KM3
telescopi di neutrini nel Mediterraneo

A.Margiotta

KM3

unica sigla INFN per 2 telescopi sottomarini nel Mar Mediterraneo

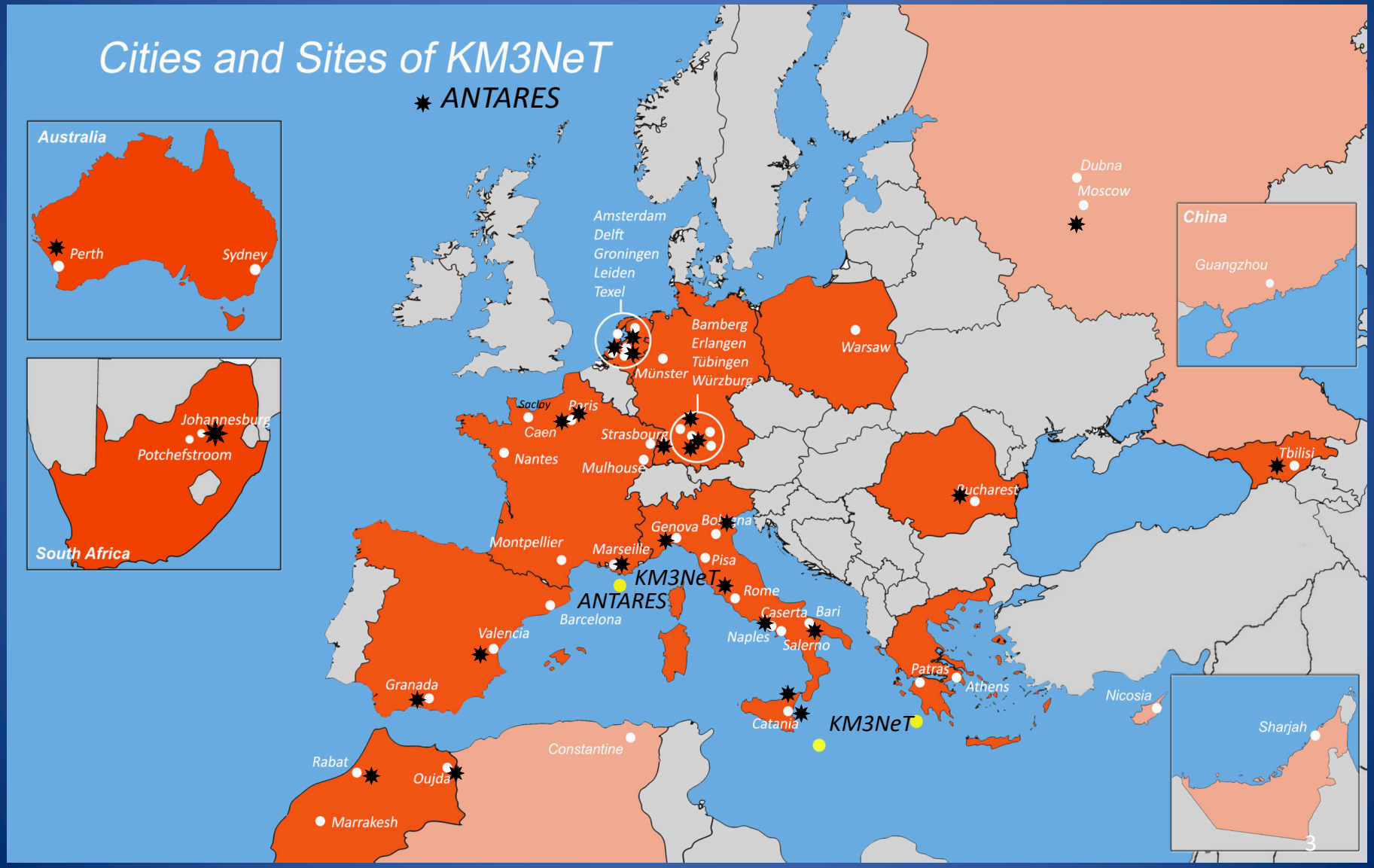
ANTARES

(https://antares.in2p3.fr)

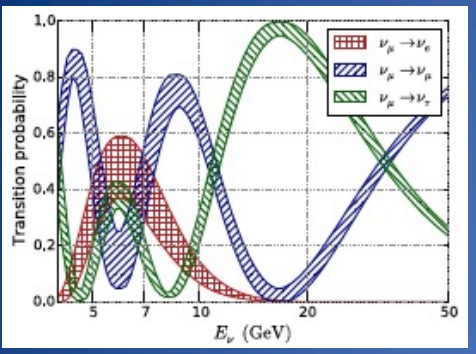
KM3NeT

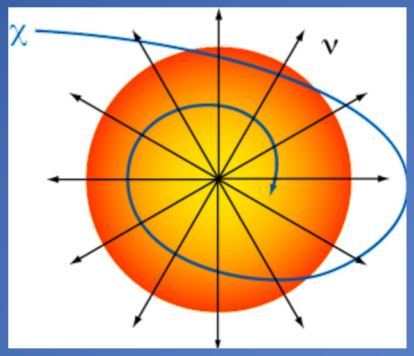
(https://www.km3net.org)

ANTARES / KM3NeT – le collaborazioni

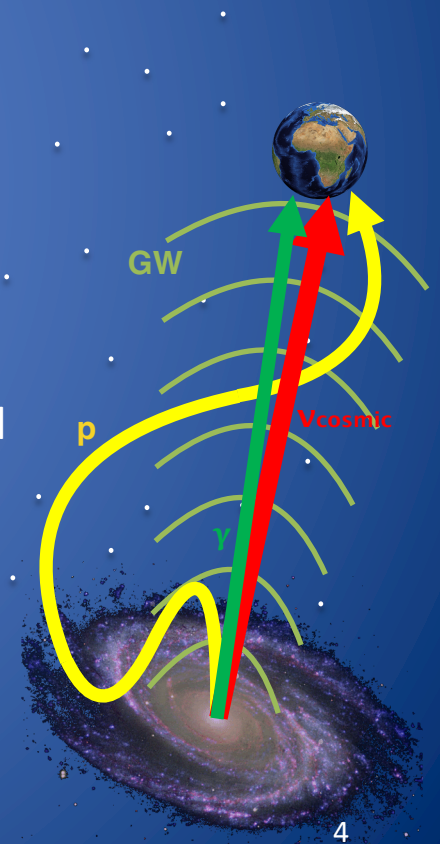


obiettivi scientifici





Low Energy MeV < E_ν < 100 GeV	Medium Energy 10 GeV < E_ν < 1 TeV	High Energy E_ν > 1 TeV
neutrino mass hierarchy Supernovae	Dark matter Monopoles, Nuclearites	Cosmic ν Origin and acceleration mechanism of HE CR
oscillations of atmospheric ν	BSM physics	Perfect probes : undeflected and unabsorbed
		Multimessenger approach

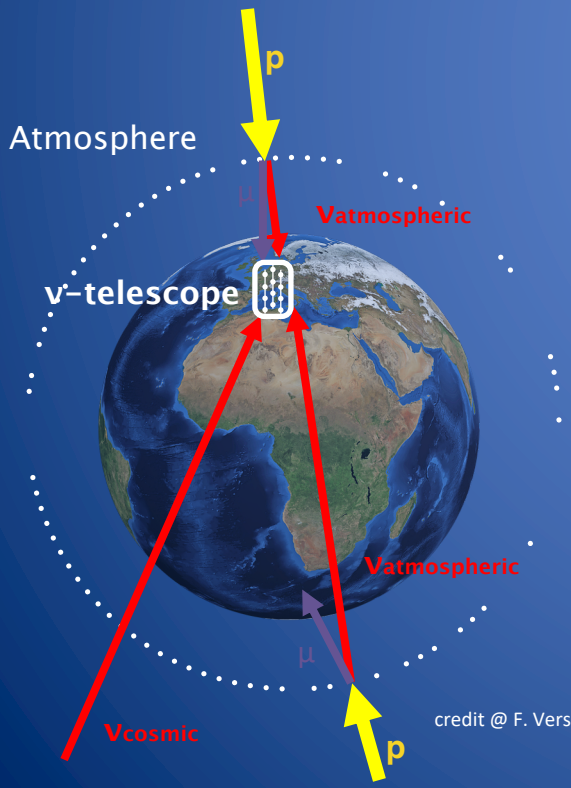


+ oceanography, biology, seismology,…

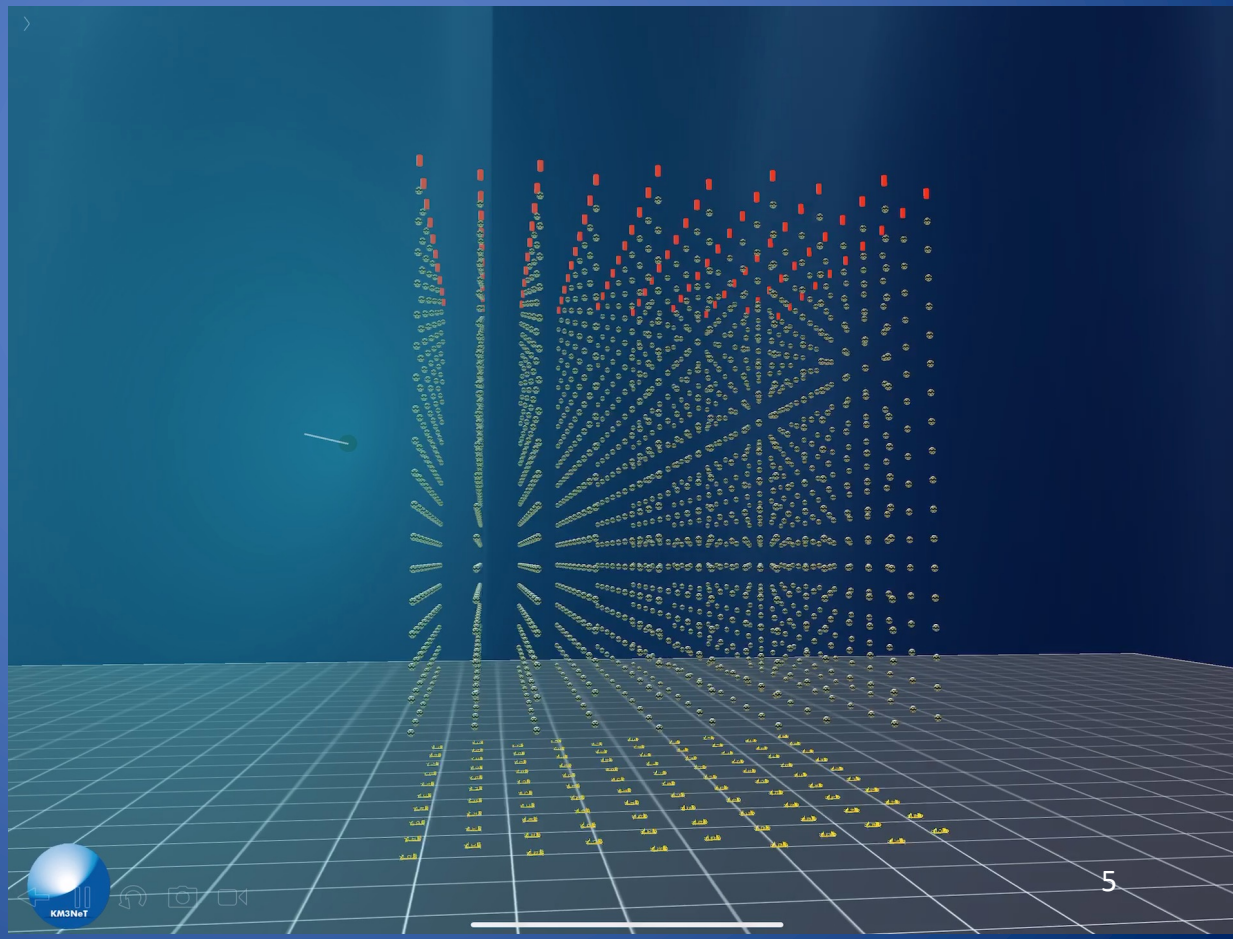
credit @ F. Versari

come funziona un telescopio di neutrini

- reticolo 3D di sensori ottici (fotomoltiplicatori)
- fotoni Cherenkov emessi in un mezzo trasparente lungo la traiettoria di particelle cariche ultrarelativistiche prodotte nelle interazioni di neutrini
- tempo, altezza segnale, posizione ➔ ricostruzione della direzione del neutrino



credit @ F. Versari



The ANTARES neutrino telescope

M. Ageron et al., NIMA656 (2011) 11

- 885 10” PMTs
- 12 lines
- 25 storeys/line
- 3 PMTs / storey
- all-data-to-shore
- Volume 0.01 km^3

