Upgrade and physics perspective of ALICE at the LHC

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Abstract. ALICE at the LHC, collecting data in Pb-Pb, p-Pb and pp collisions, aims for the characterisation of the strongly interacting matter at unprecedented energy densities. While the first running period until 2018 can provide detailed description of the global and bulk phenomena and a first set of intriguing results on rare probes of heavy-ion collisions, many important questions involving rare processes cannot be addressed in details with the current experimental setup. In this talk, we give an overview of the ALICE Upgrade program focusing on the physics prospects related to heavy-quarks, quarkonia, low-mass dileptons, jets and exotica searches achievable in high luminosity Pb-Pb collisions at the LHC. We also discuss the technological challenges and choices of the detector upgrades to be installed during the LHC Long Shutdown 2.

1. Introduction

ALICE has delivered new exciting experimental results from high-energy heavy-ion collisions at the Large Hadron Collider (LHC). The ALICE operation in the LHC Run 1 (2009-2013) focused on the light quark sector, such as establishing the presence of strong elliptic flow [1, 2] and strong quenching of high momentum charged particles at LHC [3], exceeding the values measured at RHIC. Moreover, the first measurements in the heavy quark sector brought intriguing results, such as the observed D meson elliptic flow, and quenching of identified open charm mesons [4, 5] and the quarkonia suppression at forward rapidities with a different trend than shown by the RHIC results [6].

The ALICE data taking in the LHC Run 2 (2015-2018) before the LHC Long Shutdown 2 (LS2), most likely will bring comprehensive and completed results on the experimental probes of the prospected ALICE baseline physics program: anisotropic flow of light hadrons, inclusive momentum spectra and nuclear modification of the heavy flavour mesons (D mesons), global jet properties in heavy-ion collisions. While the first characterisation of the heavy quark sector could be achieved with the expected statistics of 1 nb^{-1} delivered integrated luminosity by the LS2 precision measurements would require higher statistics $\sim$10 nb^{-1} in Pb-Pb collisions at top LHC energy.

ALICE is actively pursuing its upgrade program for LS2 and beyond, to perform precision measurements of the following physics topics in heavy-ion collisions: study of heavy quark thermalisation, measurement of low mass dileptons and thermal photons, measurement of gamma-jets with particle identification and search for exotic heavy nuclear states. Detailed description of the general ALICE Upgrade program and the physics goals can be found in [7] and more specific topics related to the upgraded Inner Tracking System in [8, 9].

2. Upgrade strategy

In the currently ongoing LHC Long Shutdown 1 (LS1, 2013-2014) ALICE completes its detector setup, by finishing the installation of the Transition Radiation Detector modules (TRD), adding the last module of the Photon Spectrometer (PHOS) and installing new electromagnetic calorimeter modules (DCAL) opposite the existing ones (EMCAL) [10], allowing improved di-jet and gamma-jet measurements.

The ALICE detector upgrade will take place in the LS2 (2018-2019). The upgrade will enhance the rate capability of ALICE to be able to record and inspect Pb-Pb collisions at a high rate of 50 kHz, since the interesting physics observables are mostly signals at low transverse momentum with a large background, and thus untriggerable (such as the charmed baryons or low mass dileptons). To collect reference data for heavy-ion measurements, the rate capabilities are extended up to few 100 kHz for high luminosity pp and p-Pb collisions.

The ALICE Upgrade consists of new detectors and changes to the existing ones [7]. To allow the installation of a new Inner Tracking System (ITS), the current beam pipe will be replaced with a smaller diameter one. The current ITS will be fully replaced with a new upgraded detector. The Time Projection Chamber (TPC) read-out chambers will be replaced with Gas Electron Multiplier (GEM) read-out chambers to cope with the required faster read-out rates. A new forward tracking system towards the Muon Spectrometer will be installed: the Muon Forward Tracker (MFT). The trigger detectors (V0, T0) will also undergo a general upgrade. The remaining detectors will upgrade their electronics to conform with the increased rate requirements [7].

The online-offline (O^2) systems will also undergo a structural change, merging the data acquisition, the trigger system and the offline system functionalities into a unified framework. The data acquisition will handle continuous and triggered detector read-out in combination with a new central trigger system and a new high level trigger infrastructure performing on-the-fly reconstruction. The O^2 system has to handle a factor of 100 more statistics in the recorded data then present.

