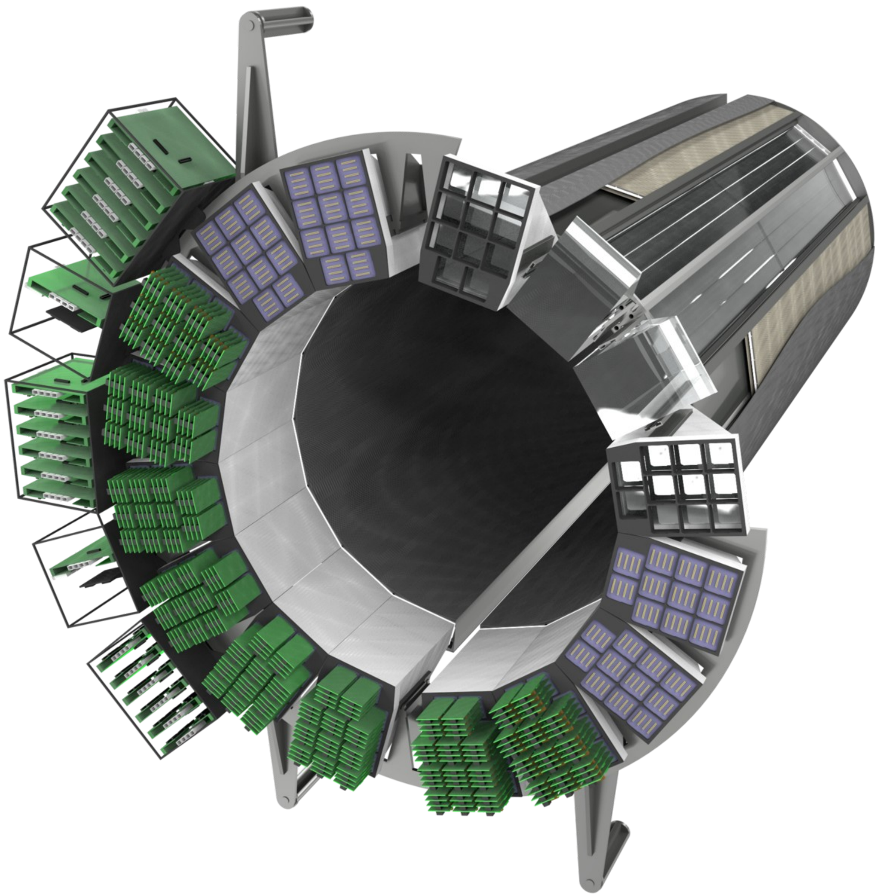
The Barrel DIRC Detector for the PANDA Experiment at FAIR



TIPP 2017 conference

Roman Dzhygadlo (GSI)
for the PANDA Cherenkov Group

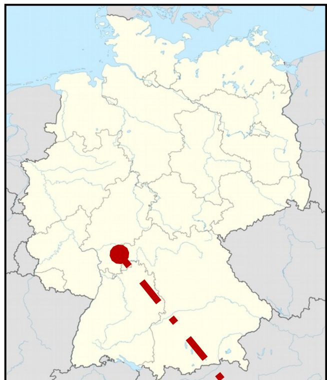
- PANDA experiment
- Barrel DIRC design
- Expected performance
- Validation in beam tests
- Summary & outlook

The PANDA Cherenkov Group:

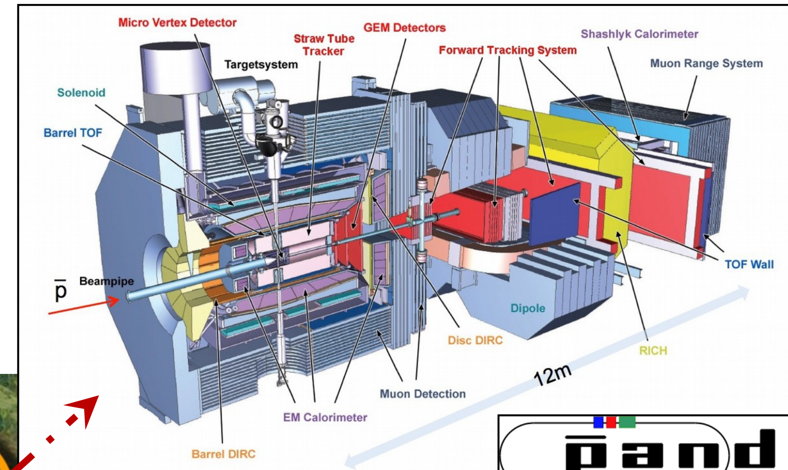
panda
FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
GSI
JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ
FAIR

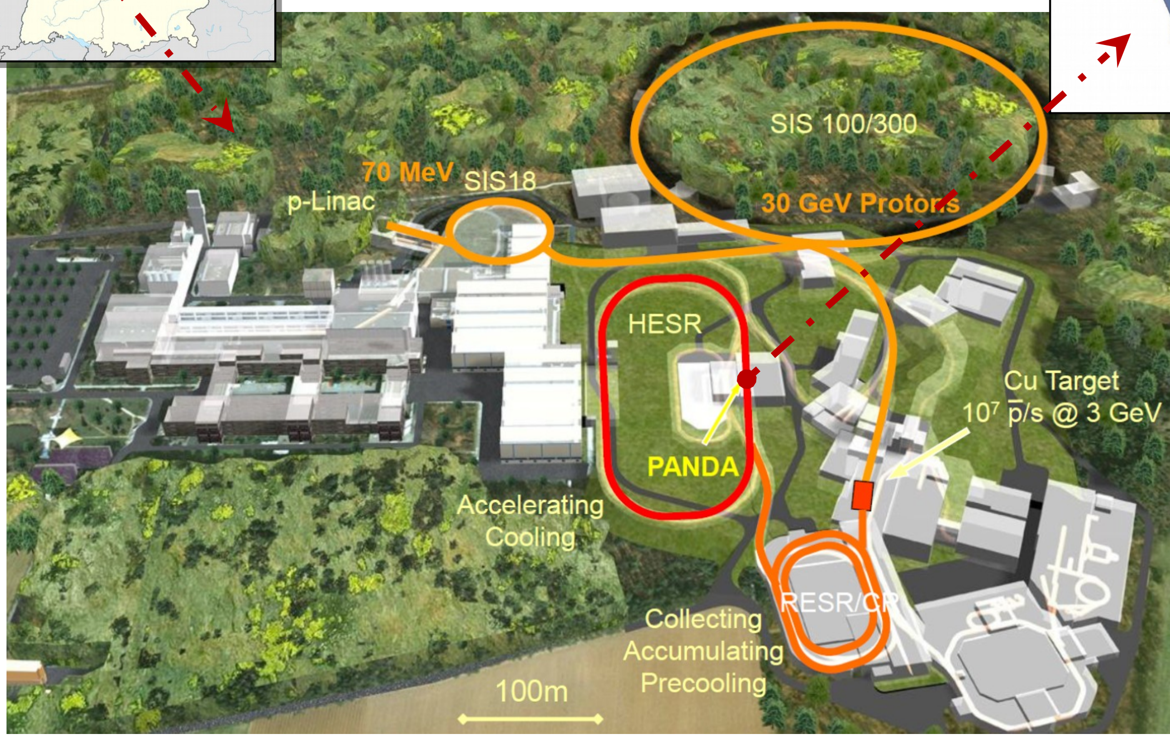
The PANDA Experiment at FAIR

Facility for **A**ntiproton and **I**on **R**esearch at GSI near Darmstadt, Germany



- FAIR Accelerator Complex
- PANDA Experiment
- Barrel DIRC Detector

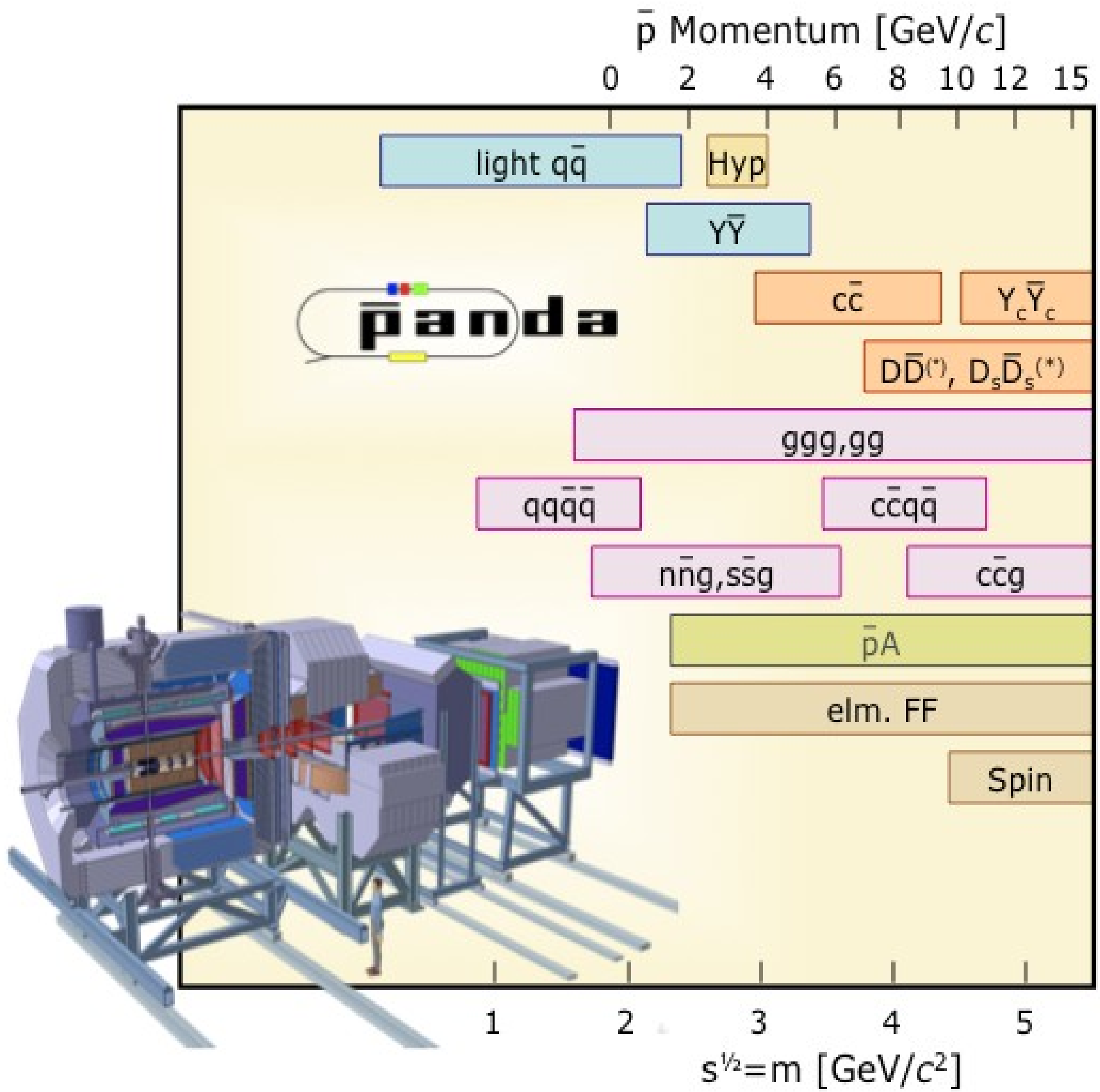




- High Energy Storage Ring
- 5×10^{10} stored cooled antiprotons
- 1.5 to 15 GeV/c momentum
- Cluster jet / pellet target
- High luminosity mode
  $\Delta p/p \approx 10^{-4}$ (stochastic cooling)
  $L = 1.6 \times 10^{32}\ cm^{-2}s^{-1}$
- High resolution mode
  $\Delta p/p \approx 5 \times 10^{-5}$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

PANDA Physics Program

Study of QCD with Antiprotons



Non-perturbative QCD

Hypernuclei

Precision Hadron Spectroscopy

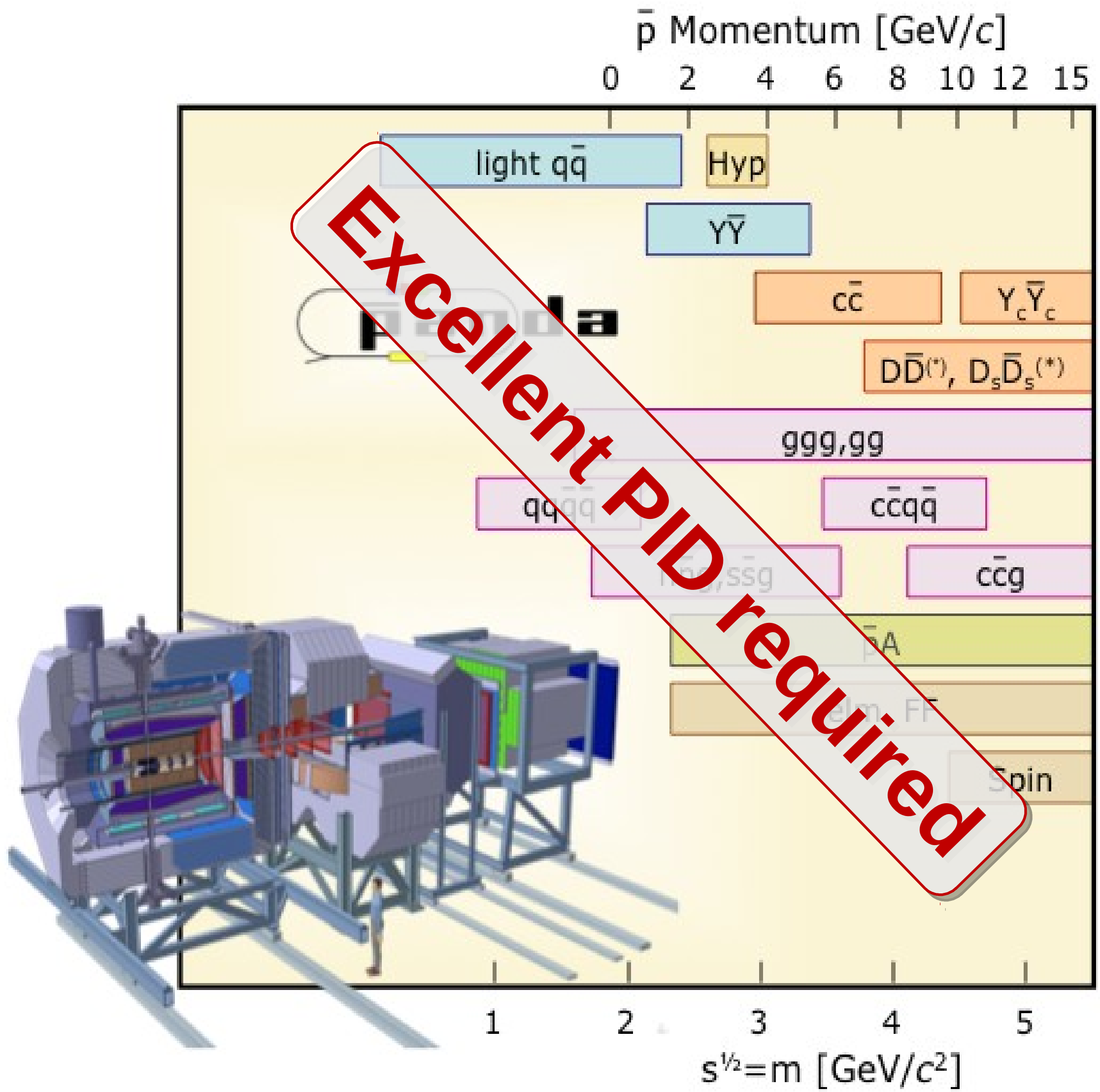
Exotic States (Glueballs, Hybrids)

