Neutrino Astrophysics

at ANITA

Tom Weiler
Vanderbilt University

μ

ANITA (Gorham, … Saltzberg, … Vieregg) find …

Either,

incredible: The first new particle type in 50 years,

or,

credible: New SM systematic,

or,

unbelievable: It’s wrong (it’s not - P. Gorham talk)

The Data

(1 & 1/2 events)

The Events: Flight #1 lasted 30 days

Event #1 (rough): versions 1-5, all Sept 2016

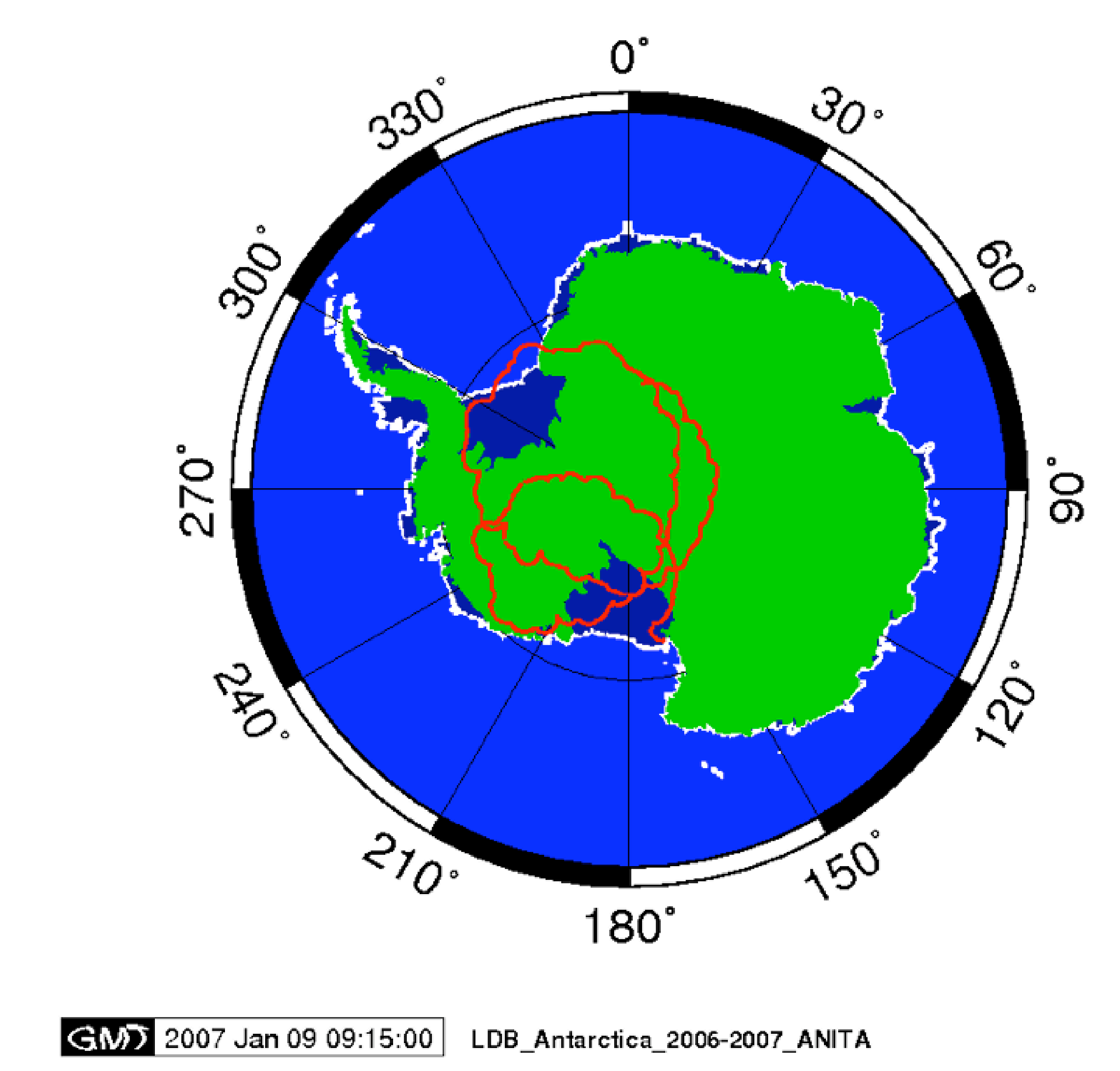
E~ 600 +- 400 PeV
theta ~ - 27 degrees below

