Muon momentum spectra with mini-ICAL

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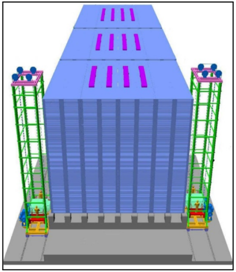
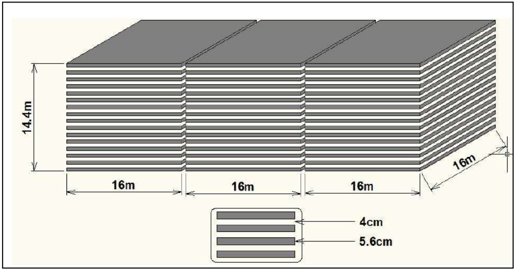
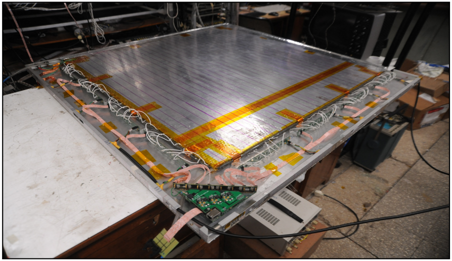
Motivation to set up mini-ICAL





- Performance of Magnet: Measured magnetic field (using pickup coils and Hall probes) vs 3D simulation
- Performance of RPC including DC-DC supply, FE electronics in fringe B-field, EMI, closed loop gas system.
- Feasibility of Muon Spin Rotation (μSR) for information about B-field complementary to sense loop and hall probe data.
- Measure $\Phi(\mu^+)$, $\Phi(\mu^-)$ for $\sim 0.5\,\text{GeV} < \text{E} < 1.3\,\text{GeV}$ at Madurai (near equator) and compare with simulation (by Athar, Honda)
- Proof of principle test of cosmic muon veto detector.

mini-ICAL



- 11 layers of iron of size 4 m × 4 m × 5.6 cm.
- Currently RPCs are placed in the central 2 m × 2 m where the magnetic field is uniform.
- The size of the RPCs 174 cm × 183.5 cm × 1.8 cm.
- The width of the readout strips is 2.8 cm with an interstrip gap of 0.2 cm (pitch of the strip is 3 cm).
- Using the orthogonal readout strips and the layer number, the 3 co-ordinates for a particle's trajectory are obtained.

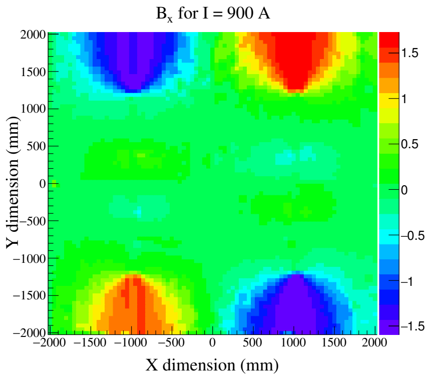
Simulation code for miniICAL

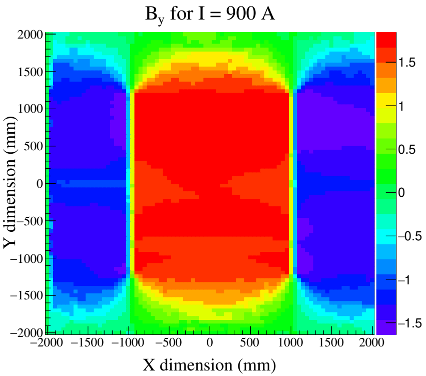
GEANT4 based simulation code for mini-ICAL detector. The salient features of the simulation code are:

- Geometry is designed as the actual detector, along with room and building in which mini-ICAL detector is placed.
- Discrete muon events obtained from simulation of primary cosmic rays using CORSIKA at the detector site.
- To digitize the data and include all the detector properties mentioned below, a INO specific algorithm is developed.
  - Detector inefficiencies
  - Strip multiplicity
  - Time resolution
  - Detector noise
  - Hardware trigger

