# PSF Analysis

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## Overview

- List of data available for analysis and discussion of statistics
- Tools used for analysis
- Discussion of cuts used for PSF analysis
- PSF Analysis
    - Test Beam Setup
    - Methodology
    - Results
- Comparison to AO data
- Tail Events
    - Cuts motivated by tail events
- Future adjustments in PSF
- Conclusions

# Test Beam PSF Analysis

**•Statistics**

Below is a list of the number of events that can be used for analysis of the PSF, and an approximation of the total number of reconstructed events we will have after running tb_recon using an efficiency of **4.977%.**

| Run Type | #Events | TB Recon |
|---|---|---|
| •20 GeV 0 deg | 4874652 | 242611 |
| •20 GeV 45 deg | 608517 | 30285 |
| •5 GeV 0 deg | 916505 | 45614 |
| •5 GeV 30 deg | 576783 | 28706 |
| •2 GeV 0 deg | 817340 | 40679 |
| •2 GeV 30 deg | 423916 | 21098 |

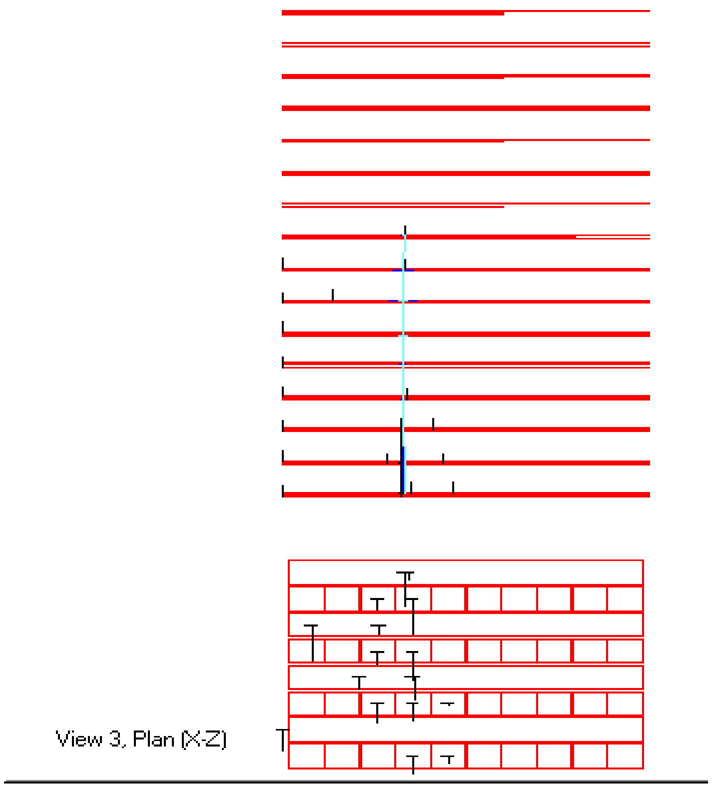
We need to also note that there were 3 different converter lengths used during the test beam run, the converter used has an impact on the PSF and thus analysis should be done with only one converter length per setup. The runs at 20GeV 0 deg have predominately 2.7% converter and thus we do not lose as much as we might in other run types.

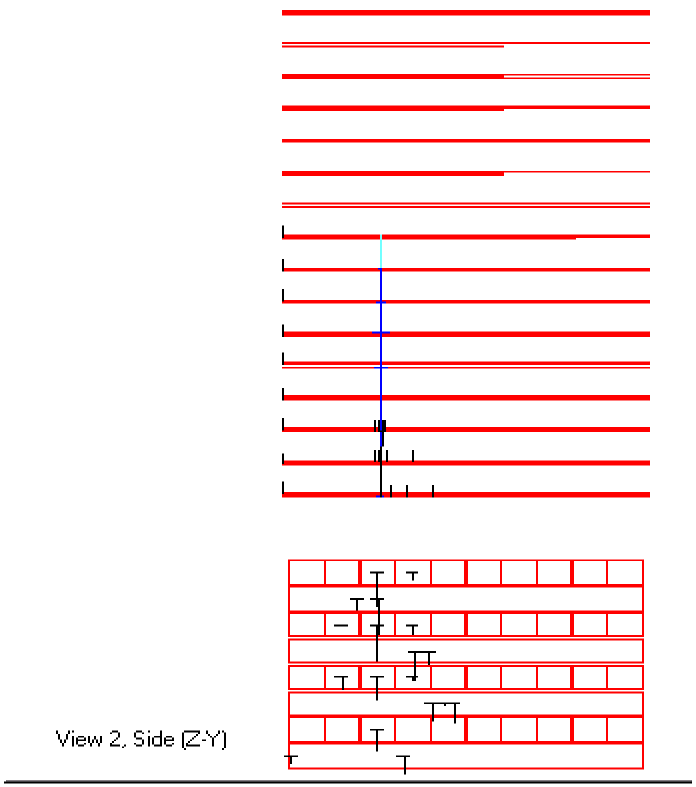
## Tools Use for PSF Analysis

- **tb_recon** was used to get the data from the raw root files and to reconstruct the events
- **tb_ana** was used to do preliminary cuts to the data and create useful ntuples for PSF analysis
  - tb_ana is an augmented version of tb_recon where NO reconstruction is done, it has a similar centella.in file and is flexible enough to allow implementation of complex cuts and preliminary analysis.
- **Root Scripts** were used to do the final analysis, i.e. implementation of complex cuts that we may wish to change repeatedly throughout the analysis, creation of post script documents for presentation of data, and other processes not suited for implementation in tb_ana.

