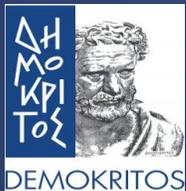


Atmospheric neutrinos with the first detection units of KM3NeT - ARCA

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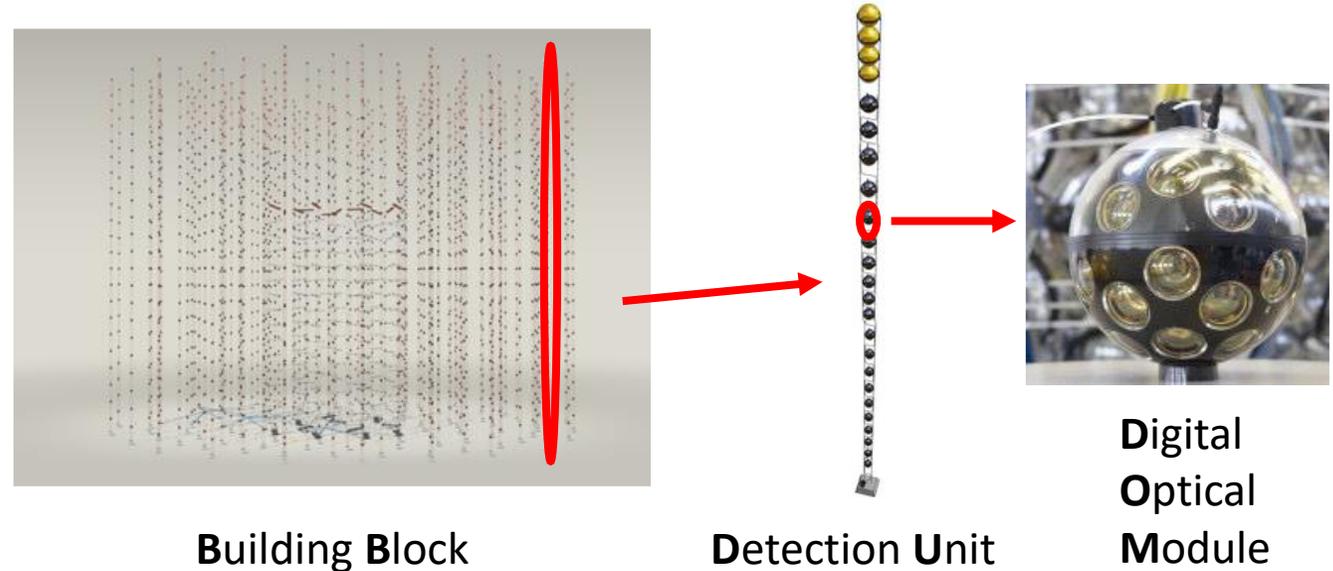


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2 detectors in the Mediterranean Sea:

- **ORCA** @2450 m: Dedicated to low energy neutrino oscillation studies.
- **ARCA** @3500 m: Dedicated to high energy neutrino astronomy.



ARCA will consist of **2 blocks** with **115 Detection Units (DUs) each**, with **90 m** distance between them. The ARCA DU is a vertical slender string equipped with **18 Digital Optical Modules (DOM)** 36 m distant. Each DOM is equipped with **31 3" PMTs**.

Atmospheric muons and neutrinos are expected to dominate the observed rate, but

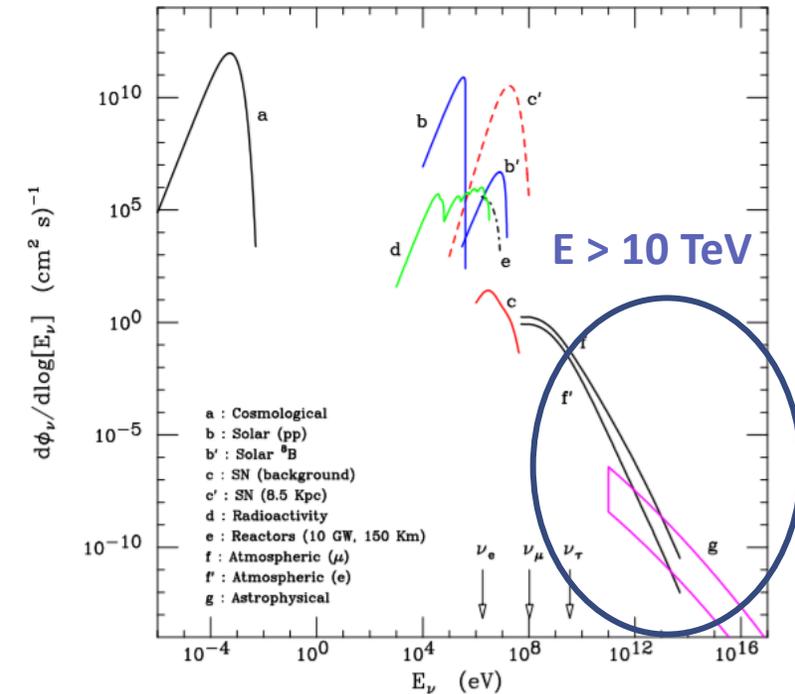
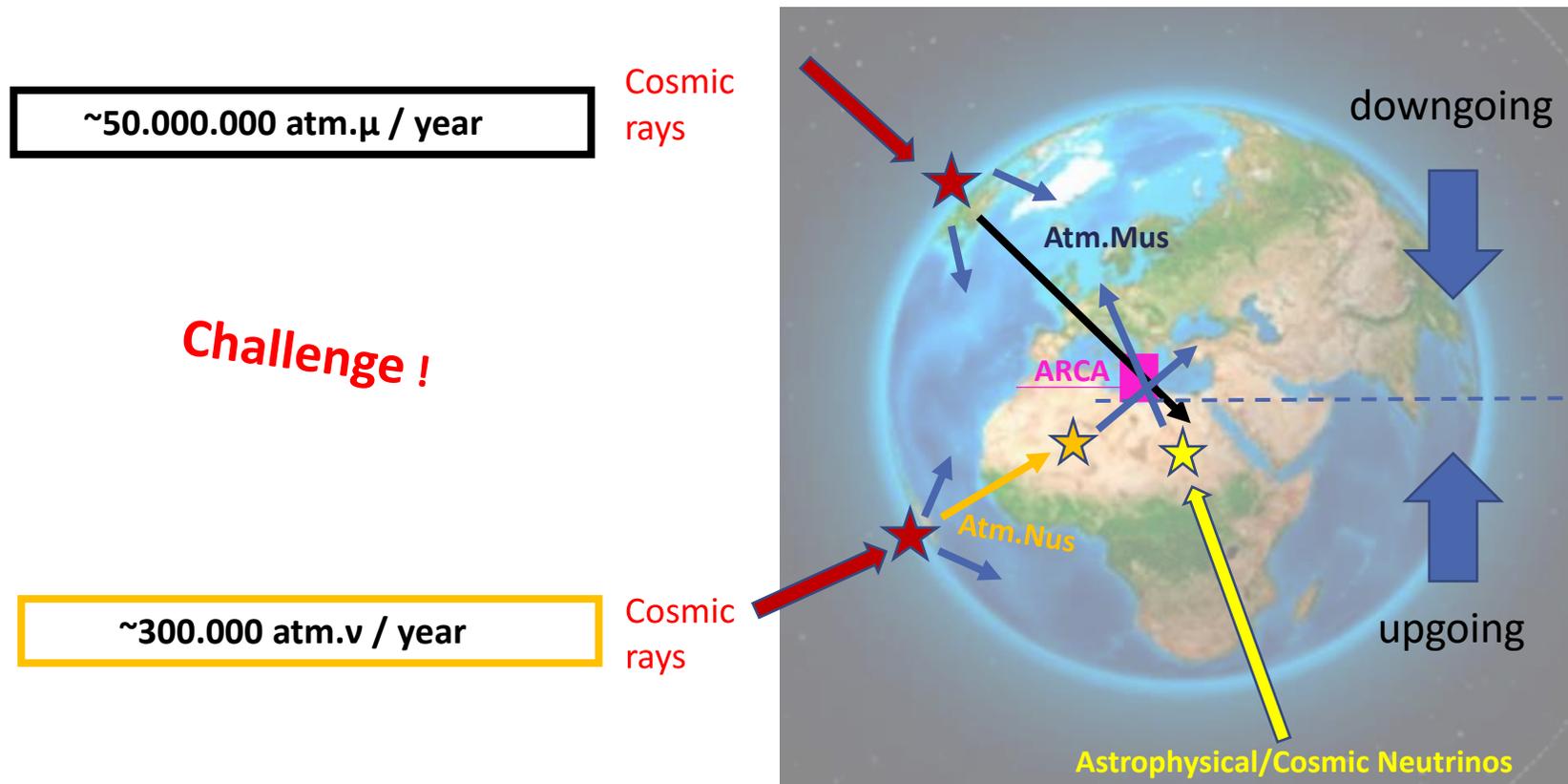


ARCA goal: Detection of high energy astrophysical neutrinos -
detection of astrophysical point sources.

