Event Parameter Analysis Of Candidate Events

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1.0 Introduction

A small set of easily measured parameters can be used to estimate the probability of a single event coming from a sample distribution generated from Monte Carlo simulation. If 5 parameters are used to characterize event, a probability density function (pdf) for that type of event can be approximated by a normalized 5 dimensional histogram of events. Using the measured parameters for an candidate event, the probability of the event coming from a specific Monte Carlo distribution can be found by finding the fraction of simulated events that have a combination of parameters which are less likely than does the candidate event.

Monte Carlo generated distributions can be made for both signal and background events. Relative probabilities for a measured event being signal-like or background-like can then be estimated. Several types of background events are considered

1.1 Application

This method of analysis will be used only on specific candidate events: those with a track topology that mimics a tau neutrino charged current interaction and subsequent tau decay through a single charged mode. The criteria of such events are:

1. No track from the primary vertex is identified as an electron or muon.
2. One track from the primary has an identified kink of more than 5 mrad.
3. The event triggers the spectrometer.

1.2 Background event types

Two types of events satisfy the first criteria for a tau-like topology: *neutral current*, in which there is no charged lepton to identify and c*harged current events in which the charged lepton cannot be identified*. For muon neutrino charged current events the inability to identify the resulting muon is determined by the acceptance of the MID system: only events whose muon misses the MID proportional tubes are considered. For electron neutrino charged current events the inability to identify the electron is determined by the radiation length of the emulsion stacks it traverses. If the electron's path is such that it does not travel through 2 radiation lengths of material before it exits the emulsion stacks it is considered unidentifiable. This includes all interactions in bulk module B4.

The second criteria for a tau-like topology is satisfied by events in which one of the particles from the primary decays through a mode involving only *one charged daughter* and by events where one of the particles from the primary undergoes a significant *scatter.* The only decay type of events included in this analysis are charged current interactions which produce charm particles: D, D_s, and $\Lambda_{c.}$

Since the relative flux of prompt and non-prompt muon neutrinos has not yet been determined, background muon neutrino interactions from both sources are studied independently. Normalization to the proper of prompt and non-prompt muon fluxes can be carried out later.

There are a total of 9 background types considered:

1. **CC Charm decay events from ν_e**
2. **CC Charm decay events from prompt ν_μ**
3. **CC Charm decay events from non-prompt ν_μ**
4. **CC scatter events from ν_e**
5. **NC scatter events from ν_e**
6. **CC scatter events from prompt ν_μ**
7. **NC scatter events from prompt ν_μ**
8. **CC scatter events from non-prompt ν_μ**
9. **NC scatter events from non-prompt ν_μ**

2.0 Parameters

The 5 parameters used in this analysis are as follows;

Polar Angle - The difference between the normalized unit momentum vector (transverse to the neutrino direction) of the primary track with the kink and the vector sum of the unit transverse momenta of all other tracks from the primary.

Lepton Angle- The angle between the primary track with kink and the incoming neutrino direction.

Decay Length - The distance between the primary vertex and the kink. For scatter background events this is the distance between scatter centers as each track may have more than one scatter.

Post-Kink Momentum- The momentum of track from the kink.

Kink Angle- The magnitude of the kink.

3.0 Distribution of simulated events

The standard E872 Monte Carlo is used to generate and interact neutrinos for sample distributions. The routines used to propagate the particle resulting from the neutrino interaction are modified slightly to facilitate the recording of tracks in the emulsion stacks. An analysis routine uses this recorded track information to calculate and output the event parameters to a file. The standard E872 Monte Carlo has no provision for propagating and decaying charmed particles: these are added. Only the period 4 geometry is used.

3.1 Monte Carlo

The first modification of the standard E872 Monte Carlo a means of recording the position and direction of all charged particles as they travel through the emulsion stacks. The GEANT geometry files of the emulsion modules are complete and include the plastic bases on which the emulsion sits. These plastic sheet are set as sensitive planes for the event propagation. As charged particles enter or exit the plastic sheets the track position and direction are recorded as segments. The true Monte Carlo position and direction are used. These tracks are recorded for up to a distance of 2.0 cm away from the primary vertex. The event is then propagated through the rest of the spectrometer as usual to check for trigger, muon ID etc.

The second modification of the standard E872 Monte Carlo is the addition of charmed particles (D, D_s, and Λ_c) to the GEANT store of trackible particle. The event generator LEPTO produces these particles in charged current interactions but GEANT as used in the standard E872 Monte Carlo does not recognize them and they are not propagated. Since only single charged decay modes are studied, when defining these particles for GEANT only single charged decay modes are included. This forces a single charged decay and allows for more efficient production of useful simulated events. A correction factor (the fraction of single charged decays) is easily applied to the entire generated sample.

The particle properties of the charm particles introduced to GEANT are found in table 1.

TABLE 1. Charged Charm particles properties included in event parameter study

	D	D_s	Λ_c
Mass	1869 GeV	1968 GeV	2284
Lifetime	1.06×10^{-12} sec.	$.467 \times 10^{-12}$ sec.	$.206 \times 10^{-12}$ sec.

TABLE 1. Charged Charm particles properties included in event parameter study

	D		D_s		Λ_c	
Decay modes (fraction)	$K^0 e \nu_e$	.069	K^0K^+	.036	$p\ K^0$	.023
	$K^0 \mu \nu_\mu$	.070	$K^0 K^0 \pi^+$	.043	$p\ K^0\ \pi^0$	.033
	$K^0 K^0 \pi^+$	.020	$K^0 \pi^+$	.008	$\Lambda\ \eta\ \pi^0$	.036
	$K^0 \pi^+$	.027	$\tau \nu_\tau$	.070	$\Sigma \pi^0 \pi^+$	.069
	$K^0 \pi^+\pi^0$	.097			$\Sigma e \nu_e$	.021
	$K^0K^0K^+$	.018			$\Sigma \mu \nu_\mu$	.020

The GEANT simulation allows for only 6 decay mode to be specified. In the case of the Λ_c, the six decay modes used in the simulation are the 6 most probable single charged decays and represent 77% of the single charge decay modes.

Calculation of the event parameters uses the recorded track information and the true Monte Carlo vertex. Calculation of the *polar angle* and *lepton* angle use only the first recorded segments of the relevant track. The *decay length* is calculated using the true vertex position and the point of intersection of the last pre-kink segment and the first post-kink segment of the kinked track. The *kink* angle is the angle between the last pre-kink segment first post-kink segment. The *post-kink momentum* used is the true Monte Carlo momentum of the post kink track.

The output of the Monte Carlo contains other event information besides the 5 parameters described above. Included in the file are: the assigned *weight* of the event, the *number of charged tracks* from the primary, the *GEANT code* of the particle producing the kinked track, the *trigger* type, a code indicating the *decay mode* (if the event is a charm decay), a record of the *neutrino type*, the GEANT *material code* for the material in which the interaction occurred, the interacted *neutrino energy* and the interaction *z position*.

