Modeling of the Inner Tracking System of the NICA/MPD setup

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The international project “NICA” is aimed at the study of the properties of nuclear matter in the region of the maximal baryon density that is achieved at the energy range of the NICA collider (3A < √s < 11A GeV).
Physics tasks of the NICA heavy-ion program (to be studied for different ions from p to Au by scanning in energy from 3 to 11A GeV)

- Event-by-event fluctuation in hadron productions (multiplicity, Pt etc.);
- Femtososcopic correlation;
- Directed and elliptic flows for various hadrons;
- Multi-strange hyperon production (including hypernuclei): yield and spectra as the probes of nuclear media phases;
- Photon and electron probes;
- Charge asymmetry

Study of strange particles is of interest because the strangeness enhancement in heavy-ion induced interactions (relative to elementary p+p collisions) might be a signature for the deconfinement phase transition.

High precision measurements of short-lived heavy flavor hadrons requires the using of the vertex detector in the experimental setup.
Vertex detectors of modern experiments studying AA-collisions

Typical vertex tracker consists of a few layers of silicon position-sensitive detectors. Main purpose is to register the decays of short-lived particles near the interaction point.
Main advantages of using the vertex tracker

- Improving the accuracy of the primary and secondary vertices reconstruction;
- Lowering of the registration threshold of charged particles with low Pt;
- Reliable identification of short-lived particles (multistrange hyperons, hypernuclei and charmed mesons) by determining the invariant mass of their decay products.

\[
\Lambda^0 \rightarrow p + \pi^-
\]
\[
\Xi^- \rightarrow \Lambda + \pi^-
\]
\[
\Omega^- \rightarrow \Lambda + K^-
\]
\[
^3\text{He}_\Lambda \rightarrow ^3\text{He} + \pi^-
\]
\[
D^0 \rightarrow K^- + \pi^+
\]
ALICE Inner Tracking System

The present ITS consists of 6 cylindrical layers of silicon detectors:
- 2 inner layers - Silicon Pixel Detectors (SPD);
- 2 middle layers - Silicon Drift Detectors (SDD);
- 2 outer layers - double-sided Silicon micro-Strip Detectors (SSD).

After upgrade ITS will consist of 7 cylindrical SPD layers segmented in pixels with dimensions of 20 x 20 μm².

http://alice-detector-facilities.web.cern.ch
Inner tracker MVD+STS consists of 4 MAPS layers (MVD) with pixel size 20×40 µm² and 8 tracking layers of silicon microstrip detectors (STS).

http://www.fair-center.de/de/fuer-nutzer/experimente/cbm/
MPD ITS consists of a Time Projection Chamber (TPC) and Inner Tracker (IT), which is planned to build of the pixel and microstrip sensors.

Silicon position-sensitive detectors for MPD IT

**Double Side microstrip Silicon Detector (DSSD)**

- Sensitive area: 62×62 mm²
- Thickness: 300 μm
- Number of strips on one side: 1024
- **Space resolution:** $\sigma_{r\phi} = 20 \mu m$, $\sigma_z = 120 \mu m$

**Monolithic Active Pixel Sensor (MAPS)**

- Sensitive area: 15,3×30 mm²
- Thickness: 50 μm
- Number of pixels: 512×1024
- **Space size:** 20×20 μm².
- **Space resolution:** $\sigma_{r\phi} = 5 \mu m$, $\sigma_z = 5 \mu m$
Computer simulation of the MPD Inner Tracker

Main tasks:

- Designing the IT geometric models;
- Estimating the IT pointing resolution as a function of particle $P_T$;
- Estimating the IT occupancy in Au–Au collisions at $\sqrt{s_{NN}} = 9$ GeV;
- Estimating the IT strange particle identification power.
IT geometric models on the base of microstrip detectors

4-layer option with a chess-like pattern of sensor ladders in the layers.
Beam pipe $\phi = 100 \text{ mm}$

5-layer option with a fan-like pattern of sensor ladders in the layers.
Beam pipe $\phi = 80 \text{ mm}$
IT geometric model on the base of microstrip and pixel detectors

Mixed IT consists of 6 layers of silicon detectors:
2 inner layers - Monolithic Active Pixel Sensor (MAPS)
4 outer layers - Double-sided Silicon micro-Strip Detectors (DSSD).