10” PMT

450 m

Detector completed in 2008
duty cycle ~95%

40 km to shore

JunctionBox

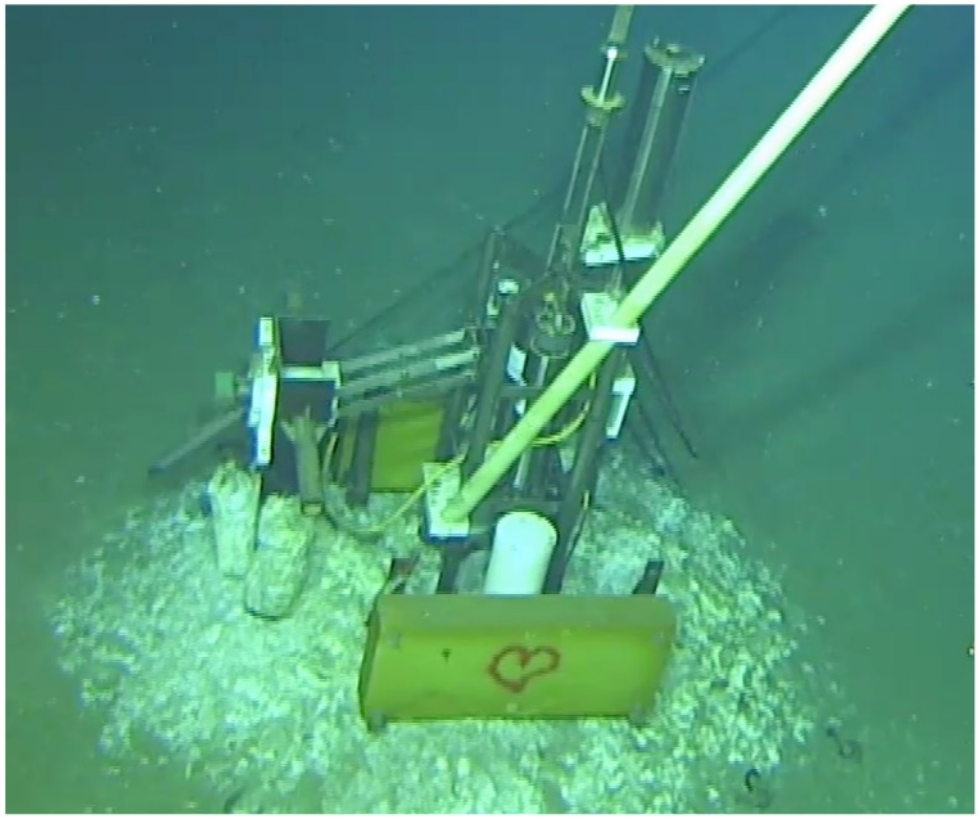
Interlink cables

70 m

FINE PRESA DATI – 12 febbraio 2022

- Line1 2006

2022



Storia di ANTARES a Bologna

Ingresso nella collaborazione nel 2000

Importanti contributi nella gestione del detector e analisi dati:

- Stefano Cecchini – Quality Manager (dal 2003)
- Annarita Margiotta – Resp. Monte Carlo (SW e produzione) (2008-18)
  – Publication Committee (2014-18)
  – Chair dell'Institute Board (dal 2016 a oggi)
- Giorgio Giacomelli – Chair del Publication Committee (2010-12)
- Maurizio Spurio – Chair del PC (2012- 14)
  – Deputy Spokesman (dal 2014 a oggi)
- Giulia Illuminati – Chair di WG astronomia
- **Numerose pubblicazioni con corresponding authors bolognesi**

Pubblicazioni ANTARES con c.a. bolognese

1. J.A. Aguilar et al., Zenith distribution and flux of atmospheric muons measured with the 5-line ANTARES detector, Astropart. Phys. 34 (2010) 179 - A. Margiotta
2. J.A. Aguilar et al., Search for a diffuse flux of high-energy νμ with the ANTARES neutrino telescope. Phys. Lett. B 696 (2011) 16 - S. Biagi & M. Spurio
3. S. Adrián-Martínez et al., Measurement of the atmospheric ν_μ energy spectrum from 100 GeV to 200 TeV with the ANTARES telescope, Eur. Phys. J. C73 (2013) 2606 - L. Fusco
4. S. Adrián-Martínez et al., Constraints on the neutrino emission from the Galactic Ridge with the ANTARES telescope, Physics Letters B 760 (2016) 143 - L. Fusco
5. A. Albert et al., All-flavor Search for a Diffuse Flux of Cosmic Neutrinos with Nine Years of ANTARES Data, ApJL 853 (2018) L7 - L. Fusco, F. Versari
6. A. Albert et al., The cosmic ray shadow of the Moon observed with the ANTARES neutrino telescope Eur.Phys.J. C78 (2018) 1006 - T. Chiarusi
7. A. Albert et al., ANTARES and IceCube Combined Search for Neutrino Point-like and Extended Sources in the Southern Sky, Ap. J. 892 (2020) 92 – G. Illuminati
8. A. Albert et al., Monte Carlo simulations in the ANTARES underwater neutrino telescope, JCAP01 (2021) 064 – A. Margiotta
9. A. Albert et al., Measurement of the atmospheric nu_e and nu_μ energy spectra with the ANTARES neutrino telescope, Phys. Lett. B 816 (2021) 136228 – M. Spurio e F. Versari
10. A. Albert et al., Search for neutrinos from the tidal disruption events AT2019dsg and AT2019fdr with the ANTARES telescope, ApJ 920 (2021) 50 - G. Illuminati

CONTINUA NEI PROSSIMI ANNI PER LE ANALISI FINALI...

Avventura entusiasmante!

- Detector pionieristico
- Ambiente marino profondo ostile e meno conosciuto dell'ambiente spaziale
- Numerose sfide tecnologiche affrontate e vinte
- Messa a punto di strategie di analisi dati
- Esperienza fondamentale per i progetti futuri, KM3NeT e non solo

Meeting di Collaborazione RAVENNA 2005

Mediterranean and Antarctic Neutrino Telescope Symposium BOLOGNA 2012

KM3NeT

Infrastruttura di ricerca nel Mediterraneo
2 telescopi di neutrino: medesima tecnologia
diversa densità dei moduli ottici

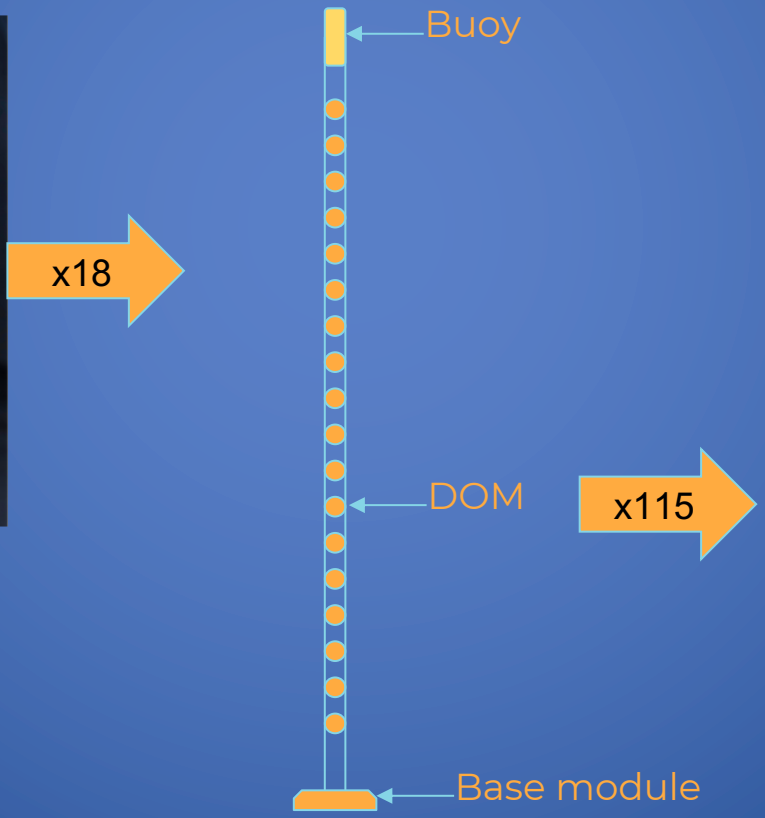
KM3NeT 2.0 Letter of Intent:
J.Phys. G43 (2016) 084001

KM3NeT - il detector

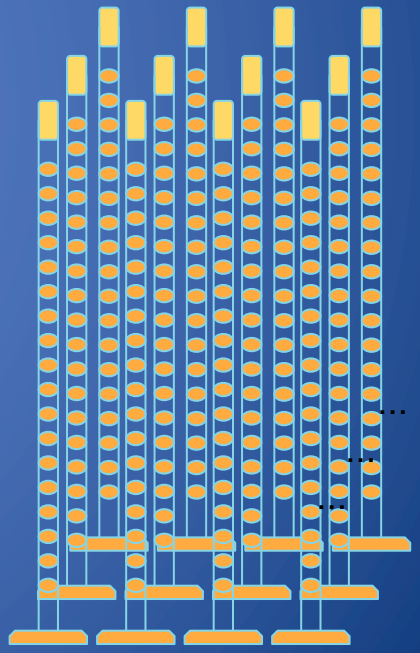
Digital Optical Module (DOM)
arXiv:2203.10048

- 31x3” PMTs
- ns timing
- ~10 cm spatial positioning

Detection Unit (DU)



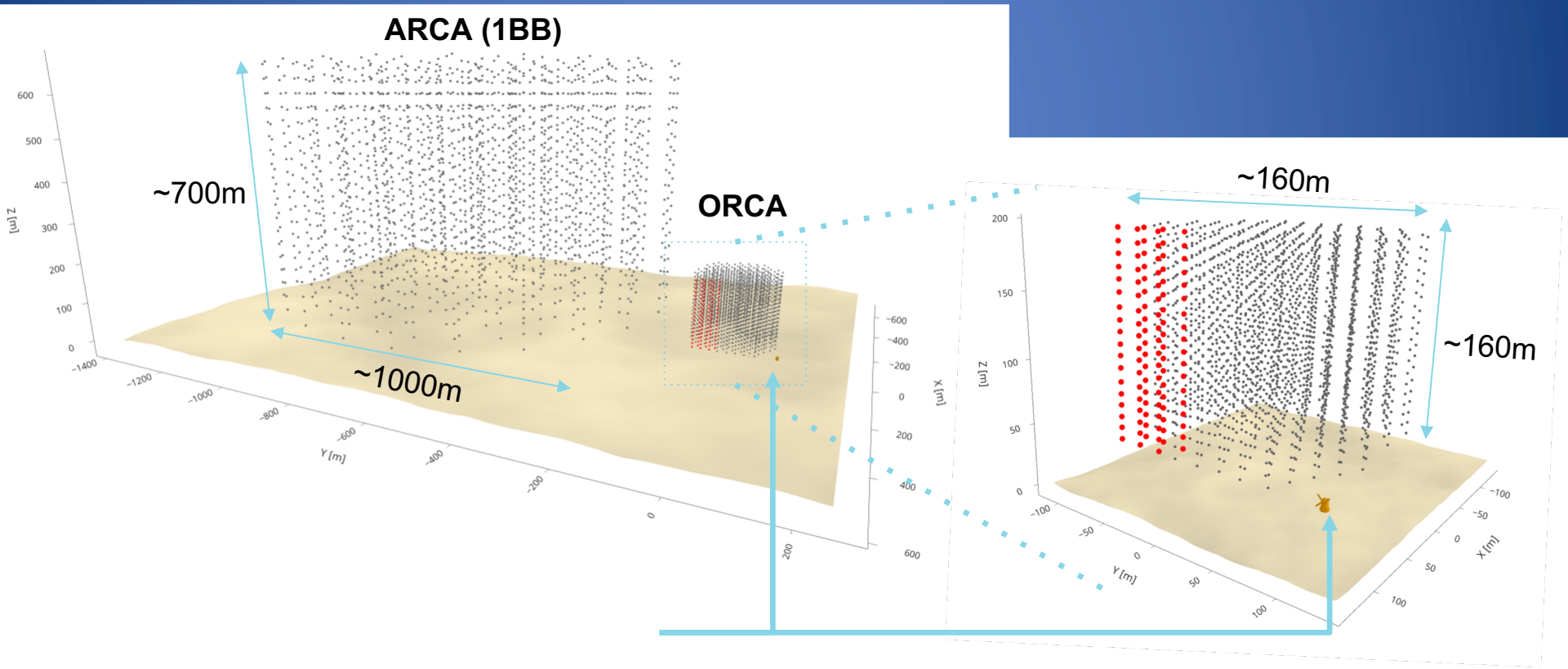
Building Block (BB)