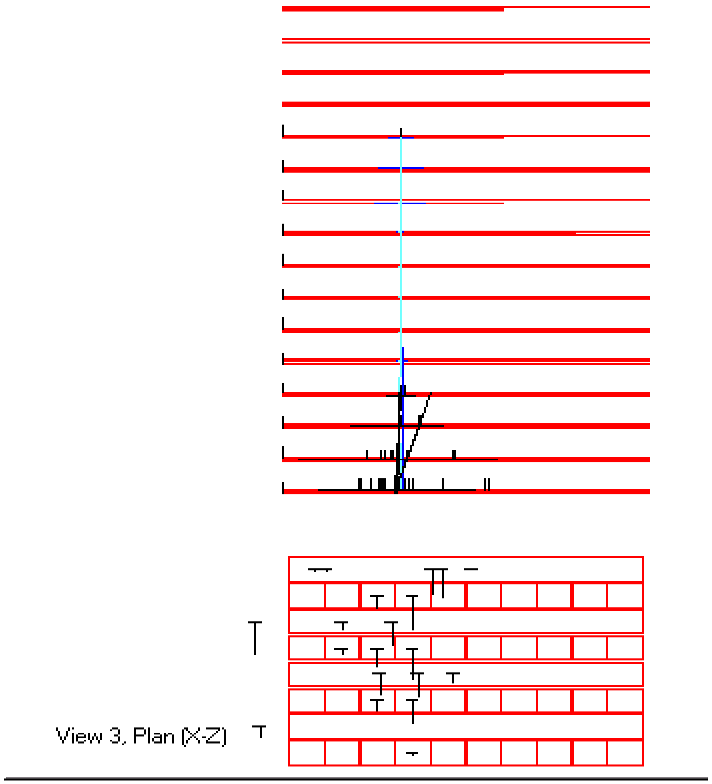
# Test Beam PSF Analysis

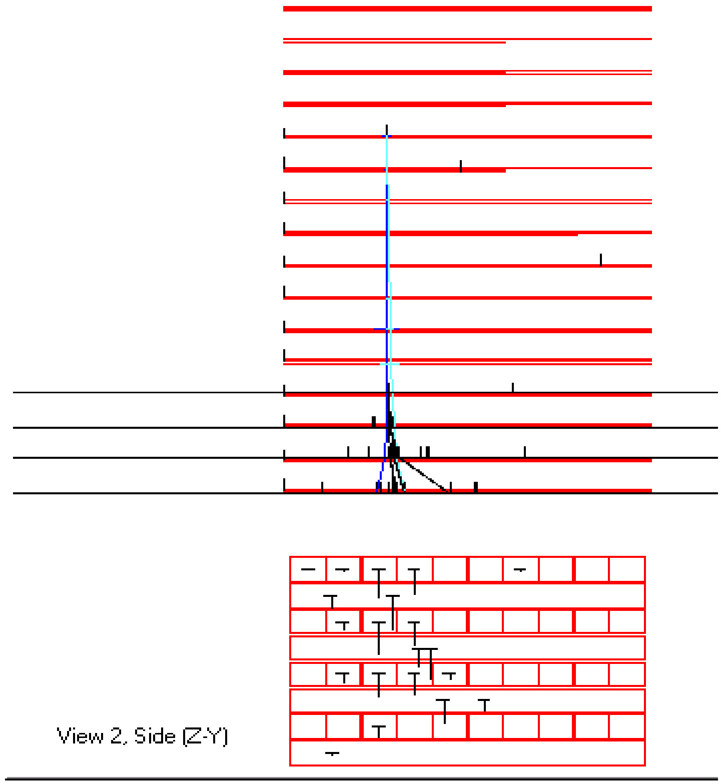
Here we see some accurately reconstructed events



