Reducing Background in the τ neutrino mass limiting decay $\tau^{\pm} \rightarrow K^{\pm}K_s\rho^0\nu_\tau$

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Abstract

The search for a limit to the mass of the neutrino, one of nature's least understood particles, is a fundamental problem in particle physics, and its results have implications in the fields of particle physics, astrophysics, and cosmology. Of the three neutrino flavor masses, the τ neutrino mass is least constrained by direct measurement, with the most stringent limit at present being the ALEPH Collaboration's value of 18.2 MeV at the 95% confidence level [2]. Another more recent measurement by the CLEO Collaboration has a less restrictive limit of 28 MeV at the 95% confidence level [3]. This study hopes to improve that upper limit, using an alternate procedure that requires very high statistics and excellent particle identification.

A search for the decay $\tau^{\pm} \rightarrow K^{\pm} K_s \rho^0 \nu_\tau$ is performed using the BaBar detector at the PEP-II electron-positron collider at the Stanford Linear Accelerator (SLAC). The estimated branching fraction for this decay with the sum of the invariant masses of the pions greater than or equal to 770 MeV, the central mass of a ρ^0, is very small (approximately between 4×10^{-8} and 4×10^{-10}). BaBar, with its large effective cross section for τ pairs, its high luminosity, and its kaon identification capability, is an ideal detector to search for these τ decays, which could help place a more restrictive limit on the τ neutrino mass.

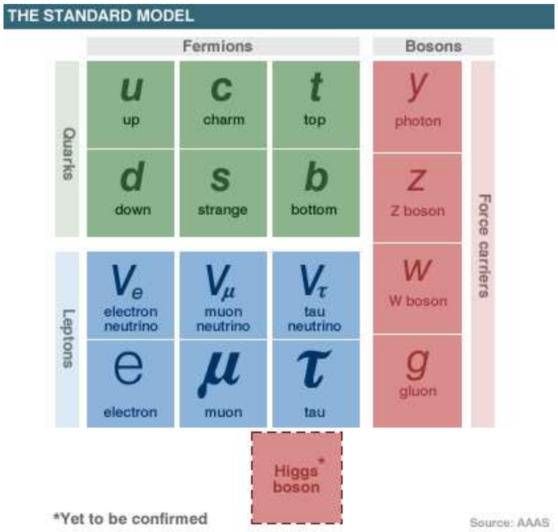
Contents

List of Figures

List of Tables

1 Introduction

1.1 The Standard Model of Particle Physics



*Yet to be confirmed

Source: AAAS

Figure 1: The Standard Model of Elementary Particles

The current Standard Model of Particle Physics is shown in the diagram above. Elementary particles can be classified as *fermions*, which are particles that have a half integer spin, and *bosons*, particles that have an integer spin. In the Standard Model, matter particles, all of which are fermions, are further subdivided into quarks and leptons. The lepton family consists of the electron, the muon and the tau, and the chargeless neutrinos. The leptons fall naturally into three families or generations, arranged by increasing mass. The electron, one of the major constituents of matter, is the lightest of the three, and is a first generation lepton. The muon is found in cosmic rays, and along with its neutrino μ_τ makes up the second generation of leptons. The tau lepton has the largest mass of the three, and is created only in particle accelerators. All matter particles have their own anti-particles, which have the same mass and spin as their corresponding particle, but carry opposite charge. There are six quarks: up, down, strange, charmed, top and bottom, denoted by u, d, s, c, t, b (and three 'colors', which are not shown). These particles, like the leptons, fall into three generations. Quarks, unlike leptons, do not naturally exist individually, but combine to form heavier particles called hadrons. A hadron consisting of a quark and an anti-quark is called a meson. Mesons have an integer spin, and are thus bosons. A hadron made up of three quarks is called a baryon. The proton and neutron are the two most common examples of baryons. Baryons have half integer spin and are thus fermions. The Standard Model also includes force carriers, or gauge bosons. The word boson indicates that all these particles have integer spin. The boson that mediates the electromagnetic force, for example, is the photon, a neutral, massless particle. Another fundamental force is the strong force, which binds quarks together to form hadrons. This force is mediated by bosons called gluons, of which there are eight in total. The weak force is mediated by the $W^{\pm}$ and Z^{0} bosons, which are massive and, in the case of the $W^{\pm}$, are charged. The Standard Model does not account for the gravitational force.

1.2 PEP-II Asymmetric B factory

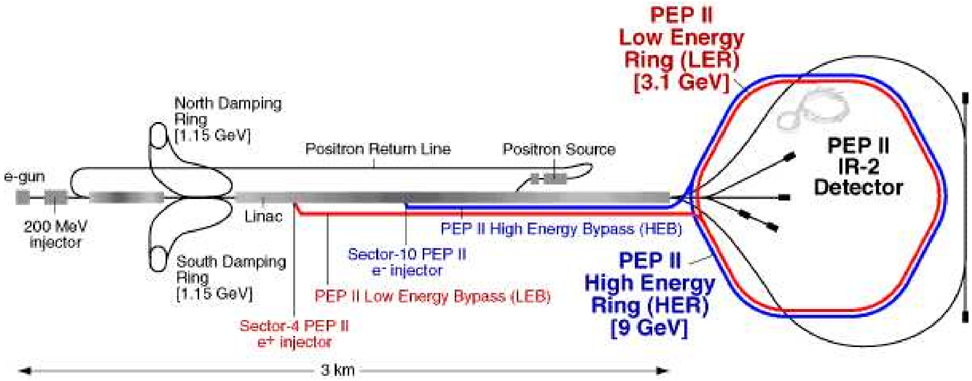


Figure 2: PEP-II Collider

The PEP-II is an asymmetric e^+e^- collider, which operates at the $\Upsilon(4S)$ resonance. Part of the 3 km linear accelerator at SLAC (Linac) acts as the injector, supplying high energy electrons and positrons which are stored in two independent rings, one on top of the other, as seen in the diagram. The electron beam is at a higher energy of 9 GeV, while the positron beam is at an energy of 3.1 GeV. This difference in energies creates a moving collision center of mass (the B^0 mesons resulting have significant momenta in the laboratory frame, although they are almost at rest in the center of mass (CM) frame), which is essential in the study of charge-parity (CP) violating decays.

1.3 The BaBar Detector

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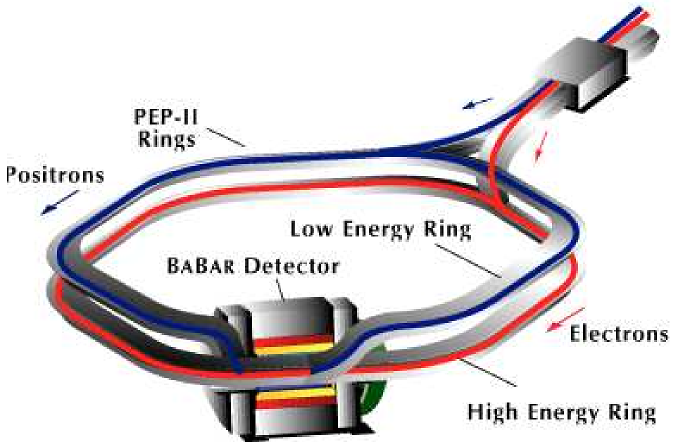

Figure 3: BaBar Detector

The electrons and positrons from the PEP-II rings collide head-on at the BaBar detector, as shown above in Figure 3. The BaBar detector was constructed primarily to study CP violation in the decay of neutral B mesons. It consists of five main parts, shown in Figure 4

Silicon Vertex Tracker (SVT)

