Muonless Events in ICAL at INO

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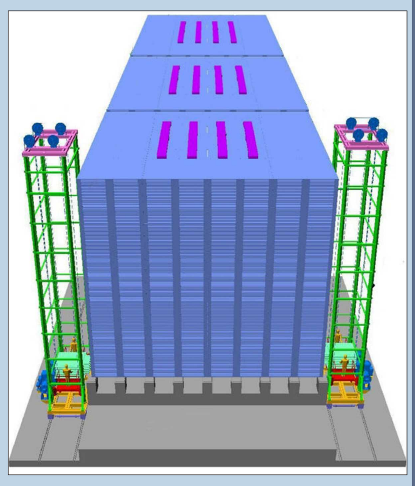
India-based Neutrino Observatory

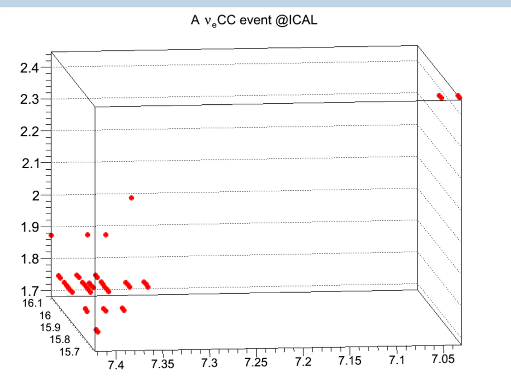
The ICAL Detector @ INO

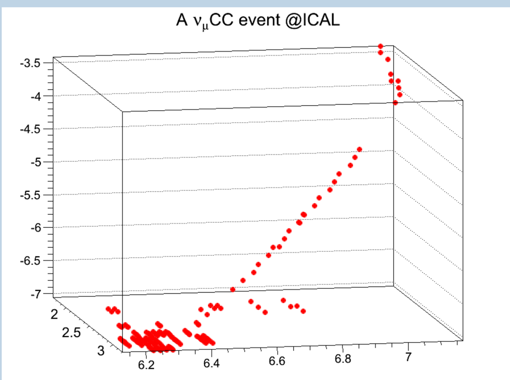


- India-based Neutrino Observatory or the INO, an upcoming experimental facility to house the Iron Calorimeter (ICAL).
- The ICAL aims to study the interactions of atmospheric neutrinos and antineutrinos.
- It is a giant magnetized neutrino detector, with Resistive Plate Chambers (RPCs) as the active detector elements.
- It comprises of 3 modules, with ∼30,000 RPCs, and 151 iron layers weighing ∼50kton in total.
- The RPC layers are interspaced with iron plates of 5.6 cm thickness⇒
  - ☺Clearer muon tracks obtained.
  - ☺Most electrons get absorbed.

The ν-Events in ICAL

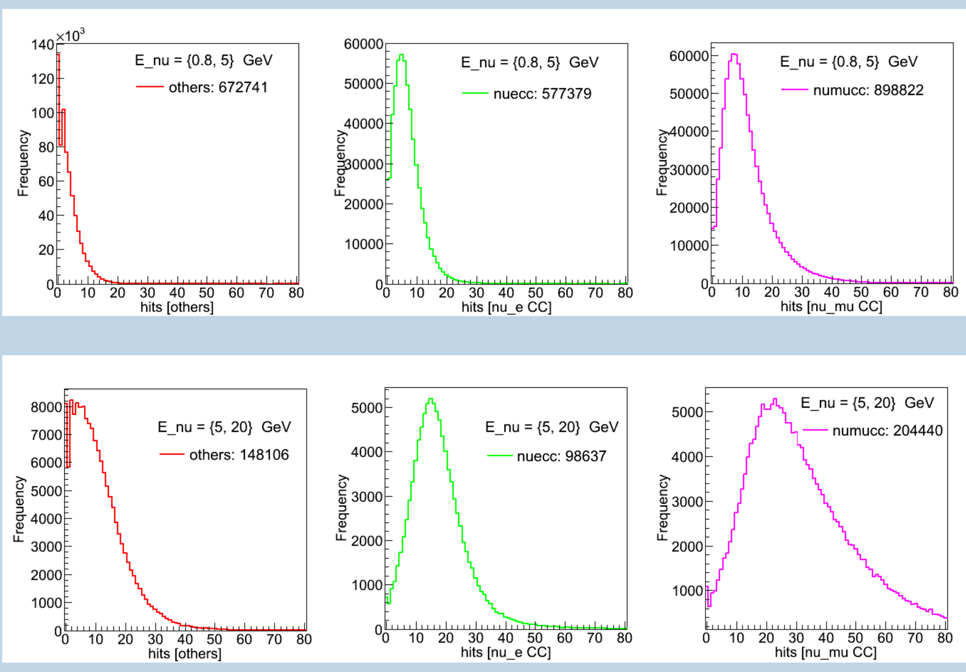
- Events in ICAL@INO can be classified as those with muon tracks and those without.
- "Muonless" events = ν_e**CC** + [others(all NCs & ν_τCC) + ν_μCC(Low energy or Horizontal)].
- Applying certain selection cuts, we can obtain an events sample rich in atmospheric ν_eCC events.
- The cuts are based mostly on the number of hits and number of layers hit.





