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TRACKING PERFORMANCES OF SEVERAL FRONT-ABSORBER DESIGNS

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Abstract

The tracking performances of the ALICE forward muon spectrometer are investigated for several front-absorbers designs. The obtained mass resolution is compared to the one of the absorber proposed in the LOI. Out of punchthrough considerations, two absorbers compositions, including a Carbon+Concrete sandwich design, allow to reach the requested mass resolution for the Υ *'s. Almost identical behaviours are observed versus rapidity and transverse momentum of resonances for both new candidates. These proposed designs improve the mass resolution performances and could stand as suitable absorber options for the forward muon spectrometer of ALICE. The Carbon+Concrete absorber has been retained for the Technical Proposal [1].*

1 Introduction

The muon arm of ALICE contains three absorber sections [1]: the front absorber in the acceptance region ($2^o < \theta < 9^o$), the beam shielding which surrounds the beam pipe, and the muon filter between the tracking and the trigger chambers. The front absorber has the double task of reducing the forward flux of charged particles by at least two orders of magnitude and of decreasing the decay muon background by limiting the free path of primary muonic decays of π 's and K 's into the forward spectrometer. With a length of 10 λ_{int}, the front absorber keeps the hadron punch-through within acceptable limits. By starting close to the vertex at $z = 90$ cm, it lowers the muon decay background.

This note will only focus on the tracking properties of several front absorber designs. Optimization of these absorbers in term of shielding is addressed elsewhere [2]. The influence of the front absorber on the dimuon mass resolution issues from its radiation length distribution [3]. Optimization of the front absorber in term of mass resolution is achieved by using low-Z materials in the absorber layers close to the vertex and high-Z shielding materials at the rear end [4]. Under these configuration, the scattering center of the mixtures is flinged back at the rear end of the absorber. Larger the level arm formed by the apparent scattering point and the vertex, better the estimation of muon emission angle at the production vertex. As shown in the paper [3], it is possible to derive the angular resolution for a given compound absorber.

