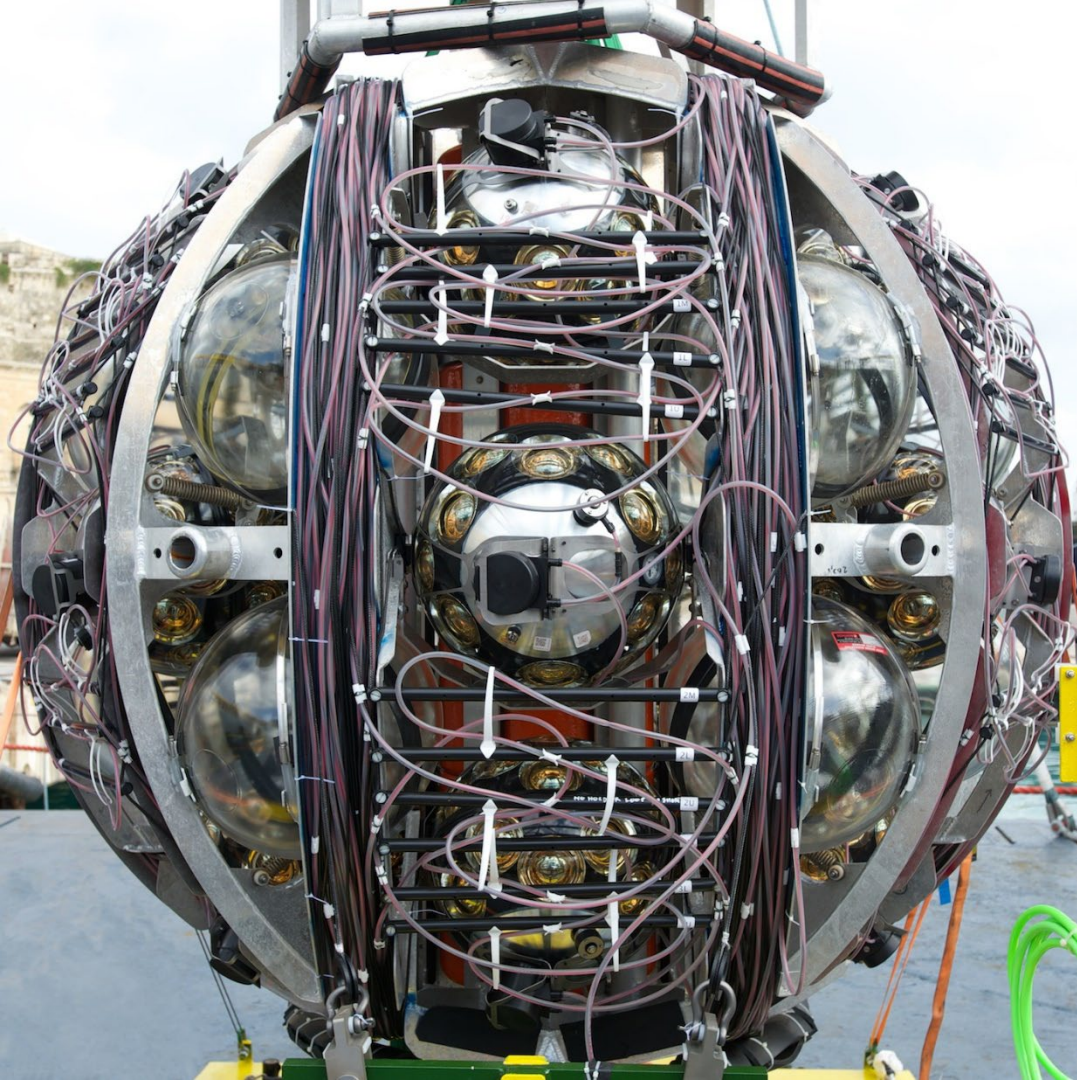




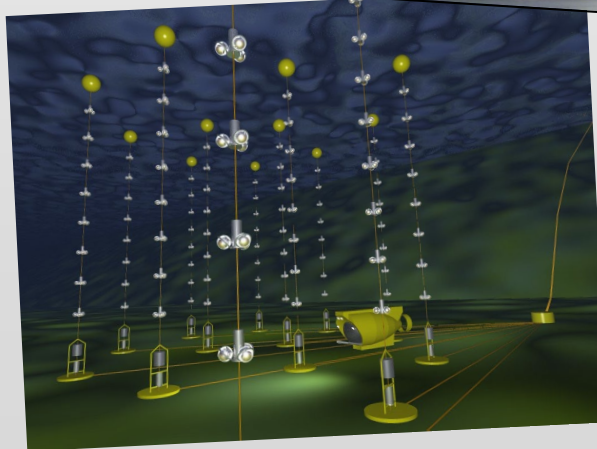
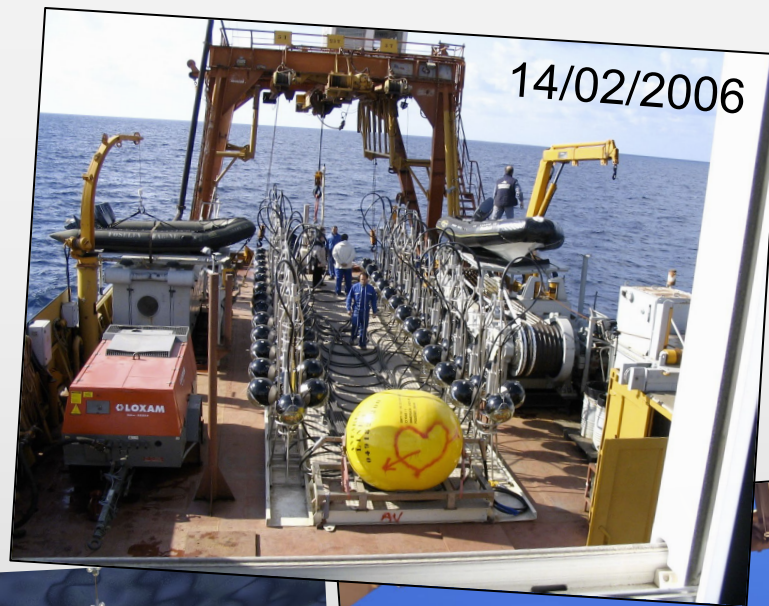
## Status of the KM3NeT neutrino telescope project + ANTARES

Aart Heijboer  
Nikhef, Amsterdam  
On behalf of the KM3NeT Collaboration



# ANTARES

- First Under-Sea neutrino telescope
- Precursor to KM3NeT
- Decommissioned 3 weeks ago after 14 years of operation.
- Competitive results
  - Northern hemisphere
  - Galactic plane
  - Dark matter

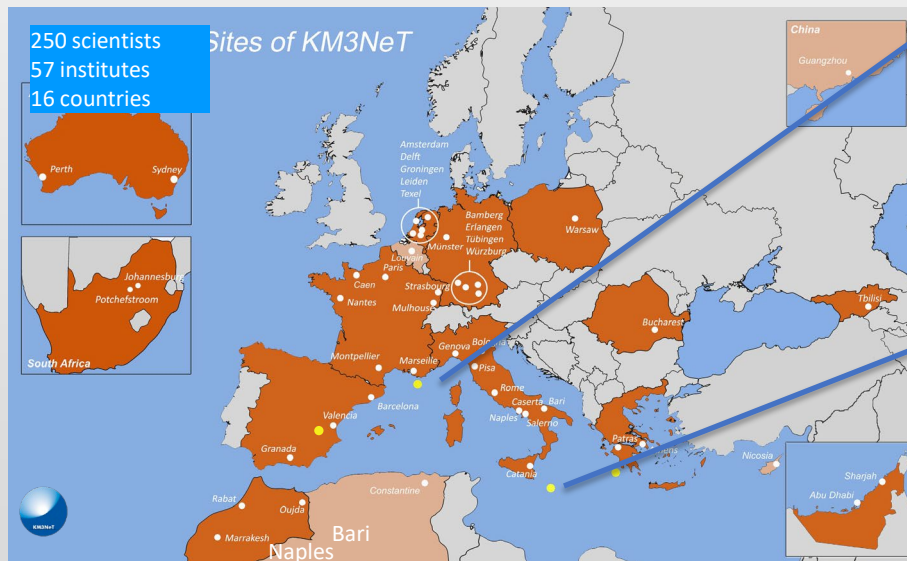
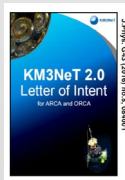




# KM3NeT



- Multi-site, deep-sea neutrino telescope
- Selected by ESFRI roadmap
- Single collaboration, Single technology



[KM3NeT 2.0: Letter of Intent](#)

J. Phys. G: Nucl. Part. Phys. 43 (2016) 084001

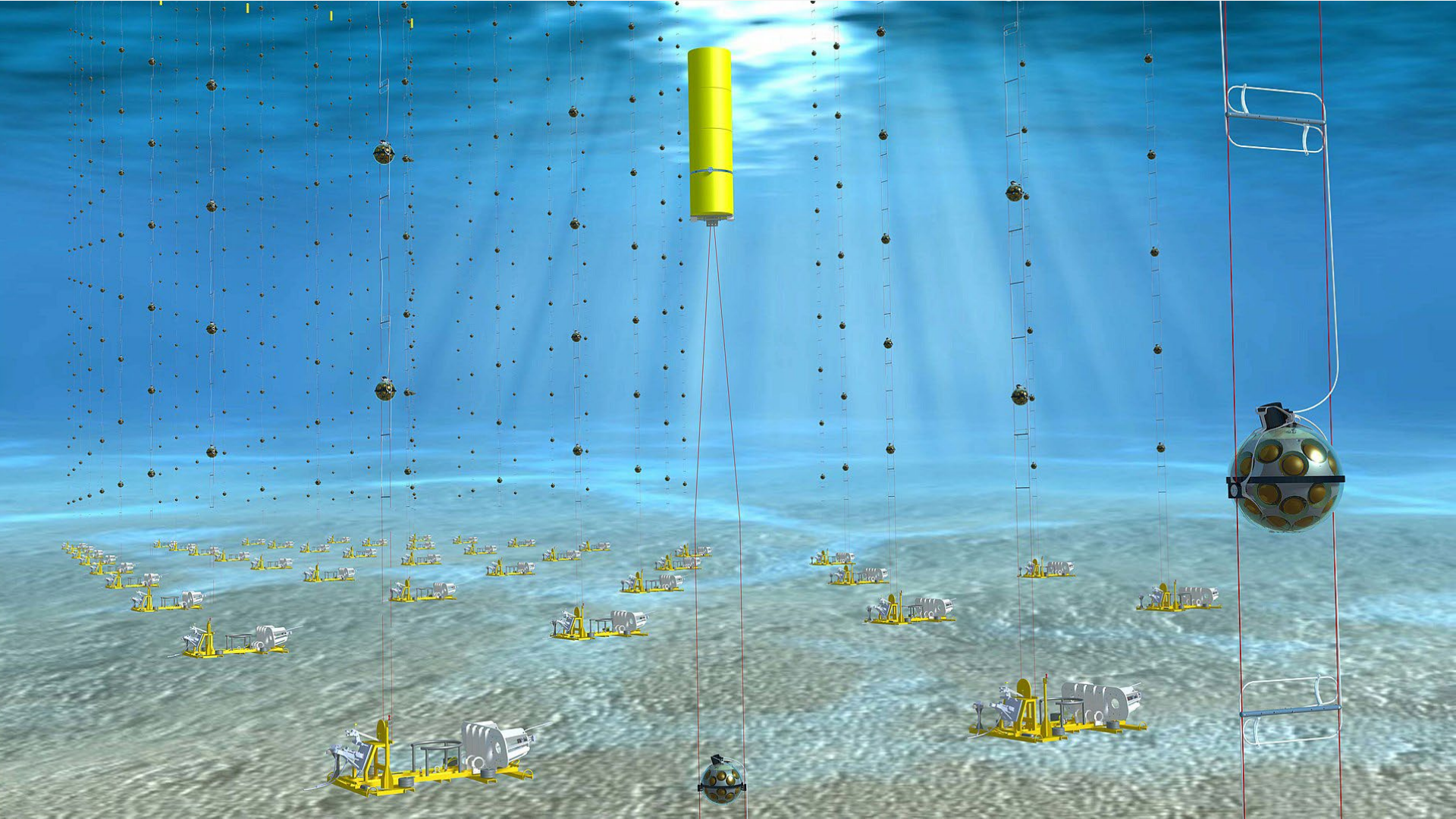


**Oscillation Research  
with Cosmics In the Abyss**



**Astroparticle Research  
with Cosmics In the Abyss**







# Introduction: Technology



Digital Optical Module (DOM)