3. Detector projects

3.1. New Inner Tracking System

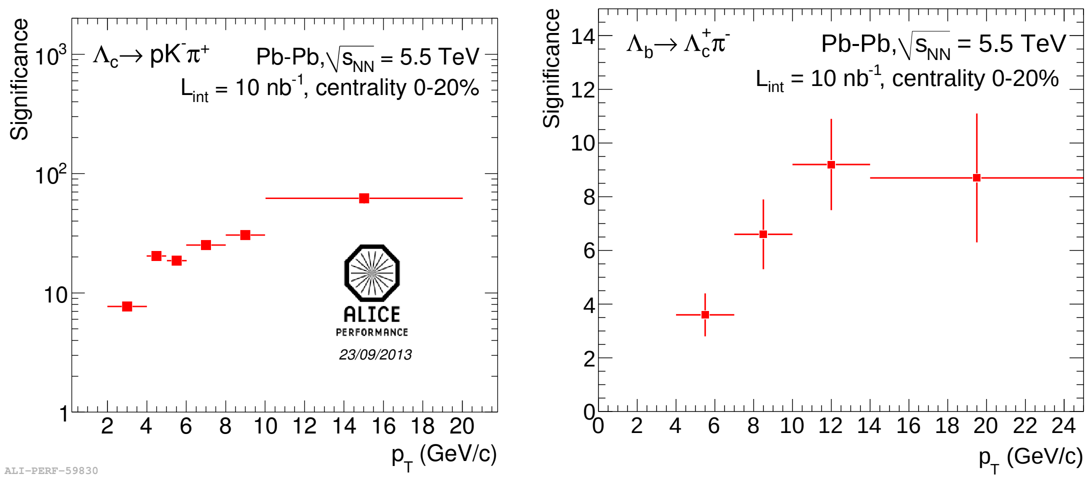

Figure 1. Expected significance of the $\Lambda_c \rightarrow pK^-\pi^+$ (left panel) and $\Lambda_b \rightarrow \Lambda_c^+\pi^-$ measurements as a function of p_T in the 0-20% centrality for Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV [9].

The new beam-pipe will allow the installation of an upgraded ITS, closer to the interaction point compared to the current detector setup (present first layer is at 39 mm radial position with respect to the upgraded one at 22 mm). The upgraded ITS will consist of seven layers with a largely reduced material budget with respected to the current ALICE-ITS and the upgraded inner tracker setup of ATLAS and CMS [8, 9].

The reduction in the material budget is achievable using Monolithic Active Pixels Sensors (MAPS) with a silicon material budget of 50 μm instead of the current 350 μm. Furthermore, optimisation of the electrical power and signal cable layouts, the mechanical and cooling structures leads to the 0.3 X/X$_0$ target material budget for the 3 inner layers and 0.8 X/X$_0$ for the 4 outer layers. The layers will consists of high granularity pixel sensors with pixel size from 20 μm x 20 μm up to 50 μm x 50 μm, operated in continuous read-out mode.

