Beam Tests and Performance Studies for the PANDA Micro-Vertex-Detector

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On behalf of the PANDA MVD group

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The PANDA Experiment

• High precision hadron spectroscopy
• Search for hybrids and glueballs
• Study of exotic states (X,Y,Z,...)
• Nucleon structure
• Hyper-nuclear physics

The Micro-Vertex-Detector

• High vertex resolution (<100 μm)
• Rates up to 10 kHz/channel
• 10-year dose → 10 Mrad

• 100μm x 100μm Si pixel sensors
  Disks and barrel layers
• 65μm pitch Si strip sensors
  Barrel layers and fwd wheels
"Four pion" characterization

$2\pi^+ \text{ and } 2\pi^- \text{ propagated from a common vertex}$

$2T$ solenoidal magnetic field

Initial direction of the pions distributed homogeneously:

- $\vartheta$ in $[10, 140]^{\circ}$
- $\phi$ in $[0, 360]^{\circ}$

Initial momentum 1 GeV/c
Four Pion Scans - Results

Circular Scan

Radial Scan

Radial Scan

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Vertex resolution quite stable during the circular and radial scans

Vertex resolution degrades for $|z| > 5\text{mm (PR)}$

Momentum resolution well constant $\delta p/p \sim 1.8\text{-}1.9\%$

In all the scans X resolution consistently worse than Y ...
Vertex Resolution: X vs Y

The geometrical coverage around the IP is not completely homogeneous along $\phi$

The target pipe breaks the symmetry

Bigger distance between the IP and the first measured hit point depends both on $\vartheta$ and $\phi$
Physics Case: Realistic Kinematics

Two effects of the forward boost:
- the x-y discrepancy disappears
- the transverse coordinates of the vertices are better determined than the longitudinal ones
The Vertex Reconstruction Performance

\[ \bar{p} p \rightarrow \psi(2S) \rightarrow J/\psi \rightarrow \pi^+ \mu^+/\mu^- \]

J/\psi

\[ \sigma_x = 42 \mu m \]

Vertex Kin/Vtx

J/\psi

\[ \sigma_z = 60 \mu m \]

\[ m = 3.044 \text{ GeV/c}^2 \]

\[ \sigma = 0.111 \text{ GeV/c}^2 \]

\[ \Psi(2S) \]

\[ \sigma_z = 56 \mu m \]
Hardware Studies with Tracking Stations
The Tracking Stations

Strip Tracking Station:

- Four planes
- Single/double sided
- 1.92 $\times$ 1.92 cm$^2$ area
- 300 $\mu$m thick
- 50 $\mu$m pitch
- 90° stereo angle

Front-end: APV25S1
Trigger: 4 scintillators

Pixel Tracking Station:

- Four sensors, 100 $\mu$m x 100 $\mu$m cells, active area 3.2 mm x 2 mm
- Thickness: Epi-Si 100 $\mu$m, Cz-substrate (not thinned) 575 $\mu$m, fe chip 300 $\mu$m + PCB and capacitors

Front-end chip: custom trigger-less ASIC (ToPix3)

Common clock distributed to both systems
From the DAQ to Data Analysis

Raw data conversion:
- Position of the sensors
- Channel by channel energy calibration
  - FE mapping
  - Masked channels

Iterative alignment procedure

Energy Calibration: Injected charge + Eloss

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Event Building

Different definition of “event” in the two subsystems:

• Strip TS → set of hit points recorded in a trigger window
• Pixel TS → set of hit points with compatible timestamp
Event Building

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• Strip TS → set of hit points recorded in a trigger window
• Pixel TS → set of hit points with compatible timestamp

Timestamp offsets between the two systems can be easily determined and corrected
Beam Spots

First Pixel Plane

First Strip Plane

2.7 GeV/c proton beam @ COSY (Jülich)
Setup Comparisons

**SETUP A**

<table>
<thead>
<tr>
<th></th>
<th>(\sigma_x (\mu m))</th>
<th>(\sigma_y (\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Est.</td>
<td>232 (\mu m)</td>
<td>234 (\mu m)</td>
</tr>
<tr>
<td>Res. S1</td>
<td>598 +/- 9</td>
<td>601 +/- 9</td>
</tr>
<tr>
<td>Res. S2</td>
<td>253 +/- 4</td>
<td>255 +/- 4</td>
</tr>
<tr>
<td>Res. S3</td>
<td>427 +/- 6</td>
<td>435 +/- 6</td>
</tr>
</tbody>
</table>

