Search for neutrino emission from extended sources with the IceCube detector

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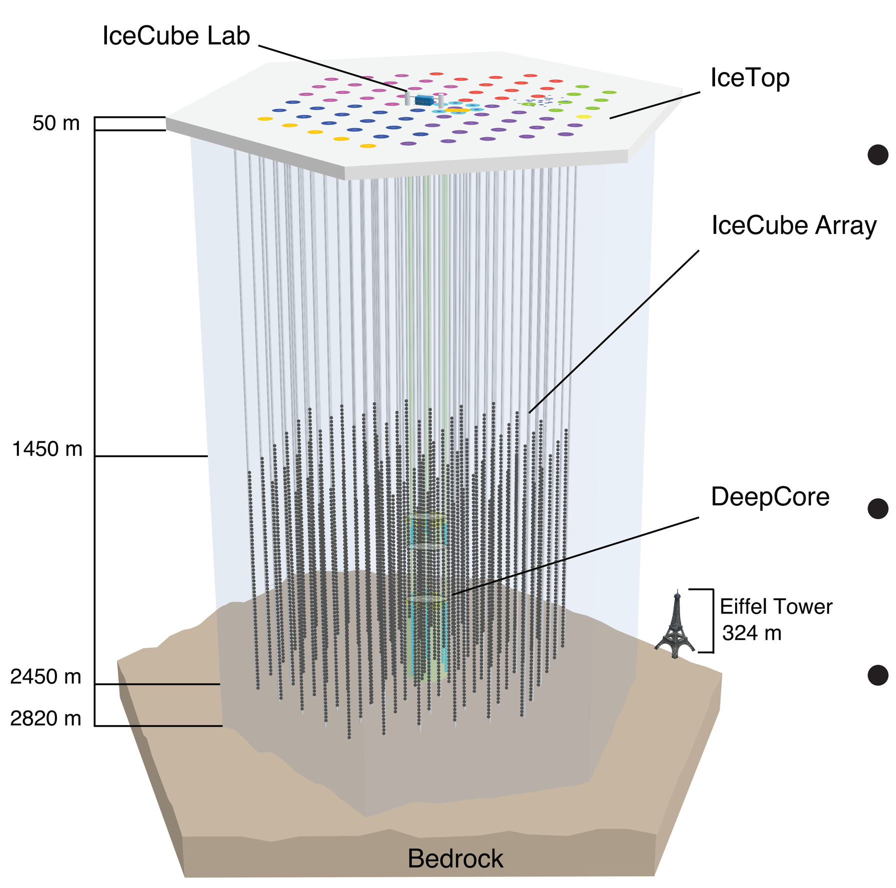
Abstract

The IceCube Neutrino Observatory, a cubic kilometer telescope located in the Antarctic ice, offers unique opportunities to study high-energy neutrino emission from galactic and extragalactic sources. The Galactic plane is the brightest source of gamma rays in the sky, and it is believed to be also one of the brightest sources of very energetic neutrinos. In 2013 the first observation of an astrophysical high-energy neutrino flux was announced by the IceCube collaboration and, although no clear sources have been found so far, it is reasonable to investigate whether a Galactic component might be contributing to the observed flux. As indicated by the HESS gamma-ray survey and by Milagro as well, many of the sources populating the Galactic plane are in fact extended sources. The sensitivity and discovery potential of IceCube for neutrinos coming from extended regions using 6 years of data will be presented.

The IceCube detector



- IceCube is the largest neutrino detector on Earth. It is located 1.5 km below the glacier surface in the deep ice of Antarctica.
- 86 strings have been deployed, each containing 60 Digital Optical Modules (DOMs) with a PMT to measure Cherenkov radiation of high energy leptons propagating through the ice.
- Neutrinos have neutral charge ⇒ travel straight from the source to Earth.
- Neutrinos only interact weakly ⇒ travel large distances without being hindered by matter.
- Astrophysical neutrinos are tracers of hadronic interactions ⇒ help to clarify cosmic ray acceleration processes.