Magnetic field map

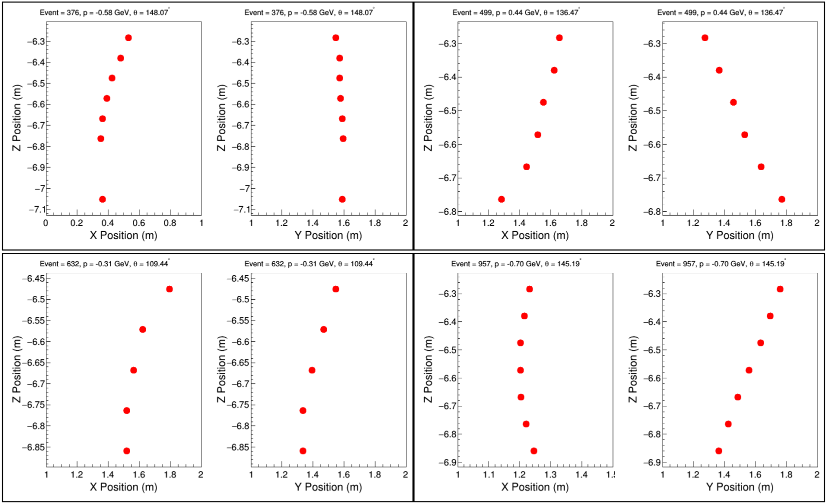
Magnetic field map used for the simulation as well as during reconstruction.





Simulated field is within 5–10 % of measured field.

Few clean muon trajectories



Bending in X-side due to magnetic field in Y-direction.

Reconstruction of track

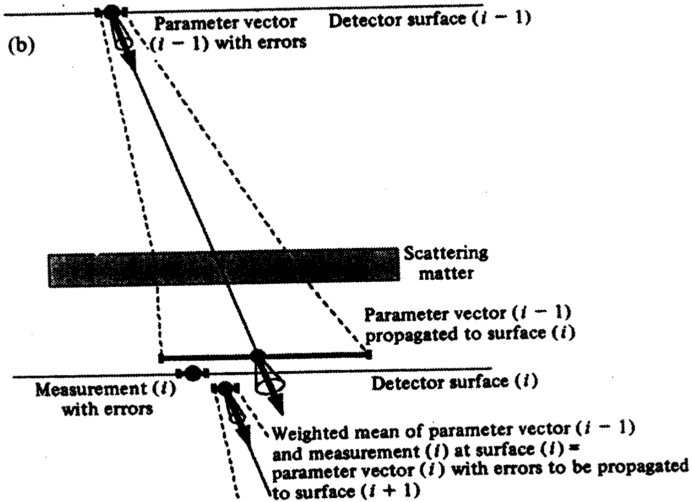
There are two modes of operation for miniICAL detector.

- Without magnetic field
  - This mode will be used to estimate all the detector uncertainities and detector properties.
  - Without magnetic field, there is no bending of tracks, a simple straight line fit can be used to fit the data.
  - Initial alignment of position and calibration of time will also be done.
- With magnetic field
  - This mode will be used to estimate the muon momentum from bending of track.
  - Kalman filter algorithm already developed for ICAL detector simulation will be used.
  - Detector uncertainities computed when magnetic field is off will go as input here.
  - The magnetic field map is same as used in simulation.

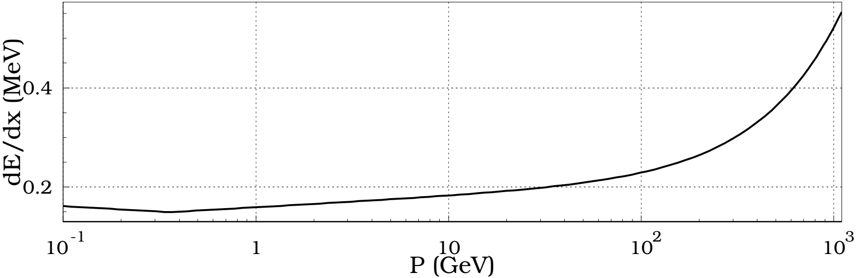
Reconstruction of track

- The primary signature of muon is a presence of a track.
- It is important to identify the strip hits produced by muon track and to reconstruct its kinematic properties.
- The track reconstruction is performed in two stages:
  - Track Finding
  - Track Fitting
- The track finding algorithm analyses the topology of the strips in order to identify seed tracks for fitting algorithm.

