ANTARES search for high-energy neutrinos from TeV-emitting blazars, Markarian 421 and 501, in coincidence with HAWC gamma-ray flares

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on behalf of the ANTARES and HAWC Collaborations

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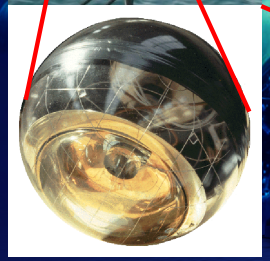
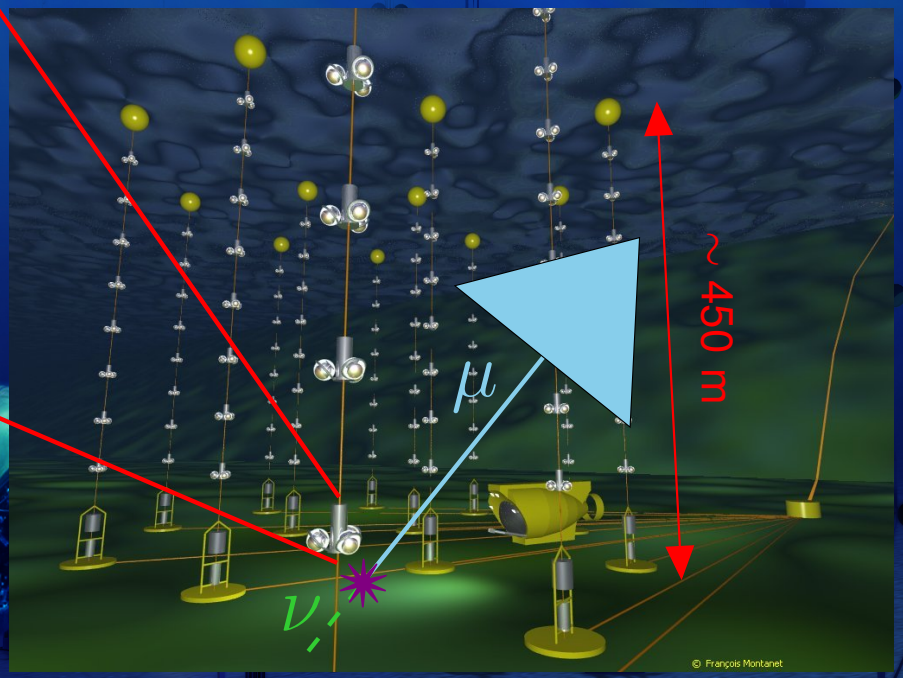
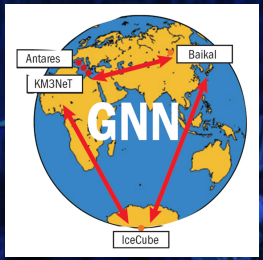
The ANTARES neutrino telescope

ANTARES in numbers :

- Water Cherenkov detector, $\sim$0.1 km^3
- 40 km offshore Toulon, France
- 2475 m depth in Mediterranean Sea
- 2007 $\rightarrow$ start of operation
- 3D array of 885 PMTs
- 12 vertical detection lines
- 25 storeys per line
- 3 10”-inch PMTs per storey







Data set

The ANTARES data set :

$\hookrightarrow$ Covers the same period as HAWC.

Mrk 421 : Nov 27th, 2014 - Jan 01st, 2018 with LT : $\sim$1100 **days**

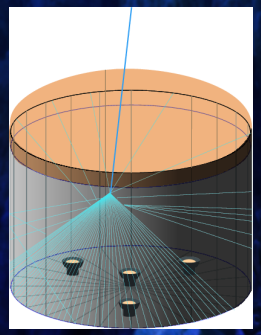
Mrk 501 : Nov 27th, 2014 - Jun 28th, 2016 with LT : $\sim$562 **days** (trimmed)

Track-like event signatures $\Longrightarrow$ only CC interactions of muon neutrinos are considered.