**0.1° expected angular resolution
for E > 100 TeV**

Essential step for detecting neutrinos of astrophysical origin is **the rejection of the background from atmospheric muons**.

To detect astrophysical neutrinos, we investigate the very high energy region of the spectrum where the atmospheric neutrino rate is expected to be lower than the astrophysical one.



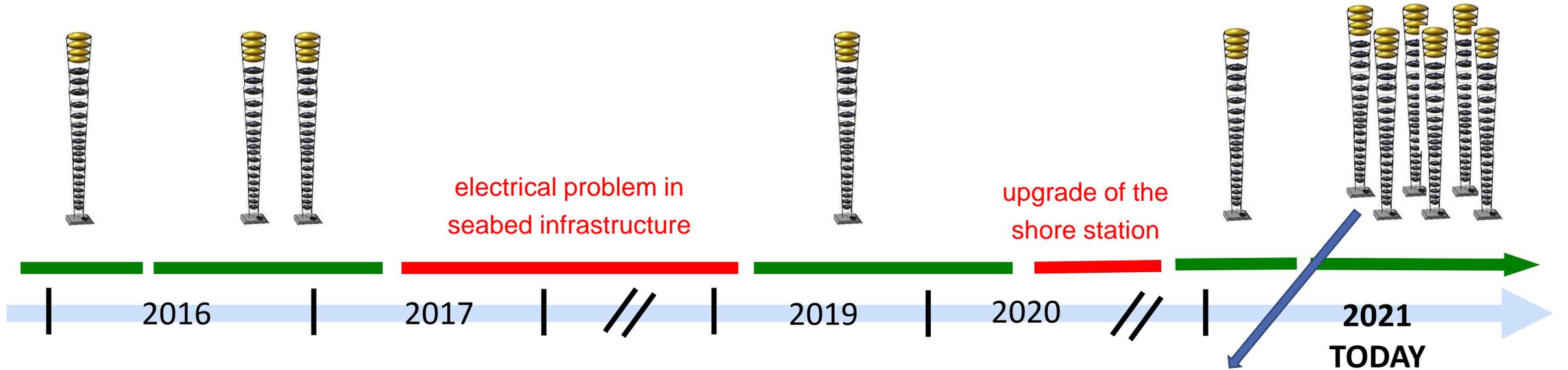
“INTRODUCTION TO NEUTRINO PHYSICS”, Paolo Lipari, <https://cds.cern.ch/record/677618/files/p115.pdf>

~600 ν of astrophysical origin / year

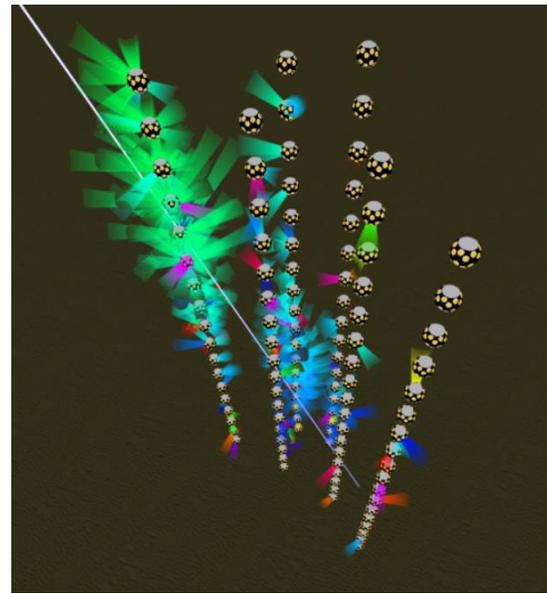
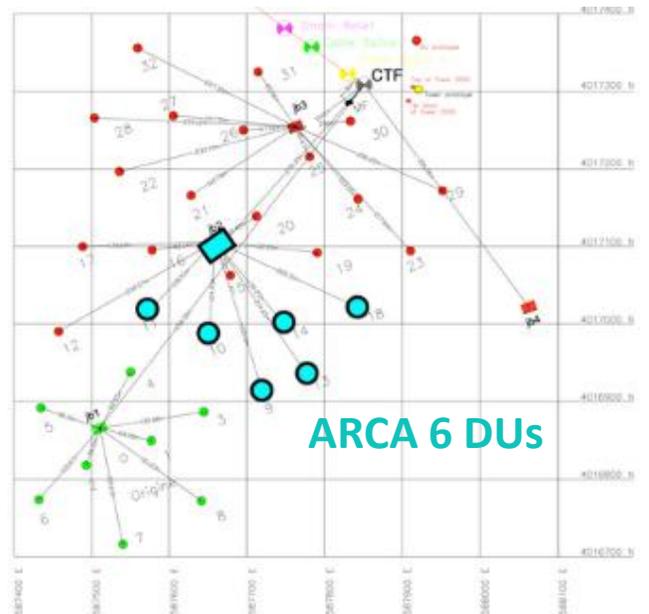
- Numbers refer to ARCA with 2 building blocks of 115 DUs each
- Applied astrophysical flux:

$$1.2 \cdot 10^{-4} \left(\frac{E}{\text{GeV}} \right)^{-2} e^{\left(-\frac{E}{3 \text{ PeV}} \right)} \text{ GeV}^{-1} \text{ m}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$

