Transient Point Source Analyses in the ANTARES Neutrino Telescope

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for RICAP-13 on behalf of
the ANTARES Collaboration

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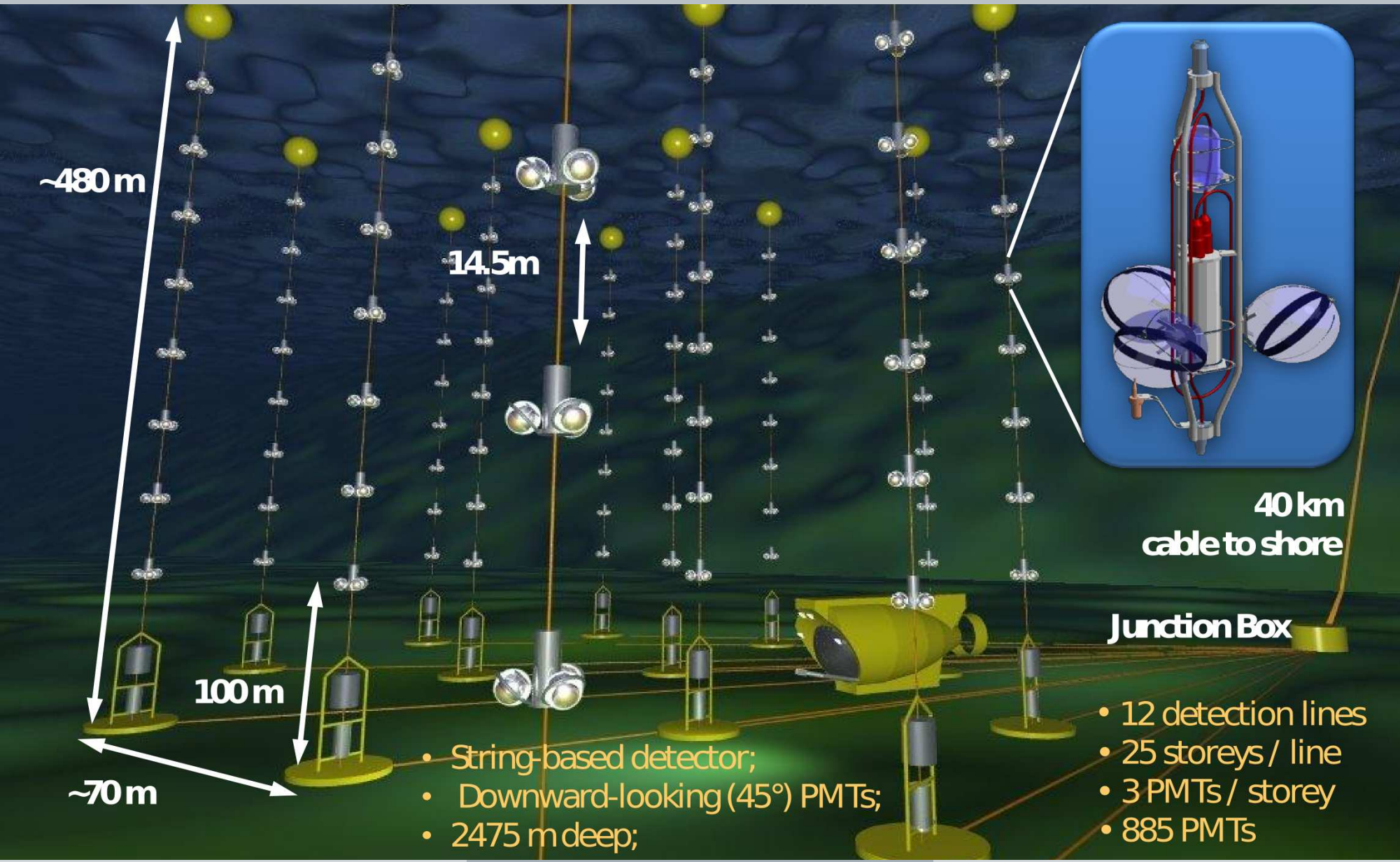
Outline

The ANTARES Neutrino Telescope

The ANTARES Neutrino Telescope

ANTARES is a Neutrino Telescope placed underwater in the sea bed of the Mediterranean Sea at the south of Toulon (France)

The ANTARES Neutrino Telescope

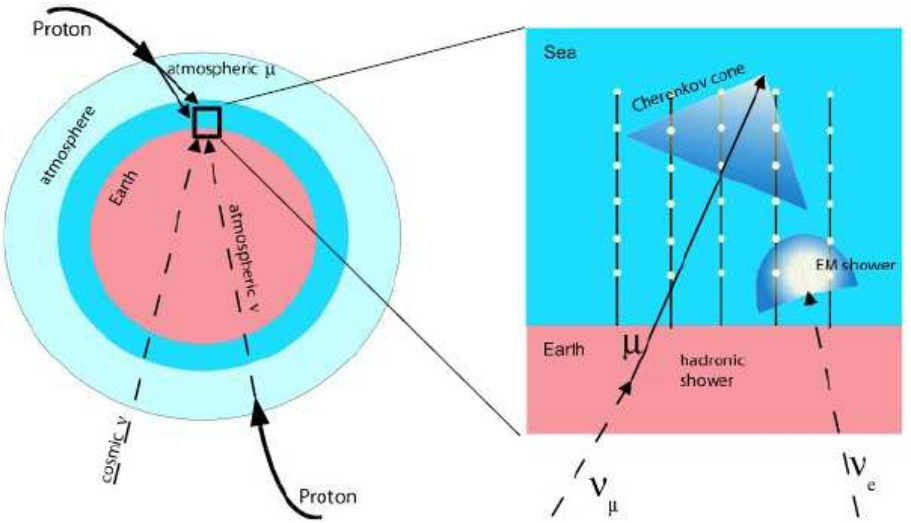


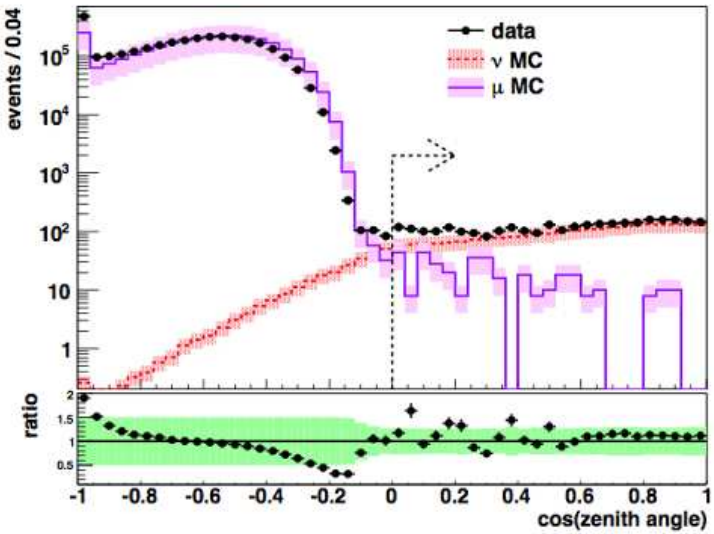
Detection Mechanism

Atmospheric muons ~10 per second

Atmospheric neutrinos few per day

Cosmic neutrinos few per year (may be)

