KM3NeT/ARCA Expectations for Starburst Galaxies Observation

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In collaboration with

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on Behalf of the KM3NeT Collaboration

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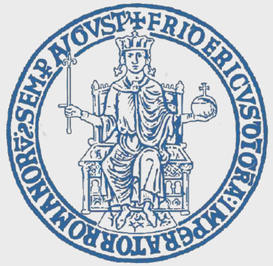
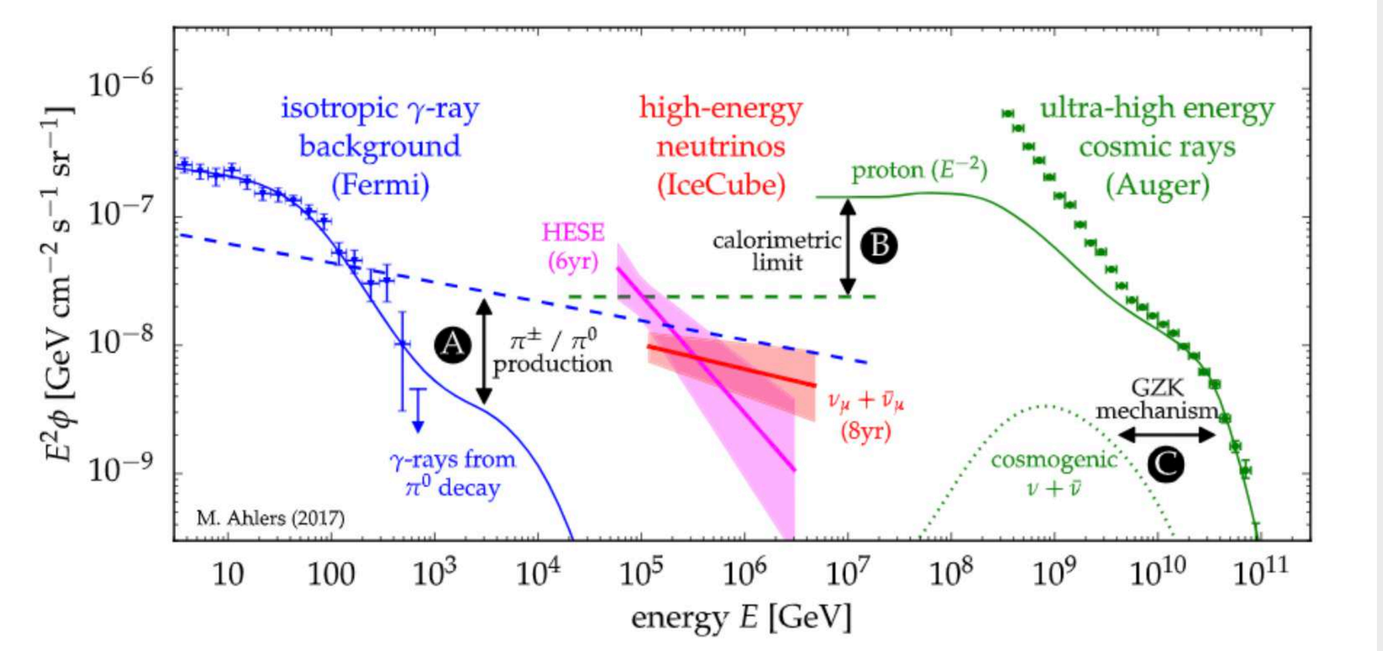


Multi-Messenger Puzzle

Astrophysical environments: factories of high-energy messengers such as Cosmic rays, Gamma-rays, neutrinos and Gravitational waves

M. Ahlers, F. Halzen / Progress in Particle and Nuclear Physics 102 (2018) 73–88.
https://doi.org/10.1016/j.ppnp.2018.05.001



✦ Which sources power the Astrophysical Messengers fluxes?

✦ The energy budget for the messengers is the same. This suggests a common origin

Neutrinos: possible key messengers to solve the origin puzzle

The KM3NeT Detector

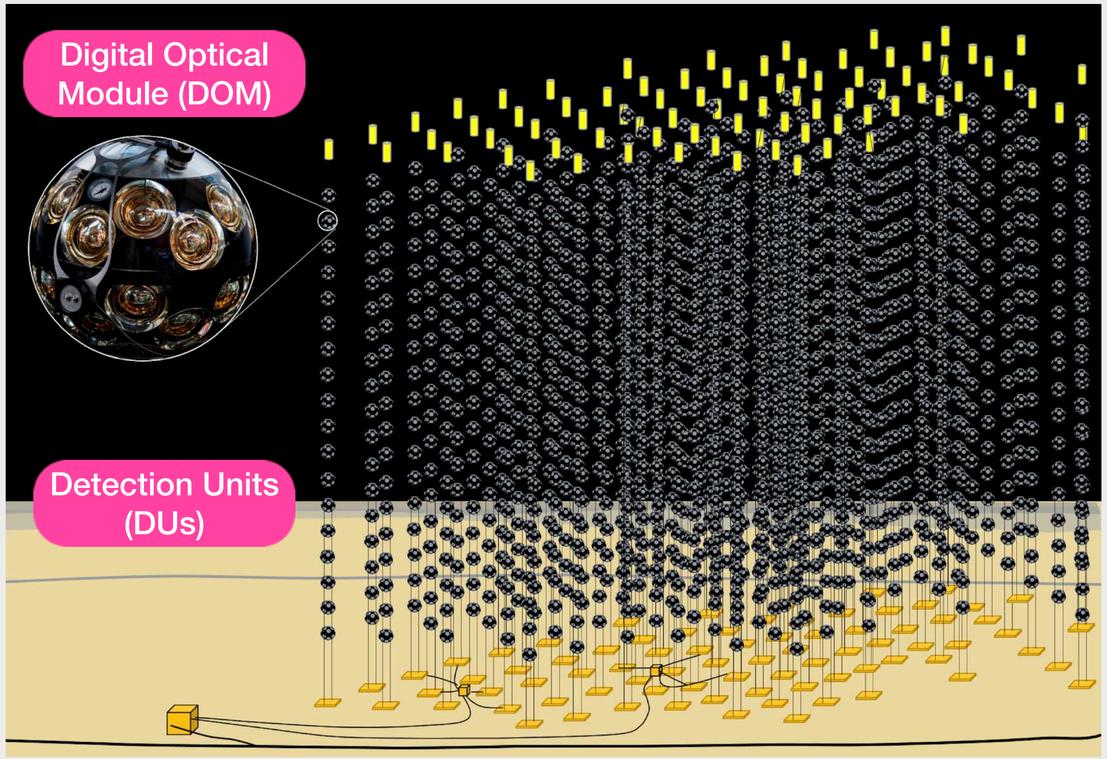
The KM3NeT detector (under construction): ARCA (Astroparticle Research with Cosmics in the Abyss) and ORCA (Oscillation Research with Cosmics in the Abyss).

doi; 10.1088/0954-3899/43/8/084001

ARCA: Study of the high-energy astrophysical Neutrinos

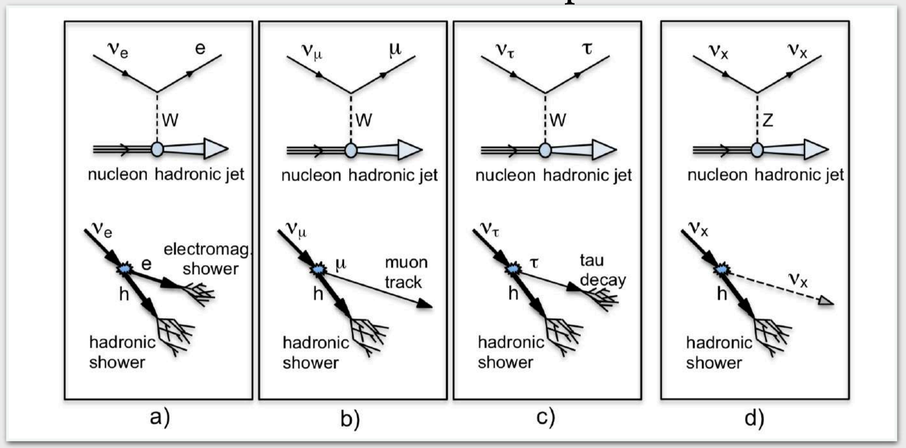
ORCA: Study of Neutrino Physics

https://www.km3net.org/

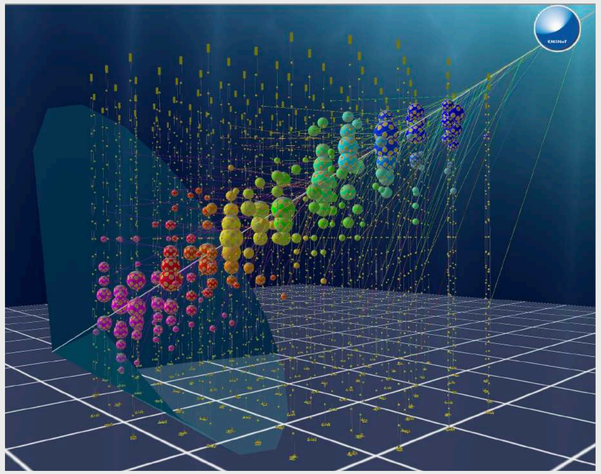


Already Operative! 19 Operative DUs for ARCA and 9 for ORCA

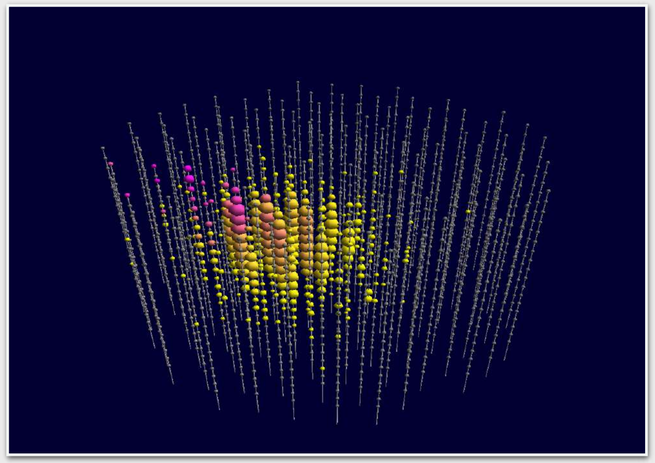
Detection Principle:



Track-like event



Shower-like Event

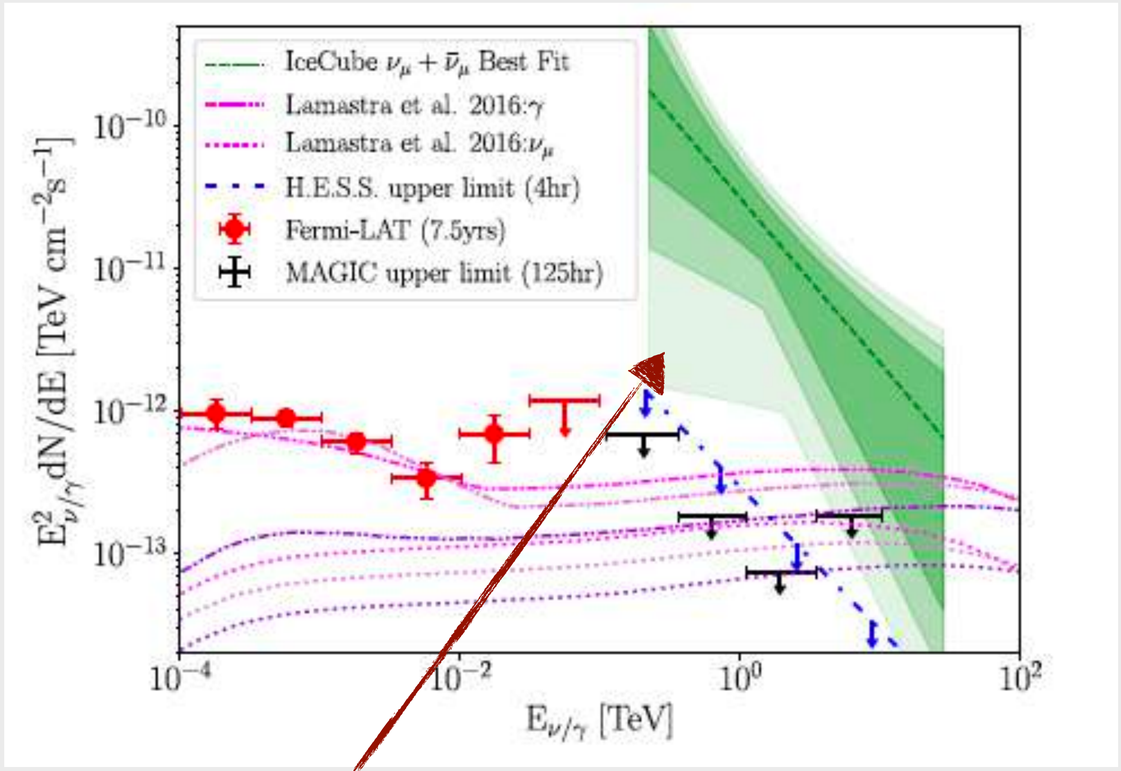


Starburst Galaxies as Neutrino Factories

Intense Star-forming activity

Point-Source

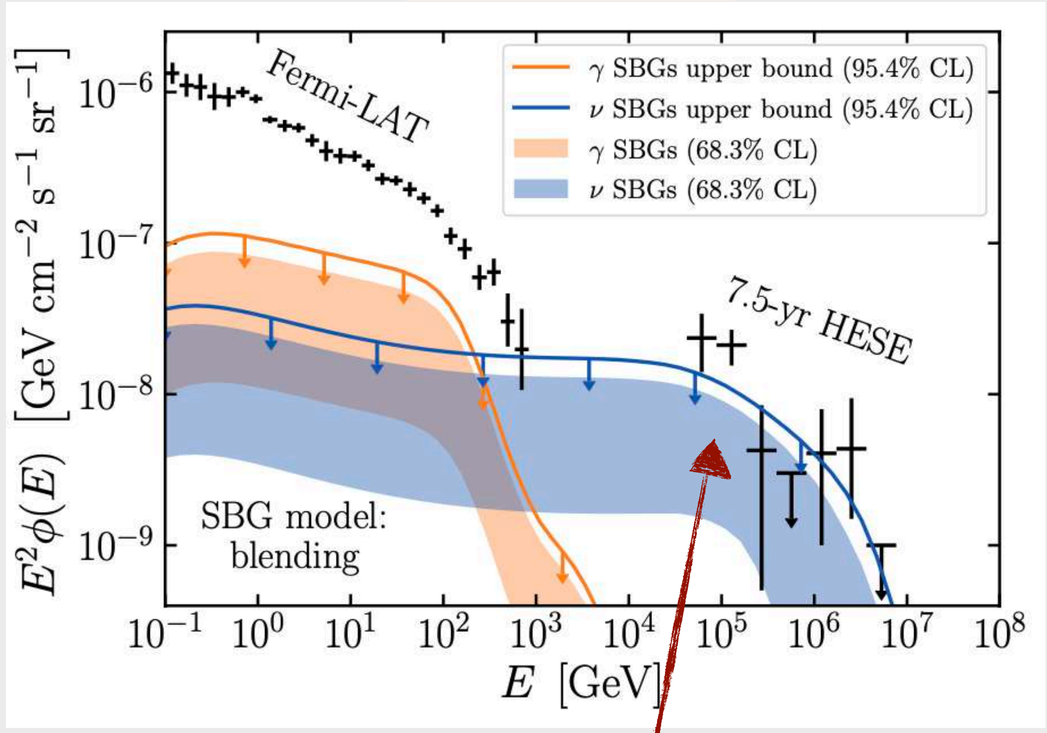
PRL 124 (2020) IceCube (arxiv: 1910.08488)



Is the 2.9σ excess (over the background hypothesis) a tracer of the SBG activity?

Diffuse Emission

Ambrosone et al. MNRAS 503 (arxiv:2011.02483)



SBGs might explain a part of ICeCube's measurements

Which is the expectations for KM3NeT/ARCA about this source class?

Analysis Method

Goal: Evaluate the possibility for KM3NeT/ARCA115 to constrain SBG fluxes

→ Analysis with a possible diffuse SBG flux

→ Studying the most promising SBG point-like sources

Method: Calculated the sensitivity at 90 % C.L. and comparison with SBGs SED

→ Cut&Count approach

→ Frequentist statistic (using the Feldman&Cousins upper limit calculation)

→ Monte Carlo simulation of KM3NeT/ARCA115

Sensitivity definition:

(Phys. Rev. D, 57:3873–3889, 1998)

$$\Phi_{90} = \frac{\bar{\mu}_{90}}{n_s}\Phi_\nu$$

Φ_ν → *Signal neutrino spectrum*

$\bar{\mu}_{90}$ → *average upper limit*

n_s → *signal events*

Diffuse Analysis

Considered the energy range [100 GeV - 10 PeV]

