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Past, present and future of open charm measurements at the CERN SPS energies

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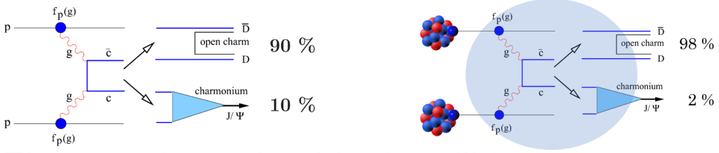
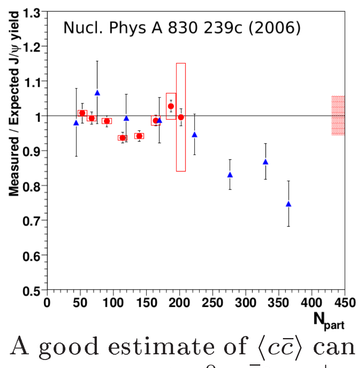
1. Motivation

The study of heavy flavour production is a sensitive tool for new detailed investigations of the properties of hot and dense matter formed in AA collisions.



The $\langle c\bar{c}\rangle$ pairs produced in the collisions are converted into open charm mesons and charmonia. It was suggested that colour screening in the plasma would reduce and eventually prevent the binding of charm quarks and anti-quarks to produce charmonia [1]. However, due to initial state effects in nucleus-nucleus reactions, the overall scaled number of the $\langle c\bar{c}\rangle$ pairs produced in nuclear collisions may be reduced [2]. Thus the effect of the medium on $c\bar{c}$ binding can only be quantitatively determined by comparing the ratio of J/ψ to $\langle c\bar{c}\rangle$ in nucleus-nucleus to that in proton-proton reactions. In Pb+Pb collisions the onset of color screening should already be seen in the centrality dependence of the J/ψ to $\langle c\bar{c}\rangle$ ratio.

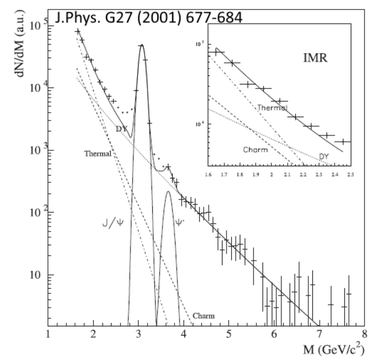


At $N_{part} \approx 200$ the NA60 experiment observed a significant drop of experimental J/ψ yield relative to theoretical estimates, which is known as anomalous J/ψ suppression [3]; It was initially attributed to onset of QGP formation in nuclear collisions, however other explanations have also been proposed.

A good estimate of $\langle c\bar{c}\rangle$ can be obtained by measuring production yields of D^0, $\bar{D}^0$, D^+, D^-, because they carry about 85% of the total charm for central Pb+Pb collisions at 150A GeV/c (from pHSD). Thus, measurements of open charm production are urgently needed for the interpretation of J/ψ results. Also, such measurements would allow to test the validity of theoretical models based on pQCD and Statistical model approaches, which provide very different predictions for charm yields at SPS energies.

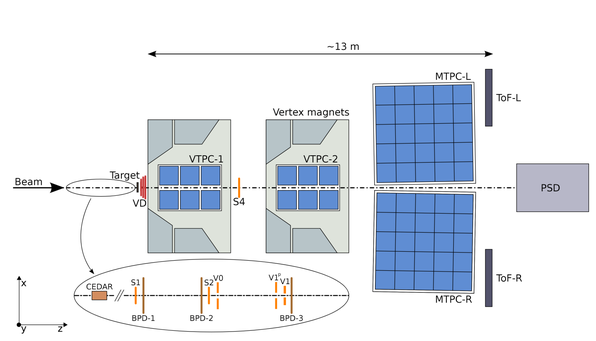
2. Previous measurements

The first estimate of the upper limit of mean multiplicity of D and $\bar{D}$ mesons by a direct measurement was done by the NA49 experiment in Pb+Pb collisions at the top SPS energies. Invariant mass distribution of identied kaons and pions was studied, and the estimated upper limit appeared to be on the level of the statistical model prediction. [4]



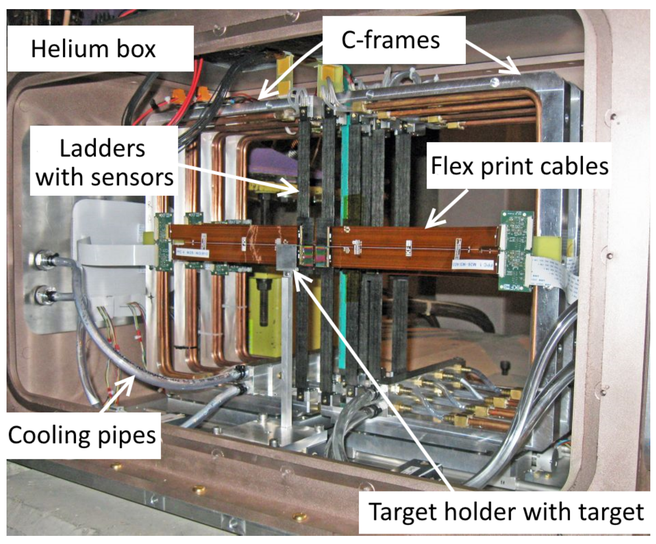
The NA38/NA50 and NA60 experiments measured precisely charmonia production at the top SPS energies (158A GeV/c), via measurements of dimuon production [5,6]. The increased production of dimuon pairs was observed be NA50, which could be attributed to enhanced production of open charm. By this, an indirect estimate of open charm was provided.

