KM3NET EXPERIMENTAL ACTIVITIES

R. Coniglione for the KM3NeT collaboration
LNS-INFN

KM3NET

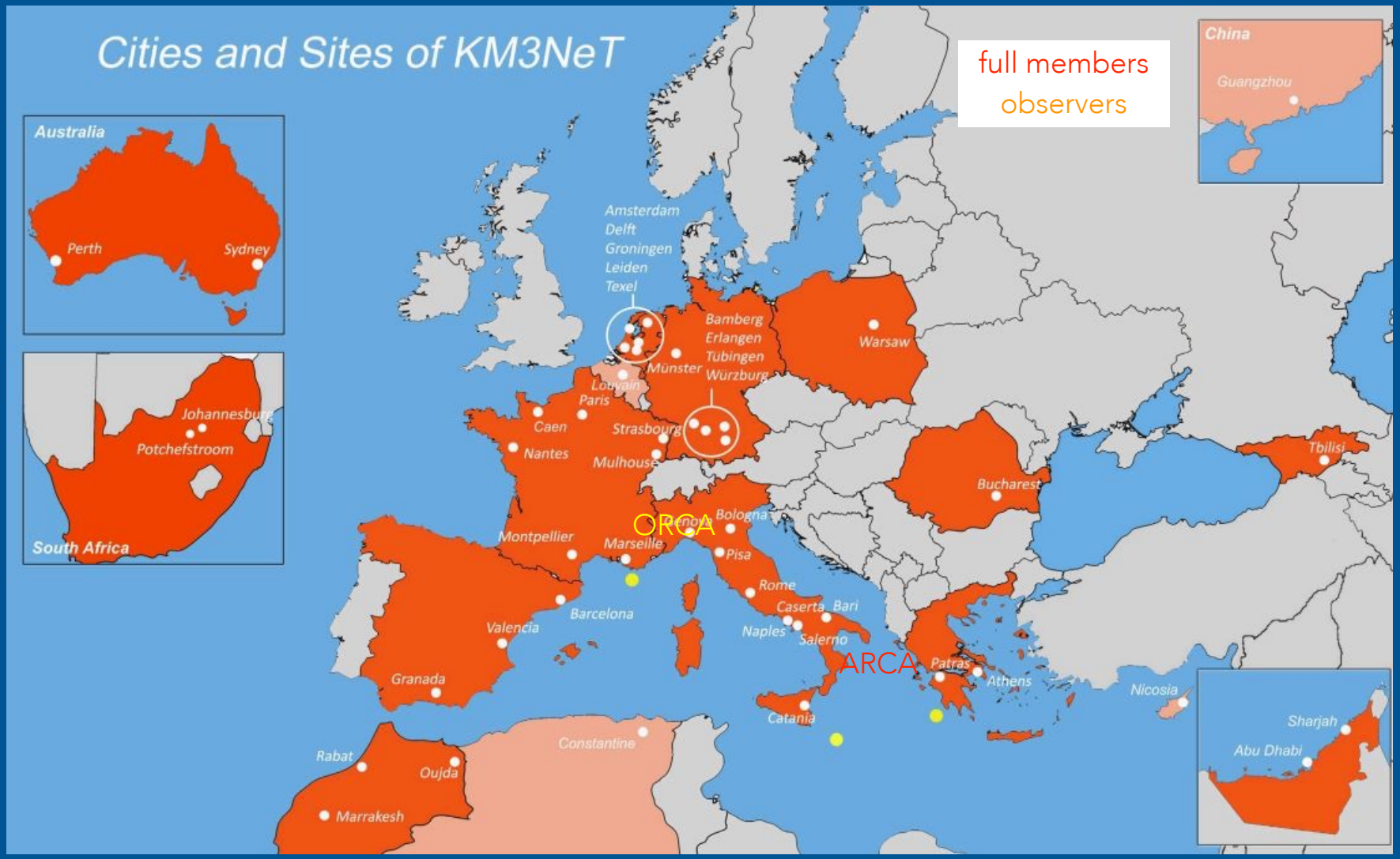
KM3NeT is a research infrastructure hosting two neutrino detectors in the Mediterranean Sea

- 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 COLLABORATION

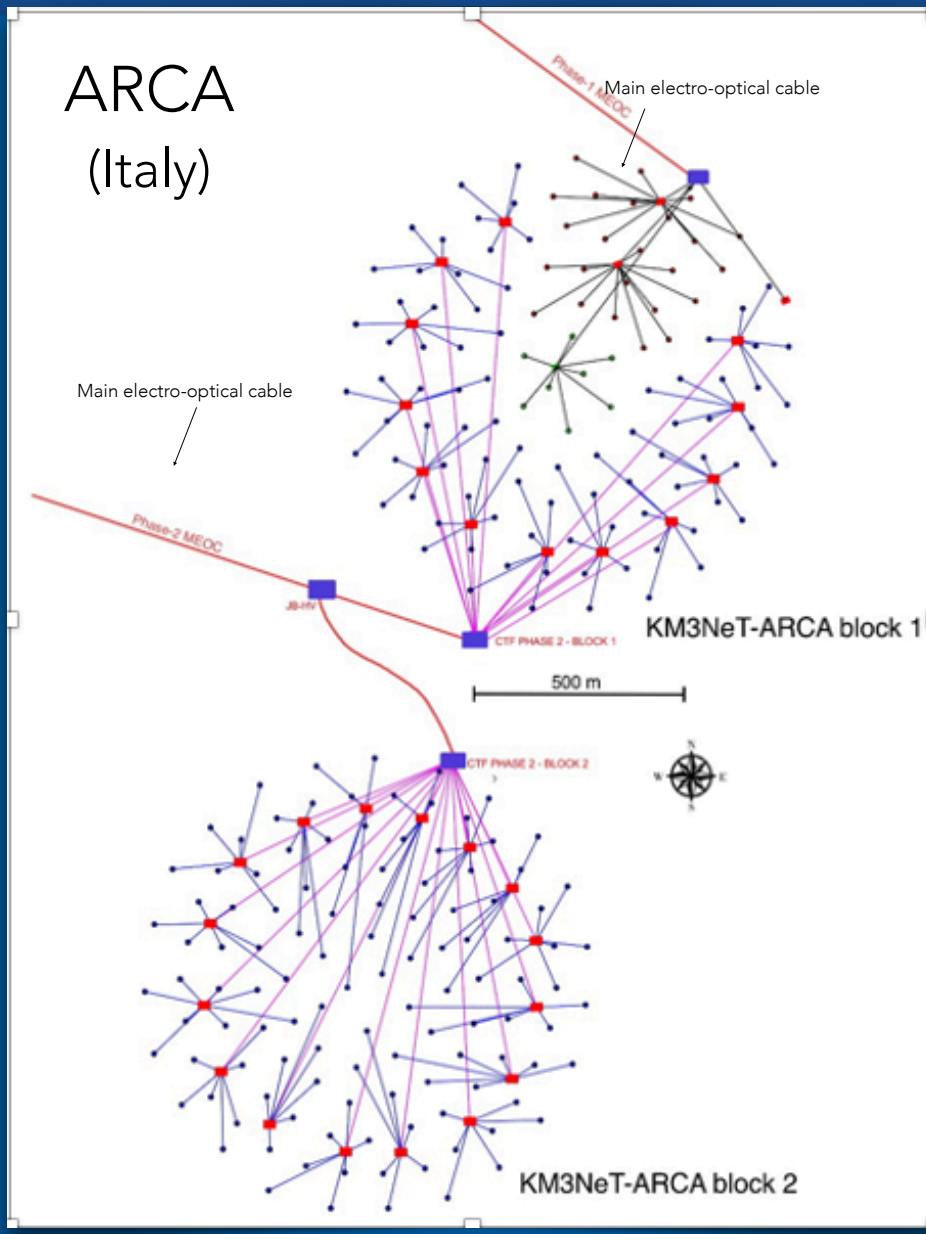
About 270 collaborators in 56 institutes in 17 countries



THE KM3NET/ARCA DETECTOR

ARCA

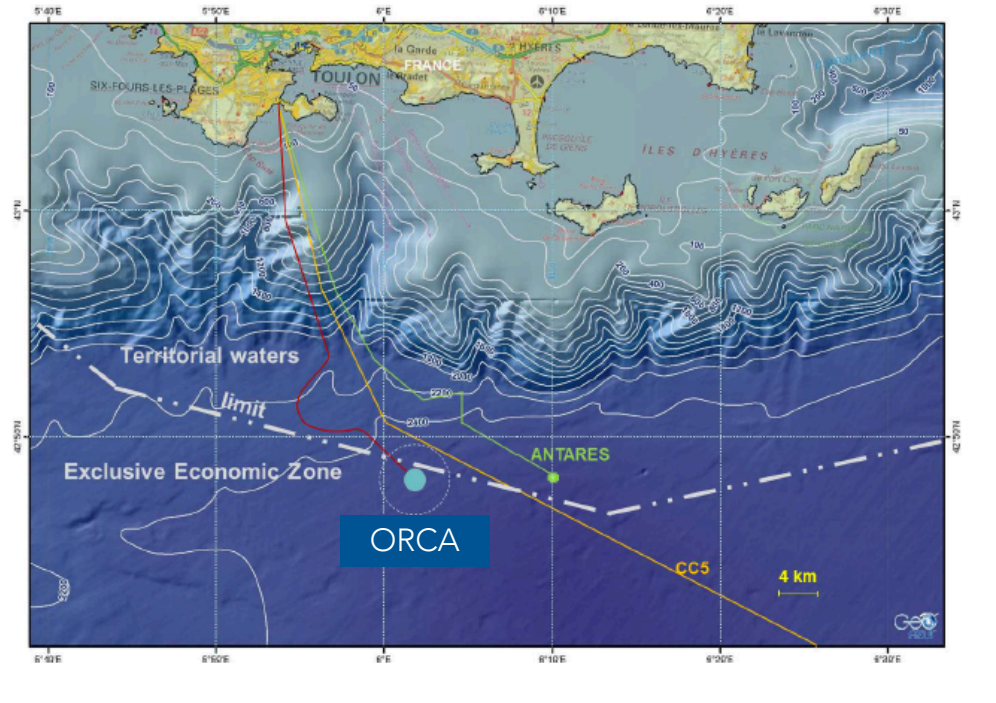
- Depth ~3500 m
- Two blocks of 115 Detection Units each
- Average distance between Detection Units ~90 m
- Vertical distance between DOMs ~36 m
- **Volume (0.5 × 2) km³ ≈1 Gton**

