Tracking Efficiency in CLEO-III and CLEOc

Matt Adams
Physics Department, Wayne State University, Detroit, MI, Zip
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New physics is expected to be found at future TeV energy-scale colliders. Such new physics is expected to show up at the 10% level for a 500GeV collider. CLEO3 data was taken at 10GeV, and so the new physics could be expected to arise at the 0.1% level. Such precision requires an excellent understanding of the tracking efficiency. We measured the tracking efficiency to see if our understanding would reach these limits. We compared this data to Monte Carlo data to test our ability to measure new physics in asymmetries. We find that we are able to measure the efficiency to the order of 0.1%.

I. INTRODUCTION

New colliders operating at the TeV scale are expected to produce new physics previously inaccessible at lower energies. To be able to detect this new physics at at lower energies such as those used in CESR, we need to understand the tracking and triggering efficiency to the level of 0.1%. We use radiative Bhabha events to construct a tracking efficiency by completely reconstructing a radiative Bhabha event except for one track, and then we search for that one track. We run a similar Monte Carlo simulation, searching for one track, and compare the efficiences.

Measuring foreward-backward asymmetries is one way of detecting new physics in e^+e^- and other colliders. Some of the new physics that could be found includes gauge boson Kaluza-Klein towers in extra dimensional models and string excitations.[1] We plot the cosine of the polar angle θ distribution in the detector and look for deviations from the Standard Model(SM). The SM is modeled by Monte Carlo simulation. Any deviation from the Monte Carlo simulation in the real data corresponds to a deviation from the SM. We are looking for these deviations at the 5σ level.

II. TRACKING EFFICIENCY

We reconstruct radiative Bhabha events, except for one track, and construct an efficiency based on whether we found that track or not. We use with slight modification cuts created in an earlier study done by Mohammed Alfiky.[2] The crucial change made from Mohammed's cuts has to do with the position of the collision when it is not in the exact center of the detector. Previously, all events were assumed to originate from the center of the detector, but this caused a 10% lowering of the efficiency at $\cos\theta = 0$. We corrected this by measuring θ and *phi* from the track momentums, and not from the center of the detector. As Mohammed does, we tag the side of the detector that has one charged track and one photon shower. We then predict that there should be a track on the opposite side of the dectector with the remainder of the energy not found in the tag track and photon shower, and equal but opposite momentum. The cuts we used in reconstructing these events are as follows:

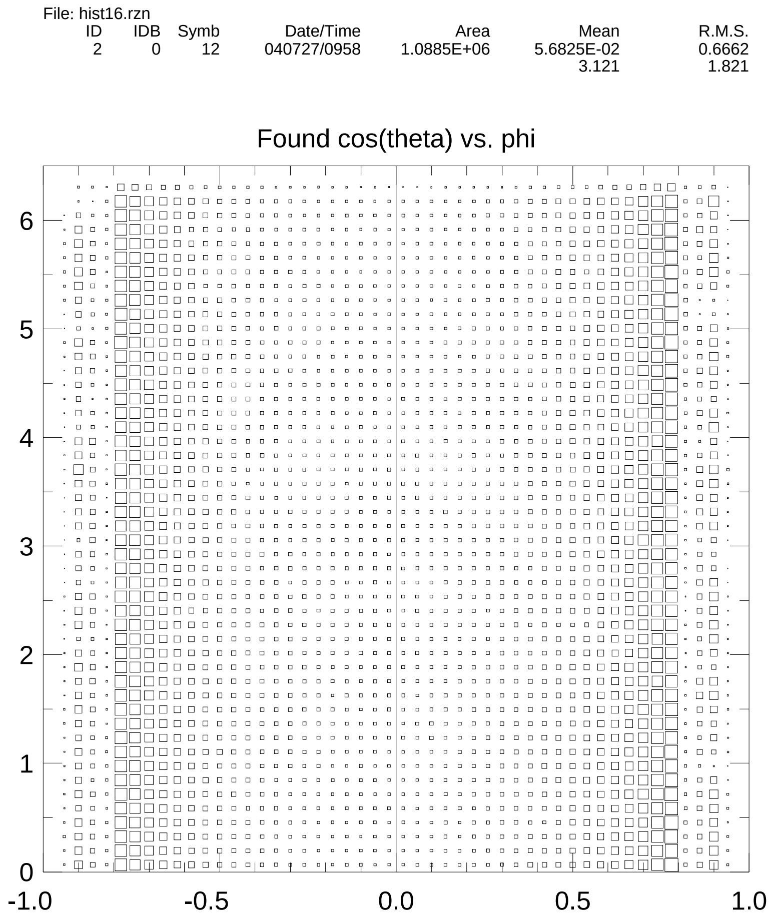

FIG. 1: The 2-dimensional histogram of $\cos\theta$ vs. ϕ for events where the predicted track was found.

1. Each event must have three showers in the calorimeter that pass a noise cut. The noise cut was calculated in bins of $\cos\theta$ by fitting to a power function and second order polynomial. The power function modelled the noise, and we removed 90% of the area under the power function.

2. The event must conserve energy, so the sum of the three showers must equal the center of mass energy.

3. The showers have a 2 to 1 topology meaning that the showers of one charged particle and a photon are on one side of the calorimeter, and the shower of the other charged particle is on the opposite side.

4. The biggest shower is the one for the charged particle without the radiated photon. We require this shower's energy to be close to the beam energy.

5. We neglect showers that fall in the overlap region between the endcap and the barrel.

6. We only select events that have two or fewer tracks.

7. We require that the tag shower energy matches the tag track energy.

8. If a found track does not match energy with its shower, we remove it as a bad tag.

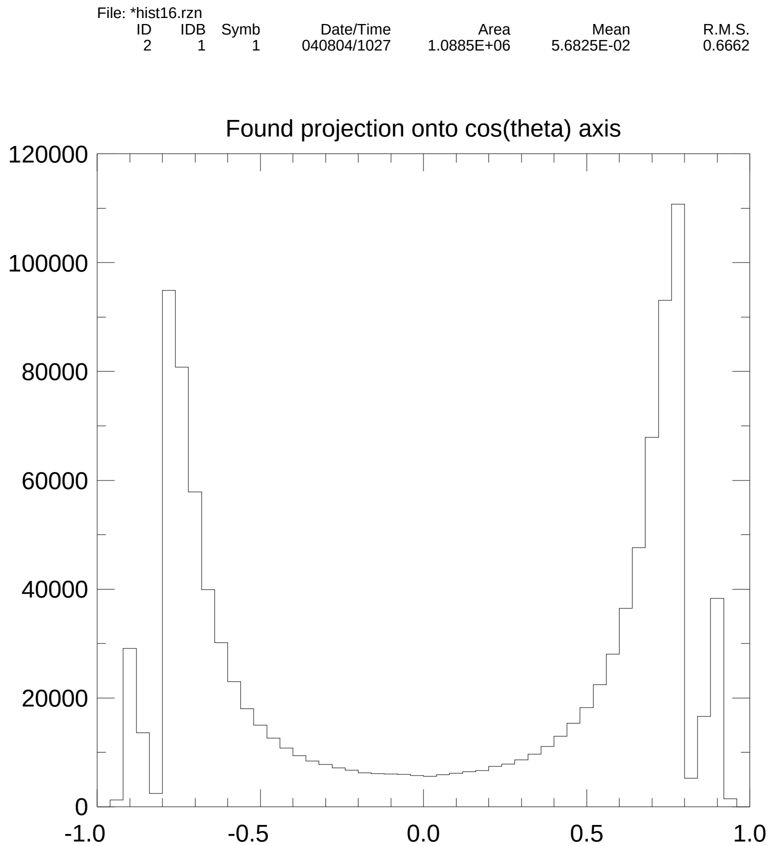

FIG. 2: The projection of figure 1 onto the $\cos\theta$ axis.

