Prospects for heavy flavour measurements with the ALICE inner tracker upgrade

Cristina Terrevoli (for the ALICE Collaboration)

Univerity and INFN Cagliari, I-09042 Monserrato (CA) ITALY

E-mail: cristina.terrevoli@cern.ch

Abstract.

ALICE is the general purpose heavy-ion detector at the CERN LHC. Its goal is to investigate the properties of the strongly interacting matter under the extreme conditions of density and temperature reached in Pb–Pb collisions, with the aim to characterize the Quark-Gluon Plasma (QGP). In this scenario, the upgrade of the ALICE inner tracker targets physics topics in which ALICE can bring a unique contribution to the QGP characterization via the heavy flavour probes. We present an overview of the inner tracker upgrade and the expected physics performance for heavy flavour measurements.

1. Introduction

Among the probes useful to investigate the properties of the QGP, heavy quarks play a special role because they are produced in the very initial stage of the collisions and they carry information about the properties of the traversed medium. An accurate measurement of heavy flavour provides information on fundamental properties of the medium, such as the transport coefficient, the thermalization and hadronization mechanisms. Interesting results have been obtained in the first three years of data-taking at the LHC, but there are still open questions, which would require measurements beyond the present capabilities of the ALICE apparatus. Among them, the most interesting are the measurements of the nuclear modification factor ($R_{\rm AA}$) and anisotropy of the azimuthal distributions of charm and beauty mesons down to transverse momentum below 1 GeV/c. Another completely unexplored field is the measurement of the production of heavy flavour baryons, like the $\Lambda_{\rm c}$, that can bring insight on the heavy quark hadronization mechanism in the presence of a partonic medium. At present such measurements are limited by the resolution of the Inner Tracking System (ITS), which, in particular, is not sufficient to measure in Pb–Pb collisions the production of $\Lambda_{\rm c}$ baryons, that have a mean proper decay length of only 60 μm. Another limitation of the present ALICE central barrel detectors to the measurement of heavy flavours at low momentum is the maximum achievable readout rate, which prevents the full exploitation of the luminosity expected to be delivered by the LHC after the Long Shutdown 2. An upgrade of the inner tracking system based on todays frontier technologies will improve the current performance in the pointing and momentum resolution, providing in addition a high tracking efficiency down to very low transverse momentum. Moreover, a faster readout, for all the central barrel detectors, will allow for a data collection rate, in Pb–Pb collisions, a factor 100 larger than at present, and this will contribute to enhance the ALICE physics performance very significantly.

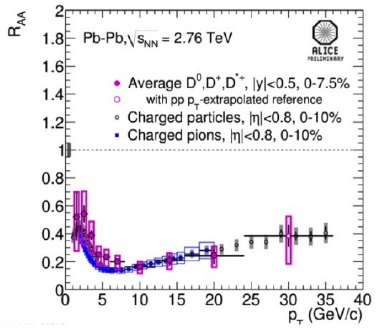

Figure 1. R_{AA} of D mesons compared with the R_{AA} of charged pions in Pb–Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV.

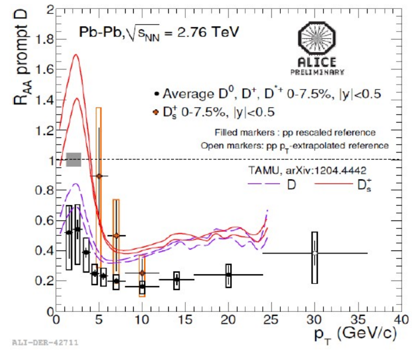

Figure 2. $\mathrm{D_s}$ R_{AA} compared with the theorethical models and D mesons R_{AA}.

2. ITS Upgrade concept

The current ITS has been designed to have an excellent capability to separate primary and secondary vertices of heavy flavour hadrons. It is composed of six layers of silicon detectors (pixels, drifts, and strips) with the innermost layer at a radius of 3.9 cm. The features of the ITS Upgrade [1] as compared with the present ITS are the following: (i) the innermost layer closer to the beam line at 2.2 cm, (ii) reduced material budget from the current 1.1% per pixel layer, to ∼0.3%, (iii) smaller size pixel cells (from $50 \times 425\mu$m to (20-30)×(20-30)μm), (iv) a seventh detector layer. This will allow for a significant improvement of the tracking performance and the momentum resolution. In particular, the impact parameter resolution will be improved by a factor of three in the transverse direction and a factor of six in the longitudinal direction. Furthermore a continuous readout of Pb–Pb interactions at ∼50 kHz will permit to exploit the upgrade LHC luminosity after 2018. The upgrade is targeted for the second long shutdown in 2017-2018.

