KM3NET/ARCA expectations for starburst galaxies observation

Walid Idrissi Ibnsalih, Antonio Ambrosone, Antonio Marinelli, Gennaro Miele, Pasquale Migliozzi, Maria Rosaria Musone

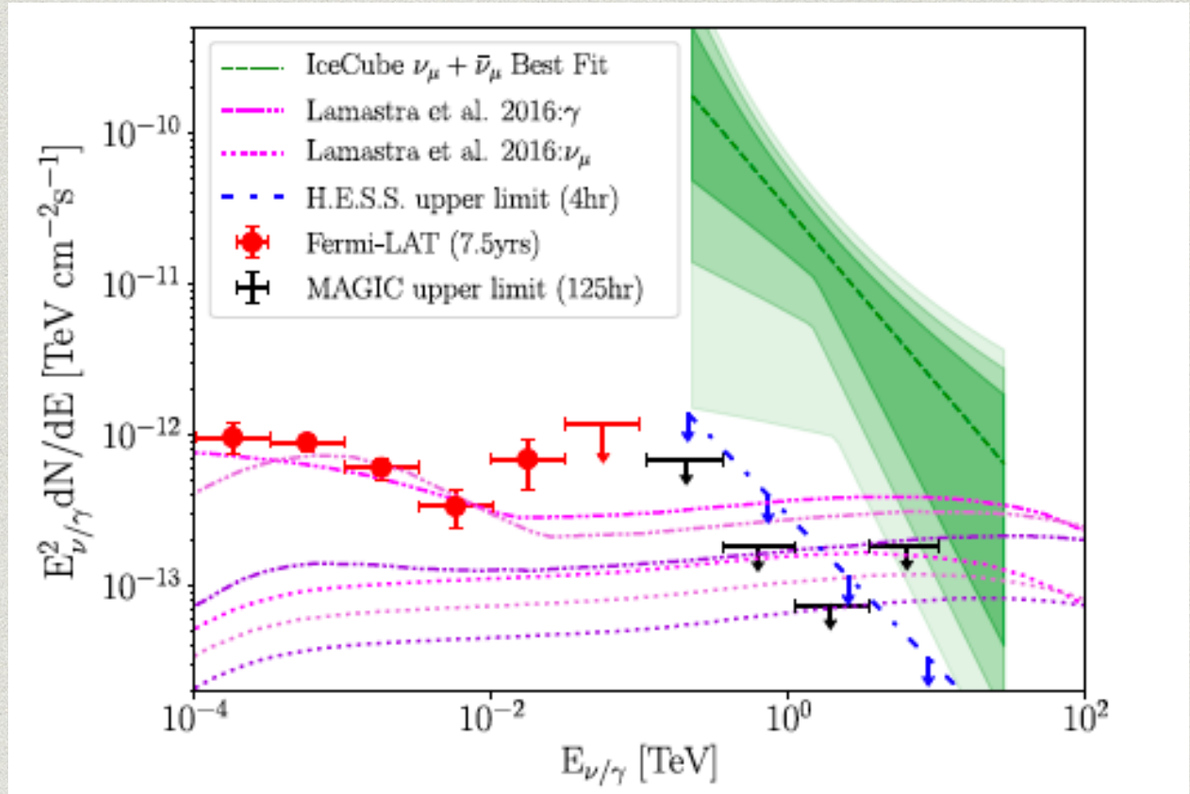
on behalf of KM3NeT Collaboration

Starburst Galaxies (SBG) as Neutrino Factories

Intense Star-forming activity

Point-Source

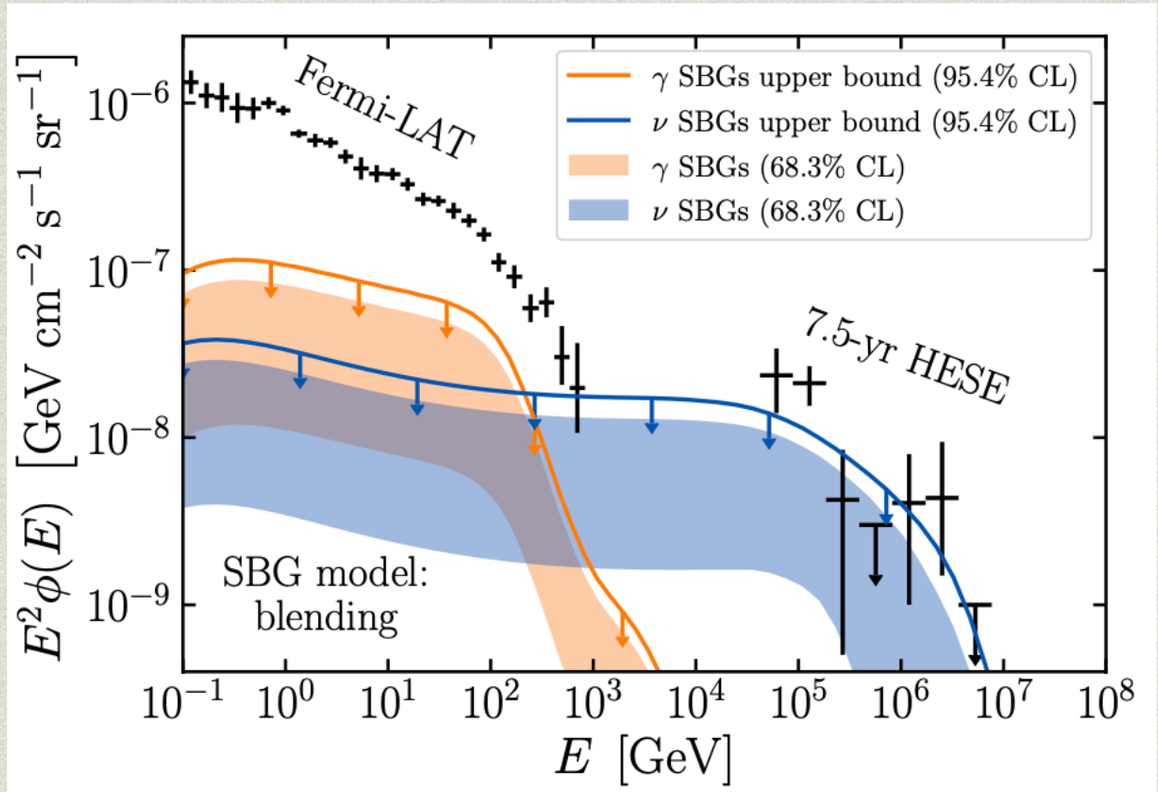
PRL 124 (2020) IceCube (Arxiv: 1910.08488)



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 to detect this source class?

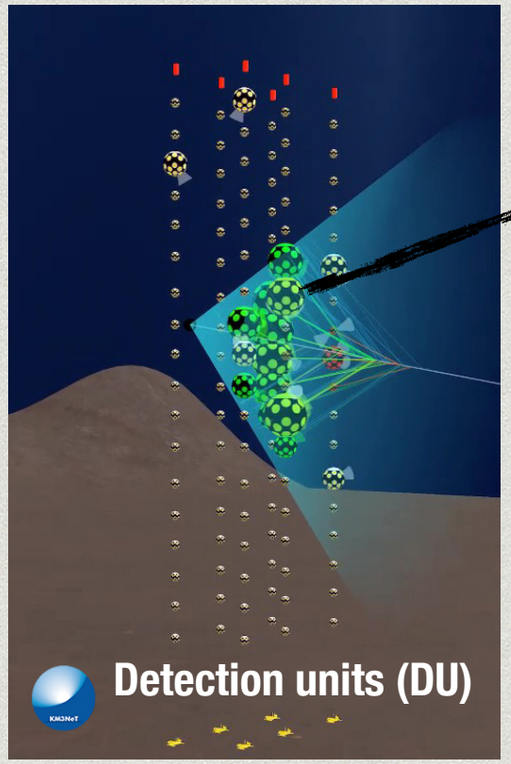
KM3NET neutrino telescope

ARCA:

- Main goal: High energy astrophysics
- TeV-PeV energy range
- 230 strings (115 for each block)
- 18 DOMs per string with 36 m spacing
- Depth ~3500 m about 100 kilometre off-shore the small town of Portopalo di Capo Passero on Sicily, Italy.

ORCA:

- Main goal: Neutrino oscillations
- 1-100 GeV energy range
- 115 strings
- 18 DOMs per string with 9 m spacing
- Depth of about 2500 m about 40 km off-shore Toulon, France.

