LNF general seminar

THE KM3NET EXPERIMENT

ROSA CONIGLIONE
FOR THE KM3NET COLLABORATION

INFN - LABORATORI NAZIONALI DEL SUD (ITALY)

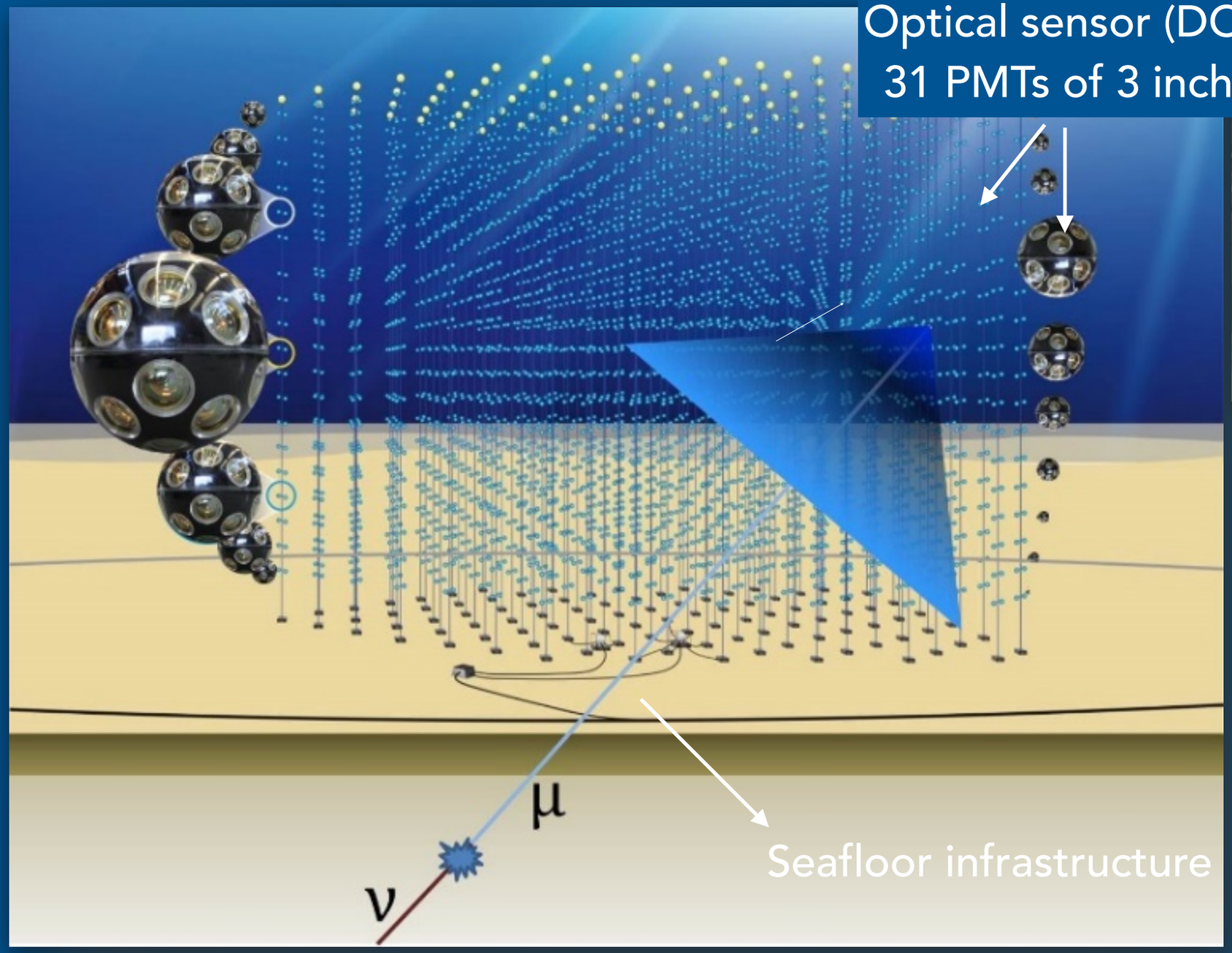
KM3NET

KM3NeT is a research infrastructure hosting two neutrino detectors in the Mediterranean Sea

- KM3NeT/ARCA (Astroparticle Research with Cosmics in the Abyss)
  - observation of high energy (GeV ÷ PeV) neutrino sources ☛ a telescope offshore Capo Passero (Sicily-Italy) is in construction at a depth of 3500m
- KM3NeT/ORCA (Oscillation Research with Cosmics in the Abyss)
  - determination of the neutrino mass hierarchy ☛ a detector offshore Toulon (France) able to detect neutrinos of tens of GeV is in construction at a depth of 2500m

1 collaboration 1 technology 👉 2 detectors

THE KM3NET DETECTORS



A building block

👇

An array of 115 DU

↘

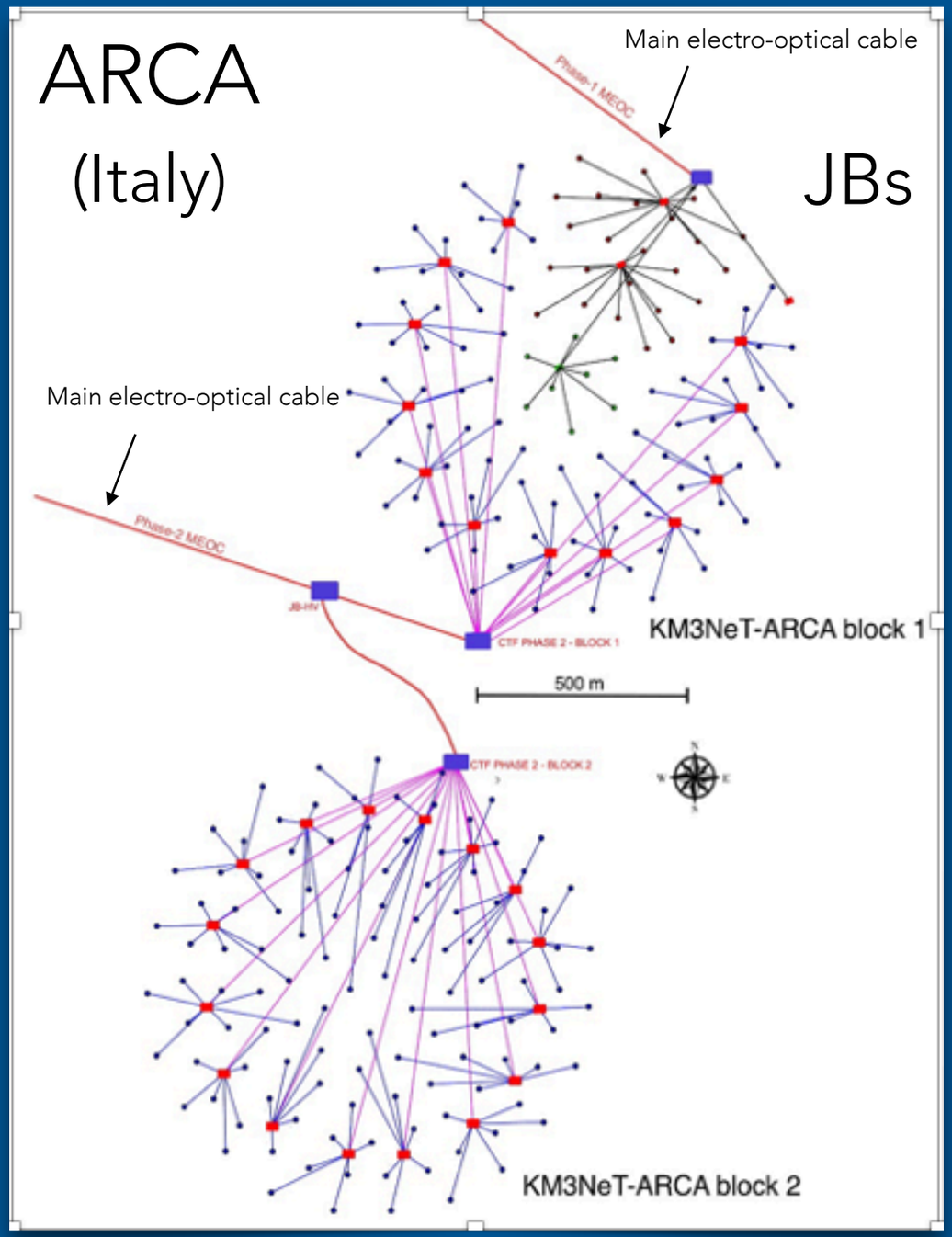
Detection Unit (DU)

Detectors in construction

THE KM3NET/ARCA DETECTOR

ARCA

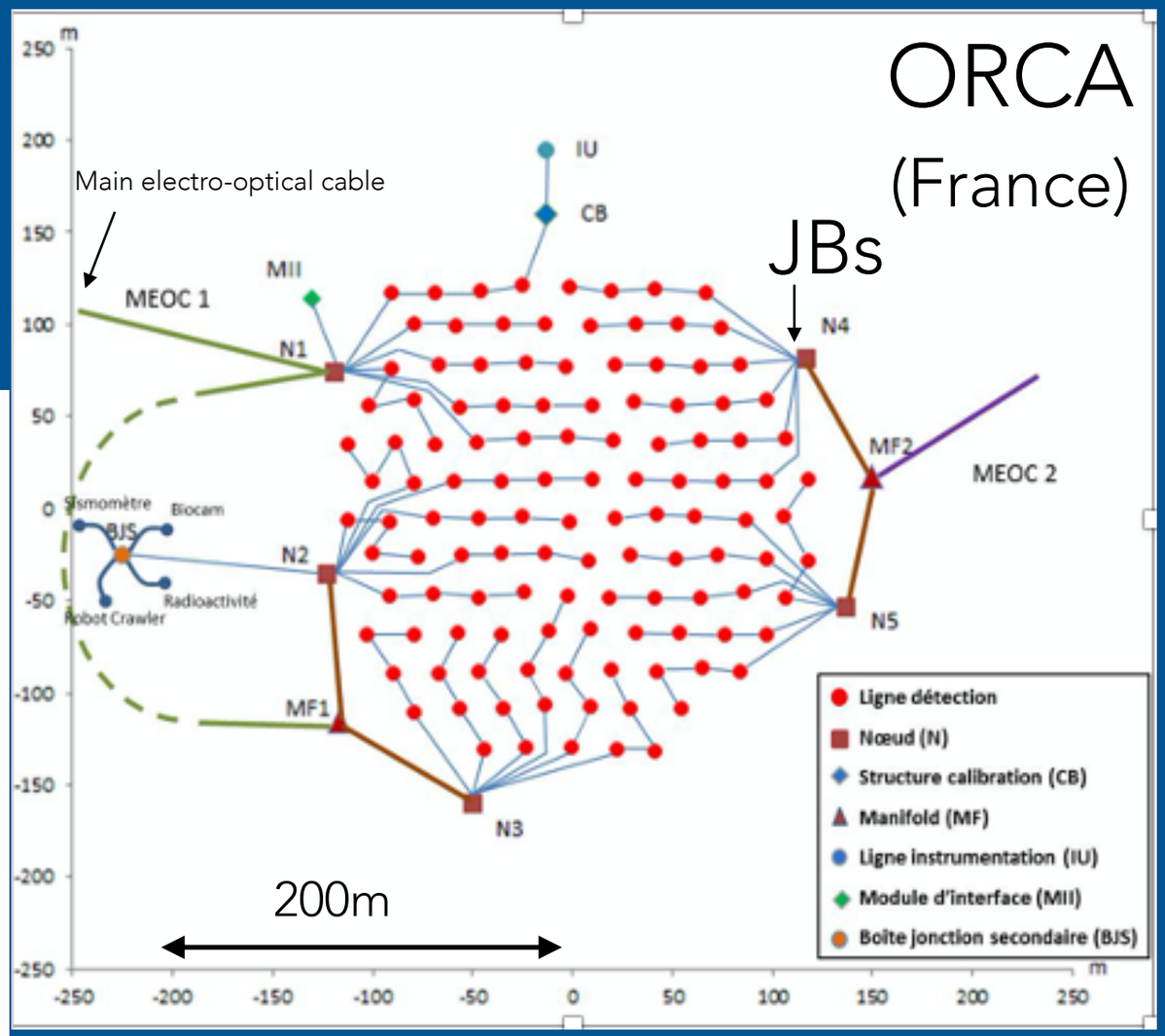
- Depth ~3500 m
- Two blocks of 115 Detection Units each
- Average distance between Detection Units ~90 m
- Vertical distance between DOMs ~36 m
- **Volume (0.5 × 2) km³ ≈1 Gton**



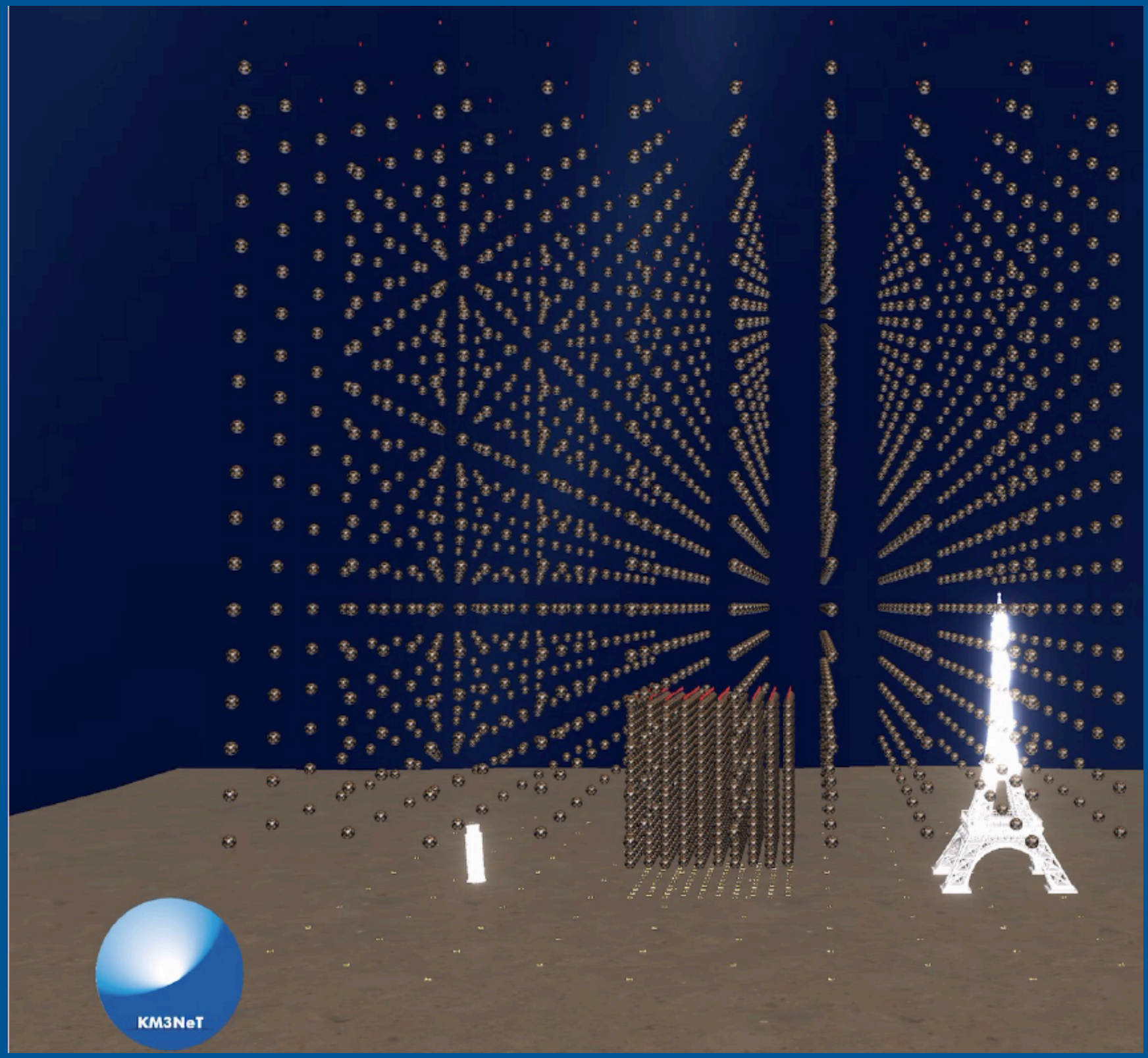
THE KM3NET/ORCA DETECTOR

ORCA

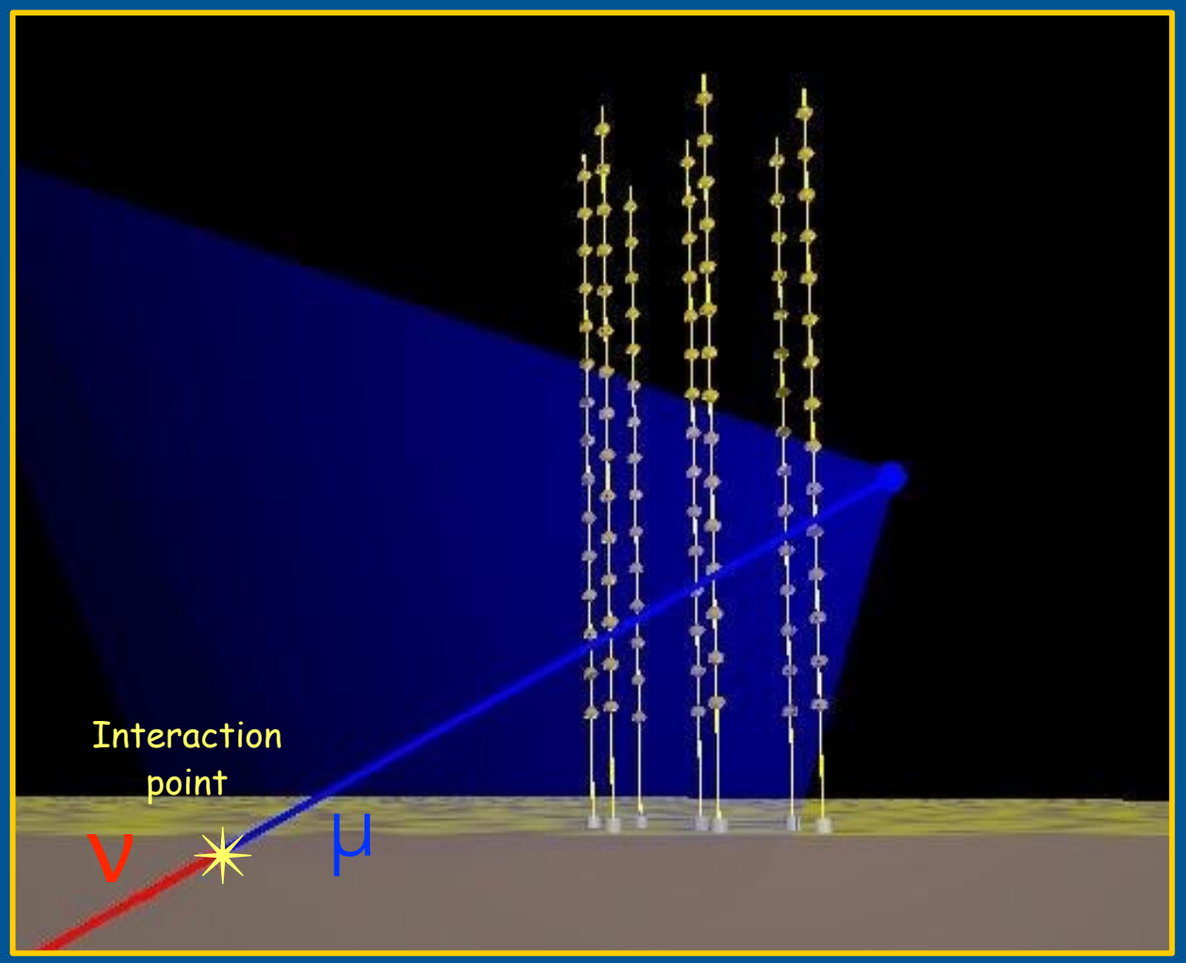
- Depth ~2500 m
- One block of 115 Detection Units
- Average distance between Detection Units ~20 m
- Average vertical distance between DOMs ~9 m
- **Volume ≈ 7 Mton**



THE KM3NET DETECTORS

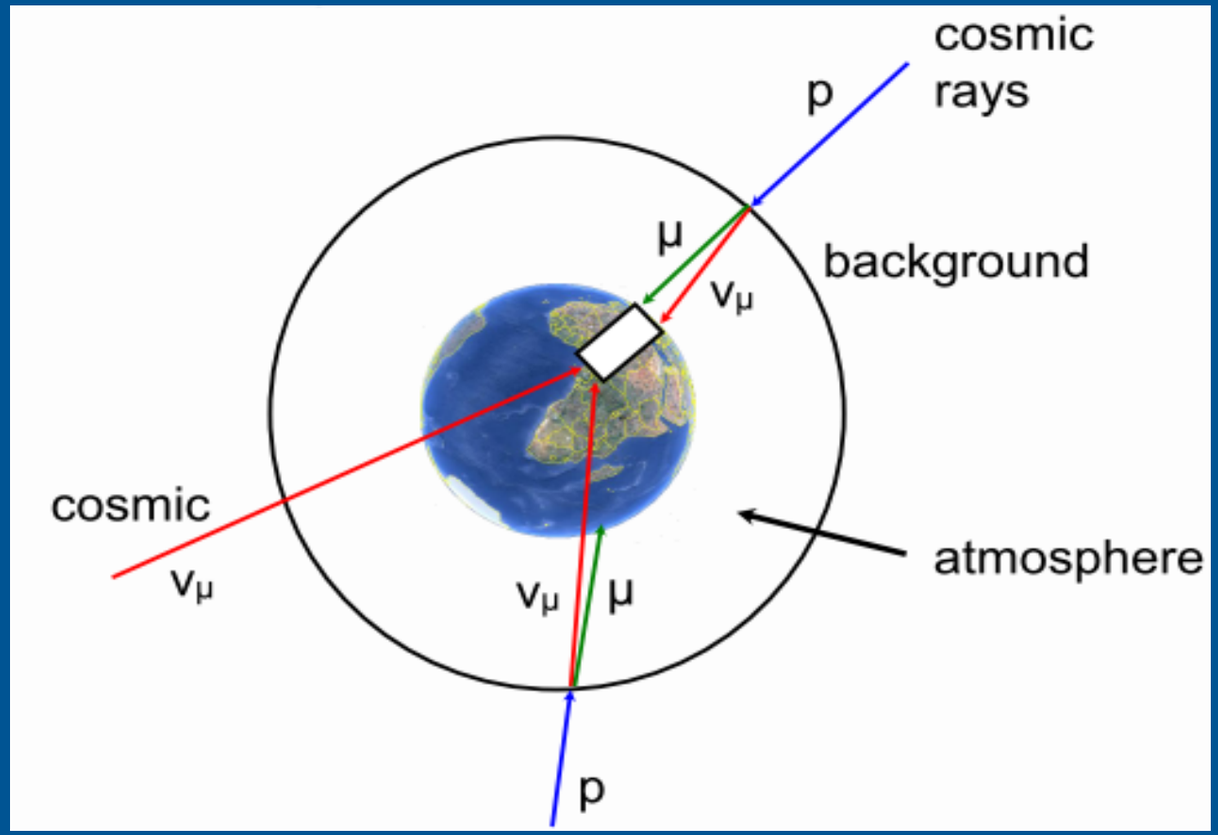


DETECTION PRINCIPLE

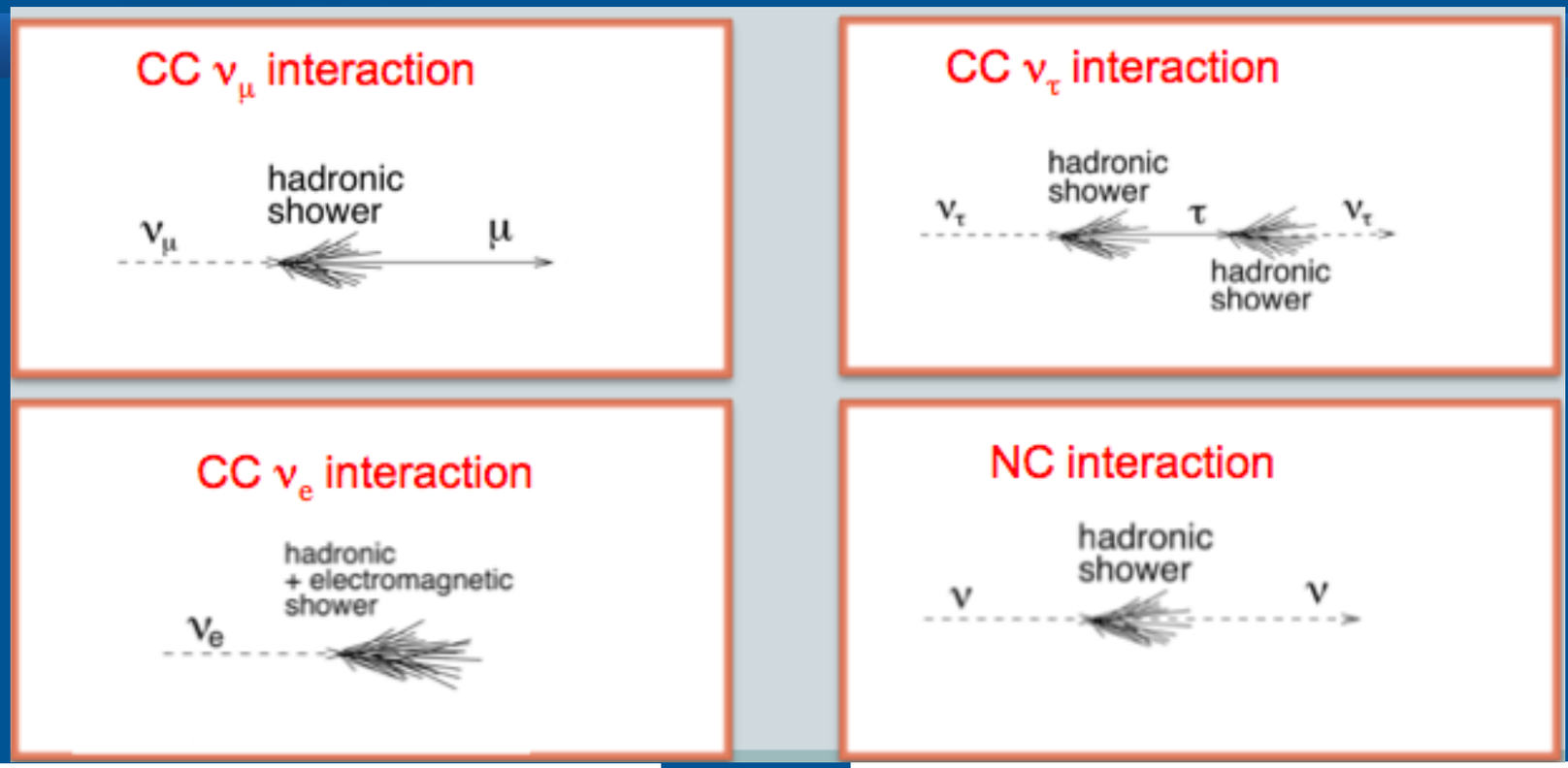


- The neutrinos interact in the water/ice or rocks around the detector and produce secondary particles that emit Cerenkov light in a cone at 42° w.r.t the particle direction.
- Light detected by means of optical sensors (photomultipliers)
- From the arriving time of photons and from the positions of the photomultipliers is possible to determine the direction of the secondary particles. If muons, generated by ν_μ, the precision in the reconstruction of the direction is very high (0.1°-0.2°). High energy neutrinos are collinear with muons
- Possible to detect also ν_e

