Tracking in the Muon System

The following documentation describes the algorithms used in the *muo_trackreco* package. The goal of this package is to identify and determine the momentum of muon tracks from couples of segments (two segments respectively in A and B-C layers) in the muon system. The rcp-file (*MuoTrackReco.rcp*) provides the possibility of using two different ways for muon track finding: *combinatorial algorithm* or *fit algorithm*

I. COMBINATORIAL ALGORITHM

This algorithm is a fast one used in Level 3 trigger (*MuoTrackAlgCombi.cpp*).

- Segments are first grouped in pairs. A couple of segments is defined by two elements, namely a segment in A layer (before the toroid) and another in B or C-layer (after the toroid). B and C layers are considered together because there is no significant magnetic field between them. A segment in A layer is associated with another in B-C layer if both segments are in the same region (barrel or endcaps) and in the same octant. In addition, in the WAMUS detector, segments in octant 7 (respectively octant 3) are also associated with segment in octant 0 (respectively octant 4) because chambers in layer A overlap in octants 0 and 7 (respectively octant 3 and 4) inside the barrel detector.

- Some quantities related to couples of segments are calculated: residual in drift direction and residual in axial direction. Figure 1 illustrates how the residual in drift direction is determinated using segments in horizontal chambers. In the (x,y) plane, x_A and x_B are the positions of the center of gravity of segment A and segment B along the x axis. x_{mid} is defined as the middle of the position of the centers of gravity ($x_{mid} = \frac{x_A+x_B}{2}$). y_A (respectively y_B) corresponds to the y coordinate at x_{mid} position along segment A (respectively segment B) direction. The residual in drift direction is defined as $y_A - y_B$. The same calculation is performed for the residual in axial direction ($z_A - z_B$) in the (x,z) plane.

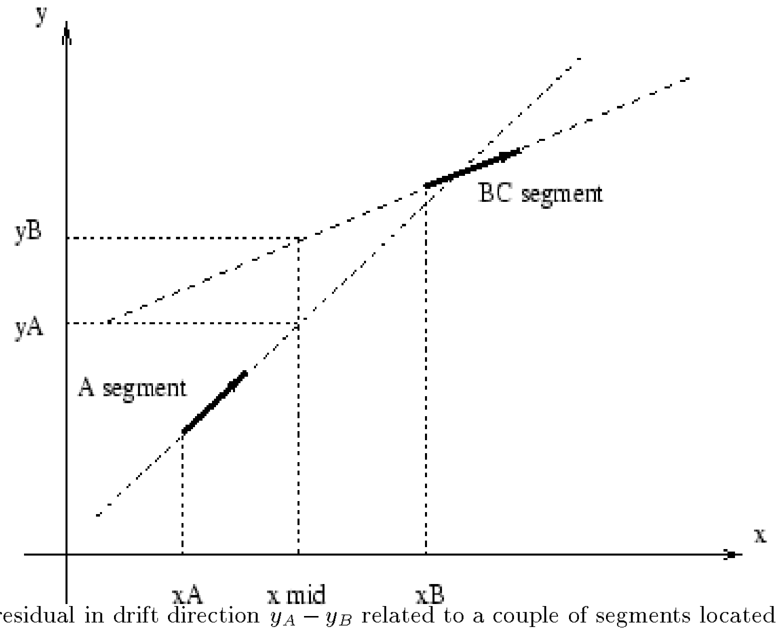

FIG. 1. Calculation of the residual in drift direction $y_A - y_B$ related to a couple of segments located in horizontal chambers. $xmid$ is $\frac{x_A+x_B}{2}$

- The list of segment pairs is sorted out in increasing order of residuals in drift direction.

- Tracks are created using couples of segments with residuals in drift and axial direction lower than some maximum values fixed in the rcp-file. The track momentum is evaluated using a parametrization depending on the difference in angles of A and B-C segments (see *D0 Note 3714*):

  – for WAMUS:

$$p = \frac{0.98}{angle_{drift}} \quad (1)$$

where $angle_{drift}$ is the difference in angles of A and B-C segments in drift direction.

