UNIVERSITÉ DE GENÈVE

Recent Results from

IceCube
SOUTH POLE NEUTRINO OBSERVATORY

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for the IceCube Collaboration

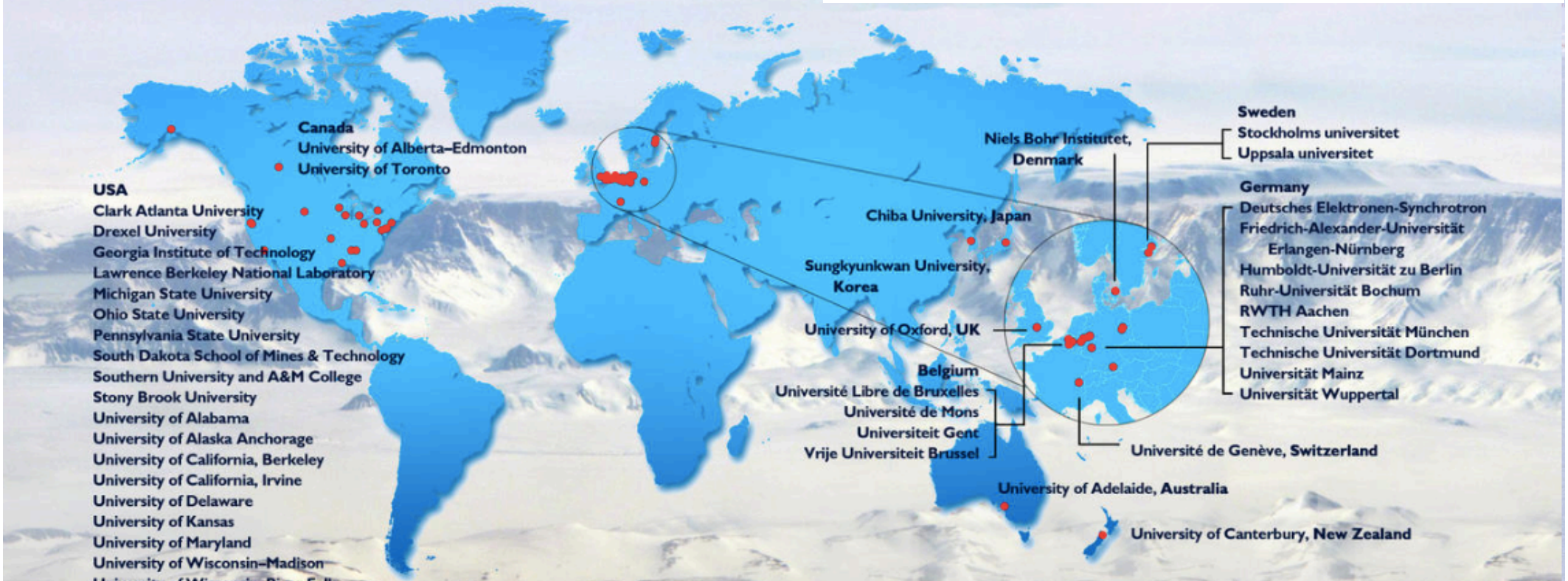
June 15, 2017

Martin Wolf, IceCube/NSF

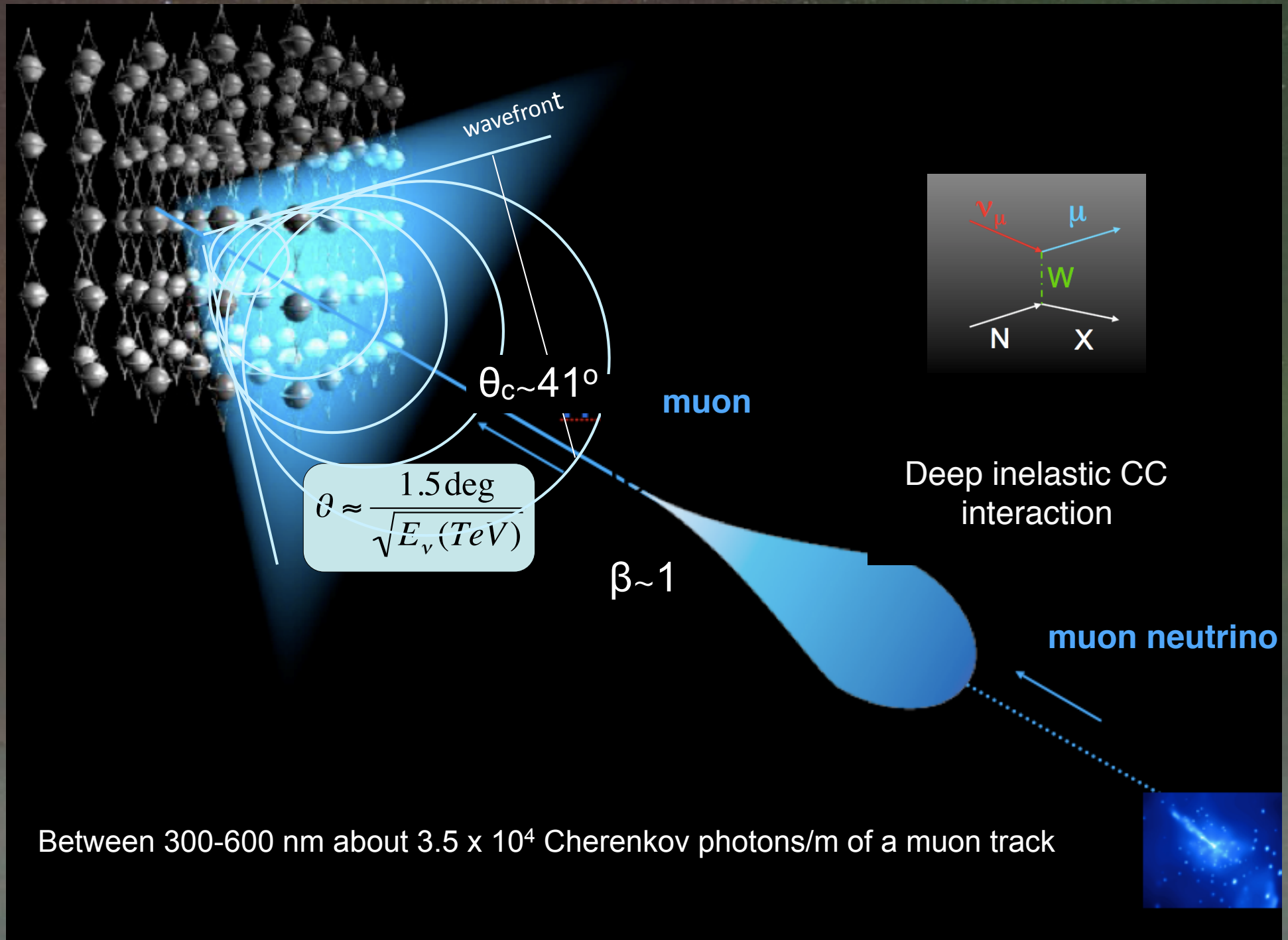
Selected IceCube Collaboration results

- Dark Matter constraints from IceCube
- Cosmic Neutrino searches: ‘granted neutrinos’ from CR interactions in the Galaxy and outside; diffuse neutrinos and source searches
- Outlook

12 countries — 48 institutes — 300 scientists

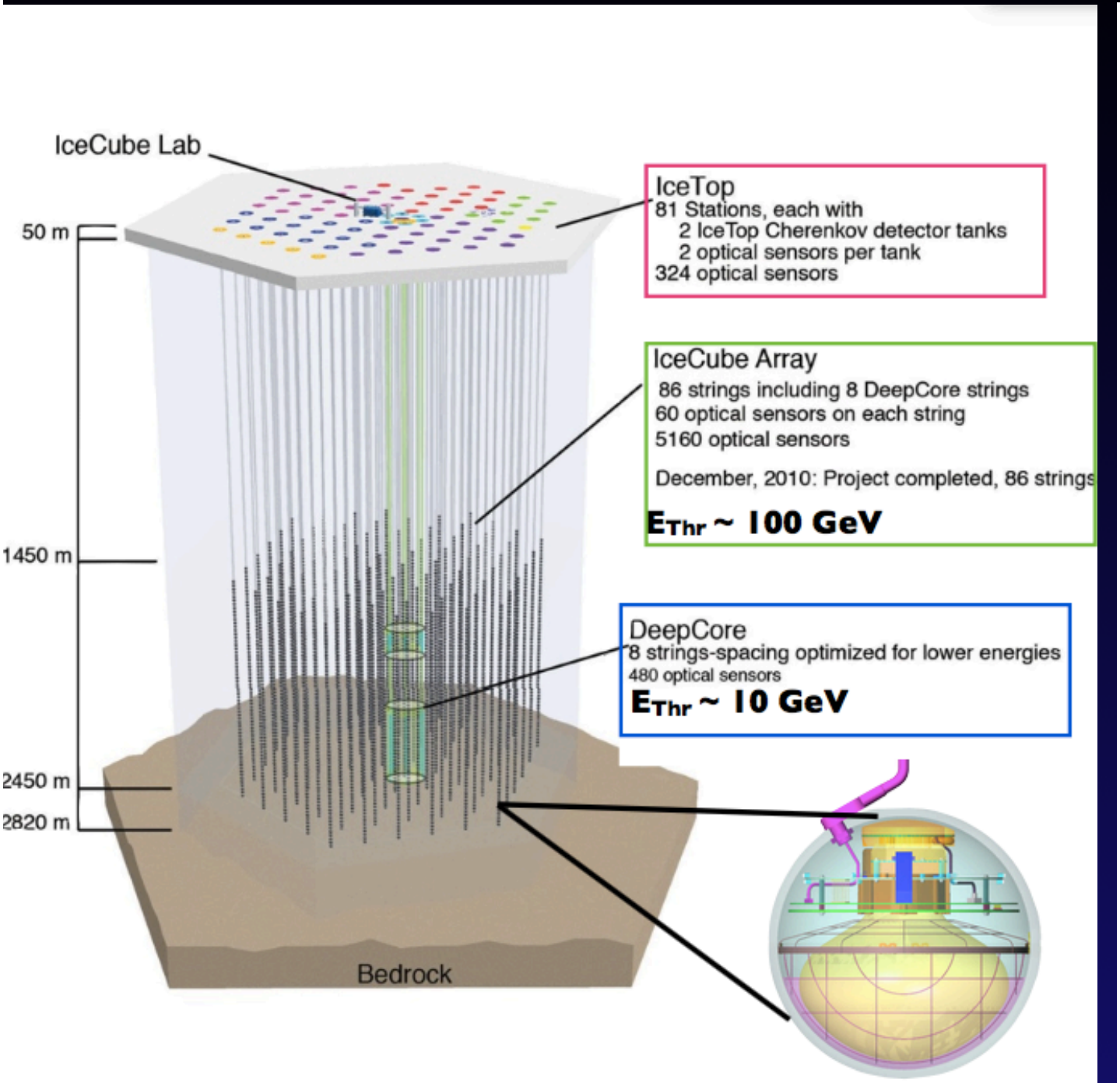


Cherenkov Neutrino Telescope



Between 300-600 nm about 3.5 x 10^4 Cherenkov photons/m of a muon track

The IceCube Observatory



Gigaton Detector at the South Pole

86 strings with 60 Digital (DOMs) Optical Modules each = 5160 DOMs in Ice Began operations in full configuration (IC86) in May 2011

Livetime > 99% (since 2014)

97-98% of data

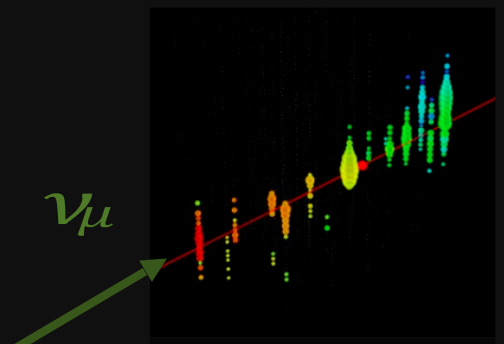
97-98% (analysis-ready, full-detector configuration data)

>98% sensor modules full functional

Neutrino topologies

time

CC Muon Neutrino

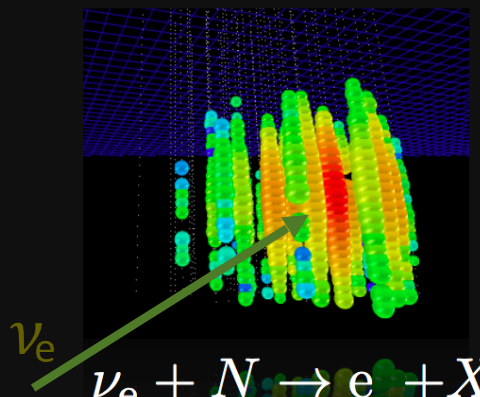


$$\nu_\mu + N \rightarrow \mu + X$$

track (data)

factor of ≈ 2 energy resolution
< 1° angular resolution

Neutral Current /Electron Neutrino



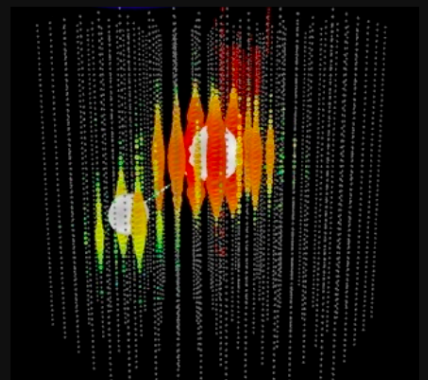
$$\nu_e + N \rightarrow e + X$$

$$\nu_x + N \rightarrow \nu_x + X$$

cascade (data)

≈ ±15% deposited energy resolution
≈ 10° angular resolution
(at energies > 100 TeV)

CC Tau Neutrino



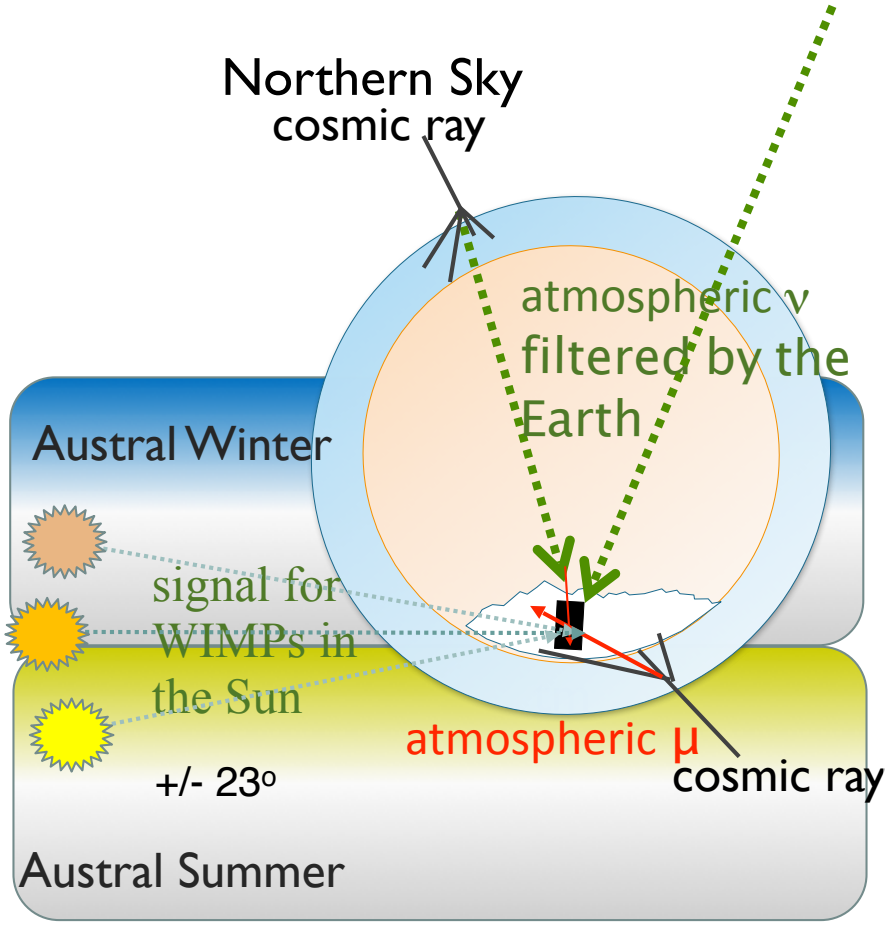
$$\nu_\tau + N \rightarrow \tau + X$$

"double-bang" and other signatures (simulation)

