ALICE technologies proposed for the VD of NA61/SHINE in connection to the future MPD Si tracker

Grigory Feofilov, Sergey Igolkin, Vladimir Zherebchevsky, Dmitri Nesterov, Nikita Prokofiev, Nikolay Maltsev, Alina Rahmatullina
Saint-Petersburg State University

The NICA days 2019 and IVth MPD Collaboration Meeting,
21-25 October 2019, CZiITT, Warsaw
https://indico.cern.ch/event/802303/overview
https://indico.cern.ch/event/802303/contributions/3605935/
Reported by Grigory Feofilov, Tuesday, 22.10.2019 ,MPD/NA61 Joint Session, 15:35-15:55

Job is partially supported by RFBR grant #18-02-40097
Why heavy quarks are one of the main motivations?

- Study the early stages in heavy-ion collisions
- Probe to study thermalization of Quark Gluon Plasma (QGP)
- Microscopic insight into transport properties of the medium

Challenges for open charm at SPS and NICA
Physics motivations and the first feasibility studies for open charm measurements with NA61/SHINE

NA61/SHINE simulations


Based on models:

- HSD(Hadron String Dynamics model) Int.J.Mod.Phys.E17 1367

→ see the report by Pawel Staszel at this conference
Matter induced changes in the yield of quarkonia

1986  Charmonim suppression in AA collisions
• All charmonia are produced before QGP formation
• Suppression takes place in QGP
• Some charmonia may survive beyond Tc

2013 Mechanisms contributing to matter induced changes in the yield of quarkonia:
Color screening (upper left);
ionization by thermal gluons (lower left);
and recombination (right)

(Berndt Müller, arXiv:1309.7616)

→ see also the report by Pawel Staszel at this conference
Challenges for open charm measurements

Reconstruction from hadronic decay channels

Challenge-1: Short life-time

<table>
<thead>
<tr>
<th>Meson</th>
<th>Decay Channel</th>
<th>Cτ</th>
<th>Branching Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>D⁰</td>
<td>D⁰ → K⁻ + π⁺</td>
<td>122.9μm</td>
<td>(3.91±0.05)%</td>
</tr>
<tr>
<td>D⁰</td>
<td>D⁰ → K⁻ + π⁺ + π⁺ + π⁻</td>
<td>122.9μm</td>
<td>(8.14±0.20)%</td>
</tr>
<tr>
<td>D⁺</td>
<td>D⁺ → K⁻ + π⁺ + π⁺</td>
<td>311.8μm</td>
<td>(9.2±0.25)%</td>
</tr>
<tr>
<td>D⁺</td>
<td>D⁺ → K⁻ + K⁺π⁺</td>
<td>149.9μm</td>
<td>(5.50±0.28)%</td>
</tr>
<tr>
<td>D⁺⁺</td>
<td>D⁺⁺ → D⁰ + π⁺</td>
<td>--------</td>
<td>(61.9±2.9)%</td>
</tr>
</tbody>
</table>

Vito Manzari, LXV Conf.Nucl.Phys., 29.06-03.07.2015, SPb
Challenge-2: Low yields
General requirements for open charm measurements:

1) Precise vertexing (at the level of better ~20 -30μm for particles with pT~ 1 GeV/c)
2) Fast detectors (< 30 μs) with high granularity
3) The low material budget (<0.3% X\Xo)
4) Large acceptance is desirable to accept 100% of the D0s produced and to match the VTPC-1 of NA61/SHINE

.Vertex Detector projects are based on novel CMOS pixel detectors (Monolyth Active Pixel Sensors – MAPS)

--- see the report by Vladimir Zherebchevsky at this conference
Challenges faced by the Vertex Detectors