Method

This analysis uses an unbinned maximum likelihood test [4], that calculates the significance of an excess of neutrinos above the background for a given direction. For a data sample of N total events, the p.d.f. of the i^{th} event with reconstructed energy E_i and angular distance to the source $|\vec{x}_i - \vec{x}_s|$ is given by:

$$P_i(|\vec{x}_i - \vec{x}_s|, E_i, \gamma, n_s) = \frac{n_s}{N} S_i + \left(1 - \frac{n_s}{N}\right) B_i$$

where S_i and B_i are the signal and background p.d.f. respectively, and n_s is the number of signal events. The signal p.d.f. used is given by:

$$S_i = s_i(|\vec{x}_i - \vec{x}_s|, \sigma_i, \sigma_{src})\epsilon_i(E_i, \delta_i, \gamma)$$

s_i is the space contribution and depends on the angular uncertainty σ_i, the angular difference between the reconstructed direction of the event and the source position and the extension of the source. The spatial probability distribution function is still assumed to be a 2-D Gaussian but, contrary to the regular point source analysis, the width is determined by:

$$S_i = \frac{1}{2\pi(\sigma_i^2 + \sigma_{src}^2)} \exp\left(-\frac{|\vec{x}_i - \vec{x}_s|^2}{2(\sigma_i^2 + \sigma_{src}^2)}\right)$$

The energy ϵ_i and background B_i p.d.f remain the same as for the regular point source method described in Ref. [5].

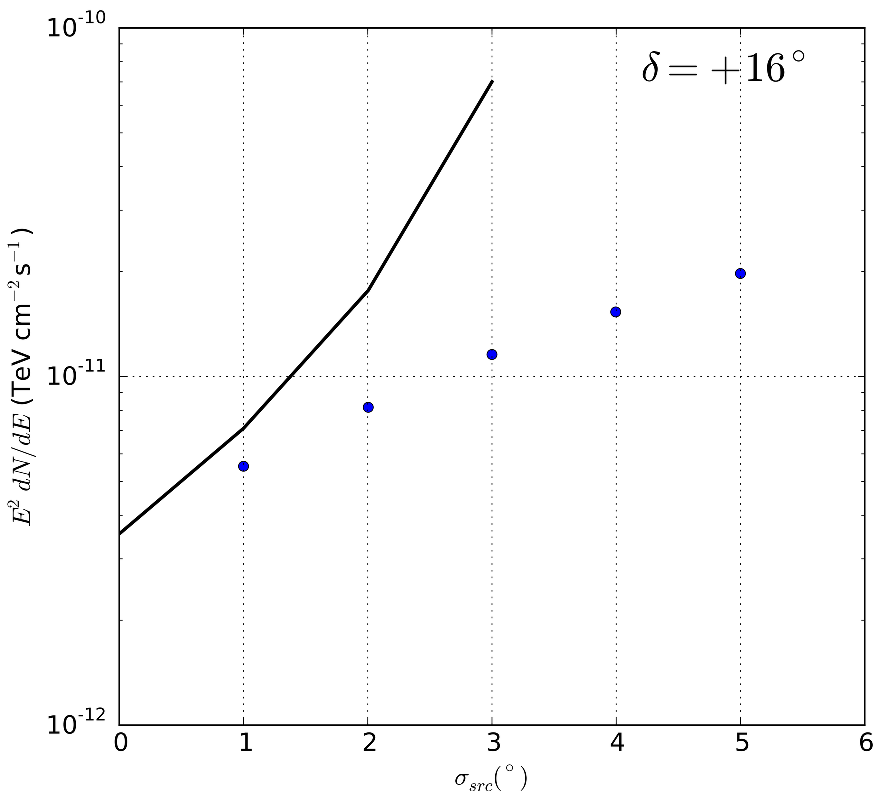
Scientific Motivation

The γ-ray astronomy provides a strong motivation to look for extended sources:

- the HESS survey of the inner part of the Galactic Plane has revealed a number of bright extended γ-ray sources [1];
- the same sources are seen by the Fermi-LAT survey of the Galactic Plane above 100 GeV [2];
- it is possible that these are locations of recent injections of $E > 1$ TeV cosmic rays in the Galaxy [2].

