Atmospheric Muon Background Suppression for KM3NeT

School for Astroparticle Physics
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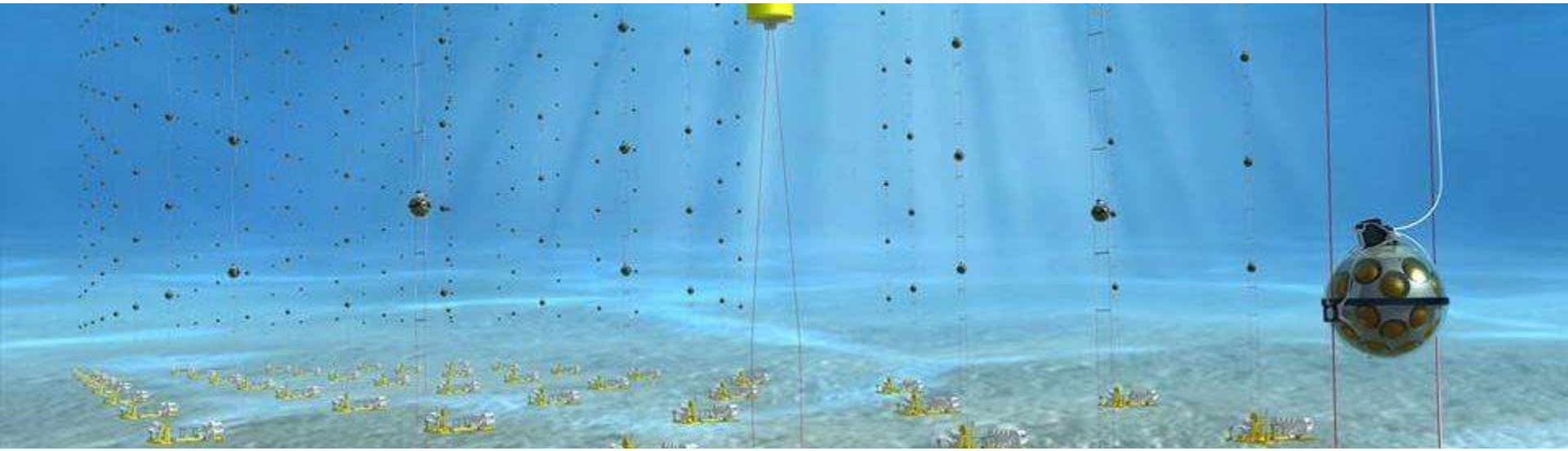
Introduction - Motivation

Recently Ice Cube collaboration reported the discovery of 53 neutrino events with energies from ~30 TeV up to 3 PeV!

Based on these results they also published astrophysical as well as atmospheric neutrino fluxes!

Such a study of the astrophysical neutrino flux with KM3NeT will be possible very soon!

KM3NeT



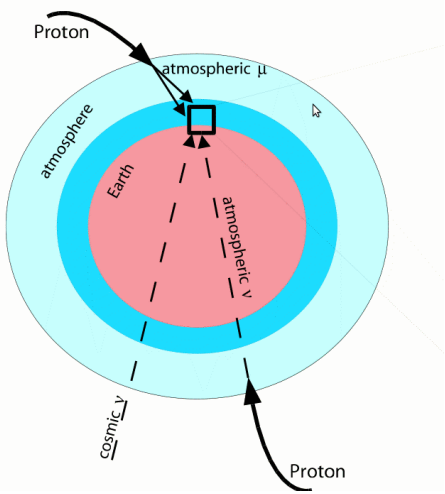
- Next generation neutrino telescope located in the Mediterranean.
- Will have a detector volume of several cubic kilometers!
- Two Cherenkov array telescopes under the umbrella of KM3NeT:
  - ARCA (Astroparticle Research with Cosmics in the Abyss) aims to detect high energy astrophysical neutrinos to study the cosmic flux.
  - ORCA (Oscillation Research with Cosmics in the Abyss) aims to the detection of lower energy neutrinos (GeV range) for the Neutrino Mass Hierarchy.
- Each telescope consists of thousands of sensor modules (Digital Optical Modules – DOMs), organized in vertical Detection Units (strings), with 18 DOMs each, attached to the seabed.

Neutrino Telescopes: Background sources

- Noise:
  - The decay of ^{40}K produces photons which can be detected.
- Bioluminescence.
- Background: Muon and neutrinos created in the atmosphere.
  1) Atmospheric neutrinos
     - Reach the detector from all directions.
     - Have a different (softer) energy spectrum than the astrophysical neutrinos.
     - Irreducible background.
  2) Atmospheric Muons:
     - Only downgoing events.
     - Can be suppressed by applying a cut on the direction of the muons.

Removing the Atmospheric Muon Background

- First approach (standard up to now):
  - Reject all downing events.
  - No atmospheric muons remain to the final sample.
  - Easy to implement but loose all the events coming from above.
  - For high energy neutrinos earth is opaque.
  - Reduce the contribution of the high energy neutrinos.



- A way to enhance the contribution of high energy events:
  - Require the interaction vertex to be inside the detector to reduce incoming muon tracks.
  - Find appropriate physical quantities that can be associated to tracks entering the detector.
  - Use them to reliably differentiate between signal and background events.