# Test Beam PSF Analysis



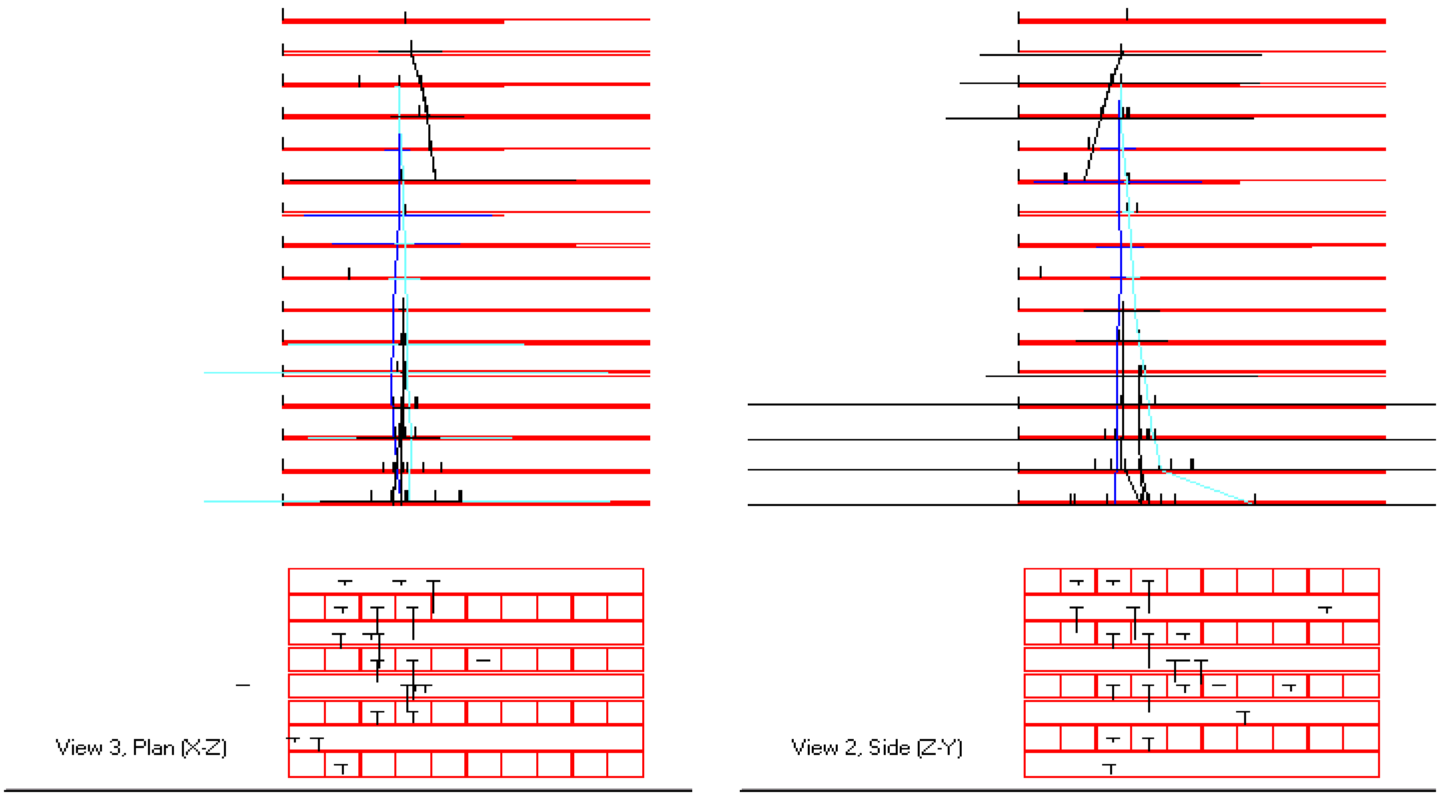
**Cuts Made in analysis**

- vertex != first plane
  - removed since implies out of tracker conversion
- vertex != dead zone
  - removed due to lack of data at these points
- 10 MeV<eneSum<Beam Energy
- no tracks starting above the reconstructed gamma
  - removed because situation implies incorrect reconstruction or multiple gammas
- Energy Agreement abs[(eneTag-eneSum)/eneTag]<0.25
  - Required since energy of incoming gamma dramatically effects the PSF
- we require that NO clusters exist in a radius around a projection of the gamma to the plane above it's starting point.
  - Implemented to remove events that may be reconstructed incorrectly due to low energy used in reconstruction or misalignment of tracker

The Energy Agreement cut uses eneSum for energies less then 10 GeV since it is most accurate in that range.

