PHOBOS Track Reconstruction

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1. Introduction
2. Front-end Tracking
3. Hough PR
4. Template Approach
5. Summary

PHOBOS Tracking activity from Feb. 1999 to yesterday is summarized here. No number will be given at this presentation. Just have a fun with many event displays.

Introduction

Tracking Status

$\boxed{\text{February 1998}}$: PHOBOS tracking meeting (M. Baker, G. Roland, K. Wozniek, and myself)

- K.W. →continue Template approach
- I.P. →rebuild Hough PR of G. Roland on Phat
- Findable track definition was reviewed

$\boxed{\text{March, April 1998}}$:

- Principle of Hough PR was tested with simplified geometry
- Full version of Hough PR was made
- A new structure of template is being tested...

We are approaching to our goal. But I am still worrying about inefficiency & ghost level. Let's go anyway...

Definition of Findable

- No two consecutive missing hits along the track.
- No more than one missing hit in layers A-D
- No more than one missing hit in layers E-J
- No more than one missing hit in layers K-P

Quick view of Tracking Algorithm

1) Front-end tracking (Straight line part):

A clustering algorithm (Mulguisin-Jet Finder) is applied. Hits are projected to $\eta - \phi$ space and clusters are identified either by cone or box. Different cone sizes can be used for different layers. A cluster satisfying the good track seed condition becomes a track seed.

2) In-field algorithm (Curved line part):

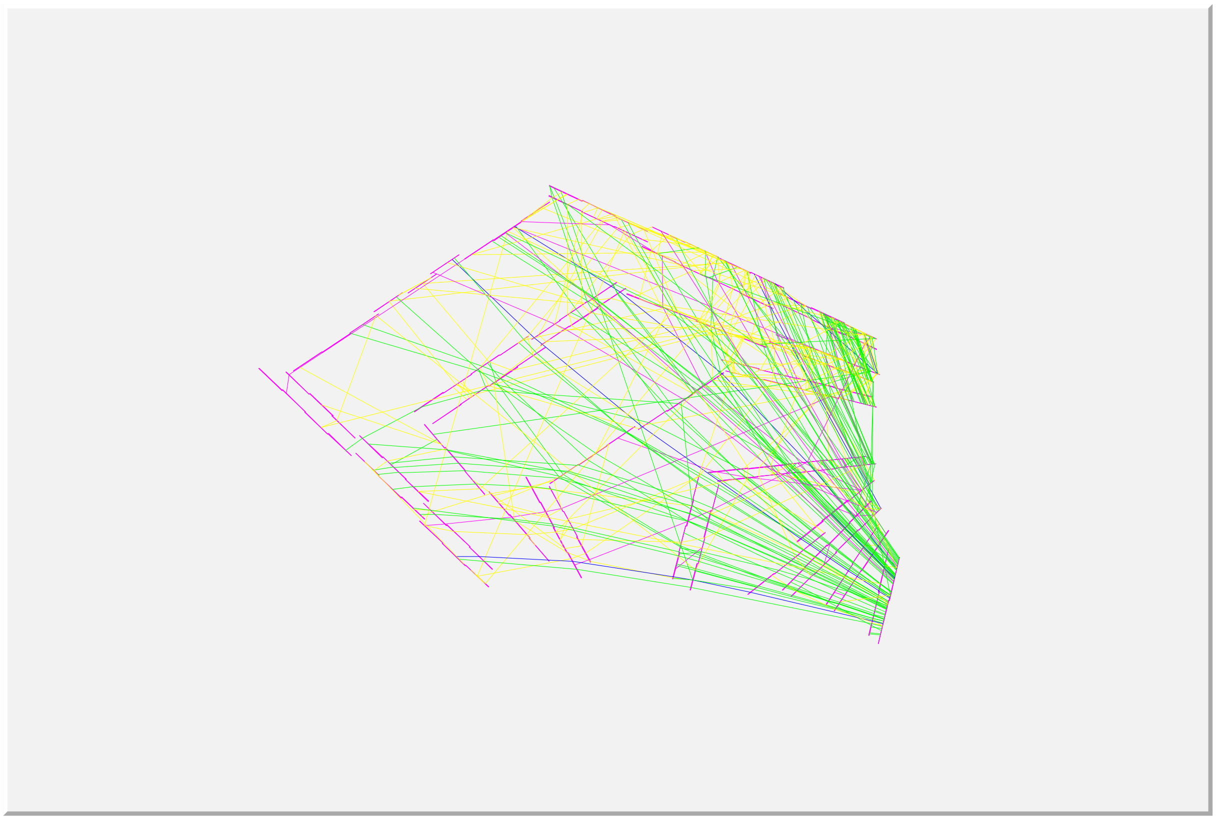
Hough Pattern Recognition is applied. Two hits on two neighboring layers form a match-stick which provides charge, momentum, and θ information. For a given track seed(θ, ϕ), only relevant hits and match-sticks are considered. Match-sticks are chained to form a track candidate.

3) Final track selection (χ^2 fit):

It is hard or practically impossible to get an analytical trajectory of particle path. $\rightarrow$Template Approach is adopted.

Templates are generated as a function of charge, momentum, and θ (and Particle species later) by using of GEANT simulation. χ^2 is obtained based on the template and its error.

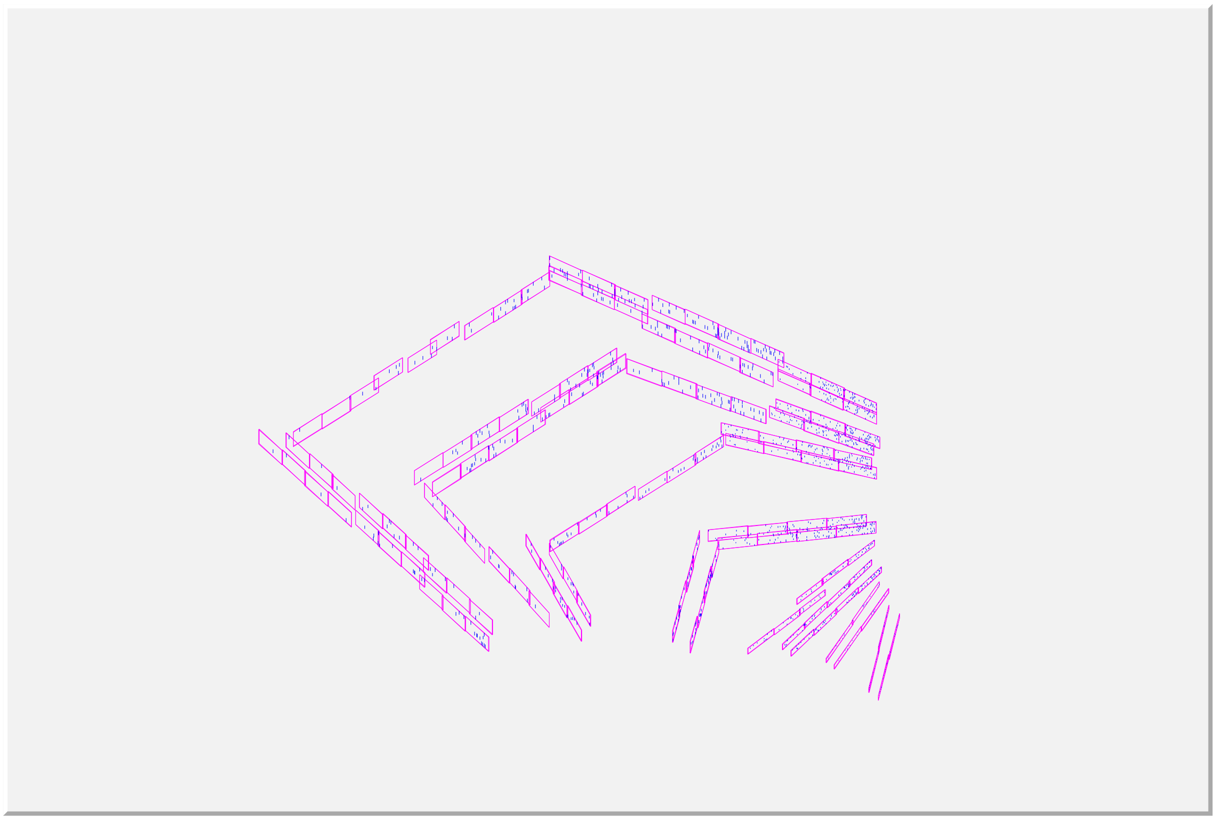
Example Event Display of a typical Au-Au collision



This event has few hundreds of tracks passing through the Spectrometer P. Greens are pions, Yellows are leptons, Blues are kaons.

This is a very discouraging event display....

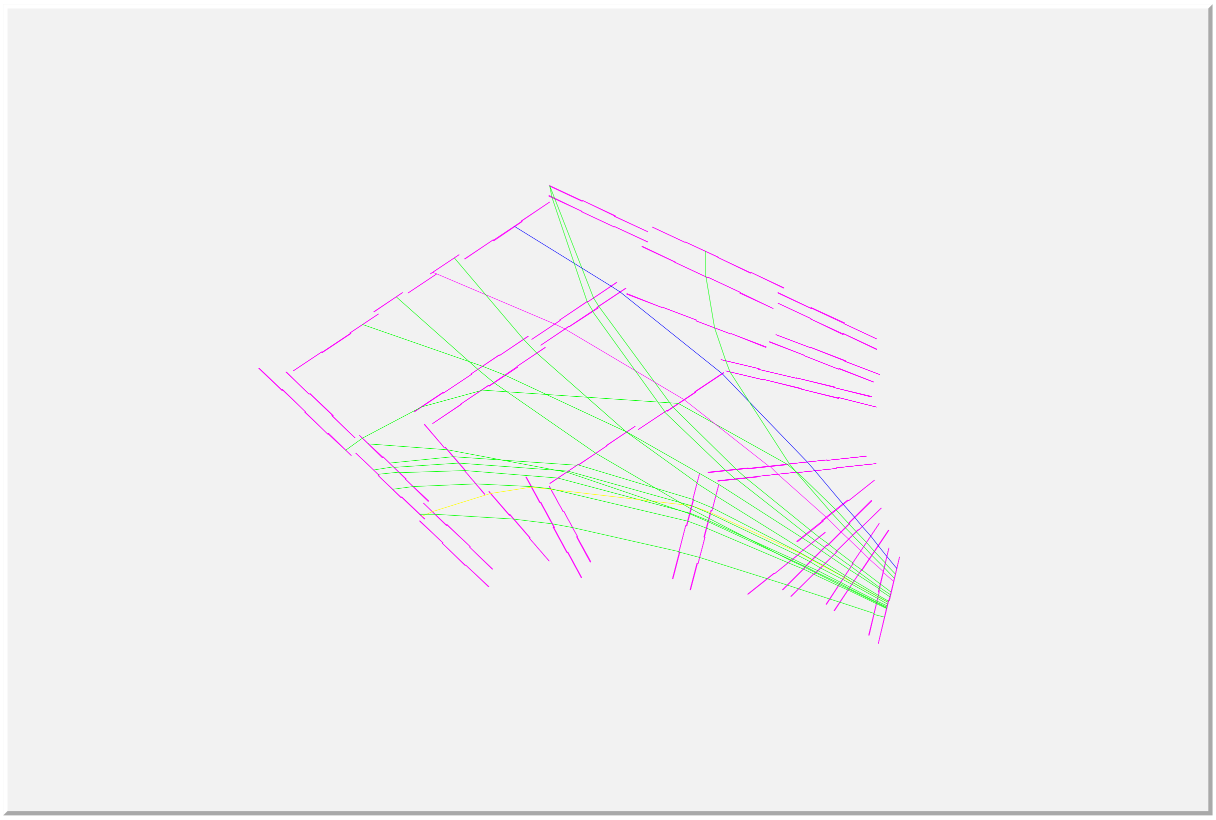
What you really see in the Detector is ..