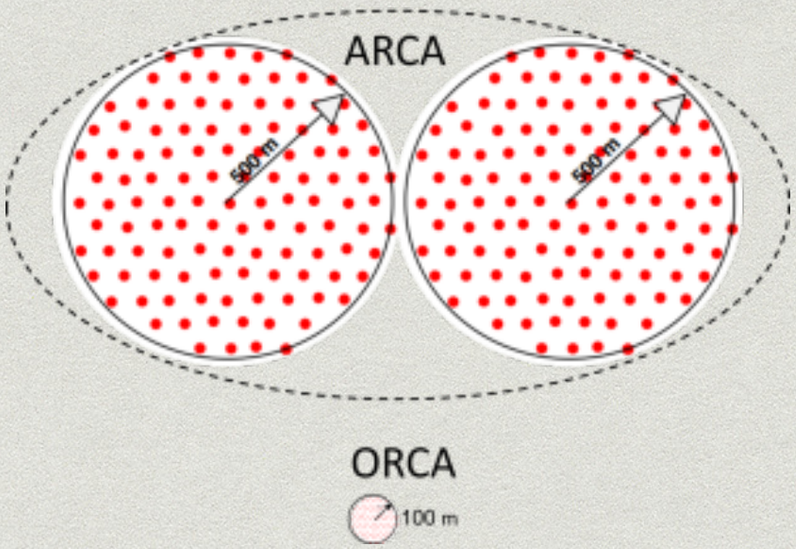


Digital optical module (DOM)

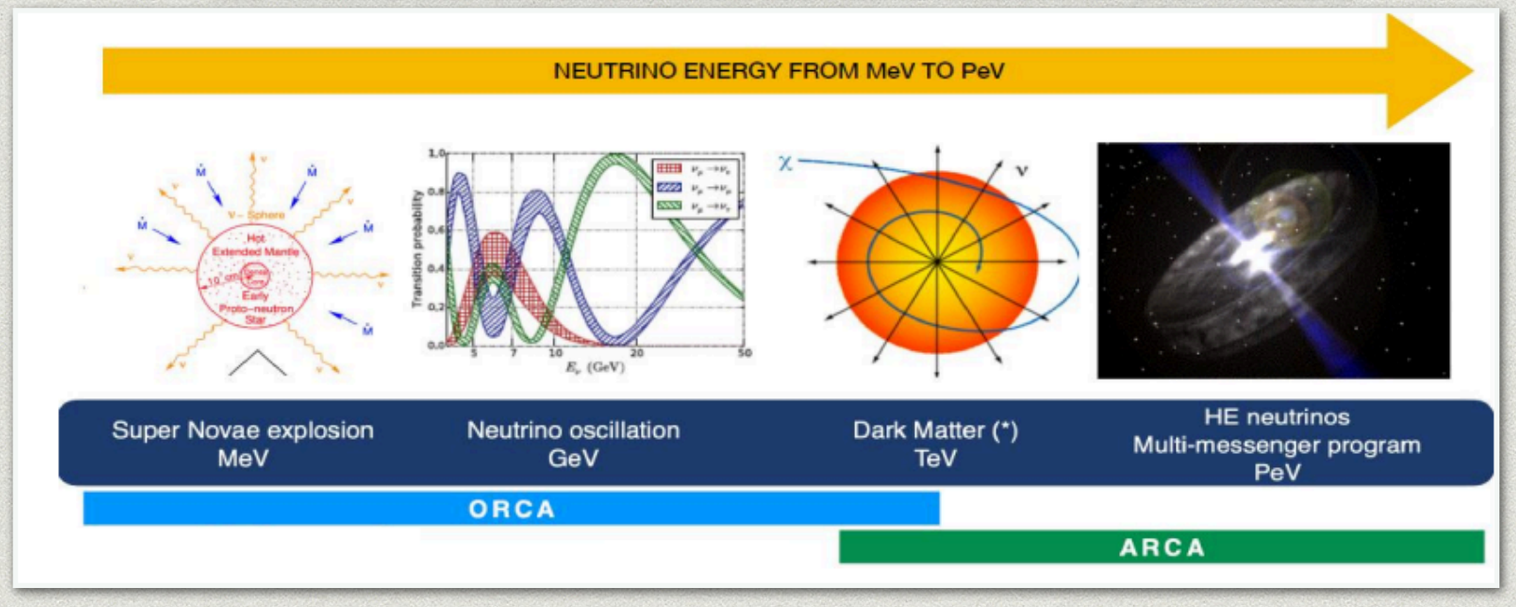
Detection principle

Cherenkov light produced by the relativistic particle resulting from the interaction of a incoming neutrino with water medium.

- **Both detectors share same technology**



Science with KM3NeT neutrino telescope

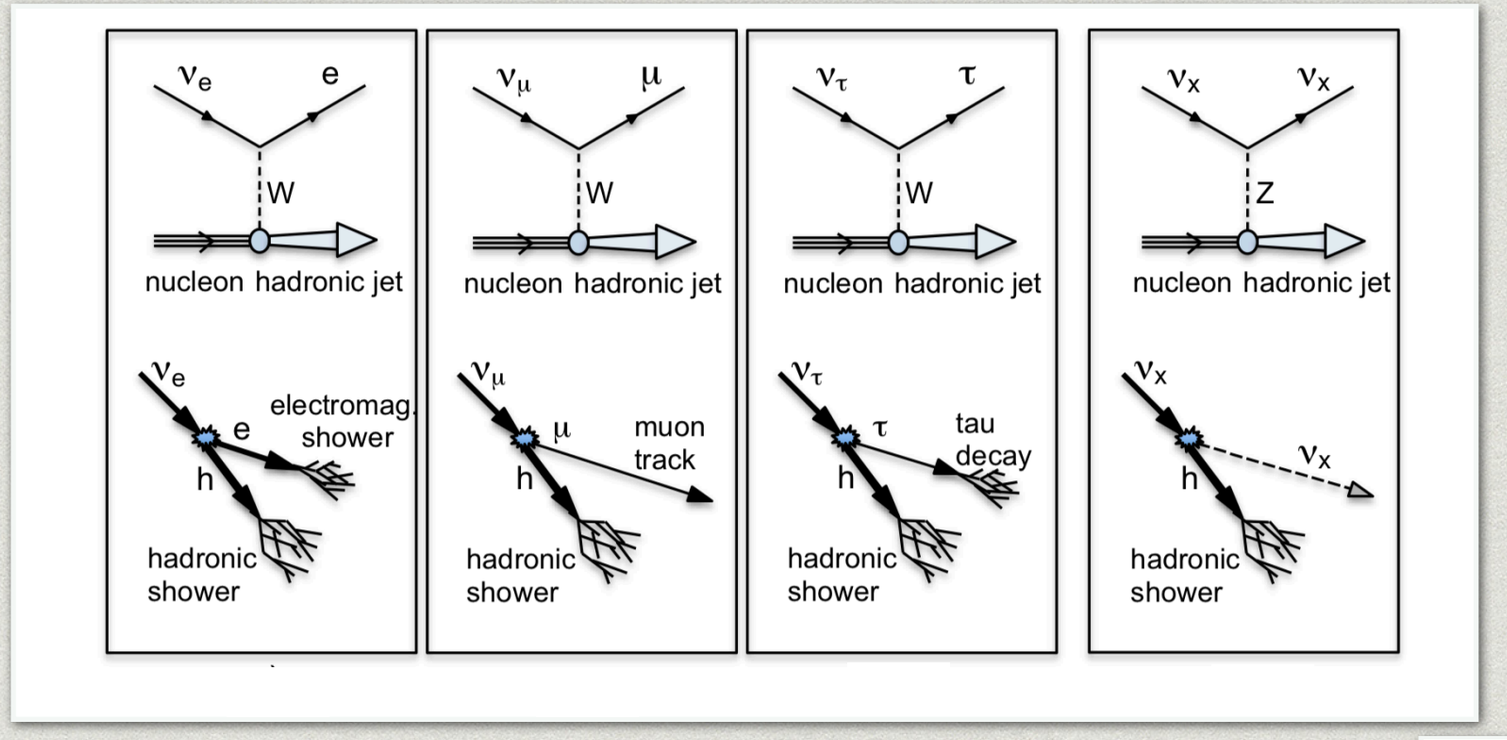


Despite the detectors are under construction, KM3NeT is already operative

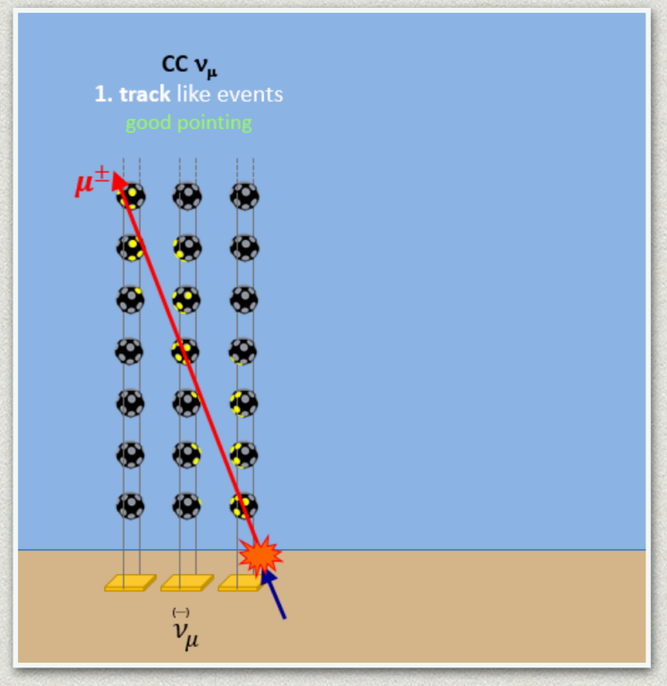
EVENT TOPOLOGY

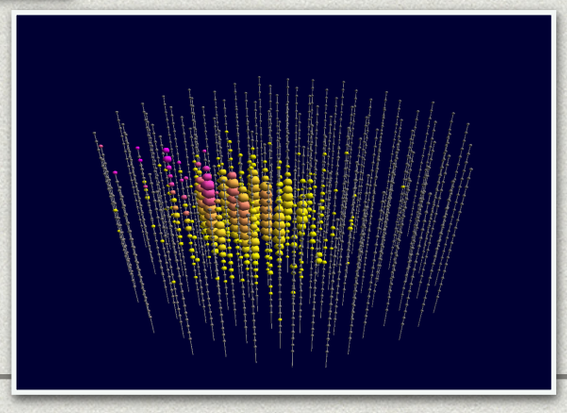
- $\nu_l + N \rightarrow l + X$ *via CC (charge current)*
- $\nu_l + N \rightarrow \nu_l + X$ *via NC (neutral current)*

l is referred to the leptonic flavour (e,μ,τ)