We construct an efficiency based on whether a charged track was found in the drift chamber opposite the track we have already tagged. We are interested in measuring the efficiency as in varies across $\cos\theta$. We do not expect to find any variation in ϕ, but for completeness we plot a 2-dimensional histogram of $\cos\theta$ vs. ϕ for the tag track's momentum for all events that pass our selection criteria. Each time we find a track, we plot a histogram again of the tag track's momentum from the same event. The purpose of the efficiency is to plot a value of "1" if a track is found, and a value of "0" if it is not. Because the calculated predicted momentum will never be the exact value of the measured found momentum, the efficiency can talk on values greater than one when the difference is enough that for one event, the tag track and found track are plotted in different bins of $\cos\theta$. For this reason, in the found histogram we plot the tag track's momentum so that when we divide, we get a value of either "1" or "0" for any given event. We project the graphs onto the $\cos\theta$ axis, which means we are summing over all angles of ϕ for each $\cos\theta$ bin in the histogram. Finally we divide the projected histogram of the found tracks by that of the tag tracks. (see figures 1-3)

The histogram we have after dividing is a plot of the CLEO tracking efficiency across $\cos\theta$. We fit this histogram to a second order polynomial. We chose a second order polynomial to see if any variation in the efficiency showed up in the center of the detector or at the edges.

In searching for extra-dimensional effects, we need to compare the asymmetries we measure in the real data to those expected in the SM, which is modeled by Monte Carlo(MC)

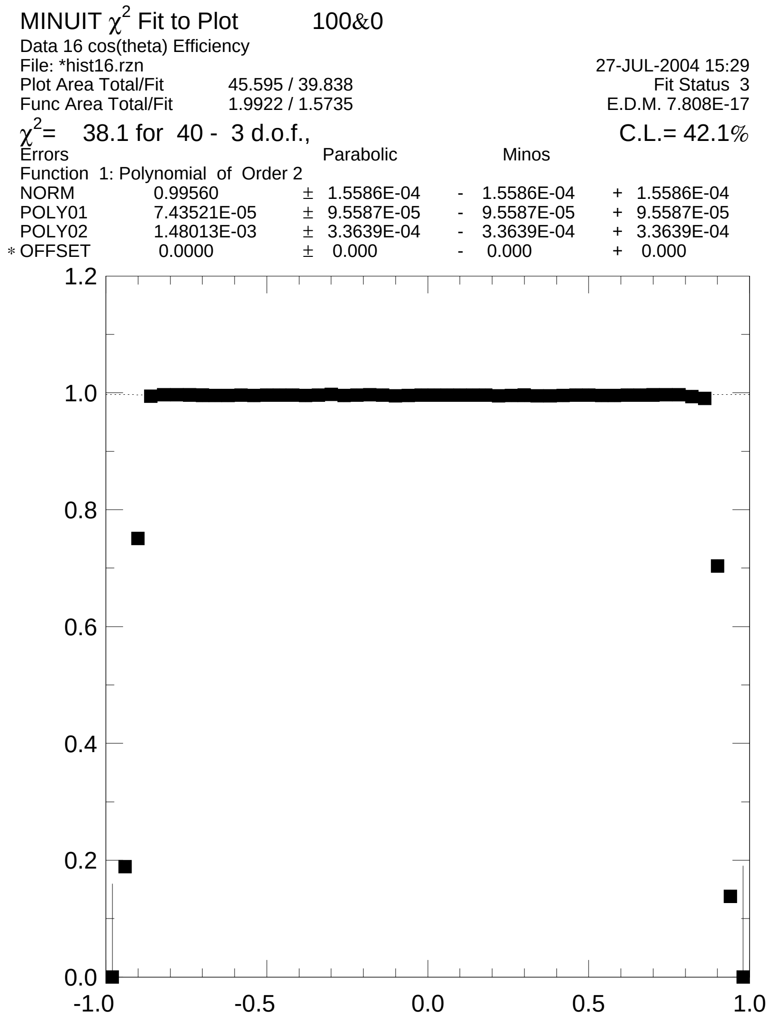

FIG. 3: The efficiency for CLEO III data set 16.

simulation. Therefore, we also need to understand the MC efficiency. Studies done by Professor Ryd[3] at Cornell University show that there is about a 3% inefficiency in the MC simulation at CLEO. He defined an efficiency based on $D\bar{D}$ events, so we used the our definition of efficiency using radiative Bhabha events to compare to his results. We generated single track MC events, and plotted efficiences as described above based on whether we found the track or not after implementing our selection criteria. The selection criteria for the MC simulation were:

1. The shower matching the track must have an energy close to the beam energy

2. We require that the shower energy matches the track energy.

Mohammed Alfiky demonstrates in his Masters Thesis that the efficiency of a single track MC simulation is equivalent to our radiative Bhabha derived efficiency.[2]

III. ASYMMETRY MEASUREMENT

We chose to study Bhabha and muon pair asymmetries. We used the following selcection criteria for these events.