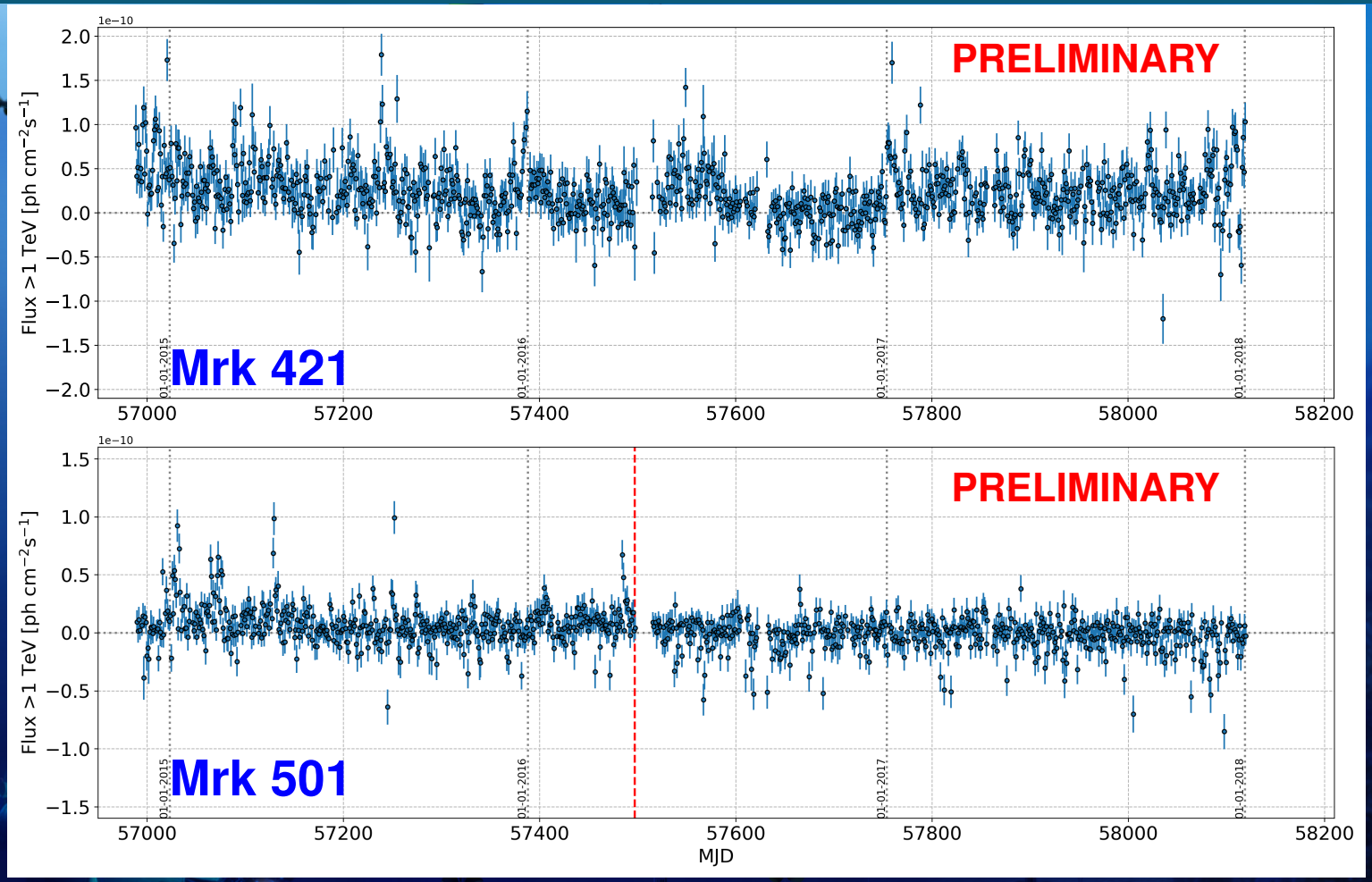
Visible sky

ANTARES : $\delta \in [-90°; +53°]$ HAWC : $\delta \in [-26°; +64°]$

- Water Cerenkov detector ($\sim$0.022 km^2)
- 300 WCDs
- 4 PMTs per tank (3$\times$8" + 1$\times$10")
- 4100 m a.s.l. in the Sierra Negra, Mexico.
- 2015 $\rightarrow$ completed



