Muonless Events in ICAL at INO

Ali Ajmi[a] **and S. Uma Sankar**[b]

[a]*Homi Bhabha National Institute*
Anushaktinagar, Mumbai 400 094, India.
[b]*Indian Institute of Technology Bombay*
Mumbai 400 076, India.
E-mail: aliajmi@tifr.res.in, uma@phy.iitb.ac.in

The primary physics signal events in the Iron Calorimeter at India-based Neutrino Observatory are the ν_μ charged current (CC) interactions with a well defined muon track. Apart from these events, Iron Calorimeter can also detect other types of neutrino interactions, i.e. the electron neutrino charged current interactions and the neutral current events. It is possible to have a dataset containing mostly ν_eCC events, by imposing appropriate selection cuts on the events. The ν_μCC and the neutral current events form the background to these events. This study uses Monte Carlo generated neutrino events, to design the necessary selection cuts to obtain a ν_eCC rich dataset. An optimized set of constraints are developed which balance the need for improving the purity of the sample and having a large enough event sample. Depending on the constraints used, one can obtain a neutrino data sample with the purity of ν_e events varying between 55% to 70%.

1. Introduction

India-based Neutrino Observatory or the INO, an upcoming experimental facility will house the Iron Calorimeter (ICAL). The ICAL aims to study the interactions of atmospheric neutrinos and antineutrinos [1]. It is a giant magnetized neutrino detector, with Resistive Plate Chambers (RPCs) as the active detector elements [2, 3, 4]. It comprises of 3 modules, with ~30,000 RPCs, and 151 iron layers weighing ~50kton in total. A sketch of ICAL is shown in figure 1.
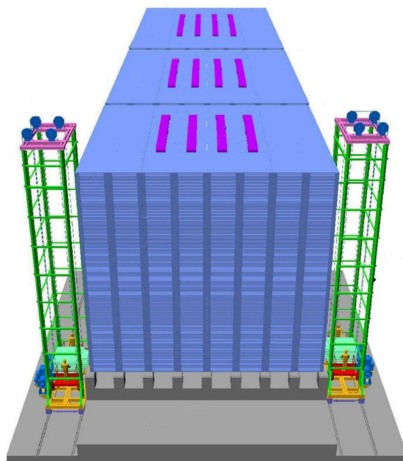

Figure 1: A Schematic Sketch of the INO Detector.

The RPC layers are interspaced with iron plates of 5.6 cm thickness. This enables the detector to obtain clearer muon tracks. Simultaneously, this also leads to the absorption of most electrons.

2. The ν-events at ICAL

Charged current (CC) neutrino interactions produce leptons of corresponding neutrino flavor, while the neutral current (NC) interactions do not give any lepton. Muons produced in the ν_μCC interactions form tracks in the detector. The ν_eCC events give electrons which can produce electromagnetic showers, but no track can be seen. In case of the NC events, only the hadrons can be observed in the detector. The ν_μs with lower energy and in the horizontal direction [5] are confined to a few layers, with no clear muon track.

Events in ICAL at INO can be classified into events with muon tracks and those without such tracks. We refer the latter as the "muonless" events, which basically comprise the ν_eCC events, "others" (all NC and few ν_τCC) and the low energy or horizontal ν_μCC events.

The following study is done with neutrino interactions generated by the Nuance neutrino event generator [6] equivalent to 500 years kton data. The generated events are then simulated in the ICAL detector using GEANT4.

Applying certain selection cuts, we can obtain an events sample rich in atmospheric ν_eCC events. The cuts are based mostly on the number of hits and number of layers, which are discussed in the following section.

3. Hits and layers

A signal picked up by the copper strips of the RPC is referred to as a "hit". The detector thus records a number of hits during an event. We study the distributions of these hits for the ν_μCC events, ν_eCC events, and the NC events, in different ranges of E_ν, as shown in figure 2 and 3.
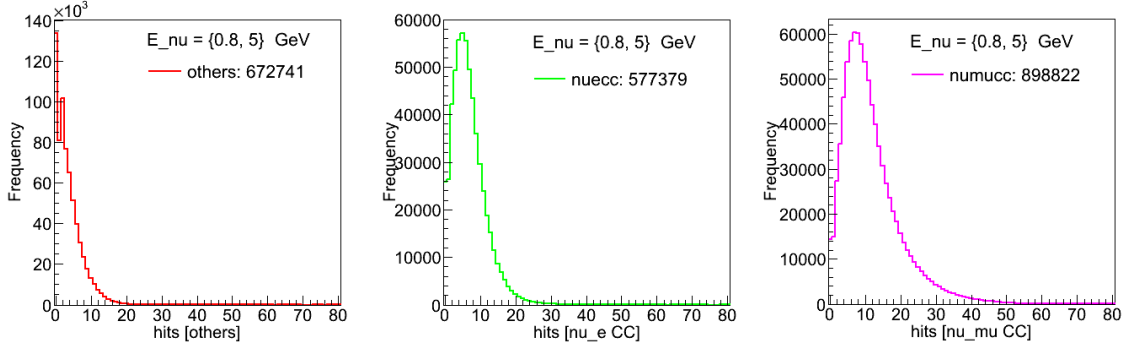

