The Barrel DIRC Detector for the PANDA Experiment at FAIR

TIPP 2017 conference

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

The PANDA Cherenkov Group:
The PANDA Experiment at FAIR

Facility for Antiproton and Ion Research at GSI near Darmstadt, Germany

- FAIR Accelerator Complex
- PANDA Experiment
- Barrel DIRC Detector

- High Energy Storage Ring
- $5 \times 10^{10}$ 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
PANDA Physics Program

Study of QCD with Antiprotons

Non-perturbative QCD
Hypernuclei
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. $\pi/K$ separation up to 3.5 GeV/c

- **Endcap Disc DIRC**
  - Goal: 4 s.d. $\pi/K$ separation up to 4 GeV/c

*EvtGen kaon phase space example*  
antiproton momentum: 7 GeV/c

*Endcap Disc DIRC for PANDA at FAIR*
Mustafa SCHMIDT, 23.05  
R1, Particle identification
Detection of Internally Reflected Cherenkov Light

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

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- 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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![Diagram of Cherenkov effect with charged particle traversing radiator](image)
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- Some photons are always totally internally reflected for \( \beta \approx 1 \) tracks.
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- Radiator and light guide: polished, long rectangular bar made from Synthetic Fused Silica (“Quartz”).
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- Some photons are always **totally internally reflected** for \(\beta \approx 1\) tracks.

- **Radiator and light guide**: polished, long rectangular bar made from **Synthetic Fused Silica** (“Quartz”).

- 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 silica 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):**
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- Included in TDR as design option
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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:

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

tracking resolution 2-3 mrad

Photon yield

GEANT simulation
Baseline design,
3 bars per bar box,
3-layer spherical lens

Single Photon Cherenkov angle resolution (SPR)
Expected Performance

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Geometrical reconstruction:

Cherenkov track resolution:

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tracking resolution 2-3 mrad

Photon yield

Single Photon Cherenkov angle resolution (SPR)

Yield and SPR reach performance goal
Expected Performance

Baseline design with geometrical reconstruction

\[ N_{\text{sep}} = \frac{|\mu_1 - \mu_2|}{0.5(\sigma_1 + \sigma_2)} \]
Expected Performance

Baseline design with geometrical reconstruction

\[ N_{\text{sep}} = \frac{|\mu_1 - \mu_2|}{0.5(\sigma_1 + \sigma_2)} \]

Geant simulation
(green color \(\sim 3\) s.d. separation)
Expected Performance

Baseline design with geometrical reconstruction

\[ N_{\text{sep}} = \frac{|\mu_1 - \mu_2|}{0.5(\sigma_1 + \sigma_2)} \]

Geant simulation (green color ~ 3 s.d. separation)

from earlier: kaon phase space for 7 GeV/c

Barrel DIRC PID 3 s.d. goal
Expected Performance

Baseline design with geometrical reconstruction

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

Geant simulation (green color ~ 3 s.d. separation)

Baseline design meets or exceeds PID requirements

Track-by-track max. likelihood fit

from earlier:
kaon phase space for 7 GeV/c

Barrel DIRC PID 3 s.d. goal

TIPP'17, May 23, Beijing

Roman Dzhygadlo 9/17
Expected Performance

Time imaging reconstruction

Baseline design (narrow bars)  Cost-saving design (wide plates)
Expected Performance

Both designs meet or exceed PID requirements for entire acceptance range

Baseline design (narrow bars)

Cost-saving design (wide plates)
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

Readout Electronics

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

**Geometrical reconstruction:**

- Cherenkov angle per track

**Time imaging:**

- Log-likelihood difference

$\theta_{\text{track}} = 25^\circ$

- beam data
- fit to the data
- $\sigma = 2.5$ mrad
- fit to the sim
- $\sigma = 2.2$ mrad

$\sim 3.4$ s.d. $\pi/K @ 3.5$ GeV/c

- pions
- protons

$\sim 3.6$ s.d. $\pi/K @ 3.5$ 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 mm³)
- 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. $\pi/K$ 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
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
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Thank you for the attention
Backup slides
Simulation and Reconstruction

- Event generation
- Particle transport
- Digitization
- Hit Finder
- Reconstruction

Gean3, Geant4

Geometry/material

- MCP-PMT
- Eljen EJ-550 optical grease
- Epotek 301-2 glue
- Front-coated mirror
- Expansion volume (Tank/Prism)
- Focusing (different lenses)
- Radiator (narrow bars/plate)
Geometrical Reconstruction

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

**Number of photons**: 12

\[
\chi^2 / \text{ndf} \quad 21.55 / 62
\]
\[
\theta_c \quad 0.7995 \pm 0.0026
\]
\[
\sigma \quad 0.0137 \pm 0.0016
\]
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:

\[ L_H = \prod_{N} \text{pdf}(x_i, y_i, t_i; H) \times P_{N_0}(N) \]

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