Status of the ICAL detector simulation and reconstruction

Outline

- Event Generator (Nuance)
- GEANT4 simulation
- Digitisation
- Track Finder Algorithm
- Track Fitting Algorithm
- Some results of single muon track
- Future plan for improvements

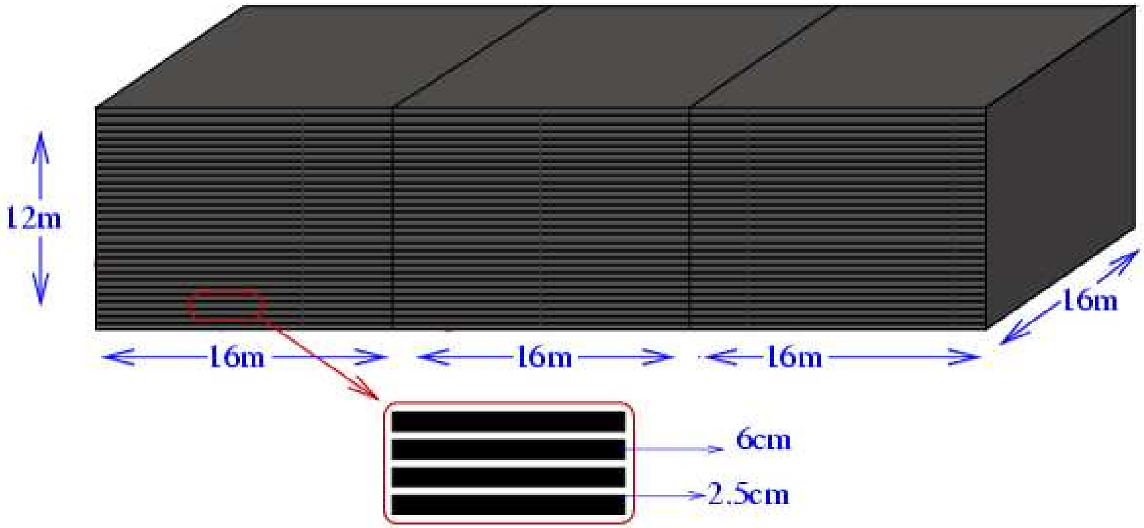
Event generation

NUANCE output for format for detector simulation (as input)

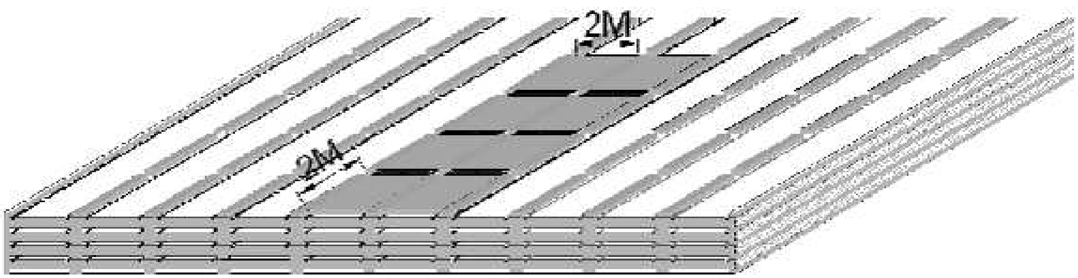
```
2  9    14  1135.1   318.30  -593.85   27.872    0.583  -24.703 0.211118E+05
2  1    13  1135.1   318.30  -593.85    5.386    0.767   -4.284 0.211118E+05
2  2   111  1135.1   318.30  -593.85   11.447   -0.456  -10.314 0.211118E+05
2  3    22  1135.1   318.30  -593.85    0.003    0.001    0.001 0.211118E+05
2  4  -211  1135.1   318.30  -593.85    3.090   -0.318   -2.721 0.211118E+05
2  5   211  1135.1   318.30  -593.85    6.025    0.427   -5.375 0.211118E+05
2  6   211  1135.1   318.30  -593.85    0.632   -0.147   -0.294 0.211118E+05
2  7  2212  1135.1   318.30  -593.85    0.423    0.424   -0.415 0.211118E+05
2  8  -211  1135.1   318.30  -593.85    0.107   -0.036   -0.098 0.211118E+05
2  9   310  1135.1   318.30  -593.85    0.761   -0.078   -1.203 0.211118E+05
```

Now we using both ascii as well as rootuple format as input, eventually only rootuple.

