#### RICAP-22, 6-9 September 2022

Depth:

3451.00m





HDG:

42.86°



Simone Biagi on behalf of the KM3NeT Collaboration INFN — LNS



## The physics case



Neutrino Energy from MeV to PeV

# The neutrino telescopes of KM3NeT

#### **ARCA: Astroparticle Research with Cosmics in the Abyss**

- 2 Building Blocks
- 115 Detection Units each, interspacing ~90 m
- 18 Digital Optical Modules (DOM) per DU, inter-DOM spacing 36 m
- Total active volume 1 km<sup>3</sup>, ≈ 500 Mton/blo
- 3500 m depth, SE the Sicilian coasts
- 2 Main Electro-Ontical Cables (MEOC) for e of a network of 9+8 inter-link cables





# The neutrino telescopes of KM3NeT

**ORCA: Oscillation Research with Cosmics in the Abyss** 



- 1 Building Block
- 115 Detection Units (DU), interspacing ~20 m
- 18 Digital Optical Modules (DOM) per DU, inter-DOM spacing 9 m
- Active volume  $\approx$  7 Mton



## **Neutrino event topologies**



Tracks

Showers

## The KM3NeT collaboration

#### 55 institutes in 16 countries 4 continents – 2 detectors



September 8th, h 09:30: A. Margiotta, The ANTARES neutrino telescope

#### Neutrino Astrophysics in the Mediterranean Sea



- Origin of Cosmic Rays
- Neutral messengers point back to their sources
  - Neutrons are short-lived, photons are likely to interact ⇒ Neutrinos as cosmic probe
- Neutrinos are produced at sources via hadronic interactions
  - Cosmic diffuse flux
  - Point-like sources
  - Multi-messenger approach

- Detection principle: large volume of transparent medium instrumented with PMTs
- Located in the Northern Hemisphere
  - Complementary to IceCube
  - Southern sky sources, "Milky-Way optimised"
- Medium: Deep Sea Water
  - Very small light scattering = good angular resolution
  - Natural background (<sup>40</sup>K and bioluminescence) taken into account.

Mkn 501 RX 11713 7-39 Crab SS433 GX339-4 Vela Galactic Centre

## **KM3NeT Technology in a nutshell**

#### **Digital Optical Module**



- DOM: 31 x 3" PMTs
- Digital photon counting
- Directional information
- Wide acceptance angle
- All data to shore
- Gbit/s on optical fiber
- Custom White Rabbit
- 18 DOMs / String

Detection Unit (string)





DOM: JINST 17 (2022) P07038 Unfurl: JINST 15 (2020) P11027

- Unfurling by autonomous ROV
- Rapid deployment
- Multiple strings in one sea campaign



- September 8th, h 16:18: A. Simonelli, New measurements on an improved 3" Hamamatsu photomultiplier
- September 8th, h 16:36: I.C. Rea, The multi-PMT optical module of KM3NeT

~200 m ORCA

ARCA

Ε

200



**Phase-1 completion = 32 Detection Units** 

## Selected triggered events

z-t-Plot for DetID-116 Run 12555, FrameIndex 29183, TriggerCounter 679, Overlays 729, Trigger: MX 3DM 3DS 2022-07-06 06:48:38 UTC

![](_page_9_Figure_3.jpeg)

- September 8th, h 16:54: T. Chiarusi, The KM3NeT data acquisition system Status and evolution
- September 8th, h 17:12: C. Bozza, Scalable solutions for the Control Unit of the KM3NeT DAQ system

## **Selection of atmospheric neutrinos**

![](_page_10_Figure_1.jpeg)

ARCA6

### **KM3NeT Effective Areas ARCA6 + ORCA6 compared to ANTARES**

![](_page_11_Figure_2.jpeg)

ARCA2

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

## Atmospheric muon flux ARCA2 + ORCA1

![](_page_12_Figure_2.jpeg)

- Single-DOM measurement
- Useful to validate the calibration process
- Results compared with ANTARES and Bugaev model

![](_page_12_Figure_6.jpeg)

### Point source search

![](_page_13_Figure_2.jpeg)

14

### Dark matter search

Search for an excess flux of neutrinos from the Sun or enter, from DM decay, or DM-DM annihilation.

![](_page_14_Figure_3.jpeg)

- First results with ARCA6, no excess observed.
- Limited exposure, more data will improve the sensitivity.
- Other results: secluded dark matter; analysis of power spectrum (i.e. anisotropies)

## **Core Collapse Supernovae**

Eur. Phys. J. C81 (2021) 445

![](_page_15_Figure_2.jpeg)

#### **ORCA 1 BB + ARCA 1BB**

 $>5\sigma$  for ARCA+ORCA for  $27 M_{\odot}$ 

at a distance < 25 kpc

ARCA6+ORCA6 already sensitive to 60% of Galactic CCSNe (<11 kpc) Joint real time trigger operational for SNEWS since early 2019

September 7th, h 15:40: M. Bendahman, Neutrinos from core-collapse supernovae at KM3NeT

## **ARCA Reconstruction Performances**

#### Track-like and shower-like events

**Tracks** (v<sub>µ</sub> CC) **ideal tool for astronomy** 

Ang. Resol. < 0.2° above 10 TeV •

Median Angular resolution [<sup>0</sup>]