KM3NeT-ARCA: Construction phase

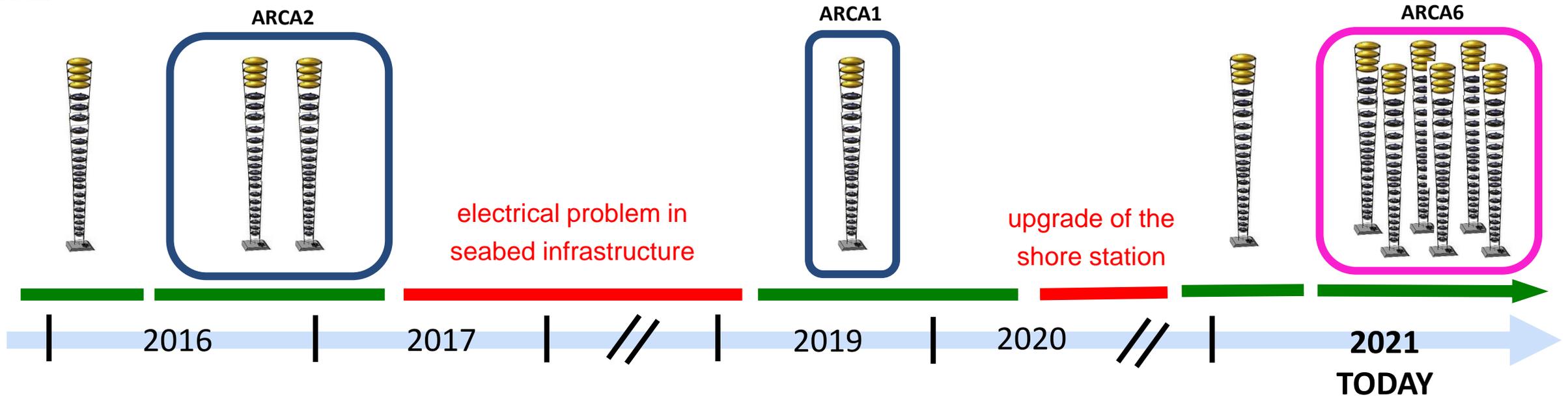


Current ARCA : 6 DUs
 1st ARCA Sector : 32 DUs



reconstructed event display

*Reminder:
 Full Building Block : 115 DUs
 Full ARCA detector : 230 DUs

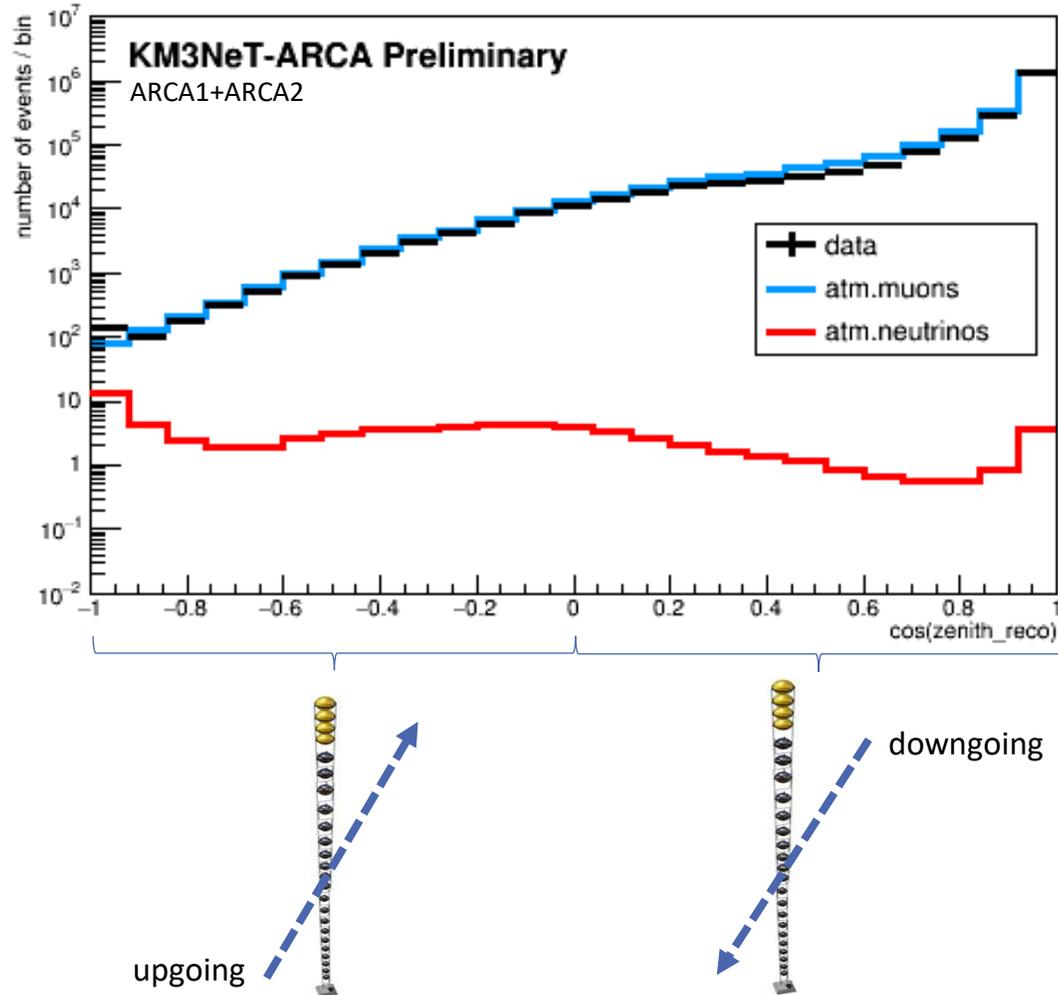


- **Atmospheric Neutrino** candidates from two different data taking periods:
 - 53 days of 2 operational DUs – ARCA2*
 - 207 days of 1 operational DU – ARCA1*

Goal of the analysis :
 ~1% volume ➡ capable of detecting atmospheric neutrinos

- Status and detection prospects for the current ARCA configuration with 6 operational DUs (ARCA6).

All reconstructed events



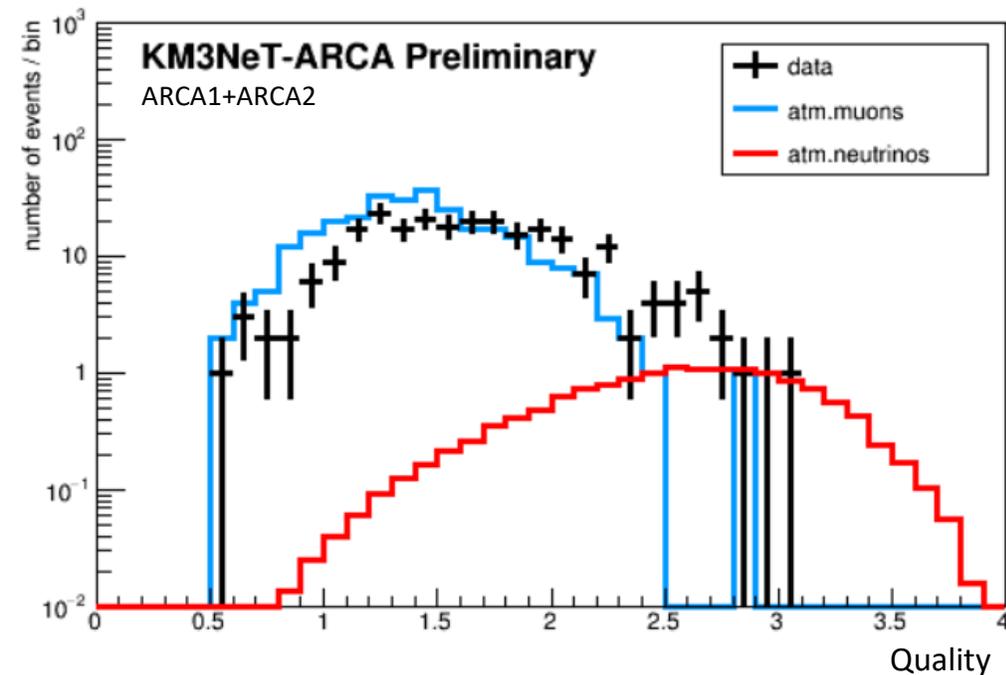
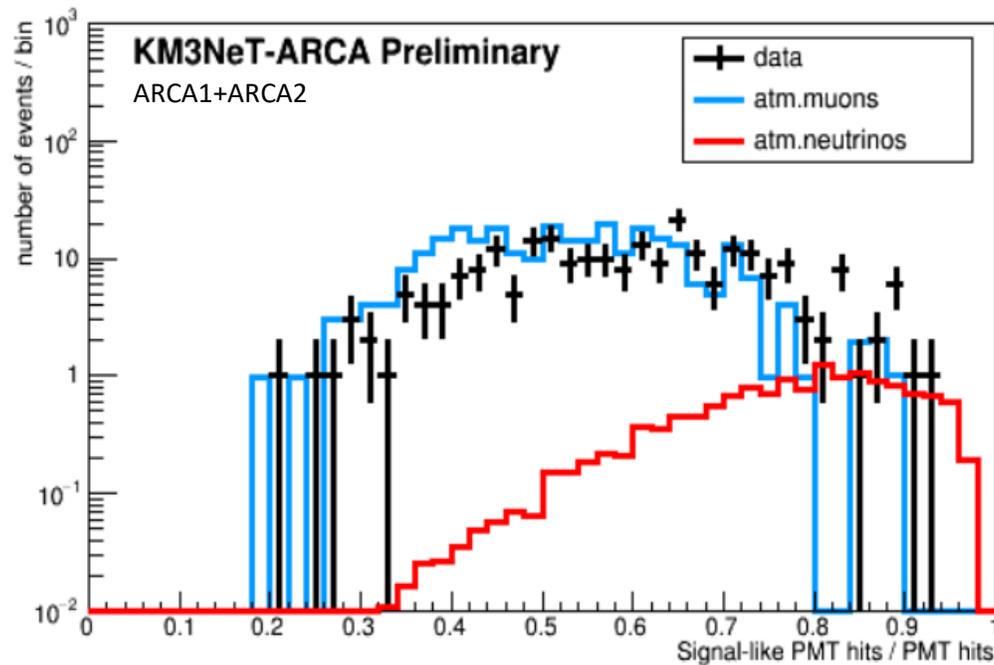
The atmospheric muon contribution dominates the observed rate.

