Open charm measurements in NA61/SHINE at the CERN SPS

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for the NA61/SHINE Collaboration

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Outline

1. Introduction
2. Physics motivation for Charm measurements
3. Performance of Small Acceptance Vertex Detector
4. Proposed measurements beyond LS2
Introduction
NA61/SHINE Experiment

Beam detectors and triggering → a set of upstream scintillator and Cherenkov counters and beam Position detectors provides timing reference, charge and position measurements

Time Projection chambers → four large four small volume TPC's serve as tracking detectors, provide PID

Time of Flight walls → used for hadron identification

Projectile Spectator Detector (PSD) → a calorimeter which is positioned downstream of the time of flight detectors measure energy of projectile fragments.

Small Acceptance Vertex Detector → precise tracking close to the target

Beams:
- ions (Be, Ar, Xe, Pb) $\rho_{beam}=13A-150A \text{ GeV/c}$
- hadrons (n, K, p) $\rho_{beam}=13-400 \text{ GeV/c}$
- $\sqrt{s_{NN}}= 5.1-16.8 \text{ (27.4) GeV}$
Physics motivation
Model predictions for $\langle c\bar{c} \rangle$ in central Pb+Pb at 150A GeV/c

- Different models differ in predictions of $\langle c\bar{c} \rangle$ by factor $\approx 50$
- To discriminate models the $\langle c\bar{c} \rangle$ produced in full phase space is needed → measurement of open charm mesons

HSD
Linnyk, Bratkovskaya, Cassing, IJMP E17 1367

pQCD
Gavai et al. IJMP A 10 2999
Braun-Munzinger, J. Stachel, PLB 490, 196

HRG, Quark Coalesc. Stat.
Gavai et al. IJMP A10 2999
Braun-Munzinger, J. Stachel, PLB 490, 196

Quark Coalesc. Dyn.
Levai, Biro, Csizmadia, Csorgo, Zimanyi, JP G27, 703

SMES
Gazdzicki, Gorenstein, APP B30, 2705
Measurements of $\langle c\bar{c}\rangle$

0-20% Pb+Pb at 150A GeV/c

Hadrons containing charm considered for measurements in NA61/SHINE

<table>
<thead>
<tr>
<th>Hadron</th>
<th>Decay channel</th>
<th>$c\bar{c}$ [μm]</th>
<th>BR</th>
</tr>
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<tbody>
<tr>
<td>$D^0$</td>
<td>$\pi^+ + K^-$</td>
<td>123</td>
<td>3.89%</td>
</tr>
<tr>
<td>$D^+$</td>
<td>$\pi^+ + \pi^+ + K^-$</td>
<td>312</td>
<td>9.22%</td>
</tr>
<tr>
<td>$D_s^+$</td>
<td>$\pi^+ + K^- + K^+$</td>
<td>150</td>
<td>5.50%</td>
</tr>
<tr>
<td>$\Lambda_c$</td>
<td>$p + \pi^+ + K^-$</td>
<td>60</td>
<td>5.00%</td>
</tr>
</tbody>
</table>

Measuring $D^0$, $\bar{D}^0$, $D^+$, $D^-$ provides good $\langle c\bar{c}\rangle$ estimate

PHSD, Elena Bratkovskaya & Taesoo Song, private communication
J/ψ suppression as signal of deconfinement

Medium reduces probability of J/ψ production


Data was interpreted in terms of final state interaction in the deconfined medium created in nucleus-nucleus collisions.

To validate this interpretation we need to control experimentally $\langle c\bar{c} \rangle$ -> measurements of Open Charm!!!
Performance of Small Acceptance Vertex Detector (SAVD)
Vertex Detector tests with Pb+Pb at 150A GeV/c

SAVD:
- 16 MIMOSA-26 sensors located on 2 horizontally movable arms.
- Target holder integrated with SAVD base plate

Achieved goals:
- tracking in the large track multiplicity environment
- precise Primary Vertex reconstruction
- TPC and SAVD track matching
- first search for $D^0$ signal
Main project components

MIMOSA-26AHR
- 1152x576 pixels of 18.4x18.4µm²
- 3.5 µm resolution, 0.05% $X_0$
- Readout time: 115.2 µs, 50µm thin
PICSEL Group, IPHC Strasbourg

ALICE ITS ladder
- Ultra light carbon fibre
- < 0.3% $X_0$ including water cooling
St. Petersburg, CERN

CBM Micro Vertex Detector Prototype
- Sensor integration
- Flex print cables, Front-end boards
- Read-out based on TRB3 FPGA Board
Goethe University Frankfurt am Main
Main project components (c.d.)

