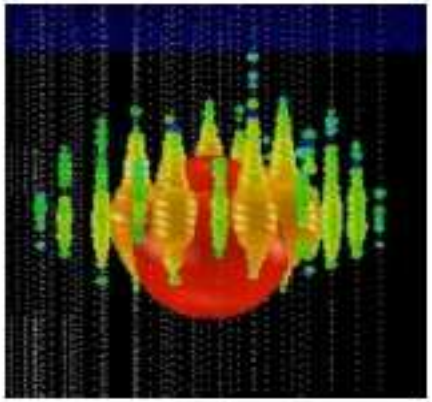
IceCube & ANTARES

Constraints to the IceCube signal from ANTARES
&
Combined Point Source Analysis IceCube/ANTARES

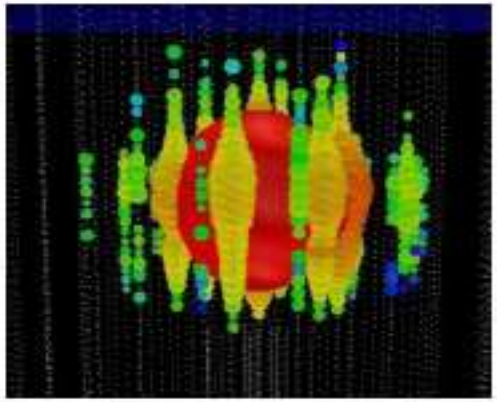
J. Brunner
CPPM
20/01/2015

IC79+IC86 ν UHE Search

2 events observed in the PeV energy region in IC 86 sample

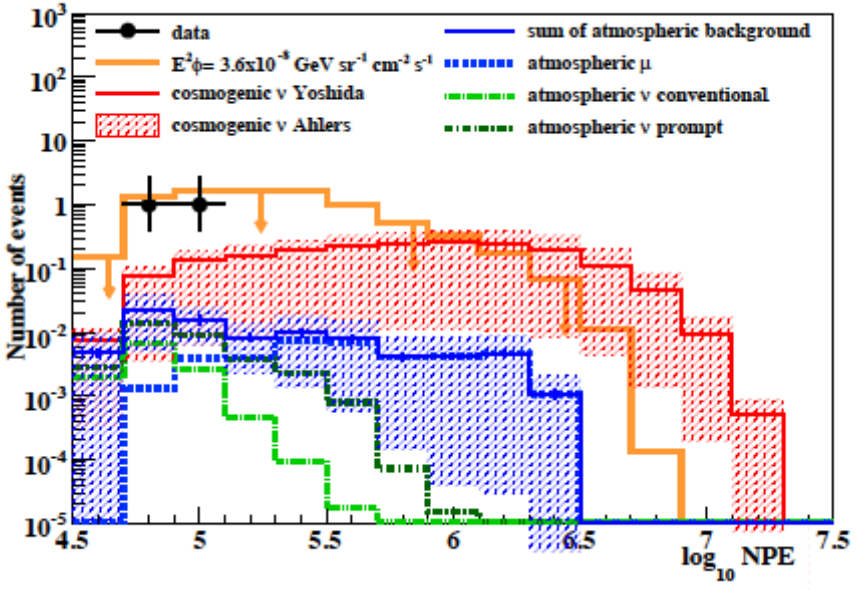


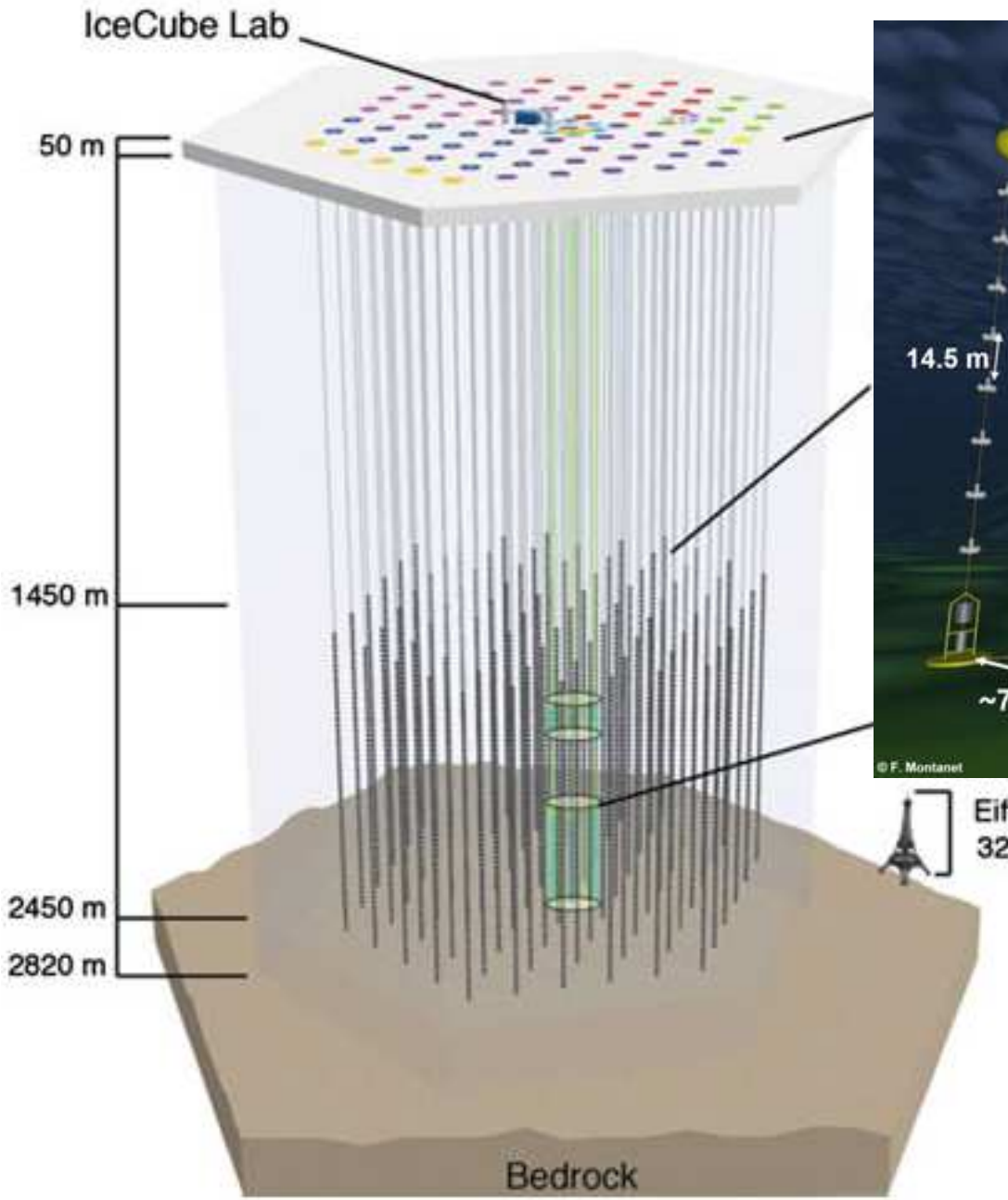
Ernie
GMT: 2012/1/3 9:34:01

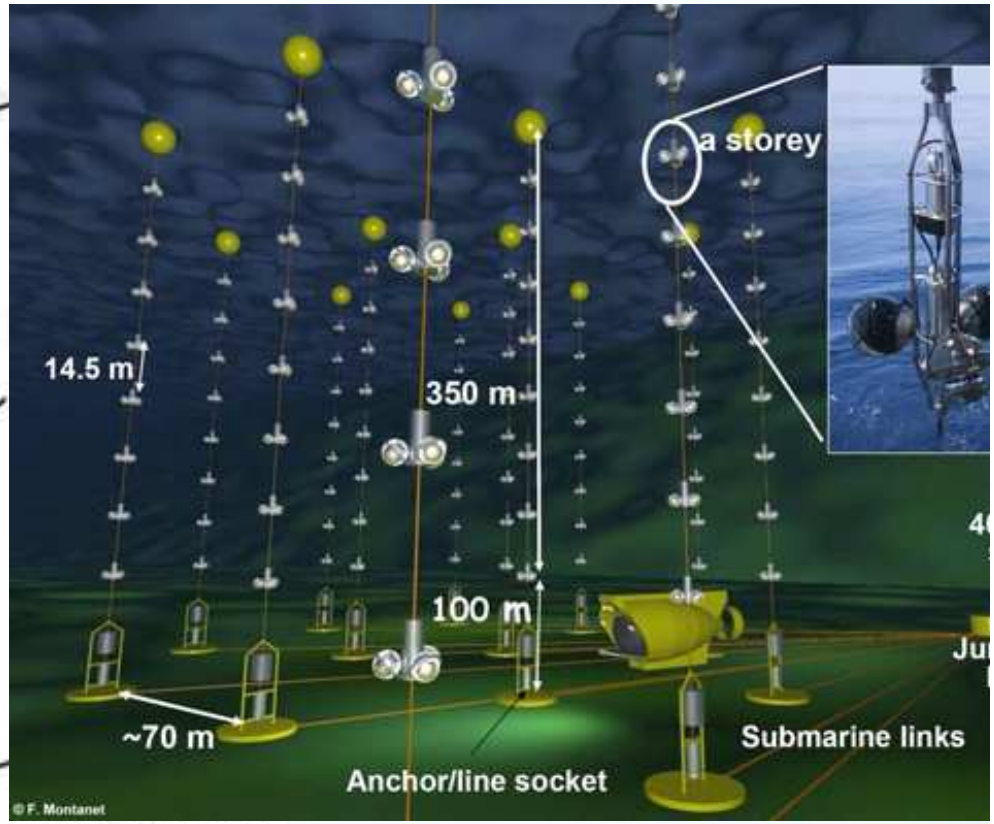


Bert
GMT: 2012/8/8 12:23:18

2.8 σ beyond conventional background
📖 Phys. Rev. Lett. 111, 021103 (2013)





