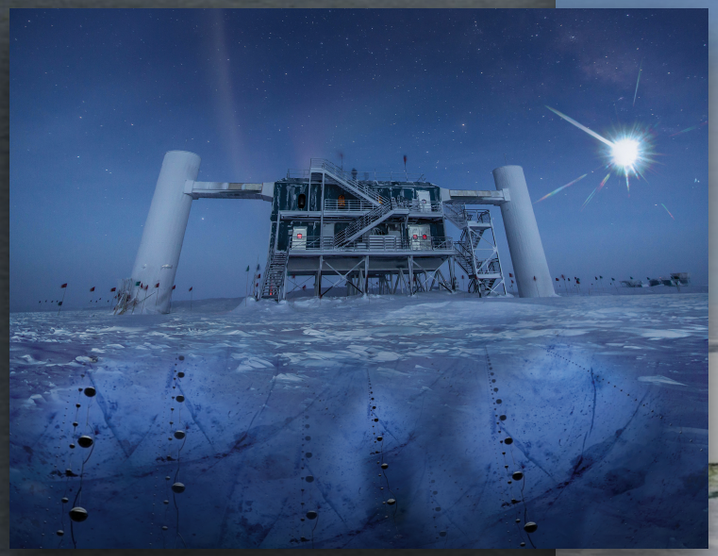
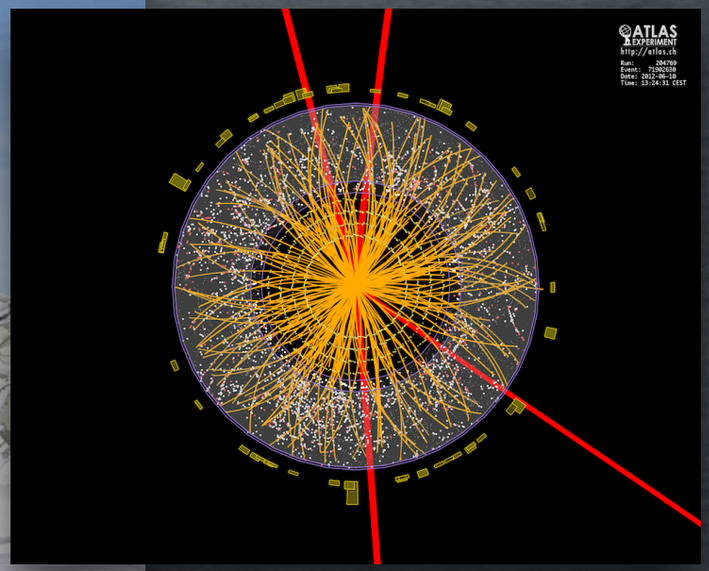
Breaking the Standard Model with High-Energy Neutrino Observatories





Derek B. Fox
Penn State University

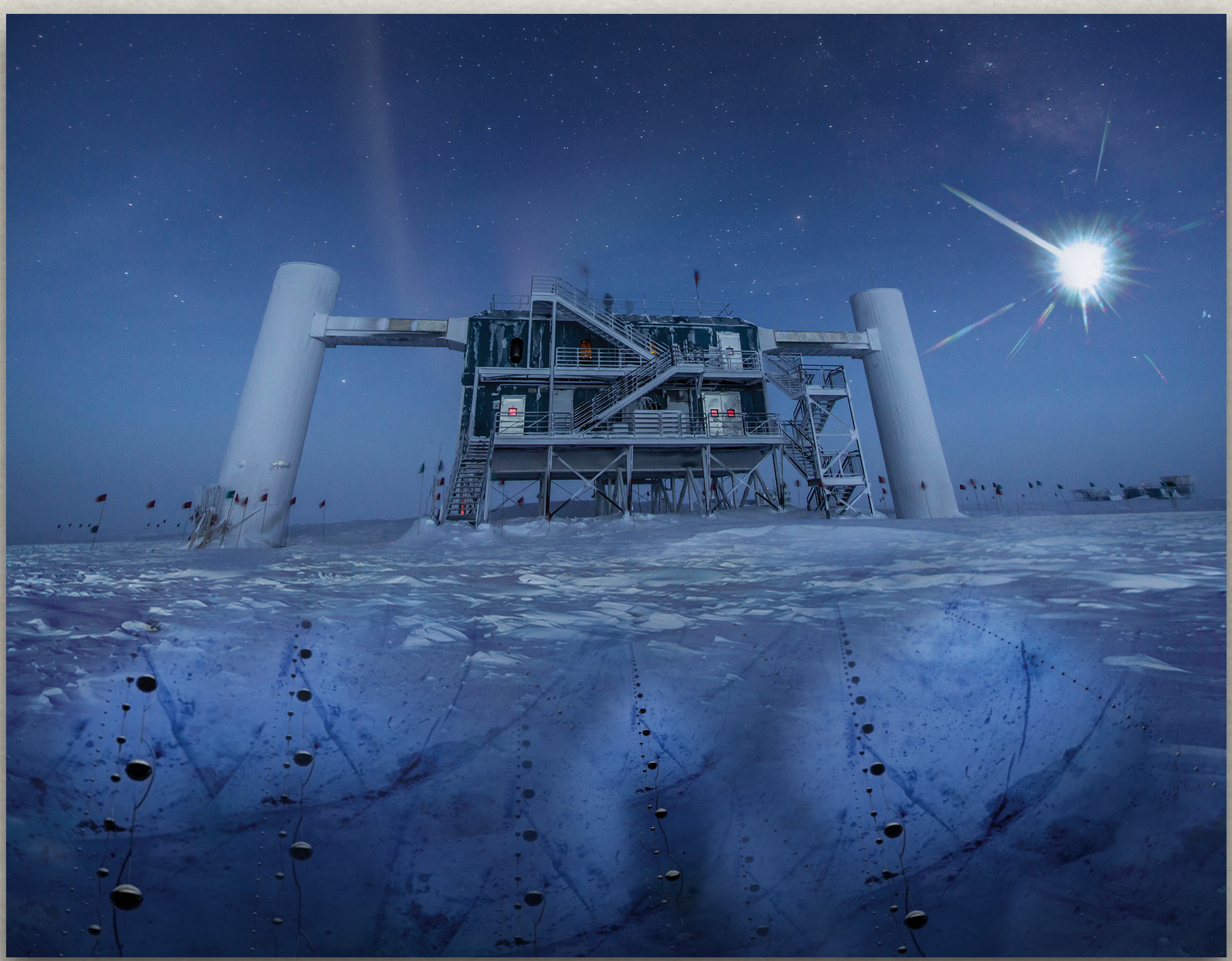
ArXiv:1809.09615

SLAC Experimental Physics Seminar
22 January 2019

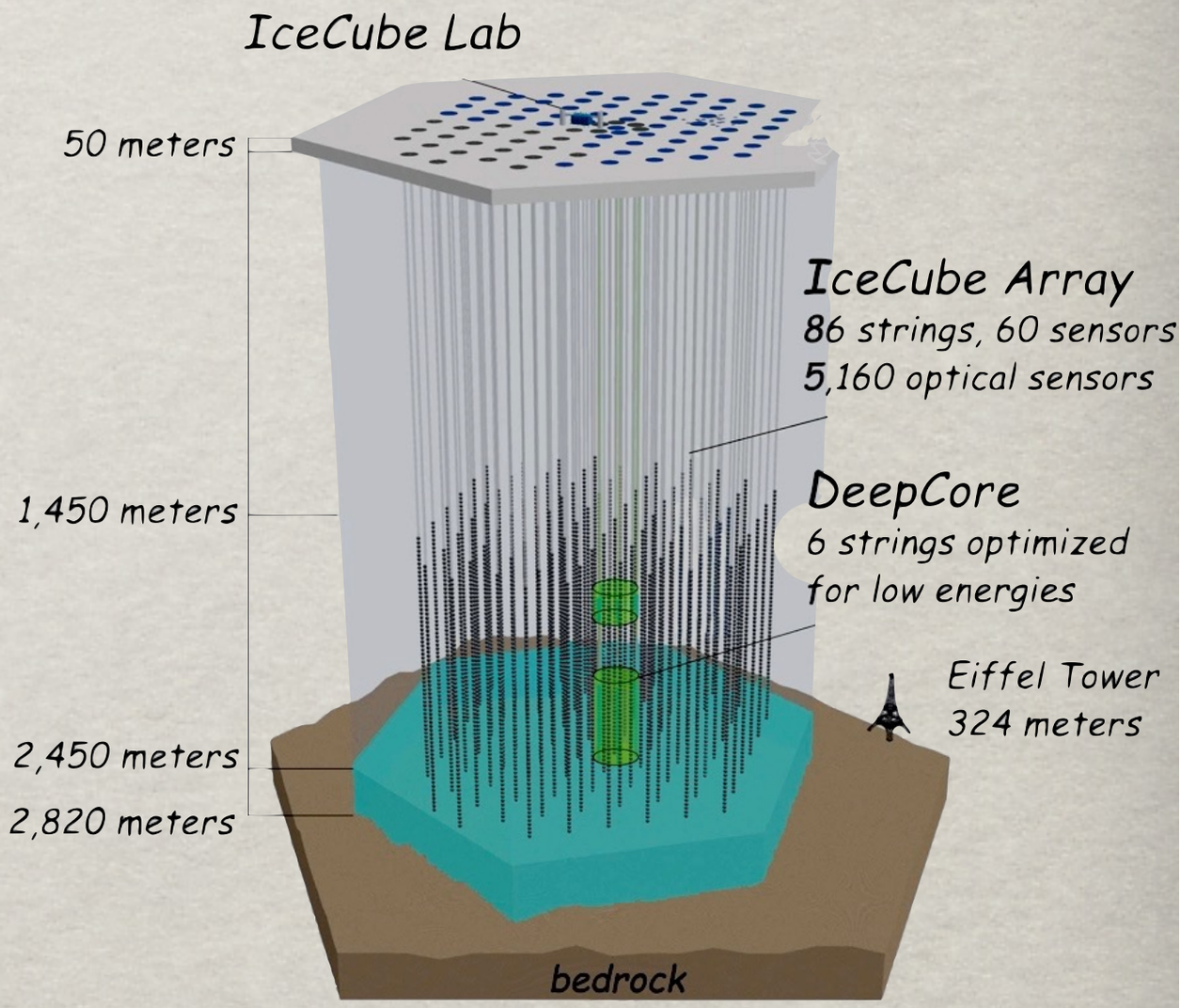
Breaking the Standard Model with High-Energy Neutrino Observatories

1. High-Energy Neutrinos from the Cosmos
2. ANITA Anomalous Events
3. The Pieces of the Puzzle
4. What Lies Ahead

1. High-Energy Neutrinos from the Cosmos



IceCube Neutrino Observatory



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- High-energy neutrinos,
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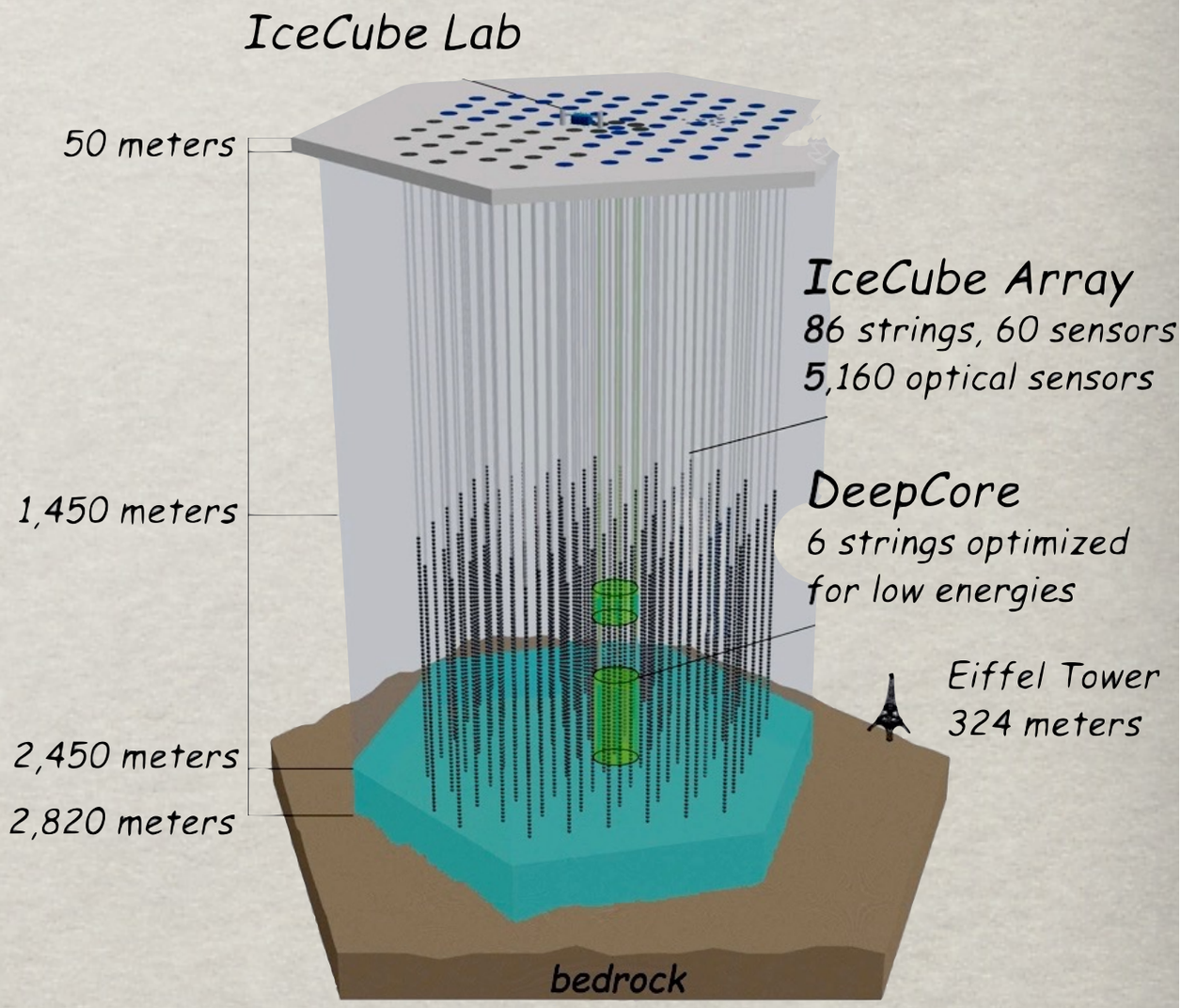

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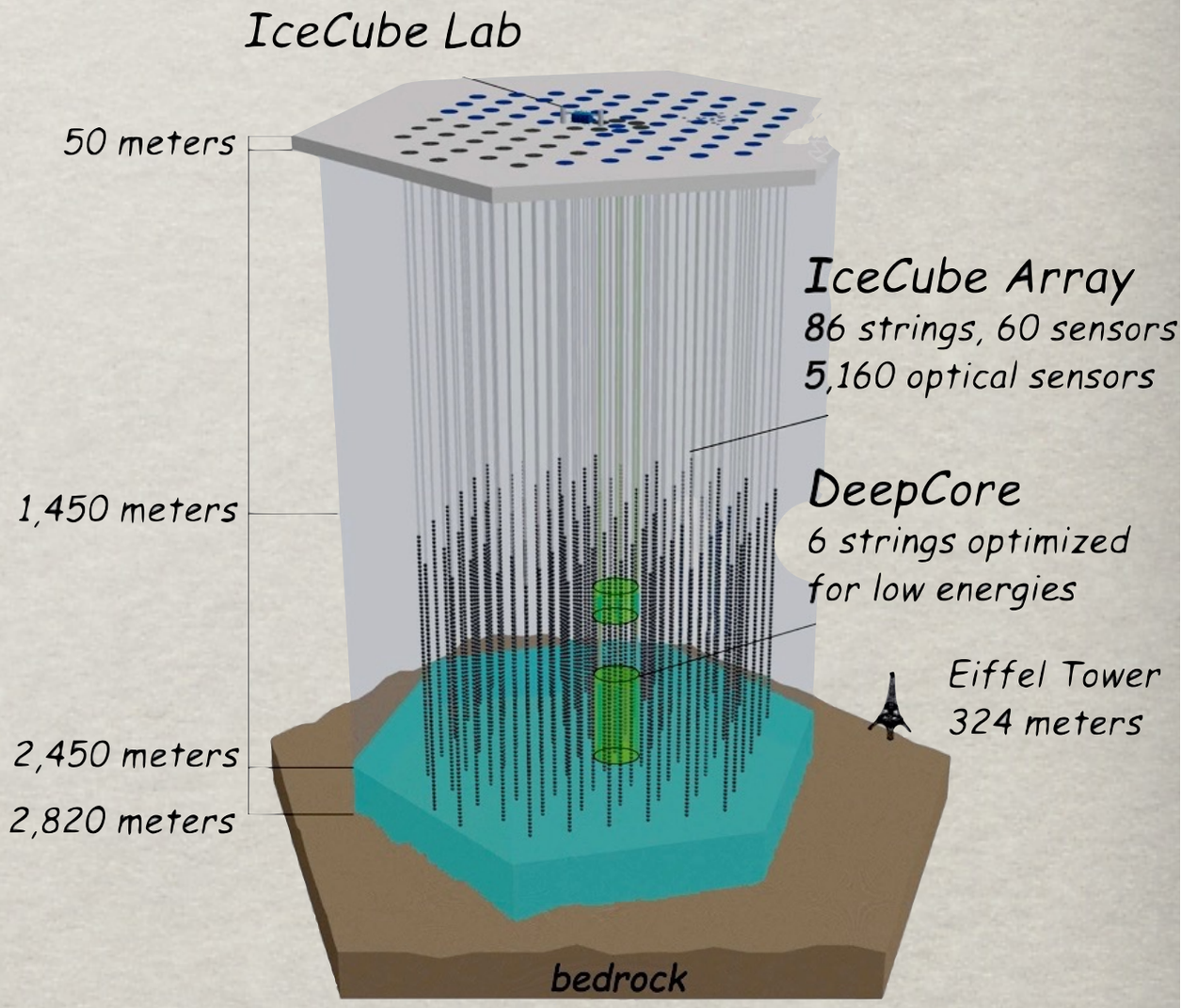

