Analysis of High Energy Starting Events with the KM3NeT/ARCA detector

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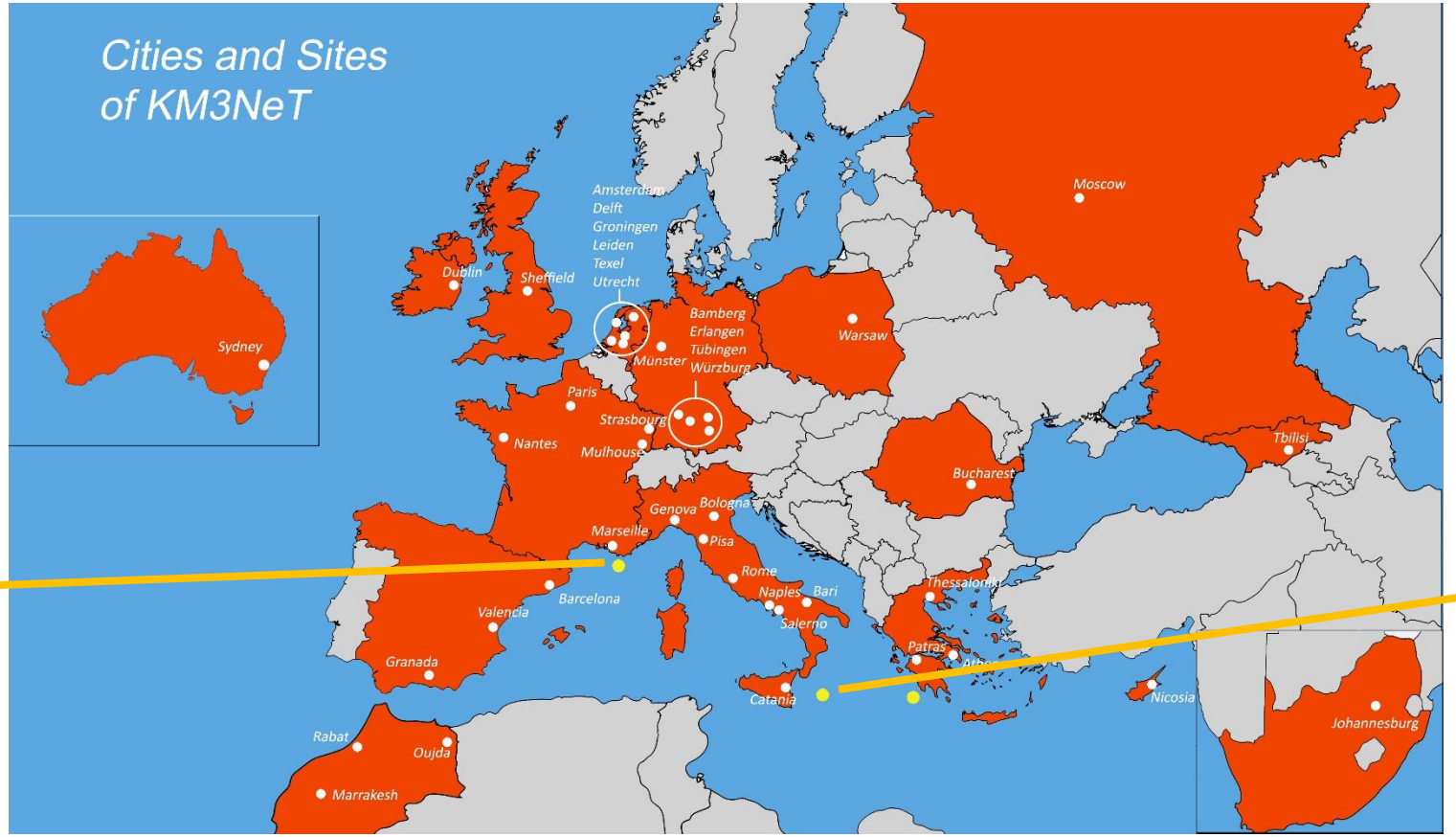
KM3NeT

Distributed large scale infrastructure housing the next generation neutrino detectors in the depths of the Mediterranean Sea



16 countries
40 institutes
220 scientists

Oscillation Research with Cosmics in the Abyss (ORCA)

Neutrino mass hierarchy

Astroparticle Research with Cosmics in the Abyss (ARCA)

High energy neutrino astrophysics

talk by P. Coyle

KM3NeT/ARCA telescope

ARCA Telescope:

Search for point sources

Measurement of the diffuse astrophysical flux

The KM3NeT /DOM:

- Directional information
- Isotropic ~4π field of view
- Hit time accuracy ~1ns
- Photocounting – high noise rejection already at DOM level
- Large photocathode area

Building block:

115 DUs

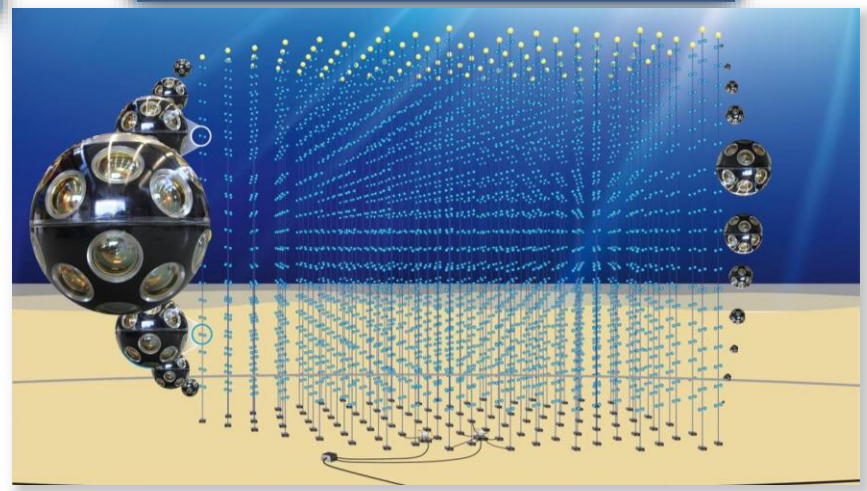
18 DOMs / DU

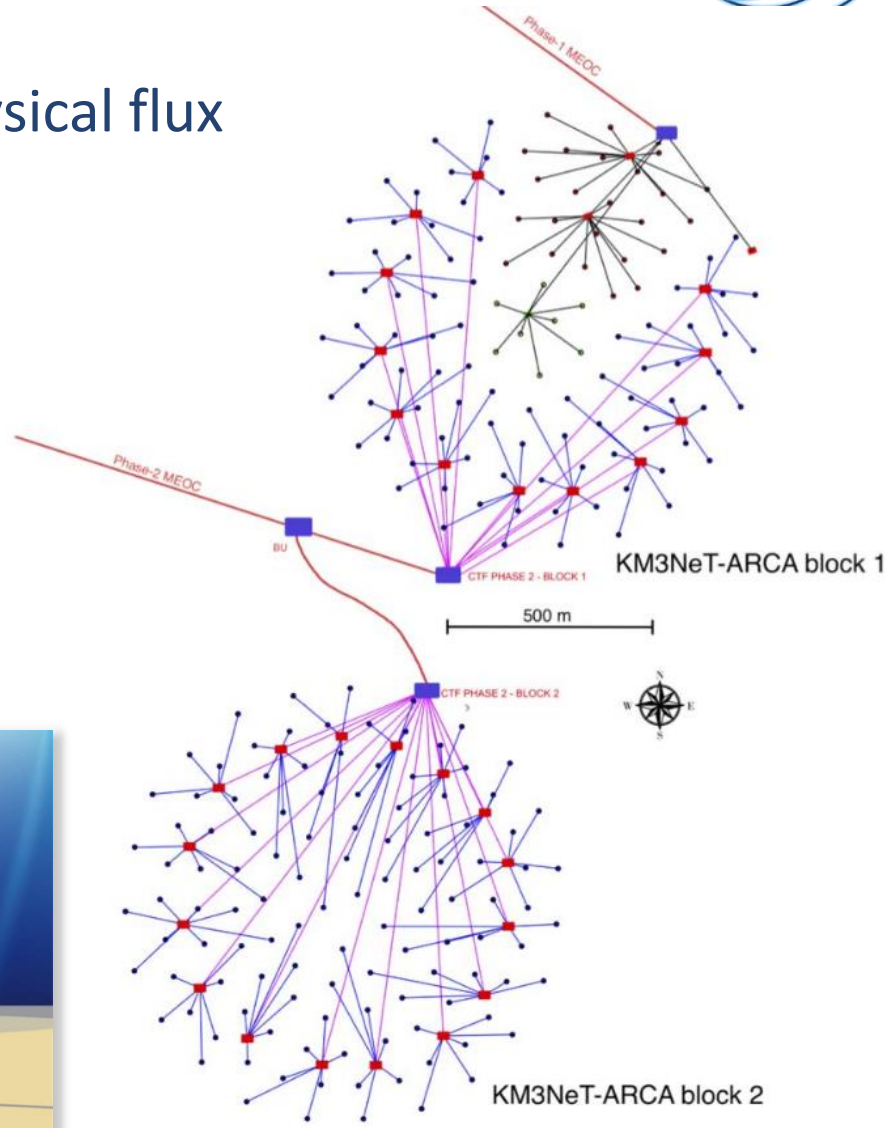
DOM spacing: ~36m

DU spacing: ~90m

Depth: ~3500 m

talk by R. Bruijn

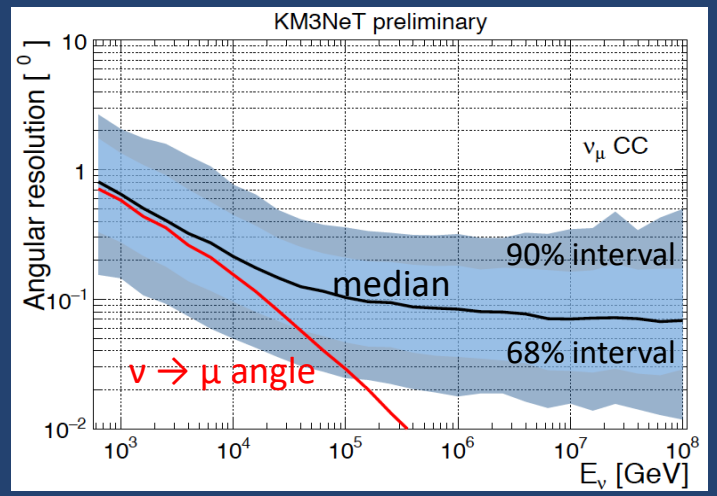




ARCA angular and resolution

KM3NeT DOM and water properties: excellent angular resolution

Track events:



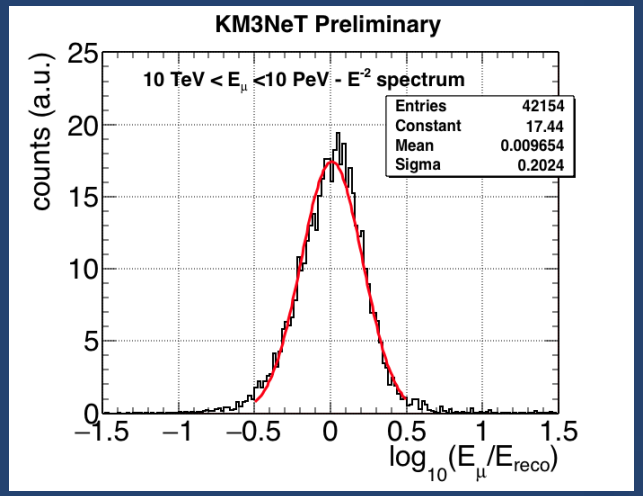
Angular resolution:

< 0.2° $E_\nu \geq 10$TeV

< 0.1° $E_\nu \geq 100$TeV

Energy resolution:

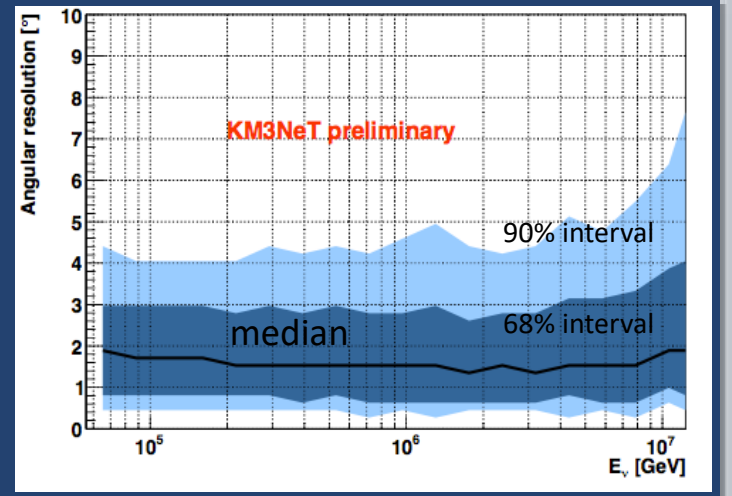
20% in $\log_{10}(E_\mu)$

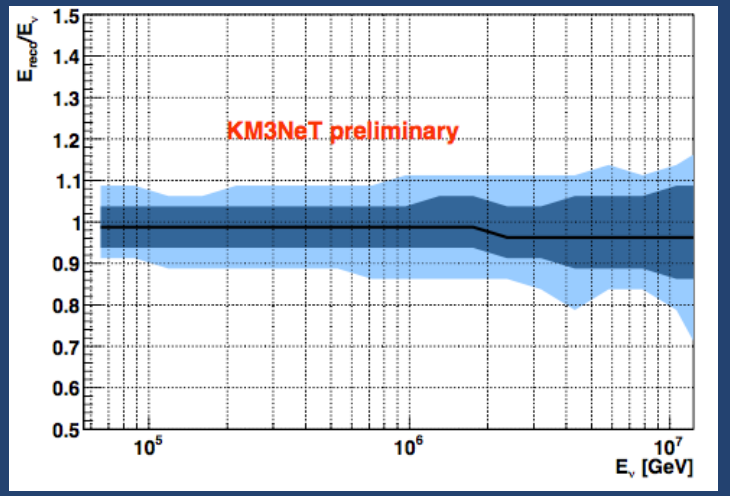


Shower events:

Angular resolution:

< 2° $E_\nu \geq 60$TeV





Energy resolution:

5% $E_\nu \geq 60$TeV

Plots for ν_e CC events

High Energy Starting Events

Starting events:

- Rejection of atmospheric muon background
- Rejection of atmospheric neutrinos accompanied by muons (self vetoes)
- More precise estimation of neutrino energy
- Isotropic (almost) field of view

A High Energy Starting Events (HESE) analysis with KM3NeT/ARCA:

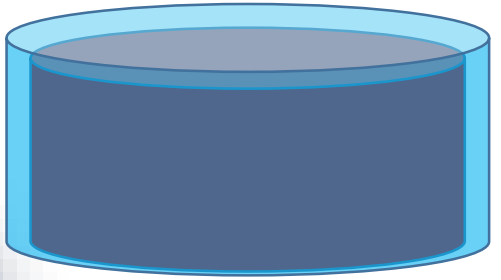
- Reject incoming muons to ARCA:
  Select a sample of starting track-like events.
- Perform track / shower differentiation:
  Select a sample of contained shower-like events.
- Combine the above samples:
  Form a HESE sample.
- Use this HESE sample to estimate the discovery potential of ARCA to an astrophysical flux.

Starting tracks – vertex containment

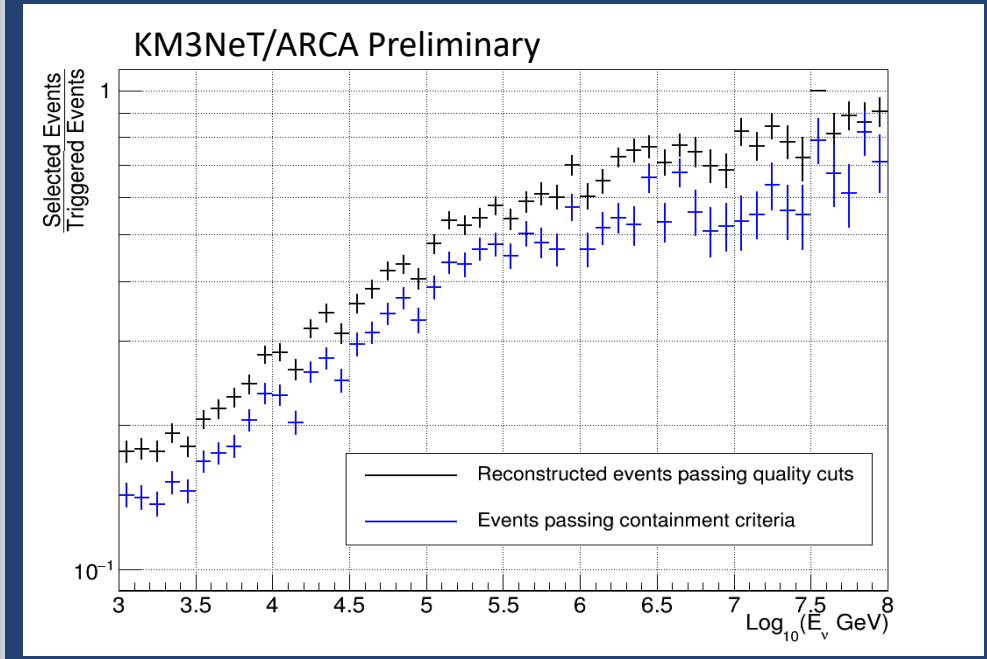
Starting track-like events:

- Select well reconstructed track events.
- Select events having the reconstructed vertex inside a fiducial volume.

ARCA

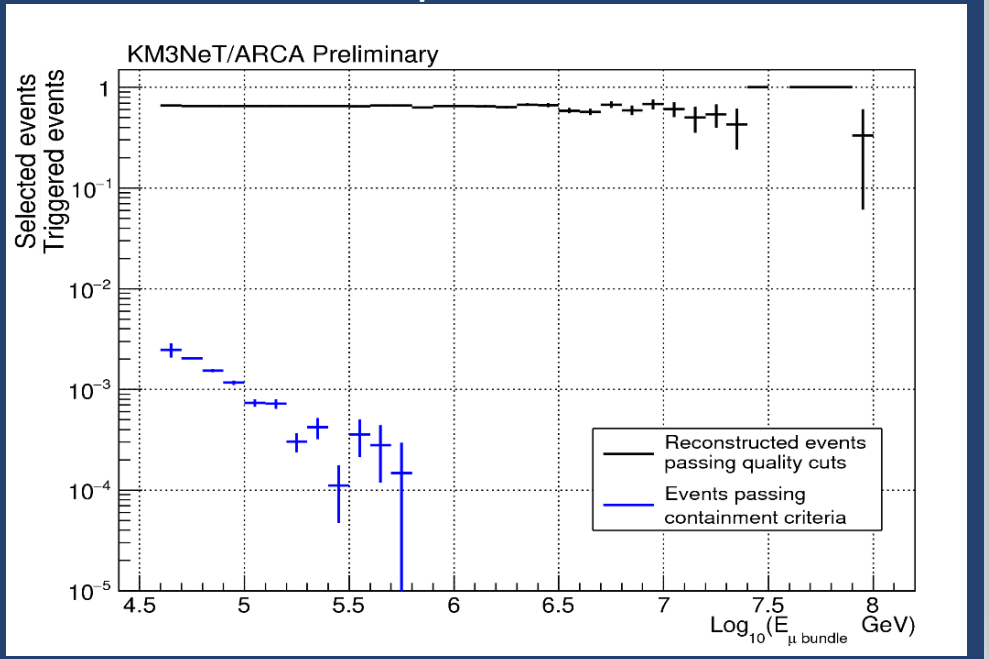


Efficiency of selected events with respect to all triggered events



$\nu_\mu + \overline{\nu_\mu}$ CC events

Atmospheric muons



Vertex containment:

- High efficiency for neutrino events
- Powerful rejection on incoming atmospheric muons
- However, further rejection is needed

Starting tracks – final selection

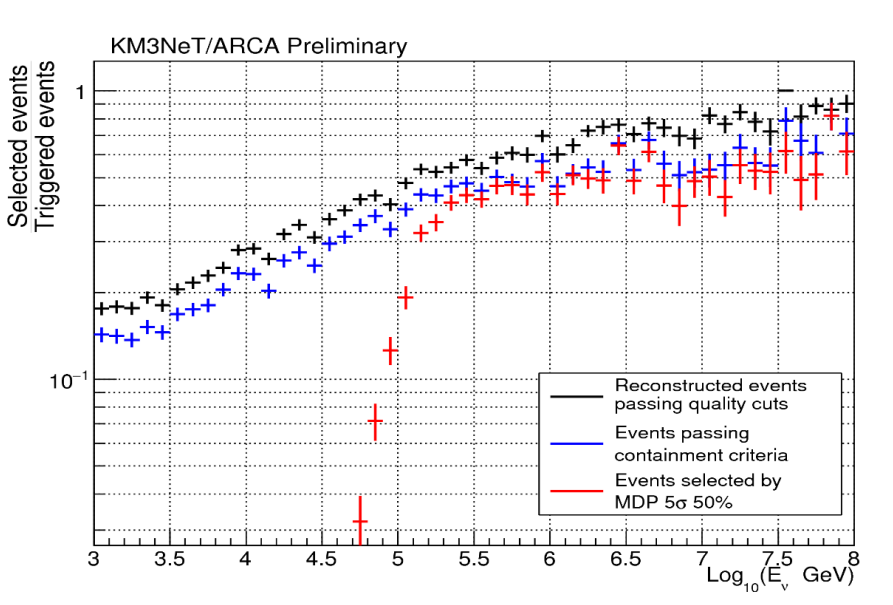
Starting track-like events:

- Select well reconstructed events.
- Select events having the reconstructed vertex inside a fiducial volume.
- Extract topological event-based variables:
  - Identify incoming events.
  - Focus on high energy events.
- Use a BDT classifier for the final selection.
  - Signal: Truly contained starting track events with $E_\nu > 30$ TeV.
  - Background: Through going tracks (ν_μ CC and atmospheric muon events).
- Final cuts on BDT output and E_{reco} with the Model Discovery Potential (MDP) technique.

Simulated events:

- Astrophysical flux per ν flavour: $\Phi_\nu = 2.3 \cdot 10^{-18} \left(\frac{E_\nu}{100\ \text{TeV}}\right)^{-2.5}$ GeV^{-1} · cm^{-2} · s^{-1} · sr^{-1}
- Backgrounds:
  - atmospheric ν fluxes: Honda (with knee correction) + Enberg
  - atmospheric muons (MUPAGE)

Starting tracks – final selection



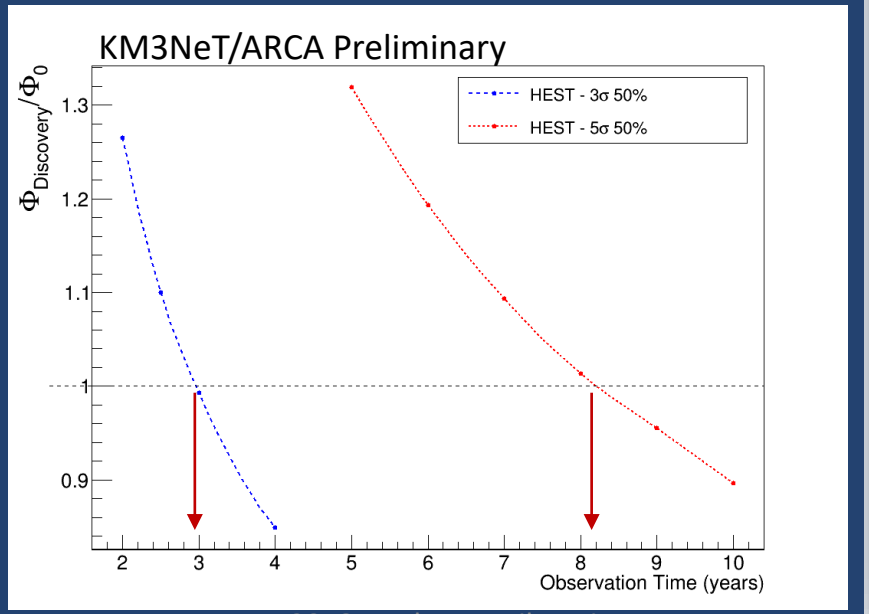
Cuts on BTD output and E_{reco} have excellent efficiency for high energy events.

Discovery of the astrophysical flux:

3σ in ~3 years

5σ in ~8 years

using only high energy starting tracks.



Final signal sample:
94% are true starting tracks

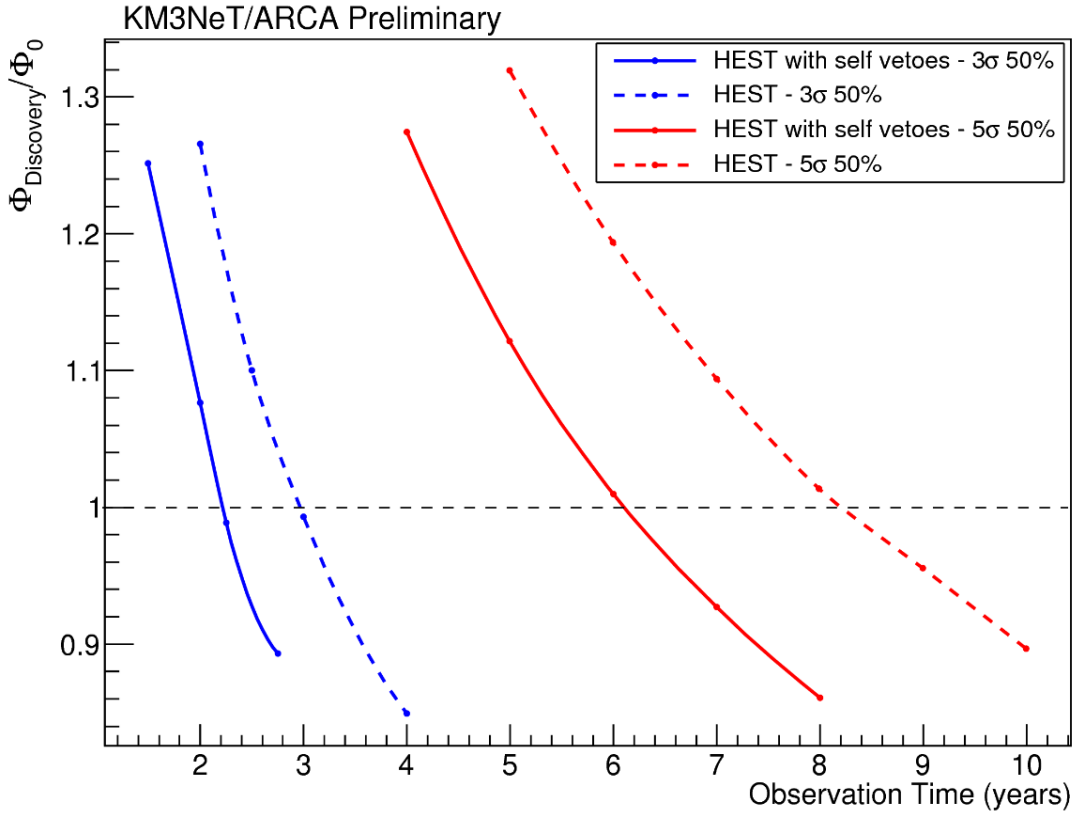
Final background sample:

