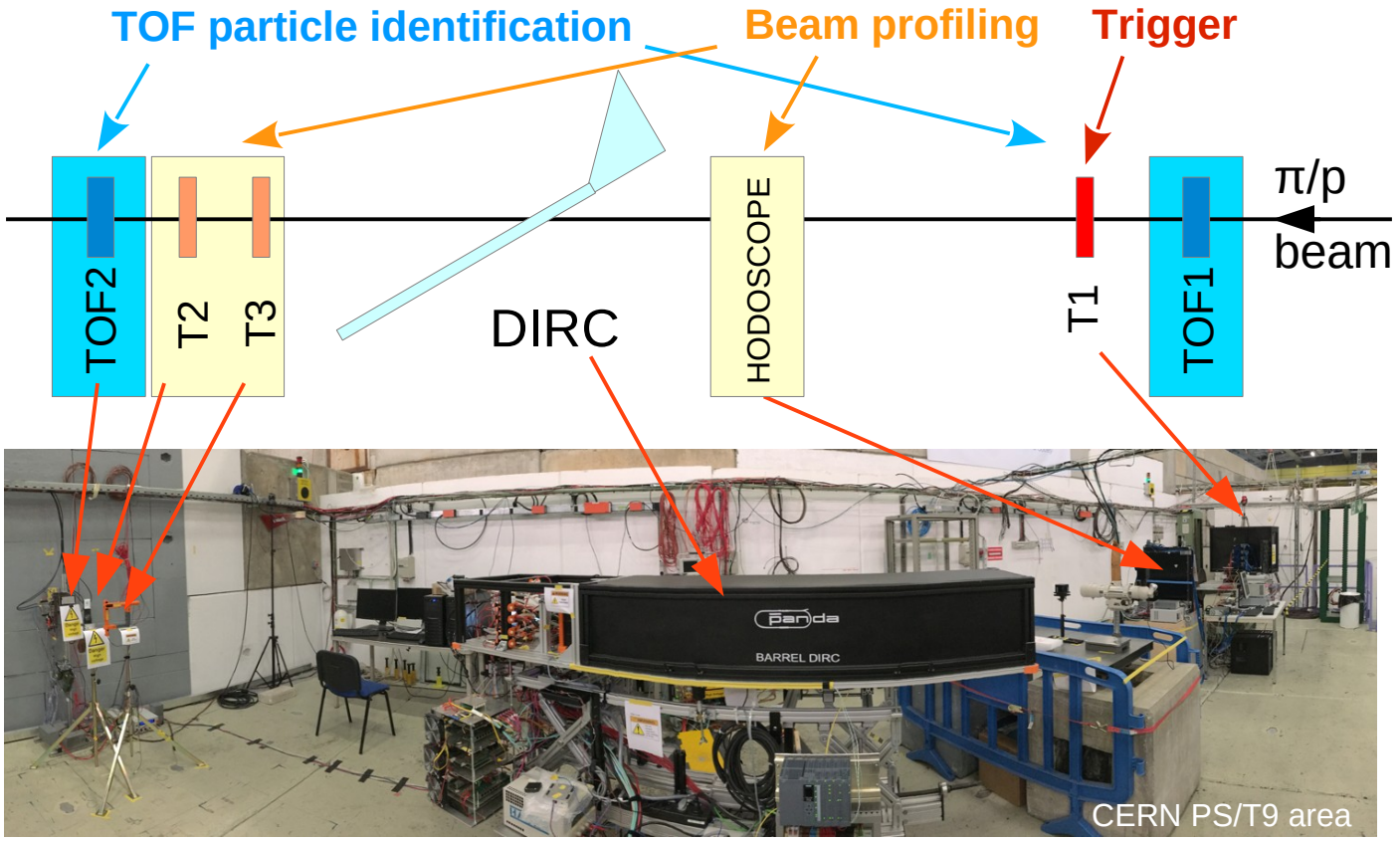


Time imaging reconstruction — Geant simulation

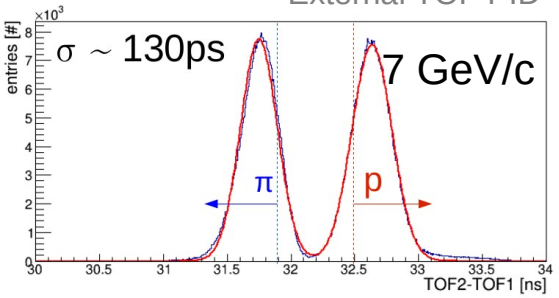


➡ Design meets and exceeds PID requirements

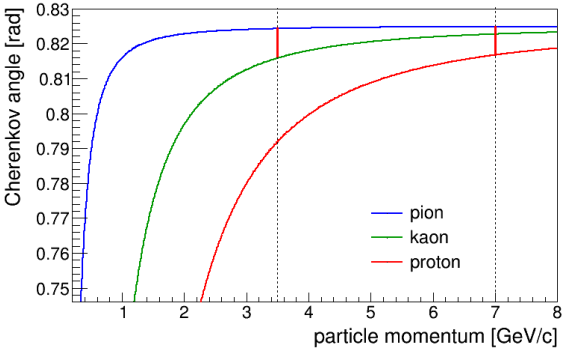
Beam Test at CERN 2018



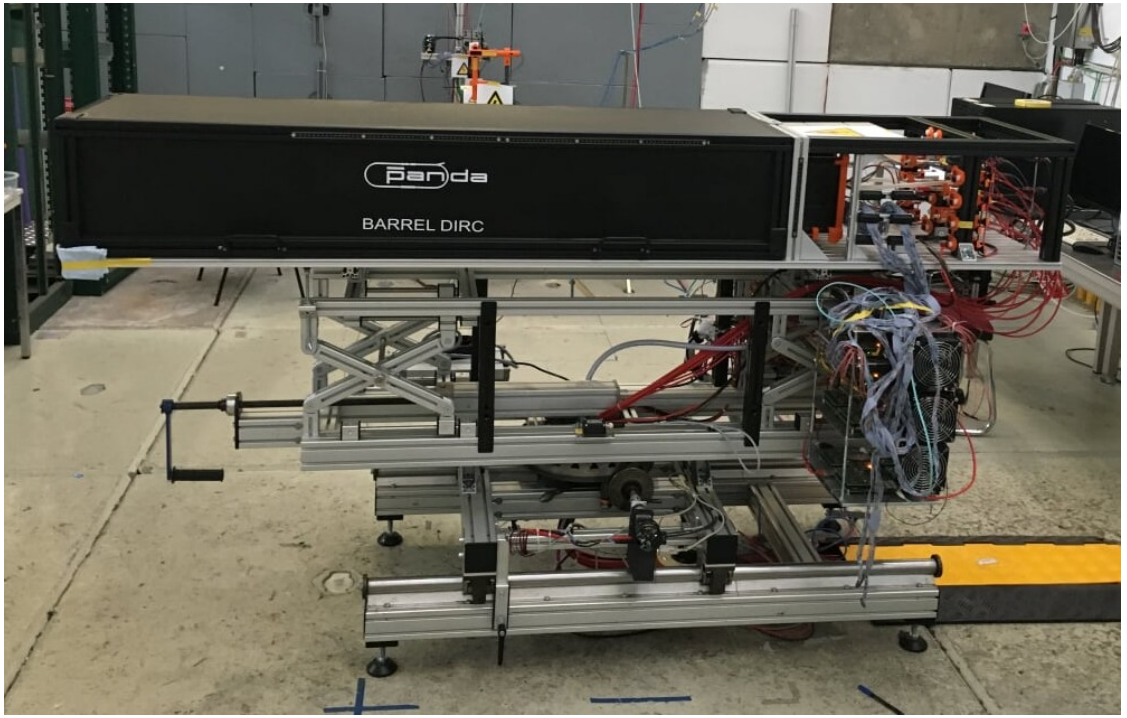
External TOF PID

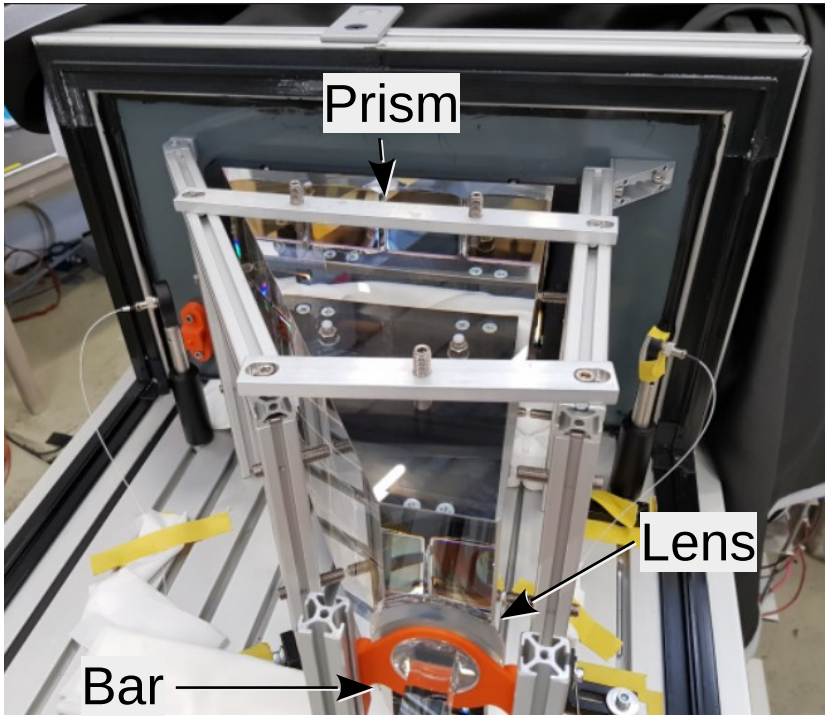


Most of the data taken at 7 GeV/c
