PRIMEX NOTE –6

PrimEx Trigger Simultation Study

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Introduction

This documents describes a Monte Carlo simulation study for the PrimEx experiment. The study focused on determining π^o trigger efficiency and upper limits on trigger and HYCAL detector rates. Some details of the parameters which defined the geometry in the simulation are given. Specifics of the event generators are given along with a description of how the trigger was simulated. Finally, a summary of the results of two studies are presented. One of the π^o acceptance efficiency and the other of the trigger and detector rates due to beam background.

Simulation Program psim

The program used for PrimEx simulation in this study is called *psim*. This is a GEANT3 based program which is part of a group of programs called *primsim*. All of the primsim code is kept under CVS control on the Jlab unix cluster. Instructions for obtaining the code from the CVS repository can be found at http://www.jlab.org/primex/simulation/index.html. In this section, details on the detector geometry, beamline components and event generators are given. Also given are brief descriptions of some of the other programs in the primsim package used for manipulating the simulated data. Finally, details of the energy smearing algorithm and trigger simulation code are discussed.

Geometry

This section outlines some specifics of the geometry used in the current simulation study. An illustration of the overall setup can be seen in figure 1.

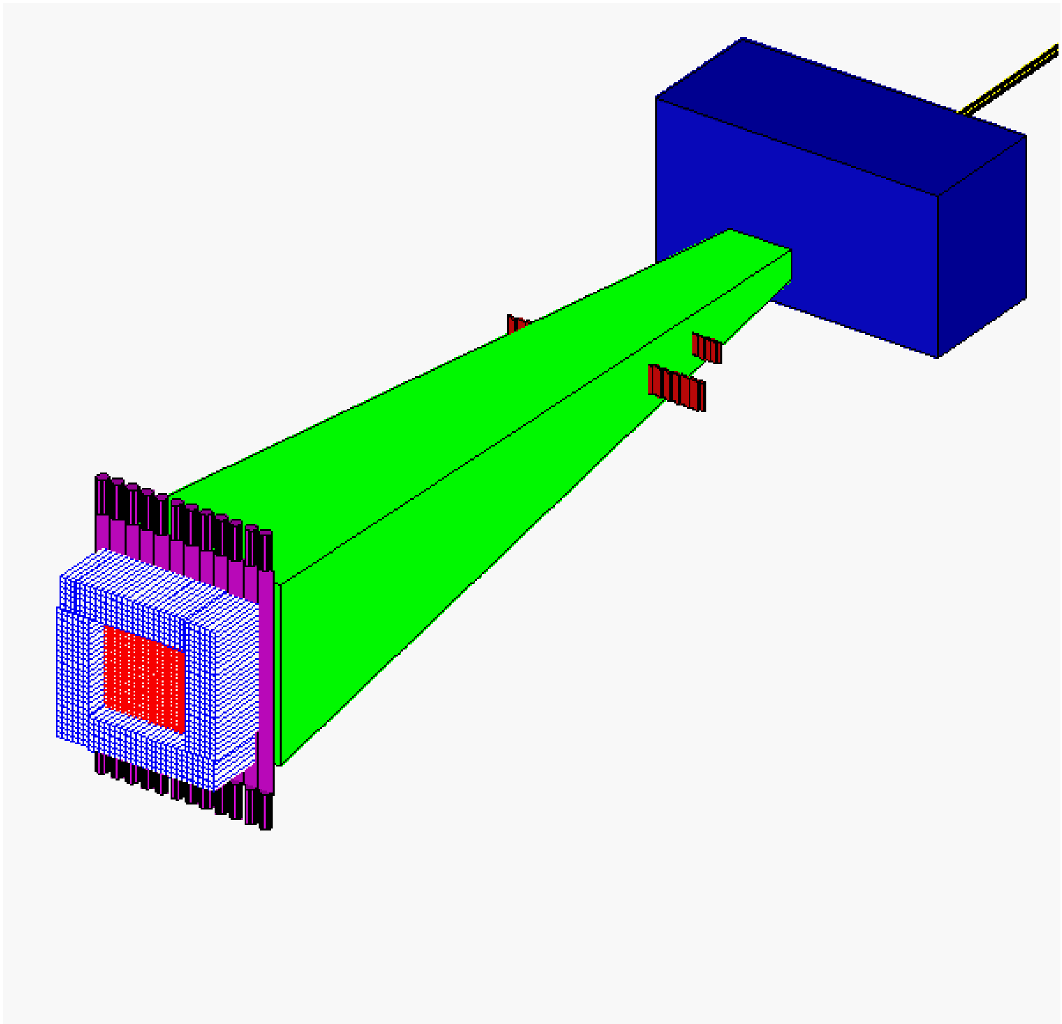

Figure 1 PrimEx setup as defined in the GEANT3 program "psim". The blue box is the dipole and the large green trapezoid is the helium bag.

HYCAL

The HYCAL detector was composed of 1152 PbWO4 modules and 576 Pb−Glass modules. Each module was composed of the detector itself, an air gap, a layer of wrapping, and another air gap. The dimensions used in the simulation are shown in figure 2.

The PbWO4 modules were arranged in a 34 x 34 grid with the central 4 modules removed for a beam hole. The Pb−glass were arranged in a shifted geometry around the PbWO4 modules in 4 groups of 24 x 6 blocks. Figure 4 illustrates the geometry used.

About 5cm upstream of the Pb−glass, 12 veto scintillators are defined with the dimensions 11cm x 160cm x 0.25". These are made of BC408 material. No wrapping was defined for the current study. A diagram of the relative positioning along the beam line of the veto detectors along with several other components can be seen in figure 3. A hole was defined in the veto counters to coincide with the beam hole in HYCAL which allow the beam to pass through.

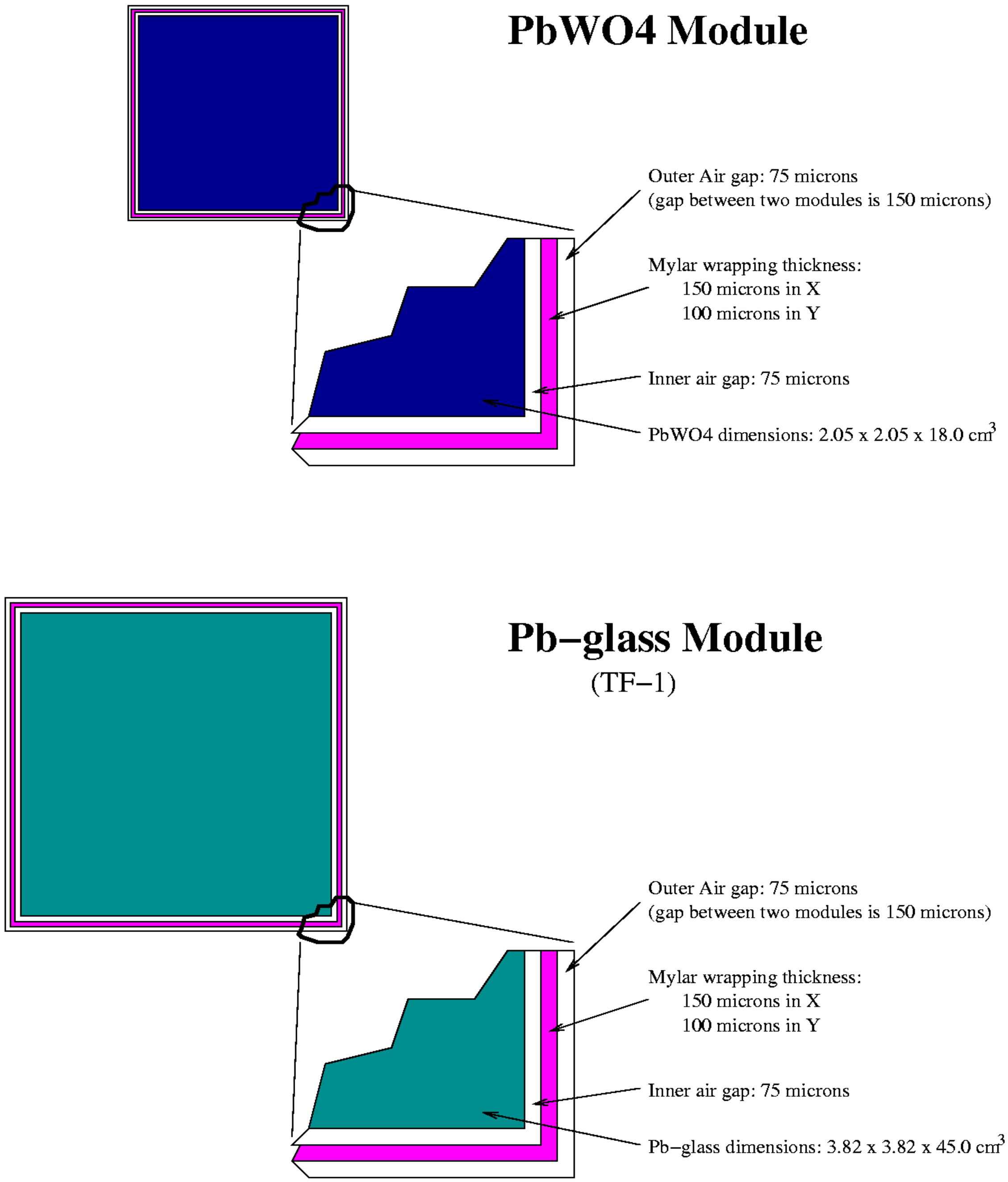

Figure 2 Dimensions of PbWO4 and Pb−glass modules used in simulation. Each module was composed of mylar wrapping and two air gaps surrounding the detector.

