High energy neutrino astronomy with KM3NeT

piera sapienza for the km3net collaboration

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KM3NeT Physics case

KM3NeT is neutrino research infrastructure in the deep Mediterranean Sea that hosts $\nu$ telescopes to:

- observe high energy cosmic neutrinos and discover their sources
- determine neutrino mass hierarchy

ARCA (off shore Capo Passero, It @ 3500 m depth) – this talk
- ORCA (off shore Toulon, Fr @2500 m depth) – J. Hofestadt talk

Same collaboration, same technology, two installation sites
Since 2016 KM3NeT is back in the ESFRI road map

IceCube discovery of HE cosmic neutrinos enforce KM3NeT physics case

=> KM3NeT has almost full sky coverage for $\nu_\mu$ and unprecedented angular resolution (about 0.1° tracks and 2° showers)

KM3NET TELESCOPE DESIGN

- Detection principle: Optical Cherekov radiation
  - 6 order of magnitude in energy (GeV-PeV) covered
  - All flavor detection
- 3D array built with a modular design
- Optical sensor: multi-PMT (DOM)
- Detection units (DU)
  - Vertical slender strings host 18 DOMs
- Building blocks of 115 DUs each
- Power and data distributed by a backbone cable with breakouts at each DOM
- Sea network of submarine cables and Junction Boxes connected to shore via a main e/o cable
- All data to shore

<table>
<thead>
<tr>
<th>ARCA</th>
<th>ORCA</th>
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<tbody>
<tr>
<td>Location</td>
<td>Italy</td>
</tr>
<tr>
<td>DU distance</td>
<td>90 m</td>
</tr>
<tr>
<td>DOM spacing</td>
<td>36 m</td>
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<tr>
<td>Instrumented mass</td>
<td>0.5 Gton</td>
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</table>
DOM - Digital Optical Module

- 31 x 3” PMTs
- LED & acoustic piezo inside
- Tiltmeter/compass
- Gbit/s fibre DWDM
- Hybrid white rabbit

- Digital photon counting
- Directional information
- Wide acceptance angle
- Improved $^{40}\text{K}$ rejection capability
  $\Rightarrow$ (500 Hz, for double coincidences, ...)
- Compact and cost effective design: 1 DOM equivalent to 3 Antares OMIs
From technology validation to construction

Prototype DOM deployed at Antares site April 2013

Test of photon counting capabilities and directional sensitivity of DOM

Prototype DU (three DOMs) deployed in Capo Passero May 2014

ARCA DUs in Capo Passero since December 2015
Muon flux dependence on depth
DU calibration
Trigger implementation
PMT efficiency correction
MC comparison
6-7 kHz $^{40}$K, < 1% bioluminiscence

References
[3] K. Melis, In-Situ Calibration of KM3NeT, these proceedings
ARCA DETECTION UNIT

- 18 DOMs integrated on vertical e/o cable supported by two parallel Dynema ropes
- DUs arranged on the LOM mounted on the anchor and ready for deployment
- DU unfurled after deployment and connection to seabed network
- Unfurling triggered by ROV then proceed under buoy pull

LAUNCHER VEHICLE

- Compact structure
- Rapid deployment
- Autonomous unfurling
- Recoverable

700 m
The First DU installed in situ 3500 m
Track reconstruction on data sample

A muon event seen and reconstructed in two DUs
A PHASED APPROACH TOWARDS 1km$^3$

<table>
<thead>
<tr>
<th>PHASE</th>
<th>BLOCKS</th>
<th>PRIMARY DELIVERABLES</th>
<th>FUNDS</th>
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<tbody>
<tr>
<td>1</td>
<td>0.2</td>
<td>Proof of feasibility and first science results</td>
<td>fully funded</td>
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<tr>
<td>0.1 km3</td>
<td></td>
<td>24 ARCA strings</td>
<td></td>
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<tr>
<td>10xANTARES</td>
<td></td>
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<td>ARCA</td>
<td>2</td>
<td>Study of neutrino signal reported by IceCube</td>
<td>partially funded</td>
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<tr>
<td>2</td>
<td></td>
<td>All flavor neutrino astronomy</td>
<td></td>
</tr>
<tr>
<td>1 Gton</td>
<td></td>
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Three ARCA DUs have been deployed. ARCA DU3 failed soon after unfurling. It was recovered within a dedicated campaign and failures analysed. *Post mortem* analysis lead to review project and procedures.
Upgoing track like $\nu_\mu$ CC event

Contained shower $\nu_e$ and NC event

$\nu_\mu$ are the golden channel for neutrino astronomy
Deep sea water properties, i.e. long scattering length allow to achieve very good angular resolution

Energy resolution about 0.3 in $\log(E_\mu)$
Angular resolution about 0.1° ($E_\nu > 10$ TeV)
Energy resolution about 10%
Angular resolution about 2° ($E_\nu > 10$ TeV)
SENSITIVITY TO ICEBUBE NEUTRINO FLUX

ALL FLAVOR ANALYSIS

- **Track channel**: analysis for up-going events based on Max. likelihood
- Pre-Cuts on $\theta_{\text{zen}} > 80^\circ$, $\Lambda$ (reconstruction quality parameter), $N_{\text{hit}}$ (number of hits -> parameter related to the muon energy)

  - **Cascade channel**: contained events
    - **Vertex cut**: cut on position of reconstructed vertex ($z<200\text{m}$ AND $r<500\text{m}$)
    - **Energy cut**: cut on the total ToT of the event ($\text{ToT}>12\ \mu\text{s}$)

LoI $\Rightarrow$ Combined discovery at $5\sigma$ significance (50% probability) in less than one year

Updated results on track analysis (R. Coniglione ICRC2017) $\Rightarrow 5\sigma$ in one year!!!
GALACTIC SOURCES

Sensitivity to Galactic sources calculated with \( \nu \) fluxes estimated from HE \( \gamma \) observed fluxes in the hypothesis of fully hadronic emission and 100% transparent sources.

Good perspectives for \( \nu \) detection and/or model constraints for galactic sources (also Fermi Bubbles, Galactic, Plane, ...)

![Graph showing 3\(\sigma\) discovery potential and sensitivity for various sources over time.](image-url)
**Sensitivity to point-like sources for $\nu_\mu$**

- ARCA can survey almost the whole sky with a discovery potential @ 5$\sigma$ about one order of magnitude better than IceCube in the Southern hemisphere for equivalent exposure

- ARCA will have a sensitivity better by more than a factor 20 w.r.t. ANTARES
CONCLUSIONS

• KM3NeT entered the construction phase
  – first two strings in the Capo Passero site operated for 1 year
  – data in agreement with MC

• IceCube data expected to be confirmed in less than 1 year of full exposure

• Good perspectives for Galactic source detection (point-like, Galactic halo, ...) due to km3net location
12 Countries
>40 Institutes
>220 Scientists

South Africa recently joint the Collaboration