TWIST TN 74
Detection of Magnetic Field Misalignment Using Michel Spectrum Positrons

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A method was devised to detect a magnetic field misalignment using only the paths of Michel spectrum positrons. GEANT simulations were then used to test it. These simulations produced unexpected results which were not fully understood. Despite these difficulties, it was determined that a misalignment of $\approx \frac{1}{8}^\circ$ could be detected with this method. A more precise determination of magnetic field misalignment may be possible if the unexpected results are studied further.

1 Introduction

In order to be able to properly reconstruct muon decays inside the TWIST spectrometer to a precision of 10^{-3}, eventually 10^{-4}, the magnetic field must be properly aligned with the detector. Thus, precise knowledge of a misalignment is important.
If decay positrons could be used for such purposes, a misalignment could be detected during any run. This study used GEANT simulations to examine the feasibility and usefulness of such a method.

2 Geometry

It is first useful to understand the geometrical arrangement of the detector and the magnetic field.

Figure 1 shows the setup used by GEANT. The axes U,V, and Z define the coordinate system for the detector; X and Y belong to the GEANT world coordinate system. The vector **B** is the magnetic field. The orientation of **B** is

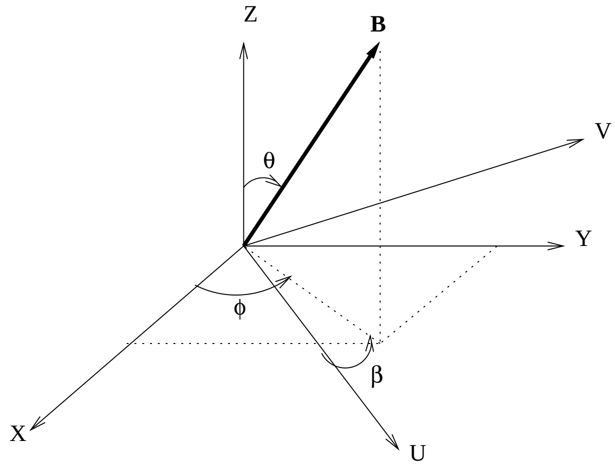

Figure 1: The magnetic field with respect to the detector and GEANT world axes.

set in GEANT with the angles θ and ϕ. θ opens from the positive Z axis and ϕ from the positive X axis. Since the detector is defined in U and V, the extra angle β has also been included in this diagram. ϕ and β are offset by the same amount as X and U, 45°.

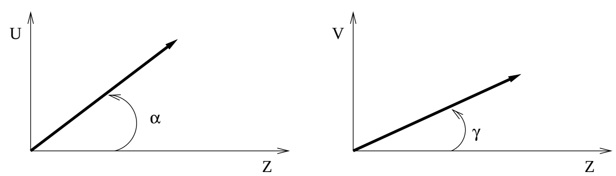

Figure 2: **B** projected on the UZ and VZ planes.

Figure 2 depicts **B** projected in the UZ and VZ planes. The angle alpha in the UZ plane and opens from the positive Z axis. Similarly, gamma is the angle in the VZ plane.

In UVZ, **B** is given by:

$$\mathbf{B} = |\mathbf{B}|\langle \sin\theta\cos\beta, \sin\theta\sin\beta, \cos\theta\rangle \tag{1}$$

The UZ projection of **B** is given by:

$$\mathbf{B_{uz}} = |\mathbf{B}|\langle \sin\theta\cos\beta, 0, \cos\theta\rangle \tag{2}$$

The VZ projection of **B** is given by:

$$\mathbf{B_{vz}} = |\mathbf{B}|\langle 0, \sin\theta\sin\beta, \cos\theta\rangle \tag{3}$$

From (2):

$$\tan\alpha = \frac{\sin\theta\cos\beta}{\cos\theta} = \tan\theta\cos\beta = \tan\theta\cos(\phi - 45°) \tag{4}$$

And from (3):

$$\tan\gamma = \frac{\sin\theta\sin\beta}{\cos\theta} = \tan\theta\sin\beta = \tan\theta\sin(\phi - 45°) \tag{5}$$

