An Analysis of a Time of Flight System for E907

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As noted in the proposal for E907, there is a gap in the particle identification of the experiment for particles with momentum between 0.7 GeV/c and 2.7 GeV/c. This gap is to be filled with a Time of Flight (TOF) counter. Below a momentum of 0.7 GeV/c, the dE/dx measurement in the TPC provides 3σ separation of the K's and π's. While above that momentum, the Cherenkov counter provides the separation.

Using the GEANT based hn_geant Monte Carlo code, I have looked at the requirements on the TOF system that would be desirable. There are three issues that need to be considered: the size and placement of the scintillator, the timing resolution of the counters, and the segmentation of the counters. I will discuss the first two of these issues and save the last for a later discussion.

Location and Size

To study this in the Monte Carlo, I chose four locations to implement TOF counters as full thin planes extending out to the edges of the master volume in GEANT. The four possible TOF locations were: right after the TPC and Jolly Green Giant magnet, just before the second magnet, just after the second magnet and right before the RICH. Every time a particle crossed one of the planes, a hit was recored and the time, path length, type of particle, position, momentum, etc. were written out to an ntuple for later off-line processing. In addition, thin planes were added at each of the six faces of the master CAVE volume to detect the particles which escaped. This was necessary because, as the TOF plane moved down stream of the targets, a larger number of particles were escaping.

We first examine the locations farthest from the target, since they will not require as strict timing resolution as the closer locations. Immediately a problem is noticed if we look after the second magnet. We can clearly notice the shadow of the magnet steel when we plot the positions of the hits. This can be seen in Figure 1. When this is compared with the hits seen immediately before the second magnet, as shown in Figure 2, it is clear that a large number of particles are being absorbed in the magnet steel. Hence if we wish to achieve particle

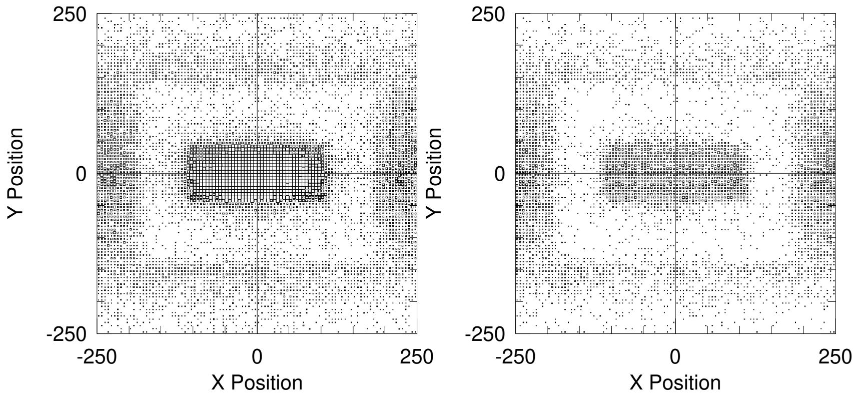

Figure 1: The distribution of hits immediately after the second magnet. The plot on the left is for all tracks while the one on the right only shows hits from tracks with momentum between 0.7 and 2.7 GeV/c. The scale on the X and Y direction is in centimeters.

identification on particles in the momentum range where only the TOF will provide particle ID, 0.7 - 2.7 GeV/c, we need to be before the second magnet. In the hn_geant simulation, it is placed at z= -251 cm, which is about 3.3m upstream of the Jolly Green Giant Magnet. This location is roughly the one specified by the proposal as well as the one which gives the largest time difference between particles without suffering from the loss in the steel.

The next question is the required size of the TOF scintillator. Examining Figure 2(b), we note that the particles of interest are hitting the plane over the whole x region. When looking at those hits along the side walls of the CAVE volume in Figure 3, we see particles of interest are escaping from the simulation. To get an estimate of the true size of the region hit by the particles of interest, we use the hits immediately after the Jolly Green Giant (JGG) magnet. The distribution of hits after that magnet is shown in Figure 4. These hits are simply propagated to the plane before the second magnet using their momentum at the TOF plane immediately after the JGG. This should be valid as there is no magnetic field in the region through which the tracks are propagated. The distribution resulting from this propagation is shown in Figure 5. Here we see that an ideal detector is about 300cm in Y and up to 900cm in X. Of course smaller detectors would simply not measure some of the particles on the fringes.

