Energy resolution and charge identification efficiency of muons in INO ICAL detector

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Introduction

The motivation for the design of the Iron Calorimeter (ICAL) detector at the India-based Neutrino Observatory (INO) is to make precise measurements of neutrino (ν) parameters using atmospheric νs. It is crucial to know the energy and direction of incoming νs. This involves measuring the direction, momentum and the sign of the electric charge of the charged particles such as muons produced in interactions of neutrinos with the target nucleons of the iron in the ICAL. The magnetic (B)-field due to magnetized iron plays a crucial role for both partial and fully contained muons. Muons will be detected using resistive plate chamber (RPC) detectors. The design of the ICAL magnet is similar to that in the MONOLITH proposal [1]. The details of ICAL detector and preliminary results of simulations have been presented in the INO Report [2]. This contribution presents the effect of B-field on energy resolution and charge identification (ID) efficiency of muons.

Simulation results

Studies have been carried out to look for the effect of B-field on energy resolution and charge ID efficiency of muons. The simulation code called GEANT4 [3] is used for the detailed simulation of the ICAL geometry and propagation of particles. Muons having energies (1- 20) GeV are incident symmetrically in all azimuthal directions at different zenith angles ($\cos(\theta) = 0.25$ to 0.95) in the central region of the detector where the B-field is nearly uniform. An algorithm based on the Kalman Filter [4] is used to reconstruct the muons momentum by considering the tracks close to vertex (with cut on χ^2/no. of degrees of freedom < 10). The reconstructed momentum obtained from the simulation is plotted in the range of 0 to $2P_{in}$, where P_{in} is the input momentum. The full width at half maximum (FWHM) of the distribution is taken for gaussian fitting of the reconstructed momentum in the range of P_{in} - FWHM to P_{in} + FWHM. Figure 1 shows the distribution of the reconstructed momentum for 5 GeV muons incident corresponding to $\cos(\theta) = 0.95$, where θ is the zenith angle, symmetrically for all azimuthal directions at magnetic field of 1.5 tesla (T). The standard deviation (σ) obtained from the fit is used to find out the energy resolution of muons. The charge identification efficiency of muons has been estimated within the range of 3 σ.

The energy resolution of muon is affected

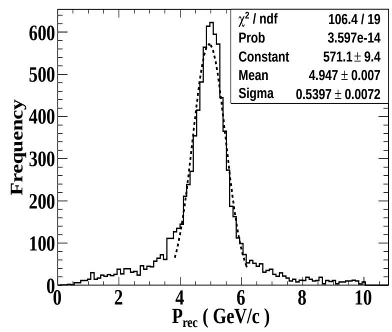

FIG. 1: Reconstructed momentum distribution of 5 GeV muon at $\cos(\theta) = 0.95$, dashed line shows the gaussian fitting of the distribution

by multiple scattering, bending (sagitta) of the trajectory and the number of hit points used to fit the track [5]. At low energy, resolution is affected by multiple scattering and it reduces with increase of energy. Figure

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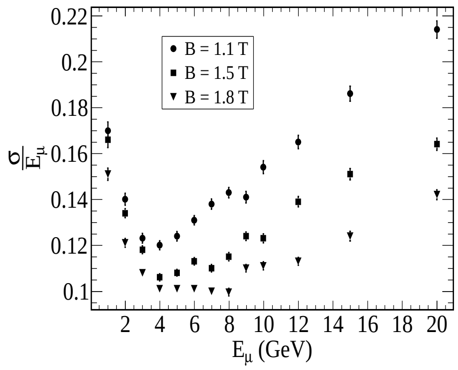

FIG. 2: Resolution versus energy of muon at various magnetic field for $\cos(\theta) = 0.95$

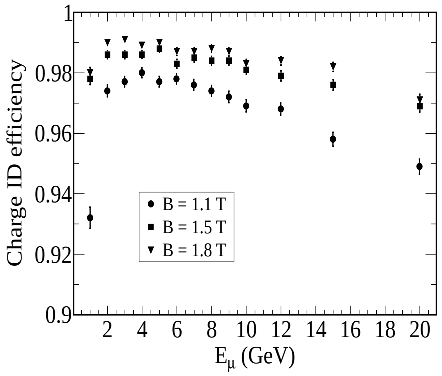

FIG. 3: Charge identification efficiency versus energy of muon at various magnetic field for $\cos(\theta) = 0.95$

2 shows the variation of the muons energy resolution for different B-field strengths. For a given B-field, the energy resolution improves with the energy of the muons having a minima at an energy of about 4 GeV and then it becomes poorer with higher energy. At low muons energy ($E \leq 4$ GeV), resolution improves with energy as number of hit points required to fit the track increases. At higher energy, poorer resolution can be attributed to the uncertainty in sagitta measurement. For a given energy, resolution improves with increase in magnetic field due to increase in bending of trajectory as a result of less uncertainty in measurement of sagitta. It has been observed that at higher energy, resolution improves ~ 34 % at 20 GeV from magnetic field 1.1 T to 1.8 T for the muon incident at zenith angle of $\cos(\theta) = 0.95$. Similar behavior has been observed for energy resolution of muons with B-field strengths at $\cos(\theta) = 0.85$, 0.65, 0.45, 0.35 and 0.25. The minimum in energy resolution obtained is $\sim$10 % for 5 GeV muons at magnetic field of 1.5 T. The energy resolution of muons has been fitted with a function $\frac{a}{E^{\alpha}} + bE$, where " a " arises from multiple Coulomb scattering which is important at very low energies and " b " is due to the error in position measurement which is important at high energies, where the bending is very small (leading to a larger error on sagitta measurement). The parameter α takes a value of 0.5 to 0.6. It has also been found that the parameter α takes the same range of values while fitting the reconstructed momentum in the range of P_{in} - n.FWHM to P_{in} + n.FWHM, where n = 2, 3.

Figure 3 shows the variation of charge ID efficiency of muons with energy at different magnetic field strengths. It shows that the charge ID efficiency is more than 90% for all energy and it increases with increase of magnetic field. At higher energy, the fall in charge ID efficiency is due to more uncertainties in sagitta measurements. The charge ID efficiency is nearly constant at high energy for large values of zenith angles ($\cos(\theta)$ < 0.85).

In summary, from the above studies, it has been observed that energy resolution as well as charge ID efficiency of muons improves with magnetic field. Also the present calculation shows momentum resolution can be improved with an improved Kalman Filter.

References

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