The SVT is the innermost layer of the BaBar detector, which provides precise position information on charged tracks, and is also the sole tracking device for very low-energy charged particles (for example, slow pions in D decays). Also, the SVT serves as the sole source of vertex information for particles like the K_S^0, which decay within the volume of the Vertex Tracker. Since BaBar

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[1] The description of the BaBar detector in this section is based on a much more detailed account of the detector's construction and performance in the “BaBar Physics Book” [1]

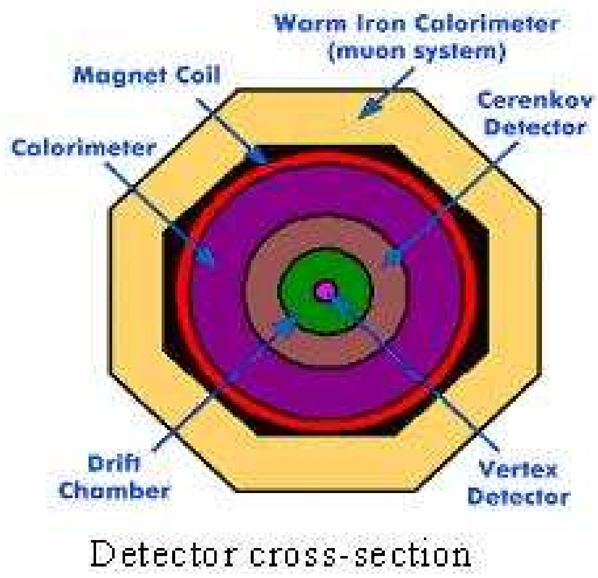

Figure 4: BaBar Detector Cross-Section

events are boosted in the forward direction, the machine components of the SVT are located in the backward region.

The Drift Chamber (DCH)

The DCH provides up to 40 measurements of space coordinates per track, assuring high reconstruction efficiency for tracks with transverse momentum greater than 100 MeV. Combined with the Silicon Vertex Tracker and the magnet coil, the BaBar tracking system provides excellent spatial and momentum resolution for the exculsive reconstruction of the CP decays of B mesons. The mechanical structure of the Drift Chamber is built using light materials and the gas mixture is helium based, in order to minimize multiple scattering. The design of the DCH, like that of the SVT, is optimized to reduce the material in the forward end.

Detector of Internally Reflected Cherenkov Light (DIRC)

The Detector of Internally Reflected Cherenkov light, or DIRC, is a new type of detector based on the phenomenon of Cherenkov radiation. Cherenkov radiation is emitted by particles travelling faster than the speed of light in a material. The DIRC relies on the detection of Cherenkov photons trapped in the radiator due to total internal reflection. The DIRC is devoted to particle identification, and in particular, provides excellent kaon identification. The DIRC radiator consists of 144 long, straight bars of synthetic quartz, arranged in a 12-sided polyogonal barrel.

Electromagnetic Calorimeter

The Electromagnetic Calorimeter (EMC) at BaBar makes use of quasi-projective CsI(Tl) crystals which point towards the interaction point (IP), and is used to detect gammas. Since many of the lower-energy gammas (that are not background) arise from the decay of neutral pions into 2 gammas ($\pi^0 \rightarrow \gamma\gamma$), the detector helps to efficiently reconstruct the π^0 with good mass resolution.

The Muon and Neutral Hadron Detector

The Instrumented Flux Return (IFR) consists of a central barrel, and two end-caps. The large iron structure is segmented and instrumented with Resistive Plate Counters (RPC's). This graded segmentation improves the identification of muons at low momentum. The active volume of the detector is filled with a gas mixture of argon and freon. It provides muon identification by detecting charged particles which penetrate a significant amount of material, and, along with the EMC, neutral hadron identification (such as ${K_L}^0$).

2 Motivation

The neutrino is one of nature's least understood particles. Since neutrinos are chargeless, and interact very weakly with matter, they cannot be detected directly in decay reactions. Their presence is inferred from energy-momentum conservation. Originally thought to be massless, recent experiments have shown that neutrinos indeed have a small but non-zero rest mass. The consequences of non-zero rest mass for neutrinos have large implications in physics and cosmology. Of the three flavor neutrinos, the τ neutrino mass is least constrained by *direct* measurement. Current upper limits include the ALEPH Collaboration's value of 18.2 MeV at the 95% confidence level [2] and a more recent measurement by the CLEO Collaboration with a less restrictive limit of 28 MeV at the 95% confidence level [3]. One possible way to place a more restrictive upper limit on the mass of the τ neutrino would be to find a single event that when kinematically reconstructed would constrain the mass of the τ neutrino by having a small difference between the observed visible mass and the known mass of the tau lepton.

2.1 The Signal Event

Tau pairs are created by the e^+e^- collisions at the BaBar detector. Each τ will then decay into other particles. The decay which is to be isolated is a τ that decays into 5 charged particles (a 5-prong decay), and is called the signal event. The hemisphere containing this decay in the center of mass frame is thus known as the signal hemisphere. For this analysis, we consider events where the other τ decays into one charged particle plus neutral particles (1-prong). This decay is known as the tag decay (in the tag hemisphere). The signal event is $\tau^{\pm} \rightarrow K^{\pm}K_s\rho^0\nu_\tau$, where the K_S decays into a $\pi^+\pi^-$ pair, and the ρ^0 is reconstructed from another $\pi^+\pi^-$ pair. Therefore the 5 charged tracks in the signal hemisphere reconstructed by the detector are 2 π^+ tracks, 2 π^- tracks, and a charged K track. The only missing track is that of the τ neutrino, which is not detected. In the tag hemisphere, the tau can either decay into a lepton (e or μ) and *two* neutrinos - one τ neutrino, and another antineutrino of the same flavor as the lepton produced. This is known as a lepton tag, and is very useful in seperating signal events from background, since a lepton produced on the tag side is strongly indicative of a τ decay. The other one prong decays considered are hadron decays where the τ decays into one charged hadrons plus neutrals, including *one* neutrino. These decays are of the following type: $\tau^- \rightarrow \pi^-\pi^0\nu_\tau$ or $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau$ ($\tau^- \rightarrow \rho^-\nu_\tau$ or $\tau^- \rightarrow \rho^-\pi^0\nu_\tau$, where $\rho^- \rightarrow \pi^-\pi^0$).

2.2 Phase Space Calculations and the ρ^0 Resonance

The branching fraction of a particular decay is the number of times the decay occurs, divided by the total number of all possible decays of the particle. It is an indicator of how likely it is that a particular decay will occur. The phase space factor (density of final states) contains kinematical information about the decay, and the higher the phase space factor, the more ways energy can be distributed among decay products, and the more likely the decay is to occur, and the higher its branching fraction. Therefore, a τ decay into one or three charged particles will have a higher phase space factor than the 5-prong signal event. The measured branching fractions for various τ decays are given in Table 1 [4].

