PROCEEDINGS OF SCIENCE

Magnetic field simulations and measurements on mini-ICAL

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The proposed ICAL detector is designed to detect muons generated from interaction of ν_μ and anti-ν_μ with Iron. It is designed with a maximum magnetic field of about 1.5 Tesla (with 90% of its volume having > 1 Tesla magnetic field). The magnetic field is intended for charge identification and momentum reconstruction of the muons. The mini-ICAL is a fully functional 85-ton prototype detector. One of the main challenges for the mini-ICAL detector is to produce the required B-field and to measure it as accurately as possible to study muons. For the purpose of measuring the B-field in the detector, Hall sensor PCBs are used. Hall sensors provide real time measurement of B-field. Calibration and systematic study of characteristics of the Hall sensors which are used for the measurement are carried out. Out of 11 layers of iron, 3 layers (1, 6 and 11) have provision for measurement of B-field using Hall sensor. In the mentioned layers, the gap between the adjacent plates is kept 3-4 mm for the purpose of inserting of the Hall sensor PCBs. In the rest of the layers, the gap between the plates is kept 2 mm. Measurements of magnetic field in the air gap between the plates and measurement of fringe field is done with a precision of 3% for the top layer. This will help in completing the study on the final magnetic field configuration of ICAL.

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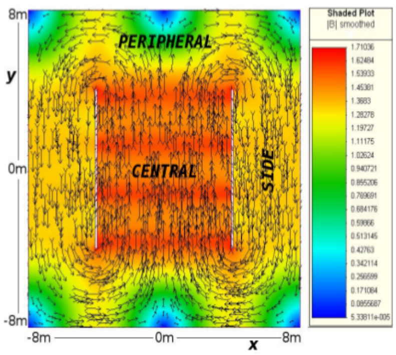

Figure 1: Magnetic field map for the ICAL

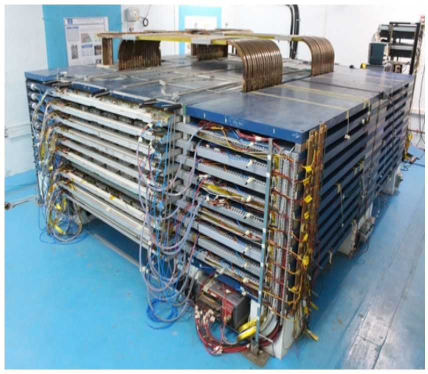

Figure 2: mini-ICAL

1. The mini-ICAL Geometry

ICAL is a magnetized 51 k-Ton detector with B_{max} ~ 1.5 Tesla. This allows measuring the charge and momentum of muons produced in charged current interactions of atmospheric muon neutrinos [1], [2]. The mini-ICAL (Fig. 2) is an 85-Ton prototype ICAL detector. One of the aims of mini-ICAL is to compare the measured and simulated magnetic field to validate the magnet design.

The mini-ICAL consists of 11 layers tiled with soft iron plates of 56 mm thickness. Each layer is 4 m x 4 m in dimension. 10 air-gaps of 40 mm thickness between the iron layers accommodate Resistive Plate Chambers capable of detecting charged particles. The current that passes through two sets of hollow Oxygen-free high conductivity copper coils with 30 mm x 30 mm cross section and a 17 mm bore for water cooling, each having 18 turns, produces the magnetic field in the mini-ICAL. Each iron layer of mini-ICAL is tiled with 7 plates of iron. There are four types of plates, named A, B, C and D. Either 3 mm or 4 mm wide gaps are kept between the iron plates in the 1st, 6th and 11th layers to insert Hall probe sensors to measure magnetic field.