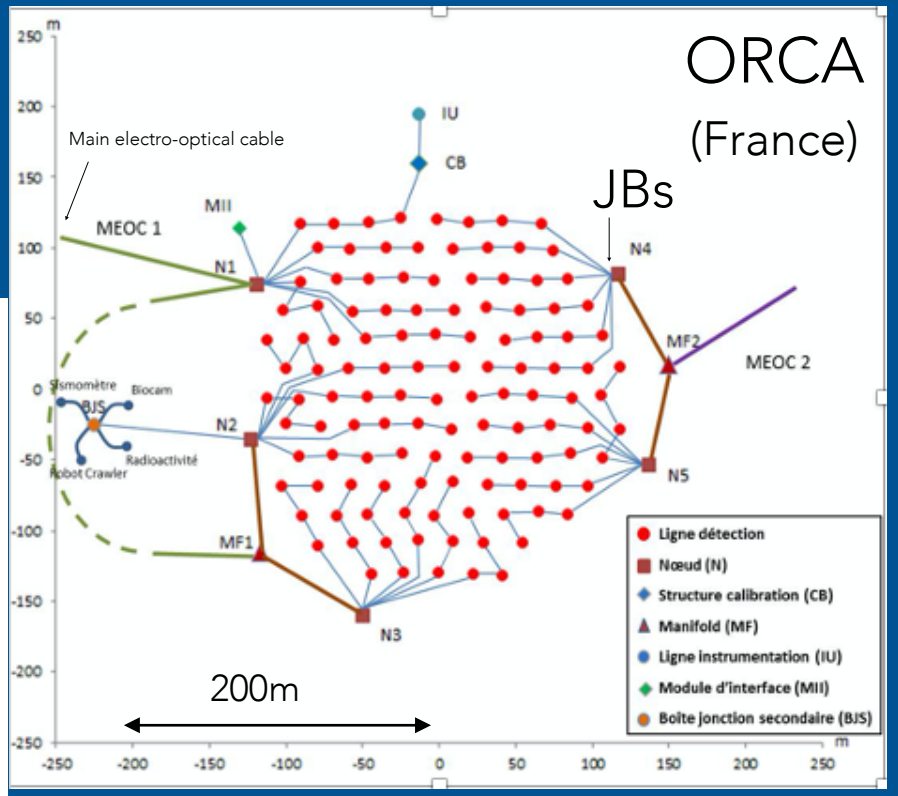


THE KM3NET/ORCA DETECTOR

ORCA

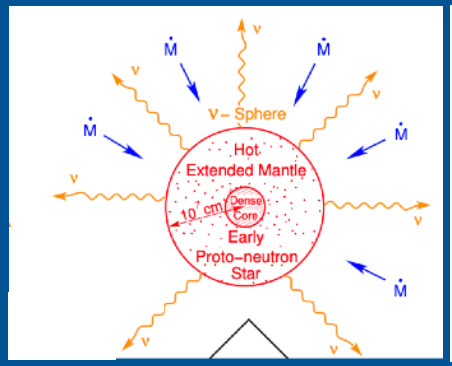
- Depth ~2500 m
- One block of 115 Detection Units
- Average distance between Detection Units ~20 m
- Average vertical distance between DOMs ~9 m
- **Volume ≈ 7 Mton**

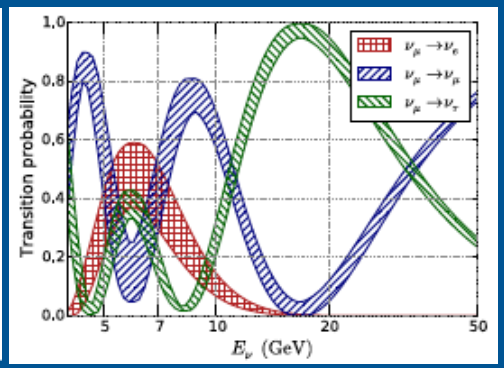


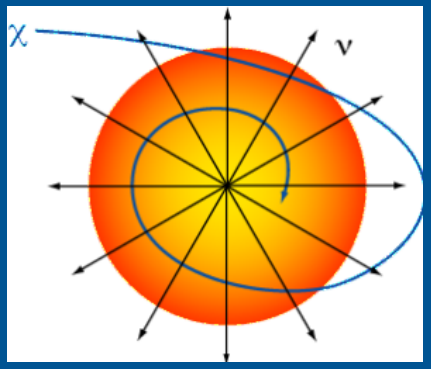


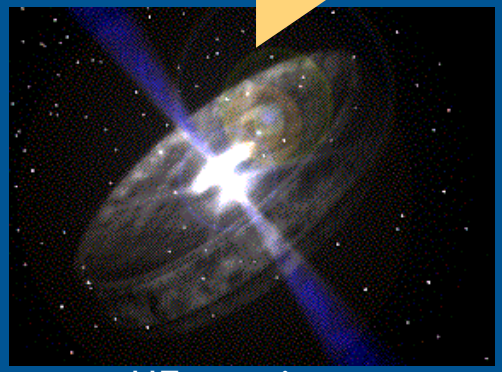
THE PHYSICS

Neutrino Energy from MeV to PeV









Super Novae explosion
MeV

Neutrino oscillation
GeV

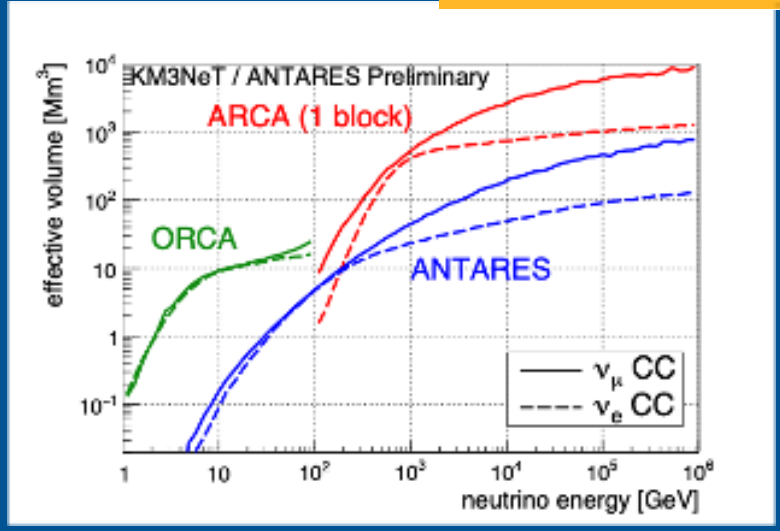
Dark Matter
TeV

HE neutrinos
Multi-messenger program
PeV

ARCA + ORCA

ORCA

ARCA



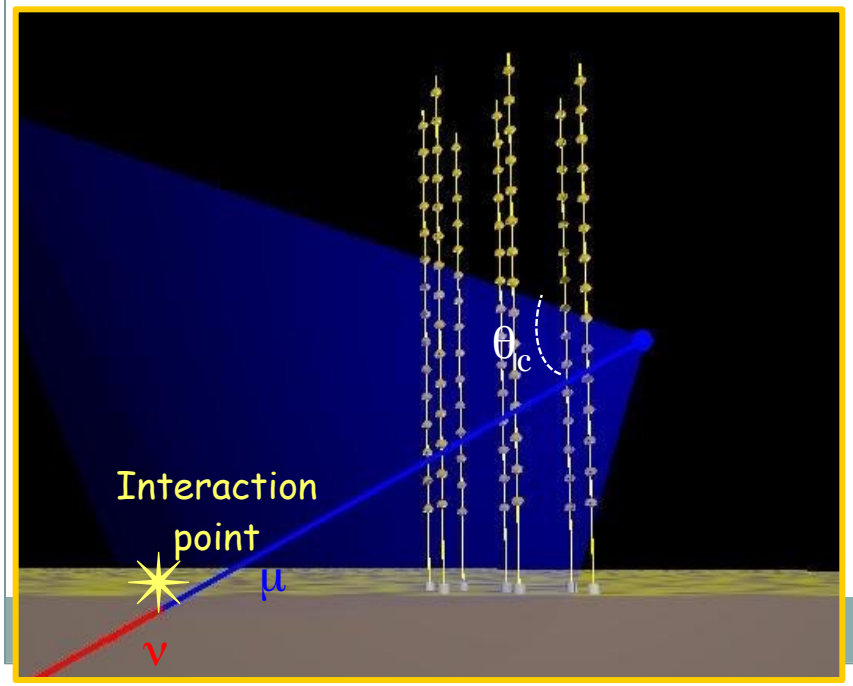
ANTARES 👉 A small size detector (0.01 km³) taking data for more than 10 years and now dismantled

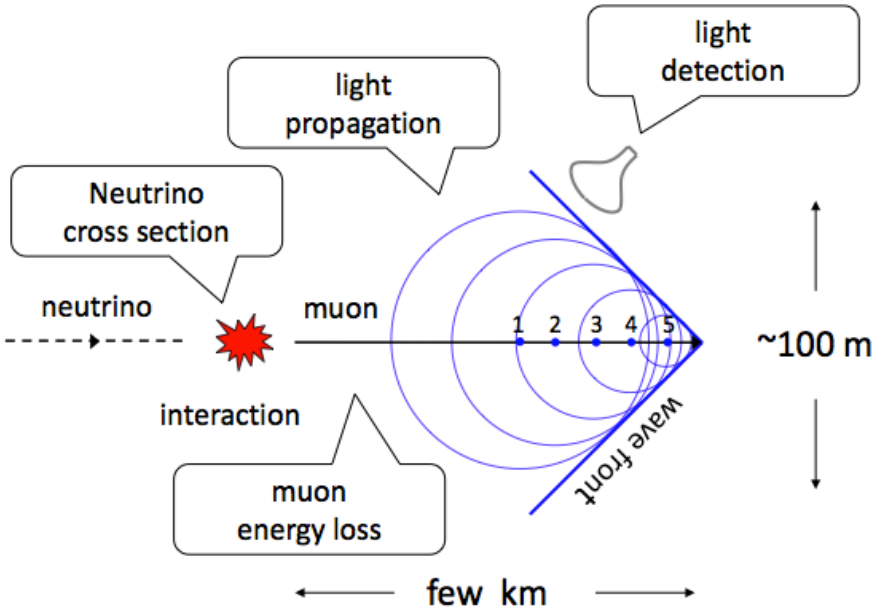
For a general overview of the KM3NeT physics see the Letter of Intent (LoI)

Journal of Physics G: Nuclear and and Particle Physics 43 (2016) 084001.

Detection principle of underwater/ice neutrino telescopes

- 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

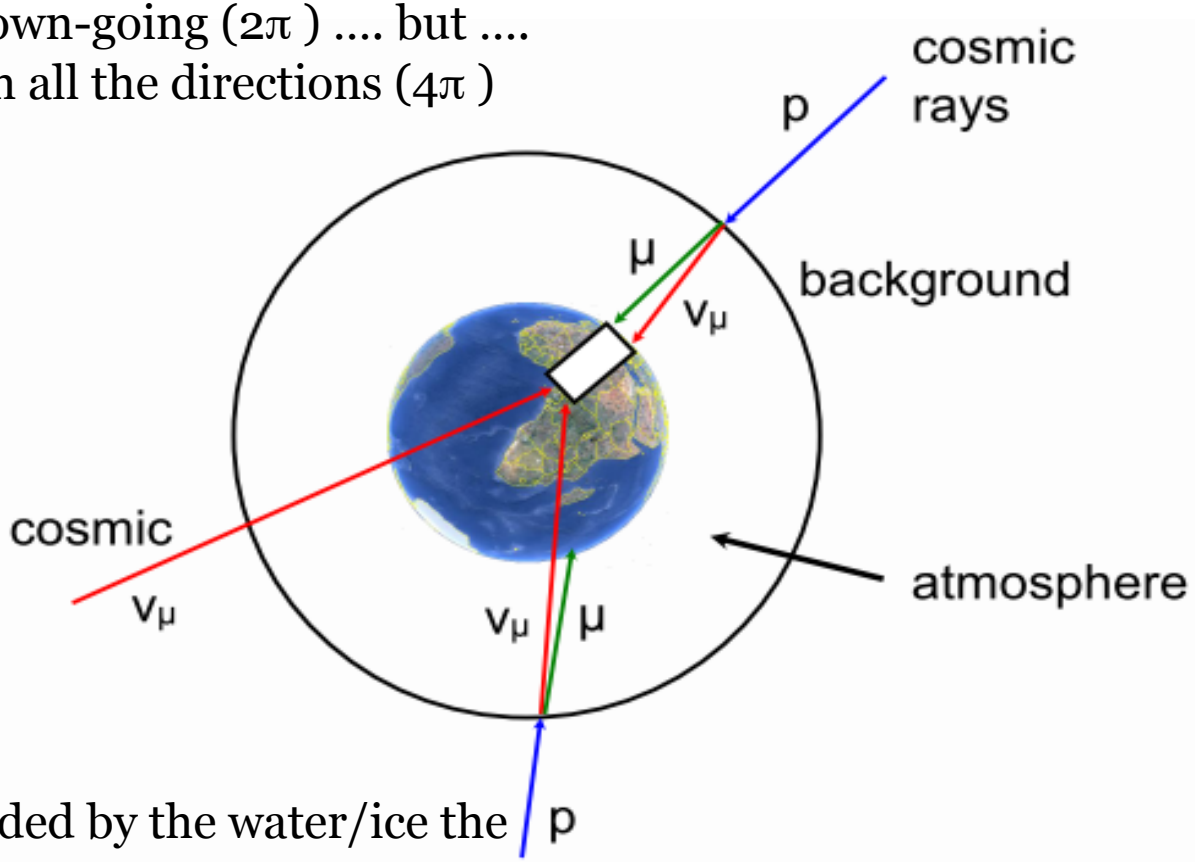




Background of atmospheric muons and atmospheric neutrinos

From the interaction of Cosmic Ray with the atmosphere:

- Atmospheric muons only down-going (2π) .... but ....
- Atmospheric neutrinos from all the directions (4π)



Even if the detectors are shielded by the water/ice the atmospheric muon flux is high

Search for extraterrestrial up-going neutrinos

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:

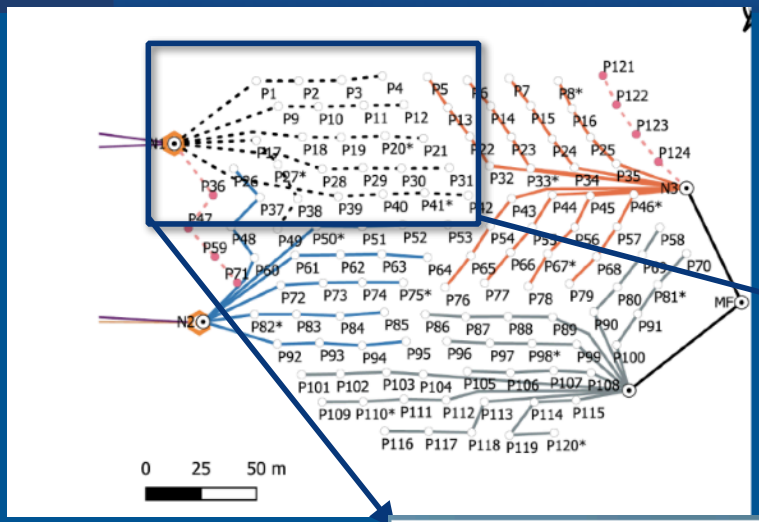
- 31 3” PMTs (photocathode aerea ≃ 3 × 10” PMTs)
- LED and Piezo
- Front-end electronics -> FPGA

DU

18 DOMs in a DU

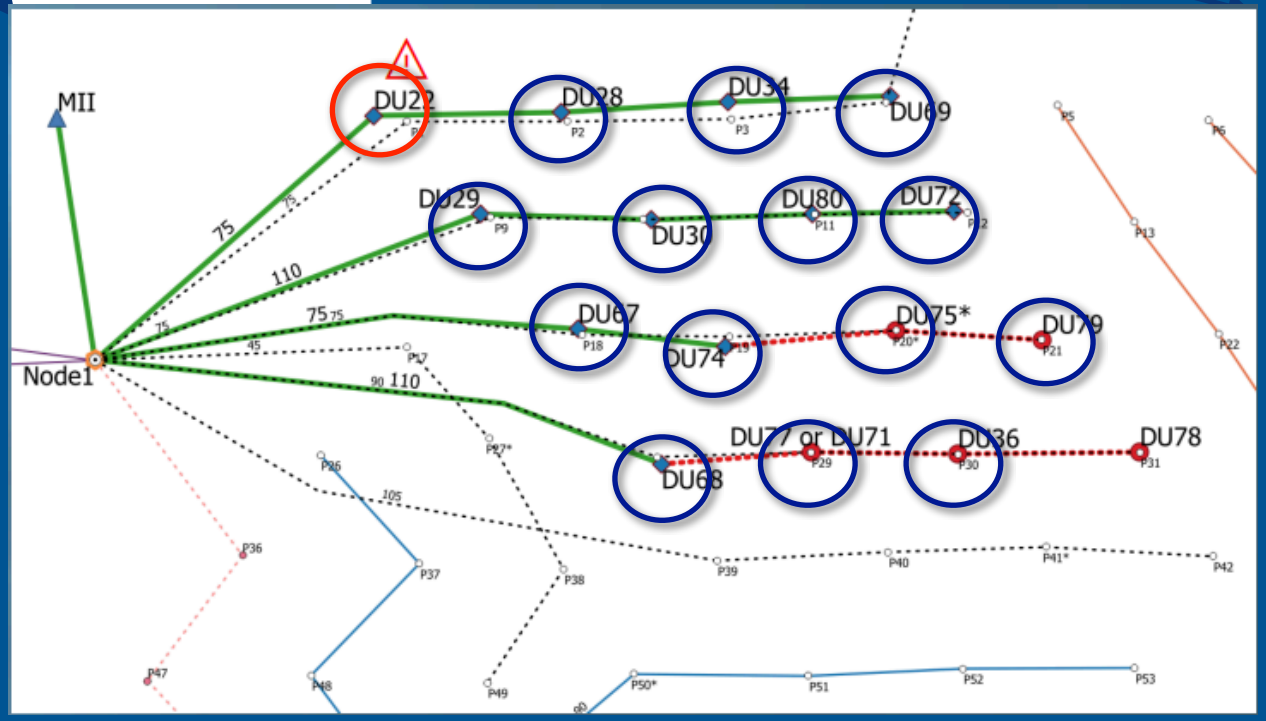
JB

THE KM3NET/ORCA STATUS

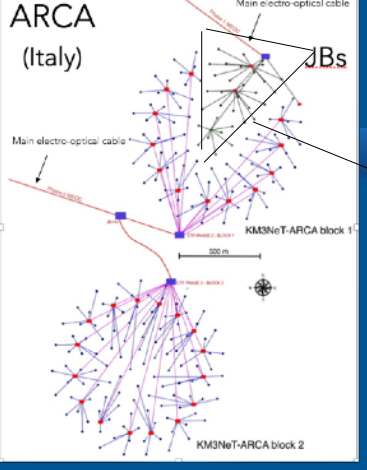


Many sea campaigns/year

- 15 DUs in water
- 14 DUs taking data 👉 ORCA14
- 1 node
- 3 Autonomous Beacon (AB)

