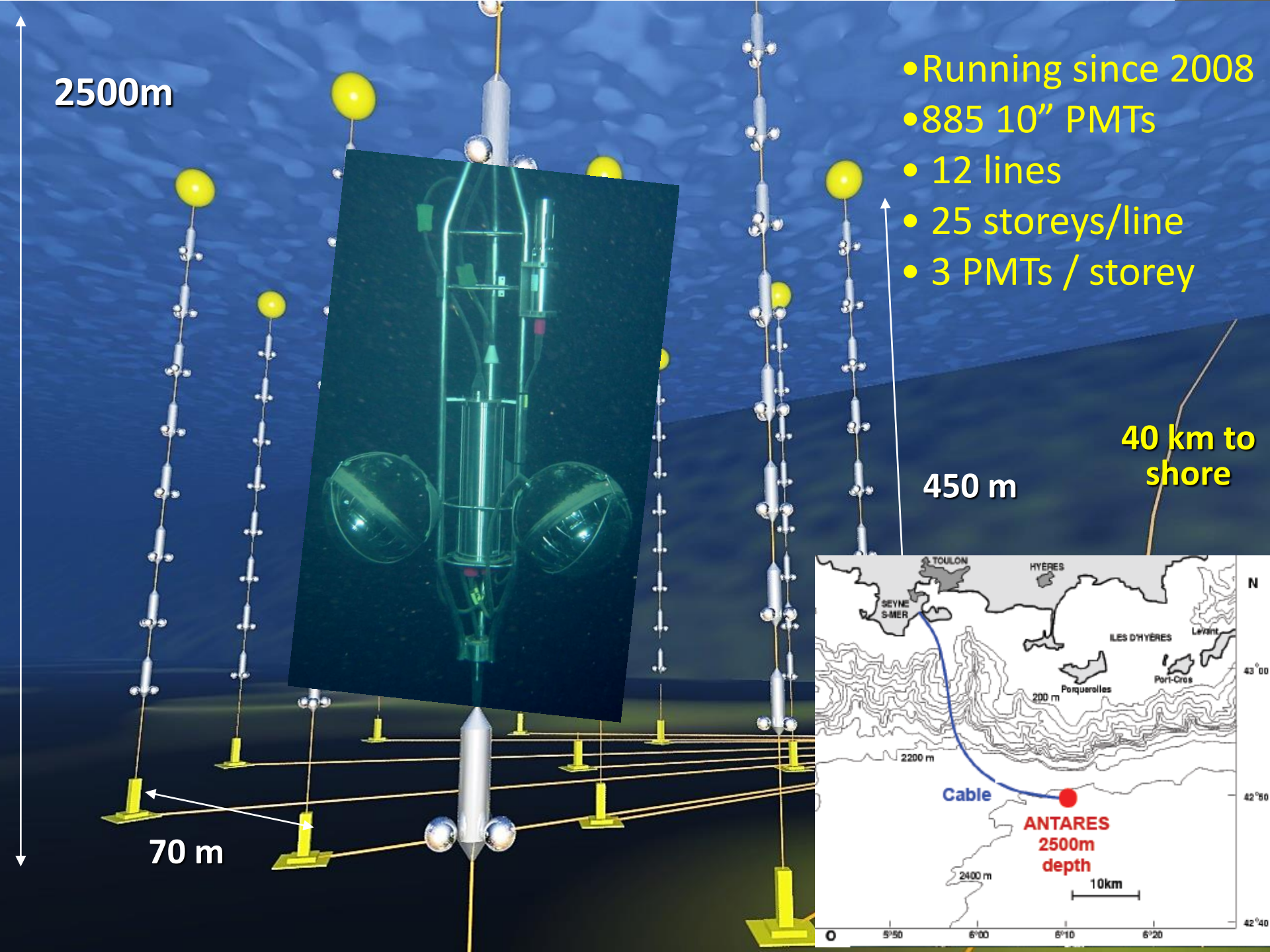
Results from the ANTARES Neutrino Telescope

Maurizio Spurio

VLVnT– Roma 14/09/2015



- Running since 2008
- 885 10” PMTs
- 12 lines
- 25 storeys/line
- 3 PMTs / storey

The scientific goals of ANTARES

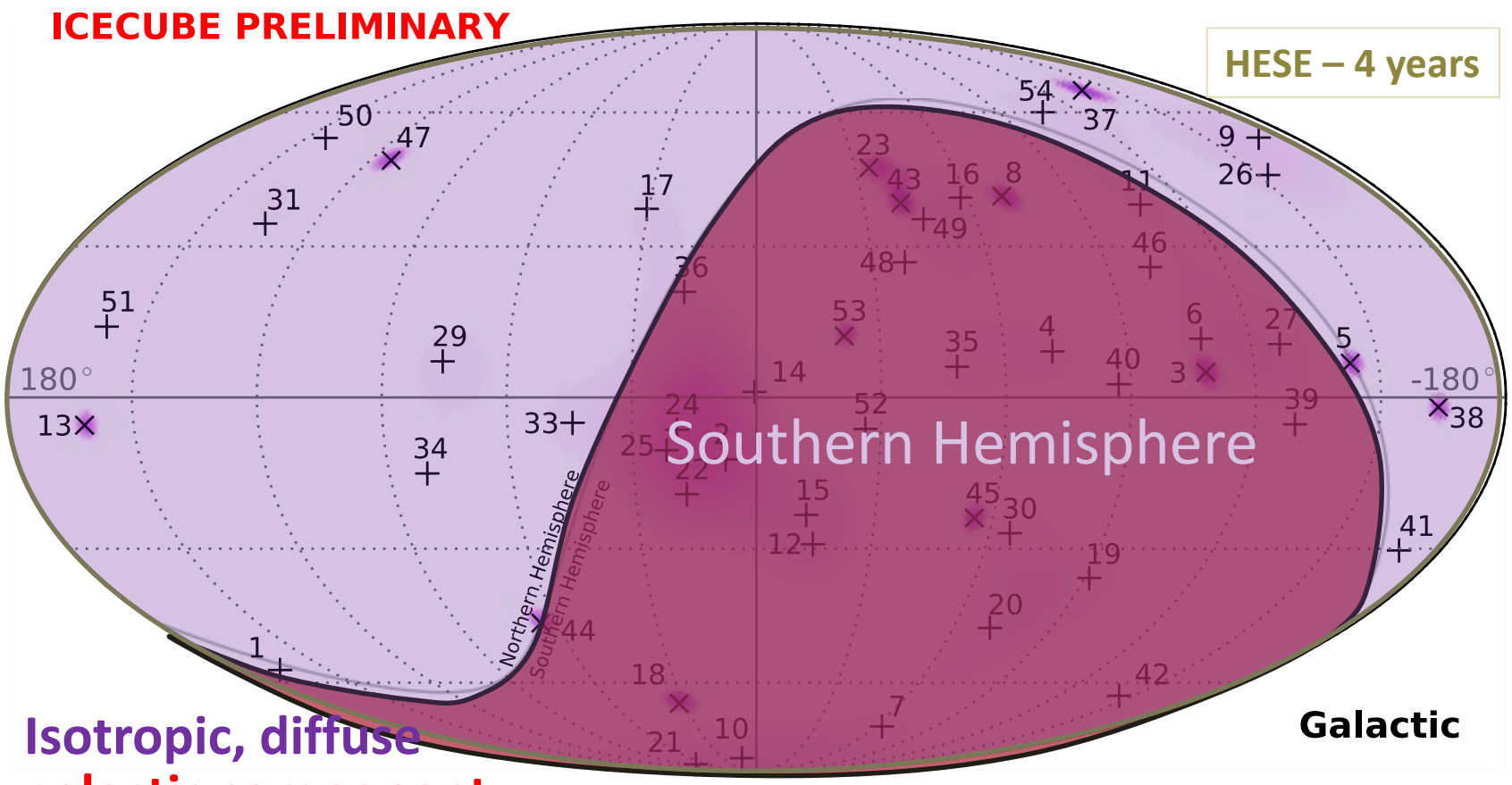
- **Neutrino astrophysics**
- **Multi-messenger studies**
- **Dark Matter searches**
- Study of atmospheric neutrinos
- Particle physics: nuclearites, monopoles
- Acoustic detection
- Sea sciences

J. Brunner, Plenary Wed

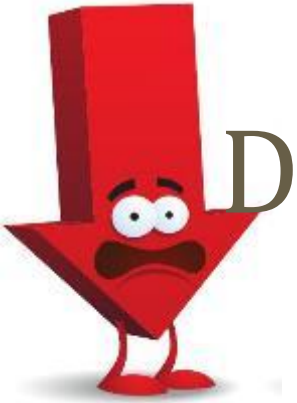
Lahmann C/60

Not covered in this talk

On the quest for the origin of the IC cosmic signal



Isotropic, diffuse
+ galactic component

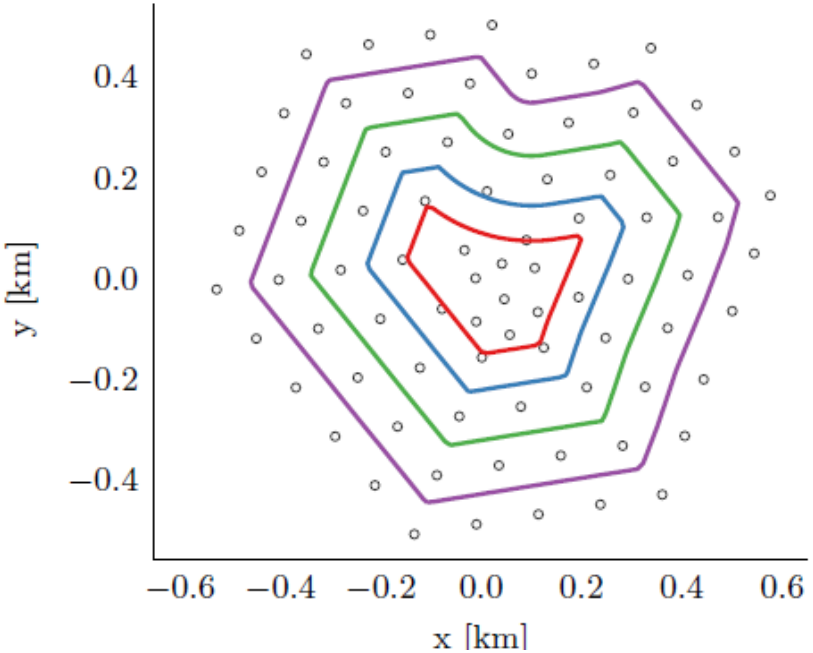


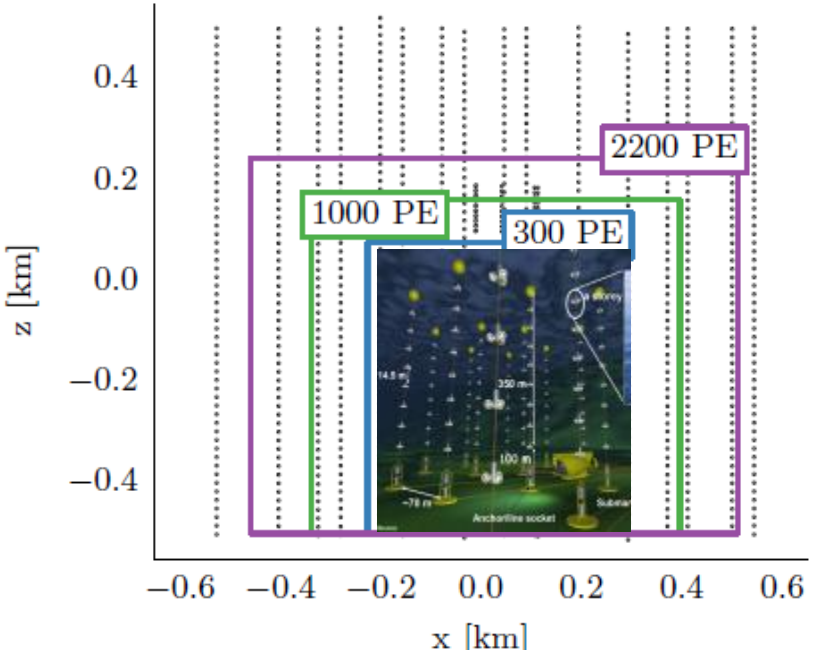
Down in IC = Up in ANTARES

PHYSICAL REVIEW D **91,** 022001 (2015)

