The neutrino astronomy status and activity related to the WP3 group of NaNeT project

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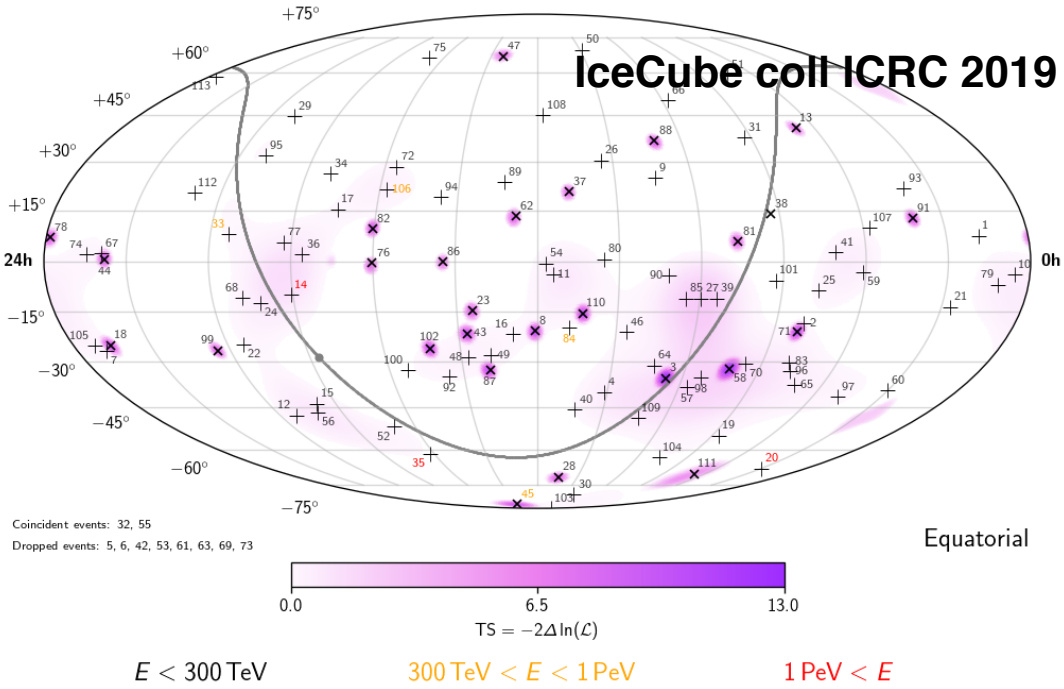
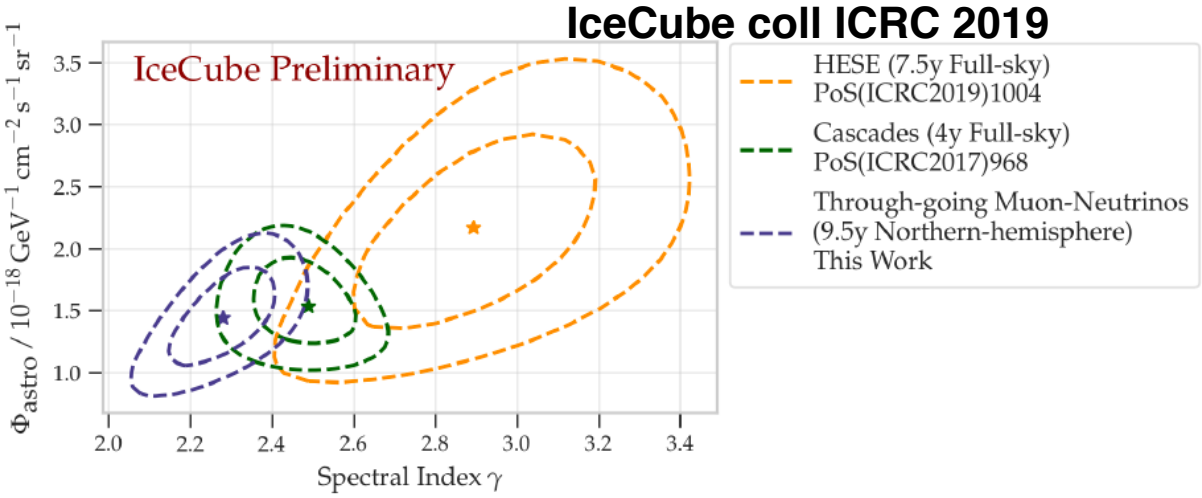
KICKOFF PRIN Meeting NANET 27-28/01/2010

Status of high energy ν Astronomy

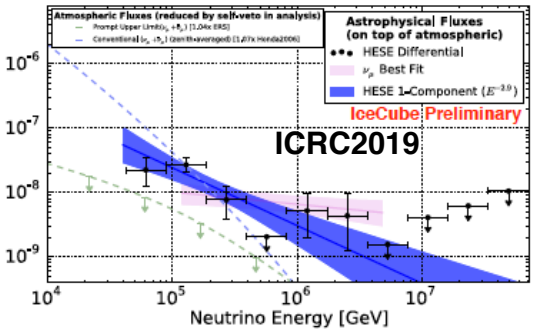
IceCube skymap of the HESE events collected up to now.



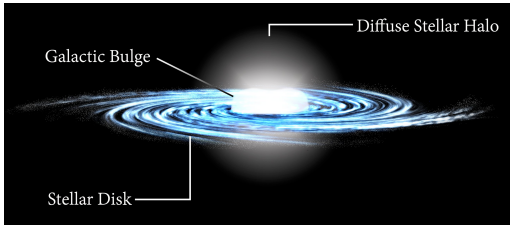
Discrepancy of the SEDs of different neutrino samples measured by IceCube



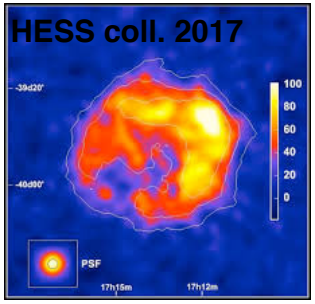
Summary about astrophysical ν factories



After 9years of operations IceCube already collected more than 100 of HESE type events and more than 50 astrophysical muonic neutrino events from the northern hemisphere characterized respectively by two power-law SEDs with **α~2.9 and α~2.2**



The last upper limits for the **diffuse Galactic emission** contribution obtained by IceCube/ANTARES set this value at **< 8.5% of the total IceCube astrophysical flux**

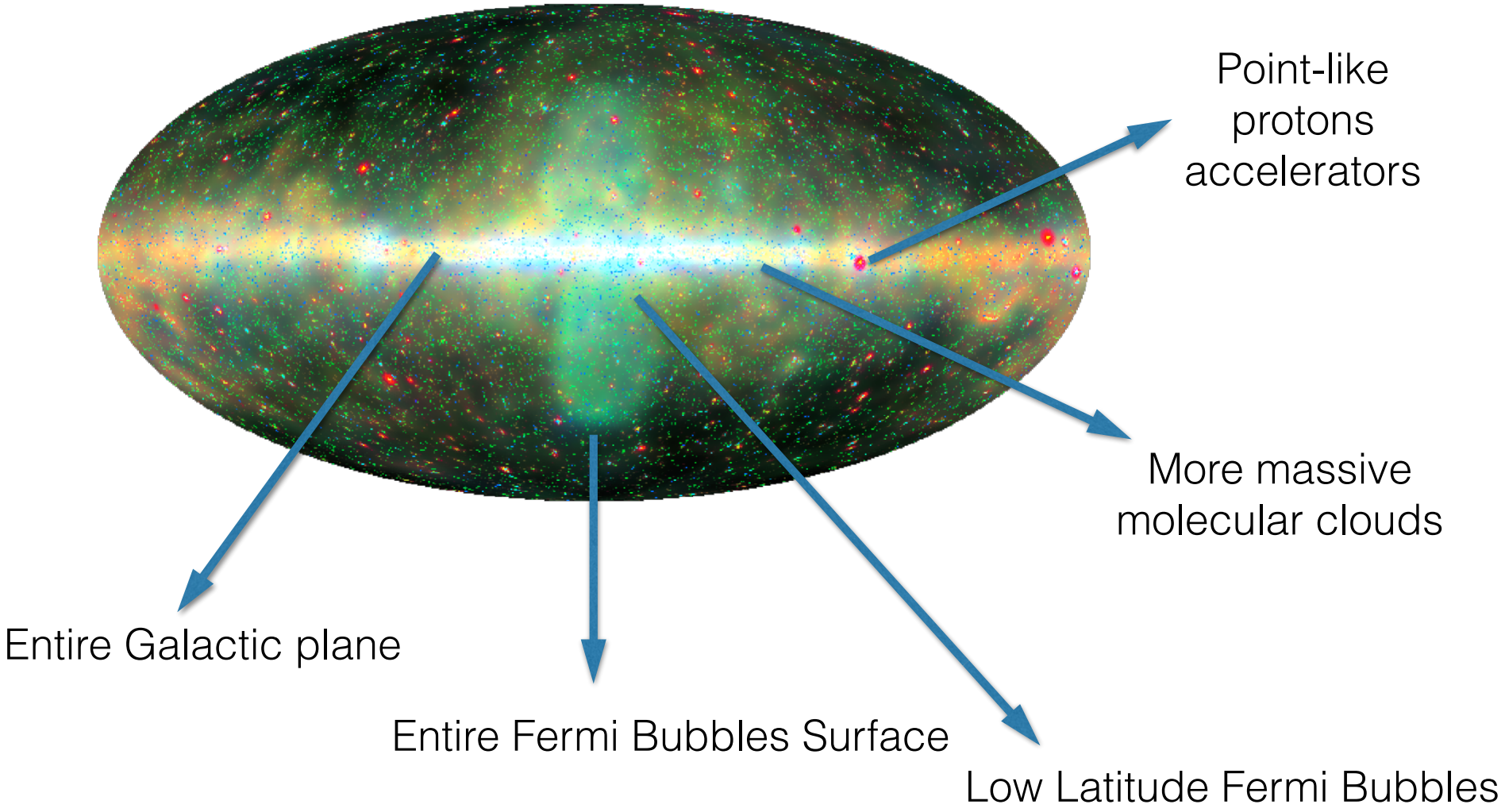


No associations for the moment with known **Galactic Pevatrons**, maybe due to <u>small duration of the hadronic Pevatron phases</u>

Still under discussion which extragalactic population of powerful sources contribute more to the observed astrophysical neutrino flux, <u>few % from GRB, 25-30% Blazars? Starburst galaxies? other AGNs?</u>

Looking for Galactic neutrino Emitters

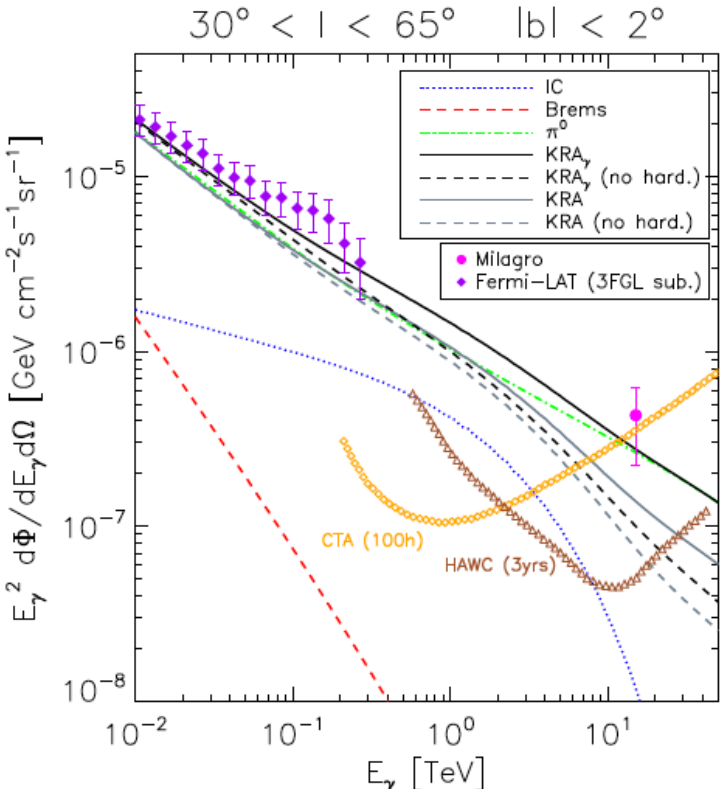
Where we should expect Galactic ν

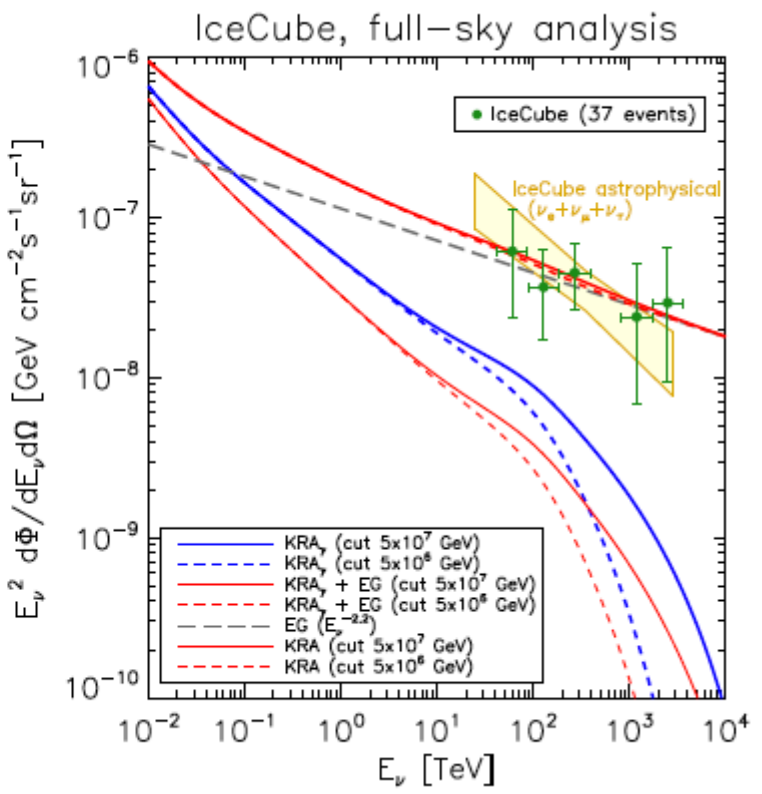


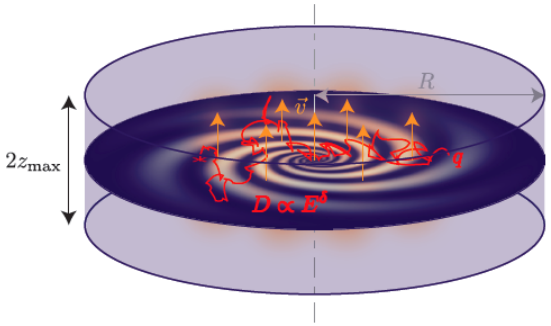
Contribution of diffuse Galactic ν to the full sky

Gaggero, Grasso, Marinelli, Urbano, Valli, APJ Letter arXiv:1504.00227

We introduced a new model of Galactic cosmic rays trasport with a diffusion coefficient radially dependent to explain the high-energy gamma-ray emission.

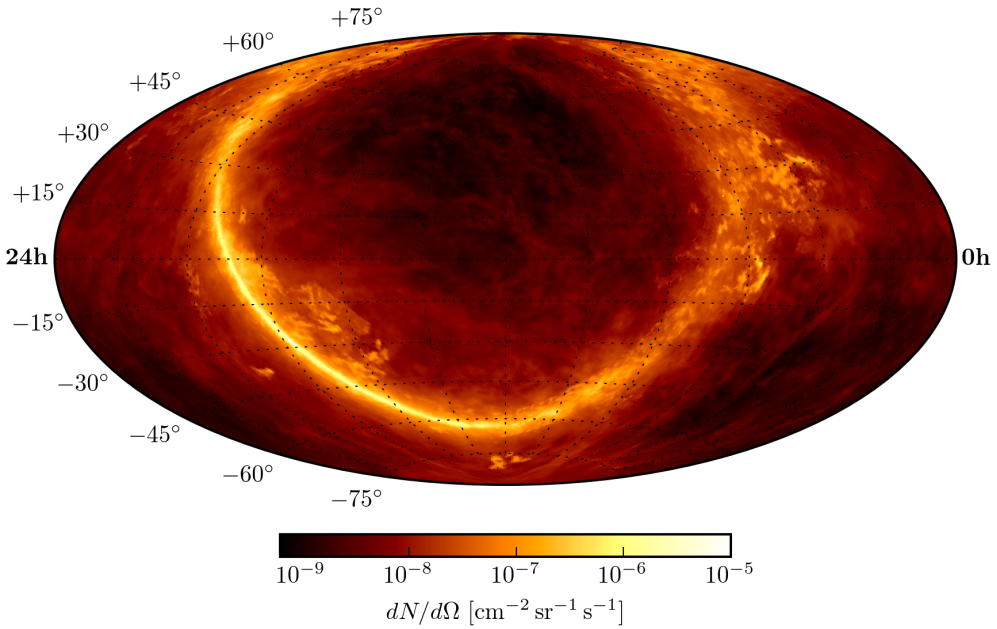






The contribution of diffuse Galactic neutrino flux resulted to be less than 15% of the measured Icecube full sky flux

Upper limits of Galactic ν from IceCube + ANTARES

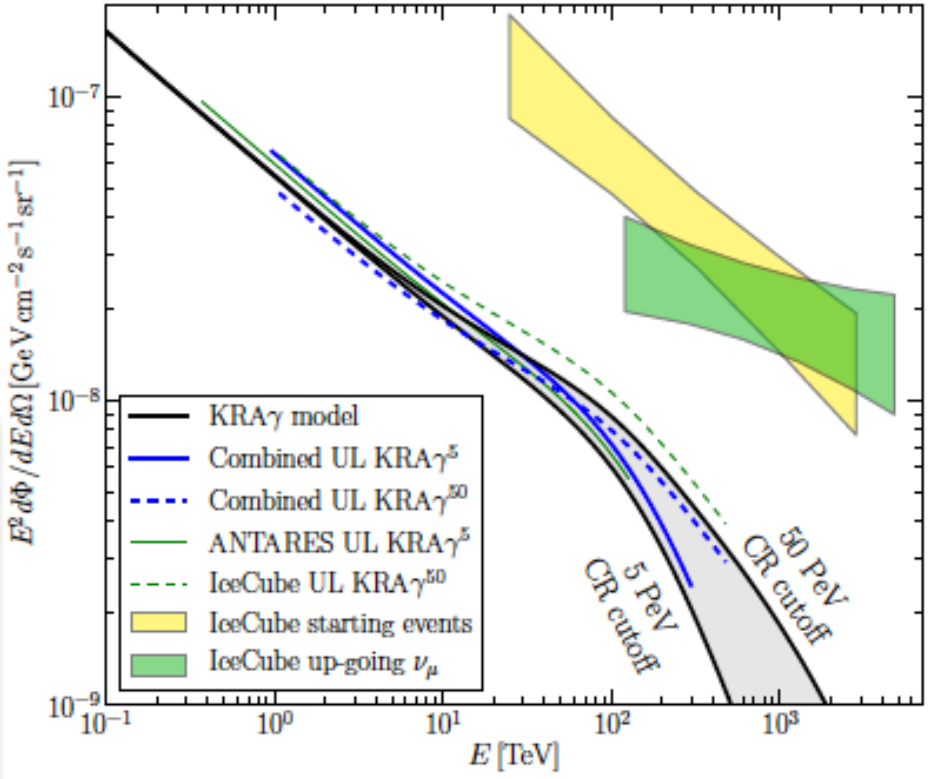


IceCube+Antares-arXiv180803531A

The same template of previous analyses is used with the two cut-offs 5 and 50 PeV for protons