Muon Events

1. There must be exactly 2 tracks.
2. The energy in the calorimeter must be less than .5 GeV.
3. To exclude cosmic ray muons, we cut $d0 < .5mm$ and $z0 < 1cm$.
4. The sum energy of the two tracks must equal the center of mass energy.
5. Acollinearity of $\theta_1 + \theta_2 - \pi < .7$

Bhabha Events

1. Showers in the Calorimeter must be above the noise cut.
2. There must be exactly 2 tracks
3. There must be exactly 2 showers
4. The energy sum of the two tracks must equal the center of mass energy.
5. Acollinearity of $\theta_1 + \theta_2 - \pi < .7$
6. Acollinearity for ϕ, $0 < \phi_1 - \phi_2 - \pi < 1.1$

We made asymmetry measurements in two different ways. The first method we used was to construct a foreward-backward asymmetry using this equations:

$$A_{fb} = \frac{N_{e-(\cos\theta\, >\, 0)} \;-\; N_{e-(\cos\theta\, <\, 0)}}{N_{e}-} \tag{1}$$

and compared the real data asymmetry to the Monte Carlo simulation asymmetry. The second method we used was modeled from a paper written by Thomas Rizzo[1]. We fitted to a curve the $\cos\theta$ distribution of the electrons for Bhabha events, and the μ^- for muon pair events. We then used this curve to compare to the SM, again using the MC simulation(see Figures 4,5). Extradimensional effects would manifest themselves in these plots of the angular distribution in the linear term of a quadratic fit. If the linear term of the fit for the real data differs by more than 5σ from the MC prediction, we believe that we are observing new physics not accounted for in the MC simulation.