In-Medium Modifications

Nucleon Structure

PANDA Physics Program

Study of QCD with Antiprotons



Non-perturbative QCD

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Precision Hadron Spectroscopy

Exotic States (Glueballs, Hybrids)

In-Medium Modifications

Nucleon Structure

DIRCs in PANDA

Two DIRC detectors for hadronic PID:

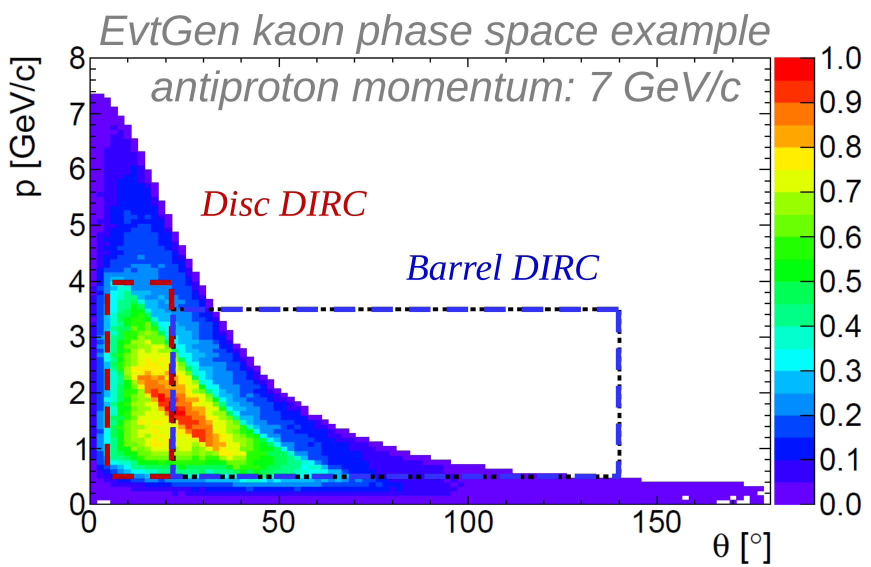
- Barrel DIRC

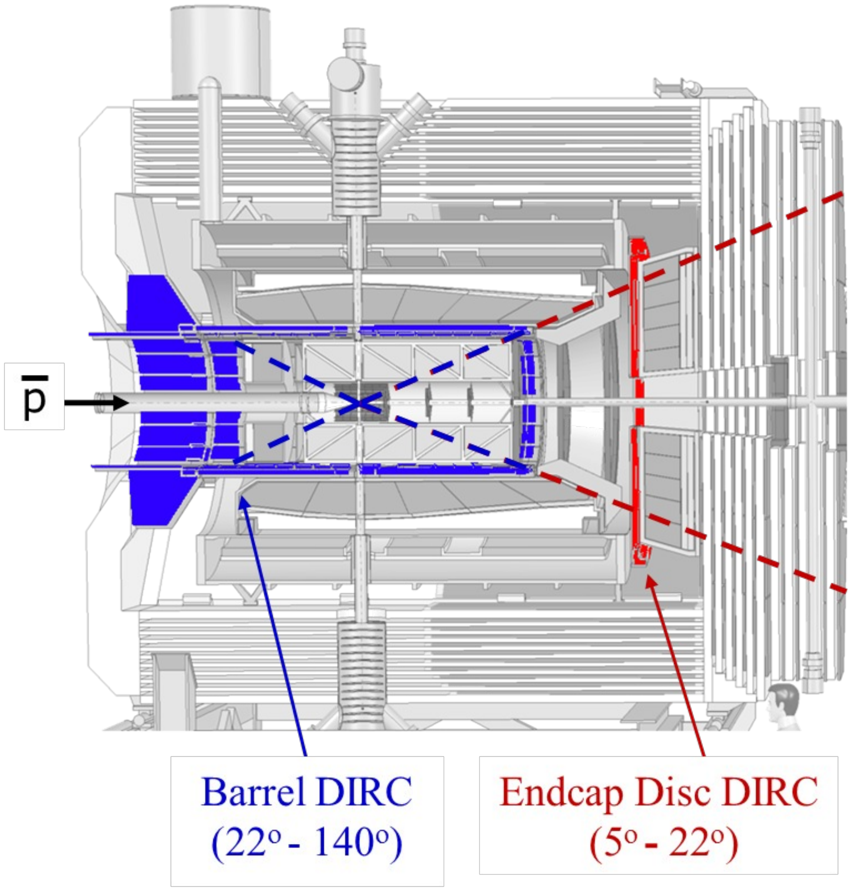
  German in-kind contribution to PANDA

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

- Endcap Disc DIRC

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





Endcap Disc DIRC for PANDA at FAIR
Mustafa SCHMIDT, 23.05
R1, Particle identification

DIRC Principle

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

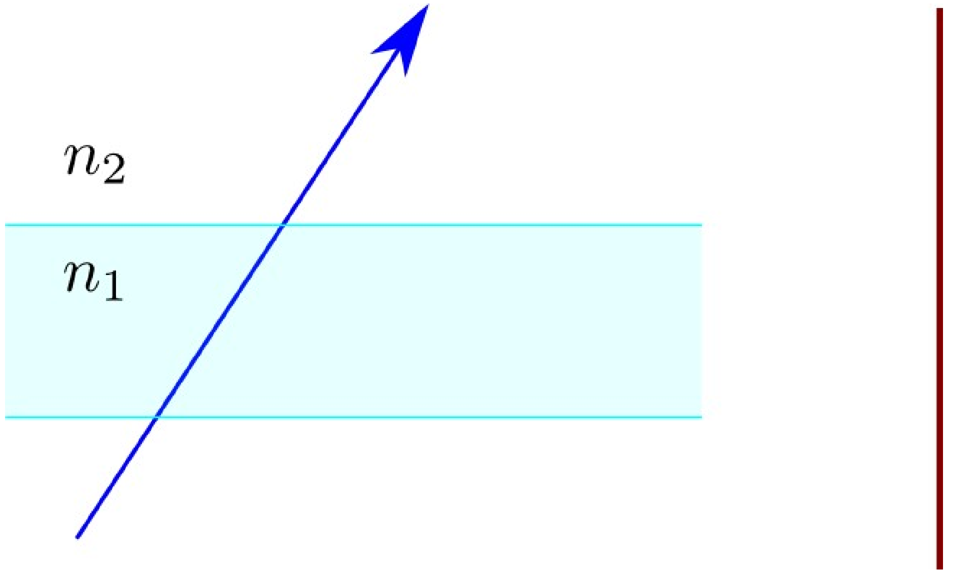
Novel type of Ring Imaging CHerenkov detector
based on total internal reflection of Cherenkov light.

DIRC Principle

Detection of Internally Reflected Cherenkov Light

Novel type of Ring Imaging CHerenkov detector based on total internal reflection of Cherenkov 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 $\cos \theta c = 1/\beta n(\lambda)$.



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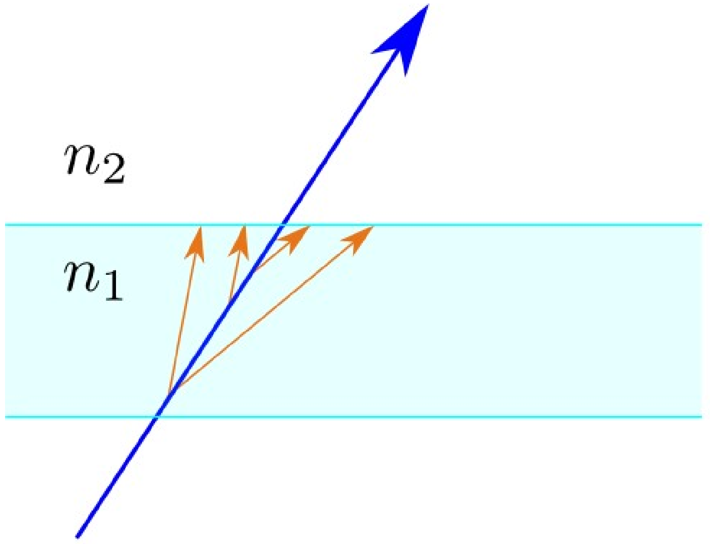

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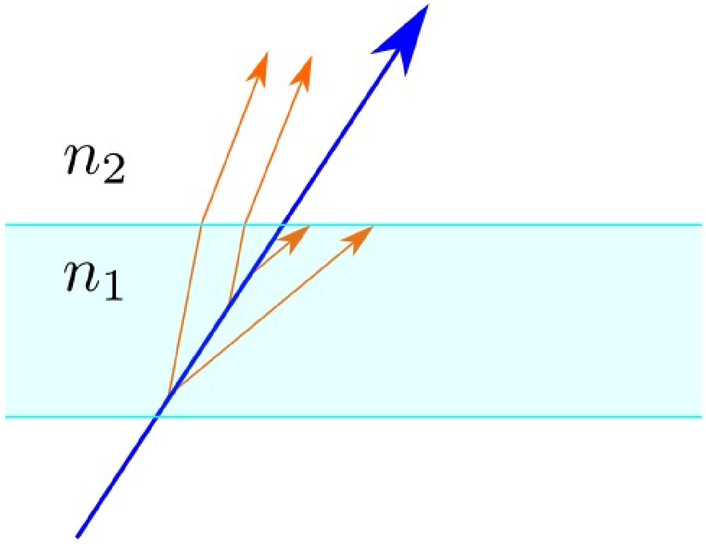

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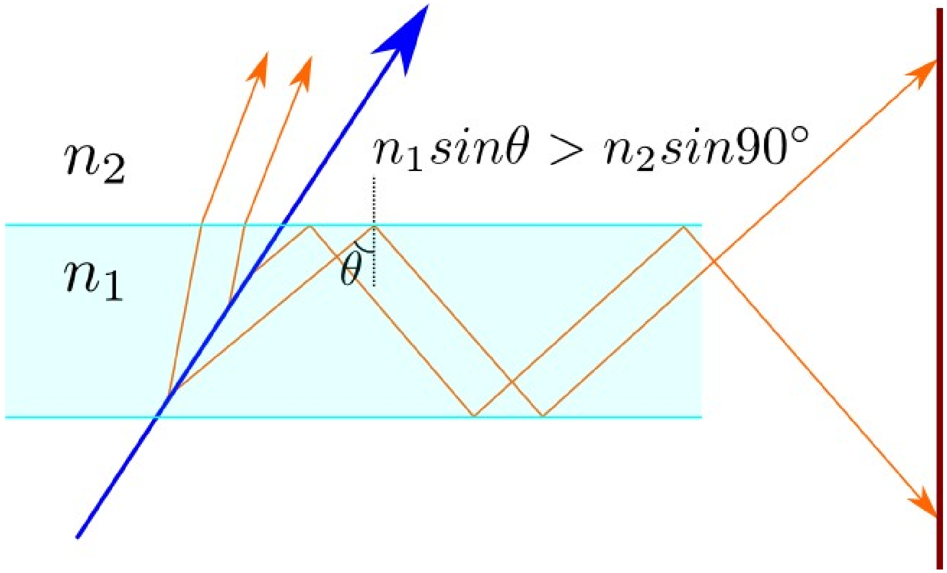

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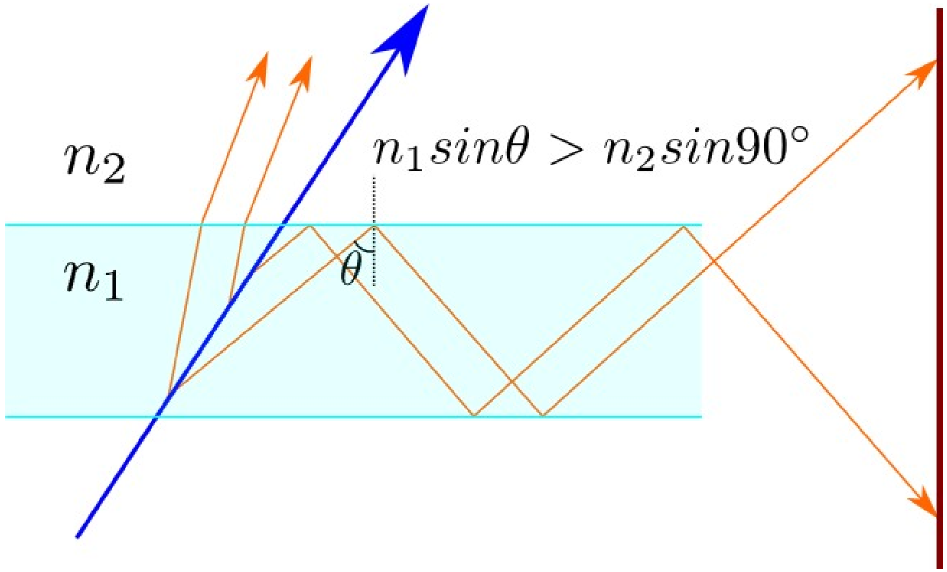