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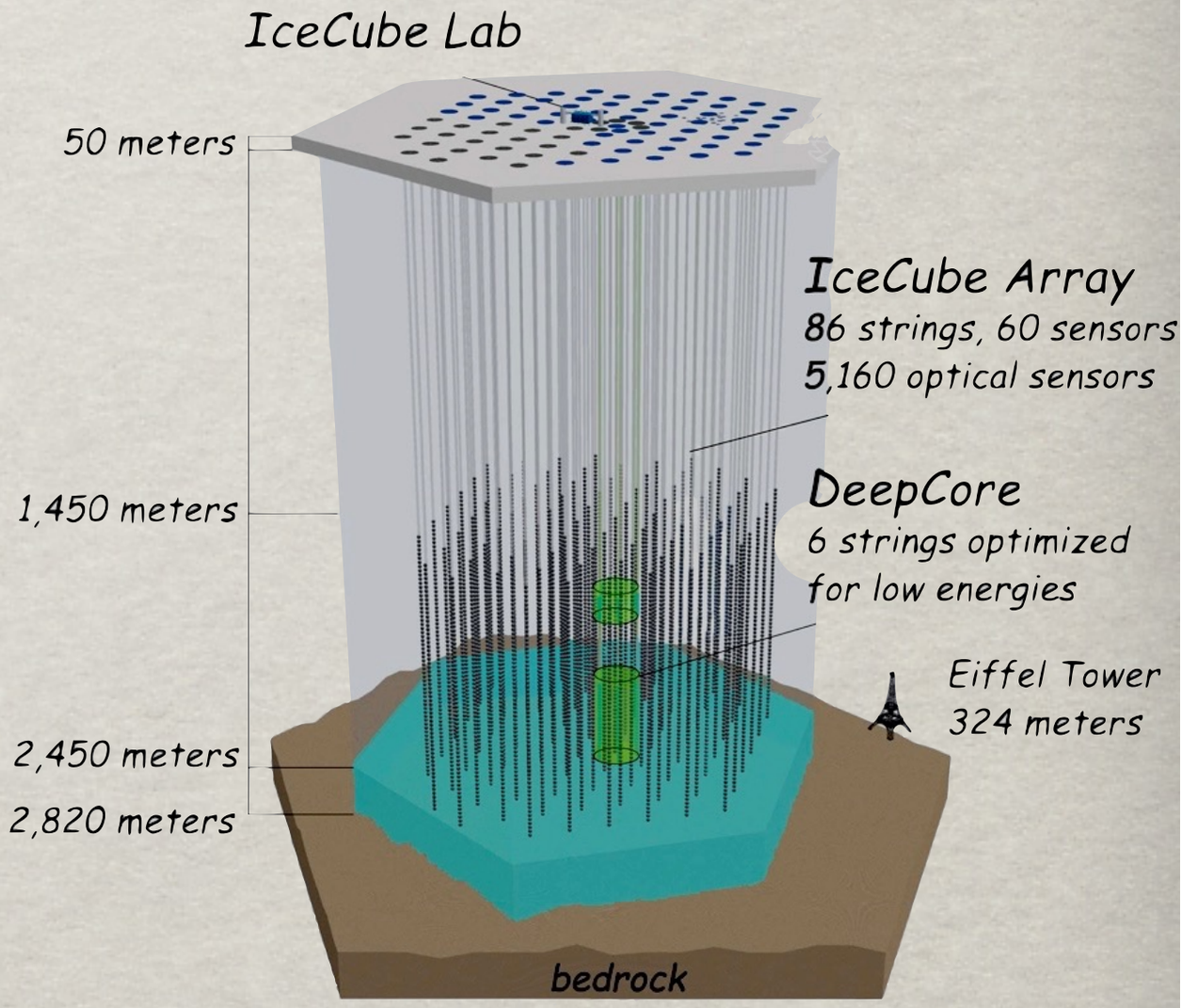

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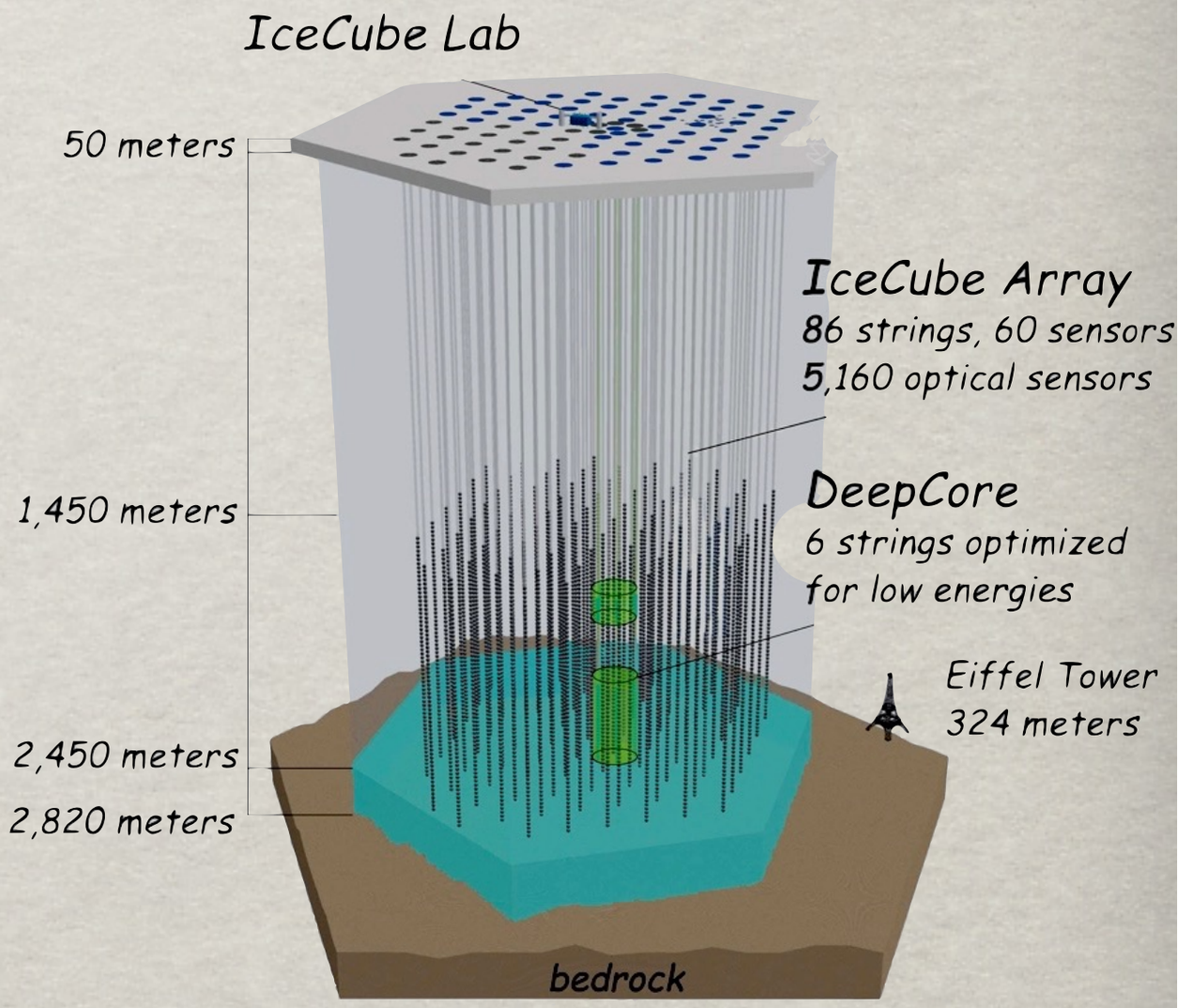

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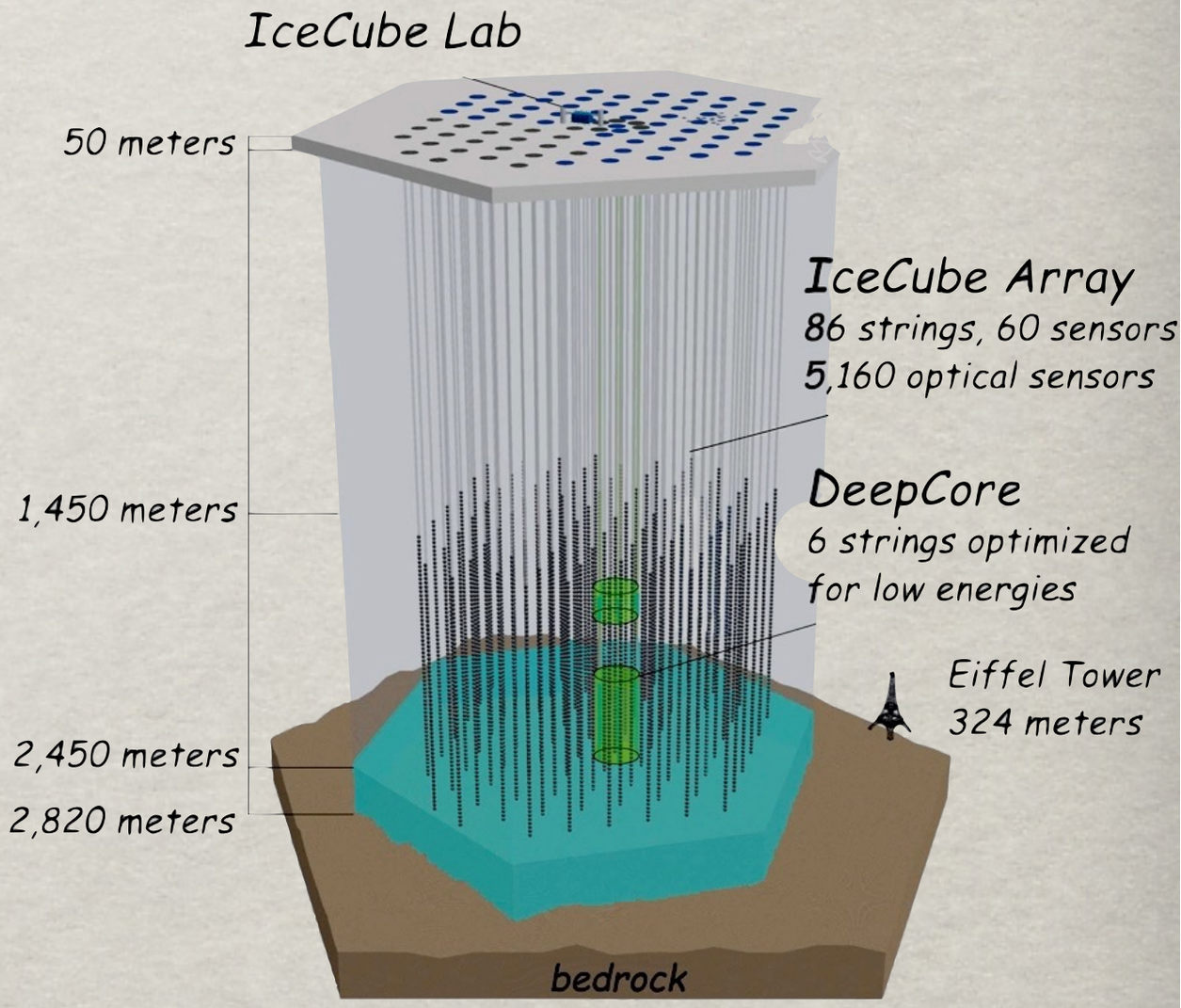
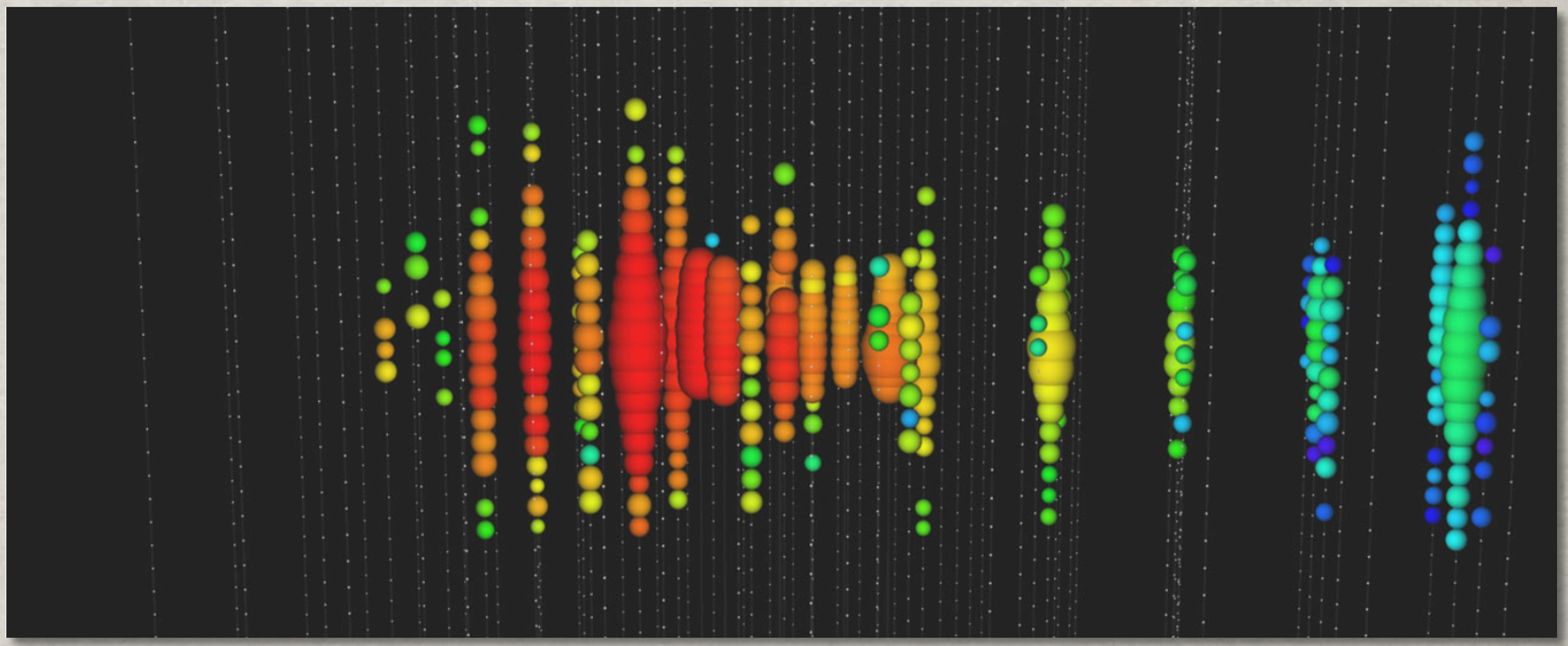
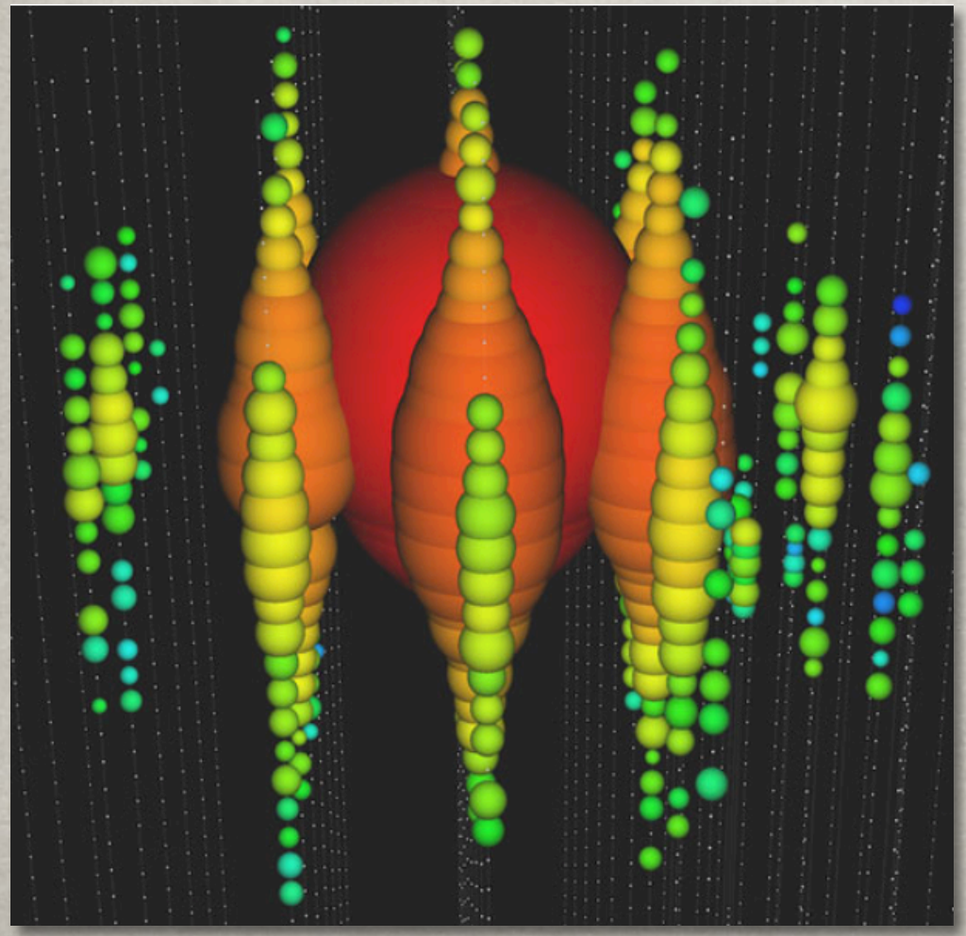
- Tracks (c.c. muon/tau, ~deg) and Cascades (other, >15 deg)



