# Ultra High Energy event in KM3NeT

Valentin Pestel, IRN Neutrino Lyon, June 2025



### KM3NeT: sea-water cherenkov telescopes

#### Use sea water as detection volume

 Neutrino interaction produces charged secondary(ies), inducing cherenkov radiation

# Need for a (very) large array of photosensors

 Story started in Mediterranean Sea with ANTARES, in operation with 0.1km<sup>3</sup> between 2008 and 2022



### KM3NeT technology

**Digital Optical Module (DOM)** 



- 31x3" PMTs
- ns timing
- acoustic receiver
- compass/accelerometer



#### **KM3Net** 21 countries 68 institutes 360 scientists





Regular sea operation extend both telescopes, until completion foreseen in 2028

### Physics cases



#### **Atmospheric muons**

Only down-going, main background for neutrino

Cosmic-rays physics

#### **Atmospheric neutrinos**

- Neutrino oscillation physics
  - Oscillation parameters, NMO, BSM
  - e.g. Nu tau appearance tomorrow @IRN

#### **Astrophysics neutrinos**

- Neutrino astronomy
  - Point-source search, diffuse flux measurement, multi-messenger observation
  - e.g. point-sources tomorrow @IRN

### Target performances and calibration

**Track ARCA:** ~0.1° pointing, factor 2 on energy (E > 100 TeV) **Track ORCA:** ~3 deg at 100 GeV

Positioning: < 20cm

• Acoustic system, measurement every 10 min

#### DOM orientation: ~5°

• Compass, measurement every 10 min

#### Timing: ~1ns

• Pre-deployment calibration, <sup>40</sup>K, atm. muons, laser-beacon

#### **PMT** response (gain, efficiency)

•  $^{40}$ K, measurement every ~10 days



### **Event reconstruction**

#### Maximum Likelihood Estimation based

- Use pre-computed multidimensional light PDF
  - Expressed in track-PMT system of coordinates

#### **Reconstruction done in stages**

- Coarse trajectory fit
- Fine trajectory fit
- Start and stop point determination
- Energy estimation

#### Similar process for the shower reconstruction



## KM3-230213A

### KM3-230213A

#### February 13, 2023, 01:16:47 UTC

- 21 DUs at the time (ARCA 21)
- Extreme luminosity





### Track-like event

#### **Clear agreement with a muon track**



Almost horizontal direction: Zenith angle 89.4° (cos ~ 0.01)

[Observation of an ultra-high-energy cosmic neutrino with KM3NeT, 2025]

### Energy measurement

#### Monte-Carlo based energy measurement

- Generated samples from 1 PeV to 1000 PeV
- Absorption length ± 10%
- Likelihood built from interpolation

 $E_{\mu} = 120^{+110}_{-60} \ PeV$ 

Neutrino energy obtains under E<sup>-2</sup> spectrum assumption

$$E_{\nu}=220^{+570}_{-100}\,{\rm PeV}$$

[Observation of an ultra-high-energy cosmic neutrino with KM3NeT, 2025]



#### KM3-230213A trajectory



### Interpretation

Observation of an ultra-high-energy cosmic neutrino with KM3NeT

**Companion papers:** 

- On the Potential Galactic Origin of the Ultra-High-Energy Event KM3-230213A
- On the potential cosmogenic origin of the ultra-high-energy event KM3-230213A
- <u>Characterising Candidate Blazar Counterparts of the Ultra-High-Energy Event</u> <u>KM3-230213A</u>
- <u>The ultra-high-energy event KM3-230213A within the global neutrino landscape</u>

Many more contribution to come



### Blazar and cosmogenic neutrinos

#### Blazar and HE/UHE neutrinos scrutinized

- 17 candidates in ± 3° region
- 3 Blazars with "coinciding" activity
  - Not unexpected considering a ± 3° region

#### First hint at cosmogenic neutrinos ?

- UHE cosmic rays (> EeV) significantly interact with CMB photons
- Produces UHE neutrinos through meson decay





### Cosmic neutrino flux



Probability of single observation in KM3NeT, but none in IceCube and Auger: 0.5% (2.6  $\sigma$ )

### KM3-230213A: What's next

#### **Better pointing achievable**

- Based on MC, for 100 PeV muon
  - 50% of events better than 0.12°
  - $\circ$  90% of events better than 0.28°
- Requires acoustic emitters positioned with ~50cm accuracy
- Dedicated hardware to be deployed at the next ARCA sea campaign this summer
  - Can be applied retroactively to KM3-230213A



#### More analyse of the event itself and its possible origin to come

### Outlook

#### KM3-230213A is the highest energy neutrino ever detected: ~220 PeV

- Remarkable performances from the early 21 lines ARCA detector
- Open-up an observational window to an unexplored energy regime

#### No clear counterpart or source identified

- Hint of a new component; cosmogenic neutrinos? Cosmic sources ?
- Further analysis of KM3-230213A and future detections are essentials

#### Exciting result from KM3NeT

• Many more to come on Astronomy, Neutrino oscillations, Cosmic Rays etc ...



















(b) The radio light curve for PMN J0606-0724 that experiences a major flare in close coincidence to the neutrino arrival (Section 5.2).







### Background probability



### Atmospheric neutrino background





### Calibration target

	Тороlоду	Energy resolution	Pointing resolution
ARCA	Track (> 100 TeV)	-50% +100%	< 0.1°
	Shower	±10%	1-2°
ORCA	Track (> 100 GeV)		3°
	Shower (> 100 GeV)		15°