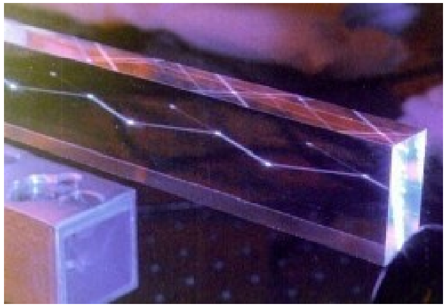

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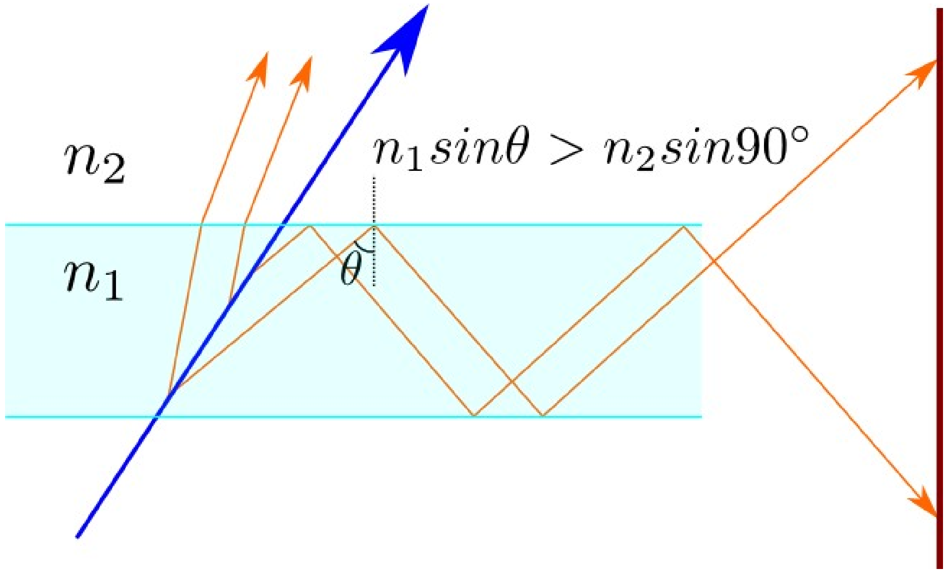
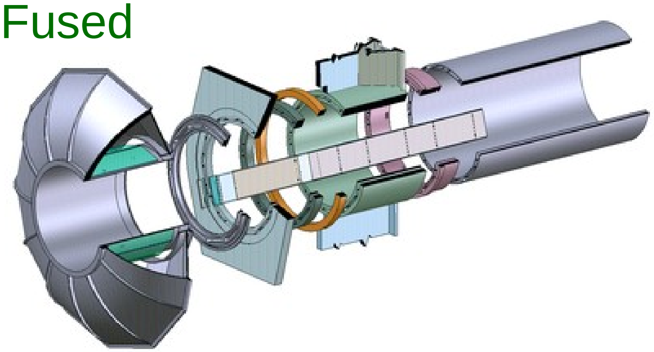
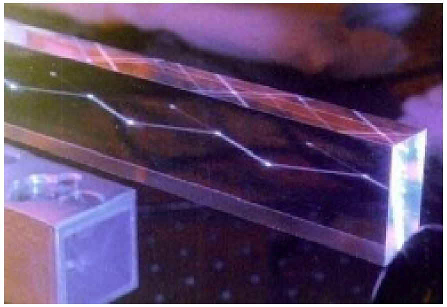
- Proven to work (BABAR-DIRC).





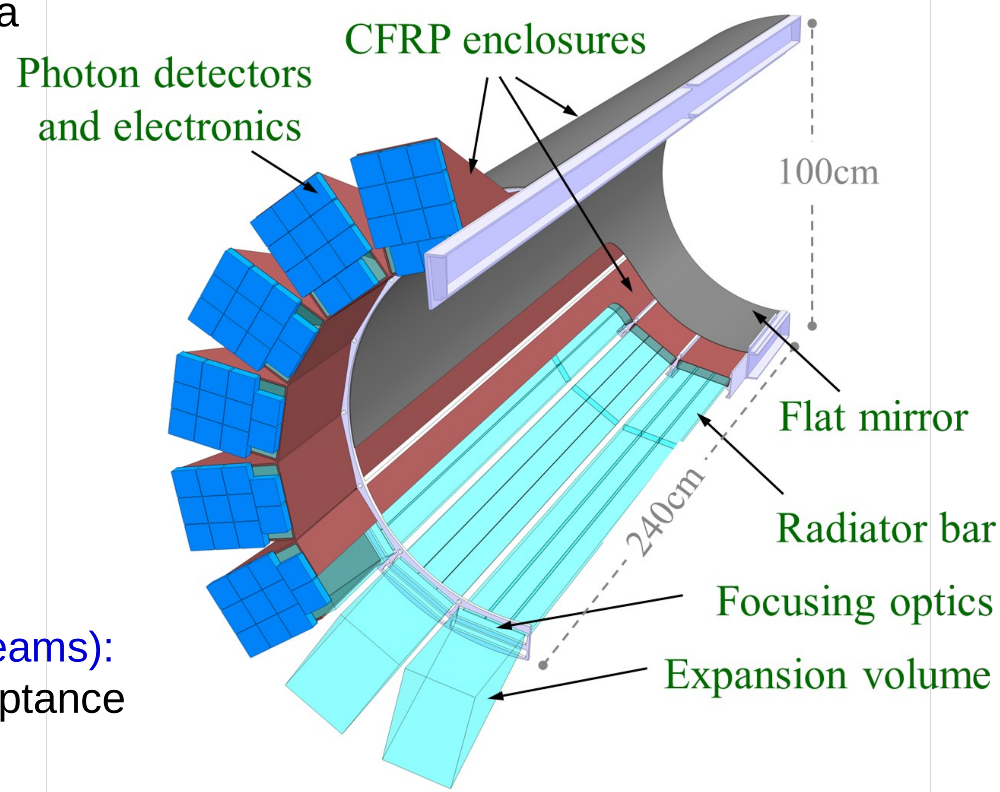


Barrel DIRC Baseline Design

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
  ~11,000 channels of MCP-PMTs
- Fast FPGA-based photon detection
  ~100ps per photon timing resolution
- Expected performance (simulation and particle beams):
  better than 3 s.d. π/K separation for entire acceptance



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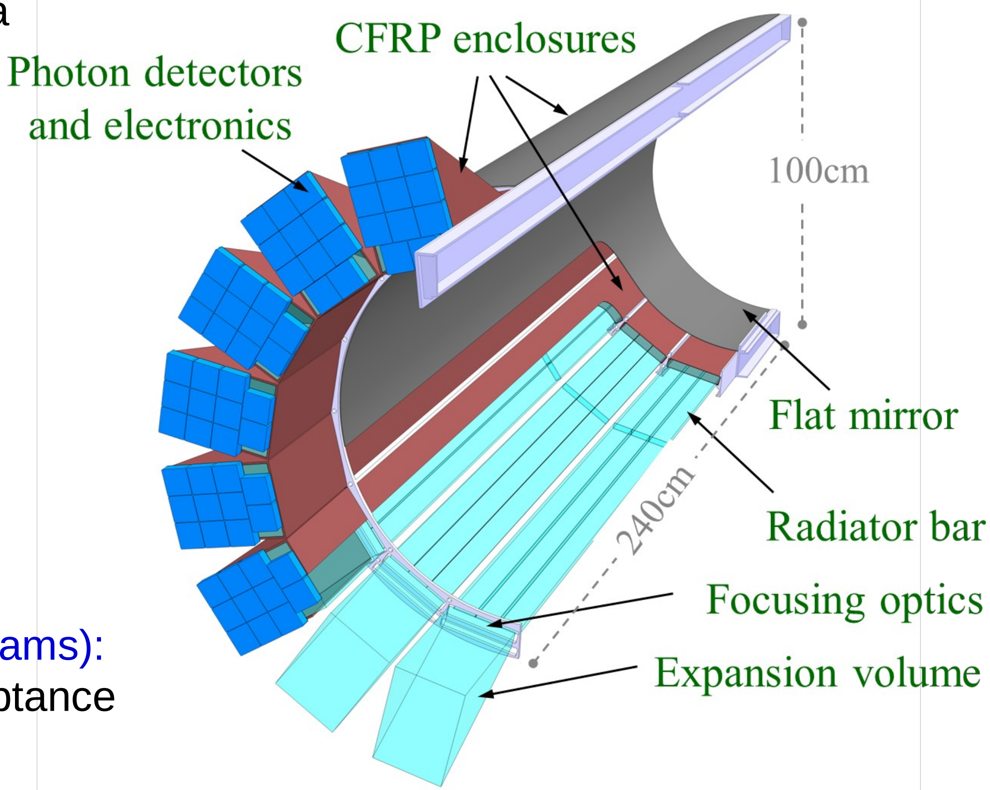


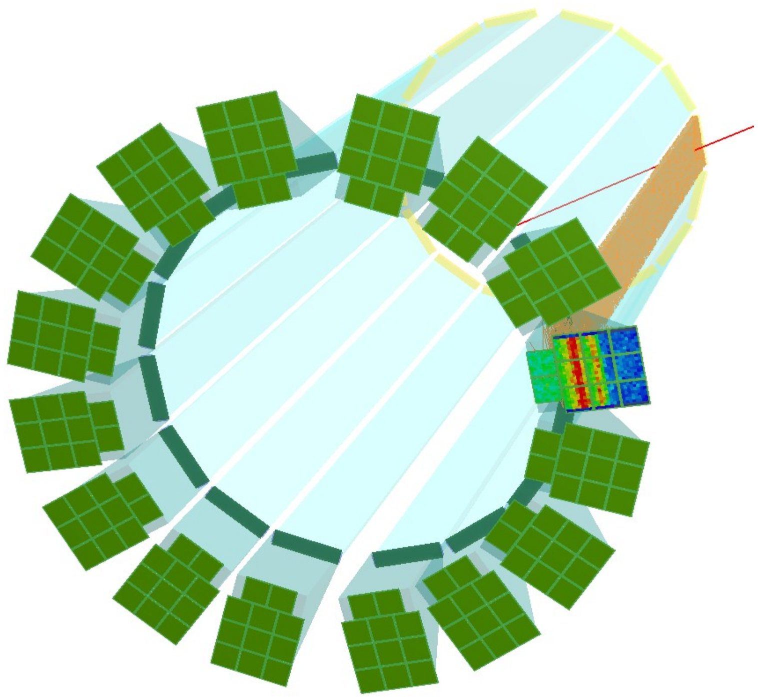
Conservative design: similar to BABAR DIRC, baseline design for TDR

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

Barrel DIRC Cost-Saving Design

Replacing 3 bars/bar box with 1 wide plate saves significant fabrication costs

- 16 radiator plates (16 sectors), synthetic fused silica *(instead of 48 narrow bars)*
  17mm (T) x 160mm (W) x 2400mm (L)
- Focusing optics: cylindrical lens system
- Expansion volume and readout same as baseline
- Expected performance (simulation and particle beams):
  better than 3 s.d. π/K separation for entire acceptance
- Included in TDR as design option



GEANT simulation

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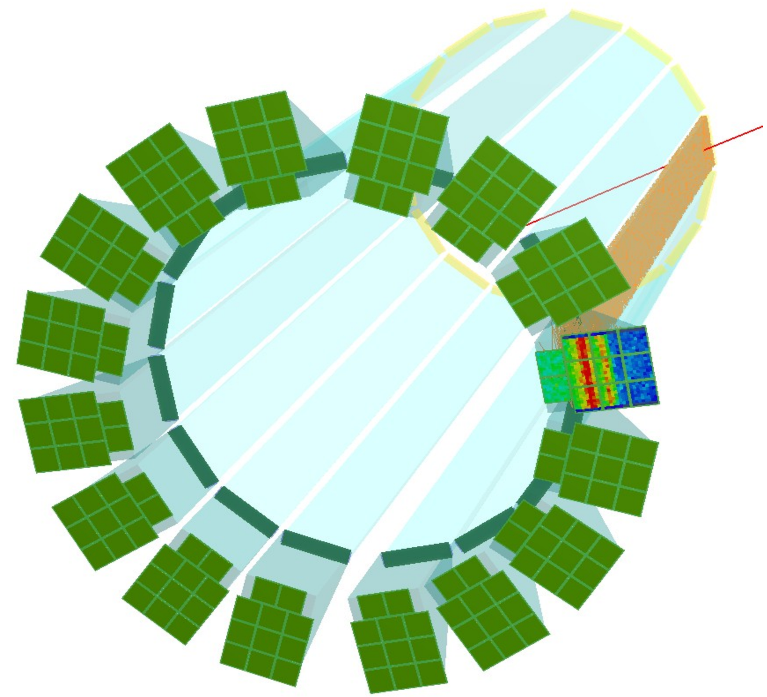


GEANT simulation

Wide plate design would reduce cost – but it is no longer a “BABAR-like” DIRC

Belle II TOP counter uses wide plates (450mm), completed installation in May 2016

May expect similar performance (TOP goal: 3 s.d. π/K up to 4 GeV/c)