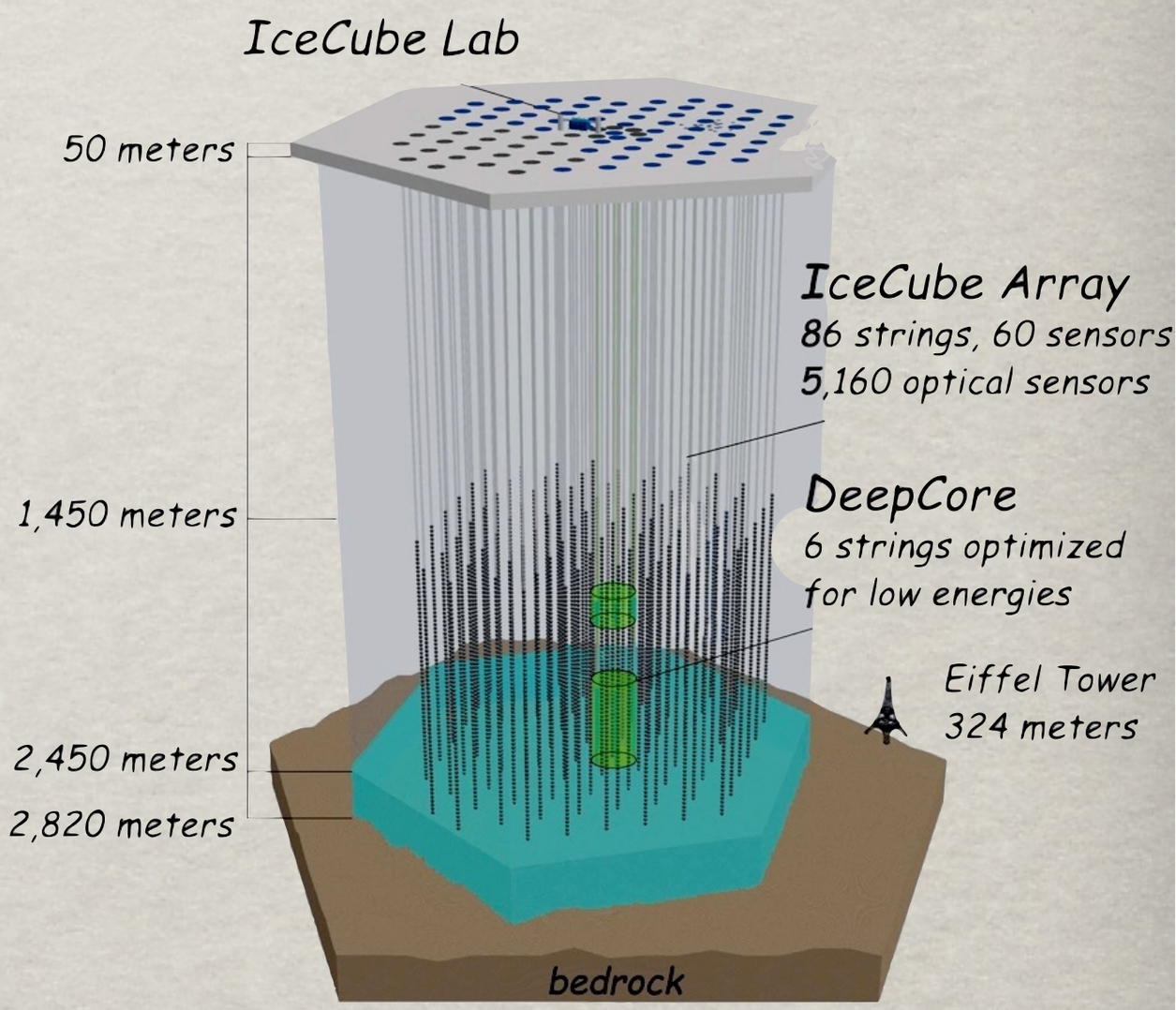
Track ~1°





Cascade ~15°

Neutrino Astronomy



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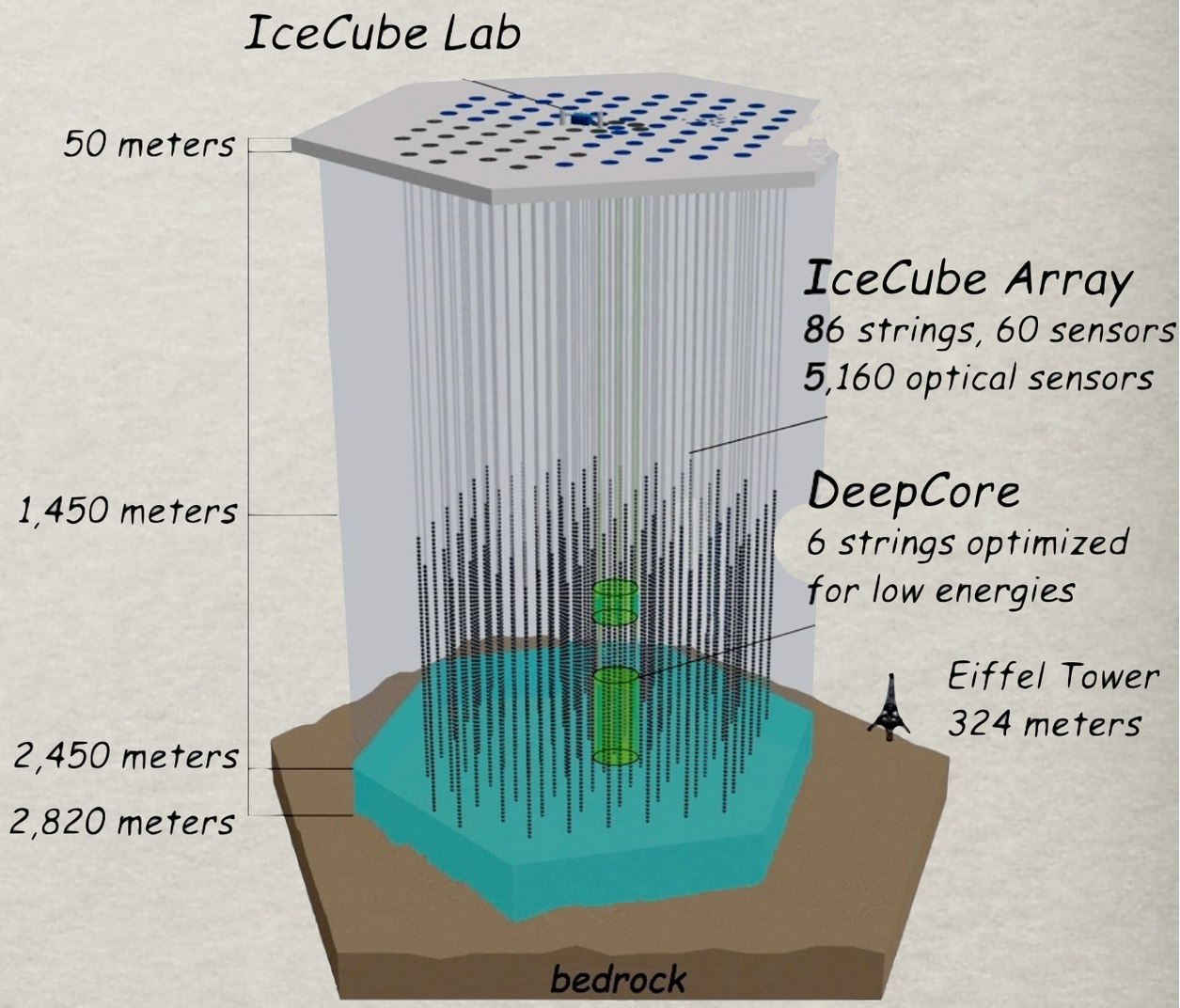

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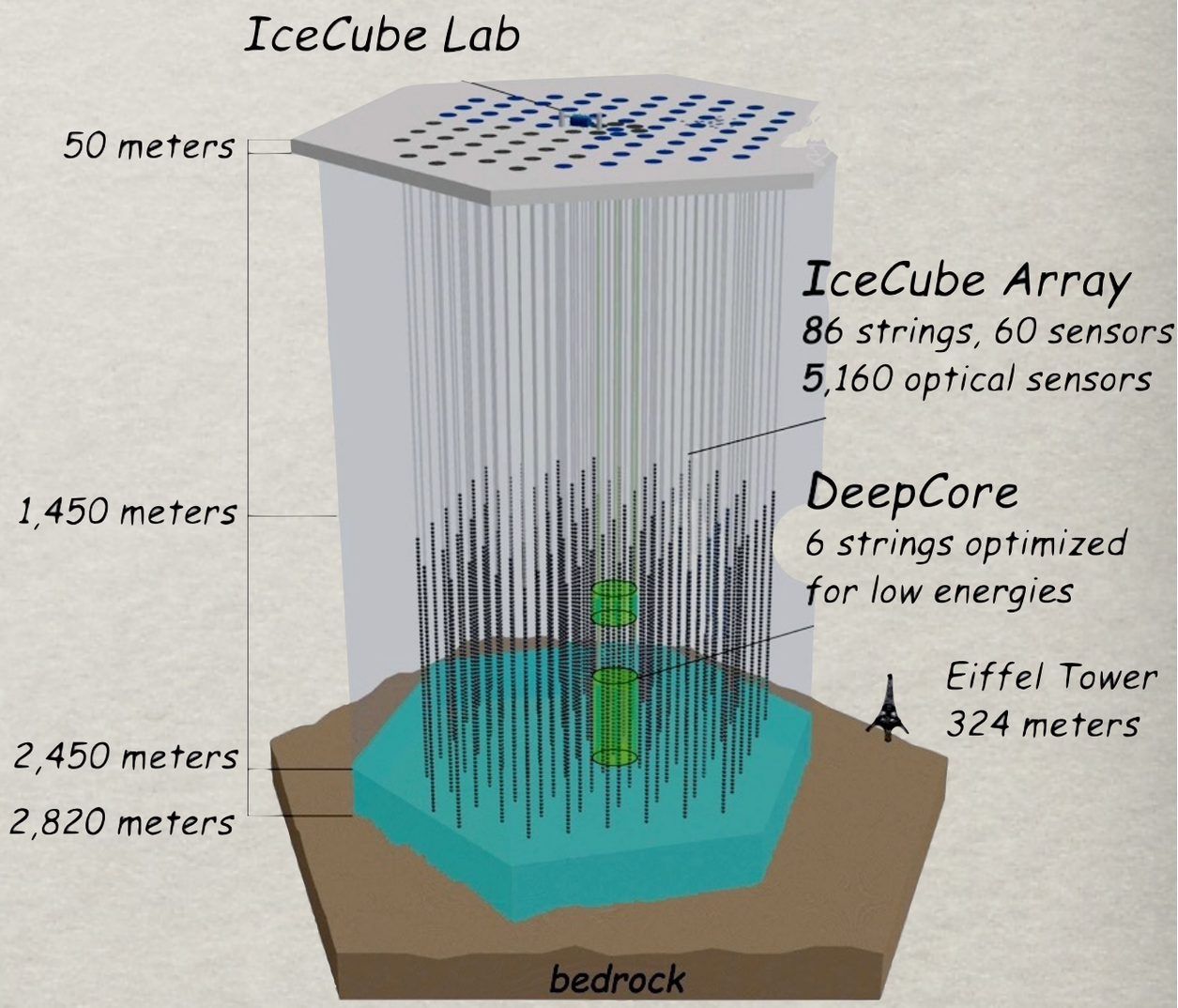

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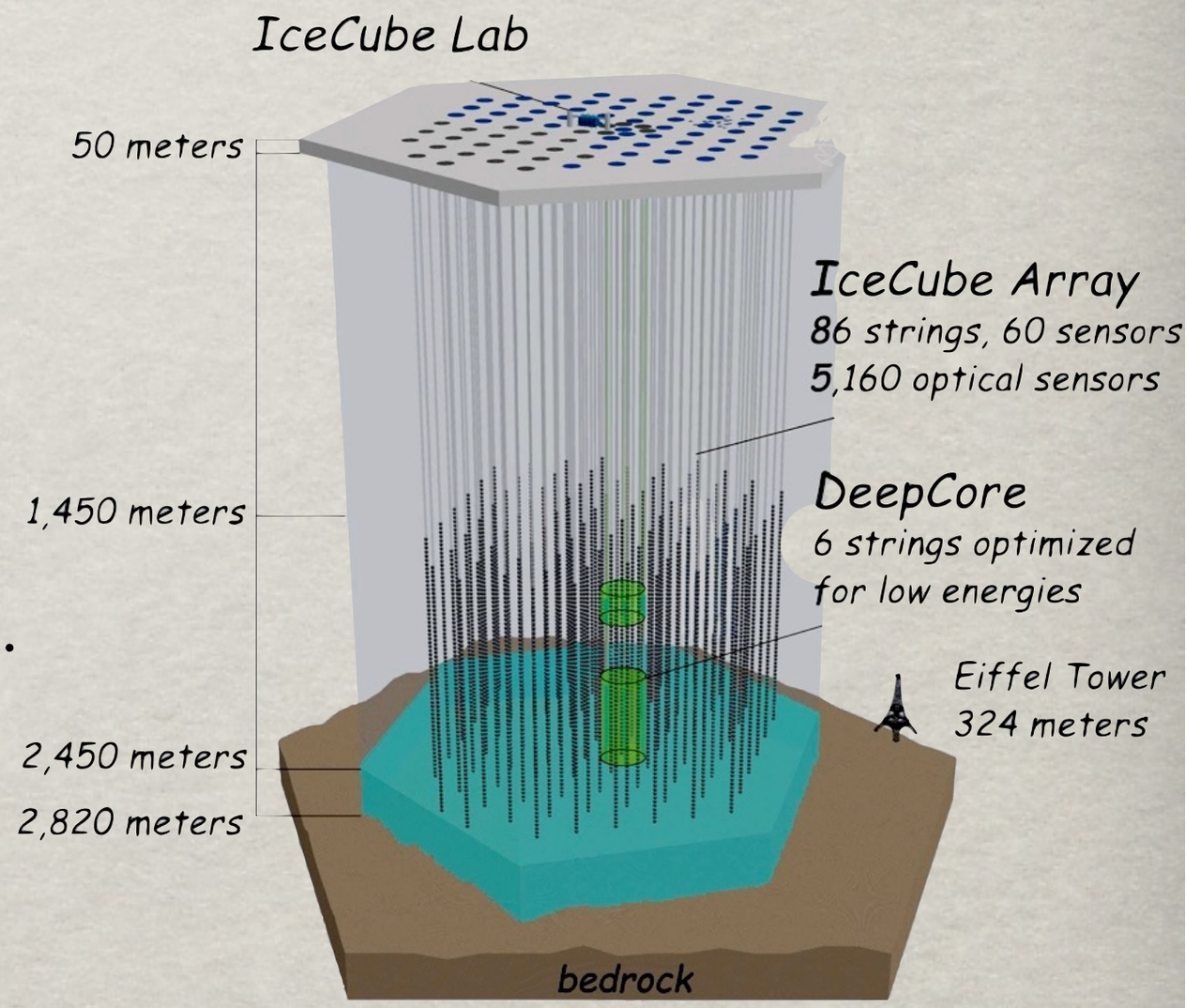

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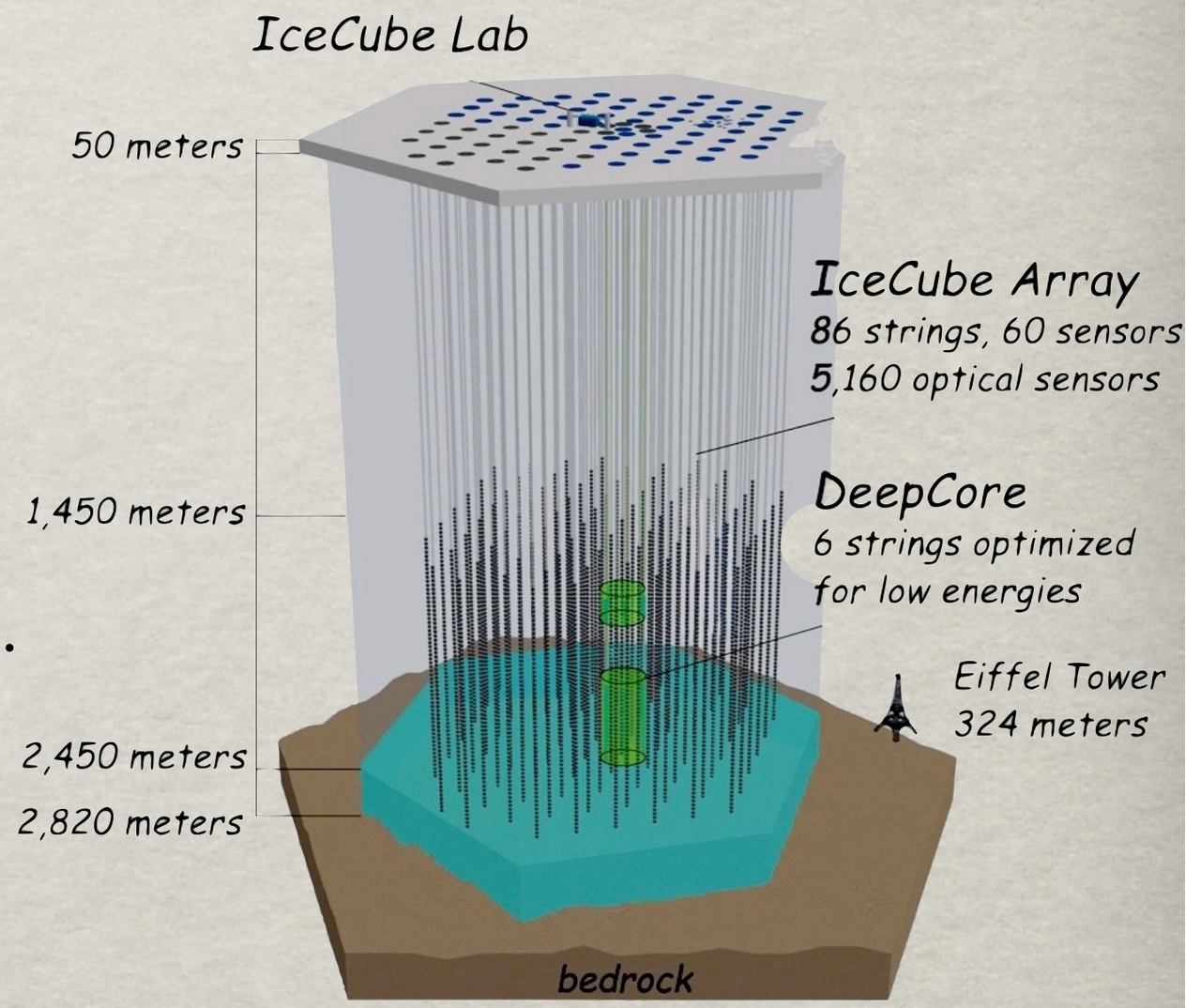

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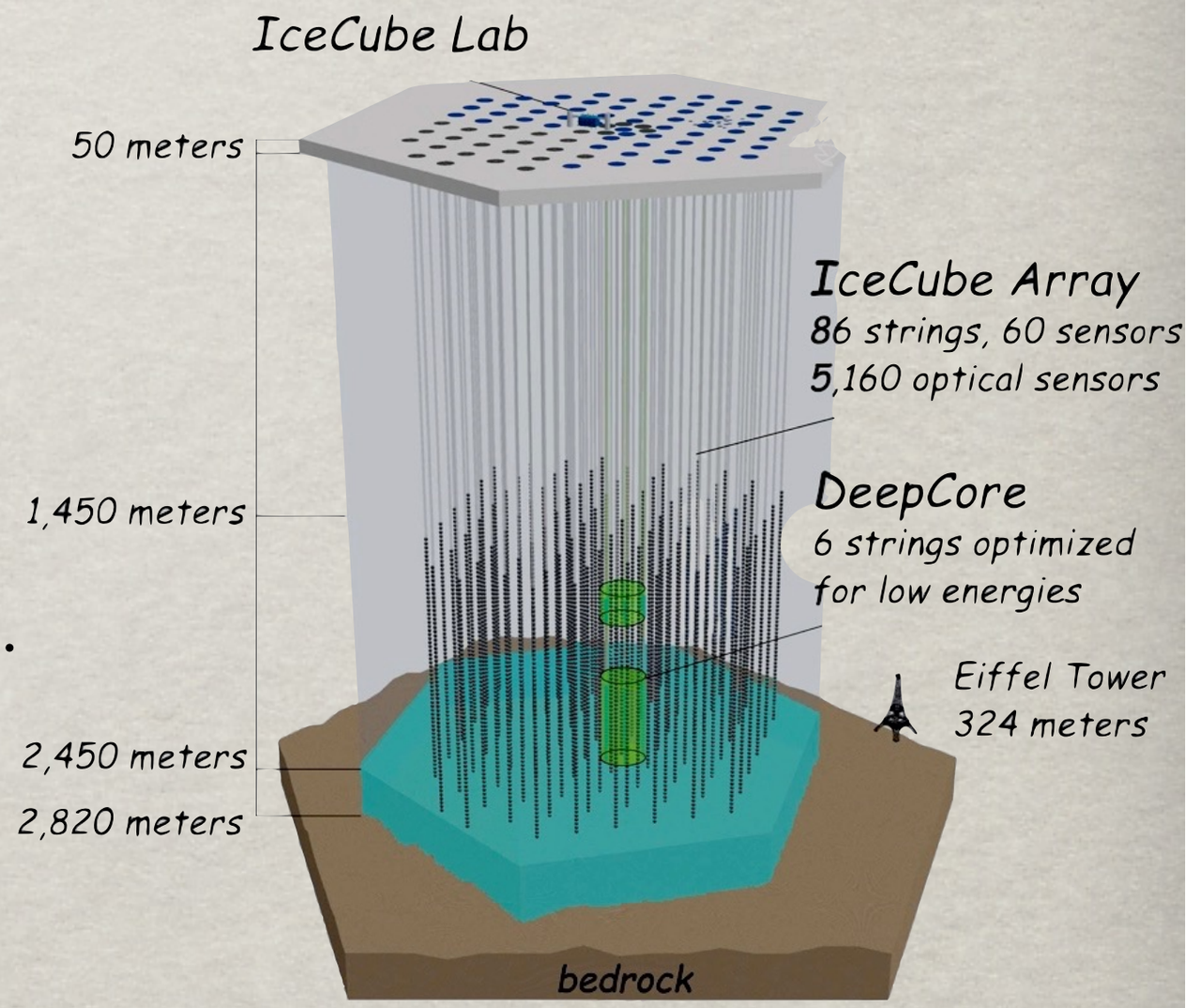