The Events: Flight #3 lasted 22 days

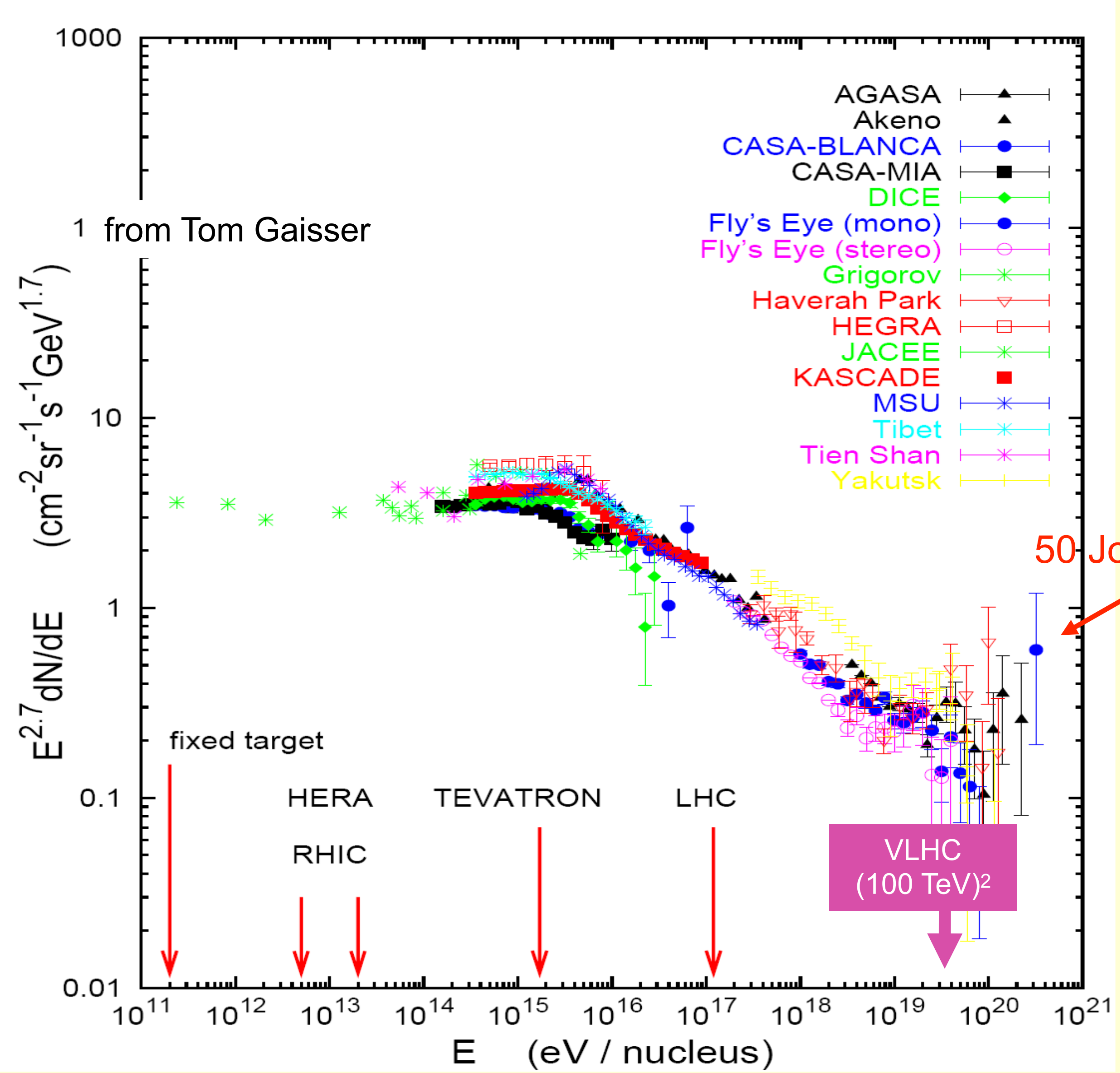
Event #2 (gold-plated): pub’d

E~ 560 +300 -200 PeV
theta ~ - 35 degrees below

ANITA flight path, launched 15Dec2006



CR Spectrum above a TeV



Chronologically ordered:

- Kistler-Laha - high E ICube mu maybe higher tau, May 2016
- The Events, flights #1 (Sep 2016) and #3, Mar 2018
- RM to Zas - transition radiation - NOT! June 2016
- Shoemaker and Cherry - Sterile Neutrino, Feb 2018
- Anchordoqui, et al (Moi, Sterile Nu's) March 2018
- Huang - Sterile Neutrino April 2018
- Dudas - broken R w/ EeV Gravitino May 2018
- A. Connolly - staus July 2018
- Penn State - staus, and more Sept 2018
- Broken R-parity Oct 2018
- Zas take two - validate P-R&W (+13yrs), Nov 2018
- Halzen's visit - IceCube cold water Nov 28, 2018

And more (mostly 2019): (a lot of authors per event)

DG Cerdeno,P Reimitz, K Sakurai,C Tamarit, broken B+L
B. Chauhan, S. Mohanty, LQ DM
LA Anchordoqui, I Antoniadis, SUSY sphalerons
L Heutier, Y. Mambrini, M Pierre DM —> NuR+NuR
Hooper, S Wegsman, C Deaconu, A. Vieregg SHDM & Askaryan
JM Cline, C Gross, W Xue, DM and SUSY
S Chipman, R Diesing, MH Reno, I Sarcevic, SM fails
L Heutier, D Kim, JC Park, S Shin, boosted DM (like “Cline”)
D Borah, A Dasgupta, UK Dey, G Tomar, light/heavy DM (like “Cline”)
I Esteben, J Lopez-Pavon, I Martinez-Soler, J Salvado, axions in Ionosphere
KD deVries and S Prohira, transition radn revised
IM Shoemaker et al, ice anomalies (too physically small)
LA Anchordoqui et al., these proceedings, … M Masip … J Soriano

ANITA Flight#2 trigger not sensitive to these events

ANITA Flight#3, started Dec 2014 lasted 22 days

Delta theta ~ 3 degrees but anomalies had non-inverted E/H-Polzn, occurred at large energies,

- and interpreted as (way) below horizon angle

Violating

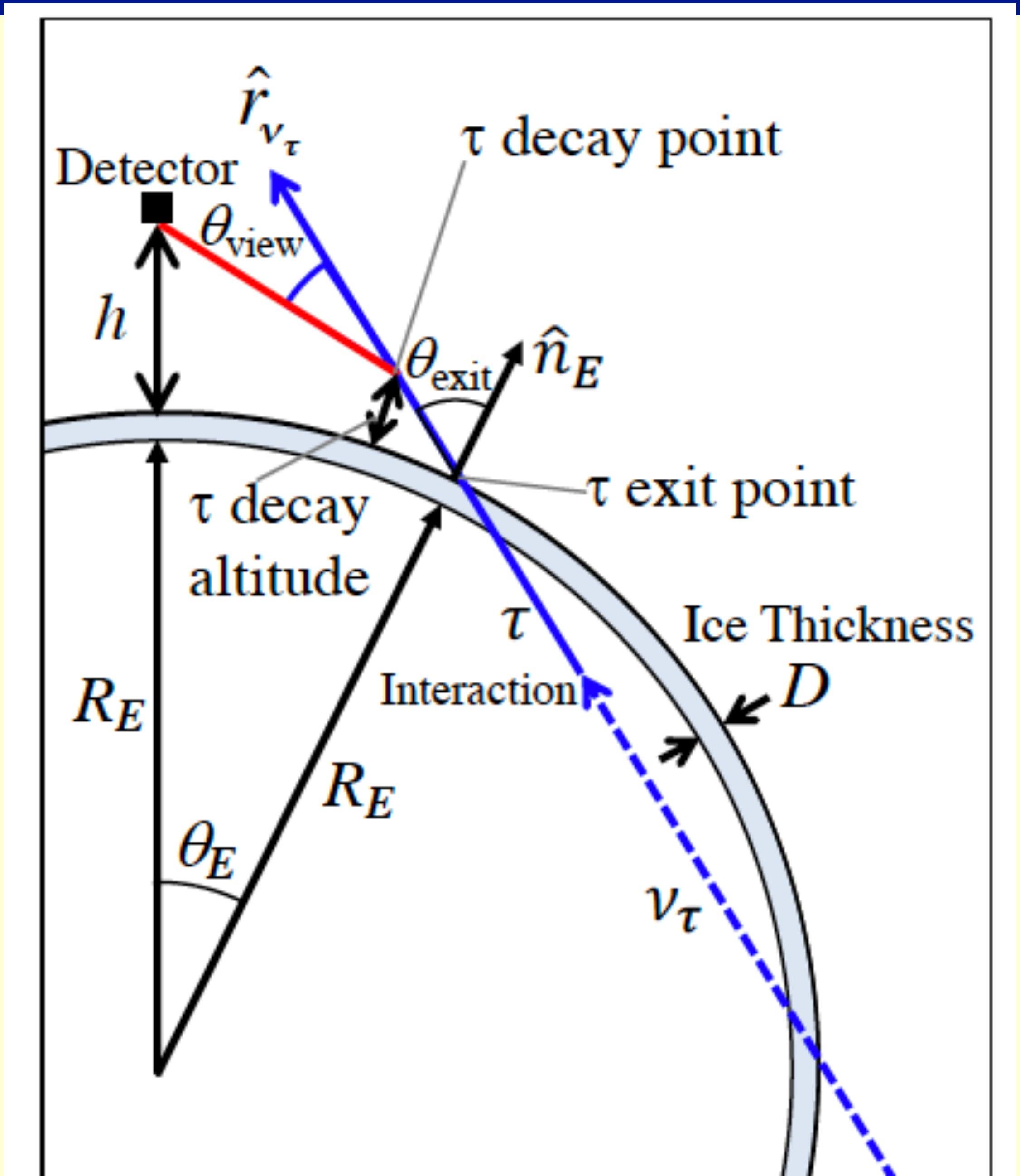
1) Energy-continuum, and Angle-continuum by

