TRIUMF Experiment E614
Technical Note

Simulation of a Time Expansion Chamber as a Means of Correlating Initial Muon Track Direction and Polarization in the Target

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Abstract

In Monte Carlo simulations, a Time Expansion Chamber (TEC) was placed upstream of the solenoidal fringe field. The chamber was used to reconstruct the incoming muon track and correlate its angle with the spin direction of the muon as it stopped in the target. A cut on the polar angle of the initial muon track was found which retained ~12% of all muons stopping in the target while reducing the mean depolarization $< 1 - P_\mu >$ of the retained events to ~2 $\times 10^{-4}$. This result was obtained using a highly convergent beam with a focus 160 cm upstream of the target. A more parallel beam was found to produce poorer results. The spatial resolution of the TEC had only a small effect on the results. A comparison of the above results to those obtained using additional drift chambers to track the muon, favors the use of a TEC.

Introduction

A central goal of the E614 experiment is to measure the product $P_\mu \xi$ to a precision of less than three parts in 10^4. The mean depolarization ($< 1 - P_\mu >$) must therefore also be less than three parts in 10^4. One way to guarantee this is to exploit the near perfect polarization of the muon beam in vacuum upstream of the solenoidal fringe field. A very low mass device, such as a Time Expansion Chamber (TEC), can be inserted to measure the track direction and hence the polarization at this point. Assuming that the propagation of muons through the TEC and the rest of the E614 detector is understood, the spin direction of the muons stopping in the target should be correlated with the track direction reconstructed from the TEC. A suitable cut on the initial track angle should then reduce the mean depolarization of the surviving events to desirable levels.

The degree of correlation, and therefore the efficiency of the cut, depends on the emittance of the muon beam, the position resolution of the TEC and the degree to which the TEC disturbs the muon tracks. Each of these factors is discussed below.

Monte Carlo Simulation

Monte Carlo simulations were performed using version 1.0 of the GEANT E614 simulation code. The geometry, as adopted at the April 1998 collaboration meeting, was modified by removing the ten drift chambers (upstream and downstream) used for muon tracking and replacing them with Time Expansion Chambers (TECs) centered 174.25 cm upstream and downstream of the target. The modified version thus includes, from the stopping target outward, two proportional chambers, 22 drift chambers, one plane of plastic scintillator of thickness 400 μm, four more proportional chambers, a helium-filled beamline extending to 150 cm from the target and finally, the TECs.

TECs were described and proposed for use in E614 in Technical Note 17 [1]. The TEC used in the present simulation consisted of a rectangular box 29.5 $\times$ 3.6 $\times$ 3.6 cm^3 filled with DME gas at a pressure of 20 torr. At its upstream end the DME was separated from the beam line vacuum by a 6 μm mylar foil. At its downstream end it was separated from a 1 atm helium-filled beam line by a 100 μm mylar foil. The TEC was divided into two rectangular drift volumes, one each to provide xz and yz muon track information. The drift field is established (but not simulated in this study) by a plane of 34 100 μm field wires located at the lower edge of the yz drift volume, out of the way of the muon beam. Between the field wires and the outer wall of the TEC, was a plane of 33 10 μm sense wires with 1 mm spacing. The xz drift volume was identical, except that it was rotated 90 degrees with respect to the yz volume. The xz drift volume was centered 177.25 cm from the target, while the yz drift volume was centered 171.75 cm from the target.

In the simulation, the TEC generated 33 x and 33 y distances from the sense planes to the muon track. An gaussian uncertainty of 200 μm (σ) was added to each recorded distance. This represents a pessimistic estimate of the TEC resolution [1]. A linear fit of the (x, z) and (y, z) coordinates returned the slopes of the muon track in the xz and yz planes which were then combined to get the polar angle θ of the track before it entered the strong solenoidal field. $1 - cos$ of the muon spin direction as it stopped in the target was then plotted versus $sin\theta$. The TEC was placed far from the center of the target, where the solenoidal field is weak, for three reasons: 1) such devices do not function in high magnetic fields, 2) muon tracks are not significantly deflected and can be assumed to be straight, and 3) the amount of matter the muons must pass through before being analyzed is minimized.