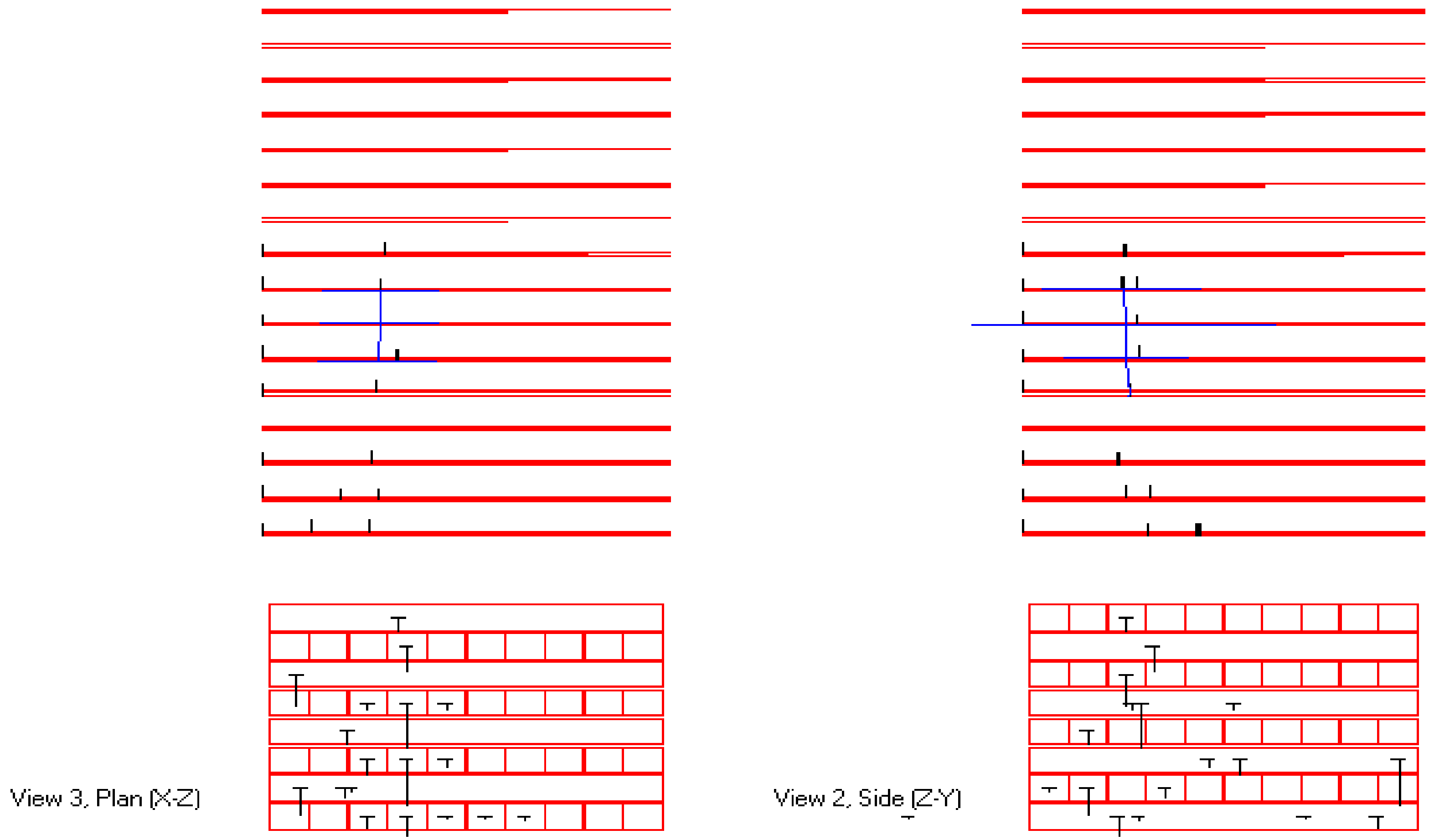
# Test Beam PSF Analysis

The event below shows a track reconstructed above the gamma particles and would thus be removed from further analysis.



# Test Beam PSF Analysis

This event shows numerous characteristics we look for in events we would like to remove: a cluster above what was reconstructed as the main gamma product, both projections do not have the same length, the energy in the calorimeter (2.8 GeV) appear too high for the event, and there are missing data for plane 12 which is below the gamma. This event would be removed with the appropriate radius above the gamma cut.

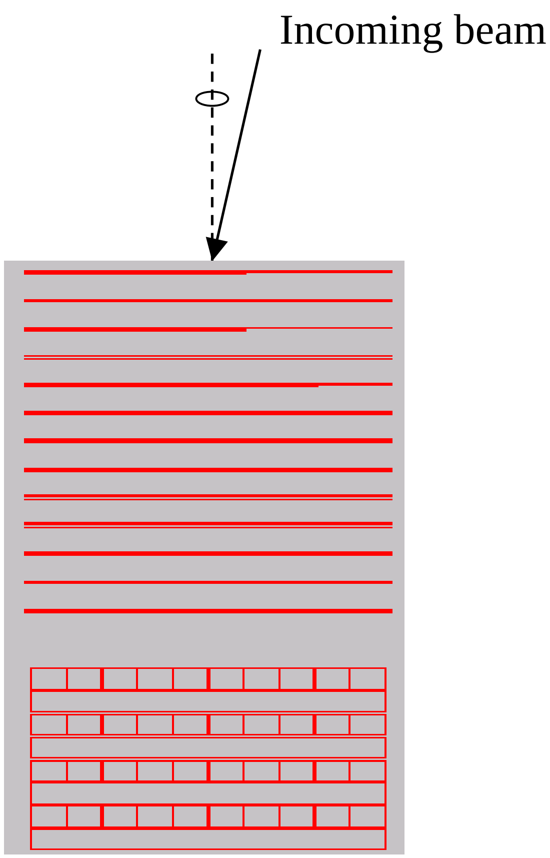


## Analysis Procedure

- Find beam vector
- Take the inner product of the misalignment vector and each incoming gamma vector
- Find the integral of the PSF as a function of angle and specifically the points of 68% and 95% containment
    - Calculate error associated with values
- Compare data with AO predictions
    - Account for difference in conversion material
- Examine the tail events of the PSF
- Implement cuts to remove events that can be explained

## Finding the beam vector

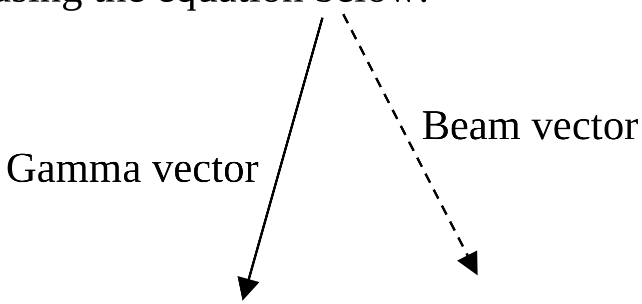
The sketch below shows the incoming beam relative to the tracker. The dotted line is the z axis and the x axis is coming out of the surface. Theta is defined as the angle between the z axis and the incoming vector, phi is defined as the angle between the x axis and the projection of the incoming vector onto the xy plane.




