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Required and Achievable Precision of the Alignment of the ALICE Forward Muon Spectrometer

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Abstract:
In this note the effect of a misalignment of the Alice forward muon spectrometer with respect to the barrel detectors is studied. The observed change of the mass resolution and of the mass peak position allows to estimate the required precision of the alignment.
In the second part of this note the achievable precision of an alignment with reconstructed muon tracks is analyzed.

Required and Achievable Precision of the Alignment of the ALICE Forward Muon Spectrometer

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October 7, 2003

1 Introduction

In this note the effect of a misalignment of the Alice forward muon spectrometer with respect to the barrel detectors is studied. The observed change of the mass resolution and of the mass peak position allows to estimate the required precision of the alignment.

In the second part of this note the achievable precision of an alignment with reconstructed muon tracks is analyzed.

2 Misalignment Effects

In order to get a good angular resolution of the tracks reconstructed by the muon detector, the tracks are fitted to the primary vertex. The primary vertex is reconstructed by the ITS pixel detector with high precision. As a consequence of a misalignment between the muon detector and the ITS, the muon tracks would be fitted to a systematically shifted vertex position which leads to a systematic effect on the reconstructed track angle.

To study the effect of a misalignment, 1000 events with one Upsilon each decaying into two muons were simulated. The momentum and rapidity distribution of the Upsilon were taken from a parametrisation (AliGenMUONlib). The primary vertex was simulated at (0,0,0).

A misalignment was introduced by fitting the reconstructed muon tracks to a vertex that was shifted from the correct position at (0,0,0). The amount of the shift was 100 μm, 1 mm, 1 cm and 10 cm in the x, y and z direction, respectively.

The effect of the misalignment is shown in figures 1, 2 and 3[1]. The reconstructed invariant mass is quite insensitive to a misalignment in the x or y direction. Only for the extreme shift of 10 cm in y a significant change of the position and the width of the mass peak is observed. The robustness of the reconstructed mass can be explained by the fact that both muon tracks are shifted in the same way. So the angle between the two tracks, which determines the invariant mass, is almost unchanged.

A misalignment in z, however, changes the angle between the two tracks and leads to a systematically shifted mass. For a misalignment of 1 cm the effect on the mass is about 20 MeV. On the other hand the resolution of the mass is not very sensitive to the z alignment.

[1] Even in the well aligned case the mean position of the mass peak is about 70 MeV higher than the nominal Υ mass. This is due to a systematically overestimated reconstructed momentum. Fortunately this has no effect on the considerations about alignment presented in this note.

