The Forward RICH detector at PANDA

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Talk outline

- Focusing Aerogel RICH concept
- PANDA Forward RICH design
- MC simulated performance
- Optical measurements
- Test beam 2019 results
- Conclusion & outlook

The Forward RICH detector at PANDA, DIRC2019
The Forward RICH detector at PANDA, DIRC2019
Parameters of the PANDA Forward RICH

- **Purpose:** Charged PID in the Forward Spectrometer
- **Acceptance:** $|\theta_X| < 10^\circ$, $|\theta_Y| < 5^\circ$
- **Dimensions:** 3m (X) x 1m (Y) x 0.8m (Z)
- **Expected material budget:** $\leq 10\% \, X_0$
- **Expected PID performance:**
  - 3 s.d. $\pi/K$ separation: $P = 2\div10$ GeV/c
  - 3 s.d. $\mu/\pi$ separation: $P = 0.5\div2$ GeV/c (complementing the Muon System)
- **Physics cases:** processes with high charged hadrons multiplicity in the final states for high beam momenta
Quartz vs Aerogel as Cherenkov Radiator in a RICH detector

Band width correspond to the chromatic dispersion of refractive index in the 350-700 nm wavelength range

Aerogel has much larger Cherenkov angle difference and less chromatic dispersion than Fused silica. This results in PID capability for higher momenta.
Focusing aerogel improves proximity focusing design by reducing the contribution of radiator thickness into the Cherenkov angle resolution.

First real-life application in Belle2 ARICH

T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70
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DiRICH FEE (GSI)
- Designed for H12700 readout
- 12x32ch preamp+disc+TDC
- 2 Gbps output link

Mirrors
- Flat
- 2 mm float glass
- Al+SiO$_2$ coating

Aerogel radiator
- Focusing 2- or 3-layer aerogel
- $n \approx 1.05$
- 3 x 1 m$^2$ area
- 40 mm thickness

Photon Detector
H12700 MaPMTs (Hamamatsu), 1400 pcs
- flat panel
- 87% active/total area ratio
- 8x8 anode pixels of 6mm size
1. Physics (Geant4)
   ✓ Electromagnetic processes
   ✓ Multiple scattering
   ✓ Hadron interactions
   ✓ Optical processes (aerogel, mirror, PD)

2. Digitization
   ✓ PD pixelization
   ✓ PDE
   ✓ PD dark counting
   ✓ Dead time
   ✓ Timing resolution

3. Reconstruction
   ✓ Hit preselection
   ✓ Fit $\theta_c(\phi_c)$ dependence

4. Calibration of beta resolution for fast simulation

5. PID
   ✓ Probabilities calculation

Full MC simulation is implemented in PandaRoot
Track-based reco
Trace back a PD hit position (X,Y) to the midpoint of a track segment in the radiator and find \((\theta_c, \phi_c)\).
Event reconstruction

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DIRC2019
Reconstruction efficiency
(reconstructed $\beta$ is within $\pm 3\sigma$ of expected)

K identification efficiency
at 1% $\pi$ misidentification

The Forward RICH detector at PANDA,
DIRC2019
MC FRICH PID uniformity
H12700 PD, 3 layers, p⁻ beam @ 10 GeV/c

π reco efficiency

K reco efficiency

K identification efficiency at 2% π misidentification
Mirror study

- Main option chosen after review of technologies: float glass with Al & SiO$_2$ coating. Pieces of 300x420 mm$^2$ can be produced in Tomsk.
- A few μm flatness – quite good.
- Reflectance is measured for several samples as a function of wavelength and angle of incidence.
Reflectance as function of AoI

Laser measurements

Tomsk sample
Float glass + Al (215 nm) + SiO$_2$ (130 nm)

<table>
<thead>
<tr>
<th>$\lambda$ (nm)</th>
<th>Reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>407</td>
<td>0.88</td>
</tr>
<tr>
<td>475</td>
<td>0.88</td>
</tr>
<tr>
<td>518</td>
<td>0.86</td>
</tr>
<tr>
<td>641</td>
<td>0.84</td>
</tr>
</tbody>
</table>
Forward scattering is known to contribute to the Cherenkov angle resolution in an aerogel RICH

*R. De Leo et al, NIMA 457 (2001) 52*
RMS scattering angle vs light path in aerogel

FS RMS(θ) ≈ 1mrad for 40 mm path length. To be compared with 4.8mrad of SPR → effect is negligible.
Absolute QE of MaPMT H12700

