

Probing Star-forming Environments with KM3NeT/ARCA: expectations for the full detector

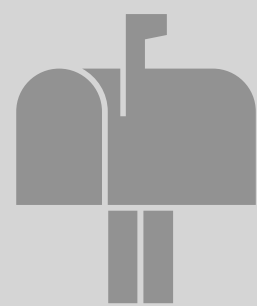
Antonio Ambrosone, Walid Idrissi Ibnsalih

In collaboration with

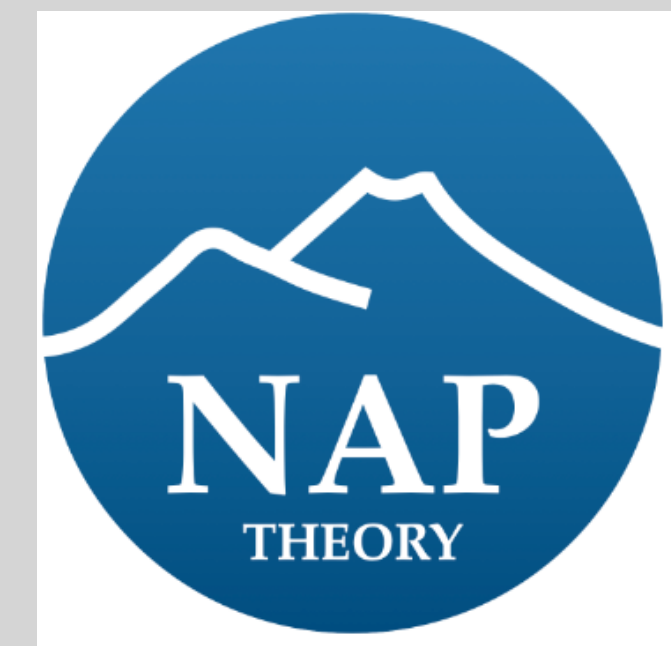
Antonio Marinelli, Gennaro Miele, Maria Rosaria Musone, Pasquale Migliozzi

on Behalf of the **KM3NeT Collaboration**

TeV Particle Astrophysics (TeVPA), Naples, 11-15 September 2023



antonio.ambrosone@unina.it



The KM3NeT Detector

KM3NeT is a neutrino detector under construction. It is distributed in two parts. ARCA (Astroparticle Research with Cosmics in the Abyss) and Orca (Oscillation Research with Cosmics in the Abyss).

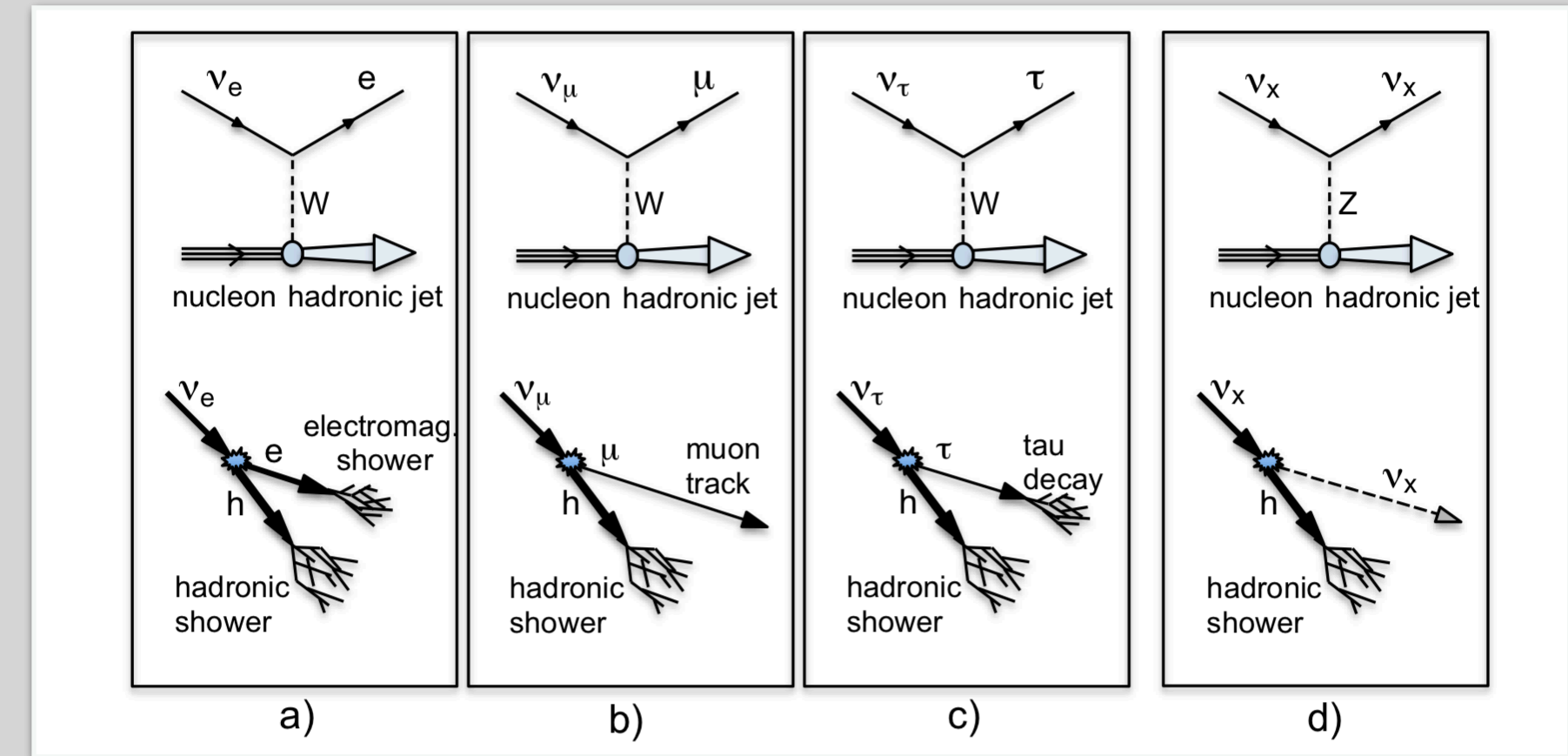
See Letter of Intent for KM3NeT 2.0, doi; 10.1088/0954-3899/43/8/084001