Two muon beam tunes of differing emittance were studied in the simulation. Both had a momentum of 29.8 MeV/c and were started 280 cm upstream of the target. It was assumed here that the last quadrupole magnet in the M13 beamline was centered 300 cm upstream of the target. The nominal foci of both tunes were set 160 cm upstream of the target, which was 14.5 cm downstream of a point midway between the xz and yz drift volumes of the TEC. At its focus, the "convergent" M13 tune had a spot size of 0.94 mm (FWHM) in x and 5.0 mm (FWHM) in y. Its divergence (FWHM) in x and y was 6.6 mrad and 100 mrad, respectively. Its total emittance was therefore 6.2 mm-mrad in x and 500 mm-mrad in y. The "parallel" tune was a simulation of the M15 beamline which had a spot size of 10 mm (FWHM) in x and 8 mm (FWHM) in y, and a divergence of 14 mrad (FWHM) in x and 17 mrad (FWHM) in y. Its emittance was 140 mm-mrad in both x and y.

A solenoidal magnetic field aligned with the beam axis was used. The value of its longitudinal component at the origin was 2.2T and fell rapidly starting around $z = 150$ cm. The radial field component peaked at around $z = 160$ cm and then fell off rapidly upstream and downstream of that point. Both the muon momentum and spin were propagated through the field. Muons were allowed to decay but the decay positrons were not tracked.

Results

Due to the small size in x and y (3.6 cm) of the TEC, and the large track angles of the convergent beam tune, 0.5% of the incident muons stopped in the walls or wires of the TEC. For the parallel tune, none of the incident muons stopped in the TEC. The surviving muons passed through the remainder of the spectrometer with typically 78% of them stopping in the target. For each of these the depolarization, $1 - cos\theta_s$, was histogrammed versus $sin\theta$. Here θ_s is the direction of the muon spin as it stopped in the target and θ is the polar angle of the muon track as measured by the TEC outside of the strong field region. This histogram for the convergent beam tune is shown in Fig. 1.

There is a strong correlation between the depolarization and the angle of the initial muon track. Hence a cut on the measured muon track angle will reduce the mean depolarization. The effect of such a cut is shown in Table I.

Cut on TEC angle (rad)	% μ surviving	mean depolarization($\times 10^{-4}$)
θ=0.03	52	6.9
θ=0.02	32	4.0
θ=0.01	12	2.2
θ=0.005	3	1.7

Table I. Percentage of muons surviving cut which also stop in the target, and mean depolarization as a function of a cut on the initial muon polar angle measured in the TEC. These results were obtained with the convergent beam tune.

At the cut value of 0.01 rad, the mean depolarization falls below 3×10^{-4}. Of those muons which stop in the target 12% survive this cut. Since 78% of all incident muons stop in the target, the total percentage of initial muons which can be used in an experiment thus becomes $0.78 \times 12 = 9.4$. Tighter cut values do not significantly improve the depolarization.

Attempts to increase the number of muons surviving this cut while keeping the depolarization small depend on multiple scattering, the spatial resolution of the TEC and the beam tune. The effect of multiple scattering is shown in Fig. 2. Here the correlation of the TEC muon angle and the depolarization is presented with multiple scattering turned on and off throughout the entire detector. As expected the correlation is better in the absence of multiple scattering, as is the efficiency of the cut on the TEC muon track angle (compare Tables