3. Heavy Flavour results with the current Inner Tracking System

The energy-loss mechanism for different parton species is among the observables useful to investigate the properties of the QGP matter. Theoretical models predict a dependence on the colour charge and mass of partons propagating through the medium. In particular, a larger energy loss is expected for gluons, together with a suppression of gluon radiation at small angles for partons with larger mass (dead cone effect). This dependences can be investigated using the nuclear modification factor R_{AA}, the ratio of the p_{T} distribution in Pb–Pb and the p_{T} distribution in pp, scaled by the number of binary nucleon-nucleon collisions. The expected pattern is $R^{\pi}_{\mathrm{AA}} < R^{D}_{\mathrm{AA}} < R^{B}_{\mathrm{AA}}$ [2]. The R_{AA} of D mesons (D^0, D^+, D^{*+}) was measured in central Pb–Pb collisions at $\sqrt{s_{NN}}$ =2.76 TeV and compared with that of charged pions [3], as shown in Fig. 1. The data suggest that the suppression of D mesons might be smaller than for pions in the low momentum region, but the large systematic uncertainties prevent a firm conclusion. The measurement of the B mesons R_{AA} is not accessible with the current setup of the ALICE detector. The upgrade of the ITS will open the possibility to study B mesons down to zero p_{T}. Moreover the improved tracking resolution and efficiency, together with the higher statistics, will improve the p_{T} coverage and the accuracy of D meson measurements. Another open question concerning the heavy-flavour interaction with the QGP medium, involves the hadronization of heavy quarks in the medium, which can be studied by measuring the baryon/meson ratio for charm and beauty (Λ_{c}/D and Λ_{b}/B): coalescence models predict an increase of baryon-to-meson ratio [5]. With the current set-up of ALICE, the analysis of Λ_c and Λ_b is not accessible in Pb–Pb due to the limited precision and statistics. Another important test for coalescence models is that, if coalescence contributes to the charm hadronization, the D_s is expected to be enhanced with respect to the other D mesons at low p_T. There is an hint of this enhancement [4](see Fig. 2), but it is necessary to improve tracking precision, statistics and to extend the measurement to low p_T to have a conclusive answer. The measurement of the elliptic flow v_2 is sensitive to the thermalitazion of charm and beauty in the QGP. Models predict a large D meson v_2 at low momentum and a mass dependence of v_2 ($v_2(B) < v_2(D)$) [6, 7]. The ALICE measurement of D meson v_2 down to 2 GeV/c shows a positive value of v_2 at intermediate p_T in semi-central collisions, but with a limited precision. The measurement is not accessible for B mesons. The new ITS will allow for a precise measurement of the D meson v_2 down to zero p_T and will open the possibility for the measurement of B meson v_2.

4. ITS Upgrade physics performance

Several simulation studies have been carried out to quantify the improved performance of the upgraded ITS and the higher statistics achievable thanks to the continuous read-out (up to 10 nb^{-1} of integrated luminosity). The D meson measurement will be extended at low and high p_T, with improved statistical precision. In Fig. 3 the expected R_{AA} of D^0 mesons is shown: the upgraded ITS allows to reach down to zero p_T. In Fig. 4 the statistical uncertainty of the D^{*+} measurement is shown. The analysis can be carried out in a wider range (currently 3-36 GeV/c) with high significance (20-100), taking advantage of the higher precision and statistics. A direct measurement of beauty will be possible via non-prompt D^0 and J/ψ, as shown in Fig. 5

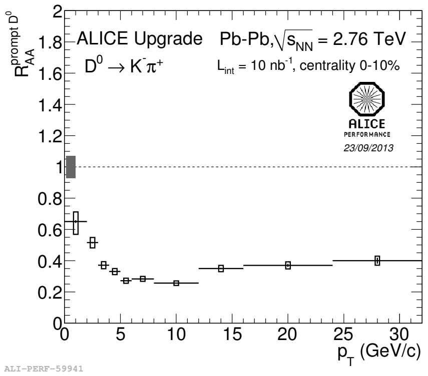

Figure 3. R_{AA} of D^0 in Pb–Pb at 5.5 TeV with the ALICE upgrade.

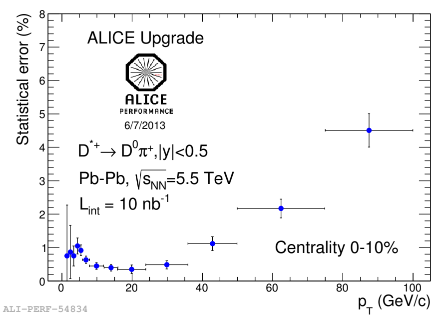

Figure 4. Statistical uncertainties of the D^* measurement in Pb–Pb 5.5 TeV with the ALICE upgrade.

(left), where the statistical uncertainty for non-prompt J/ψ is presented. This will allow for the measurement of the v_2 of B mesons for the first time. The Λ_c baryon will be accessible for $p_T > 2$ GeV/c in Pb–Pb thanks to the improved resolution, with a higher precision. In Fig. 5 (right) the double ratio Λ_c/D in Pb–Pb over pp is shown together with two theoretical predictions. Studies on the Λ_b reconstruction are also ongoing: the baryon will be accessible for the first time via its decay in Λ_c.

Also the D_s analysis will benefit for the much larger available statistics, with expected precise measurements of R_{AA} and v_2 down to low p_T (see Fig. 6).