ARCA: Study of the high-energy astrophysical Neutrinos

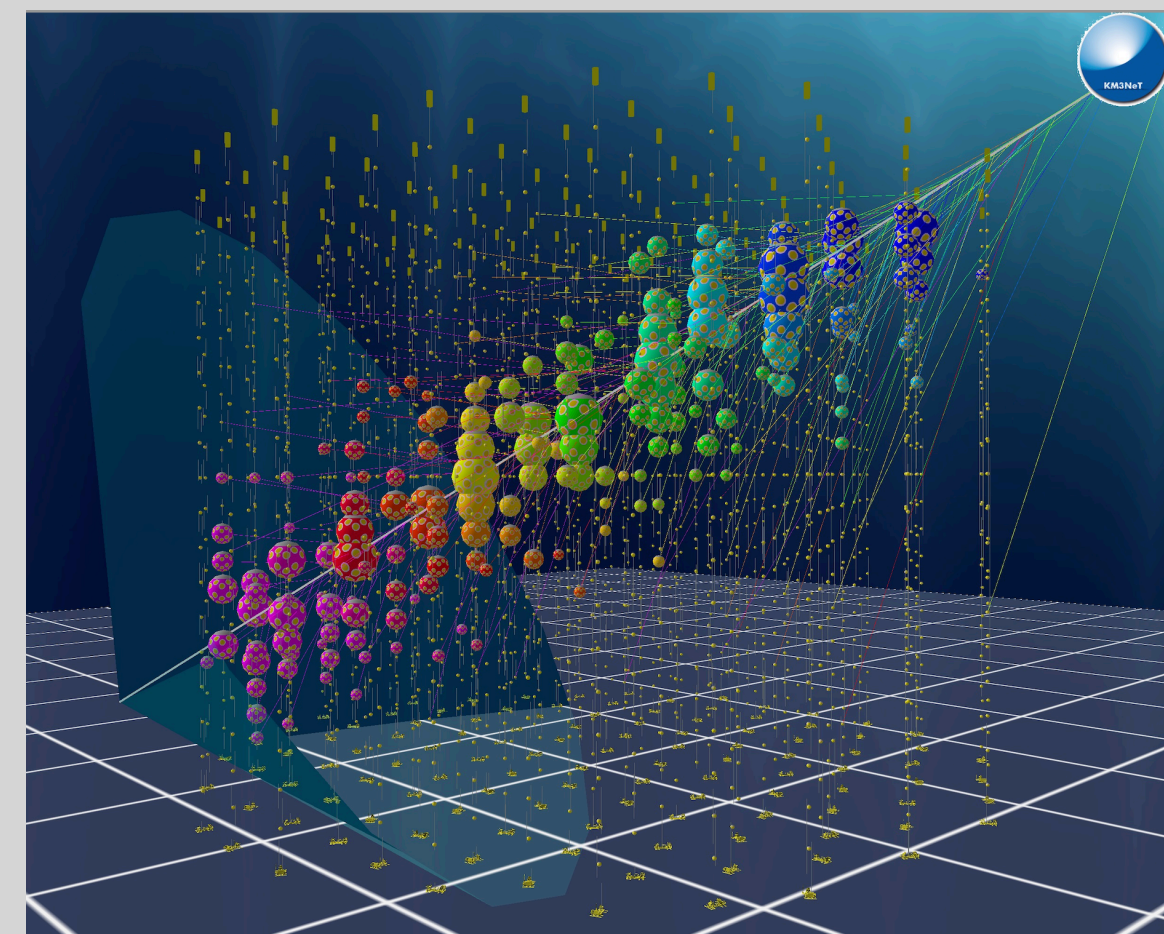
ORCA: Study of Neutrino Physics

<https://www.km3net.org/>

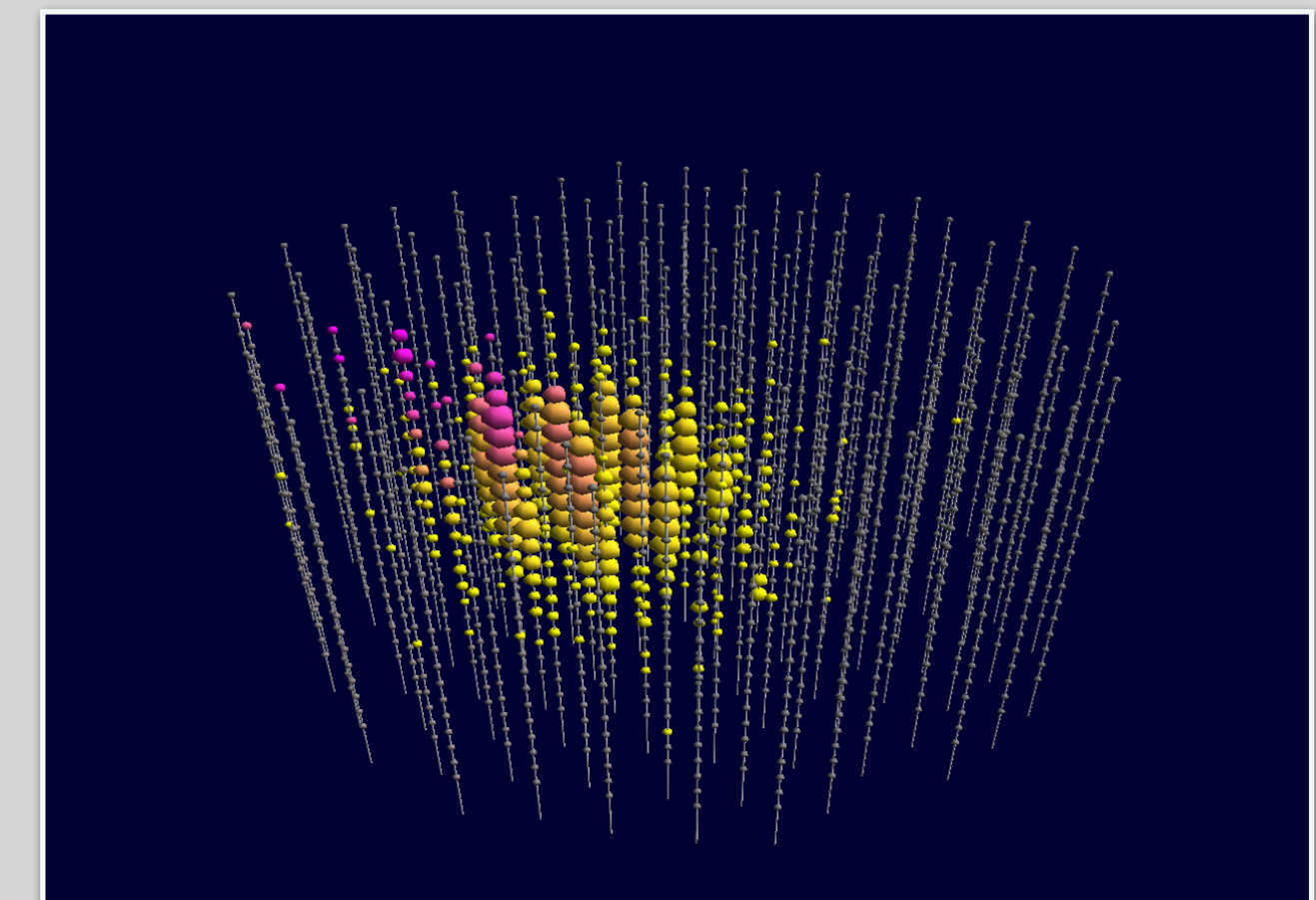
Detection Principle:



Track-like event



Shower-like Event



Although the detectors are under construction, KM3NeT is already operative (21 DUs for ARCA)

Neutrino Selection

- **Background:** μ atmospheric, ν atmospheric (ν_μ, ν_e, ν_τ)

- **Signal:** νE^{-2} Spectrum (ν_e, ν_μ, ν_τ)