3 Strategy

Being charged particles, positrons follow the direction of the B field. Decay positrons orbit about the B field lines as they exit the detector. If the magnetic field is misaligned, then the spirals will all be pitched at the same angle as the field. Thus, the decay positron tracks can be used to map the direction of the magnetic field inside the detector. By using the position of the positrons in UVZ, the angles α and γ can be found. A misalignment in the magnetic field should then become immediately apparent, as at least one of these angles would be nonzero. It should also be possible to determine the direction of the misalignment using (4) and (5).
To get the angles alpha and gamma, the plots shown in figure 2 must be created from data by averaging all the decay positron tracks. If a decay positron track is averaged, a straight line going down the middle of the spiral results. If this is done for many tracks, a number of various lines with the same slope should result. Taking the mean of these lines should then yield a good indication of the magnetic field direction. In each DC plane, all positron hit positions were averaged. A hit position was defined as the center of a wire which recorded a hit. In one plot, the mean hit position in U planes was plotted against the Z position of these planes. In an other plot, the same thing was done for V planes. The result was two plots with 22 points each upstream and 22 points each downstream. These plots were generated using profile histograms. These histograms are generated by an HBOOK routine which calculates the mean and RMS of y for each x bin. Once the plots were generated, PAW was used to fit straight lines to them. This produced the needed plots. The slopes of these fitted lines gave $\tan\alpha$ and $\tan\gamma$.
GEANT simulations were used to answer two questions; does this method work? And how well does it work? Once these questions were answered, this method was tested with real data.

4 GEANT simulations

The first simulation done had the purpose of verifying that the geometry was properly understood. A pencil beam of mono energetic positrons was shot from the target, towards the downstream end of the detector. The magnetic field was set to 2T with $\theta = 1°$ and $\phi = 0°$. The positrons had a momentum of $50\frac{MeV}{c}$. Figure 3 depicts the results of this test.

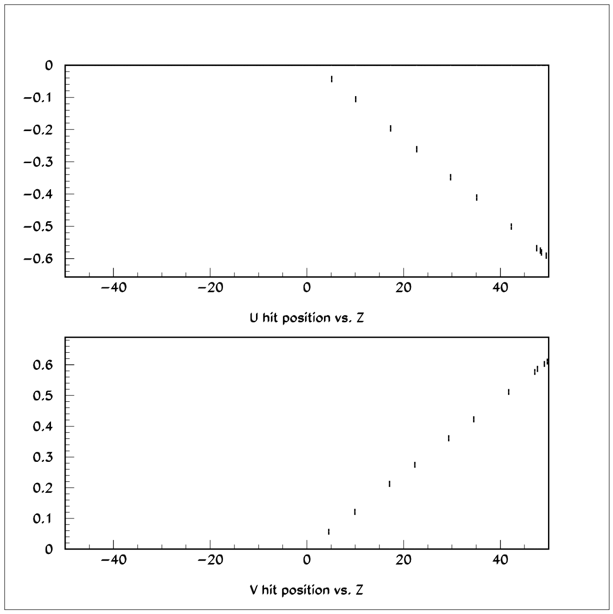

Figure 3: Mean hit positions of DC planes for positron pencil beam (cm)

	Predicted	Measured
$\tan\alpha$	-1.234×10^{-2}	$(-1.233 \pm 0.019) \times 10^{-2}$
$\tan\gamma$	1.234×10^{-2}	$(1.225 \pm 0.019)^{-2}$

Table 1: Results from a positron pencil beam.

Table 1 compares the slopes of the lines fitted to the plots in figure 3 with the values predicted by (4) and (5). The results demonstrate that the technique works as expected.
Next, muon decays were simulated using the full Michel spectrum. To keep things simple, only θ was varied with $\phi = 0°$. Thus the expressions giving the expected values of tan alpha and tan gamma are:

$$\tan\alpha = -\frac{\tan\theta}{\sqrt{2}} \qquad (6)$$

$$\tan\gamma = \frac{\tan\theta}{\sqrt{2}} \qquad (7)$$

Seven runs of 10^5 events each, were generated in GEANT with $|\mathbf{B}| = 2T$ and $\phi = 0°$. θ was varied from $1°$ to $0°$, being halved in each successive run.

5 Results

The GEANT data was analyzed with MOFIA using a cut requiring $\cos\theta > 0.65$ (theta being the track angle), which corresponds to $\theta \approx 50°$; as well as a cut requiring the momentum$> 40\frac{MeV}{c}$. The reason for this was to cut high angle tracks which exit the detector before reaching the end, and positrons with low momentum which scatter too much. The intended result was positrons which form nice spirals all the way through the detector. Also, only simple clean events were analyzed to avoid other complications.