The new ULs comprises 2780 days of ANTARES (shower + tracks) and 2431 days of IceCube (tracks)

The new ULs for the case of 5 PeV cut-off for protons we set the maximal Galactic diffuse neutrino flux at the level of 8.5% of the total measured astrophysical flux measured by IceCube



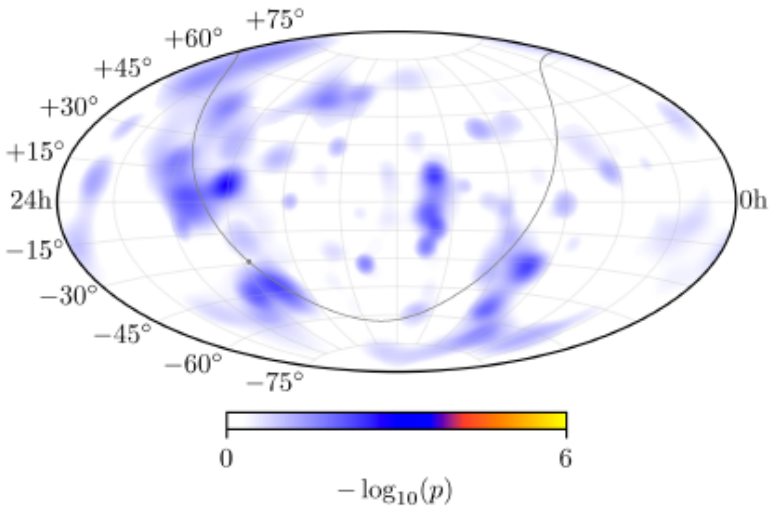
Last results on Galactic ν with IceCube shower events

IceCube Cascade analysis 2019 IceCube+Antares 2018 analysis

	7yr Cascades				Previous Work			
Template	p-value	Sensitivity	Fitted Flux	UL	p-value	Sensitivity	Fitted Flux	UL
KRA_γ^5	0.021	0.58	0.85	1.7	0.29	0.81	0.47	1.19
KRA_γ^{50}	0.022	0.35	0.65	0.97	0.26	0.57	0.37	0.90
Fermi-LAT π^0	0.030	2.5	3.3	6.6	0.37	2.97	1.28	3.83

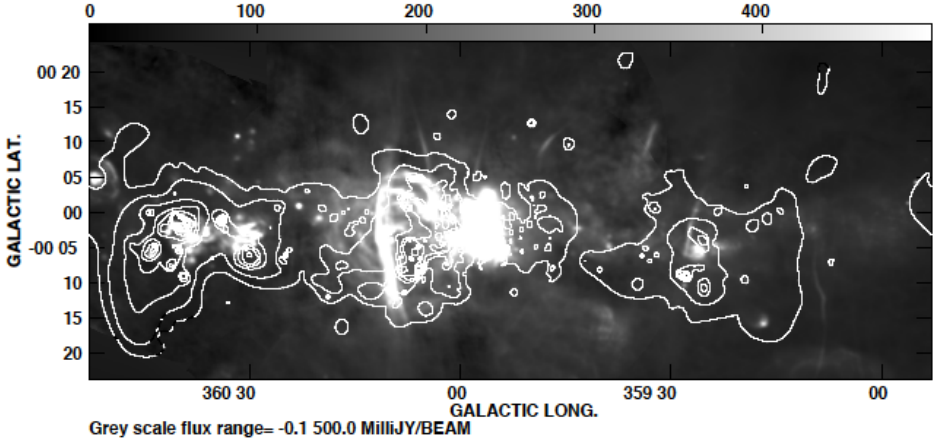
IceCube coll. ArXiv1907.06714

Pre-trial IceCube sensitivity



IceCube found a excess of 2.2 σ confirming that the diffuse Galactic component should be <10% of total astrophysical IceCube flux

CMZ: special Laboratory for Astrophysical Mechanisms

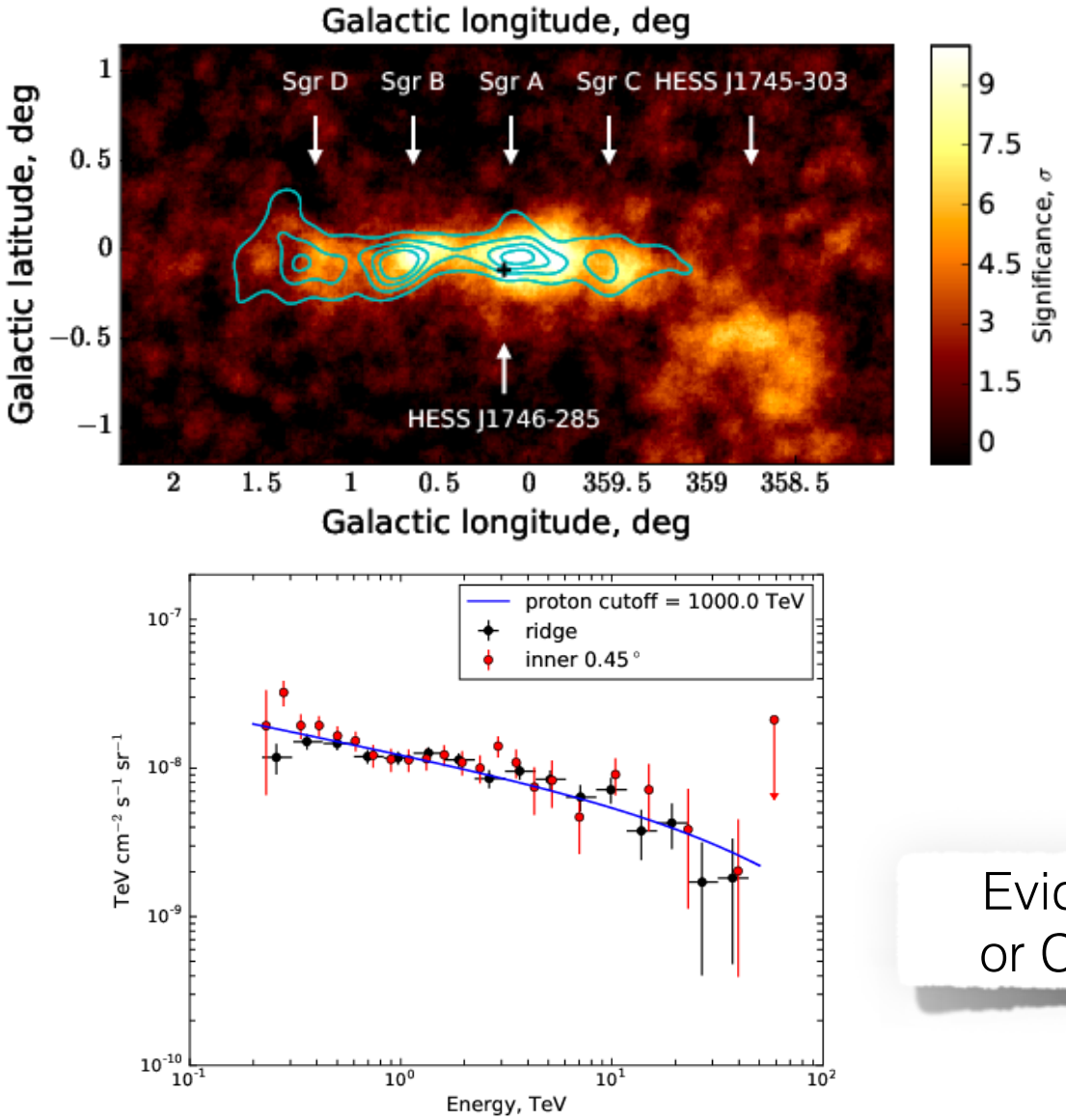


Hewitt et al. arXiv:1206.6882

Several hundreds of Parsecs surrounding the central SMBH

- Density of Gas 10^4 cm^-3 (2 orders of magnitude the average Galactic density at high scales)
- Total Molecular gas reservoir ~ 4 x 10^4 M⊙ (~5% of the total gas in the Milky Way)
- Star formation rate less than expected (higher activity in the past), high temperature, turbulent region, emitting radio, optical, UV, X and gamma, v -> the most promising region for ESTER sample

New analysis of HESS for the central 200 parsecs



arXiv:1706.04535 HESS coll.

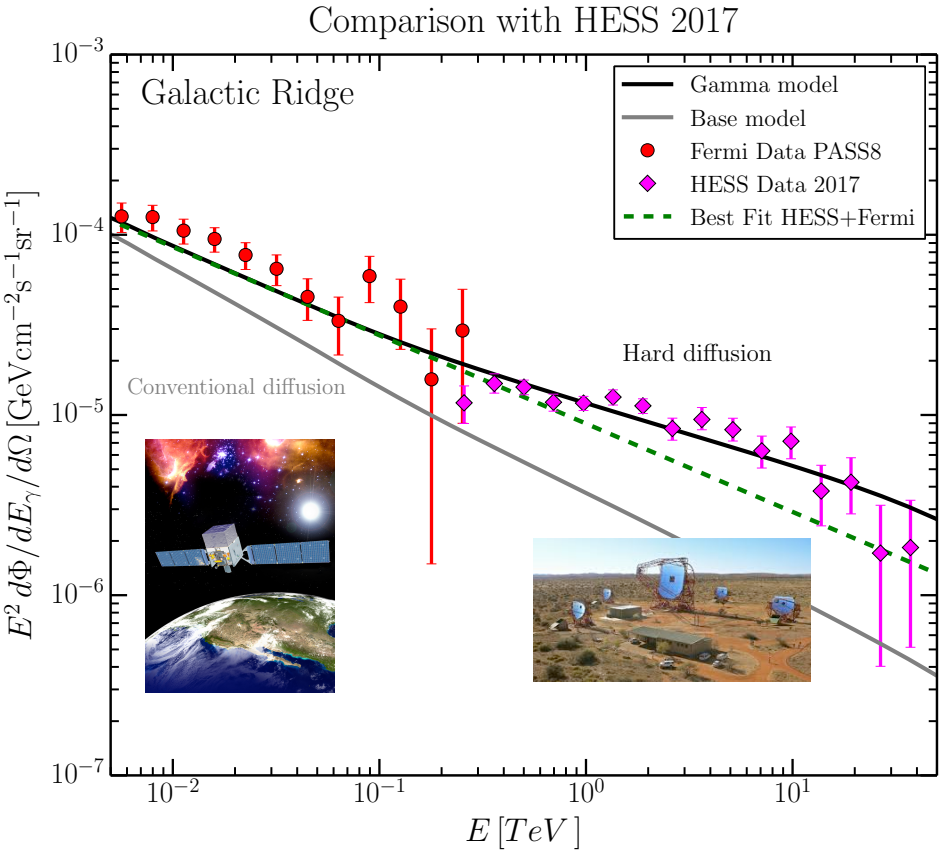
New morphological and spectral analysis of the gamma-ray emitting region with 250 hours of data

Spectral features of new GR 2017 similar to the ones of "Pacman" region

Evidence of fresh CRs from Pevatron or CR sea hardening close to the GC

Explaining the the GeV-TeV diffuse emission on the central 200 parsecs.

PRL 119C1101 Gaggero, Grasso, Marinelli, Taoso, Urbano



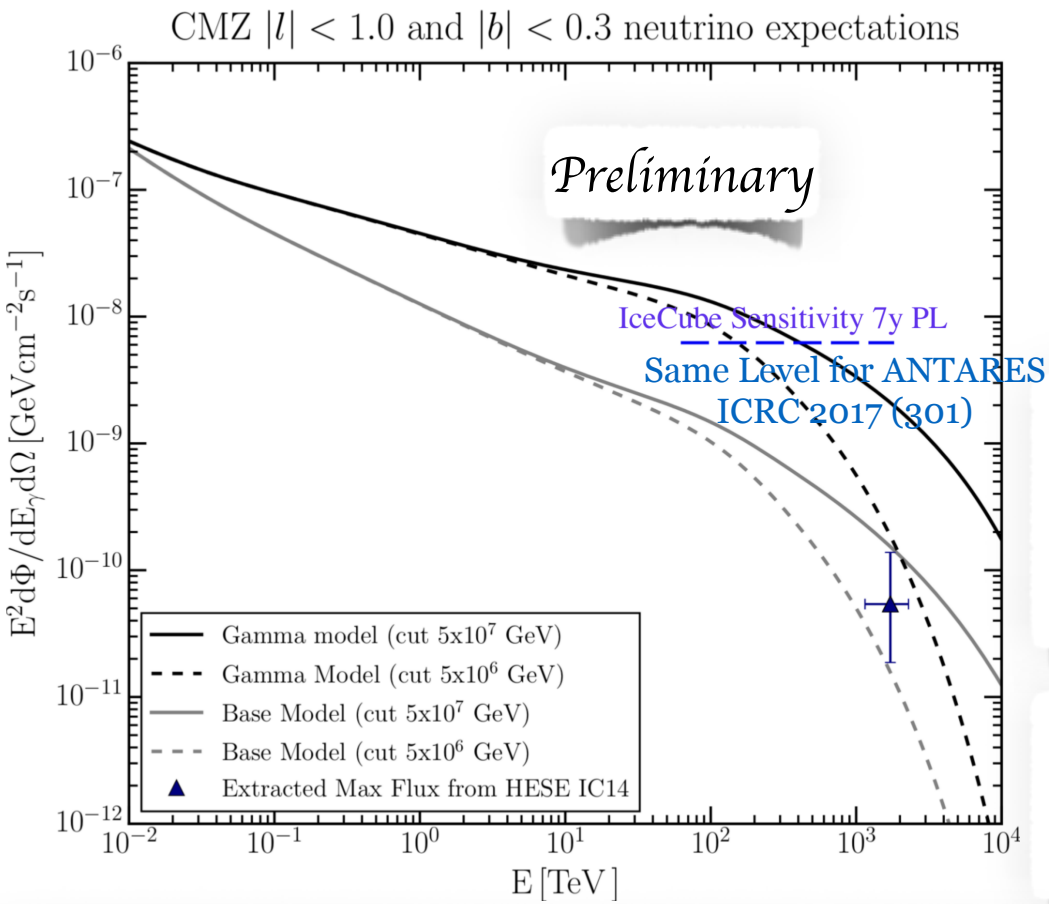
$$\Phi_{GR} = 1.181 \times 10^{-5} \left(\frac{E_\gamma}{1TeV}\right)^{-2.42} GeV^{-1} cm^{-2} s^{-1} sr^{-1}$$

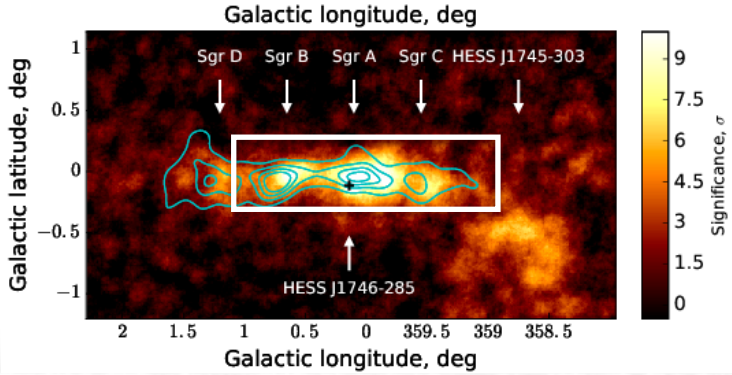
Gamma & Base models with Ferriere source distribution ('01)

The presence of all the Sagittarius clouds represent a preferential target region for CRs

Gamma model fit well with the hard spectrum measured

Neutrino from the 200 pc of the CMZ (HESS 2017)





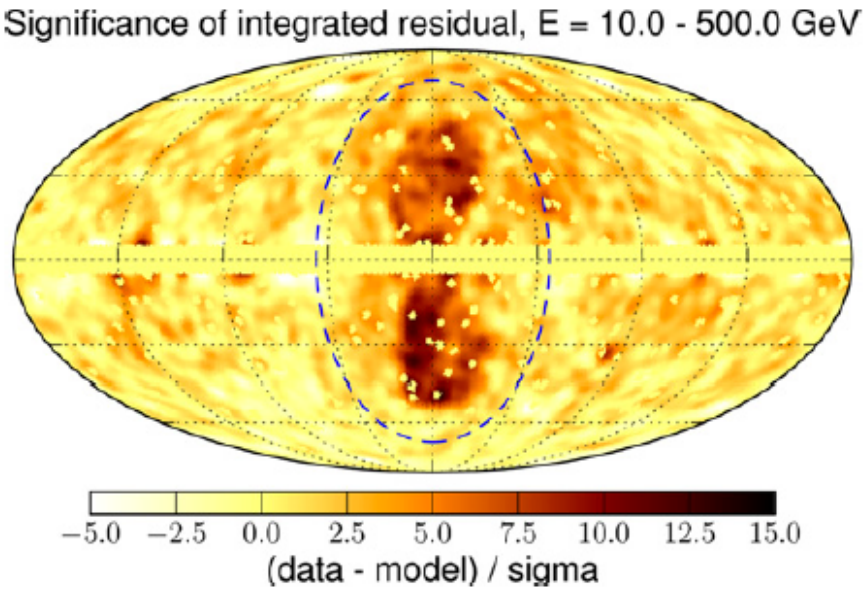
Integrating the flux of the full 200 parsecs better chances to see the signal for IceCube and ANTARES

Good visibility should be expected for KM3NeT/ARCA

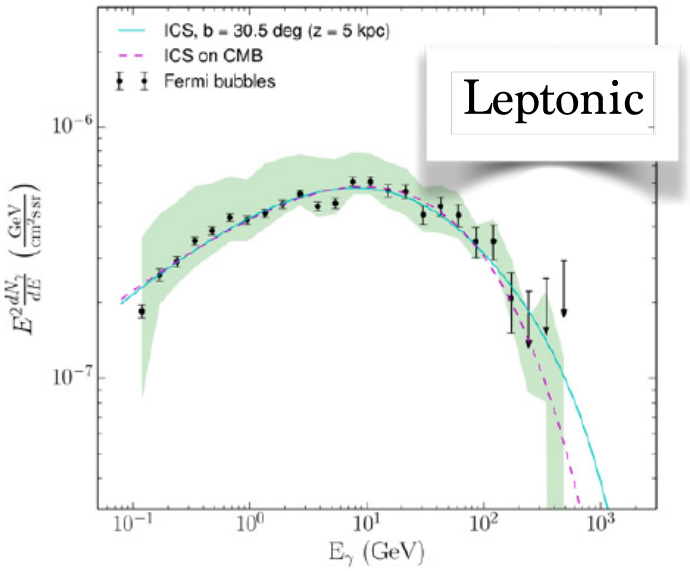
The extrapolated max flux from IC14 (1041 TeV) still more compatible with 5 PeV cutoff, we expect more HESEs in this region of the sky!

