KM3NeT/ARCA SENSITIVITY TO TRANSIENT NEUTRINO SOURCES

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On behalf of the KM3NeT Collaboration

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Abstract

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The KM3NeT Collaboration is constructing a km^3-volume neutrino telescope in the Mediterranean sea, called ARCA (Astroparticle Research with Cosmics in the Abyss), that will achieve an unprecedented sensitivity to high-energy cosmic neutrinos. This telescope will be able to reconstruct the arrival direction of the neutrinos with a precision of 0.1°. The configuration of ARCA makes it sensitive to neutrinos in a wide energy range, from sub-TeV up to tens of PeV. Moreover, this detector has a large field of view and a very high duty cycle, allowing for full-sky (and all-flavours) searches. All these features make ARCA an excellent instrument to study transient neutrino sources.

Atmospheric muons and neutrinos, produced by primary cosmic rays, constitute the main background for ARCA. This background can be several orders of magnitude higher than the expected cosmic neutrino flux. In this work, we introduce an event selection which reduces the background up to a negligible level inside the region of interest and within the search time window. The ARCA performance to detect a transient neutrino flux, including the effective area, sensitivity and discovery potential, are provided for a given test source, and for different time windows.

KM3NeT/ARCA

ARCA, located 100 km away from Portopalo di Capo Passero (Sicily) at a depth of 3500 m, is the high energy array of the two KM3NeT detectors. It will consist of two building blocks with 115 lines each. These lines, known as Detection Units (Fig.[1]), have embedded several photo-multiplier tubes. The objective is the detection of the **Cherenkov light** that the charged particles associated with a neutrino interaction generate.

The design of ARCA, which holds a volume of 0.48 km^3, allows this detector to cover an energy range ideal for its main objective: the observation and study of sources in the Universe which emit high-energy neutrinos. In a **multi-messenger context**, this detector will be able to send alerts and perform the follow-up of cosmic events such as transient sources (i.e. with a time-dependent emission).

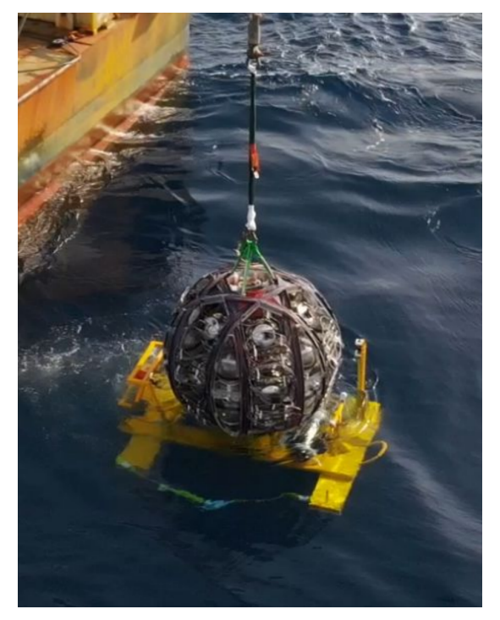


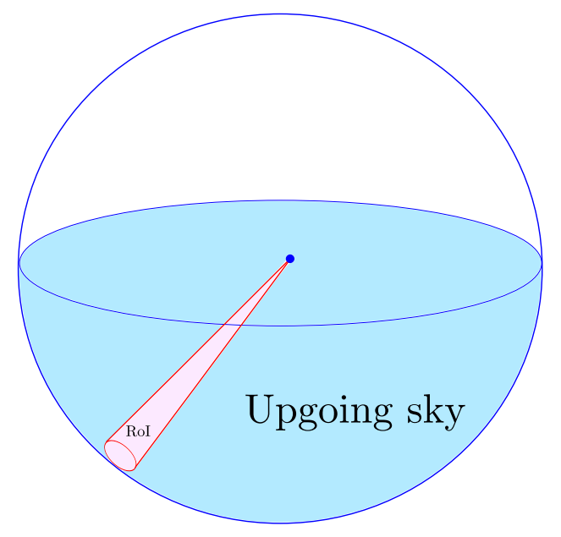
Fig. 1: Deployment of a Detection Unit of ARCA last April. Check here a video of this deployment.

