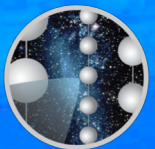


A view of the Universe with the IceCube and ANTARES Neutrino Telescopes

© François Montanet

Ignacio Taboada
Georgia Institute of Technology

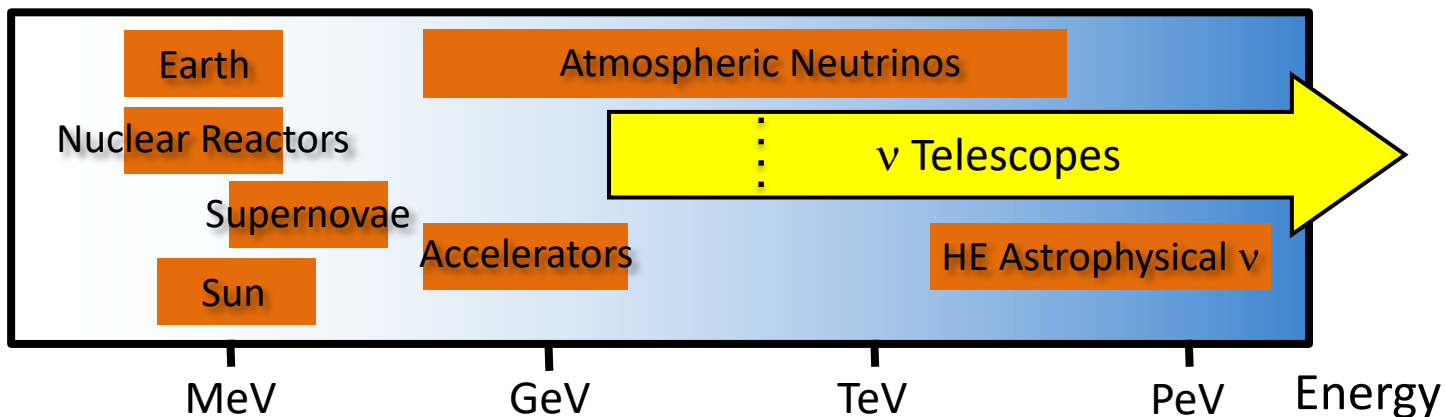


ICECUBE



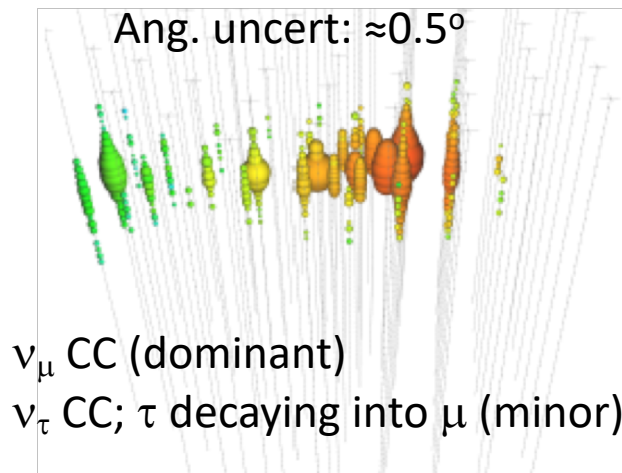
Neutrino 2018, Heidelberg

Neutrino Telescopes



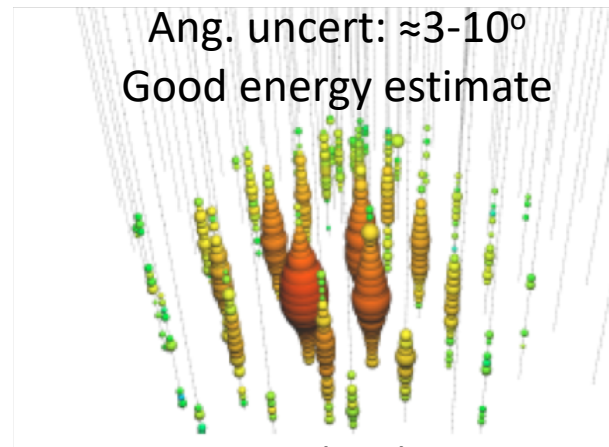
tracks
 “Traditional ν astro channel”
 Ang. uncert: $\approx 0.5^\circ$

Astro:Atm ν:Atm μ
 $1:10^4:10^{10}$



ν_μ CC (dominant)
 ν_τ CC; τ decaying into μ (minor)

cascades / showers
 Ang. uncert: $\approx 3-10^\circ$
 Good energy estimate

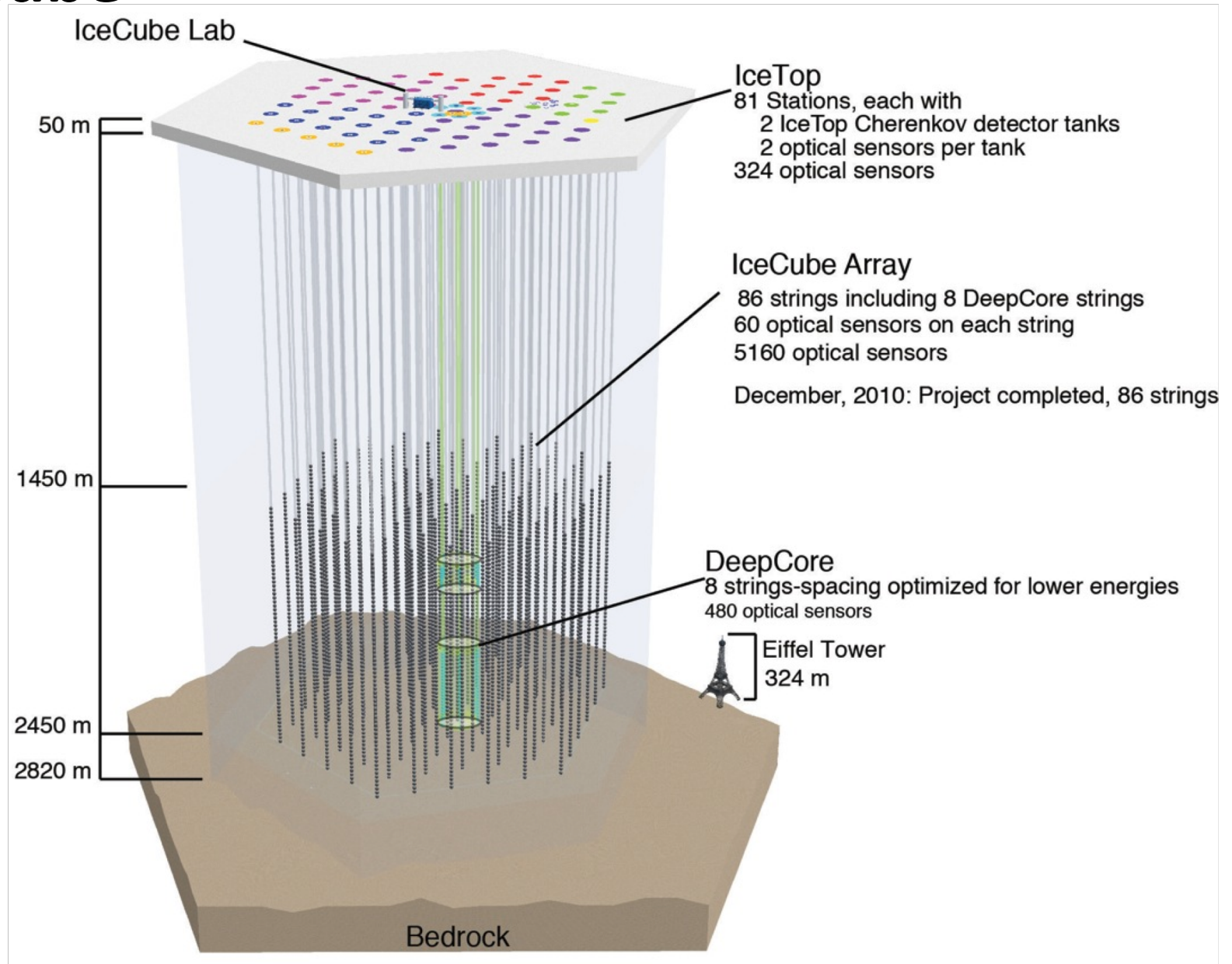


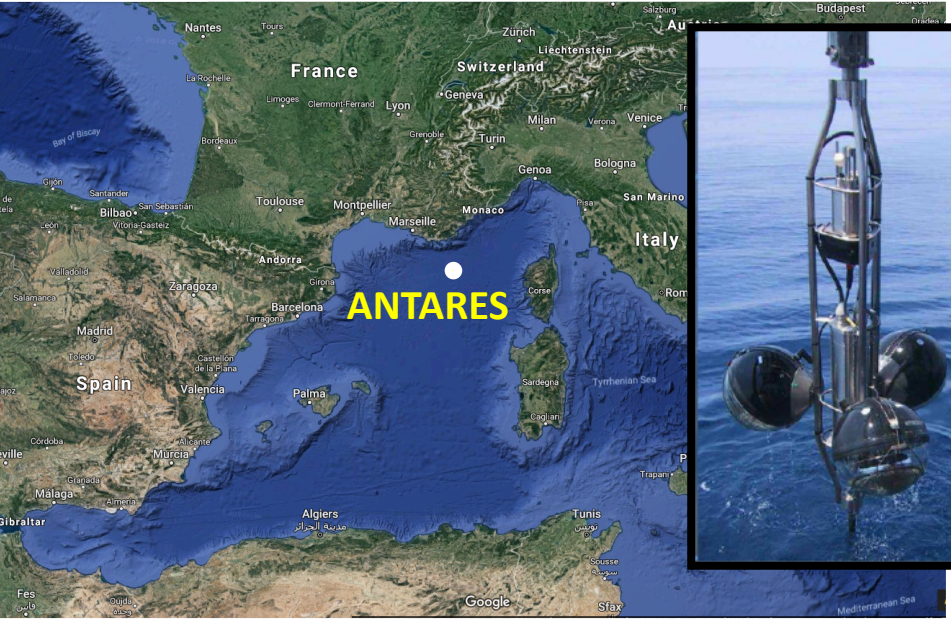
All other CC/NC/Glashow ν
 interaction (*)