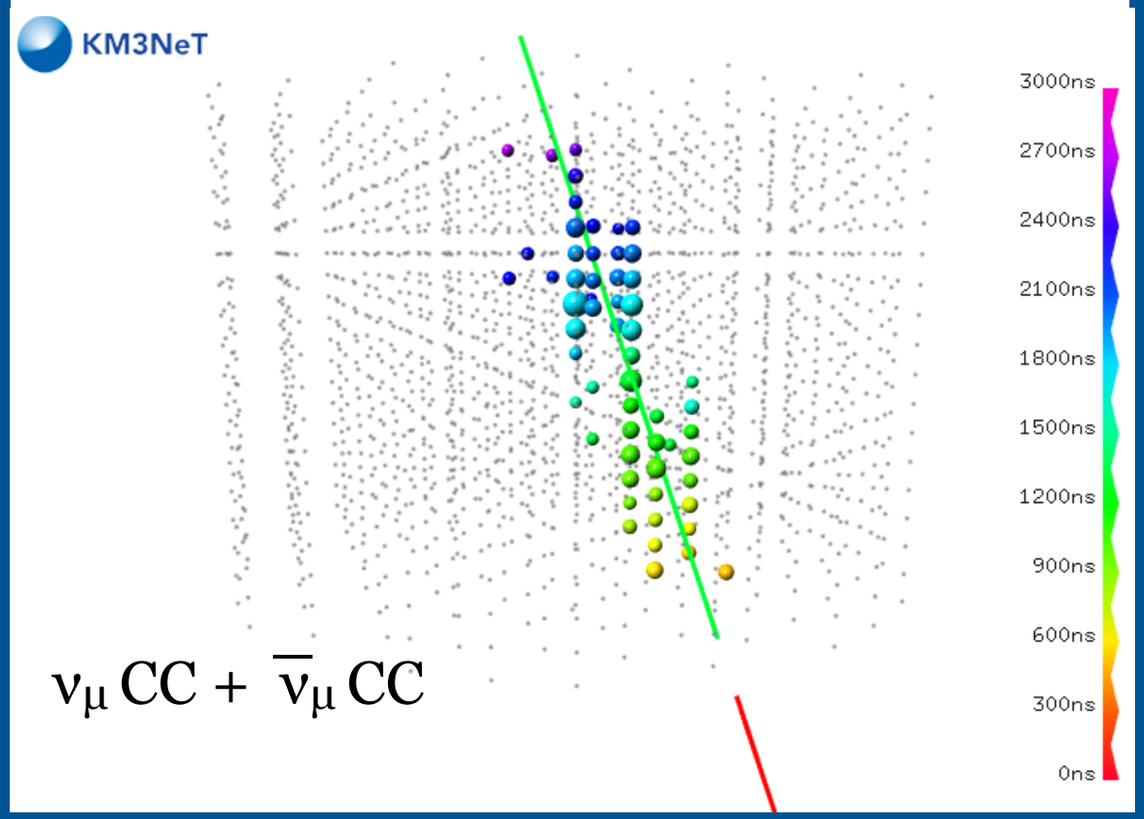
For high energy studies:
background from the interactions of Cosmic Ray with the atmosphere: muons and neutrinos produced



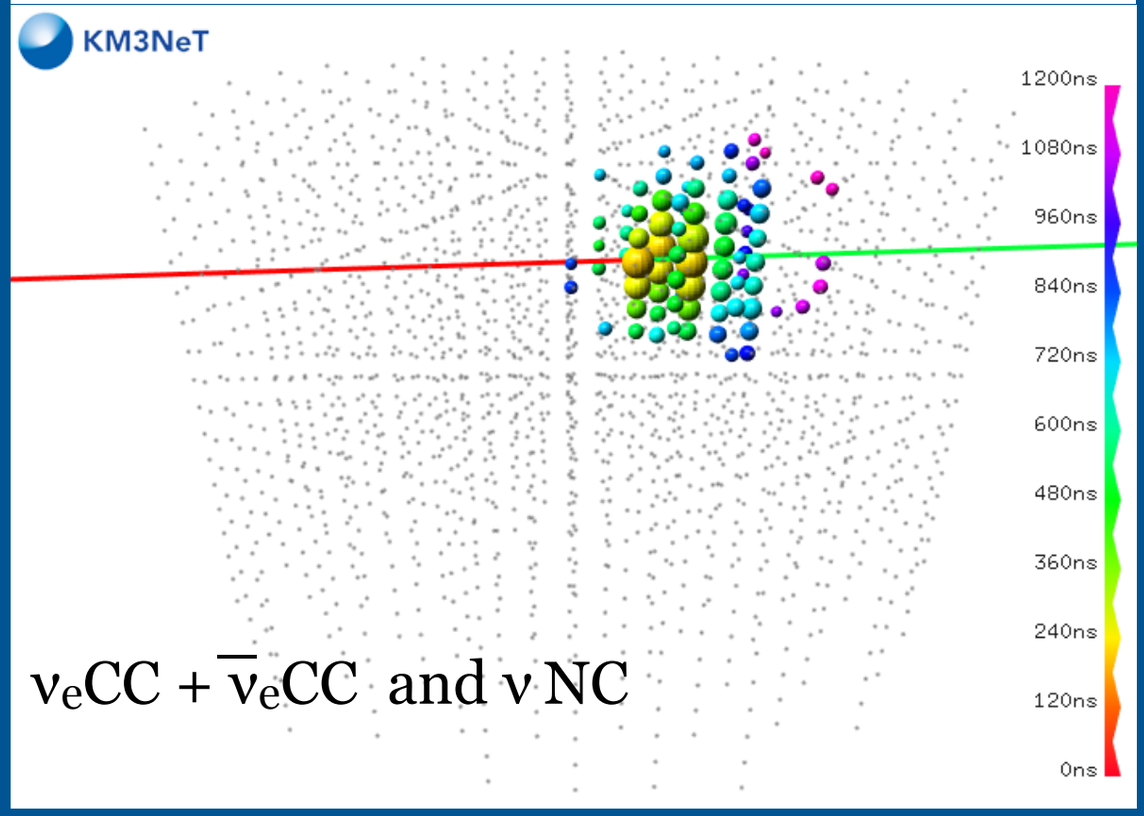
DETECTION PRINCIPLE



"Track-like" events mainly from ν_μ CC interactions

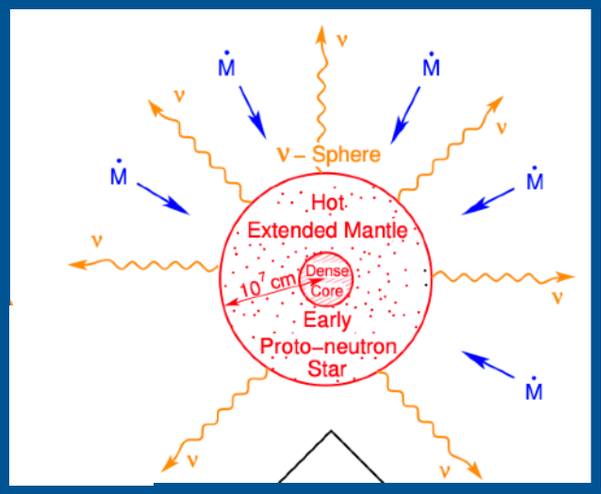


"Cascade-like" events mainly from ν_e CC and NC interactions

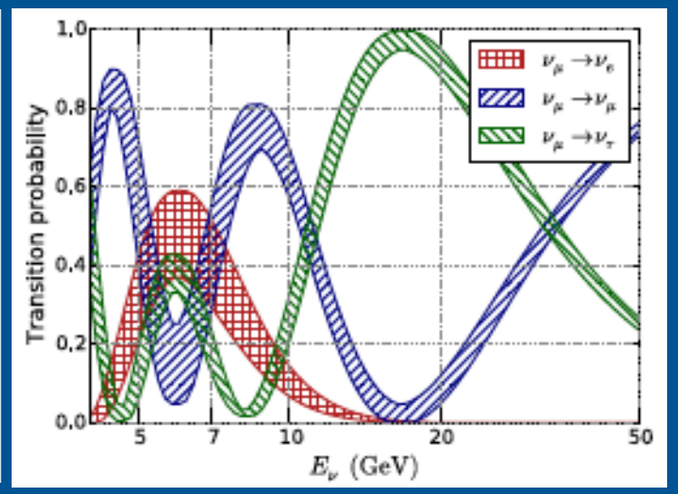


THE PHYSICS

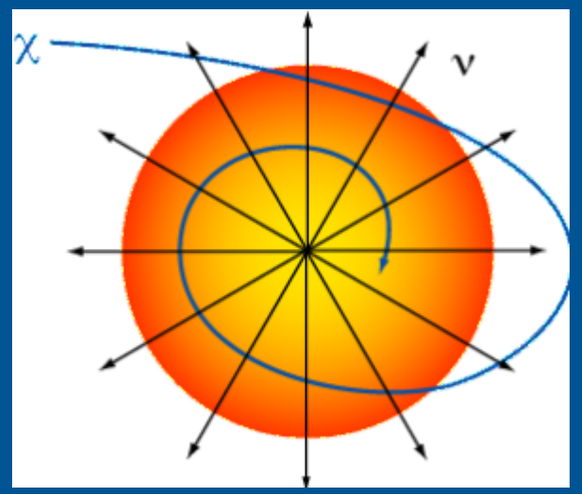
Neutrino Energy from MeV to PeV



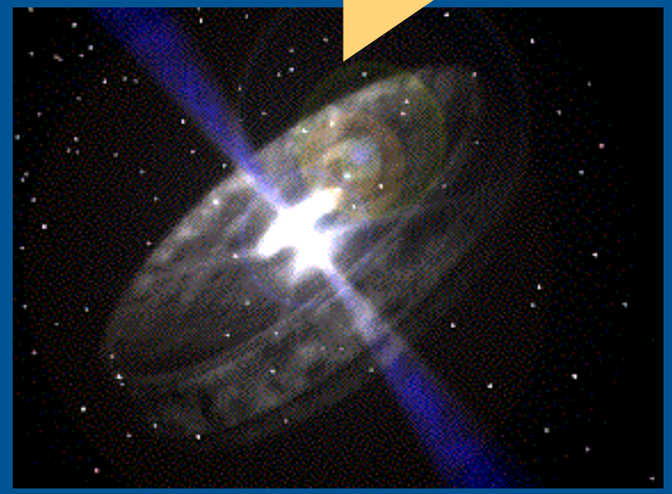
Super Novae explosion
MeV



Neutrino oscillation
GeV



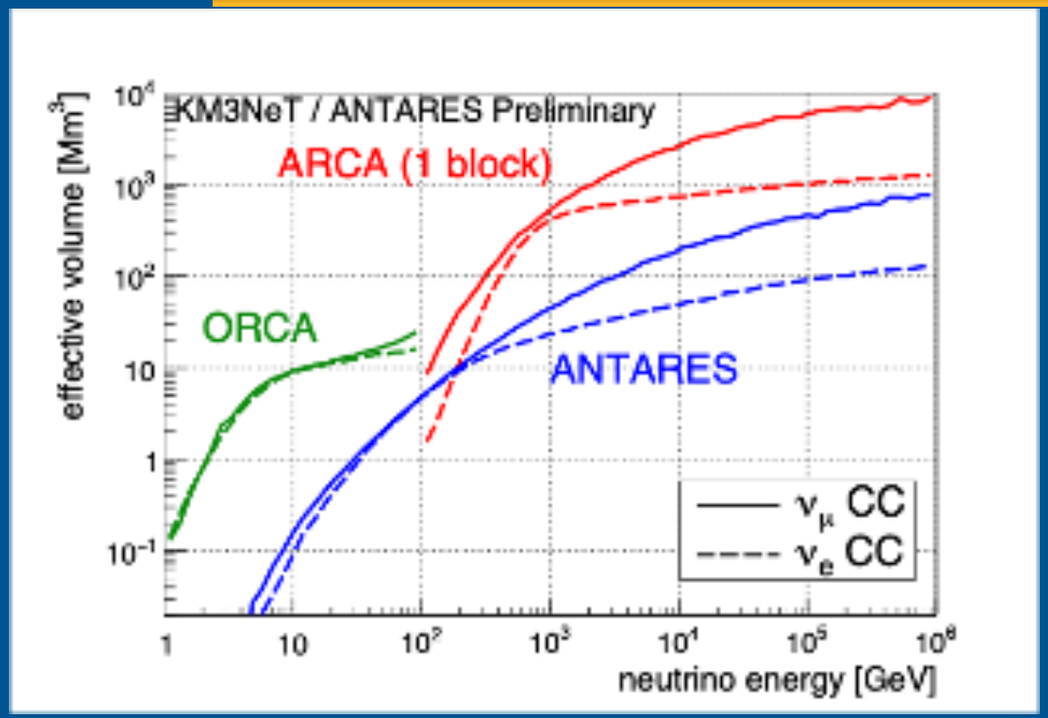
Dark Matter
TeV



HE neutrinos
Multi-messenger program
PeV

ARCA + ORCA

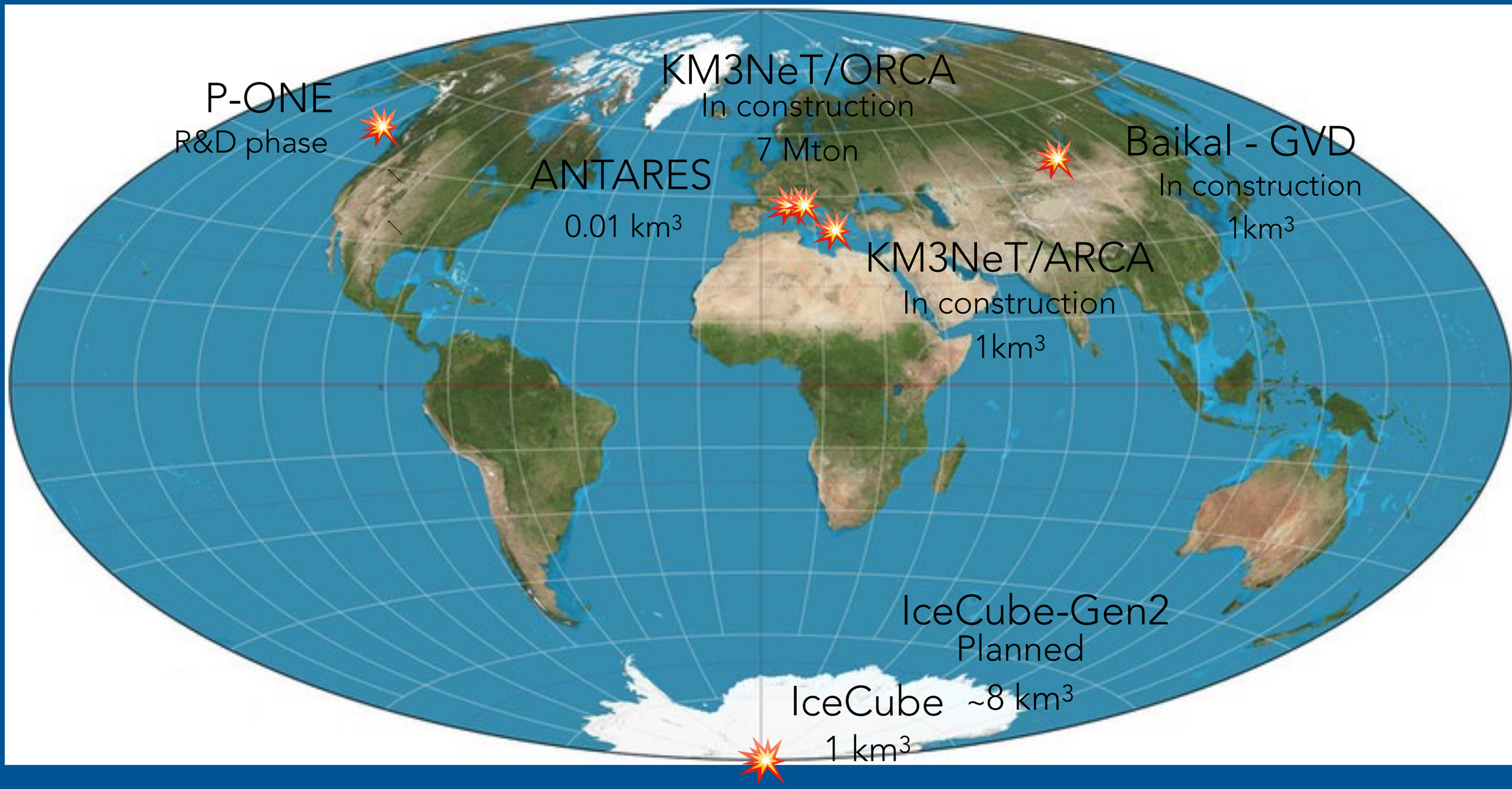
ORCA



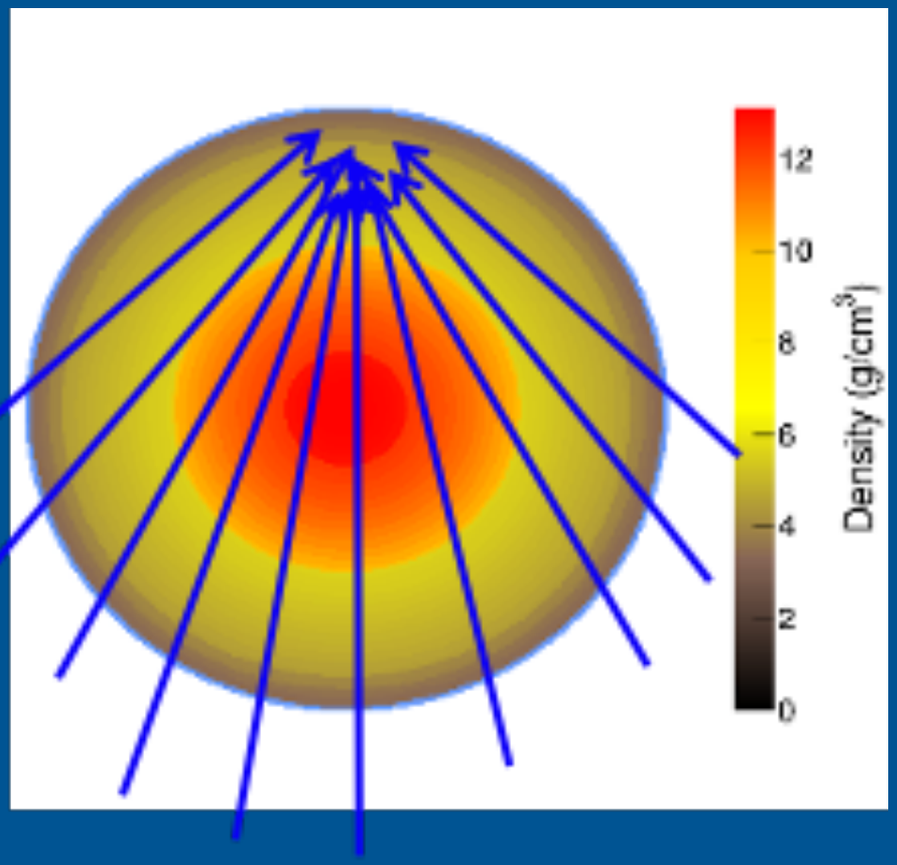
ARCA

ANTARES:
A small size detector (0.01 km³) working from more than 10 years

A GLOBAL VIEW OF THE UNDER WATER/ICE NEUTRINO DETECTORS



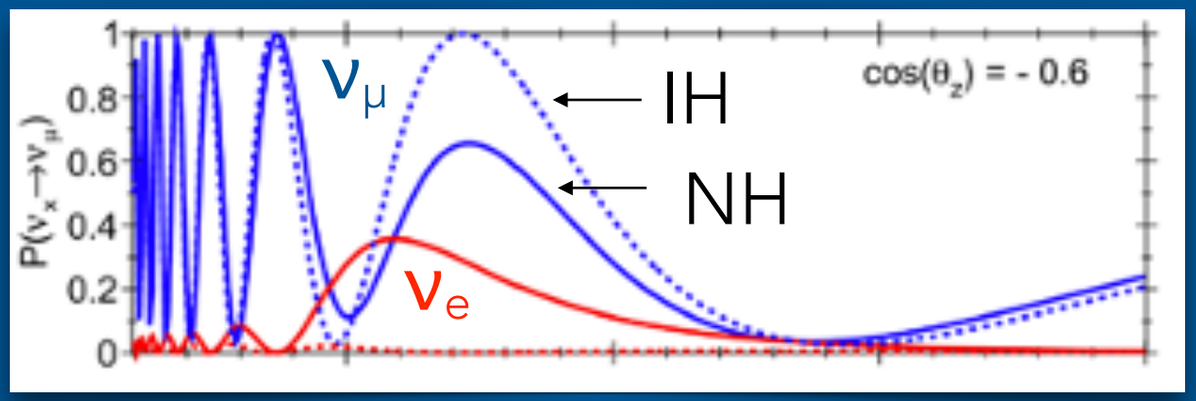
ORCA: THE NEUTRINO OSCILLATION PHYSICS



Atmospheric neutrino measurement >1 GeV

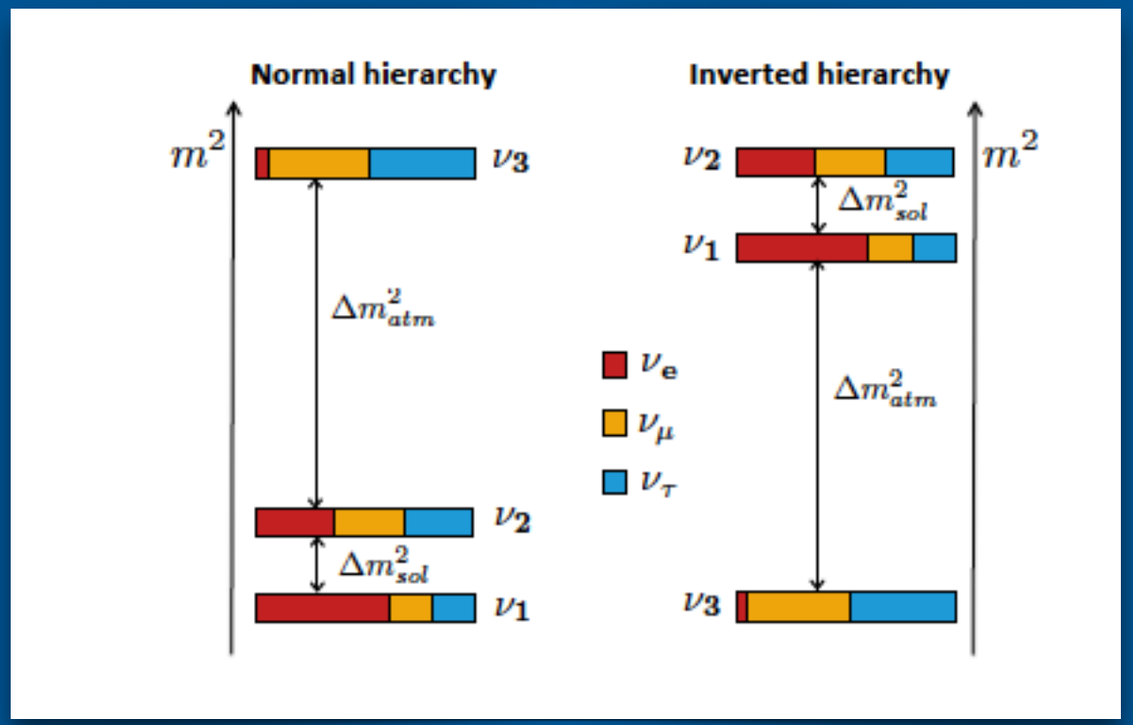
A "for free" beam of neutrinos of known composition (ν_e and ν_μ) and energies

- Neutrino mass ordering determination
- Neutrino oscillation parameters: sensitive to θ_{23} and Δm^2_{31}
- Sterile neutrinos
- Tau appearance
- .....



