Effect of magnetic field variation on the precision measurements at ICAL: Simulation study

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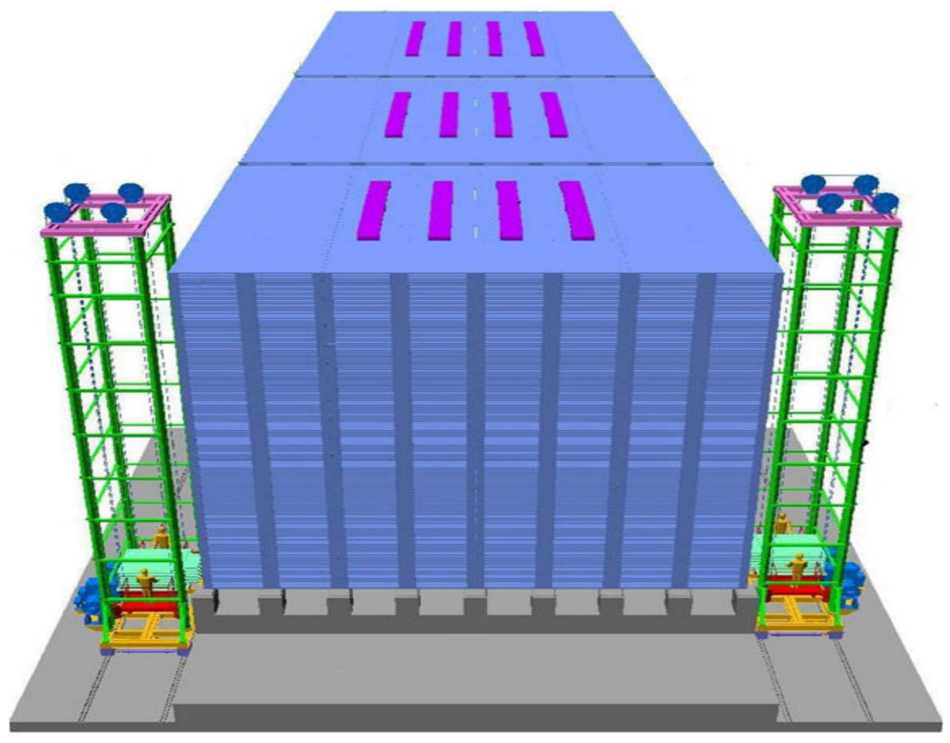
Introduction

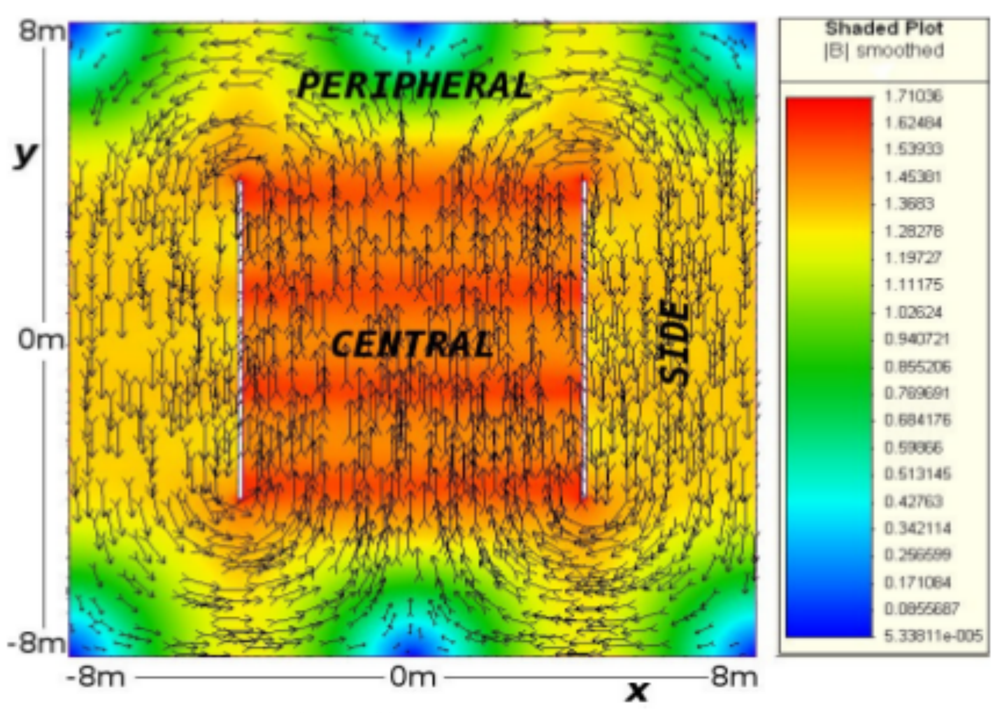
- **ICAL** is a magnetized 51 k-Ton detector with $B_{max} \sim 1.5$ Tesla. This allows measuring the charge and momentum of muons produced in CC interactions of atmospheric muon neutrinos.



