Upgrade of the ALICE Detector

P. Riedler on behalf of the ALICE collaboration

CERN, CH-1211 Geneva 23, Switzerland

1. Introduction

The ALICE experiment [1] is a dedicated experiment to study strongly interacting matter at the extreme energy densities reached at heavy ion collisions at LHC. ALICE is taking data during heavy ion collisions as well as during proton-proton collisions mainly to collect comparison data for heavy ion physics.

The experiment consists of two parts: the barrel housed inside a 0.5 T magnetic field and a forward muon spectrometer with a dipole of equally 0.5 T. A schematic view of the ALICE experiment and its sub-detectors is shown in Figure 1. The barrel detectors cover a pseudorapidity range of $|\eta| \leq 0.9$, while the muon spectrometer extends the sensitivity over $-4 < \eta < -2.5$. The detector has been designed to sustain the maximum interaction rate of 10 kHz expected in Pb-Pb collisions. The track density in Pb-Pb collisions in the layer closest to the interaction point (radius=3.9 cm) amounts to $\approx 50$ hits/cm$^2$. However, the expected radiation levels are significantly higher. The LHC shutdown foreseen for 2017/18 will allow to address the upgrade of several sub-detectors, in especial the inner tracking system (ITS), the installation of a new forward calorimeter (FOCAL), the extension of the muon spectrometer (MFT - Muon Forward Tracker) and the installation of a detector with enhanced particle identification (VHMPID). An increased rate capability of the largest detector in ALICE, the time projection chamber (TPC), is also under investigation. Furthermore, it is foreseen to improve the data acquisition and high level trigger systems (DAQ and HLT) to achieve more bandwidth and to use more sophisticated and complex triggers. Currently the collaboration is studying the different detector upgrade proposals and prepares a global upgrade plan. This contribution will present the different upgrade projects under study for the ALICE experiment.

© 2012 Published by Elsevier B.V. Selection and/or peer review under responsibility of the organizing committee for TIPP 11. Open access under CC BY-NC-ND license.

Keywords: ALICE, LHC, particle physics experiment, detector, upgrade
lower than in other LHC experiments. At 3.9 cm radius the expected values for a 10 year operation scenario are in the order of $10^{13}$ 1 MeV $n_{eq}$ and a few hundred krad [1].

The ALICE experiment has been optimized for heavy ion running and has some very distinct and unique features, such as:

- a wide transverse momentum range coverage ranging from 100 MeV/c to about 200 GeV/c
- a low $p_T$ cut-off at around 100 MeV/c
- very good tracking and PID capability
- dedicated di-electron and di-muon detection systems
- a high resolution calorimeter for direct photons

The experiment consists of 18 sub-detector systems, which complement each other in achieving this performance. In the following a short description of the main sub-detector systems is given. Details on the experimental apparatus can be found in [1]. The location of the different sub-detector systems is shown in Figure 1.

The tracking information of charged particles is provided by a large time projection chamber (TPC) [3] in combination with the inner tracking system (ITS) [4]. The ITS consists of three sub-systems made of silicon detectors. A more detailed description of the ITS and the plans for its upgrade are given in section 2.2. Several sub-systems contribute to the particle identification: the time-of-flight (TOF) detector, the TPC, the HMPID (high momentum particle identification) and the silicon drift detectors inside the ITS. The TRD (transition radiation detector) surrounds the TPC and consists of large area drift chambers. It allows to separate electrons from the background of high $p_T$ pion tracks. ALICE also has an electromagnetic calorimeter based on Pb0scintillators with a large acceptance ($110^\circ$ azimuthal, $\eta \approx \pm 0.7$). The EMCAL is placed back to back with the Photon Spectrometer (PHOS), a smaller, high granularity lead-tungsten calorimeter. The photon multiplicity detector (PMD) measures on an event by event basis the multiplicity and spatial distribution of photons originating from the collisions. In the very forward region a muon spectrometer is located after an absorber and consists of a set of tracking stations before, inside and after the dipole magnet.

The wide range capabilities of the ALICE apparatus still leave open physics questions to be addressed. Among these ones are the detailed study of heavy flavor production, hadronization, the small-x structure of protons and nuclei and long range rapidity correlations. The aim of the upgrade of the ALICE experiment is to exploit the current performance, to increase the coverage of the apparatus and to enhance the measurement capabilities to address these questions. In the following section an overview of the upgrade plans for the ALICE experiment is presented.