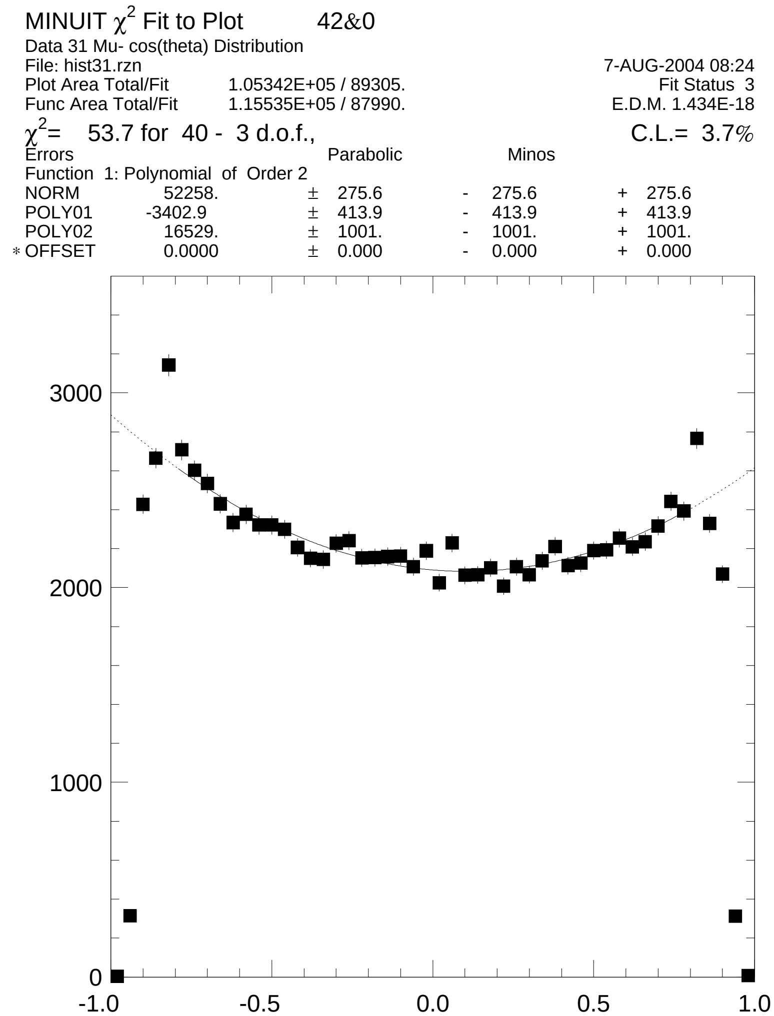

FIG. 4: The $\cos\theta$ distribution for μ^- particles in CLEOc, data set 31.

IV. RESULTS

We found that we can measure the tracking efficiency on the order of 0.1%, and that the the efficiency is uniform across CLEO. Table 1 shows the tracking efficiences for most of the CLEO III and CLEOc data sets. The efficiencies were fit to a second order polynomial. Table 1 shows that the linear and quadratic terms are consistent with zero, so the efficiency is uniform across the detector. Taking Data Set 16 for example, the normalization term is .9956 and the error is $1.5586 \cdot 10^{-4}$. So the efficiency is:

$$\frac{1.5586 \cdot 10^{-4}}{.9956} = 1.5655 \cdot 10^{-4} = .01565\% \tag{2}$$

We fit only in the region of the barrel detector only($|\cos\theta| < .79$). In the endcap detector, the efficiency drops off rapidly because of the overlap between the two detector regions and due to proximity to the beamline. We conclude from this that the efficiency is uniform across the detector in the region we are fitting.

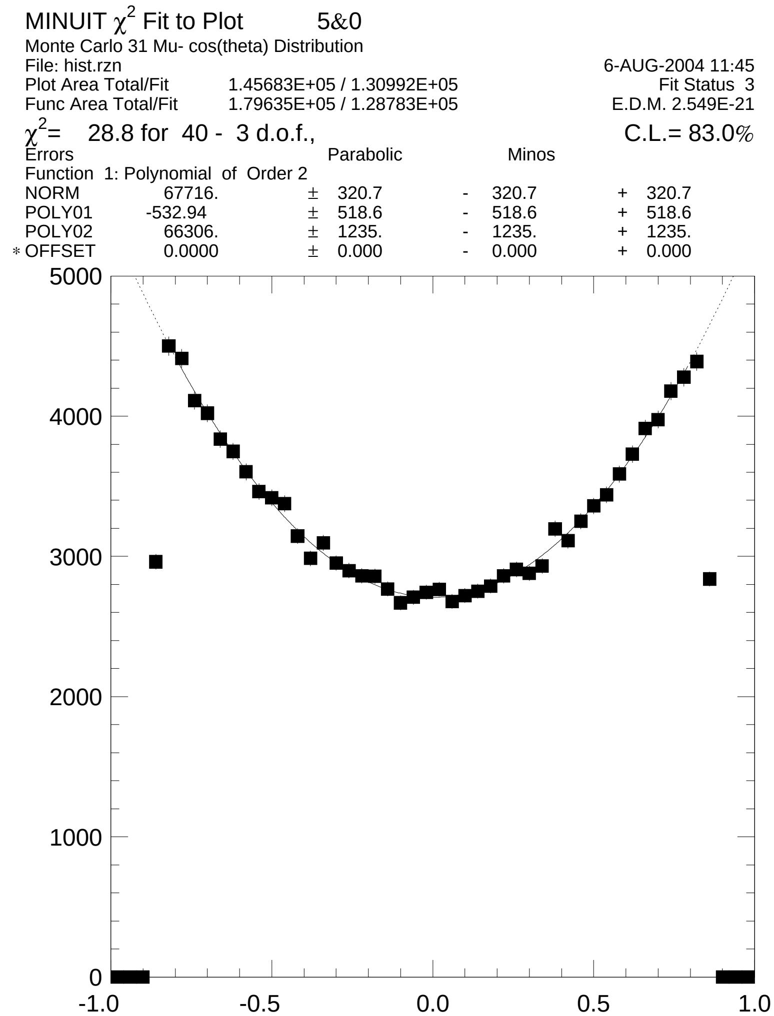

FIG. 5: The $\cos\theta$ distribution for μ^- particles in the MC simulation of CLEOc, data set 31.

