TRACKING/MUON/ANAL/CDFR/965
Version 1.0
July 31, 1989

CTC Tracking Studies with Cosmic Rays

Alain Gauthier
University of Illinois

1 Introduction

The CTC tracking plays an important role in almost every CDF analysis, it is therefore necessary to understand systematic effects associated with it. From the point of view of tracking, one single cosmic ray passing straight through the detector is reconstructed offline as two independent opposite-sign tracks, each with its own characteristics (P_T , ϕ,...). Since in reality, both tracks are the *same* particle, a perfect detector and reconstruction would give the same parameters for each track. One can look for possible systematic shifts in the data by comparing the parameters of the two reconstructed tracks.

This note presents such a study of CTC tracking using cosmic-ray data gathered during special runs in January and June 1989.

2 Cosmic-Ray Data-Taking

2.1 Triggering on Cosmic Rays

Cosmic-ray events are different from normal $\overline{P}P$ data in several ways. From the point of view of triggering, there were three main considerations when deciding what to use:

- Since this data is taken without beam in the Tevatron, the Beam-Beam Counters cannot be used as a Level 0 trigger.
- The rate of cosmic rays integrated over the whole detector is of order 100 kHz; it has to be reduced to a level that can be recorded on tape.
- For tracking study purposes, only cosmic rays passing in the vicinity of the beam pipe are useful and should be recorded to tape.

The solutions to these concerns were slightly different for the two running periods. A brief summary of the three trigger tables used to take cosmic-ray data is shown in tables 1–3; the last column of each table indicates the triggers required for an event to go to tape. The trigger rate for events out of Level 2 was about three per minute. Figure 1 shows the distribution of time interval between events written to tape.

2.1.1 January 1989 Data

Initially, the problems mentioned above were addressed with the following solutions. The Level 0 decision was a coincidence of the first two axial CTC superlayers, SL0 & SL2. It was necessary to require a Level 1 muon trigger to reduce the resulting large Level 2 input rate; the muon trigger threshold was set wide-open to 2 GeV . A Level 2 CFT track was also required; by design of the CFT, only radial tracks passing near the beam pipe can satisfy this trigger. The CFT trigger threshold was also set wide-open to P_T bin 0 (90% efficient at 3.0 GeV). The corresponding trigger table is called COSMIC_KADEL [1].

2.1.2 June 1989 Data

While in January, the only goal was the study of CTC tracking, the June data is also used to understand the trigger efficiency of the Central Muon Level 1 trigger [2]. Therefore, the Level 1 muon trigger was removed as a requirement for events to go to tape (the muon trigger data was still recorded). This was possible because a new CTC-CDT Level 0, which had been implemented for the last few weeks of the run, maintained an acceptable event rate. It required a triple-coincidence between the CTC superlayers SL0 & SL2 and with hits in two of the four layers of one side of the CDT. The Level 2 part remained unchanged. Since for both purposes of tracking and muon trigger studies, only higher P_T cosmic rays can be used reliably, only events with a 2.5 GeV track from the Level 3 "DF" tracking were written to tape [3].

Since two muon trigger threshold were used during the 1988–1989 run, two trigger tables were needed for muon trigger studies: COSMIC_CFT_1_CMU_3 and COSMIC_CFT_1_CMU_5 [1]. However, for the purposes of CTC tracking studies, they are identical and no distinction will be made here between data taken with either table.

2.2 Data Sample

The total sample of cosmic rays on tape consists of 19198 events. The list of run numbers and tapes containing the raw data is shown in table 4.

3 Tracking Cosmic Rays

The events were tracked with the latest tracking code available in the "DEVELOPMENT" area of CDF offline code on July 9, 1989. However, because cosmic rays are different from $\overline{P}P$ data for which the detector and analysis code were developed, they need a special treatment to get realistic tracks. The extra code necessary for this task was developed and provided to me by Richard Kadel [4].

3.1 Determination of T0

An important parameter for tracking is the event T0, which determines when in the CDF live time window the event occurred. It gives the CTC TDC start time from which each hit position is calculated. Because the cosmic rays can occur anywhere within this time window, it is necessary to determine T0 on an event-by-event basis. The central and wall hadron calorimeters are used to determine that T0 in the Analysis_Control module COZFLT. This module checks for consistent timing and energy from the information stored in the TOWE bank (obtained by running the module CALORIMETRY on the raw data). Only events which have *both* top and bottom TDC's are accepted. Moreover, if the energy deposited in the calorimeter is below 0.1 GeV , the event is rejected because the TDC timing for such hits is unreliable.

The summary of events satisfying these timing requirements is shown in table 6 under "COZFLT". Note that one expects more events to be lost in the June data because the CTC-CDT trigger has a larger solid angle acceptance than the muon trigger for cosmic rays that miss one side of the detector.

For the events with acceptable timing, the T0 was determined by taking the average time of the tower with the highest energy deposition (presumably where the cosmic ray actually passed) and correcting for the travel time from the calorimeter to the beam pipe (equation 1). For these events that also satisfied equation 2, the time difference between the upper and lower TDC is shown in figure 2.

$$\text{(1)} \qquad \mathrm{T0\ (ns)} = (\mathrm{MAX}(\mathrm{TDC}_{LO}) + \mathrm{MAX}(\mathrm{TDC}_{UP}))/2 - 10$$

4 Study of Cosmic-Ray Tracking

The choice of plots shown in the next sections resulted from discussions and suggestions from Peter Berge [5]. The reconstructed cosmic-ray data is located on the tapes listed in table 5. The track parameters were obtained from the data stored in the CTCS banks [6] on those tapes.

4.1 Track Selection

Since we want to compare the two tracks created by cosmic rays, only events which have two reconstructed 3D opposite-sign tracks (equation 2) are considered in the following study. The number of events accepted by this cut is listed in table 6 under "COSMIC_FLT CUT 1". Figures 3–6 show the quality of the fitted tracks in those events, as determined from the number of hits used and the residuals, for both axial and stereo views.

$$\text{(2)} \qquad \begin{aligned} \text{Number of 3D Tracks} &\equiv 2 \\ Q(1) &= -Q(2) \end{aligned}$$

The final comparison described in the next section is based only on events in which both tracks satisfy the conditions of equation 3. These cuts are also indicated on figures 3–6, and the number of events passing these cut is listed in table 6, under "COSMIC_FLT CUT 2". The error on the track parameters for the events passing that last cut are shown in figures 7–11, and their P_T distribution is shown in figure 12.

$$\text{(3)} \qquad \begin{aligned} \text{Axial Hits} &> 44 \\ \text{Axial Residuals} &< 300\mu m \\ \text{Stereo Hits} &\geq 15 \\ \text{Stereo Residuals} &< 300\mu m \end{aligned}$$

4.2 Comparing both Tracks of Cosmic Rays

For all remaining events, the quantity Δ_i (equation 4) is plotted in figures 13–17 for each one of the five parameters defining the CTC tracks (curvature, Cot(θ), ϕ, D0, and Z0).

$$\Delta_i = \frac{\alpha_i^+ - \alpha_i^-}{\sqrt{d\alpha_i^{+\,2} + d\alpha_i^{-\,2}}} \tag{4}$$

$$\text{where}: \quad \alpha_i = \text{Fitted track parameter, } i = 1,5$$

The choice of this equation is such that if there are no systematic shifts and the errors are well-understood, the distributions would have a mean of 0 and a sigma of 1.

5 Conclusion

There are a few points to notice about Figures 13–17. Only the curvature and ϕ distributions show an offset larger than the typical errors. Still, the latest tracking code shows a clear improvement from earlier versions, as can be seen in figure 18 which shows the same comparison for the curvature match in the January data, both with old and new tracking (the June data was not processed with the old tracking). The ϕ distribution (figure 15) shows the most deviation from the expected gaussian shape; all explanations I have at this time are only speculations.

I leave the exercise of further, more detailed, interpretation to the reader and to tracking experts. Any comments or questions are welcome and can be sent by VAXMail to FNALD::GAUTHIER.

References

[1] All trigger tables are in the area `ONLINE$UTILITY:[TRIGGER.PRODUCTION.TABLES]` on the B0 cluster.

[2] CDF Note **937**, *Efficiency of the Level 1 Central Muon Trigger.*

[3] In retrospect, this was unnecessary because the trigger rate was only three events per minute and looking at the online event display, some events that did not pass this requirement might have been used offline.

[4] R. Kadel, personal communication.

[5] P. Berge, personal communication.

[6] The CTCS bank is defined in the include file `C$TRK:DSCTCS.INC`.

