CERN Summer Students programme

Understanding the Muon Forward Tracker's acceptance using a Monte Carlo simulation

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Abstract

The new Muon Forward Tracker (MFT) is based on the Sillicon Pixel Detectors (SPD) technology and it has been installed in 2020 as part of the upgrade of A Large Ion Collider (ALICE), one of the main LHC experiments. It aims at improving the vertexing capability of the apparatus in the forward pseudorapidity region. In this project, I implemented a new toy Monte Carlo simulation to help understanding the MFT acceptance and analyzing its output. My results include the impact evaluation of individual SPDs and broader MFT regions with a physical interpretation.

Acknowledgements

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1 Introduction

A Large Ion Collider Experiment (ALICE) has been specifically designed to exploit the potential of nucleus-nucleus collisions in the study of quark-gluon plasma, but it is also a general purpose detector which allows to study nucleon-nucleon and nucleon-nucleus collisions. It is constituted out of several components, one of them being the Muon Forward Tracker which is designed to help reconstructing muon tracks in the pseudo-rapidity range $-4 < \eta < -2.5$. It is located close to the collisions' vertex (45.3 cm in average) upstream of the hadron absorber and the former muon spectrometer as illustrated on Fig.1.

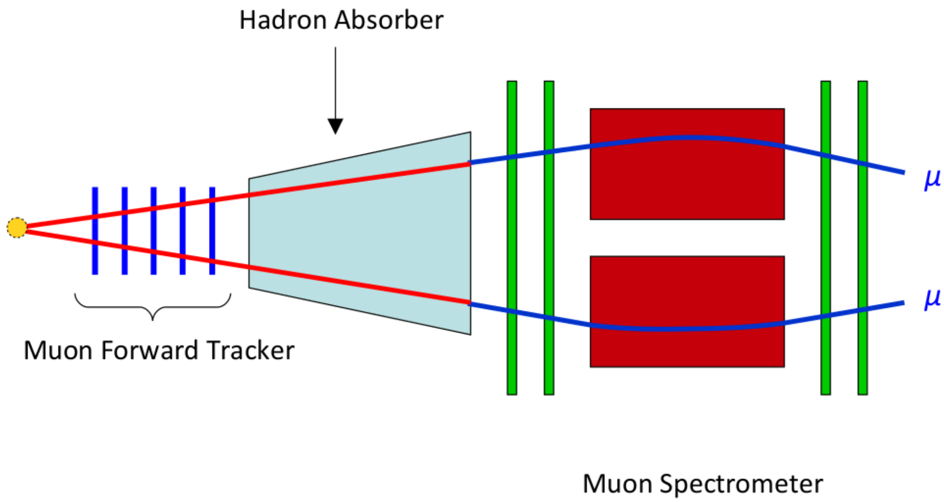


Figure 1: Schematic representation of muon tracking in the upgraded ALICE experiment (extracted from [1])

The muons' kinematic distributions can be obtained from the MFT: azimuthal angle ϕ, pseudorapidity η, transverse position (x, y). In order to better understand the shape of these distributions and their most frequent fluctuations, this project proposes a new toy Monte Carlo simulation which estimates the MFT's response to a set of generated particles. Beyond the agreement obtained at first order between the Monte Carlo simulation and the real data obtained from the MFT, discrepancies between them can be used to either estimate uncertainties in the reconstruction procedure or identify technical issues in the MFT operations and evaluate their impact.

2 MFT geometry

According to the Technical Design Report [2], the MFT is constituted out of 936 Sillicon Pixel Detectors (SPDs) also referred to as sensors. 28 of them are permanently "dead" *i.e.* they are excluded from the data acquisition. These sensors are then identified by which half, disk, face, zone, ladder and chip of the MFT they correspond to. The MFT geometry is represented on Fig.2.