– for FAMUS:

$$p = \frac{0.9}{sinangle} + \left| \frac{1.9}{cos(\theta_A)} + \frac{1.1}{cos(\theta_B)} \right| * sign(sinangle) \quad (2)$$

where θ_A and θ_B are the polar angles of A and B-C segments in spherical coordinates and where sinangle is defined by: $sinangle = sin(\theta_B) - sin(\theta_A)$. This parametrization includes an energy loss correction.

II. FIT ALGORITHM

This algorithm provides a calculation of the track momentum based on a fit of segment pairs taking into account the propagation in the toroid magnetic field, multiple scattering and the energy loss in the toroid (*MuoTrackAlgFit.cpp*).

- First we group segments into pairs as for the combinatorial algorithm. In this case, we allow the A and BC layer segments to be in different but adjacent octants. For instance, A segment in octant 0 with $Arctan(\frac{y_A}{x_A}) \leq \frac{\pi}{8}$ is also associated with BC segment in octant 1. If $Arctan(\frac{y_A}{x_A}) > \frac{\pi}{8}$, this A segment is coupled with BC segment in octant 0 or 7.

- We compute a first estimation of the track momentum from geometrical calculation. The magnetic field in the toroid is set to be constant ($1.8T$). If L represents a straight line approximation of the particule path in the toroid and θ the angle between A and BC segments in the deviation plane, an estimation of the track transverse momentum is given by:

$$P_t = \frac{300MeV \times B \times L}{\theta} \quad (3)$$

  The P_t value is corrected by a constant energy loss of $0.016 \times L$ (energy loss in iron $\approx 15.74MeV/cm$) This first quick estimation is used as an input for the fit.

- A simple toroid geometry corresponding as much as possible to the *Geant* geometry is used. The track is propagated step by step from the center of gravity of BC segment to the one of A segment using circular helices in space. At each step, an energy loss correction is performed using a function giving $\frac{de}{dx}$ as a function of momentum.

- This propagation allows to perform a 2D fit in the deviation plane (either (z,x) or (z,y) depending on the octant) of the couple of segments using *Minuit* with 5 parameters. For instance in the (z,y) plane the 5 fit variables are:

  – the track position along z-axis at fixed y_B (the position of the center of gravity of segment B along y-axis)

  – $\frac{1}{P_t}$ where P_t is the track transverse momentum at fixed y_B

  – the angle in the deviation plane between z-axis and the momentum direction ($0 \leq \theta \leq 2\pi$)

  – two multiple scattering angles at two fixed planes (if e is the toroid width in the deviation plane, the multiple scattering planes are located at $\frac{e}{\sqrt{12}}$ from the middle of thetoroid).

  Constant errors have put in the fit: $0.08cm$ for the position error in both layers, $0.007mrad$ for the angle error in layer A, $0.001mrad$ for the angle error in layer BC. The errors on multiple scattering angles are calculated with: $\delta\theta = \frac{0.014}{P_{MS}}\sqrt{\frac{x_{MS}}{1.76}}$ where P_{MS} is the momentum at the multiple scattering plane and x_{MS} is the muon path from the enter of the toroid to the multiple scattering plane.

  As a result of the fit, we also obtain the position of the track at y_A (the position of the center of gravity of segment A along y-axis) and the track momentum components along z and y axis P_z, P_z at y_A.

III. RESULTS

A sample of single muons with transverse momentum from 5 GeV to 50 GeV with $-1 \leq \eta \leq 1$ have been used to test the fit algorithm. The results are presented here only for events which are in the barrel detector.

- Figures 2 and 3 show the momentum resolutions $\frac{\Delta P}{P} = \frac{P_{fit} - P_{sim}}{P_{sim}}$ and $P\Delta\frac{1}{P}$. P_{sim} represents the simulated momentum at the simulated point closest to the segment center of gravity in the considerated layer. We see that the achieved resolution is $P\Delta\frac{1}{P} \approx 20\%$ which corresponds to the nominal expected value (*see D0 Note 3365, March 29,1997* and section IV). But Figure 3 shows also a small shift of the maximum which remain to be understood and corrected. Figure 4 doesn't show any dependency of the resolution with energy. This is also expected if one considers figure 8. Figure 5 shows the momentum resolution $\frac{\Delta P}{P}$ as a function of the simulated phi angle for A layer and BC layers. We see that in the phi regions where cracks are present between two chambers ($\phi \approx 0^0$ or $\phi \approx 90^0$ ...) the momentum resolution is decreasing.