Tracks

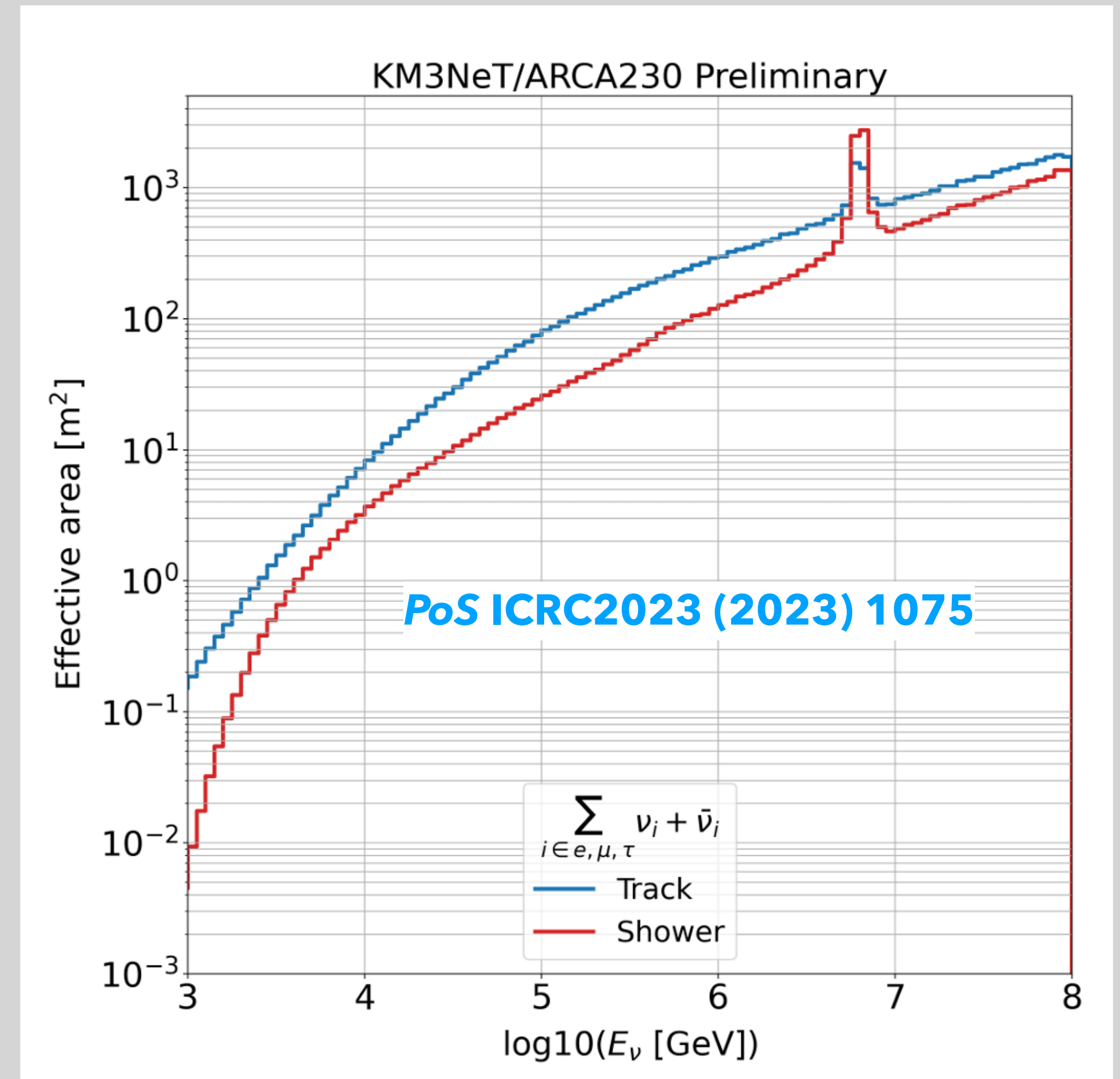
- **Up-going cut** ($\theta < 100^\circ$)
- **Long-track events** (Len > 300 m)

Cascades

- **All sky**
- **Contained events**
(fiducial volume)
($R_{det} < 600, Z_{det} < 650$)

For both channels, we finalize the selection by using a Boosted decision tree (BDT) (Machine learning technique)

See (PoS ICRC2023 (2023) 1074) for more details and (EPJ Web Conf. 280 (2023) 03001, J.Phys.Conf.Ser. 2429 (2023) 1, 012028)



Analysis Framework

The Detector Response Functions are used to obtain the expected signal and background distribution

Maximum Binned Likelihood Method

- Point-Like (extended) Analysis:

Binning in $\log(E_{\text{reco}})$ and in cone angle (α)

- Diffuse Analysis:

Binning in $\log(E_{\text{reco}})$

$$\mathcal{L} = \prod_{i,j} P(n_{i,j} | \lambda \mu_s^{i,j} + \mu_b^{i,j})$$

We determine the Test Statistics (TS)

$$\text{TS} = \log \frac{\mathcal{L}(\lambda)}{\mathcal{L}(\lambda = 0)}$$

Example: Signal and Background distribution

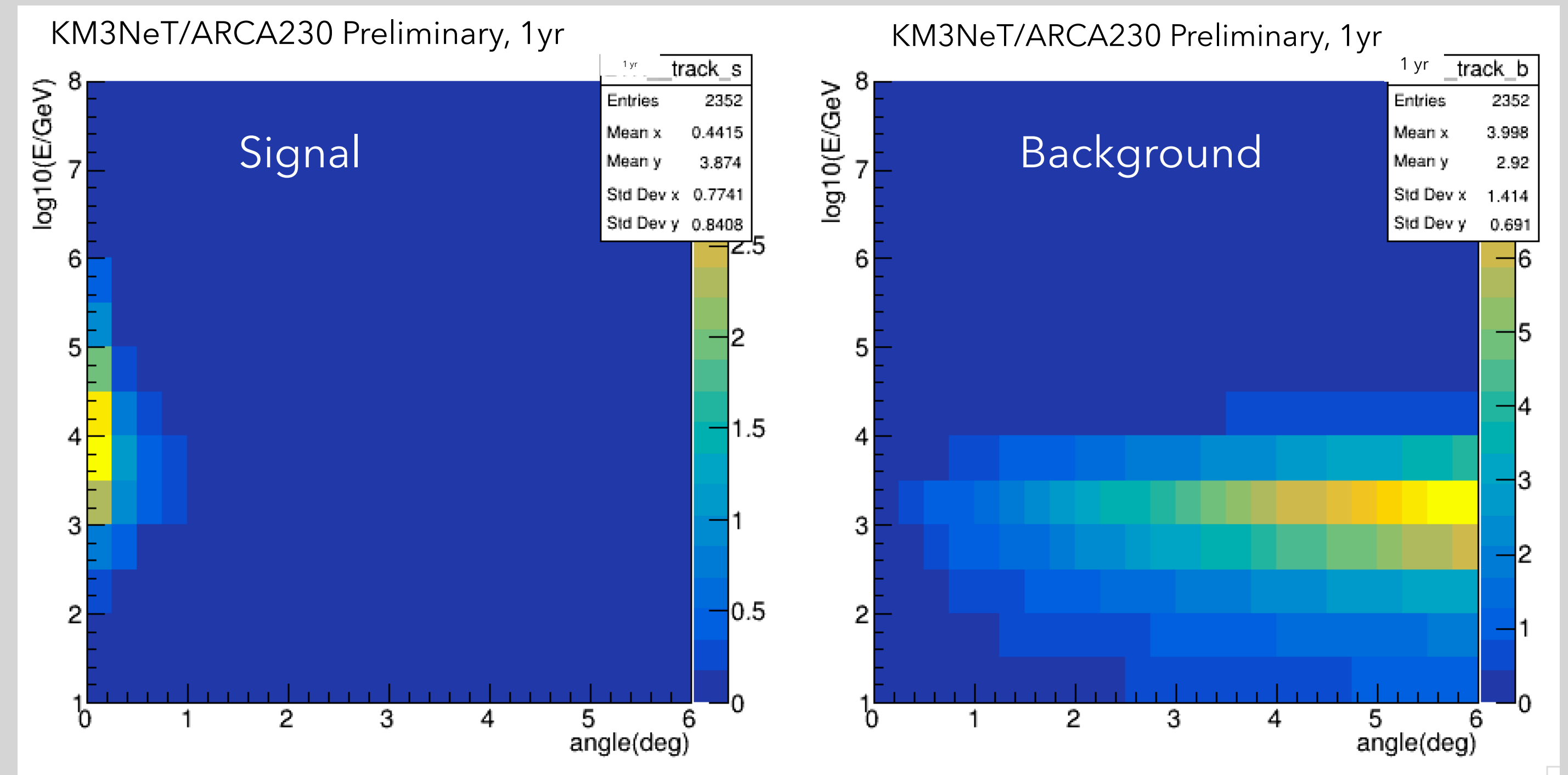
- ◆ We study the sensitivity by using the Pseudo experiment (PE) technique

