Algorithm for rejection of non-shower hits in Milagro

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1 Introduction

Milagro trigger is defined when greater than a present number of hits occur within a period of 300 ns. The common stop comes much later. Most of the time, tube with the largest pulse height(pemax) will be located within the 300 ns of shower spread. We will call the hit time of pemax, tmax. The distribution of hit times with respect to the time of the pemax tube, called tt, is shown in Figure 1.

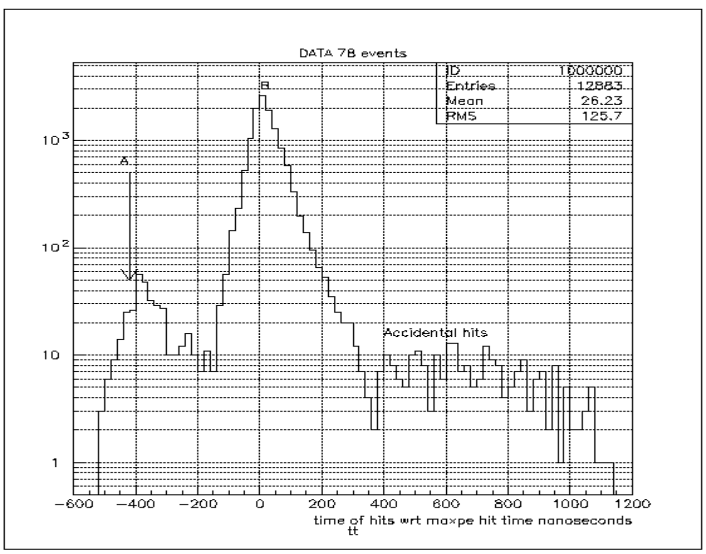


Figure 1: Hit time distribution for Data: A corresponds to a shower which arrives early compared to tmax. B corresponds to a corresponds to a shower which contains tmax

This distribution shows that the shower gate remains open for some 1800 nanoseconds. Accidental hits are evident to the right of the main peak. The main peak has a width of 300 ns. The secondary peak to the left of the main peak corresponds to a trigger with maximum pulse height arriving late compared to the shower indicated by the peak. It is instructive to look at the two dimension distribution of tt and rr, where rr is the distance of each hit from pemax hit. This is shown in Figure 2.

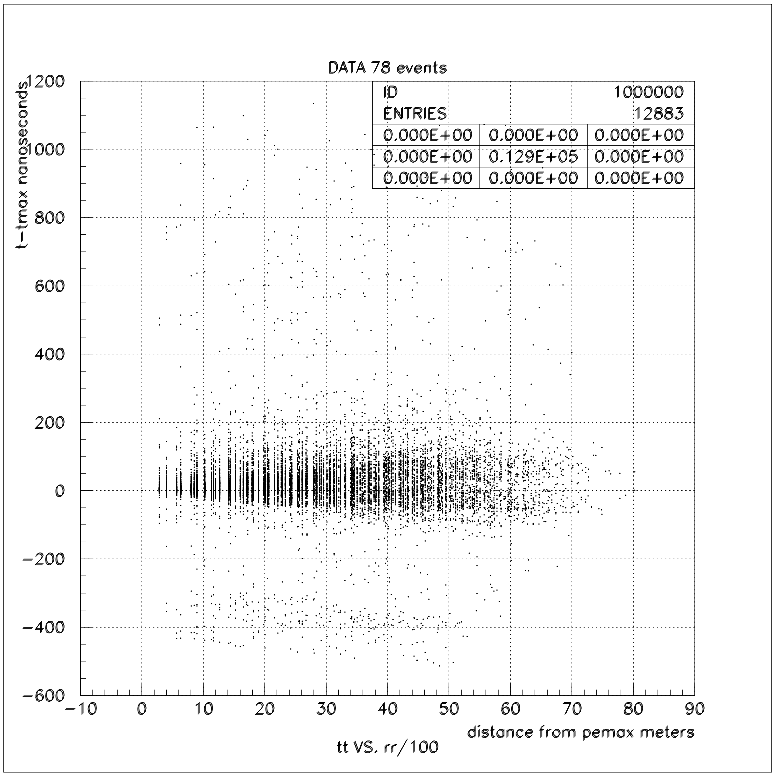


Figure 2: Time versus distance for all hits for data. Time is tt=(t-tmax) and distance,rr, is from the hottest tube

This 2d plot illustrates three points: (1) accidental background, (2) an early shower with respect to hottest tube and (3) the main spread of showers which we shall discuss below.

We have developed a method by which maximum pulse height hits not associated with the main shower and obvious accidental background outside of the shower time band are first eliminated. Then the remaining hits are searched for new hottest tube, pemax1. Then we examine the two dimensional distribution of hit times with respect to the time corresponding to pemax1, and the distance of each hit counter from pemax1(called t and r). We first do this with Stefan's MC showers which were thrown out to ± 100 m from pond center, starting at 100 GeV and distributed over 0 to 45 degrees.

2 Study of characteristics of MC events

We choose events for which nhittop is greater than 80 hits. For each event we find the hottest tube and then plot distribution of tt in Figure 3.