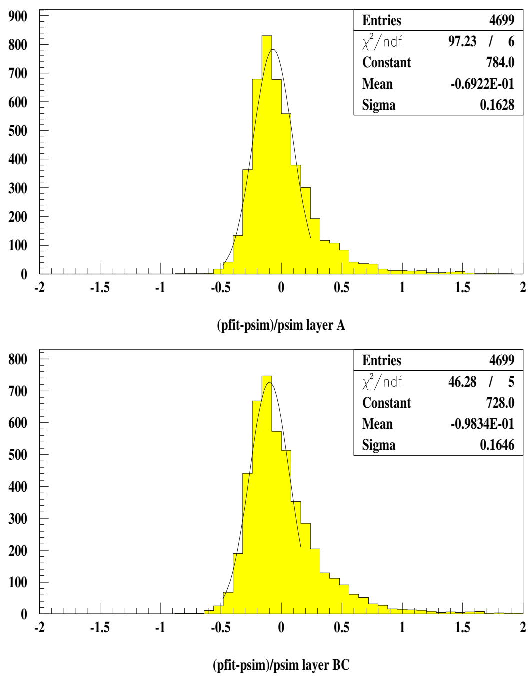

FIG. 2. Resolution in P for A and BC layers. P_{sim} represents the simulated momentum at A or BC layers and P_{fit} represents the fitted momentum at the same position.

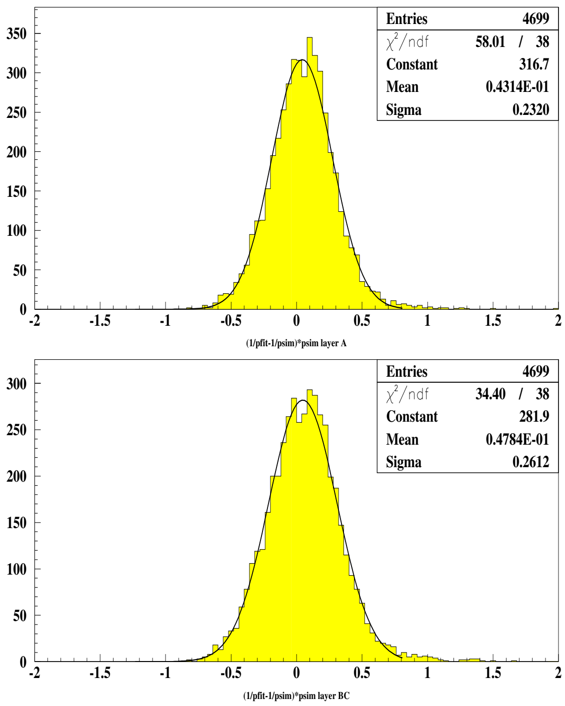

FIG. 3. Resolution in $\frac{1}{P}$ for A and BC layers

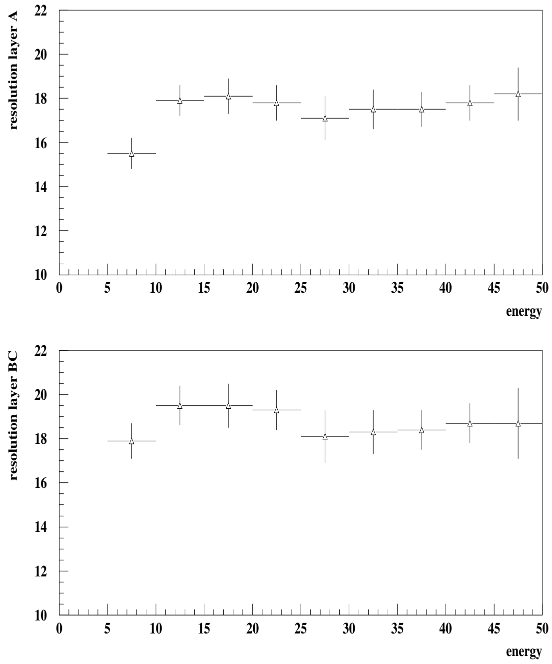

FIG. 4. Resolution $\frac{\Delta P}{P}$ for A and BC layers as a function of energy