ARCA/ORCA medesima tecnologia varia la distanza tra DOM

ARCA: ~90 metri in orizzontale
~18 metri in verticale

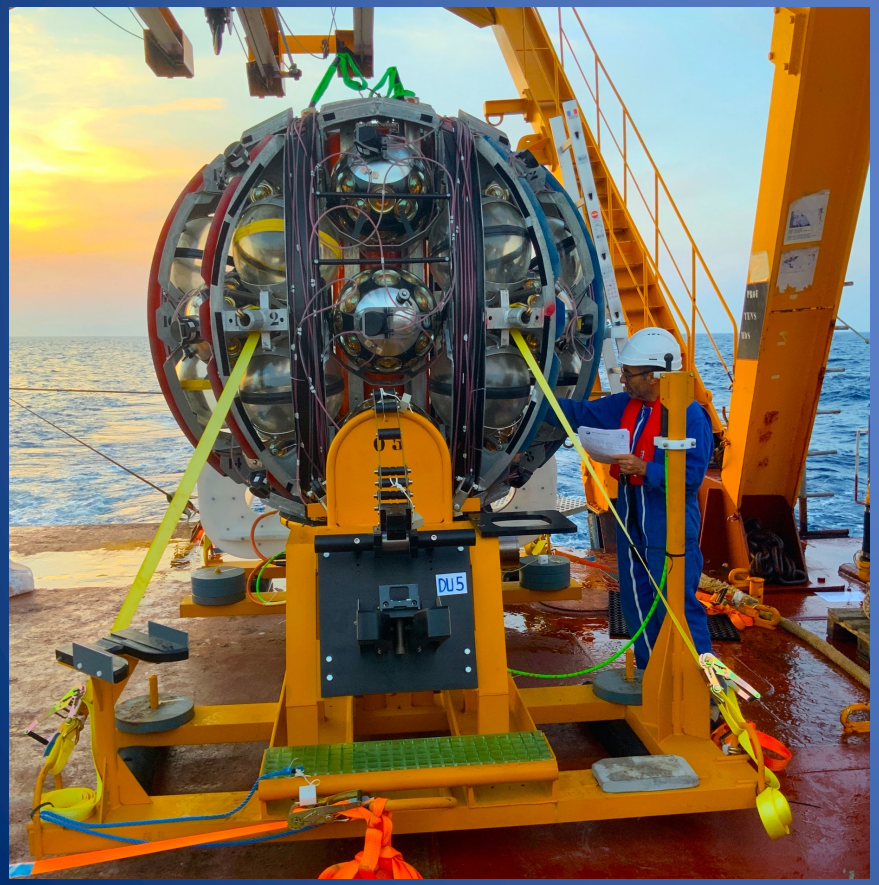
ORCA: ~20 metri in orizzontale
~9 metri in verticale



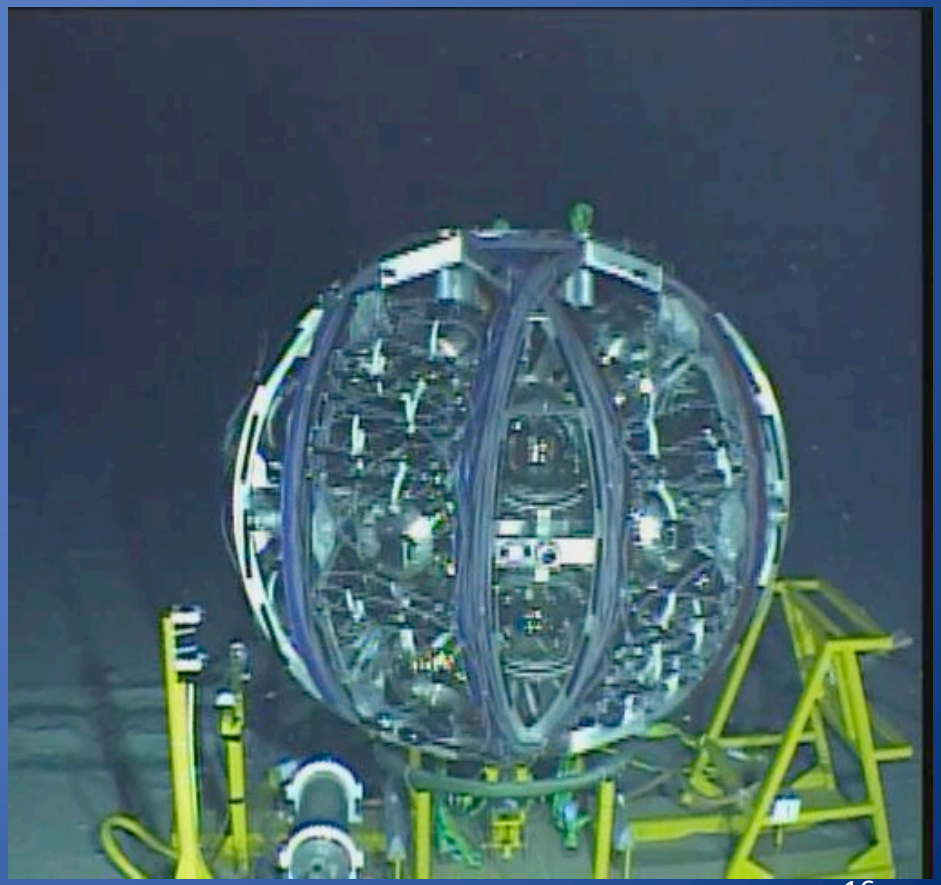
DU avvolta attorno a un LOM (Launcher of Optical Modules)

JINST15 (2020)P11027

Pronta per il deployment

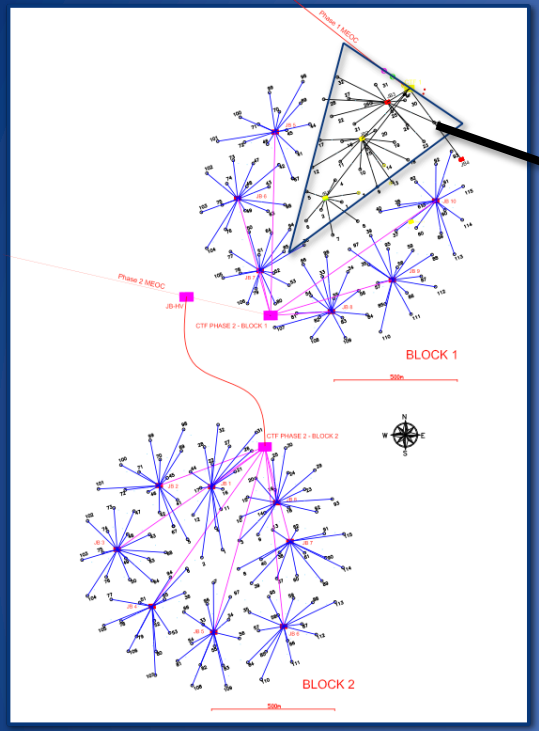


In fondo al mare

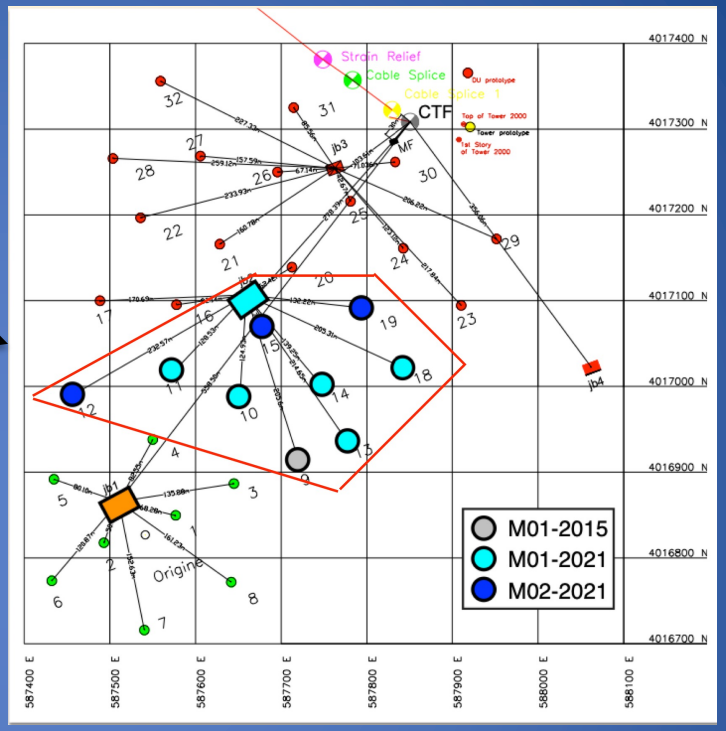


Stato costruzione KM3NeT/ARCA

Progetto complessivo
2 BB = 230 DU~1km³



Phase-1
(32 Dus)



DATA with ARCA6 ● + ●
End of deployment 14 April 2021
End of commissioning 12 May 2021
End of data taking as ARCA6 10 Sept. 2021

Data on disk 👉 114 days
Data Taking efficiency 94%

DATA with ARCA8 ● + ● + ●
End of deployment 15 of September 2021
End of commissioning 25 September 2021

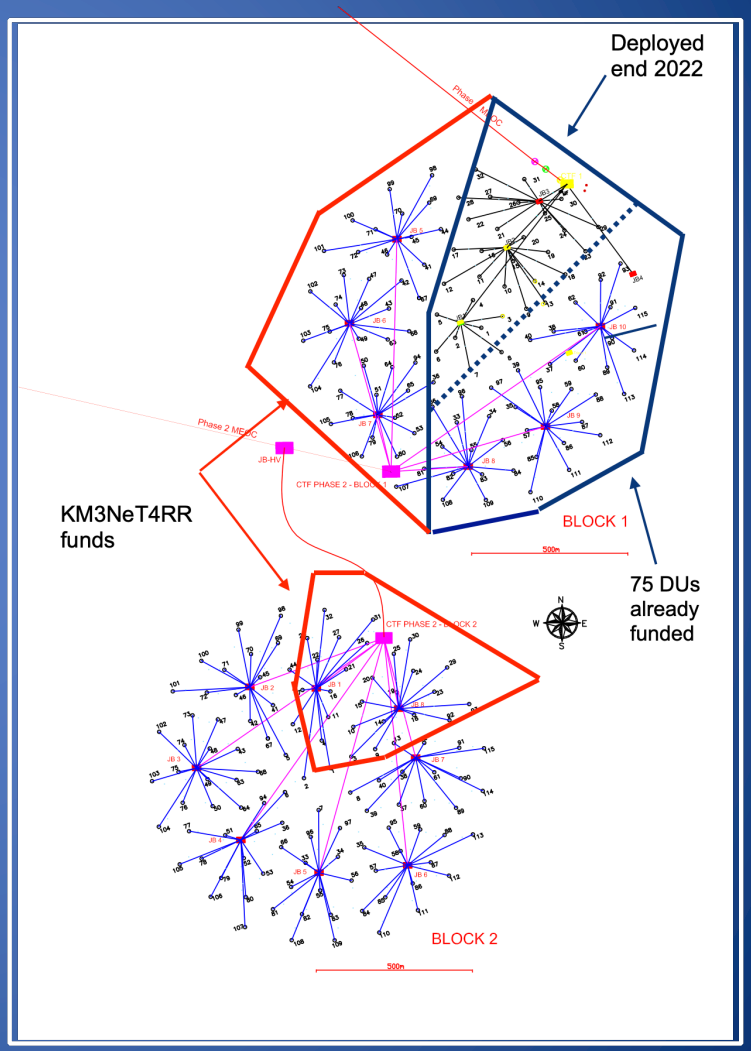
Data on disk 👉 ~ 170days
Data Taking efficiency 93%