Atmospheric and astrophysical neutrinos above 1 TeV interacting in IceCube

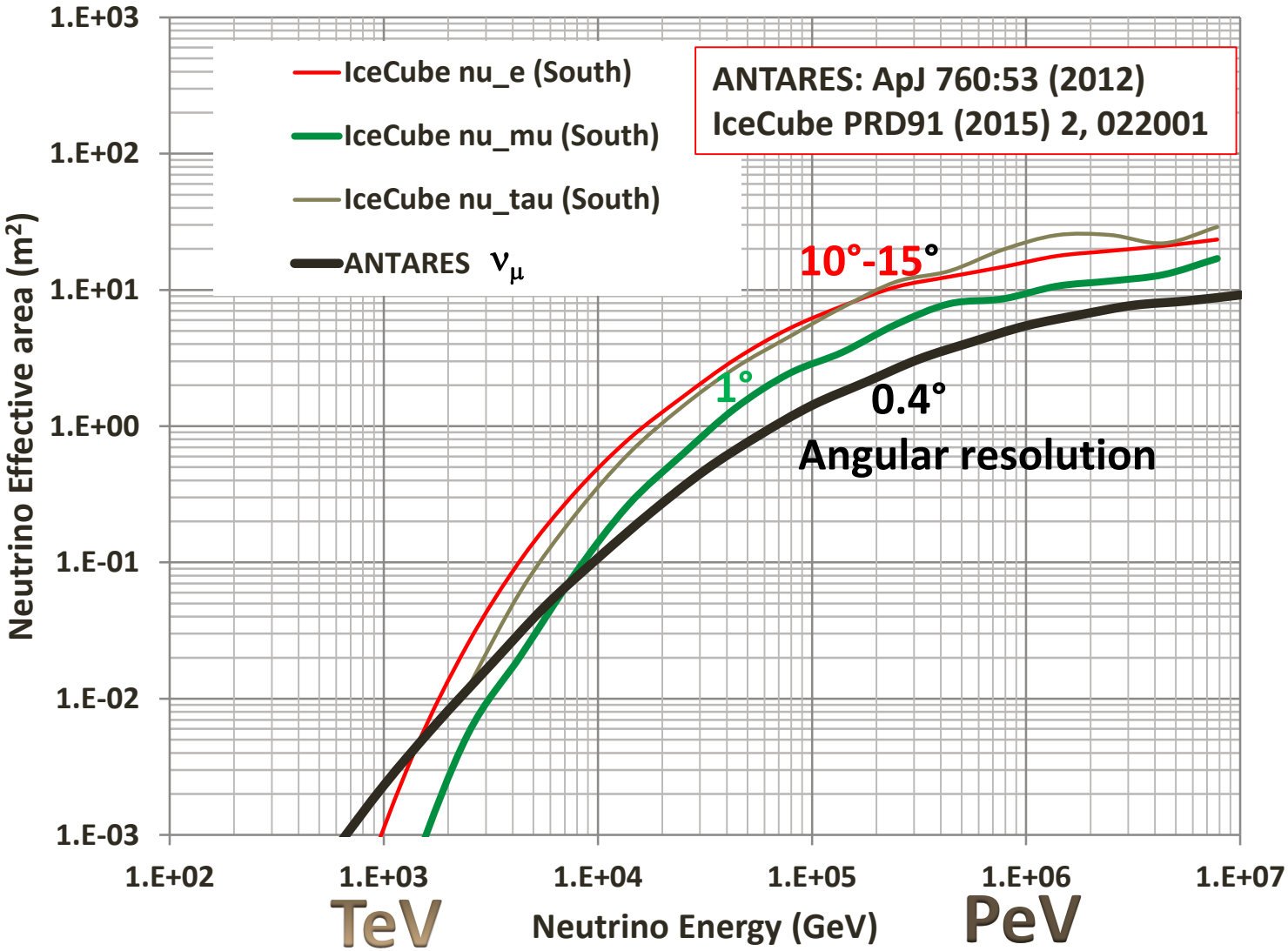
M. G. Aartsen,[2] M. Ackermann,[48] J. Adams,[15] J. A. Aguilar,[23] M. Ahlers,[28] M. Ahrens,[39] D. Altmann,[22] T. Anders
C. Arguelles,[28] T. C. Arlen,[45] J. Auffenberg,[1] X. Bai,[37] S. W. Barwick,[25] V. Baum,[30] R. Bay,[7] J. J. Beatty,[17,18]





Almost in scale

Effective areas - A_{eff}



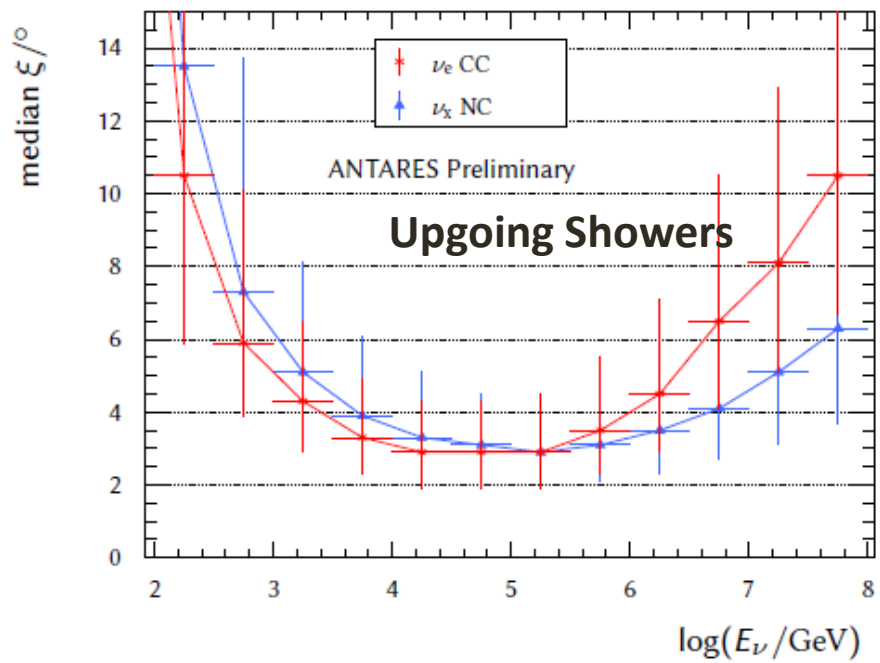
Neutrino astrophysics: ν_μ and showers

- **ANTARES data**: 1622 days from 2008 to 2013 (plus 5 line period)
- **6261** muon neutrino candidates (90% purity)- median 0.4° for E^{-2}
- A new reconstruction of cascades presented @ICRC2015
- for E^{-2} flux with 1:1:1 flavor composition, the cascade topology **increases signal event rate by 30%**

- **156 upgoing cascade events** (90 % purity)
- Angular resolution <4° from showers 10 TeV to 1 PeV
- **Showers NOT included in most results presented here.**

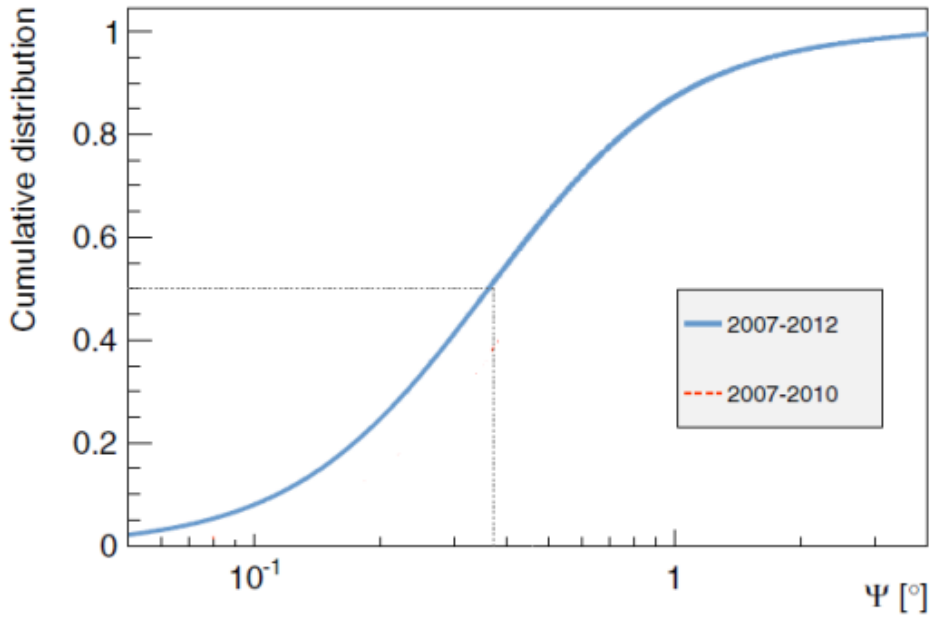
- **MC simulation:** run-by-run method

Fusco B/82

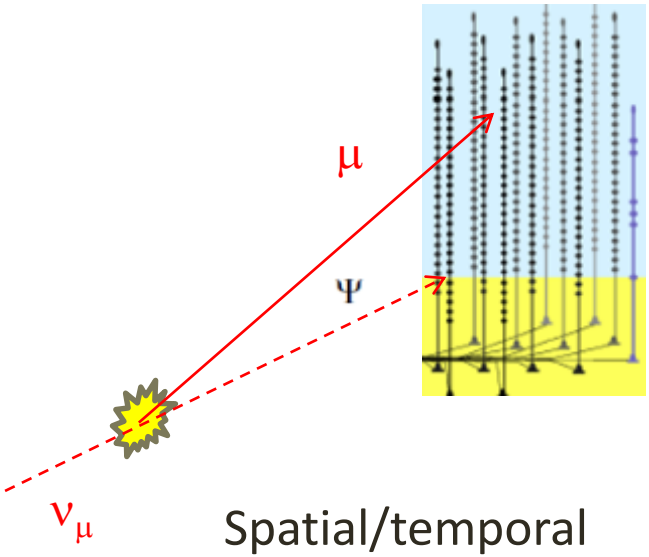


A) Point Sources

- The ν_μ channel allows ANTARES to behave as a **telescope**
- 50% of reconstructed ν_μ in 0.4° (for E^{-2} spectrum), 90% purity
- Proxy estimate of the energy (cosmic signal has harder spectrum)
- Background of atmospheric ν_μ in 1° = **O**(1) event



THE ASTROPHYSICAL JOURNAL LETTERS, 786:L5 (5pp), 2014 May 1

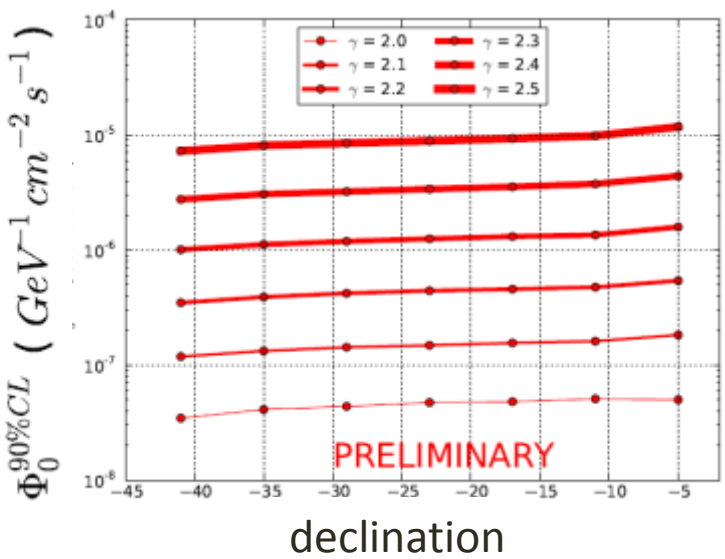


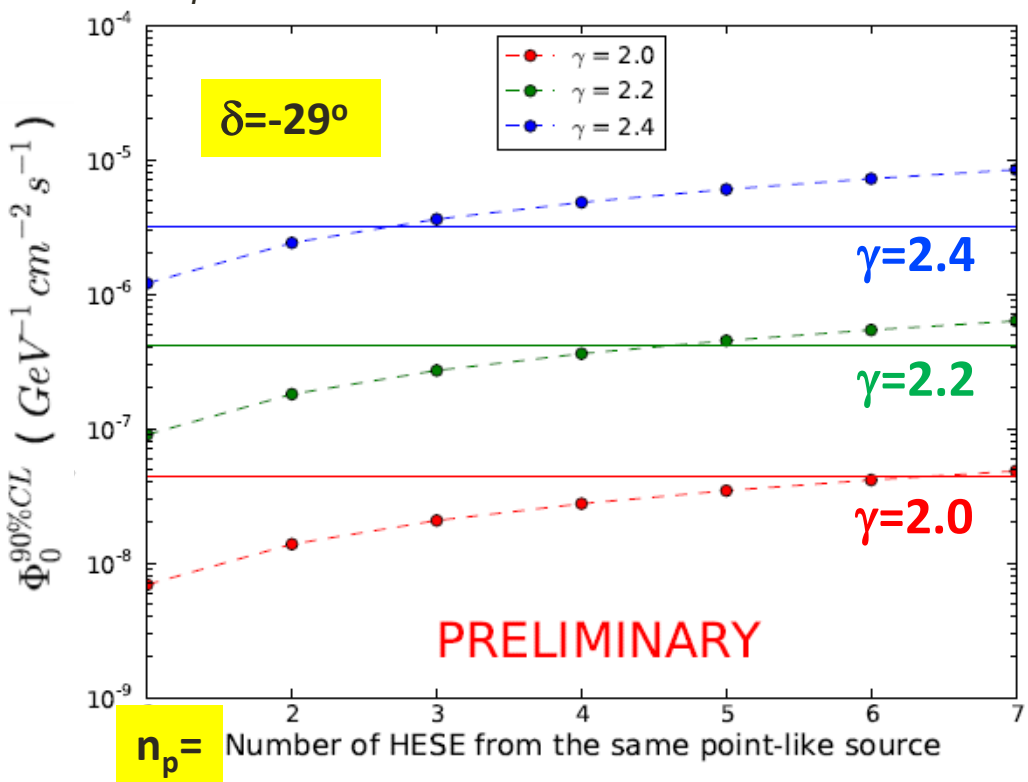
Spatial/temporal collettive effects:

Coleiro/Gracia D/89

A.1 An hidden point-source $\Phi_0 E^{-\gamma}$ producing n_p HESE

- The ANTARES 90% C.L. upper limit excludes that a single point-like source produces n_p>6 HESE, assuming γ=2.0.
- A single point-like source yielding n_p>3 is excluded for γ=2.3