Sensitivity Definition

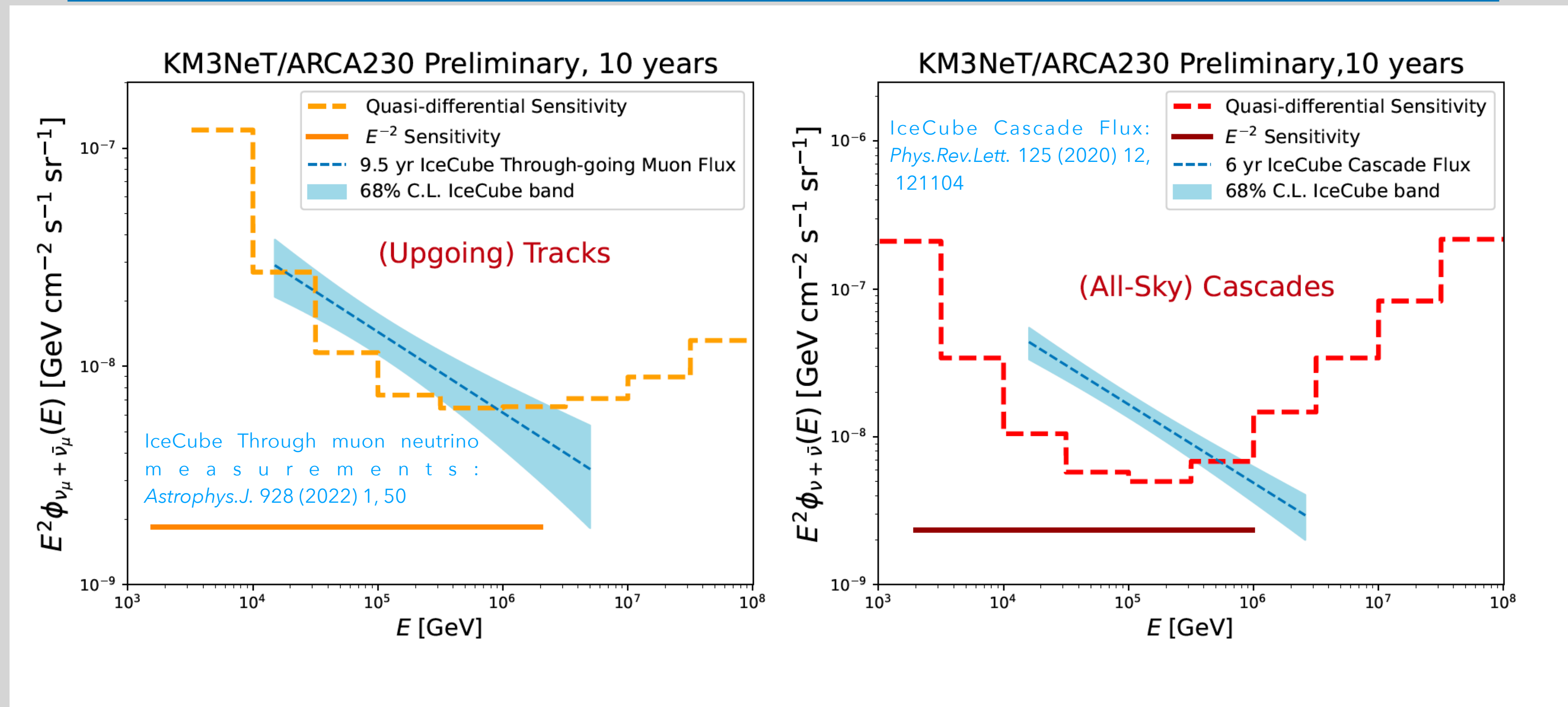
TS_m is the median TS in the background-only distribution

$$\int_{\text{TS}_m}^{+\infty} d(\text{TS} | \lambda_{90}) d\text{TS} = 90 \%$$

See *PoS ICRC2023 (2023) 1150* for more details



Diffuse Analysis Result



◆ KM3NeT/ARCA sensitivity for tracks and cascades peak at different energies

◆ KM3NeT/ARCA will crucially probe the diffuse neutrino flux in few years of Data Taking

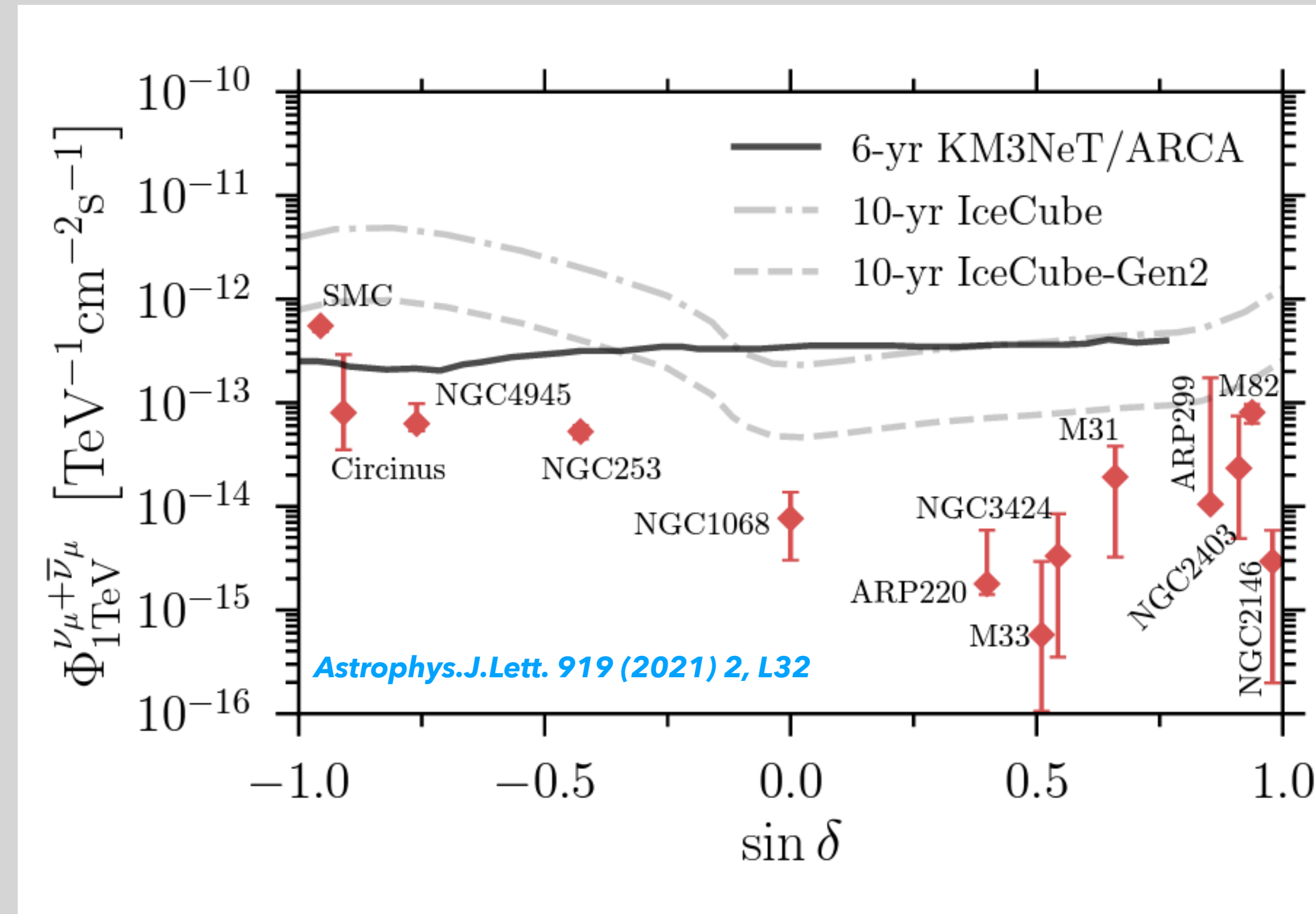
◆ KM3NeT/ARCA Differential Limits set the capabilities of the detector independently on the energy spectrum



