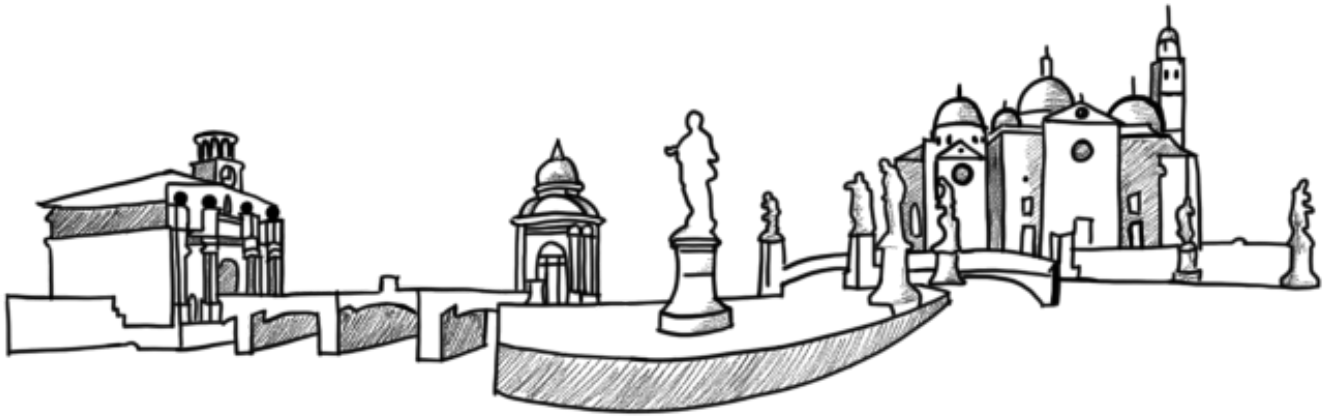
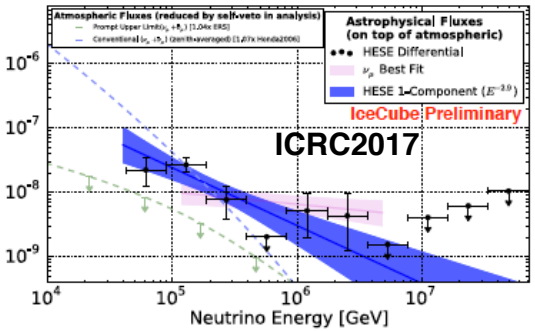
Exploring the activity of blazars and their observability through a neutrino telescope

Extreme19 22-25/01/2019 Padova

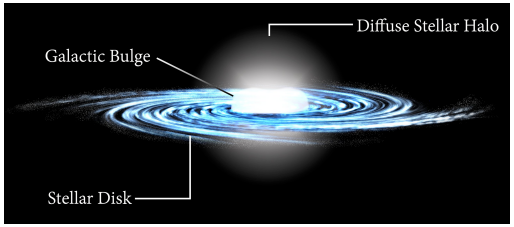


Antonio Marinelli
INFN and Dipartimento di Fisica Pisa
in coll. with Ankur Sharma, Rodrigo Sacahui Reyes & Mabel Osorio

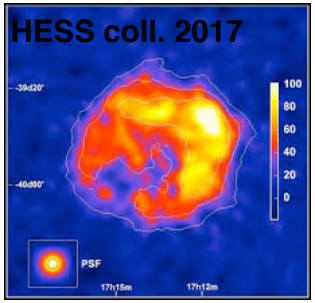
Neutrino astronomy status



After 8 years of operations IceCube already collected more than 100 of HESE type events and around 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**

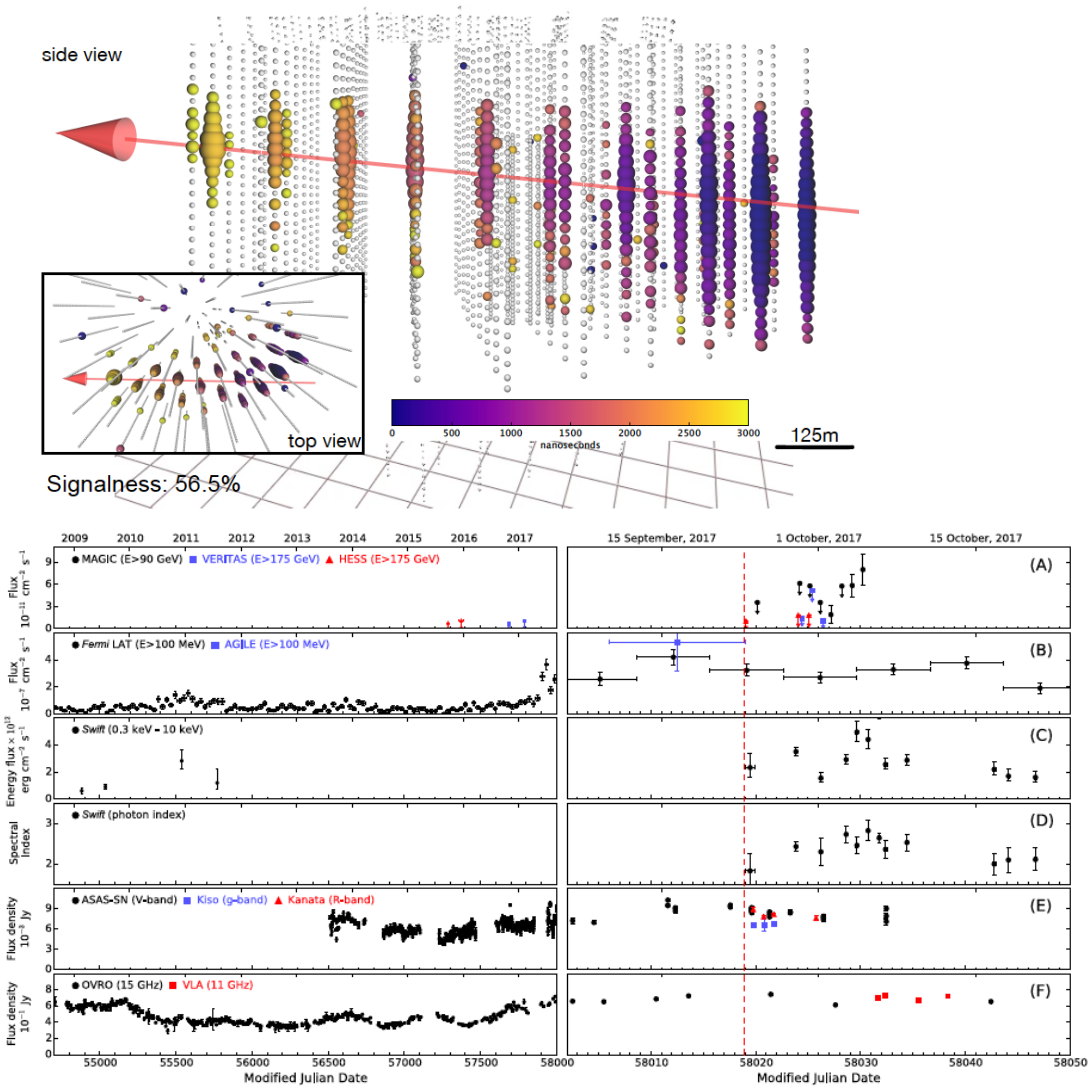


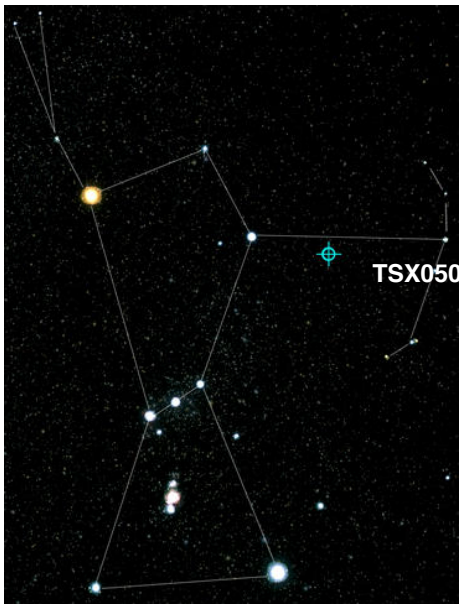
No associations for the moment with known **Galactic Pevatrons**, maybe due to small duration of the hadronic Pevatron phases