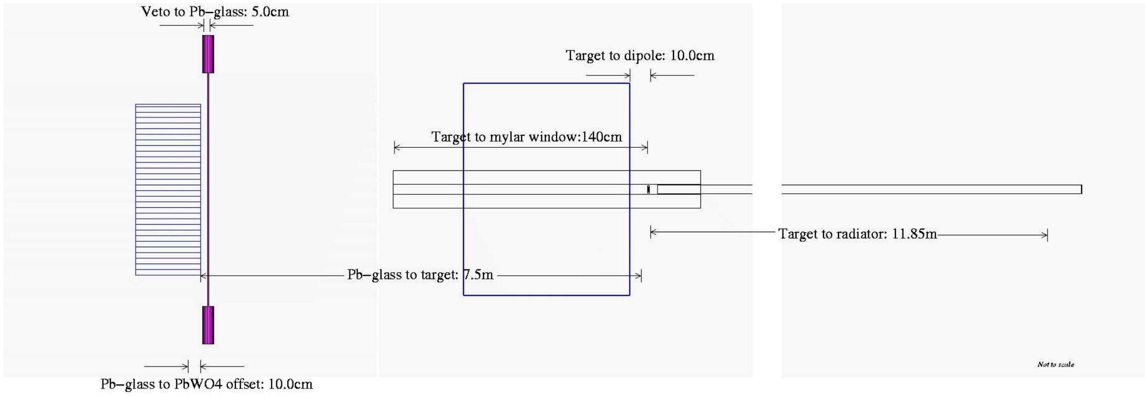

Figure 3Relative distances along beam line of elements defined in psim.

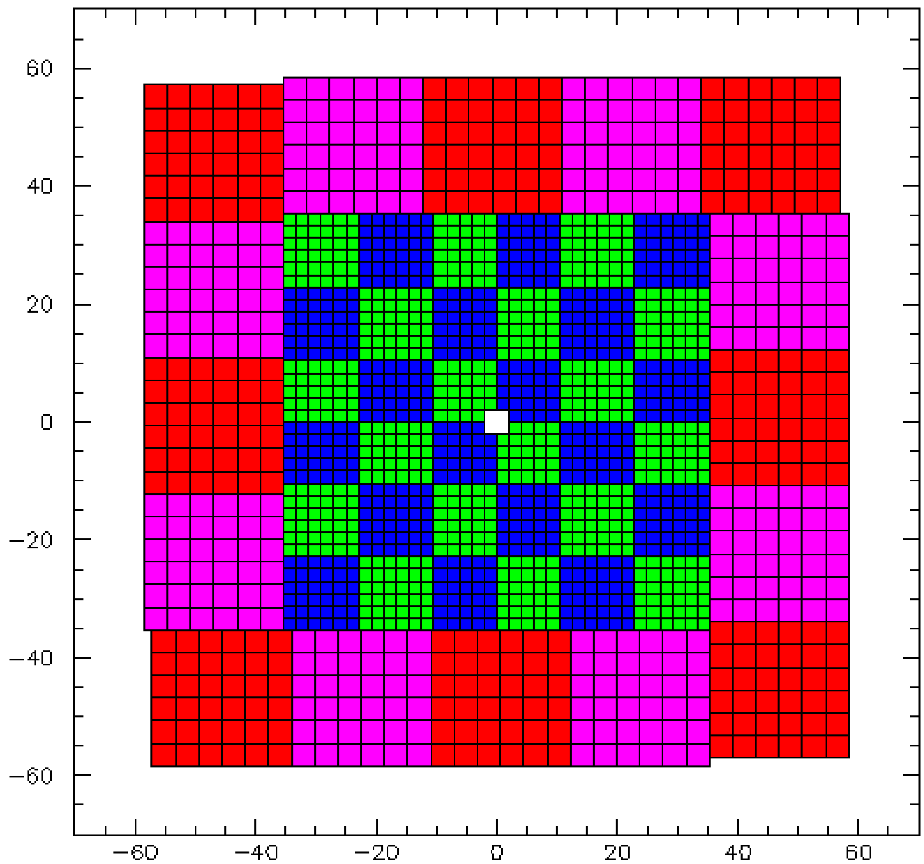

Figure 4 HYCAL geometry. The larger Pb−glass detectors are arranged in a shifted geometry so as to remove any gap at the border with the smaller PbWO4 detectors.

Dipole

The dipole magnet is defined to be an iron block 82.5" x 45.75 " x 36.0". It has gap constructed of two boxes made of vacuum with dimensions 18.25" x 8.125" and 40.0cm x 2.1". Note that the actual experiment will have an aluminum vacuum box with a non–rectangular shape. This aluminum "box" was not defined for the current simulation study. The actual vacuum box also has a thin mylar window that will serve as both the exit window from the vaccum and the entrance window to the helium bag. This is discussed in the next section on beam line components.

Beamline

Other components which defined the beamline are the vacuum beam pipe, the target, and the helium bag. The relative positions of these can be seen in figure 3.

The vacuum beam pipe was defined as an aluminum pipe with a 2" outer diameter and 2mm thick walls. The pipe ran from upstream of the tagger radiator position all the way into the vacuum box defined inside the dipole. Thus, the vacuum extended continuously from the radiator to the heluim bag.

The target used was 5% r.l. of Pb. A target ladder was defined to be made of 0.5" thick aluminum with six 1" diameter holes for the targets. All three of the planned physics targets (Pb, Sn, and C) were defined in the simulation, each with a 5% r.l. thickness. The ladder was positioned such that the Pb target was centered on the beamline.

The helium bag was defined as 500 micron thick mylar filled with helium gas. The bag shape was trapazoidal with the upstream end matching the shape of the 1st dipole vacuum box and the downstream end a 1.3m square covering the entire front face of HYCAL.

Bremstrahlung Generator

The bremstrahlung generator was composed of two parts. The first simply sampled energy from a 1/E distribution. The lower limit was set to 50MeV and the upper limit was set equal to the electron beam energy, 5.734 GeV. The second part of the photon generator sampled the angular distribution using the sampling function:

$$\frac{dn}{d\vartheta} \propto \frac{1}{(1+(\vartheta/\vartheta_c)^2)^2}$$

where ϑ_c is defined as the ratio of the electron mass to the electron beam energy. The beam energy used for the current study was 5.734 GeV. In reality, the generated angluar distribution did not exactly match the input sampling function. The source of this discrepancy was not pursued since having a larger halo would only make the background worse, thus, giving more confidence in the determined rates as upper limits. A plot showing the input sampling function and the resulting angular distribution can be seen in figure 5.

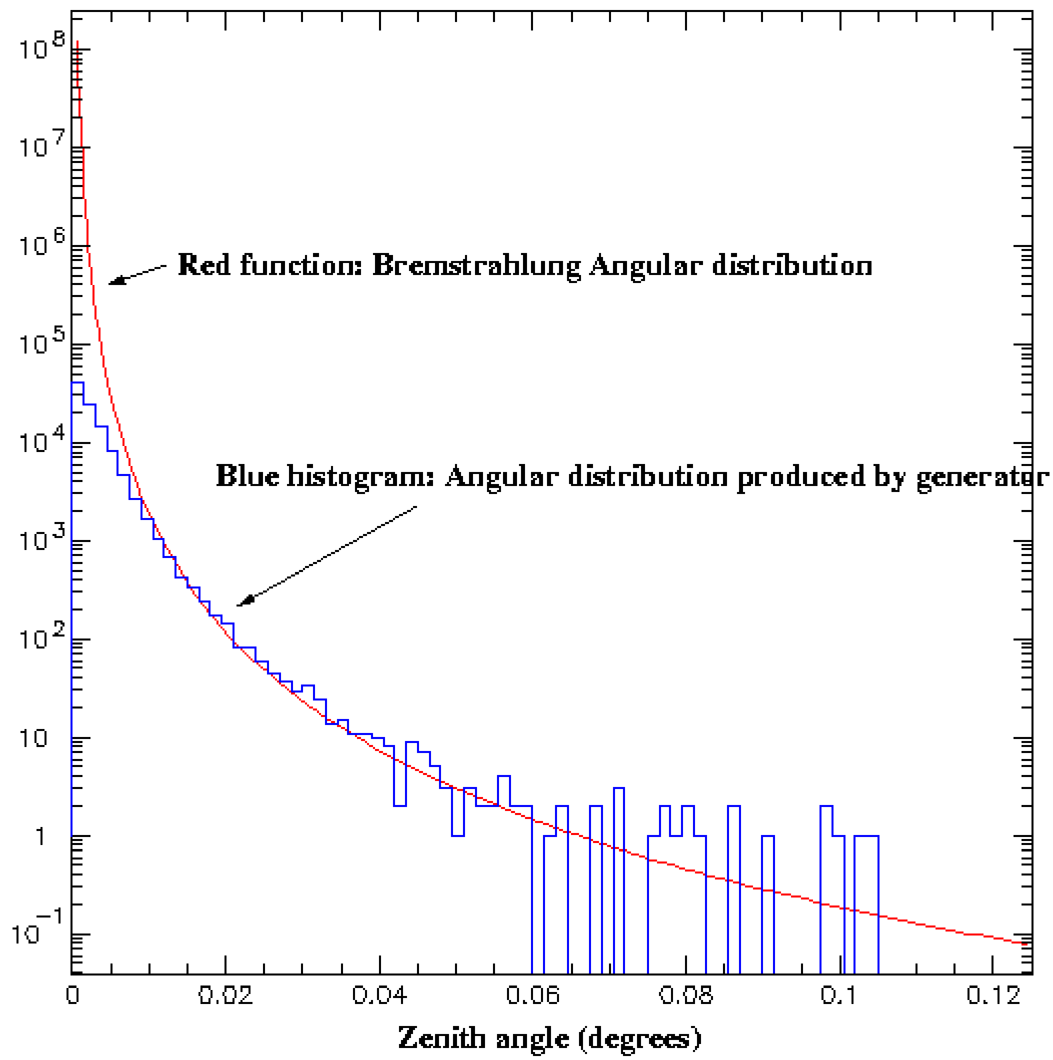

Figure 5 Angular distribution of bremstrahlung sampling function and resulting distribution from event generator.

π^0 Generator

The π^0 generator used the 1/E sampling function of the bremstrahlung generator for sampling energies from 50MeV up to the beam energy of 5.734GeV. It then generated π^0 's in 1 of three angular distributions corresponding to Primakoff, Nuclear coherent, and interference as the underlying mechanism. The generator recorded the mechanism used to produce the π^0 for later study, though this was not used in the current study. The distributions used, however, were derived from the known distributions from 6GeV photons incident on Pb. Geant was allowed to decay the π^0 and the 3−momentum and particle types of the resulting decay products were recorded.