(*) Actually ν_τ interactions may have complicated topologies

See also, Poster #192. Spiering et al (GVD)

IceCube





ANTARES

Running since 2007

885 10" PMTs

12 lines

25 storeys/line

3 PMTs / storey

2500 m deep

$\sim 0.01 \text{ km}^3$

450 m

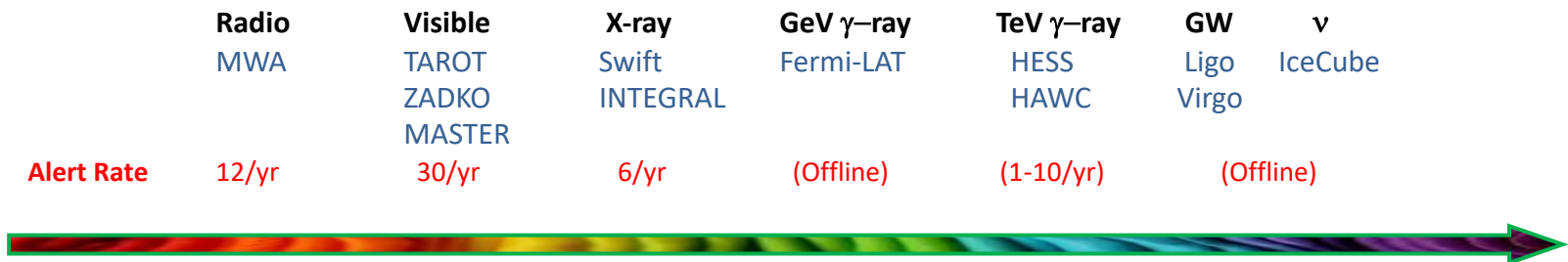
40 km to shore

Junction Box

70 m

Interlink cables

ANTARES Multi-messenger



ANTARES Alerts:

- Doublet of neutrinos (~ 0.04 events/yr)
- Single neutrino with direction close to local galaxies (~ 1 TeV, ~ 10 events/yr)
- Single HE neutrinos:
 - HE ν (~ 5 TeV, 20 events/yr)
 - VHE ν (~ 30 TeV, $\sim 3-4$ events/yr)

Performances:

- Time to send an alert: ~ 5 s
- First image of the follow-up: < 20 s
- Median angular resolution: 0.5°

Statistics of sent neutrino alerts
(07/2009-02/2018)

272 to robotic telescopes
 14 to Swift
 4 to INTEGRAL
 22 to MWA
 2 to HESS

JCAP 02 (2016) 062
 (FRBs) MNRAS 475, 1427–1446 (2018)
 (GRBs) MNRAS 469, 906–915 (2017)

Poster #185. Brunner et al. (ANTARES)
 Poster #198. G. Illuminati et al. (ANTARES)

IceCube Multi-messenger

Real-time alerts. Since 04/2016, $\approx 6\text{-}8/\text{yr}$

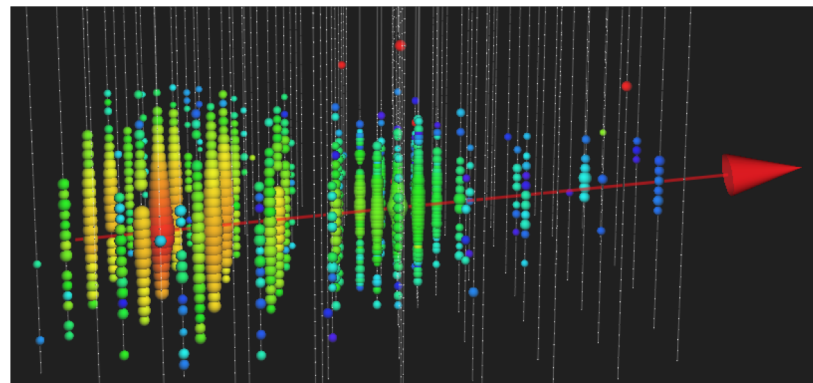
Latency ~ 2 min.

Improved selection summer 2018

Good angular resolution ($0.5^\circ - 2^\circ$ 90%)

50% astrophysical fraction

Astropart. Phys. 92 (2017) 30



First public ν Alert: IceCube-160427

Extensive real-time and offline follow up:

PTF, ZTF, HAWC, VERITAS, MAGIC, HESS, Fermi LAT, Fermi GBM, Swift, etc.

A&A 607 (2017) A115

Poster #184. Rauch et al. (IceCube)

Poster #194. Kintscher et al. (IceCube)

Real-time search for ν -GW coincidences

ApJ 850 (2017) L35

IceCube-170922A & TXS 0506+056

TITLE: GCN CIRCULAR

NUMBER: 21916

SUBJECT: IceCube-170922A - IceCube observation of a high-energy neutrino candidate event

DATE: 17

FROM: E

Claudio Ko
report on

On 22 Sep,
probability
Extremely
normal on

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; Y
K

Cred

Subjects: Gamma

Referred to by AT
10844, 10845, 10

[Tweet](#) [Rec](#)

We searched for
neutrino event e
10787) with all-sk
ray Space Telesc
and also included
located inside the

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

ATel #10817; *Razmik Mirzoyan for the MAGIC Collaboration*
on 4 Oct 2017; 17:17 UT

Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Optical, Gamma Ray, >GeV, TeV, VHE, UHE, Neutrinos, AGN, Blazar

Referred to by ATel #: 10830, 10833, 10838, 10840, 10844, 10845, 10942

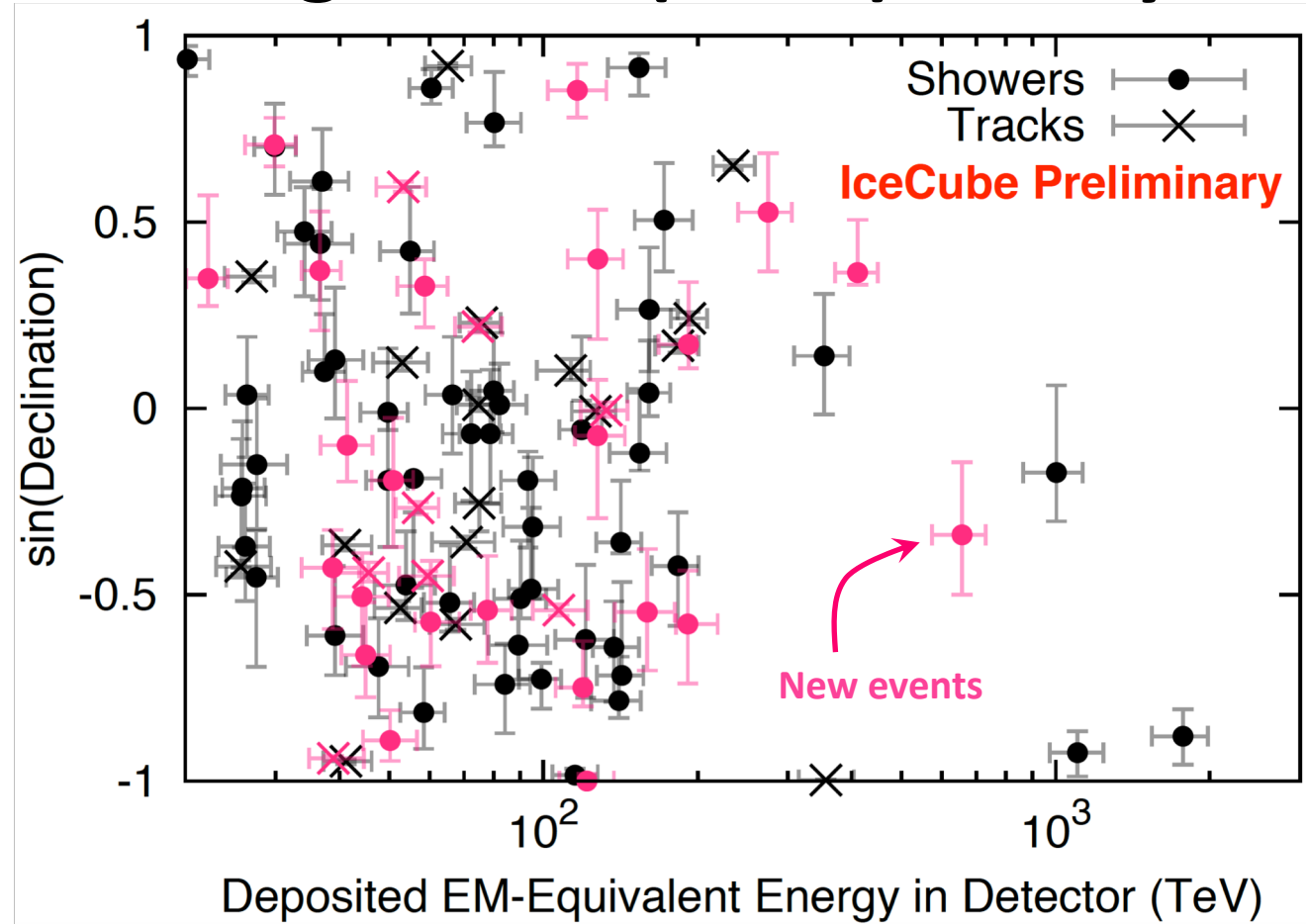
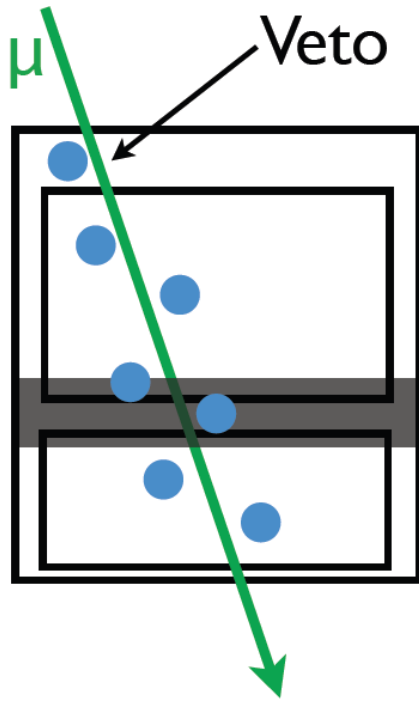
[Tweet](#) [Recommend 448](#)