Fermi Bubbles observation with VHE gamma rays

Spectrum and morfology of the Bubbles Ackermann et al. 2014 Between 100 MeV and 500 GeV



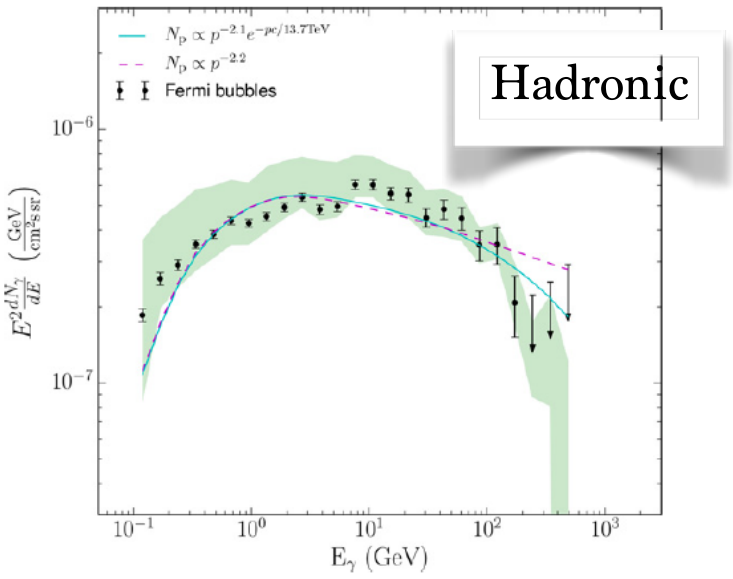
Residual map obtained excluding the Galactic and subtracting all known Fermi sources



Leptonic

Fermi-LAT coll APJ 2014

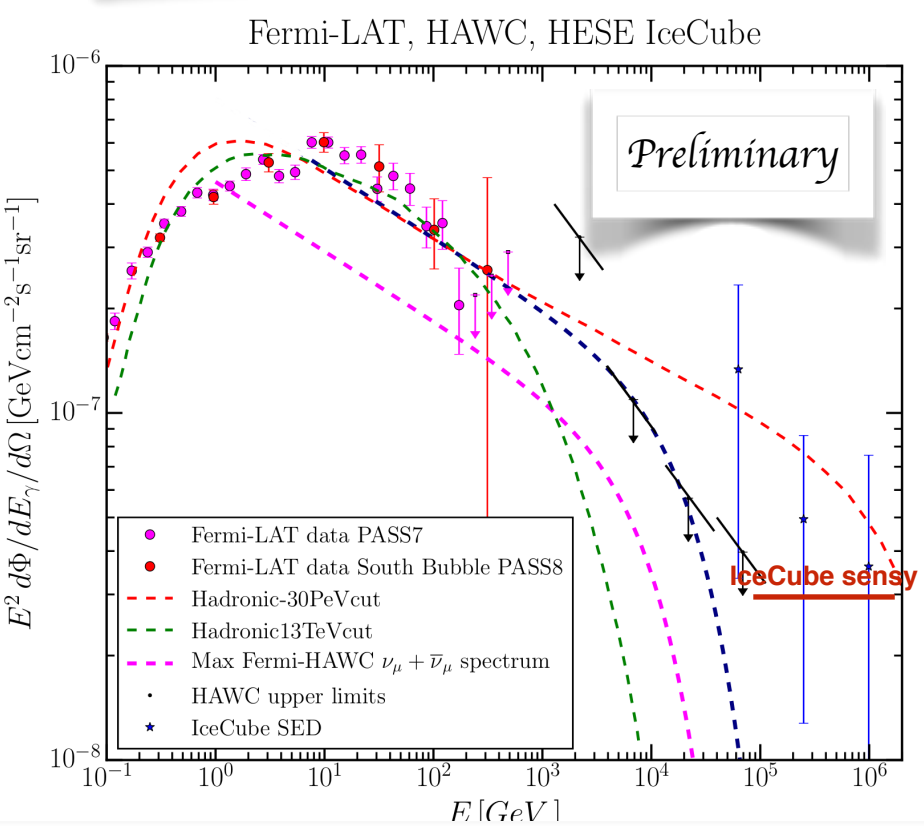
In the last 4 years different scenario have been analyzed. Stil open the possibility of a hadronic component

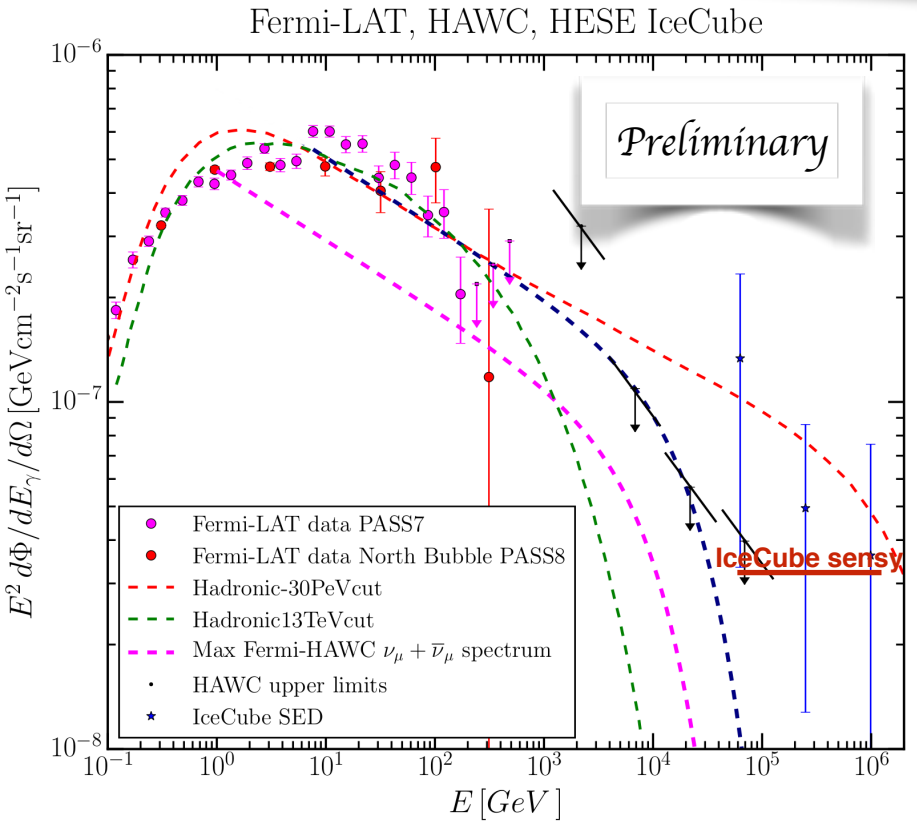


Hadronic

Introduction of PASS8 data for the Fermi Bubbles

PASS8 data allow for the same SED modeling of PASS7

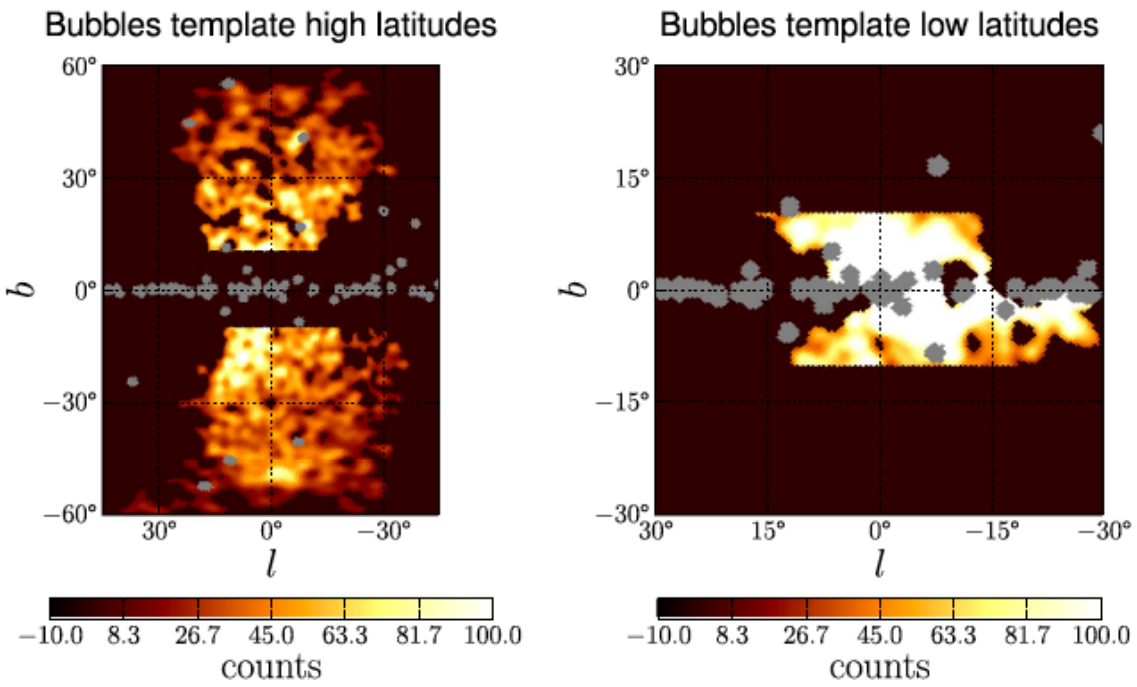




Introduction of PASS8 data for Bubble South

Introduction of PASS8 data for Bubble North

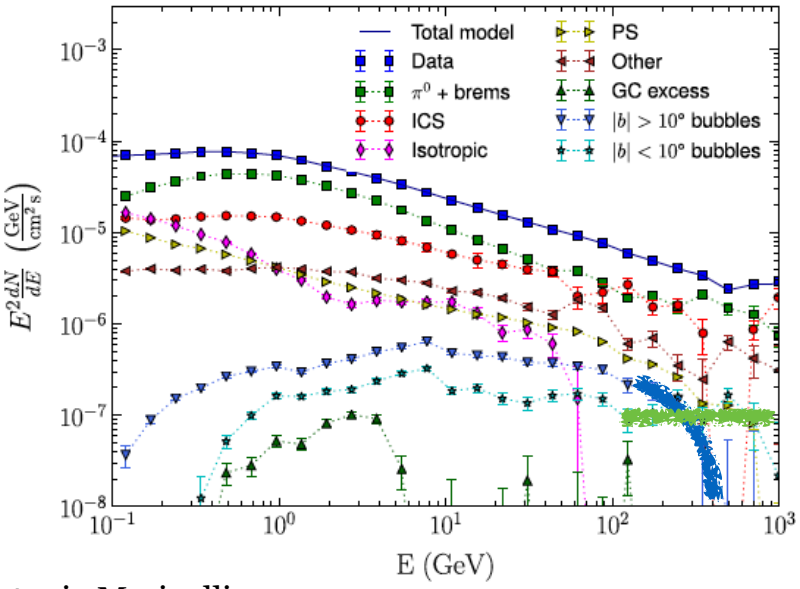
New Fermi-LAT analysis for low latitude Bubbles



New Fermi-LAT paper

APJ 2017

The Fermi-LAT coll. look now to the Bubbles template at |b|<10°

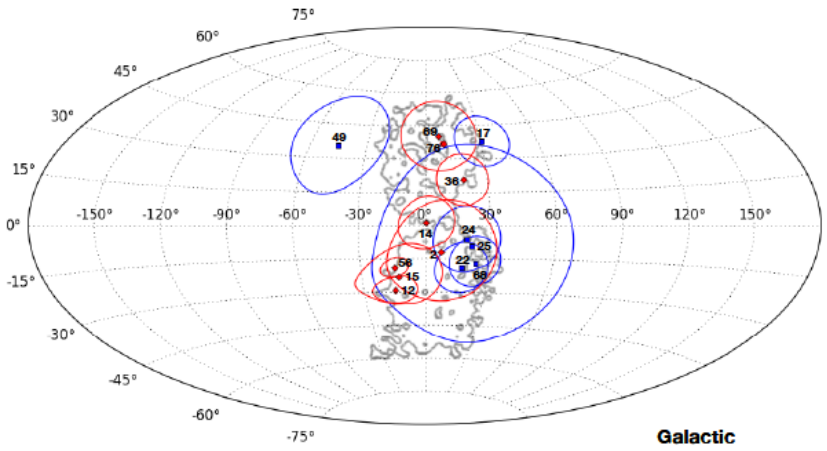


Possibility that the low latitude Fermi Bubbles have a different behavior with a harder SED for E>100 GeV

Bubbles |b|<10°

Bubbles |b|>10°

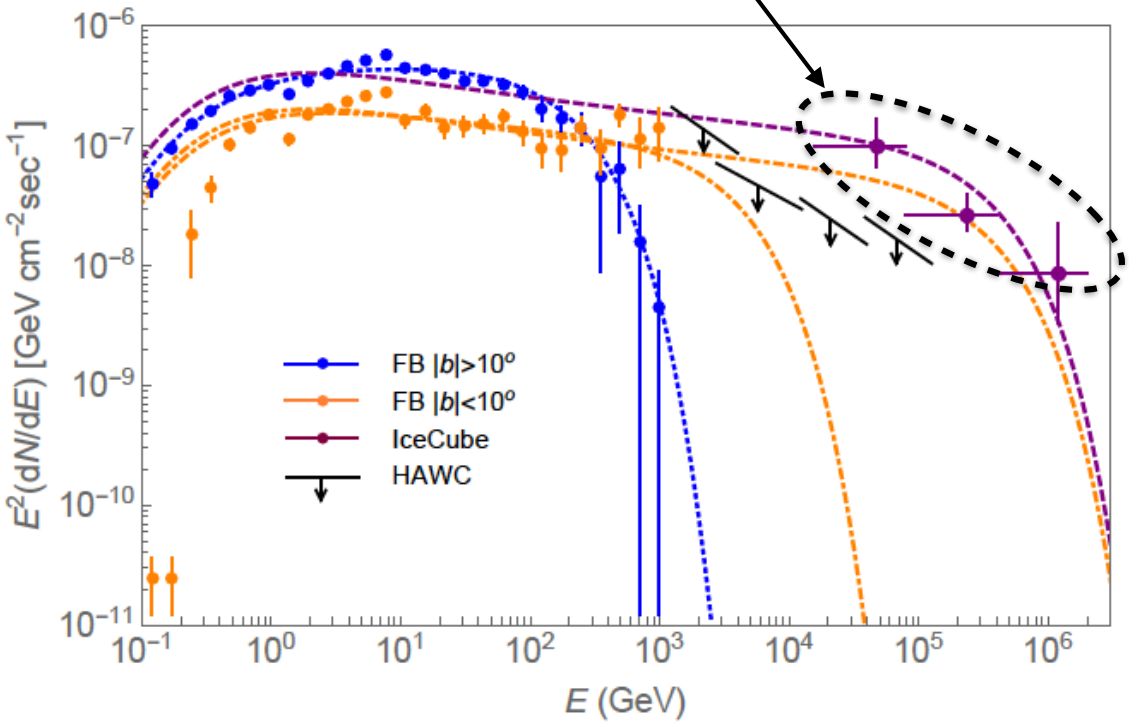
Coparison of new gamma-ray SED and ν SED



Razzaque & Yang Galaxies 2018

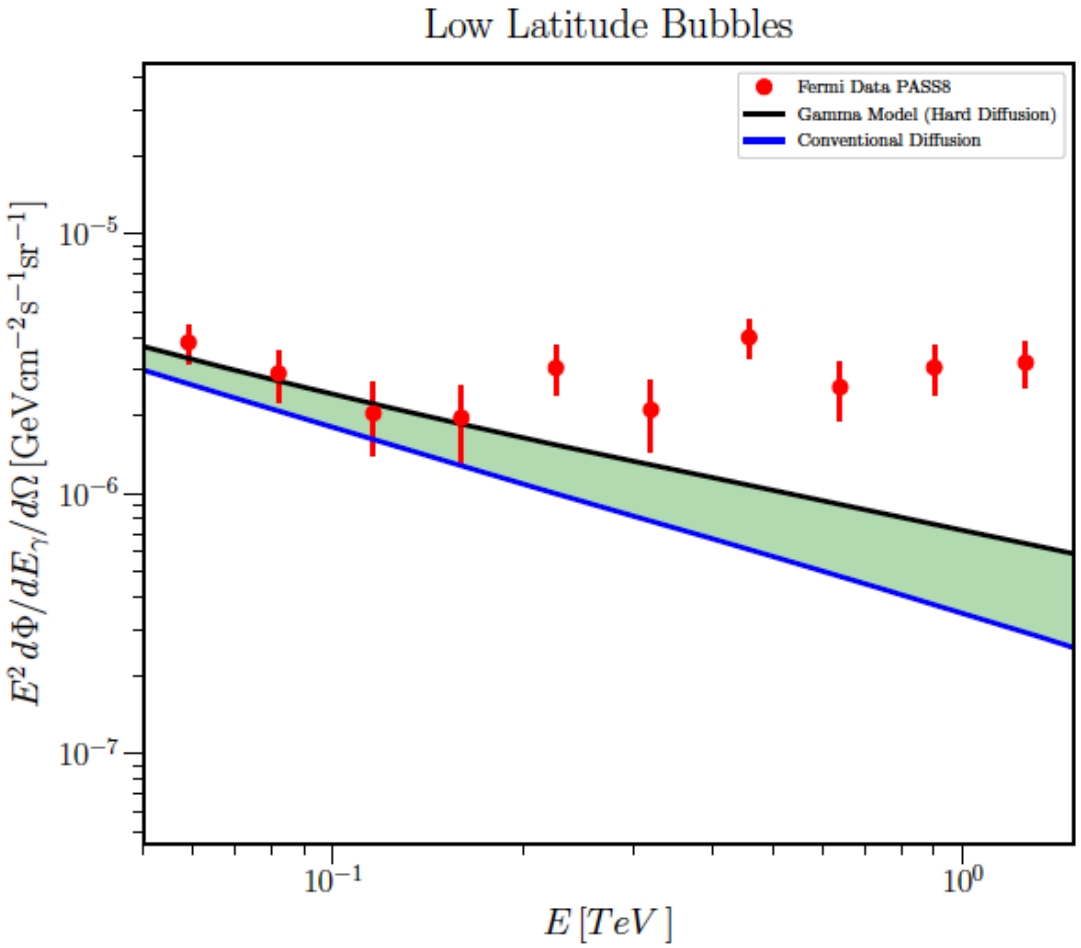
IC neutrino events: 8 strongly and 6 weakly-correlated HESE events with the surface of FB

The possibility to have a harder SED for the low latitude Bubbles can reconcile the Fermi-LAT and HAWC data with the inferred neutrino SED for the HESE catalog.