Search method

- **Binned cut-and-count technique:** we set the event selection cuts on the variables of the reconstruction (table [1]).
- **Time windows** (flare durations) evaluated: 1000 seconds, one day and ten days.
- Results obtained for a **reference source** at $(\theta, \varphi) = (70^\circ, 300^\circ)$.
- **Upgoing events** only (i.e. events crossing the Earth before reaching the detector).
- Events reconstructed with the official KM3NeT reconstruction algorithm for **tracks** [1].
  - *Track-like events:* hit pattern compatible with a line, characteristic of a muon's pathway in water. Typical of ν_μ CC and some ν_τ CC events.
  - *Shower-like events:* the hit pattern is a quasi-spherical light emission from a given point. Typical of ν_e CC, ν NC and some ν_τ CC events.

Zenith	Angle from the zenith of the upgoing sky
β_0	Angular error estimation
Length	Track extension in meters
Likelihood	Quality parameter

Tab. 1: Some variables of the reconstruction



- **Region of Interest:** sky region selected to search for space coincidences with an identified signal.
  - Given by the angle between the reconstruction direction of each event and the direction of the source.
- **Cosmic neutrino** spectrum considered: $\Phi = 10^{-9}(E/\text{GeV})^{-2}\ \text{GeV}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$
- **Atmospheric neutrino** spectrum: Honda2006 model [2] with a correction at the knee in the cosmic-ray spectrum.

Optimization procedure. The Model Rejection Factor

Optimization scheme

1. **Determination of the pre-cuts:** used to reduce as much as possible the shower contamination in our clean track sample.
   - Variables used in the optimization: reconstructed β_0 and track length.
     - We expect showers to have large values of β_0 and small length values.
   - We searched for the pre-cuts that reduce the shower contamination to 1% or less while the survival fraction of track signal events is maximised.
   - Best pre-cuts: shower cont. of 0.94% and 72% of track signal that survives.
2. **Determination of the RoI radius:** based on the Model Rejection Factor.
   - The optimum RoI radii provided by the minimum MRF for the three time windows considered are given in table [3].
   - MRF is not sensitive to cuts in the likelihood (the background is very much reduced once the pre-cuts are applied and the search is restricted to the optimum RoI).