They provide the expected capabilities of KM3NeT/ARCA outside the energy of the IceCube Flux

Point-Like Analysis: Theoretical Expectations

The Expected Neutrino Emission from local SBGs discovered by Fermi-LAT as GeV γ -ray emitters



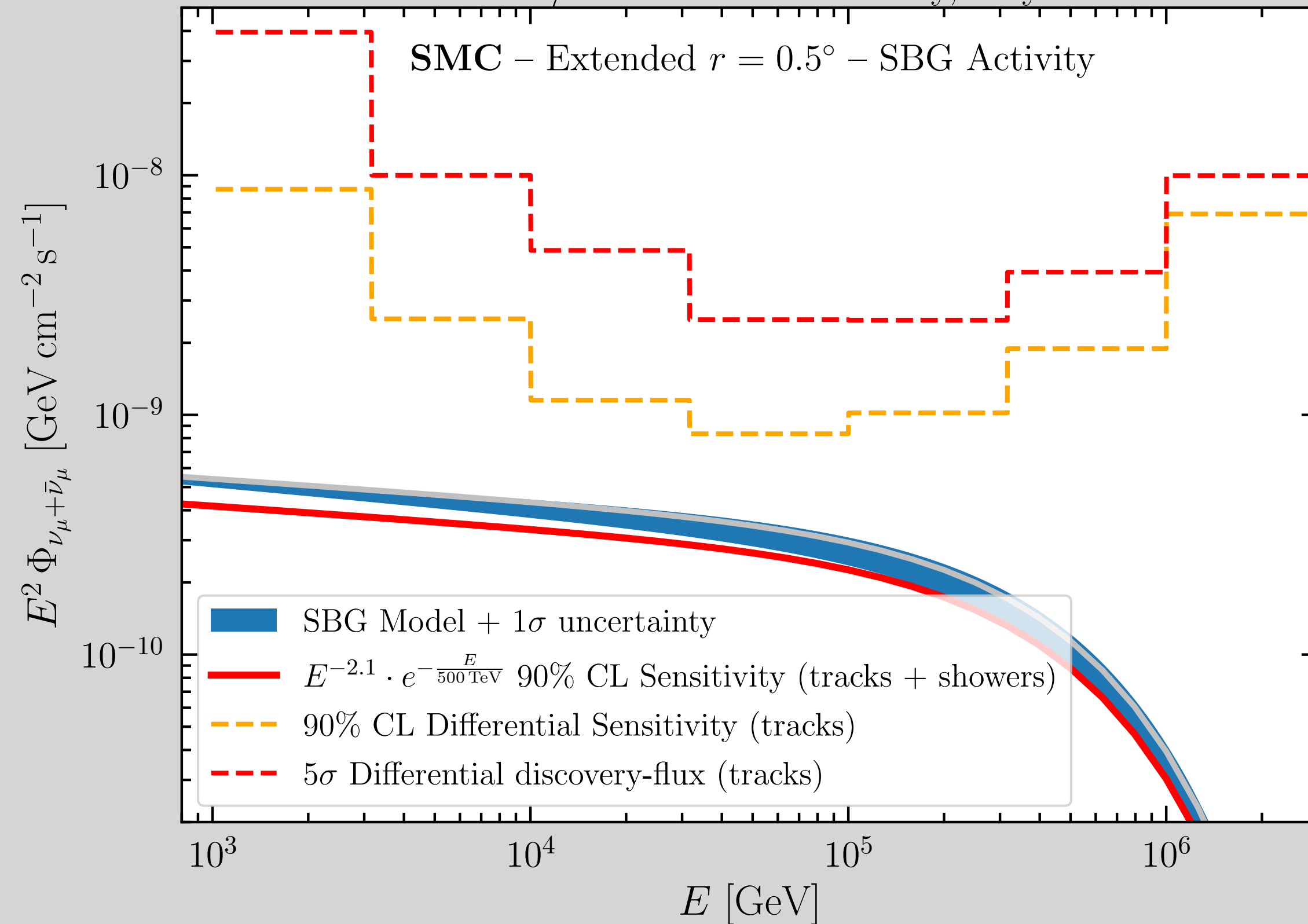
These normalizations take only into account the SBG activity. It does not consider a possible (in a few cases) AGN activity

- ◆ SMC can in principle be constrained by KM3NeT/ARCA after few years of data taking
- ◆ The Circinus Galaxy might also be in the reach of KM3NeT/ARCA
- ◆ NGC 1068 can only be probed as AGN source (see IceCube result *Science* 378 (2022) 6619, 538-543)

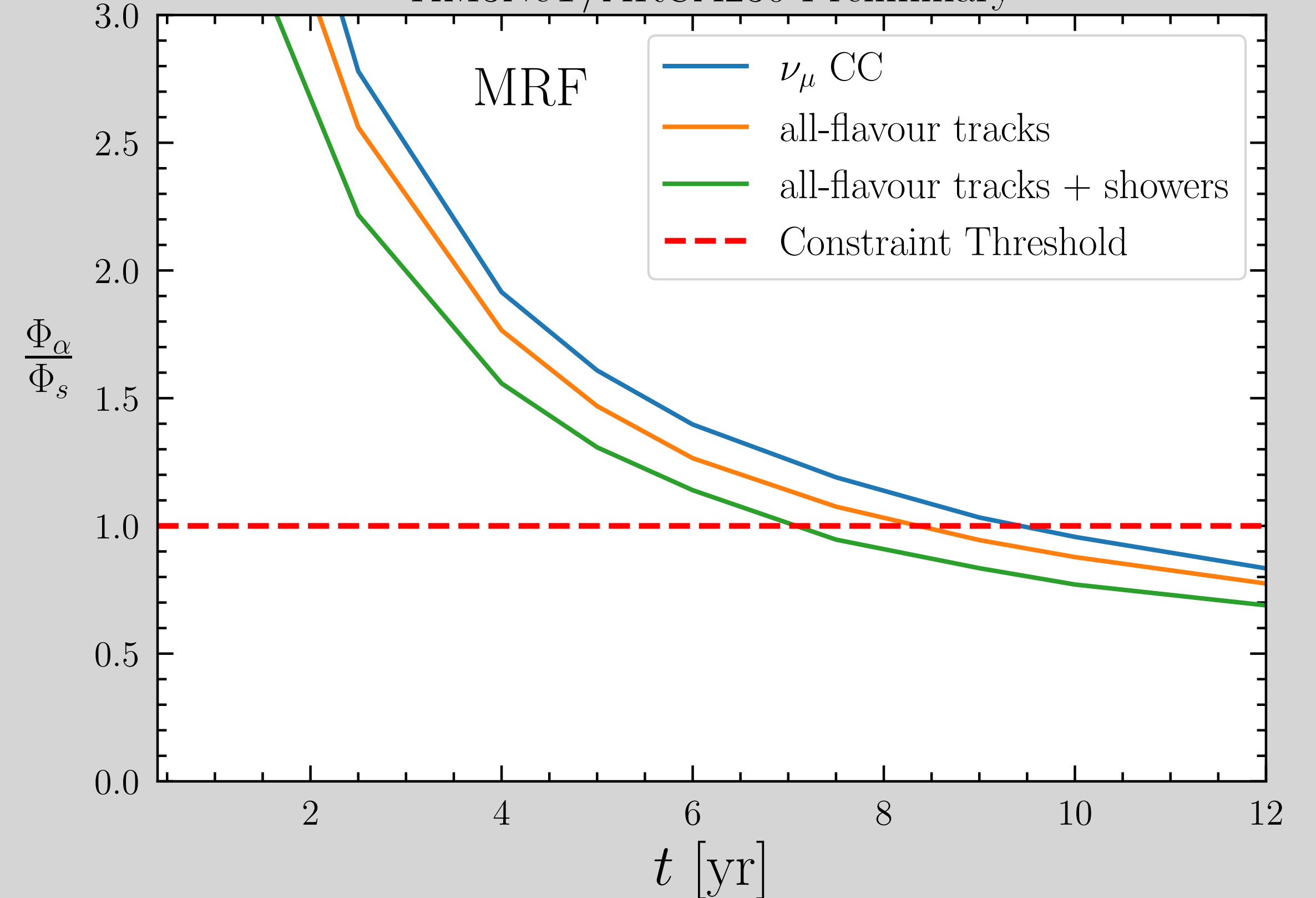
The Small Magellanic Cloud (SMC)