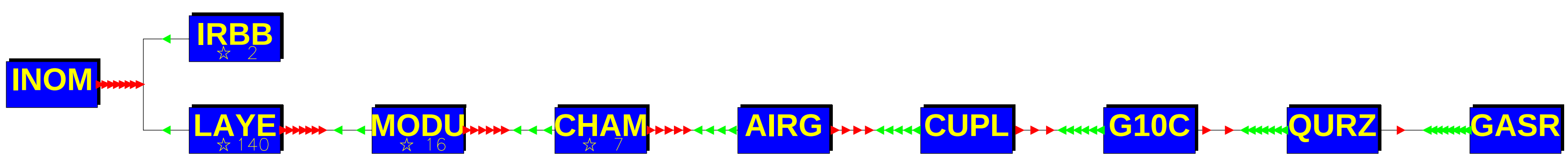
Basic INO geometry in simulation



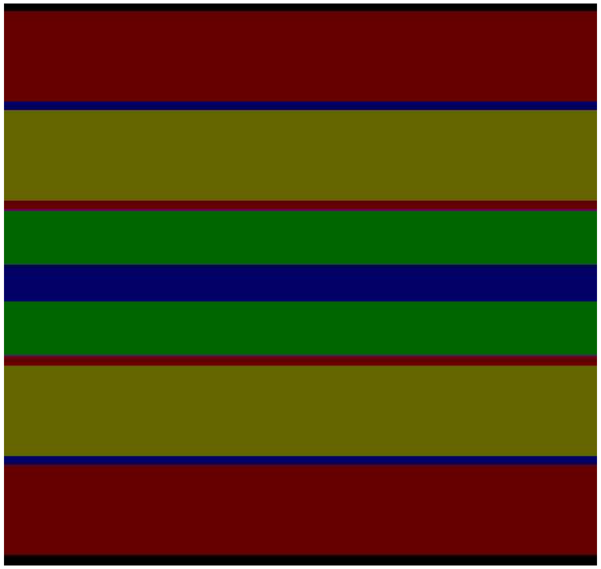
Electronics and available IRON sheets forces us to use dimension 16m × 48m × 12.8m with iron thickness 5.6cm



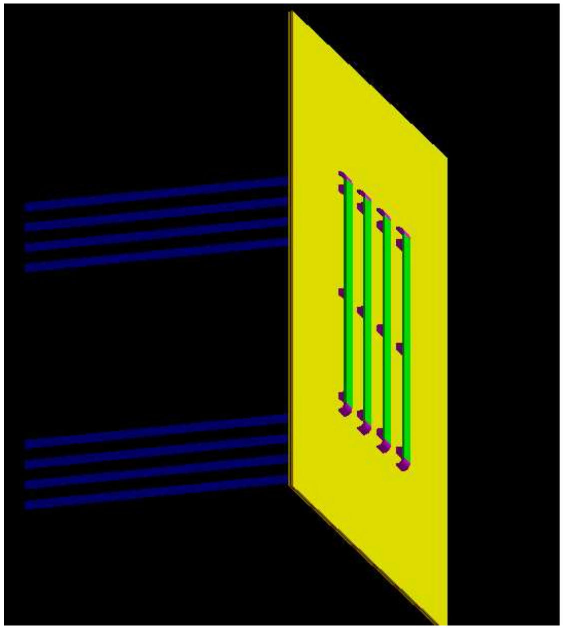
We have started with very very simple geometry

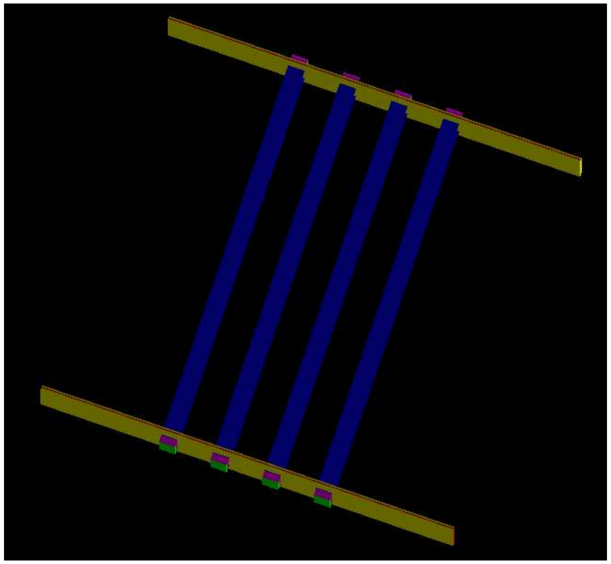


Present detector with support structure and magnetic coils



- blue → Gas
- green → Glass
- red → Copper
- yellow → Honey-comb
- blue → Aluminium
- red → G10