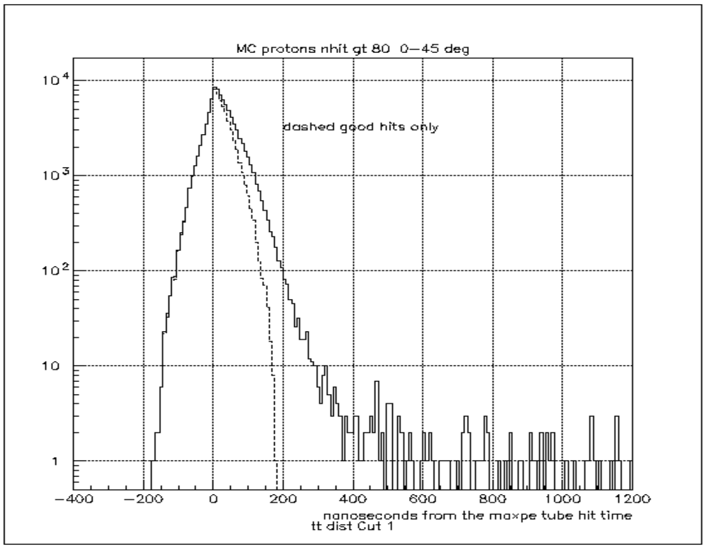


Figure 3: Hittime distribution for protons, tt= t-tmax

A glance at Figure 3 shows the lack of accidentals in the simulations. The figure also shows that there are no early hits. The shower spread is also about 300 ns. The large time stragglers reflect those particles which come late with respect to the shower front. The dashed curve shows the distribution after the cuts to be described later have been applied. The cut distribution is symmetric around zero nanoseconds.

In Figure 4 we compare the space angle difference between reconstructed and true angles for two cases:(a) when no hits are thrown out and (2) only using good fits indicated by the dashed curve in Figure 3. The purpose of this comparision is to show that making the cut does not change the reconstructed angles in any significant way.

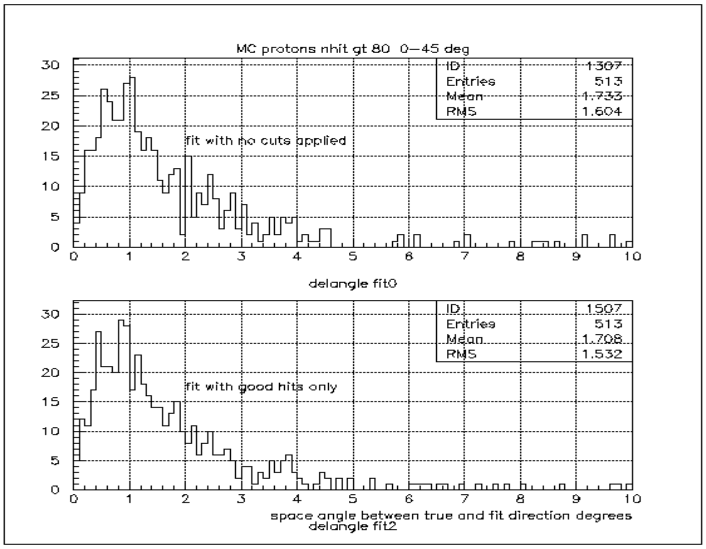


Figure 4 a and b: Space angle difference before and after removing hits, for protons

2.1 Time versus distance plots for proton events

In plots 5 through 8, the simulated proton data is divided into four different ranges of zenith angles and then time from pemax vs distance from pemax are displayed. To obtain a clear indication of hits consistent with speed of light in water pemax is required to be large, greater than 400 pes. All these plots clearly show three characteristics of these showers:(a) The presence of hits along the speed of light in water line from the pemax, the top band, (b) the localization of hits within a cone which is successively more open as zenith angle increases, indicated by the solid lines and (3) presence of hits trailing with respect to the shower plane.

