ParticleID for KM3NeT/ORCA

Final presentation on my thesis work

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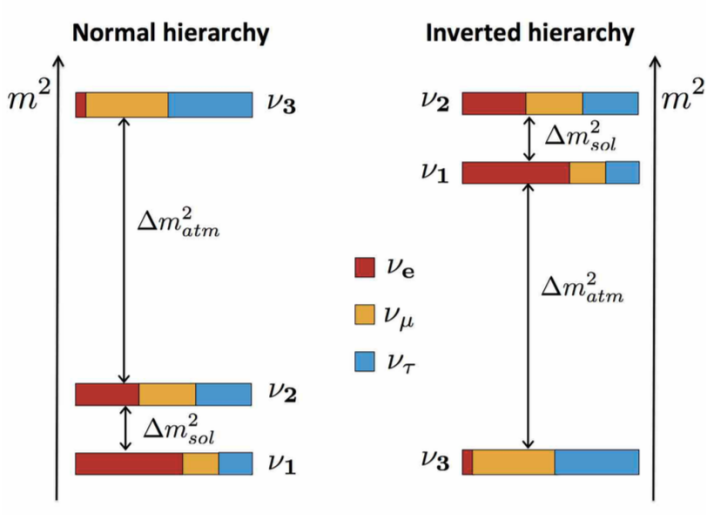
Outline

Neutrino Mass Hierarchy

Neutrinos can change flavor $\triangleright$ non-zero masses.
Masses themselves are unknown $\triangleright$ $\Delta m^2_{ij} \equiv m^2_i - m^2_j$.



Neutrino Mass Hierarchy:

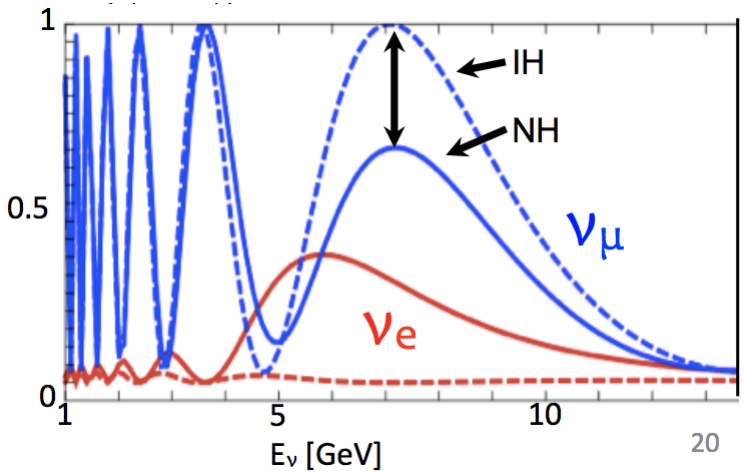
- Normal Hierarchy (NH)
  $m_1 < m_2 < m_3$;
- Inverted Hierarchy (IH)
  $m_3 < m_1 < m_2$.

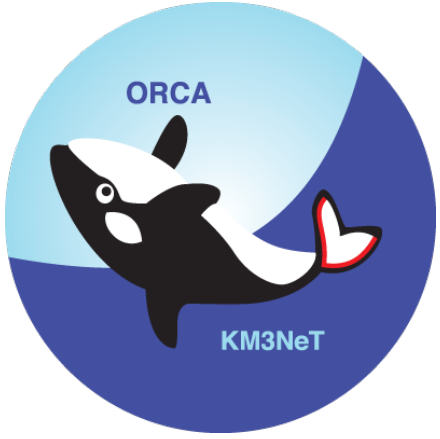
How is it possible to determine the NMH?

Measuring NMH with Atmospheric Neutrinos

- Natural beam of known composition (ν_e, ν_μ);
- Oscillation pattern distorted by Earth matter effects (hierarchy-dependent);
- Measure E_ν and θ_ν of upgoing neutrinos.