Expected Performance

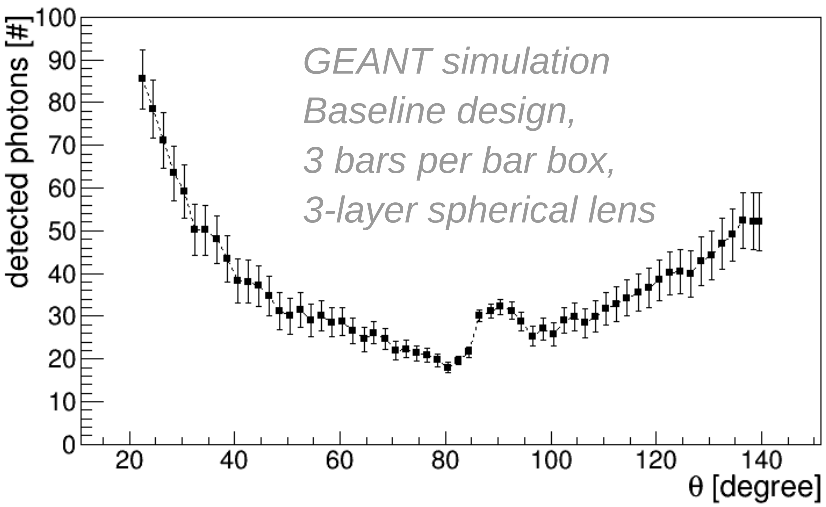
Reconstruction method:
- Geometrical (BABAR-like)
- Time imaging (Belle II TOP-like)

Geometrical reconstruction:

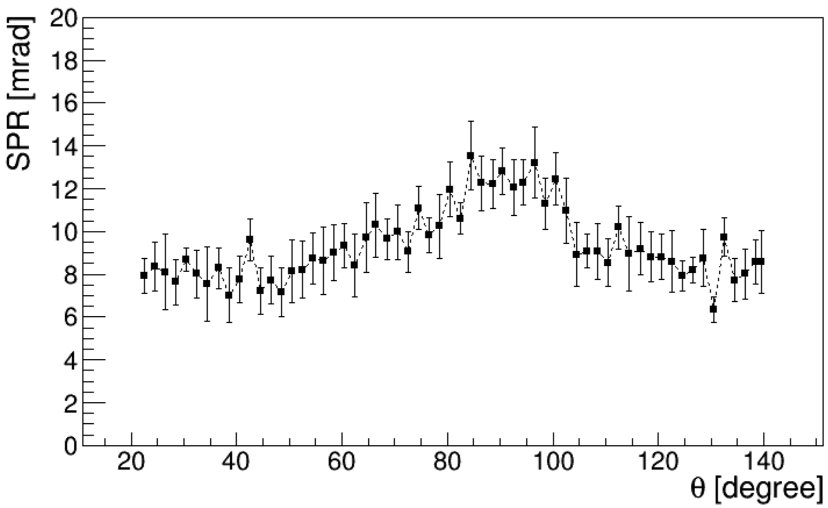
Cherenkov track resolution: $\sigma_{\theta_C}^{\text{track}} = \sqrt{\left(\frac{\sigma_{\theta_C}^{\text{photon}}}{\sqrt{N_{\text{photons}}}}\right)^2 + (\sigma^{\text{correlated}})^2}$

tracking resolution
2-3 mrad

Photon yield



Single Photon Cherenkov angle resolution (SPR)



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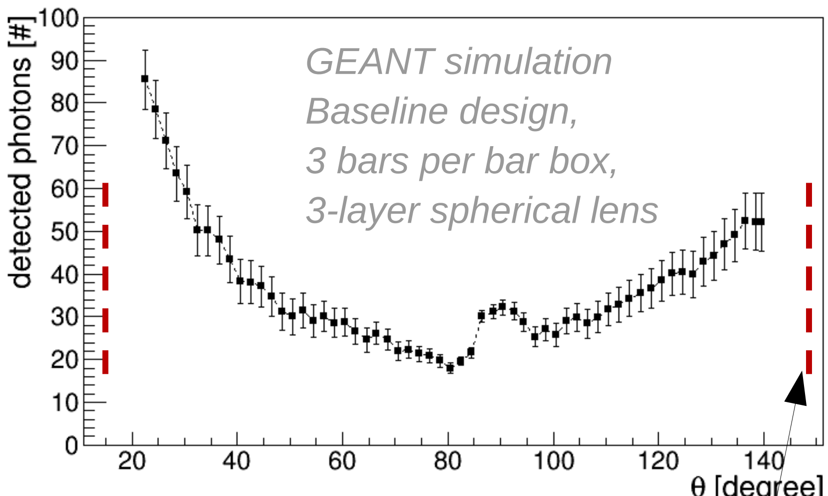

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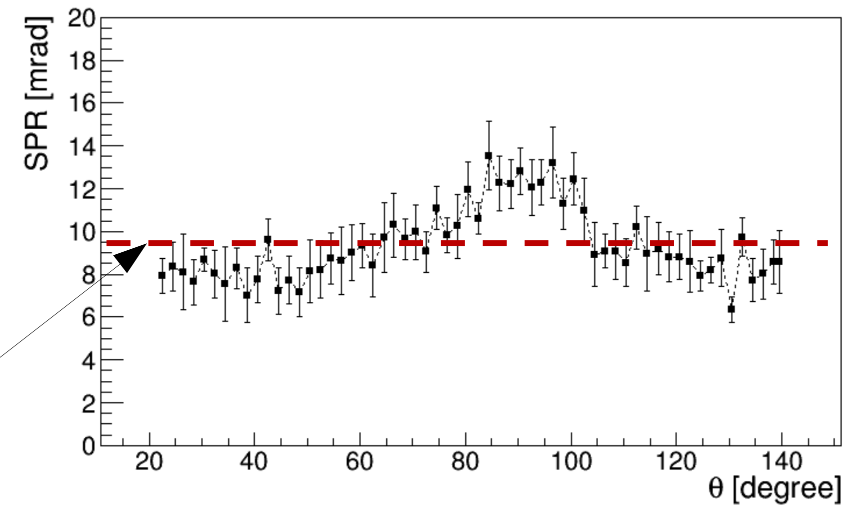
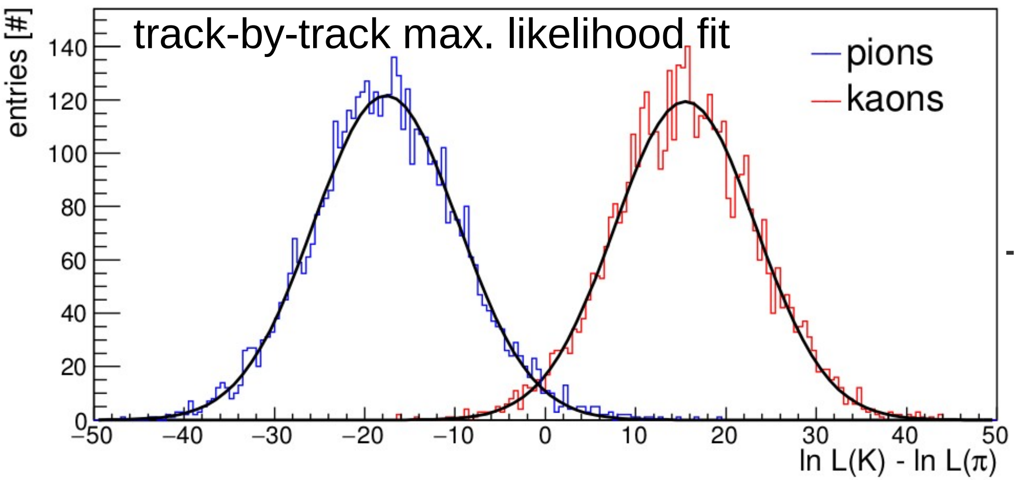


Yield and SPR reach performance goal

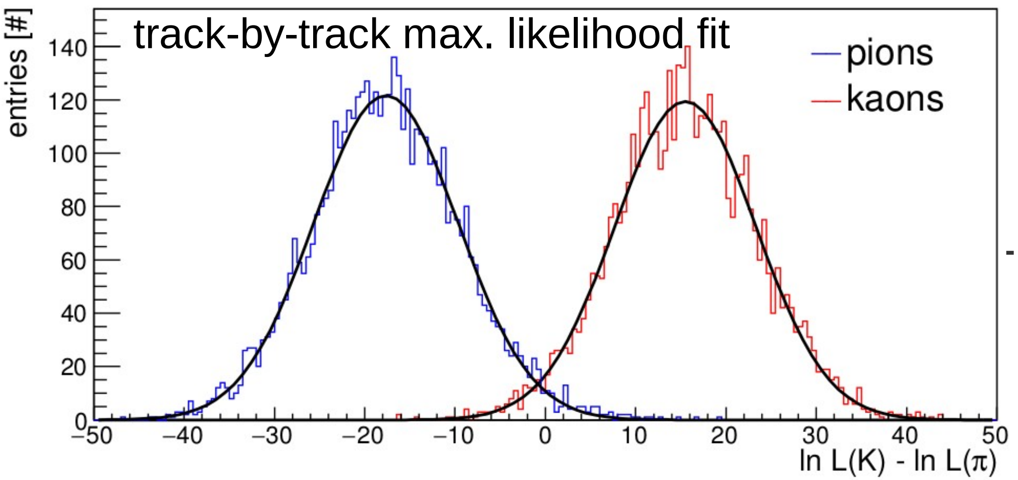
Expected Performance



Baseline design with geometrical reconstruction

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

Expected Performance



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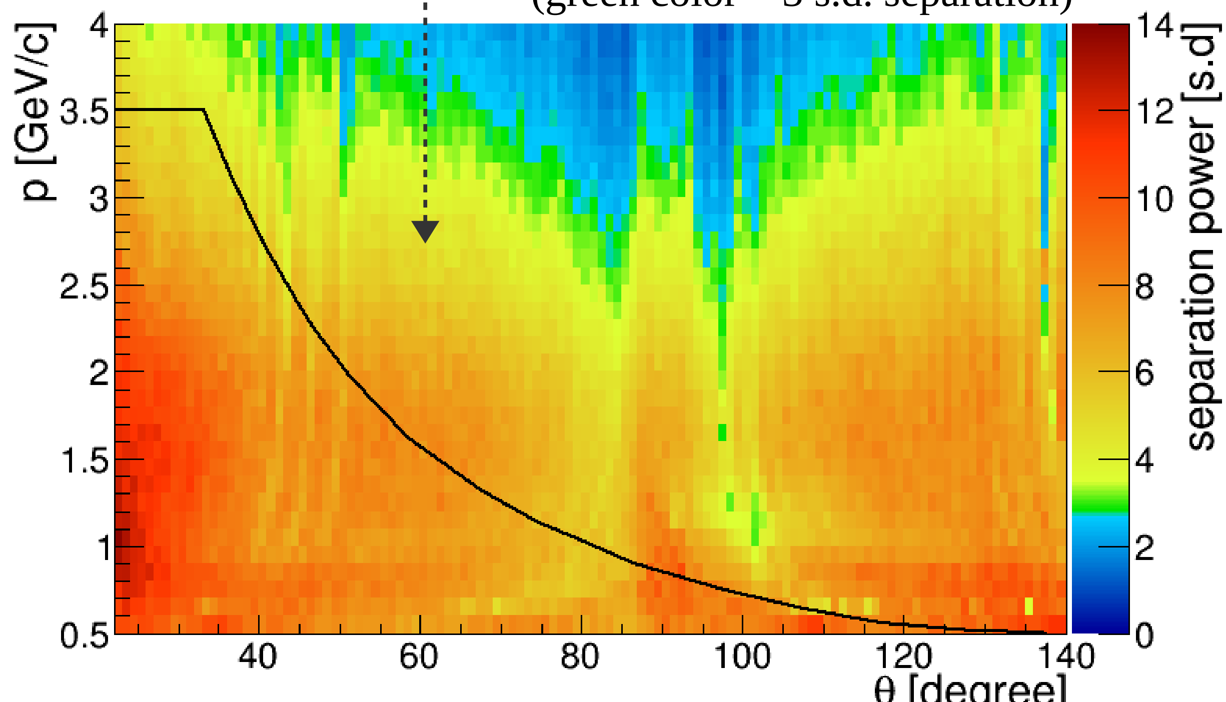
Geant simulation

(green color ~ 3 s.d. separation)



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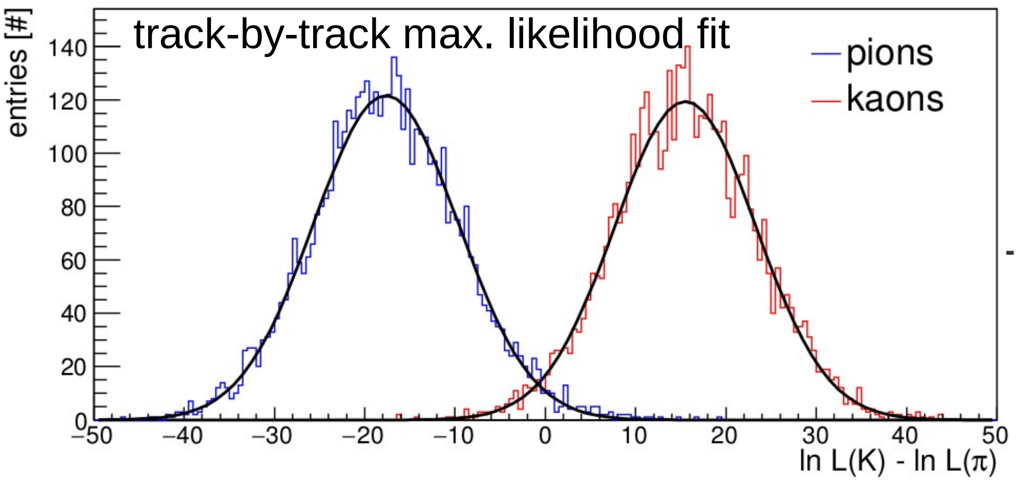

