The PANDA Micro-Vertex-Detector

Group report / DPG EuNPC 2009

4. Mai 2009  | Tobias Stockmanns for the PANDA Collaboration | HK 40.1
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- Introduction to the PANDA detector at HESR
- The Micro-Vertex-Detector of PANDA
  - Requirements
  - Setup of the MVD
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- Summary / Outlook
Main Physics Program

**PANDA – AntiProton Annihilations at Darmstadt**

- $qq$ potential in the charmonium system
  - precision measurements of $cc$-states (not only $J^{PC} = 1^{--}$)
  - $cc$ above $DD$-threshold $\rightarrow$ measurement of $D$-mesons

- Search for Hybrids $qqg$ and/or Glueballs $gg$

- Spectroscopy of new charm states

- Charmed and multi-strange baryon spectroscopy

- Electromagnetic processes ($pp \rightarrow e^+e^-$, $pp \rightarrow \gamma\gamma$, Drell-Yan)

- Properties of single and double hypernuclei

- Properties of hadrons in nuclear matter

\textit{→ P. Gianotti – HK 24.1}
High Energy Storage Ring

Electron cooler $E < 8 \text{ GeV}$

Injection

Cooling: electron/stochastic

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>$P_{\text{max}}$</td>
<td>$15 \text{ GeV/c}$</td>
</tr>
<tr>
<td>High resolution: $L$</td>
<td>$10^{31} \text{ cm}^{-2} \text{ s}^{-1}$, $\delta p/p &lt; 4 \times 10^{-5}$</td>
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<tr>
<td>High luminosity: $L$</td>
<td>$2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$, $\delta p/p &lt; 10^{-4}$</td>
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</table>
Detector requirements:

- $4\pi$ coverage (partial-wave-analysis)
- high rates ($2 \times 10^7$ annihilations/s)
- good PID ($\gamma, e, \mu, \pi, K, p$)
- good PID ($\gamma, e, \mu, \pi, K, p$) (~1%)
- momentum resolution (~1%)
- vertexing for $D, K^0_S, \Lambda$
- efficient trigger
- no hardware trigger

(raw data rate ~TB/s)
PANDA Spectrometer
PANDA Spectrometer

- Pellet or cluster jet target
- Dipole magnet for forward tracks
- Solenoid magnet for high $p_t$ tracks: Superconducting coil & iron return yoke
PANDA Spectrometer

Silicon Microvertex  
Central Tracker  
Forward Drift Chambers
PANDA Spectrometer

Muon Detectors

Forward RICH

Barrel DIRC

Barrel TOF

Endcap DIRC

Forward TOF
PANDA Spectrometer
Micro-Vertex-Detector
Requirements MVD

- Good spatial resolution in r-phi \( \Rightarrow \) momentum measurement of soft pions from D* decays
- Good spatial resolution specially in \( z \) \( \Rightarrow \) vertexing, D-tagging
D-Meson decays

Beam $P = 8 \text{ GeV/c}$

Distribution of secondary vertex from D-meson decays for a beam kinetic energy 8 GeV/c.

$\Rightarrow$ Need to optimize resolution in the $Z$ direction!
Requirements MVD

- Good spatial resolution in \( r\-\phi \) \( \rightarrow \) momentum measurement of soft pions from \( D^* \) decays
- Good spatial resolution specially in \( z \) \( \rightarrow \) vertexing, D-tagging
- Good time resolution (\( O(20 \text{ ns}) \)) \( \rightarrow \) ‘DC’-beam (\( 2 \cdot 10^7 \text{ events/s} \))
- Amplitude measurement \( \rightarrow \) improvement of resolution \( dE/dx \) to improve particle ID
Particle Identification with MVD

- 800 MeV/c
- 400 MeV/c
- 50 MeV/c
- 200 MeV/c

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Requirements MVD

- Good spatial resolution in r-phi

- Good spatial resolution specially in $z$

- Good time resolution ($O(20 \text{ ns})$)

- Amplitude measurement

- Modest radiation hardness ($O(10^{14} \text{ n}_{eq} / \text{ cm}^2)$)

- Momentum measurement of soft pions from $D^*$ decays

- Vertexing, D-tagging

- ‘DC’-beam ($2 \cdot 10^7 \text{ events/s}$)

- Improvement of resolution $dE/dx$ to improve particle ID

- Depends on target material
Radiation Damage Pixel Barrel

pp @ 5 GeV/c for one year operation

φ_{max} \approx 2 \cdot 10^{13} \#/cm^2

φ_{max} \approx 1.5 \cdot 10^{11} \#/cm^2

φ_{max} \approx 2 \cdot 10^{12} \#/cm^2

φ_{max} \approx 6 \cdot 10^{11} \#/cm^2
Radiation Damage Disks

\[ \phi_{\text{max}} \approx 5 \times 10^{12} \text{ [#/cm}^2\text{]} \]

\[ r_{\text{MAX}} = 150 \text{ mm} \]

\[ \phi_{\text{max}} \approx 6 \times 10^{13} \text{ [#/cm}^2\text{]} \]

\[ \phi_{\text{max}} \approx 3 \times 10^{13} \text{ [#/cm}^2\text{]} \]

\[ \phi_{\text{max}} \approx 2 \times 10^{12} \text{ [#/cm}^2\text{]} \]

\[ \phi_{\text{max}} \approx 1.6 \times 10^{12} \text{ [#/cm}^2\text{]} \]
Requirements MVD

