Propagation of error in the physics analysis with the variation in magnetic field in the ICAL detector

Honey Khindri

Homi Bhabha National Institute

December 15, 2022

Overview

- Introduction and Motivation
- Experimental Inputs
- Simulations
- Analysis
- Results
    - Effect on θ_{23}
    - Effect on Mass hierarchy
- References

Introduction and Motivation

ICAL (Iron Calorimeter)

- ICAL is a proposed magnetized 51 k-Ton detector with $B_{max} \sim 1.5$ Tesla
- Designed to detect muons (1GeV to 20GeV) generated from charge current interaction of atmospheric ν_μ and $\overline{\nu}_\mu$ with the iron

$$\nu_\mu N \rightarrow \mu^- X$$
$$\overline{\nu}_\mu N \rightarrow \mu^+ X$$

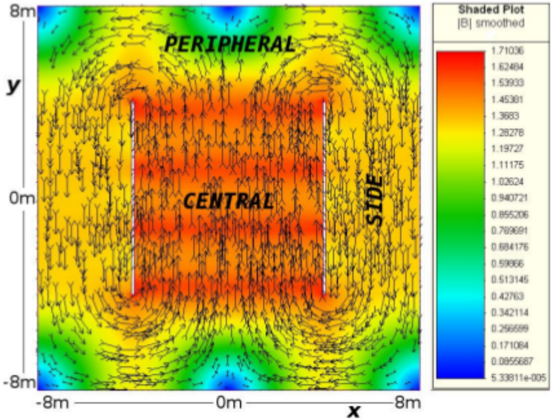
- Purpose of making magnetized detector
    - Charge identification of μ^- and μ^+
    - Reconstruct momentum of muons
- ICAL is designed to have excellent CID that can help in studying matter effect on ν_μ and $\overline{\nu}_\mu$ that can resolve neutrino mass ordering by determining the sign of Δm^2_{32}
- Hence accurate measurement of magnetic field is very important

Magnetic field map

A magnetic field map is generated using MAGNET software for the ICAL geometry.

It is divided into 3 regions:

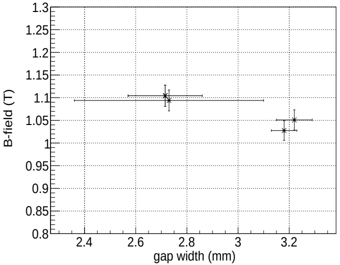
- Central region I
- Side region II
- Peripheral region III

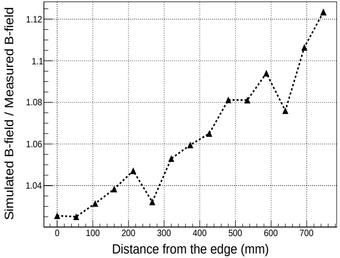


Region III has specially variable field in both magnitude and direction

Mini-ICAL

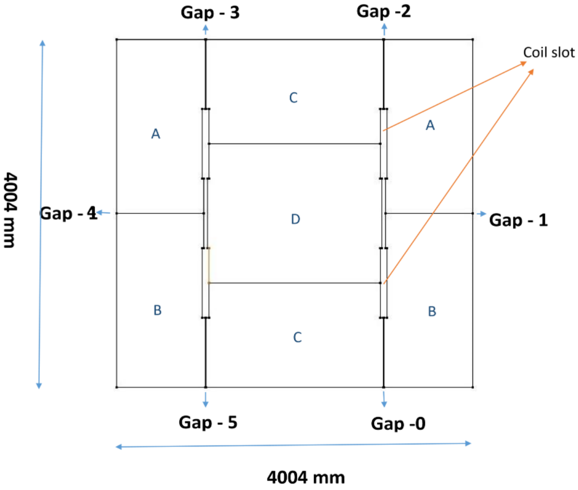
- Mini ICAL (85 Ton prototype detector) magnetic field measurement data for 500 amps
- Simulation data from MAGNET software





- Gap thickness measurement plays a crucial role
- Measurement of magnetic field is achievable with an accuracy of $\sim$ 3–5%

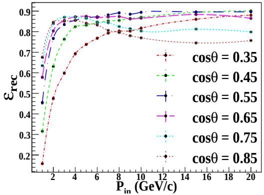
Mini-ICAL (upper view)

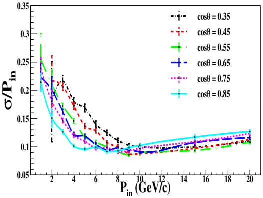


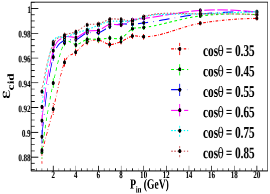
Simulations

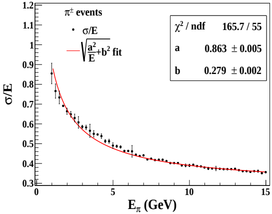
A GEANT4 simulation study is done for ICAL with magnetic field map generated using MAGNET software. Following parameters are studied:-

- Reconstruction efficiency
- Muon charge identification
- Muon momentum resolution
- Hadron energy resolution







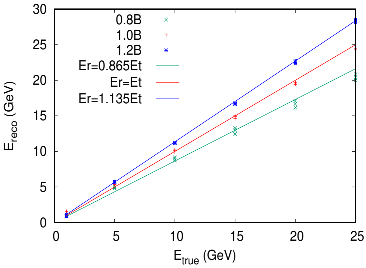


[S Ahmed et al., 2015 arXiv:1505.07380]

Change in momentum and resolution

Events were generated in GEANT4 with true B_{map} and reconstruction of energy is done with false B_{fB} field.