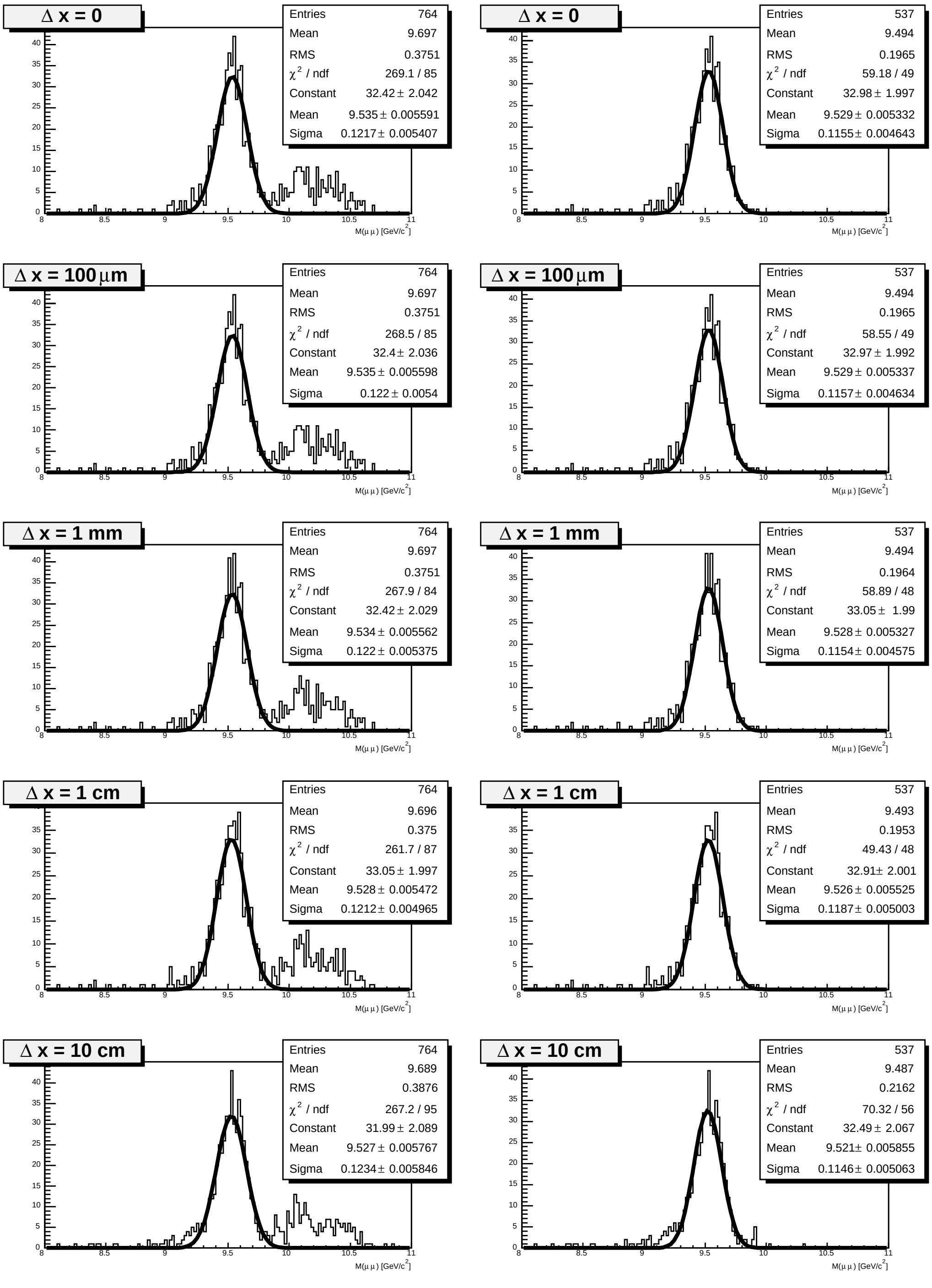

Figure 1: Reconstructed invariant mass of muon pairs for events with Υ and Υ' mesons (left) and with Υ mesons only (right). For the two plots at the top the correct vertex was used in the reconstruction. For the plots below a systematic shift of 100 μm, 1 mm, 1 cm and 10 cm in the $\mathbf{x}$ direction was introduced.

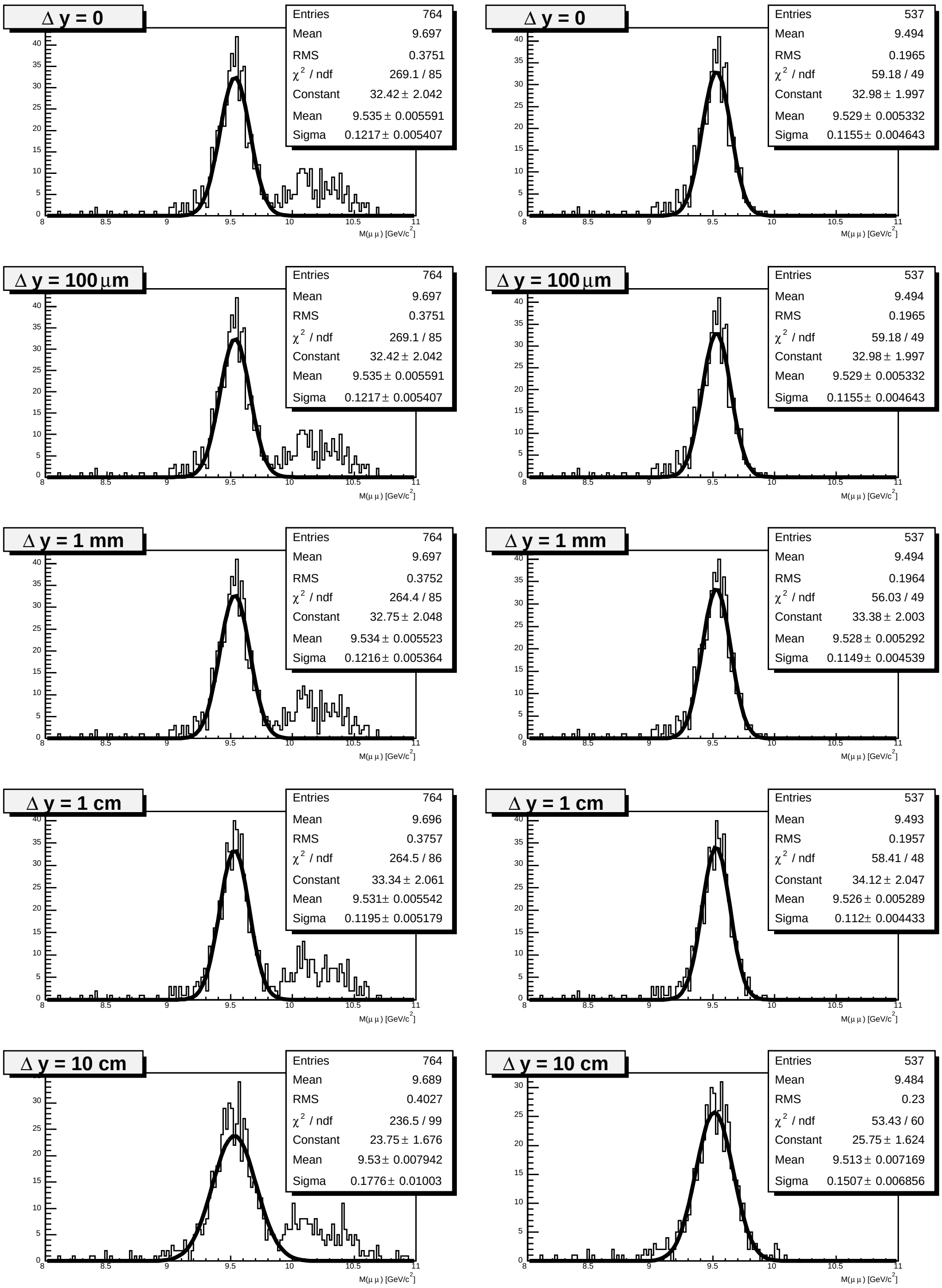

Figure 2: Reconstructed invariant mass of muon pairs for events with Υ and Υ' mesons (left) and with Υ mesons only (right). For the two plots at the top the correct vertex was used in the reconstruction. For the plots below a systematic shift of 100 μm, 1 mm, 1 cm and 10 cm in the **y** direction was introduced.