Digitisation

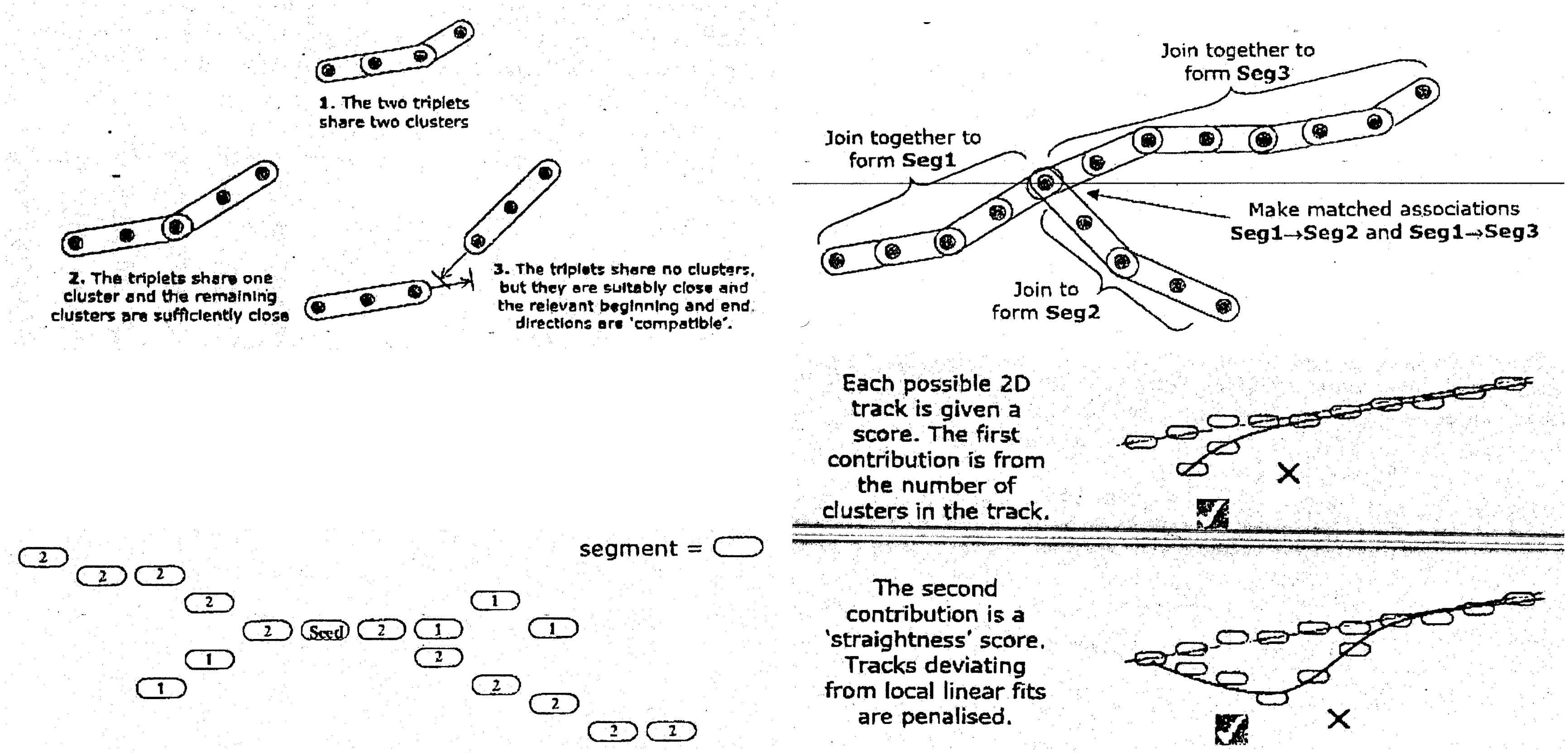
- Use threshold energy ($\#$ of electron-ion pair) to consider signal in a strip.
- Add inefficiency in strips though random number, e.g. 90%
- Noise in strips, add noisy strip (in the moment it is arbitrary, will put number according to real RPC)
- Convert StripId to physics co-ordinate through database (inverse of digitisation)
- Combined X and Y strips for a 2D hit (muon position).
- On the average, multiplicity of RPC hits is ~ 1.2
- In simulation, included that in a simple manner. At most we can have energy in three strips, but need to put proper fractions as a function of track position (from data).
- Combined nearby hits (X-Y strips) to form cluster.
- Instead of Hits, use clusters in track finder/fitter.
- Expected better resolution (need to simulate more events to see this improvement).

Digitisation

- Accept hits with only single strips too (which reduces inefficiency of hits). But, not debugged fully.
- Combined nearby hits to form a cluster, basic elements for track finder algorithm.
- To reject hadronic shower in track finder algorithm, special algorithm is used, which uses total hits in that RPC modules.
- Error in cluster, just Strip Width/$\sqrt{12}$, which is not true for the cases, where cluster contains more than one layer of strips. Will use value from cosmic data collected by RPC chambers and clustering algorithm.
- Smear time of hit by 1ns (will put appropriate value from hardware)
- Use 100ps as least count of TDC

Track Finder Algorithm

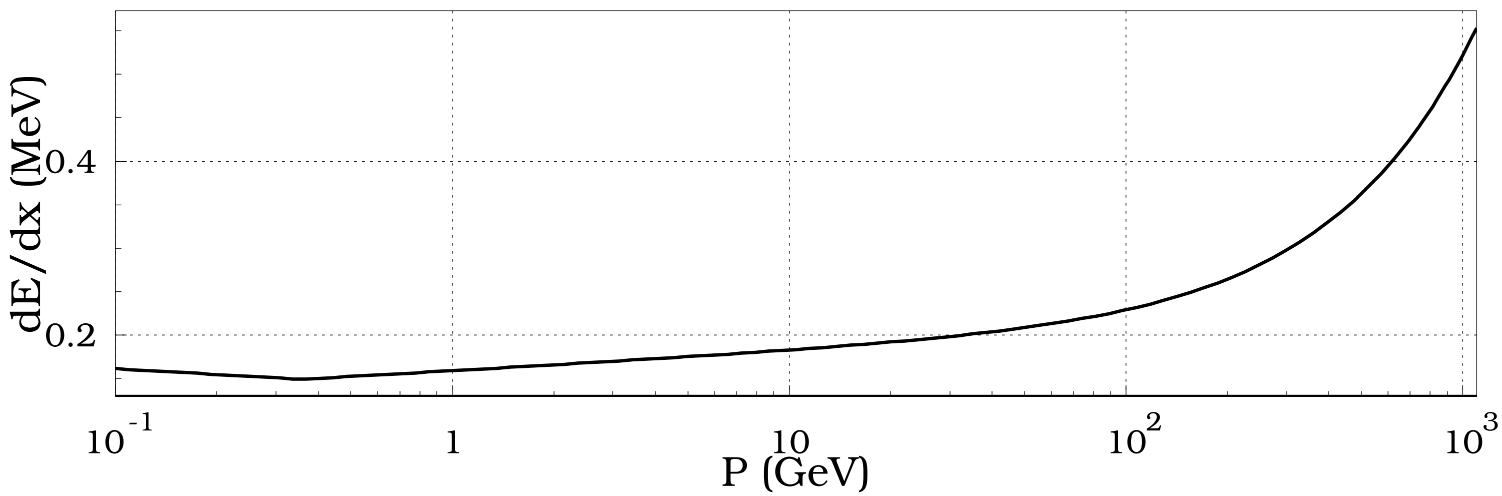
- Used MINOS algorithm
- Triplet : Formation (allowed maximum gap of two layers), join them in a chain, sort out the best choice as track candidate