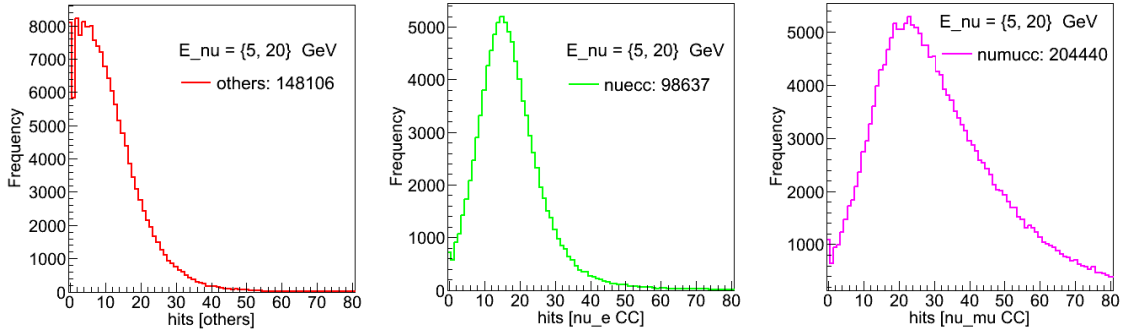**Figure 2:** Hits Disribution in the neutrino energy bin $E_\nu=\{0.8,5.0\}$GeV.

Figure 3: Hits Disribution in the neutrino energy bin $E_\nu=\{5.0,20.0\}$GeV.

The number of hits in ν_μCC events is greatly enhanced with the increase in energy. The increment in number of hits (h) is much less for ν_eCC events and is hardly seen in case of the NC events. So, a lower threshold of $\sim$10 hits suppresses a large fraction of the NC events and the low energy ν_e, ν_μCC events.

The muons of the ν_μCC events travel through several layers. So, an upper cut on the number of layers (L) removes most events with μ-tracks.

4. Selection of ν_eCC rich events sample

We aim to select an events sample of ν_eCC events with minimum contamination from the NC or the ν_μCC events. Various selection criteria have been devised [7] and a few of them are discussed here.

4.1 Average hits per layer

The e^-/e^+s travel shorter distance than the hadrons. The muon tracks give mostly 2-3 hits in a layer. So, a ν_eCC event gives hits in a fewer layers than an event with a muon track, of equivalent energy. A lower cut on the average hits per layer (hpl) should eliminate events containing μ tracks.

4.2 Maximum Hits Difference (mhd)

The ν_eCC events contain electrons, which lead to electromagnetic (EM) showers and hence should give a huge number of hits. Most of the electrons are absorbed by thick iron layers. However, if the shower starts at the edge of the iron layer, a sudden increment in the number of hits in the following layer is expected. This difference in the number of hits in the two adjacent layers in an event is calculated and is maximized over all such pairs in that event. A cut on this value of mhd selects more ν_eCC events, as shown in table 1.

Selection Criteria	ν_eCC	others	ν_μCC	ν_eCC purity
h>10; L≤5;	163807	82717	107350	46%
h>10; L≤5; mhd>5	82500	34701	38824	53%
h>15; L≤5;	68702	32953	36211	50%
h>15; L≤5; mhd>5	50295	21844	23991	52%

Table 1: Effect of the cut on the mhd (maximum hits difference). [500 years NH data in E_ν={0.1,100}GeV.]

4.3 Comparing the hits in each layer

The underlying principle of this criterion also rests on the concept of the EM shower. It attempts to recognise a pattern in the number of hits in adjacent layers, in two possible ways. We seek events with additional 5-6 hits in the next layer. Alternatively, we also look for events with a majority of the hits present in one layer. We define *majority* as 50% or 60% of the total number of hits. Effect of this selection criterion is shown in table 2.

Selection Criteria	ν_eCC	others	ν_μCC	ν_eCC purity
hits>15; layers≤5;	68702	32953	36211	50%
hits>15; layers≤5; $h_L > h_{L\pm1}+5$	47009	21191	22934	52%
hits>15; layers≤5; $h_L > 50\%$ hits	38479	13745	16934	56%
hits>15; layers≤5; $h_L > 60\%$ hits	29123	9038	11948	58%

Table 2: Event counts in the sample selected by the cut. [500 years NH data in E_ν={0.1,100}GeV.]