(7 GeV/c π/p sep. ≈ 3.5 GeV/c π/K)



Beam Test at CERN 2018



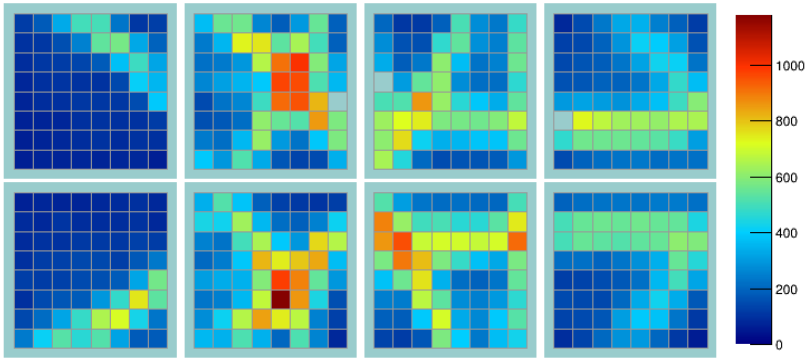


Beam Test at CERN 2018

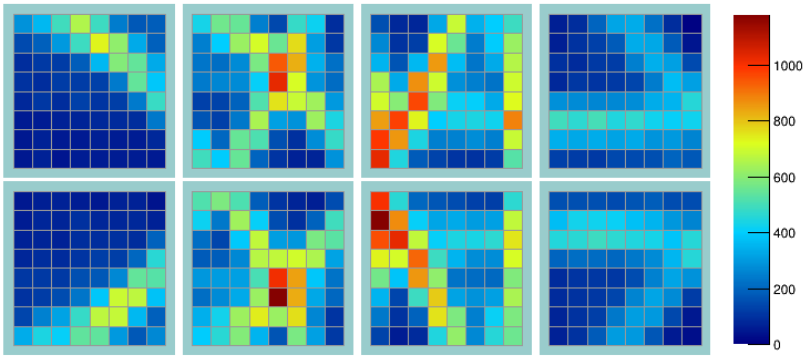
- Goal: validate near final design
- Narrow bar (17x32x1250 mm^3)
- Fused silica prism
- 4x2 MCP-PMT array
- Focusing with 3-layer spherical lens
- ~200 ps time precision

Hit patterns, 2k pions @ 20 degree polar angle:

Beam data

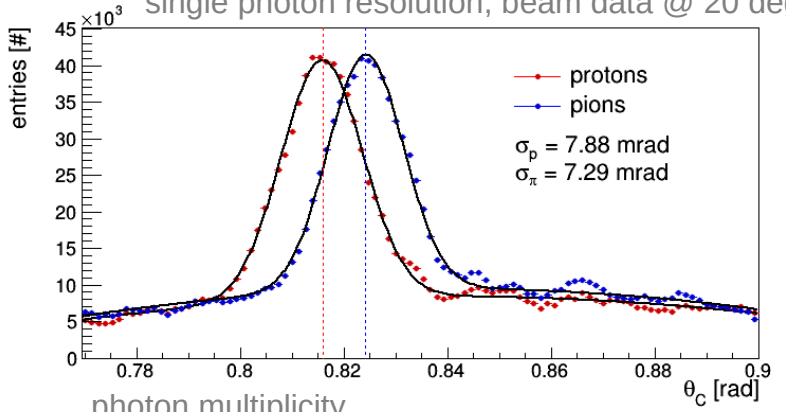


Gean4 simulation

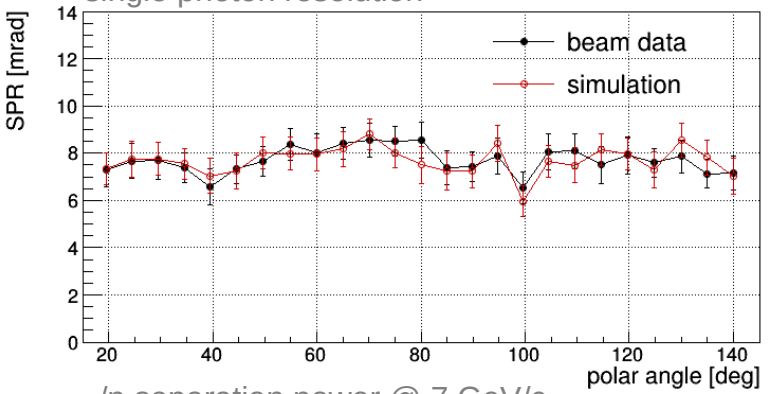


Beam Test at CERN 2018

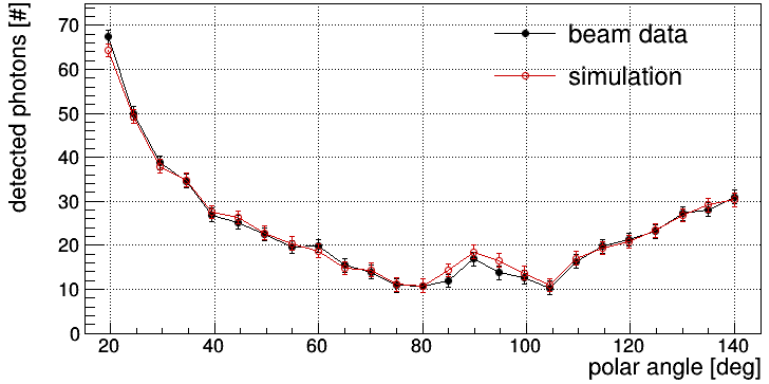
single photon resolution, beam data @ 20 deg