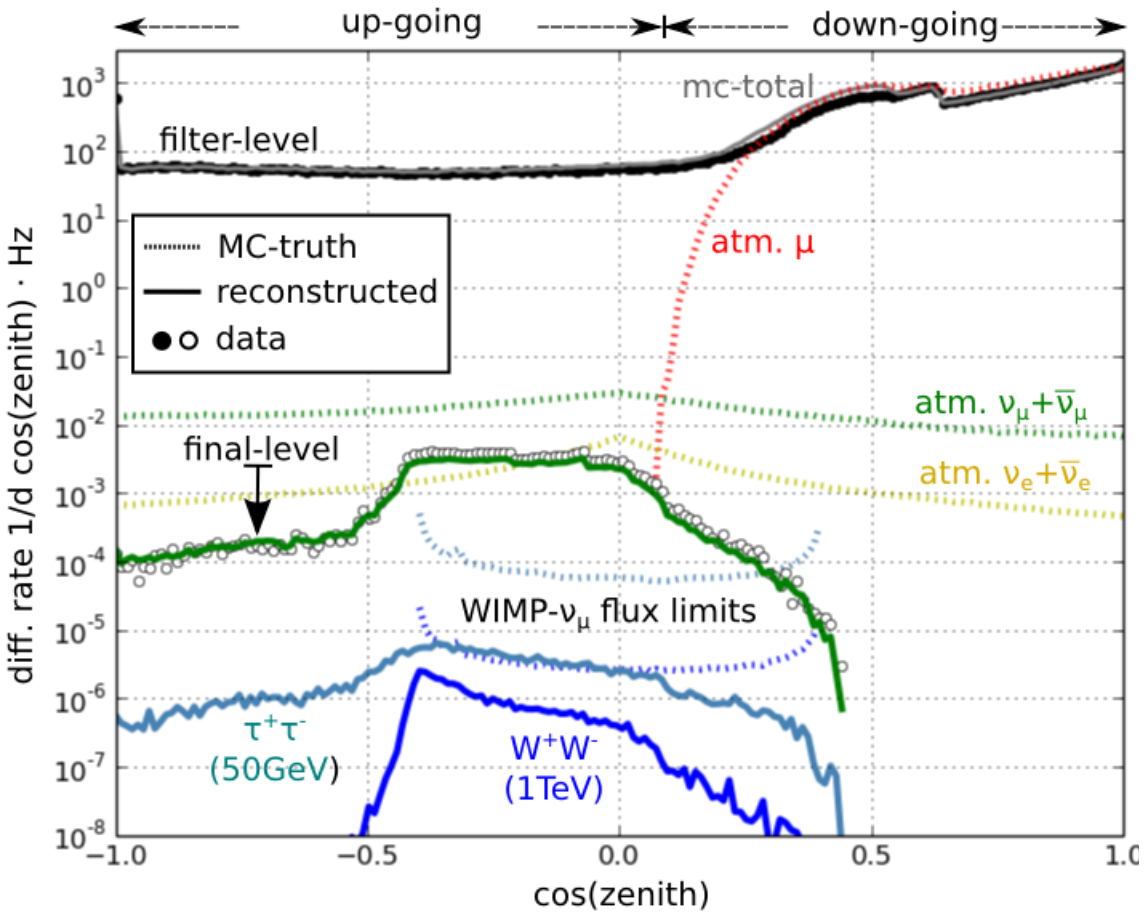
(not observed yet)

Martin Wolf, IceCube/NSF

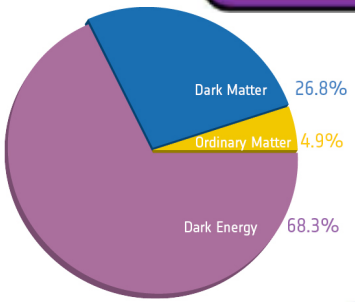
Signal and Backgrounds

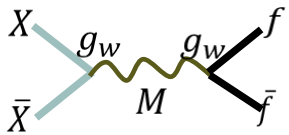


Southern Sky



Indirect Dark Matter searches





$\Omega_X = m_X n_X$ $\Omega_{DM} \sim 0.27$

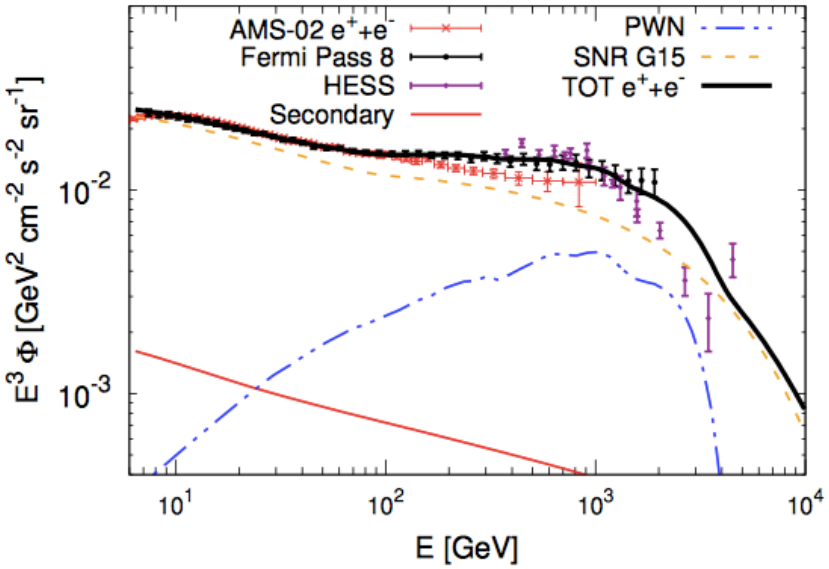
After Planck

$$n_X = \text{constant} \propto \frac{1}{< \sigma v >}$$

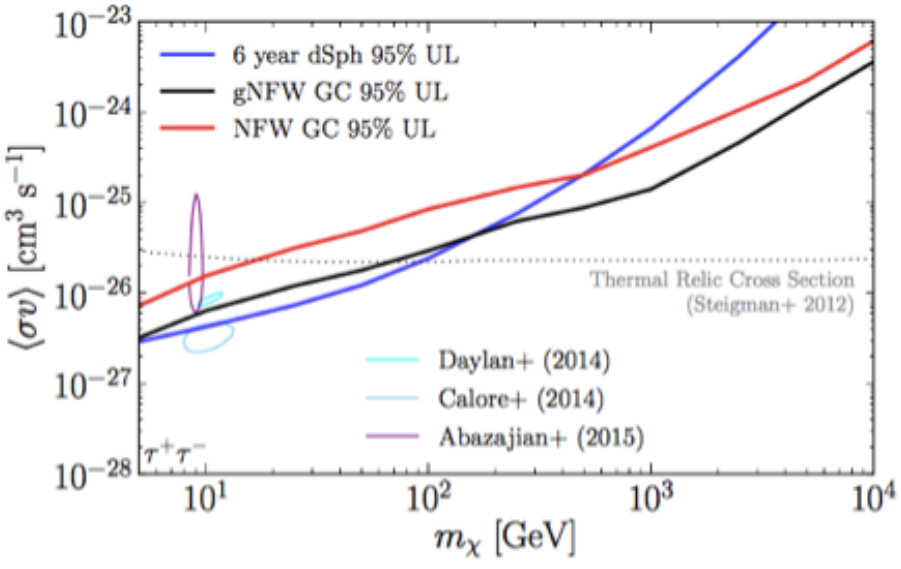
$$\langle \sigma_{ann} v \rangle \approx \frac{(g_w^2/4\pi)^2}{M^2} \approx 3 \,.\, 10^{-26}\ cm^3/s$$ WIMP Miracle

Indirect searches have the potential to locate DM in the Universe but **hints have a hard time to survive among secondary CR backgrounds**

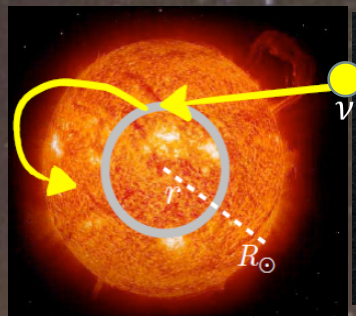
Fermi-LAT GeV gamma excess:
arXiv:1704.03910



Di Mauro et al, arxiv:1703.00460



Dark matter searches in IceCube



$$\Gamma_{\rm capt} = \frac{\rho_{\rm DM}}{M_{\rm DM}} \sum_i \sigma_i \int_0^{R_\odot} dr\ 4\pi r^2\, n_i(r) \int_0^\infty dv\ 4\pi v^2\, f_\odot(v)\, \frac{v^2 + v_{\odot\rm esc}^2}{v}\, \wp_i(v, v_{\odot\rm esc})$$

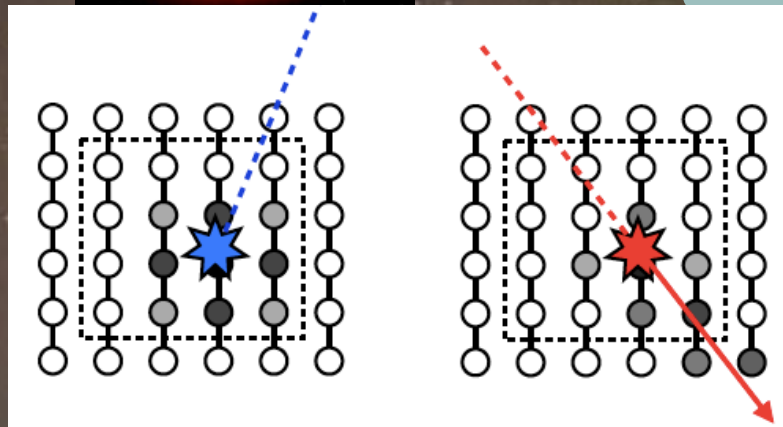
DM number density

Scattering Cross Section
$\sigma_{SD} \propto J(J+1)$
$\sigma_{SI} \propto A^2$

Number density of element i -> Solar Model

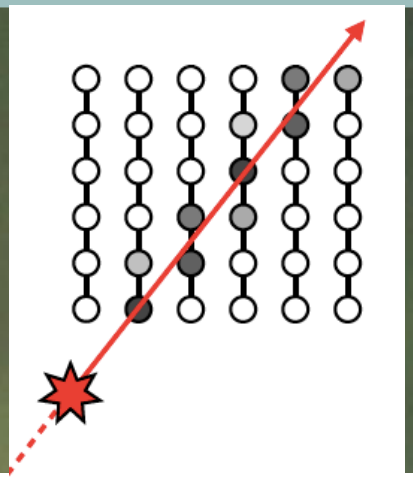
velocity distribution (in solar frame, without Sun's gravity)

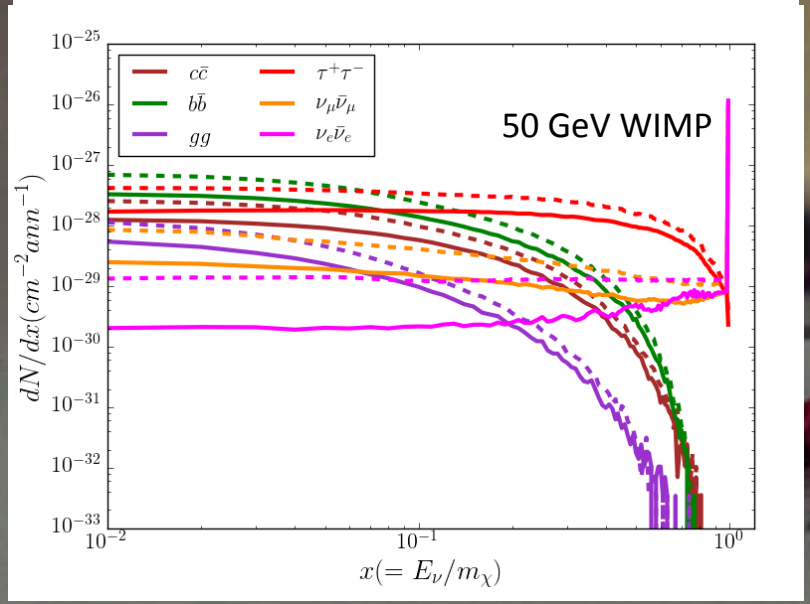
effect of solar gravity

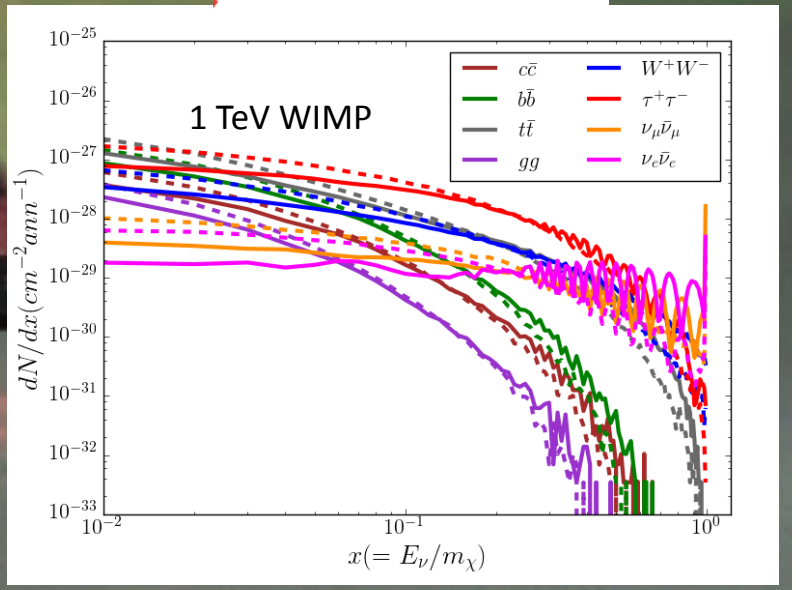


Annihilation rate = 2 capture rate at equilibrium

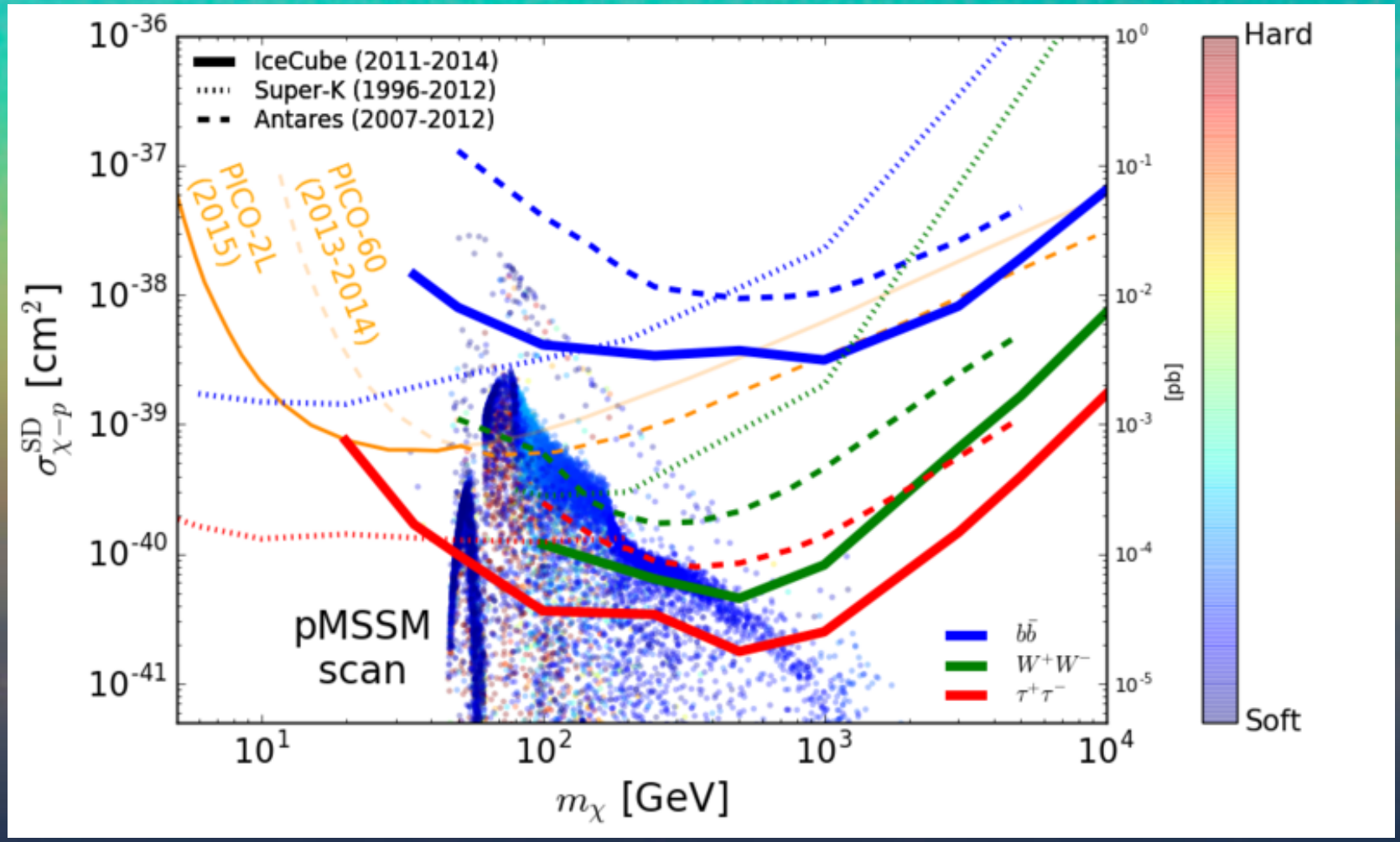
Upgoing thoroughgoing neutrino induced muons fingered by the Earth or 'starting events'