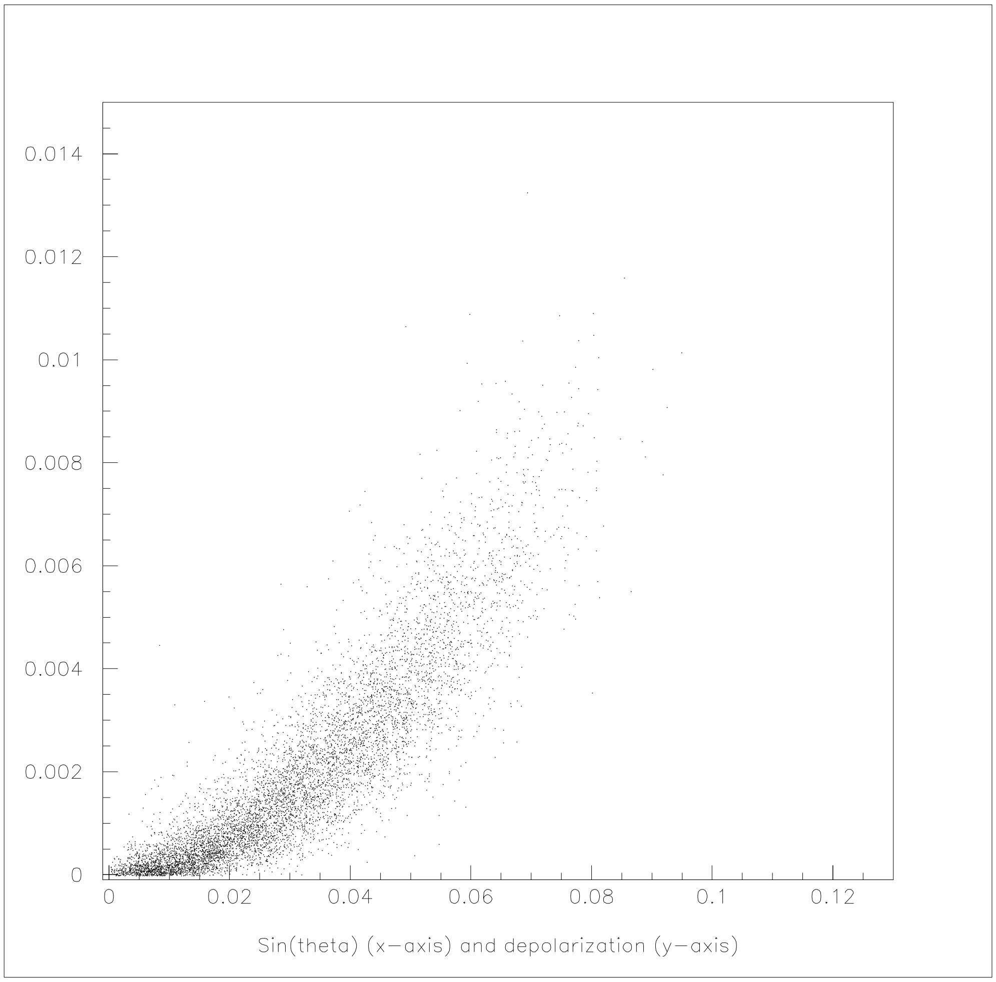

Figure 1: Muon depolarization at the target vs. TEC muon angle for a convergent beam.

