Upgrade of the ALICE Experiment

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Abstract

While groundbreaking measurements on the properties of strongly interacting matter in p+p, p+A and A+A collisions at the LHC are being performed, it is clear that many important questions in heavy-ion physics will remain unanswered in this first phase of beam times up to 2017. The ALICE is setting up a program of detector upgrades to be installed in the LHC shutdown planned for 2017/18, to address the new scientific challenges. We will discuss examples of the scientific frontiers and upgrade projects under study for the ALICE experiment.

1. Introduction: the physics frontiers for ALICE

In the first years of operation ALICE has demonstrated its excellent capabilities to measure high-energy nuclear collisions at the LHC, delivering exciting results on *elliptic flow*, which appears to be even larger than at RHIC [1], strong *quenching* of high momentum hadrons including first measurements using *identified open charm* mesons [2] and intriguing results on the centrality dependence of charmonium production [3], to just name a few examples. Further data taking up to 2017 will improve the understanding of heavy-ion collisions significantly and will very likely yield comprehensive results on many experimental probes, as e.g. the details of anisotropic flow of light hadrons, inclusive momentum spectra of heavy flavor mesons including their nuclear modification, or the global features of jets in nuclear collisions, all-in-all the baseline program of the ALICE experiment.

Still, crucial measurements will not be possible. For illustration let us consider the study of collective motion of charm. While the measurement of spectra of open charm mesons is challenging, it has already been shown to be feasible, and a further increase in statistics to $0.1\,\mathrm{nb}^{-1}$ (or $1\,\mathrm{nb}^{-1}$ for rare triggered probes) should allow precision measurements of the most abundant D mesons. However, anisotropic flow studies generally require an order of magnitude higher statistics, thus calling for $\approx 10\,\mathrm{nb}^{-1}$ in Pb-Pb collisions. In addition, it is known from light hadrons, that significant differences essential for theoretical understanding of collective flow are observed between mesons and baryons. This requires a measurement of charmed baryons, as e.g. the Λ_c. Furthermore, it is crucial for studies of equilibration properties to cover the lowest transverse momenta possible. Both, the measurement of the Λ_c, and a significant measurement at very low p_T will profit enormously from an improved background rejection and secondary vertex resolution of the tracking detectors. Similar arguments hold for other important physics

[1] A list of members of the ALICE Collaboration and acknowledgements can be found at the end of this issue.

Table 1: Comparison of the physics performance for selected observables between the approved scenario (1 nb^{-1} of delivered integrated luminosity, out of which 0.1 nb^{-1} is used for minimum-bias data collection) and the proposed upgrade (10 nb^{-1} of integrated luminosity. Given are minimum accessible p_T and relative statistical uncertainty.

Observable	Approved		Upgrade	
	$p_{\mathrm{T}}^{\mathrm{Amin}}$ (GeV/c)	statistical uncertainty	$p_{\mathrm{T}}^{\mathrm{Umin}}$ (GeV/c)	statistical uncertainty
D meson from B decays R_{AA}	3	30 % at $p_{\mathrm{T}}^{\mathrm{Amin}}$	2	1 % at $p_{\mathrm{T}}^{\mathrm{Amin}}$
D meson elliptic flow (v_2 = 0.2)	1	50 % at $p_{\mathrm{T}}^{\mathrm{Amin}}$	0	2.5 % at $p_{\mathrm{T}}^{\mathrm{Amin}}$
Charm baryon-to-meson ratio	not accessible		2	15 % at $p_{\mathrm{T}}^{\mathrm{Umin}}$
J/ψ R_{AA} (forward rapidity)	0	1 % at 1 GeV/c	0	0.3 % at 1 GeV/c
J/ψ R_{AA} (mid-rapidity)	0	5 % at 1 GeV/c	0	0.5 % at 1 GeV/c
ψ(2S) yield	0	30 %	0	10 %
Low-mass e^+e^- spectral function	not accessible		0.3	20 %

signals of the quark-gluon plasma, that will not be accessible with the current apparatus and the available integrated luminosity up to the long shutdown in 2017/18. Overall, an upgraded ALICE setup at high luminosity should allow

1. precision studies of primary charm (open and hidden) including flow and correlations,
2. measurements of low mass lepton pairs and thermal photons,
3. studies of jet modification via gamma-jet and jet-jet correlations including particle ID, and
4. the search for heavy nuclear states.

ALICE is preparing an upgrade program that builds on the existing strengths of the experimental setup, such as excellent tracking performance, in particular at low momenta, efficient secondary vertex reconstruction, very low material budget, and excellent particle identification. The upgraded ALICE detector will significantly improve the performance in most of these areas, except for particle identification, which will be preserved. Furthermore, the upgraded experimental setup will have enhanced rate capabilities to allow an inspection of Pb-Pb collisions at an interaction rate of 50 kHz. This is necessary to be able to exploit the physics potential, because many of the signals involve rare, but untriggerable probes, like low momentum open charm with its very low signal-to-background ratio. Fortunately, the signal-to-background for these observables will be much better in p-p, such that only a moderately higher luminosity ($\approx$ 200 kHz) will be needed for reference measurements. It will also be possible to measure with the upgraded apparatus at that luminosity. A crucial part of the upgrade is the development and implementation of a significantly improved inner tracking system (ITS). Examples for the performance improvement for important observables are given in Table 1. More information on the improvements and further details on the ALICE upgrade can be found in [4].

Other new detectors are being investigated to possibly further enhance the measurement capabilities for the signals mentioned above. Additionally, with an appropriate detector at large rapidity an opportunity arises for measurements, where the influence of small-x partons is more and more important. This is the region, where effects of gluon saturation [5] should be most prominent. Signals consistent with gluon saturation have been observed at RHIC [6], but these remain inconclusive, because the interpretation is hampered by the very limited kinematical reach. The larger beam energy of the LHC will allow us to enter a new physics regime with access to much smaller values of x and a larger phase space for saturation due to the expected larger saturation scale.