After the IceCube neutrino event EHE 170922A detected on 22/09/2017 (GCN circular #21916), Fermi-LAT measured enhanced gamma-ray emission from the blazar TXS 0506+056 (05 09 25.96370, +05 41 35.3279 (J2000), [Lani et al., Astron. J., 139, 1695-1712 (2010)]), located 6 arcmin from the EHE 170922A estimated direction (ATel #10791). MAGIC observed this source under good weather conditions and a 5 sigma detection above 100 GeV was achieved after 12 h of

Work on-going

September 22, 2017: a neutrino alert issued by IceCube
Fermi and MAGIC identify a spatially coincident flaring blazar (TXS 0506+056)
Very active multi-messenger follow-up from radio to γ -rays

High-Energy Starting Events (HESE) – 7.5 yr



Prior result 6 years [ICRC 2017 arXiv:1710.01191](#)

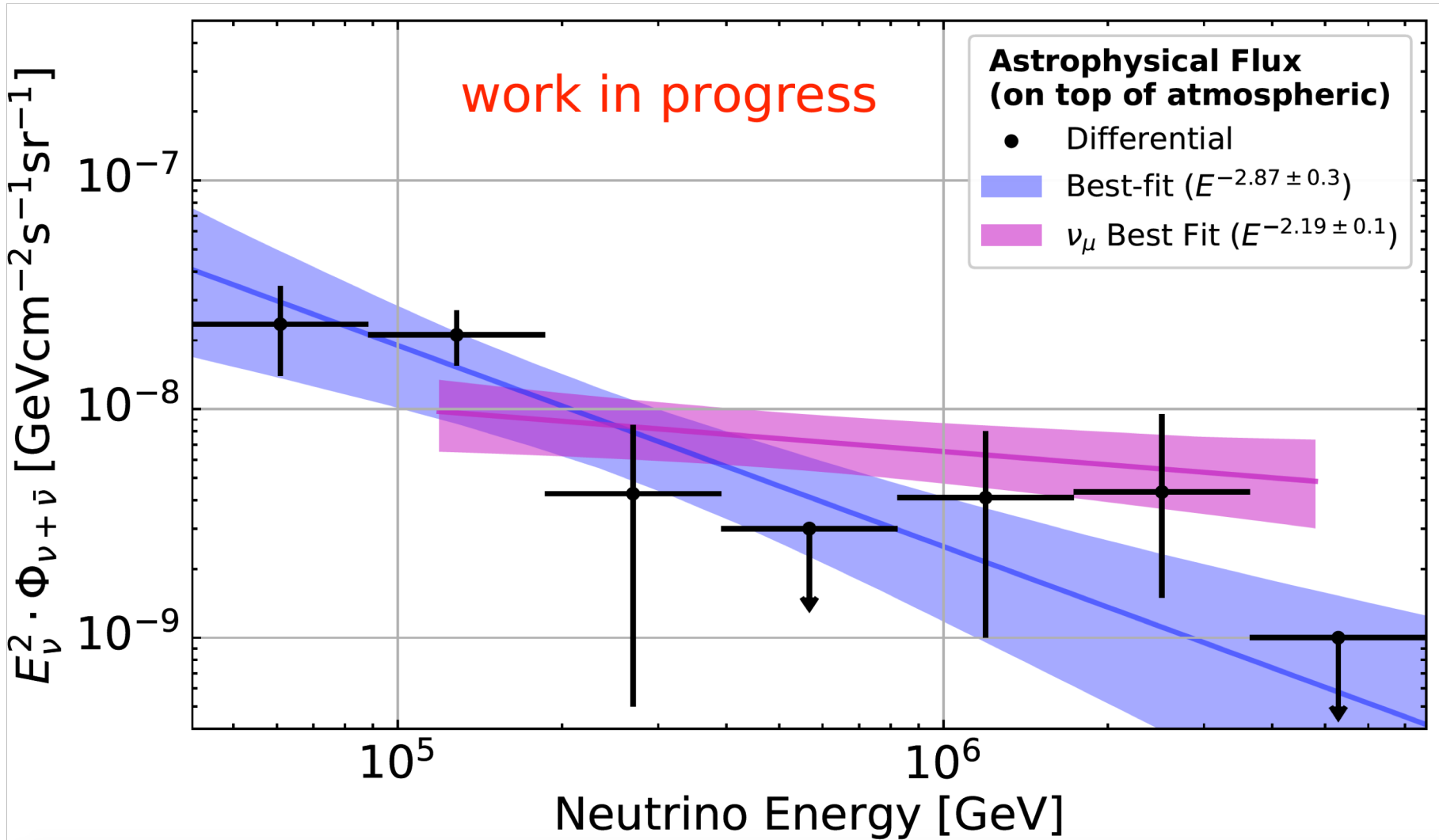
Updates to calibration and ice optical properties

103 events, with 60 events >60 TeV

→ Changes to RA, Dec, energy

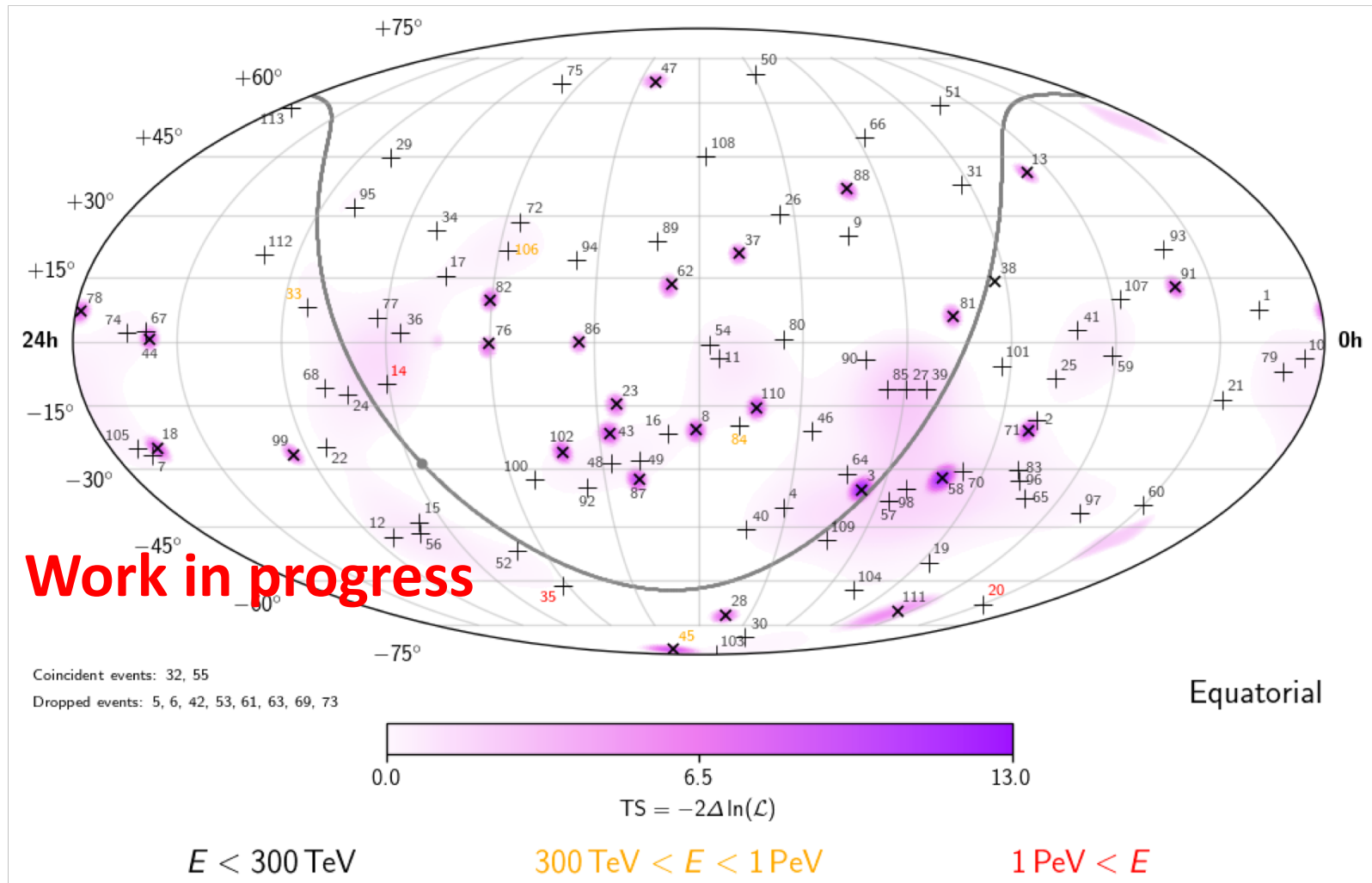
[IceCube. Nature volume 551 \(2017\) 596](#)
[Poster #175. Wandkowsky et al. \(IceCube\)](#)