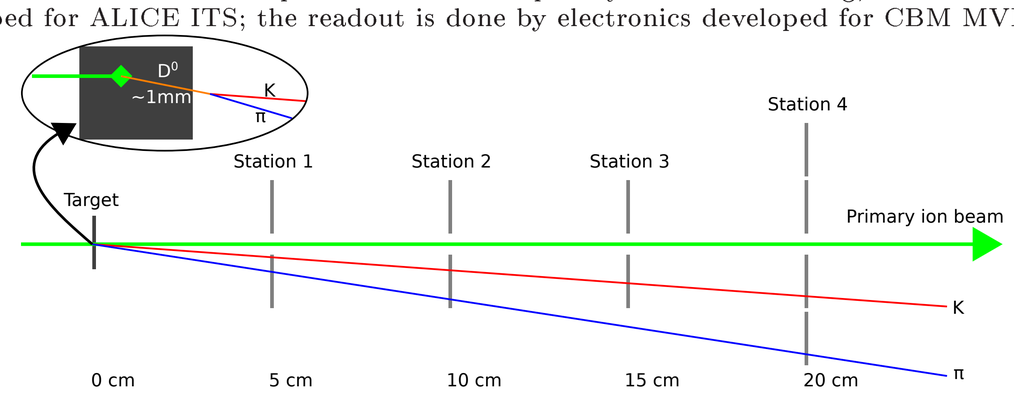
3. Vertex Detector project in the NA61/SHINE experiment



NA61/SHINE is a fixed-target experiment that can use the full momentum range available for primary and secondary beams at the CERN SPS.
In 2016 NA61/SHINE was upgraded with new high resolution Small Acceptance Vertex Detector (SAVD) to allow precise measurements of open charm mesons. NA61/SHINE is planning to further upgrade the detector after 2020 for study of short-lived particles.

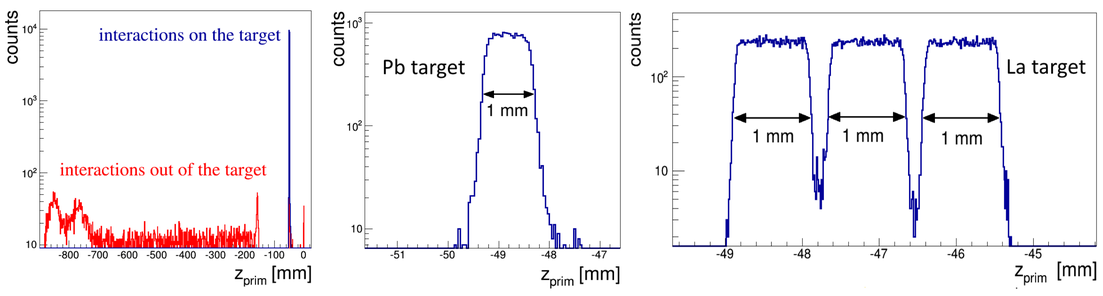
Measurements of open charm mesons are challenging since the yields of D mesons are very low and their lifetime is short ($c\tau \approx 100\mu m$). Recognition of open charm requires precise track and vertex resolution, which are delivered by SAVD.
The SAVD consists of two spectrometer arms composed each of four detector stations, which are located 5, 10, 15 and 20 cm downstream of the target. It is constructed from high-resolution MIMOSA-26 silicon pixel sensors developed by IPHC Strasbourg, which are installed on low-material budget carbon-fibre ladders developed for ALICE ITS; the readout is done by electronics developed for CBM MVD.





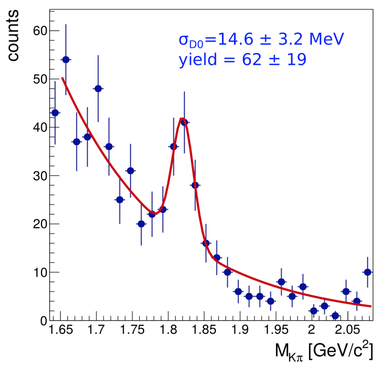
To distinguish the daughter particles of D^0 mesons (π and K) from hadrons produced in the primary nucleus-nucleus interaction point, one aims to select only hadron pairs generated in a secondary decay vertex
→ precise primary and secondary vertex reconstruction required.
$c\tau(D^0) = 122\mu m$, however, due to Lorentz boot ($\beta\gamma \sim 10$) the displacement is on the level of 1 mm.

