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Prospects for heavy-flavour measurements in Pb–Pb collisions at the LHC with the new ALICE inner tracker

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The ALICE experiment at the LHC studies Pb–Pb, pp, and p-Pb collisions with the aim of investigating the properties of the high-density state of strongly-interacting matter produced in Pb–Pb collisions. Heavy quarks are sensitive probes to test the medium transport properties, degree of thermalization, and hadronization processes since they are formed at shorter time scale with respect to the deconfined state. The physics motivations for the ALICE upgrade will be outlined, starting from the current measurements and showing the performance foreseen after the upgrade of 2018.

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1. Heavy-flavour physics motivation for the ALICE upgrade

Charm and beauty quarks are well-suited probes for investigating the deconfined state of strongly-interacting matter formed in high-energy heavy-ion collisions, the quark-gluon plasma (QGP). Heavy quarks are formed in initial hard scattering processes, hence on a shorter time scale with respect to the QGP. They interact with the medium via both inelastic (medium-induced gluon radiation, or radiative energy loss) [1] and elastic (collisional energy loss) [2] processes. Due to the smaller colour coupling factor of quarks with respect to gluons and the 'dead-cone effect', which reduces small-angle gluon radiation for heavy quarks with moderate energy-over-mass values [3], the energy loss for heavy quarks is expected to be smaller than for light quarks and the latter smaller than for gluons. The energy loss mechanism and the transport coefficient of the QGP can be studied experimentally via the nuclear modification factor, R_{AA}, which is the ratio of the yield measured in Pb–Pb to that observed in pp, scaled with the number of binary nucleon-nucleon collisions. The expected hierarchy in the energy loss results in a hierarchy of R_{AA}, namely $R_{\mathrm{AA}}(B) > R_{\mathrm{AA}}(D) > R_{\mathrm{AA}}(light)$ [4].

In nuclear collisions, anisotropic patterns of particle production originate from the initial anisotropy in the spatial distribution of the nucleons participating in the collision. The anisotropy is described by the coefficients $v_n = \langle \cos[n(\phi - \Psi_n)] \rangle$ of the Fourier expansion of the azimuthal angle (ϕ) distribution of particles with respect to the initial-state symmetry plane for the considered harmonic Ψ_n. For non-central collisions the overlap region of the colliding nuclei has a lenticular shape and the anisotropy is dominated by the second coefficient v_2 (elliptic flow). At low transverse momentum p_{T}, charmed hadron v_2 offers a unique opportunity to test whether quarks with large mass ($m_{\mathrm{c}} \approx 1.5$ GeV$/c^2$) participate in the collective expansion and possibly thermalize in the medium [5, 6]. At low and intermediate p_{T}, the heavy flavour particle elliptic flow is also expected to be sensitive to possible hadronization of heavy quarks by recombination with light quarks from the medium. At high p_{T}, it can constrain the path-length dependence of parton energy loss, complementing the measurement of the nuclear modification factor R_{AA}.

The measurement of strange mesons and of baryons in the charm sector is interesting to assess the hadronization mechanisms. In a QGP the production of strange quark is enhanced [7, 8] with respect to pp collisions giving rise to a large production of $\mathrm{D_s}$ with respect to non-strange D mesons if recombination is the dominant hadronization mechanism at low and intermediate p_{T} [9]. The $\mathrm{D_s}$ R_{AA} is expected to be larger than 1 in the intermediate p_{T} region ($1-3$ GeV$/c$). Further insight in the hadronization mechanism is given by the baryon-over-meson ratio, which is observed to be enhanced in the intermediate p_{T} region in the light sector. In the heavy-flavour sector the measurement of the Λ_{c}-over-D in heavy-ion collisions has not yet been possible.

The ALICE experiment [10] consists of a central barrel composed of various detectors for particle reconstruction at midrapidity, a forward muon spectrometer, and a set of forward detectors for triggering and event characterization. ALICE collected samples of pp collisions at $\sqrt{s} = 900$ GeV, 2.36 TeV, 2.76 TeV, 7 TeV, and 8 TeV as well as Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and p-Pb collisions at $\sqrt{s} = 5.02$ TeV during the LHC Run I (2009-2013). The resolution on the secondary vertex reconstruction is provided by the Inner Tracking System (ITS) detector composed of six silicon layers with three different technologies, in particular by the innermost layers of pixels.