Low latitude Bubbles in comparison to diffuse Model

A.Marinelli et al. RICAP2018



The Fermi-LAT data in the region of the low latitude Bubbles (|b|<10°) can be explained through diffuse Galactic component just up to hundred of GeVs

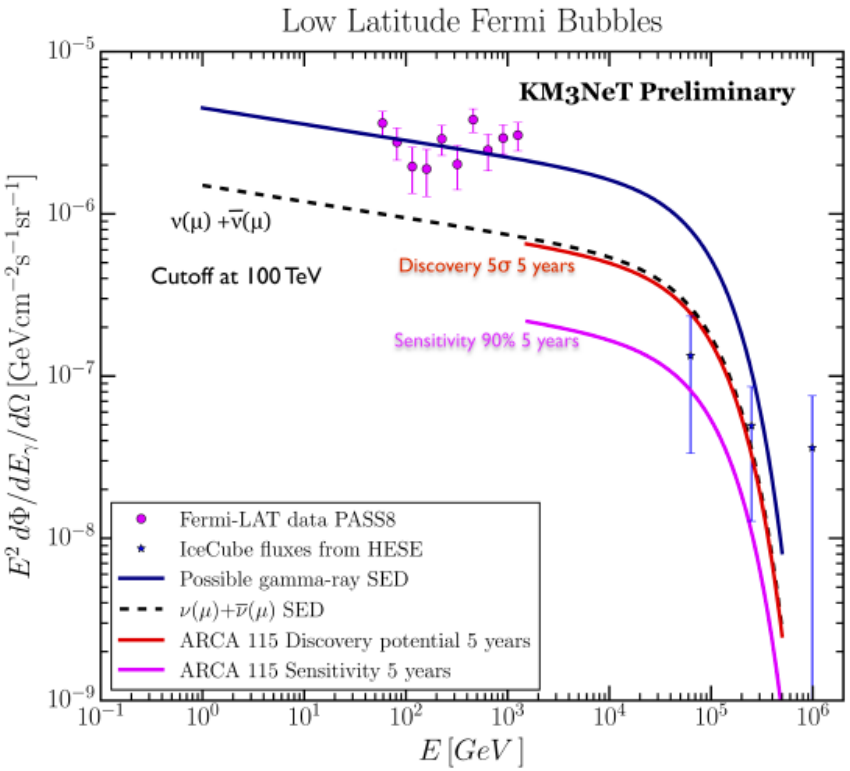
The gamma-ray hardening at low latitude Bubbles (|b|<10°) need to be understood

If this hardening in the gamma-ray SED is really due to the low latitude Bubbles and not just unresolved sources, give more chances to observe correlated ν events

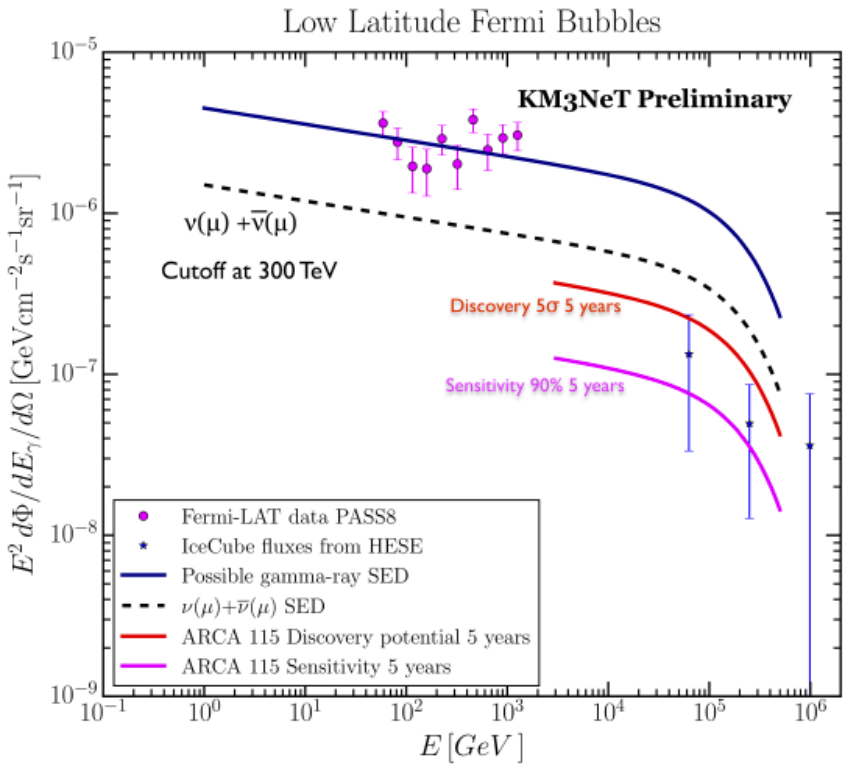
Sensitivity of KM3NeT to the Low latitude Bubbles

A.Marinelli et al. ICRC2019

100 TeV Cutoff



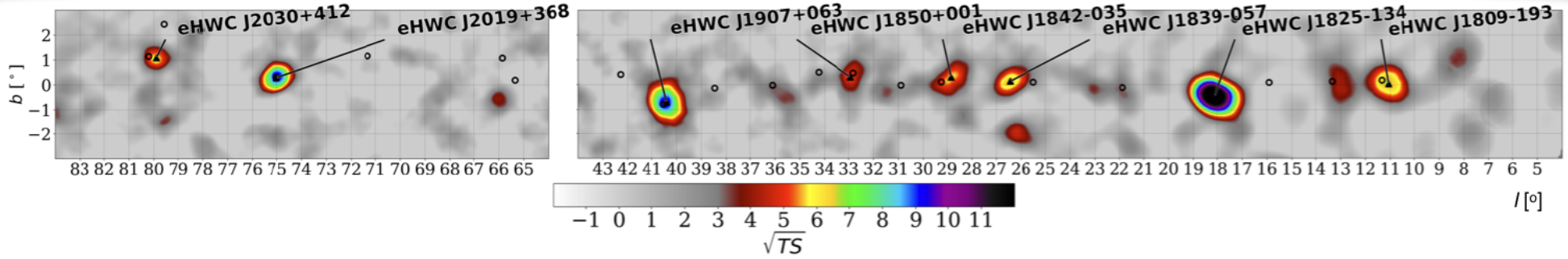
300 TeV Cutoff



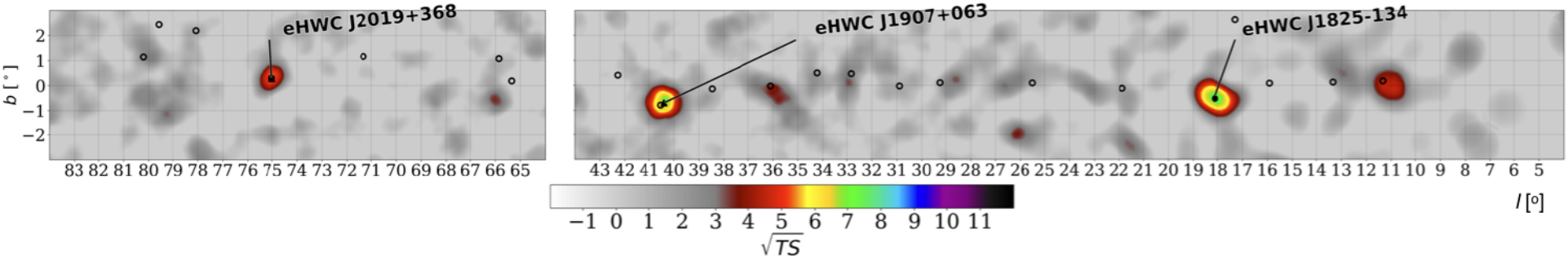
If this hardening in the gamma-ray SED is really due to the low latitude Bubbles and not just unresolved sources KM3NeT/ARCA will collect a **ν** excess in less than 5y

Gamma-ray point like emitters with energy above 56 TeV

HAWC point-like maps along Galactic plane for sources with energy E > 56 TeV



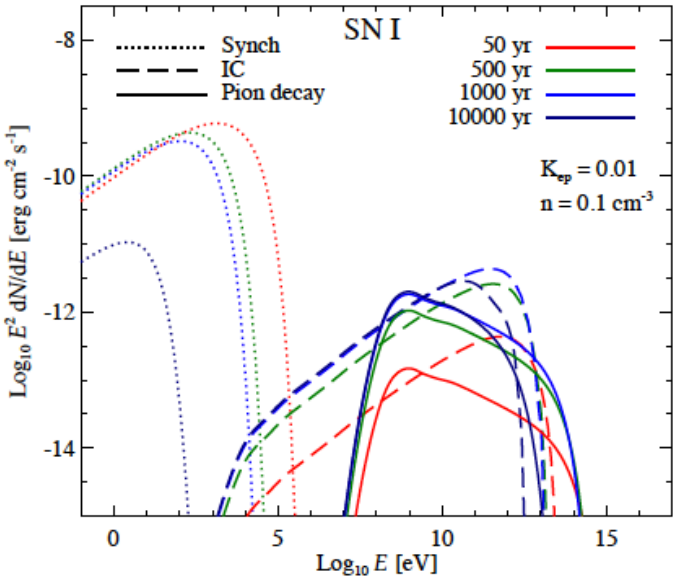
HAWC point-like maps along Galactic plane for sources with energy E > 100 TeV

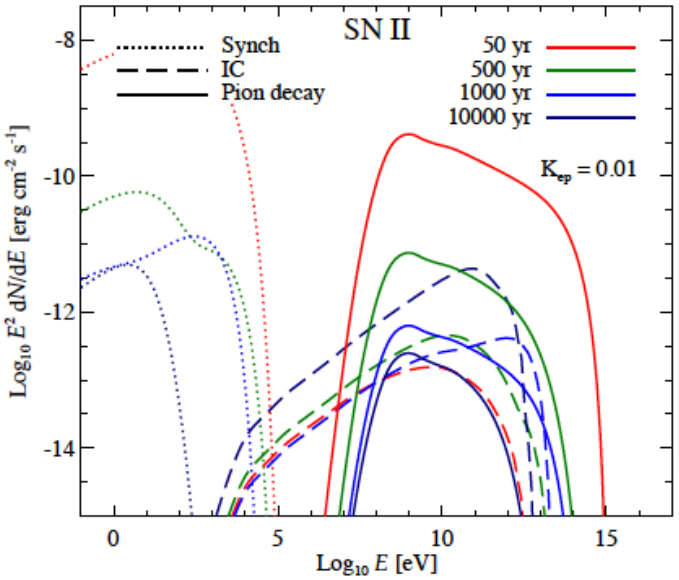


9 sources are detected at more than 56 TeV, 3 of them emit at more than 100 TeV, mostly associated with PWNs with no clear presence of hadronic Pevatrons. Maybe a reason why IceCube don't see point-like Galactic excess.

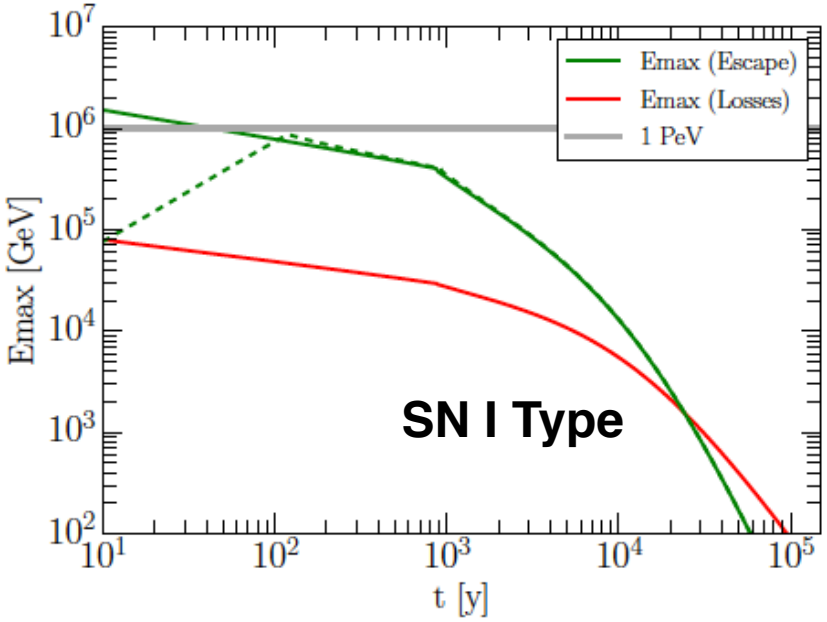
SNRs gamma-ray emission evolves with time

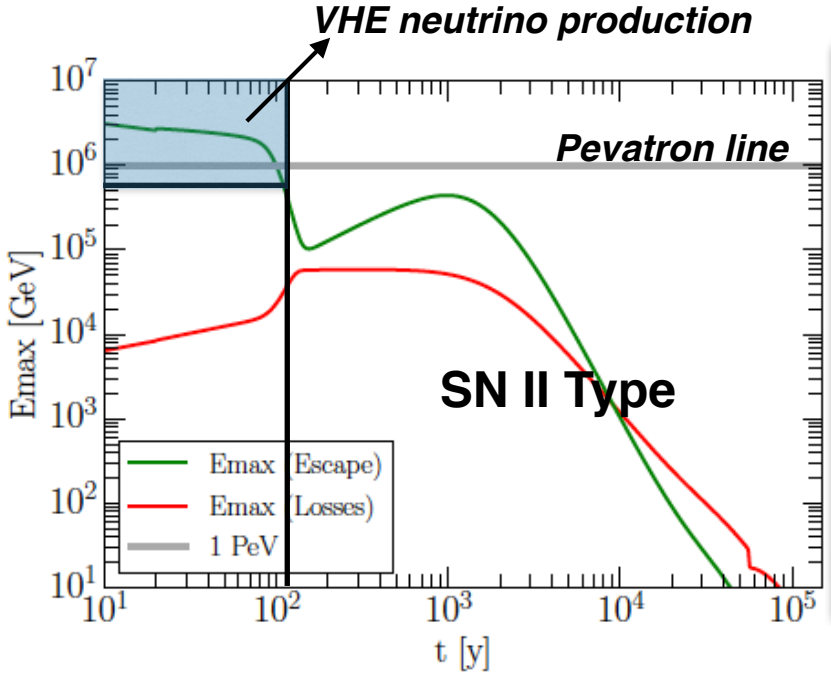
Gaggero et al. MNRAS2017





With more than 500 years inverse Compton component becomes dominant respect to the pion decay

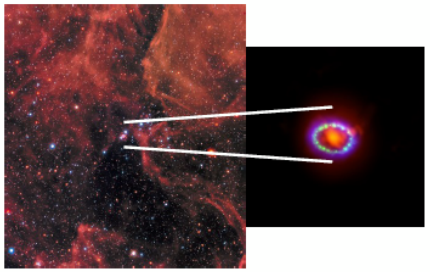




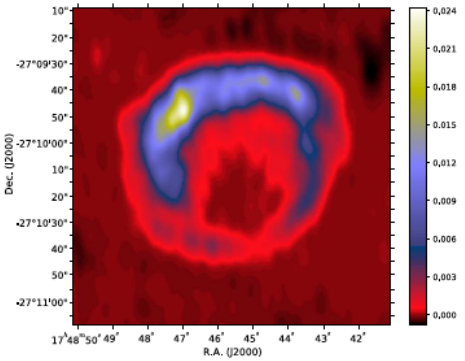
Possibility to observe SNR as a point -like neutrino emitters only with a SNR life < hundreds of years

Looking to the age of SNRs to select point-like ν emitters

The young remnants



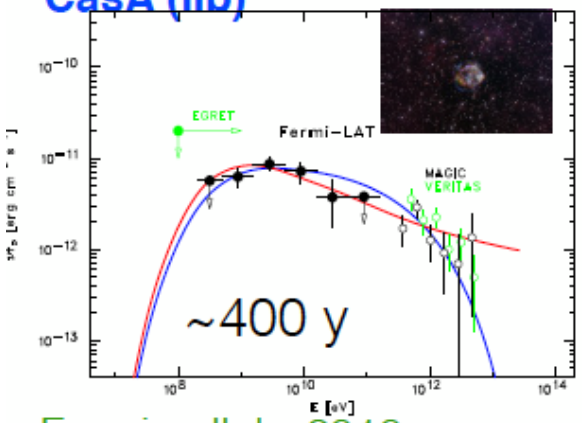
SN1987A:
the youngest remnant in the Local Group, 50 kpc, projenitor: blu spupergiant



G1.9+03
The youngest remnant in our Galaxy (~100) located in the GC region

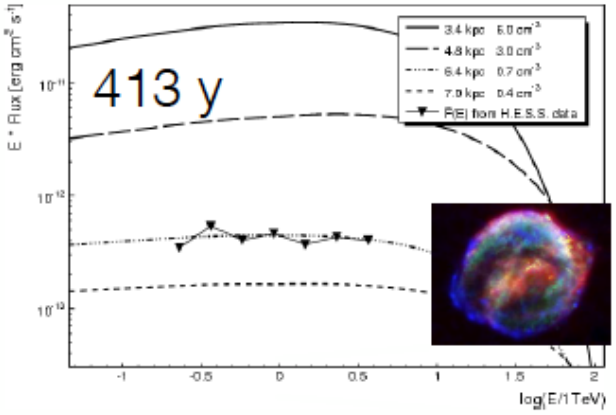
Middle-aged remnants:

CasA (IIb):