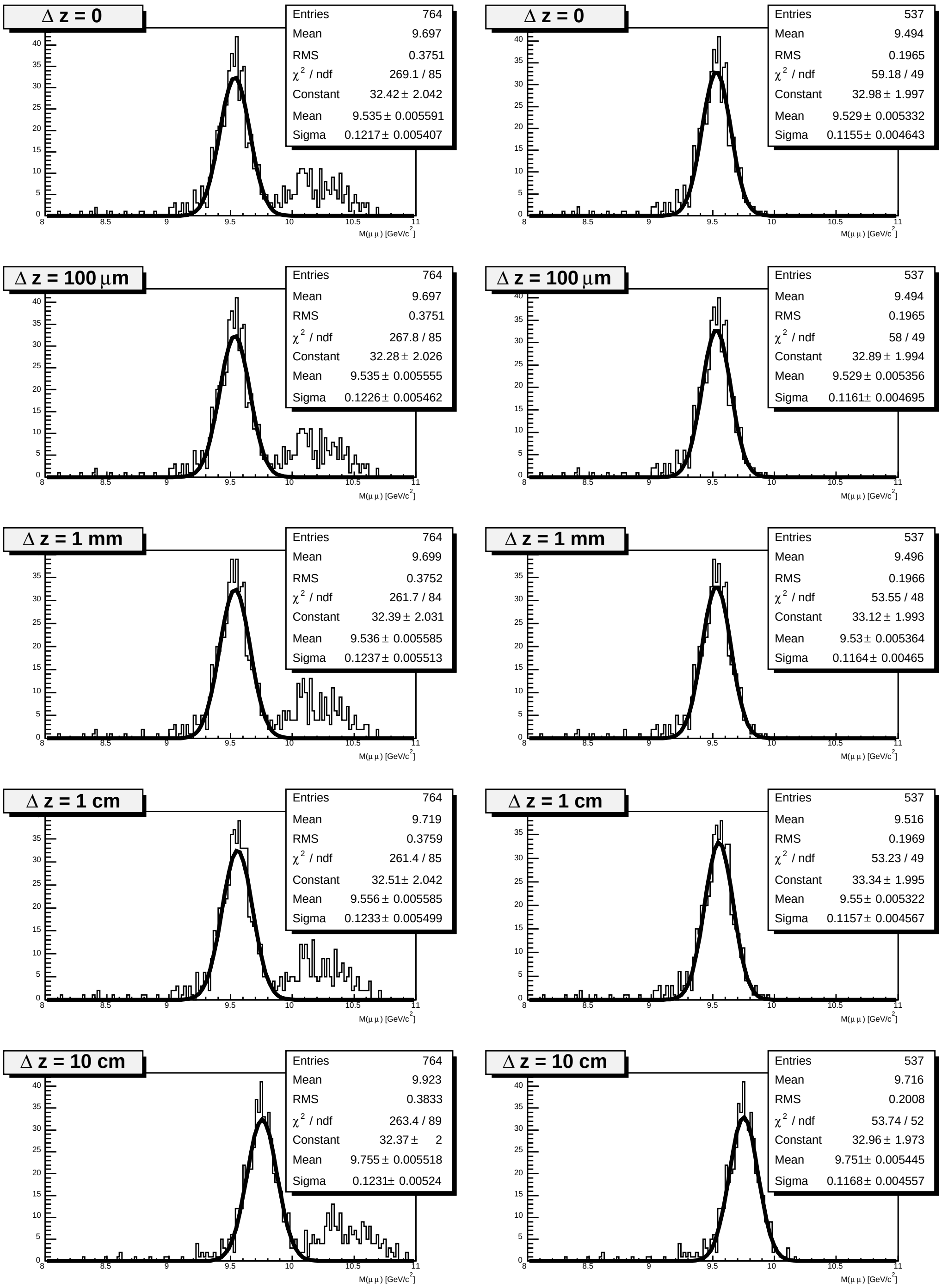

Figure 3: Reconstructed invariant mass of muon pairs for events with Υ and Υ' mesons (left) and with Υ mesons only (right). For the two plots at the top the correct vertex was used in the reconstruction. For the plots below a systematic shift of 100 μm, 1 mm, 1 cm and 10 cm in the **z** direction was introduced.

3 Alignment Precision

The position resolution of muon tracks at the vertex is dominated by multiple scattering in the absorber. The mean scattering angle $\delta\theta$ in the rz plane is given by ([1])

$$\delta\theta = \frac{13.6\ \mathrm{MeV}}{\beta cp} z\sqrt{x/X_0}\,[1 + 0.038\ln(x/X_0)] \tag{1}$$

with p being the momentum, βp the velocity and z the charge of the particle. x is the thickness and X_0 the radiation length of the material. The mean displacement of the track due to multiple scattering is

$$\delta r = \frac{1}{\sqrt{3}} \cdot x \cdot \delta\theta. \tag{2}$$

$\delta\theta$ and δr are correlated. Their correlation coefficient is

$$\rho = \frac{\sqrt{3}}{2} \approx 0.87. \tag{3}$$

Using these formulas the resolution at the vertex of a muon track with momentum p and polar angle θ can be calculated. In x and y direction the resolution is given by

$$\sigma_{x/y} = \sqrt{\delta r^2 + 2\cdot\rho\cdot\delta r\cdot\delta\theta\cdot\frac{\Delta z}{\cos^2\theta} + \left(\delta\theta\cdot\frac{\Delta z}{\cos^2\theta}\right)^2}. \tag{4}$$

Here Δz is the distance of the vertex from the absorber. The z resolution of a muon track is

$$\sigma_z = \sqrt{\left(\frac{\delta r}{\tan\theta}\right)^2 + 2\cdot\rho\cdot\frac{\delta r}{\tan\theta}\cdot\delta\theta\cdot\frac{\Delta z}{\sin\theta\cdot\cos\theta} + \left(\delta\theta\cdot\frac{\Delta z}{\sin\theta\cdot\cos\theta}\right)^2}. \tag{5}$$

These resolutions determine the precision of the alignment relative to the ITS. The variation of the absolute position of the event vertex does not enter here because the alignment parameters are deduced from the difference of the vertices reconstructed by the ITS and the muon detector. The values of the parameters that are used in the following calculations are listed in table 1.