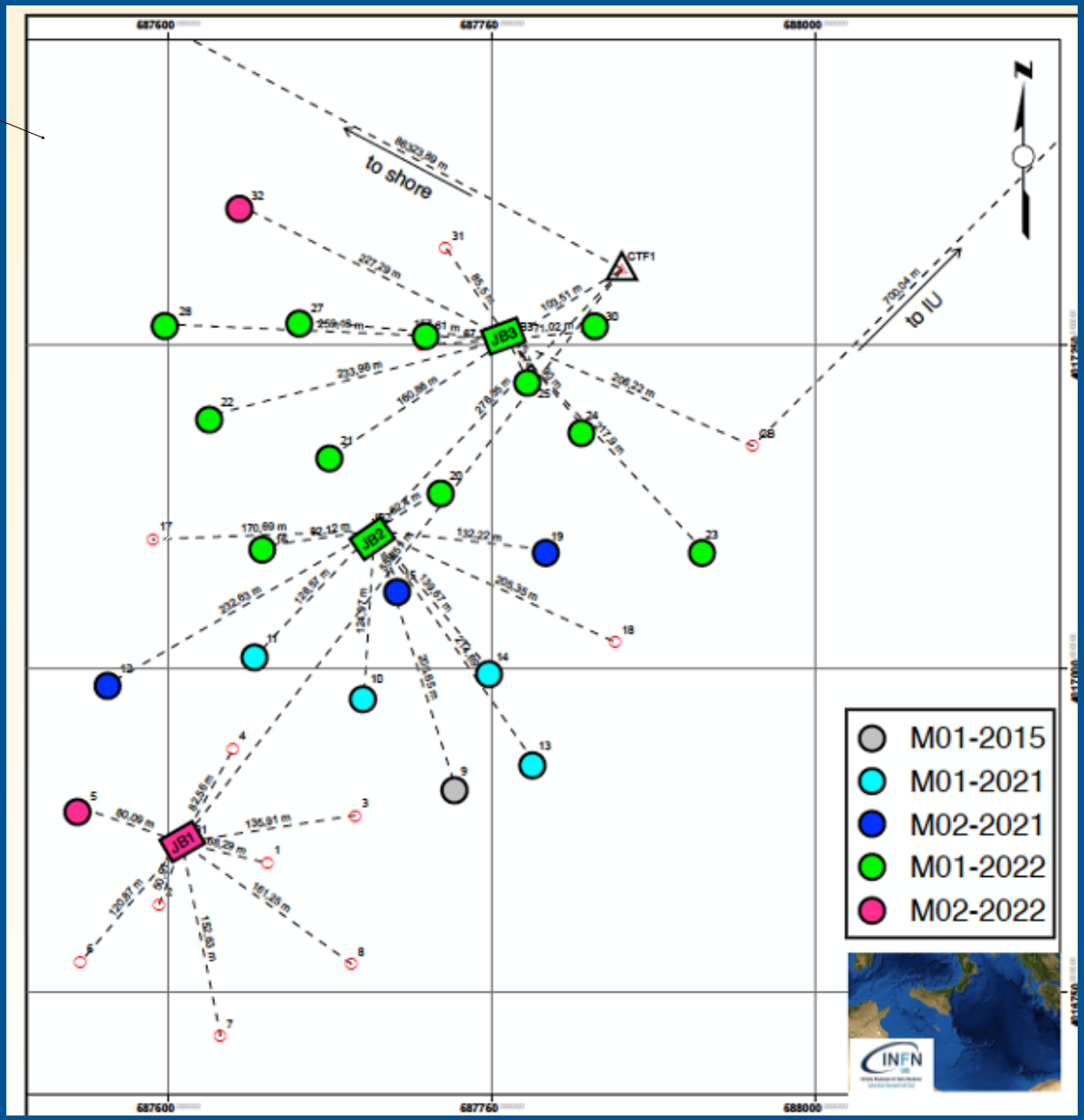


THE KM3NET/ARCA STATUS

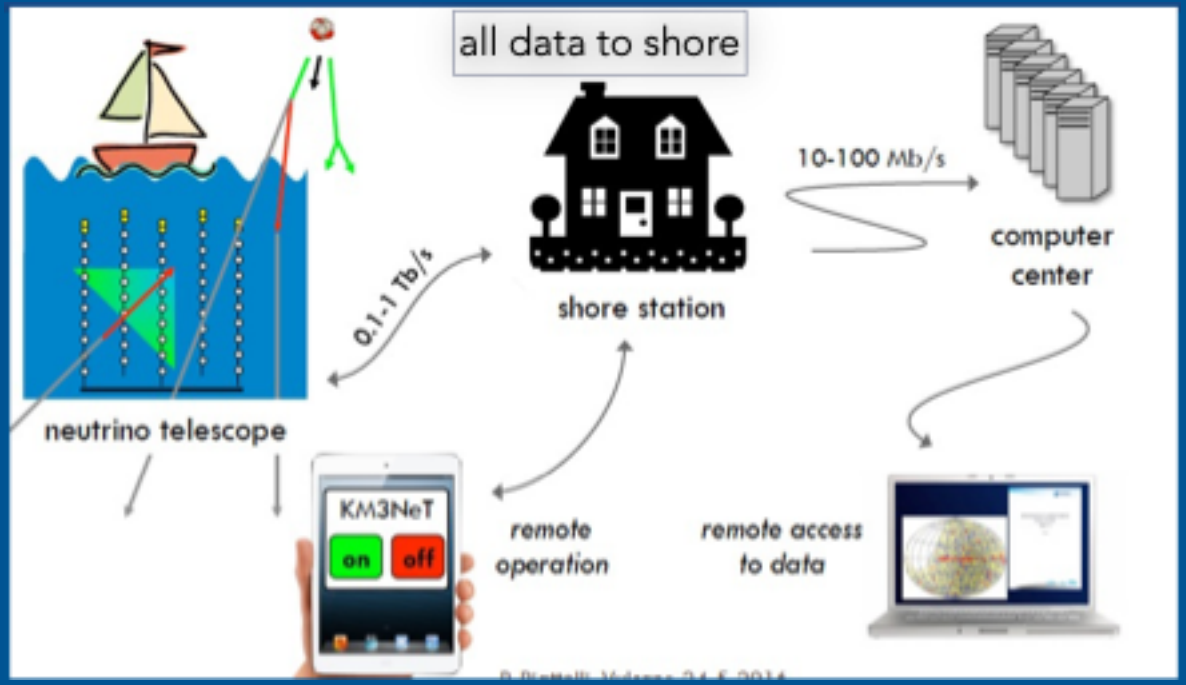


Usually two sea campaigns/ year: spring and autumn

- 21 DUs taking data 👉 ARCA21
- 3 JBs
- 3 trypod TAB (Trypod Autonomous beacon



THE KM3NET ARCHITECTURE



Data acquired since the first string installed

👇

Physics results from a reduced detector configuration already available

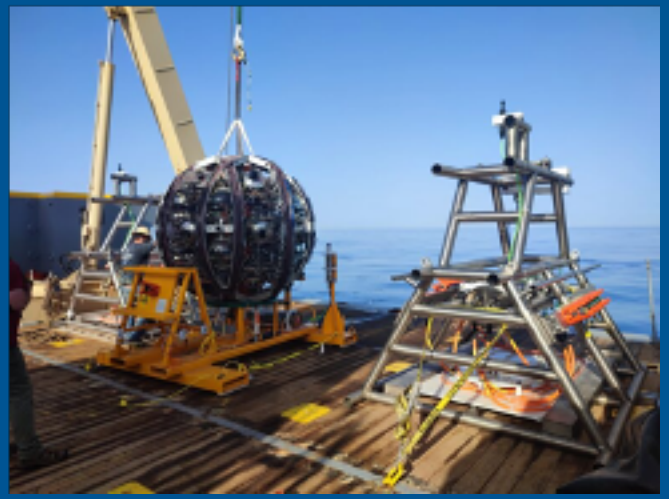
ORCA Shore Station

ARCA Shore Station

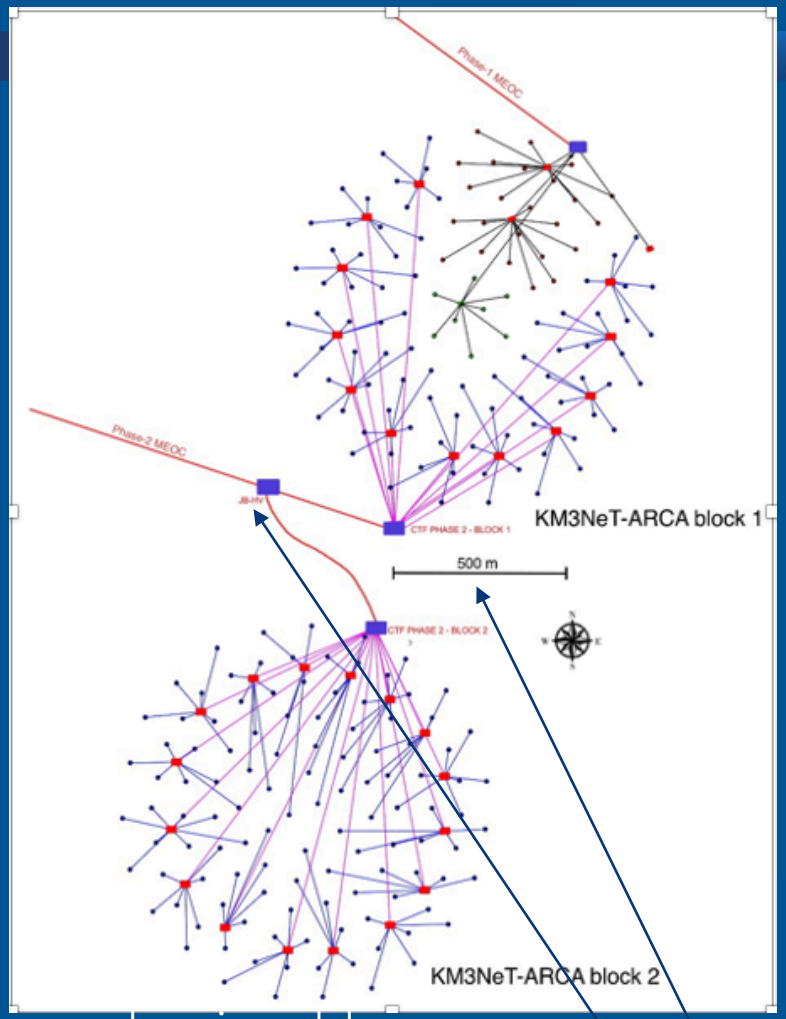
ARCA JUNE 2022 SEA CAMPAIGN

June 2022 the biggest sea campaign from ever

11 DUs and 2 JBs + recovery of TJB



ARCA SECOND BRANCH STATUS



All the first block can be now served

Second main cable:

- In Nov 2020 deployed the second main cable
- In 2021 second Power Feed Equipment (PFE) in shore station
- In November 2022 deployed Cable Termination Frame and connection with the cable. The CTF hosts 4 Medium Voltage Converter (MVC)

ALCATEL SEA CAMPAIGN NOV 2022

Cable Termination Frame

KM3NeT4RR italian project

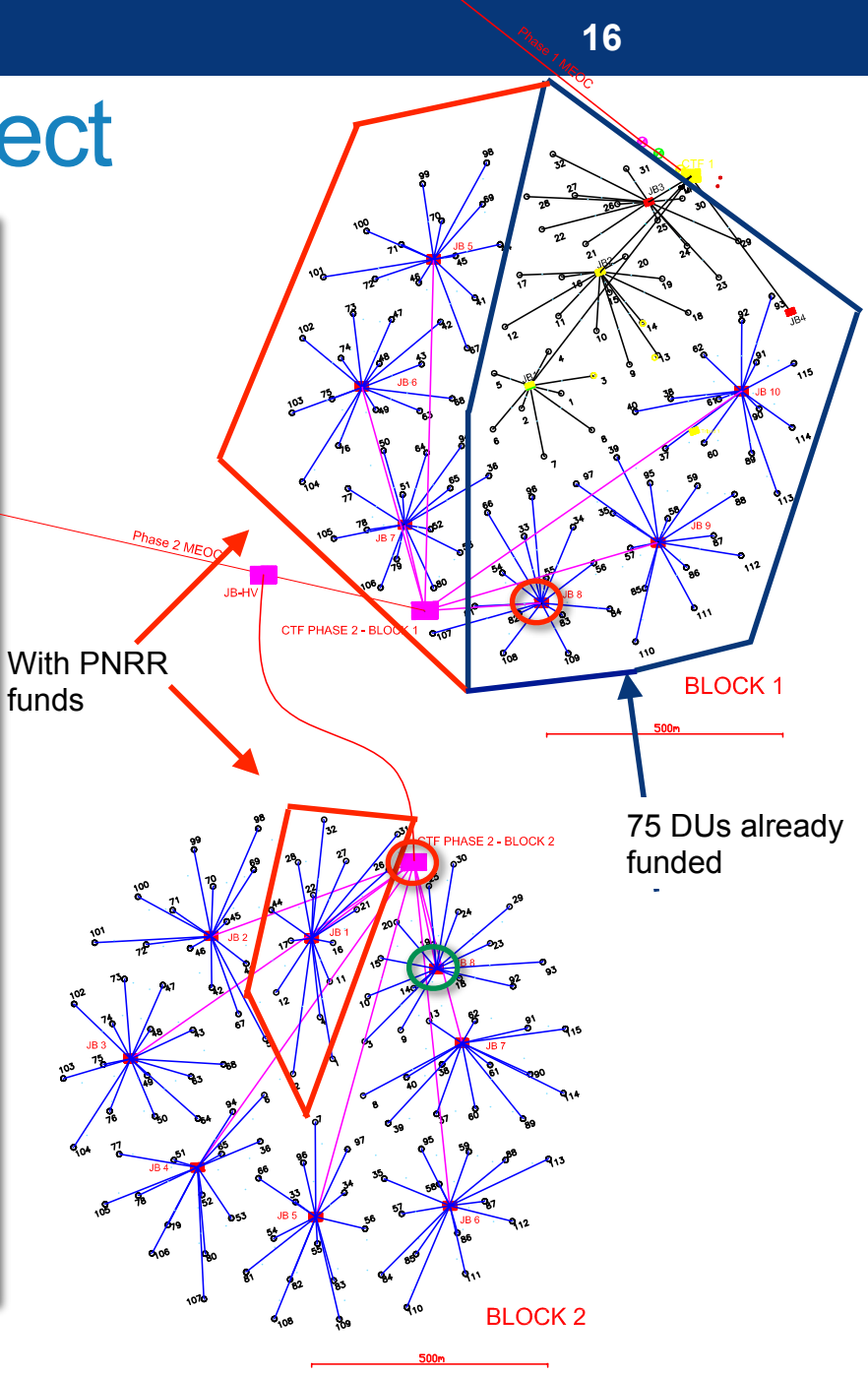
Inside the PNRR (Piano Nazionale di Ripresa e Resilienza) a call dedicated to the reinforcement of existing research infrastructures has been published at the end of 2021. Project submitted end of February.
Project started the first of December 2022
Duration of the project 30 months

Approved funds 67M€

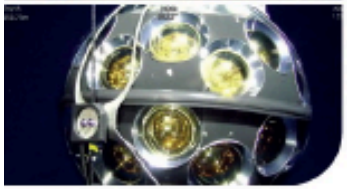
- ~ 50 DUs
- The related sea floor infrastructure (5 JBs + 1CTF + IL cables)
- The reinforcement of INFN KM3NeT laboratories
- Human resources

This funds will allow the completion of the first block and the construction of about 15 DUs of the second block of the ARCA detector.

