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# Muon physics at forward rapidity with the ALICE detector upgrade

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## Abstract

ALICE is the experiment specifically designed to study the Quark-Gluon Plasma (QGP) in heavy-ion collisions at the CERN LHC. The ALICE detector will be upgraded during the Long Shutdown 2, planned for 2019–2020, in order to cope with the maximum interaction rate of 50 kHz of Pb-Pb collisions foreseen for Runs 3 and 4. The ambitious programme of high-precision measurements, expected for muon physics after 2020, requires an upgrade of the front-end and readout electronics of the existing Muon Spectrometer. This concerns the Cathode Pad Chambers (CPC) used for tracking and the Resistive Plate Chambers (RPC) used for triggering and for muon identification. The Muon Forward Tracker (MFT), an internal tracker added in front of the front absorber of the existing Muon Spectrometer, is also part of the ALICE detector upgrade programme. It is based on an assembly of circular planes made of Monolithic Active Pixel Sensors (MAPS), covering the pseudorapidity range  $2.5 < \eta < 3.6$ . The MFT will improve present measurements and enable new ones. A selection of results from physics performance studies will be presented, together with an overview of the technical aspects of the upgrade project.

## Keywords:

ALICE upgrade, ALICE muon upgrade, Muon Forward Tracker, Muon identifier, Muon Tracking Chambers upgrade.

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## 1. Introduction

The ALICE experimental programme encompasses a broad set of measurements based on muons in the Muon Spectrometer [1], covering a pseudorapidity range of  $2.5 < \eta < 4$ . The Muon Spectrometer consists mainly of the following elements: a hadron absorber, allowing reliable muon identification; ten tracking chambers based on Cathode Pad Chambers grouped in five stations with 1.1 million readout channels and a spatial resolution of around 100  $\mu\text{m}$  in the bending direction; and four trigger chambers based on Resistive Plate Chambers with a time resolution of 2 ns, grouped in two stations with 21k readout channels. The muon physics program in ALICE includes the study of quarkonia production, open heavy flavor production and low mass dimuons. The Muon Spectrometer has delivered a wealth of results on these topics. Still there

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<sup>1</sup>A list of members of the ALICE Collaboration can be found at the end of this issue.

are some limitations. Improving upon these limitations would not only extend the present measurements but also open the possibility of new measurements. To this purpose, an upgrade strategy for the Muon Spectrometer is in place, which forms part of the broader ALICE upgrade program.

## 2. Motivations for the upgrade of the Muon Spectrometer

The main limitation of the current Muon Spectrometer comes from the multiple scattering effects induced on the muon tracks by the hadron absorber, resulting in the inability to determine precisely the muon production vertex. This prevents the disentanglement of open charm and open beauty production without making assumptions relying on physics models. It is impossible to separate prompt and displaced  $J/\psi$  mesons, thereby losing an important source for the study of beauty production. Additionally, there are significant statistical uncertainties, specially at low masses and low  $p_T$ , in single muon and dimuon analyses due to the high background coming from semi-muonic decays of pions and kaons. Also, there is limited mass resolution for the light neutral resonances. Apart from these, the readout of the present system is not designed to cope with the high rates (Pb-Pb collisions with an interaction rate of 50 kHz) foreseen in Runs 3 and 4 in ALICE (from 2021).

To overcome these limitations, there is a comprehensive upgrade strategy, which forms part of the broader ALICE upgrade strategy [2, 3]. To cope with the high rates, the readout electronics of several detectors will be upgraded, including the muon tracking and the trigger chambers. Also, two new silicon trackers will be installed, facilitated by a narrower beam pipe. In the central rapidity region, the present Inner Tracking System will be replaced by a new pixel tracker. In the forward rapidity region, a new silicon pixel tracker called the Muon Forward Tracker (MFT) will be installed, which will add vertexing capabilities to the Muon Spectrometer, thereby overcoming the aforementioned limitations.

## 3. Muon trigger and tracking stations upgrade

The muon trigger chambers will be upgraded to become the muon identifier (MID) which will operate in a continuous readout mode [4]. The readout rate will be more than two orders of magnitude larger compared to the present design. To reduce ageing effects in the Resistive Plate Chambers (RPC), the charge per hit has to be limited. This will be realized by using the same types of RPCs at lower gain with a new front-end (FE) chip (FEERIC) that provides signal amplification. The present FE chip does not provide signal amplification. The RPCs that have already accumulated a large integrated charge - the ones closest to the beam pipe - will be replaced. The FEERIC cards have been produced already and a sample was tested in ALICE. The performance of the RPC equipped with FEERICs is similar to the current ones. The left panel of Fig. 1 shows the efficiency of the RPC equipped with FEERIC as a function of time. The efficiency is very high ( $> 97\%$ ) in both the bending and non-bending planes across different collision systems.