Table 1: Measured branching fractions for various τ decays [4]

Measured Decay Mode	Branching Fraction	Phase Space Factor	Type
$\tau^- \rightarrow \pi^- \nu_\tau$	$1.11 \pm 0.012 \times 10^{-1}$	4.92	CM
$\tau^- \rightarrow \rho^- \nu_\tau$	$2.54 \pm 0.014 \times 10^{-1}$	3.89	CM
$\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$	$3.0 \pm 3.2 \times 10^{-3}$	4.86	CM
$\tau^- \rightarrow \pi^- \nu_\tau$	$1.11 \pm 0.012 \times 10^{-1}$	2.5×10^{-5}	Rel
$\tau^- \rightarrow \rho^- \nu_\tau$	$2.54 \pm 0.14 \times 10^{-1}$	2.1×10^{-5}	Rel
$\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$	$3.0 \pm 3.2 \times 10^{-3}$	2.24×10^{-7}	Rel
$\tau^- \rightarrow K^- K^0 \nu_\tau$	$1.55 \pm 0.17 \times 10^{-3}$	7.07×10^{-8}	Rel
$\tau^- \rightarrow K^- K^0 \pi^0 \nu_\tau$	$1.57 \pm 0.21 \times 10^{-3}$	4.44×10^{-11}	Rel
$\tau^- \rightarrow K^0 \overline{K^0} \pi^- \pi^0 \nu_\tau$	$3.1 \pm 2.3 \times 10^{-4}$	6.01×10^{-15}	Rel

Also, the phase space factor increases with a decrease in the mass of the ρ^0 as seen in Table 2, since there is 'extra' energy to distribute around in different ways.

The estimated branching fraction for the signal event is 4×10^{-10}. However, the resonance amplitude of the ρ^0 at its central value of 770 MeV should cause an increase in the branching fraction by 2 orders of magnitude (based on other resonant and non-resonant decay channels). However, since 84.7% of τ decays are one-prong, a factor of 0.847 must be taken into account (since all events that are not one prong are automatically rejected on the tag side). Also, a factor of 0.686 must be taken into consideration, since the $K_S \rightarrow \pi^+ \pi^-$ has a branching fraction of 68.6%

Table 2: Phase space factors from the Monte Carlo phase space generator NUPHAZ [5], [6]

ρ^0 Mass (MeV)	Relative Phase Space Factor
770	1.00
765	2.98
760	7.04
755	14.42
750	26.32
745	44.78
740	71.16
735	107.21
730	155.67

The center of mass phase space as a function of τ neutrino energy is calculated and plotted below:

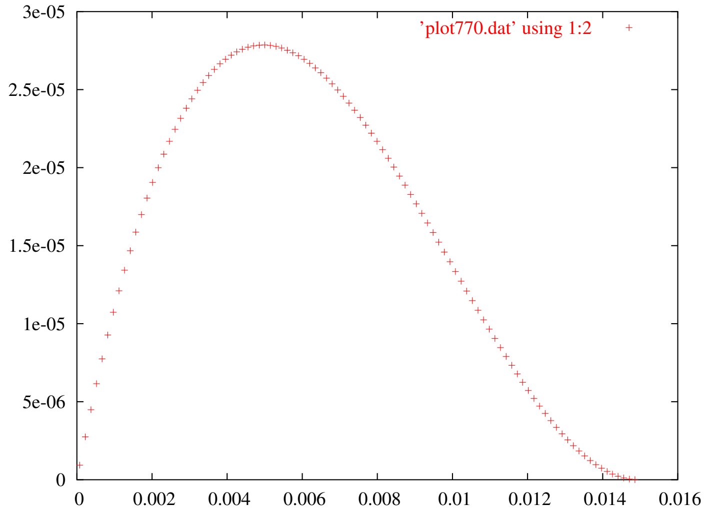

Figure 5: 4-body Phase Space Distribution as a function of ν_τ mass

Towards the end of phase space (at 16 MeV), the phase space factor is very small, because there are very few ways to distribute energy among the decay particles. The phase space curve peaks for a ν_τ mass of a few MeV/c^2.

3 Multiple-Event Background Analysis

3.1 Types of Background

In order to isolate a possible signal reaction, it is necessary to eliminate other decays that occur in the detector, known collectively as background. These decays arise from other products of the electron-positron collision, through a continuum (as opposed to a collision forming the $\Upsilon(4S)$ resonance). The reactions $e^+e^- \to c\overline{c}, u\overline{u}, d\overline{d}$, or $s\overline{s}$, collectively known as $e^+e^- \to q\overline{q}$ (production of quarks pairs) result in decays that cause a majority of the non-τ background.

The types of decays studied here are:

1. $c\overline{c}$ and uds background

   The decays that result from charm pairs are known as $c\overline{c}$ background, while the decays resulting from up, down and strange pairs are collectively known as uds background. These decays have the wrong topology in general, and so should be eliminated by a cut on the the number of tracks and the thrust variables, which will be discussed in Sections 3.3 and 3.4.

2. D, D^* decays

   This type of background is from decays of D and $D*$ mesons, which are contained in the $c\overline{c}$ background data set. However, since these decays are likely to be the most problematic source of background, owing to the fact that they can closely resemble the signal, these decays are also studied exclusively.

3.2 Monte Carlo Background Generation

In order to fully study these background decays, only simulated (Monte Carlo) data sets are used in this study. The $c\bar{c}$ Monte Carlo data sets generate all known reactions resulting from the pair, according to particle decay tables, while the uds Monte Carlo data sets account for all known decays involving u, d and s quarks. The original data sets used are Tau1-N skims, which means that the decays included must have one charged particle in one decay hemisphere, and N charged particles in the other (1-N topology), where N$\geq$ 3 .This eliminates decays where both hemispheres have 1-prong decays. The $c\bar{c}$ and uds decays are simulated using the JetSet package, and the detector simulation is based on GEANT4. In order to analyze the data for a possible signal event. All the background events generated in the MC background data sets should be eliminated.

3.3 Preliminary Cuts on Tau1-N skims

The first set of cuts on the background Monte Carlo is performed by skimming the data sets using C++ code that reconstructs the decays, and selects candidates for further study. The following basic cuts are included in the code:

1. Only events with zero total charge are selected. Events with non-zero charge are seen in the dataset. This is due to incomplete reconstruction of an event, which occurs when 1 or more charged particles are not

detected. Since these events are incomplete, kinematic reconstruction is not possible, and thus these events are rejected

2. The number of charged tracks of an event must equal 6, since signal events have 5 charged tracks in the signal hemisphere, and one charged track in the tag hemisphere. This removes events with a 1-3 topology, which are more common than the 1-5 signal.

3. Events with one charged kaon track are selected, since the signal had one charged kaon in the 5-prong hemisphere, and no charged K track in the tag hemisphere. Again, this eliminates a significant number of events

4. Events with one reconstructed ${K_S}^0$ are selected, as the signal has one ${K_S}^0$ on the signal side, and none on the tag side

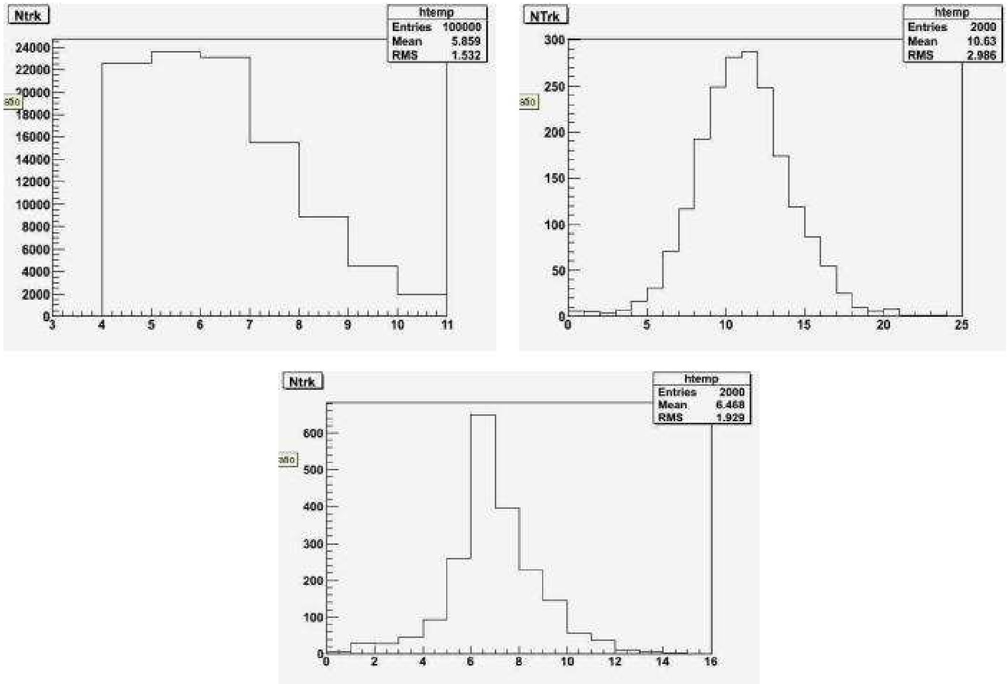

Figure 6: Histograms of the number of charged tracks - Top-left: A sample of 100,000 *uds* events; top-right: 2000 D^* events; bottom: 2000 τ signal decays. The number of events is plotted as a function of the number of tracks