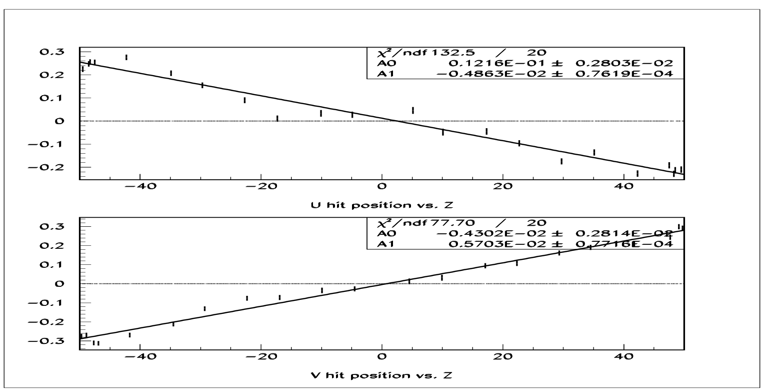

Figure 4: Mean hit position of positrons in DC planes. $\theta = 1°$(cm)

Figures 4 and 5 show the results at the angular extremities of the study.
It was quickly realized that there was a problem. All the values for $\tan\alpha$ and $\tan\gamma$ were too small in magnitude by the same factor, about 2.5. This is depicted in figure 6.

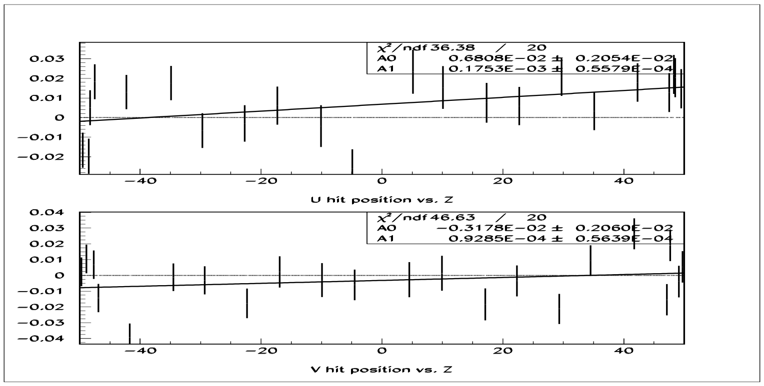

Figure 5: Mean hit position of positrons in DC planes. $\theta = 0°$(cm)

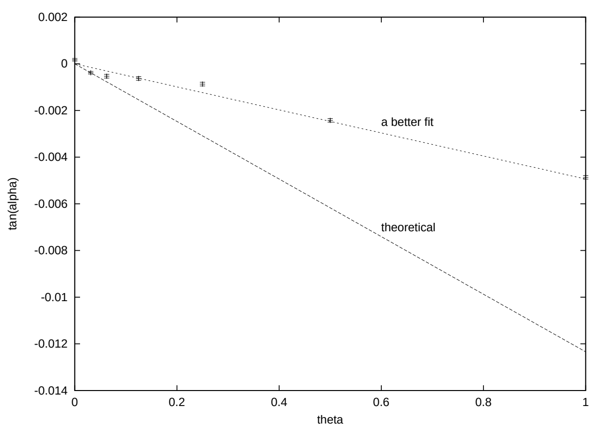

Figure 6: $\tan\alpha$ as a function of θ. Theoretical curve is $-\frac{\tan\theta}{\sqrt{2}}$, a better fit is$-\frac{\tan\theta}{2.5\sqrt{2}}$

There were other problems, which seemed to be related to this unknown factor. The data points for mean plane hit position vs Z formed only approximately straight lines, contrary to what was expected. This appeared to be due to certain regions which were almost horizontal, as those circled in figure 7.

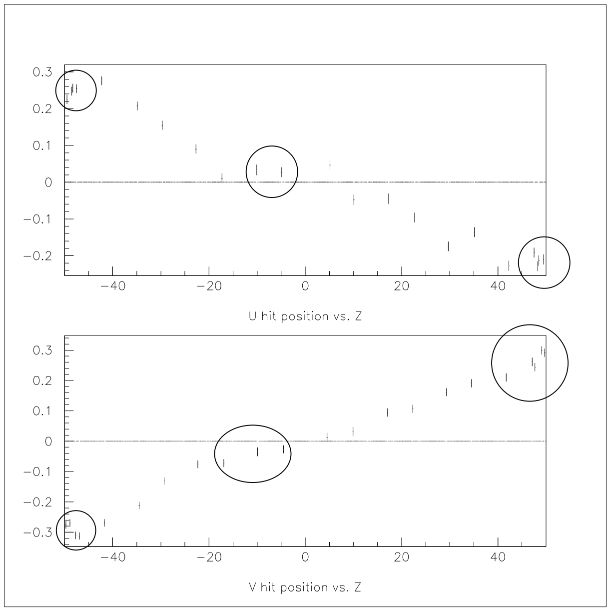

Figure 7: What is happening in the circled regions?