High-Energy Starting Events (HESE) – 7.5 yr



Poster #175. Wandkowsky et al. (IceCube)

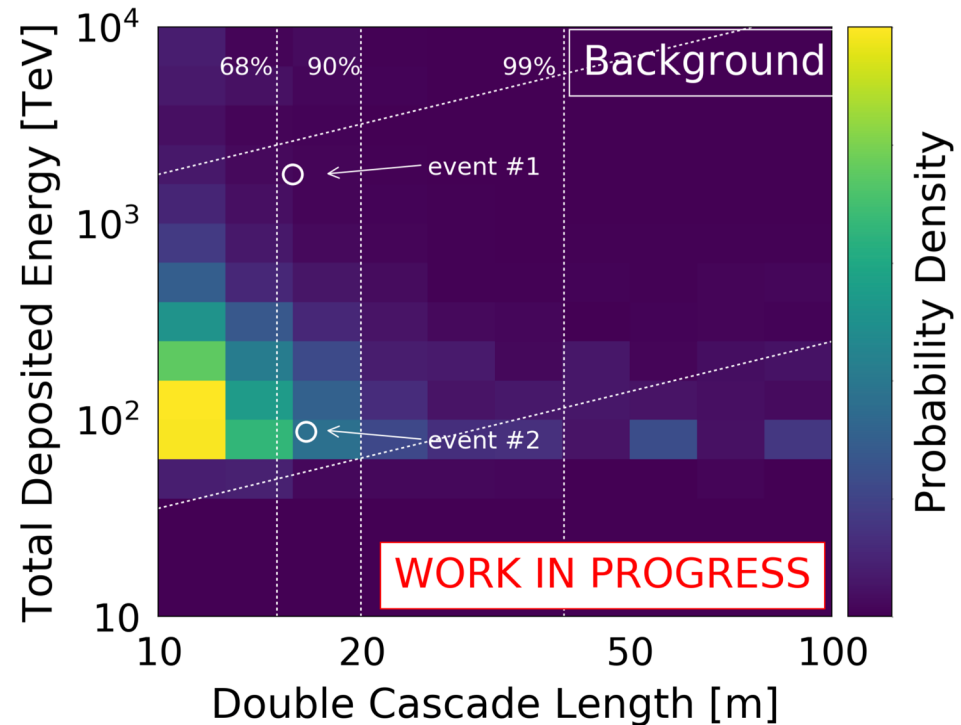
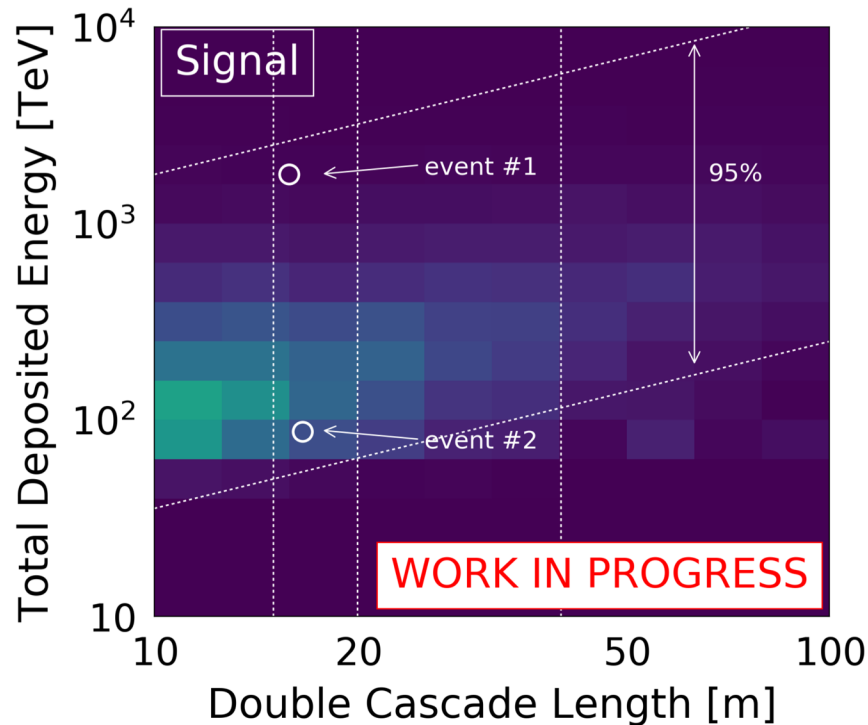
High-Energy Starting Events (HESE) – 7.5 yr



No evidence for point sources, nor a correlation with the galactic plane

Poster #175. Wandkowsky et al. (IceCube)

High-Energy Starting Events (HESE) – 7.5 yr



Two double cascades have been identified

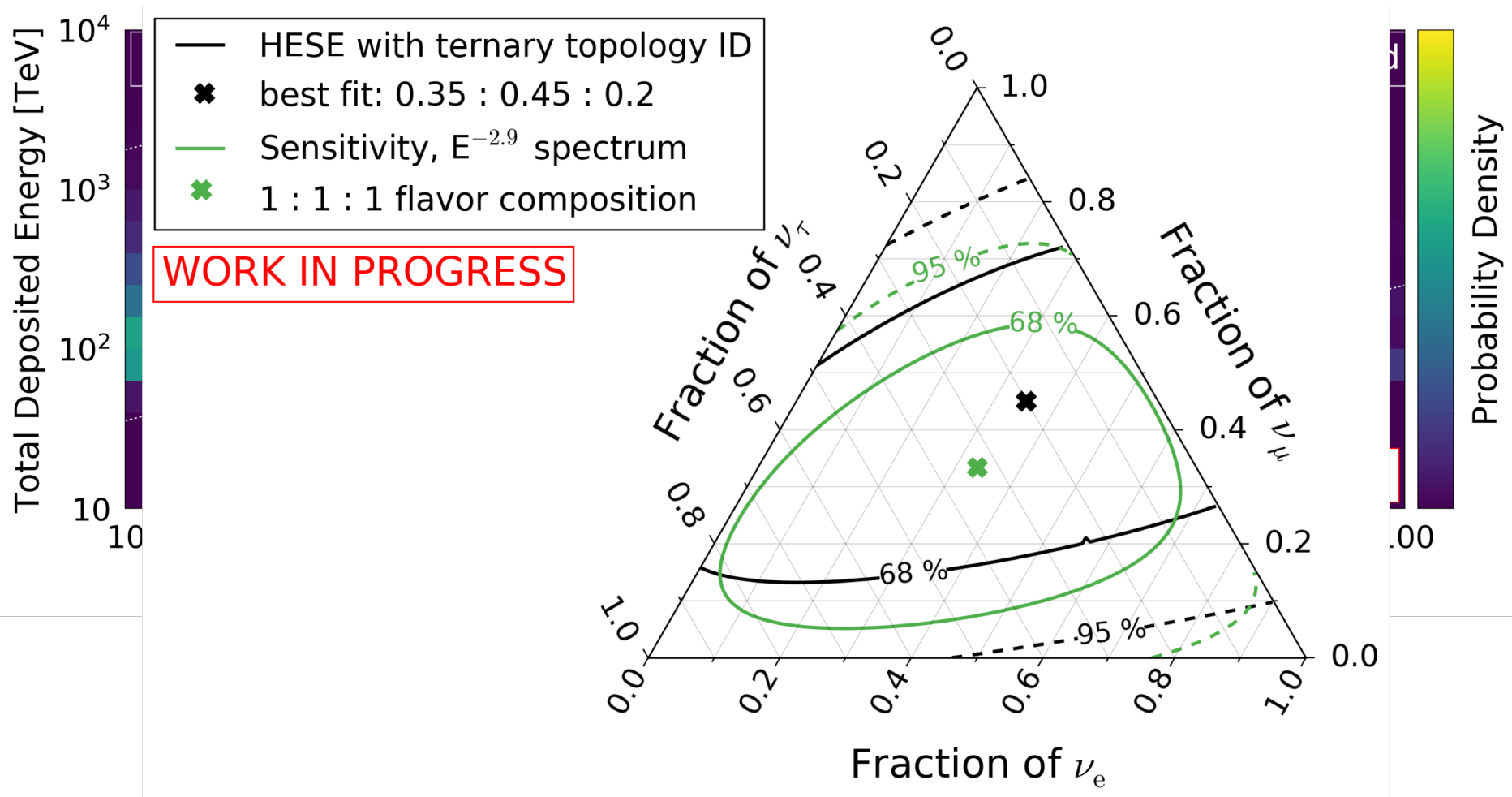
Double cascades can arise from ν_τ or mis-identified bckg (astro ν / atm).