Utilities

The psim program wrote resulting data out to a file with a specific format. While this format is far from optimal, it does incorporate some sparsification and compression ensuring minimal disk space requirements. Several utilities were developed for manipulating and viewing these files. Brief descriptions are given here.

psim_count – Count how many events are in a file/files
psim_dump – Dump formatted contents of file to terminal
psim_addevents – add together several events to simulate pileup
psim_filter – Extract events meeting certain requirements from a file
psim_book – Create hbook from contents of input file
psim_view – Graphical single event viewer (see figure 6)

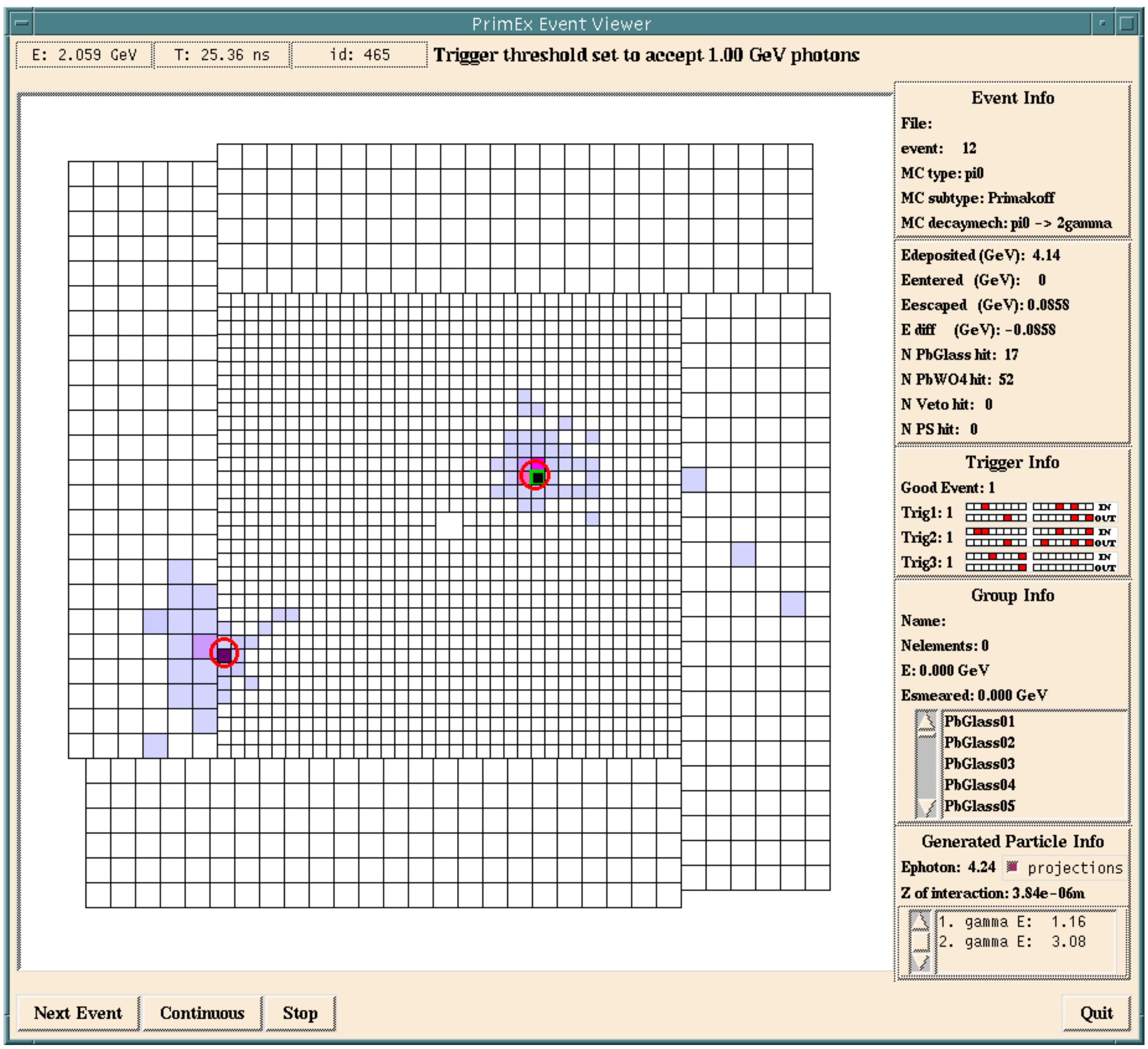

Figure 6 A π^o event displayed in psim_view. A single event viewer program which can be used to view simulated events.

HYCAL Smearing

To better simulate the detector response of the HYCAL elements, two smearing factors were applied. The first was a gain factor that did not change event to event. These factors were randomly generated once by sampling a gaussian function with a sigma equivalent to a 10% change in the energy detected. Each PbWO4 and Pb−glass detector had its own gain factor. The values were hard−coded into the programs so that gain factors would be consistent during multiple replays. A histogram of the distribution of the actual values can be seen in figure 7.

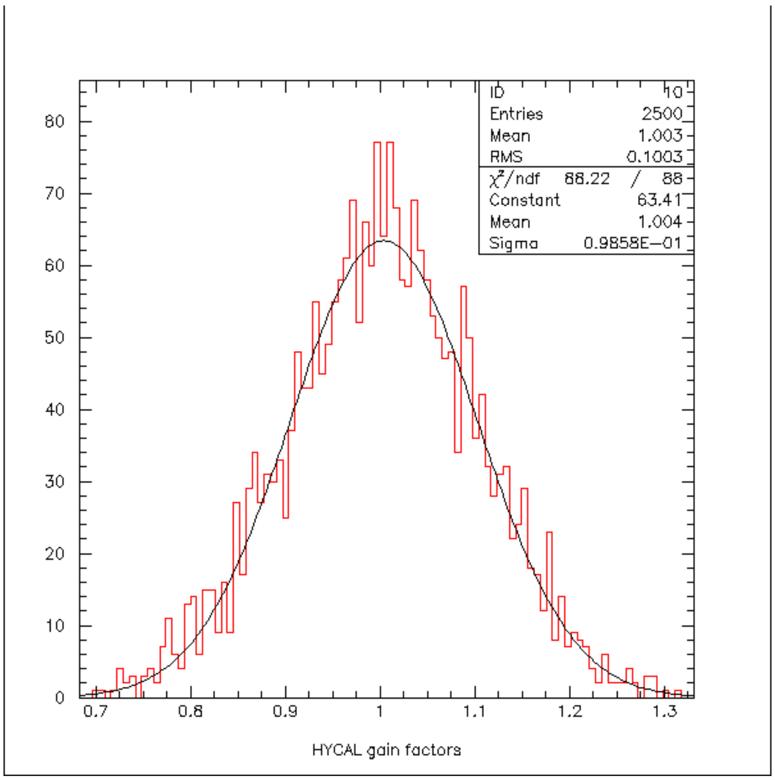

Figure 7Distribution of gain factors used in smearing detected energy in HYCAL elements. An additional 2% error was applied on an event by event basis to each detector.

The second factor was a smearing factor randomly sampled from a gaussian with a sigma equivalent to a 2% scaling for PbWO4 and a 4% scaling for Pb−glass. A new value was generated for each detector for each event.

A plot showing the combined effects of these two gain factors is shown in figure 8.

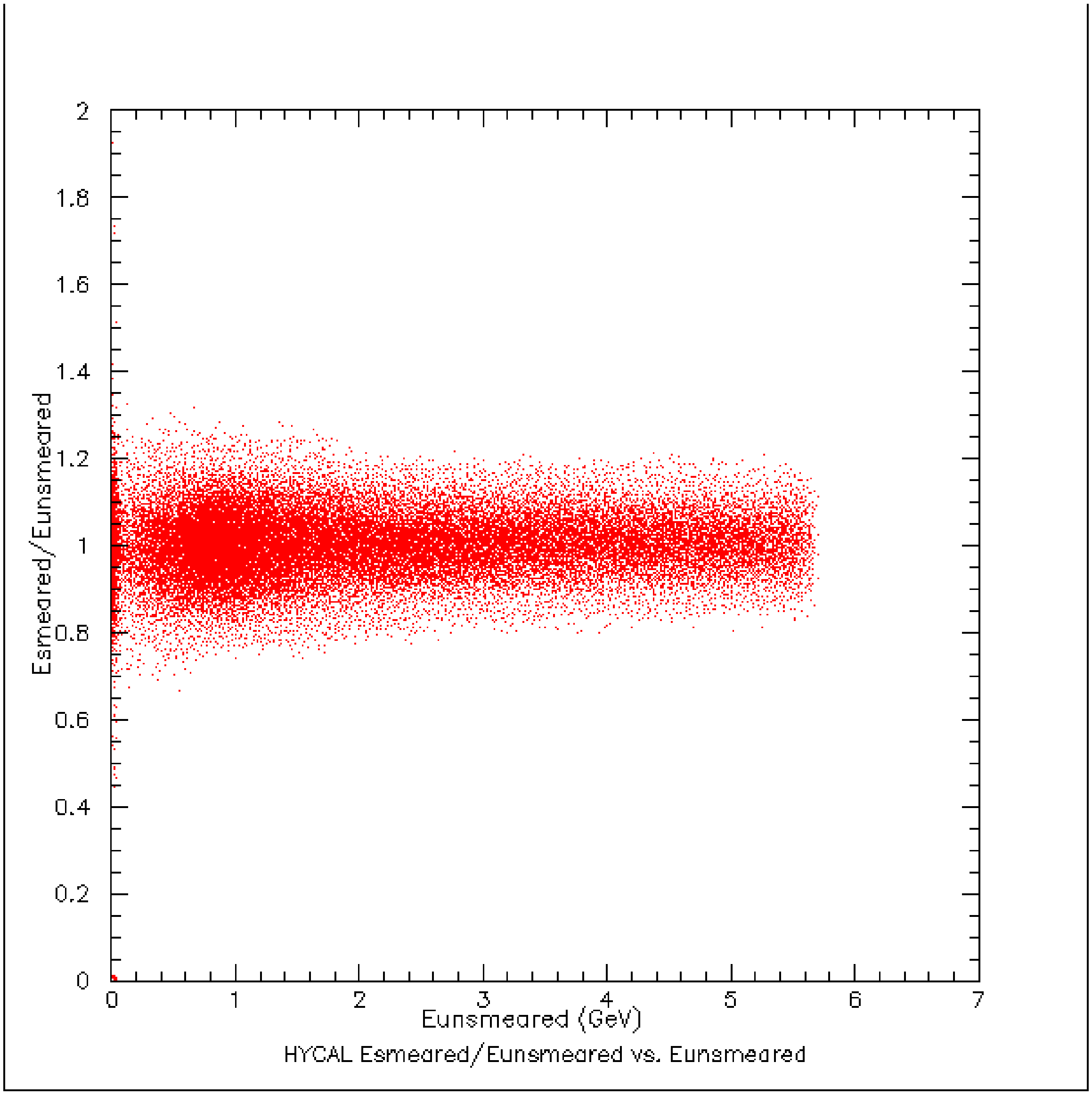

Figure 8 Smearing of HYCAL energy. The smeared to unsmeared ratio of total energy detected by HYCAL is shown vs. the un−smeared energy.