The ALICE measurement of D meson R_{AA} [11] shows a large modification of the p_{T} distribution in Pb–Pb with respect to pp collision, comparable to the effect observed with charged hadrons. The comparison with the CMS measurement of J/ψ from B decays [12] shows that D mesons are more suppressed than B mesons, at least at high p_T, supporting the expected hierarchy in the energy loss. Currently, the precision of the measurement is limited at low p_T, where mass effects are expected to be stronger, due to the large combinatorial background and at very high p_T, due to the limited statistics. The direct measurement of beauty R_{AA} via non-prompt D mesons is not accessible due to the lack of statistics and resolution.

The D meson elliptic flow is measured [13] to be positive in the range $2 < p_T < 6$ GeV$/c$ and its magnitude is comparable to that of light-flavour hadron v_2. This indicates that the interactions with the medium constituents transfer to charm quarks information on the azimuthal anisotropy of the system. Also for this measurement it would be desirable to reduce the uncertainties and to measure v_2 separately for prompt and secondary D mesons to access the heavy quark mass dependence.

A preliminary measurement of the D_s R_{AA} [14] for $p_T > 4$ GeV$/c$ is compatible, within the large uncertainties on the D_s measurement, to the non-strange D meson R_{AA}. In order to draw a conclusion on the hadronization mechanism, the low-p_T reach has to be improved as well.

The Λ_c reconstruction is among the most challenging heavy flavour measurements, because the small separation of the secondary vertex (mean proper decay length $c\tau \approx 59$ μm) does not allow for an effective background rejection based on the decay topology selection. With the current detector, the Λ_c signal could be observed only in pp collisions.

2. Upgrade strategy

The requirements for the heavy flavour measurements of the ALICE upgrade physics programme are: a strong improvement of the tracking precision at low p_T and the capability to exploit the projected increase of the LHC Pb–Pb luminosity after the second long shutdown (LS2, 2017-18). The latter requires a readout at up to 50 kHz with a minimum-bias trigger, because the low-p_T heavy flavour measurements are characterized by a very low signal-to-background ratio that prevents from using dedicated triggers.

The upgrade strategy implies [15]:

- A new ITS: with higher spatial precision, reduced material thickness and fast readout;
- A new smaller-radius beam pipe to allow the innermost ITS layer to be closer to the interaction point;
- The replacement of the readout multi-wire chambers of the TPC (Time Projection Chamber) with GEM (Gas Electron Multiplier) detectors and new pipelined electronics;
- Upgrade of the readout of Transition-Radiation Detector (TRD), Time-Of-Flight (TOF) detector, PHOton Spectrometer (PHOS) and Muon spectrometer and of the forward trigger detectors and trigger system;
- Merging of Online (High Level Trigger and Data AQuisition) and Offline systems to allow for a hundred times larger acquisition rate.

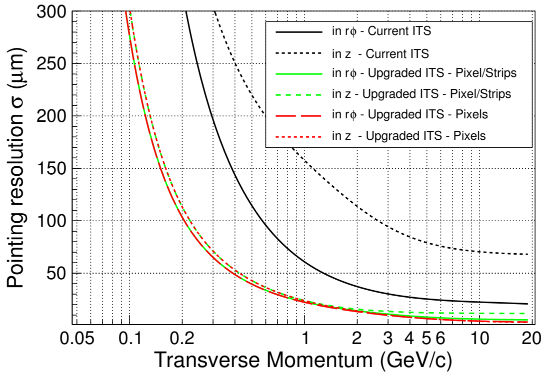

Figure 1: Impact parameter resolution for the current ITS (black) and two layout scenarios for the new ITS (green and red) in the longitudinal (solid) and transverse (dashed) directions [15].

The high-rate upgrade and an integrated Pb–Pb luminosity of 10 nb^{-1} will allow ALICE to collect a minimum bias sample hundred times larger compared to the original physics programme of the experiment, while for rare probes the increase will be a of factor of ten [15].

3. The ITS upgrade

The baseline design of the new ITS detector features seven layers of monolithic pixel with a resolution of 4 μm in both directions and a material budget of 0.3% of X_0 per layer. The outcome of the simulations performed with the Fast-Estimation-Tool described in [16] indicate that an improved tracking efficiency and p_{T} resolution in stand-alone mode is obtained by grouping the layers in an innermost triplet, an intermediate pair and an outermost pair. The possibility of including PID capabilities in the new ITS by instrumenting the four outermost layers with strip detectors is being evaluated.

