PROCEEDINGS OF SCIENCE

ALICE Upgrade and physics perspectives

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ALICE at LHC, collecting data in Pb+Pb, p+Pb and pp collisions, aims for the characterization of the QCD matter at high temperature and energy density. While the first running period until 2017 can provide detailed description of the global and bulk phenomena and a first set of 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 paper we give an overview of the ALICE Upgrade program focusing on the physics prospects and the technological challenges and choices of the detector upgrades to be installed during the LHC Long Shutdown 2.

XXI International Workshop on Deep-Inelastic Scattering and Related Subject -DIS2013,
22-26 April 2013
Marseilles,France

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1. Introduction

ALICE has delivered new exciting experimental results on high-energy heavy-ion collisions at the Large Hadron Collider (LHC). The first years of operation 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 [3] at LHC, exceeding the values measured at RHIC. The first measurements in the heavy quark sector brought intriguing results, such as the observed elliptic flow, as shown in Fig. 1, and quenching of identified open charm mesons [4, 5] and the quarkonia suppression at forward rapidities with different trend than shown by the RHIC results [6].

Data taking until 2017, the beginning of the LHC Long Shutdown 2 (LS2), most likely will bring comprehensive results on the experimental probes of the ALICE baseline physics program: anisotropic flow of light hadrons, inclusive momentum spectra and nuclear modification of the heavy flavour 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} by the LS2, precision measurements would require higher statistics $\sim$10 nb^{-1} in Pb+Pb collisions at the top LHC energy.

ALICE is actively pursuing an 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 ALICE Upgrade program and the physics goals can be found in [7].

2. Upgrade strategy

In the currently ongoing LHC Long Shutdown 1 (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) [8].

The ALICE detector upgrade will take place in the LHC Long Shutdown 2 (2017-2018). The upgrade will enhance the rate capability of ALICE to be able to record and inspect Pb+Pb collisions at high rate of 50 kHz, since the interesting physics observables are mostly rare signals at low transverse momentum but 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. To allow the installation of a new inner tracking system, the current beam pipe will be replaced with a smaller diameter one. The Inner Tracking System (ITS) will be fully replaced with a new ITS, 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 remaining detectors will upgrade their electronics to conform with the increased rate requirements.

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 system. The data

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acquisition will handle continuous and triggered detector read-out in combination with a new central trigger system and a new high level trigger infrastructures performing on-the-fly reconstruction. The O^2 system has to handle a factor of 100 more statistics in the recorded data then at present.

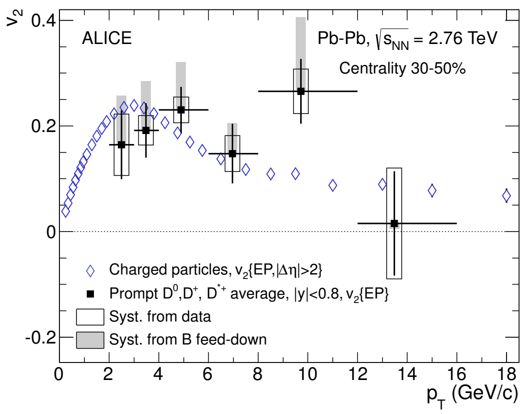

Figure 1: Comparison of charged particle and combined D meson elliptic flow in the 30-50% centrality in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [4].

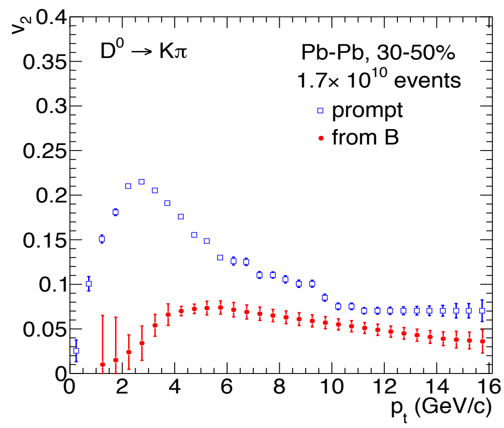

Figure 2: Estimated statistical uncertainty on v_2 of prompt and secondary D^0 mesons for $L_{int} = 10$ nb^{-1} simulated data measured with the help of the upgraded ITS detector in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV [9].

3. Detector projects

3.1 New Inner Tracking System

The new beam-pipe will allow the installation of a new inner tracking system (first layer is at 22 mm radial position), closer to the interaction point as the current setup (first layer is at 39 mm). The new detector would consist of seven layers with a largely reduced material budget with respect to the current ALICE and the upgraded setup of ATLAS and CMS [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_0 target material budget for the 3 inner layers and 0.8 X_0 for the 4 outer layers. The layers would consists of high granularity pixel sensors with pixel size from 20 μm x 20 μm (inner layers) up to 50 μm x 50 μm (outer layers).