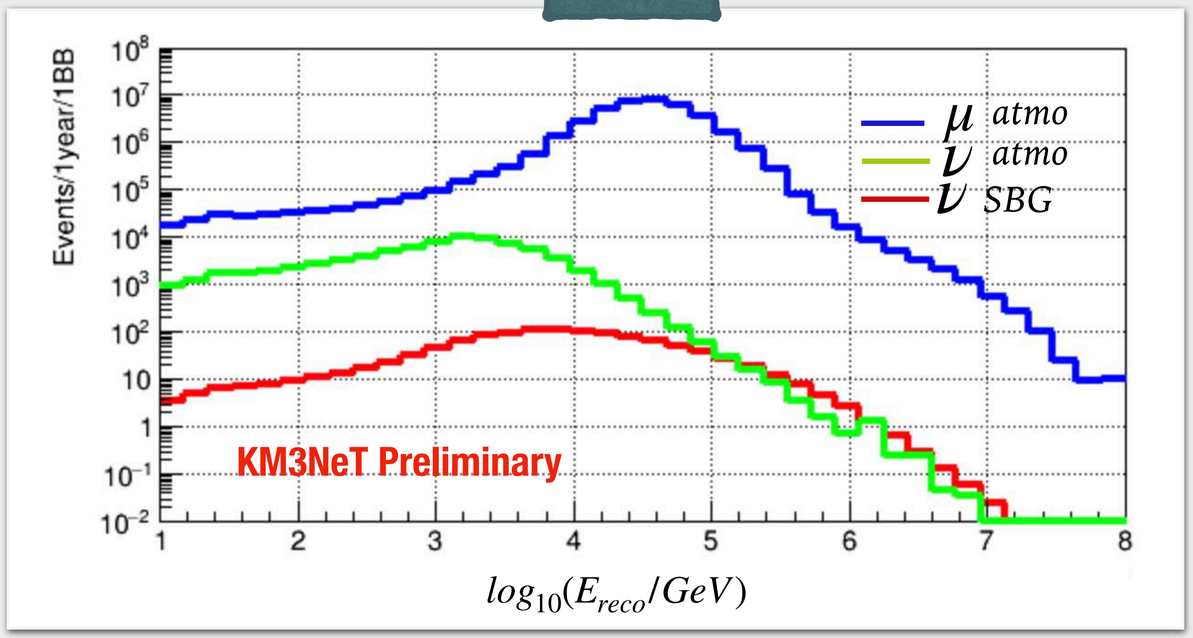
- Background: μ atmospheric, ν atmospheric $(\nu_\mu, \nu_e, \nu_\tau)$
- Signal: ν diffuse SBG $(\nu_\mu, \nu_e, \nu_\tau)$ → Model developed by Ambrosone et al. MNRAS 503 (arxiv:2011.02483)

Selection

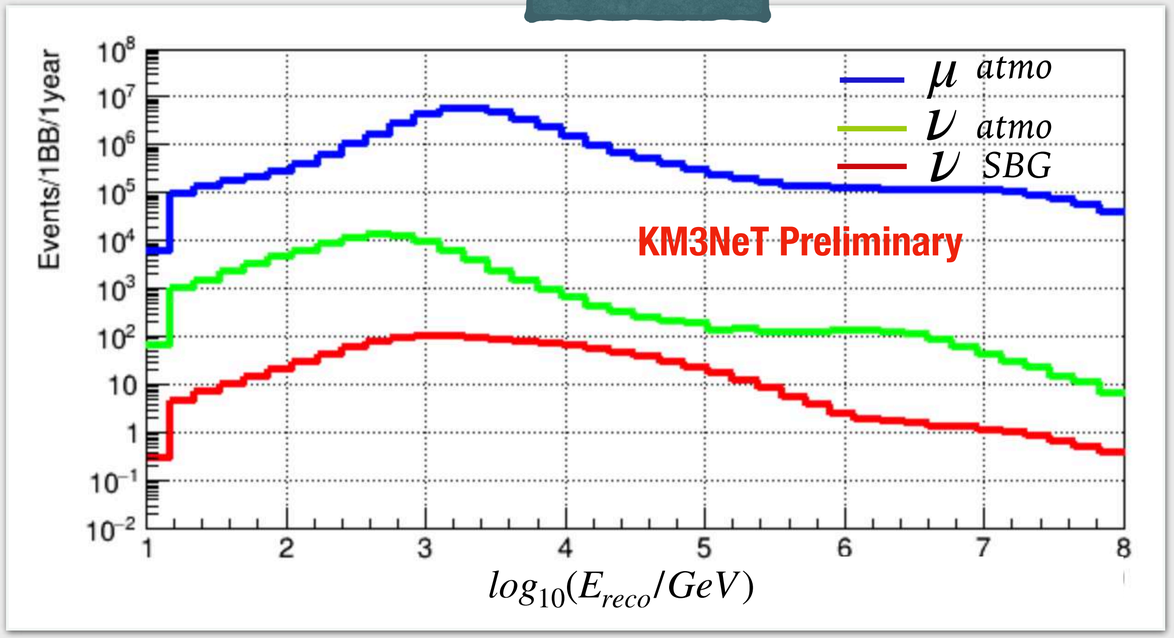
→ **Up-going Track Events** $(\theta < 100^\circ)$

→ **All Sky Cascade Events**

Tracks



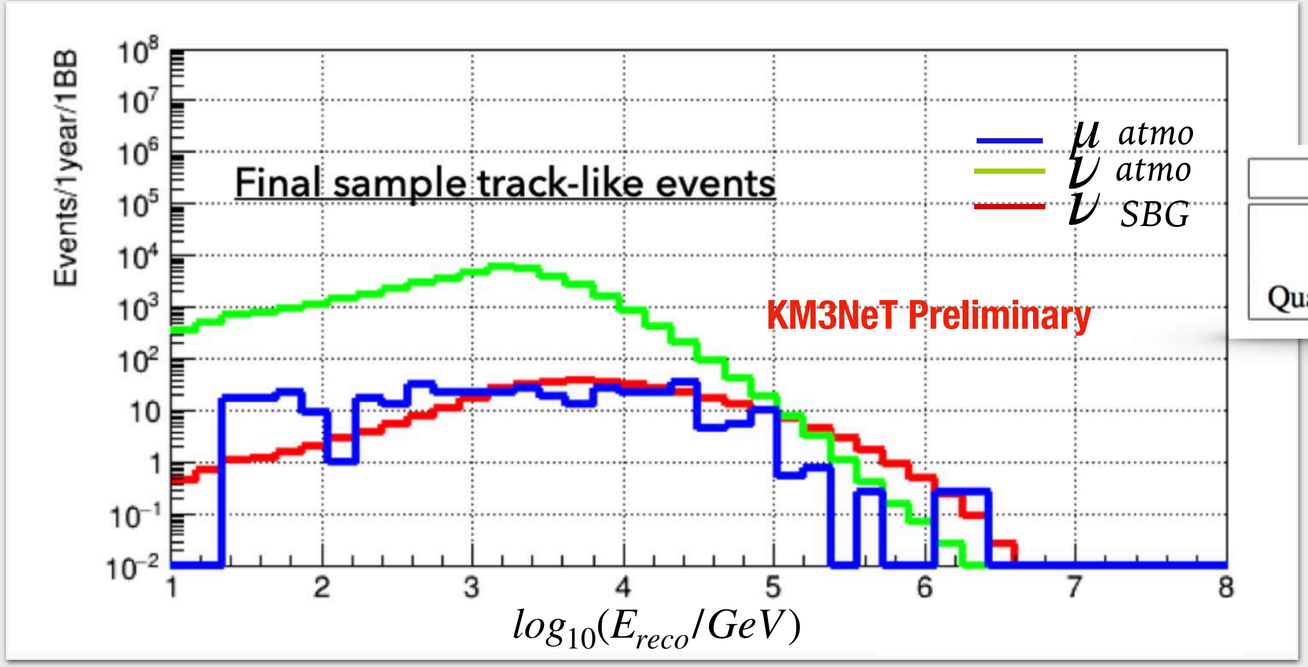
Cascades



Diffuse Analysis: Tracks Selection

Selection chain:

- **Up-going cut** $(\theta < 100^{\circ})$
- **Selection on quality reconstruction variables**
- **Long-track events (Len > 300 m)**
- **Selection using a multivariate with machine learning (Boost decision tree, BDT)** → **Optimized for good track up-going**



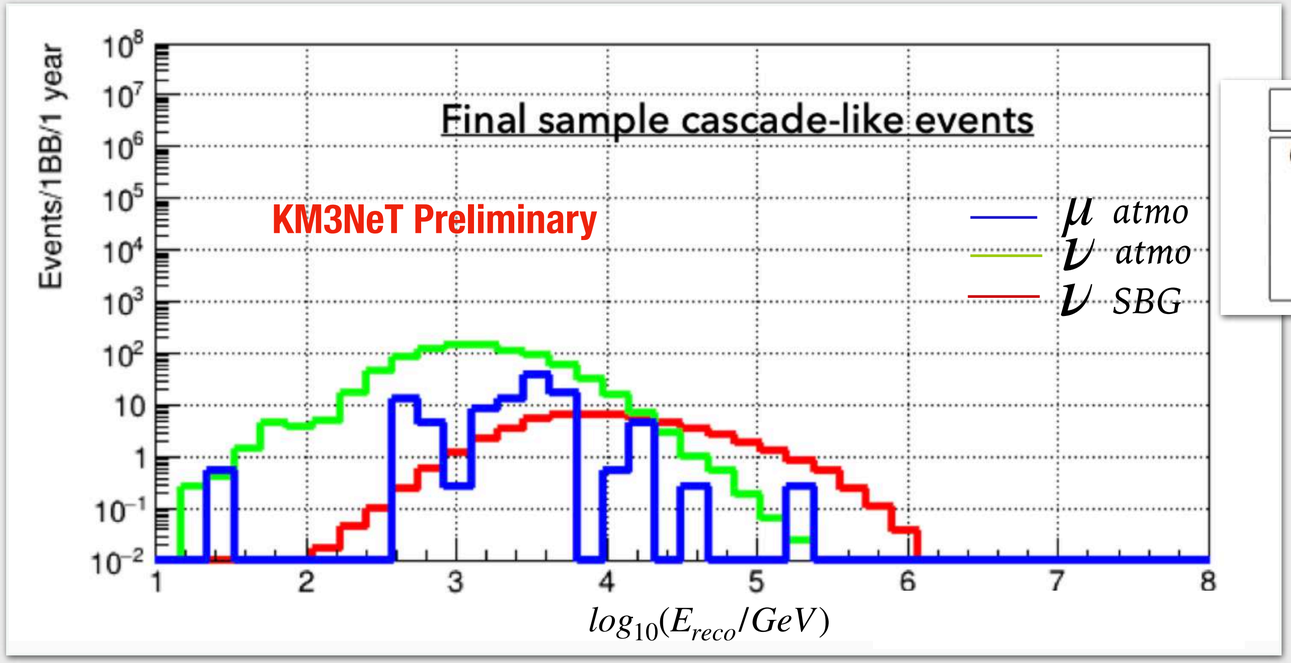
Events for 1 BB/1 yr (all energy range)

