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

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Abstract

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Abstract

An updated analysis of a targeted search for high-energy neutrinos from Markarian 421 and Markarian 501 is reported. They are two of the closest and brightest extragalactic sources in the TeV band. In contrast to other types of active galactic nuclei (AGN), BL Lacs are characterized by rapid and large-amplitude flux variability. Such radio-loud AGNs are candidate sources of the observed high-energy cosmic rays. Because their jet is collimated to our line of sight, the hadronic interactions with the surrounding medium can produce an accompanying neutrino and gamma-ray flux. The recent detection of high-energy neutrinos from the direction of TXS 0506+056 motivates a search for high-energy neutrinos from blazars with enhanced gamma-ray activity.

These two targeted blazars are subject of long-term monitoring campaigns by the HAWC TeV gamma-ray observatory located in Mexico. ANTARES is a high-energy neutrino telescope located in the Northern Hemisphere, in the Mediterranean Sea.

This contribution presents the latest results of a search and extends previously presented results to a longer period that covers ANTARES data collected between November 2014 and December 2017. The gamma-ray light curves for each source were used to search for temporally correlated neutrinos, potentially produced in hadronic processes.

Principle of the analysis

Physics goal :

- Search for ν/γ time correlation using flares from blazars, **Mrk 421** and **Mrk 501**, visible by the High-Altitude Water Cherenkov Observatory (HAWC).
- Time information from the flares improves the analysis restricting the data to period of interest and hence reducing the background. Correlation between neutrinos and gamma-rays emissions is assumed (same light curves).
- 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 :

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

- **S :** $P_S(x) = \underline{P_S(\alpha)} \cdot \underline{P_S(E)} \cdot \underline{P_S(t)}$ Terms : spatial, energy, time
- **B :** $P_B(x) = \underline{P_B(\sin(\delta))} \cdot \underline{P_B(E)} \cdot \underline{P_B(t)}$

DATA/MC set

The ANTARES data set period (covers the same period as HAWC) :

- Mrk 421 : 27/11/2014 - 01/01/2018 [56988-58119] LT : 1099.93 days [3.009 y]
- Mrk 501 : 28/11/2014 - 28/06/2016 [56989-57567] LT : 561.55 days [1.537 y]

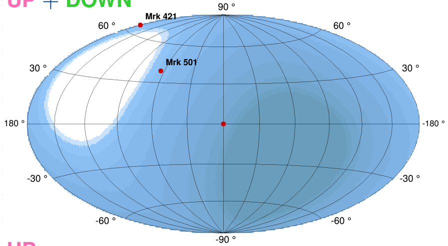
Track-like event signatures $\Longrightarrow$ only CC interactions of muon neutrinos are considered.

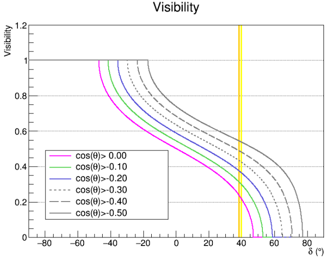
Parameters and cuts

- 1.1 Considered spectra
  - $E^{-\gamma}\, exp(-E/E_{cut})$ with $\gamma = 1.0$ and cutoff @ 1 PeV for both sources
  - $E^{-\gamma}$ with $\gamma = 2.0, 2.5$ for both sources $\gamma = 2.25$ for Mrk 501 only [1]
- 1.2 Considered flares [2] :
  - all flare blocks and high peaks with flares which pass *average* $+ 2\sigma$ threshold
- 1.3 Considered cuts :
  - Few cuts on track reconstruction quality parameter.
    The cut on track quality parameters is optimised for each source on the basis of maximizing a model discovery potential (MDP) for $3\sigma/5\sigma$ significance for each neutrino spectrum
  - One cut on the reconstructed zenith angle θ.
    The cos(θ)>0 keeps only up-going events, thus it's considered to accept a bit down-going events as long as the DATA/MC agreement remains good. Thus, cos(θ)>-0.1 cut as that fulfill the conditions is selected. It provides a gain in the visibility $\sim$ 13% for both sources ($\delta \sim 39^\circ$)
  - One cut on angular error estimate β : $\beta < 1.0^\circ$