The beam vector is found by taking the variables **cos(phi)tan(theta)** and **sin(phi)tan(theta)** and computing their averages, from there we can find <theta> and <phi> that we now define as the incoming beam vector.

## PSF Calculation

We take the beam vector to be the true vector of each incoming gamma and thus any deviation from this vector is error inherent to the system. The distribution of angles between these two vectors is defined as the PSF(Point Spread Function) and is found by using the equation below.




**PSF = arccos[ sin<theta> * sin theta * (cos<phi> * cos phi + sin<phi> * sin phi) + cos<theta> * cos theta]**

Where <theta> and <phi> represent the beam vector and theta and phi represent the event vector.

## Containment Angles and Error

The integral of the PSF is found using a root script which takes the integral of the PSF histogram up to the point in question. The error in the containment angles is also calculated at this point using the equation below.

**Error = sqrt[ ratio*(1-ratio)/ nEvents]/slope**

Where: the "ratio" is the value of the integral at the point in question, "slope" is the slope of the integral at the point in question, and "nEvents" is the number of events in the entire PSF histogram.

## AO Comparison

The predictions of the PSF from the AO are seen below for the energies of interest.

| Energy | | PSF | | | | Aeff | |
|---|---|---|---|---|---|---|---|
| | | Front | Back | Total | | | |
| 0.01 | | 0.399668611 | 0.5236 | 0.4152 | | 80 | 97 |
| 0.02 | | 0.274008611 | 0.4869 | 0.30473 | | 890 | 1236 |
| 0.03 | | 0.176273056 | 0.3909 | 0.21694 | | 1293 | 2254 |
| 0.05 | | 0.106461944 | 0.267 | 0.15146 | | 1886 | 4733 |
| 0.07 | | 0.075046944 | 0.1911 | 0.10756 | | 2627 | 6682 |
| 0.1 | | 0.054801722 | 0.1339 | 0.07711 | | 3307 | 8155 |
| 0.3 | | 0.019023528 | 0.0473 | 0.02698 | | 3973 | 9928 |
| 1 | | 0.006736772 | 0.0158 | 0.00902 | | 5584 | 12164 |
| 3 | | 0.003019331 | 0.0066 | 0.00401 | | 5854 | 12996 |
| 10 | | 0.001288015 | 0.003 | 0.00174 | | 6123 | 13698 |
| 30 | | 0.000668441 | 0.0018 | 0.00092 | | 5976 | 13095 |
| 100 | | 0.000460753 | 0.0012 | 0.00062 | | 6960 | 14508 |

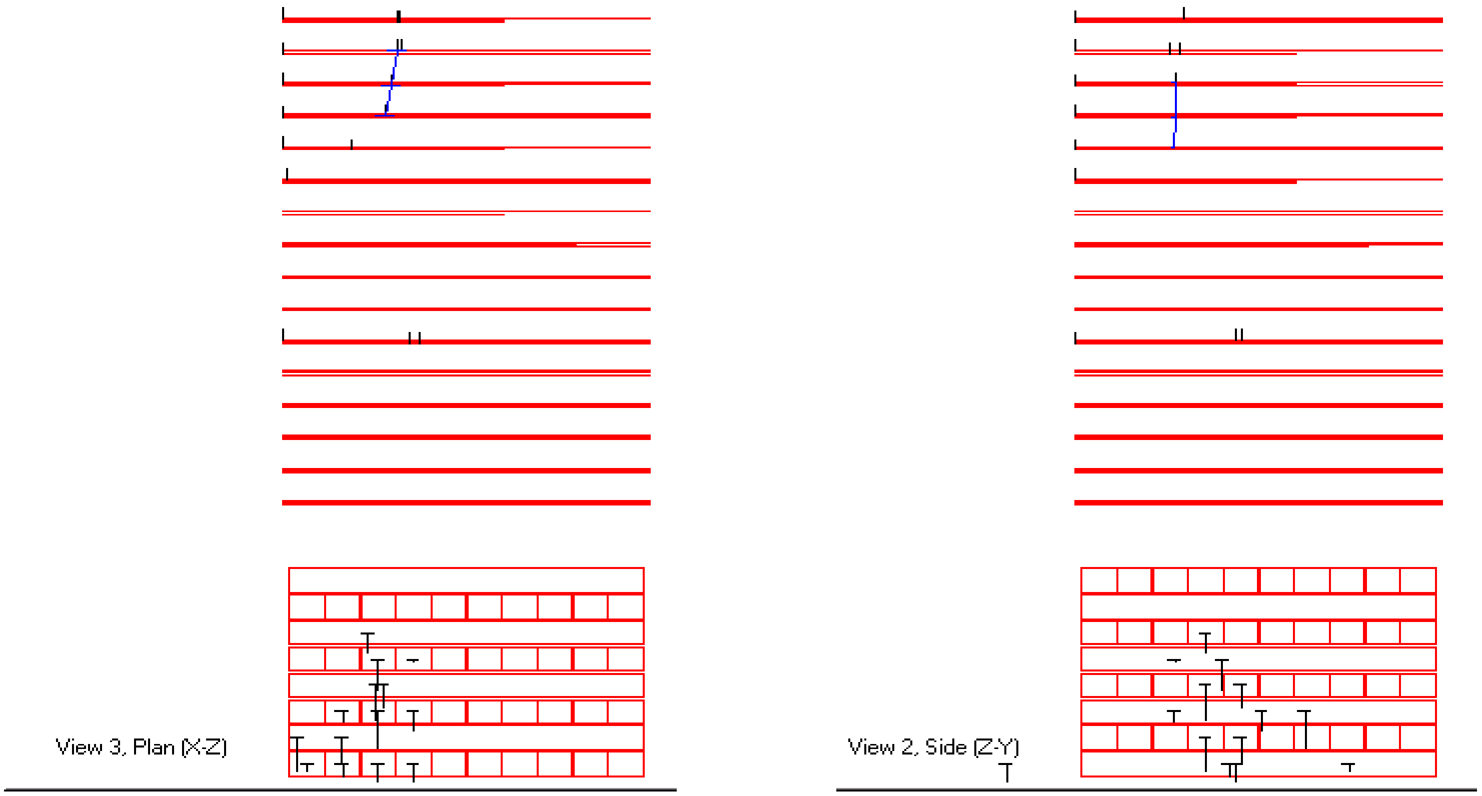
The predictions from the AO must be corrected for since there is more material in the tracker then was used in the AO predictions. This difference should increase the PSF from the AO by about 20%. This brings our data within error of the AO predictions.