- **track event**
  - → **atmospheric μ - ν_μ via CC**
- **shower event**
  - → **ν_e via CC - ν_x via NC**
- **double bang event**
  - → **ν_τ via CC**





A visual example of a shower (on the left) and track event (on the top) within KM3NeT

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 the SBGs spectral energy distribution (SED)

- **Cut and Count approach**
- **Frequentist statistic (using the Feldman and Cousins upper limit calculation)**
- **Monte Carlo simulation of KM3NeT/ARCA115**

Sensitivity definition:

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

neutrino flux

average upper limit

signal events

DIFFUSE ANALYSIS

The energy range considered [100 GeV - 10 PeV]:

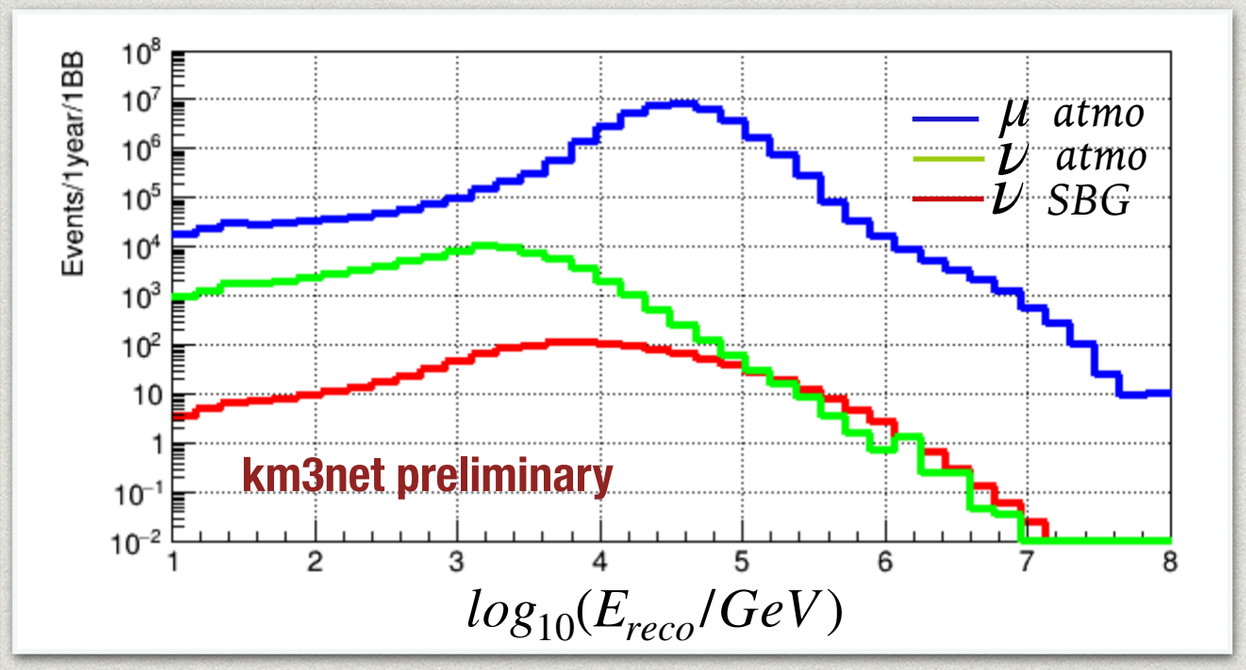
- **Background:** atmospheric μ, atmospheric ν (ν_e , ν_μ)
- **Signal:** ν diffuse SBG (ν_e, ν_μ, ν_τ)

Selection events:

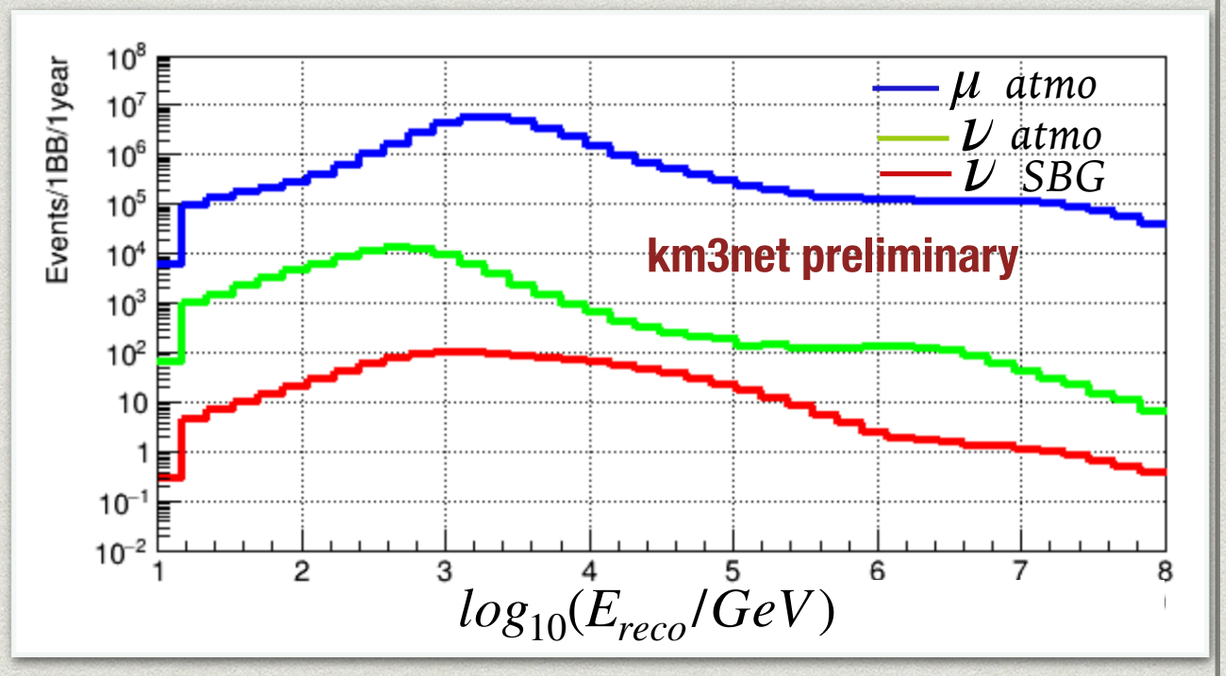
→ Selection for the track-like events was performed considering only up-going events

→ Selection for the cascade-like events was performed considering full sky scenario

Energy reconstruction (track-like algorithm)



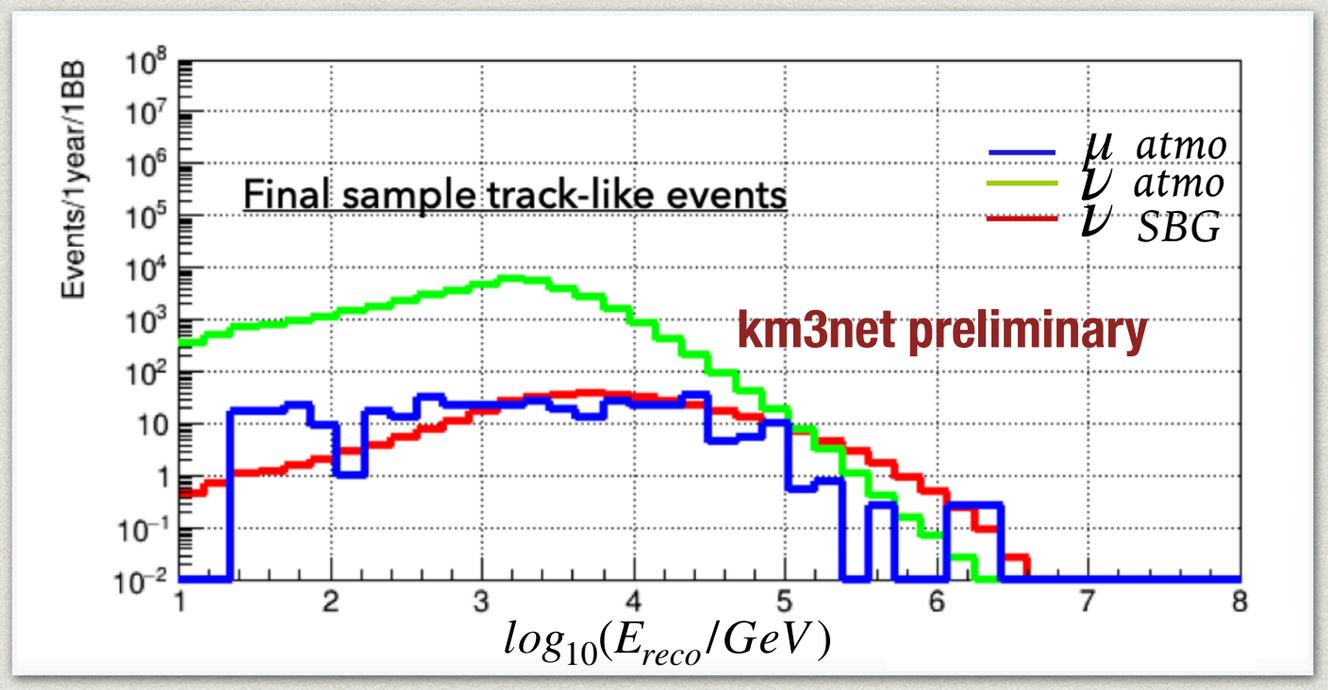
Energy reconstruction (shower-like algorithm)