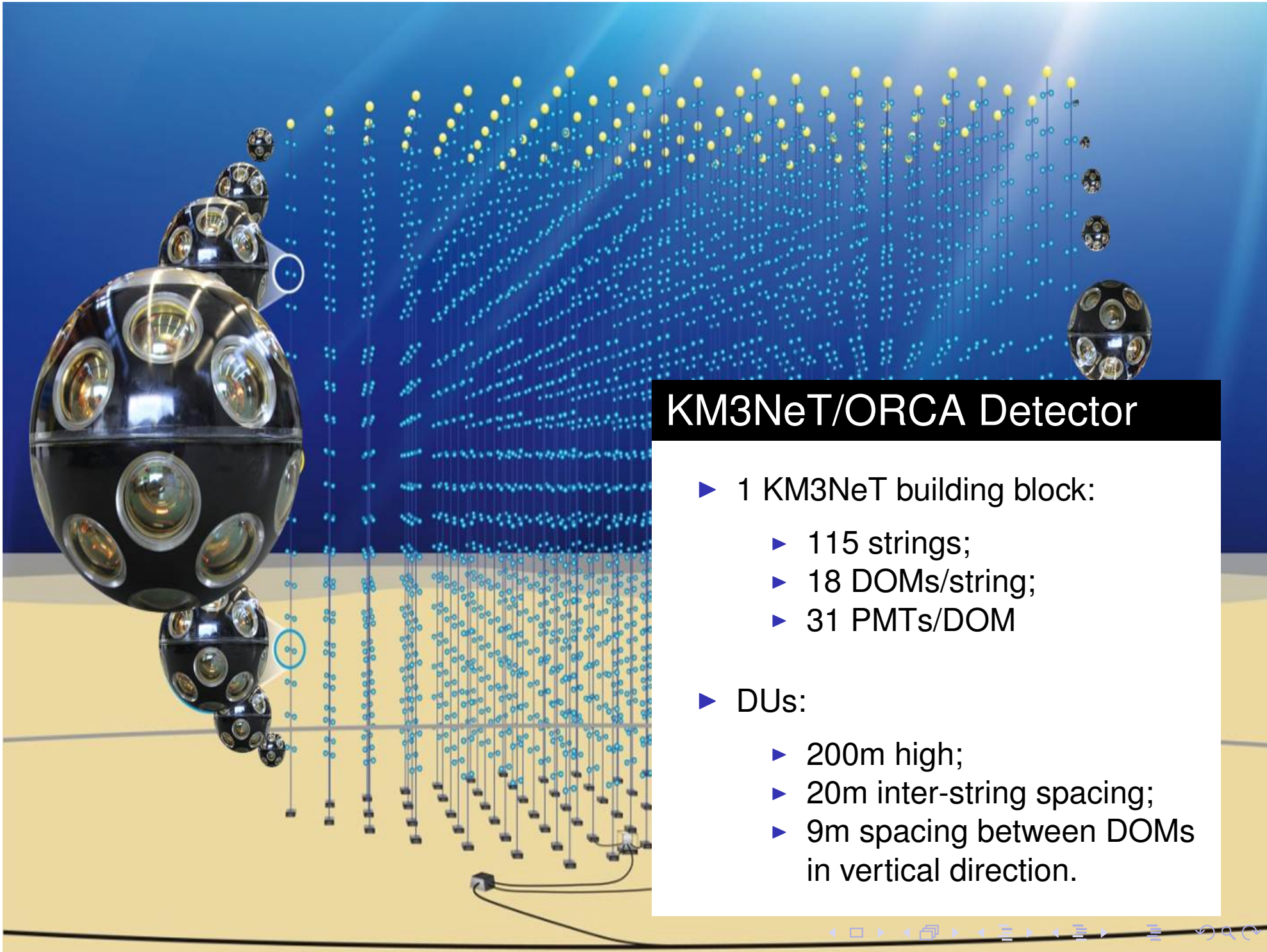
$P(\nu_\mu \rightarrow \nu_\mu)$ for $\theta = 30\circ$





KM3NeT/ORCA
(**O**scillation **R**esearch with **C**osmics in the **A**byss)

Measurement of the Neutrino Mass Hierarchy (NMH) detecting atmospheric neutrinos, using Cherenkov detector in the Mediterranean Sea.



KM3NeT/ORCA Detector

- 1 KM3NeT building block:
  - 115 strings;
  - 18 DOMs/string;
  - 31 PMTs/DOM
- DUs:
  - 200m high;
  - 20m inter-string spacing;
  - 9m spacing between DOMs in vertical direction.

Event Signature

The detection of neutrinos is based on the detection of Cherenkov light produced by relativistic particles emerging from a neutrino interaction with the sea water.