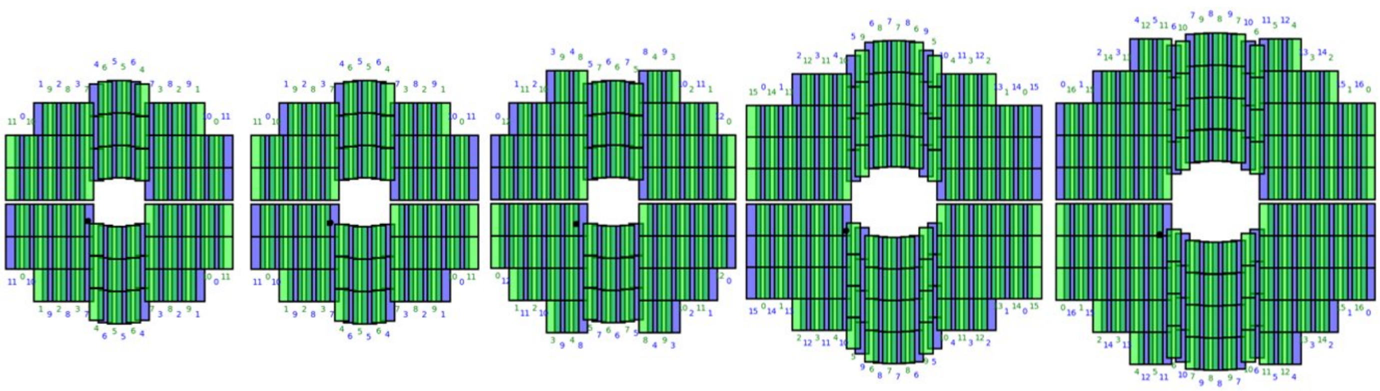


Figure 2: Geometry of MFT disks

Ladder indices are shown next to each ladder's edge. Front sensors are represented in green, back sensors in blue

3 The toy Monte Carlo simulation

In order for the toy Monte Carlo software to simulate the kinematic distributions obtained from the MFT, the following steps are implemented:

1. A set of particles are generated uniformly in $\phi \in [-\pi, +\pi]$ and $\eta \in [-4.2, -2.0]$ (to cover the full MFT acceptance) with a small dispersion from the nominal vertex position ($z_{\text{vertex}} \sim \mathcal{G}(0, \sigma = 56.1\,\text{mm})$).

2. The algorithm extrapolates the position of each particle on the 10 planes (5 disks, 2 faces) of the MFT (tracks are supposed to be perfectly linear).

3. The algorithm determines which MFT sensors have been hit.

4. Hit sensors that correspond to unoperational sensors (either because they are permanently “dead” or because they are temporarily in error) are removed.

5. Only the particles’ tracks which satisfy the minimum selection criteria (at least 5 hits on at least 4 disks) are kept in the MC output.

In order to assert the validity of this code, an event display has been implemented in another program. It allows to visualize the sensors’ position as well as the particle’s hit’s position on each plane.

For instance, the event display shown on Fig.3 shows that a given particle has hit two sensors on the first disk (on front and rear faces). One can then visually identify them and check whether the hit sensors given by the toy MC simulation agree with the event display.

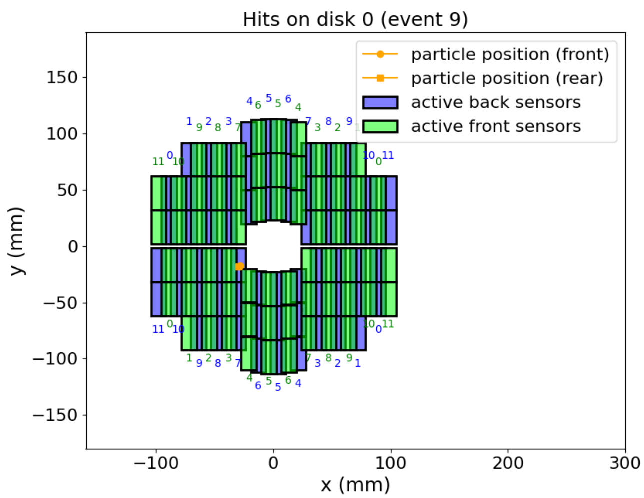


Figure 3: Example of an event display for the disk 0

4 Analysis and interpretation

The output of the toy MC simulation has then been compared to real data obtained from the MFT. The analysis study discussed below was focused on only one specific run: Run 535047 - period LHC23e - April 23, 2023, 01:28:52 - 07:18:44. This run was chosen because ALICE magnets were offline, otherwise the induced magnetic field would have significantly deviated the particles’ tracks and the linear track hypothesis implemented in the simulation would have been less relevant.