3.2 5 Parameter distributions

The generated Monte Carlo data are used to fill 5 dimensional histograms which in the limit of large statistics approach probability density functions. In regions of the histogram where statistical fluctuations of the bin population are not significant define the useful regions of the histogram as an approximation. The number of generated events needed to fill a 5 dimensional histogram with Z bins in each dimension increases with Z as Z^5. The greater Z the greater, the greater the resolving power of the histogram but at a cost in computing time. For this analysis 7 bins in each dimension are used, with 500K -1.4M events of each background type resulting in histograms with populations adequate for estimating to ~5% level.

The bin divisions for each parameter are set individually and are not equal. Individual distributions of each of the parameters are used to determine the bin limits. The distributions of the parameters can be seen in figures 1-10. For all parameters in all background types the distributions show one peak: a *single* most probable value for that parameter.

Once the bin limits are set the 5 - dimensional histogram is filled with the weighted values of the entire set of simulated events of that type.

Since each individual parameter distribution has only one maximum the 5 dimensional binned distribution will have one maximum. This represent the most probable combination of parameters. Bins adjacent to the most probable bin will be more probable (higher probability density) than the bins further away. Bins with equal weighted population represent equally probable combinations of parameters.

For any given bin the weighed population of all other bins that have *lower probability* density (lower weighted population) is summed. The ratio of this sum to the weight of the entire simulated event sample represents the fraction of simulated events that have a combination of parameters less likely than the parameters of that bin. Associated with each bin of the histogram is not only a weighted population, but the <u>fraction</u> of events in the entire sample that are <u>less probable</u> than the events within that bin.

4.0 Candidate event evaluation

Candidate events satisfying the criteria for a tau-like topology can be evaluated as to the *probability that a simulated event has parameters consistent with a generated distribution of that event type.* The following question can be answered: For a given event type (tau, CC charm, CC scatter or NC scatter) what fraction of simulated events have a combinational of parameter values that are less likely than those of the (measured) candidate event?

Evaluating the fraction described above is trivial once the histograms and the sums described in the previous section have been completed. One only needs to find which bin describes the candidates events parameters.

4.1 Limits of evaluation

4.1.1 Statistical limits to calculating the fraction of events which are less likely

Using the histogram to determine the above described fraction becomes unreliable for small values of the fraction. An acceptable lower limit is estimated by choosing the fraction at which the most likely bin population falls below three. Plots of bin population vs. fraction of events less likely are shown in figures 11 & 12.

4.2 Relative rates

Since the evaluation is applied to events of only a specific topology, the relative likelihood of an event being a background or signal also requires knowledge of the relative rates of tau like topology for background processes.

4.2.1 Charm decay background

The rate at which an event produces a charm particle that undergoes a single charge decay and triggers the spectrometer is measured with the Monte Carlo. Corrections to charm production rates in neutrino CC interactions simulated in LEPTO are found to be unnecessary. Charm production rates found in LEPTO are shown in fig 5.

The following table shows the frequency of the criterion of tau like topologies for CC neutrino interactions.Charm Decay Background

TABLE 2. Frequency of single charged charm decay events produced in Monte Carlo sample of prompt ν_μ non-prompt ν_μ and ν_e

	prompt ν_μ	non-prompt ν_μ	ν_e
Total number of CC interactions	35.9K	129K	170K
ΣWeight: entire sample	3.59M	3.74M	16.6M
ΣWeight: events producing charm	120.3K	73.2K	592K
ΣWeight: events producing charm with single charged decay	34.8K	21.4K	168K
ΣWeight: events producing charm with single charged decay, lepton is “lost’ and spectrometer is triggered	11.5K	11.4k	153K
Fraction of entire sample with tau-like topology	.00325	.00305	.00921

4.2.2 Scattering background

The rate of observing scattering background is dependant on the total length of tracks scanned. Using the generated Monte Carlo sample a rate of *scatters per unit length* is found.

The average number of scatters per length is calculated by summing the entire track length scanned for the sample and dividing by the number of scatters found. Even though a track from the primary may have more than one scatter, each scatter is

treated individually. The following table shows the frequency of scatters for both NC and CC scatter background events.

TABLE 3. Frequency of scatter events produced in Monte Carlo sample of prompt ν_μ non-prompt ν_μ and ν_e

	CC prompt ν_μ	NC prompt ν_μ	CC ν_e	CC non-pr. ν_μ	NC non-pr. ν_μ	NC ν_e
Total number of interactions	10,930	4978	19.9k	17.5k	4980	4978
ΣWeight: entire sample of *events*	1.71M	442K	1.76M	517k	145k	417k
ΣWeight: *events* having a least one scatter, lepton lost and trigger	374k	332K	95.1k	203k	83.5k	328k
Σ (Weight * # of scatters / length): *events* having a least one scatter, lepton lost and trigger	355k/cm	403K/cm	90.8k/cm	253k/cm	125k/cm	393k/cm
Rate of tau like topology scatters per cm of track scanned	.207/cm	.911/cm	.051/cm	.498/cm	.862/cm	.942/cm