- **97%** are true starting tracks
- **1%** are true shower like events
- **2%** are incoming atmospheric muons

Starting tracks – Self veto studies

Self vetoes:

- Reject atmospheric neutrinos by identifying accompanying muons (created at the same atmospheric shower).
- Background samples:
  - atmospheric ν with CORSIKA (downgoing), a fraction of which are accompanied by muons
  - atmospheric ν Honda + Enberg (upgoing)
  - atmospheric muons (MUPAGE)

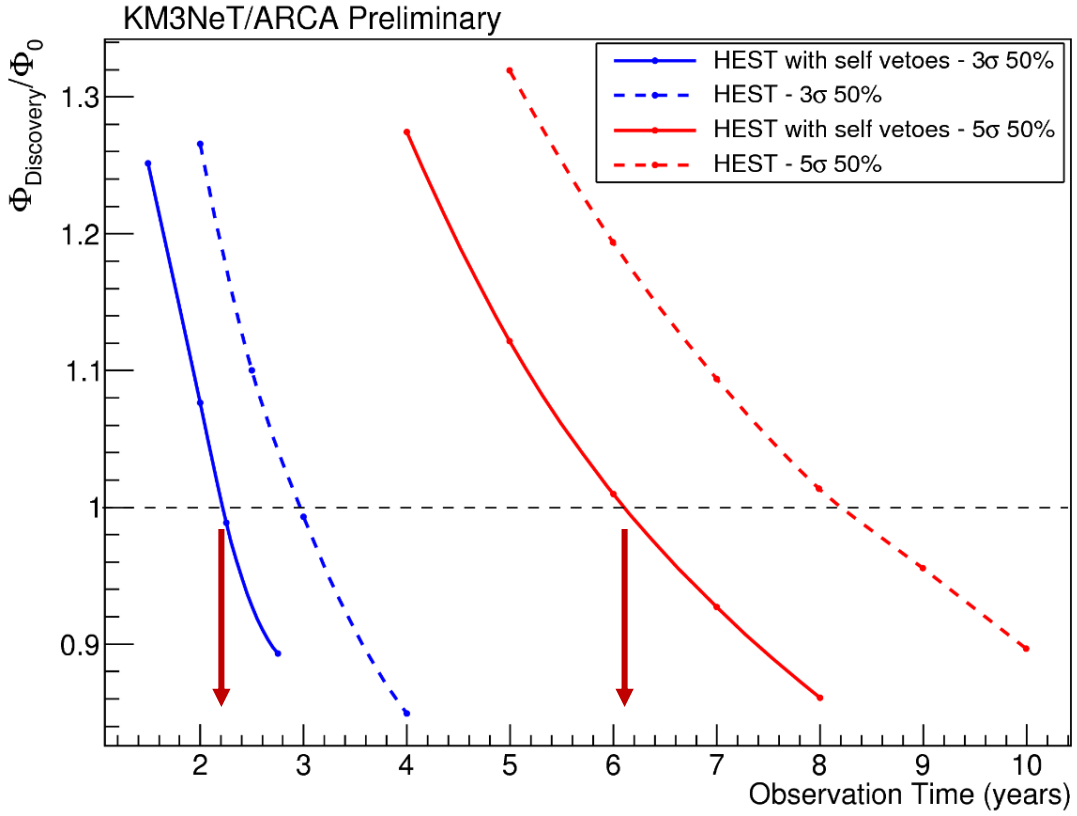


Starting tracks – Self veto studies

Self vetoes:

- Rejected practically **ALL** atmospheric neutrinos accompanied by muons
- A reduction on the total atmospheric neutrino background of **~32%**

- Leading to reduction in observation time needed for discovery **~25%**
- Discovery **using only starting track events**
  3σ in ~2.25 years
  5σ in ~6 years

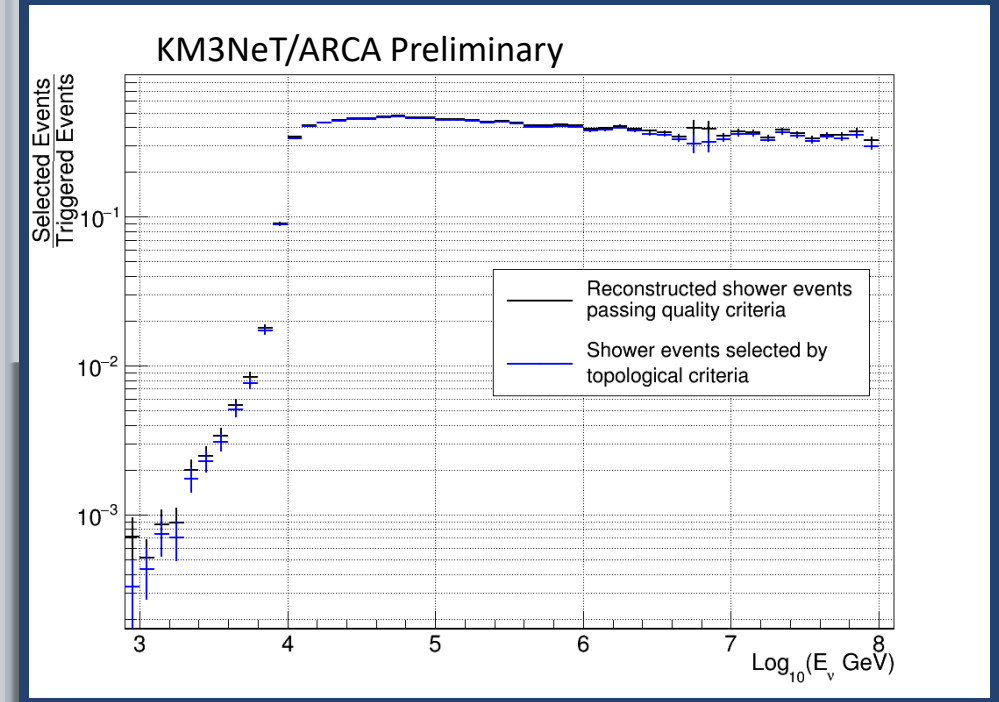


Contained Showers – First step

Contained shower-like events:

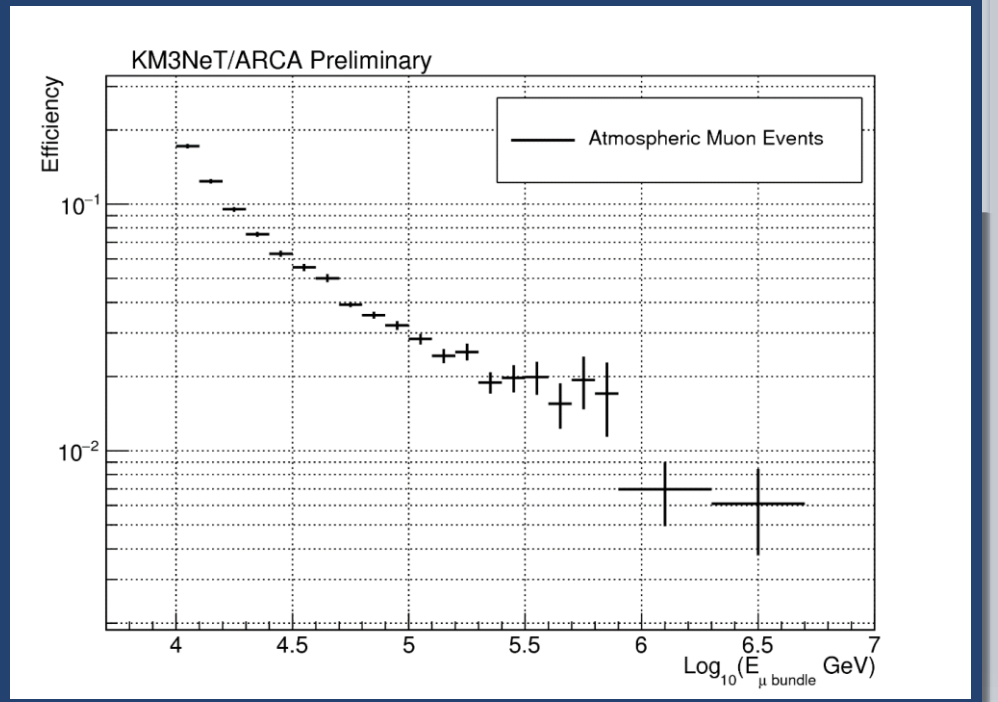
- Select well reconstructed shower events with the reco vtx inside the volume of ARCA.
- Apply a series of selection criteria designed to reject track events.

Efficiency of selected events with respect to all triggered events



All shower events

Atmospheric muons

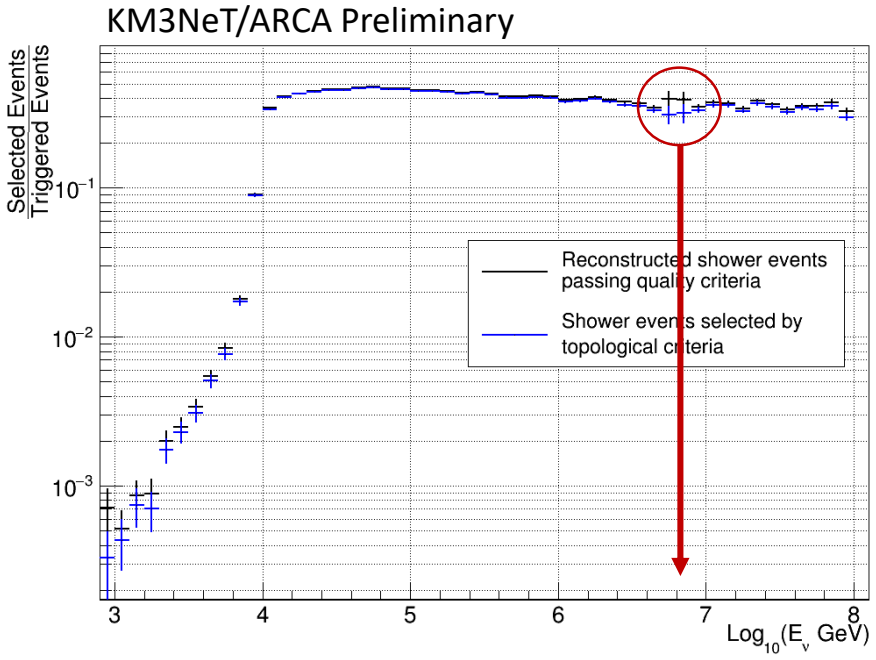


Selection criteria:

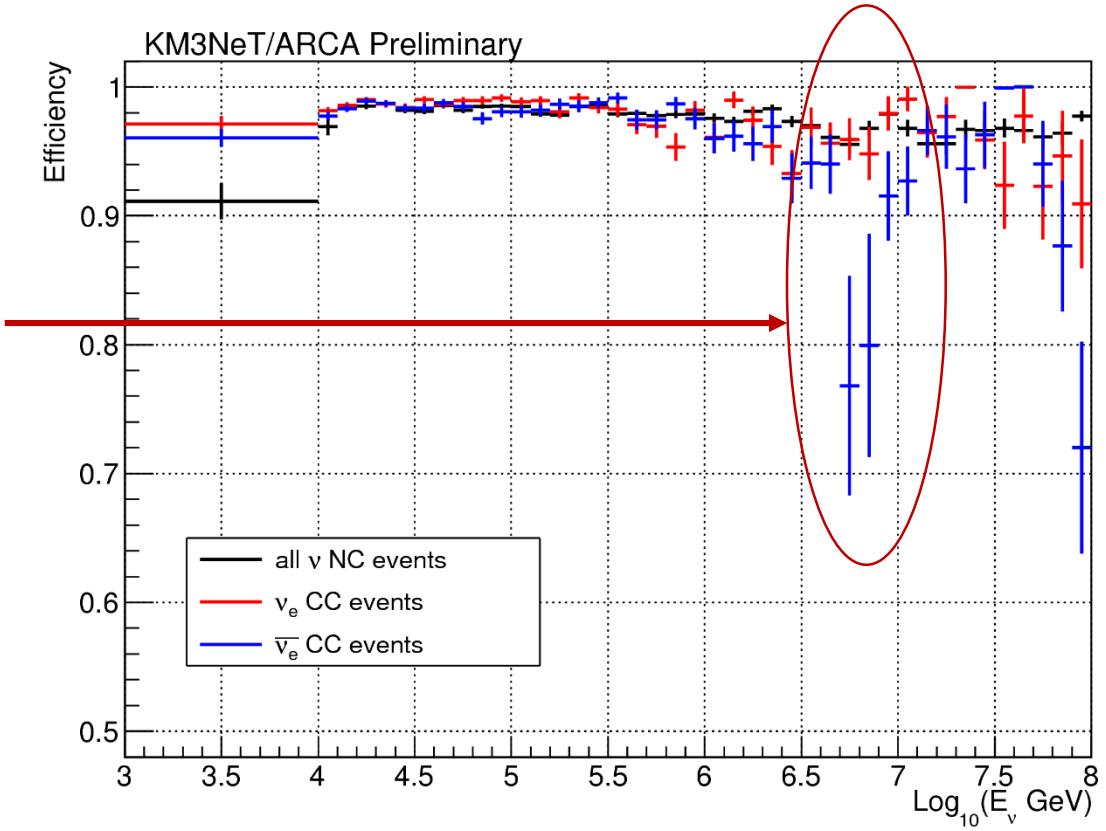
- Excellent efficiency for shower events
- Powerful rejection on true track events
- However, further discriminating power is needed

