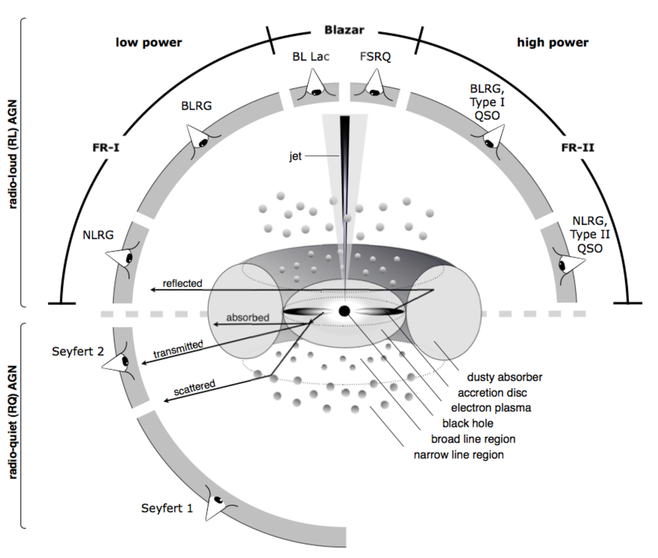
Time-dependent search for neutrino emission from Mrk 421 and Mrk 501 observed by the HAWC gamma-ray observatory with the ANTARES data

Mukharbek Organokov[1], Thierry Pradier[1]
on behalf of the ANTARES Collaboration
[1]Institut Pluridisciplinaire Hubert Curien, CNRS, France
mukharbek.organokov@iphc.cnrs.fr, thierry.pradier@iphc.cnrs.fr

Introduction



The VHE extragalactic sky is dominated by emission from blazars [1], a class of a radio-loud AGN [2]. Two blazars, Mrk 421 and Mrk 501, the brightest and closest BL Lac objects known, at luminosity distances d_L = 134 Mpc with redshift z = 0.031 and d_L = 143 Mpc with redshift z=0.033 respectively, are the first and the second extragalactic objects discovered in the TeV energy band. This analysis focuses on the search of spatial/temporal correlation between neutrinos (ν) detected by ANTARES and γ-ray emission from flares detected by HAWC from these blazars in the period Nov. 2014 - Apr. 2016, and reported in [3].

ANTARES and HAWC

The ANTARES [4] telescope designed to search for high-energy neutrinos (E_ν > 100 GeV) from astrophysical sources by detecting the Cherenkov light emission of neutrino-induced charged particles in the very deep waters of the Mediterranean Sea.
The HAWC [3] telescope was designed to search for high-energy γ-rays (100 GeV < E_γ < 100 TeV) from astrophysical sources by detecting the Cherenkov light emission of gamma-ray-induced charged particles in extensive air showers.

The ANTARES data sample:

Covered period: November 26th, 2014 - April 20th, 2016 (MJD: 56988-57497)
Effective detector livetime: 503.7 days, covers same period of observation as HAWC.

Time-dependent search method

- An unbinned likelihood-ratio maximization method [5, 6, 7]:
  For a given direction in the sky and at a given time to determine the relative contribution of background and signal components.

$$\ln(L) = \left(\sum_{i=1}^{N} \ln[N_S S_i + N_B B_i] \right) - [N_S + N_B] \quad (1)$$

→ S_i and B_i: signal and background PDFs for an event i, at time t_i, energy, declination δ_i:
  * S_i: $P_s(\alpha) \cdot P_s(E) \cdot P_s(t)$
  * B_i: $P_b(\sin(\delta)) \cdot P_b(E) \cdot P_b(t)$