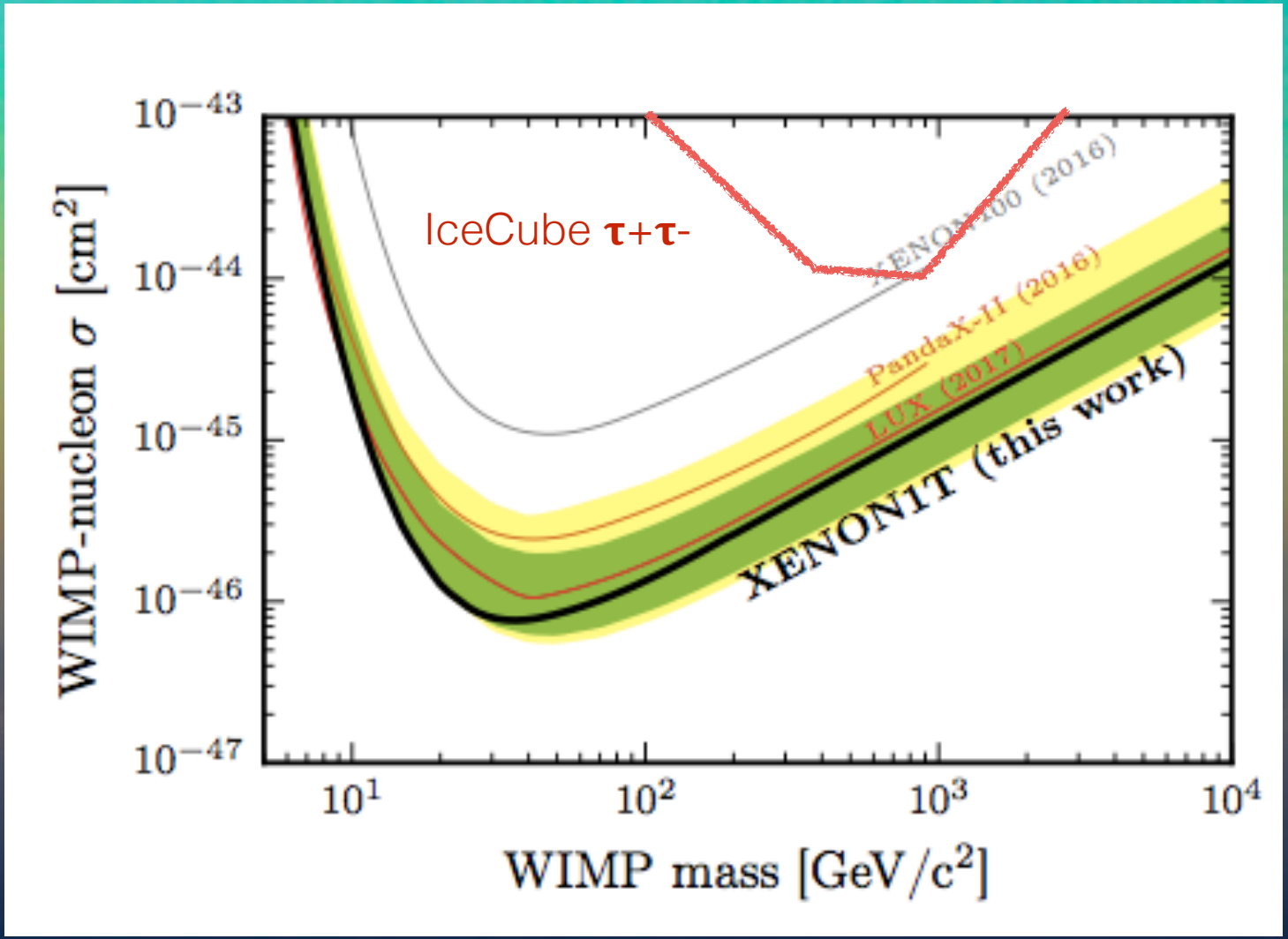
Solar DM limits from IceCube on the spin dependent scattering cross section



Mostly sensitive to spin dependent since the Sun is an H reservoir
3 years of data: 532 days of livetime

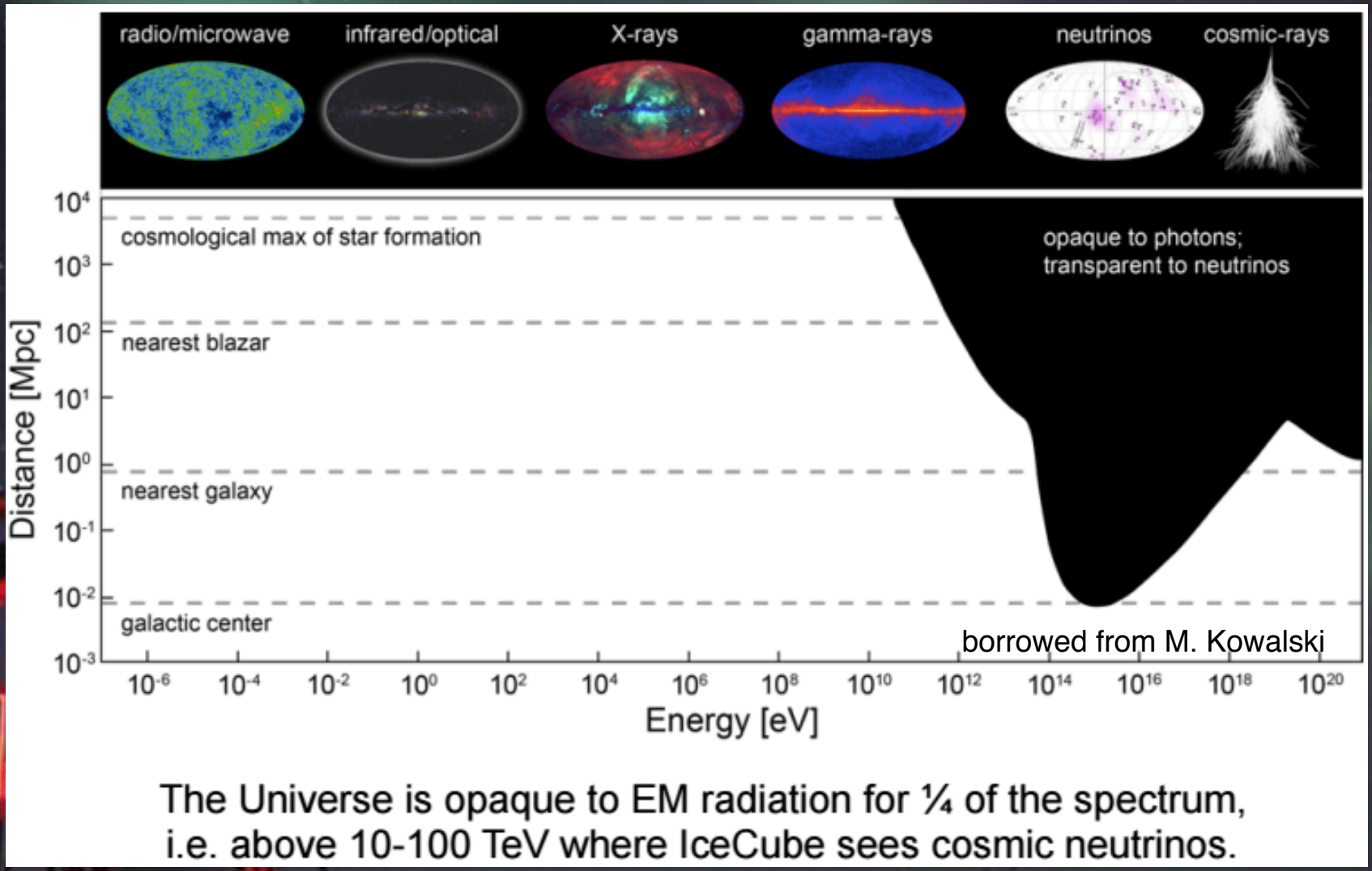
EPJC 77 146 (2017)

Solar DM limits from IceCube on the spin independent scattering cross section

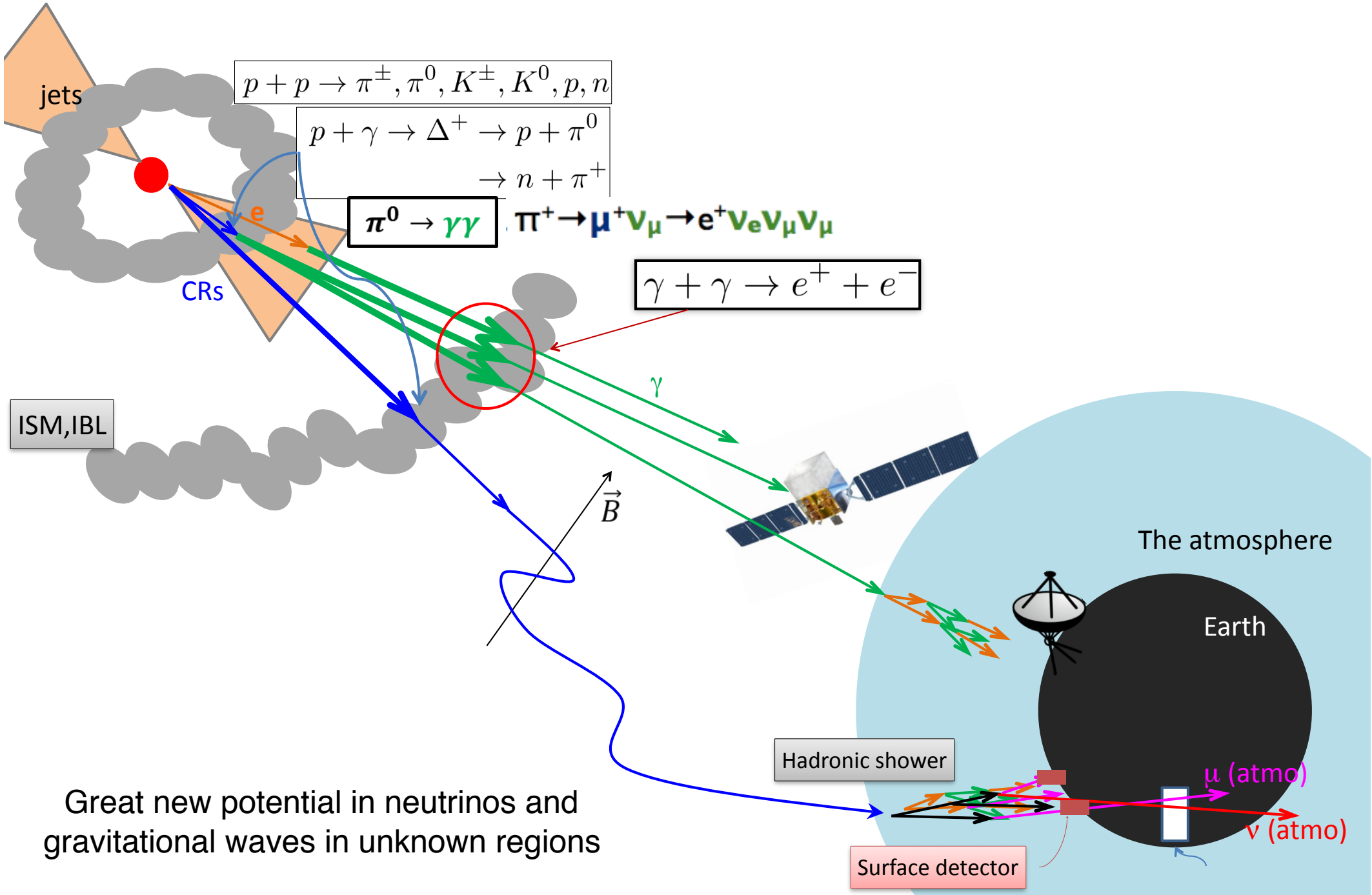


E. Aprile et al, XENON1T results

Multi-messenger horizons

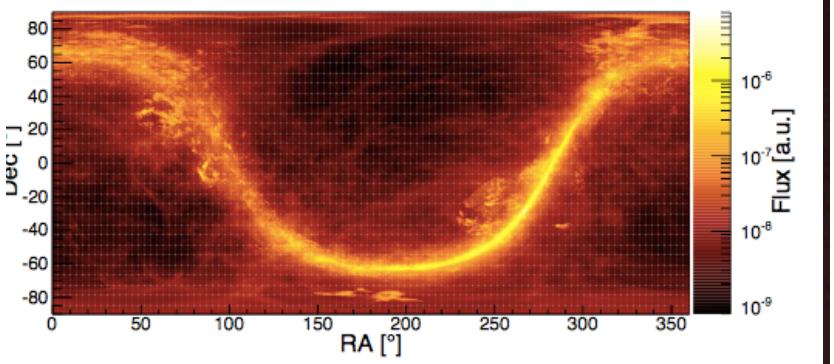


The Universe is opaque to EM radiation for ¼ of the spectrum,
i.e. above 10-100 TeV where IceCube sees cosmic neutrinos.