◆ The SMC is simulated as an extended source (disk with $r = 0.5^\circ$) $\sim 1^\circ$ of extension

KM3NeT/ARCA230 Preliminary, 10 years



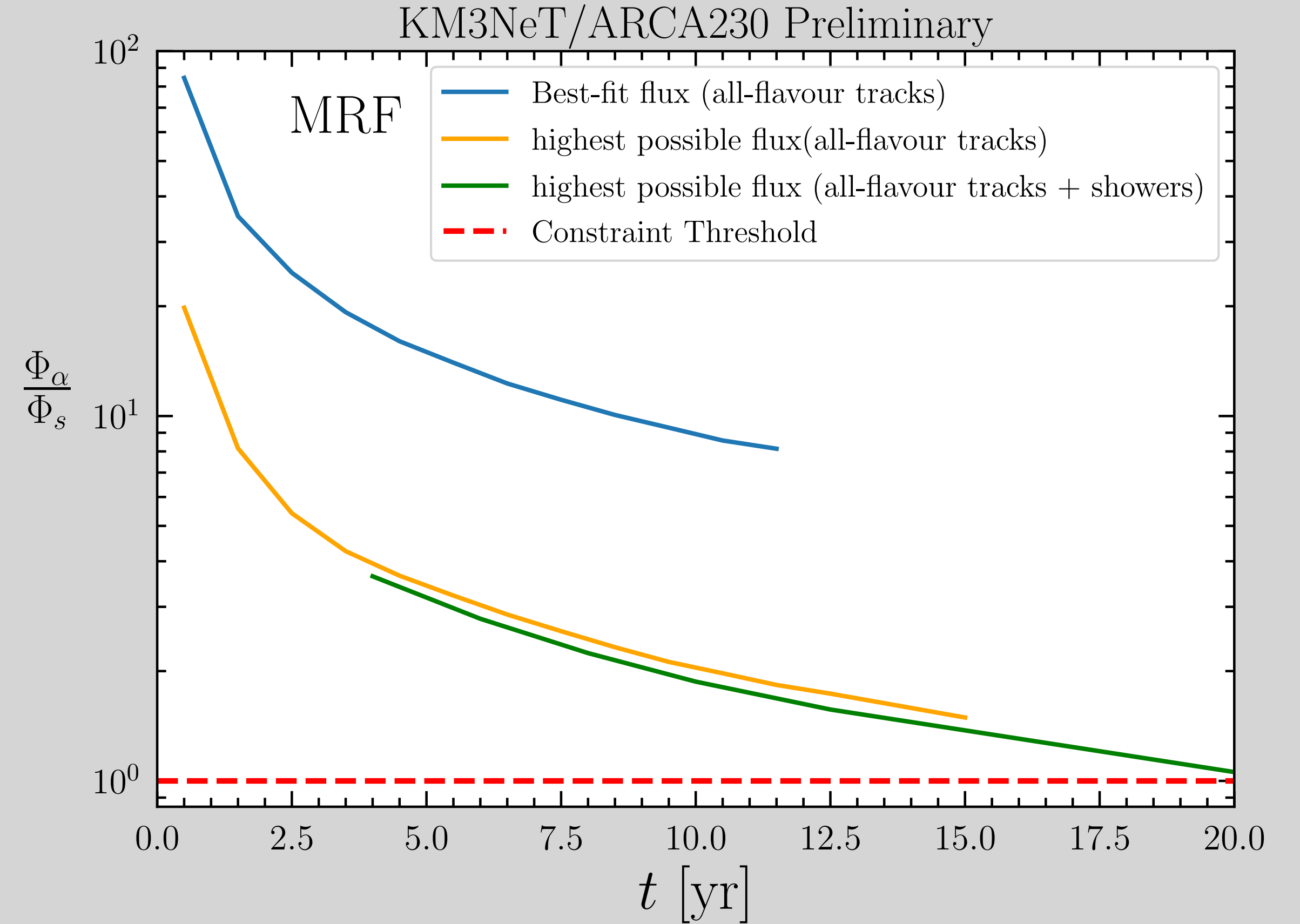
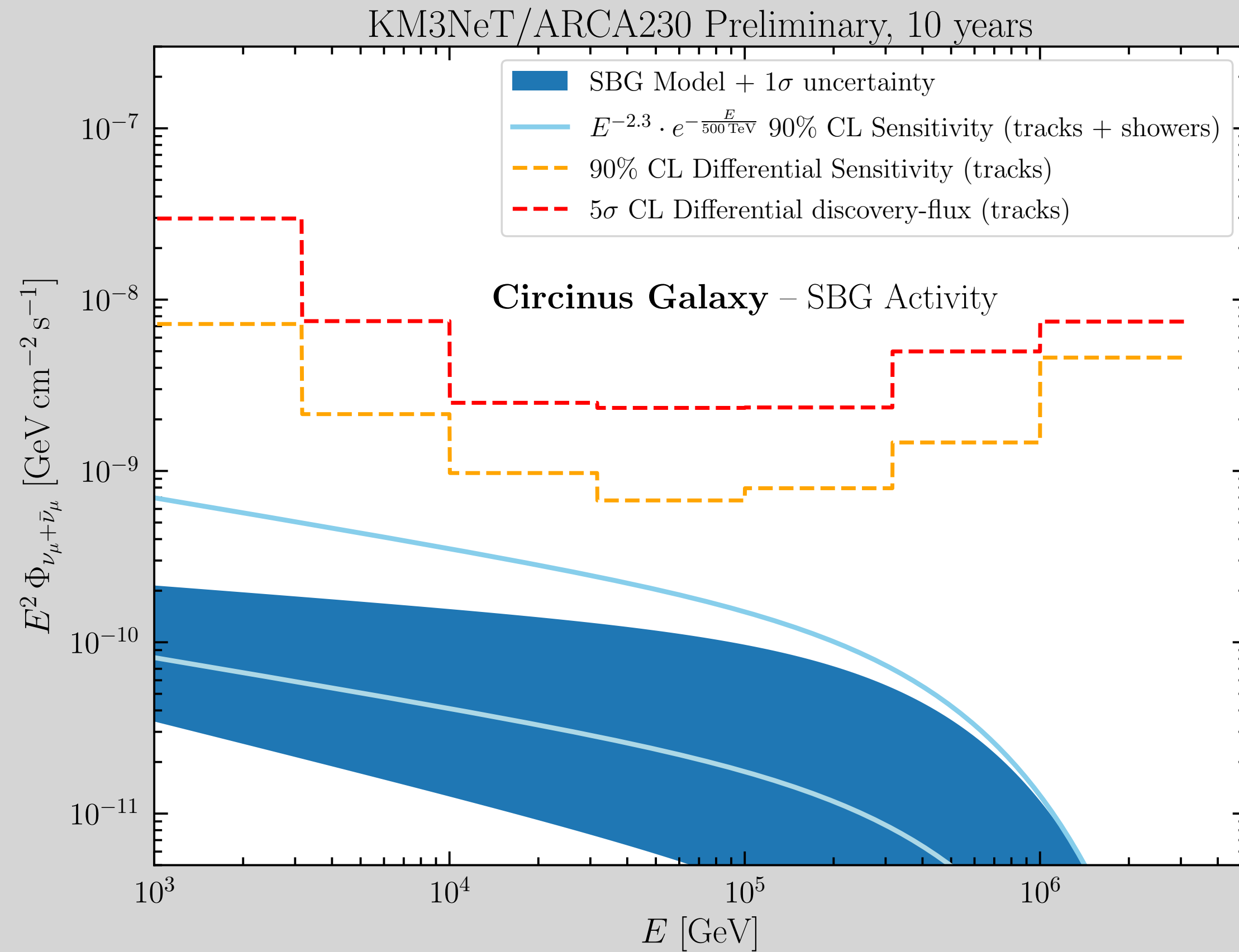
KM3NeT/ARCA230 Preliminary