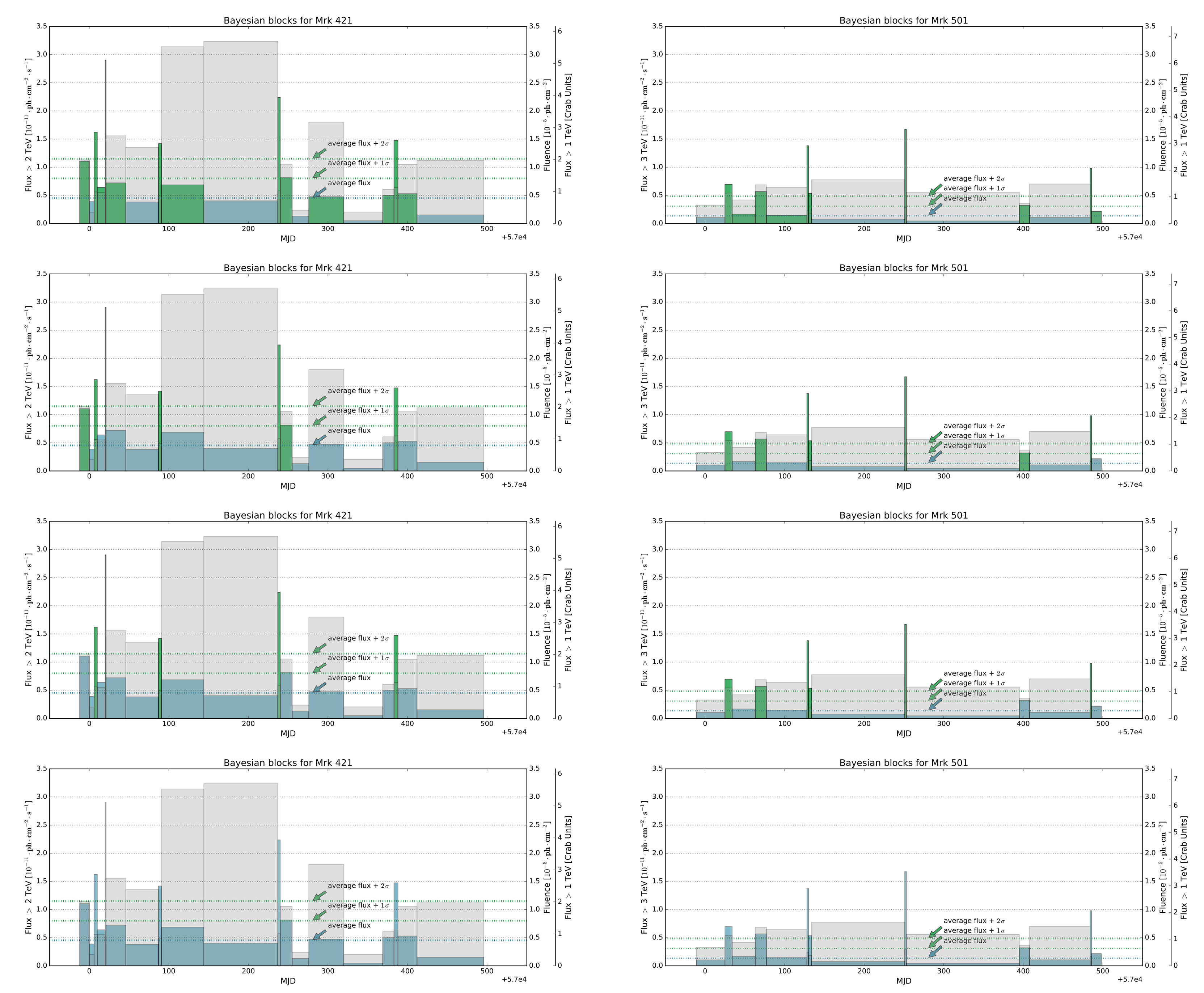
→ N_S and N_B: unknown signal events and known background rate (a priori when building the L)

→ The energy PDF for the signal event is produced according to the studied energy spectra: $E^{-2.0}$, $E^{-2.5}$, $E^{-1.0}\exp(-E/1\,\mathrm{PeV})$ for both sources and extra $E^{-2.25}$ for Mrk 501.

→ The signal time PDF shape is extracted directly from the γ-ray light curve assuming a proportionality between the γ-ray and the ν fluxes. Several flare selection conditions considered: all, pass thresholds: *average flux*, *average flux*+1σ, *average flux*+2σ.