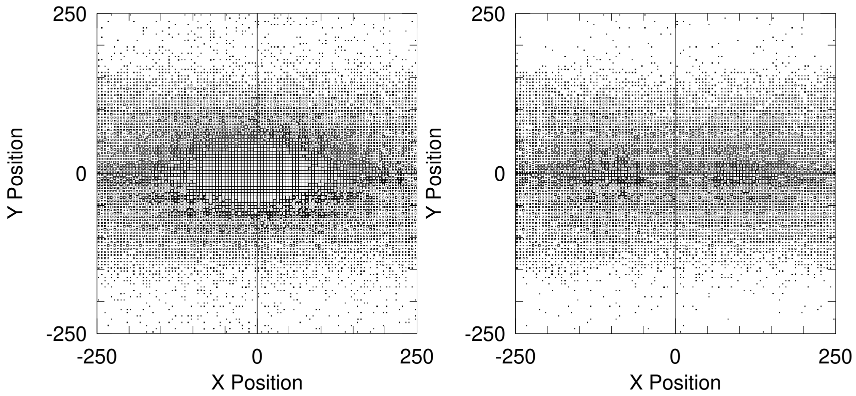

Figure 2: The distribution of hits immediately before the second magnet. The plot on the left is for all tracks while the one on the right only shows hits from tracks with momentum between 0.7 and 2.7 GeV/c. The scale on the X and Y direction is in centimeters.

Time Resolution

We next look into the timing properties required for the detector. Using the same ntuple written out by the hn_geant Monte Carlo simulation, the raw time of the hits at the TOF plane do not exhibit a clean peaking structure. We show the plot of the hit times for the π's in Figure 6. The large variation in hit times are a result of differing path lengths depending upon where the particle hit on the plane. A plot of the path lengths for the tracks from particles with momentum between 0.7 and 2.7 GeV/c is shown in Figure 7. This path length difference can be normalized by scaling the time to a 700cm path length and correcting for the proper t_0 of the interaction point. When this is done we see very sharp time spectra which is a direct function of momentum as shown in Figure 8.

Now to estimate the desired time resolution, we observe that at low momentum the separation in the time the track arrives at the TOF counter is larger than at the higher momentum. Thus one considers the highest momentum range of interest. Having the true time of flight for the particle from the Monte Carlo allows us to consider various resolutions for the detector. To estimate the effect upon particle identification, the true time is smeared by the assumed resolution of the detector, R_d. We have both the initial time of the primary interaction, t_0, as well as the time the track passed through the plane, T_d. Thus to calculate the time of flight we use:

$$T = ((T_d + G_1 * R_d) - (t_0 + G_2 * R_0)) * (700.0/s)$$

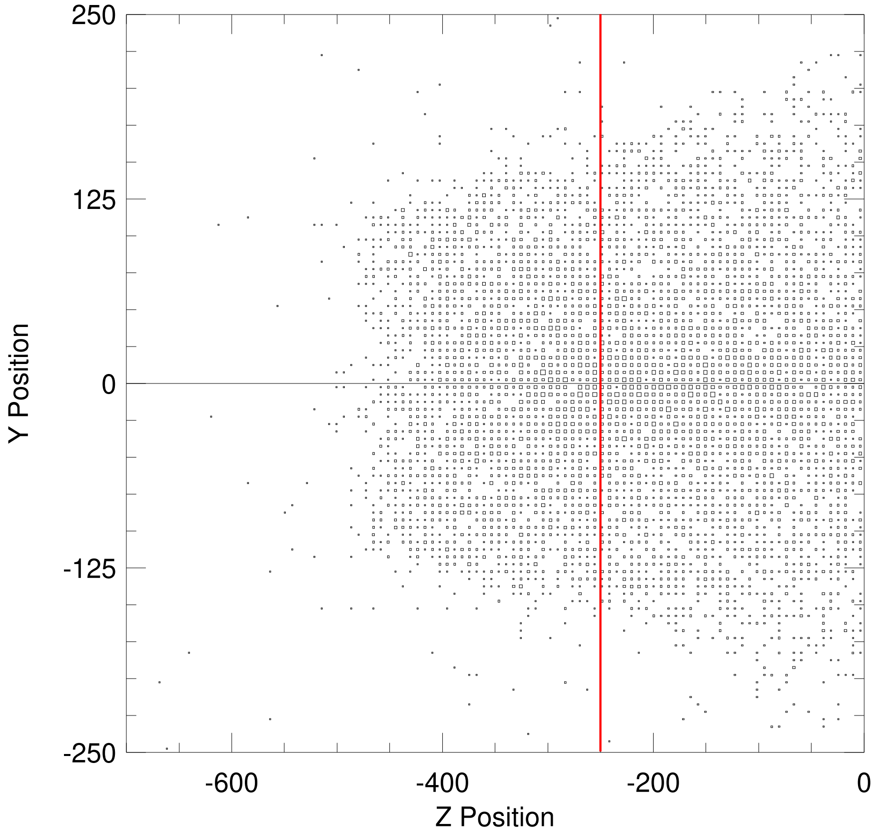

Figure 3: The distribution of hits on the side wall of the master volume. immediately before the second magnet. The plot only shows hits from tracks with momentum between 0.7 and 2.7 GeV/c. The scale on the Z and Y direction is in centimeters. The red vertical line shows the location of the scintillator right before the second magnet.