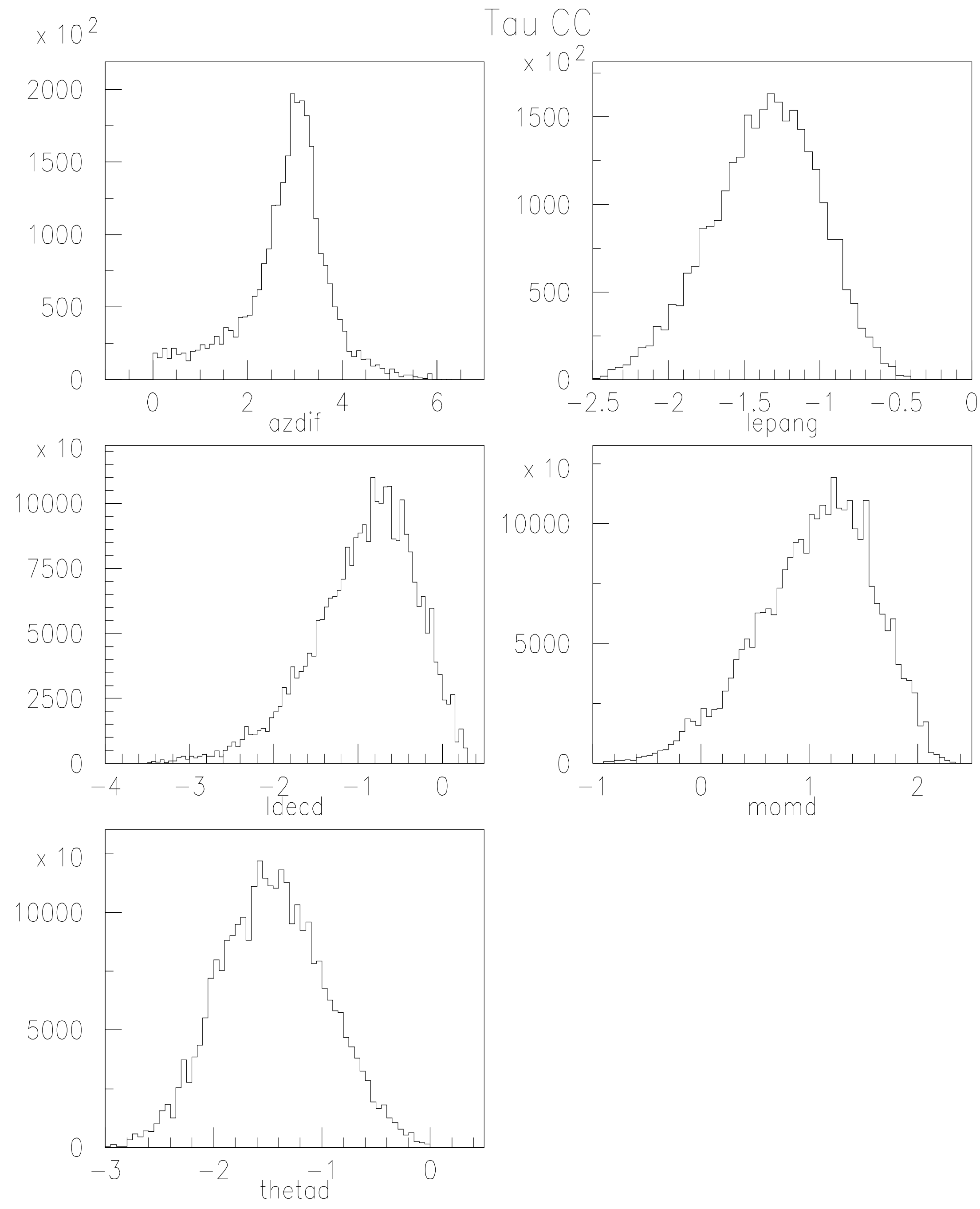

Figure 1. Parameter distributions for ν_t CC interactions.

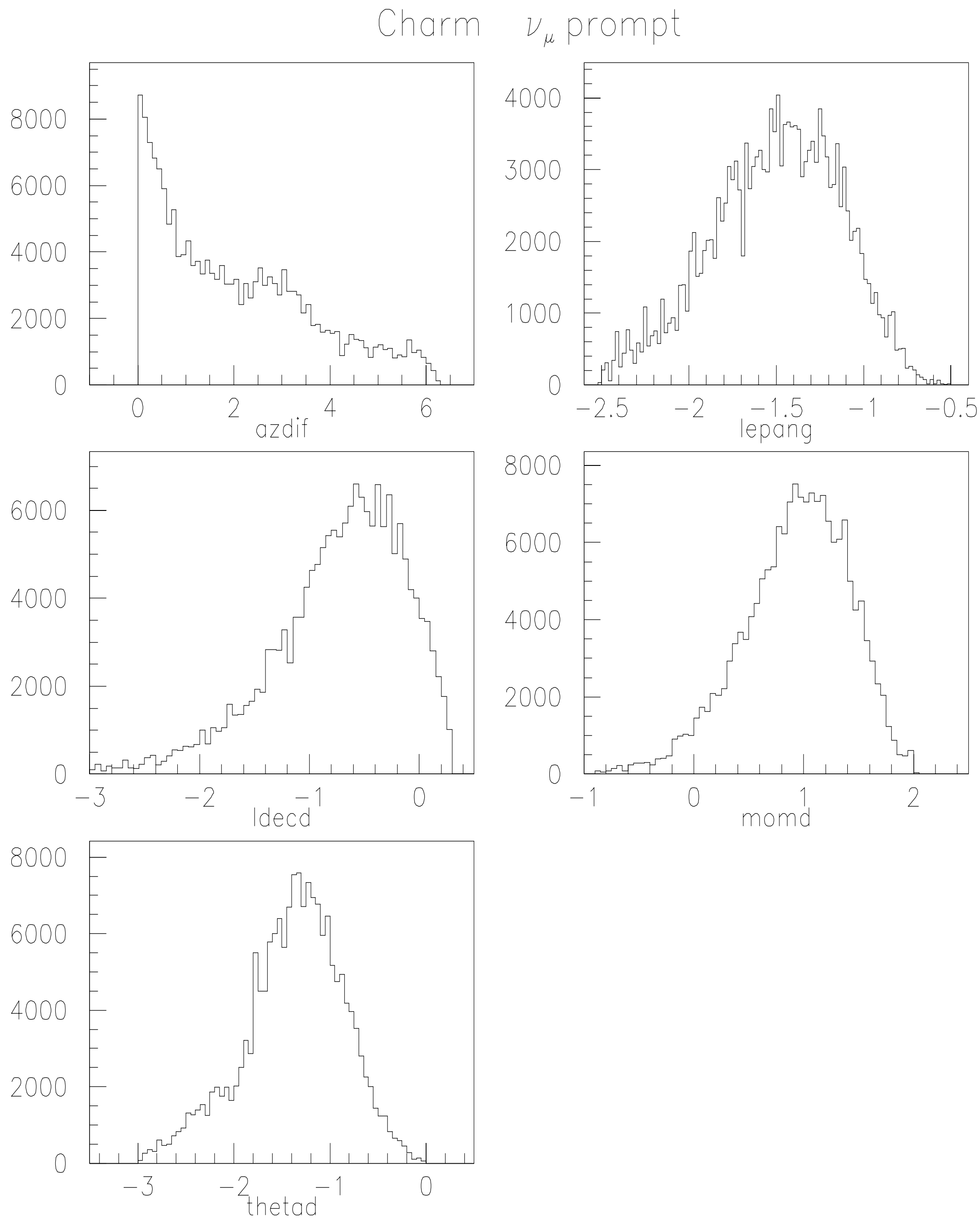

Figure 2. Parameter distributions for ν_μ CC interactions producing charm.