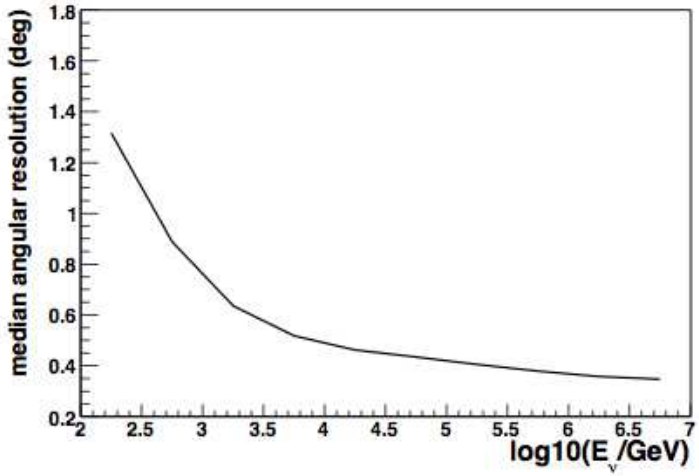


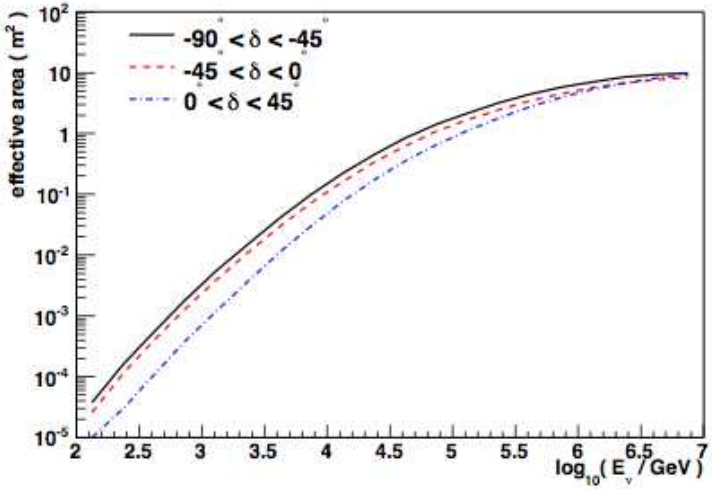


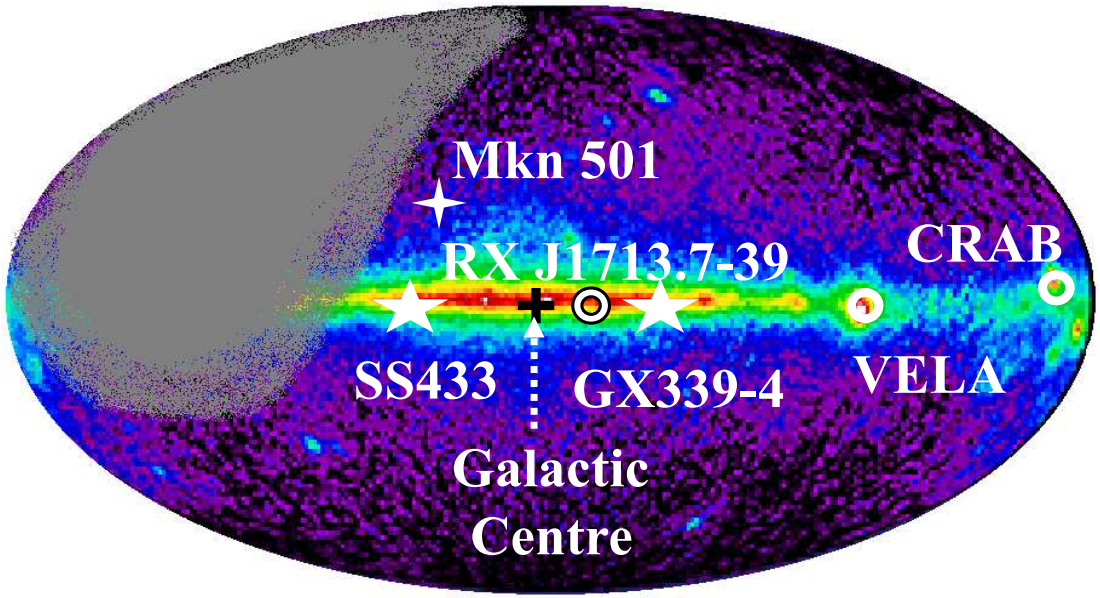
- Atm muons: quite easy to remove (zenith + quality cuts)
- Atm neutrinos: irreducible isotropic background, low energy

ANTARES Performance

- 12-line data taking since 2008
- ∼7000 detected neutrinos
- Median angular resolution 0.3-0.4°above ∼10 TeV
- Effective area ∼1m^2 @30 TeV
- Visibility of $^3/_4$ of the sky, most of the galactic plane
- Real-time data processing