You are seeing again very pessimistic view..

In each layer, we have hundreds of hits....

Our Goal is Finding Findable tracks



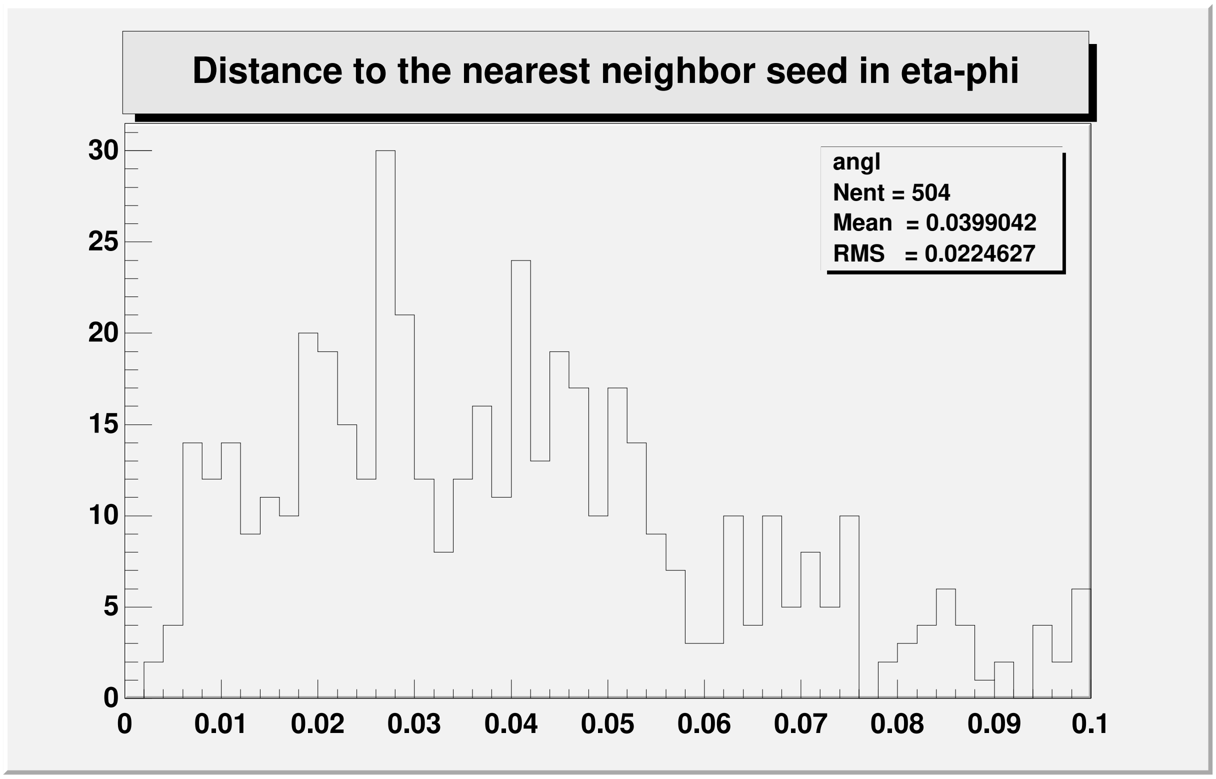
```
Event 0 has 16171 MC tracks and 17445 MC hits

                 ID  Q   P    theta    phi  # of hits / layer
      findable  0:   9 -1 0.285 51.967 -0.023  14  13 1111111011101021
      findable  1:   3 -1 0.160 48.826 -0.013  14  13 1112111011011011
      findable  2:   9 -1 0.848 44.553  0.015  17  13 2211111110101120
      findable  3:   9 -1 0.179 30.837 -0.024  20  14 1211110131102212
      findable  4:   8  1 0.596 41.368  0.029  15  14 1112111111101101
      findable  5:  12 -1 0.775 28.608 -0.035  13  13 1111110111101110
      findable  6:   9 -1 0.262 54.139  0.050  16  14 1111211011111012
      findable  7:  15 -1 0.662 34.956 -0.019  18  13 2211110112101120
      findable  8:   8  1 0.527 43.224 -0.007  21  15 2111111121202112
      findable  9:   8  1 0.820 48.220  0.033  16  13 2111111022101110
      findable 10:   8  1 0.896 53.732  0.019  16  13 1111121021101110
      findable 11:   9 -1 0.422 53.090  0.022  14  12 1111111011201020
      findable 12:   8  1 0.363 33.260 -0.008  18  14 1111210111111022
      findable 13:   9 -1 0.246 48.959  0.045  15  12 1111211012201010
      findable 14:   9 -1 0.266 50.392 -0.043  14  13 1111111011101021
      findable 15:   9 -1 0.377 62.825  0.049  16  14 1211111012111011
      Number of MC seeds & findables: 52 16
```

Front-end tracking

Clustering algorithm

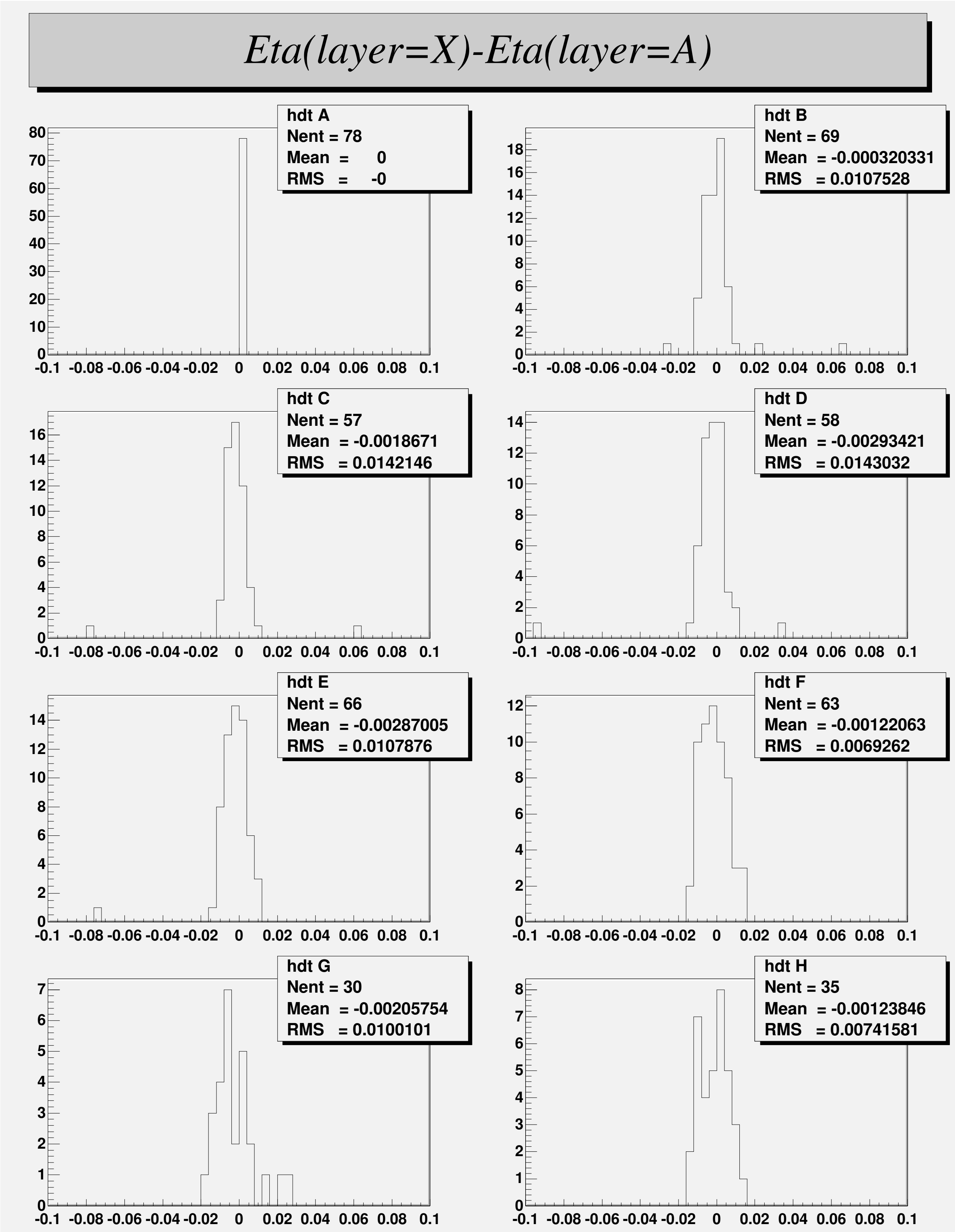
Cone size is optimized in the way to separate close seeds as many as possible and and not to loose broad seed (low P, large MS).

Average distance between two neighboring seeds and angular dispersion of seed are two important factors for the efficiency of track seed reconstruction.

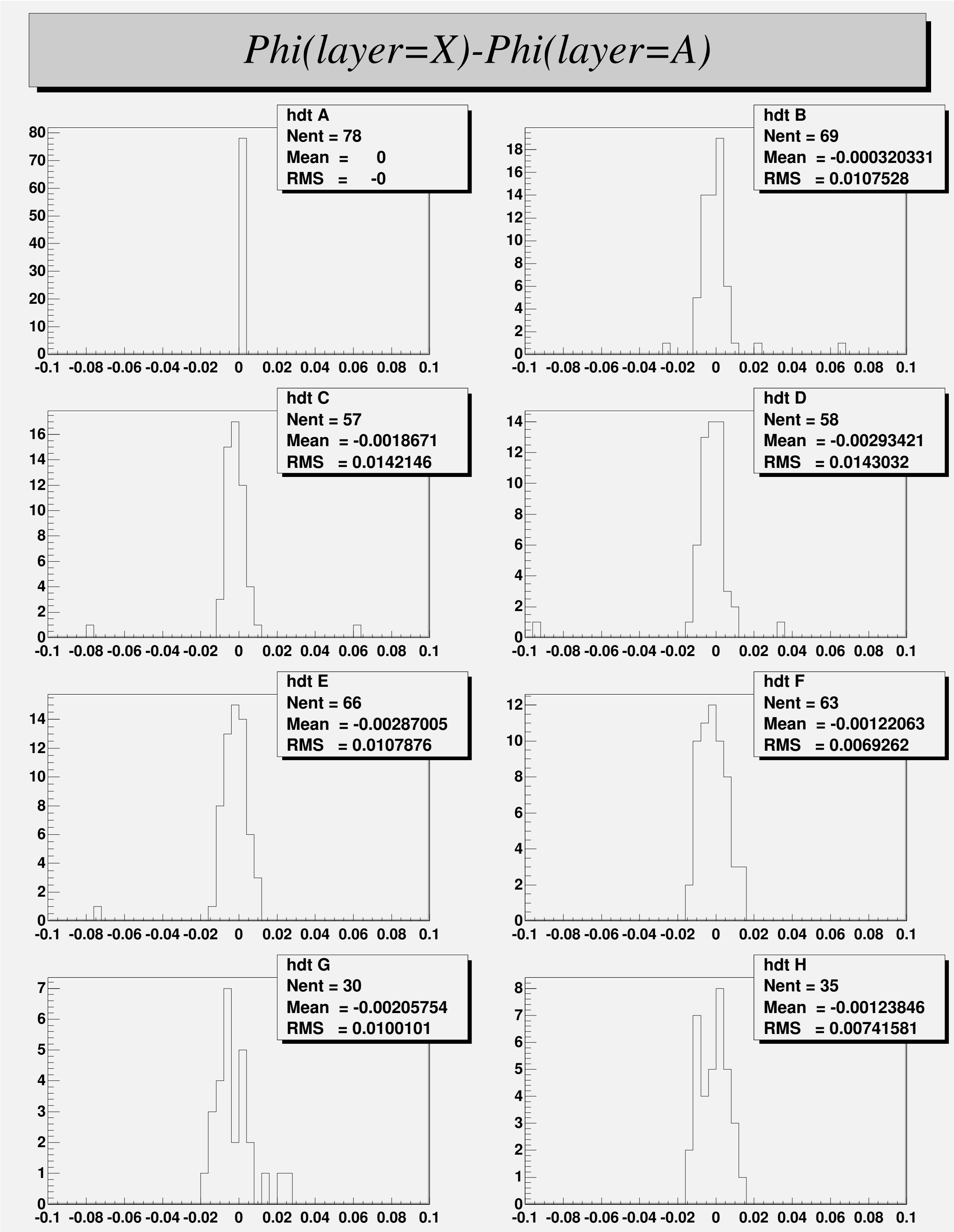


Average angular separation to the nearest track seed is $\sim$0.04.