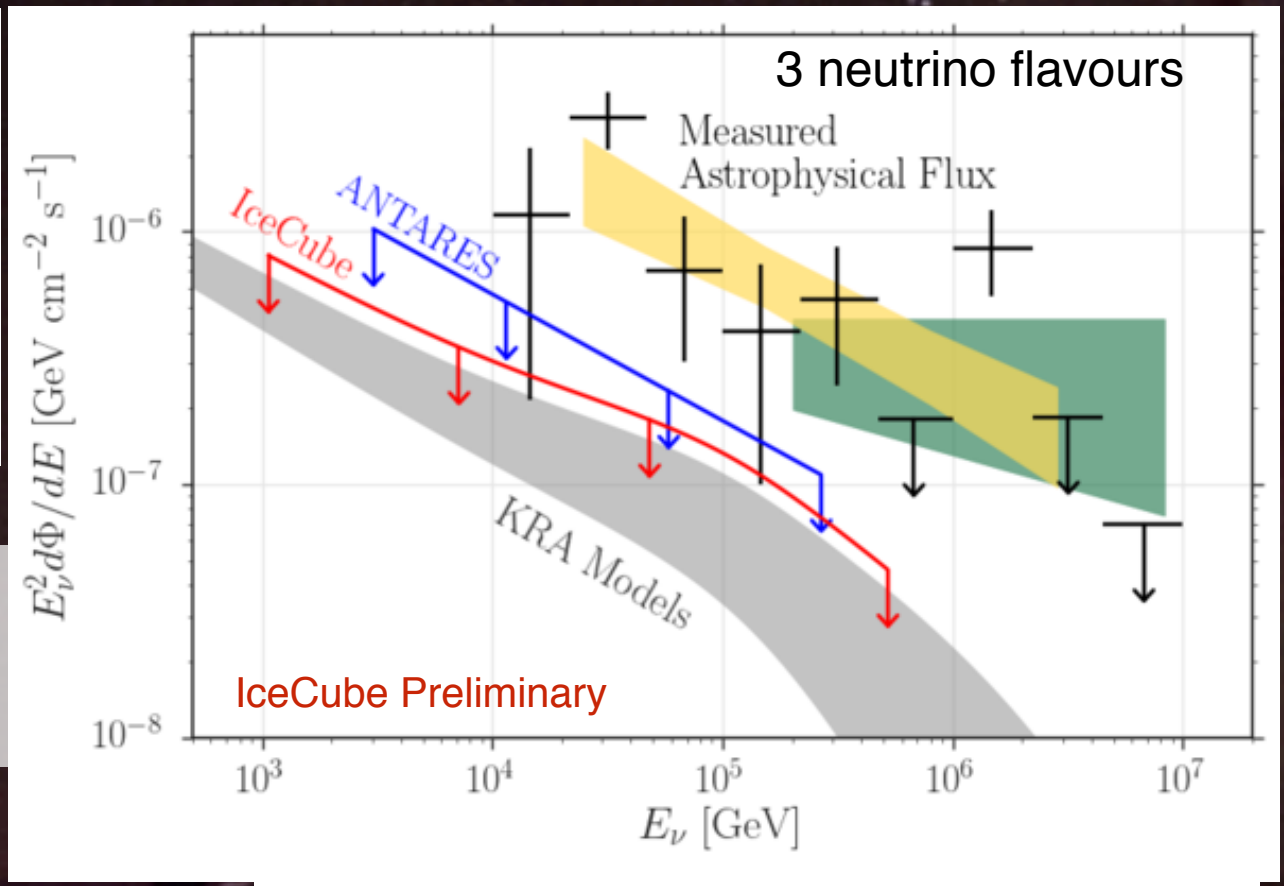
Great new potential in neutrinos and gravitational waves in unknown regions

Neutrinos from CR interactions in the Galaxy



(a) KRA-γ (50 PeV cutoff) template

Models from
Gaggero et al 2015; arXiv:1504.00227
reproducing Fermi-LAT data
UL: 1.2 x KRAγ (50PeV)



Possible galactic contribution to the diffuse neutrino flux less than 14% above 1 TeV

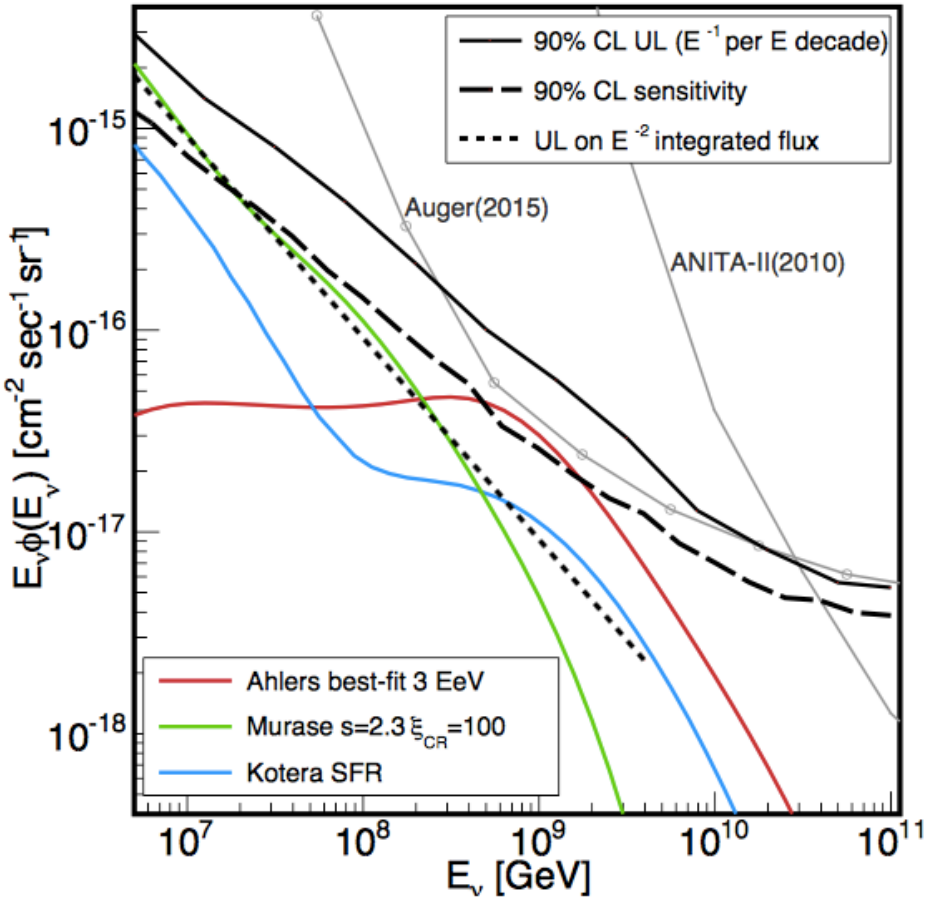
IceCube 7 yr upper limit (90%CL) 1-500 TeV
ANTARES upper limit arXiv:1602.03036

Diffuse muons 191 TeV and 8.3 PeV $E^{-2.13\pm0.13}$ (arXiv:1607.08006)

4 yr High Energy Starting Events > 30 TeV $E^{-2.5\pm0.09}$ (arXiv:1507.03991)

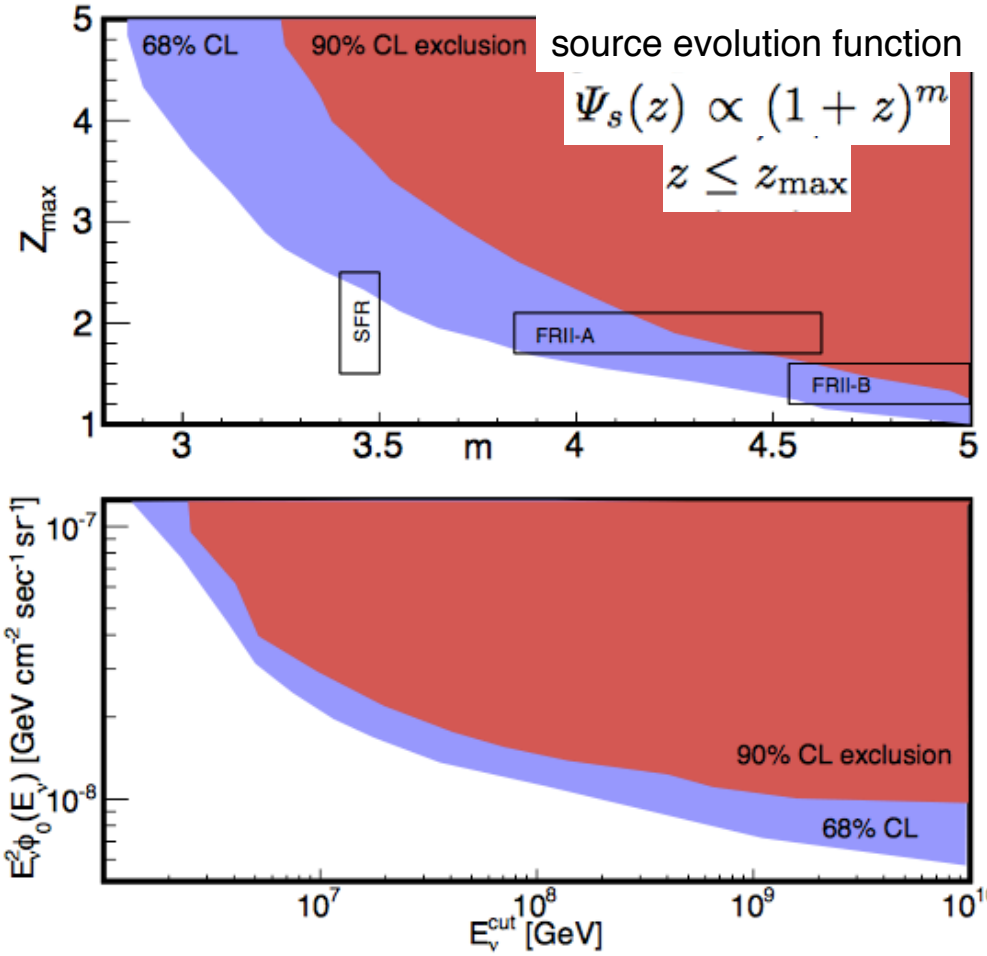
Neutrinos from CR+CMB interaction at GZK cut-off

7 yr EHE analysis of > 10 PeV neutrinos (new results at ICRC2017): hypothesis of atmospheric origin rejected at 3.6 σ



Phys. Rev. Lett. 117 (2016)

IceCube results disfavor a large portion of the parameter space where m ≥ 3.5 for sources distributed up to zmax = 2

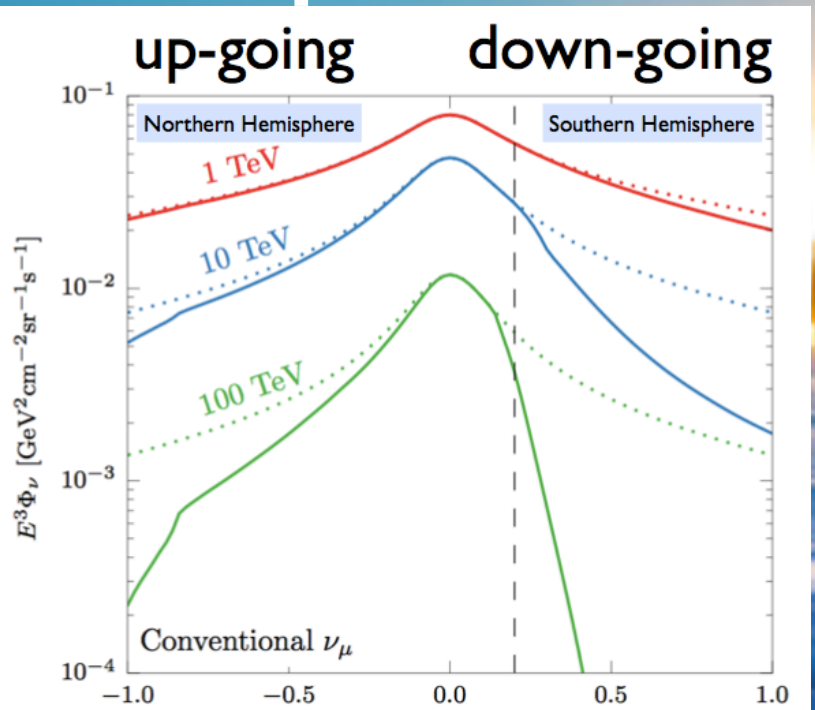


$E^2\phi \geq 6 \times 10^{-9}$ GeV cm^{-2} s^{-1} sr^{-1} is disfavored for neutrino fluxes extending above 10^9 GeV

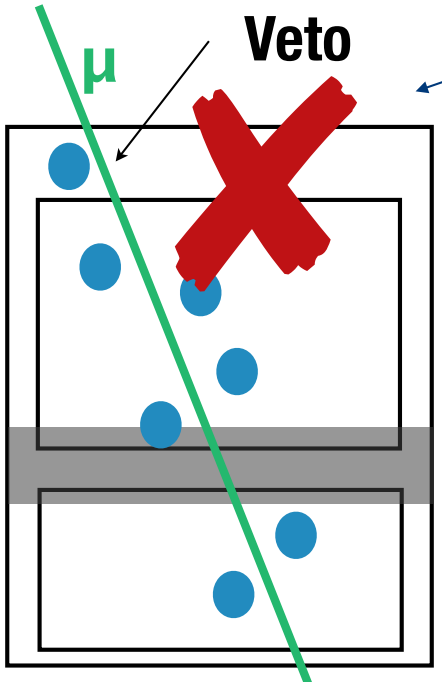
Vetoing atmospheric backgrounds

Schönert, Resconi, Schulz, Phys. Rev. D, 79:043009 (2009)

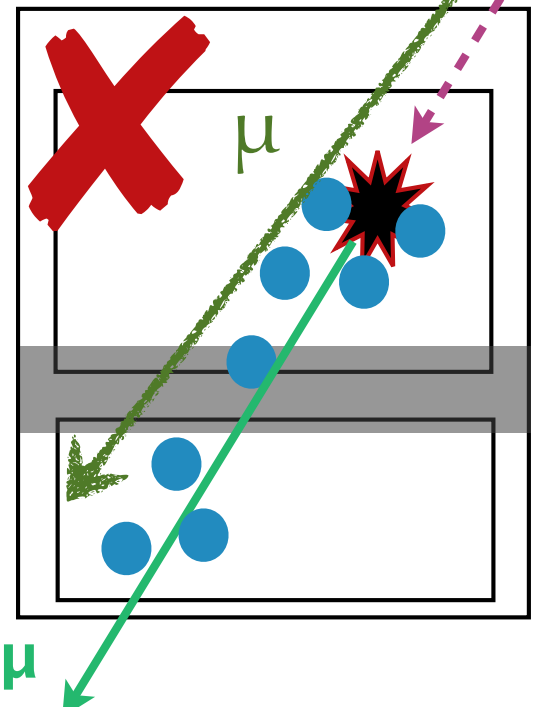
Gaisser, Jero, Karle, van Santen, Phys. Rev. D, 90:023009 (2014)