Table 1: Trigger Table: COSMIC_KADEL

LEVEL	NAME	REQUIRED
0	CFT_L0_L2	Y
1	CENTRAL_MUON_2	Y
2	EXECUTE_MUON_CLUSTERING_oops	
	CENTRAL_MUON_3	Y
3	VERTEX_VTVERT_200	
	CTC_TRACK_3GEV	
	TRIGGER CMU_FILT_V4	

Table 2: Trigger Table: COSMIC_CFT_1_CMU_3

LEVEL	NAME	REQUIRED
0	CTC_SL0_CTC_SL2_CDT_2	Y
1	AUTOMATIC_ACCEPT	Y
	BBC_INTIME_50MILLIHZ	
	CENTRAL_MUON_3	
2	BBC_INTIME_PREREQ_V9	
	STIFF_TRACK	Y
3	FASTER_DFCTRK	
	STIFF_TRACK_2PT5	Y

Table 3: Trigger Table: COSMIC_CFT_1_CMU_5

LEVEL	NAME	REQUIRED
0	CTC_SL0_CTC_SL2_CDT_2	Y
1	AUTOMATIC_ACCEPT	Y
	BBC_INTIME_50MILLIHZ	
	CENTRAL_MUON_5	
2	BBC_INTIME_PREREQ_V9	
	STIFF_TRACK	Y
3	FASTER_DFCTRK	
	STIFF_TRACK_2PT5	Y

Table 4: Cosmic-Ray Raw Data Tapes

TRIGGER TABLE	TAPE	FILE NAME	DATE
COSMIC_KADEL	CD6193	R18805AA.RAW	Jan 25, 1989
COSMIC_KADEL	CD6194	R18814AA.RAW	Jan 26, 1989
COSMIC_KADEL	CD6262	R18839AA.RAW	Jan 28, 1989
COSMIC_KADEL	CD6467	R18983AA.RAW	Feb 6, 1989
COSMIC_CFT_1_CMU_3	CD9809	R20702AA.RAW	Jun 13, 1989
COSMIC_CFT_1_CMU_3	CD9810	R20702AB.RAW	Jun 14, 1989
COSMIC_CFT_1_CMU_5	CD9813	R20739AA.RAW	Jun 16, 1989
COSMIC_CFT_1_CMU_5	CD9814	R20739AB.RAW	Jun 17, 1989
COSMIC_CFT_1_CMU_3	CD9815	R20740AA.RAW	Jun 17, 1989

Table 5: Reconstructed Cosmic-Ray Data Tapes

TRIGGER TABLE	TAPE	FILE NAME
COSMIC_KADEL	CF4407	COSMIC_KADEL.CTC (old tracking)
	CF5466	KADEL_CMU2.CTC (new tracking)
COSMIC_CFT_1_CMU_3	CF5464	R20702_CMU3.CTC
		R20740_CMU3.CTC
COSMIC_CFT_1_CMU_5	CF5467	R20739_CMU5.CTC

Table 6: Cosmic-Ray Events

TRIGGER TABLE	TRIGGERS	ON TAPE	OFFLINE FILTERS		
			COZFLT	COSMIC_FLT	
				CUT 1	CUT 2
COSMIC_KADEL	6716	5551	1976	1759	1057
COSMIC_CFT_1_CMU_3 COSMIC_CFT_1_CMU_5	37768	13647	4414	3952	2392

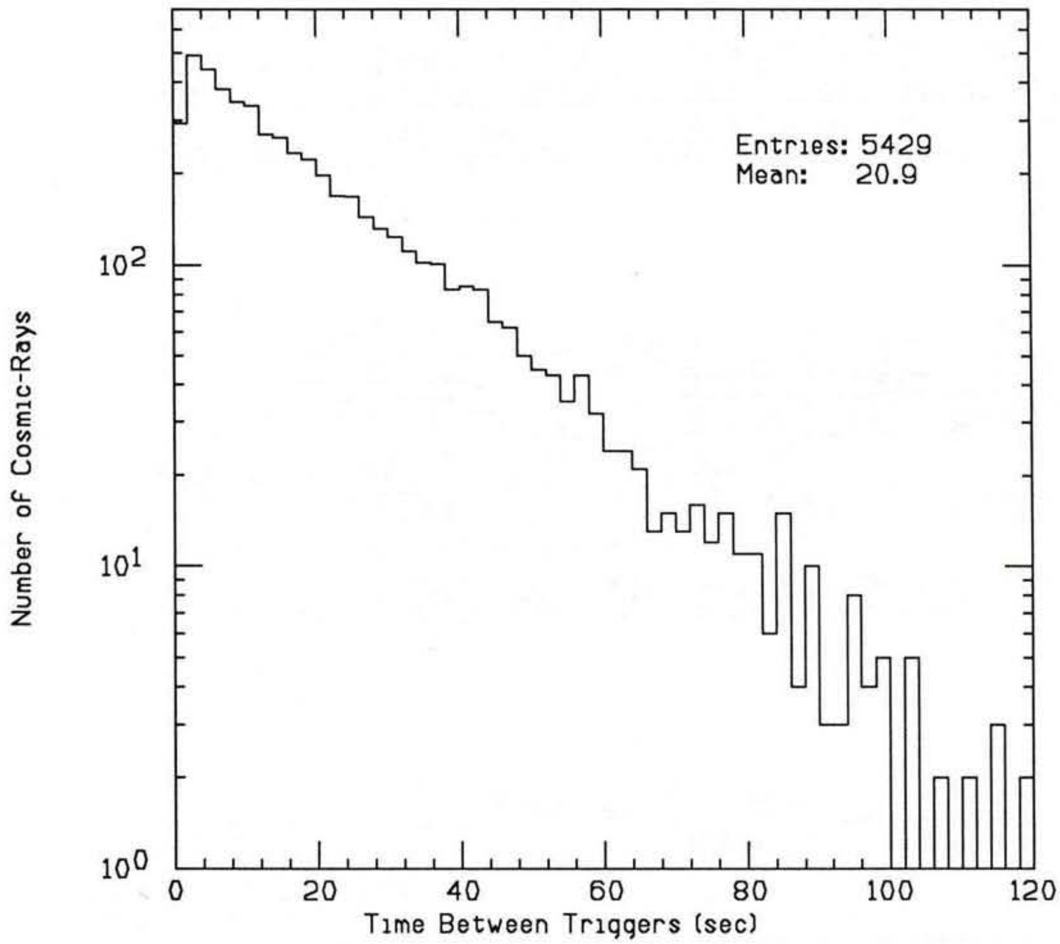

Figure 1: Distribution of time interval between cosmic-ray events on the raw data tapes. The plot here shows only the data from the January run.

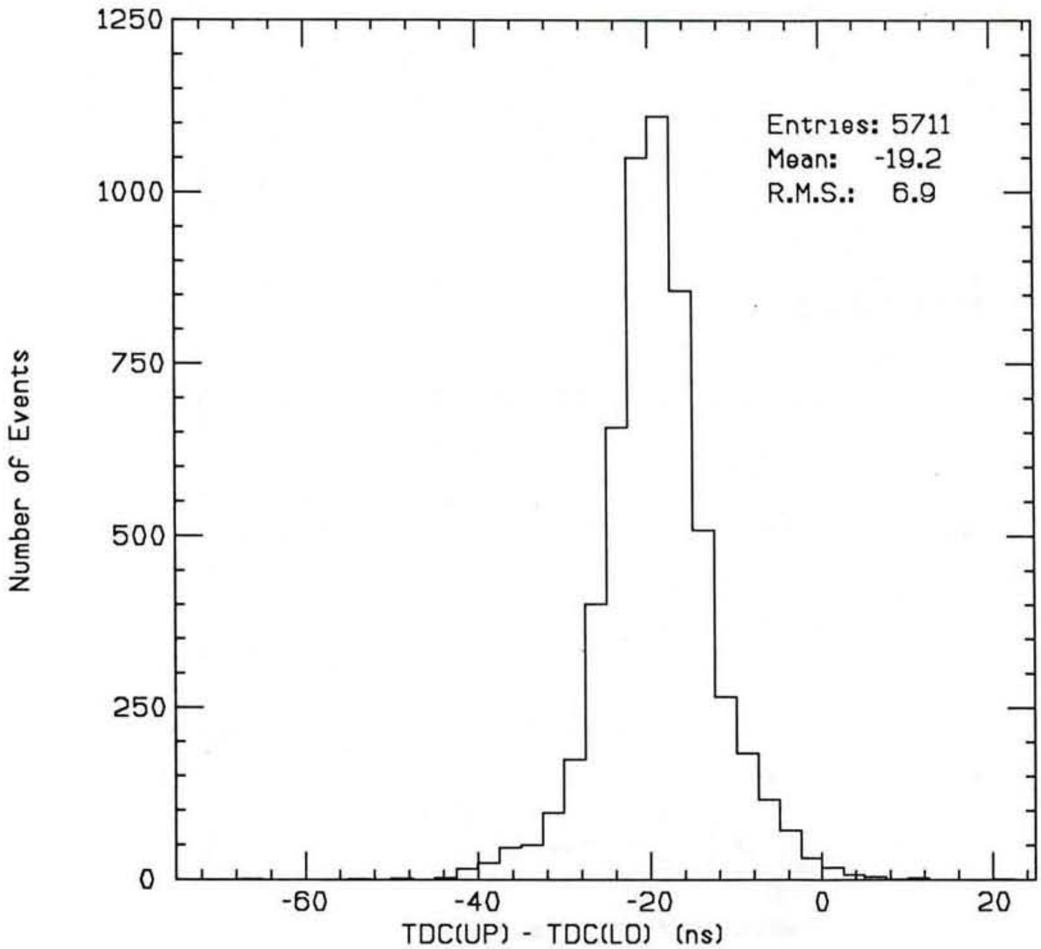

Figure 2: Raw distribution of the time difference between the top and bottom hadron TDC times for cosmic rays in events satisfying equation 2.