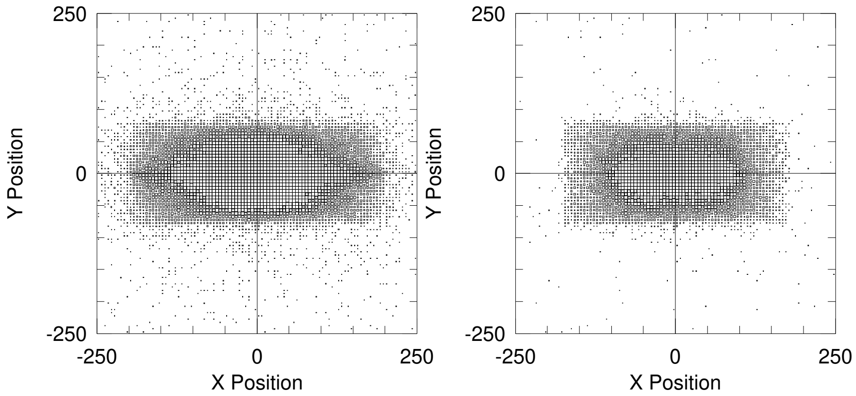

Figure 4: The distribution of hits immediately after the Jolly Green Giant magnet. The plot on the left is for all tracks while the one on the right only shows hits from tracks with momentum between 0.7 and 2.7 GeV/c. The scale on the X and Y direction is in centimeters.

where T is the normalized time of flight, R_0 the resolution of the time for the primary interaction, s is the track length from the primary interaction point, and G are random numbers with a unit Gaussian distribution. The first issue arises about how well one can know t_0, the time of the primary interaction and the start of measuring the track length. The position of the primary interaction correlates extremely well with t_0 and thus a modest knowledge of the primary interaction point, $\sim$ 3mm will only contribute 10ps to the resolution, a negligable amount. A more important source is simply the knowledge of when the primary proton enters the target. Here it is assumed that no significant knowledge is obtained from the beam-line but only from another piece of scintillator which is placed into the beam. The resolution of this measurement is accounted for by the R_0 smearing term added to the t_0 in the equation above. Since it is likely to be a smaller piece of scintillator, one might hope for a better resolution, but this is by no means certain. Of course precise knowledge of when the beam arrives from the beam-line would be even better.

Now it is time to examine the result of various resolutions for the TOF counters and how that effects the ability to resolve K's, π's, and protons. In Figures 9–11, the resulting distribution of hit times for the three particle types in the highest momentum bin is shown for resolutions of 50ps, 100ps, and 150ps on each of the two times, t_0 and the detector hit time. Of course at lower momentum even the 150ps resolution provides good separation between the particles as shown in Figure 12. Using this data, we can obtain the separation between the pions and kaons for various momentum bins as a function of various resolutions as shown in Table 1. The separations given in the table are calculated

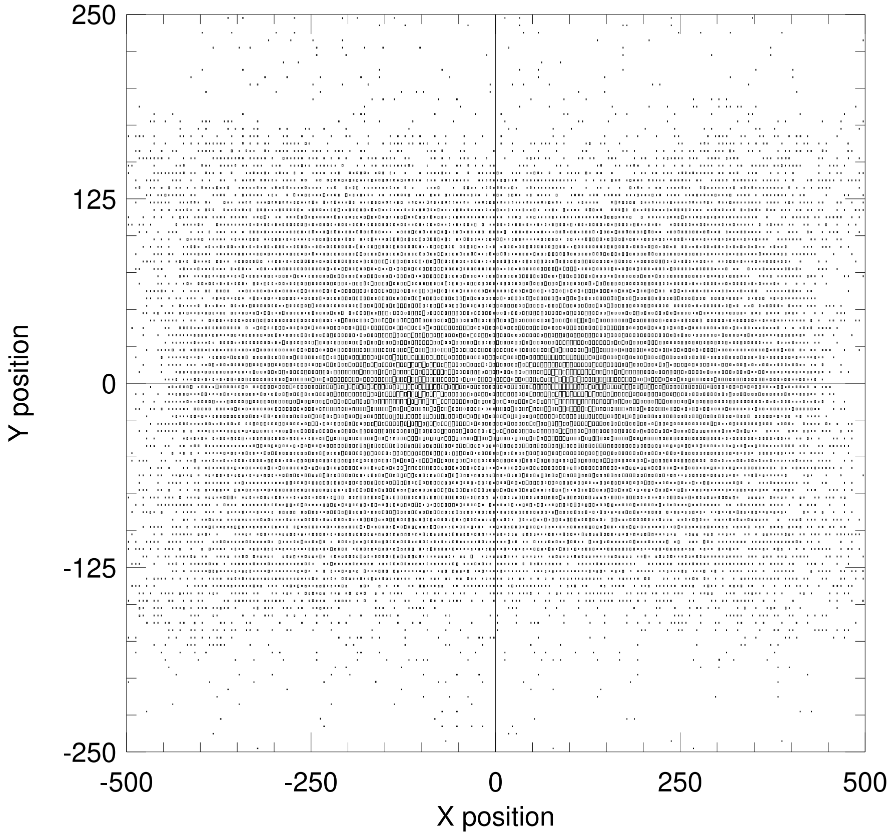

Figure 5: The distribution of hits immediately before magnet. The plot only shows hits from tracks with momentum between 0.7 and 2.7 GeV/c, which where projected from after the JGG magnet. The scale on the X and Y direction is in centimeters.

