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π^+ Acceptance Corrections for $\pi \to \mu$ Decay

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1 Introduction

Pions are produced from many reactions in the target of CLAS experiments. As they pass from the target thru the CLAS detector, pions can decay into muons. The purpose of this paper is to examine the influence of this decay upon the acceptance of the pion. A Monte Carlo calculation (GSIM) is used to calculate the acceptance with and without decay.

2 Reaction Kinematics

The calculation looks at pions from photoproduction, $\gamma p \to \pi^+ n$, for a photon energy E_γ of 1 GeV. The kinematics of the reaction is shown in Fig. 1. For $E_\gamma =$ 1 GeV, the pion lab momentum ranges from 1 GeV/c at 0° to 0.33 GeV/c at a lab angle of 135°, the maximum angle accepted in the detector. For other values of E_γ, the pion momentum at forward angles increases rapidly with increasing E_γ, while at backward angles the pion momentum increases slowly and remains less than 0.5 GeV for E_γ below 2.6 GeV.

The maximum opening angle of the muon relative to the direction of the decaying pion is given by [1]

$$\theta_{max} = \arcsin\left(\frac{p_\mu^*}{m_\mu}\frac{m_\pi}{p_\pi}\right)$$

Here p_μ^* is the momentum of the muon in the pion's rest frame and p_π is the momentum of the pion in the lab frame. With $p_\mu^* = 29.79$ MeV/c, the angle becomes

$$\theta_{max} = \arcsin\left(\frac{39.35}{p_\pi}\right)$$

where p_π is the pion's momentum in MeV/c. The dependence of the maximum opening angle on pion momentum is shown in Fig. 2. The maximum opening angle is less than 1.1° for pions with momentum greater than 1.5 GeV/c. At 1 GeV the angle is 2.2°, and at the lowest momentum accepted by this simulation, 0.35 GeV/c, it is 6.5°.

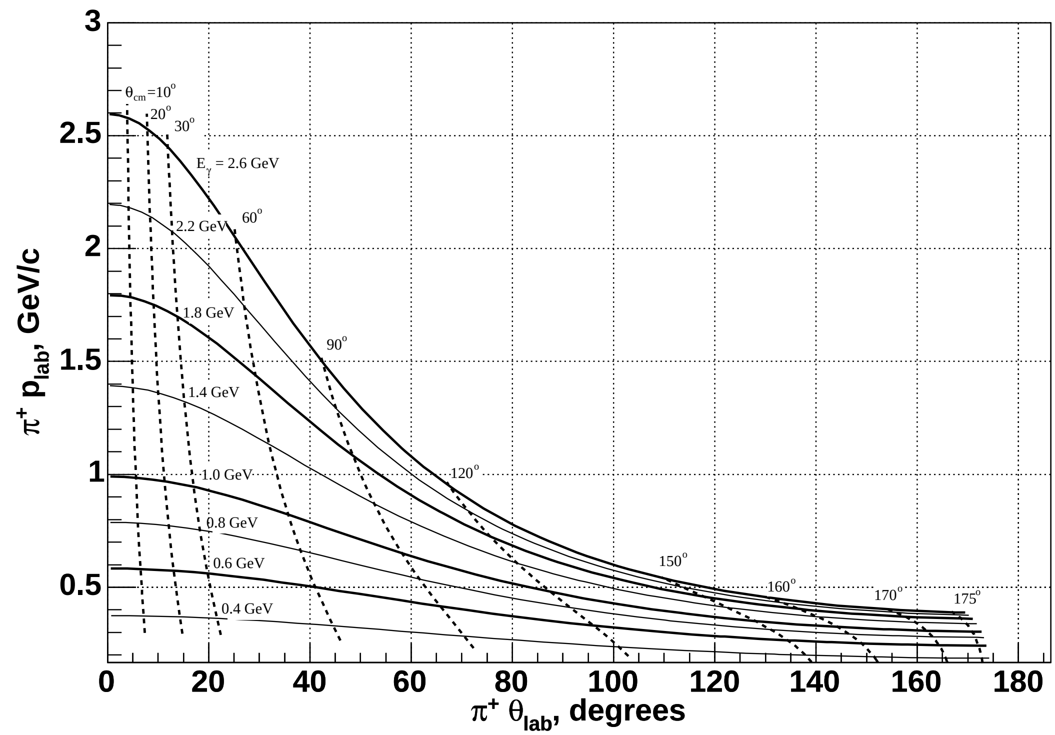

Figure 1: Kinematics for the reaction $\gamma p \to \pi^+ n$. The solid lines represent constant values of the incident photon energy E_γ. The dashed lines represent constant values of the center-of-mass angle.