Trigger Simulation

The PrimEx trigger was simulated for this study to help test the logic and to identify weaknesses. The simulation used the smeared energy values to form sums that would be presented to the discriminators. Any discriminator that fired, would set an input bit to one of the MLU's. These MLU's were emulated in software. They were "programmed" at the beginning just as the real MLU's would be programmed before taking actual data. Three MLUs were needed for the trigger design. For the purposes of the simulation, trigger1 was for the horizontal strips, trigger2 was for the vertical strips, and trigger3 was the combination of trigger1 and trigger2. See the (forthcoming) PrimEx note on the PrimEx trigger design for more details.

All of the trigger simulation (including the energy smearing) was not done by psim itself but, rather, by the utlity programs which read the files produced by psim. This allows for variations of the trigger to be tested on the same data as was used for this study. These data files are stored in the JLab tape silo in */mss/home/davidl/primex/simulation_output/??*.

Photon Beam Flux

The photon beam rate stated in the PrimEx Proposal (and CDR pg. 58) is $7.2\,x\,10^7\,eq.\,\gamma/sec$ [¥]. The currently stated limit of the photon tagger is about 2MHz per T–counter. Since the T–counter's overlap by about 20%, this gives a photon beam rate of:

$$Q=\frac{(19\,Tcntrs)(2MHz)(0.8\,geometry\,overlap)}{\ln(0.95/0.77)}=1.5\,x\,10^8\,eq.\,\gamma/sec \tag{1}$$

For the purposes of background studies which include pile–up effects, this larger value is used.

π^0 Trigger Simulation

A simulation using 500K generated π^0 events was done to study the acceptance efficiency of the trigger. The results of that study are presented here.

Trigger design

The trigger design was driven by the kinematic constraints of having 2 photons from a π^0 decay entering HYCAL with a minimal separation of about 30cm. The trigger aimed at detecting 2 clusters, thus, rejecting events with single clusters. This was achieved by fanning in large groups of detectors to form strips which span the width of HYCAL. This will be done in hardware by using 2 stages of fan–in modules. The first is the UVA120A and the second is the UVA125A. Figure 4 shows an illustration of the UVA120A groups. The fanned–in strips will be passed through a discriminator whose outputs will drive the input bits of 2 CAMAC Memory Lookup Units (MLU). The output of the first two MLUs will drive a third MLU which will produce the final trigger.

The threshold used by the discriminators is defined by the design to be ½ of the minimum desired photon energy ($E_{\gamma\,min}$) for which we want 100% acceptance. The exact threshold used will be determined by the acceptable background rates/deadtime.

Trigger Efficiencies

¥ Page 27 of the CDR states a tagging rate of 50MHz for just the top 19 T–counters. It is not clear at this time that this is actually achievable. The $7.2\,x\,10^7\,eq.\,\gamma/sec$ rate assumed T–counters firing at 1MHz. At 50MHz per 19 T–counters (with 20% overlap) individual T–counters would be running at about 3.3MHz.

The desired value for acceptance efficiency is determined by events in which enough information is garnered by HYCAL to reconstruct the π^0. It is for this reason that a "good" test was defined to select only those events. An event which passed the good test had two particles from a π^0 decay, each having $E_{\gamma\, min}$ or greater energy and each projected from their point of creation to hit in the HYCAL fiducial volume. The fiducial area of HYCAL was defined to be between 1.5 PbWO4 modules and 17 PbWO4 + 5 Pb−glass modules in both X and Y. The fraction of "good" events for which the trigger fired was taken as the acceptance efficiency.

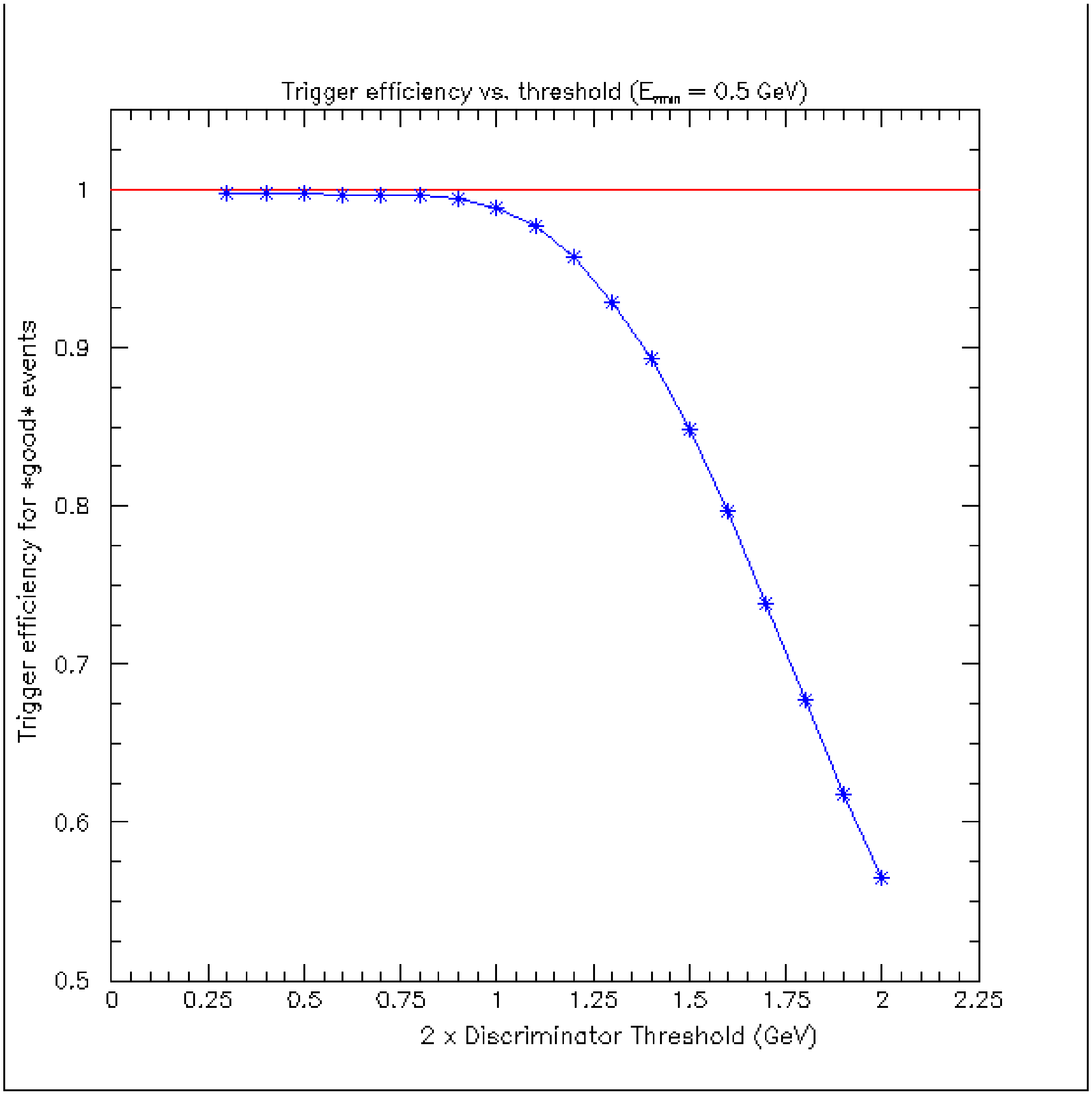

Figure 9Expected PrimEx trigger efficiency for measuring 500MeV or greater photons vs discriminator threshold. The values on the x−axis are actually twice what the discriminator would be set to.

Figure 9 shows a plot of the acceptance efficiency vs. $E_{\gamma\, min}$. In order to see how sensitive the efficiency is to threshold, the "good" test was always performed for

$E_{\gamma\, min} = 500 MeV$.

Trigger Failures

The small fraction of events which passed the "good" test but failed to fire the simulated trigger were examined more closely. The reason for the failures was always the result of energy escaping from HYCAL. This is most likely due to the either the initial photon or an energetic shower product traveling through one of the cracks. These types of events will lack the information necessary to reconstruct the π^0 and so, cannot really be considered failures of the trigger.

Simulation of Beam Background

A simulation of the beam background was done using psim and the photon event generator. The simulation threw $1.5 x 10^9$ photons with a 1/E distribution from 50MeV to 5.734GeV. Events with less than 1 MeV deposited in PrimEx detectors were discarded. A total of 2,066,622 events were kept.

Calculation of Accidental/Pile−Up Rates

Photon beam backgrounds can produce false triggers by simulating the conditions of a real π^0 decay. This can be done by a single beam photon, but it can also result from two or more beam photons depositing energy either directly or indirectly, into the calorimeter in a short amount of time. To calculate the trigger rates due to combinations of events, we must add the results of two or more simulated events together. The rates of these combined events must then be determined, taking care to explicitly include the probability of actually having N beam photons interact within a certain time window w . For the purposes of this calculation, a value of $w = 50\, ns$ is used. This is almost certainly larger than what will actually be implemented. However, in the interest of developing a calculation that can ultimately be taken as an upper limit, liberal estimates will be used wherever possible.