- Changed algorithms to include large bending at the tail and also change in sign of P_Z components.
- Need optimisation mainly for a gap

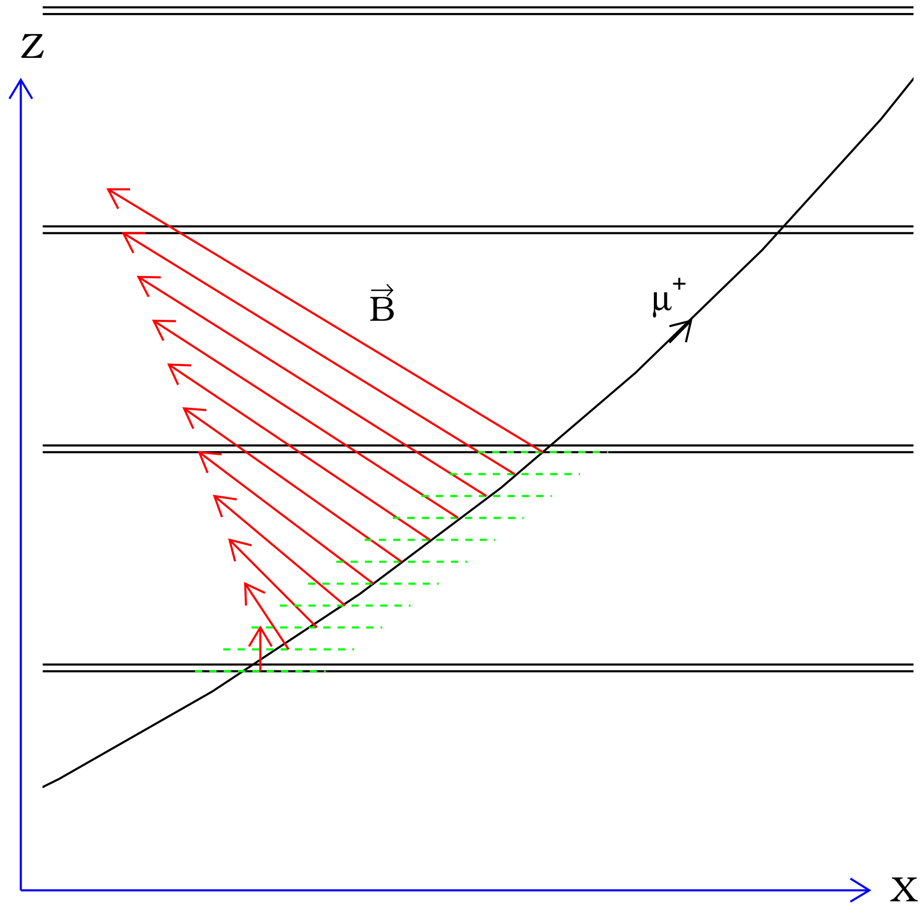
Steps in track fitting algorithm

- Used hits from Track Finder
- Do fit for both directions
  - Will use RPC timing for only one directional fit
  - Check how precisely Kalman fit able to choose right direction
- Initial track direction/position is taken from only first two layers with q/p=0, whereas track has five parameters (x,y,dx/dz,dy/dz,q/p)
- Extrapolation to next layer, where we have RPC hits, this is done without any standard packages
  - $dE/dx(in\ iron) = (14.9 + 0.96\times \mid log(P^{2.8}) \mid +0.033 \times P \times (1.0 - P^{-0.33})) \times 10^{-2}\ MeV/gm - cm^2$ (from CMS)



Steps in track fitting algorithm

– Transform co-ordinate system such that magnetic field is along Z' axis



– Get distance to the crossing point of helix and plane

– Get the track parameters at the crossing point

– Return back to INO co-ordinate system (from CLEO)

– Step size is 5mm, need optimisation of CPU time and performance

Steps in track fitting algorithm

  - Use density of different material by hand (not exactly from database, but with the same parameters in Ical0DetectorParameterDef)

- Calculate Kalman gains, update track parameters, errors using extrapolation and true hits (Standard Kalman technique)
- Move forward and backward
- Update hits in different layer by comparing extrapolated points (using track parameters in previous layer) and true hit points
  Need optimisation - balance between multiple scattering, noise etc
- Interpolate tracks to another half layer to get track parameter. muons vertex is anywhere in between two layers.