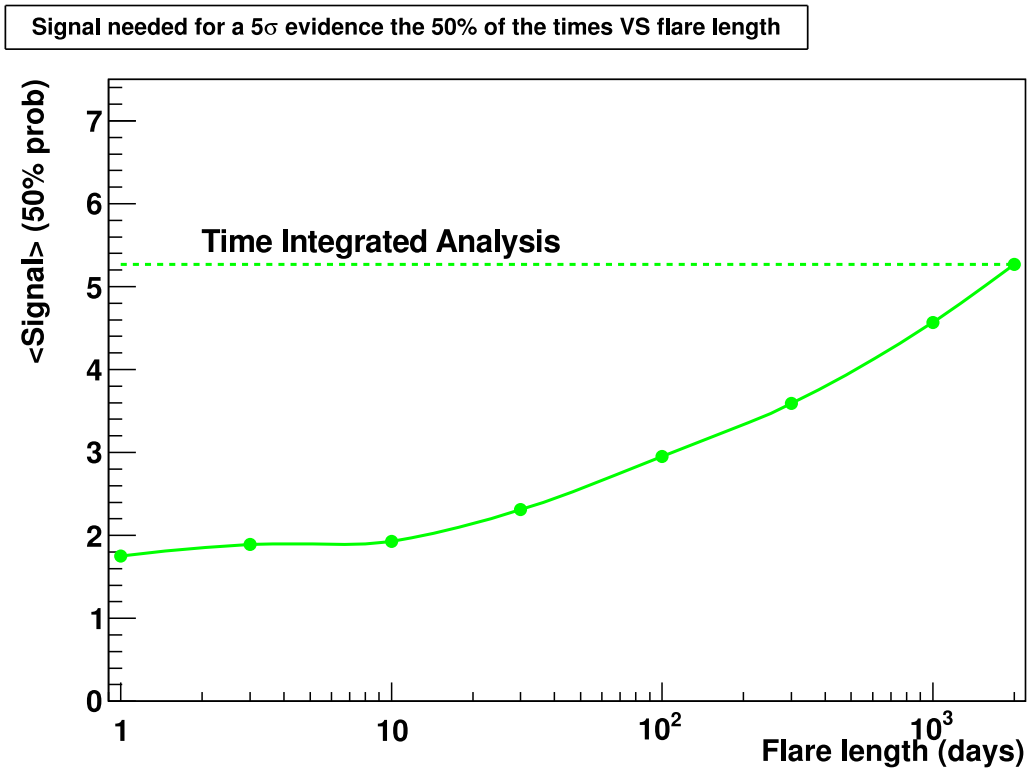






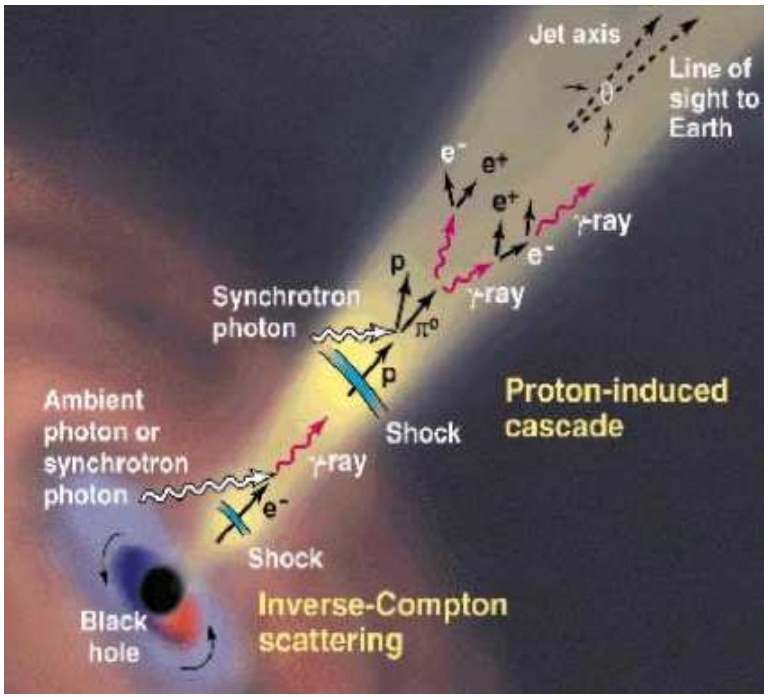
Transient Analyses

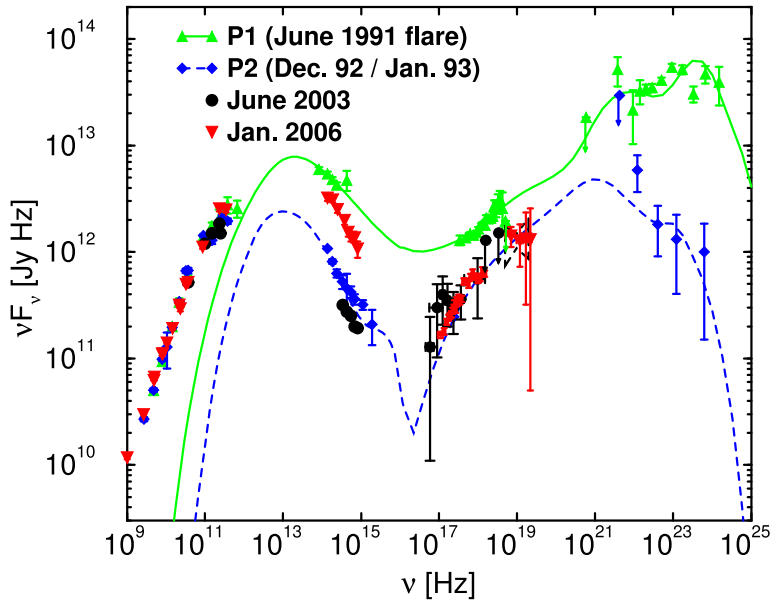
- ANTARES can perform a wide range of analyses
- Point Source analyses: discovering of astrophysical neutrino sources
- **Multi-messenger study**: Variable light emission sources time info as expected time for neutrino signal
- Improved performance with respect to not using time info at all



Transient Physics

- Motivation: link CR/ν/γ via Fermi mechanism
- "Leptonic", "Hadronic" and "Lepto-Hadronic" models
- Open questions over jet composition: relativistic fraction, maximum energies, CRs and UHECRs origin...



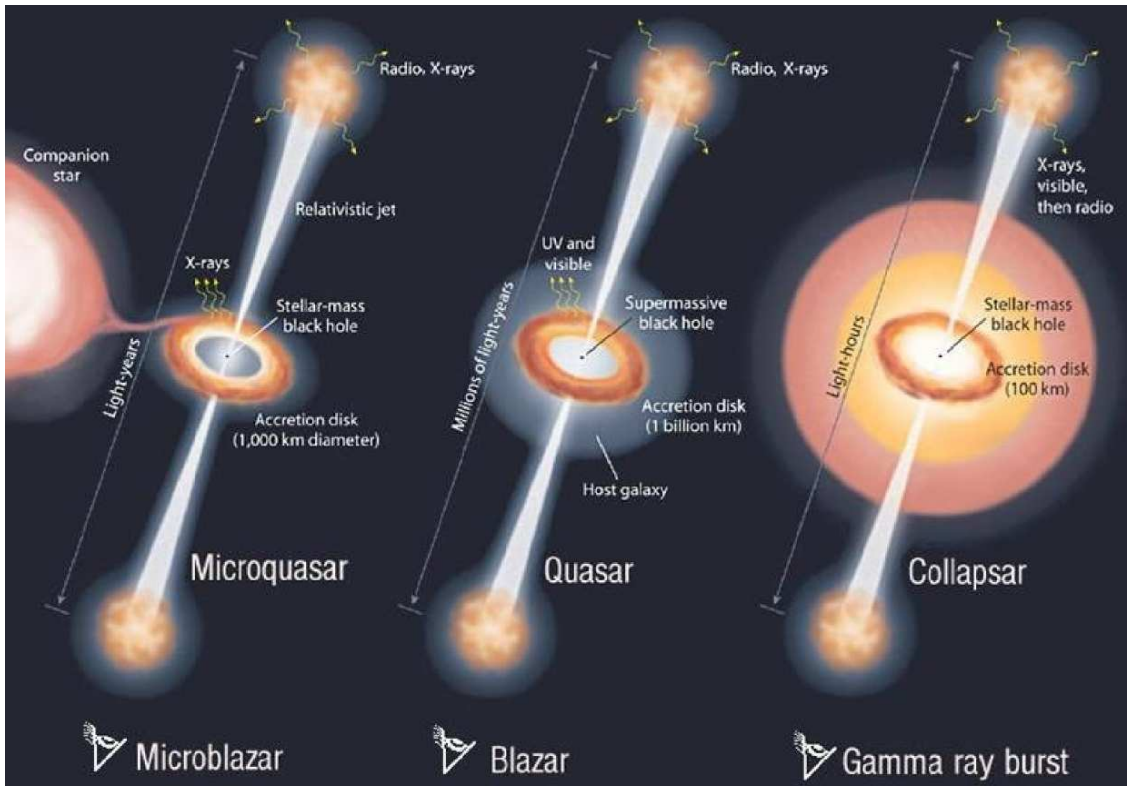


SED sample for Blazar 3C279

Transient Physics

Coincidence of γ and neutrino emission: different transient sources can be analyzed

