A MAPS based Inner Tracking System of the Multi-Purpose Detector at the NICA collider

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The outline

- The physics case - an attempt to deconfine quarks through density fluctuations of the fireball under critical conditions
- A role of the rare probes (heavy hyperons and charmed mesons) in search of hints of critical point
- Transition from strips to pixels and the MAPS “invasion”
- The new ALICE ITS2 saves NICA a generation period
- The MPD ITS project and plans for its implementation
Look for a needle in a “hay” of tracks for rare events

The Inner Tracking System or Vertex tracker is a multilayer telescope which measures the position of particle hits positions to restore the track trajectory. It’s special task to be located as close as possible to the interaction point and to be as precise as possible to identify specific decays of particles carrying strangeness, charm or beauty i.e. S, C, or B - quarks.
To deconfine quarks: to heat or to enhance density fluctuations

2022 – 2025: SIS-100 FAIR

Interaction rate [Hz]

Collision energy \( \sqrt{S_{\text{NN}}} \) [GeV]

Energy region of max. baryonic density
The basic task for the Inner Tracking System

Identification of particles through inspection of Inverse Mass distributions

\[ M^2 = \text{sum}(E_i)^2 - \text{sum}(P_i)^2 \quad (c=1) \]
The MAPS "Invasion"

Owing to the industrial development of CMOS imaging sensors and the intensive R&D by HEP community

... several HI experiments have selected CMOS pixel sensors for their inner trackers and intensive R&D for ATLAS

STAR HFT
0.16 m² – 356 M pixels

CBM MVD
0.08 m² – 146 M pixel

ALICE ITS Upgrade (and MFT)
10 m² – 12 G pixel

sPHENIX
0.2 m² – 251 M pixel
New ALICE ITS#2: sharing of technology

A new ITS: closer to IP, thinner, higher position resolution

- Closer to IP: 39mm ➔ 22mm
- Thinner: ~1.14% ➔ ~ 0.3% (for inner layers)
- Smaller pixels: 50µm × 425µm ➔ 27µm × 29µm
- Increase granularity: 20 chan/cm³ ➔ 2k pixel/cm³
- Faster readout: x 10² Pb-Pb, x 10³ pp
- 10 m² active silicon area: 12.5 G-pixels, σ ≈ 5µm

ALPIDE (ALICE Pixel Detector) - Developed for the ALICE upgrade (ITS and MFT) will be used (or it is proposed) for several other HEP detectors and non-HEP applications

NICA MPD (@JINR)  sPHENIX (BNL)  proton CT (tracking)  CSES – HEPD2  ...

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The ALPIDE sensor

ALICE CMOS Pixel Sensor

CMOS Pixel Sensor using 0.18µm CMOS Imaging Process

- High-resistivity (> 1kΩ cm) p-type epitaxial layer (25µm) on p-type substrate
- Small n-well diode (2 µm diameter), ~100 times smaller than pixel => low capacitance (~fF)
- Reverse bias voltage (-6V < V_{BB} < 0V) to substrate (contact from the top) to increase depletion zone around NWELL collection diode
- Deep PWELL shields NWELL of PMOS transistors

Pixel capacitance ≈ 5 fF (@ V_{bb} = -3 V)

C_{in} ≈ 5 fF

Q_{in} (MIP) ≈ 1300 e^{-} \Rightarrow V \approx 40 mV

2 x 2 pixel volume

collection electrode

Epitaxial Layer P-
Substrate P++
NA \approx 10^{16}

Artistic view of a
SEM picture of
ALPIDE cross section

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The ALPIDE Readout

ALICE Pixel DEtector (ALPIDE)

- 1024 pixel columns
- 512 rows
- 50μm thick
- 30mm x 15mm
- Pixel matrix
- Pads over matrix
- Bias, Data Buffering, Interface

Signal processing circuitry integrated in pixel matrix

- 130,000 pixels/cm² 27x29x25 μm³
- Charge collection time < 30ns (Vᵇᵇ = -3V)
- Max particle rate: 100 MHz/cm²
- Fake-hit rate: < 1 Hz/cm²
- Power: ≈ 300 nW/pixel (< 40 mW/cm²)

Matrix Layout

Pixel Layout

L. Musa (CERN) – International Winter Meeting on Nuclear Physics, Bormio, 8-11 Jan 2019

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New ALICE ITS#2 beats records on material budget

ALICE Pixel Detector (ALPIDE)

Inner Barrel Production completed and all layers assembled

Inner half-barrel

Material budget

Single stave, perpendicular tracks

Tilted staves with overlap, inclined tracks

Mean X/σ = 0.260%

Mean X/σ = 0.358%

L. Musa (CERN) – International Winter Meeting on Nuclear Physics, Bormio, 8-11 Jan 2019
New ALICE ITS#2: ......and number of pixels