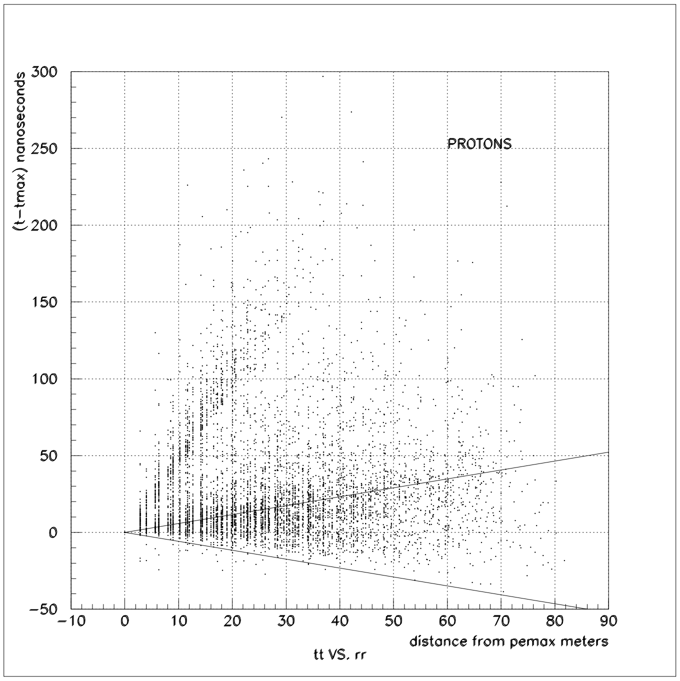


Figure 5:Protons between 0-10 deg

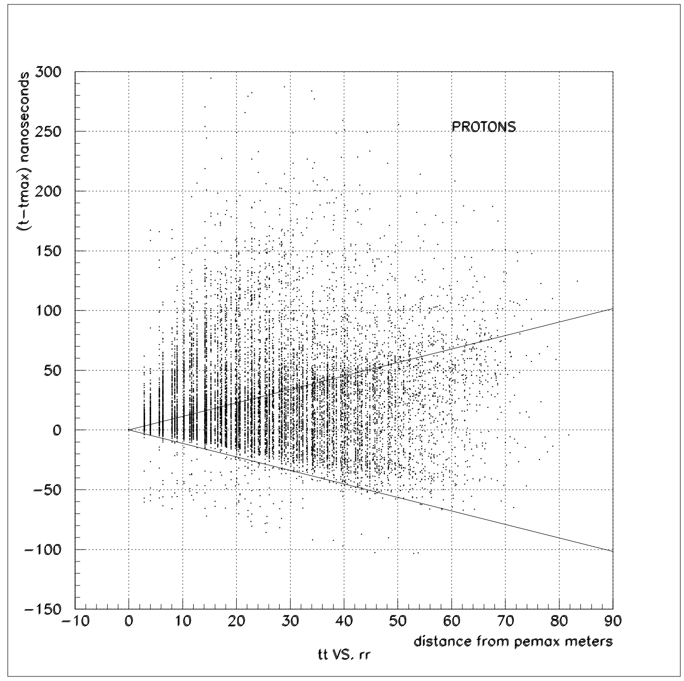


Figure 6:Protons between 10-20 deg

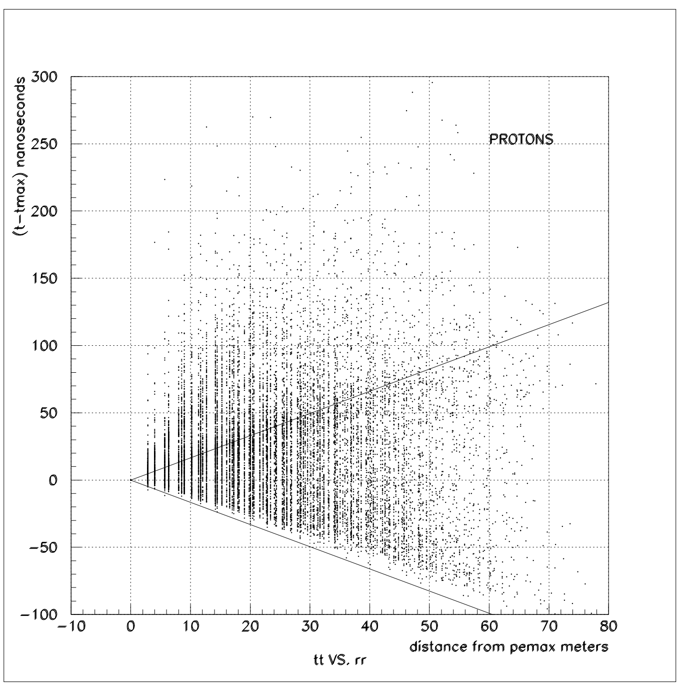


Figure 7:Protons between 20-30 deg

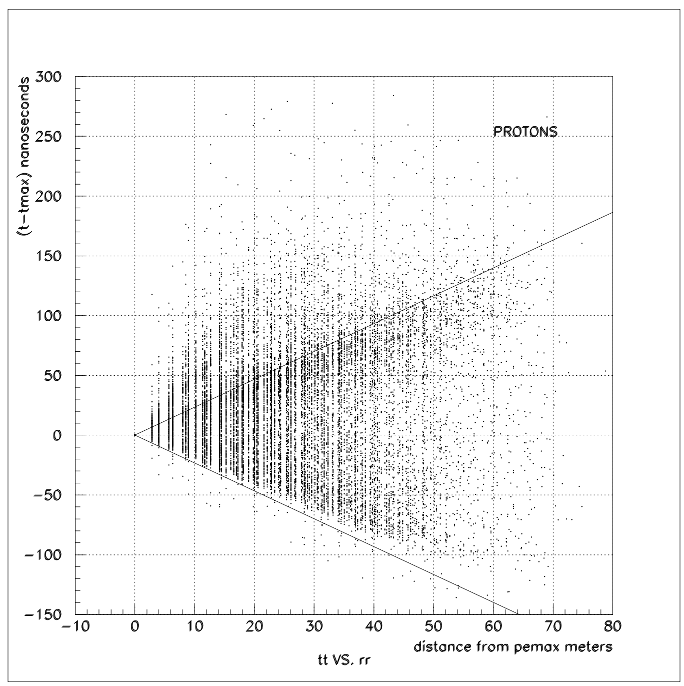


Figure 8:Protons between 30-45 deg

Similar plots for gamma primaries in Figures 9 through 12.

