Introduction to Neutrino Astronomy and KM3NeT-Cubic Kilometre Neutrino Telescope

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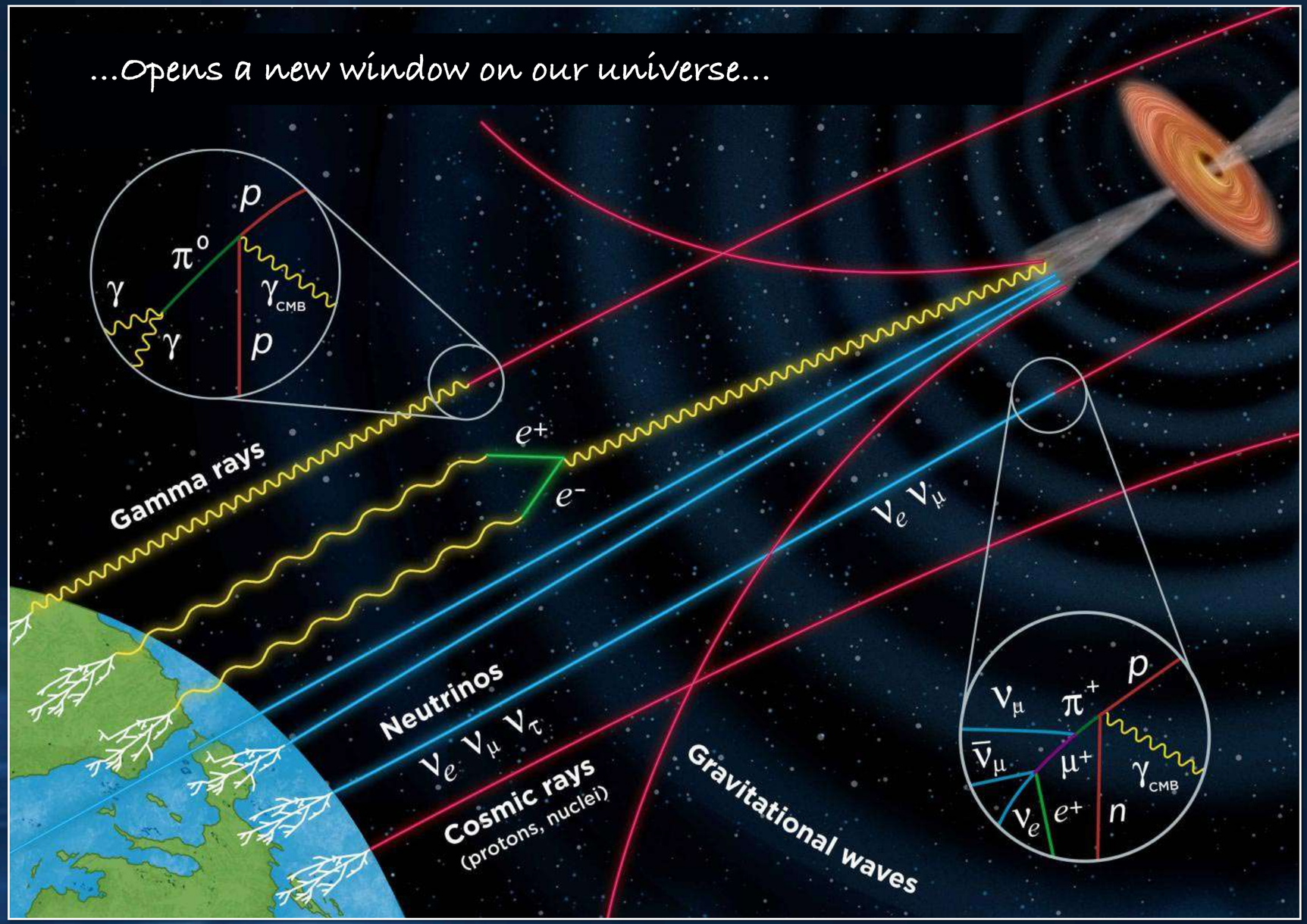
on behalf of the KM3NeT Collaboration

1st Astrophysics in the New Era of MM Astronomy International Conference

4-8 Dec 2023, Poços de Caldas, Brazil

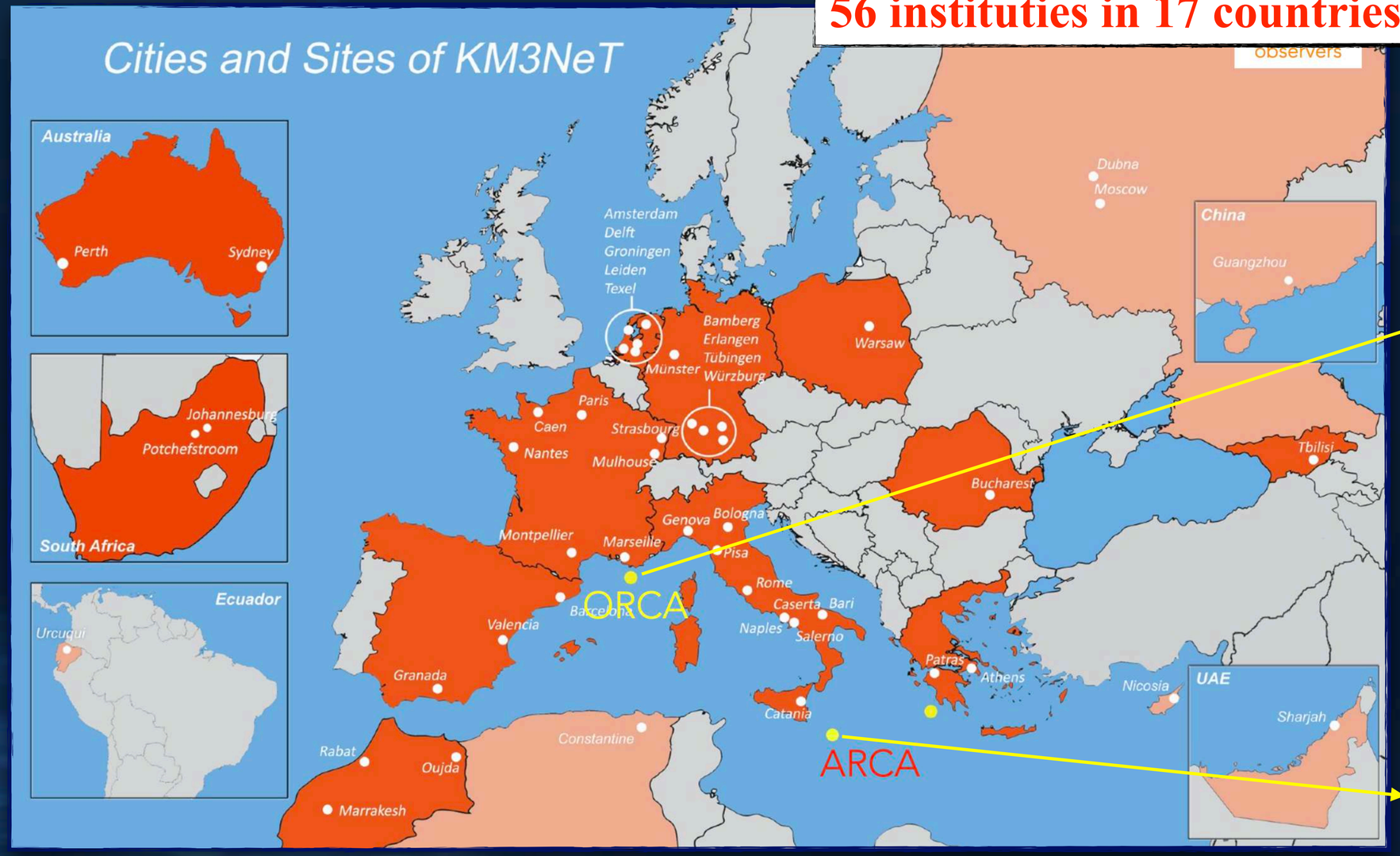
Neutrino Astronomy



- Neutrinos: neutral, stable, weakly interacting
  - -not absorbed by background light/CMB (access to cosmological distances)
  - -not absorbed by matter (access to dense environments)
  - -not deviated by magnetic fields (astronomy over a wide energy range)
- 'Smoking gun' signature for hadronic processes
- Correlated in time/direction with electromagnetic and gravitational waves: Multi Messenger Astronomy