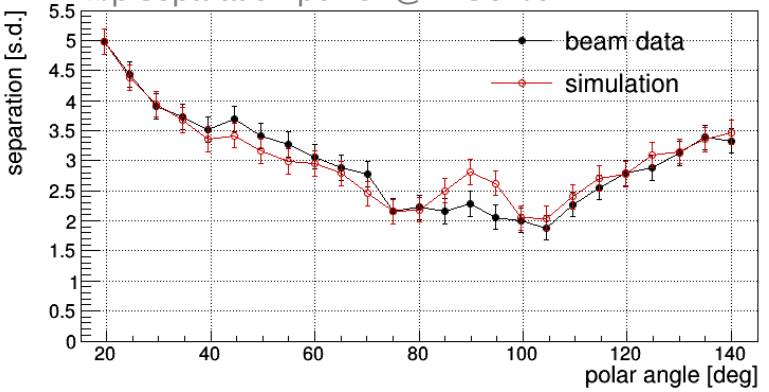
single photon resolution



photon multiplicity



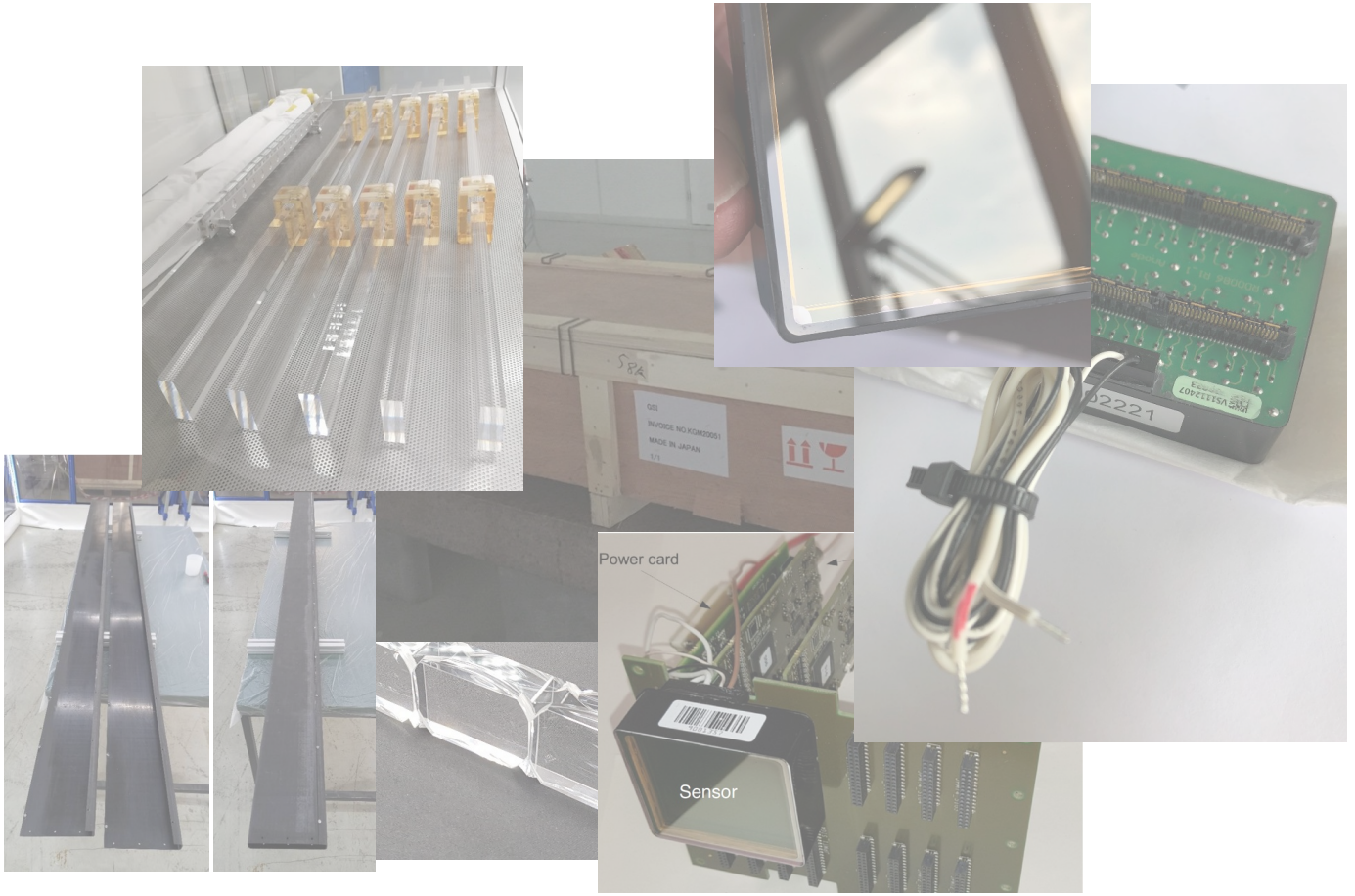
π/p separation power @ 7 GeV/c



➡ Good performance and agreement with Geant simulations

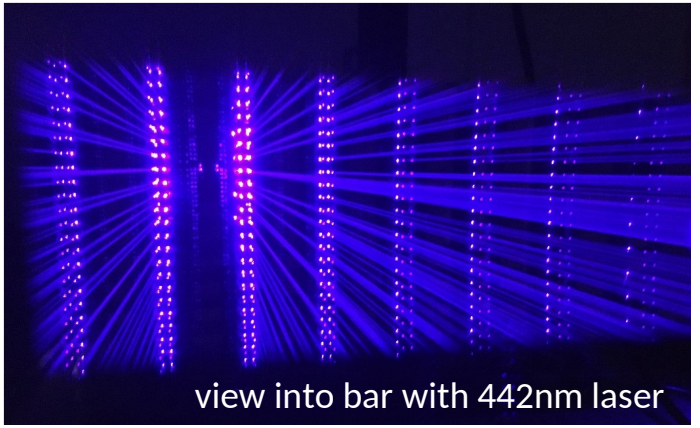
Component Production

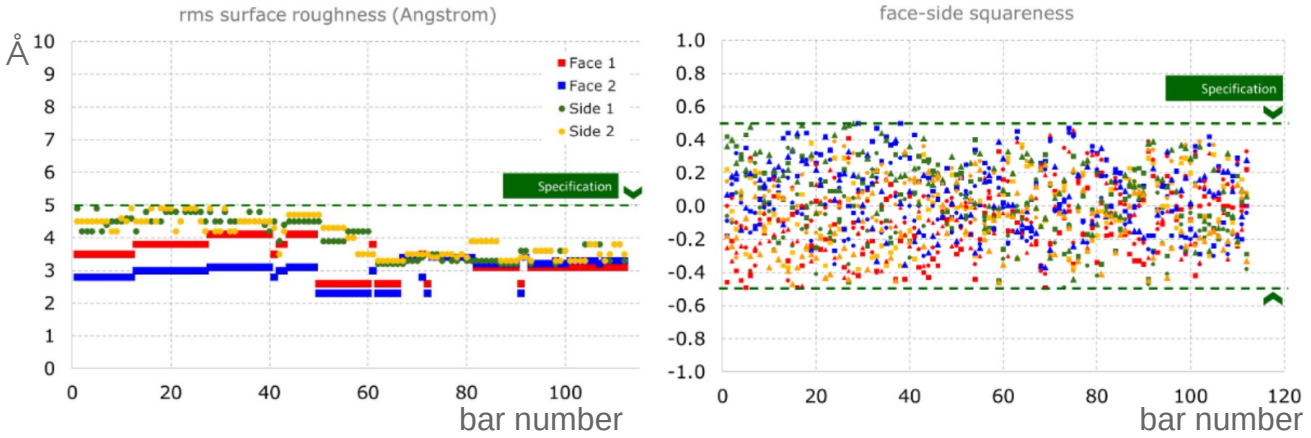
- Radiator bars
- MCP-PMTs
- Lenses, prisms
- Electronics
- Bar boxes

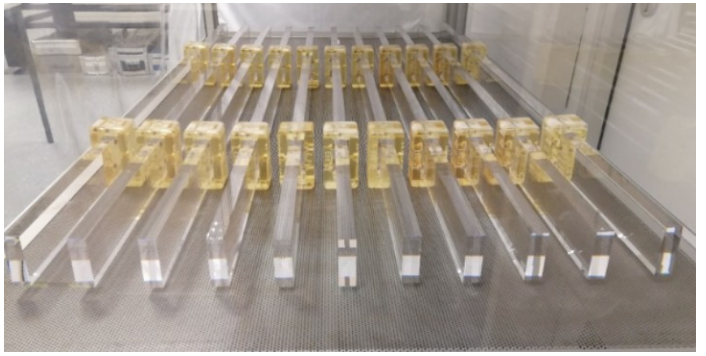


Component Production: Bars

- Contract awarded to Nikon Corp, Japan 09/2019
- Production of 112 DIRC bars successfully completed in Feb 2021 ahead of schedule
- Very good documentation and communication with the producer
- Nikon QA: all bars meet fabrication specifications