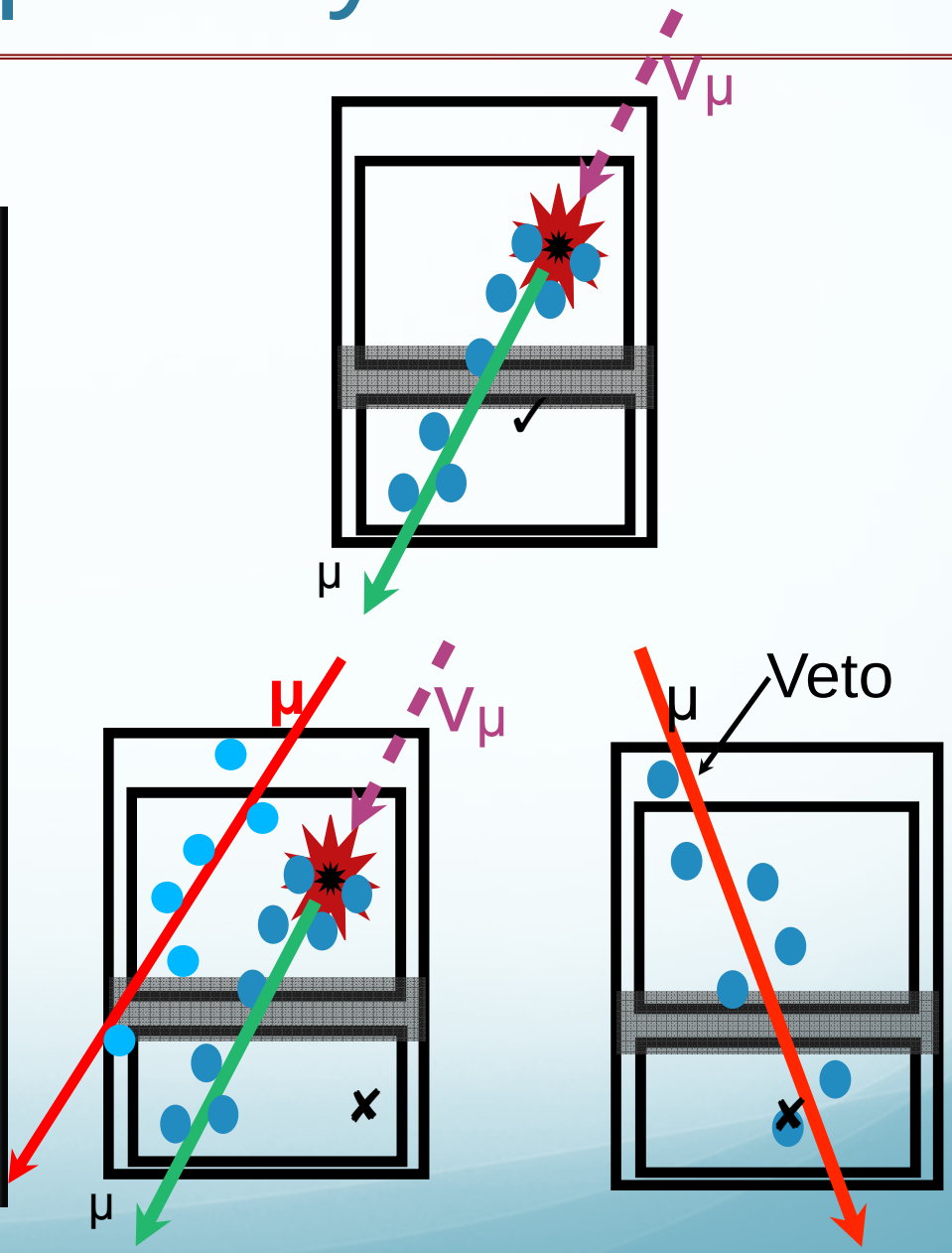


Almost in scale

Follow up analysis

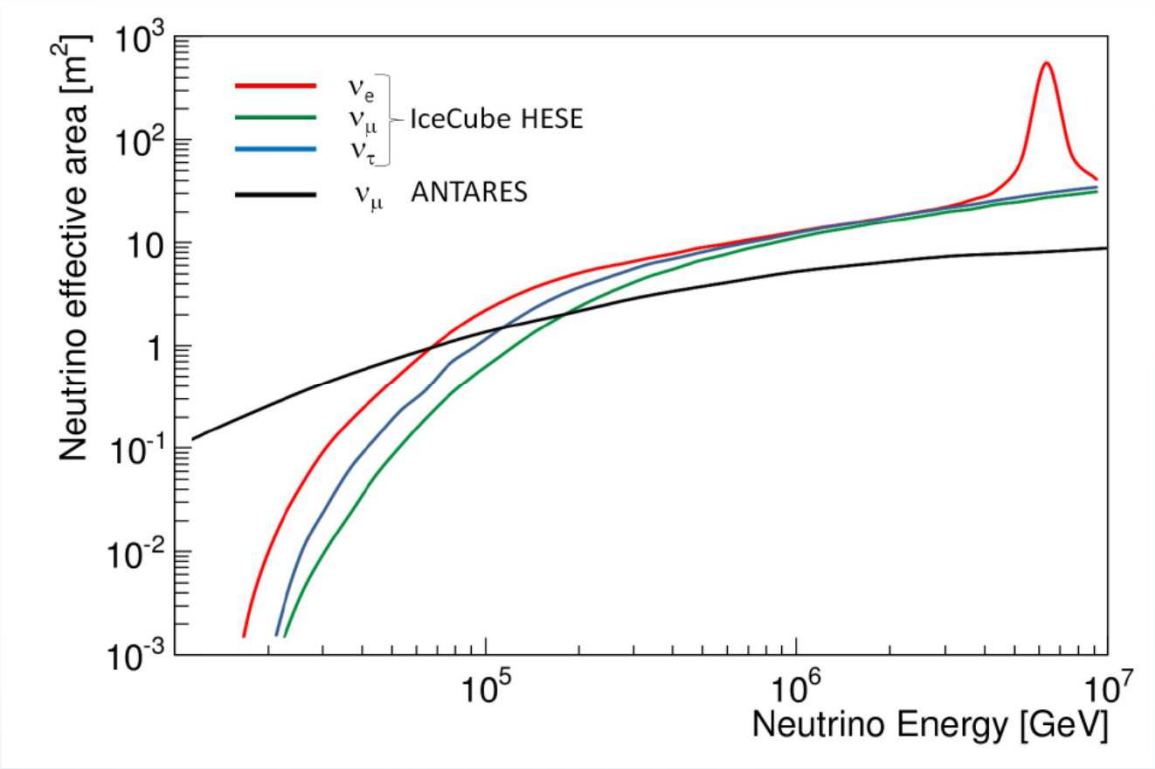
2 yr : May 2010 – May 2012 (662 days)

- Explicit contained search at high energies (cut: Q_{tot}>6000)
- 400 Mton effective fiducial mass
- Use atmospheric muon veto
- Sensitive to all flavors in region above 60TeV
- Three times as sensitive at 1 PeV
- Estimate background from data



High Energy Starting Events (HESE)

IC-HESE vs. ANTARES A_{eff}



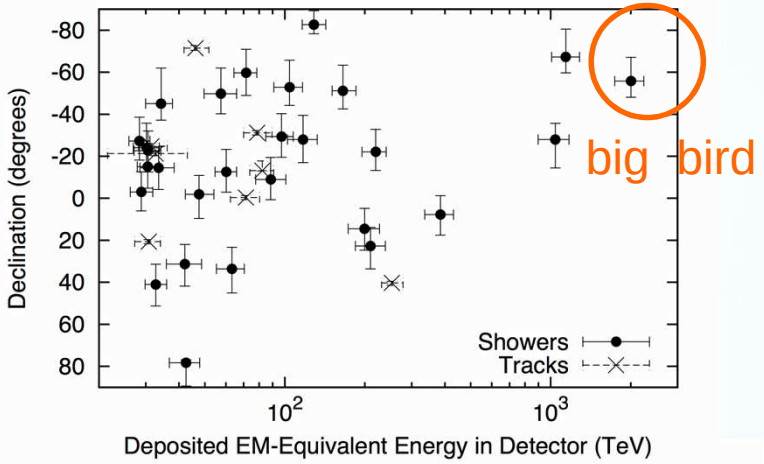
- IceCube → 4π, high energy sample (E_ν>30 TeV), almost background free
- ANTARES→ ν_μ only, **Southern sky only**
- $A_{eff}^{\text{ANTARES}} > A_{eff}^{\text{HESE}}$ at E_ν < 60 TeV

Follow up analysis: the IceCube signal

2 year analysis:
28 events
4.1σ
(📖Science 342, 2013)

→

3 year analysis:
37 events
5.7σ
(📖PRL, 113, 101101, 2014)