Hits and Layers

Studying the hits distributions of all 3 event types:



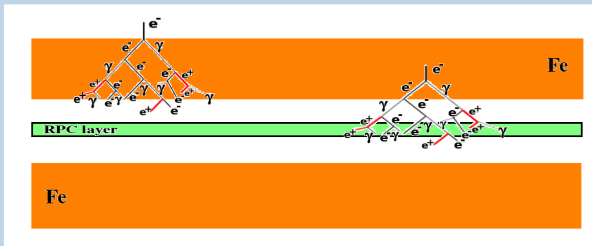
- ν_μCC events: number of hits (h) greatly enhanced with increasing energy.
- This increase is much less for ν_eCC events and hardly seen in case of the NC events.
- So, a lower threshold of ∼10 hits suppresses a large fraction of NC events and low energy ν_e, ν_μCC events.
- An upper cut on the number of layers (L) removes most events with μ-tracks.
- Various selection criteria have been devised and a few of them are discussed here.

(i) Average hits per layer

- The e^-/e^+s travel shorter distance than the hadrons. Muons of the ν_μCC events travel through several layers.
- The muon tracks give mostly 2-3 hits in a layer.
- A lower cut on the average hits per layer (hpl) should eliminate events containing μ tracks.

(ii) Maximum Hits Difference (mhd)

- The ν_eCC events contain electrons ⇒ Expect a huge number of hits.
- Most of them are absorbed by thick iron layers.
- If the shower starts at the edge of the iron layer, a sudden increment in number of hits in the following layer is expected.
- Difference in the number of hits in two adjacent layers in an event is calculated
- This difference is maximized over all such pairs in that event.



A schematic diagram of the electron shower in the detector. The effects of mhd-cut are shown below:

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%

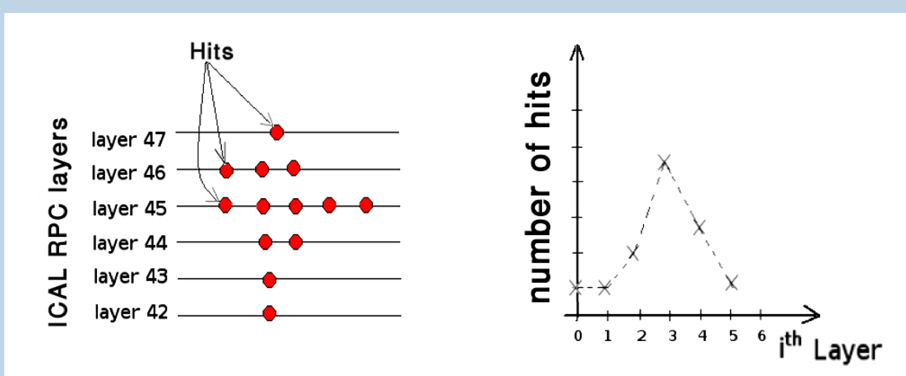
(iii) Comparing the hits in each layer

- The underlying principle rests on the concept of the EM shower.
- This criterion seeks a pattern in the number of hits in adjacent layers.
- We seek for events with additional 5-6 hits in the next layer.
- Also, we seek for events with majority of hits in one layer like 50% or 60% of the total number of hits

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%

(iv) 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 the right panel, the lowest layer hit is labelled to be **0**, the next layer is **1** and so on.
  - We consider the Mean or RMS value of the layerwise hits distribution of each event.