Atmospheric muons come from the upper part of the detector;
however, they may be mis-reconstructed as upgoing events.

The search for atmospheric neutrinos is focused on the upgoing muon track as atmospheric muons are totally absorbed by Earth.

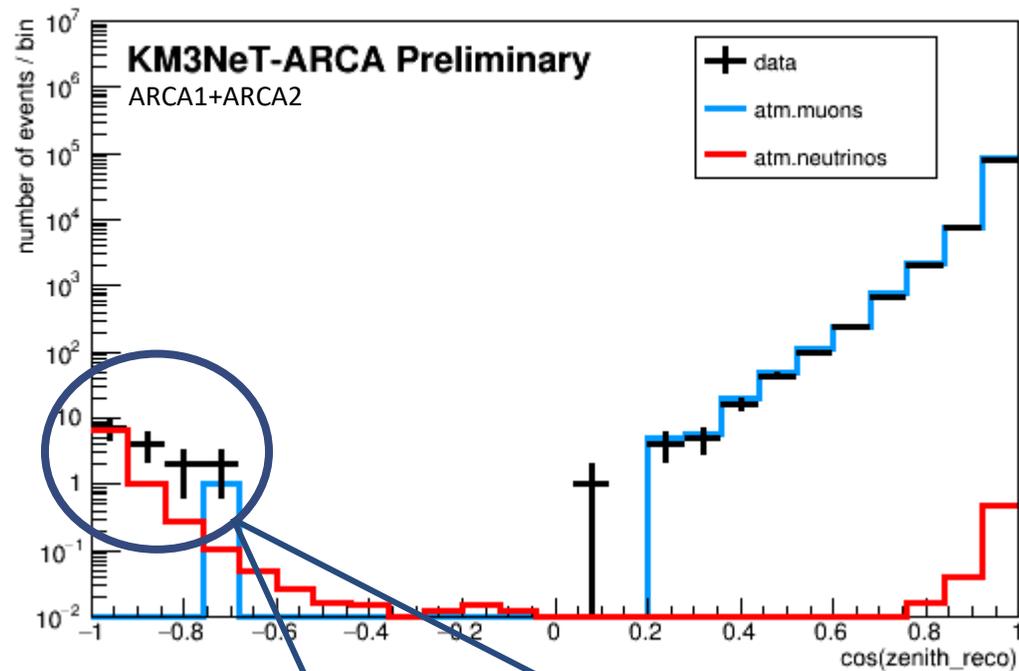
In order to reject mis-reconstructed atmospheric muons, selection requirements were applied based on quality criteria.

Two of the observables used for event selection are shown for an intermediate step of the analysis, for upgoing events*.



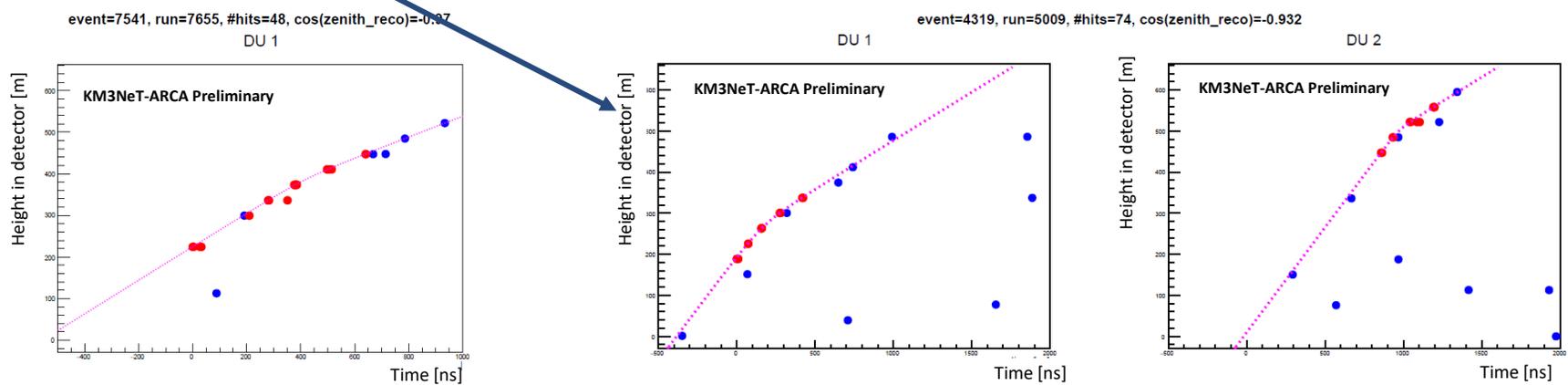
*details in the proceedings

After the selection requirements

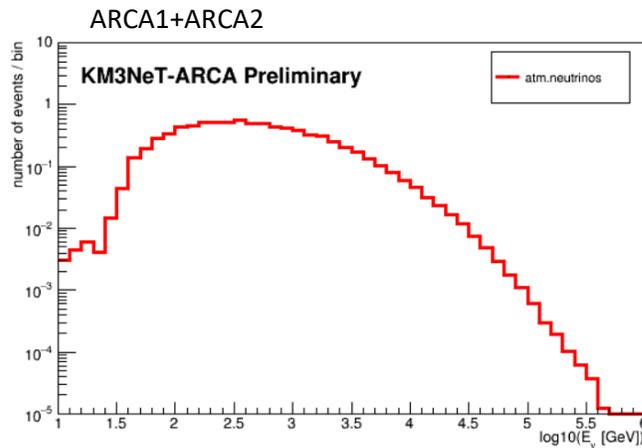
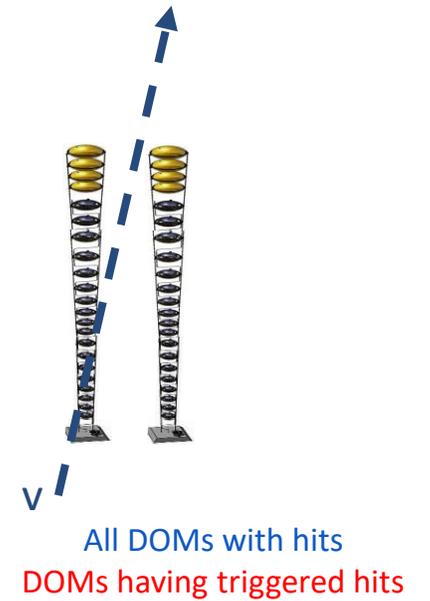
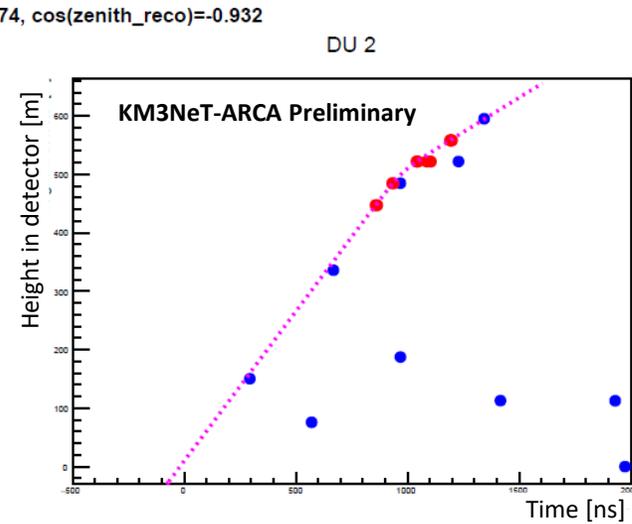
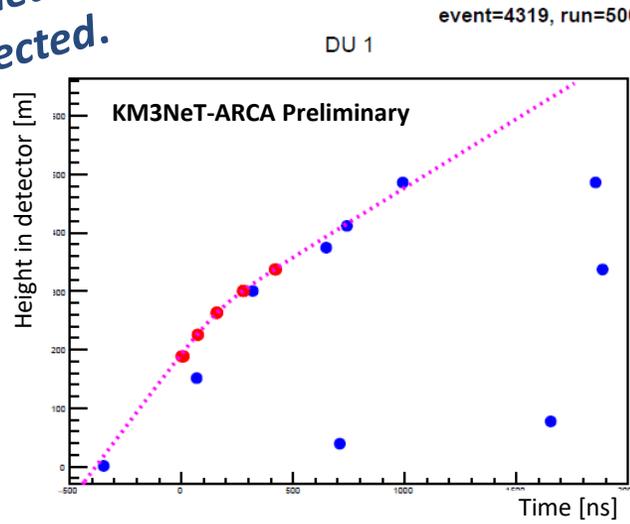


A set of reconstruction quality requirements was applied in order to reject mis-reconstructed atmospheric muon events.