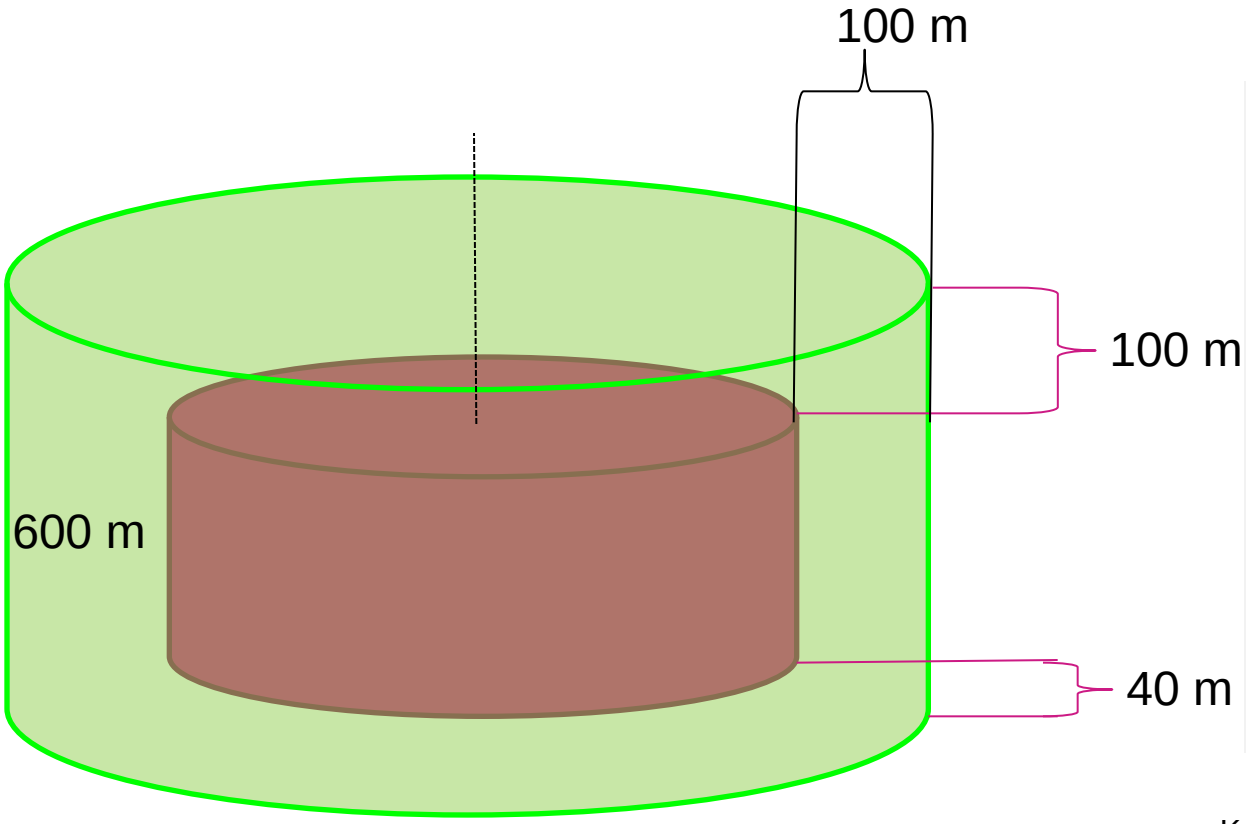
Removing the Atmospheric Muon Background

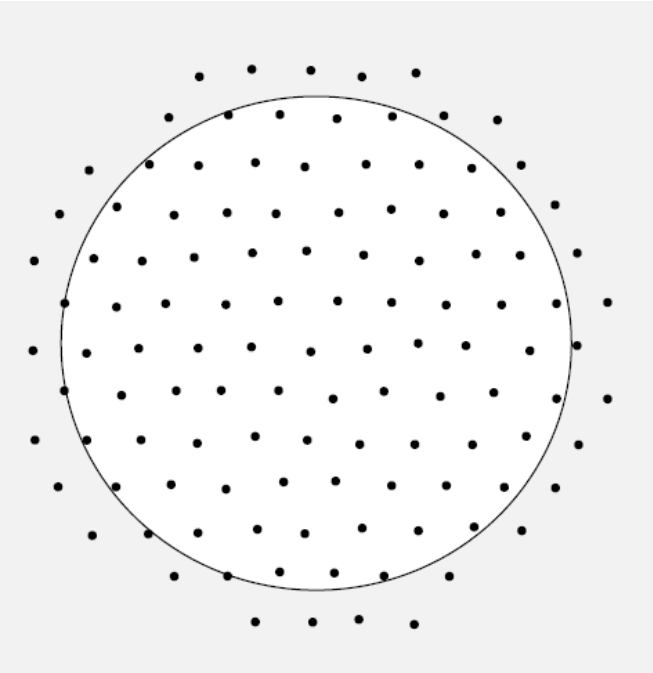
- For this study:
  - Use MC data
  - Use only 1 ARCA block
  - Signal $\nu_\mu \rightarrow \mu$ via CC interactions, interacting inside the volume of the detector.
  - Background:
    - 2 samples of atmospheric muon bundles, one with medium (E_{bundle} > 10 TeV , livetime ~ 3 months) and one with high bundle energies (E_{bundle} > 50 TeV , livetime ~ 3 years)
    - All $\nu_\mu \rightarrow \mu$ events interacting outside the volume of the detector.
  - Focus on high energy events (E_ν > 30 TeV) passing the quality cuts introduced by the reconstruction algorithm.

  - This is an ongoing work.

Fiducial Volume

1) Require the interaction vertex to be inside a cylinder slightly smaller that the detector (fiducial volume).

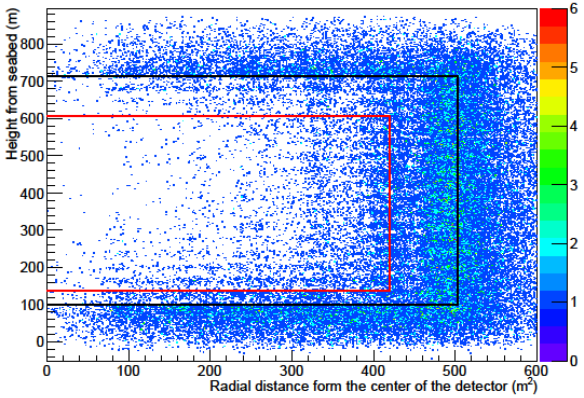


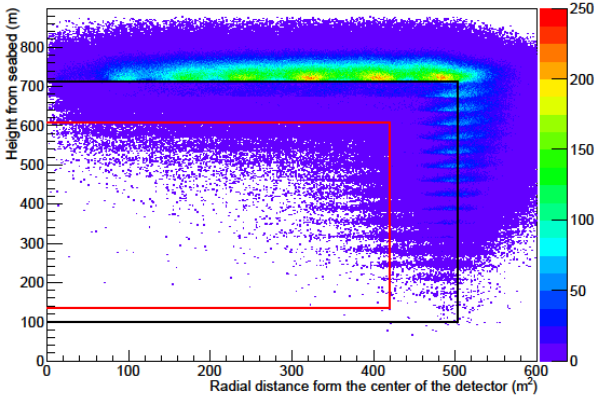


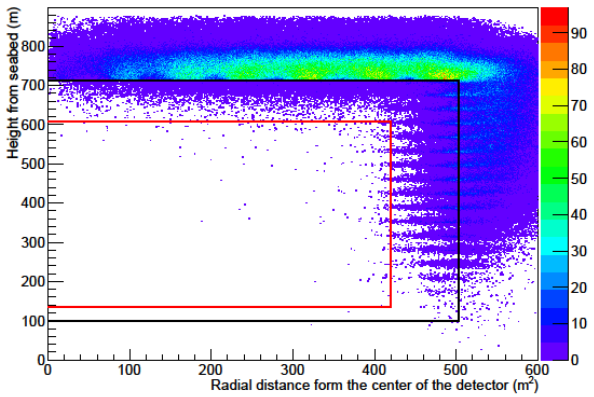
Fiducial Volume

Reconstructed vertex for background events (should be outside the detector)

Neutrino events interacting outside the detector	Medium energy atmospheric muon bundles	High energy atmospheric muon bundles