CC ν interactions

- $\nu_\mu + N \rightarrow \mu + X$: Track-like
- $\nu_e + N \rightarrow e + X$: Shower-like
- $\nu_\tau + N \rightarrow \tau + X$: Shower-like

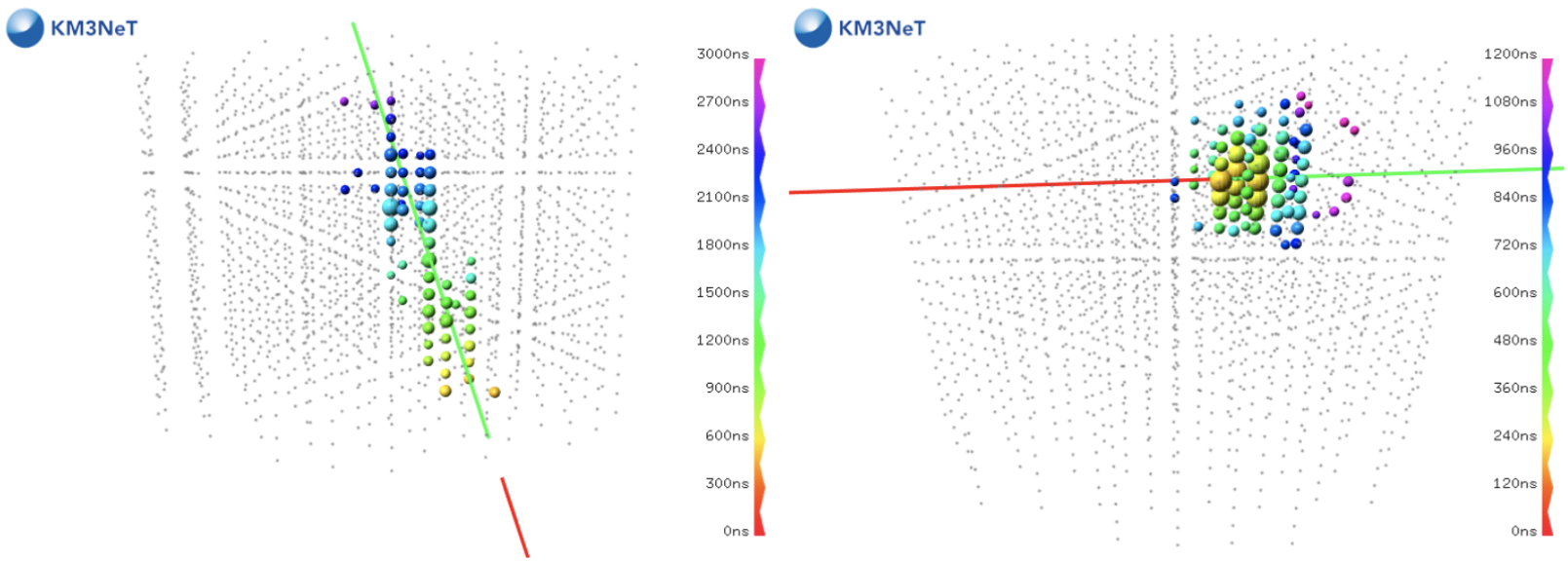
NC ν interactions

- $\nu_x + N \rightarrow \nu_x + X$: Shower -like

Particle Identification (PID)

The events are classified according to their signatures:

- Track-like ▷ straight signature;
- Shower-like ▷ point-like compared to the track-like