The KM3NeT Collaboration

56 instituties in 17 countries

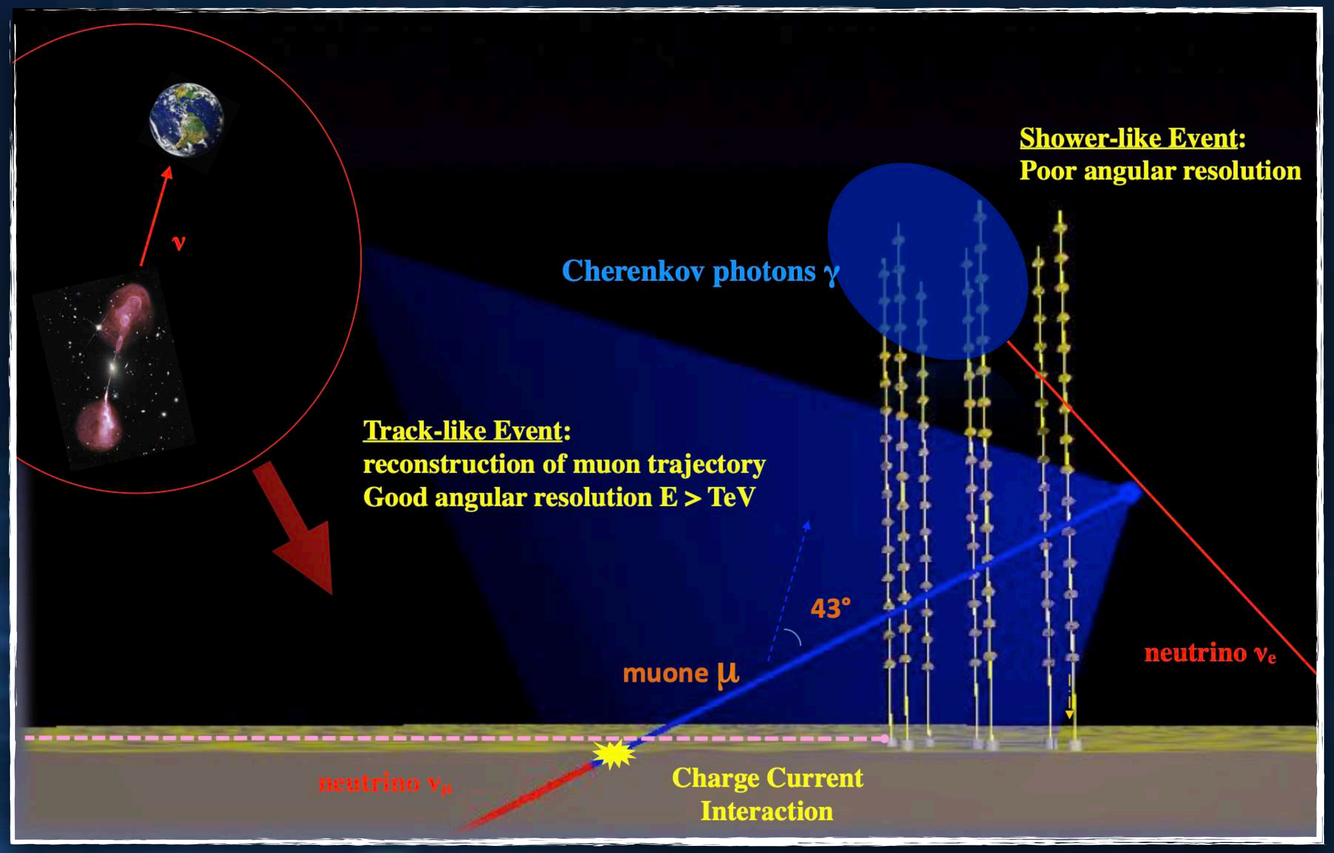


ORCA (Oscillation Research with Cosmic in the Abyss)

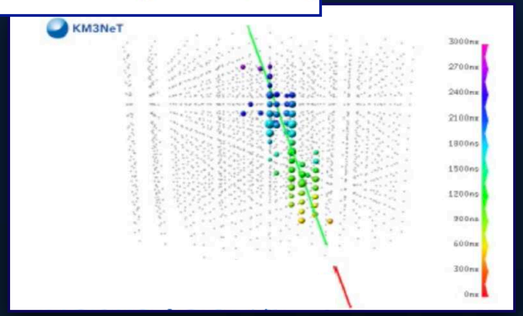
ARCA (Astroparticle Research with Cosmics in the Abyss)

Cosmic neutrino detection principle

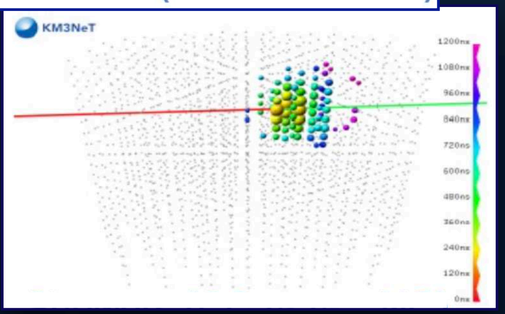
- Detection of Cherenkov photons induced by the neutrino interaction products using a 3D array of optical sensors
- Large volume of transparent medium to detect cosmic neutrinos ⟶ water/ice
- Time, position and amplitude of PMT pulses (hits) allow both direction and energy reconstruction

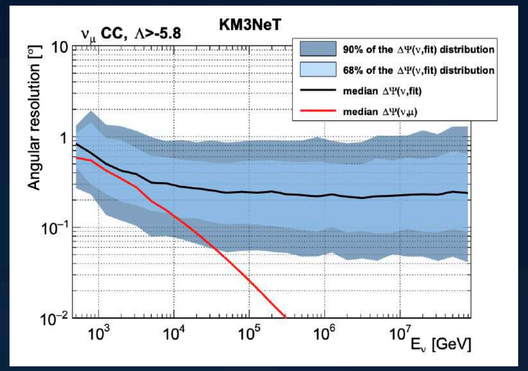


Tracks (CC ν_μ ν_τ)

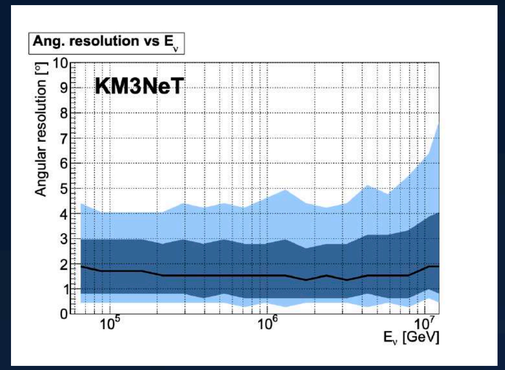


Showers (CC ν_e ν_τ – NC)





Angular ~0.1° at 100 TeV



Angular ~1° at 100 TeV

The KM3NeT technology and infrastructure

The basic elements:

- DOM (Digital Optical Module)
- DU (Detection Unit)
- Seafloor network: electro-optical cables and JBs (Junction Boxes)

DOM

- 17” glass sphere with 31 3” PMTs
- LED and Piezo
- Front-end electronics

DU

- ~ 250/750 m (ORCA/ARCA)
- 18 DOMs (~9/36 m btw DOMs)
- Anchor
- Buoy

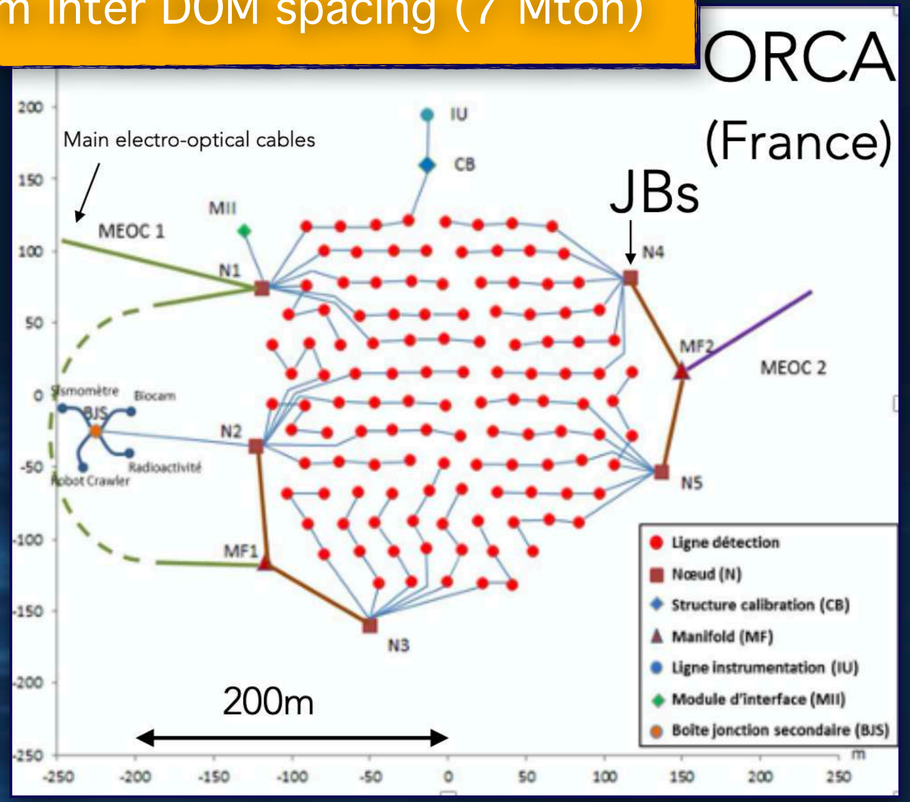
JB

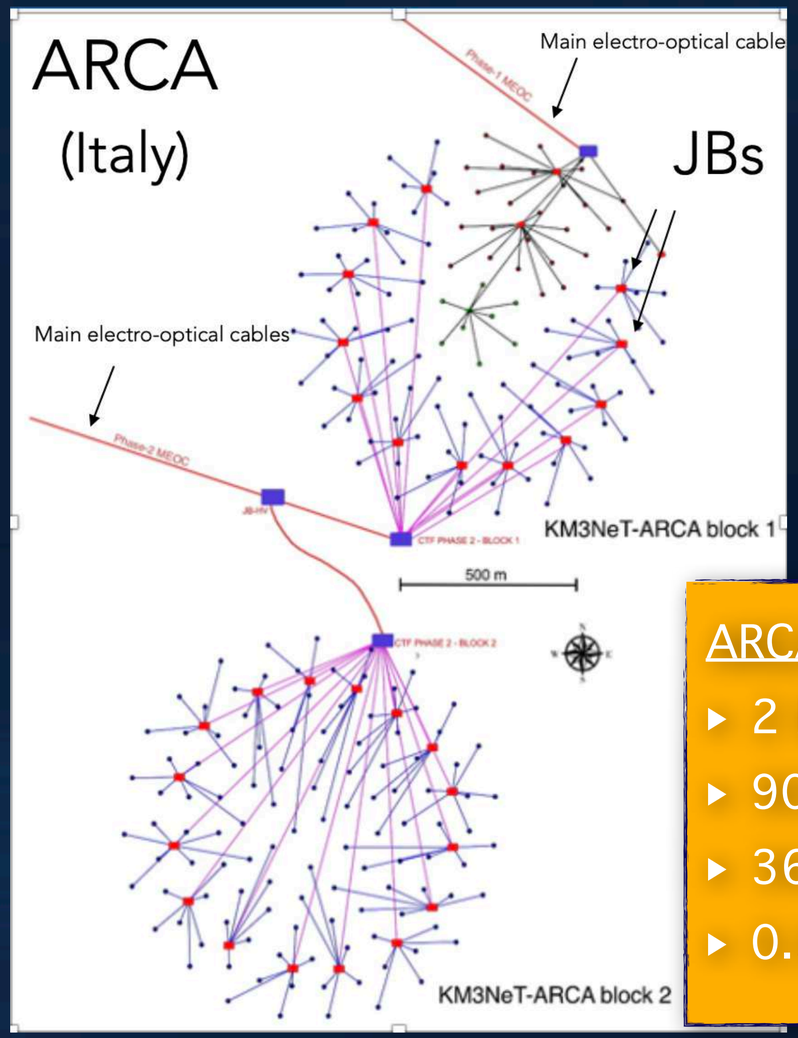
The KM3NeT technology and infrastructure

All data to shore

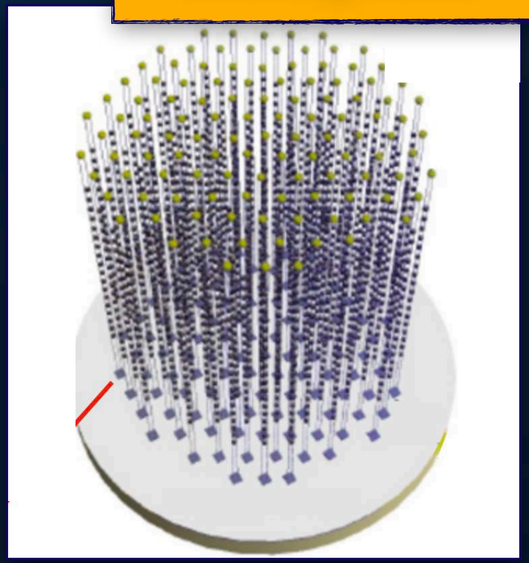
ORCA:

- 1 building block (BB) of 115 DUs
- 20 m DU interspacing
- 9 m inter DOM spacing (7 Mton)