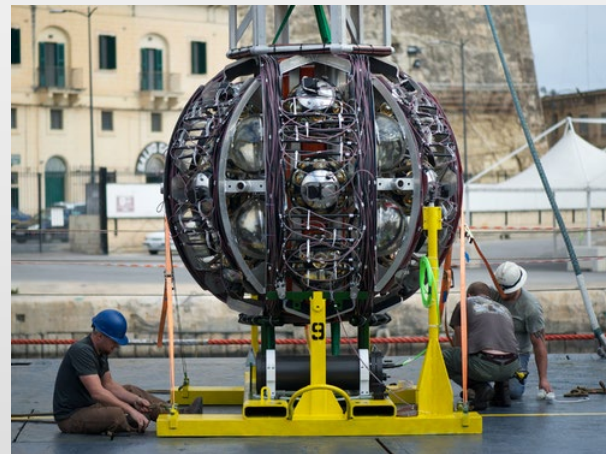
- Multi-PMT : 31 x 3" PMTs
- Gbit/s on optical fiber
- Positioning & timing



Detection Unit (DU)

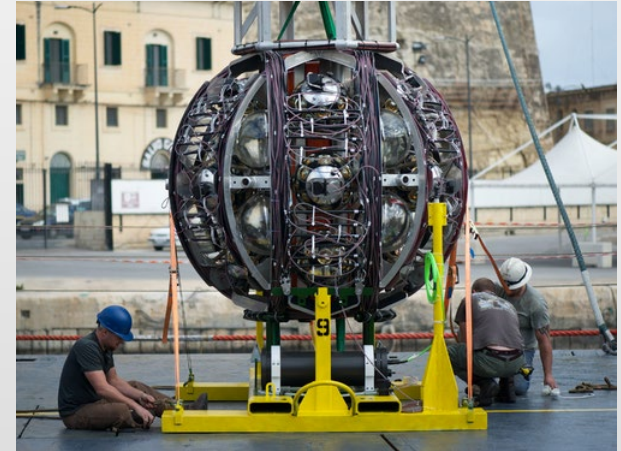
- 18 DOMs
- Low-drag design

Deployment Vehicle



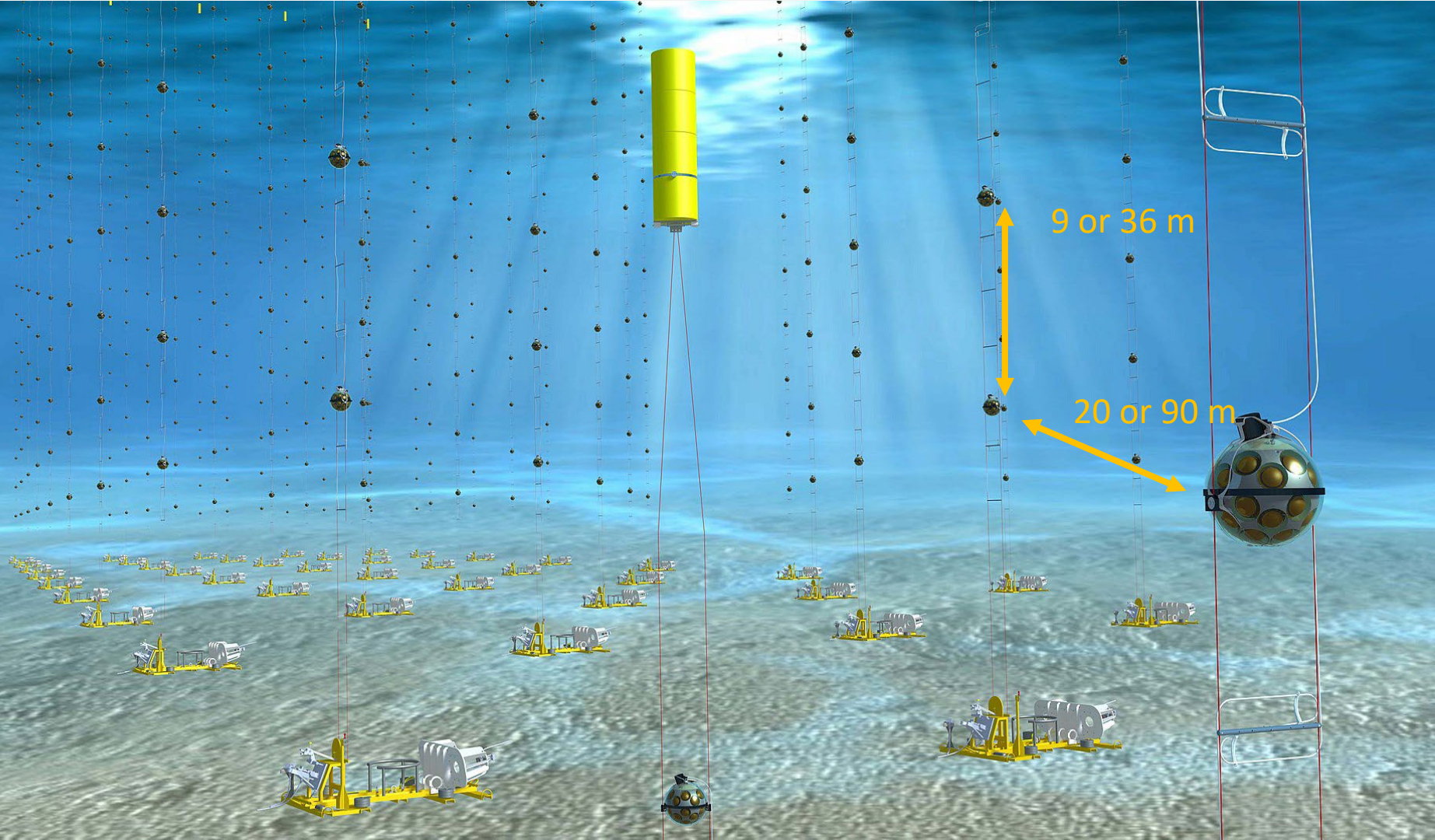
- Rapid deployment
- Multiple DUs per sea campaign
- Autonomous/ROV unfurling
- Reusable

# Introduction: Technology

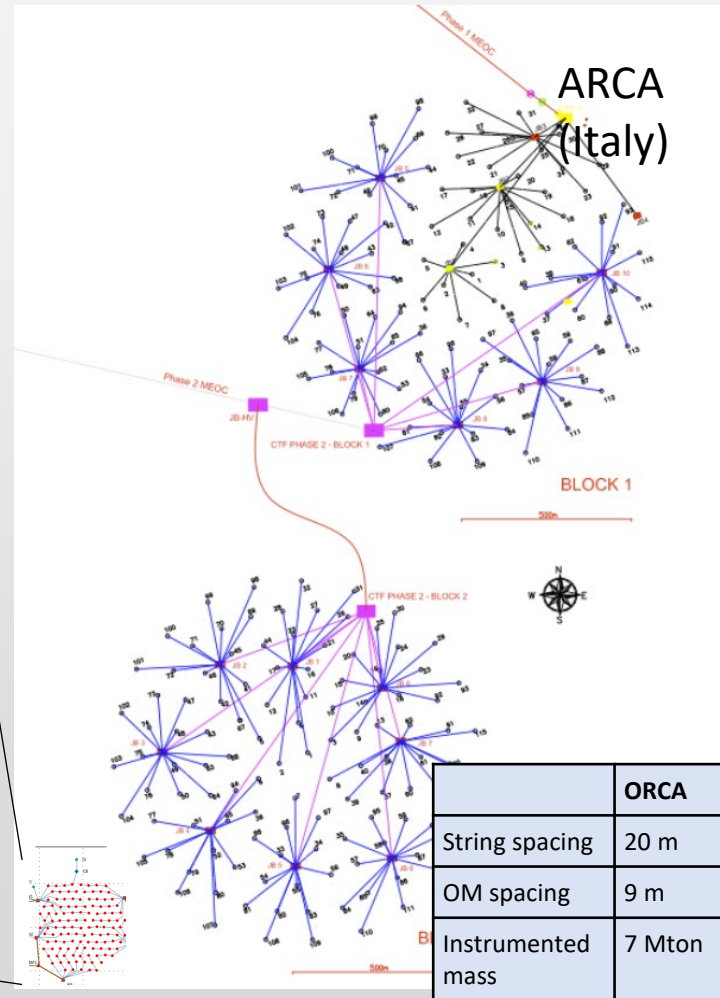
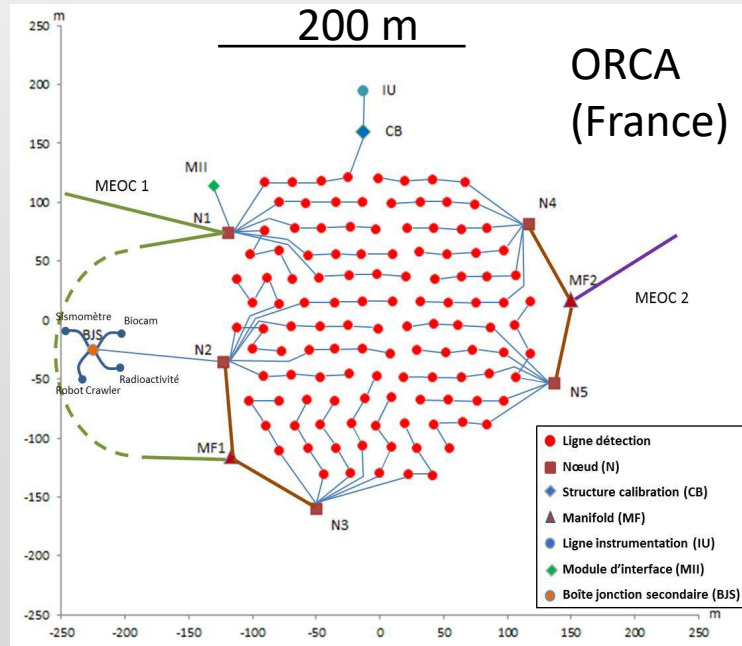