To start with, the number of beam photons in any given time w between 50MeV and 5.734 GeV is:

$$N_\gamma = w * Q \ln(5.734/0.050) = 36 \; per\, 50ns$$

The values of 50 MeV and 5.734 GeV were used in the bremstrahlung generator for the simulation. Photons were generated in a 1/E distribution between these limits.

In order to determine the trigger rates due to accidentals/pileup, we must add together from 1 to 36 separate simulated events. Events in the simulation were only kept if at least 1 MeV was deposited in the PrimEx setup. This includes not only the calorimeter, but also the veto counters and the pair spectrometer. The simulated events have therefore been pre−sorted into two groups: 1.) the photon interacted in a way affecting PrimEx, and 2.) the photon did not affect PrimEx. The second group of events was discarded, but the number of discarded events was recorded. This gives rise to a binomial distribution. The ratio of the group 1 events to the sum of group 1 and group 2 events is used as the probability of a given beam photon depositing energy in a PrimEx detector. It is defined as:

$$P_c = \frac{N_k}{N_T} \tag{2}$$

where:

N_k = Number of events kept (i.e. 1 MeV or more deposited in PrimEx detectors)

N_T = Number of events thrown

The value of P_c is roughly 0.0014.

The trigger rate is calculated as a function of the number of photons added together. The total trigger rate will then be the integral of this function. This is given more explicitly in the following formulae:

$$R_M = P_c^M (1-P_c)^{N-M} C_{MN} T_M \frac{1}{50\,ns} \tag{3}$$

and

$$R_{tot} = \sum_{M=1}^{65} R_M \tag{4}$$

where:

R_{tot}	is the total trigger rate due to accidentals/pileup
M	is the number of beam photons affecting PrimEx
R_M	is the trigger rate due to exactly M beam photons combining
N	is 36, the number of beam photons in a 50ns time window
P_c	is the probability of a single beam photon affecting PrimEx
C_{MN}	accounts for the counting statistics (see below)
T_M	is the fraction of "M photon" events which fire the trigger

The values C_{MN} are the so called binomial coefficients. They are defined as [§]:

§ Young, "Statistical Treatment of Experimental Data" McGraw−Hill, 1962

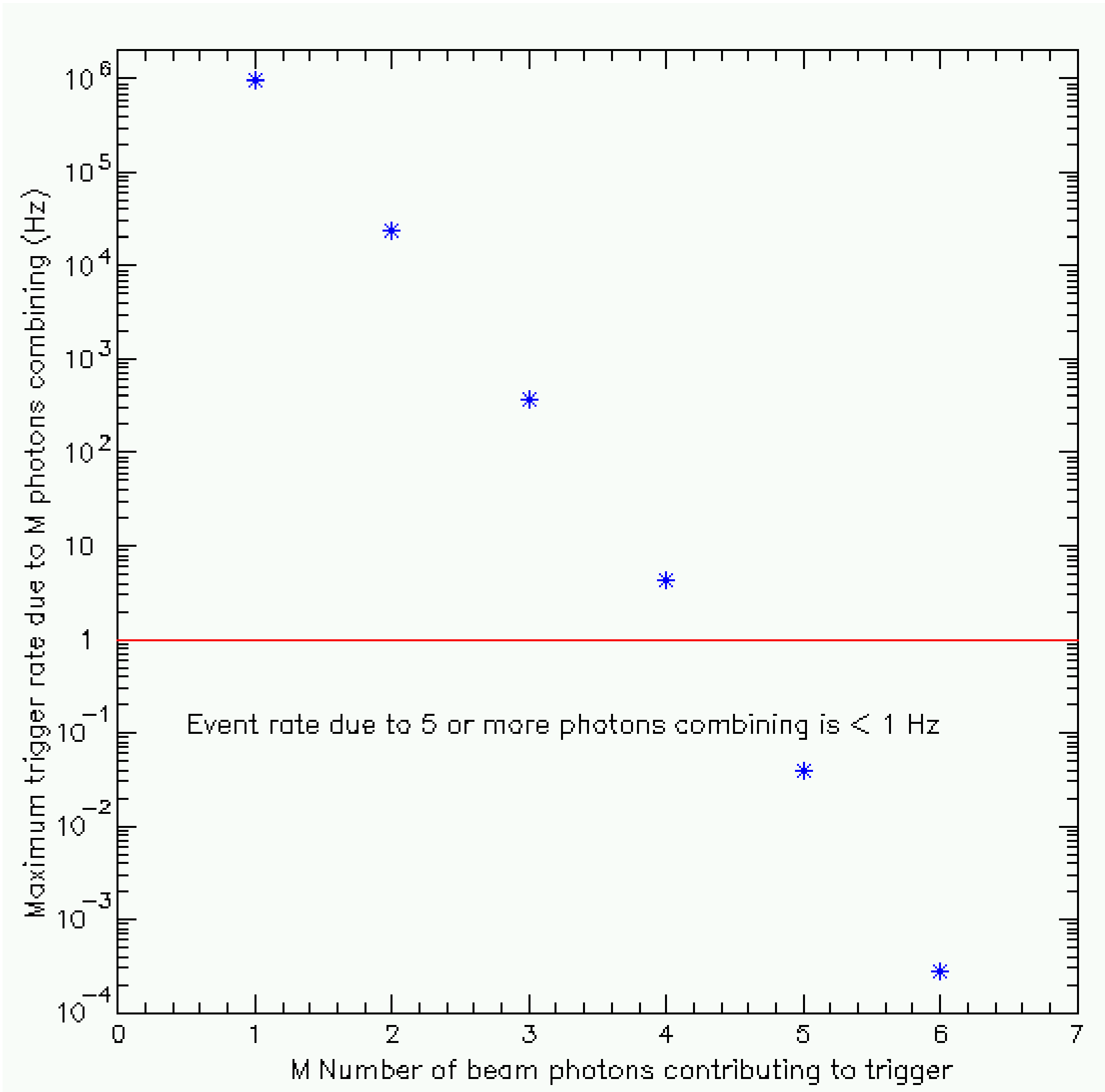

Figure 10Maximum trigger rate due to accidentals/pileup vs. number of beam photons contributing. These points assume a perfectly loose trigger which accepts every event depositing 50MeV or more in a PrimEx detector. The line indicates the 1 Hz limit. The total rate due to 5 or more photons combining will be less than 1 Hz regardless of the trigger used.

$$C_{MN}=\frac{N!}{(N-M)!M!}$$

The C_{MN} values actually get quite large (10^{10} !) However, since the probability P_c is so small, the large values of C_{MN} are suppressed such that only a few of the smallest M values are relevant. The maximum value of M for which a non–negligible contribution to the total trigger is made can be determined as follows:

Set T_M to its maximum value of 1 in equation 3, to calculate the upper limit on the values of R_M. This is shown in figure 10. It can be easily seen that for $M > 4$ photons, the P_c^M term suppresses the the rate to less than 1Hz, maximum. Thus, the values of T_M need only be determined up to $M \leq 4$. This can save considerable effort since the determination of T_M values can require large resources (disk space and CPU) if done for the entire range $1 < M < 36$

Trigger Rates due to Beam Background

Using the formula derived in the previous section, the trigger rates were determined for combining from 1 to 4 beam photons at various discriminator thresholds. The range of thresholds corresponded to $E_{\gamma\, min}$ values between 250MeV and 1 GeV. Figure 11 shows a plot of the calculated rates.

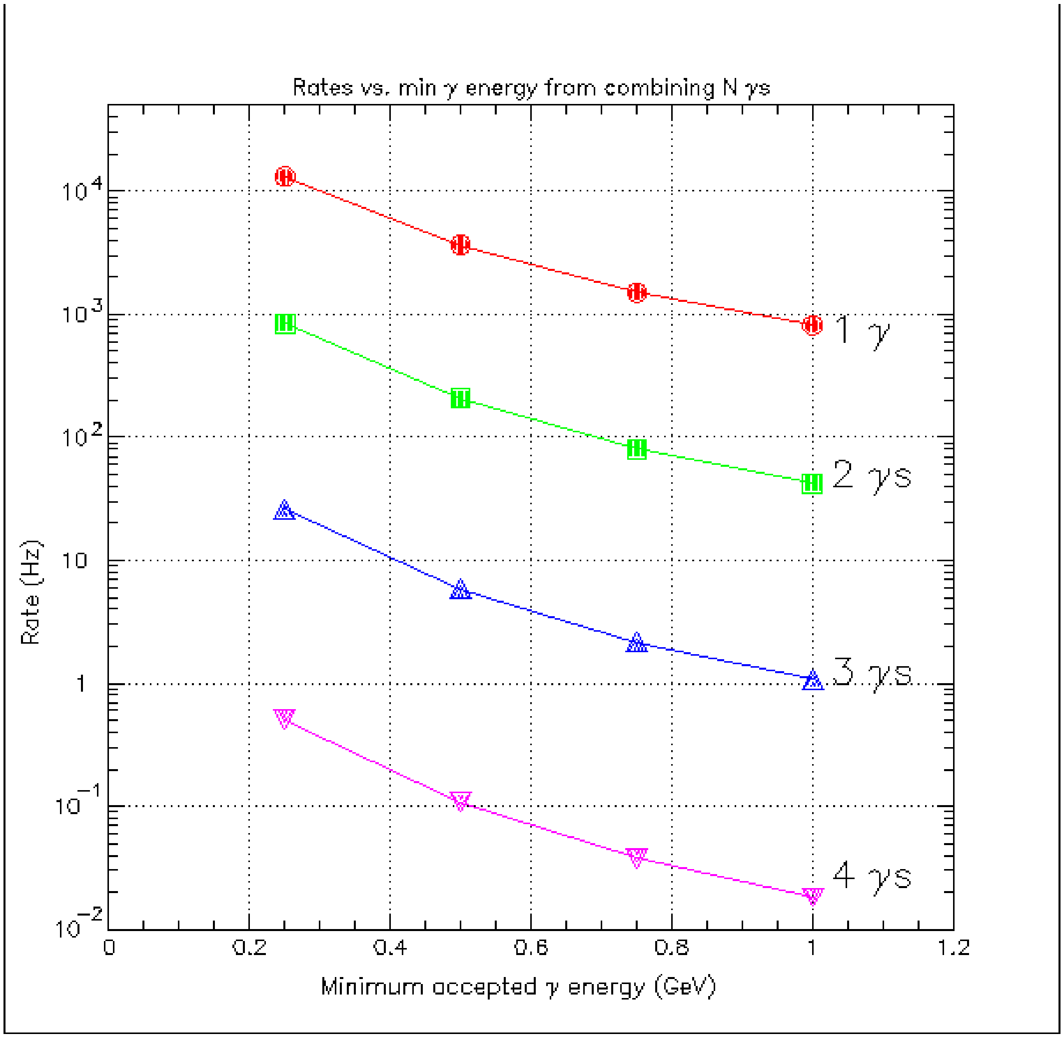

Figure 11 Trigger rate vs. minimum accepted energy from π^o decay photons. The 4 curves show the rate due to pile−up from 1,2,3, and 4 beam photons.