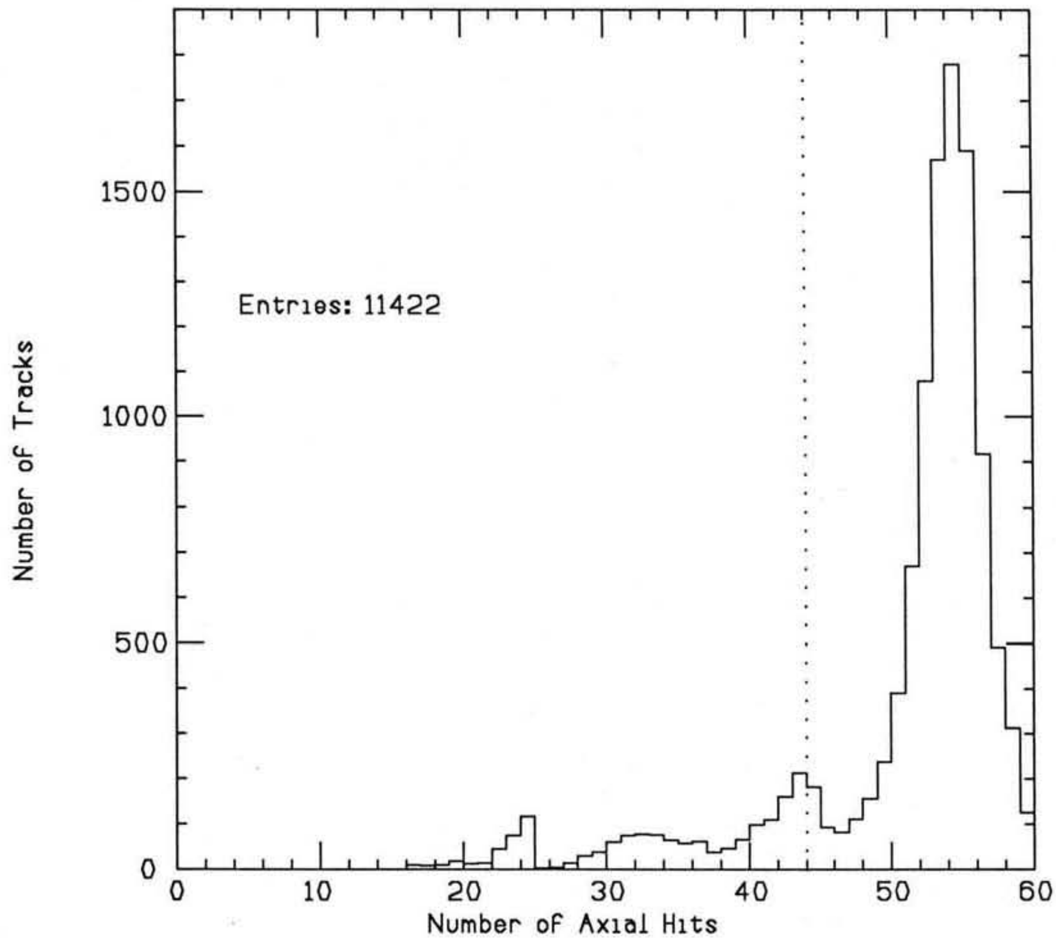

Figure 3: Number of axial hits for all cosmic-ray tracks in events satisfying equation 2. The dashed line shows the cut of equation 3.

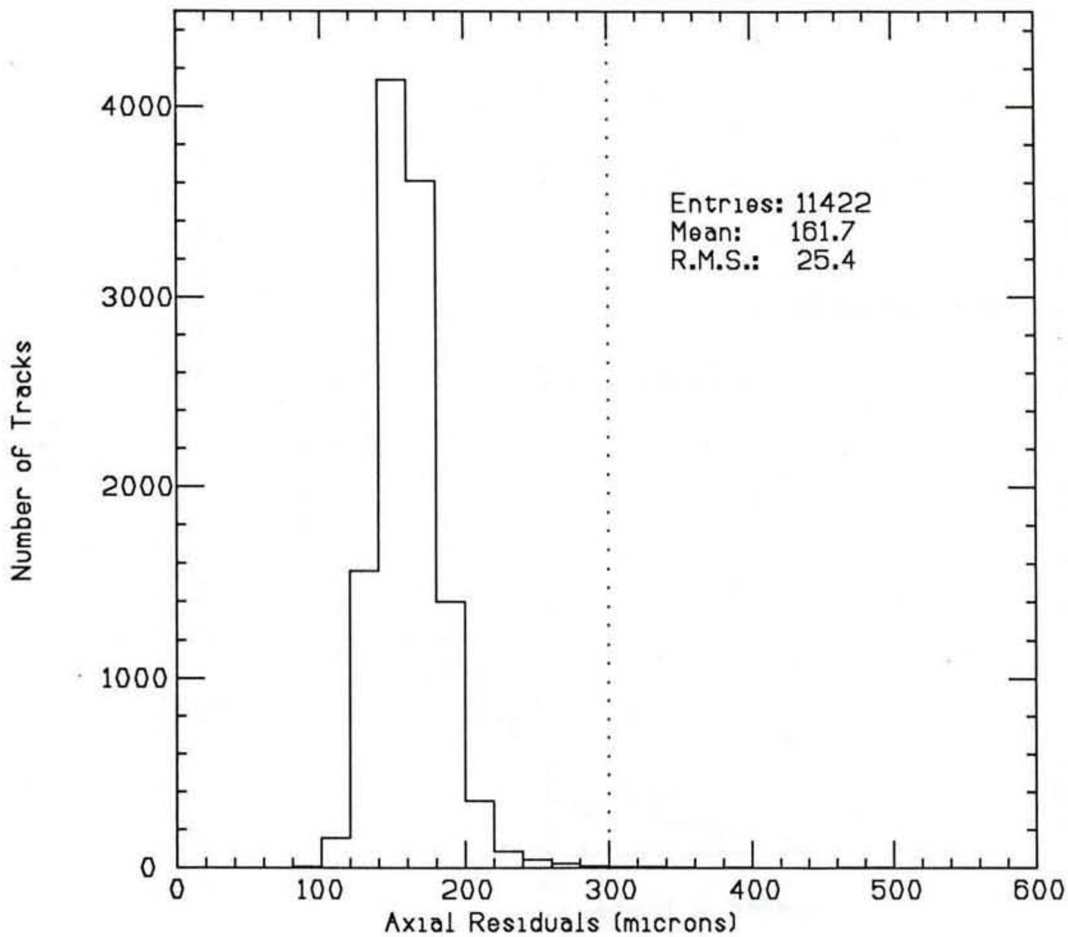

Figure 4: Axial residuals for all cosmic-ray tracks in events satisfying equation 2. The dashed line shows the cut of equation 3.