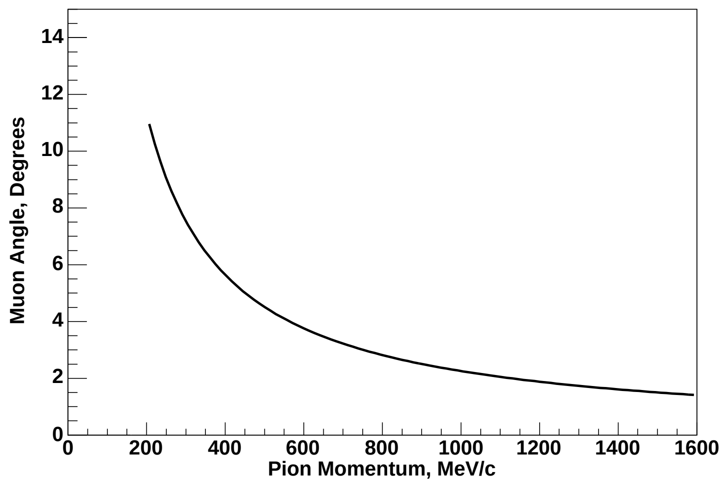

Figure 2: Maximum angle for the direction of muons relative to the direction of the decaying pion for the process $\pi \to \mu\nu$.

3 Calculation

The calculations were performed on the cluster at the University of Richmond. The cluster uses the Beowulf Distributed Process Space (BProc) which handles the start of processes on the master and migrates them to nodes on the cluster.[1] Events were randomly generated from a SAID prediction for the cross section. After conversion to a PART bank format, the events were passed to GSIM and then analyzed by a1c. The banks produced by a1c were used to create a PAW ntuple. Ntuples from separate runs of about 300,000 events were converted to a ROOT tree and chained for analysis.

To look at the effect of pion decay, the calculation was done twice. One calculation allowed the pion to decay in the GSIM analysis, while the second calculation did not allow decay. Setting GSIM's FFREAD card key DCAY to 0 turned off decay in the simulation.

About 10 million events were generated at a rate of 7 events/sec. The calculation was expedited by distributing the work over the nodes of the University of Richmond cluster.

4 Results

The thrown and accepted events for one sector in the case of a run with decay are shown in Fig. 3. The distribution of thrown events reflects the prediction

[1] A description of the system as well as example calculations are given on a web site at the University of Richmond,
www.richmond.edu/~ggilfoyl/research/spiderwulf/cluster_home.html.

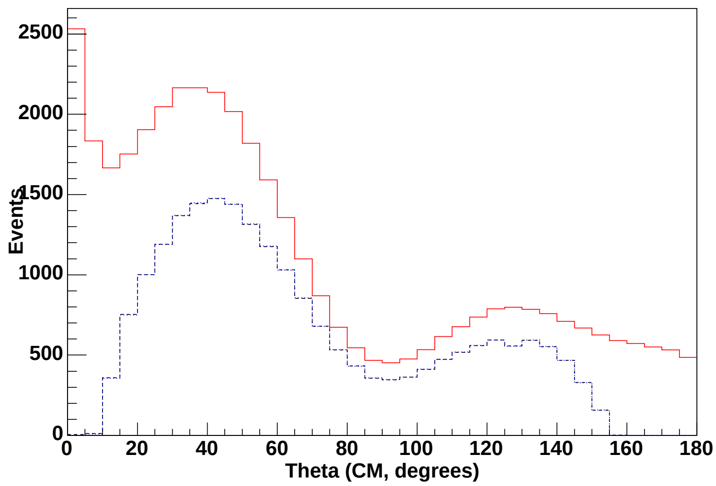

Figure 3: The center-of-mass distribution for thrown (red-solid) and accepted (blue-dashed) events for one sector in a run with 200,000 events.

of the SAID analysis. The acceptance is calculated by comparing the accepted to thrown events. Fig. 4 shows the acceptance for the events with and without decay in the center-of-mass system. Fig. 5 shows the acceptance in the lab system. Compared to no-decay events, the acceptance for decay events is less by about 10% at most angles.