The performance of a vertex detector, in particular its capability to separate secondary vertices of heavy flavour decays from the main interaction vertex, is determined by the impact parameter resolution (σ_{d_0}). This is the convolution of the primary vertex resolution and the track pointing resolution. For Pb–Pb collisions the uncertainty on the primary vertex position, whose determination is based on a large number of reconstructed tracks, is negligible with respect to that of the track spatial position, and therefore the d_0 resolution coincides with the track pointing resolution. The upgraded ITS will provide an improvement of the impact parameter resolution of a factor six in the z and a factor three in the $r\phi$ directions, as shown in Fig. 1, where the comparison of the current (black) and upgraded (colours) ITS is reported.

4. Physics performance

The fraction of prompt and displaced D^0 mesons can be measured by exploiting the different shapes of the impact parameter distributions of primary and secondary mesons. The main factors determining the performance achievable with this method are the available statistics, the uncertainty deriving from the subtraction of the background impact parameter distribution, and the resolution

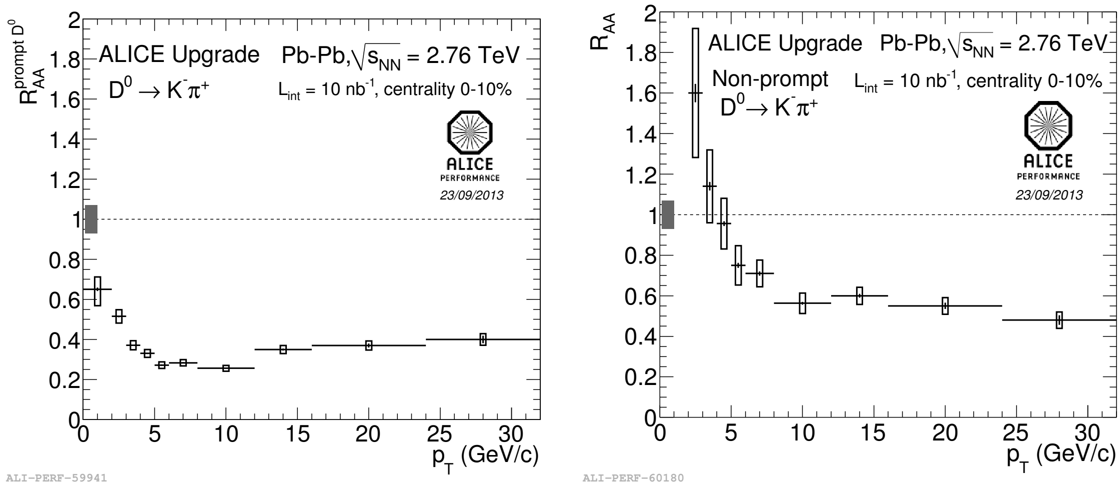

Figure 2: Performance for prompt (left) and feed-down (right) D^0 meson R_{AA}.

on the D meson impact parameter. In the current analysis the statistical precision was not enough to determine the fraction of prompt charm with this method. With the improved impact parameter resolution it will be possible to determine the fraction of prompt and secondary D mesons and calculate the R_{AA} of the two components (Fig. 2). Recent studies prove that the D meson p_T range accessible with an integrated luminosity of 10 nb^{-1} extends to $\sim$ 100 GeV/c with a statistical uncertainty of few % (cf. relative error on the D^{*+} signal in Fig. 3, left panel).

The performance on the v_2 measurements of charm and beauty mesons using prompt and secondary D^0 mesons is shown in Fig. 3, right panel. The precision of the measurement will allow for addressing the mass-dependence of the elliptic flow in a wide p_T range.

With the high rate upgrade and the new ITS the measurement of B mesons in Pb–Pb collisions via non-prompt J/ψ becomes possible. Beauty can be measured via the $B \to J/\psi\, X$ decay channel, using a simultaneous fit of the pseudoproper decay length and the invariant mass distribution of the J/ψ candidates. In the left panel of Fig. 4 the comparison of the pseudoproper decay length resolution for current and upgraded ITS shows an improvement of a factor of three. The expected relative uncertainties on non-prompt J/ψ (shown in the right panel) result to be of a few % down to $p_T = 1$ GeV/c up to about 10% at 10 GeV/c.

In Fig. 5 (left side) the expected performance for the D_s R_{AA} is reported. The statistical uncertainties will allow for a precise comparison with non-strange D mesons.