   5.8 sigma (prob ~ 10-6), and

2) Auger and ICube isotropic limits by 7sig (prob ~10-8); transient point flux can be tuned.

Tom Weiler, Vanderbilt University

Many angles (from Romero-Wolf et al.) :



Constraints

Standard Model

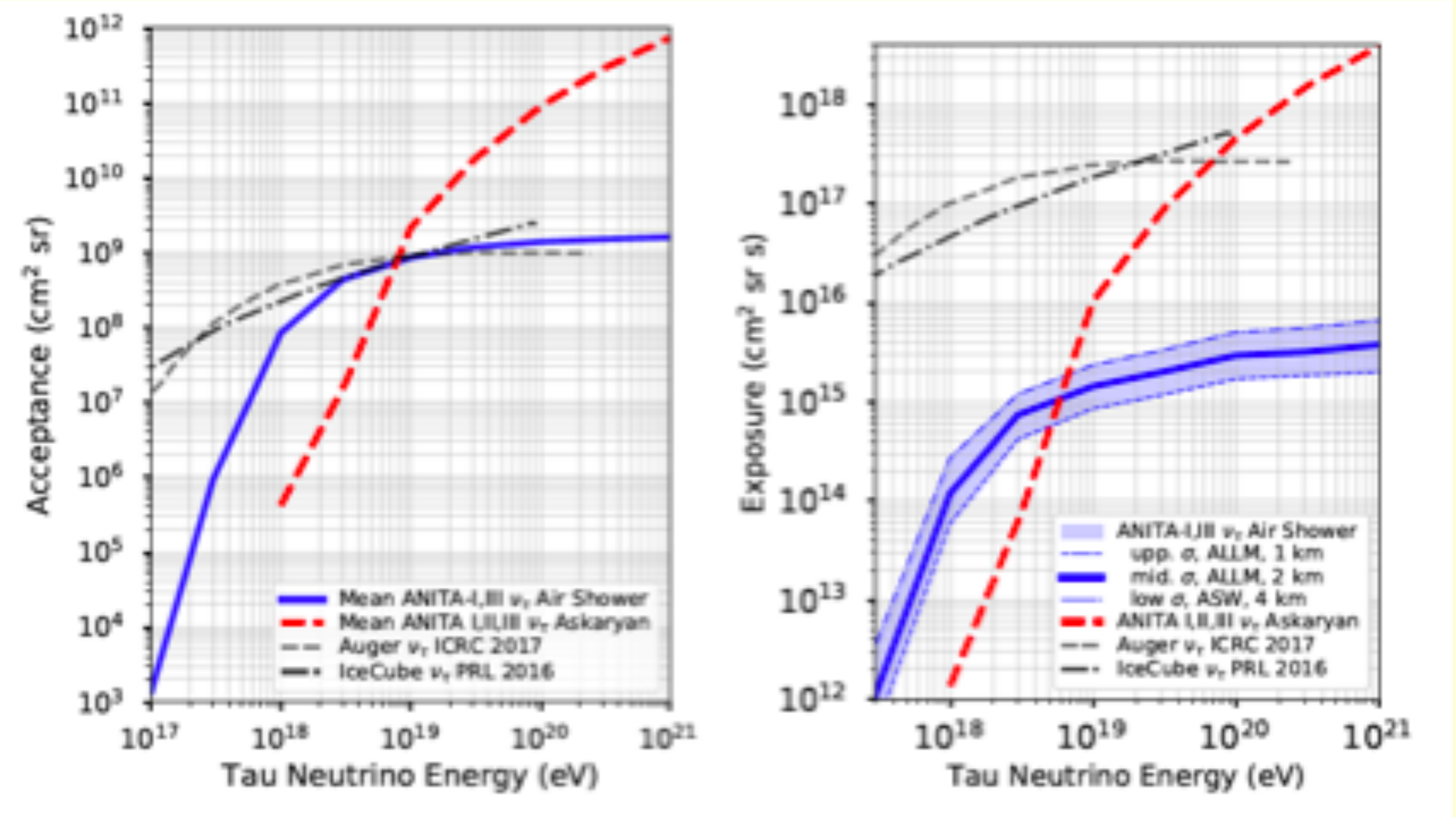
Neutrino fluxes, diffuse and point sources