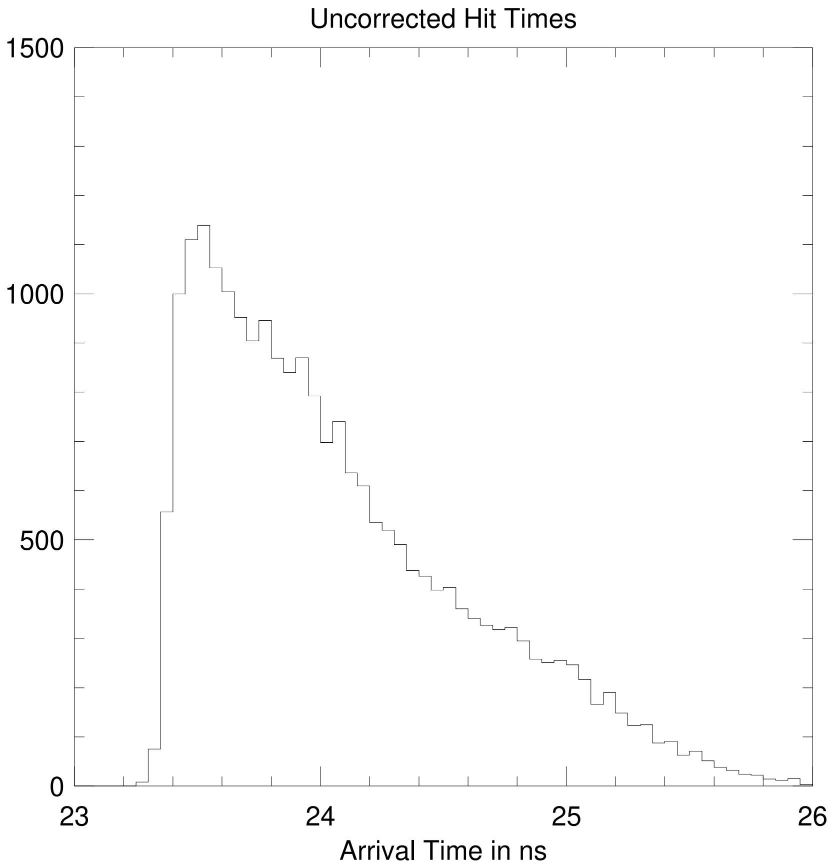

Figure 6: The unnormalized hit times for pions at the TOF counter.

