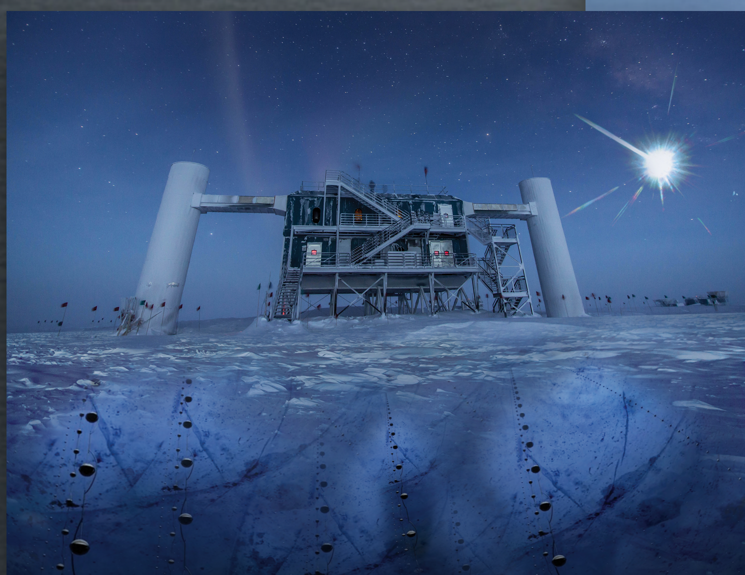
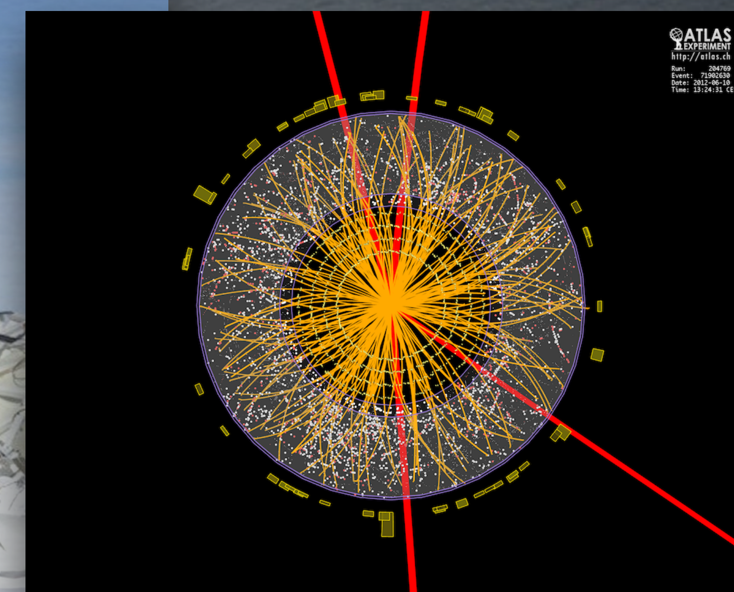
The ANITA Anomalous Events and LHC LLPs





Derek B. Fox
Penn State University

ArXiv:1809.09615

Fourth Workshop of the LHC LLP Community
Science Park, Amsterdam
23 October 2018

ANITA Anomalous Events and LHC LLPs

1. What are the ANITA Anomalous Events?
2. AAEs and the Standard Model
3. More Pieces of the Puzzle
4. AAEs and LHC LLPs

1. What are the ANITA Anomalous Events?

What is ANITA?

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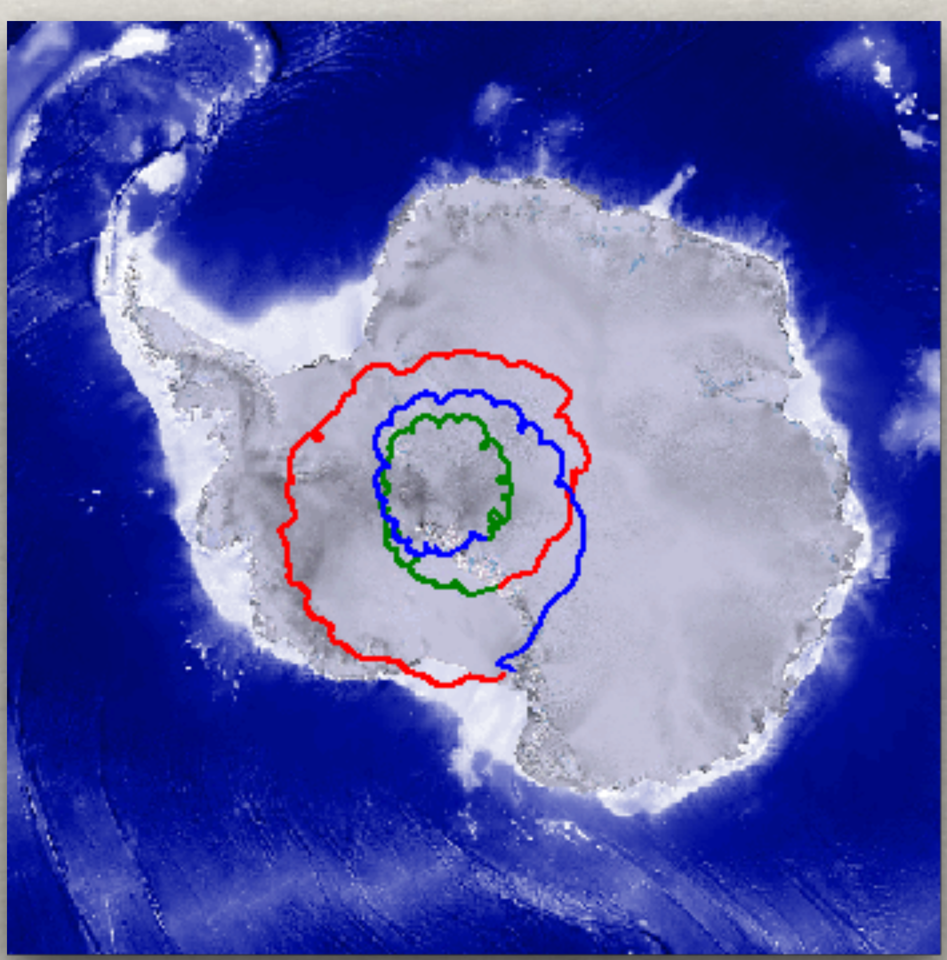

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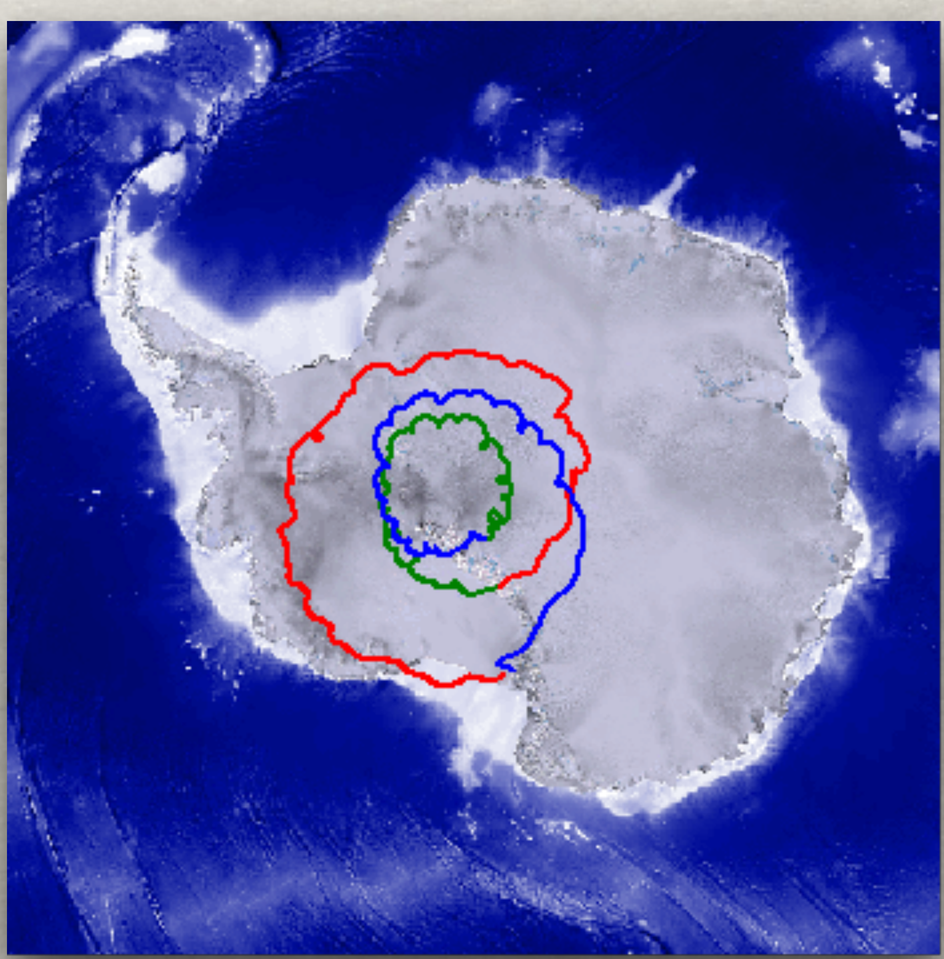

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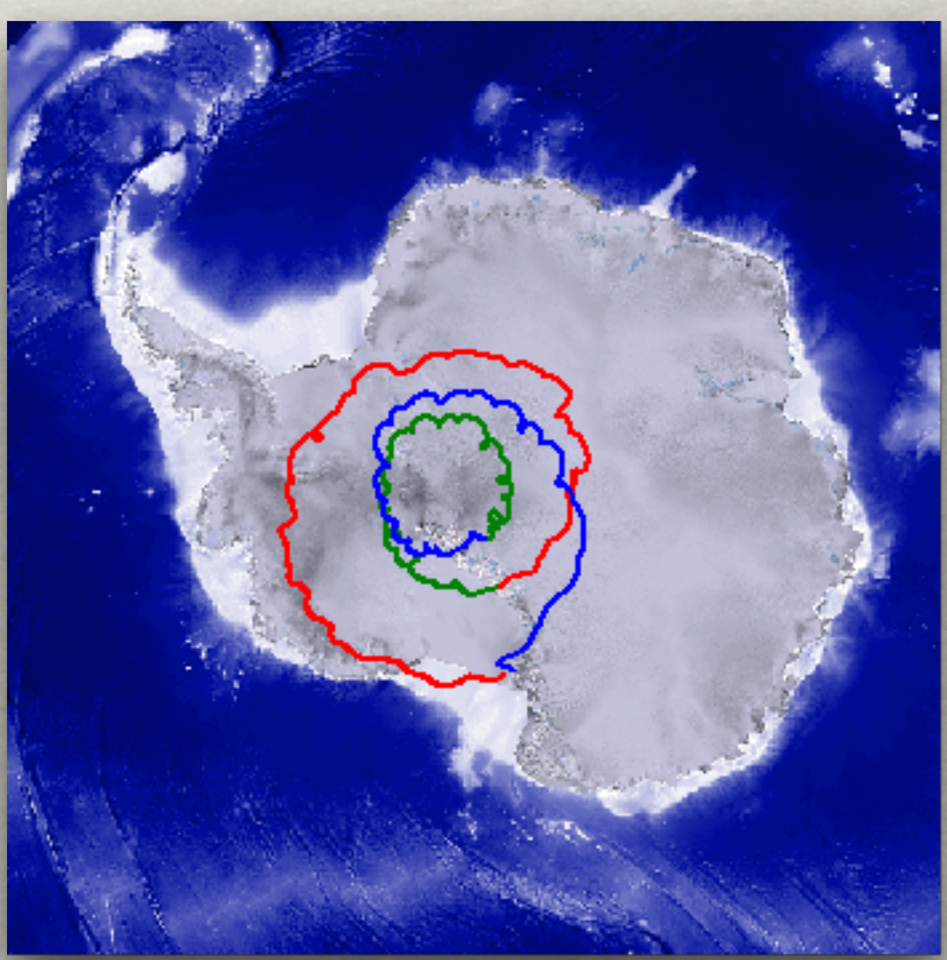
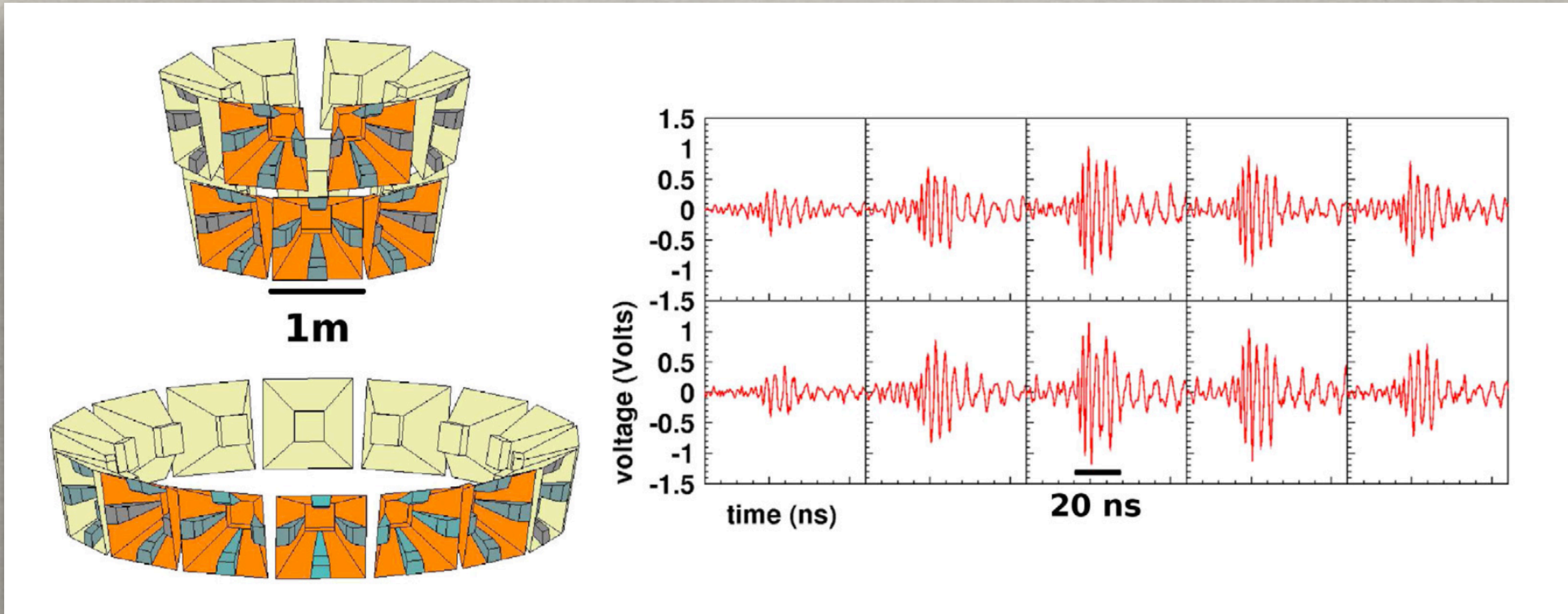
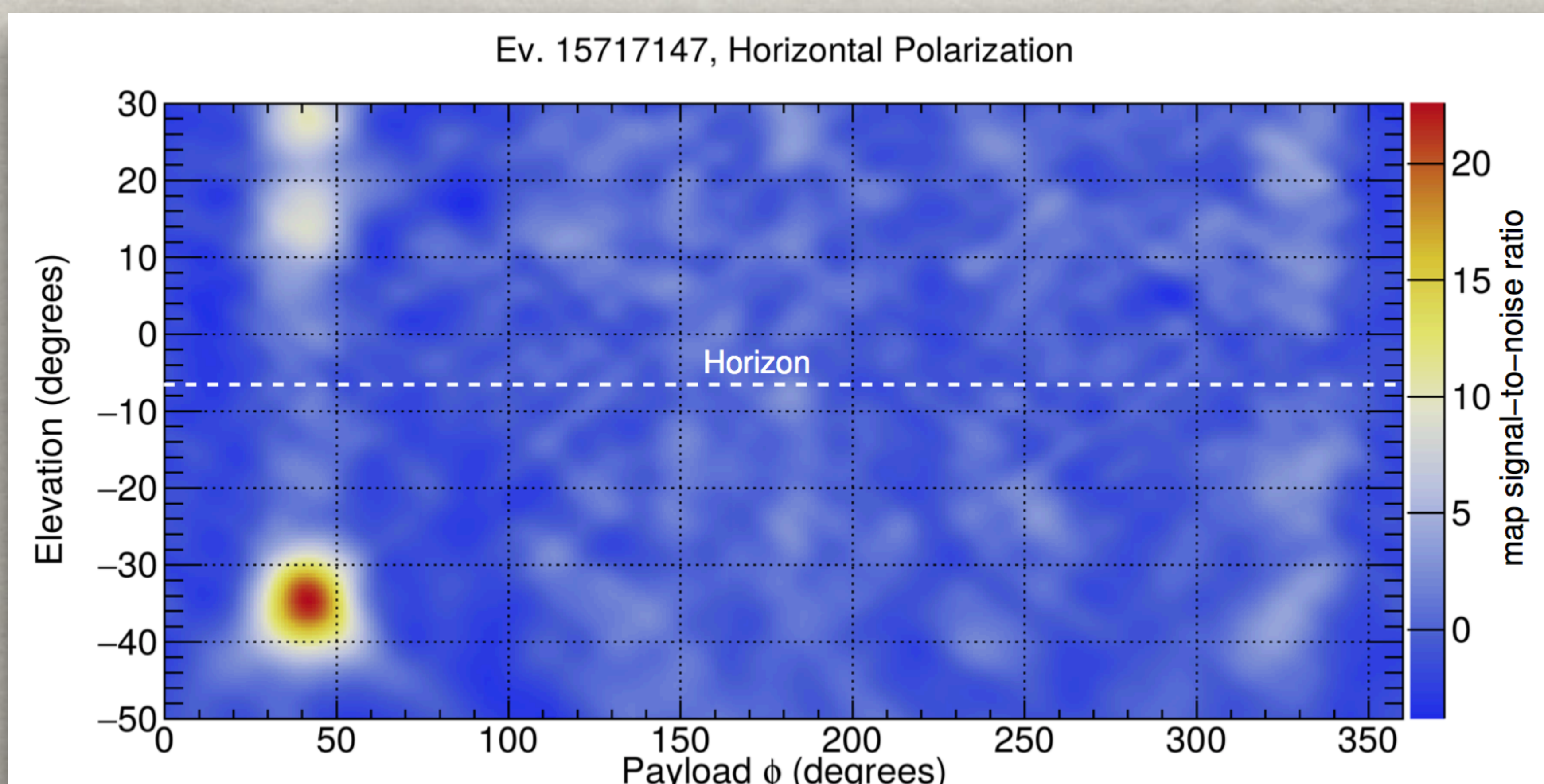
- One candidate Askaryan event from talks (not published)



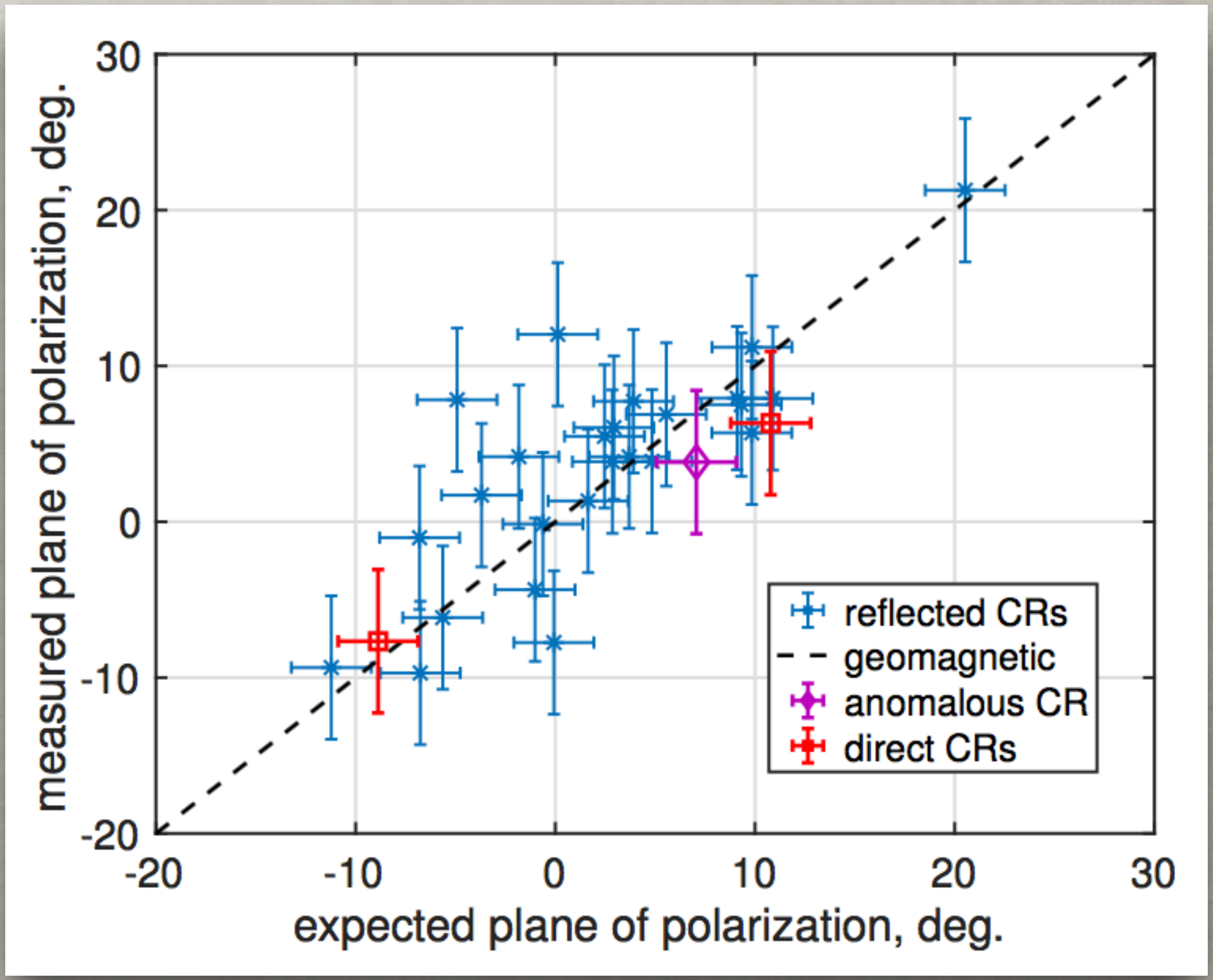


Romero-Wolf+15



Gorham+18

ANITA Anomalous Events



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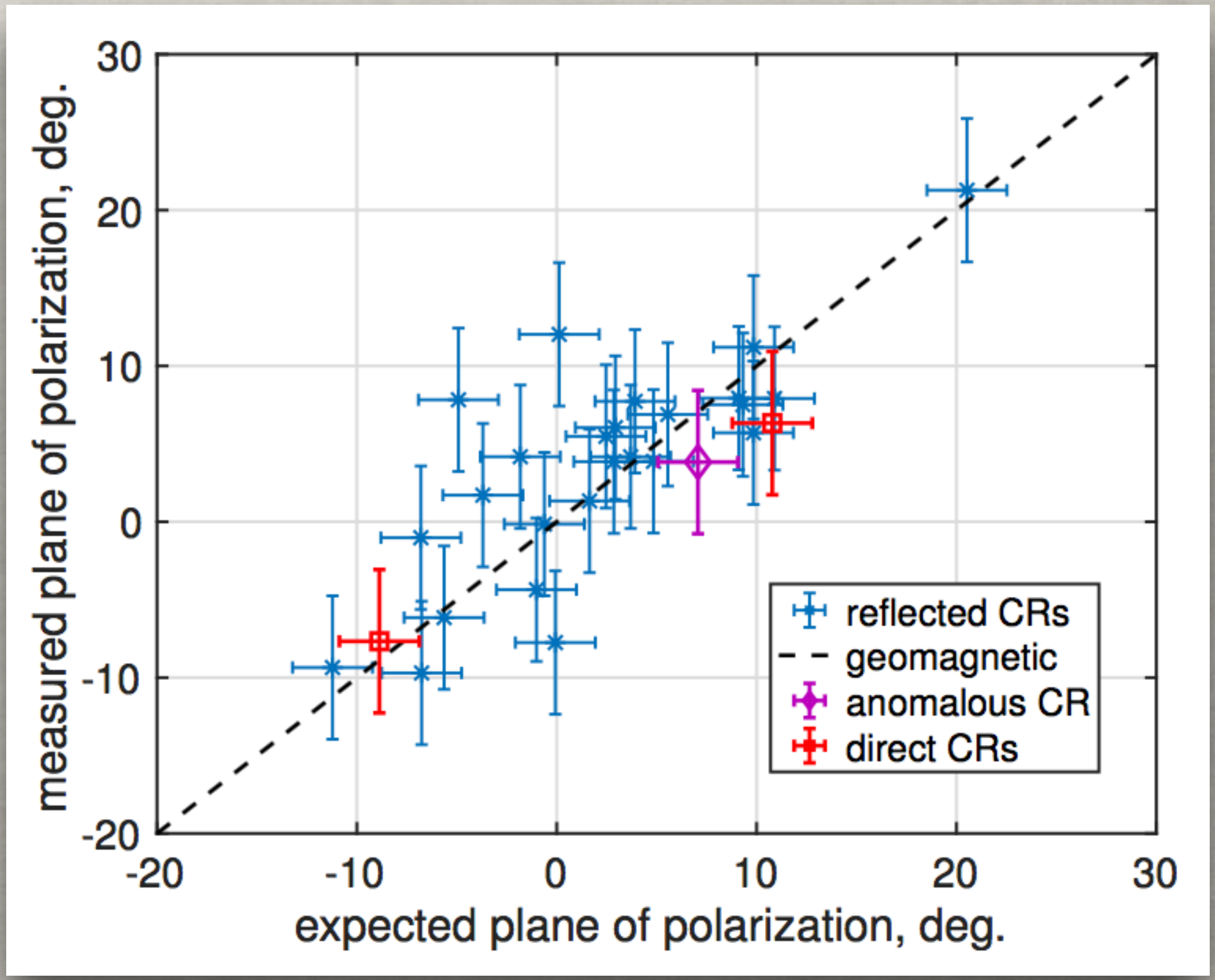