Futuro prossimo

Entro il 2022 : 28 DUs in presa dati

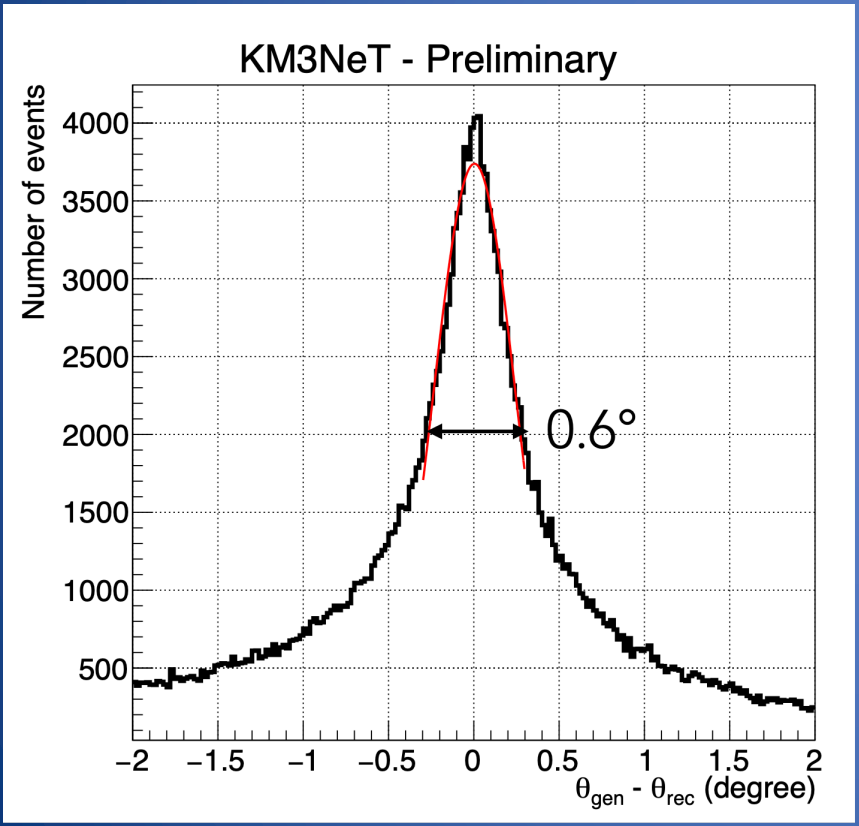
Finanziate in totale 75 DUs

Richiesta di finanziamento PNRR
KM3NeT4RR
completamento di 1 BB
+
~25 DUs del secondo BB



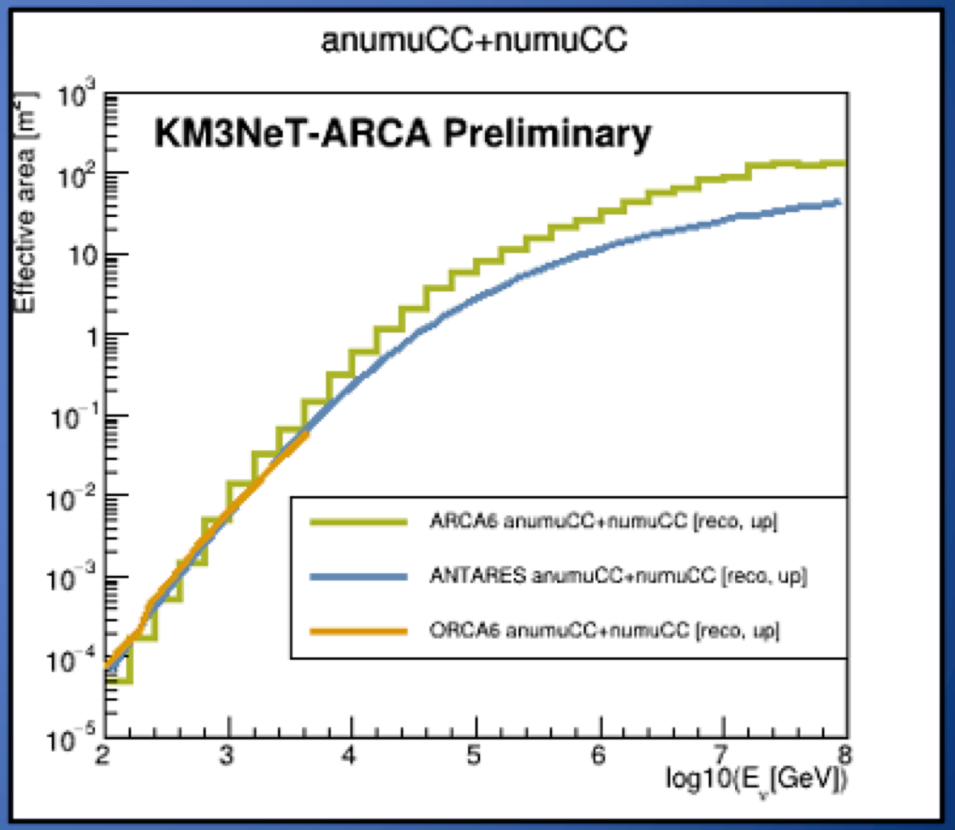
PNRR a BO : ~ 500 kEuro (contact: T. Chiarusi)
per adeguamento laboratori e test bench
SEGUIRANNO AGGIORNAMENTI...

ARCA6 angular resolution and effective area



Zenith angular resolution 0.6° (FWHM)

Selection 👉 up - going tracks

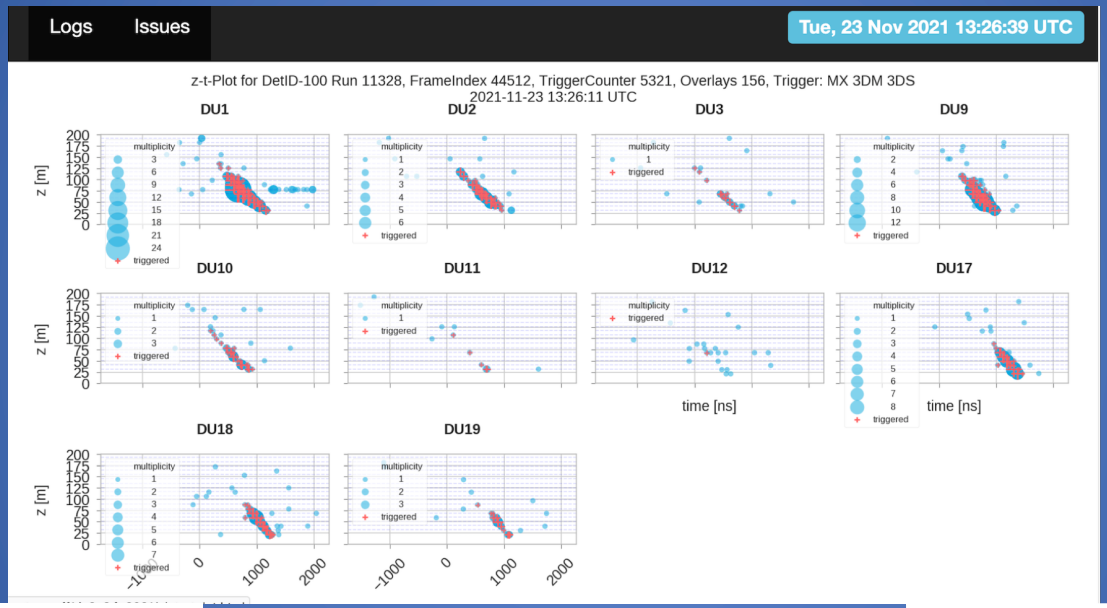


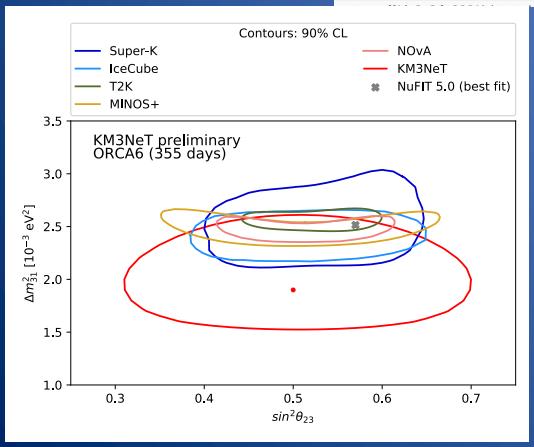
Effective area ≥ ANTARES eff. area

KM3NeT/ORCA

Obiettivo: costruzione di 1 BB (Dipende dalla disponibilità dei fondi)

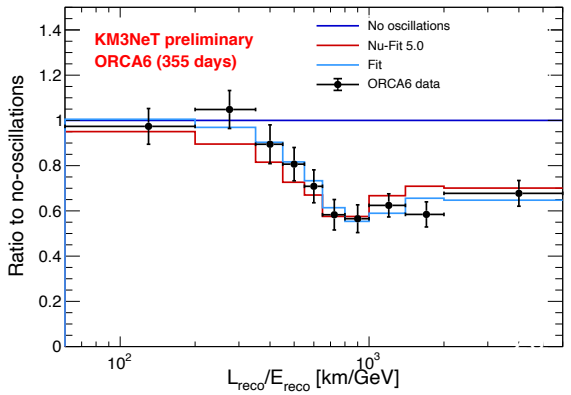
Attualmente: 6 DU da Feb20, 10 DU da Nov21





ORCA6 presentati a ICRC 21

Presto nuovi risultati con ORCA10



KM3 a Bologna

RICERCATORI

- P. Castaldi – P.A. UniBO - Dip. Ing. Energia Elettrica e dell'Informazione
- T. Chiarusi – Primo Ric. INFN – coordinatore DAQ KM3NeT/ConfComm KM3NeT
- G. Illuminati – RTDa – UniBO – coordinatrice WG Astro-MM KM3NeT/ ANTARES
- G. Levi – Ricercatore UniBO – Progetto e manutenzione del SW di assistenza integrazione KM3NeT
- A. Margiotta – P.A. UniBO – Chair Publication Committee KM3NeT/ Chair Inst.Board ANTARES
- M. Spurio – P.O. UniBO – Deputy Spokseman ANTARES

DOTTORANDI

- F. Benfenati, F. Filippini

TECNICI

- G. Balbi (Firmware per Bologna Common Infrastructure)
- L. Degli Esposti (Bologna Common Infrastructure)
- A. Paolucci (Bologna Common Infrastructure, shore station di PortoPalo)
- G. Pellegrini (progettazione schede elettronica, Integrazione Base Module)
- C. Valieri (Local Quality Supervisor, Integrazione Base Module)

DAQ – T. Chiarusi

- All-data-to-shore: no trigger/selezione off-shore

•2 submarine detectors :
- **ARCA** - 3500m u.s.l. - 100 km from Portopalo
- **ORCA** - 2500m u.s.l. - 50 km from Toulon