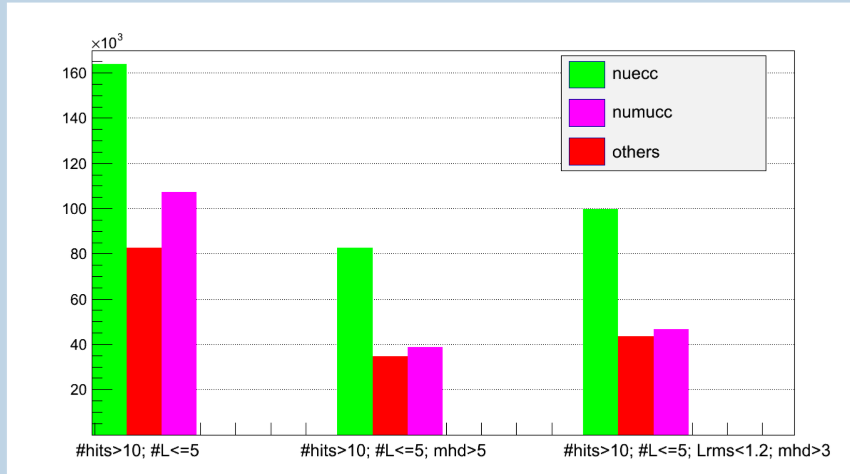
A schematic diagram

- In such a plot, the ν_μCC gives a broader peak than the ν_eCC / NC.
- So, selecting events with such sharper peaks ⇒ rejecting a major fraction of ν_μCC events.
- We parametrize this criteria by either the mean or RMS value of this distribution.

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%

Effects of Combined selection cuts

Effects at a glance: The comparative effect of a few selection criteria:



A few more effects are shown here in details:

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%

Results and Conclusion

1. 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

One may thus conclude:
- Purity of ν_e CC in the total sample decreases with increasing sample size.
- Improving on the purity depletes the vertical events fraction.

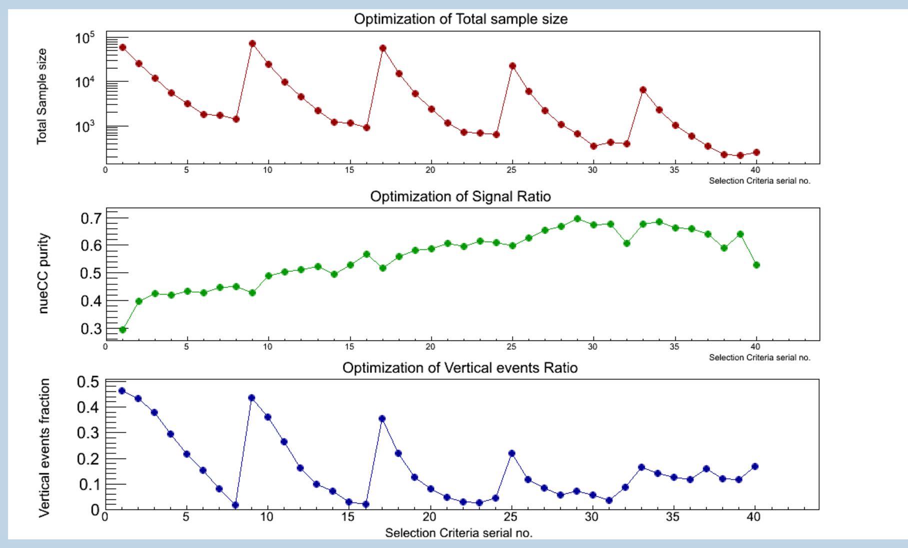


Fig.:A simultaneous comparison of purity, vertical events fraction and sample size against varying selection cuts

2. Application of the selection cuts with optimum sample-sizes lead to:
   - ν_e**CC purity: ∼ 60%** with ∼ 100 events per year.
   - ν**NC purity: ∼ 47%** with ∼ 1800 events per year, provided noise is under control [1].
3. 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 [1].

References

1. A. Ajmi and S. U. Sankar, JINST 10, P04006 (2015), arXiv:1501.03252 [physics.ins-det] .

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