DIFFUSE ANALYSIS: TRACK-LIKE SELECTION

Selection chain:

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



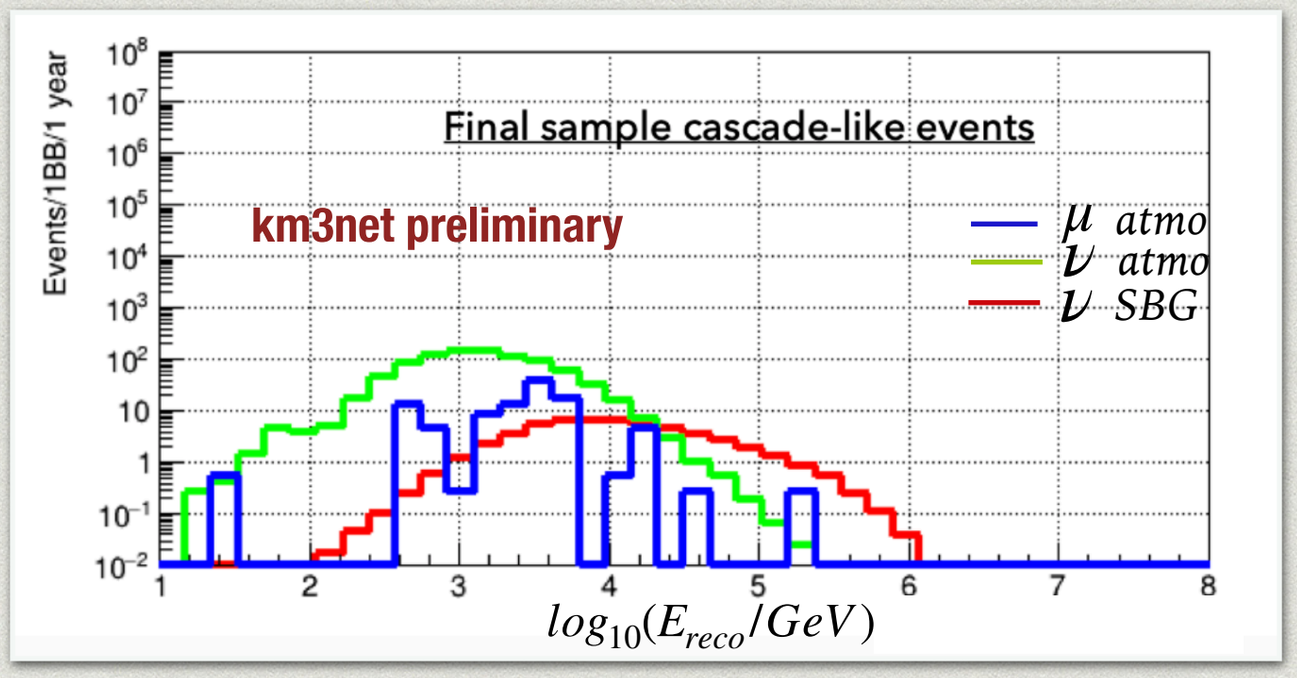
Events for 1 BB/1 yr (all energy range)

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: CASCADE-LIKE 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**



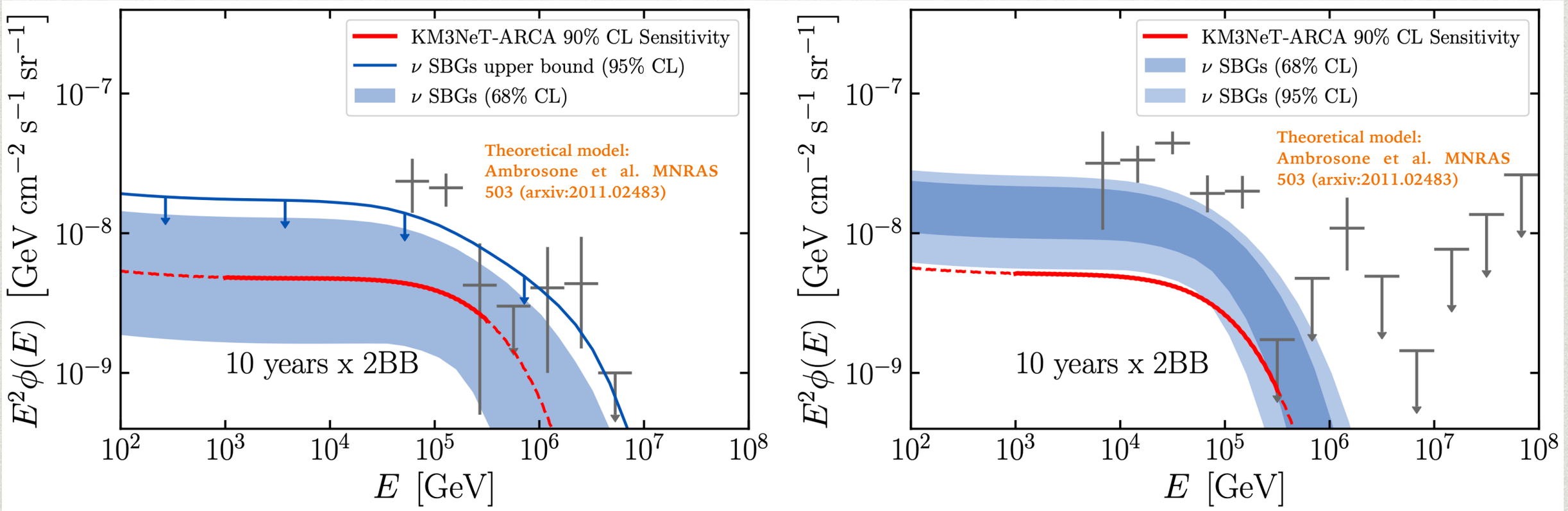
Events for 1 BB/1 yr (all energy range)

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

INTEGRATED SENSITIVITY FOR DIFFUSE FLUX

COMBINED TRACK-LIKE AND CASCADE-LIKE EVENTS

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

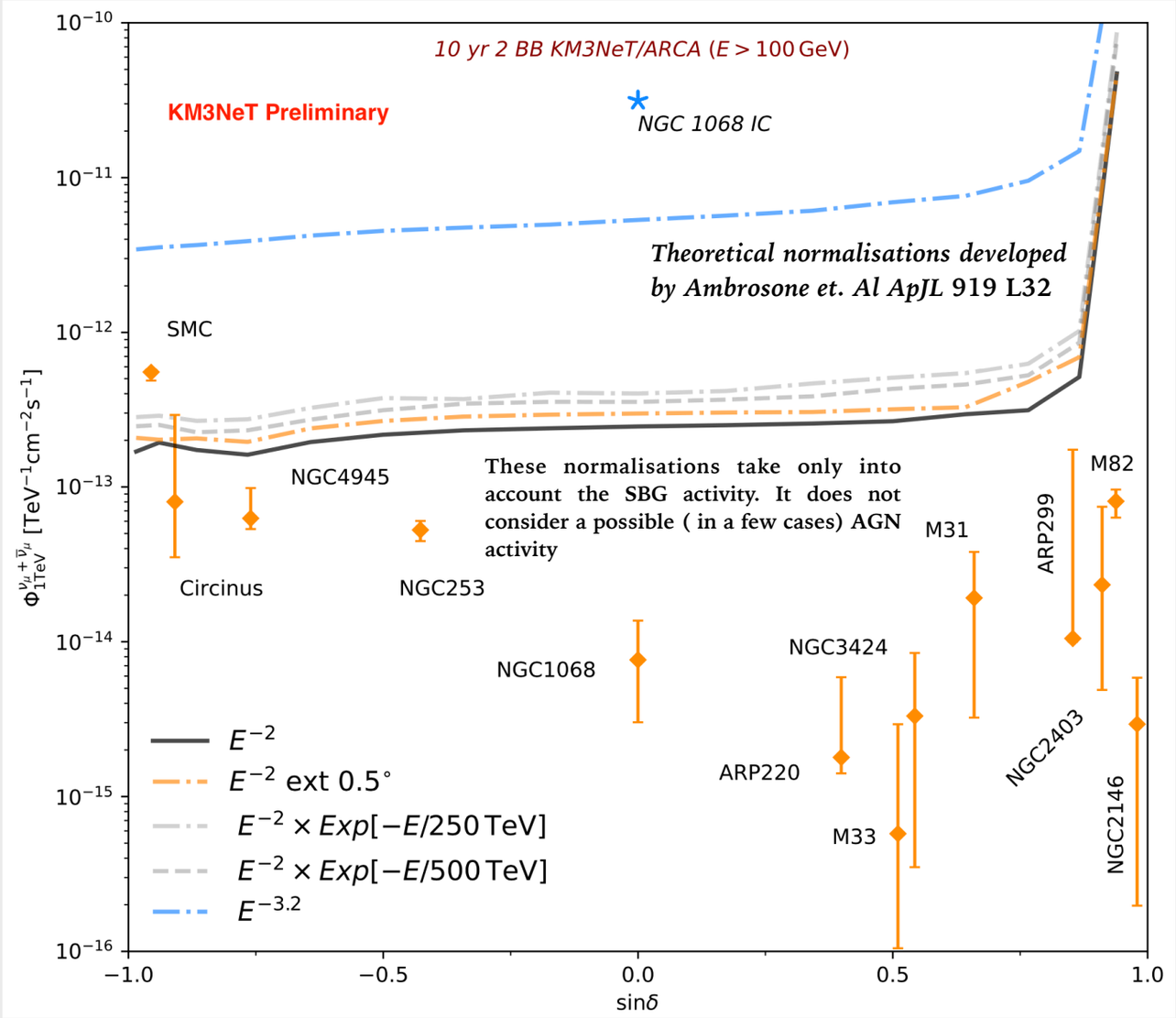


The computed sensitivity is compared with two different SBG scenarios: on the left the expected signal was calculated from HESE (IceCube) and Fermi-LAT EGB, otherwise on the right using CASCADE (IceCube) and Fermi-LAT EGB.

