Towards the Very Large Volume Mediterranean Neutrino Telescope, KM3NeT

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KM3NeT

OUTLINE

- Physics case & Main objectives
- KM3NeT Design
- Telescope performance
- Conclusions
Physics Case & Main objectives

- **Main physics goals**
  - Origin of Cosmic Rays and Astrophysical \( \nu \) sources
    - Galactic Candidate \( \nu \) Sources (SNRs, Fermi Bubbles, microquasar, ...)
    - Extragalactic Candidate \( \nu \) Sources (AGN, GRB, ...)
    - Diffuse Fluxes

- **Implementation requirements**
  - Construction time \( \leq 5 \) years
  - Operation over at least 10 years without “major maintenance”

- **Cabled platform for deep-sea research**
  - Environmental sciences
  - Geology and geophysics
  - Marine biology and oceanography
Sky view of the KM3NeT

FOV for up-going neutrinos shown

24h per day visibility up to declination $\delta \sim -50^\circ$

Visibility > 25% of time  
Visibility > 75% of time

KM3NeT covers most of the sky (87%) including the Galactic Centre

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**KM3NeT lay-out**

KM3NeT in numbers
- ~12000 OMs
- ~300 DU
- 20 storey/DU
- ~40m storey spacing
- ~1 km DU height
- ~180m DU distance
- ~5 km³ volume
- ~220 MEuro cost

Detection Unit (DU): mechanical structure holding OMs, environmental sensors, electronics,...

DU is the building block of the telescope

Optical Module (OM): pressure resistant sphere containing photo-multippliers

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Optical Module - Multi-PMT

- 31 3” PMTs (~30% max QE) inside a 17” glass sphere with 31 bases (total ~6.5W)
- Cooling shield and stem
- First full prototype under test

- Single vs multi-photon hit separation
- Large (1260 cm$^2$) photocade area per OM

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Front End Electronics

- Read-out SCOTT ASIC
  - Time over threshold with adjustable thresholds
  - Digitised output
  - Zero suppression

- System on chip
  - FPGA for data buffering and formatting
Data Network and transmission

- All data to shore (no trigger undersea)
- Data transport on optical fibers (data, slow control)
- Optical point-to-point connection to shore
- DWDM technique => minimize numbers of fibers

Star layout

Ring layout

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Point source Sensitivity & Discovery potential
Full detector (308 DUs)

1 year of data taking – $E^{-2}$ ν-spectrum

- KM3NeT sensitivity 90%CL
- KM3NeT discovery 5σ 50%
- IceCube sensitivity 90%CL
- IceCube discovery 5σ 50%
- 2.5÷3.5 above sensitivity flux. (extrapolation from IceCube 40 string configuration)

flux sensitivity and discovery flux (5σ, 50% probability) for point sources at $\delta=-60^\circ$ vs the assumed cut-off of the energy spectrum.

|Observed Galactic TeV-g sources (SNR, unidentified, microquazars)
★Galactic Center

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Galactic Candidate ν Sources – SNRs

Origin of Cosmic Rays => SNR paradigm

Assuming that VHE γ emitters are CR accelerators.

As an example, assuming that the RXJ1713.7-39.46 (the most luminous γ ray source) is a hadron accelerator then the ν spectrum can be calculated from the γ spectrum:


\[
\Phi(E) = 16.8 \times 10^{-15} \left( \frac{E}{\text{TeV}} \right)^{-1.72} e^{-\sqrt{\frac{E}{2.1 \text{ TeV}}}} \text{ GeV}^{-1} \text{ s}^{-1} \text{ cm}^{-2}
\]

Significance of discovery of SNR RXJ1713

as a function of years of running time

>8 years required for a significant (>5σ) discovery

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Extragalactic ν Sources – GRBs

- Alert from satellite detectors (known time & direction)
- Short time window (<2h) for GRB prompt neutrino emission
- High energy neutrinos (> 100TeV)
- Application of energy cut on the reconstructed muon energy

Detection of down-going GRB neutrinos events is feasible

The expected number of detected neutrino events from GRBs per year and steradian.

Expected Neutrino fluence from GRBs

- 1000 GRBs/year (4500m depth)
- 300 GRBs/year (3500m depth)
- Half KM3NeT

- 2.5 signal events/year
- 0.45 background events/year

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Ultra high energy neutrinos from
- A multitude of objects such as Active Galactic Nuclei or GRBs
- The interaction of cosmic rays with intergalactic matter, radiation, cosmic microwave background

- No tight angular cut for reducing the background of atmospheric neutrinos
- Rely on a cut on the reconstructed muon energy.

KM3NeT ($E^{-2}$) diffuse $\nu$ flux sensitivity (effective energy cut $E_\nu > 500$ TeV)

$$3 \cdot 10^{-9} \text{ (GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1})$$

Diffuse flux sensitivity of the KM3NeT neutrino telescope for one year of observation time.

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The expected neutrino flux for one bubble is
\[ E^2 F_\nu \sim 4 \times 10^{-7} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \]
Galactic Candidate $\nu$ Sources – Discovery Improvements

Use of the full experimental information on a track by track basis:
- reconstructed muon energy, and
- track resolution (muon reconstruction parameter errors)

Histogram: True
Line: Predicted from reconstruction errors

Signal ($E^{-2}$ $\nu$ spectrum)
Background (atmo-$\nu$)

Angle between reconstructed muon track and parent neutrino (Degrees)

10 TeV < $E\nu$ < 100 TeV
Galactic Candidate $\nu$ Sources – Discovery Improvements

154 DUs (half KM3NeT)

$E^{-2}$ $\nu$ point source at -60° declination

Discovery Potential (3 sigma) vs Flux for one year of data taking

Improved method

Without energy information

Flux in units of $10^{-9}$ (GeV$^{-1}$ cm$^{-2}$ s$^{-1}$)

Without energy information:  $1.6 \times 10^{-9}$ (GeV$^{-1}$ cm$^{-2}$ s$^{-1}$)

Using full exp. information:  $1.2 \times 10^{-9}$ (GeV$^{-1}$ cm$^{-2}$ s$^{-1}$)

Binned technique:  $2.5 \times 10^{-9}$ (GeV$^{-1}$ cm$^{-2}$ s$^{-1}$)

RXJ1713.7-39.46 (0.6° angular radius)

1y Discovery potential WITH energy and shape
- 3σ: $3.0 \times$ RXJ1713 flux for 50% discovery
- 4σ: $4.1 \times$ RXJ1713 flux for 50% discovery
- 5σ: $5.6 \times$ RXJ1713 flux for 50% discovery

1y Discovery potential WITHOUT energy and shape
- 3σ: $3.7 \times$ RXJ1713 flux for 50% discovery
- 4σ: $4.6 \times$ RXJ1713 flux for 50% discovery
- 5σ: $7.2 \times$ RXJ1713 flux for 50% discovery

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Conclusions

- KM3NeT will cover most of the sky with unprecedented sensitivity
- Promising Galactic Candidate neutrino Sources
- KM3NeT-Preparatory Phase ongoing Final design and prototyping activities in progress
- Discovery potential for Galactic Candidate neutrino Sources can be further improved using the reconstructed energy estimation, the angular resolution on a track by track basis and the application of advanced filters using the known source's direction

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