7 → 9 track-like events

1º angular resolution

muon takes some energy away

total expected background: 11 events

21 → 28 cascade-like events

10° - 45° angular resolution

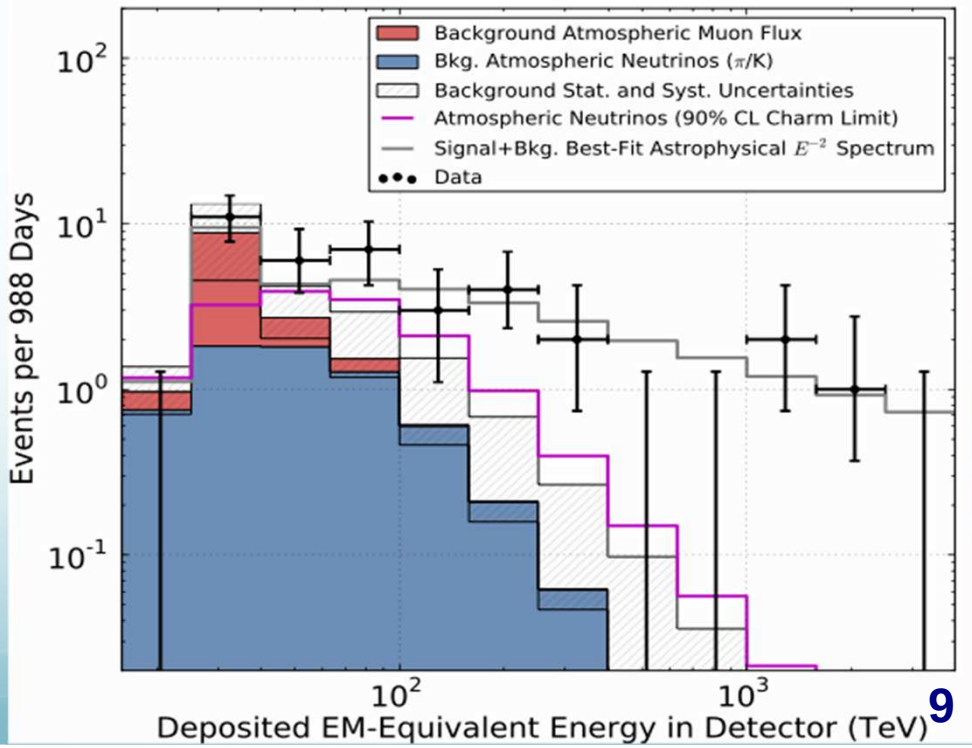
15% visible energy reconstruction

Best fit (per flavor):

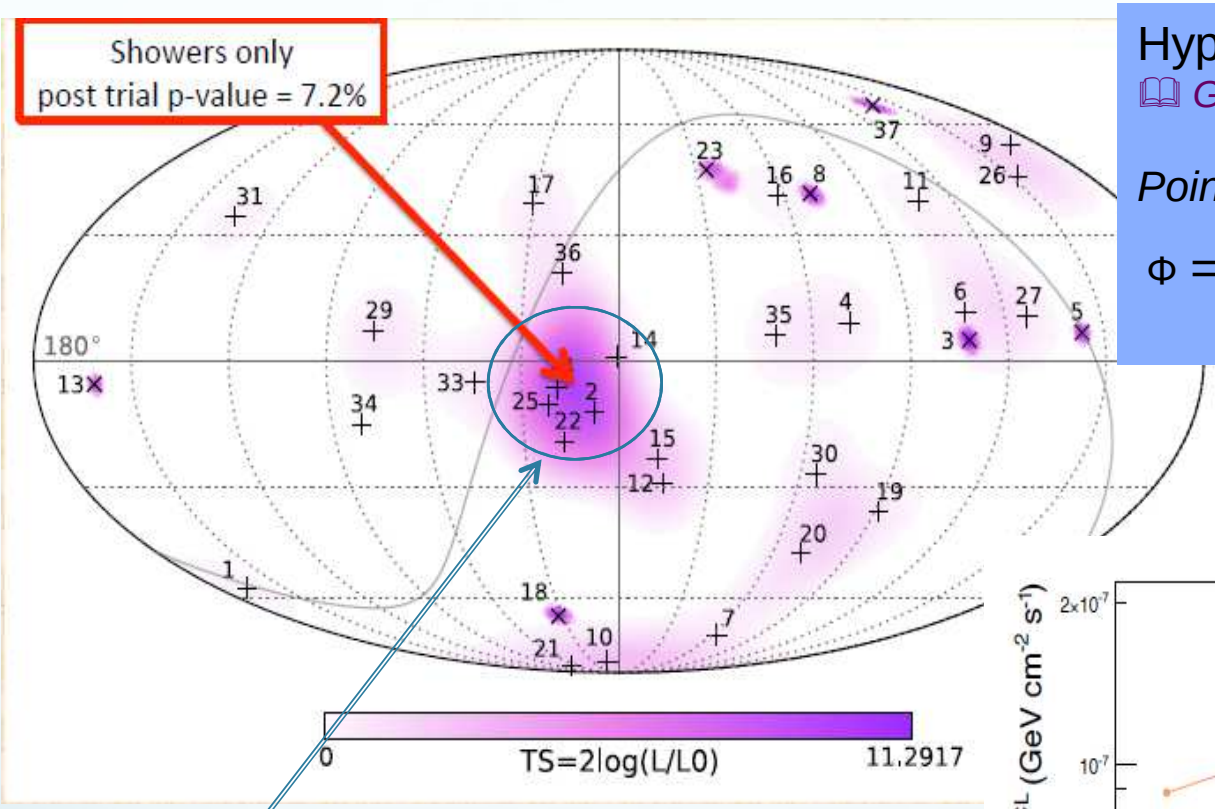
$0.95 \pm 0.3 \times 10^{-8}\ E^{-2}\ GeV\ cm^{-2}\ s^{-1}\ sr^{-1}$

highest energy event @ 2 PeV

cutoff at ~2.3 PeV ?



A source near the Galactic Center?

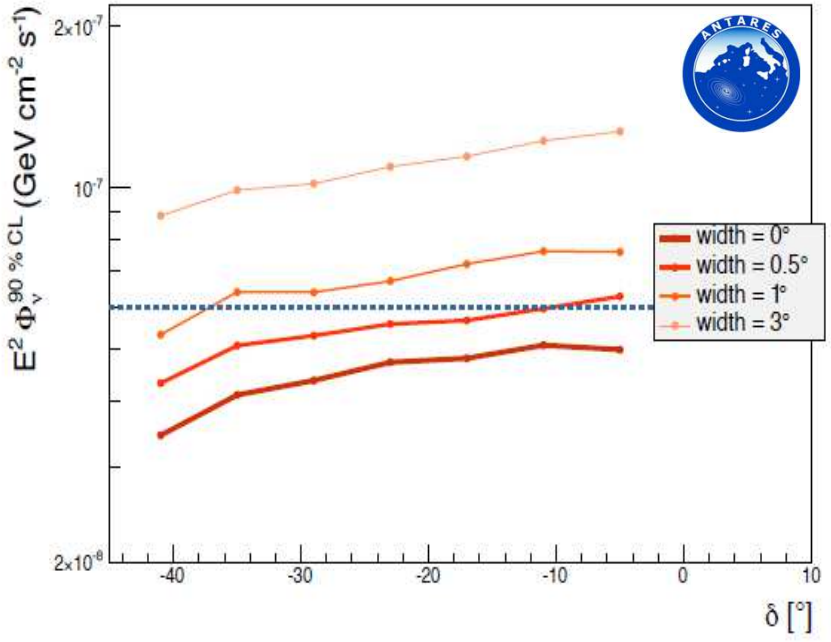


Hypothesized Galactic Source ?

📖 *Gonzalez-Garcia et al, APP 57 (2014)*

Point Source at (α,δ)=(−79°, −23°):

$\Phi = 6 \times 10^{-8}\ E^{-2}$ GeV cm^{-2} s^{-1}

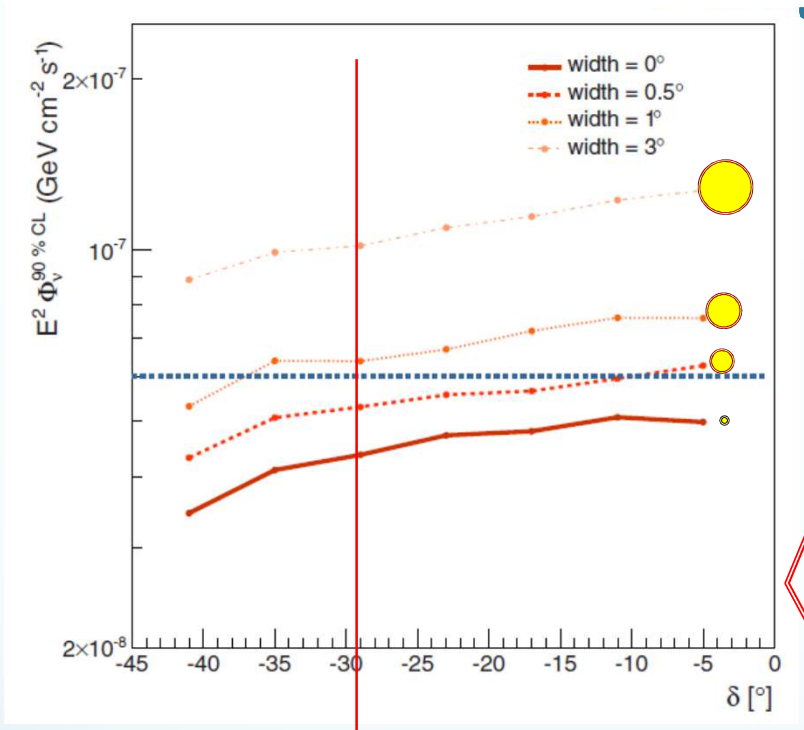


ANTARES excludes single point source (E^{-2} spectrum) as origin of the cluster within 20° off GC