ARCA is extremely sensitive for this possible diffuse flux SBG and in few years of data taking it will put sever constrain on such a scenario

Point-like Analysis

KM3NeT/ARCA115 expectations for nearby known SBG sources

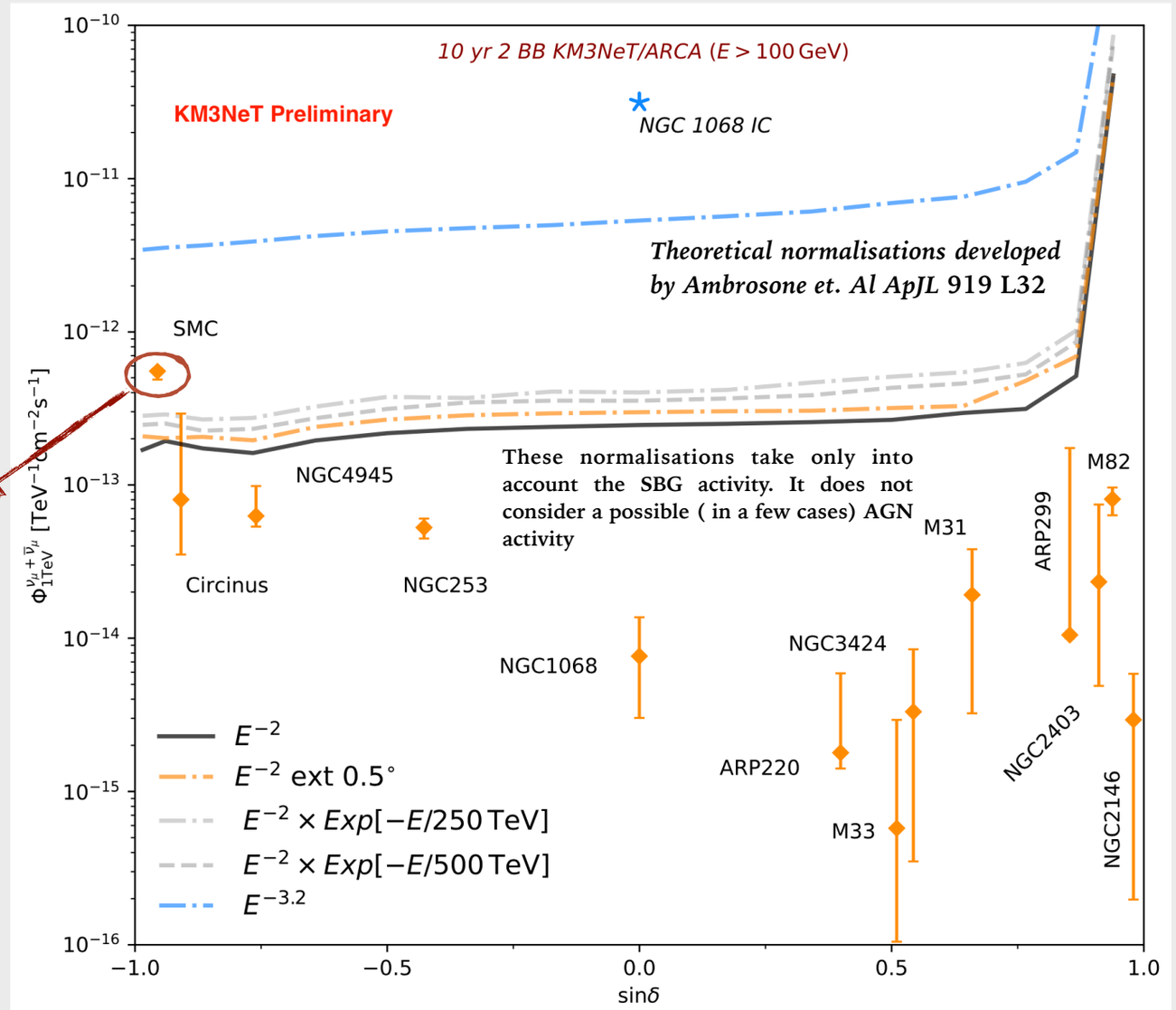


Even though each source is characterised by its own spectrum, ARCA seems sensitive for the SBGS in the southern sky, where it has more visibility

Point-like Analysis

KM3NeT/ARCA115 expectations for nearby known SBG sources

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

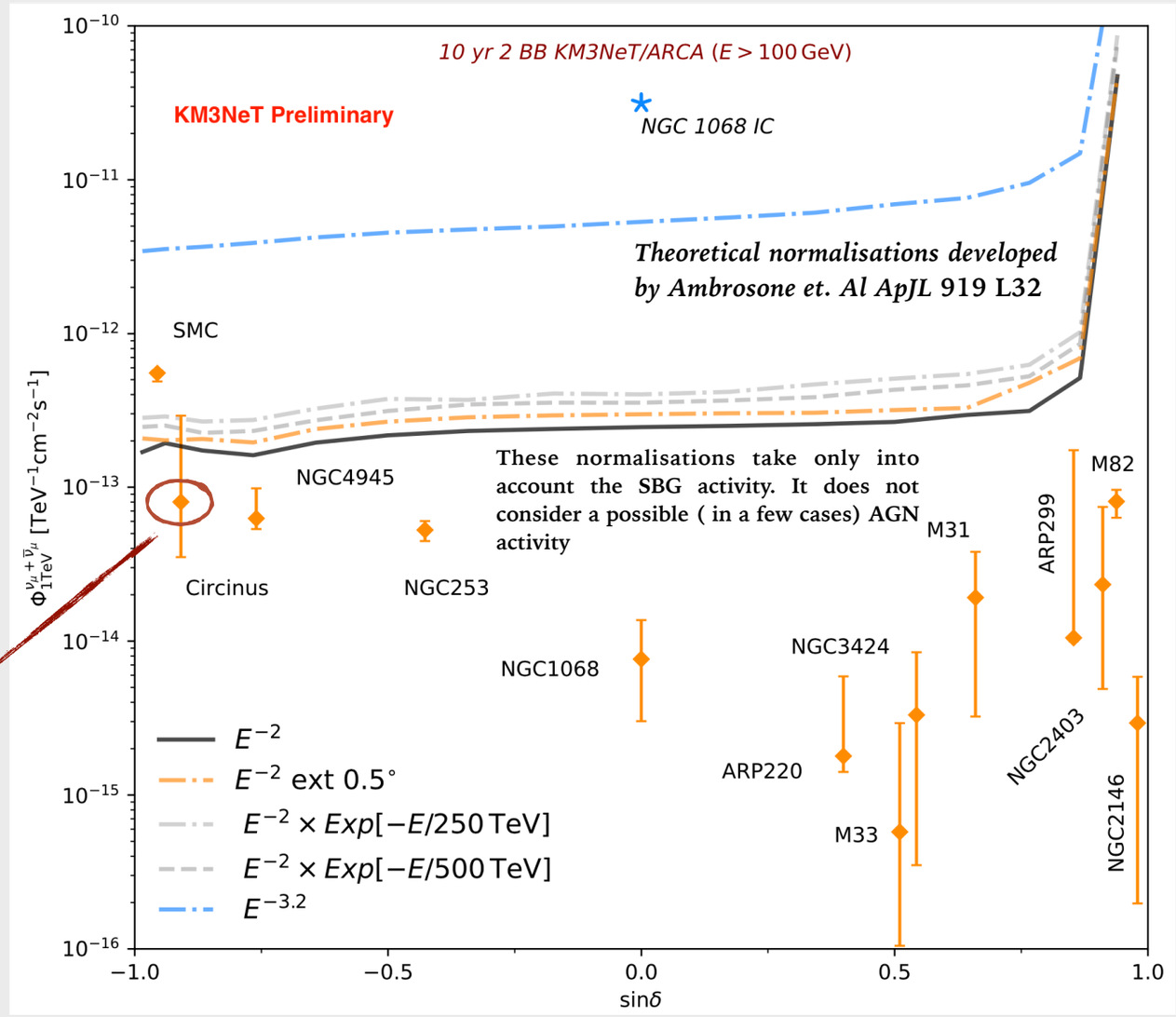


Even though each source is characterised by its own spectrum, ARCA seems sensitive for the SBGS in the southern sky, where it has more visibility