Needed:

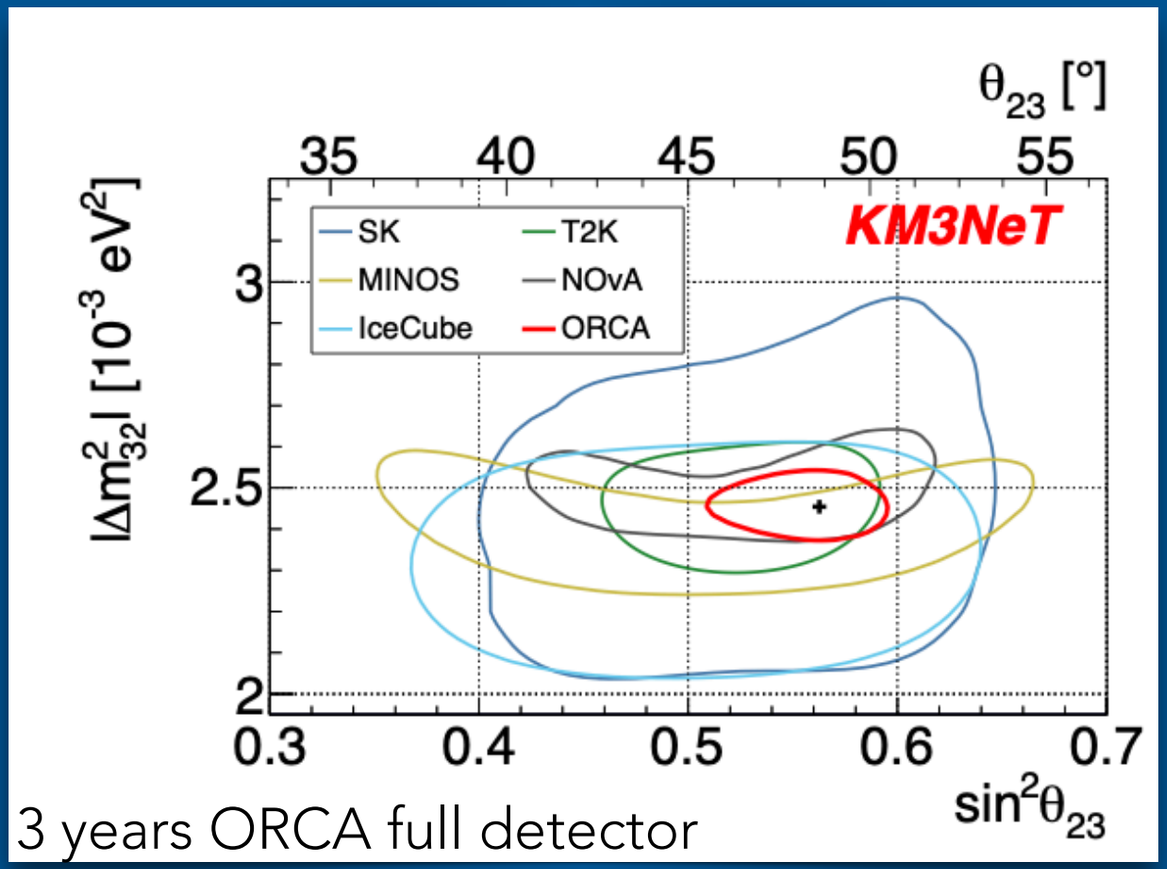
- Good angular and energy determination
- Good ν_e/ν_μ discrimination



THE MAIN ORCA PHYSICS GOALS

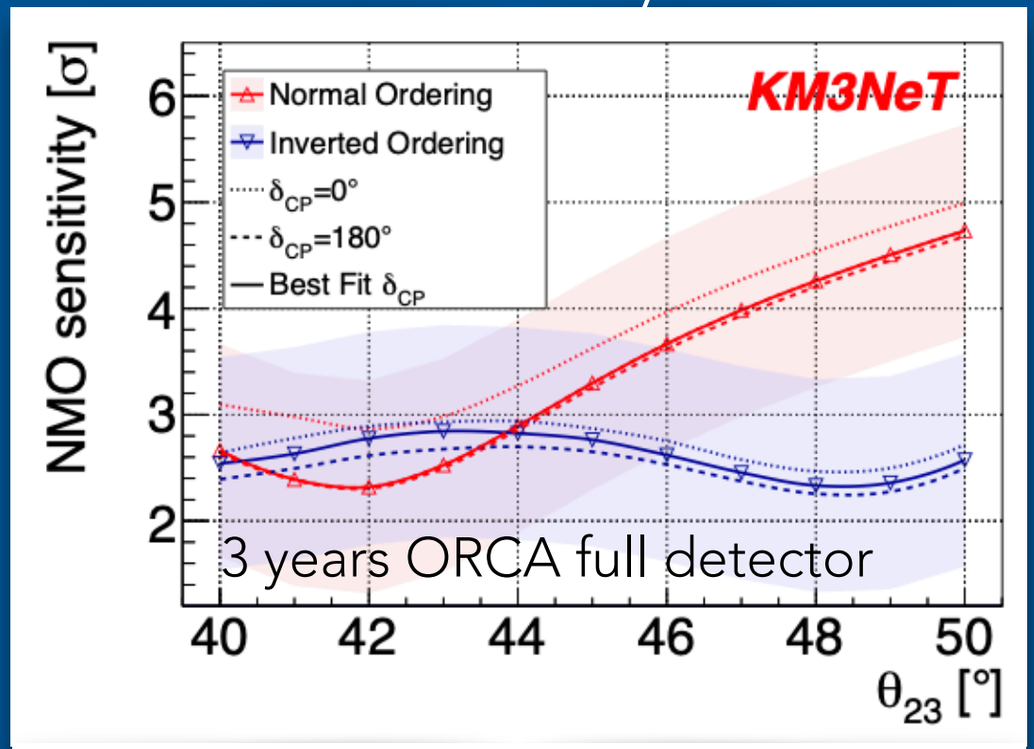
ORCA: NEUTRINO OSCILLATIONS WITH ATMOSPHERIC NEUTRINOS

Measurements of mixing parameters

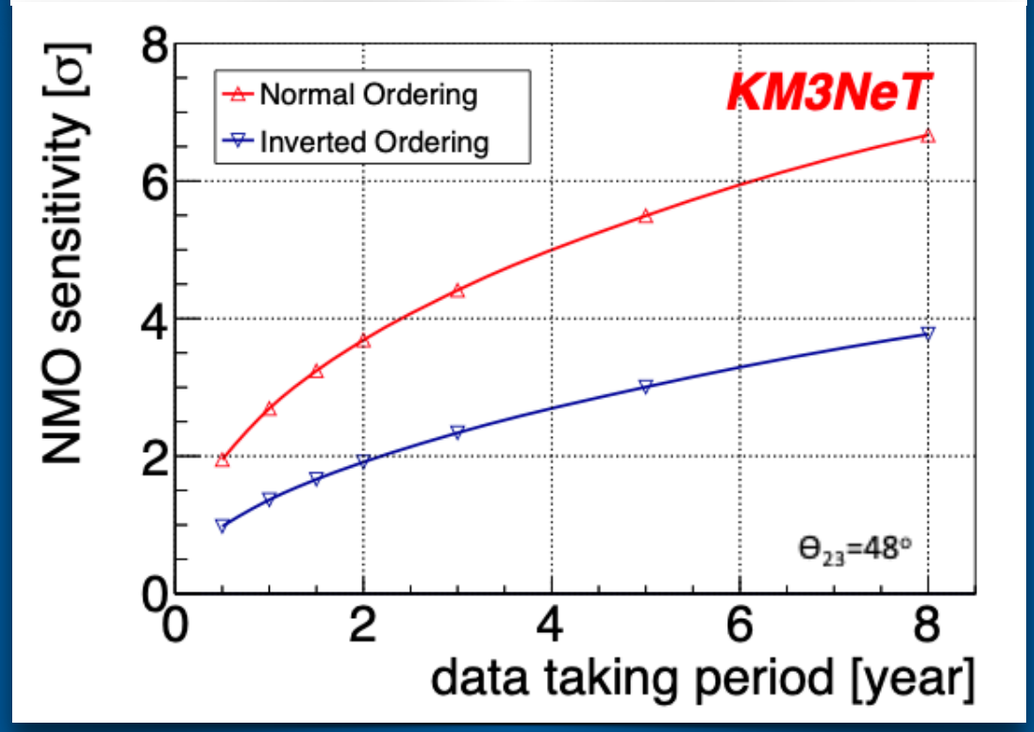


3 years ORCA full detector

Measurements of the neutrino mass hierarchy

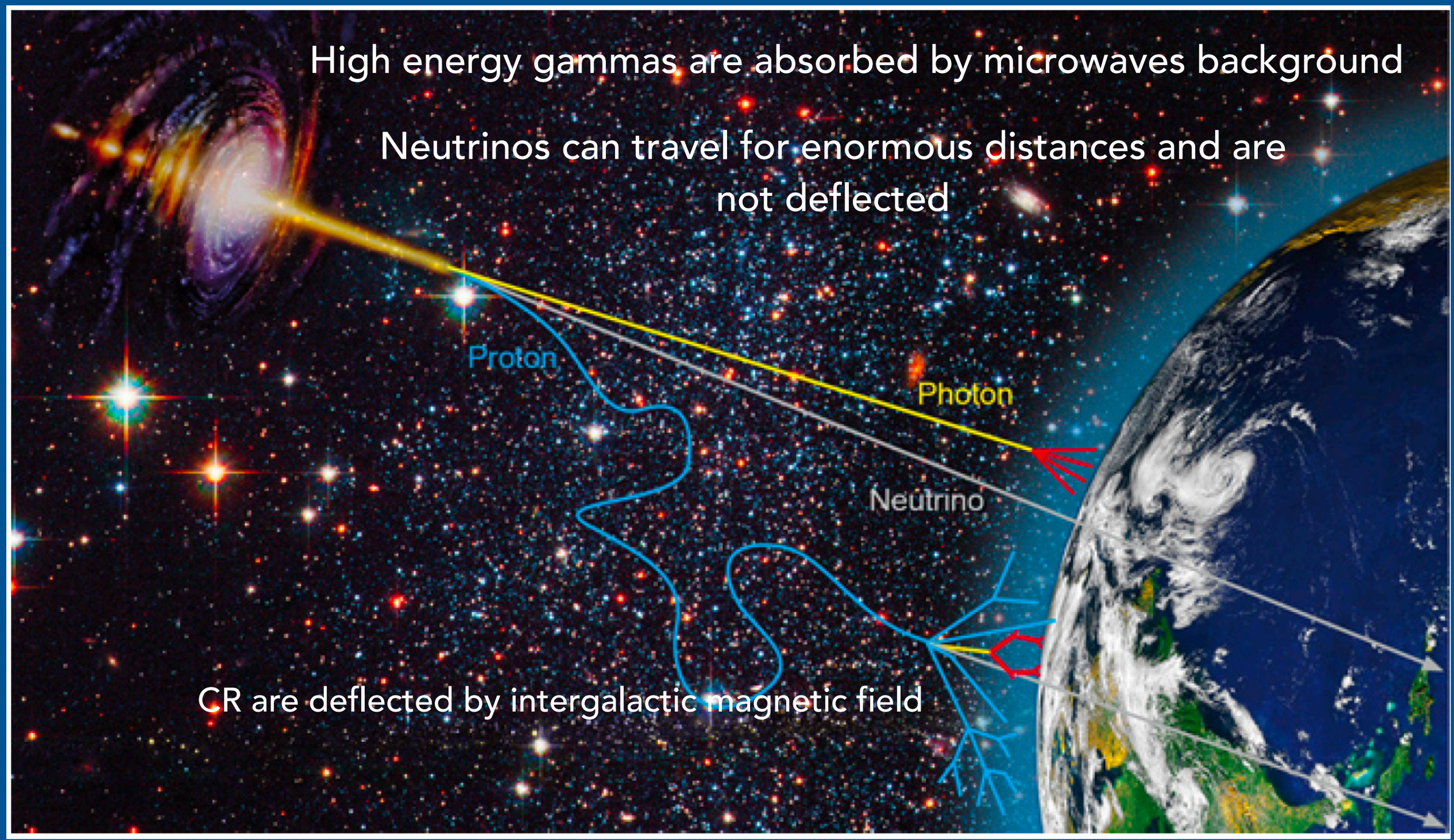


3 years ORCA full detector

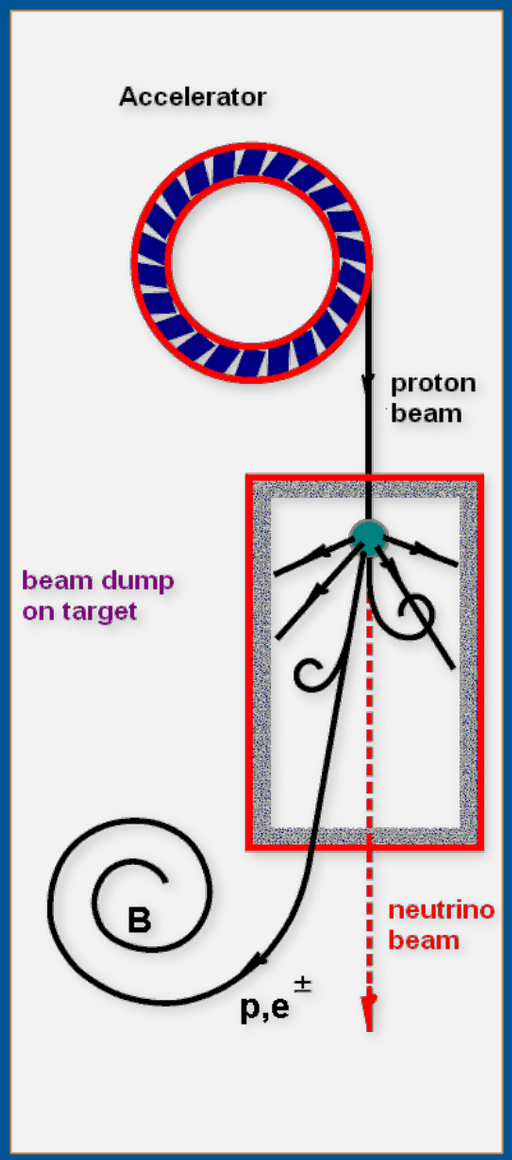


https://arxiv.org/abs/2103.09885 17 March 2021

High energy neutrinos: a new messenger to observe the sky



The astrophysical beam dump



Leptonic production of high energy γ

Inverse Compton

$e + \gamma_{Synchrotron} \rightarrow e' + \gamma'_{HE}$

Hadronic production of ν and high energy γ

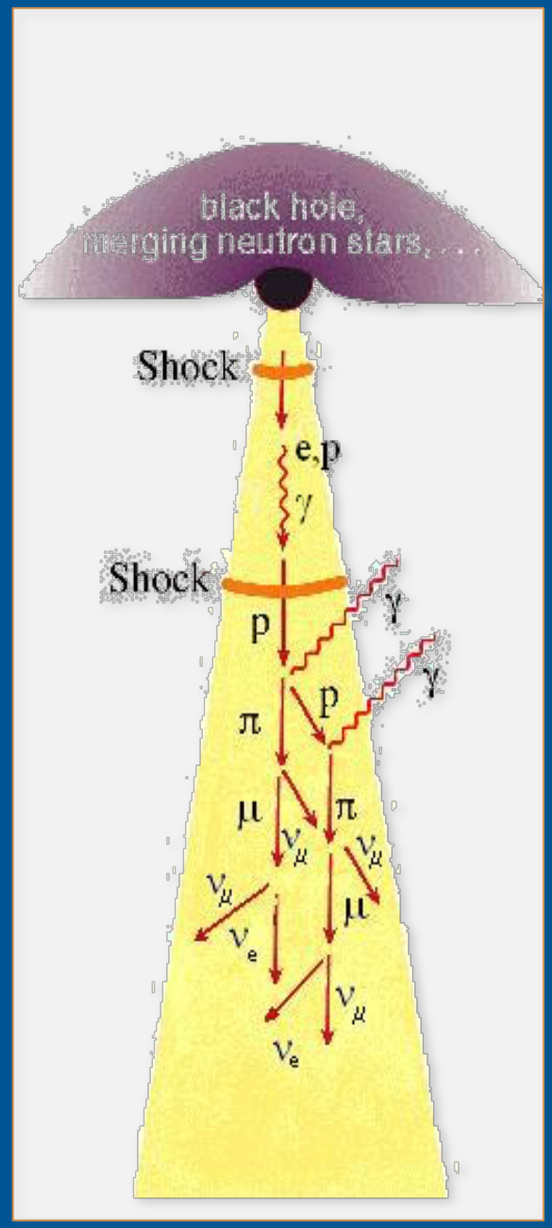
$p + p \rightarrow X,\pi$

$p + \gamma \rightarrow N\pi$

Pion and muon decays

neutral pions → ***HE gammas***

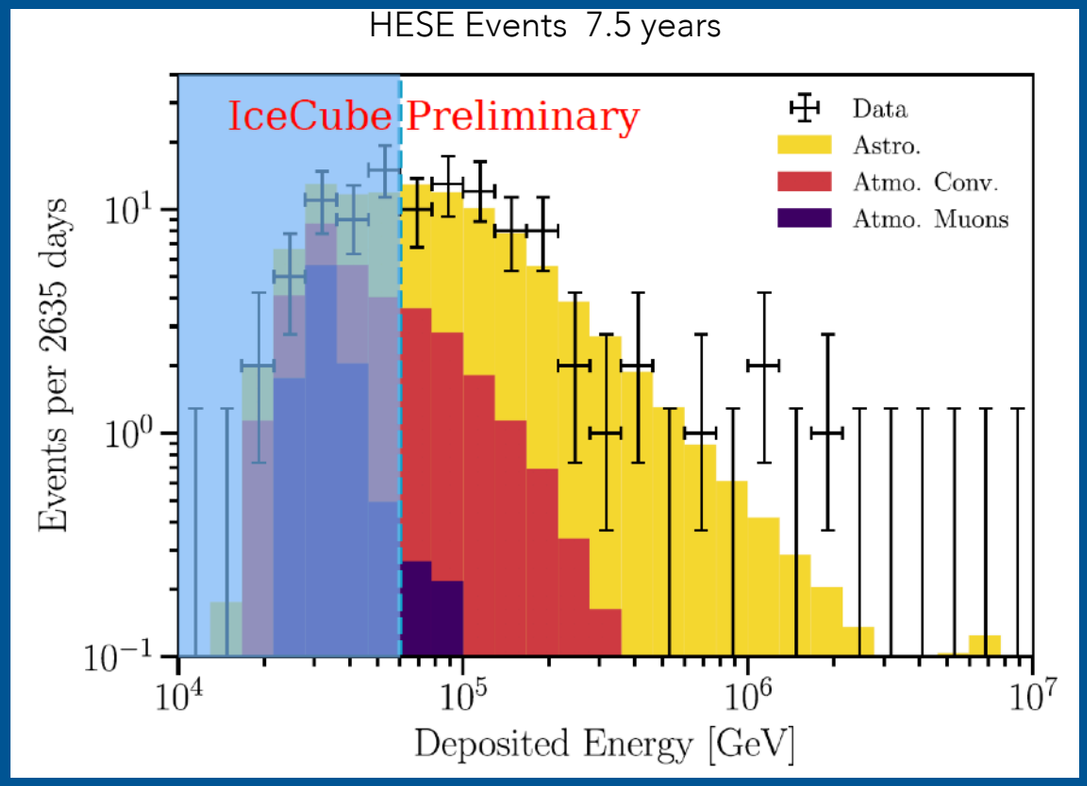
charged pions → **HE ν_μ ν_e**

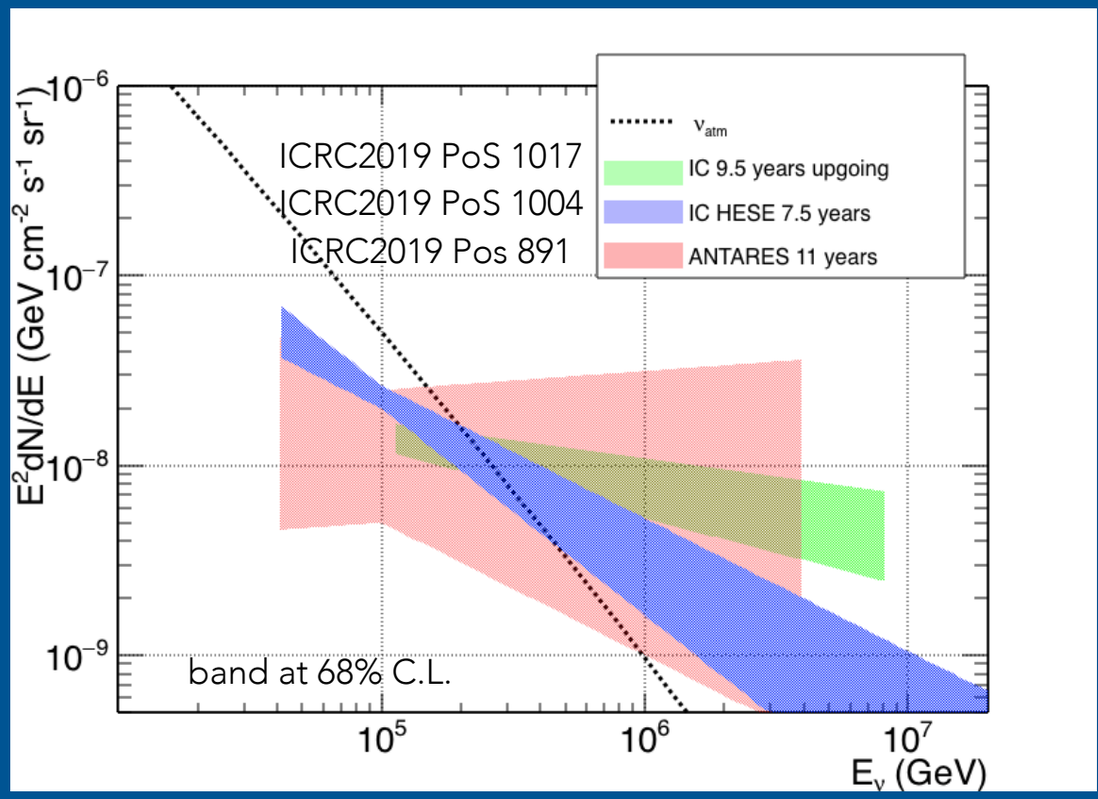


Neutrino detections from astrophysical sources: a clear signature for hadronic processes