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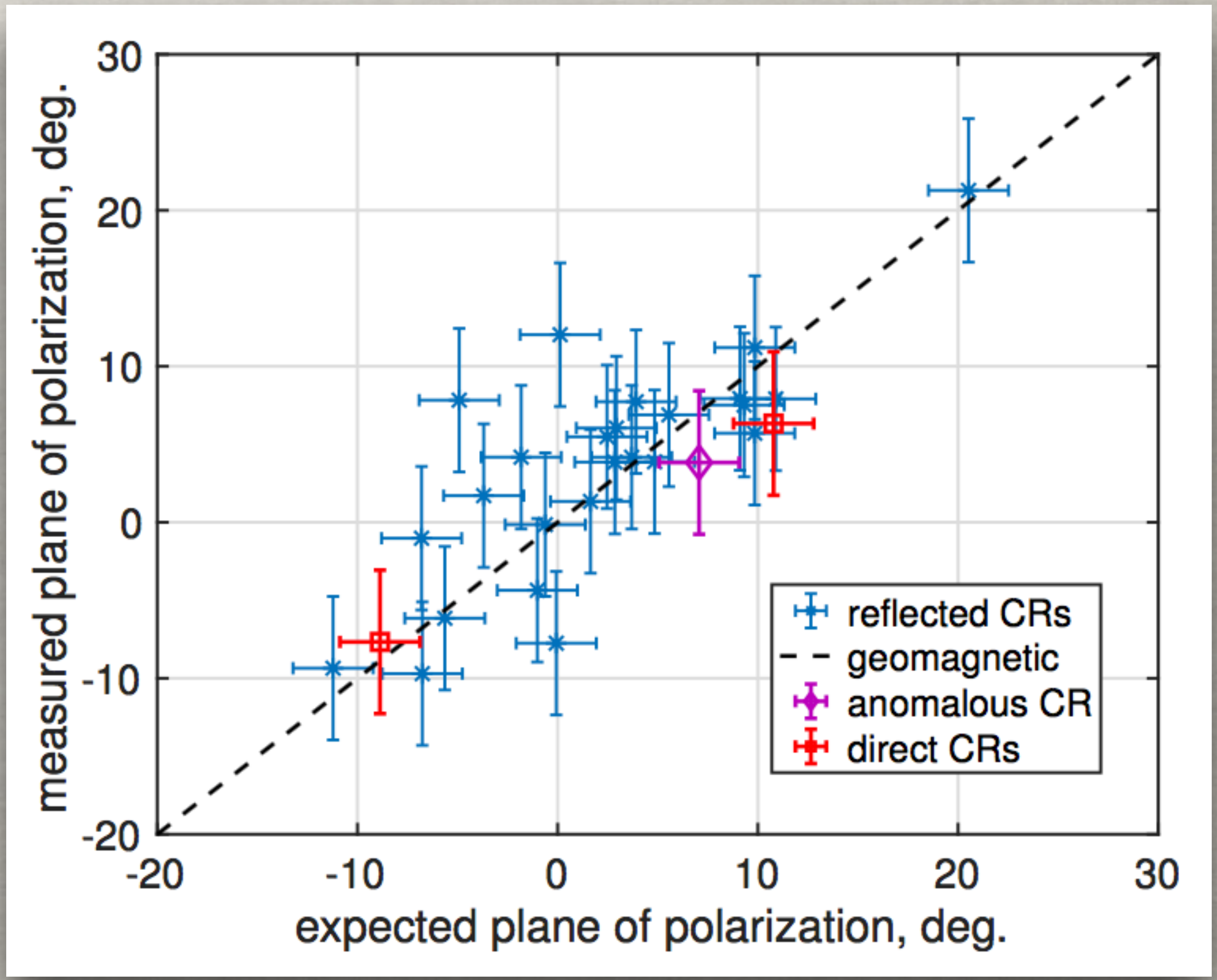

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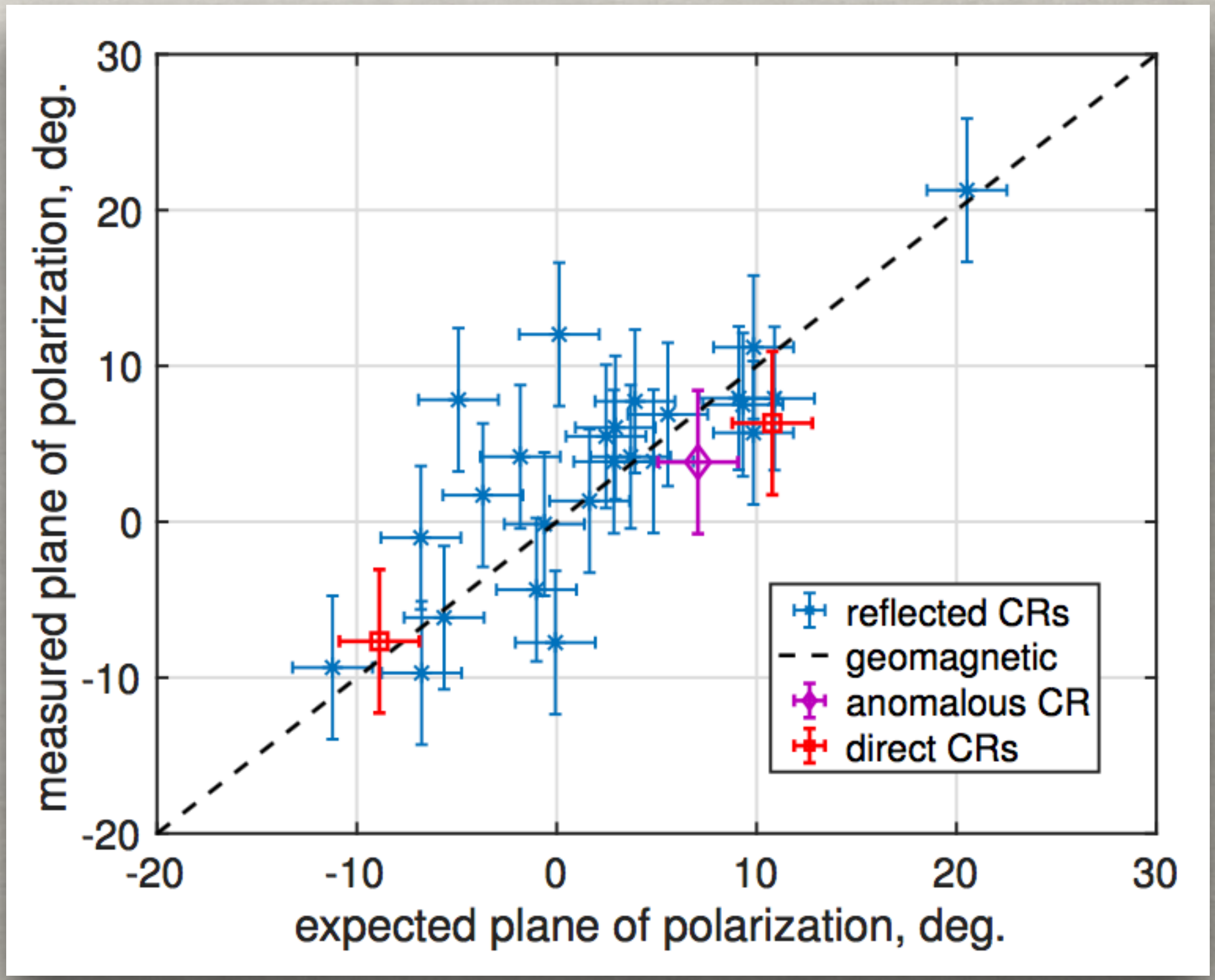

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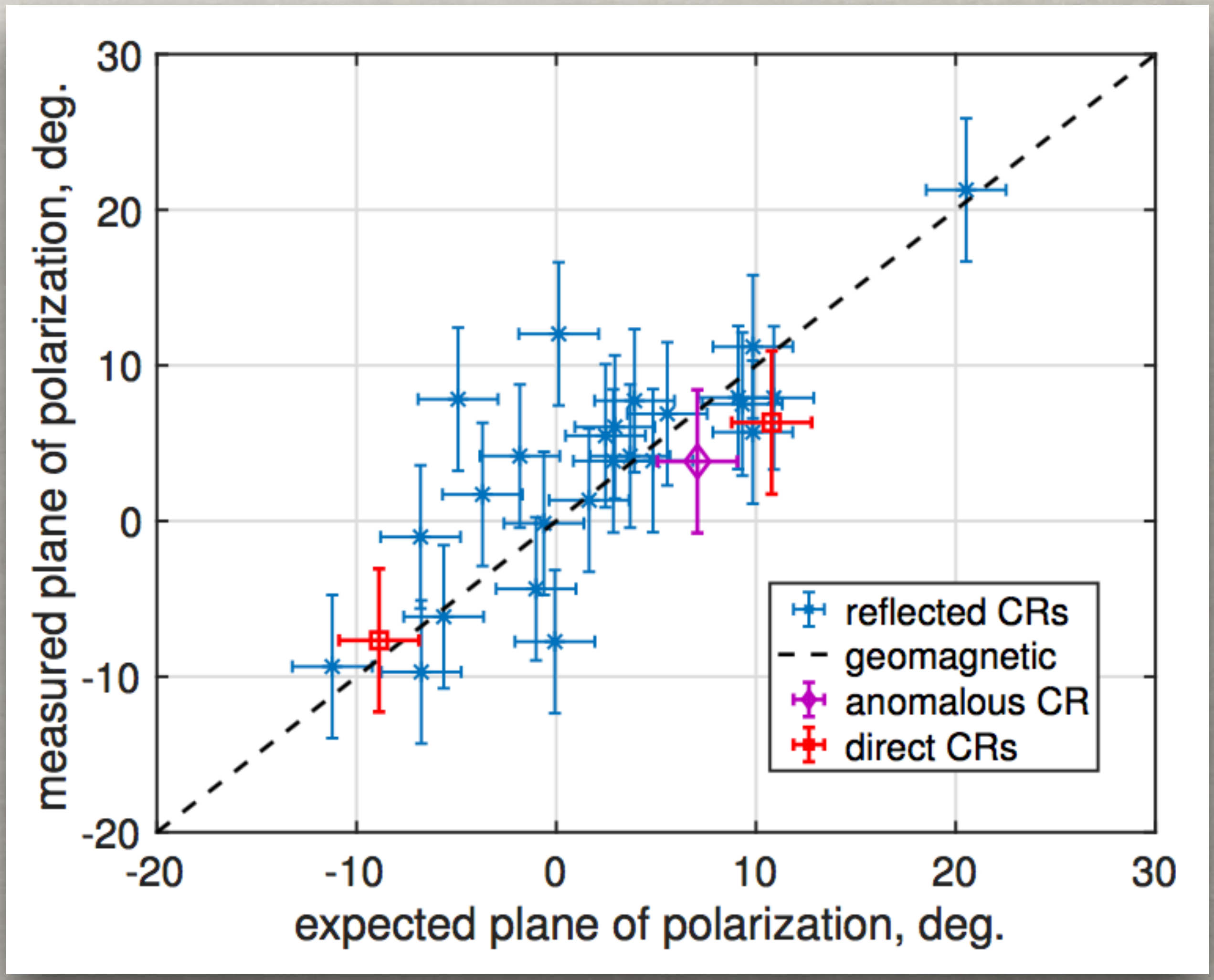

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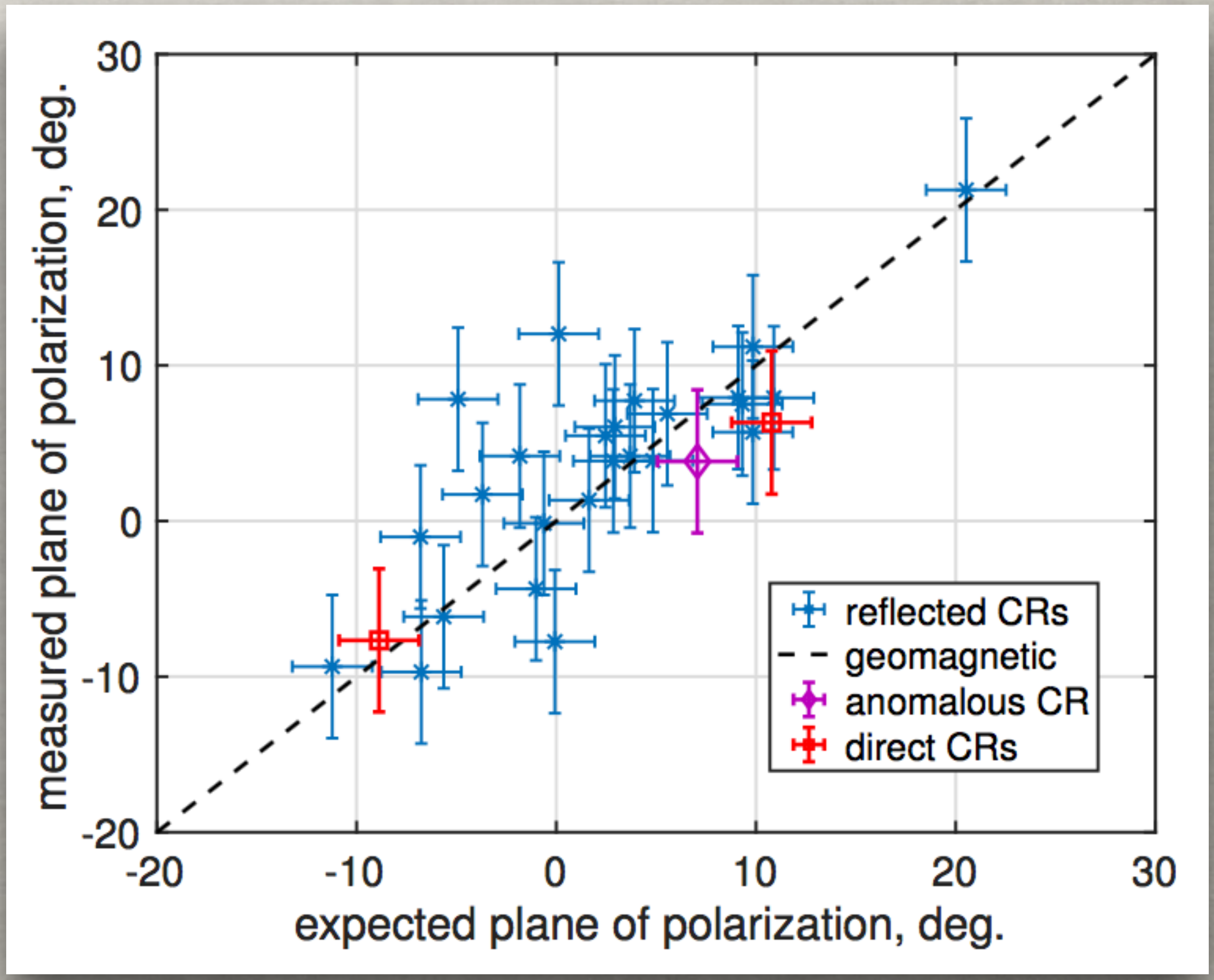

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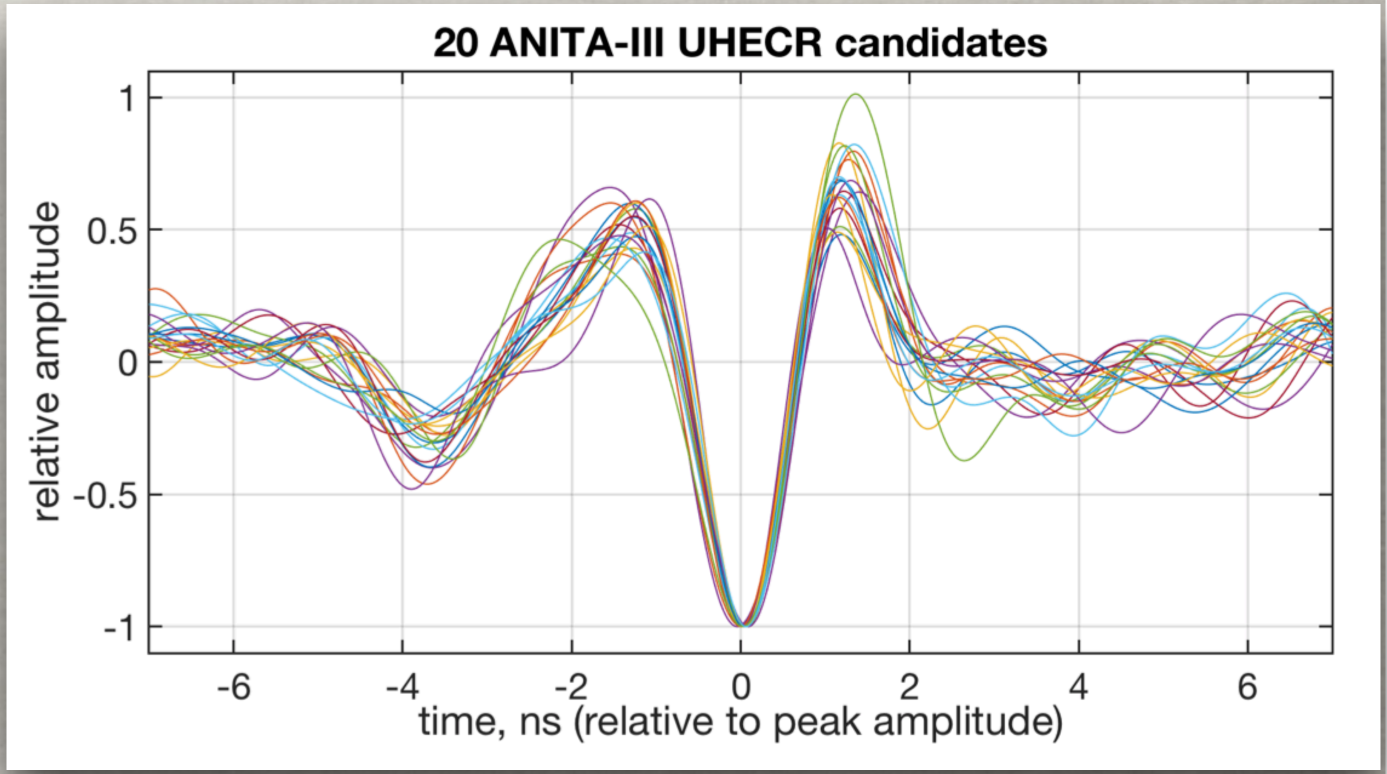

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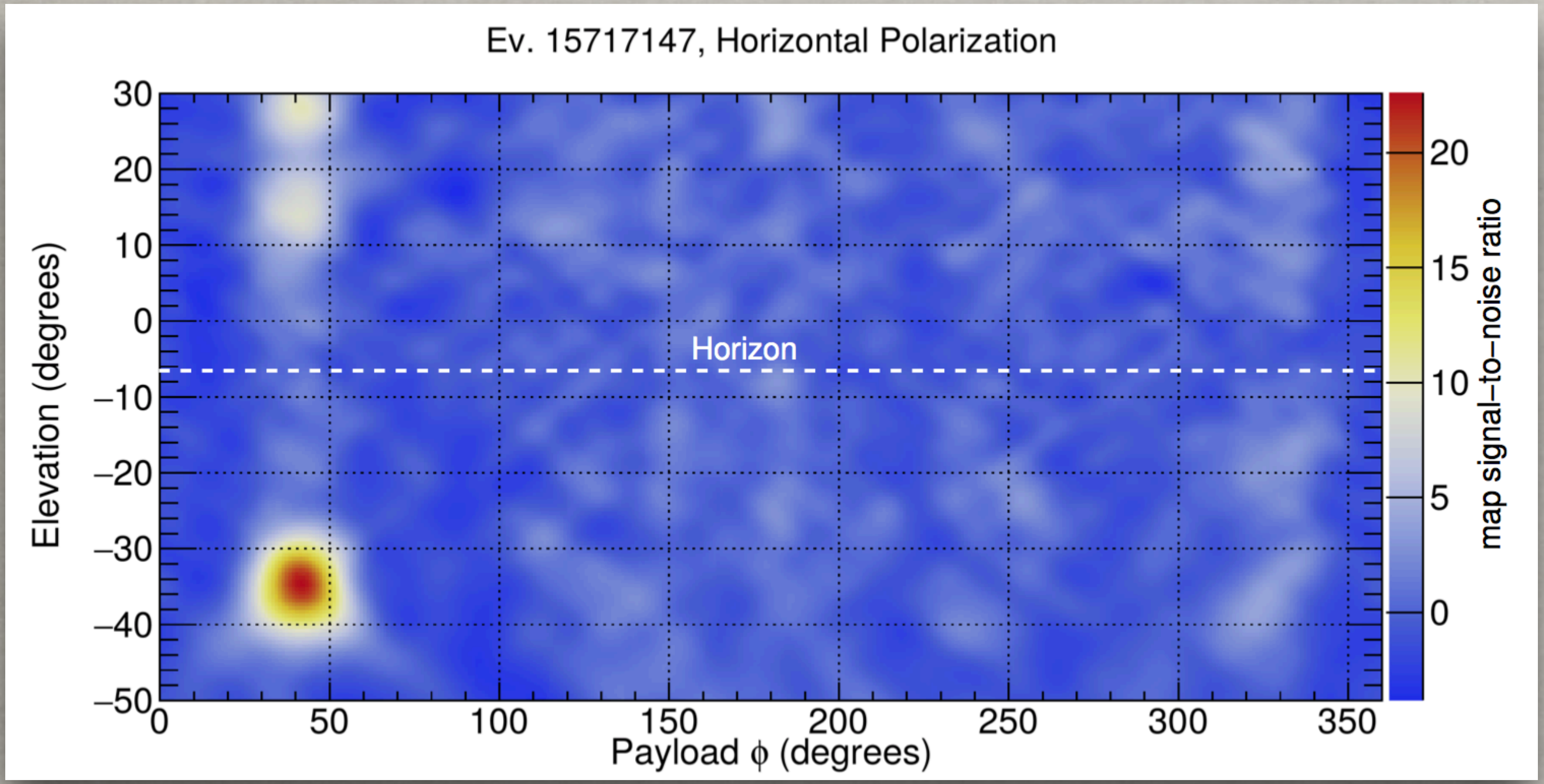
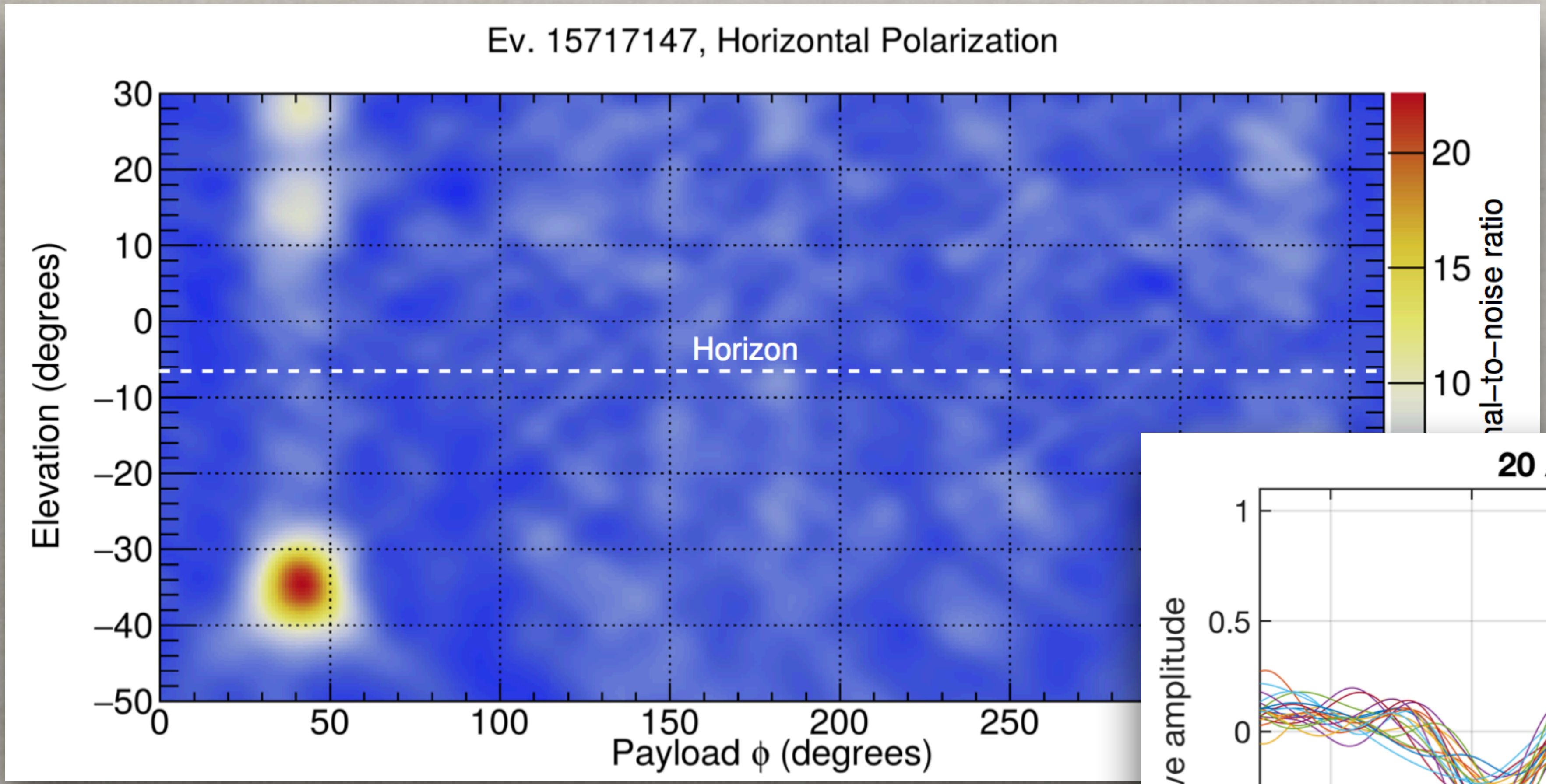