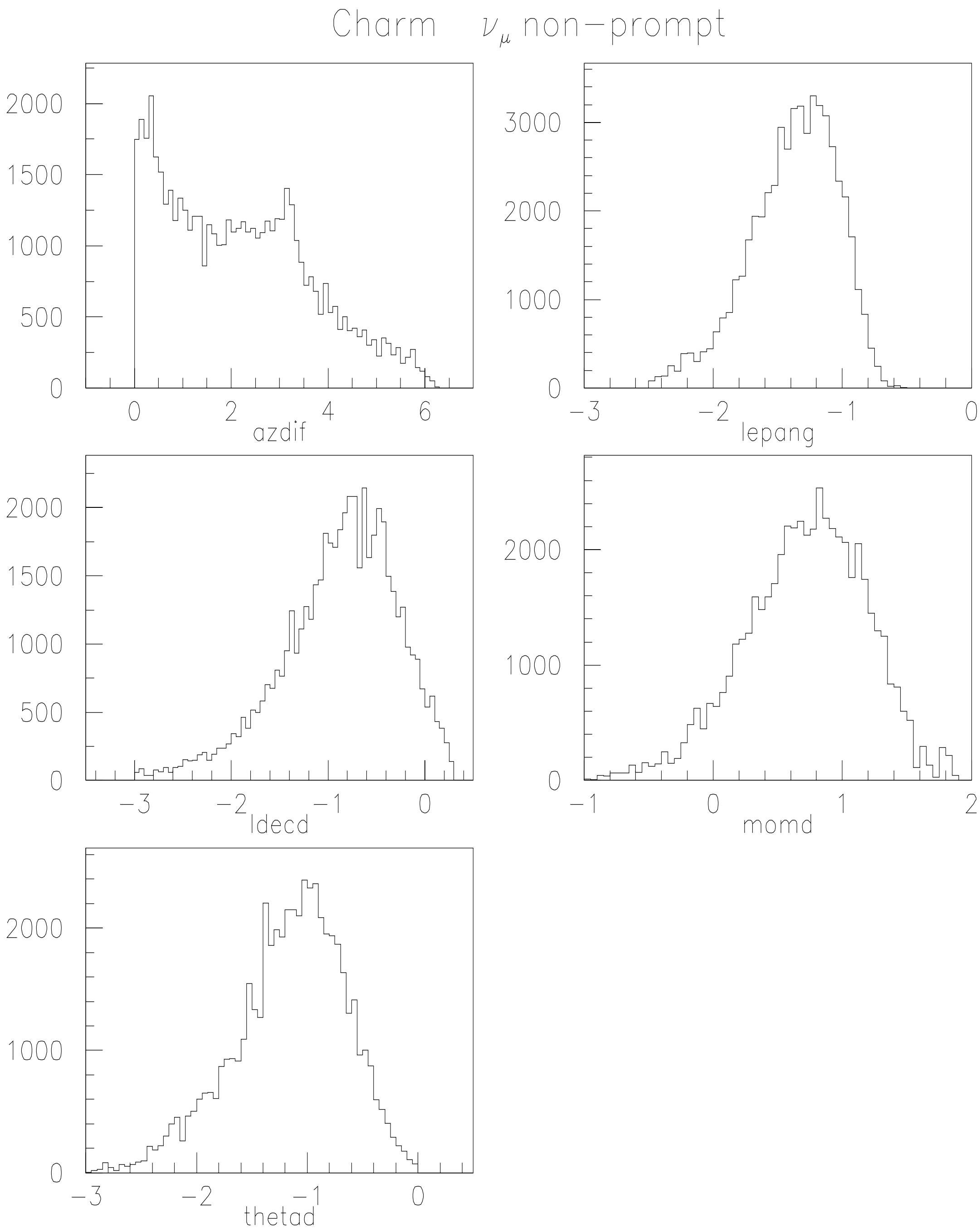

Figure 2. Parameter distributions for ν_μ CC interactions producing charm.

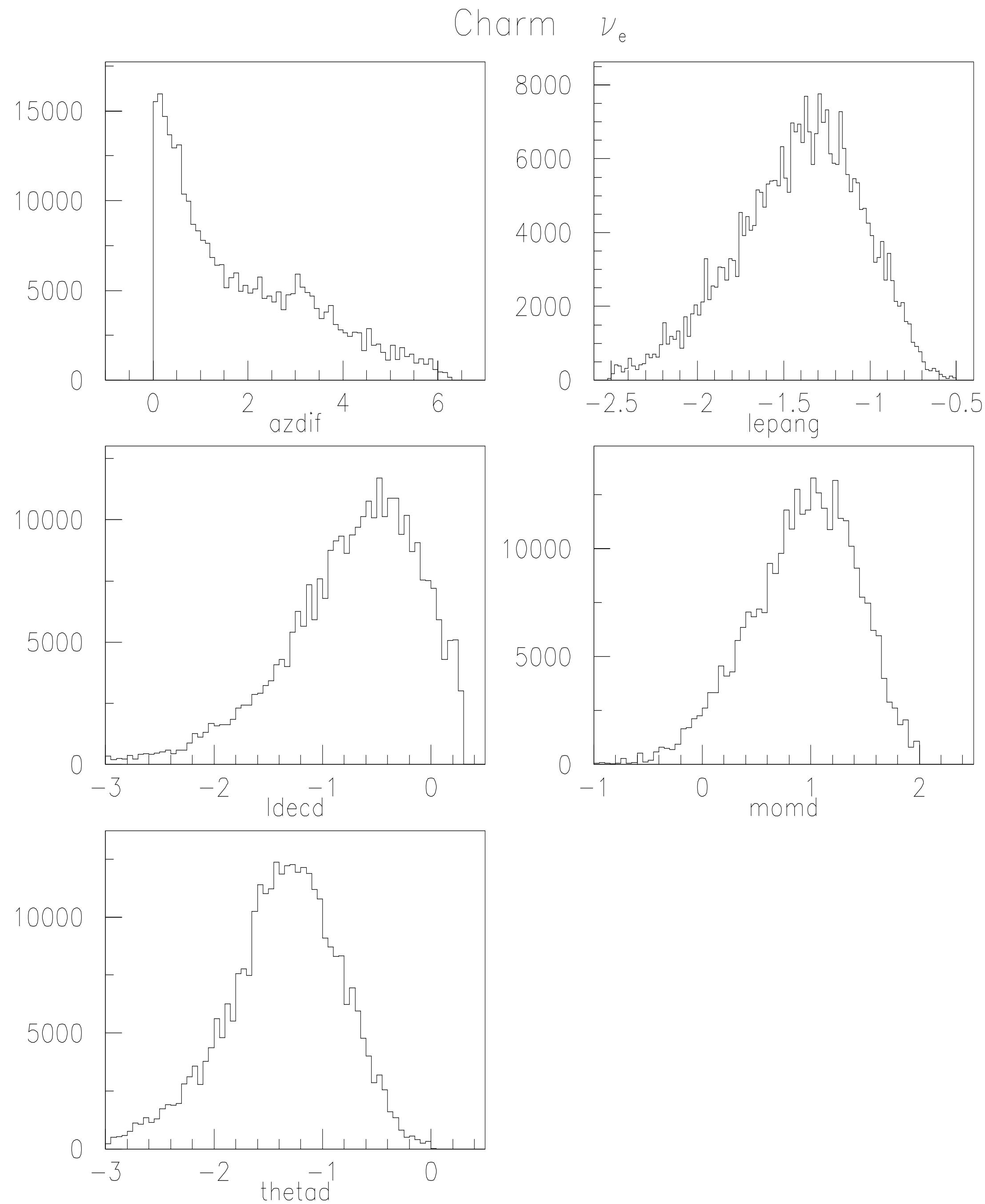

Figure 4. Parameter distributions for ν_e CC interactions producing charm.