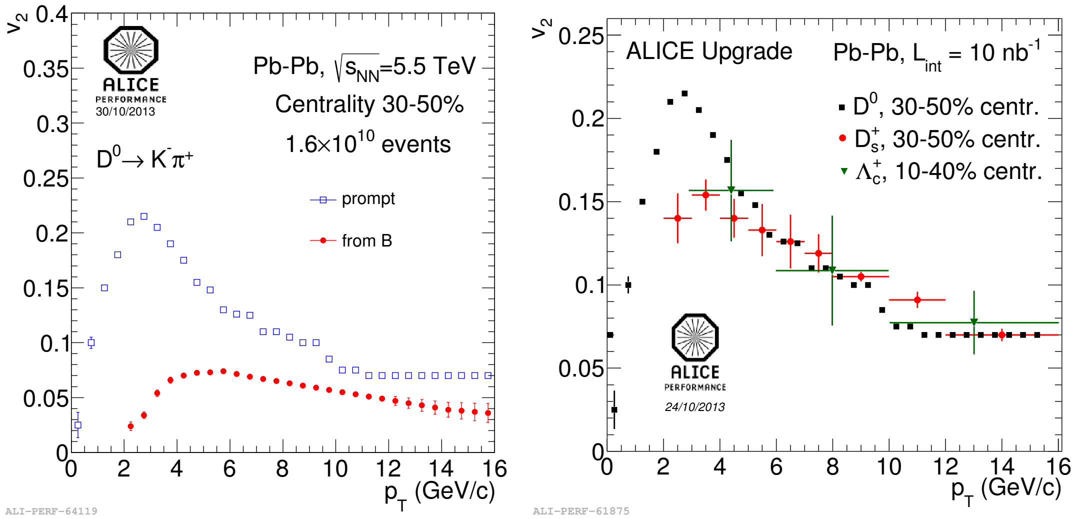

Figure 2. Comparison of the estimated statistical uncertainties on elliptic flow of prompt and secondary D mesons (left panel) and of prompt D mesons with D$_s^+$ and Λ_c^+ (right panel) in the 30-50% centrality in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.5 TeV [8, 9].

The new detector design, with the required 4-6 μm spatial resolution, will allow a factor of 3 (in rϕ) and 5 (in z) improvement in the vertex resolution, a factor of 3 improvement in the standalone tracking momentum resolution and a high ∼83 % standalone tracking efficiency at p$_T$ = 100 MeV/c. These improvements give access to the measurement of charmed and beauty baryons (typical life-time of O(10) μm) and to the discrimination of prompt and secondary heavy quark production. Fig. 1 shows an example on the expected significance of the Λ_c^+ and Λ_b measurements, that will be accessible in Pb-Pb collisions with the ALICE Upgrade and high rate data taking at top LHC energy. Fig. 2 shows the expected separation and statistical uncertainties of prompt and secondary D meson elliptic flow measurements and of prompt D meson, D$_s^+$ and Λ_c^+ elliptic flow measurements with the upgraded ITS at top LHC energy in Pb-Pb collisions. The detailed physics program and performance of the upgraded ITS is described in [9].

3.2. New GEM read-out for the TPC

The Time Projection Chamber in ALICE [10] is a unique tracking and particle identification detector among the LHC experiments, providing high precision tracking and energy loss measurements.

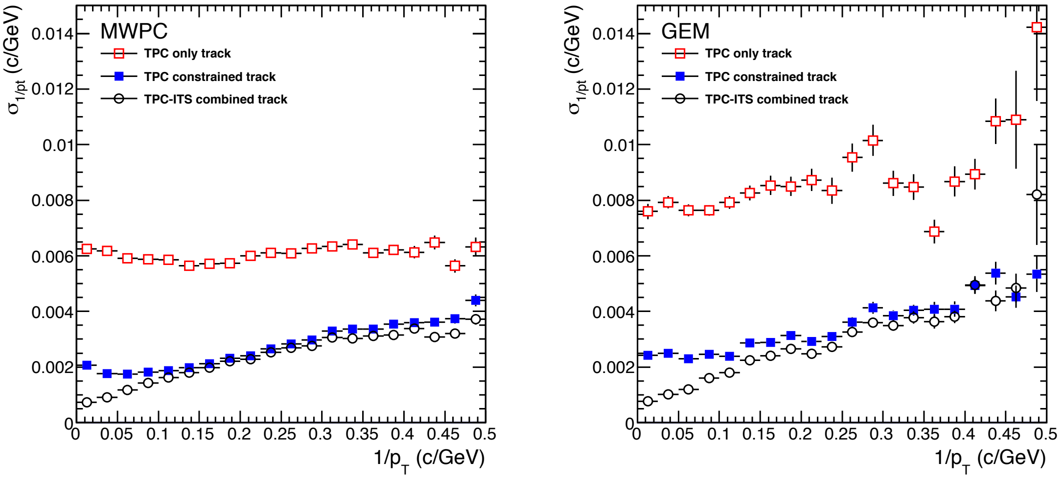

Figure 3. Comparison of the momentum resolution as a function of $1/p_T$ for the present MWPC (left panel) and the proposed GEM (right panel) read-out chambers. The red squares represent track information only from the TPC, the blue squares represent track information only from the TPC including the vertex point in the track fit, and the black circles represent tracks combining the ITS and TPC information [7].