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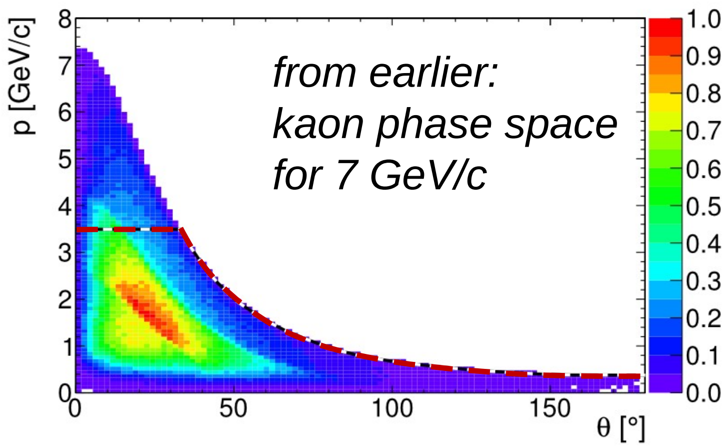
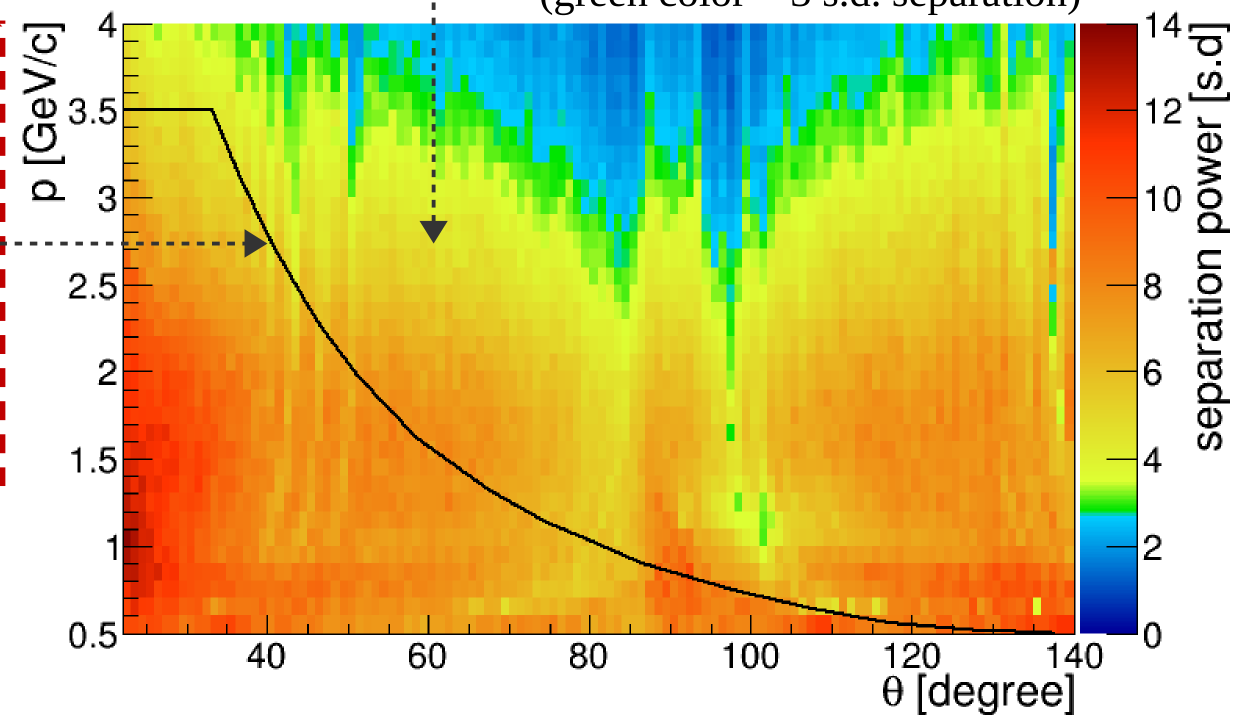


Barrel DIRC PID 3 s.d. goal

Geant simulation

(green color ~ 3 s.d. separation)



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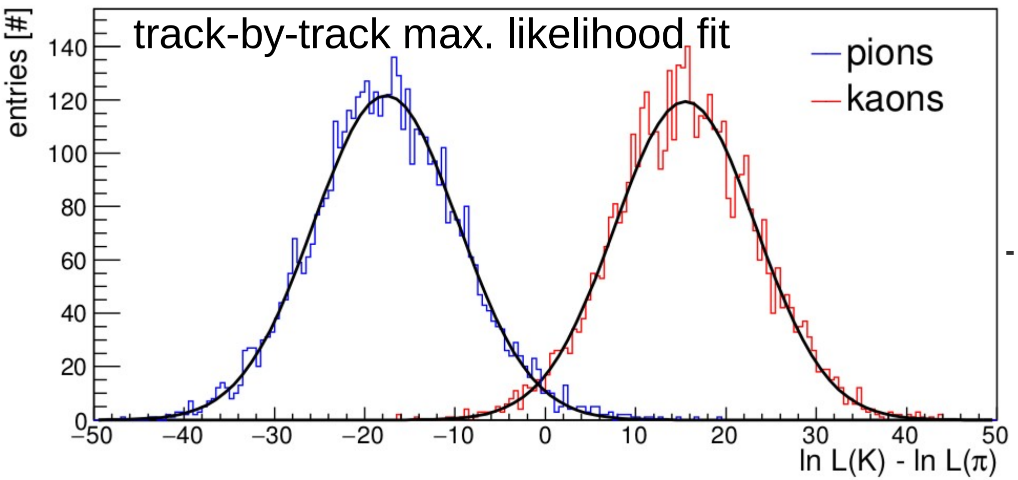

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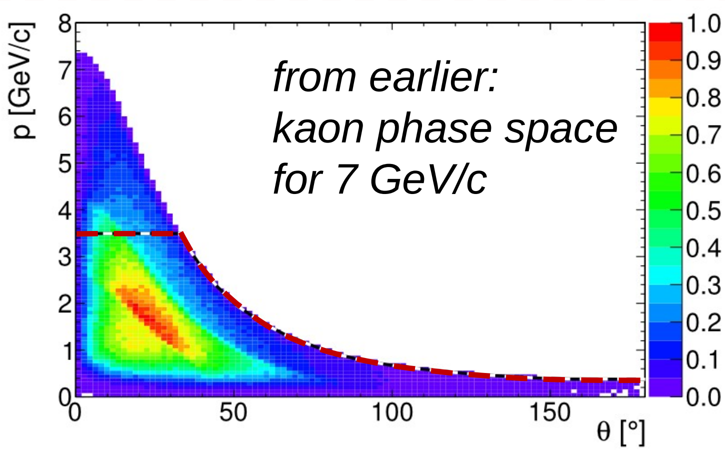

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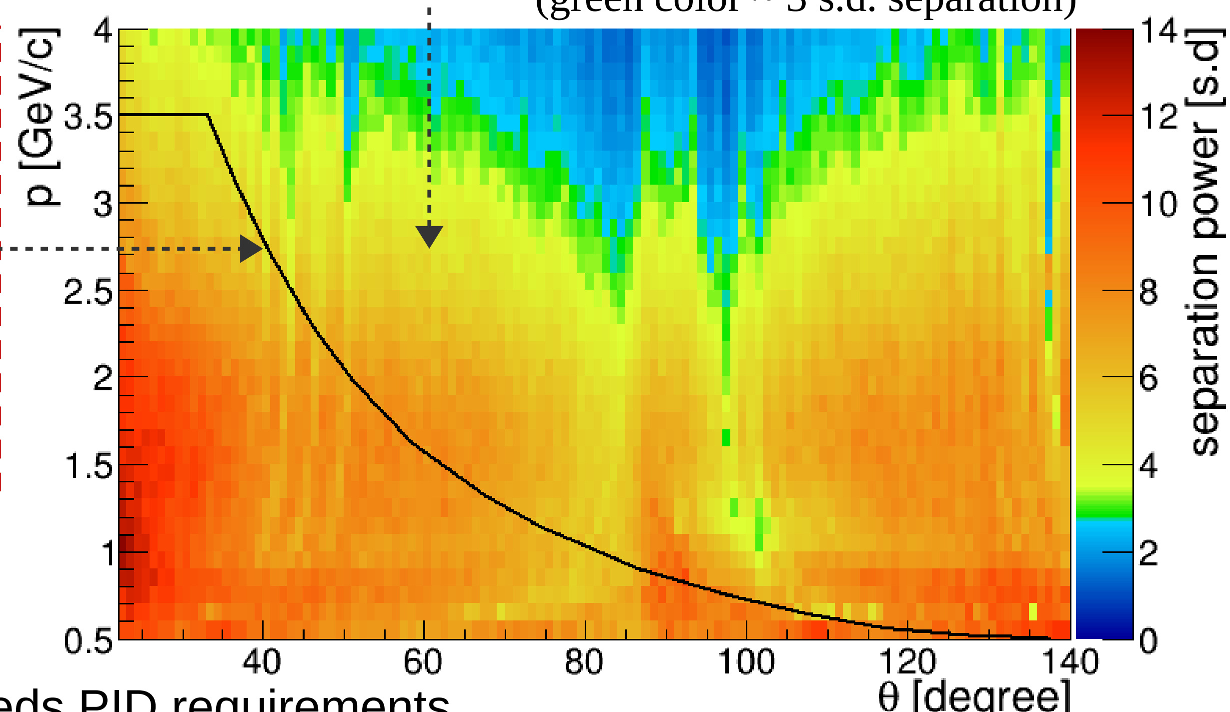
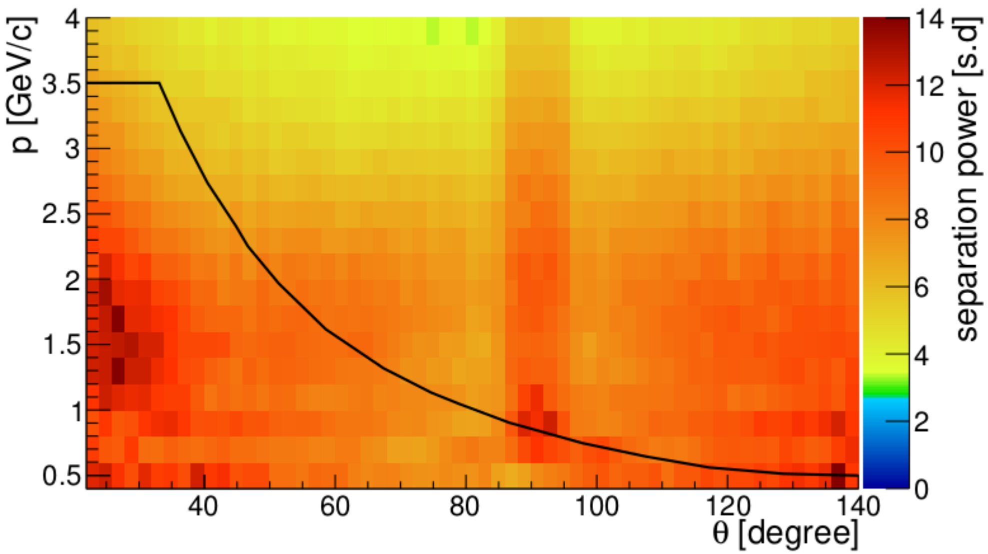


➡ Baseline design meets or exceeds PID requirements

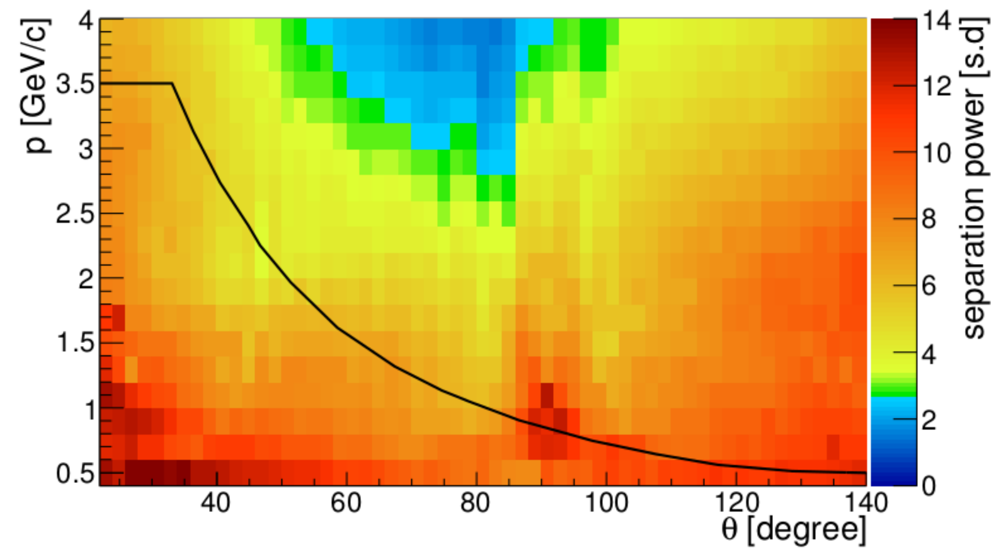
Expected Performance

Time imaging reconstruction

Baseline design (narrow bars)



Cost-saving design (wide plates)



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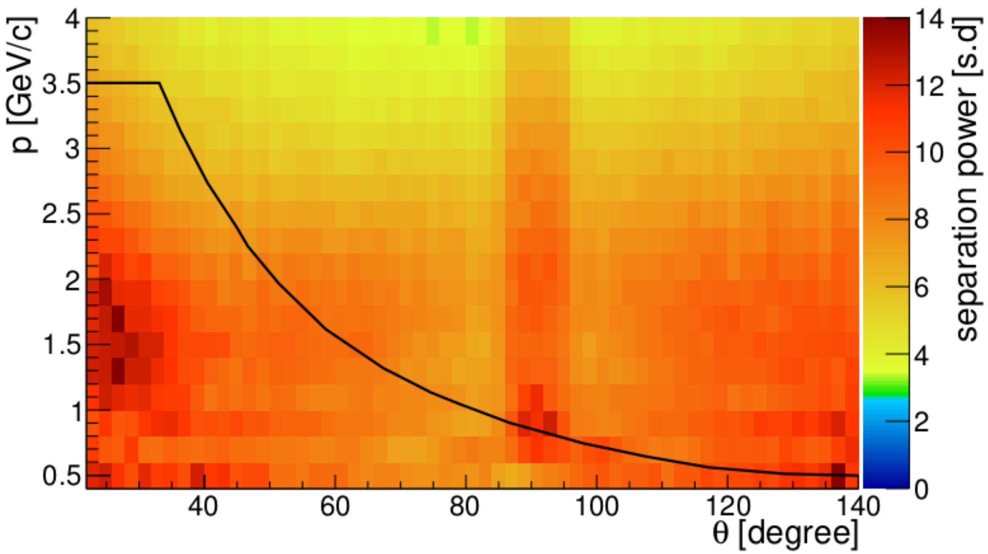