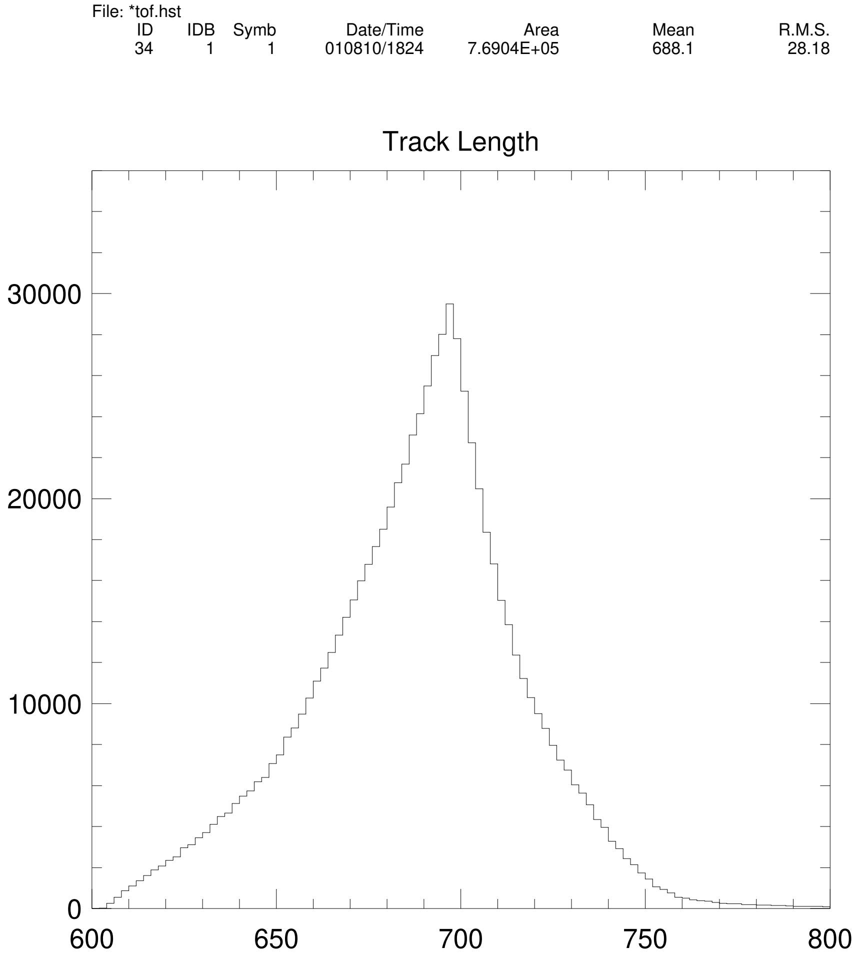

Figure 7: The distribution of track lengths for the tracks having hit the TOF counter. Here we have only used tracks coming from the target and in the desired momentum range.

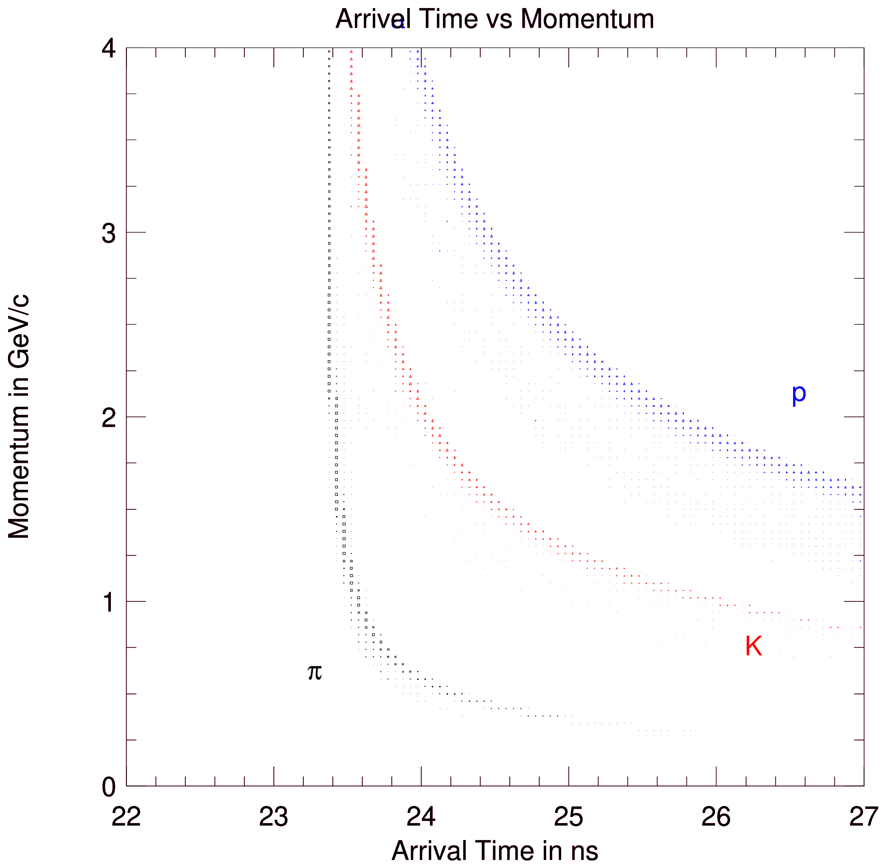

Figure 8: The normalized hit times as a function of momentum for π's in black, kaons is red and protons in blue. These times have no detector resolution effects included.

Momentum	Resolution						
(GeV/c)	50ps	100ps	150ps	0ps,100ps	50ps,100ps	0ps,150ps	50ps, 150ps
1.0 - 1.33	5.3	4.7	4.0	5.1	5.0	4.7	4.6
1.33 - 1.67	5.6	4.1	3.1	5.0	4.7	4.0	3.8
1.67 - 2.0	5.4	3.3	2.3	4.4	4.0	3.2	3.0
2.0 - 2.33	4.4	2.5	1.7	3.5	3.1	2.4	2.3
2.33 - 2.67	3.6	2.0	1.3	2.7	2.4	1.8	1.8
2.67 - 3.0	2.9	1.5	1.0	2.1	1.9	1.4	1.4

Table 1: Separation achieved for various timing resolutions. When there are two resolution values given, the first is the beam resolution and the second is the detector resolution. If only one resolution is given, it is assumed for both. The values in the table are separations given in terms of sigmas as described in the text.

by dividing the difference in the means by the sum in quadrature of the two RMS widths. Assuming the 100ps mentioned in the proposal is valid for both the plane and the initial time, the distribution of hits as a function of momentum is shown in Figure 13, but this resolution does not give 3σ separation at the high end of the momentum range.