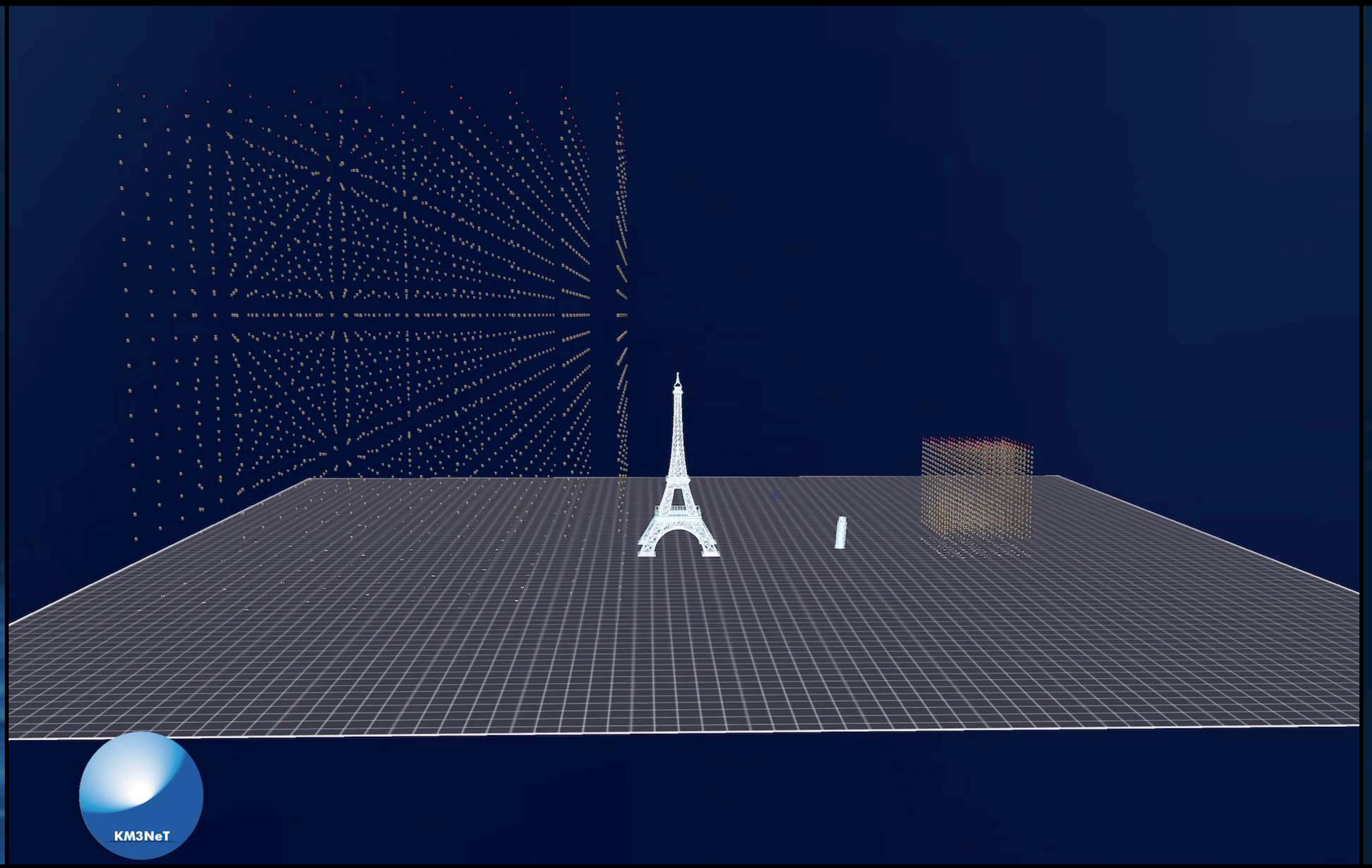
Building Block



ARCA:

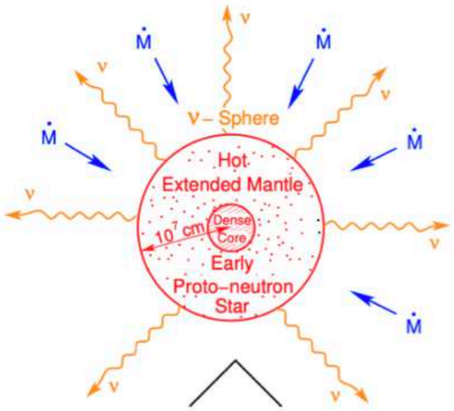
- 2 building blocks of 115 DUs
- 90 m DU interspacing
- 36 m inter DOM spacing
- 0.5 km3=500Mton/block

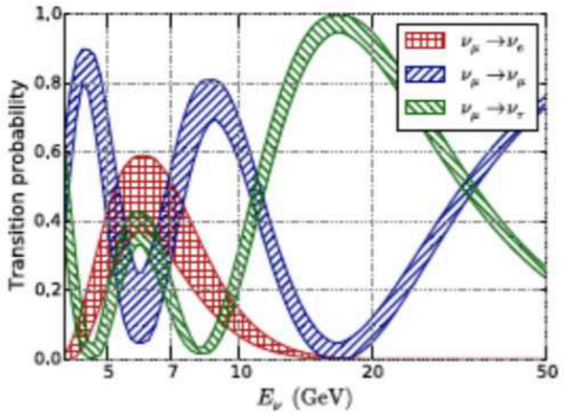
KM3NeT: ARCA and ORCA

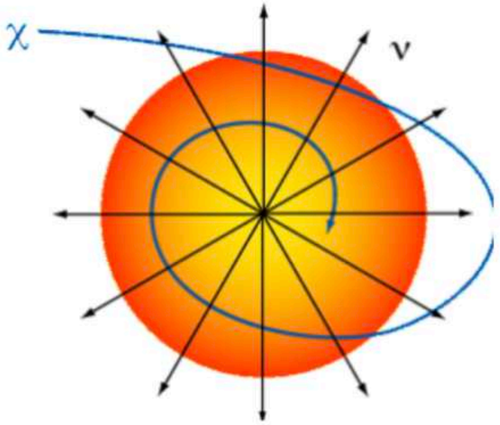


Neutrino telescopes: science with a multi-energy scale

NEUTRINO ENERGY FROM MeV TO PeV







Super Novae explosion MeV	Neutrino oscillation GeV	Dark Matter (*) TeV	HE neutrinos Multi-messenger program PeV

ARCA

ARCA

ORCA

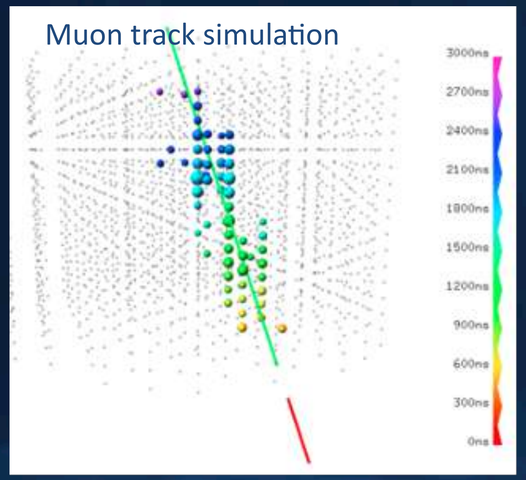
Time synchronisation and calibration of the detector

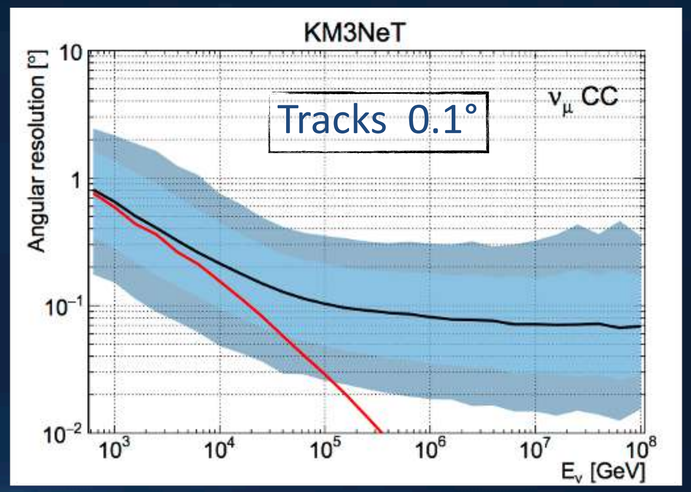
Detector angular resolution

- Rejection of atmospheric muons
- Source identification

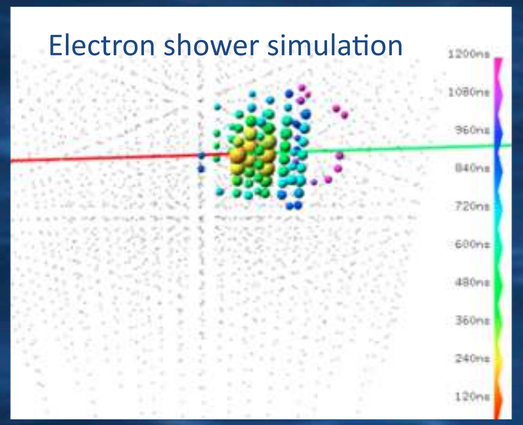
Time Synchronisation and calibration is the key parameter to optimise angular resolution.

