A Discovery Potential Analysis for KM3NeT/ARCA Detector

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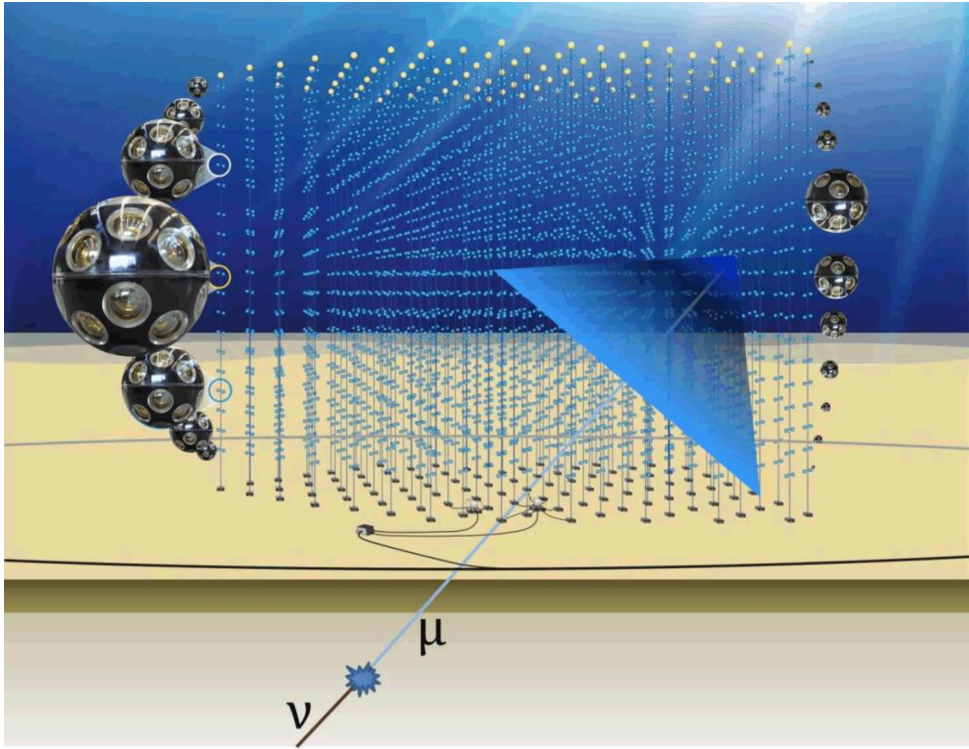
Introduction 1/3

KM3NeT/ARCA Telescope:

- 2 Building blocks each:
  115 string, 18 DOMs in each string.
- Depth ~3500 m
- 100 km off-shore of Portopalo di Capo Passero, Sicily.
- Astrophysics with HE neutrinos.
- Currently under Construction!



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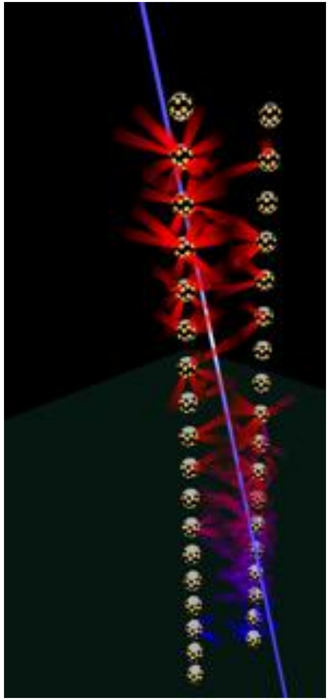


Graphic representation of an atmospheric muon bundle event “seen” by ARCA!

Colors show the times of hits detected.

Line is the reconstructed track.

Introduction 2/3

Signal:

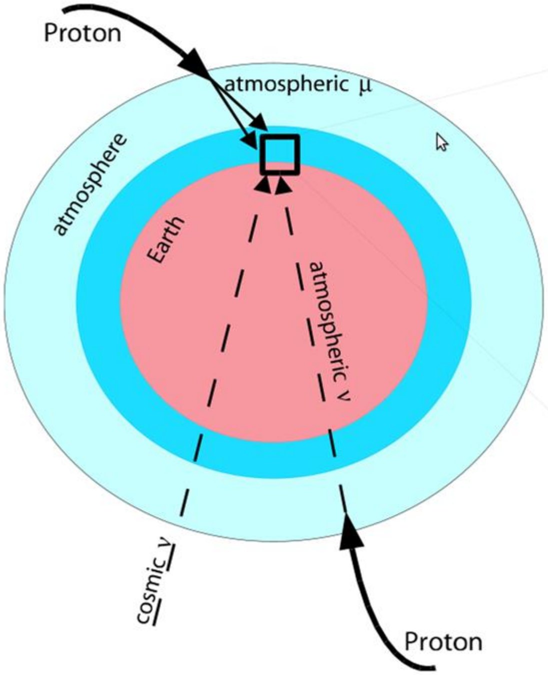
- HE Cosmic neutrinos.

Background:

- Atmospheric neutrinos ("irreducible" background).
- Atmospheric muons → Challenging!