Neutrino cross sections

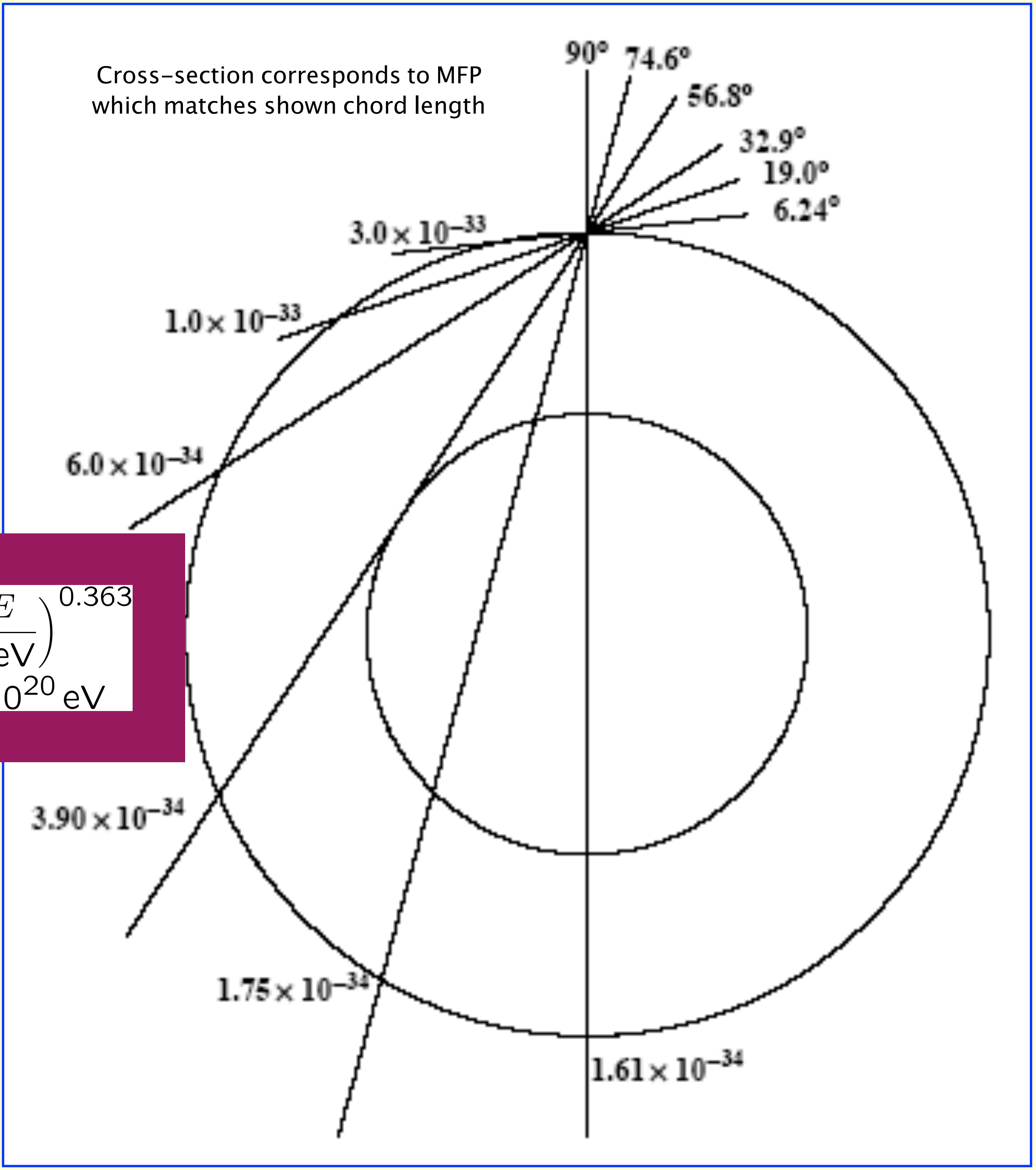
DM masses and cross sections

DM capture rates

Acceptance and Exposure



Earth Absorption versus Neutrino Cross-Section



$$\sigma_{GQRS} = 0.5 \times 10^{-33}\,\mathrm{cm}^2 \left(\frac{E}{\mathrm{PeV}}\right)^{0.363}$$
$$= 0.5 \times 10^{-31}\,\mathrm{cm}^2 \text{ at } 10^{20}\,\mathrm{eV}$$

Acceptance and Exposure

The main conclusion is that the observation of τ-lepton events from a diffuse neutrino flux by the ANITA flights is inconsistent with the limits placed by IceCube and Auger with Standard Model parameters by several orders of magnitude. Although the acceptance of ANITA is smaller than but comparable to IceCube and Auger, the significantly higher duty cycle of these observatories makes their exposure more than two orders of magnitude higher than ANITA at neutrino energies above 10^{19} eV and significantly more at energies below that. The con-

Despite ANITA's exposure in this ν_τ air shower channel being smaller than IceCube and Auger, the acceptance is comparable to those observatories at energies $> 10^{18}$ eV. This is indicative that ANITA may be highly sensitive to point source fluxes and transients. This will

And sensitive to transient skies

Kistler & Laha

Immediately raised two issues:

1. Propagating mu may be misidentified tau, energy scales as mass => x17;

   and

2. New source of nu flux.

And nu cross section may be reduced !

Penn State (11 pages of 12 were Xperimental)

KM3Net may wish to consider supplementing their detector array with temperature or infrared sensors to provide an independent means of mass discrimination for track events.

