The Detector of the PANDA-Experiment at FAIR

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PANDA at FAIR - Facility for Antiproton and Ion Research

Accelerator facility at Darmstadt (GSI) under construction

Primary beams: Protons up to 30 GeV/c, heavy ion beams up to 35 GeV/c (U$^{92+}$)

Secondary beams: Radioactive beams, antiprotons up to 15 GeV/c

PANDA at FAIR:

Located at slow ramping synchrotron storage ring for internal target (HESR)
Cooled $\bar{p}$ beam

<table>
<thead>
<tr>
<th>Mode</th>
<th>High Luminosity</th>
<th>High Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta p/p$</td>
<td>$\approx 10^{-4}$</td>
<td>$4 \cdot 10^{-5}$</td>
</tr>
<tr>
<td>$\mathcal{L}$ [cm$^{-2}$s$^{-1}$]</td>
<td>$10^{32}$</td>
<td>$10^{31}$</td>
</tr>
</tbody>
</table>
The \textbf{PANDA} -Experiment

\[ \bar{p} p \] annihilation, fixed hydrogen target
\[ \bar{p} \] momenta: 1.5 GeV/c - 15 GeV/c

Hadron spectroscopy
- Light mesons
- Charmonium
- Open charm
- Search for exotics
- Baryons (double strange, charmed)

Proton structure
Mesons in nuclei
Hypernuclei

Exclusive studies require full reconstruction of final states
The PANDA Detector

The Detector of the PANDA Experiment at FAIR
The Tracking Detectors: The Micro Vertex Detector

Innermost detector, closest to primary interaction vertices
Essential for precise determination of secondary decay vertices
Barrel shell structure (4 layers), disk structure (6 pieces) in forward direction

Double sided silicon strip detectors, pixel detectors

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>time resolution</td>
<td>6 ns</td>
</tr>
<tr>
<td>pixel</td>
<td>28 μm pos. res.</td>
</tr>
<tr>
<td>strips</td>
<td>14 μm pos. res.</td>
</tr>
<tr>
<td>vertex resolution</td>
<td>50 μm</td>
</tr>
</tbody>
</table>
4200 Ar/CO$_2$ (90/10) filled Al-mylar drift tubes
Arranged in cylindrical volume around MVD
Avalanche multiplication: gain $\approx$ 100

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner radius</td>
<td>15 cm</td>
</tr>
<tr>
<td>Outer radius</td>
<td>42 cm</td>
</tr>
<tr>
<td>Tube diameter</td>
<td>10 mm</td>
</tr>
<tr>
<td>Tube length</td>
<td>150 cm</td>
</tr>
<tr>
<td>$\rho/\phi$ plane resolution</td>
<td>150 $\mu$m</td>
</tr>
<tr>
<td>z resolution</td>
<td>1 mm</td>
</tr>
</tbody>
</table>
The Forward Spectrometer: Forward Tracker

Based on 10 mm diameter straw tubes as in central tracker
Momentum acceptance better than $0.03 \times \bar{p}_{beam}$
($B_{dipole}$ scaled according to $\bar{p}_{beam}$)
Three pairs of planer tracking stations in front, behind and inside (for low momentum particles) magnet yoke

<table>
<thead>
<tr>
<th>Coverage</th>
<th>$\pm 10^\circ$ horizontally</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>$\pm 5^\circ$ vertically</td>
</tr>
<tr>
<td>Position resolution</td>
<td>0.1 mm / layer</td>
</tr>
<tr>
<td>$\Delta p/p$</td>
<td>$&lt; 1 %$</td>
</tr>
</tbody>
</table>
The Tracking Detectors: The PANDA-GEMs

- Forward GEM Tracker
- Forward Tracking inside Solenoid
  - 3 stations with 4 projections each
  - Radial, concentric, x, y
  - Central readout plane for 2 GEM stacks
  - Large area GEM foils developed at CERN (50µm Kapton, 2-5µm copper coating)
  - ADC readout for cluster centroids
  - Approx. 35000 channels total