- Since ICAL has **excellent CID** that can help in studing matter effect on ν_μ and $\bar{\nu_\mu}$ that can resolve neutrino mass ordering by determining the sign of Δm^2_{32}
- Recently, several measurements at the 85 ton mini-ICAL detector indicated that it may be possible to get agreement between measured and simulated field values to within a few percent [2].
- Here we present a preliminary and first study of the effect of errors in the measurement of the magnetic fields on the physics goals of ICAL.

Simulations study of muons

The GEANT4 code is used to generate the ICAL geometry which comprises three modules of 151 layers of 56 mm iron, separated by a 40 mm gap in which the active detector elements, the RPCs, are inserted. Current passed through copper coils wound around the detector to generate magnetic field as shown in figure below.



- Muon of different energies are generated at different angles and location and thier hit pattern is studied with different B-field.
- There is a "true" magnetic field, $B(x, y, z)$, which bends the muons into the observed muon track.
- These tracks are fitted with the computed or simulated magnetic field map, which may be different from the actual one.
- For simplicity, 6 scenarios, when the fitted magnetic field is $0.8B, 1.2B, 0.95B, 1.05B, 0.98B, 1.02B$ are considered, that is 20%, 5% or 2% smaller or greater than the true magnetic field.
- The reconstructed energy E_{reco}, the energy resolution σ, and the charge identification efficiency in each case is calculated.

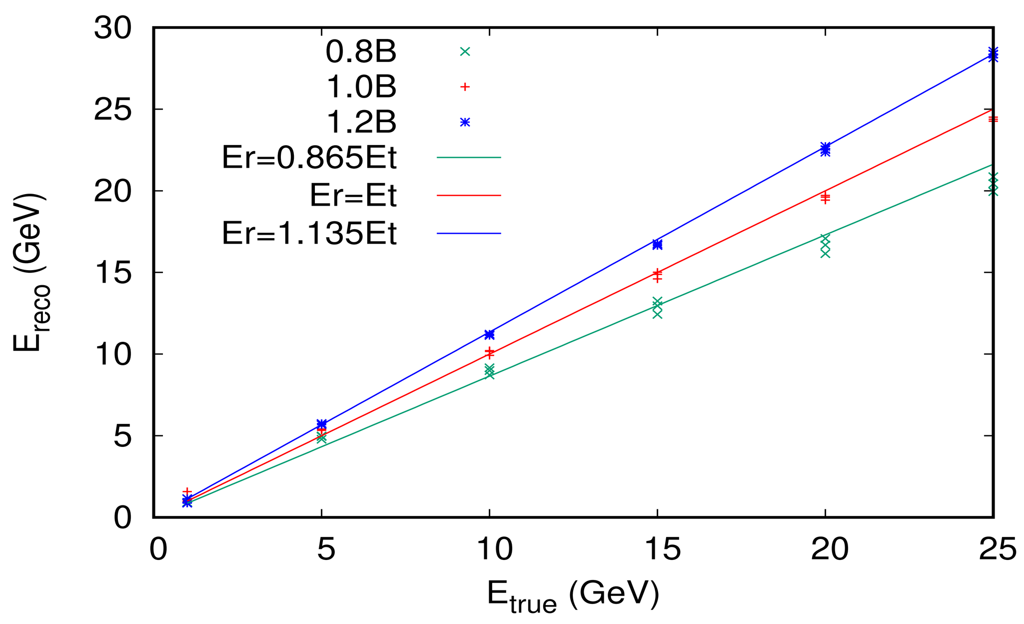
Precision measurement of θ_{23}

- NUANCE Neutrino Generator [5] 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}	$8.57°$	$[7.671°, 9.685°]$
$\sin^2\theta_{23}$	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.
- The variation of the reconstructed energy (E_{reco}) with true energy for cos$\theta = 0.4$, 0.6 and 0.8 is shown in the figure below for the $B_{fit} = 0.8$ B and 1.2 B.