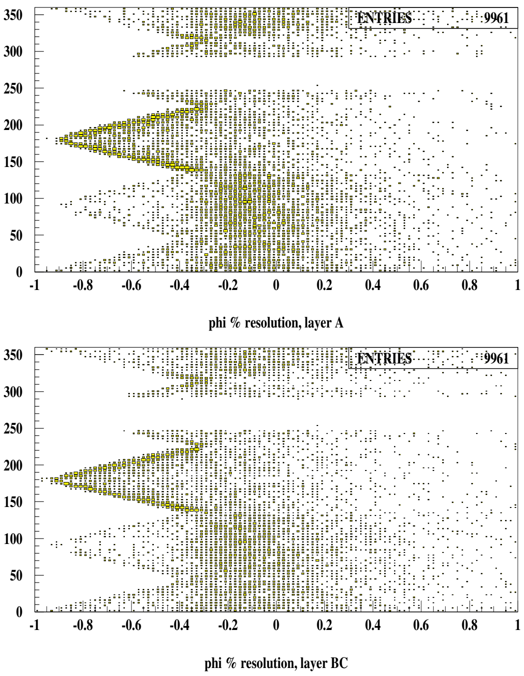

FIG. 5. Resolution $\frac{\Delta P}{P}$ as a function of the simulated phi angle for A and BC layers

- Figure 6 shows the momentum resolution comparison $\frac{\Delta P}{P}$ between the two algorithms. We compare the momentum resolution for the fit algorithm $\frac{P_{fit}-P_{sim}}{P_{sim}}$ in A layer with the resolution for the combinatorial algorithm $\frac{P_{combi}-(P_{sim}A+P_{sim}B)/2}{(P_{sim}A+P_{sim}B)/2}$ where $P_{sim}A$ (repectively $P_{sim}B$) is the simulated momentum in A layer (respectively B layer). The fit algorithm provides a momentum resolution of about 16% whereas the combinatorial one gives a resolution of about 30%.

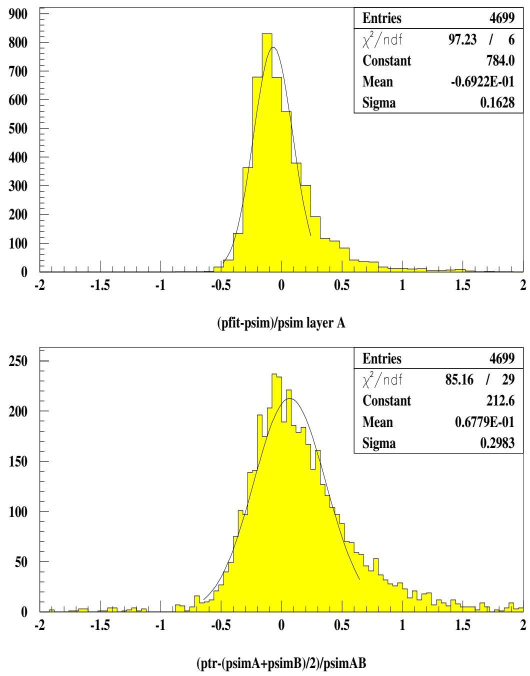

FIG. 6. Momentum resolution $\frac{\Delta P}{P}$ for the fit algorithm in layer A (above) and for the combinatorial algorithm (below)

- Figure 7 shows the achieved angle resolution: $\frac{\Delta\theta}{\theta} \approx 15\%$ for A layer and $\frac{\Delta\theta}{\theta} \approx 2\%$ for BC layers. The better resolution for BC layer is due to the fact that B and C layers are combined to find segments which provides a better angular resolution of them.