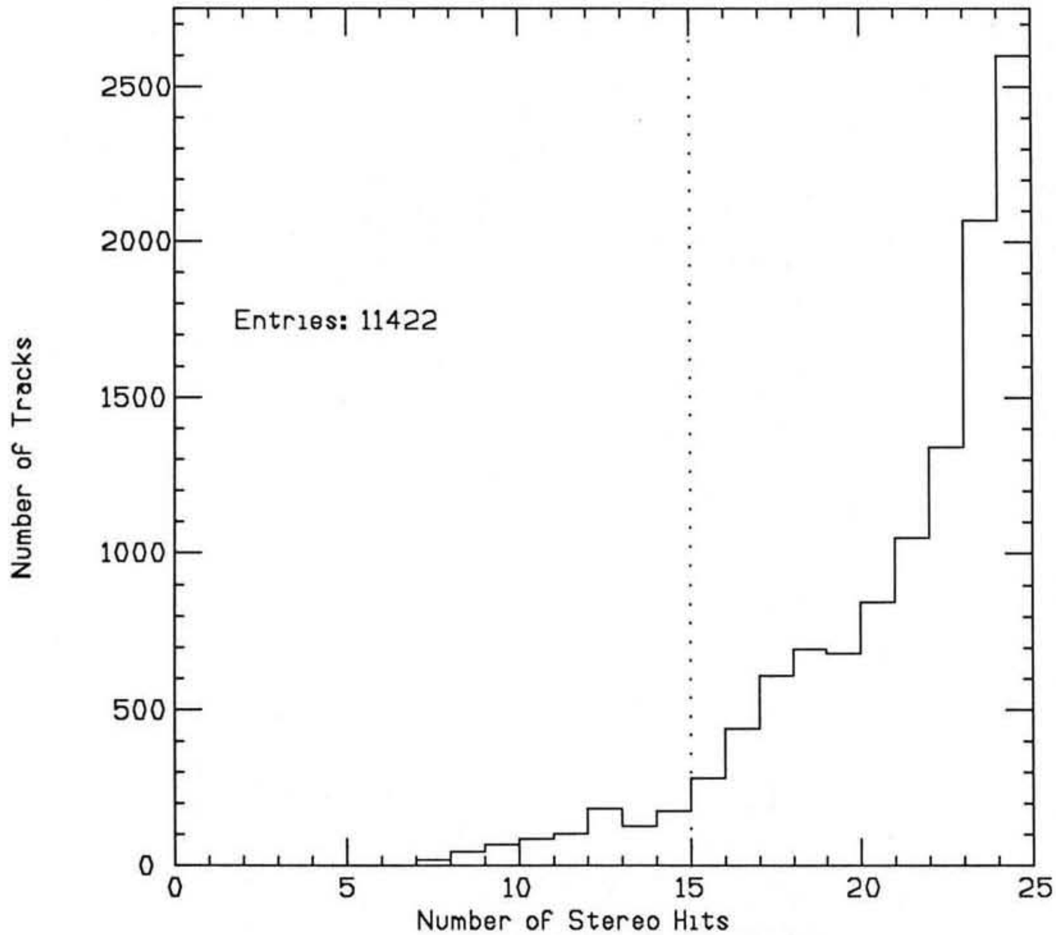

Figure 5: Number of stereo hits for all cosmic-ray tracks in events satisfying equation 2. The dashed line shows the cut of equation 3.

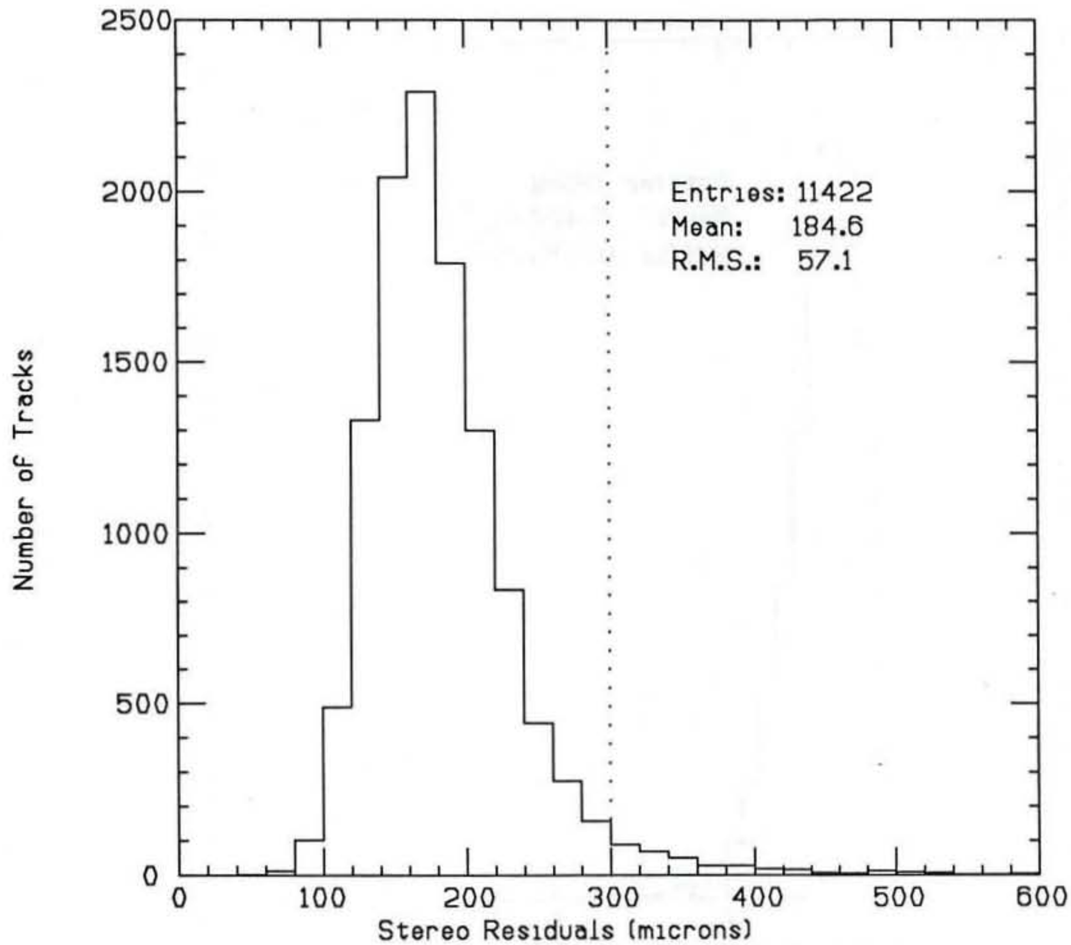

Figure 6: Stereo residuals for all cosmic-ray tracks in events satisfying equation 2. The dashed line shows the cut of equation 3.

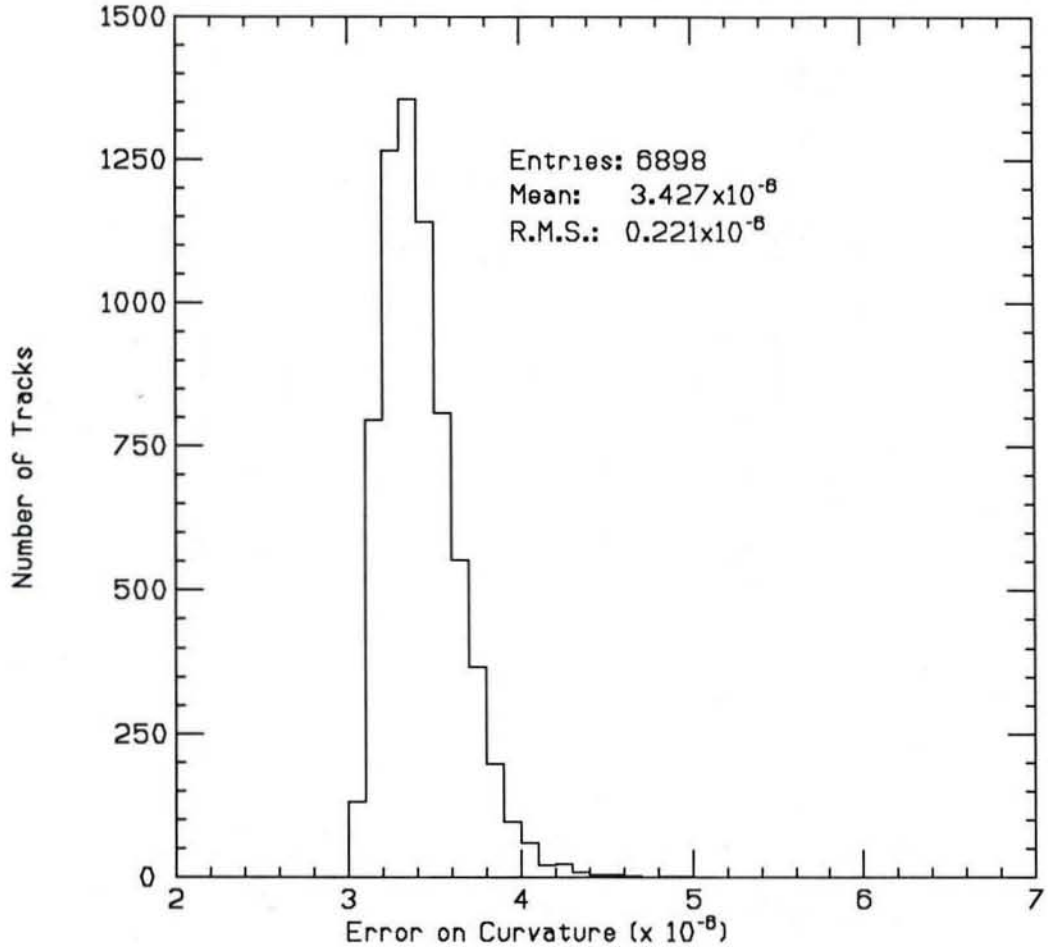

Figure 7: Error on curvature for cosmic-ray tracks in events satisfying equations 2 and 3.