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

The case of TXS 0506+056

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





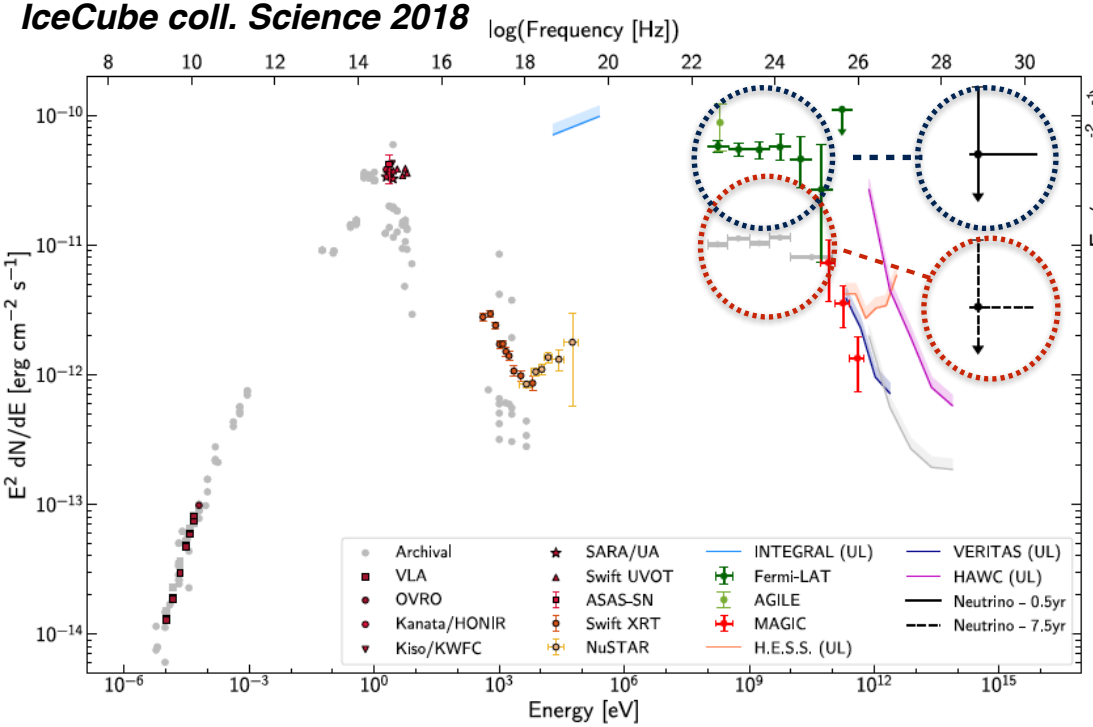
BL-Lac object at Z=0.336

Object between the 3% of more luminous object of the 3FHL of Fermi-LAT

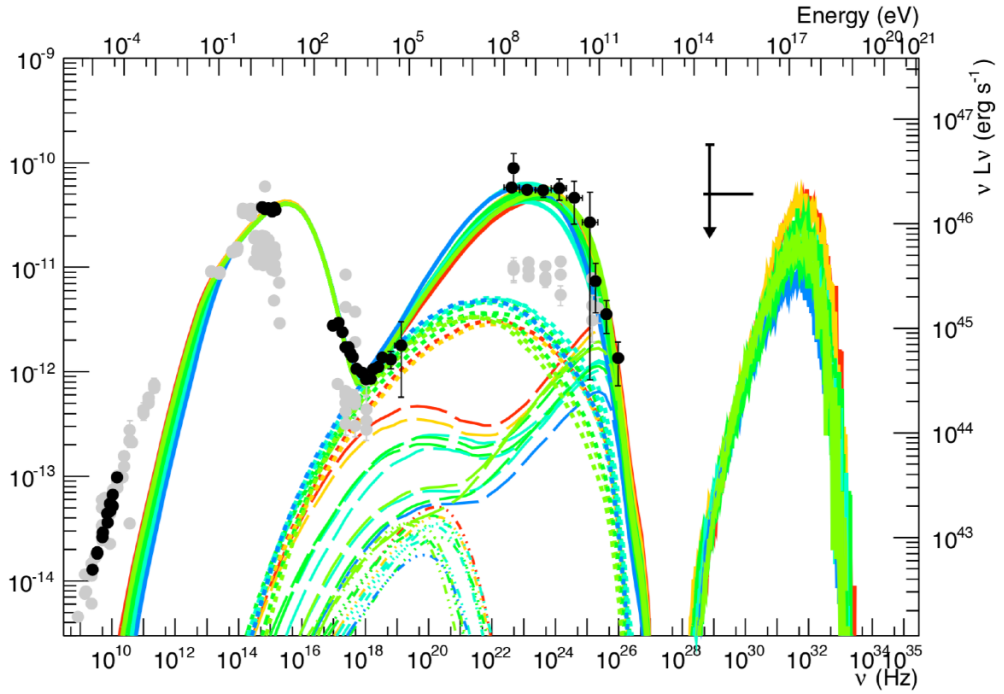
Hints from the SED of TXS 0506+056

The Multi-Messenger SED

IceCube coll. Science 2018



Cerruti et al. 2018

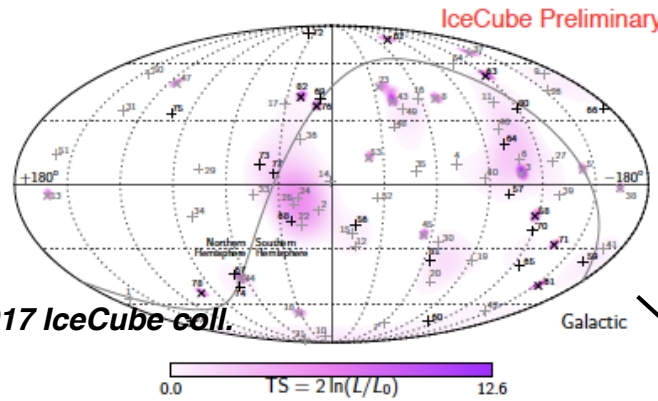


It is possible to correlate the level of gamma-ray flux at 100 GeV with the corresponding neutrino flux at hundreds of TeV through the lepto-hadronic model explained in **Petropoulou et al. 2015, when the synchrotron emission from the pion cascades sits in the Fermi-LAT range.**

For the case of TXS0506+056 the neutrino flux corresponding to the IceCube neutrino event IC170922 should have been on a bit higher energies, however this model is not excluded.

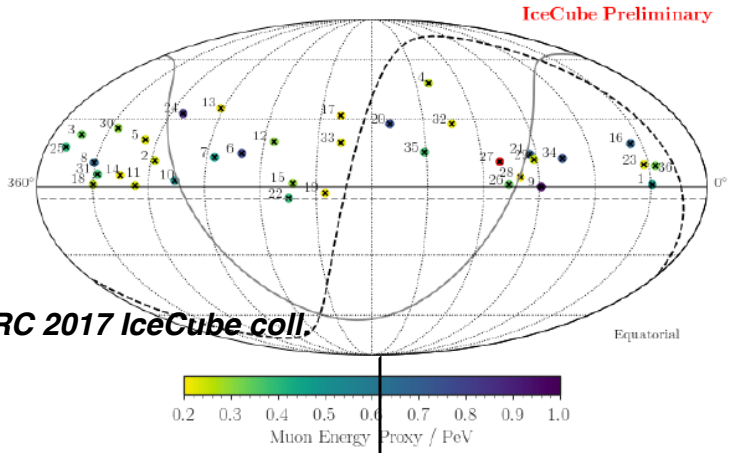
Building a sample of candidates

22 Track-like
events between the HESE sample



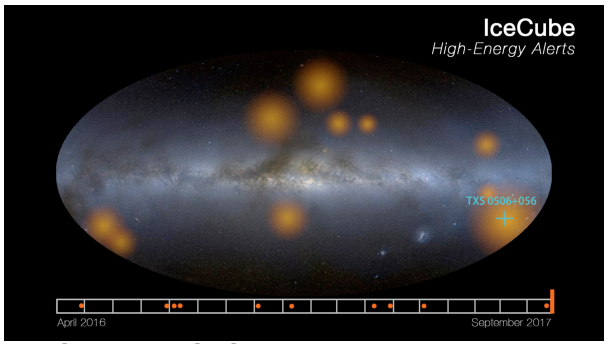
ICRC 2017 IceCube coll.

36 Track-like
events between the northern sample



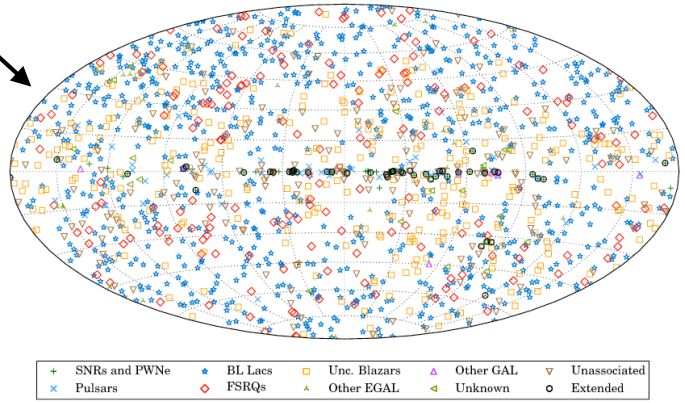
ICRC 2017 IceCube coll.

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 created Blazar sample

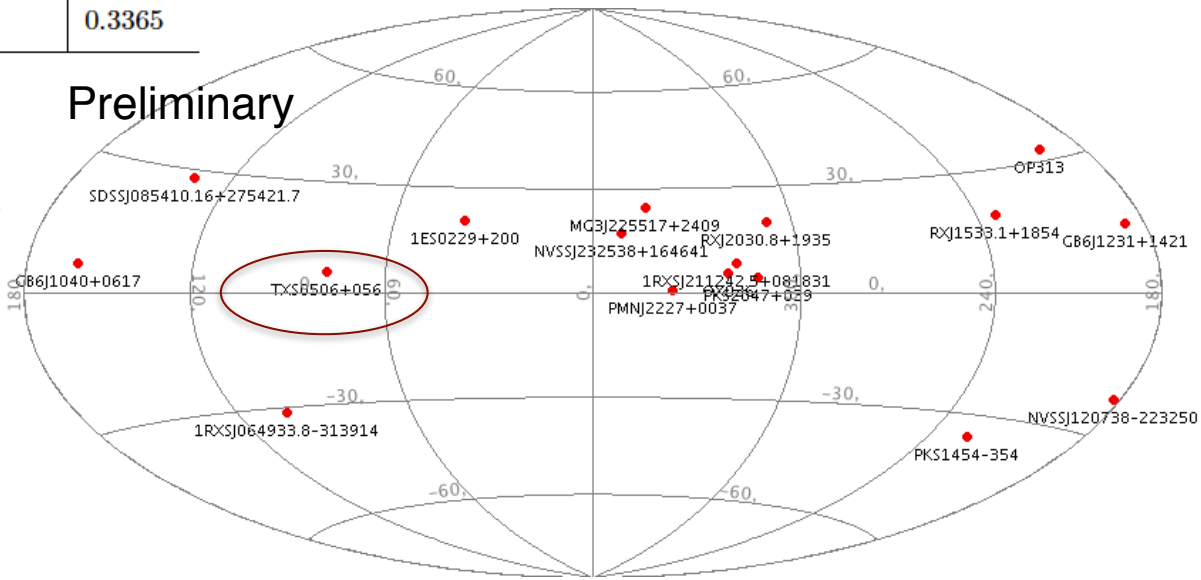
S.no.	Source Name	RA (deg)	Dec.(deg)	Source Class	z
1	MG3 J225517+2409	343.805	24.1807	bll	-
2	RX J2030.8+1935	307.751	19.6032	bll	0.27
3	RX J1533.1+1854	233.312	18.8712	bll	0.305
4	PKS 2047+039	312.508	4.1466	bll	-
5	1RXS J211242.5+081831	318.18	8.3179	bll	-
6	PMN J2110+0810	317.518	8.2021	fsrq	1.58
7	OX 036	320.921	5.5629	fsrq	1.941
8	1ES 0229+200	38.2236	20.2984	bll	0.1390
9	OP 313	197.649	32.351	fsrq	0.998
10	NVSS J232538+164641	351.423	16.8334	bll	0.25
11	SDSS J085410.16+275421.7	133.532	27.8826	bll	0.494
12	1RXS J064933.8-313914	102.386	-31.6491	bll	≥ 0.563
13	GB6 J1040+0617	160.147	6.3023	bll	0.7351
14	NVSS J120738-223250	181.95	-22.4809	bll	-
15	GB6 J1231+1421	187.866	14.368	bll	-
16	PKS 1454-354	224.382	-35.6478	fsrq	1.424
17	PMN J1505-3432	226.25	-34.5472	bll	1.554
18	PMN J2227+0037	336.972	0.6101	bll	-
19	TXS 0506+056	77.3636	5.7066	bll	0.3365