5. Conclusions

ALICE has a strong upgrade physics programme for precision QGP studies, in particular for a deeper understanding of energy loss mechanisms, azimuthal anisotropy and in-medium

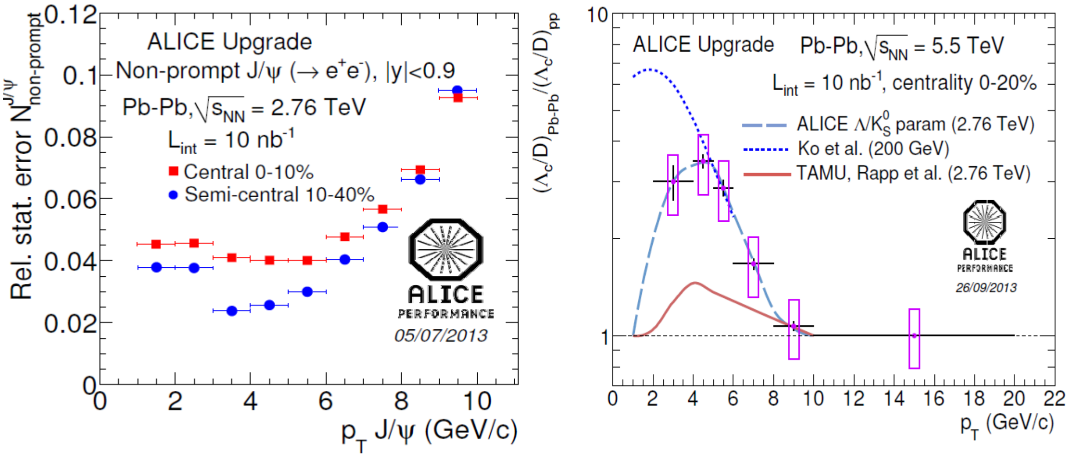

Figure 5. (Left) Non-prompt J/ψ yield: statistical uncertainty, for central and semi-central collisions, with the ALICE upgrade. (Right) Λ_c/D^0 ratio in Pb–Pb vs pp collisions, measured with the ALICE upgrade.

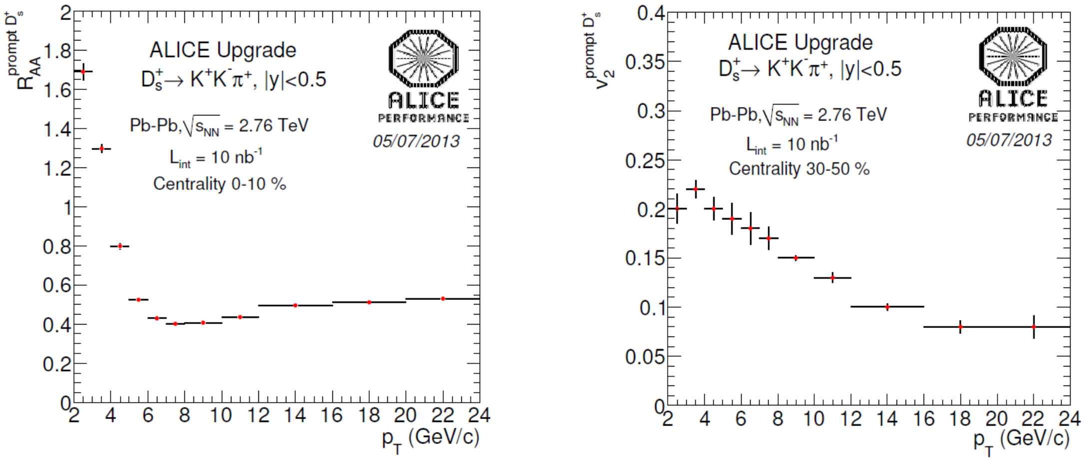

Figure 6. (Left) Statistical uncertainty on R_{AA} for D_s with the ALICE upgrade. (Right) v_2 for D_s with the ALICE upgrade.

hadronization, where heavy flavour measurements play a central role. The main requirements for the upgrade are enhanced rate capabilities and a new Inner Tracking System. These features will provide a strong increase of the statistical precision in the measurements of yields and spectra of heavy flavour mesons and baryons.

References

[1] ALICE Collaboration, 2012 ITS Upgrade Conceptual Design Report *CERN-LHCC-2012-013*
[2] Dokshitzer Y L and Kharzeev D, et al 2001 *Phys. Lett.* B **519** 199.
[3] Abelev B et al 2012 (ALICE Collaboration) arXiv:1203.2160.
[4] Innocenti G et al (ALICE Collaboration) 2012 *Quark Matter 2012* http://qm2012.bnl.gov
[5] Lee S H, Ohnishi K, Yasui S, Yoo I and Ko C, 2008 *Phys. Rev. Lett.* **100** 222301
[6] Aichelin J, Gossiaux P and Gousset T 2012 arXiv:1201.4192
[7] Uphoff J, Fochler O, Xu Z and Greiner C 2012 arXiv:1205.4945