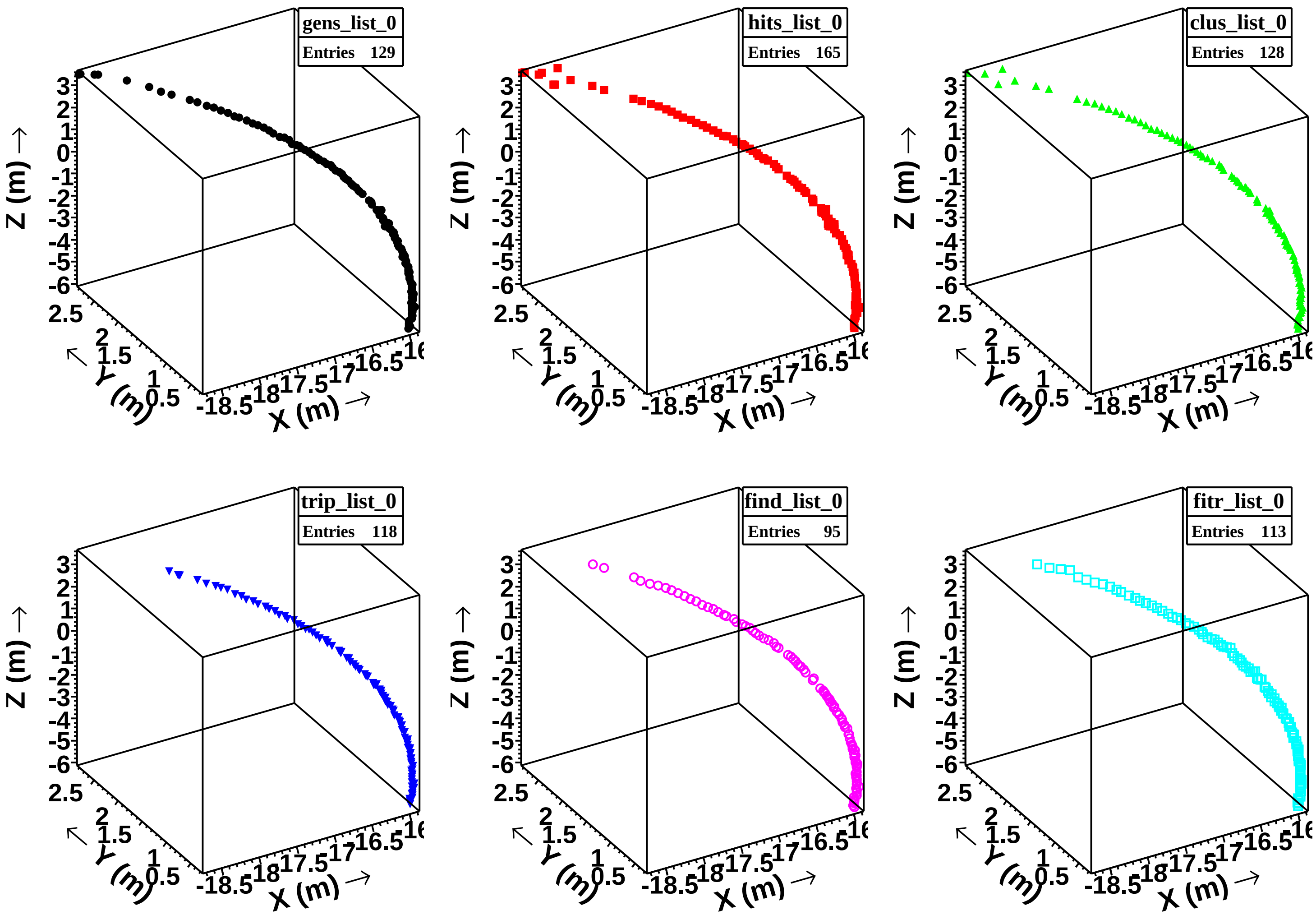
Out of many corrections/modifications :

- Tried to use Hits with only single strip, but its performances is not tested properly.
- tuned with single muon track, run with Nuance output, but not optimised at all for those samples
- ....
- Many more

Some features :

- No extra software library except GEANT4, root and CLHEP, which are needed for simulation itself. Need Linux platforms, compatible with GEANT4.
- Code is written with simple C++ class. There is no inheritance, not a good code, but simpler for new comer/learner.