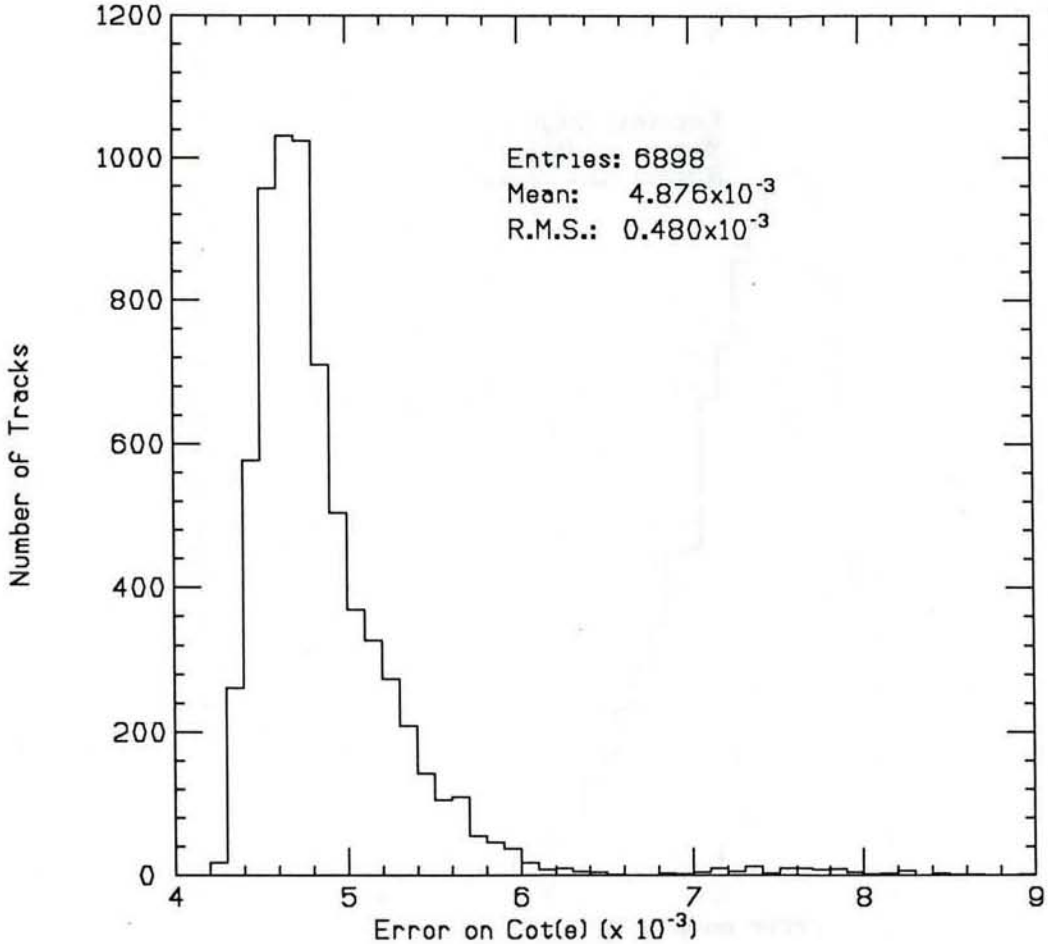

Figure 8: Error on Cot(θ) for cosmic-ray tracks in events satisfying equations 2 and 3.

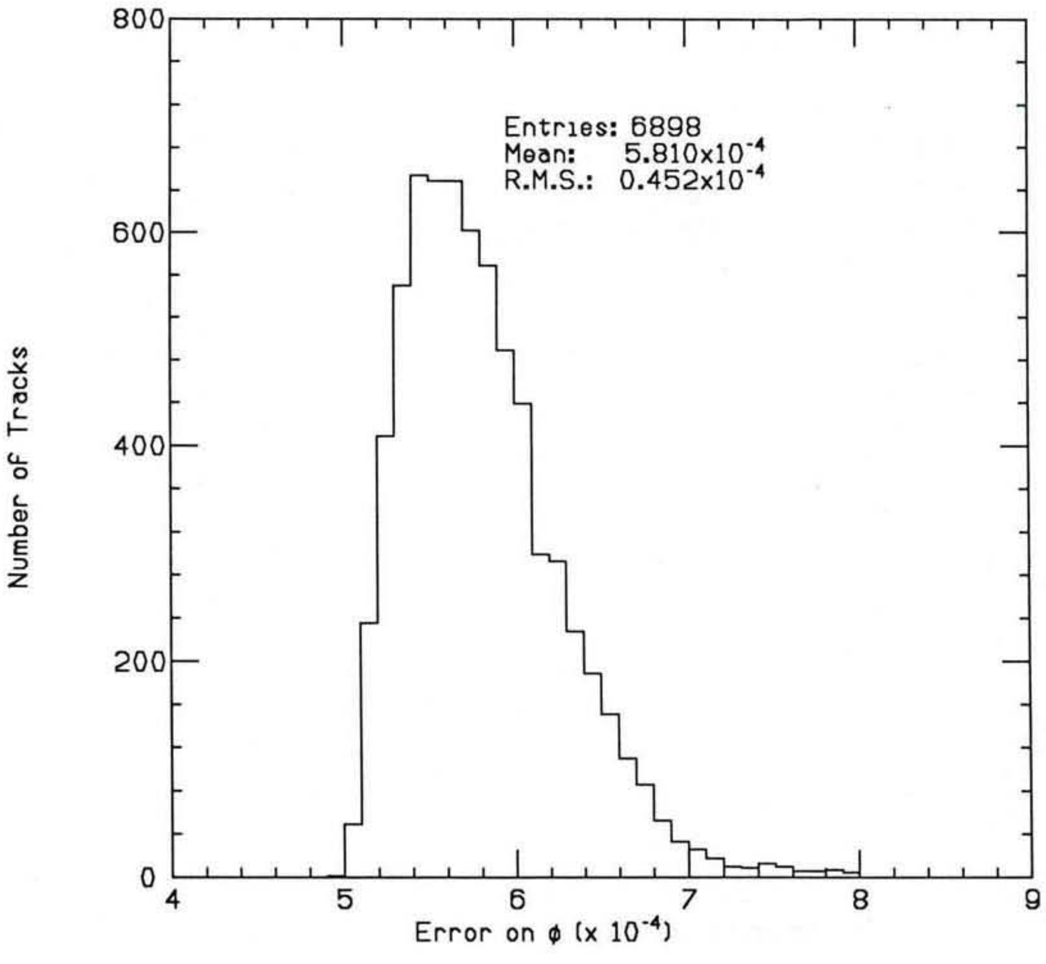

Figure 9: Error on ϕ for cosmic-ray tracks in events satisfying equations 2 and 3.

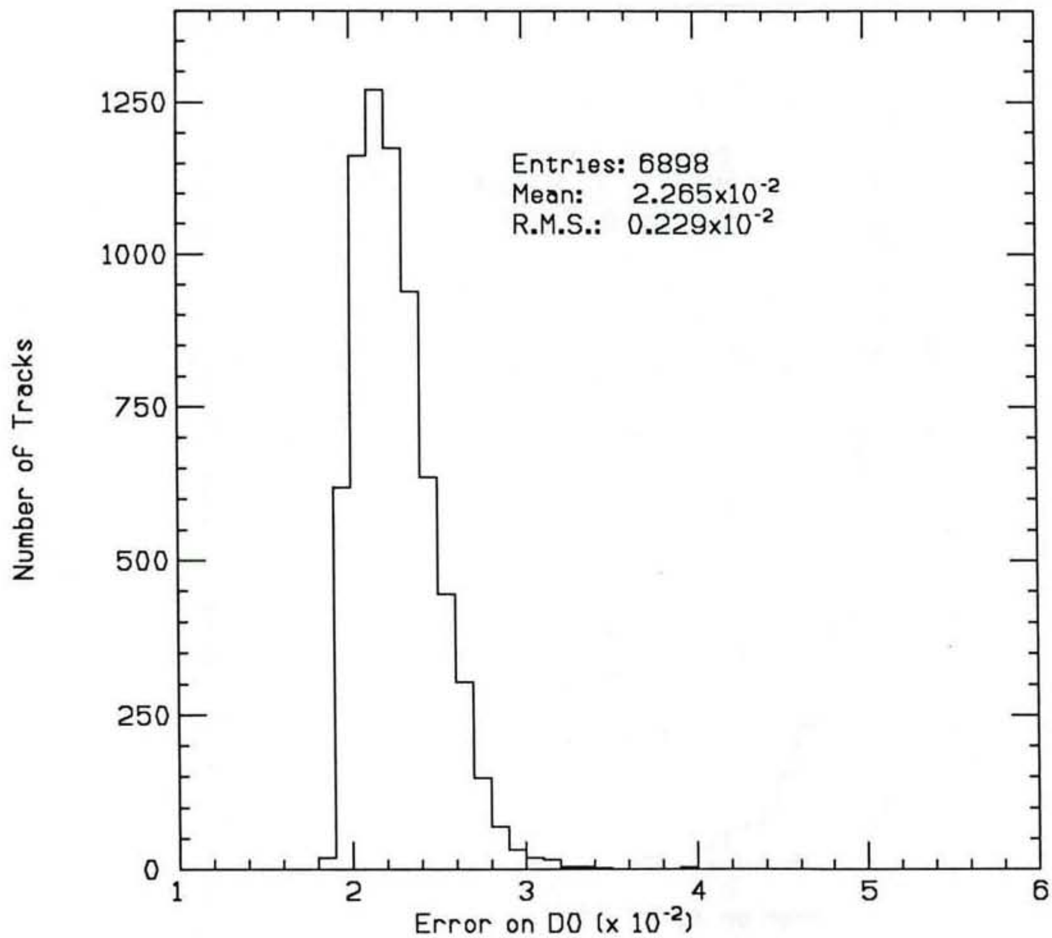

Figure 10: Error on D0 for cosmic-ray tracks in events satisfying equations 2 and 3.