Ev. 15717147, Horizontal Polarization
Horizon
Elevation (degrees)
Payload ϕ (degrees)
map signal−to−noise ratio
30
20
10
0
−10
−20
−30
−40
−50
0
50
100
150
200
250
300
350
20
15
10
5
0

Gorham+18



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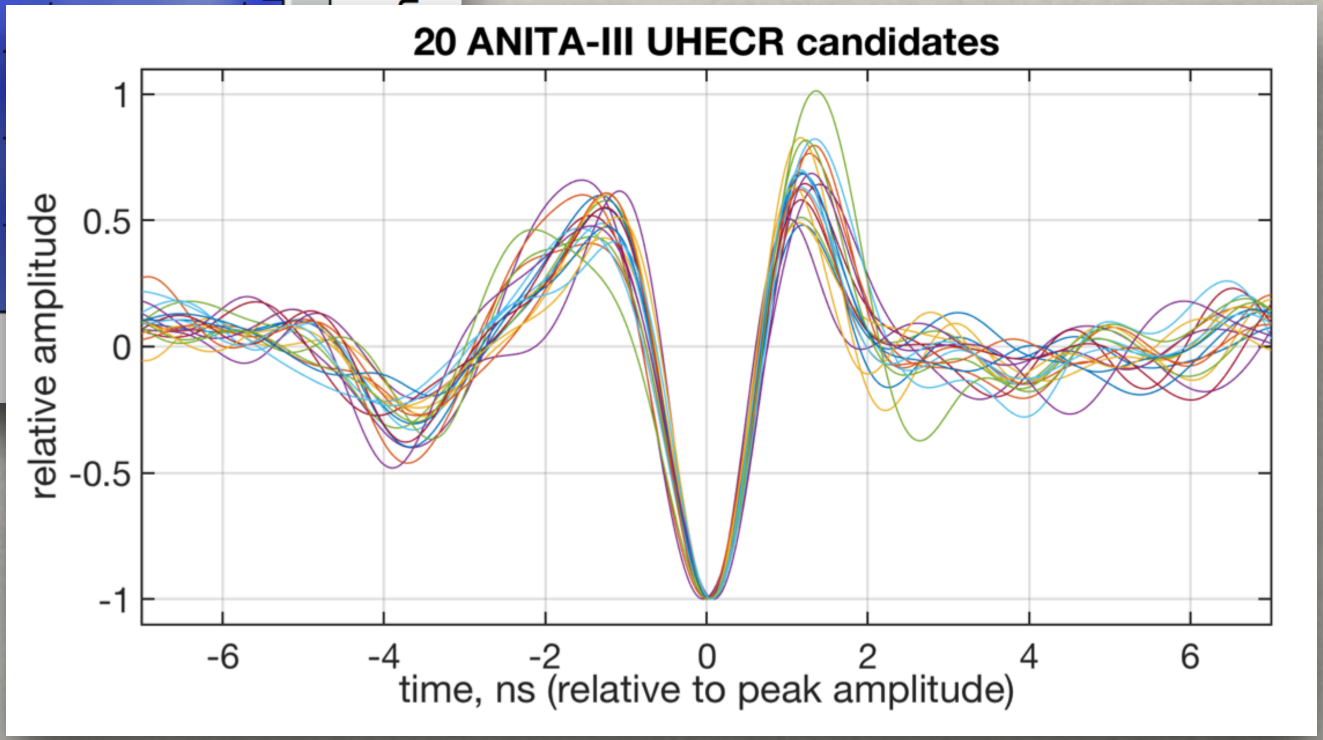
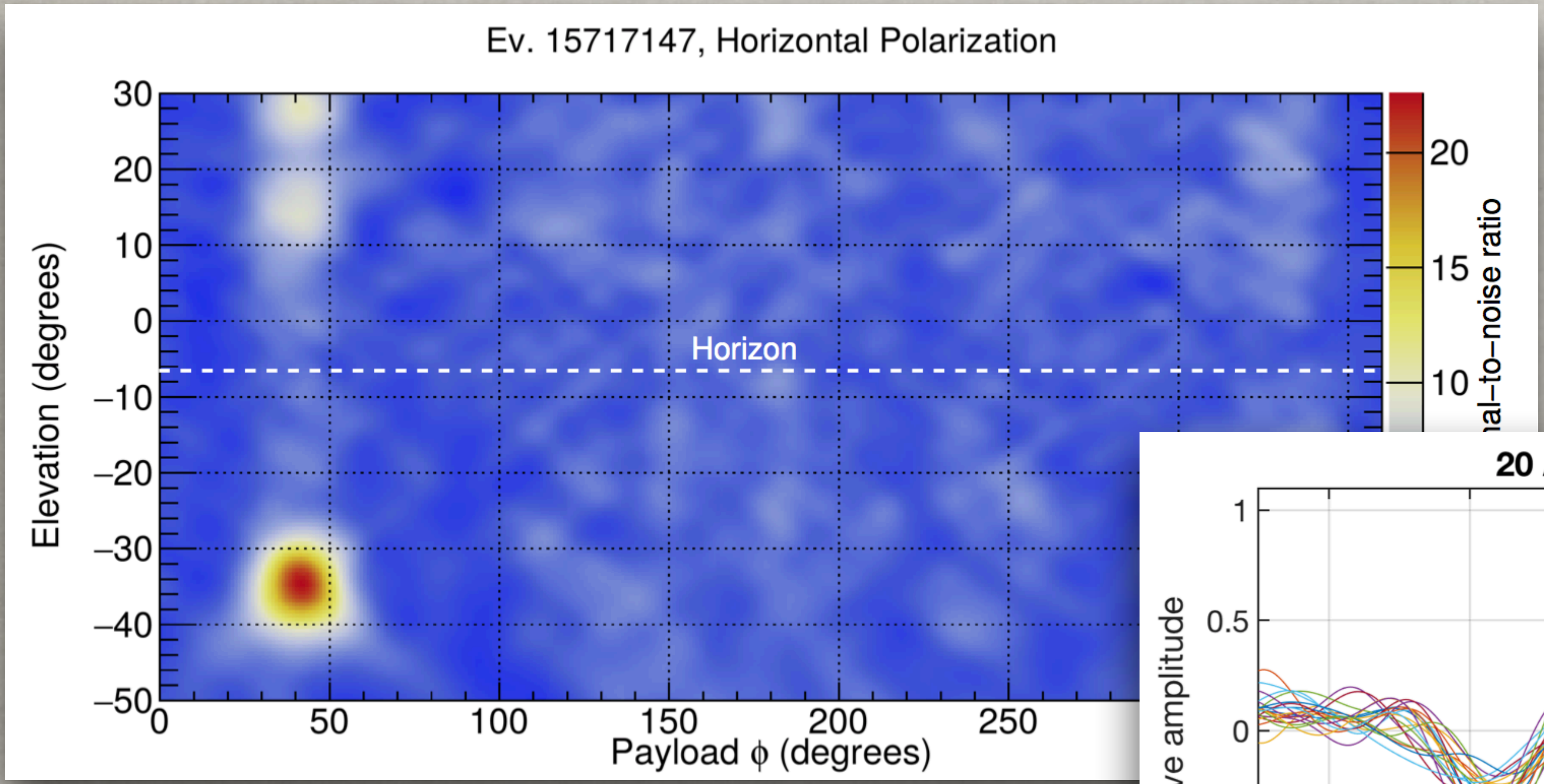


20 ANITA-III UHECR candidates
relative amplitude
time, ns (relative to peak amplitude)

Gorham+18



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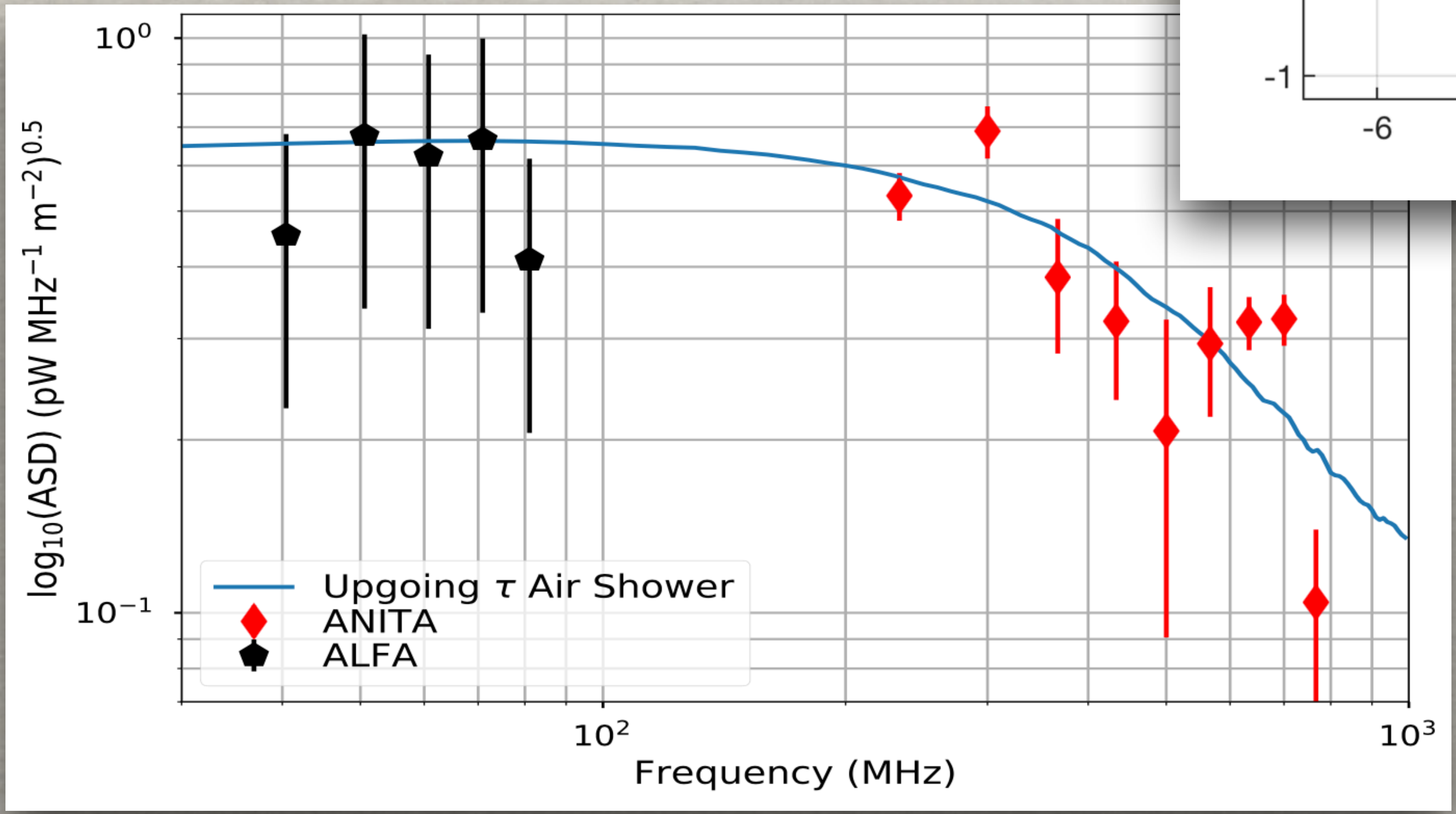
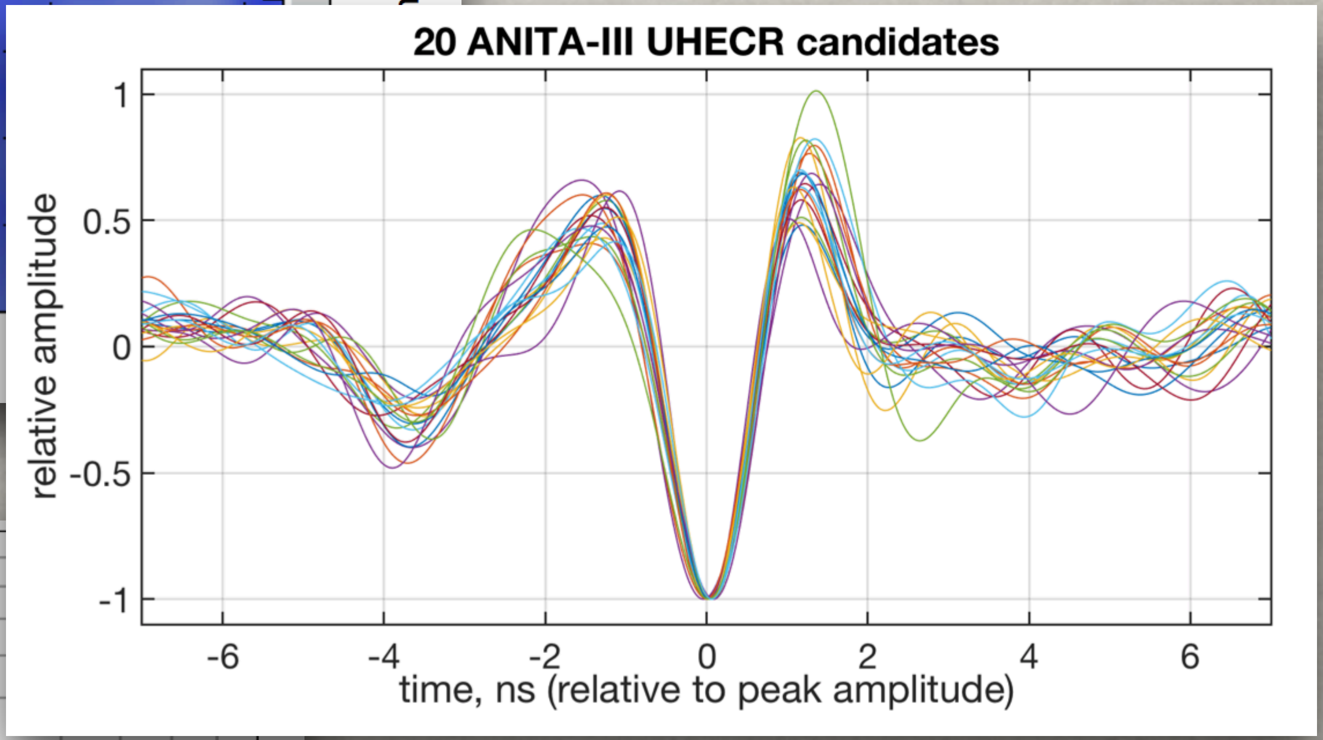


Upgoing τ Air Shower
ANITA
ALFA
Frequency (MHz)



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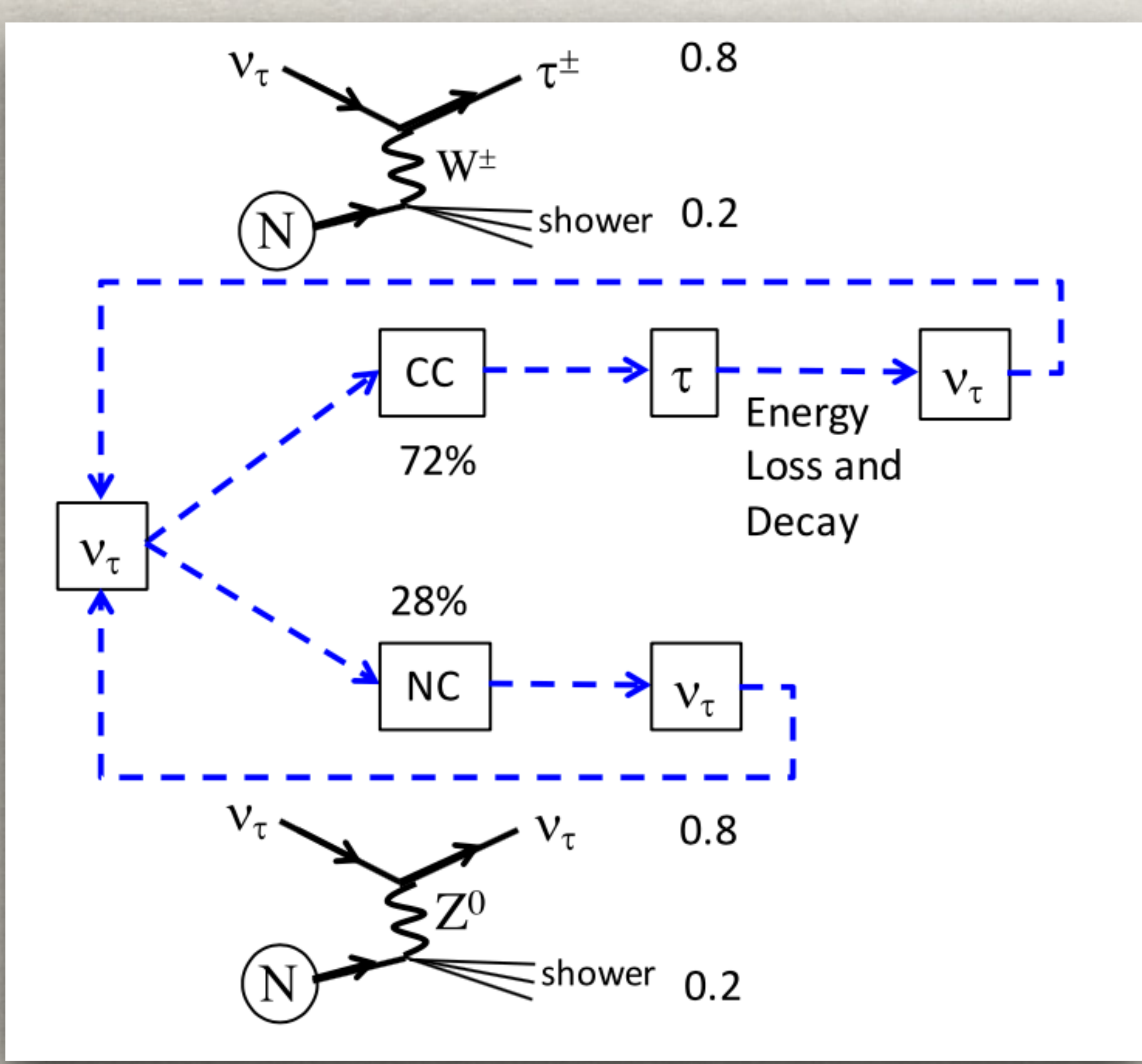
Gorham+18

2. AAEs and the Standard Model



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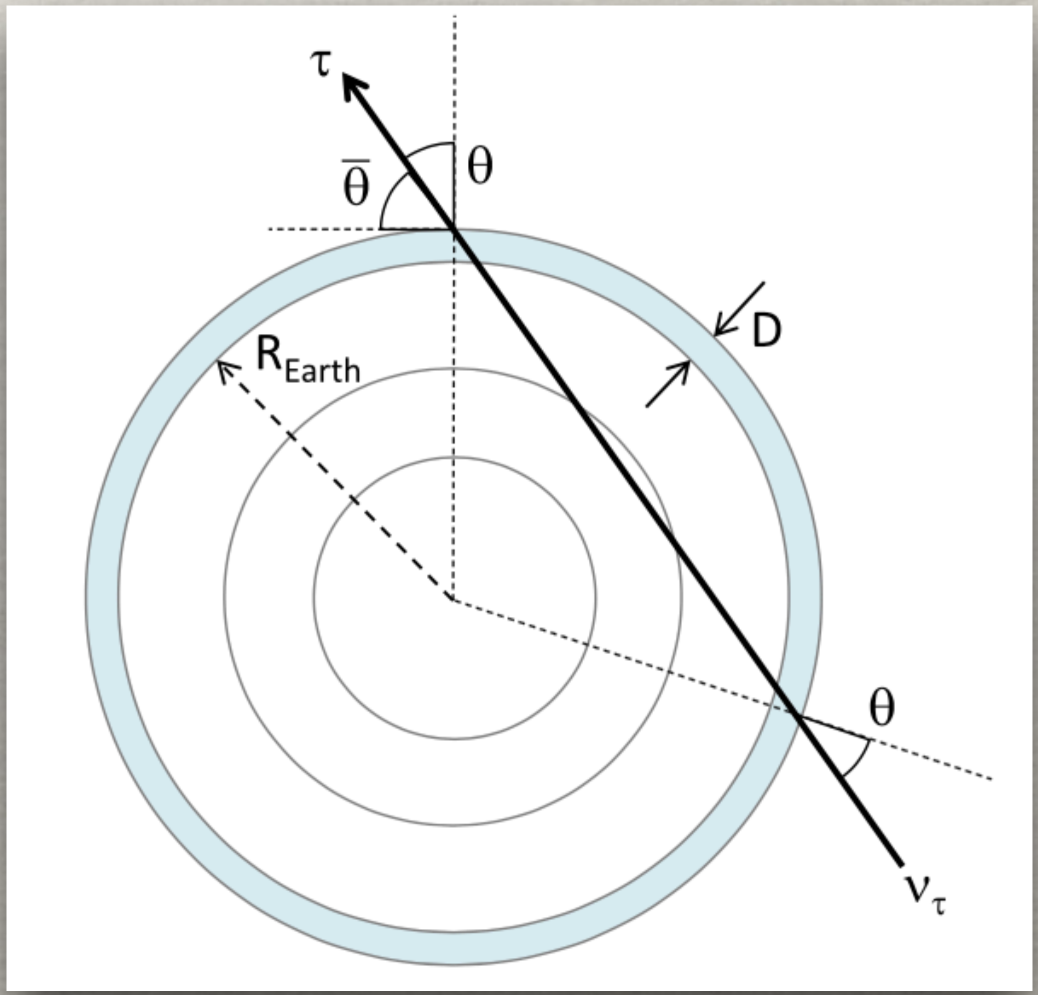

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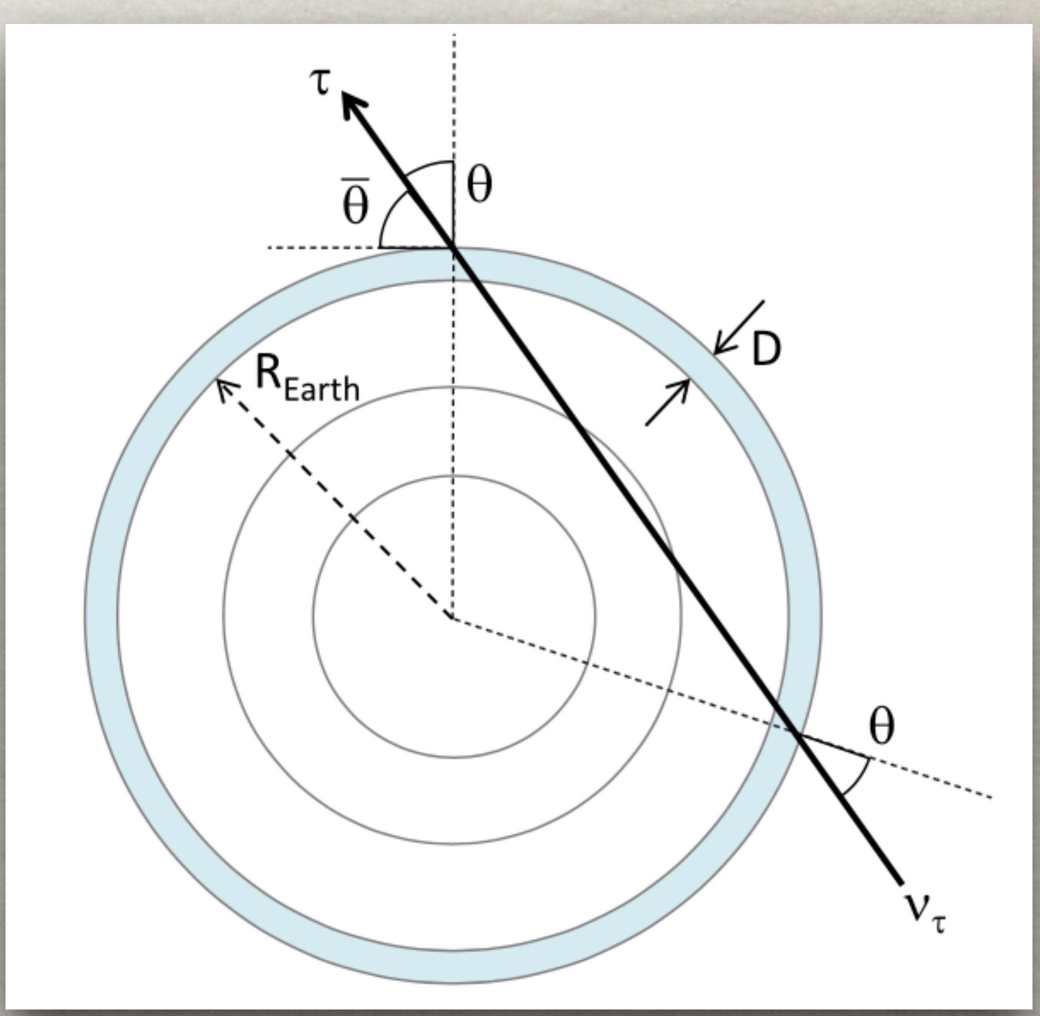
AAEs & the SM