Track seed width in η

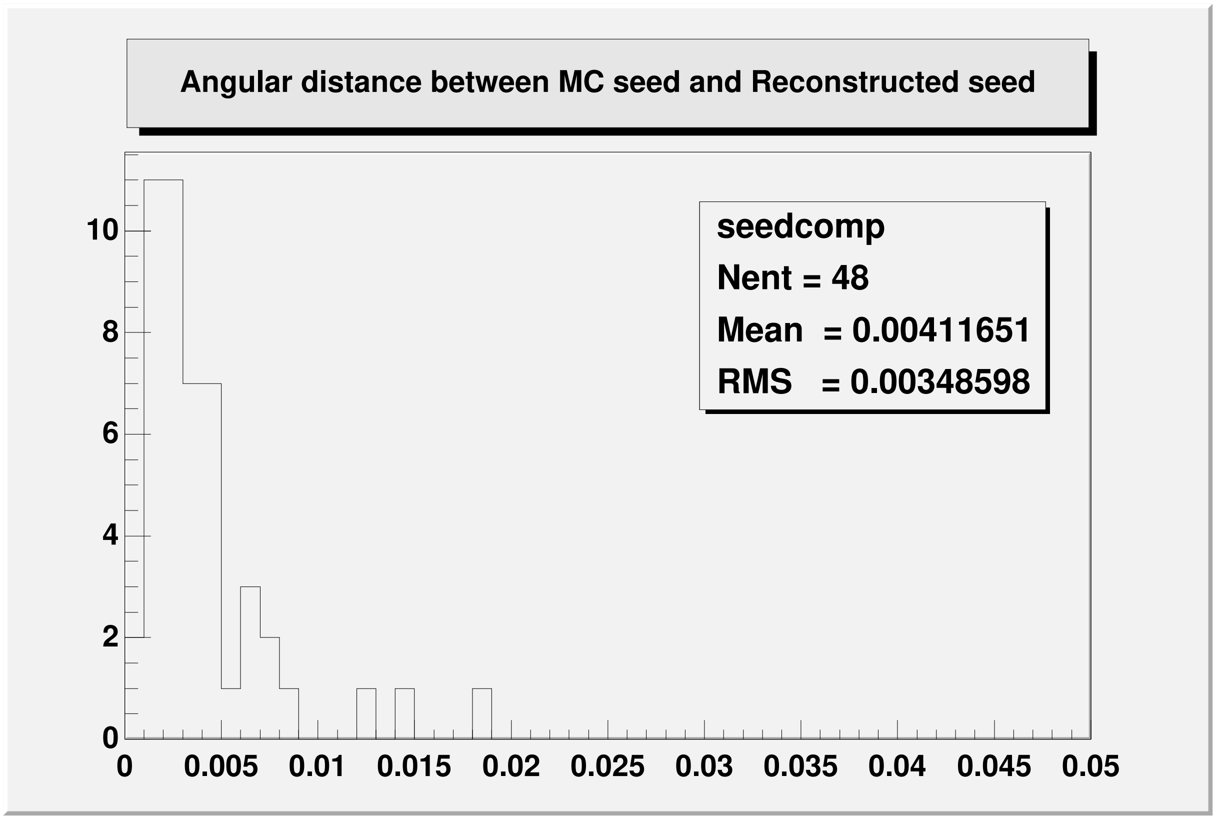


Track seed width in ϕ



Track seed resolution

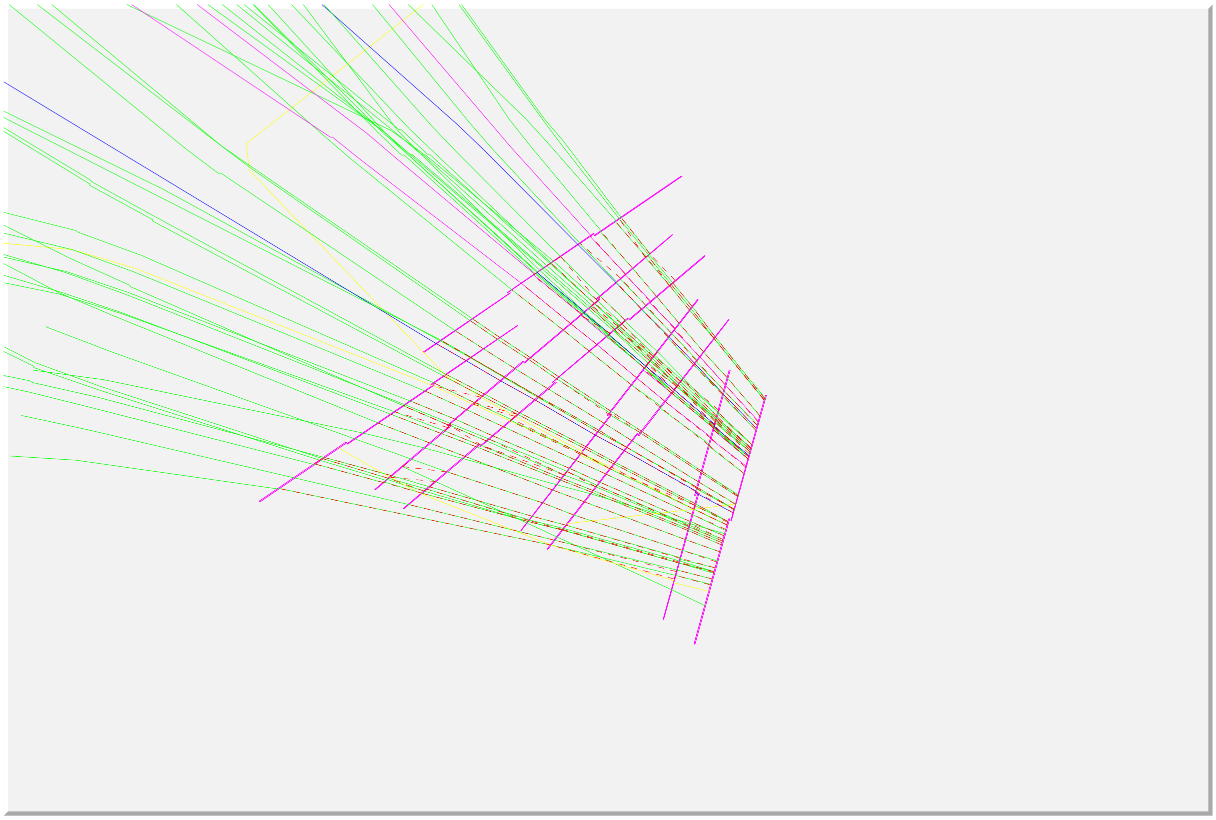
We use 0.02 as our cone size. The following plot shows the distance between reconstructed seed and matched MC truth seed (matched = when there are 3 common hits).



The resolution obtained is 0.004.

Event Display

Here is an example event display of a typical Au-Au event.



Green - pion
Yellow - lepton
Blue - kaon
Pink - other

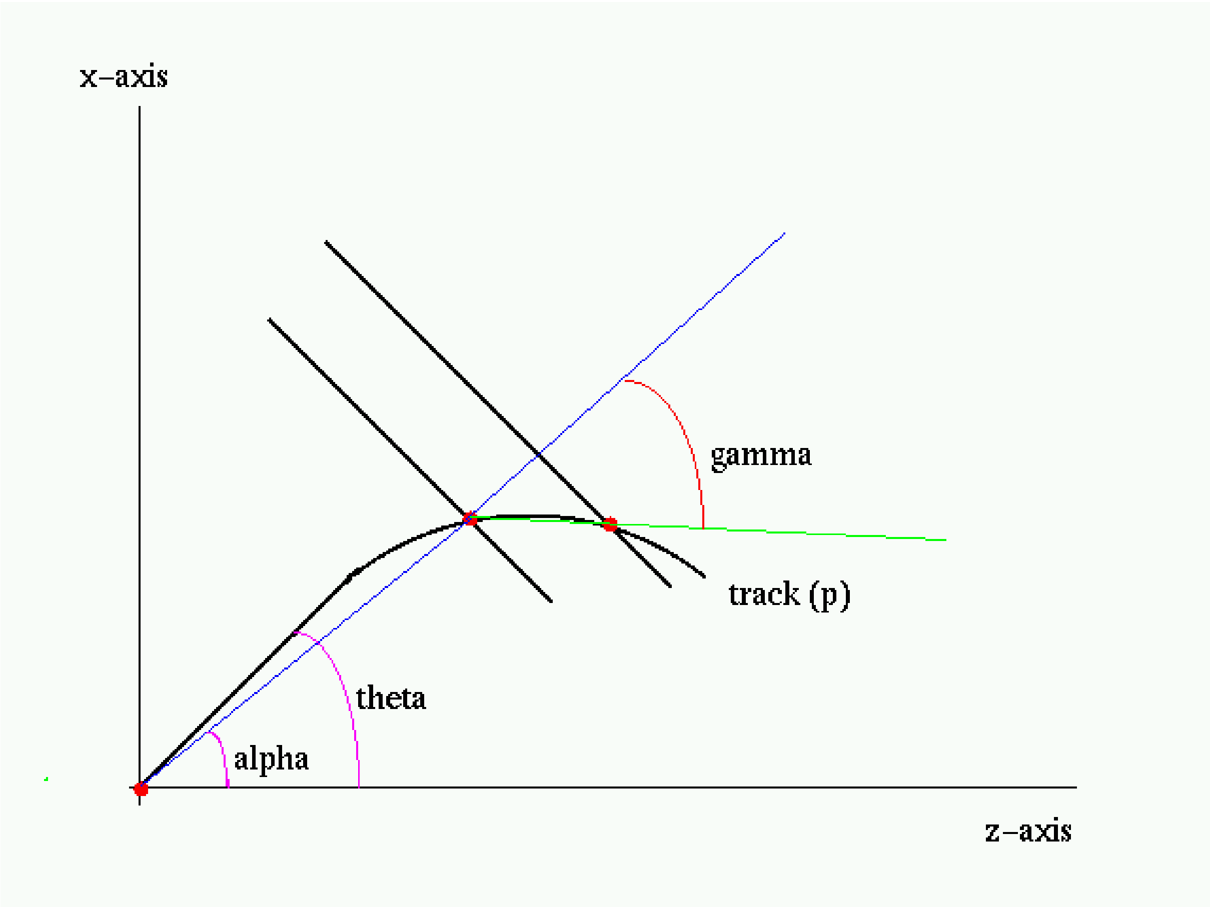
52 MC seeds : 48 reconstructed

Hough PR

Hough Transformation

Three points, primary vertex and two hits in the magnetic field, on a track are uniquely determined by tracks charge, momentum, and direction.

$$(Q, \vec{P}) \leftrightarrow (Q, P, \theta) \leftrightarrow (\alpha, \gamma)$$



Hough Transformation means getting (Q, P, θ) from (α, γ). We make a `look-up table` to provide (Q, P, θ) information for given two hits combination (or Match-Stick).