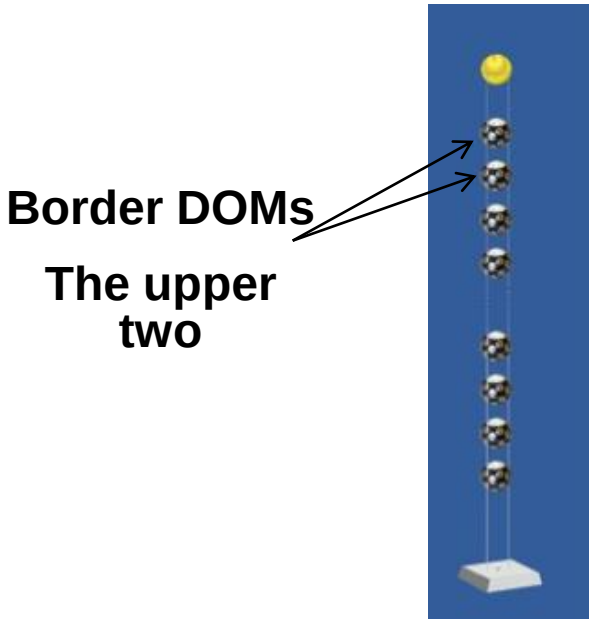


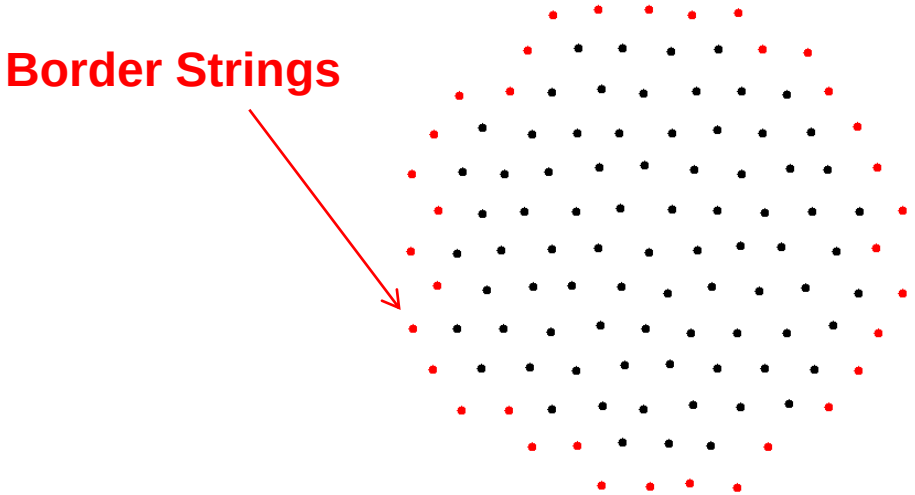
By requiring the reconstructed vertex to be inside the fiducial volume

Reduction ~ 81%	Reduction ~96%	Reduction ~99.5%

Border Activity

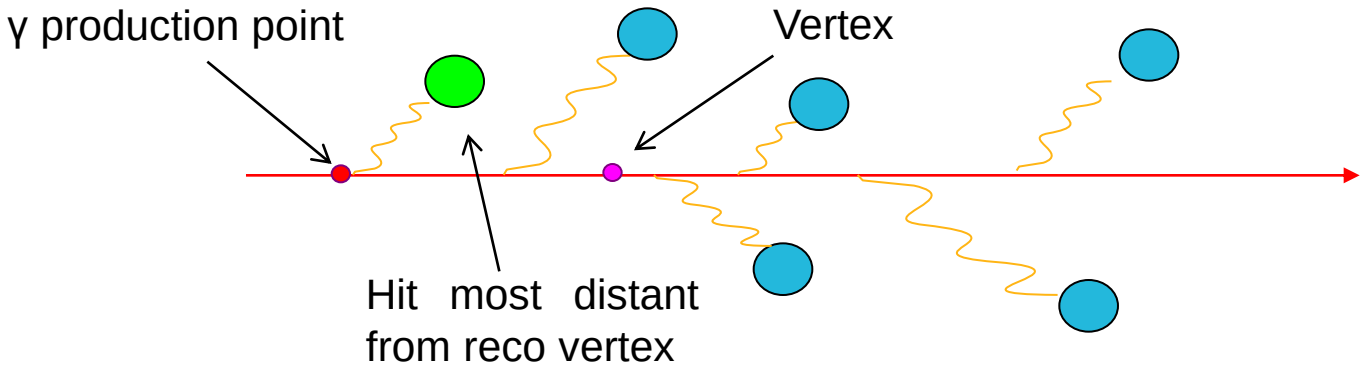
2) Expected border activity for incoming muons. Mark the events:
   - largest light deposition (Time over Threshold) at a border DOM.
   - first in time hit, consistent with the track hypothesis, also at a border DOM.





Activity Behind Vertex

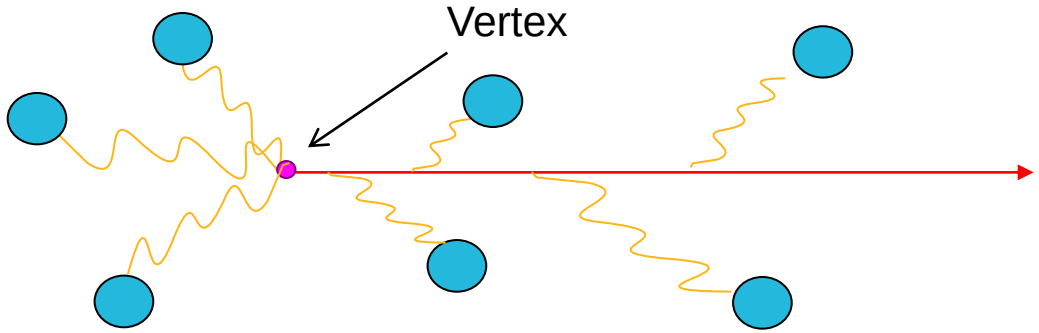
3) Incoming tracks are expected to have activity behind the vertex.
   - Mark the event if the production point of hits consistent with the reconstructed track is outside the fiducial volume