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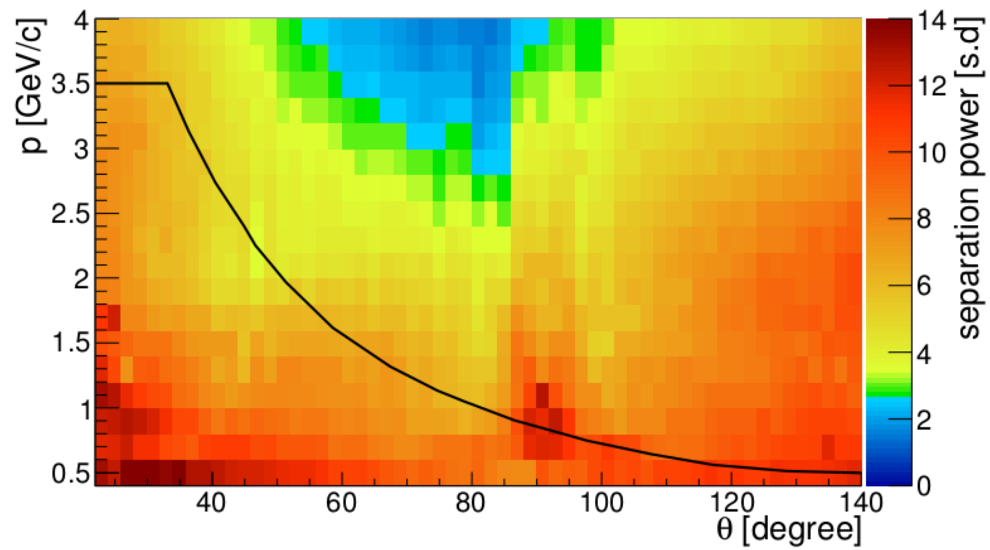
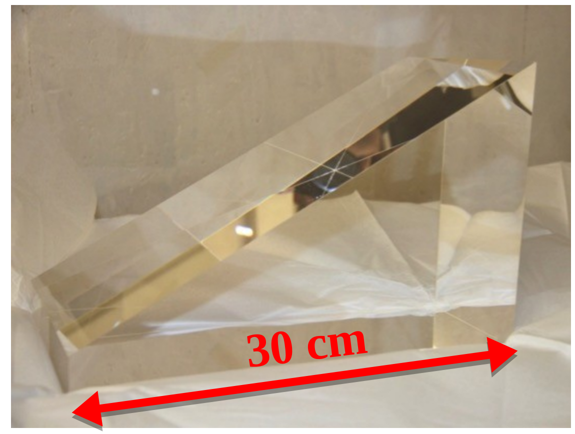
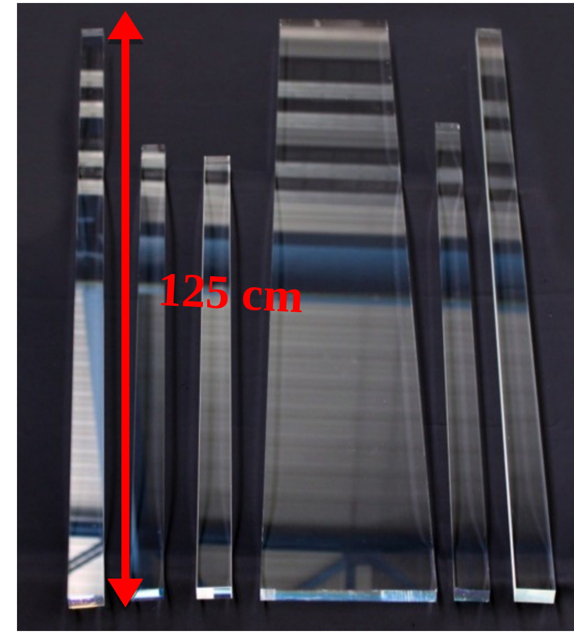


➡ Both designs meet or exceed PID requirements for entire acceptance range

Key components

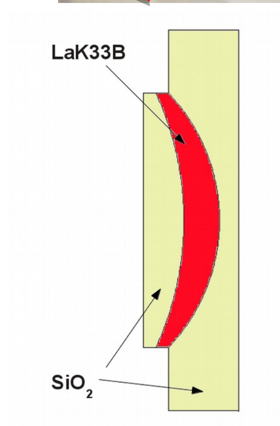
- Radiators
  ~30 bars/plates produced by 8 companies
  (AOS/Okamoto, InSync, Nikon, Zeiss, Zygo;
  Heraeus, Lytkarino LZOS, Schott Lithotec)

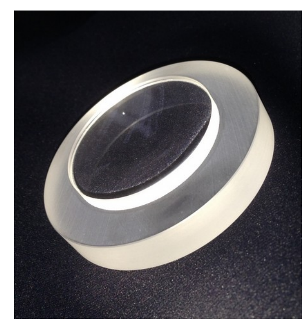


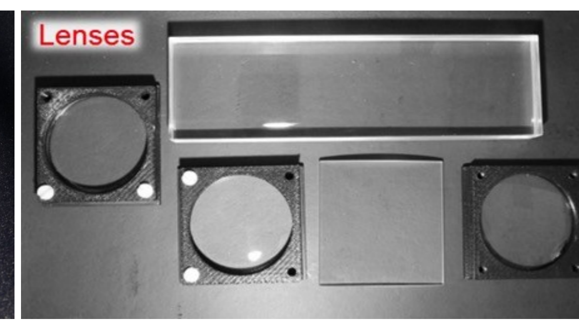


- Several solid fused silica prism prototypes (30° - 45° top angle) built by industry

- Focusing system
  Designed several
  spherical and cylindrical lenses,
  with and without air gap,
  several prototypes built by industry

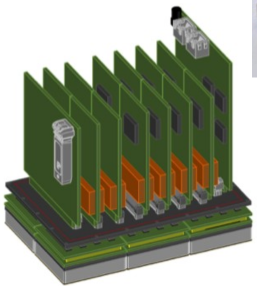


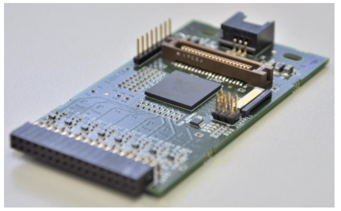




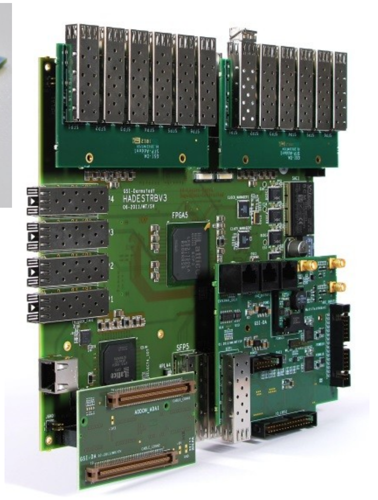
- Micro-channel Plate Photomultipliers (MCP-PMTs)
  excellent timing and magnetic field performance
  used to have issues with rate capability and aging, now solved;
  sensors of choice for Belle II TOP, LHCb TORCH, PANDA DIRCs

Readout and Mechanical Design





DiRICH, PADIWA, and TRB3



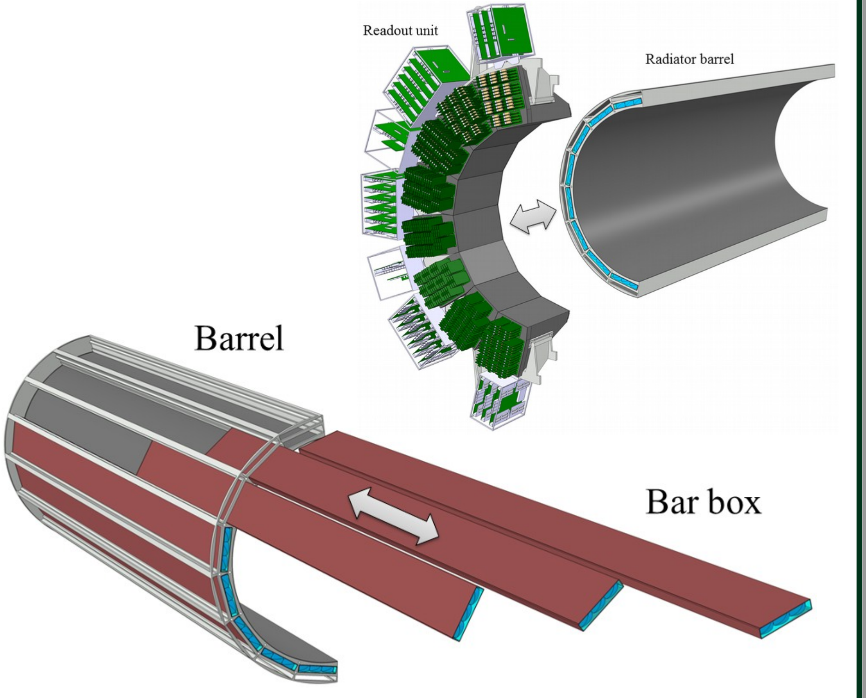
Readout Electronics

~100ps timing per photon for small MCP-PMT pulses – amplification and bandwith optimization

20MHz average interaction, trigger-less DAQ

Current approach: HADES TRBv3 board with PADIWA amplifier/discriminator

Near future: DiRICH, integrated backplane, joint development with HADES/CBM RICH



Mechanical Design

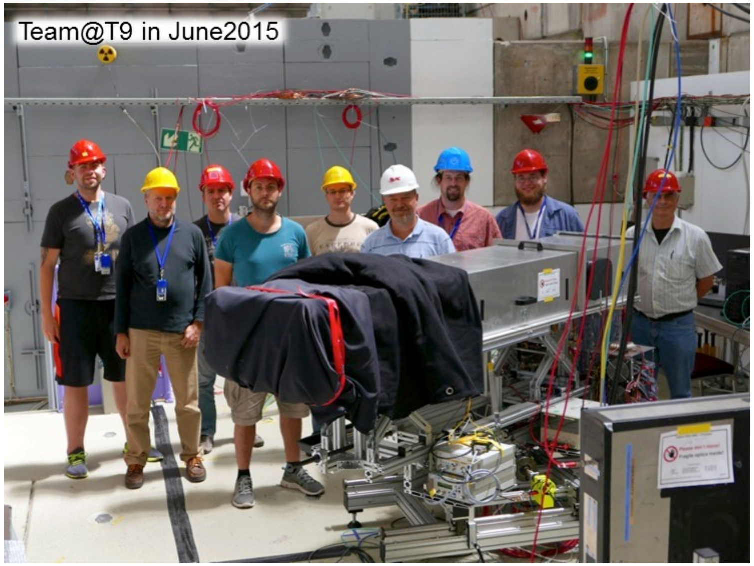
Light-weight and modular, allows staged bar box installation, access to inner detectors

Mechanical support elements made from aluminum alloy or carbon fiber (CFRP)

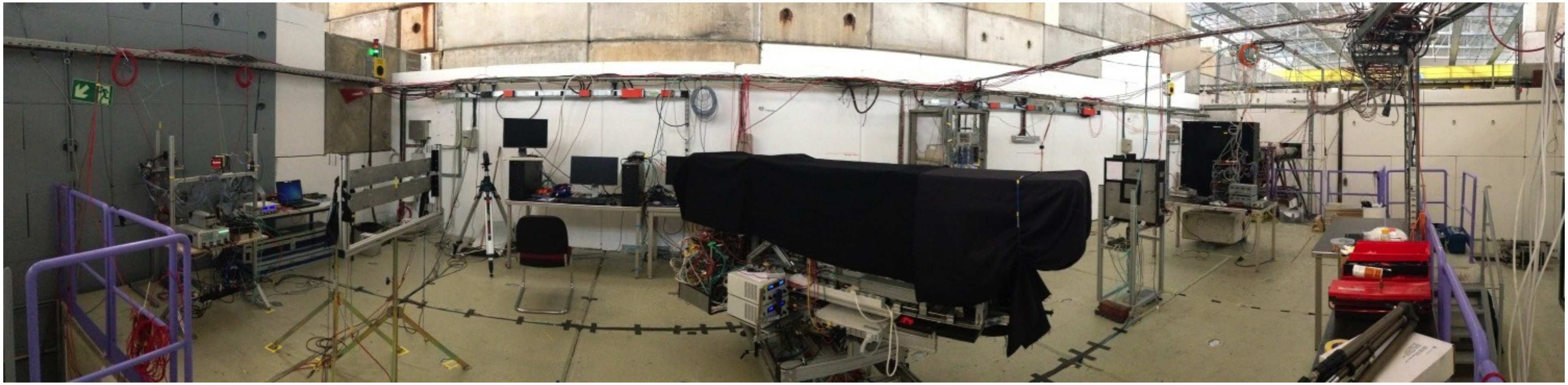
Boil-off nitrogen flush for optical surfaces

Beam Test at CERN 2015

- Fused silica prism as expansion volume
- 5 x 3 array of Planacon MCP-PMTs
- Narrow bar as radiator
- Many different imaging/lens configurations
- Momentum and angle scans
- ~500M triggers during 34 days of data taking



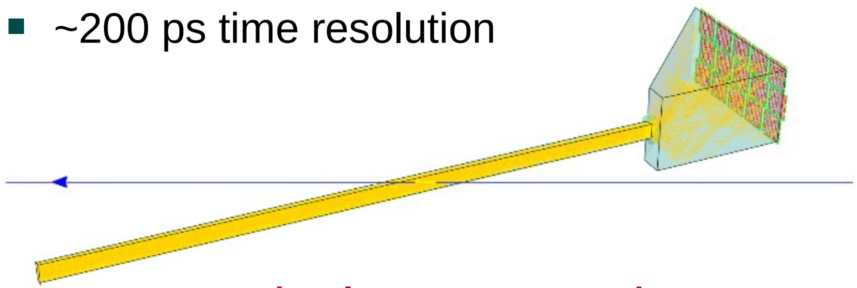
Goal: validation of PID performance of baseline design (narrow bars)