Table design

With the acceptance of the spectrometer ($0.4 < \theta < 1.3$) and momentum range of our physics interest ($100\,\mathrm{MeV} \sim 1\,\mathrm{GeV}$), α varies between the θ acceptance and γ varies between ± 2 depending on charge. Considering few % momentum resolution and the resolution of the track seed direction (0.2 degree), $200(\alpha)$ by $400(\gamma)$ table is reasonable.

A Hough Table means a two dimensional histogram of 200 by 400 bins filled with either $1/P$ or θ of the ideal trajectory (MULS=0).

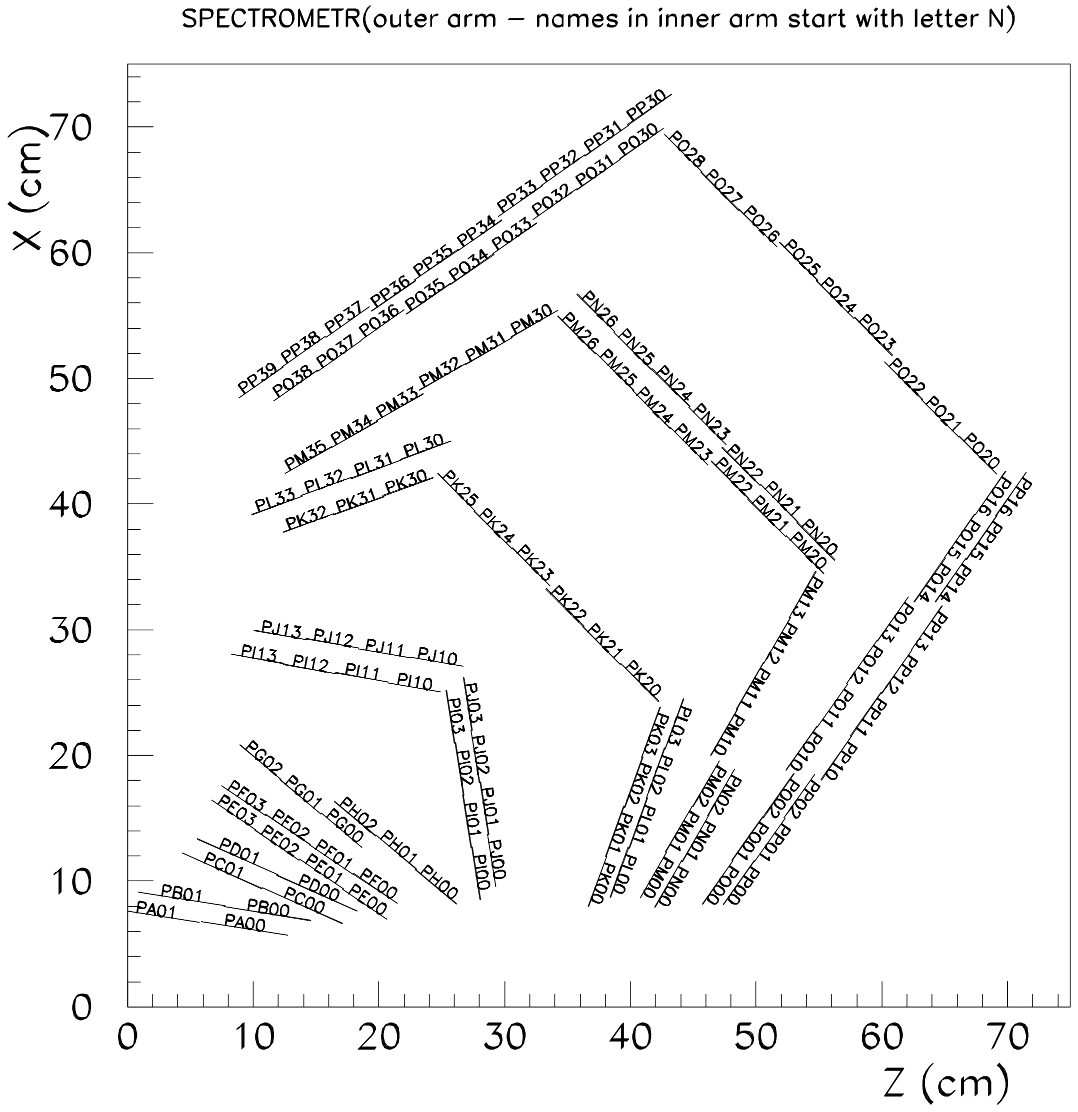
One can directly obtain P and θ for a given match-stick by looking the table.

Error Table

We make the same format tables but filled by $\sigma(1/P)$ and $\sigma(\theta)$ in order to provide the errors from the Hough Transformation (calculated by using of many realistic tracks with MULS=1).

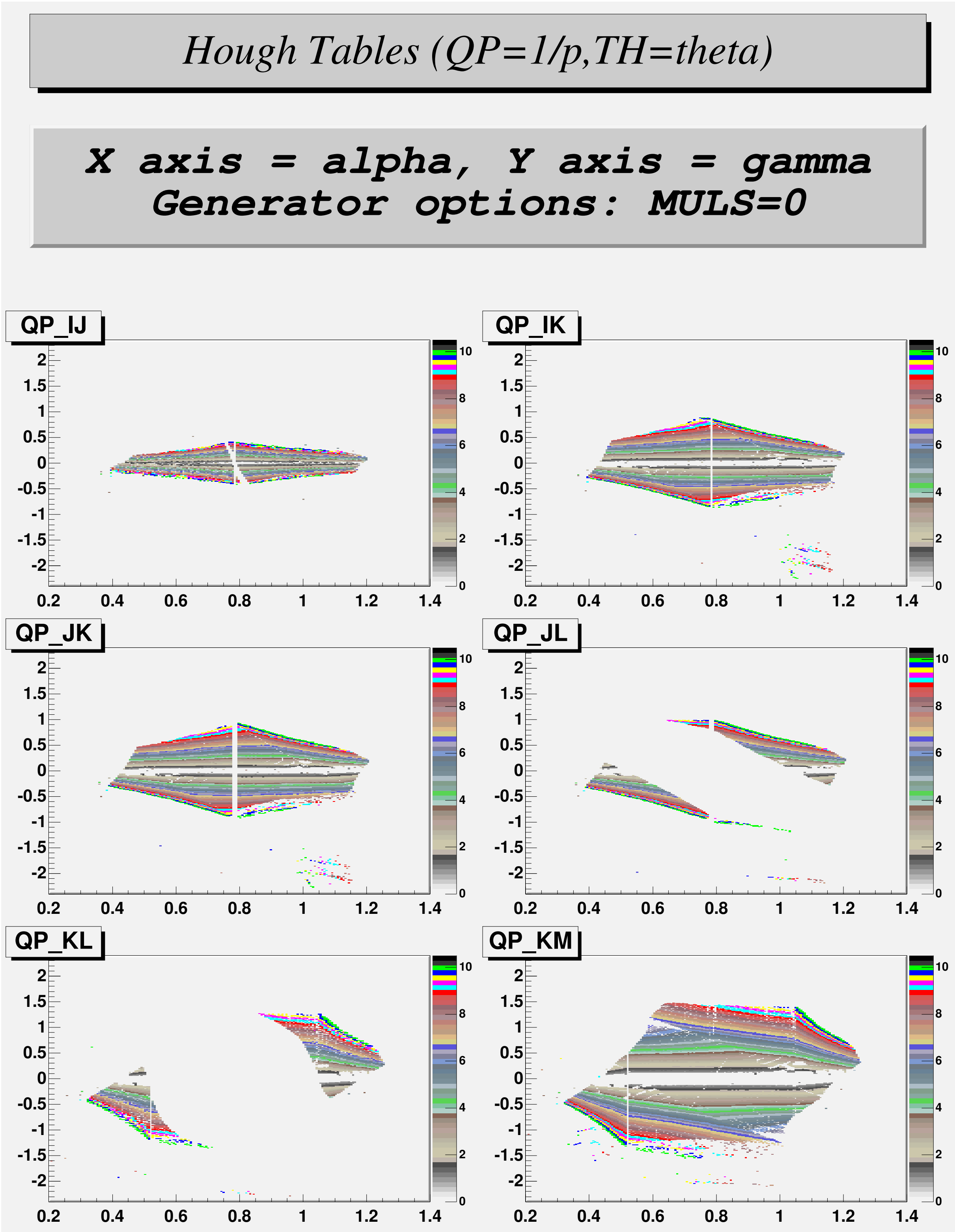
Spectrometer Geometry

Since we have now many missing layers (not like in our previous simple geometry), we have to consider Match-Stick connecting hits between two non-consecutive layers. Fortunately, we don't have any two successive missing layers!



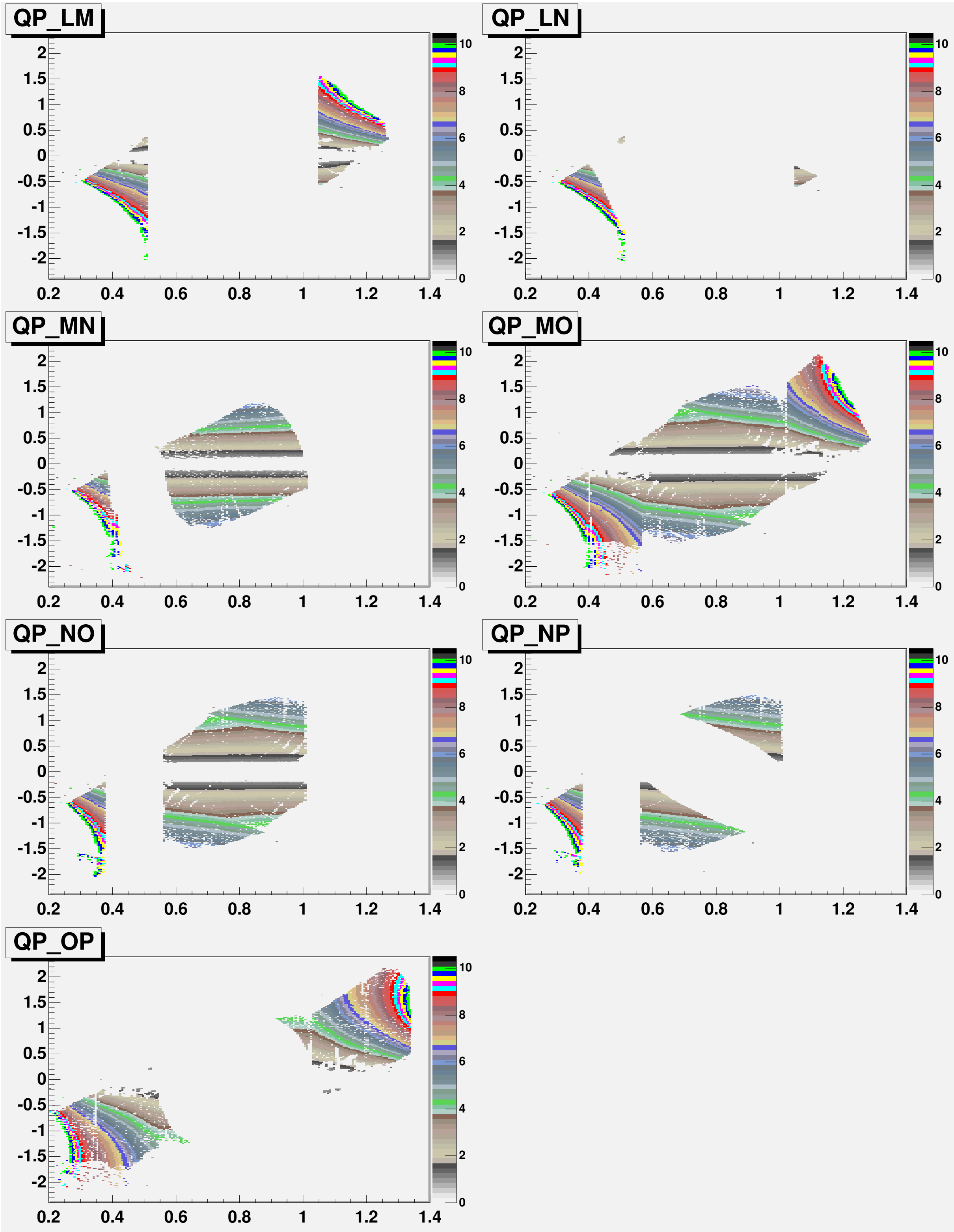
Then we have 13 combinations, IJ, IK, JK, JL, KL, KM, LM, LN, MN, MO, NO, NP, OP.