Separate study of tauness of the double cascade events ongoing

Poster #174 Stachurska et al. (IceCube)

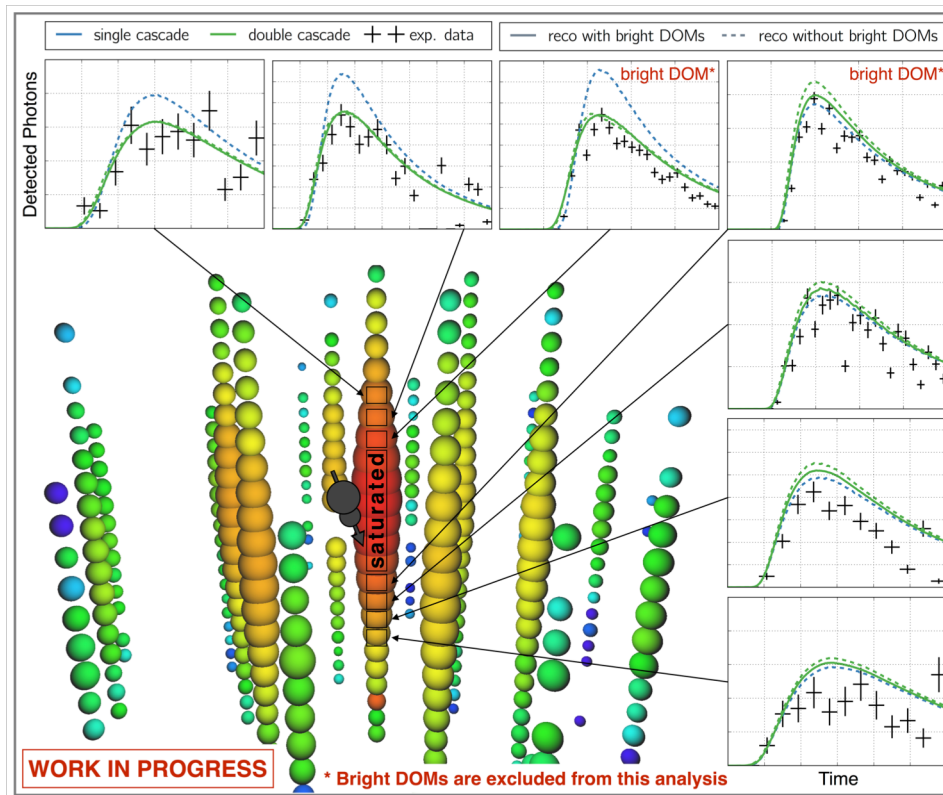
Poster #176 Meier et al. (IceCube)

High-Energy Starting Events (HESE) – 7.5 yr

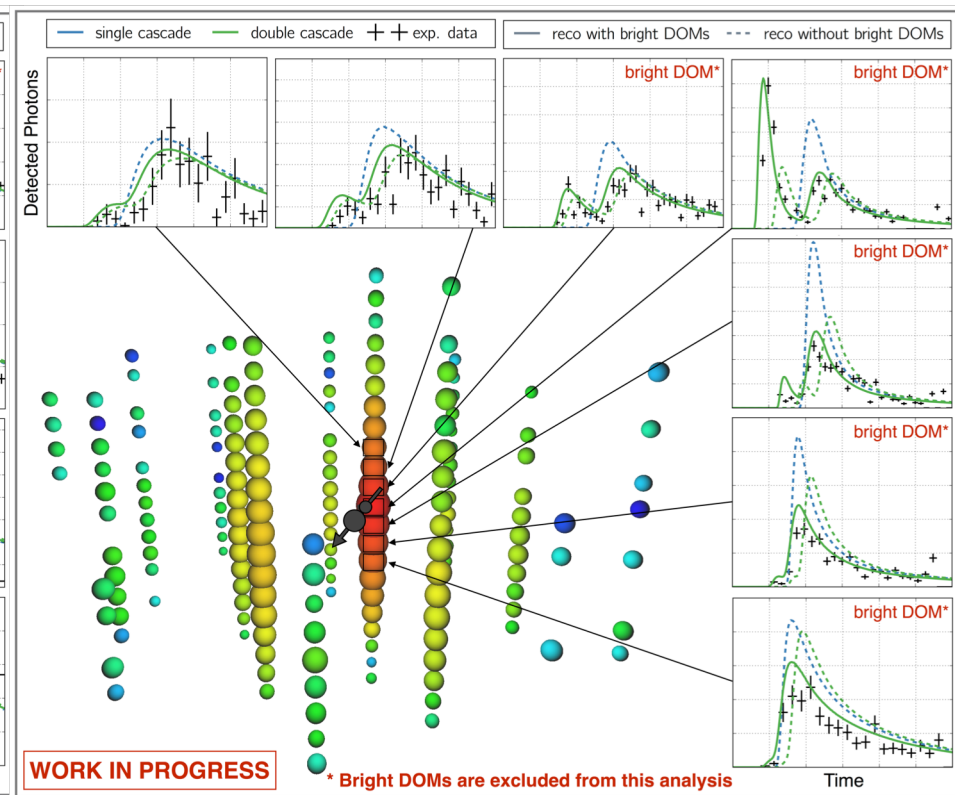


Poster #174 Stachurska et al. (IceCube)
Poster #176 Meier et al. (IceCube)

High-Energy Starting Events (HESE) – 7.5 yr



Double cascade Event #1



Double cascade Event #2

“Bright” DOMs not used in reconstruction
Direction and two reconstructed cascades shown in dark gray

ANTARES – Diffuse flux

Sample:

- 2007 – 2015, 2450 days of livetime
- All-flavour analysis (track+showers)

Event selection chain + energy-related cut applied to

- obtain a high-purity neutrino sample
- maximize sensitivity

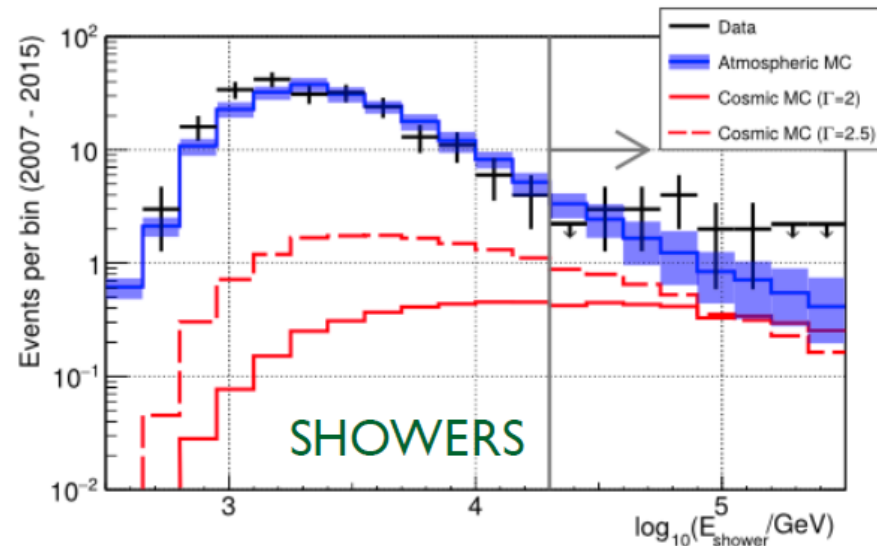
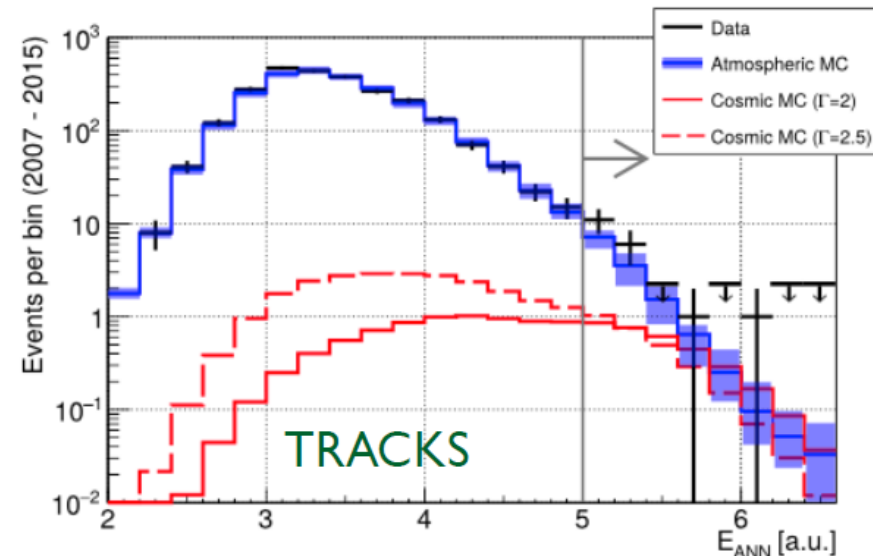
Signal modeled according to the IceCube flux

Result:

33 events (19 tracks + 14 showers) in data
 24 ± 7 (stat.+syst.) events background in MC

1.6σ excess, null cosmic rejected at 85% CL

ApJ 853, (2018) L7



ANTARES – Point Sources

Poster #188. Fusco et al. (ANTARES)
Poster #195. Illuminati et al. (ANTARES)
Poster #200. Organokov et al. (ANTARES)

Sample:

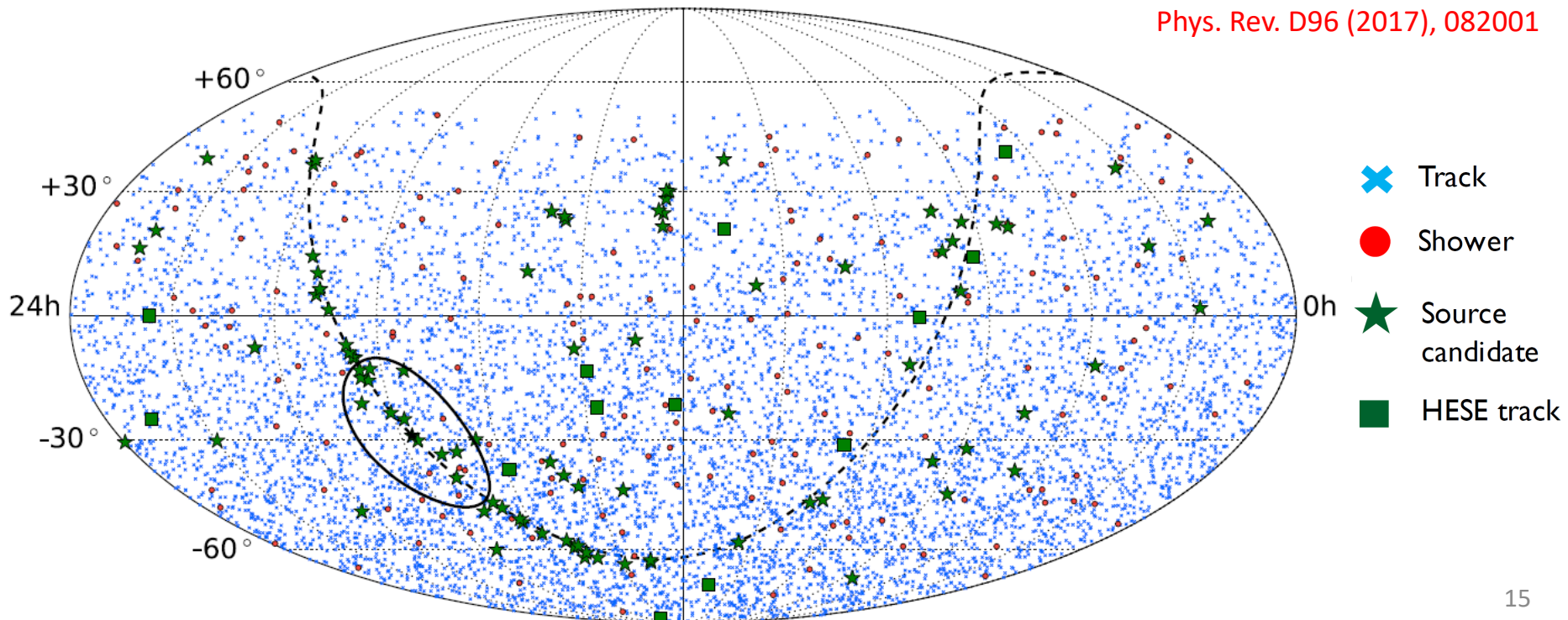
- 2007 – 2015, 2424 days of livetime
- All-flavor analysis: 7622 track-like, 180 shower-like neutrino candidates
- Maximum likelihood method used to search for clusters of neutrinos from point sources

Full-sky search

1°x1° squares over ANTARES visible sky

Candidate list searches

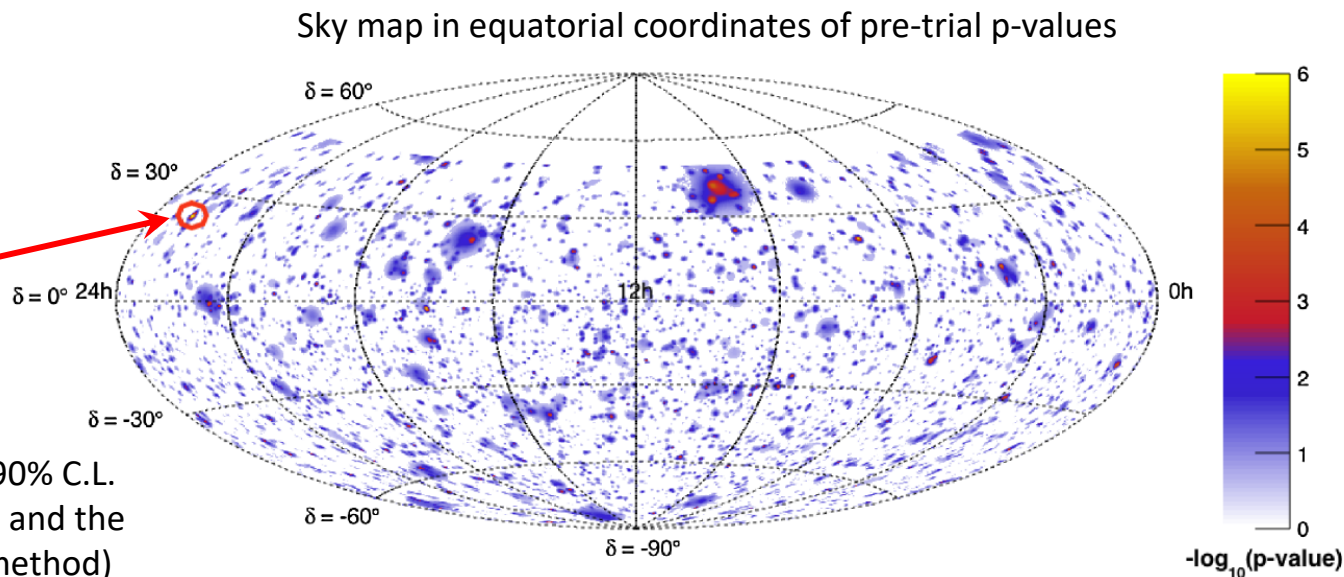
106 known astrophysical objects (Pulsars, SNRs, ...), 13 IceCube HESE tracks



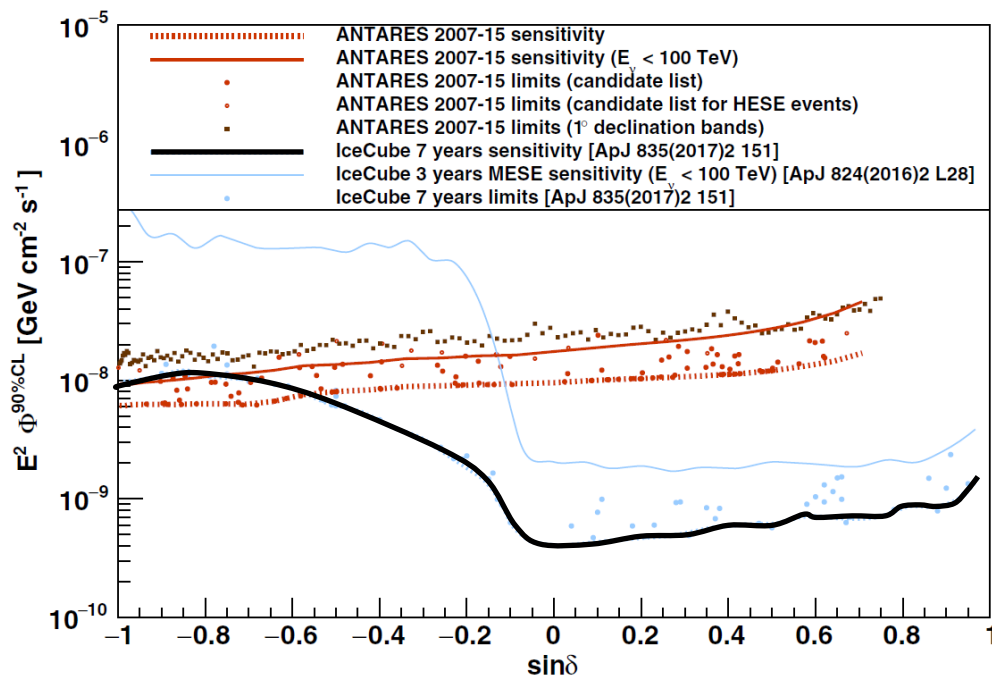
ANTARES – Point Sources

Most significant cluster c
the full-sky search (1.9σ
post-trial significance)

$\alpha = 343.8^\circ$ $\delta = 23.5^\circ$



Sensitivities and upper limits at a 90% C.L.
on the signal flux from the Full-sky and the
Candidate list searches (Neyman method)