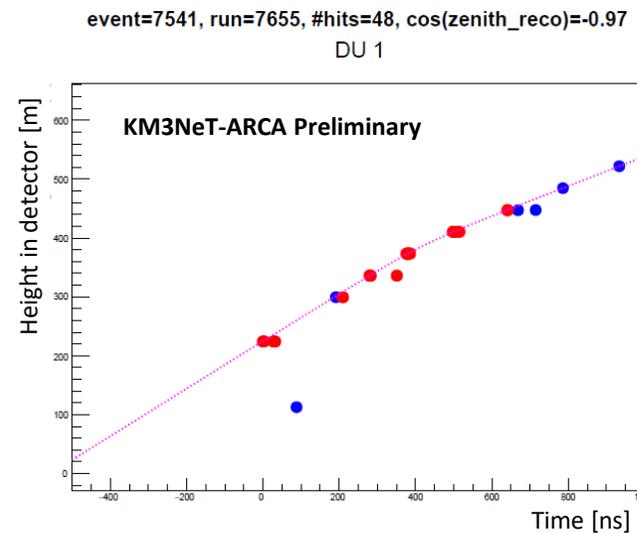
15 events observed as neutrino candidates
 (8 events expected from atmospheric ν ,
 1 coming from atmospheric μ background).



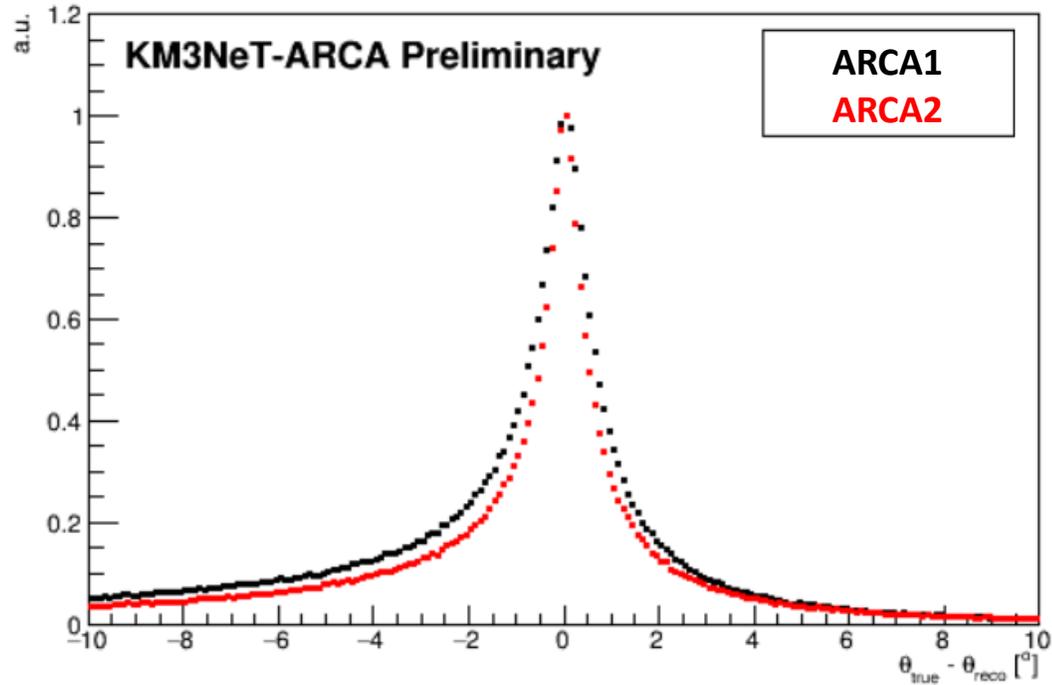
Upward going atmospheric neutrino candidates have been selected.



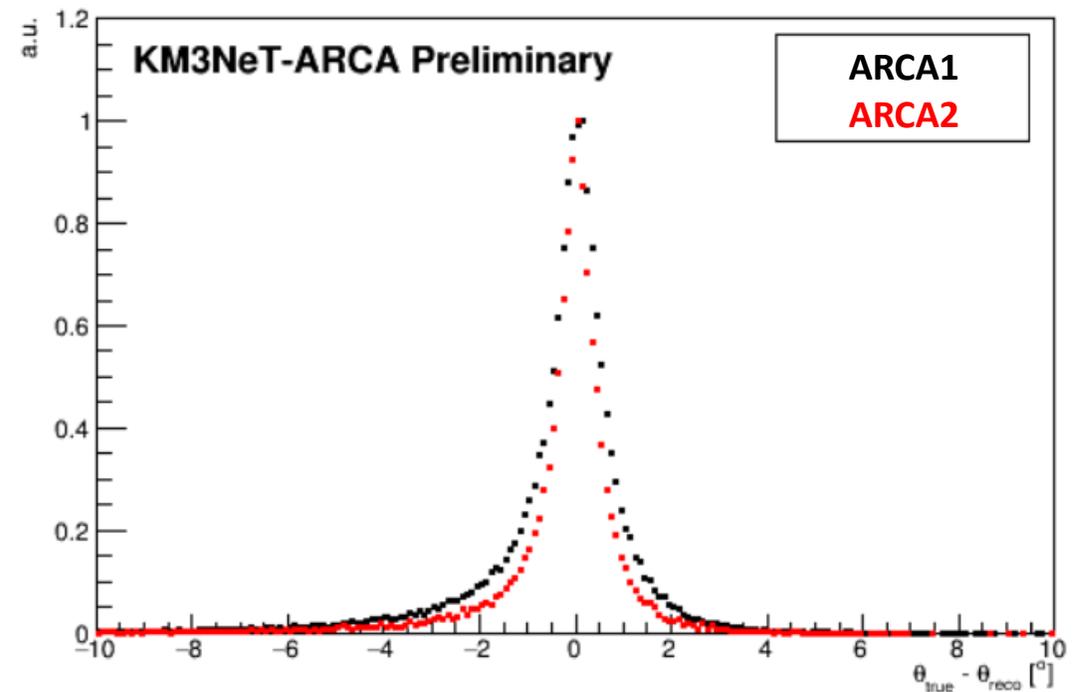
True (MC) neutrino energy for upgoing events expected to fulfill the selection criteria.



All reconstructed events



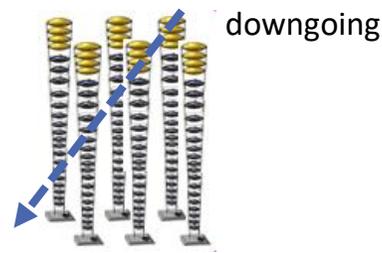
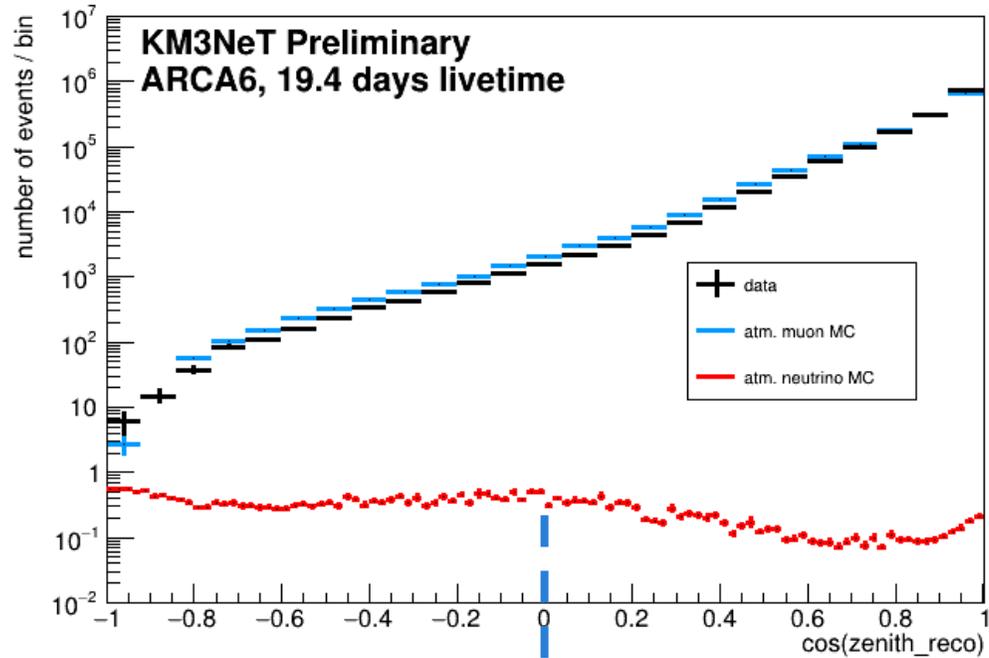
After the selection requirements