A crude event display (3D hist): 12 GeV muon

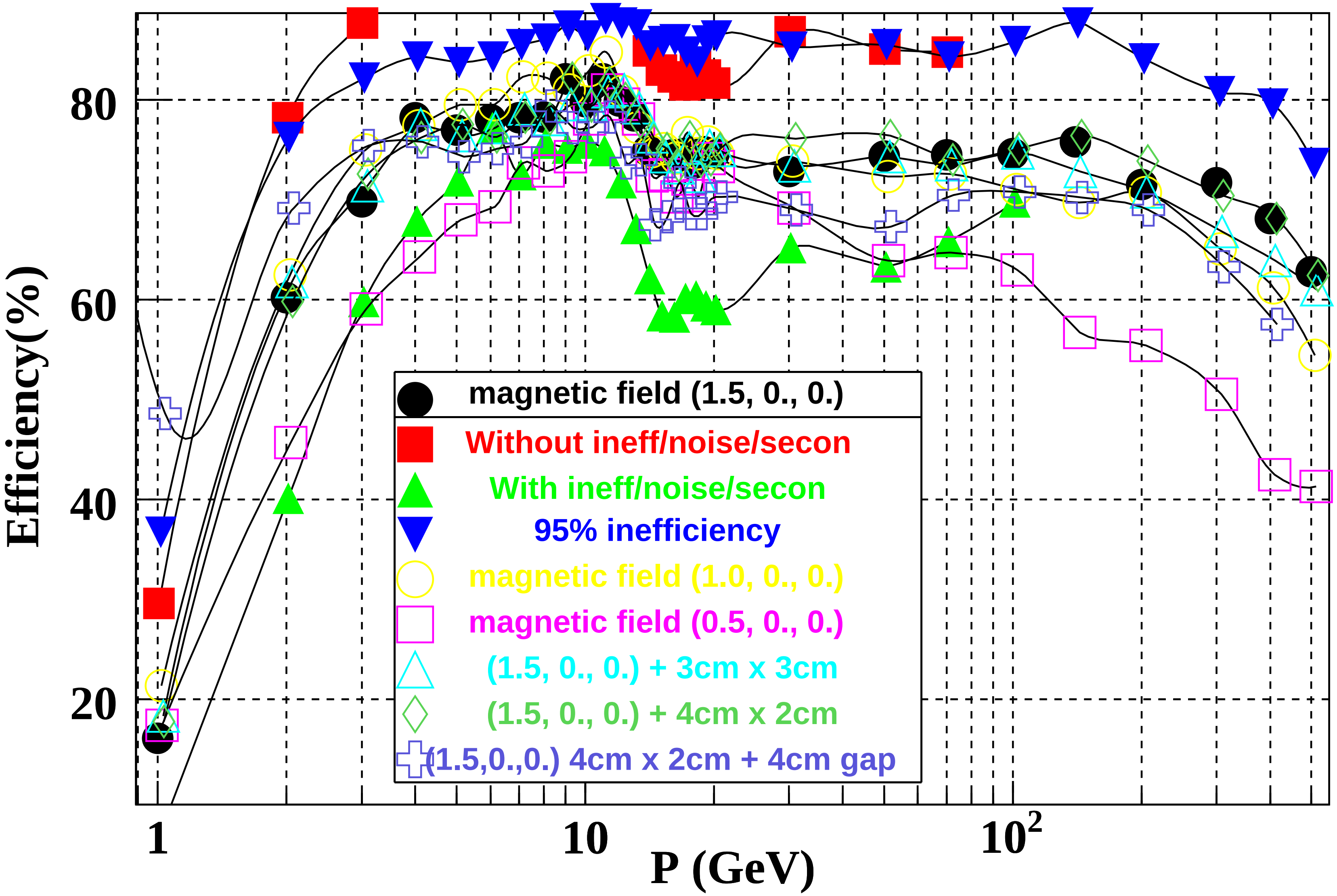


Trajectory
hit Hits from strip Clusters
Track segment cls in Finder track cls in Fitted track