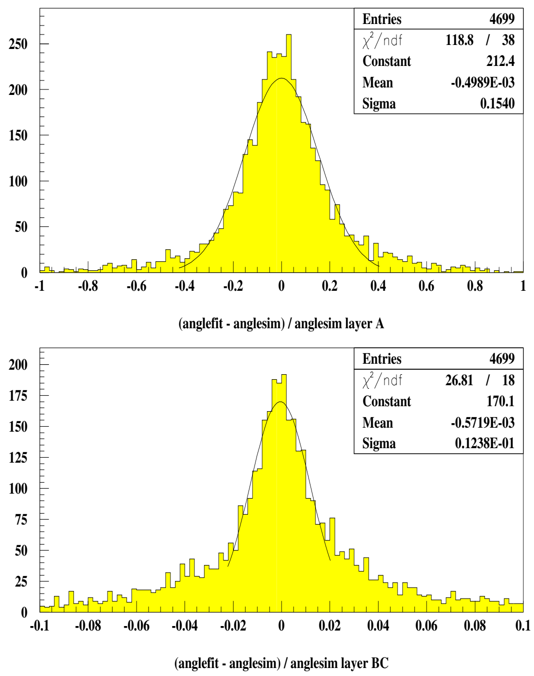

FIG. 7. Angular resolution $(angle_{fit} - angle_{sim})/angle_{sim}$ for A and BC layers

IV. CONCLUSION

We saw that the *muo_trackreco* package provides two ways to find local muon tracks in the muon system. The momentum resolution achieved is about 20% in $\frac{1}{P}$. Obviously this resolution will be mostly improved by matching muon tracks with the central tracker. Figure 8 resumes the momentum resolutions obtained with the combinatorial and fit algorithms (for respectively FAMUS and WAMUS) in comparison with the nominal expectations computed in *D0 Note 3365, March 29,1997.*

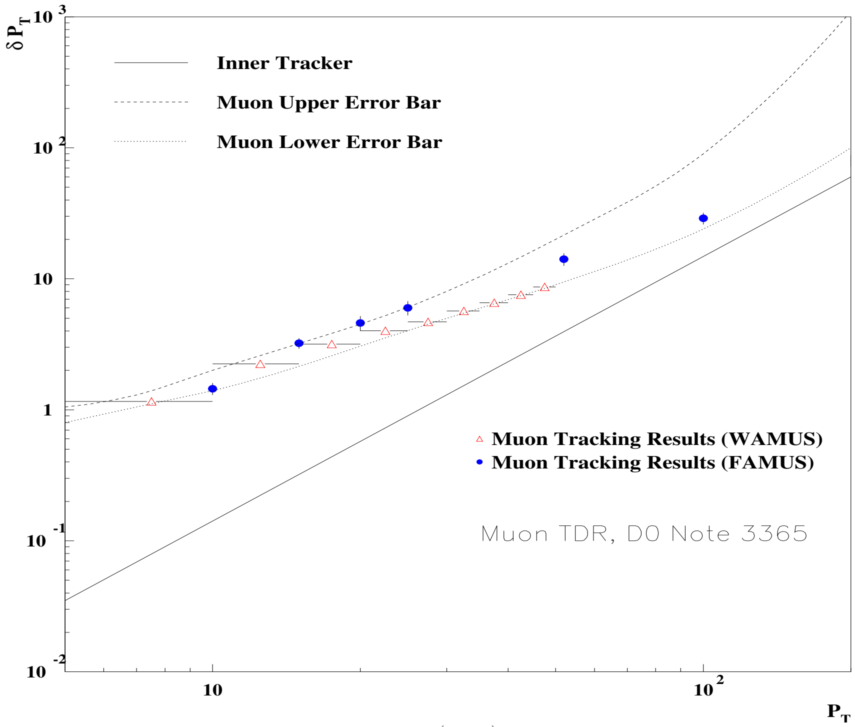

FIG. 8. Momentum resolutions achieved in *muo_trackreco* (dots) compared with the theoritical expected values (lines). For WAMUS, the fit algorithm has been used. For FAMUS, it was the combinatorial algorithm.