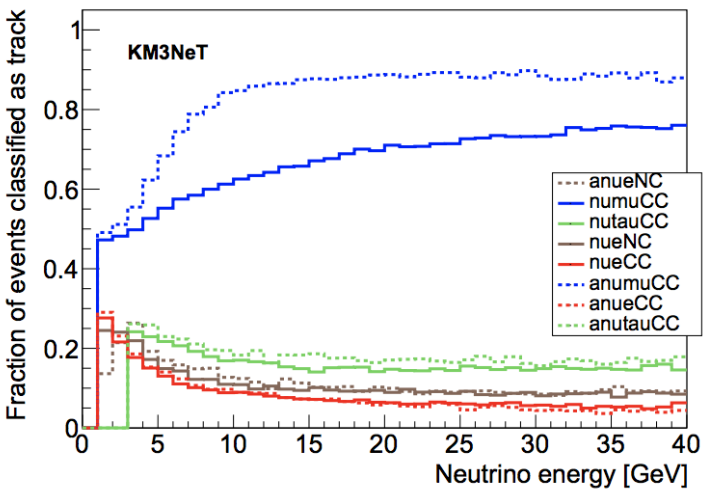


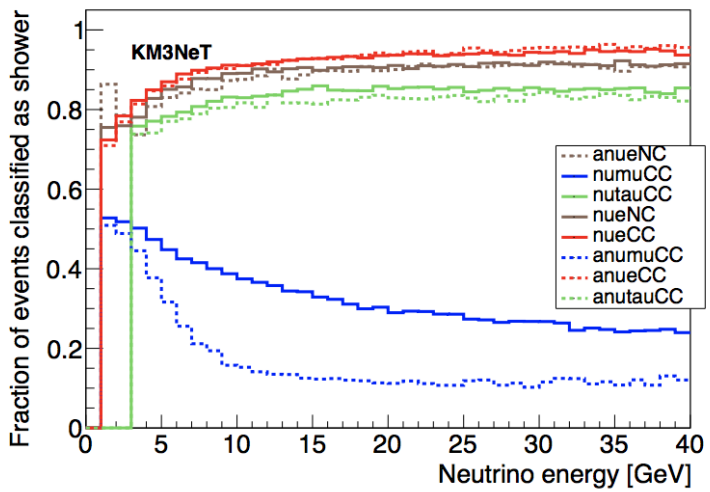
KM3NeT/ARCA simulation, TeV neutrino energies

KM3NeT/ORCA Analysis

Track/Shower Identification

- ✓ Random Decision Forest (RDF);
- ✓ RDF's output ▷ Probability of identifying an event correctly;
- ✓ Cut chosen ▷ 50%;
- ✓ 2 PID bins ▷ Track or Shower.





At 10*GeV*:

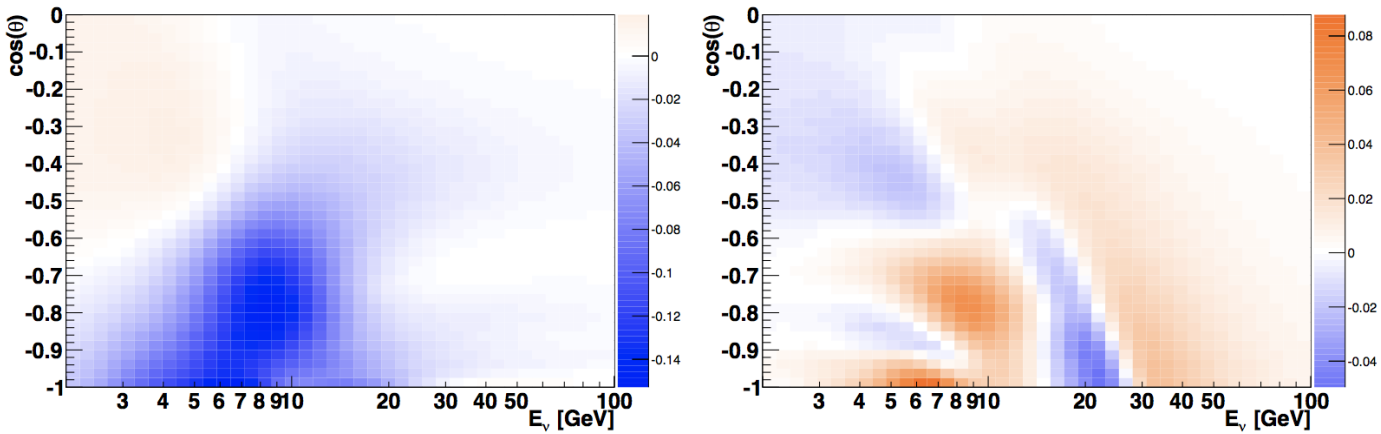
- 70% of ν_μ CC events as track-like;
- 90% of ν_e CC events as shower-like.

KM3NeT/ORCA Analysis

Sensitivity Studies

Asymmetry $\rightarrow$ Difference between the number of expected events for NH and IH in the plane $E_\nu - \cos\theta$.

$$A = \frac{N_{IH} - N_{NH}}{\sqrt{N_{NH}}}$$



Asymmetry is evident around 5-25 GeV for track-channel and around 3-10 GeV for shower-like.