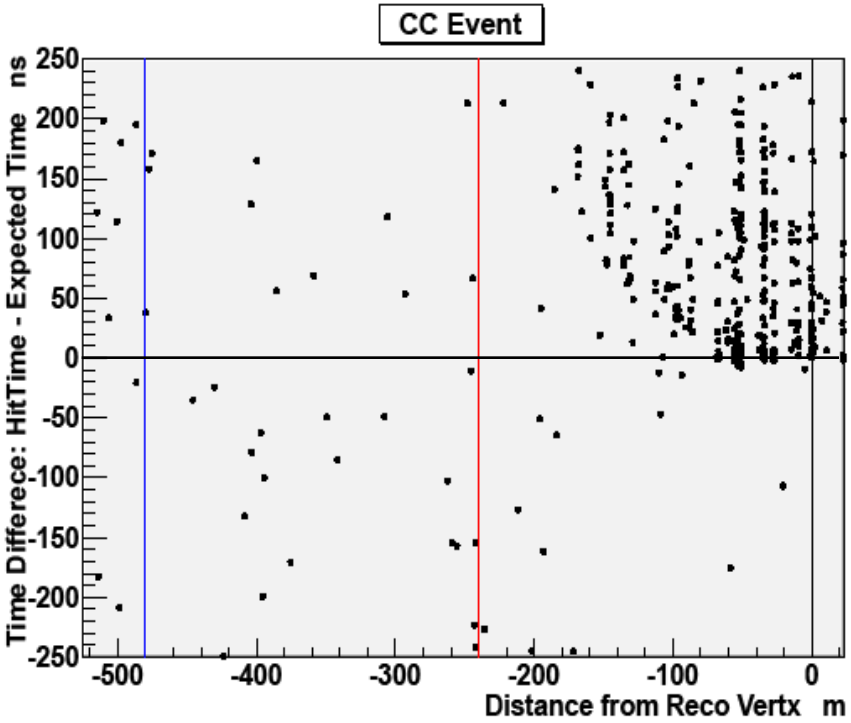
Number of DOMs / Shower Activity

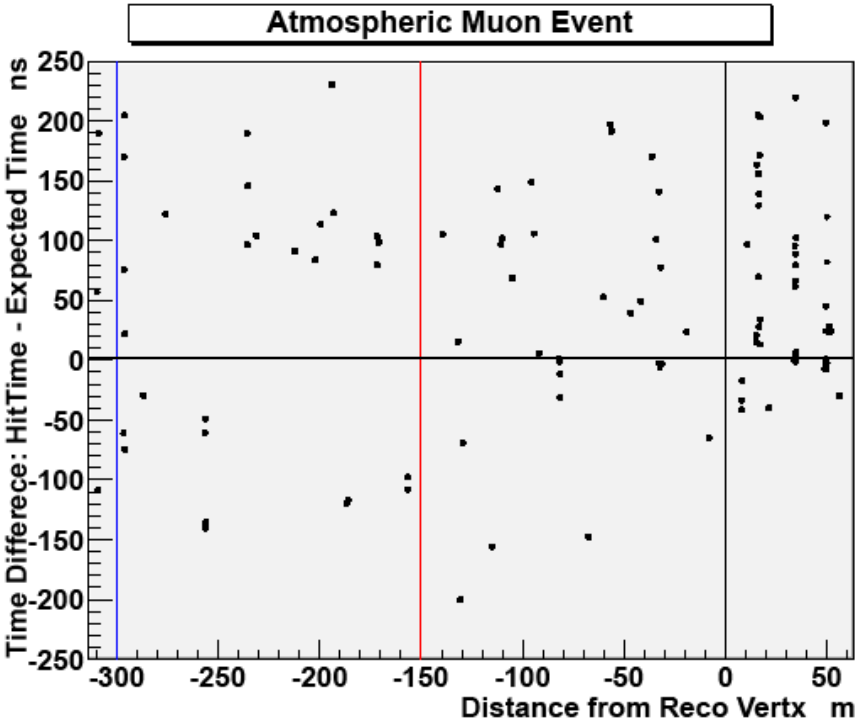
4) Number of DOMs with high activity:
   - related to the neutrino and muon energy.

5) Events with a vertex inside the detector are expected to have some shower activity, in contrast to incoming muons.
   - The light deposition (Time over Threshold) located behind the reconstructed vertex.



Shower Activity

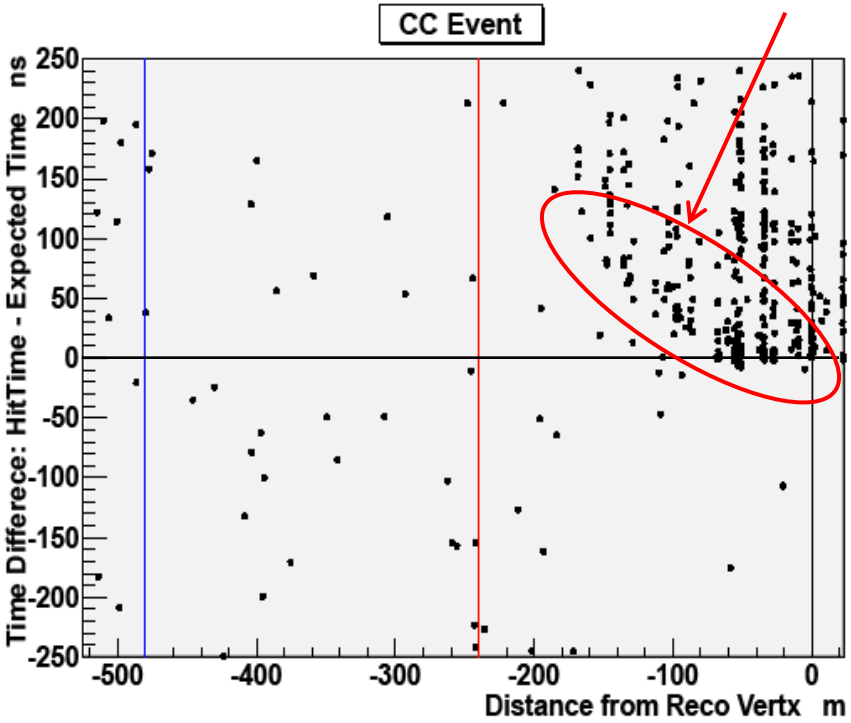


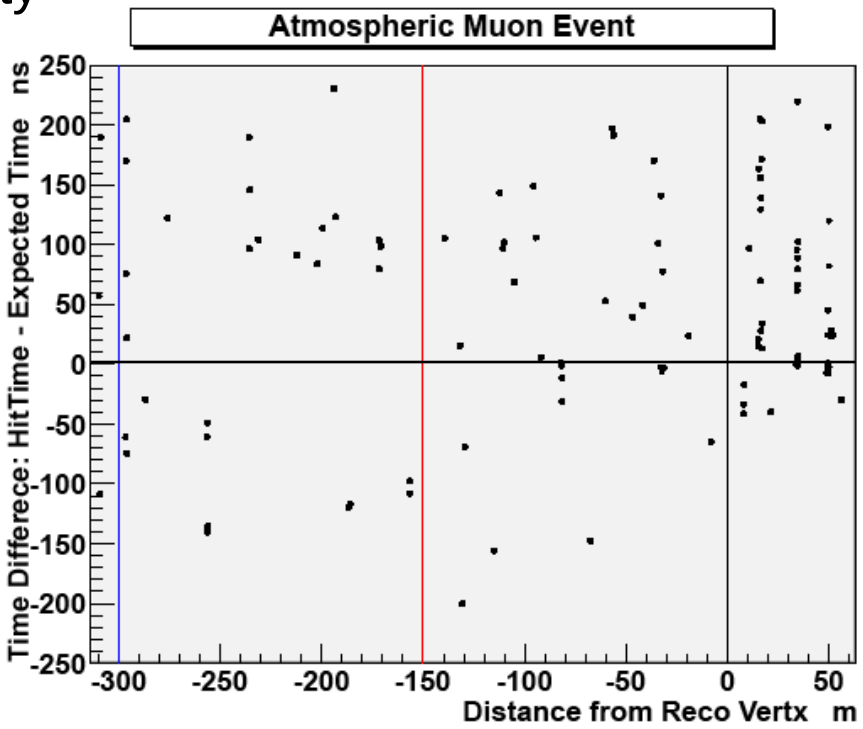


6) Ensure that the activity behind vertex is due to a (localized) shower and not to random noise. Divide the space behind the reconstructed vertex in two halves, look at the:

- ratio of the deposited light.
- ratio of the pulses.