~ 125 DU funded so far



KM3NeT4RR



INFN
Istituto Nazionale di Fisica Nucleare

PARTNERS

INAF
Politecnico di Bari
Università degli Studi della Campania Luigi Vanvitelli
Università di Catania
Università degli Studi di Genova
Università degli Studi di Napoli Federico II
Sapienza Università di Roma
Università degli Studi di Salerno

KM3NeT4RR

The proposal has been possible because of KM3NeT is:

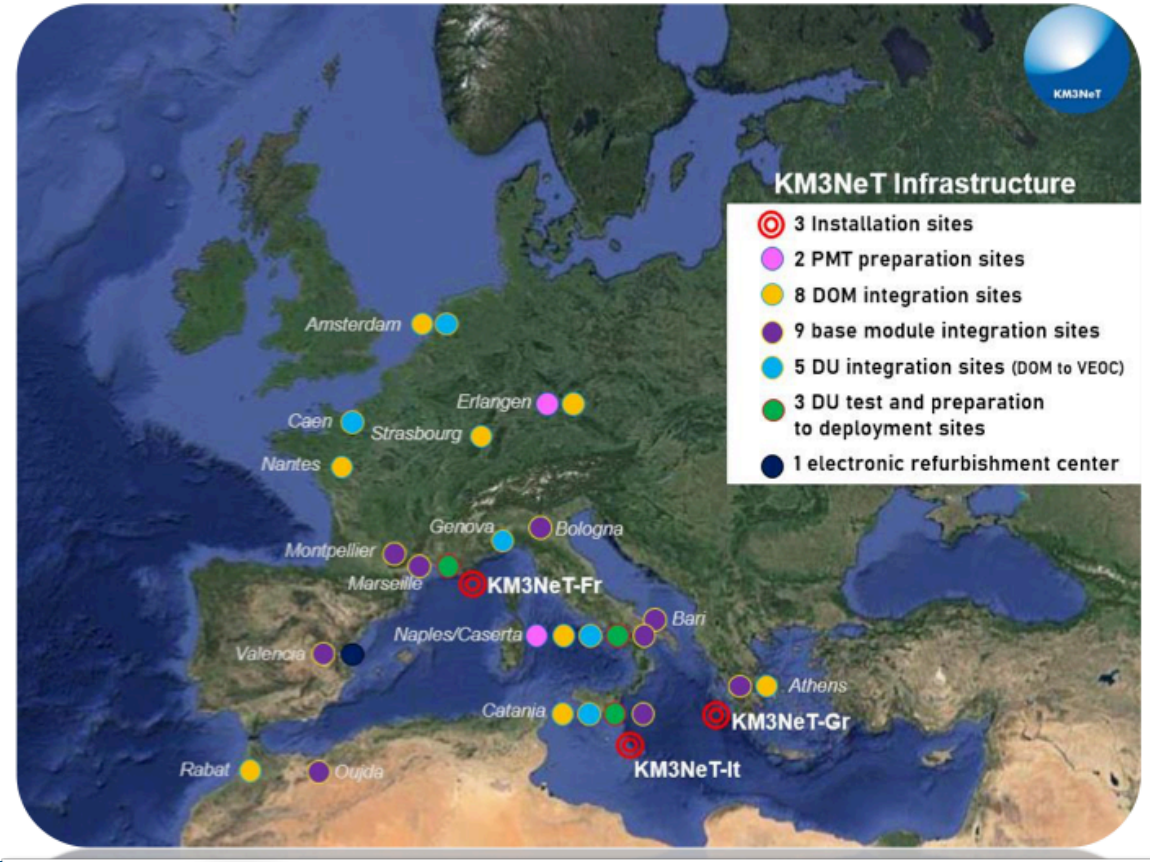
- **ESFRI RI**
- **PNIR RI**
- **Strategic RI for the Sicilian Region**

Co-Applicants

- INAF (OA-Catania and OA-Palermo)
- Politecnico Bari
- Università Campania
- Università Catania (DFA - DEI)
- Università Genova
- Università Sapienza Roma
- Università Salerno
- Università Federico II Napoli

Budget approved 67M€ (97% in Southern Italy)

DETECTOR CONSTRUCTION



DOMs
- 8 integration sites
- 946 DOMs integrated (52 DUs worth)
- 36 currently on bench

BMs
- 8 integration sites (Welcome to Oujda!)
- 53 BMs integrated
- 4 currently on bench

DUs
- 6 integration sites (Welcome to Caen!)
- 37 DUs integrated
- 7 currently on bench
- 19 deployed

@ INFN - LNS
- BM Int.
- DU Int.

@ INFN Sez. Catania
- DOM Int.

@ INFN Sez. Napoli
- DOM Int. -> Napoli
- BM Int. -> CACEAP
- DU Int. -> CACEAP

@ INFN Sez.Bari
- BM Int.

@ INFN Sez.Bologna
- BM Int.

@ INFN Sez. Genova
- DU Int. Processo 1

EXPERIMENTAL ACTIVITIES @ LNS

- Preparation of sea campaign (logistics and customs documents)
- Upgrade of DAQ hardware and software @Capo Passero Shore station
- **Sea Network upgrade (JBs + interlink cables)**
- **Integrazione DU Integration**
- **Integrazione BM Integration**
- Procurement
- Detector operation

ARCA DU INTEGRATION

@LNS Catania harbour

DOM integration
@Napoli, CT
For ARCA also @Nikhef, Erlangen, Athens

Integration of VEOC to DOMS
@Genova, LNS

Integration to the Base Module
@Napoli, LNS (+ Genova)

Base Module integration
@Bologna, Bari, LNS

Test and calibration
@Napoli, LNS (+Genova)

LOM loading
@Napoli, LNS

Stack preparation and test
@Napoli, LNS

Finalization and pre-boarding test in Malta

THE INTEGRATION

Process 1 - DOM-backbone integration

Vertical Electro Optical Cable (VEOC) is connected electrically and optically to the DOMs. Check of optical and power budget at penetrator level

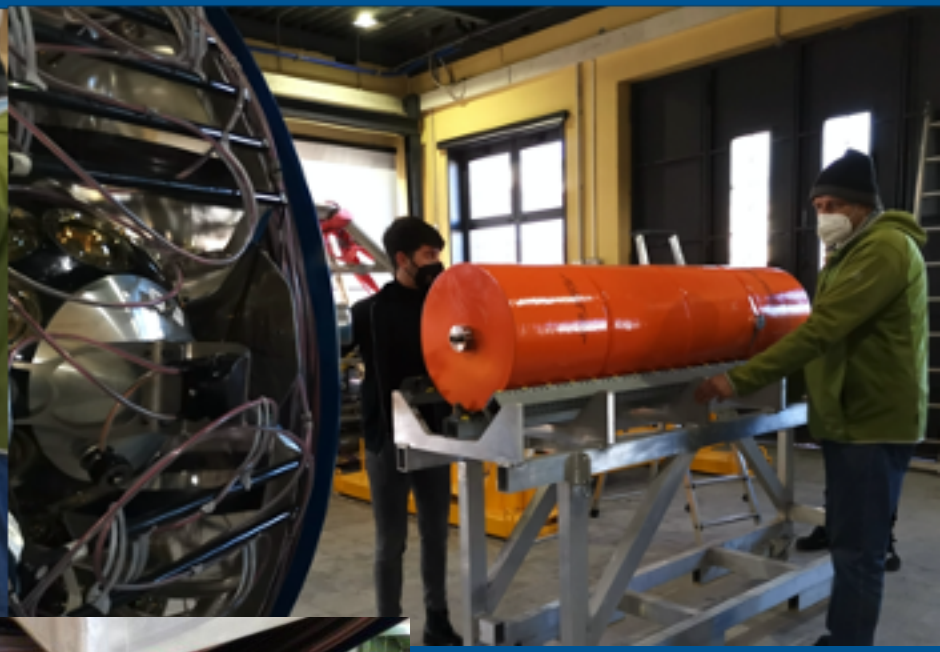
THE INTEGRATION

Process 2 - Base Module integration
Base Module contains electronic cards for the control of DOMs and calibration devices.
First the BM is integrated as a single module and after connected with the DU

Process 3 - Test of the DU functionalities in dark box and calibration with laser

THE INTEGRATION

Process 4 - LOM Loading
Loading of 18 DOM integrated on LOM and buoy insertion. Check of optical and power budget at base level



Process 5 - Stack preparation
Buoy and anchor integration

THE INTEGRATION

Process 6 - DU pre-deployment tests @Malta
Vacuum check on each DOM
Hydrophone and beacon mounting
Optical and power functional tests
Visual inspections

THE INTEGRATION ORGANIZATION

All the integration is managed by the KM3NeT international collaboration

Supervised by the Technical Project manager 👉 Miles LIndesy Clark

Coordinated by the DU coordinators 👉 Daan van Eijk & C. Mollos

Coordinated by the BM coordinators 👉 I. Sgura

DU integration responsible at each site 👉 @LNS P. Sapienza

BM integration responsible 👉 @ LNS G. Larosa

Weekly meeting to discuss about technical issues and status

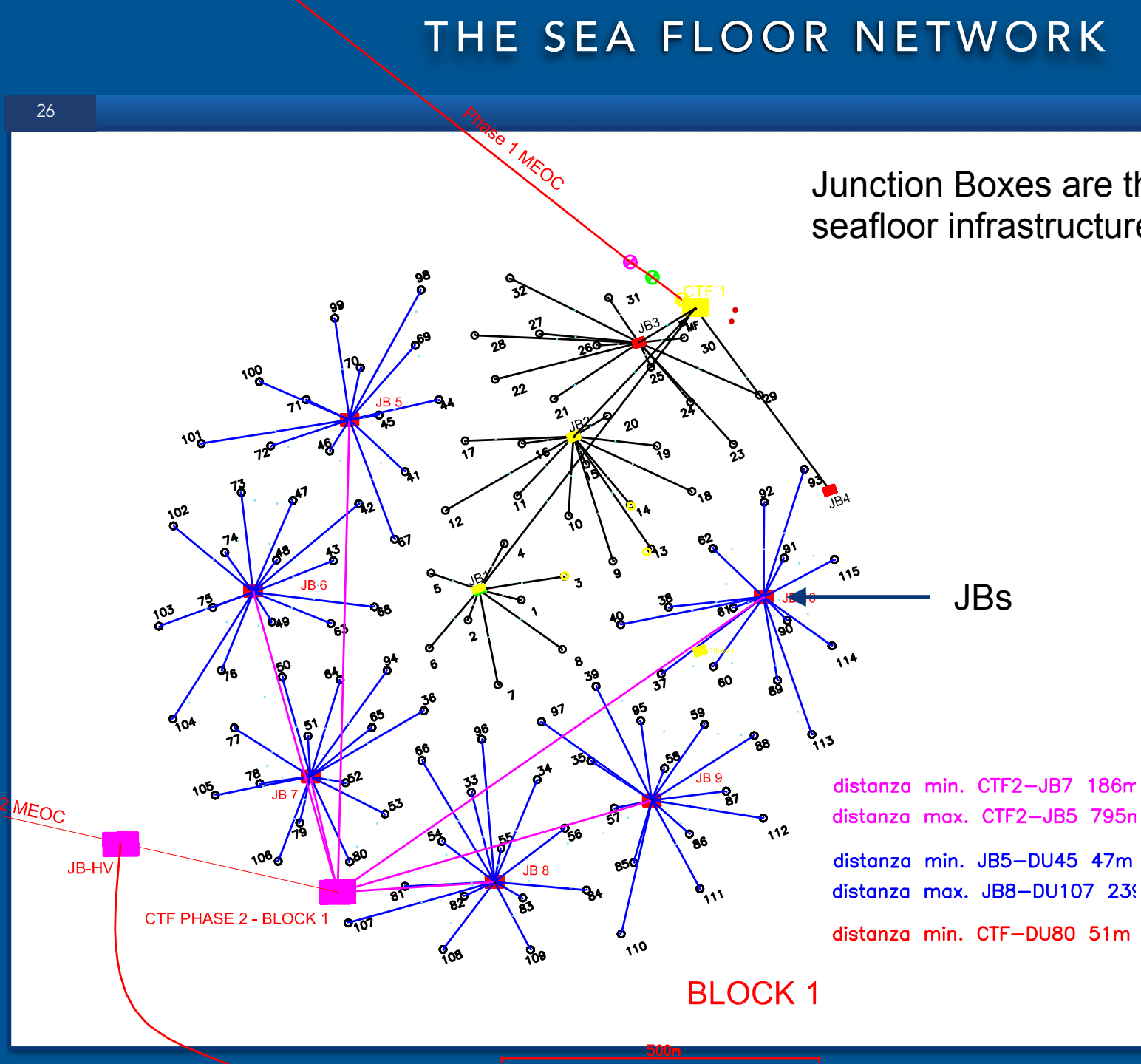
Large amount of documents in Google Drive:

- GANTT for the integration plan activities
- Documents for the description of the procedures
- Test reports
- Non Conformity Report (NCR)
- Design Change Report (DCR)
- Shipment and Report Sheets from/to sites

👉 QualityAssurance and Quality Control group

THE SEA FLOOR NETWORK

Junction Boxes are the nodes of the seafloor infrastructure.