2. ALICE Upgrade Plans

The upgrade plans for ALICE are determined by the results obtained at the current Pb-Pb runs and not by luminosity upgrade considerations. However, the access times for carrying out the upgrade installations are defined by the LHC shutdown. Therefore the ALICE upgrade plans are aligned with the LHC shutdown plans. A first time window to install upgrade detectors will be the LHC shutdown foreseen for 2017/18. A second phase will be in parallel with the LHC shutdown foreseen for 2020-22.

The first call for proposing upgrade projects for the ALICE experiment was launched in spring 2011. The Expressions Of Interest (EOI) of various projects have been submitted to the collaboration. In July 2011 a dedicated workshop was organized to discuss in detail the physics targets for the upgrade. Each of the projects which submitted an EOI is preparing a Letter Of Intent (LOI) for autumn 2011. These projects will then be discussed within the collaboration and a preliminary
decision on the approval within the collaboration will be taken in early 2012. In spring 2012 the projects approved by the collaboration will be presented to the LHCC. Following this, the next step will be the preparation of Technical Design Reports (TDR).

Several projects have submitted an EOI and are currently preparing the LOI and Conceptual Design Reports (CDR). These projects are a Forward CALorimeter (FOCAL), an upgrade of the Inner Tracking System (ITS), a Muon Forward Tracker (MFT) and a Very High Momentum Particle Identification Detector (VHMPID). Several improvements to parts of the existing detectors, such as an upgrade of the TPC readout electronics and an upgrade of the DAQ have also been proposed and will be discussed along with the larger upgrade projects. In the following subsections the four upgrade projects currently under discussion are being presented. A schematic view of ALICE and the location of the proposed detector upgrades within the apparatus is shown in Figure 1.

2.1. The FOrward CALorimeter - FOCAL

The FOCAL is an electromagnetic calorimeter located in the very forward region of the experiment, covering a pseudorapidity region $\eta$ between approximately 2.5 and 4.5 at about 350 cm from the interaction point. It will measure photons and neutral mesons, such as $\pi^0$ and $\eta$ using approximately 21 layers of tungsten (W) interleaved with position sensitive silicon detectors. The proposed W thickness is 3.5 cm. The possibility to distinguish high momentum photons ($\sim$200 GeV/c) originating from $\pi^0$ decays from those ones which are directly generated in the collision is one of the main tasks of the FOCAL. It will allow to study the small-x structure of protons and nuclei in proton-heavy ion and heavy-ion collisions. A schematic view of a possible FOCAL layout is shown in Figure 2.

To cope with the high particle multiplicity environment it is necessary to use high granularity silicon pixel detectors. Several technical implementations are currently under study, of which one is the use of monolithic silicon pixel detectors as being proposed for the STAR upgrade [5]. These types of monolithic silicon pixel detectors are also under study for an ITS upgrade. An alternative silicon detector option is the use of silicon pad detectors with cell sizes with less than 1 cm length on each side. A final decision on the silicon detector technology has not yet been taken and will depend also on possible synergies with other upgrade projects.
2.2. The Inner Tracker System upgrade

The current ALICE ITS consists of 6 layers of silicon detectors. The two innermost layers are made of hybrid silicon pixel detectors, followed by two layers of silicon drift detectors. The two outermost layers consist of double sided silicon strip detectors. The high granularity of the pixel layers provide precise tracking information close to the interaction point, while the drift and strip detector layers provide tracking and Particle IDentification (PID). The ITS layers cover the radii from 3.9 cm up to 43 cm with a total material budget of only 7%.

The study of heavy flavor baryons and an extended charm coverage at low $p_T$ are two physics goals which will be possible to achieve with an upgraded ITS. It shall also provide the possibility to measure exclusive B-decays. A very high performance silicon tracker with up to 9 layers has been proposed which will improve the impact parameter resolution by a factor 2-3. The innermost layer will be placed at about 22 mm radius profiting from a smaller new beam-pipe. Especially for the innermost layers the material budget constraints are very stringent, aiming for a total of 0.3-0.5% $X_0$. Pixel sizes of approximately 20-30 μm will be required in the inner layers to improve the pointing resolutions in $r\phi$ and to increase the background rejection capability in $z$. For the outer layers with an expected lower hit density the option to use silicon strip detectors with reduced strip length of about 2 cm is also under consideration. The $\eta$ coverage of the new ITS will be extended to $|\eta| \leq 1.2$. A schematic view of the upgraded ITS is shown in Figure 3.