System integration and project leadership:
Jagiellonian University Krakow,
supported by AGH Krakow, WUT Warsaw
Why Vertex Detector is needed to measure open charm?

$D^0 \rightarrow \pi^+ + K^-$

- Daughters of $D^0$ ($\pi$ and $K$) are recognized as a pair forming a secondary vertex displaced from the primary vertex
- $c\tau(D^0) \approx 122$ $\mu$m, however, due to Lorentz boost ($\beta\gamma \approx 10$) the displacement is on the level of 1 mm.
- This holds also for other charm mesons like $D^+$, $D^-$, $D^+_s$
- The Lorentz Boost makes the measurements significantly easier than in case of collider experiments

Vertex detector is needed to reconstruct **primary vertex** and **secondary vertexes** with high precision.
Vertex Detector performance

Spacial resolution of the sensor $< 5\mu m$ as expected

\[ \sigma_{x/y} = \sqrt{\frac{2}{3}} \sigma_{dev_{x/y}} \]

Reconstruction of primary vertex allows to separate in- and out-target interactions

Spacial primary vertex resolution:
- $\sigma_x = 5 \mu m$
- $\sigma_y = 1.8 \mu m$
- $\sigma_z = 30 \mu m$

Worse resolution in $x$ due to presence of magnetic field $(B_y)$
VD – TPC track matching

Extrapolate SAVD tracks to TPC volume.

Pre-selection: cut on y-slopes of tracks.

After cuts on dx and dy clear correlation peaks are seen in $d\rho_x$ and $d\rho_z$.

Matching with TPC provides: momenta and PID to VD tracks

$\rightarrow$ invariant mass distribution
VD: search for $D^0$

First results for 140k (trigger set for detector test → not precise centrality measurement)

Background suppression → cuts on:
1. track $p_T$
2. track impact parameter $d$
3. longitudinal distance $V_z$ (pair vertex to primary vertex)
4. parent impact parameter $d_p$

Analysis details:
1. Global fit (VD+TPCs) using Kalman Filter
2. PID not used yet (should reduce background by factor of 5)

$\sigma_{D^0}=14.6 \pm 3.2$ MeV

yield = $62 \pm 19$

Allocated beam time in 2018: 10M 0-20% central Pb+Pb → 2.5k $D^0 + \bar{D}^0$
Performance for Xe+La at 150A GeV/c

- Large statistic Xe+La data taken in late 2017 at 150A and 75A GeV/c for minimum bias and 0-20% central events.

- Segmented target was used (tree 1mm thick La blocks squeezed together). The structure of the target can be well seen in the $z_{\text{prim}}$ distribution plot.

- Obtained primary vertex resolution: 1.3, 1.0 and 15 $\mu$m in $x$, $y$ and $z$ coordinate, respectively. Significant improvement as compare to test measurement due to better setup of sensor thresholds.

- Xe+La data should allow for reinterpretation of $J/\psi$ yields measured by NA60 for medium size systems.
Proposed measurements beyond LS2
LS2 upgrades of NA61/SHINE setup

For details of upgrade of VD see poster of A. Merzlaya

Construction of Vertex Detector (VD) for $D^0$, $\overline{D^0}$ decay reconstruction

Replacement of the TPC read-out electronics to increase data rate to 1 kHz

New trigger and data acquisition system

New Time-of-Flight detectors

Upgrade of Projectile Spectator Detector

Upgrades are needed to increase rate capability of NA61/SHINE by one order of magnitude to 1 kHz
Anticipated results

- Precise measurements of charm hadron production by NA61/SHINE are expected to be performed in 2022-2014 (see tables in A. Merzlaya poster).

- The Lorentz boost makes the measurements significantly easier than in case of collider experiments.

- Unlike in a typical collider experiment the acceptance extends down to $p_T=0 \rightarrow$ accurate measurements of total charm meson yields.