- Rapid deployment
- Multiple strings/sea campaign
- Autonomous/ROV unfurling
- Reusable





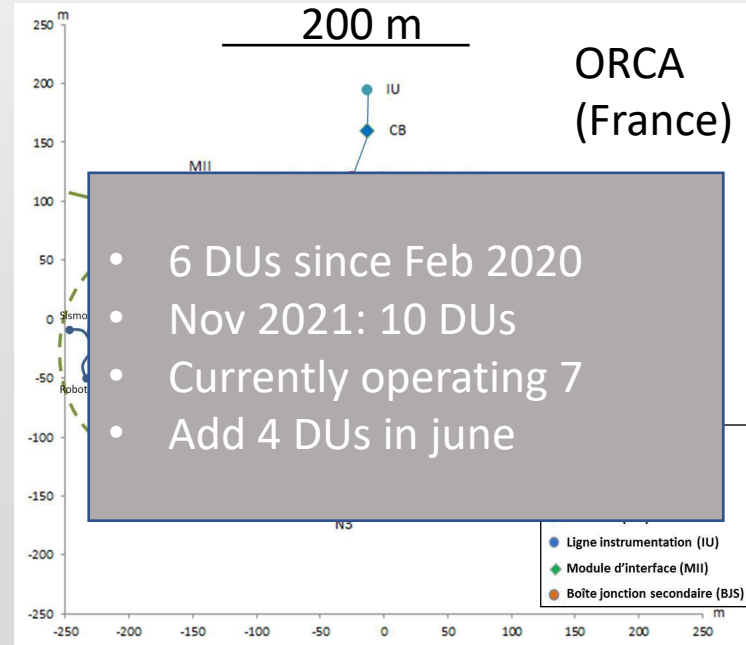
# Building blocks



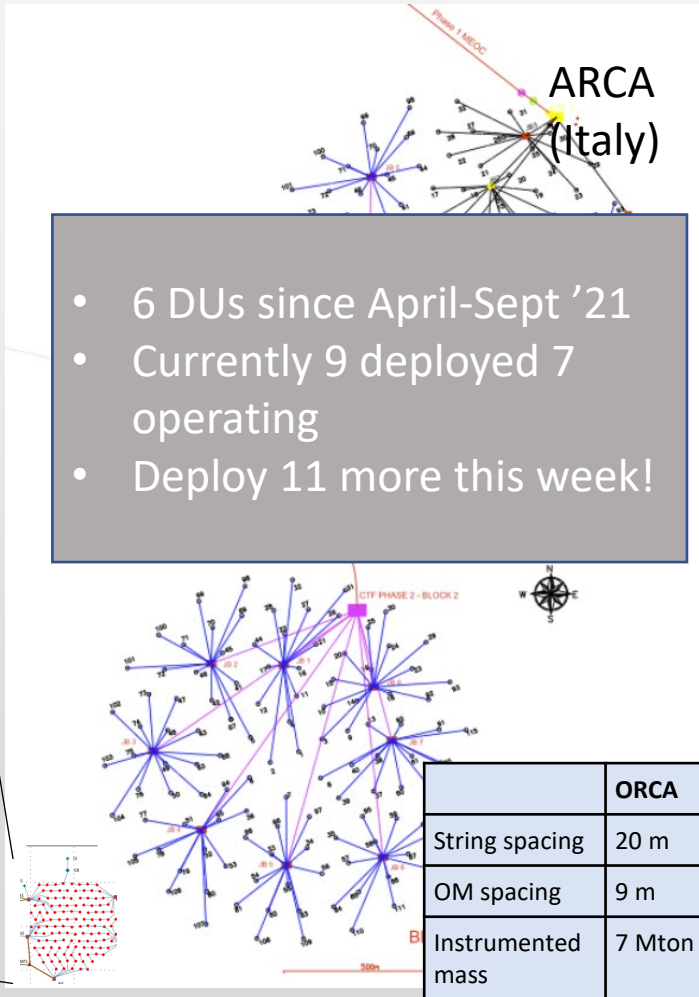
|                   | ORCA   | ARCA       |
|-------------------|--------|------------|
| String spacing    | 20 m   | 90 m       |
| OM spacing        | 9 m    | 36 m       |
| Instrumented mass | 7 Mton | 500*2 Mton |



# Building blocks



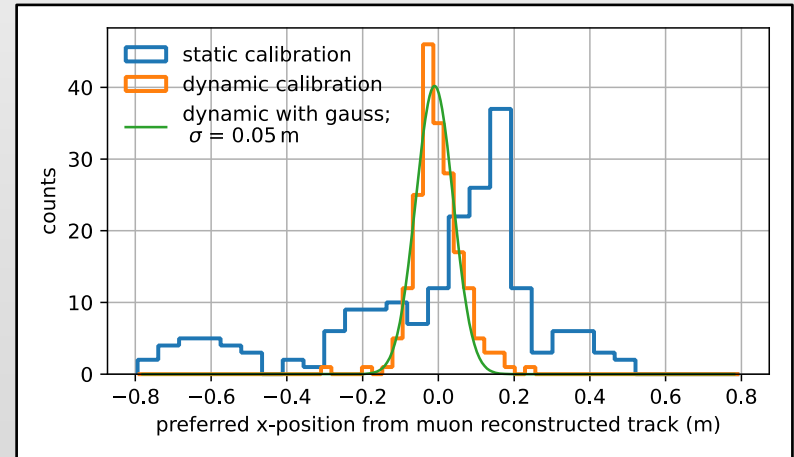
- 6 DUs since April-Sept '21
- Currently 9 deployed 7 operating
- Deploy 11 more this week!



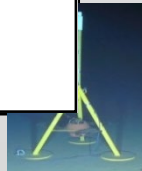
|                   | ORCA   | ARCA       |
|-------------------|--------|------------|
| String spacing    | 20 m   | 90 m       |
| OM spacing        | 9 m    | 36 m       |
| Instrumented mass | 7 Mton | 500*2 Mton |

# Calibration / alignment

- Acoustic system for dynamic alignment
- Precision  $O(10\text{ cm})$
- Checked with muons



Acoustic beacon

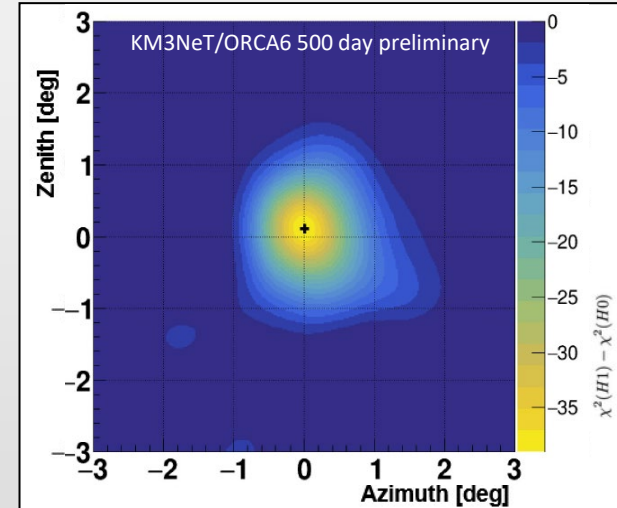
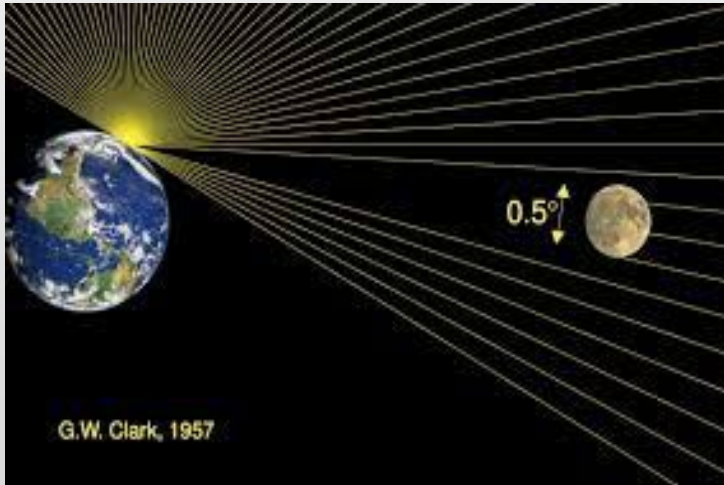




# Checking resolution / alignment

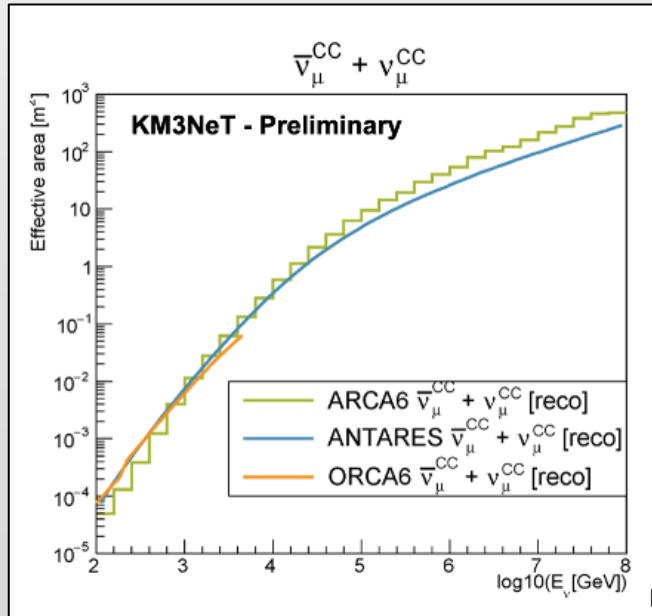


- No standard candle source
- Cosmic rays to the rescue



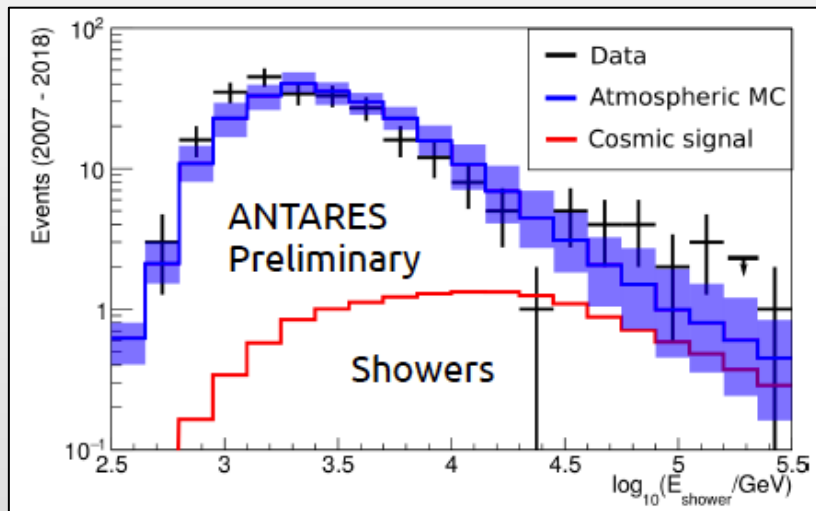
|              | Sun                         | Moon                        |
|--------------|-----------------------------|-----------------------------|
| Significance | 6.0 $\sigma$                | 2.4 $\sigma$                |
| Amplitude    | $1.42 \pm 0.38$             | $0.70 \pm 0.29$             |
| Resolution   | $0.68^\circ \pm 0.12^\circ$ | $0.54^\circ \pm 0.16^\circ$ |