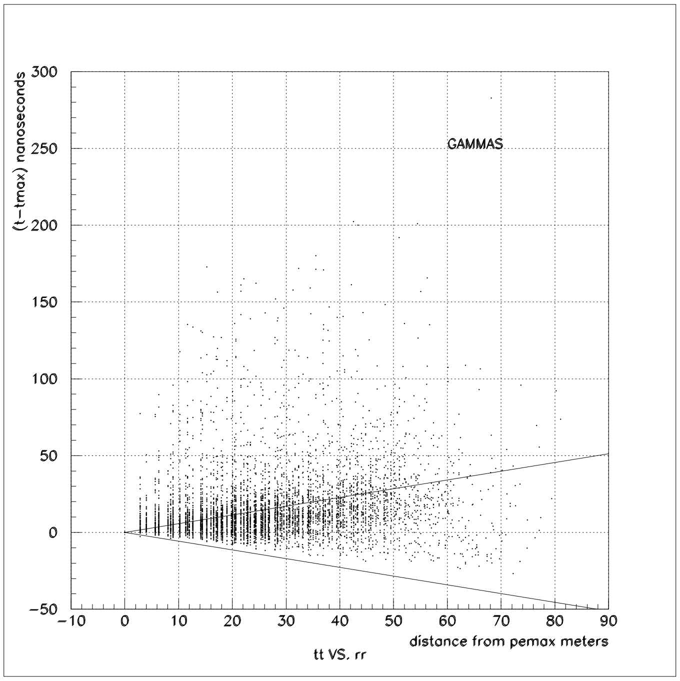


Figure 9:Gammas between 0-10 deg

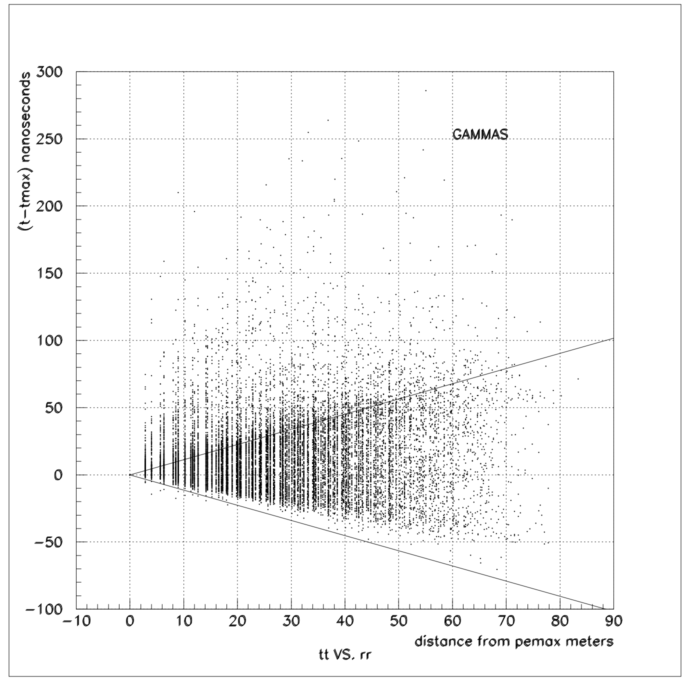


Figure 10:Gammas between 10-20 deg

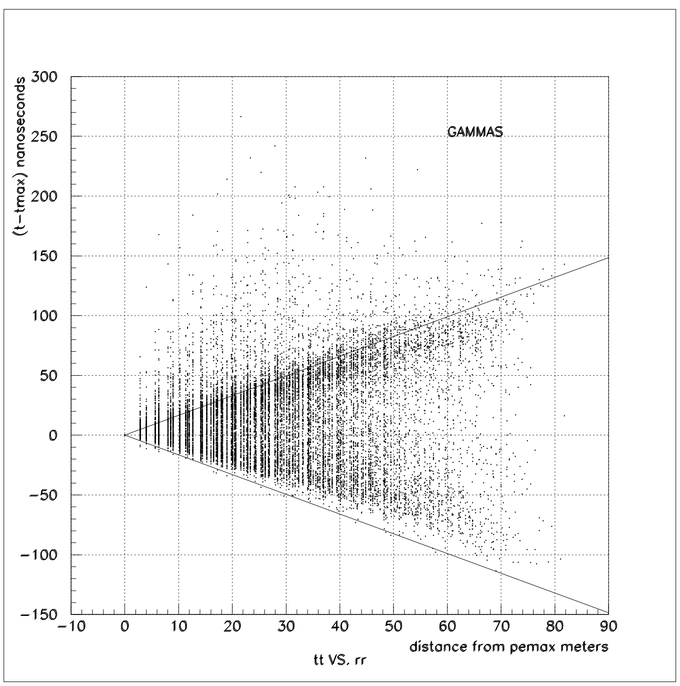


Figure 11:Gammas between 20-30 deg

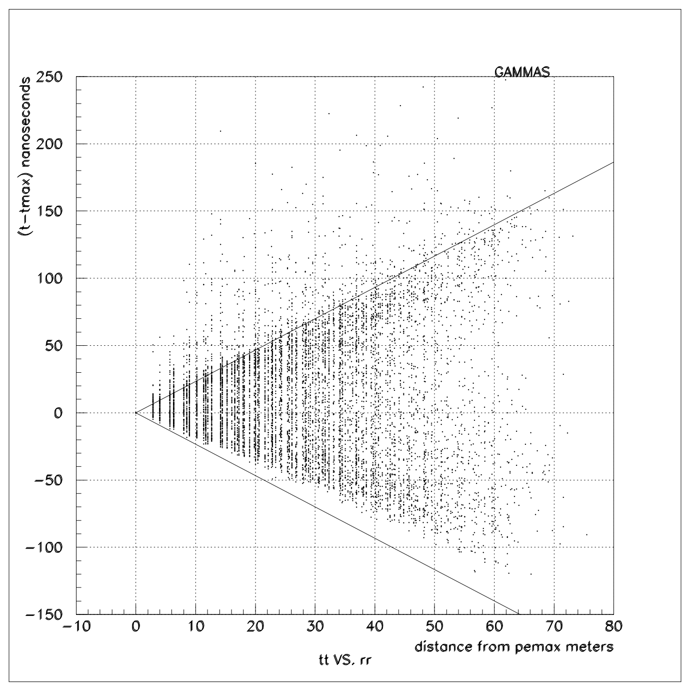


Figure 12: Gammas between 30-45 deg

To compare with these distributions of simulated events with what is observed in the data, saturation of the pemax tube was corrected approximately and then plots similar to the above for Milagro data are shown in figures 13-16