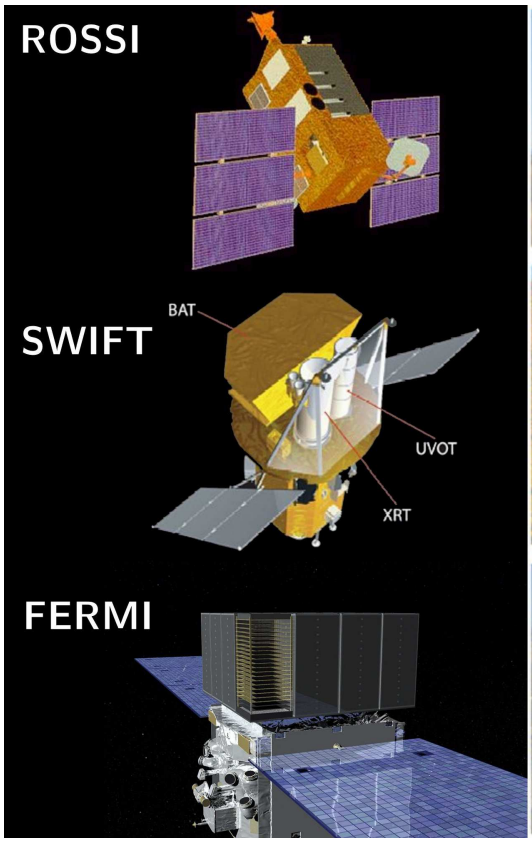
1. GRBs: Most energetic known events in the Universe (sec $\leftrightarrow$ days)
2. μ-quasars: Galactic variable sources (hours $\leftrightarrow$ months)
3. AGNs: Extra-galactic variable sources (hours $\leftrightarrow$ months)



Optical Counterparts

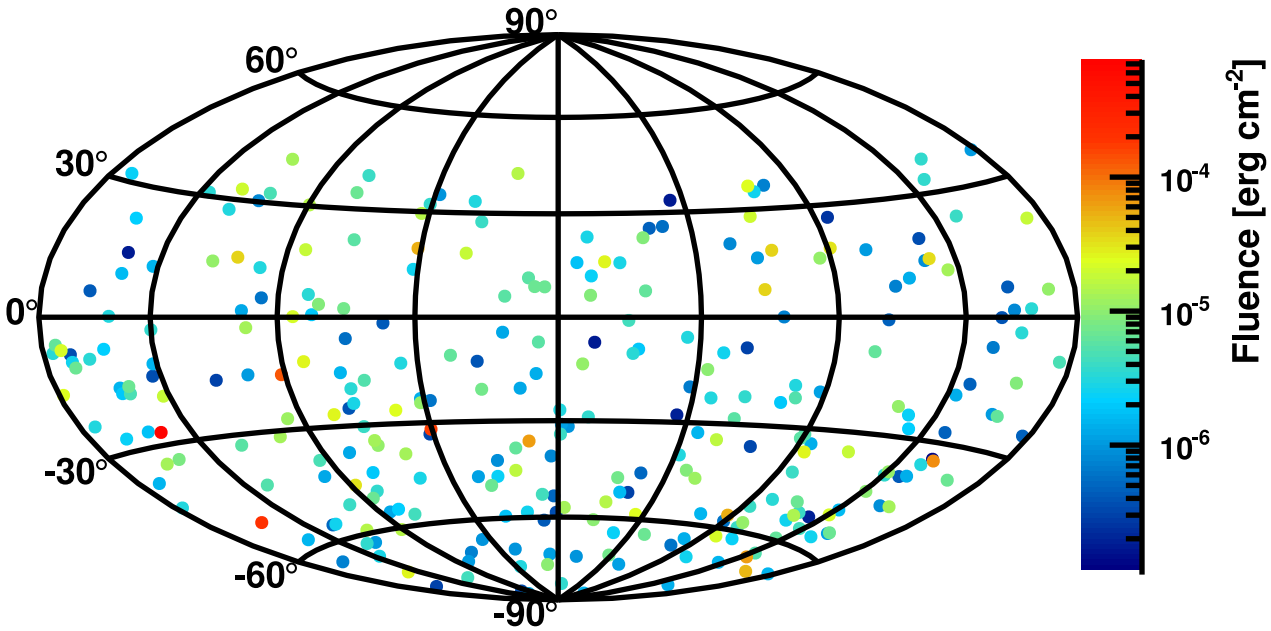
Supported by multi-wavelength telescope observations:

- Satellites: Rossi RXTE/ASM and Swift BAT/XRT for X-Rays and FermiLAT for γ-Rays
- IACT: HESS, MAGIC, VERITAS for HE and UHE γ-Rays



GRB selection

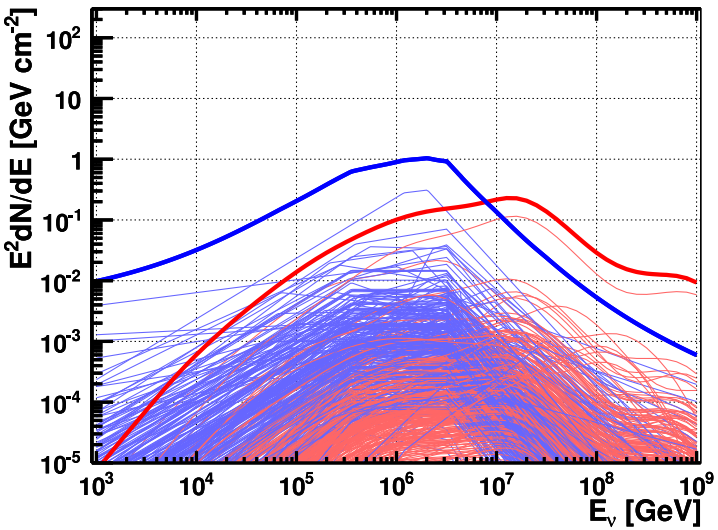
- Stacked GRBs within 2008 – 2011
- Long GRB selection only (short GRB class much less understood)
- 296 long GRBs (6.55 hours)
- Multi-messenger info provided by FERMI, SWIFT and GCN (Gamma-ray Coordinates Network) alerts.