The formulas above assume a homogeneous material distribution. This is not the case for the absorber. A first estimation using the Branson formalism to describe the multiple scattering in the absorber yields a deterioration of 10 % compared to the results obtained from the simple approach used here.

Assuming a flat η distribution in the muon spectrometer acceptance from 2.5 to 4, a mean resolution as a function of p_t can be calculated. This is show in figure 4.

By folding the resolution distribution with a muon momentum spectrum, a mean resolution per muon track is obtained. Here only the spectra of muons from open charm and beauty decays are considered because they dominate at high p_t ([2]). The spectra were obtained from the PYTHIA generator and are shown in figure 5. The ratio between the total number of muons from charm and from beauty decays is assumed to be 20. Because

x/X_0	60
x	413 cm
Δz	90 cm

Table 1: Parameters of the muon absorber

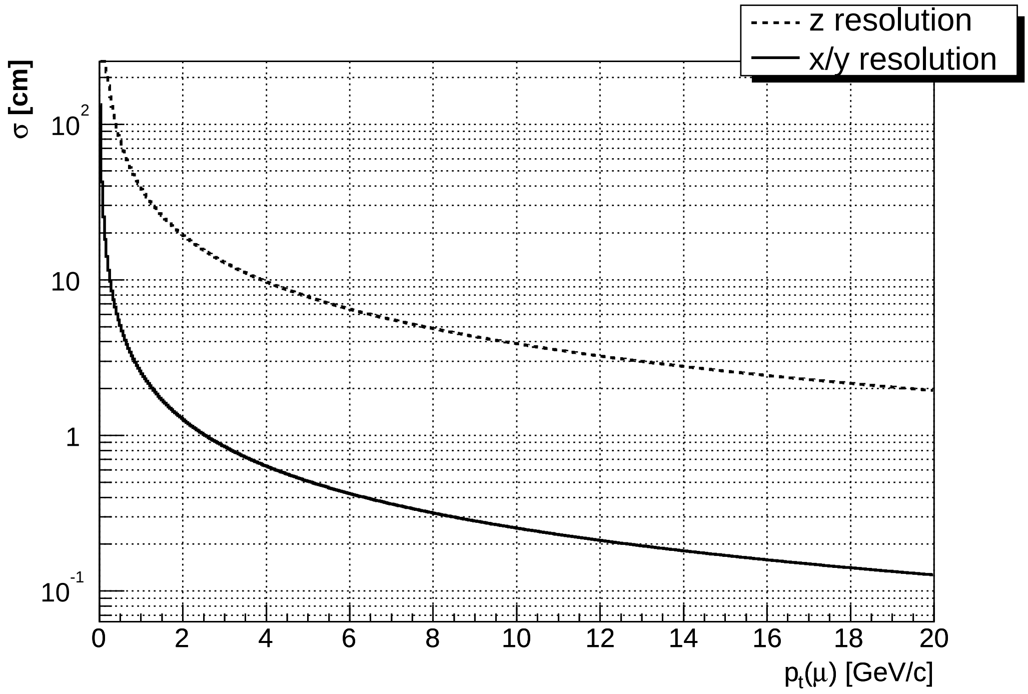

Figure 4: Resolution of a muon track at the vertex in x or y and in z direction versus the transverse momentum.

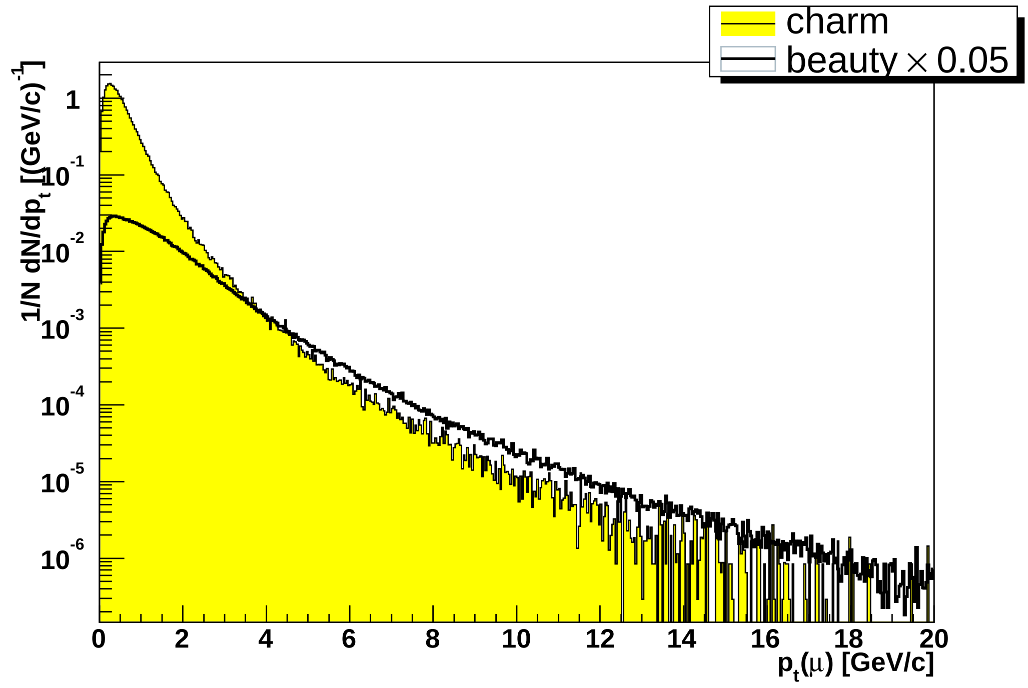

Figure 5: Transverse momentum distribution of muons from charm and beauty decays. The beauty spectrum is scaled down by a factor of 20.

the c and b spectra are very similar for high p_t, this ratio has no big influence on the results of this note.