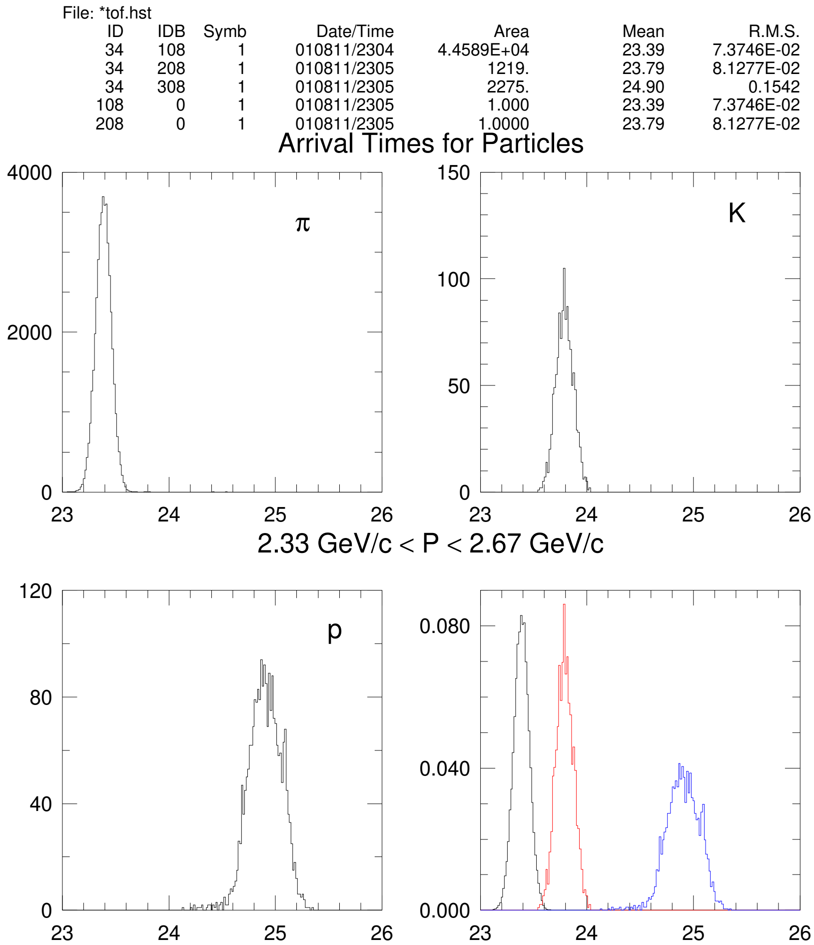

Figure 9: The normalized hit times for pions, kaons and protons assuming 50ps resolution on the detector and initial times. The last plot show all three species on one plot with the all three distributions normalized to unit area. The pions are shown in black, kaons in red and protons in blue. In all four plots we have restricted ourselves to tracks with a total momentum between 2.33 GeV/c and 2.67 GeV/c.