The existing read-out chambers are multi-wire proportional read-out chambers (MWPC) operated in a gated mode to separate the charge collection of electrons and ions [10]. The gated mode is required, otherwise the large space charge build-up, due to ion back flow, would cause field distortions that would lead to deteriorated tracking performance. The gated operation and the current gas mixture employed in the drift volume limit the TPC read-out rate to a few kHz.

To maintain the tracking and particle identification capabilities in high rate operations, the read-out MWPCs and the read-out electronics will be replaced. The MWPCs will be substituted by triple Gas Electron Multiplier (GEM) read-out chambers, operated in a continuous, triggerless read-out mode. GEMs would allow a TPC operation at 50 kHz in Pb-Pb collisions due to their intrinsic ion-feedback suppression [7]. The expected momentum resolution of the GEM setup is shown in Fig. 3 in comparison with the present MWPC setup. The tracking performance is similar for tracks reconstructed from the combined ITS and TPC space points, noting that the current pad plane layout was designed for the MWPC read-out chambers. Its optimisation for the GEM read-out chambers is expected to further improve the performance.

3.3. New forward tracking for the Muon Spectrometer

To improve the physics capabilities of the Muon Spectrometer of ALICE [10], located at large rapidities ($-4.0 < \eta < -2.5$), a new detector is proposed: the Muon Forward Tracker (MFT) [11], adding secondary vertex reconstruction capability for muon tracks. The MFT will be located upstream to the hadron absorber of the Muon Spectrometer, close to the upgraded ITS. The MFT will consist of five tracking planes, built on the same MAPS technology as the upgraded ITS with similar material budget per plane: 0.4 X/X_0 and spatial resolution <5 μm.

The Muon Spectrometer with MFT will perform quarkonia (J/ψ, ψ') and differential low mass dimuon measurements down to very low transverse momenta, complementary in rapidity range with the upgraded ITS and complementary both in rapidity and in transverse momenta with other LHC experiments. The addition of MFT to the Muon Spectrometer is expected to improve the signal-over-background (S/B) and systematic errors for quarkonia measurements,

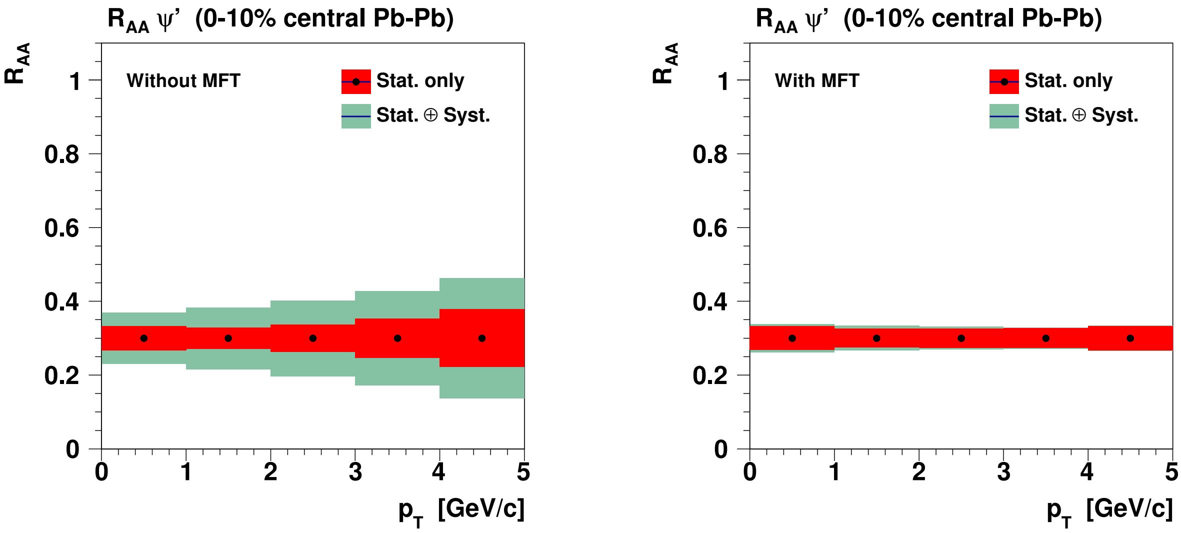

Figure 4. Expected statistical and systematical uncertainties of the nuclear modification factor R_{AA} of the ψ' in central Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV without MFT (left panel) and with MFT (right panel) for a 10 nb^{-1} integrated luminosity [11, 12].