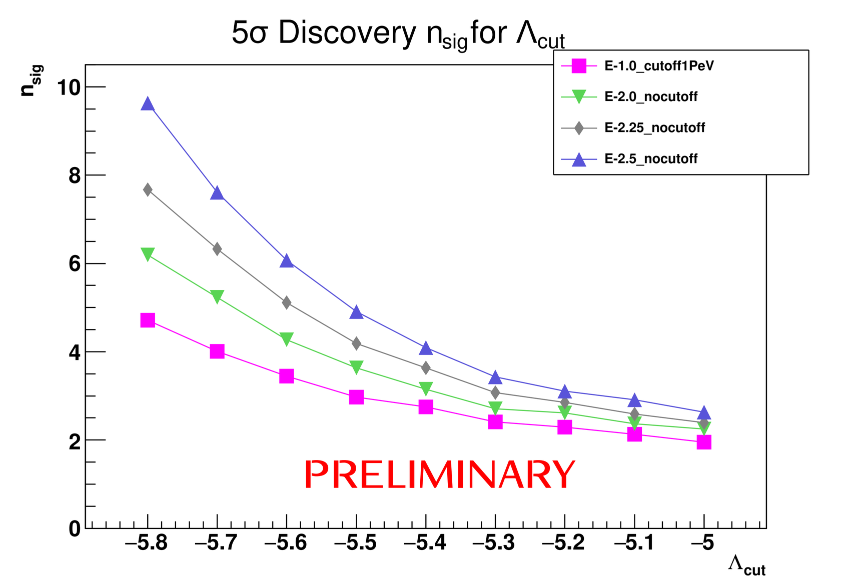
- Test Statistic: $TS = 2(\ln(L^{max}_{s+b}) - \ln(L_b))$
  Evaluated by generating pseudo-experiments simulating background and signal around the considered source. L^{max}_{s+b} is maximized w.r.t. N_S parameter.

Light curves of blazars

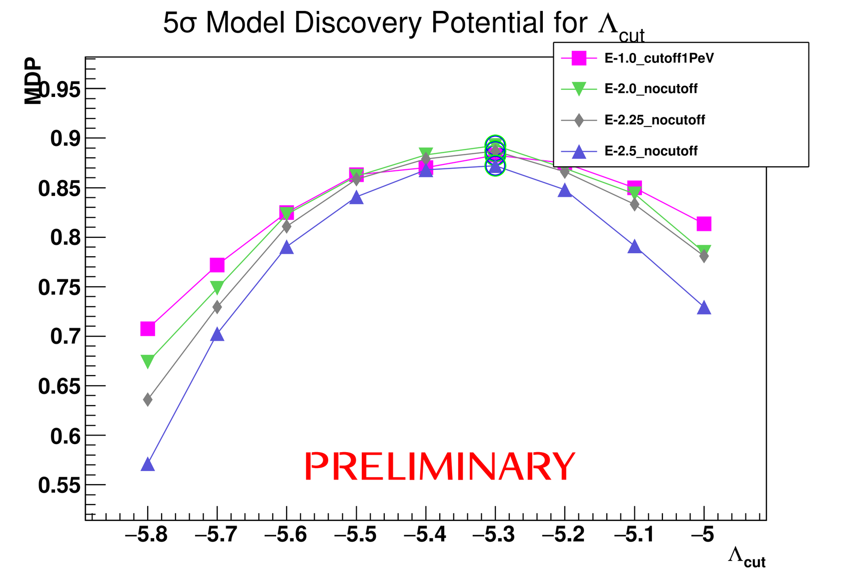


Analysis performance

- Injection of neutrinos ideally only on the selected flare periods ⇒ raise loss of neutrinos, because of the probability to arrive outside this period ⇒ derived N_S required for discovery for the selected peaks is then rescaled as if like neutrinos injected on all flares.
- Conversion $N_S \to F$, the equivalent source flux, is done through the acceptance of the detector.