The proposed program will allow to perform systematic study of $D^0$, $\bar{D}^0$, $D^+$, $D^-$, $(D^+_s)$ production versus collision energy and centrality.
Uniqueness of NA61/SHINE program

- **LHC** and **RHIC** at high energies ($\sqrt{s_{NN}} \geq 200$ GeV): significantly limited acceptance due to collider kinematics and related detector geometry

- **RHIC BES** collider and fixed-target ($\sqrt{s_{NN}} = 3–39$ GeV): measurement not considered in the current program

- **NICA** ($\sqrt{s_{NN}} < 11$ GeV): measurements during stage 2 (after 2023) are under consideration (overlap in energy with NA61/SHINE)

- **J-PARC-HI** ($\sqrt{s_{NN}} \leq 6$ GeV): under consideration, may be possible after 2025.

- **FAIR SIS-100** ($\sqrt{s_{NN}} < 5$ GeV): sub-threshold charm production measurements are considered. Systematic charm measurements are planned with SIS-300

→ only NA61/SHINE is able to measure open charm in heavy ion collisions in full phase space in the near future
Summary

NA61/SHINE open charm production measurements started in 2017 with SAVD → expected first physics results soon

After LS2 high statistic Pb+Pb data taking with upgraded detector is proposed

The results from high statistic runs are expected to:

• distinguish between many existing models of charm production in Pb+Pb collisions
• initiate a measurement of collision energy dependence of open charm yield
• verify signal of the QGP formation by measurements of centrality dependence of charm production
Backup slides
Measurement program with SAVD

2016: Pb+Pb at 150A GeV/c
- Detector commissioning
- Good detector performance
- D⁰ likely seen

2017: Xe+La at 75 and 150A GeV/c
- Improved sensor efficiency
- Improved primary vertex resolution (dx=1.3µm, dy=1.0µm, dz=15µm)
- Large statistics collected:
  - 5.1 MEvents@150AGeV/c
  - 4.0 MEvents @75A GeV/c
- Analysis ongoing, expected good data quality
- Expected open charm data suited for comparison with NA61/SHINE

2018: Pb+Pb at 150A GeV/c run scheduled
## Request for Open Charm measurements

<table>
<thead>
<tr>
<th>Year</th>
<th>Beam</th>
<th>#days</th>
<th>#events</th>
<th>#(D^0 + Dbar^0)</th>
<th>#(D^+ + D^-)</th>
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</thead>
<tbody>
<tr>
<td>2022</td>
<td>Pb at 150A GeV/c</td>
<td>42</td>
<td>250M</td>
<td>38k</td>
<td>23k</td>
</tr>
<tr>
<td>2023</td>
<td>Pb at 150A GeV/c</td>
<td>42</td>
<td>250M</td>
<td>38k</td>
<td>23k</td>
</tr>
<tr>
<td>2024</td>
<td>Pb at 40A GeV/c</td>
<td>42</td>
<td>250M</td>
<td>3.6k</td>
<td>2.1k</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>0–10%</th>
<th>10–20%</th>
<th>20–30%</th>
<th>30–60%</th>
<th>60–90%</th>
<th>0–90%</th>
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</thead>
<tbody>
<tr>
<td>#(D^0 + Dbar^0)</td>
<td>31k</td>
<td>20k</td>
<td>11k</td>
<td>13k</td>
<td>1.3k</td>
<td>76k</td>
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<tr>
<td>#(D^+ + D^-)</td>
<td>19k</td>
<td>12k</td>
<td>7k</td>
<td>8k</td>
<td>0.8k</td>
<td>46k</td>
</tr>
<tr>
<td>⟨W⟩</td>
<td>327</td>
<td>226</td>
<td>156</td>
<td>70</td>
<td>11</td>
<td>105</td>
</tr>
</tbody>
</table>
Simulated results on $D^+ + D^-$
Anticipated results

SMES predictions
Rapid changes in $K^+\pi^+$ (HORN) were observed in Pb+Pb collisions. It was predicted within SMES as a signature of onset of deconfinement.

NEW RESULTS:

- plateau like structure visible in p+p
- Be+Be consistent with p+p
- $<K^+>/<\pi^+>$ in Ar+Sc in between p+p, Be+Be and Pb+Pb
Tentative conclusions from 2D scan

Data on particle ratios and fluctuations indicate four domains of hadron production separated by two thresholds:

- **onset of deconfinement**
- **onset of fireball**

Completion of Ar+Sc analysis and new data for Xe+La awaited to verify this picture.
We would like to thank the CERN EP, BE, EN and IT Departments for the strong support of NA61/SHINE

The NA61/SHINE Collaboration