High Energy Starting Events' Analysis:

- No background from atmospheric muons. ✓
- Estimation of neutrino Energy. ✓
- Reduced background from atmospheric neutrinos by identifying accompanying muons. ✓



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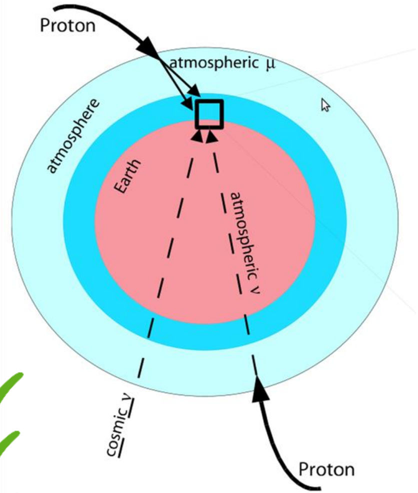
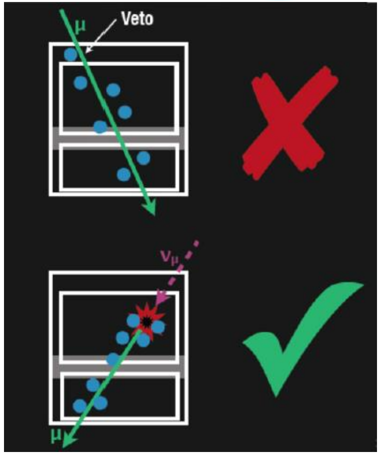




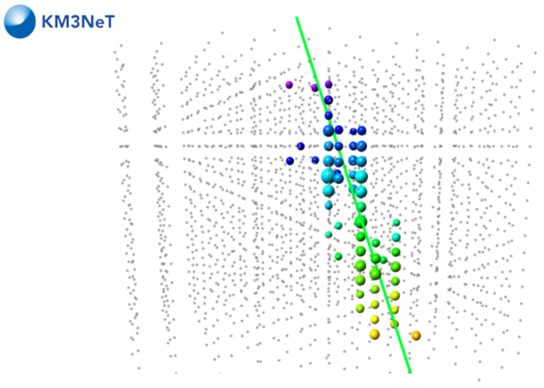
Introduction 3/3

A HESE analysis focuses on:

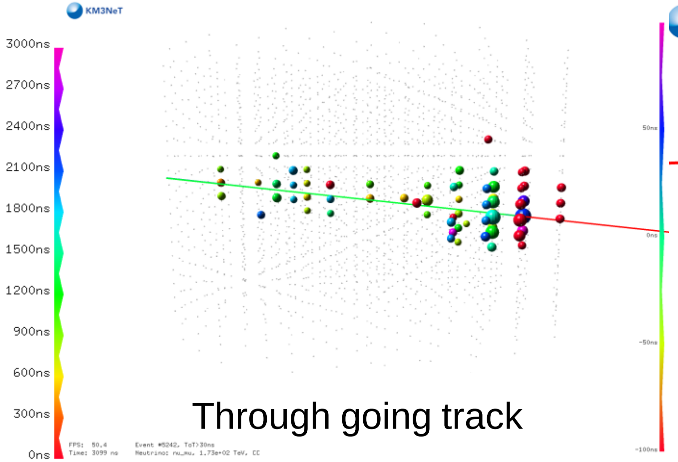
- Staring Track Events ($\nu_\mu \rightarrow \mu$ via CC interaction inside the detector).
- Shower Events (all flavours via NC interaction, $\nu_e \rightarrow e$ via CC interaction inside the detector).

We need:

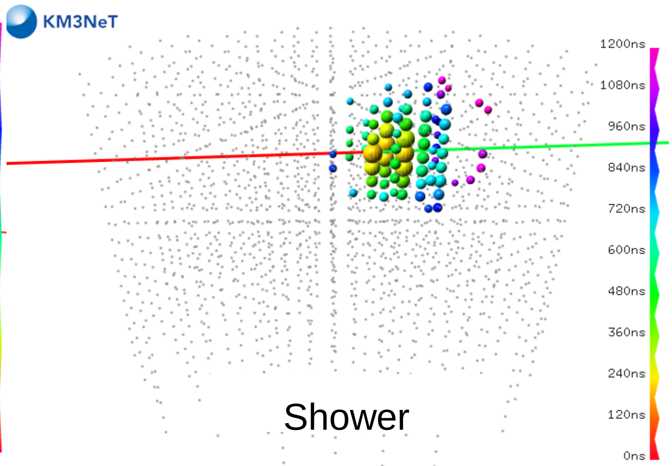
- A tool to select starting tracks from all track events.
- A tool to discriminate between track / shower events.



Starting track



Through going track



Shower

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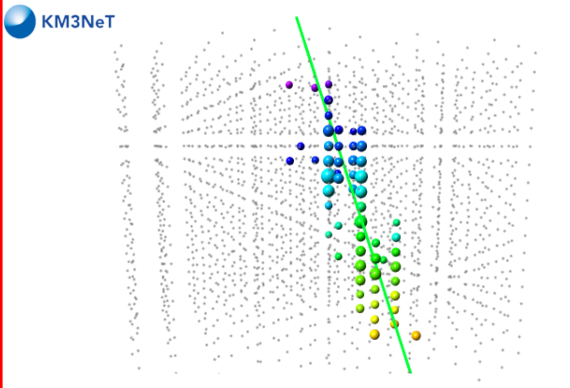
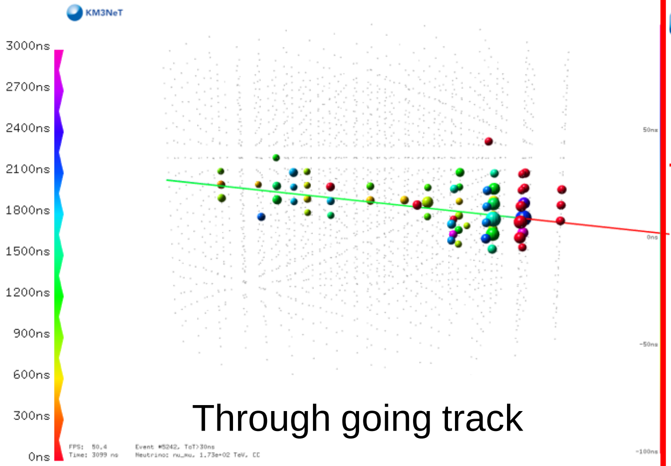
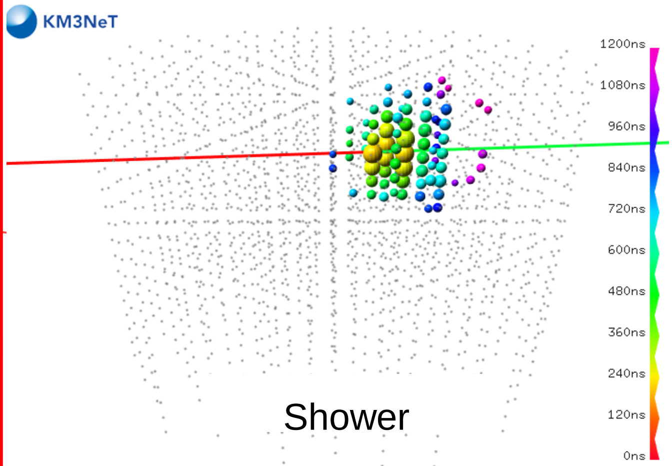