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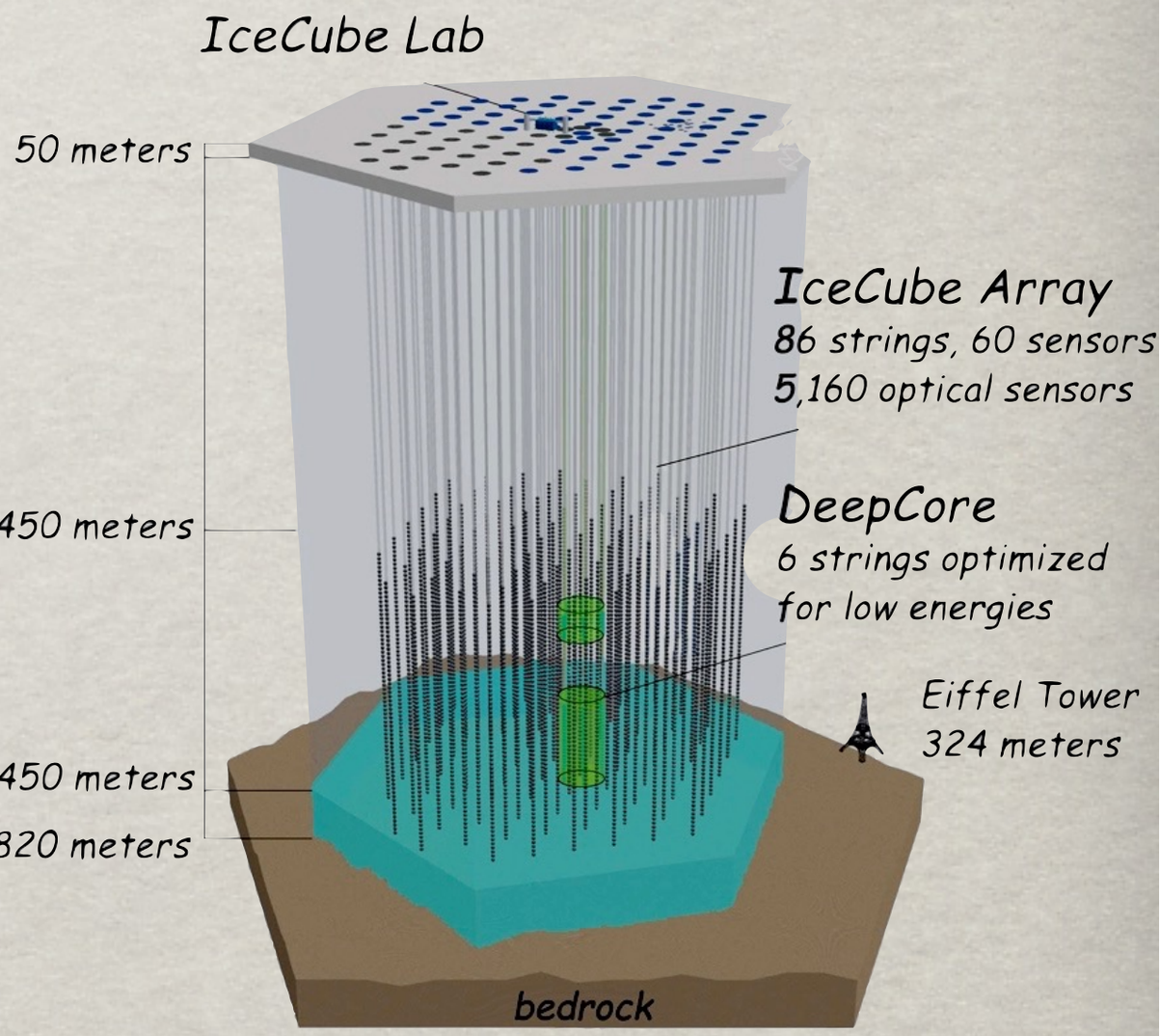

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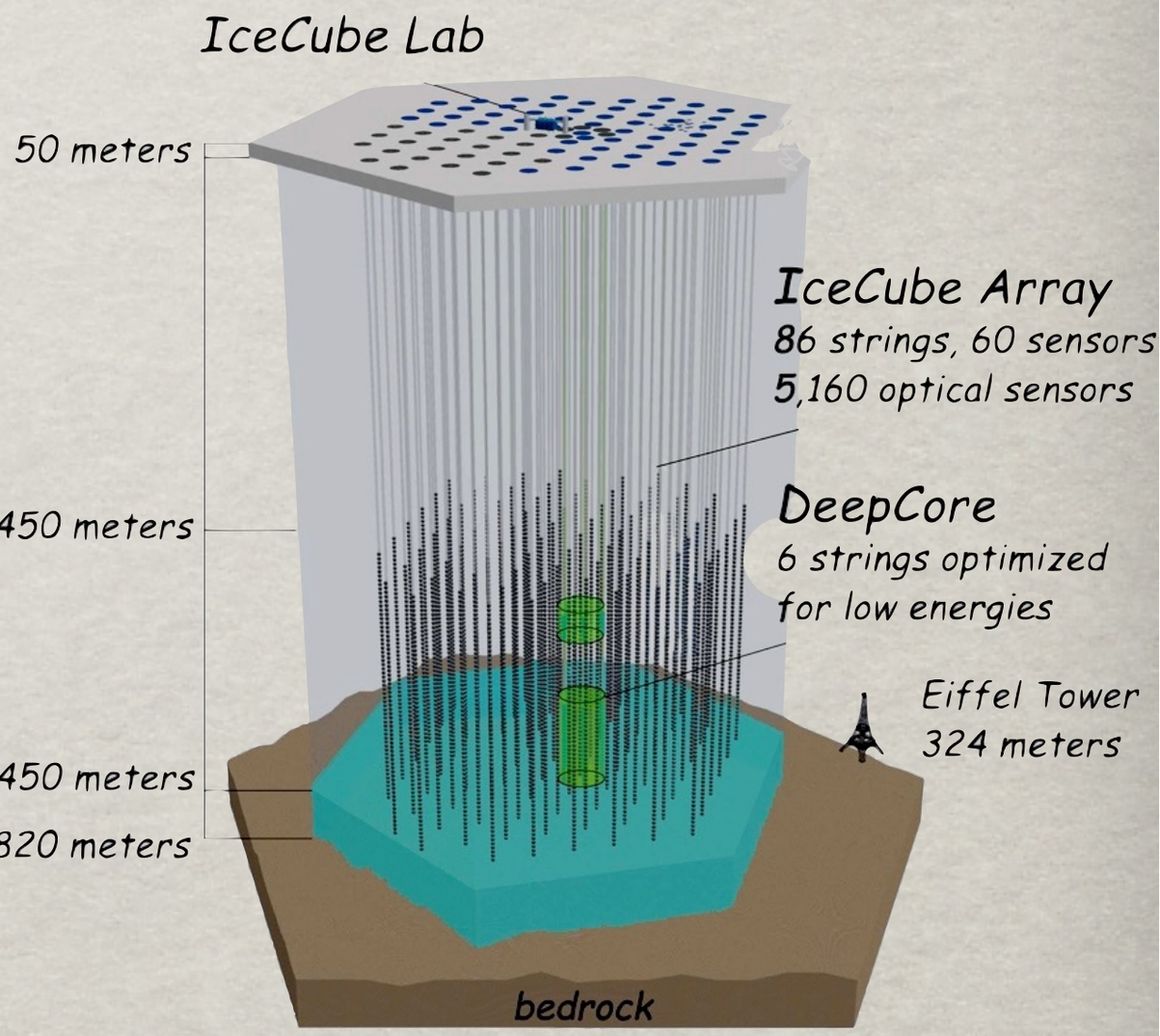

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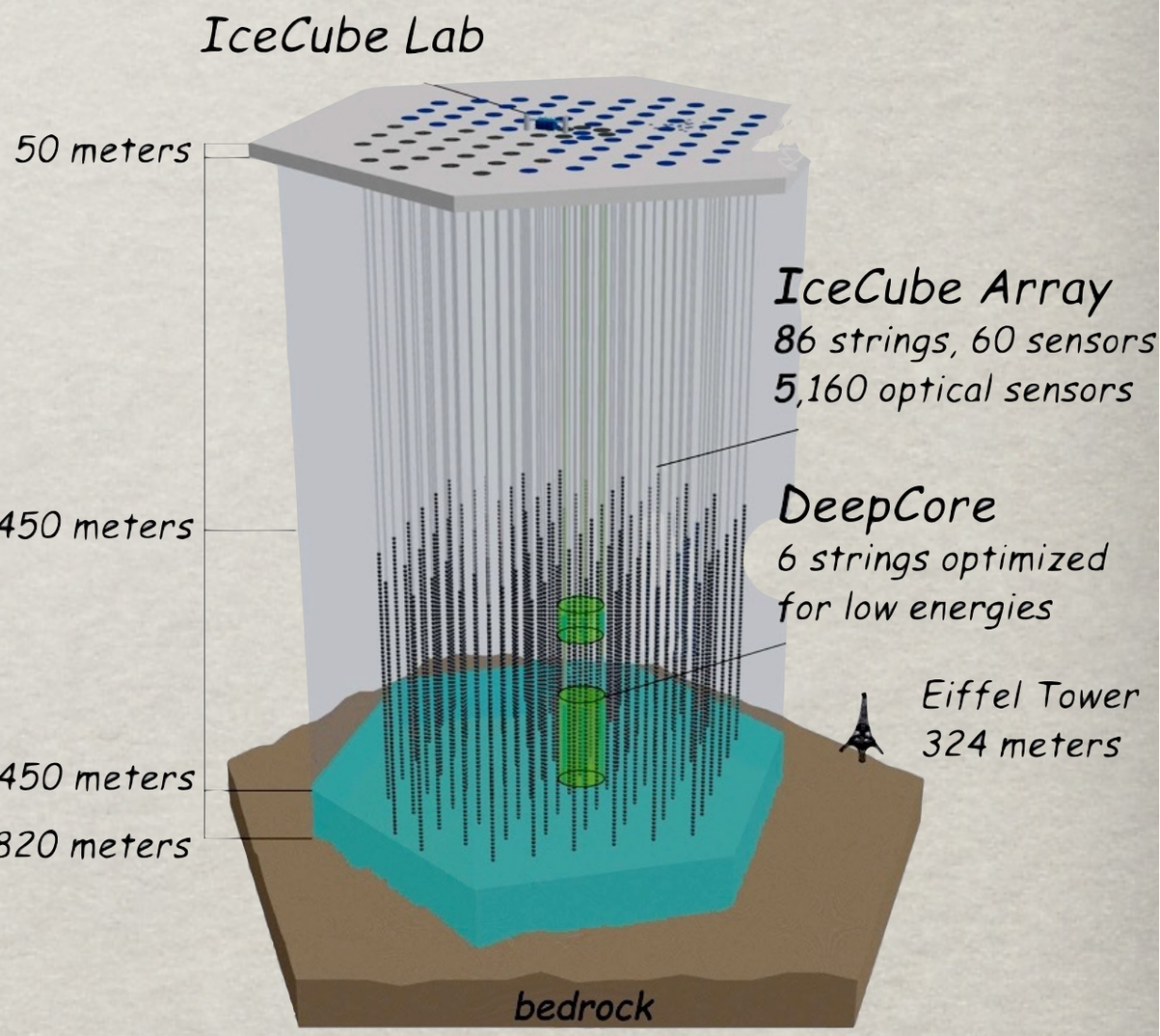

IceCube's High-Energy Cosmic Neutrinos

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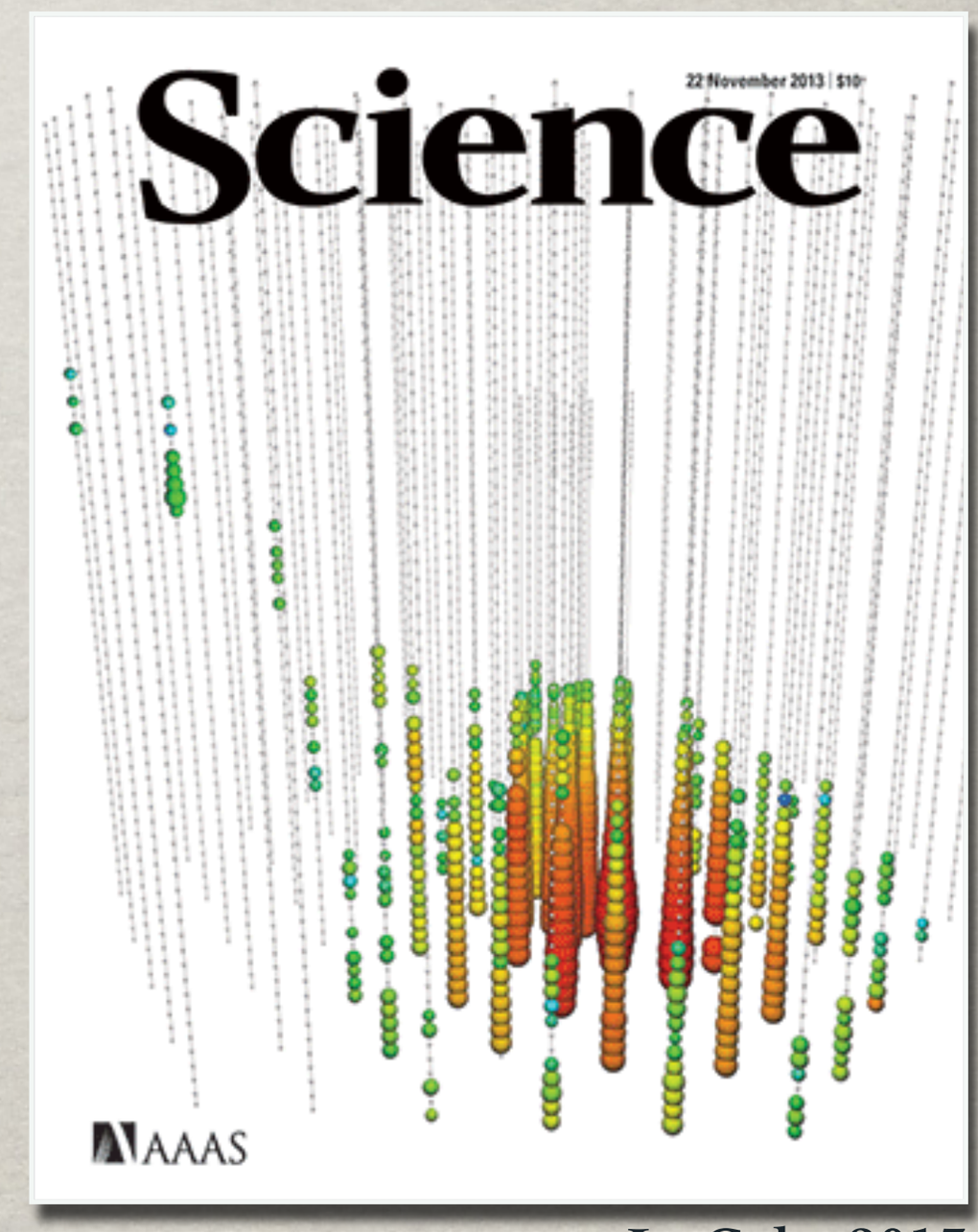

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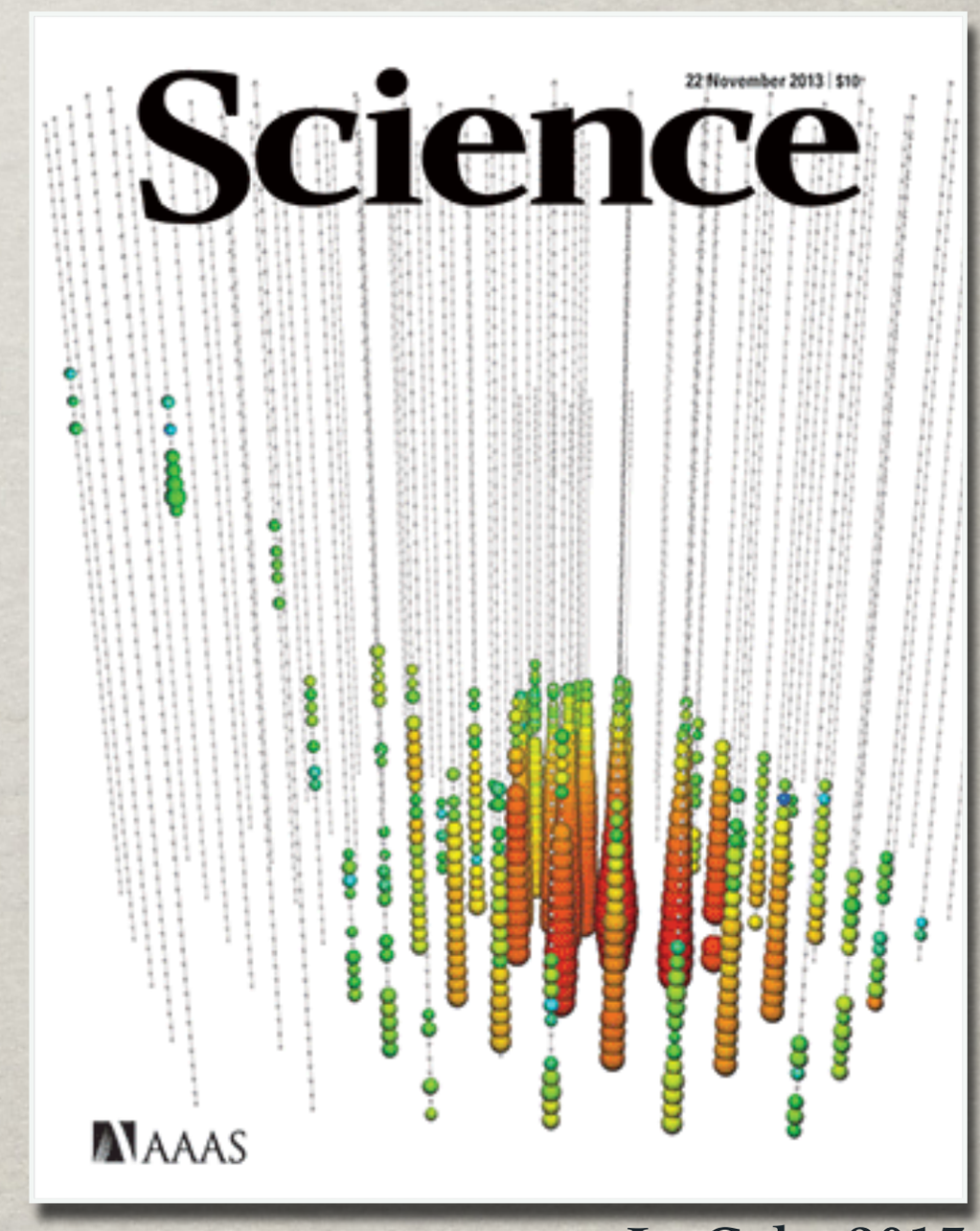