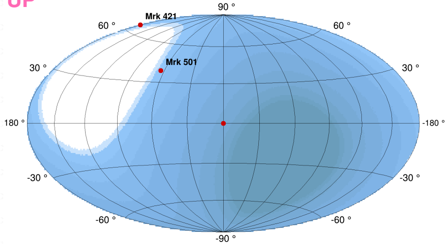
ANTARES Visibility

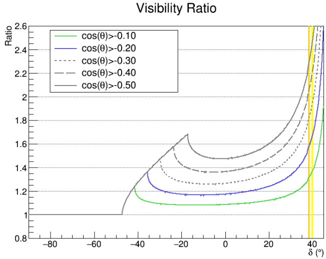
UP + DOWN



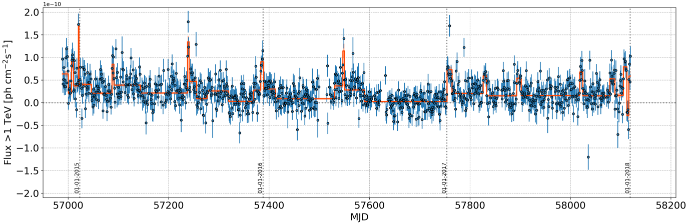


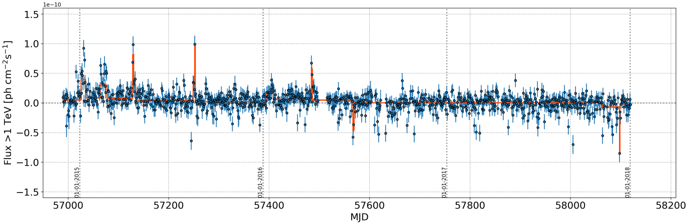
UP





Bayesian Blocks [3] [4] for Mrk 421$^{\mathrm{u}}$ and Mrk 501$^{\mathrm{d}}$

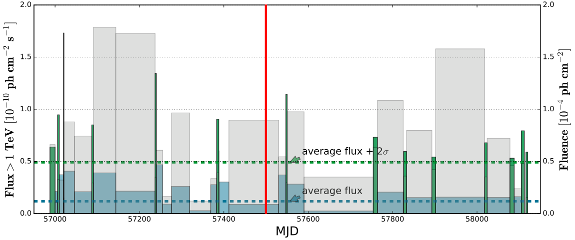


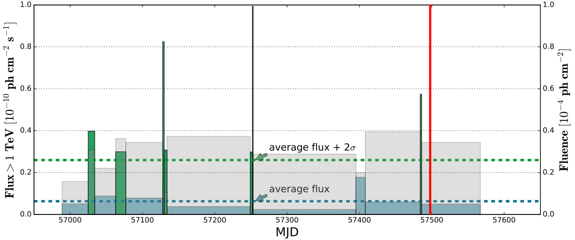


3. Raw-data LCs granted by HAWC is used. The HAWC's Bayesian blocks algorithm applied, $\mathrm{ncp_{prior}} = 6$ is taken as suggested in 17-month monitoring paper Abeysekara et al., Astroph.J. 841 (2017) no.2, 100.

4. This analysis extends the last analysis 27/11/2014-19/04/2016 (sensitivities @ NEUTRINO2018) with flare blocks from 17-month monitoring paper Abeysekara et al., Astroph.J. 841 (2017) no.2, 100 up to 01/01/2018

Final time PDFs[5] [6] for Mrk 421[u] and Mrk 501[d]





5. Red line shows the edge of the analysis with flare states from Abeysekara et al., Astroph.J. 841 (2017) no.2, 100
6. Green color shows case of high peaks with flares which pass *average* $+ 2\sigma$ threshold

Results

No significant excess found $\rightarrow$ UL @90%CL are set

Those with p-value<0.5 :

- p=0.40, post-trial 0.59 for Mrk 421 with $E^{-1} \cdot e^{-E/1PeV}$ | $\Lambda > -5.2$ | case of peaks
- p=0.43, post-trial 0.63 for Mrk 421 with E^{-2} | $\Lambda > -5.2$ | case of peaks

Some comparisons :

IceCube :[7]

- Mrk 421 : p-value 34.6%, best-fit $\hat{n}_s = 0.00$ [UL : $5.79 \cdot 10^{-13}$ TeV cm^{-2} s^{-1}
- Mrk 501 : p-value 72.1%, best-fit $\hat{n}_s = 0.00$ [UL : $4.58 \cdot 10^{-13}$ TeV cm^{-2} s^{-1}

ANTARES (for E^{-2})

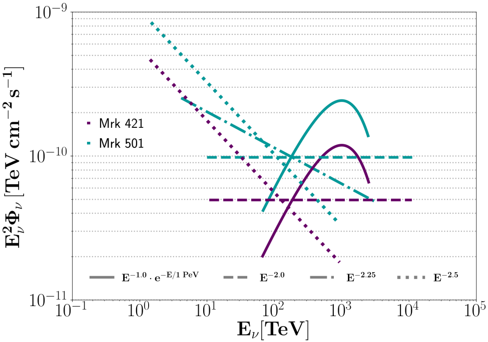
- Mrk 421 : p-value 43.4%, best-fit $\hat{n}_s = 0.00$ [UL : $4.96 \cdot 10^{-11}$ TeV cm^{-2} s^{-1}
- Mrk 501 : p-value 68.2%, best-fit $\hat{n}_s = 0.00$ [UL : $9.79 \cdot 10^{-11}$ TeV cm^{-2} s^{-1}

x100 better UL with usage of x3 times longer period of searches $\rightarrow$ **visibility** is crucial.