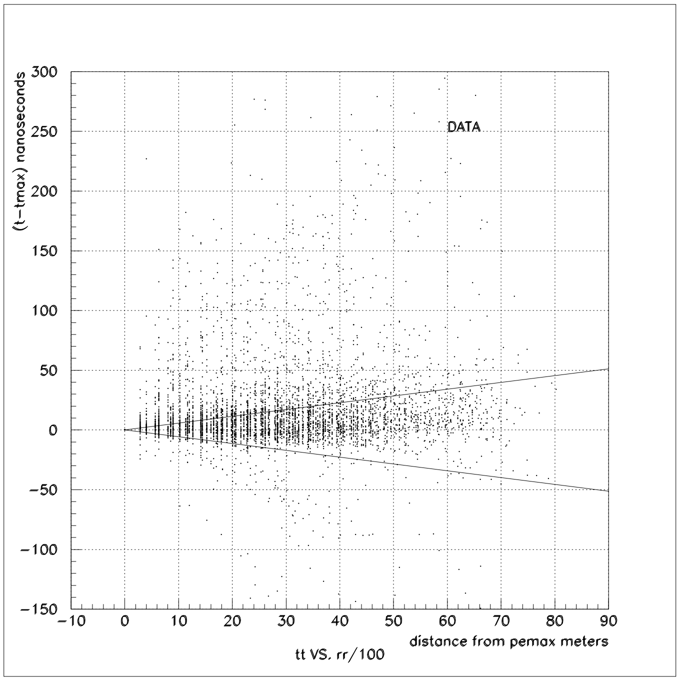


Figure 9:Data between 0-10 deg

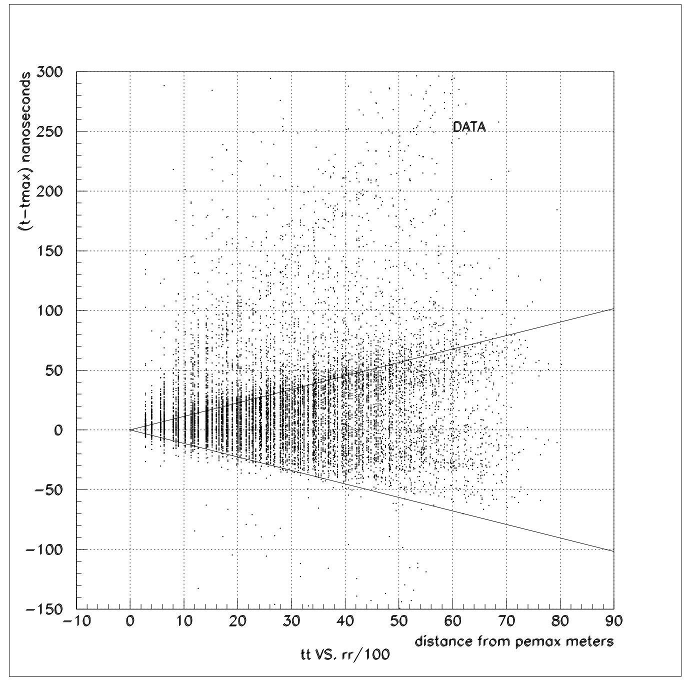


Figure 10:Data between 10-20 deg

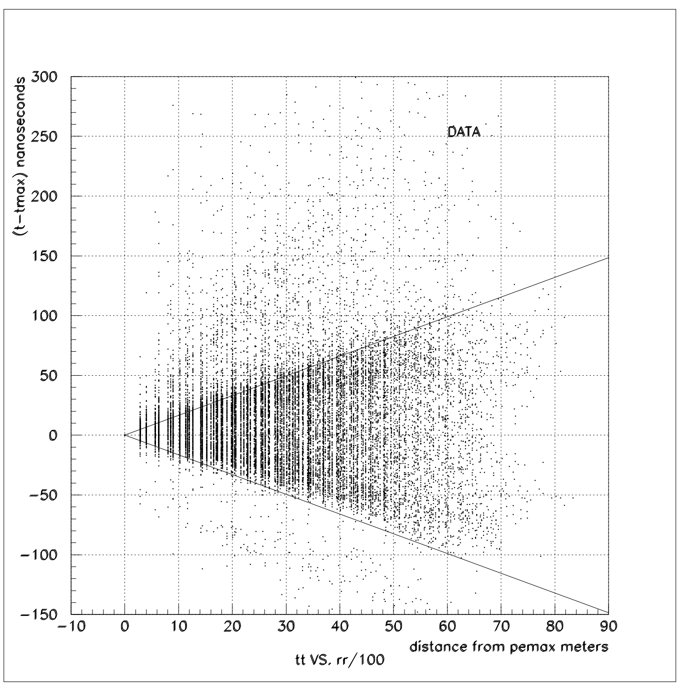


Figure 11:Data between 20-30 deg

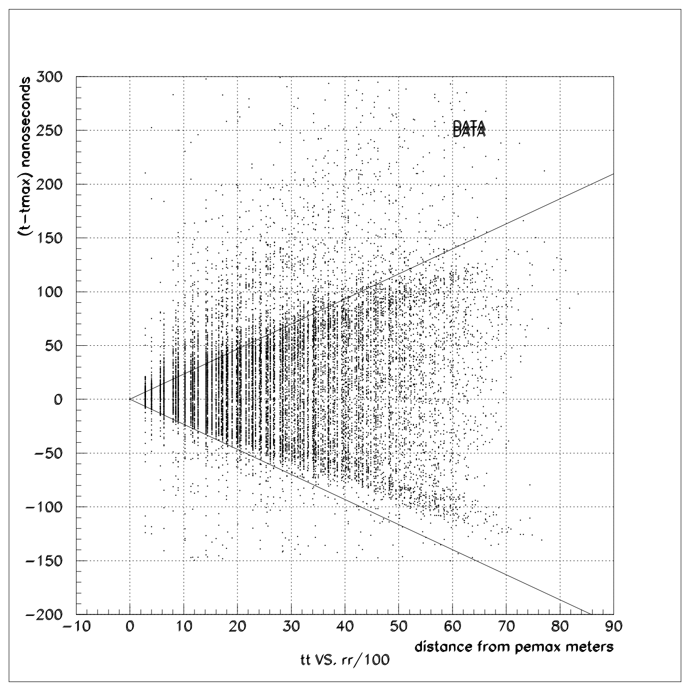


Figure 12: Data between 30-45 deg

3 Cuts imposed on Data

The cuts we apply to data have been designed to retain good hits around the shower, identify out of time large hits and cut out hits which correspond to hits from light travelling with the speed of light in water.

