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The Possibilities of Using Particle Punch-Through for Muon System Alignment

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Abstract

The alignment method presented here is based on the expectation that the spectra of positively and negatively charged particles, exiting the calorimeters and entering the muon system, are similar. A systematic distortion of these two spectra may then be interpreted as arising from a misalignment of the muon measurement system. Results of Monte Carlo studies and estimates of the sensitivity of this method are presented which indicate that an alignment accuracy of the order of 50 microns can be achieved within a relatively short period.

1 Introduction

Uncertainties in the alignment of the air-core toroid muon system dominate the momentum resolution for muons with momenta greater than $p_\mu > 100\ GeV/c$ [1]. Currently two different methods of alignment have been proposed within ATLAS. The first of these [2] uses light rays projected radially through silicon strip detectors whereas the second method [3] uses muon tracks from the decay $Z^0 \rightarrow \mu\mu$. The benefit of having a variety of alignment methods is that it allows cross-checks between them and makes it possible to isolate systematic effects.

The idea of the method presented here is transparent: a distortion of the system alignment in a set of three mattresses will manifest itself as an absolute shift between the sagittae of positively and negatively charged particles. It can be expected that the momentum spectra and multiplicity of punch-through particles entering the muon system from the calorimeter will be similar as most of any small initial imbalance *prior* to the calorimeters will be diluted in the shower process. Differences in absorption cross-sections for positive an negative particles within showers can potentially give rise to small differences however it should be possible to at least isolate a momentum interval within which this is not the case.

The assumption of equality between positive and negative punch-through spectra is used here as a working hypothesis and is discussed in Section 2. Clearly experimental data should be used which requires direct measurement with charged particle sign identification. The degree of "asymmetry" between the positively and negatively charged momentum spectra can then be used to correct for the alignment of the muon detectors. It could be foreseen, albeit with large statistics, that a more detailed alignment could be undertaken to correct for tilts and rotations etc.

2 Particle Punch-Through Spectra

Available experimental data on the characteristics of punch-through are unfortunately rather sparse [4]. Published results are based on limited statistics, and positive and negative particles are not presented separately. Hence, the central assumption of the approach presented here was tested to first-order using a GEANT simulation.

Two-jet events with $p_T^{jet} > 20\ GeV/c$ were generated using PYTHIA and simulated using a GEANT description of the ATLAS detector configuration. A total of 53,768 events were processed and the information from the first sensitive layer of the muon system was studied. The respective muon momentum spectra are shown in Figure 1 for the barrel region of ATLAS. This indicates