ALICE Pixel DEtector (ALPIDE)

102 Million pixel, average noise uniform ~ 5e

Layer-4

Layer-6

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Plans for ALICE ITS#3: exchange of the IB

Vertex Detector (innermost 3 layers)

Truly cylindrical vertex detector

Pipe: \( r \approx 16 \text{mm}, \Delta R = 0.5 \text{mm} \)
\( L_0: r \approx 18 \text{mm}, L_1: r \approx 24 \text{mm}, L_2: r \approx 30 \text{mm} \)

Layers supported by high-thermal conductive carbon foam

Open cell carbon foam

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Stage I: **TPC, TOF, ECAL, ZDC, FFD + ITS(OB)**

Stage II: **ITS(IB) + EndCap (CPC, Straw, TOF, ECAL)**

MPD-ITS (OB) is now recognized at Stage I

Transfer of High Tech Instrumentation Know-How from CERN to NICA-MPD

Stage I: *overall commissioning starts in 2022 (t.b.c.)*

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CERN will procure, test and deliver to NICA

- 19'000 ALPIDE Monolithic Active Pixel Sensors for the MPD ITS
- 4'500 SAMPA electronic circuits for the TPC readout
- 5'000 FEAST DC/DC converters for the ECAL MPD
- Jigs and fixtures for module and supermodule assembly for the MPD ITS
- Training of personal for assembly and QA certification modules and supermodules of the MPD ITS
- Provision of complete technical and commercial information on parts of the new ALICE Inner Tracking System, including drawings, internal technical reports, quotes, etc.
MPD ITS based on the ALPIDE MAPS CERN technology

Beam pipe $\varnothing = 40$ mm
ITS pointing resolution within STAR–ALICE toy model

R-\(\phi\) Pointing Resolution vs. Pt

ALICE

MPD

R-\(\phi\) Pointing Resolution vs. Pt

New ITS

Old ITS

\(\varnothing = 40 \text{ mm}\)

\(\varnothing = 50 \text{ mm}\)

\(\varnothing = 60 \text{ mm}\)

Pions

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Selection criteria

$D^0$ selection parameters:
- distances of closest approach to the collision vertex $DCA_{\pi,K}$,
- two-track separation $DCA_D$,
- decay path $\lambda_D$,
- pointing angle $\theta_D$.

Selection criteria:
$DCA_{\pi} > C_1 \& \& DCA_K > C_2 \& \& DCA_D \leq C_3 \& \& \lambda_D > C_4 \& \& \theta_D < C_5$

The parameters of the corresponding selections are optimized by maximizing the signal significance:

$Sg(a) = \int_{0}^{a} \frac{S}{\sqrt{S + B}} da$

where $S$ and $B$ are the estimated numbers of the signal and background events.
Example: cuts selections for $D^0$

$\text{dca}_K > 0.01 \text{ cm} \& \text{dca}_\pi > 0.01 \text{ cm} \& \text{dist}_{\pi K} < 0.02 \text{ cm} \& \text{path}(D^0) > 0.025 \text{ cm} \& \text{angle}(D^0) < 0.2 \text{ rad}$
**D^+ and D^0 reconstruction**

\[ t_1 = t_2 = t_3 = 50 \mu \text{ (IB ITS3)} \quad t_4 = t_5 = 700 \mu \text{ (OB ITS2)} \]

M(\pi^+,K^-): signal+background(100M)

\[ S/\sqrt{B+S} = 5.3 \]

S/B = 0.1
S = 380
Eff = 0.8%

M(D^0) = 1.8650 \pm 0.0002 \text{ GeV}
\sigma(D^0) = 0.016 \pm 0.001 \text{ GeV}

M(\pi\pi K): signal+background(100M)

\[ S/\sqrt{B+S} = 7.0 \]

S/B = 0.12
S = 440
Eff = 0.5%

M(D^+) = 1.866 \pm 0.002 \text{ GeV}
\sigma(D^+) = 0.016 \pm 0.001 \text{ GeV}

DCA(\pi, K, D^0), path(D^0), angle(D^0) cuts
Strange particle reconstruction results

\[ M(\pi,\rho): \text{signal+background (5K)} \]

Counts

\[ 4 \times 10^3 \]

\[ 4 \times 10^2 \]

\[ 4 \times 10^1 \]

\[ 4 \times 10^0 \]

\[ 4 \times 10^{-1} \]

\[ 4 \times 10^{-2} \]

\[ 4 \times 10^{-3} \]

\[ M(\pi,\rho), \text{GeV} \]

\[ M(\Lambda,\pi): \text{signal+background (5K)} \]