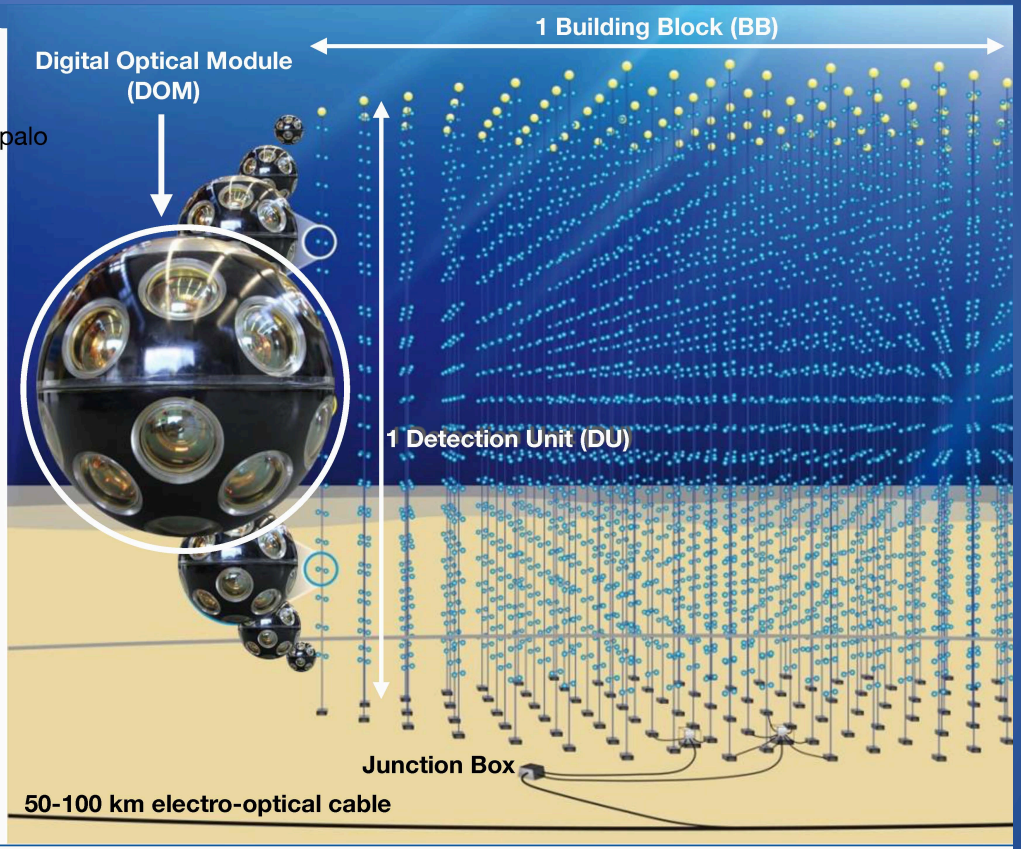
•*Building Block*
- •**115** *Detection Unit* (DU)
  - •**18** *DOM* + **1** *Base Module*/DU
    - •**31** x 3"*PMT*/DOM

2185 ethernet nodes / BB:
⟹ **67735 optical channels / BB**
⟹ **2185 acoustic channels / BB**

•***"All data to shore"*** concept
i.e. trigger-less, streaming readout, continuous readout…
O(100 Gbps) global throughput/BB.

Phase 1 : ***32*** DUs in ARCA and ***6*** DUs ORCA
To be completed by mid 2021 (ORCA already completed)

Phase 2 : 2x BB in ARCA 1xBB ORCA
To be completed by 2026

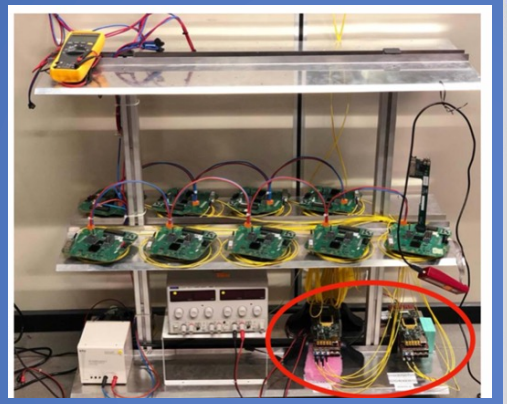


S. Aiello et al., The Control Unit of the KM3NeT Data Acquisition System, Comp. Phys. Comm., 256 (2020) 107433 – c.a. T. Chiarusi

- Bologna Common Infrastructure: F. Benfenati, F. Filippini + contributo insostituibile del servizio di Elettronica (G. Balbi, L. Degli Esposti, G. Pellegrini) e del Centro di Calcolo (A. Paolucci)

Phase 1

Phase 2



Test WWRS BM

- Test bench di servizio per la collaborazione.
- Accessibile in remoto
- Fondamentale per la verifica di progetto delle DU
- Dicembre 2021 test di integrazione e funzionamento del nuovo Base Module (WWRS)
- partecipazione di molti colleghi di Bologna, Bari, Roma, LNS,....

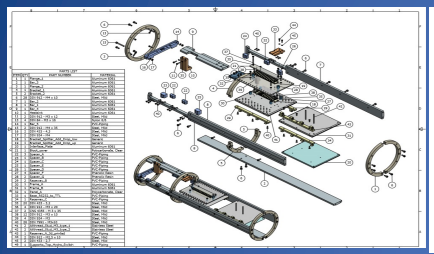
RICHIESTA PNRR → AMMODERNAMENTO ED ESTENSIONE BCI per includere l'emulazione della stringa di monitoraggio ambientale

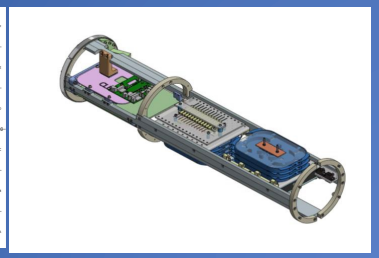

KM3NeT

Laboratorio integrazione Base Modules di ARCA

A. Margiotta, G. Pellegrini, C. Valieri

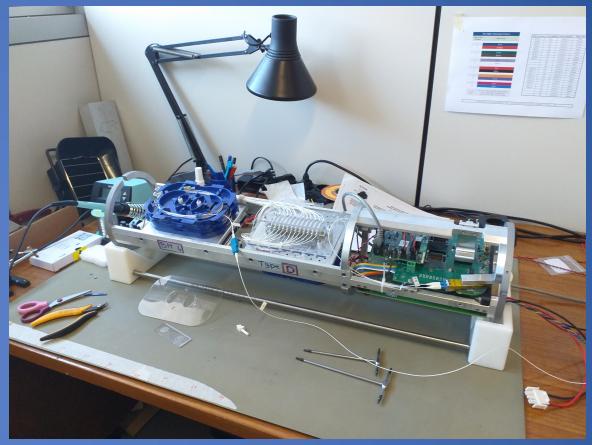
1. Frame di alluminio, prodotti dall'Officina Meccanica (per Phase1)



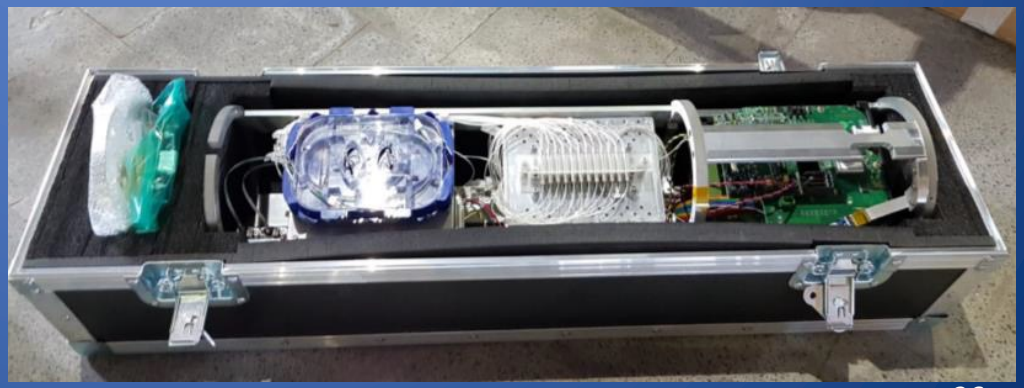


2. BM: contengono I circuiti elettro-ottici per il trattamento e il trasferimento del segnale dai PMT al main cable verso terra ➔ giunzione di fibre ottiche - C. Valieri

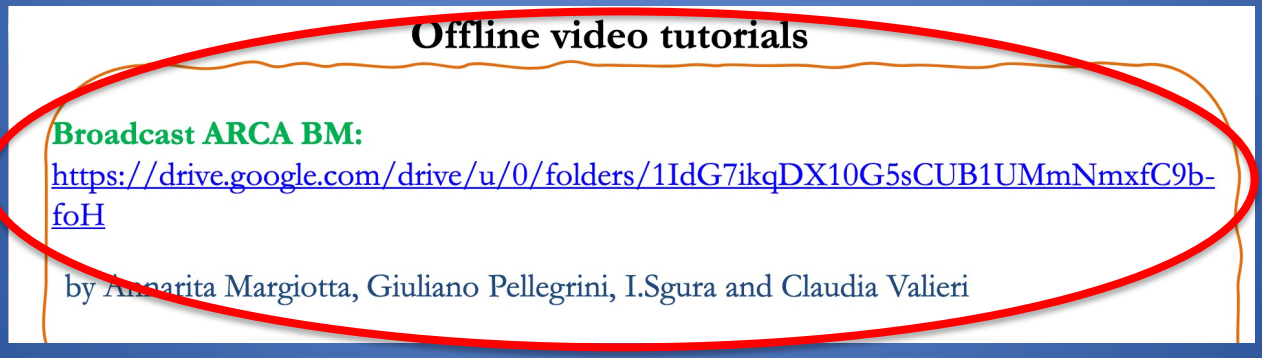
3. integrazione dell'elettronica di controllo del trasferimento dati e di altri dispositivi ausiliari - G. Pellegrini
4. test di funzionamento sull'intero apparato elettro-ottico - G.Pellegrini; C. Valieri

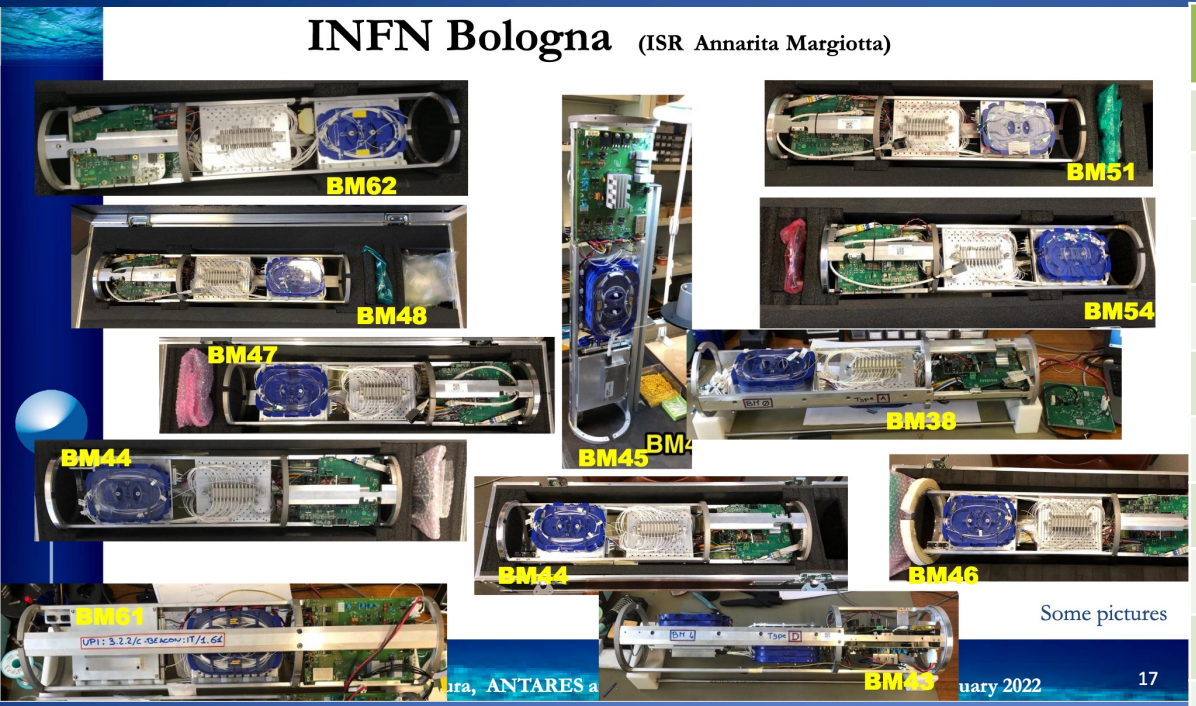


5. spedizione ai siti di integrazione delle Detection Units



- Attività di integrazione mantenuta durante la pandemia, con ovvi ritardi
- Preparazione di video tutorial dedicati a nuovi siti di integrazione dei BM in altri laboratori (LNS, Caserta, ...)
- Disseminazione delle abilità acquisite → uso massiccio di meeting online, scrittura di documentazione





20 BMs dei richiesti 31 + la base “speciale” per la Calibration Unit (Detection Unit dedicata al monitoraggio ambientale) integrati a Bologna in circa 2 anni, pandemia inclusa...