One of the goals for the ALICE upgrade is the Λ_c measurement in Pb–Pb collisions. The Λ_c features a $c\tau$ of 59 μm only, hence identifying the Λ_c through its decay topology is only possible at high p_T with the current impact parameter resolution ($\sim$ 60 μm at 1 GeV/c, see Fig. 1). In the current analysis in pp collisions, the topological selections are kept loose and the particle identification is crucial for the signal extraction. In the high multiplicity environment of Pb–Pb collisions, this is not enough and a better impact parameter resolution is mandatory to perform the measurement. On the right-hand side of Fig. 5, the double ratio Λ_c-over-D in Pb–Pb over pp is shown together with two theoretical predictions. The projected precision will allow for distinguishing among different scenarios for the recombination of charm quarks.

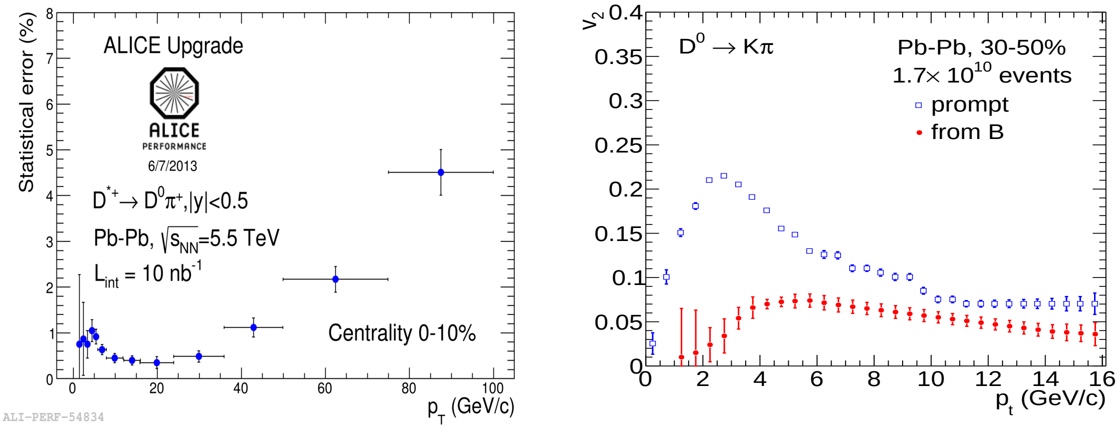

Figure 3: Statistical uncertainty on D^{*+} signal (left) and performance on v_2 for D and B mesons (right) in the high-rate scenario.

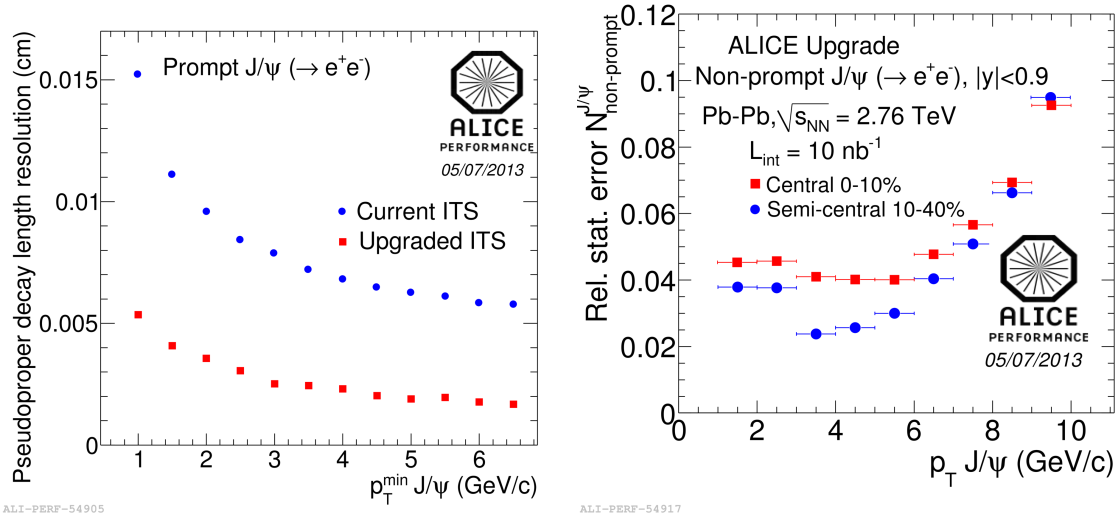

Figure 4: Pseudoproper decay length resolution on prompt J/ψ as a function of p_T (left) and relative statistical uncertainty on the non-prompt J/ψ signal (right).