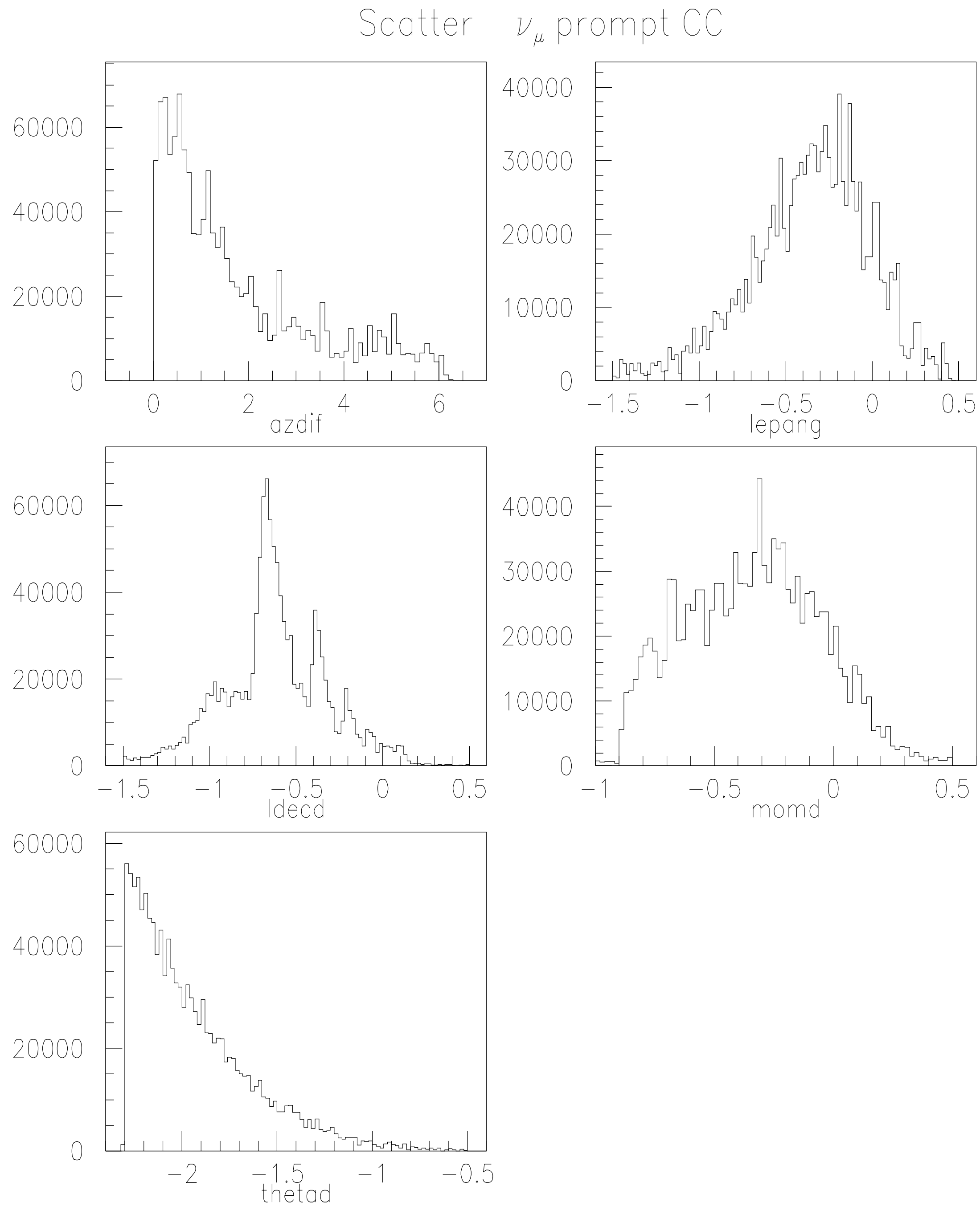

Figure 5. Parameter distributions for ν_μ (prompt) CC interactions with a scatter.