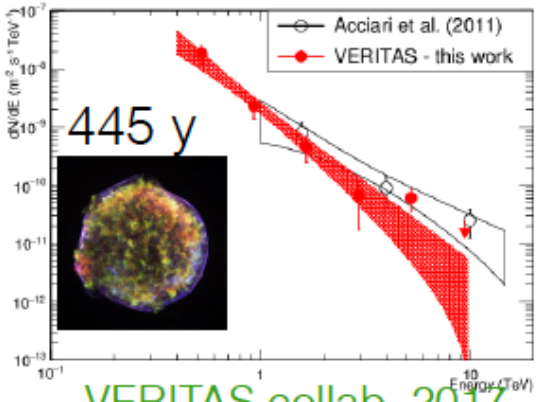


Fermi collab. 2010

Kepler SN 1604 (Ia):



Tycho SN 1572 (Ia):



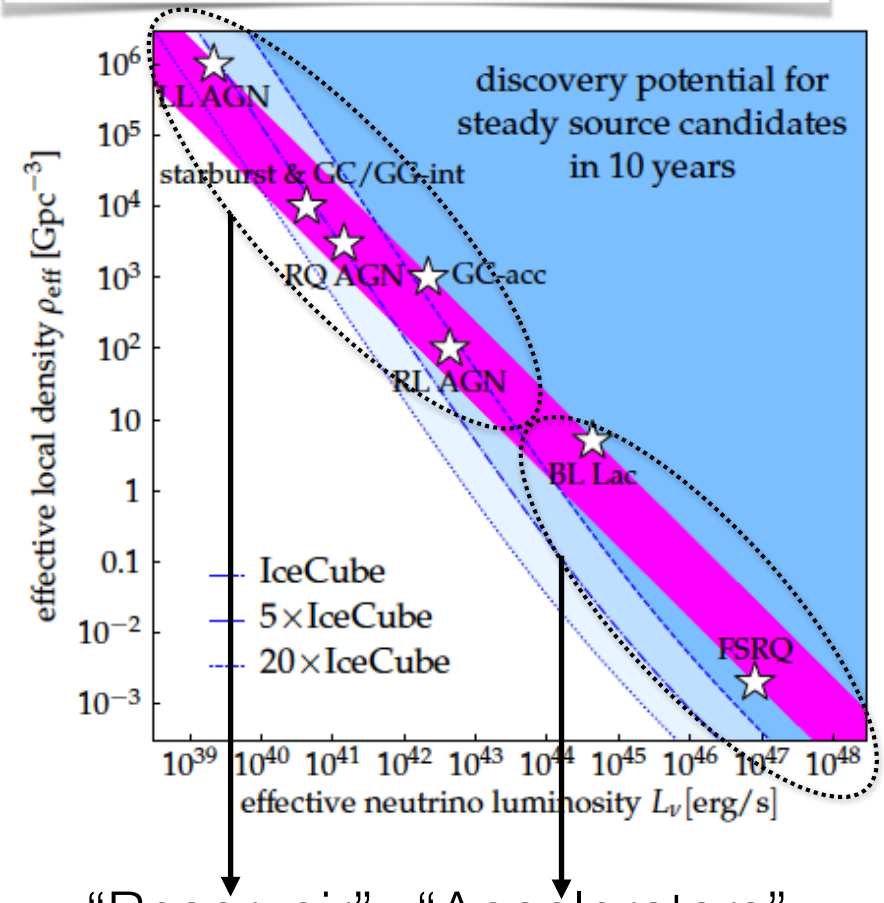
VERITAS collab. 2017

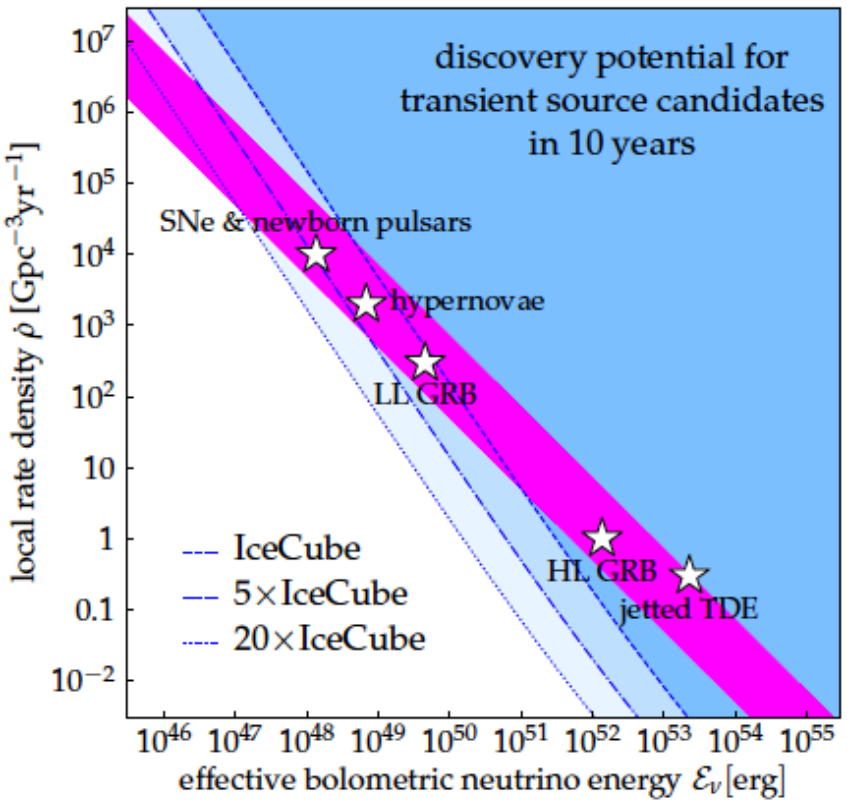
Should we concentrate only on these kind of SNRs to see the point-like hadronic emission?

Looking for Extragalactic neutrino Emitters

Looking for different extra-galactic ν factories

Ackermann et al. Astro2020SWP





"Reservoir" "Accelerators"
Not properly steady

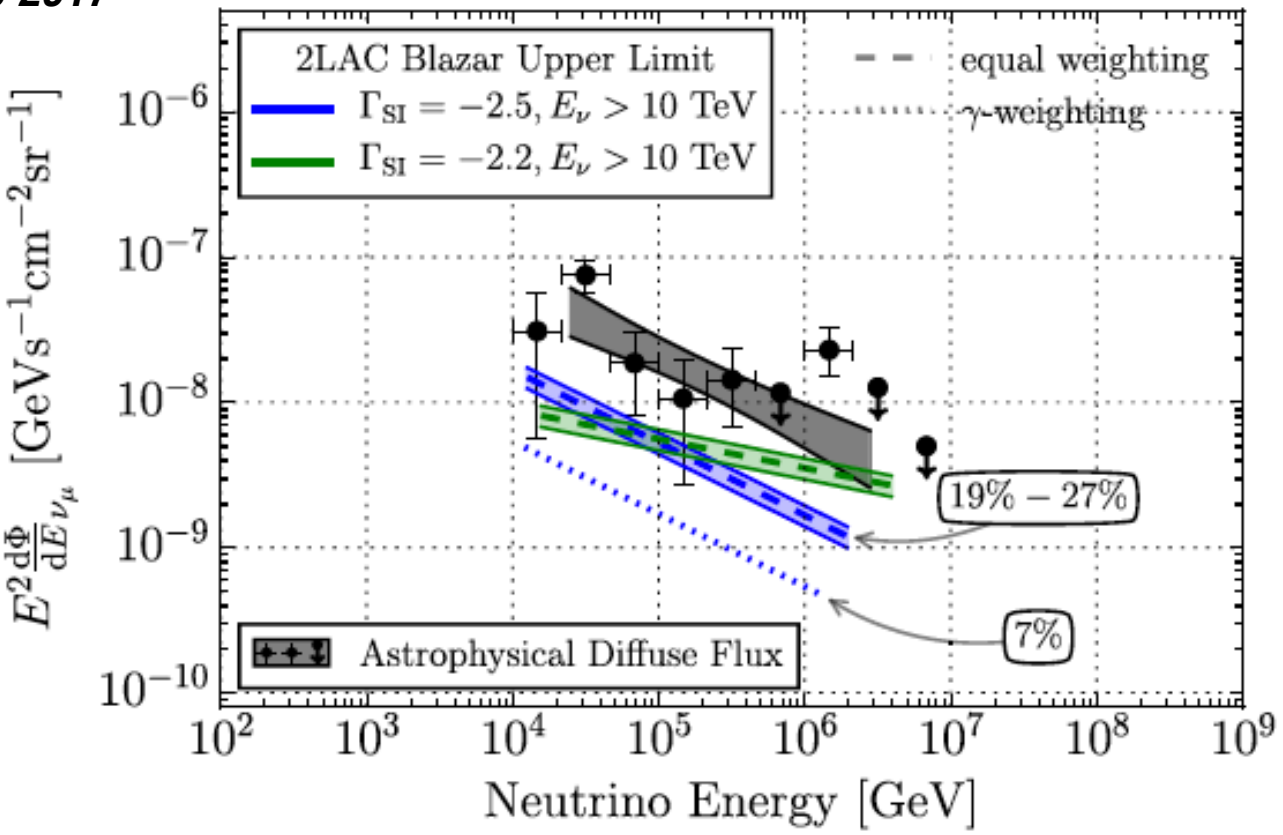
Small duration,
ν energy?

Any evidence of multiple events and the only MM case of TXS0506+056 can suggest faint and dense source population

Blazars contribution to IceCube flux

The maximal neutrino SEDs for the known blazars where obtained considering a staking analysis with 2009-2012 data set

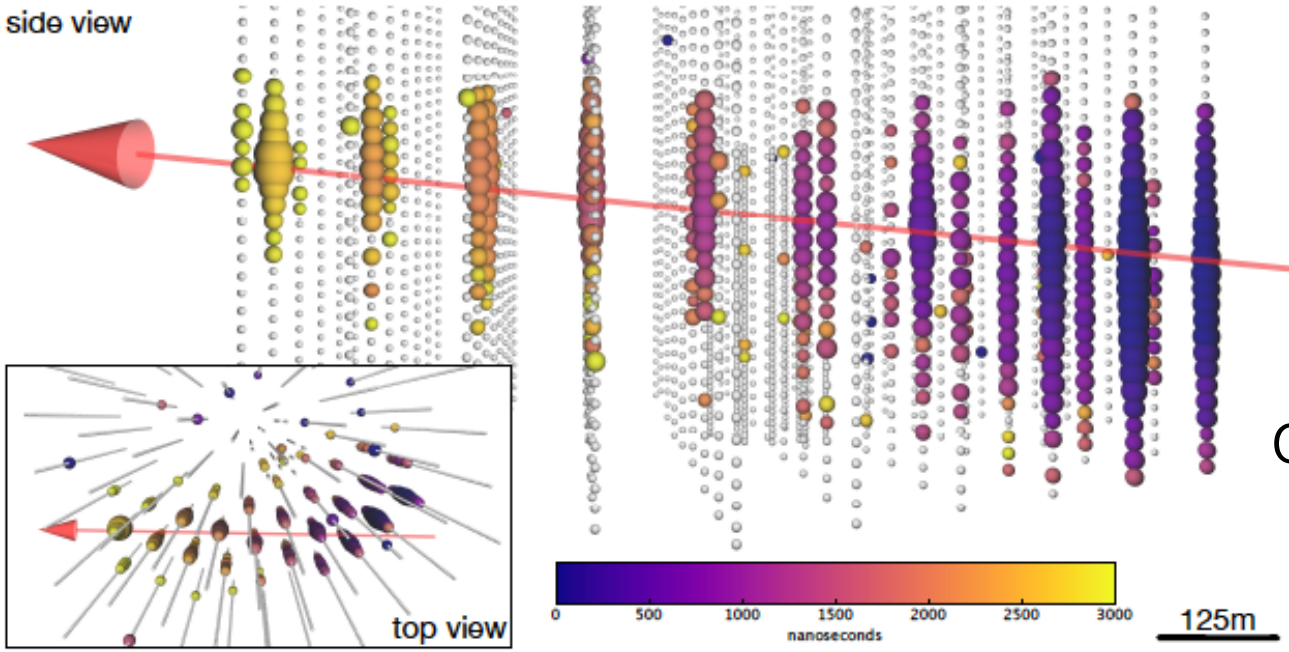
IceCube coll. ApJ 2017



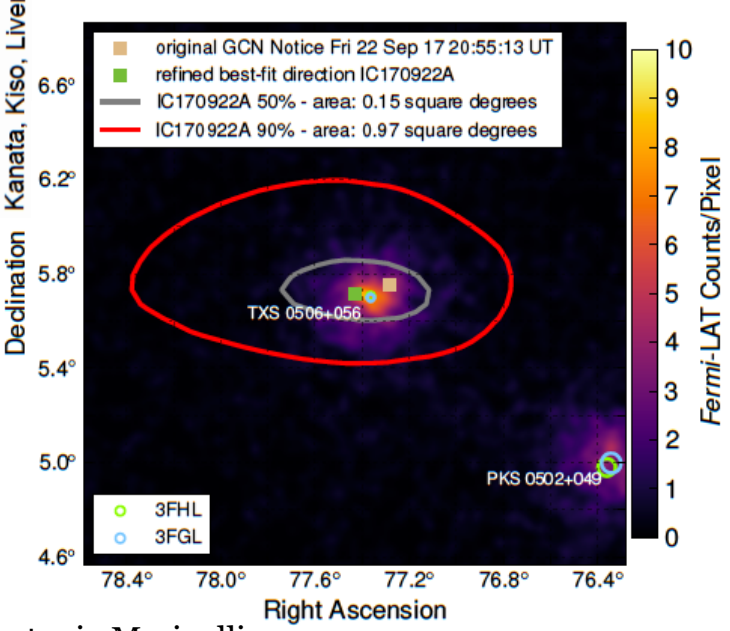
The upper limit of 27% to the total astrophysical IceCube flux is obtained considering a generic spectrum and a steady state

First multimessengers observation of a Blazar

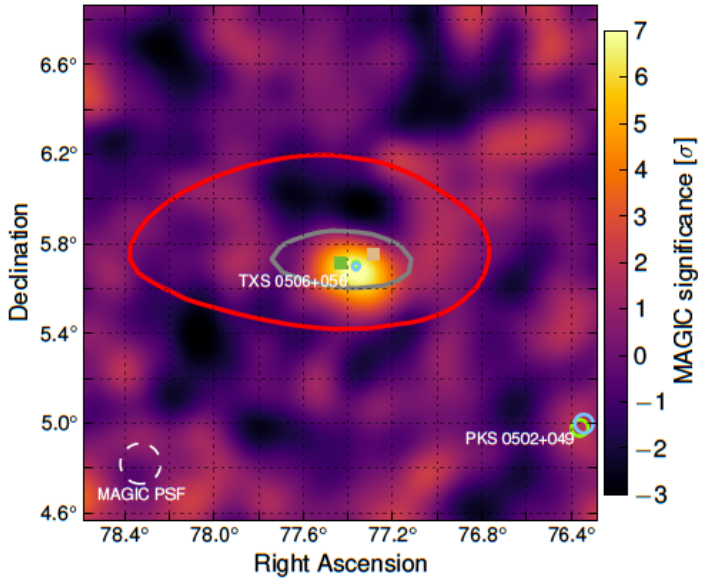
IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kapteyn, Kanata, Kiso, Liverpool, Subaru, Swift, VERITAS, VLA, Science 2018



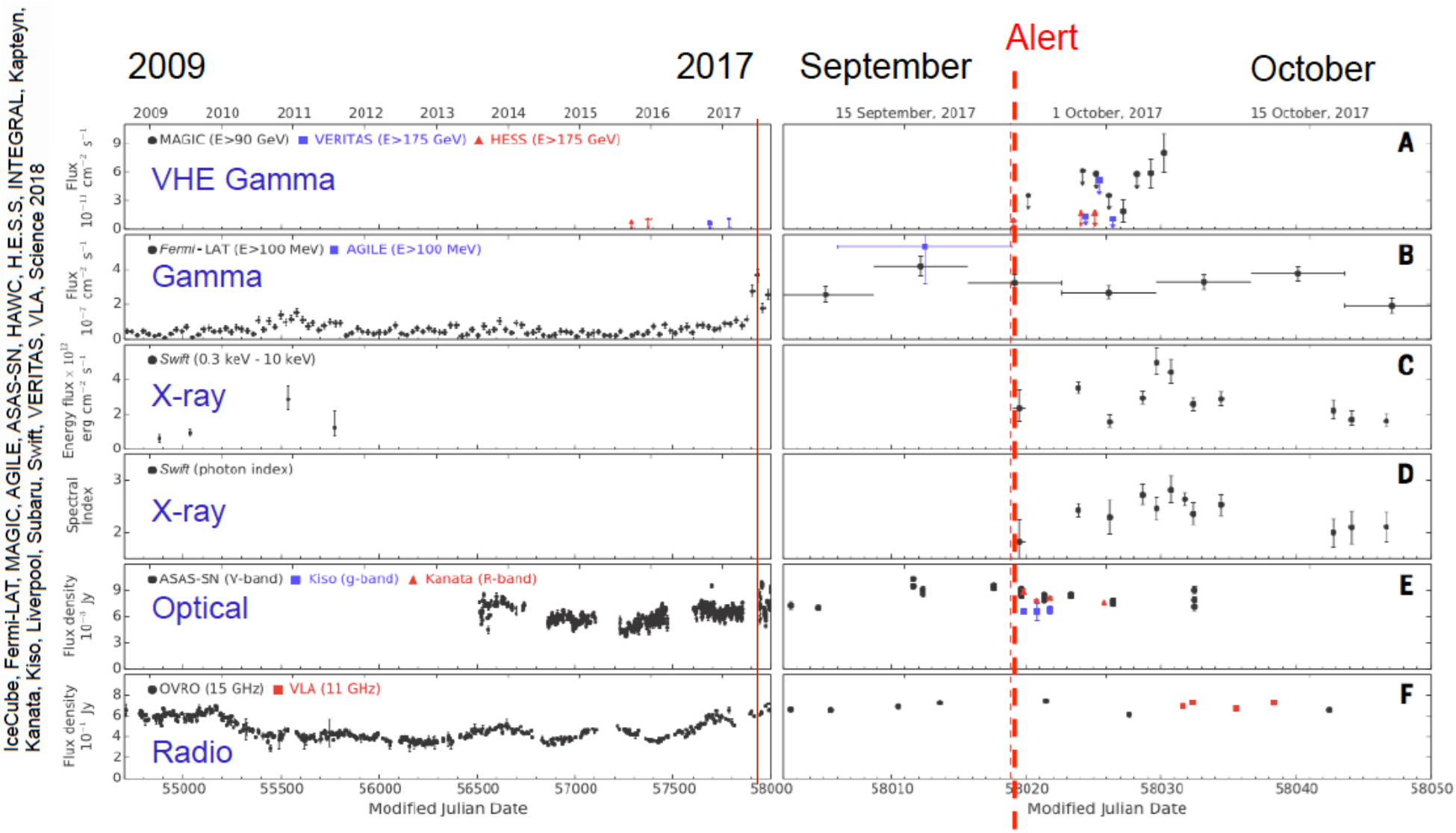
A 290 TeV muonic neutrino oberved by IceCube on 22 of September 2017 obtain a gamma-ray counterpart