Challenge to minimize material

Station No. | 1 | 2 | 3 | 4
---|---|---|---|---
Weight [kg] | 20 | 20 | 30 | 40
Distance to target [cm] | 81 | 117 | 153 | 189
Outer diameter [cm] | 90 | 90 | 112 | 148
Resolution trajectory position | < 100 µm
**Particle Identification**

Accurate PID key requirement to unveil many aspects of \( \overline{PANDA} \) physics program

Various dedicated high developed PID systems able to classify particle species over whole kinematic range:
- Cherenkov detectors: DIRCs, RICH
- Time of flight systems
- Muon detection system

**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

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**The Detector of the \( \overline{PANDA} \) -Experiment at FAIR**
Particle Identification: The PANDA Barrel DIRC

DIRC: Detection of Internally Reflected Cherenkov light
Compact fused silica (quartz) bars, spherical lenses, prisms
MCP-PMT read out: excellent timing, B-field performance

$\beta > 1/n$

$\cos \theta_C = 1/\beta \ n(\lambda)$

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<table>
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<tbody>
<tr>
<td>n radiator</td>
<td>1.47</td>
</tr>
<tr>
<td>$\pi/K$ separation</td>
<td>3 $\sigma$ (up to 3.5 GeV/c)</td>
</tr>
<tr>
<td>$\gamma$ time res.</td>
<td>100 ps</td>
</tr>
<tr>
<td>PMT channels</td>
<td>10000</td>
</tr>
</tbody>
</table>
Particle Identification: The \( \bar{\text{PANDA}} \) Barrel DIRC

**Figure 3.2:** Phase space map of the achievable \( \pi/K \) separation power in standard deviations without a dedicated Cherenkov detector in the TS region. The map is based on \( 5 \times 10^6 \) single track kaon/pion events simulated and reconstructed with the PandaRoot framework.

**Figure 3.3:** Schematic of the basic DIRC principle.

The radiator for a DIRC counter is typically a highly-polished bar made of synthetic fused silica. The average Cherenkov angle for synthetic fused silica (\( n = 1.473 \) at 380 nm) is shown as a function of the particle momentum in Fig. 3.4 (top). For a particle with a Cherenkov angle, some of the photons will always be trapped inside the radiator due to total internal reflection and propagate towards the ends of the bar. An optical interface is attached to the forward end of the bar to redirect the photons to the backward (readout) end. If the bar is rectangular and highly polished, the magnitude of the Cherenkov angle will be conserved during the reflections until the photon exits the radiator via optional focusing optics into the expansion volume (EV). The Cherenkov ring expands in the EV to transform the position information of the photon at the end of the bar into a direction measurement by determining the positions on the detector plane. By combining the particle momentum measurements, provided by the tracking detectors, with the photon direction and propagation time obtained by the photon sensor pixel, the Cherenkov angle and the corresponding PID likelihoods are determined.

**Figure 3.4:**
- **Top:** Cherenkov angle as function of the particle momentum for charged particles in synthetic fused silica.
- **Bottom:** Cherenkov angle difference in synthetic fused silica for pions and kaons, kaons and protons, and for pions and protons.

### 3.3 DIRC PID Performance

The PID performance of a DIRC counter is driven by the Cherenkov track angle resolution \( \delta \), which can be written as

\[
\delta = \sqrt{\frac{\sigma_{\text{track}}}{N} + \sigma_{\text{SPR}}}
\]

where \( N \) is the number of detected photons and \( \sigma_{\text{SPR}} \) is the resolution of the Cherenkov angle measurement per photon (single photon resolution, SPR). \( \sigma_{\text{track}} \) is the uncertainty of the track direction within the DIRC, which is dominated by multiple scattering and the resolution of the \( \bar{\text{PANDA}} \) tracking detectors, which is expected to be about 2 mrad for high-momentum particles in the barrel region.