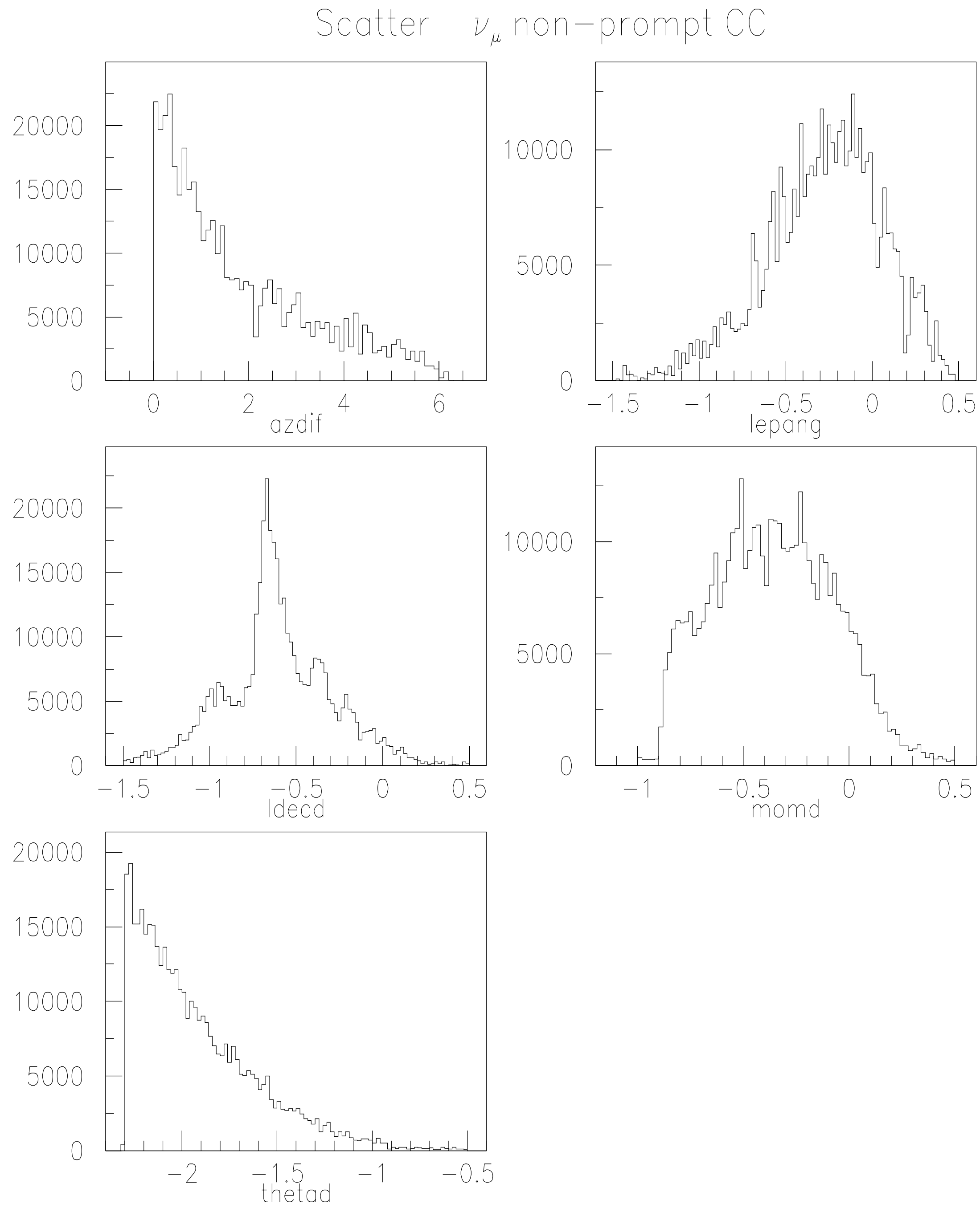

Figure 6. Parameter distributions for ν_μ (non-prompt) CC interactions with a scatter.

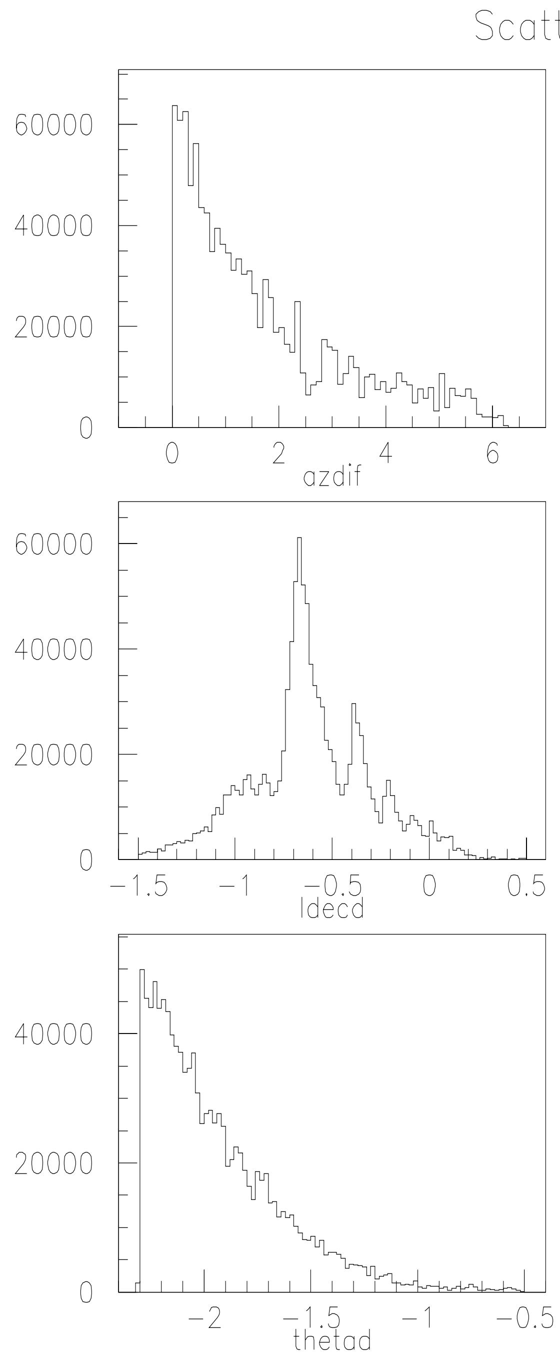

Figure 7. Parameter distributions for ν_e CC interactions with a scatter.

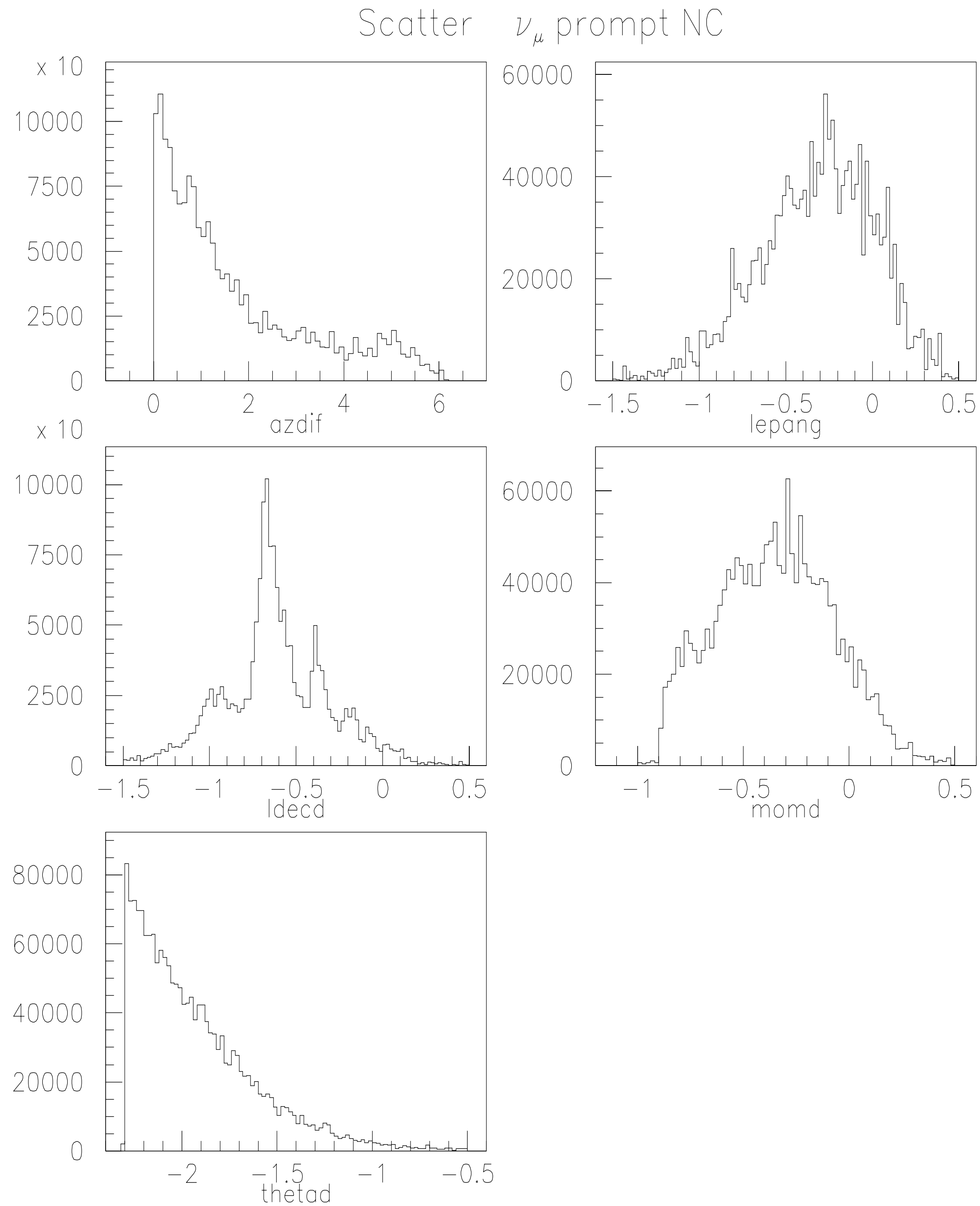

Figure 8. Parameter distributions for ν_μ (prompt) NC interactions with a scatter.