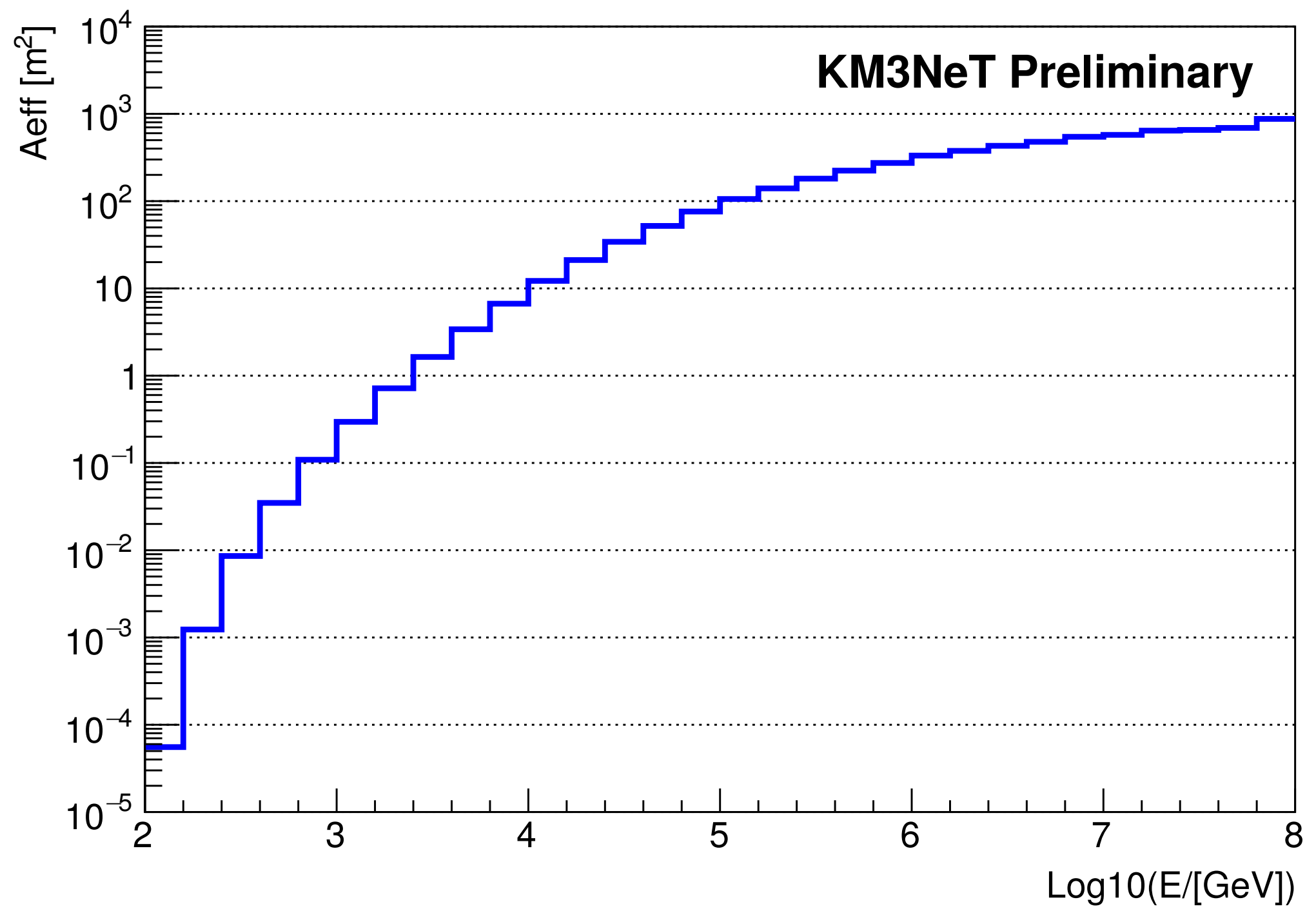


Fig. 3: Effective area for two building-blocks of ARCA using the optimum pre-cuts obtained.