A zenith angle resolution of 1.4° (ARCA1) and 1.1° (ARCA2) is obtained for **all reconstructed events**.

A zenith angle resolution of 1° (ARCA1) and 0.7° (ARCA2) is obtained for **events fulfilling the selection requirements**.

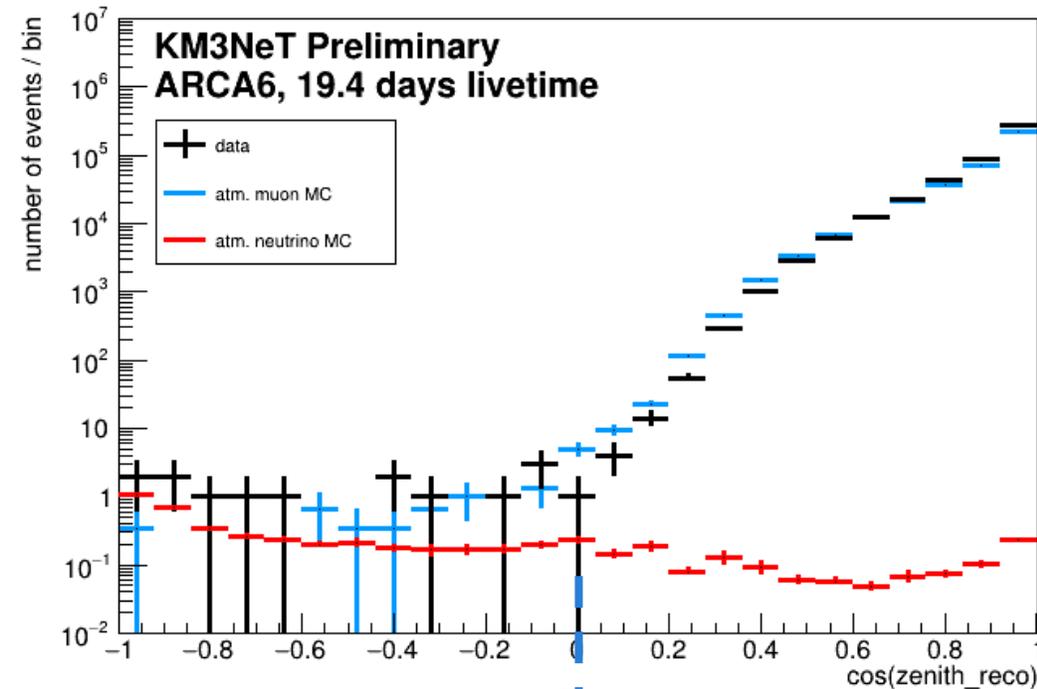
All reconstructed events



Reasonable Data/MC agreement.

Loose selection requirements are applied due to the limited livetime* and **15 events are observed as upward going** (4 events expected from atmospheric ν , 7 coming from atmospheric μ background).

After the selection requirements

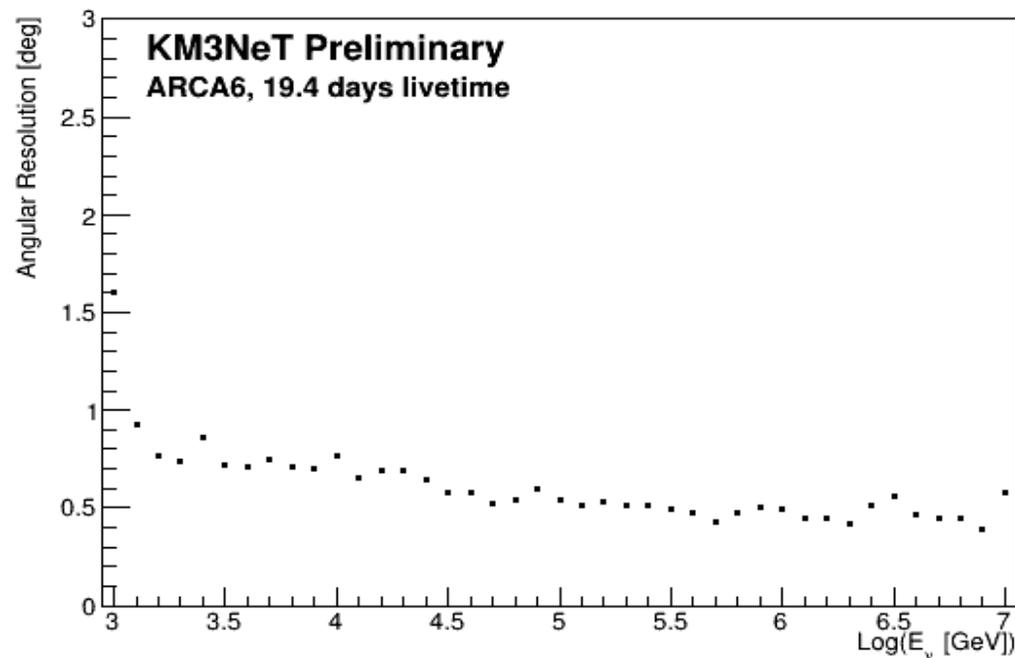


*details in the proceedings

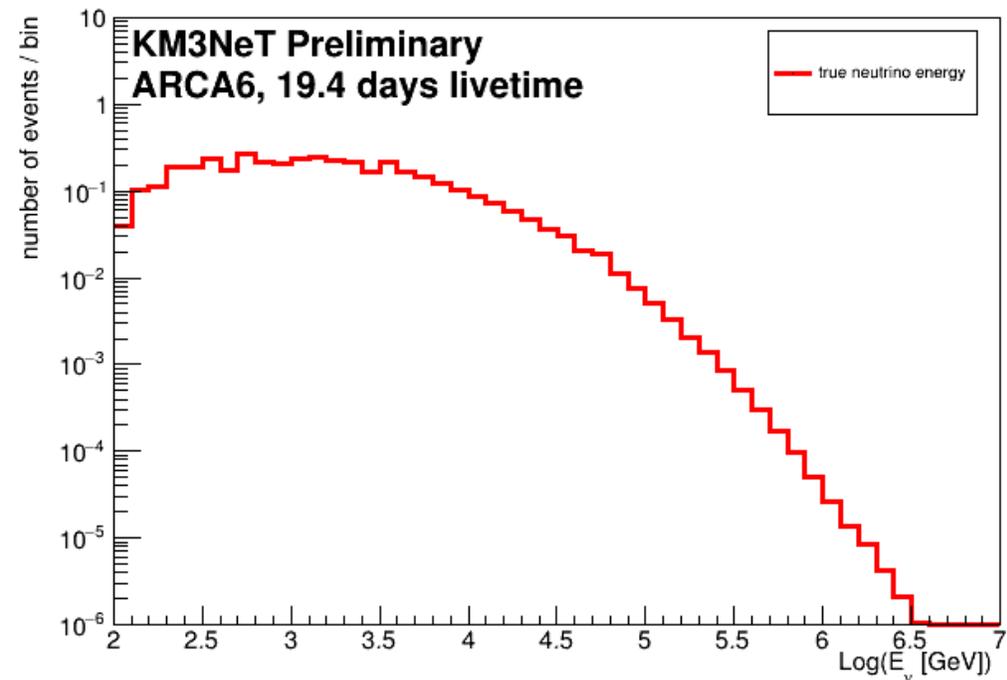
$\nu + \bar{\nu}$ CC MC

Excellent angular resolution at high energies already with ARCA6 !