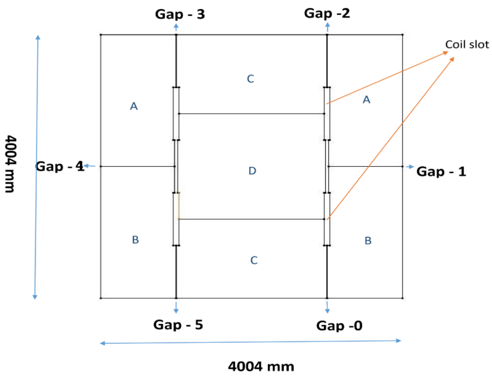

Figure 3: mini-ICAL upper views

2. Magnetic field Measurement system

CYSJ106C GaAs Hall Effect Element sensors are mounted on PCB (Fig. 4) which are inserted in the gaps between the iron plates at specific locations [3] (gap 0,2,3,5 in the Fig. 3). They measure magnetic field in real time (steady state). Their basic material is Mono-crystal GaAs and have resolution of about 10 Gauss. Also because of low cost and good temperature stability these CYSJ106C GaAs Hall sensors were found suitable for the purpose. 16 such sensors are mounted on a Hall probe. Arduino is used for selection of the sensor output.

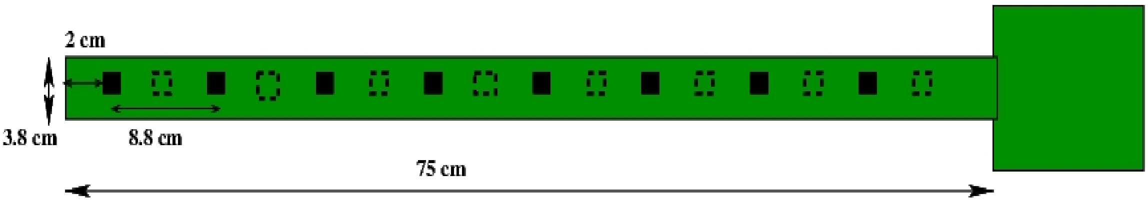

Figure 4: Hall probe sensor

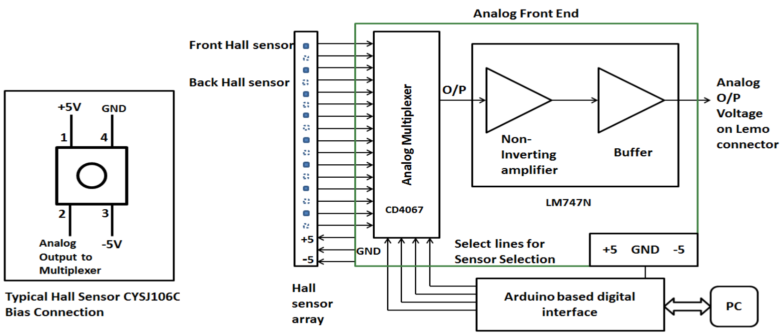

Figure 5: Schematic of the set up of Hall probe

3. Calibration System

Offset voltage (V_0) is calculated two ways: keeping the Hall PCB away from the mini-ICAL and measuring the voltage (Fig. 6) at different times, and other way is centering the V-I curve for each sensor (Fig. 7). It has been observed that offset voltage from centering V-I curve follows a similar pattern as the average of offset voltage measured by Hall sensors in the absence of the magnetic field.

Electromagnet (Fig. 8) is used to calibrate the Hall sensor w.r.t various values of known magnetic field. And data is fitted with the straight line to get the slope(m) (Fig. 9).