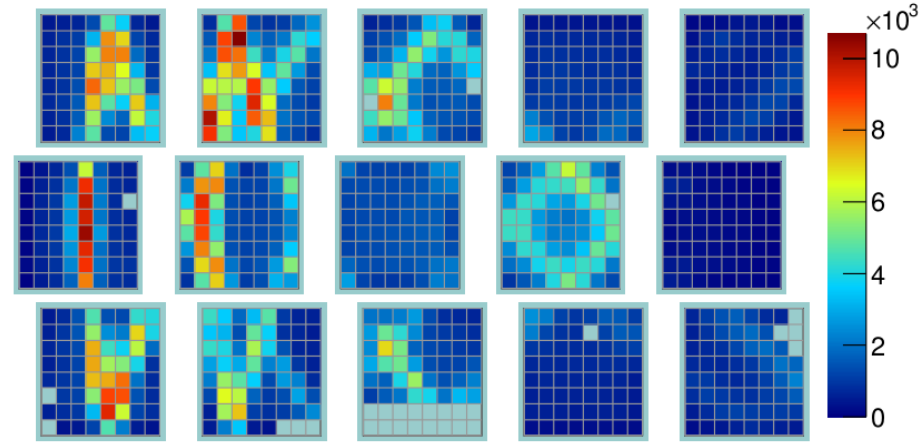
Beam Test at CERN 2015: Narrow Bar

- Goal: validate PANDA Barrel DIRC design and test components for DIRC@EIC

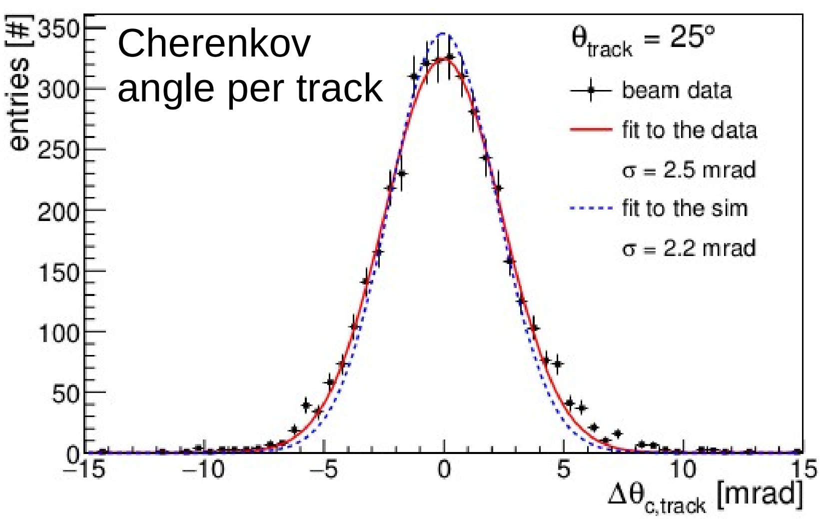
- Narrow bar (17x32x1250 mm³)
- Fused silica prism
- Focusing with 3-layer spherical lens
- ~200 ps time resolution



Hit patterns, proton tag:

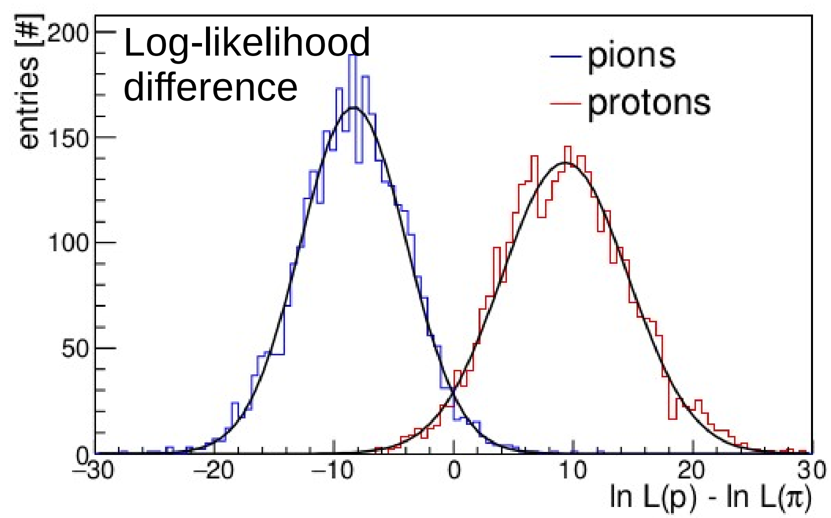


- Geometrical reconstruction:



→ ~3.4 s.d. π/K @ 3.5 GeV/c

- Time imaging:

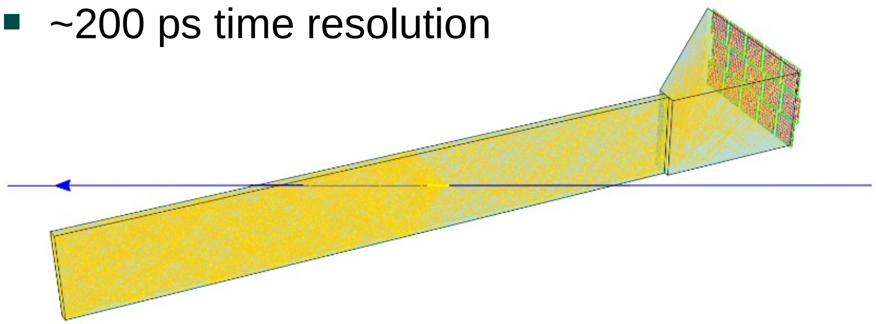


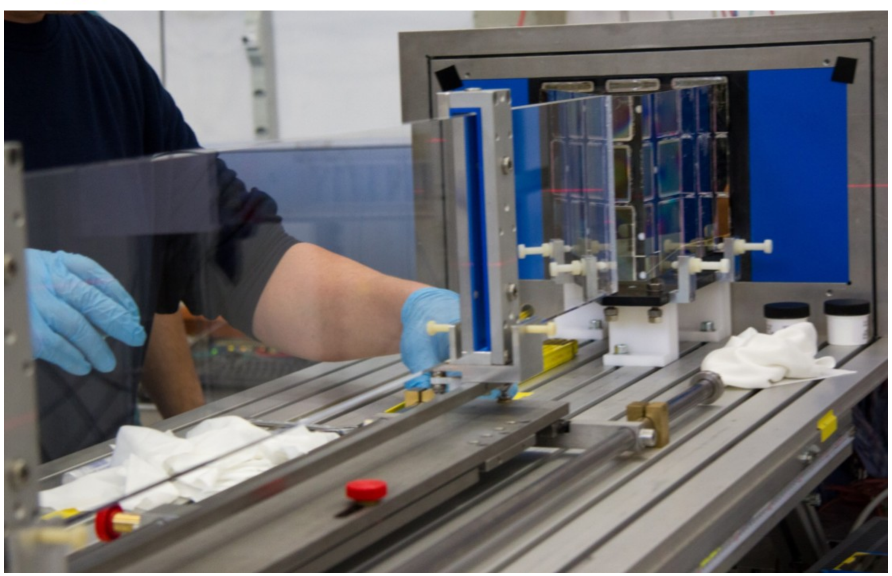
→ ~3.6 s.d. π/K @ 3.5 GeV/c

Beam Test at CERN 2016: Wide Plate

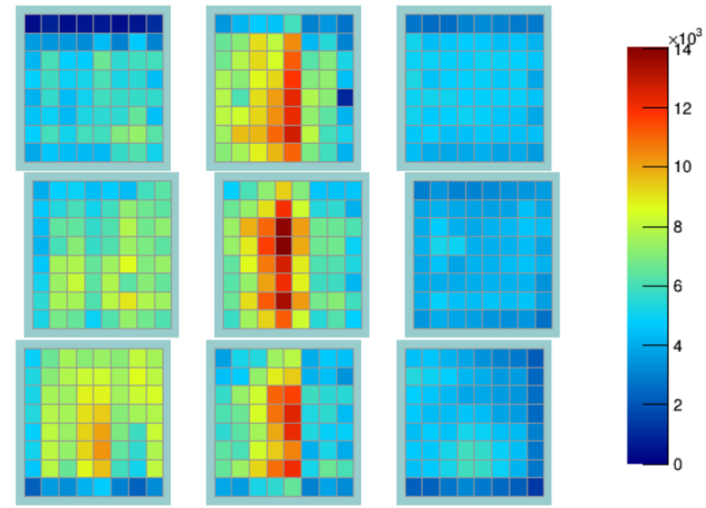
- Goal: validate plate as cost saving option for PANDA Barrel DIRC and DIRC@EIC

- Plate (17x175x1225 mm^3)
- Fused silica prism
- Focusing with 2-layer cylindrical lens
- ~200 ps time resolution

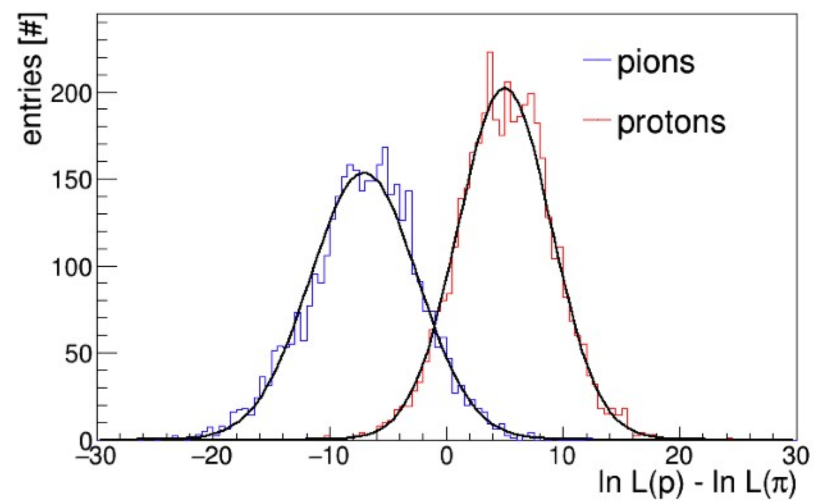




Hit patterns, proton tag:



Time imaging:

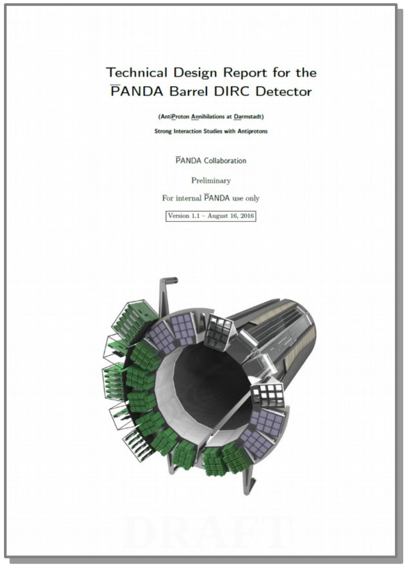


~3.2 s.d. π/K @ 3.5 GeV/c

Summary and Status

- The PANDA Barrel DIRC is a key component of the PANDA PID system
  - Simulations predict 3 s.d. π/K separation up to 3.5 GeV/c
  - Successfully validated PID performance in particle beams
  - Technical Design Report currently in review
- Design with narrow bars and 3-layer spherical lens meets or exceeds the PANDA PID requirements
  - Simulation and PID performance validated with particle beams (CERN 2015)
- Cost-saving design with wide plates and 3-layer cylindrical lens also exceeds PANDA PID performance
  - Simulation and PID performance validated with particle beams (CERN 2016)
- PID performance of narrow bars superior to wide plates
  - More robust in terms of background and timing resolution

➡ baseline design for PANDA Barrel DIRC


Technical Design Report for the
$\overline{\text{P}}$ANDA Barrel DIRC Detector

(AntiProton Annihilations at Darmstadt)

Strong Interaction Studies with Antiprotons

$\overline{\text{P}}$ANDA Collaboration

Preliminary

For internal $\overline{\text{P}}$ANDA use only

Version 1.1 – August 16, 2016

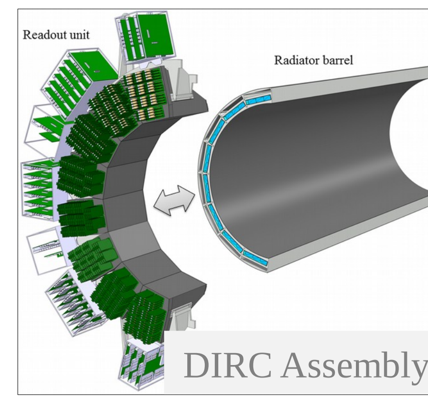
DRAFT

Outlook

2017-2023: Component Fabrication, Assembly, Installation

- 2017: TDR approval, prepare for tender process
- 2018-2020: Industrial fabrication of fused silica bars and prisms
  Industrial production of MCP-PMTs
- 2018-2019: Production and QA of readout electronics
- 2018-2022: Industrial fabrication of bar containers and mechanical support frame, gluing of bars/plates, construction of complete bar boxes
  Detailed scans of all sensors
  Assembly of readout units
- 2023: Installation of mechanical support frame in PANDA, insert bar boxes, mount readout modules

DIRC bar with laser



DIRC Assembly

Outlook

2017-2023: Component Fabrication, Assembly, Installation

DIRC bar with laser

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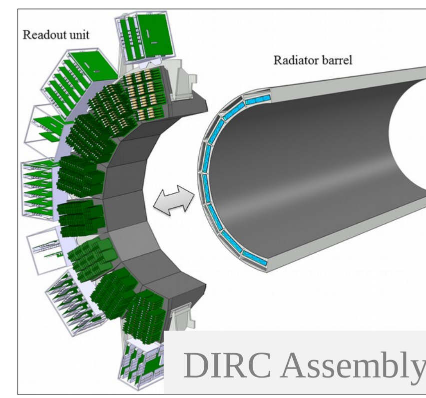