HAWC data



- The precise shape of the signal time PDF (assumed to have a square shape) is extracted directly for the γ-ray LC assuming the proportionality between γ-ray and ν fluxes.
- **Bayesian blocks algorithm** : used to determine the periods of interest for coincident ν search. The red dashed line : the date outside of which there is no activity found $\rightarrow$ the data is not used.

Performance

Physics goal :

- Search for ν/γ time correlation using flares from blazars, **Mrk 421** and **Mrk 501**
- Correlation between ν and γ-rays emissions is assumed (same LCs)
- Time information from the flares improves the analysis restricting the data to period of interest and hence reducing the background.
- A hybrid analysis between point source (no time information) and time-dependent analysis (with time information from flares, important on short timescales)

Mixture : **S**+**B**

2-component parametrization with **S**$\rightarrow$0 $\Rightarrow$ full data sample as **B**.

Likelihood :

$$\ln(\mathrm{L}) = \sum_{i=1}^{N} \ln\Big[N_S \cdot P_S(x) + N_B \cdot P_B(x)\Big] - \Big[N_S + N_B\Big]$$

N_S is fitted by maximizing the likelihood L

S : $P_S(x) = \underline{P_S(\alpha)} \cdot \underline{P_S(E)} \cdot \underline{P_S(t)}$

B : $P_B(x) = \underline{P_B(\sin(\delta))} \cdot \underline{P_B(E)} \cdot \underline{P_B(t)}$

Terms : spatial, energy, time

Results

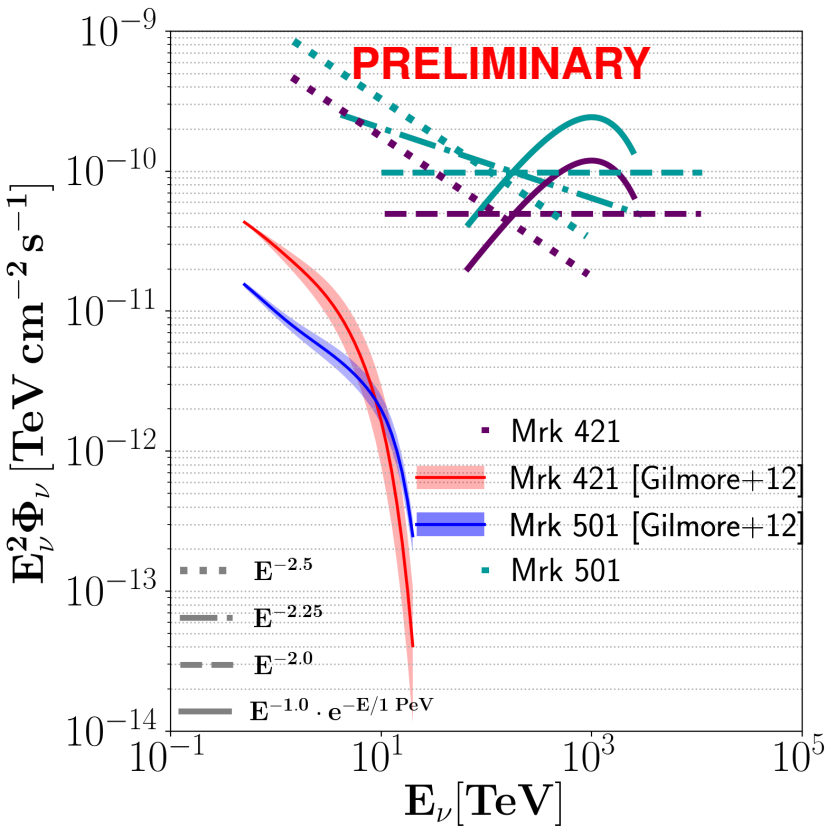
No significant excess found in this search