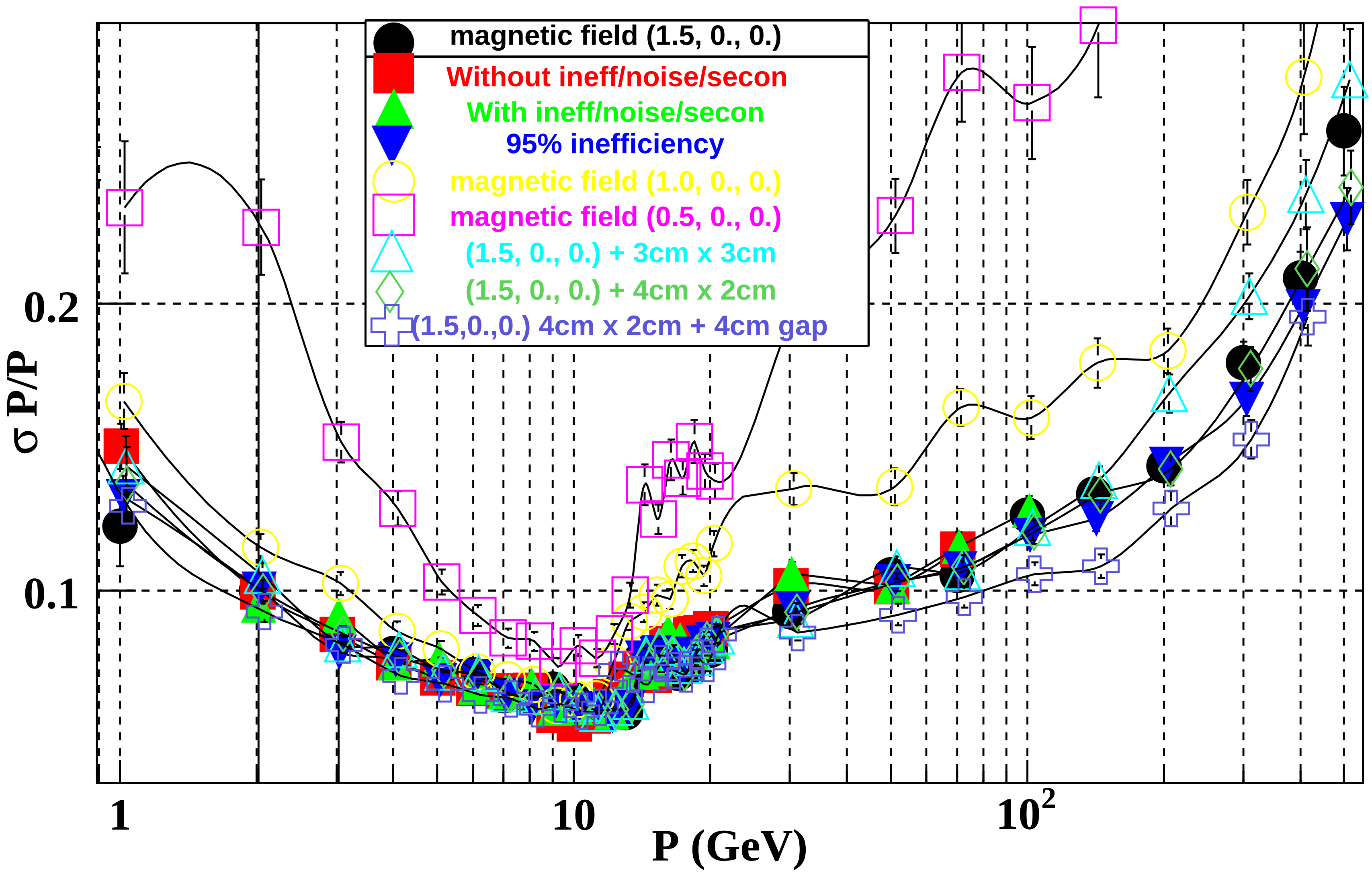
Track finder algorithm rejects most of the noise hits

Efficiency of track fitter, after all steps

Performances with single muon simulation, where muons passed vertically upward with a smearing of 100 mrad in polar angle and 2π in azimuthal angle.