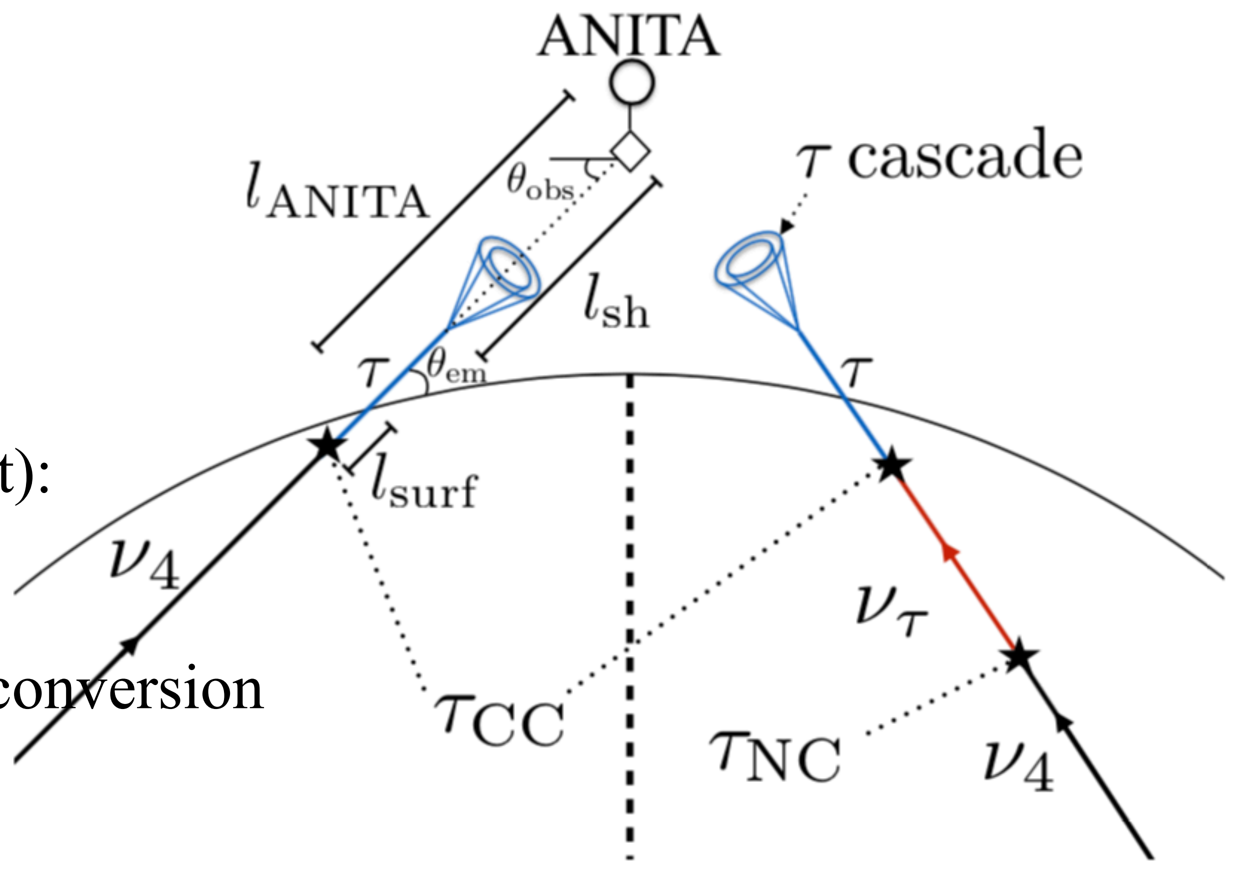
The particle should couple to the tau or tau neutrino. Its cross section for nuclear interactions at ~EeV energies should be one or two orders of magnitude less than the total neutrino cross section of 15nb at 1 EeV, so that its mean free path through the Earth is >1000km, while allowing for a reasonable branching ratio in UHECR neutrino + nucleon interactions [52, 53]. Its lifetime should be of order $\tau_{BSM} \sim 10\ (m_{BSM}/500\ \text{GeV})$ ns, so that at EeV energy it propagates roughly an Earth radius.

Remarkably, particles satisfying these criteria are anticipated within existing gauge-mediated supersymmetry breaking (GMSB) supersymmetric (SUSY) models.

Cherry & Shoemaker - sterile nu

Transition Radiation gives 3x10^-3 per event, or prob ~ 10 ^-6 for two events - RW et al.;

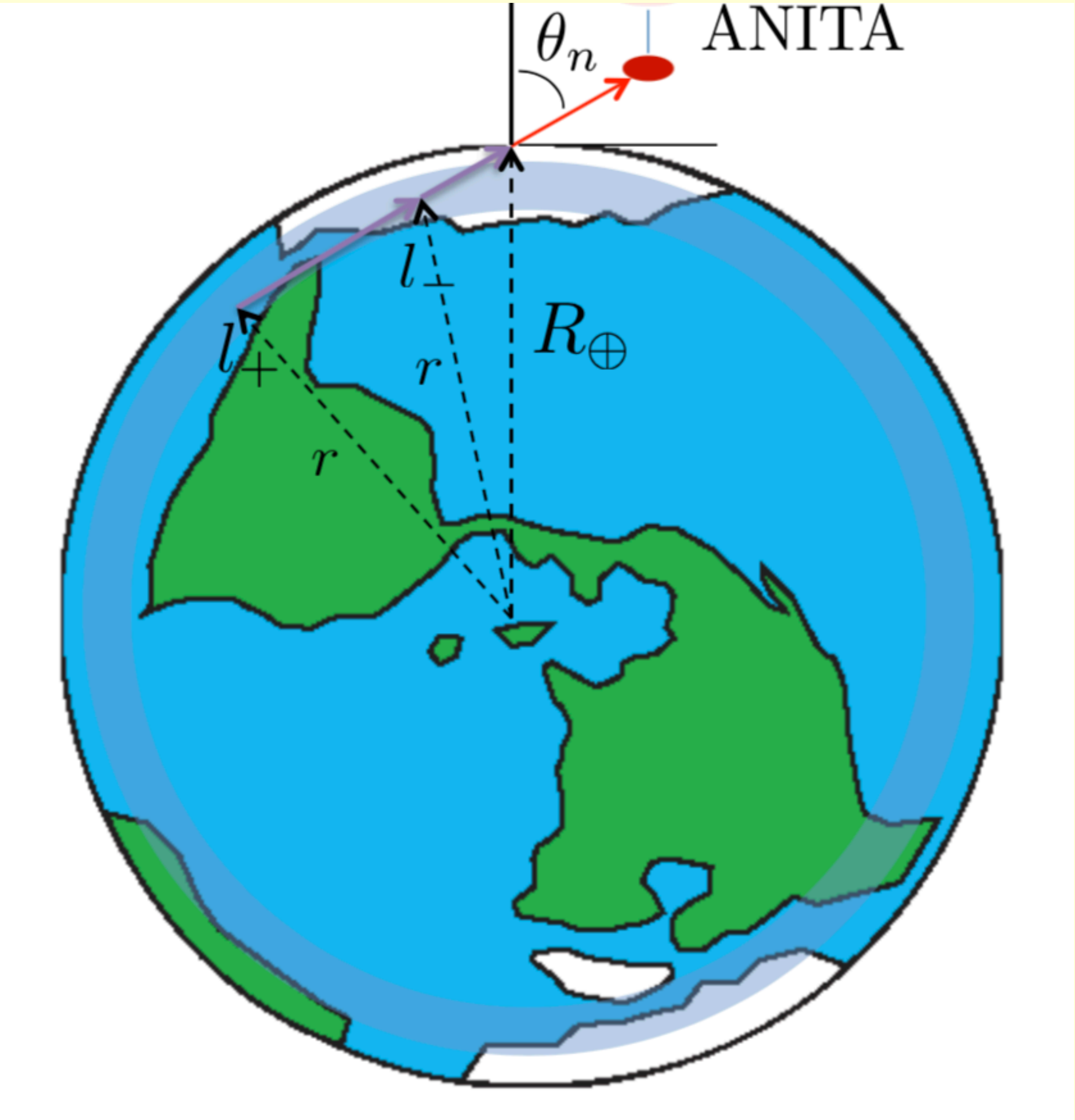
So an incident Sterile Nu ?