📖 Astrophys. J. Lett. 786:L5 (2014)

ANTARES has upper limits

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

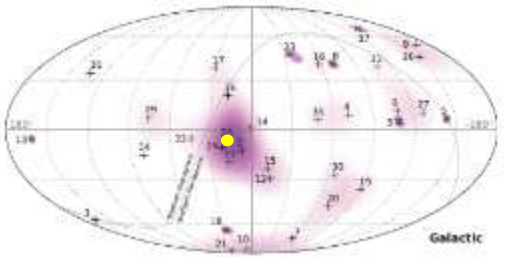


For different energy spectra $E^{-\Gamma}$:
(similar method using the A_{eff})

$\Gamma =$	$\Phi_0^{A,\Gamma}$ (GeV cm^{-2} s^{-1})
2.0	4.0×10^{-8}
2.1	1.2×10^{-7}
2.2	3.2×10^{-7}
2.3	8.4×10^{-7}
2.4	2.2×10^{-6}
2.5	5.5×10^{-6}

$$E^2\Phi^{A,2.0} \equiv \Phi_0^{A,2.0} \simeq 4.0 \times 10^{-8}\ \text{GeV cm}^{-2}\text{s}^{-1}\text{, point-like}$$
$$\simeq 5.0 \times 10^{-8}\ \text{GeV cm}^{-2}\text{s}^{-1}\text{, for } 0.5°$$
$$\simeq 6.5 \times 10^{-8}\ \text{GeV cm}^{-2}\text{s}^{-1}\text{, for } 1°$$
$$\simeq 10 \times 10^{-8}\ \text{GeV cm}^{-2}\text{s}^{-1}\text{, for } 3°$$

Results



$$\Phi_0^{p,\Gamma} = 4\pi \cdot \left(\frac{n_p}{N_{IC}}\right) \cdot \Phi_0^{D,\Gamma}$$

	IceCube $\Phi_0^{p,\Gamma}$ (GeV cm^{-2} s^{-1})					ANTARES 90% C.L. upper limit
$\Gamma =$	$n_p = 1$	$n_p = 2$	$n_p = 3$	$n_p = 4$	$n_p = 5$	
2.0	$6.9\ 10^{-9}$	$1.4\ 10^{-8}$	$2.1\ 10^{-8}$	$2.8\ 10^{-8}$	$3.5\ 10^{-8}$	$4.0\ 10^{-8}$
2.1	$2.6\ 10^{-8}$	$5.1\ 10^{-8}$	$7.7\ 10^{-8}$	$1.0\ 10^{-7}$	$1.3\ 10^{-7}$	$1.2\ 10^{-7}$
2.2	$9.0\ 10^{-8}$	$1.8\ 10^{-7}$	$2.7\ 10^{-7}$	$3.6\ 10^{-7}$	-	$3.2\ 10^{-7}$
2.3	$3.3\ 10^{-7}$	$6.6\ 10^{-7}$	$9.9\ 10^{-7}$	-	-	$8.4\ 10^{-7}$
2.4	$1.2\ 10^{-6}$	$2.3\ 10^{-6}$	-	-	-	$2.2\ 10^{-6}$
2.5	$3.9\ 10^{-6}$	$7.9\ 10^{-6}$	-	-	-	$5.5\ 10^{-6}$

- The ANTARES 90% C.L. upper limit excludes that a single point-like source produces n_p>5 HESE, assuming Γ=2.0.
- A single point-like source yielding n_p>2 is excluded for Γ=2.3
- A clusters made of $n_p \geq 2$ is excluded for Γ> 2.3.

AGNs close to Ernie and Bert?

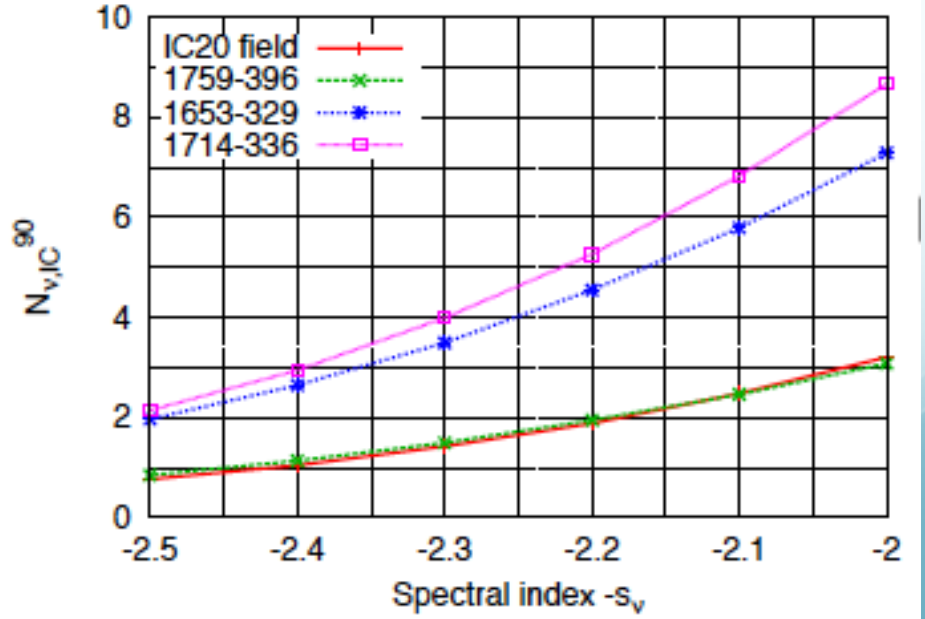
TANAMI collaboration reported observations of 6 bright blazars locally compatible with the 2 first PeV IceCube events IC14 and IC20.

📖 Krauß, F. et al. 2014, A&A, 566, L7

Source	N_{sig}	p	Limit 10^{-8} GeV^{-1} cm^{-2} s^{-1}	$N_{\nu,IC}=1$	$N_{\nu,IC}=2$	$N_{\nu,IC}=3$	$N_{\nu,IC}=4$
0235–618	0	1	1.3	-2.4	-2.1	-2.0	-1.9
0302–623	0	1	1.3	-2.4	-2.1	-2.0	-1.9
0308–611	0	1	1.3	-2.4	-2.1	-2.0	-1.9
1653–329	1.1	0.10	2.9	<-2.5	-2.5	-2.3	-2.2
1714–336	0.9	0.04	3.5	<-2.5	-2.5	-2.3	-2.2
1759–396	0	1	1.4	-2.4	-2.1	-2.0	-1.8

Soon on arXiv

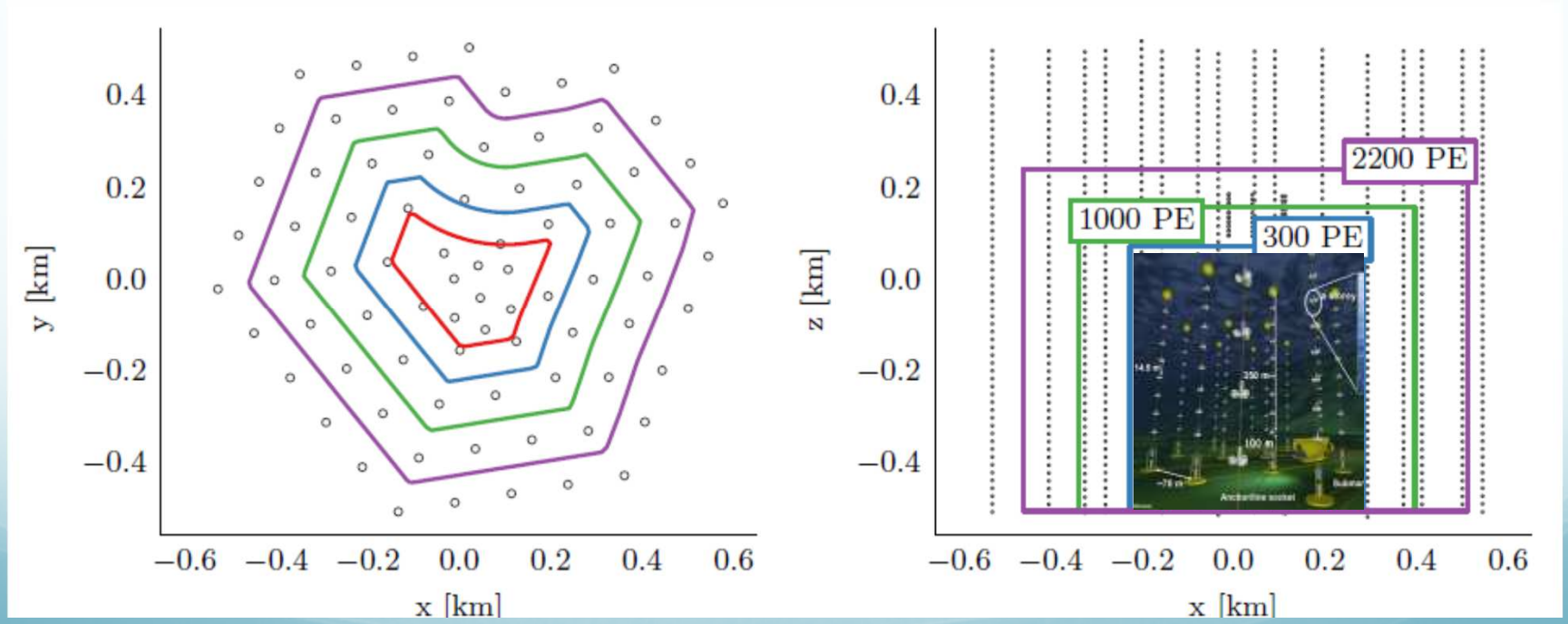
→ Relevant constraints on spectral index of potential source