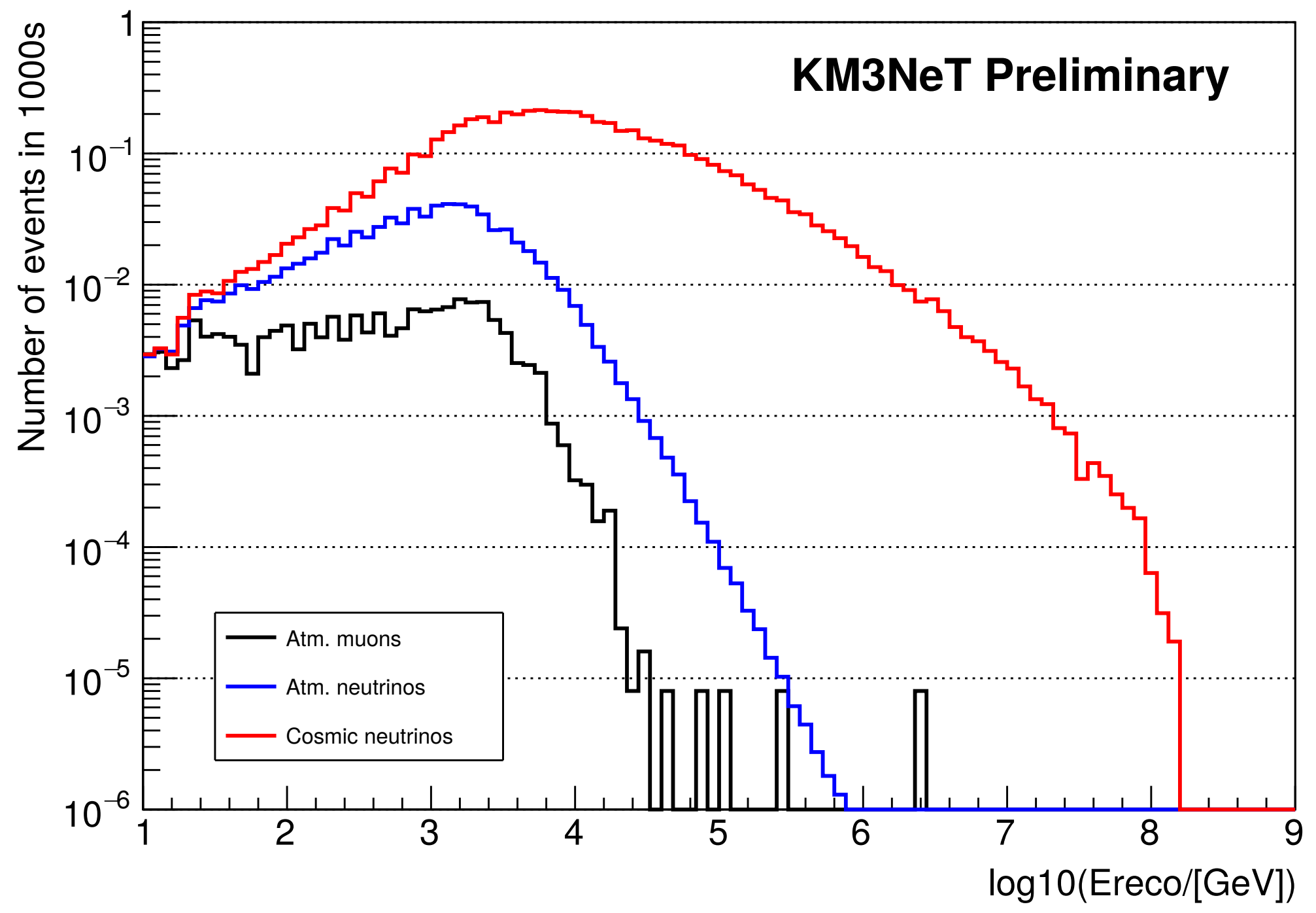


Fig. 2: Energy distribution of events for one building block of ARCA with the pre-cuts applied.

Optimum pre-cuts and RoI radius for a time window of 1000 s:
Upgoing cut + $\log_{10}\beta_0 < -0.7$ + length > 340 m + RoI radius = 6.5°

	Upgoing cut	+ β_0 cut	+ length cut	RoI (6.5°)
Cosmic ν	10.4	6.4	5.4	5.3
Atm. ν	1.4	0.79	0.74	$5.1 \cdot 10^{-3}$
Atm. muons	3.4	0.21	0.16	$0.96 \cdot 10^{-3}$

Tab. 2: Expected number of events for 1000 s of operation of one building block of ARCA, for a source located at $(\theta, \varphi) = (70^\circ, 300^\circ)$.

- The pre-cuts are independent of the time window.
- The median angular resolution once the pre-cuts are applied is 0.3°
- Background three orders of magnitude below the signal for this selection.

Fluence Sensitivity and Discovery Potential

- The expected number of signal events is related to the acceptance through the flux normalization factor Φ_0.
- Fluence sensitivity = average Feldman-Cousins [3] upper limit divided by the acceptance

$$\mathrm{A}_{cc} = \int \mathrm{d}t \int \mathrm{d}E_\nu A_{eff}(E_\nu) E_\nu^{-\gamma}.$$