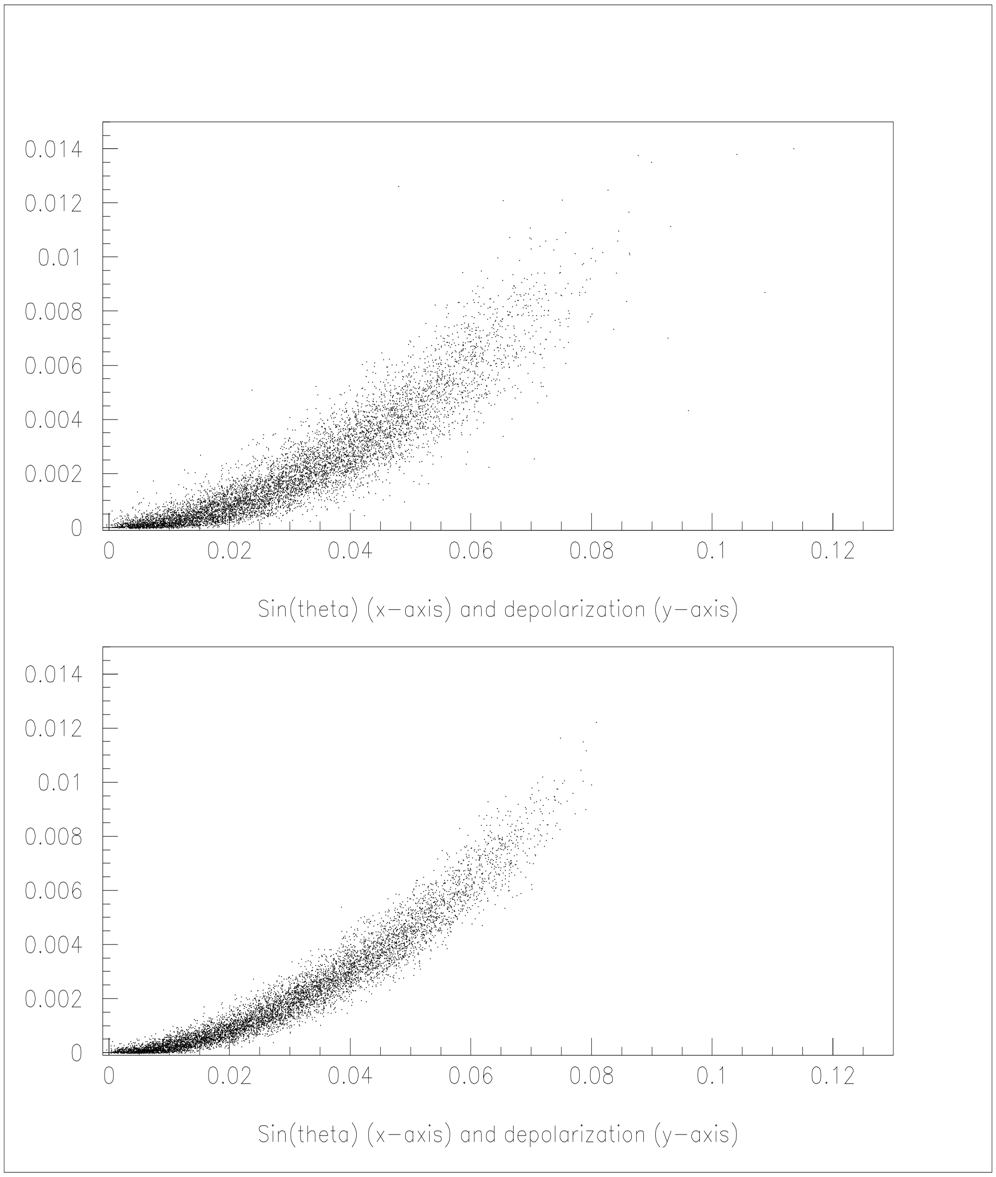

Figure 2: Effect of multiple scattering on the correlation of TEC muon angle and depolarization at the target. Top: multiple scattering included; bottom: multiple scattering not included. These results were obtained using the convergent beam tune.

I and II). However, it is unlikely that the amount of multiple scattering can be significantly reduced because the only scattering centers that can perhaps be made thinner are the plastic scintillator disk and the 100 μm mylar window on the downstream end of the TEC.

Cut on TEC angle (rad)	% μ surviving	mean depolarization($\times 10^{-4}$)
θ=0.030	53	7.0
θ=0.020	35	3.6
θ=0.010	15	1.4
θ=0.005	5	0.83

Table II. Percentage of muons surviving cut which also stop in the target, and mean depolarization as a function of a cut on the initial muon polar angle measured in the TEC. These results were obtained with the convergent beam tune.

It is likely that the spatial resolution of the TEC can be improved from the assumed 200μm. The effect on the TEC angle - depolarization correlation is shown in Fig. 3 for resolutions of 200, 100 and 50 μm. The difference between 200 and 50 μm is small, indicating that multiple scattering or beam properties dominate over resolution effects. A comparison of Tables III and I shows that only a small improvement in the depolarization (from 2.2×10^{-4} to 1.9×10^{-4}) is possible, and that there is no significant improvement in cut efficiency.

Cut on TEC angle (rad)	% μ surviving	mean depolarization($\times 10^{-4}$)
θ=0.030	53	6.8
θ=0.020	33	3.8
θ=0.010	12	1.9
θ=0.005	4	1.2

Table III. Percentage of muons surviving cut which also stop in the target, and mean depolarization as a function of a cut on the initial muon polar angle measured in the TEC. These results were obtained with the convergent beam tune and a TEC resolution of 50 μm (σ).

The convergent beam tune had a spot size elongated in y and very narrow in x. It was also highly convergent in y and nearly parallel in x. For these reasons, it was thought that the y and θ_y values measured in the TEC may provide a better correlation with depolarization than the polar angle used previously. The correlations with y and θ_y are shown in Fig. 4. In this case two cuts are required to reduce the mean depolarization: one on the reconstructed y coordinate and another on θ_y. However, the results are not much different from those obtained with the single cut on the polar angle. Accepting only events for which $0.3 < y < 0.7$ cm and $-0.02 < \theta_y < 0.02$ rad, the mean depolarization was reduced to 3.7 $\times 10^{-4}$. Of those muons stopping in the target, 29.5% survived the cuts. This result is very similar to the polar angle cut at 0.02 rad from Table I.