## Tail Events

Scanning the tail events of the PSF distribution allows us to see if there are any events being used in the PSF calculation that should not be used. While scanning events we compiled a list of observed and explainable problems in the data and then correlated those problems to possible physical reasons and finally to possible solutions or cuts to these problems.

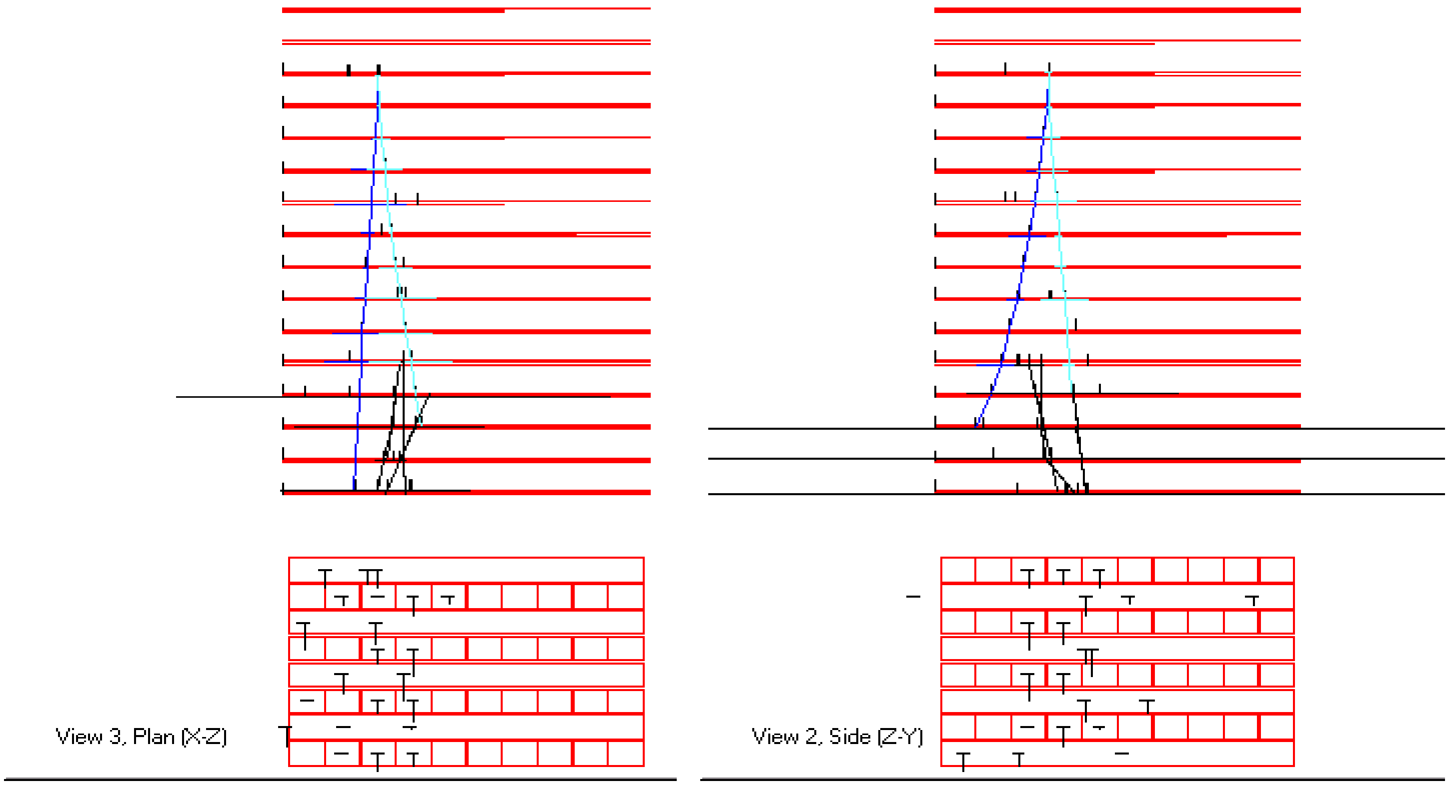
| Observed Prob. | Possible Physical explanation | Cut/Solution |
|---|---|---|
| •no clusters below gamma | eneSum too high for event | require clusters in SG |
| •clusters above gamma | misalignment, eneSum | cut in radius above gamma |
| •large angle between products | eneSum too high for event | cut on angle |
| •tracks start on different planes | bad conversion | require if 2 tracks then same |
| •paths don't align with cal vert | eneSum too high, possible 2 g's | cut on alignment angle |
| •too many hits around g | bad/shower conversion | req. limit on #clusters around |