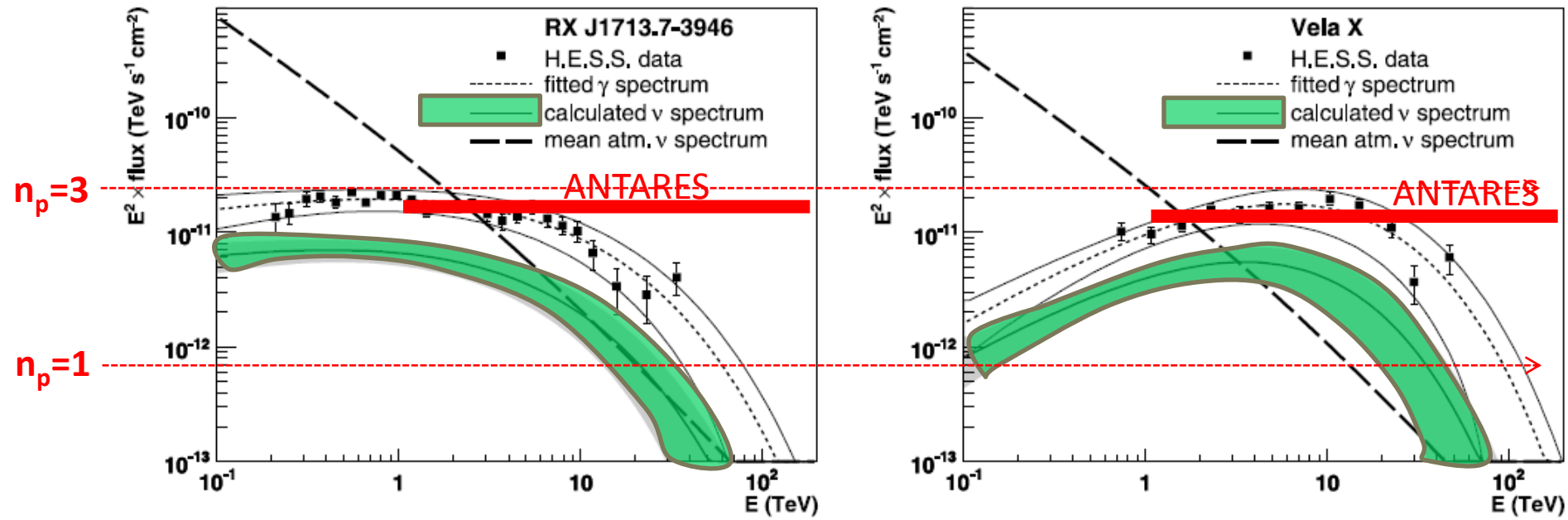




A.2 Galactic PeVatrons

- Models predictions up to $E^2\Phi = 10^{-8}$ GeV s^{-1} cm^{-2}
- ANTARES dedicated study of 50 pre-selected sources using data set 2007-2012 (no significant excess)
- Unbinned searches: no excess (most significant at 2.2σ)

THE ASTROPHYSICAL JOURNAL LETTERS, 786:L5 (5pp), 2014 May 1



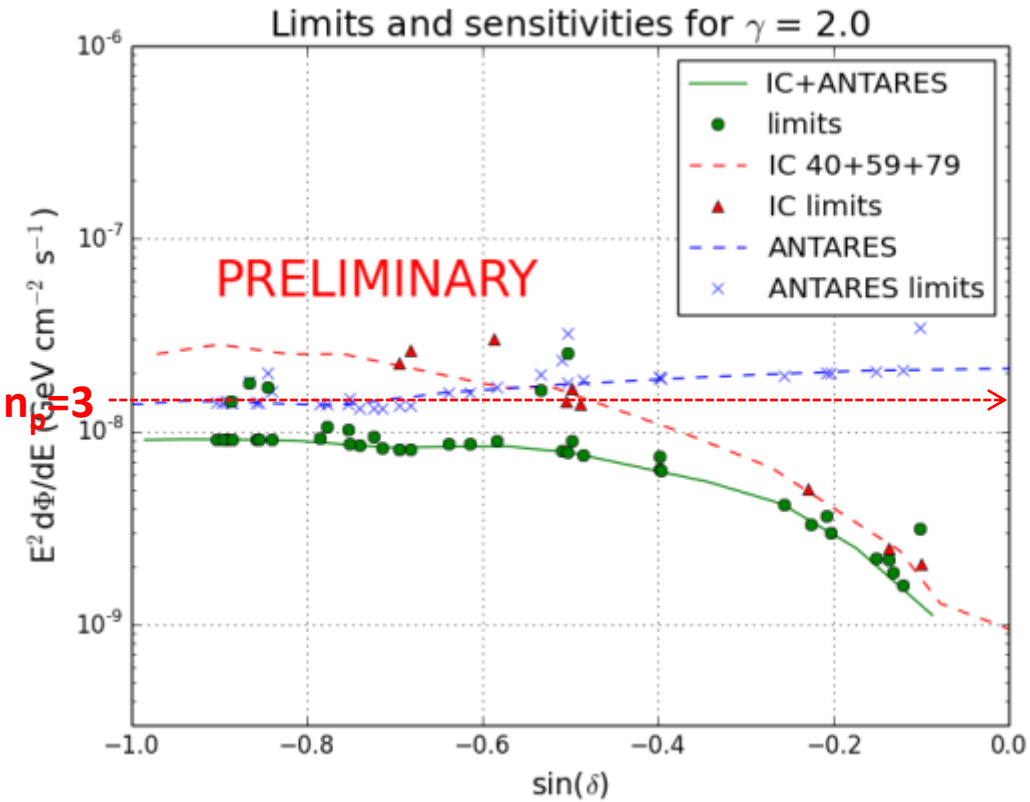
A. Kappes et al., ApJ, 656:870(2007)

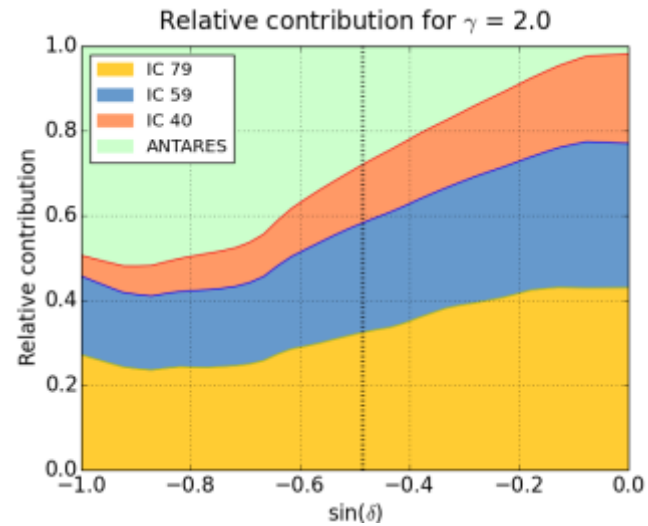
A.3 Joined ANTARES-IC searches

- Point-source analysis using the ANTARES 2007-2012 and the IC40, IC59, and IC79 samples for the Southern Hemisphere

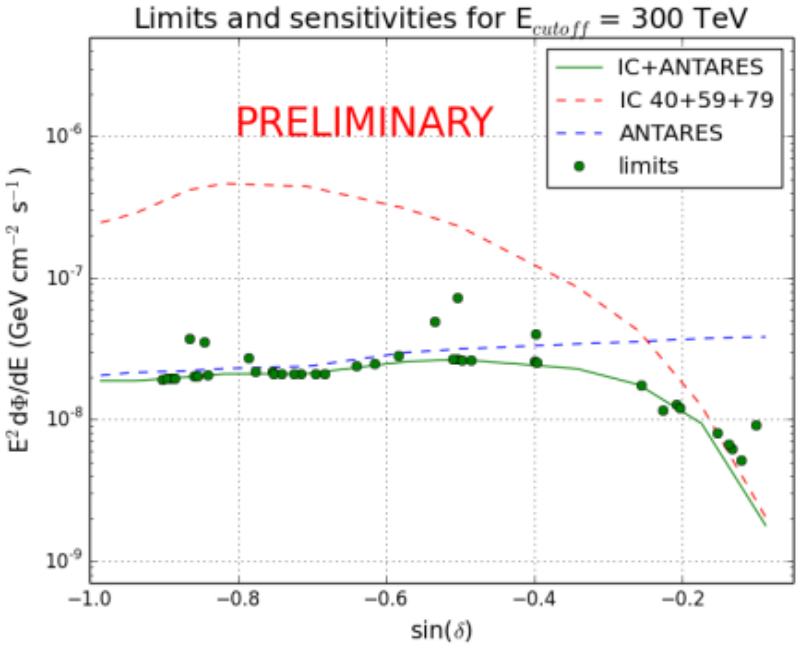
Barrios-Martì D/50

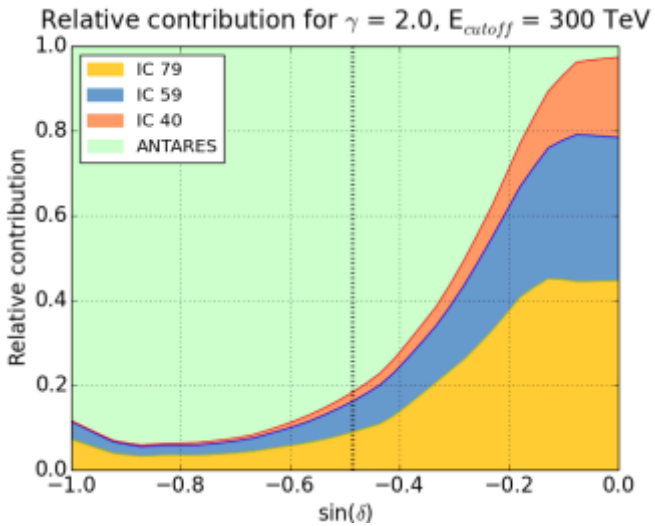
Paper in preparation

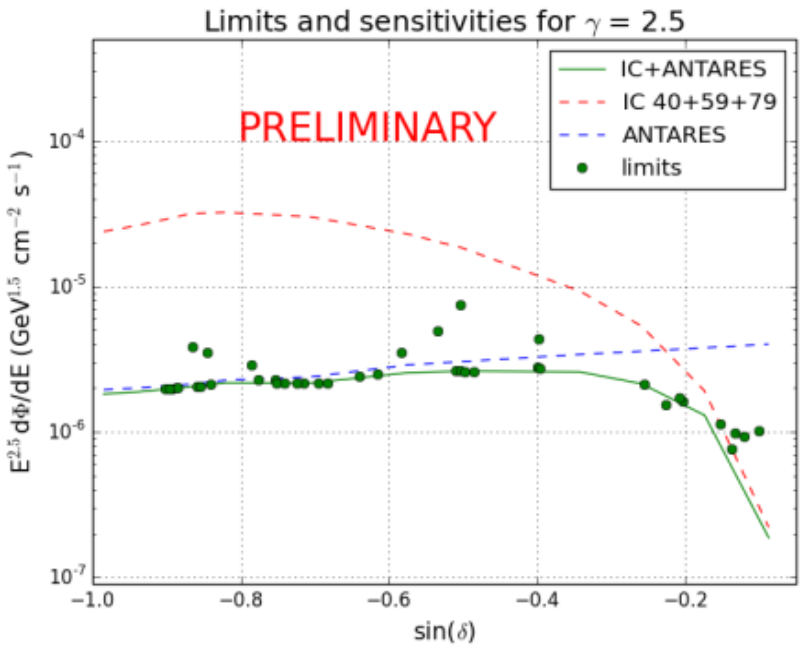


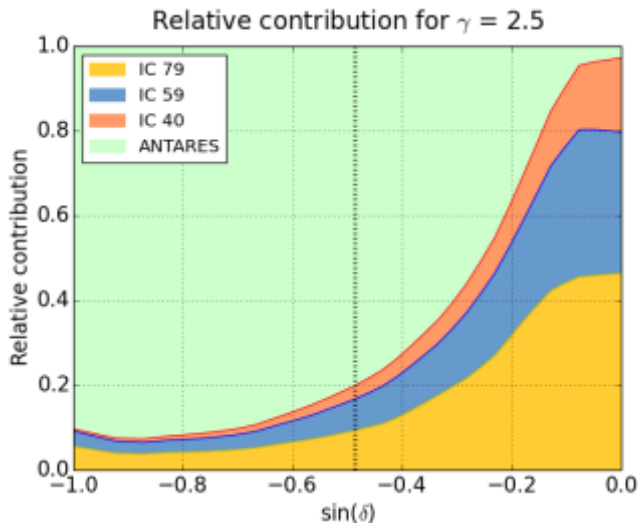


Combined 90% CL sensitivities (green line) and limits (points) for an E^{-2} source spectrum. Blue (Red) curves/points indicate ANTARES (*IceCube*) sensitivities/limits