Selection	Atmospheric muons	Atmospheric neutrinos	Signal diffuse SBG
Triggered events	39389987.	79139.1	1206.7
Up-going	263816.2	58395.9	715.1
Quality cut + BDT selection	389	42400.3	345.9

Diffuse Analysis: Cascades Selection

Selection chain:

- **Contaminent events ($R_{det} < 600$, Z_{det}<650)**
- **Short length events (Len<300 meters)**
- **Selection on quality reconstruction variables**
- **Selection with a BDT trained and optimizeted for cascade events**



Events for 1 BB/1 yr (all energy range)

Selection	Atmospheric muons	Atmospheric neutrinos	Signal diffuse SBG
Containment events	29303243.	31779.3	643.4
Track length	2520488.4	15918.8	411.0
Quality cut	389871.1	4394.5	259.7
BDT cascade	103.9	898.7	54.4

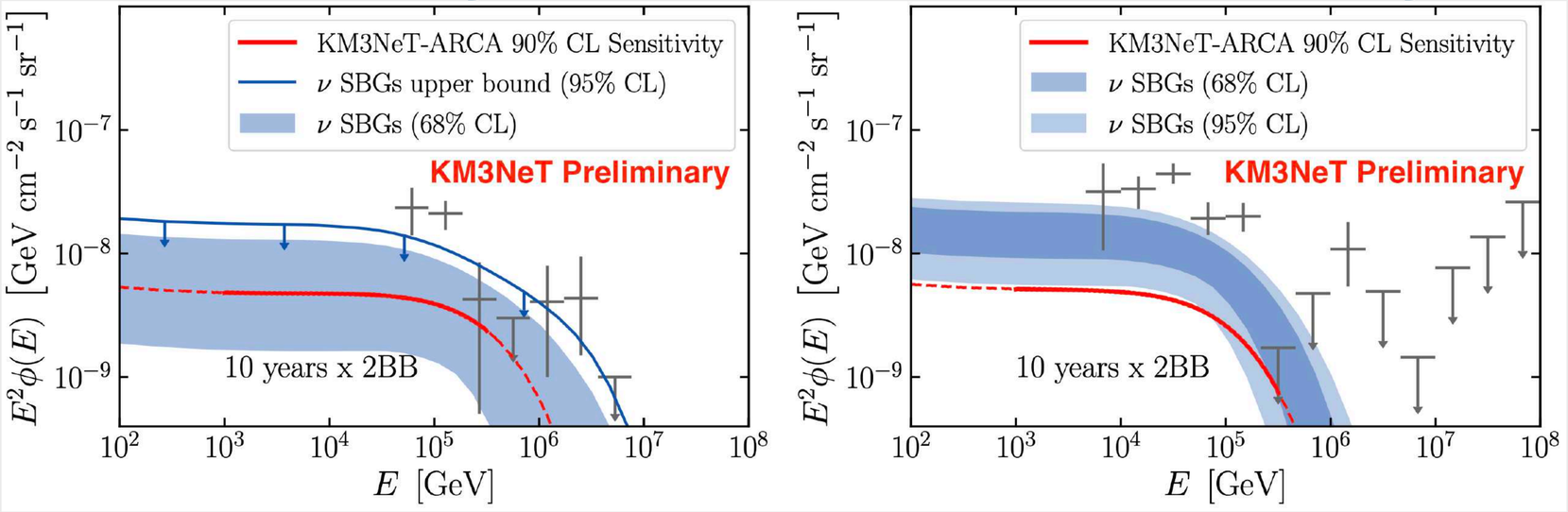
Diffuse Analysis: RESULT

COMBINED TRACK-LIKE AND CASCADE-LIKE EVENTS

$$\Phi_{90} = \frac{\bar{\mu}_{90}}{n_s}\Phi_\nu$$

sensitivity at 90 % C.L. KM3NeT/ARCA 2BB/10 yr

Theoretical model: Ambrosone et al. MNRAS 503 (arxiv:2011.02483)



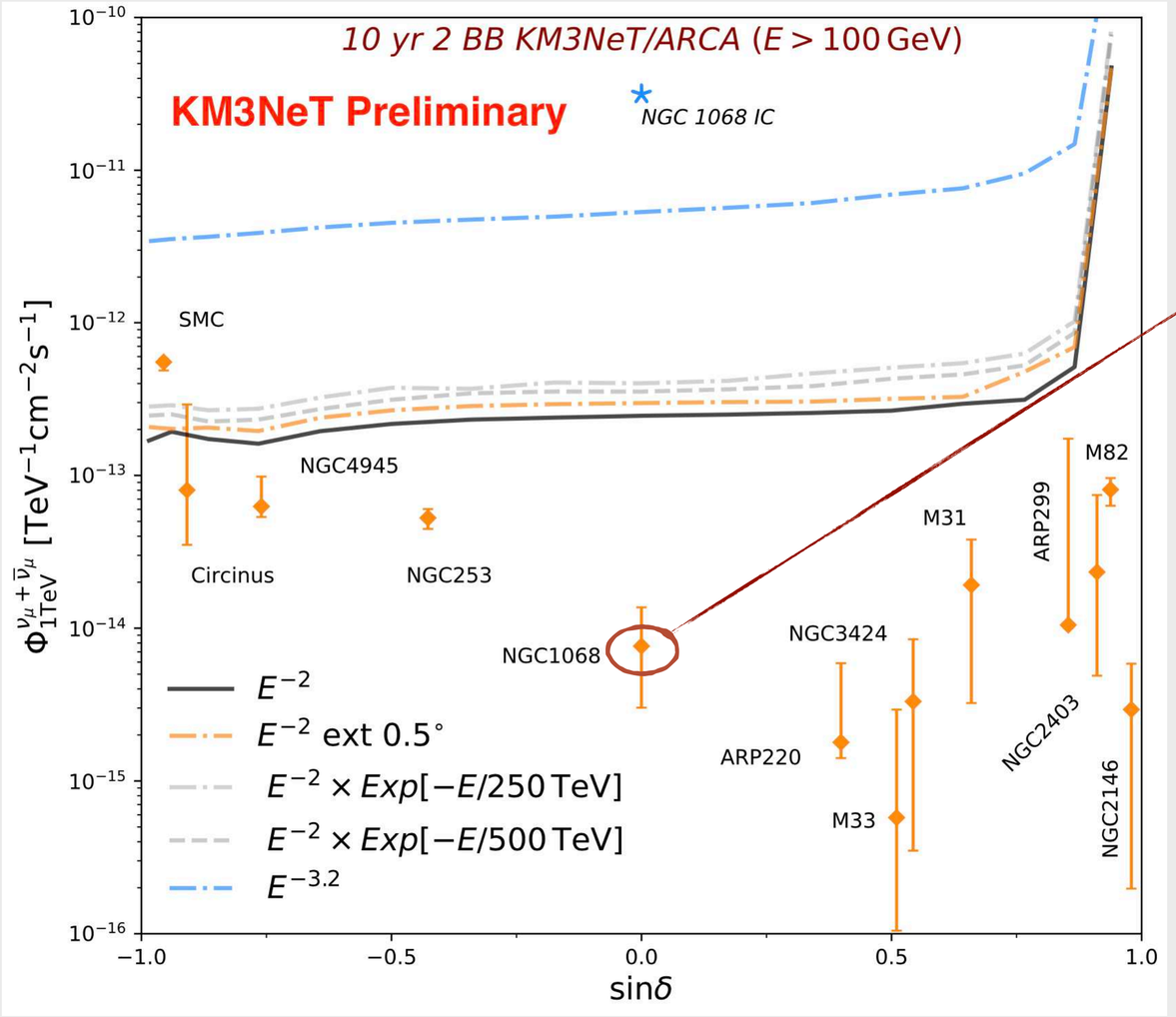
The sensitivity is shown in the range where 90% of the signal is concentrated

The sensitivity is compared with two different SBG scenarios: on the left the expected signal was calculated from HESE (IceCube) and Fermi-LAT EGB, on the right using CASCADE (IceCube) and Fermi-LAT EGB.