The muon tracking chambers (MCH) will be upgraded with new front-end electronics (FEE) and a new readout chain to cope with the higher rates in Run 3 and 4 [4]. The FEE is designed to operate at 100 kHz, incorporating a safety margin. A new front-end chip called SAMPA has been developed in common with the ALICE Time Projection Chamber upgrade project. The present FE boards will be replaced by new Dual SAMPA (DS) boards, each hosting two SAMPA chips providing a total of 64 readout channels. The data from the DS boards will be shipped out through FE links implemented on printed circuit boards. New concentrator boards (SOLAR) will accumulate data from several DS boards through the FE links and send them to the new Common Readout Units (CRU) of the ALICE central Data Acquisition System. The SOLAR board implements the GBT protocol [5]. The full readout chain has been successfully tested in beam tests at CERN in 2017. The production of all the components of the readout chain will begin in late 2018.

## 4. Muon Forward Tracker

The Muon Forward Tracker (MFT) will add vertexing capabilities to the Muon Spectrometer and will be installed before the hadron absorber, covering a pseudorapidity range  $2.5 < \eta < 3.6$  [3, 6]. In the upgrade

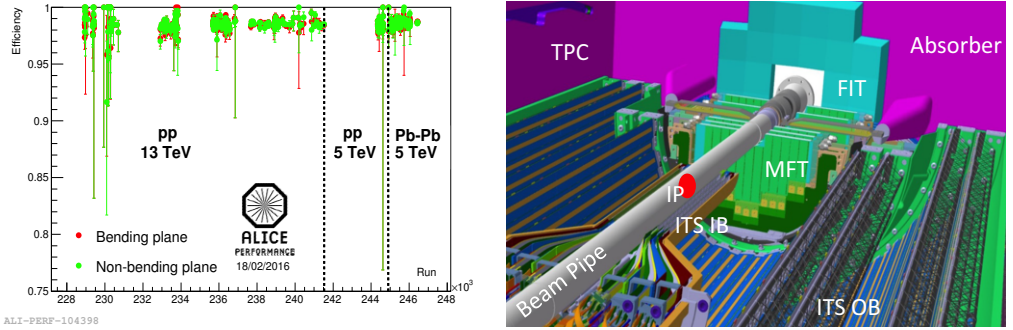


Fig. 1. The left panel shows the efficiency of the Muon Trigger Chamber RPC equipped with FEERIC, measured in ALICE in 2015. The right panel shows the position of the MFT in ALICE. The MFT half-cone is shown which is placed along the beam axis towards the Muon Spectrometer between the Interaction Point (IP) and the hadron absorber.

scenario, the extrapolated muon tracks coming from the muon tracking chambers after the absorber will be matched to the MFT tracks before the absorber. This will result in high pointing accuracy, allowing a reliable measurement of their offset with respect to the primary vertex of the interaction. The silicon pixel sensor used for MFT is ALPIDE, which is a common development with the new Inner Tracking System [7] of ALICE. ALPIDE is based on Monolithic Active Pixel Sensors (MAPS) and is fabricated using 180 nm Towerjazz technology [8]. The pixel size is  $27 \mu\text{m} \times 29 \mu\text{m}$  and the spatial resolution is better than  $5 \mu\text{m}$ . MFT has a cone structure - formed by two half cones. Each half cone consists of five half-disks positioned along the beam axis, in the direction of the Muon Spectrometer. Each half-disk consists of structures called ladders which host the ALPIDE chips. The position of MFT is shown in the right panel of Fig. 1.

## 5. Physics measurements with the Muon Forward Tracker

The MFT will allow significant improvements and new insights into measurements concerning charmonia production, open heavy flavor production and low mass dimuons [3]. Here we will briefly discuss some of these measurements.

MFT will serve as a useful tool to discriminate between different models of charmonium regeneration in the QGP. This will be achieved by separating the prompt and the non-prompt  $J/\psi$  and reducing the uncertainties on the  $\psi(2S)$  measurements in the Pb-Pb collisions. MFT will allow the separation of prompt and non-prompt  $J/\psi$  down to zero  $p_T$ , by measuring the pseudo-proper decay time ( $t_z$ ) associated to the secondary vertex [3], falling within the  $J/\psi$  mass window. The separation is performed statistically by a simultaneous fit. The fit on the invariant mass spectrum fixes the normalization of the background and the inclusive  $J/\psi$ . The fit on the pseudo-proper decay time ( $t_z$ ) then separates the non-prompt from the prompt  $J/\psi$ . The left panel of Fig. 2 shows the combined fit on  $t_z$  in the  $J/\psi$  mass window  $3.0 < m_{\mu\mu} < 3.2 \text{ GeV}/c^2$  in the  $p_T$  bin  $0 < p_T < 1 \text{ GeV}/c$ .

