KM3NeT/ARCA sensitivity to neutrino point sources

A. Trovato[1] and J. Barrios-Martí[2] for the KM3NeT Collaboration

[1] INFN-LNS, via S. Sofia 62, 95123 Catania, Italy

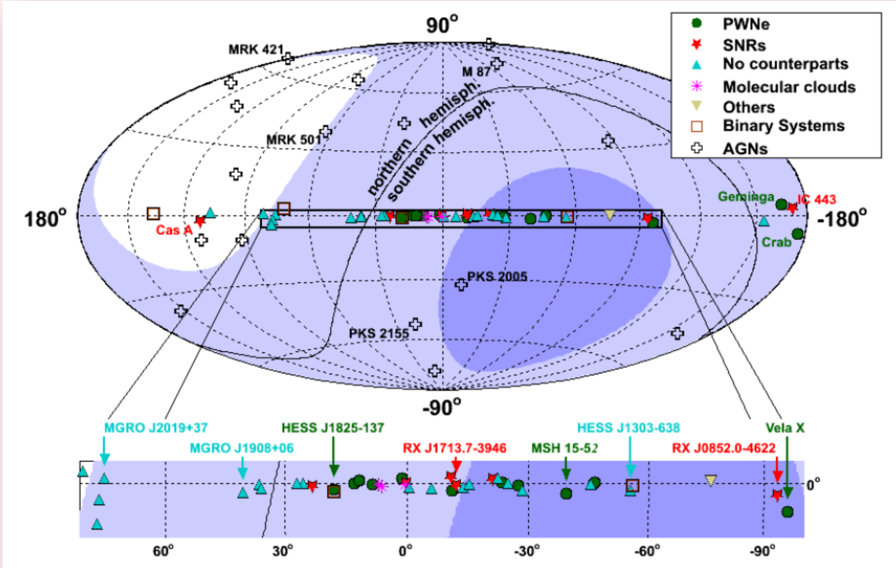
[2] Instituto de Física Corpuscular, IFIC (UV-CSIC), Parque Científico, C/Catedrático José Beltrán 2, E-46980 Paterna, Spain

Neutrino Astronomy

High-energy (E>TeV) neutrinos can travel through the entire Universe without being deflected or absorbed thus carrying information about the most violent phenomena where hadronic processes play a major role.
Under the hypothesis of hadronic gamma emission and transparent sources, models for galactic neutrino sources are well constrained by TeV gamma-ray observations and allow to obtain realistic detection perspectives.

KM3NeT field of view

From its location in the Northern hemisphere and thanks to the rotation of the Earth, KM3NeT will observe upward-going neutrino from most of the sky (about 3.5π sr) including galactic centre and most of the the galactic plane.



Analysis method

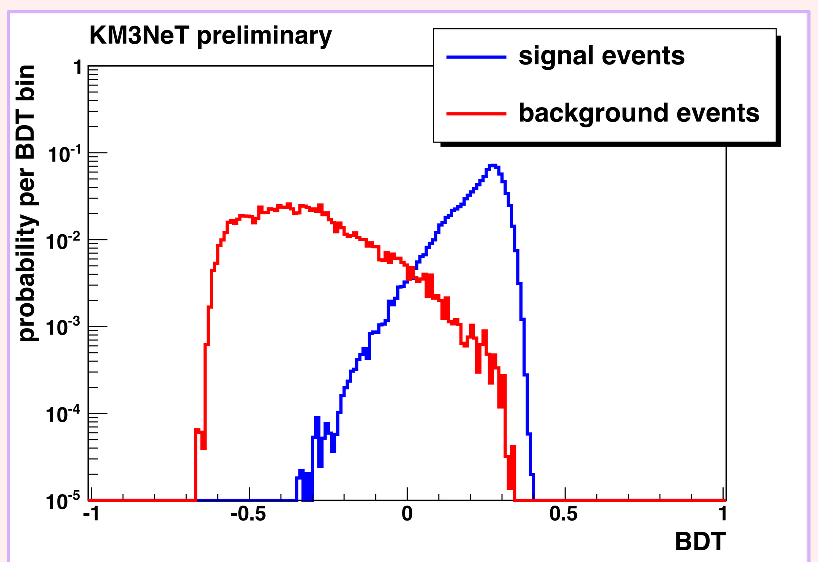
In point sources searches, the simulated events are analysed through statistical techniques to look for an excess around the source position.