2. ALICE rate capabilities and the upgraded ITS

Within the current ALICE apparatus, the TPC with its long drift time is limiting the rate capabilities. Using the multi-wire readout chambers, a gated operation (at a maximum of 3.5 kHz) is necessary to limit ion feedback to the drift volume, which would otherwise lead to intolerable space-charge distortions. To be able to inspect a significantly higher interaction rate, new readout chambers based on triple-GEMs will be developed. These would be continuously read out (no gating) and should have small enough ion feedback to allow an operation at 50 kHz interaction rate. R&D on the GEM readout chambers is ongoing with an emphasis on achieving the projected low ion feedback and in particular on demonstrating the necessary stability in a high multiplicity/high rate environment. In a pipelined readout data would be shipped from the TPC front-end at 10 MHz for later inspection in a high level trigger system (HLT). The readout electronics of all existing detector systems will be modified to accommodate the rate capabilities. Some systems will likely share the pipelined electronics with the TPC, other detectors, e.g. the electromagnetic calorimeter (EMCal), might preferably be readout on L1 triggers provide by a hardware trigger unit.

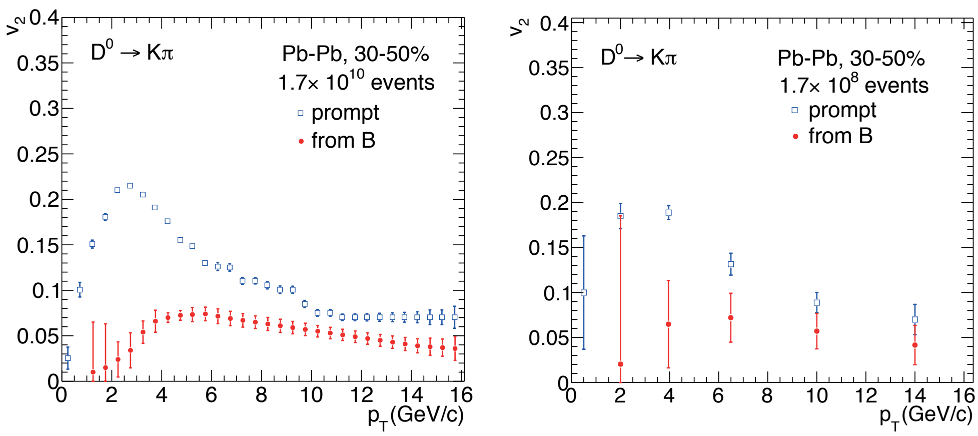

Figure 1: Estimated statistical uncertainties on v_2 of prompt and secondary D^0 mesons for $1.7 \cdot 10^{10}$ events (left) in the 30–50% centrality class, which correspond to 10 nb^{-1}, and for $1.7 \cdot 10^{8}$ events (right), which correspond to about 0.1 nb^{-1}.

The high rate upgrade scenario results in $\approx$ 1 TB/s of input to the online systems, where most of the data originates from the TPC readout. This necessarily will be reduced in particular for the TPC information via cluster finding and cluster-track association, as well as standard Huffman encoding. An average output rate to tape storage of the order of 10 GB/s after this data compression should be achievable.

A completely new Inner Tracking System (ITS) will be developed. The most important features of the new design in addition to enhanced rate capabilities will be:

- A decrease of the radial distance of the first layer to the beam to 22 mm (from 39 mm),
- a reduction of the layer thickness possibly down to 50 μm (from 350 μm), and
- a higher granularity with pixel sizes as small as 20x20 μm^2.

The new ITS will improve the secondary vertex resolution by a factor of ≈ 3 and allow measurements down to much lower values of p_T. Furthermore the high efficiency and low contamination of the new ITS should allow for enhanced level 2 trigger capabilities. Details on the design can be found in [7]. As an example of the estimated performance Fig. 1 shows simulations of an elliptic flow measurement of prompt and secondary D mesons for 0.1 nb^{-1} (left) and for 10 nb^{-1} (right), the latter of which would only be accessible with the upgrade.

3. Additional Detector Upgrades

A number of additional upgrades further enhancing the ALICE detector setup is currently under study. The Muon Forward Tracker (MFT), adding tracking in front of the muon absorber, would allow us to reconstruct possible secondary vertices of muon tracks. This would remove the largest limitation of the current forward muon measurements, enabling the identification of J/ψ from B decays and improving the performance for low mass dileptons. The MFT would use silicon tracking with technologies very similar to those considered for the ITS upgrade.

The VHMPID[2], a new RICH detector, should be able to identify hadrons on a track-by-track basis up to $p_T = 25\,\mathrm{GeV}/c$. The detector would be placed in front of possible new electromagnetic calorimeter elements to allow efficient hadron identification in jets. It would consist of a focusing RICH with a pressurized gaseous C_4F_{10} radiator of $\approx$ 50 cm length, using spherical mirrors, a CsI-based photon detector and front-end electronics based on the Gassiplex chip.

The Forward Calorimeter (FoCal) for large-η measurements would consist of an electromagnetic calorimeter with small Molière radius and extreme granularity, most likely a SiW sandwich design with cell sizes of $\approx$ 1 mm^2. While the demands on energy resolution are moderate for forward measurements, the small opening angle of neutral pion decays and the overall large particle density in Pb+Pb collisions will require good position resolution and two-particle separation power. The detector would allow a detection of neutral pions and direct photons in an η and $p_T$range not accessible to existing experiments. An optional hadronic calorimeter part would improve jet reconstruction and isolation cuts for photon measurements.

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