4.4 Overall Hits Pattern (rms)

The hits in different layers of ν_eCC events are non-uniform. The hits are mostly over concentrated in some layers, while entirely sparse in the rest (owing to the EM shower nature). This is reflected in a layerwise hits distribution, in figure 4.
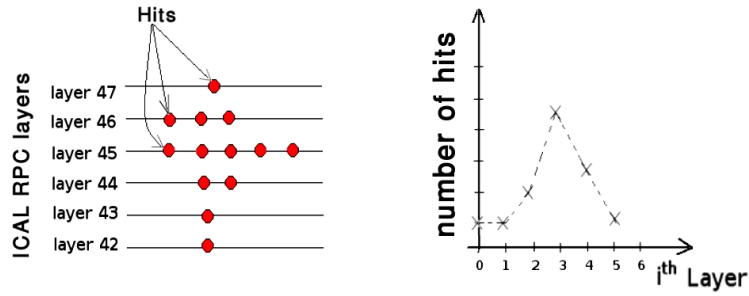
Figure 4: Schematic Diagram of hits in the RPC layers: the hit pattern among various layers in an event (left panel) and the number of hits vs layer number (right panel)

In the right panel of figure 4, the lowest layer hit is labelled to be **0**, the next layer is **1** and so on. In such a plot, the ν_μCC gives a broader peak than the ν_eCC / NC. So, selecting events with such sharper peaks leads to rejecting a major fraction of ν_μCC events. We parametrize this criteria by either the mean or RMS value of this distribution, and the effect is shown in table 3.

Selection Criteria	ν_eCC	others	ν_μCC	ν_eCC purity
h>15; L≤5	68702	32953	36211	50%
h>15; L≤5; rms<1.2	56254	24916	25431	53%
h>10; L≤4	125321	56177	62113	51%
h>10; L≤4; rms<1.2	111858	47961	52860	53%

Table 3: Effect of the rms cuts (*rms* is the RMS or Root Mean Square of the layerwise hits distribution). [500 years NH data in E_ν={0.1,100}GeV.]

5. Effects of Combined selection cuts

Appropriate combination of these criteria improves the percentage of purity of ν_eCC events in the selected sample. A few such combinations are shown in table 4.

Selection Criteria	ν_eCC	others	ν_μCC	ν_eCC purity
h>10; L≤4; rms<1.2; max hits diff.>3	86157	35115	37026	54%
h>10; L≤5; rms<1.2; max hits diff.>3	99814	43409	46455	56%
h>10; mean<2; rms<1.2; max hits diff.>3	83954	35130	36127	54%
h>10; mean<2; rms<1.2; max hits diff.>5	60959	23063	24129	56%
h>10; mean<2; rms<1.2; max hits diff.>5; hpl>4	51249	18247	18922	58%

Table 4: Effects of combined selection criteria. [500 years NH data in E_ν={0.1,100}GeV.]

6. Results and Conclusion

The hits and layers criteria can alone fetch a ν_eCC sample of ∼50% purity. With the additional selection criteria, we can improve the purity of the sample. The most effective criteria are listed here along with the sample-sizes:

Selection Criteria	ν_eCC purity	Sample size (500 y)
Maximum Hits diff.	53%	156,000
Overall Hits Pattern	58%	88,000
Comparing hits in layers	60%	43,000
Single layer hits	68%	6,500

Table 5: Obtainable ν_eCC purity in the total sample and the corresponding sample size for 500 years of NH data.

The purity of ν_eCC events in the total sample decreases with increasing sample size. It has also been observed that attempts to improve on the purity depletes the vertical events fraction. Appropriate selection cuts can be applied, while retaining optimum sample-sizes. This leads to a maximum ν_e**CC purity** of $\sim$ **60%** with ~ 100 events per year. We can also obtain an event sample with νNC purity of $\sim 47\%$ with ~ 1800 events per year, provided noise is under control [7].

The contribution of the muonless events in determining the neutrino mass hierarchy is not zero, rather ~ 1. But the statistical fluctuations in the data are too large for this contribution to have a significant effect [7].

References

[1] Anushree Ghosh, Tarak Thakore, and Sandhya Choubey. *Determining the Neutrino Mass Hierarchy with INO, T2K, NOvA and Reactor Experiments.* **JHEP**, 1304:009, 2013. [doi:10.1007/JHEP04(2013)009]

[2] V.M. Datar, Satyajit Jena, S.D. Kalmani, N.K. Mondal, P. Nagaraj, et al. *Development of glass resistive plate chambers for INO experiment.* **Nucl.Instrum.Meth.**, A602:744–748, 2009. [doi:10.1016/j.nima.2008.12.129]

[3] M. Sajjad Athar et al. *India-based Neutrino Observatory: Project Report. Volume I.*, 2006. [url: http://www.ino.tifr.res.in/ino/OpenReports/INOReport.pdf]

[4] Naba K. Mondal. *India-based Neutrino Observatory.* **Pramana**, 79:1003–1020, 2012. [doi:10.1007/s12043-012-0444-9]

[5] Y. Fukuda et al. *Study of the atmospheric neutrino flux in the multi-GeV energy range.* **Phys.Lett.**, B436:33–41, 1998. [doi:10.1016/S0370-2693(98)00876-4]

[6] D. Casper. *The Nuance neutrino physics simulation, and the future.* **Nucl.Phys.Proc.Suppl.**, 112:161–170, 2002. [doi:10.1016/S0920-5632(02)01756-5]

[7] Ali Ajmi and S. Uma Sankar. *Muonless Events in ICAL at INO.* **JINST**, 10(04):P04006, 2015. [doi:10.1088/1748-0221/10/04/P04006, arXiv:1501.03252]