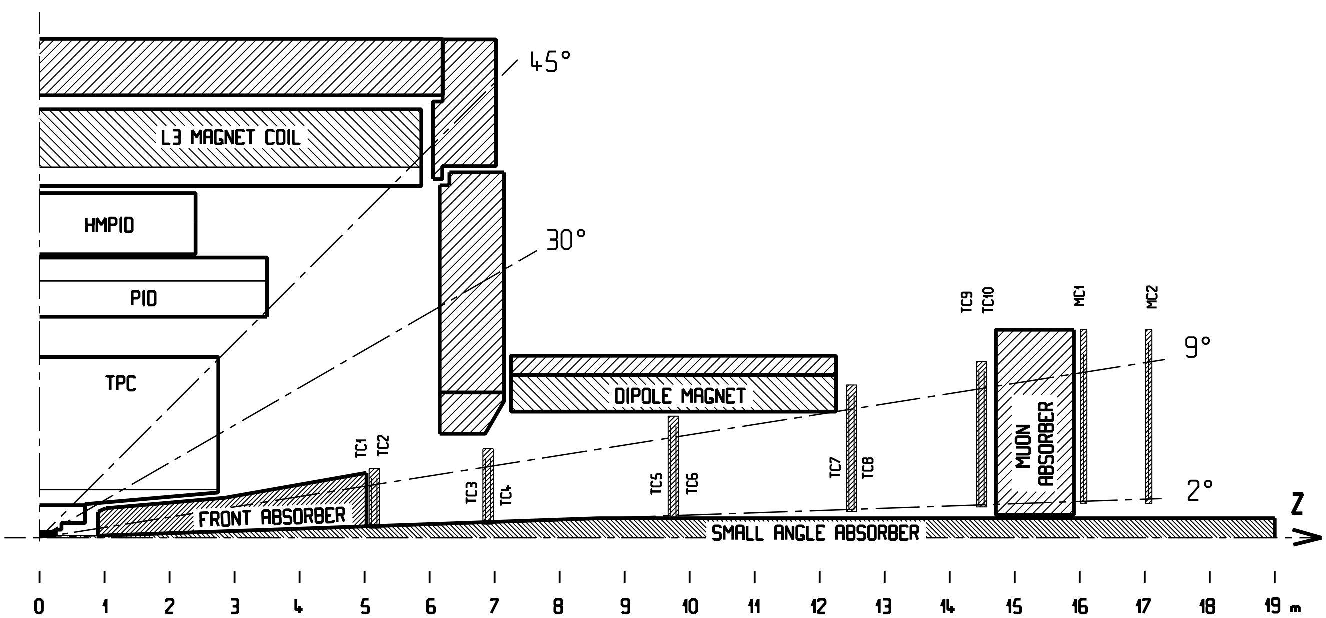

Figure 1: *Layout of the 9° dipole spectrometer used for the GEANT simulations.*

2 Method

To estimate the tracking performances with these new absorbers, the same chain of simulation and reconstruction programs exposed in the note [5] has been used. Calculations are based on the GEANT package for the set-up description. All relevant physics processes are included in this GEANT simulation (e.g. multiple scattering, energy loss, bremsstrahlung, etc.). Independent parametrized distributions in transverse momentum and rapidity are used to generate resonances [1].

The main parameters of the detector (the layout of the tracking chambers, their spatial resolution and efficiency, the dipole magnetic field, etc.) are kept at the nominal values [5]. The resonances are emitted in the apparatus and the correlated unlike sign muons are accepted if they cross all the tracking stations, according to the global majorities of $3/4 \otimes 1/2 \otimes 3/4$ for the downstream, middle and upstream stations. The general layout of the detector used for the tracking simulations is shown on figure 1. In order to extract the proper effect of the absorber material on the dimuon mass resolution, only the absorber is modified.

The dimuon mass calculation is made in two steps [5]:

- in the first step, a vector momentum estimation of the muon is deduced from an estimation of the deflection angle in the dipole magnetic field between the upstream and downstream tracking stations, neglecting the absorber effect. At this level, only muons of $p_{xz} > 2.5$ GeV/c are kept for further analysis. In fact, this threshold corresponds to a 4.5 GeV/c momentum cut due to the energy loss in the absorber. The track fit starting with the momentum estimation is a standard chisquare minimization with five parameters (ie: without vertex constraints). Correlations between the measurements in all the tracking stations due to the multiple scattering are taken into account using covariance matrix.

- in the second step, tracks are enforced to join the vertex using the Branson plane which z position is evaluated once for all for a given absorber. The energy loss of muons in the absorber is taken into account as a mean correction along the track.

At the end of this procedure, the momenta of the particles at the emission vertex are obtained and the invariant mass of the dimuon is derived.

3 The Absorber Layouts

Compared to the LOI absorber, which is taken as a reference, the mass resolution performances of two new absorbers designs are investigated. The layouts of these aborbers are given in figure 2. The relevant characteristics of the aborbers for the tracking are summarized in the table 1.

The LOI option [7] consists of a central carbon core starting at $z = 0.9$ m and ending at $z = 4.4$ m covering the angular range ($2^o < \theta < 12^o$). A tungsten beam shield cone starts at a radial distance of 4 cm and is shaped along the 2^o line but does not exceed a radius of 30 cm. An outer tungsten shield between 12^o and 15^o protects the TPC against