Figure 12 shows the integrated rate obtained by summing the four curves in figure 11.

This indicates most of the background triggers will come from a single beam photon.

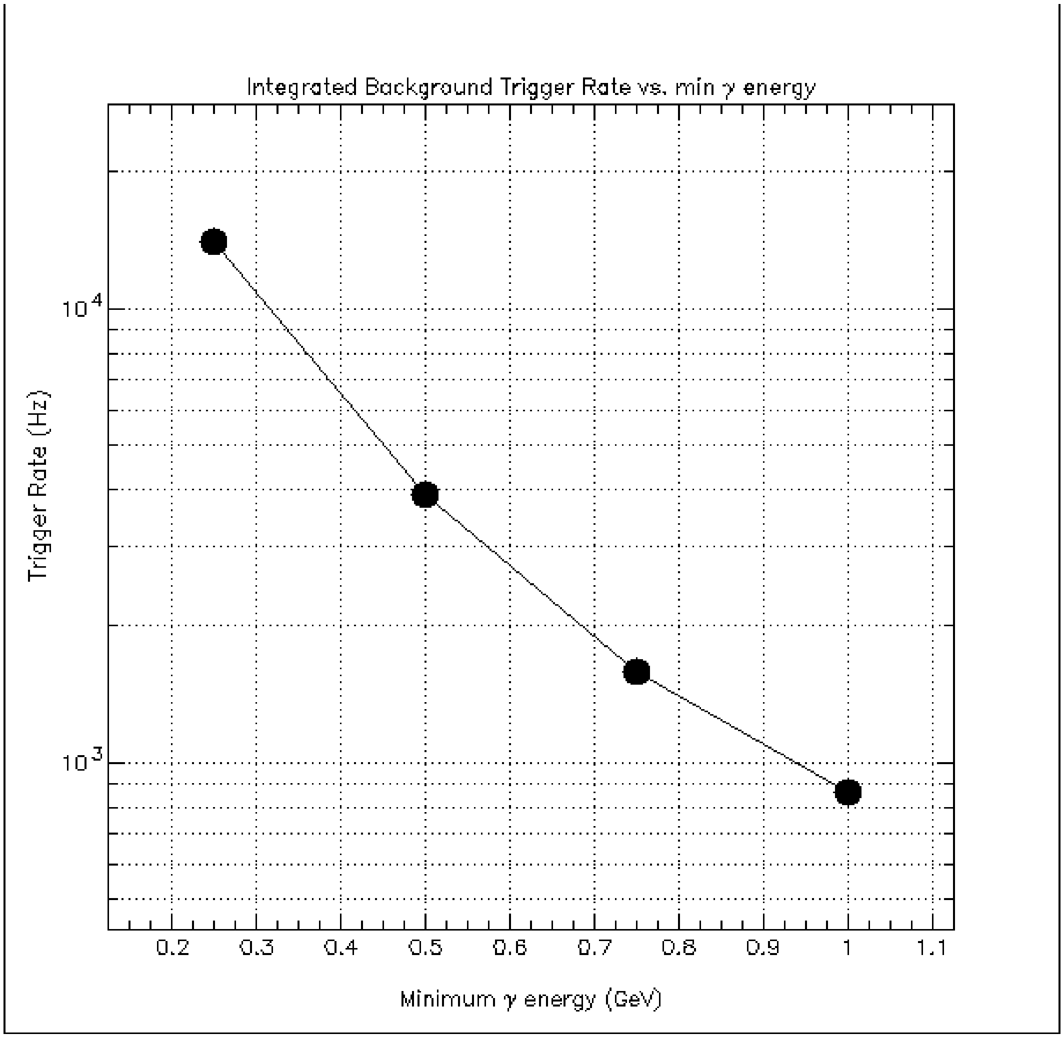

Figure 12 Total rate due pileup/accidentals a function of $E_{\gamma\,min}$.

Processes Contributing to Beam Backgrounds

A plot of ϑ vs. z can be seen in figure 13. The angle is that if the initial bremstrahlung photon and z is the position along the beam line of the initial interaction point. This illustrates the various sources of the background events which will spray HYCAL.

The two main processes simulated by GEANT which contribute to the background rates are e+e− pair production and Compton scattering. Figure 14 shows a histogram of the z position of the initial interaction point for events which would have fired the trigger. The background events leading to triggers was clearly dominated by pair production in the beam pipe (upstream of the target) and Compton events in the helium bag. A large number of events also came from the mylar window which defined the boundary beween the vacuum and the helium bag. A majority of the events produced in the mylar window which would cause a trigger were Compton events. This is because the e+e− pairs are produced at relatively small angles such that they go through the beam hole.

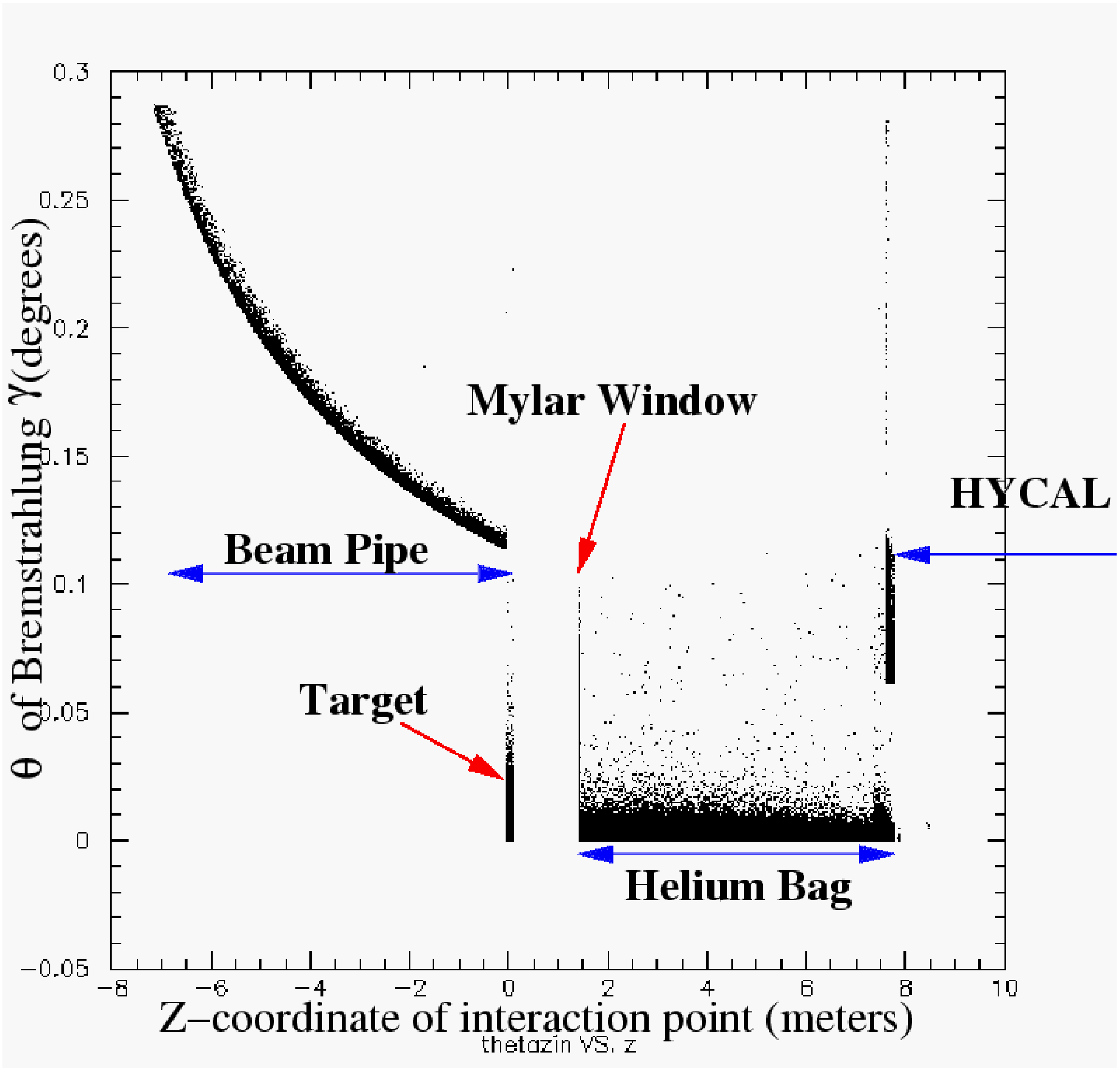

Figure 13 Zenith angle of initial beam photon vs. position along the beamline of initial interaction by beam photon which lead to at least 1MeV deposition in PrimEx.