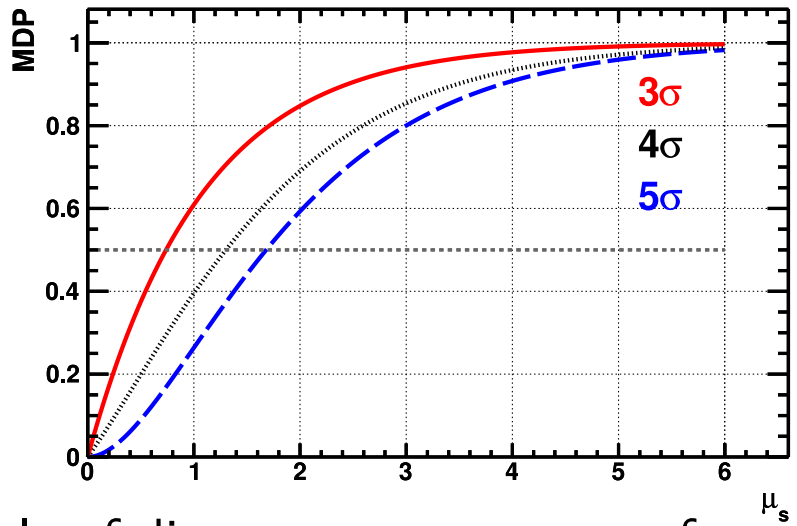
Sky distribution of the selected 296 gamma-ray bursts in equatorial coordinates. The photon fluence of each burst is indicated by the colors

GRB analysis

- Extended Maximum Likelihood search quality cut optimized per GRB highest discovery probability
- GRB simulations of expected neutrino fluence: NeuCosmA [Hümmer et al. (2010)] and Guetta [Guetta et al. (2004)] model spectra
- Quality cut optimized for **NeuCosmA** model



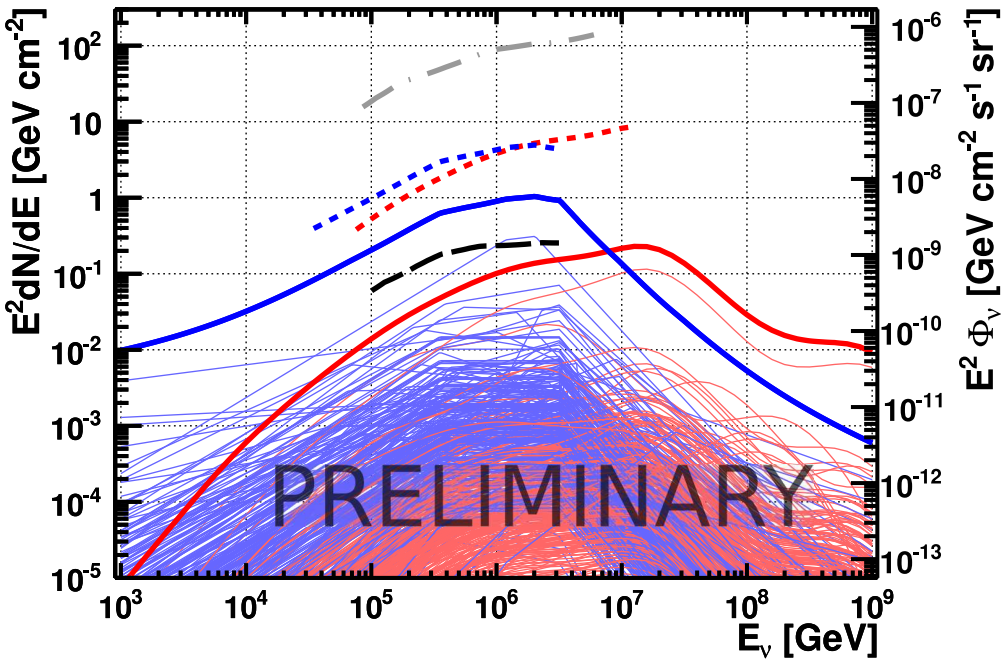
NeuCosmA and Guetta spectra.
Thick: sum of the 297 individual spectra



Sample of discovery power curves for GRB110918

GRB results

- No event found in stacked GRB search windows
- Expected events: 0.48 (Guetta), 0.061 (NeuCosmA), 0.05 (bkg)
- Improvement in ANTARES upper limits with respect previous analysis



Upper limits @90% C.L. (dashed) for Guetta and NeuCosmA
Grey: previous limit, 40 GRBs (Adrián-Martínez et al., 2013 / JCAP 1303 (2013) 006)
Black: IceCube IC40+59 limit, 215 GRBs (Abbasi et al., 2012 / Nature, 484:351-354, 2012)