B-field	(f-1)	E_{reco} vs E_{true}
$B = B_{correct}$	0.0	$E_{reco} \sim E_{true}$
$B = 0.8B_{correct}$	-0.2	$E_{reco} = 0.865E_{true}$
$B = 1.2B_{correct}$	+0.2	$E_{reco} = 1.135E_{true}$
$B = 0.98B_{correct}$	-0.02	$E_{reco} = 0.987E_{true}$
$B = 1.02B_{correct}$	+0.02	$E_{reco} = 1.014E_{true}$



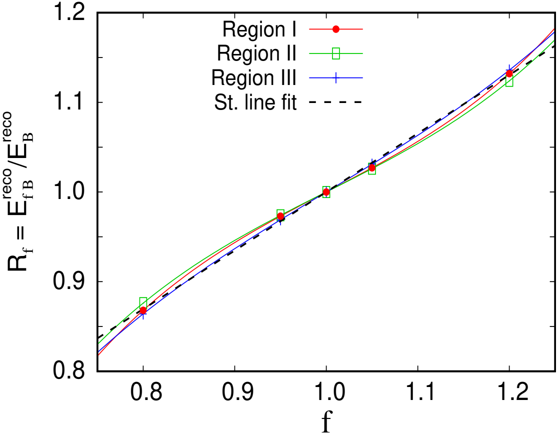
Analysis

NUANCE Neutrino Generator [3] was used to generate 1000 years of atmospheric neutrino events with the Honda 3D fluxes. They are oscillated using following parameters:-

Parameter	True value	Marginalization
θ_{13}	8.57°	$[7.671^\circ, 9.685^\circ]$
$\sin^2\theta_{23}$	0.5	[0.415, 0.616]
$\lvert\Delta m^2_{32}\rvert$	2.47×10^{-3} eV^2	$[2.395, 2.564] \times 10^{-3}$ eV^2
$\sin^2\theta_{12}$	0.304	Not marginalised
Δm^2_{21}	7.6×10^{-5} eV^2	Not marginalised
δ_{CP}	0°	Not marginalised

- The normal ordering was assumed throughout. The data was scaled to 10 years so all results correspond to 10 years exposure at ICAL.
- "Data" is generated as per true magnetic map and "Theory" as per magnetic field = fB

GEANT4 Analysis of magnetic field variation



- For larger (20 %) deviation of magnetic field from field map leads to non-linear deviation of reconstructed energy
- For smaller deviations (upto 5%) the deviation is almost linear therefore we have parameterized the change by fitting with straight line.

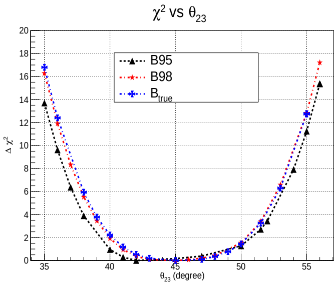
Analysis

Study is done considering the following cases of magnetic field:-

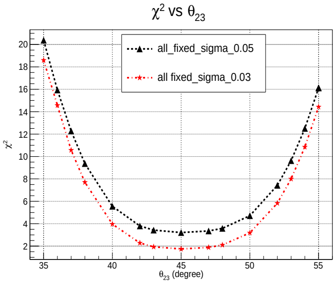
- Considering the magnetic field map as true B-field.
- Considering systematic change in the B-field map (f = constant).
- Considering random Gaussian variation in the B-field map (σ = 3–5% about central value).

Results θ_{23} *[Preliminary results]*

Systematic variation in B-field map



Random Gaussian variation in B-field

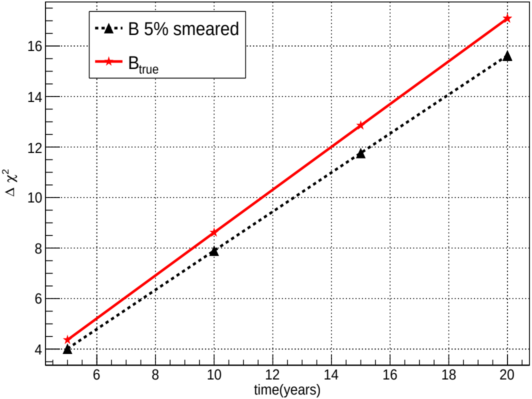


- Fit gets worse for 5% although no significant change for 2% $(;\chi^2_{min} = 29)$
- Best fit value is 42^0 compare to true input of 45^0

- Fit gets worse for 5% as compare to 2% change in magnetic field
- Best fit value remains same as true input of 45^0

Mass hierarchy sensitivity *[Preliminary results]*

- Events were generated using NO and χ^2 was calculated assuming IO in the theory.



- Sensitivity of the ICAL for mass hierarchy decreases with 5% smearing in B-field.

Conclusion

Magnetic field is measured in mini-ICAL and compared with simulations done using MAGNET software. A study is done to estimate the effect of error in measurement of magnetic field on physics analysis for ICAL.

References :-

- S Ahmed et al., INO Collaboration, Physics Potential of the ICAL detector at the India-based Neutrino Observatory (INO), INO/ICAL/PHY/NOTE/2015-01 (2015) arXiv:1505.07380 [physics.ins-det].
- Honey Khindri et.al., Magnetic field measurements on the mini-ICAL detector using Hall probes, JINST 17 (2022) 10, T10006.
- D. Casper, The Nuance neutrino physics simulation and the future, Nucl. Phys. Proc. Suppl. 112 (2002) 161. [hep-ph/0208030]

Thank You