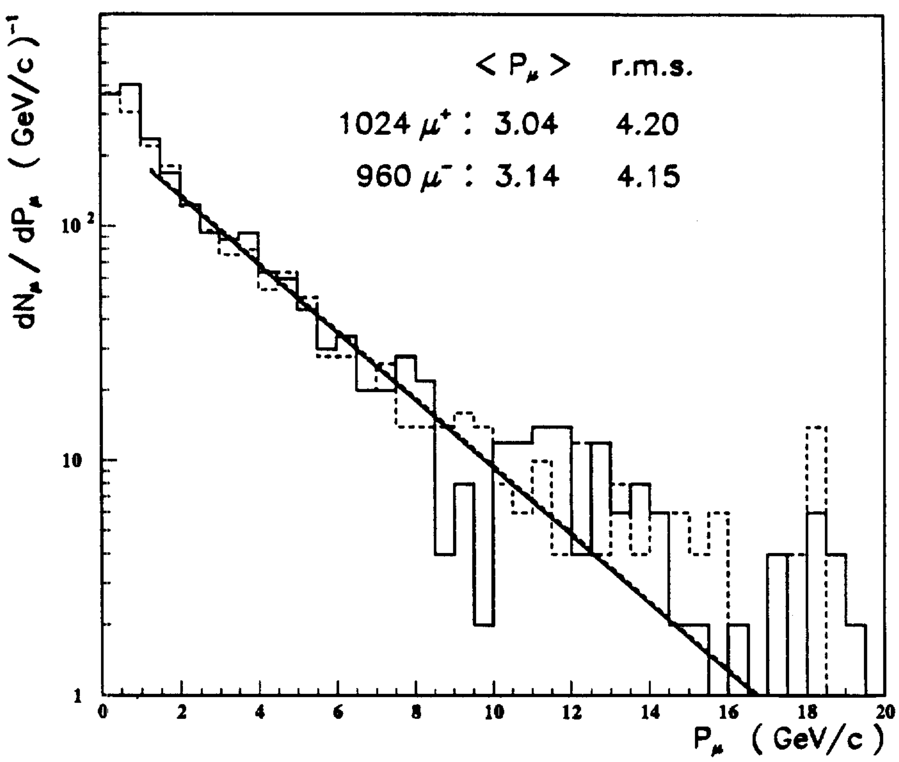

Figure 1: *A GEANT comparison of momentum spectra for positively and negatively charged muons leaving the ATLAS calorimeters in the barrel region. The dashed histogram represents that of the μ^- with the solid histogram representing the μ^+. The straight lines reflect the approximate spectrum used in the model.*

that, within the available statistics, the basic assumption of the method is correct. The spectra are similar and have an largely exponential shape with an average value of about 3 GeV/c.

3 Preliminary Studies Using a Two-Dimensional Model

A simple two-dimensional model was used to estimate the statistics required to achieve an alignment accuracy of the order of 50 μm. This is in order to cirumvent the problem of limited GEANT statistics and to test the feasibility of the measurement itself.

The model is constructed as follows :

- Tracking detectors are placed inside a homogeneous, toroidal, magnetic field of strength 0.6 T over a total lever-arm of 550 cm in the radial direction. The size of the detector in the bending plane is limited to 220 cm. The geometry is similar to that described in the ATLAS LoI [5].
- A total of 100,000 charged particles were sent into the muon system, perpendicular to the detector plane. The particle momenta were generated according to an exponential distribution with an average momentum value of 3 GeV/c. This is an approximation to that shown in Figure 1 as is indicated by the overlaid curves.
- Only particles which traverse the full three mattresses on the system were considered. This requirement is equivalent to a cut on the momentum of 1.5 GeV/c where roughly 40% of particles are rejected. For the purposes of calculations used later, a more conservative cut-off at 3 GeV/c is used. Note that this is the momentum *after* the calorimeters, ie. inside the muon system.
- The effects of coordinate precision are incorporated by smearing the hits prior to performing a full helix fit and reconstructing the muon momentum using the techniques of [7]. The effects of coordinate smearing are investigated in Section 5.

The resulting distribution of sagitta values is shown in Figure 2. The influence of a 2% momentum resolution factor, representing the dominant multiple scattering contribution in this momentum range, is included. This resolution contribution is *symmetric* however and so does not induce any noticeable shift in the total distribution. The average value of the sagitta obtained is 13.61 ($\pm$0.01) cm with an *r.m.s.* of 5.11 cm for the momentum cut of 3 GeV/c.

Thus, to achieve an accuracy of 25 μm, it is necessary to collect about 4.2 $\times 10^6$ tracks of charged particles leaving the calorimeter in one *subsystem* of mattresses. Of course, higher statistics would be required to perform a more complex alignment in three-dimensions.

The rejection of low momenta particles narrows the sagitta distribution. Figure 3 shows the dependence of the sagitta distribution *f.w.h.m.* values on the lower momentum cut-off value of the particle registered, P_{min}. Figure 3 also indicates the corresponding statistics required to achieve an accuracy in the average sagitta value at the levels of 25 μm and 50 μm. Clearly, by selecting the value of P_{min} carefully it is possible to significantly decrease the accumulation time.