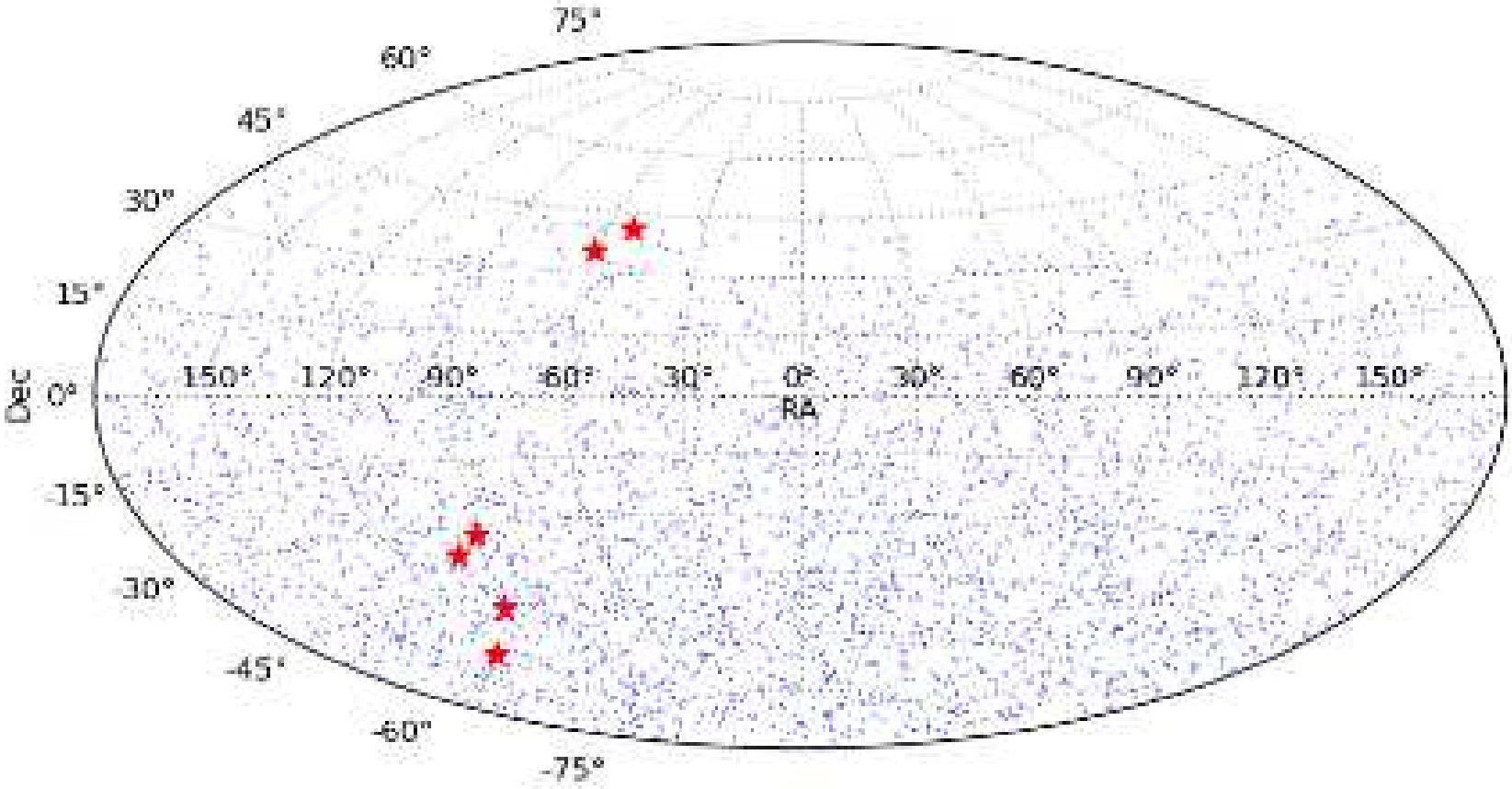
μ-quasar selection

- Six μ-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

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

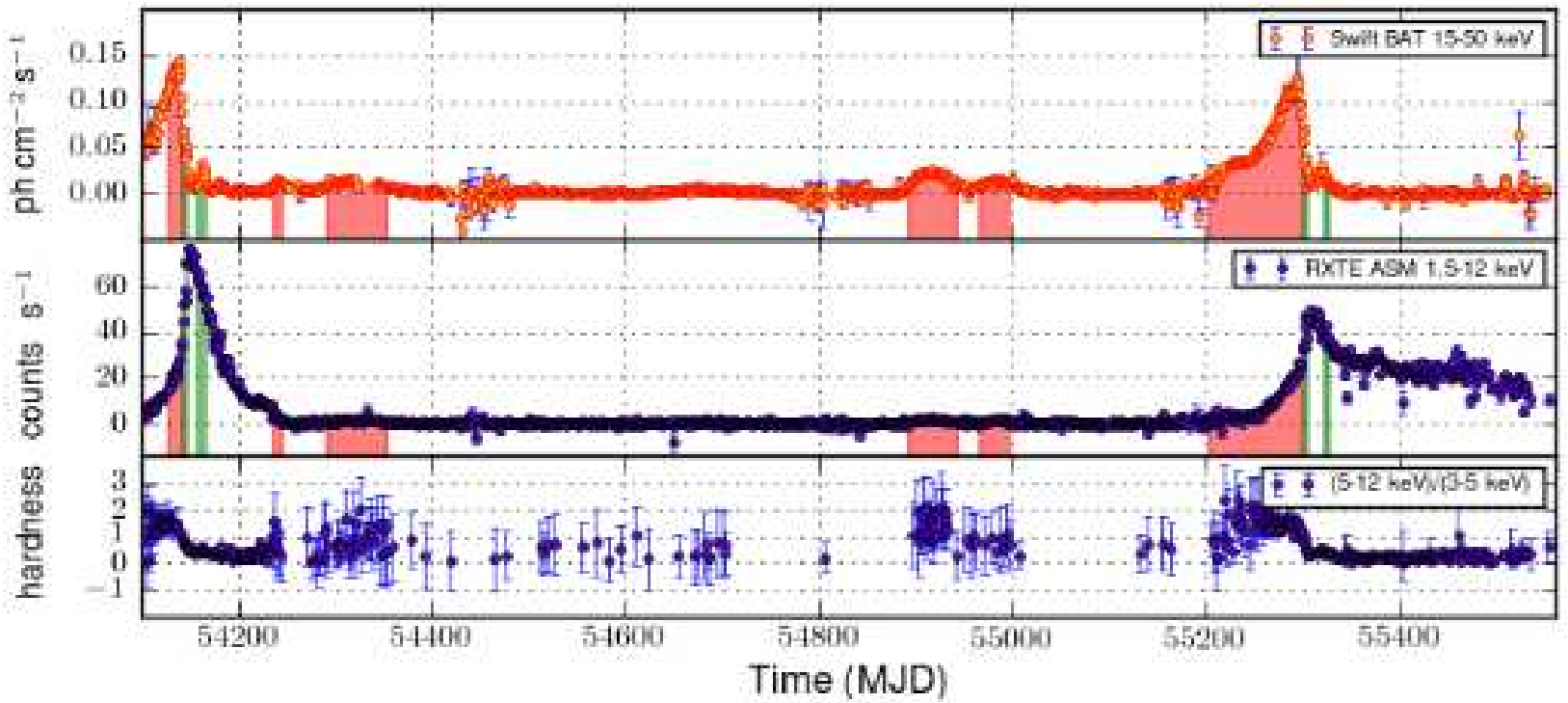
μ-quasar selection



ANTARES skymap for the 3058 neutrino candidates in the case of a $\lambda_{cut} > -5.2$ in equatorial coordinates (ANTARES events and studied μ-quasars)

μ-quasar analysis

- ANTARES data period 2007 - 2010 (813 live time days)
- Multi-messenger info provided by SWIFT, ROSSI and FERMI.
- Optimization cuts selects 3058 neutrino candidates ($\lambda_{cut} > -5.2$) and 5709 neutrino candidates ($\lambda_{cut} > -5.4$)