THE HIGH ENERGY NEUTRINOS: THE EXISTING DATA

First evidence of cosmic neutrino in 2013





Big uncertainties present in the data

- Single power law? Statistics not enough to distinguish between different models.
- Currently no model is significantly preferred compared to a single power law (ICRC2019 PoS 1004)

Neutrino origin not known

THE HIGH ENERGY NEUTRINOS: THE EXISTING DATA

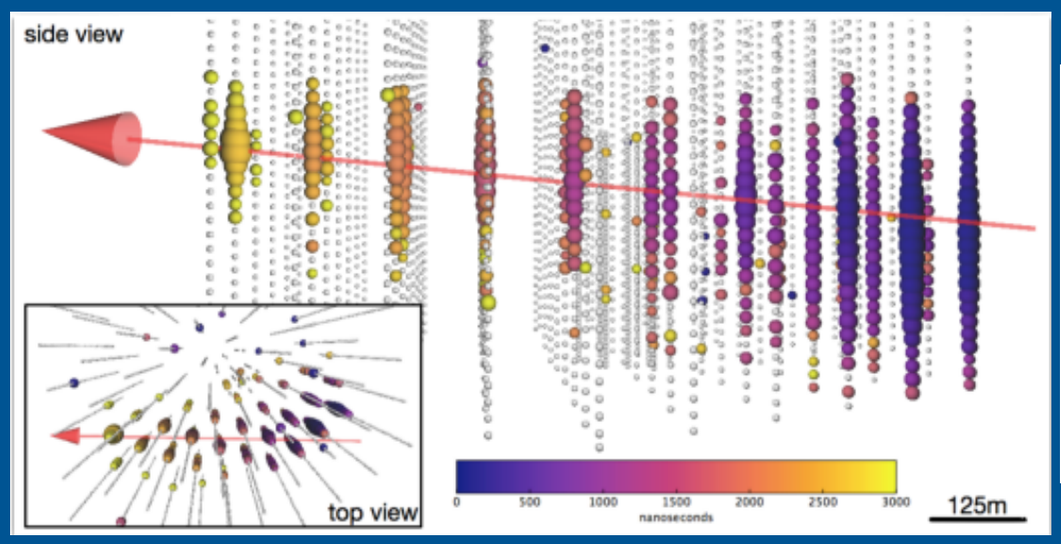
Thanks to multi-messenger observation the first source of neutrino was discovered (~3**σ** significance) 👉 the blazar TXS 0506+056

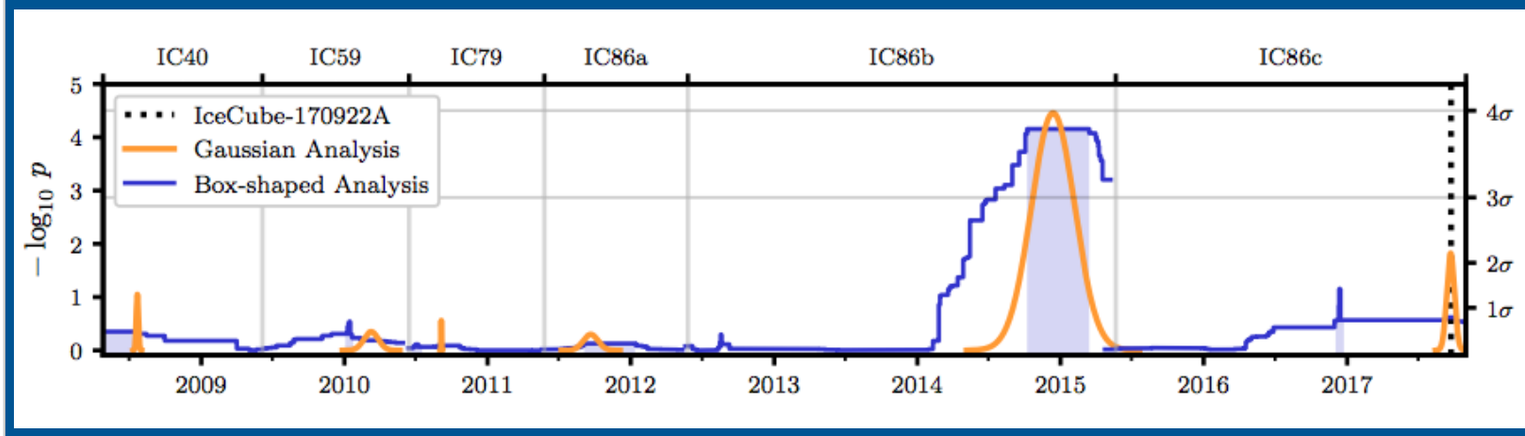
No counterpart observation in the period 2014-2015

horizontal track with a good angular resolution

$5.7\ ^{+0.50}_{-0.30}$ - below the horizon

most probably E_ν = 290 TeV





IceCube Coll. Science 361, eaat1378 (2018)

OPEN QUESTIONS

- Which classes of sources contribute to the observed diffuse neutrino flux ?

- Which mechanism is responsible for the neutrino emission p-p or/and p-γ ?

- Which is the flavor composition ?

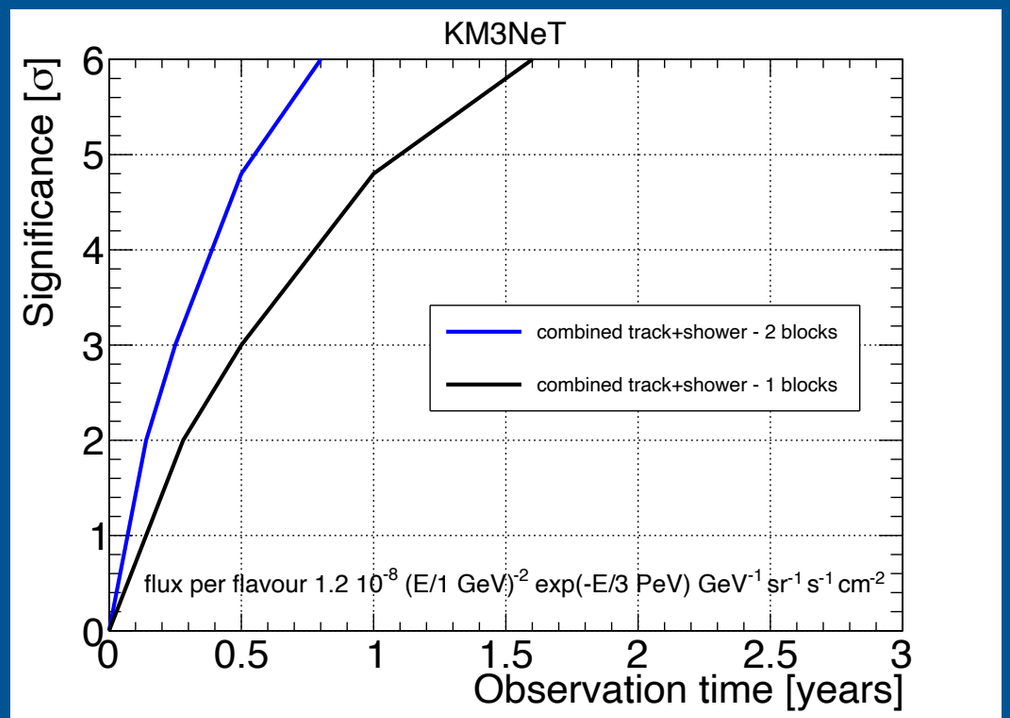
- Are neutrinos and gammas/CR observed from the same sources?

- Which is the contribution of neutrino from the Galactic plane ?

ARCA: THE MAIN PHYSICS GOALS

ARCA: ASTROPHYSICS AND MULTI MESSENGER

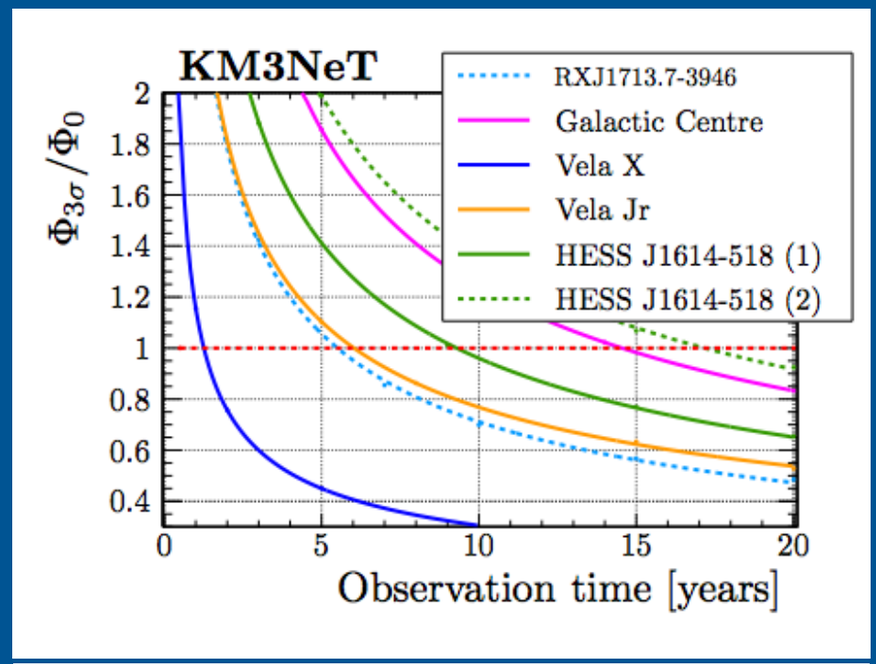
Detection of cosmic diffuse neutrinos

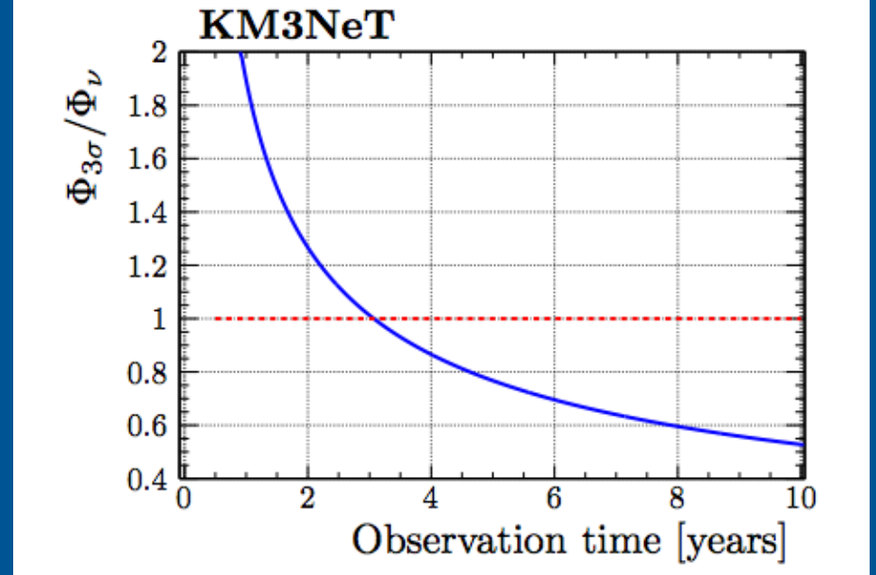


5σ ~ 1 year for one block detector (115 DUs)

Astrop. Phys. 111 (2019) 100 -110

Galactic sources





Observation within a few years if their **γ**-ray emission is of purely hadronic origin.
Stacking Vela Jr and RX J1713.7-3946 👉 **3σ** significance within 3 years.

EVENT TYPE AND ANGULAR RESOLUTION

	TRACK*	CASCADE*
ANTARES	0.3°	3°
KM3NET	0.1°	1.5°
ICECUBE	0.3°	7°-8°
BAIKAL -GVD	0.25°	3° - 3.5°

*Resolution at 100 TeV

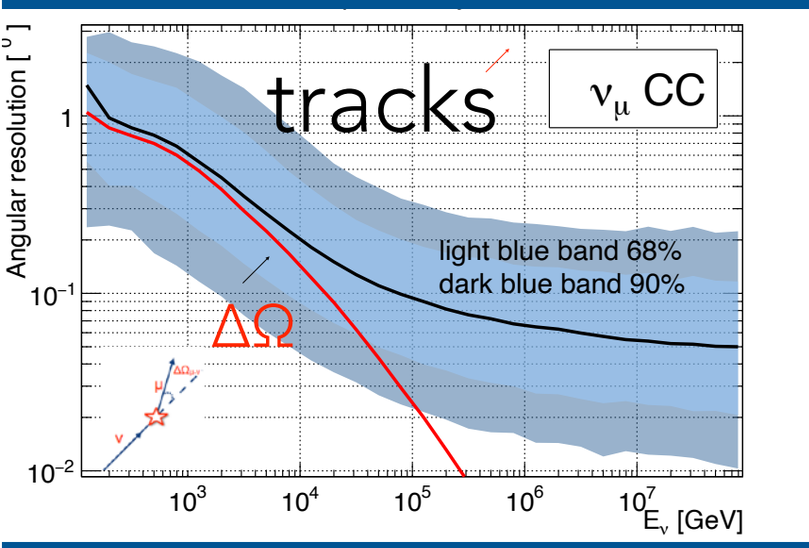
Tracks: very long path (Eμ>1TeV several km)
Big lever arm

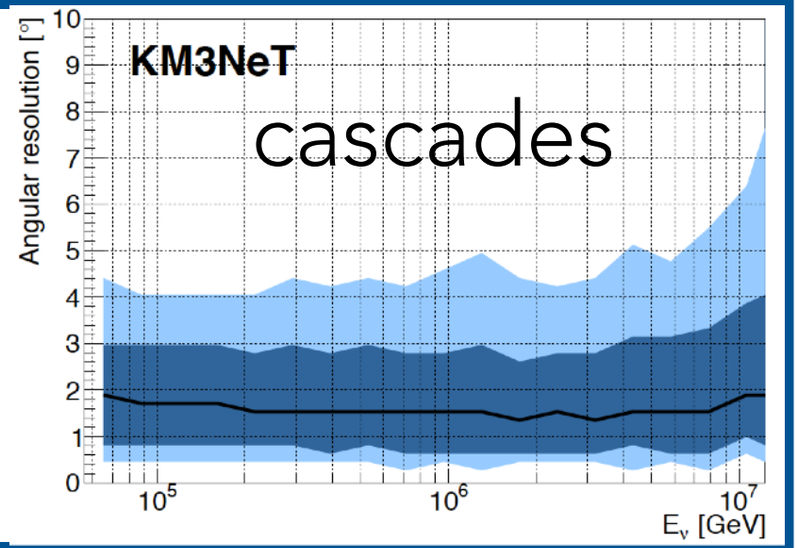
- Good angular resolution

Cascades: small path (Ecasc >1TeV some tens of meters)

- Modest angular resolution

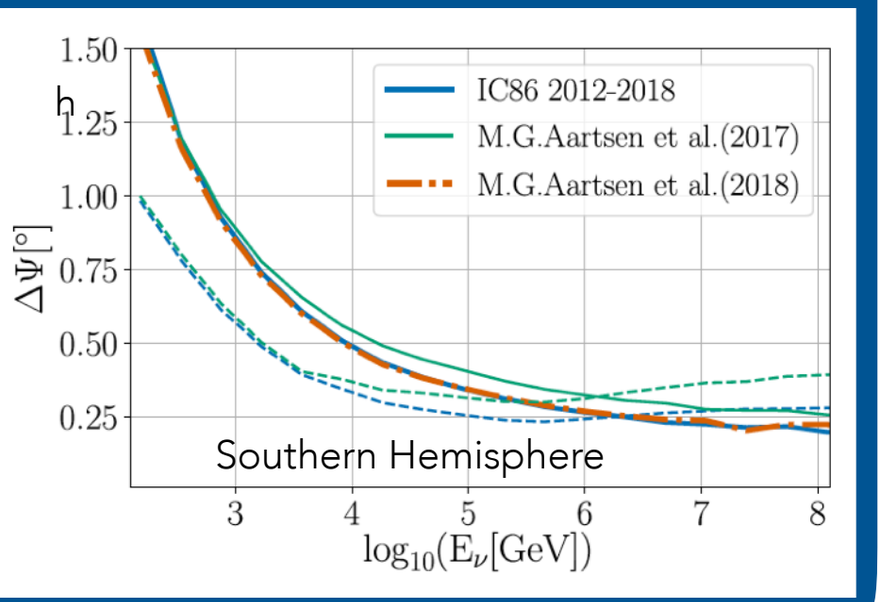
KM3NeT





IC resolution for tracks

from arXiv:1910.08488, 15 October 2019



EVENT TYPE AND ANGULAR RESOLUTION

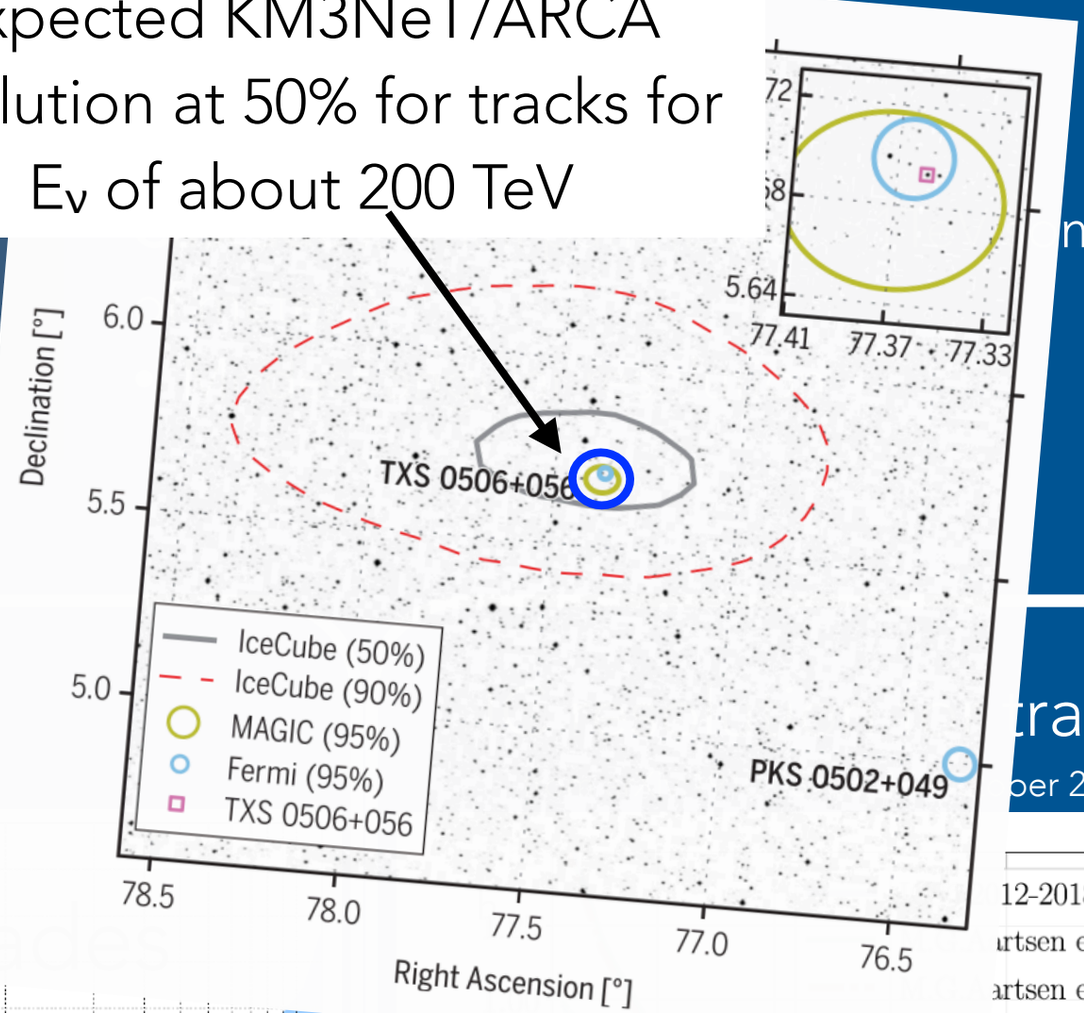
	TRACK*	CASCADE*
ANTARES	0.3°	
KM3NET	0.1°	1
ICECUBE	0.3°	7°-8°
BAIKAL -GVD	0.25°	3° - 3.5°

*Resolution at 100 TeV

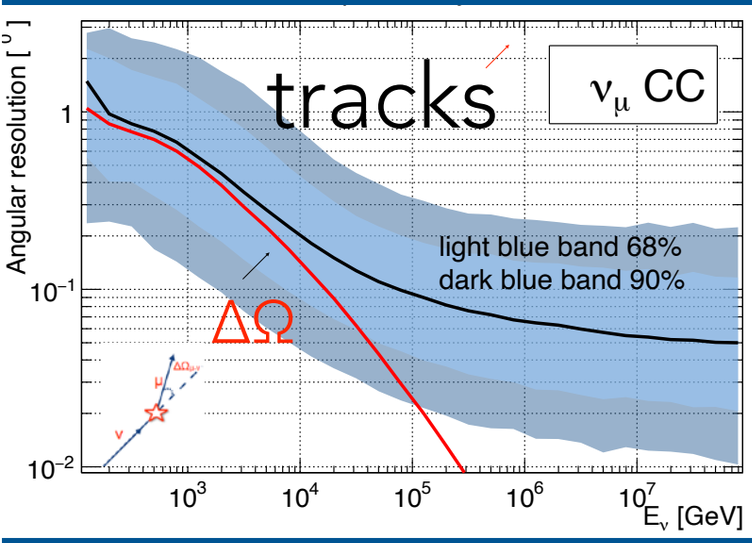
Tracks: very long path (Eμ>1TeV several km)