Hits behind reco vertex mainly due to hadronic acivity





Detector's edge

Half the distance

Reco vertex position

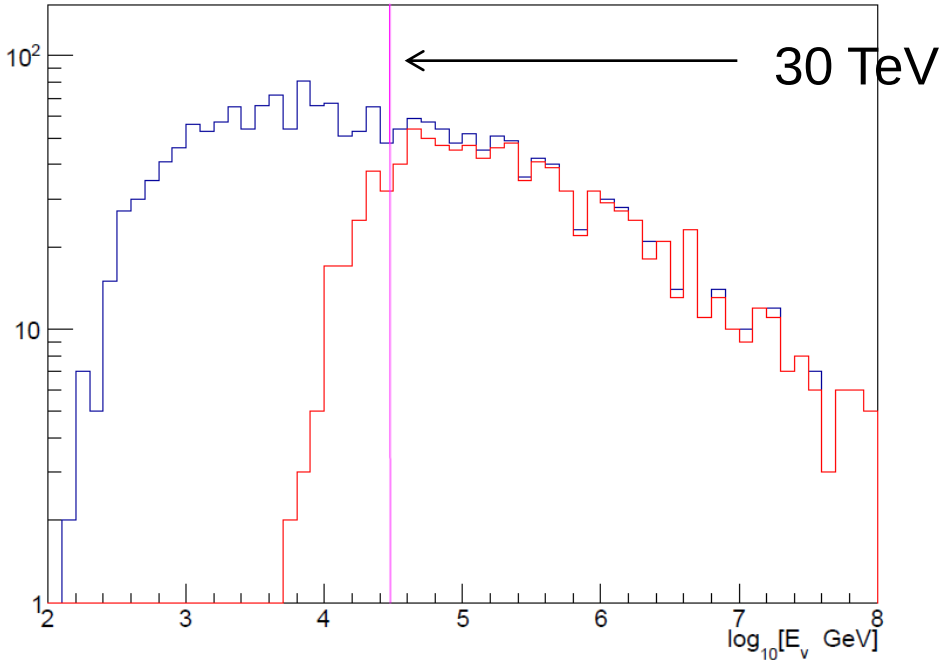
Removing the Atmospheric Muon Background

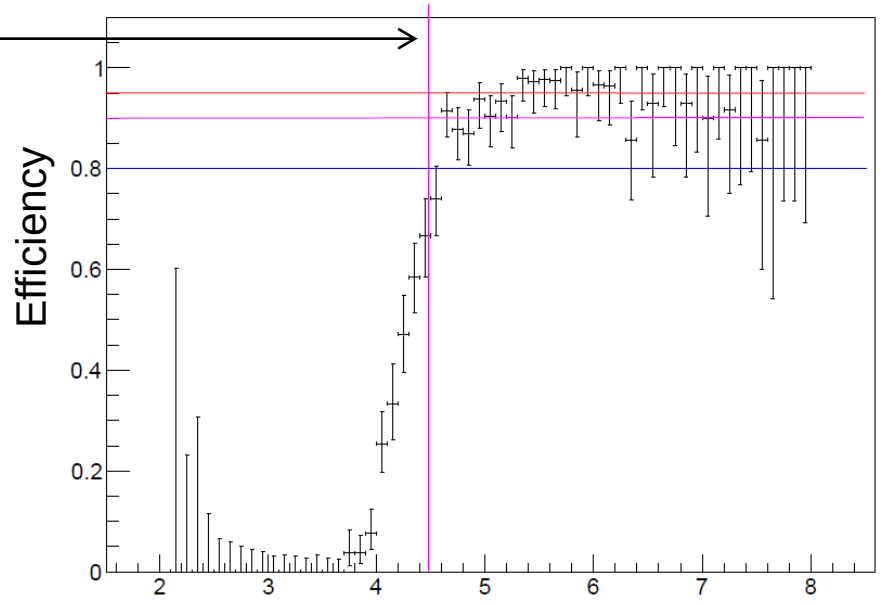
1) Use events with a well reconstructed track.
2) Require the reconstructed vertex to be inside the fiducial volume.
3) Use MVA techniques to exploit the quantities mentioned above.
   - Train a Boosted Decision Tree (BDT) with part of the sample of the events passing steps 1 and 2.
   - Find the BDT values where the neutrino signal has an efficiency of 90%.
   - Evaluate the rest of the sample.

- For the training/testing I used:
  - half of the signal sample.
  - CC events interacting outside the fiducial volume (3%).
  - medium energy atmospheric muon bundle sample (3%).
  - high energy atmospheric muon bundle sample (3%).

Results / Signal

- Using the BDT value for a 90% efficiency of the signal training sample





Events having their reco vertex inside the fiducial volume

Events remaining after the BDT

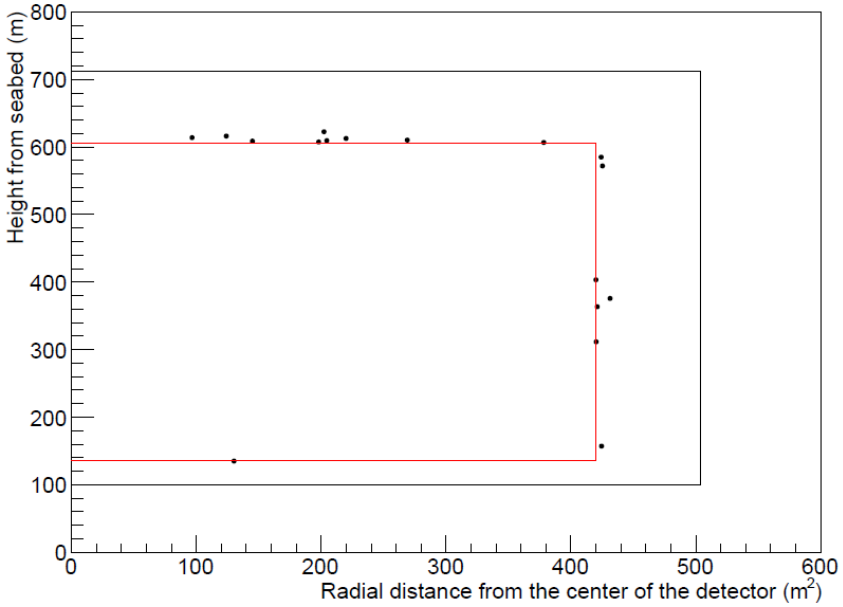
Results / Backgound

- Medium energy atmospheric muon bundle sample:
  - Starting with 24.607 events having the reconstructed vertex inside the fiducial volume.
  - Left with only 1 (misreconstructed) event (livetime ~ 3 months).