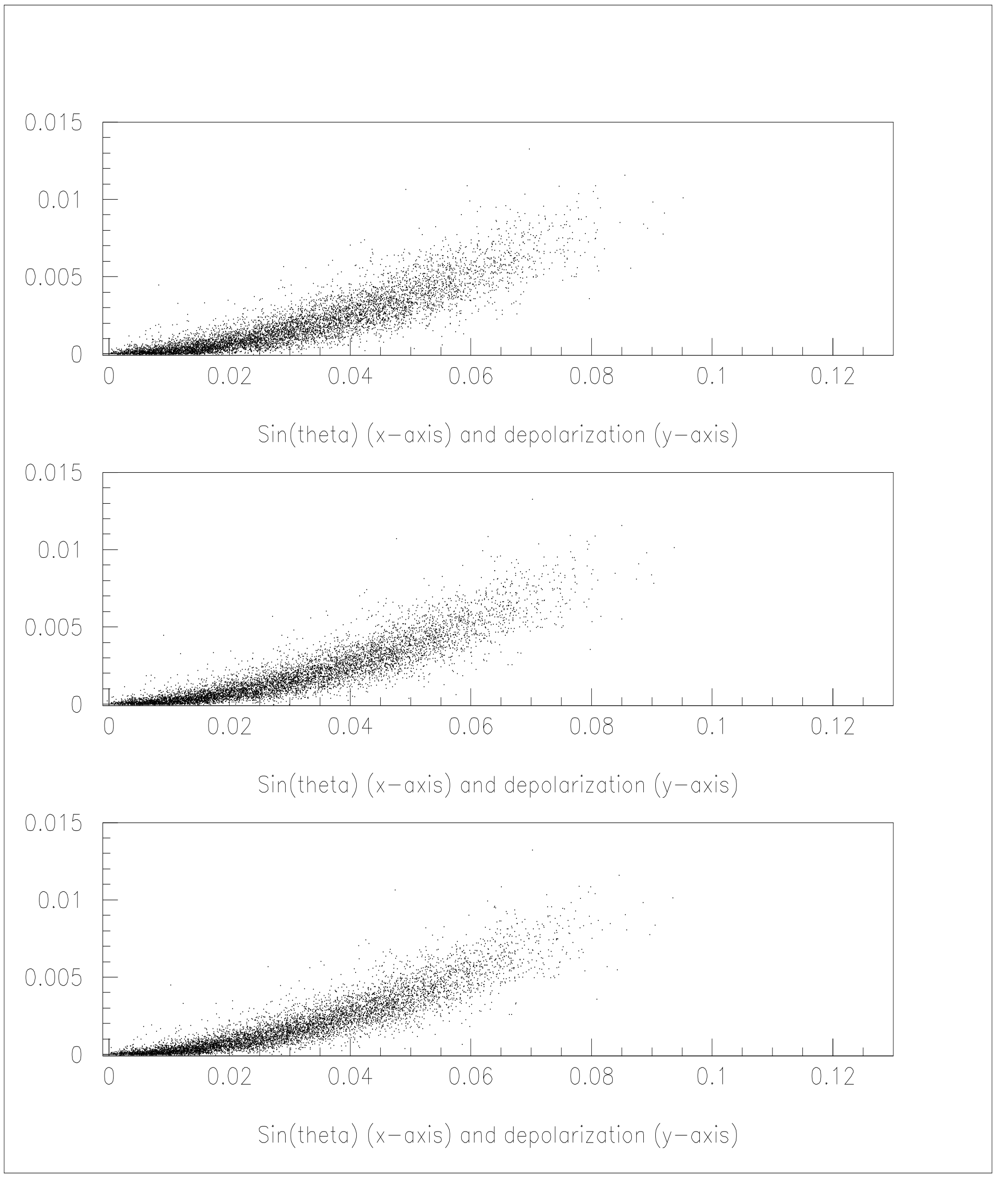

Figure 3: Effect of TEC resolution on the correlation between TEC muon angle and depolarization. The convergent beam tune was used and TEC resolutions of 200μm (top), 100 μm (middle) and 50 μm (bottom) were assumed.