My Analysis

Steps

- Variables trained;
- ParticleID with BDT;
- NMH significance measurement.

My Analysis

Variables

- Shower Reconstruction MC Algorithm;
- Two energy ranges:
  - $E_\nu < 20 GeV$;
  - $E_\nu = 1 - 100 GeV$.

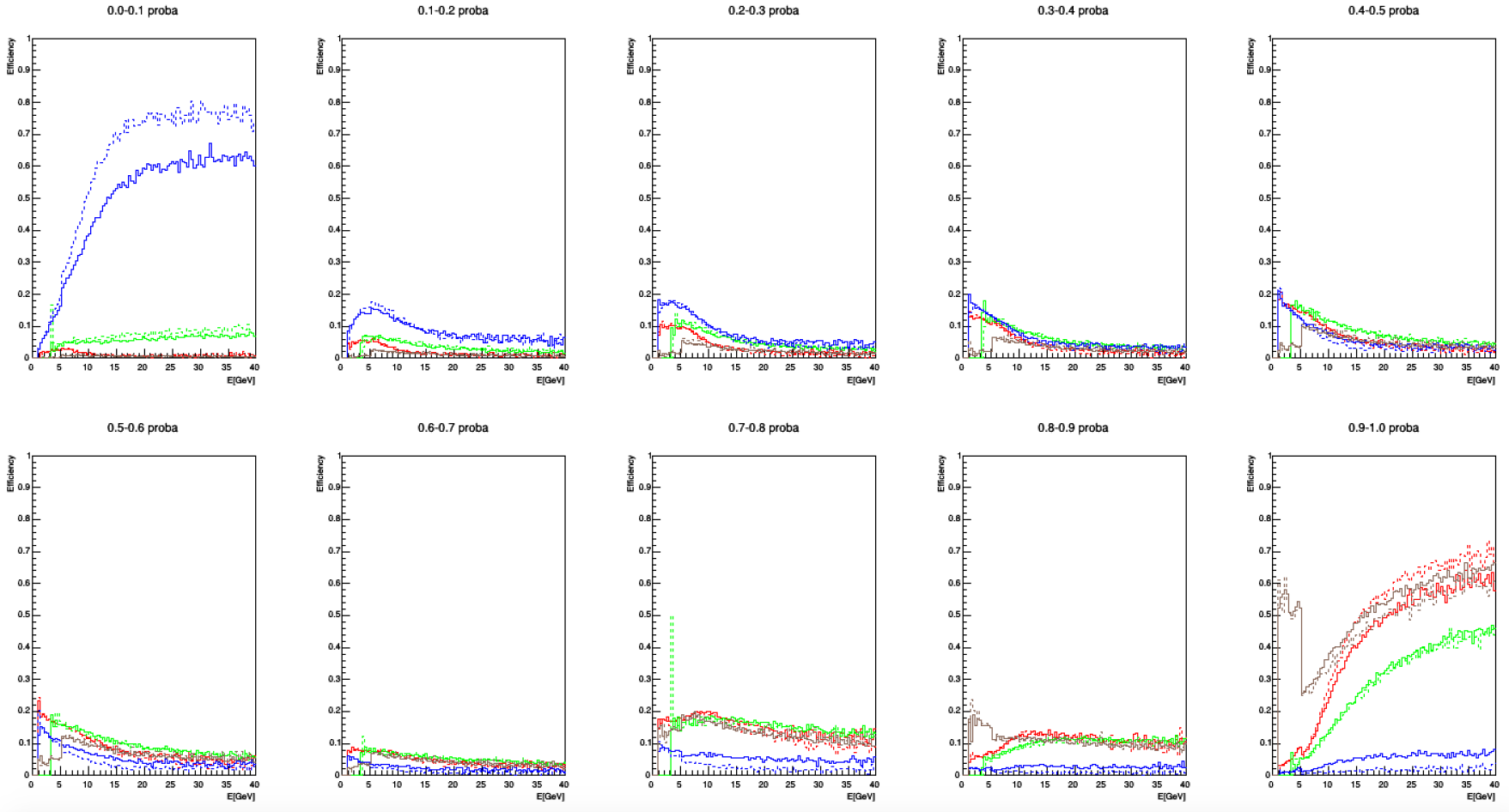
Why neutrino events with $E_\nu < 20 GeV$?
Because for this energy range the difference between NH and IH appears clearly.