4 Particle Rates and Alignment Time Estimates

Rates of charged particles from minimum bias events are estimated in [6]. This indicates that the rates of particles exiting the rear of the ATLAS calorimeters depend on the minimum momentum cut-off used. The estimated rates are shown in Table 1, averaged over the barrel region. For a minimum momentum P_{min} = 3 GeV/c, as is used here, the rate is estimated to be

Low Momentum Cut-off (GeV/c)	*Particle Rates* (Hz/cm^2)
0.0	$\approx$ 0.2
5.0	$\approx 1.2 \times 10^{-3}$
10.0	$\approx 1.0 \times 10^{-4}$
20.0	$\approx 4.0 \times 10^{-6}$

Table 1: *Approximate charged particle rates entering the barrel muon system from the rear of the ATLAS calorimeters as a function of the minimum momentum cut-off [5].*

$\approx 7.5 \times 10^{-3}$ Hz/cm^2. It is then possible to estimate the time period required for the passage

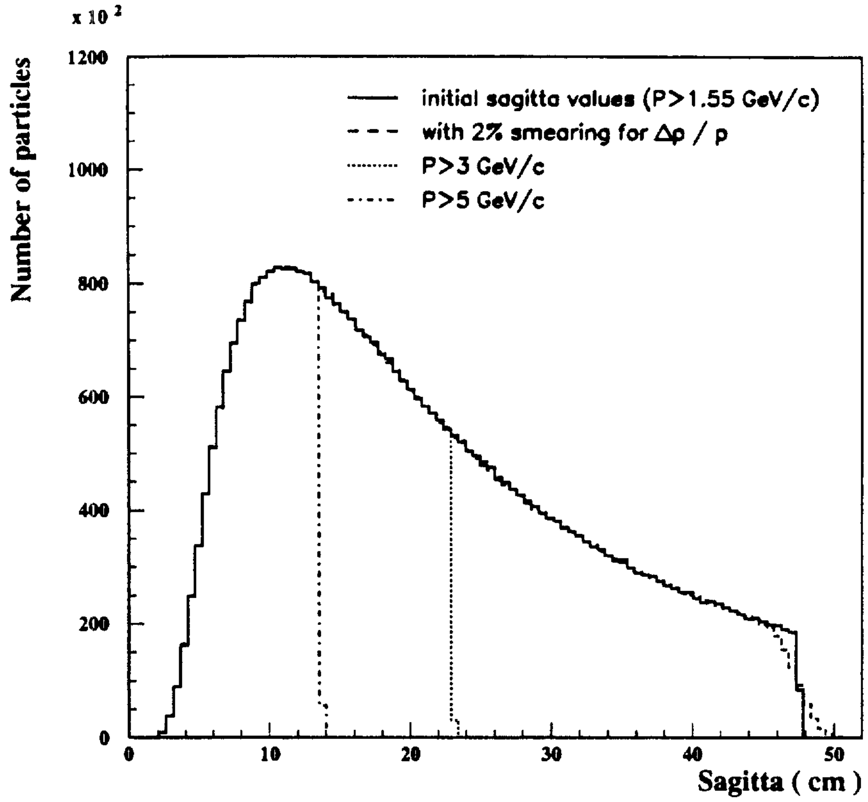

Figure 2: *Distributions of sagitta values obtained for punch-through particles using the mode described in Section 3 for different momentum cuts (solid histogram for 1.55 GeV/c cut, dotted — for 3 GeV/c cut and dashed-dotted histogram for 5 GeV/c cut). The dashed line refers to the sagitta values taking into account the 2% resolution from multiple scattering for momentum cut of 1.55 GeV/c.*

of sufficient particles through a given mattress subsystem after correcting the values of Table 1 for the different radii at which the calculations are performed[1]. The rates of punch-through particles passing the P_{min} cut is then found to be roughly :

$$Expected\ Rate\ of\ Alignment\ Muons\ =\ 300\ Hz\ per\ mattress\ subsystem \quad (1)$$

Thus, the number of particles required to align a mattress system to within 25 μm will pass through a mattress subsystem in a period of roughly 4 hours.

This raises the possibility of running with a dedicated minimum bias trigger for short periods with the DAQ essentially saturated in order to accumulate the required statistics.

[1]The calculations shown in [5] are for the outer surface of a calorimeter at a radii of 420 cm, whereas the geometry of the muon system here starts at 500 cm.