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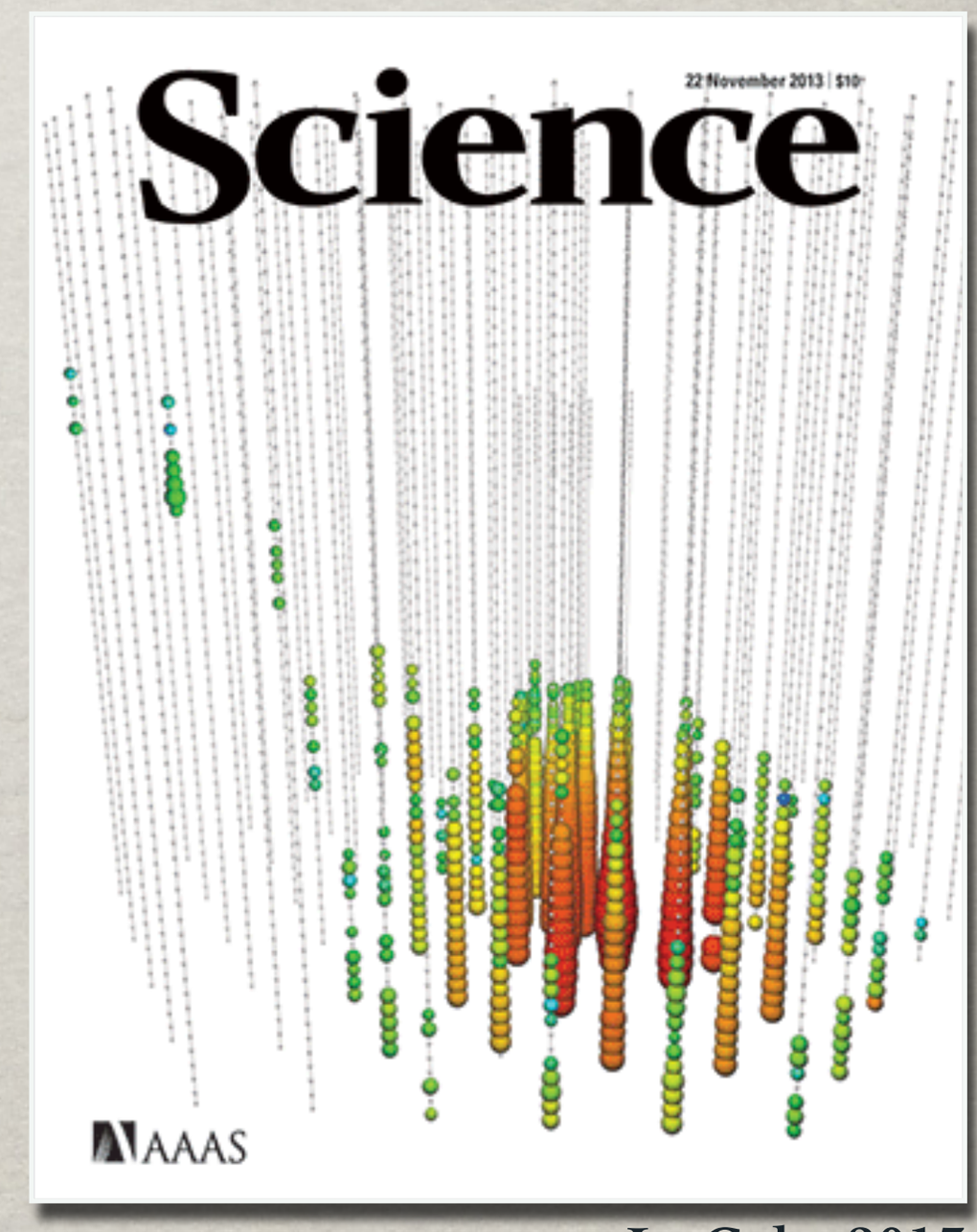

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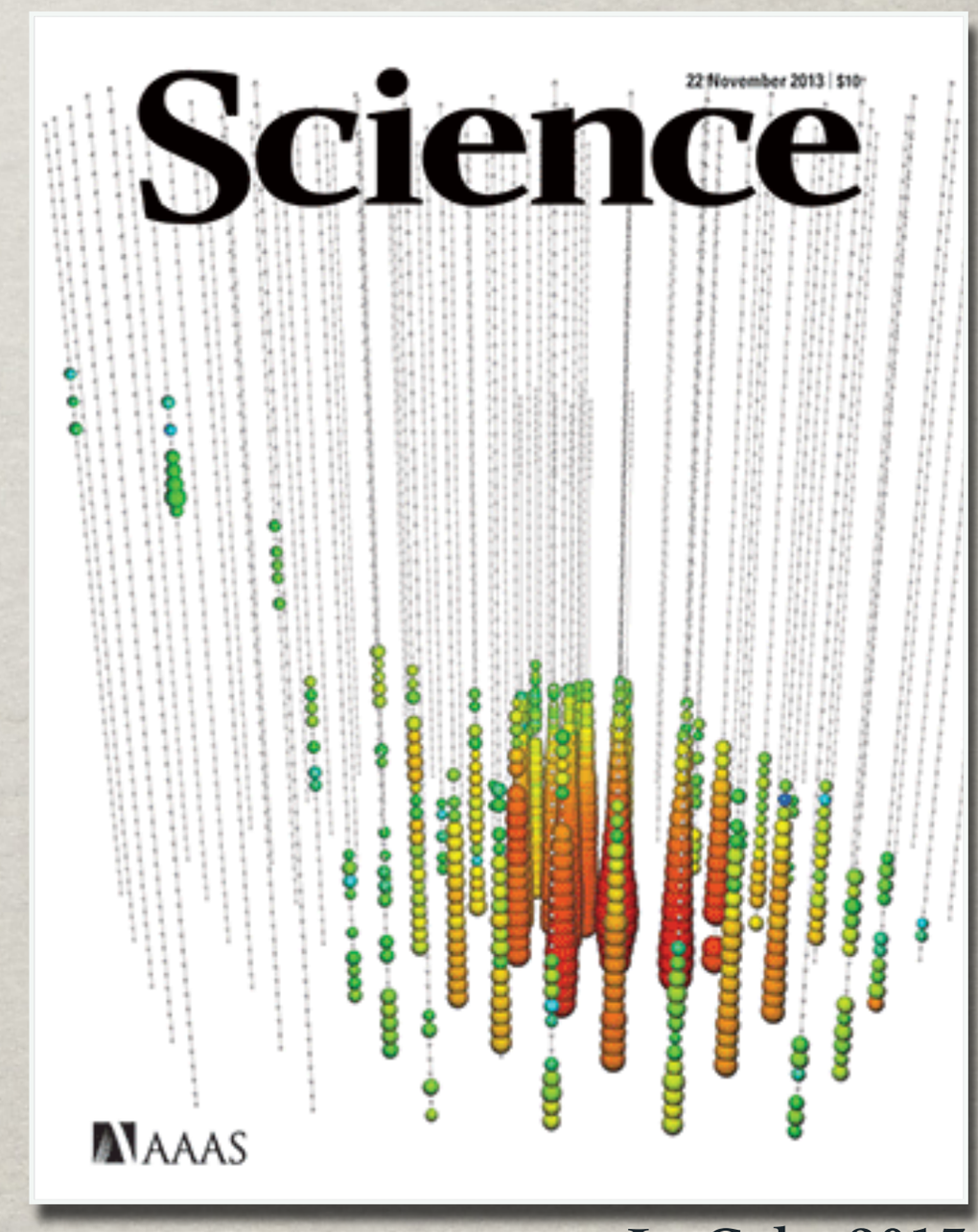

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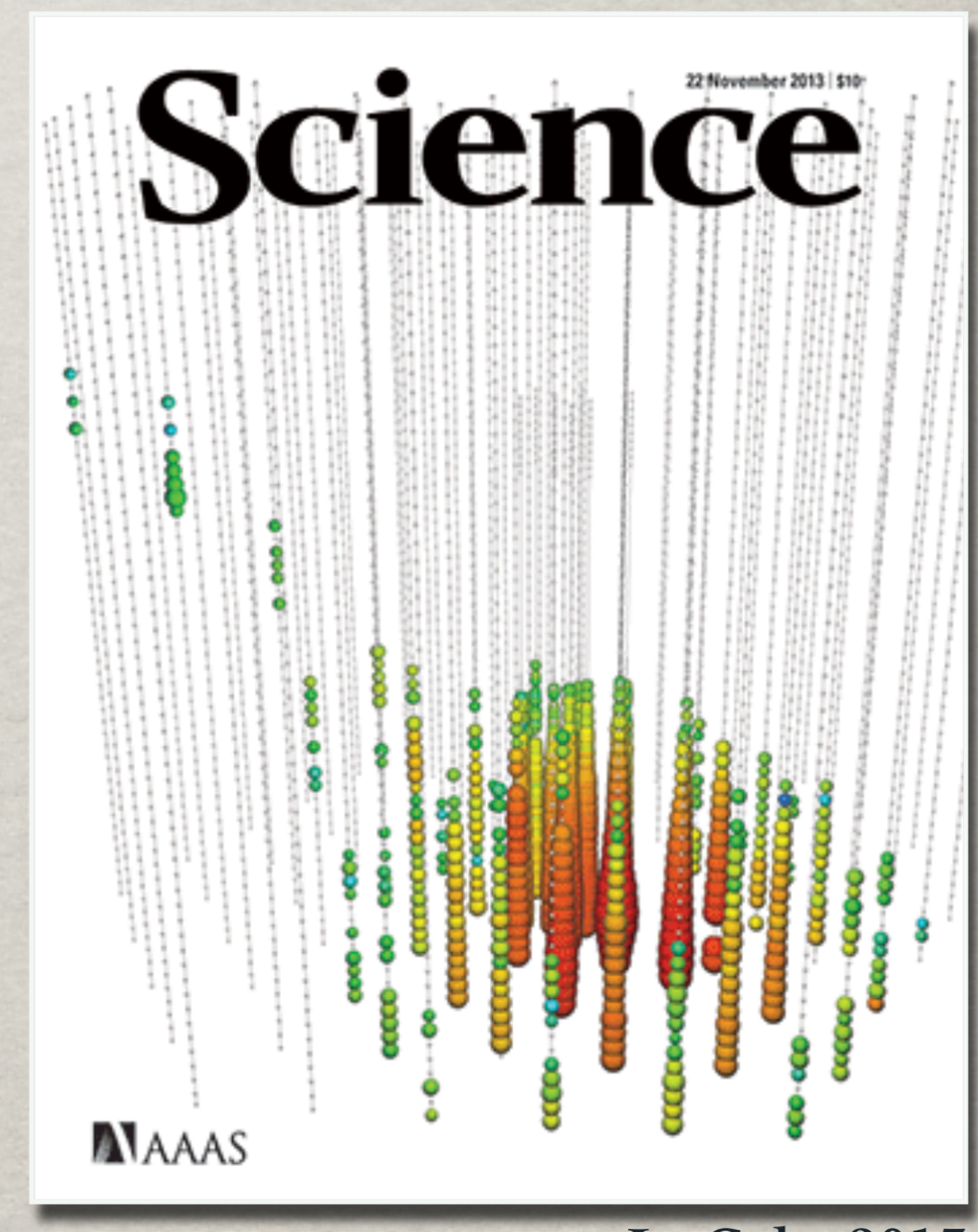

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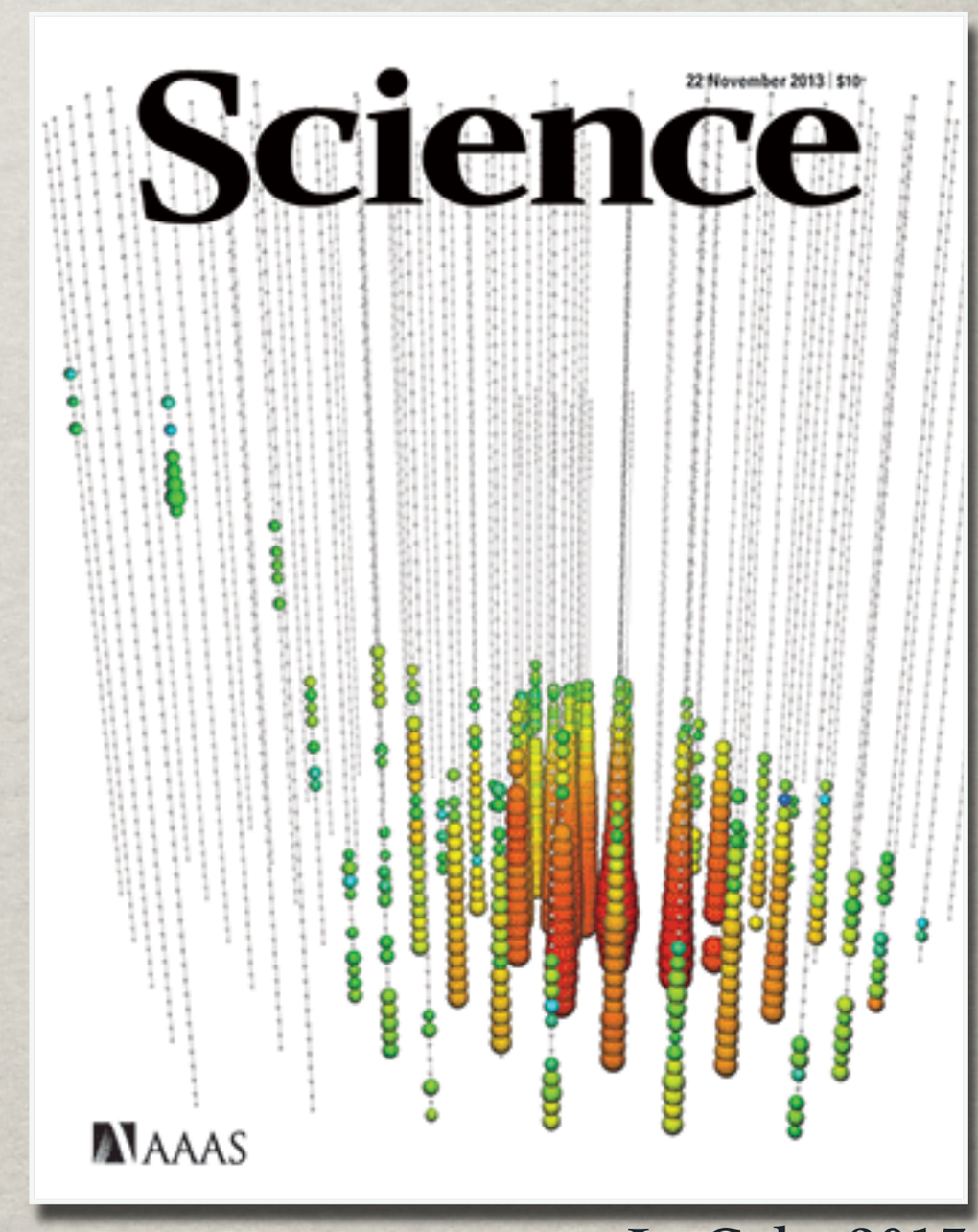