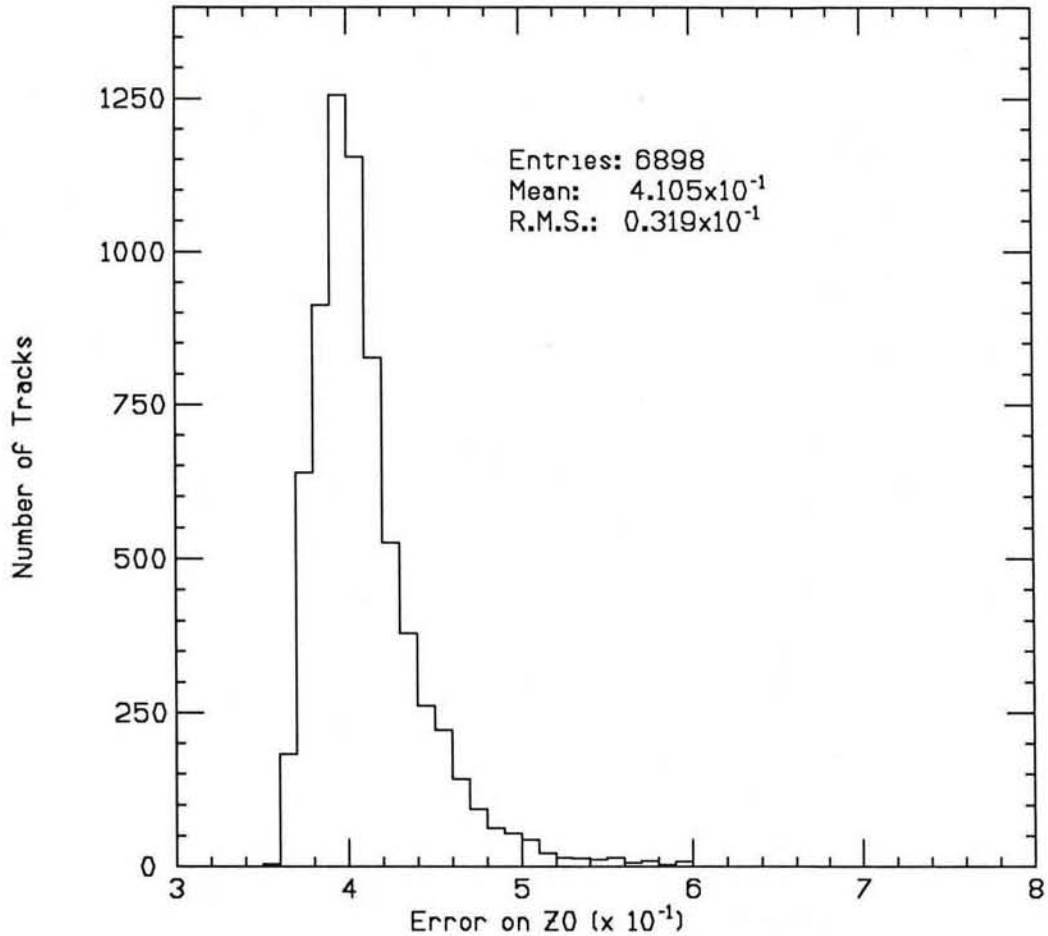

Figure 11: Error on Z0 for cosmic-ray tracks in events satisfying equations 2 and 3.

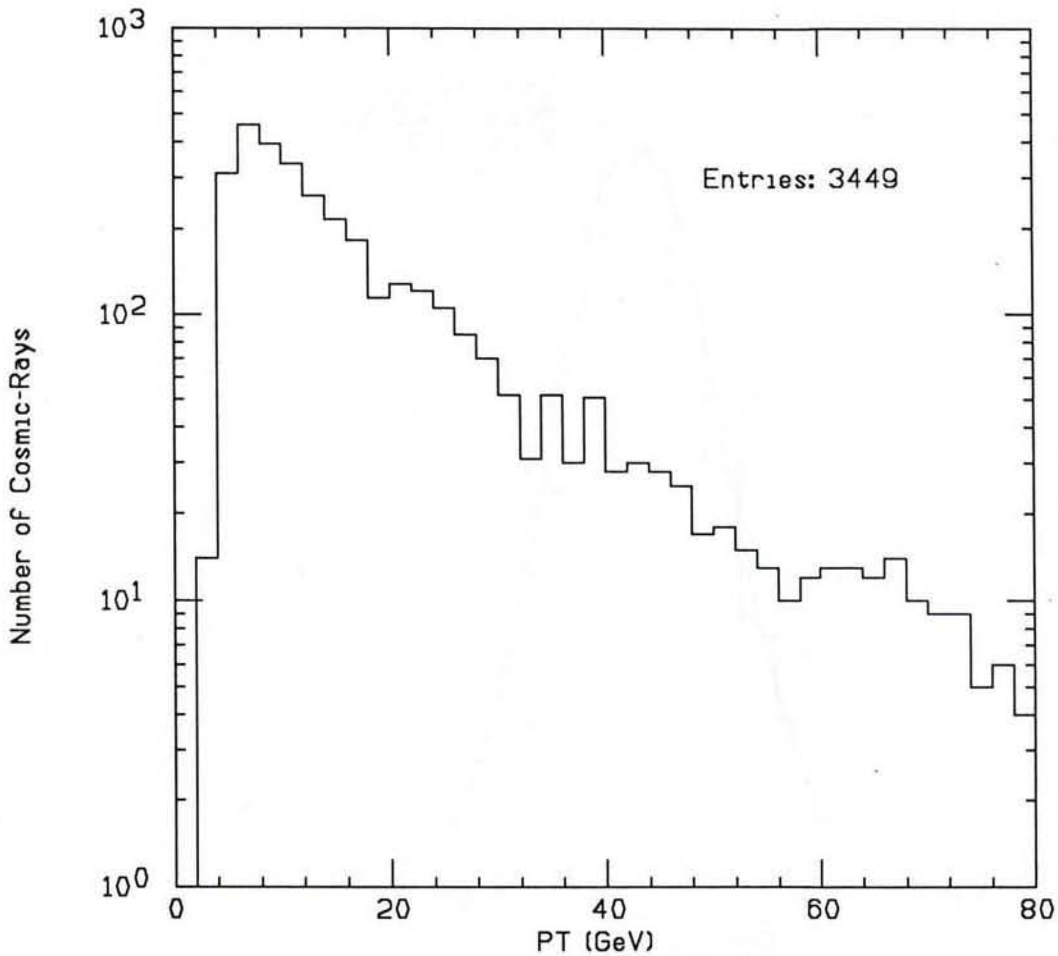

Figure 12: Transverse momentum for cosmic-ray tracks satisfying equations 2 and 3. There is only one entry per event, the average P_T of the two tracks is entered in this plot.

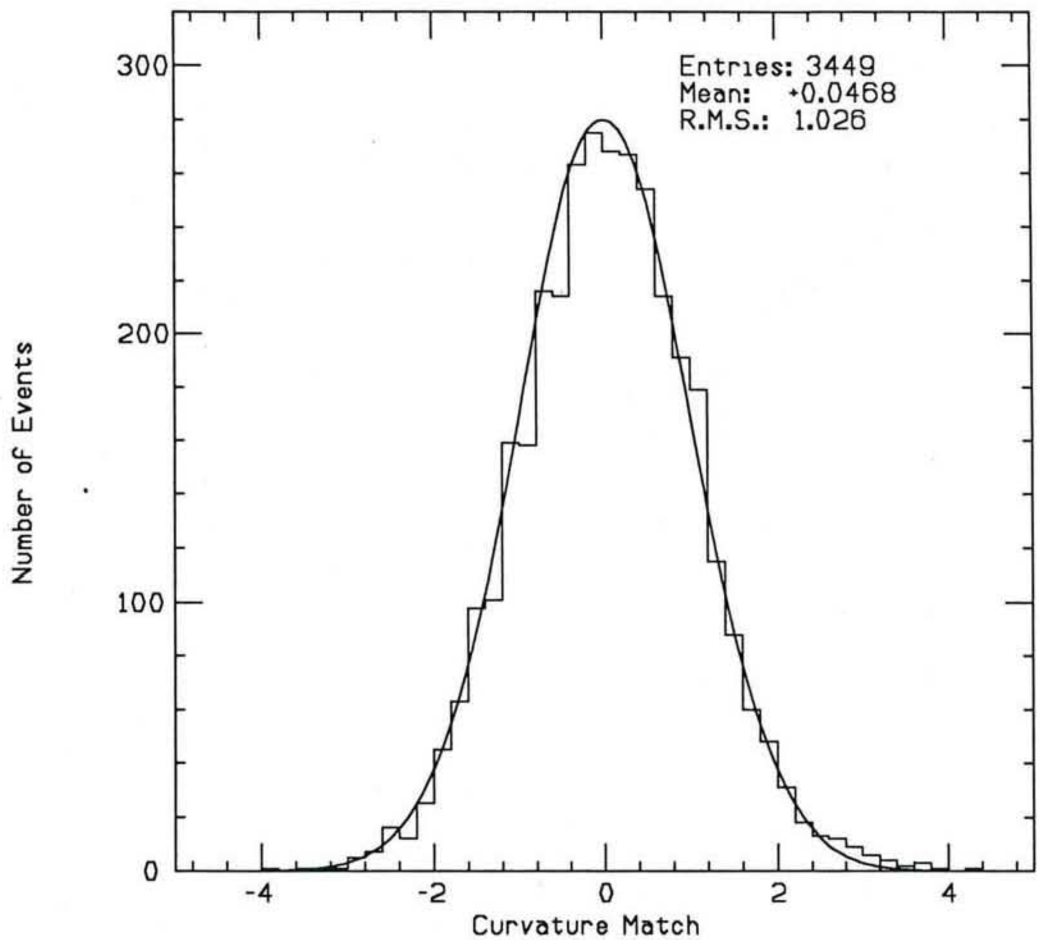

Figure 13: Curvature match between the two tracks in cosmic-ray events. The curve is a gaussian of mean 0 and sigma 1, normalized to 3449 entries.