Radiator bar dimensions: 17 mm × 53 mm × 2400 mm

48 radiator bars in 16 sectors

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Thomas Held (Ruhr-Universität Bochum)
Particle Identification: The PANDA Barrel TOF system

- Low momentum particle PID (< 1 GeV)
- Excellent time resolution of $\approx 100$ ps
- System of scintillator tiles read out by SiPMs (two sides)
- Light weight construction

<table>
<thead>
<tr>
<th>Scintillator</th>
<th>Plastic (EJ-228 or EJ-232)</th>
</tr>
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<tbody>
<tr>
<td>Read out</td>
<td>SiPM (Hamamatsu)</td>
</tr>
<tr>
<td>FEE</td>
<td>TOF PET ASIC (PETsys electronics)</td>
</tr>
</tbody>
</table>
Emagnetic Calorimetry

PANDA physics: Complete reconstruction of multi-photon and lepton-pair channels of utmost importance
Good energy and spatial resolution for photons up to 15 GeV
High yield and background rejection
Target spectrometer: Homogeneous barrel part plus two endcaps
Forward spectrometer: Sampling calorimeter

<table>
<thead>
<tr>
<th>Energy threshold</th>
<th>10 MeV</th>
</tr>
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<tbody>
<tr>
<td>Spacial coverage</td>
<td>98 % of $4\pi$</td>
</tr>
<tr>
<td>Single crystal rate</td>
<td>up to 1 MHz</td>
</tr>
</tbody>
</table>
Electromagnetic Calorimetry: The Target Calorimeter

2nd generation PbWO$_4$ (PWO-II), improved light yield, radiation hardness, 15744 crystals
Operating at -25 °C ($\times$ 4 light yield)
Read out: Large area APDs (2 per crystal), vacuum photo tetrodes (inner forward endcap)

<table>
<thead>
<tr>
<th>Radiation length</th>
<th>0.9 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molière radius</td>
<td>2.1 cm</td>
</tr>
<tr>
<td>Crystal dimensions</td>
<td>$20 \times 2.5 \times 2.5$ cm$^3$</td>
</tr>
<tr>
<td>Time resolution</td>
<td>$\leq 1$ ns ($&gt;100$ MeV)</td>
</tr>
<tr>
<td>Energy res. $\frac{\sigma_E}{E}$</td>
<td>$1% \oplus \frac{2%}{\sqrt{E[GeV]}}$</td>
</tr>
<tr>
<td>Spacial resolution</td>
<td>$\leq 1.5$ mm</td>
</tr>
</tbody>
</table>
Electromagnetic Calorimetry: The Forward Calorimeter

Shashlik type sampling calorimeter:
Lead absorbers, plastic scintillators, PMT readout

\[
\frac{\sigma_E}{E} \leq 1.3\% \oplus \frac{2.8\%}{\sqrt{E \text{[GeV]}}} \oplus \frac{3.5\%}{E \text{[GeV]}}
\]
The Magnets

Ideal combination of superconducting solenoid (target region) and dipole (forward spectrometer, below 5°/10°)

<table>
<thead>
<tr>
<th></th>
<th>Solenoid</th>
<th>Dipole</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field</strong></td>
<td>2 T</td>
<td>1 T</td>
</tr>
<tr>
<td><strong>Diameter</strong></td>
<td>inner/outer 1.9/2.3 m</td>
<td>1 m × 3 m opening</td>
</tr>
<tr>
<td><strong>Length</strong></td>
<td>4.9 m</td>
<td>2.5 m</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>300 t</td>
<td>220 t</td>
</tr>
</tbody>
</table>

Solenoid:
- Instrumented flux return
- Field inhomogeneity ≤ 2 %

Dipole ramping operation fully synchronous with storage ring, ramp speed 1.25 %/s
High interaction rate, wide physics objectives: triggerless DAQ

Time distribution: SODA

Time tag / hit

Selection after event building

Detector Frontends
Data Concentrators
Burst Building Network
Compute Nodes: 1\textsuperscript{st} level selection
Computer Farm: 2\textsuperscript{nd} level selection
Storage
Timeline

Detector component construction started in 2014
Most/all phase 1 TDRs completed in 2017/2018
Mounting of the detector in $\bar{\text{PANDA}}$ hall starting 2021
Commissioning 2024
$\bar{\text{PANDA}}$ -experiment will be operational from 2025 on

Doing hadron physics from $\bar{\rho}p$ collisions
Unveil many of today’s QCD puzzles

Thomas Held  (Ruhr-Universität Bochum)  The Detector of the $\bar{\text{PANDA}}$ -Experiment at FAIR