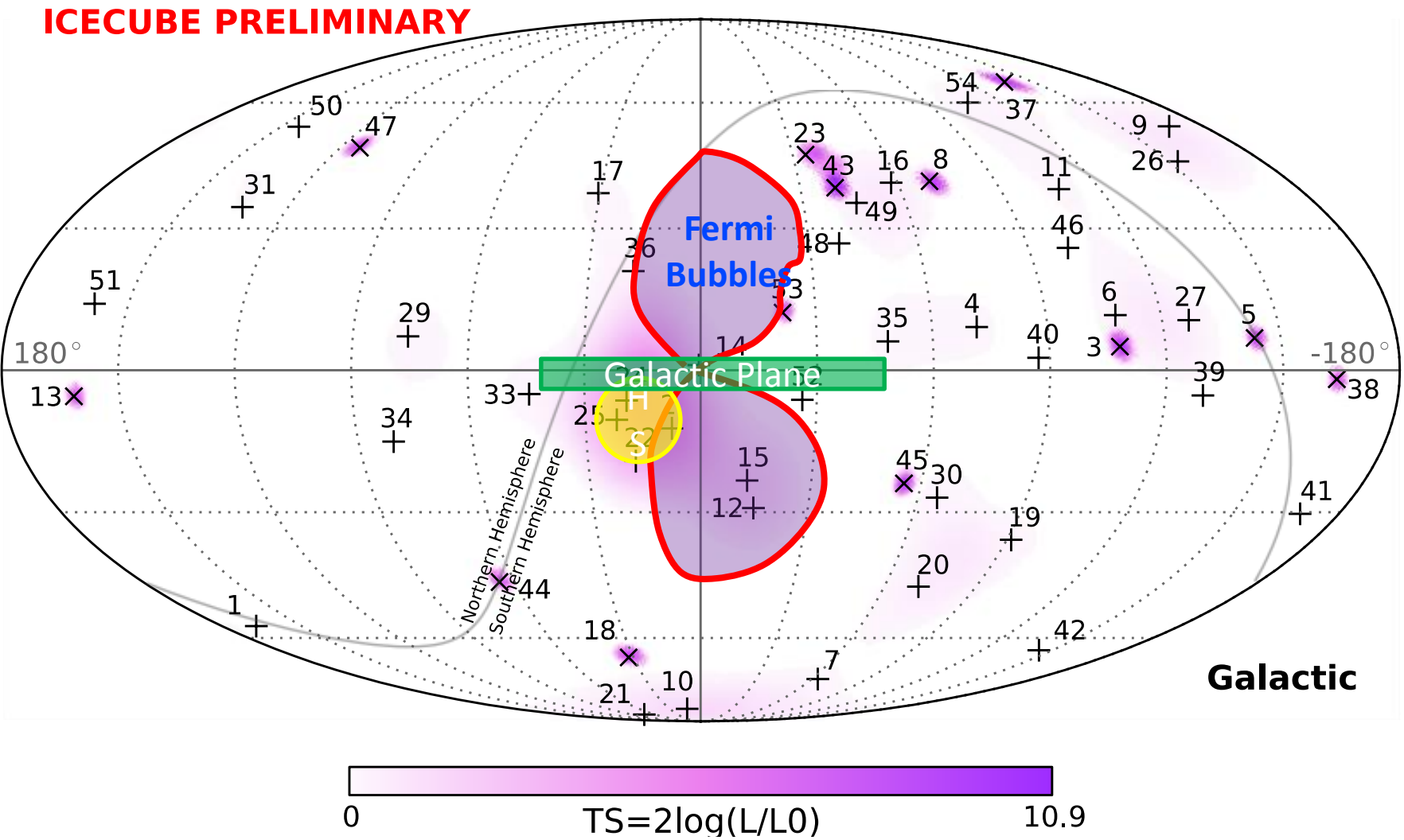




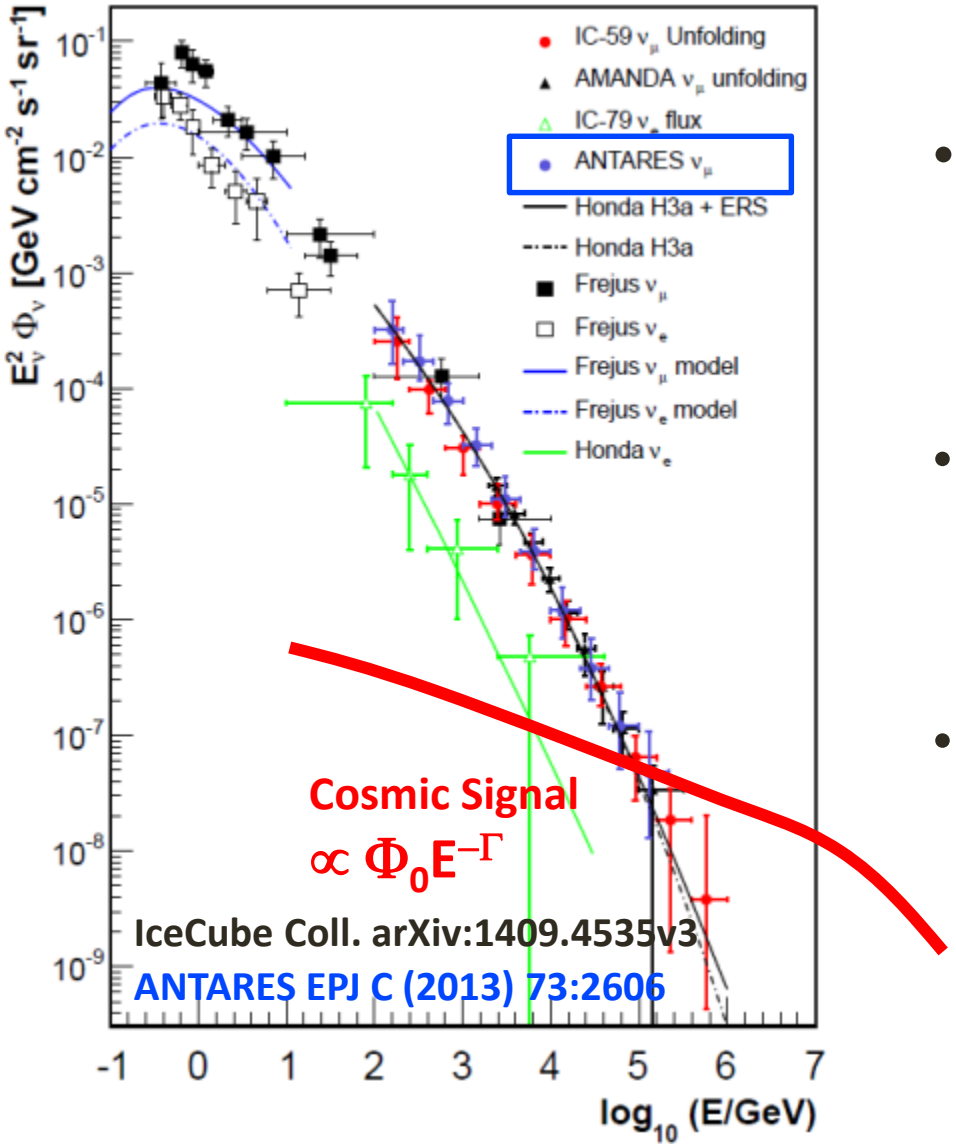


Top: 90% CL sensitivities and limits for an E^{-2} source spectrum and exponential cutoff at E = 300 *TeV*. **Bottom**: For spectral index Γ=2.5

B) Enhanced diffuse flux



- Atmospheric neutrinos → irreducible background



- The expected signal spectrum is **harder** than the background of atmospheric neutrinos
- The search methods rely on the event-by-event estimate of the ν_μ energy (the muon light yield gives a proxy)
- Comparison between the signal region and off-signal zones

B.1 The Galactic ridge

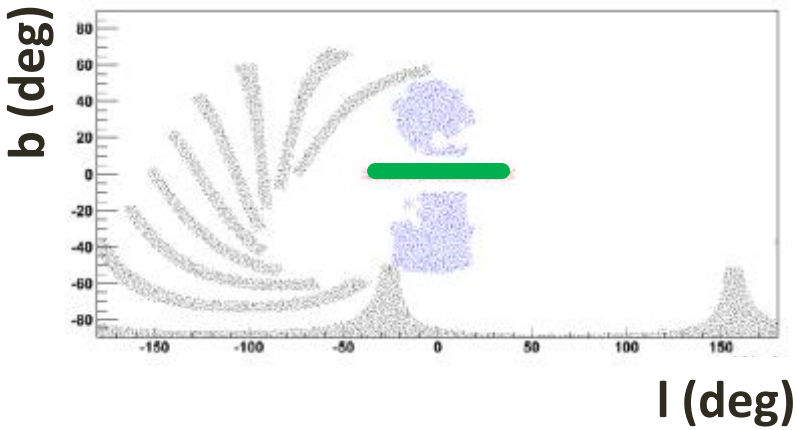
Marinelli, D/48
Fusco, D/34

- ν's and γ-rays produced during propagation of CRs in our Galaxy:

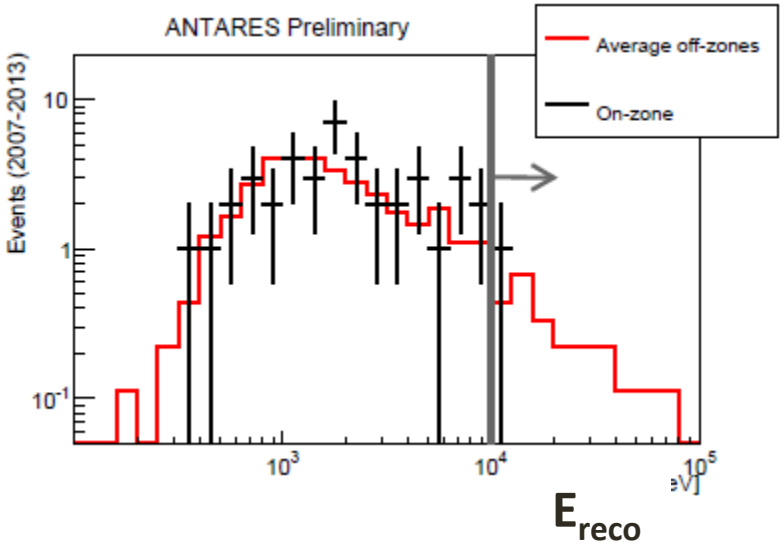
$$p_{CR} + p_{ISM} \rightarrow \pi^0 \pi^{\pm} \ldots$$

$$\pi^0 \rightarrow \gamma\gamma, EM\ cascade$$ **Fermi-LAT**

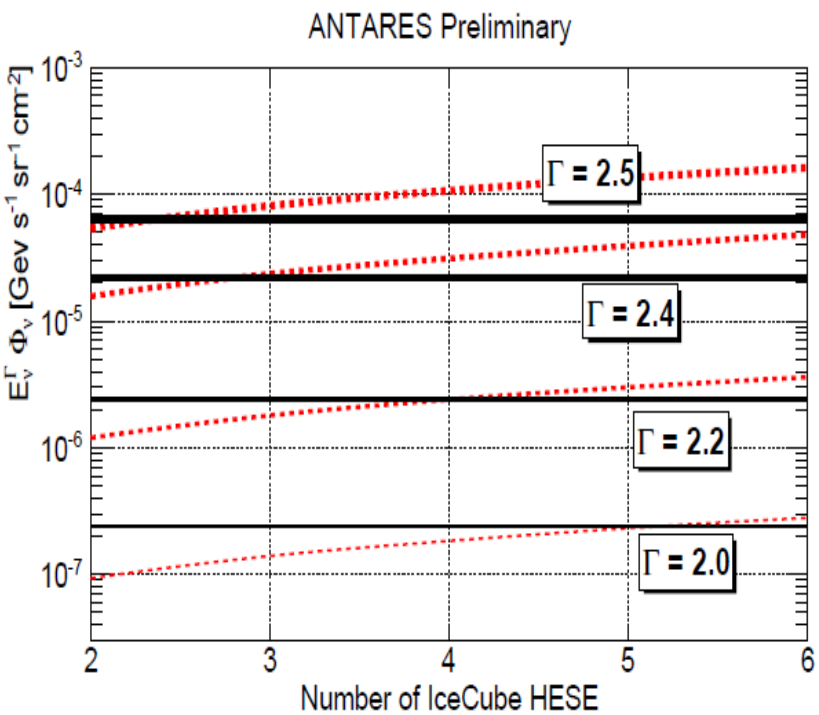
$$\pi^{\pm} \rightarrow \nu_\mu, \nu_e \ldots$$ **IceCube ANTARES**

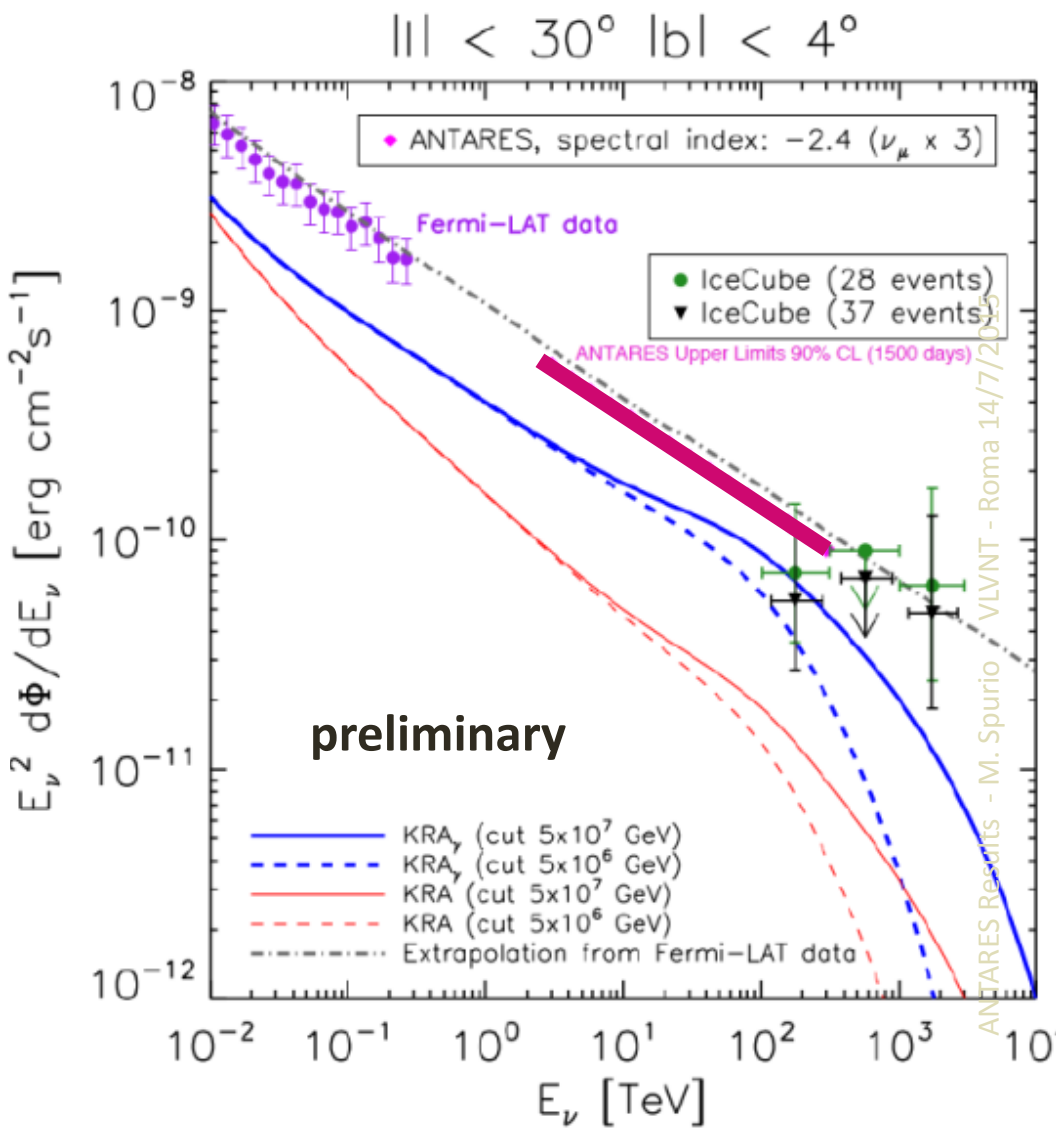


- Search for ν_μ, data 2007-2013
- Search region |l|<30°, |b|<4°
- Optimized for γ=2.4-2.5
- Counts in the signal/off zones
- No excess in the HE neutrinos
- 90% cl upper limits in the $3<E_\nu<300$ TeV region



- Figure right: ANTARES limits compared with Fermi-LAT and IceCube in the ON region
- Figure bottom: 90% cl limits from the Galactic Plane compared to the expected flux producing a n_p IceCube HESE events vs. γ.