Phase1 CONCLUSA

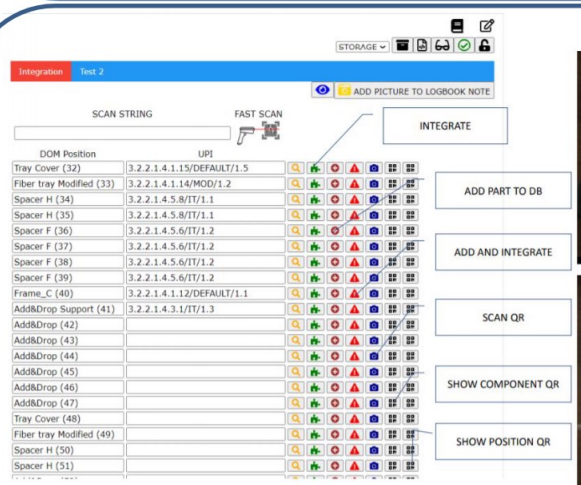
Pronti a partire con la produzione dei BM di nuovo design (WWRS)

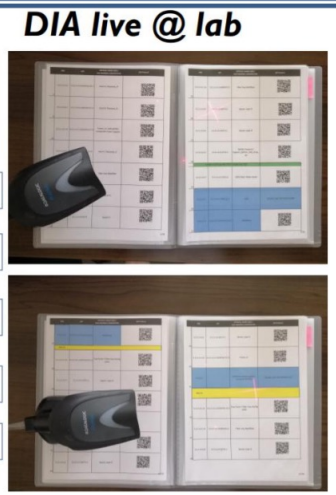
RICHIESTA PNRR per ammodernamento laboratorio

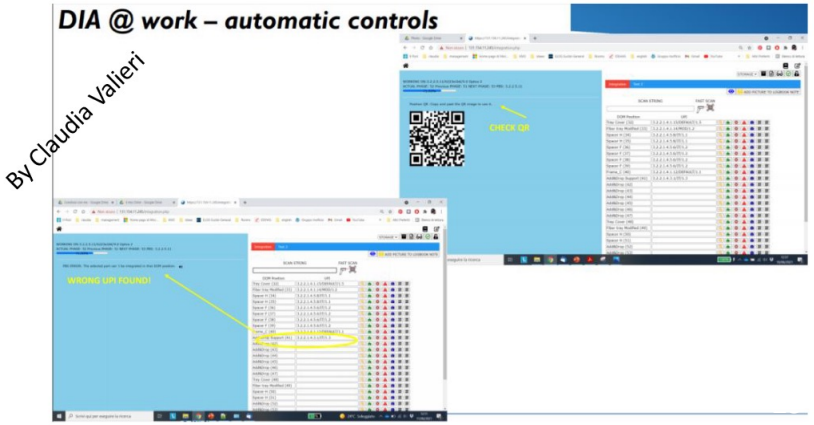
N°	Base module
1	3.2.2/C:IT/1.52
2	3.2.2/A:IT/1.38
3	3.2.2/B:IT/1.39
4	3.2.2/C-BEACON:IT/1.43
5	3.2.2/D:IT/1.42
6	3.2.2/A:IT/1.44
7	3.2.2/B:IT/1.45
8	3.2.2/C-BEACON:IT/1.61
9	3.2.2/D:IT/1.47
10	3.2.2/C:IT/1.46
11	3.2.2/A:IT/1.48
12	3.2.2/D:IT/1.54
13	3.2.2/D:IT/1.51
14	3.2.2/C:IT/1.57
15	3.2.2/D:IT/1.62
16	3.2.2/C:IT/1.59
17	3.2.2/A:IT/1.63
18	3.2.2/A-IT/1.67
19	3.2.2/C:IT/1.69 (in progress)
20	3.2.2/A:IT/1.68 (to do)

Integrazione e KM3DIA - G. Levi

- KM3DIA : applicazione web di supporto per la gestione dell'integrazione in KM3NeT totalmente sviluppata da G. Levi
- Utilizzata inizialmente per l'integrazione dei moduli ottici, estesa all'integrazione dei Base Module di ARCA e ORCA
- Software ufficiale della collaborazione, mantenuto da G.L. sul Cloud nazionale dell'INFN
- Accesso diretto al DataBase ufficiale

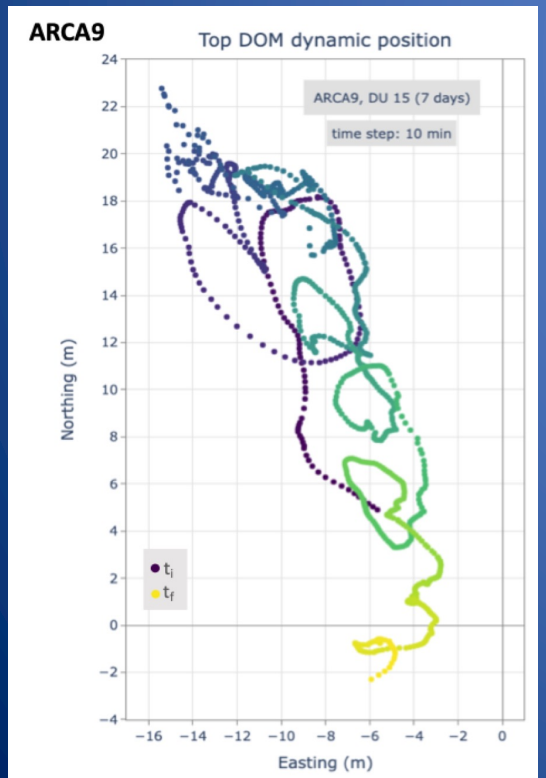






Calibrazione del detector

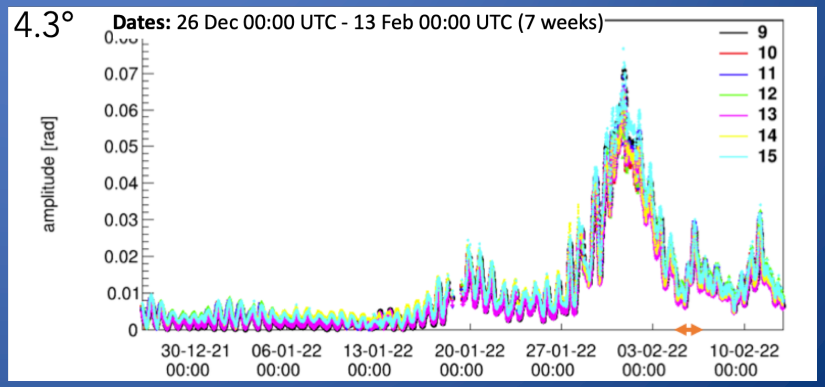
- Ricostruzione della forma della stringa (flottante per l'azione delle correnti sottomarine)
- posizione dei moduli ottici tramite triangolazione acustica
- in collaborazione con esperti della Facoltà di Ingegneria (Prof. P. Castaldi)
- ~28 m max spostamento del DOM più alto



E' essenziale un calcolo corretto della posizione dei DOM per una accurata ricostruzione delle tracce.

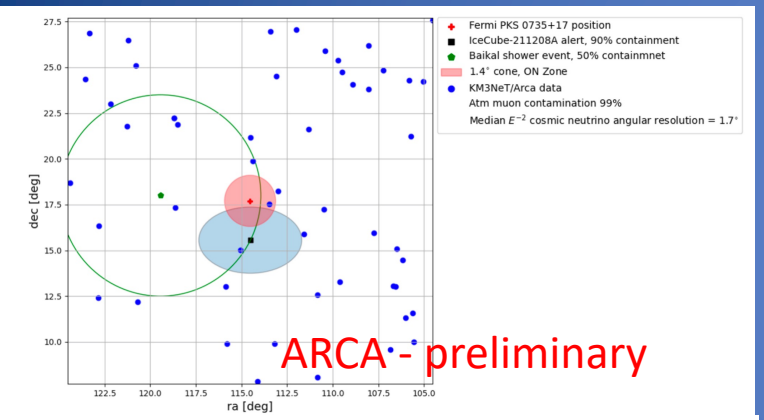
dynamic positioning

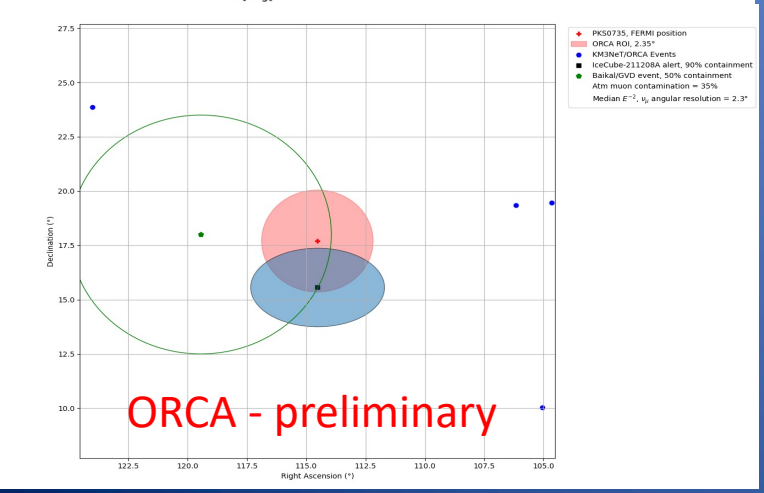
Tilt amplitude



Analisi dati

- Attività che coinvolge più o meno tutti i fisici di KM3NeT-BO
- Giulia Illuminati coordina i WG di Astro-Multimessenger
- Esempio: ricerca eventi in coincidenza con blazar e eventi da IceCube e Baikal GVD, affiancata da Francesco Filippini (dottorando)





ATEL
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.

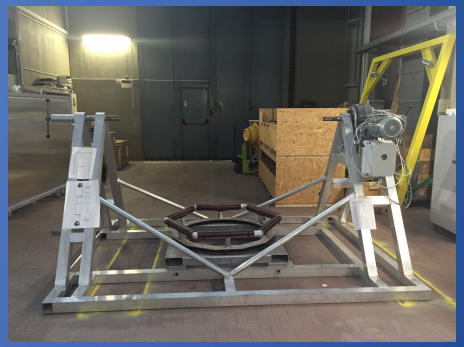
ATel #15290; *F. Filippini, G. Illuminati (Univ. Bologna, INFN Bologna), A. Heijboer, C. Gatius, R. Muller (Nikhef), D. Dornic, F. Huang, S. Le Stum (CPPM, Aix-Marseille Univ.), J. Palacios GonzÃ¡lez (IFIC), S. Celli, A. Zegarelli (Univ. La Sapienza, INFN Roma), R. Coniglione (INFN LNS), D. Samtleben (Nikhef, Leiden Univ.), Y. Y. Kovalev, A. Plavin (ASC Lebedev) on behalf of the KM3NeT Collaboration*
*on **21 Mar 2022; 10:54 UT***
Distributed as an Instant Email Notice Transients
Credential Certification: Damien Dornic (dornic@cppm.in2p3.fr)

Un ringraziamento sincero a tutti i servizi della sezione di Bologna!