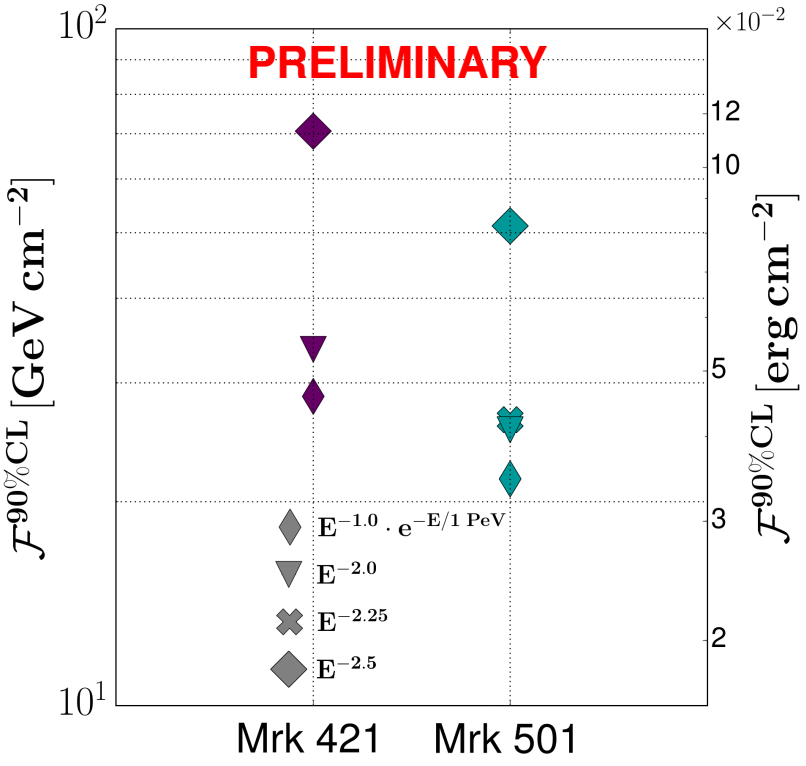
$\Longrightarrow$ **UL @ 90%CL are set**

Those with p-value<0.5 :

- **Mrk 421** : $p = 0.40$ ($\sim 0.8\sigma$), post-trial 0.59, $\hat{\mathbf{n}}_s$ **= 0.00**
  with case of short high peaks selected
  with $E^{-1} \cdot e^{-E/1PeV}$ spectrum.
- **Mrk 501** : $p = 0.43$ ($\sim 0.8\sigma$), post-trial 0.63, $\hat{\mathbf{n}}_s$ **= 0.00**
  with case of short high peaks selected
  with E^{-2} spectrum.