The new detector design, with the required 4-6 μm spatial resolution, will allow a factor of 3 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. The 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. 2 shows the expected separation of prompt and secondary D meson elliptic flow measurement with the new ITS at the top LHC energy in Pb+Pb collisions. The detailed physics program and performance of the new ITS is described in [9].

3.2 New GEM read-out for the TPC

The Time Projection Chamber in ALICE [8] is a unique tracking and particle identification detector among the LHC experiments, providing high precision tracking and energy loss measurements. The read-out chambers are multi-wire proportional read-out chambers (MWPC) equipped with wire grids: anode wires, cathode wires and the gating grid. In the absence of trigger, the gating grid prevents the electrons to enter to the amplification region and the ions from previous events to enter to the drift volume where they would cause field distortions leading to deteriorated tracking performance. The gated operation mode and the read-out electronics limit the read-out rate to 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 replaced by triple Gas Electron Multiplier (GEM) read-out chambers operated in continuous read-out mode. GEMs due to their intrinsic ion feedback suppressions would allow a TPC operation at 50 kHz in Pb+Pb collisions [7].

3.3 New forward tracking for the Muon Spectrometer

To improve the physics capabilities of the Muon Spectrometer of ALICE [8], located at large rapidities (-4.0 $< \eta <$ -2.5), a new detector is proposed: the Muon Forward Tracker (MFT), 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 new ITS. The MFT will consist of five tracking planes, built on the same monolithic active pixel technology as the new ITS with similar material budget per plane: 0.4 X_0 and spatial resolution <5 μm.

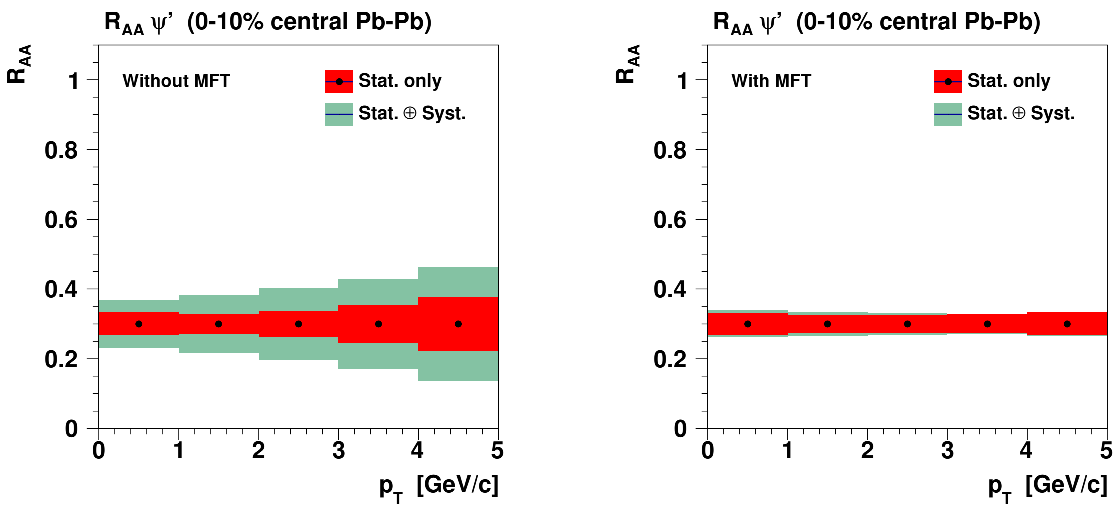

Figure 3: Expected statistical and systematical uncertainties of the nuclear modification factor R_{AA} of the ψ' in central Pb+Pb collisions without MFT (left panel) and with MFT (right panel) [10].

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 ITS and complementary both in rapidity and in transverse momenta with other LHC experiments. The addition of MFT to the Muon Spectrometer would improve the signal-over-background

(S/B) and systematic errors for quarkonia measurements, eg. in case of ψ' by a factor of 3 - 10 depending on the transverse momentum. Fig. 3 shows the expected reduction of statistical and systematic uncertainties of the ψ' nuclear modification factor in central Pb+Pb collisions at the top LHC energy. The low mass dimuon measurements would also benefit 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 [10].

3.4 Prospects for forward physics at ALICE

While ALICE is actively pursuing the upgrade goals for the Long Shutdown 2, 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 an extreme granularity (cell size of $\sim$1 mm^2), most likely in a SiW sandwich design. The same MAPS technology would be used for read-out as for the new ITS and MFT, focusing on the good position resolution and two-particle separation. 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 [11].

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 characterization 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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