All of the data sets for CLEO III and CLEOc that we have studied so far show comparable efficiencies, which indicates that the efficiency is consistent over time. Our results show that the efficiency is a flat line, or in other words uniform across the detector(see Figure 3). In almost all cases, the linear and quadratic terms are consistent with 0 at the 3σ level or better(see Table 1).

For the MC tracking efficiency, we found as Professor Ryd[3] did, that the MC efficiency is lower than the real data efficiency. At the suggestion of Professor Ryd, we plotted separate efficiences for the different bunch numbers in the beam. We determined that the inefficiency is related to the bunch number of the event. Figure 6 shows the MC efficiency for bunches 1-5 and bunch 10. The normalization term is .98003. Figure 7 shows the efficiency for bunch 5 only. Bunch 5 is much more inefficient the the others, .95777. We concluded that the MC simulation for our definition of efficiency is less efficient than the real data as Professor Ryd also found using his definition of efficiency. There appears to be a bug in the MC simulation code dealing with bunch 5, and we expect the MC efficiency to be significantly improved when the error is fixed.

We were unable to reach any definitive results yet with our asymmetry measurements. Both of the approaches we took depend on comparison with the MC simulations. Since

TABLE I: A list of efficiences for CLEO III and CLEOc data sets The efficiency was fit to a second order polynomial. This table shows the linear and quadratic terms with their errors for that fit.

Data Set	Efficiency	Linear Term	Quadratic Term
16	$.9956 \pm 1.6 \cdot 10^{-4}$	$7.45 \cdot 10^{-5} \pm 9.56 \cdot 10^{-5}$	$1.48 \cdot 10^{-4} \pm 3.36 \cdot 10^{-4}$
17	$.9952 \pm 1.2 \cdot 10^{-4}$	$-1.29 \cdot 10^{-4} \pm 6.9 \cdot 10^{-5}$	$2.1 \cdot 10^{-3} \pm 2.5 \cdot 10^{-4}$
18			
19	$.9946 \pm 1.5 \cdot 10^{-4}$	$-6.00 \cdot 10^{-5} \pm 8.6 \cdot 10^{-5}$	$2.5 \cdot 10^{-3} \pm 3.1 \cdot 10^{-4}$
20			
21			
22	$0.9952 \pm 1.6 \cdot 10^{-4}$	$1.13 \cdot 10^{-4} \pm 1.0 \cdot 10^{-4}$	$1.3 \cdot 10^{-3} \pm 3.6 \cdot 10^{-4}$
23	$0.9953 \pm 1.9 \cdot 10^{-4}$	$2.10 \cdot 10^{-5} \pm 1.1 \cdot 10^{-4}$	$2.0 \cdot 10^{-3} \pm 4.0 \cdot 10^{-4}$
24	$0.9933 \pm 2.2 \cdot 10^{-3}$	$-3.58 \cdot 10^{-4} \pm 1.1 \cdot 10^{-3}$	$5.6 \cdot 10^{-3} \pm 4.9 \cdot 10^{-3}$
25	$0.9958 \pm 1.7 \cdot 10^{-4}$	$-6.56 \cdot 10^{-5} \pm 9.9 \cdot 10^{-5}$	$1.2 \cdot 10^{-3} \pm 3.8 \cdot 10^{-4}$
26	$0.9971 \pm 9.2 \cdot 10^{-4}$	$-6.33 \cdot 10^{-4} \pm 1.1 \cdot 10^{-4}$	$1.5 \cdot 10^{-3} \pm 3.5 \cdot 10^{-4}$
27	$0.9955 \pm 1.6 \cdot 10^{-4}$	$8.73 \cdot 10^{-5} \pm 5.6 \cdot 10^{-4}$	$-2.5 \cdot 10^{-3} \pm 2.1 \cdot 10^{-3}$
28			
29			
30			
31	$0.9948 \pm 3.0 \cdot 10^{-4}$	$-1.16 \cdot 10^{-4} \pm 2.0 \cdot 10^{-4}$	$1.9 \cdot 10^{-3} \pm 6.8 \cdot 10^{-4}$
32	$0.9958 \pm 2.0 \cdot 10^{-4}$	$-2.78 \cdot 10^{-4} \pm 1.4 \cdot 10^{-4}$	$5.4 \cdot 10^{-4} \pm 4.7 \cdot 10^{-4}$
33			
34			

the MC simulation has a bug making it less efficient than the real data, we cannot make accurate comparisons. The first method we employed, counting the paritcles on one side of the detector versus the other side of the detector, gave the following preliminary results shown in Table 2.