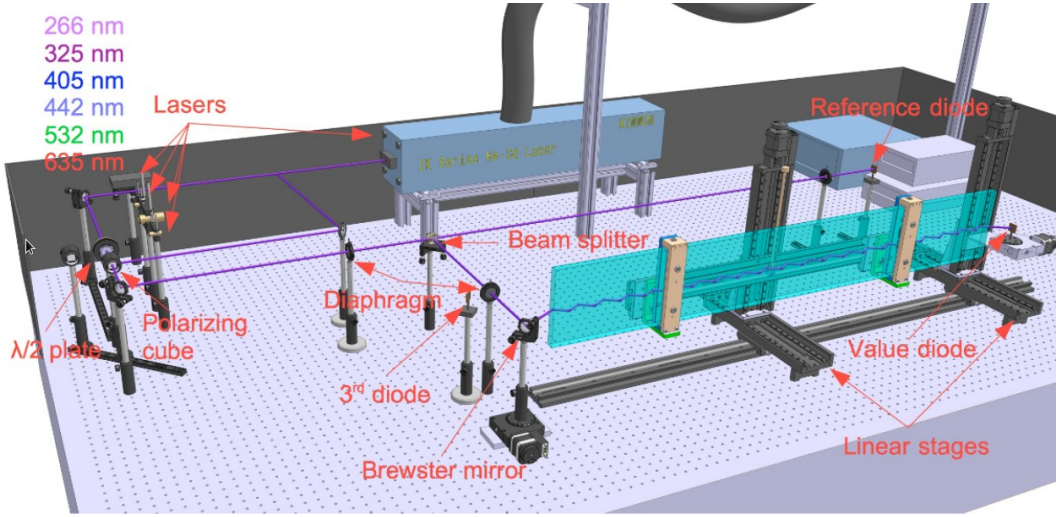


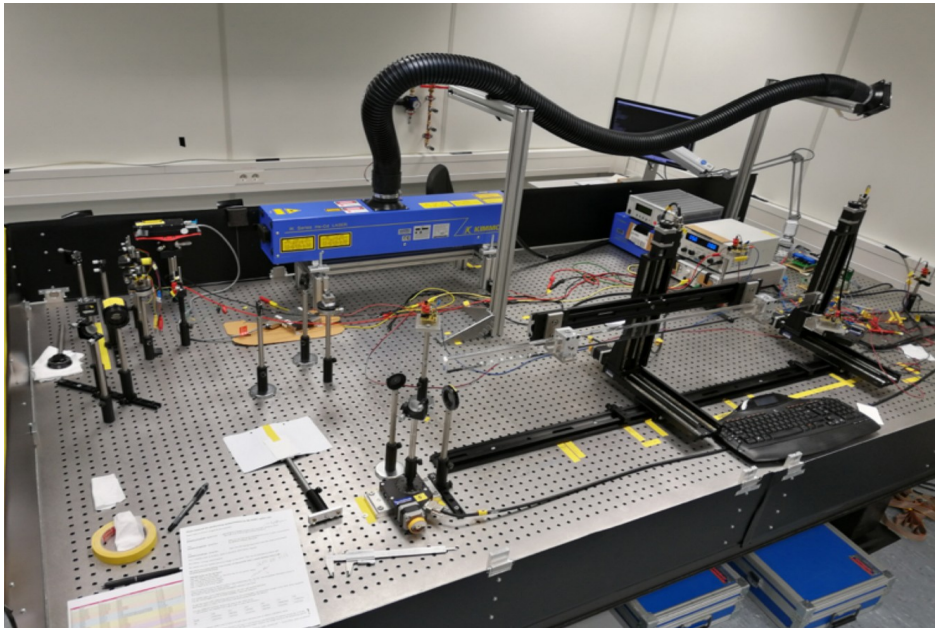




Component Production: Bars

- Nikon QA: all bars meet fabrication specifications
- Additional QA @ GSI with laser scanning setup
  (for subsurface damage study)

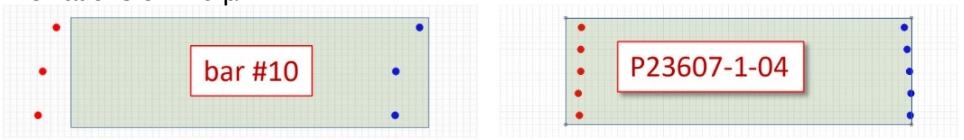




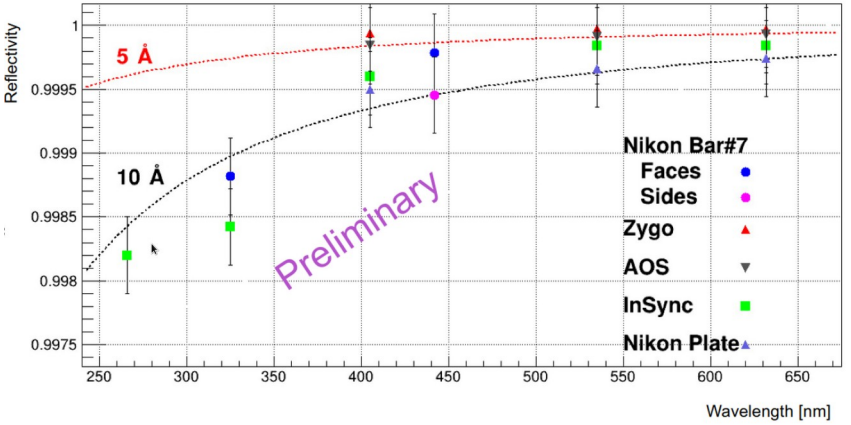
Component Production: Bars

- Shape deviations of bar sides and striae detected
- No significant influence on Barrel DIRC performance
- Preliminary results give no hint for significant subsurface damage
- Gluing tests are started at Helmholtz Institute Mainz