- High energy atmospheric muon bundle sample:
  - Starting with 379 events having the reconstructed vertex inside the fiducial volume.
  - Left with only 2 (both misreconstructed) events (livetime ~ 3 years).

- CC neutrino events interacting outside the fiducial volume:
  - Starting with 5.720 events having the reconstructed vertex inside the fiducial volume.
  - Left with 17 events all having their true vertex inside the volume of the detector but outside the fiducial volume

Results / Background



- CC neutrino events interacting outside the fiducial volume:
  - Starting with 5.720 events having the reconstructed vertex inside the fiducial volume.
  - Left with 17 events all having their true vertex inside the volume of the detector but outside the fiducial volume

Conclusions / Outlook

- This approach to reject incoming / atmospheric muons looks very promising!
- Achieve a very high suppression of the background (more than a factor of 10^4)!
- Retain a high efficiency for the signal events!
- When signal is weighted with the astrophysical flux most recently reported by ICECUBE, the number of background events is of the same order of to signal events per year.

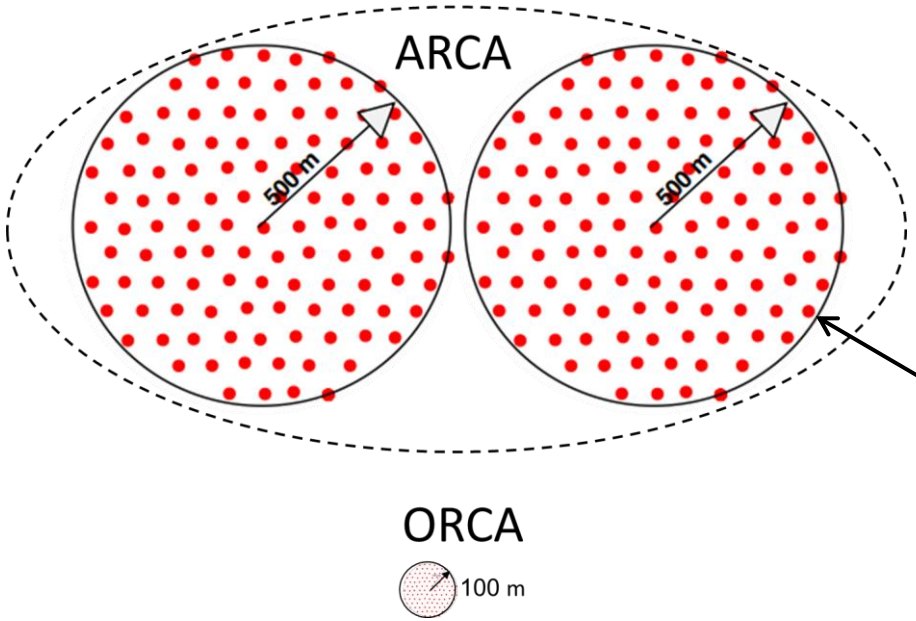
- Next steps:
  - use atmospheric shower events to explore the possibility for self vetoes.
  - apply this method to the astrophysical analysis in order to study the possible improvement of the sensitivity and the discovery potential.

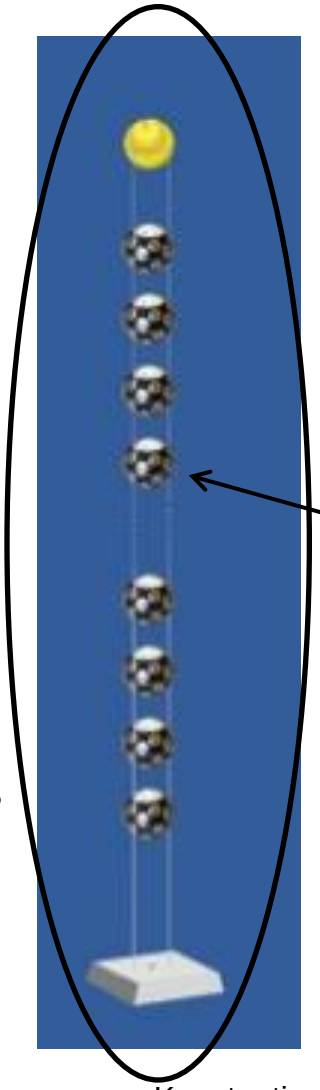
Thank you!

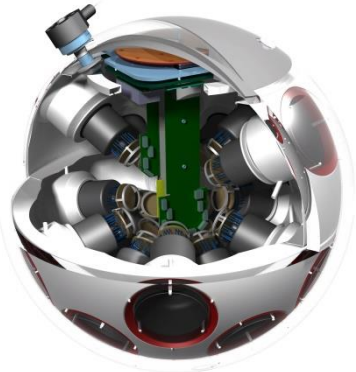
Questions / Suggestions?

Back up

KM3NeT







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Results / Signal

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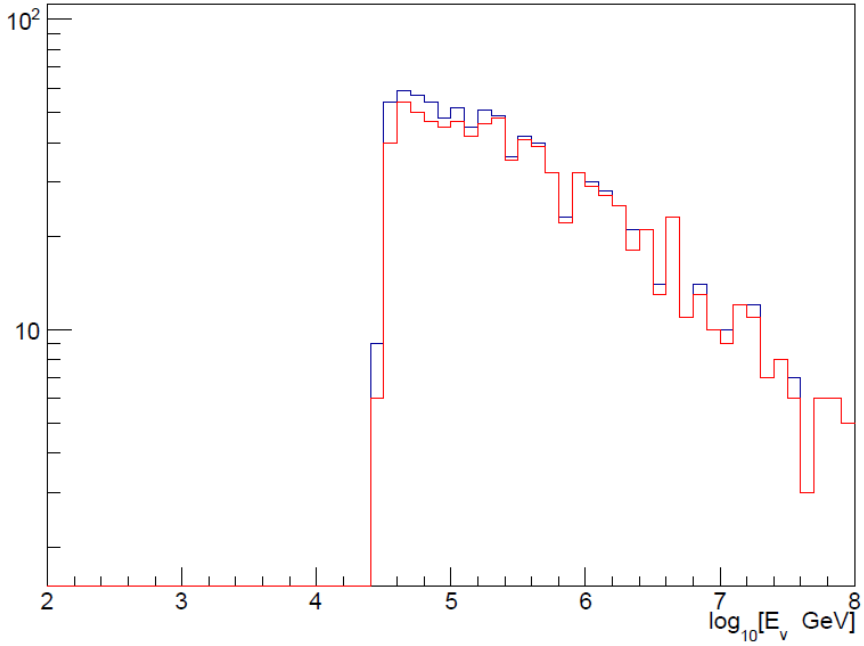