The event below shows how clusters do not reach the bottom of the tracker but there is a large amount of energy deposited in the calorimeter.



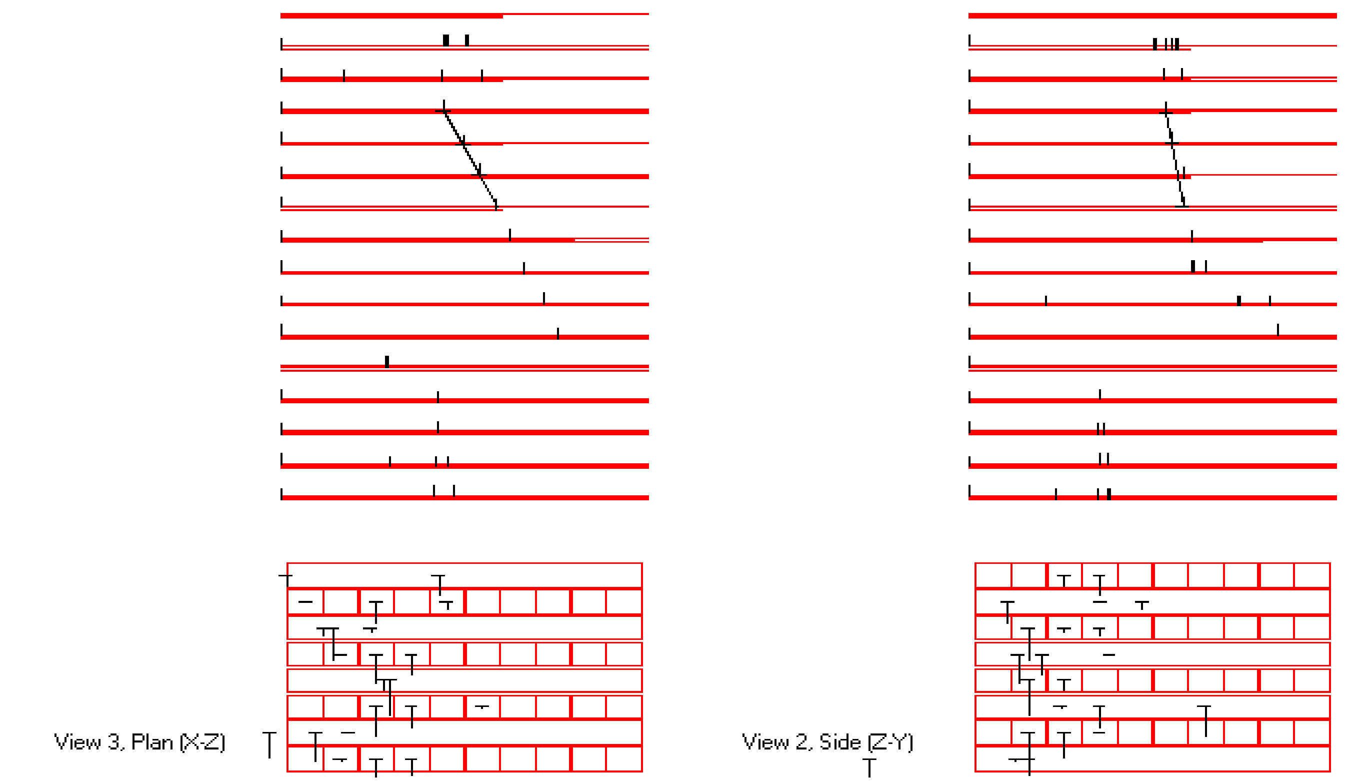
# Test Beam PSF Analysis

The event below shows a large amount of energy deposited in the calorimeter while there is a large angle indicative of lower energy events between the main gamma product(blue) and the secondary(light blue)