Starting track



Through going track

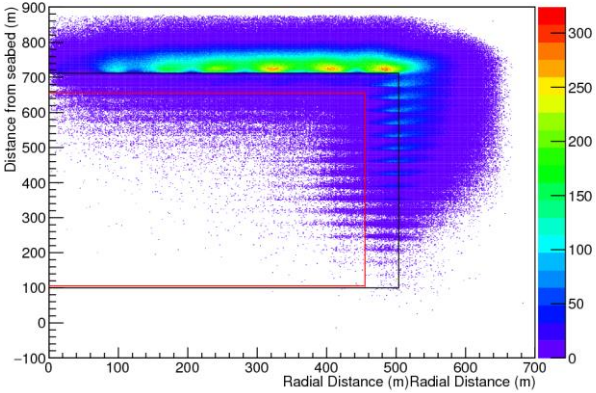


Shower

MAMBA, a tool to reject the Multiple Atmospheric Muon BAckground

Technique:

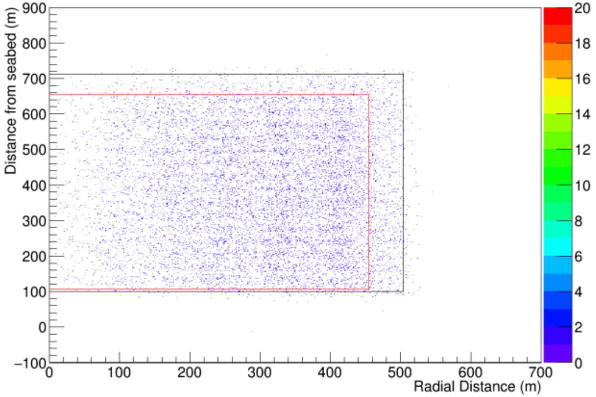
- Select well reconstructed events (Standard track reconstruction for ARCA).
- Select events having the reconstructed vertex inside a fiducial volume.
    - Developed a new technique to find the neutrino vertex.
    - Rejecting > 85% background and only ~17% signal.



Reconstructed vertices

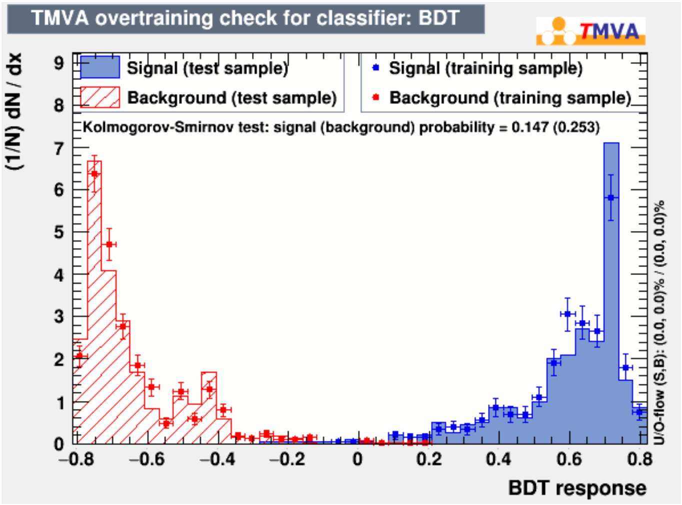
←Atmospheric muons

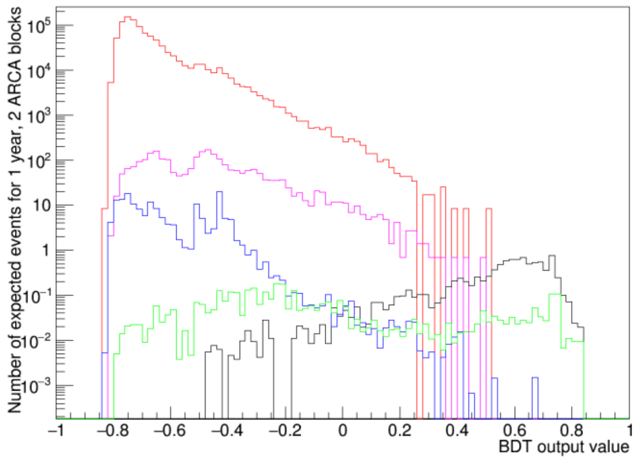
Truly contained events →



- Use a BTD with 10 event based variables to identify Starting Tracks.

MAMBA BDT and BDT output





Atmospheric muons with medium energies.

Atmospheric muons with high energies.

ν_μ interacting outside det

All ν_μ and ν_e shower events

HEST events

No overtraining observed

BDT output value for all events not used for training.

- MRF technique is used to find the sensitivity.
- MDP technique is used to find the discovery potential.