15 BL-lacs and 4 FSRQs result spatially correlated (inside the ~1° of angular incertitude) with astrophysical ν_μ.

3 of them are extreme blazars. From them no signature of major gamma-ray activity in coincidence with the neutrino events

Skymap in equatorial coordinates

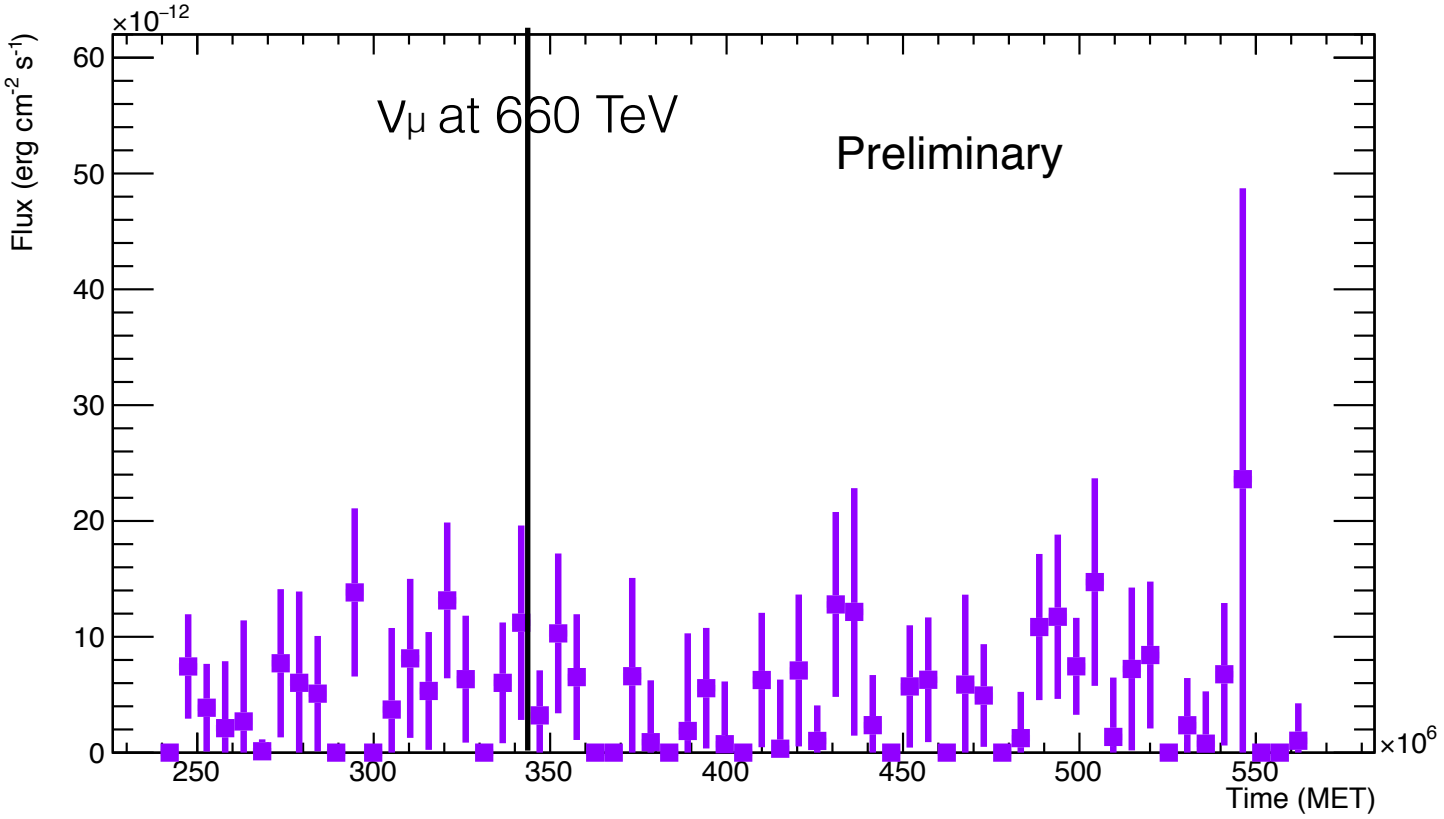
Preliminary



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

The case of the extreme Blazar 1ES 0229+200

1ES0229+200 Z=0.139



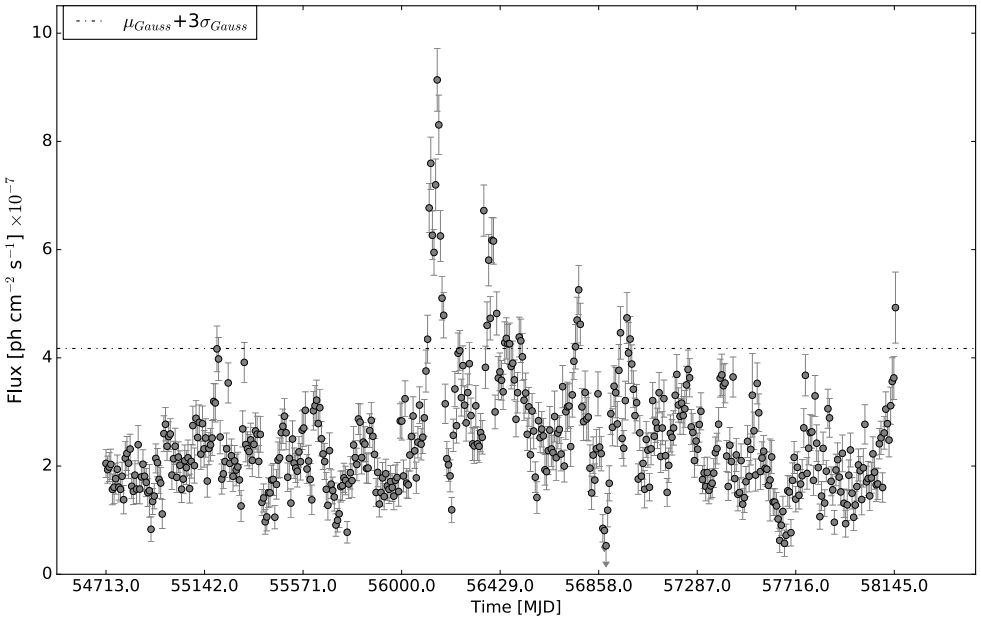
We produce the gamma-ray light curve with Fermi-Lat with a binning of 2 months

Spatially connected with a ν_μ of 660 TeV (deposited energy)
However no significant activities are visibile on gamma-ray in coincidence with the neutrino event.

The luminosity of TXS 0506+056 flares

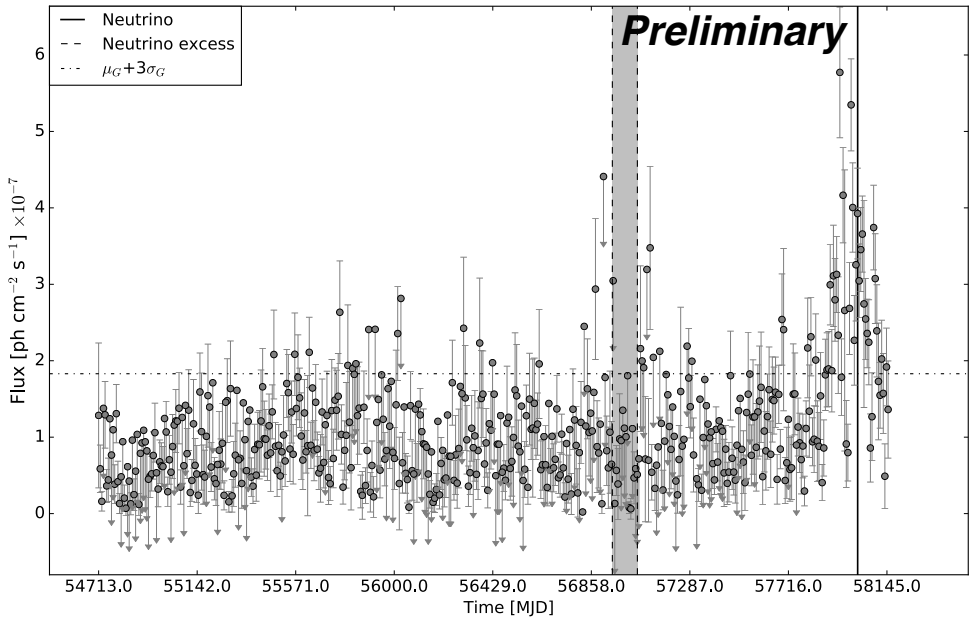
- The gamma-ray light curves are obtained integrating from 1 GeV to 300 GeV.
- We select the emissivities above the average (μ) + 3σ and μ + 1σ to obtain the luminosity.
- We consider a isotropic luminosity