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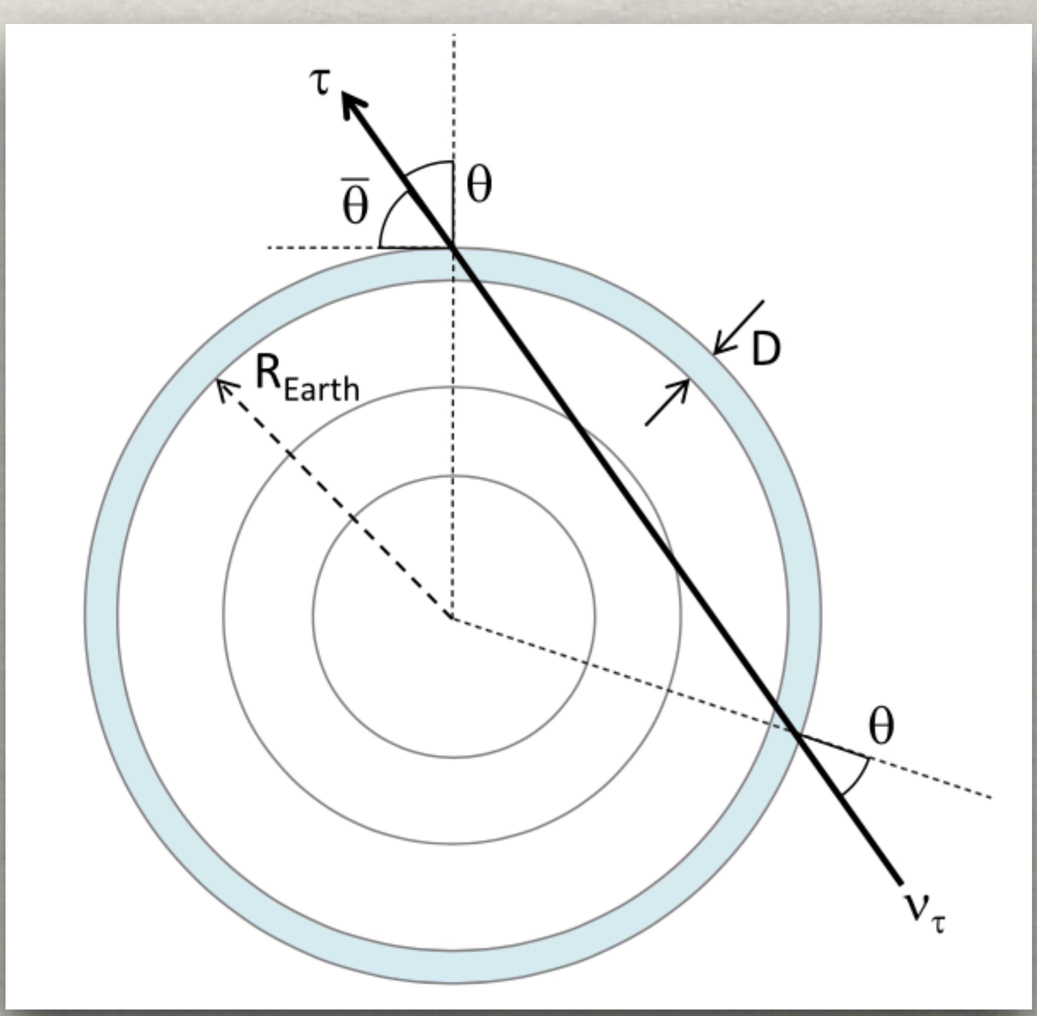
AAEs & the SM

- SM explanations for AAEs excluded on at least two grounds:



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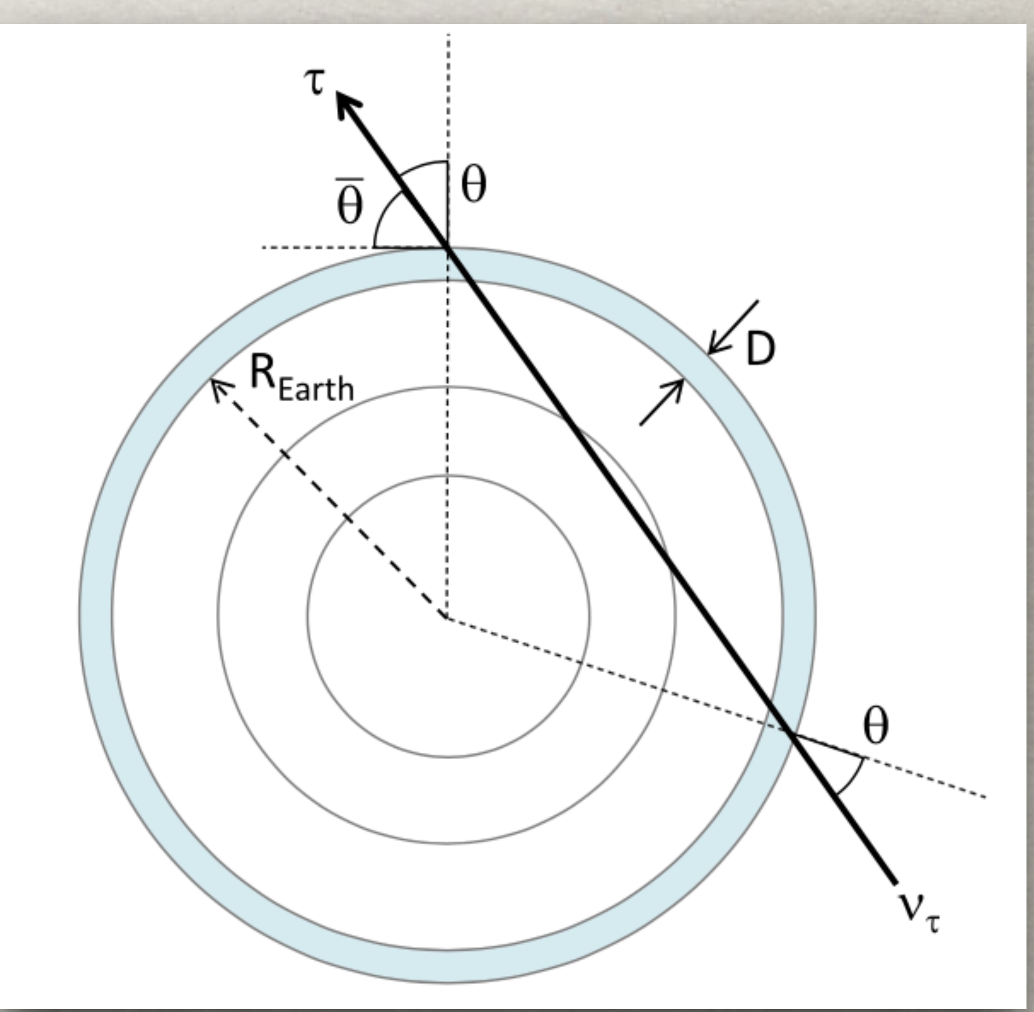

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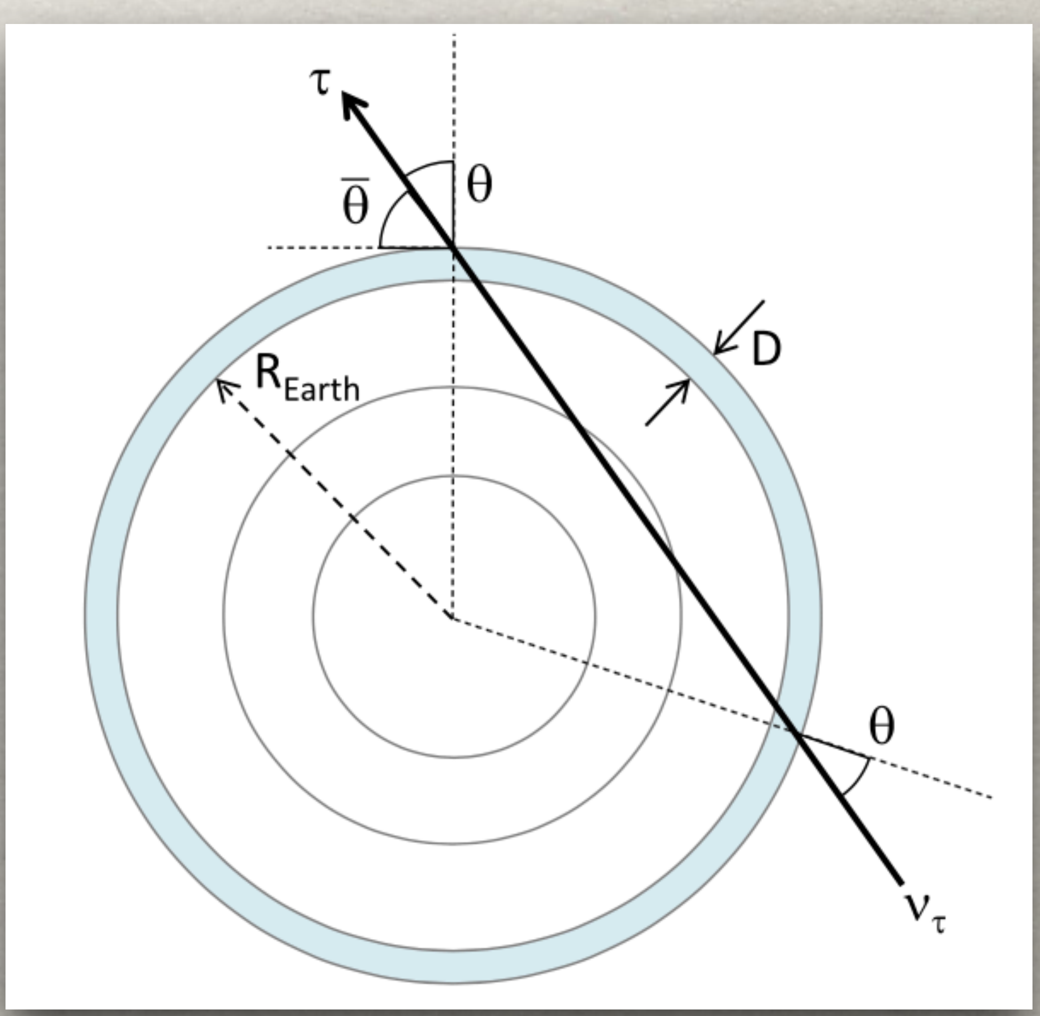

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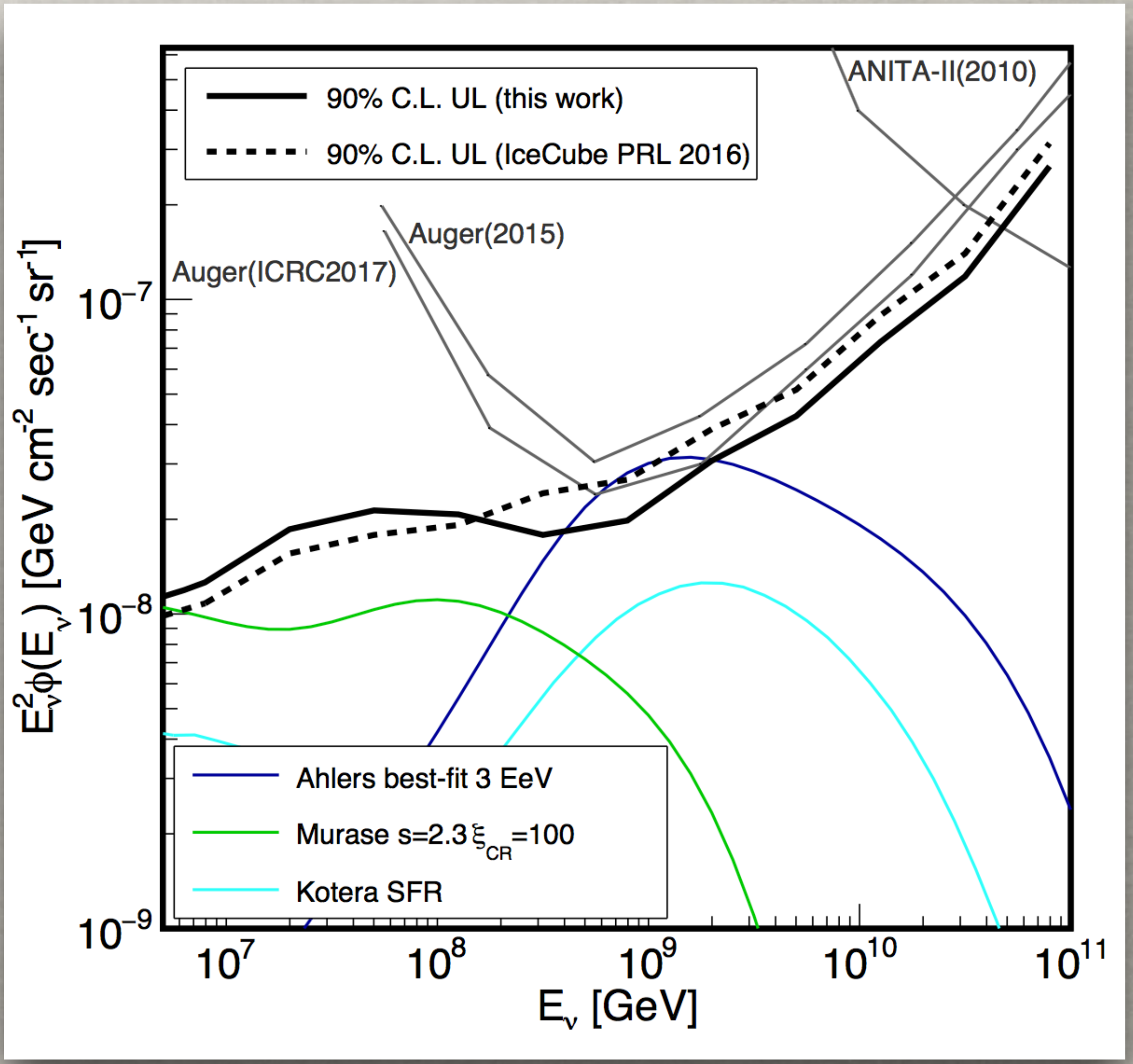

IceCube+18

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 ± 0.4 EeV	$0.56^{+0.30}_{-0.20}$ EeV
Zenith angle z'/z	117°.4 / 116°.8 ± 0°.3	125°.0 / 124°.5 ± 0°.3
Earth chord length ℓ	5740 ± 60 km	7210 ± 55 km
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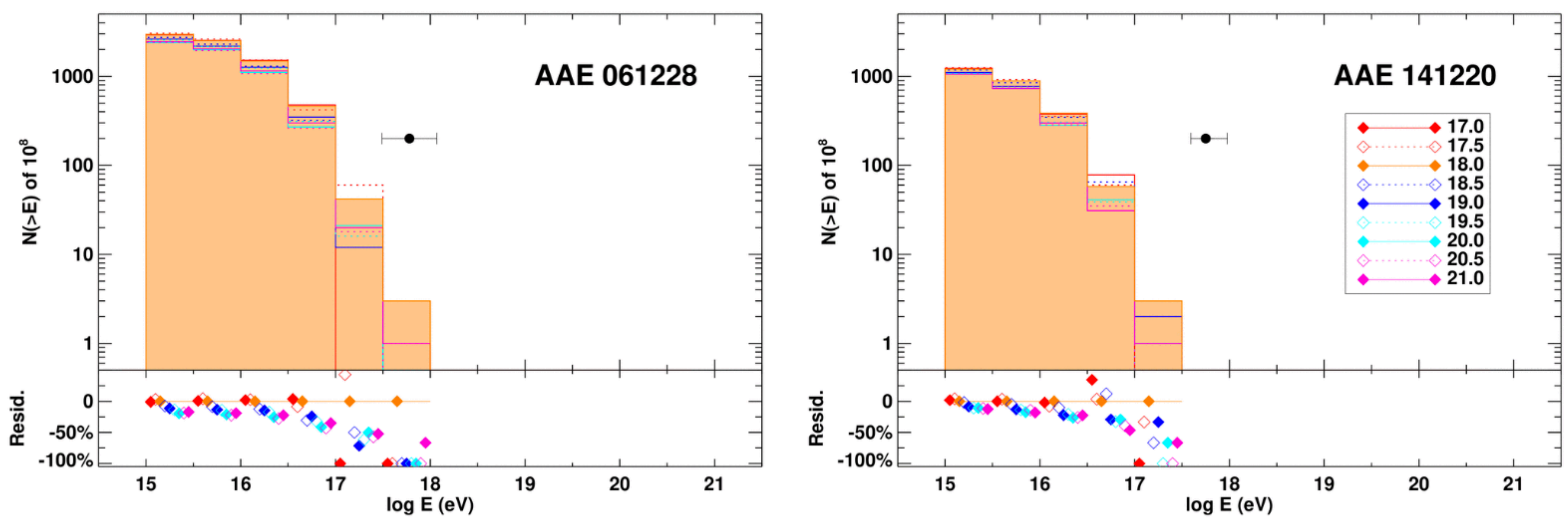

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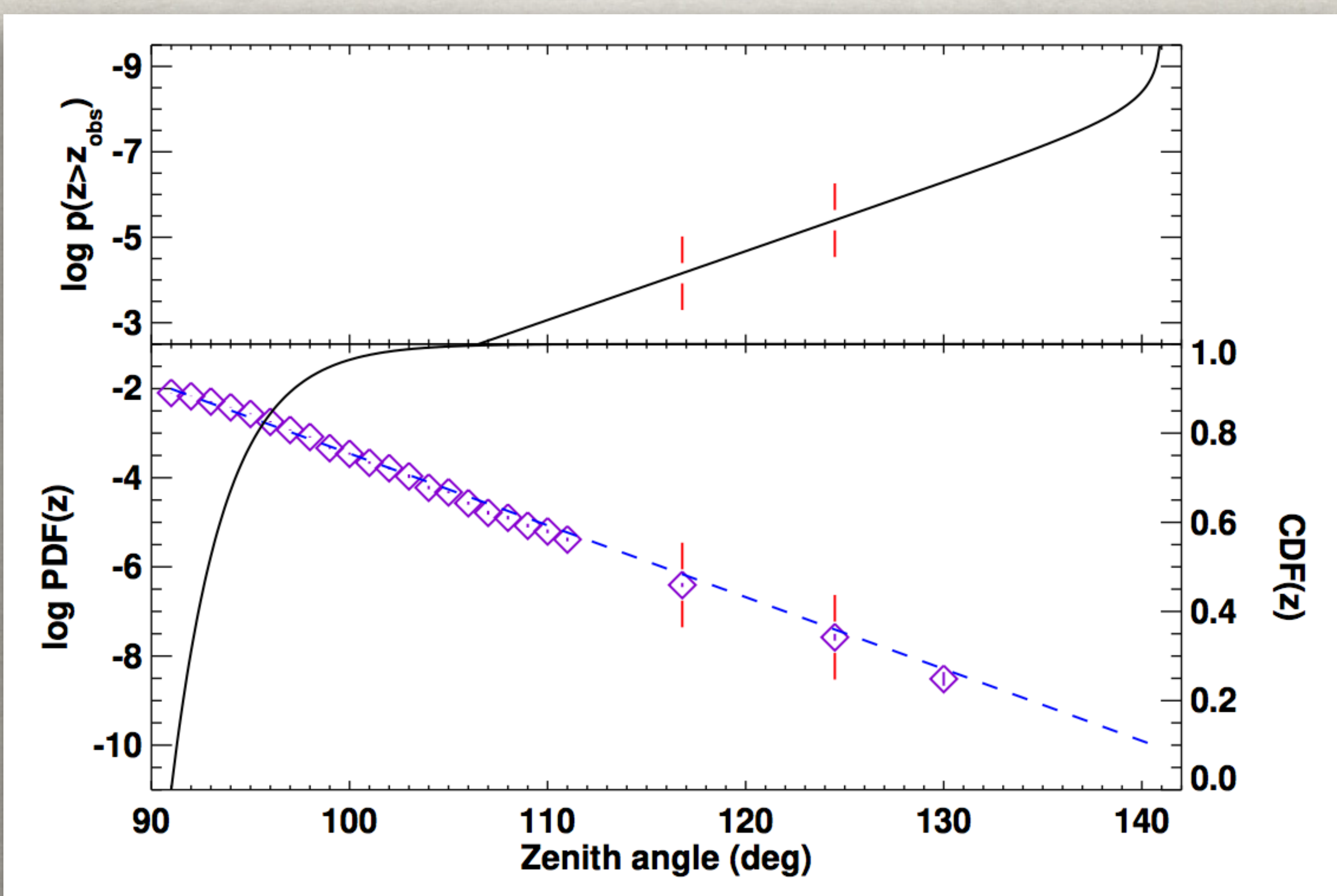
AAE Zenith Angles



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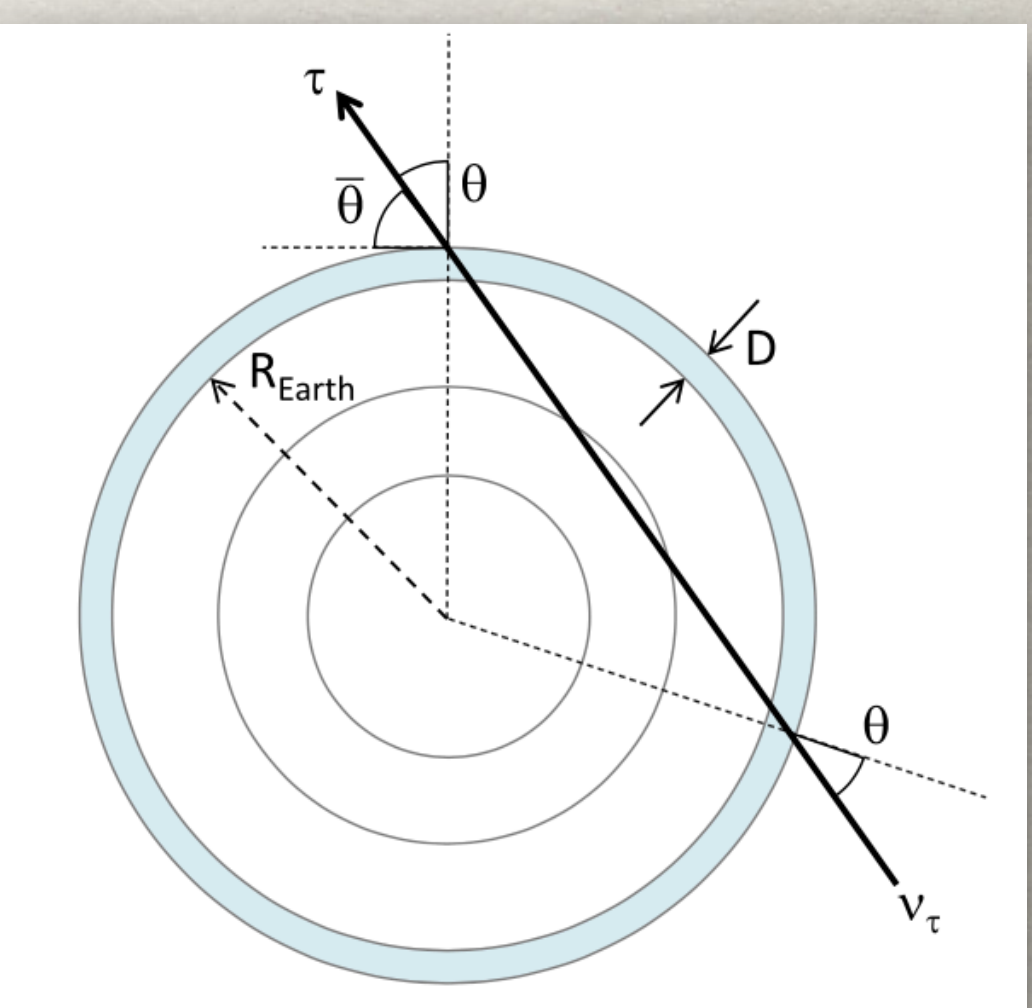