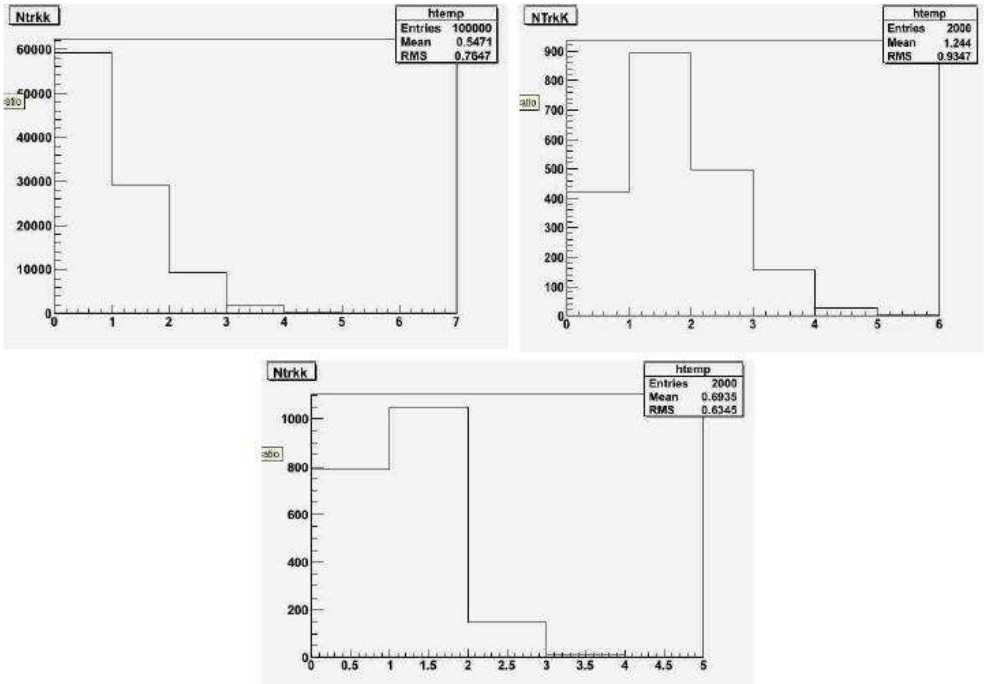

Figure 7: Histograms of the number of charged kaon tracks - Top-left: A sample of 100,000 *uds* events; top-right: 2000 D^* events; bottom: 2000 τ signal decays (number of events vs. the number of charged kaon tracks

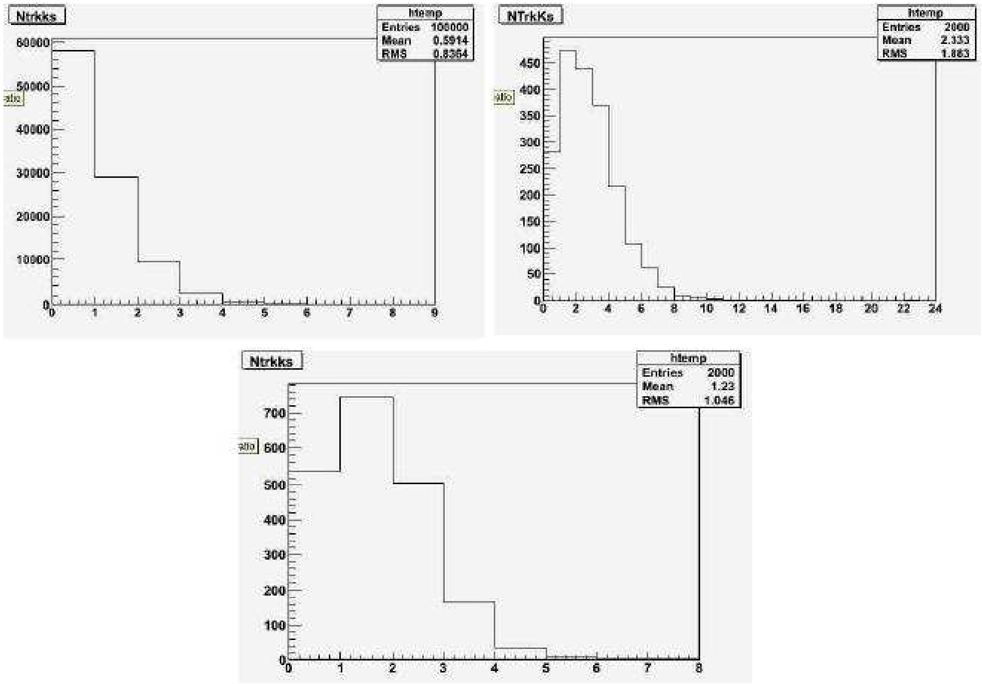

Figure 8: Histograms of the number of ${K_S}^0$ tracks - Top-left: A sample of 100,000 *uds* events; top-right: 2000 D^* events; bottom: 2000 τ signal decays (number of events vs. number of ${K_S}^0$)

3.4 Secondary Cuts on MC Background

After preliminary cuts are made, a significant reduction in the background is seen. A number of events survive these cuts, and more restrictive cuts are made using ROOT. The variables used to discriminate between background and possible signal events are discussed below (the histograms following are plotted with the number of events as a function of the variable):

1. **Tau Mass**

   The first cut made is on the mass of the reconstructed τ in the signal hemisphere. In order to classify as a good event to study the neutrino mass, the mass of the reconstructed τ should be near the central value of 1.777 GeV. therefore an upper limit of 1.8 MeV is placed on the reconstructed τ mass.

2. **Thrust**

   The thrust of a decay reaction describes the relative motion of the decay products to one another. Its ranges in value from 0.5 to 1, and a decay reaction with a high value for thrust will have particles that move in a jet-like manner. This is a very effective variable to eliminate $q\overline{q}$ decays, since they tend to be more isotropic and thus have a lower thrust value than τ decays. The thrust of an event must therefore be greater than 0.92

3. **Number of Gammas**

   The number of gammas in an event must be less than or equal to 5.

This eliminates events that have a higher energy, since signal events would be likely to have a maximum of 2 high-energy gammas resulting from a π^0 decay in the tag hemisphere. Some lower energy background gammas may also be detected, and thus an upper limit of 5 gammas is set. Setting a limit of 5 gammas also means that the maximum number of π^0 's possible in the event (by the reconstruction of the decay $\pi^0 \to \gamma\gamma$) is 2, which is the maximum allowed number of π^0's resulting from the possible tag-side decays $\tau^- \to \pi^-\pi^0\nu_\tau$ or $\tau^- \to \pi^-\pi^0\pi^0\nu_\tau$.