MAMBA
Sensitivity and discovery potential

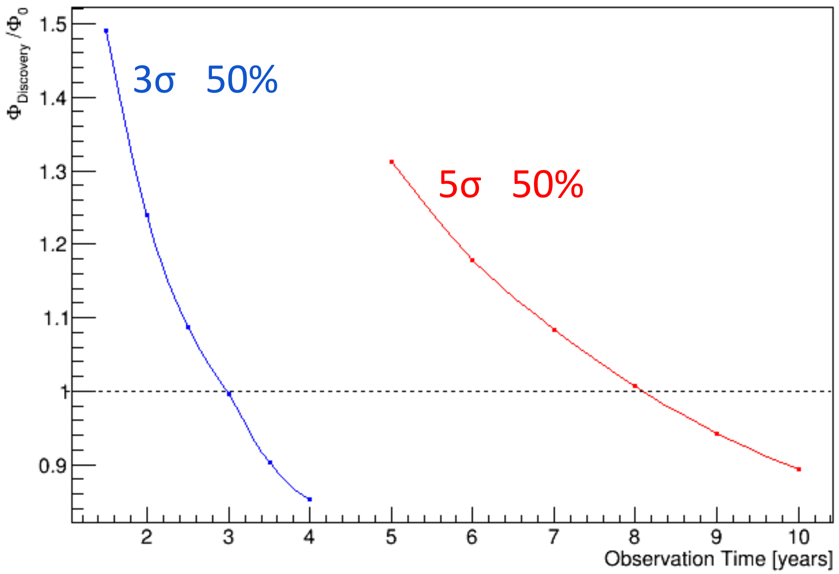
- ARCA (2 blocks) **sensitive** (90% CL) to astrophysical flux in 1.3 years.
  - Astrophysical flux:
    $\Phi_{astro} = 2.3 \cdot 10^{-18} \cdot (E_\nu/100\mathrm{TeV})^{-2.5}$
    in GeV s^{-1} cm^{-2} sr^{-1} .

- Signal events:
  - 91% correctly identified as HEST,
  - only 9% contamination from shower events!

- Background events:
  - Atmospheric muons left in the final sample ~ 2%

- Discovery:

  3σ : 3 years   5σ : ~ 8 years



Using MAMBA to reduce the "irreducible" background

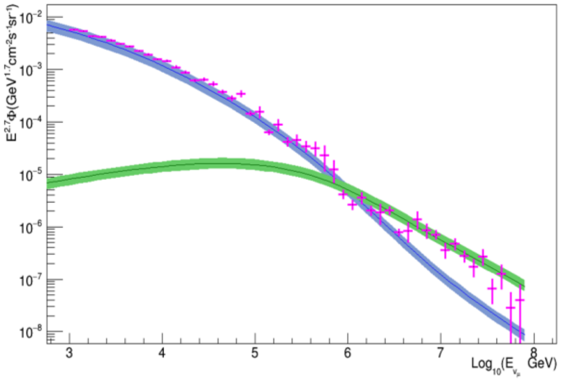
Signal:

- HE Cosmic neutrinos.

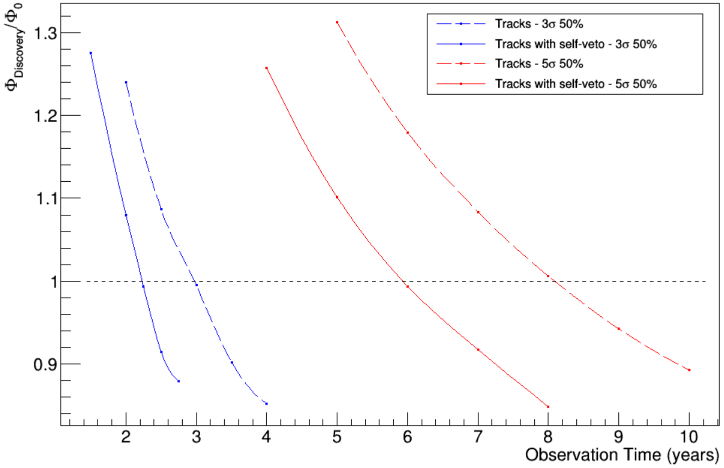
Background:

- ~~Atmospheric muons.~~
- Atmospheric neutrinos .

Can we reduce the atmospheric neutrino background?



- CORSIKA, a program that simulates atmospheric showers.
- "CORSIKA" sample for atmospheric neutrinos from above was analysed:
  - Practically **all** neutrinos accompanied by muons were **rejected**!
  - Background events reduced by **33%**.
  - 3σ discovery in 2.25 years, 5σ discovery in 6 years! (**25% decrease in time**).



