Performance Testing and Tuning of Kalman Track-Fitting for CLEO III

Daniela Silva

Department of Mathematics,

Wayne State University, Detroit, MI, 48202

Abstract

CLEO III will use a Kalman track fitter. Given is a detailed description of how the fitter works and what problems were found. Comparisons were made between the two different fitting packages, KalmanFilter and Klmn3, using Monte Carlo simulations. The purpose of this comparison was to determine KalmanFilter worked the best. Our tests indicated that the two fitters were comparable.

Introduction

The goal of this project was to test the Kalman fitters and identify any problems with the fits. A Kalman track fitter, using information about where in the detector a particle went, tells us the position and momentum of the particle at any point in time. The Kalman fitter reads a list of preliminary helix fits, which it then processes and stores as fit tracks. Klmn3 is a C++ wrapped version of the CLEO II fitting package klmn, which is written in Fortran. KalmanFilter is a new package completely written in C++, which makes it more easily extensible in the C++ software system so there are no language interfacing issues.

We use Monte Carlo simulation, which is randomly created tracks, to test the fitters because we know how the tracks were created. Monte Carlo simulates the detector response, including physical processes. Two of the processes that Kalman fitters must account for are multiple scattering and energy loss.

Track Parameters

A particle has position and momentum. We want the best momentum closest to the interaction point, where most of the tracks are created. Electrodynamics tells us that in a constant magnetic field the track will go around in circles tracing out a helix with a radius that is proportional to the transverse momentum (perpendicular to the field direction). If we measure the curvature and know the magnetic field, we can get the transverse momentum. Because the particle is going to follow a specific path we can represent the particle's trajectory at any point, which is enough information to give us the entire path. By expressing the tracks position and momentum at a suitably chosen point we can get rid of one of the six parameters, leaving us five (see Figure 1). The fitting packages we tested have a 5–parameter helix representation for tracks. Three of the parameters describe the particle momentum and two parameters give us its location in space. The five parameters are: C,ϕ_0, D, λ, and z_0.

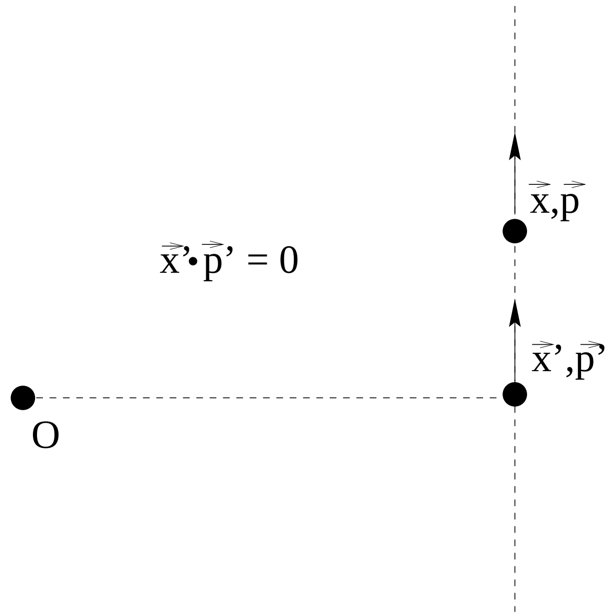


FIGURE 1. Track parameters.

C describes the curvature, where $\frac{1}{2c}$ equals the radius of curvature. ϕ_0 is the ϕ of the track momentum at the distance of closest approach to the z-axis. D is the signed impact parameter in the x-y plane. λ is cotθ, where θ is the polar angle of the momentum measured from the positive z axis. z_0 is the z of the track at the point of closest approach to the origin in the x-y plane. These parameters do not tell us the location in space of where the particle was produced, nor its decay. The particle's position is described as its point of closest approach to the reference point.

Processes That Affect the Fit

Processes that can alter the helix fit include multiple scattering and energy loss. Multiple Scattering is what happens when a charged particle collides with the atoms of some material, causing the particle's direction to change. The particle scatters in the two planes perpendicular to its path without losing energy (see Figure 2). The scatterings that occur in each plane are independent of one another.

As a particle passes through material it also loses energy, which affects its trajectory. Energy loss is the product of the interactions between a particle with the detector walls and gas molecules. During energy loss there is a gradual decrease in the particle's radius of curvature, causing the track to spiral more tightly. Figure 3 shows an example of energy loss.