# Neutrino Astronomy (ARCA + ORCA)



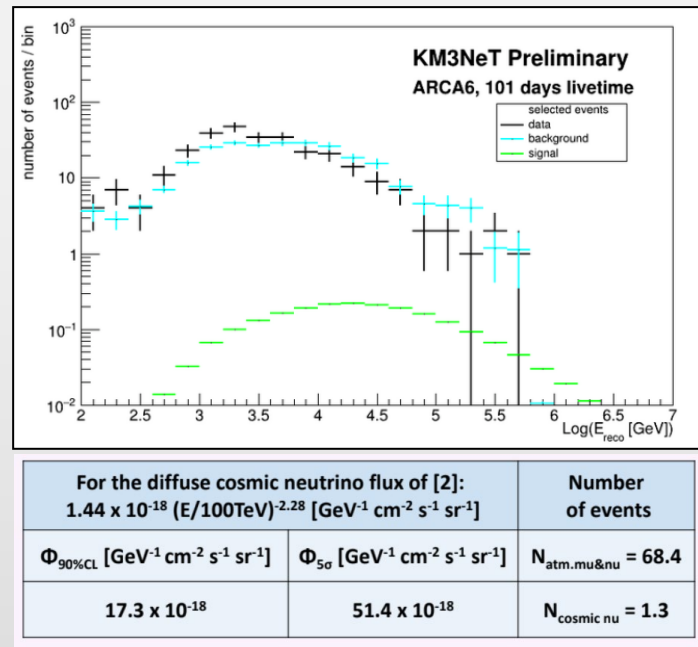
- KM3NeT today ~same acceptance as ANTARES
- ANTARES has factor 40 more live time at the moment

# Cosmic neutrinos



Antares data fully compatible with cosmic flux

- Data: 50 events (27 tracks + 23 showers)
- Background :  $36.1 \pm 8.7$



ARCA 6, 101 days

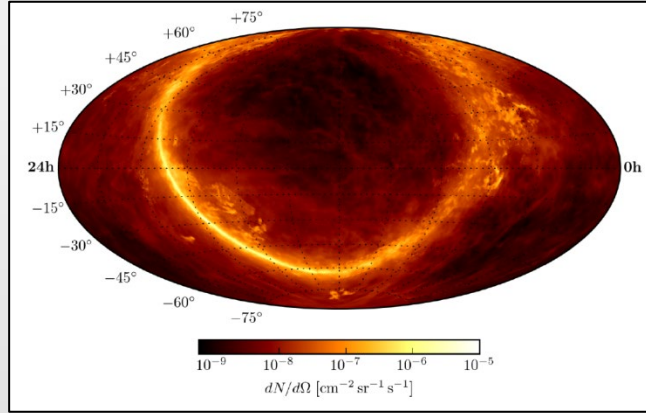
- Sample dominated by muon,
- No high-E excess due to neutrinos
- Results compatible with background



P0173

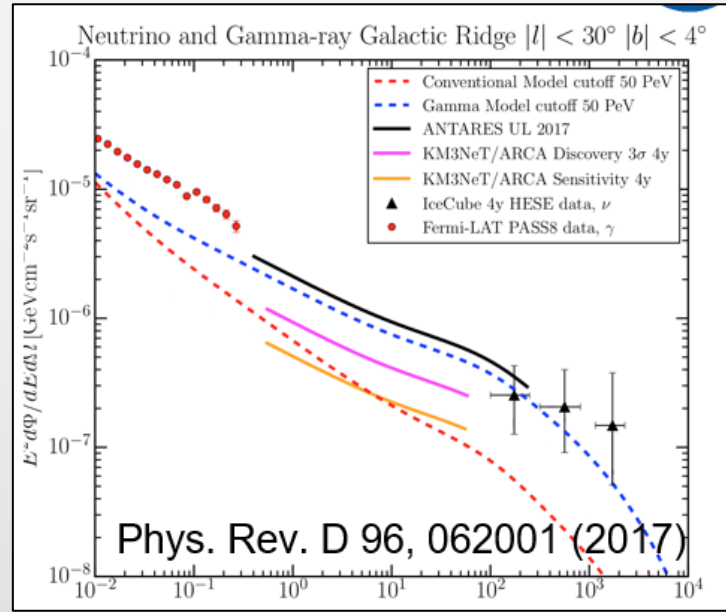


# Galactic ridge



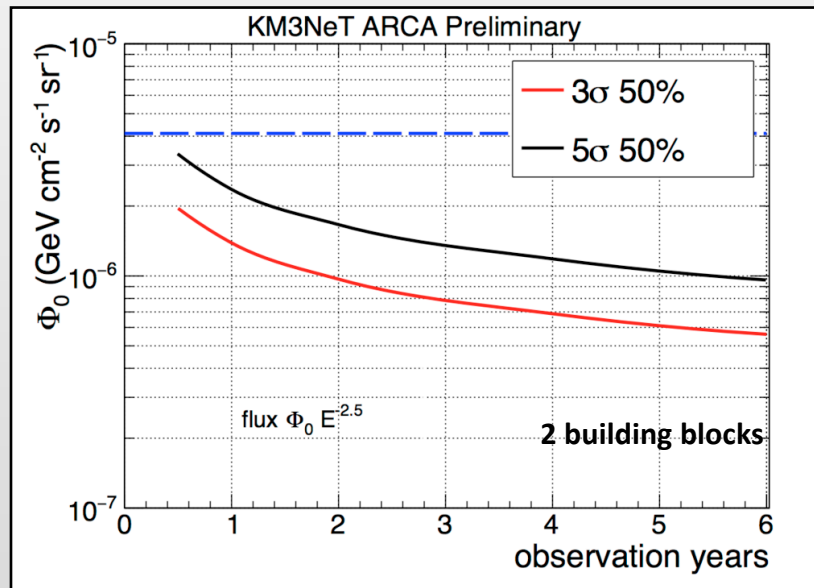
## 100 days ARCA6

|                                                                                                                                    |                       |
|------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Simulated signal flux<br>$1.2 \times 10^{-8} (E/1\text{GeV})^{-2.4} [\text{GeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$ |                       |
| MC simulated signal in ON region                                                                                                   | $1.81 \times 10^{-4}$ |
| Background events:<br>mean over 9 OFF regions ( sum )                                                                              | 4.3 (39)              |
| ON region events:                                                                                                                  | 8                     |

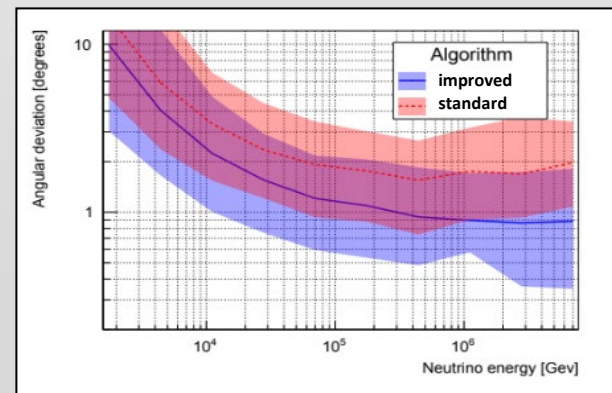
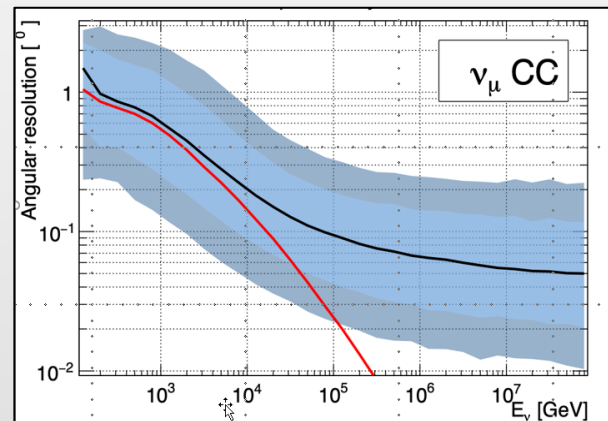


- Unblinded 'pilot analysis', 100 days ARCA 6  
-> no signal as expected
- ANTARES has very competitive limits (~IceCube) and is close to unblinding new analysis (Poster P0531)
- Guaranteed signal for full ARCA detector