Counts

\[ 45 \]

\[ 40 \]

\[ 35 \]

\[ 30 \]

\[ 25 \]

\[ 20 \]

\[ 15 \]

\[ 10 \]

\[ 5 \]

\[ 0 \]

\[ M(\Lambda,\pi), \text{GeV} \]

\[ M(\Lambda,K^-): \text{signal+background (1M)} \]

Counts

\[ 900 \]

\[ 800 \]

\[ 700 \]

\[ 600 \]

\[ 500 \]

\[ 400 \]

\[ 300 \]

\[ 200 \]

\[ 100 \]

\[ 0 \]

\[ M(\Lambda,K^-), \text{GeV} \]

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**Impact of Beam pipe diameter on efficiency**

D-meson parameters in 100M central Au+Au collisions at $\sqrt{s_{NN}} = 9$ TeV

<table>
<thead>
<tr>
<th>Particle</th>
<th>$D^0$</th>
<th>$D^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decay channel</td>
<td>$D^0 \rightarrow K^- + \pi^+$</td>
<td>$D^+ \rightarrow K^- + \pi^+ + \pi^+$</td>
</tr>
<tr>
<td>Multiplicity (HSD)</td>
<td>$10^{-2}$</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>BR, %</td>
<td>3.9</td>
<td>9.1</td>
</tr>
<tr>
<td>IB option</td>
<td>ITS3(50(\mu))</td>
<td>ITS2(200(\mu))</td>
</tr>
<tr>
<td>S/B(2(\sigma))</td>
<td>0.43</td>
<td>0.10</td>
</tr>
<tr>
<td>Significance</td>
<td>15.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Efficiency, %</td>
<td>1.9</td>
<td>0.13</td>
</tr>
</tbody>
</table>
Current limitations of experimental data on D meson

Thermal generator: D meson’s $p_t$ - spectrum

Abdel Nasser TAWFIK† and Ehab ABBAS
Thermal Description of Particle Production in Au-Au Collisions at STAR Energies

Yu. Murin for the MPD ITS Team
MC and reconstructed $p_t$-spectra of $D^0$-mesons and their decay products

- **D$^0$ mesons**
- **Pions**
- **Kaons**
Stage I: Installation of OB (2022-23)

Stage II: OB+IB (2022+25)?

~ 9 500 ALPIDE MAPS in 5 cylinders of 2 barrels

4,9 \times 10^9 pixels, active area 3,9 m^2.

Stage I: 64 mm in diameter

Stage II: 38 mm in diameter
Current Activities
1. Mechanics for integration of ITS with Beam Pipe and TPC - JINR
Current Activities

2. Start production of ultralight CF mechanics in SPbSU and VBLHEP
Truss length is 1540 mm. Modules (HICs) are located on two cooling plates. OB stave carriers 196 sensors. The MPD ITS need is 42 OB staves.

Current Activities
3. Start Assembly of HICs in Dubna and China (2020 Q1) and Staves (2021 Q1)
Planned Activities

4. Development of ITS3 together with ALICE ITS3 team
Planned Activities
5. Preparing the Technical Design Report and Organization of the MPD ITS Consortium

Technical Design Report

The Inner Tracking System
of the MPD experiment

Dec. 2019
Conclusions and summary
major milestones of the MPD ITS project (tentatively!)

- **2018 – 2019** – simulations and start of delivery of parts from CERN
- **2019** – organization of the Russian-Chinese Consortium
- **2019** – Writing TDR (Draft)
- **2019-2020** – Production of first HICs at VBLHEP and CCNU
- **2020 – 2021** – Mechanics including parts for integration
- **2020 – 2021** – updating the readout chain (with China and ?)
- **2020 – 2023** – R@D effort on IB together with ALICE
- **2021 – 2023** – Production HICs, assembly of OB staves (with China)
- **2023 (?)** – ITS-OB assembly, bench testing, commissioning
- **2025 (?)** – ITS-OB+IB commissioning (Stage II)
The MPD-ITS project is both scientific- and time-wise well justified.

The project has a solid reason to be accomplished in two stages.

The MPD-ITS(OB) (stage 1) one is now recognized and approved for financing at JINR.

The MPD-ITS(IB) (stage 2) contains R@D proposed to be performed under the supervision of ALICE Collaboration (ITS-3).

The project effort due to its technical complexity cannot be undertaken by JINR alone and calls for organization of a Consortium of Institutes from Russia and China (and elsewhere!) functioning at least till 2025.
Thank you for attention and RFBR for GRANT # 18-02-401119!