1. Finding the median time of particle swarm and selecting hits associated with the swarm:

   First we order all hit times with respect to time of the hottest tube in the shower layer (in most cases the hottest tube should be the earliest tube). Then the median time for all hits, tmed, is calculated. This ordinarily corresponds to the hit time corresponding to the center of the shower swarm. We also calculate the times which contain 90 percent of all hits, t_5 and t_{95}. Then cuts are applied such the events retained must have

   (a) For t<tmed, (t-tmed)>(t_5-tmed)

   (b) For t≥tmed, (t-tmed)<(t_{95}-tmed)

   Then we require that the pemax time, tmax, is less than 50 ns away from the average time of tubes nearby within 10 meters of pemax, provided there are more than 2 hits in this range. Otherwise we compare tmax with tmed and make a decision whether max tube is associated with the shower.

2. Finding the new hottest tube for selected shower events:

   After this first pass, we again determine the max tube, pemax1 and its time tmax1 for the tubes which are in the shower swarm and then recalculate the t versus r distribution with respect to the new hottest tube.

3. Throwing out hits due to scattered light:

   Finally we ask which tubes are consistent with being hit due to scattered light from pemax1 and throw them out. This is done for hits which have (t-tmax1) > (-10 ns $+4.6\times$ r(m)).

   This procedure was applied to both simulations and data. Simulations showed that space angle difference was unaffected for majority of the showers(see Figure 4) when these cuts were applied.

   Applying the cuts to the data, recovered about 80% of nofits. The cut effects mostly large angle events as seen from the figures 5 through 12.

Next we show the characteristics of some representative no-fit events that were recovered by this method.

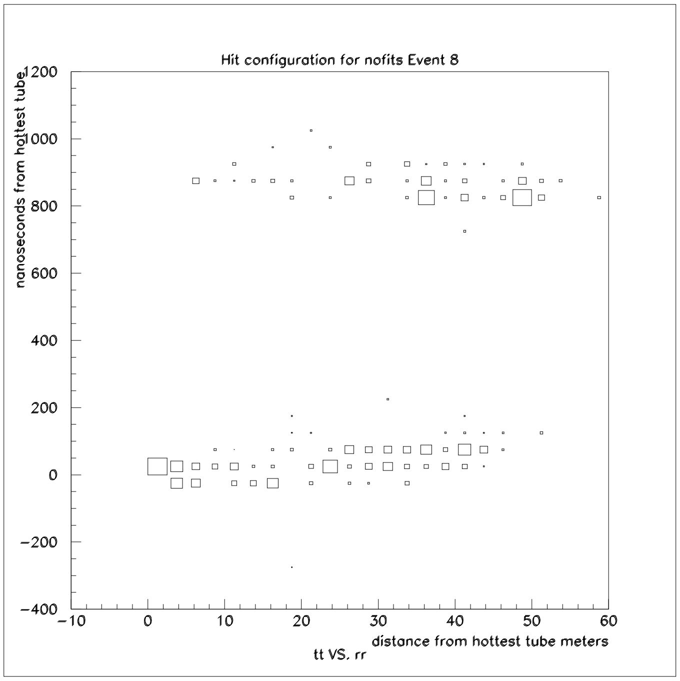


Figure 13:Event 8 hit config

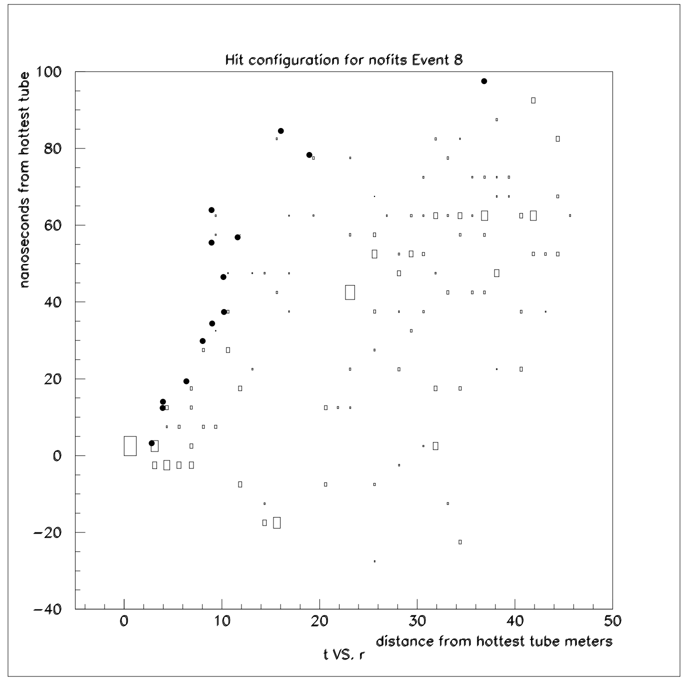


Figure 14: Event 8 usable hits

Figure 13 shows hittimes versus distance from the hottest tubes before any cuts have been made for event 8. In this events two showers hit the pond during the data gate. The largest tube is seen to belong to the early shower. Figure 14 shows the result of applying cuts to this data set. The zero time corresponds to the new hottest tube. The fitted zenith angle for this event was 20°.

Figures 15 and 16 are similar plots corresponding to event 9. Zenith angle for this event is 36°.