THE JUNCTION BOXES

Block diagram of the transport and distribution of electricity and of the optical data link from the on-shore station to the off-shore site @ 3500 m depth

THE JUNCTION BOXES

Junction box - schematic diagram and main characteristics

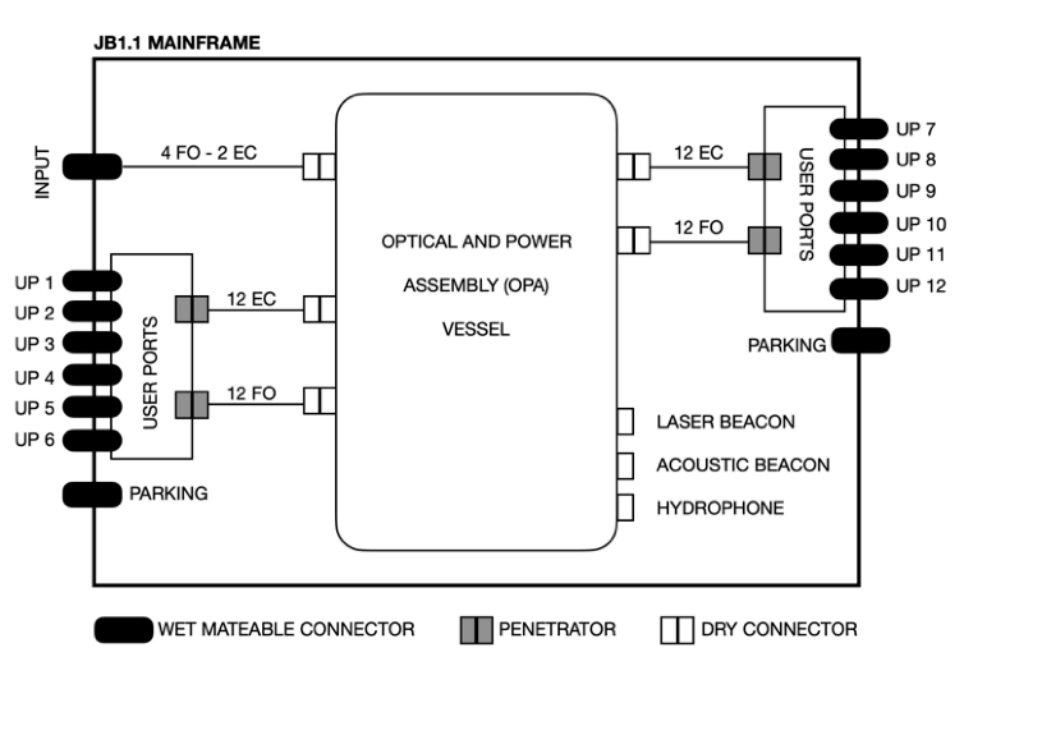


TABLE I. - Main Carachteristcs of JB1.1	
# Input	1
# Output	12
Input voltage	375 Vdc
Output voltage	375 Vdc
Max output current	1 Ampere
Max data thruputs	1 Gbit/s
Lifetime	> 20 Years
Operational depth	3500 m
Operational temperature at seabed	13 °C
Mechanical mainframe material	Titanium Gr. 2
Vessel material	Titanium Gr. 2
Reliability	Intrinsic redundancy

THE JUNCTION BOXES

- Hi- Reliability design
- Full intrinsic redundancy of all function
- The component with Space/Military standard

Intensive test session

Environmental tests and qualification procedures under the highest level of space and oil & gas standards

THE JUNCTION BOXES

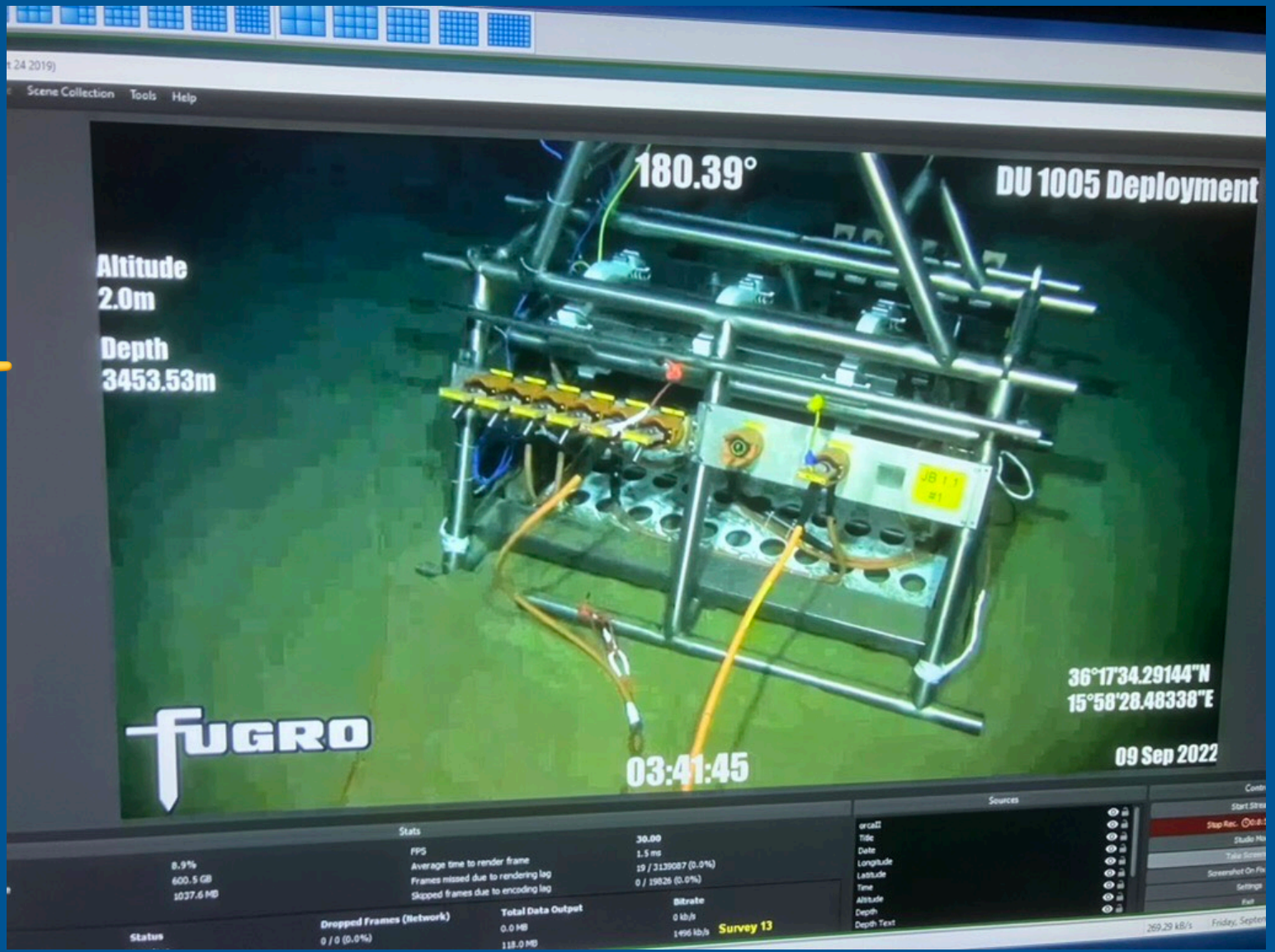
Junction Boxes ready to be deployed (June 2022)

THE JUNCTION BOXES

Junction Box just before deployment (Sept 2022)

THE JUNCTION BOXES

Junction Boxe at sea bed @3500m (Sept 2022)



LNS e KM3NeT

Tutti i LNS contribuiscono alla riuscita di KM3NeT ed in particolare

- Amministrazione
- Servizio fondi esterni
- Reparto di elettronica e rivelatori
- Reparto infrastrutture marine
- Divisione tecnica

KM3NeT challenges

Costs increasing constantly

- Electricity
- Transportations
- Sea campaign costs
- Components

Shortage of components

- Titanium
- Semi-conductors (piezos, FPGAs, …)

Human resources for integration

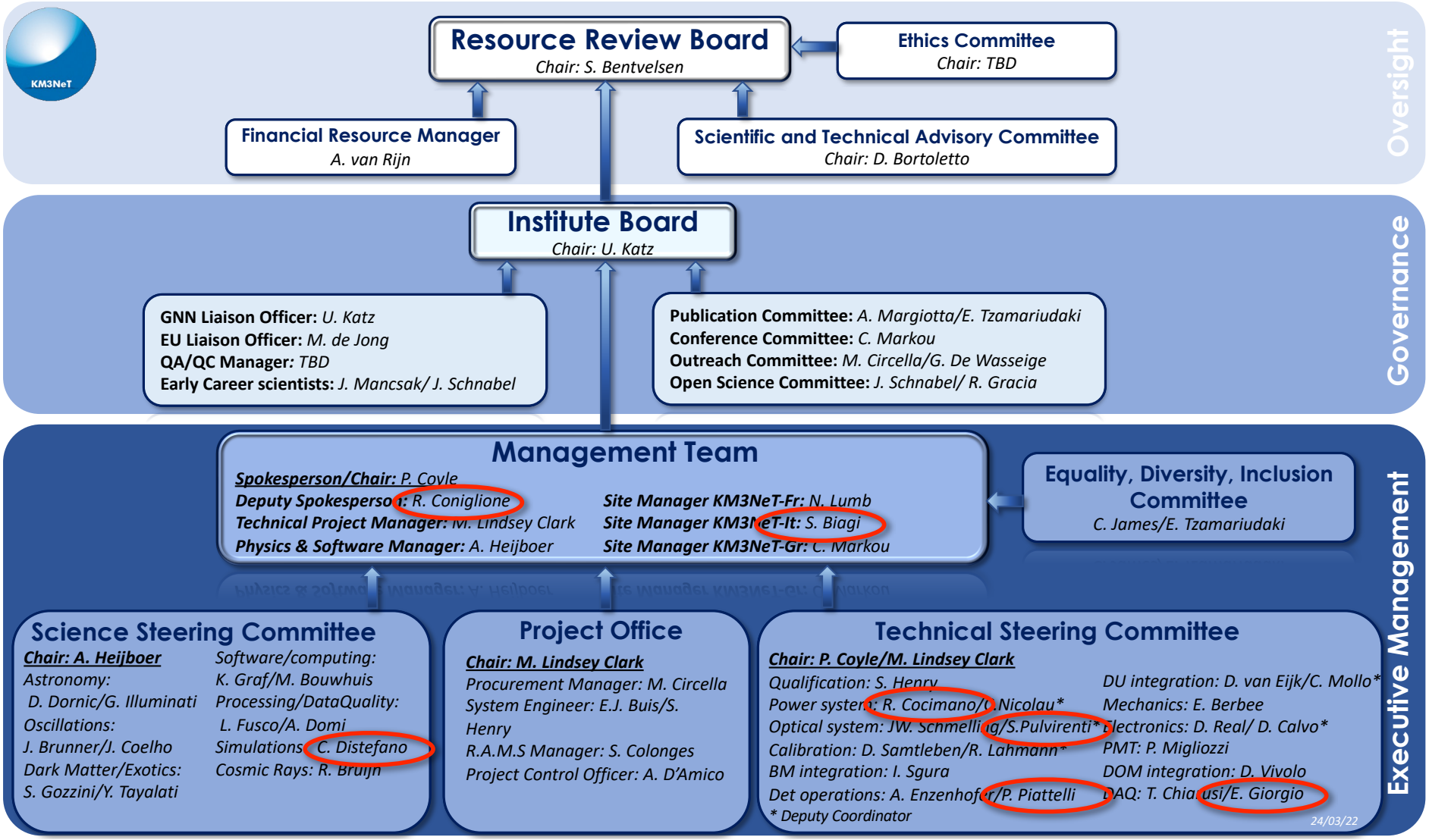
- KM3NeT4RR helps a lot for Italy
- Fr needs reinforcement