Impact parameter ($d_0$) resolution in particle tracking

\[ \sigma_{d_0}^2 = \sigma_{MS}^2 + \sigma_{geom}^2 \]

with

\[ \sigma_{geom}^2 = \left( \frac{\sigma_1 r_2}{r_2 - r_1} \right)^2 + \left( \frac{\sigma_2 r_1}{r_2 - r_1} \right)^2 \]

and

\[ \sigma_{MS}^2 = \sum_{j=1}^{n_{scatt}} (R_j \Delta \Theta_j)^2 \]

Example with two layer setup:

Multiple Scattering (MS):

\[ \sigma_{d_0} = \frac{r}{p} 13.6 \text{MeV} \sqrt{\frac{x}{X_0}} \left[ 1 + 0.038 \log \left( \frac{x}{X_0} \right) \right] \]

Very important!

- High coordinate resolution sensors are required (minimize $\sigma_1$ and $\sigma_2$)
- The first layer should be placed close to interaction point (IP) -- decrease $r_1$
- The multiple scattering should be minimized by the application of low mass, low Z materials to provide the minimal possible $X/X_0$
Challenges faced by the Inner Tracking System (ITS) design for ALICE in 1992

The challenges forced the controversial requirements in 1992(!):

- 10 micron accuracy in positioning of Si-detectors, thermo and mechanical stability
- 10 kW of power drain produced by the front-end electronics
- Ambient operational temperature of the ITS and minimum influence on the temperature field of the surrounding TPC
- 0.1 deg temperature stability of Si-drift detectors (!?)
- X/Xo per layer ~ 1% (!)

The ITS-1 performance in 2008-2018

Distribution of the energy-loss signal in the ITS as a function of momentum.

Inner Tracking System
(SPDD,SDD,SSD – 6 layers between 39 and 430 mm)

10 years of successful performance!
Minimal material budget of the ITS-1: $X/X_0 < 1\%$ per layer

- It is a result of the extensive R&D and engineering in development and application of the Carbon Fiber Composite technology for the extra lightweight, thermo- and mechanically stable ITS cooling-mechanics-alignment system for ALICE (ITS-CMA).

- The improved Carbon Fiber Composite technology is proposed for the ITS-2 and is being applied for the NA61/SHINE. It is also proposed for the MPD/NICA.
Design goals that are met for the ITS-2:

1. Coverage in transverse momentum to be as complete as possible, in particular down to zero momentum.

2. Very accurate identification of secondary vertices from decaying charm or beauty (D, J/ψ, Λ_c, Λ_b).

Comparison of ALICE, ATLAS and CMS upgrade

<table>
<thead>
<tr>
<th></th>
<th>current ALICE</th>
<th>ALICE upgrade</th>
<th>ATLAS upgrade</th>
<th>CMS upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>innermost point (mm)</td>
<td>39.0</td>
<td>22.0</td>
<td>25.7</td>
<td>30.0</td>
</tr>
<tr>
<td>x/X₀ (innermost layer)</td>
<td>1.14%</td>
<td>0.3%</td>
<td>1.54%</td>
<td>1.25%</td>
</tr>
<tr>
<td>d₀ res. rφ (μm) at 1 GeV/c</td>
<td>60</td>
<td>20</td>
<td>65</td>
<td>60</td>
</tr>
<tr>
<td>hadron ID p range (GeV/c)</td>
<td>0.1–3</td>
<td>0.1–3</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>
Precise identification of secondary vertices

Impact parameter \(~100\mu m\)

Schematic view of the D0 decay in the $D^0 \rightarrow K^-\pi^+$ channel.