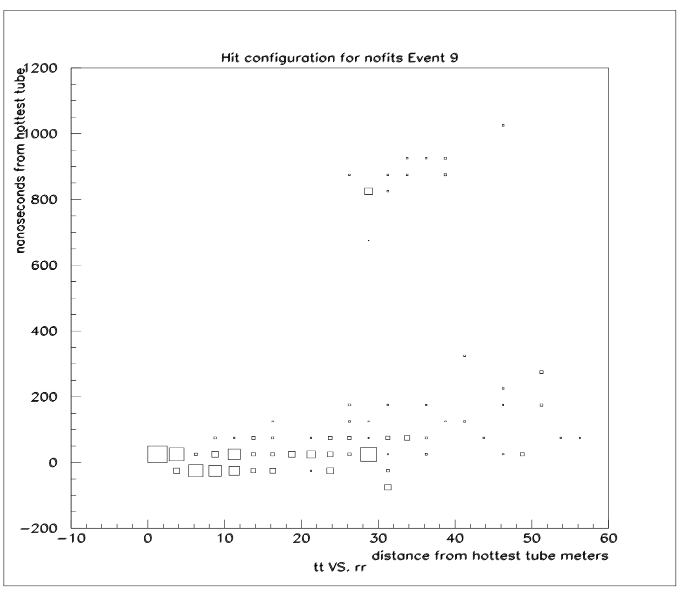


Figure 15:Event 9 hit config

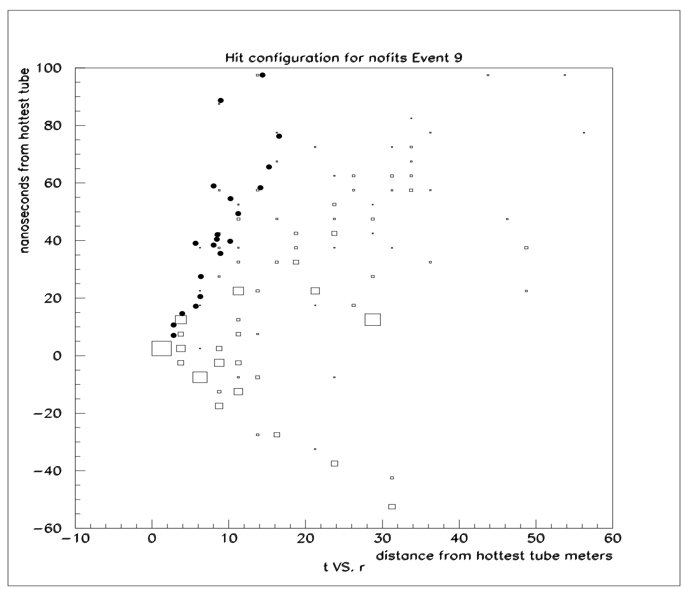
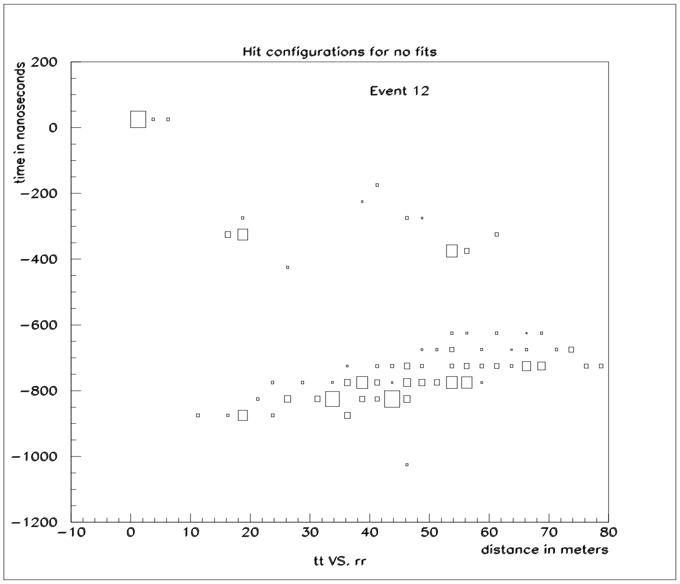


Figure 16: Event 9 usable hits

Figures 17 and 18 are similar plots corresponding to event 12. Zenith angle for this event is 45°.



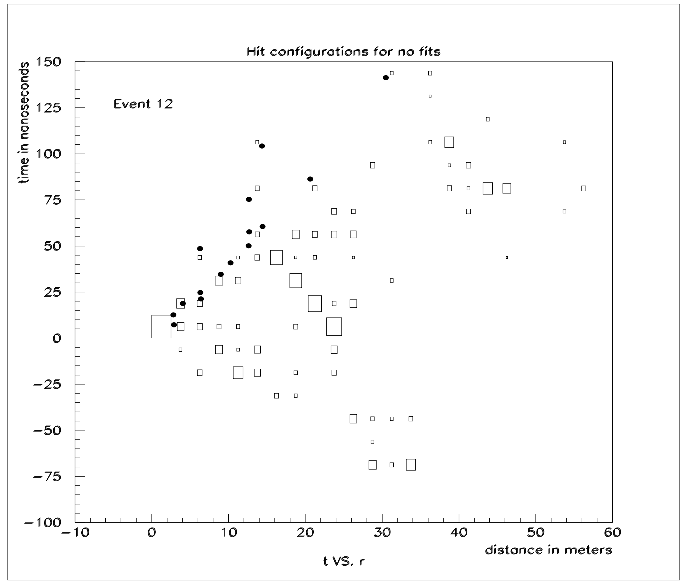
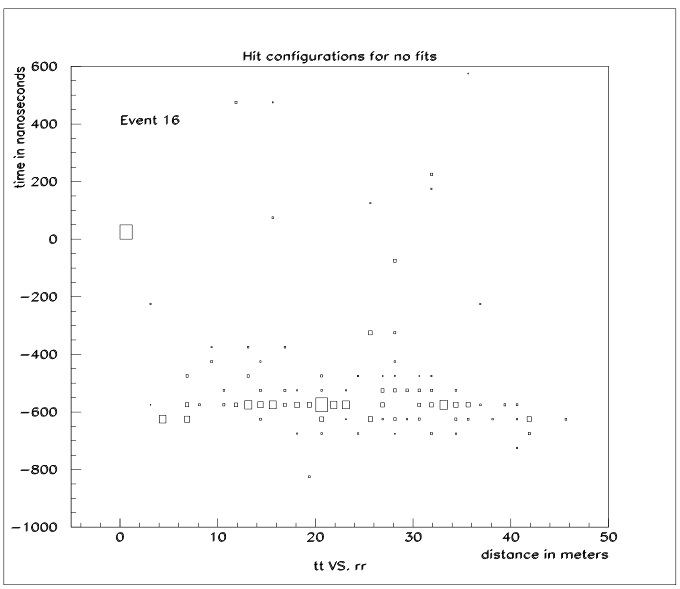


Figure 17:Event 12 hit config

Figure 18: Event 12 usable hits

Figures 19 and 20 are similar plots corresponding to event 16. Zenith angle for this event is 26°.



