The Effect of Beam Timing Structure on the Time of Arrival Distributions for Neutrinos from Pion and Kaon Decays at MiniBooNE: Draft 1

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Introduction

The main background to the MiniBooNE oscillation signal is the intrinsic ν_e content of the beam from sources other than ν_μ oscillations. This contamination is due to kaon and muon decays, and is on the order of 1%. Approximately 5% of K^+ decays and 40% of K_L^0 decays produce ν_e. It may be possible to separate the neutrinos from kaon decays and the neutrinos from pion decays using the neutrino time of arrival at the detector. The time of arrival is calculated using the model shown in Fig. 1, by the equation:

$$\Delta t = t_p + t_m + t_\nu - T \tag{1}$$

A timing cut is possible due to the mass difference and the difference in the energy distributions for kaons and pions in our beam:

$$\Delta t_{\nu,max} = \frac{2D}{(33.6E_\nu)^2 - 1} \tag{2}$$

For a detailed description of the timing cut see "Time of Arrival Distribution Differences in Neutrinos from Kaon vs. Pion Decay and Timing Cut Development: Draft1"; Novak, Monroe, Brice; 2001.

We now present a preliminary study on the effect of different beam timing structures on the efficiency of a timing cut for the reduction of background from kaon decays. In this study we show that the shape of the distribution in time does not significantly effect the efficiency of our timing cut.

Beam Timing Structure

The MiniBooNE Beam Monte Carlo starts all protons incident on the target at the same time. To create a more realistic time profile for neutrino events at the

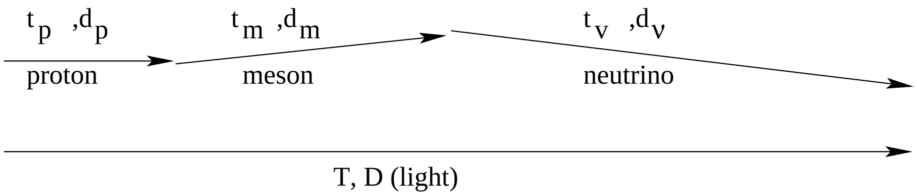

Figure 1: The analytical model for the neutrino time of arrival.

detector, we need to model the intensity of the proton beam as a function of time.

MiniBooNE will receive a pulsed 8.9 GeV proton beam from the Fermilab Booster. We will extract 15 pulses per second from the Booster and each pulse will contain on average 80 of a possible 84 proton bunches, as determined by the 53 MHz RF frequency. Taking dipole and quadrupole instabilities into account, a single proton bunch has an effective full width in time of about 4.5 ns. For this study, we selected six shapes which cover a range of possibilities for the individual bunch shape. These distributions were normalized to the same area, each has the same full width (4.5 ns), and a mean equal to zero. The functions selected were; a gaussian truncated to include two sigma, a parabola, a step function, a triangle function, and two opposing sawtooth functions (Fig. 2). Times were randomly drawn from these functions and added to the calculated travel time for a more realistic neutrino time of arrival distribution. A gaussian smearing in energy with $\sigma_E = 0.1$ GeV, and a gaussian smearing in time with $\sigma_t = 0.9$ ns were also added to model detector resolution.

Fig. 3 shows the Δt vs. E_ν distribution for neutrinos from pion decay smeared with these different distributions. We will use the timing cut to investigate the difference between these distributions for neutrinos from pion decay, neutrinos from kaons, and neutrinos from muons.

Shifting the Cut and Efficiency as a Function of Bunch Shape

The theoretical cut (Eq. 2), described in the introduction was calculated from a simplified model. In that model, all protons interact at the same time, all particles are produced along a straight line, and there is no resolution smearing. After adding in time and energy resolution smearing, the proton interaction time, angular effects, and the extra proton travel time from the bunch shape, this cut would remove a large number of the ν_μ from π^+ decay which make up our beam. To avoid cutting a large portion of our potential signal for oscillations, we introduce a shift upwards in time to our cut. The new cut is:

$$\Delta t_{\nu,max} = \frac{2D}{(33.6E_\nu)^2 - 1} + shift. \tag{3}$$

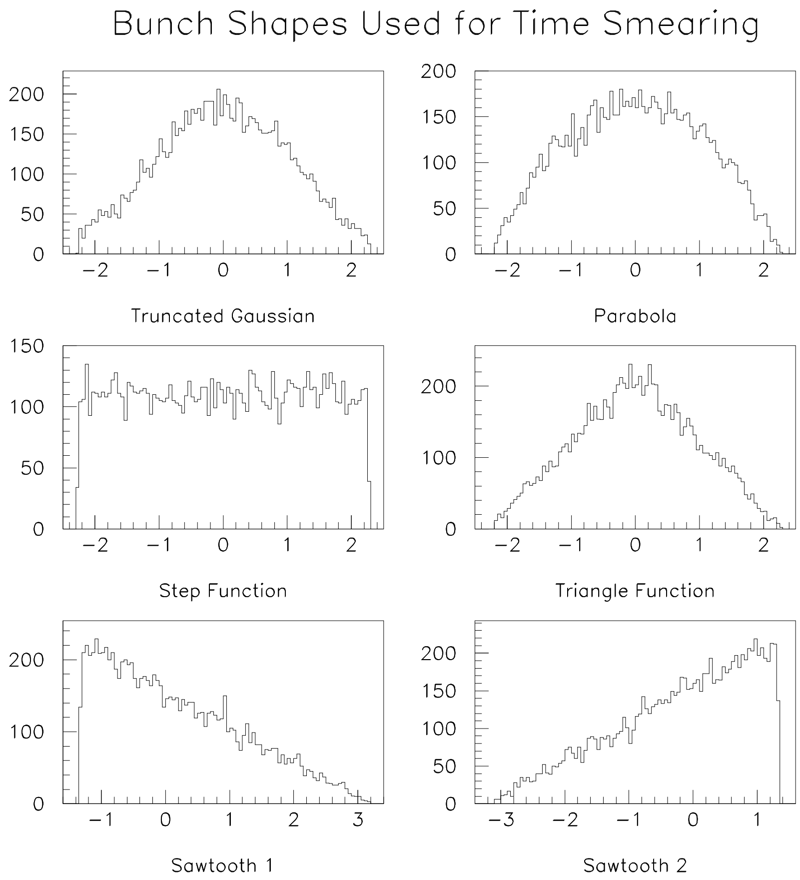

Figure 2: Bunch shape timing distributions. Each distribution is normalized to the same area, has the same full width , and mean equal to zero.

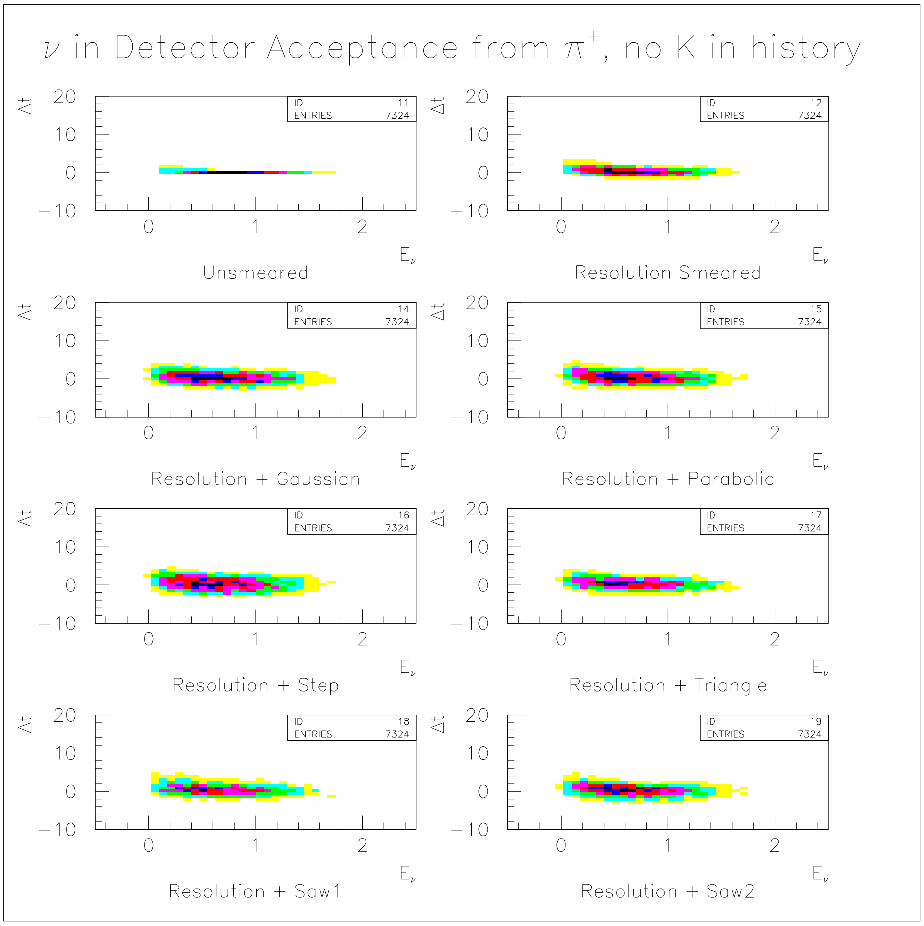

Figure 3: A plot of Δt vs. E_ν for neutrinos from pion decay. Darker color indicates more neutrinos per bin.