4. **Transverse momentum of the Charged Kaon**

   The transverse momentum of the charged kaon in the signal hemisphere compared to the direction of the decay products must be very small, since the charged K from a signal event will have a momentum vector very similar in direction to the τ. K's with a large value for this variable are most likely not from signal τ decays. We therefore require that the the transverse momentum value be less than 0.3 GeV/c^2.

5. **χ^2 per degree of freedom of the τ vertex fit**

   The χ^2 per degree of freedom is a measure of the overall vertex fit for the $\tau^\pm$ signal decays. A high value for this variable indicates that the reconstructed tracks may not actually form a vertex, whereas a χ^2 per degree of freedom value of 1 indicates that all tracks have a statistically perfect fitted vertex (an ideally reconstructed decay reaction), where all the tracks meet at the same decay point. Allowing for reconstruction errors, the χ^2 per degree of freedom variable must be less than 3, in order for an event to resemble the signal closely. This variable also eliminates a significant number of background events.

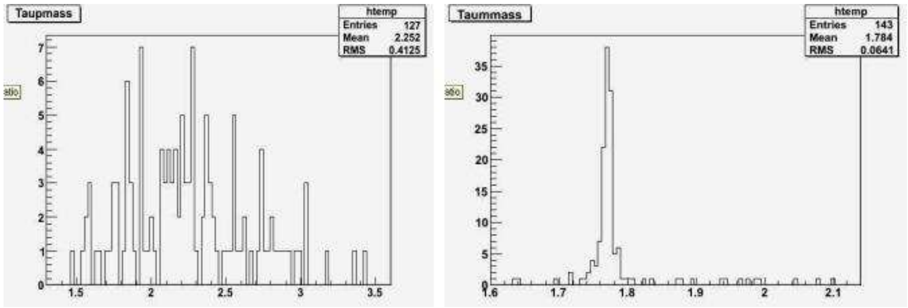

Figure 9: Reconstructed τ mass for events that pass preliminary cuts - left: A sample of 127 uds events; right: 143 τ signal decays

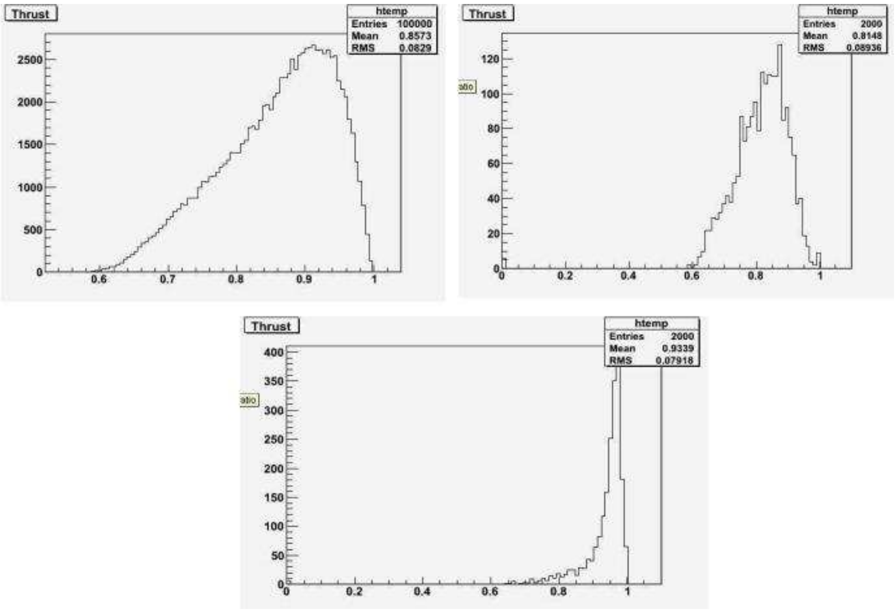

Figure 10: Histograms of the thrust - Top-left: A sample of 100,000 uds events; top-right: 2000 D^* events; bottom: 2000 τ signal decays

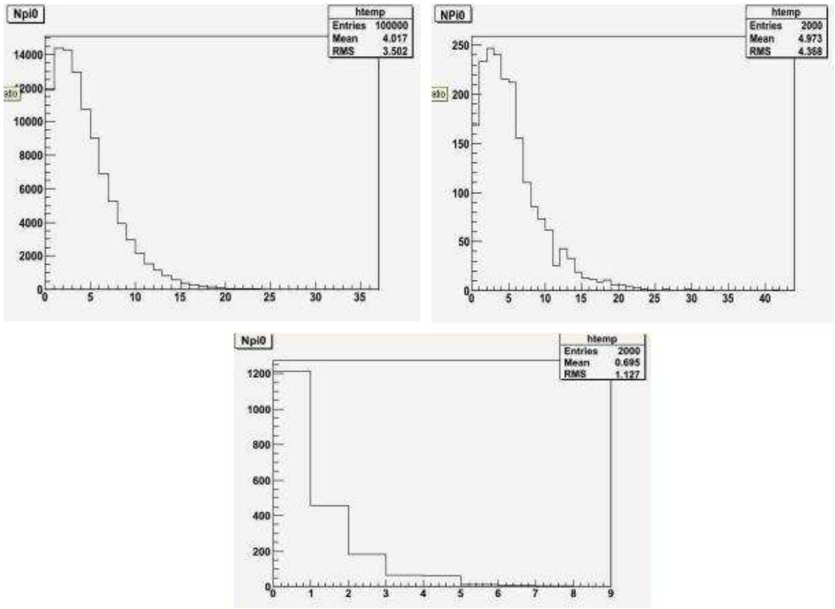

Figure 11: Histograms of the number of reconstructed π^0's - Top-left: A sample of 100,000 *uds* events; top-right: 2000 D^* events; bottom: 2000 τ signal decays

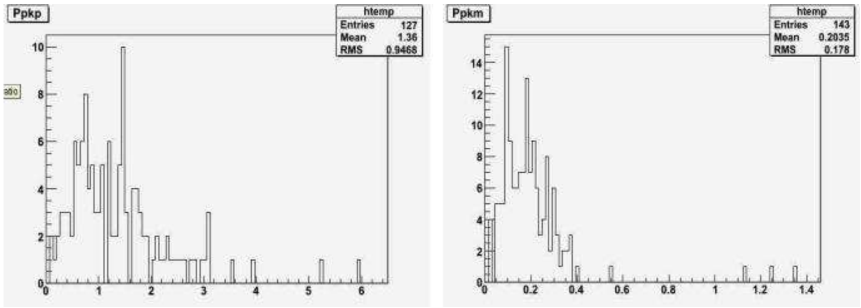

Figure 12: Transverse momentum of charged kaons (after preliminary cuts) - Left: A sample of 127 *uds* events; Right: 127 τ signal decays