Fitting algorithm (Kalman technique)



Steps in track fitting algorithm



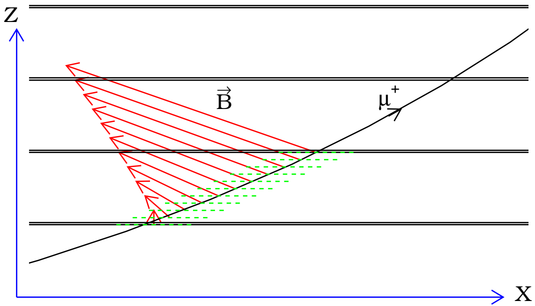
- Basic assumption, large bending is expected only in tail part, but not near top layer.
- Start with cluster from Track finder
- Simplified form of ionisation energy loss muon in iron.

Steps in track fitting algorithm (contd..)

- Expect muon is going downward only
- Initial track direction/position is taken from only first two layers (in straight section) with q/p=0, whereas track has five parameters (x,y,dx/dz,dy/dz,q/p)
- Extrapolation to next layer, irrespective of that has hits from track finder.

Extrapolation

- 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 mini-ICAL co-ordinate system
- Step size is 5mm.



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

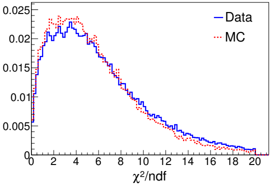
The Propagation Matrix

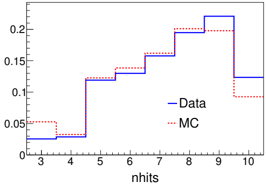
$$F_{k-1} = \begin{pmatrix} 1 & 0 & \delta z & 0 & \frac{1}{2}B_y(\delta z)^2 \\ 0 & 1 & 0 & \delta z & \frac{1}{2}B_x(\delta z)^2 \\ 0 & 0 & 1 & 0 & B_y\delta z \\ 0 & 0 & 0 & 1 & B_x\delta z \\ 0 & 0 & 0 & 0 & 1+\epsilon \end{pmatrix}$$

- This is an simplified form of propagation with the assumption that particle is going almost along Z-direction, which is not true for large inclination angle and can not applicable at all for track, which change direction in Z.
- Propagate track in the forward direction, then backward and calculate track parameter in each layer.
- Update cluster lists (finder track information) in different layer by comparing fitter track parameters with all clusters in that layer.

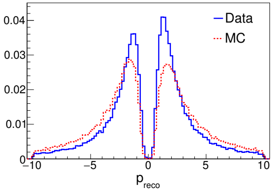
Reconstruction of mini-ICAL data

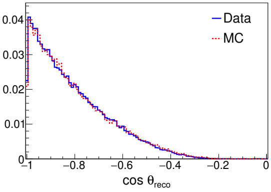
This is just observation, due to small variation of efficiency in different region of a RPC as well as variation of RPC in different layer, this results need to be corrected for efficiency before comparing with theoretical calculation.

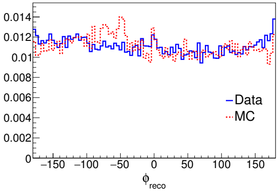




Expected ratio of # of $\mu^+$and μ^- at low energies, though measurement has large uncertainty due to mag field, proper noise etc.







Conclusion

- Commissioning of miniICAL with 10 layers of RPC is complete.
- mini-ICAL detector with magnetic field operational since May with 1.4T field.
- Magnetic field measurement is closely matched with simulation (MagNet7)
- There is no unexpected noise in RPC electronics due to fringe field
- Observed muon spectrum is also closely matched with Corsika predictions
- Measurement of momentum spectrum can be used to improve neutrino flux at Theni.

Thank You