Potential sources (suspect):

1. SHDM
2. Topological Defects
3. Exotic active-sterile conversion

Anchordoqui et al (includes Moi) - heavy right-hand nu DM:



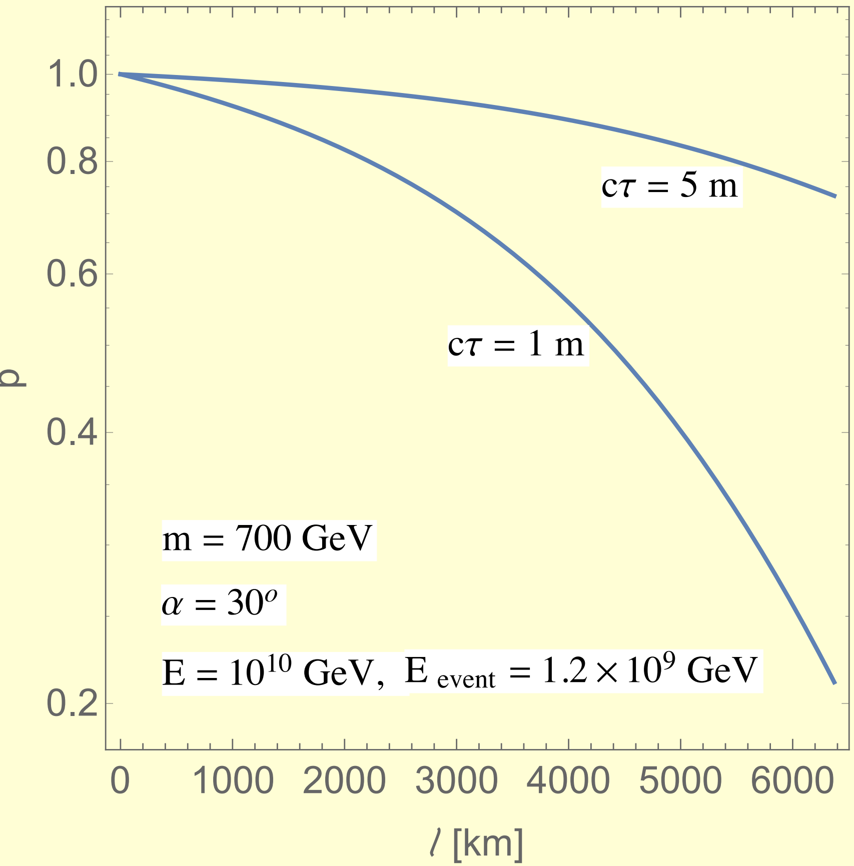
Angles :

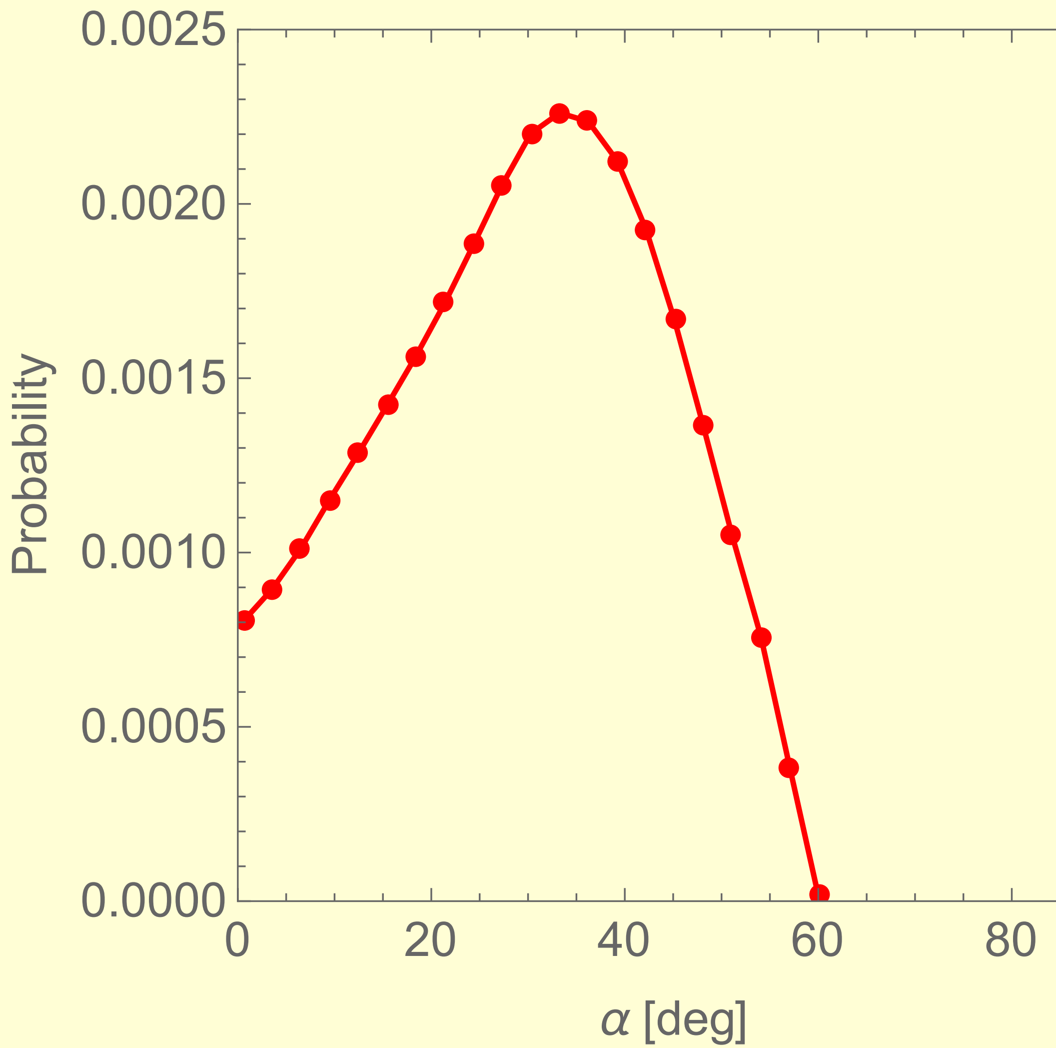
The competition between the falling (with increasing θ_n) $e^{-R_\oplus \cos\theta_n/\lambda}$ term and the rising $\mathcal{E}(\theta_n)$ term in Eq. (1) determines the most probable angle of observation. The distribution is maximized at $\theta_n = 60°$ by a combination of ANITA's efficiency and the dark matter distribution in the Earth, we require

$$\left.\frac{d^2\,\text{Rate}}{d\,|\cos\theta_n|^2}\right|_{\cos\theta_n=\frac{1}{2}} = 0\,. \qquad (3)$$

This result becomes a constraint on the model parame-

Larger chord lengths cross the Earth but do not decay;
Shorter chord lengths suffer decay enroute.