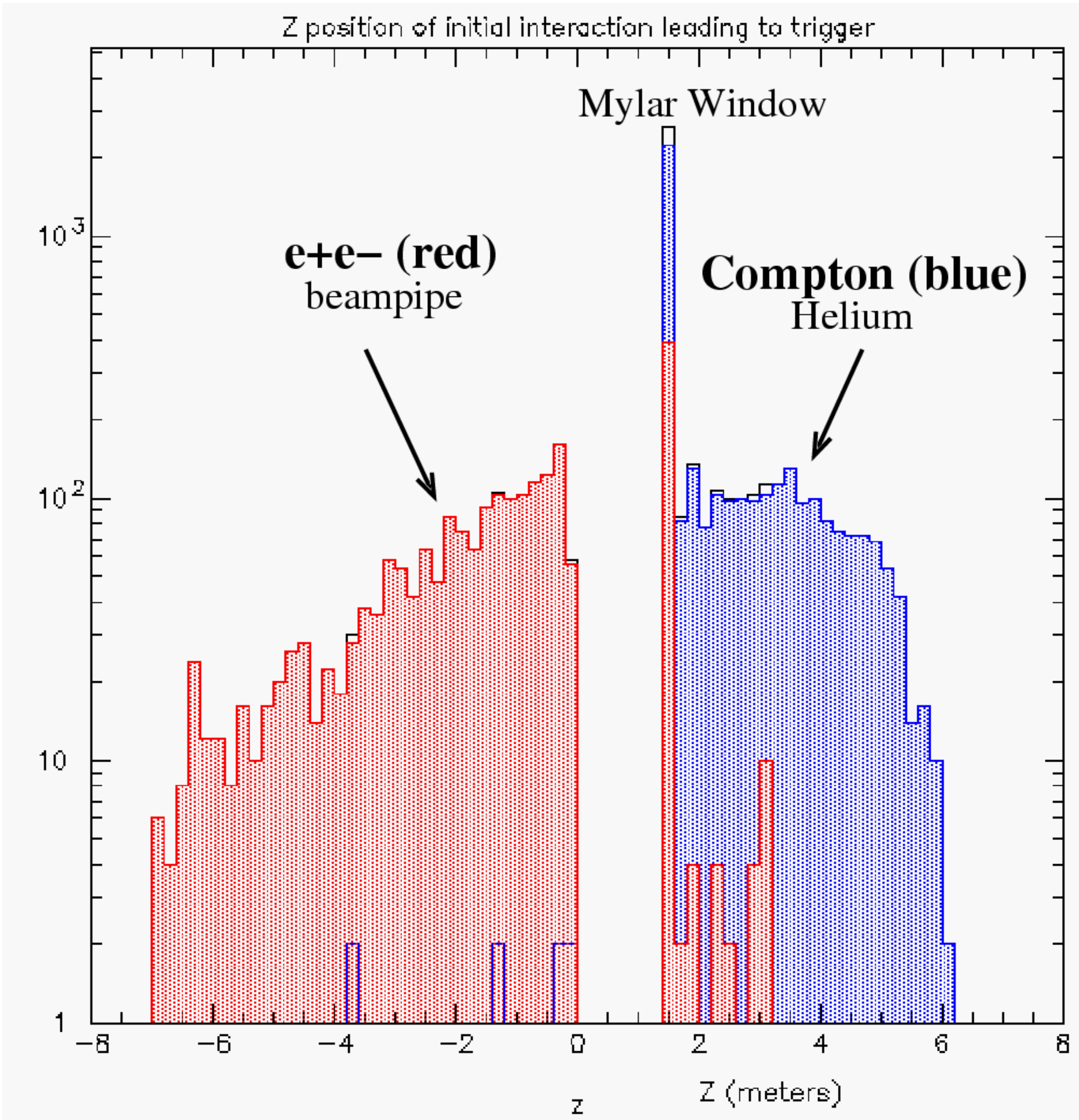

Figure 14 Position along beam line of initial interaction of beam photon which lead to a trigger.

To further investigate how the upstream e+e− pair production events resulted in a trigger, one specific event was studied. The event is shown in figure 15 as it appears in the single event viewer *psim_view*. A special genrator was made which generated e+e− pairs with the 3−momenta and interaction coordinates present in this event. Figure 16 shows a typcial shower resulting from an event with these same starting parameters. The study revealed that about 20% of these events would fire the trigger. One way to likely reduce the rate from the upstream beam pipe would be to simply increase its diameter. This study did not explore this so no quantitative data are available to define the correlation between trigger rate and beam pipe diameter.

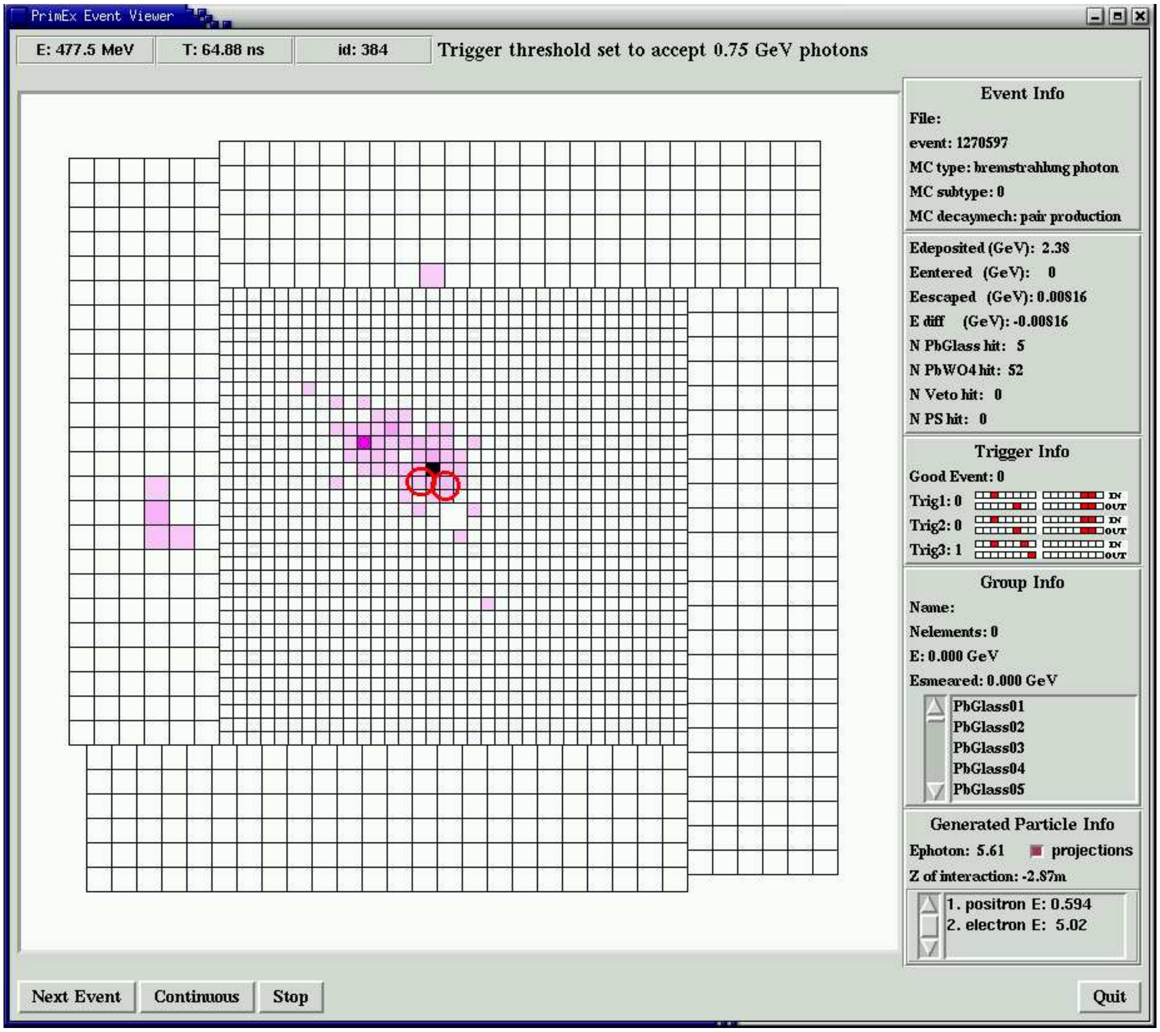

Figure 15 Single photon beam background event which fired the trigger.

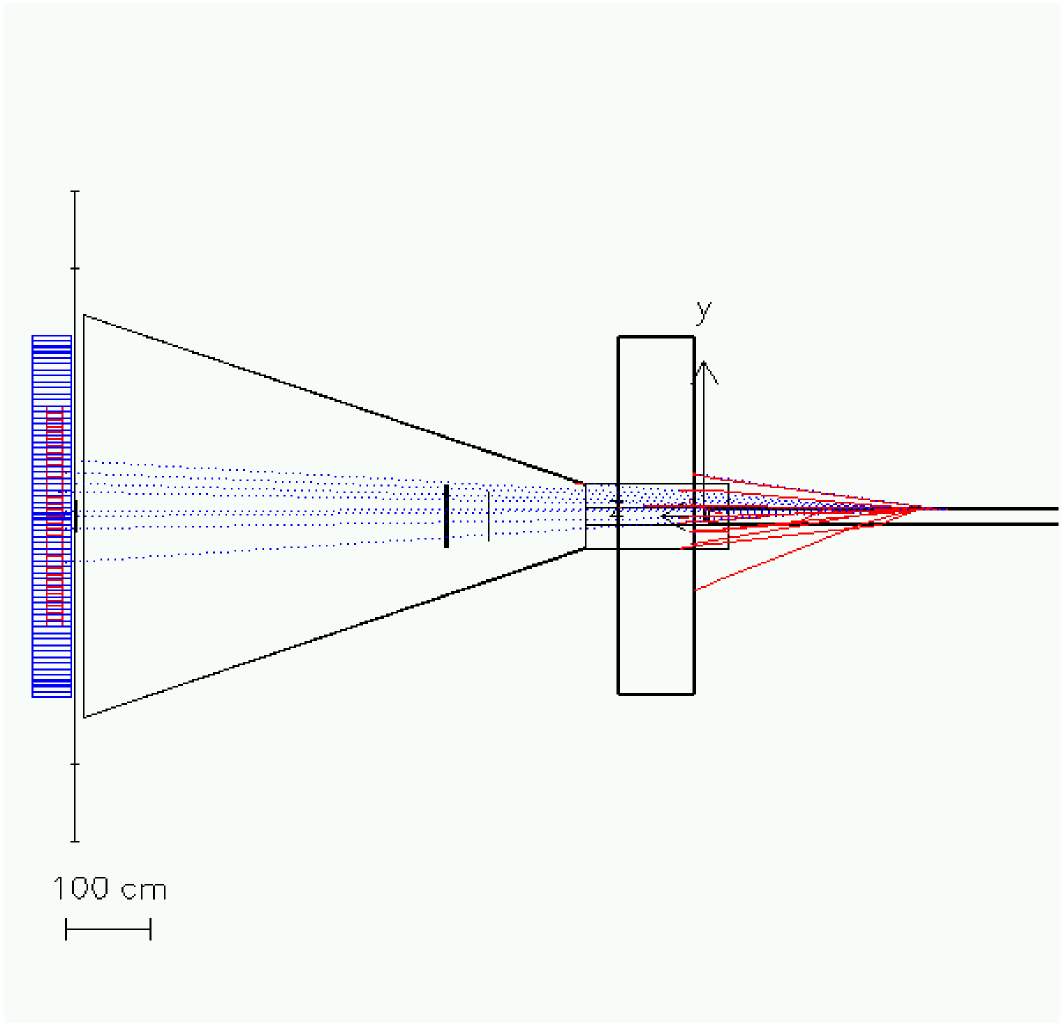

Figure 16 A typcial shower arising from a specialized event generator which produced events similar to that in figure 15.