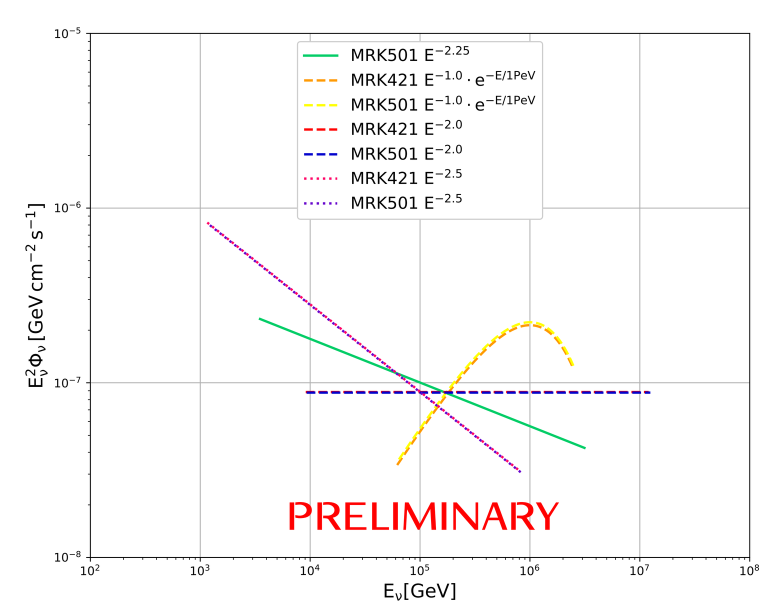


- Cuts:
  - on the cosine of the zenith angle of the reconstructed events $\cos(\theta) > -0.1$
  - on the error on the direction of the reconstructed events $\beta < 1.0°$
- The Λ_{cut} is optimized for each source on the basis of maximizing Model Discovery Potential for 5σ level for each ν spectrum.
- MDP: probability to make a discovery assuming that the model is correct [8].

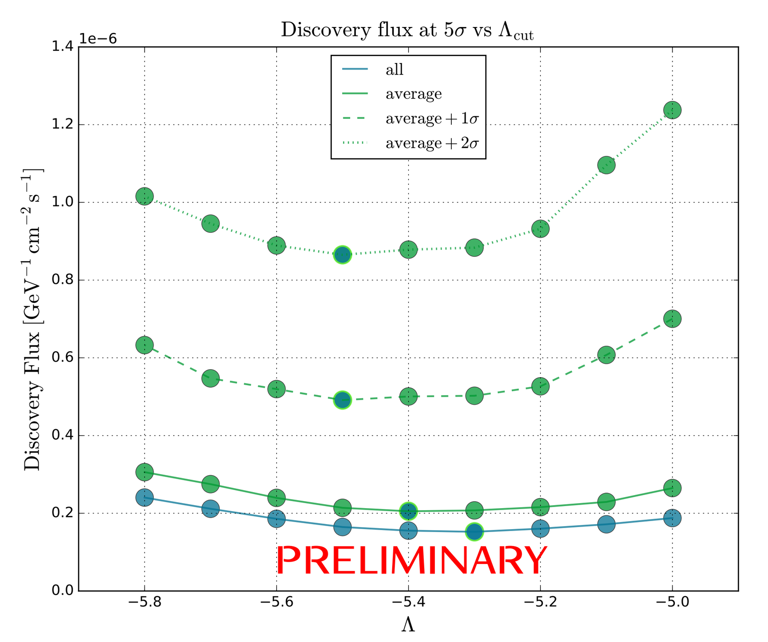


Results

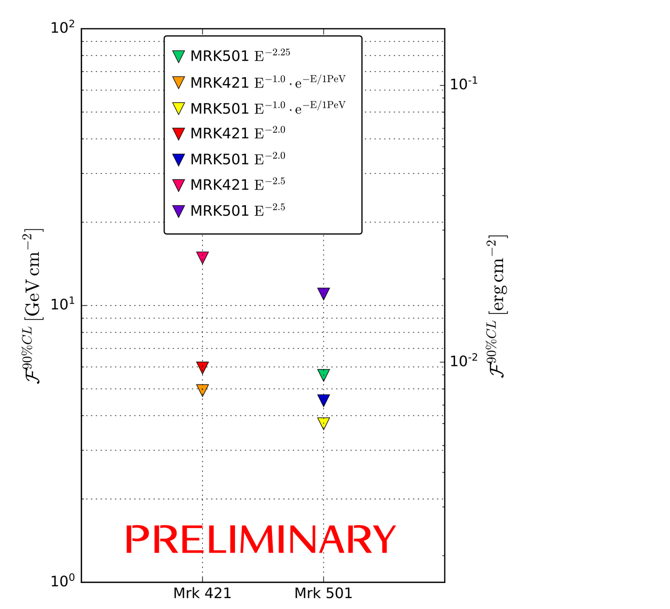
- Neutrino energy flux sensitivities at 90% C.L.