The survival probability of a pion can be estimated from its flight length and momentum. The probability P of survival is:

$$P = \exp(-L/\lambda_D)$$

where L is the flight-length from target to scintillation counters and λ_D, the decay length, is given by

$$\lambda_D = \frac{p}{m_\pi c} c\tau$$

Here τ is the mean-life of the pion in it's rest frame (26 ns), and p is the lab momentum of the pion.

The survival probability can be compared to the ratio of decay to no-decay acceptance. At a lab angle of 27°, the pion has a momentum of 0.89 GeV/c giving a decay length of 50 m. With a flight path of about 5.3 m, the survival probability is 0.90. This compares to the ratio of decay to no-decay acceptance of 0.933 ± 0.016 from Fig. 5. At an angle of 117°, the pion has a momentum of 0.34 GeV/c giving a decay length of 19 m. The flight path of about 3.8 m gives a survival probability of 0.82. The acceptance ratio at this angle is 0.871 ± 0.045. At both angles, the survival probability is less than the acceptance ratio, suggesting that some decay-muons are being accepted as pions.

Since events with a decay muon might be expected to produce an anomaly in kinematic reconstruction, a kinematical fit was performed on the data to see

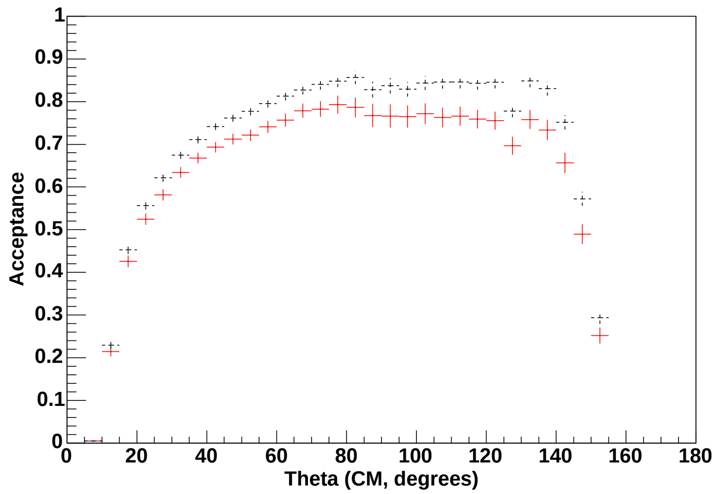

Figure 4: The center-of-mass acceptance for pions that don't decay (black-dashed) and those that do decay (red-solid).

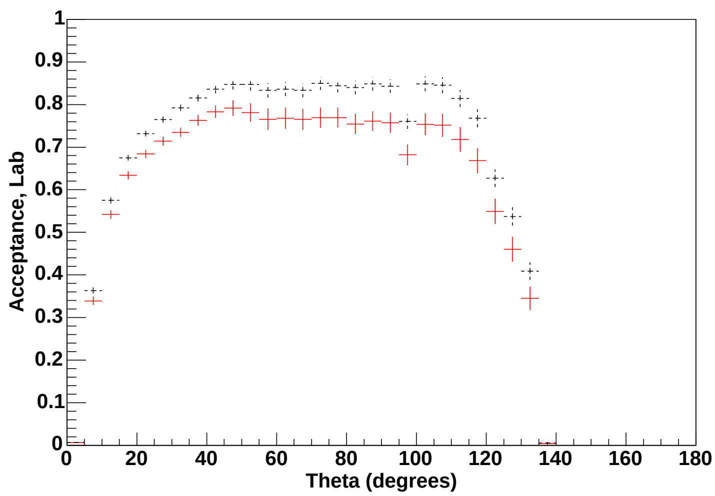

Figure 5: The acceptance in the lab for pions that don't decay (black-dashed) and those that do decay (red-solid).

if decay events could be identified. The calculation used the method described by Williams and Meyer [2]. The results for the confidence level are shown in Fig. 6. A cut at a confidence level of 0.1 did not produce a significant difference for the comparison of decay and no-decay acceptance. The calculation of the confidence level will need further attention since the slope of the plot is expected to be flat.