My analysis

Particle Identification (PID)

- Boosted Decision Tree (BDT);
- BDT's Output $\rightarrow$ Probability B/S (range 0-1) divided in 10 parts (0-0.1,...,0.9-1);
- 2 PID bins (track or shower) $\rightarrow$ 10 PID bins.

Data Set with 99 variables



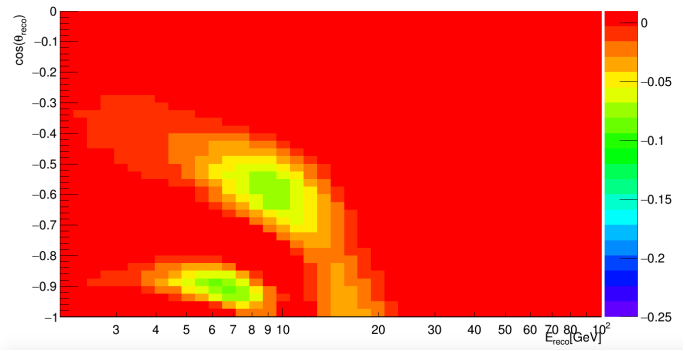
Each histogram shows the percentage of events that are correctly classified according to the PID.

My Analysis

Sensitivity Studies

Asymmetry plots in $E_\nu - \cos\theta$ plane.