Multimessenger observation from MeV to TeV



Time dependent multi-wavelength observation of the Blazar TXS 0506+056

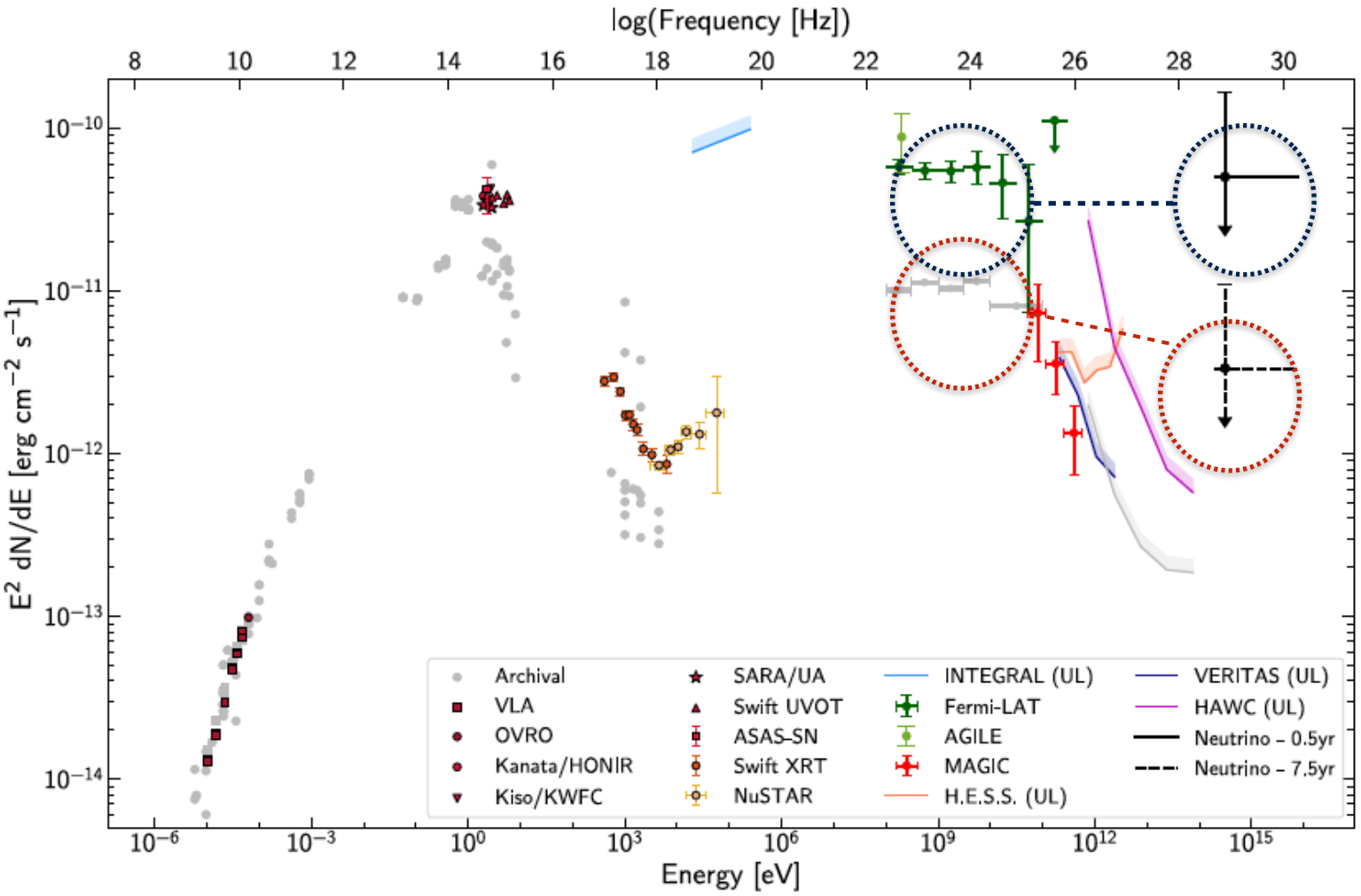


Spectral Energy Distribution studies

IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kapteyn, Kanata, Kiso, Liverpool, Subaru, Swift, VERITAS, VLA, Science 2018

The Multi-Messenger SED

Redshift 0.3365±0.0010
(S. Paiano et al. 2018)



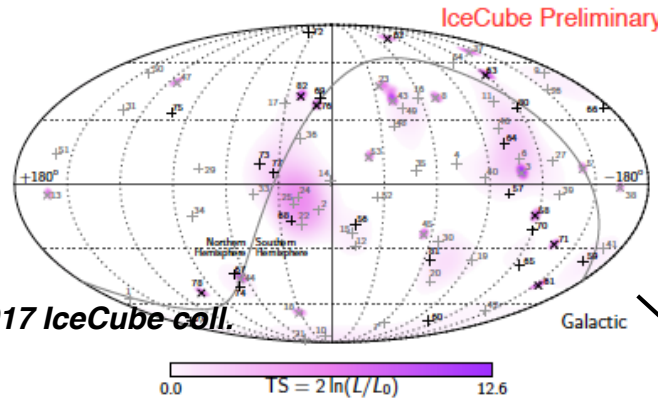
Level of gamma at 100 GeV can be correlated at level of neutrino at 100 TeV though:
-Proton-Syncrhotron
- Lepto-Hadronic

↓

Example Petropoulou et al. MNRAS2015

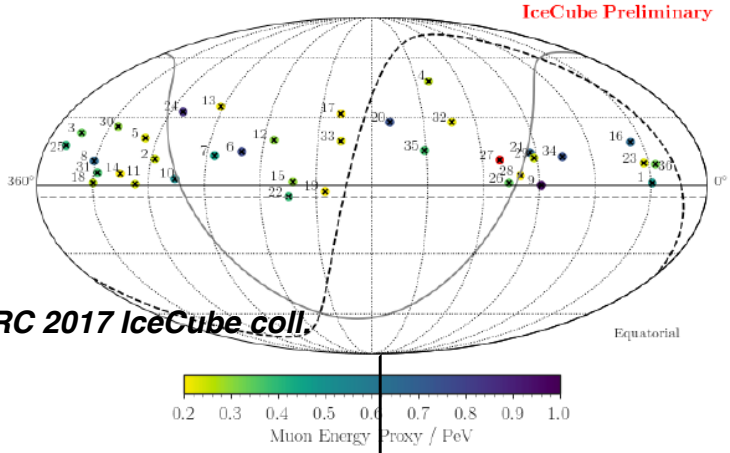
Building a sample of gold Blazar candidates

22 Track-like
events between the HESE sample



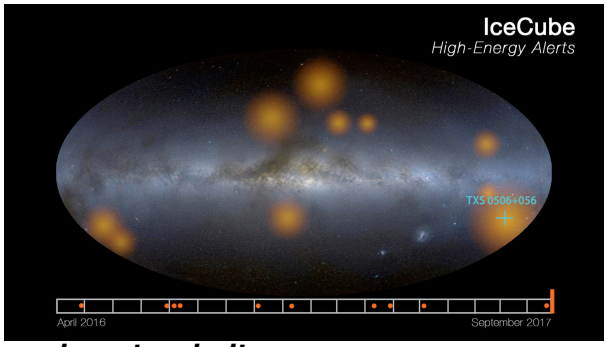
ICRC 2017 IceCube coll.

36 Track-like
events between the northern sample



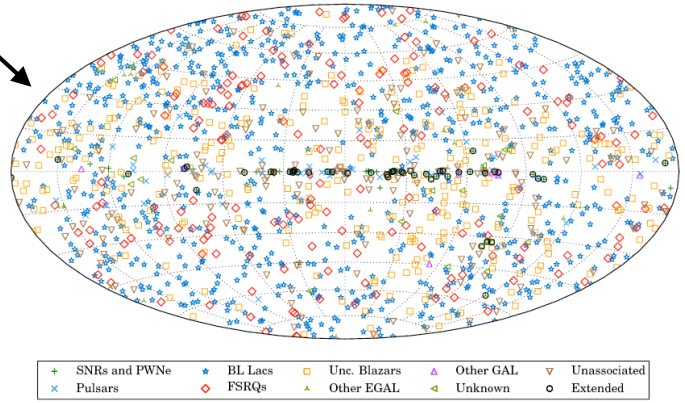
ICRC 2017 IceCube coll.

14 Track-like events
part of EHE or HESE (Alerts)



IceCube experiment website

Extract BL-Lacs and FSRQs of 3FHL
in coincidence with the astro-ν_μ



The obtained preliminary sample

Table 1: Sample of blazars in spatial coincidence with selected IceCube ν_μ events

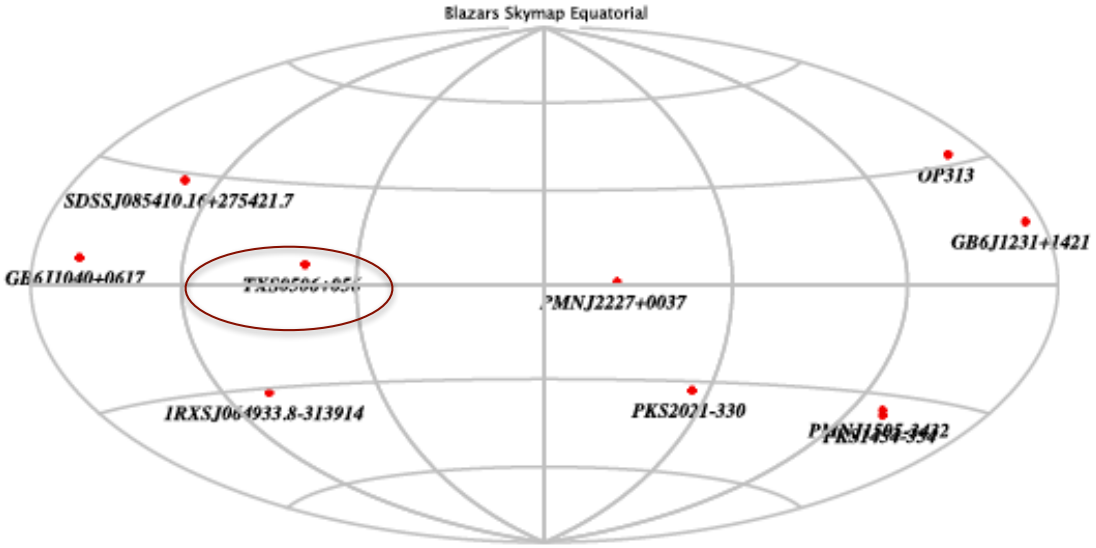
S.no.	Source Name	RA (deg)	Dec.(deg)	Source Class	z
1	OP 313	197.649	32.351	fsrq	0.998
2	SDSS J085410.16+275421.7	133.532	27.8826	bll	0.494
3	1RXS J064933.8-313914	102.386	-31.6491	bll	≥ 0.563
4	GB6 J1040+0617	160.147	6.3023	bll	0.7351
5	GB6 J1231+1421	187.866	14.368	bll	0.256
6	PKS 1454-354	224.382	-35.6478	fsrq	1.424
7	PMN J1505-3432	226.25	-34.5472	bll	1.554
8	PMN J2227+0037	336.972	0.6101	bll	-
9	PKS 2021-330	306.108	-32.9047	fsrq	1.47
10	TXS 0506+056	77.3636	5.7066	bll	0.3365

7 BL-lacs and 3 FSRQs result spatially correlated (inside the ~1.3° of angular incertitude) with astrophysical ν_μ.
From them no signature of major gamma-ray activity in coincidence with the neutrino events.

Marinelli et al. ArXiv 1909.13198

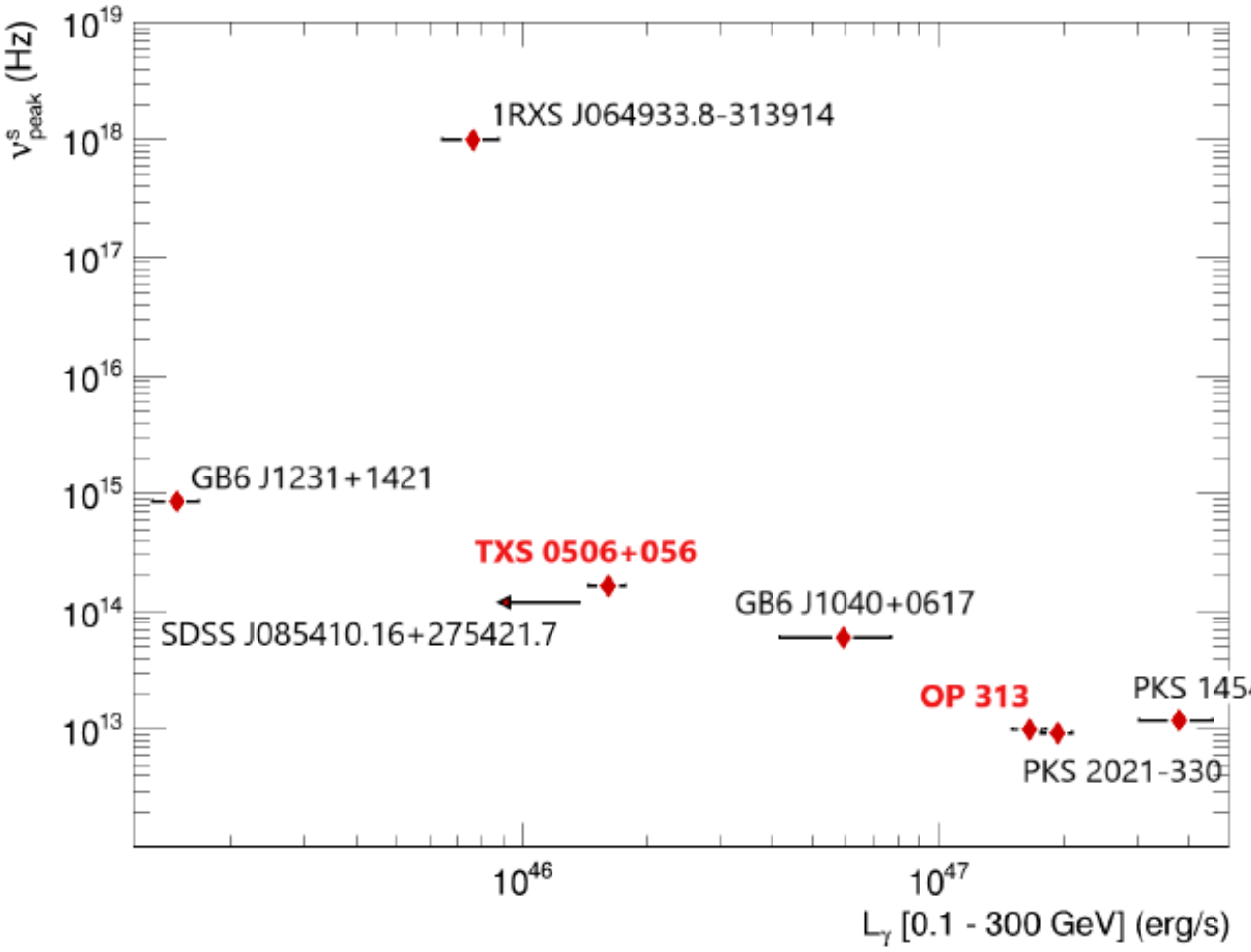
Skymap in equatorial coordinates

The sky map of Blazars spatially connected with astrophysical ν_μ to do multi-wavelength studies



The sequence of selected Blazars

Marinelli et al. ArXiv 1909.13198



L_γ with 9.5 years of Fermi data

0.1 GeV < E < 300 GeV

ν^{syn}_{peak} from 3FHL catalog

Anti-correlation between syn. peak and L_γ found for the sample

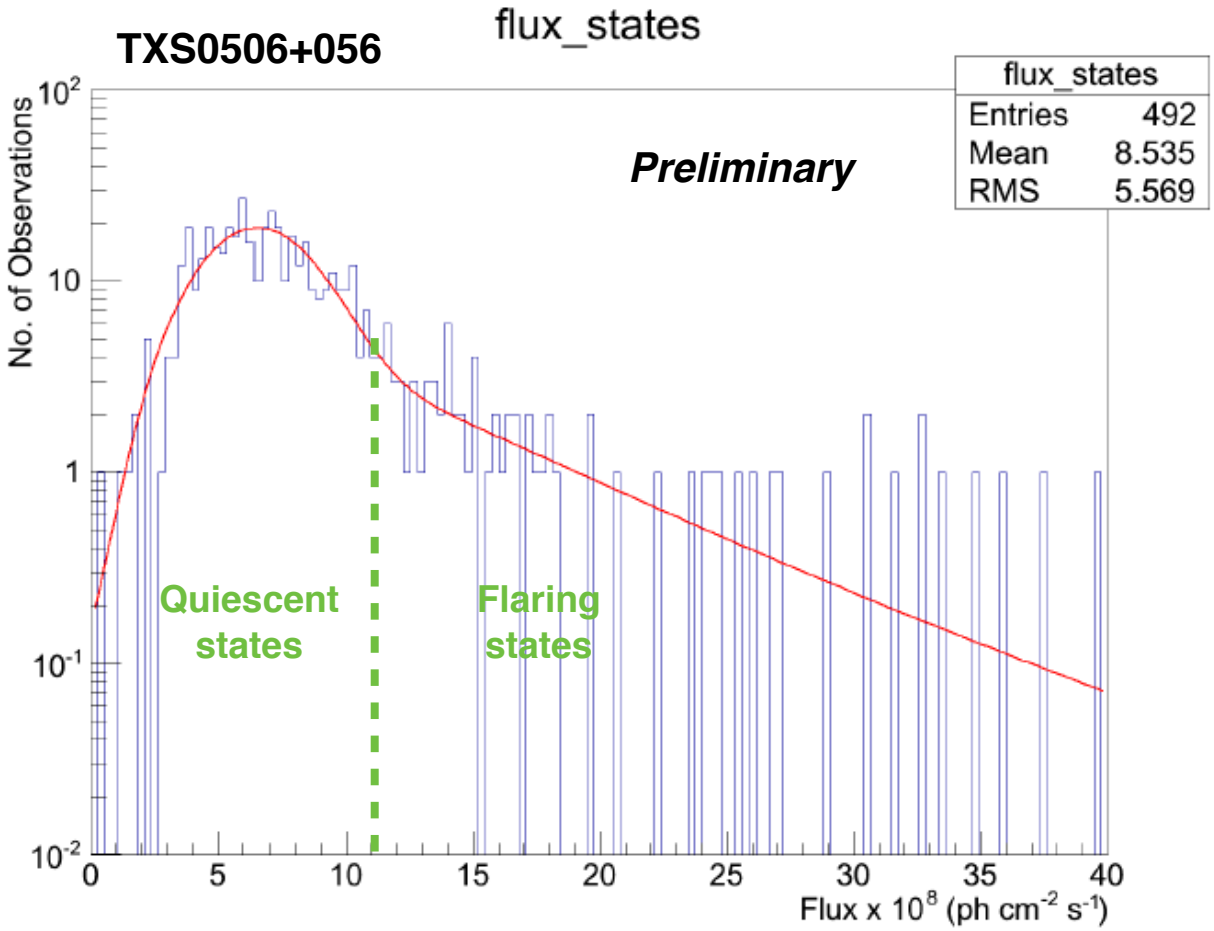
The outlier (1RXSJ064933.8-313914) is an extreme blazar

SDSS J085410.16+275421.7 shown as an upper limit due to low TS

Combined BL-Lac + FSRQ anti-correlation in agreement with ***G. Ghisellini et al. MNRAS, Feb 2017***

The gammara-ray Duty Cycle as a indicator

Marinelli et al. ArXiv 1909.13198



We use 9.5 years of Fermi-LAT observations time with 1GeV< E <100 GeV.

