THE KM3NET NEUTRINO TELESCOPE IN THE MEDITERRANEAN SEA

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FRONTIERS OF RESEARCH ON COSMIC RAY GAMMA - LA PALMA 26-29 AUGUST 2015
OUTLINE

MOTIVATION

DETECTOR DESIGN AND VALIDATION

STATUS AND PLANS

- KM3NET PHASE 1
- KM3NET 2.0
  - SENSITIVITY TO DIFFUSE AND POINT-LIKE SOURCE
  - SENSITIVITY TO GALACTIC GAMMA SOURCES
  - SENSITIVITY TO NEUTRINO MASS HIERARCHY

CONCLUSIONS
NEUTRINO ASTRONOMY
ICECUBE RESULTS

53+1 high energy neutrinos observed in 4 years 6.5 $\sigma$ (HESE) - Kopper ICRC 2015

Up-going muon track analysis: cosmic neutrino signal observed at 3.7$\sigma$

Flavour composition compatible with 1:1:1 at detector

Neutrino detection for $E > 1$ TeV with veto analysis

A 2.6 PeV track event reported very recently!

SPECTRAL SHAPE NOT FIRMILY ESTABLISHED

- SPECTRUM SOFTER THAN $E^{-2}$? CUT-OFF AT PEV ENERGY?

NO HINTS OF NEUTRINO SOURCES
WHY KM3NET?

Two km$^3$ scale detectors needed in opposite hemispheres for full neutrino sky coverage

KM3NeT aims to be the largest deep sea infrastructure in Mediterranean Sea consisting of a network of neutrino telescopes with user ports for earth and sea sciences

KM3NeT w.r.t. IceCube

- wider field of view
- better angular resolution
- larger sensitivity
THE KM3NET NEUTRINO TELESCOPE

87% sky coverage including most of Galactic Plane and the Galactic Centre for up-going muons

Detection of Optical Cherekov radiation in GeV-PeV range

Detection units (DU) – vertical slender strings with multi-PMT digital optical modules (DOMs)

Each DU host 18 multi-PMT DOMs supported by two parallel ropes

Power and data distributed by a single backbone cable with breakouts at DOMs

All data to shore

Building blocks of 115 DUs each, allow for a distributed detector
THE KM3NET MULTI-PMT DOM

Segmented cathode area 31 x 3” PMTs equivalent to 3 Antares/IceCube/NEMO Optical Module

Advantages

• good optical background rejection
• directionality
• almost homogenous coverage

=> better detection of downgoing tracks and contained events

Instrumentation inside DOM (LED & piezo, compass and tiltmeter)
THE KM3NET DETECTION UNIT

18 optical module per string

17”

31 x 3” PMTs
low-power HV
LED & piezo inside
FPGA readout
White Rabbit
DWDM

Launcher vehicle

rapid deployment
autonomous unfurling
recoverable
IN SITU PROTOTYPE VALIDATION

Harsh environment: 2500-3500 m depth

- Accessibility
- Pressure
- Corrosion
- ...

Antares demonstrated the feasibility of a deep sea neutrino telescope, however several of the technologies cannot be applied to km3net because expensive or not scalable

In situ prototype validation of detector components is a necessary step towards construction
DETECTION UNIT PROTOTYPE

Prototype DU with three DOMs
Deployed at the KM3NeT-It site at 3500m depth
Operational since May 2014
DOM PROTOTYPE RESULTS

Photon counting
High coincidence level clearly select muon events

Directional sensitivity
Muon events (coincidence level >7)
KM3NET PHASE-1

KM3NeT Phase-1: Proof of feasibility of network of neutrino detectors

- Started in January 2014
- Funded with 31 million Euro
- Detection Unit deployment in 2015-2016
- Two sites
  - KM3NeT-It (24 Strings + 8 towers)
  - KM3NeT-Fr (7 DUs)

KM3NeT-It instrumented volume is 0.1 km$^3$, i.e. 10 times larger than Antares
DETECTION UNIT PRODUCTION

First full DU already integrated and ready for deployment at the KM3NeT-Fr site

Integration of the second DU in progress. To be deployed at the KM3NeT-It sit
THE KM3NET 2.0 PROPOSAL

The detection of cosmic neutrinos in IceCube and the measure of $\theta_{13}$ triggered the KM3NeT 2.0 proposal

Two-site infrastructure

- ARCA detector for high energy neutrino astronomy at the KM3NeT-It site (off-shore Capo Passero 3500 m depth)
- ORCA detector for NMH studies with atmospheric neutrinos at the KM3NeT-Fr (off-shore Toulon 2500 m depth)
- Additional cost: 90 M€ (not yet funded)
- Proposed to ESFRI
- LoI in preparation
2 Building blocks
115 detection units (DU) per
18 DOM per DU
Vertical DOM spacing 36 m
Inter-DU spacing 90 m
Total volume ≈1 km³
KM3NET/ARCA TRACK RECONSTRUCTION

Angular resolution $\sim 0.2^\circ$ ($E_\nu > 10$ TeV)

Energy resolution $\sim 0.26$ in $\log E_\nu$ ($1$ TeV $< E_\nu < 100$ PeV)
KM3NET/ARCA CASCADE RECONSTRUCTION

1083 TeV CC $\nu_e$ event

Angular resolution about $2^\circ$

Energy resolution < 10%

KM3NeT preliminary
Atmospheric muons and neutrinos represent a huge background for high energy cosmic neutrino detection.