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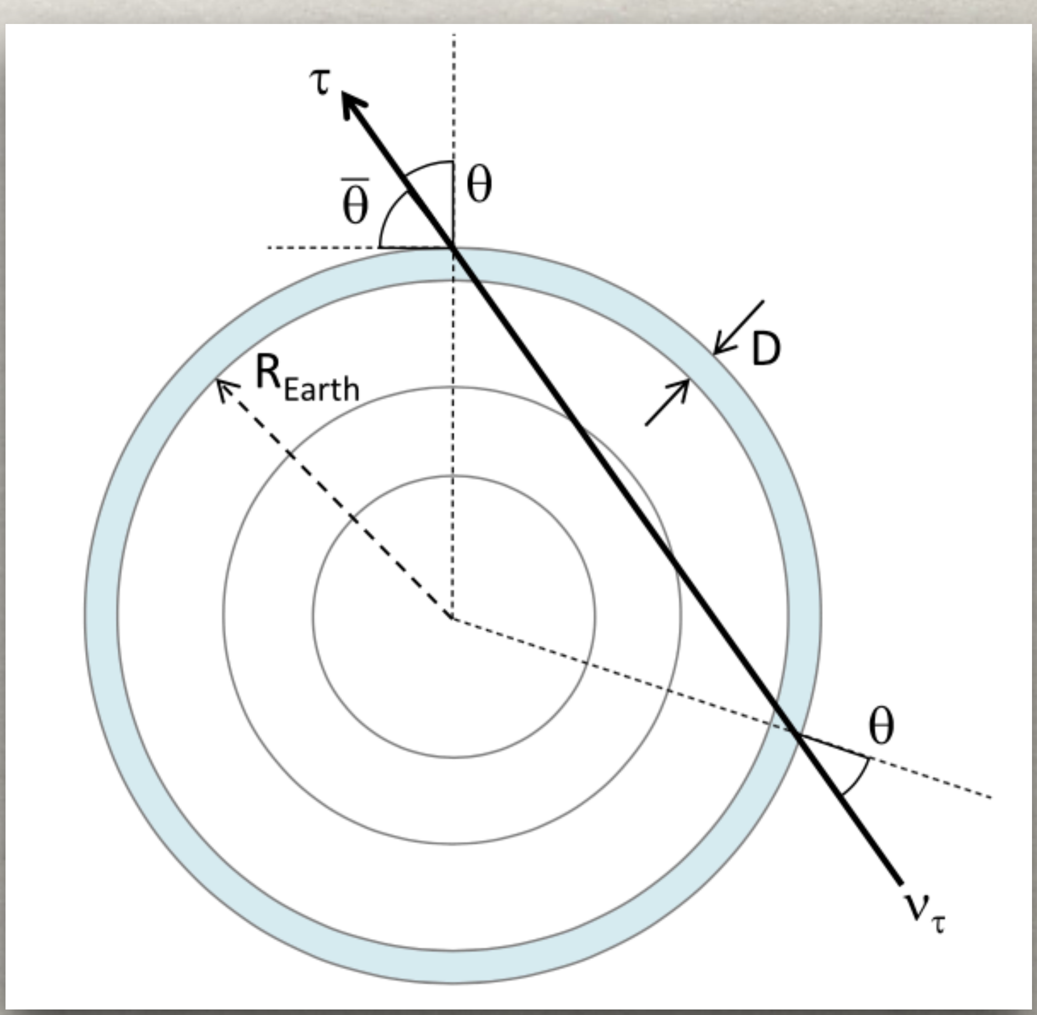

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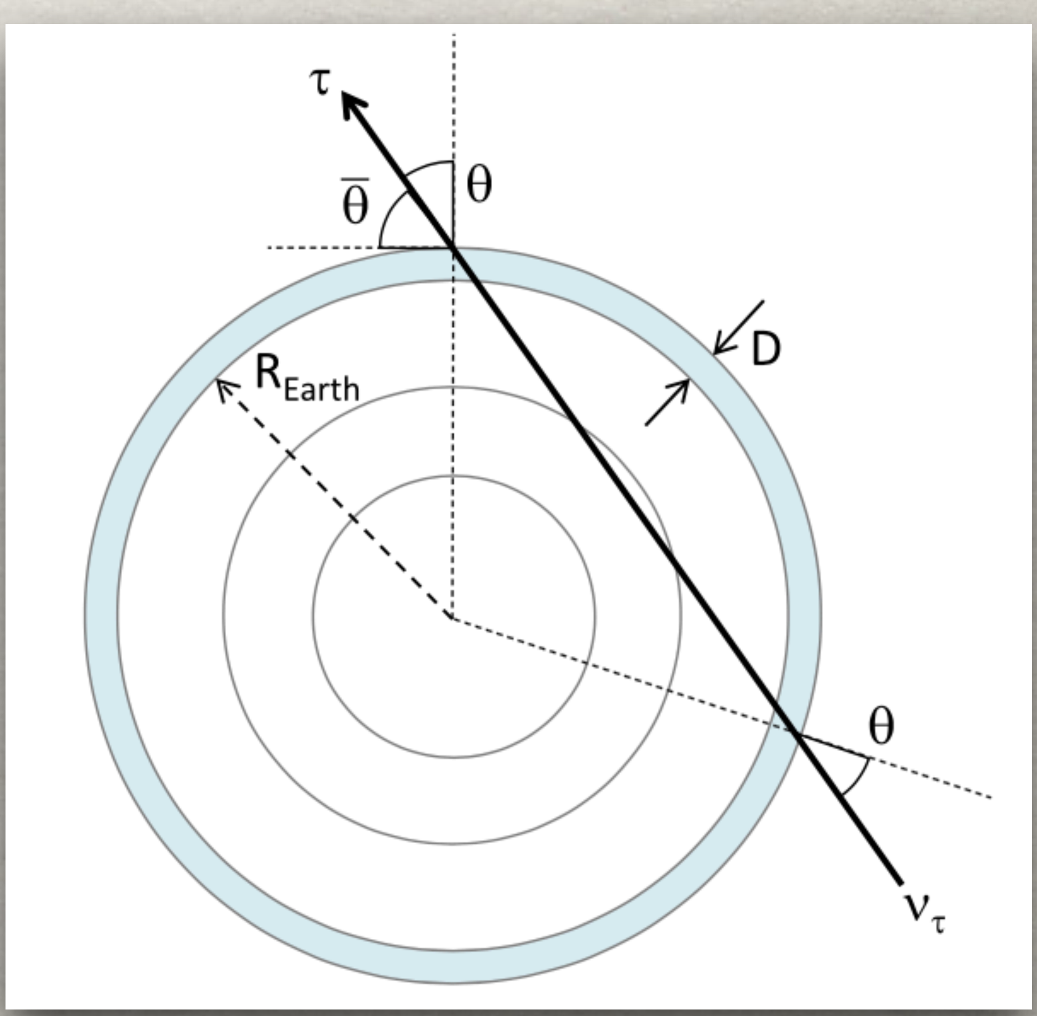

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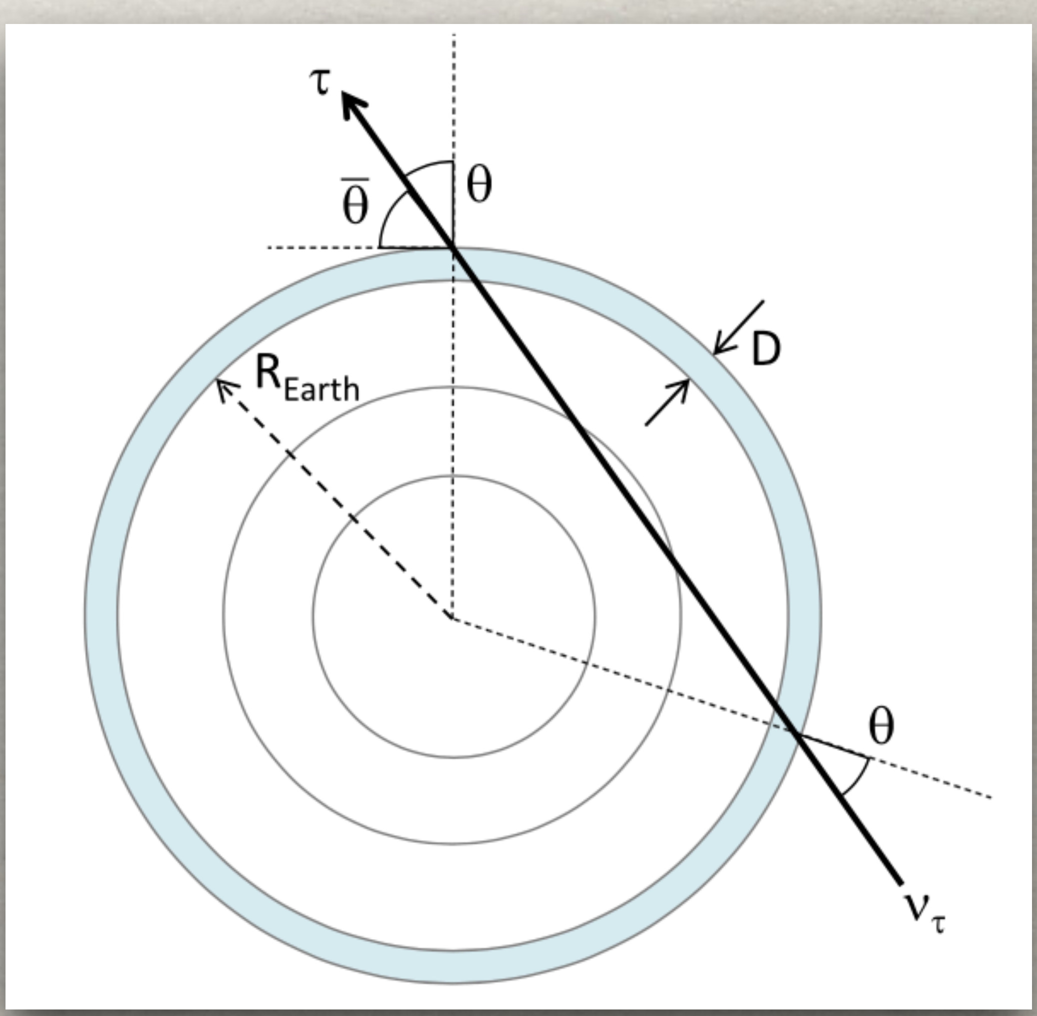

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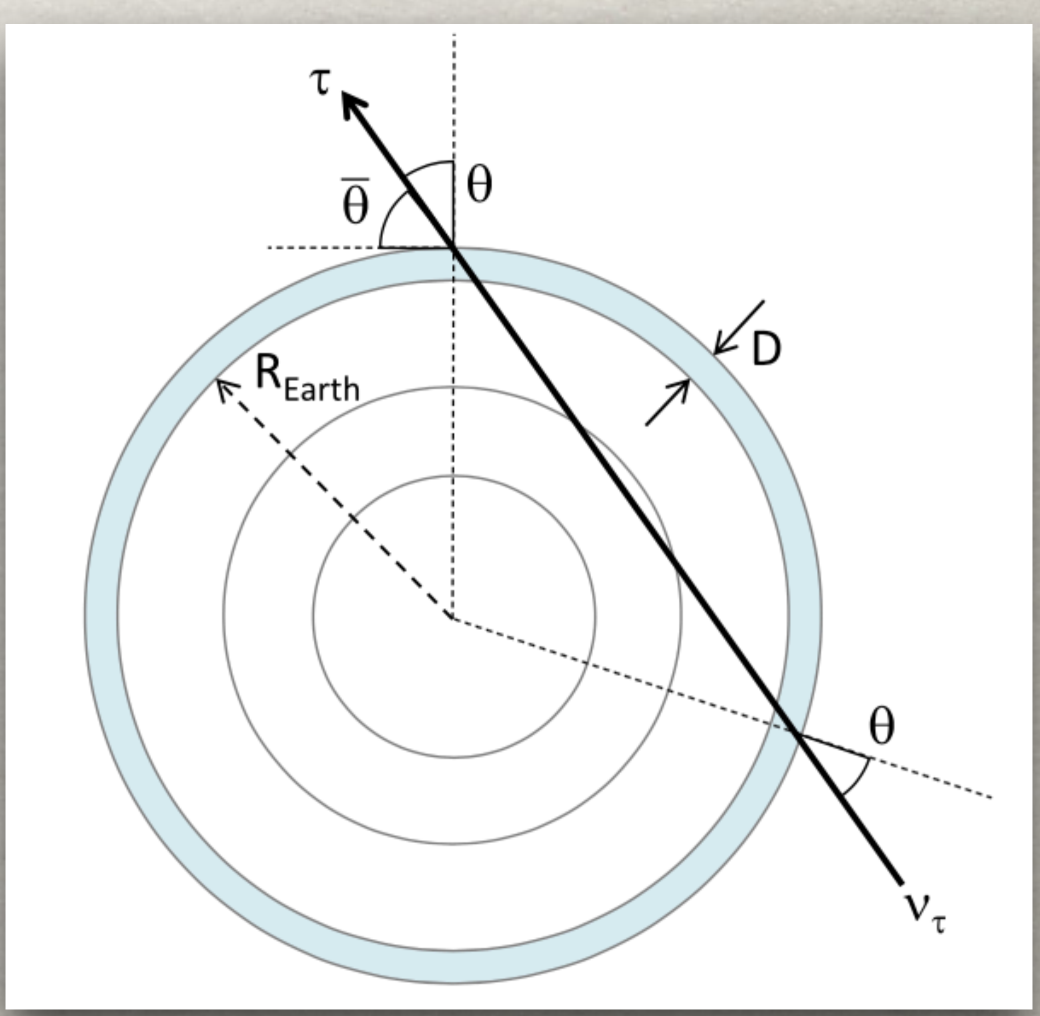

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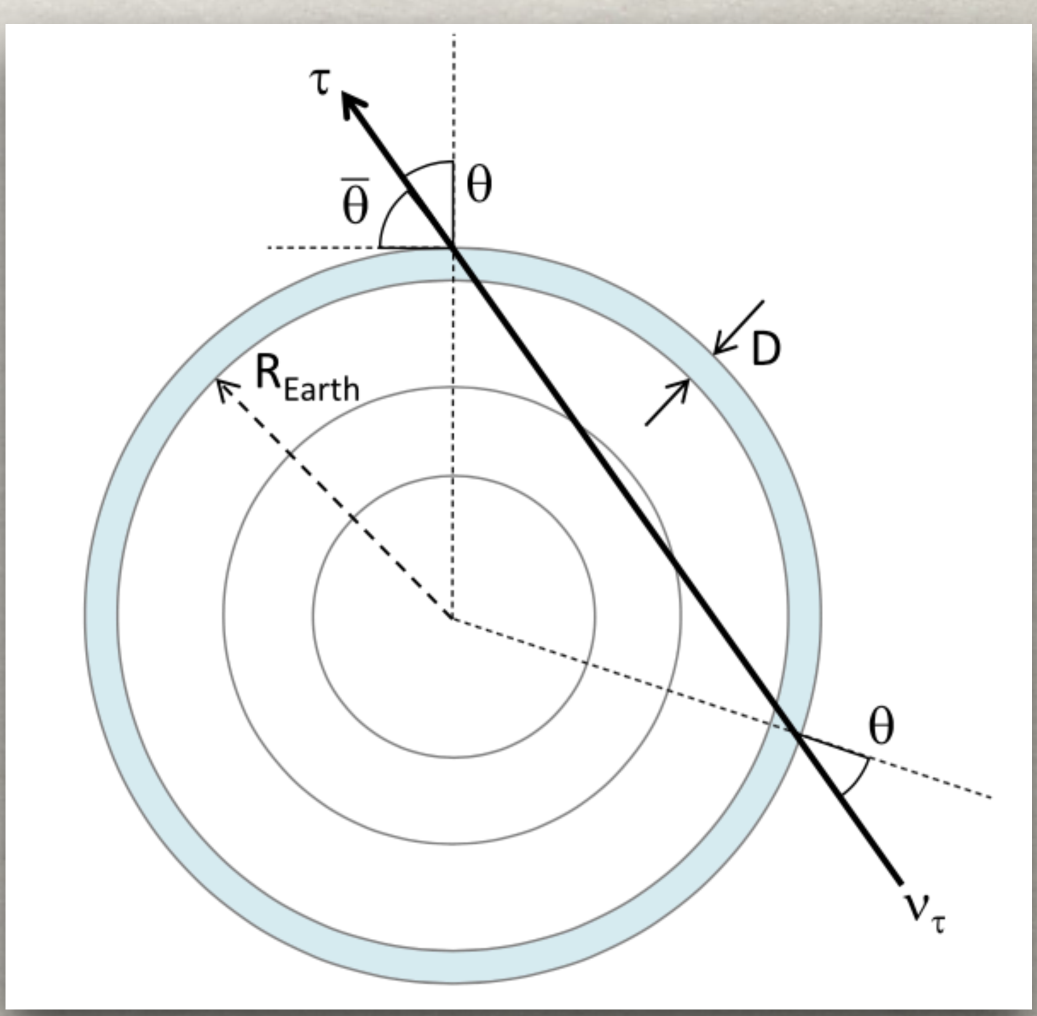

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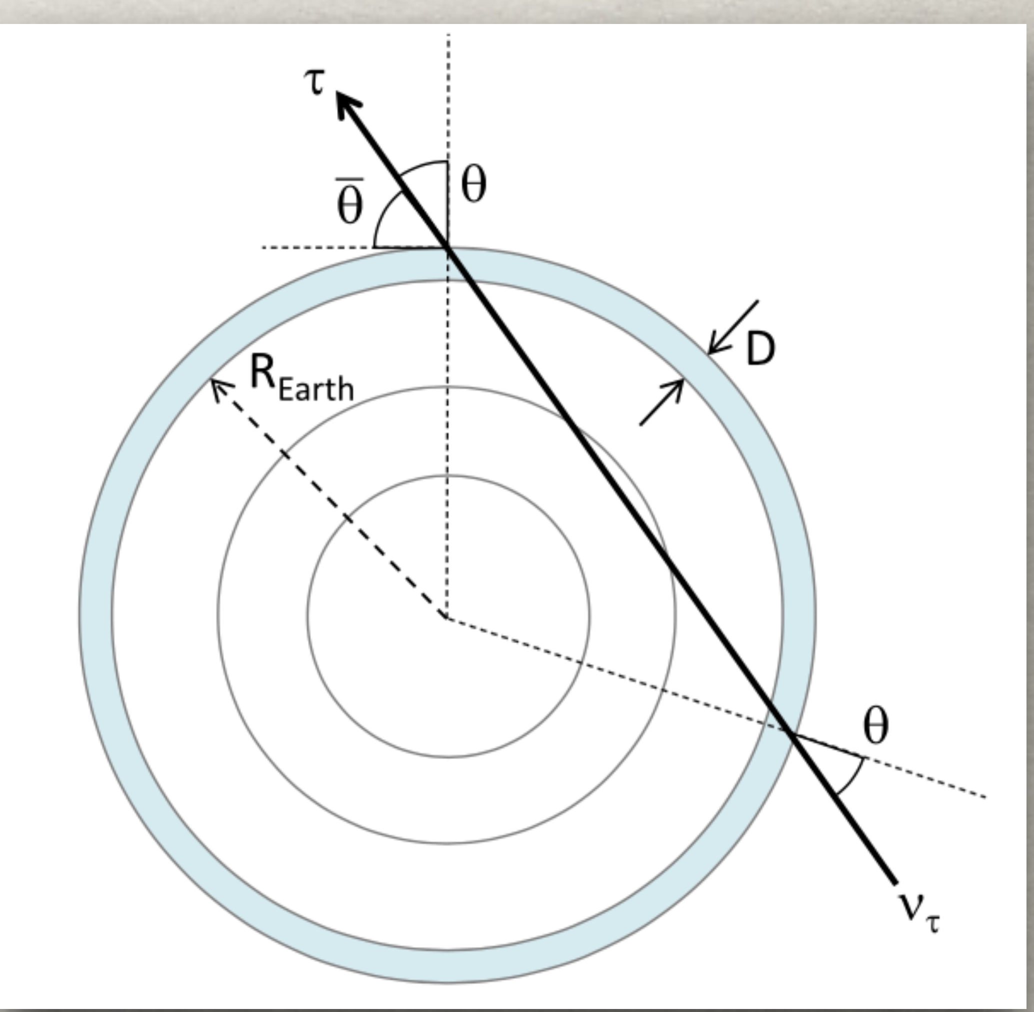

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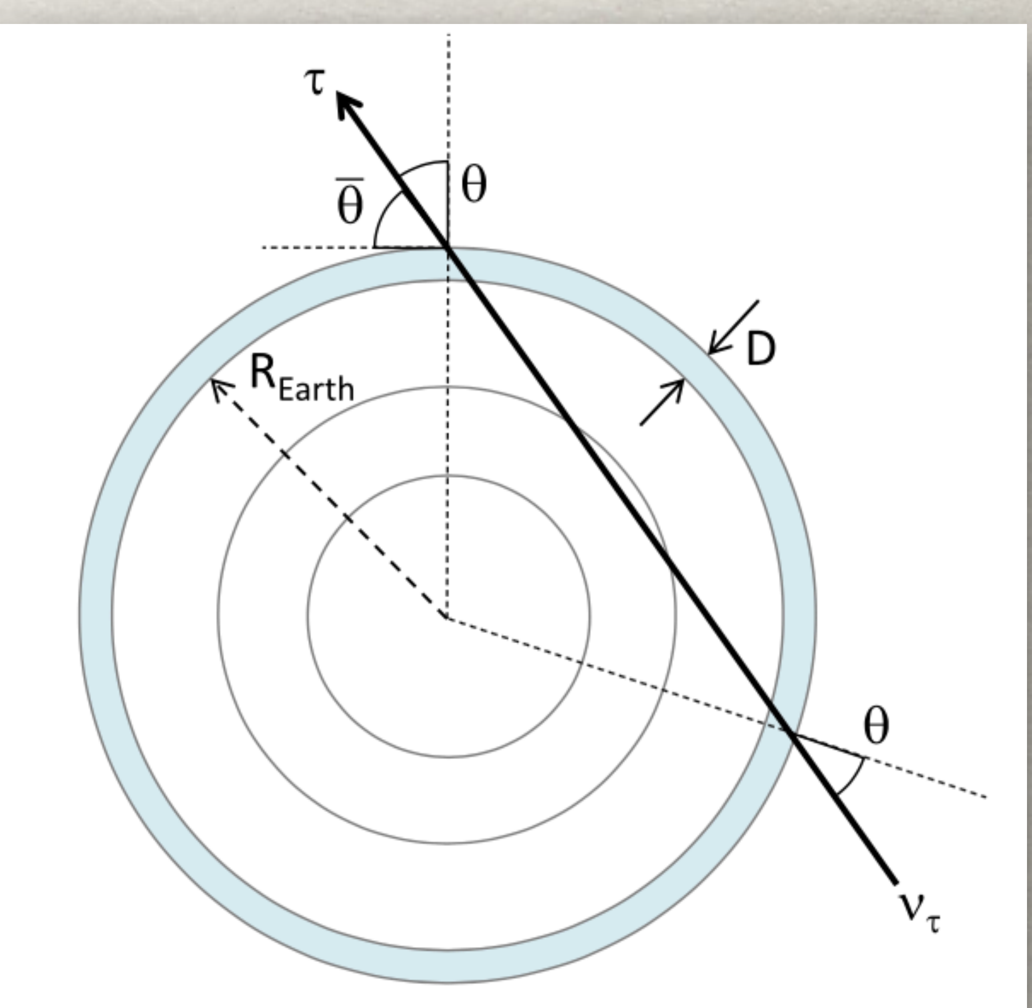

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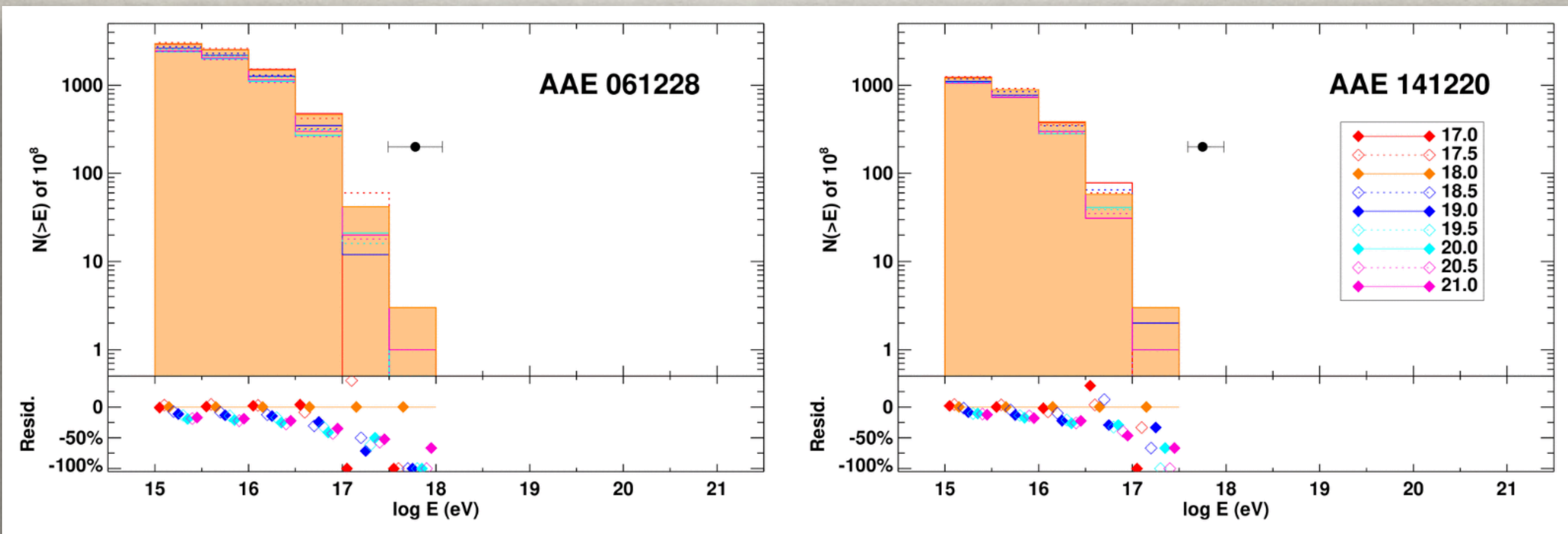