Helix fitters are not equipped to handle multiple scattering, so those processes are accounted for in the Kalman fit, which can correct for multiple scattering. To minimize this

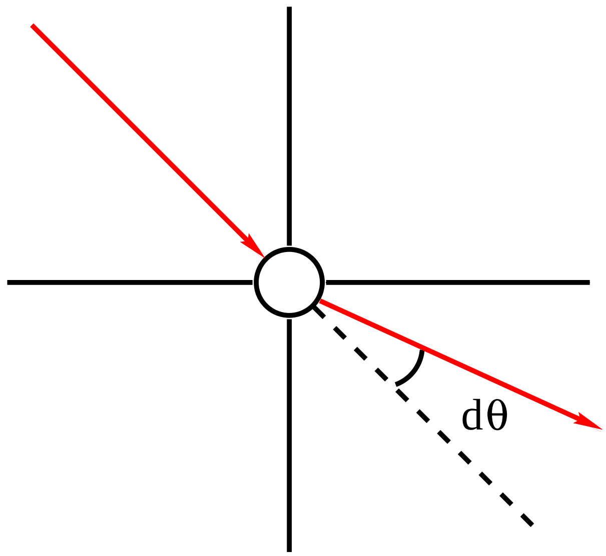


FIGURE 2. Illustration of multiple scattering.

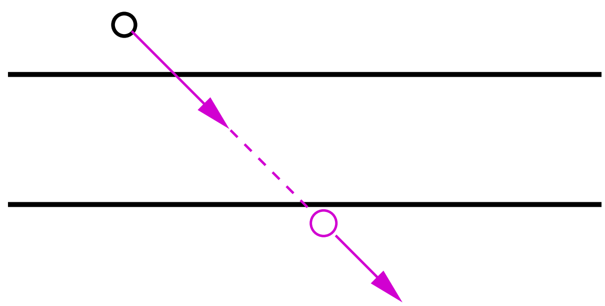
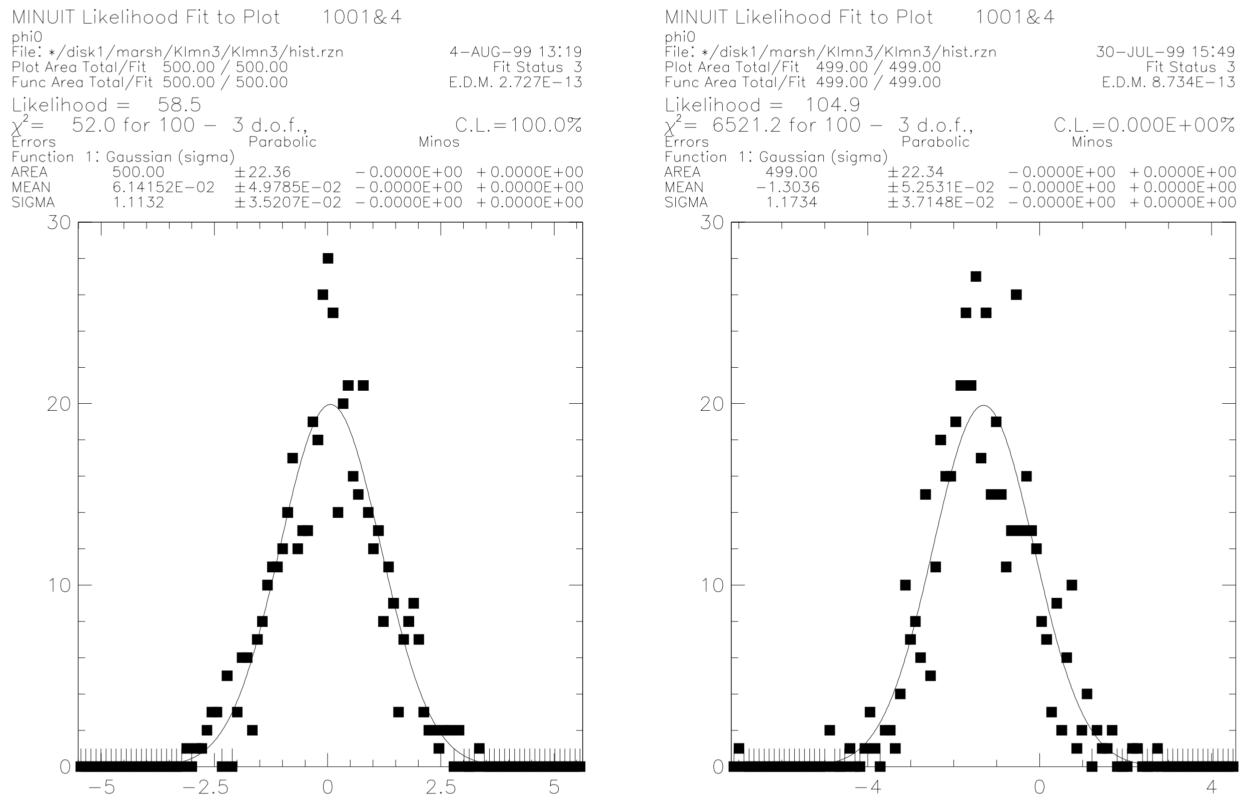