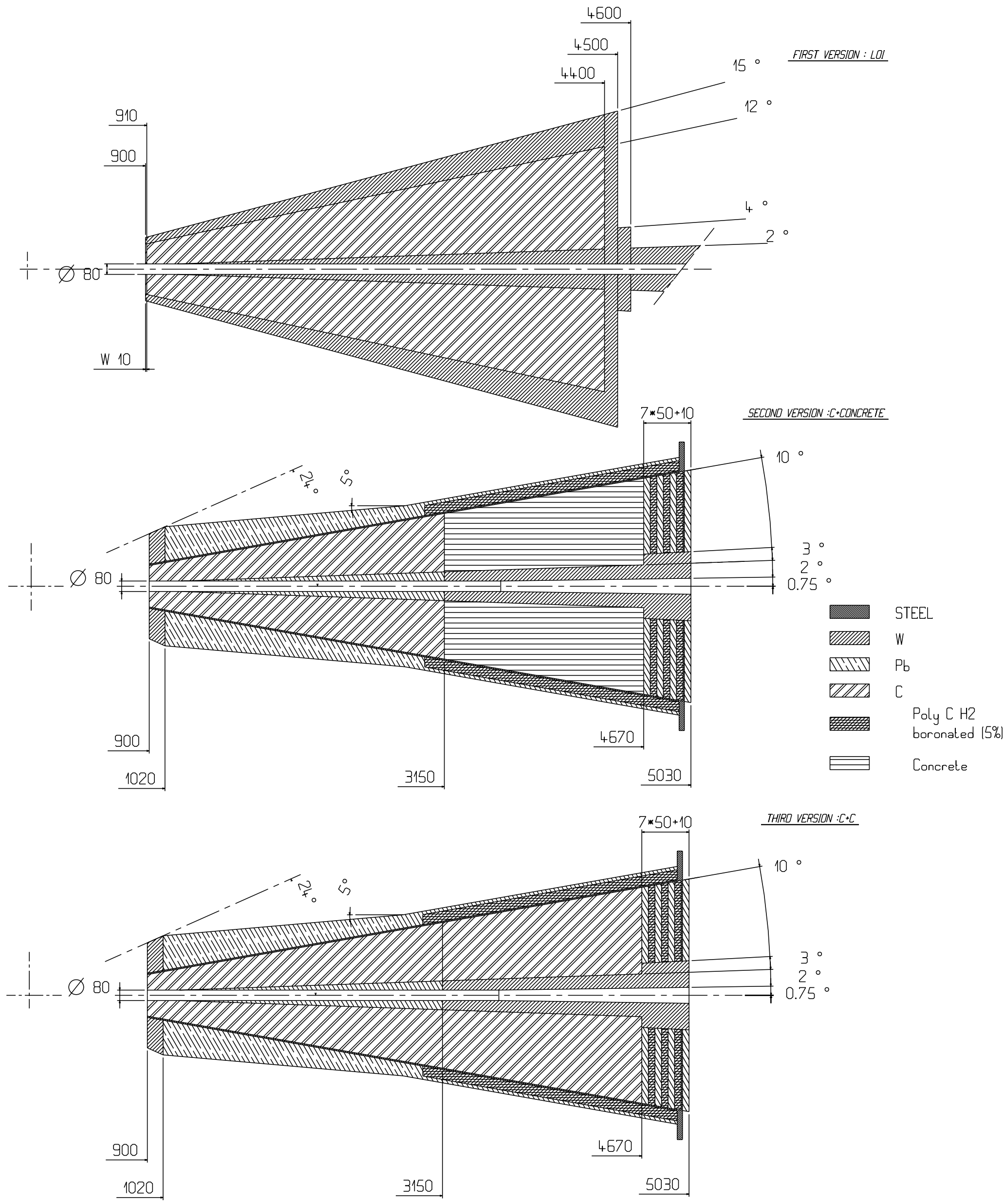

Figure 2: *Side view of the three absorbers used in the GEANT simulations.*

	Tot. Int. Length (λ_{int})	Tot. Rad. length (X_0)
LOI Absorber	8.95	47.22
2^{nd} Opt. (C+Conc.)	10.17	60.26
$3^r d$ Opt. (C only)	9.76	53.09

Table 1: *Summary of the three absorbers characteristics. Note that, the carbon density is set to 1.93 $g.cm^{-3}$ and the concrete composition is the one of standard shielding at CERN.*

particles back-scattering but this covering has no contribution to the muon momentum resolution. To prevent the back-splash, an 1 cm W-layer covers the front face of the absorber and intercepts the back-scattered particles. As will be seen this piece takes a great importance in the mass resolution. The rear face of the absorber is covered with 10 cm of tungsten between 4^o and 15^o and with 20 cm in the region 2^o to 4^o. Influence of this extra shielding is appreciable at high rapidity only.