Impact parameter resolution

Tracking efficiency (ITS standalone)
Extra Lightweight Detector Support Structures for a New Generation of Vertex Detectors

ALICE Outer Barrel Stave

Based on high resistivity epitaxial layer
Monolithic Active Pixel Sensors (MAPS)

3 Inner Barrel layers (IB)
4 Outer Barrel layers (OB)

Radial coverage: 21-400 mm

\sim 10 \text{ m}^2

| | < 1.22 over 90% of the luminous region

0.3\% X_0/layer (IB)
0.8 \% X_0/layer (OB)

Radiation level (IB, layer 0): TID: 2.7 Mrad,
1.7 \times 10^{13} 1 \text{ MeV} n_{eq} \text{ cm}^{-2}

Installation during LS2
Today: assembly and commissioning of the outer layers of the modified ITS-2—the work is going on in the period January-October 2019 according to the plan. More then 90% modules of the ITS-2 are tested;

ITS-2 Commissioning Shifts at CERN -- 29 shifts have been done by SPbSU participants

Development of the new test facility for the novel cooling scheme of the future ITS-3 is under preparations at the SPbSU
Inner Barrel (ITS-2)

Material thickness per detector layer: ~ 0.3% $X_0$
ALICE technology for ITS-2 Inner Barrel:

Record level of radiation transparency $X/X_o < 0.3\%$

Technology is proposed and is used for the NA61/SHINE VD and could be used at NICA

Thickness of detector components in terms of fraction of radiation length $X/X_o$

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness ($\mu$m)</th>
<th>$X_o$ (cm)</th>
<th>$X/X_o$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyimide cooling pipe wall</td>
<td>25 $\mu$m</td>
<td>28.41</td>
<td>0.003</td>
</tr>
<tr>
<td>Carbon fleece</td>
<td>40 $\mu$m</td>
<td>106.8</td>
<td>0.004</td>
</tr>
<tr>
<td>Water</td>
<td>1mm</td>
<td>35.76</td>
<td>0.032</td>
</tr>
<tr>
<td>Carbon fiber plate K13D2U</td>
<td>70 $\mu$m</td>
<td>26.08</td>
<td>0.027</td>
</tr>
<tr>
<td>Graphite foil</td>
<td>30$\mu$m</td>
<td>26.56</td>
<td>0.011</td>
</tr>
<tr>
<td>Thermal grease (glue)</td>
<td>100$\mu$m</td>
<td>44.37</td>
<td>0.023</td>
</tr>
<tr>
<td>Si-sensor</td>
<td>50$\mu$m</td>
<td>9.36</td>
<td>0.064</td>
</tr>
<tr>
<td>Total (without FPC)</td>
<td></td>
<td></td>
<td>0.154</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>&lt;0.3</strong></td>
</tr>
</tbody>
</table>
Material budget of CF stave for VD NA61

--- polyimide cooling pipe (D=1mm)
--- carbon fleece (20 μm)
--- graphite foil (30μm)
--- carbon fiber plate K13D2U (70 μm)

--- thermal greese
--- Si-sensor (50μm)

Estimated contributions to the material budget

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (μm)</th>
<th>X₀ (cm)</th>
<th>X/X₀ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyimide cooling pipe wall</td>
<td>25 μm</td>
<td>28.41</td>
<td>0.003</td>
</tr>
<tr>
<td>Carbon fleece</td>
<td>40 μm</td>
<td>106.8</td>
<td>0.004</td>
</tr>
<tr>
<td>Water</td>
<td>1mm</td>
<td>35.76</td>
<td>0.032</td>
</tr>
<tr>
<td>Carbon fiber plate K13D2U</td>
<td>70 μm</td>
<td>26.08</td>
<td>0.027</td>
</tr>
<tr>
<td>Graphite foil</td>
<td>30μm</td>
<td>26.56</td>
<td>0.011</td>
</tr>
<tr>
<td>Thermal greese (glue)</td>
<td>100μm</td>
<td>44.37</td>
<td>0.023</td>
</tr>
<tr>
<td>Si-sensor</td>
<td>50μm</td>
<td>9.36</td>
<td>0.064</td>
</tr>
<tr>
<td>Total (without FPC)</td>
<td></td>
<td></td>
<td>0.154</td>
</tr>
<tr>
<td>Total with FPC</td>
<td></td>
<td></td>
<td>&lt;0.3</td>
</tr>
</tbody>
</table>

