The Micro-Vertex-Detector (MVD) of the PANDA experiment *

* supported by BMBF and EU FP6 DIRAC Secondary Beams
Outline

- Introduction
- Detector development
  - Implementation
  - Hardware development
  - Mechanics aspects
- Simulation
- Summary
Introduction

- PANDA at FAIR facility
Introduction

• **High Energy Storage Ring**
  - High luminosity antiproton beam
  - Stochastic / electron cooling

• **PANDA experiment**
  - Anti-Proton Annihilations at Darmstadt
Introduction

- **Physics program**
  - Study of charmonium systems: $q\bar{q}$ potential models
    - Precision measurements below and above $D\bar{D}$ threshold
    - Discovery potential for new states
  - Search for exotic QCD states (glueballs, hybrids)
  - Charmed and multi-strange spectroscopy
  - Electromagnetic processes ($p\bar{p} \rightarrow e^+e^- / \gamma\gamma$, Drell Yan)
  - Properties of single and double hypernuclei
  - Properties of hadrons in nuclear matter

→ M. Fritsch

HK 13.2
Introduction

- PANDA - Experiment
  - Fixed target experiment
  - Frozen hydrogen and heavier nuclear targets (e.g. Gold)
  - Pellet target / Cluster-jet target
  - Design parameters
    a) High luminosity: \( L = 2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \Leftrightarrow \Delta p/p < 10^{-4} \)
    b) High resolution: \( L = 10^{31} \text{ cm}^{-2} \text{ s}^{-1} \Leftrightarrow \Delta p/p < 4 \cdot 10^{-5} \)
    Beam momentum: (1.5 ... 15) GeV / c

→ Interaction rate: \( 2 \cdot 10^7 \) events / s

→ Non-ordered time structure
Introduction

- Spectrometer

Solenoid

Dipole

Central tracker

Target spectrometer

Forward spectrometer
Introduction

- Experiment: Particle distribution
  - Enhanced emission in forward direction
  - Low-energetic particles (< 1 GeV/c) in full polar angle

**Antiproton – Gold**

$p_{\text{beam}} = 15 \text{ GeV/c}$

**Antiproton – Proton**

Elastic scattering
Introduction

- **Experiment**: Particle distribution
  - Enhanced emission in forward direction (light targets)
  - Low-energetic particles ($< 1 \text{ GeV/c}$) over full polar angle

![Graphs showing particle distribution](image)

- $\bar{p}$-p
- $\bar{p}$-Ar
- $\bar{p}$-N
- $\bar{p}$-Au
General description

• Micro-Vertex-Detector (MVD)
  - Tracking detector for charged particles
  - Innermost detector in PANDA
  - Main tasks:
    1. High vertex resolution for primary interaction vertex and secondary vertices of short lived particles and delayed decays
    2. Improvement of momentum resolution
    3. Additional input for particle-ID

\[
\begin{align*}
  D^\pm &\rightarrow \bar{K}^0 x + K^0 y \\
  c\tau &= 312 \, \mu\text{m} \\
  D^{\pm}_{S} &\rightarrow \bar{K}^0 x + K^0 y \\
  c\tau &= 147 \, \mu\text{m}
\end{align*}
\]
Requirements

- **Good spatial resolution and high spatial coverage**
  - $r$-$\phi$: Momentum measurement (e.g. soft pions $D^*$ decay)
  - $z$: Vertexing, $D$-tagging

- **Good time resolution** ($< 10$ ns) $\iff$ Quasi continuous beam

- **Amplitude measurements** $\iff$ Improvement of spatial resolution and PID

- **Radiation tolerance** ($\sim 10^{14} n_{eq} (1 \text{ MeV}) \text{ cm}^{-2} / 10 \text{ years}$)

- **Triggerless readout** $\iff$ No first level hardware trigger

- **Low material budget**
General layout

- Micro-Vertex-Detector (MVD)
  - Central part:
    Four barrel layers
  - Forward part:
    Six disk layers
  - Detector types:
    - Pixel sensors
    - Double-sided microstrip sensors

\[ r_{\text{max}} = 150 \text{ mm} \]
Implementation

- **Micro-Vertex-Detector (MVD)**
  - Central part: Four barrel layer
  - Forward part: Six disk layer
  - Detector types:
    - Pixel sensors
    - Double sided microstrip sensors

**Readout channels:**
- ~ 12 million (pixel)
- ~ 200,000 (strip)

Low power dissipation for frontend electronics required
Implementation

- **Pixel sensor**
  - Shape: Rectangular
  - 4 types of different lengths
  - Pixel cell size: $100 \times 100 \ \mu m^2$
Implementation

- Hybridization: Pixel module

![Diagram of the Micro-Vertex-Detector (MVD)]

- Standard hybrid technology
  - Thinned silicon Cz substrate
  - Epitaxial silicon layer
  - Bump bonding
  - Readout chip
  - Carbon foam
  - Glue
  - Carbon fiber
  - Cooling system
Hardware development

