Search of a neutrino signal with the ANTARES telescope



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Motivation: link CR/v/photon



Hadronic or lepto-hadronic models:

→ CR production associated with electromagnetic emission through the whole energy spectrum

➔ Possible neutrino production (if good environment conditions)

Open question of the jet composition?

- How many reach relativistic energies?
- Which energies do they reach?
- Where are the UHECRs produced?
- Signatures of CRs in blazar SEDs?
- Associated neutrino production ?



ANTARES performances

ANTARES in numbers:

- -12-line data taking since 2008
- o(7000) detected neutrinos
- Angular resolution: 0.3-0.4° (median)
- Effective area: $\approx 1m^2 @ 30 \text{ TeV}$
- Visibility: ³/₄ of the sky, most of the galactic plane
- Real-time data processing





Background suppression



⇒ Atm muons: quite easy to remove (zenith +quality cuts)
⇒ Atm neutrinos: irreducible isotropic background, low energy

Neutrino search method

<u>Neutrino source</u>: quite high energy and sharp directional distribution, possible specific time distribution

=> Search of clusters in space with a high energy content (adding the information of energy allows to gain ~25% discovery potential)



<u>2 types of point-source analysis</u>: - All sky search: significant cluster

 $=> 8-10 \text{ v per source } @ 5\sigma \text{ discovery}$

Candidate list: 50 most promising sources
 => 5-6 ν per source @ 5σ discovery



• Data from 2007-2012 (1338 live days)

• 5516 neutrino candidates (90% reconstructed better than 1 degree)







Name	α (°)	δ (°)	ns	Р	ϕ_{ν}^{90CL}
HESSJ0632+057	98.24	5.81	1.60	0.0012	4.40
HESSJ1741-302	-94.75	-30.20	0.99	0.003	3.23
3C279	-165.95	-5.79	1.11	0.01	3.45
HESSJ1023-575	155.83	-57.76	1.98	0.03	2.01
ESO139-G12	-95.59	-59.94	0.79	0.06	1.82

=> Best limits in the world for many (galactic) source candidates in the Northern hemisphere especially in the <100TeV energy range



(Shower events have low ang. res. - IC does not claim a signal)

Neutrino search method

<u>2 types of point-source analysis</u>:

- All sky search: significant cluster => 8-10 neutrinos per source
- Candidate list: 50 most promising sources => 5-6 neutrinos per source

Adding the time information:

=> 2-3 v per source @ 5σ discov

=> Increase sensitivity by a factor 2-3

=> For a very short transient (GRB), only 1 v per source is sufficient !!!



Time-dependent neutrino searches

Multi-messenger approach: coincidence of gamma and neutrino emission Different transient sources can be analysed:

- *μ*-*quasars*: *galactic variable sources* (*hours months*)
- <u>AGN</u>: extra-galactic variable sources (hours months)
- <u>GRBs</u>: Most energetic events in the Universe (sec min)



Search for v from microquasars

Six micro-quasars with *X*-ray or γ-ray outbursts in the 2007-2010 satellite data:

Circinus X-1, GX339-4, H 1743-322, IGRJ17091-3624, Cygnus X-1, Cygnus X-3

Analysis of the 6 micro-quasars:

- For 4 black hole binaries *v*-search split in two:
 - During hard X-ray states : "slow" steady jet
 - During transition hard \rightarrow soft : "fast" discrete ejection
- Cyg X-3 : γ-ray outburst using Fermi/LAT data
- Cir X-1 : X-rays + orbital phase/jet connection



Search for v from microquasars

No neutrino found in time coincidence with microquasars (813 days) => *Upper-limit on the neutrino flux (F.C. 90%)*



=> Analysis being updated with new data and new X-ray binary sources

Search for v from AGN flares



First analysis: selection of 10 Fermi flaring blazars in 2008: => Astropart. Phys. 36 (2012) 204 Updated analysis: selection of 41 Fermi and 7 TeV sources in 2008-2012: => ICRC 2013 - JCAP in preparation

Search for v from AGN flares



Search for 41 Fermi + 7 TeV blazars:

- \Rightarrow data 2008-2012 (1044 days)
- \Rightarrow 3 sources show a neutrino event in time and space coincidence with flare 3C 279, PKS 1124-186 and PKS 0235-618

Most significant source: 3C 279 for E^{-2} with p-value 1.9% (54% post-trial)



Search for v from GRB

- Selection of 296 GRBs from 2007-2011
- GRBs provided by Swift and Fermi \rightarrow look in right place and time
- Background is very low, estimated from data
- No coincident muons observed \rightarrow limits on neutrino flux
- Moving to real-time search since Summer 2013 (GCN alerts)



=> Expected events: 0.48 (Guetta), 0.061 (NeuCosmA) → 90% C.L. limits (dashed)

Search for v from GRB

Dedicated search for v_µ from GRB130427

Fermi+Swift: z=0.34, T₉₀=163s, Ra,Dec=173.14°,27.70°

Expected signal events: $6.2 \cdot 10^{-3}$ (NeuCosmA), $8.4 \cdot 10^{-2}$ (Guetta 2004)

- → background 10⁻²
- \rightarrow no coincident v_{μ} were found



Stacked search for v_{μ} **associated with GRBs with extended Time Delays** 5516 neutrino candidates from point-source search 07-12 + GRB catalogue Method: *search for spatial coincidences*, collect time delay τ for each spatial coincidence and *investigate distribution of* τ

	all G	RBs	GRBs /w z		
	n _{coinc}	ψ (dB)	n _{coinc}	ψ_z (dB)	$\psi_{ ext{LIV}}$ (dB)
median background	4.4	73.3	0.7	0	0
measurement	0	0	0	0	0
P(bkg > meas)	98.7%	98.7%	48%	48.6%	48.6%

→ no spatial coincident neutrino
 candidate with GRB sample in
 ±40 days

Summary and perspectives

✓ ANTARES : Most sensitive neutrino telsecope in the TeV-PeV range seeing the southern sky

 \Rightarrow No cosmic signal yet (but taking data until end 2016)

 Many coincident searches with other messengers (E.M., G.W., ...) Off-line : GRBs, X-ray binaries, blazars, unknowns
 On-line : optical and gamma follow-up