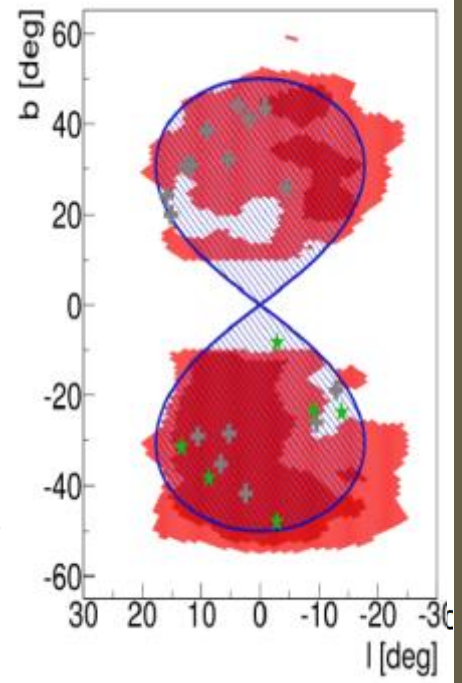


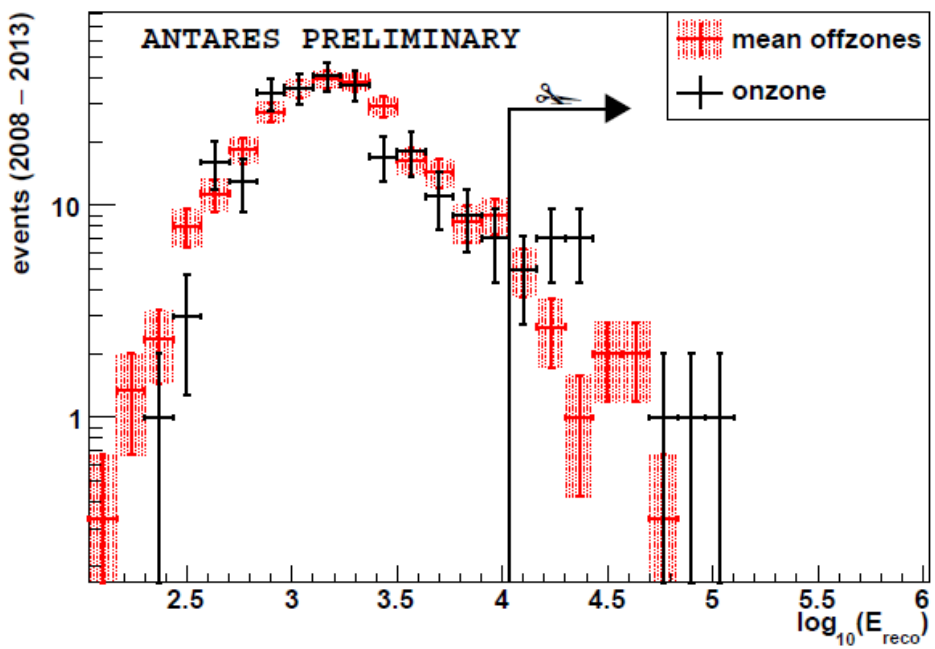


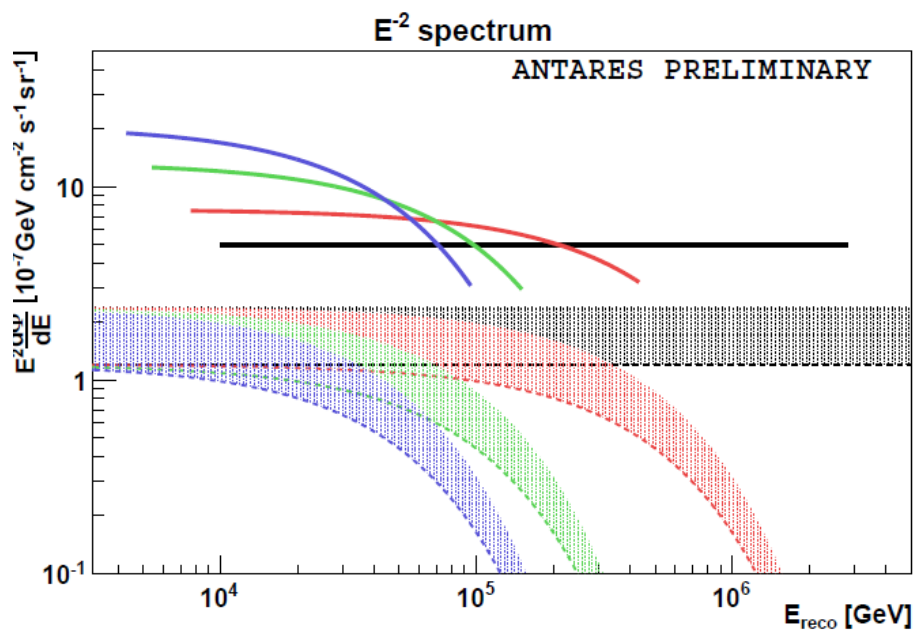
ANTARES EPJ C (2014) 74:27
and ICRC2015 update

B.2 Fermi Bubbles

- The ν can test the hadronic origin of the bubbles
- E^{-2} ,$E^{-2.18}$ spectra and different cutoff [Lunardini et al. PRD92 (2015) 2,021301]: 50, 100, 500, ∞ TeV
- comparison on-zones/off-zones (3) of $\Delta\Omega$=0.66 sr
- 2008-2013 data analyzed (806+366 days).
- 22 events observed /13 background expected

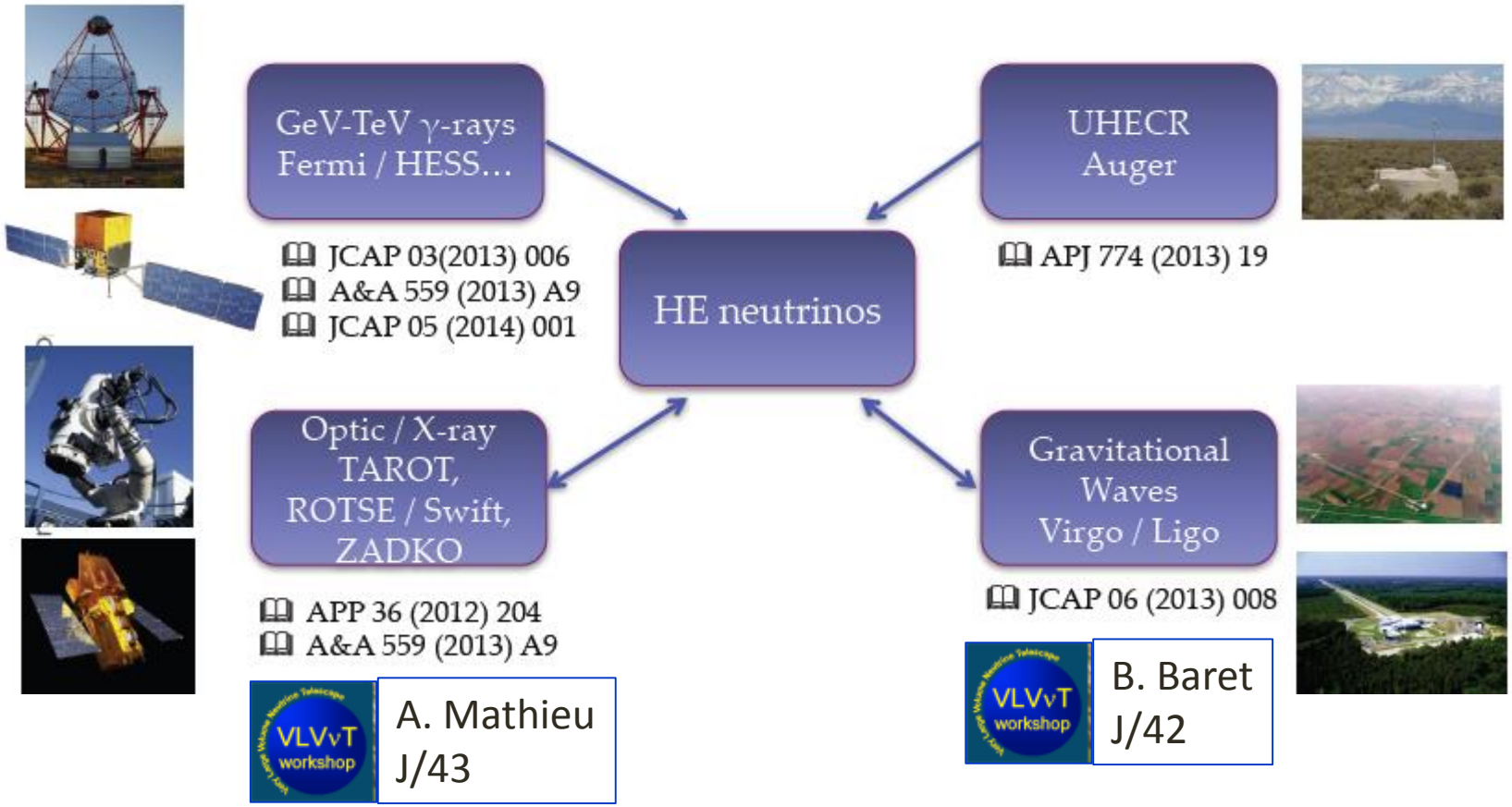






C) Transient and multi-messenger efforts

J. Brunner
Plenary Wed



A. Mathieu
J/43

B. Baret
J/42

*a multiwavelength program that monitors extragalactic jets of the Southern Sky.
Krauß, et al. 2014, A&A, 566, L7

C.1 Blazars monitored by TANAMI*

- Three blazars associated with IC14 (Bert) and three with IC20 (Ernie)
- All 6 in the FoV of ANTARES
- **From the photon flux $F_\gamma \rightarrow \nu_e$ in IceCube ~ ν_μ ANTARES**
- After unblinding, one events in correspondence of two of the blazars (IC14)
- This observation is consistent with the blazar-origin hypothesis of the IceCube event IC14 for a broad range of blazar spectra, although an atmospheric origin cannot be excluded.
- **PKS B1424–418: A high-fluence blazar in the IC 35 field (BigBird)**

A&A Lett. 576 (2015) L8

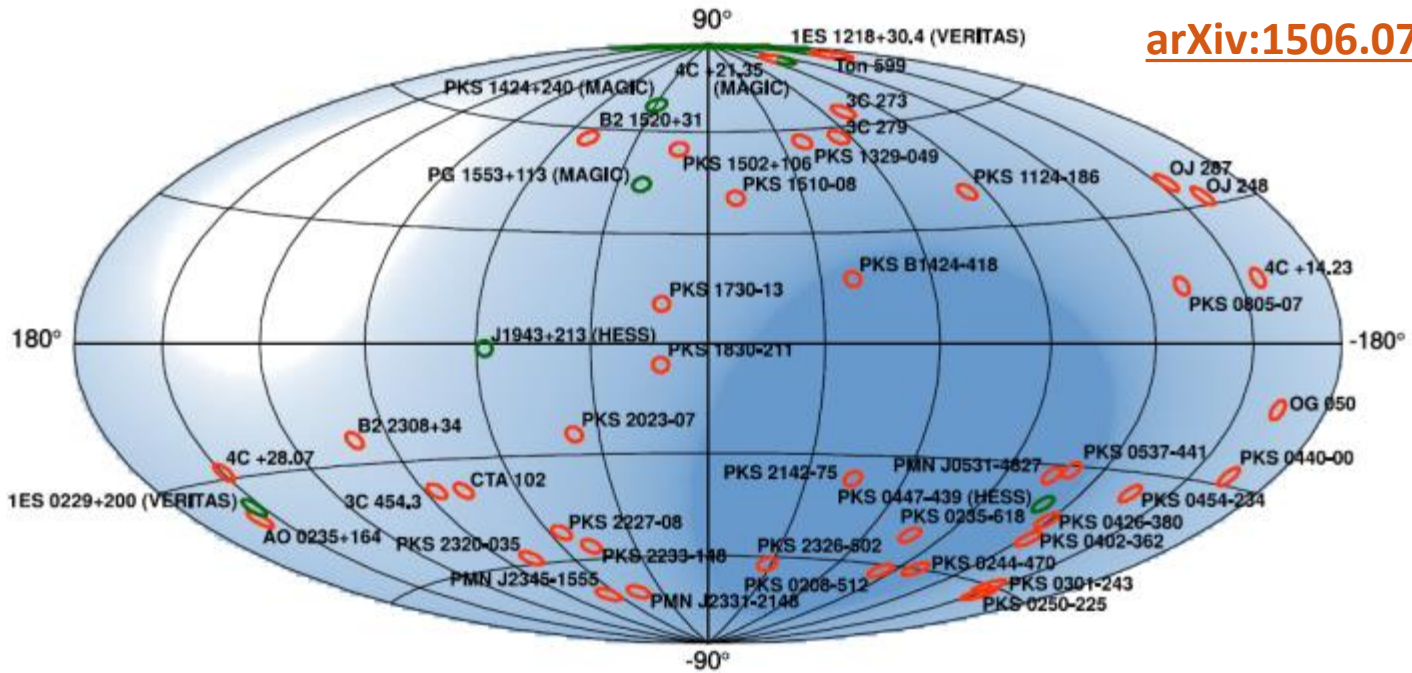
Source	Cat. Name	F_γ [GeV cm^{-2} s^{-1}]	N_{ν_e} IceCube	IC	N_{sig} ANTARES	p
0235–618	PKS 0235–618	$(6.2^{+3.1}_{-3.1}) \times 10^{-8}$	$0.19^{+0.04}_{-0.04}$	20, 7	0	1
0302–623	PKS 0302–623	$(2.1^{+0.4}_{-0.4}) \times 10^{-8}$	$0.06^{+0.01}_{-0.01}$	20	0	1
0308–611	PKS 0308–611	$(4.7^{+1.8}_{-1.8}) \times 10^{-8}$	$0.14^{+0.05}_{-0.05}$	20	0	1
1653–329	Swift J1656.3–3302	$(2.8^{+0.3}_{-0.3}) \times 10^{-7}$	$0.86^{+0.10}_{-0.10}$	14, 2, 25	1.1	0.10
1714–336	TXS 1714–336	$(1.5^{+0.3}_{-0.4}) \times 10^{-7}$	$0.46^{+0.10}_{-0.12}$	14,2,25	0.9	0.04
1759–396	MRC 1759–396	$(7.5^{+1.9}_{-1.9}) \times 10^{-8}$	$0.23^{+0.50}_{-0.40}$	14, 2, 15, 25	0	1
	PKS B1424–418		**many**	**35**	**0**	