ARCA is extremely sensitive for such a spectrum and in few years of data taking it will put sever constraints on such a scenario

Point-Like Analysis

KM3NeT/ARCA115 expectations for nearby known SBG sources



Theoretical normalizations developed by Ambrosone et. Al ApJL 919 L32

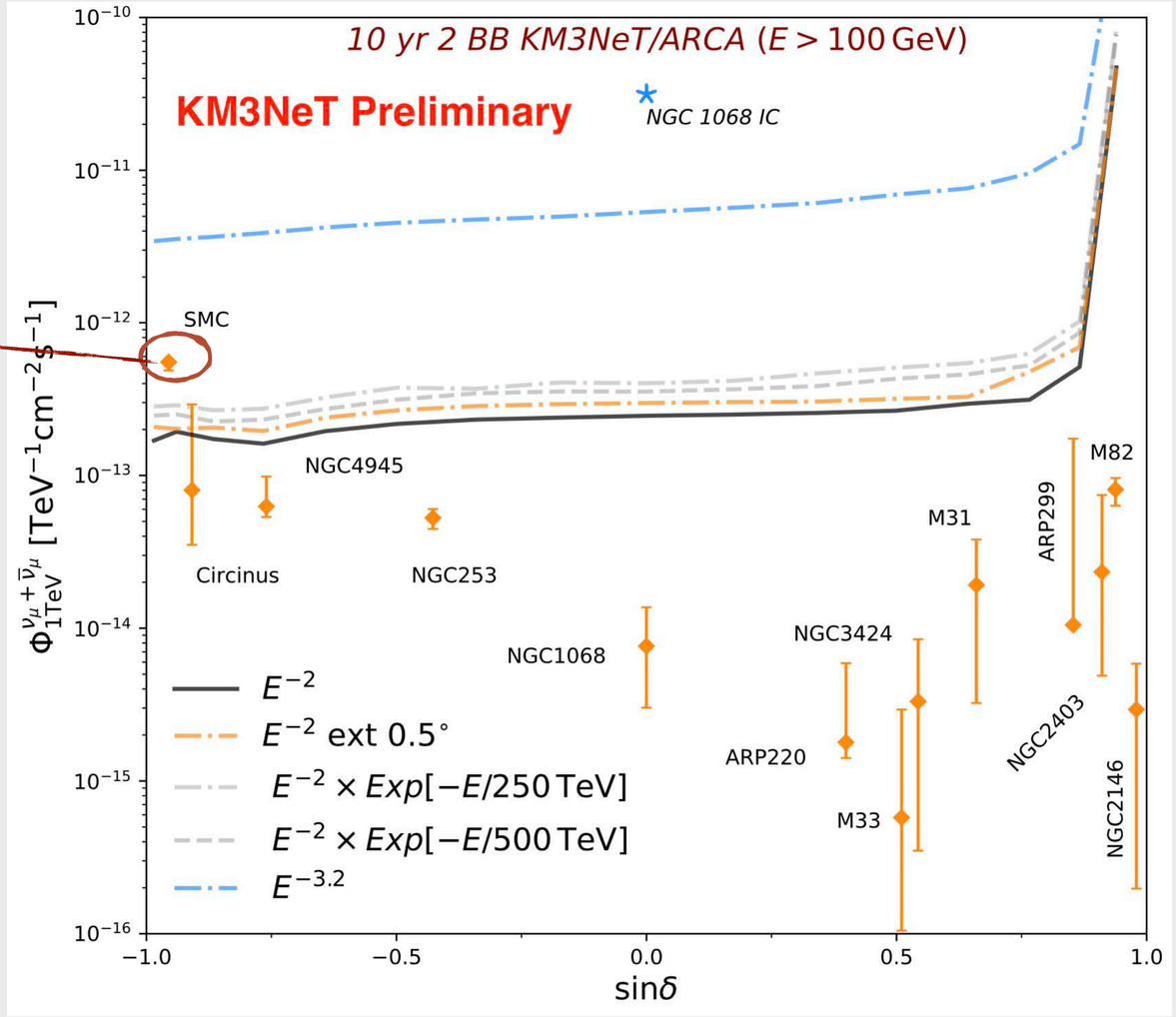
Normalizations take only into account the SBG activity.

ARCA seems sensitive for the SBGs in the southern sky, where it has more visibility

Point-Like Analysis

KM3NeT/ARCA115 expectations for nearby known SBG sources

The SMC core ($\sim 0.4^\circ$) can be constrained. The extension of the nucleus causes only about 22% degradation of the sensitivity



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Point-Like Analysis

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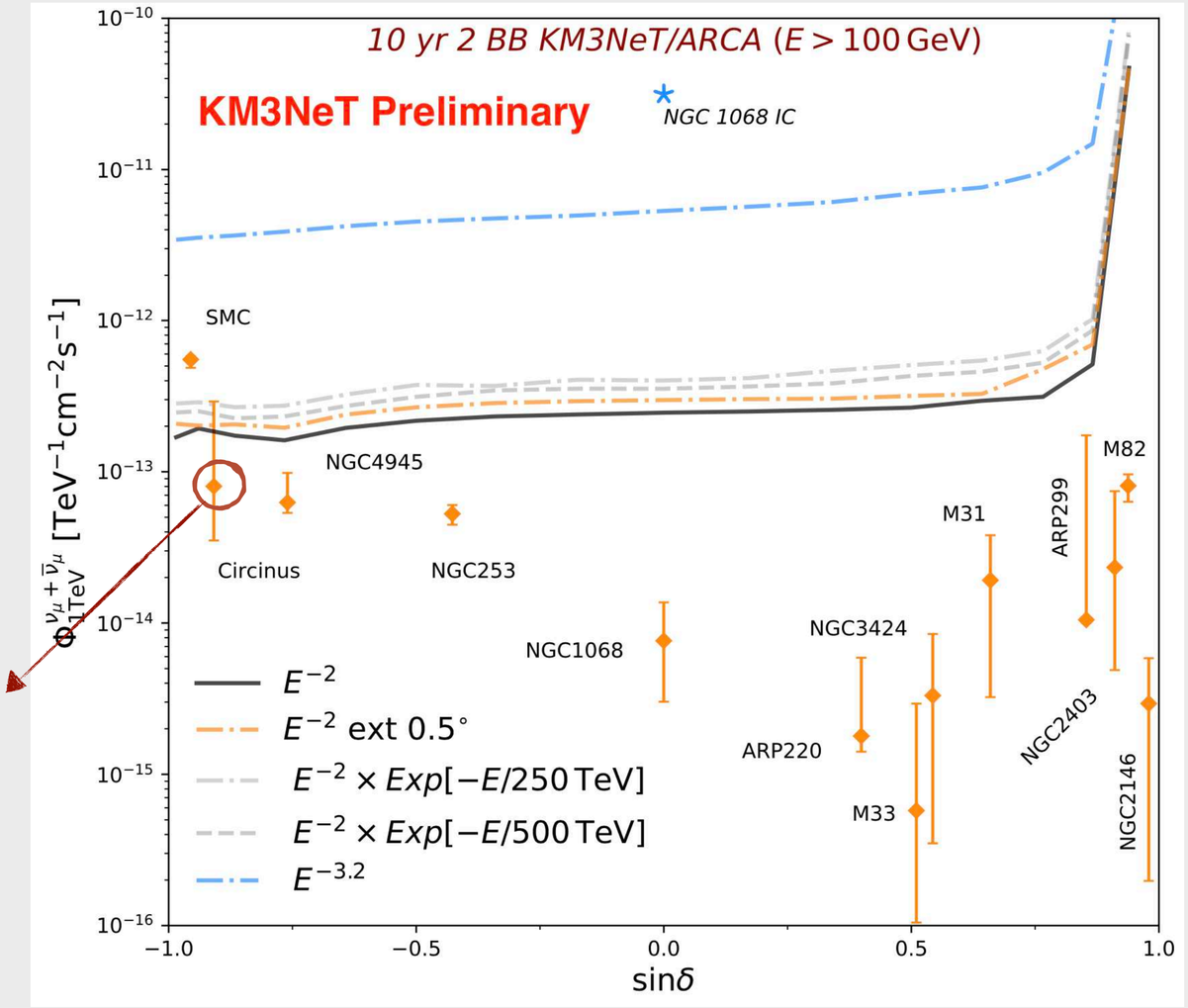


Circinus is compatible with the sensitivity within its 1σ most credible interval, even though its best-fit scenario seems to be not optimistic