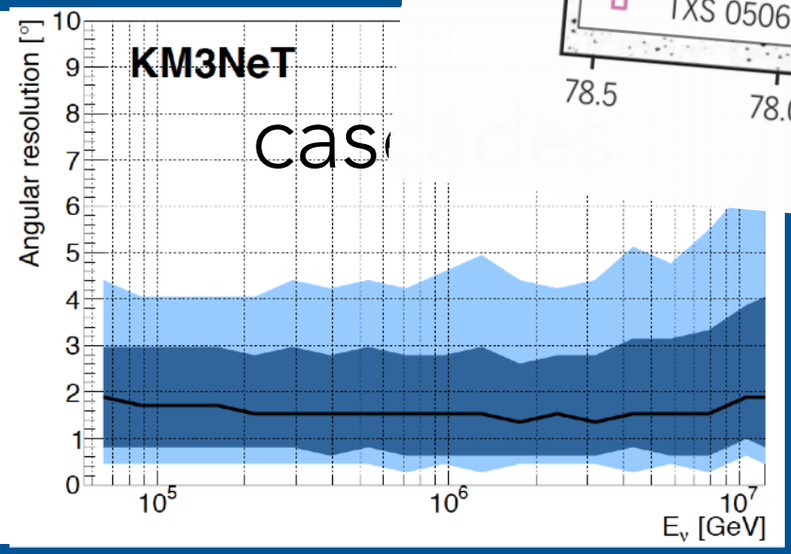
me tens

Expected KM3NeT/ARCA resolution at 50% for tracks for E_ν of about 200 TeV



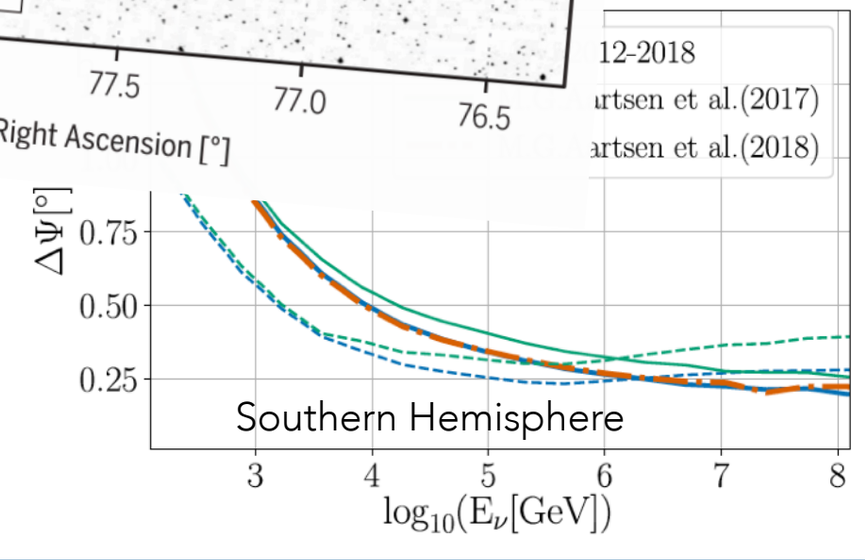
KM3NeT





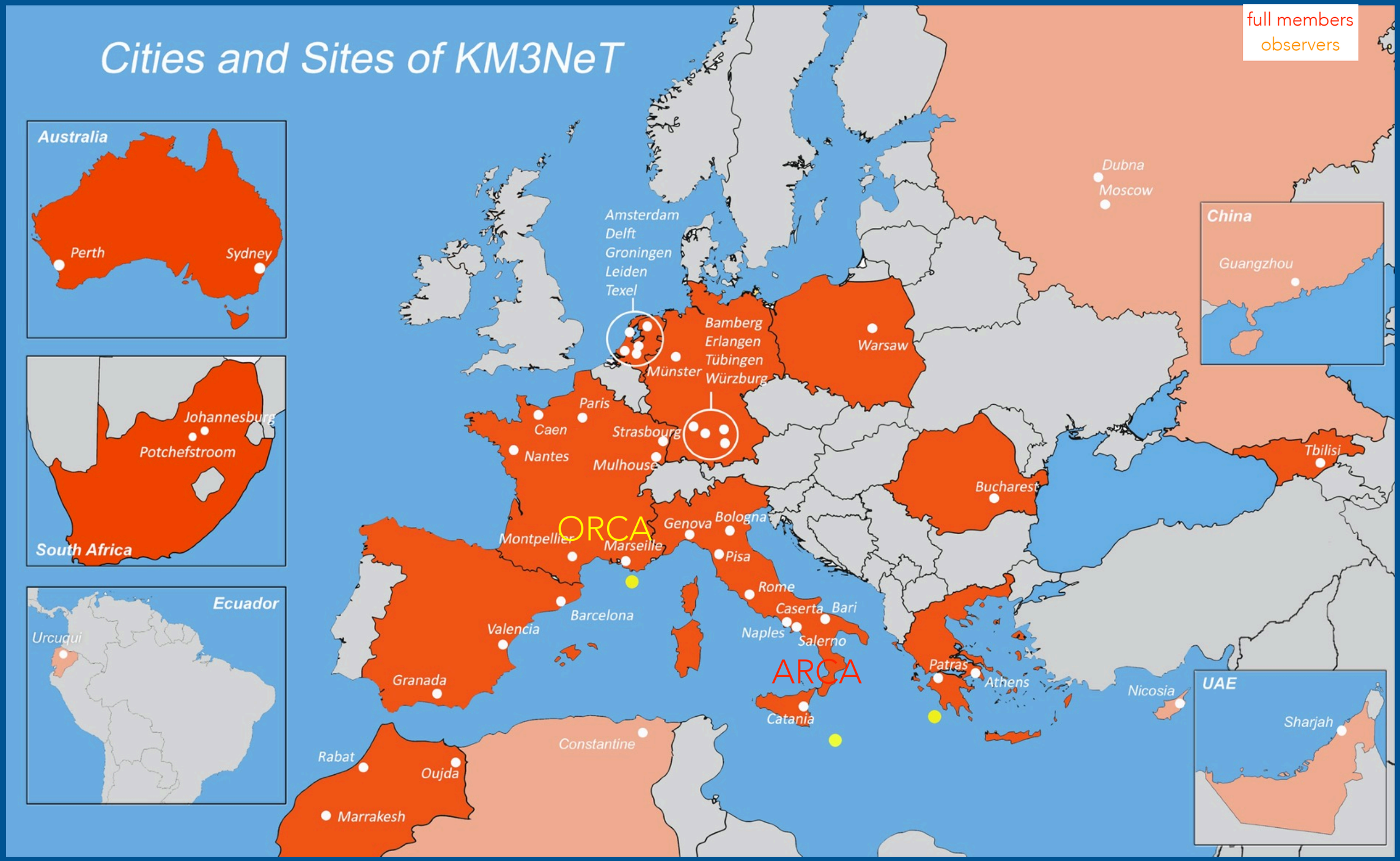
tracks

ber 2019



THE KM3NET COLLABORATION

56 institutes in 17 countries



THE TECHNOLOGY

The basic elements:

- Optical sensors 👉 DOMs (Digital Optical Module)
- Strings 👉 DU (Detection Unit)
- Seafloor network 👉 Electro-optical cables and JBs (Junction Boxes)

DOM

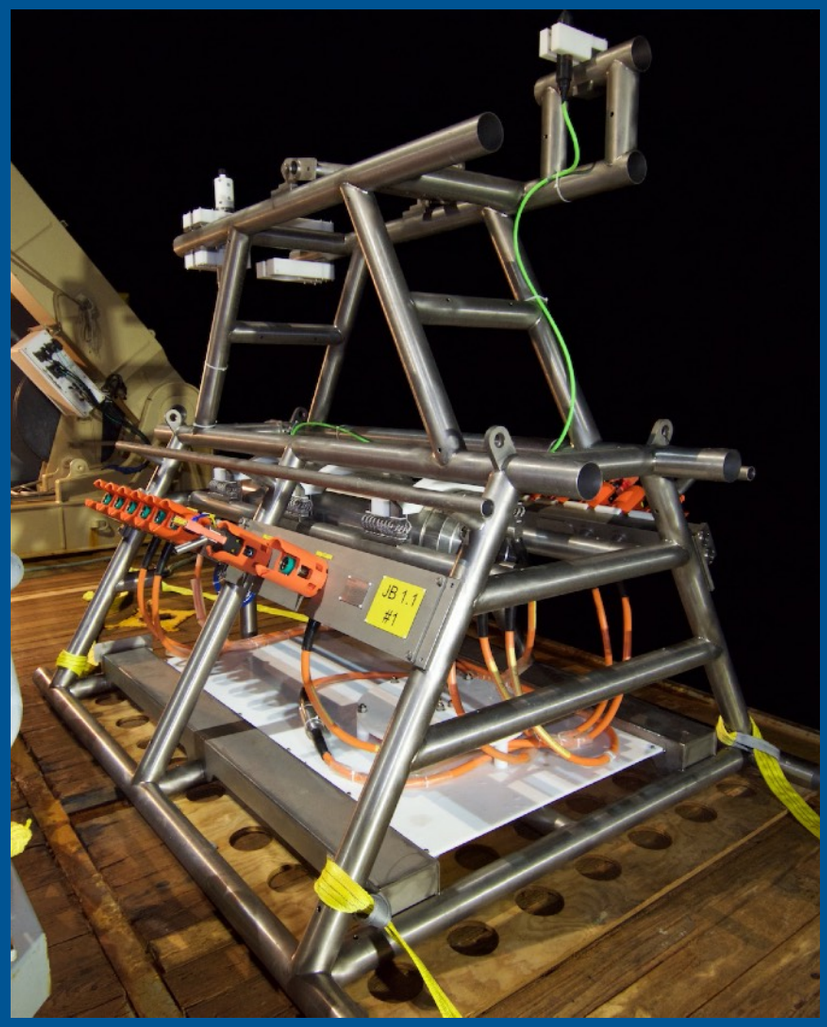
It is a 17” glass sphere with inside:

- 31 3” PMTs (photocathode aerea ≃ 3 × 10” PMTs)
- LED and Piezo
- Front-end electronics -> FPGA

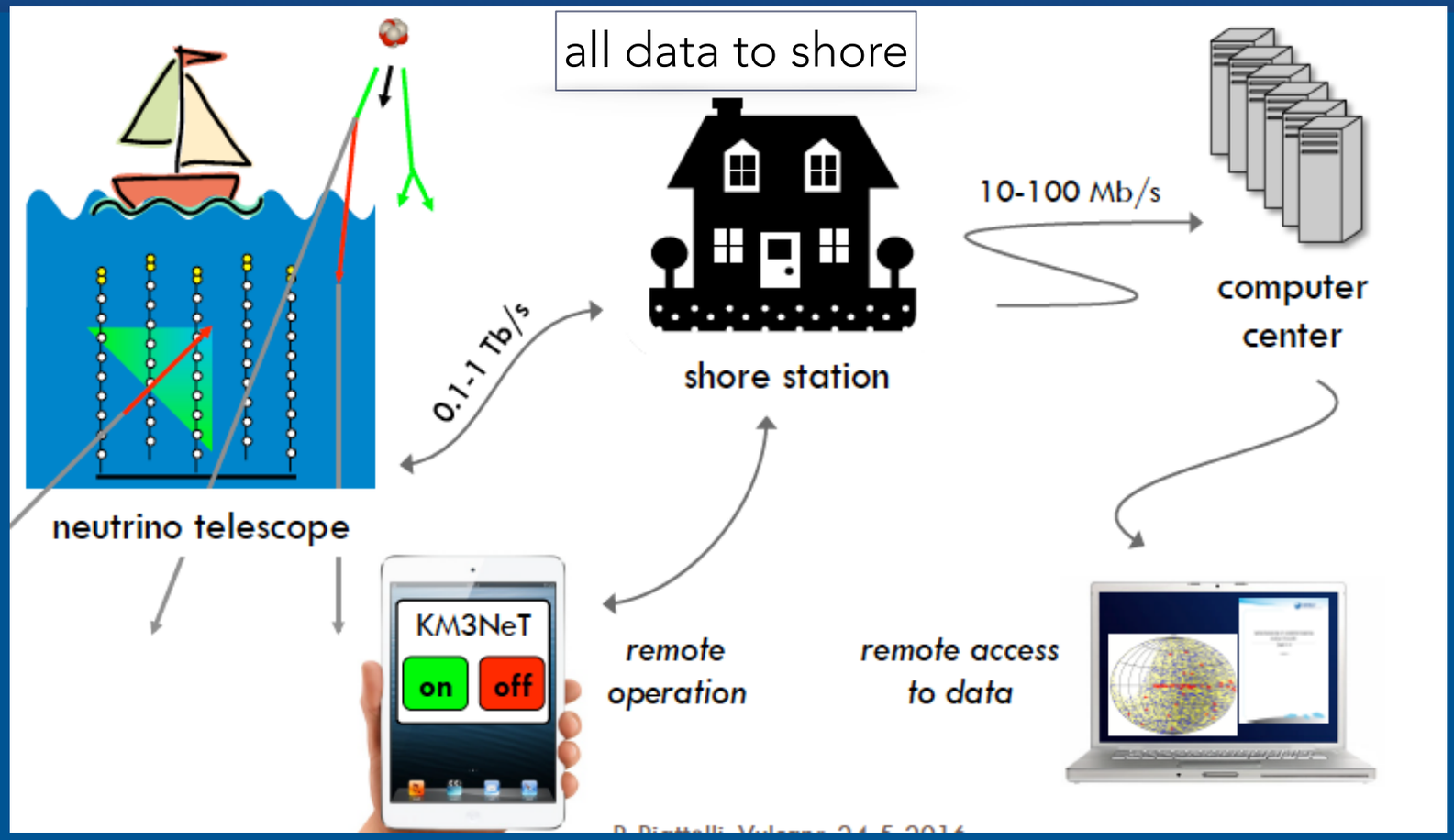
DU

18 DOMs in a DU

JB



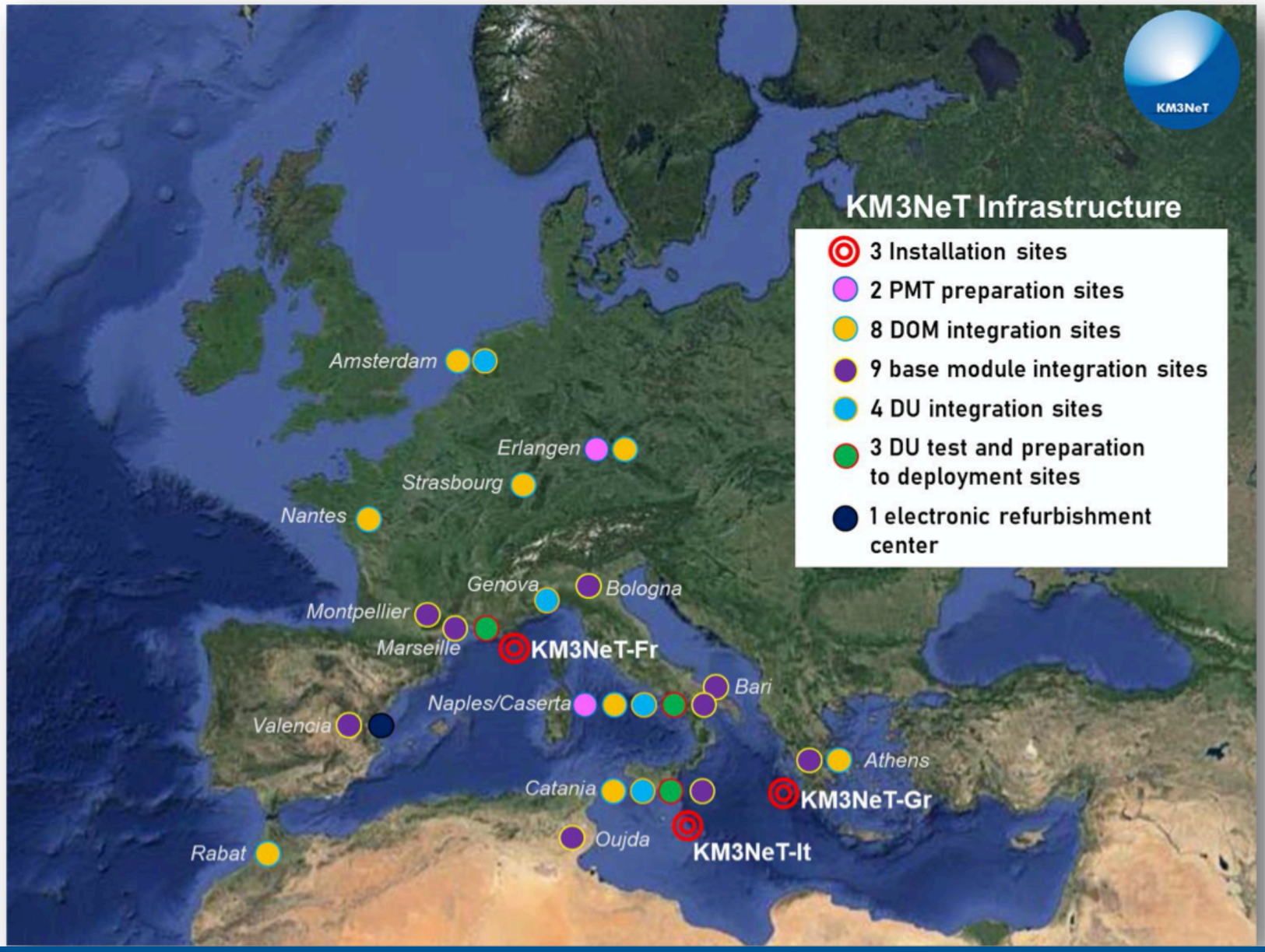
THE KM3NET ARCHITECTURE



ORCA shore station

ARCA shore station

THE DETECTOR CONSTRUCTION



DOMs:
- 8 integration sites
- 640 DOM produced (400 ARCA,240 ORCA)
- 100 currently in progress

BMs:
- 9 integration sites
- 27 BMs produced
- 6 currently in progress

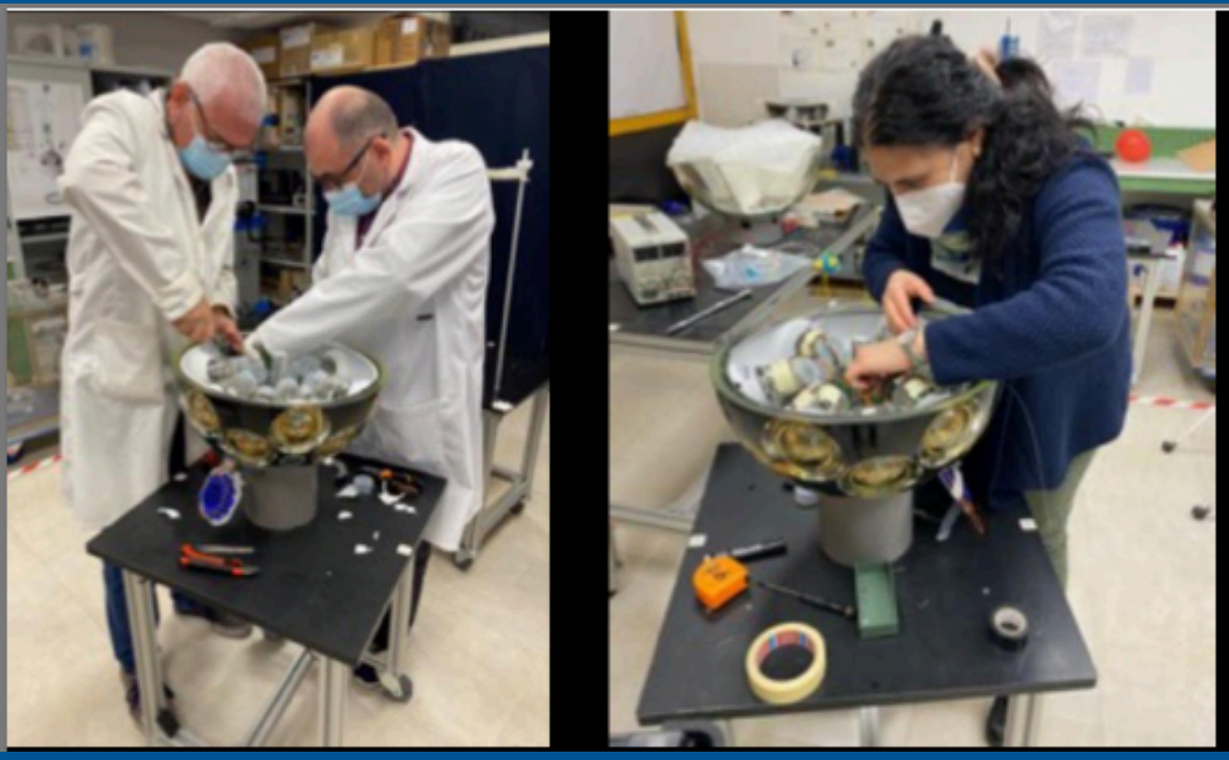
DUs:
- 5 integration sites
- 13 DUs produced
- 8 currently in progress

Total:22 integration sites!
(last year:15)

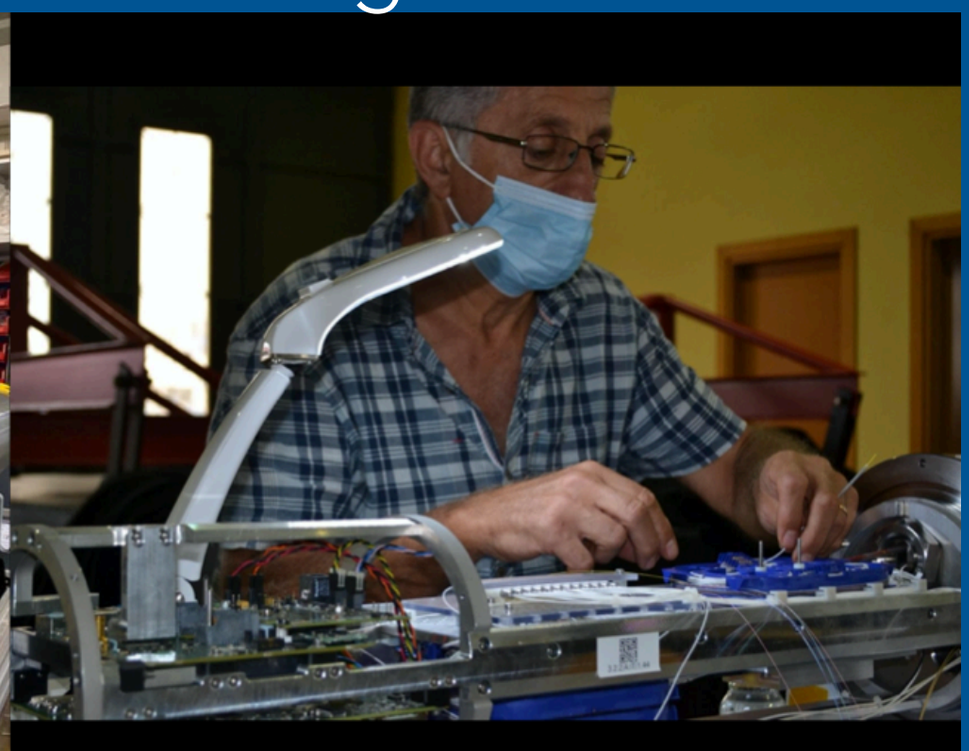
Despite pandemic big efforts are on going in the detector construction