C.2 ν_μ emission associated with GeV and TeV γ-ray flaring blazars

D. Dornic
J/44

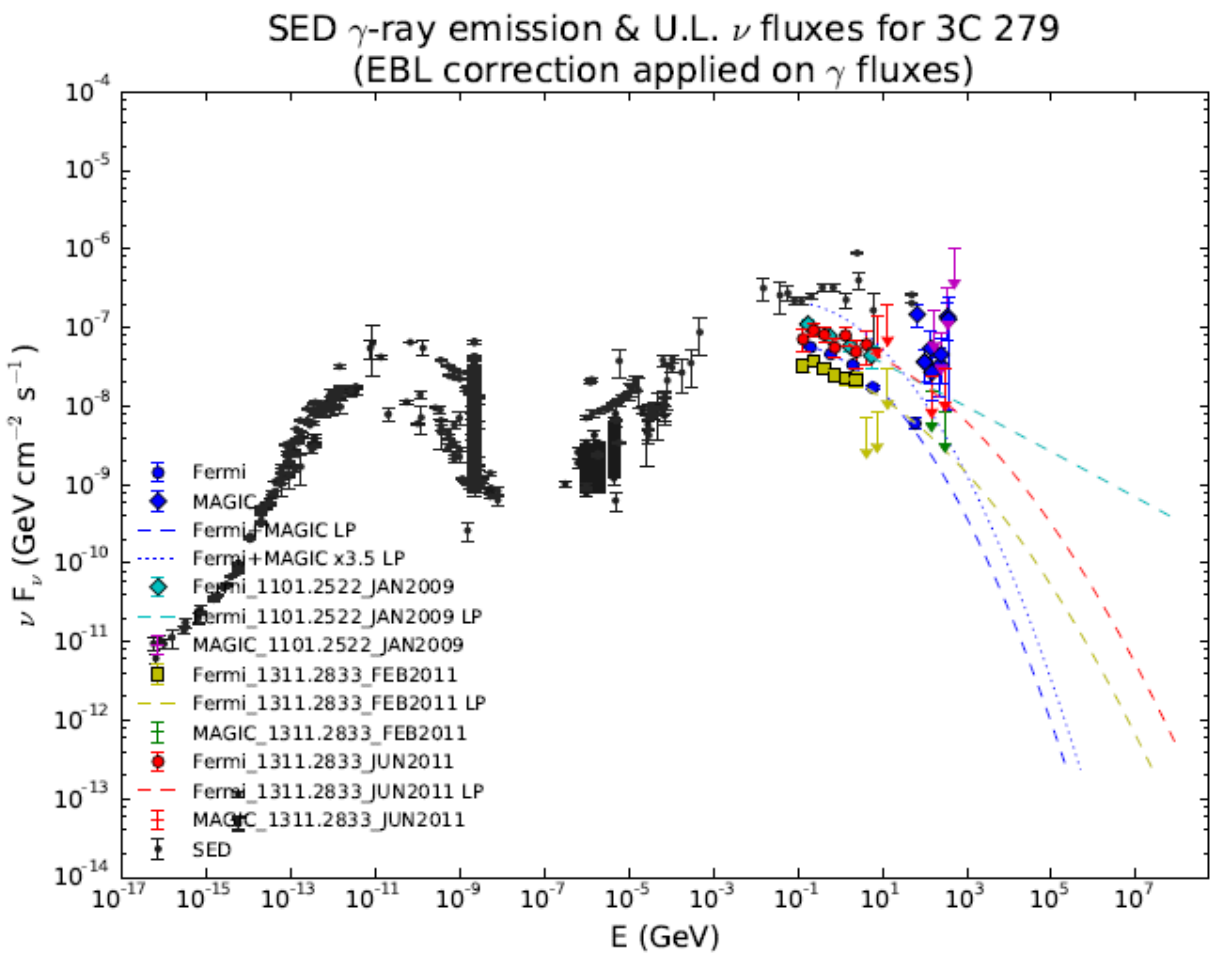
- Variable blazars monitored by FERMI-LAT and IACTs
- Search for neutrino events correlated with high activity state

arXiv:1506.07354

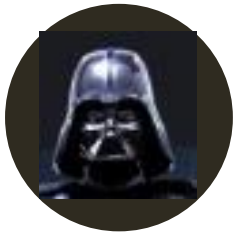


Skymap (galactic coor.) with the position of the 41 selected Fermi blazars (red circle) and the 7 IACTs blazars (green circle) on top of the ANTARES visibility

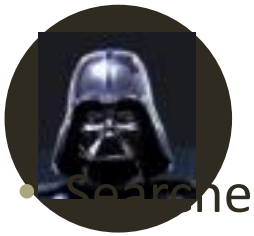
- The most significant correlation was found with 3C279 (1 ν_μ)
- However, this event had a post-trial probability of 67%, and is thus compatible with background fluctuations.
- The upper-limits on the neutrino SEDs compared with GeV-TeV γ-ray observations



Dark Matter searches



DM → ν

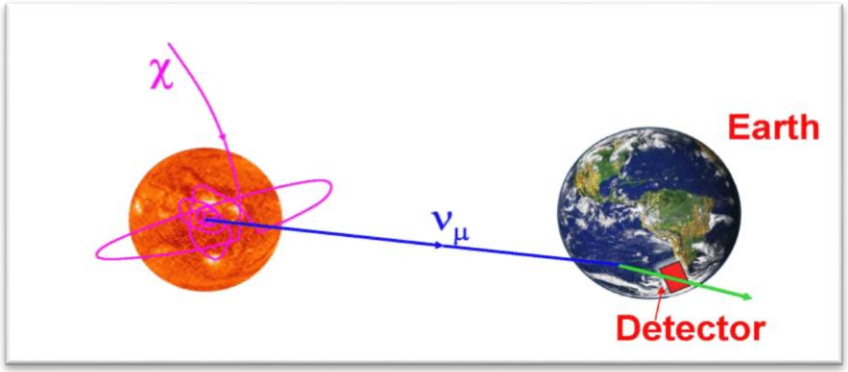


- Searches for a possible ν_μ excess due to DM annihilation from the Galactic center, the Sun core, the Earth nucleus

Dark Matter searches

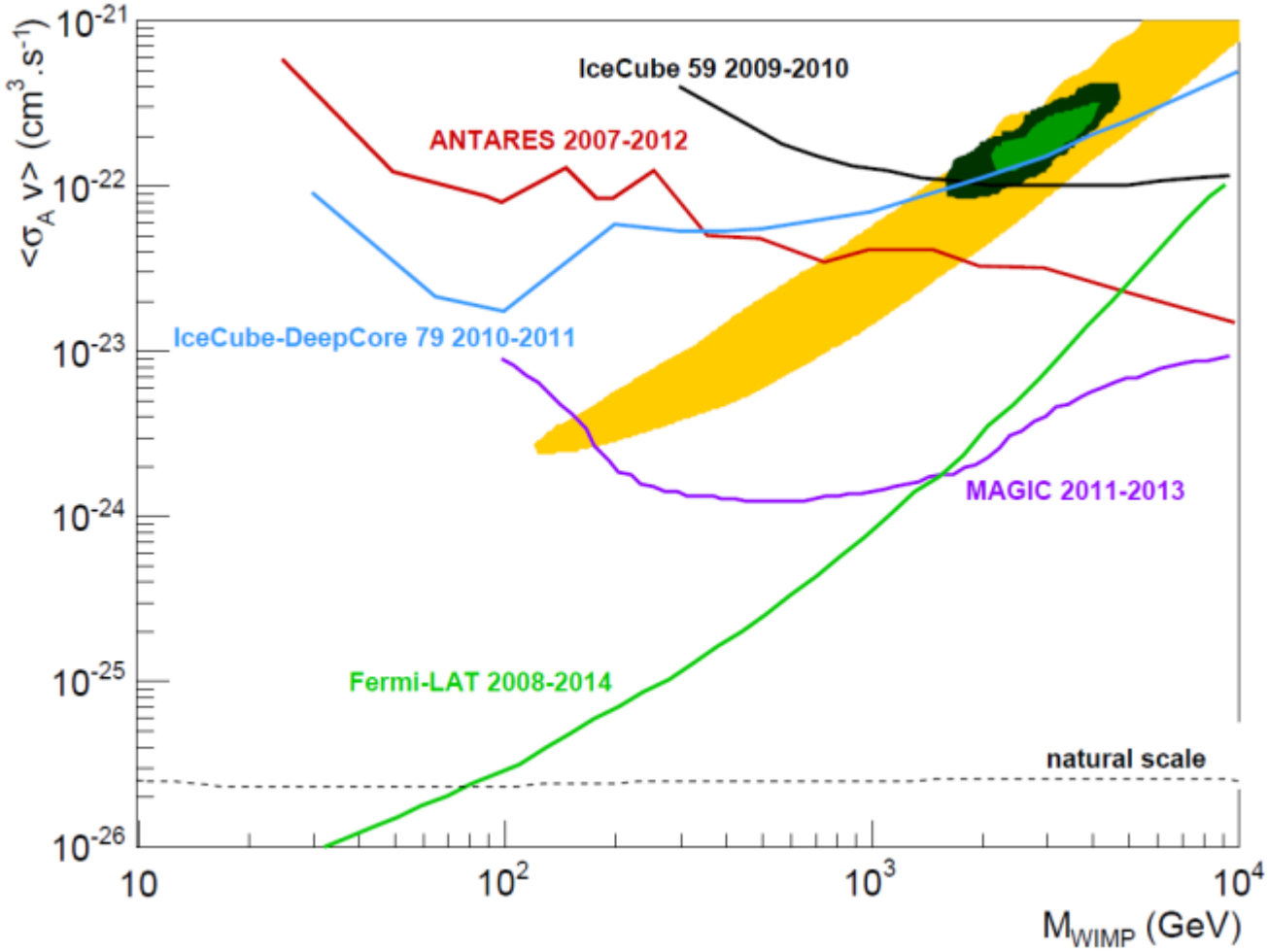
- For the Earth and the Sun analyses the DM, the ν_μ spectrum calculated with WIMPSIM [Blennow,Edsjö,Ohlsson,arXiv:0709.3898]
- For the GC and galaxy clusters spectra from [M.Cirelli et al., arXiv:1012.4515]
- Annihilations into: $b\,\bar{b}$, $\tau^+\tau^-$, W^+W^-, $\mu^+\mu^-$ and $\nu\,\bar{\nu}$ used as benchmark
- Background estimated from time scrambled data.
- The sensitivities optimized w.r.t. a search cone and reconstruction quality parameter cut.
- **No excess from any data set**

M. Ardid
D/38



Galactic Center

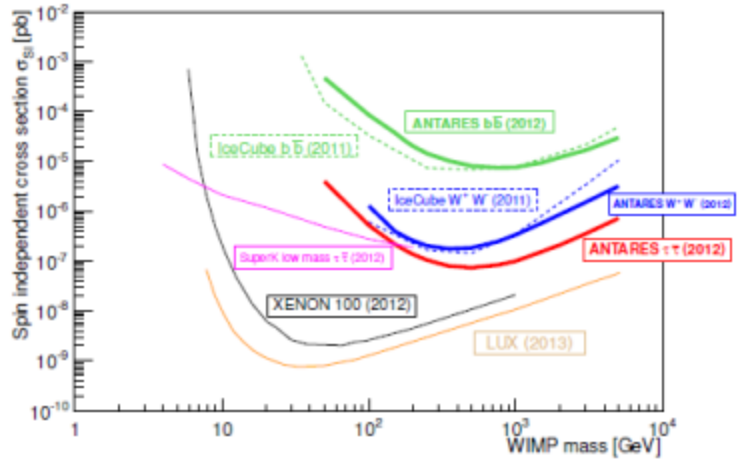
ANTARES: **arXiv:1505.04866**
IceCube : **arXiv:1505.07259**