Momentum resolution of fitted tracks

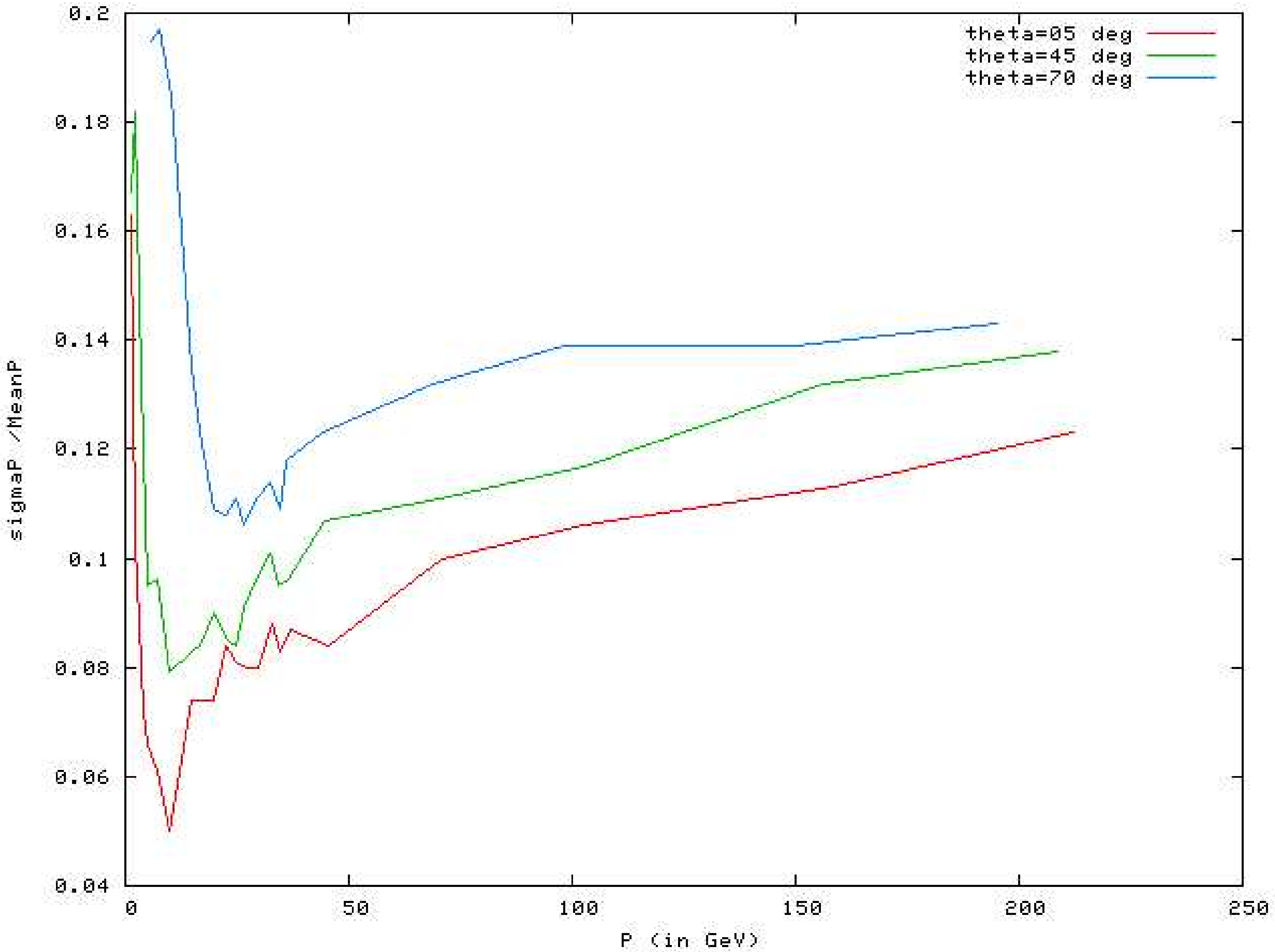


0.5 tesla magnetic field is distinctly poorer than others, not acceptable

Not much difference with strip widths !!!

Angular resolution looks same for all cases ($< 3^\circ$ at 1GeV and $< 1^\circ$ at 10 GeV).

Effect due to inclination angle



Performances is deteriorated with inclination angle, which is expected due to the effect of more multiple scattering.

Summary of single muon reconstruction

- We may reduce magnetic field by 1 tesla, but not more than that
- Wider Strip widths, does not deteriorate the performance much
- Certainly we can have different widths for X/Y strips
- Fully contained low momentum track does need not any timing information to solve ambiguity of direction.

From curvature at the beginning and end of track, one can identify muon direction unambiguously. Only upto 20 GeV, but need more study with true magnetic field configuration.

Except very low momentum (multiple scattering) there is no charge confusion. Momentum range 1 to 3 GeV it is about 1%.

Event display

Also developed dedicated/ more flexible event display for both analysis and software development.

- Nuance input to different physics parameter, distributions
- Simulation variables, hit, cluster, finder hits, fitter hits etc

Plan for coming few months

- Ghost hit/cluster, does not effect on track fitting, but for energy measurement of shower, it is really a problem.

- In Kalman fit, calculate expected position from $start - 1$ to $end + 1$ layer. In finder one might miss a layer in between. At the end of track, curvature is large. Track finder does not include it, but in the fitting time one can include that with this option.

- Up-down ambiguity, without timing : Choose best track using $prob(\chi^2, ndf)$ and ndf. For bad track, one may have good prob, but very less number of hits (ndf).

- Choose track direction, by fitting time informations, choice of

$$\chi^2_{up} = \sum_{i=2}^{12} \frac{(t_i - t_1 - c\Delta R_i)^2}{\sigma_i^2}, \chi^2_{down} = \sum_{i=2}^{12} \frac{(t_1 - t_i - c\Delta R_i)^2}{\sigma_i^2}$$

- Use real magnetic field and put uncertainty in the time of reconstruction.

- Use misalignment of detector layer in reconstruction.

- Trigger simulation is an urgent business! It is definitely important to fix the specification of the electronics.

Plan for other improvements, a long term plan

- Starting value of state vector $(x, y, dx/dz, dy/dz, q/p)$ from three points, $first$, $middle$, $last$
- Give less weight on cluster at Kalman filter, if it looks like an em/hadronic shower, mainly in the vertex point, where muon is associated with other pions etc.
- Optimisation of Showerlike (hadronic shower from $\pi^{\pm}$ or electromagnetic shower from π^0) and Tracklike clusters
- Optimise the orientation of ICAL detector, which is optimum for atmospheric neutrino as well as neutrino beam ?
- Optimisation of different detector parameters using physics ($Nuance$) events, which should be done as soon as possible, but to do that we need all previous steps.

Some other issues

- Make database for geometry such that same database can be used in simulation, digitisation and reconstruction.
- Similarly, mapping/extrapolation of magnetic field and make database for that too.
- Divide SIM, DIGI and RECO separately, such that user can test reconstruction algorithm, from a single set of simulated/digitised events. Move any point to any next points of $\underline{\mathrm{GEN} \rightarrow \mathrm{SIM} \rightarrow \mathrm{DIGI} \rightarrow \mathrm{RECO}}$ chain.

Can we detect electron in INO detector ?

No simulated result, but wild guess, though we can identify μ, hadronic shower and EM shower, we can not measure energy of hadronic/EM shower.

Anyhow, we will do this study (simulate $e/\mu/\pi$ separately).

In that context, can we identify the following processes

1. $\nu_\mu + N \to \mu + \pi_{low\ energy}$
2. $\nu_\mu + N \to \mu + n\pi$
3. $\nu_\mu + N \to \mu + \pi^0 + X$
4. $\nu_e + N \to e + X$
5. $\nu_\mu + N \to \nu_\mu + \pi^0 + X$

processes 1 & 3 : No distinction at all, if π^0 momentum is low
processes 2 & 3 : very little chance to discriminate
processes 4 & 5 : No distinction at all