Hough Table : P



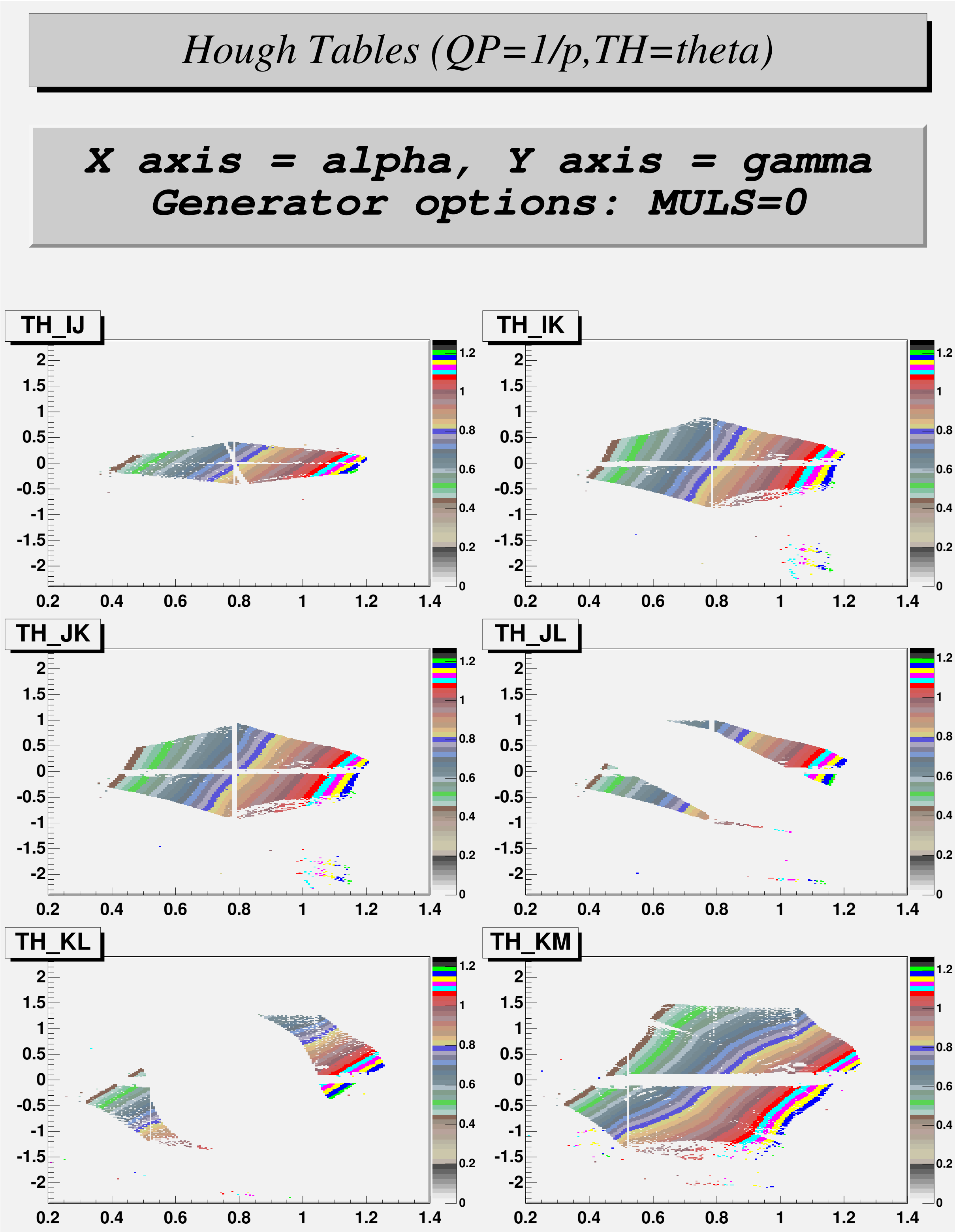
Horizontal white space represents momentum cut on 1GeV.

Hough Table : P (continue)



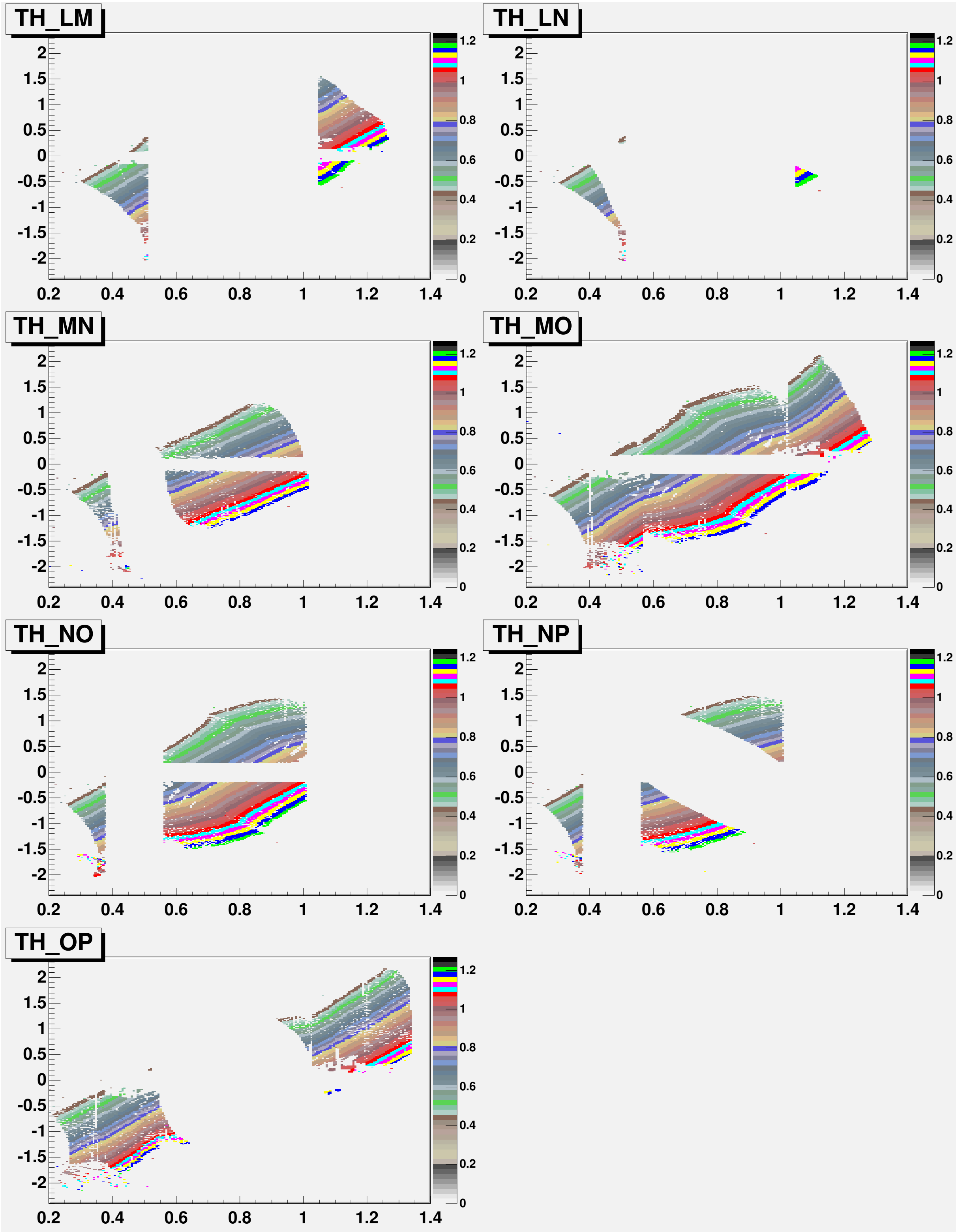
Vertical white space represents missing layers or cracks.

Hough Table : θ



Horizontal white space represents momentum cut on 1GeV.

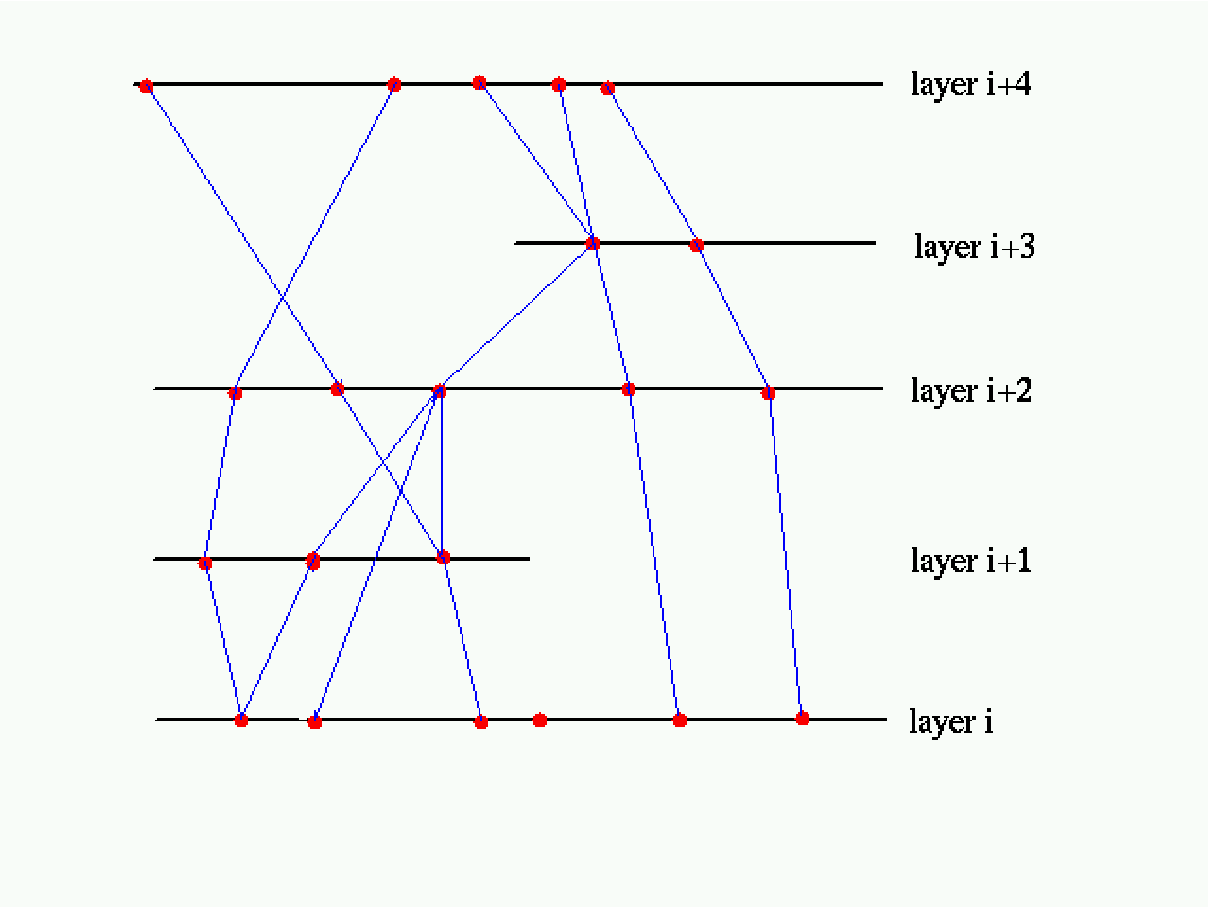
Hough Table : θ (continue)



Vertical white space represents missing layers or cracks.