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\[ \text{QE} = \frac{N_{\text{p.e.}}}{N_{\gamma}} \]
\[ N_{\text{p.e.}} = -\ln \frac{N_{0}^{\text{signal}}}{N_{0}^{\text{noise}}} \]

To do: MaPMT QE is to be scanned on wavelength and area
Test beam in June 2019

Electron and gamma test beam facility at the BINP VEPP-4M accelerator

- 3 GeV electrons
- 3 scintillation counters in coincidence for triggering
- 3 GEM with strip readout tracker stations with 70-200 μm resolution
- NaI calorimeter
Test beam layout
June 2019

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Forward RICH prototype
June 2019

4 MaPMTs readout in half by PADIWA (128 ch) and DiRICH (128 ch)

Aerogel sample with a flat mirror installed at 45° w.r.t. the PD and aerogel.
Event and hit selection
June 2019

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Track adjusted hit map – Cherenkov ring
June 2019
Evaluation of the F-RICH prototype performance

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All tracks

Tracks with pixel #20 hit

Photoelectron density distribution on radius for pixel #20 fitted by gaussian + linear background

\[ \chi^2 \text{ / ndf} = 27.13 / 16 \]

\[ N_{pe} = 22.36 \pm 0.75 \]

\[ R = 202.6 \pm 0.1 \]

\[ \text{SigmaR} = 2.976 \pm 0.095 \]

\[ Bkgr = 0.00207 \pm 0.00038 \]
Test beam 2019 results (1)

Radiator configuration
1-st layer: $n=1.0526$, $t=2\text{cm}$
2-nd layer: $n=1.0500$, $t=2\text{cm}$

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Test beam 2019 results (2)

Performance averaged on the DiRICH channels only

<table>
<thead>
<tr>
<th>Radiator</th>
<th>Parameter</th>
<th>Test beam 2019</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stack of 2 layers</strong></td>
<td>$N_{pe}$</td>
<td>22</td>
<td>39</td>
</tr>
<tr>
<td>2 cm, $n=1.0526$ +</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 cm, $n=1.0500$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R$, mm</td>
<td>201</td>
<td>199</td>
<td></td>
</tr>
<tr>
<td>$\sigma_{1pe}(R)$, mm</td>
<td>3.31</td>
<td>3.08</td>
<td></td>
</tr>
<tr>
<td><strong>Stack of 2 layers</strong></td>
<td>$N_{pe}$</td>
<td>21</td>
<td>40</td>
</tr>
<tr>
<td>2 cm, $n=1.0538$ +</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 cm, $n=1.0511$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R$, mm</td>
<td>203</td>
<td>201</td>
<td></td>
</tr>
<tr>
<td>$\sigma_{1pe}(R)$, mm</td>
<td>3.25</td>
<td>3.11</td>
<td></td>
</tr>
<tr>
<td><strong>Single layer</strong></td>
<td>$N_{pe}$</td>
<td>15</td>
<td>26</td>
</tr>
<tr>
<td>2 cm, $n=1.0538$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R$, mm</td>
<td>204</td>
<td>201</td>
<td></td>
</tr>
<tr>
<td>$\sigma_{1pe}(R)$, mm</td>
<td>3.24</td>
<td>3.17</td>
<td></td>
</tr>
</tbody>
</table>

**Effects in the calculation:** aerogel chromaticity, Rayleigh scattering, radiator thickness, pixel size, 80% efficiency factor (reflectance, light loss at aerogel surface).

**Effects left out of the calculation:** tracking resolution, multiple scattering, anode charge sharing, aerogel inhomogeneity, FEE efficiency, non-gaussian shape of $dN_{pe}/dR$. 

$\sqrt{3.3^2 - 3.1^2} \approx 1 \text{ mm}$

1.8 times less
Conclusion and outlook

- PANDA Forward RICH design is described.
- Different mirror samples were studied. Tomsk mirrors are chosen.
- Preliminary measurement of the absolute QE for H12700 showed . To be studied in more detail and negotiated with the producer.
- Light forward scattering in aerogel is studied. Effect is negligible for the PANDA F-RICH
- Results of the test beam in 2019 are presented. Single photon radius resolution agrees quite well with the calculation. Discrepancy in the photoelectrons is observed (probably due to low DQE).
- TDR will be drafted in 2019-2020. F-RICH is to be ready for installation by 2026.

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