In an attempt to understand these shapes, a simpler case was simulated. A cone of $50\frac{MeV}{c}$ mono energetic positrons was shot downstream from the target with the magnetic field set to 2T. This was done twice, once with $\theta = 0°$ and once with $\theta = 1°$. Since the particles were mono energetic, the cone became a "bubble" due to the focusing of the magnetic field, as in figure 8. Figure 9 shows the mean hit positions for the case when $\theta = 0°$, and figure 10 for the case when $\theta = 1°$.

Figure 9 appears to have an oscillating pattern when it should not. This feature is due to statistics, as there is a randomness in the point of origin of the positrons. If one positron began from a much larger radial position in the target than the rest, the mean hit position would be biased towards its track due to low statistics. Figure 10 has features similar to those seen in figure 4. Since the detector is misaligned relative to the field, the positron bubble is no longer centered along the detector Z axis. Since the DC planes are all normal to this axis, they intersect the bubble at an angle which does not result in circular sections. The non circular sections in the DC planes result in fluctuations in the mean hit positions seen in figure 10. It is possible that this is connected to equations (6) and (7) being poor models.

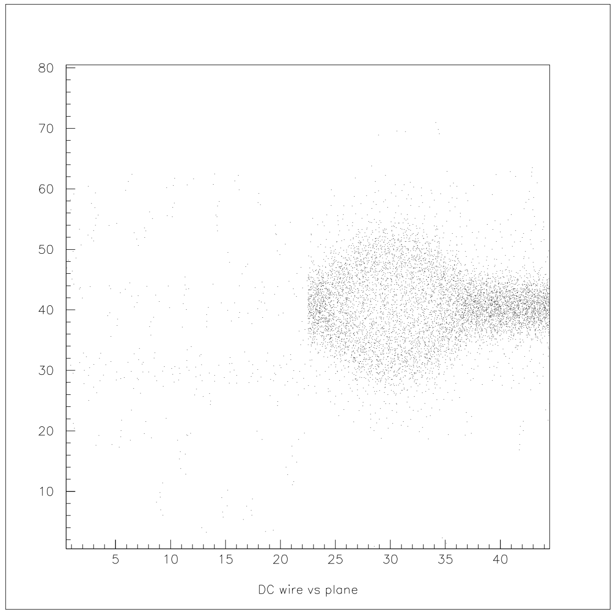

Figure 8: Mono energetic e^+ cone becomes a bubble,$|\mathbf{B}| = 2T$, $\theta = 0°$

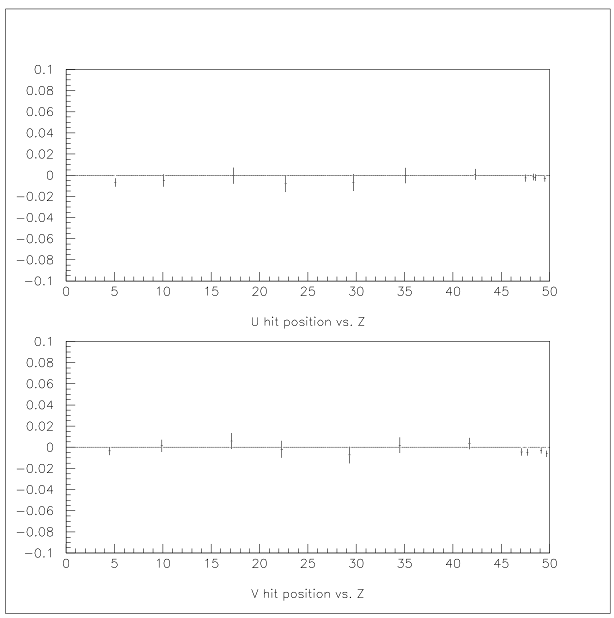

Figure 9: Mean hit position of positron cone, $\theta = 0°$ (cm)