Chaining Match-Sticks

For a given track seed, we can only have limited number of match-sticks which are consistent with the seed direction (θ). Match-sticks are chained when they are consistent in P and θ. Connected match-sticks starting from the layer I to the layer O or P form a track candidate.



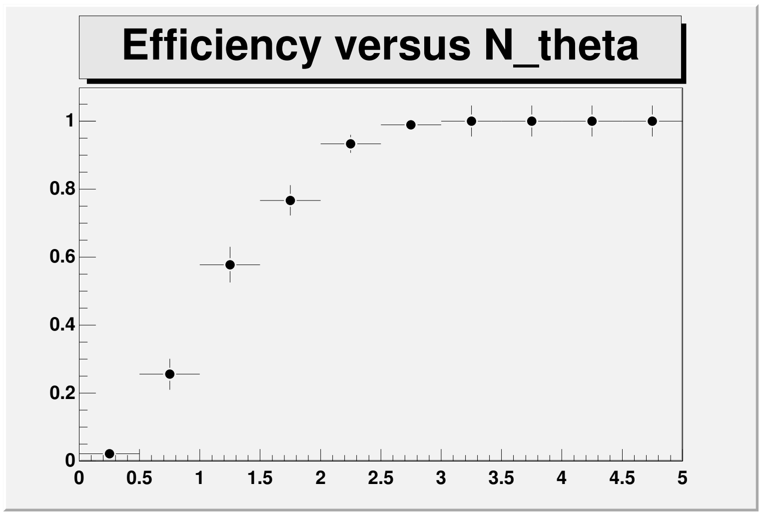
Match-sticks are chained when

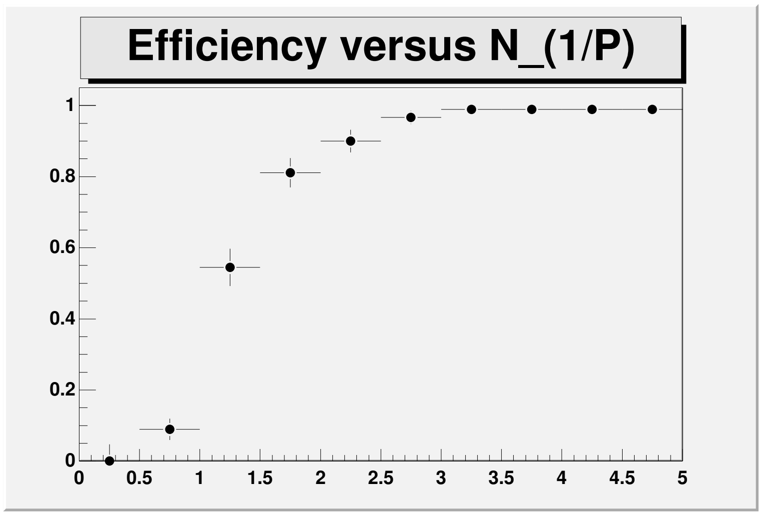
$$|(1/P)_{MS,i} - (1/P)_{MS,j}| < N_{1/P} \times (\sigma(1/P)_{MS,i} \oplus \sigma(1/P)_{MS,j})$$

and

$$|\theta_{MS,i} - \theta_{MS,j}| < N_\theta \times (\sigma(\theta)_{MS,i} \oplus \sigma(\theta)_{MS,j})$$

Optimization of cuts





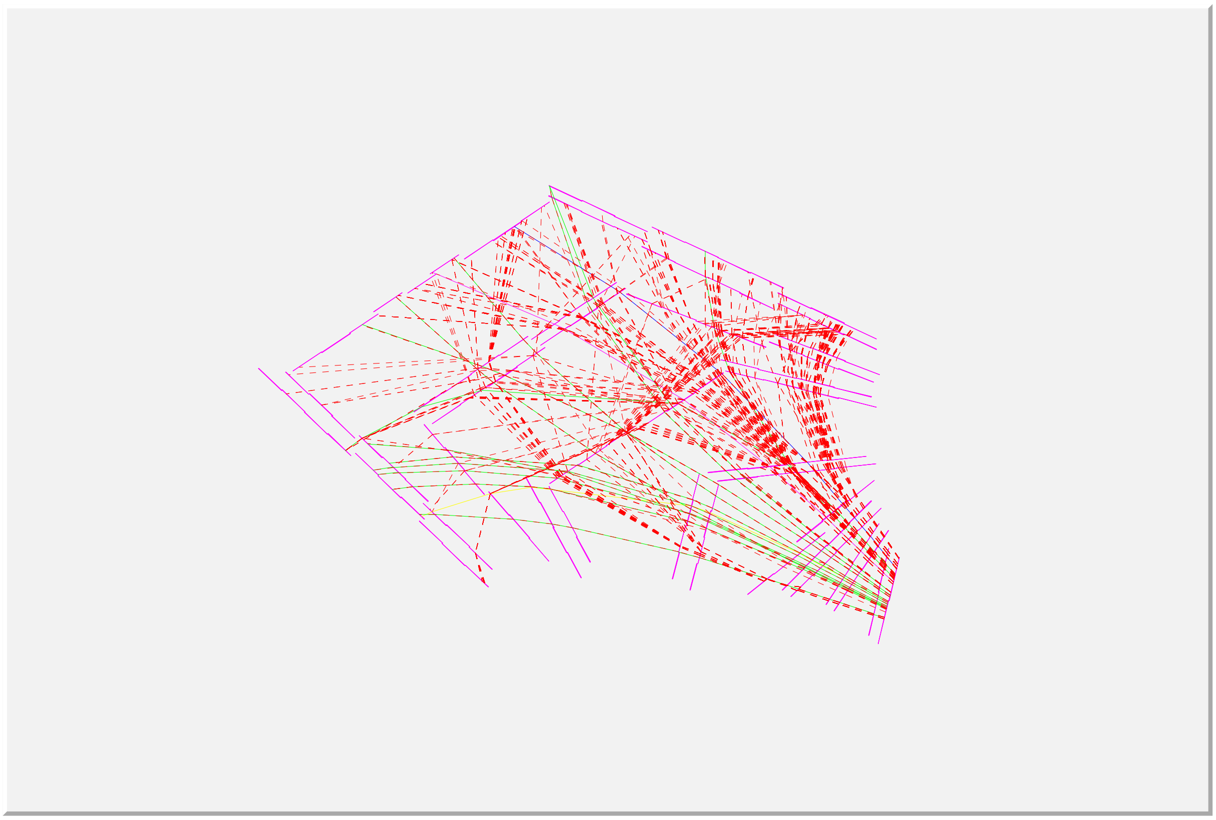
Other cuts

Charge correlation.

Vertical constraint.

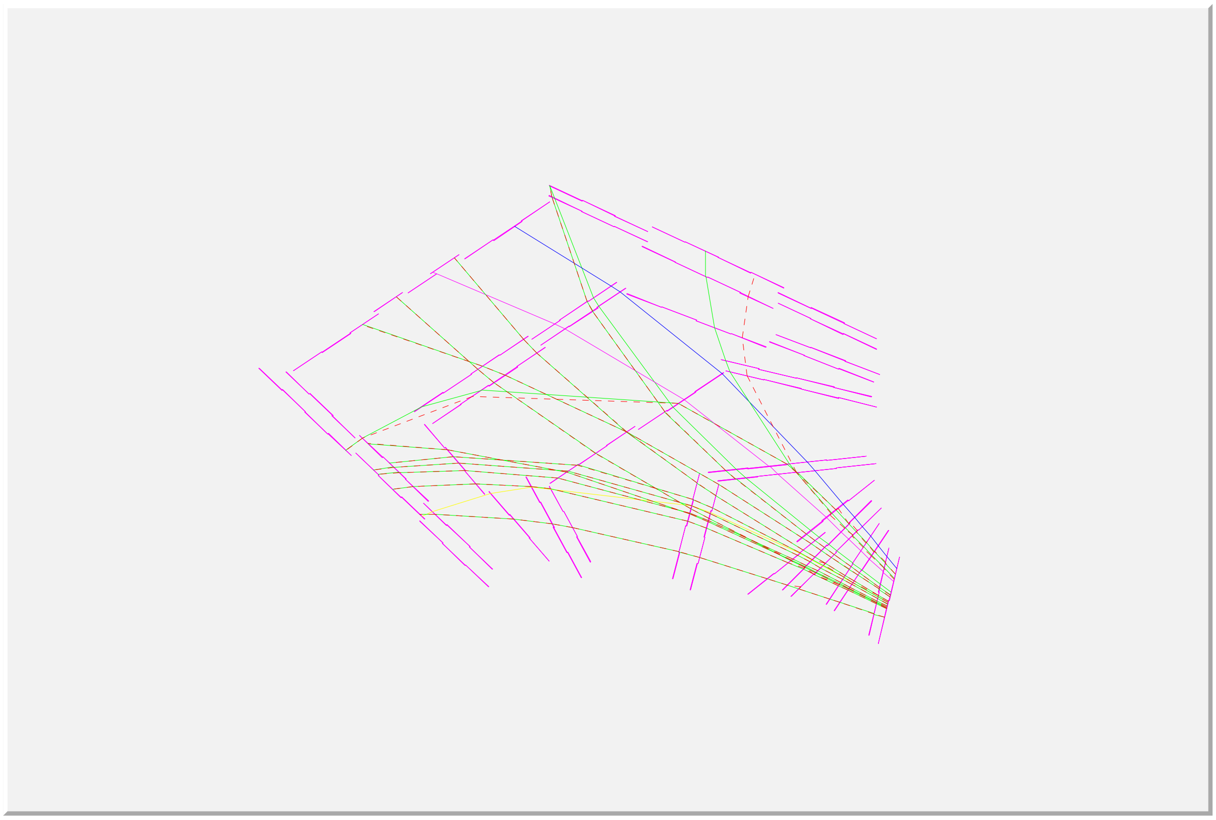
Example Event Display of all candidates

Here is what I get after chaining all Hough match-sticks. This is before applying the findable condition.



43 seeds and 581 candidates. Only 100 MeV to 1 GeV candidates can be made due to the Hough Table range.

Ideal Selection (using MC truth)



We have 16 findables. Inside there are 13 pions. 11 are well reconstructed and we lost 2 pions. There is 1 ghost.