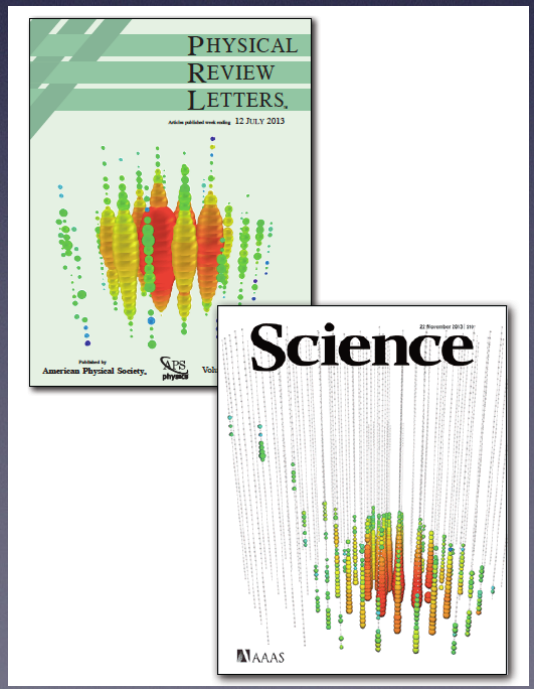
atmospheric muon tag

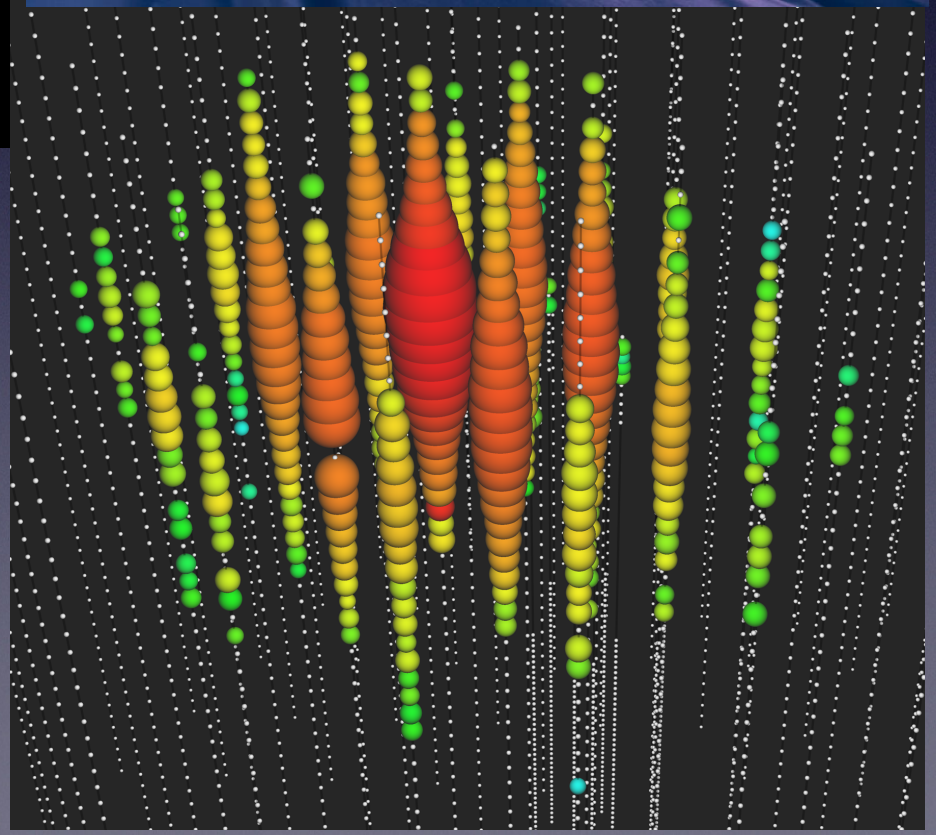


atmospheric neutrino tag



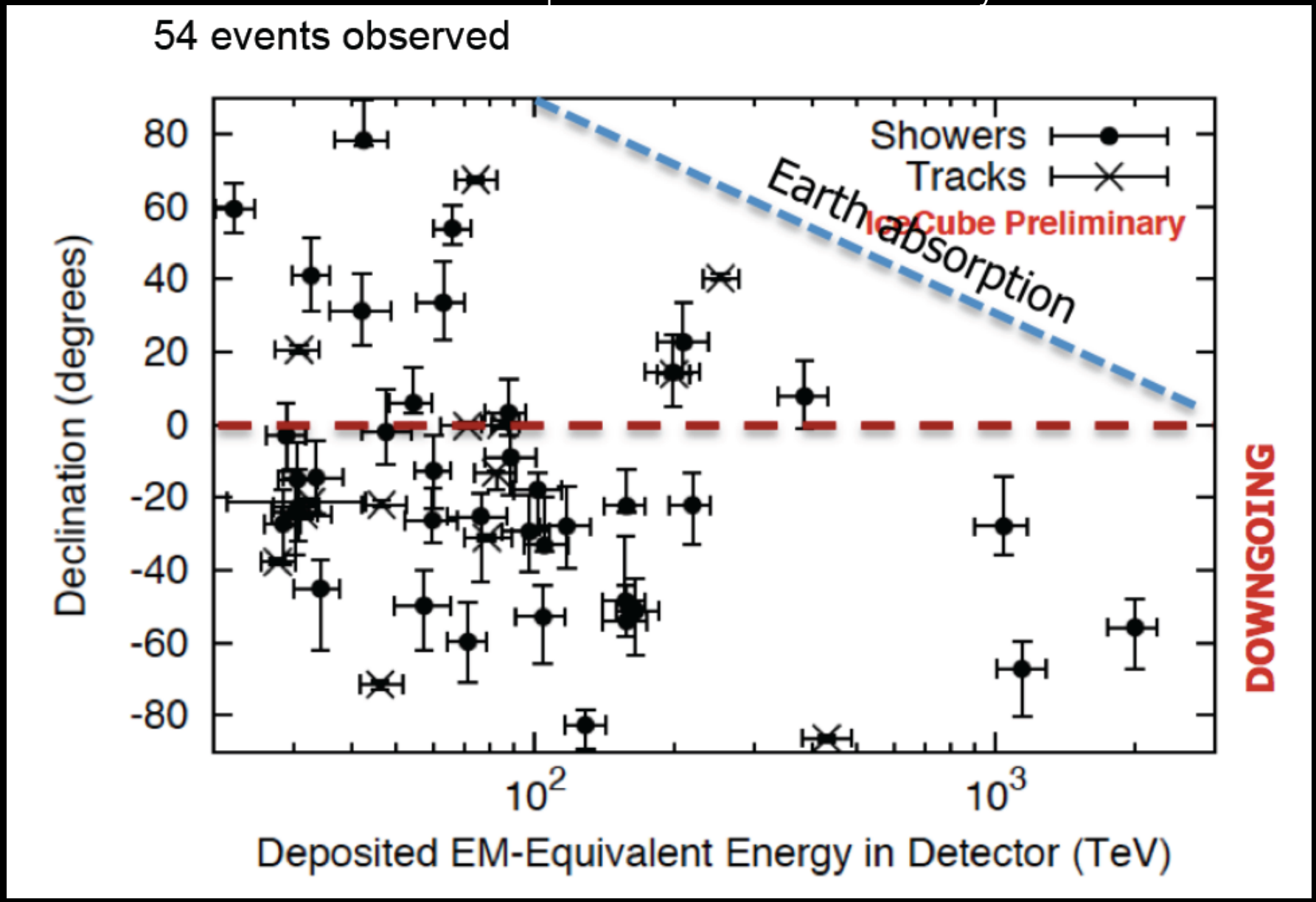
Neutrino starting high energy events



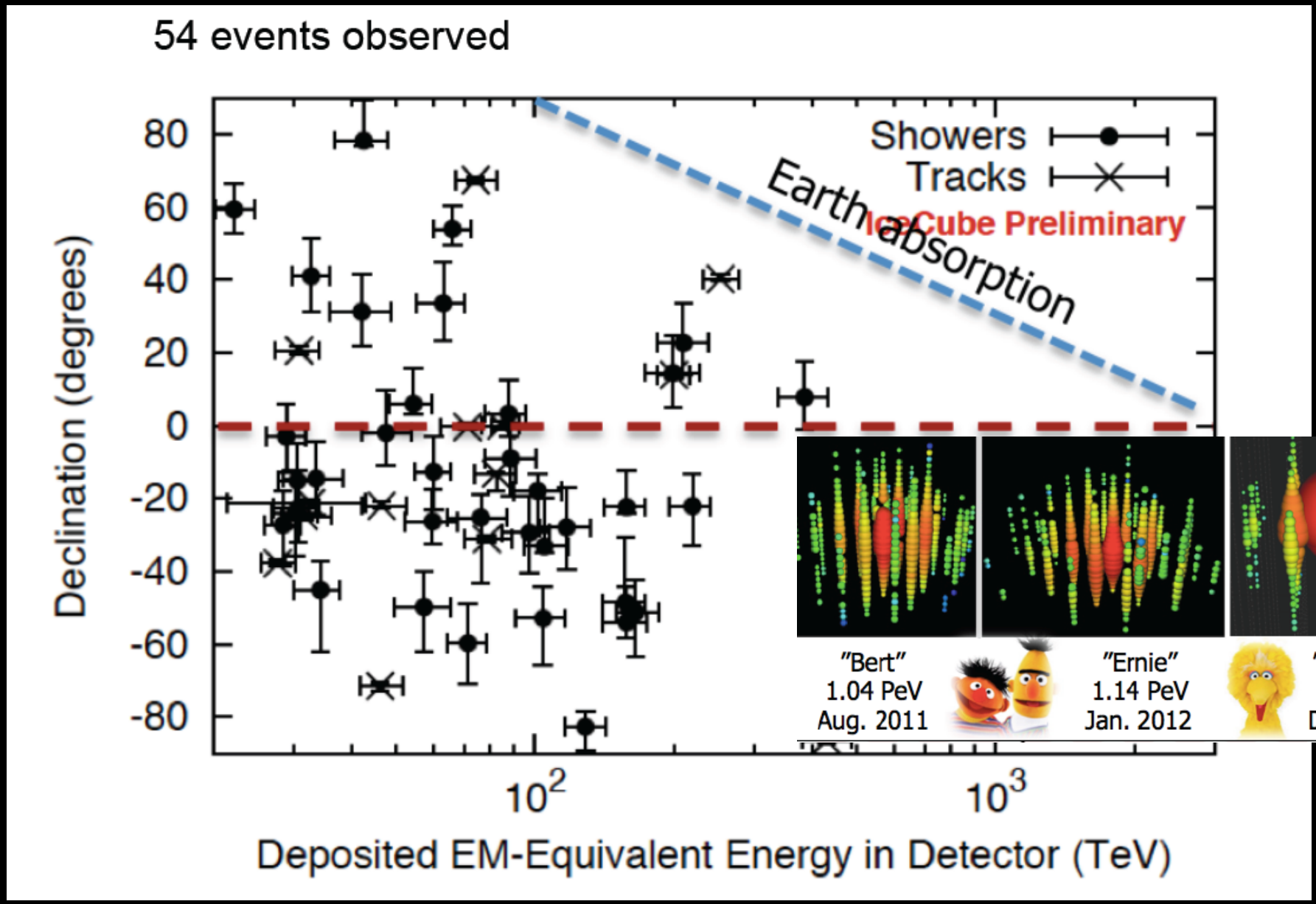


High Energy Starting Events (4 yr)

New results will be presented at ICRC for + 2 yrs

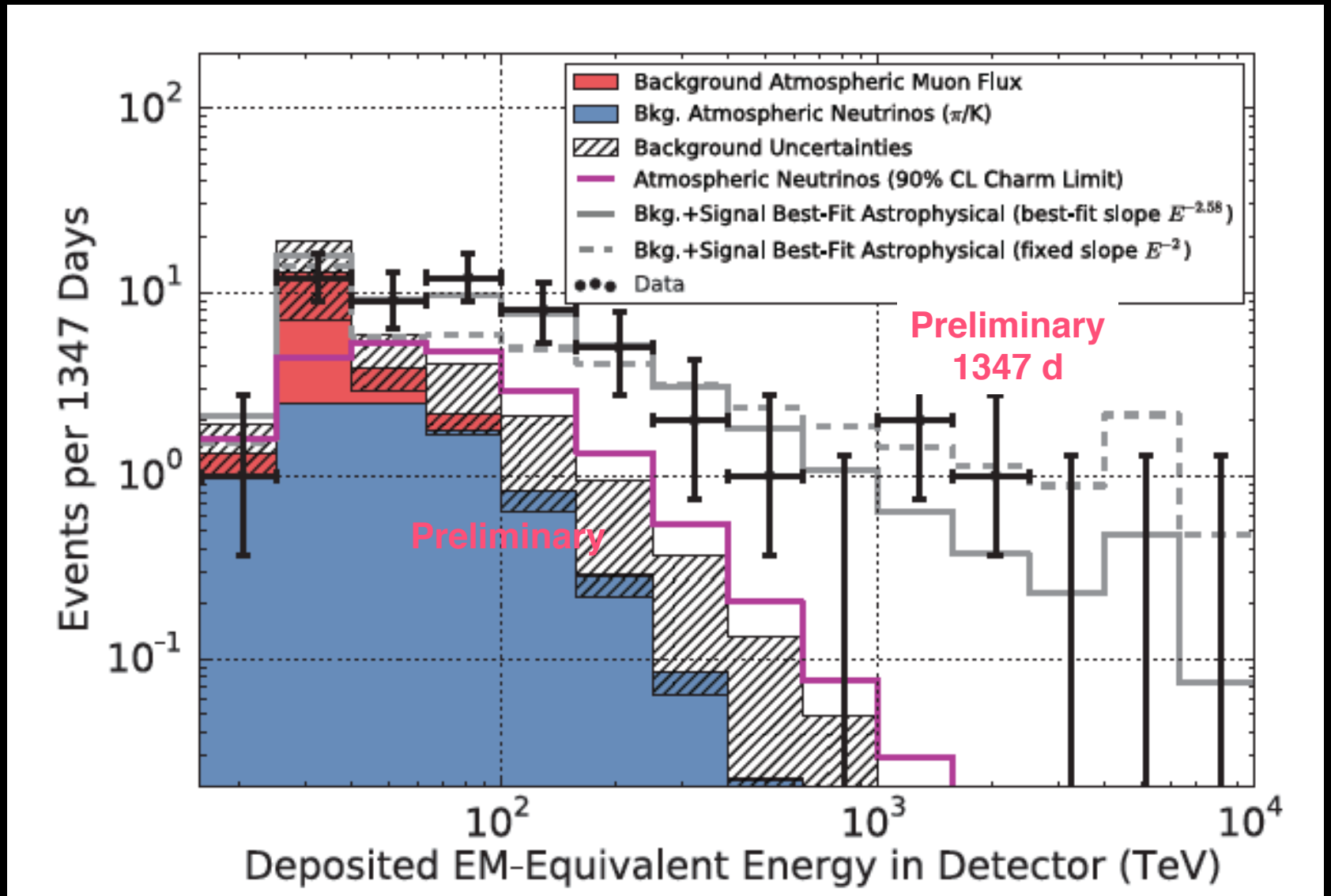


High Energy Starting Events (4 yr)



4 yr (2010-14) of HESE

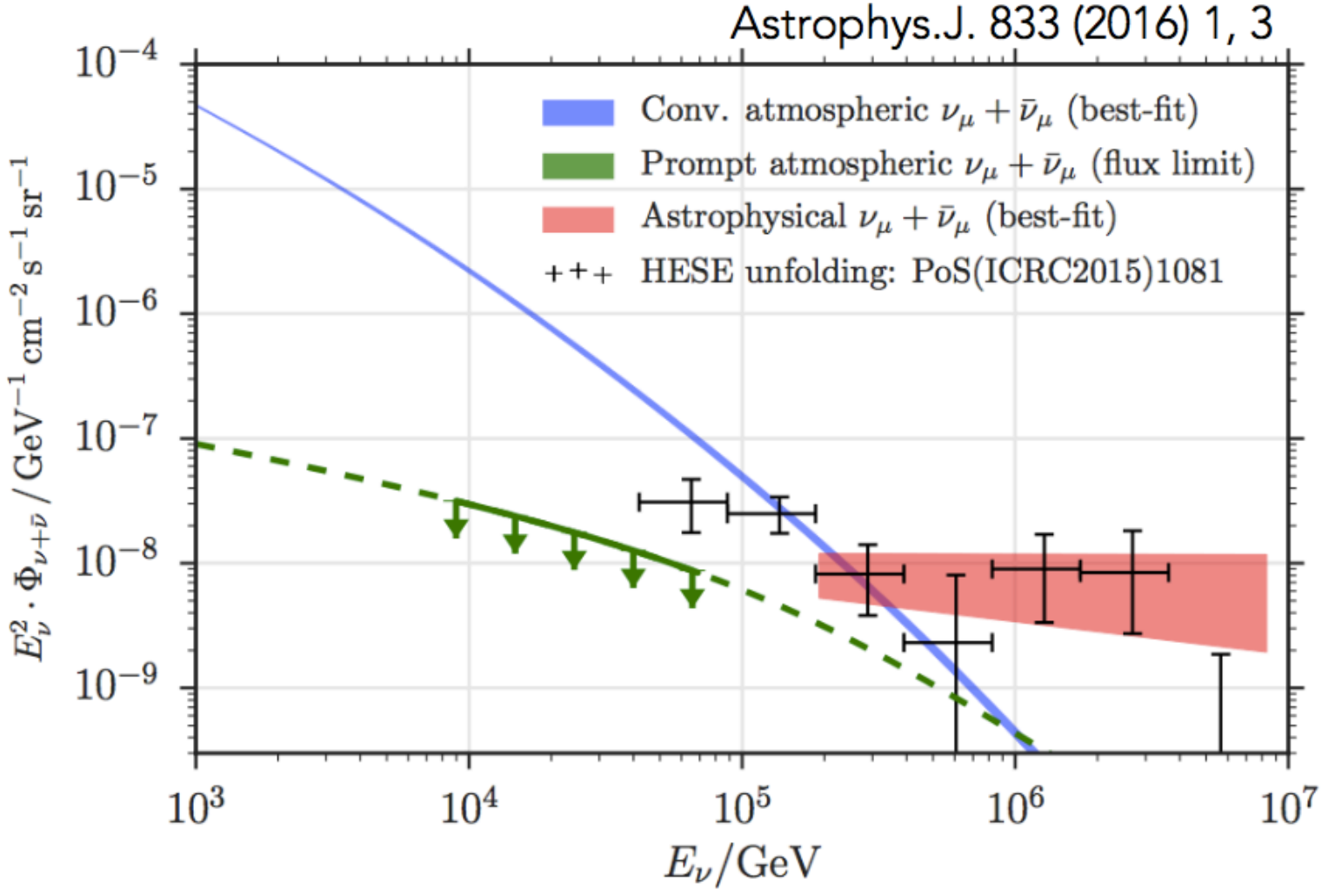
54 events (17+events in PRL 113 (2014) 101101) of which 2 are evident muon background.
The selection is based on an anti-coincidence veto + deposited charge>6000 p.e. (>30 TeV)
Measured atmospheric muon background: 12.6 ± 5.1
Atmospheric prompt component estimated using a previously set limit on atmospheric neutrinos with 59 strings: $9.0_{-2.2}^{+8.0}$ events



ICRC 2015, POS 1081, PRL 113 (2014) 101101

6 yr diffuse muon neutrino flux measurement

59 strings + 79 strings + 86 strings from 2011-2014 (new results + 2 yrs to be presented at ICRC2017).The atm. only hypothesis is excluded with significance 5.6sigma.