5. Summary

The ALICE capability for using heavy quarks as probes of the hot medium formed in Pb–Pb collisions at the LHC will be largely improved with the upgrade planned for LS2 (2018). The upgrade entails a new ITS composed of seven layers of silicon detectors, upgraded readout capabilities for all the detectors, and a new Online-Offline framework able to handle up to 50 *k*Hz rate in Pb–Pb collisions. The heavy-flavour physics goals include the measurement of Λ_c and beauty in Pb–Pb collisions and the improvement of the prompt D meson measurements down to $p_T = 0$.

References

[1] M. Gyulassy and M. Plumer, Phys. Lett. **B 243** (1990) 432

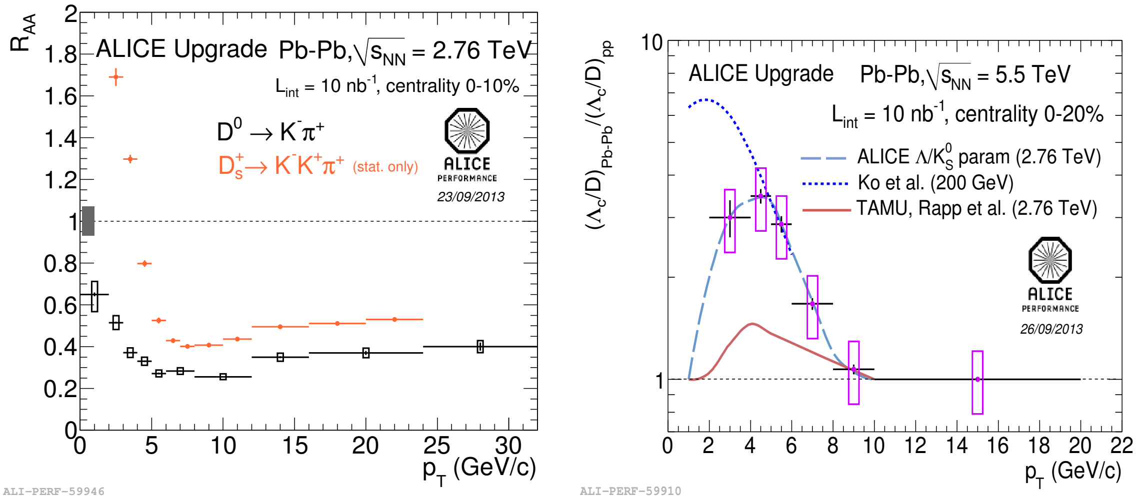

Figure 5: Left: D_s R_{AA} performance. Right: Λ_c-over-D ratio in Pb–Pb over pp.

[2] M.H. Thoma and M. Gyulassy, Nucl. Phys. **B 351** (1991) 491

[3] Y.L. Dokshitzer and D. Kharzeev, Phys. Lett. **B 519** (2001) 199

[4] Armesto et al., PRD 71 (2005) 054027

[5] S. Batsouli, S. Kelly, M. Gyulassy and J. L. Nagle, Phys.Lett. **B 557** (2003) 26 [nucl-th/0212068].

[6] V. Greco, C. M. Ko and R. Rapp, Phys. Lett. **B 595** (2004) 202 [nucl-th/0312100].

[7] J. Rafelski, R. Hagedorn, North-Holland and Elsevier. pp. 253-272 (1981).

[8] ALICE Collaboration, arXiv:1307.5543 [nucl-ex]

[9] M. He, R. J. Fries and R. Rapp, arXiv:1204.4442 [nucl-th], I. Kuznetsova and J. Rafelski, Eur. Phys. J. C 51 (2007) 113.

[10] K. Aamodt et al. [ALICE Collaboration], JINST 3 (2008) S08002.

[11] B. Abelev et al. [ALICE Collaboration], JHEP **09** (2012) 112.

[12] CMS-PAS-HIN-12-014

[13] ALICE Collaboration, Phys. Rev. Lett. 111, 102301 (2013)

[14] Nucl. Phys. A, Volumes 904–905, 2, Pages 433c–436c

[15] ALICE Collaboration, Upgrade of the ALICE Experiment Letter of Intent, CERN-LHCC-2012-12

[16] ALICE Collaboration, Upgrade of the Inner Tracking System Conceptual Design Report, CERN-LHCC-2012-13

[17] B.Abelev et al. [ALICE Collaboration] JHEP **11** (2012) 065