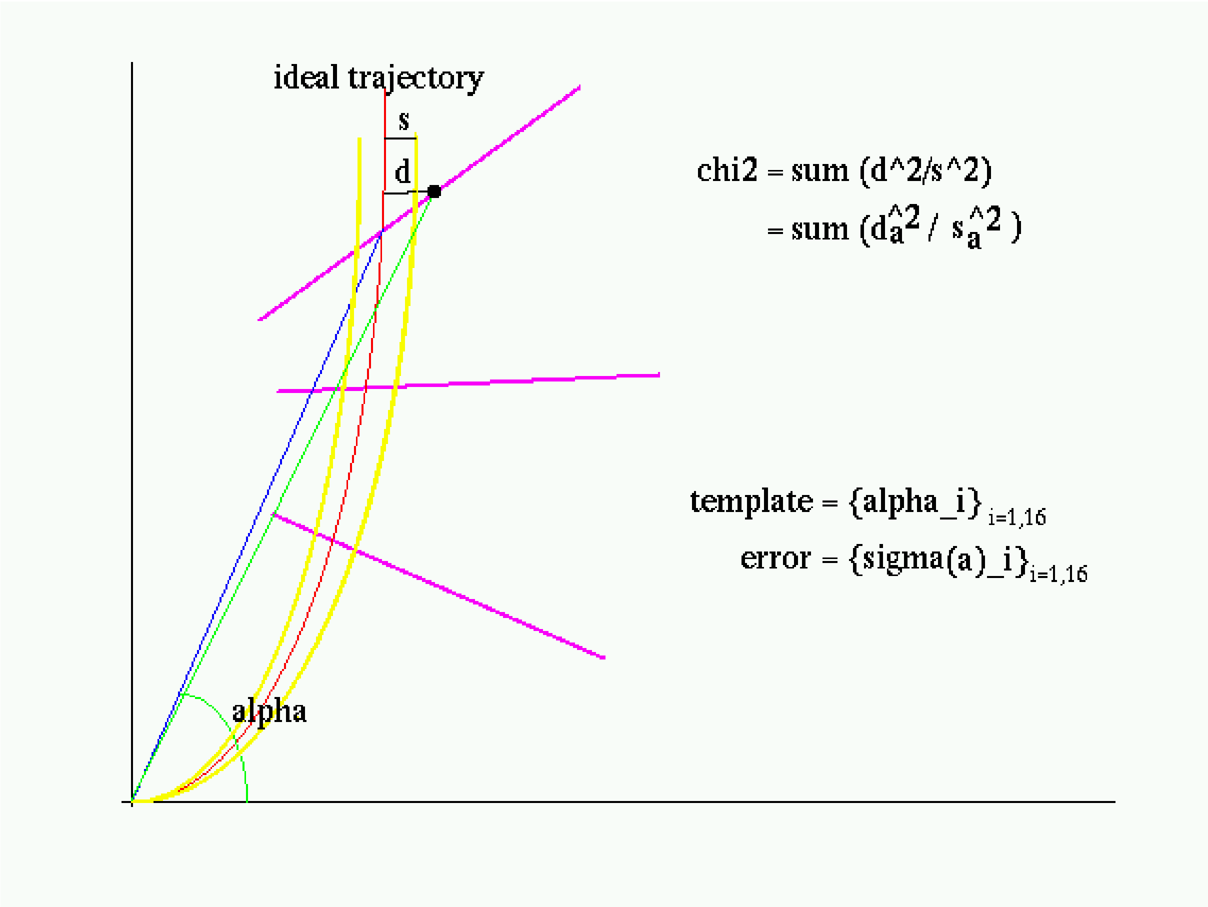
$$\epsilon = 11/13 = 85\%$$

$$\text{Ghostlevel} = 1/13 = 8\%$$

Template

Non-existence of analytical trajectory forces to use template approach.

A track template means an ideal trajectory of a track. Within our spectrometer sensor geometry, it can be represented by a set of hit position, $\{x_i, z_i\}$ where i is layer index. One can equally use a single parameter, α, instead of two parameter.

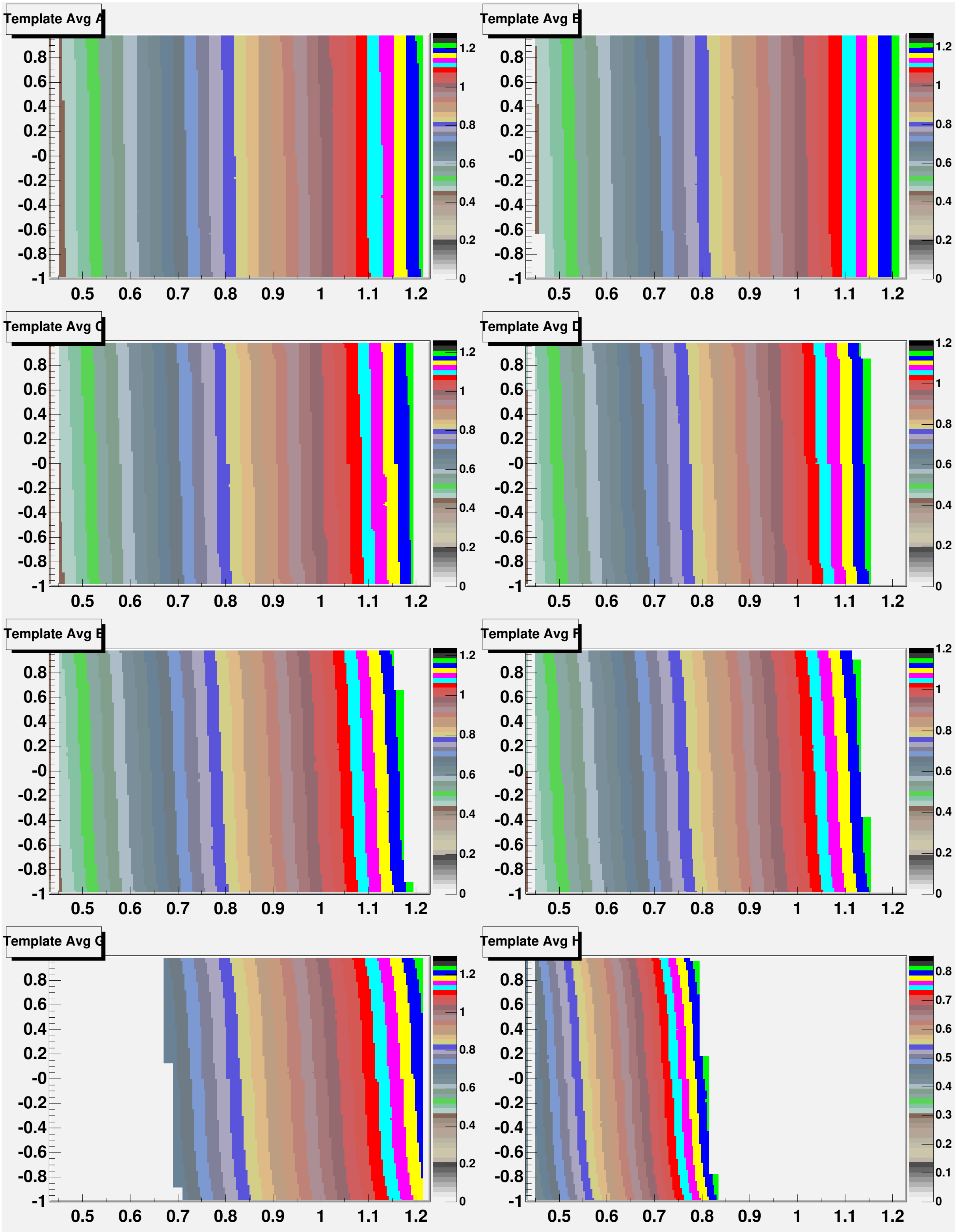


Since our template file has limited range of momentum, θ, and

Template Table Design

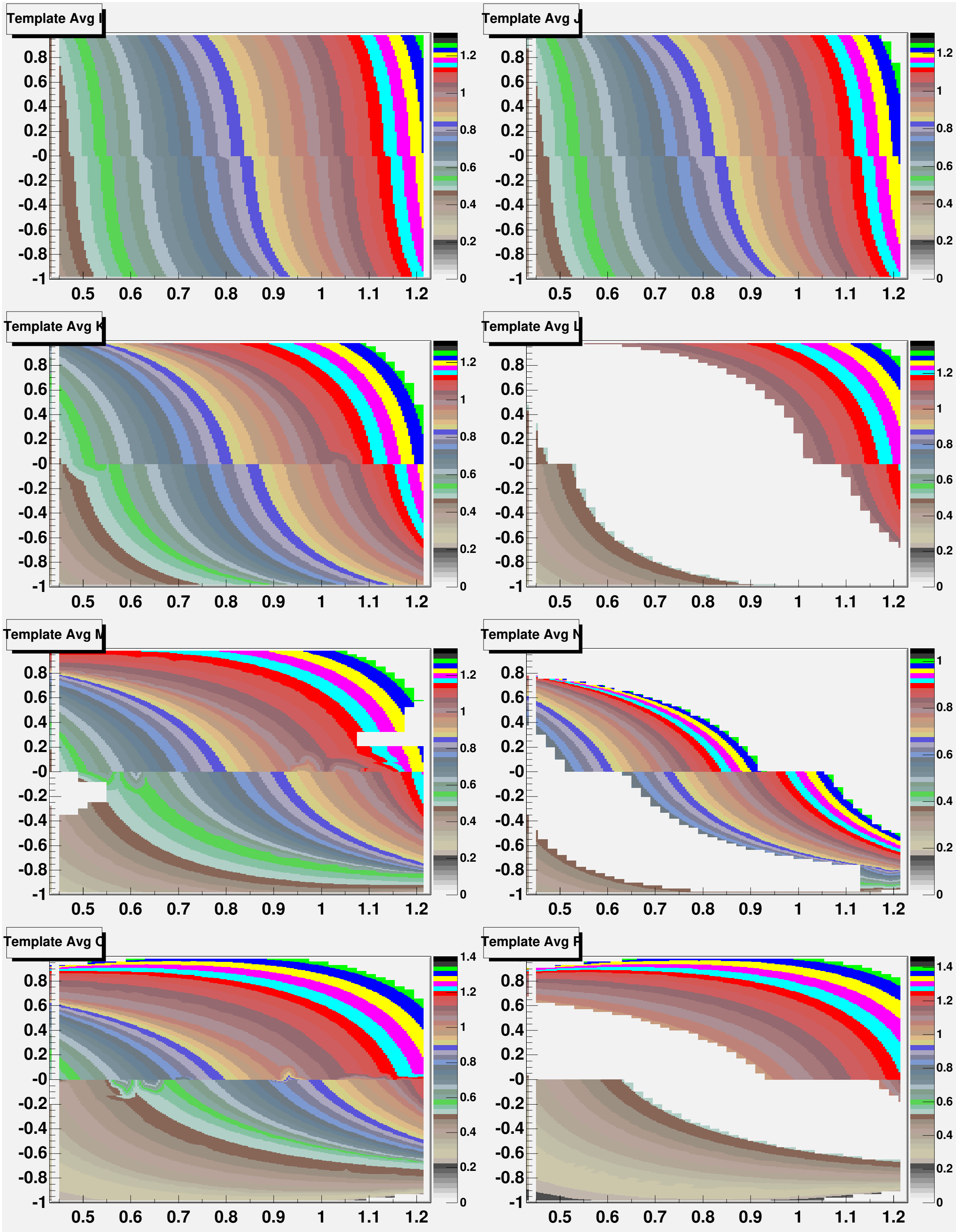
We create $200(\theta)$ by $400(Q\log(P))$ tables to save α of idea trajectories. This binning corresponds to 0.2 degree in θ and 1% in momentum error. We need 16 tables for 16 layers. 16 other tables are created for $\sigma(\alpha)$ information.