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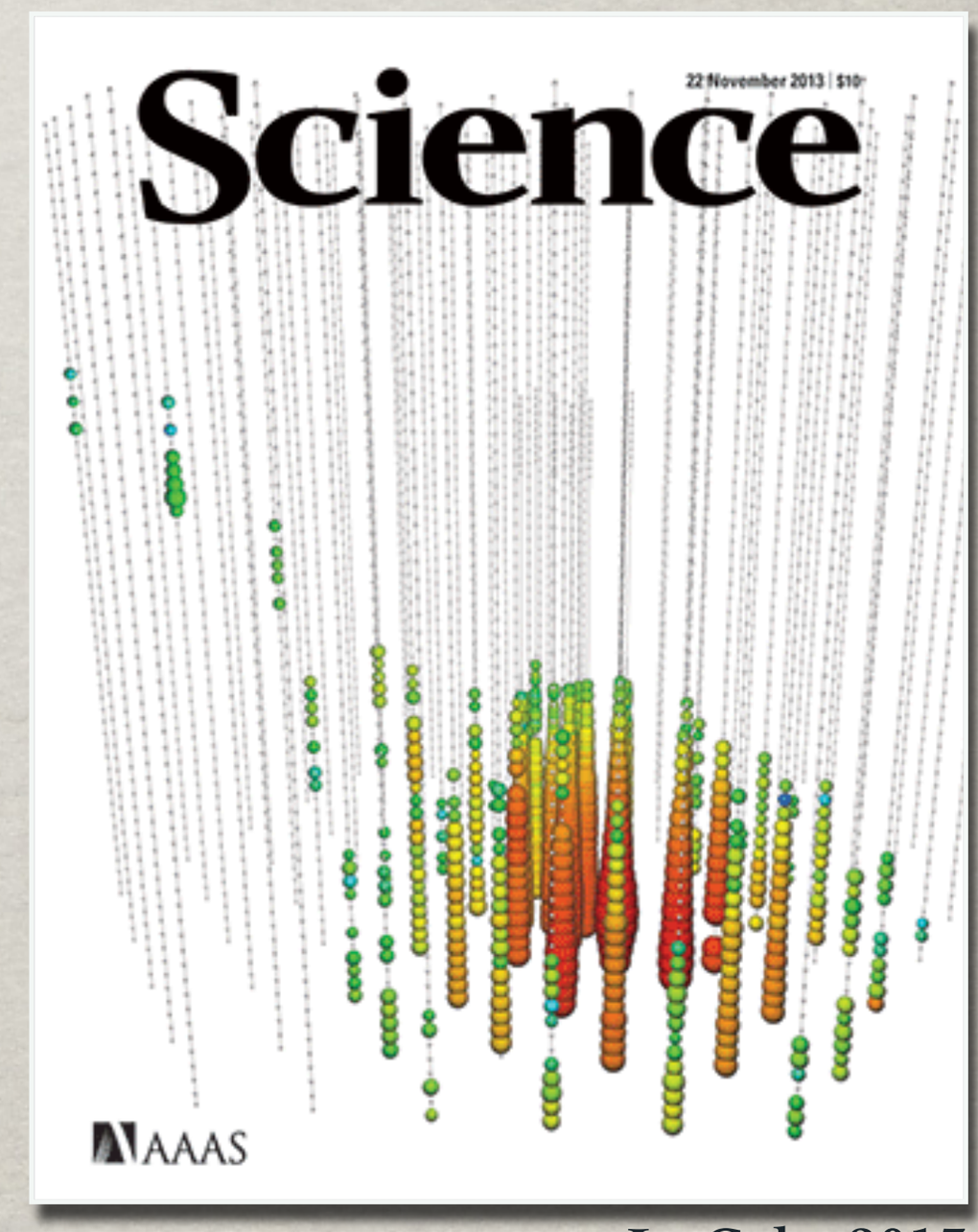
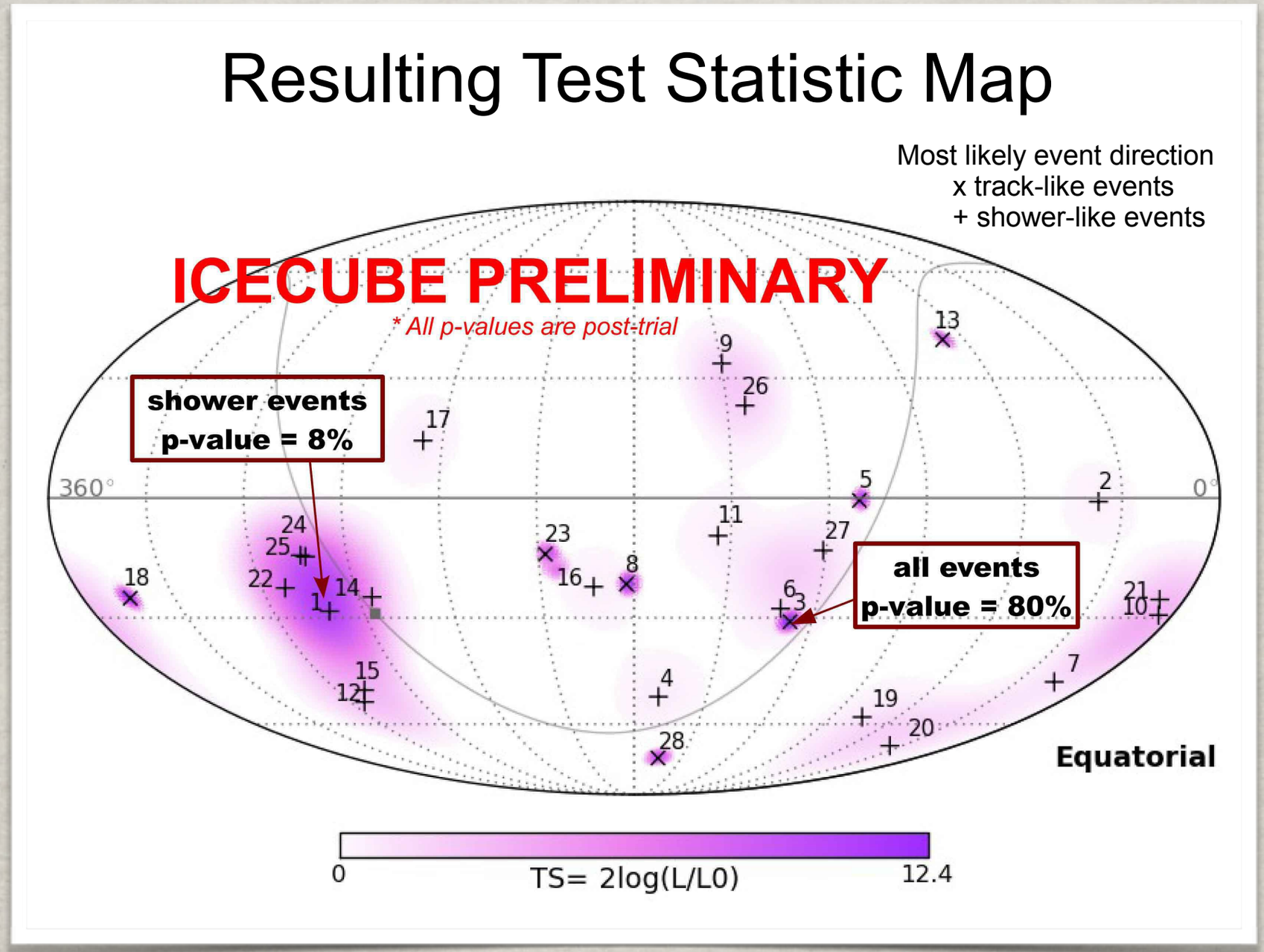


IceCube 2013

The Neutrino Sky



IceCube 2013

x Track

+ Cascade

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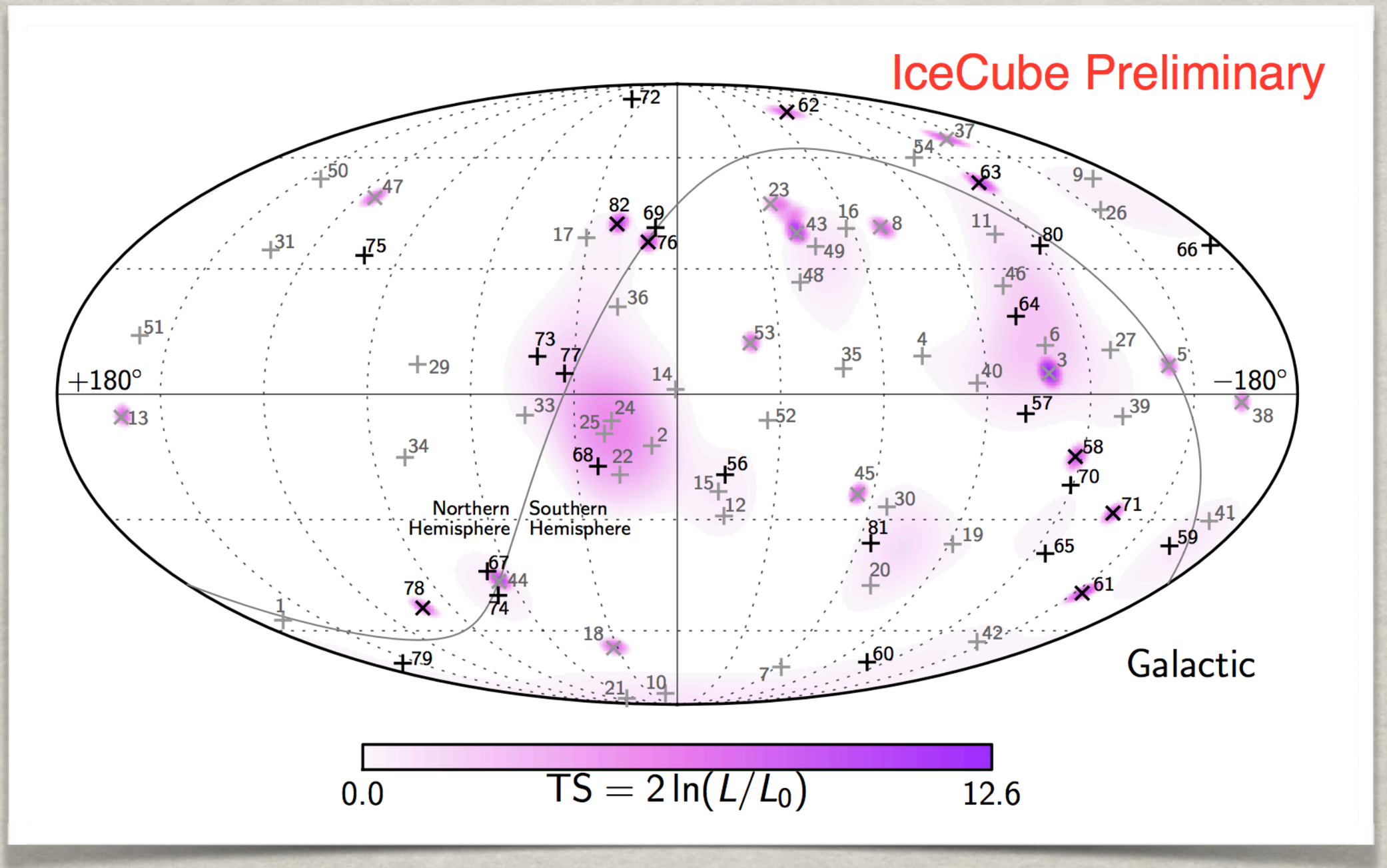

IceCube 2017

x Track

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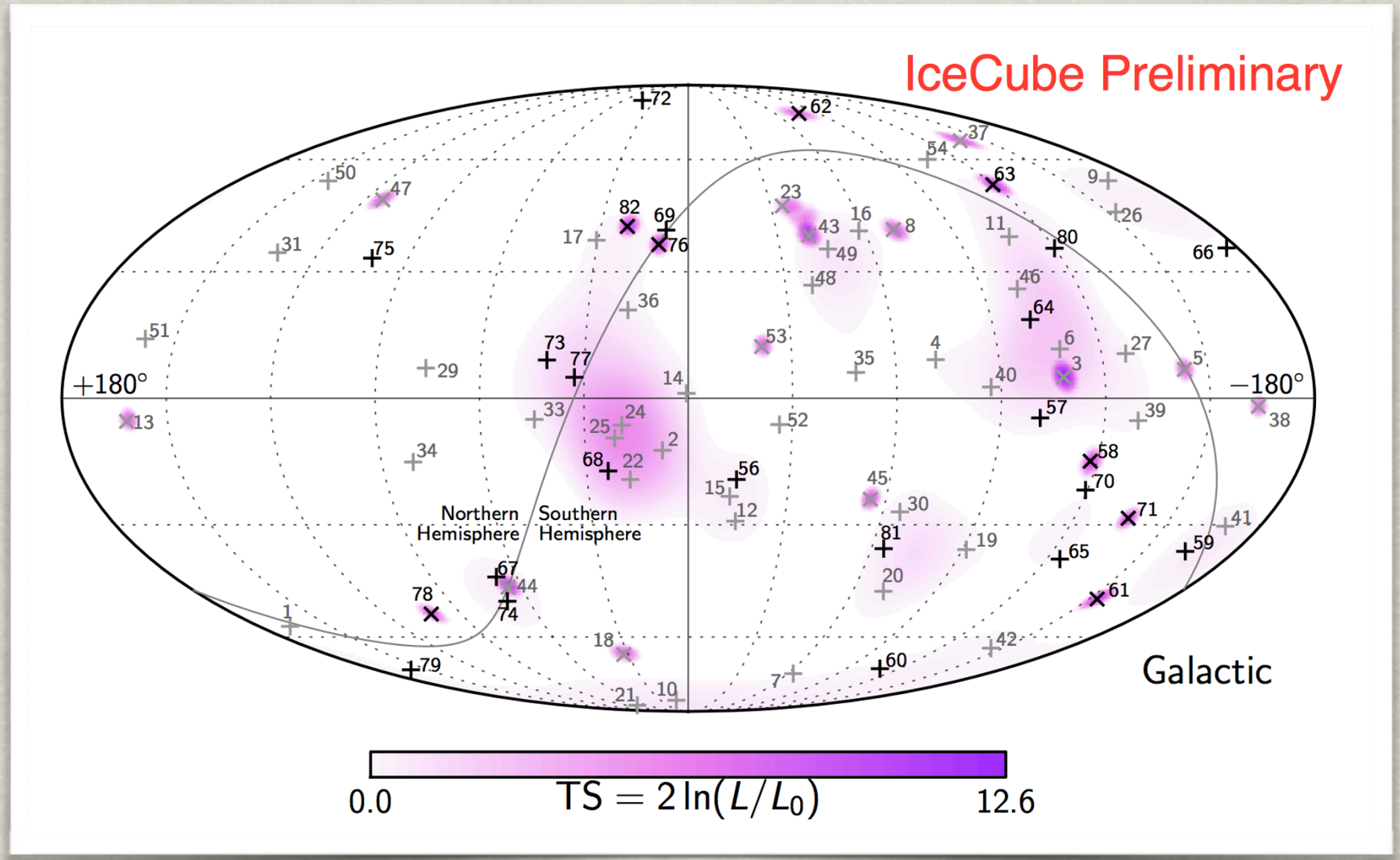
Cosmic Neutrinos



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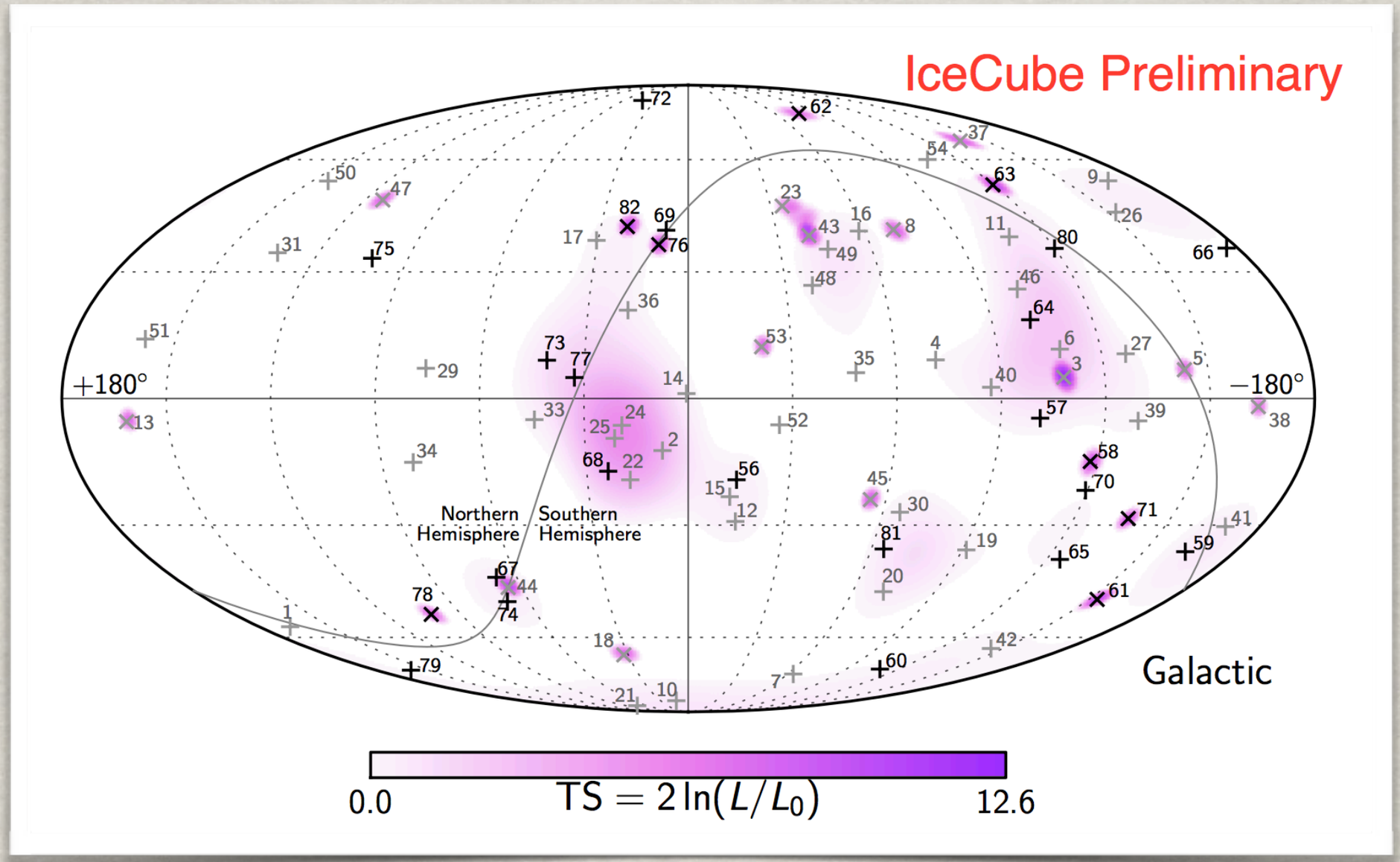

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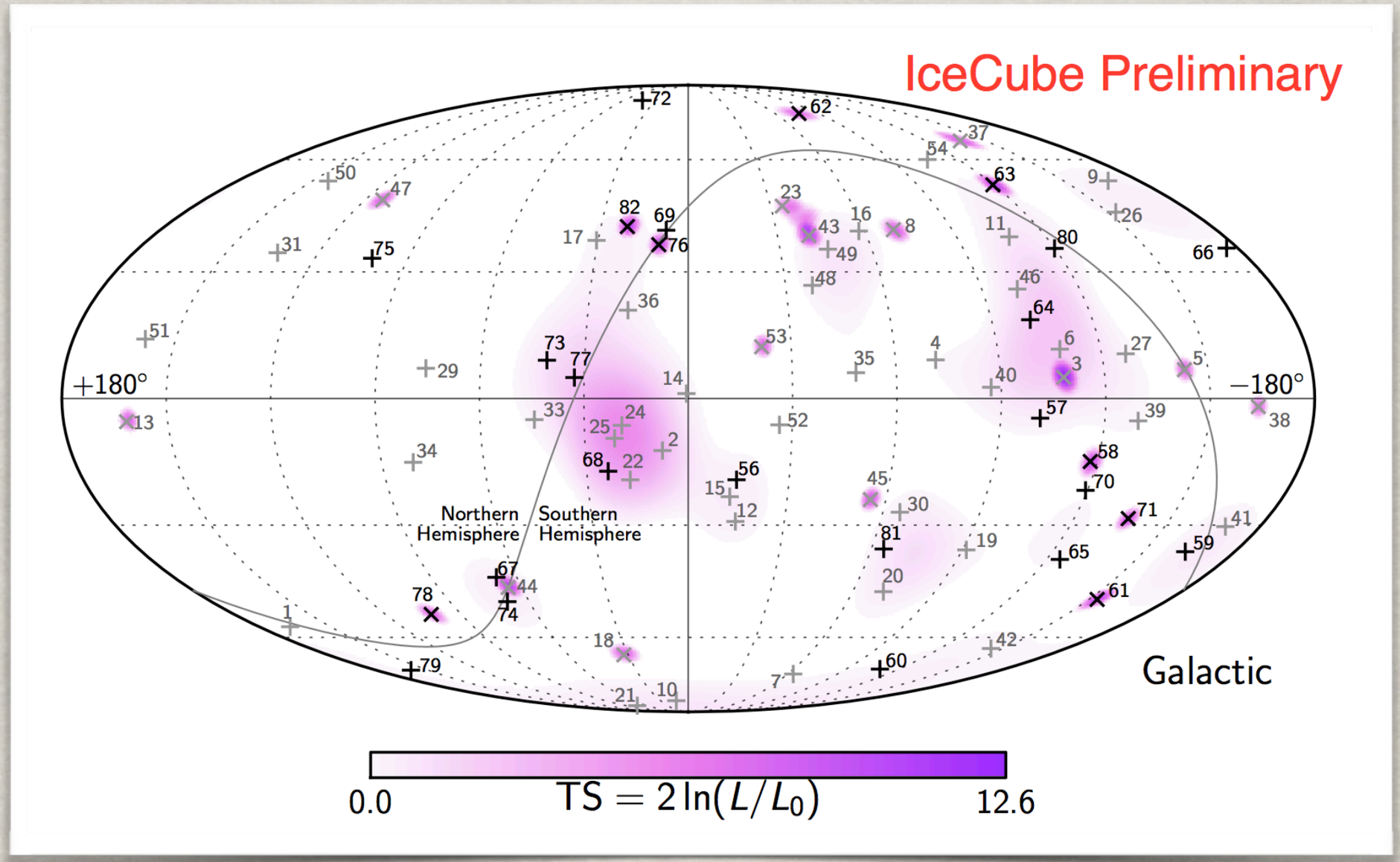