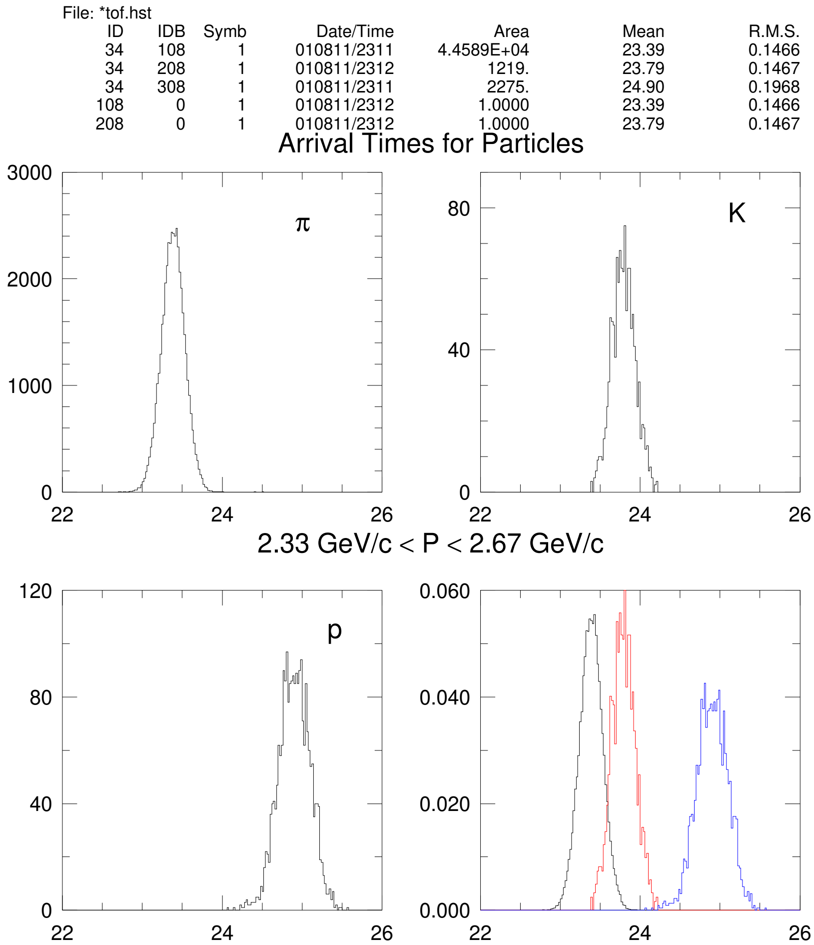

Figure 10: The normalized hit times for pions, kaons and protons assuming 100ps resolution on the detector and initial times. The last plot show all three species on one plot with the all three distributions normalized to unit area. The pions are shown in black, kaons in red and protons in blue. In all four plots we have restricted ourselves to tracks with a total momentum between 2.33 GeV/c and 2.67 GeV/c.

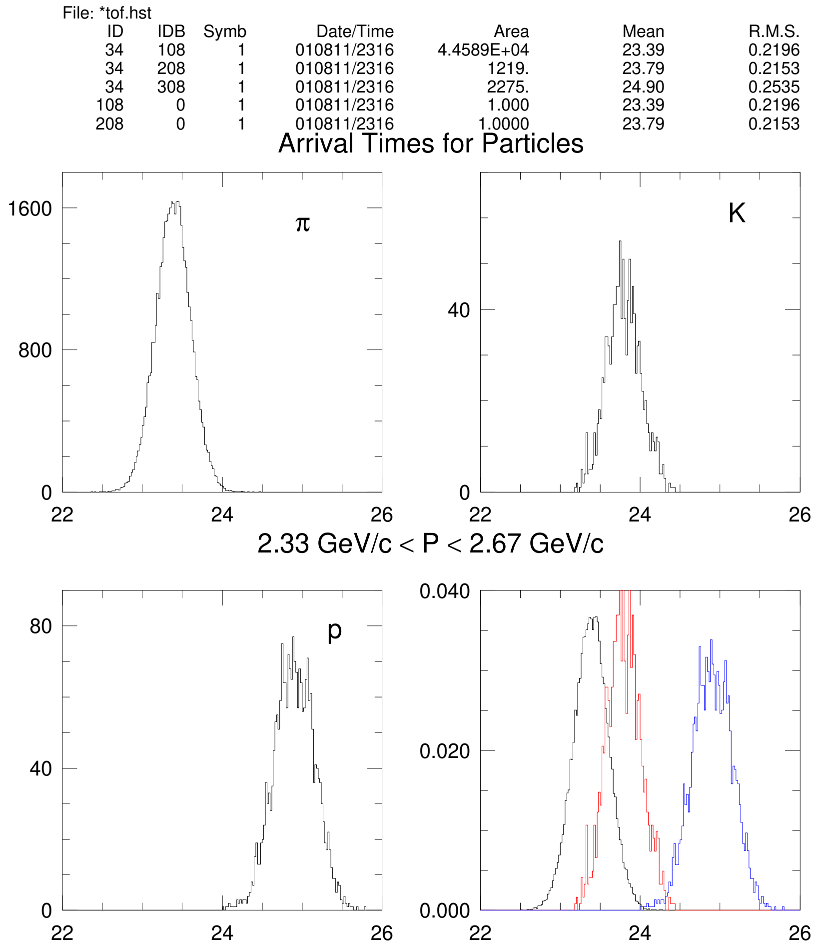

Figure 11: The normalized hit times for pions, kaons and protons assuming 150ps resolution on the detector and initial times. The last plot show all three species on one plot with the all three distributions normalized to unit area. The pions are shown in black, kaons in red and protons in blue. In all four plots we have restricted ourselves to tracks with a total momentum between 2.33 GeV/c and 2.67 GeV/c.