Latest update from IceCube

Atmospheric and Astrophysical Neutrinos above 1 TeV Interacting in IceCube

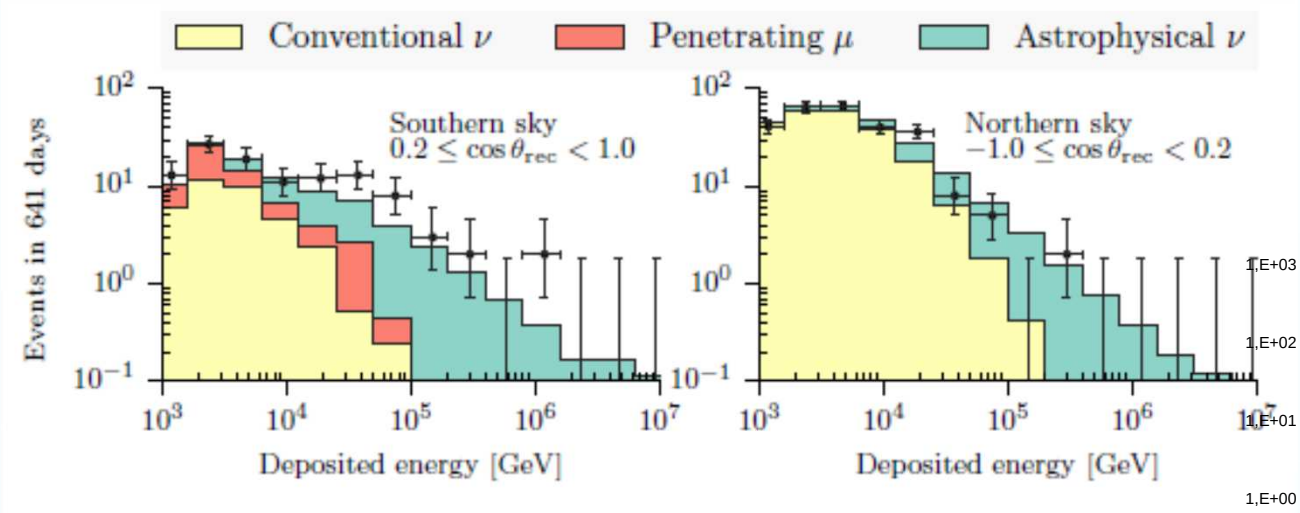
M. G. Aartsen,[2] M. Ackermann,[47] J. Adams,[15] J. A. Aguilar,[23] M. Ahlers,[28] M. Ahrens,[38] D. Altmann,[22] T. Anderson,[44] C. Arguelles,[28] T. C. Arlen,[44] J. Auffenberg,[1] X. Bai,[36] S. W. Barwick,[25] V. Baum,[29] J. J. Beatty,[17,18] J. Becker Tjus,[10] K.-H. Becker,[46] S. BenZvi,[28] P. Berghaus,[47] D. Berley,[16] E. Bernardini,[47] A. Bernhard,[32] D. Z. Besson,[26] G. Binder,[8,7] D. Bindig,[46] M. Bissok,[1] E. Blaufuss,[16] J. Blumenthal,[1] D. J. Boersma,[45] C. Bohm,[38] F. Bos,[10] D. Bose,[40] S. Böser,[11] O. Botner,[45] L. Brayeur,[13] H.-P. Bretz,[47]



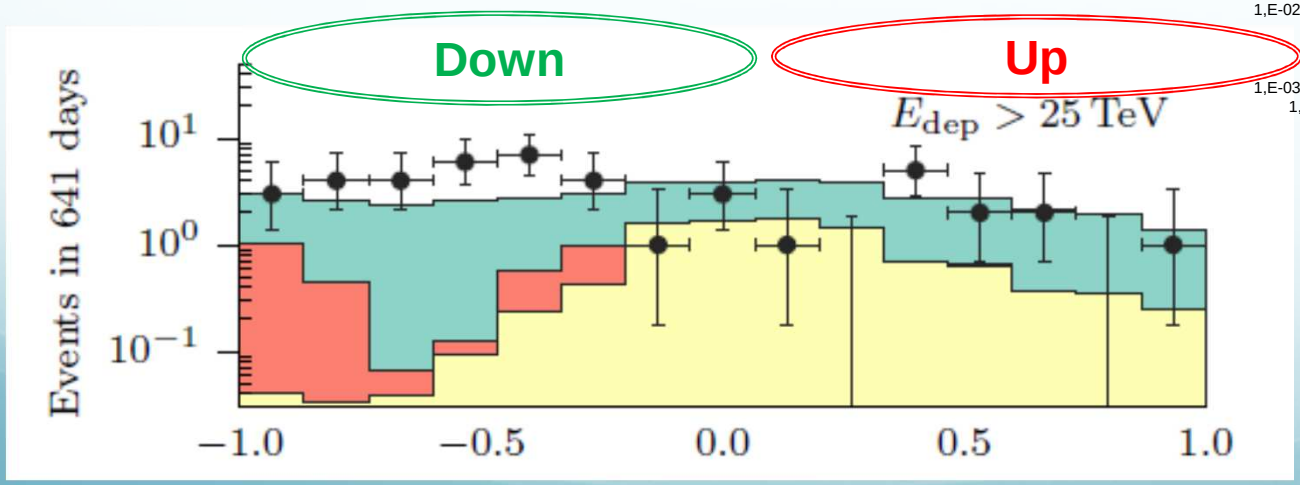
arXiv:1410.1749

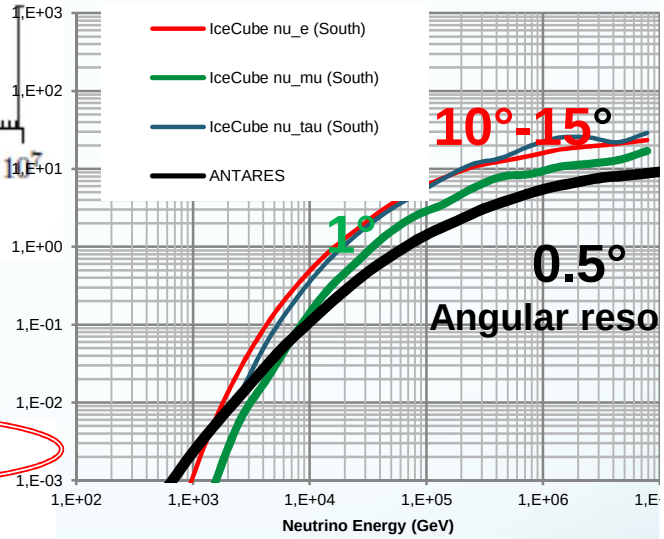
Almost to scale

Latest update from IceCube



Fit of unbroken power law, → $E^{-2.46}$
mildly excludes a spectral index of 2

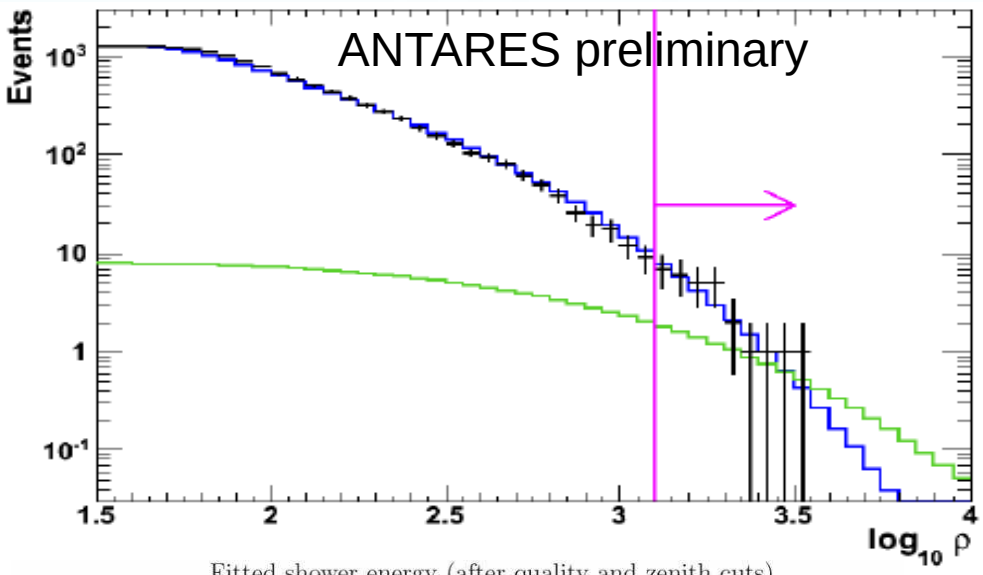




Excess in Southern sky?
Galactic contribution?