Theoretical normalizations developed by Ambrosone et. Al ApJL 919 L32

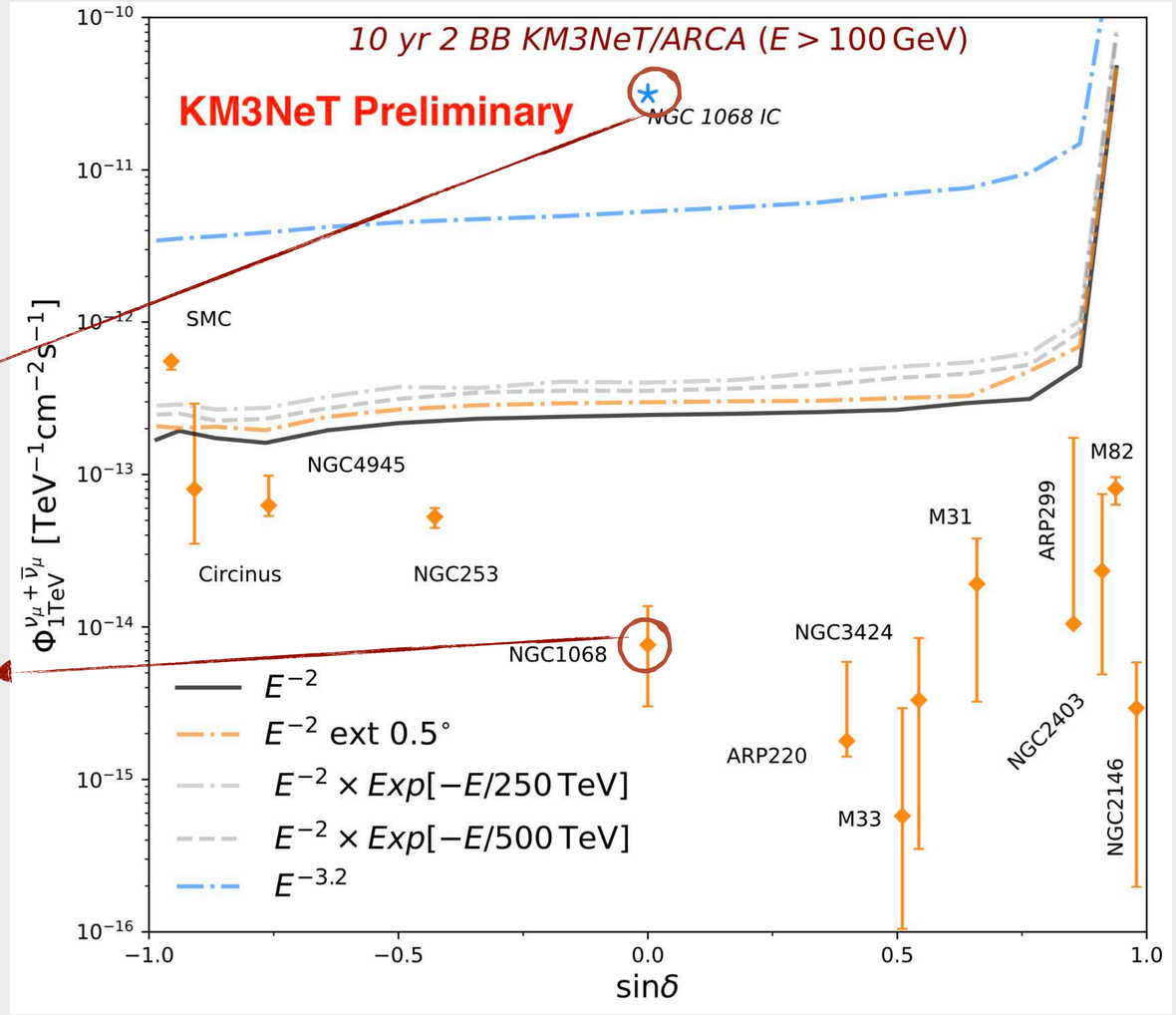
Normalizations take only into account the SBG activity.

ARCA seems sensitive for the SBGs in the southern sky, where it has more visibility

Point-Like Analysis

KM3NeT/ARCA115 expectations for nearby known SBG sources

NGC 1068 SBG activity cannot be discriminate. Nonetheless, IceCube has found a 2.9σ excess over the background. This is expected to be constrainable



Theoretical normalizations developed by Ambrosone et. Al ApJL 919 L32

Normalizations take only into account the SBG activity.

ARCA seems sensitive for the SBGs in the southern sky, where it has more visibility

Diving into the Sources: Event Selection

Method: Cut&Count approach and Frequentist Statistic (Feldman & Cousins Upper limit Calculation)

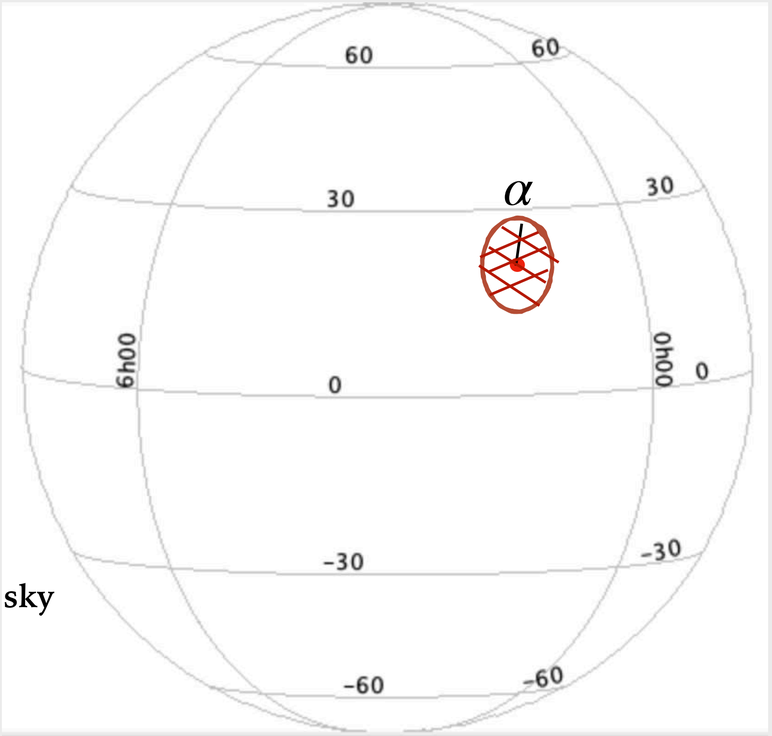
→ Only $\nu_\mu - \bar{\nu}_\mu$ CC

→ *Dedicated Simulation for each Source*

→ Model Rejection Factor minimization to optimize the sensitivity

Event Selection:

- **Signal: Neutrinos coming from the RoI, defined by α**



Nominal position of the source in the sky

Region of Interest

Diving into the Sources: Event Selection

Method: Cut&Count approach and Frequentist Statistic (Feldman & Cousins Upper limit Calculation)

→ Only $\nu_\mu - \bar{\nu}_\mu$ CC

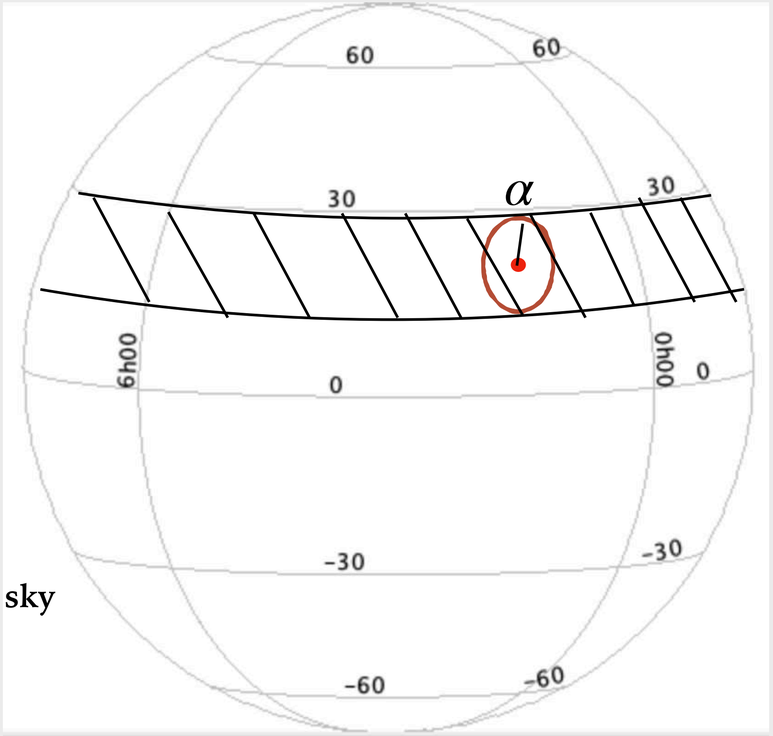
→ *Dedicated Simulation for each Source*

Model Rejection Factor minimization to optimize the sensitivity

Event Selection:

- **Signal: Neutrinos coming from the RoI, defined by α**
- **Background: All the declination band, rescaled for the dimension of the RoI**

$$\Omega_{RoI}/\Omega_{db} \simeq \pi\alpha^2/(2\pi 2\alpha) = \alpha/4$$



Nominal position of the source in the sky

Region of Interest

Diving into the Sources: Small Magellanic Cloud (SMC)