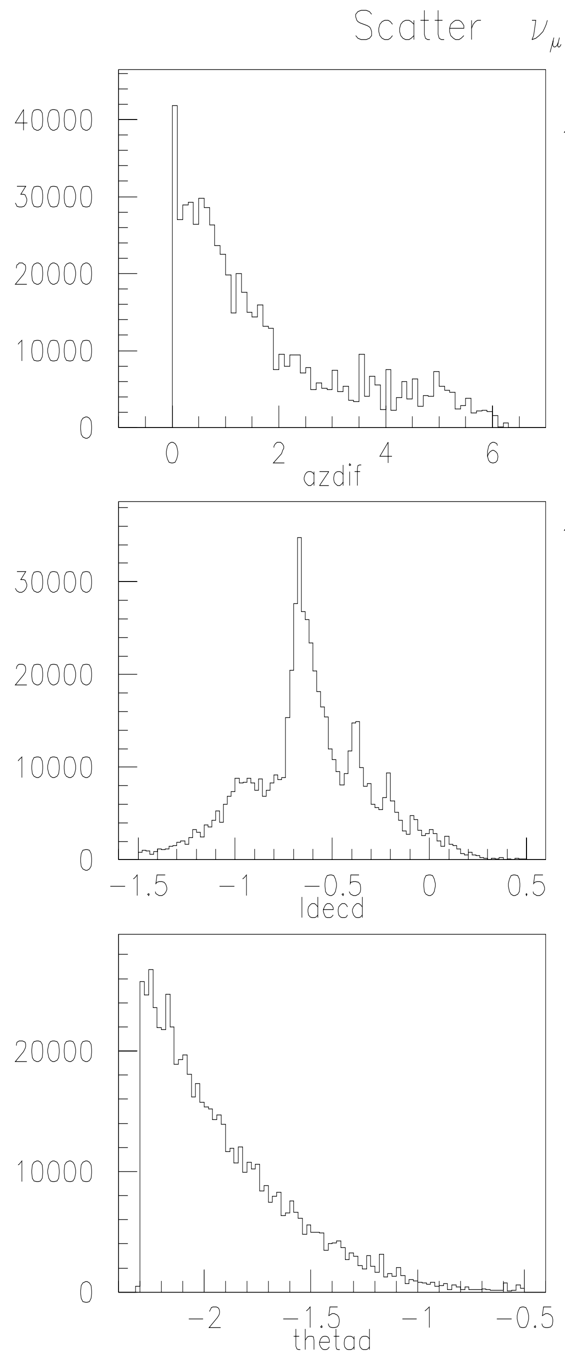

Figure 9. Parameter distributions for ν_μ (non-prompt) NC interactions with a sscatter.

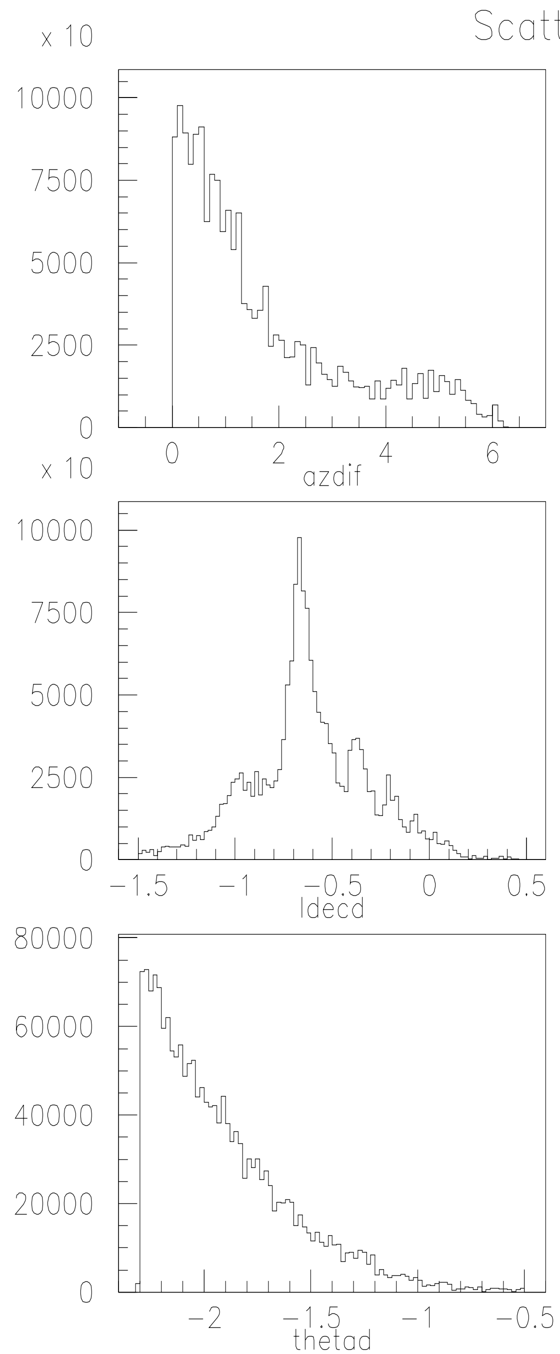

Figure 10. Parameter distributions for ν_e NC interactions with a scatter.