In aggiunta ai già citati STG, CC, LabEle menzioni speciali vanno a:

Amministrazione e Direzione: per il supporto e la pazienza

Servizio progettazione meccanica:
Realizzazione disegni del “rotatore” (per avvolgere le DU in vista del deployment)

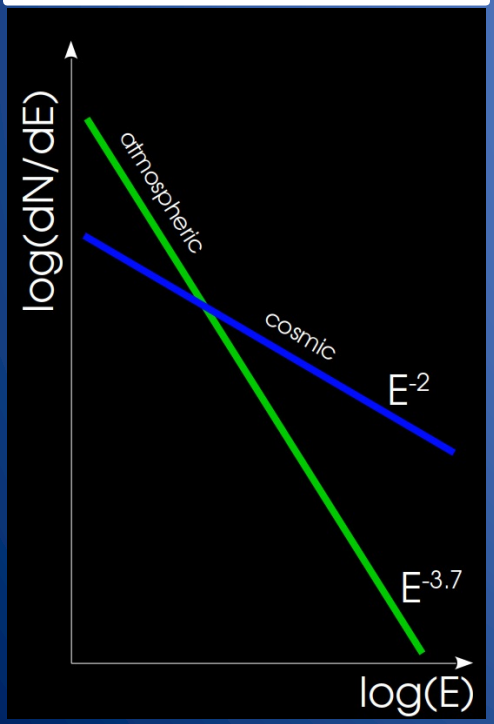


Officina Meccanica
Costruzione dei frame per i Base Modules e supporto all’installazione della Bologna Common Infrastructure (BCI)

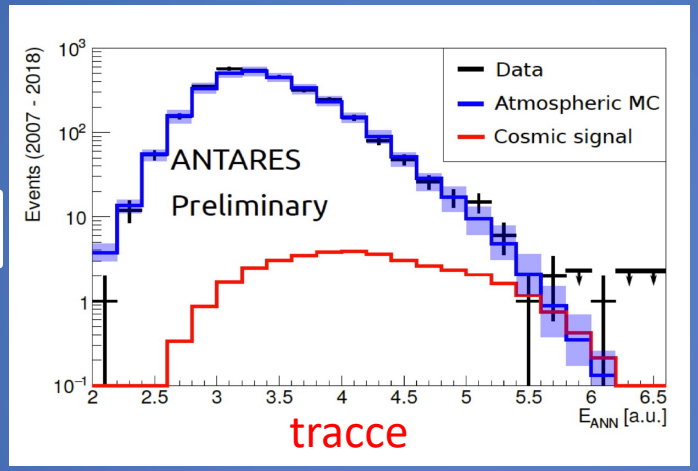
Back-up slides

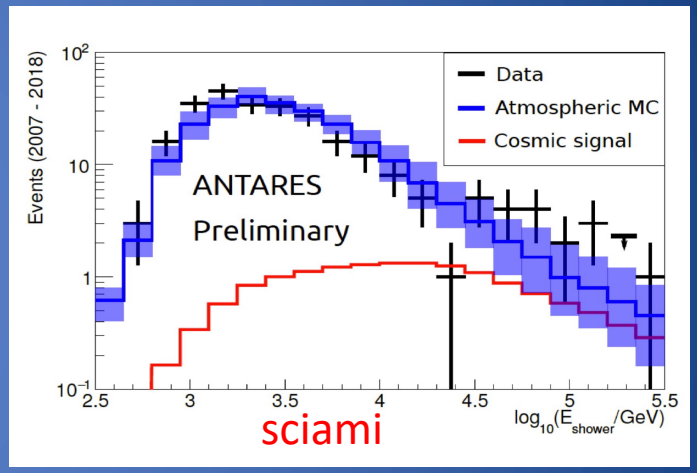
Diffuse flux of neutrinos

Diffuse High Energy flux



ANTARES 12 years - track and shower analysis





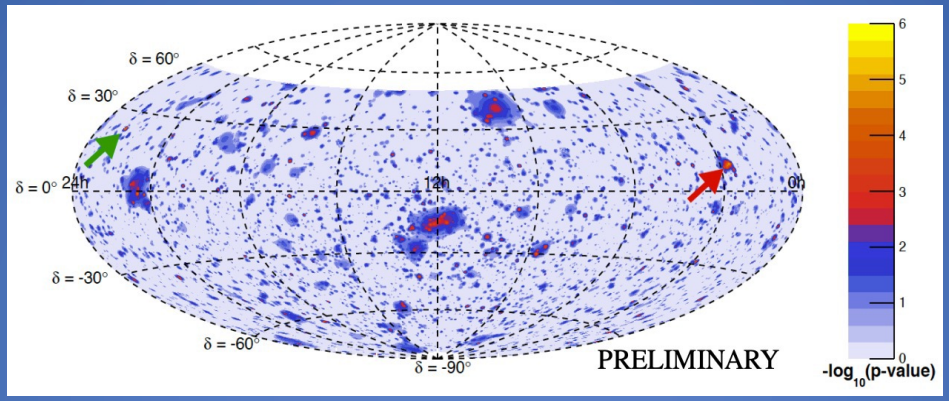
data: 50 events (27 tracks + 23 showers) 1.8σ excess
bkg MC: 36.1 ± 8.7 (19.9 tracks and 16.2 showers)

New selection criteria under study ➔ increase of data sample

Search for neutrino from pointlike sources

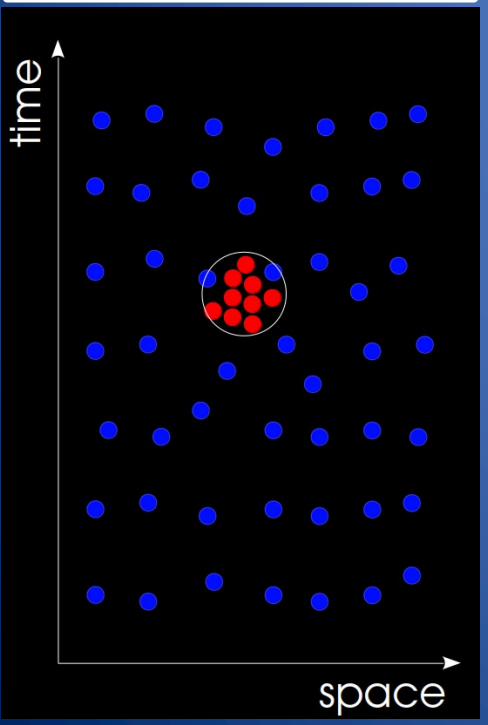
ANTARES 13 years - track and shower analysis

All-sky



Most significant spot in the sky $(\alpha, ,\delta) = (39.6°, 11.1°)$
Pre-trial: 4.3σ
Post-trial: 48%

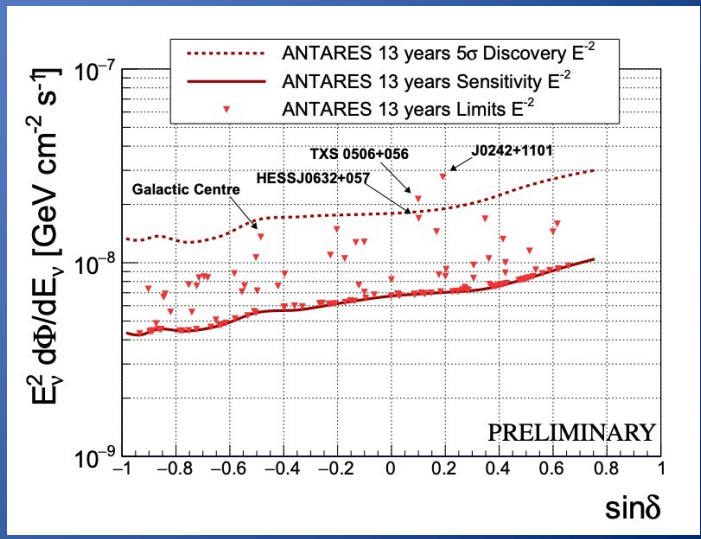
Point source and transient



Most significant source
Radio-bright blazar J0242+1101
Pre-trial: 3.8σ
Post-trial: 2.4σ

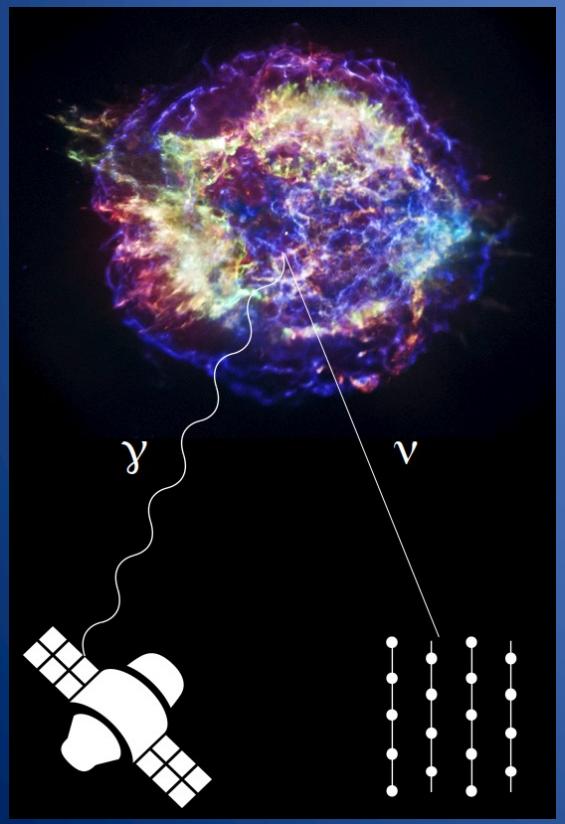
Second most significant source
TXS 0506+056 2.8σ

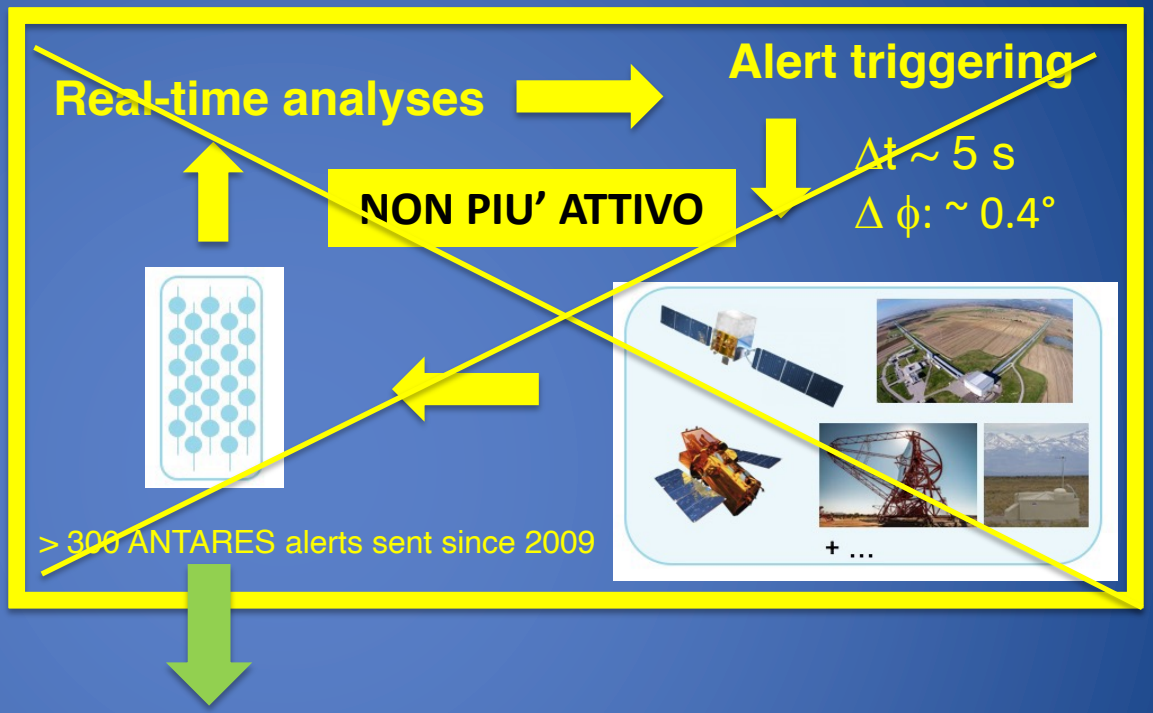
Upper limits on ν-flux from 121 astrophysical sources