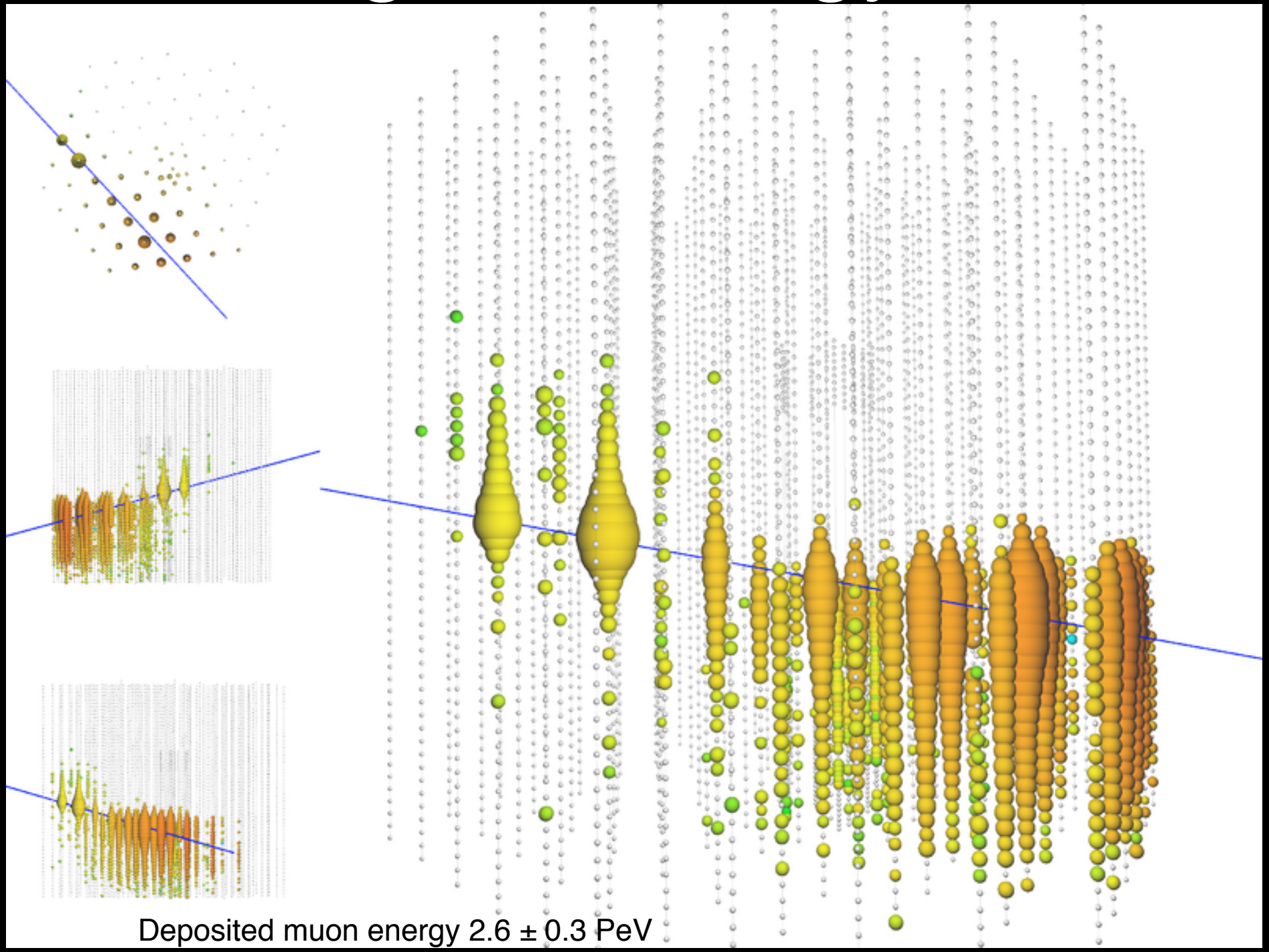
Best fit of the astrophysical neutrino flux between

190 TeV – 8PeV

$$\Phi_{\nu+\bar{\nu}} = \left(0.90^{+0.30}_{-0.27}\right) \cdot \left(E_\nu/100\,\mathrm{TeV}\right)^{-(2.13\pm0.13)}$$

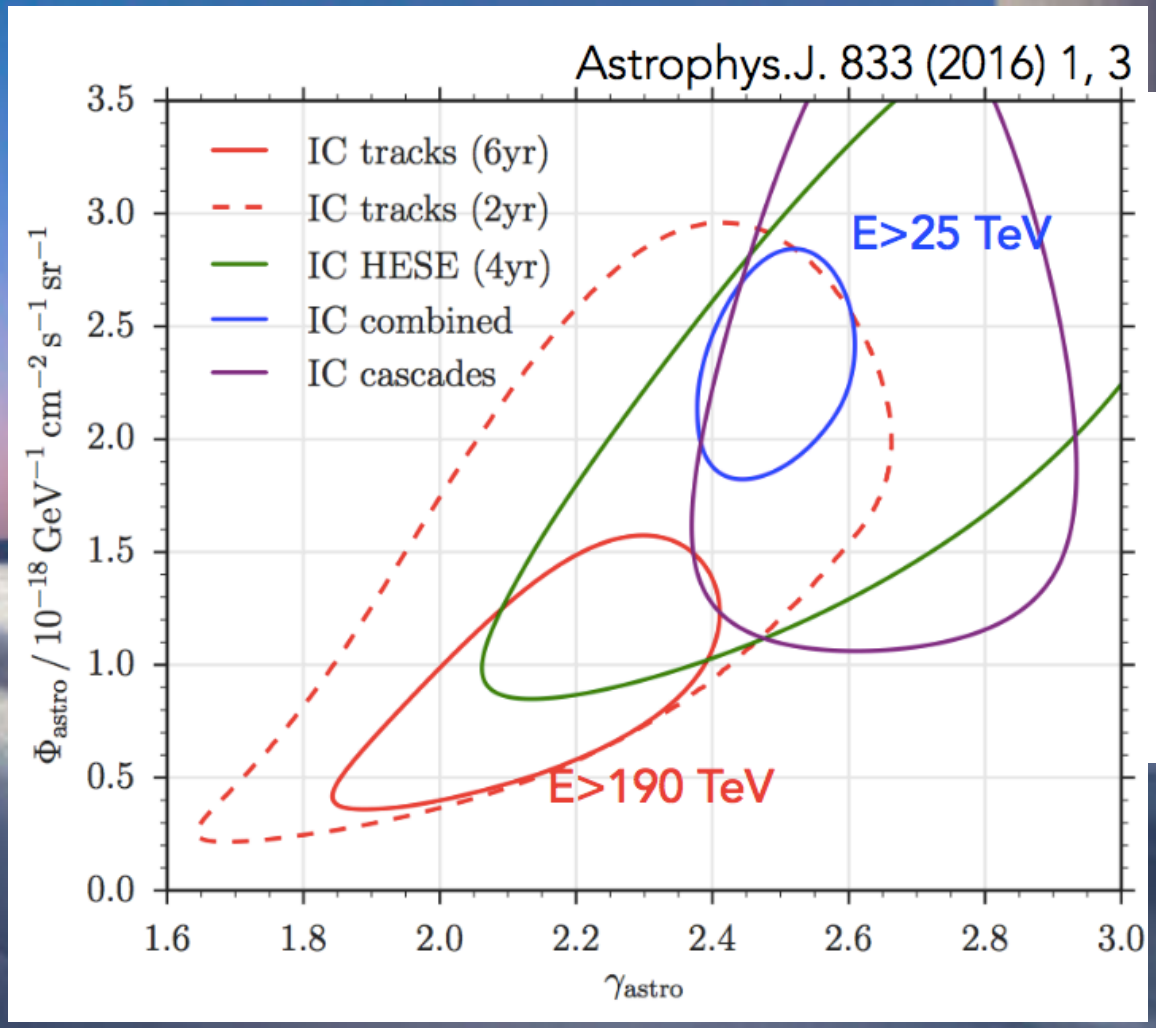
in units of $10^{-18}\,\mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{sr}^{-1}\,\mathrm{s}^{-1}$

The highest energy muon



Deposited muon energy 2.6 ± 0.3 PeV

Cascade dominated and muon track results



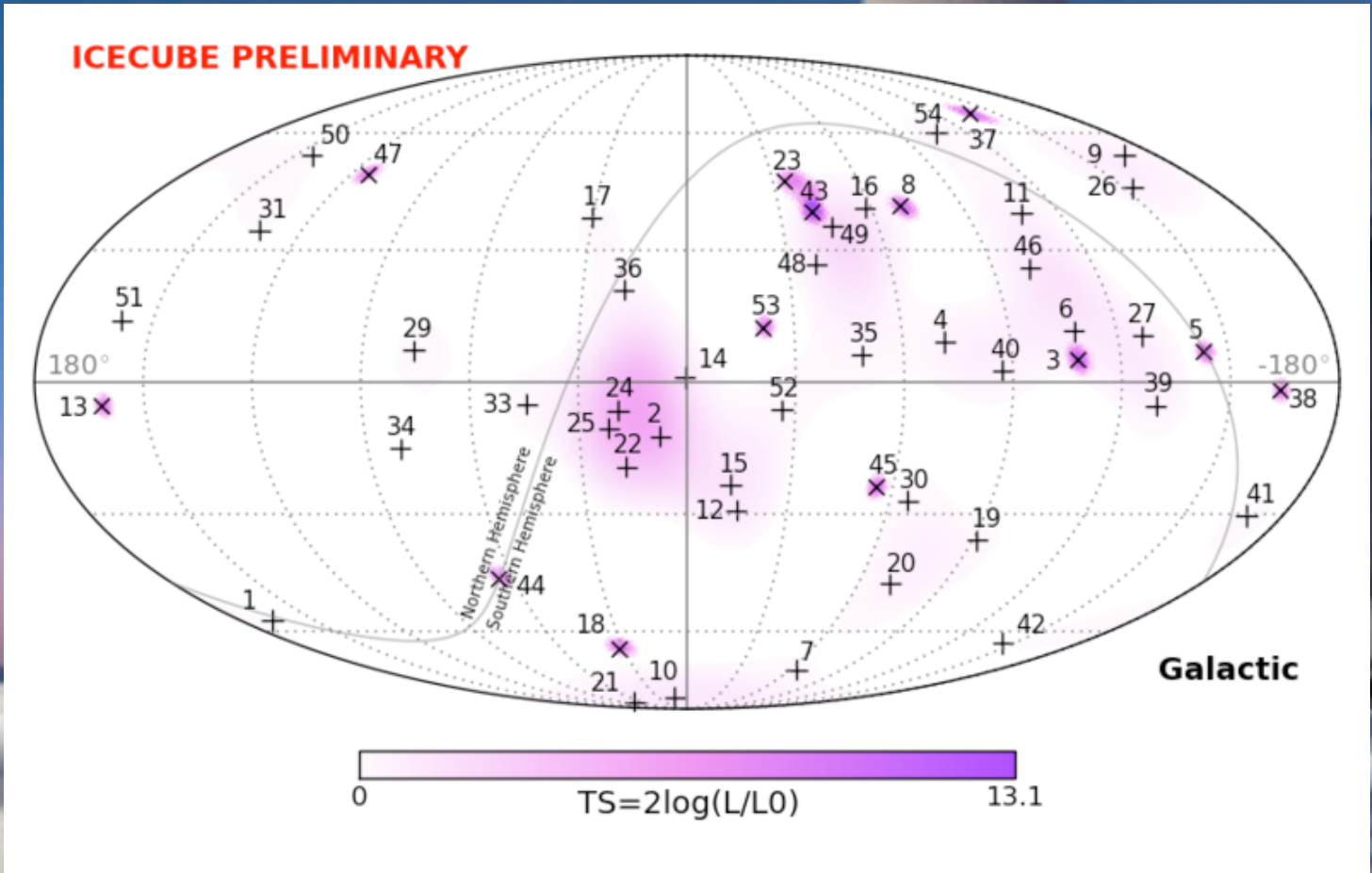
Analysis based primarily on cascades:

$\gamma = 2.5 \pm 0.1$

Based on northern sky ν_μ tracks:

$\gamma = 2.1 \pm 0.1$

Clustering tests



Clustering of events has been tested and did not yield significant evidence with post trial p-values of 44% and 58% for the shower-only and all-events, respectively. A galactic plane clustering test using a fixed width of 2.5° around the plane (post trial p-value 7%) and using a variable-width scan (post trial p-value 2.5%). UniGE led the search of correlations between IceCube highest energy neutrinos and UHECRs from Telescope Array and Pierre Auger.