Contained Showers – First step

- For NC and ν_e CC events, efficiency is > **95%**.
- For $\overline{\nu_e}$ CC events , efficiency is > **95%** except for the Glashow resonance region. Muons from $W^- \rightarrow \mu + \overline{\nu_\mu}$ are found and rejected.



All rejected events have a muon in the final state



Contained Showers – final selection

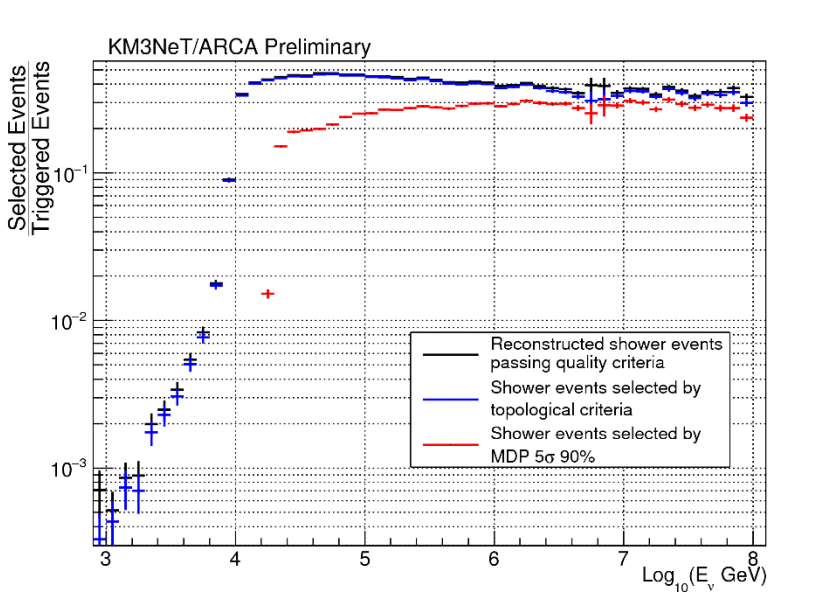
Contained shower-like events:

- Select well reconstructed shower events with the reco vtx inside the volume of ARCA.
- Apply a series of selection criteria designed to identify track events then remove them.
- Extract topological event based variables:
  - Identify shower events.
  - Identify track events.
- Use a BDT classifier for the final selection.
  - Signal: Truly contained shower events (NC events).
  - Background: atmospheric muon events.
- Final cuts on BDT output and E_{reco} with the MDP technique.

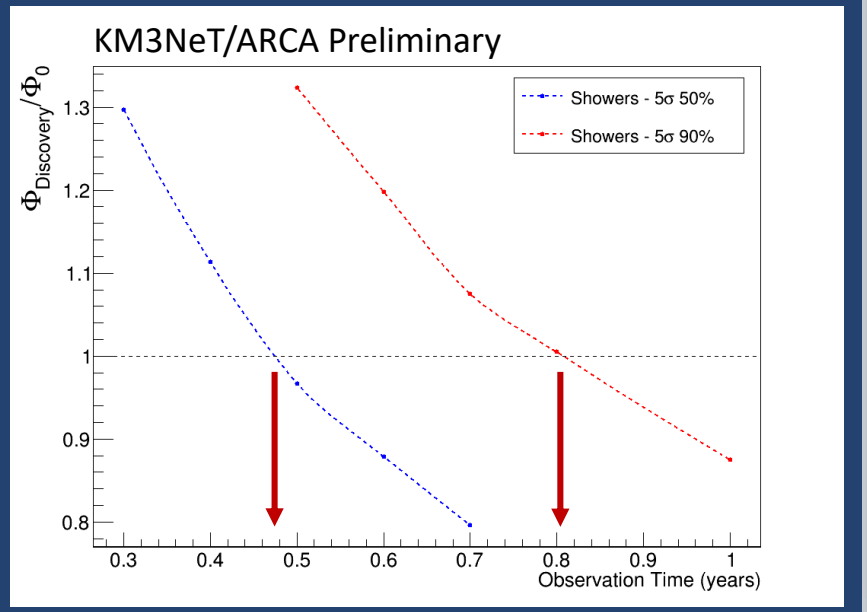
Simulated events:

- Astrophysical flux per ν flavour: $\Phi_\nu = 2.3 \cdot 10^{-18} \left(\frac{E_\nu}{100\ \mathrm{TeV}}\right)^{-2.5}\ \mathrm{GeV}^{-1} \cdot \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1} \cdot \mathrm{sr}^{-1}$
- Backgrounds:
  - atmospheric ν fluxes: Honda (with knee correction) + Enberg
  - atmospheric muons (MUPAGE)

Contained Showers – final selection



Cuts on BDT output and E_{reco} have high efficiency for high energy shower events.



5σ Discovery of the astrophysical flux :

50% prob < 0.5 years

90% prob ~ 0.8 years

using only high energy showers.