Beam pipe $\varnothing = 60$ мм
IT geometric models on the base of pixel detectors

5-layer option with a chess-like pattern of ladders in the layers.
Beam pipe $\varnothing = 60$ mm

7-layer option with a chess-like and fan-like pattern of ladders in the layers.
Beam pipe $\varnothing = 40$ mm
IT geometric models with cables

To simplify the calculation the multi-layered cables are replaced by one silicon layer with the same radiation thickness.
At the reconstruction stage the main simulation tasks include:

- generation of detector responses (Hit Producer);
- reconstruction of particle tracks using generated hits (Track Finder);
- reconstruction of the primary and secondary interaction vertices (Track Analysis).
Ideal Hit Producer

To define local coordinates of a charged particle track in a given sensor:
- fired strip or pixel numbers are computed but not the signal amplitude for the corresponding channel.
IT hit distribution in 1000 Au+Au collisions at 9A GeV

Column number of MAPS

Row number of MAPS

Strip number of DSSD
Example of IT hits in one central Au+Au collision at $\sqrt{s_{NN}} = 9$ GeV
To define local coordinates of a charged particle track in a given sensor:
- charges deposited on the strip or pixel are computed taking into account the charge fluctuations, the noise level and the electronic threshold;
- clusters of fired strips or pixels are searching for each charged particle.
Cluster Finder

![Diagram showing clusters and signals](image)

\[ x = \frac{\sum_{i=1}^{n} x_i S_i}{\sum_{i=1}^{n} S_i}, \]

- High threshold: 2 true clusters
- Low threshold: 3 clusters (2 true + 1 fake)
- Strip with slightly lower signal
- Two clusters from one particle

- a – false cluster due to low threshold;
- b – false cluster due to charge losses in silicon or noise

After the cluster was found, the local coordinate of its center of gravity is computed.
Reconstruction of charged particle tracks from sensor hits is based on the Kalman filtering formalism. Efficiency $\varepsilon > 90\%$ at $p_t > 0.4$ GeV/c for $\pi$, $p$, $K$. 
Pointing resolution for IT on the base of pixel sensors

Pointing resolution in transverse plane

Pointing resolution depends on number and radii of layers and getting better with decreasing the radii of inner layers.

\( R_1 = 14.4 \text{ mm} \)
\( R_1 = 24.4 \text{ mm} \)
Signal pileup probability of IT microstrip sensors

![Histograms showing signal pileup probability and occupancy](image)

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Mean multiplicity</th>
<th>Mean occupancy</th>
<th>Signal pileup probability, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>49</td>
<td>1.44</td>
<td>2.9±0.4</td>
</tr>
<tr>
<td>2a</td>
<td>26</td>
<td>0.61</td>
<td>2.3±0.4</td>
</tr>
<tr>
<td>3a</td>
<td>22</td>
<td>0.53</td>
<td>2.4±0.5</td>
</tr>
<tr>
<td>4a</td>
<td>9</td>
<td>0.22</td>
<td>2.4±0.7</td>
</tr>
<tr>
<td>5a</td>
<td>7</td>
<td>0.15</td>
<td>2.1±0.8</td>
</tr>
<tr>
<td>1b</td>
<td>48</td>
<td>1.29</td>
<td>2.7±0.4</td>
</tr>
<tr>
<td>2b</td>
<td>25</td>
<td>0.53</td>
<td>2.1±0.4</td>
</tr>
<tr>
<td>3b</td>
<td>22</td>
<td>0.54</td>
<td>2.4±0.6</td>
</tr>
<tr>
<td>4b</td>
<td>10</td>
<td>0.22</td>
<td>2.2±0.7</td>
</tr>
<tr>
<td>5b</td>
<td>8</td>
<td>0.16</td>
<td>2.0±0.8</td>
</tr>
</tbody>
</table>