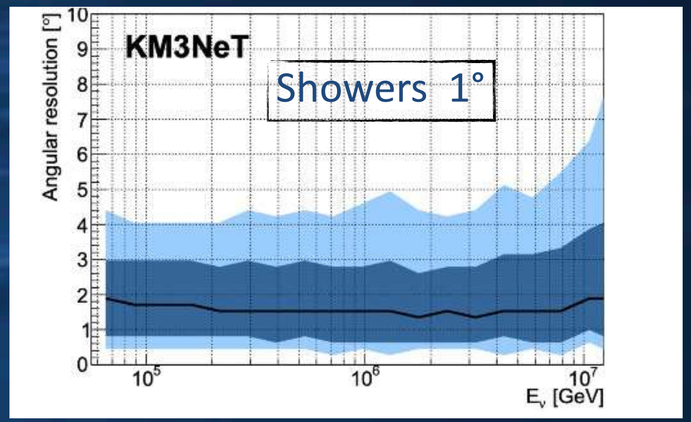
Muon track simulation

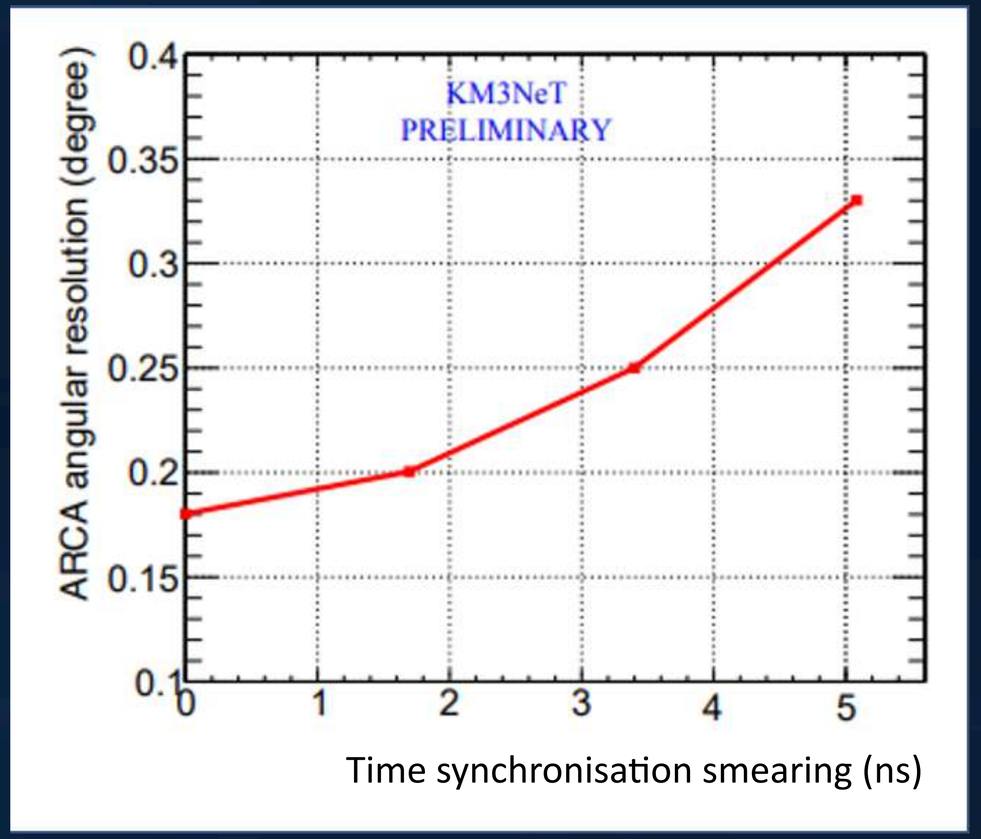




Electron shower simulation

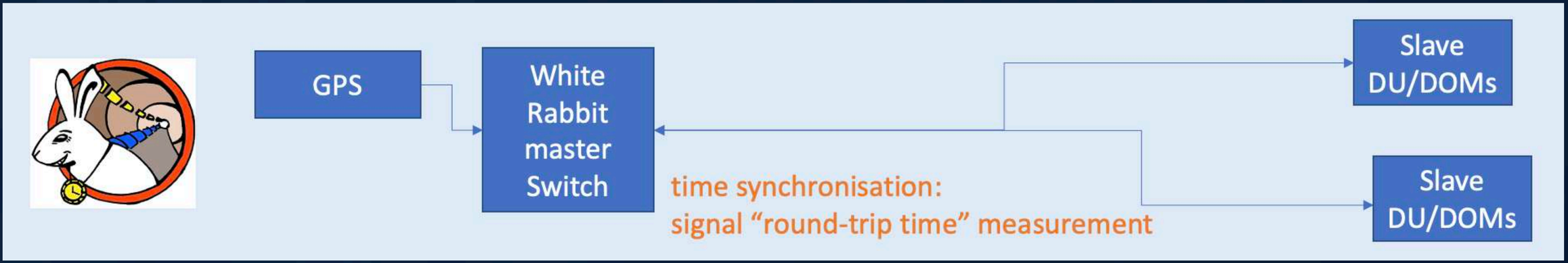






Time synchronisation and calibration of the detector

The KM3NeT time synchronization system is based on the CERN-White Rabbit protocol between the data acquisition system on shore and the detector off-shore.



The time calibration of the KM3NeT PMTs is obtained by a combination of several calibration procedures that allow the determination of the relative time offsets:

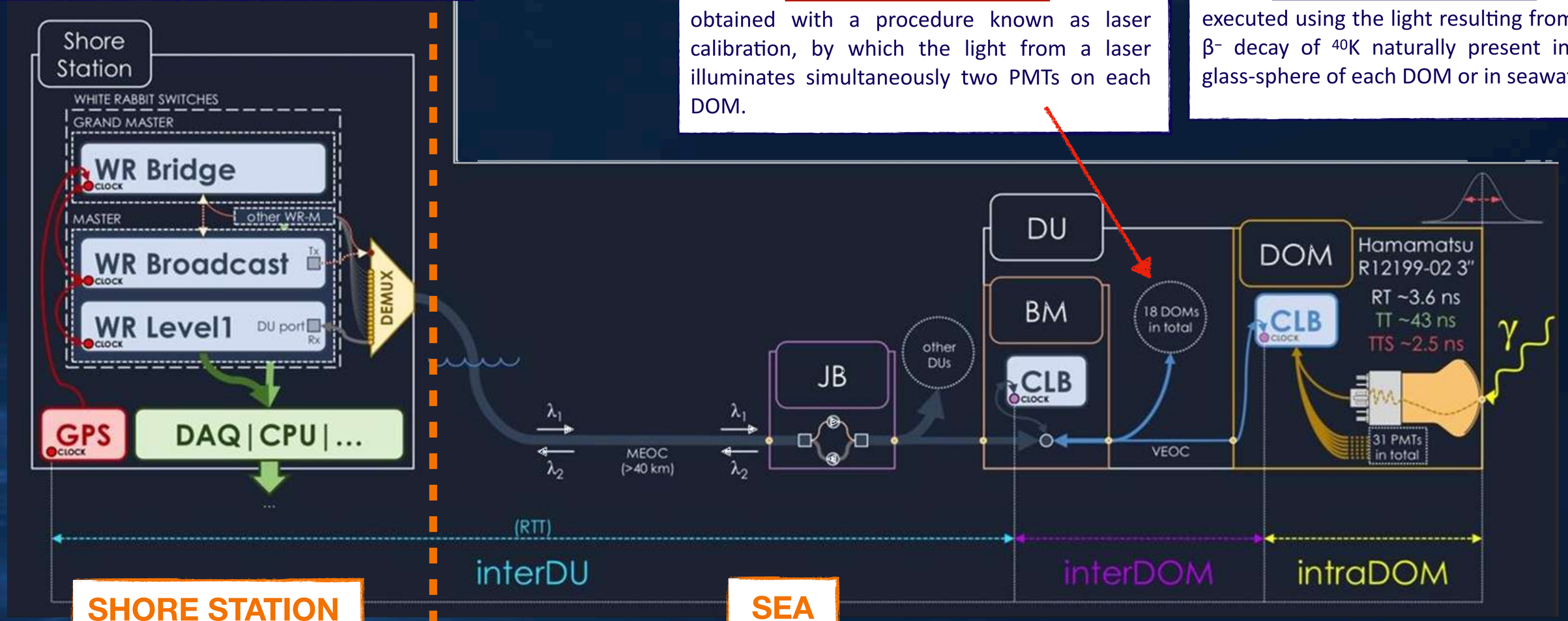
- between the PMTs in the DOM (intra-DOM)
- between DOMs in the same DU (inter-DOM)
- between different DUs (inter-DU)

Time synchronisation and calibration of the detector

Inter-DU time calibration:
relies on the accurate measurement of Round-Trip Time of the optical signal between the master clock (on shore) and each DU base.

Inter-DOM time calibration:
obtained with a procedure known as laser calibration, by which the light from a laser illuminates simultaneously two PMTs on each DOM.

Intra-DOM time calibration:
executed using the light resulting from the β^- decay of ^{40}K naturally present in the glass-sphere of each DOM or in seawater.



Time synchronisation and calibration of the detector

- PMT Gain Equalisation: PMT high voltage tuning and setting
- Detection Unit time calibration (inter-DOM): DOM time offset table
- DU Functionality tests: Power consumption verification
  Check of auxiliary calibration devices
  Piezo and hydrophones
  Nano-beacons
  Compass boards

Time synchronisation and calibration of the detector

PMT Gain Equalisation

The first step to calibrate a DU is the so called **High Voltage** (HV) **tuning** procedure, that is carried out in order to equalise the gain of all PMTs to the value of 3×10^6 .

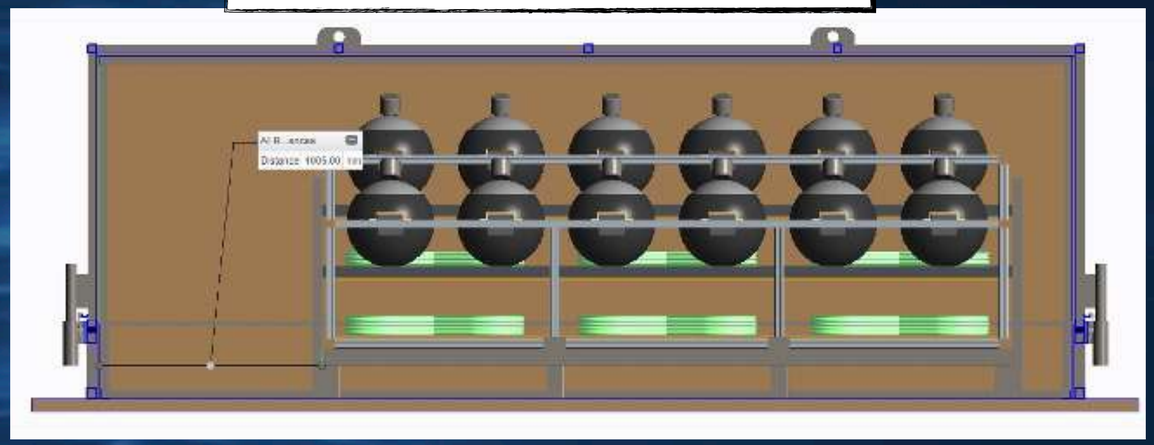
The HV procedure consists of four consecutive steps applied to data acquired for this purpose.
For this reason, designated calibration runs are taken with the HV of a subset of PMTs varied in steps between -125 V and +125 V with respect to the voltage recommended by the manufacturer, the so-called "PMT vendor" HV.

The gain and High-Voltage are related by the formula:

$$G = A \times HV^{kN}$$

where A, k, N are constants related to the dynode system of the PMT and G is the gain.