To begin with, the MC simulation was used to evaluate the impact of the different excluded chips, first the “dead” ones then the chips in fault and error. Fig.4 illustrates the agreement between the Monte Carlo results and Quality Control (QC) data (*i.e.* real data). The agreement tends to improve as the excluded map taken into account.

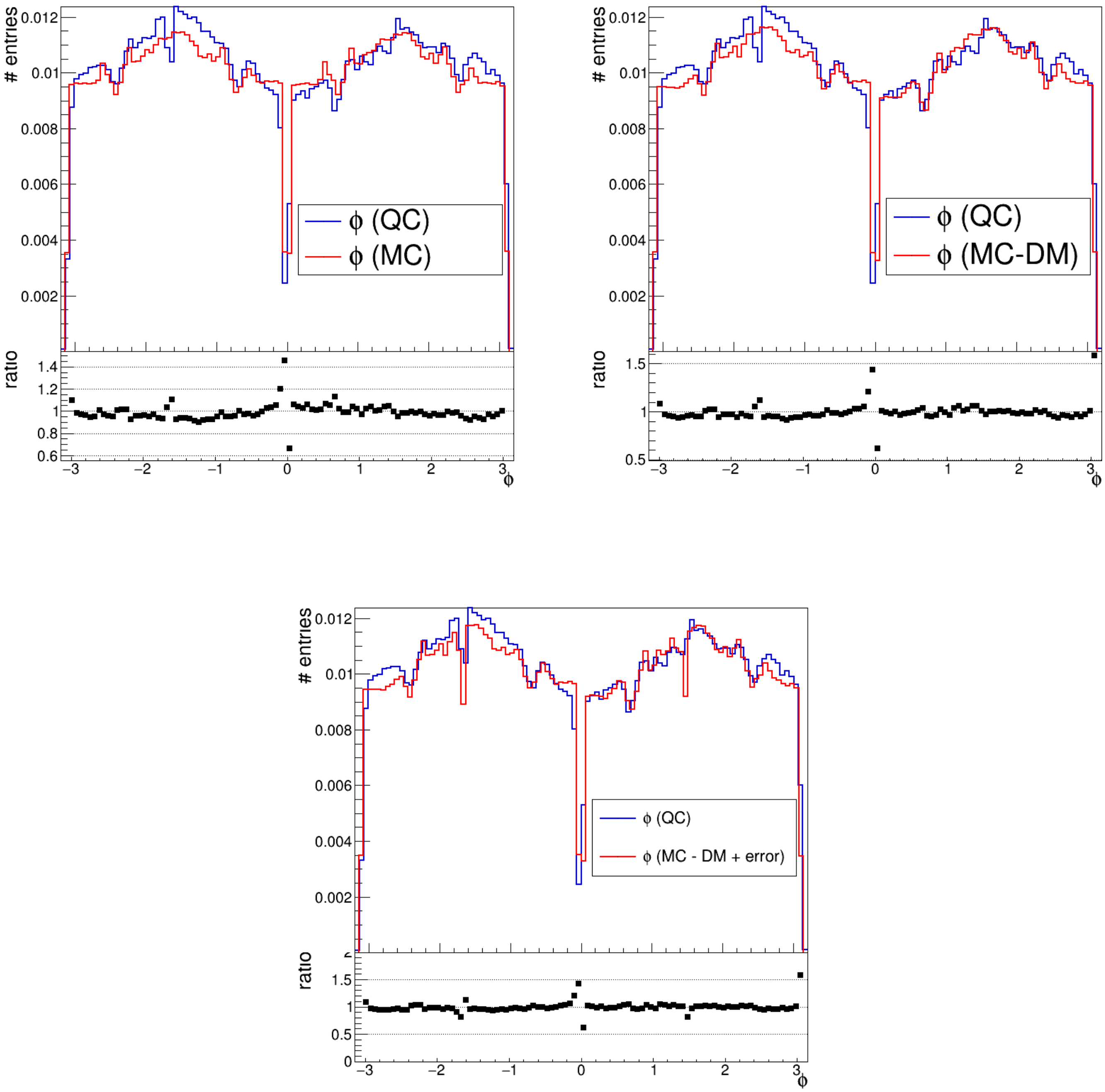
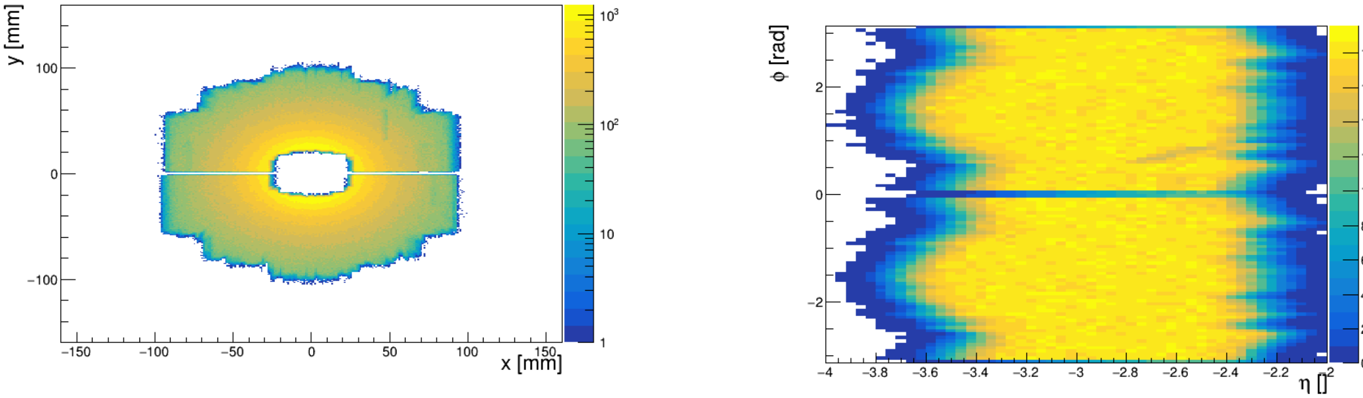