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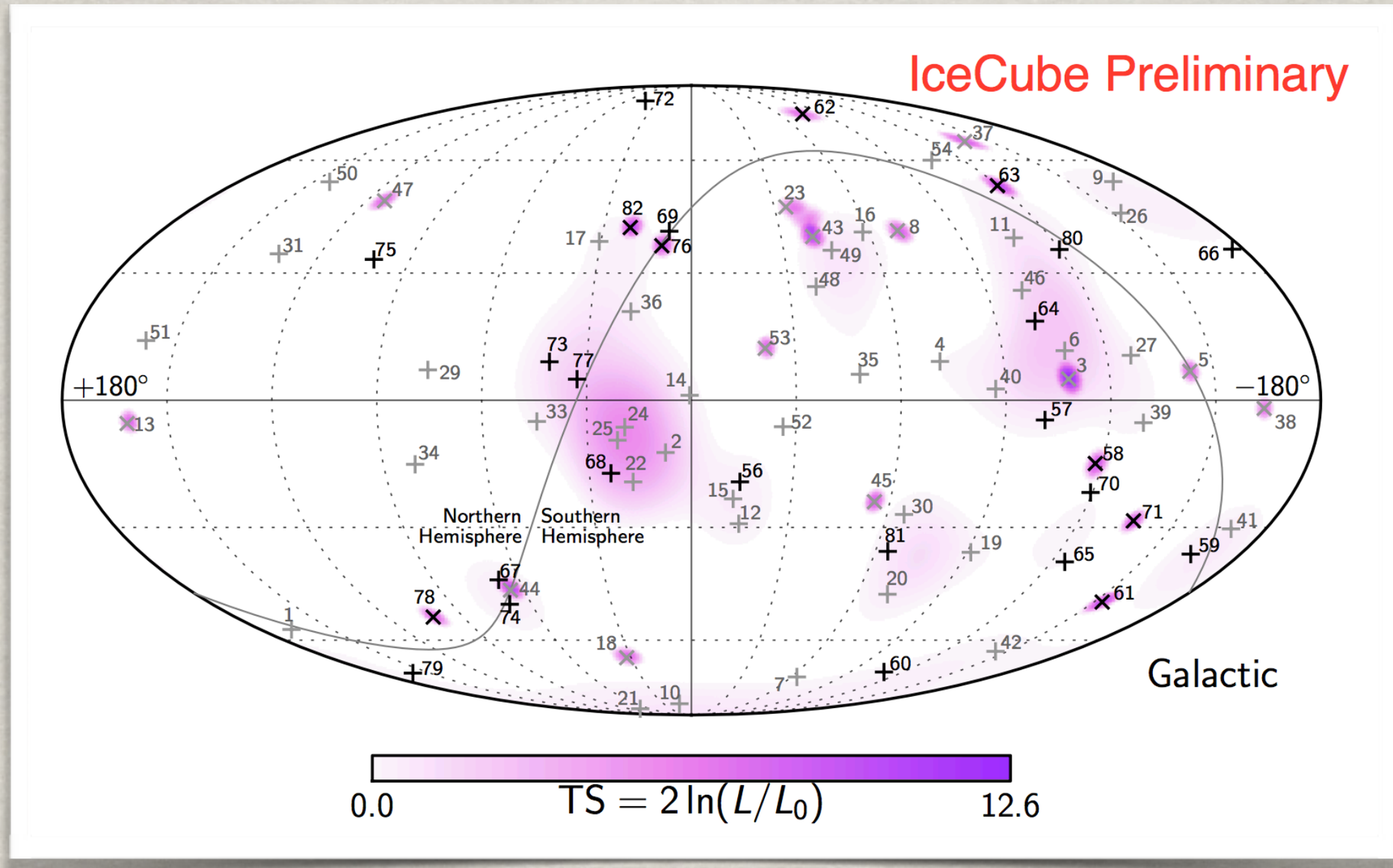
Cosmic Neutrinos

IceCube 2017



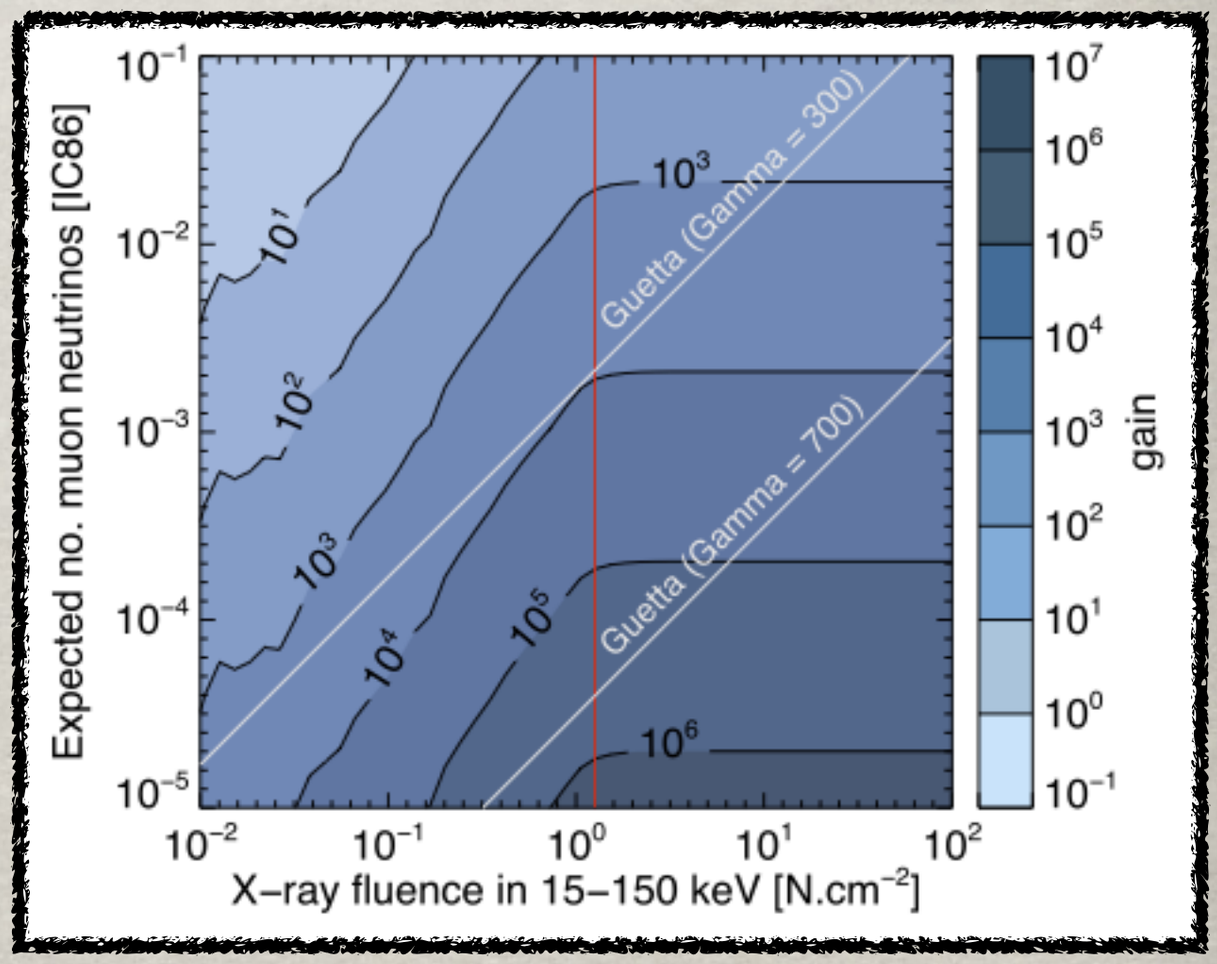
- No GRB coincidences
- No point sources
- No multiplets
- Distribution consistent with isotropy

- What next?

The AMON Idea

amon.psu.edu

AMON



Smith+2013

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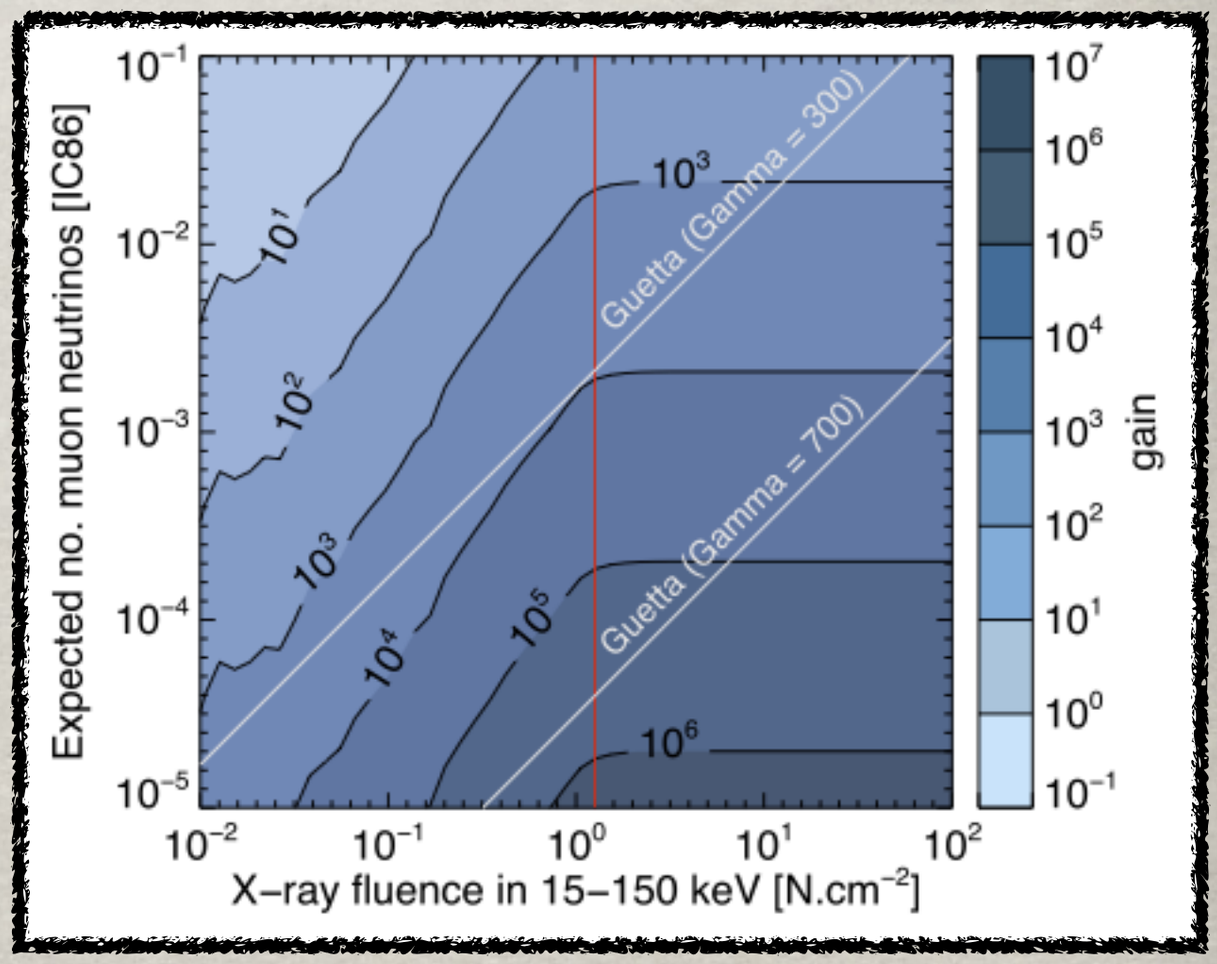

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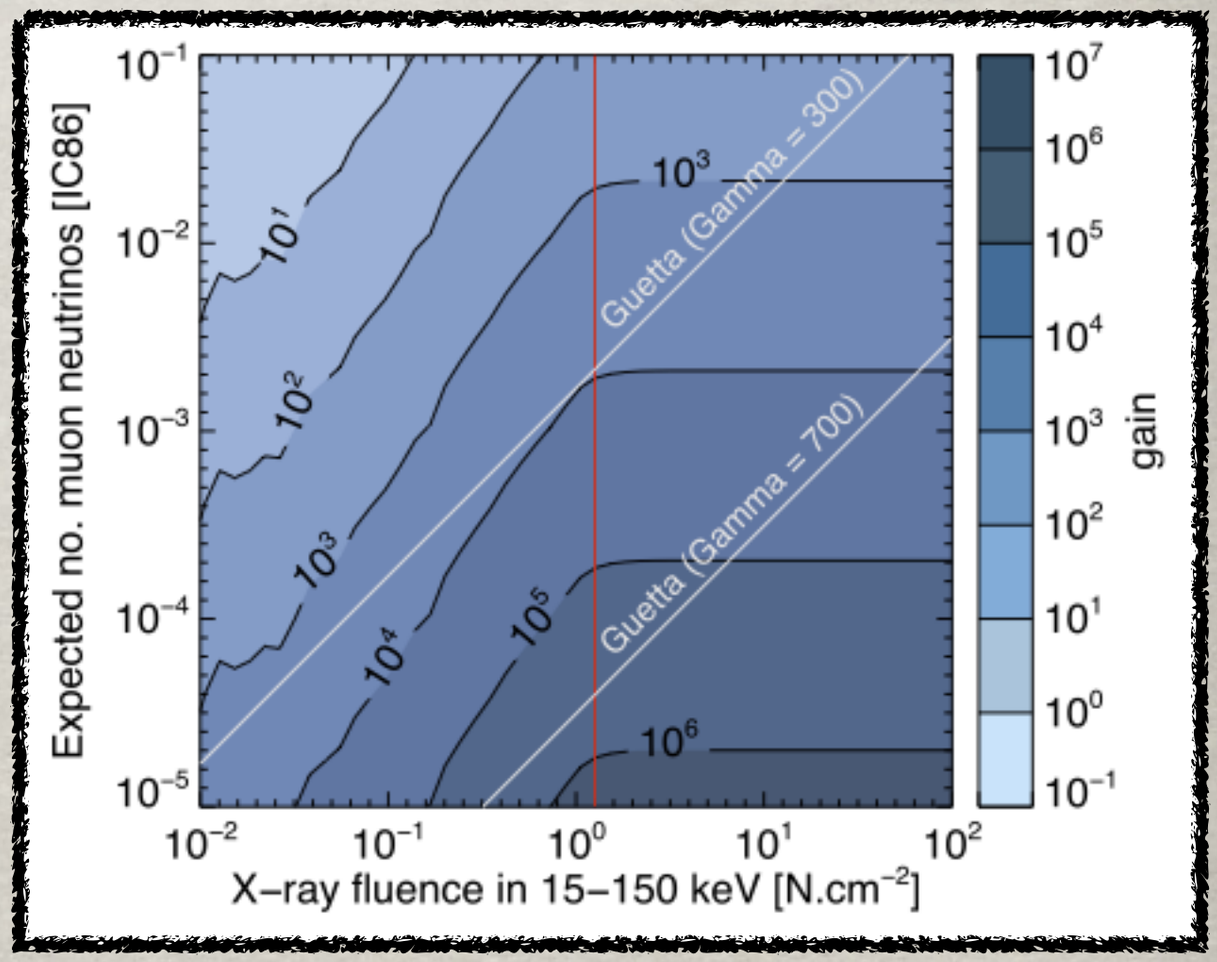

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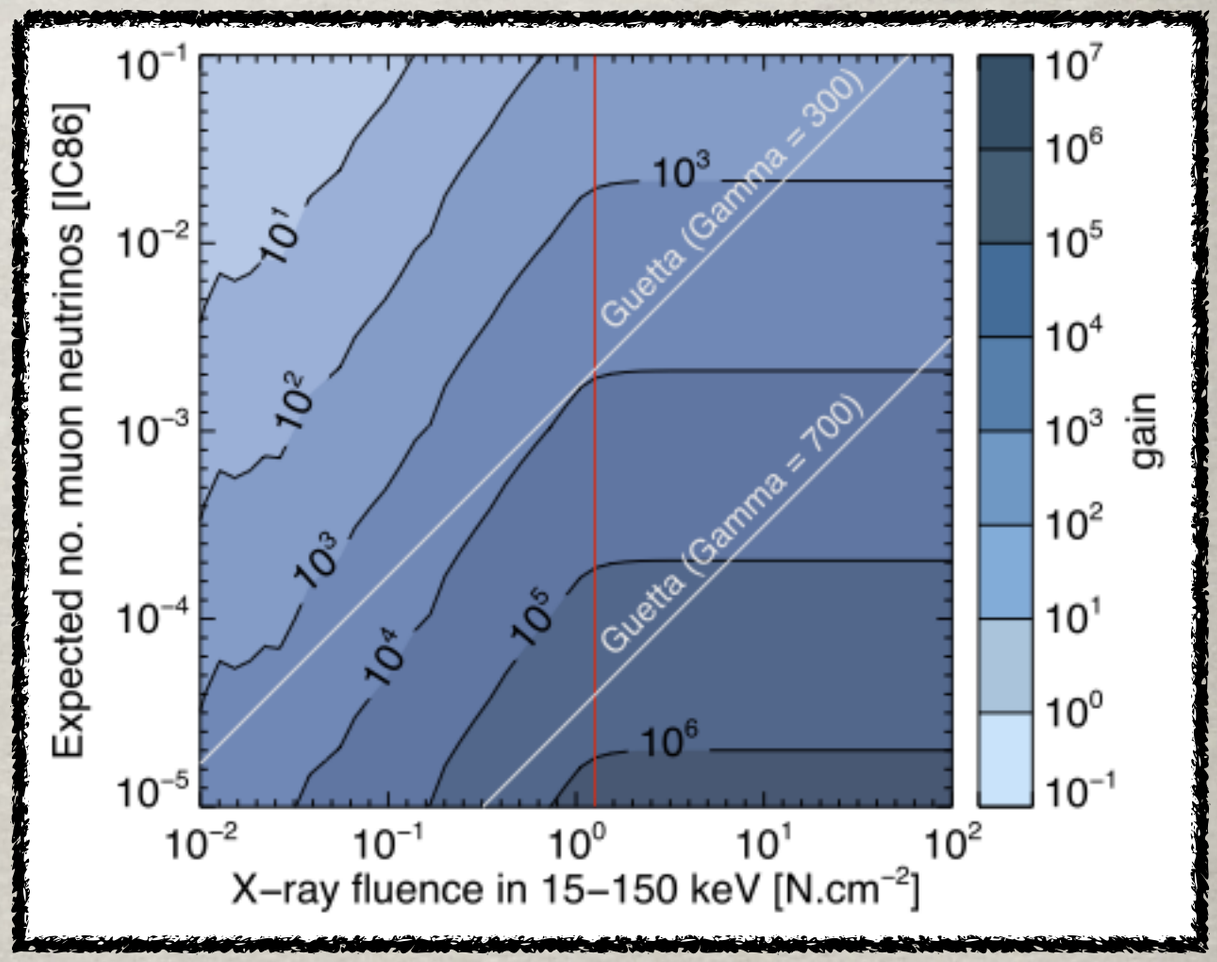