Dark Box @Catania-LNS

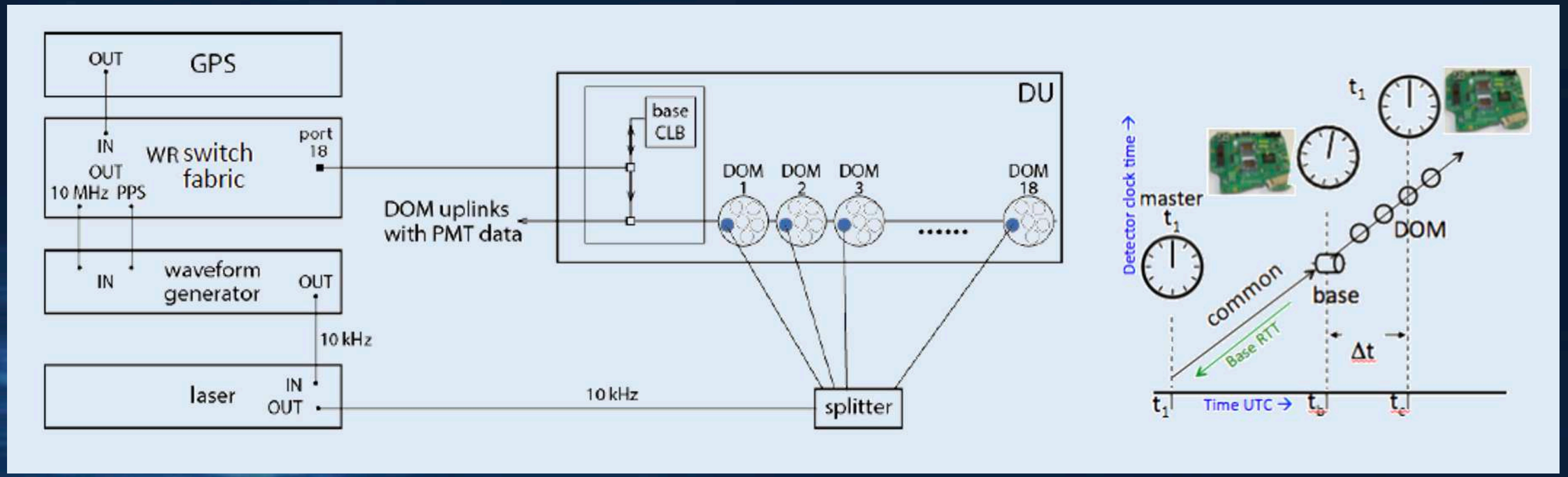


Time synchronisation and calibration of the detector

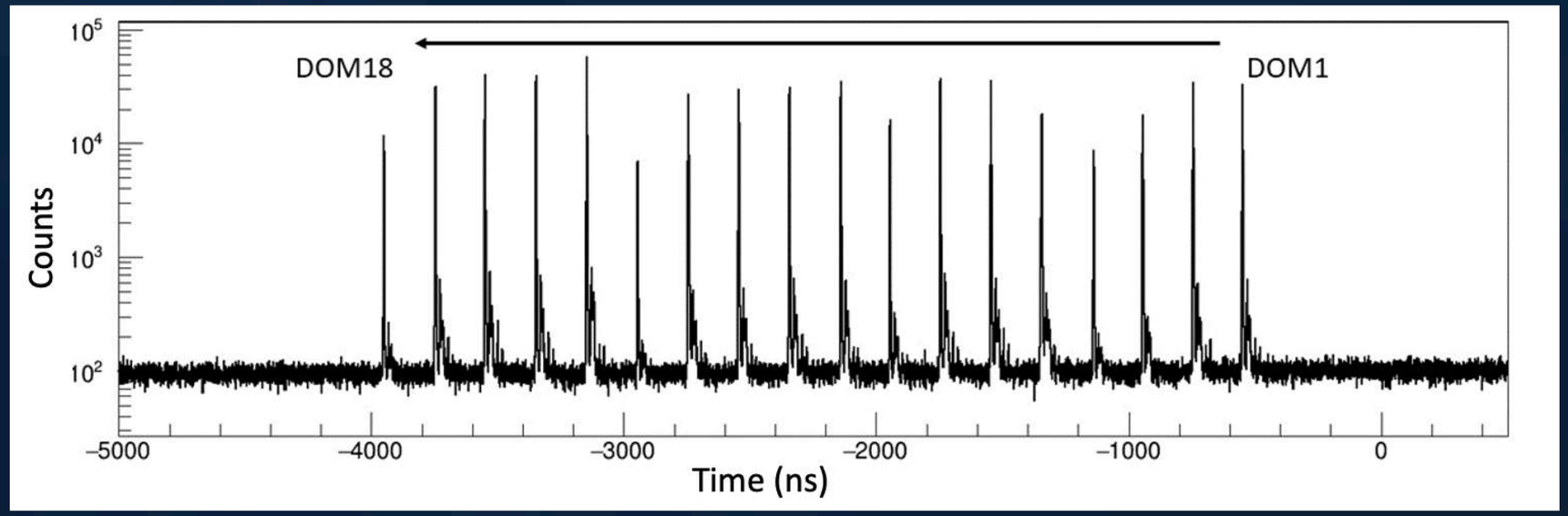
Inter-DOM time calibration

After the HV tuning, the inter-DOM time calibration is performed.

A laser pulse (split using a time and amplitude calibrated splitter) simultaneously illuminates 2 PMTs of each DOM in order to measure the time delay between the DOMs of the DU.



Time synchronisation and calibration of the detector



Laser photons detection time for the reference PMTs.
Each peak corresponds to one DOM of the DU 95. DOMs are separated by a fiber length of about 40 m, thus the average time delay between DOMs is 200 ns.

D0DU095CT		
	Ch 07	Ch 15
DOM 1	+548.11	+548.42
DOM 2	+745.79	+744.07
DOM 3	+944.02	+943.47
DOM 4	+1143.91	+1137.73
DOM 5	+1344.20	*
DOM 6	+1544.73	*
DOM 7	+1746.44	+1745.12
DOM 8	+1947.68	+1944.84
DOM 9	+2141.76	+2139.52
DOM 10	+2342.04	+2343.13
DOM 11	+2544.58	+2544.00
DOM 12	+2744.05	+2743.69
DOM 13	+2946.61	+2944.16
DOM 14	+3144.84	+3145.92
DOM 15	+3346.15	+3346.78
DOM 16	+3551.01	+3548.91
DOM 17	+3746.66	+3745.43
DOM 18	+3950.39	+3949.50

Acoustic positioning of the detector

KM3NeT uses two subsystem of the Acoustic Positioning Systems (APS) able to provide information during the deployment and the operation phases of the telescope.

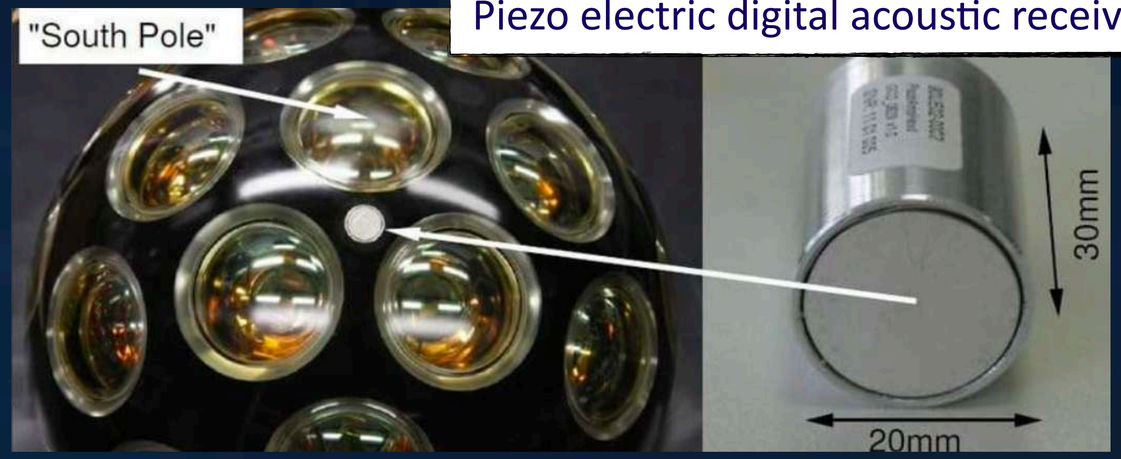
1) The NAAPS (Navigation and Absolute Acoustic Positioning System): during the deployment phase provides the position of the telescope's mechanical structures anchored on the seabed (Junction Boxes, DU bases and Calibration Units), in a geo-referenced coordinate system, with an expected accuracy of about 2 meters.

2) The RAPS (Relative Acoustic Positioning System) able to determine the positions of the DUs and DOMs in the previously geo-referenced field, via Time of Flight measurement acoustic emitted by a Long-BaseLine (LBL) of beacons.

   LBL is composed of an array of acoustic transmitters (Acoustic Beacons) and receivers (piezo) hosted on the DU bases and Junction Boxes; these elements are also synchronised with the Detector Master clock via WhiteRabbit protocol.