Figure 4: Comparison of the ϕ distribution between MC and real data depending on which chips are excluded

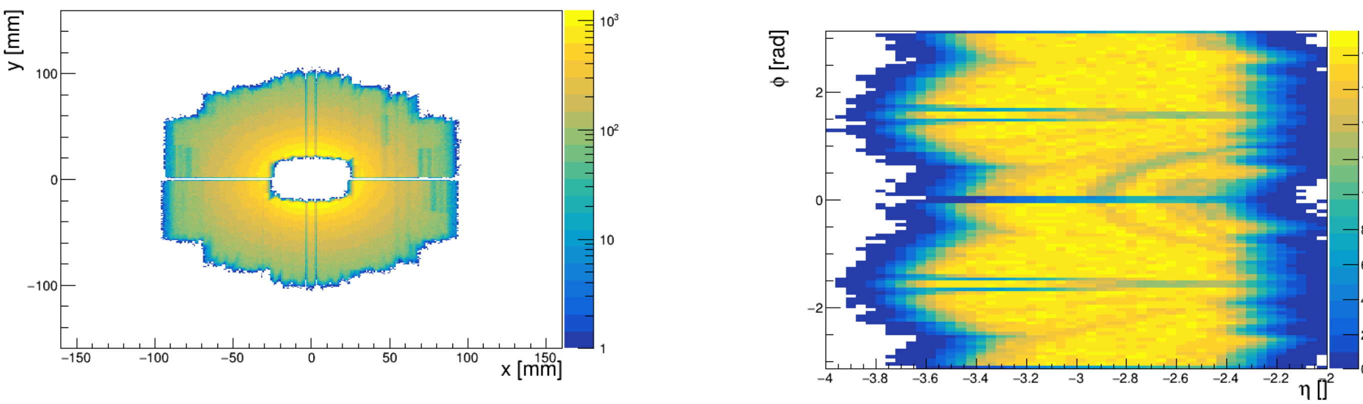
As expected, the simulation with all active sensors (Fig.4 left) is almost symmetric between negative and positive values of ϕ. This reflects the fact that the nominal geometry is perfectly symmetric between upper and lower halves as it is illustrated on Fig.2. The asymmetry is visibly broken by the addition of the dead map (Fig.4 right). Eventually, the chips in error and fault introduce a loss of statistics close to $\phi = \pm\pi/2$ (Fig.4 bottom).