The fluxes distribution is well represented by a **Gaussian + Lognormal distribution**

To this distribution of fluxes of TXS0506+056 we apply the Duty Cycle definition developed with the Milagro collaboration in 2014 (Abdo et al. APJ 2014)

$$DC = \frac{\overline{F} - F_{bl}}{\langle F_{flare} \rangle - F_{bl}}$$

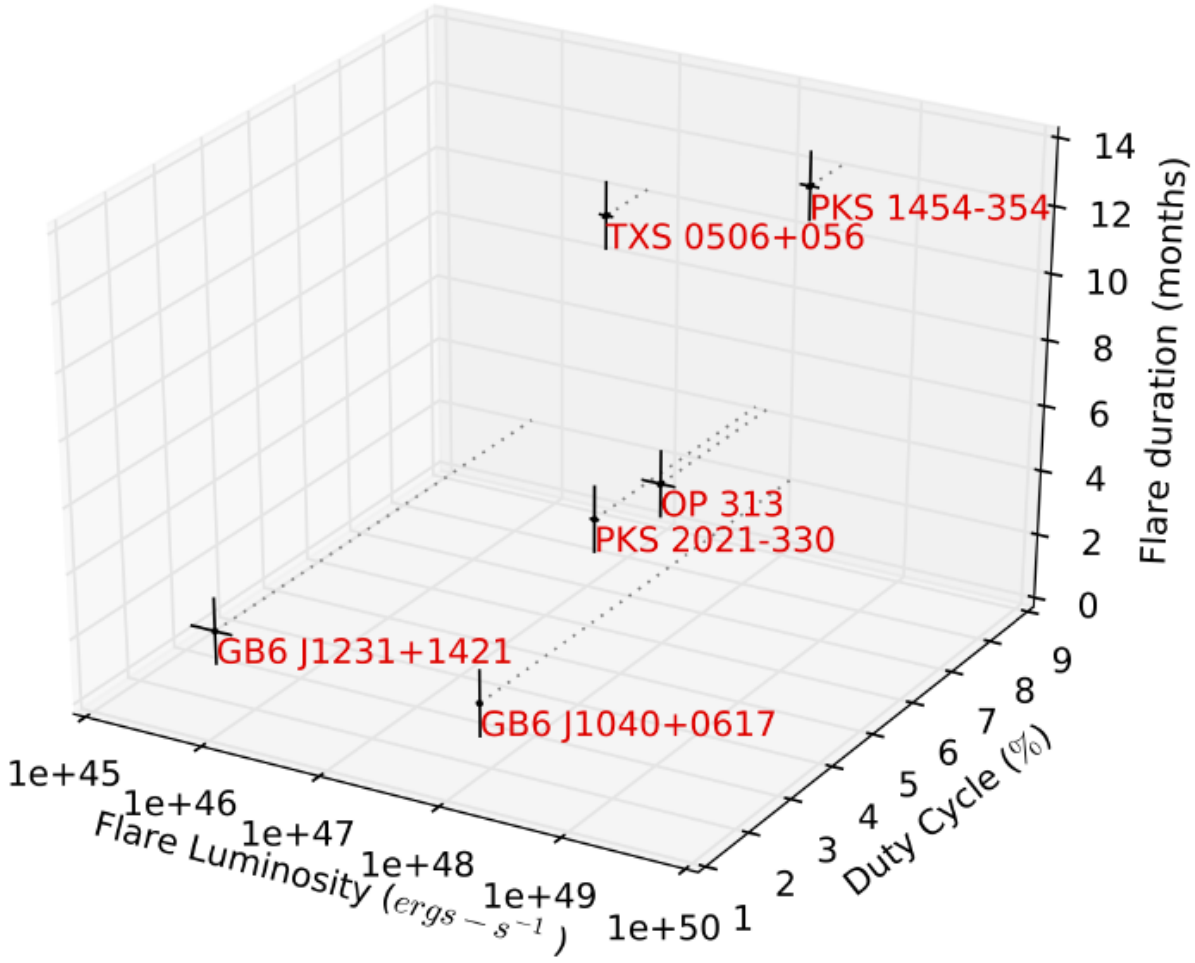
Activity description of ν emitter candidates

Marinelli et al. ArXiv 1909.13198

For the sources in our sample, we plot the integrated luminosity during their brightest flare, along with the duty cycle and the duration of the flare itself

DC for these sources calculated using the criteria of ***S. Vercellone et al. MNRAS, 2004*** but slightly modified for faint sources

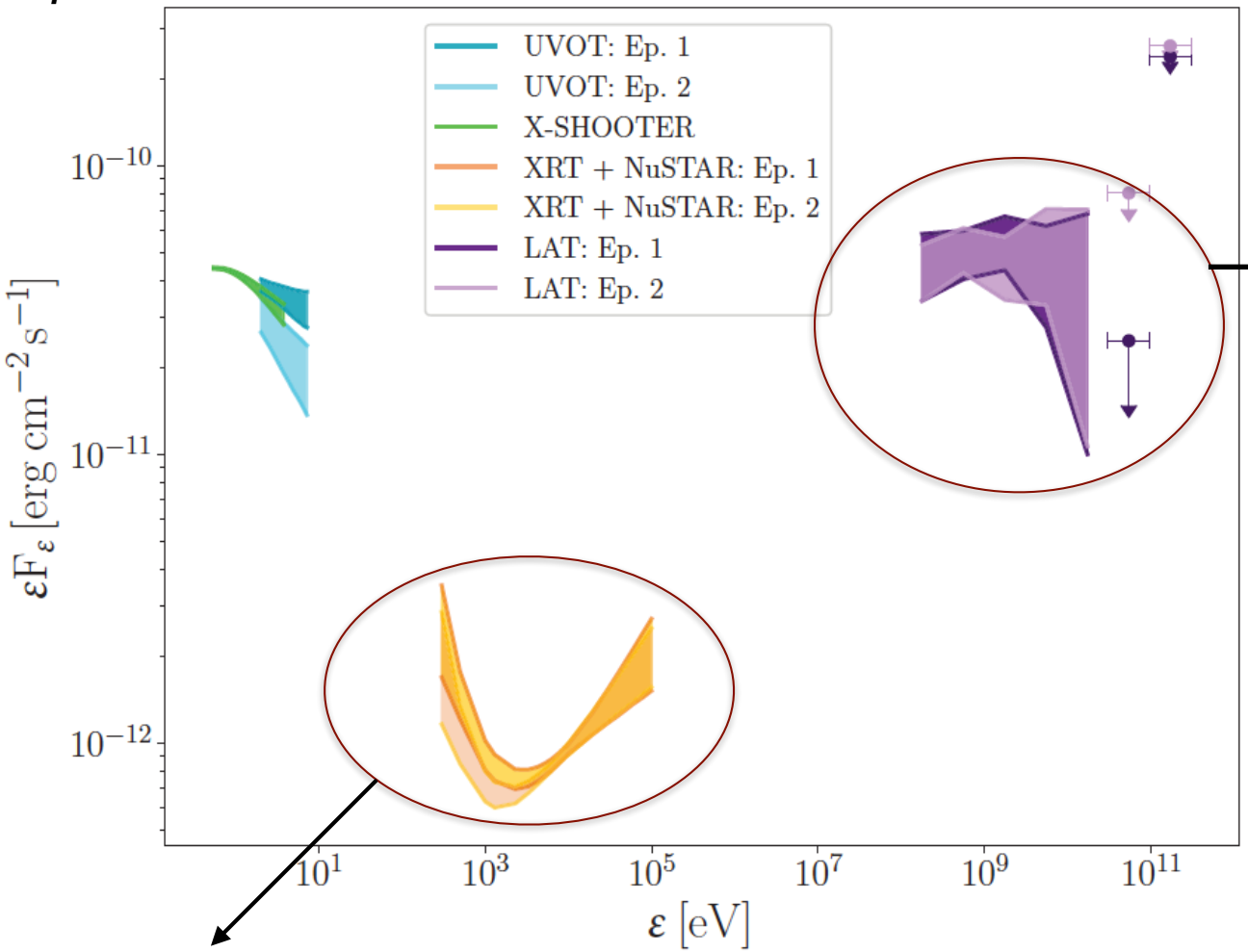
Mean flux calculated with upper limits, but for active states, only bins with errors bars completely above the threshold included. Threshold for activity defined as 1σ above the mean



If we adopt Hadronic approaches (Fermi-LAT gamma rays liked to hadronic production within the jet) we should look for promising candidates in the top right part of the plot.

From γ to ν flux of Blazar

Keivani et al. ApJ 2018



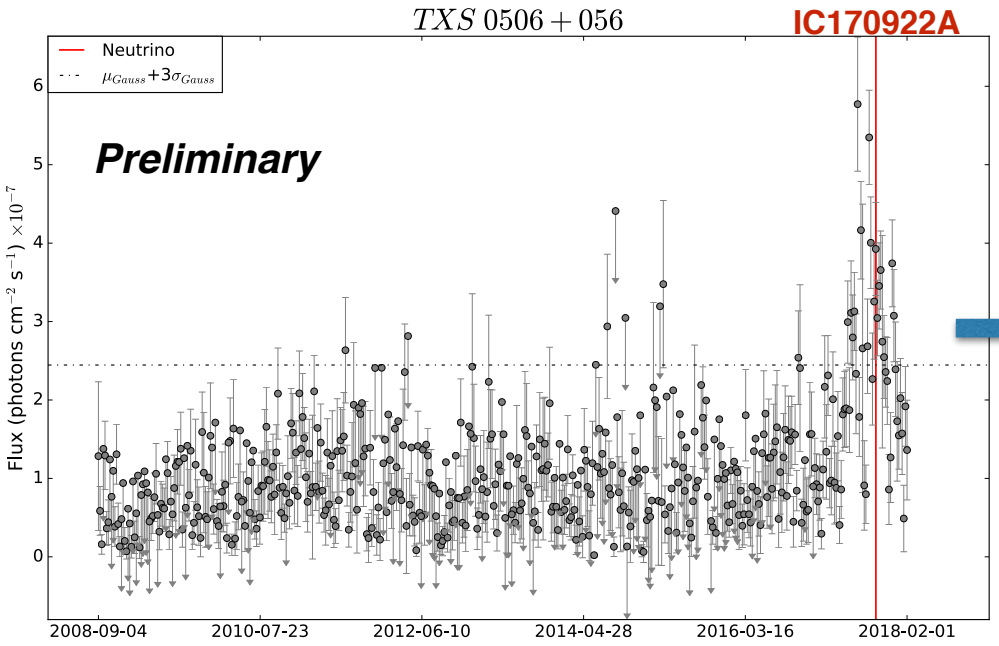
gamma rays produced through leptonic (Inverse Compton) or <u>hadronic interactions</u> (secondary prod. of pion cascade) following **Petropoulou et al MNRAS2015**

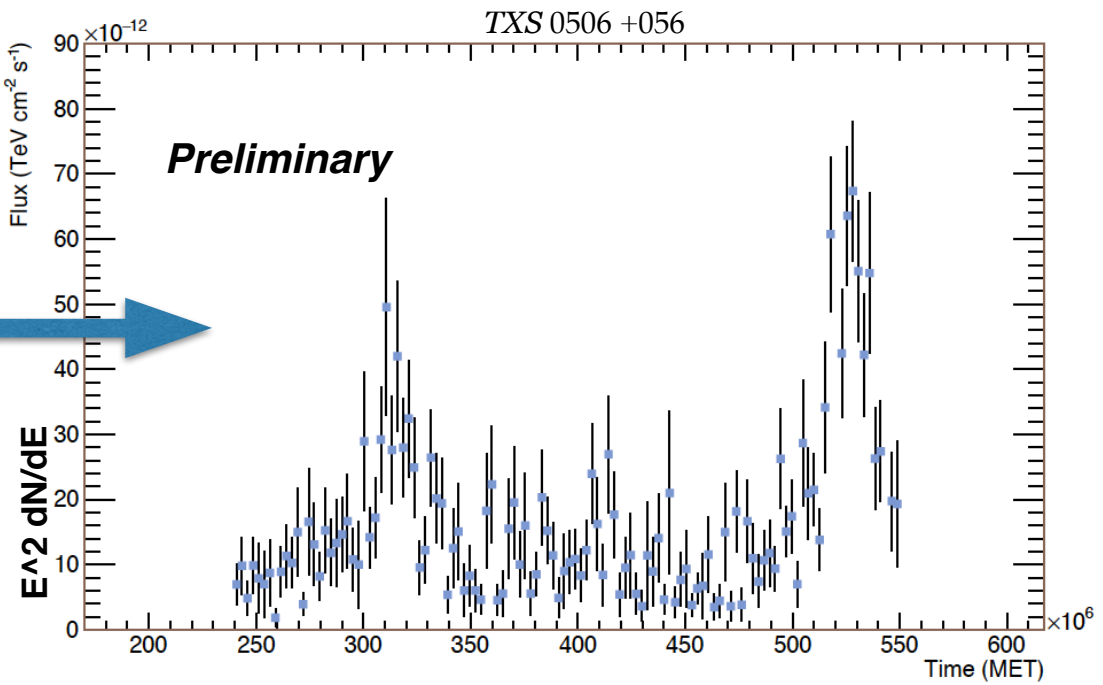
X rays produced by the electrons in the jet and used as a target for the accelerating protons

Using one of these two regions (or both) of the EM spectrum to obtain the flux of expected neutrinos

From γ to ν variability for TXS 0506+056

From gamma-ray activity to possible VHE neutrino activity





Weekly gamma-ray light curve

Monthly neutrino differential flux

1)E^-2 spectrum, 2) Franceschini et al. EBL Model,
3) Petropoulou et al.2015 for the ν calculation 4)Protons E extends at list up to 10^16 eV

Neutrino “light curve” for TXS0506+056

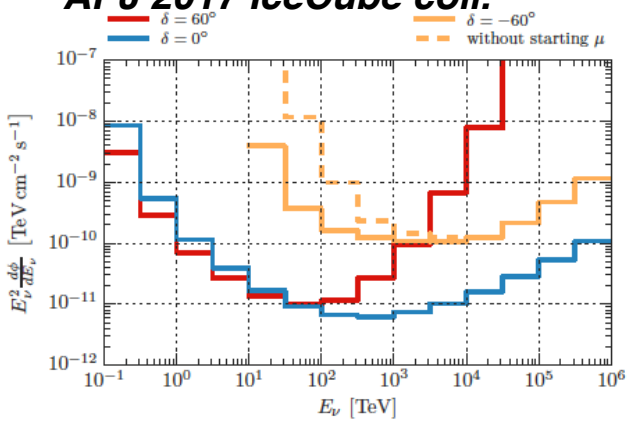
$K_{\gamma\nu} = L_{\nu\,(10TeV/1PeV)} / L_{\gamma\,(0.01\ TeV\ -\ 1\ TeV)}$

100 GeV γ produced by sync of π+/- decay prod

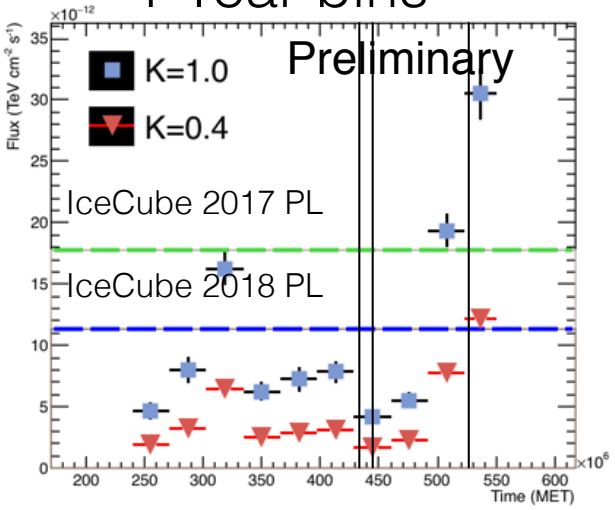
Following leptohadronic model from **Petropoulou et al. 2015**

Marinelli et al. ArXiv 1909.13198

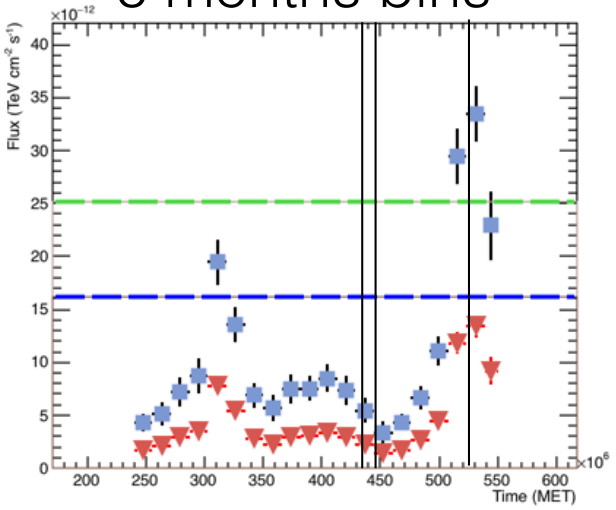
APJ 2017 IceCube coll.