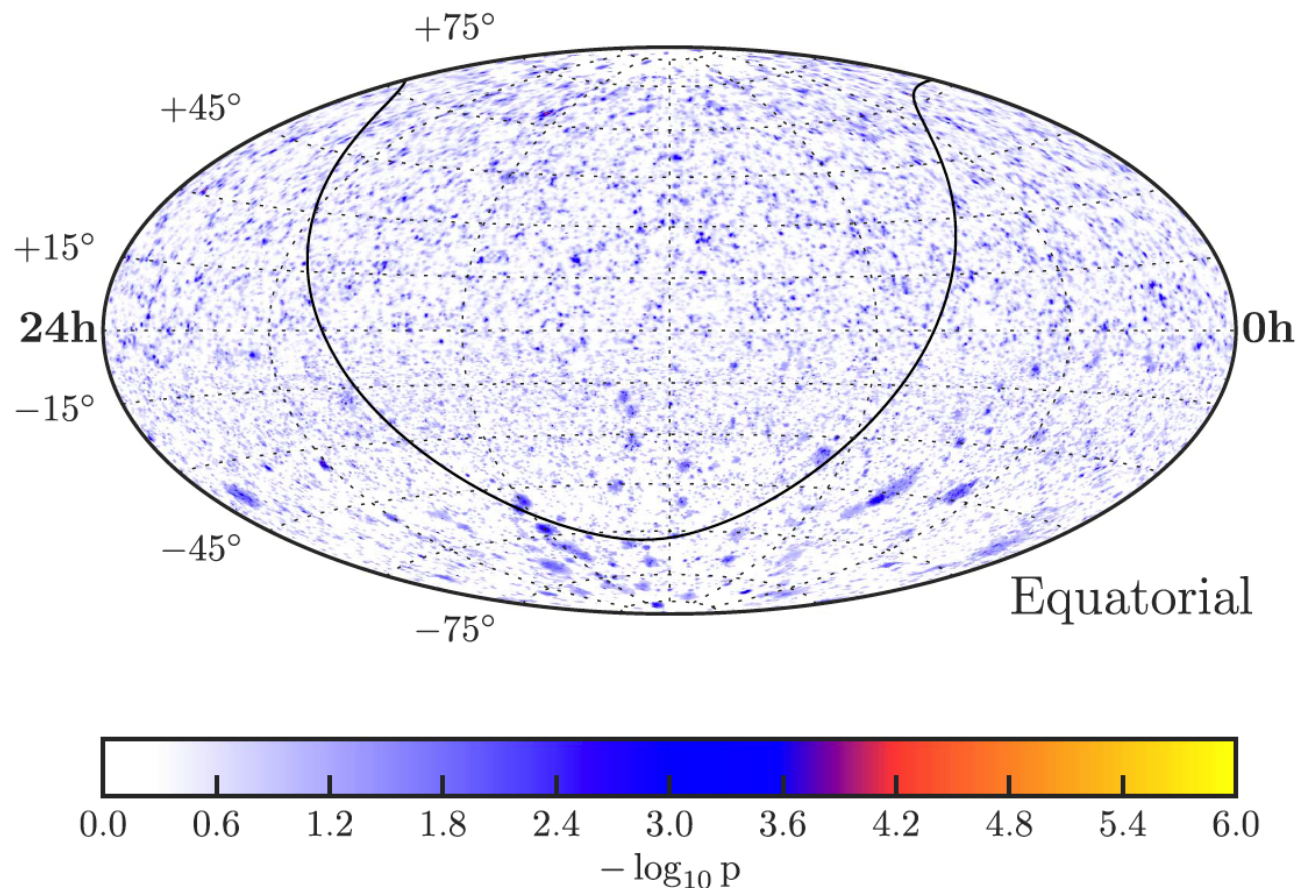


Phys. Rev. D96 (2017), 082001

ANTARES is the most sensitive
instrument for a large fraction of the
southern sky below 100 TeV

IceCube is the most sensitive
instrument in the northern sky and a
fraction of the southern sky

IceCube - Point Sources – 7 years



No significant PS
reported

No correlation with list
of 74 sources in both
hemispheres. Galactic
& Extragalactic

Most recent data periods:

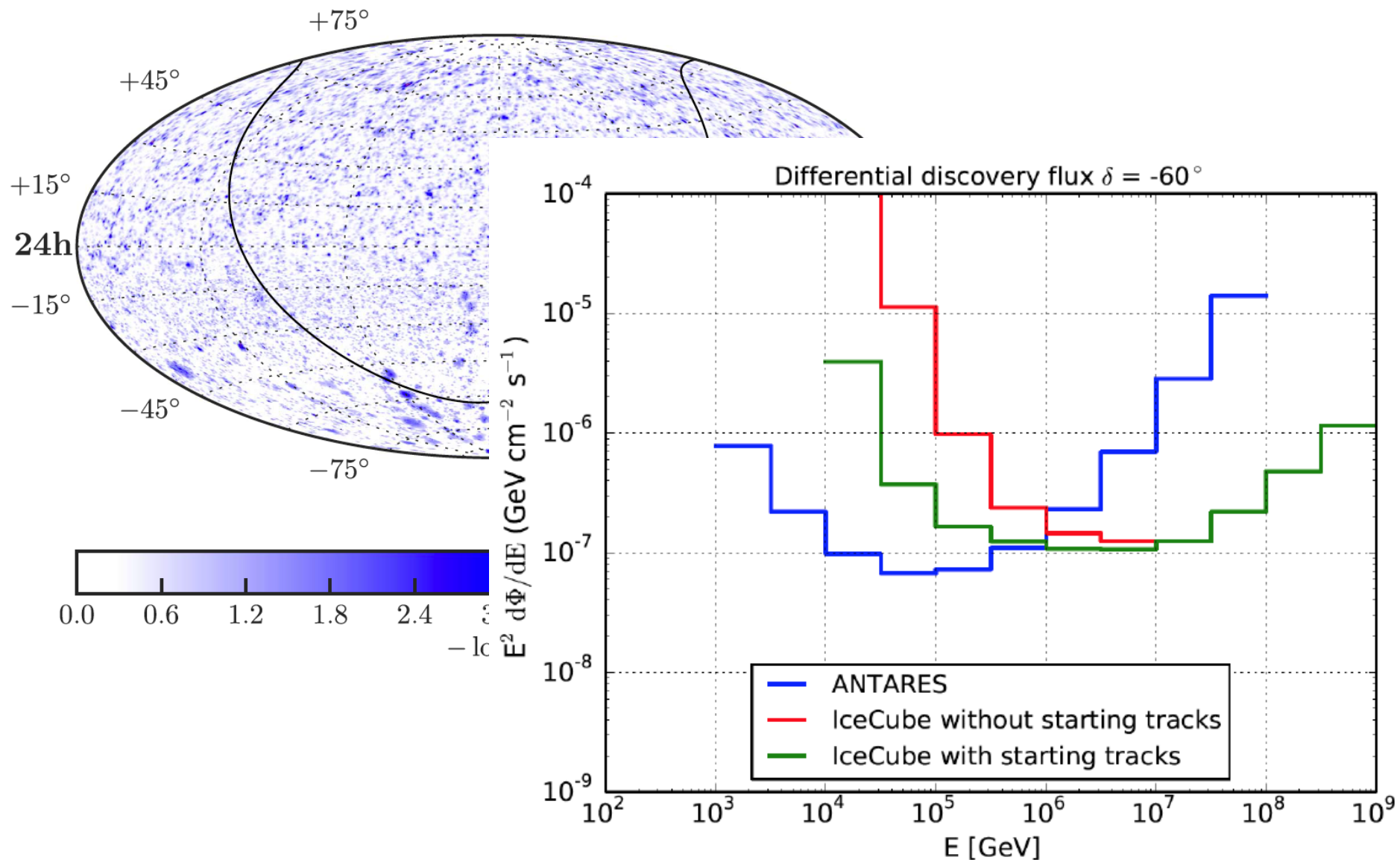
~80k northern hemisphere evt/yr (atm ν)

~35k southern hemisphere evt/yr (atm μ)