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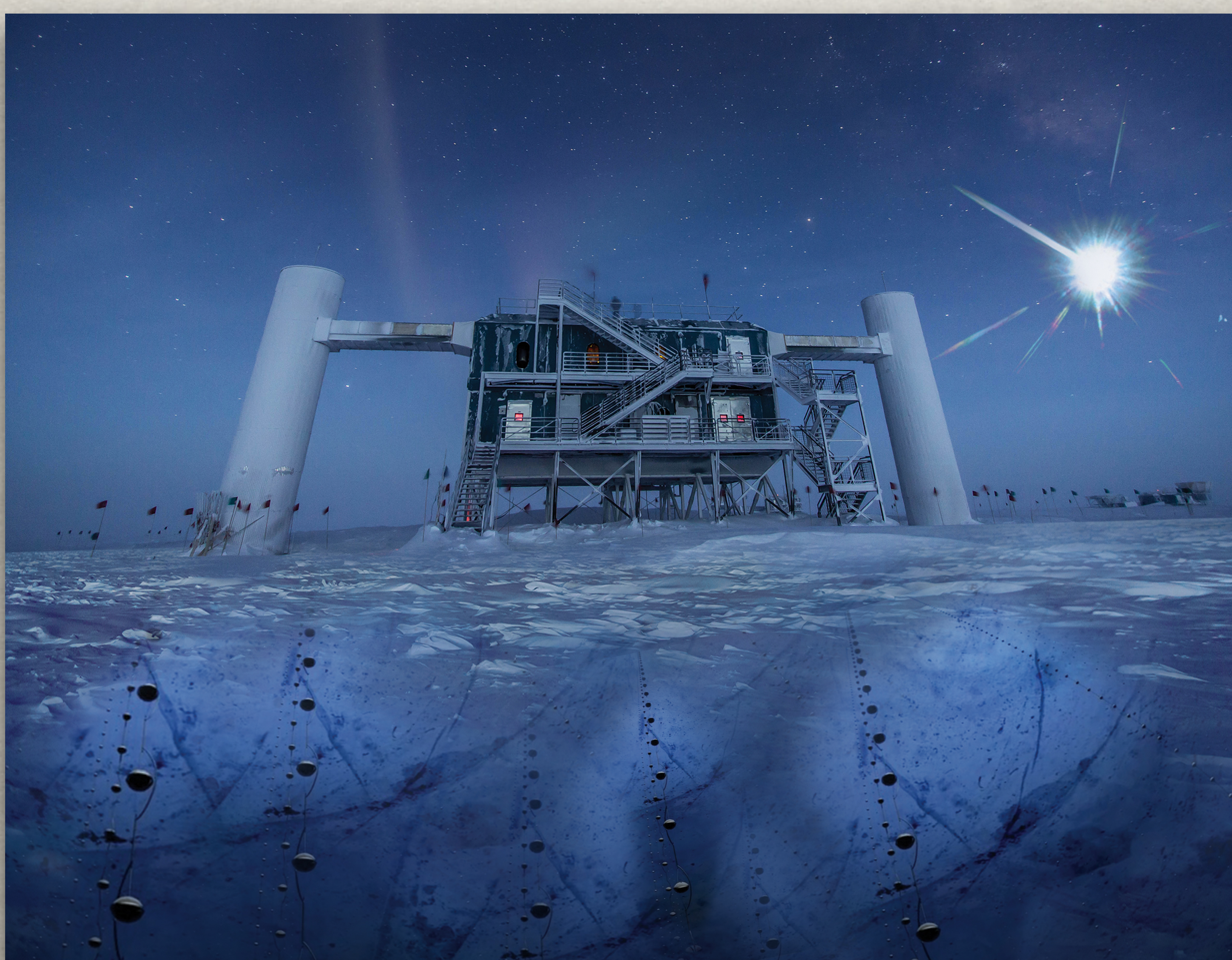
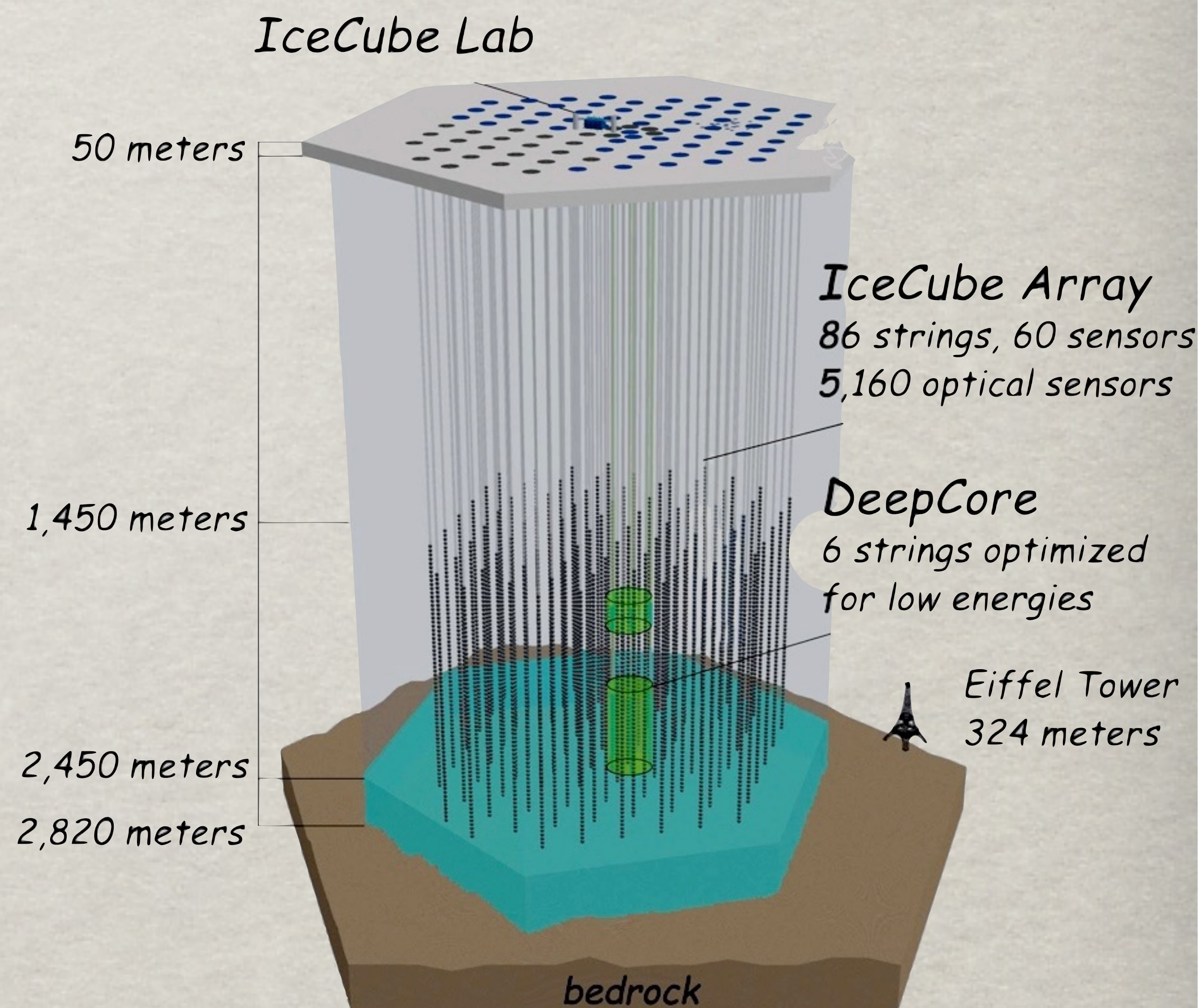
3. More Pieces of the Puzzle



IceCube Neutrino Observatory



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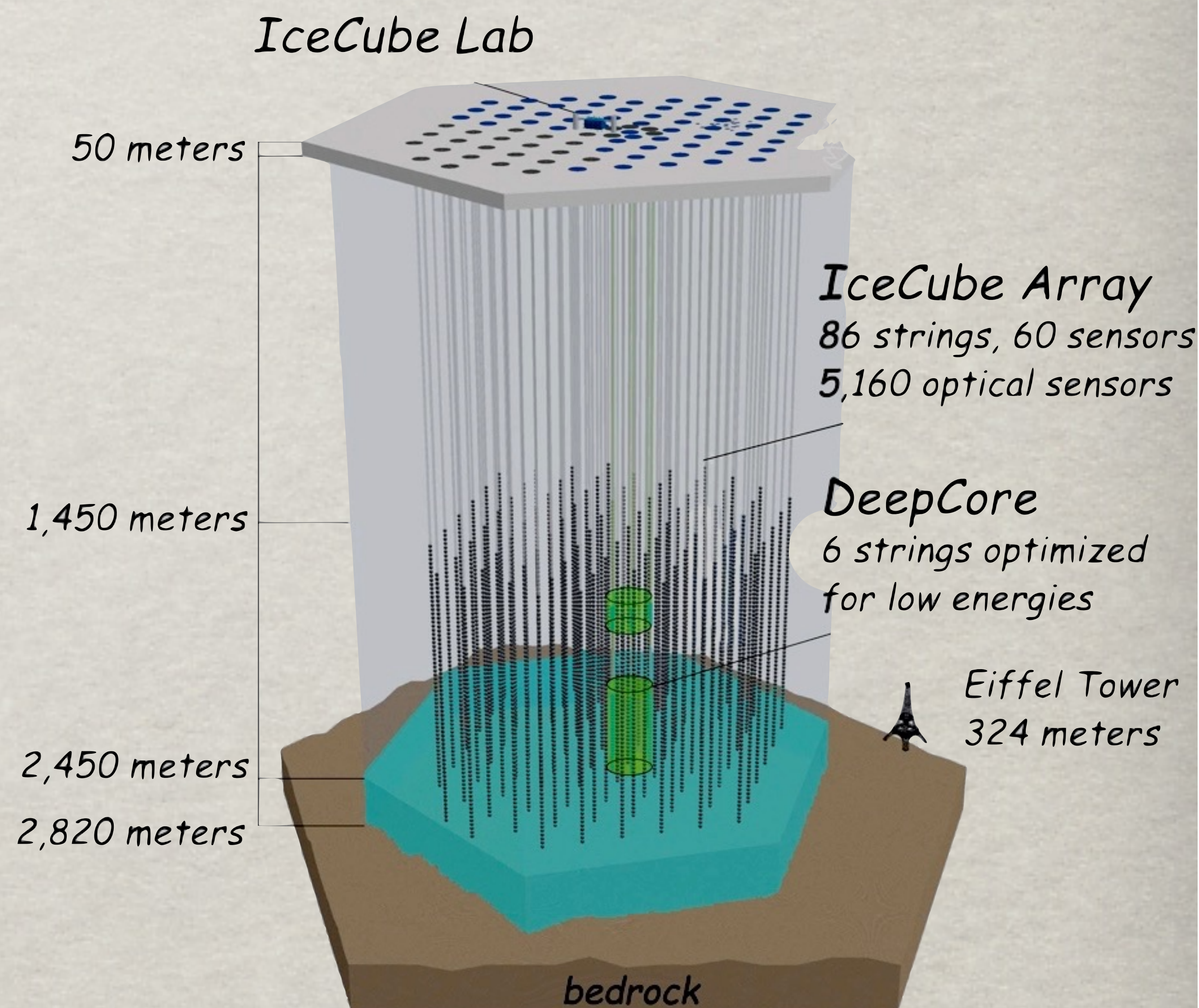
- High-energy neutrinos, $\varepsilon_\nu \gtrsim 1\ \mathrm{TeV}$



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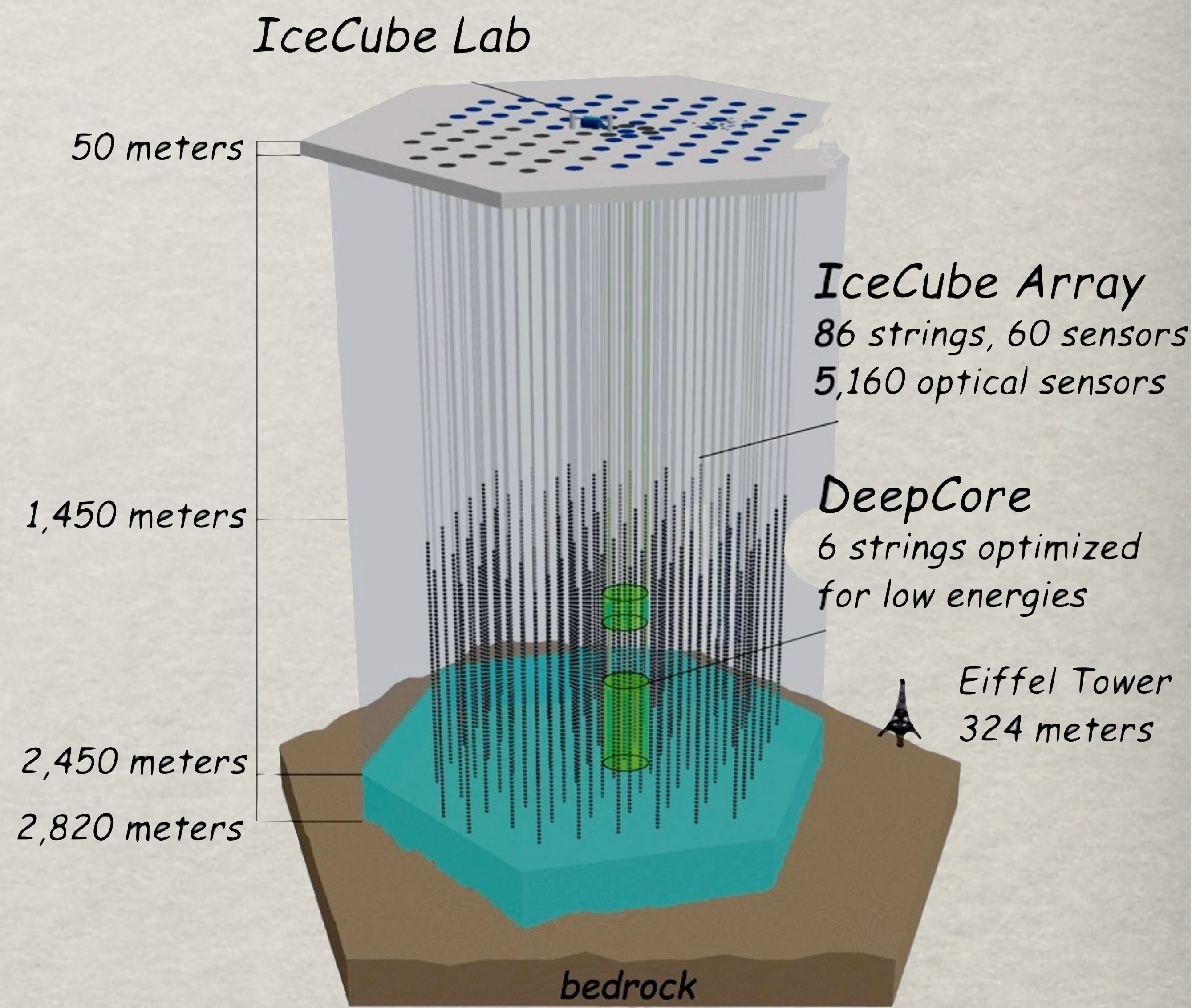

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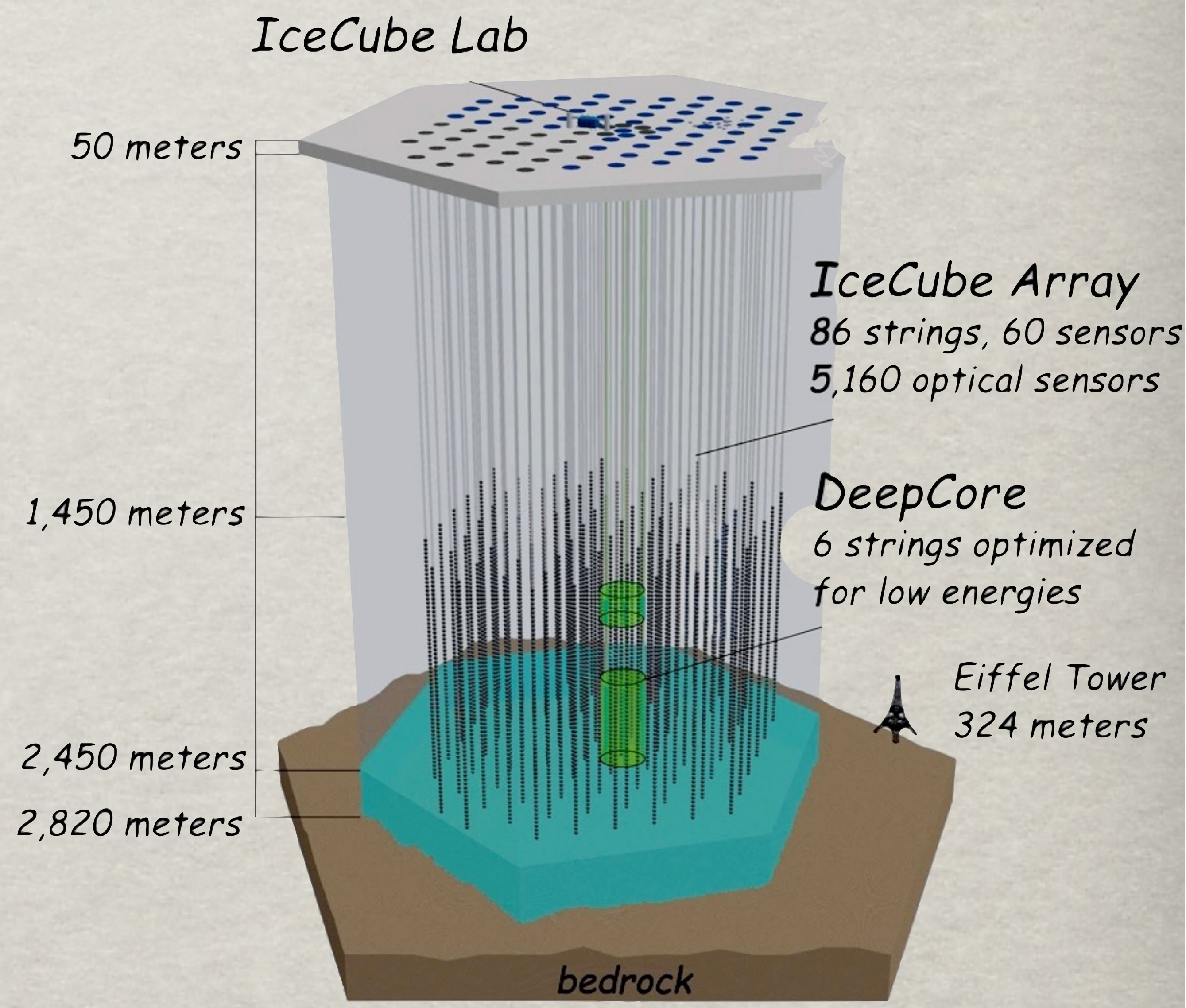

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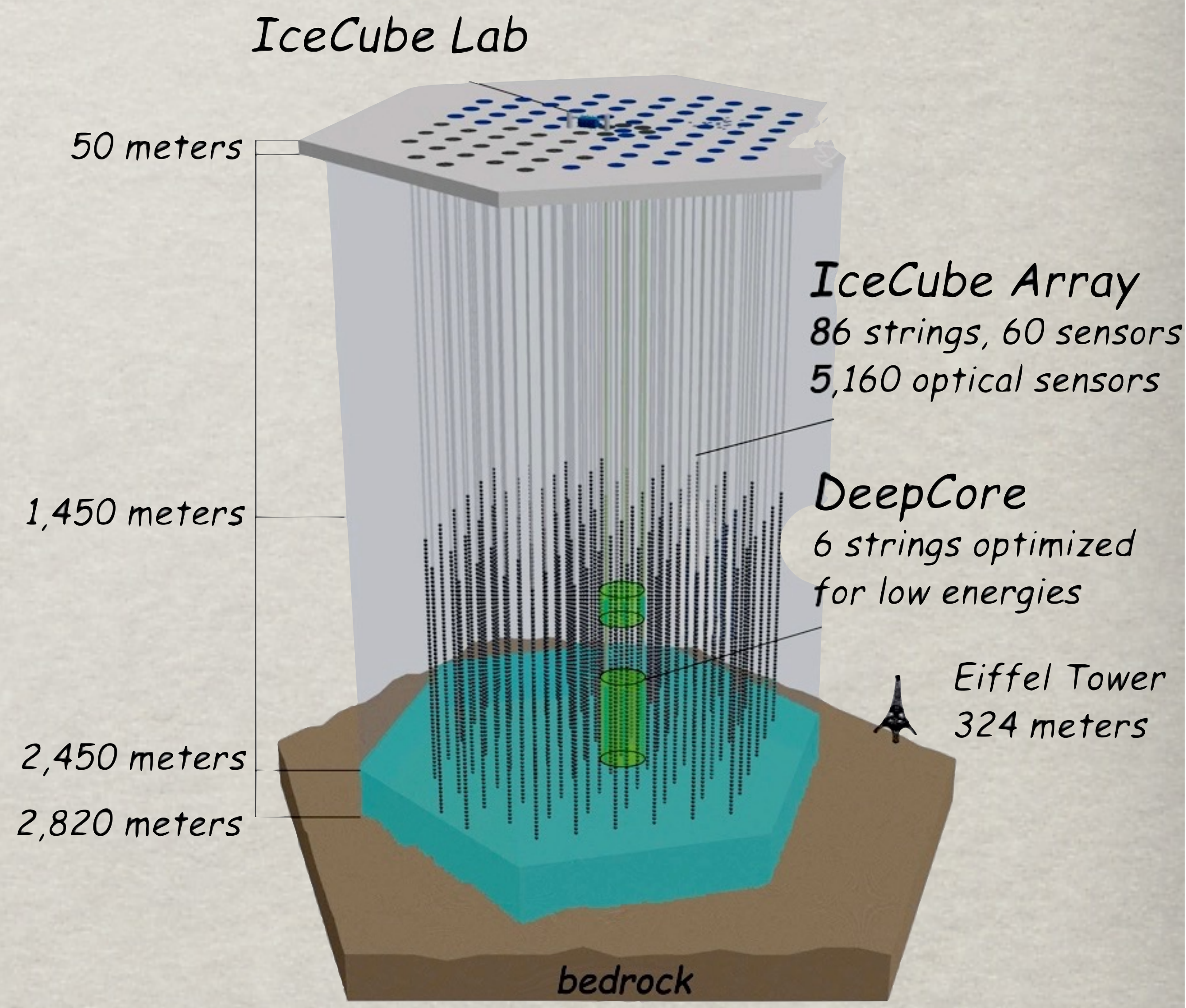