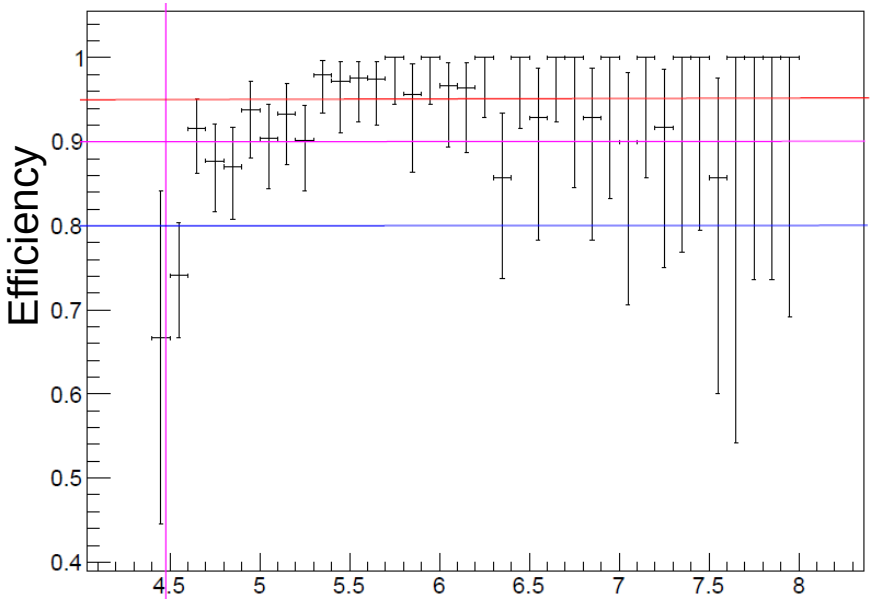

Events having their reco vertex inside the fiducial volume

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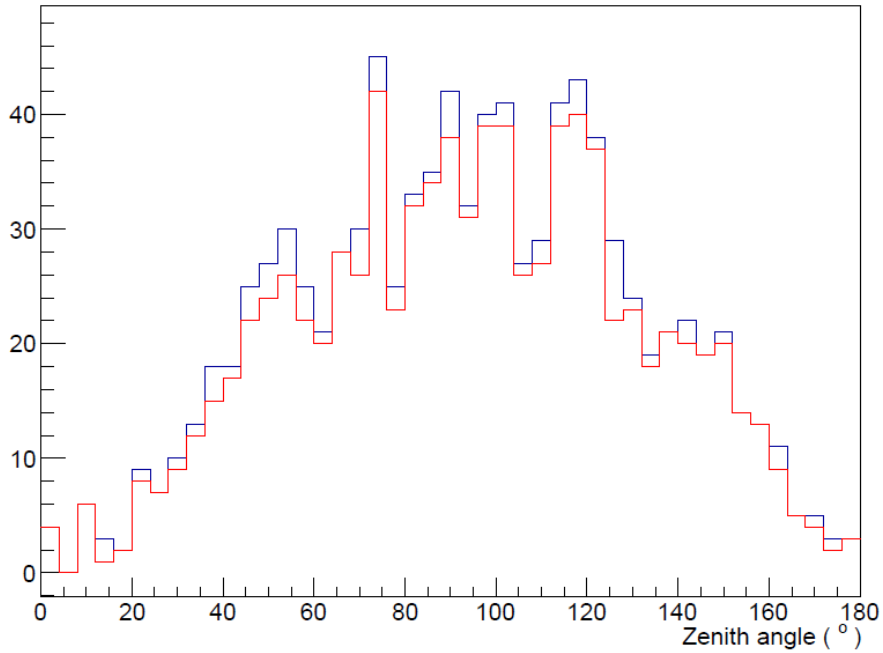