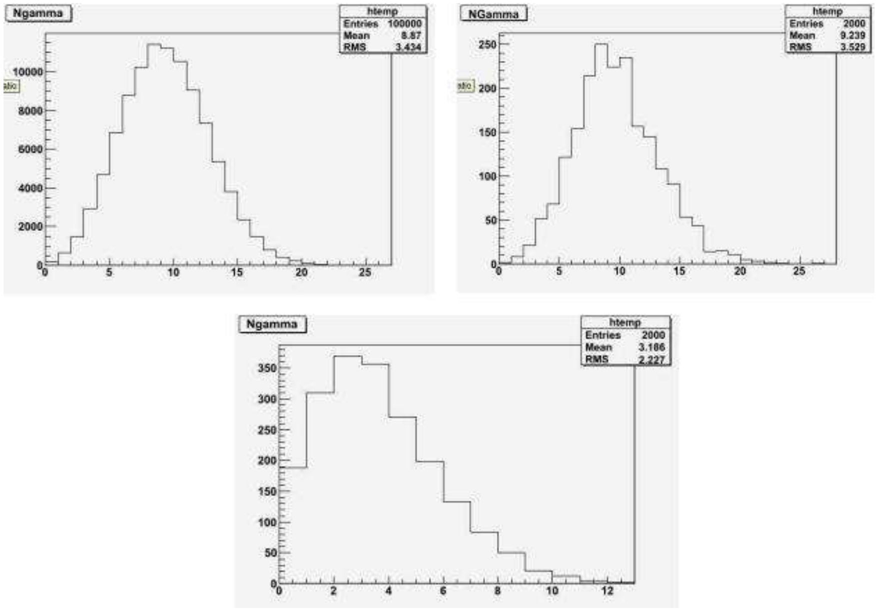

Figure 13: Histograms of the number of reconstructed gammas - Top-left: A sample of 100,000 *uds* events; top-right: 2000 D^* events; bottom: 2000 τ signal decays

The primary and secondary cuts made eliminated a majority of the events, but a handful of events from each data set survived. In order to effectively distinguish these events from signal events, these are examined individually.

4 Single-Event Analysis

The events that survive all cuts made in the skim code and with ROOT need to be looked at more closely, in order to determine a parameter that separates them from actual signal events. To do this, we utilize a program called WIRED, which is a single-event display that reconstructs the event in three dimension as seen by the detector. Using WIRED, the geometry of the events can be studied in much greater detail.

4.1 Analysis with WIRED

All events that survived prior cuts were studied with WIRED. The analysis of certain uds background events is discussed in this chapter. In all WIRED images, red tracks denote pions, yellow tracks denote kaons, green tracks denote gammas, and white tracks denote protons and anti-protons. Images of an event studied in Figures 14 show 2 π^- tracks and 2 π^+ tracks, a K^- track, and a proton track. For our signal, we must require the number of protons (and anti-protons) to be zero, and therefore the first possible cut would be to eliminate any event with a proton or anti-proton (a proton list cut)..

The event shown in Figure 15 has 3 π^- tracks and 2 π^+ tracks, of which one π^- is in the tag hemisphere, and the remaining 4 tracks are in the signal hemisphere. There is also a K^+ track (in yellow), and 2 gammas with energies of 0.99 GeV and 0.12 GeV from which a π^0 is reconstructed. In this event, however, the reconstructed π^0 is in the wrong hemisphere. A π^0 is only allowed in the tag hemisphere, to allow for the possible decays $\tau^- \to \pi^-\pi^0\nu_\tau$ or $\tau^- \to$

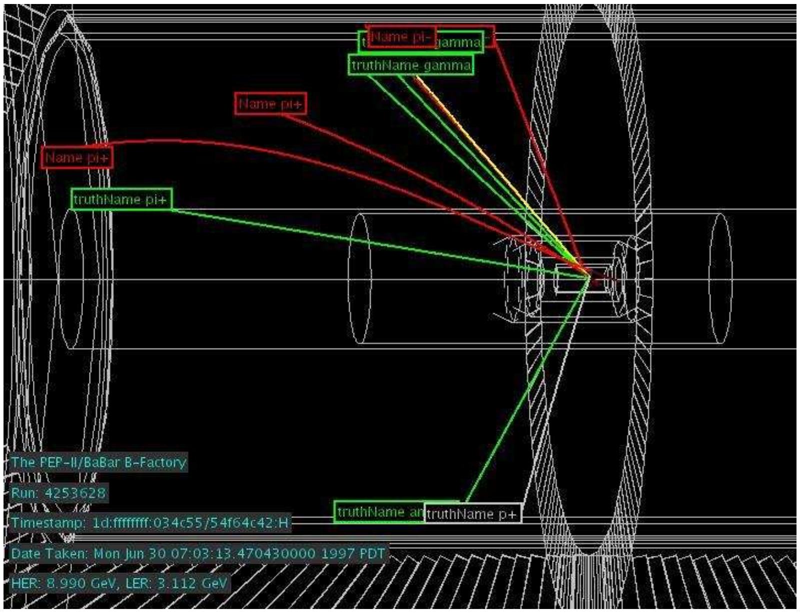

Figure 14: Event with a proton track - Side view

$\pi^-\pi^0\pi^0\nu_\tau$ (Section 2.1). Since the only tracks in the signal hemisphere must be 4 charged pion tracks and a charged kaon track, this event must be rejected. A possible cut for this type of event would be to cut on the direction of the π^0 track relative to the charged kaon. For signal events, the K^+ track will be in a direction very similar to the tau from which it was formed (because there is very little extra energy in the τ^+ rest frame), and the track of the K^+ will have a direction similar to that of the τ from which it decayed. Any π^0 tracks, which should be in the opposite CM hemisphere, will have a very different direction for momentum, and using the direction of the charged kaon track as a reference, criteria for π^0 track momentum vectors can be imposed (a π^0 momentum vector very similar to that of the charged K would be cut, since that would mean that the π^0 is in the wrong hemisphere). This cut also eliminates a significant number of surviving background events from *uds* decays.