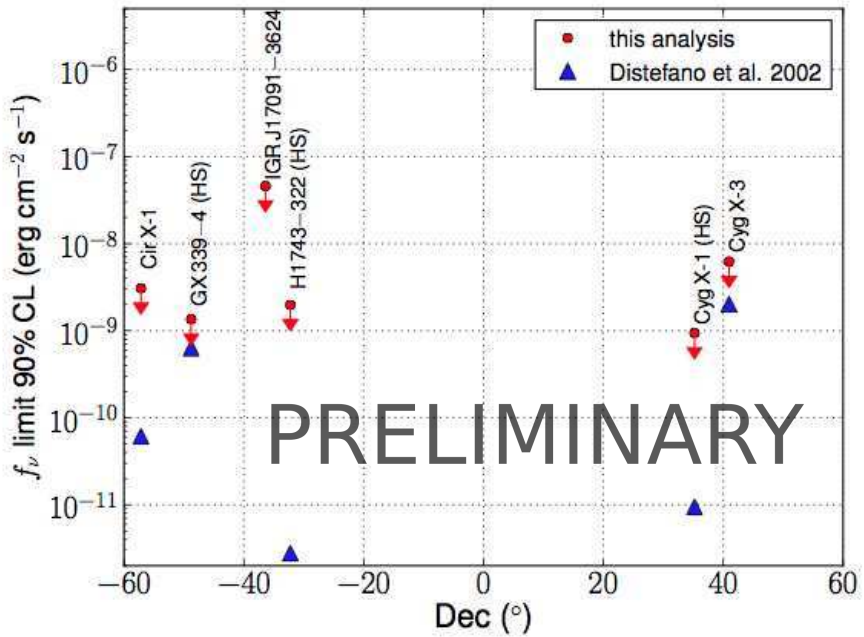


X-ray light curves of GX 339-4 between 2007 and 2010 (hard state and hard to soft transition filled areas)

μ-quasar results

- No neutrino found in time coincidence with μ-quasars
- Upper limits on neutrino flux (F.C. @90% C.L.)

Source	n_{sig}	Livetime (days)	Fluence U.L.$^{90\% C.L.}$
Cir X-1	0	100.5	16.9
GX 339-4 (HS)	0	147.0	10.9
GX 339-4 (TS)	0	4.9	19.7
H1743-322 (HS)	0	84.6	9.1
H1743-322 (TS)	0	3.3	30.3
IGRJ17091-3624	0	8.5	21.3
Cyg X-1 (HS)	0	182.8	14.1
Cyg X-1 (TS)	0	18.5	6.0
Cyg X-3	0	16.6	5.7



Model: Levinson, Waxman (2001), Di Stefano (2002) (ApJ 575, pp. 378-383) assuming a flux $E^{-2} e^{-\sqrt{E/100\text{TeV}}}$

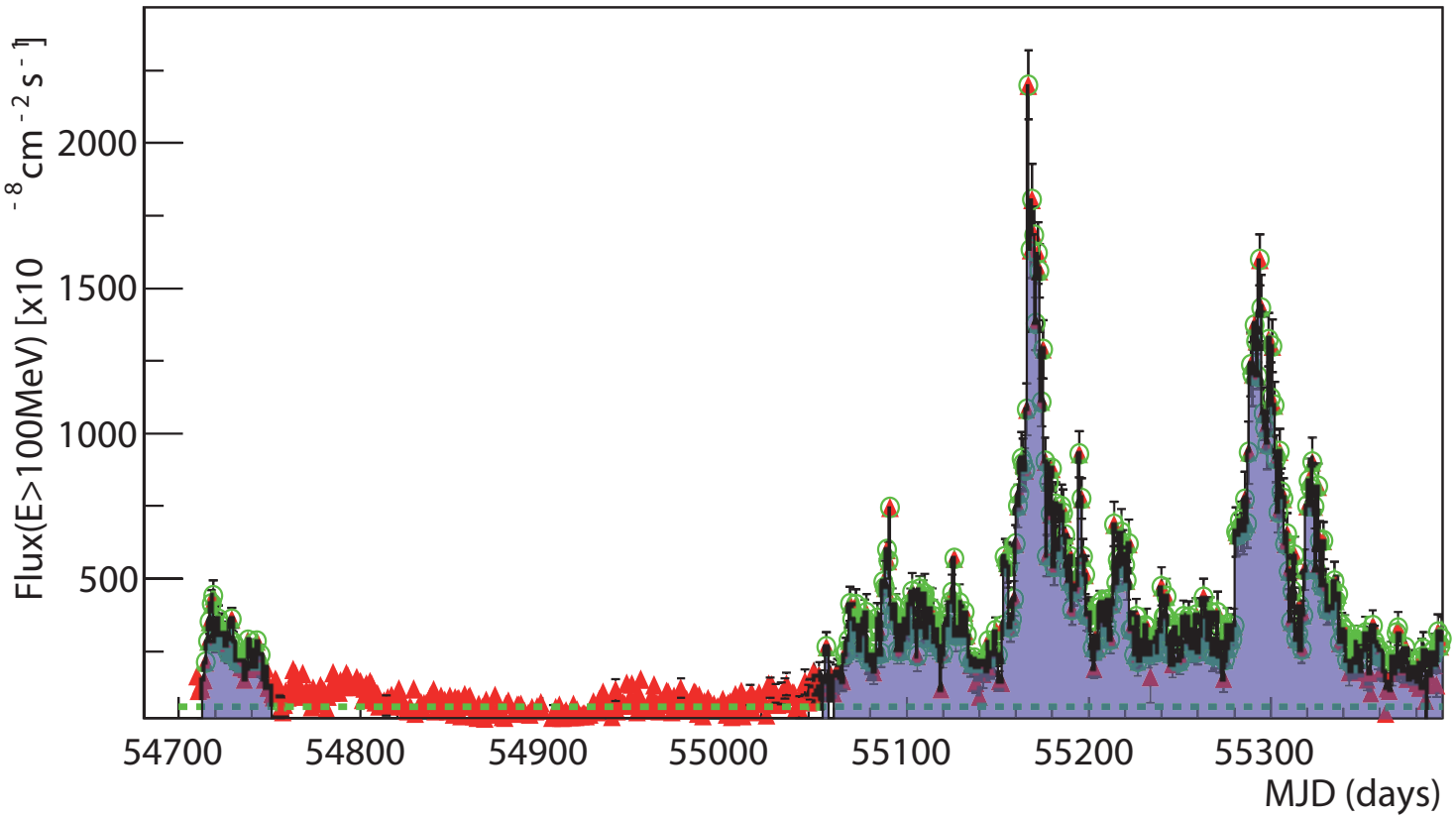
AGN selection

- First AGN ANTARES analysis (Astropart. Phys. 36 (2012) 204)
- High variability, brightness and visibility Fermi blazar sources (reported in 1FGL and LBAS catalogs)

Source	Class	Redshift	Visibility	Livetime (days)
PKS 0208-512	FSRQ	1.003	1.00	8.8
AO 0235+164	BLLac	0.940	0.51	24.5
PKS 0454-234	FSRQ	1.003	0.63	6.0
OJ 287	BLLac	0.306	0.39	4.3
WComae	BLLac	0.102	0.33	3.9
3C 273	FSRQ	0.158	0.49	2.4
3C 279	FSRQ	0.536	0.53	13.8
PKS 1510-089	FSRQ	0.360	0.55	4.9
3C 454.3	FSRQ	0.859	0.41	30.8
PKS 2155-304	BLLac	0.116	0.68	3.1

AGN analysis

- From September 6th to December 31st, 2008 (60.8 hours)
- γ-Ray light curves from FERMI.