A larger sample of events with low energy survives the selection criteria; below the energy range for which ARCA is optimized. \longrightarrow Selection of neutrino candidates is challenging.



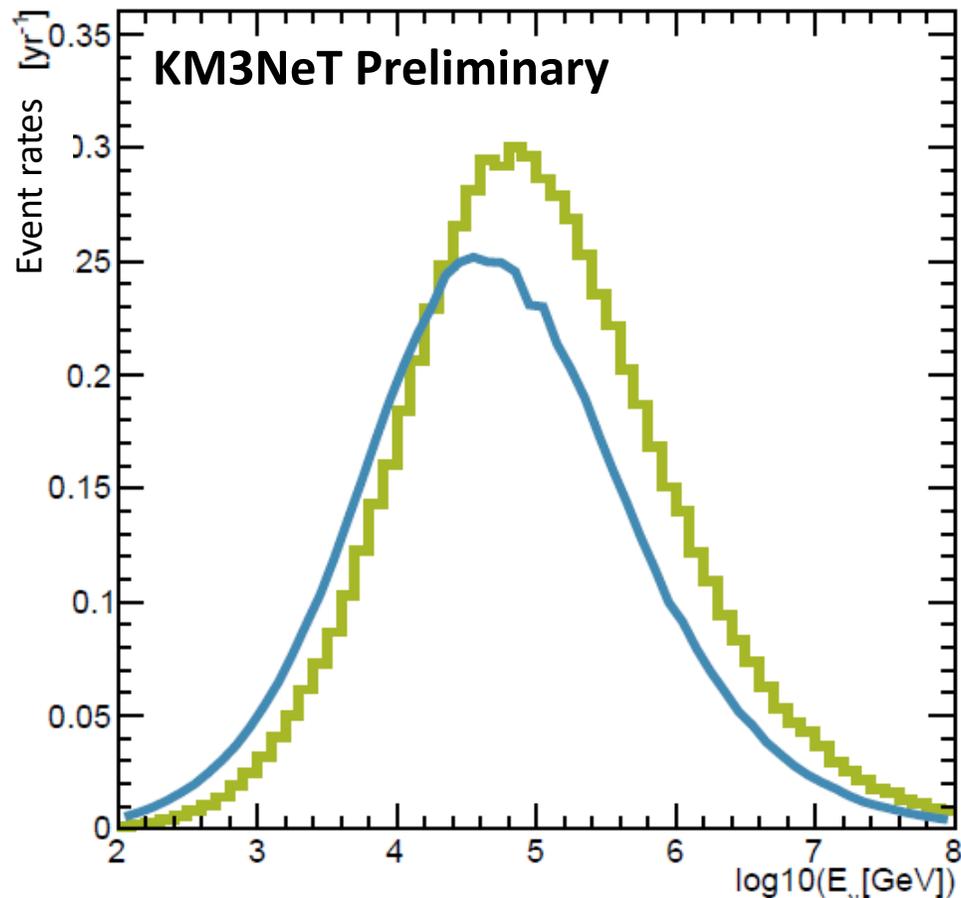
The **median of the angular resolution** for events expected to fulfill the selection criteria is **0.75°**.



The **true (MC) neutrino energy** for upgoing events expected to fulfill the selection criteria.

Expected neutrino diffuse flux

Event rates [yr^{-1}] for $\bar{\nu}_{\mu}^{\text{CC}} + \nu_{\mu}^{\text{CC}}$ [reco, up]



Applied flux = $1e-4 (E/\text{GeV})^{-2} \text{ GeV}^{-1} \text{ m}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$

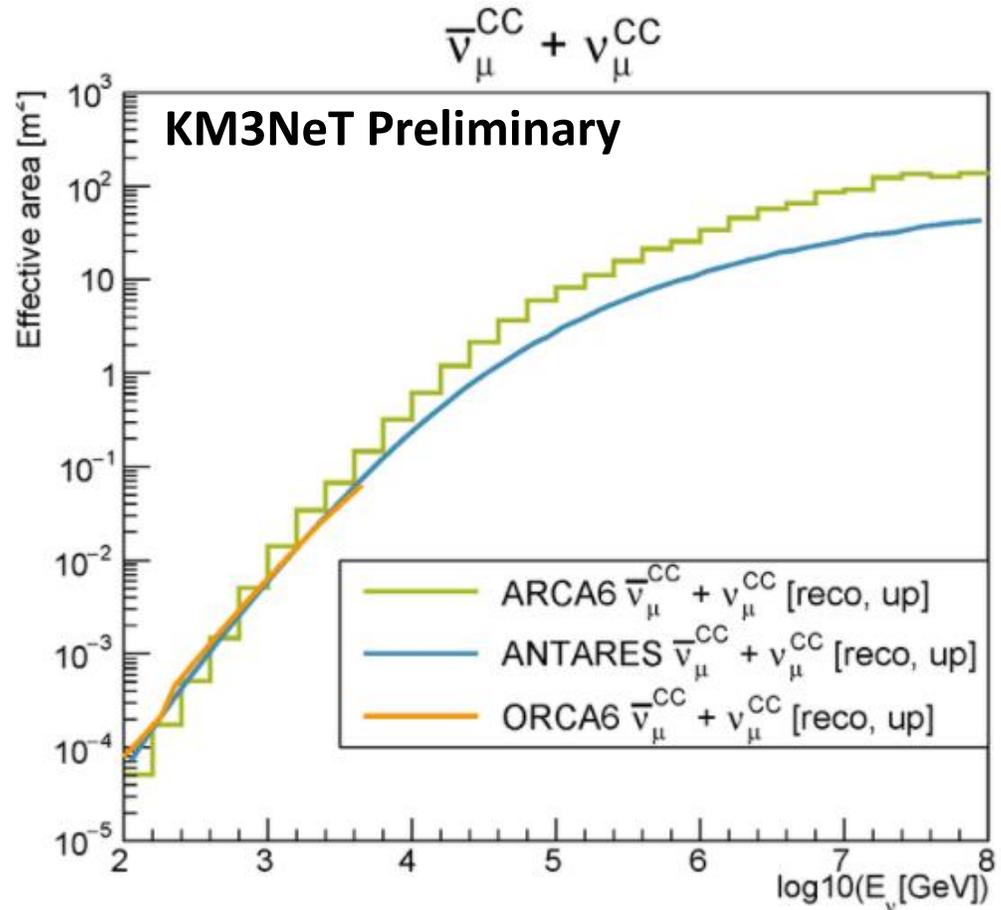
- ARCA6 $\bar{\nu}_{\mu}^{\text{CC}} + \nu_{\mu}^{\text{CC}}$ [reco, up] (tot=6.8/yr)
- ANTARES $\bar{\nu}_{\mu}^{\text{CC}} + \nu_{\mu}^{\text{CC}}$ [reco, up] (tot=6.0/yr)

Comparing to the ANTARES performance, larger number of neutrino events is expected at high energies.

Most of the events are expected for $E > 40 \text{ TeV}$.

11.5 upgoing ev/y are expected for the applied astrophysical diffuse flux.