FIGURE 3. Illustration of energy loss.

effect we try to make the material as thin as possible so not too much scattering happens.

Results

For every normal measurement of a point, we get a gaussian. We define the error to be the width of this distribution. Our measurement will have some error, so we divide the measurement (minus the true value) by what we believe the error is. If our estimation of the error is correct then the width of our gaussian will be one. What we want to see in our pull distributions is the mean at zero and the sigma to be one. When the mean does not equal zero it means that we are getting the wrong central value. When sigma is not at one then the estimation of errors is incorrect. (Figure 4) are examples of pull distributions, (a) is a good distribution, where the mean is at zero and the sigma is close to one, (b) shows a systematic bias, where the gaussian is not centered at zero and our mean and sigma values are wrong as well.



Fast Monte Carlo　　　Full Monte Carlo

FIGURE 4. ϕ_0 pull distributions.

Using the Monte Carlo simulated data we were able to show that KalmanFilter performs about the same as Klmn3. Our tests also revealed problems with the Monte Carlo. The problem appears the same for both fitters. Tables 1 and 2 show how similarly the Monte Carlo acts with both fitters. Table 3 shows how the biases in the fitters differ.

To verify that there was a problem with the Monte Carlo we generated some data with FastMC and it gave us much better results. Though the fitters are comparable in performance, the KalmanFilter is preferred because it is more extensible.

TABLE 1. KalmanFilter

Helix Parameter	Mean	σ	$\frac{\text{Mean}}{\delta_{\text{Mean}}}$	$\frac{1-\sigma}{\delta_\sigma}$
C	-0.258	1.067	13.217	4.845
ϕ_0	0.791	1.124	38.446	8.501
d_0	-0.495	0.994	27.180	.476
$\cos\theta$	-0.175	1.051	9.059	3.749
z_0	0.202	1.026	10.773	1.956

TABLE 2. Klmn3

Helix Parameter	Mean	σ	$\frac{\text{Mean}}{\delta_{\text{Mean}}}$	$\frac{1-\sigma}{\delta_\sigma}$
C	-0.260	0.968	14.718	2.518
ϕ_0	0.730	0.961	41.519	3.111
d_0	-0.500	0.938	29.197	5.113
$\cos\theta$	-0.171	0.940	9.940	4.951
z_0	0.195	0.910	11.744	7.668

TABLE 3. Comparing KalmanFilter and Klmn3

Helix Parameter	Difference in Mean	Significance of Difference
C	0.00248	0.0263599169
ϕ_0	0.06062	0.0270746765
d_0	0.00536	0.0250155546
$\cos\theta$	0.00386	0.0258173663
z_0	0.0072	0.0250946689

Acknowledgments

I am pleased to acknowledge Professor Jon Thaler and Michael Marsh, of the University of Illinois, who proposed this Research Experience for Undergraduates project and guided me through the last ten weeks. It was through their support that I was able to succeed this summer at Cornell University. I would also like to thank Professors Bonvicini and Cinabro, of Wayne State University, for giving me this research opportunity. This work was supported by National Science Foundation REU grants PHY-9820306 and PHY-9731882 and research grant PHY-9809799.

Footnotes and References

1. P. Avery, CBX 91-72, Applied Fitting Theory I General Least Squares Theory, (1991).
2. P. Avery, CBX 92-45, Applied Fitting Theory IV Formulas for Track Fitting, (1992).
3. P. Billoir, Track Fitting With Multiple Scattering: A New Method(1984) .
4. R. Kutschke and A. Ryd, CBX 96-44, Performance of KalmanFilter (1996).