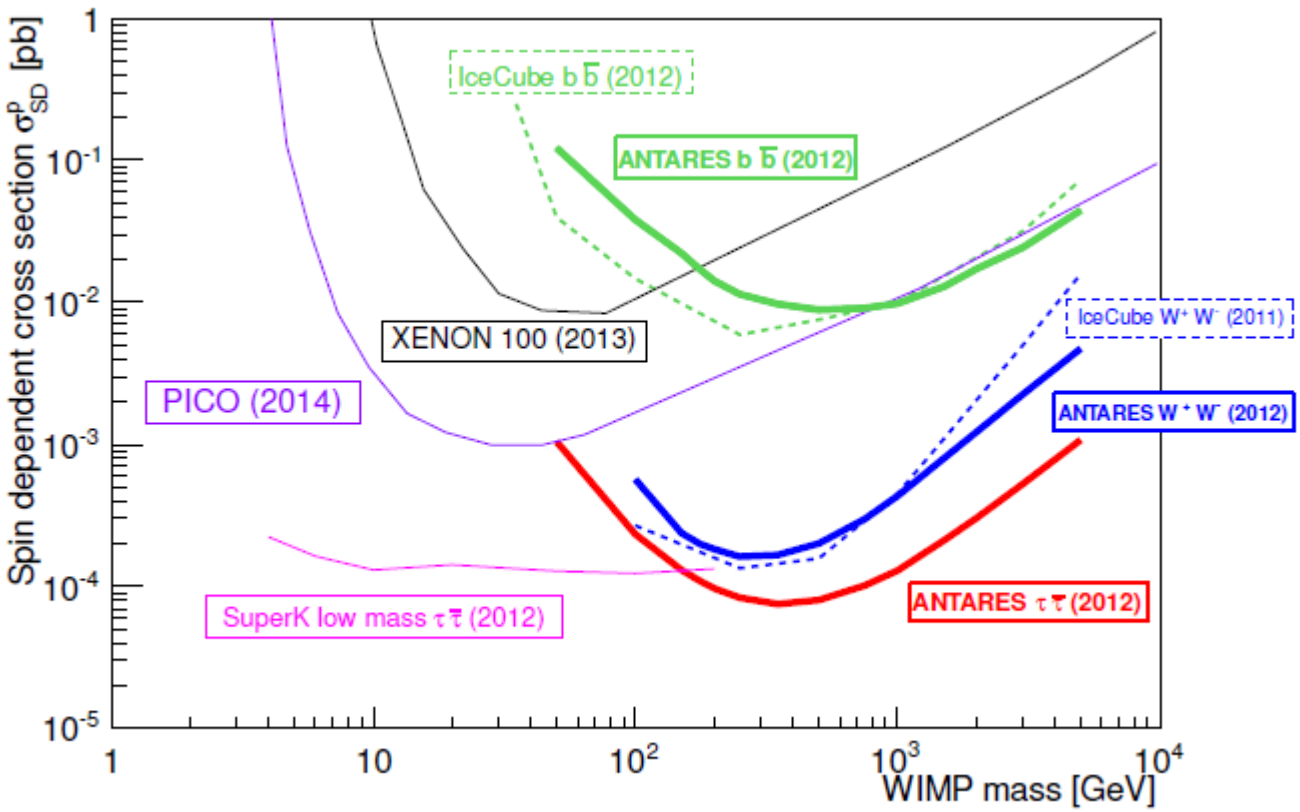
The Sun

- ν telescopes→ best results for Spin Dependent cross section

SI



SD



Summary - I

- ANTARES is significantly contributing to understand the origin of cosmic neutrinos observed by IceCube;
- **Southern sky** studied with ν_μ effective area comparable with IC-contained events and better angular resolution (~0.4°-water properties);
- Large ANTARES sensitivity for potential **point-like** sources
  - A single point-like source yielding >3 HESE is excluded for $\gamma \geq 2.3$
  - Upper limits on known GeV-TeV γ-ray sources $\sim 10^{-8}$ GeV/cm^2 s
- **Extended** sources: a common origin of few HESE in a region of $\Delta\Omega < 0.2$ sr in the Southern Sky can produce a signal in ANTARES
  - no observation of ν_μ from the Galactic ridge/IC hot spot;
  - Excluded simple extrapolation of Fermi-LAT (γ-rays) to HESE due to CR propagation;
- A large **multimessenger** effort
  - Study of flaring blazars (TANAMI) correlated with PeV HESE;

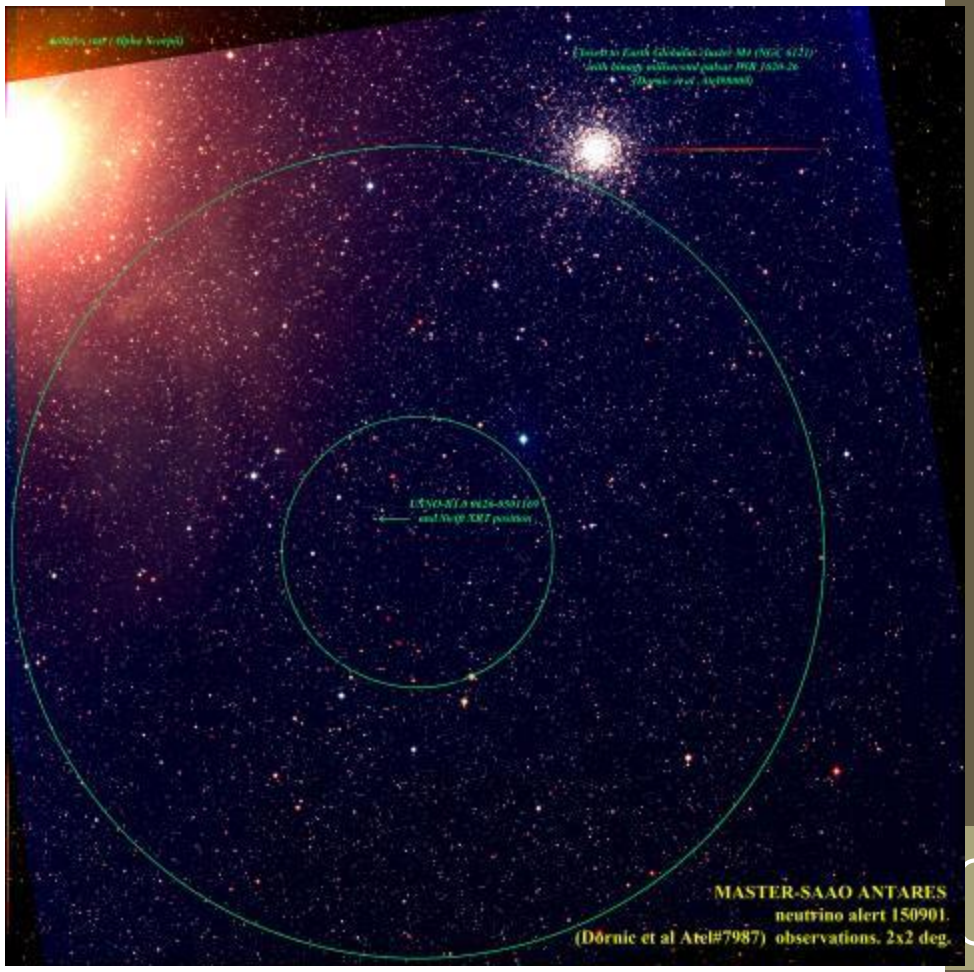
Summary - II

- **Showers** (ν_e, ν_τ, NC) now reconstructed with excellent angular resolution
  - Increase by 30% the signal for a E^{-2} spectrum (for 1:1:1 ν flux);
  - Analyses including showers in progress
- ANTARES and neutrino telescopes contribute to the indirect searches for **Dark Matter**
  - Most competitive limits for spin-dependent cross-section using studying the Sun direction
  - ANTARES rejects at 90% C.L. the interpretation of the PAMELA electron/positron as a signal from dark matter self-annihilation
- ANTARES continues data taking until the end of 2016.
- The near future: **KM3NeT- ARCA** (Phase 1)
  - 8 Towers (NEMO-style) + 24 DU (in construction phase)
  - Effective areas > x3 ANTARES
- The future of neutrino astronomy in the Northern hemisphere: KM3NeT-ARCA (Phase 2)

Spares

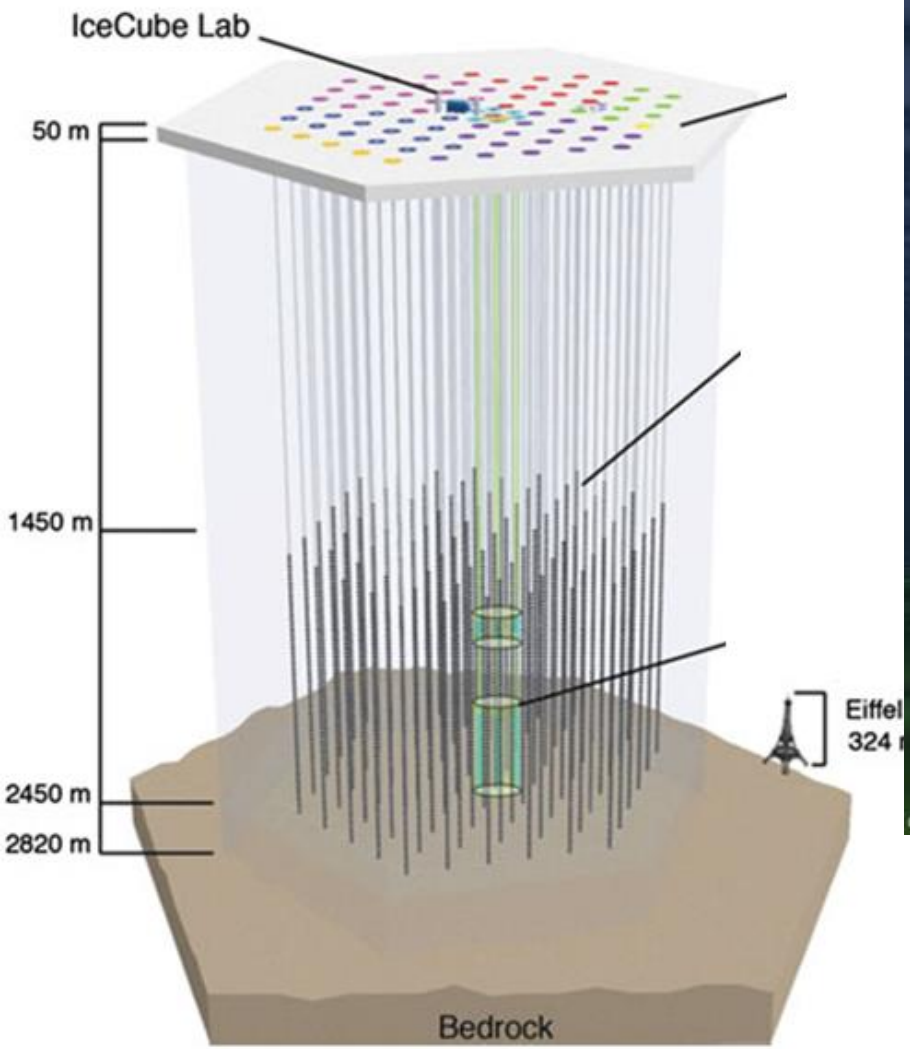
ANTARES ν @ 1/09/2015 – 7h38 UT

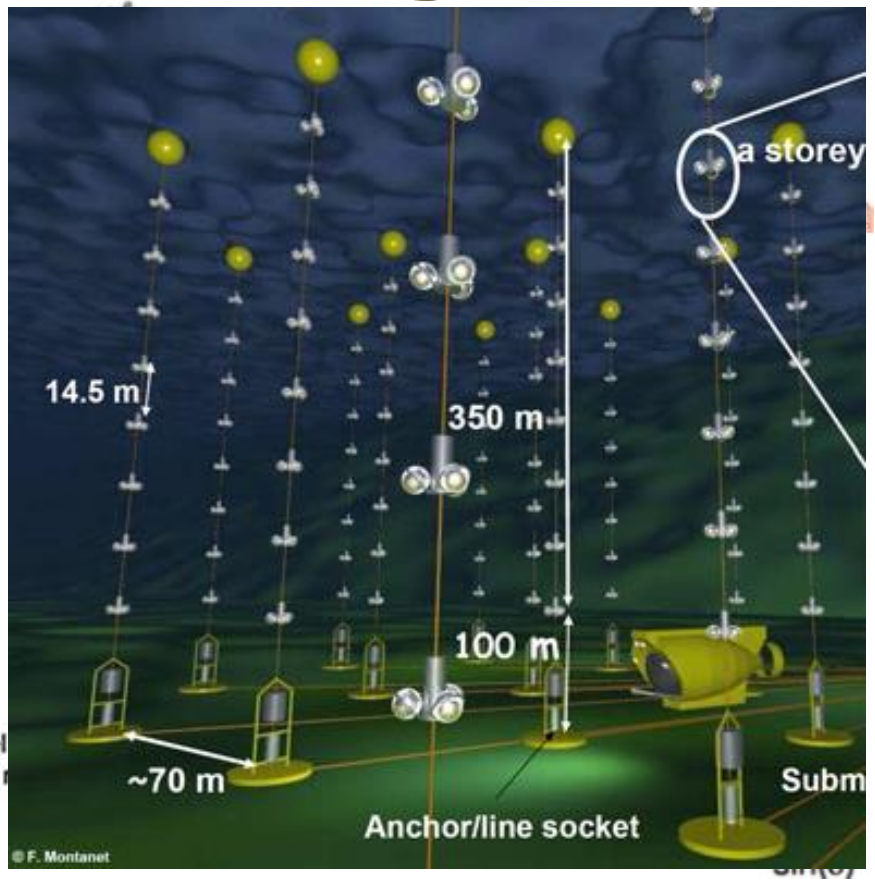
- One of the more energetic ν_μ so far (>60 TeV)
- Alert sent to robotic telescopes TAROT, MASTER and to the Swift/XRT.
- XRT has discovered an uncatalogue, bright and variable source at 0.15°.
- 10 alerts to XRT since mid 2013- no X-ray association before this one;
- We decide to publish a GCN notice and an Atels to advertise the astronomy community.
- Different Atels reporting for multi-wavelength observations: IR, optic, radio, X-ray, TeV.