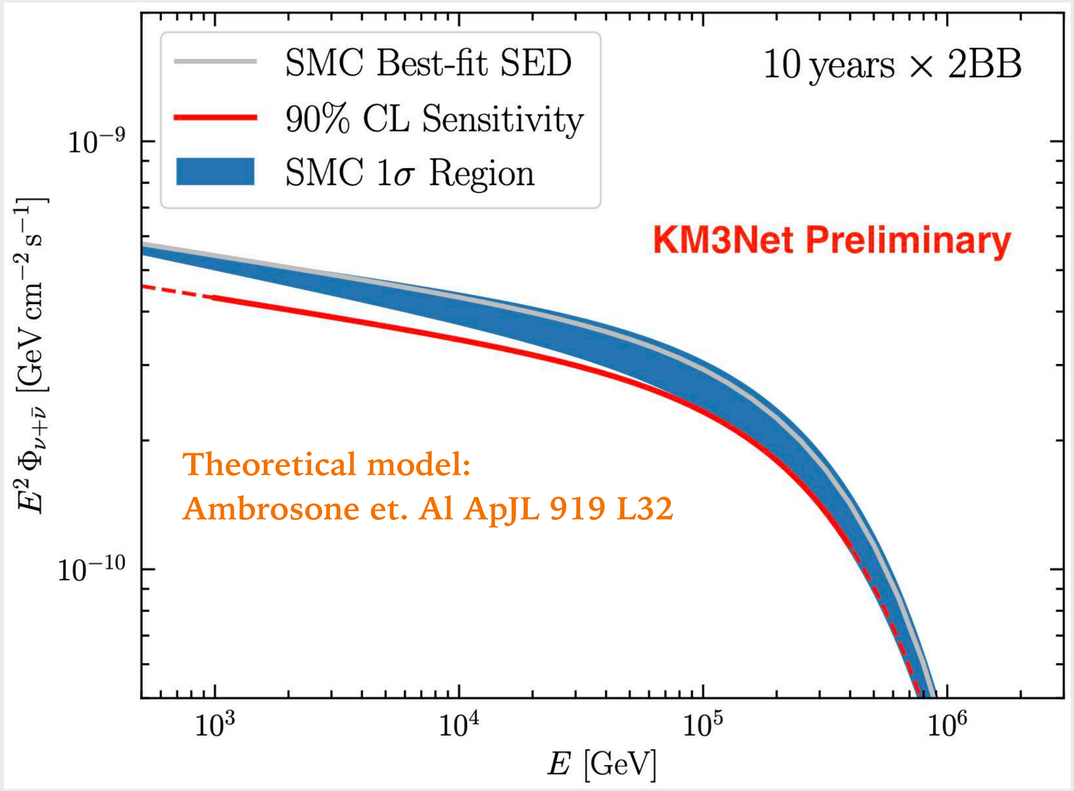
SMC simulated as an extended source of 0.5°

$$\Phi_\nu \propto \left(\frac{E}{\mathrm{GeV}}\right)^{-2.1} \times e^{-\frac{E}{500\,\mathrm{TeV}}}$$

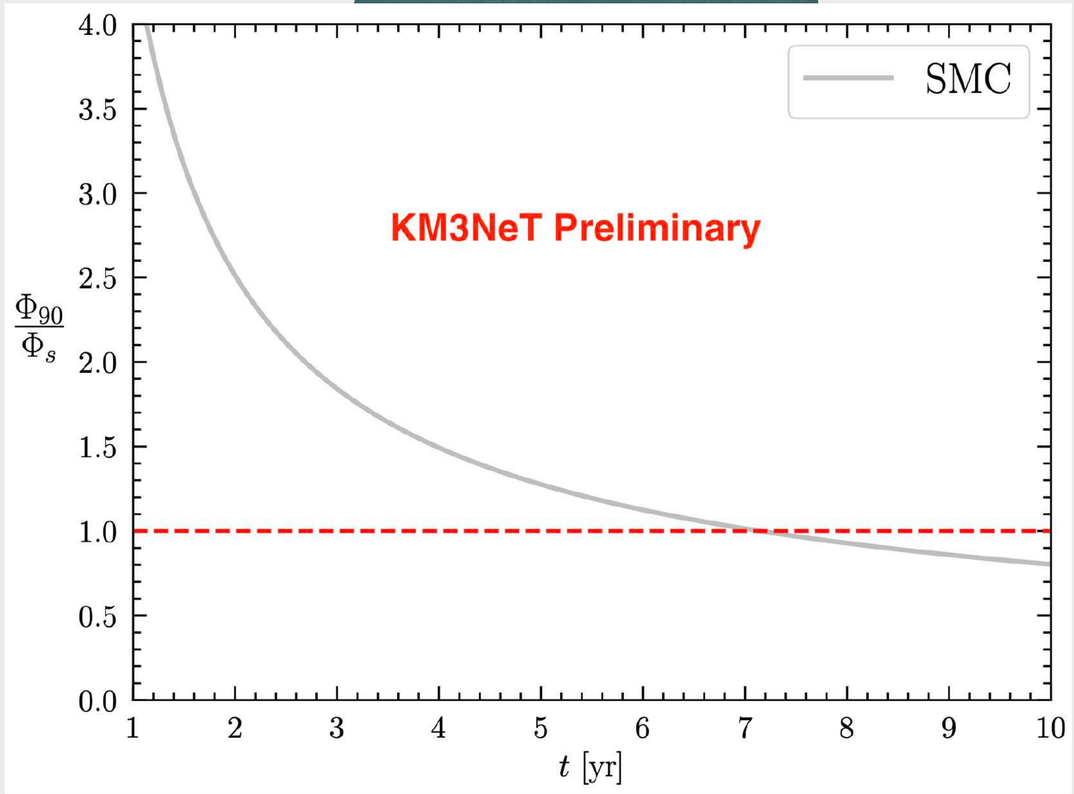
Best-fit Spectral Energy Distribution (SED) scenario

In few years of data taking, ARCA will put sever constraints on such a scenario!

Sensitivity compared with theoretical expectations



Sensitivity Gain with Time



The sensitivity is shown in the energy range where 90% of the signal is concentrated

Diving into the Sources: CIRCINUS

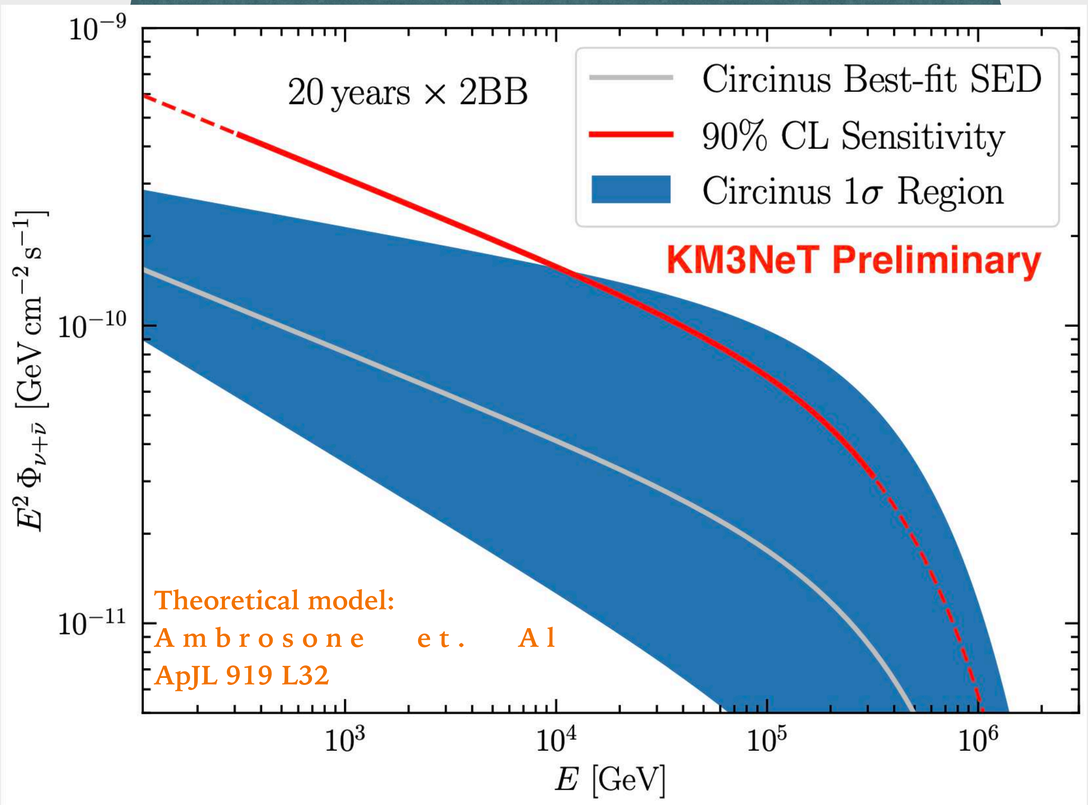
Circinus is simulated as a point-like source

$$\Phi_\nu \propto \left(\frac{E}{\mathrm{GeV}}\right)^{-2.3} \times e^{-\frac{E}{500\,\mathrm{TeV}}}$$