Atmospheric muons rejection:

- Atmospheric muons can be rejected looking at upward-going events, which can be only produced by neutrinos, the only particles that can traverse the whole Earth without being absorbed.
- Atmospheri muons mis-reconstructed as upgoing still represent a not negligible background but can be reduced to few events with cuts on:
  - ✓ the reconstructed zenith angle θ
  - ✓ the distance from the source position α
  - ✓ the reduced likelihood Λ given by the direction reconstruction algorithm

Boosted Decision Tree (BDT):

- Atmospheric neutrinos represents an unavoidable background distinguishable from the signal only on a statistical basis
- Machine learning technique based on the BDT [8] used in this case
- Variables used to feed the BDT:
  - ✓ variables related to the fit quality at each step of the muon direction reconstruction
  - ✓ final reconstructed zenith angle, declination and right ascension
  - ✓ distance of the reconstructed track from the source position
  - ✓ reconstructed track length and vertex position
  - ✓ number of hits selected in the reconstruction procedure



BDT distributions for background (including atmospheric neutrinos and muons) and signal events for the RX J1713.7-3946 analysis

Discovery potential:

- Signal flux required to obtain an observation at a given significance level (e. g. 5σ or 3σ) with 50% probability [9].
- Unbinned method [10] used → maximization of Likelihood Ratio (LR):

$$LR = \log\left[\frac{P(data\,|\,H_{bkg+sig})}{P(data\,|\,H_{bkg})}\right] = \sum_{i=1}^{n} \log \frac{\frac{n_{sig}}{n}\times P_{sig}(BDT_i) + \left(1-\frac{n_{sig}}{n}\right)\times P_{bkg}(BDT_i)}{P_{bkg}(BDT_i)}$$

LR: used as test statistic

$H_{bkg+sig}$: hypothesis of signal+background

H_{bkg}: hypothesis of background only

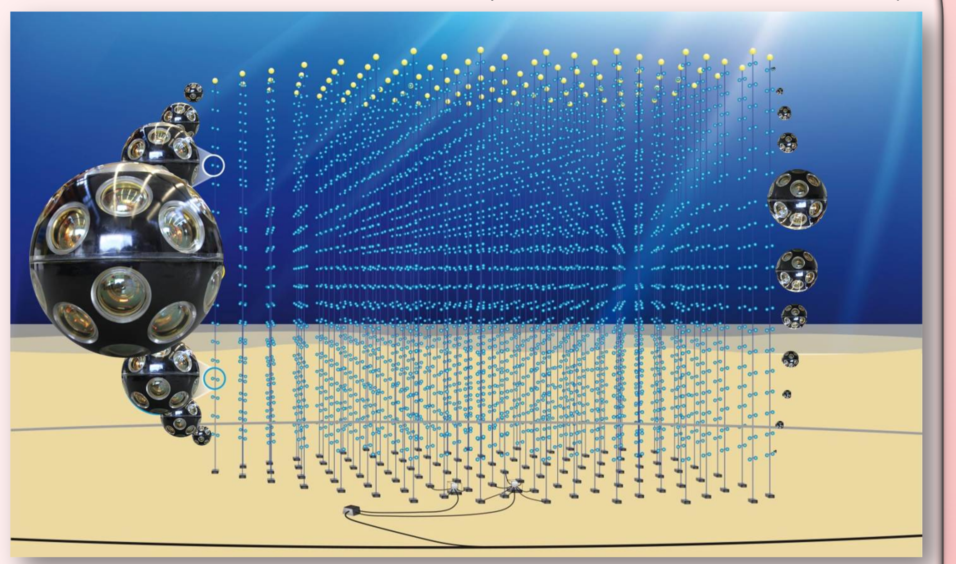
n_{sig}: free parameter

Number (n) of expected events in the detector in a given time window

Probability density function for signal (P_{sig}) and background (P_{bkg}) events estimated from the MC as a function of the BDT output

KM3NeT/ARCA neutrino telescope [1]

Detection principle: measure optical Cherenkov radiation in deep-water emitted by leptons emerging from neutrino interactions



Detector: 3D arrays of Digital Optical Modules (DOM) → 17 inch diameter pressure resistant glass spheres containing 31 photomultipliers (PMTs) with 3-inch photocathode diameter and their readout electronics.

- Detection Units (DU): vertical strings with 18 DOMs spaced 36 m
- Building block: 115 DU distant 90 m (volume ≈ 0.5 km³)

KM3NeT/ARCA will consist of 2 building blocks installed at the CapoPassero site (Italy) at a depth of 3500 m.