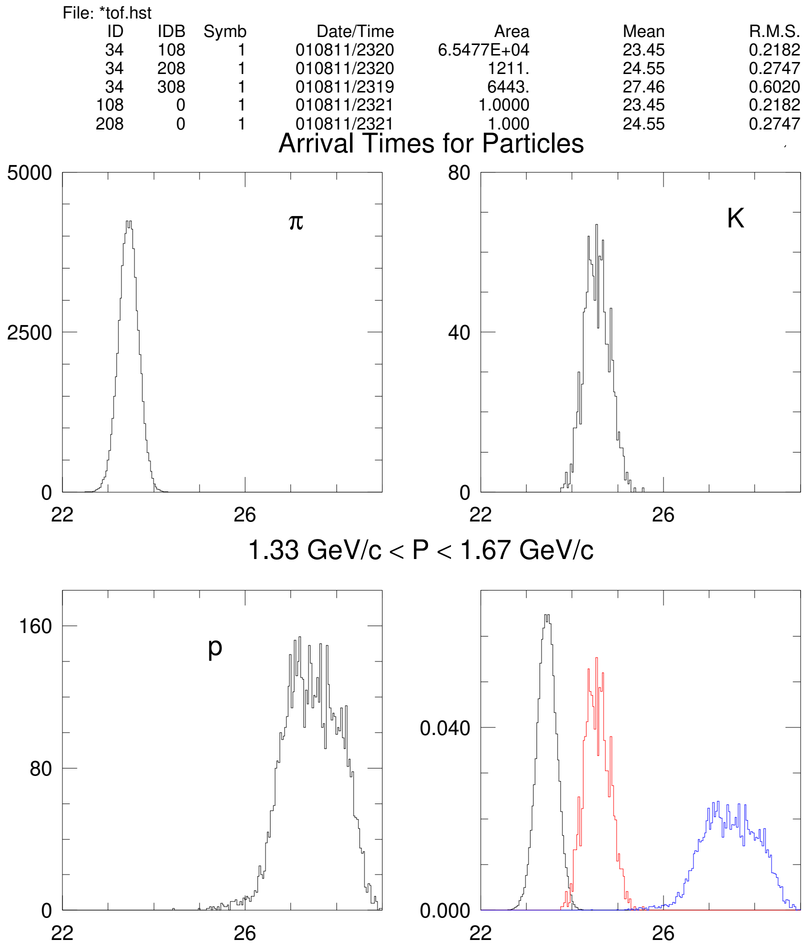

Figure 12: The normalized hit times for pions, kaons and protons assuming 150ps resolution on the detector and initial times. The last plot show all three species on one plot with the all three distributions normalized to unit area. The pions are shown in black, kaons in red and protons in blue. In all four plots we have restricted ourselves to tracks with a total momentum between 2.33 GeV/c and 2.67 GeV/c.

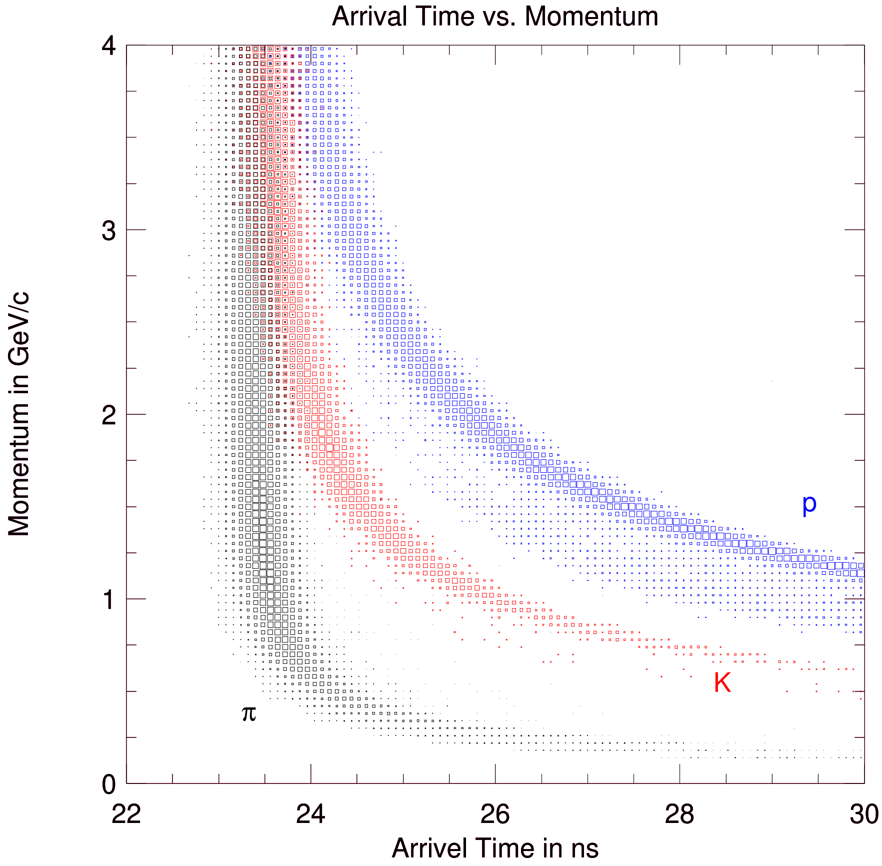

Figure 13: The normalized hit times as a function of momentum for π's in black, kaons is red and protons in blue. These times have assumed a detector resolution or 100ps on the detector and initial times.