4. Open charm measurements in NA61/SHINE



- Track spatial resolution is about $5\mu m$;
- Primary vertex spatial resolution of $\sigma_{x,y,z} = 1.3, 1.0, 15\mu m$;
- Secondary vertex spatial resolution (for D0) $\sigma_z = 50\mu$m.

The first pilot data for open charm measurements in Pb+Pb collisions at 150A GeV/c was collected in 2016. A first signal of D^0 at SPS energies was observed.
The NA61/SHINE physics data taking in Xe+La and Pb+Pb collisions at 150A GeV/c was conducted in 2017 and 2018.

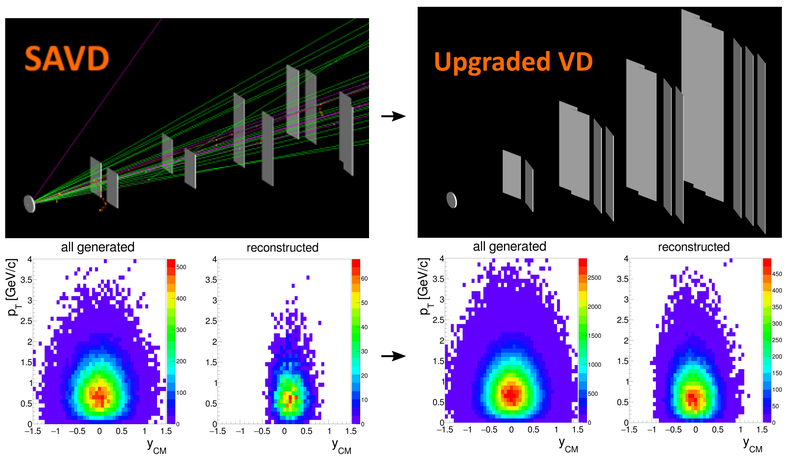


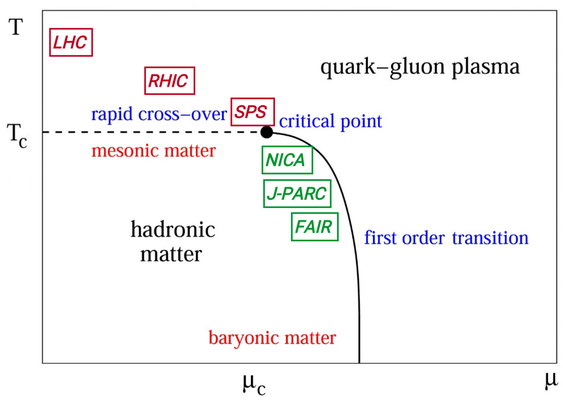
Applied cuts:

- A cut on the track transverse momentum $p_T > 0.34$ GeV/c;
- A cut on the track impact parameter $d > 34$ μm;
- A cut on the longitudinal distance between the D^0 decay vertx candidate and the primary vertex $V_z > 475$ μm;
- A cut on the impact parameter D of the back-extrapolated D^0 candidate momentum vector $D < 21$ μm.

5. Future charm measurements

NA61/SHINE will be upgraded to increase the data taking rate from 80Hz to 1kHz. The upgraded VD will be based on the same layout and mechanical support as SAVD, but will instead be based on 46 ALPIDE sensors developed for ALICE ITS with faster readout, and will have larger acceptance for each station.





Present (red) and future (green) facilities and their region of coverage in the phase diagram of strongly-interacting matter.

Only NA61/SHINE is able to measure open charm in full phase space in the near future. The corresponding potential measurements at higher (LHC, RHIC) and lower (FAIR, J-PARC) energies are necessary to complement the NA61/SHINE results and establish collision energy dependence of charm production.

- LHC and RHIC at high energies ($\sqrt{s_{\rm NN}} \gtrsim 200$ GeV): measurements of charm particles are performed in a significantly limited acceptance due to the collider kinematics and related to the detector geometry [7-10];
- RHIC BES collider and fixed-target ($\sqrt{s_{\rm NN}} = 3 - 39$ GeV): measurement not considered in the current program [11-13];
- NICA ($\sqrt{s_{\rm NN}} < 11$ GeV): measurements during stage 2 (after 2023) are considered[14];
- J-PARC-HI ($\sqrt{s_{\rm NN}} \lesssim 6$ GeV): under consideration, might be after 2025 [15];
- FAIR SIS-100 ($\sqrt{s_{\rm NN}} \lesssim 5$ GeV): not possible due to the very low cross-section at SIS-100, systematic charm measurements are planned with SIS-300 ($\sqrt{s_{\rm NN}} \lesssim 7$ GeV), no time estimation [16].

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