**SETUP B**

<table>
<thead>
<tr>
<th></th>
<th>(\sigma_x (\mu m))</th>
<th>(\sigma_y (\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Est.</td>
<td>263 (\mu m)</td>
<td>264 (\mu m)</td>
</tr>
<tr>
<td>Res. S1</td>
<td>660 +/- 21</td>
<td>654 +/- 19</td>
</tr>
<tr>
<td>Res. S2</td>
<td>288 +/- 10</td>
<td>297 +/- 9</td>
</tr>
<tr>
<td>Res. S3</td>
<td>496 +/- 16</td>
<td>494 +/- 15</td>
</tr>
</tbody>
</table>

**SETUP C**

<table>
<thead>
<tr>
<th></th>
<th>(\sigma_x (\mu m))</th>
<th>(\sigma_y (\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Est.</td>
<td>100 (\mu m)</td>
<td>98 (\mu m)</td>
</tr>
<tr>
<td>Res. S1</td>
<td>114 +/- 3</td>
<td>108 +/- 3</td>
</tr>
<tr>
<td>Res. S2</td>
<td>93 +/- 3</td>
<td>89 +/- 3</td>
</tr>
<tr>
<td>Res. S3</td>
<td>500 +/- 13</td>
<td>505 +/- 15</td>
</tr>
</tbody>
</table>

\[
\text{Est.} = \frac{\sqrt[3]{\sigma_1 \times \sigma_2 \times \sigma_3}}{\sqrt[3]{3}}
\]
Combined Analysis

Two different combined analyses. Information considered:

Hit points measured by the first two strip planes and the first pixel assembly

<table>
<thead>
<tr>
<th></th>
<th>Strip Sensor 1</th>
<th>Strip Sensor 2</th>
<th>Pixel Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_x / \mu m$</td>
<td>264</td>
<td>51</td>
<td>62</td>
</tr>
<tr>
<td>$\sigma_y / \mu m$</td>
<td>272</td>
<td>53</td>
<td>64</td>
</tr>
</tbody>
</table>

All the hits measured by the four strip sensors and the first pixel assembly

<table>
<thead>
<tr>
<th></th>
<th>Strip Sensor 1</th>
<th>Strip Sensor 2</th>
<th>Pixel Sensor</th>
<th>Strip Sensor 3</th>
<th>Strip Sensor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_x / \mu m$</td>
<td>975</td>
<td>267</td>
<td>394</td>
<td>179</td>
<td>877</td>
</tr>
<tr>
<td>$\sigma_y / \mu m$</td>
<td>908</td>
<td>249</td>
<td>368</td>
<td>164</td>
<td>811</td>
</tr>
</tbody>
</table>

Performance dominated by the scattering in the passive materials

<table>
<thead>
<tr>
<th>MC Sim</th>
<th>Pix 1</th>
<th>Pix 2</th>
<th>Pix 3</th>
<th>Pix 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeV/c</td>
<td>$\sigma_x(\mu m)/\sigma_y(\mu m)$</td>
<td>$\sigma_x(\mu m)/\sigma_y(\mu m)$</td>
<td>$\sigma_x(\mu m)/\sigma_y(\mu m)$</td>
<td>$\sigma_x(\mu m)/\sigma_y(\mu m)$</td>
</tr>
<tr>
<td>2.7</td>
<td>341 / 346</td>
<td>354 / 354</td>
<td>347 / 345</td>
<td>322 / 325</td>
</tr>
</tbody>
</table>
New Lighter Pixel Assemblies

<table>
<thead>
<tr>
<th>Component</th>
<th>First Assemblies</th>
<th>Light Assemblies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cz-substrate</td>
<td>575 µm</td>
<td>20 µm</td>
</tr>
<tr>
<td>Epi-silicon</td>
<td>100 µm</td>
<td>100 µm</td>
</tr>
<tr>
<td>Topix3</td>
<td>300 µm</td>
<td>300 µm</td>
</tr>
<tr>
<td>PCB</td>
<td>1.1 mm</td>
<td>0 (cut out)</td>
</tr>
<tr>
<td>Capacitors</td>
<td>in</td>
<td>moved away</td>
</tr>
</tbody>
</table>

New beam test at CERN (T9 area) with positive hadrons at momenta up to 10 GeV/c.

New pixel assemblies, better resolutions can be achieved.

Results for Pions

- 4 Strip planes + 4 Pixel planes
- 4 Strip planes + 1 Pixel plane
Thanks for your attention!