10-2

 $10^{3}$ 

10<sup>4</sup>

**Energy Resol.** ~ 0.27 in  $log_{10}(E_{reco}/E_{\mu})$ •  $(10 \text{ TeV} < E_{\mu} < 10 \text{ PeV})$ 

**KM3NeT/ARCA** 

10<sup>5</sup>

10<sup>6</sup>

 $(v_{\mu} - true \mu direction)$  angle

 $v_{\mu}$  CC

**Shower** ( $v_x NC + v_e CC$ ) contained events

Ang. Resol. < 2° above 50 TeV

![](_page_16_Figure_7.jpeg)

Energy Resol. < 5%

#### KM3NeT vs IceCube:

Con: <sup>40</sup>K background, bioluminescence, need for real-time positioning, deep-sea operations Pro: <sup>40</sup>K calibration, better view of the galactic center, no bubbles/dust —> better angular resolution

September 8<sup>th</sup>, h 14:50: W.I. Ibnsalih, KM3NET/ARCA expectations for starburst galaxies observation

![](_page_17_Picture_0.jpeg)

### **Neutrino selection in ORCA6**

![](_page_17_Figure_2.jpeg)

- Selection based on track signature: mostly  $v_{\mu}$
- Background: atmospheric muons
- Selection: vertex position, track fit quality, upgoing tracks
- 1237 v candidates in 354.6 days, S/B~40

![](_page_18_Figure_0.jpeg)

- Oscillation fit, binned in  $E_{reco}$ ,  $\theta_{zenith}$
- Normalization left free, various systematics on flux, energy scale, tau- and NC normalization

## Sun/Moon shadows with ORCA

- No standard candle source
- Cosmic rays to the rescue

![](_page_19_Picture_4.jpeg)

![](_page_19_Figure_5.jpeg)

![](_page_19_Figure_6.jpeg)

### **Detector construction**

![](_page_20_Picture_1.jpeg)

#### **Detector construction:** a collaboration effort!

![](_page_21_Picture_1.jpeg)

#### **ARCA infrastructure for 2<sup>nd</sup> Building Block**

#### Nov 2020: Successful laying of the second MEOC

![](_page_22_Picture_2.jpeg)

![](_page_22_Figure_3.jpeg)

![](_page_22_Figure_4.jpeg)

With two main cables it is possible to connect the full ARCA detector (2 building blocks)

# **Junction Boxes**

- Technology developed with external companies, from oil&gas
- Electronics intrinsically redundant, every component is duplicated in case of breaking
- Boards and components produced with military/space standard
- This junction box meets the requirement of a 20-year lifetime at 3500m sea depth
- With a reliable infrastructure, DU mass production can start

![](_page_23_Picture_6.jpeg)

![](_page_23_Figure_7.jpeg)

### What next? PNRR Italian funding

- KM3NeT has received the approval for PNRR funds (Italian funds for recovery after pandemic)
- These funds will allow the completion of the first building block + the realisation of two junction boxes on the second block with all detection units related —> ~130 strings in total
- Timeline of the PNRR is 3 years.
- A fantastic opportunity to enter definitely the game of neutrino astronomy

![](_page_24_Picture_5.jpeg)

# **Detection Unit deployment**

![](_page_25_Picture_1.jpeg)

# Junction Box touchdown (4x)

![](_page_26_Picture_1.jpeg)

### **Detection Unit unfurling, triggered by ROV**

![](_page_27_Picture_1.jpeg)

# LOM recovery (after unfurling)

![](_page_28_Picture_1.jpeg)

![](_page_29_Picture_0.jpeg)

# Summary

- KM3NeT is active and taking data!
- Detector performance as good as expected. First physics results.
- ORCA currently taking data with 10 lines.
  ~10 more lines ready for deployment late 2022, early 2023.
  - Funding assured, procurement and construction in progress, for ~50 strings.
- ARCA currently taking data with 19 lines.
  - Funding assured, procurement and construction in progress, for ~130 strings.
- Detector mass production in regime stage. Production rate will increase in the next years
- Interesting physics results in the next years!

![](_page_29_Picture_10.jpeg)

![](_page_29_Picture_12.jpeg)

## Why don't you join KM3NeT?

▼ Menu: General Settings

182 ns

**KM3NeT** 

#### **ARCA and ORCA Building Blocks**

37

![](_page_31_Picture_0.jpeg)

## **Time calibration**

![](_page_32_Figure_1.jpeg)

Also: lab calibration of timing differences, LED flasher, timing from reconstructed tracks. Timing resolution better than 1 ns. Coincidence rate between PMTs on a DOM for one ORCA and one ARCA line, as a function of PMT multiplicity

# Positioning

![](_page_33_Figure_1.jpeg)

![](_page_33_Figure_2.jpeg)

# Positioning

![](_page_34_Figure_1.jpeg)

Track residuals before (blue) and after (orange) dynamic position calibration. After: 5 cm resolution.

#### KM3NeT, ICHEP 2022

Independent validation: cosmic ray shadow of sun and moon

![](_page_34_Figure_5.jpeg)

## **Junction Box deployment**

![](_page_35_Picture_1.jpeg)

#### DU unfurling with fish (3x)

![](_page_36_Picture_1.jpeg)

#### ARCAI+ARCA2

### **Selection of atmospheric neutrinos**

![](_page_37_Figure_2.jpeg)