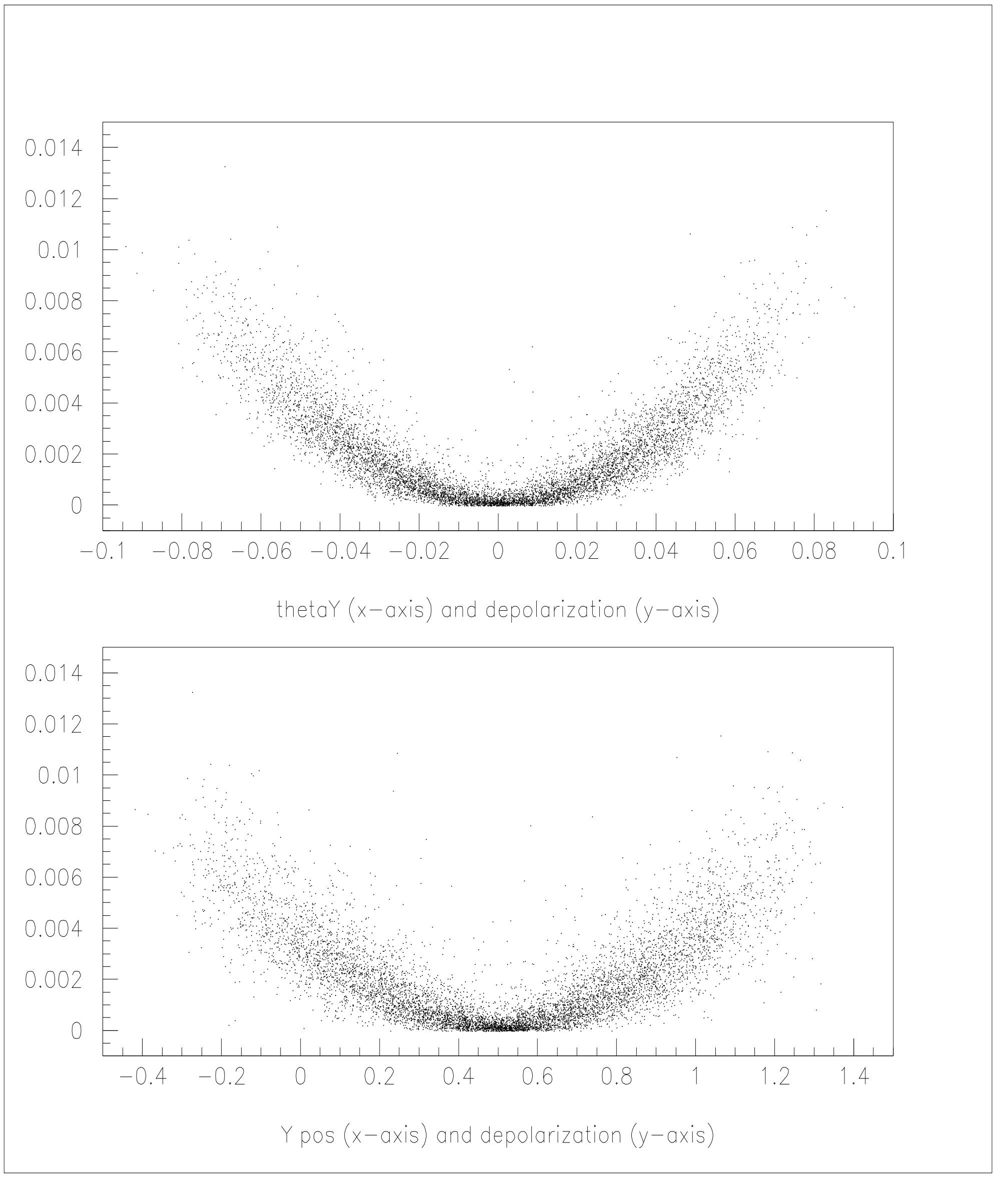

Figure 4: Muon depolarization at the target vs. reconstructed θ_y (top) and y (bottom).

All of the above results were obtained with a highly convergent M13 tune. In order to quantify the effects of beam tune on the TEC angle - depolarization correlation, a parallel tune simulating the M15 beamline was also examined. Using this tune, the correlation of the muon TEC polar angle with the depolarization was plotted as shown in Fig. 5. A comparison of Figs. 5 and 1 shows less correlation for the parallel tune than for the convergent tune. As a result the cut on muon TEC angle is much less efficient. As shown in Table IV, not even the tightest cuts can achieve depolarizations of less than 3×10^{-4}.

Cut on TEC angle (rad)	% μ surviving	mean depolarization($\times 10^{-4}$)
θ=0.030	90	19.7
θ=0.020	67	15.0
θ=0.010	26	8.9
θ=0.005	8	6.6

Table IV. Percentage of muons surviving cut which also stop in the target and mean depolarization as a function of cut on polar θ for a parallel beam.