Best-fit Spectral Energy Distribution (SED) scenario

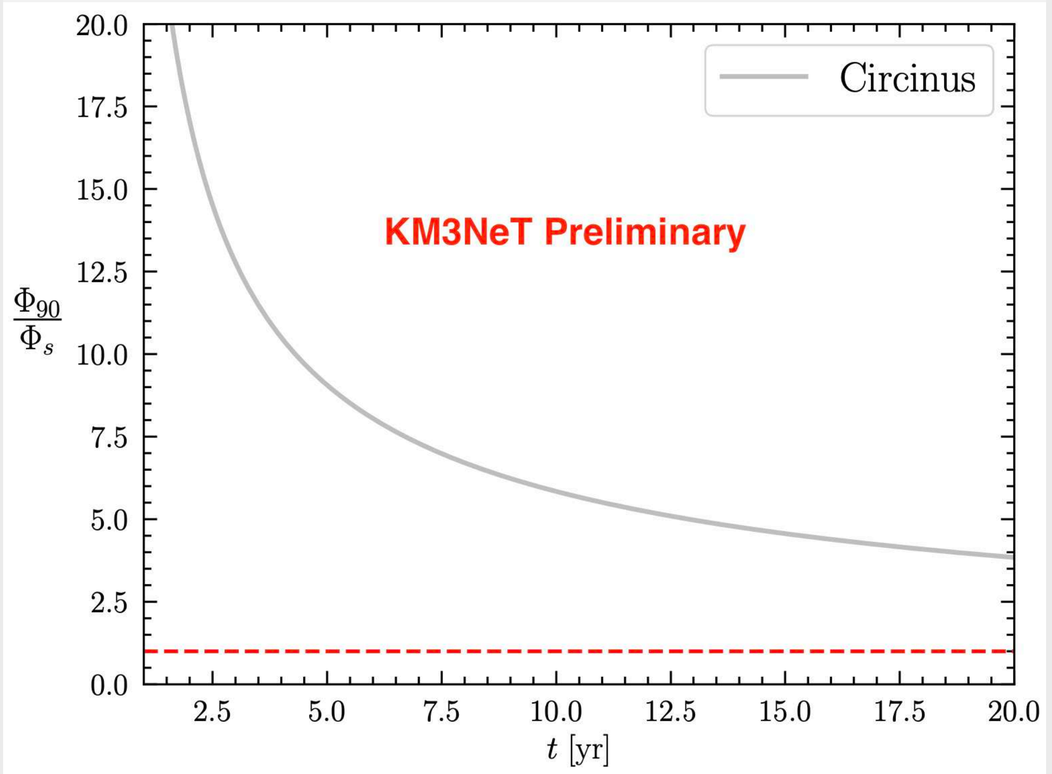
For ARCA, It will be challenging to constrain the best-fit scenario. Probably, it will be possible to constrain the upper-limit of such a scenario.

Sensitivity compared with theoretical expectations



The sensitivity is shown in the energy range where 90% of the signal is concentrated

Sensitivity Gain with Time



Diving into the Sources: NGC 1068

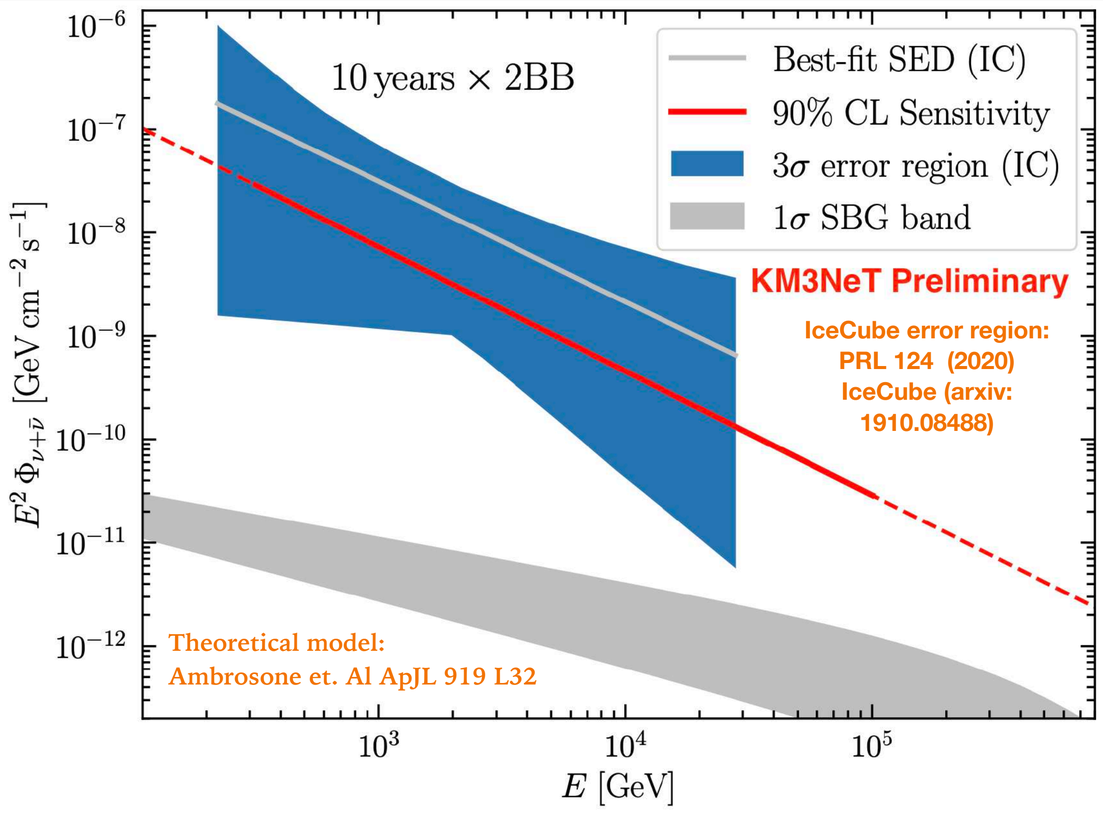
$$\Phi_\nu \propto \left(\frac{E}{\mathrm{GeV}}\right)^{-3.2}$$

NGC 1068 is simulated as a point-like source

Best-fit (Spectral Energy Distribution) SED scenario inferred by IceCube

In a single year of data taking, ARCA can constrain the inferred scenario by the IceCube collaboration

Sensitivity compared with theoretical expectations



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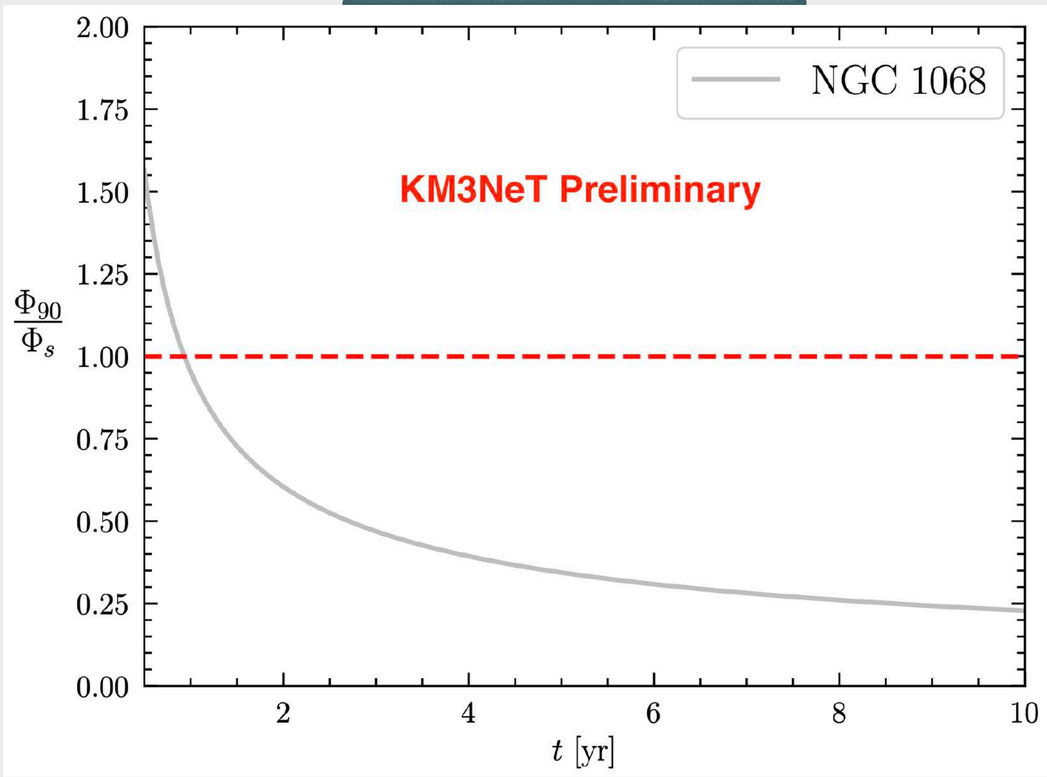
Sensitivity Gain with Time



Conclusions

KM3NeT/ARCA is a fundamental tool to unveil the Origin of the High-energy Neutrino Flux

DIFFUSE:

- the detector will be able to strongly constrain the considered hadronic scenario

- The future measurements in the range of 10-100 TeV will be crucial to better understand the physics of “Cosmic Reservoirs”

POINT-LIKE:

- In 7 years of data taking, ARCA will be able to test the potential hadronic emission coming from the core of SMC

- The SBG activity of Circinus will be more challenging to constrain

- In less than 1 year, it 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