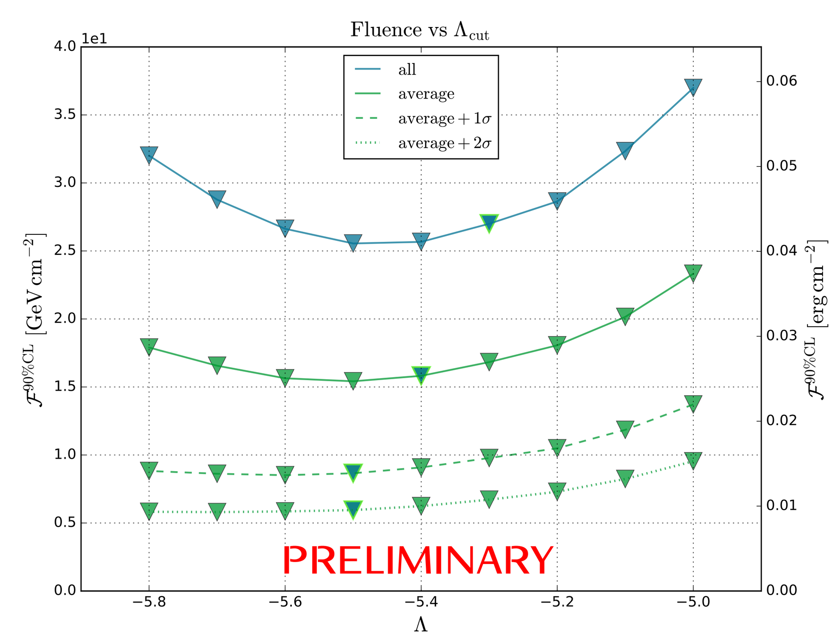
⇒ lowest flux with all flares.
Ex.: Mrk 421 with $E^{-2.0}$.
5σ level discovery fluxes vs threshold vs Λ



- Neutrino fluence sensitivities at 90% C.L.



⇒ lowest fluence with *average flux*+2σ flares.
Ex.: Mrk 421 with $E^{-2.0}$.
90% C.L. fluence sensitivities vs threshold vs Λ



Conclusion

The HAWC detector operates nearly continuously and it is currently the most sensitive wide FOV γ-ray telescope in the very promising HE band ∼ 0.1 and ∼ 100 TeV. Therefore, it opens prospects to study the most energetic astrophysical phenomena in the Universe as well as to understand the mechanisms that power them and endeavor to break the mystery of their origin. Taking into account the flare timing information given by γ-ray observations should improve the efficiency of the search for a ν counterpart with ANTARES. The next generation KM3NeT neutrino telescope [9] will provide more than an order of magnitude improvement in sensitivity [10]; therefore, such sources are promising candidates as HE ν emitters for an improved future time-dependent search.

References

[1] M. Cerruti et al., AIP Conf.Proc. 1792 (2017) no.1, 050029
[2] V. Beckmann and C.R. Shrader., PoS INTEGRAL2012 (2012) [arXiv:1302.1397]
[3] A. Abeysekara et al., Astrophys.J., 841 (2017) no.2, 100
[4] M. Ageron et al. Nucl.Instrum.Meth. A656 (2011) 11-38
[5] S. Adrian-Martinez. et al., JCAP 1512 (2015) no.12, 014
[6] A. Albert et al., JCAP 1704 (2017) no.04, 019
[7] T. Pradier, M. Organokov, A. Sanchez Losa, PoS ICRC 2017, 946, (2017) [arXiv:1711.01486]
[8] S. Adrian-Martinez. et al., Astron.Astrophys. 559 (2013) A9
[9] S. Adrian-Martinez et al., J. Phys. G43 no. 8, (2016) 084001
[10] U. Katz, see talk on Wednesday 6 at 16h20