TABLE II: Foreward-Backward Asymmetry Measurements

	Data Set 31	Monte Carlo 31
A_{fb}	$.0261 \pm .12823$	$.0068 \pm .687$

These errors represent simple counting errors propagated through the calculation. The errors on these calculations are unacceptable for analysis purposes. To be able to use this method in the future, we plan to study ways to lower the errors on our measurements.

V. CONCLUSIONS

Although we are able to measure our efficiency to within .1%, we found that this is not the only factor in measuring asymmetries. We plan to define a triggering efficiency to use

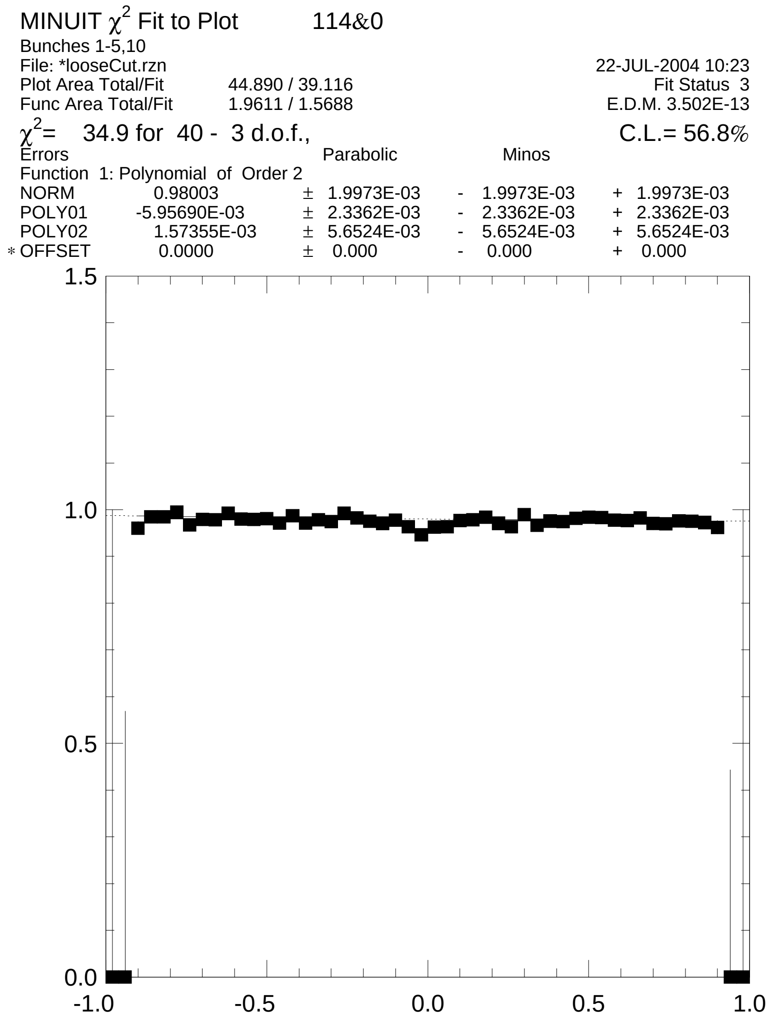

FIG. 6: The $\cos\theta$ efficiency for MC simulation of CLEOc data set 31, bunches 1-5 and 10.

along with our tracking efficiency. We are particularly interested in the triggering efficiency for muon events, as our preliminary studies show that there is an effect for these events.