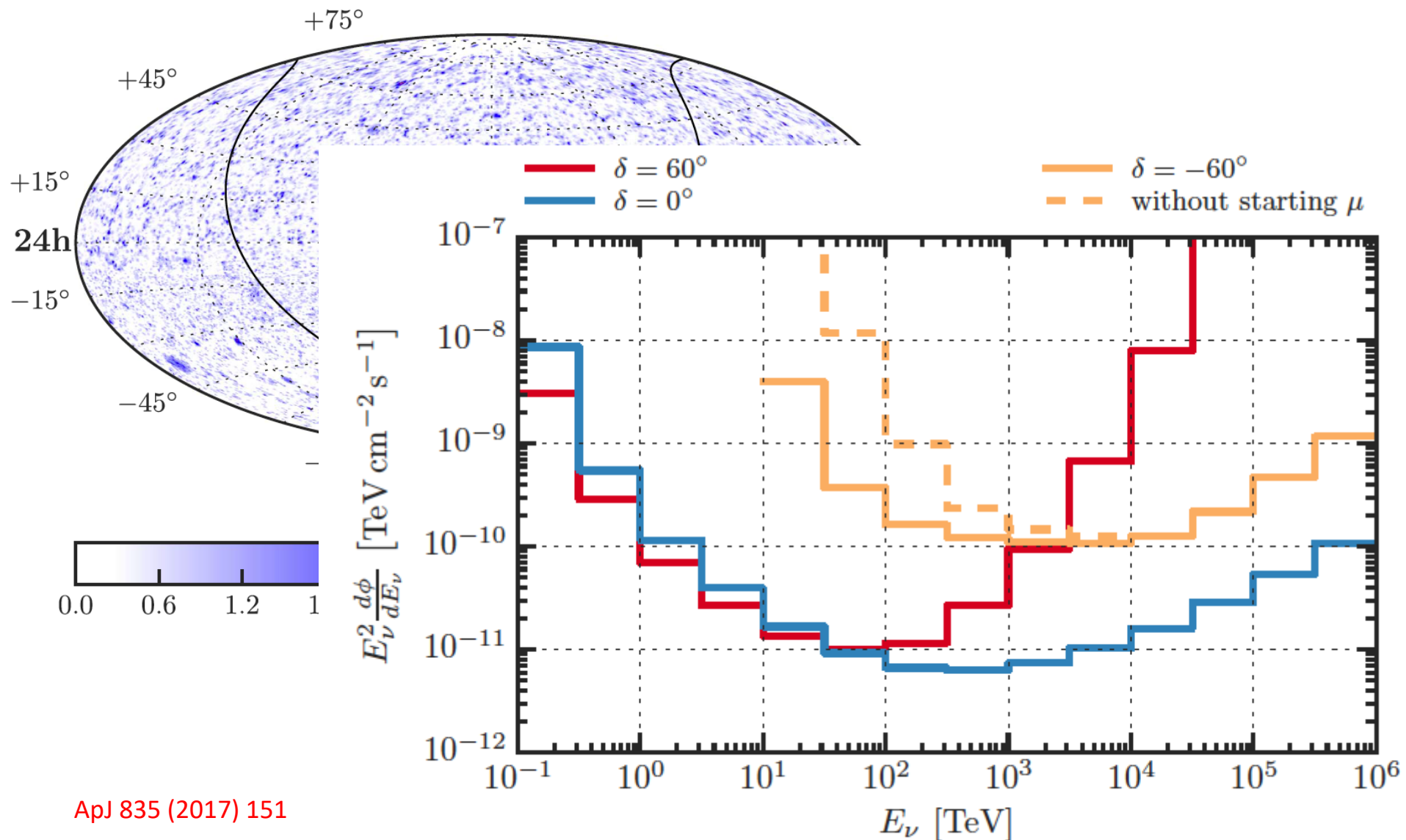
~200 starting tracks. Southern sky

ApJ 835 (2017) 151

IceCube - Point Sources – 7 years

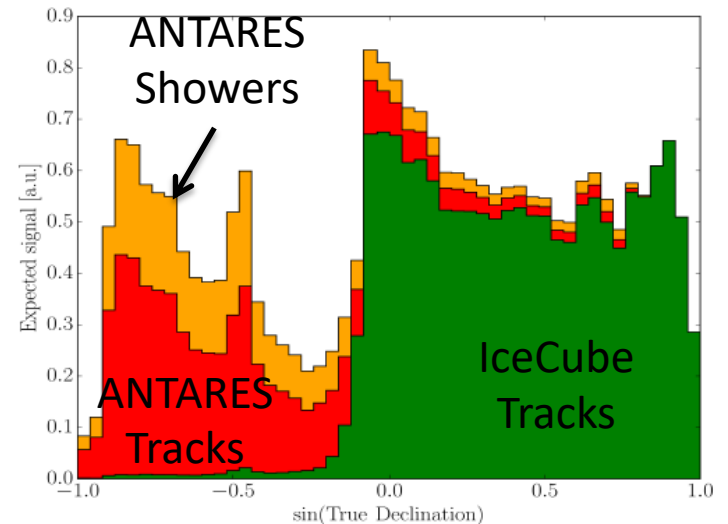
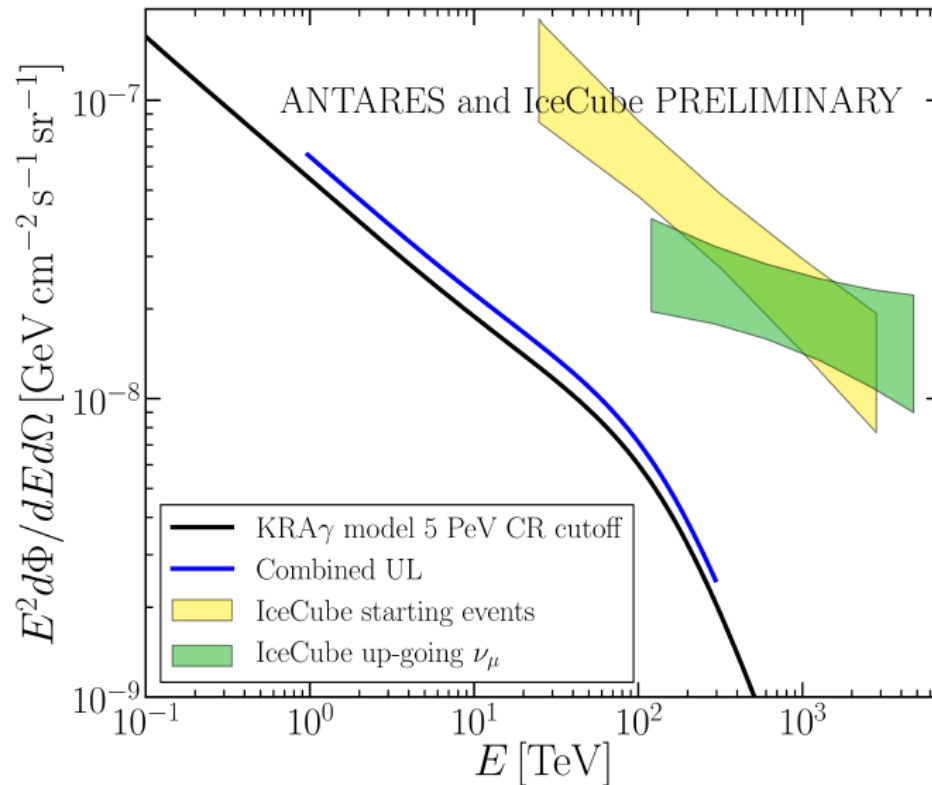


IceCube - Point Sources – 7 years



ApJ 835 (2017) 151

ANTARES & IceCube Galactic Plane

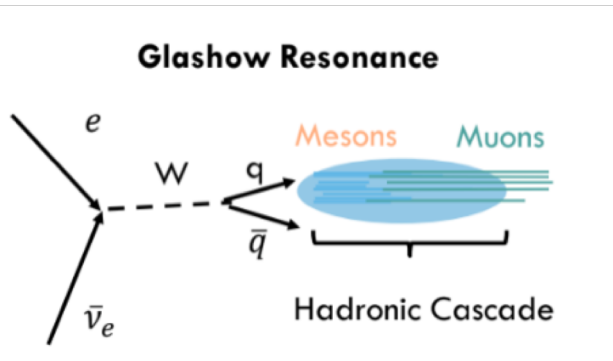


Expected Signal (Gaggero et al. PRL 2017, 119)
Relative contribution to sensitivity of
ANTARES and IceCube

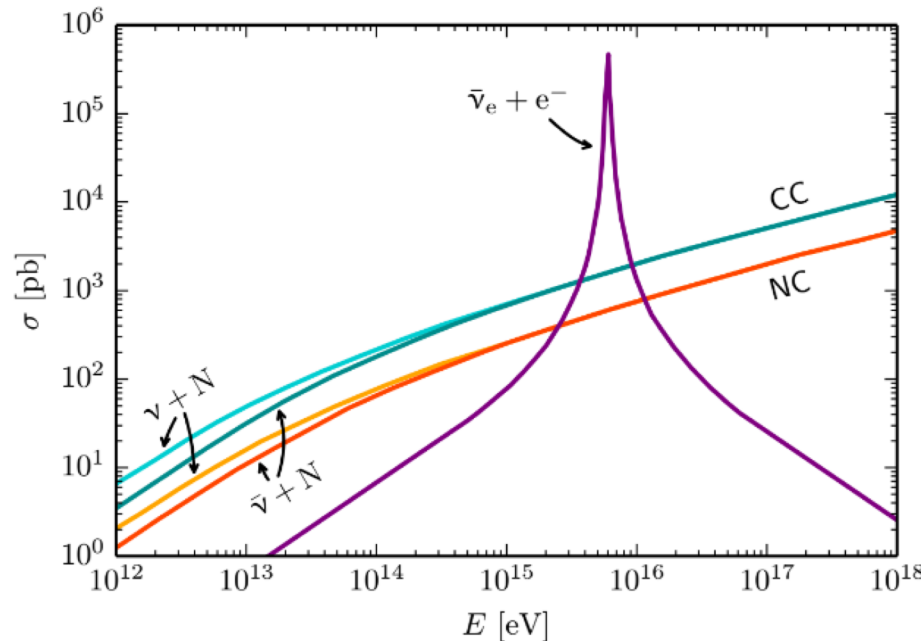
Combined U.L. at 90% CL on the three-flavor
neutrino flux of the KRA- γ model with a 5 PeV cutoff.

(ANTARES) Phys. Rev. D96 (2017) 062001
(IceCube) ApJ 849 (2017) 67

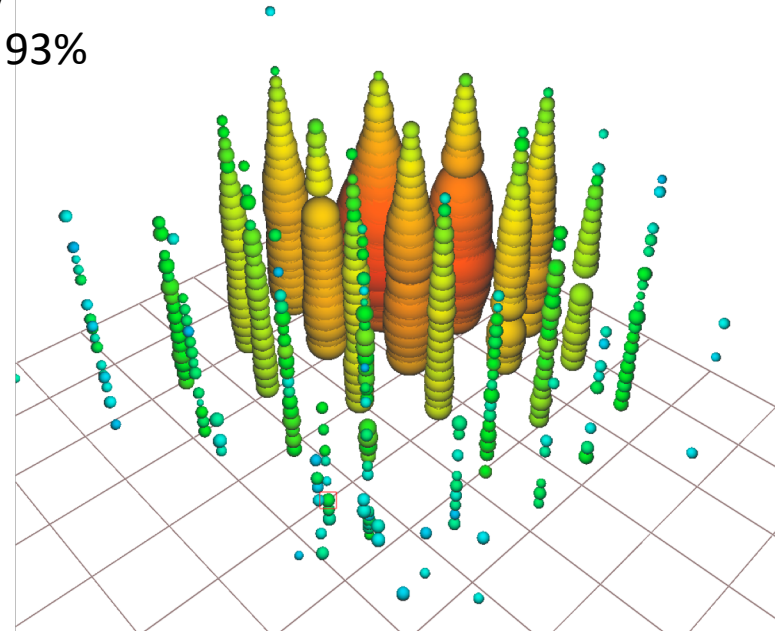
A 5.9 PeV event in IceCube



Resonance: $E_\nu = 6.3$ PeV
 Typical visible energy is 93%



Work in progress



Event identified in a partially-contained PeV search (PEPE)

Deposited energy: 5.9 ± 0.18 PeV (stat only)

ICRC 2017 [arXiv:1710.01191](https://arxiv.org/abs/1710.01191)

Potential hadronic nature of this event under study

Summary

IceCube has discovered an astrophysical neutrino diffuse flux

The ν sources – likely correlated with the sources of cosmic rays – remain unidentified.

Multi-messenger studies are critical to the identification of sources

Looking forward to hearing about the future of neutrino telescopes!
(Uli Katz)

Time ran out:

Dark Matter results

Poster #173. Yuan et al. (IceCube) (also ν -matter cross section)

Poster #133. Zornoza et al (ANTARES)

Poster #132. Zornoza et al. (ANTARES)

Transient sources of neutrinos: GRBs, fast radio bursts, blazars, etc.

Poster #191. Lincetto et al (ANTARES)

Solar Atmospheric Neutrinos

Poster #180. Rott et al (IceCube)

Cosmogenic neutrinos