Signal and background events are indistinguishable on a single event basis but show different spectra, flavour, energy and angular distributions.

Up-going and contained events are muon-free.

**Signal and Background**

<table>
<thead>
<tr>
<th>SIGNAL</th>
<th>BACKGROUND</th>
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<tbody>
<tr>
<td>Track-like and Cascade events</td>
<td>Mostly Track-like events from atmospheric muons and neutrinos</td>
</tr>
<tr>
<td>Hard benchmark spectra $E^{-2}$</td>
<td>Soft spectra $E^{-3.7} - E^{-3.7}$</td>
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* Atmospheric neutrinos represent a background for high energy neutrino astronomy but are the “signal” for Neutrino Mass Hierarchy measurement (ORCA)
SENSITIVITY TO NEUTRINO DIFFUSE FLUX

All neutrino flavour MC simulation and 3 years of live time for high energy atmospheric muons

Discovery at 5σ significance (50% probability) in less than one year
Upgoing tracks

**KM3NeT preliminary**

Discovery potential (5\(\sigma\)):
- KM3NeT/ARCA, 3 observation years
- KM3NeT/ARCA, 10 observation years
- IceCube (IC86+IC79+IC59+IC40)

**Better than IceCube for all source declination**
GALACTIC SOURCES WITH KM3NET/ARCA

- HE gamma emission observed by HESS in SNRs
- Neutrino spectra predicted from gamma spectra
- Hypotheses: 100% hadronic emission and transparent source, 0.6° disk emission

Vela X: 3σ in about 2 years
RXJ1713: 3σ in about 4 years
FERMI BUBBLES

Two huge extended regions above/below the Galactic Centre

Fermi detected hard gamma emission ($E^{-2}$) up to hundreds of GeV

In case of hadronic emission neutrino flux expected, but detectable by neutrino telescopes only if $E_{\text{cut-off}} > 100$ TeV

Results for 6 blocks published in Adrian Martinez et al Astroparticle Phys. 42 (2013) 7
DIFFUSE FLUX FROM THE GALACTIC PLANE

ARCA performance to a flux from a region of the Galactic Plane near the Galactic Center. Evaluation of the neutrino flux based on a radially-dependent cosmic-ray transport properties (D. Gaggero et al. 2015)

Preliminary results for up-going track events

Discovery at 5σ significance (50% probability) in about 5 years
ORCA – $\nu$ OSCILLATION RESEARCH WITH COSMICS IN THE ABYSS

Measurement of the Mass Hierarchy with atmospheric neutrinos passing through Earth in a deep sea Cherenkov detector at GeV energy

Oscillation signal enhanced at resonance energy in matter

Very challenging experiment…
METHOD TO DETERMINE NMH EFFECT

Both muon and electron channel contribute to net asymmetry in the atmospheric neutrino $E_\nu$-$\cos\theta_\nu$ oscillogram.

Electron channel more robust in *real* detector.

Maximum sensitivity between 5 GeV and 10 GeV.
THE ORCA BENCHMARK DESIGN

SAME TECHNOLOGY BUT VERY DENSE DETECTOR

ENERGY RANGE 1 – 20 GEV

1 block 115 strings
18 strings per DOM
20m strings spacing
6 m DOM spacing (to be optimized)
3.8 Mton instrumented volume
**ORCA SENSITIVITY PRELIMINARY RESULTS**

Sensitivity dependence on observation time ($\delta_{CP} = 0$)

- Track vs shower event classification
- Full MC detector response matrix
- Atmospheric muon contamination
- Neutral current event contamination
- Systematic uncertainties

**Neutrino Mass Hierarchy measured at 3\(\sigma\) level in about 3 years**
ORCA - SYSTEMATICS EFFECTS

• Various systematic effects taking into account
  – Oscillation parameters
    • $\Delta m^2$, $\theta_{12}$ fixed; $\theta_{13}$ fitted within its error
    • $\Delta M^2$, $\theta_{23}$, $\delta_{CP} \rightarrow$ fitted unstrained
  – Flux, cross section, detector related
    (average fluctuation w.r.t. nominal)
    • Overall normalisation (2.0%)
    • $v/\overline{v}$ ratio (4.0%)
    • $e/\mu$ ratio (1.2%)
    • NC scaling (11.0%)
    • Energy slope (0.5%)
    • $\rightarrow$ Fitted unstrained
CONCLUSIONS

First phase of KM3NeT will be completed by 2016

• Definite proof of KM3NeT technology and check of telescope performance for ARCA and ORCA
• 0.1 km$^3$ times larger than Antares

Physics case for KM3NeT 2.0 defined

KM3NeT/ARCA can investigate the neutrino sky with unprecedented resolution and sky coverage

Preliminary KM3NeT/ORCA results encouraging

• further improvements expected