Point-like Analysis

KM3NeT/ARCA115 expectations for nearby known SBG sources

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

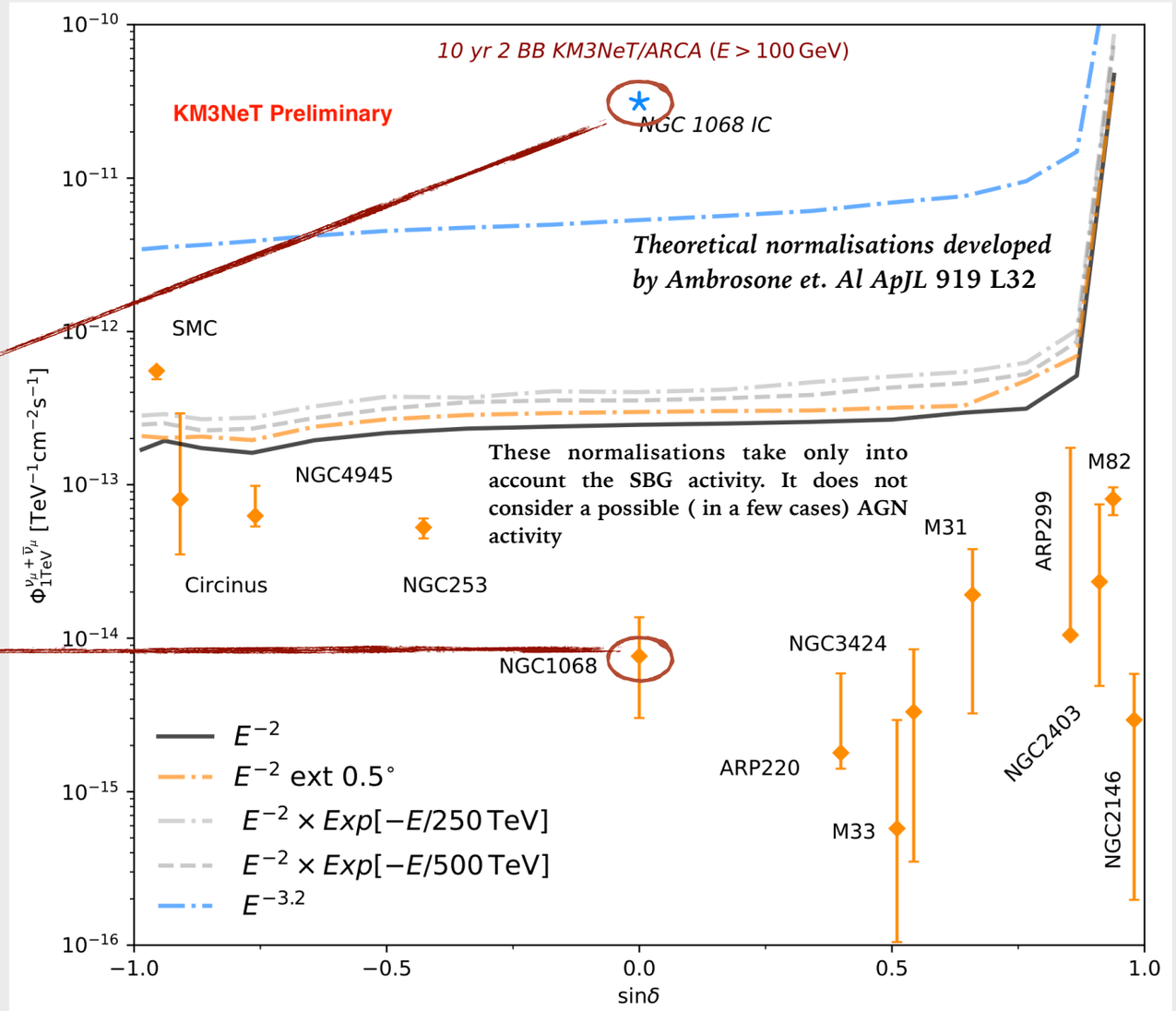


Even though each source is characterised by its own spectrum, ARCA seems sensitive for the SBGS in the southern sky, where it has more visibility

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



Even though each source is characterised by its own spectrum, ARCA seems sensitive for the SBGS in the southern sky, where it has more visibility

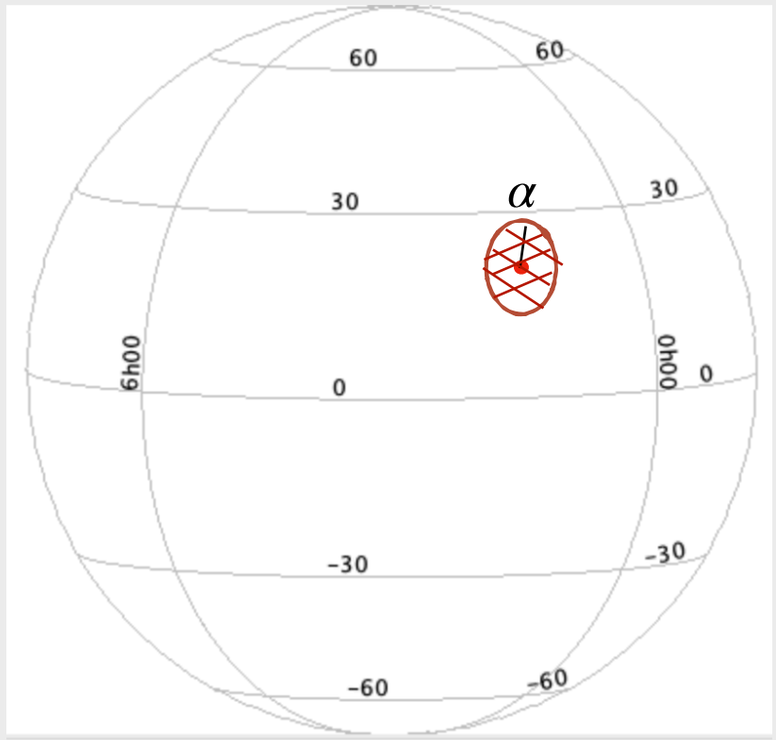
Diving into the Sources: Event Selection

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

- → Only $\nu_\mu - \bar{\nu}_\mu$ CC
- → *Dedicated Simulation for each source*
- → Model Rejection Factor minimisation to optimise the sensitivity

Event Selection:

- **Signal: Neutrinos coming from the region of interest (RoI), defined by α**



- Nominal position of the source in the sky

Region of Interest

Diving into the Sources: Event Selection

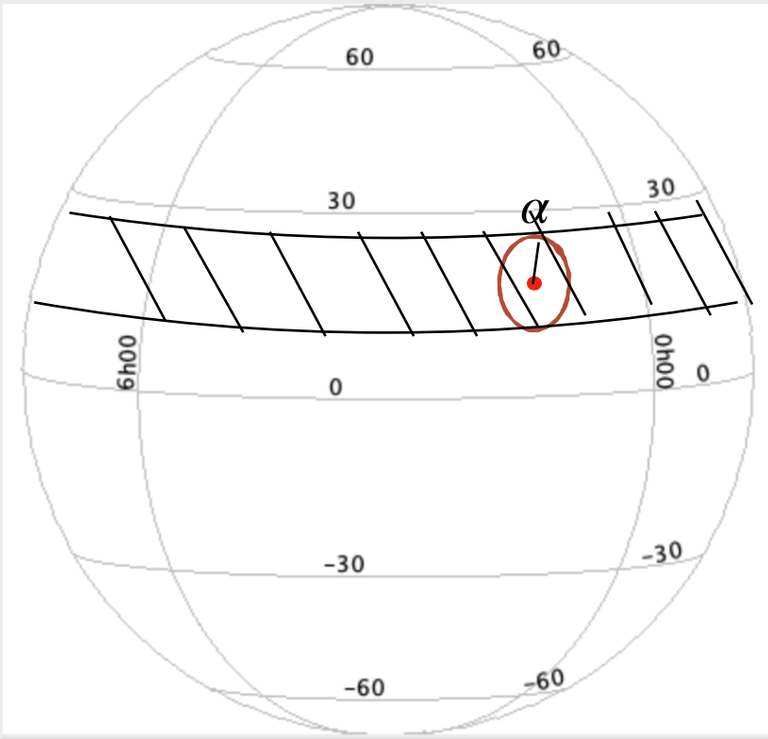
Method: Cut and Count approach and Frequentist Statistic (Feldman and Cousins Upper limit Calculation)

- → Only $\nu_\mu - \bar{\nu}_\mu$ CC
- → *Dedicated Simulation for each Source*
- → Model Rejection Factor minimisation to optimise 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