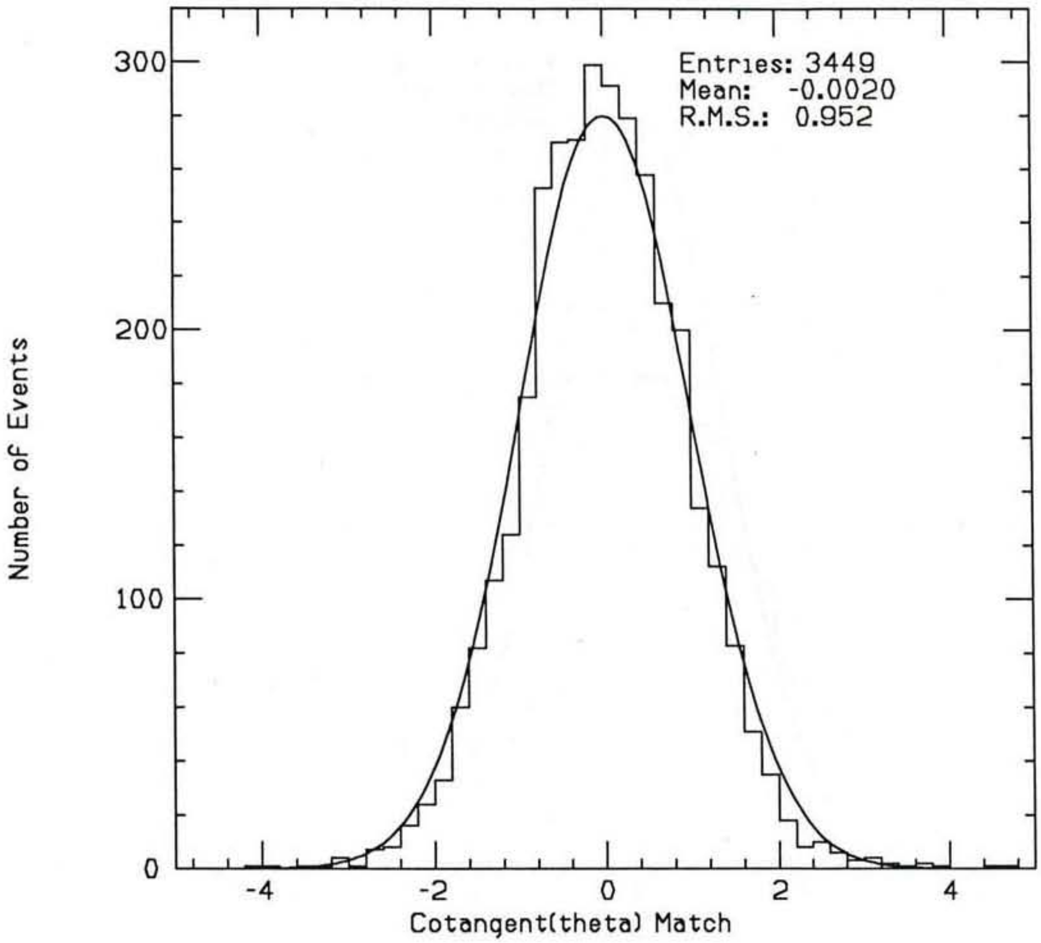

Figure 14: Cot(θ) match between the two tracks in cosmic-ray events. The curve is a gaussian of mean 0 and sigma 1, normalized to 3449 entries.

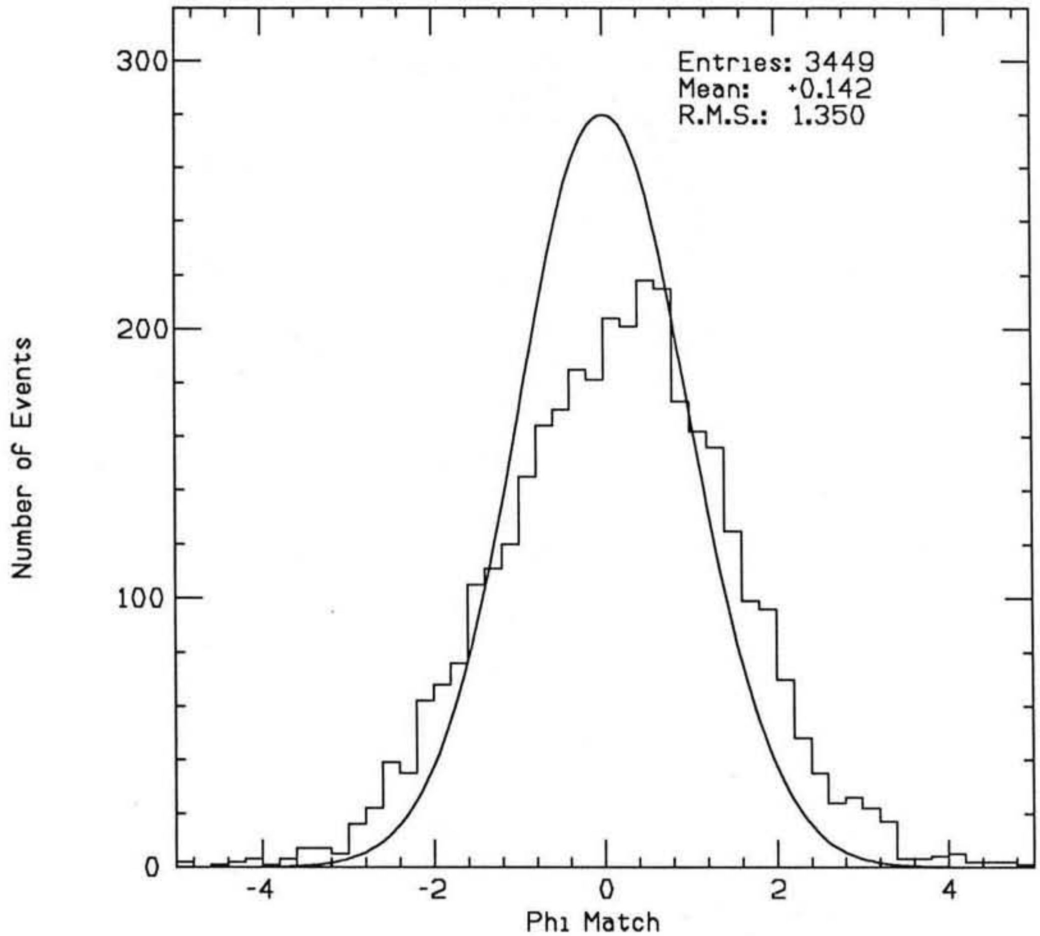

Figure 15: ϕ match between the two tracks in cosmic-ray events. The curve is a gaussian of mean 0 and sigma 1, normalized to 3449 entries.