We plan to measure the triggering efficiency by observing the two main triggers that fire for muon events. The two lines are the muon pair trigger and the two track trigger For example, everytime that the two track trigger fires, we expect the muon pair line to trigger as well. We will plot an efficiency vs $\cos\theta$ as we did before. One trigger line will represent the predicted histogram as defined above, and the other trigger line will be the found histogram. We will repeat the study with the two trigger lines reversed. Once we have a histogram for the trigger efficiency, we will mulitply it by the histogram for the tracking efficiency and the result will be the overall efficiency for CLEO.

Once the overall efficiency is obtained, we will use it to plot the $mu^-\cos\theta$ distribution. By dividing the raw distribution by the overall efficiency, we will be correcting for both the tracking and triggering efficiences. The MC simulation should also be corrected soon. We will then proceed to compare the $\cos\theta$ distributions for the real data with those of the MC simulation. The MC simulation represents the SM predictions for $e^+e^- \to f\bar{f}$ collisions. In our case we have $e^+e^- \to \mu^+\mu^-$. In the case of muons, the angular distribution is of the form $1+\cos^2\theta$. If we detect deviation from this model at the level of 5σ, we will examine

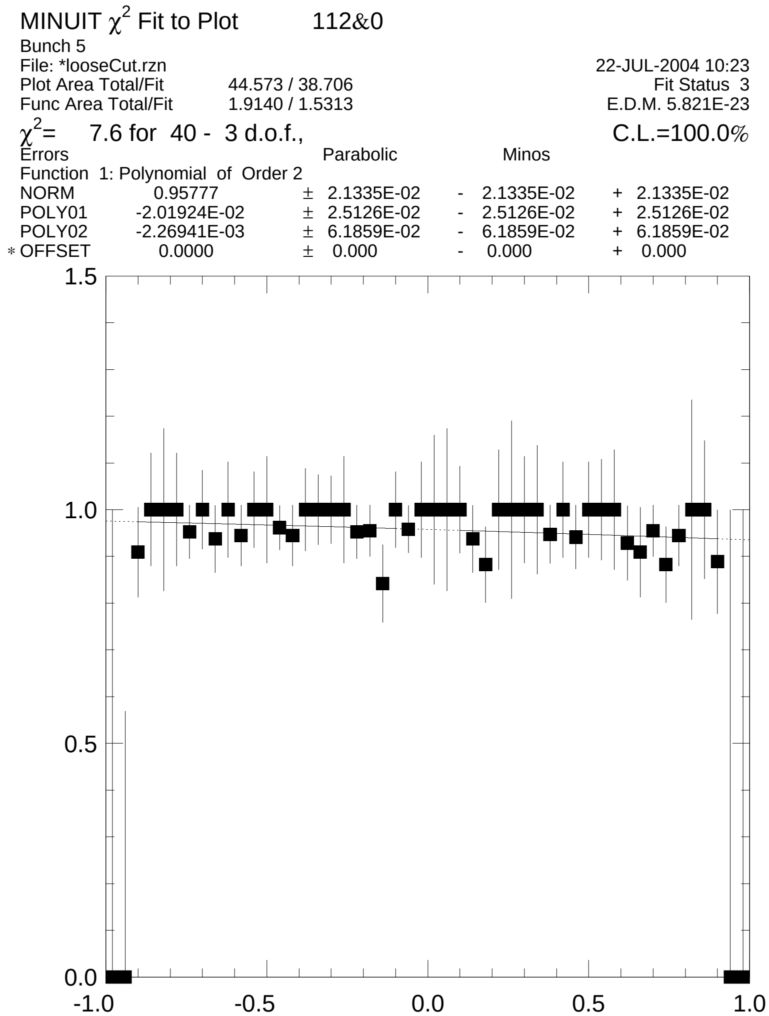

FIG. 7: The $\cos\theta$ efficiency for MC simulation of CLEOc data set 31, bunch 5

the possibility of having observed new physics.

VI. ACKNOWLEDGMENTS

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[1] Rizzo T., SLAC-PUB-9295, (2002)

[2] Mohammed Alfiky, "Search for Extra Dimensions and the CLEO Tracking Efficiency", Wayne State University, Masters Thesis 2004

[3] Anders Ryd, Presentation July 2004 CLEO Meeting