Acoustic Beacon

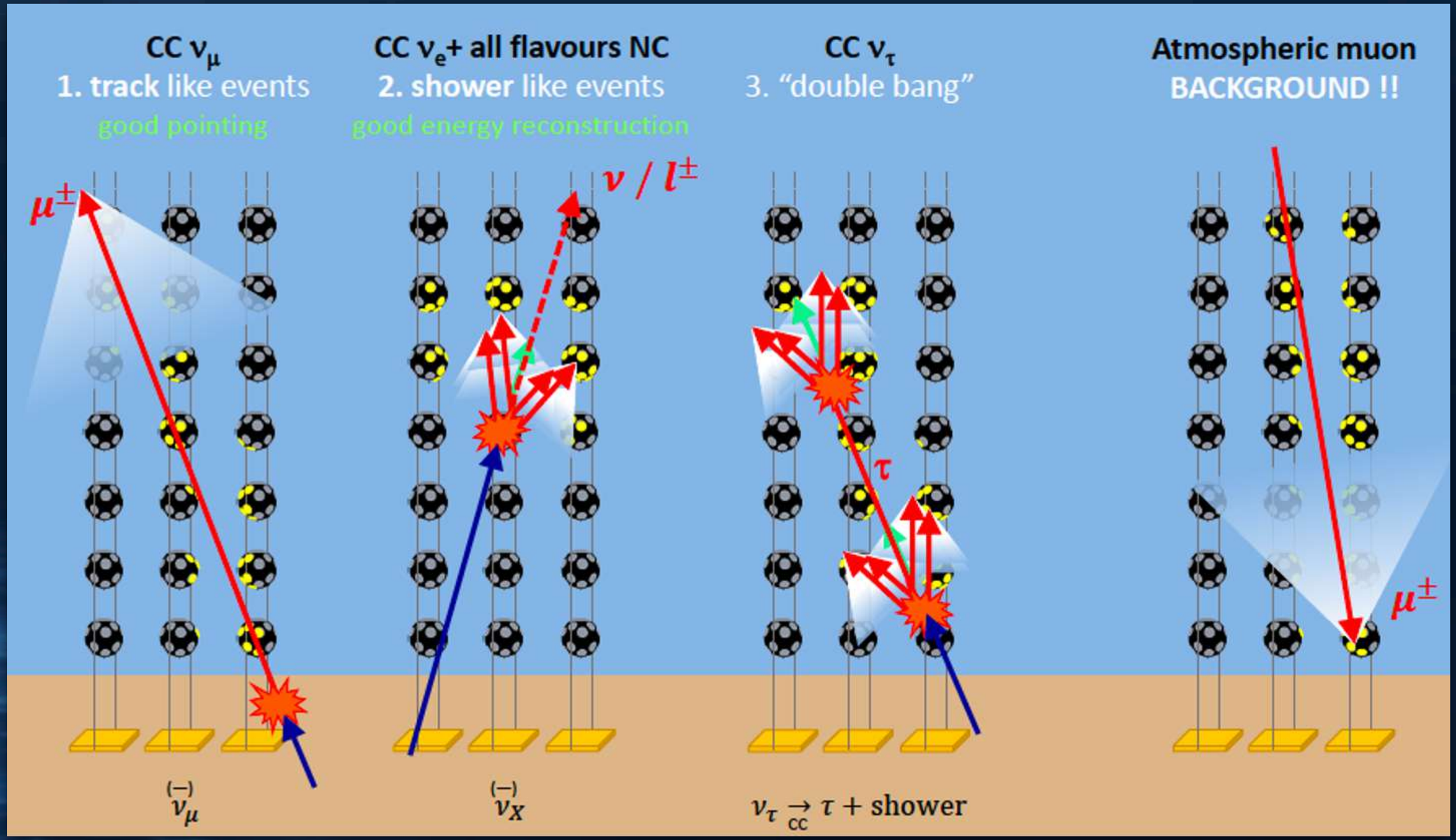
Piezo electric digital acoustic receiver



Thank you for the attention!!

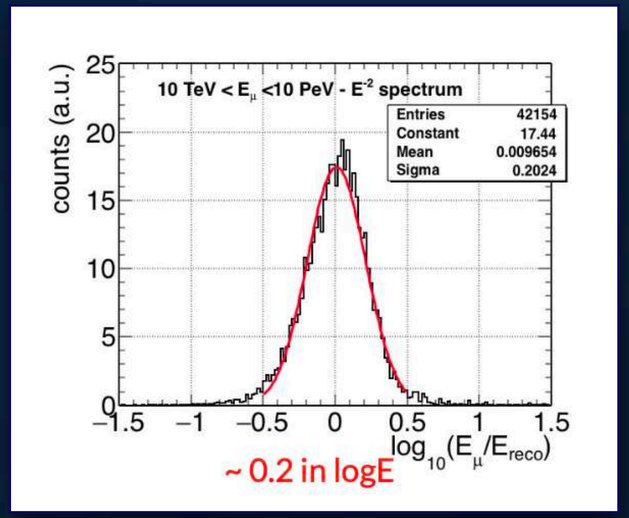
Backup slides

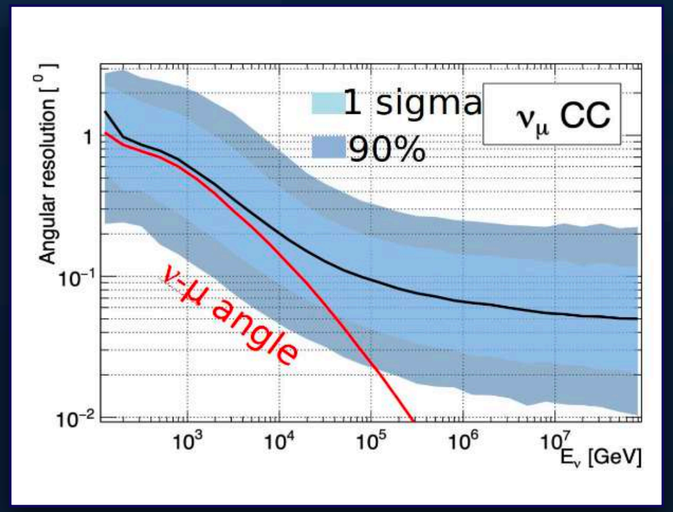
Event topologies



ARCA reconstruction resolutions

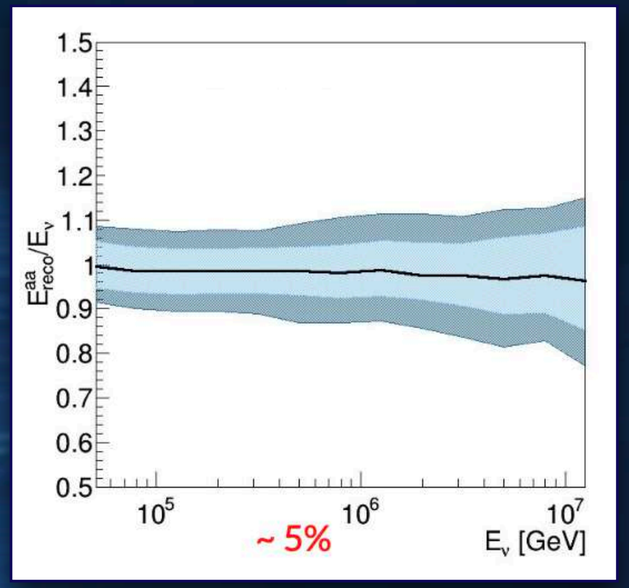
- Track:

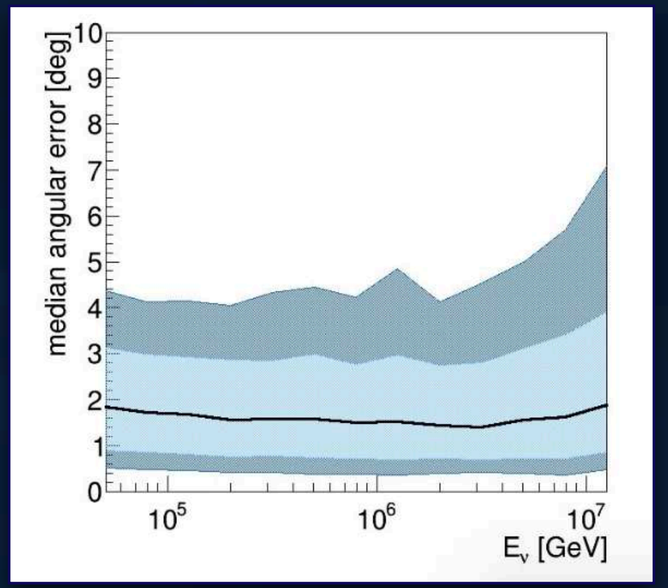




Track median angular resolution < 0.1º at E>100 TeV

- Shower:





Shower median angular resolution < 2º