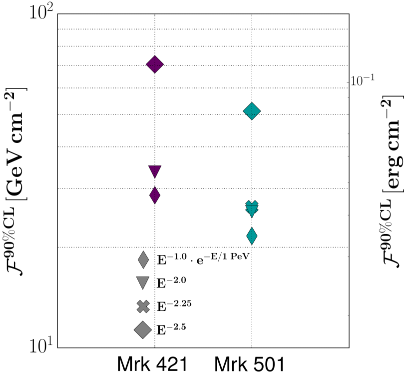
7. In : IceCube with 8 years of data [arXiv:1811.07979]

Upper Limits [8] [9]

Flux

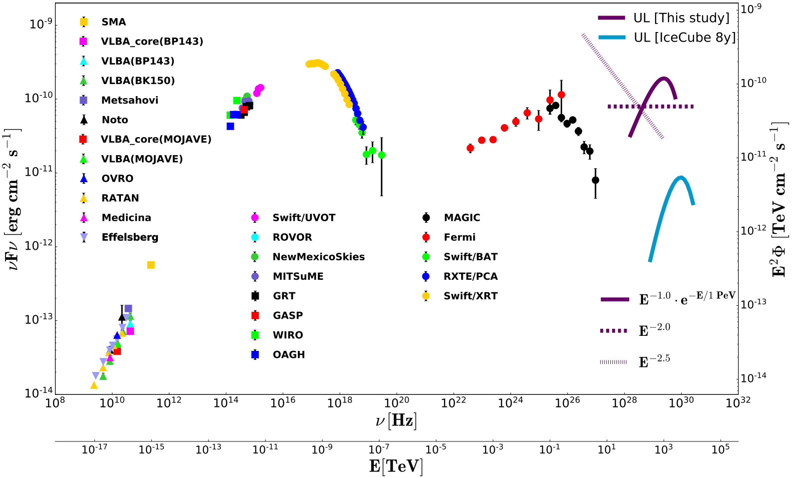


Fluence



8. **UL on flux** : case of all flares
9. **UL on fluence** : case of high peaks.

Upper Limits vs SED [10] : Mrk 421 [11]



10. Adapted from Abdo et al, 2011, ApJ 736, 131. Credit by David Paneque.
11. **HAWC measurement of Mrk 421** to be placed here (**please provide me proper info**)

(∗) Same to be done for Mrk 501

Conclusion

Conclusion

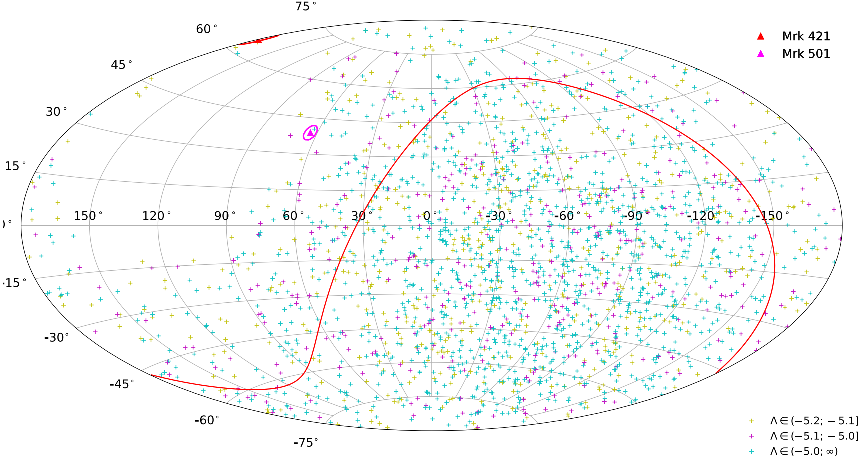
- **HAWC exchange data issue** is needed to be clarified.
- **HAWC measurement of Mrk 421 and Mrk 501** is needed
  please provide me proper info.
  For example the flux measurements at a certain energy (don't have such).
  Or might a data table to reproduce the Fig. 1 / Fig. 2 for Mrk 421 / Mrk 501 in Sara Coutiño de León et al. PoS ICRC2017 (2018) 606
- Thanks for links (if possible) to HAWC proceedings for ICRC2019 before the conference in order to let me use them for referring.

Remarks

- Comments and suggestions are welcome
  before 07/07 -> internal deadline for final version of proceedings.
- The talk is scheduled on 27/07 at 6.15 pm at NU parallel session.

BACKUP

Skymap with events selected for $\Lambda > -5.2$



$N_{ev}(\Lambda > -5.2)$: **2286**