We vary the shift from 0.5 to 3.0 ns for comparison purposes.

The timing cut efficiency vs. bunch shape for neutrinos from different sources is shown in Fig. 4. From left to right, the bunch shapes are; gaussian, parabolic, step, triangle, sawtooth 1, and sawtooth 2. These plots were generated from calculations using GEANT Monte Carlo Simulations, with the GEISHA particle generator. An energy cut on all events of $E_\nu < 1$ GeV was assumed. Ideally, we would look at only ν_μ from π^+, and only ν_e from kaon and muon decays. However, because we had low statistics, it was necessary to use all types of neutrinos to investigate our cuts.

The cut efficiency is fairly stable across the wide range of bunch shapes used. Instability in the efficiencies for cutting neutrinos with K^0_L in their parentage history and neutrinos from μ^+ are believed to be due to the low statistics of events from those sources in our simulation. Better statistics are now being generated. The stability of the cut efficiency allows us to not worry about the exact intensity distribution of our beam in time. Changes in the distribution should not significantly effect the neutrino time of arrival.

Efficiency of the timing cut does depend on the full width of the proton bunch in time (Fig. 5). We vary the bunch width from 2.0 to 5.0 ns, and find a difference in the percent cut on the order of 5%. The strange behavior of the cuts on neutrinos with neutral kaons in their history and neutrinos from muons is believed to be an artifact of our low statistics. The use of a width equal to 4.5 ns is based on beam studies described in "Time of Arrival Distribution Differences in Neutrinos from Kaon vs. Pion Decay and Timing Cut Development: Draft1"; Novak, Monroe, Brice; 2001.

Conclusions and Future Work

The ability to separate neutrinos from kaon decay from neutrinos from pion decay can greatly improve MiniBooNE's sensitivity. Variations in the shape of the intensity of the proton beam in time do not significantly effect our ability to cut kaon events using timing.

This study needs to be revisited using higher statistics, and taking neutrino type into account. We would like to study the effect of a proton bunch shape including constant tails. We would also like to study the effect of shifting the $E_\nu < 1$ GeV cut to a higher energy. Studies of the timing cut itself are being continued. If a straight timing cut is not reasonable, a likelihood analysis will be pursued.