Event simulations

Simulation codes developed by the ANTARES Collaboration [2] and adapted to km³-scale detector:

- Neutrino (10^2 – 10^8 GeV) interaction in the medium and propagation of the emerging secondary particles
- Light generation and propagation in water
- Detector response
- Track reconstruction [3] (only track analysis described here)

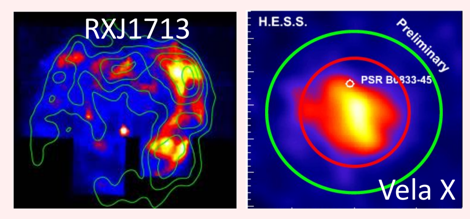
Signal events:
neutrino events weighted according to the specific model flux considered in each case

Background events (produced in the cosmic rays interaction with the atmosphere):

- atmospheric neutrinos: Honda et al. [4] conventional component + Enberg et al. [5] prompt component + cosmic ray knee correction described in [6]
- atmospheric muons: MUPAGE events generator [7]

Galactic sources: RXJ1713.7-3946 and Vela X

- HE gamma emission observed by HESS in SNRs
- Neutrino spectra predicted using gamma spectra
- Hypotheses: 100% hadronic emission and transparent source



RXJ1713.7-3946

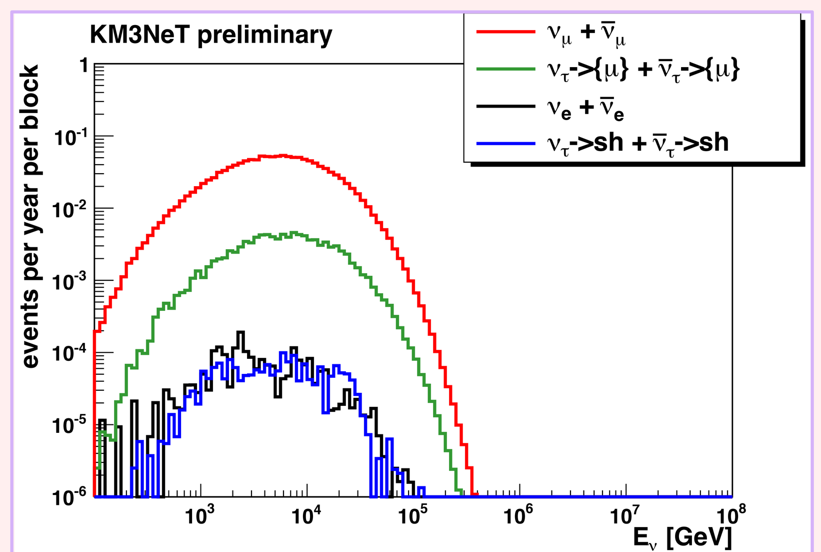
- ✓ HESS data in [11]
- ✓ Simulated as an homogeneous disk with 0.6° radius
- ✓ Neutrino spectrum [12]:

$$\Phi(E) = 16.8\times10^{-15}\left[\frac{E}{TeV}\right]^{-1.72} e^{-\sqrt{\frac{E}{2.1TeV}}}\, GeV^{-1}s^{-1}cm^{-2}$$

Vela X

- ✓ HESS data in [13]
- ✓ Simulated as an homogeneous disk with 0.8° radius
- ✓ Neutrino spectrum derived according to [14]:

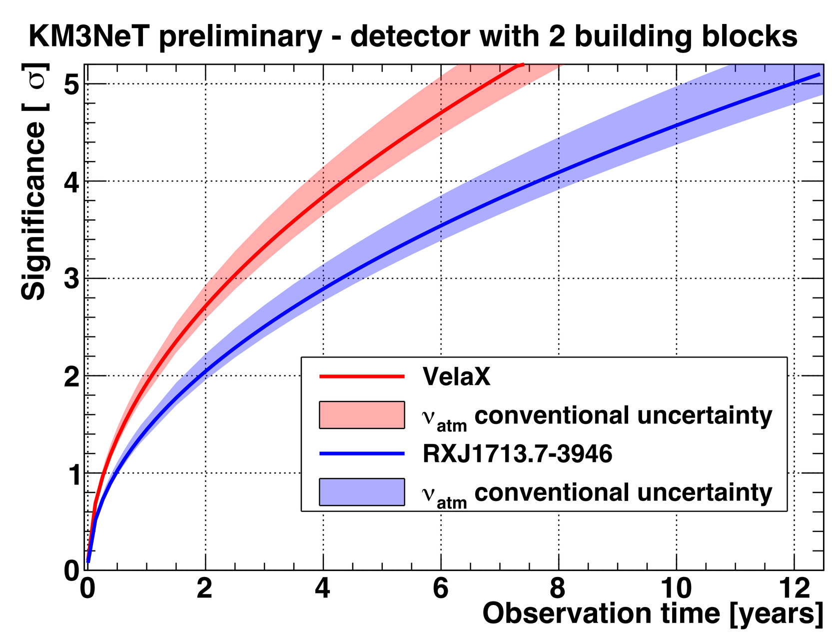
$$\Phi(E) = 7.2\times10^{-15}\left[\frac{E}{TeV}\right]^{-1.36} e^{-\frac{E}{7TeV}}\, GeV^{-1}s^{-1}cm^{-2}$$