Discussion and Conclusions

In the above simulations the TEC replaced the five pairs of drift chambers which were to be used to track the incoming muon. Previous simulations of these chambers [2] showed that a cut on the radius of the fitted muon helix could be used to reduce the mean depolarization at the target to 5×10^{-4} (see Fig. 14 of Technical Note # 14) while keeping 6% of the muons which stopped in the target. Using the same converging beam tune, the TEC allowed depolarizations of 2.2×10^{-4} while keeping 12% of the muons which stopped in the target. The TEC results are superior to those from the muon tracking drift chambers because of the smaller mass intercepted by the muon beam and because the TEC is able to measure the beam polarization before it encounters large magnetic fields.

Simulations were performed using beam tunes intermediate between the highly convergent beam and the nearly parallel beam. However the depolarization - TEC angle correlation became worse as the beam became more parallel. It is therefore recommended that instead of additional drift chambers for muon tracking, a TEC should be used in conjunction with a highly convergent beam tune.

References

[1] Yu.I.Davyydov, V.I.Selivanov, V.D.Torokov, E614 Technical Note #17, May 1998.

[2] A.R. Parikh, E614 Technical Note # 14, April 1998.

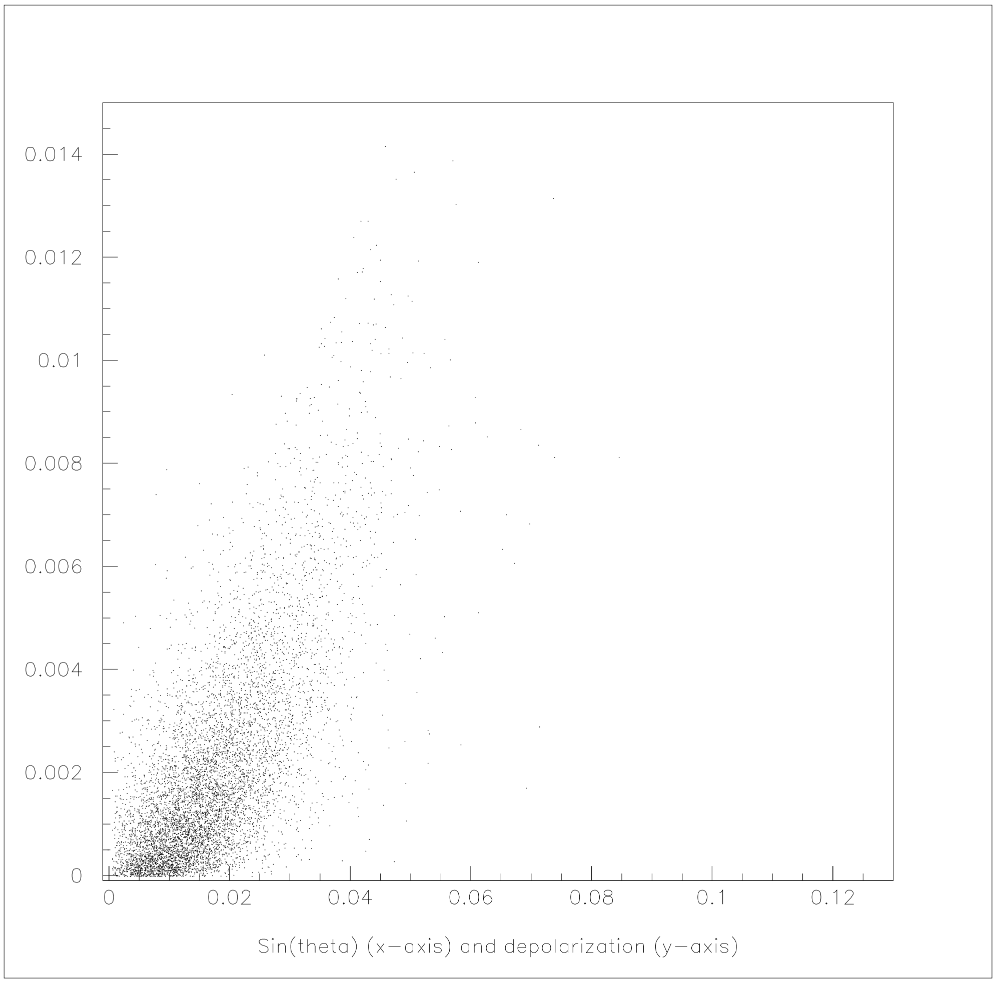

Figure 5: Muon depolarization at the target vs. reconstructed TEC muon angle for a nearly parallel beam tune.