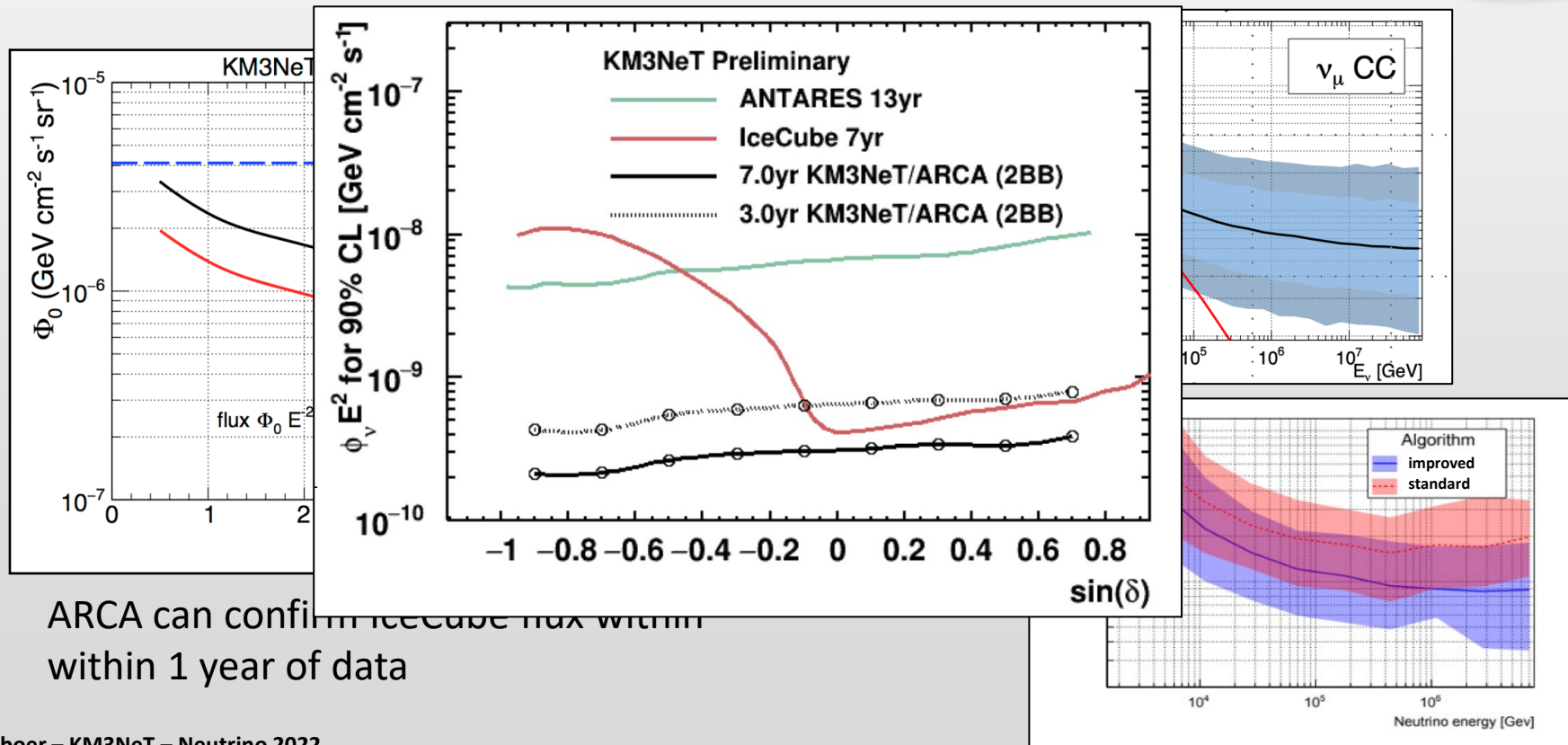
# Cosmic neutrinos



ARCA can confirm IceCube flux within  
within 1 year of data

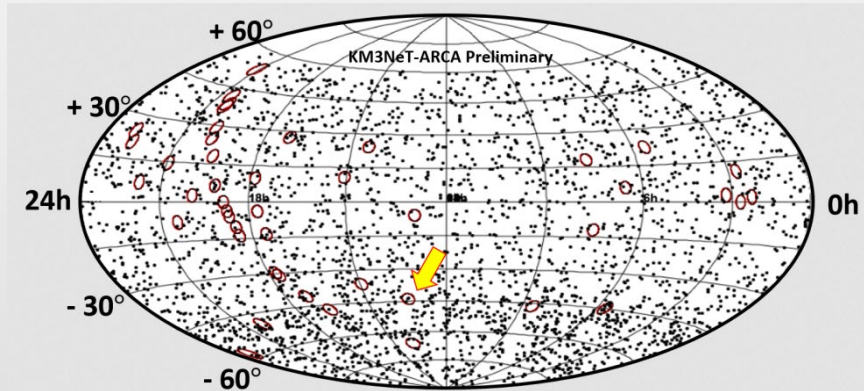


# Cosmic neutrinos

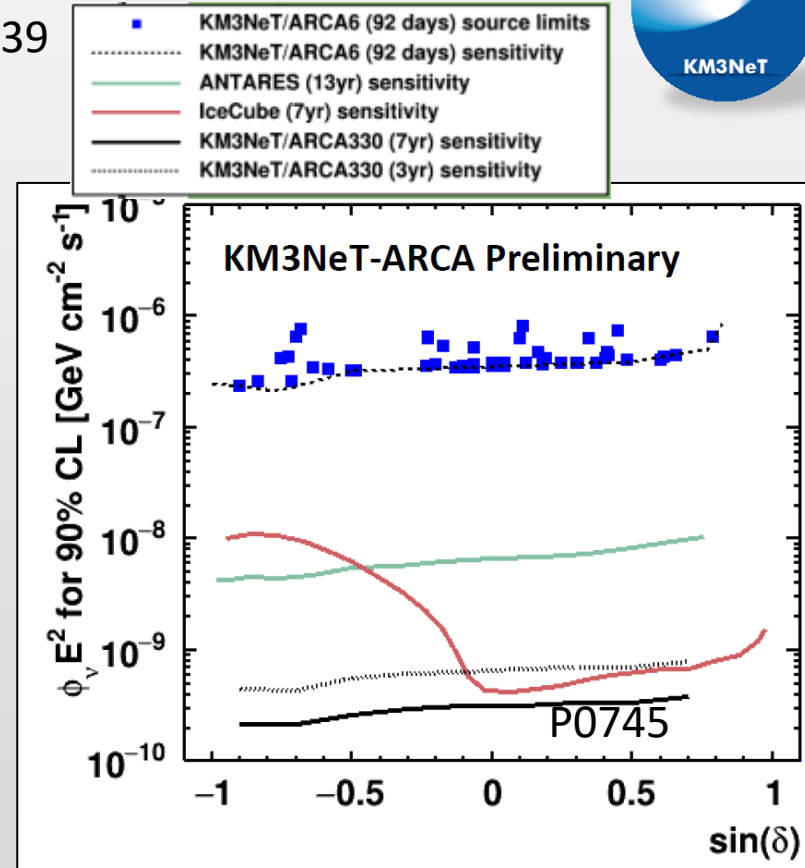




# ARCA 6, 100 days P0639

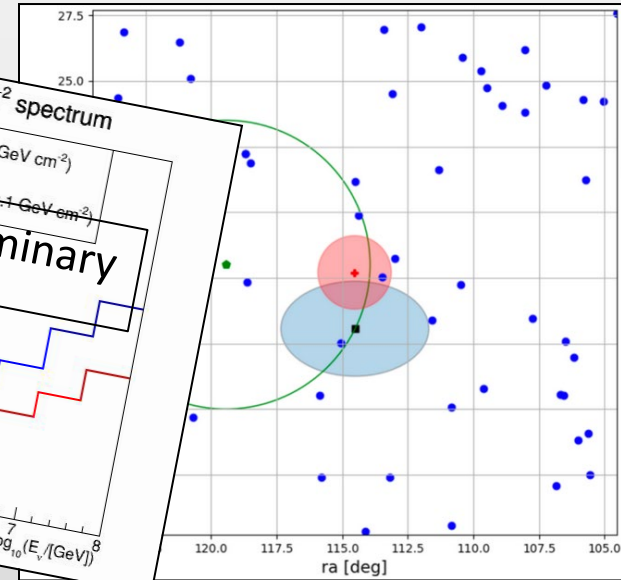
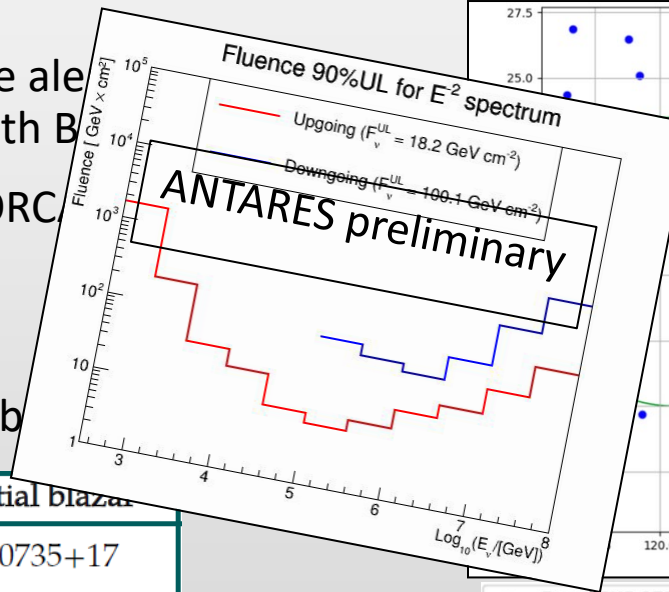


- Time integrated point source search  
May-Sept 2021, dynamic calibration
- Background dominated by muons
- Resolution  $\sim 1.3$  degree for  $E^{-2}$
- No significant excess observed
- Limits not yet competitive, as expected



# Time-dependent astronomy

- Several recent IceCube alerts possibly associated with BLAZARS
- Follow up with both ORCA and ANTARES
- No discoveries
- First KM3NeT ATEL published



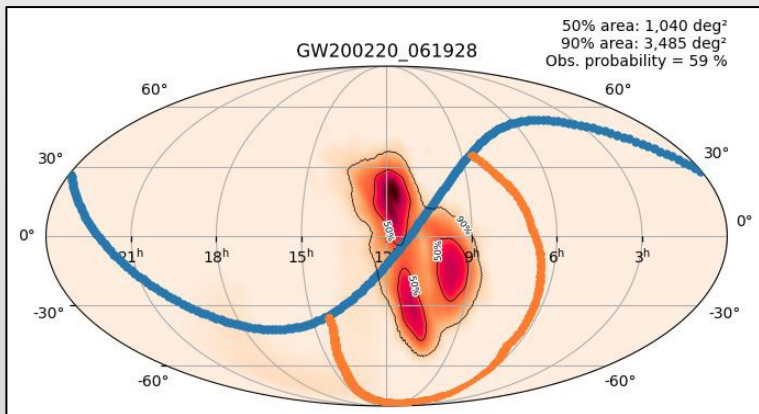
- Fermi PKS 0735+17 position
- IceCube-211208A alert, 90% containment
- Baikal shower event, 50% containment
- 1.4° cone, ON Zone
- KM3NeT/Arca data
- Atm muon contamination 99%
- Median  $E^{-2}$  cosmic neutrino angular resolution = 1.7°

P0739  
P0536

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

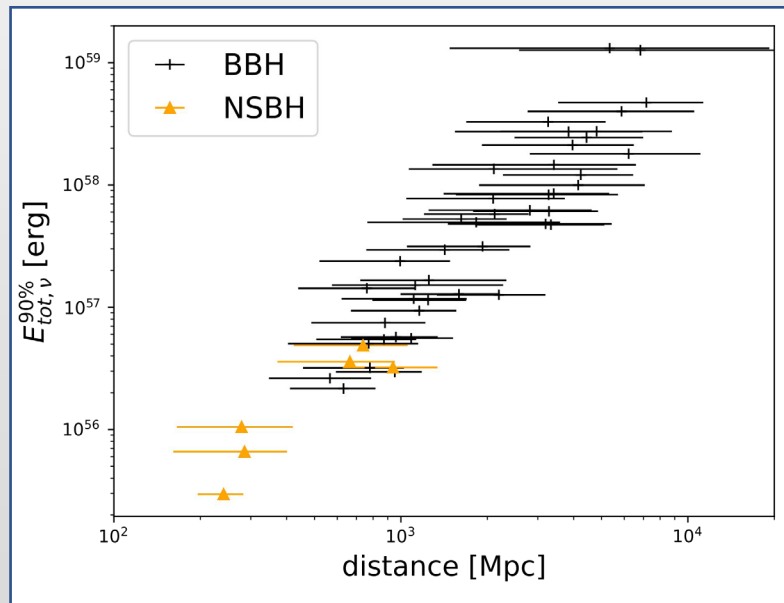
# Time-dependent astronomy

- Follow-up of Gravitational Wave events (03) with ORCA
- Limits on neutrino flux of 55 GW events in MeV and GeV-TeV ranges.