Wide program of multimessenger analyses

Multimessenger





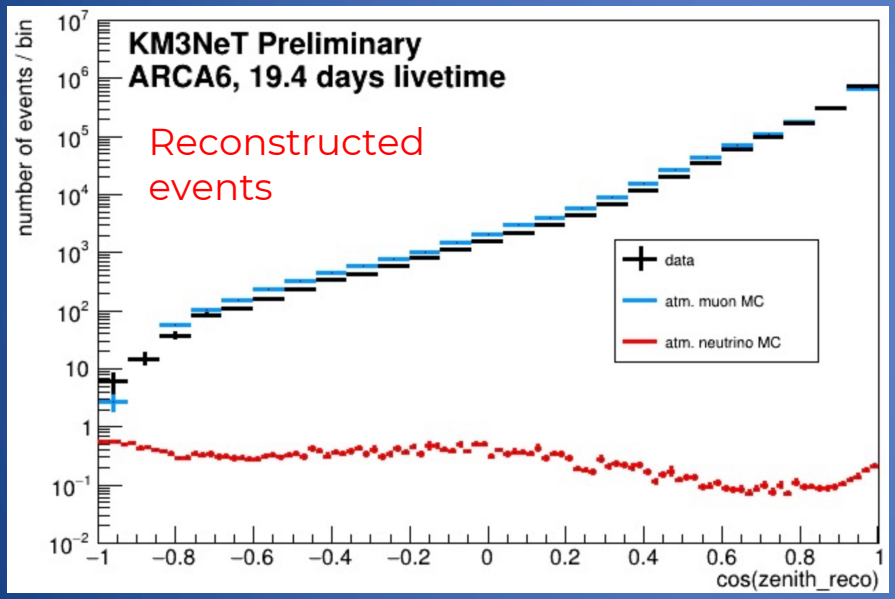
Offline analyses

Time correlation and multimessenger searches

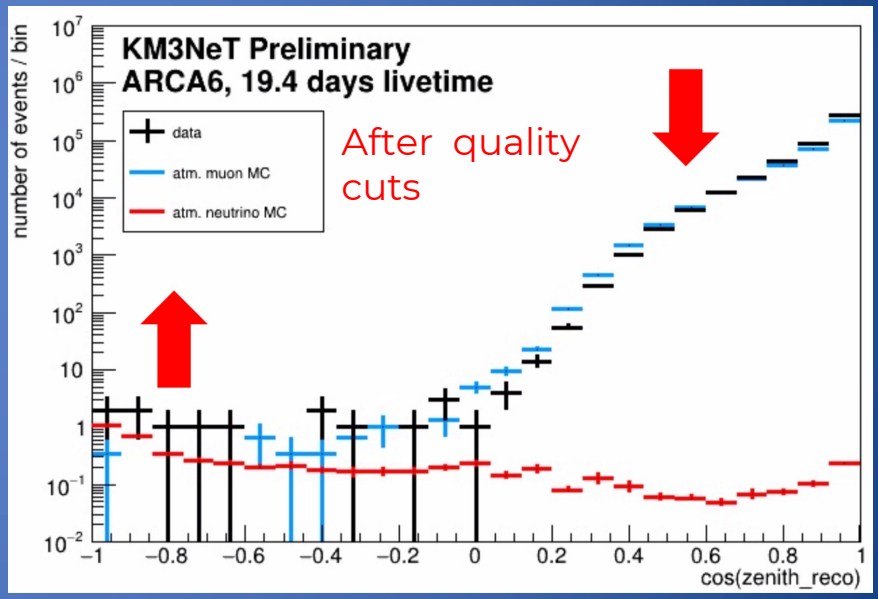
Neutrinos from IceCube and Baikal-GVD (??)

- GW events
- GRBs
- …

Preliminary results with ARCA (ARCA6)



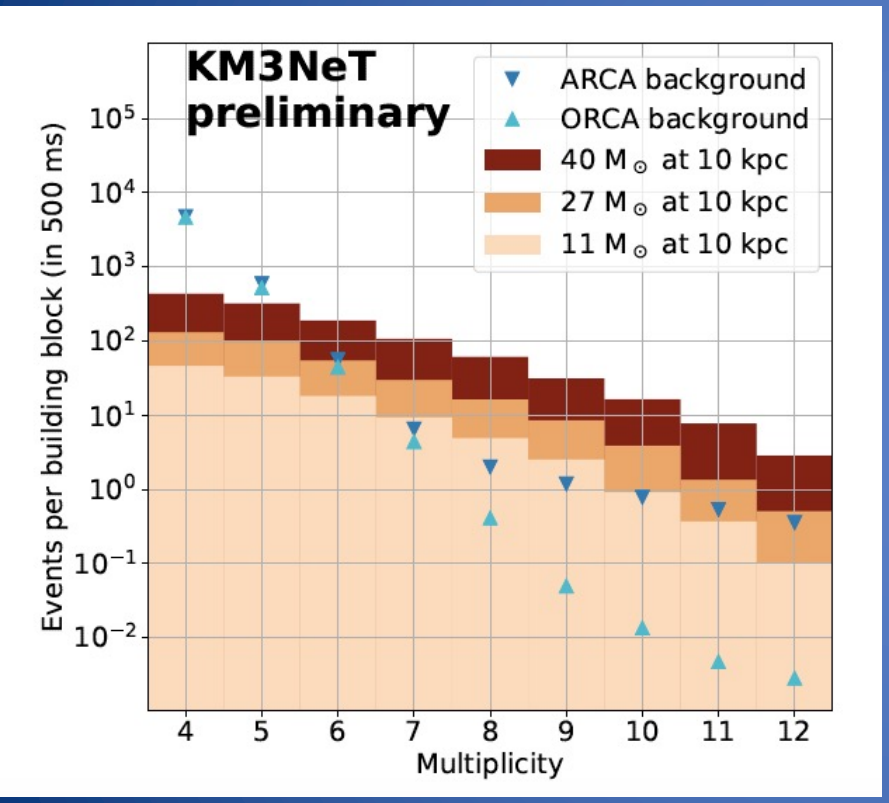
Upgoing tracks = neutrino induced events
Downgoing tracks = dominated by atm muons

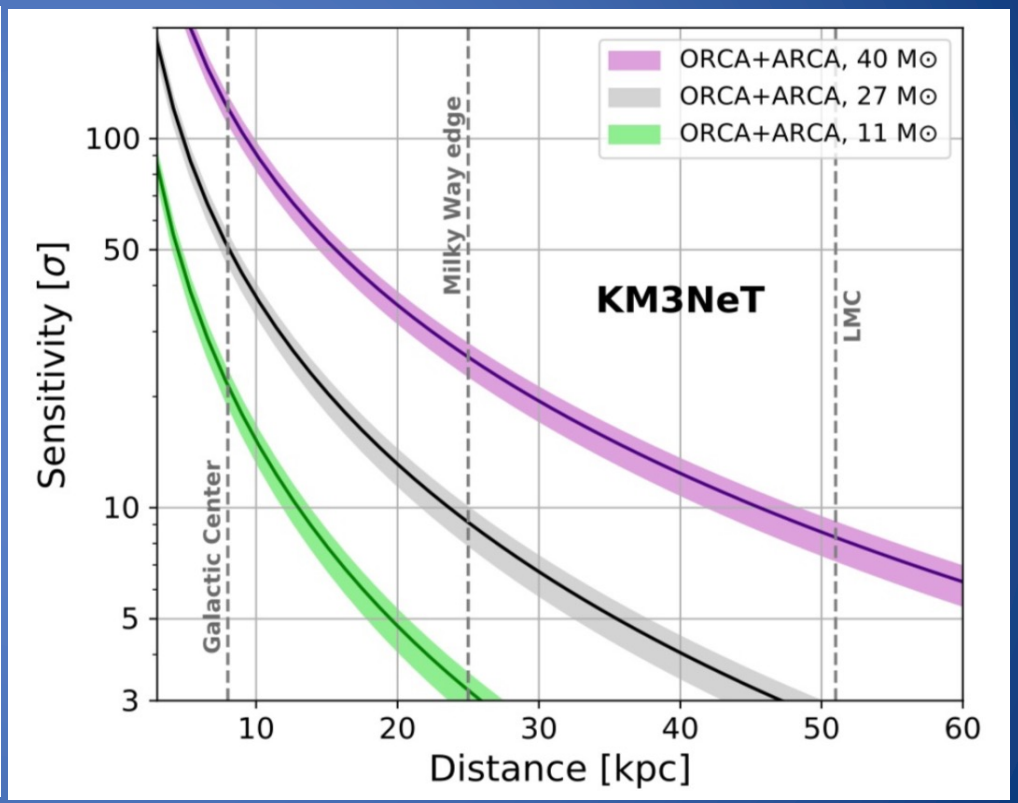


15 up-going tracks
MC expectations: 4 atm ν + 7 atm μ (BG)

Supernova monitoring

Neutrinos below 100 MeV expected at several stages of the core collapse
Cherenkov signature detected as a population of coincidences in single DOMs

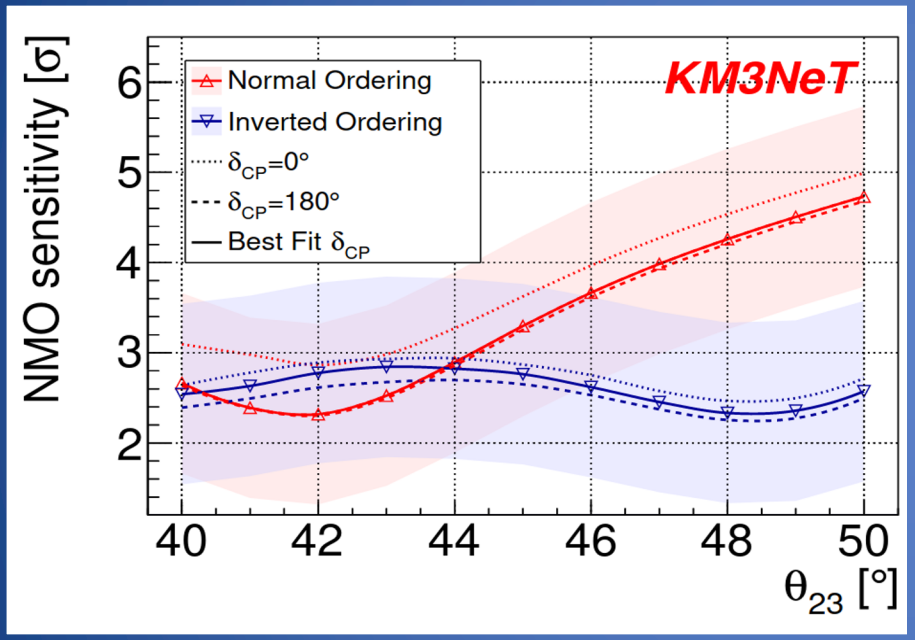


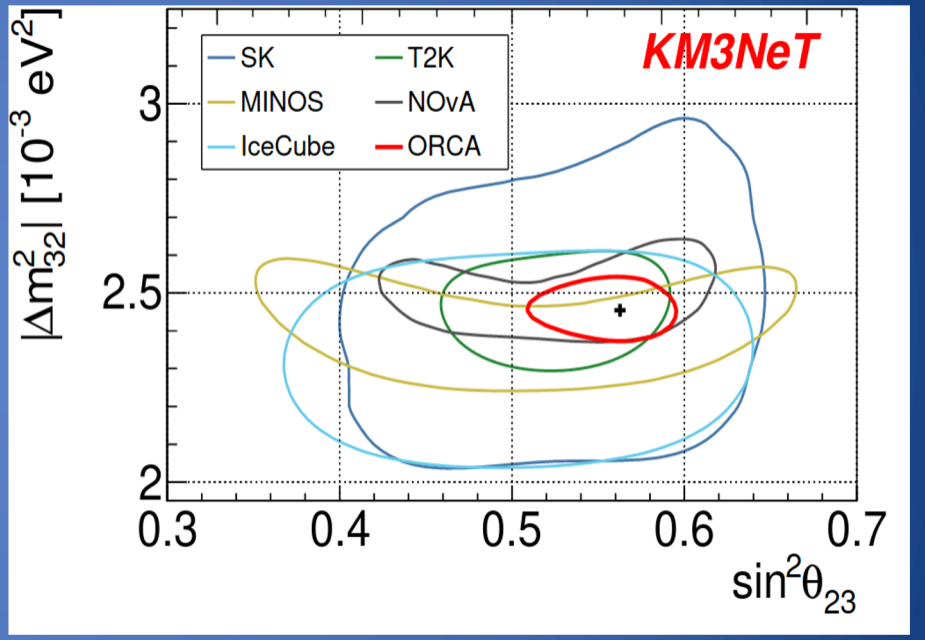


> 5 σ for ARCA+ORCA for 27M⊙ at a distance ~ 36 kpc

Eur. Phys. J. C81 (2021) 445; arXiv: 2109.05890 (in pubbl. su Eur. Phys. J. C)

Neutrino Mass Ordering





Expected results for 3 years exposure, full detector.

Eur. Phys. J. C 82, 26 (2022); arXiv:2108.06293 (in pubbl. su JHEP)

Competitive sensitivity to Δm^2_{32}, θ_{23}