Signal pileup probability is nearly uniform for all sensors of a given ladder in Au–Au collisions at $\sqrt{S_{NN}} = 9$ GeV, not exceeding the allowed level of 5%.
Reconstruction efficiency for the $\Lambda^0$ hyperons formed in Au+Au collisions at $\sqrt{S_{NN}} = 9$ GeV is used as an appropriate criterion for comparing various proposed configurations of the NICA/MPD tracking system.
\( \Lambda^0 \) reconstruction

\( \Lambda^0 \rightarrow p + \pi^- \)

\[ \varepsilon = \frac{N_{\text{rec}}}{N_{\text{gen}}} \]

\( \Lambda^0 \) signal is searched for in \( p\pi^- \) invariant mass spectrum. The background may be substantially suppressed by applying stringent selection criteria.
The decay topology of long lived $\Lambda^0$ is defined by the following parameters:

- distances of closest approach to the collision vertex $DCA_{\pi,p}(\chi^2_{\pi,p})$,
- two-track separation $DCA_{\Lambda}(\chi^2_{\Lambda})$,
- decay length $\lambda$,
- angle $\theta$.

**Selection criteria:**

\[
\chi^2_{\pi} > C_1 \land \chi^2_{p} > C_2 \land \chi^2_{\Lambda} < C_3 \land \lambda > C_4 \land \theta < C_5
\]

The parameters of the corresponding selections and of those for the $\chi^2$ values of both tracks are optimized by maximizing the signal significance:

\[
\text{sign} = \frac{S}{\sqrt{S + B}}
\]

where $S$ and $B$ are the estimated numbers of the signal and background events.
$\Lambda^0$ spectra after applying selection criteria

A higher $P_T$ threshold (e.g., 0.3 GeV/c) would reduce the detector efficiency. The efficiency drop due to selection cuts comes from the necessity to suppress the combinatorial background in order to obtain a clean invariant mass peak.
The inclusion of IT of either type in the MPD tracking system results in 60% increase of $\Lambda^0$ reconstruction efficiency at small $P_T < 600$ MeV.
Conclusions

- The capability of the tracking system for the NICA/MPD detector to reconstruct $\Lambda^0$ in central Au+Au collisions at 9A GeV was investigated for different IT layouts.

- The inclusion of the vertex tracker in the tracking system results in increasing of $\Lambda^0$ reconstruction efficiency at small transverse momenta.
Thank you for your attention!
Back up
Methods of Physical Experiment

Modeling of the Internal Tracking System of the NICA/MPD Detector

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Abstract—The internal tracking system of the NICA/MPD detector is aimed at efficiently detecting the short-lived products of nucleus—nucleus collisions. We consider various geometries of the internal tracking system based on microstrip silicon sensors and simulate its identification power in reconstructing the $\Lambda^0$ hyperons formed in central Au + Au collisions at $\sqrt{s_{NN}} = 9$ GeV.
Number of requisite sensors per layer for different IT options

<table>
<thead>
<tr>
<th>Layer number</th>
<th>4-layer It</th>
<th>5-layer IT</th>
<th>6-layer IT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Radius, mm</td>
<td>Number of ladders</td>
<td>Number of sensors</td>
</tr>
<tr>
<td>1</td>
<td>51.4</td>
<td>6</td>
<td>108</td>
</tr>
<tr>
<td>2</td>
<td>111.7</td>
<td>12</td>
<td>240</td>
</tr>
<tr>
<td>3</td>
<td>170.0</td>
<td>18</td>
<td>396</td>
</tr>
<tr>
<td>4</td>
<td>227.3</td>
<td>24</td>
<td>576</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
All DSSD ladders contain equal numbers of sectors built of one, two, or three standard 62 × 62 mm² sensors.
Estimating the occupancy of IT microstrip sensors

Signal pileup probability is nearly uniform for all sectors of a given ladder in Au–Au collisions at $\sqrt{s_{NN}} = 10$ GeV, not exceeding the level of 5%.
Pointing resolution for IT on the base of pixel sensors

Pointing resolution is getting better at low $P_T$ with increasing the number of layers.