B-field	E_{reco} vs E_{true}
$B = B_{correct}$	$E_{reco} \sim E_{true}$
$B = 0.8B_{correct}$	$E_{reco} = 0.865E_{true}$
$B = 1.2B_{correct}$	$E_{reco} = 1.135E_{true}$
$B = 0.98B_{correct}$	$E_{reco} = 0.9865E_{true}$
$B = 1.02B_{correct}$	$E_{reco} = 1.0135E_{true}$



- In addition the width varies as $\sigma(\alpha B) = \alpha\sigma(B)$.
- χ^2 **analysis:-** Here, T-Theory and D-Data,

$$\chi^2 = \min_{\xi_l^{\pm}, \xi_6} \sum_{i=1}^{N_{E_\mu^{obs}}} \sum_{j=1}^{N_{\cos\theta_\mu^{obs}}} \left(\sum_{k=1}^{N_{E'^{obs}_{had}}} \right) 2\left[\left(T^+_{ij(k)} - D^+_{ij(k)}\right) - D^+_{ij(k)} \ln\left(\frac{T^+_{ij(k)}}{D^+_{ij(k)}}\right) \right] + 2\left[\left(T^-_{ij(k)} - D^-_{ij(k)}\right) - D^-_{ij(k)} \ln\left(\frac{T^-_{ij(k)}}{D^-_{ij(k)}}\right) \right] + \sum_{l^+=1}^{5} \xi^2_{l+} + \sum_{l^-=1}^{5} \xi^2_{l-}\,, \tag{1}$$

- $\Delta\chi^2$:-

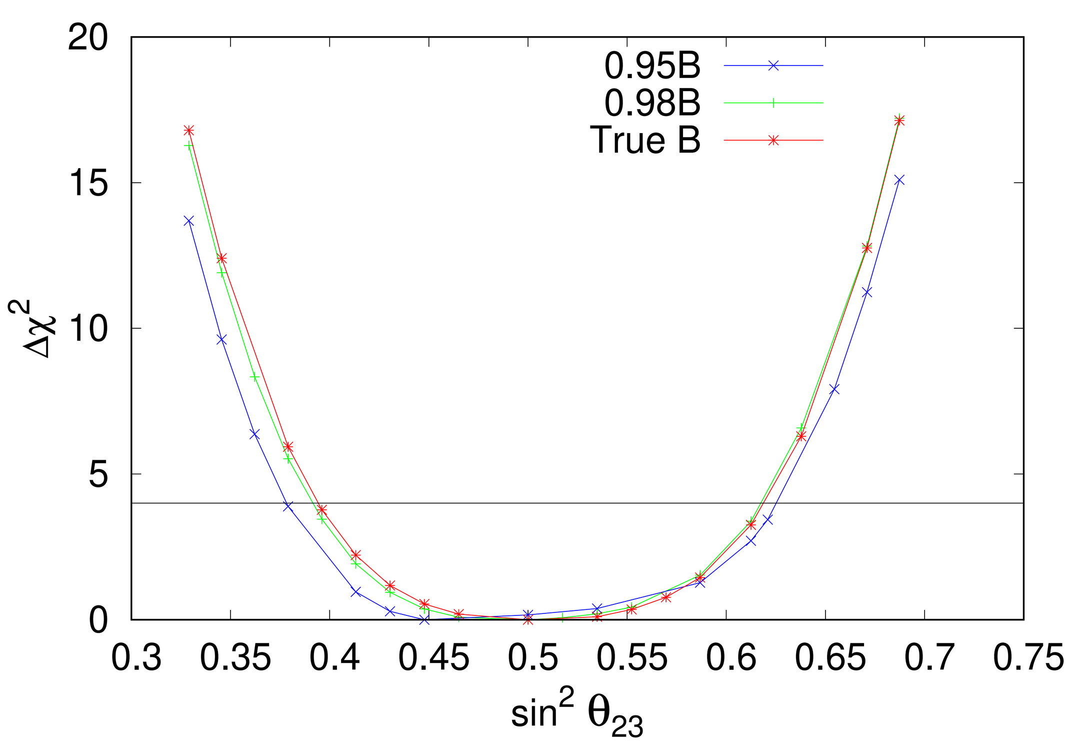
$$\Delta\chi^2(\lambda) = \chi^2_{ICAL}(\lambda) - \chi^2_0\,, \tag{2}$$

χ^2_0 being the minimum value of χ^2_{ICAL} in the allowed parameter range. With no statistical fluctuations, $\chi^2_0 = 0$, Here, λ is $\sin^2\theta_{23}$.

Results

Precision measurement of parameters: The analysis is performed for the two cases when the fitted magnetic field is 5% ($0.95B$)and 2% ($0.98B$) smaller than the true values.

- For a 2% variation, there is hardly any change in the precision measurement of θ_{23}
- The precision at 2σ ($\Delta\chi^2 = 4$) worsens by 10% for a 5% variation of the magnetic field. Moreover, the mimimum is at $\theta_{23} = 42°$ rather than the true input value of $\theta_{23} = 45°$. The minimum is also quite broad in this case
- Hence, it is clear that the magnetic field has to be measured to better than 5% accuracy in order to achieve the full potential of ICAL to precisely measure the neutrino oscillation parameters.



Future plan

- To study effect on other oscillation parameters
- To study the impact of random fluctuations, not systematic variations in the magnetic field.

References

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