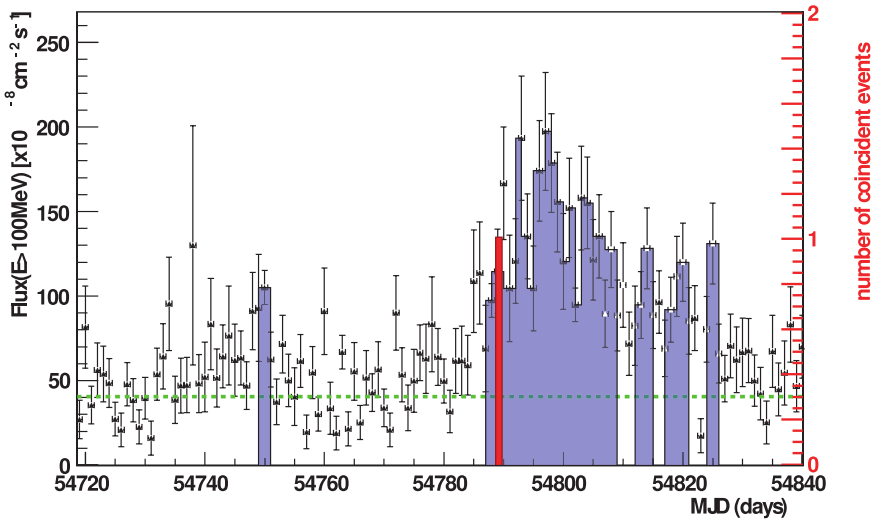


γ-Ray light curve sample for 3C 279 during studied period

AGN results

- One neutrino event compatible with 3C 279 in time and direction ($\Delta\alpha$=0.56°) $\rightarrow$ post trial value 10%
- Upper limits on neutrino flux (F.C. @90% C.L.)

Source	$n(5\sigma)$	$n_{\rm obs}$	Fluence U.L.$^{90\%C.L.}$
PKS 0208-512	4.5	0	2.8
AO 0235+164	4.3	0	18.7
PKS 0454-234	3.3	0	2.9
OJ 287	3.9	0	3.4
WComae	3.8	0	3.6
3C 273	2.5	0	1.1
3C 279	5.0	1	2.8
PKS 1510-089	3.8	0	2.8
3C 454.3	4.4	0	23.5
PKS 2155-304	3.7	0	1.6



Neutrino event during 3C 279 flare

AGN analysis prospects

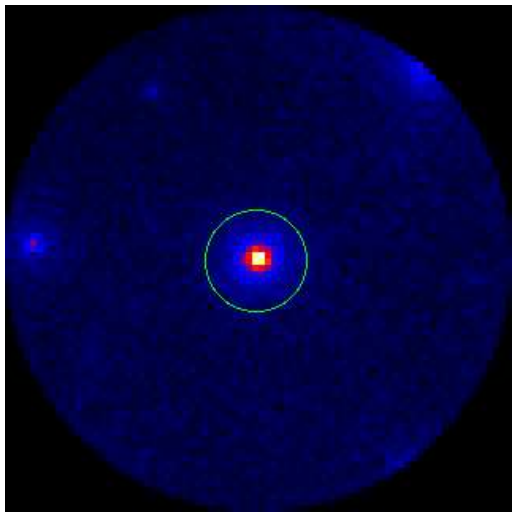
Updated analysis 2008 - 2012:

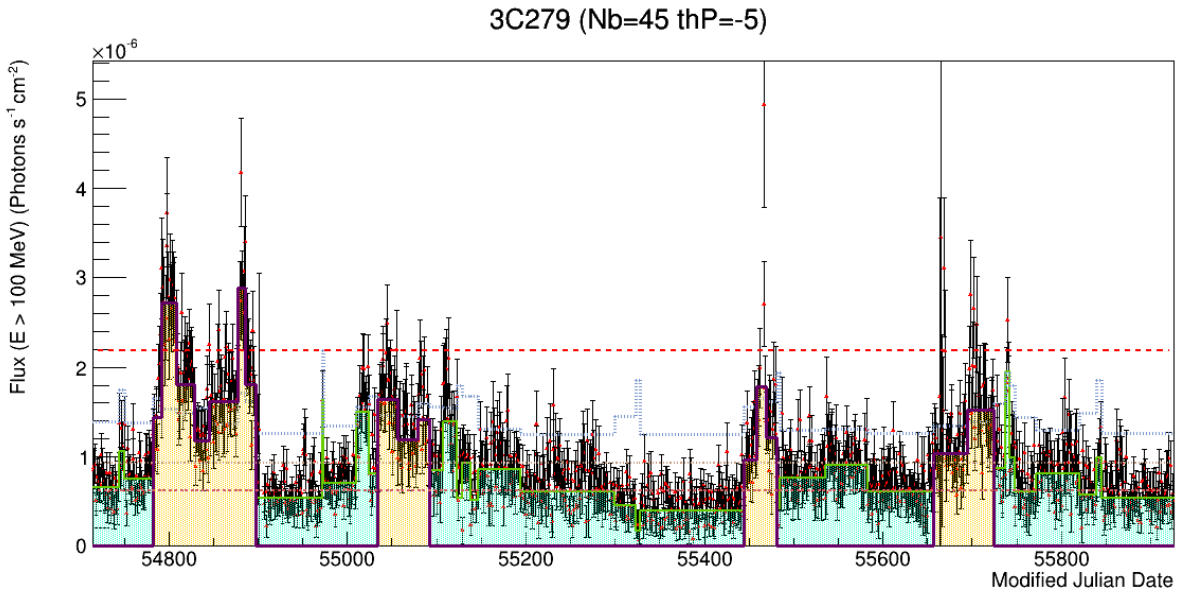
- Multi-messenger data: Fermi and IACT (HESS/MAGIC/VERITAS)
- Selection of 41 sources and 6 specially significant flares from FERMI photon counting data

Inclusion of IACT bibliography collected flares

- Developed a Maximum Likelihood Block method for denoising FERMI photon counting light curves for flaring states identification
- Various energy spectra taken in consideration: E^{-2}, E^{-2} with cutoffs @1 TeV and 10 TeV, E^{-1}
- Implementation of a possible lag in ν/γ signal in the likelihood for avoid missing short flares
- ...
- **Unblinding in process**

AGN analysis prospects





Photon counting map and light curve for 3C 279 from Sep'08 to Dec'11

AGN analysis prospects

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- ...
- **Unblinding in process**

Conclusions

1. ANTARES is the biggest neutrino telescope underwater and the biggest in the northern hemisphere
2. High duty cycle and an instantaneous field of view of 2π, including the galactic center
3. Transient and multi-messenger analyses are performed
4. Improved **GRB** upper limits (2008-2011) w.r.t. previous analysis (2007) (JCAP 1303 (2013) 006)
5. First results on μ-**quasar** analysis with ANTARES (2007-2010)
6. Incoming unblinding for **AGN** analysis (2008-2011) will update previous analysis (2008) (Astropart. Phys. 36 (2012) 204)

Thank you for your attention