Markarian 421



- μ + 3σ = 1.15 x 10^44 erg/sec
- μ + 1σ = 1.76 x 10^44 erg/sec

TXS0506+056 **IC170922A**



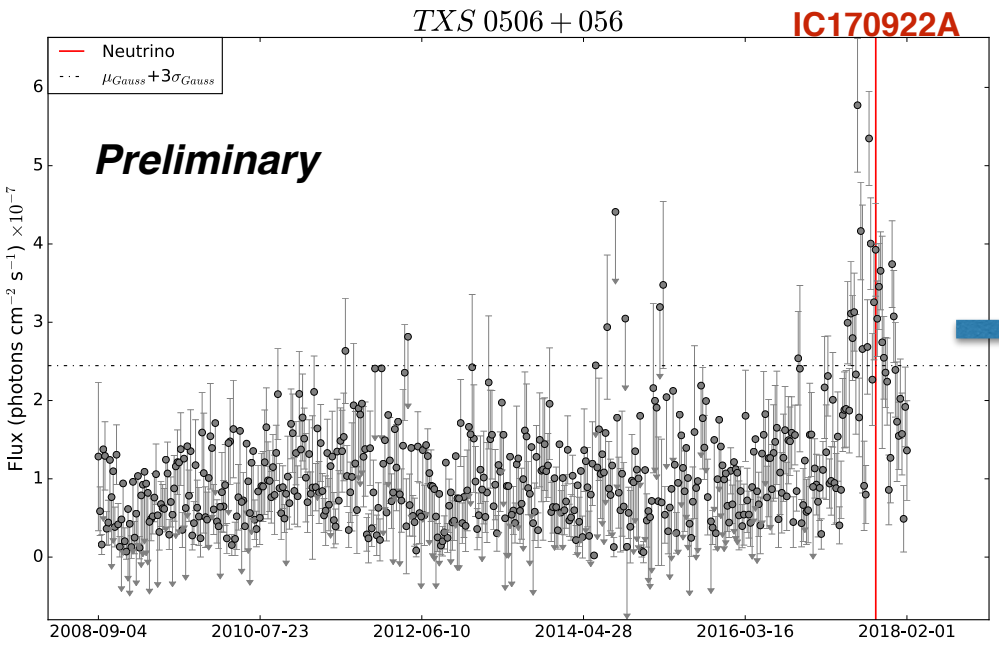
- μ + 3σ = 1.41 x 10^46 erg/sec
- μ + 1σ = 2.28 x 10^46 erg/sec

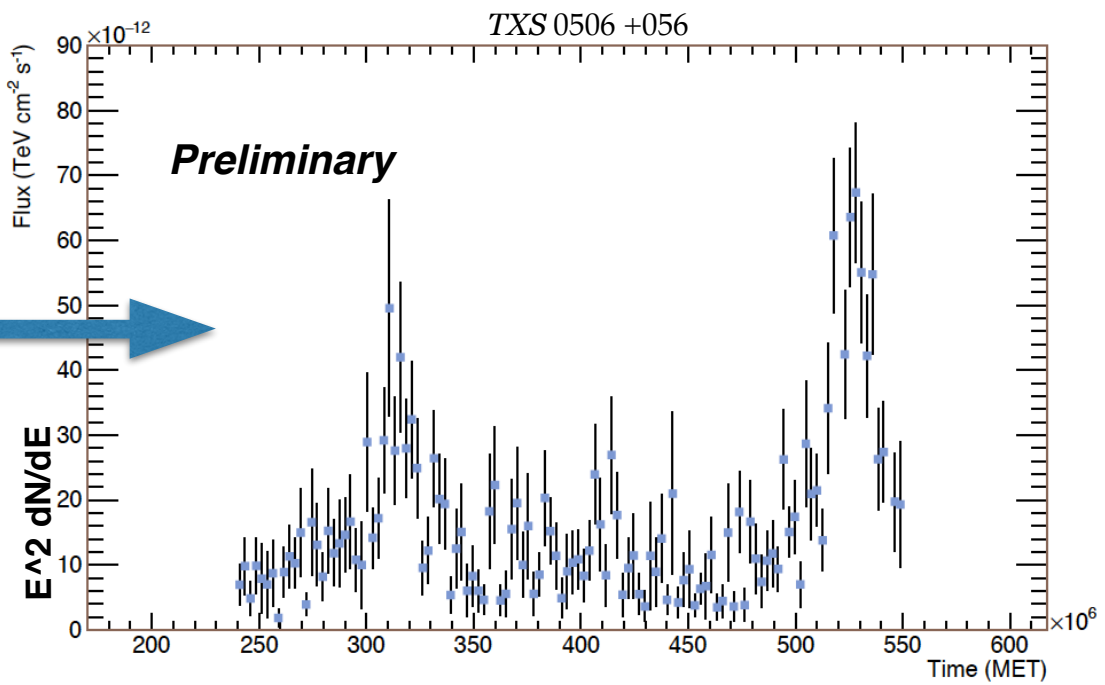
Which is the minimal flaring duration needed to observe TXS0506+056 with IceCube assuming the **Fermi photons as the synchrotron emission of charged pion decay products ?**

MNRAS2016 Petropoulou et al.

From γ to ν variability for TXS 0506+056

From gamma-ray fluxes to possible VHE neutrino fluxes





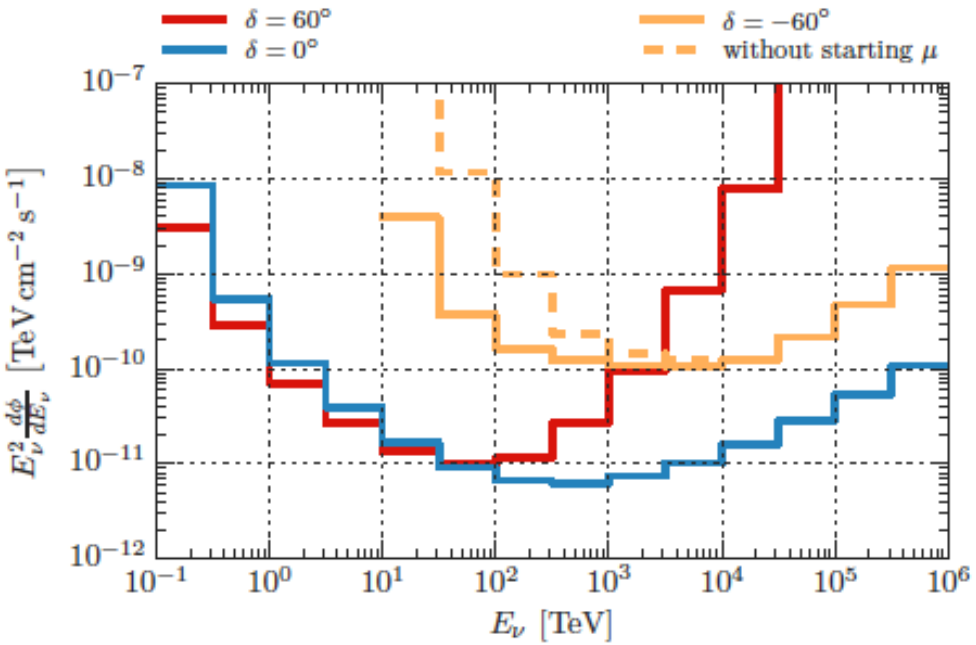
Weekly gamma-ray light curve

Monthly neutrino differential flux

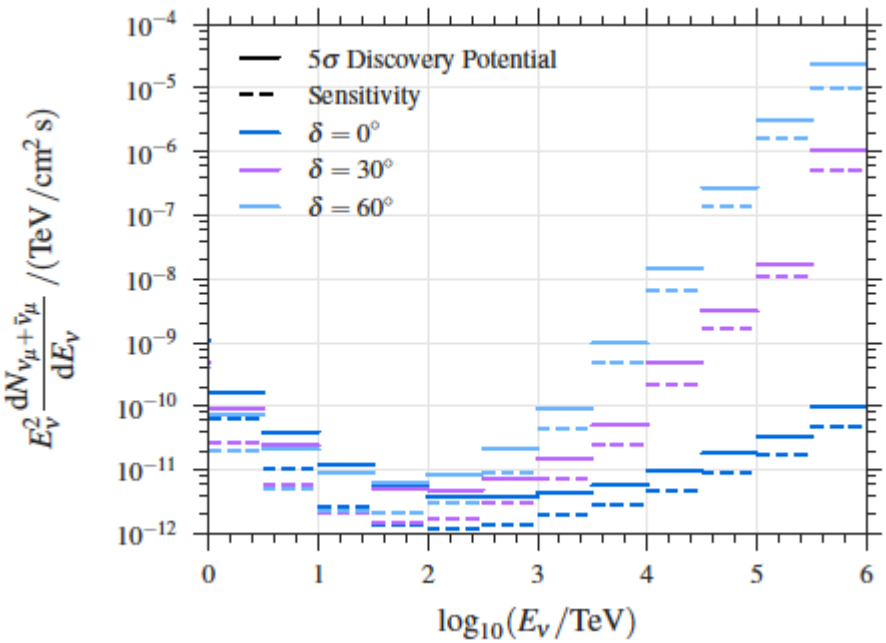
1)Power law spectrum, 2) Franceschini et al. EBL Model,
3) 100 GeV γ produced by sync of π+/- decay prod 4)Protons E extends up to 10^16 eV

Sensitivity of IceCube for point like searches

APJ 2017 IceCube coll.



arXiv:1811.07979 IceCube coll.