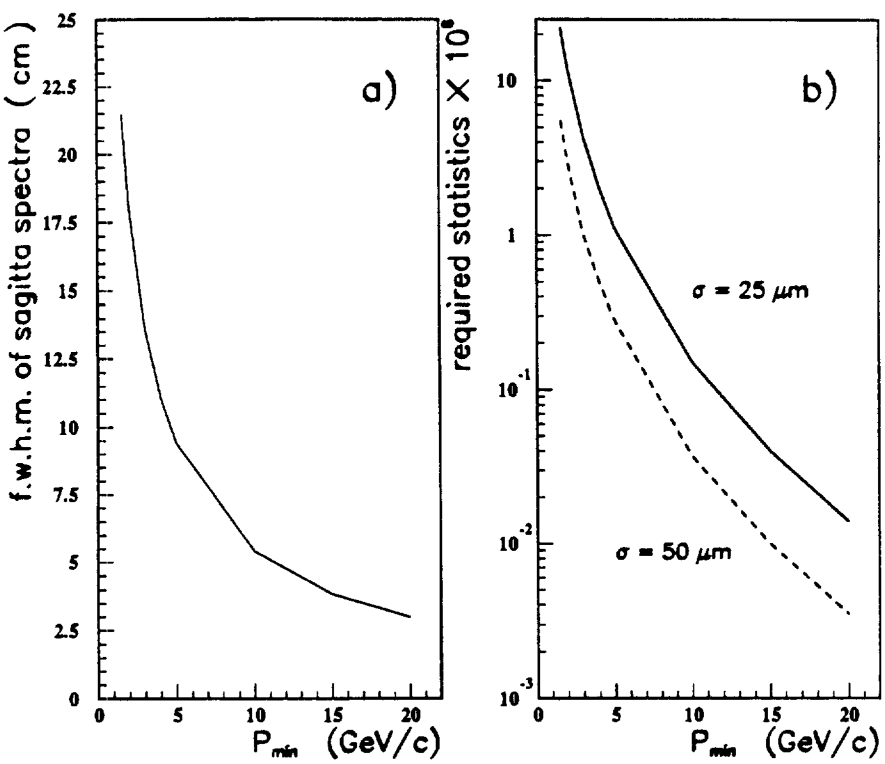

Figure 3: *(a) - Dependence of the width of the sagitta spectrum on the low momentum threshold of registered particles; (b) - Statistics required to achieve an accuracy of 25 μm (solid line) and 50 μm (dashed line) for different lower momenta thresholds.*

5 Effects of Coordinate Resolution

The effects of the detector coordinate resolution are estimated by smearing the hits in the Monte Carlo model described above. This is done by considering a sample of 4 $\times 10^6$ particles with momenta of $P \geq 3\ GeV/c$. Three mattresses are placed at distances of 200 cm from each other. Each mattress contains two sets of three sensitive layers making up two superlayers separated by an average distance of 40 cm. The helices of the charged particles are then fitted and sagitta values calculated using the radius of curvature and the track coordinates in the first and in the last layers. The average sagitta value is found to be 13.6101 ($\pm$ 0.0025) cm.

Adding a constant offset of 50 μm to the $x-$ coordinates of the generated particles in the middle (second) mattress, with the same fitting procedure, yields a new sagitta spectrum with average sagitta value 13.6047 ($\pm$ 0.0025) cm. Thus, collecting about 4 $\times 10^6$ particles with momentum value greater than 3 GeV/c it is possible to observe displacement values of less than 50 μm. The method is illustrated for a variety of input mattress displacements in Figure 4. The influence of measurement uncertaintes arising from a value of 50 μm for the x-coordinate smearing are also shown in Figure 4. It is seen that including the effect of measurement errors is symmetrical and hence negligible.