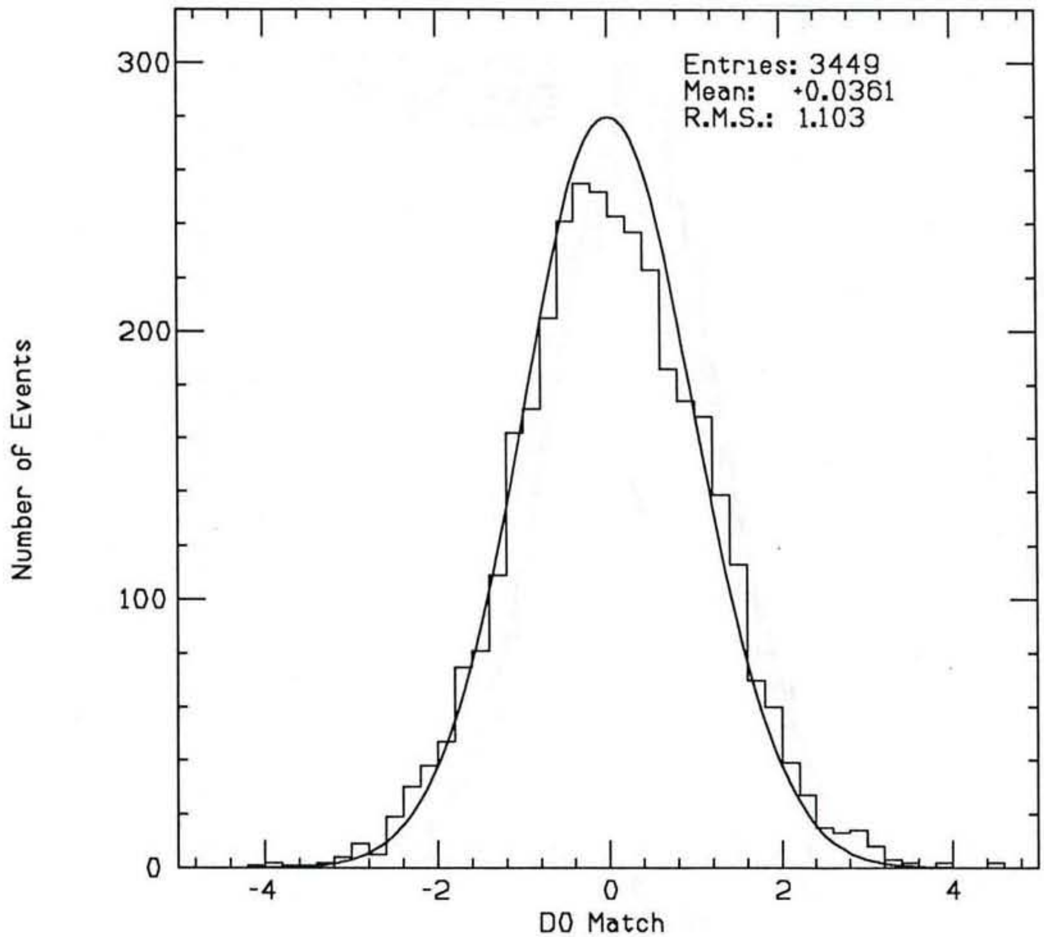

Figure 16: D0 match between the two tracks in cosmic-ray events. The curve is a gaussian of mean 0 and sigma 1, normalized to 3449 entries.

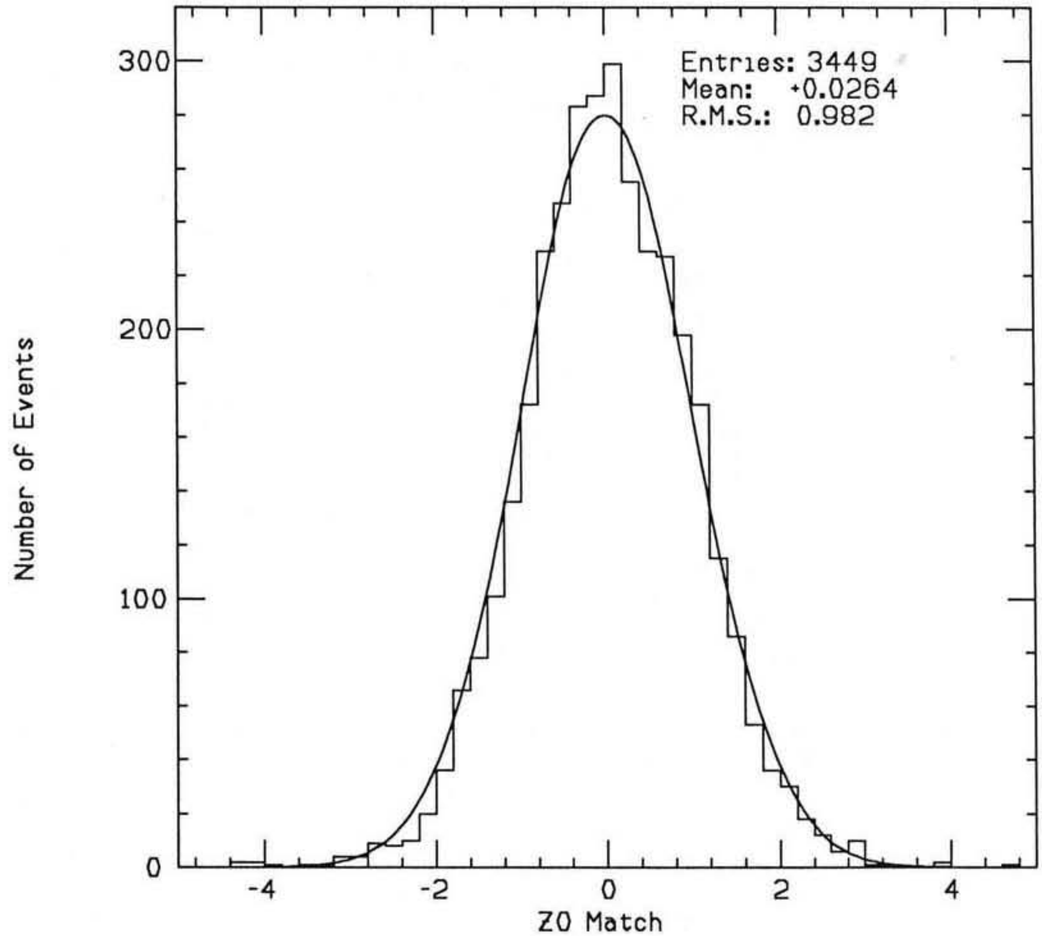

Figure 17: Z0 match between the two tracks in cosmic-ray events. The curve is a gaussian of mean 0 and sigma 1, normalized to 3449 entries.

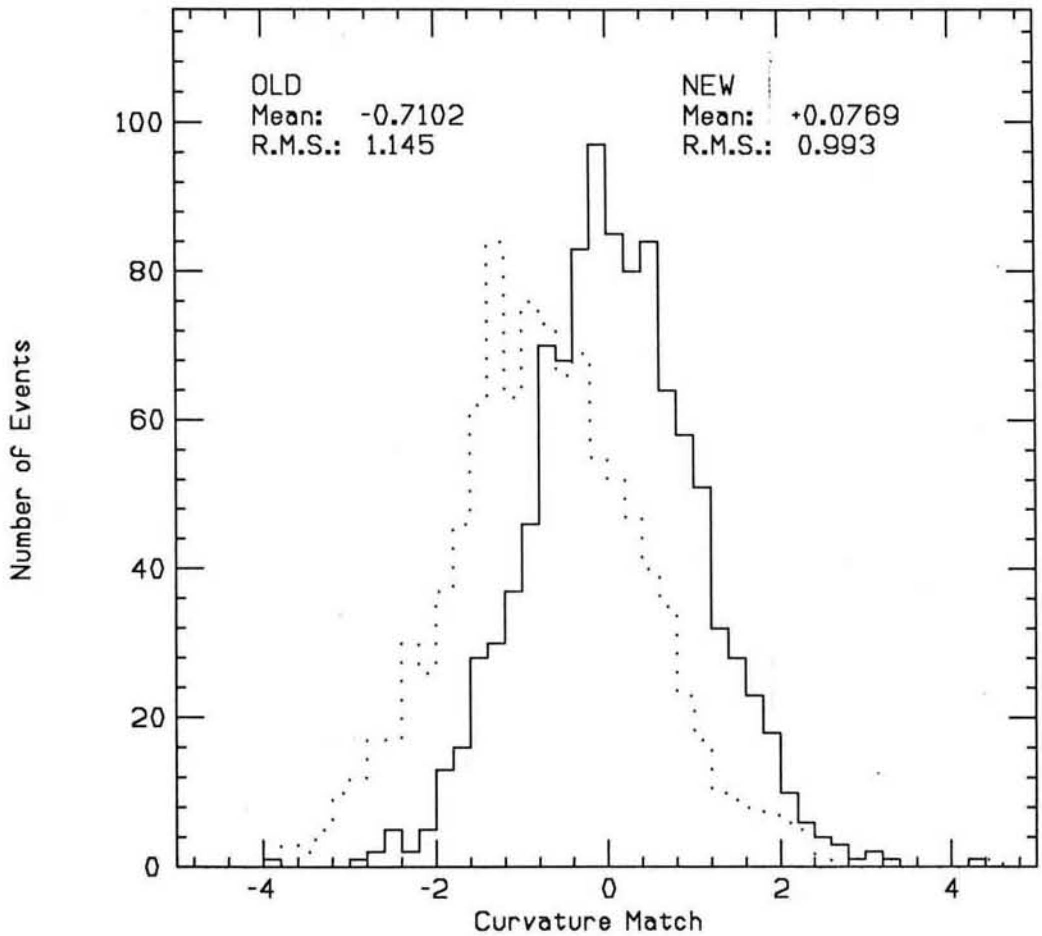

Figure 18: Curvature match between the two tracks in cosmic-ray events for the January data. The full histogram shows the results from the latest tracking (July 9, 1989) while the dashed one is for an older version (March 1989).