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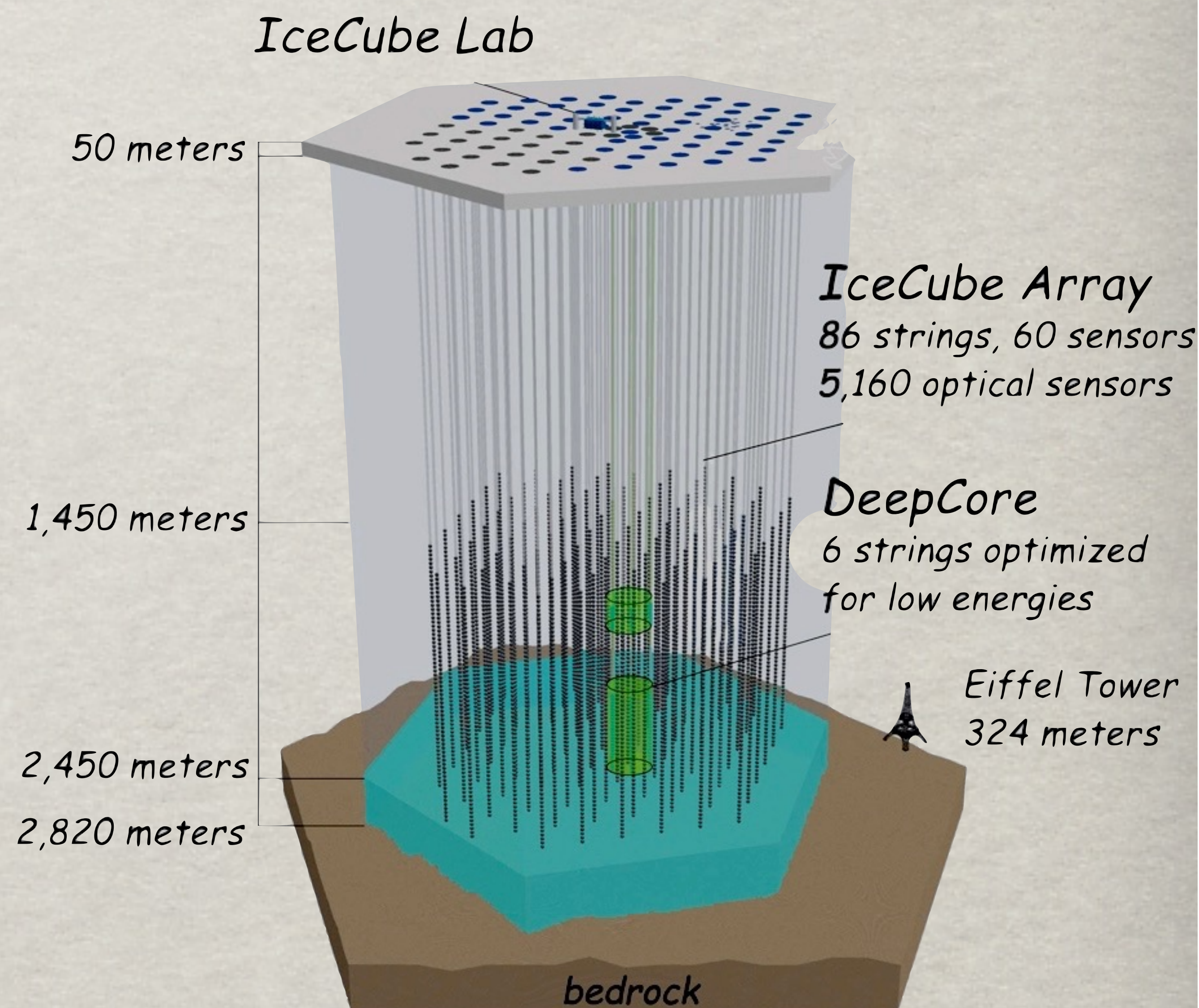
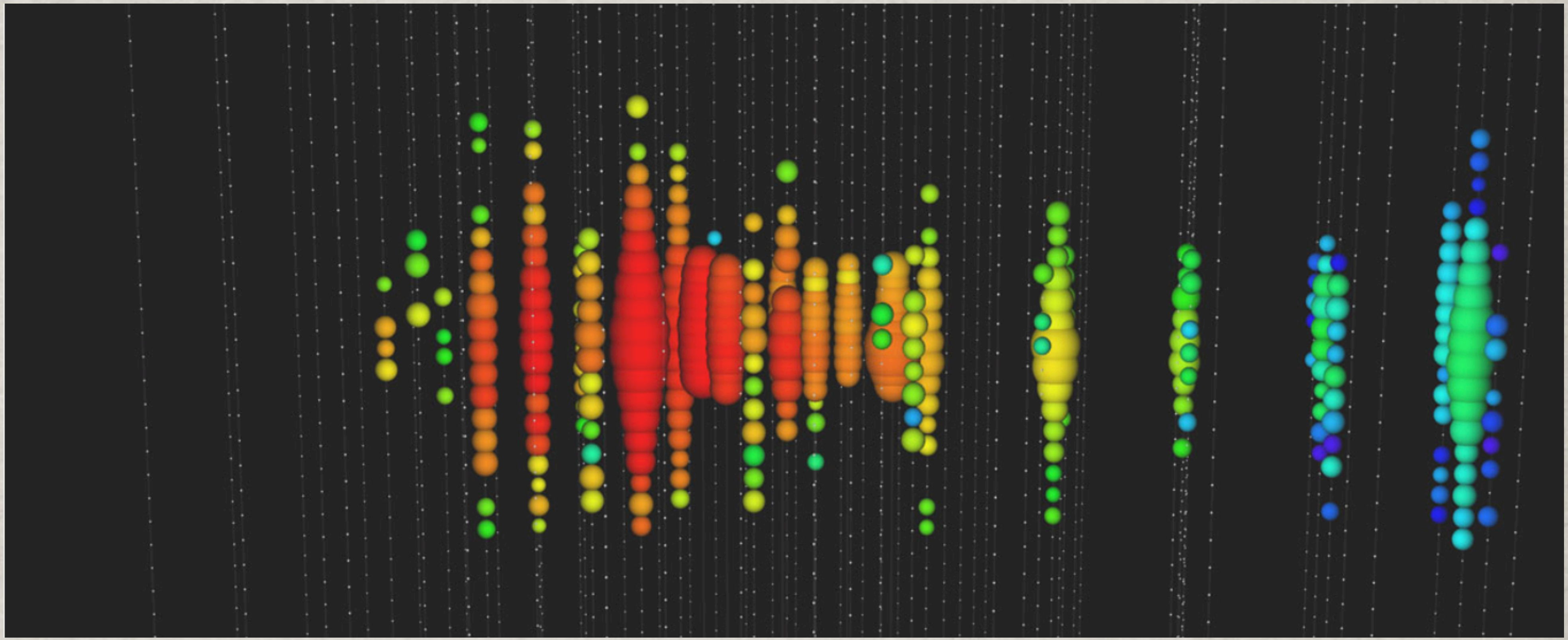
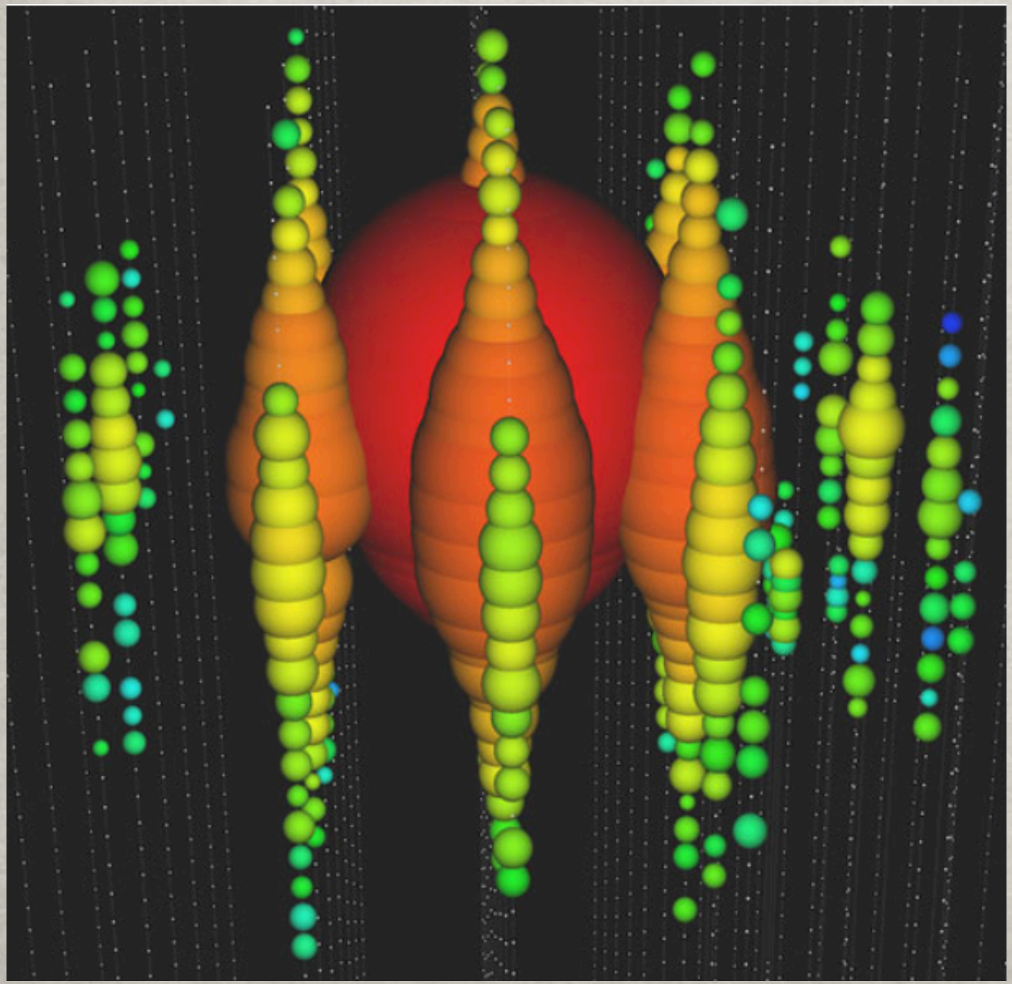
- Tracks (c.c. muon, ~deg) and Cascades (other, >15 deg)



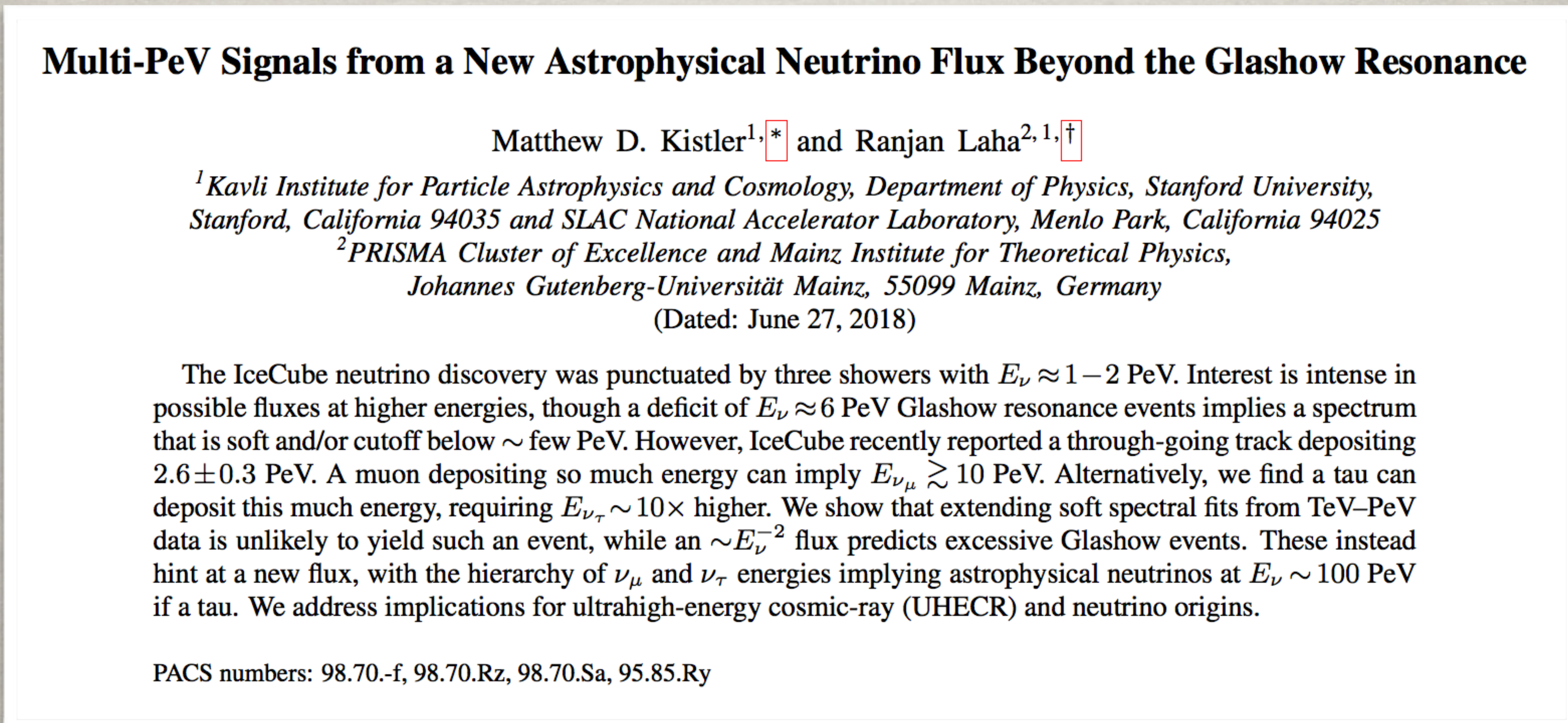
Track ~1°



Cascade ~15°



“Hidden Tau” Events


Multi-PeV Signals from a New Astrophysical Neutrino Flux Beyond the Glashow Resonance

Matthew D. Kistler[1,*] and Ranjan Laha[2,1,†]

[1] *Kavli Institute for Particle Astrophysics and Cosmology, Department of Physics, Stanford University, Stanford, California 94035 and SLAC National Accelerator Laboratory, Menlo Park, California 94025*

[2] *PRISMA Cluster of Excellence and Mainz Institute for Theoretical Physics, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany*

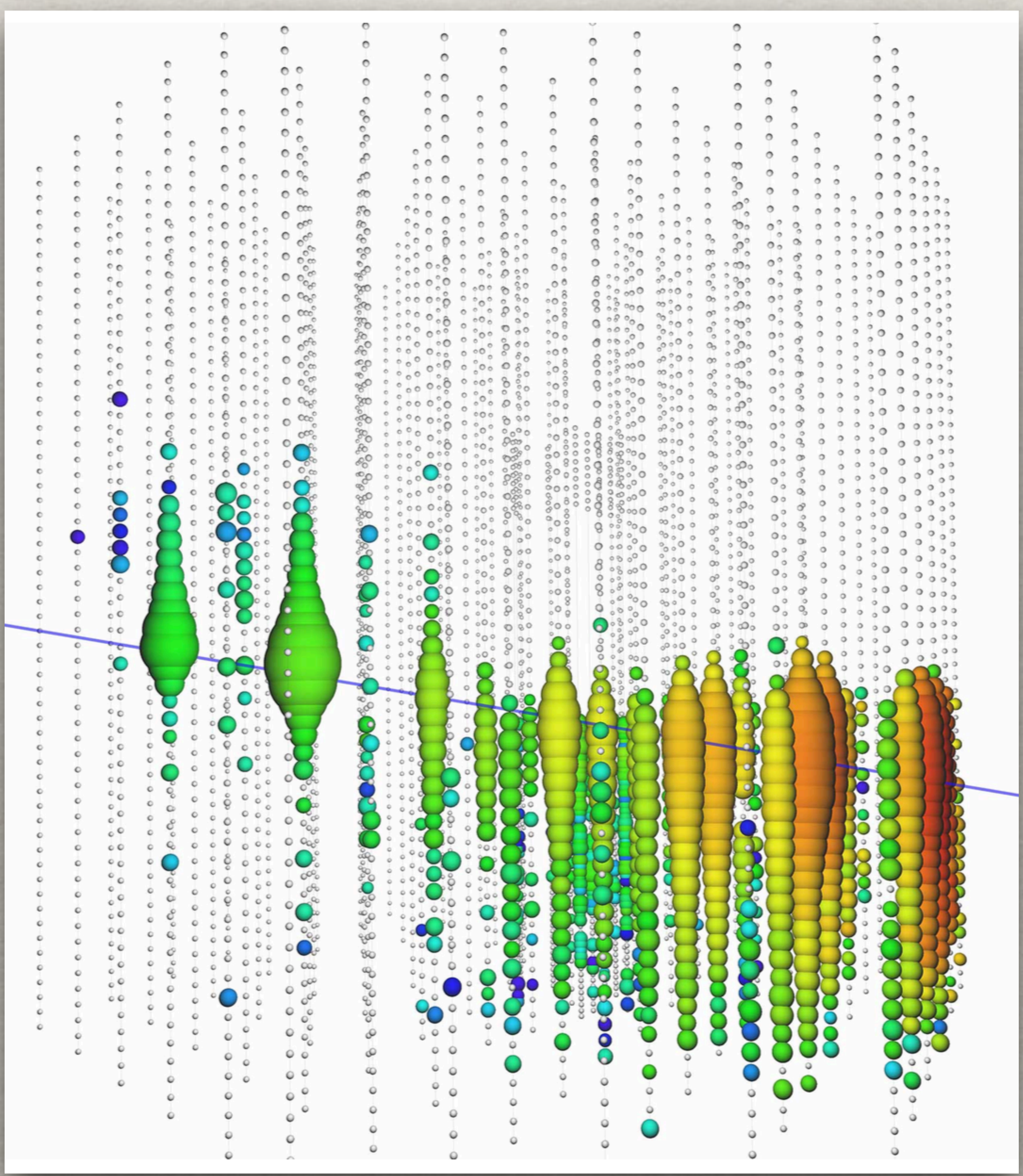
(Dated: June 27, 2018)

The IceCube neutrino discovery was punctuated by three showers with $E_\nu \approx 1-2$ PeV. Interest is intense in possible fluxes at higher energies, though a deficit of $E_\nu \approx 6$ PeV Glashow resonance events implies a spectrum that is soft and/or cutoff below $\sim$ few PeV. However, IceCube recently reported a through-going track depositing 2.6 ± 0.3 PeV. A muon depositing so much energy can imply $E_{\nu_\mu} \gtrsim 10$ PeV. Alternatively, we find a tau can deposit this much energy, requiring $E_{\nu_\tau} \sim 10\times$ higher. We show that extending soft spectral fits from TeV–PeV data is unlikely to yield such an event, while an $\sim E_\nu^{-2}$ flux predicts excessive Glashow events. These instead hint at a new flux, with the hierarchy of ν_μ and ν_τ energies implying astrophysical neutrinos at $E_\nu \sim 100$ PeV if a tau. We address implications for ultrahigh-energy cosmic-ray (UHECR) and neutrino origins.

PACS numbers: 98.70.-f, 98.70.Rz, 98.70.Sa, 95.85.Ry

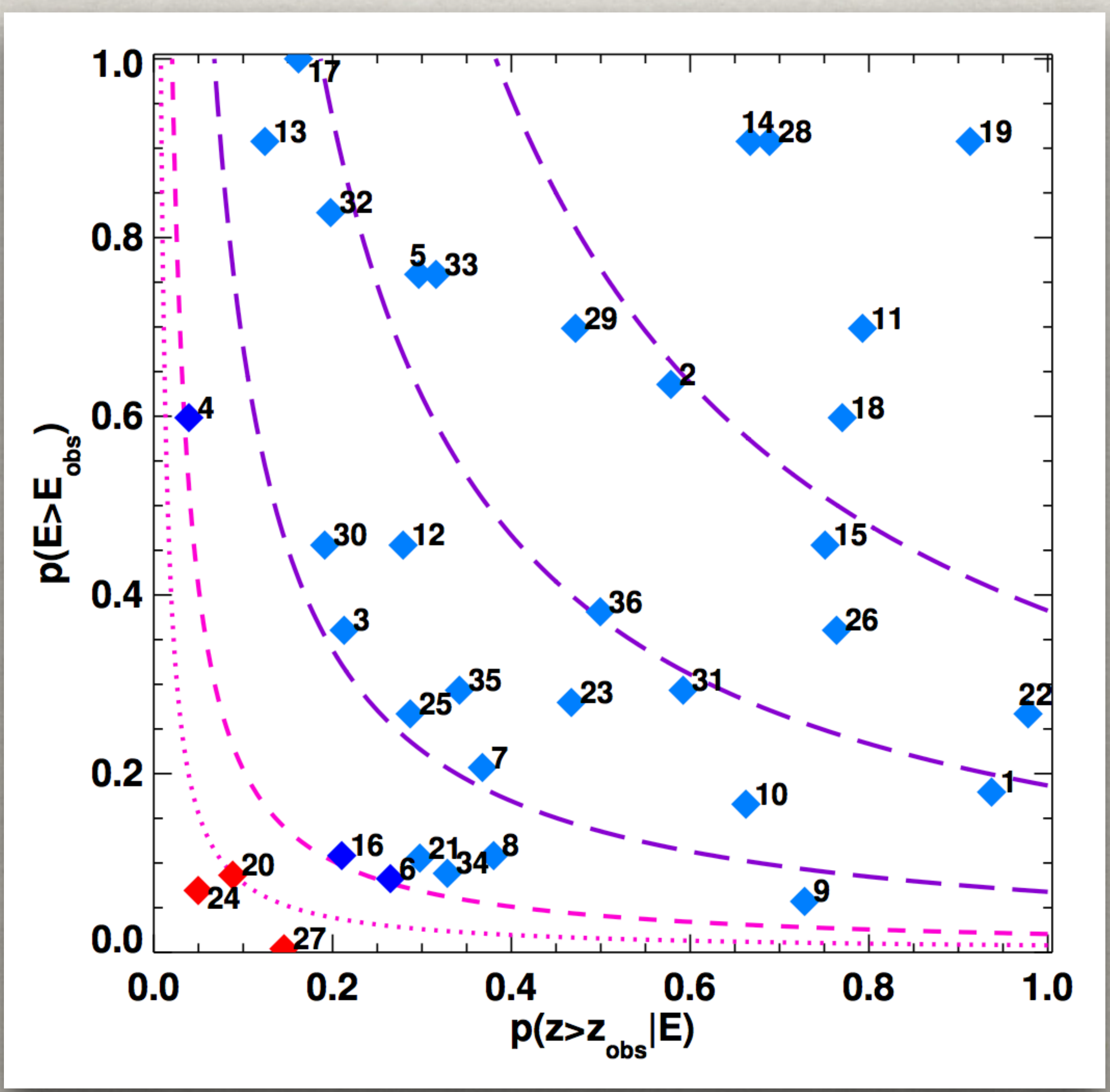
Kistler & Laha 2018

IceCube-140611



IceCube 2016

Candidate Analog Events from IceCube



Fox+18, ArXiv:1809.09615

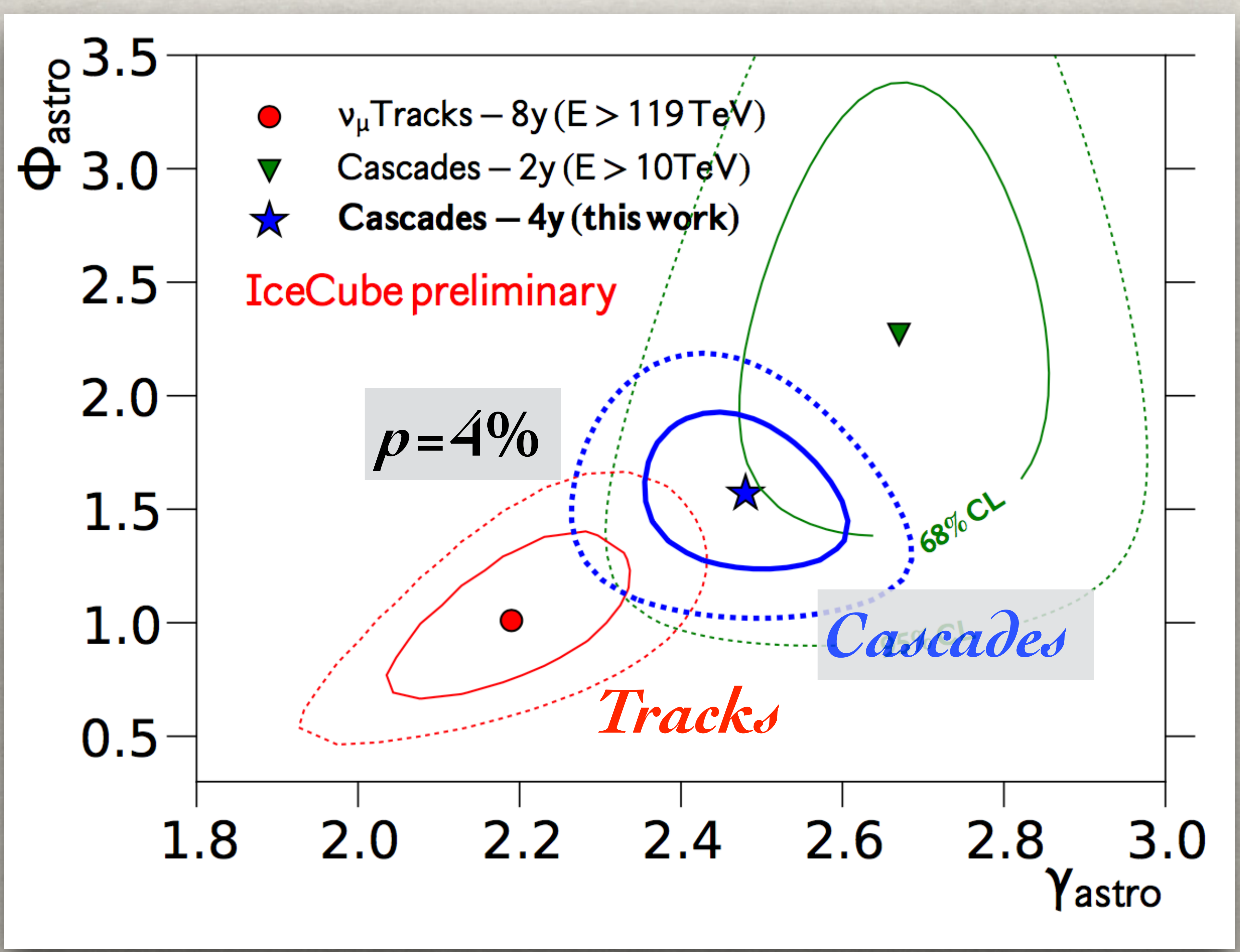
IceCube Anomalous Event Candidates

TABLE II. Properties of IceCube Anomalous Track Events

Property	**IceCube-140611**	**IceCube-140109**	**IceCube-121205**
EHE Northern Track ID	#27	#24	#20
Date & Time (UTC or MJD)	2014-06-11 04:54:24	56666.5	56266.6
Equatorial coordinates (J2000)	R.A. $110.^{\circ}34 \pm 0.^{\circ}22$,	R.A. $293.^{\circ}29$,	R.A. $169.^{\circ}61$,
	Dec. $+11.^{\circ}42 \pm 0.^{\circ}08$	Dec. $+32.^{\circ}82$	Dec. $+28.^{\circ}04$
Zenith angle z	$101.^{\circ}42$	$122.^{\circ}82$	$118.^{\circ}04$
Earth chord length ℓ	2535 km	6910 km	5990 km
As muon: $\varepsilon_{\mu,\mathrm{obs}}$ ($\varepsilon_{\mathrm{proxy}}$)	4.45 PeV	0.85 PeV	0.75 PeV
ε_{ν} (median)	8.7 PeV	1.65 PeV	1.45 PeV
Mean interaction length for ε_{ν}	1960 km	3280 km	3690 km
$p(\varepsilon > \varepsilon_{\mathrm{obs}})$	4.0×10^{-3}	6.9×10^{-2}	8.6×10^{-2}
$p(z > z_{\mathrm{obs}} \mid \varepsilon)$	1.5×10^{-1}	5.0×10^{-2}	8.8×10^{-2}
p_{joint}	4.9×10^{-3}	2.3×10^{-2}	4.5×10^{-2}
As tau: $\varepsilon_{\tau,\mathrm{obs}}$ (median)	70 PeV	13 PeV	12 PeV
Mean interaction length for $\varepsilon_{\nu} = 1\,\mathrm{EeV}$	340 km	270 km	285 km
$p_{\mathrm{SM}}(\varepsilon_{\tau} > \varepsilon_{\tau,\mathrm{obs}})$ for $\varepsilon_{\nu} = 1\,\mathrm{EeV}$	2.2×10^{-4}	3.8×10^{-6}	1.0×10^{-5}
$p_{\mathrm{SM}}(z > z_{\mathrm{obs}})$ for $\varepsilon_{\nu} = 1\,\mathrm{EeV}$, $\varepsilon_{\tau} > \varepsilon_{\tau,\mathrm{obs}}$	5.0×10^{-3}	4.5×10^{-5}	1.8×10^{-4}