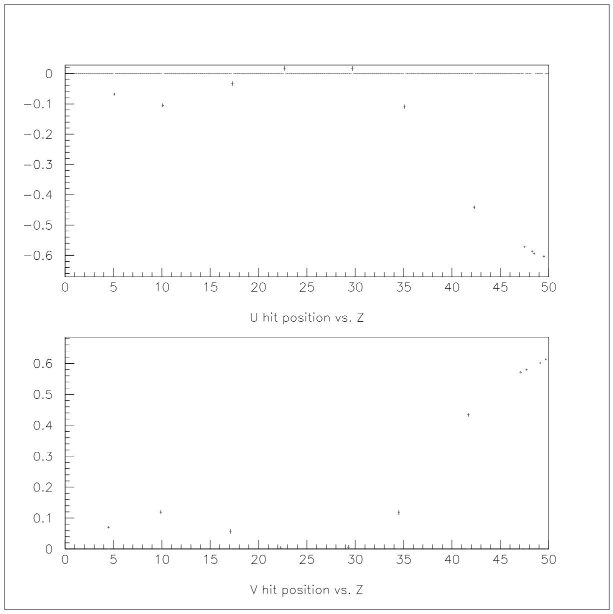

Figure 10: Mean hit position of positron cone, $\theta = 1°$ (cm)

6 Real Data Comparison

This method was not tested extensively with real data, it was only applied to three surface muon runs. The mean hit position plots for one of these are shown in figure 11, the result is similar to the GEANT simulation for a small θ.The results of the real data trials are summarized below in table 2.

Run number	7960	7961	8168
$\tan\alpha$	$(-2.478 \pm 0.446) \times 10^{-4}$	$(-2.009 \pm 0.446) \times 10^{-4}$	$(-4.375 \pm 0.445) \times 10^{-4}$
$\tan\gamma$	$(9.889 \pm 4.529) \times 10^{-5}$	$(2.221 \pm 0.455) \times 10^{-4}$	$(9.889 \pm 4.529) \times 10^{-}5$

Table 2: $\tan\alpha$ and $\tan\gamma$ measured from real data.

The real and simulated results for $\tan\alpha$ have been superimposed in figure 12; from this, it is fair to say that a misalignment of $\approx \frac{1}{8}^{\circ}$ could be seen.

7 Conclusions

Although this method gave results that were not fully understood, it can be used to detect a misalignment of $\approx \frac{1}{8}^{\circ}$; however, it cannot be used at this point to give a precise measure of the direction or magnitude of any misalignment

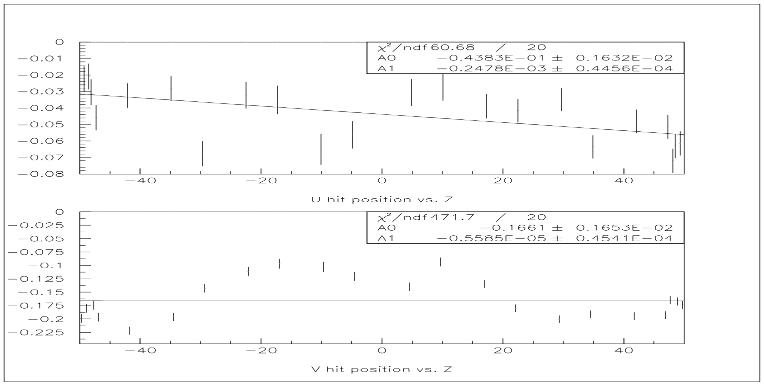

Figure 11: Mean hit position of decay positrons from real data (cm)

due to the not yet understood reduction in the $\tan\alpha$ and $\tan\gamma$ results. Further study is needed.

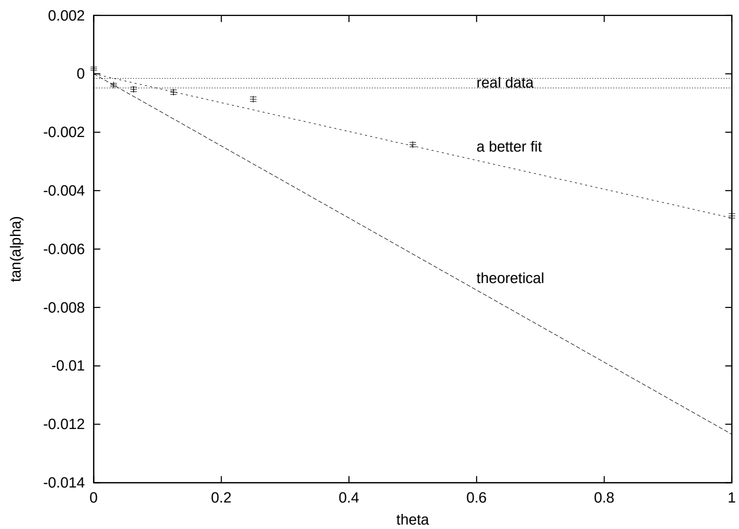

Figure 12: $\tan\alpha$ as a function of θ from real and GEANT data.