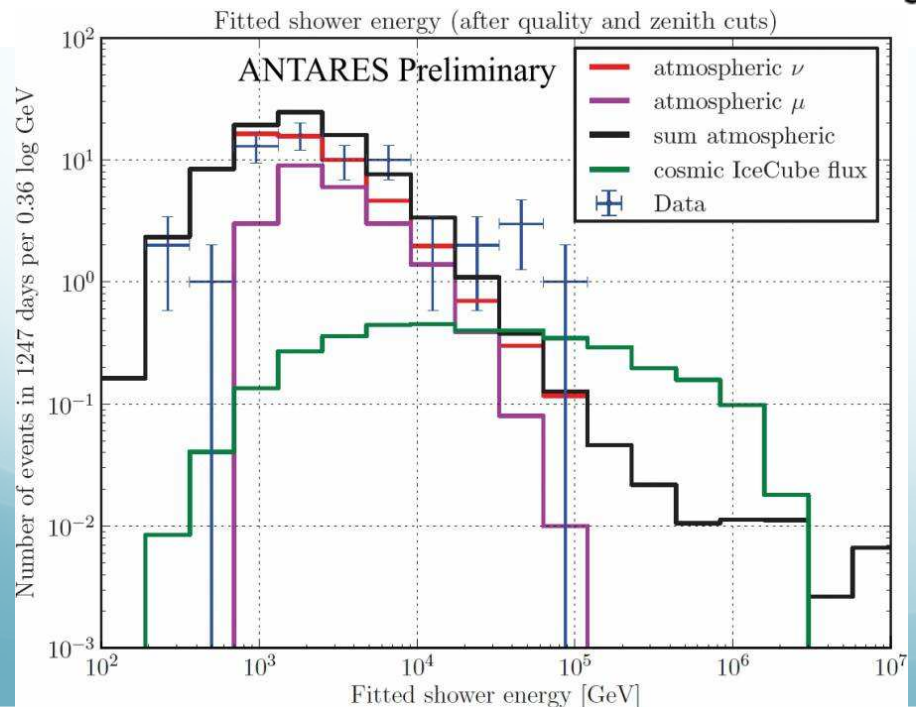
Future Constraints by ANTARES?

ANTARES Diffuse Neutrino Searches



Muons (2008-2011) 855 days
8 observed events (8.4 expected) flux limit (90%CL):
5.1×10^{-8} GeV/cm^2/s/sr

45 TeV < E < 10 PeV

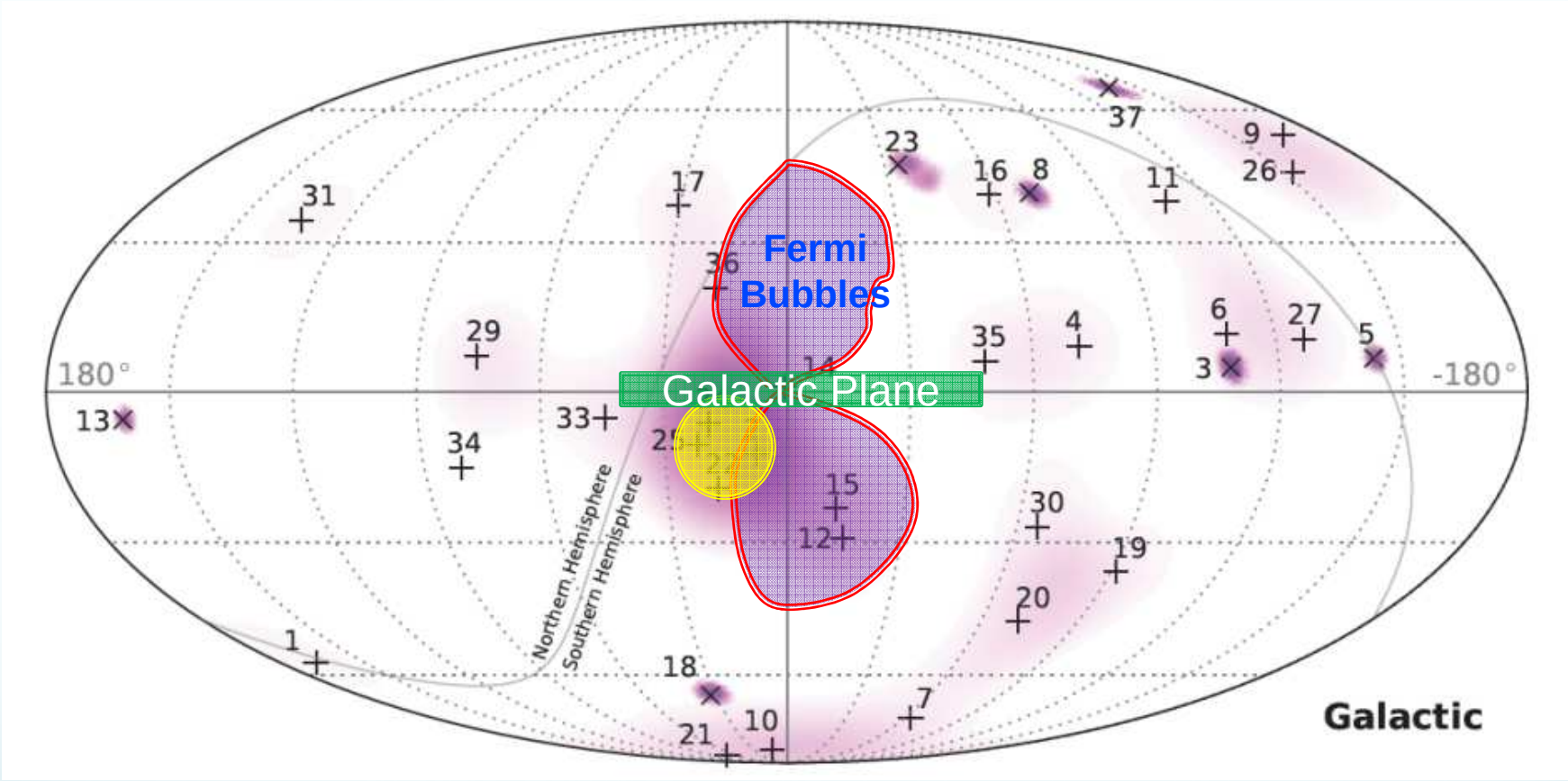


Cascades (2008-2012) 1247 days
sensitivity: 2.5×10^{-8} GeV/cm^2/s/sr

8 events observed, 4.9 expected
1.5 σ excess
signal: $1.32 * 10^{-8}$ GeV/cm^2/s/sr

Flux limit (90%CL)
4.92×10^{-8} GeV/cm^2/s/sr
23 TeV < E < 7.8 PeV
Angular resolution ~6-7°

Reducing the search window



- **Fermi-Bubble region**. Optimized for Γ=2.0, 3years of data

Off zone = 11 events ; On zone = 16 events → +1.2σ excess

- **Galactic Center region**. Optimized for Γ=2.6-2.7 and using 5y of data.

Off zone= 166 events ; On region= 177 events → +0.83σ excess

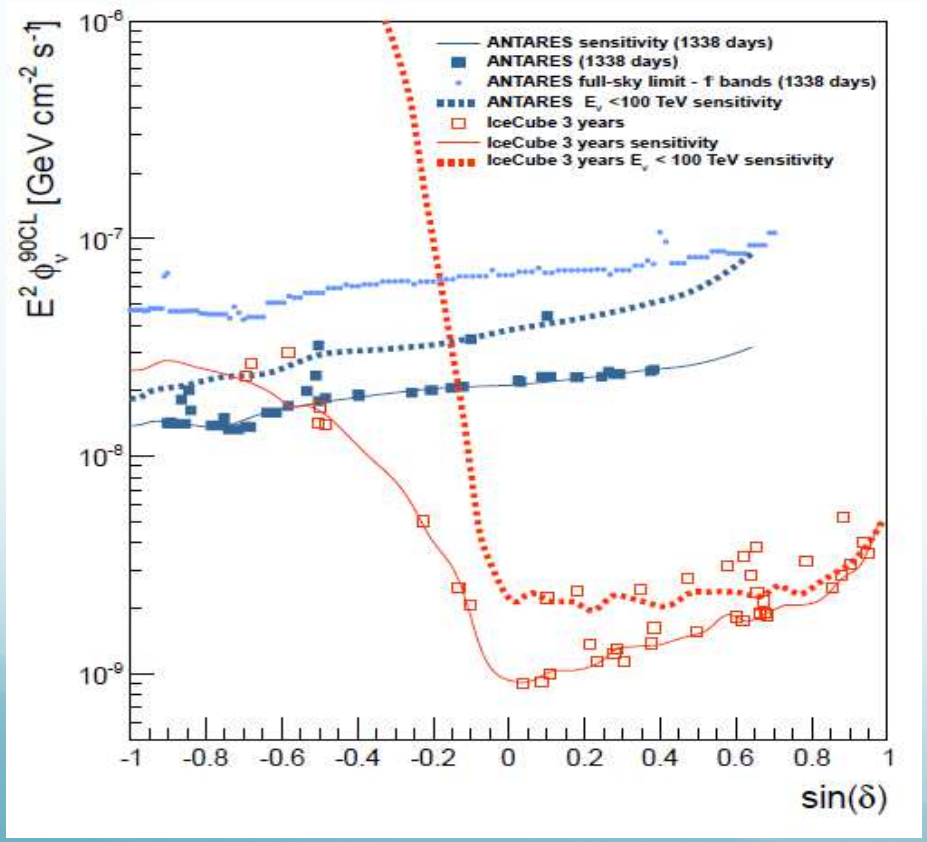
- **IC hot spot.** What size? To be optimized for IC Best fit Γ=2.2-2.4

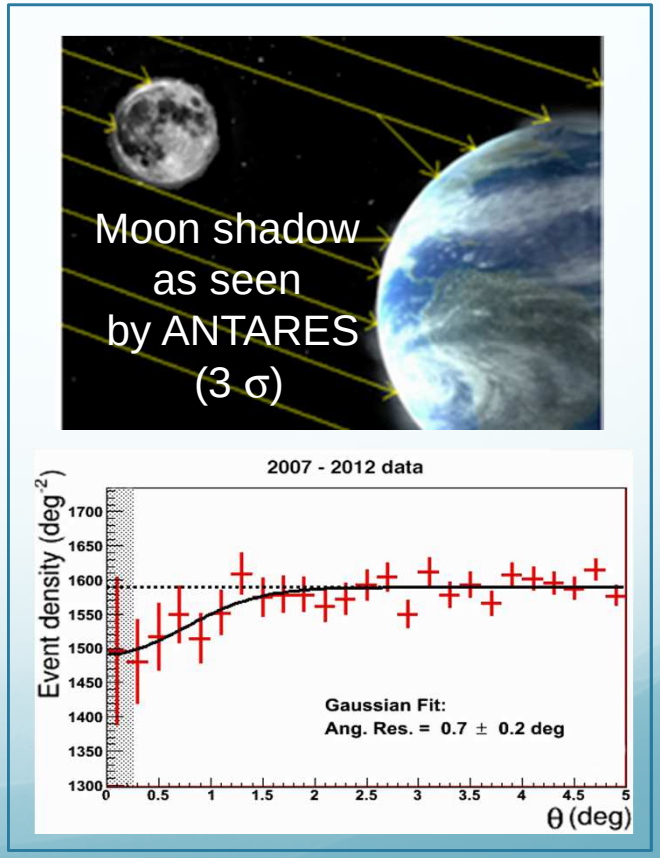
Muons only !