Fox+18, ArXiv:1809.09615

Cascades v. Tracks



IceCube 2018

Theoretical Precedents

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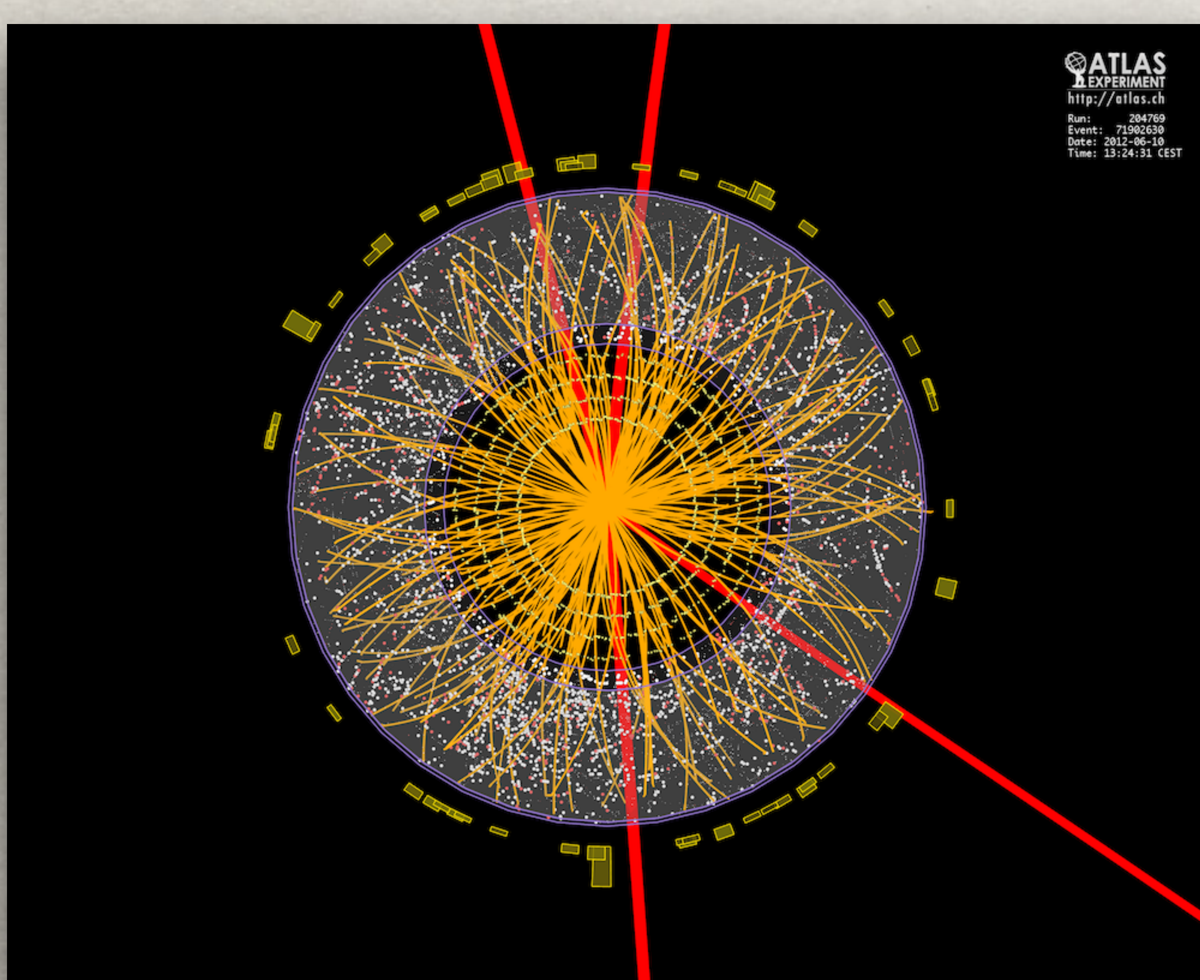
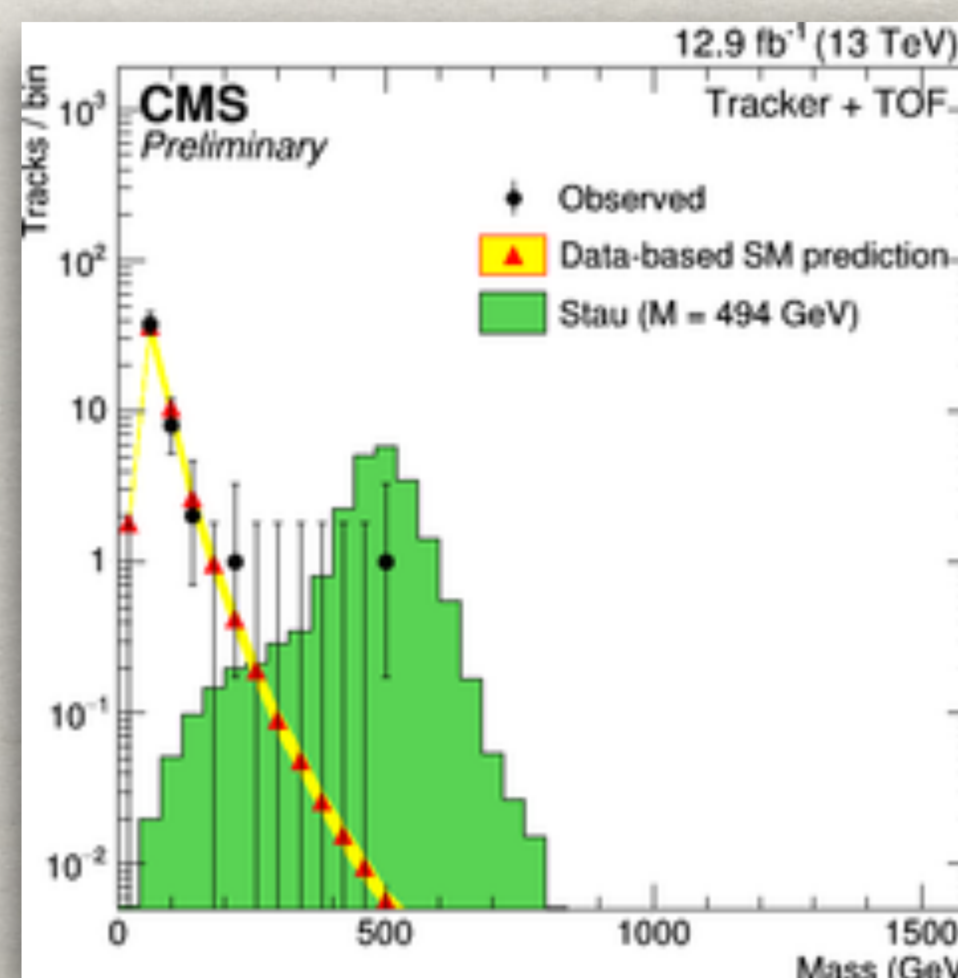
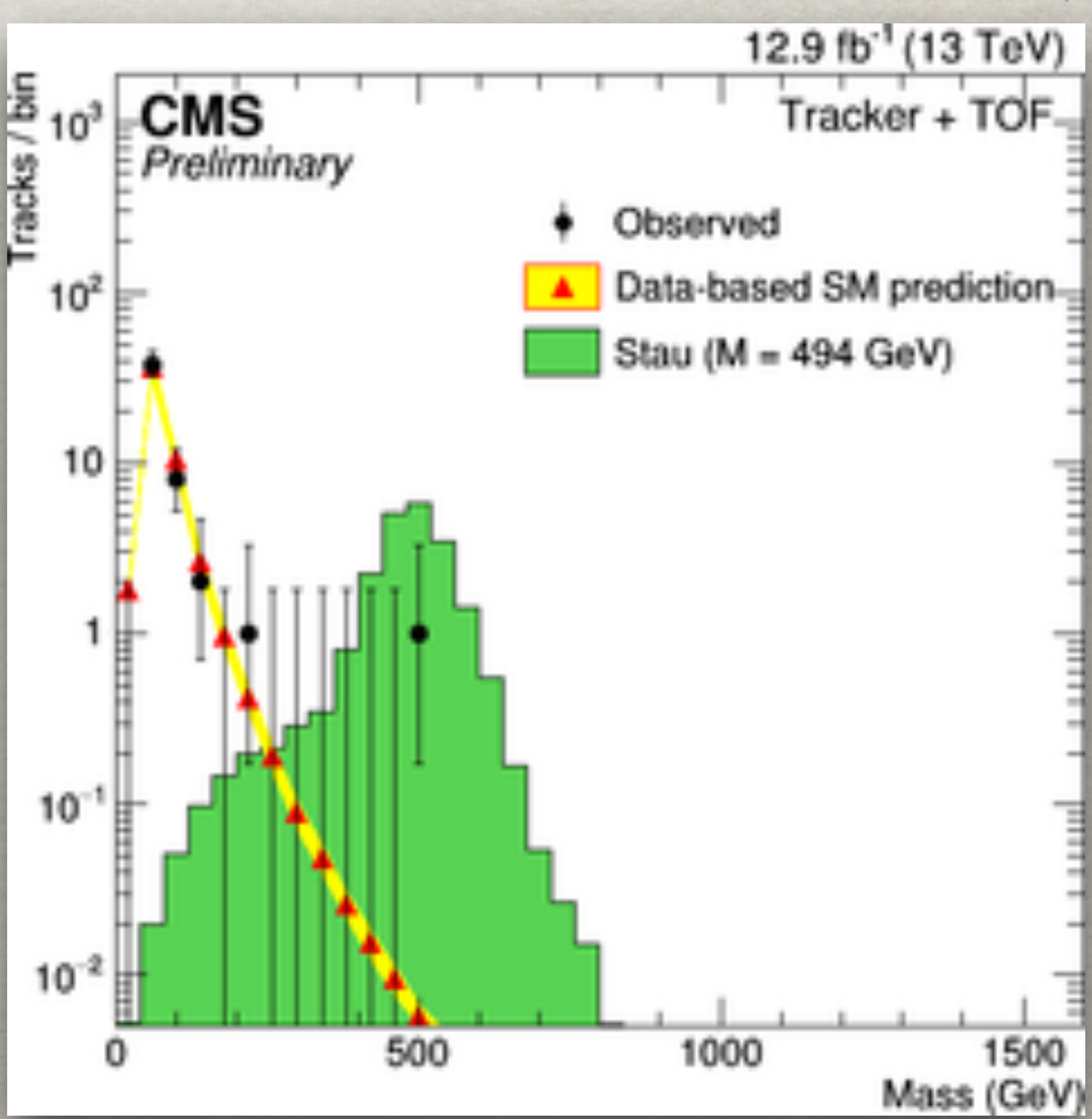
4. AAEs and LHC LLPs





CMS 2016

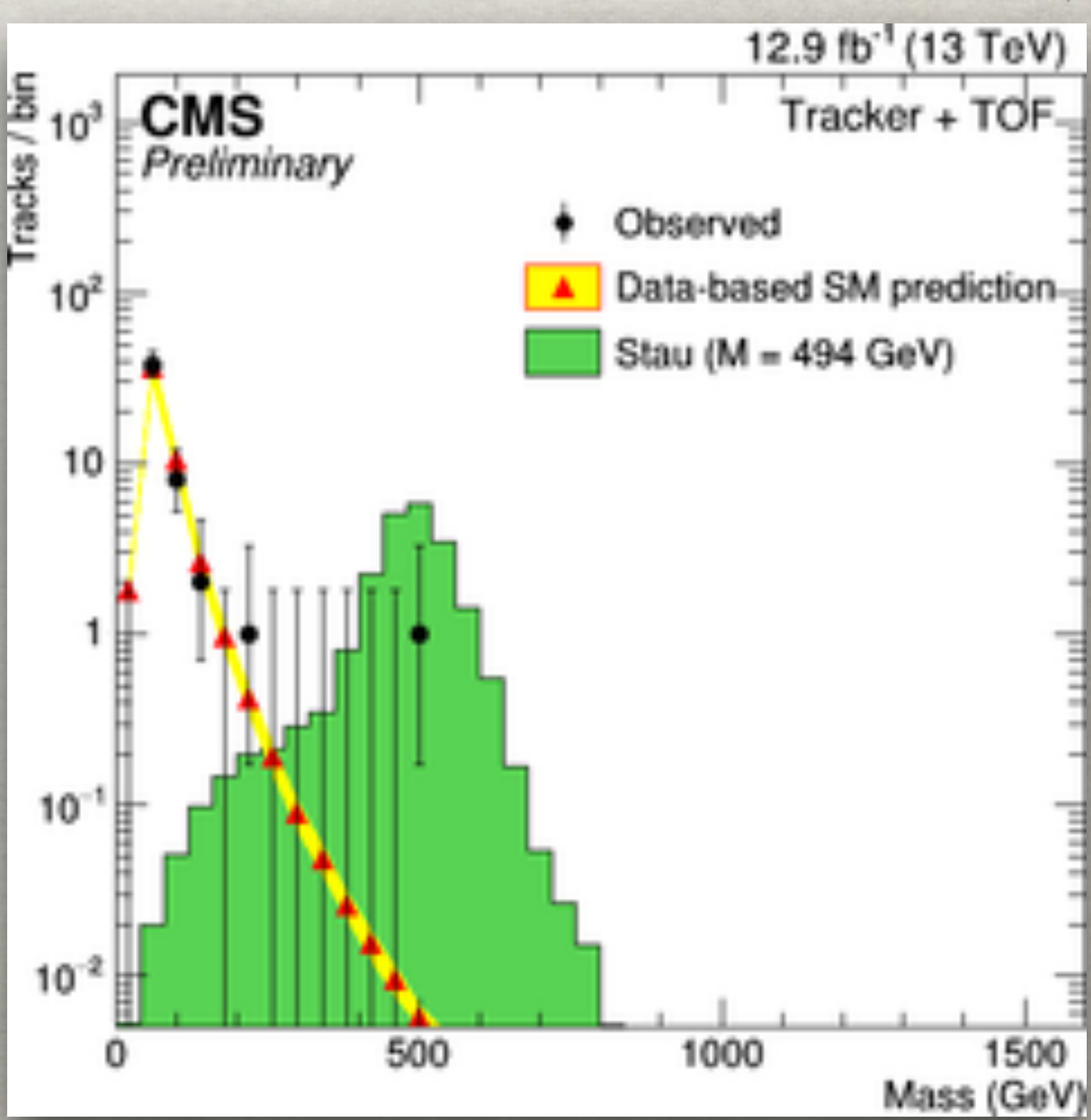
AAEs and LHC LLPs



CMS 2016

AAEs and LHC LLPs

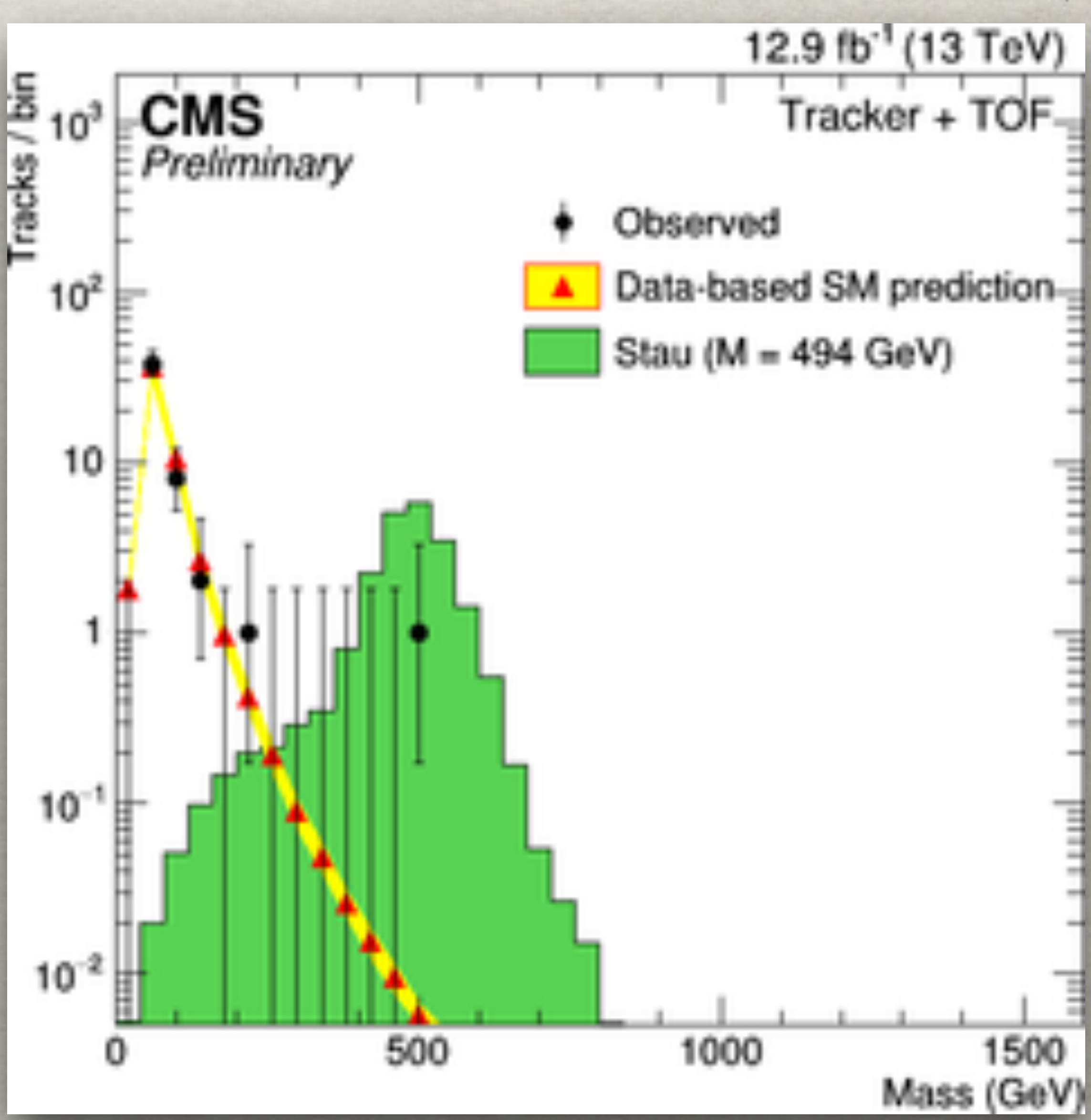
- CMS search for heavy stable charged particles with 12.9 fb^{-1} of 2016 data



CMS 2016

AAEs and LHC LLPs

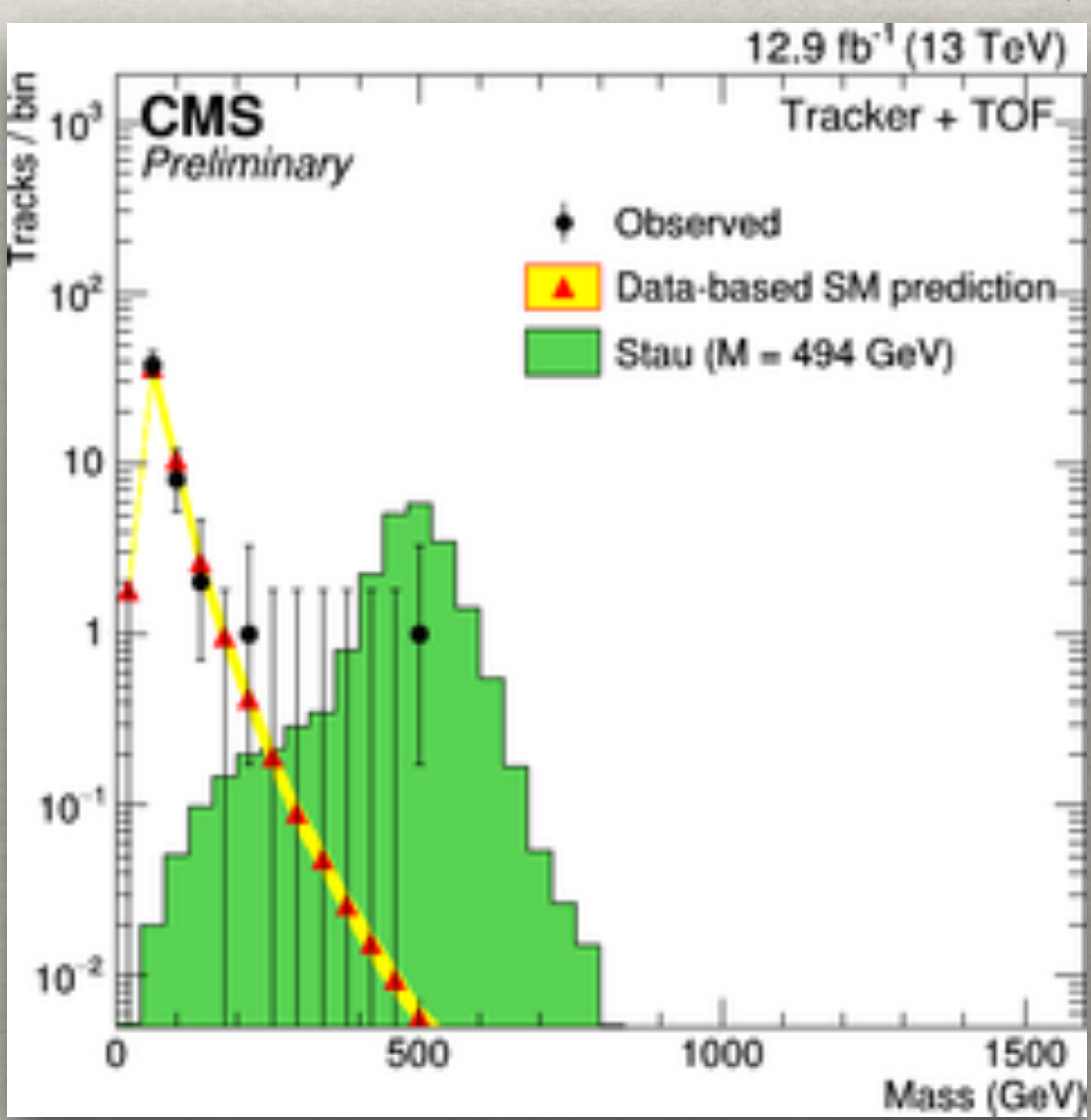
- CMS search for heavy stable charged particles with 12.9 fb^{-1} of 2016 data
- "One event with mass 510 ± 160 GeV is found in the tracker + TOF analysis."



CMS 2016

AAEs and LHC LLPs

- CMS search for heavy stable charged particles with 12.9 fb^{-1} of 2016 data
- "One event with mass 510 ± 160 GeV is found in the tracker + TOF analysis."
- Please keep doing what you're doing!



CMS 2016

Anita Anomalous Events & LHC LLPs

- ANITA has observed two anomalous events in flight over Antarctica
- Interpreted as Sub-EeV Earth-emergent Cosmic Rays (SEECRs), these require the existence of a long-lived BSM particle
- Independent support for SEECR hypothesis from IceCube
- Theoretical precedents point to SUSY NLSP "stau"
  - Relatively long lifetime
  - Decays to tau lepton + LSP
  - Intermediate cross section (?) allowing *both* production in UHE neutrino interactions *and* deep penetration through Earth
  - Potential support from CMS?
- Confirmation of SEECR phenomena may be possible with existing archival data from IceCube and Pierre Auger Observatories

Questions

- Can we talk about the 510 ± 160 GeV CMS event? What are the SM backgrounds?
- Can we have updated cross sections and lifetimes incorporating known constraints on Stau as well as associated LSP(s)
- Especially interested in SUSY scenarios that generate Dark Matter in proper abundance, e.g. SuperWIMP scenarios (let us avoid closing the Universe with overmassive gravitino)
- With proper inputs (ranges of inputs) we can test these models against ANITA and IceCube data today!
- (And explore a surprising window onto UHE neutrino sky!)

FAQs

- What if ANITA events aren't real?
  - 4 years since first publication
  - Not instrumental – definitely at least atmospheric
  - RFI seems wildly unlikely
  - Hypothetical "double bounce" events never seen from pulser
- How can we confirm the SEECR interpretation?
  - IceCube particle mass diagnostics
  - Pierre Auger fluorescence detector data
  - Other?

The End