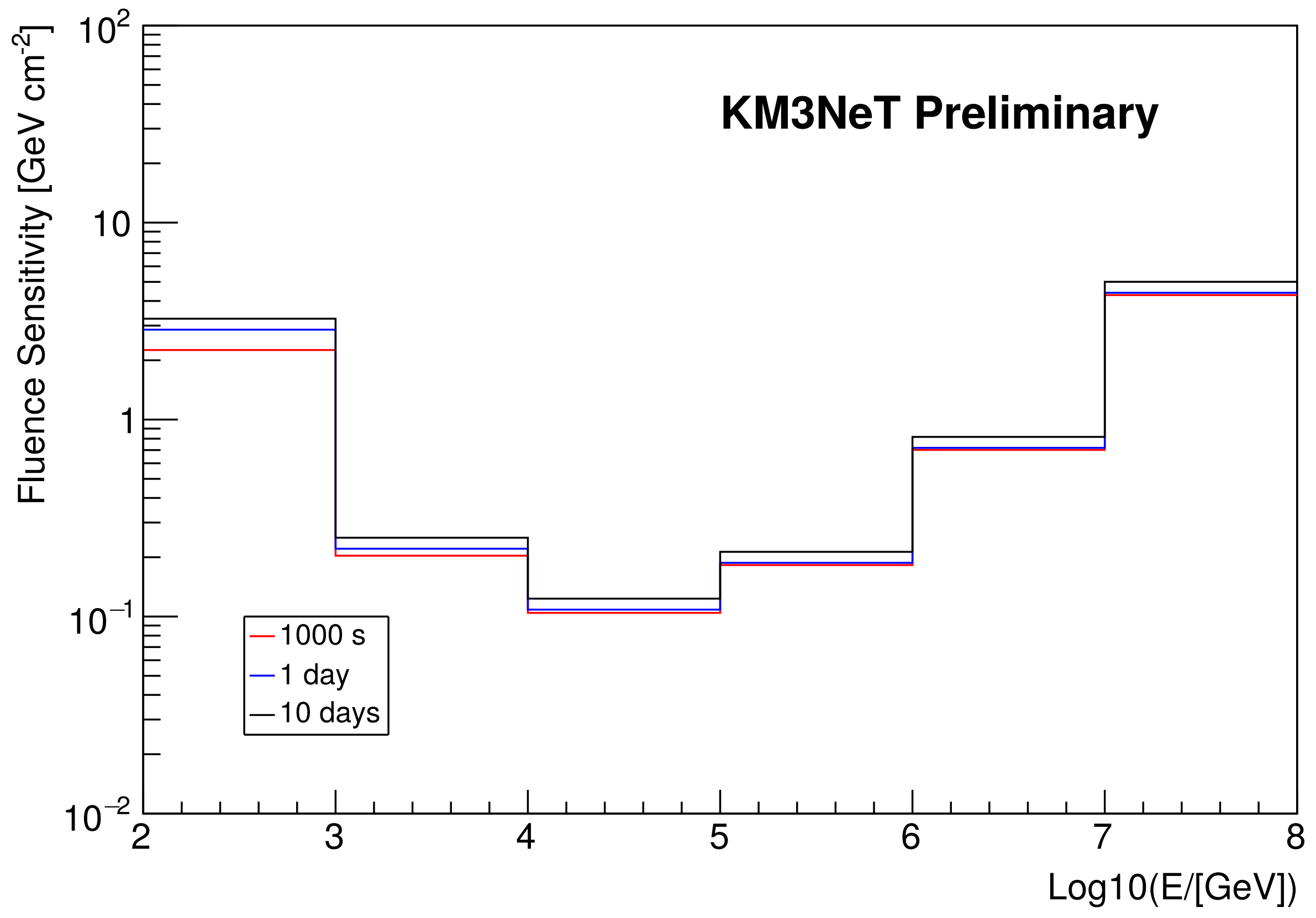


Fig. 4: Differential fluence sensitivity as a function of the neutrino energy for the two building-blocks of the ARCA detector, for the three different time windows considered in this analysis.

Time window	**Optimum RoI radius**	**Expected background events**	**Fluence sensitivity** (GeV $\cdot$ cm^{-2})	**Discovery** $N_{\text{sg}}^{5\sigma}(50\%)$
1000 s	6.5°	$1.2 \cdot 10^{-2}$	0.047	2.7
1 day	3.0°	$3.3 \cdot 10^{-2}$	0.050	3.6
10 days	2.0°	$1.2 \cdot 10^{-1}$	0.061	4.6

Tab. 3: Sensitivity and discovery potential values for the optimum RoI radius obtained using the MRF method. The expected number of background events are given for two building-blocks of ARCA.

Conclusions and perspectives

- We can compare the order of magnitude of our sensitivity for 1000 s with results from similar analyses of other neutrino telescopes:
  - ANTARES: $\sim 0.8 - 1.4$ GeV cm^{-2}, $\sim [3\ \text{TeV}, 3\ \text{PeV}]$ (upgoing) [4].
  - IceCube: $\sim 0.03 - 0.7$ GeV cm^{-2}, $\sim [10\ \text{TeV}, 100\ \text{PeV}]$ (full sky) [5].
- Our limit is about two orders of magnitude more stringent than ANTARES and has a similar order of magnitude as the best ones of IceCube.
- We plan to extend this analysis to showers & downgoing events.
- Analysis ready to be applied to the available ARCA6 data.

The sensitivity obtained with this binned cut-and-count method is comparable to the best IceCube results in similar analyses of this field, covering a broader energy range.

References:

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