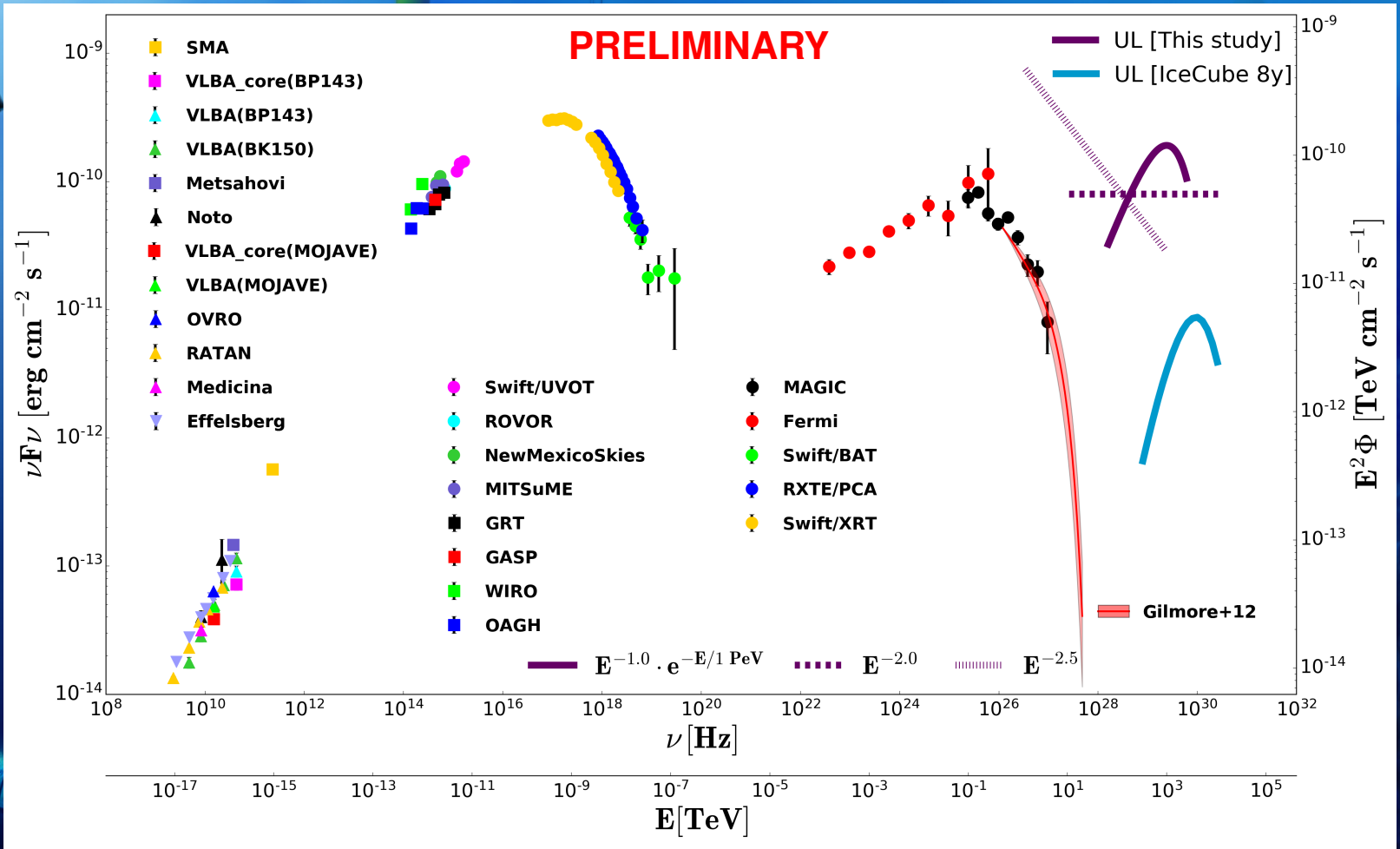
Upper limits





- The best 90% CL flux ULs : obtained with the case of all flare states selected.
- The best 90% CL fluence ULs : obtained with *average flux+2σ* threshold.
- The attenuated flux† with intrinsic spectrum§ obtained in HAWC††.
  §Credit : S. Coutiño de León. †Model : Gilmore et al., MNRAS (2012) ; ††PoS(ICRC2019)654.