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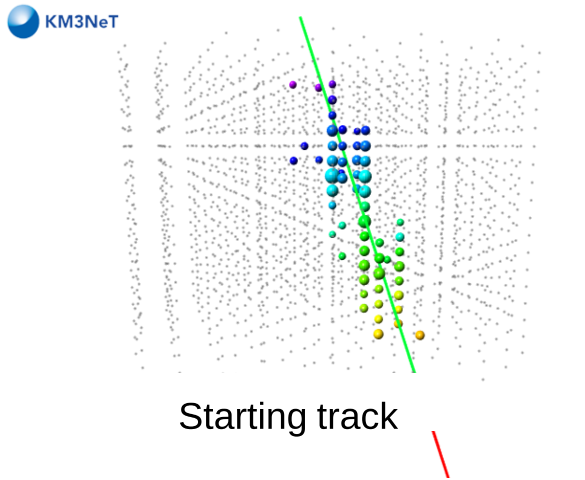
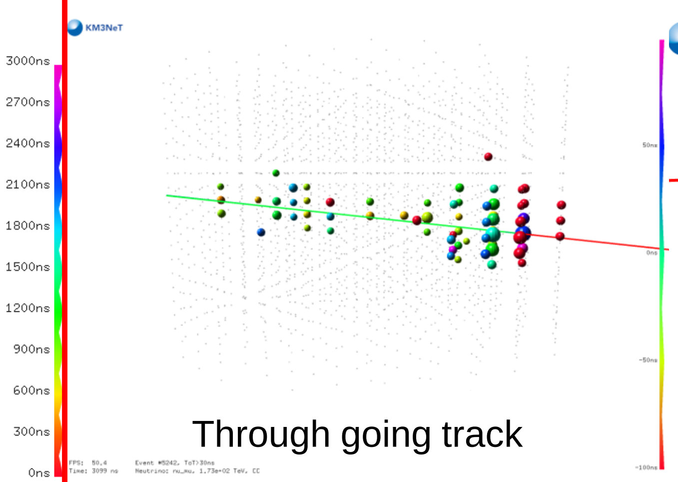
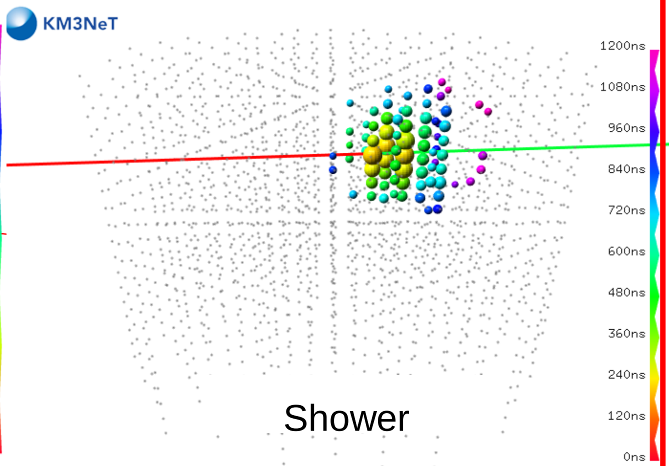


Starting track



Through going track

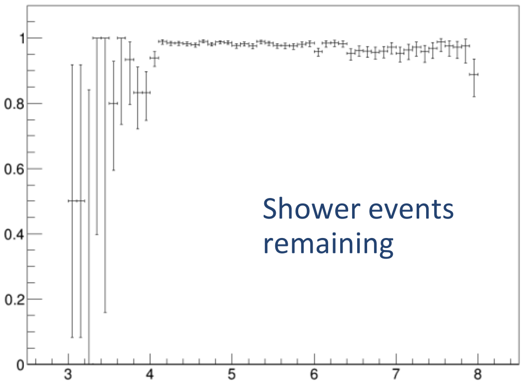


Shower

Shower / Track Differentiator

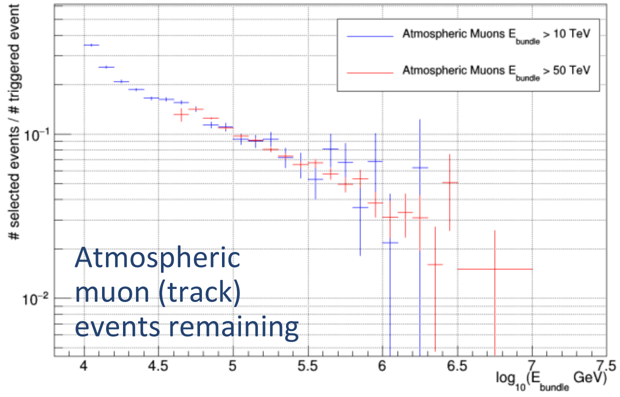
Technique:

- Well reconstructed events (standard <u>shower</u> reconstruction for ARCA).
- Events having the reconstructed vertex inside the volume of the detector.
- Developed a series of cuts based on event topologies (preliminary cuts).



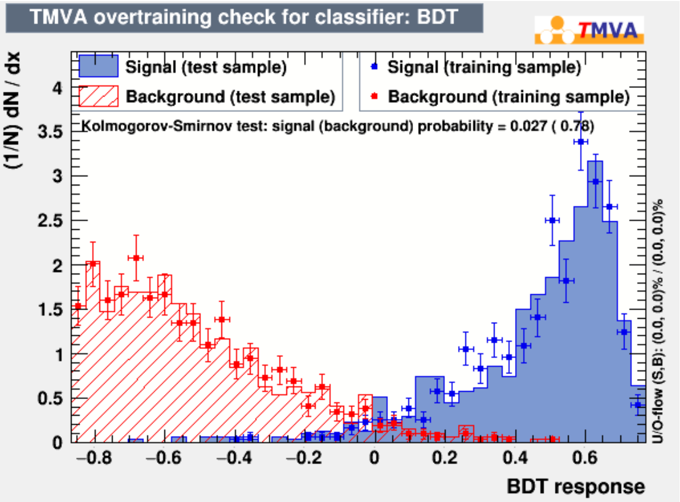
High Efficiency on real showers

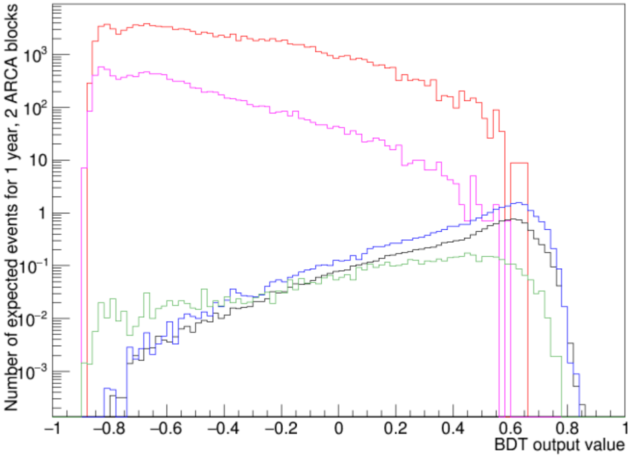
High Rejection power on real tracks



- Use a BTD for the final differentiation.