THE INTEGRATION

DOM integration



Base Module integration



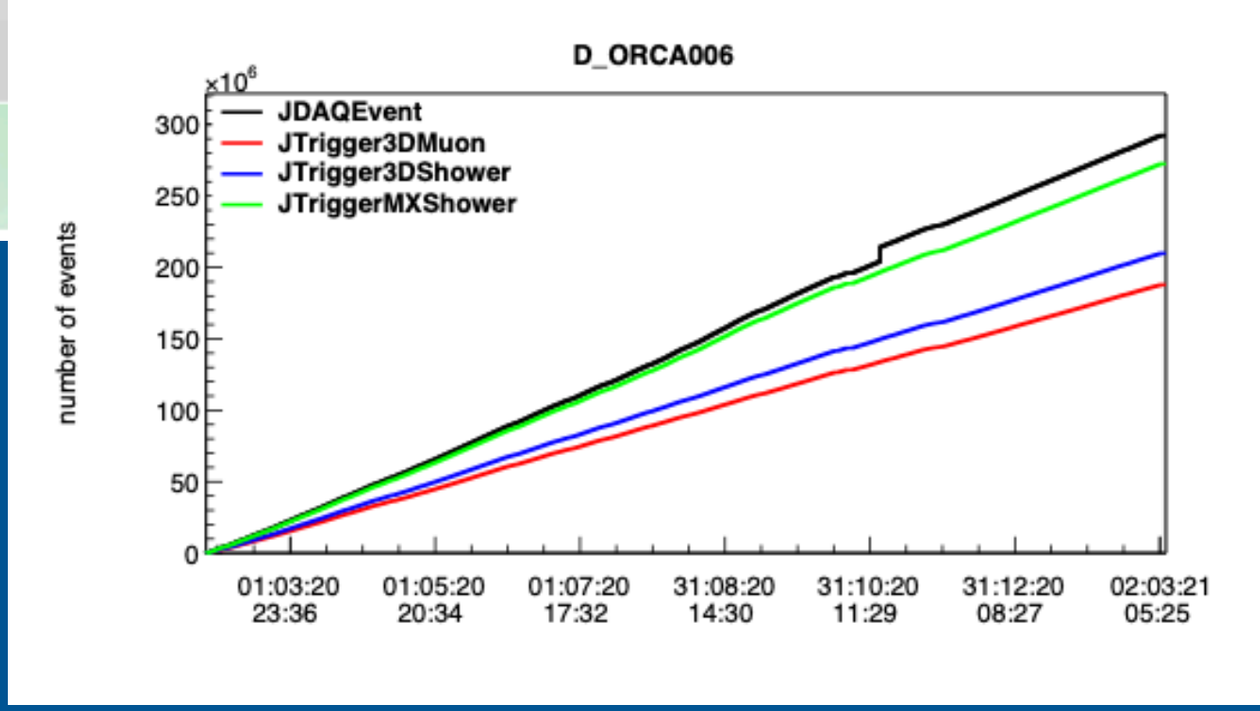
THE INTEGRATION

DU integration

ORCA STATUS

From February 2020 six detection units in operation

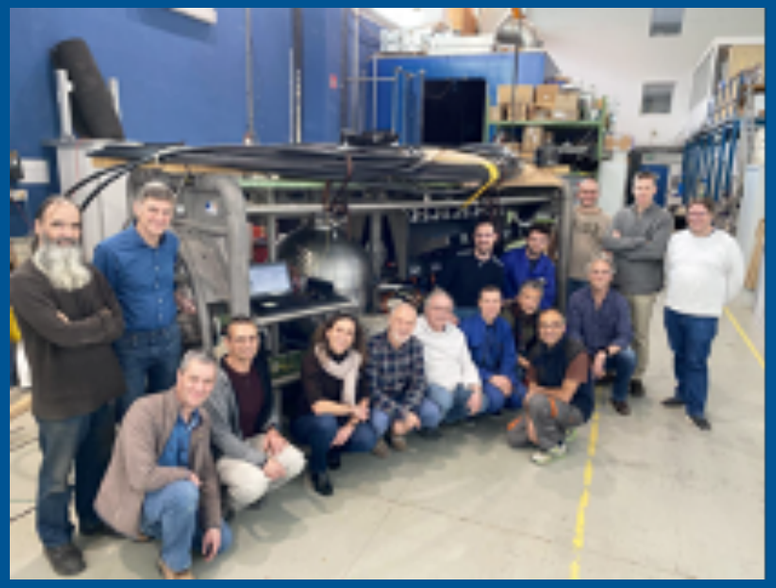
More than one year of data available



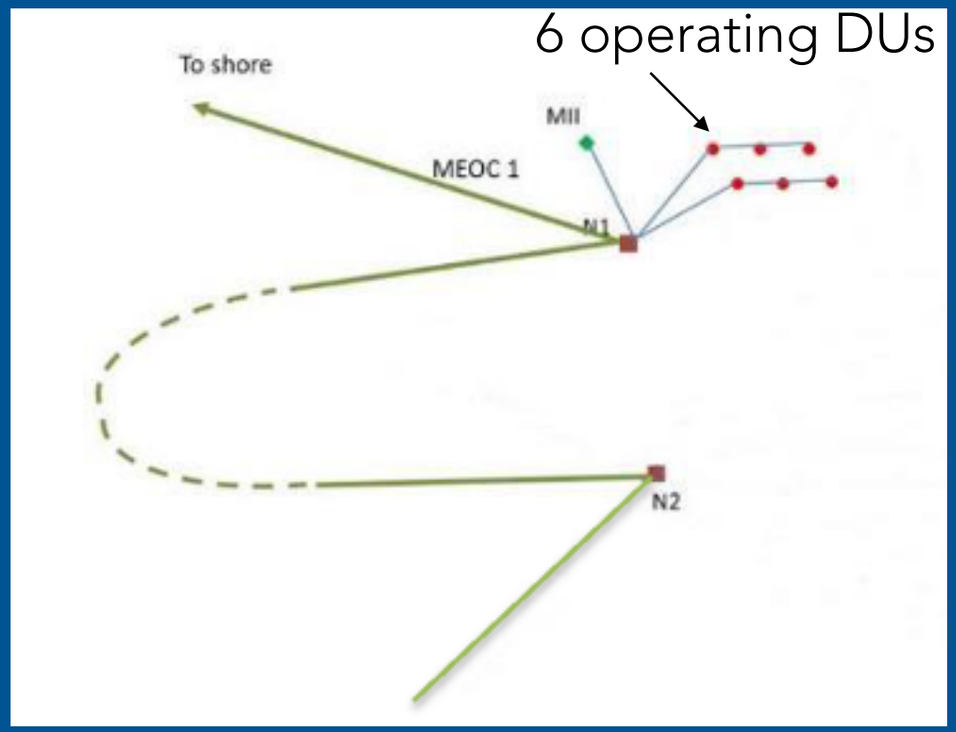
Data Taking efficiency of 98.8%

ORCA STATUS

October 2020 👉 Successful connection of a second JB

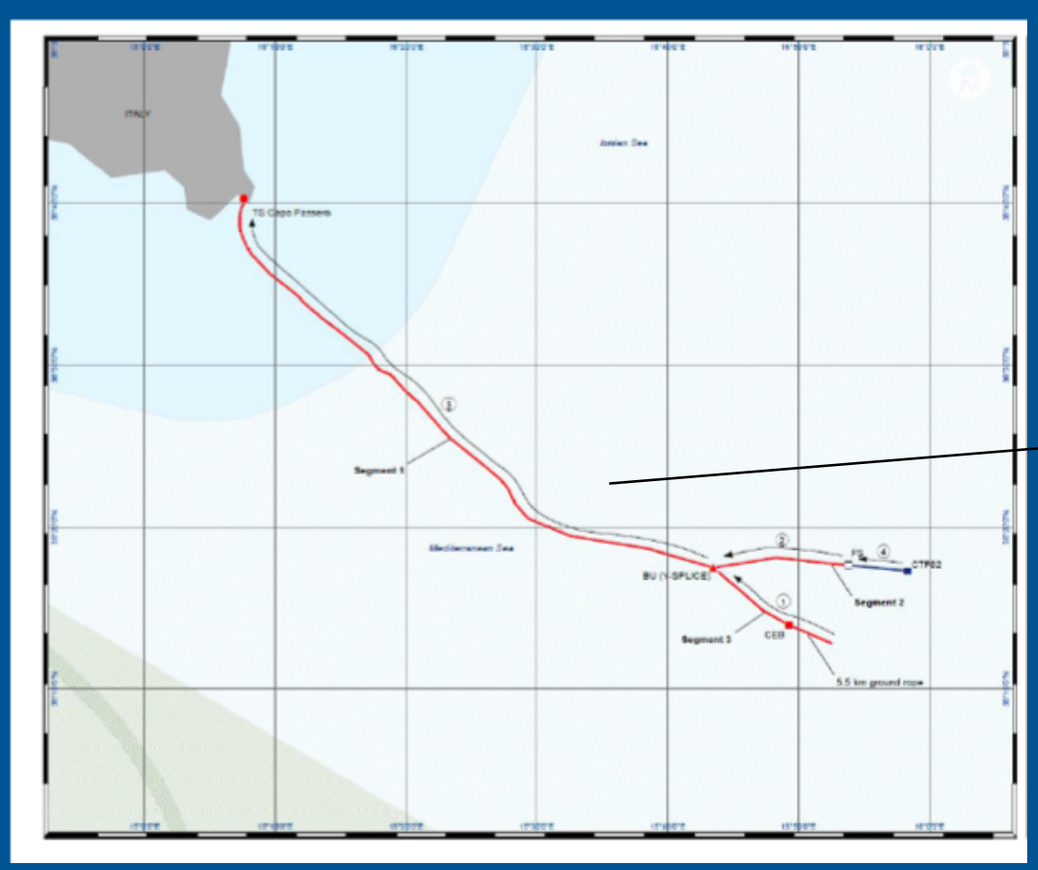


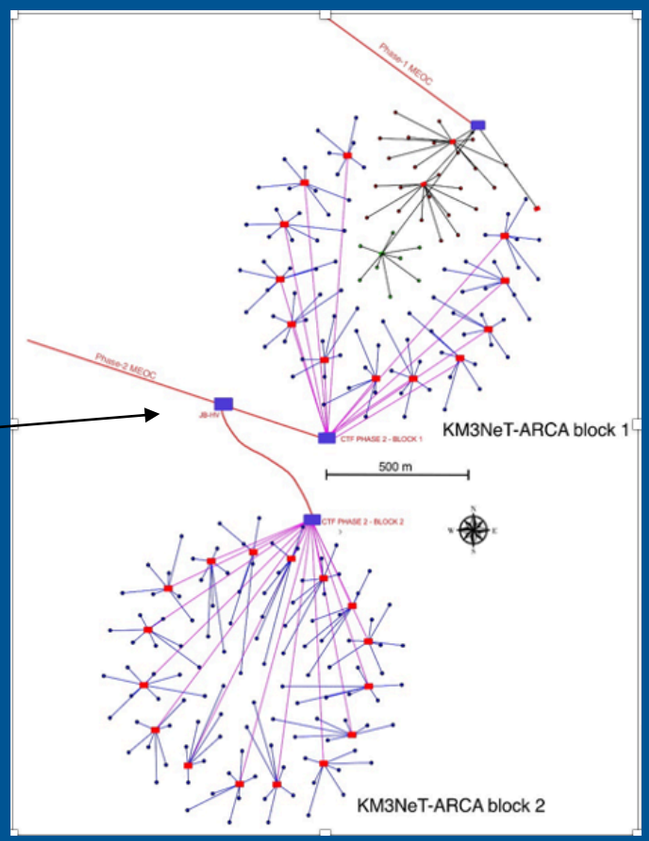
We can now connect up to 52 DUs



ARCA STATUS

Nov 2020 👉 Successful laying of a second MEOC cable (Alcatel)



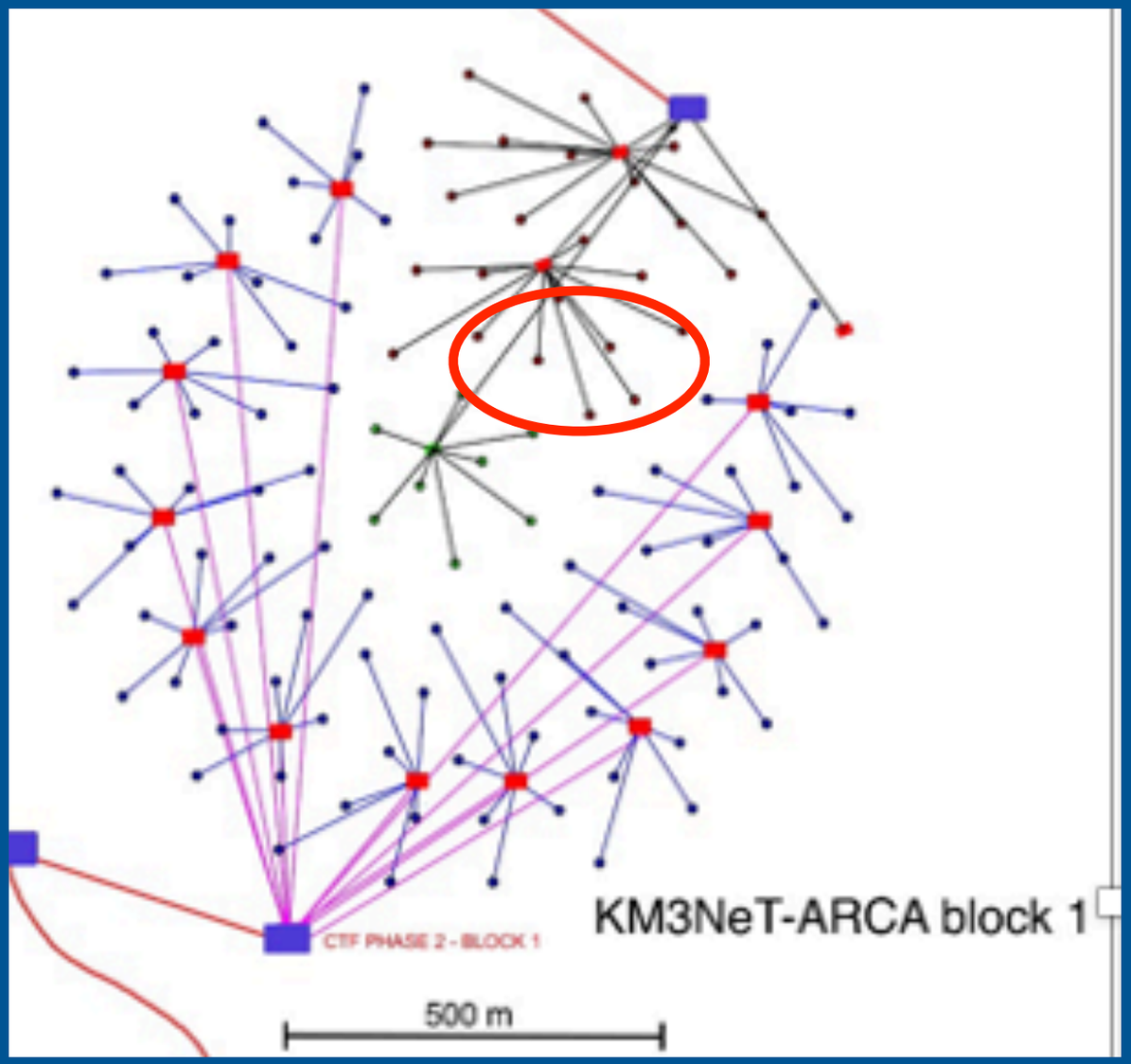


With this second main cable is possible to connect the full detector (2 blocks)

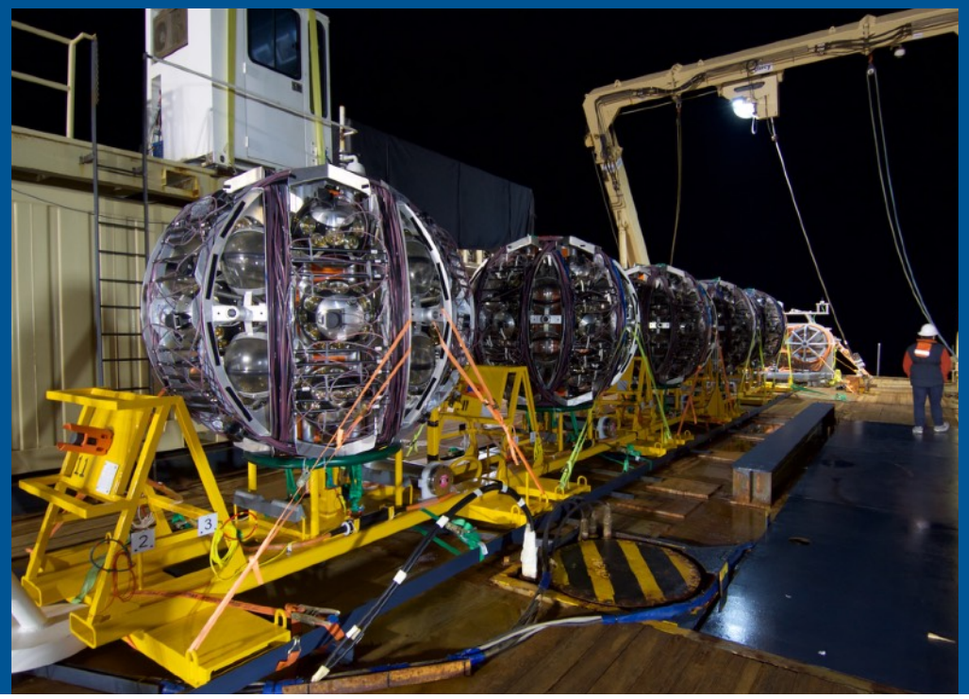
ARCA STATUS

8-15 April 2021 👉 Successful deployment of 5 DUs and 1 JB

6 DUs now in operation (1 DU deployed in Dec 2015 and still in operation)



5 DUs on deck before deployment



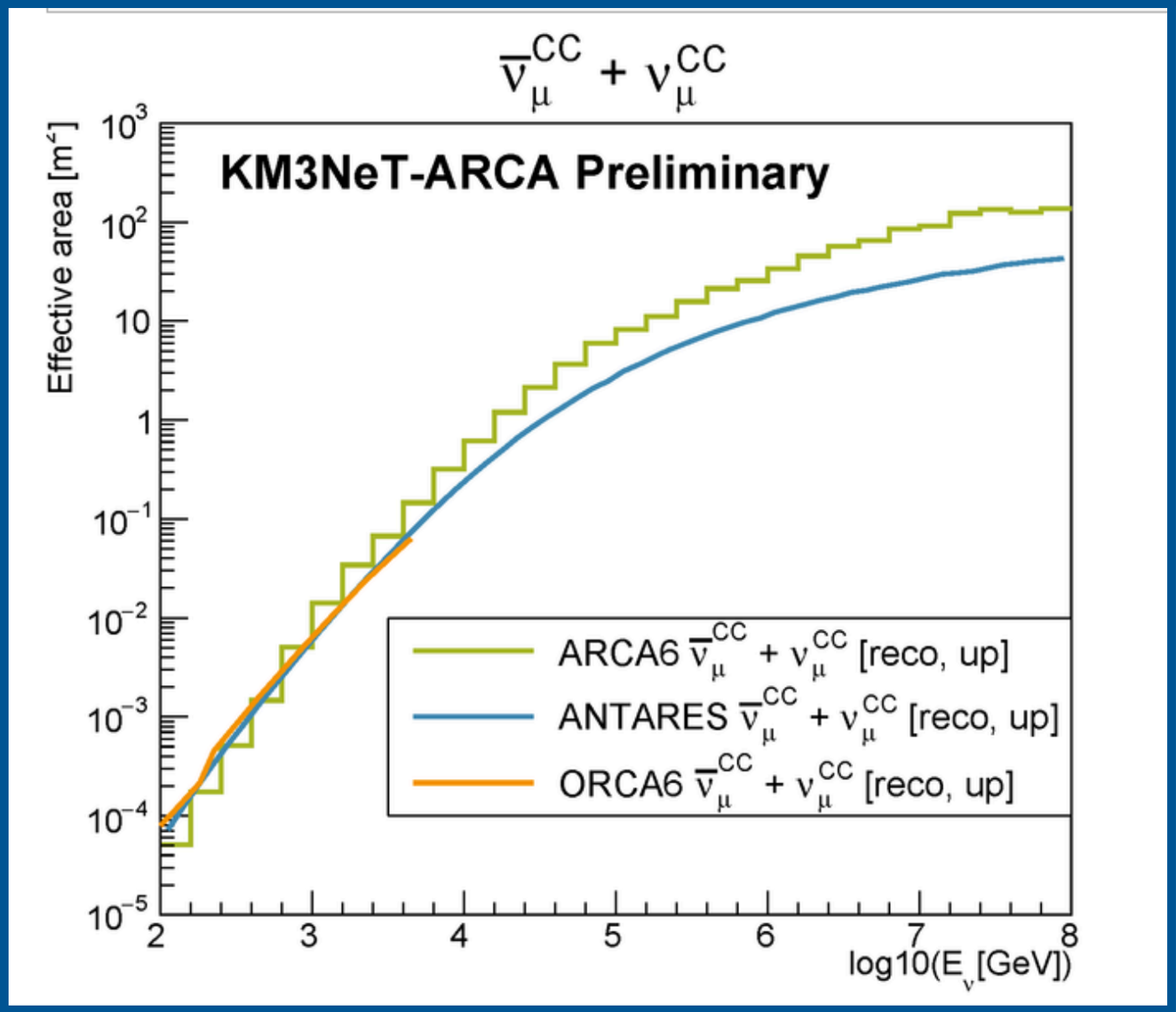
Commissioning phase over

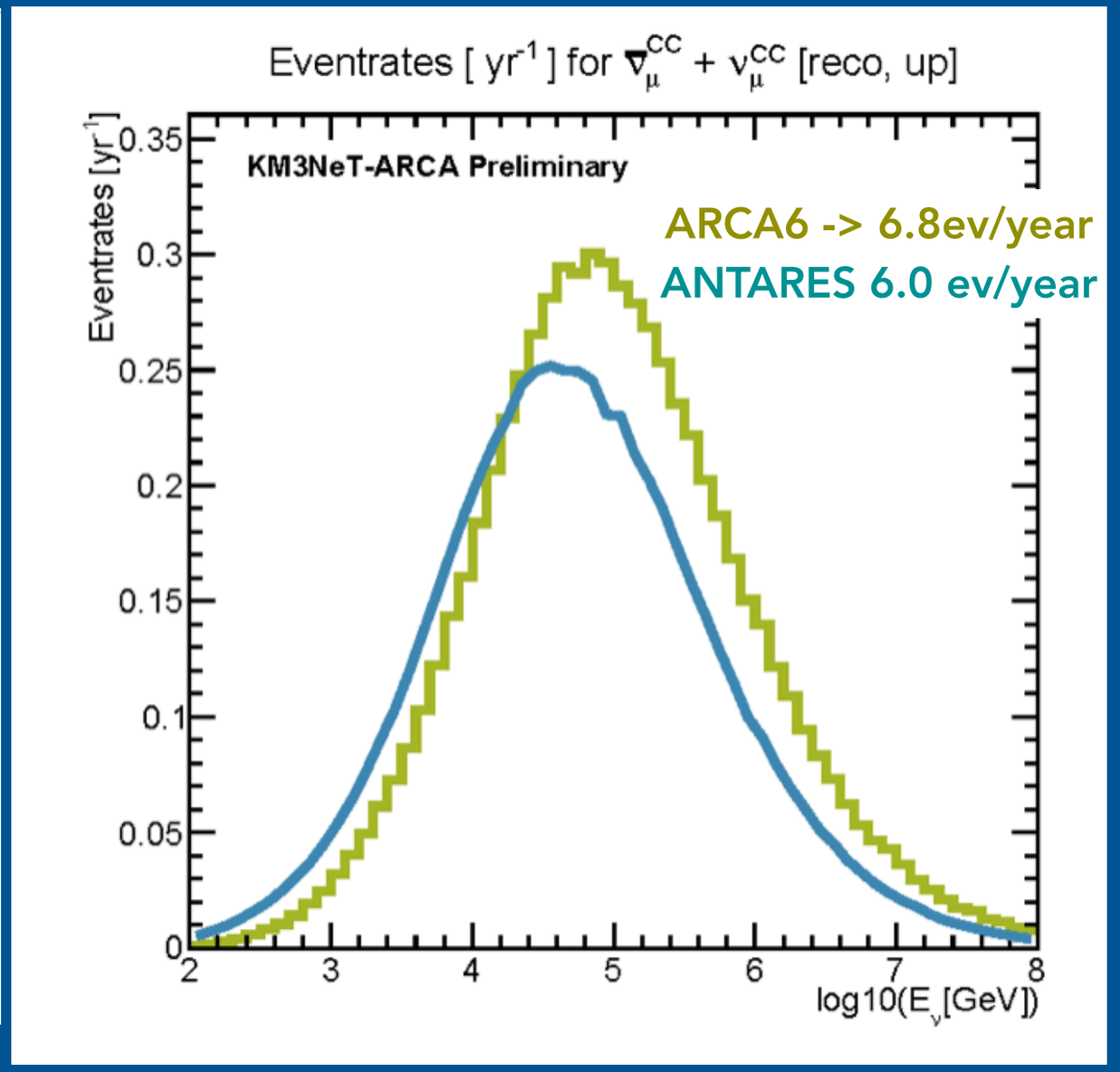
Stable data taking from 13-May

THE EFFECTIVE AREAS

Selection 👉 up going tracks

Number of events per year for a cosmic diffuse flux $\Phi = 10^{-8} E^{-2} GeV^{-1} cm^{-2} s^{-1} sr^{-1}$