The IceCube sensitivity for $\nu_\mu + \overline{\nu}_\mu$ increased in the paper of November last year, when we consider the northern hemisphere.
Here we use this sensitivity to check the possibility to observe neutrino flares from the sample of selected blazars.

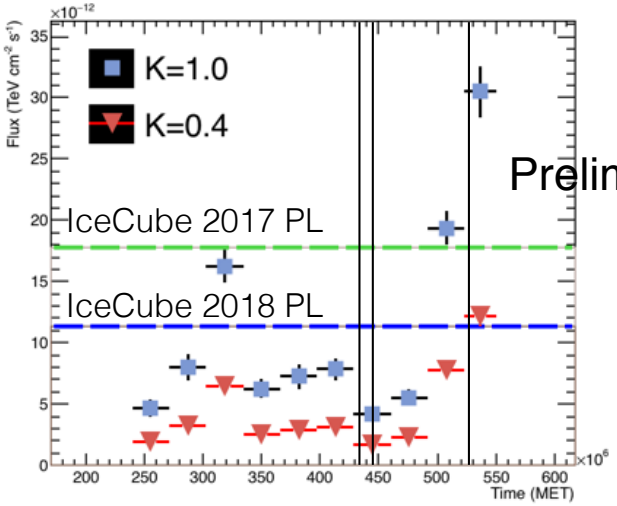
To obtain the blazar neutrino flux variability curve we can assume different proportionality factors $K_{\gamma\nu} = L_\nu$ (10TeV/1PeV) / L_γ (0.01 TeV - 1 TeV)

Neutrino variability curve for TXS 0506+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*

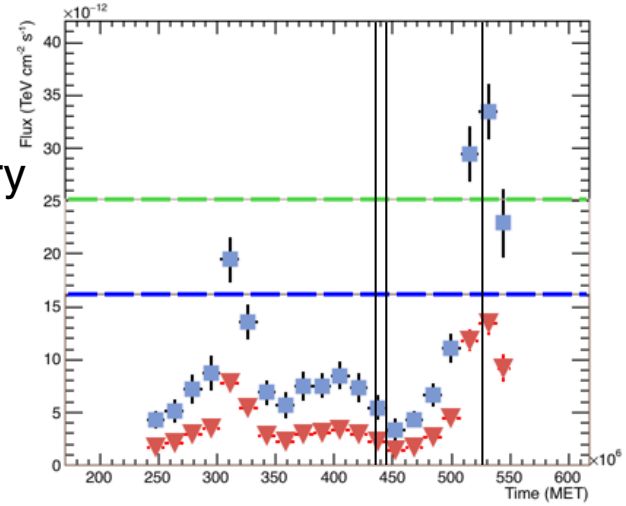
Following leptohadronic model from **Petropoulou et al. 2015**

1 Year bins



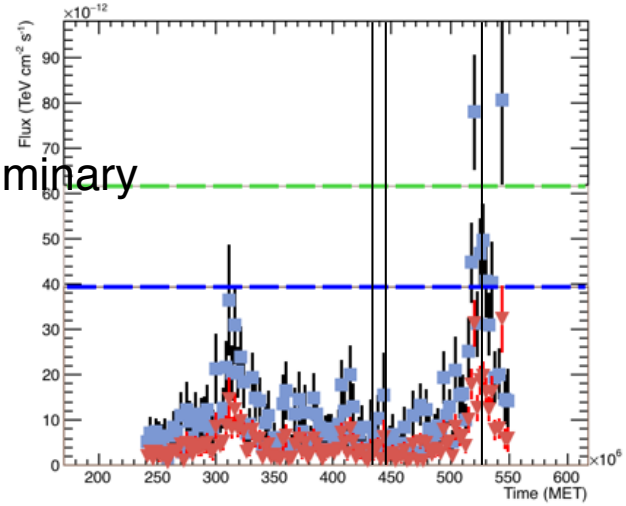
Preliminary

6 months bins



Preliminary

1 month bins



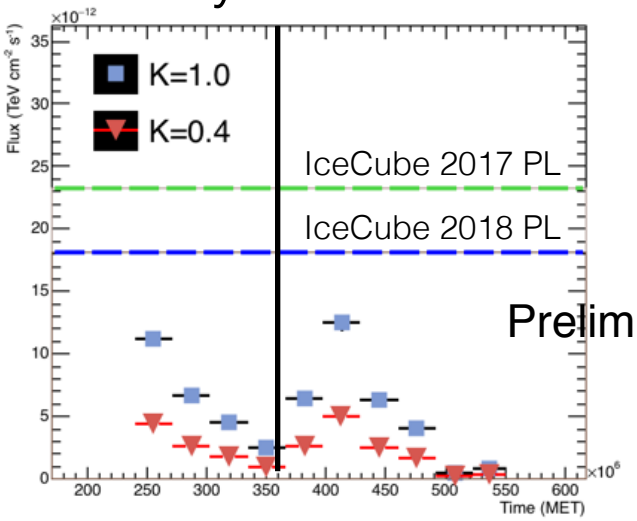
For the case of TXS0506+056, under the condition of Fermi-LaT gamma rays produced by the synchrotron emission of pion decay products, the corresponding $\nu_\mu + \overline{\nu_\mu}$ flux can be visible with the binning of 1 year, 6 months and 1 month if we assume a Kγν=1 while a 1 year bin is a minimal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

Neutrino variability curve for the FSRQ OP313

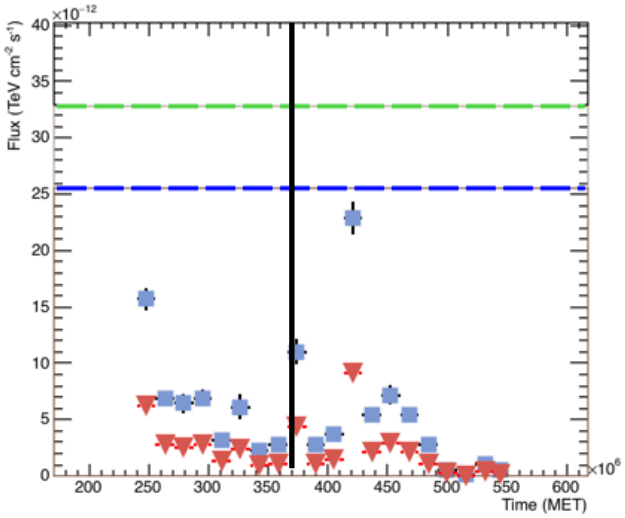
Gamma-ray Luminosity during a flaring period $\mu + 3\sigma = 7.42 \times 10^{46}$ erg/sec

$K_{\gamma\nu} = L_{\nu\,(10TeV/1PeV)} / L_{\gamma\,(0.01\ TeV - 1\ TeV)}$ *100 GeV γ produced by sync of π+/- decay prod*

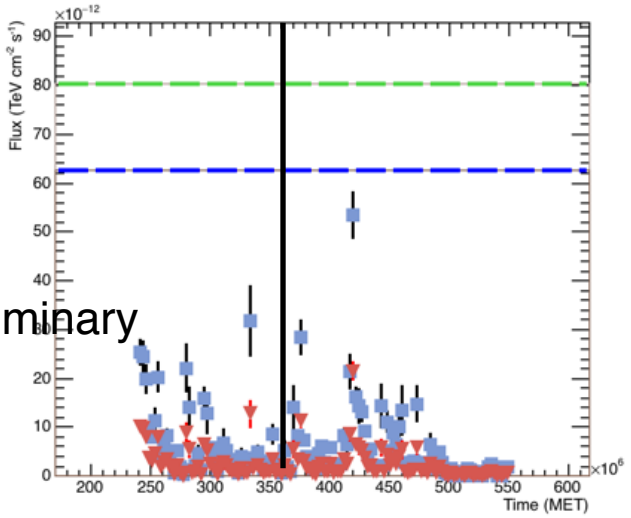
1 year bins



6 months bins



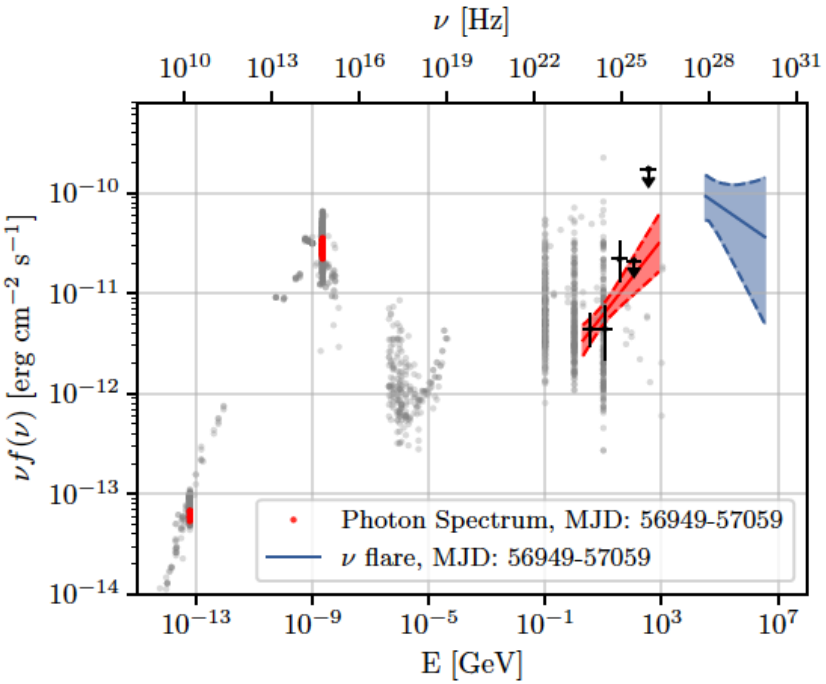
1 month bins



For the case of the FSRQ OP313, under the same lepto-hadronic condition of **Petropoulou et al. 2015**, the equivalent corresponding neutrino $\nu_\mu + \overline{\nu_\mu}$ flux can be visible with the binning of 6 months and the IceCube sensitivity 2018 if we assume a Kγν >1