◆ After ~ 8 yr, the theoretical model can be constrained providing important information on the CR transport inside the source

◆ The Differential Sensitivity peaks at ~ 100 TeV

The Circinus Galaxy



◆ Only the upper-limit of the expected neutrino flux from SBG activity can be probed after ~ 20 yr of operation for the full KM3NeT/ARCA

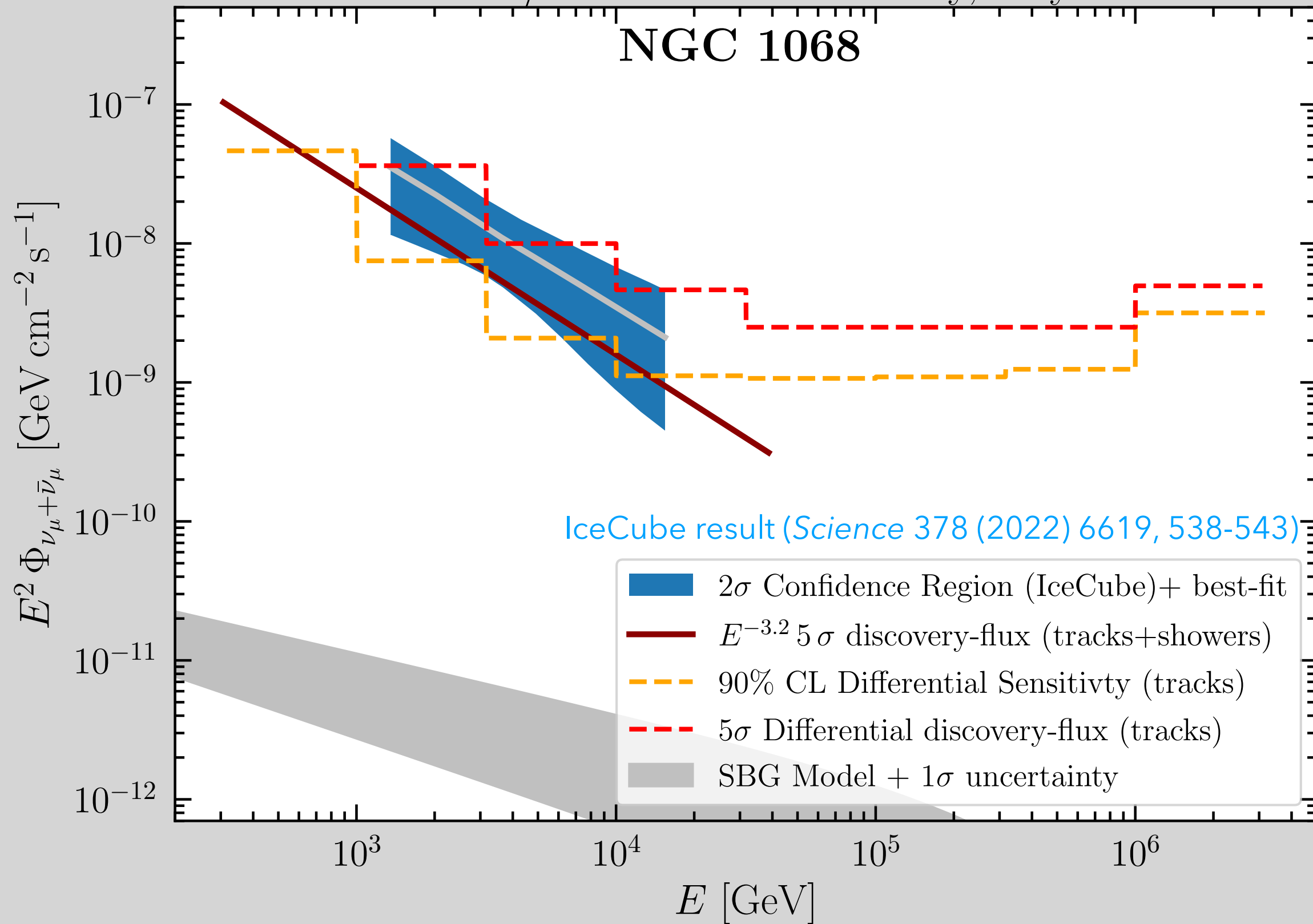
◆ The differential limits are able to constrain the AGN corona activity of this source