These figures also illustrate that discrepancies between Monte Carlo and real data remain more important in certain small ϕ regions, especially around $\phi = \pm\pi/2$.

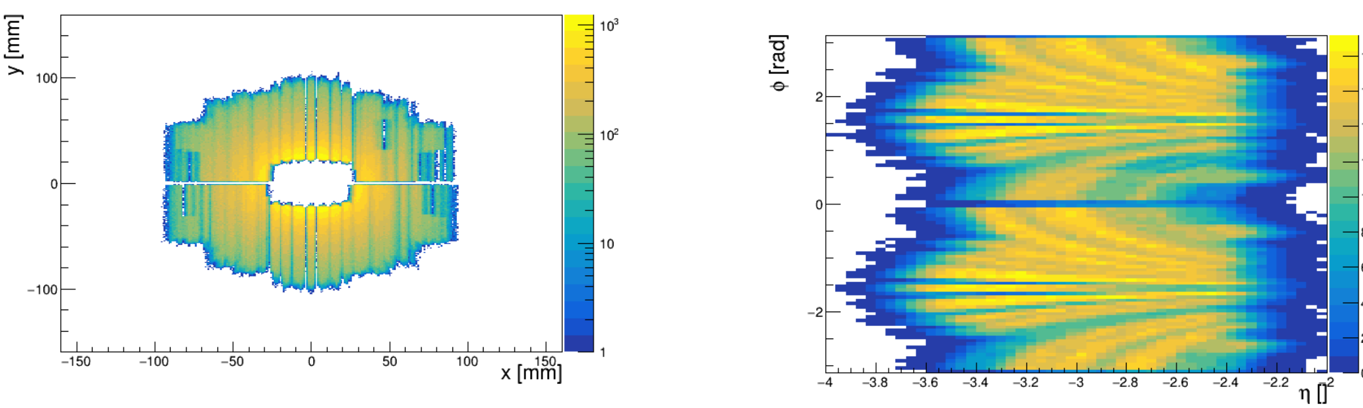
In order to understand how the discrepancies are distributed, the MC simulation output has been used to determine what chips and regions have the most impact on the tracks' statistics. These most important or sensitive regions are the most affected by more stringent criteria. To evaluate the chips' importance, MC kinematic distributions have thus been plotted in (x, y) and (η, ϕ) coordinates for a different minimum number of hits per track on Fig.5.



(a) 5 hits



(b) 6 hits



(c) 7 hits

Figure 5: X/Y and η/ϕ track distributions with respect to the minimum number of hits

Hypotheses: Selected tracks hit at least 4 disks. The dead map is taken into account. On the XY distribution, all selected tracks are projected on the first MFT plane. Default selection criterion is 5 hits

Ladder interspaces become visible at low $|x|$ for a minimum number of 6 hits. A large part of the ladder structure becomes visible for a minimum number of 7 hits as well as some punctual losses due to the dead sensors.

These observations have shown that the ladder structure plays a particularly important role in the low-$|x|$ region ($\phi \approx \pm\pi/2$).

In order to get a more precise interpretation, Monte Carlo 2D distributions were compared to the geometrical redundancy (*i.e.* how many times the sensors overlap). Assuming a fixed vertex position, all the nominal SPDs' positions have been projected on the first plane with regards to the vertex position on Fig.6 (left). The SPDs positions have then been converted into (η, ϕ) coordinates on Fig.6 (right).