The technologies under consideration for silicon pixel detectors for the ITS are hybrid silicon pixel detectors and monolithic silicon pixel detectors. Hybrid pixel detectors present a mature technology used in the four large LHC experiments. For the ALICE ITS studies are carried out to build hybrid pixel detectors with 100 μm thick sensors connected to 50μm thick readout ASICs. Monolithic pixel detectors on the other hand present the possibility to construct a lower mass detector with very high granularity. Several types of monolithic silicon pixel detector technologies and architectures are under study, such as pixel detectors with rolling-shutter architecture [5] and monolithic pixels produced in the INMAPS [6] process. Parameters that the new pixel detector will have to meet is a dissipated power of less than 0.3 W/cm$^2$ and a readout time of 50 μs or less. The innermost layer will be exposed to higher radiation levels and to hit multiplicities of about 85 hits/cm$^2$ in Pb-Pb collisions.

Studies and tests of the different technologies and architectures as well as for a new double sided
Fig. 3. Schematic view of the upgraded ITS. The muon absorber is shown on the right.

strip detector are ongoing.

2.3. The Muon Flavour Tracker

The MFT (Muon Flavour Tracker) will complement the muon arm of the experiment with tracking planes located in front of the muon absorber. By using the tracking information provided by these planes it will be possible to accurately determine the origin of the muons registered in the muon arm. The installation of the MFT in the detector will require a new beampipe with probably conical shape and the integration with the new ITS. The technology under study for the tracking planes are monolithic silicon pixel detectors with rolling shutter architecture [5] as also proposed for the ITS upgrade.

2.4. The VHMPID

The Very High Momentum Particle Identification Detector (VHMPID) will provide particle identification for pions, protons and kaons on a track by track basis in the momentum range of 10-25 GeV/c. It will be located at the bottom of the barrel part of the experiment close to the PHOS detector. The VHMPID will be a focusing RICH (Ring Imaging CHerenkov) detector with spherical mirrors. The radiator proposed is C_4F_{10} with aerogel being considered as an alternative. The detectors under study to be used for the photon detection are Multiwire Proportional Wire Counters (MPWC) operated with CH_4 and a CsI photocathode and GEM detectors with CsI coating. The proposed readout chip for the VHMPID is the GASSIPLEX chip [7] which also used in the present HMPID in the ALICE experiment.

3. Summary

The ALICE experiment is successfully taking data in proton-proton and heavy ion collisions. The current apparatus will not allow to address specific physics topics, such as detailed study of heavy flavor production, hadronization, the small-x structure of protons and nuclei and long range rapidity correlations. An upgrade of the ALICE experimental setup will improve the measurement capabilities and increase the coverage of the experiment in order to address these questions.

The first upgrade phase is planned to take place during the LHC shutdown in 2017/18. The ALICE collaboration has asked for the expression of interest of proposals for an upgrade to be submitted. The letters of intent for the different upgrade proposals are being prepared for autumn
2011. The current time-plan foresees a decision on the proposed projects within the collaboration in early 2012.

The proposals being discussed are forward calorimeter for precise measurement of high momentum photons (FOCAL), an upgrade of the inner tracking system (ITS), an extension of the muon tracking system before the muon absorber (MFT) and a new high momentum particle identification detector (VHMPID). Different technologies are under study for each of the proposals. The FOCAL, ITS upgrade and MFT are investigating the possibility to use novel monolithic silicon pixel detectors. Stringent requirements are set on material budget especially for the innermost layers of the ITS upgrade. The technical requirements for the upgrade have been defined and the studies to identify the most suitable technologies and architectures are under way. The upgrade projects proposed for the ALICE experiment will significantly increase the measurement capabilities of the apparatus and will allow to address new physics questions.

References

[1] The ALICE Experiment at the LHC, J. Instrum 3, S08002 (2008).
[2] Public ALICE web-pages, http://aliceinfo.cern.ch/Public/Welcome.html.
[3] ALICE TPC Collaboration, The ALICE TPC, a large 3-dimensional tracking device with fast readout for ultra-high multiplicity events, Nucl. Instr. and Meth. A 622 (2010), p.316f.
[4] I. Kotov, Inner tracking system of the ALICE experiment - overview, Nucl. Instr. and Meth. A 568 (2006), p. 274-276.
[5] L. Greiner et al., A MAPS based vertex detector for the STAR experiment at RHIC, Nucl. Instr. and Meth. A (2010), doi: 10.1016/j.nima.2010.12.006, in Press.
[6] M. Stanitzki, Advanced monolithic active pixel sensors for tracking, vertexing and calorimetry with full CMOS capability, Nucl. Instr. and Meth. A (2010), doi: 10.1016/j.nima.2010.11.166, in Press.
[7] J.-C. Santiard, The ALICE HMPID on-detector front-end and readout electronics, Nucl. Instr. and Meth. A 518 (2004), p. 498-500.