The second design is a novel option [2]. In the angular acceptance ($2^o < \theta < 10^o$), the absorber core is conical with the longitudinal extention 0.9 m$< z <$5.03 m . The front part of the absorber is made of a Carbon+Concrete sandwich of 2.25 m and 1.52 m length respectively. The rear shield is a combination of 4 layers of lead (20 cm cumulated) interleaved with 3 layers of boronated polyethylene (16 cm) which serves both of neutrons absorber and electrons + photons shielding. Between 2^o and 3^o and 4.67 m$< z <$5.03 m , an additional tungsten cone reinforces the shielding for the first tracking station, without significantly deteriorating the momentum resolution.

The third option only differs from the second one by the use of a Carbon piece in place of the concrete part (a full carbon absorber). As shown in table 1, this substitution decreases the total radiation length without reducing substantially the total interaction length of the absorber.

4 Mass Resolution

In order to understand our simulations in terms of mass resolution an important result from [3] is presented below. As underlined in the second paragraph, extraction of the direction of muons at the vertex (angle θ relatively to the z axis) is based on the so-called Branson correction.

This method gives in a very convenient way an estimation of θ, knowing the particle direction at the rear end of the absorber. It should be notice that the uncertainty on this angle has a large contribution to the resolution on the invariant mass of the dimuon. The derivation of the error on θ leads to the following formula:

$$\Delta\theta = \alpha \; R_a$$

with

$$\alpha = \frac{0.0136(GeV/c)}{\beta p}$$

and

$$R_a = (F_0 - \frac{F_1^2}{F_2})$$

for a particle of momentum p in (GeV/c) and velocity $\beta = \frac{v}{c}$
The quantities $F_n = \int_{Z_i}^{Z_f} \frac{z^n}{X_0} dz \;\; (n = 0, 1, 2)$ are the moments of the compound absorber where each part starting at Z_i and ending at Z_f is characterized by a radiation length X_0.
R_a is a constant depending only of the absorber characteristics (the radiation lengths X_0) and of the positions along the z axis of the different materials making up the absorber. Therefore, the relative performances of the absorber in terms of angular resolution and subsequently the dimuon mass resolutions can be compared using this R_a factor only. In the following, R_a will be used to explain the results of the simulations.

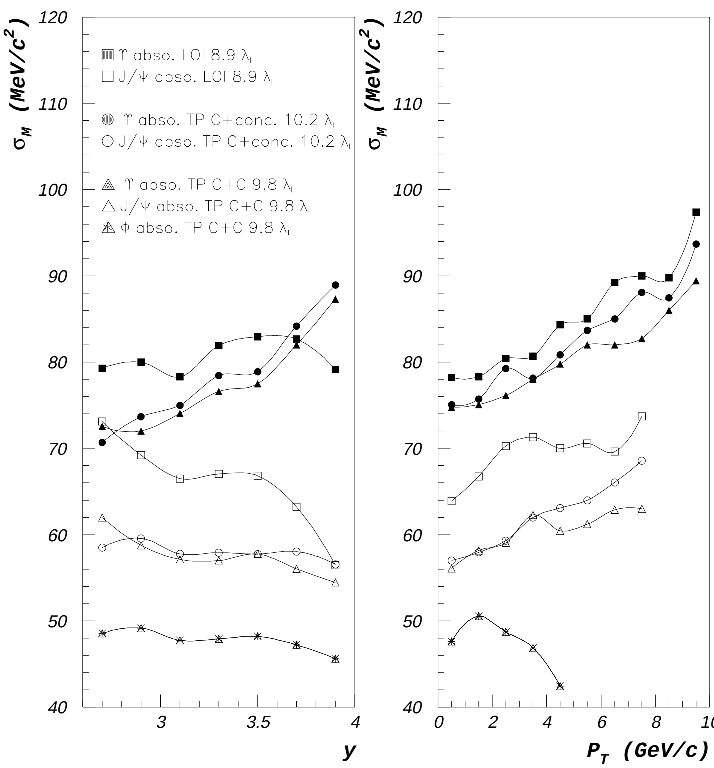

Figure 3: *Comparison of the mass resolution performances versus rapidity y and transverse momentum p_T for the J/Ψ 's and the Υ's. The current tracking parameters are: $B.l = 3$ T.m, $\sigma_x = 100\ \mu m$, $\sigma_y = 1.44$ mm.*

Rapidity and transverse momentum dependences of the mass resolution for the LOI absorber and the two new designs are given in the figure 3 for the J/Ψ and the Υ. The mass resolution for the ϕ is also given as an indication of the spectrometer performances in this mass domain.
At low rapidity, the 2^{nd} and 3^{rd} options exhibit a better mass resolution compared to the LOI layout for all resonances. This result is more and more pronounced with the decrease of resonance masses. According to the paper [3], such a behaviour is interpreted as an effect of the 1 cm W-layer in the front of the LOI absorber which deteriorates the particle momentum.
Since the behaviour of the LOI absorber has been extensively commented on in another note [5], we will focus on the new results.