Shower / Track Differentiator BDT and BDT output





Atmospheric muons with medium energies.

Atmospheric muons with high energies.

All ν_e CC events

All NC neutrino events

All ν_μ CC events

No overtraining observed

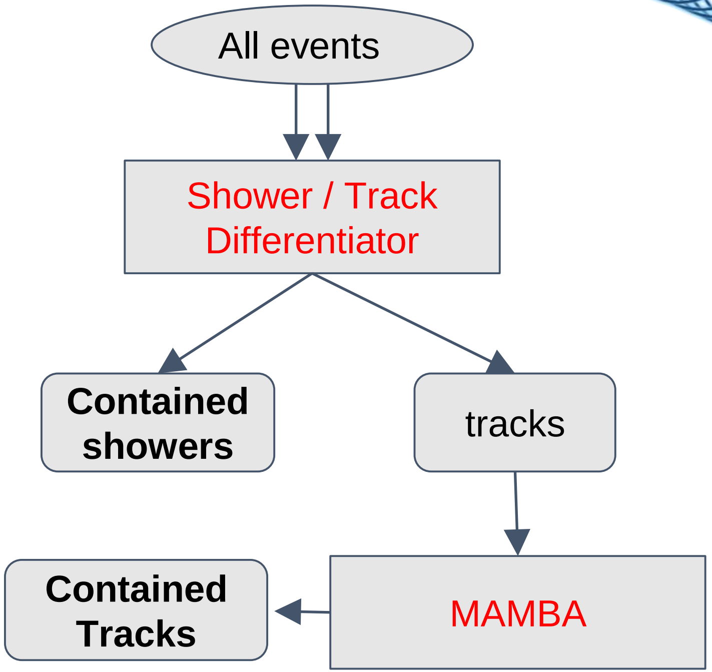
BDT output value for all events not used for training.

A High Energy Starting Events Analysis

- Using the shower / track differentiator categorise each event as “Shower” or as “Track”.
- Feed all “Track” events to MAMBA in order to find the Starting Track Events.

- Use **Contained showers** and **Contained Tracks**

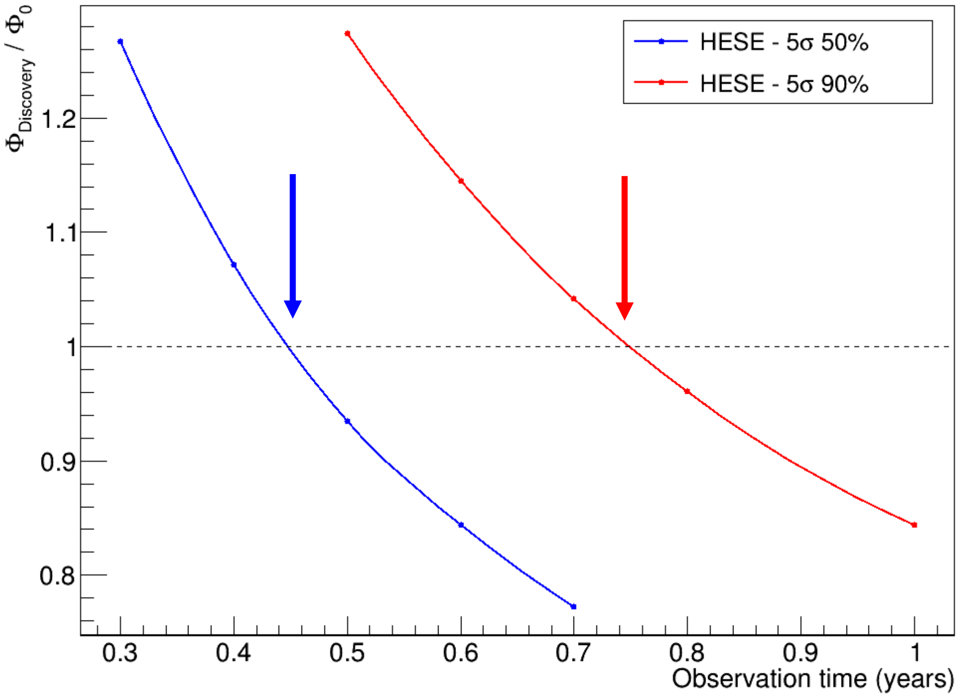
to find the discovery potential.



HESE Discovery Potential

5σ 50% discovery in less than 0.5 years

5σ 90% discovery in less than 0.8 years



Selected events

- For a 5σ Discovery (in 0.8 years of observation):

Signal events			Background events		
Found as:	"Showers"	"Tracks"	Found as:	"Showers"	"Tracks"
Number:	38.54	1.77	Number:	23.76	1.07
Correctly identified	94%	92%	Correctly identified	66%	93%

12% atmospheric muons

22% atmospheric ν_μ CC events: most with very energetic hadronic cascade

Conclusion

- An analysis using HESE was developed for the first time for ARCA.
  - MAMBA (Algorithm to reject atmospheric muons and select HEST).
    - Very efficient for rejecting incoming / atmospheric muons.
    - Very efficient for rejecting atmospheric neutrinos accompanied by muons.
  - Algorithm for track / shower differentiation.
    - Very efficient > 92%.