Deviations of ~10 µm

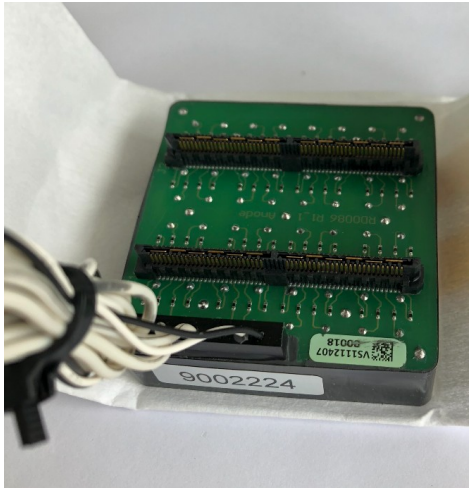


Fast feedback from Nikon with improvements

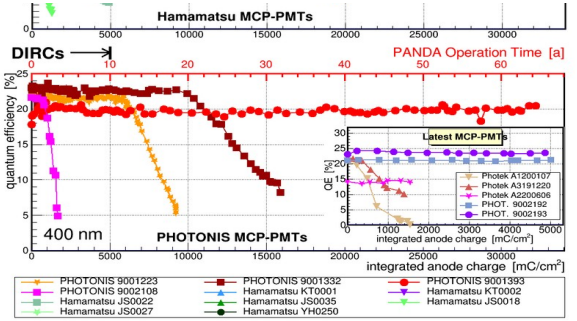


Component Production: Photon Sensors

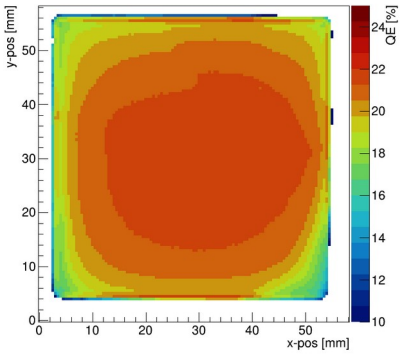
- Order for 155 MCP-PMTs placed with Photonis on Dec 22, 2020
  128 required + 27 spare
- Series production of MCP-PMTs at Photonis ramping up, starting detailed QA on first units
  1 year of delay due to Covid plus startup issues with ALD processing station
  Photonis adding second station to speed up process
- Partial first-of-series delivery in May 2022
- QA measurements in FAU Erlangen