The mean resolution per muon track integrated over all muons with $p_t > 4$ GeV/c is

$$\bar{\sigma}_{x/y} = 4.5 \text{ mm} \quad (6)$$
$$\bar{\sigma}_z = 7.0 \text{ cm}. \quad (7)$$

For a low p_t cut at 2 GeV/c the mean resolution is

$$\bar{\sigma}_{x/y} = 8.1 \text{ mm} \quad (8)$$
$$\bar{\sigma}_z = 12.4 \text{ cm}. \quad (9)$$

When the position measurements of N tracks are combined the resolution will be improved by a factor $\sqrt{N}$. Figures 6 and 7 show the resolution as a function of N for the two different p_t cut scenarios.

With the rate of muon tracks the resolution can be calculated as a function of time. The rate is given by

$$\frac{\partial N(\mu)}{\partial t} = \mathcal{L} \cdot \sigma_\mu \cdot A = \mathcal{L} \cdot (2 \cdot \sigma_{c\bar{c}} \cdot Br(c \to \mu) \cdot A_c + 2 \cdot \sigma_{b\bar{b}} \cdot Br(b \to \mu) \cdot A_b). \quad (10)$$

$\mathcal{L}$ is the luminosity, σ_μ the cross section for events with a muon and A the acceptance of the muon spectrometer. The contributions from charm and beauty decays are determined by the heavy quark pair production cross section $\sigma_{c\bar{c}/b\bar{b}}$, the fraction Br of heavy quarks decaying to muons and the acceptance A_c and A_b, respectively.

The values, which were used to calculate the muon rate, are listed in tables 2 and 3. The branching ratio to muons is assumed to be 10 % for charm and beauty quarks.

In lead lead collisions the muon rate is 51 Hz and 470 Hz for a p_t cut at 4 GeV/c and 2 GeV/c, respectively. In proton proton collisions the rates are 0.9 Hz and 8.7 Hz for the same p_t cuts. The resolution as a function of time that was calculated from these rates is shown in figures 8 to 11 for the different scenarios.

The rates are valid for single muon events. Because the muon trigger selects dimuon events the rate of triggered events is lower than the quoted rates. The reduction factor depends on the p_t cut on the second muon. For a p_t cut at 1 GeV/c there will be only a small reduction because there is about one muon in each (central) event with a p_t of more than 1 GeV/c (cf. fig. 7.14 in [2]). For a p_t threshold at about 2 GeV/c the reduction will be one order of magnitude more. This estimation assumes that the momenta of the two muons are uncorrelated.

	$\mathcal{L}$	$\sigma_{c\bar{c}}/2$	$\sigma_{b\bar{b}}/2$
Pb-Pb	10^3 b^{-1}s^{-1}	10×36.4 b	10×1.08 b
pp	10^6 b^{-1}s^{-1}	6.74 mb	0.2 mb

Table 2: Luminosity and cross sections for lead lead and proton proton collisions ([2]). The factors 10 and 2 for the cross section values take into account the extrapolation from central events in one hemisphere to the full phase space.

	A_c	A_b
$p_t > 4$ GeV/c	$2.0 \cdot 10^{-4}$	$5.1 \cdot 10^{-3}$
$p_t > 2$ GeV/c	$2.4 \cdot 10^{-3}$	$2.9 \cdot 10^{-2}$

Table 3: Acceptance of muons from charm and beauty decays for different p_t cuts.

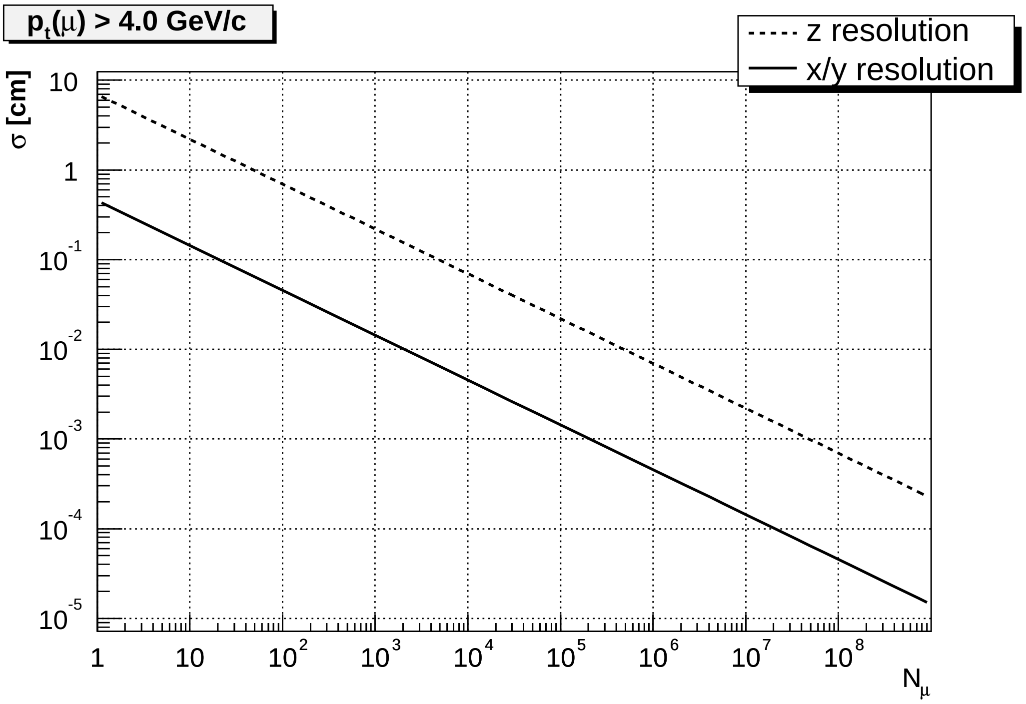

Figure 6: Resolution versus the number of muon tracks for muons with $p_t > 4$ GeV/c.