KM3NeT summary

- Large KM3NeT experimental activities already in place (COVID didn't stop the activities 👉 sea campaign in April and September 2021 in full COVID lockdown)
- With KM3NeT4RR the experimental activities will be intensified 👉 more technicians for integration and deadlines to be respected

Full support of LNS departments needed

KM3NeT Organigramma



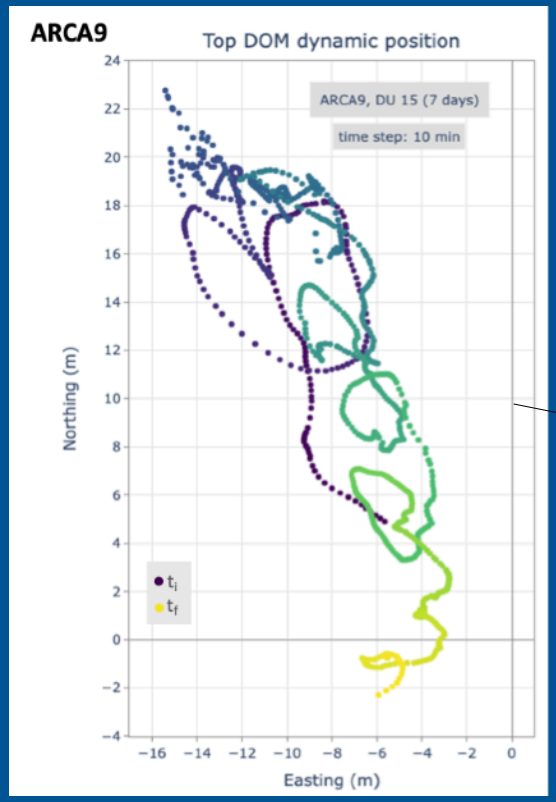
Physics results

11	Combined Analysis of KM3NeT + CTA with Gammapy	T. Unbehaun (tim.unbehaun@fau.de)	KM3NeT/ARCA	Astronomy	G. Ferrara
14	First search for neutrino counterparts from gravitational wave sources with KM3NeT	Sébastien Lestum (lestum@cppm.in2p3.fr), Godefroy Vannoye (vannoye@cppm.in2p3.fr), Mathieu Lamoureux (mathieu.lamoureux@uclouvain.be), Feifei Huang (feifei.huang@cppm.in2p3.fr), Damien Dornic (ddornic@cppm.in2p3.fr), Gwenhael de Wasseige (gwenhael.dewasseige@uclouvain.be)	KM3NeT	Astronomy	M. Boettcher
15	PKS* neutrino follow-up with ORCA/ARCA	Francesco Filippini (francesco.filippini9@unibo.it), Juan Palacios Gonzalez (juanpala@ific.uv.es), Rasa Muller (rasm@nikhef.nl), Feifei Huang (feifei.huang@cppm.in2p3.fr), Sebastien le Stum (lestum@cppm.in2p3.fr), Giulia Illuminati (giulia.illuminati3@unibo.it), Damien Dornic (ddornic@cppm.in2p3.fr), Angela Zegarelli (angela.zegarelli@roma1.infn.it), Silvia Celli (silvia.celli@roma1.infn.it)	KM3NeT ORCA+ARCA	Astronomy	G. Pavalas
16	Search for cosmic neutrino point sources and extended sources with 6-8 lines of KM3NeT/ARCA (and ANTARES)	Rasa Muller (rasm@nikhef.nl), Barbara (barbara.caiffi@ge.infn.it), Vladimir Kulikovskiy (Vladimir.Kulikovskiy@ge.infn.it), Matteo Sanguineti (Matteo.Sanguineti@ge.infn.it), Aart Heijboer (aart.heijboer@nikhef.nl), Thijs van Eeden (t.j.uan.van.eeden@nikhef.nl)	KM3NeT/ARCA	Astronomy	T. Chiarusi
17	Study of the diffuse astrophysical neutrino flux with KM3NeT/ARCA data	A. Sinopoulou (sinopoulou@inp.demokritos.gr), E. Drakopoulou, F. Filippini(francesco.filippini9@unibo.it), E.Tzamariudaki	KM3NeT/ARCA	Astronomy	S. Navas
24	Online Multi-Messenger Program of KM3NeT	William Assal, Silvia Celli, Jerome de Favereau de Jeneret, Pavel Demin, Damien Dornic, Feifei Huang (feifei.huang@cppm.in2p3.fr), Vladimir Kulikovskiy, Emmanuel Le Guirriec, Sebastien Le Stum, Andres Jorge Tanasijczuk, Hichem Tedidit, Godefroy Vannoye.	KM3NeT	Astronomy	T. Chiarusi
26	Monitoring the neutrino sky for the next Galactic Core-Collapse Supernova with KM3NeT	Godefroy Vannoye (vannoye@cppm.in2p3.fr)	KM3NeT	Astronomy	S. Navas
28	KM3NeT/ARCA expectations for starburst galaxies observation	Walid Idrissi Ibnsalih, Antonio Ambrosone, Maria Rosaria Musone, Antonio Marinelli, Pasquale Migliozzi,Ofelia Pisanti, Gennaro Miele	KM3NeT	Astronomy	S. Navas
25	Cosmic ray muon rates measured with KM3NeT ARCA and ORCA detectors and their sensitivities towards detecting the prompt muons	P. Kalaczyński	KM3NeT	Cosmics	O. Kalekin
27	Sensitivity of the KM3NeT detector to a flux of nucleartites	Alice Paun (alice.paun@spacescience.ro), Gabriela Pavalas (gpavalas@spacescience.ro), Vlad Popa	KM3NeT	DM/Exotics	G. Ferrara
10	Probing neutrino invisible decay with KM3NeT/ORCA6	V. Carretero (victor.carretero@ific.uv.es)	KM3NeT/ORCA	Oscillations	C. Markou
12	Sensitivity to quantum decoherence in neutrino oscillations	N. Lessing (nadja.n.lessing@fau.de)	KM3NeT	Oscillations	M. Bouwhuis
13	First limits on neutrino non-standard interactions with KM3NeT/ORCA6	J. Manczak (jmanczak@ific.uv.es)	KM3NeT/ORCA	Oscillations	T. Pradier
18	Measurement of neutrino oscillations with KM3NeT/ORCA	Zineb Aly (aly@cppm.in2p3.fr)	KM3NeT/ORCA	Oscillations	O. Kalekin
19	Neutrino reconstruction with Graph Neural Networks in KM3NeT/ORCA6	João Coelho (jcoelho@apc.in2p3.fr) Shen Liang (shen.liang@u-paris.fr)	KM3NeT/ORCA	Oscillations	P. Mijakowski
20	Parameter-based particle identification using machine learning techniques in KM3NeT/ORCA	Alfonso Lazo (Alfonso.Lazo@ific.uv.es) Lukas Maderer	KM3NeT/ORCA	Oscillations	A. Moussa
22	Searches for sterile neutrinos with KM3NeT	Alba Domi (Alba.Domi@ge.infn.it) João Coelho	KM3NeT	Oscillations	G. Ferrara
29	Different optical modules for different cosmic neutrino detectors	Emanuele Leonora	KM3NeT	Technical	G. Ferrara
30	Full ARCA performances (update PS/diffuse) with tracks+sho	Thijs van Eeden (t.j.uan.van.eeden@nikhef.nl)	KM3NeT	Astronomy	C. Markou