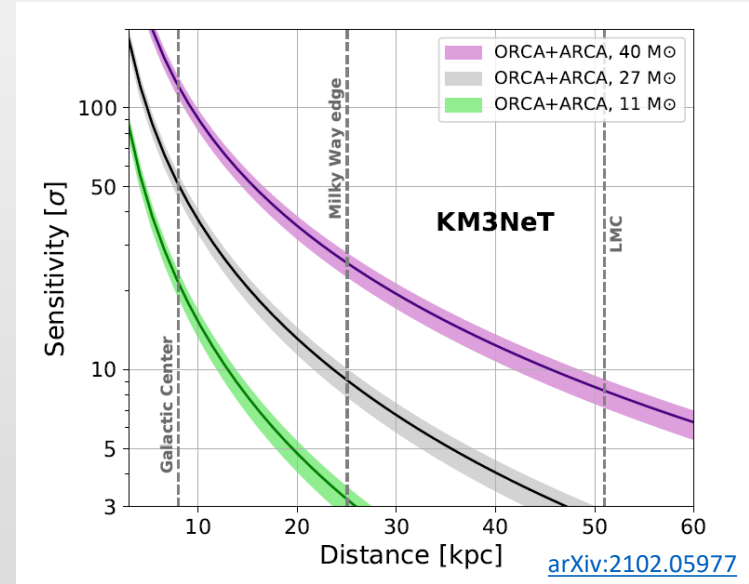
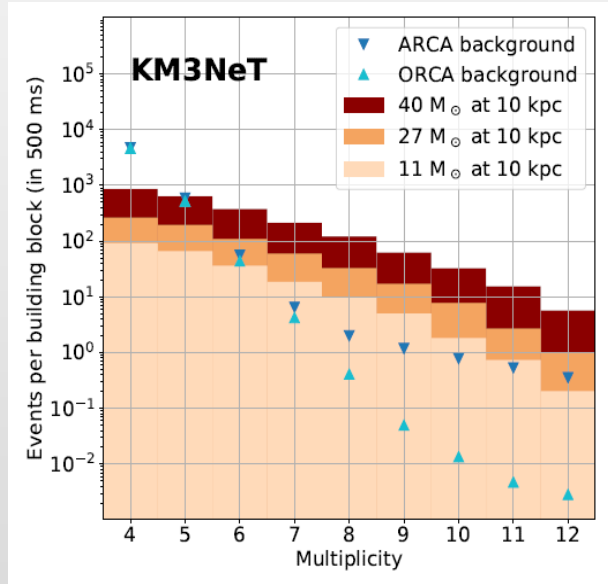
Search for 1000s in 30 degree area around the GW confidence region.

## GeV-TeV neutrinos





# (MeV) Supernova neutrinos

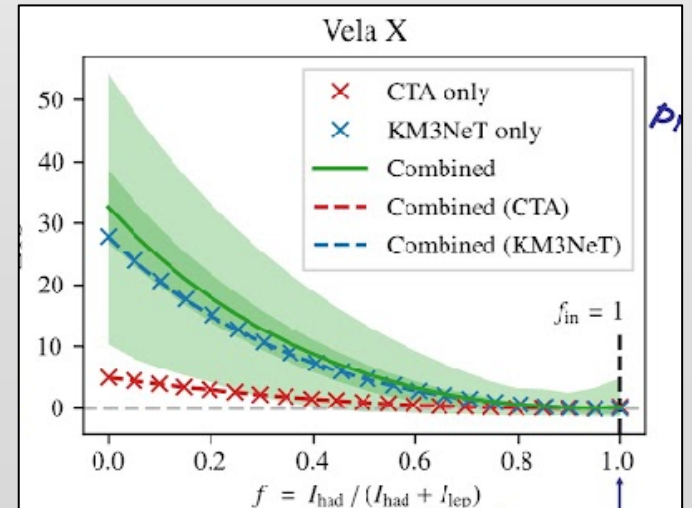
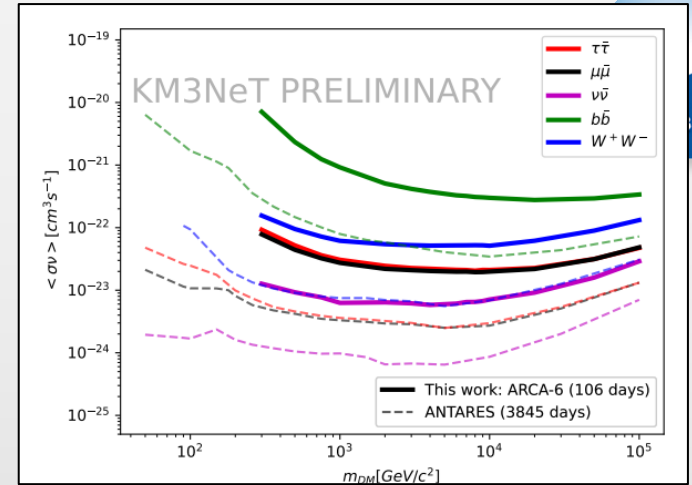


P0574

- Alert system already operational!
- Integrated in SNEWS network
- Currently (ORCA6) would trigger on e.g. 27  $M_{\odot}$  at  $\sim 10$  kpc

# Other topics..

- Starburst Galaxies (P0452)
- Dark matter, sensitivity
- Combination  
KM3NeT/CTA (P0519)
- Cosmic Ray physics
- Monopoles, Nuclearites

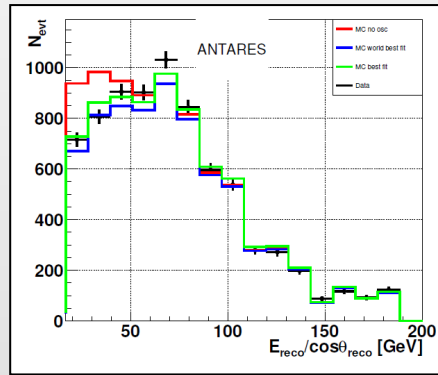
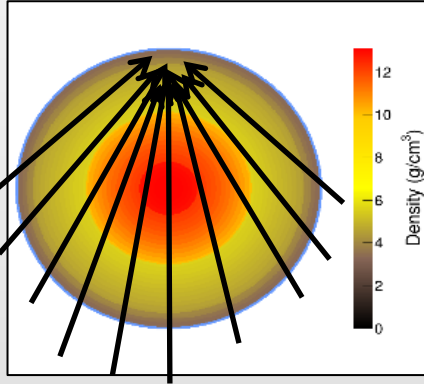




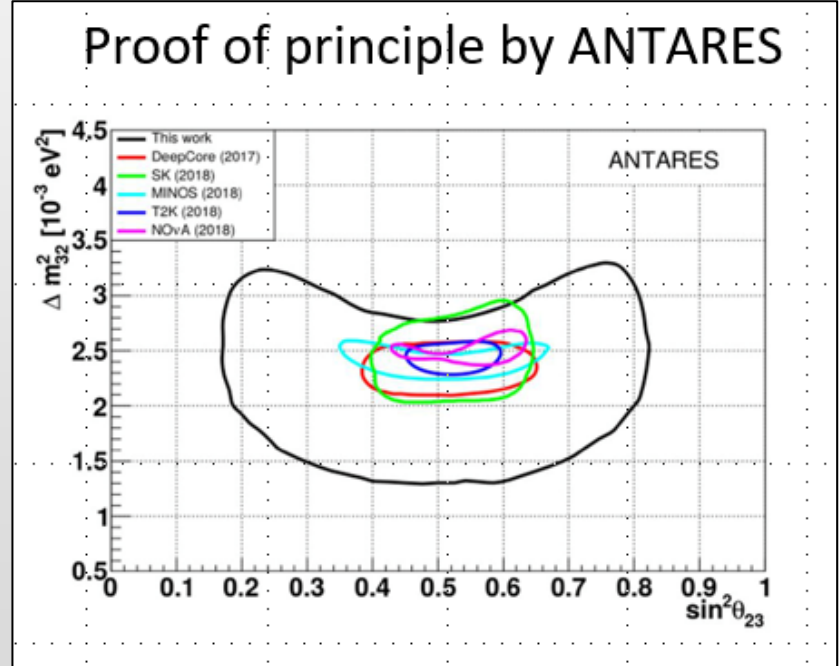
# Neutrino oscillation physics (ORCA)



# Neutrino oscillations



- See oscillations
- Measure atm. mixing parameters
- Neutrino Mass ordering
- New physics (sterile, decay, NSI)



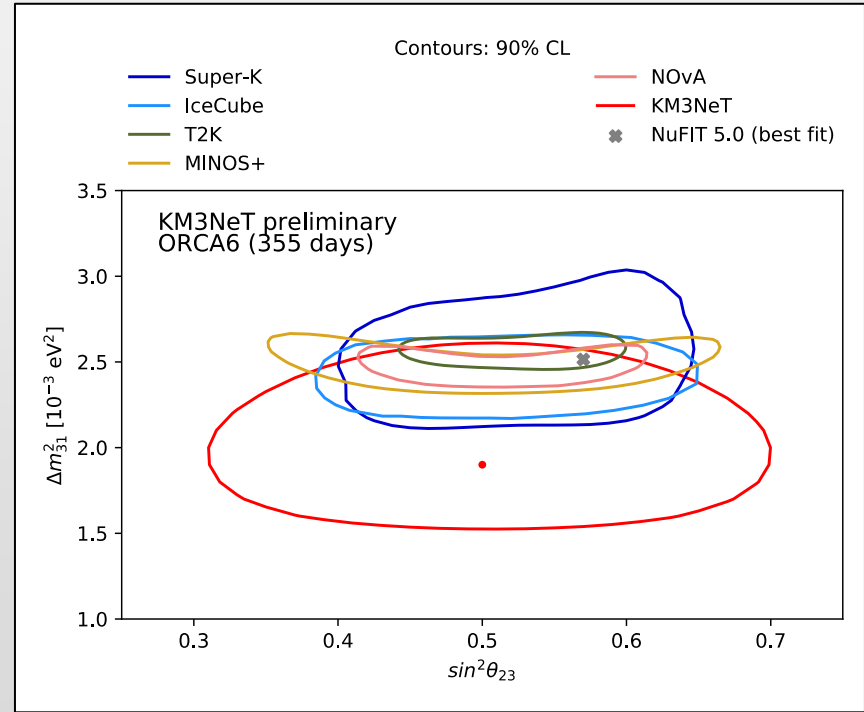
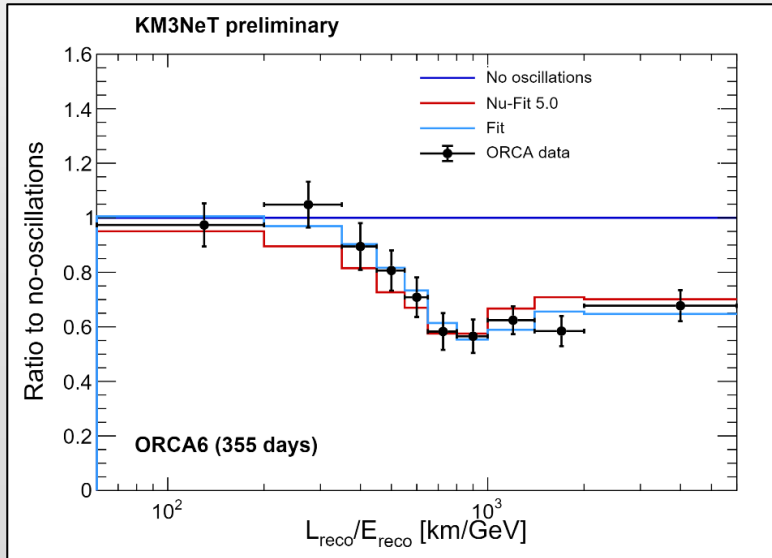
J. High Energ. Phys. (2019) 2019: 113



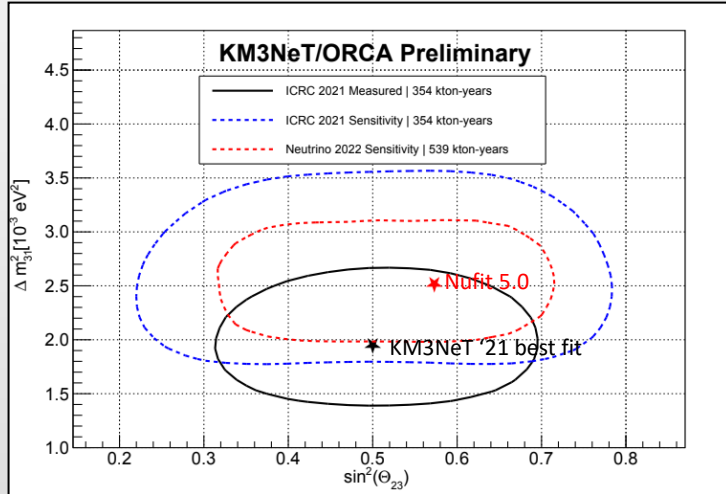
# Neutrino oscillations : ORCA 6



1 year of data with 6 lines of ORCA  
 $\approx 1$  kton-year.