- Good spatial resolution in r-phi ➞ momentum measurement of soft pions from D* decays
- Good spatial resolution specially in z ➞ vertexing, D-tagging
- Good time resolution (O(20 ns)) ➞ ‘DC’-beam (2⋅10^7 events/s)
- Amplitude measurement ➞ improvement of resolution dE/dx to improve particle ID
- Modest radiation hardness (O(10^{14} n_{eq} / cm^2)) ➞ depends on target material
- Triggerless readout ➞ no first level hardware trigger
Simulated maximum data rate

- Simulated maximum data rate for 4 GeV/c p on Cu:
  - Pixel module (12 cm²): 32·10⁶ s⁻¹ → 1.3 Gbit/s
  - Front-End chip (1 cm²): 5.5·10⁶ s⁻¹ → 220 Mbit/s (assuming 40 bit/hit)

Maximum hit rate of FE on module

Hit distribution on module with highest rates
Requirements MVD

• Good spatial resolution in r-phi ➔ momentum measurement of soft pions from D* decays

• Good spatial resolution specially in \(z\) ➔ vertexing, D-tagging

• Good time resolution (O(20 ns)) ➔ ‘DC’-beam (2 \(10^7\) events/s)

• Amplitude measurement ➔ improvement of resolution dE/dx to improve particle ID

• Modest radiation hardness (O(10^{14} \text{ n}_{eq} / \text{cm}^2)) ➔ depends on target material

• Triggerless readout ➔ no first level hardware trigger

• Low material budget ➔ low momentum particles energy resolution calorimeter
Momentum distribution and multiple scattering

pp @ 8 GeV/c

pAu @ 8 GeV/c

800 µm silicon

mean deflection angle

2 mrad ➔ 20 µm error / cm path

Multiple scattering dominates resolution for low momentum particles

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Hybrid Pixel Module

**sensor:**
- epi-Silicon
  - 50, 75, 100 µm thick epi-Layer on CZ substrate
  - thinned down to 75 – 150 µm
- alt. oxygen enriched silicon
  - thinned down to 150 – 200 µm

**front-end chip:**
- custom development (ToPix)
- (100 µm)$^2$ pixels
- 100 x 100 pixel matrix
- untriggered readout
- 130 nm IBM process

**readout:**
- Module Controller Chip?

\[ D. \text{ Calvo – HK40.2} \]
ToPix Development

ToPix2
- 320 readout cells \((100 \, \mu m)^2\)
- 5x2 mm\(^2\) size
- analogue + digital circuit

Epi-pixel sensor
- bump bonded on ALICE FE
- thinned down to:
  - 100 \(\mu m\) (49 \(\mu m\))
  - 120 \(\mu m\) (75 \(\mu m\))
  - 150 \(\mu m\) (98 \(\mu m\))
Strip Detector

rectangular sensor:
- double sided silicon strip sensor
- pitch: 130 µm (0.65 µm)
- size: 6.7 x 3.3 x 0.03 cm³
- stereo angle 90°

trap sensor:
- double sided silicon strip sensor
- pitch: 70 µm
- size: 6.1 x 3.5 x 0.03 cm³ 15°
- stereo angle 15°

front-end electronic:
- custom development together with GSI
- untriggered readout
Hardware development

First small sensor prototype with APV readout
Pixel support structures
Support Structures Strips

- Strip barrel design
Concept for strip disks

Disk layer / Forward part
Use of carbon sandwich structure

- Stave support: Sandwich structure (Carbon – Rohacell – Carbon)
- Barrel support: Half-shell and saw-tooth support
- Carbon foam with high thermal conductivity
SIMULATION PROGRAM
Simulation Studies of Mechanical Design

**CAD Converter**

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

➔ T. Würschig – HK 40.3
Performance of MVD

Momentum resolution of PANDA detector with and without MVD

$\sigma(p) [1\text{GeV/c } \pi]$ without MVD = 2.6 %

$\sigma(p) [1\text{GeV/c } \pi]$ with MVD = 1.4 %
Performance of MVD

Track parameter resolution with and without MVD

1 GeV/c pions

R. Jäkel PhD thesis in preparation
Secondary vertex resolution

- Fully reconstructed $D^+D^-$ pairs
- Vertex resolution:
  - 35 $\mu$m in $x$ and $y$
  - 77 $\mu$m in $z$ (at 6.57 GeV/c beam momentum)

R. Jäkel PhD thesis in preparation
TEST SYSTEMS
Lab-Testsysteem
FE-I3: Threshold and Noise

Pixel Row Index vs. Threshold (a.u.)

- Mean: 179.5
- Sigma: 43.1

Pixel Column Index vs. Injected Charge (a.u.)

- Mean: 179.5
- Sigma: 43.1

Threshold vs. TDAC Dependency

- Mean: 200.1
- Sigma: 1.2

Injected Charge (a.u.) vs. Entries

- Mean: 324 (a.u.)
- Sigma: 8.8 (a.u.)
Strip Test Station Bonn/Dresden

Test station: DTS1 (Lab setup)
- Evaluation of silicon strip sensors
- Modular setup allowing further prototype testing
Beam Telescope Bonn

Test-beam setup in Bonn
Summary

- The Micro-Vertex-Detector is one of the most challenging subdetectors within PANDA.
- It faces the highest radiation load, highest hit rates, very stringent requirements on the radiation length and by far the highest number of readout channels.
- In the course of the PANDA project a very sophisticated simulation software was (and is still) developed which allows us to optimize all different design parameters of the detector and do realistic simulations of the physics performance.
- The hardware development is on a good track and we think that we have the necessary technologies at hand which allows us to build this detector. Nevertheless there is still a lot of work ahead of us.