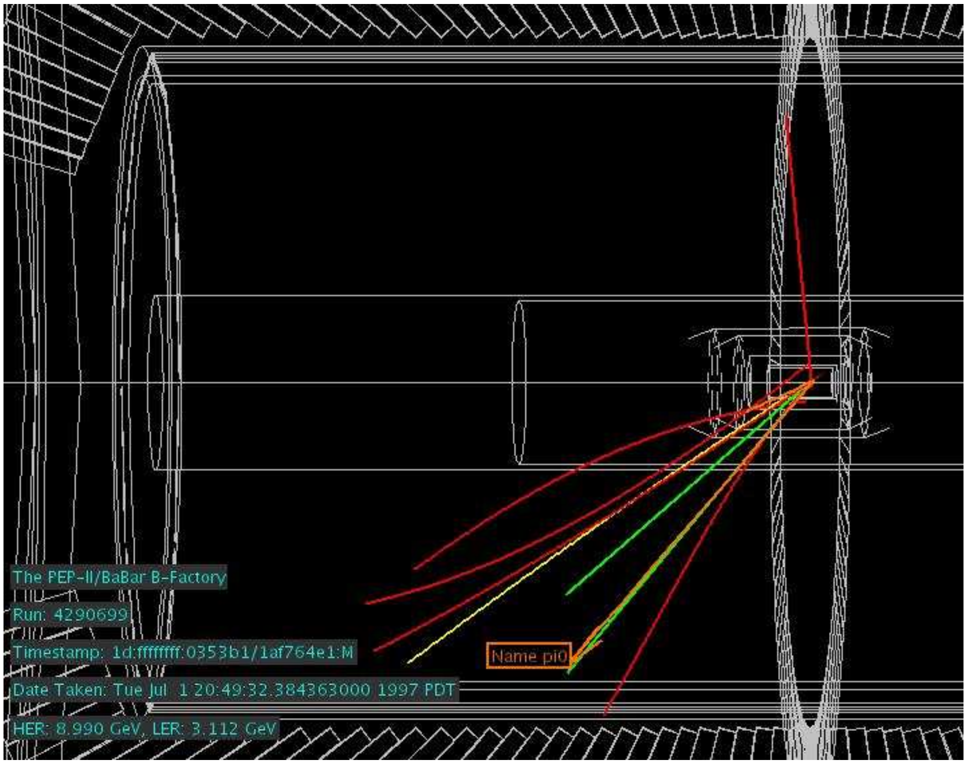

Figure 15: Event surviving all cuts with a proton track

The event seen in Figure 16 and 17 has 3 π^- tracks and 2 π^+ tracks, of which one π^- was misidentified by the detector, and is actually a π^+. There is also a K^+ track (in yellow), and 4 gammas with energies of 20 MeV, 80 MeV, 0.2 GeV and 1.1 GeV in the CM frame. All these gammas appear to be in the signal hemisphere, and since the signal event has no high energy gammas (low-energy gammas are possibly from background events in the detector), a cut on the number of high-energy gammas is a possibility. However, this cut is not precise enough, since high-energy gammas can be produced in the signal hemisphere from π^0 decays with backward-going gammas, and good signal events can be eliminated. An alternative cut which would work, without reducing signal efficiency significantly, is a cut on the pion track lists. Since one of the π^+ tracks is very short, a tighter cut on the tracks (GoodTracksTight) should eliminate this event.

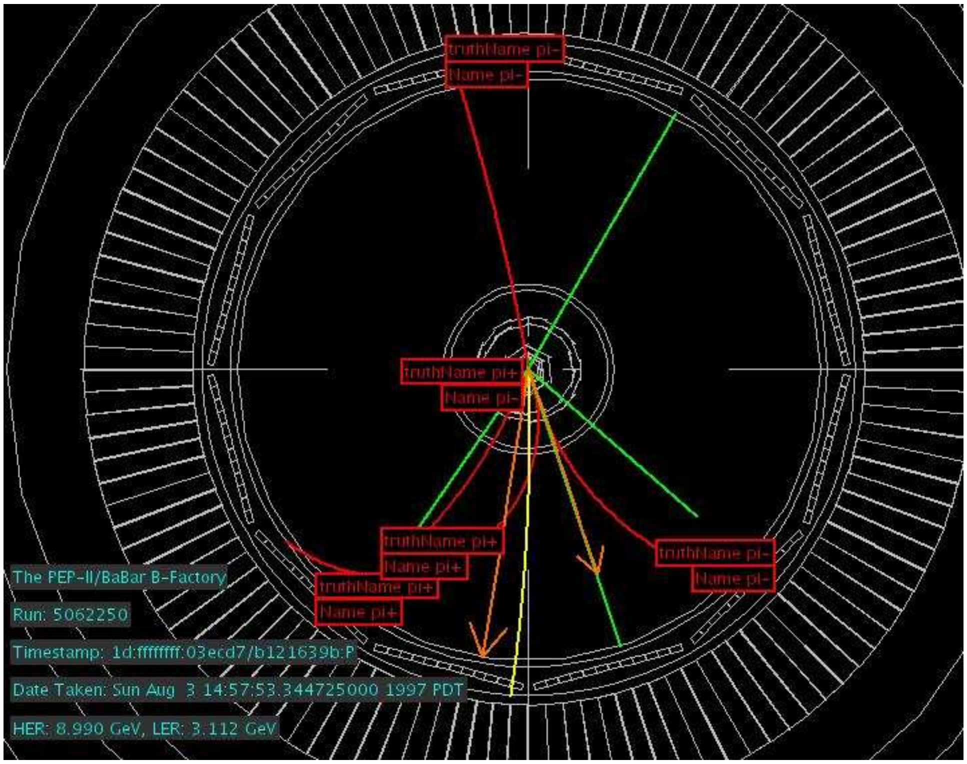

Figure 16: A cross-sectional view of the surviving event with a π^0 in the signal hemisphere

The next event has 2 π^- tracks and 2 π^+ tracks, 1 K^+, and a reconstructed ${K_S}^0$ shown in Figure 18. This event should not have zero total charge, but did survive the cut made on event charge in the skim code. This is probably because one of the particles produced knocks off a charged particle from some

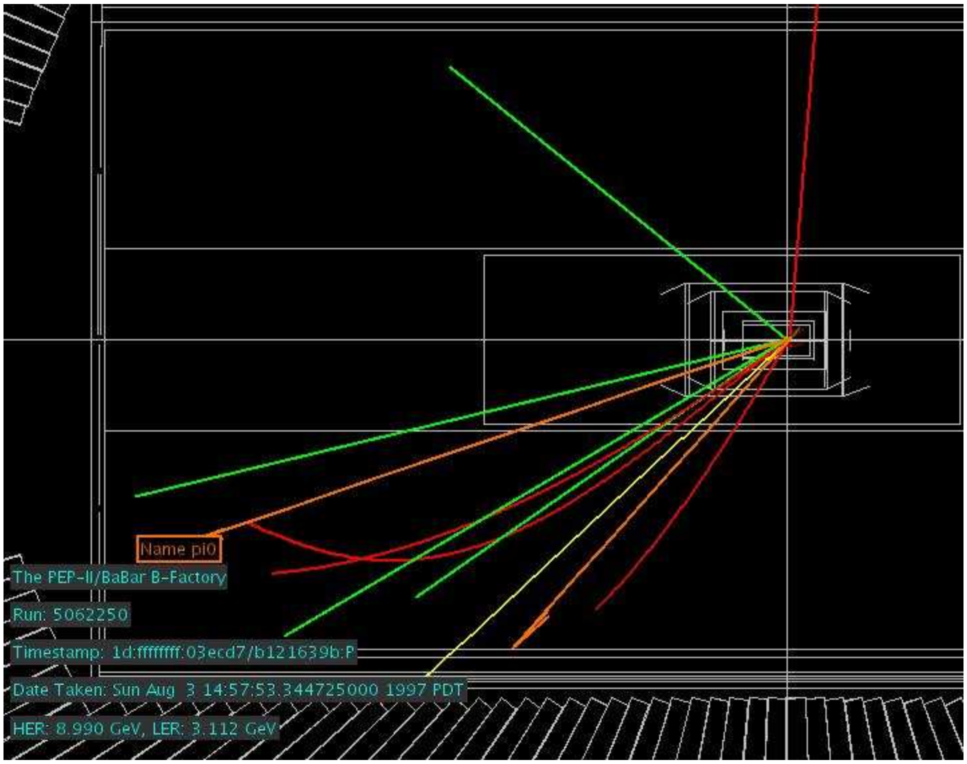

Figure 17: A view of the above event through the side of the detector

material in the detector, and thus the total charge of the event is seen as zero. Events like this (where the total charge is incorrectly recorded as zero due to scattering) can be discarded by putting a minimum cut on track energy and/or track quality.