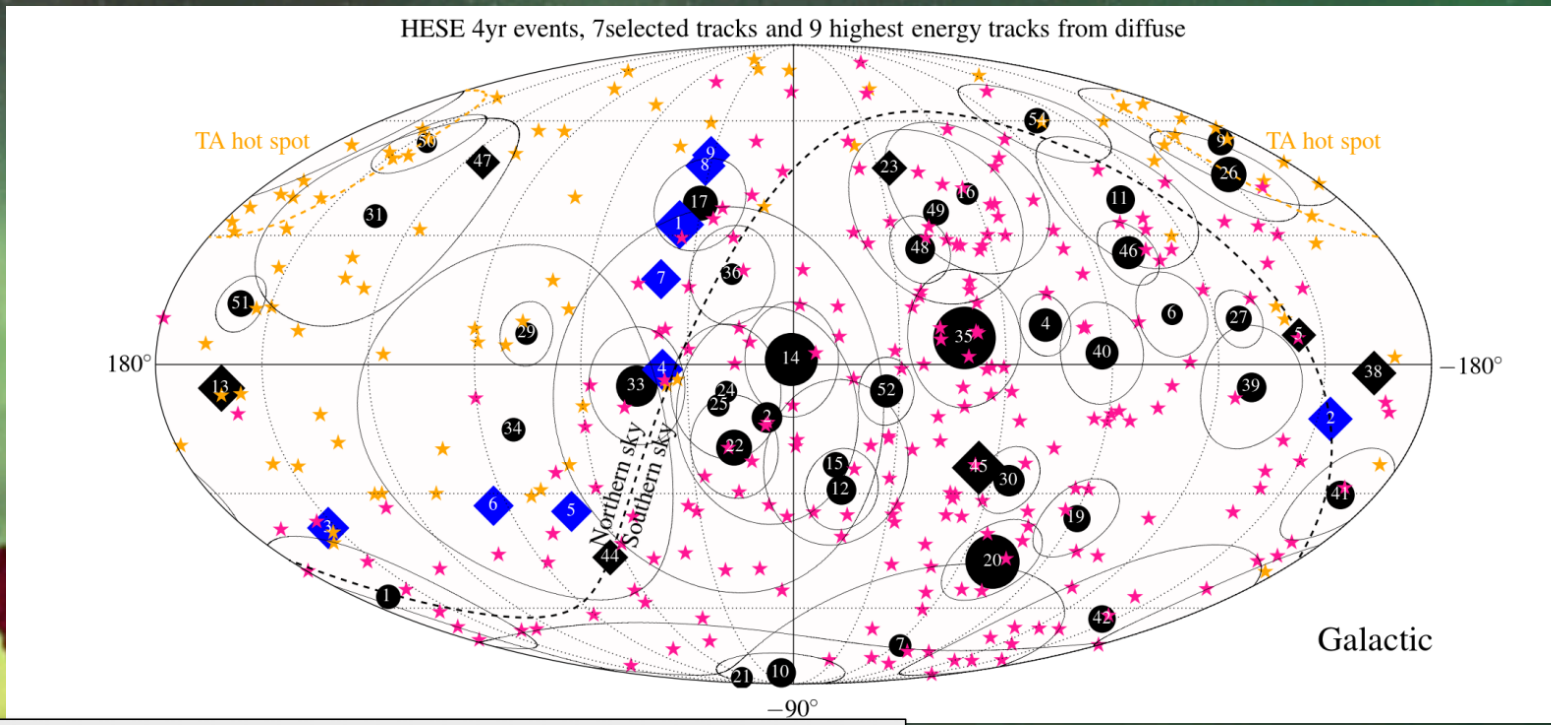
Neutrino-UHECR correlation

231 Pierre Auger events (E>52 EeV, zenith angle < 80°, ang res ≃0.9°)
87 Telescope Array events (E>57 EeV, zenith angle < 55°, ang res ≃ 1.5°)
4 yr of diffuse HESE: 39 cascades (ang. res ≃ 10°-15°) + 7 muon tracks (ang res ≃1°) + 9 muon neutrino induced upping tracks E > 100 TeV from 6 yrs of upping muon diffuse search

JCAP 1601 (2016) no.01, 037

Orange stars: TA UHECR
Magenta stars: Auger UHECR
Black dot: HESE Cascades
- Energy ~ size of the dot
- Circle ~ Angular uncertainty
- Number ~ HESE event num.

Diamonds: High Energy Tracks
- Black selected HESE tracks
- Blue Diffuse ana. Tracks
- Energy ~ size of the diamond



Cascades, D=6°:

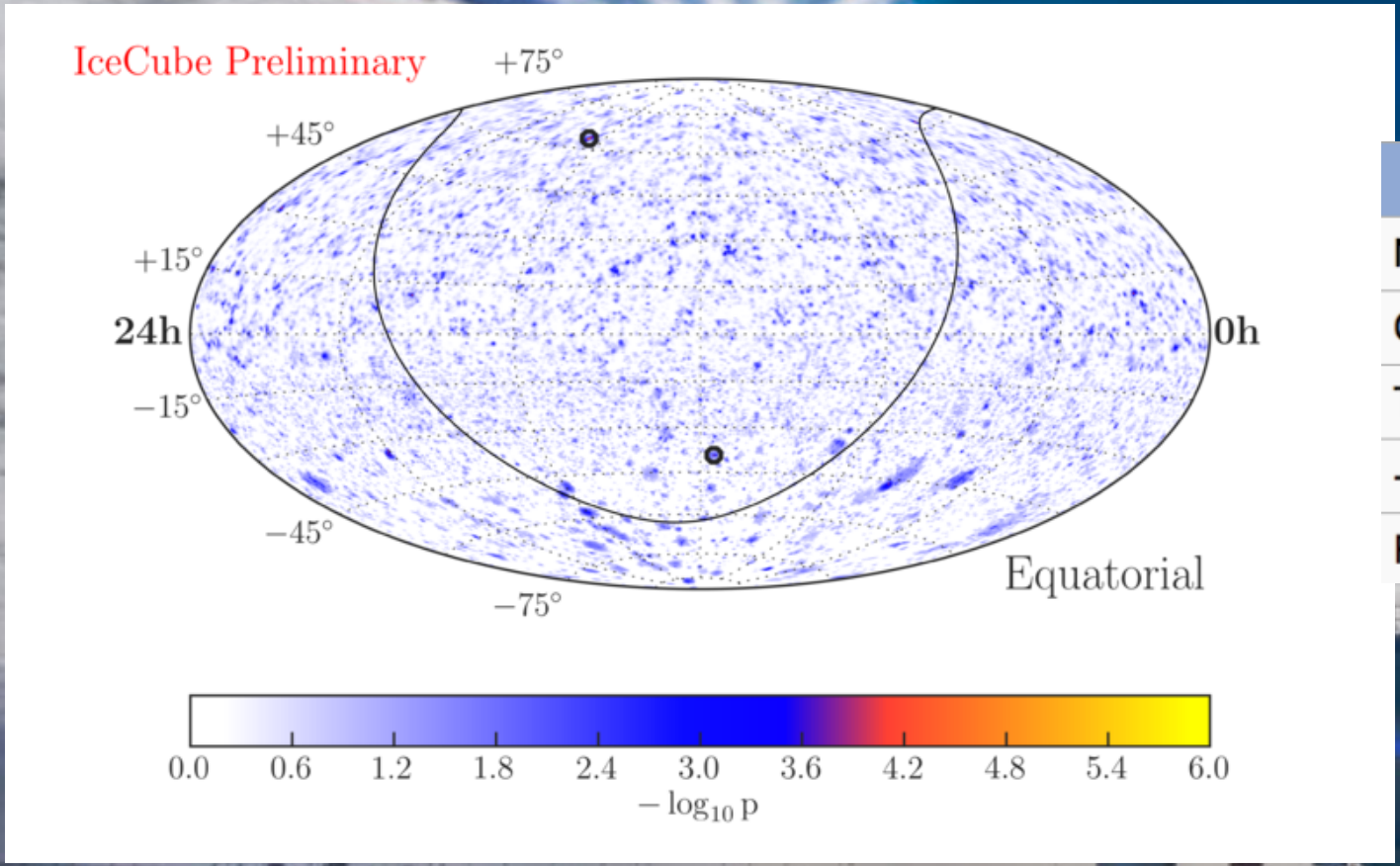
post-trial p-value = 8×10^{-4}

with respect to an isotropic flux of CRs.

Result update with new TA events (lower significance in the hot spot) at ICRC2017

Cluster search with 7 years of data

Downing muons and well reconstructed atmospheric neutrinos above 100 GeV
1 year of 40 strings, 59, 79, and 86 from 2011-2014

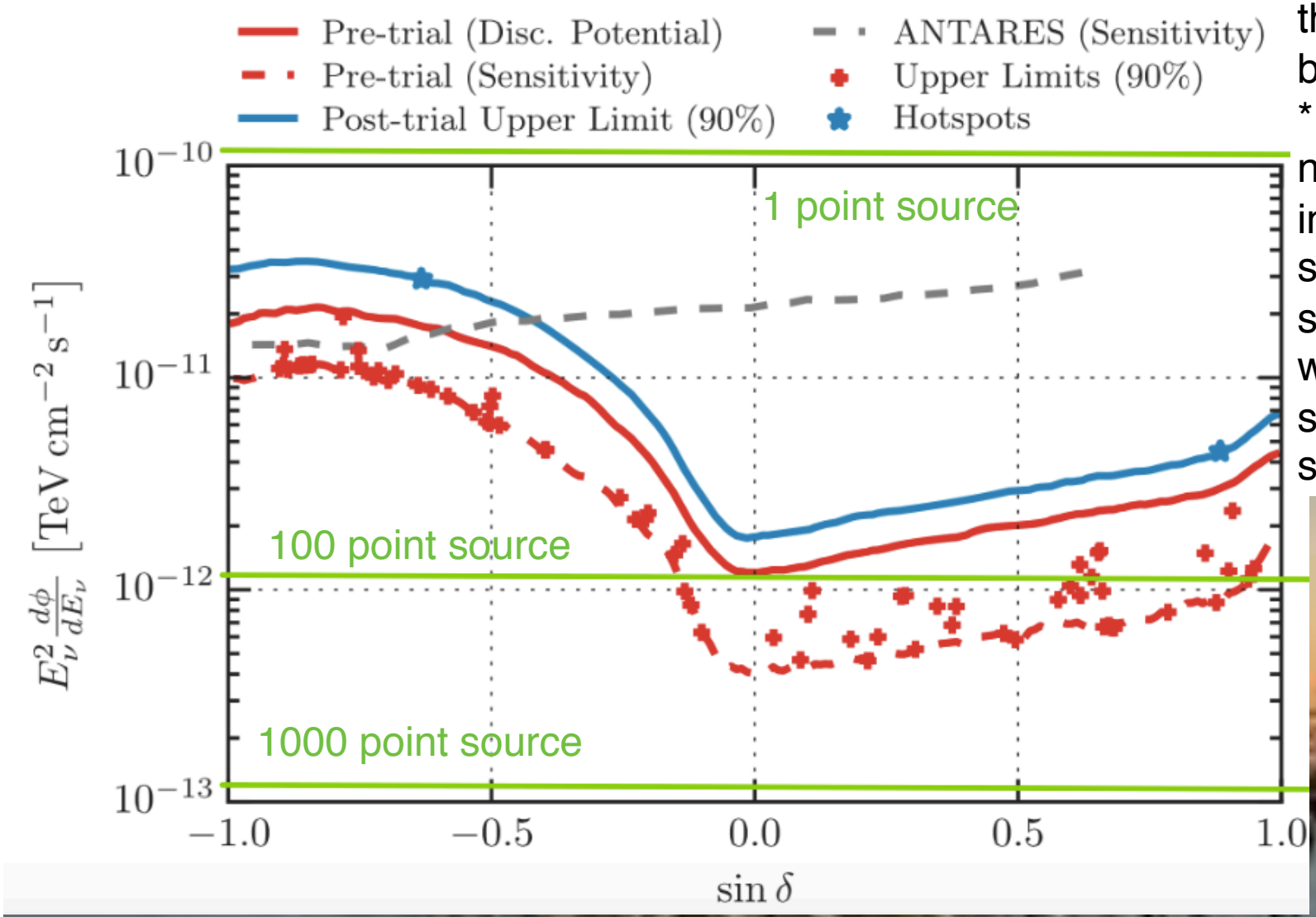


Hottest spots are background compatible

Hemisphere	North	South
N_Sources	27.22	15.54
Gamma	1.95	2.84
Test statistic	18.99	20.26
-log10(Pre-Trial P)	5.24	5.33
Post Trial P	44%	39%

ApJ 835 (2017) 2, 151

Upper limits from 7 years of point source searches



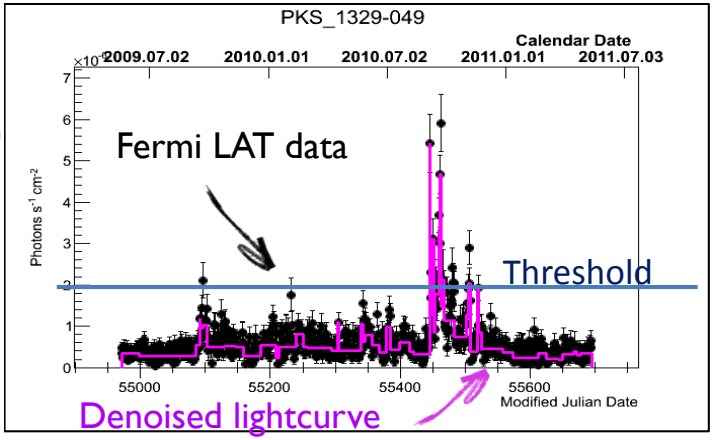
For comparison the green lines show the best fit diffuse muon flux * 4π divided by the number of points indicated (assumes same experimental sensitivity for all sources while it depends on source position in the sky)

Extragalactic sources: AGNs

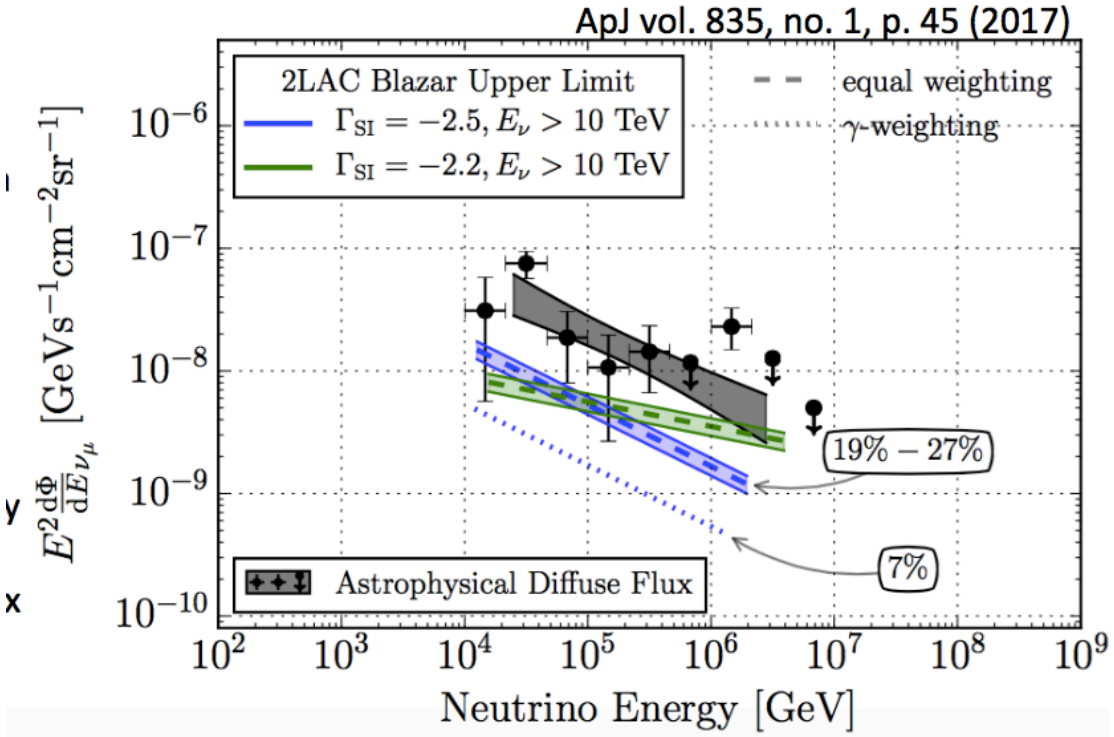
- Strong constraints on hadronic emission from GRBs and AGNs
- Multi-messenger searches enabled!