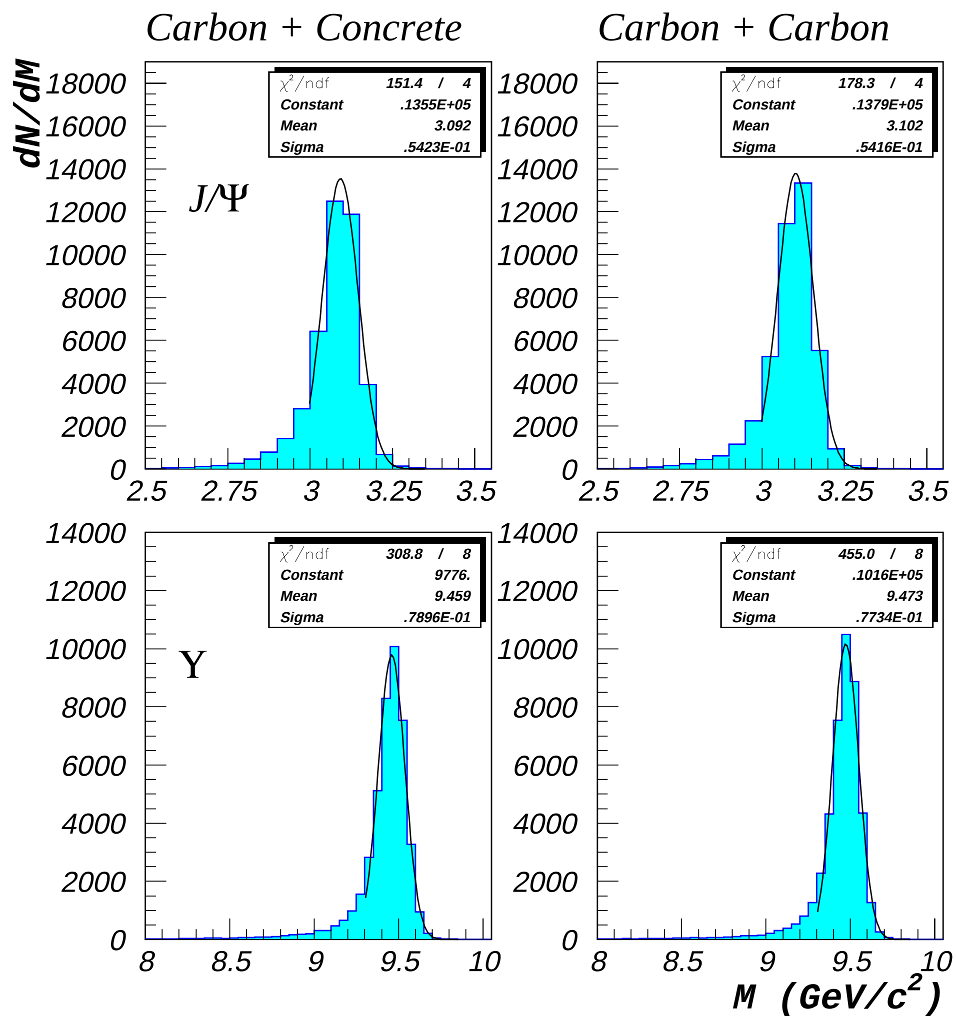

Figure 4: *Dimuon mass resolution over the whole phase space for the J/Ψ and the Υ calculated for the Carbon+Concrete and Carbon+Carbon absorber options. The current tracking parameters are: B.l = 3 T.m, σ_x = 100 μm, σ_y = 1.44 mm.*

One can see from figure 3 that the Υ mass resolution for both options, is getting worse and worse at high rapidity and high transverse momentum of resonances due to the limitation of the spatial resolution $\sigma_x = 100\ \mu$m for large particle momentum. Concerning the J/Ψ, the mean energy of the decay muons being lower than for the Υ, the deterioration of the mass resolution due to the chamber resolution is hidden by the effect of the multiple scattering in the absorber.