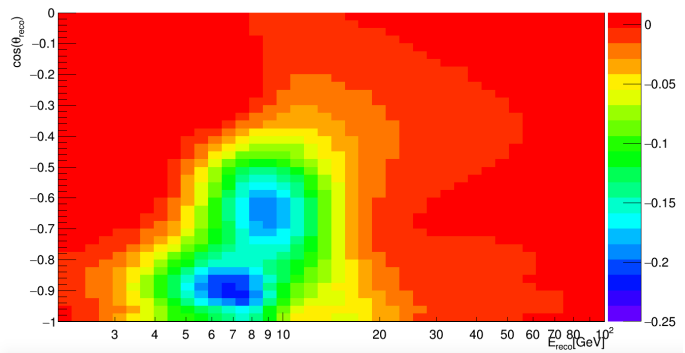
Track-channel



Default Method

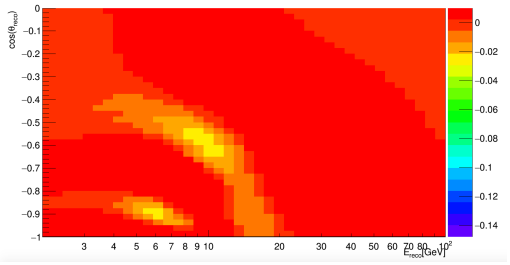
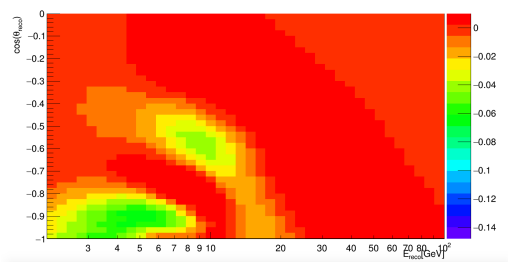
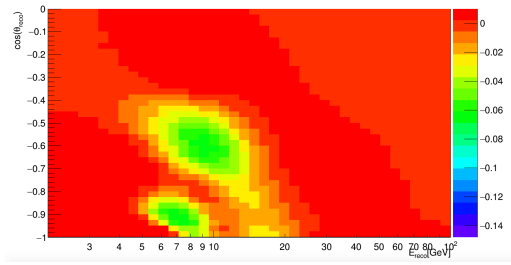
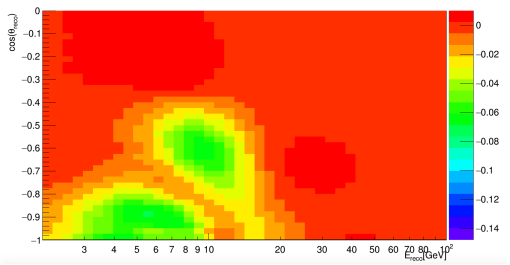
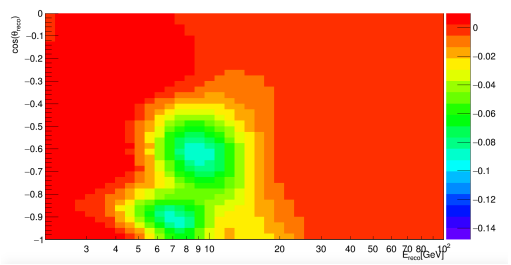
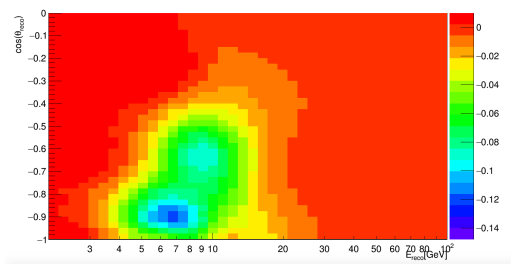
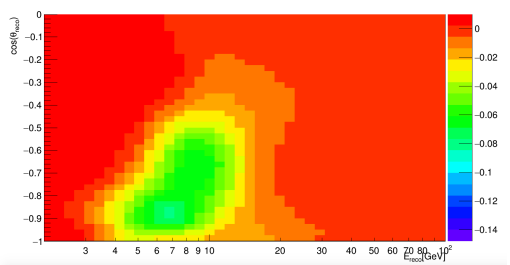
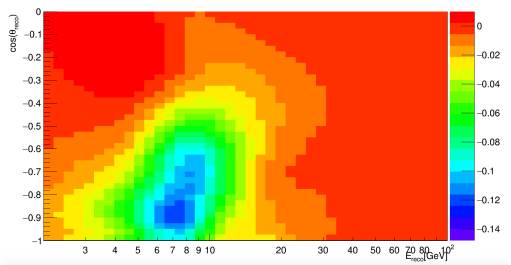
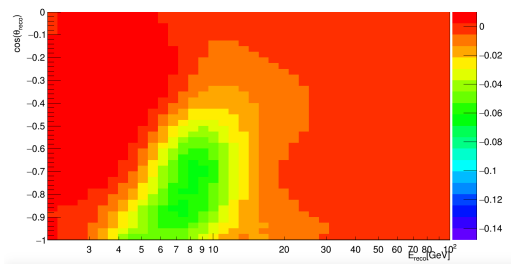
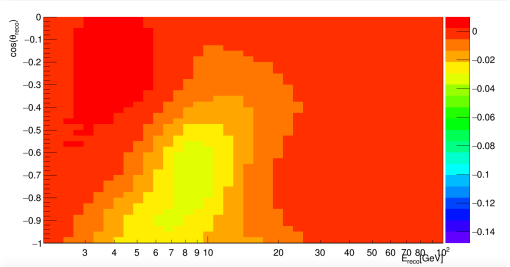
- Cut on probability range;
- 2 PID bins (track or shower);

Shower-channel



New Method

- Probability range divided in 10 parts;
- 10 PID bins.

Asymmetry $\rightarrow$ Significance S of the NMH.

Default Method

- S_{cut} for 2 PID bins:

$$S_{cut} = \sqrt{S_l^2 + S_r^2},$$

where l and r represent the left part and the right part of the cut.

New Method

- S for each of 10 PID bins:

$$S_{tot} = \sqrt{\sum_i S_i^2}$$

where i represents the 10 PID bins.

Assumption

- Evaluate the significance $\rightarrow$ Simplification of the study of sensitivity to the NMH;
- No fit of the oscillation parameters (kept fixed);
- Energy and angular resolutions fixed.

Results

Data Set	$S_{cut}[\sigma]$	$S_{tot}[\sigma]$
99 variables	4 (30%)	4,38
99 variables E_ν	4,12 (40%)	4,49
7 variables	3,74 (40%)	3,89
7variables E_ν	3,82 (40%)	3,95

Conclusion

- High significance value for $E_\nu < 20 GeV$;
- Comparing S_{cut} with S_{tot} there is an increase in the significance:
  - 0.38σ for 99 variables;
  - 0.37σ for 99 variables and $E_\nu < 20 GeV$;
  - 0.15σ for 7 variables;
  - 0.13σ for 7 variables and $E_\nu < 20 GeV$;
- The several PID bins should lead to an increase in the sensitivity for NMH measurement;
- Futher studies will included fit of the oscillation parameters.