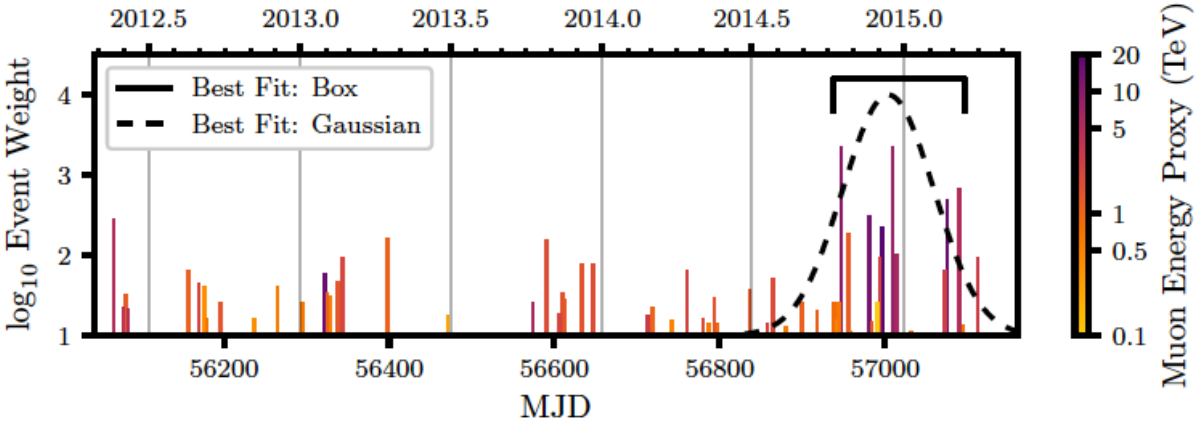
The spectral hardening observation for γ

Padovani et al. MNRAS 2018



IceCube coll. Science 2018

TXS0506+056 &13 associated muonic neutrinos

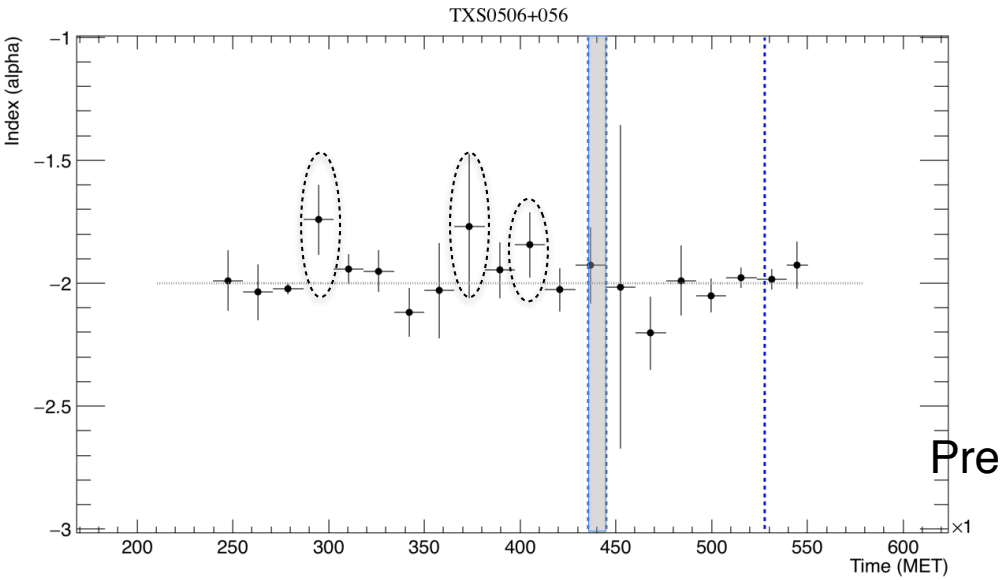


To connect the neutrino flare TXS0506 of 2014/2015 with the Fermi-LaT gamma-ray spectrum obtained during the same period through a hadronic emission a harder spectrum at more than 10 GeV is preferred. This point out that also lower and harder SEDs at GeVs can be a footprint of a hadronic component. **Padovani et al. 2018**

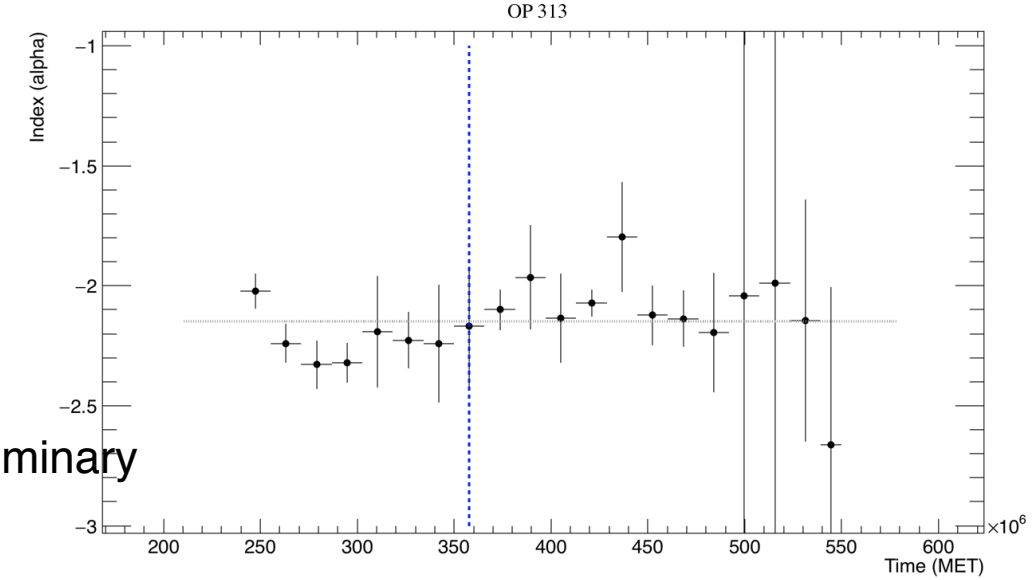
The α variability for TXS0506+056 and OP313

- *Power law SED assumed for the gamma rays of Fermi-LAT γ*
- *Franceschini et al. EBL model assumed*
- *6 Months binning assumed, and γ integrated between 0.1 to 300 GeV*

BL-lac



FSRQ



Preliminary

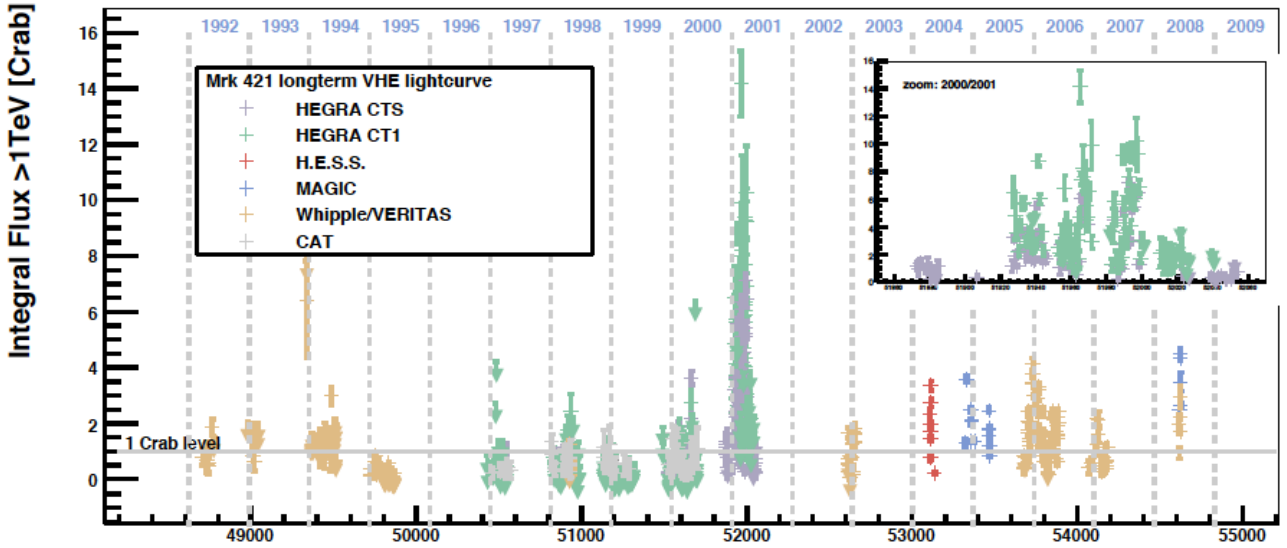
With a six months binning TXS0506+056 shows at least 3 hardening more significative than the one related to the 2014/2015 IceCube flux