Point-source searches

❖ Antares updated muon search 2007-2012 (1340 days)

- 5516 neutrino candidates (90 % of which being better reconstructed than 1º)
- No significant excess
- Same most significant cluster with 6 additional events: p-value = 2.1% (2.3 σ)
  Compatible with background hypothesis



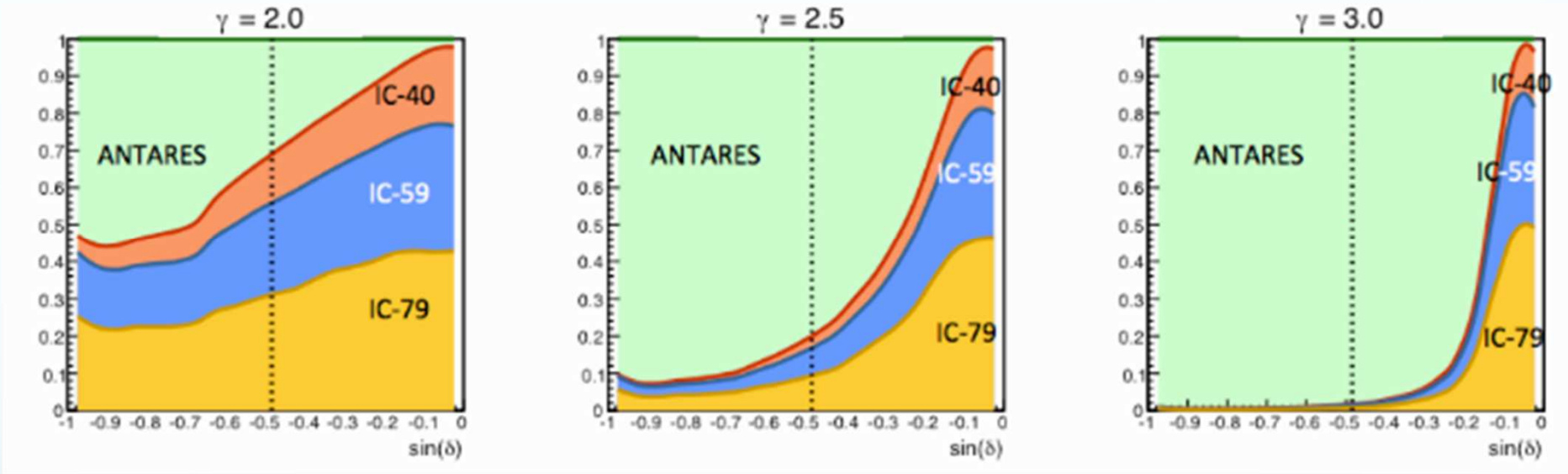


📖 S. Adrian-Martinez et al., Astrophys. J. Lett. 786 L5, 2014

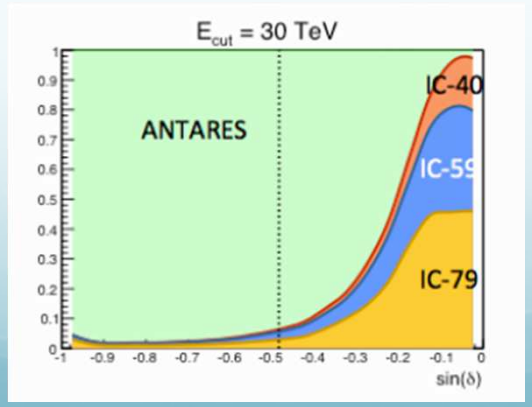
Join ANTARES-IceCube search

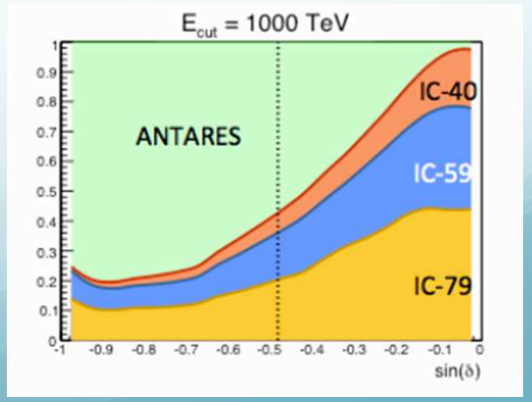
ANTARES 2007-2012 and the IC40, IC59, and IC79 samples for the Southern Hemisphere

Fraction of signal events which would be detected by each sample ($E^{-\gamma}$):



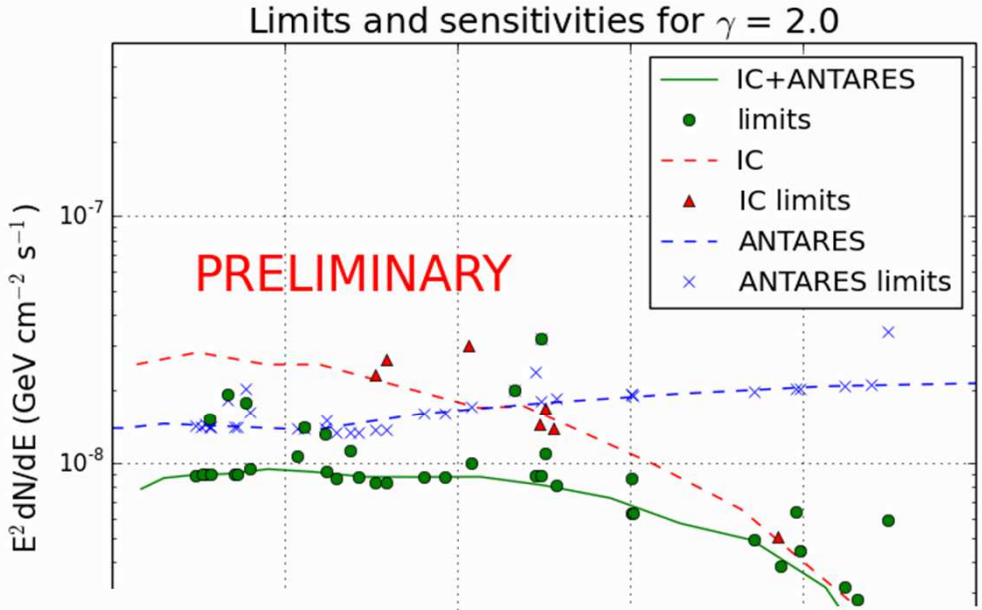
$$\frac{d\Phi}{dE} = \Phi_0 E^{-2} e^{-\sqrt{\frac{E}{E_{cutoff}}}}$$