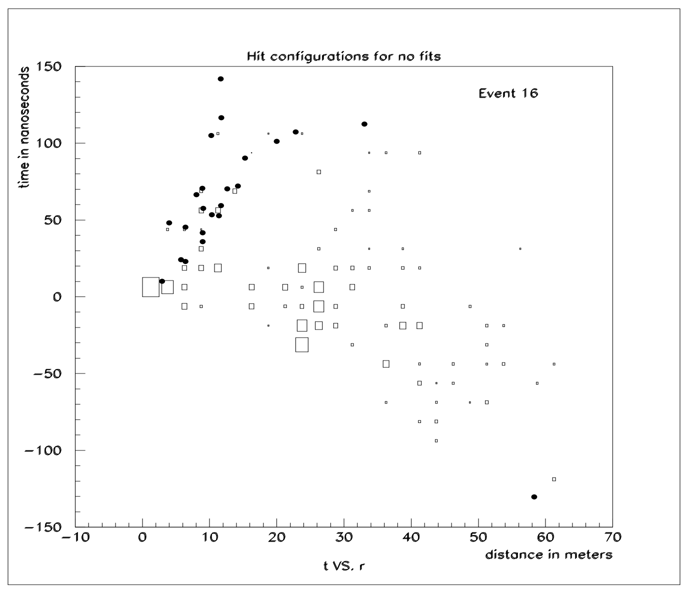
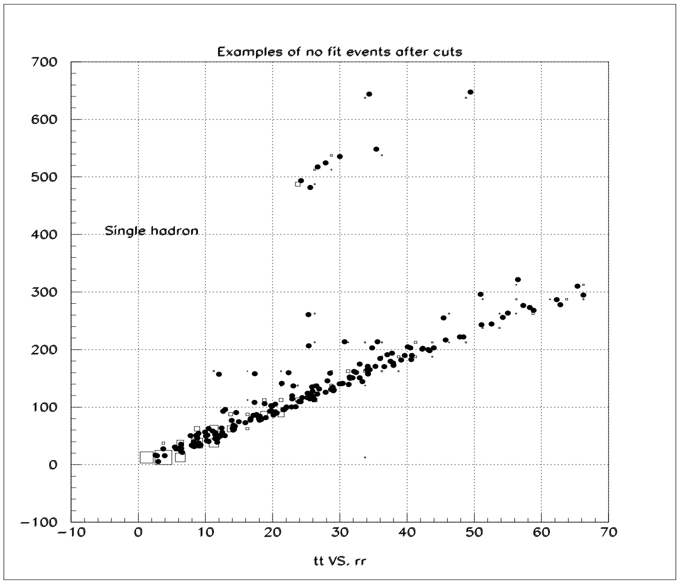


Figure 19:Event 16 hit config

Figure 20: Event 16 usable hits

In Figures 14,16,18 and 20 the large black dots correspond to hits which correspond to speed of light in water travel time from the hottest tube. These hits were rejected before calculating the final angles.

Events which do not have a fit before or after cuts are generally single hadrons or horizontal muons. An example of a single hadron event and an example of a horizontal muon event are shown in Figures 21 and 22.



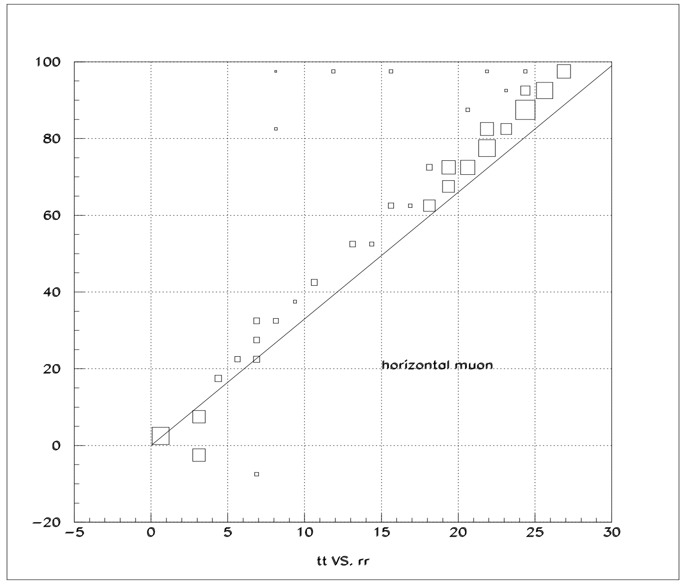


Figure 21:A single hadron

Figure 22: A horizontal muon

The straightline in Figure 22 corresponds to speed of light trace with respect to the hottest hit - hittimes corresponding to an almost horizontal muon traversal of the air shower layer.

4 Conclusion:

We have shown that event hit pattern can be cleaned up by a simple procedure to eliminate (1) acausal hits due to accidental coincidences, and (2) some of the ' scattered light hits'. Application of the same cuts to simulated events shows that the reconstructed angles are essentially not biased by these cuts. A large fraction of the events which fail on-line reconstruction are recovered by this procedure. For a data sample of 140,000 events there were 5498 nofits for on-line reconstruction and out of these 4376 or 88 percent were recovered by the procedure outlined here. Those events which failed even after these cuts were applied fell into two major categories: single hadron triggers and triggers due to almost horizontal muon traversals. These two types of events occurred with similar probablities(not shown).

We are working on applying these cuts to Crab data to see if the angular resolution can be improved.