• Pixel sensor
  ➢ Specifications
    ✓ Epi-Silicon layer: (50 ... 100) μm
    ✓ Thinned substrate: ~ 50 μm
    ✓ Alt.: Thinned oxygen enriched silicon
  ➢ Measurements
    ✓ Sensor characterization
    ✓ Radiation damage test (neutrons)
Hardware development

- ToPix readout chip
  - Specifications
    - Time over threshold technique for untriggered readout
    - CMOS 130 nm technology
    - 116 × 110 pixel matrix (100 × 100 μm² cell size)
    - Low power consumption (< 500 mW/cm²)
  - Measurements
    - Testing procedures

![Diagram showing the ToPix readout chip and its specifications.](image-url)
Hardware development

- **ToPix readout chip**
  - **Specifications**
    - Time over threshold technique for untriggered readout
    - CMOS 130 nm technology
    - 100 × 100 pixel matrix (100 × 100 μm² cell size)
    - Low power consumption (< 500 mW/cm²)
  - **Measurements**
    - Testing procedures
    - Total ionizing dose test with X-rays
Hardware development

- **ToPix readout chip**
  - Specifications
    - Time over threshold technique for untriggered readout
    - CMOS 130 nm technology
    - 100 × 100 pixel matrix (100 × 100 μm² cell size)
    - Low power consumption (< 500 mW/cm²)
  - Measurements
    - Testing procedures
    - Total ionizing dose test
    - ToPix prototype connected to epi-sensor
Implementation

• Strip sensor

  ➢ Shape:
    Trapezoidal (disk)
    Rectangular (barrel)

  ➢ Readout: Pitch / stereo angle:
    \[ 130 \, \mu \text{m} / 90^\circ \] (barrel)
    \[ 70 \, \mu \text{m} / 15^\circ \] (disk)
Implementation

- Hybridization: Strip module

**Disk part**

- Readout along sensor sides
- Bending at top

**Barrel part**

- Readout short strips
- Readout long strips
- Pitch adapter
- Frontend Smd

**Implementation**
Implementation

- Hybridization: Strip super-module

**Disk part**
- Support
- Cooling

**Barrel part**
- Disk part
- Support
- Cooling
Hardware development

• Test system for strip sensors

↑ Tracking Station at COSY beam time
← Lab setup

From lab-scale test system to tracking station
Hardware development

• Test system for strip sensors

DPG contributions:
→ R. Schnell    HK 10.5
→ M. Becker     HK 21.3
→ K. Koop       HK 36.61

From lab-scale test system to tracking station
Hardware development

- Digital Readout system

ATLAS FE 13 characterization

Noise distribution

Threshold: 324
Noise: 8.8

40 MHz  60 MHz  80 MHz
Mechanics aspects

- Overall detector integration

Global frame

- Carbon fibre structure

Central support frame

- 3 point fixation to central support frame
- 2 half frames
- Integration of all MVD parts
- Prototype commissioned
Mechanics aspects

• Support concept

Barrel layer

- Staves hosting detector modules
- Pixel barrel layer: Upstream cone
- Strip barrel layer: Cylinder over full length, sawtooth structure

Pixel layer

Strip layer

Carbon fibre / Carbon foam structure
Mechanics aspects

- Support concept

Forward part

- Pixel disks
  - Half-disks hosting detector modules
  - Spacers in between disk layers
  - Suspensors for attachment to frame

- Strip disks
  - Dedicated support for super-module
  - Support ring with fixed super-modules attached to frame
Carbon structures

- Light material support

- Sandwich structure:  
  (Carbon – Rohacell® – Carbon)

- Stiffening structure:  
  2 layers of carbon fibre (400 μm)
Mechanics aspects

- Routing concept

![Diagram showing mechanics aspects of the Micro-Vertex-Detector (MVD) of the PANDA experiment. The diagram illustrates the routing concept with labels for circular occupancy and circular or bundled at top/bottom.](image-url)
Mechanics aspects

- **Routing concept**
  - “Packets” for individual modules
  - Upstream routing along beam pipe
  - Dedicated routing for pixel disks

![Diagram showing routing concepts](image)
Mechanics aspects

• Routing concept

$r_{\text{max}} = 150 \text{ mm}$

Beam pipe
Mechanics aspects

- Cooling concept
  - Coolant: Water (18°C)
  - Under-pressure mode using hydrostatic pressure
- Active part:
  - Ø 2 mm pipe (steel alloy)
- Upstream routing:
  - Ø 4 mm flexible plastic pipes

Barrel layer

Micro fittings: Thermoplastic resin

Test setup

Thermal FEM analysis
Mechanics aspects

- Cooling concept
  - Coolant: Water (18°C)
  - Under-pressure mode using hydrostatic pressure

- Disk layer
- Carbon foam cutting
- Glueing: 2 foam disks embedding cooling pipes
- Drilling and baking