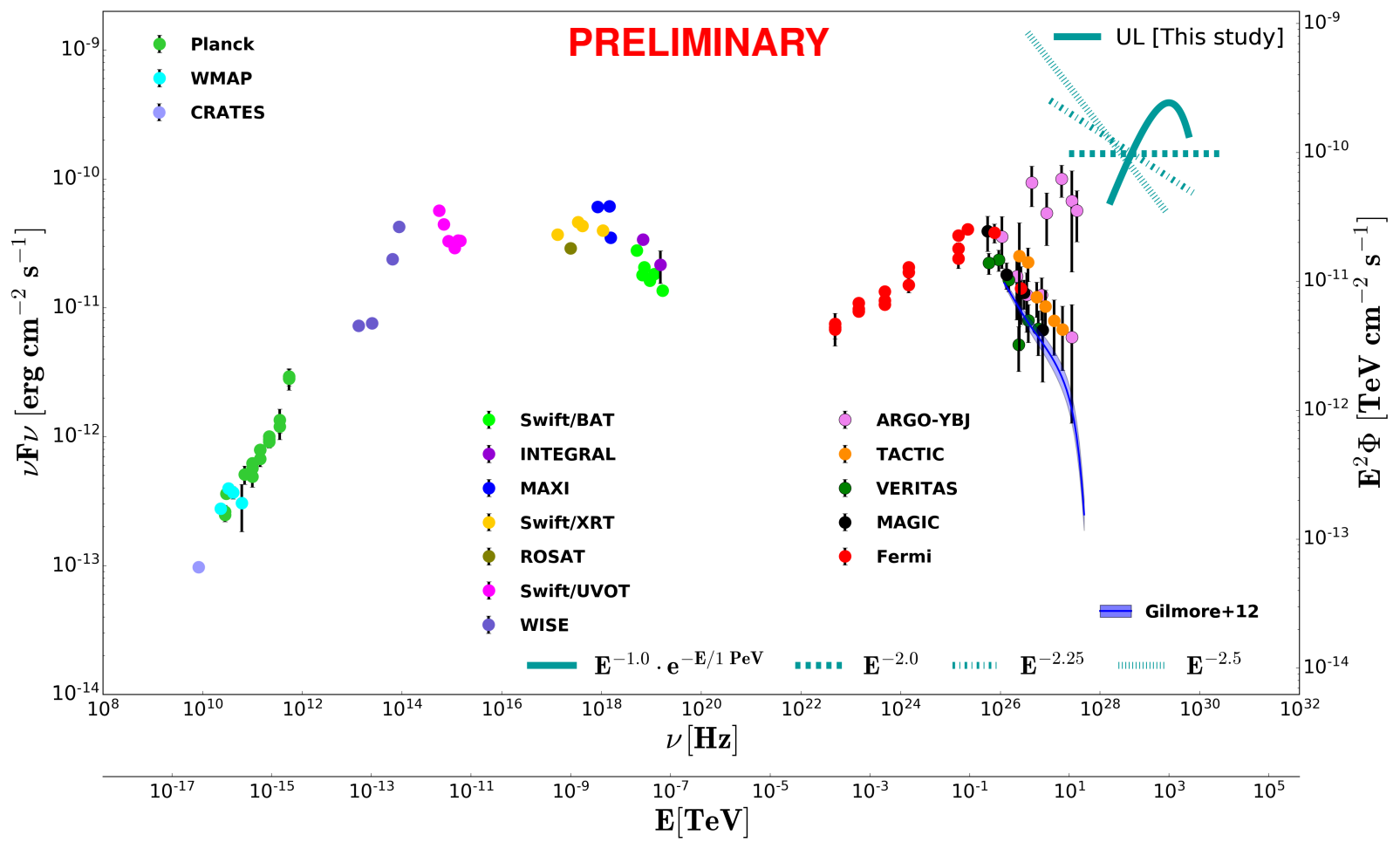
Neutrino flux ULs vs γ-ray SED[1] of Mrk 421



The IceCube 8y search† UL§ is with the default spectrum†† for non-flaring (quiescence) period.
§Credit : René Reimann. †Aartsen et al., EPJ (2019) ; ††Petropoulou et al., MNRAS (2015).

1. Taken during MW2009 campaign. Adapted from Abdo et al, 2011, ApJ 736, 131. Credit : David Paneque.

Neutrino flux ULs vs γ-ray SED [2] of Mrk 501



2. Build with SED Builder Tool of the ASI SSDC. For references see : PoS(ICRC2019)972

Conclusion

Summary

- No significant excess found in this search
- Upper limits on neutrino flux is set
- Upper limits on neutrino fluence is set

Outlook

- Search for ν from blazars with KM3NeT
  - multi-km^2 size
  - better sensitivity
  - better angular resolution

see ANTARES/KM3NeT Highlight talk (H15)

PoS(ICRC2019)006 **11:30, July 30**