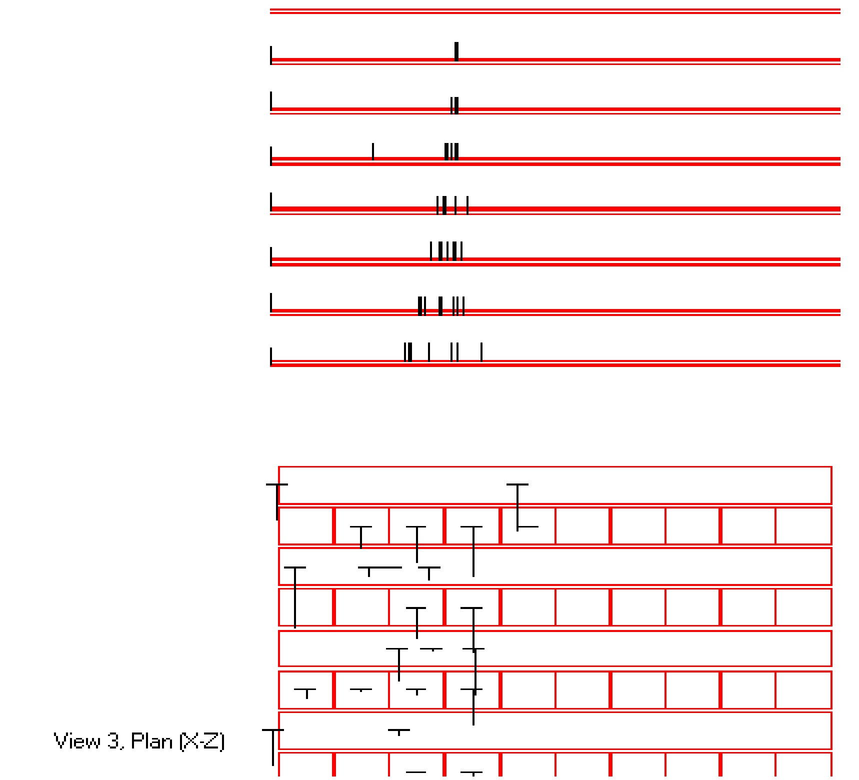
# Test Beam PSF Analysis

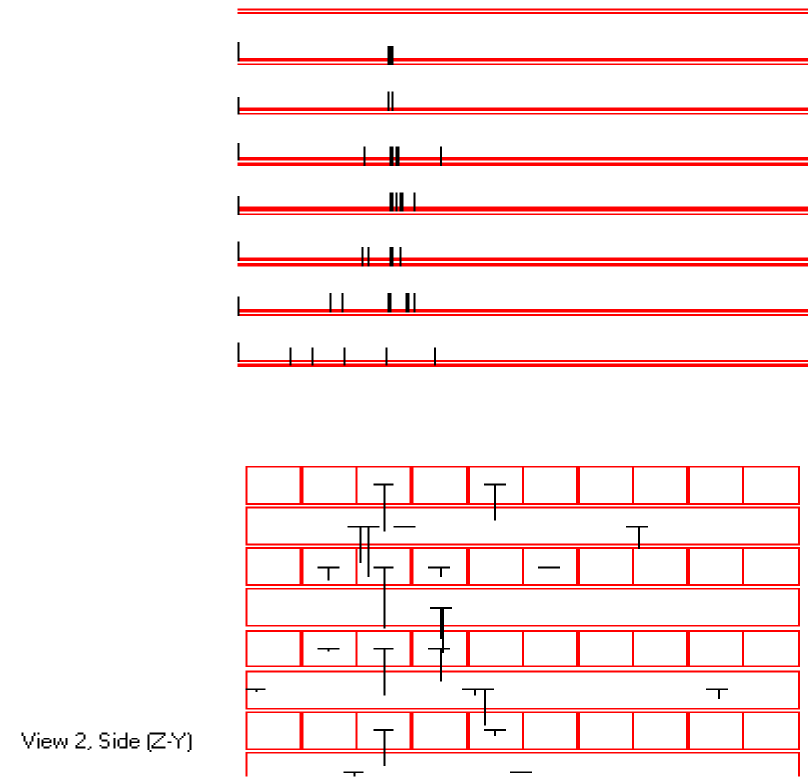
In the below event we see that the reconstructed vertex in the tracker and the vertex in the calorimeter do not align with each other as we would expect.



# Test Beam PSF Analysis

The below event shows a showering effect that makes reconstruction of an accurate gamma virtually impossible. The event was reconstructed but the reconstructed tracks were removed to show the cascade effect more clearly.



## **Future adjustments to PSF**

- Implement alignment corrections for deviations of tracker from drawn specs.
- Implement proposed cuts to remove explainable tail events
- Run analysis on more runs to get better statistical error
- Examine the effect of opening the energies allowed for particle reconstruction.
    - This would allow for clearer reconstruction of some of the events seen but may introduce events where the reconstruction was too lose.

## Conclusions

- The preliminary PSF results appear reasonable and comply with the AO
- Further analysis is needed to bring the 95% containment within a factor of 3 of the 68% as required by the astrophysical community.
    - Implementation of cuts motivated by event scans should reduce the 95% containment
    - Accounting for misalignment of the tracker layers should improve reconstruction of events and reduce the tails of the PSF distribution
- Accurate Monte Carlo data is needed for further comparisons.