Lifetime measurement

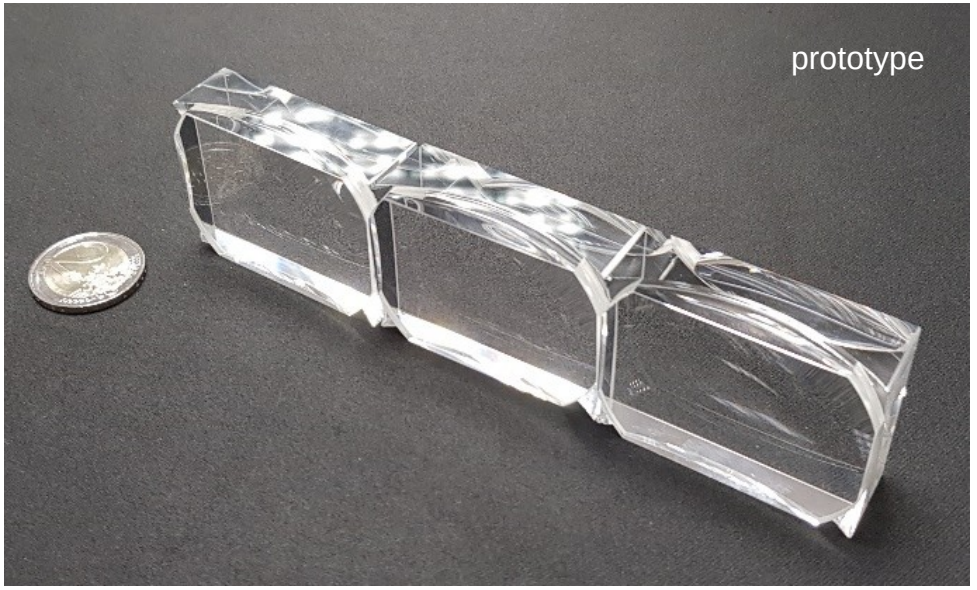


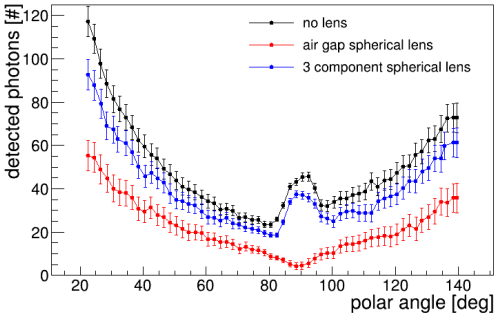
2D QE scan

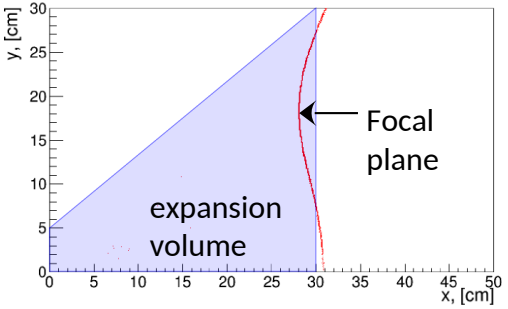


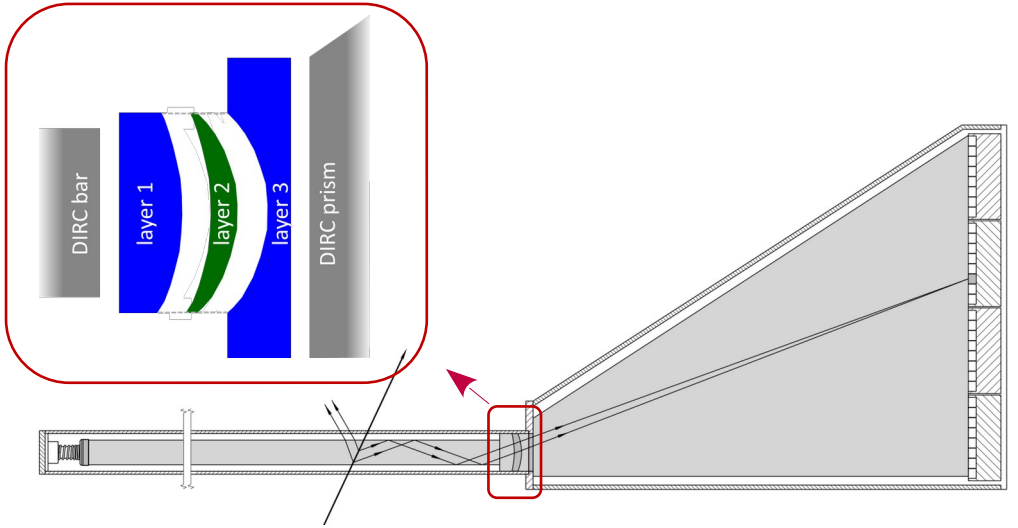
➡ see talk by S. Krauss on Sep 15

Component Production: Lenses





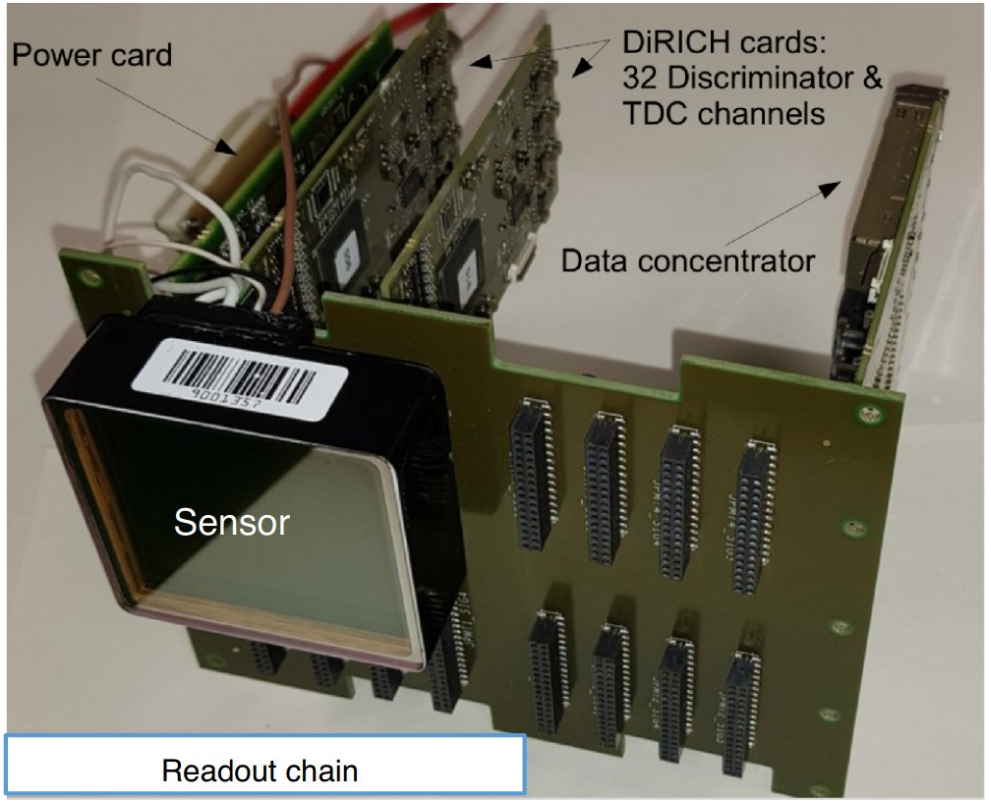




- 3-layer compound spherical lenses
- Multiple vendors are available (Germany, USA)
- Focal plane measurement (collaboration with hpDIRC at EIC)

➡ see talk by J. Schwiening on Sep 14

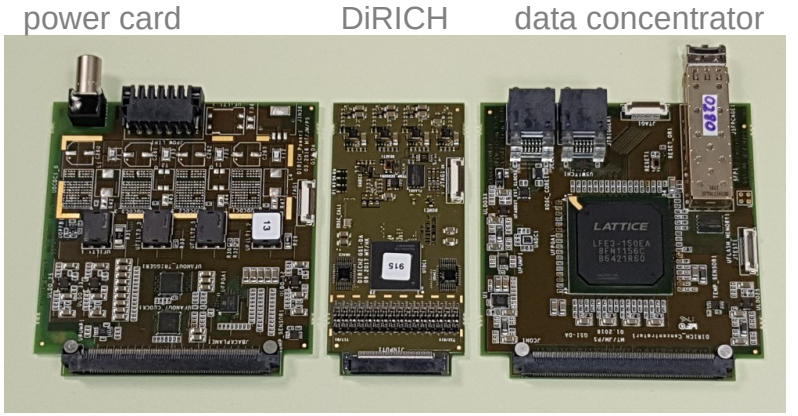
Component Production: Electronics



DiRICH readout backplane

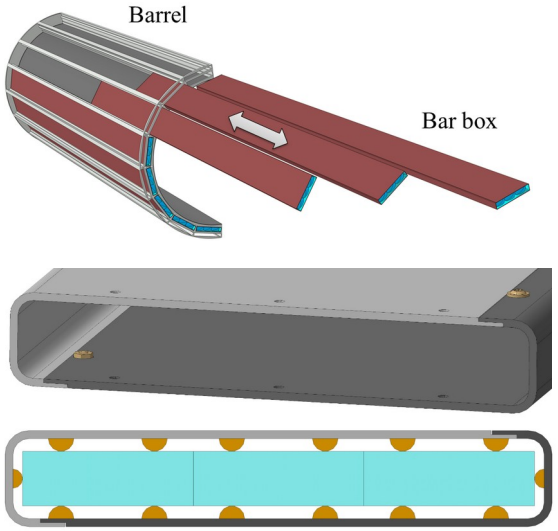
(Collaboration with PANDA, CBM, HADES)

- Highly integrated
- Minimal cabling
- ~10 ps internal time precision (disc. +TDC)
- ~50 mW /channel power consumption