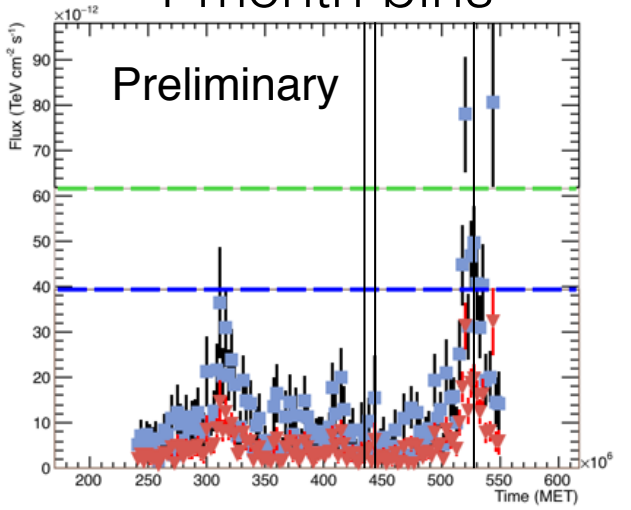
1 Year bins



6 months bins



1 month bins



For the case of TXS0506+056, under the condition of Fermi-LaT gamma rays produced by the synchrotron emission of pion decay products, the corresponding $\nu_\mu + \overline{\nu_\mu}$ flux can be visible with the binning of 1 year, 6 months and 1 month if we assume a $K_{\gamma\nu}=1$ while a 1 year bin is a minimal duration for seen a flare if $K_{\gamma\nu}=0.4$

Multimessenger with 10 y of ANTARES data

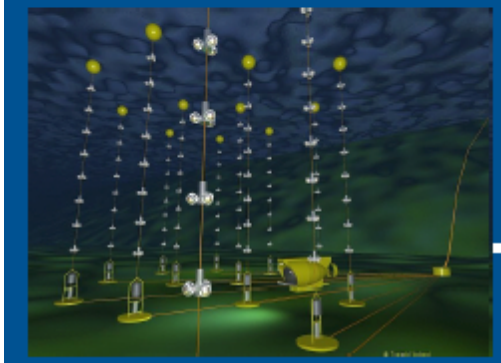
Presented at ICRC 2019 KM3NeT coll.

MULTIMESSENGER

D. Dornic - #871 Talk Tuesday Nu9e

14

ANTARES sends alerts



Shore station

On-line reconstruction

trigger

GCN alerts

Average delay: ~6 s

Angula resolution 0.4°-0.5°

in 10 years

311 alerts sent to robotic telescopes

18/25 followed by Swift

4 followed by Integral

4 followed by MWA

2 followed by HESS

NO transient source associated to ANTARES alerts so far

What we can do here in the context of the NANET WG3 PRIN activities

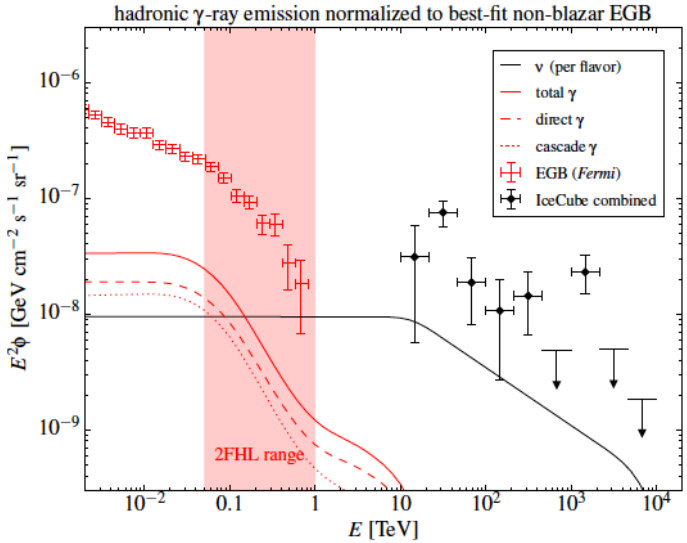
We use a global classification for extragalactic neutrino factories

We divide the sources in : “Accelerators” & “Reservoir”

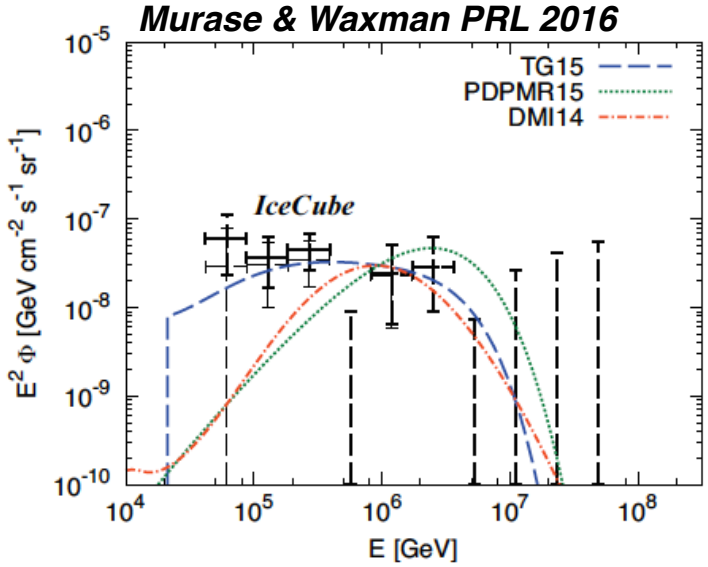
Reservoirs: Starburst & Starforming Galaxies with low luminosity but higher density.
Not trivial multi-messenger connection but assured hadronic production.

Accelerators: BL-lacs, FSRQ and other jetted AGNs, higher luminosity and lower density.
Variability factor to be considered.
More easier multi-messenger analysis with gamma-rays and UHECRs

Bechtol et al. ApJ 2017



Murase & Waxman PRL 2016

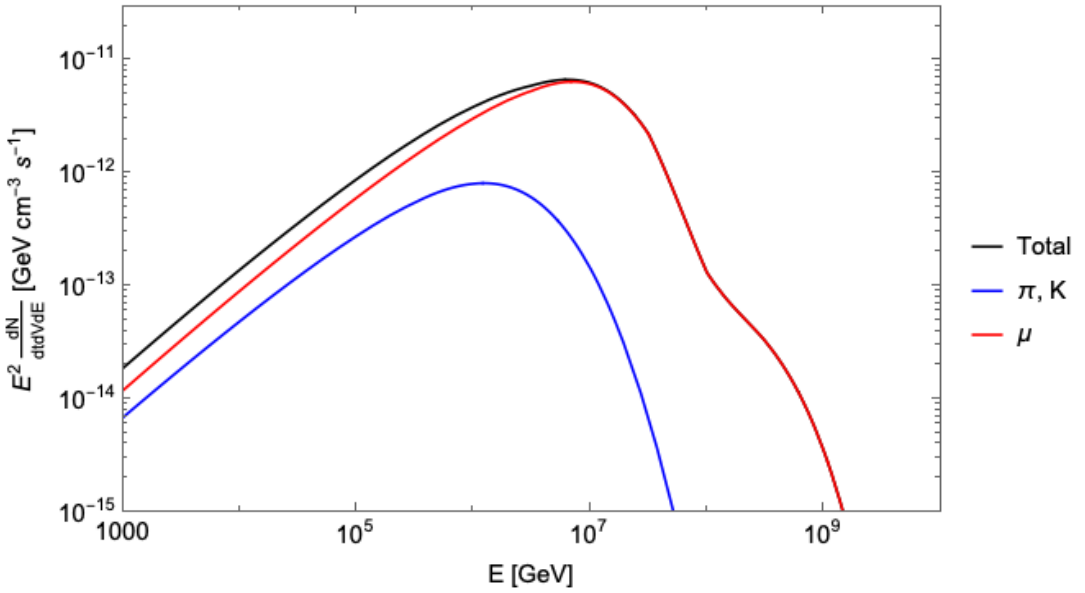


Preliminary ν SEDs obtained semianalitically

Preliminary analysis
on a **single accelerator**
assuming a B=103G, and
Γ(p)=2, for the future

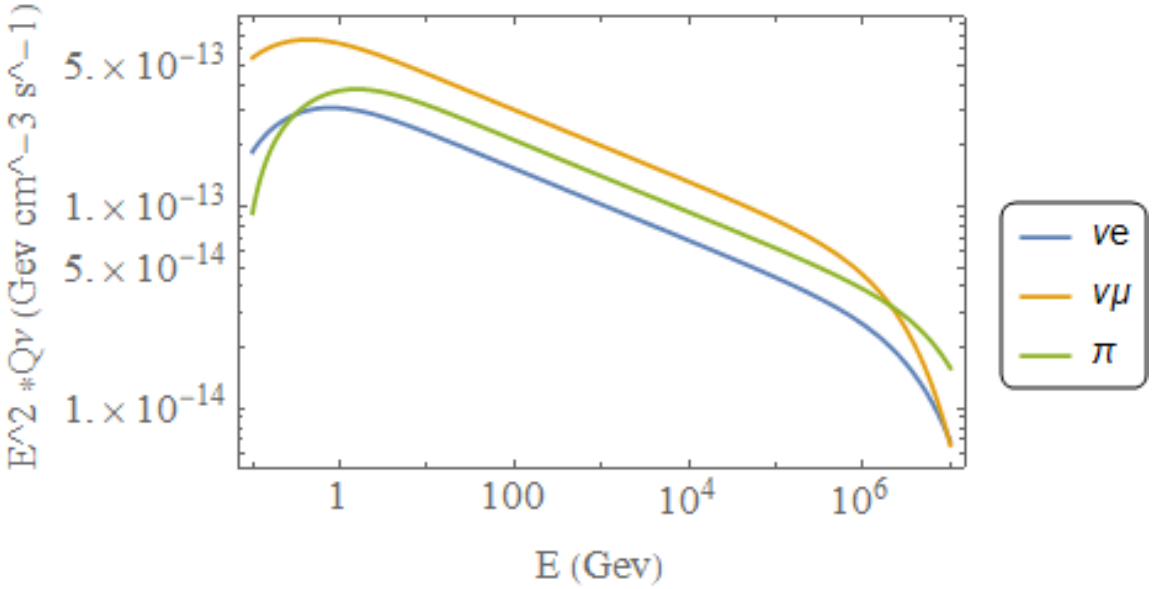
Damiano will produce it
though a dedicated simulation

from Damiano Fiorillo



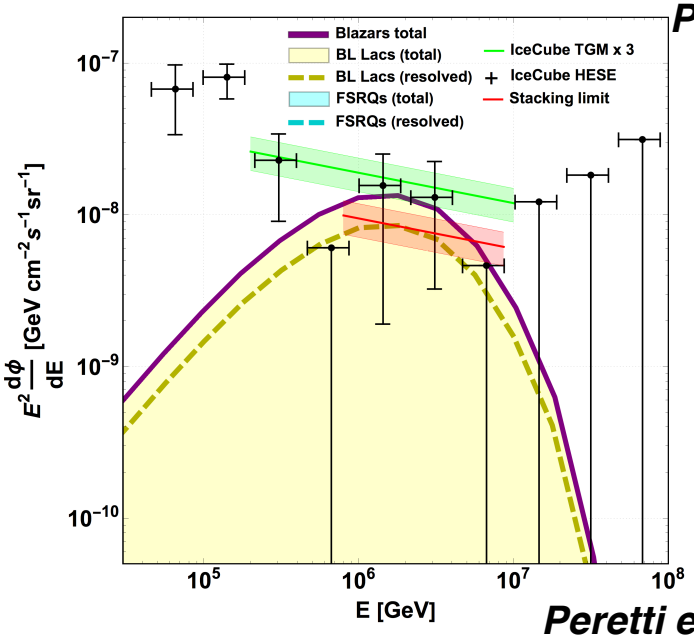
Preliminary SED calculation
on a **single reservoir** following
Peretti et al. MNRAS 2019

from Antonio Ambrosone



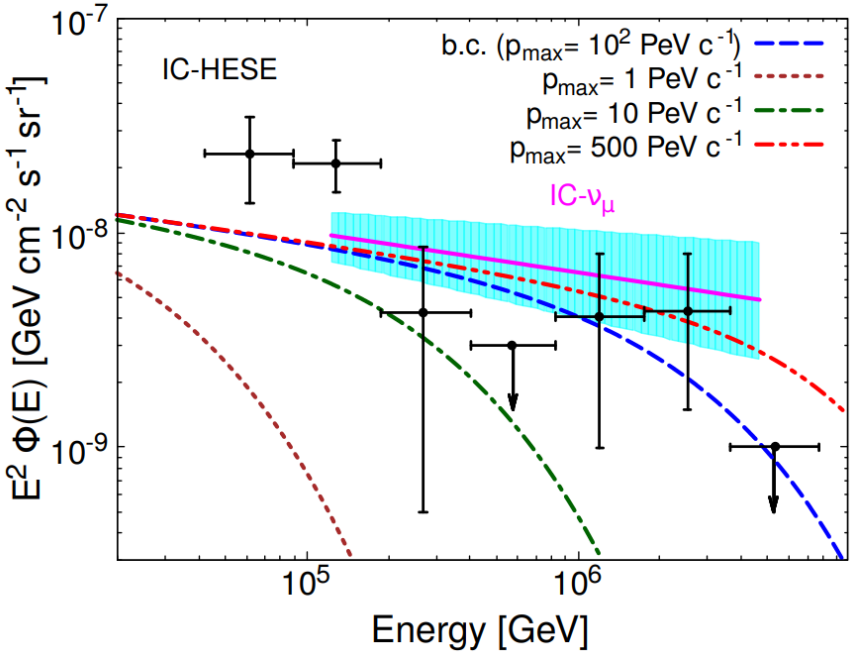
Recent ν global SED considering known sources

Palladino et al. APJ 2019



A recent example for the class of Blazars (**accelerators**) normalizing with gamma rays

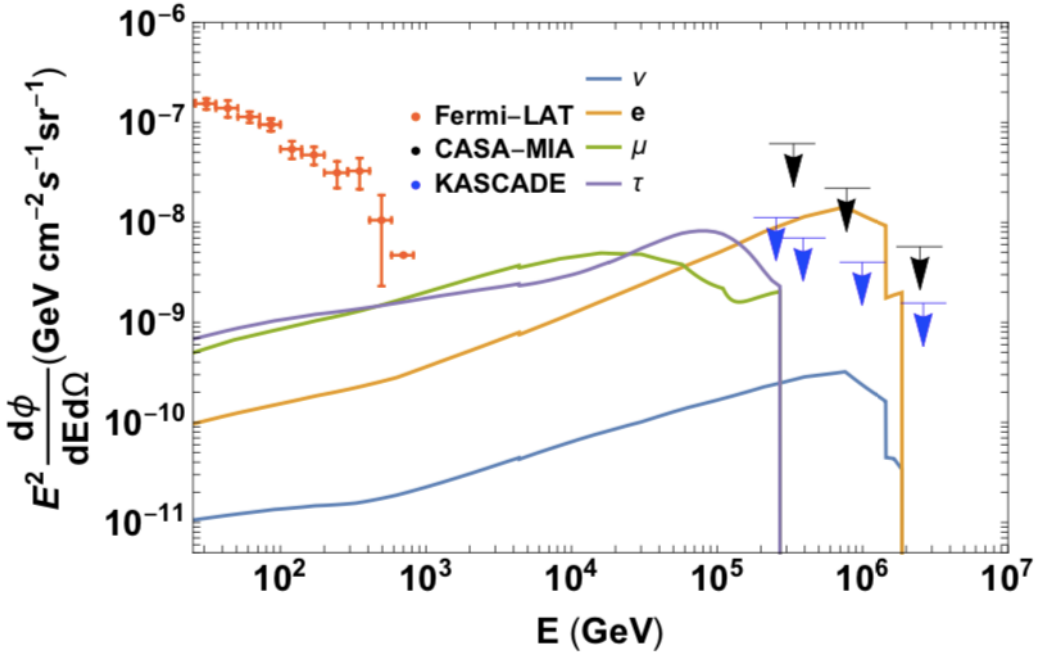
Peretti et al. APJ 2019



A recent example for the **reservoirs** normalizing with neutrinos from IceCube

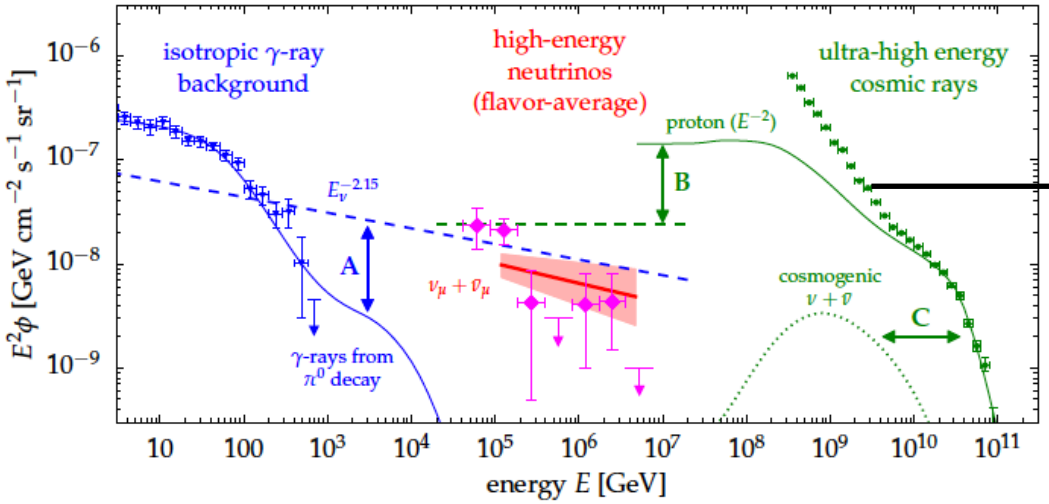
Introduction of possible ν SED from DM decay

Chianese et al. JCAP 2019



These gamma-ray fluxes where obtained from DM decay, similarly can be can be produced neutrino fluxes.

Ackermann et al. Astro2020SWP



No constraints from UHECRs when considering the DM decay ν component.

SUMMARY and CONCLUSIONS

- Since 2013 more than 100 astrophysical ν were detected with no particular excess from some region of the Sky, different classes of ν factories needed to justify a global SED.

- The total diffuse ν Galactic component seems to be limited at the level of the 10% of the full sky astrophysical ν flux.

- Not clear which extragalactic sources (or dark matter?) contribute more to the remaining 90% of astrophysical ν

- We will add a ν component from DM to different astrophysical components for fitting the IceCube HESE and EHE SEDs

- Open to any kind of suggestion for linking the Global Neutrino Network (IceCube + KM3NeT + Baikal) and NANET activity.