See also: **arXiv:1508.01180**

Neutrino telescopes: the Eiffel Tower scaling law





Almost in scale.

True for **upgoing events**

ANTARES and the IceCube cosmic neutrinos

HESE

E>60 TeV	Data	Bck	Data-Bck	Best Fit	Normalization to the North
All events	20	2.7	17.3	18.2	**9.8**
Up (North)	5	1.4	**3.6**	**6.7**	**3.6**
Down (South)	15	1.3	**13.7**	**11.5**	**6.2**

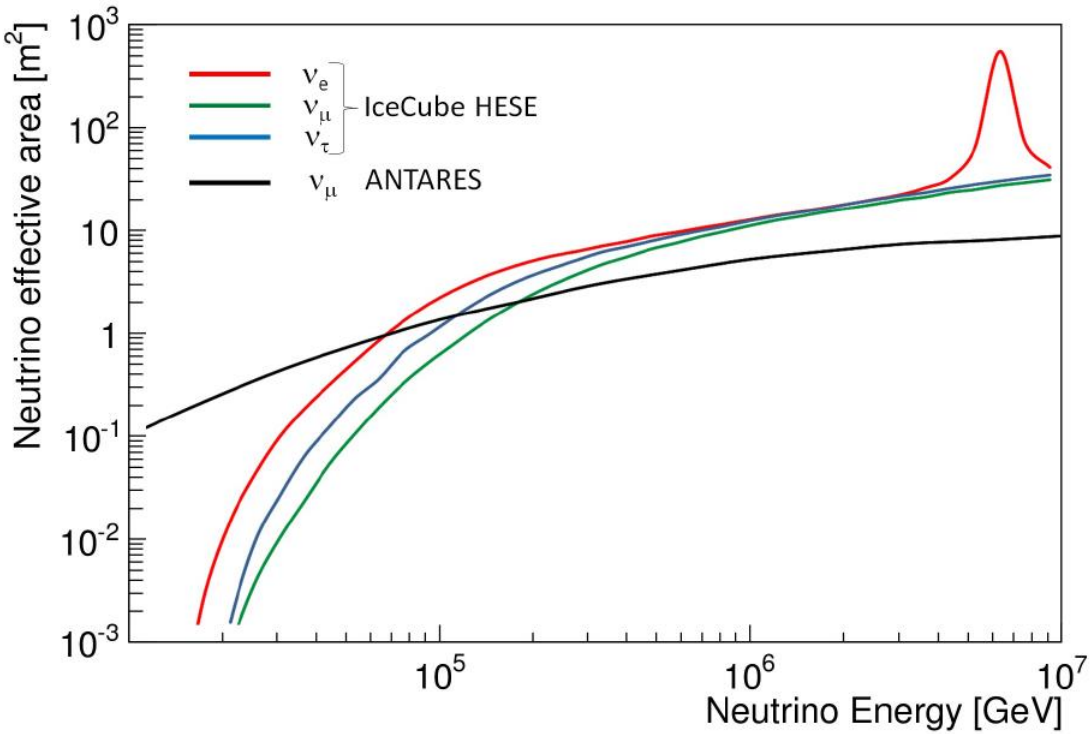
>40% excess of events from South, if you normalize to the North

PRD91 (2015)

E>25 TeV	Data	Bck	Data-Bck	Best Fit	Normalization to the North
All events	43	11.7	31.3	29.1	**12.8**
Up ($\sin\delta>0.06$)	11	5.3	**5.7**	**12.1**	**5.7**
Down($\sin\delta<-0.06$)	29	4.8	**24.2**	**15.0**	**7.1**

>50% excess of events from South, if you normalize to the North

IC-HESE vs. ANTARES A_{eff}



- Comparisons among experiments must be done using the effective areas, which depend on the particular analysis

Atmospheric neutrinos

- The ν_μ channel allows a proxy estimate of the energy
- of reconstructed ν_μ within 0.4° (for E^{-2} spectrum)

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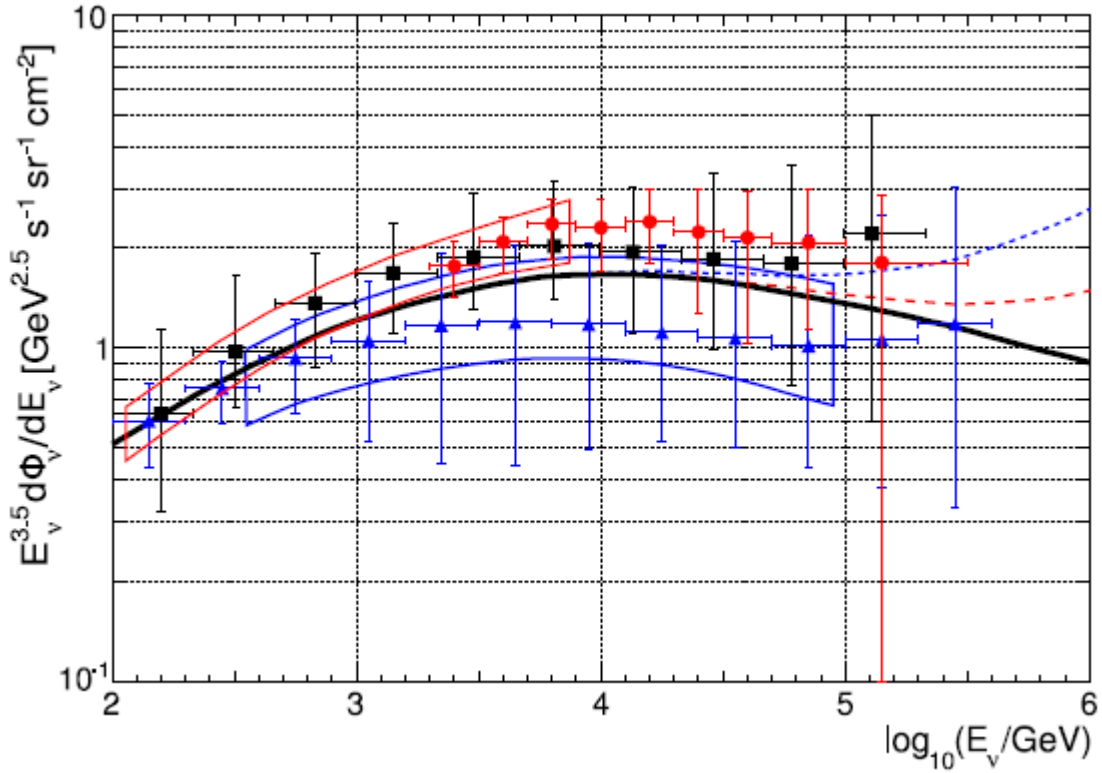
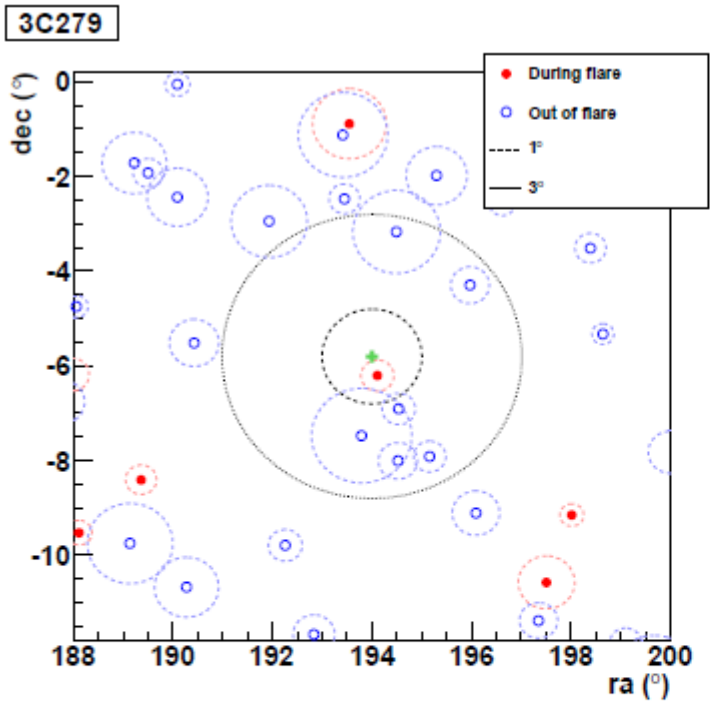
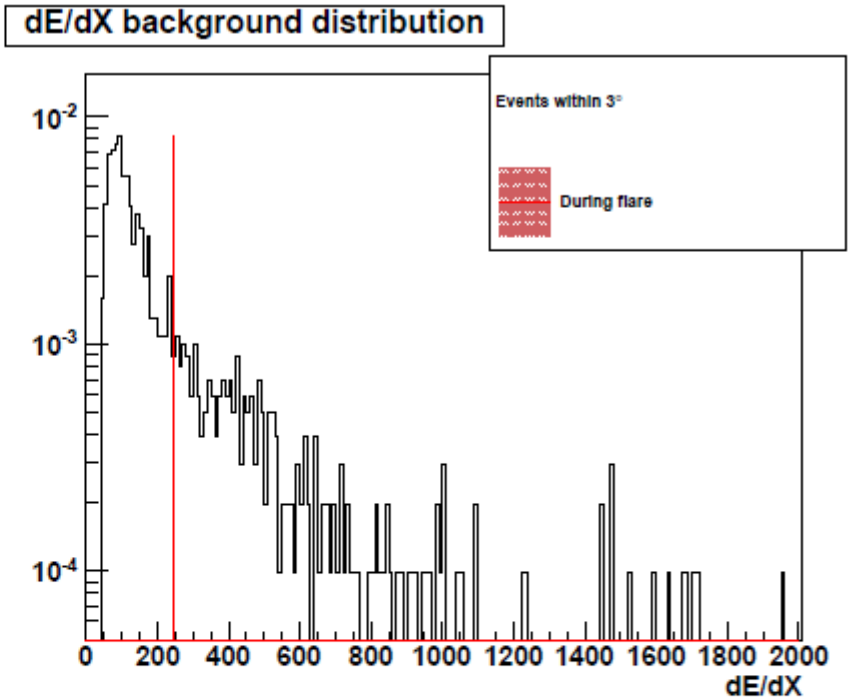


3C 279 Blazar



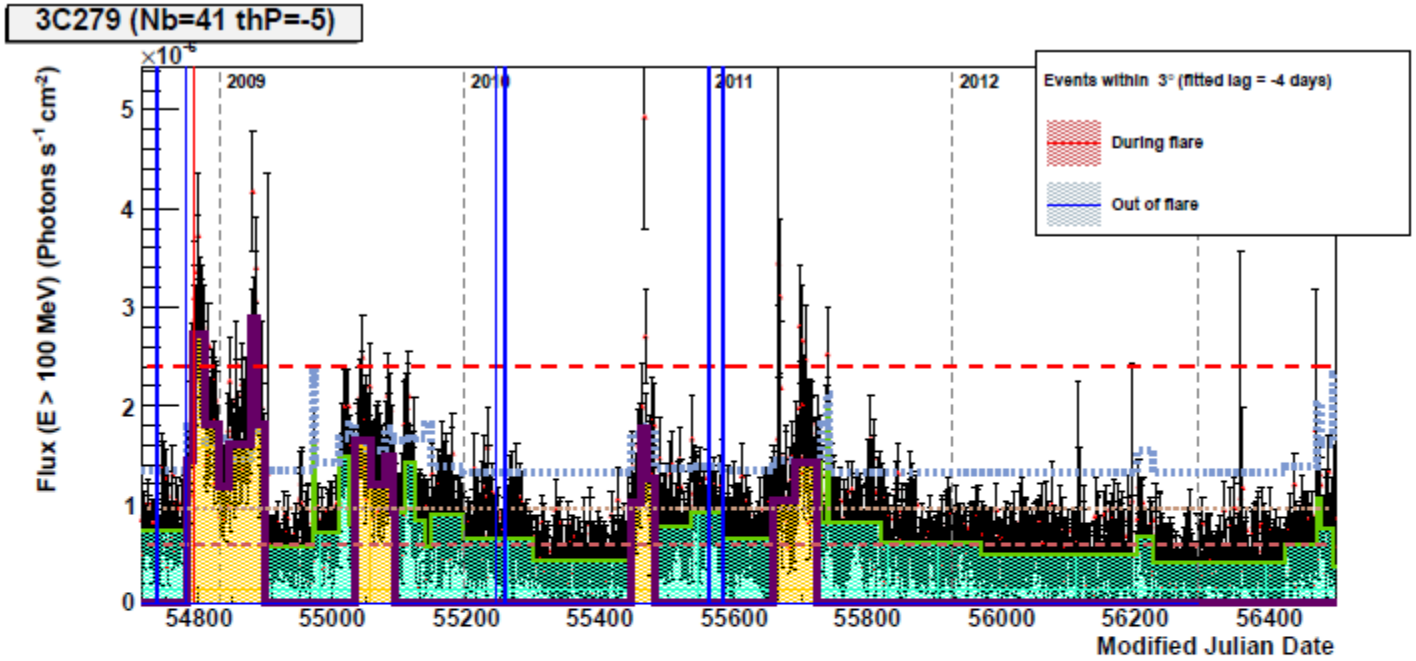


3C 279 (279 flaring days)

BEST: 3.3% (67%) E^{-2}

1 **event** (0.8 fitted signal) compatible in time and direction, in 54789 MJD (-4 days of fitted lag) at 0.4°(244 dE/dX, $\beta = 0.3°$, Λ=-4.5, elevation=-50°)

3C 279 Blazar



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