Final signal sample:
93% are true contained shower-like events

Final background sample:

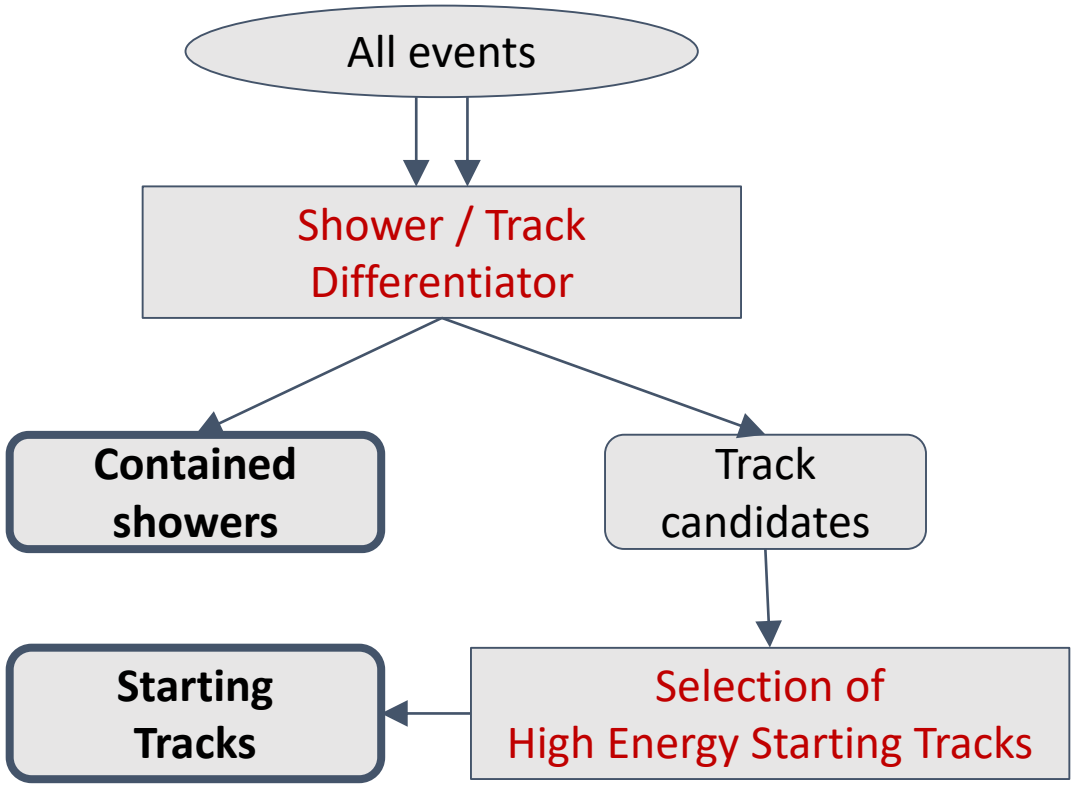
- **88%** are true contained shower-like events
- **12%** are incoming atmospheric muons

HESE selection

- Use shower/track differentiator to categorize each event as “contained showers” or as “track candidate” event.
- Select high energy starting tracks from the “track candidates” sample.

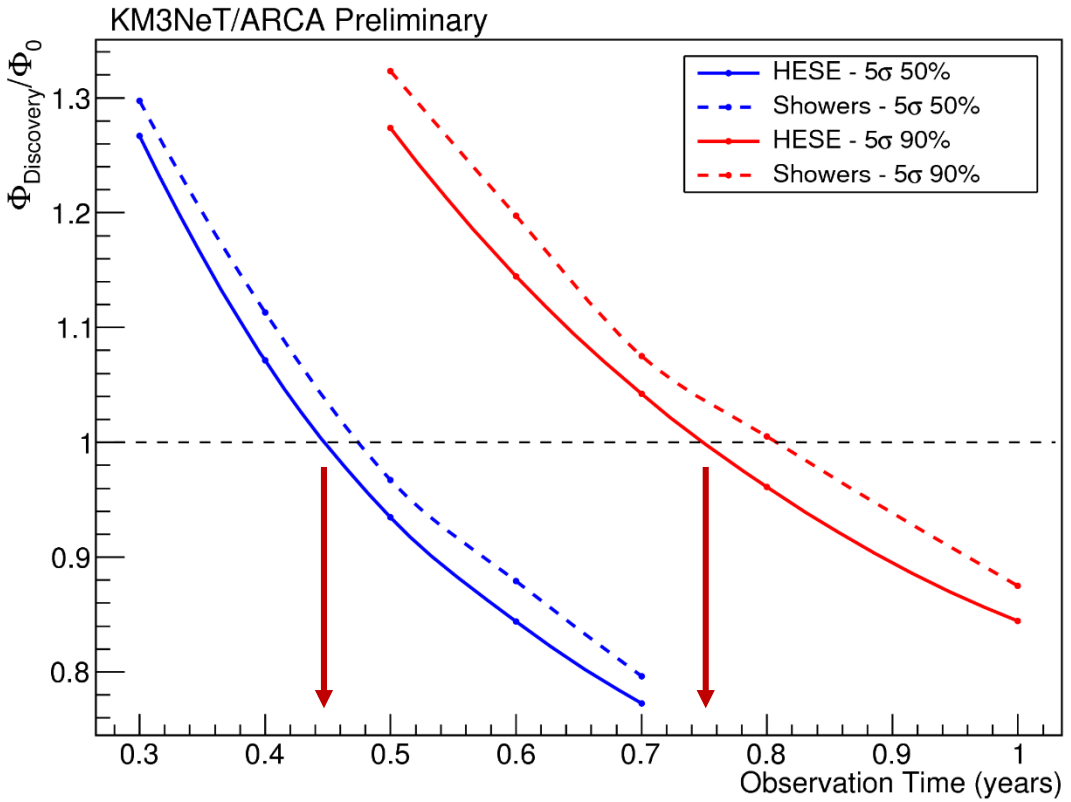
→ High purity samples of starting tracks and contained sowers .

- Use the MDP technique to select the final HESE sample.



HESE – Discovery potential for ARCA

- 5σ discovery of the astrophysical flux:
  50% probability **< 0.5** years
  90% probability **< 0.8** years!
- Final shower sample:
  - Signal: 94% correctly identified
  - Background: ~12% contamination of atmospheric muon events
- Final track sample:
  - Signal: 92% correctly identified
  - Background: ~7% contamination of atmospheric muon events



$$\Phi_\nu = 2.3 \cdot 10^{-18} \left(\frac{E_\nu}{100\ \text{TeV}}\right)^{-2.5} \text{GeV}^{-1} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1}$$

Conclusions

- High purity samples of high energy starting track and contained shower-like events were obtained using BDT based tools forming a HESE sample. This sample was used to perform an independent analysis for KM3NeT/ARCA discovery potential.

- Self veto effect has been explored. A **32% reduction** on the total atmospheric neutrino background is expected.

- Using HESE KM3NeT/ARCA is expected to make a **5σ discovery** of the astrophysical flux with **50% and 90%** probability in **less than 0.5 and 0.8 years,** respectively.

- Data from the first 2 ARCA strings are under analysis.

Real event as recorded by the 2 first deployed ARCA lines