Another *uds* event studied (Figure 19) had a τ^- signal decay with 2 π^-, 3 π^+ tracks, 1 K^- and 2 low-energy gammas (75 and 45 MeV). The reconstructed mass of the signal tau lepton is 1.33 GeV, which is much lower than the central 1.777 GeV. In order for a event to be a good candidate for kinematic reconstruction, the visible mass must be within 25 MeV of the central value of 1.777 GeV, so a lower limit on the reconstructed τ mass would eliminate a

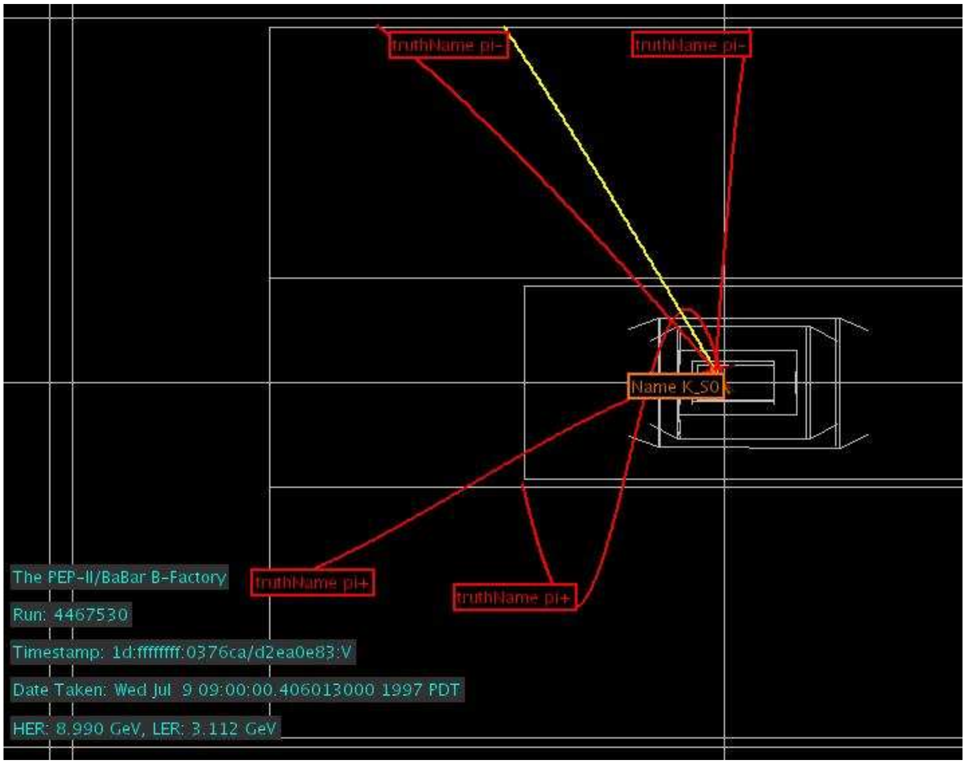

Figure 18: Event with non-zero total charge

significant number of background events. Also, the tag (1-prong) side appears to have only one charged pion track, with no gammas or reconstructed π^0 tracks. Since the only undetected track is a neutrino, it is possible that the energy of the pion track is inconsistent with the decay $\tau^+ \rightarrow \pi^+ \nu_\tau$, and that is another possible way of eliminating this event.

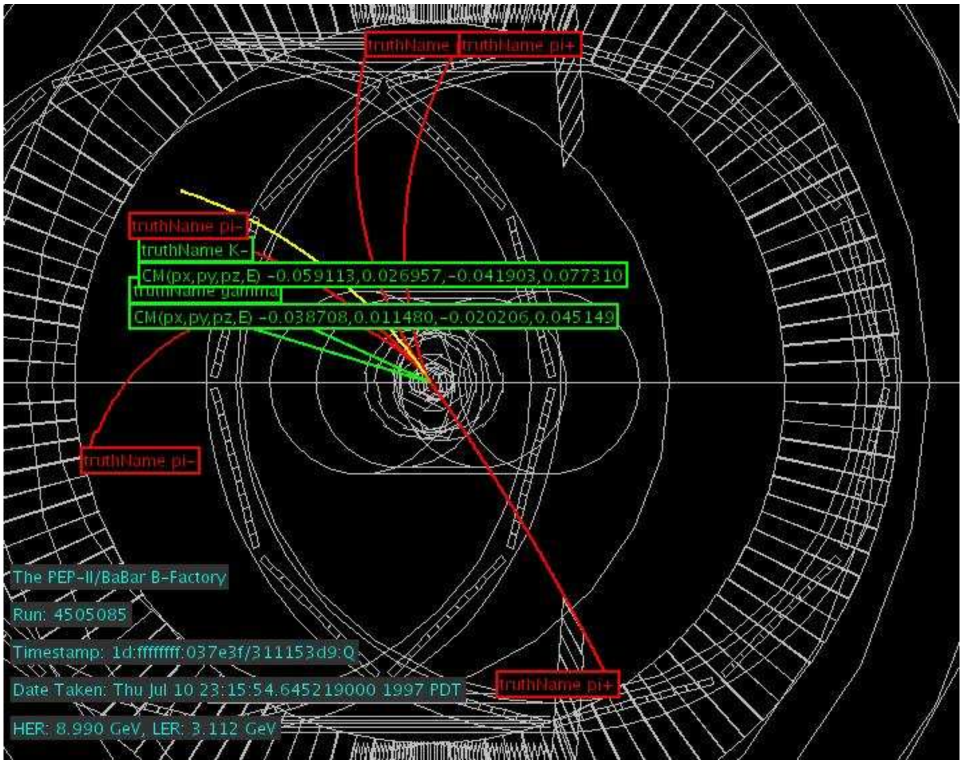

Figure 19: *uds* background event with reconstructed τ mass of 1.33 GeV

All the surviving *uds* background events should be eliminated by the following cuts:

1. A cut on the mass of the reconstructed tau on the signal side - the mass must be between 1.75 GeV and 1.8 GeV
2. A cut on the motion of reconstructed π^0's relative to that of the charged kaon
3. A cut on the proton list, which effectively cuts out any event with a proton or anti-proton

4. A cut on minimum track energy

5. A full reconstruction requirement described below:

4.2 Kinematic Reconstruction

The events that pass all previous cuts can be completely reconstructed as a pair of τ decays if the tag side has only one neutrino. This would mean a hadronic decay on the tag-side. In this case, the neutrinos in both hemispheres are undetected, but all other tracks in both hemispheres are completely reconstructed (all the information about momentum and energy is known). In each hemisphere, using conservation of energy-momentum, it should be possible to completely reconstruct this event, and obtain energy-momentum information about the undetected τ neutrinos.

If the tag side has two neutrinos (the decays $\tau^- \to e^-\overline{\nu}_e\nu_\tau$ or $\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau$), a complete reconstruction of the tag side of the decay is not possible. However, there is a one-prong lepton tag which strongly favors decays of tau leptons. This lepton tag is a very efficient way of minimizing $q\overline{q}$ background.

5 Conclusions

5.1 Results

All the background events studied so far can be eliminated with preliminary and secondary cuts, or after imposing the cuts discussed using WIRED. All the events in the D background data set (10,000 generated events) and D^* (2000 events) were eliminated. All events from Runs 1, 2, and 4 of the uds 1-N skims, as well as Runs 1 and 2 of the $c\bar{c}$ 1-N skims have been surpressed with the cuts in this study. Future background analysis includes completion of the analysis of $q\bar{q}$ 1-N skims. The cuts described in this study should be effective in getting rid of almost all background events.

5.2 Signal Efficiency

The cuts imposed to get rid of background events also reduce the signal efficiency substantially. Starting with a data set of 2000 signal events, 143 events survived preliminary cuts (an efficiency of 7.15%), while secondary cuts made with ROOT reduced the number of surviving events to 68 (3.4% of the total data set). The cuts introduced after WIRED analysis are likely to reduce signal efficiency even further. One of the future goals of this project will be to ensure that the signal efficiency remains at a few percent, through modification of selection criteria.

5.3 Summary

After all simulation (MC) background data sets can be eliminated, the cuts need to be made on real BaBar data sets. Any event surviving all cuts should be a good candidate for the signal decay. However, a kinematic reconstruction of surviving events remains the most powerful method to distinguish between background and signal events. Either a lepton tag, or a complete kinematic reconstruction of the hadron tag and signal hemispheres should allow us to confirm that a surviving event is a signal τ decay.

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