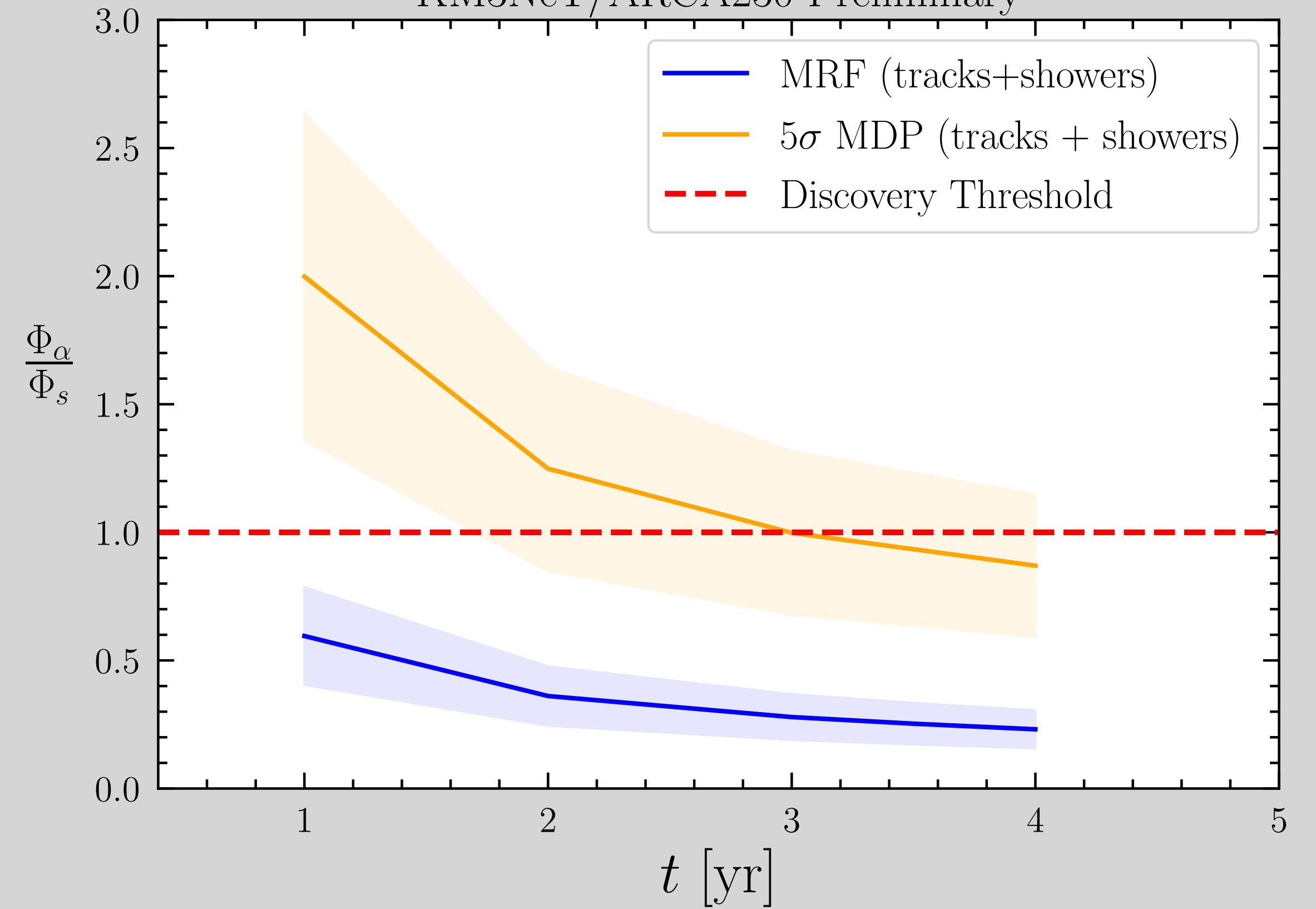
Important target for data analysis!

NGC 1068

KM3NeT/ARCA230 Preliminary, 10 years



KM3NeT/ARCA230 Preliminary



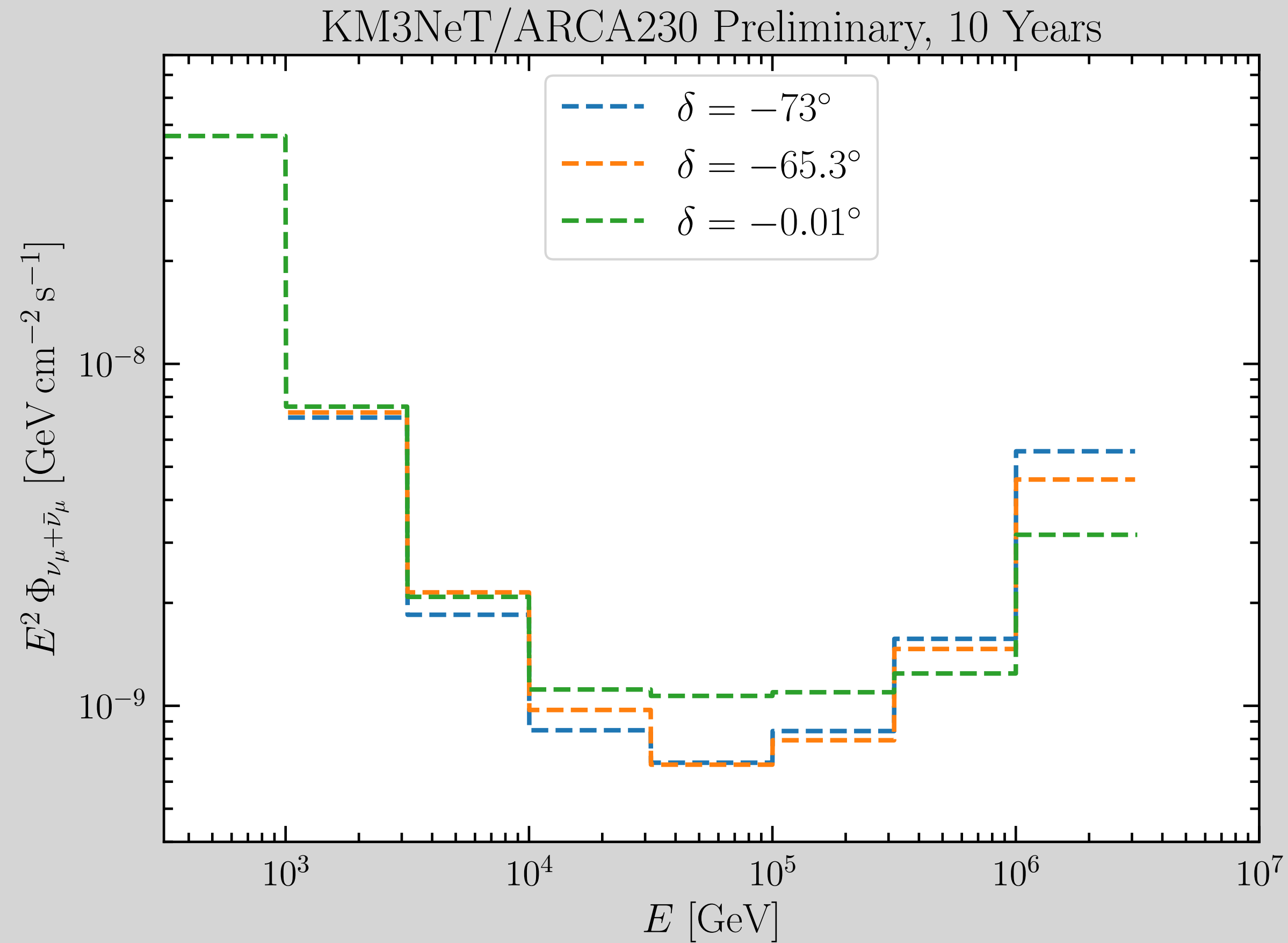
◆ KM3NeT/ARCA, after 3yr of data taking, will be able to discover at 5 σ a $E^{-3.2}$ spectrum with the normalization IC has measured

◆ SBG Activity cannot explain NGC 1068 Neutrino Emission



It is difficult to probe the SBG activity of this source through neutrino observations

Sensitivity Dependence on Declination



◆ The sensitivities are calculated considering point-like neutrino source emissions (No extension)

◆ For very low declination bands, the sensitivity at high energy gets worse

Conclusions

DIFFUSE:

- ◆ KM3NeT/ARCA full detector will strongly constrain the properties of the diffuse neutrino spectrum in few years of data taking
- ◆ The future measurements in the range of 10-100 TeV will be crucial to understand better the role of sources like SBG as well as γ -ray opaque sources

POINT-LIKE:

- ◆ In a few years of data taking, ARCA will be able to test the potential hadronic emission coming from SMC
- ◆ The SBG activity of Circinus will be more challenging to constrain
- ◆ The detector in less than 1 year will be able to constrain the scenario inferred by IceCube for NGC 1068. Even though this does not constrain SBG activity, it will strongly affect its AGN activity

Future Improved in the event selection will improve even further the expected energy-dependent sensitivity of KM3NeT/ARCA