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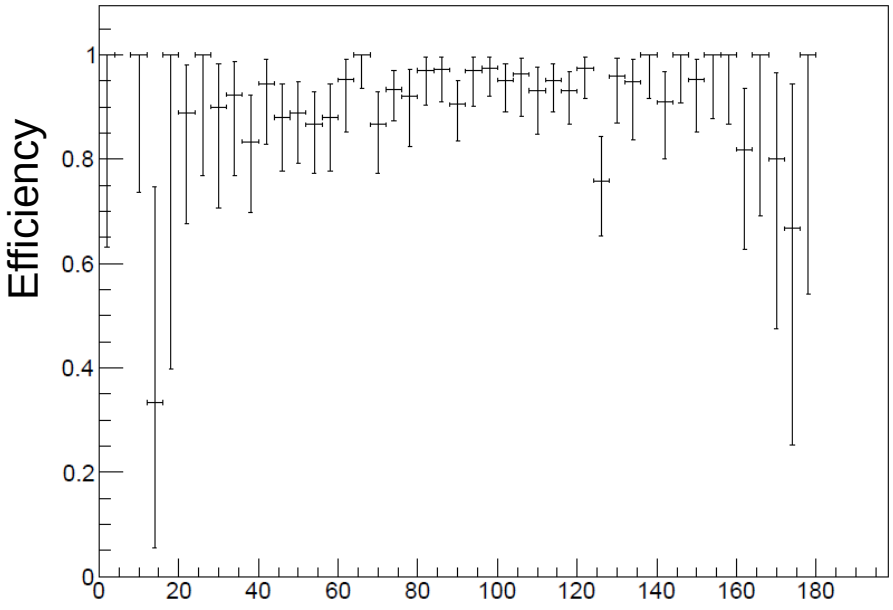
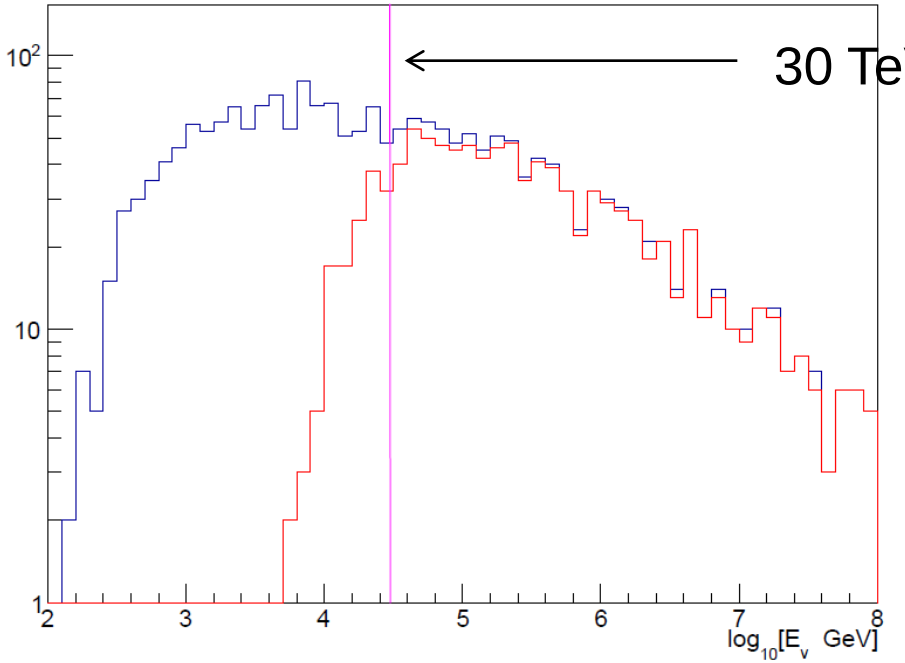
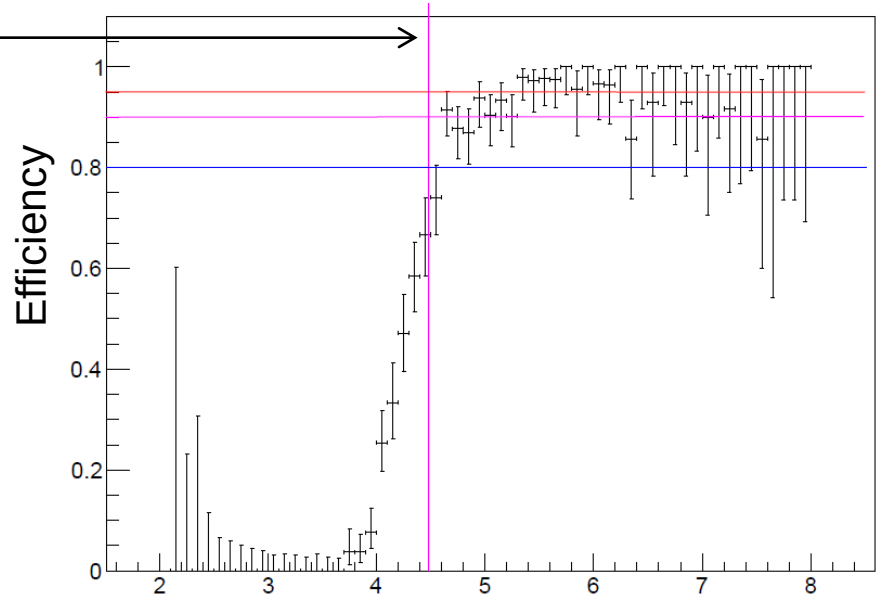


Results / Signal

- Using the BDT value for a 90% efficiency of the signal training sample
  - Efficiency for all CC events ~50%.





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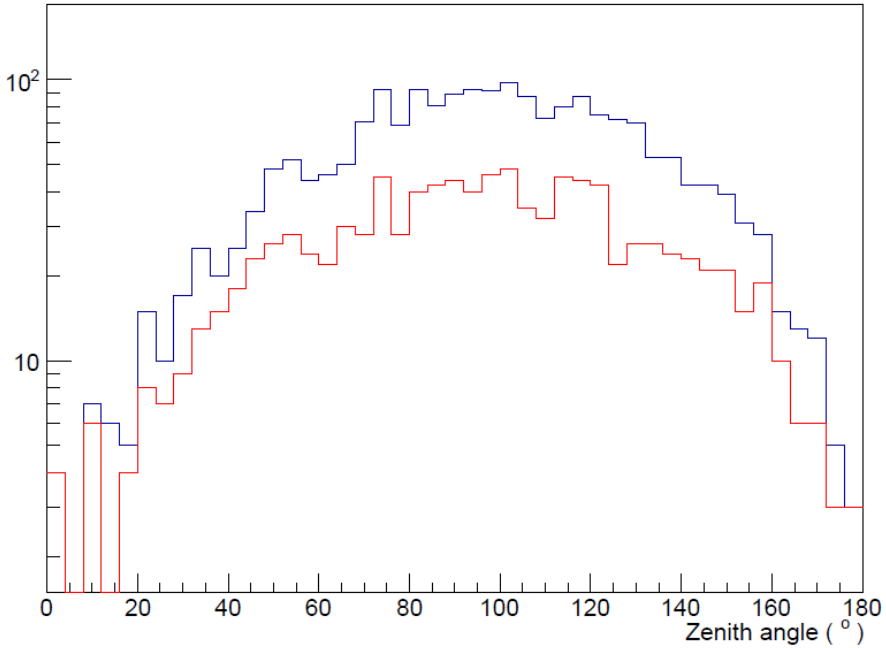

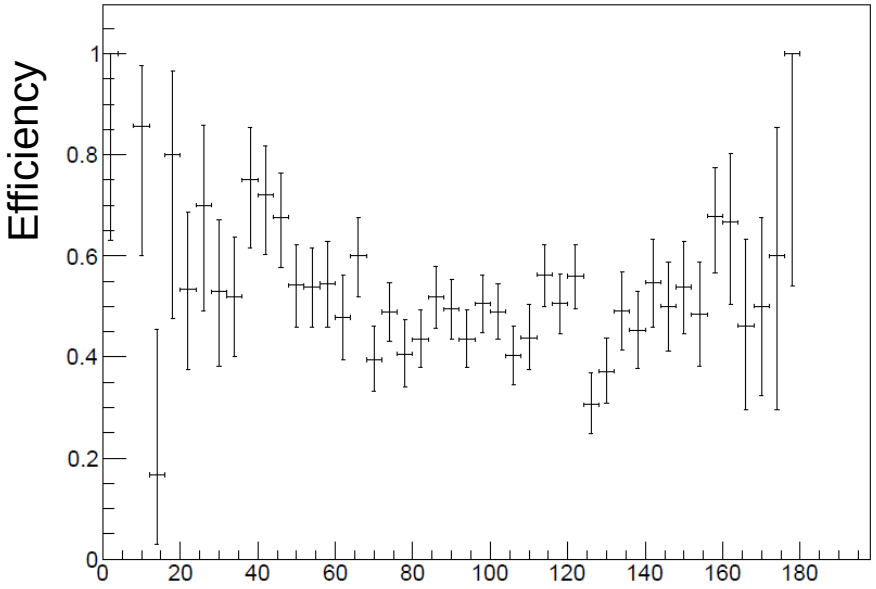

Events having their reco vertex inside the

Events remaining after the BDT