Energy loss, for mass=0.8 PeV,
E(initial)=10 EeV,
and c*tau = 1m and 5m.

Pmax = 0.22%, Exit-angle = 34 degrees,
and E(shower) = 0.7 EeV,
consistent with ANITA.

Problem with almost all models is non-observation of Ice Cube:

$$\frac{\#\text{IceCube}}{\#\text{ANITA}} \sim \frac{1\text{km}^3 \times 3000\text{days}}{4\text{km}^2 \times 53\text{days} \times D} \simeq \frac{10\text{km}}{D} \simeq 1\text{-}15$$

* ~10 if new particle is “charged”.

unobservable. *(iii)* Data from the fourth ANITA flight is currently being analyzed and may lead to further enlightenment. The second generation of the Extreme Universe Space Observatory (EUSO) instrument, to be flown aboard a super-pressure balloon (SPB) in 2022 will monitor the night sky of the Southern hemisphere for upgoing showers emerging at large angles below the horizon [28]. EUSO-SPB2 will provide an important test both of the unusual ANITA events and of the ideas discussed in this Letter.

Francis Halzen at Valencia lunch 2018 Dec, negates Penn State reinterpretation

says a couple of things:

1. All Ice Cube events are standard;
2. Ice surface is bumpy
   - (but on scales of 1m, not on scales of shower size, 20-100m)

     => systematic “error”

Conclusion:

A new mass/energy scale is psychologically right (E higher by 7 orders of magnitude , but is it correct?

or do SM systematics contain something new?

The (BSM) data needs some confirmation:

EUSO-SPB2 and POEMMA, IceCube (gens 1 and 2) KM3NET, ANITA-4 analysis and ANITA-5, to come…

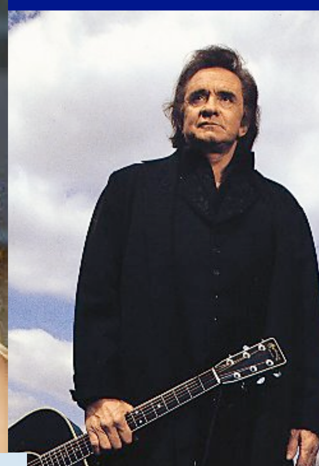
Also, (A Connolly) BEACON, GRAND (China), TAROGE (Taiwan)

And tests: Gal vs Xgal (Earth is offset in MW halo), new particle vs SM, …

Extra slides:

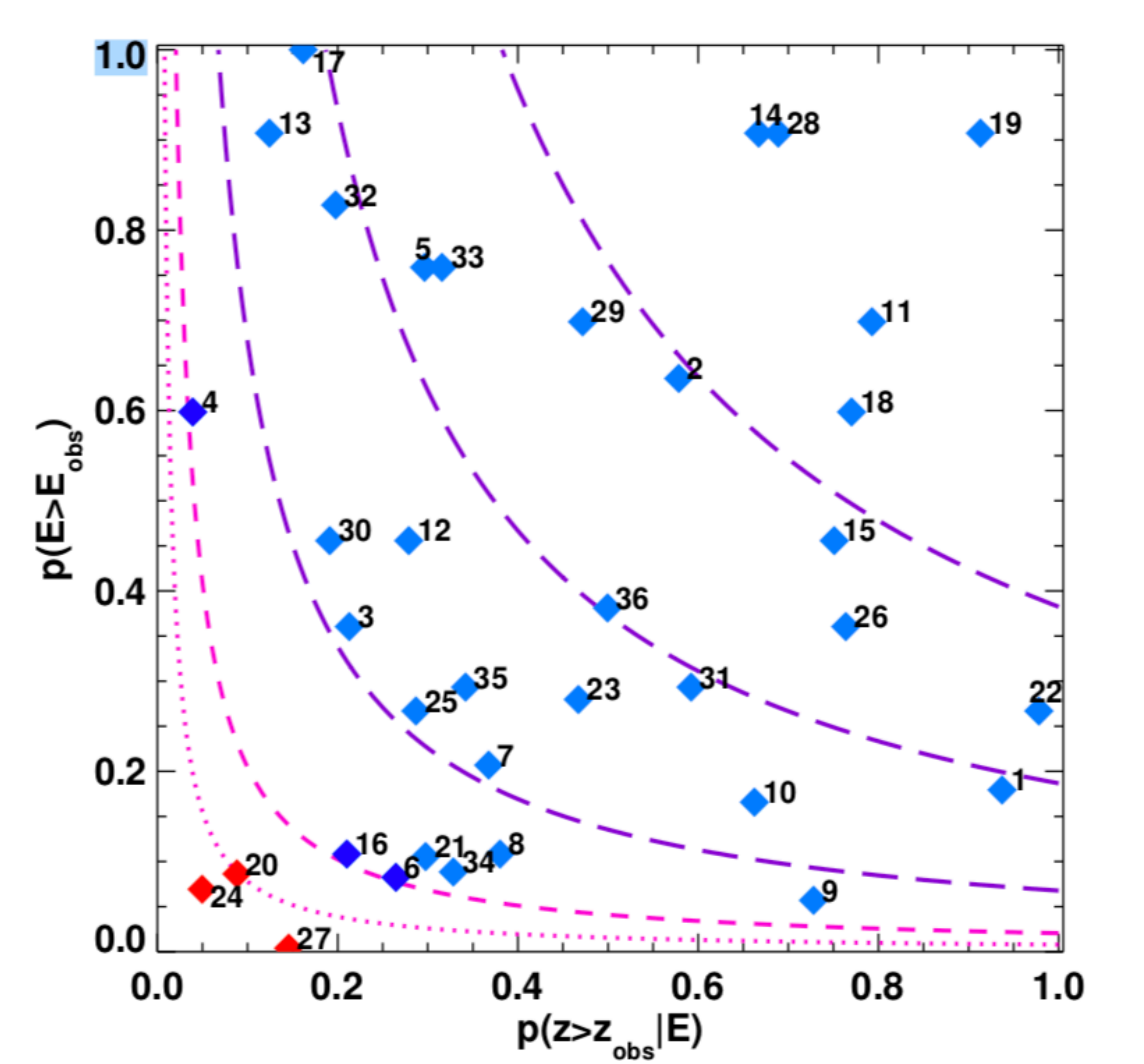
A Nashville (and Munich) Quiz !
Hint: final entry was Steppenwolf lead singer