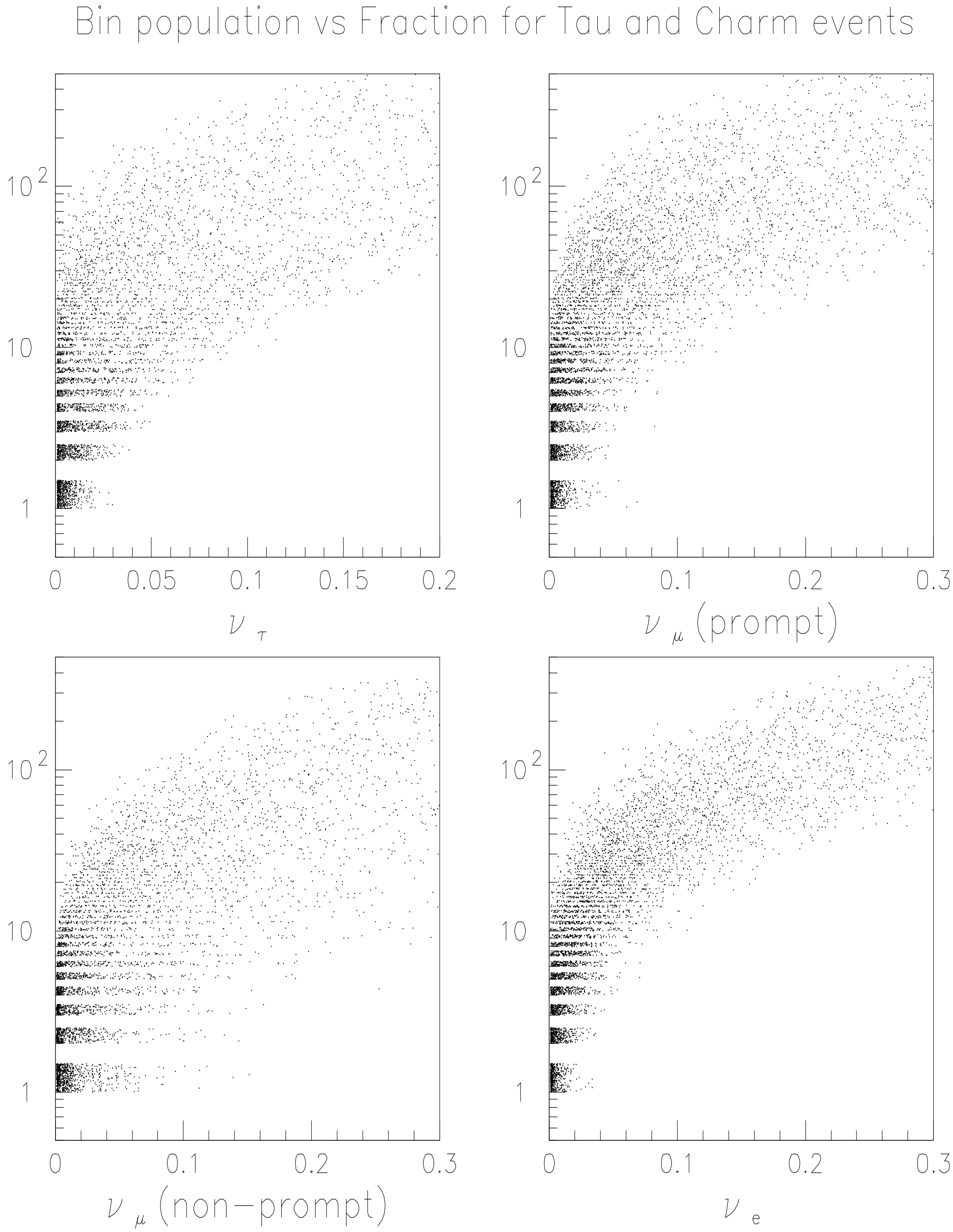

Figure 11. Bin population vs. fraction.

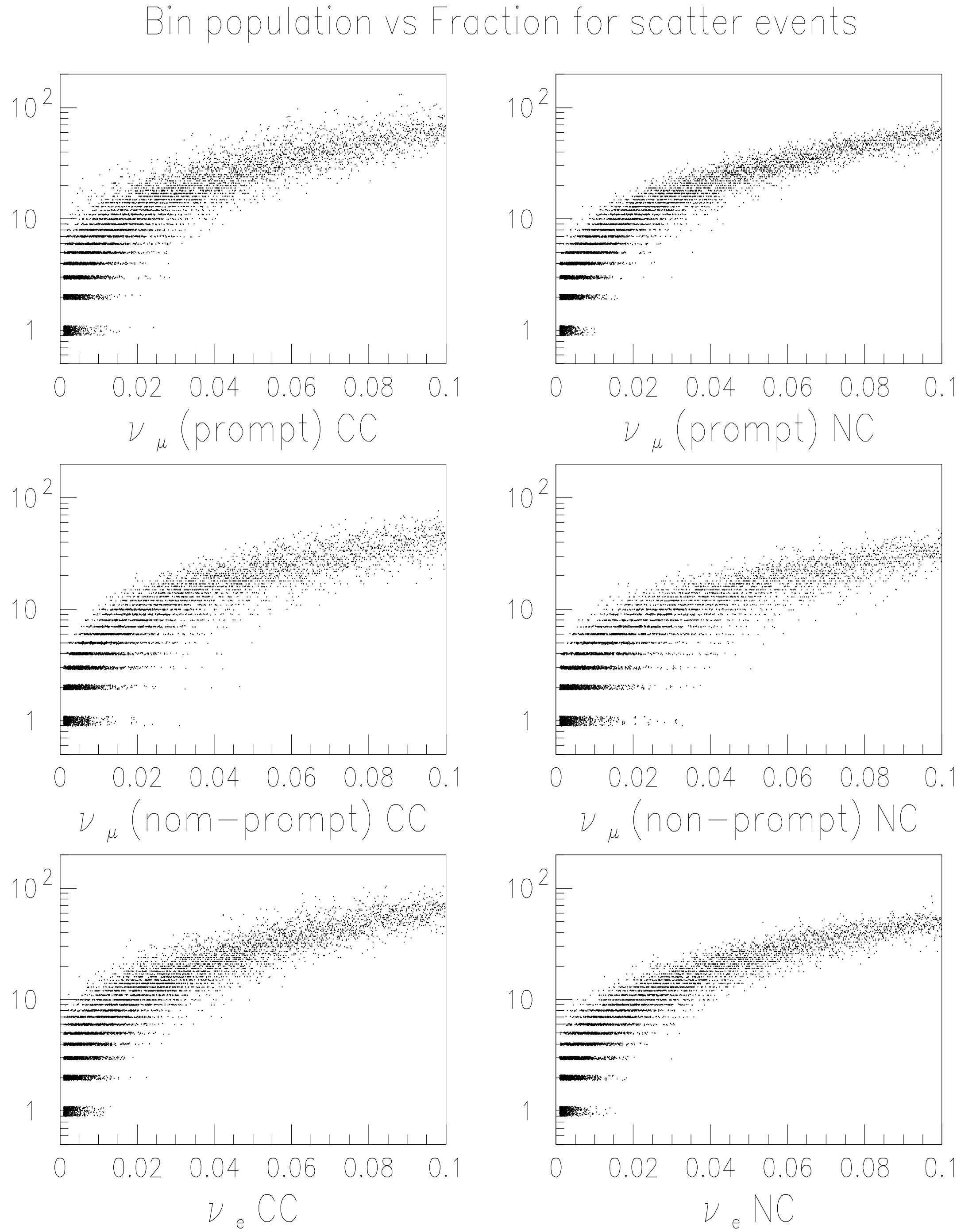

Figure 1. Bin population vs. fraction