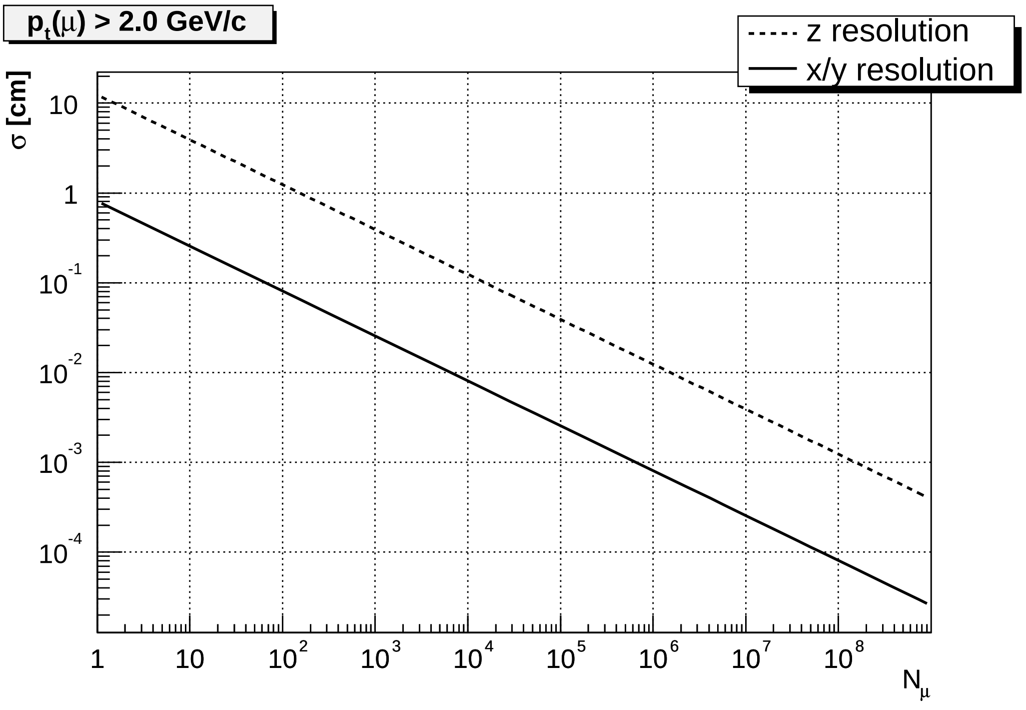

Figure 7: Resolution versus the number of muon tracks for muons with $p_t > 2$ GeV/c.

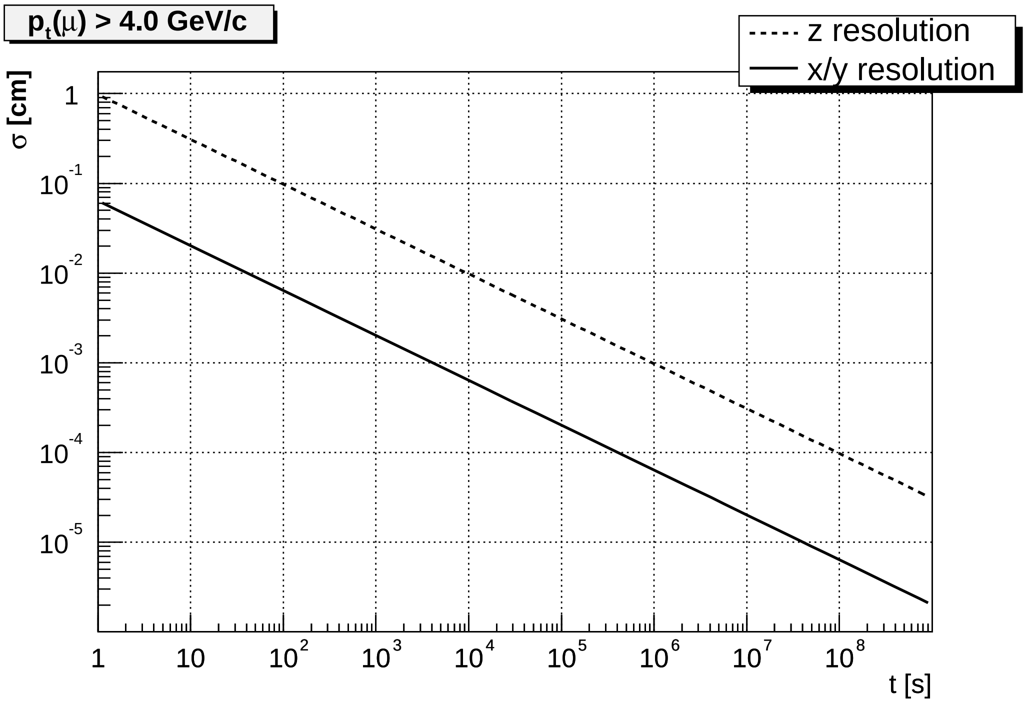

Figure 8: Resolution versus time in lead lead collisions for a p_t cut at 4 GeV/c.