One should also notice that the obtained resolution for the Carbon+Carbon option is slightly improved compared to the Carbon+Concrete option. For both new options the mass resolution over the whole phase space is around 80 MeV for the Υ and around 60 MeV for the J/Ψ as shown in figure 4. These resolutions are better than the necessary values required to separate the excited level from both resonance families. This result seems to lead to the conclusion that the Carbon+Carbon option is better from the tracking point of view. In fact, for a constant absorber length, the number of λ_{int} for the Carbon+Carbon option is lower than for the Carbon+Concrete option. If the number of λ_{int} is kept at a fixed value of 10 then as shown in figure 5 the angular resolution on the muon direction and then the mass resolution is the best for a compound absorber of 286 cm of carbon $(376-90)$ and 98 cm of concrete $(474-376)$ and 35 cm of Pb/Polyethylene sandwitch. Hence, a Carbon+Concrete compound absorber shows both an improved behaviour concerning the background and a gain in mass resolution. However, it should be pointed out that the difference in mass resolution between both new options is relatively modest. In any case, a clear improvement is observed compared to the LOI absorber ($R_a = 2.48$).

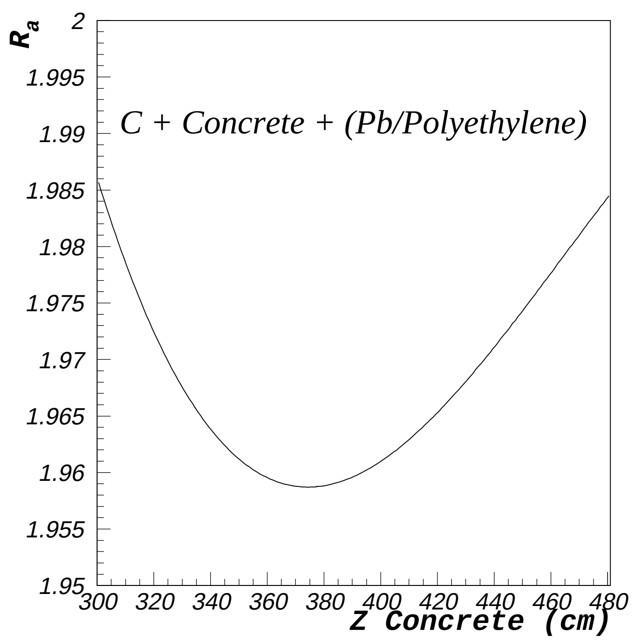

Figure 5: *R_a as a function of the z position of the frontier between the carbon and the concrete for a constant* 10 λ_{int} *absorber. R_a is explained in the text.*

5 Conclusion

The dimuon mass resolution has been calculated for three kinds of absorbers; the LOI set-up and two new designs, namely Carbon+Carbon and Carbon+Concrete options. The results show that the new reference absorber design as chosen in the Technical Proposal of the muon arm [1] improves substantially the mass resolution especially for the J/ψ's family. The analysis of the results in terms of angular resolution due to Branson correction leads to the conclusion that the 1 cm W-layer in the front of the absorber deteriorates the mass resolution.

Both new designs present similar resolution behaviour as a function of rapidity and tranverse momentum. The slight differences have been explained in the same manner with the help of the R_a factor (see text above).

Finally, the smooth dependence of the mass resolution as a function of rapidity and transverse momentum is found acceptable for a safe analysis of the dimuon physics even for the Υ's family ($70 MeV/c^2 < \sigma_M < 90 MeV/c^2$). Nevertheless, the spatial resolution of the chambers for small radii would pay to be better than the 100 μm required for the rest of the chambers in order to keep a constant mass resolution at all rapidities. Moreover, the track finding efficiency could gain from an improved spatial resolution especially in these regions of high hit densities.

References

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