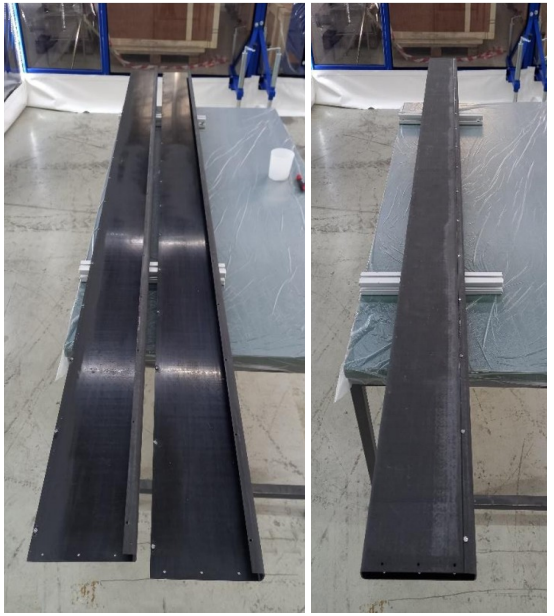


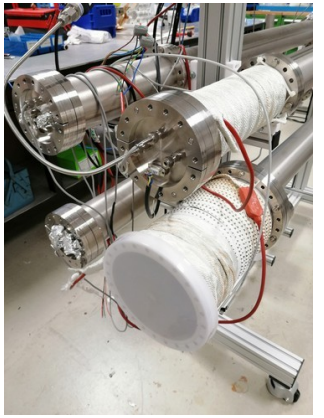
Component Production: Bar Boxes

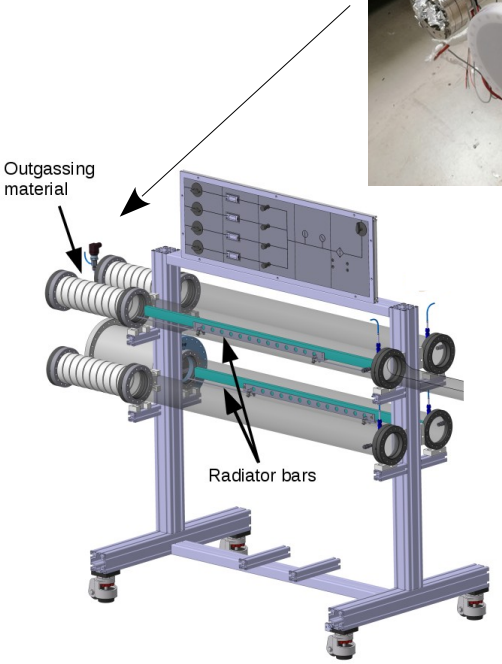
- Carbon fiber reinforced polymer (CFRP)
- Low material budget
- Study of long-term outgassing behavior



Prototype of L-elements

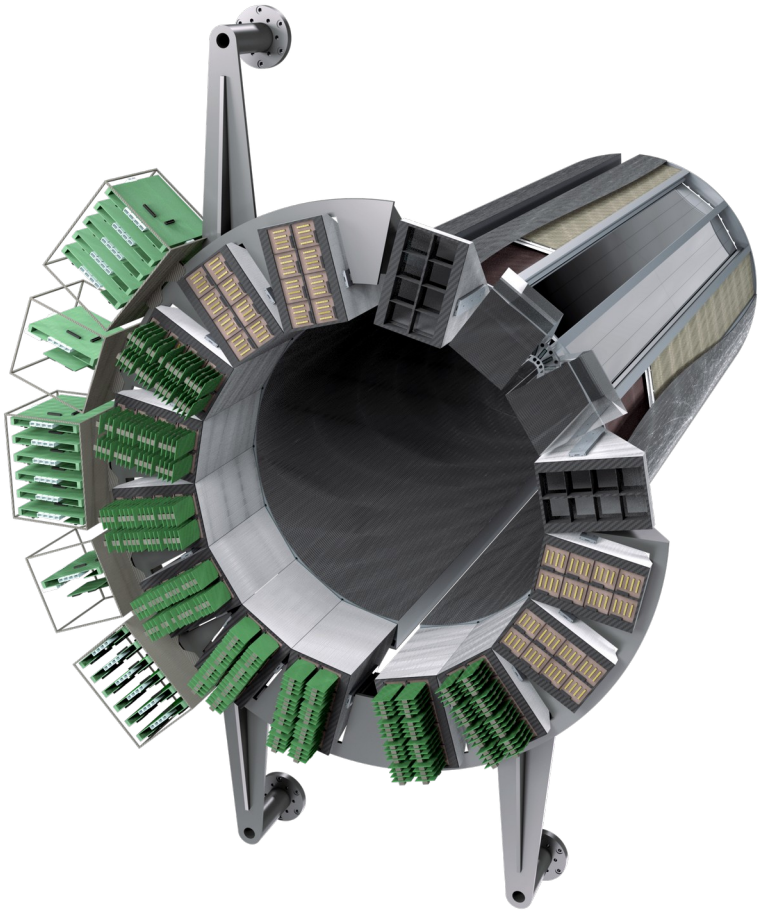






Summary

- The PANDA Barrel DIRC is a key component of the PANDA PID system
- Design features narrow bars and 3-layer spherical lens and compact expansion volume
- Simulations predict more than 3 s.d. π/K separation up to 3.5 GeV/c. Validated with beam tests
- Component fabrication:
  - Radiator bars (done)
  - MCP-PMTs (in progress)
  - Lenses, bar boxes, electronics (next)



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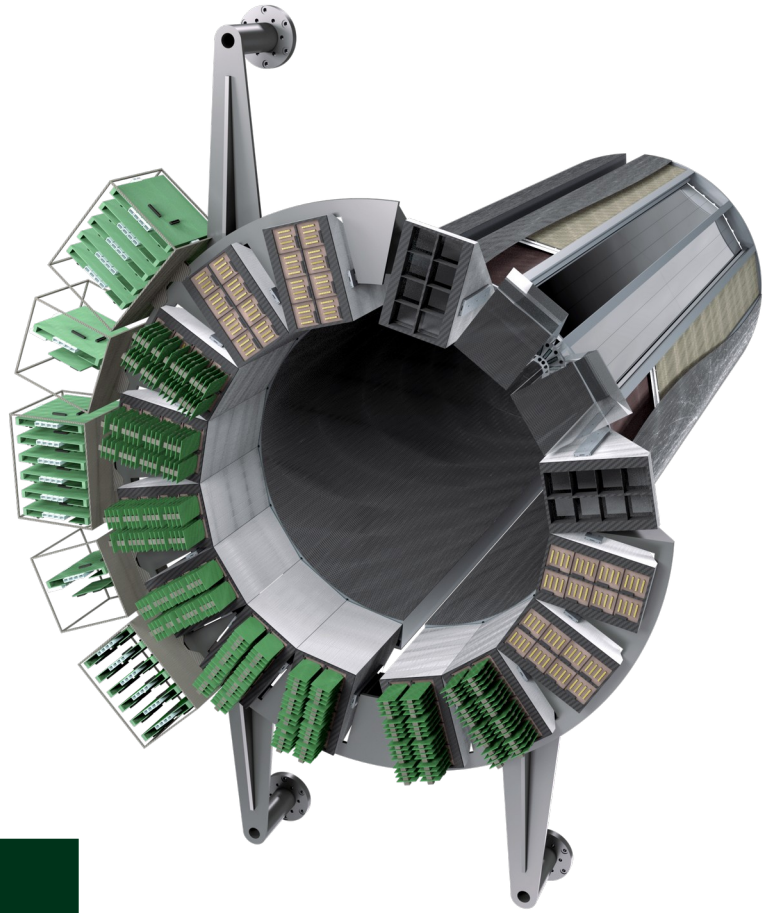

Thank you for the attention