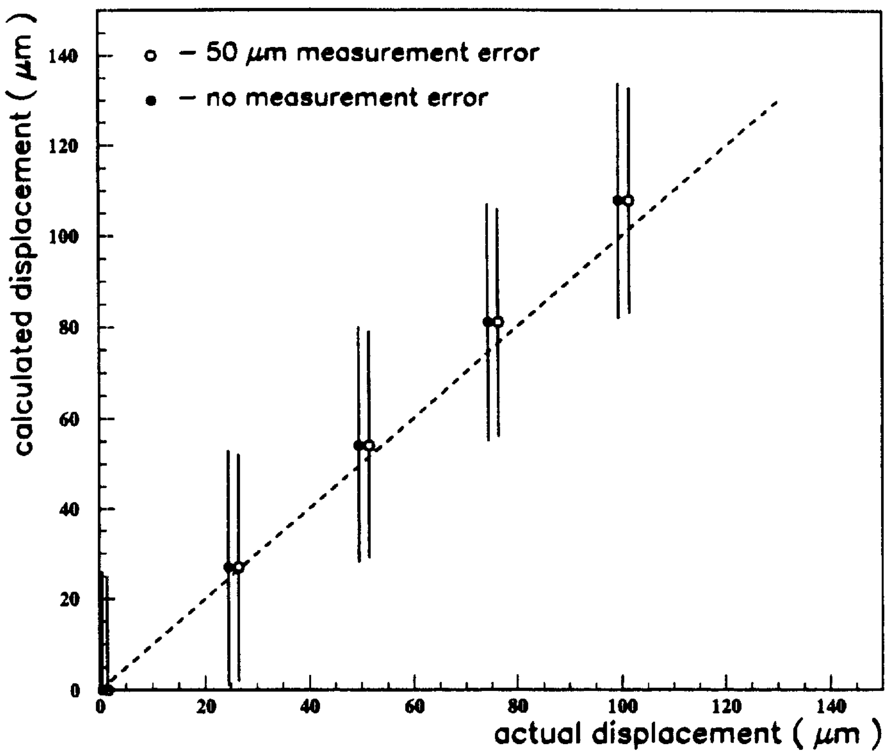

Figure 4: *The correlation between actual and calculated displacement values for cases with and without coordinate resolution effects. A total of 4 $\cdot 10^6$ particles, with momenta greater than 3 GeV/c, are used for each point. The dashed line corresponds to a perfect correlation between actual and retrieved displacements.*

A tool is available for the purpose of making more detailed muon simulations. This makes it possible to perform "fast Monte Carlo" calculations of the muon system response by eliminating the need to trace minimum bias particles through the showering in the calorimeters. This is described in more detail in the Appendix.

6 Conclusions

The principles of new, complementary alignment method are outlined. Preliminary Monte Carlo studies of the number of events and conditions indicate that approximately 4×10^6 particles with momenta greater than 3 GeV/c are required to reach alignment accuracies of less than 50 μm within a relatively short period of time. Based on the punch-through calculations of [6] it is estimated that $\approx$ 300 such particles pass through a barrel mattress subsystem every second. The symmetrical effects of multiple scattering and the measurement errors are shown to be negligible in the model studied.

The amount of time taken for such alignment will depend on the trigger and DAQ used but is expected to be of the order of a few days. Higher statistics may make it possible for a more complete three-dimensional alignment to be achieved.

A number of routines to eliminate lengthy punch-through shower simulations are presented in the Appendix for use in a future fast Monte Carlo.

7 Acknowledgements

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References

[1] A. Halley, *"Contributions to the Muon Resolution in the Air-Core Toroid"*, ATLAS Note MUON-NO-016, 1993.

[2] W. Blum, *"Muon Chamber Alignment - A Proposal"*, ASCOT/EAGLE Note MUON-NO-007, 1992.

[3] A. Nisati, *"Alignment of Muon Chambers With $Z \rightarrow \mu^+\mu-$ Events"*, ASCOT/EAGLE Note MUON-NO-009, 1992.

[4] D. Green and D. Hedin, *"Muon Rates at the SSC"*, NIM A297 (1990) 111.

[5] The ATLAS Collaboration, *"Letter of Intent for a General-Purpose Experiment at the LHC at CERN"*, CERN/LHCC/92-4,LHCC/I 2, 1992.

[6] A. Cheplakov, A. Kriushin and R. St.Denis, *"Muon Production in a Single Pion Showering of (5÷500) GeV/c Momenta Inside (8÷14) λ Absorber"*, ATLAS Note MUON-NO-013, 1992.

[7] A. Halley, *"A Simulation Study of Muon Reconstruction in the Air-Core Toroid"*, ATLAS Note MUON-NO-015, 1992.