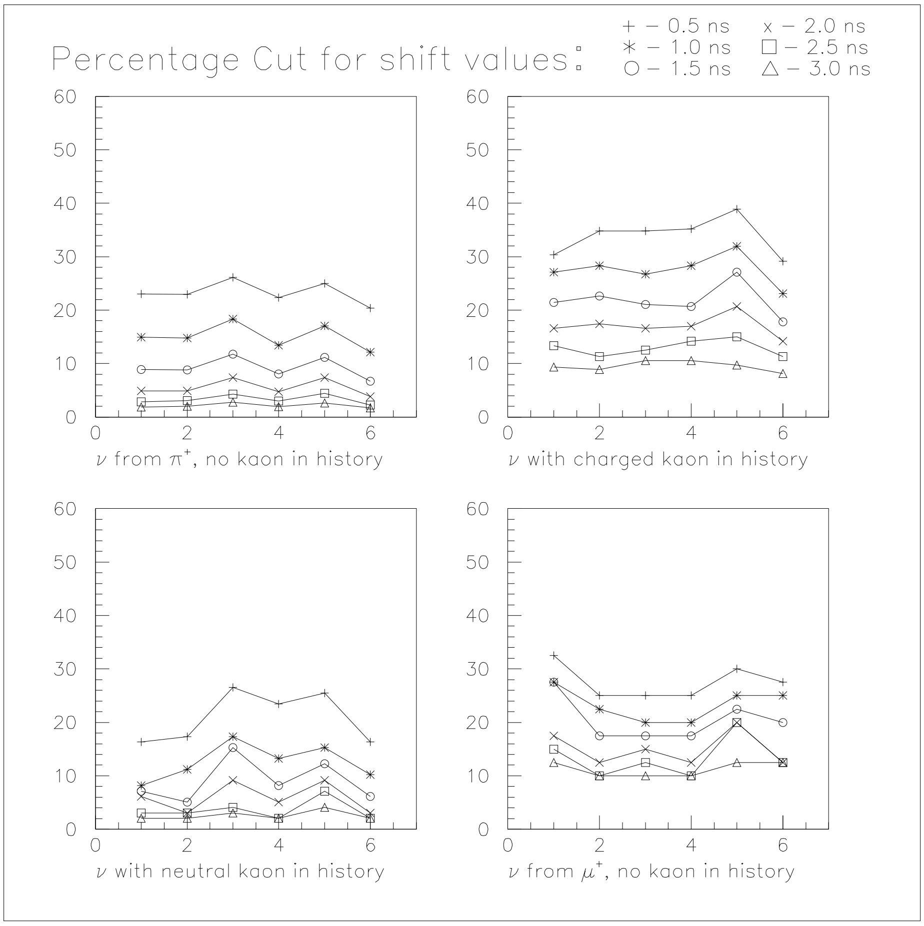

Figure 4: Timing cut efficiency vs. bunch shape for neutrinos from different sources. Bunch shapes are; 1: gaussian, 2: parabolic, 3: step function, 4: triangle function, 5: sawtooth 1, 6: sawtooth 2.

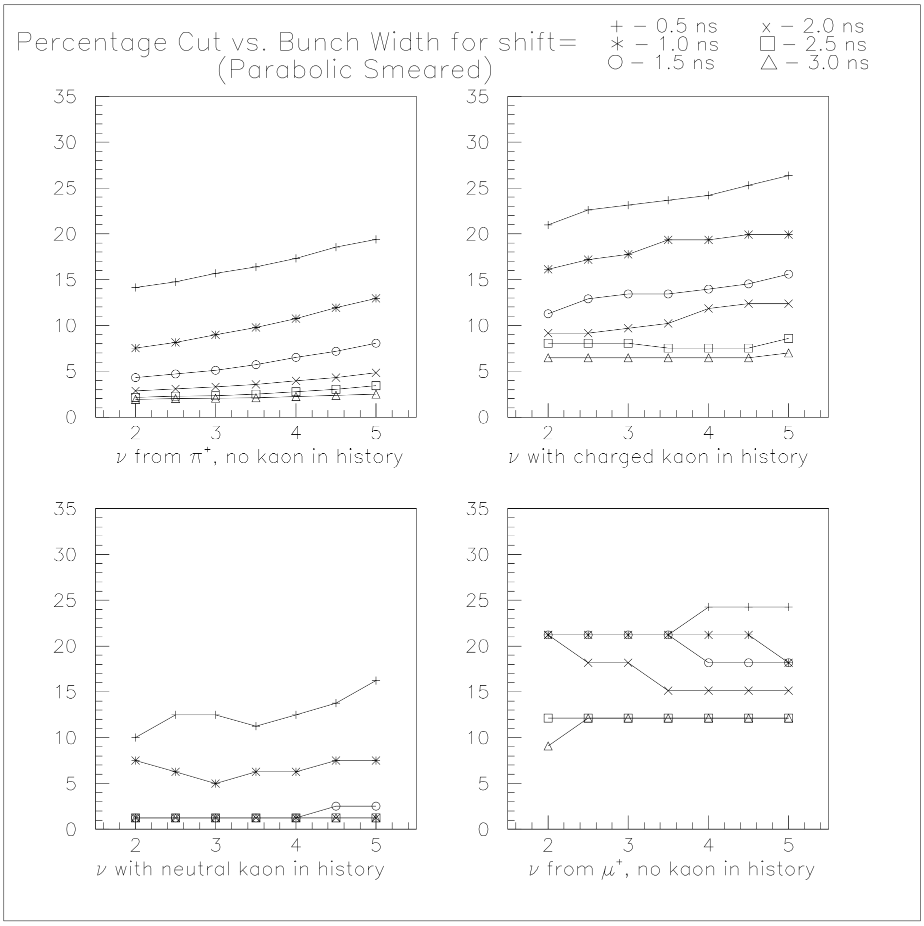

Figure 5: Timing cut efficiency vs. bunch width for neutrino times smeared with the parabolic bunch distribution.