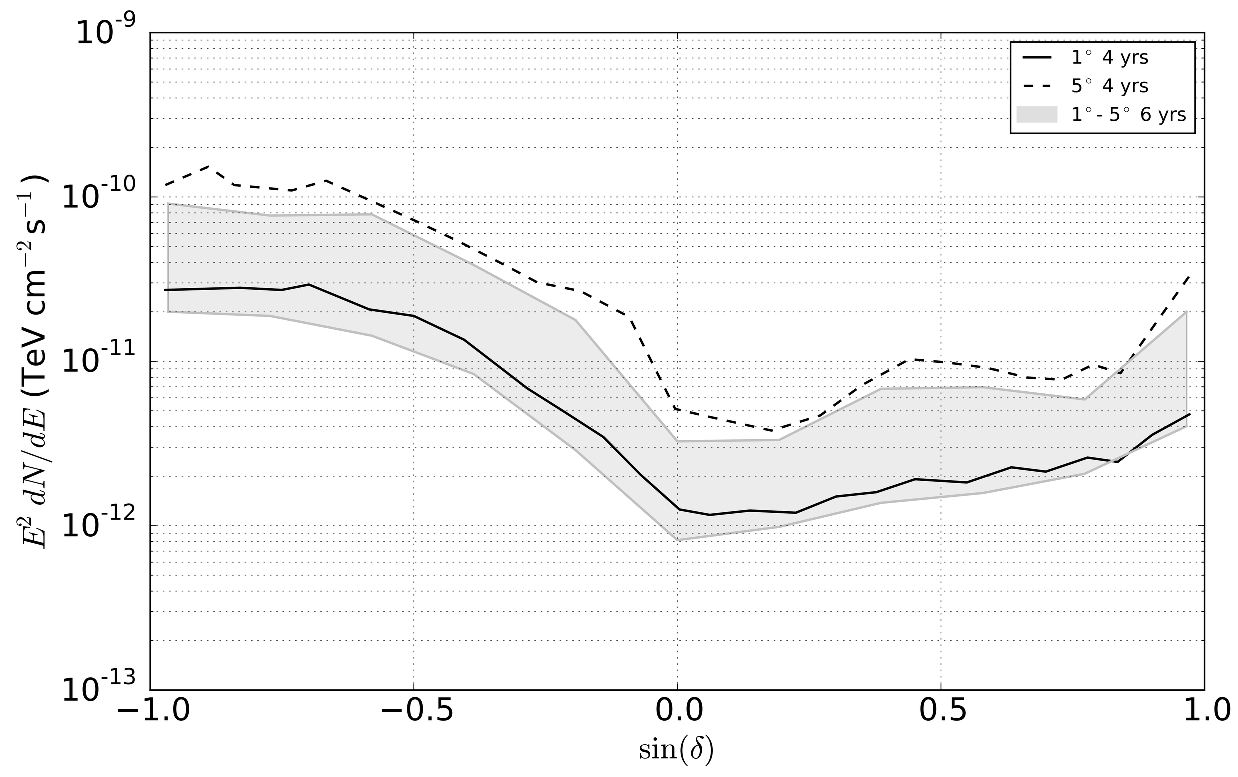
⇓

If the observed γ-rays are produced by CR interactions, a very-high-energy neutrino flux should be associated as well. If detected, this would represent an unambiguous proof of the hadronic nature of the sources.

