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Statistical methods for point-like neutrino searches

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Summary. — The search of high energy neutrinos ($> 100\,\text{GeV}$) from point-like sources is one of the main goals of under-water or under-ice neutrino telescopes. In this report the sensitivity and discovery potential estimated with two different statistical methods for a multi kilometer under-water telescope are compared.

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The main goal of neutrino telescopes is the search of neutrinos from point-like sources, that is based on the detection of an excess of signal from uniform background in a given direction in the sky.

The background is represented by atmospheric muons and neutrinos produced in the interaction of a high energy cosmic ray with the atmosphere. The expected performance of a neutrino telescope is calculated by means of Monte Carlo (MC) simulations that generate neutrino from point-like source and from background, their interaction and the detectors response. The MC software adopted for the simulations in this work is the ANTARES software adapted to a km^3-scale detector.

In order to detect very small number of events from cosmic sources amongst large backgrounds statistical methods are needed. The two main methods used are the binned and unbinned methods.

In the binned method the sky is divided into bins of declination and right ascension and the fluctuations on the number of events detected are analyzed inside the bin. The search of an excess due to events from a source is performed assuming a Poisson distribution of the events and optimizing the cone aperture. The Model Rejection Factor (MRF) [1] and Model Discovery Potential (MDP) [2] have been applied to evaluate the sensitivities and the discovery fluxes, respectively. The average number of events from a point-like source, at a given declination and spectral index is estimated by means of MC simulations, as well as the average number of background events inside the selected search cone centered on the source direction. The parameters that are optimised in order to minimise the MRF and MDP are the size of the search cone around the source, the cut on the reconstruction quality parameter and the cut on the number of hits that is related to the neutrino energy.

$\delta = -60°$	*Flux Unbinned*	*Flux Binned*
1 year of data taking	$(GeV cm^{-2} s^{-1})$	$(GeV cm^{-2} s^{-1})$
Discovery 90%$C.L_{5\sigma}$	$2.14 \cdot 10^{-9}$	$2.87 \cdot 10^{-9}$
Discovery 90%$C.L_{3\sigma}$	$1.18 \cdot 10^{-9}$	$1.66 \cdot 10^{-9}$
Sensitivity 90%$C.L$	$0.64 \cdot 10^{-9}$	$0.86 \cdot 10^{-9}$

Fig. 1. – Sensitivity and Discovery Potential for the KM3NeT detector for ν point source at declination $-60°$ and 1 year of data taking.

The unbinned maximum-likelihood method is based on a likelihood function, LR, which depends on probability density functions (PDF) for the signal ($P_{sig}(\alpha_i)$) and for the background ($P_{bkg}(\alpha_i)$), for a given angular distance from the source α_i, and the total number of events N: $LR = \sum_{i=1}^{N} \log \frac{\frac{n_{sig}}{N} \times P_{sig}(\alpha_i) + (1 - \frac{n_{sig}}{N}) \times P_{bkg}(\alpha_i)}{P_{bkg}(\alpha_i)}$.

The number of signal events, n_{sig}, is found by maximizing the likelihood ratio of the background plus signal hypothesis against the background-only case. The number N of events in each sample corresponds to the number of background events expected in one year of data taking and the PDF functions were estimated by means of MC simulations. The MC samples are constructed, with values of declination and right ascension of reconstructed tracks randomizing the last one.

The preliminary estimates of the discovery potential and sensitivity calculated with the binned and unbinned methods for the KM3NeT detector [3] are reported in fig. 1. An average improvement of the sensitivity and discovery of about 25% is found when the unbinned method is applied.

The unbinned sensitivity at 90% CL of the KM3NeT detector to neutrino point sources, assuming E^{-2} spectrum based on one year of observation time, is shown in fig. 2 (dashed grey line) as a function of the source declination. For comparison the plot shows the sensitivity flux for the KM3NeT detector estimated with the binned method (grey full line) [3] and for IceCube [4] (black dashed line) estimated with an unbinned method and a likelihood that exploits the reconstructed energy information. The differences in shape of the sensitivity curves for KM3NeT and IceCube are caused by the different geographic location, the effect of neutrino absorption in the Earth and the different detector responses as a function of the zenith angle. The estimated unbinned sensitivity can be further improved if a dependence of the likelihood on the reconstructed neutrino energy is included.

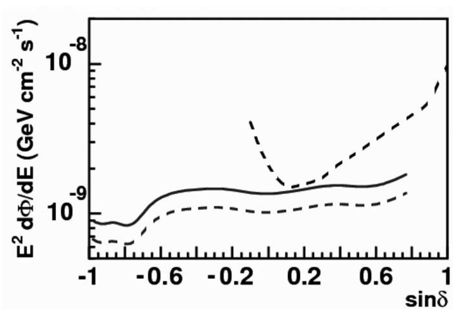

Fig. 2. – Sensitivity for one year of observation, as a function of the source declination (see text).

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