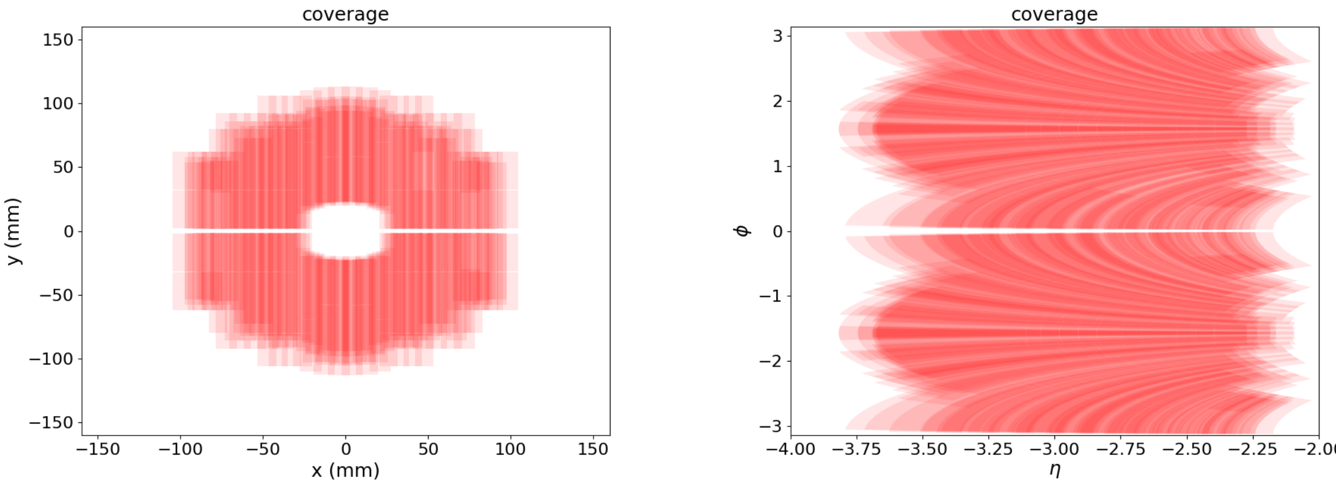


Figure 6: chips' redundancy in cartesian coordinates (left) and (η, ϕ) coordinates (right)

Inactive "dead" SPDs are not represented

The ladder structure is apparently visible in the X/Y distribution as well as in the η/ϕ one but the ladder structure does not have the same effect in every region.

The disks are aligned in such a way that the peripheric ladders' overlap is usually homogeneous at high $|x|$.

On the contrary, the central ladders are almost perfectly aligned such that the redundancy is maximal at $x = 0$. The chips' interspaces are also well-aligned at low $|x|$ such that the redundancy is minimal at $x = \pm 7mm$. The low-$|x|$ region thus shows the highest contrast in redundancy values.
Besides, the central ladders at low $|x|$ correspond to a very small ϕ range centered around $\phi = \pm\pi/2$. On the other hand, contributions of several ladders ladders tend to average out for ϕ closer to 0 and $\pm\pi$.

The analysis of the redundancy thus explains the heterogeneous distributions observed in Fig.5 and provides a reasonable interpretation for the distribution of discrepancies in Fig.4.

Other effects have been investigated in the MC simulation to better reproduce the MFT real conditions:

1. Introduction of a small transverse vertex dispersion: $\delta_x, \delta_y \sim \mathcal{G}(0, \sigma = 0.1\,\text{mm})$. The effect found on the kinematic distributions is negligible (less than 1% difference overall and less than 2% difference for individual ϕ bins).

2. Shifting the mean longitudinal position of the vertex: $z_{\text{vtx}} \sim \mathcal{G}(\langle z \rangle \in [-50\,\text{mm}, +50\,\text{mm}], \sigma = 56.1\,\text{mm})$. Only a small effect was found for the ϕ distribution (less than 2% overall and 5% for individual ϕ bins). High effect on η distribution and bad agreement with the data.

3. Implementation of a small unknown transverse misalignment ($\delta_x, \delta_y \sim 120$ µm). The effect on track distribution is negligible (less than 5‰difference overall).

5 Conclusion and future developements

Data comparison in this report shows that the toy Monte Carlo simulation agrees well with real data at first order despite some remaining discrepancies.

Aside from this agreement, discrepancies allowed to evaluate the impact of the different SPDs' regions and shed light on the existence of more sensitive zones.

With regards to the state of knowledge acquired at the end of this study, some perspectives and directions for the future may be considered:

Other effects may be taken into account for the particle's position: rotational misalignment, reconstruction's uncertainty, multi-scattering etc.

Comparison between MC simulation and real data may be pushed further to precise the origin of discrepancies.

References

[1] Antonio Uras. “The ALICE MFT Project: Motivations and Expectations”. Rencontres QGP France. 2012.

[2] *Muon Forward Tracker*. Tech. rep. 2015.