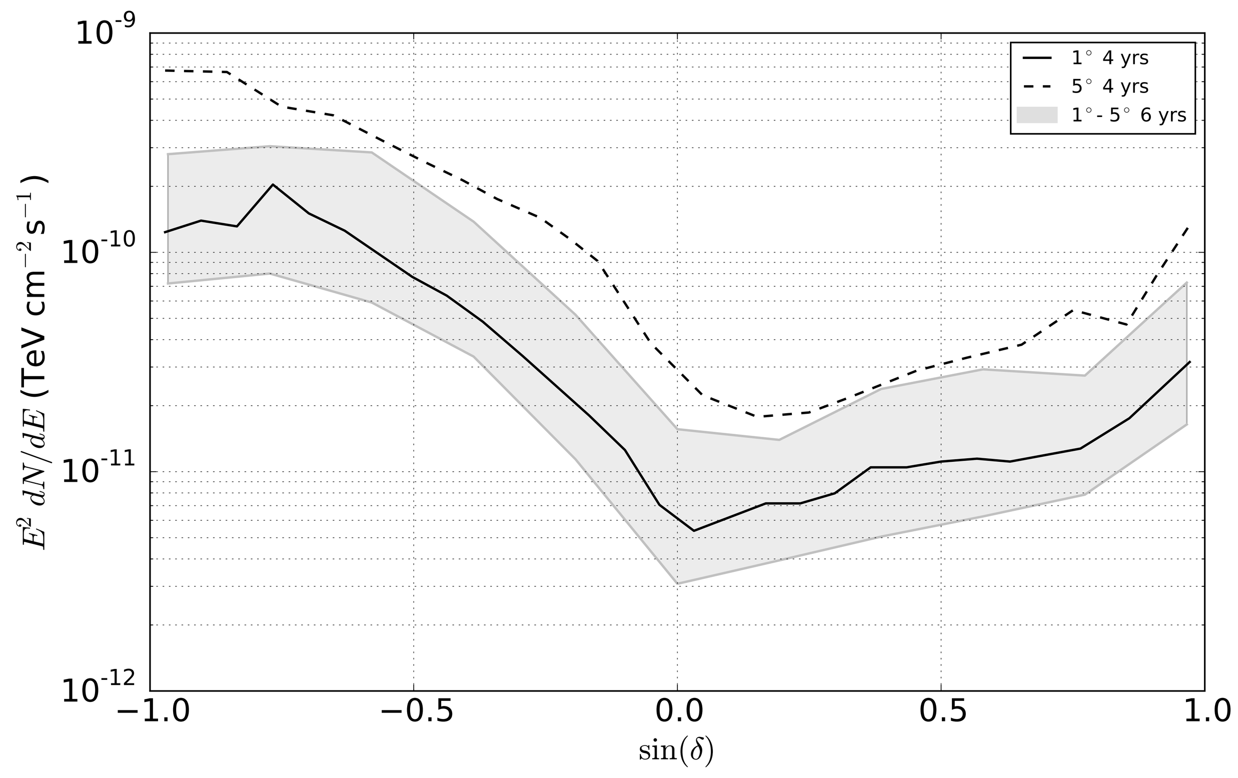


Assuming the presence of extended sources and modelling the signal injection accordingly to its extension, this plot shows the comparison between an analysis that uses the regular point source method to analyse this signal and an analysis that instead takes into account the spatial extension in the likelihood method, assuming each time a different spatial extension from 1° to 5° [3].

Sensitivity and Discovery Potential



Sensitivity for an E^{-2} neutrino flux from an extended source considering various extensions from one to five degrees, using the correct extension in the likelihood. The silver band represent the 6 years sensitivity interval from 1° to 5° source extension, whereas the black solid and dotted lines represent the sensitivity for 1° and 5° for 4 years of data.



Discovery potential for an E^{-2} neutrino flux from an extended source considering various extensions from one to five degrees, using the correct extension in the likelihood. The silver band represent the 6 years discovery potential interval from 1° to 5° source extension, whereas the black solid and dotted lines represent the discovery potential for 1° and 5° for 4 years of data.

References

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[4] J. Braun, M. Baker, J. Dumm, C. Finley, A. Karle, and T. Montaruli, *Astroparticle Physics* **33** (Apr., 2010) 175–181, [arXiv:0912.1572].

[5] **IceCube** Collaboration, M. Aartsen et al., *Phys.Rev.Lett.* **113** (2014) 101101, [arXiv:1405.5303].