18 contributions + 1 plenary to Neutrino 2022

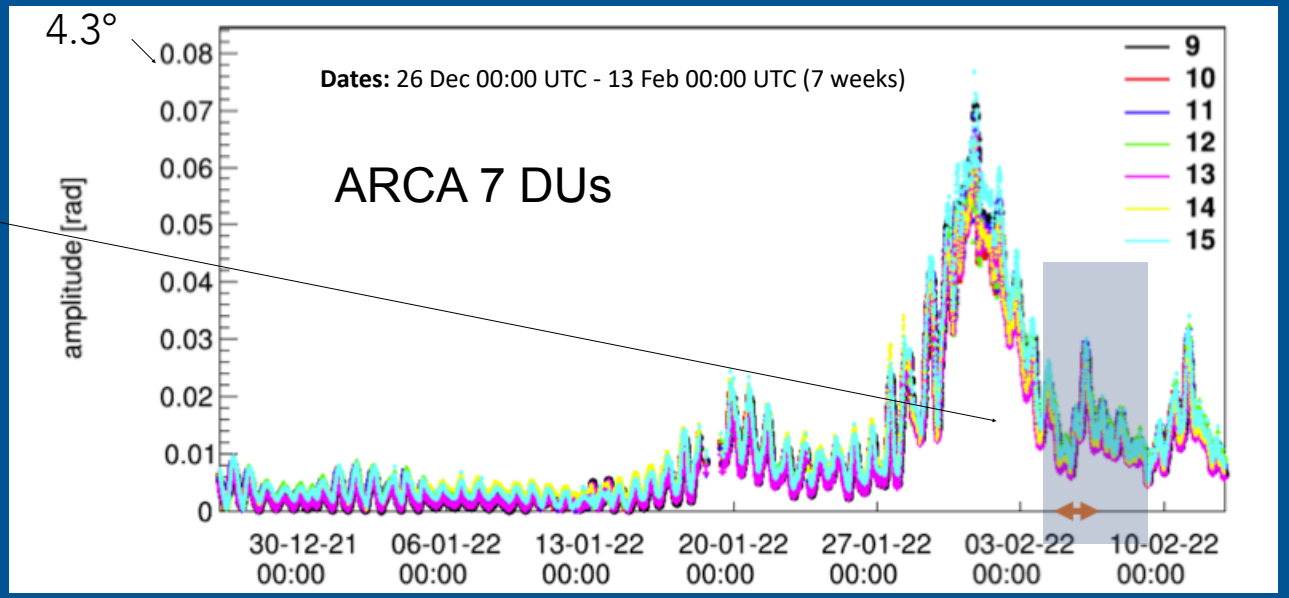
Position

Based on acoustic beacon and piezo



~28 m max displacement of the topmost DOM

Tilt amplitude

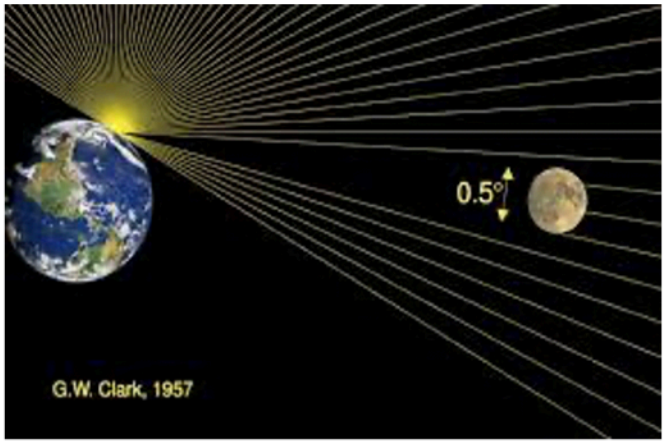


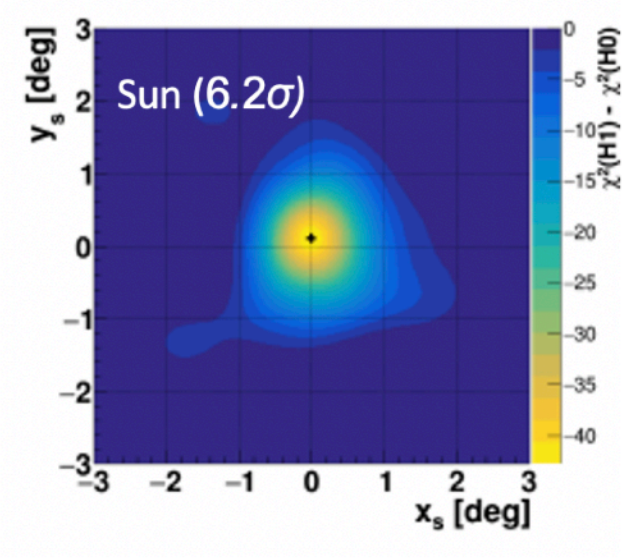
Dynamic positioning applied to the data

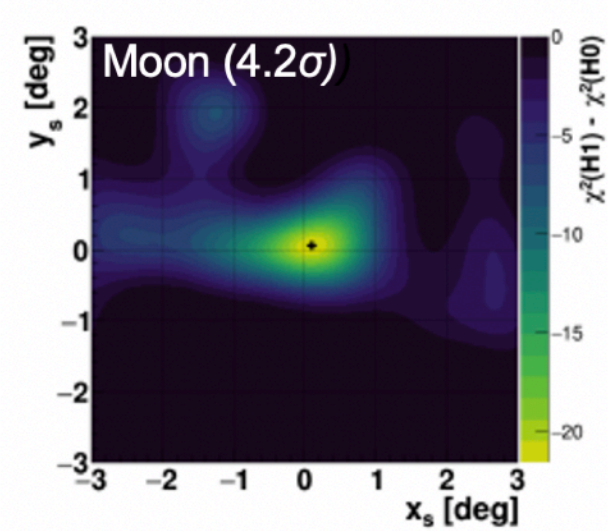
ORCA FIRST RESULTS

Checking resolution: Sun/Moon shadows with ORCA

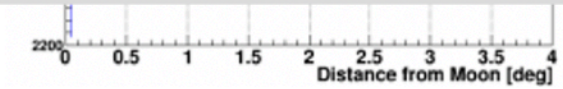
- No standard candle source
- Cosmic rays to the rescue





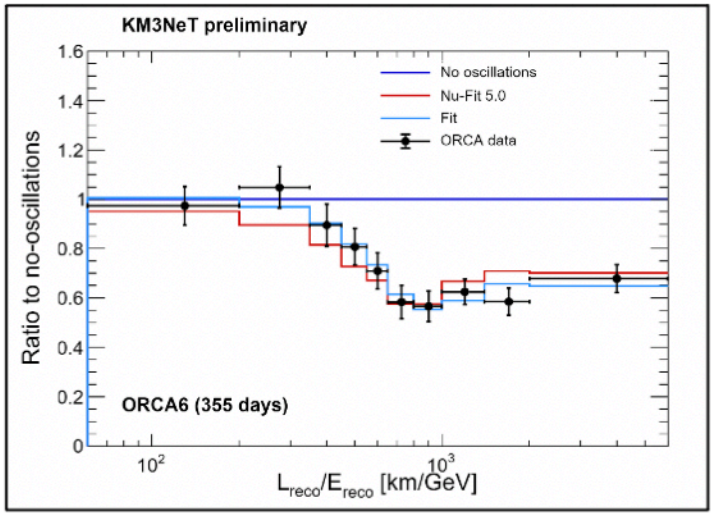


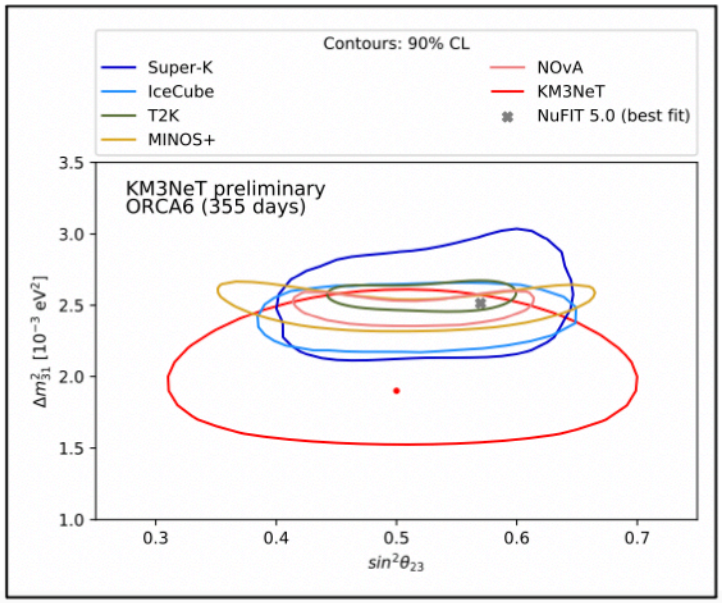
	Sun	Moon
Significance	6.0 σ	2.4 σ
Amplitude	1.42 ± 0.38	0.70 ± 0.29
Resolution	0.68° ± 0.12°	0.54° ± 0.16°



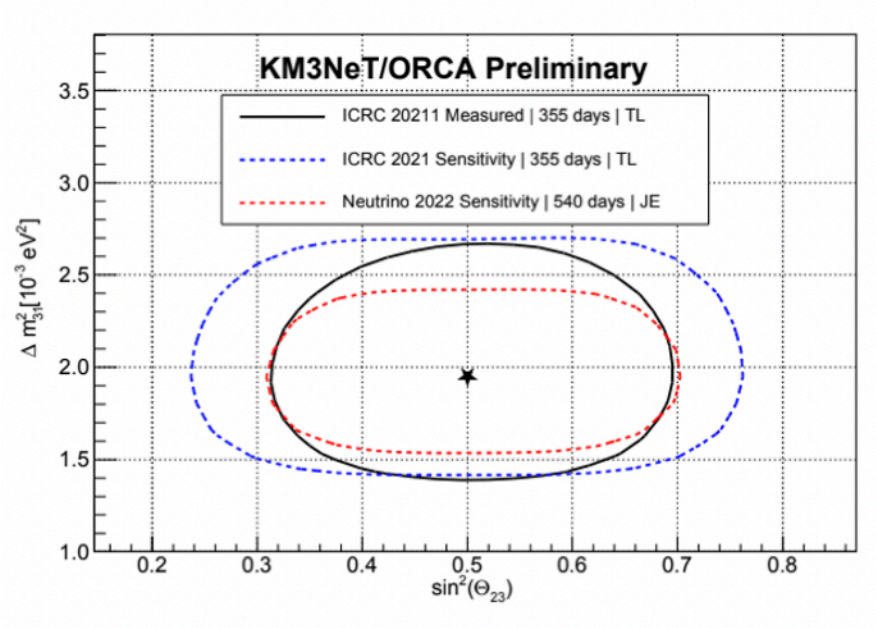
ORCA6 OSCILLATIONS: FIRST RESULTS

1 year of data with 6 lines of ORCA





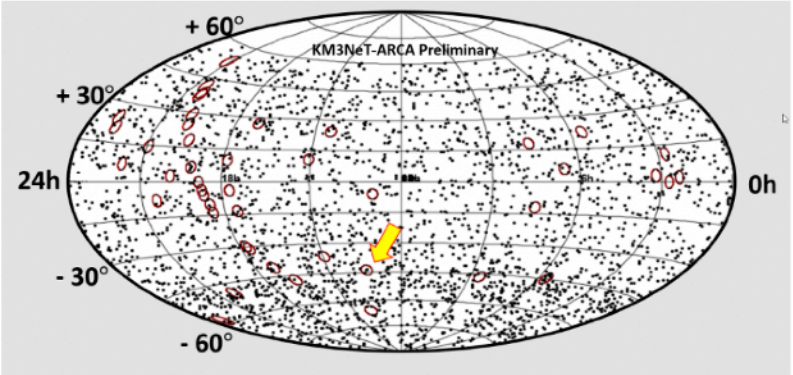
Update coming soon

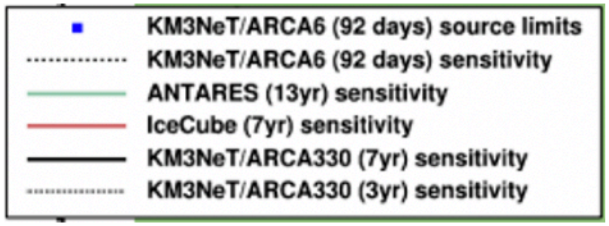


- More data 355 -> 540 days
- Better selection & particle identification
- Neutrino Sample increased by a factor 4
- Unblind in next months

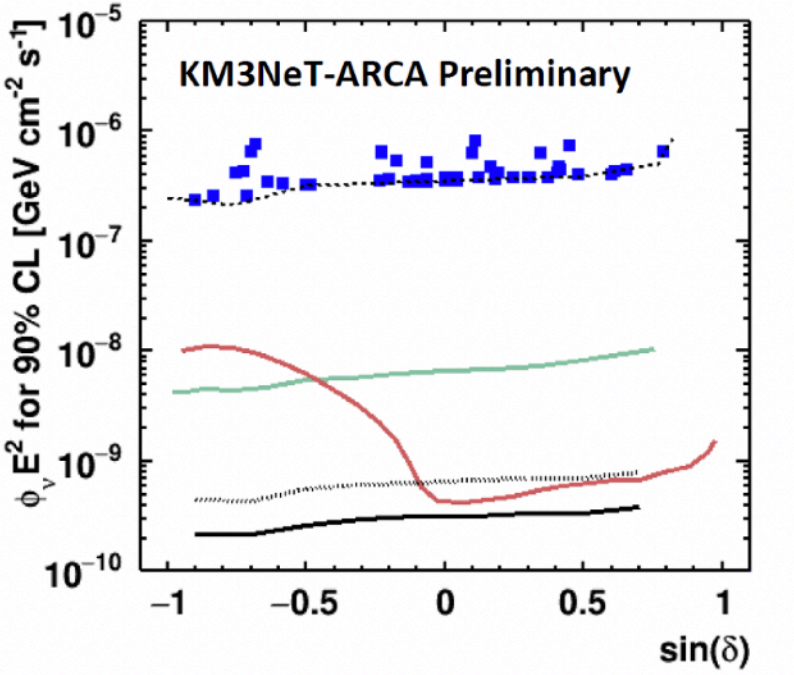
ARCA6: FIRST UPPER LIMITS

Astronomy: ARCA 6, 100 days





- Time integrated point source search May-Sept 2021, dynamic calibration
- Background dominated by muons
- Resolution ~1.3 degree for E^{-2}
- No significant excess observed
- Limits not yet competitive, as expected



ARCA6: FOLLOW UPS

First KM3NeT ATEL published

https://www.astronomerstelegram.org/?read=15290

Search for neutrino counterpart to the blazar PKS0735+178 potentially associated with IceCube-211208A and Baikal-GVD-211208A with the KM3NeT neutrino detectors.

ATel #15290; *F. Filippini, G. Illuminati (Univ. Bologna, INFN Bologna), A. Heijboer, C. Gatius, R. Muller (Nikhef), D. Dornic, F. Huang, S. Le Stum (CPPM, Aix-Marseille Univ.), J. Palacios GonzÃ¡lez (IFIC), S. Celli, A. Zegarelli (Univ. La Sapienza, INFN Roma), R. Coniglione (INFN LNS), D. Samtleben (Nikhef, Leiden Univ.), Y. Y. Kovalev, A. Plavin (ASC Lebedev) on behalf of the KM3NeT Collaboration*
*on **21 Mar 2022; 10:54 UT***

IC alert	Potential blazar
IC211208A	PKS 0735+17
IC220205B	PKS 1741-03
IC220225A	PKS 0215+15
IC220304A	TXS 0310+022