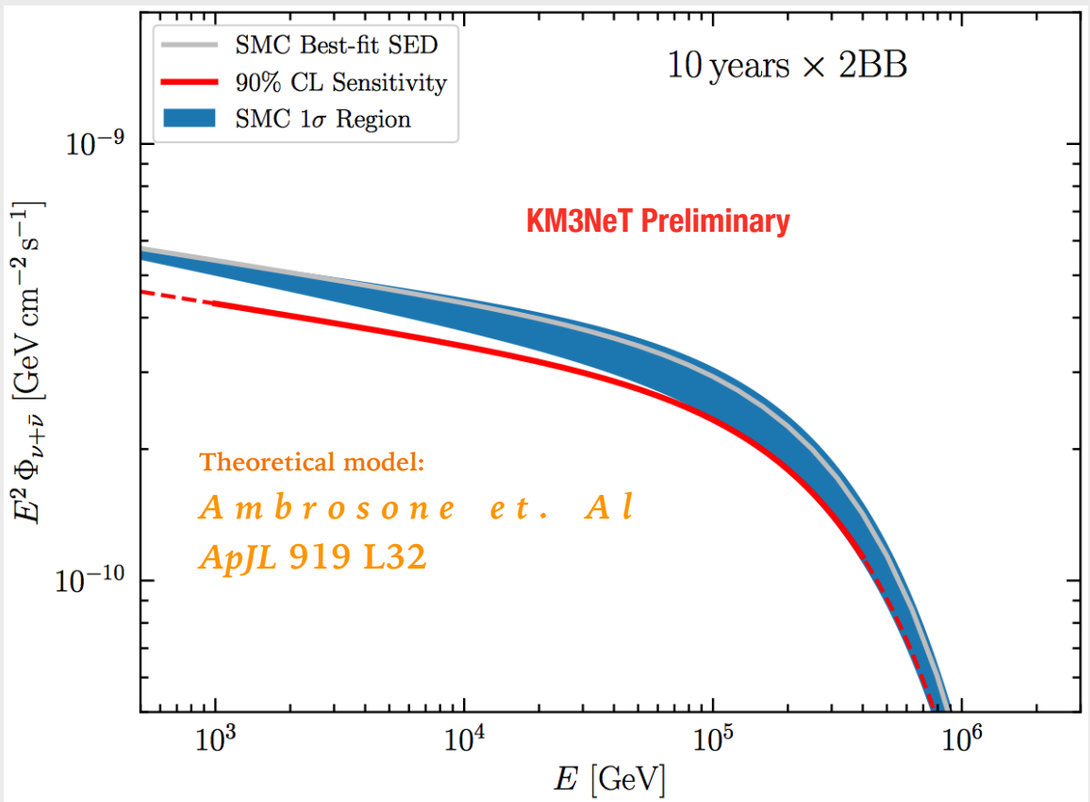
Diving into the Sources: SMC

SMC simulated as an extended source of 0.5°

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

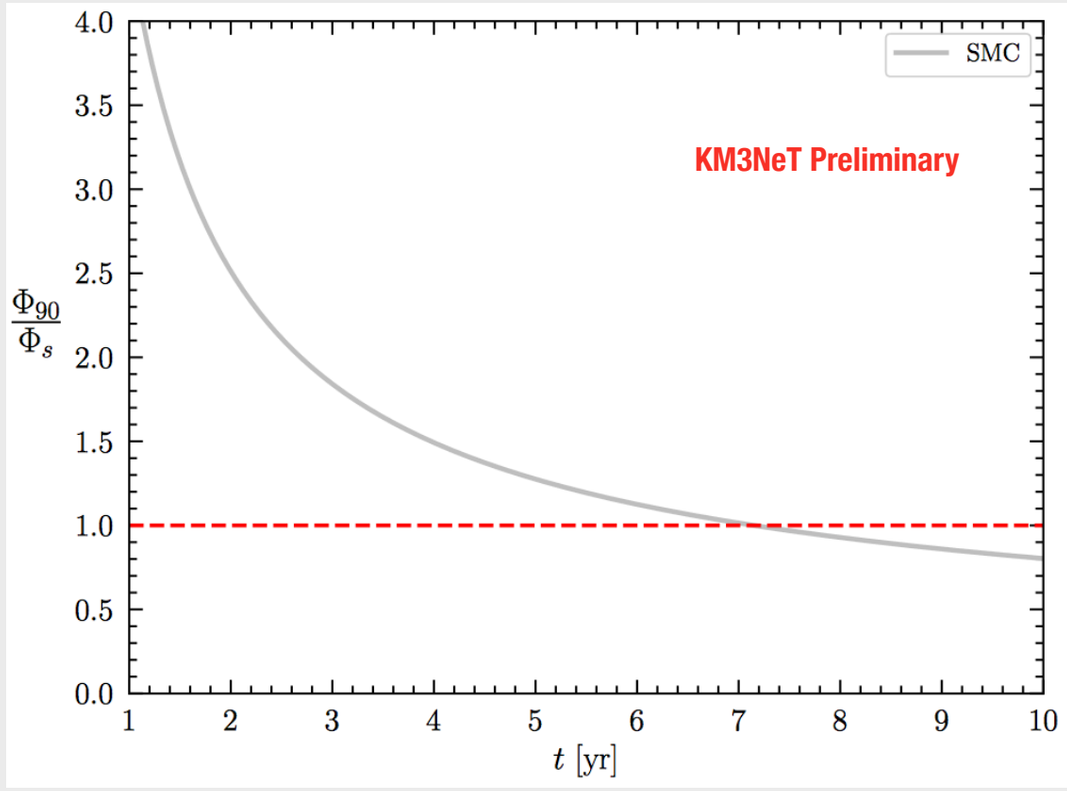
In few years of data taking, ARCA will put severe constraints on such scenario!

Sensitivity compared with theoretical expectations



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

Sensitivity gain with time



The integrated sensitivity as a function of the time. KM3NeT/ARCA will be able to constrain the SMC flux in 7 years

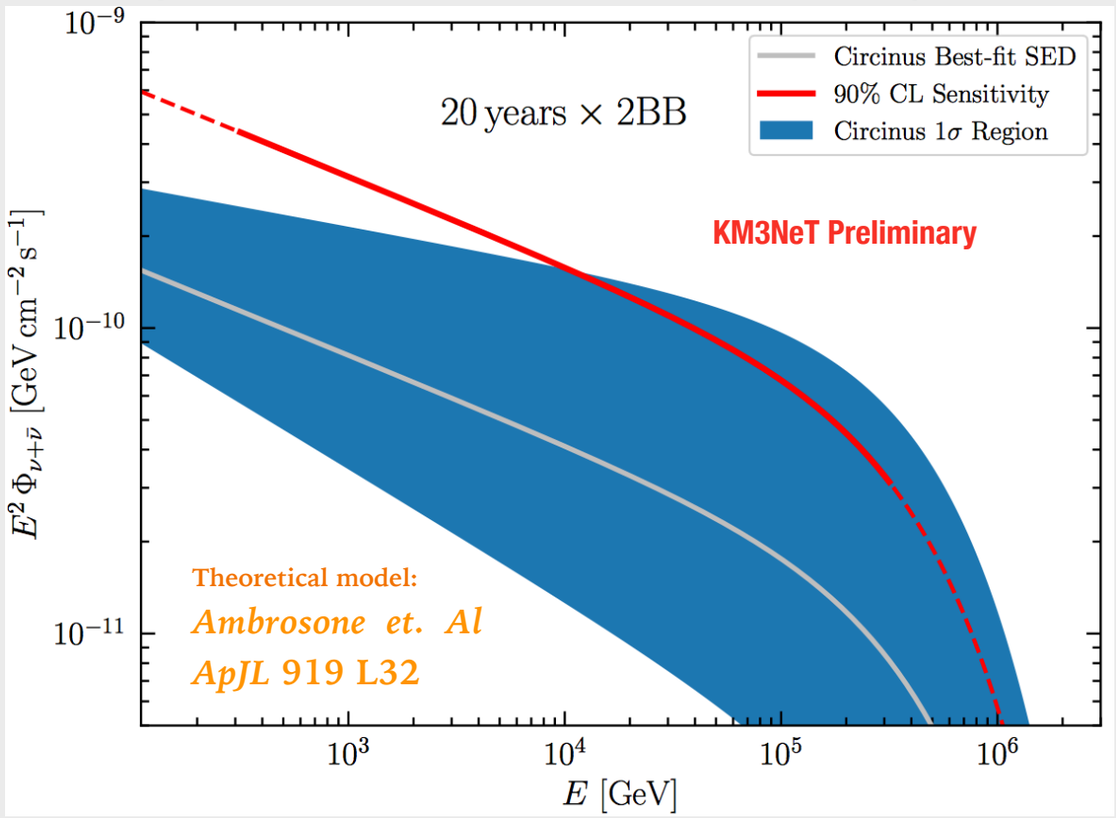
Diving into the Sources: CIRCINUS

Circinus is simulated as a point-like source

$$\Phi_\nu \propto \left(\frac{E}{\text{GeV}}\right)^{-2.3} \times e^{-\frac{E}{500\,\text{TeV}}}$$ Best-fit SED scenario