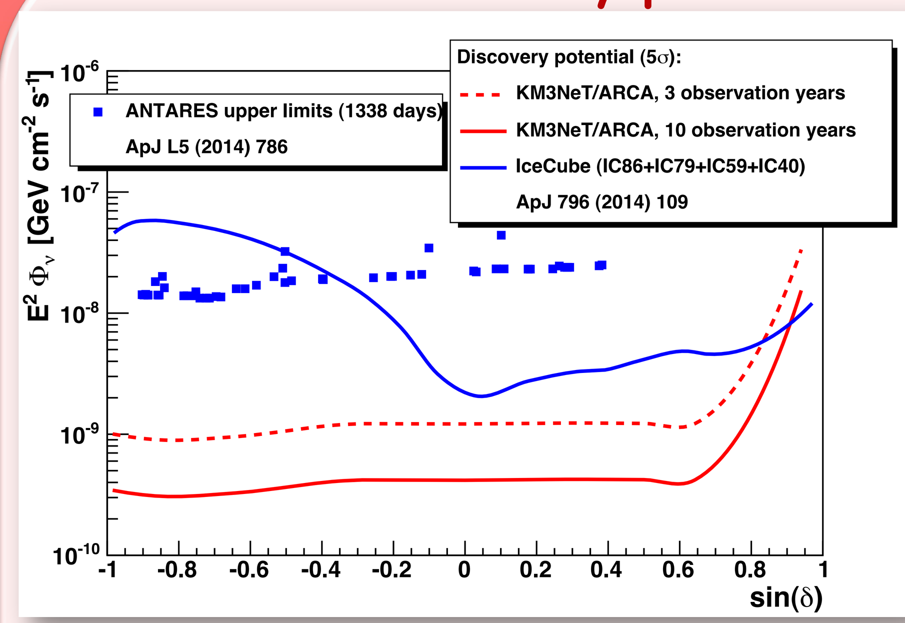
Energy distributions of the reconstructed events for CC interaction of different species of neutrinos expected from RX J1713.7-3946 after the cuts θ<102° and α<1°

Significance of the observation as a function of the observation time for KM3NeT/ARCA

- Observation with 3σ significance expected after about 2.5 and 4 years for the Vela X and the RXJ1713.7-3946 respectively
- An extension of KM3NeT at 6 blocks permit to reach a 5σ observation after about 2.5 and 4 years for the Vela X and the RXJ1713.7-3946 respectively



Discovery potential for E^{-2} point source



- KM3NeT/ARCA 5σ discovery flux for a generic point source with an E^{-2} spectrum as a function of the declination
- E^{-2} spectrum: approximation for the spectrum of extragalactic candidate neutrino sources
- 3 years observation time chosen to have for KM3NeT/ARCA a comparable exposure w.r.t. the IceCube results in [15]

KM3NeT has a very large field of view thus not only complementing, but also overlapping to a large extent the IceCube one

References

[1] P. Piattelli et al. (KM3NeT Collaboration), these proceedings (ID=1158).
[2] A. Margiotta et al. (ANTARES Collaboration) NIM A 725 (2013) 98.
[3] A. Trovato et al. (KM3NeT Collaboration), these proceedings (ID=1114)
[4] M. Honda, T. Kajita, K. Kasahara, S. Midorikawa, and T. Sanuki, Phys. Rev. D 75(2007) 043006.
[5] R. Enberg, M. H. Reno, and I. Sarcevic, Phys. Rev. D 78 (2008) 043005.
[6] M. G. Aartsen et al. (IceCube Collaboration), Phys. Rev. D 89 (2014) 062007.
[7] Y. Becherini et al., Astropart. Phys. 25 (2006) 1.
[8] A. Hoecker et al. PoS ACAT 040 (2006) 034018.
[9] G.C. Hill et al., World Scientific eProceedings, Statistical problems in particle physics, astrophysics and cosmology (2005) 108.
[10] J. Braun et al., Astropart. Phys. 29 (2008) 299.
[11] F. Aharonian et al. (H.E.S.S. Collaboration), A&A 464 (2007) 235-243; Corrigendum in A&A 531 (2011) C1.
[12] S.R. Kelner et al., Phys. Rev. D 74 (2006) 034018.
[13] A. Abramowski, et al. (H.E.S.S. Collaboration), 548 (2012) A38.
[14] F. L. Villante and F. Vissani, Phys. Rev. D 78 (2008) 103007; F. Vissani and F.L. Villante, NIM A 588 (2008) 123 and F. Vissani, Astr.Ph. 26 (2006) 310.
[15] M. G. Aartsen et al. (IceCube Collaboration), Astroph. J. 796 (2014) 109.