Effective areas >= of ANTARES

THE NEXT IMPORTANT SEA CAMPAIGNS

September - October 2021

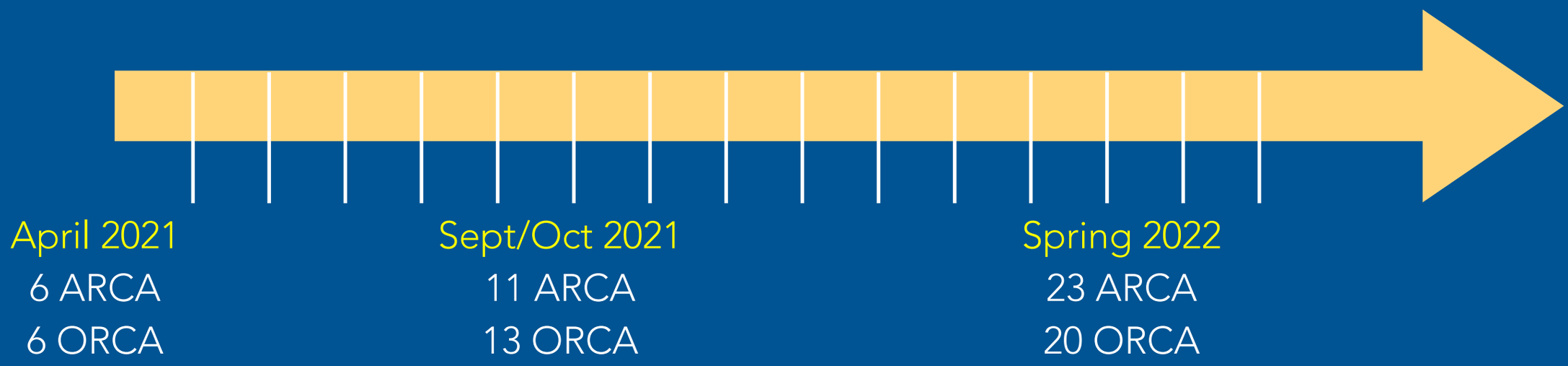
5 DUs at ARCA site

7 DUs + CU (Calibration Unit) at ORCA site

Spring 2022

12 DUs + 1JB +1 CB (Calibration Base) + 1 IU (Instrumentation Unit) at ARCA site

3-4 DUs at ORCA site

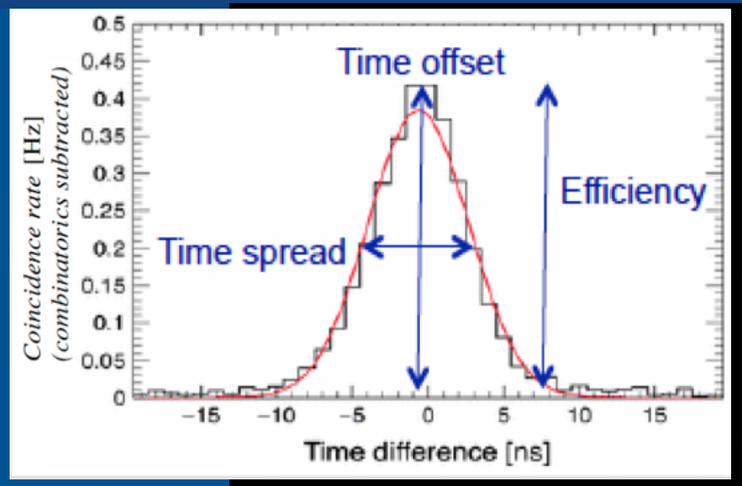


DETECTOR TIME CALIBRATION

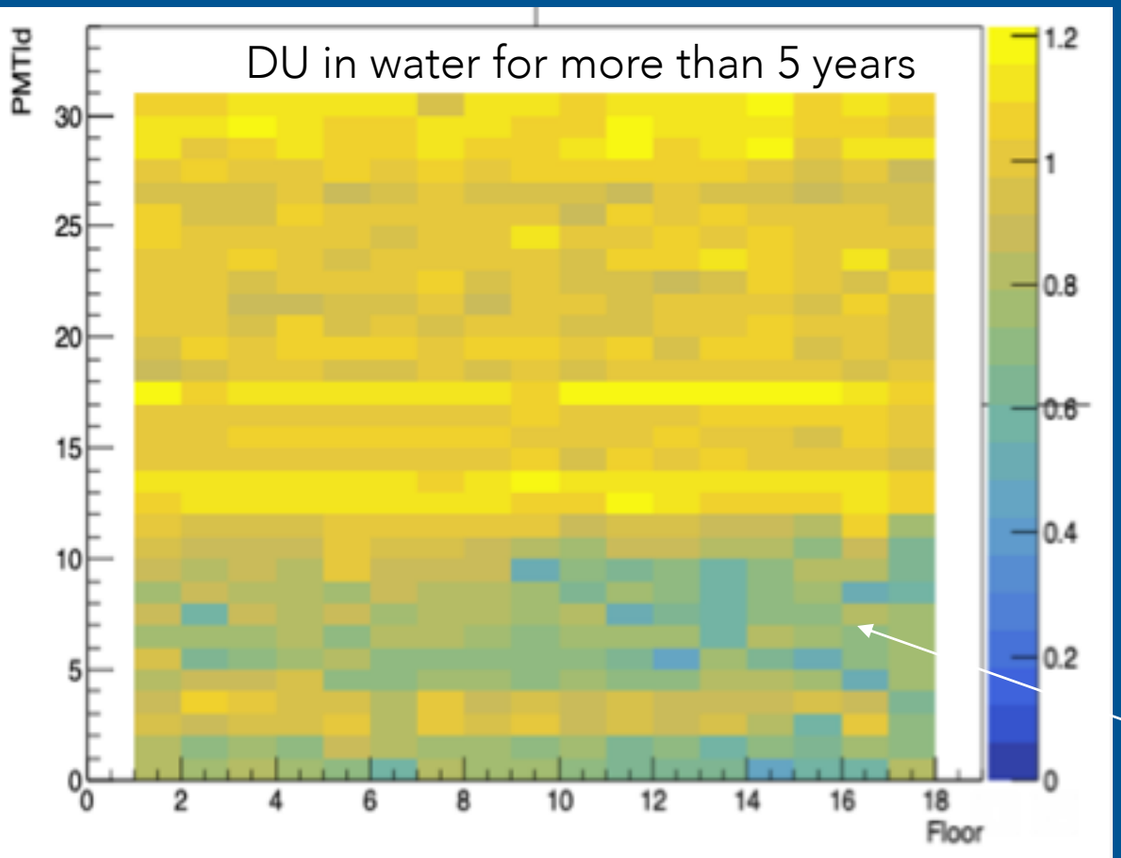
IN SITU CALIBRATIONS

Time offsets:

- Intra DOM PMT time offset 👉 K40
- Inter DOM time offset 👉 LED beacon
- Inter Line time offset 👉 White Rabbit based + laser beacon



From K40 also PMT detection efficiency



Atmospheric muons a good probe to test time calibrations

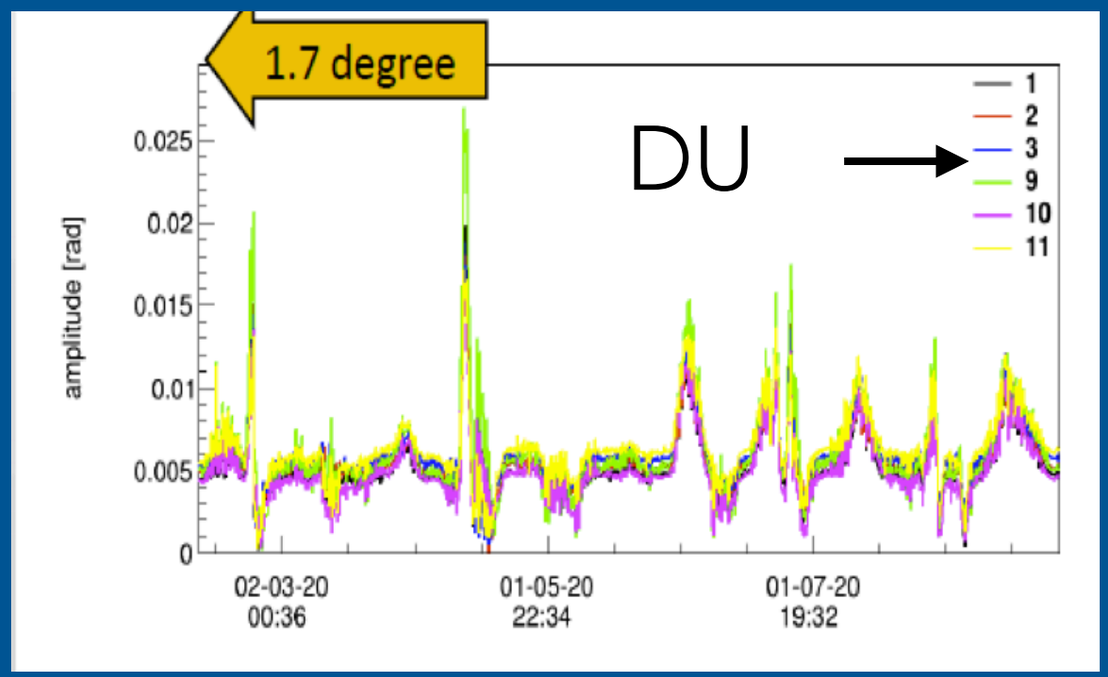
Sedimentation for up-looking PMTs

DETECTOR POSITIONING

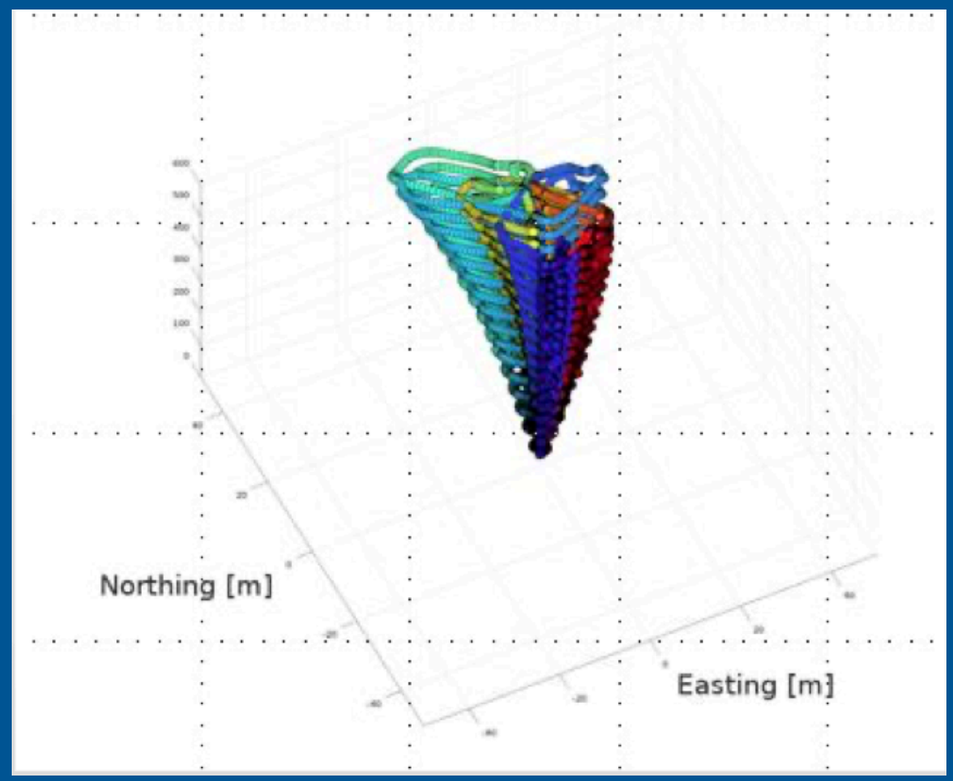
BASED ON ACOUSTIC POSITIONING SYSTEM

Global fit of acoustic signal arrival time

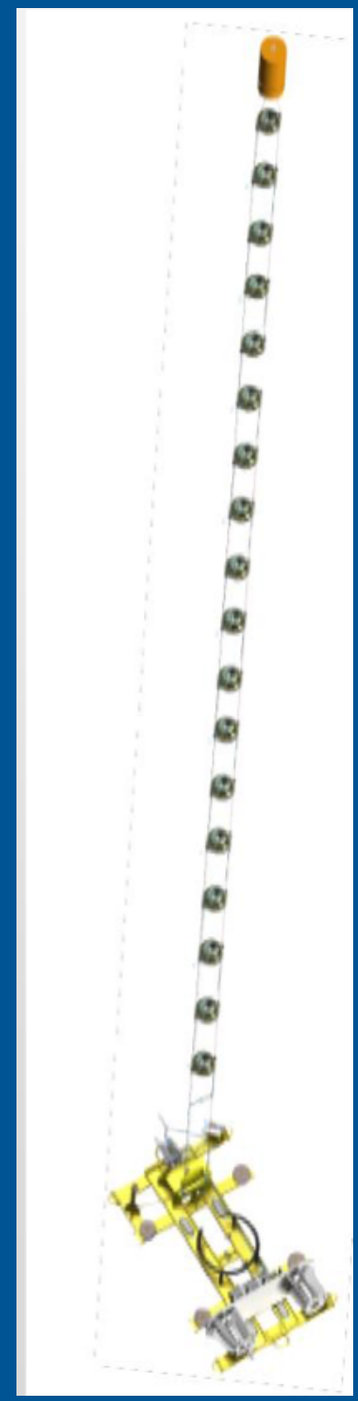
Coherent movement of ORCA 6 lines



August 2019 ARCA1



Deviation from vertical position due to sea currents



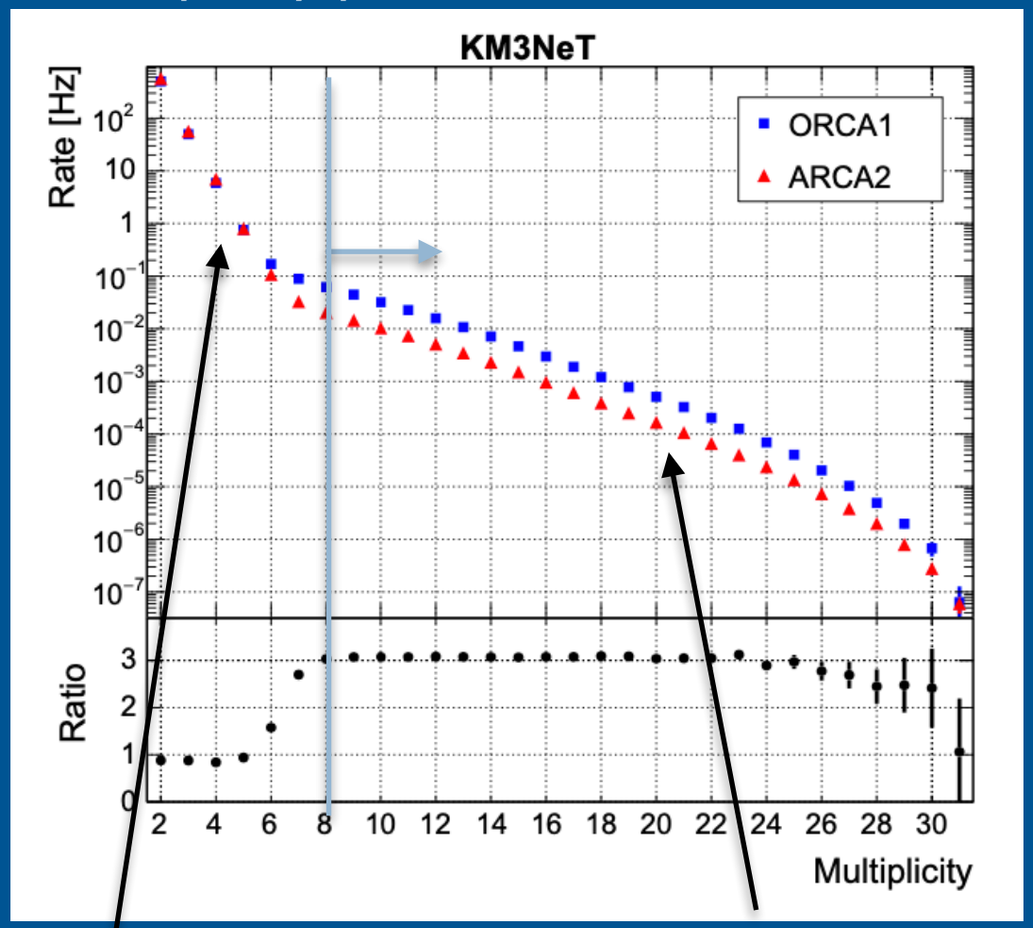
FIRST RESULTS

Eur. Phys. J. C (2020) 80-99

Measurement of the atmospheric muon flux as a function of the depth

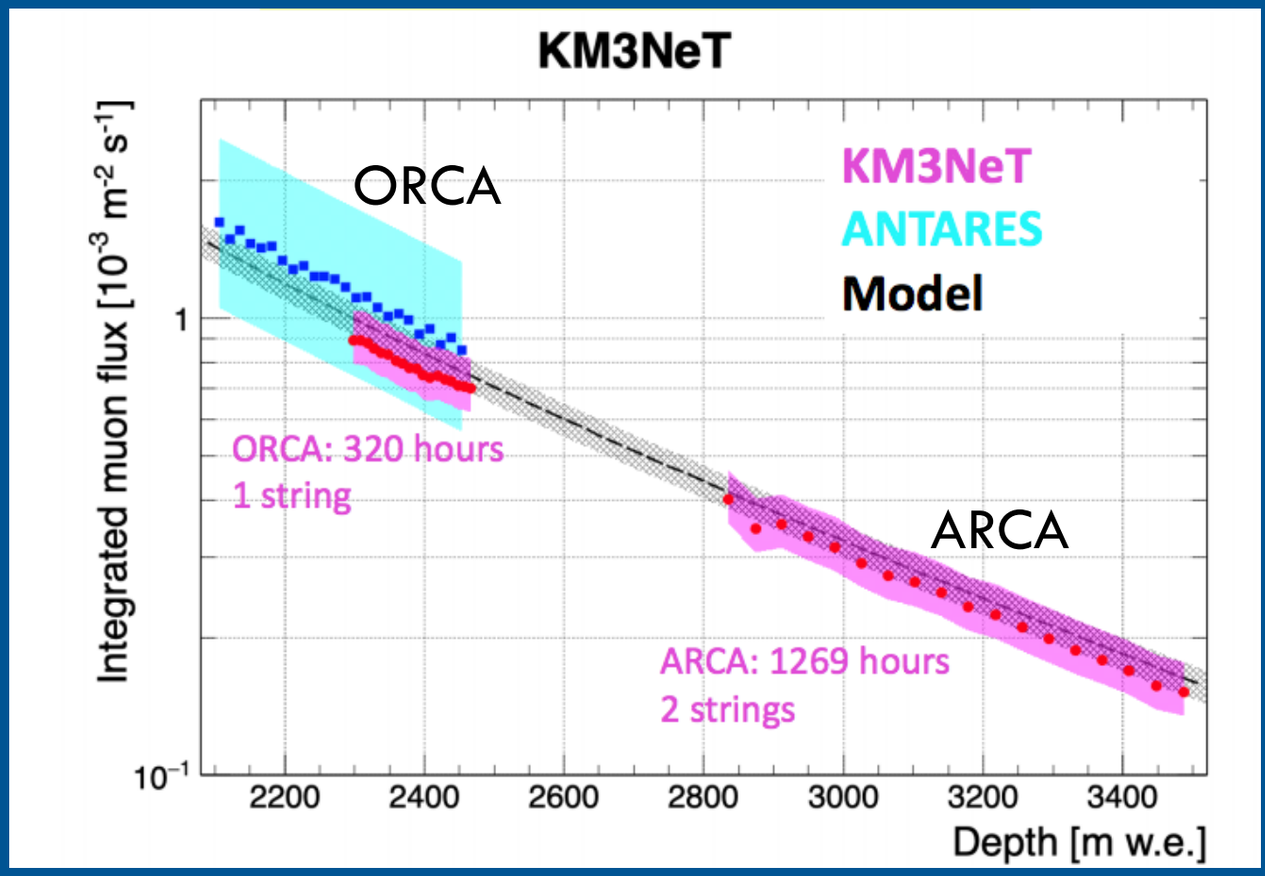
DOM rate for m ≧ 8 as a function of the depth of DOM 👉 Atmospheric muons flux depth dependence