eg. in case of ψ' by a factor of 3 - 10 depending on the transverse momentum. Fig. 4 shows the expected reduction of statistical and systematic uncertainties of the ψ' nuclear modification factor in central Pb-Pb collisions at top LHC energy. The low mass dimuon measurements also benefits from the MFT capabilities with the improved combinatorial background suppression, originating from semi-muonic decays of pions and kaons, yielding an increased S/B by a factor of 10 and improved mass resolution by a factor of 3-5 [11, 12]. The improvement of the mass resolution due to MFT is shown in Fig. 5.

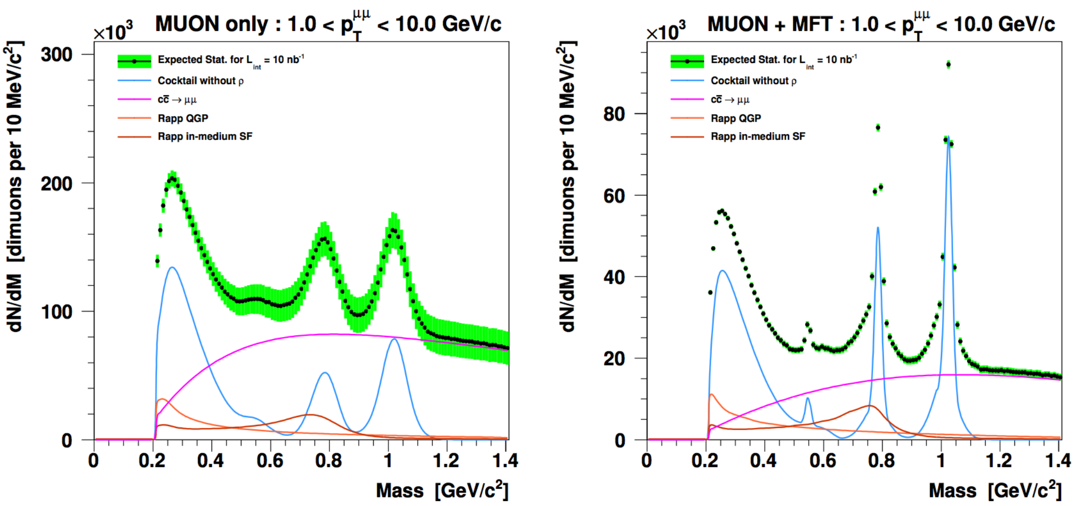

Figure 5. Expected low mass dimuon spectrum (combinatorial background is subtracted) in 0-10% most central Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV, normalised to 10 nb^{-1} integrated luminosity without MFT (left panel) and with MFT (right panel) [11, 12].

3.4. Prospects for forward physics at ALICE

While ALICE is actively pursuing the upgrade goals for the LS2, new studies are carried out on a Forward Calorimeter (FoCal) to add direct photon and neutral pion measurement capabilities in the forward region $\sim 3 < \eta < 5$, opposite to the Muon Spectrometer. This project is in the conceptual phase, not yet approved by the ALICE Collaboration. The electromagnetic calorimeter would feature a very high granularity (cell size of ~ 1 mm^2), most likely in a SiW sandwich design. The same MAPS technology would be used for read-out as for the upgraded ITS and MFT, focusing on the good position resolution and two-particle separation. The electromagnetic calorimeter could be complemented by a hadronic calorimeter that would improve the jet reconstruction performance. The FoCal would allow detection of direct photons and neutral pions in a pseudo-rapidity and transverse momentum range that is not accessible for existing experiments, but where saturation effects are expected to appear [13].

4. Summary

The ALICE Upgrade program targets the LHC Long Shutdown 2 for detector installation to exploit the physics potential of the high luminosity LHC heavy-ion operations and to perform detailed and quantitative characterisation of the high density and temperature phase of strongly interacting matter, with a physics program extending beyond the LHC Long Shutdown 3.

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