Time domain :

- Untriggered scans in time, space, energy (ApJ 807, 2015)
- Triggered by Fermi-LAT data for long term AGN and SGR (ApJ 807, 2015, ApJ 744, 2012) monitoring (about 50 flares in 3 years)
- No significant flare



Time independent Stacked search

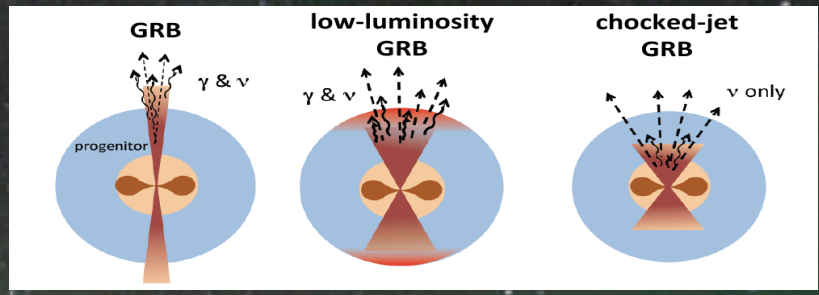


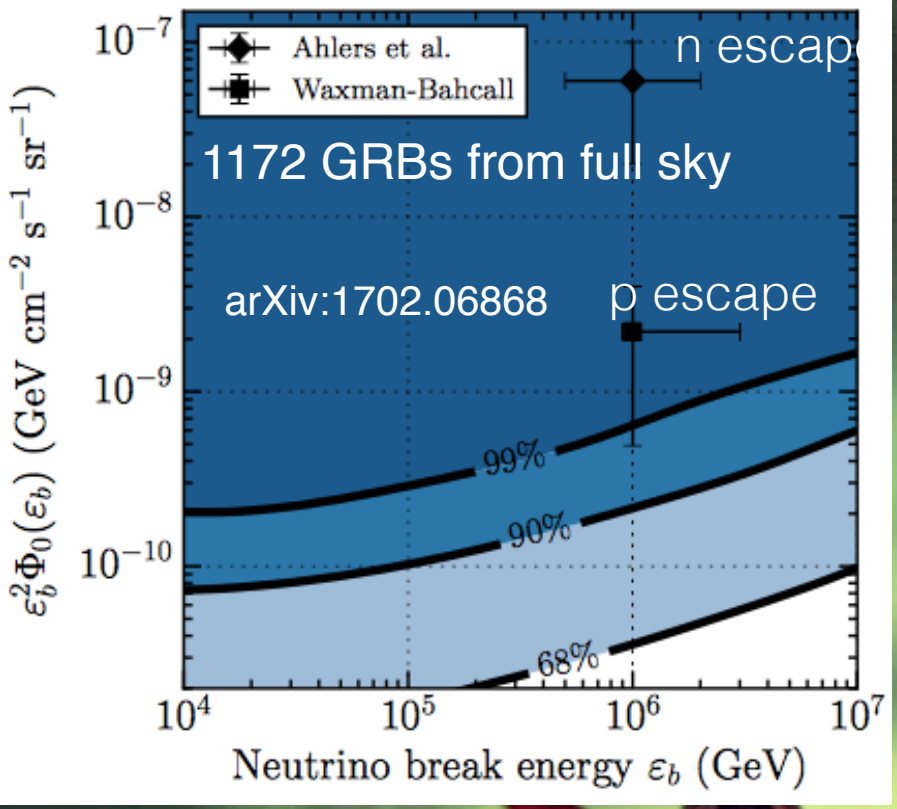
Stacked neutrino point source search with Fermi-LAT catalog of 862 Blazars: upper limit are about ∿30% lower than currently measured diffuse flux

Gamma-ray bursts

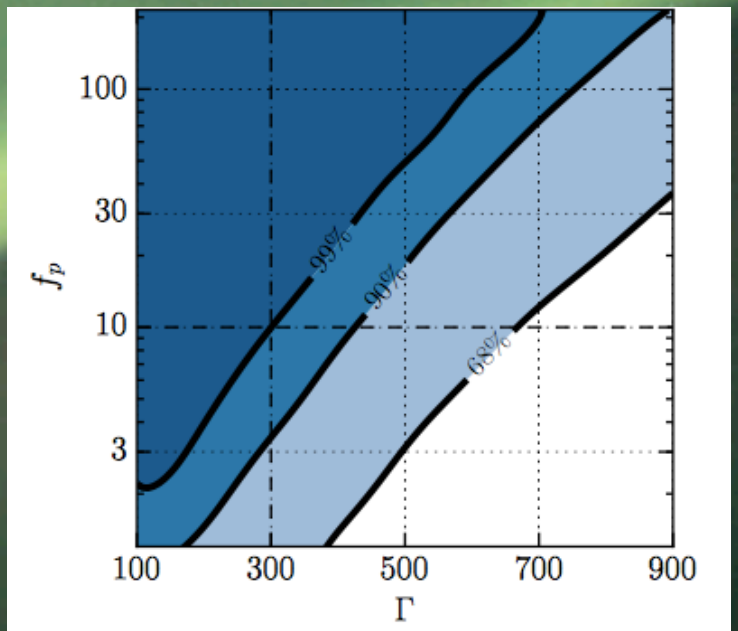
- Triggered and untriggered GRB searches
- GCN Alerts and ToO programs

Models assume GRBs are sources of UHECRs





The internal shock and photospheric fireball models are shown to be excluded at the 99% CL for benchmark model parameters. Models that yet cannot be severely constrained require small baryon loading and large Lorentz factors

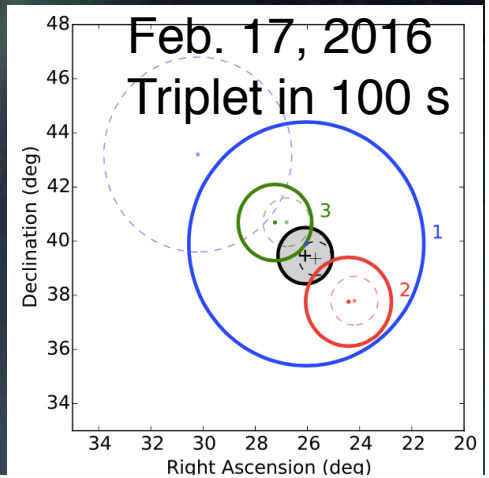


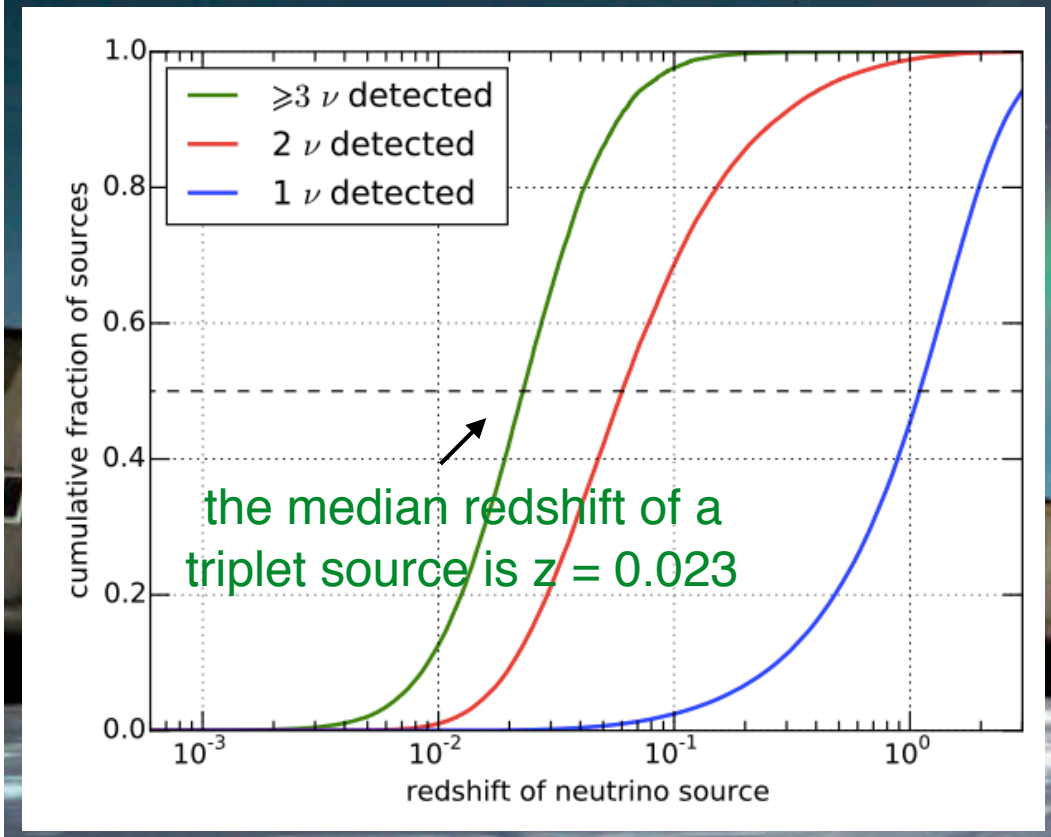
Most significant GRB110207A: Swift- localized long GRB (T_{100} = 109.32 s) at dec = -10.8° in coincidence with a muon neutrino candidate inside 1° with moderate reconstructed muon energy of Eμ≳12 TeV and post-trial significance consistent with background.

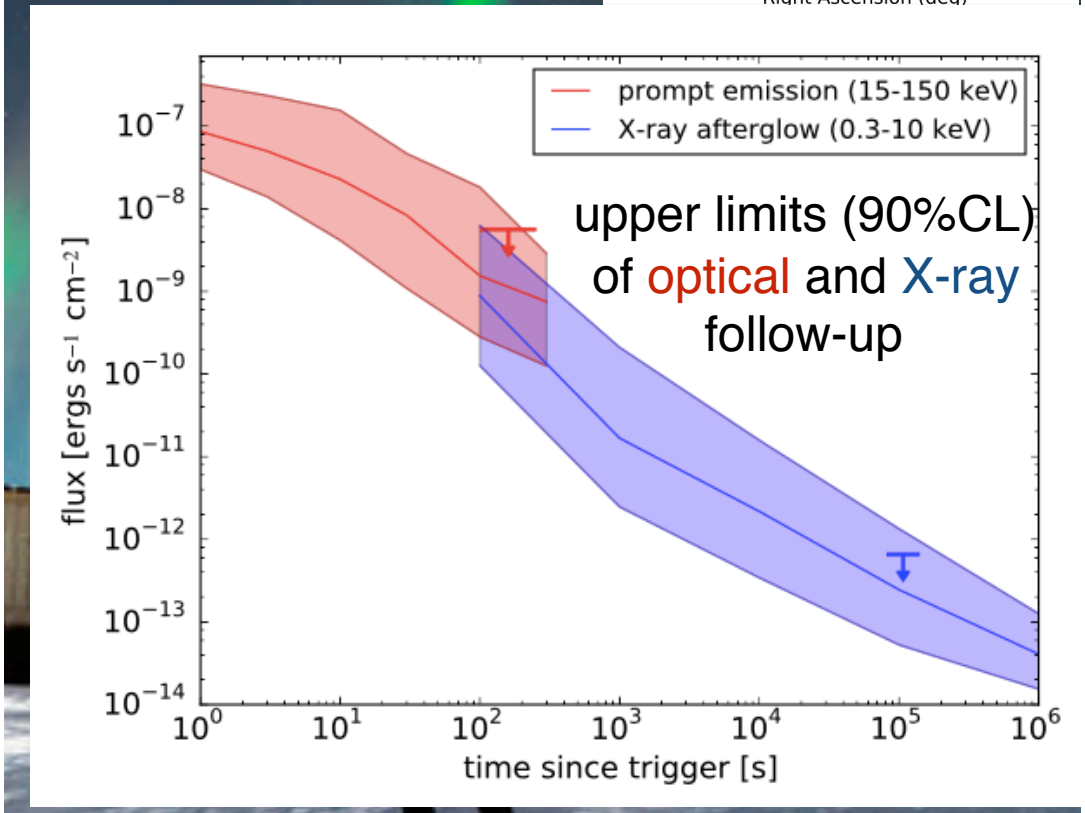
Follow-up programs

IceCube, HAWC, VERITAS, Swift (100 s after), Fermi, MASTER, LCO, ASAN-SN , arXiv:1702.06131

The triplet is consistent with a point source and expected once every 13.7 yrs from a random coincidence of atmospheric backgrounds and prob. of being background of 32%.







Simulation of transient neutrino sources with a density of 4×10^{-6} Mpc^{-3} yr^{-1} (∿few% CCSN rate) distributed in redshift according to the star-formation rate assuming that CSSNe produce the detected astrophysical neutrino flux.

Would a GRB be detectable in follow up observations? Swift GRB light curves and their X-ray afterglows (the line is the median of the flux and the band includes 80% of GRBs)

IceCube in GCN!

2015

[Previous | Next | ADS]

Detection of a multi-PeV neutrino-induced muon event from the Northern sky with IceCube

Related
7868 HAWC TeV gamma-ray follow-up observation of the sky region of IceCube's multi-PeV neutrino-induced event
7856 Detection of a multi-PeV neutrino-induced muon event from the Northern sky with IceCube

ATel #7856; *Sebastian Schoenen and Leif Raedel (III. Physikalisches Institut, RWTH Aachen University) on behalf of the IceCube Collaboration*
on 29 Jul 2015; 20:47 UT
Credential Certification: Marcos Santander (santander@nevis.columbia.edu)

bjects: Neutrinos, Request for Observations

eferred to by ATel #: 7868

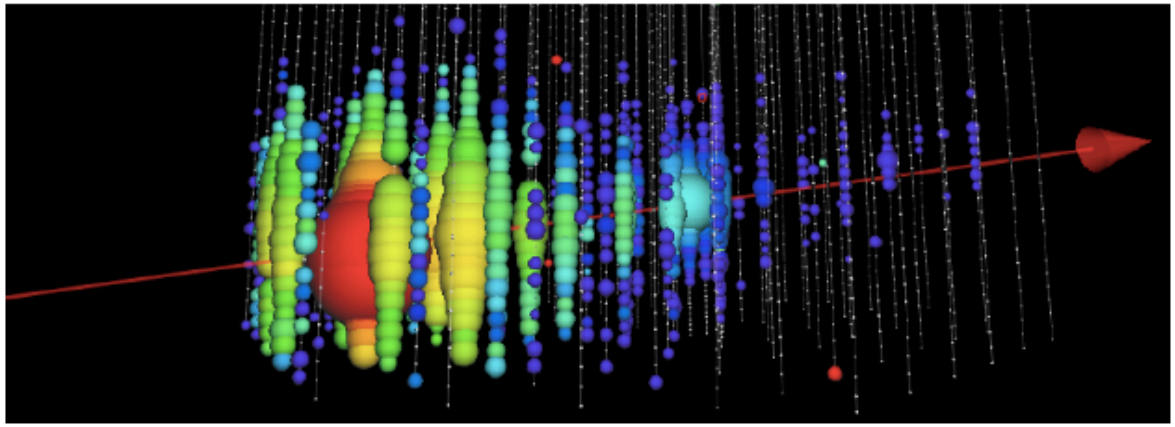
veet

ATel #7856

e observed a muon event with an energy of multiple PeV originating from a neutrino interaction the vicinity of the IceCube detector. IceCube is a cubic-kilometer neutrino detector installed in e ice at the geographic South Pole mostly sensitive to neutrinos in the TeV-PeV energy range. The ent is the highest-energy event in a search for a diffuse flux of astrophysical muon neutrinos using eCube data recorded between May 2009 and May 2015. It was detected on June 11th 2014 6819.20444852863 MJD) and deposited a total energy of 2.6 +/- 0.3 PeV within the instrumented olume of IceCube, which is also a lower bound on the muon and neutrino energy. The constructed direction of the event (J2000.0) is R.A.: 110.34 deg and Decl.: 11.48 deg. For mulated events with the same topology, 99% of them are reconstructed better than 1 deg and 50% tter than 0.27 deg. The probability of this event being of atmospheric origin is less than 0.01%. he IceCube contact persons for this event are Leif Raedel (RWTH Aachen University, edel@physik.rwth-aachen.de) and Sebastian Schoenen (RWTH Aachen University, hoenen@physik.rwth-aachen.de)

2016

more recent ICECUBE-160427A



9 alerts in first realtime alert system

Follow-ups to ICECUBE-160427A

- GCN 19364 – Fermi Gamma-Ray Burst Monitor - No detection
- GCN 19360 – Fermi LAT – 5 unrelated blazars
- GCN 19361 – HAWC – no detection
- GCN 19362 – MASTER – no detection
- GCN 19377 – VERITAS – no detection
- GCN 19392 – iPalomar Transient Factory – 3 transients, all AGN
- GCN 19427 – FACT Cherenkov TeV Telescope – no detection
- GCN 19426 - Interplanetary Network – no detection
- GCN 19381 - Pan-STARRS - 7 SN candidates, one consistent with type Ic supernova.

arXiv:1612.06028

Outlook

- Updates and New Results at ICRC 2017 in Busan

- IceCube Gen2:

  Phase 1 proposal submitted to NSF for 7 dense strings:
  - new calibration devices
  - Neutrino oscillations with comparable precision to T2K/NOvA
  - Tau flavour identification: 3 sigma discovery in 3 years