Large underwater neutrino telescope (KM3NeT)

Piera Sapienza on behalf of the KM3NeT Consortium

• Motivation & candidate HE $\nu$ sources
• How Do Neutrino Telescopes Work?
• KM3NeT
  – Location & field of view
  – Design Goal & Technological Challenges
  – Detector Performance
• Summary
Why HE neutrinos?

Neutrinos will provide *unique* info on High Energy Universe

- Cosmic accelerator
- Protons $E>10^{19}$ eV (100 Mpc)
- Protons $E<10^{19}$ eV
- VHE $\gamma$: horizon about 10 Mpc
- VHE $\gamma$: absorbed on dust and radiation and do not disentangle between lepton and hadron mechanisms
- Protons/nuclei: deviated by magnetic fields, interact with radiation (CMB)

HE neutrinos probe far High Energy Universe and dense core of CR sources

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Detection principle
TeV- PeV energy range => Optical Cherenkov

Detector volumes of the order of km³ needed for ν astronomy

- Upward-going neutrinos interact in rock or ice or sea/lake water.
- Emerging charged particles (in particular muons) produce Cherenkov light in water/ice.
- Detection by array of photomultipliers.
- \( \nu_\mu \) is the golden channel for astronomy.

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Potential Galactic Neutrino Sources

- The accelerators of cosmic rays
  - Supernovae Remnants
  - Pulsar wind nebulae
  - Micro-quasars
  - ...

- Unidentified sources ("γ TeV only" H.E.S.S. objects)

- Interaction of cosmic rays with interstellar matter
  - Galactic Halo
  - Molecular clouds
Potential Extra-Galactic Neutrino Sources

• AGNs
  – Models are rather diverse and uncertain
  – Neutrino flux estimates can be inferred by
    • $\gamma$ TeV telescope (but EBL interaction)
    • Auger results (i.e. Cen A association if confirmed)

• Gamma Ray Bursts
  – Unique signature: Coincidence with gamma observation in time and direction (background free detection)
  – sensitivity increases with increasing effective area

• Starburst Galaxies
• Source stacking possible
High energy $\nu$ telescope world map

ANTARES, NEMO, NESTOR

Mediterranean $\text{km}^3$

AMANDA
IceCube

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What is KM3NeT

• KM3NeT is a consortium of 40 EU institutions from 10 countries that includes ANTARES, NEMO and NESTOR collaborations

• Aims to construct a future cubic-kilometre sized neutrino telescope in the Mediterranean Sea

• Focus of scientific interest: Neutrino astronomy in the TeV - PeV energy range

• Platform for deep-sea research (marine sciences)
KM3NeT Design Study aims at developing a cost-effective design for the construction of a km3 size deep underwater neutrino telescope in the Mediterranean Sea.

KM3NeT Preparatory phase prepares for the construction by defining legal, financial and governance issue as well as production plans of the telescope components.

KM3NeT Preparatory Phase will be extended up to March 2012.
Watching the sky upside-down
South Pole vs. Mediterranean Field of View and $\gamma$ TeV sky

Visibility is shown for up-going $\nu$
For a $\nu$ telescope located in Mediterranean
Visibility of given source depends on declination

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The origin of (galactic) Cosmic Rays

SNR RXJ1713.7-3946: the first hadronic $\gamma$-ray source?

Origin of CR is a major question

... but no conclusive evidence about CR acceleration sites

The only SNR known from radio to 100 TeV
Hess VHE $\gamma$ observations

- 21.3 TeV$^{-12}$ cm$^{-2}$ s$^{-1}$ flux @ 1 TeV
- $E^{-\alpha}$ spectrum up to about 30 TeV,
- Spectral index $\alpha \approx 2$
- $\gamma$ observed up to 100 TeV

x-ray hot spots $\Rightarrow$ mGauss magnetic field:
1. Inverse compton dramatically reduced
2. Protons can be accelerated up to $E >$ PeV
(Aharonian et al. Nature 2007)

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“guaranteed” HE $\nu$ sources?