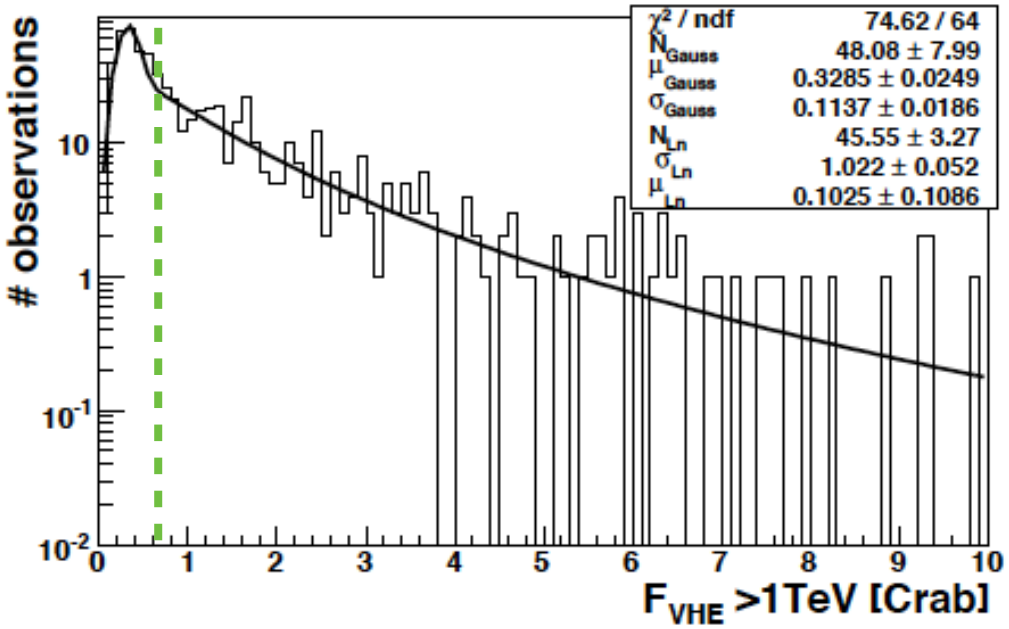
Also for OP313 the 200 TeV neutrino event spatially correlated seems not to be associated with a 100 GeV spectral hardening

Evaluating the level of activity for these Blazars

Long time observation of blazars like Mrk421 show that high-energy activity is intermittent, on - off description can apply also for most of the known Blazars.

Tluczycont, Bernardini et al. A&A 2010



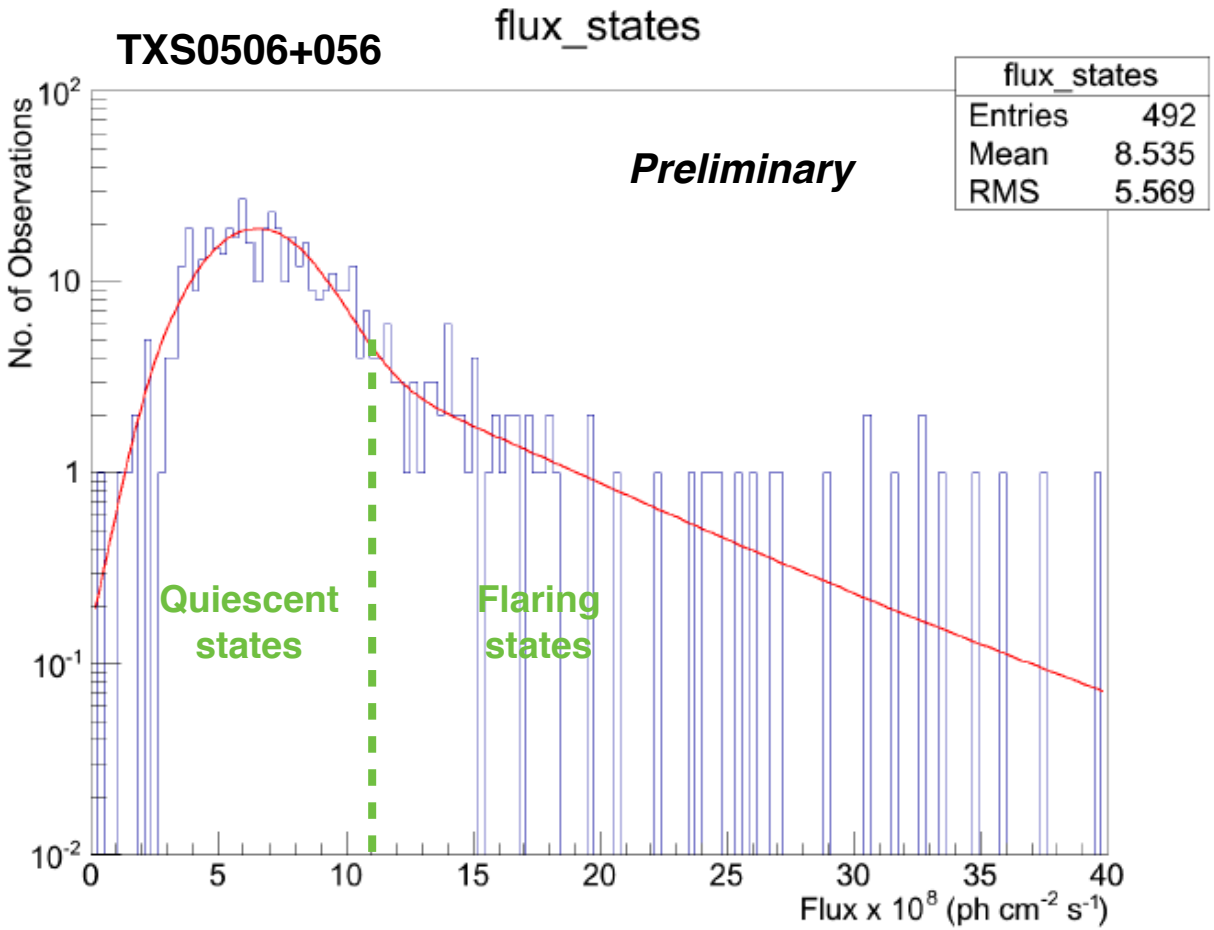


The **Duty Cycle** definition is simply the **ratio between the time of flaring state and the total observational time.**

$$DC = \frac{T_{HE}}{T_{HE} + T_{bl}}$$

In the integrated flux distribution the **quiescent state** (Tbl) is described by a **Gaussian** while the **flaring state** (T_{HE}) is described by a **log-normal function.**

Duty Cycle estimation for TXS 0506+056



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

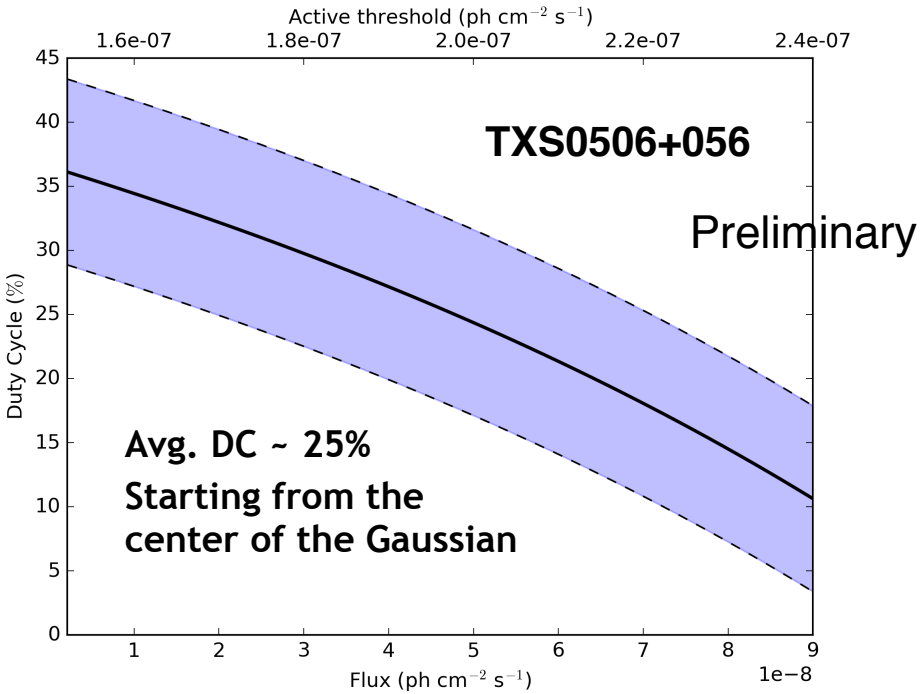
The fluxes distribution is well represented by a **Gaussian + Lognormal distribution**

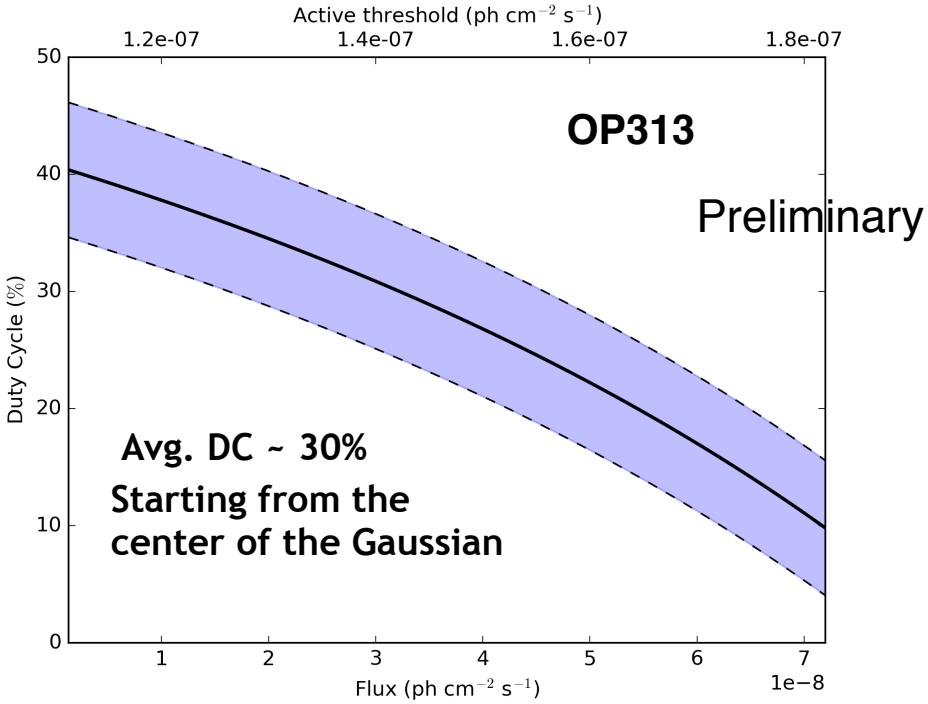
To this distribution of fluxes of TXS0506+056 we apply the Duty Cycle definition developed with the Milagro collaboration in 2014 (Abdo et al. APJ 2014)