Discriminator Rates

The discriminator rates for each of the strips was calculated using the same procedure used to determine the trigger rates. The results are shown in figure 17. These rates were determined using the same 50 ns time window as was used for the trigger. A more realistic value might be something closer to 10 ns. The values shown in figure 17 can therefore be taken as an upper limit with confidence .

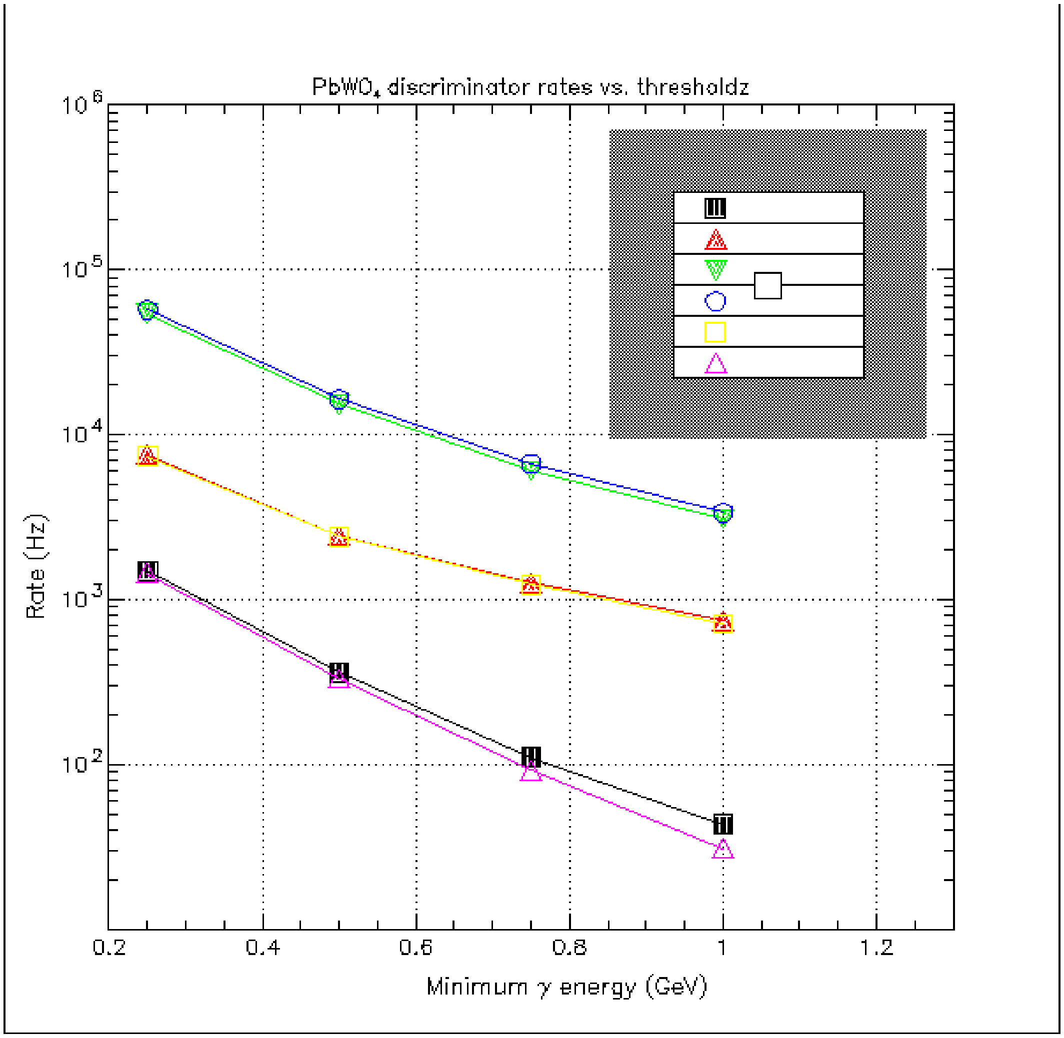

Figure 17 Maximum discriminator rates expected for strips in PbWO4.

Detector Rates

The rate we expect to see individual detectors fire is also an important quantity. Figure 18 shows a plot of the rate as a function of integrated energy for PbWO4 detectors at several positions. The detectors closest to the beam can expect to see a 100 kHz rate of events with 10 MeV or more deposited. For the PbWO4 farthest from the beam (on a cardinal axis) a rate closer to 200 Hz can be expected. These rates were calculated from singles and do not include pileup effects.

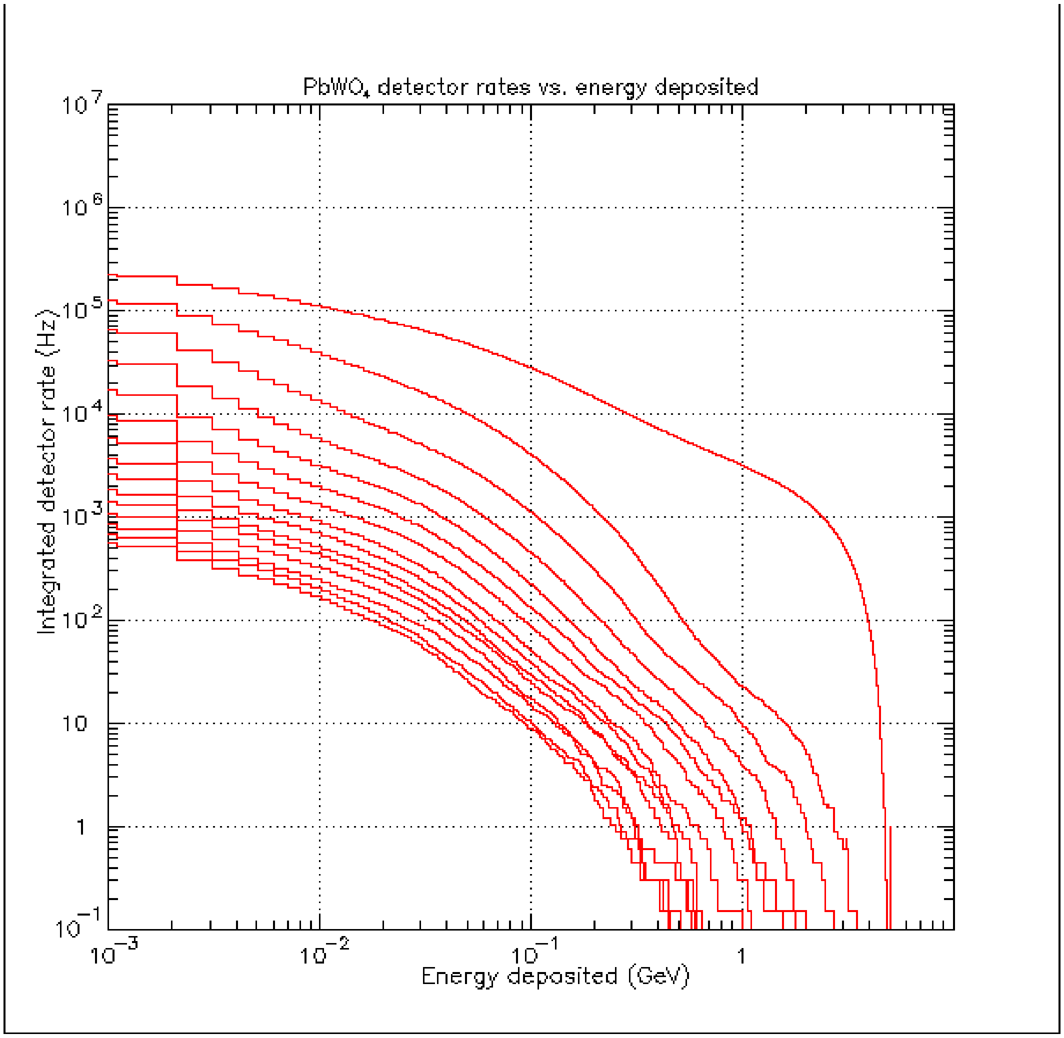

Figure 18 Detector rates vs. lower limit of deposited energy. The curves represent the rates at which the indicated energy or more is deposited in a single detector. Each individual curve represents a detector position along one of the cardinal directions. The symmetry of HYCAL allows 8 detectors to contribute to each curve.

Summary

A Monte Carlo simulation study of the PrimEx detector was performed using the primsim package available in the PrimEx CVS repository on the JLab CUE. A study of both the π^o acceptance efficiency of the trigger as well as the background rates was done.

PrimEx can expect a 99.7% acceptance efficiency for $\pi^o \rightarrow \gamma\gamma$ events which have the proper kinematics to illuminate the fiducial volume of HYCAL.

Discriminators viewing PbWO4 strips closest to the beam will fire at < 20kHz rates. Strips farther from the beam will fire at < 2kHz.

PbWO4 detectors closest to the beam hole will have 1MeV or more energy deposited at a rate of < 200kHz. All PbWO4 detectors except those lining the beamhole will see 1GeV or more energy deposited at a rate of < 20 Hz.

Liberal estimates were made wherever possible to allow great confidence in these values as upper limits.

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