multiplicity plot of PMTs in the DOM



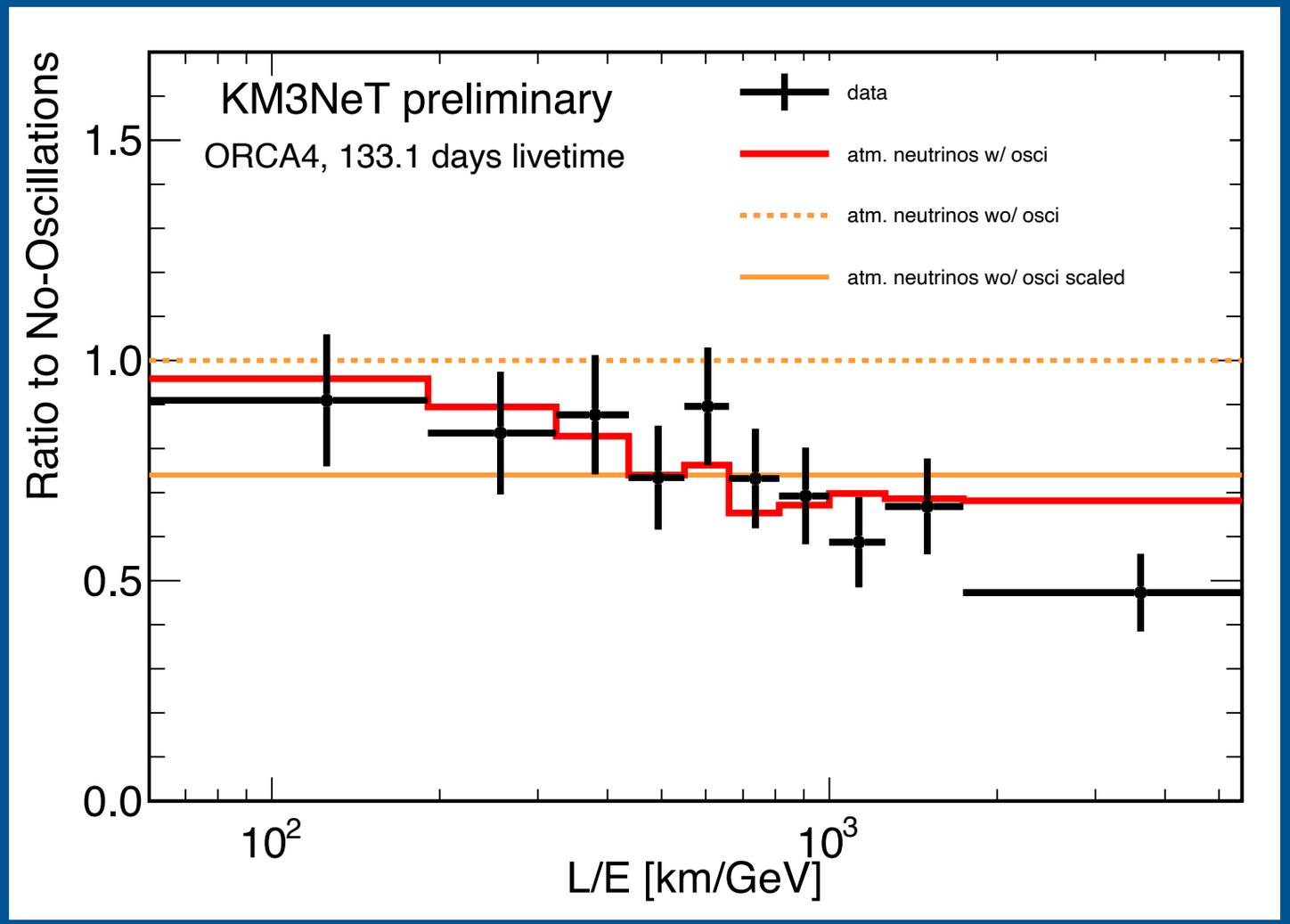
m<6 👉 40K

m>8 👉 atmospheric muons



FIRST RESULTS

ORCA4



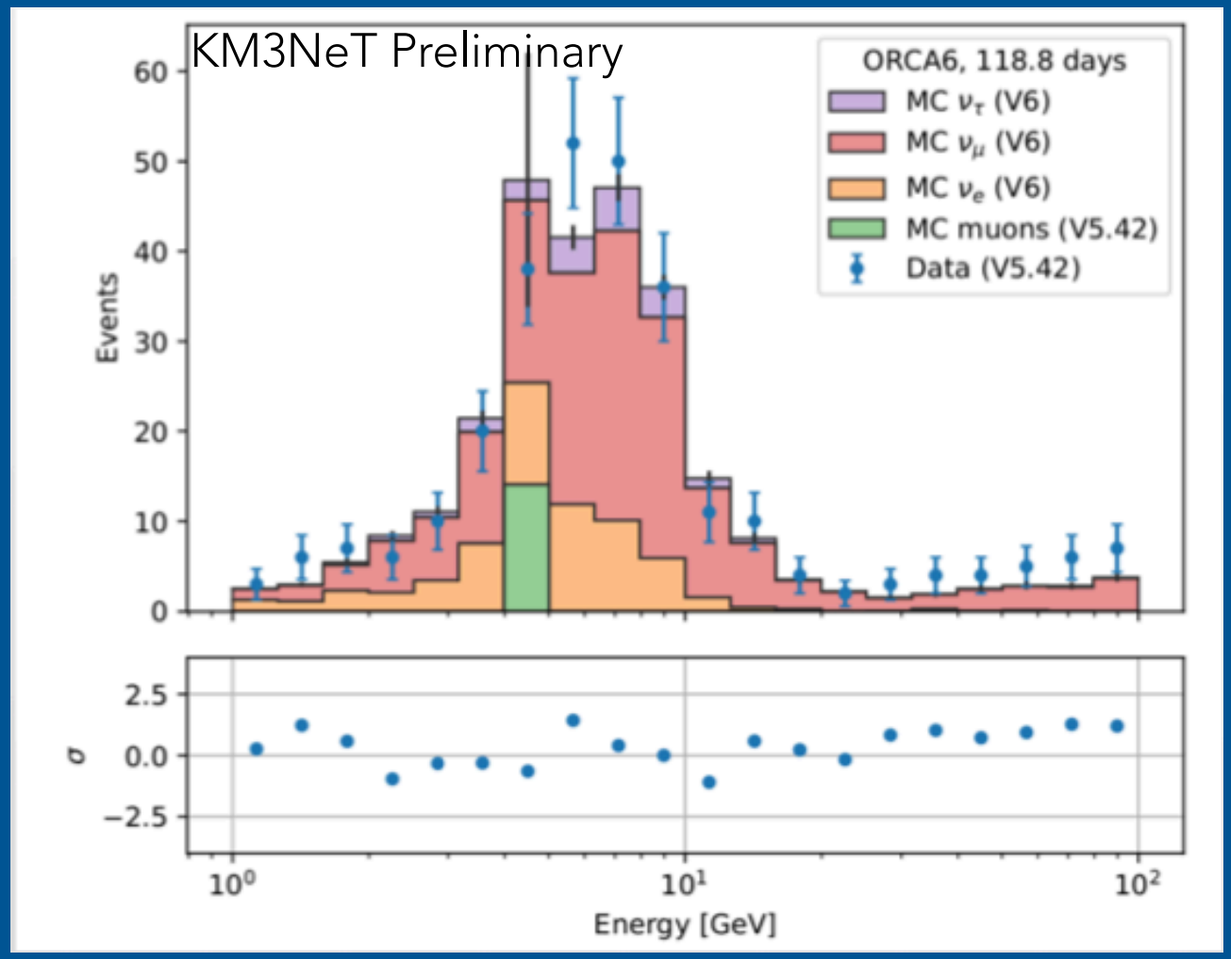
no-oscillation hypothesis disfavoured at ~2.5 sigma

Very good agreement Data /MC

We see neutrino oscillation

FIRST RESULTS

ORCA6 first neutrino sample

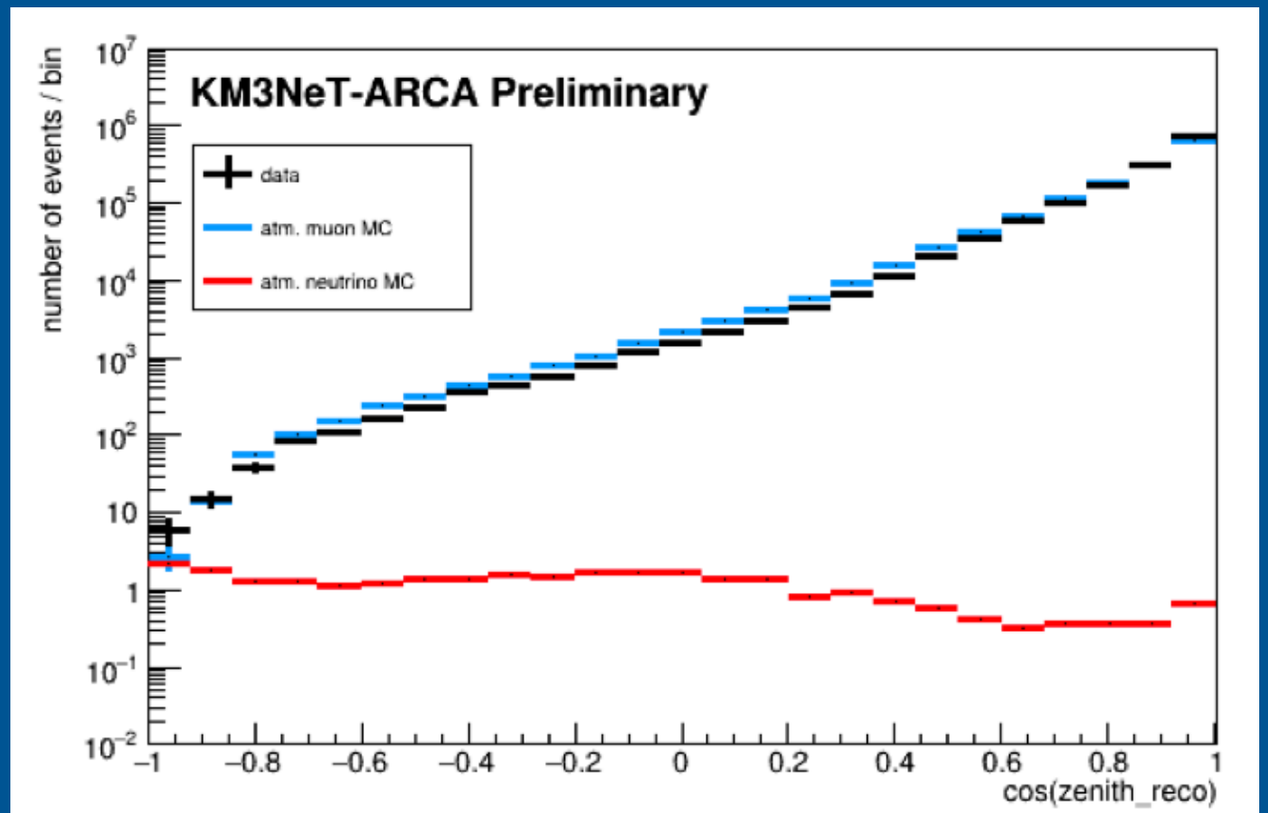


From first sample of selected neutrinos 3-4 neutrino per day
With the present livetime a factor 10 more neutrinos w.r.t. ORCA4

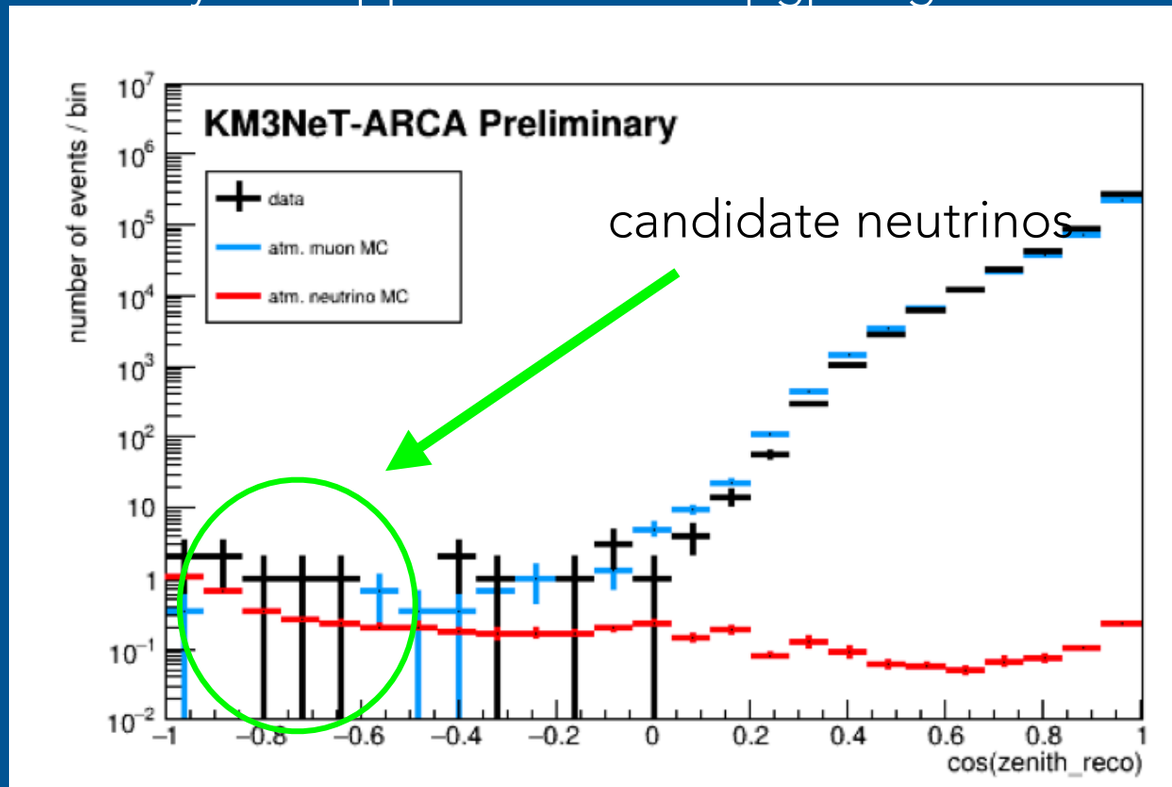
ARCA6: FIRST RESULTS

Data: 19 days ARCA 6 string

No Quality cuts applied



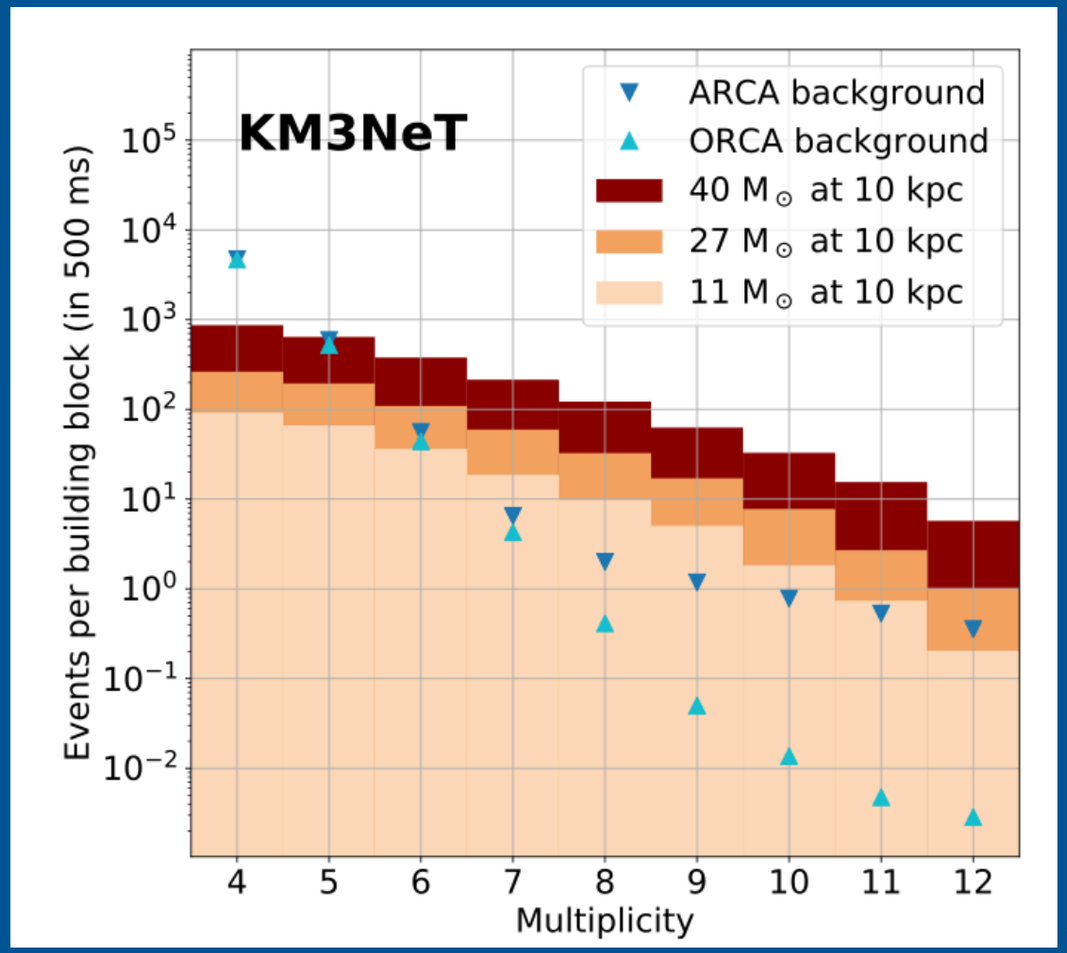
Quality cuts applied to select upgpoing-neutrinos

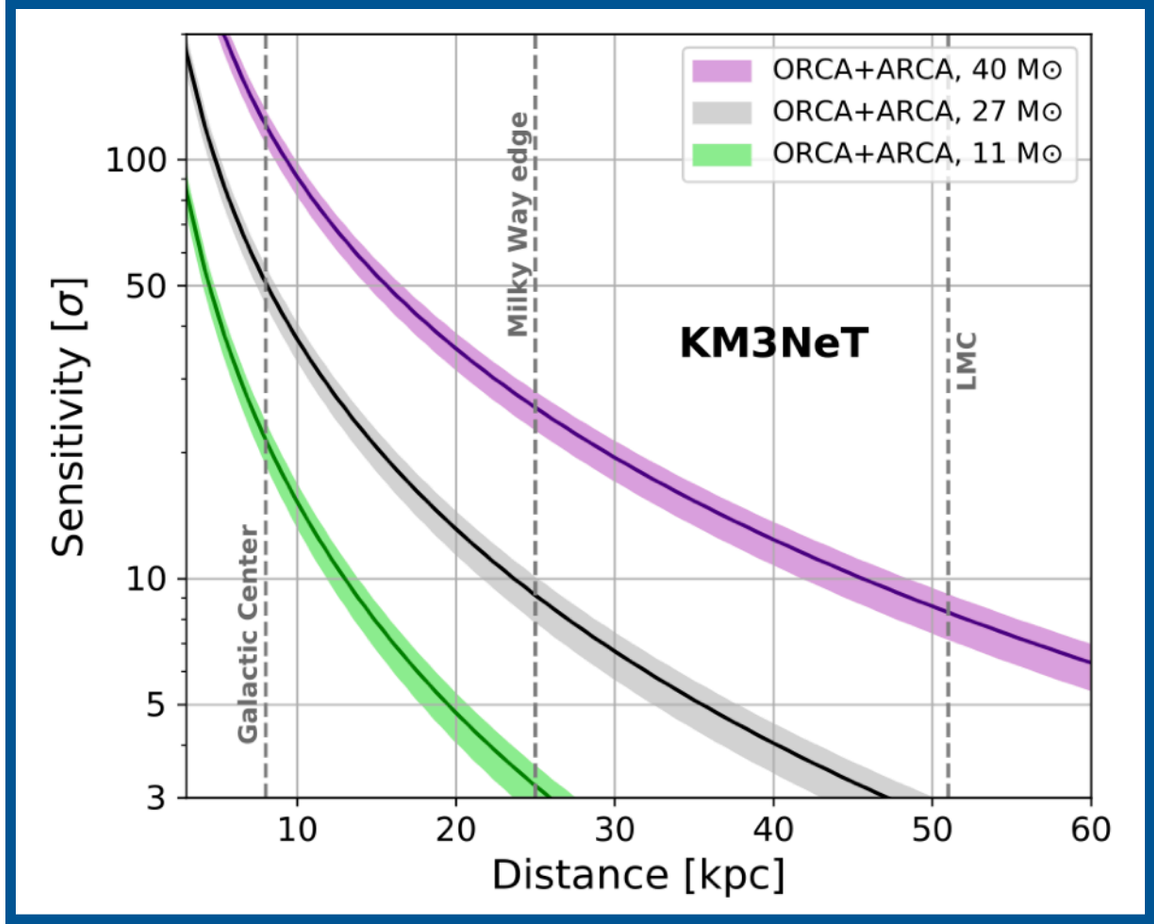


Coszen < - 0.8	**Coszen < 0**
Data : 5	Data : 15
(a)NumuCC: 2.0	(a)NumuCC: 4.0
Mupage : 0.7	Mupage : 7.0

CORE COLLAPSE SUPERNOVAE

Accepted on APJ C https://arxiv.org/abs/2102.05977



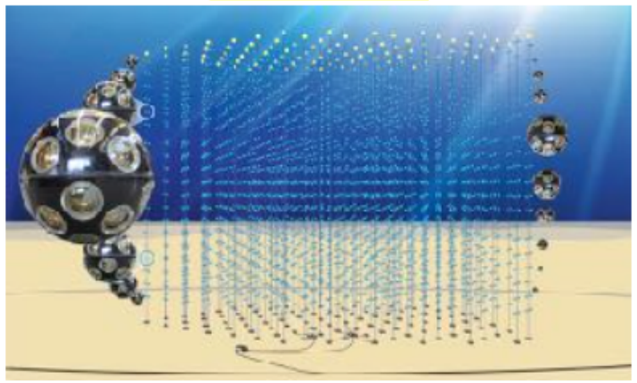


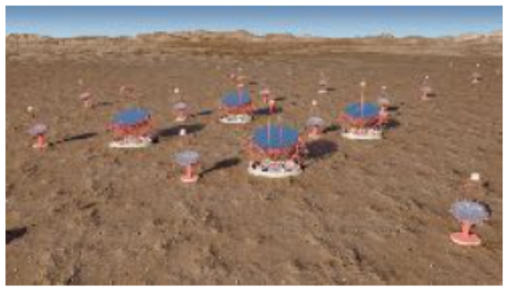
>5σ for ARCA+ORCA for 27M⊙ at a distance <25kpc

A trigger for CCSN already implemented
Integrated in SNEWS

KM3NET MULTI-MESSENGER PROGRAM

- **Follow-up of neutrino alerts**
- **Joint sub-threshold analysis**





- **Follow-up of EM/GW alerts**
- **Offline time/space correlation search with catalogues (GRB, AGN, XRB, SN, FRB…)**

SUMMARY

- First 6 ORCA DU operating from more than 1 year
- First ARCA DU operating from more than 5 years + 5 DUs from 2 month
- Good data/MC agreement 👉 good detector knowledge

👇

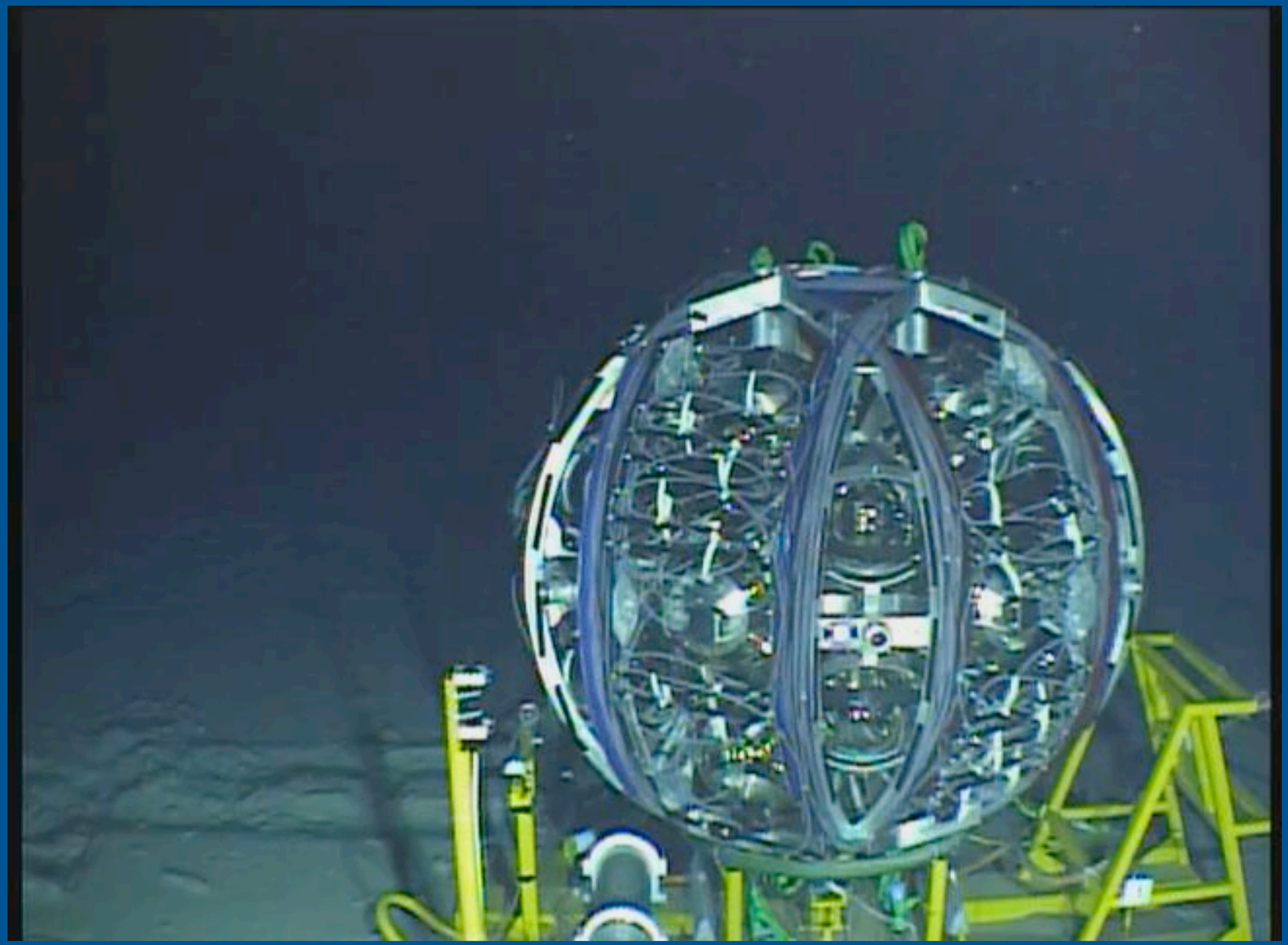
Well established technology

Big efforts to maintain the time schedule in COVID era

MOVIE: DU DEPLOYMENT

Deployment DU

MOVIE: THE UNROLLING



MOVIE: LOM AT SEA SURFACE