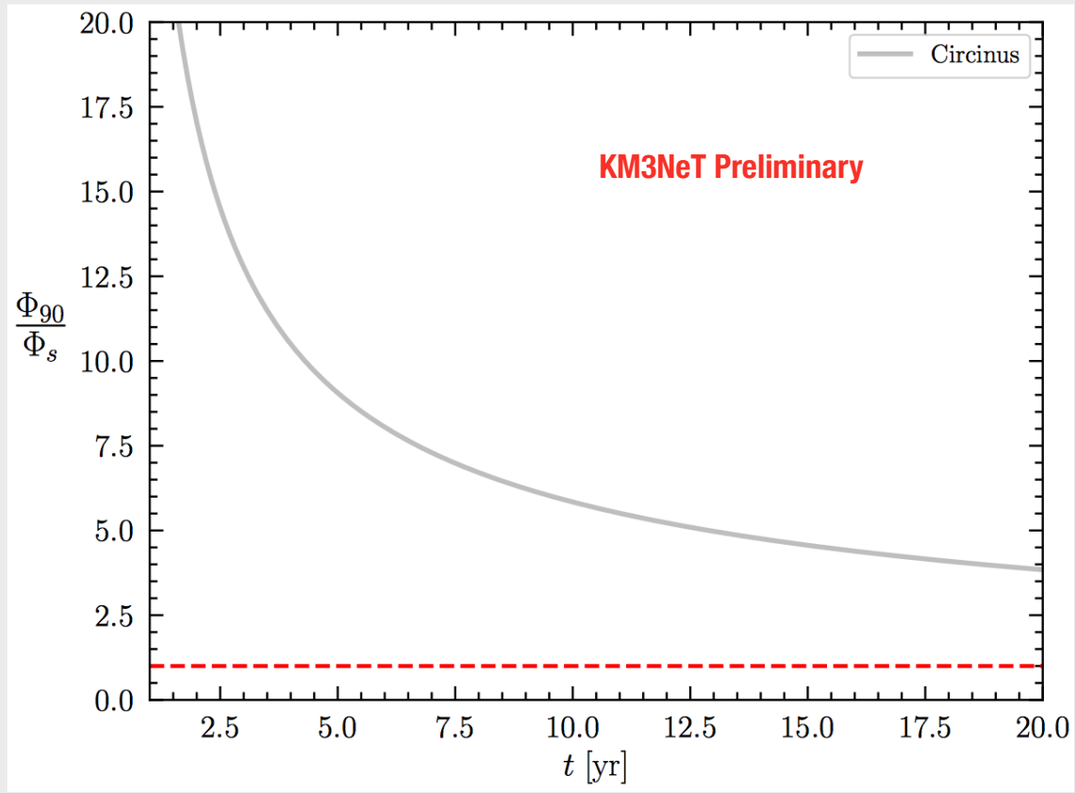
For ARCA, It will be challenging to constrain the best-fit scenario. Probably, it will be possible to constrain the upper-limit of such scenario.

Sensitivity compared with theoretical expectations



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

Sensitivity gain with time



The integrated sensitivity as a function of the time.

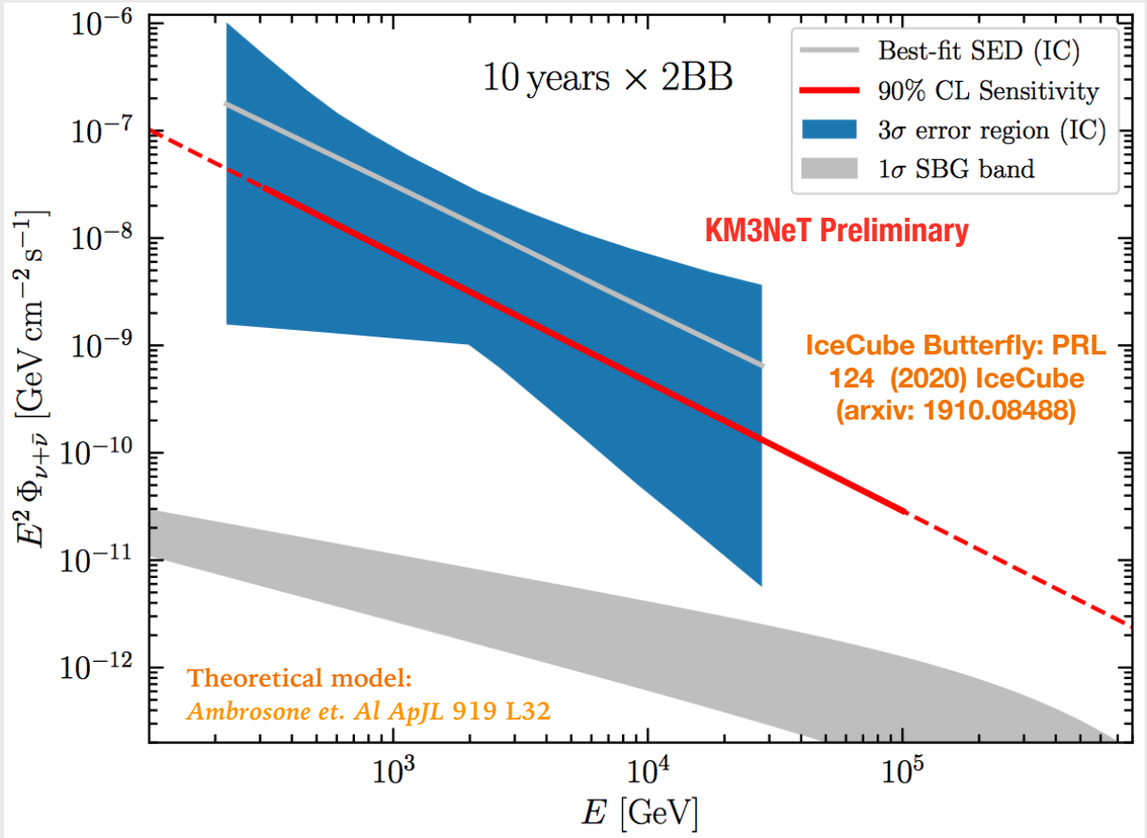
Diving into the Sources: NGC 1068

NGC 1068 is simulated as a point-like source

$$\Phi_\nu \propto \left(\frac{E}{\mathrm{GeV}}\right)^{-3.2}$$ Best-fit SED scenario inferred by IceCube

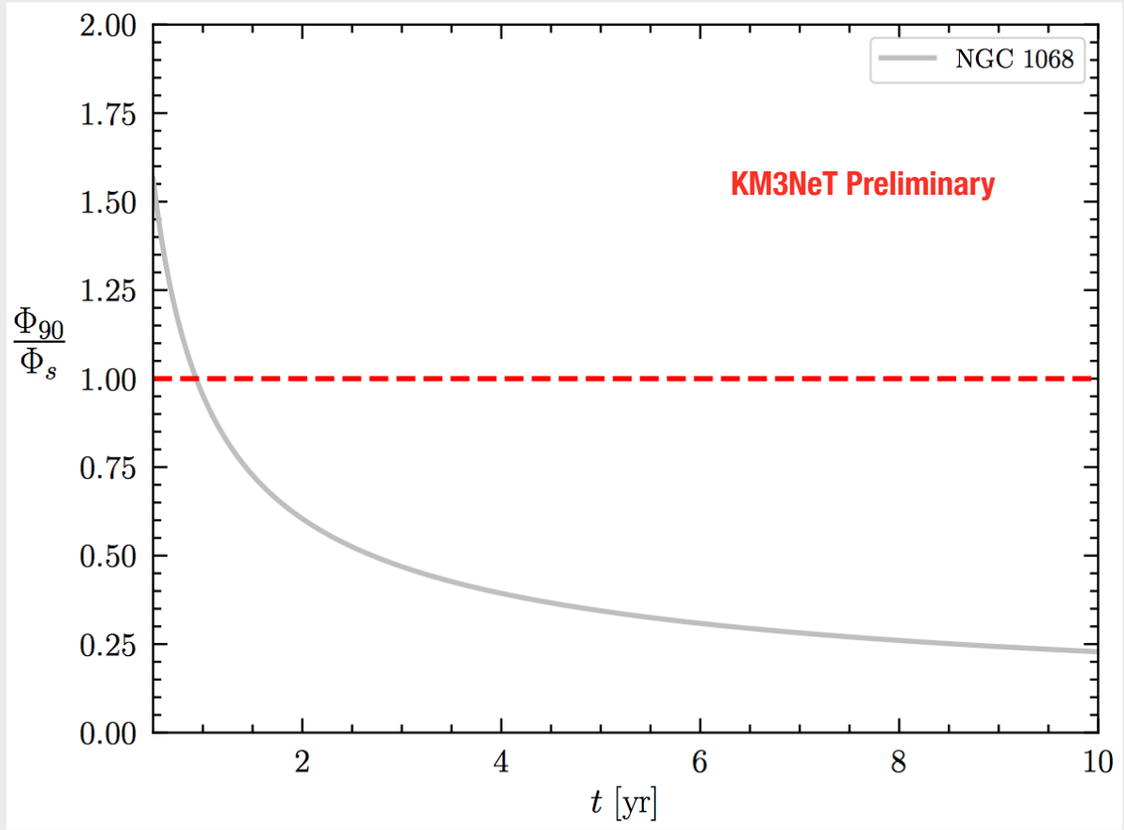
In a single year of data taking, ARCA can put constrain on the inferred scenario by the IceCube collaboration

Sensitivity compared with theoretical expectations



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

Sensitivity gain with time



The integrated sensitivity as a function of the time. The detector will be able to constrain this scenario in less than 1 year

Conclusions

KM3NeT/ARCA is a fundamental tool to unveil the origin of the high-energy neutrino flux

DIFFUSE:

- The detector will be able to test the calorimetric scenario assumed for hadronic scenario.
- The future measurements around hundreds of TeV will give more informations about the physics of Cosmic reservoirs as well as to suggest the maximal energies of the contained supernovae remnants.

POINT-LIKE:

- In a few 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.
- 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.