Prompt and displaced  $J/\psi$  separation is possible down to zero  $p_T$  within 5% statistical and systematic uncertainties. This gives us access to beauty measurements. It is possible to measure the beauty  $R_{AA}$  down to zero  $p_T$  within 7% statistical and systematic uncertainties. The right panel of Fig. 2 shows the beauty  $R_{AA}$  in the central and forward rapidity regions. The MFT nicely complements the central barrel measurements. It is to be noted that the MFT simulations have been performed only at low  $p_T$ .

The MFT will also improve measurements of higher charmonium states. MFT will improve on the uncertainties of the  $\psi(2S)$  measurement in central Pb-Pb collisions, improving the signal-to-background by a factor of 5-6. Precise measurements of  $J/\psi$  and  $\psi(2S)$  production down to zero  $p_T$  are expected to be sensitive to the mechanism of charmonia regeneration in the Quark Gluon Plasma [6].

Low-mass dimuon measurements in ALICE provide an important insight to the bulk properties and evolution of the hot and dense QCD matter formed in the Pb-Pb collisions. They are currently limited by

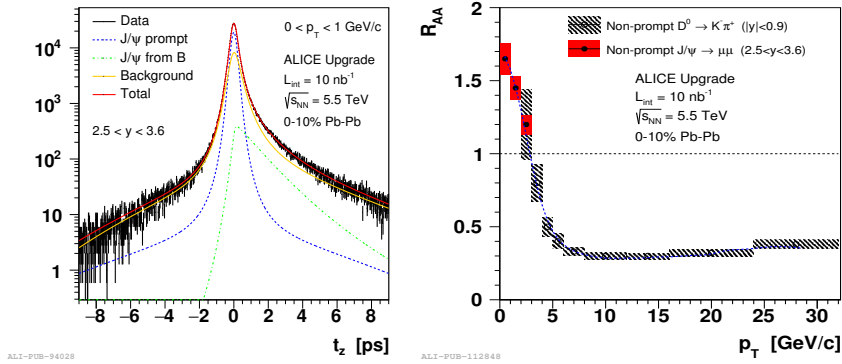


Fig. 2. The left panel shows the combined fit of the pseudo proper decay time,  $t_z$  in the  $J/\psi$  mass window  $3.0 < m_{\mu\mu} < 3.2 \text{ GeV}/c^2$  in the  $p_T$  bin  $0 < p_T < 1 \text{ GeV}/c$ , for the statistical separation of the prompt and displaced contributions. The right panel shows the performance of the measurement of the nuclear modification factor of the  $J/\psi$  and  $D^0$  from beauty decays in the forward and central rapidity region, respectively, with the upgraded ALICE detector.

the high combinatorial background from the semi-muonic decays from kaons and pions. The MFT will not only reduce the combinatorial background but also improve the mass resolution, thanks to the precise measurement of the opening angle of muon pairs. For example, the mass resolution of  $\phi$  in the decay channel  $\phi \rightarrow \mu\mu$  for all  $p_T$  will improve from  $51 \text{ MeV}/c^2$  to  $15 \text{ MeV}/c^2$  [3]. This will greatly improve the measurement of the QGP-induced spectral function modification of light vector mesons, which was predicted as a signature of chiral symmetry restoration [9].

## 6. Conclusions

The measurements based on the Muon Spectrometer in the forward rapidity region could be improved and extended by enhancing the track spatial resolution close to the interaction point and the readout rate. The MFT will provide vertexing capabilities to the Muon Spectrometer, thereby improving the physics program of ALICE in Runs 3 and 4 starting from 2021. New and improved measurements will be possible, especially in the study of quarkonium production, open heavy flavor production and low-mass dimuons. In the existing Muon Spectrometer, the front-end electronics and the readout chain will be completely replaced to cope with the high rates foreseen in Runs 3 and 4. The ALPIDE chips used by the MFT (and the new ITS) are a result of a comprehensive R&D program in ALICE and all of them have already been produced. All other components for the spectrometer readout and the MFT are either in production or pre-production stage.

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