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

Comparison of DC for ν emitter candidates

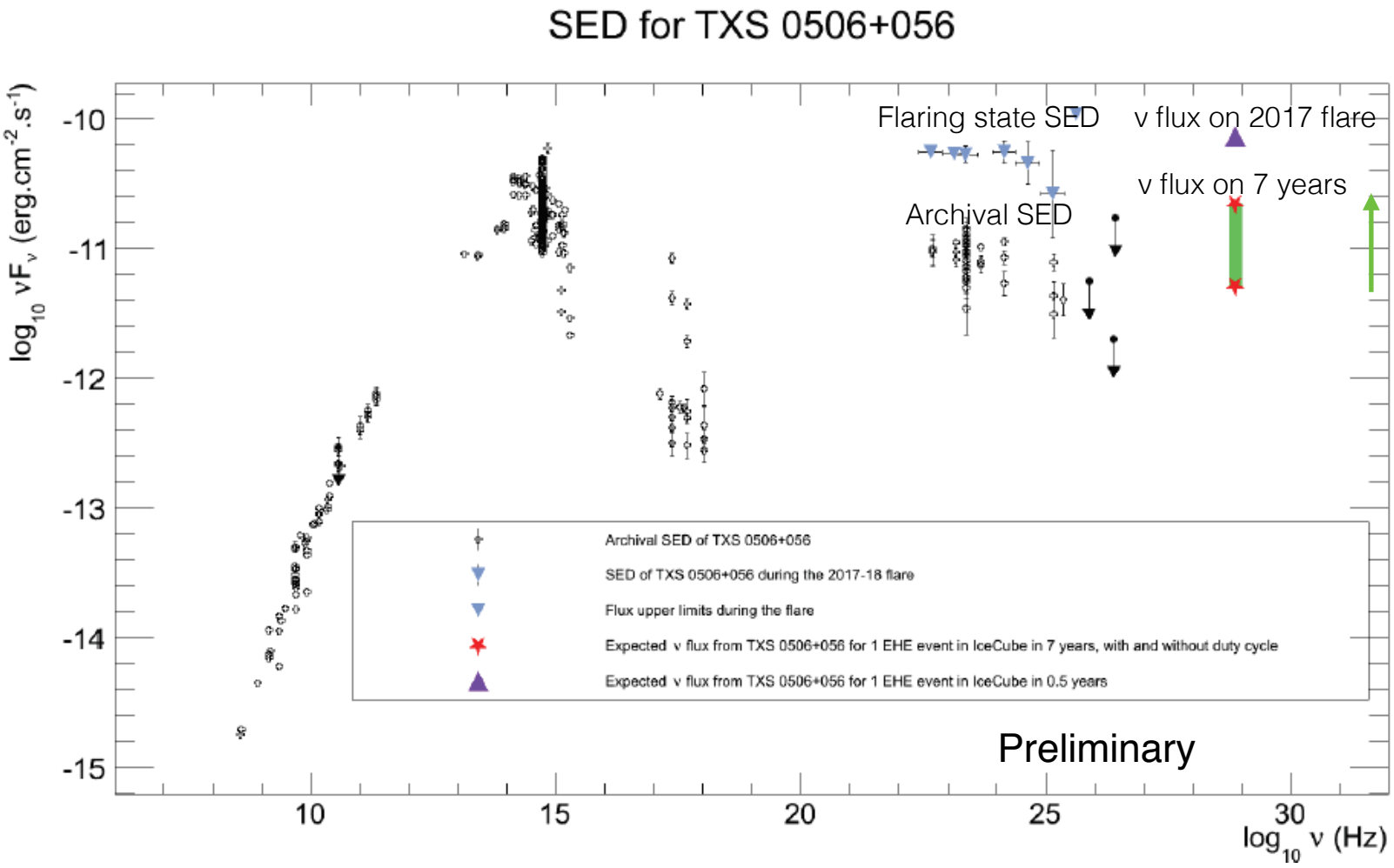
- *Franceschini et al. EBL model assumed.*
- *Weekly binned Fermi-LAT light curve considered.*





If we assume a on-off state description of the blazar state we obtain that a BL-lac like **TXS0506+056 is active only 1/4 of the time**

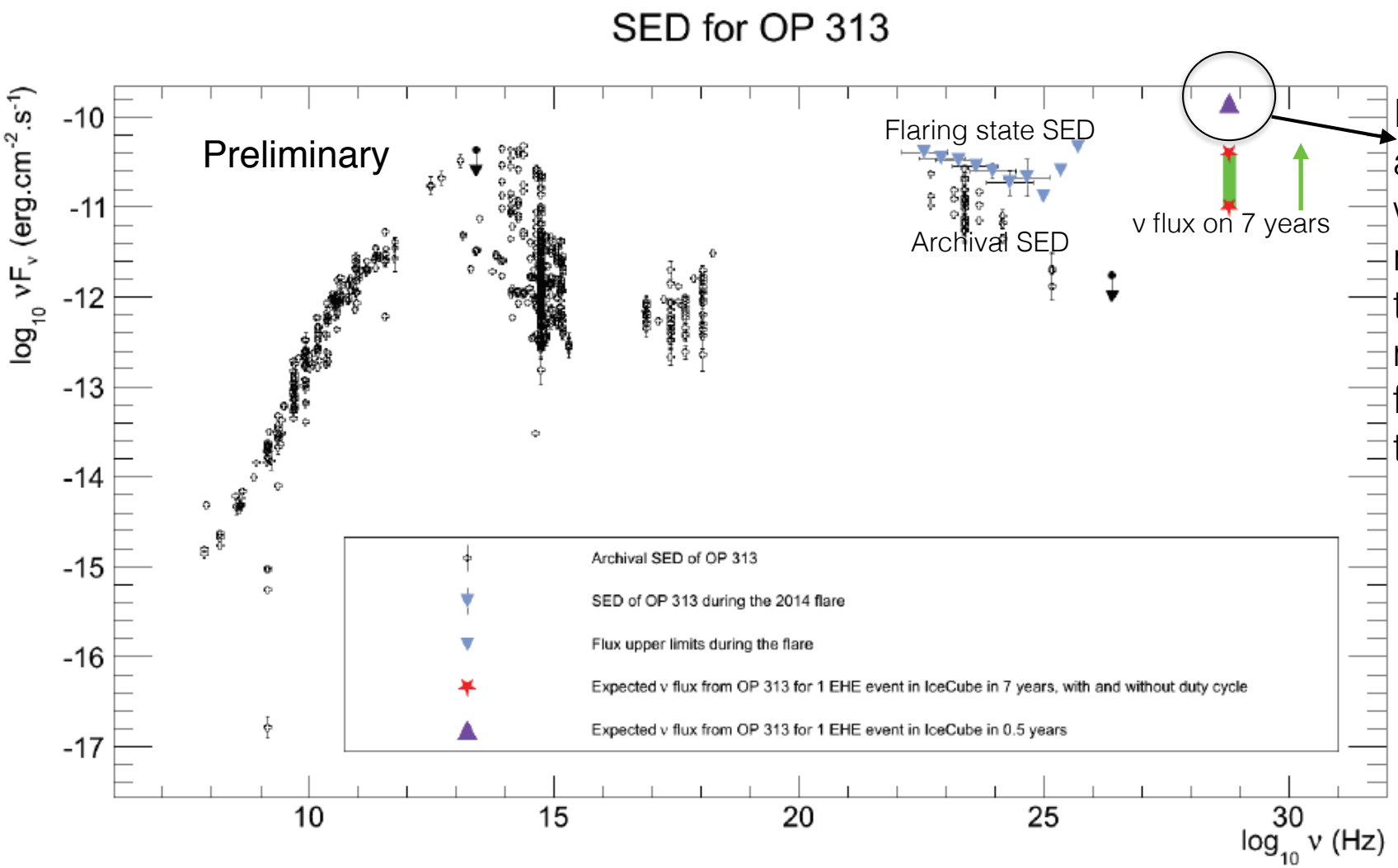
Possible changes in the SED after DC estimation



DC of 25% applied to the total observational time of 7 years for IceCube.

The obtained average Duty Cycle can be more important when we look at energies higher than GeV and can change the expected level of neutrino flux when we look for long observational periods (Entire IceCube observational time).

Changes on the OP313 SED



In this case this is a virtual flux since we assume the neutrino inside the time window of the major gamma-ray flare observed for this FSRQ

The Duty Cycle changes the expected neutrino flux needed to produce the astrophysical neutrino event of 200 TeV observed by IceCube still allow the connection with the archival SED observed by Fermi-LAT.

SUMMARY and CONCLUSIONS

- We already have a list of 20 Blazars within the 1° error of astrophysical ν_μ above 100 TeV observed by IceCube; 3 of them are extreme Blazars.
- If we follow the lepto-handronic scenario, connecting 100 TeV-1PeV neutrinos with 10-100 GeV photons, TXS0506+056 seems to be a special case, for the moment, with the September 2017 event.
- In this multi-messenger context (ν - ♉), considering the maximal luminosity of the selected sample of blazars, the minimal flare duration should be of months.
- If we look for a multi-messenger observation, like the case of IC170922 and the flaring gamma-ray of TXS 0506+056 the preferential way to obtain more than 3σ is to have multi Km^3 detectors around the world.