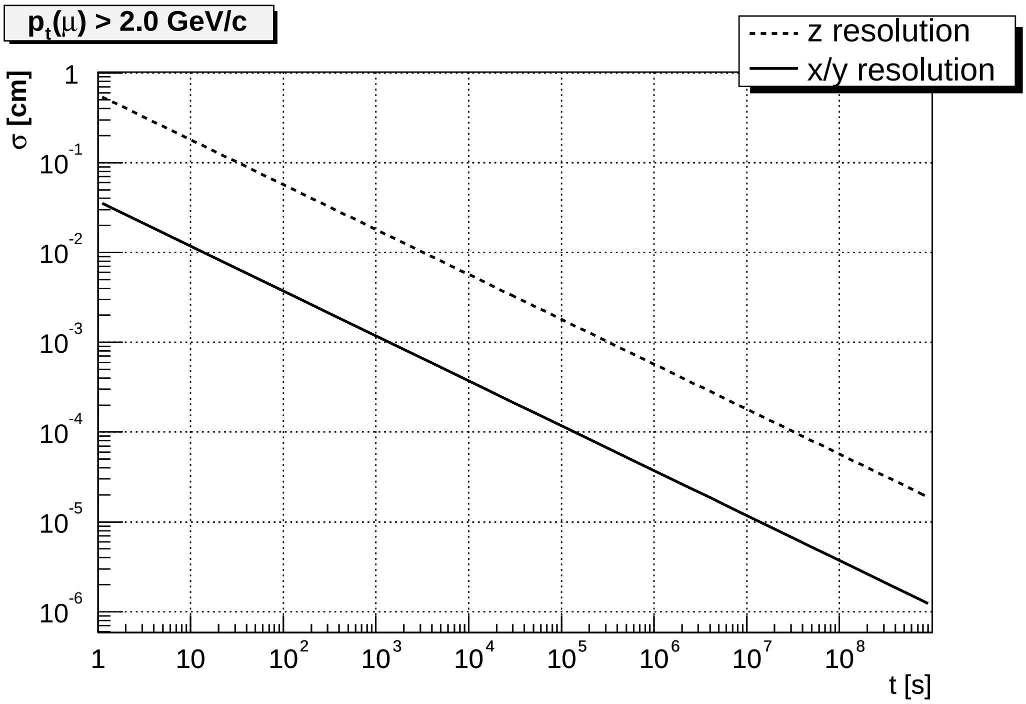

Figure 9: Resolution versus time in lead lead collisions for a p_t cut at 2 GeV/c.

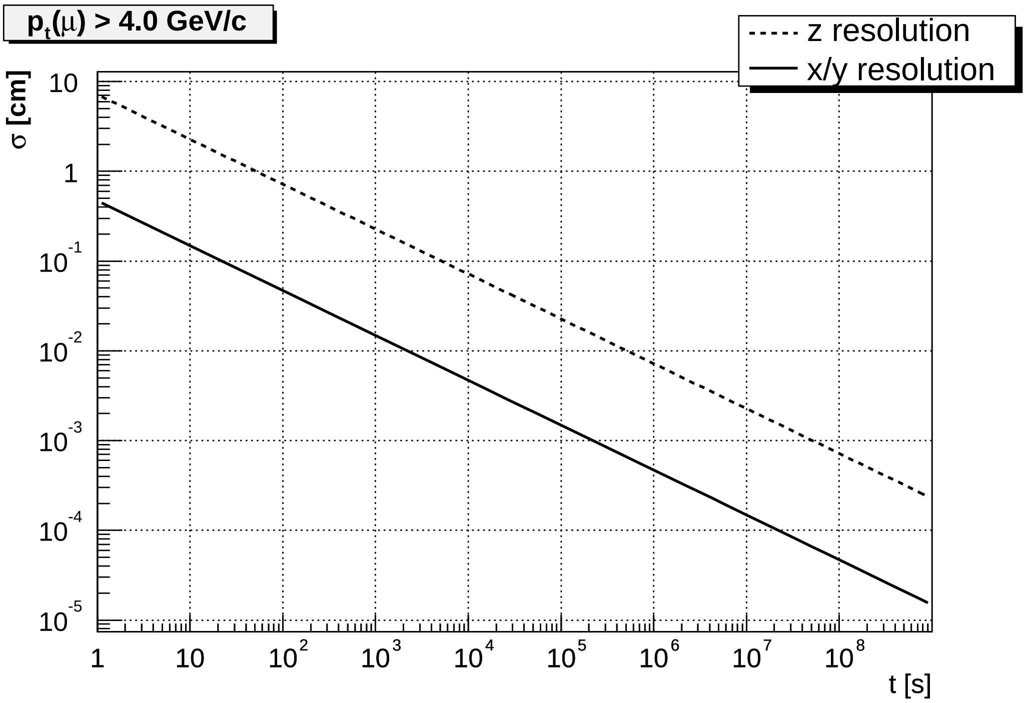

Figure 10: Resolution versus time in proton proton collisions for a p_t cut at 4 GeV/c.