RXJ1713.7-3946
In the hypothesis of hadronic mechanisms $\nu$ spectrum can be derived from VHE $\gamma$ spectrum
Points Hess
dashed blue $\gamma$ dashed red $\nu$ (Blasi et al)
solid red (Vissani et al 2.5 ev/year km$^2$)

Vela Junior “twin” source of RXJ1713.7-3946
(High flux, high magnetic field, “young” SNR)

Another very interesting source, if hadronic, is Vela X, a very intense PWN, A.Kappes et al., astro-ph 0607286
The KM3NeT Conceptual Design Report

- Presented to public at VLVnT08 workshop in Toulon, April 2008
- Summarises (a.o.)
  - Physics case
  - Generic requirements
  - Pilot projects
  - Site studies
  - Technical implementation
  - Development plan
  - Project implementation

Available on www.km3net.org

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KM3NeT Design Goals

• Lifetime > 10 years without major maintenance, construction and deployment maximum 4 years

• Some technical specifications:
  – time resolution 2 ns
  – position of OMs better than 40 cm accuracy
  – two-hit separation < 25 ns
  – PM dark rate < 20% of $^{40}\text{K}$ rate
Technological implementation

- Big technological challenges due to hostile environment (several thousands meters under sea) we have to cope with pressure, corrosion, low accessibility
- Photo-sensors and optical modules
- Data acquisition, information technology and electronics
- Mechanical structures
- Deep-sea infrastructure
- Deployment
- Calibration
Optical modules – one 8” PMT/OM

New photocathode developments by Hamamatsu High Q.E.
... or many PMTs

• Basic idea: Use up to 31 small (3” or 3.5”) PMTs in standard sphere
• Advantages:
  – increased photocathode area on a single OM
  – improved 1-vs-2 photo-electron separation $\rightarrow$ better sensitivity to coincidences
  – directionality
• Prototype arrangements under study
Detection Units

- DU is the mechanical structure that hosts OMs, environmental sensors, electronics,…
- Tower-like structures once unfurled lead to a three-dimensional arrangement of OMs ⇒ better track reconstruction

Deployment of prototype tower

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Front-end electronics & Data transmission

• For both standard large and multi-PMT OM, front-end electronics can consist of an ASIC chip and a FPGA
• All-data-to-shore concept
• => trigger and filtering on shore
• Rate dominated by optical background
  \(^{40}\text{K}\) and bioluminescence
• Point to point data transmission on optical fibre under investigation
Detector Performance - Simulation

Example: a km$^3$ \( \nu \) telescope based on towers
Hexagonal detector foot-print
- 127 DU, D = 180 m
- 20 storeis, d = 40 m
- 3 OM pairs/storey

Angular resolution: blue line intrinsic spread \( \Delta \Omega_{\nu \mu} \)
squares \( \Delta \Omega_{\mu \mu \text{rec}} \)

At low energy dominated by intrinsic \( \Delta \Omega_{\nu \mu \nu} \)
at high energy by detector resolution

\( \Delta \Omega_{\mu \mu \text{rec}} \) about 0.1° @ 10 TeV
Sensitivity to point-like sources - preliminary results -

- KM3NeT will cover most of the sky with a sensitivity around TeV$^{-12}$ cm$^{-2}$ s$^{-1}$ for a $E^{-2}$ spectrum
- Improvement on sensitivity for point-like sources expected using unbinned method and exploitation of energy info
### Some candidate hadronic $\gamma$ TeV sources


<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>$\delta$ (degrees)</th>
<th>Spectral index $\alpha$</th>
<th>Gamma Flux @1 TeV (TeV$^{-1}$ cm$^{-2}$ s$^{-1}$)</th>
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</table>

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Summary and Perspectives

• High Energy Neutrinos are expected to provide unique information on High Energy Universe
• Pilot experiments in deep-sea neutrino telescopes provided the proof of feasibility of underwater neutrino telescopes
• Technologies mature to undertake the construction of a deep km$^3$ underwater $\nu$ telescope in the Mediterranean Sea
• KM3NeT detector in Mediterranean Sea will cover a field of view of about 3.5 $\pi$ and survey most of Galactic Plane where many $\gamma$ TeV were discovered. In particular the intense, best known SNR RXJ1713.7-39-46