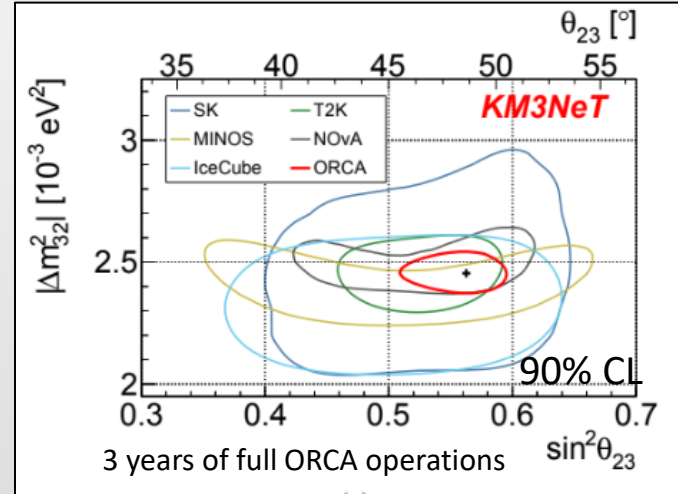


# future improvement



*soon*

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

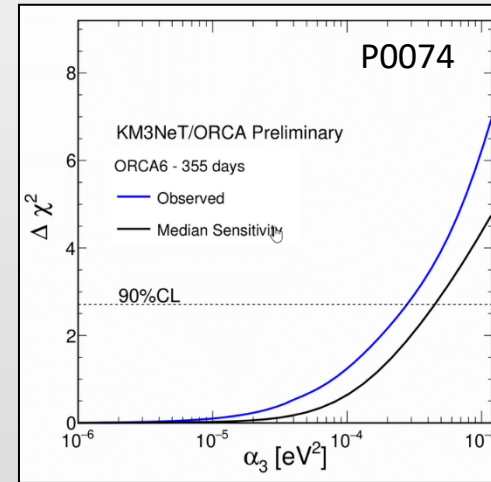
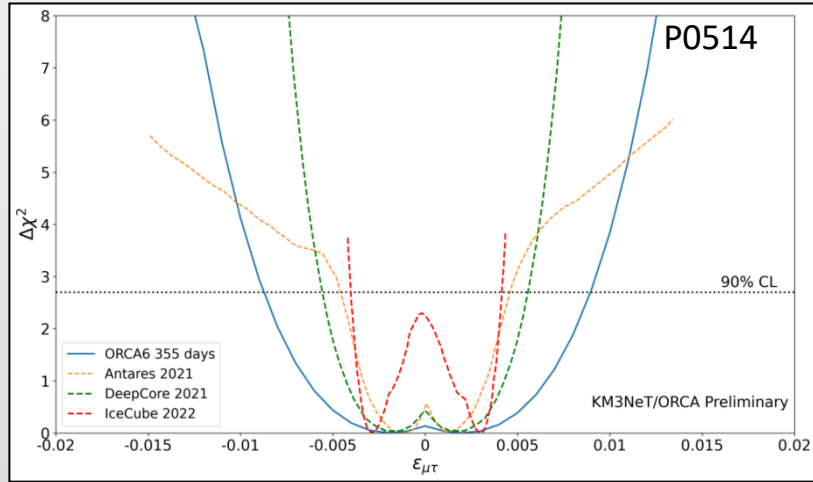


*later*

- Completed ORCA detector will reach unprecedented sensitivity

# First new physics searches

*Same 1 yr ORCA6 data sample : oscillation fits with new physics:*



| Experiment           | L.L.(90%CL) (ps/eV) |
|----------------------|---------------------|
| <b>ORCA6</b>         | <b>2.4</b>          |
| <b>ORCA115 (10y)</b> | <b>180</b>          |
| T2K, NOvA            | 1.5                 |
| T2K, MINOS           | 2.8                 |
| K2K, MINOS, SK I+II  | 290                 |

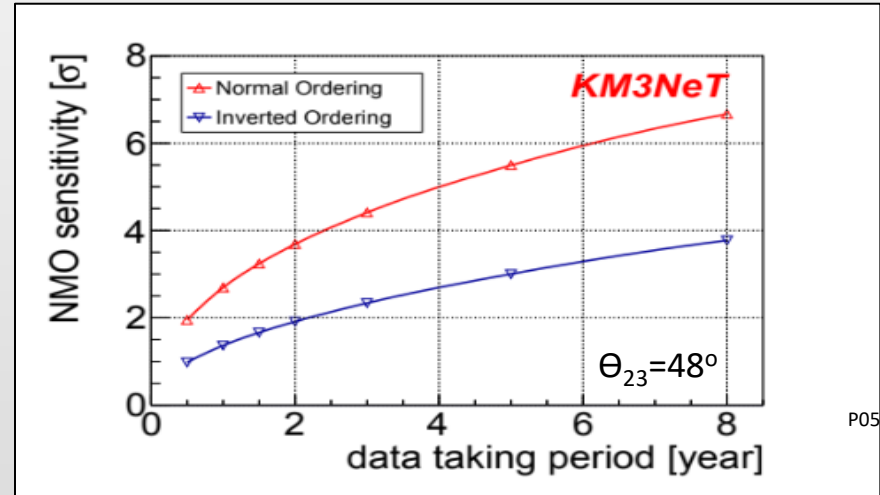
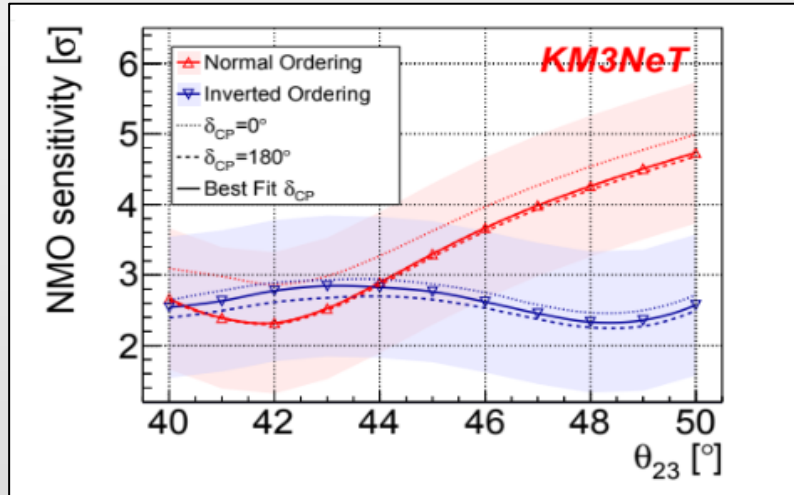
*Constraining non-standard interactions*

- 1 year ORCA6 already starting to become competitive with similar experiments

*Neutrino decay / lifetime*

- Proof of principle
- Full ORCA detector will be world-leading

# NMO sensitivity of full ORCA

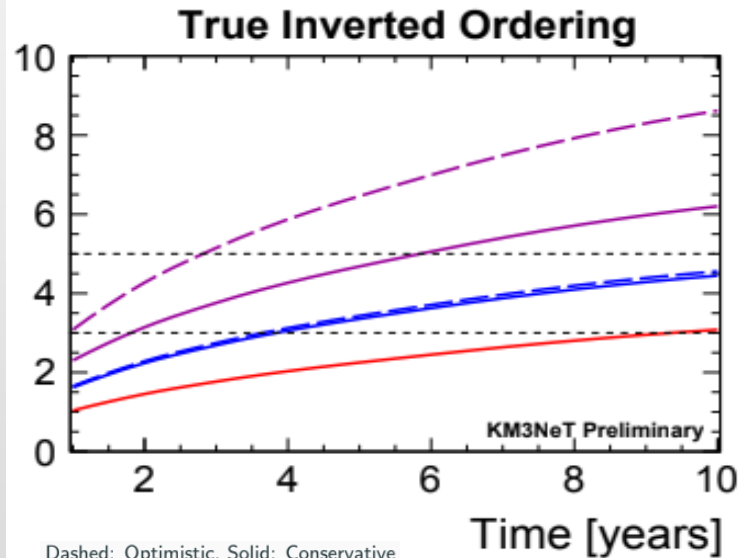


Neutrino mass ordering

P0530



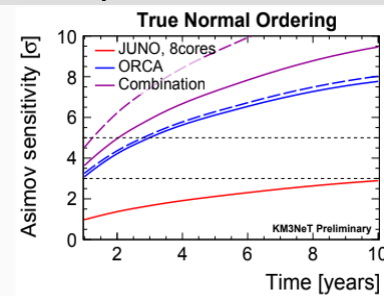
# Mass ordering – combine with Juno



Dashed: Optimistic, Solid: Conservative

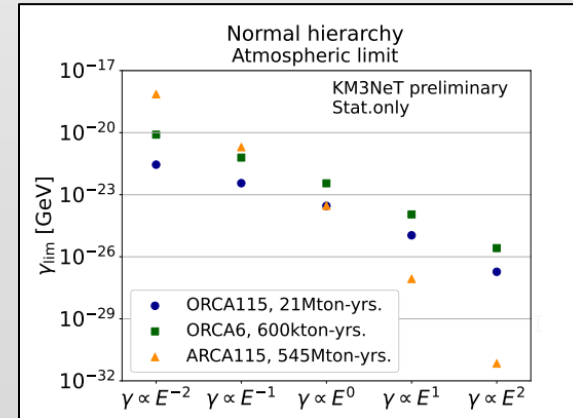
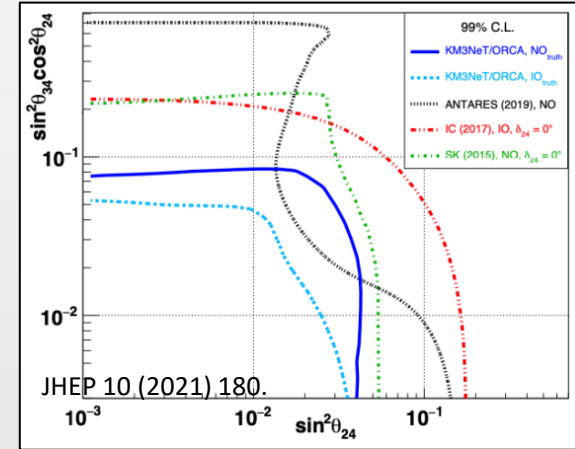
Phys. Rev. D, 101:032006, Feb 2020.