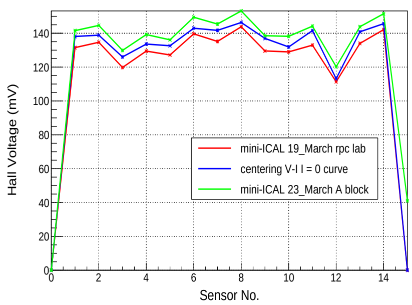

Figure 6: Offset voltage in the absent of magnetic field

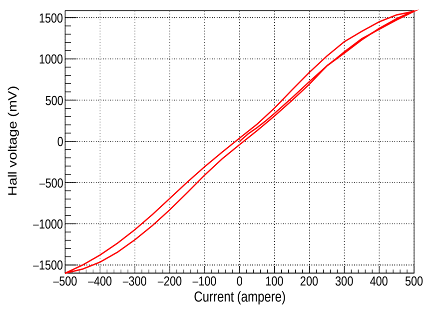

Figure 7: Hall voltage vs current after centering the V-I curve

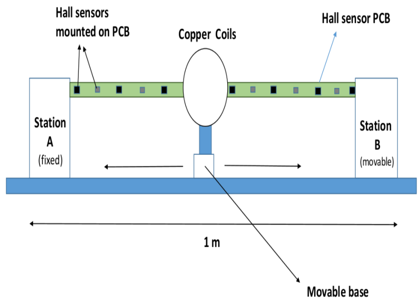

Figure 8: Calibration set up

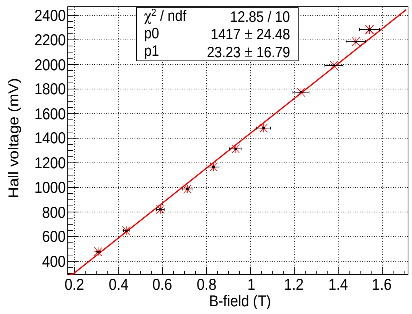

Figure 9: Calibration plot for sensor-2

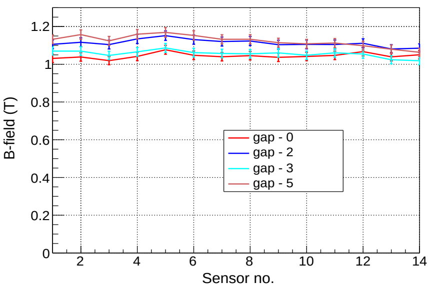

Figure 10: Magnetic field for the gap-0,2,3 and 5

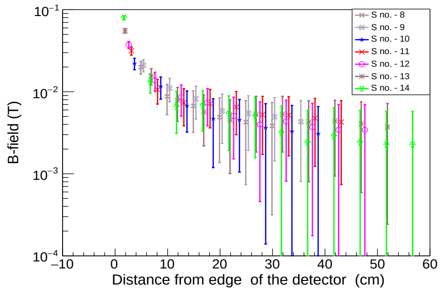

Figure 11: Fringe field of the mini-ICAL

4. Results

The magnetic field is calculated using

$$B = \frac{V - V_0 + V_\epsilon}{m}. \tag{1}$$

Here, V is the measured Hall voltage, V_0 is the offset voltage, m is the slope of calibration fit, and there is an extra offset V_ϵ = 8 mV (due to alternate positioning of the Hall sensors on the Hall PCB). For error estimation $\delta B = \frac{B}{m}\sqrt{\frac{\Delta {V_0}^2}{B^2} + \Delta m^2}$ is used. Here, $\Delta V_0 = \pm 5$ mV (error in offset measurement), $\Delta m = \pm 30$ mV/T (error in slope of the fit).

The mini-ICAL is ramped up to 500 ampere and magnetic field measurements are taken in gap 0, 2, 3 and 5 (Fig. 3). Fig. 10 shows the field in the gaps. The magnetic field value is different in different gaps due to variation in the width of air gaps. Fig. 11 shows fringe field outside the iron plate for top layer. Magnetic field is about 10±3 mT at a distance of 10 m from the iron plate.

References

[1] A. Kumar et al., Pramana **88**, 79 (2017).

[2] D. Indumathi and M. V. N. Murthy, "A question of hierarchy: matter effects with atmospheric neutrinos and anti-neutrinos", 10.1103, Phys. Rev, **D 71** 013001, arXiv: hep-ph/0407336 [hep-ph].

[3] H. Khindri et.al., Magnetic field measurements on the mini-ICAL detector using Hall probes, JINST **17** (2022) 10, T10006.