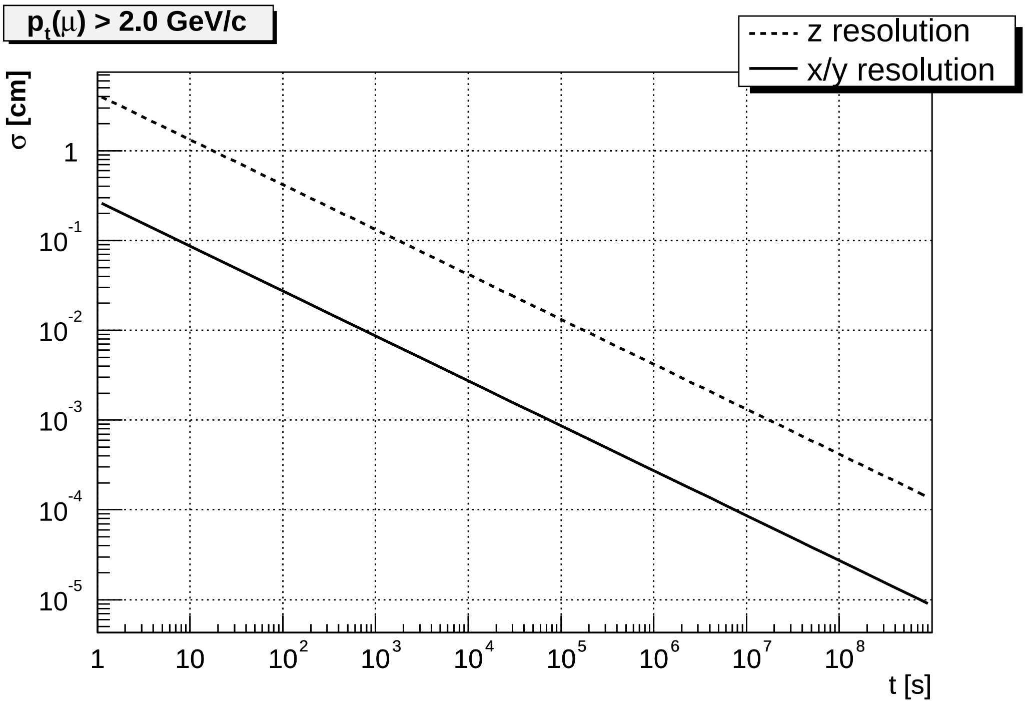

Figure 11: Resolution versus time in proton proton collisions for a p_t cut at 2 GeV/c.

3.1 Life time effects

Neglected so far is the fact, that muons from charm and beauty decays do not come from the primary vertex due to the life time of the heavy quarks. The influence of this effect on the alignment will be estimated now.

To study the life time effect on the alignment, charm and beauty events were simulated using a parametrisation for the momentum and rapidity distributions (AliGenMUONlib). The distance of the extrapolated muon tracks from the primary vertex is plotted in figure 12 for beauty events and for muons with a p_t of at least 2 GeV/c. The mean distance is $\bar{d} = 0.34$ mm. The contribution to the position resolution at the vertex from this deviation is

$$\bar{\sigma}_{x/y}^{decay} = 0.24 \text{ mm} \quad (11)$$

$$\bar{\sigma}_{z}^{decay} = 0.26 \text{ cm}. \quad (12)$$

The estimated values for charm are about a factor 3 smaller. There is no strong dependence on the p_t cut because the increased decay length at higher momenta is more or less compensated by a decreased angle between the muon and its mother particle. A comparison to the values in equations 6 to 9 shows that the effect due to the life time of the heavy hadrons can be neglected. This is only valid if it does not introduce a systematic effect. The alignment procedure has to be chosen carefully to avoid such a bias.

The life time effect is not negligible in case of pions and kaons. Because there is a large contribution to the number of tracks in the muon spectrometer from pion and kaon

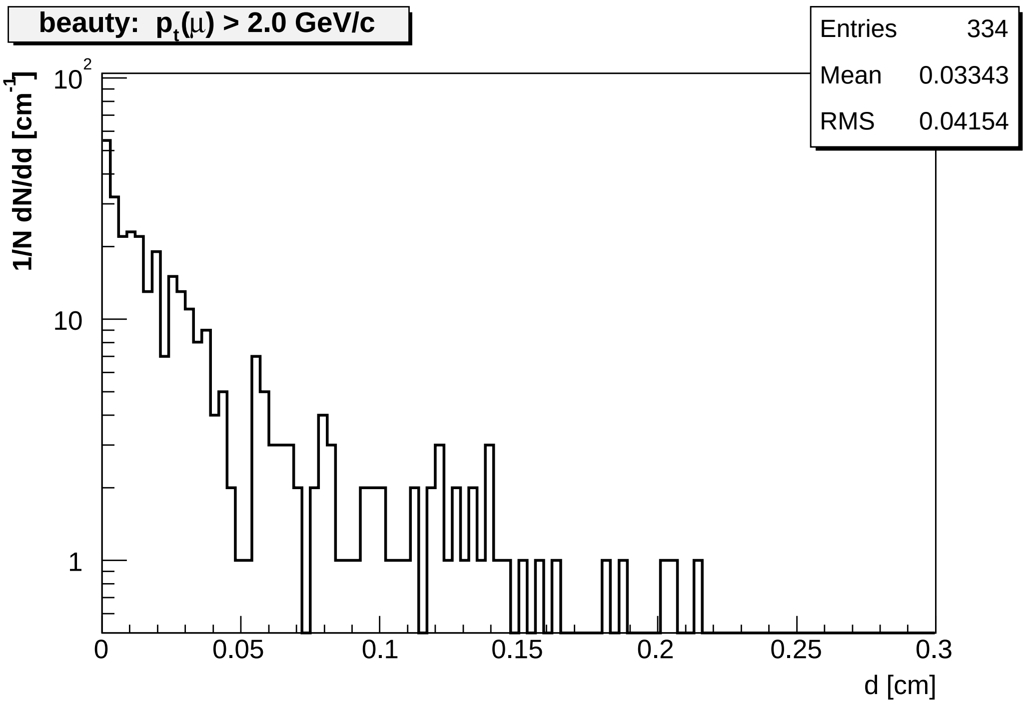

Figure 12: Distance of extrapolated muon tracks from the primary vertex for beauty events and a p_t cut at 2 GeV/c.

decays at low p_t (cf. fig. 7.14 in [2]), the scenario with a p_t cut at 4 GeV/c might be more realistic that the scenario with a p_t cut at 2 GeV/c.

4 Acknowledgements

I want to thank Lenaic Couedel and Gines Martinez for providing the muon momentum spectrum and Andreas Morsch for sharing his expertise.

References

[1] Particle Data Group, Review of Particle Physics, The European Physical Journal C (2000)

[2] Alice, The Forward Muon Spectrometer, Addendum to the ALICE Technical Proposal (1996)