FLAVOUR	Upgoing Events / Year
$\nu_{\mu}^{\text{CC}} + \bar{\nu}_{\mu}^{\text{CC}}$	6.8
$\nu_{e}^{\text{CC}} + \bar{\nu}_{e}^{\text{CC}}$	1.7
$\nu_{\tau}^{\text{CC}} + \bar{\nu}_{\tau}^{\text{CC}}$	2.0
All NC	1.0

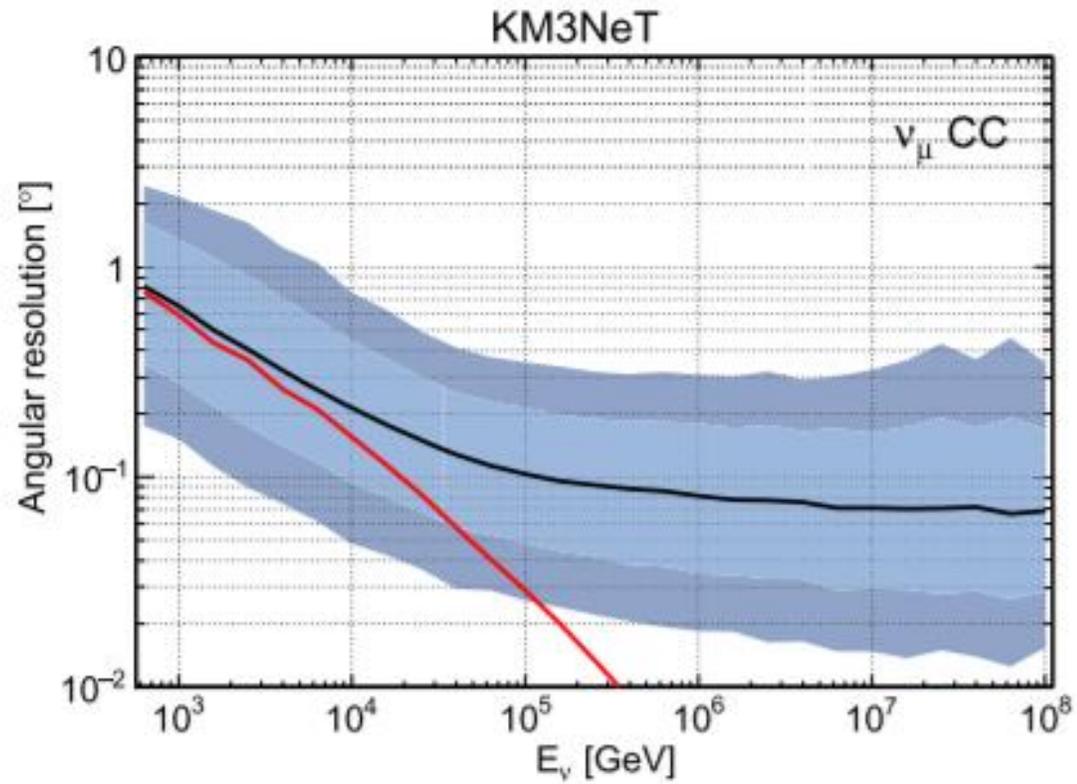


Performance comparison of ARCA6, current ORCA with 6 DUs (ORCA6) and ANTARES configurations.

ARCA6 and ANTARES have comparable effective areas for low energies. For $E > 10$ TeV, *ARCA6 has significantly higher effective area.*

In the energy range between 100 GeV and 10 TeV, ARCA6 and ORCA6 configurations have comparable effective areas.

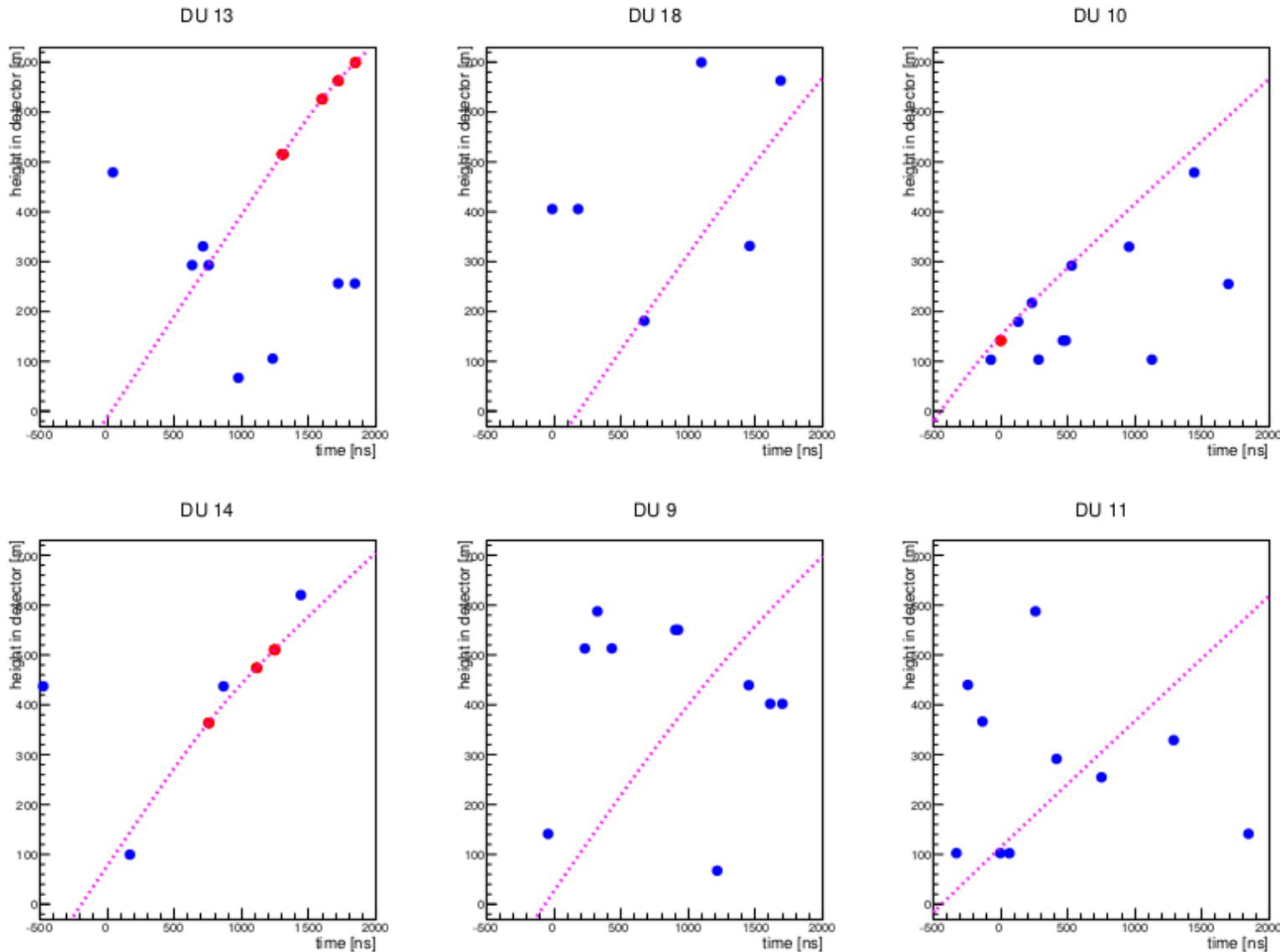
- ARCA is in the construction phase. Currently 6 operational DUs.
- Atmospheric neutrino candidates detected from different data taking periods of ARCA.
- Even with ~1% instrumented volume ARCA can detect *atmospheric neutrinos!*
- *260 days of ARCA with 1 DU & 2 DUs in operation:*
 - *15 atmospheric neutrino candidates observed.*
 - *Muon zenith angle resolution: 1° (ARCA1) and 0.7° (ARCA2).*
- *First results show reasonable Data/MC agreement for ARCA6. Indications of upgoing neutrino events already from ~19 days of livetime.*
- *An angular resolution of 0.75° is expected after the event selection.*
- *11.5 upgoing neutrino ev/y are expected; comparable to ANTARES*
 - * *astrophysical diffuse flux: $10^{-4} \left(\frac{E^{-2}}{\text{GeV}} \right) \text{GeV}^{-1} \text{m}^{-2} \text{s}^{-1} \text{sr}^{-1}$*
- *ARCA6 and ORCA6 effective areas comparable to that of ANTARES for $E < 10 \text{ TeV}$; ARCA6 significantly larger than ANTARES for $E > 10 \text{ TeV}$.*



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An angular resolution better than 0.1° is reached for events with energy higher than 100 TeV.

event=299071, run=9672, #hits=178, cos(zenith_reco)=-0.969



Indications of upgoing tracks from neutrinos even in ~19 days of the recently operating 6 lines in ARCA.

All DOMs with hits
DOMs having triggered hits