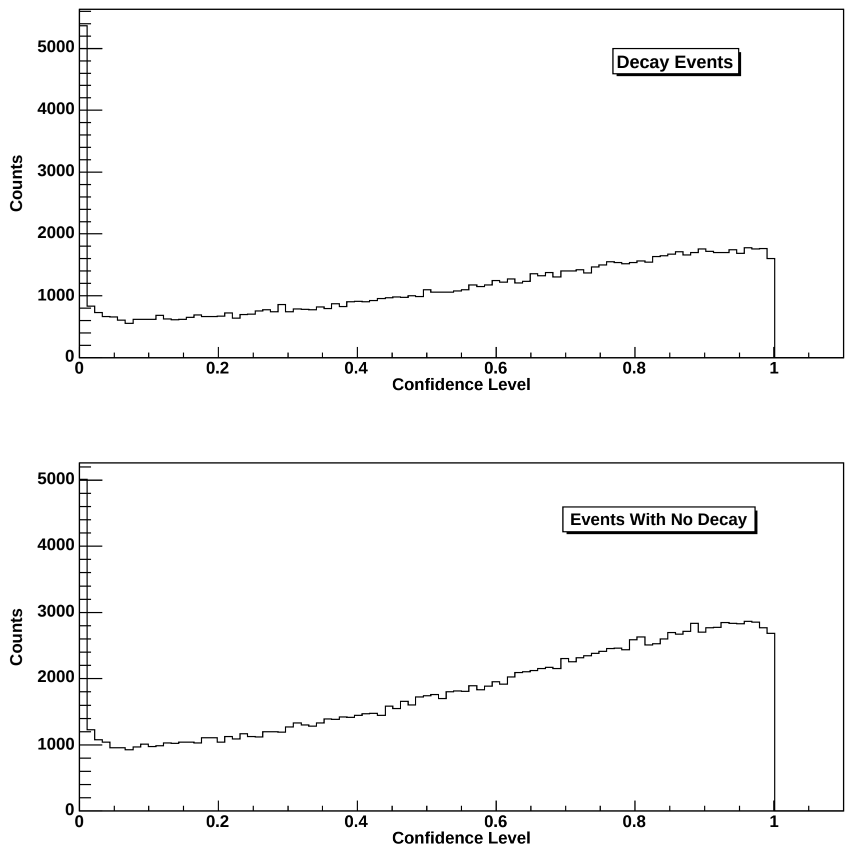

Figure 6: Confidence Level distribution obtained from a kinematic fit to $\gamma p \rightarrow \pi^+ n$

5 Conclusions

For 1 GeV photons, the loss of pions due to decay is significant at all angles. There are two possibilities to consider. In one, the pion decays at a large angle and is rejected by track fitting. In the second, the pion decays at a small opening angle such that the event is accepted as a pion. The analysis of this event could give the wrong momentum and angle for the pion. The problem can be corrected by GSIM modeling, but will require a good representation of the event in GSIM.

At higher photon energies, the correction for decay will be less at forward angles where a higher momentum will give a larger decay length. However at backward angles, lower momenta will give a shorter decay length and a larger correction.

Decay corrections will be even more important in reactions that produce kaons. For example, a 2 GeV/c kaon has a decay length of 15 m and a maximum opening angle for muon decay of 34°. Also there are other decay channels to consider, such as $\pi^+\pi^\circ$ which has a 21% branching ratio.

6 Acknowledgments

The calculations were assisted by Gerry Gilfoyle who provided time and guidance on the University of Richmond cluster. Dick Arndt is thanked for creating the function that gave pion distributions from the SAID analysis.

References

[1] W. S. C. Williams, in High Energy and Nuclear Physics Data Handbook, Section IX, Relativistic Kinematics.

[2] M. Williams and C. Meyer, Kinematic Fitting in CLAS, CLAS-Note 2003-017.