DIRC Assembly

Thank you for the attention

Backup slides

Simulation and Reconstruction

Event generation

↓

Particle transport

↓

Digitization

↓

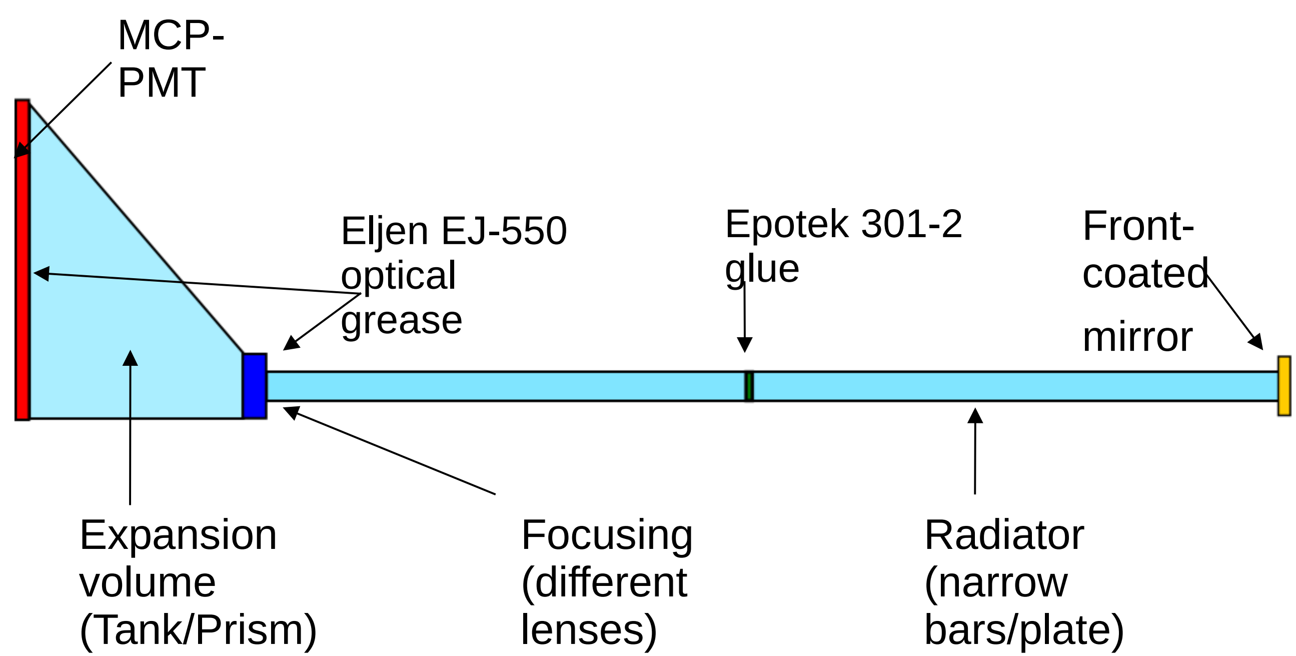
Hit Finder

↓

Reconstruction

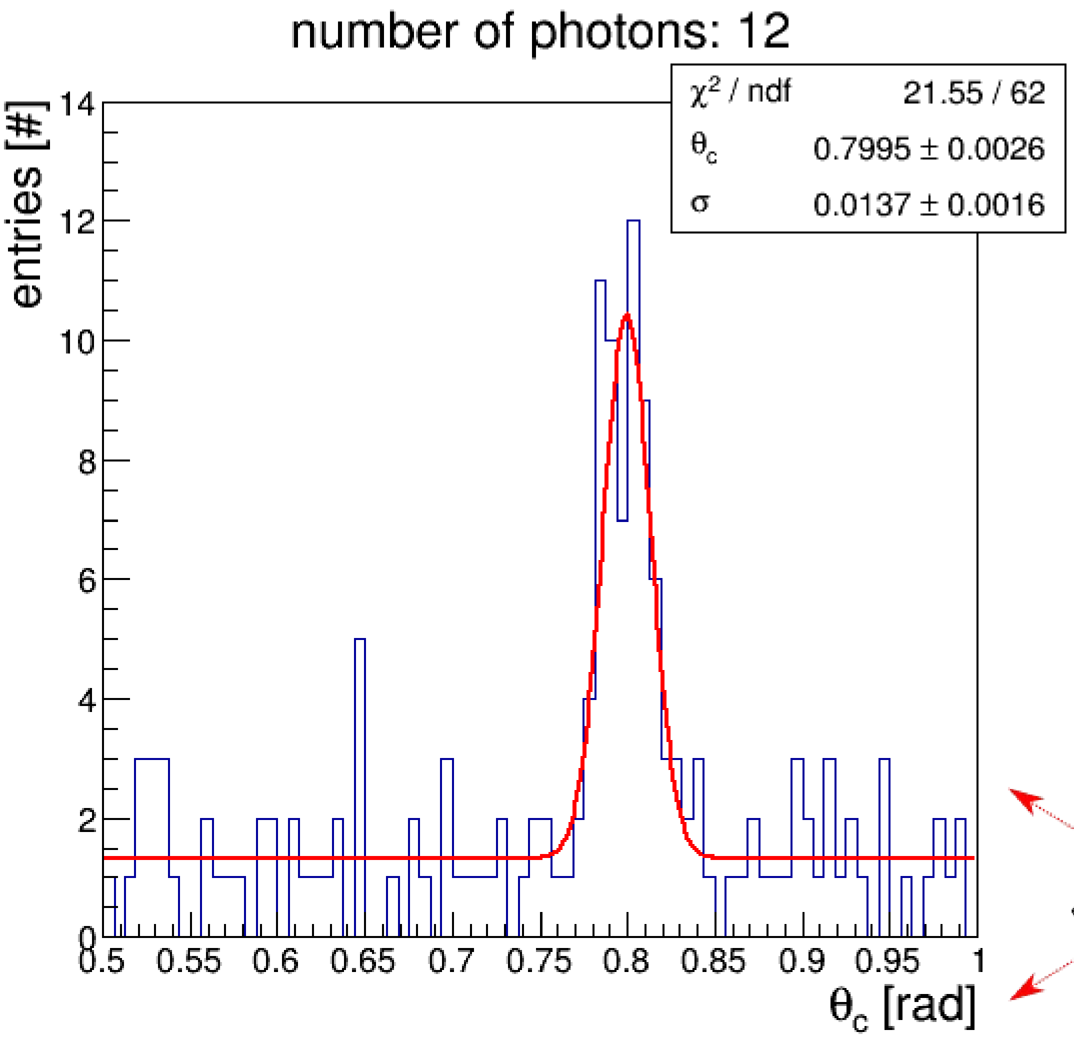
Gean3, Geant4

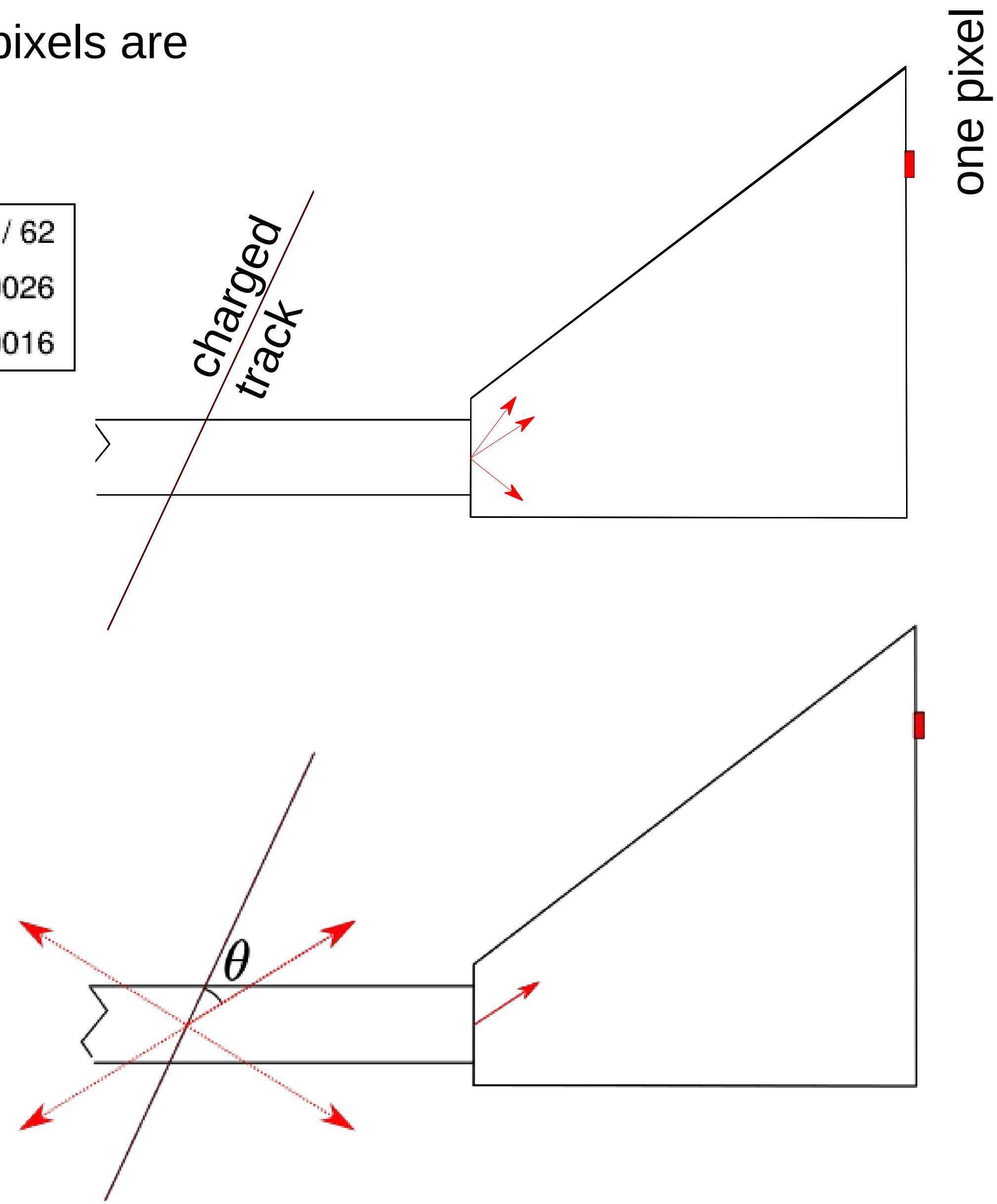
Geometry/material



Geometrical Reconstruction

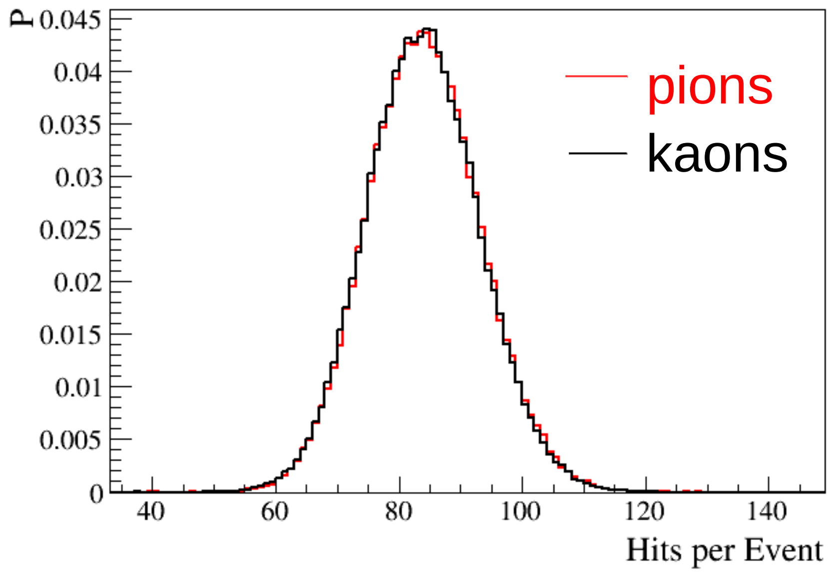
- Reconstruction: direction from LUT for hit pixels are combined with charge track direction



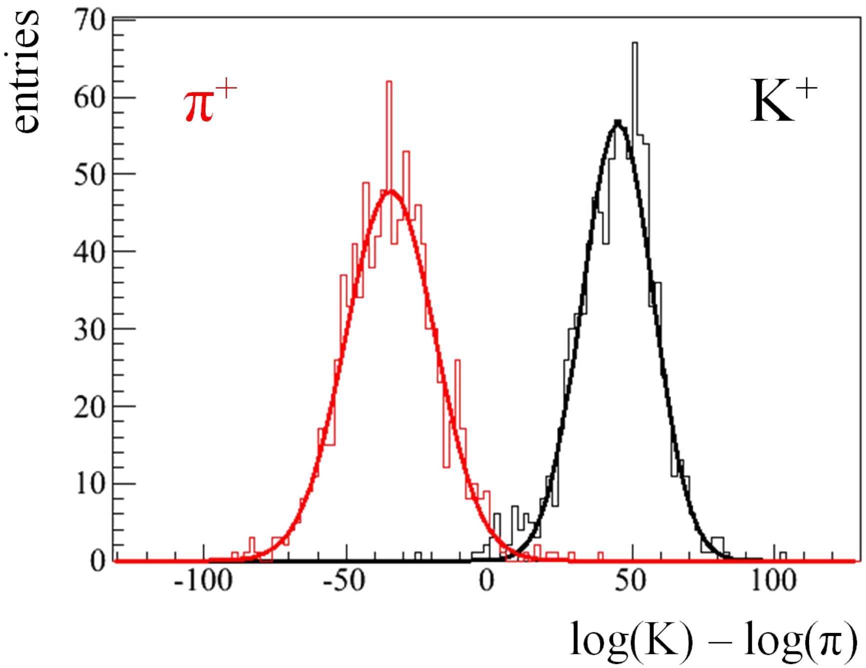


Time Likelihood Imaging

- Reconstruction: arrival time of each photon from given track is compared with PDF to calculate time-based likelihood for the photon to originate from a given particle



Example: momentum = 3 GeV/c
angle = 22°



- Full likelihood:

$$L_H = \prod_N \mathrm{pdf}(x_i, y_i, t_i; H) \times P_{N_0}(N)$$

➔ Clean π/K separation at 3.5 GeV/c even without optics