“ What's Hot in Recent Particle (Astro)Physics ”




Penn State folks propose to validate data, and stau model, with IceCube:



Fixes:

It is possible that this discrepancy could be reduced by a more aggressive suppression of the neutrino-nucleon cross section, as has been suggested in some beyond Standard Model scenarios [27–29]. The effect will reduce the τ-lepton exit probability at lower emergence angles in favor of higher emergence angles. Other possibilities that could resolve this discrepancy include sterile neutrinos [32], the decay in Earth of a quasi-stable dark matter particle [33], and supersymmetric sphaleron transitions [34]. This will

Rate (with our "improvement):

The event rate integrated over the entire Earth at a particular time is

$$\text{Rate} \equiv \frac{dN}{dt} = 4\pi \int_0^{R_\oplus} r^2\, dr\, \frac{n(r,t)}{\tau_{\nu_{R,1}}}\,,$$

where $n(r,t)$ is the number density of $\nu_{R,1}$ at time t and $R_\oplus$ is the Earth's radius. The observable rate today ($t = t_0$), as a function of nadir angle θ_n is given by

$$A_{\text{eff}} \frac{d\,\text{Rate}}{d\,|\cos\theta_n|} = 2\pi A_0 \times 2\pi \int_{R_\oplus \sin\theta_n}^{R_\oplus} r^2 dr\, \frac{n(r,t_0)}{\tau_{\nu_{R,1}}} \times \left(e^{-(l_+/\lambda)} + e^{-(l_-/\lambda)}\right) \mathcal{E}(\theta_n)\,, \qquad (1)$$

where $l_\pm$ are the roots of $R_\oplus^2 + l^2 - 2R_\oplus l \cos\theta_n = r^2$, i.e.,

$$l_\pm = R_\oplus \left(\cos\theta_n \pm \sqrt{\left(\frac{r}{R_\oplus}\right)^2 - \sin^2\theta_n}\right)\,,$$

from Penn State folks (1809.09615) :

TABLE I. Properties of the ANITA Anomalous Events

Property	**AAE 061228**	**AAE 141220**
Flight & Event	ANITA-I #3985267	ANITA-III #15717147
Date & Time (UTC)	2006-12-28 00:33:20	2014-12-20 08:33:22.5
Equatorial coordinates (J2000)	R.A. 282°.14064, Dec. +20°.33043	R.A. 50°.78203, Dec. +38°.65498
Energy $\varepsilon_{\rm cr}$	$0.6 \pm 0.4\,{\rm EeV}$	$0.56^{+0.30}_{-0.20}\,{\rm EeV}$
Zenith angle z'/z	$117.°4$ / $116.°8 \pm 0.°3$	$125.°0$ / $124.°5 \pm 0.°3$
Earth chord length ℓ	$5740 \pm 60\,{\rm km}$	$7210 \pm 55\,{\rm km}$
Mean interaction length for $\varepsilon_\nu = 1\,{\rm EeV}$	290 km	265 km
$p_{\rm SM}(\varepsilon_\tau > 0.1\,{\rm EeV})$ for $\varepsilon_\nu = 1\,{\rm EeV}$	4.4×10^{-7}	3.2×10^{-8}
$p_{\rm SM}(z > z_{\rm obs})$ for $\varepsilon_\nu = 1\,{\rm EeV}$, $\varepsilon_\tau > 0.1\,{\rm EeV}$	6.7×10^{-5}	3.8×10^{-6}
$n_\tau(1\text{–}10\,{\rm PeV}) : n_\tau(10\text{–}100\,{\rm PeV}) : n_\tau(> 0.1\,{\rm EeV})$	34 : 35 : 1	270 : 120 : 1

Exclusion of the three events in Table II from the EHENT sample is required to yield a distribution in energy and zenith angle for the remaining EHENTs (n = 33) that is consistent (p = 50% for the combined analysis) with the cascade-only spectrum and normalization, and thus resolves the longstanding tension between the PNT analysis and other sample.

(EHENT = Extremely High Energy (>200 TeV) Northern Tracks)

Having excluded SM explanations at >5σ confidence have argued that the SEECR phenomenon, if confirmed, can support a discovery-level claim of "beyond the Standard Model" (BSM) physics. Existing supporting observations from IceCube – namely, the otherwise puzzling tension between the astrophysical neutrino spectrum inferred from primarily northern track events versus other samples, the singular event IceCube-140611, and our identification of two further SEECR candidates in the IceCube $\varepsilon_{proxy} > 200$ TeV northern track sample, provide reason to think this will happen soon. Confirmation of the reality of the SEECR phenomenon would in turn demonstrate the existence of a responsible BSM particle.

(Sub-EeV Earth-Emerging Cosmic-Rays = SEECRs)

The Events: Flight #4: under analysis

If there was not an event, …

If there was a clean event, …

So, …

Peter Gorham's statement:

We have considered and tested many possibilities
(we have generally been internally much more skeptical than anyone else)
and nothing has worked so far. We have looked at statistical phase distortion, atmospheric effects like inversion layers, transient electric fields that might counteract the magnetic fields, we have done high fidelity FDTD modeling, extracting detailed profiles of the local surfaces to investigate possible focusing effects, etc, etc. The latter effect, a large scale ellipsoidal bowl in the surface, is something we are vetting out right now, but so far, although it is possible (ANITA could be outside the secondary focus of an ellipsoidal surface with the air shower at the primary focus, that would do it), we have very good satellite altimetry of the ice surface and no feature with the right focal length has turned up.

And more,

Many people have suggested some kind of internal surface layers or cracks/crevasses etc. as possible causes. But having been on the polar plateau a few times and looked hard at miles of undisturbed ice I disagree with Francis -- the ice sheets are remarkably homogeneous, compared to the glaciers or shelves (both events are on deep smooth sheet ice). What layering there is has very small dielectric contrast compared to the air-to-surface, and it any internal reflection would be causally later (many ns) than the primary reflection, so it is very hard to see how a broadband reflection from such a layer could precede and mask the much larger air-to-ice reflection.

Cheers, Peter

Escher's Angels and Devils"

Looking back, $n_\nu \sim (1+z)^3$,

And so the absorption is greatly
Enhanced for ν's from high-z sources