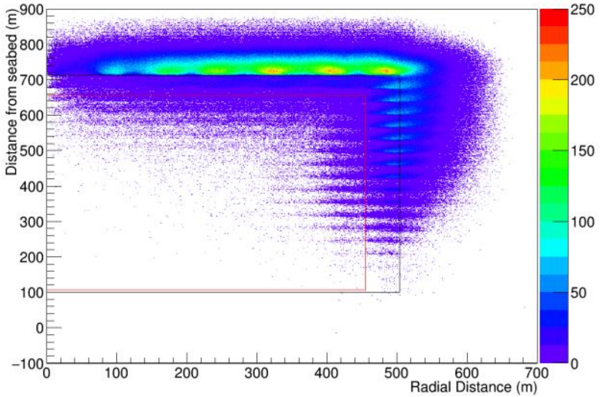
- We can confirm the IceCube astrophysical flux with a <u>significance of 5σ in less than a year with KM3NeT/ARCA!</u>

Thank you!

Questions?

Back up

MAMBA
Reconstructed vertices



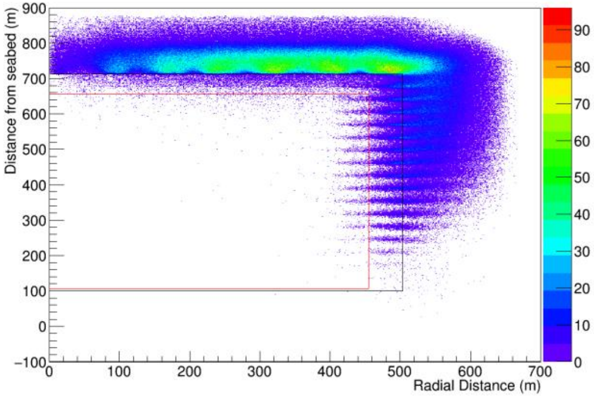
Atmospheric muons:

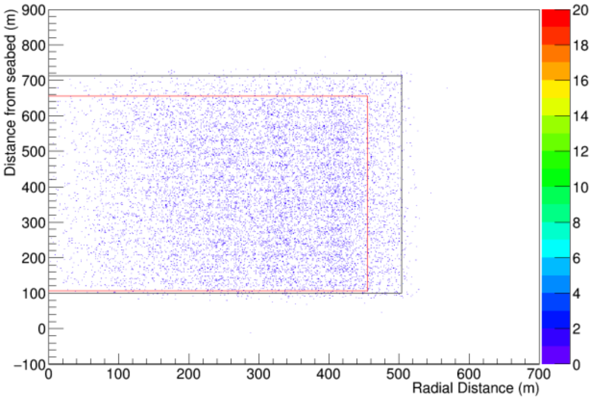
←Low energy sample

Reduction 84%

High energy sample→

Reduction 95%





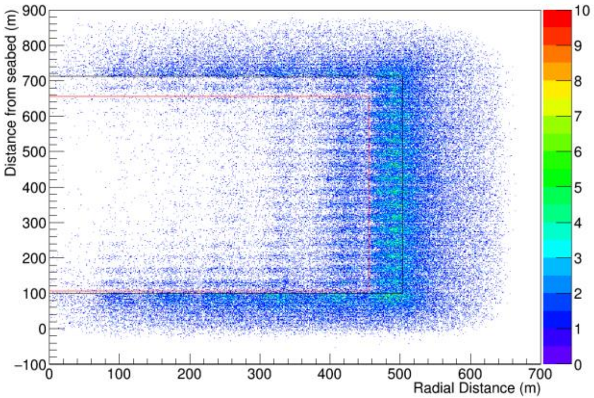
ν_μ events:

← Truly contained

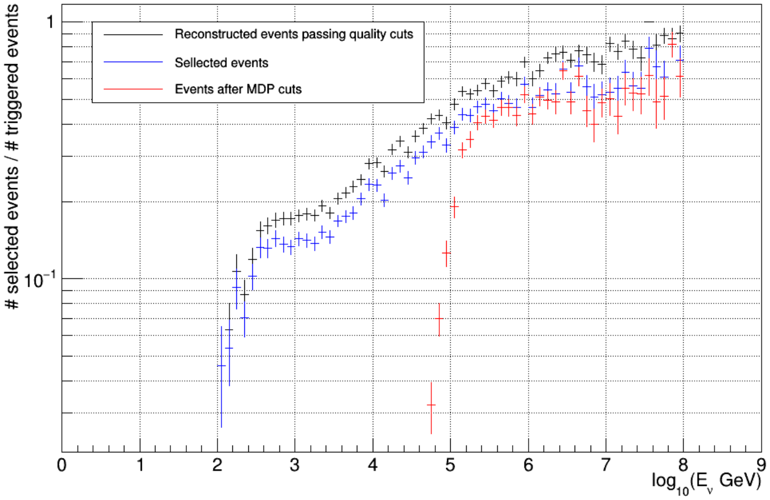
Reduction 17%

with ν vertex out of the det→

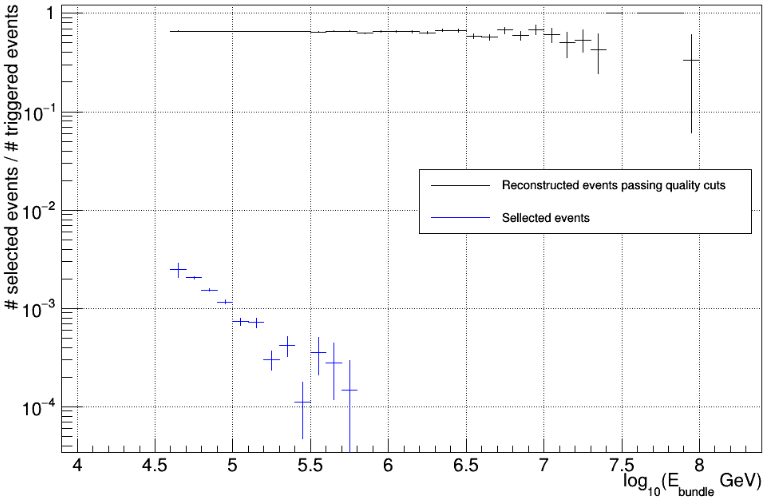
Reduction 63%



MAMBA
Efficiency after each step



Efficiency of truly contained track (ν_μ and anti ν_μ) events

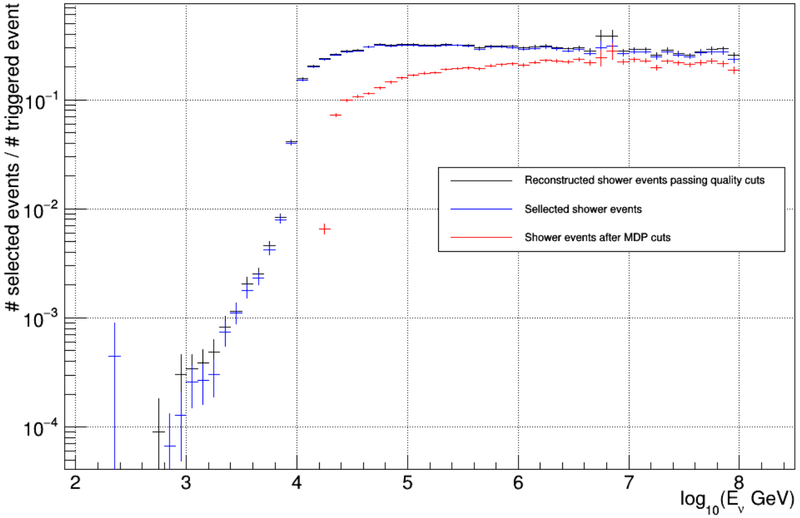


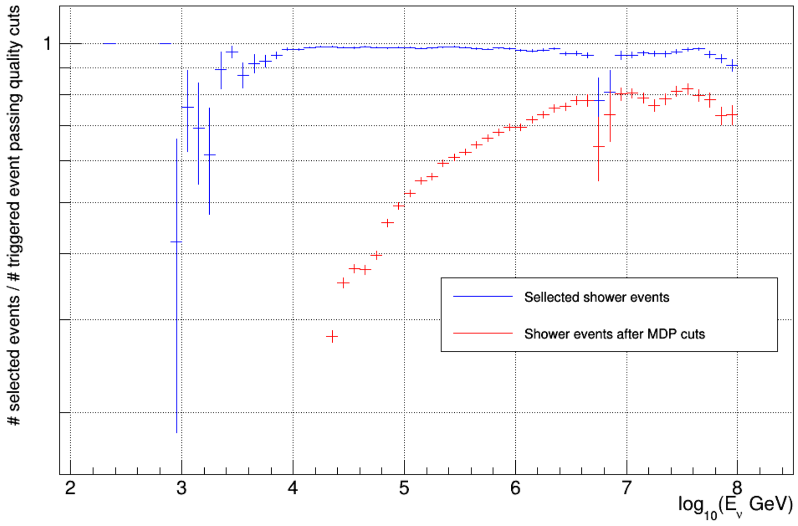
Efficiency of mupage $E_{bundle} \geq 50$ TeV events

Equivalent plot for track events interacting out of the detector in backup

HESE efficiency of shower sample after each step

Using the cuts for 5 σ discovery, efficiency for shower events (all NC + ν_e CC) :





HESE selected events

	shower sample		track sample	
Type of event	Signal	Background	Signal	Background
ν_μ CC	0.72	3.58	0.80	0.61
ν_μ NC	1.23	5.35	0.00	0.00
$\overline{\nu_\mu}$ CC	0.55	1.68	0.73	0.38
$\overline{\nu_\mu}$ NC	0.95	2.07	0.00	0.00
all ν_μ	3.45	12.68	1.96	0.99
ν_e CC	10.41	4.32	0.01	0.00
ν_e NC	1.22	0.38	0.00	0.00
$\overline{\nu_e}$ CC	9.22	3.27	0.08	0.00
$\overline{\nu_e}$ NC	0.97	0.26	0.00	0.00
all ν_e	21.82	8.23	0.09	0.00
ν_τ CC $\rightarrow \mu$	0.23	-	0.06	-
ν_τ CC$\rightarrow$ shower	5.96	-	0.02	-
ν_τ NC	1.28	-	0.00	-
$\overline{\nu_\tau}$ CC $\rightarrow \mu$	0.14	-	0.05	-
$\overline{\nu_\tau}$ CC$\rightarrow$ shower	4.69	-	0.02	-
$\overline{\nu_\tau}$ NC	0.97	-	0.00	-
all ν_τ	13.27	-	0.15	-
μ_{atm} $E_{bundle} \geq 10$ TeV	-	0	-	0
μ_{atm} $E_{bundle} \geq 50$ TeV	-	2.84	-	0.08
total	38.54	23.76	1.77	1.07

Table 6: Number of expected signal and background events for all types of events, for the cuts used for the minimum MDP for 5σ with a probability of 90%, for 0.8 years for both shower and HEST categories.

Track Sample

- MDP technique gives different cuts on the reconstructed energy and on the BDT value for each sample.
- For the track sample:
  - Higher cut on the reconstructed energy.
  - Cut at reconstructed track E ≥ $10^{5.2}$ - $10^{5.3}$ GeV.
- Softer cuts on the reconstructed energy like E ≥ $10^{5.0}$ GeV, also allow just a minimal contribution of atmospheric muon events in the final sample.
  - Increase in signal (astro ν) ~ 90%.
  - Increase in background (atm ν)~ 280%.
- Shower sample is “large”, and the contribution of atmospheric ν_μ is greater that ν_e. So cuts in high values of the track reconstructed energy are favored.