- When fitting both datasets with wrong NMO hypothesis -> disagreement on value of  $\Delta m_{31}$
- Juno offers large boosts of ORCA sensitivity to NMO determination.
- Details of energy-scale systematic important



# Other capabilities

- Sterile neutrinos (P0609)
- Neutrino Decoherence (P0297)
- Dark Matter (P0549)
- Graph neural networks (P0503)
- Particle Identification (P0287)

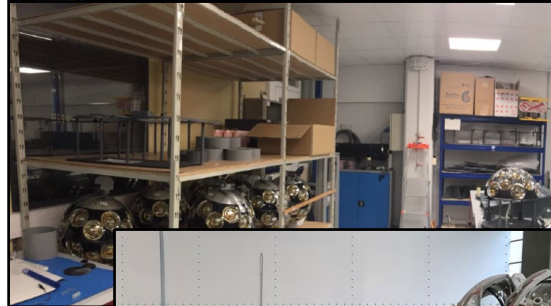


# *Production ongoing*

Amsterdam



Nantes

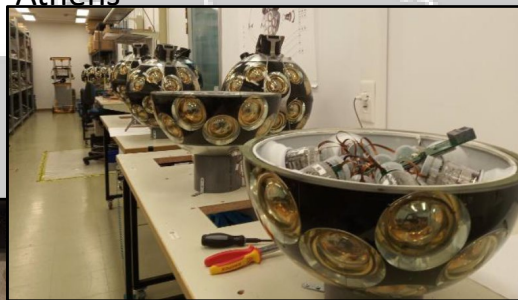


Erlangen



Bologna

Athens



Genova



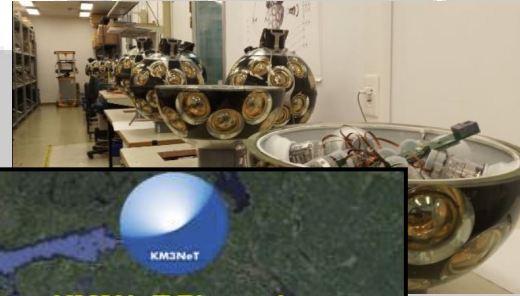
Catania





# Production ongoing

Athens

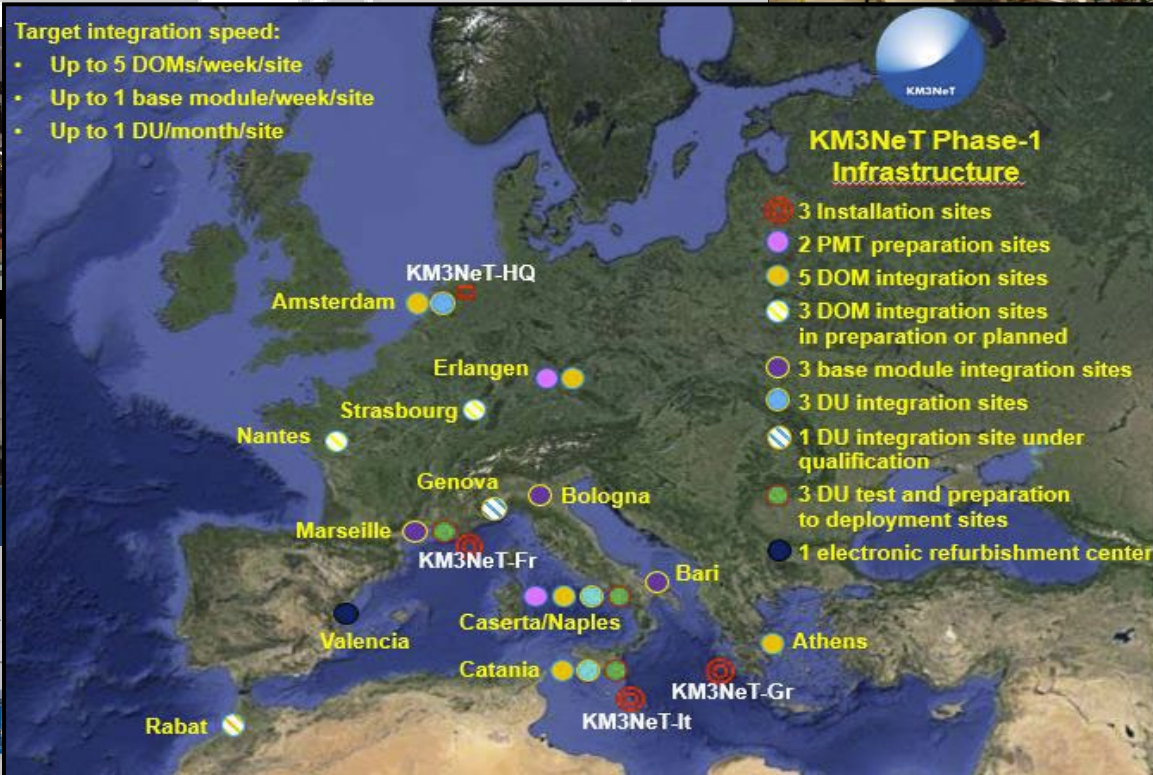


Amsterdam



## Target integration speed:

- Up to 5 DOMs/week/site
- Up to 1 base module/week/site
- Up to 1 DU/month/site



Genova



Nantes



Catania

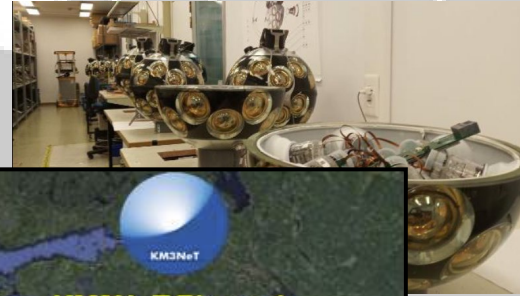


Bologna



# Production ongoing

Athens

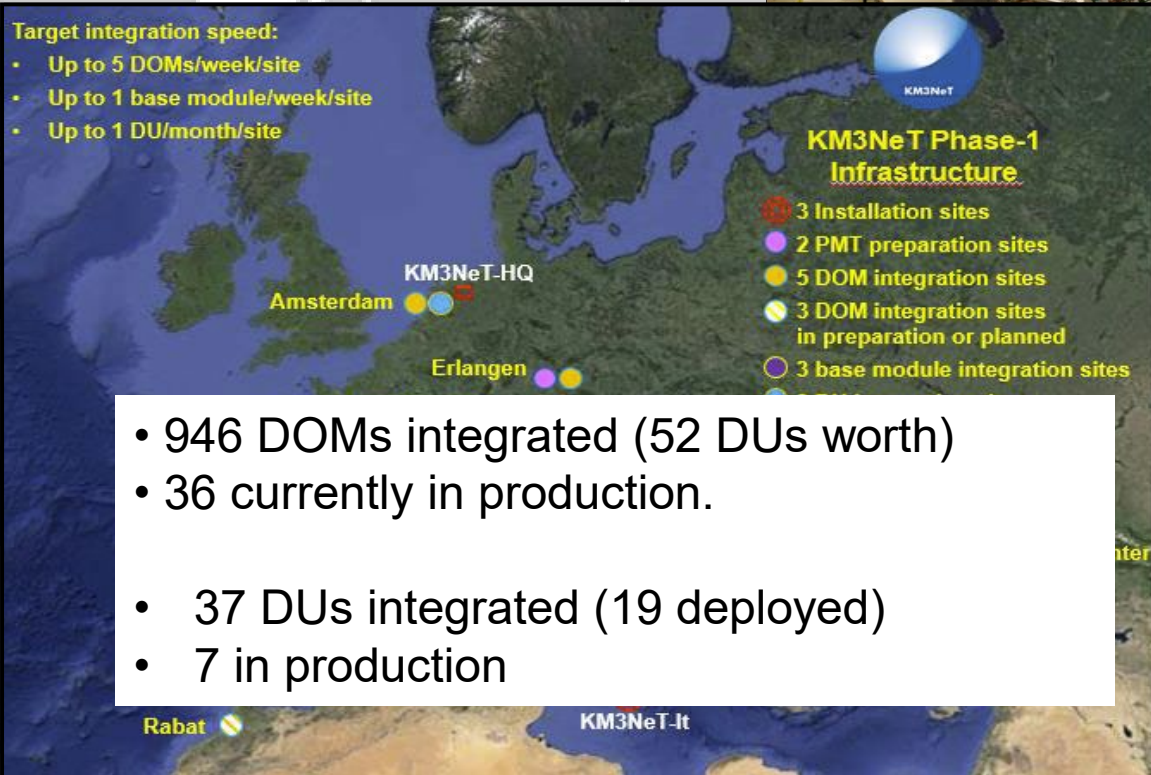


Amsterdam



## Target integration speed:

- Up to 5 DOMs/week/site
- Up to 1 base module/week/site
- Up to 1 DU/month/site



Genova



Nantes



Catania



Bologna





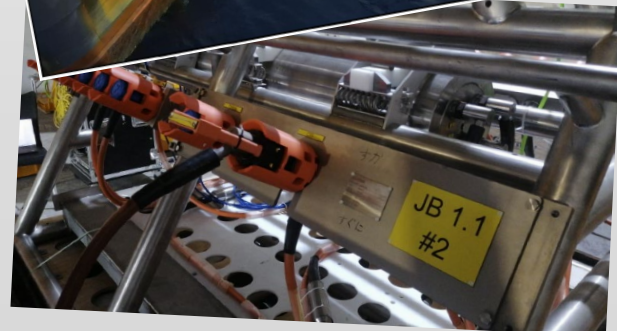
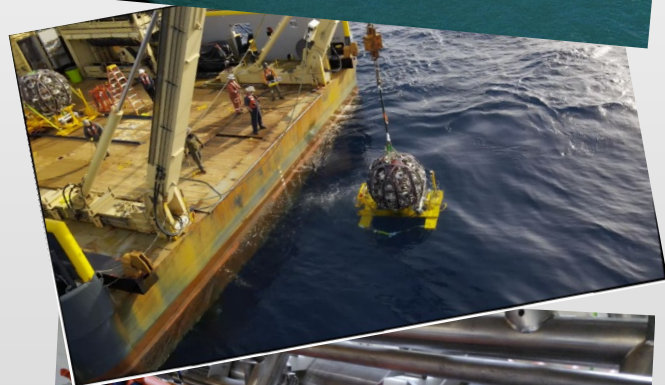
# Next milestones...



Detection Units in staging area @ Malta

- 8 More DUs to be deployed this year in ORCA.
- Deploying 11 DUs + 2 Junction boxes ~now in ARCA.

Latest news [insert here]



# Conclusions

- 14 years of ANTARES has come to an end
- KM3NeT taking over
- First analyses; construction ramping up.
- Spanning 8 decades in energy: oscillations & astronomy
- First oscillation results of ORCA, good prospects for NM0
- Rich variety of (pilot) Astronomy analyses
- Pointing resolution for all flavours