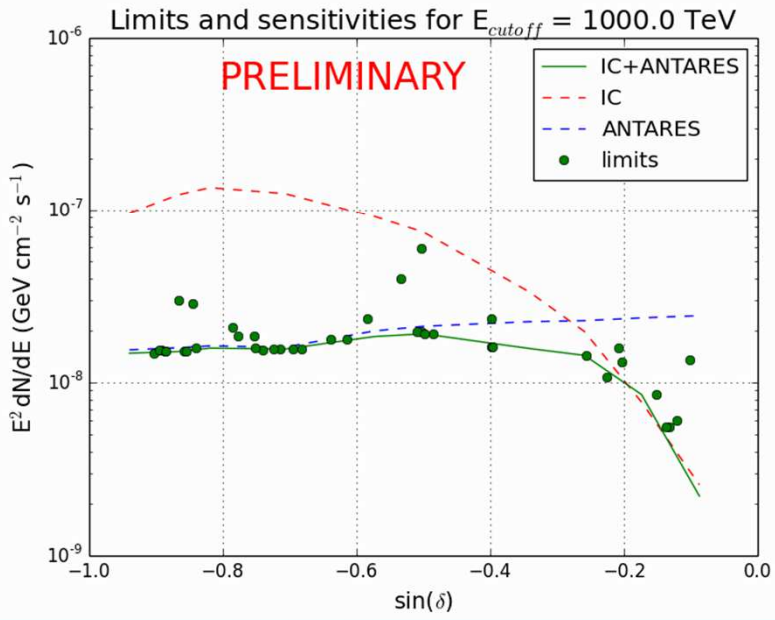


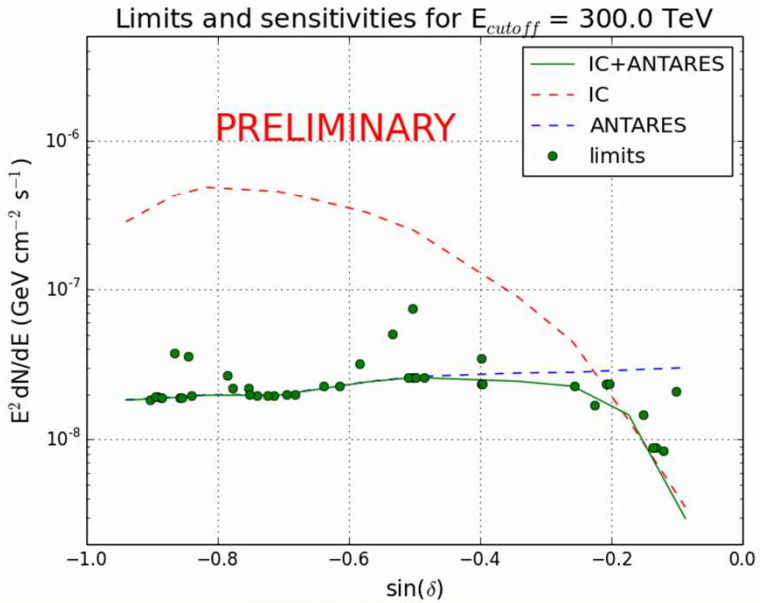


Join ANTARES-IceCube search

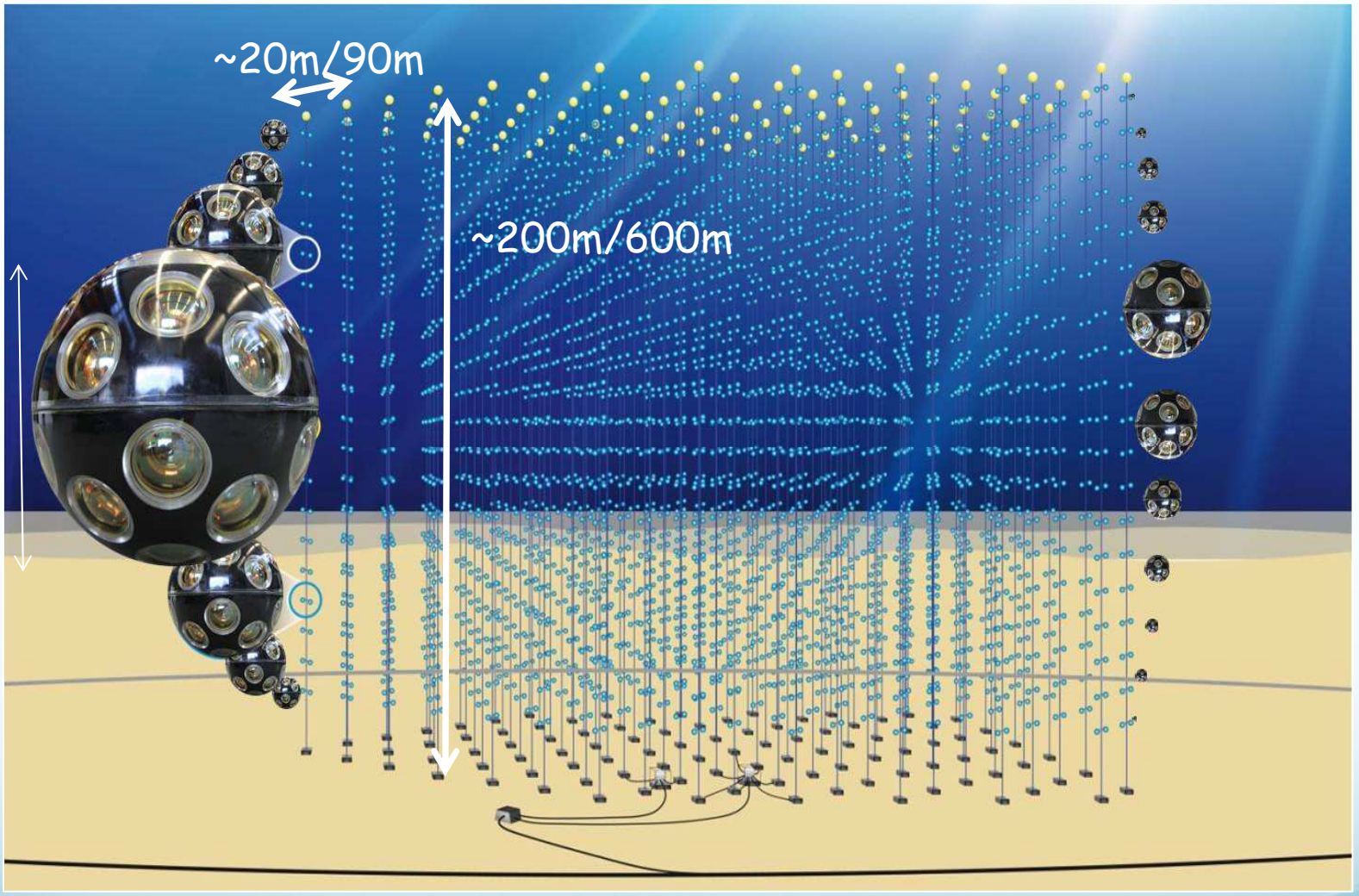
Joint publication
In preparation







Detector technology



- 31 3” PMTs
- Digital photon counting
- Directional information

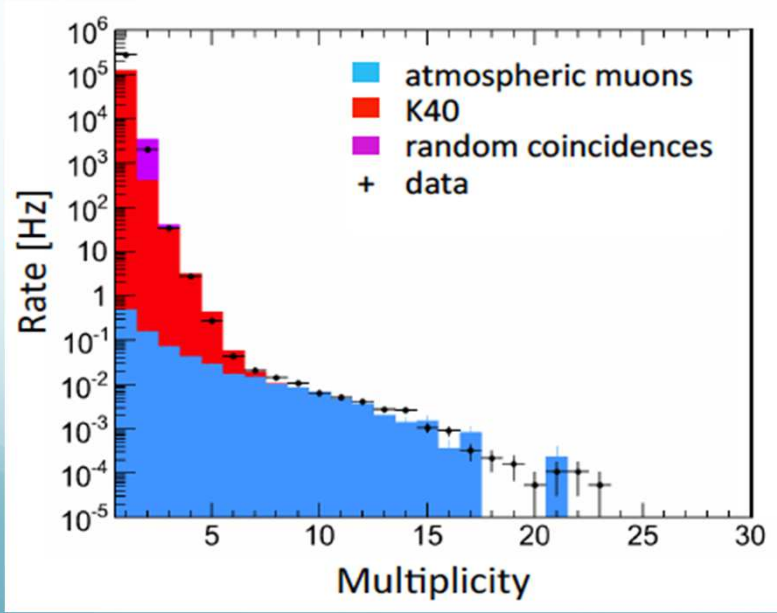
- Wide angle of view
- More photocathode than 1 ANTARES storey
- Cost reduction wrt ANTARES

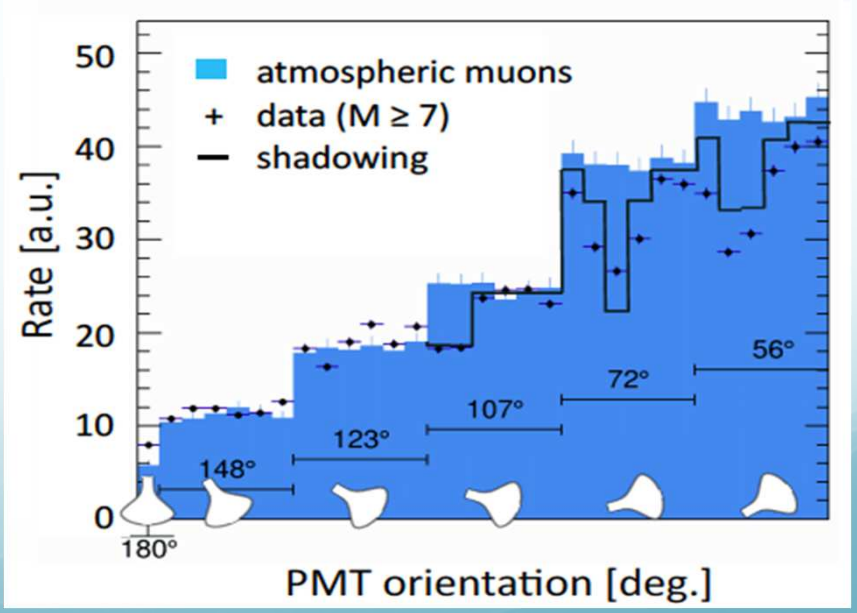
1st prototype @ ANTARES

April 2013: First DOM installed on ANTARES instrumented line

Validates photon counting and directionality performances

📖 Eur. Phys. J. C (2014) 74:3056





Conclusion

- Confirmed Astrophysical Neutrino signal form IceCube
- Intriguing event cluster & Nord/South asymmetry hints to Galactic component
- Constraints from ANTARES for various source models:
- → Point source or (small) extended source close to Galactic center
- → Point source at bright Blazars close to IC PeV events
- Spectral indices in the range -2.0 to -2.5 tested
- First combined Point source Analysis from 6 years ANTARES & 3 years IceCube

FUTURE

- Cascade events to search for correlations with IceCube
- Large extended Source models

KM3Net