Template : α



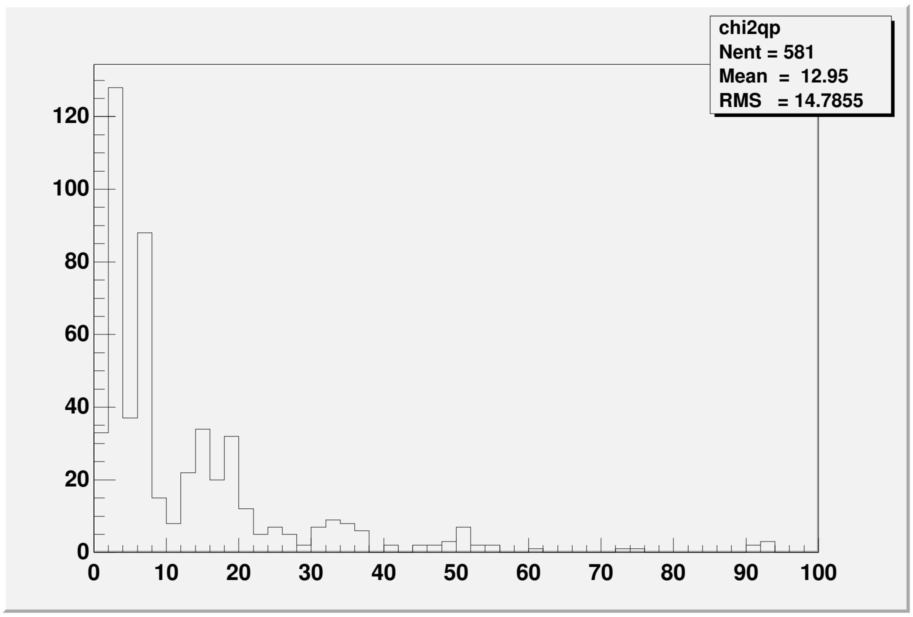
$\alpha \sim \theta$ due to very small magnetic field.

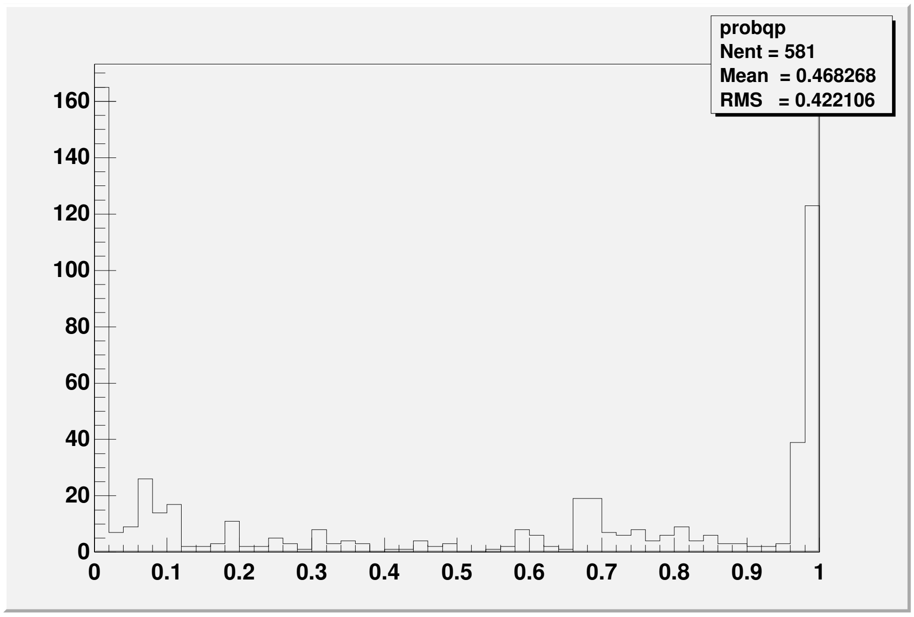
Template : α (continue)



χ^2 and Probability Distributions

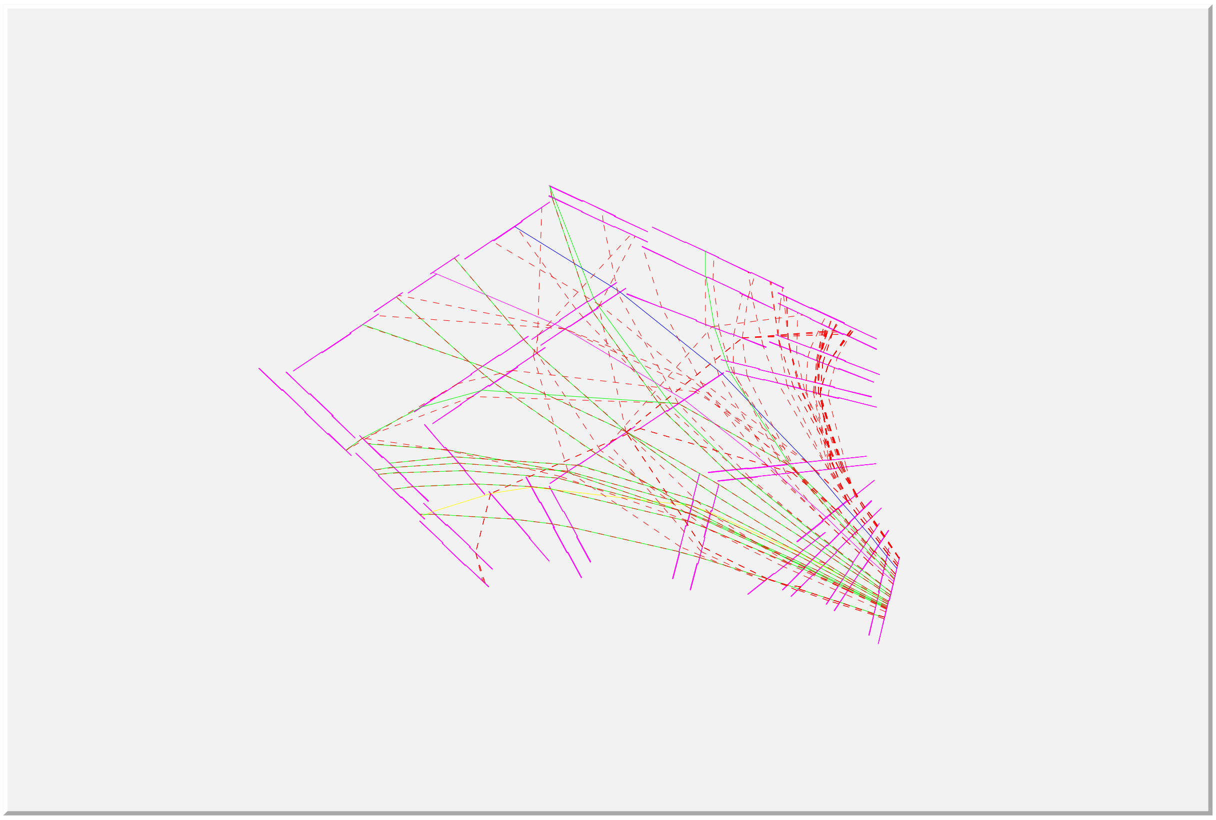
Below is the probability distribution of the reconstructed track.





Track Selection I

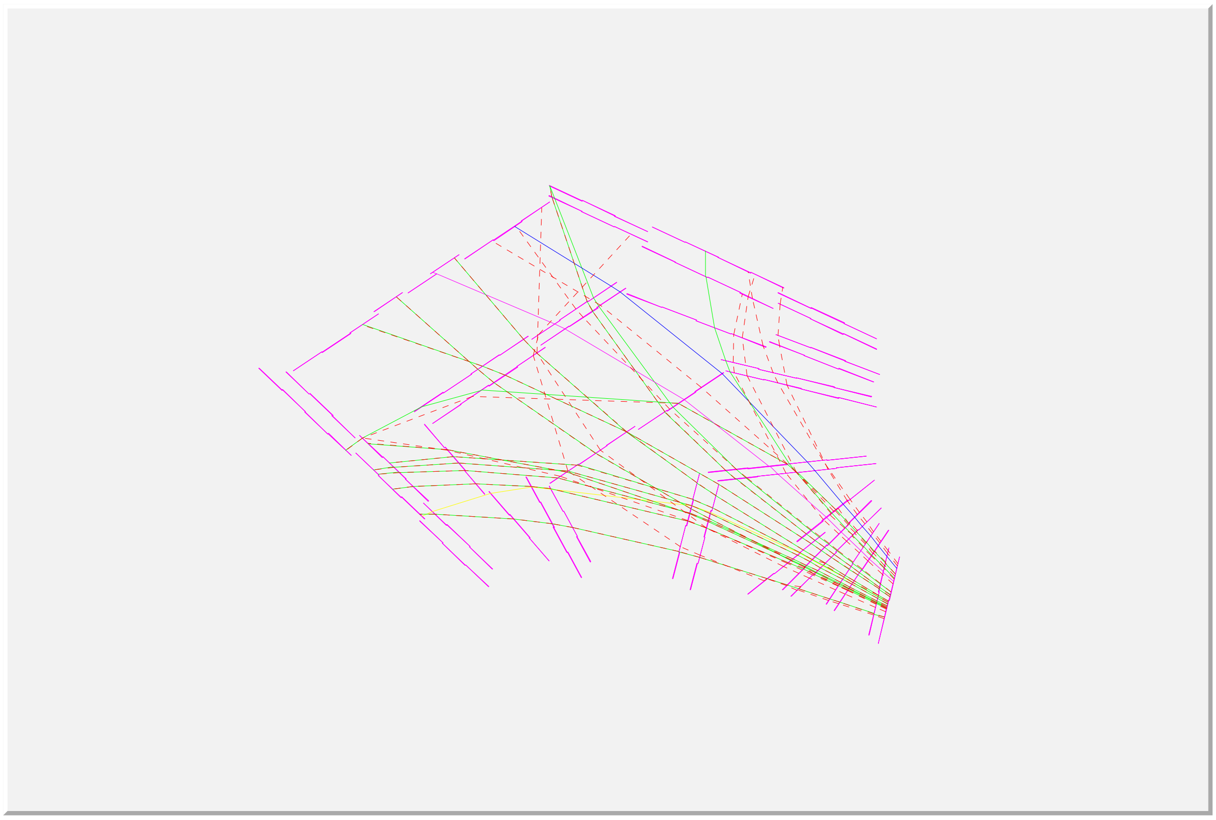
- Select only candidates satisfying findable definition
- If two candidates share a hit, select the one with bigger probability.



There are 87 candidates left.

Track Selection II

We allow only a track candidate which is most probable (maximum probability at this moment) for a given track seed.



Total 20 candidates left. We have 16 findables. Inside there are 13 pions. 11 are well reconstructed and we lost 2 pions. There are 9 ghost.

$$\epsilon = 11/13 = 85\%$$

$$\text{Ghostlevel} = 9/13 = 70\%$$

Summary

Benchmark Test

Au-Au event	CPU time (sec)
Unpacking Hough tables & Templates	10.7
Front-end tracking	0.3
Hough Transformation	24.7
Track candidate generation	0.8
Track selection	0.2

My Laptop (Pentium MMX, 534 bogomips) spent 40 seconds to do all the reconstruction chain including MC study.

Table generation

- Hough table (5% in p, 1 degree in θ) : 18minutes
- Hough Error table (5% in p, 1 degree in θ, 20 particles) : 95 minutes
- Template (5% in p, 1 degree, 10/p particles) : 473 minutes (on pheasant)

A day's job.

Fine bin tables are better in principle, but CPU time consumption increase rapidly.

Comments and Conclusion

- Many details are not shown in the transparencies (Ideas to minimize CPU time, etc.)
- Still more ideas are needed to clean up ghosts.
- Generation of tables: Finer bin, Z-vertex, P, Particle species .
- Fine tuning of parameters.
- This job is doable. But the main issues are "Efficiency versus P", "Fraction of Ghosts versus P".
- How to find secondary vertices?
- Code upgrade for : Dedx, Primary vertex, alignment database, etc.
- More work on Hit merging is necessary (association merged hits to MC hits especially). Phat data structure.....