➢ Technology is proposed for the NA61/SHINE VD
Small Acceptance VD layout

VD housing box filled with He

Mimosa-26 sensors mounted on extra-lightweight CF cooling panels

C-shape support frames
Small Acceptance VD (SAVD) of the NA61/SHINE at the pilot run at the SPS in 2016

- Left: VD installed between beam pipe and first Vertex TPC (window removed)
- Target to be mounted inside VD enclosure

- Right: close-up of stations/ladders with sensors inside VD
- Sensors attach to feed-throughs in enclosure

→ see also the reports by Pawel Staszel at and by Dariusz Tefelski at this conference
6 planes for NA61 VD/SHINE

PRIORITIES

- The innermost layers (closest to the vertex) should have the highest granularity and the lowest material budget (and low Z materials)
- TPC-VD track matching
- High-precision (~ 10-20 mkm) determination of secondary vertices for D0, strange and also multi-strange particles...
The setup in preparation for application of ALPIDE sensors to be used in the NA61/SHINE LAVD
One of the possible solutions:

1. **Use ALICE MAPS — sensors ALPIDE**
2. Use carbon ultra-lightweight support and cooling structures developed for the upgrade of ALICE at the LHC

--- see the report by Vladimir Zherebchevsky at this conference
Tooling for Carbon Fiber 30 cm staves production at the SPbSU
ALICE concept for the next generation heavy-ion experiment at the LHC

EoI document, Dec 2018, is submitted to European Strategy for Particle Physics Preparatory Group (arXiv: 1902.01211)

- The aim is to build a nearly massless barrel detector (ITS-3) consisting of truly cylindrical layers based on **Curved wafer-scale ultra-thin silicon sensors with MAPS technology**, featuring an unprecedented low material budget of **0.05% X/Xo per layer**
- The R&D is started
- High potential for applications at NICA!

Photo: from the report by L. Musa (CERN) – SQM, Bari, 10-15 June 2019
Summary:

1) The ITS/ALICE technology is being applied for the NA61/SHINE VD:

2) the record level of radiation transparency <0.3% X/Xo for the innermost layers can be achieved to ensure ~10-20 μ accuracy in secondary vertices determination

3) The ITS/ALICE technology provides the possibility of easy replacement of detector staves and keeping ~10 μ positioning accuracy

4) Flexibility to add layers of detectors

5) Prototyping of the mechanical layout of the LAVD in the ALICE/ITS technology is ongoing.

6) Technology is proposed for NICA experiments
Back-up slides
Primary vertex resolution December pilot run

From the slides on the VD data analysis by Pawel Staszel

\[ \chi^2 / \text{ndf} \quad 59.66 / 23 \]
\[ \text{Const} \quad 134.1 \pm 5.3 \]
\[ \text{Mean} \quad 0.0001088 \pm 0.0003050 \]
\[ \text{Sigma} \quad 0.01029 \pm 0.00027 \]

\[ \chi^2 / \text{ndf} \quad 38.39 / 11 \]
\[ \text{Const} \quad 243.2 \pm 9.8 \]
\[ \text{Mean} \quad -0.0001043 \pm 0.0001085 \]
\[ \text{Sigma} \quad 0.003575 \pm 0.000096 \]

\[ \chi^2 / \text{ndf} \quad 3 \]
\[ \text{Const} \quad 13 \]
\[ \text{Mean} \quad 0.0013 \]
\[ \text{Sigma} \quad 0.06371 \pm \]

\[ \sigma_x \sim 10 \mu \quad \sigma_y \sim 3 \mu \quad \sigma_z \sim 63 \mu \]

Work for D0s is in progress!
Motivation for open charm

As a tool to study the formation of a deconfined medium formed in high energy AA collisions – to test the color screening effects on binding of charm quarks to color neutral J/psi production [1]

Fig.1 Schematic view of J/psi production in pp collisions (see [2])


→ see also the report by Pawel Staszel at this conference