Appendix : A Punch-Through Parameterisation Tool For Fast Muon Simulation

In order to estimate the reliability of the method the following routines may be used to parameterise the output from a full GEANT simulation in the SLUG+DICE framework. The FORTRAN code is written to avoid the tracking of particles produced in the inner cavity as well as the hadron shower development inside the calorimeters[2]. Including the time required to generate a full PYTHIA minimum-bias event, the program takes less than 0.2 seconds[3] per event. The code is written in CMZ format and is available as:

CERNVM on CHEPLAKO 191 in the file PUNCH CAR

The code employs the methods described in [6] and is based upon the parameterisation of the hadron fragmentation function. This is used to calculate coordinates and momentum of secondary particles on the outer surface of the calorimeter. The initial values of the primary hadron momenta are the only input used for the calculations. Thus, instead of primary hadron momenta, the *output* momenta and coordinates of *secondary* muons and hadrons are placed in GENZ banks for the subsequent fast tracking in the free region of the air-core toroid. The new contents of the bank are then transfered into GEANT KINE banks for the standard tracking of charged particles inside the muon system.

The program compares well with the results of full, detailed GEANT simulations. This is shown in the results of a comparison based upon processing the tapes written with GEANT simulation of two-jets events (a total of 38 tapes). This is displayed in Figure 5. Taking the vertex information to obtain the initial hadron momenta the position and momentum of secondary particles in the first sensitive layer of muon system are calculated. The result of the calculations are compared with the results of the complete GEANT simulation in Figure 5. It is apparent that using described method is in agreement with the complete GEANT simulation within a factor of 2, satisfactory for many purposes.

[2]The code may also be applied to the problems of optimising the muon detectors.

[3]IBM 168 equivalent.

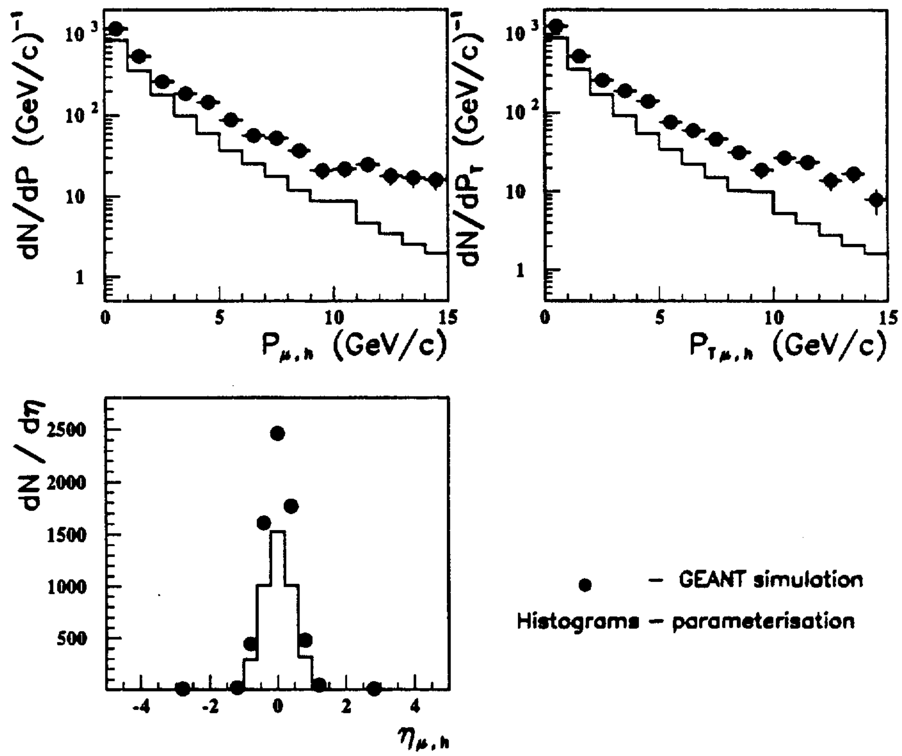

Figure 5: *A direct comparison between the parameterisations used for the fast Monte Carlo parameterisation and a complete GEANT simulation. The points represent the simulation with the parameterisation shown as a histogram.*