Cooling concept: Water (18°C) in an under-pressure mode using hydrostatic pressure. The disk layer is made of carbon foam and is cut using CAD. Glueing involves embedding cooling pipes between two foam disks. Drilling and baking complete the process.
Simulation

**CAD Converter**
translates CAD drawings (STEP-files) into ROOT geometries ➞ access to full pandaROOT simulation with realistic detector design

Full MVD ROOT geometry
Simulation

- Count rate studies

  - Maximum count rates / frontend: \( \sim 10^6 \) Evts / s
  - Anisotropic distribution

<table>
<thead>
<tr>
<th>Pixel part</th>
<th>Strip part</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{p} - p @ 15 \text{ GeV} )</td>
<td>( \bar{p} - p @ 15 \text{ GeV} )</td>
</tr>
</tbody>
</table>
Simulation

• Count rate studies

- Integrated rate over all frontends: ~ 3 Gevts / s
Simulation

- Spatial coverage
  - 2D mapping: Number of MVD points / track

_design optimization for a minimum of 4 trackpoints_
Simulation

- Spatial coverage
  - 2D mapping: Number of MVD points / track
  - \( \pi^+ \): 0.2 GeV/c \( \rightarrow \) 1.5 GeV/c
  - \( \pi^- \): 0.2 GeV/c
  - \( p \): 0.2 GeV/c

- No significant effect for particle ↔ antiparticle
- No significant energy dependence
- No significant effect for different particle species

\( \rightarrow \) S. Bianco HK 43.6
Simulation

• Radiation length studies \((\text{Geantino})\)
  
  - 2D mapping of overall material budget

- More isotropic in barrel part
- Anisotropic routing of pixel disks
- Hotspots in upstream region
Simulation

- Radiation length studies (Geantino)
  - 2D mapping of main components

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- Radiation length studies (Geantino)
  - 2D mapping of main components
Simulation

- Radiation length studies (*Geantino*)
  - 1D profile scan for polar angle

![Graph showing radiation length studies](image)

- < 1% / layer (Σ < 10%)
- 10% < Σ < 18%
- 30% < Σ < 68%
Performance

- Momentum resolution
  - 1 GeV/c pions (0;0;0)
    - $\sigma(p)$ without MVD = 2.6 %
    - $\sigma(p)$ with MVD = 1.4 %
    - $\sigma(p_t)$ without MVD = 2.9 %
    - $\sigma(p_t)$ with MVD = 1.4 %
    - Improvement by 50%

- Single track resolution
  - No resolution along z without MVD

  $p$, $p_t$, $z$, $x$, $y$
Performance

- Energy loss information ... under study
  → D. Pohl       HK 21.7

- Primary vertex resolution

→ R. Jäkel       PhD thesis

\[ pp \rightarrow \pi^+ \pi^- \quad 15 \text{ GeV/c} \]

\[ \sigma_z \leq 70 \mu m \]
Performance

- Energy loss information ... under study
  → D. Pohl HK 21.7

- Vertex resolution $\bar{p}p \rightarrow D^+ D^-$
  \[(6.57 / 7.50 / 8.50) \text{ GeV/c}\]

<table>
<thead>
<tr>
<th>momentum $GeV/c$</th>
<th>vertex resolution $[\mu m]$</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>primary</td>
</tr>
<tr>
<td></td>
<td>$\sigma_{prim,x}$</td>
</tr>
<tr>
<td>6.57</td>
<td>30.7</td>
</tr>
<tr>
<td>7.50</td>
<td>30.4</td>
</tr>
<tr>
<td>8.50</td>
<td>30.0</td>
</tr>
</tbody>
</table>

→ R. Jäkel PhD thesis

→ Primary and secondary vertex resolution:
  $\sigma_{x,y} \leq 35 \mu m$
  $\sigma_z \leq 100 \mu m$
Performance

- Physics analysis $\bar{p}p \rightarrow D^+ D^-$
  - Reconstruction: $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$
  - Conservative approach

$$R = \frac{\sigma(\bar{p}p \rightarrow D^+ D^-)}{\sigma(\bar{p}p \rightarrow X)} = \frac{2.83 \text{nb} \cdot (0.092)^2}{60 \text{mb}} = 4.0 \cdot 10^{-10}$$

6 orders of magnitude lower

$\rightarrow$ arXiv:0903.3905v1

6 prong
$3\pi^+ 3\pi \pi^0$
$2K2\pi^+ 2\pi$

S/N $\sim 2$

$D^\pm$ decay length

$D^\pm \rightarrow \bar{K}^0 x + K^0 y$
$c\tau = 312 \mu m$
Summary

• Advanced stage of MVD detector development

• Start of prototyping

• Parallel software development to check physics performance

• Still some challenging tasks ahead ...
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H. Kleines, D. Pohl, M. Mertens, J. Ritman
MVD: Active detector volumes only

MVD: Detailed CAD model