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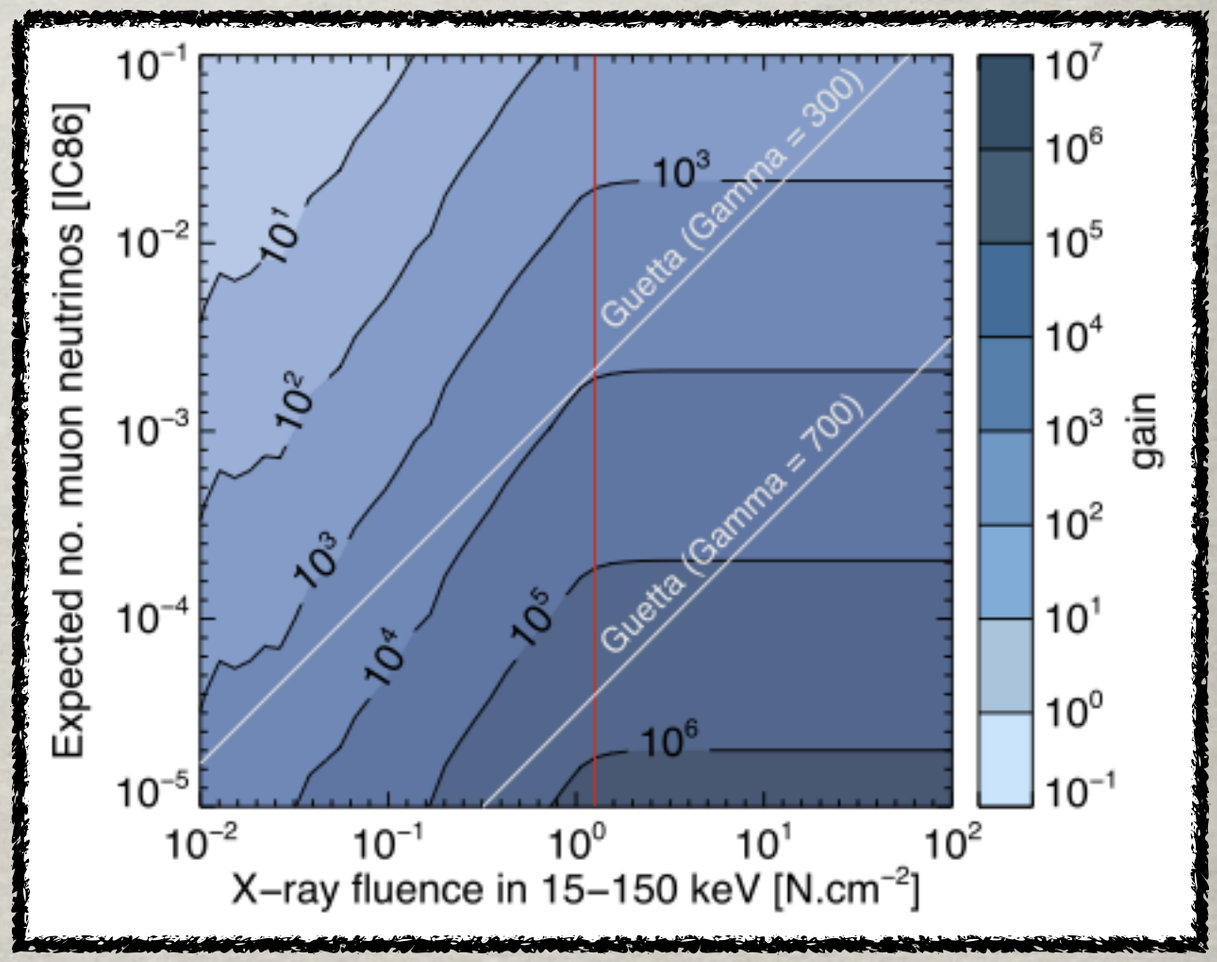

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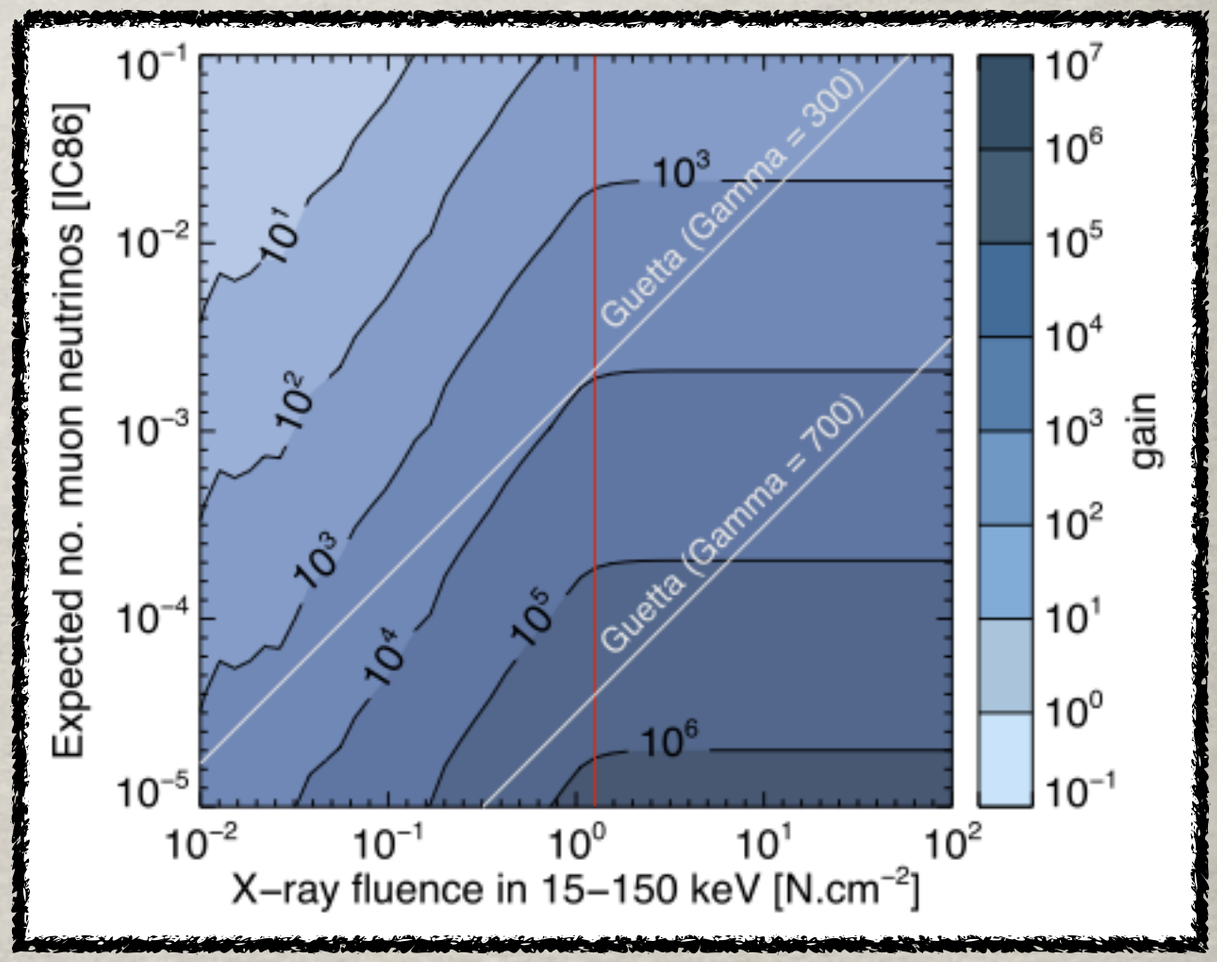
- **For cosmic neutrinos:** Efficiency improvement from follow-up of smaller gamma-ray localizations

AMON



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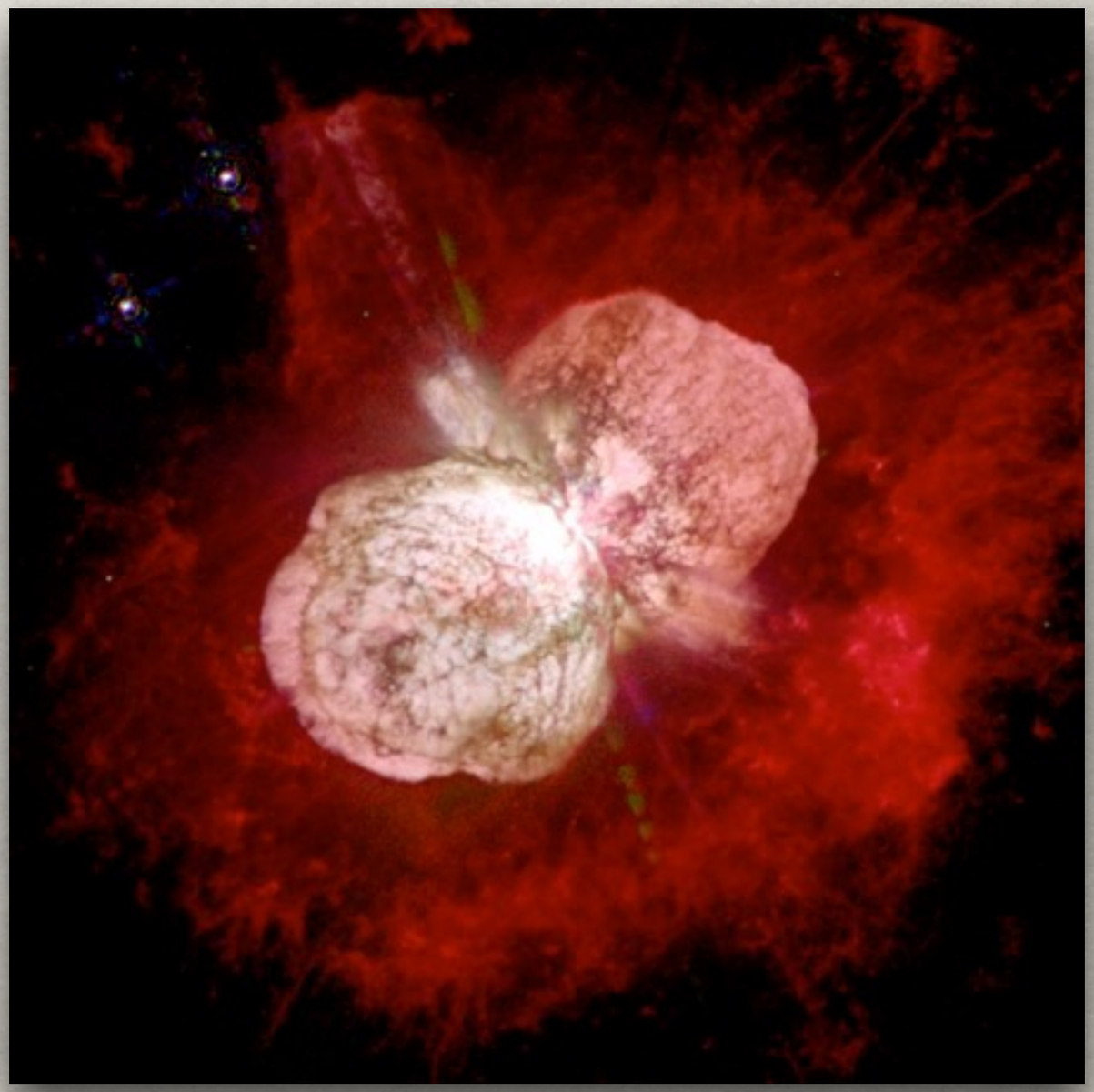
Likely-Cosmic Neutrino Alerts



Likely-Cosmic Neutrino Alerts

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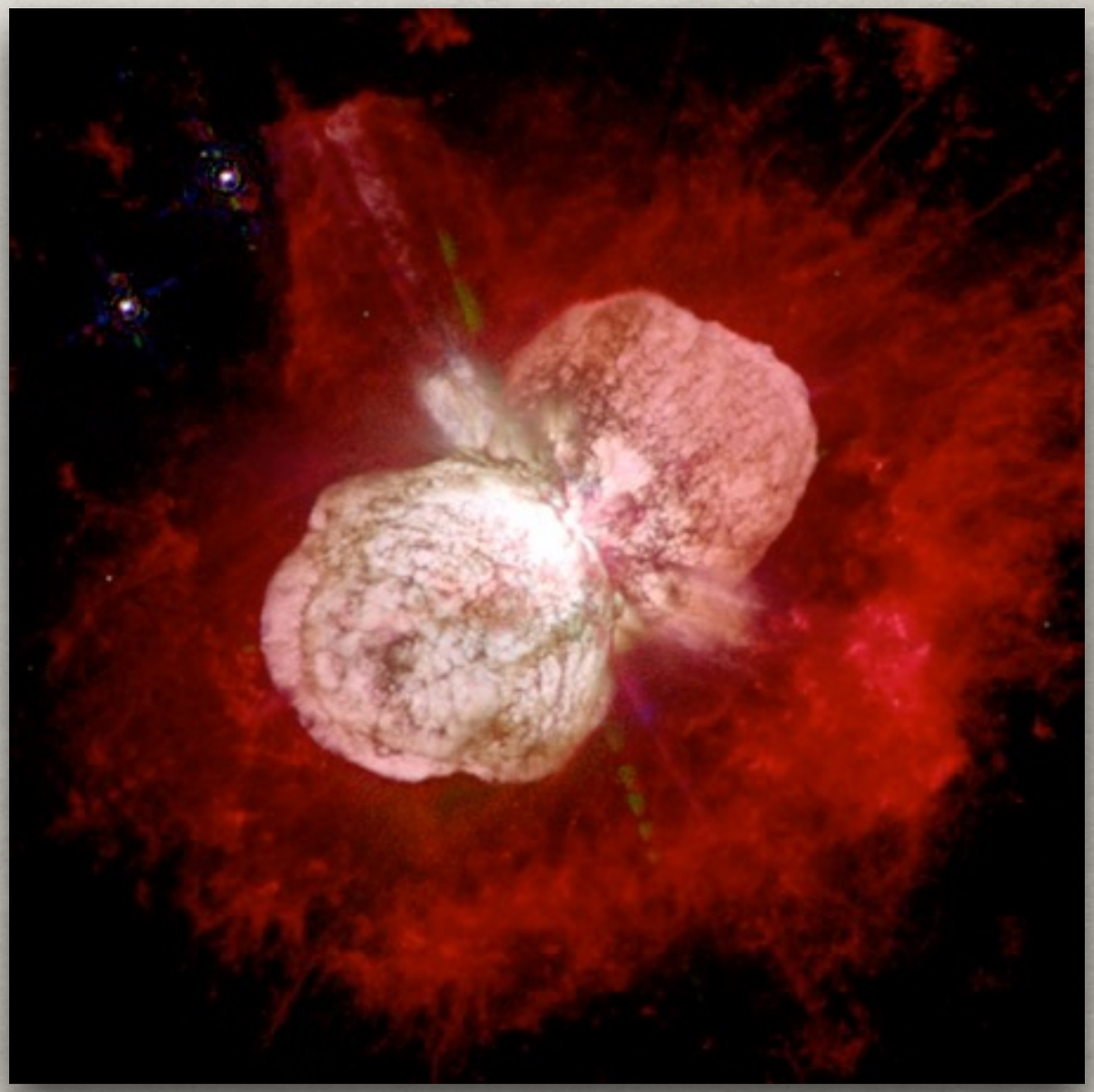

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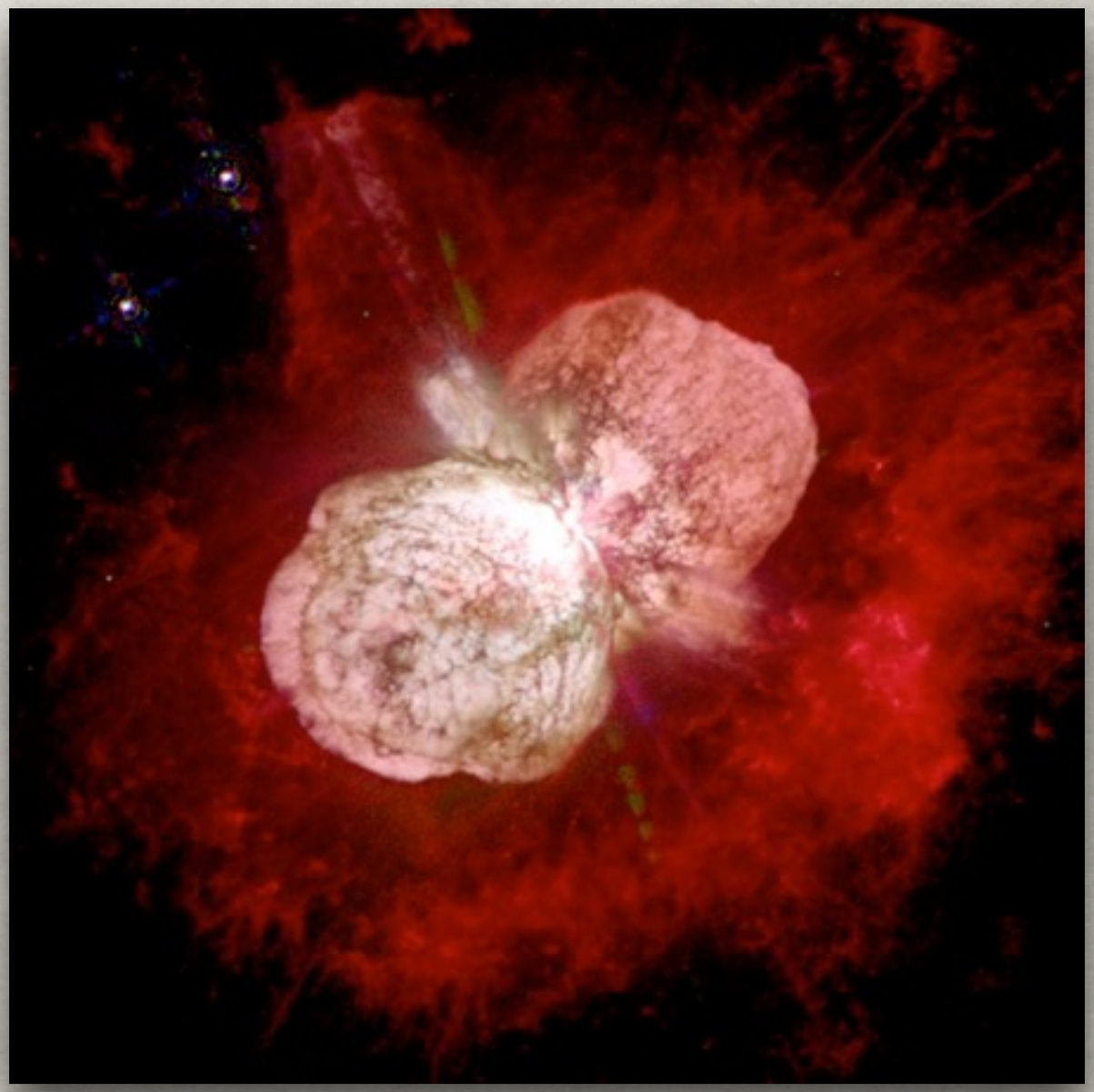

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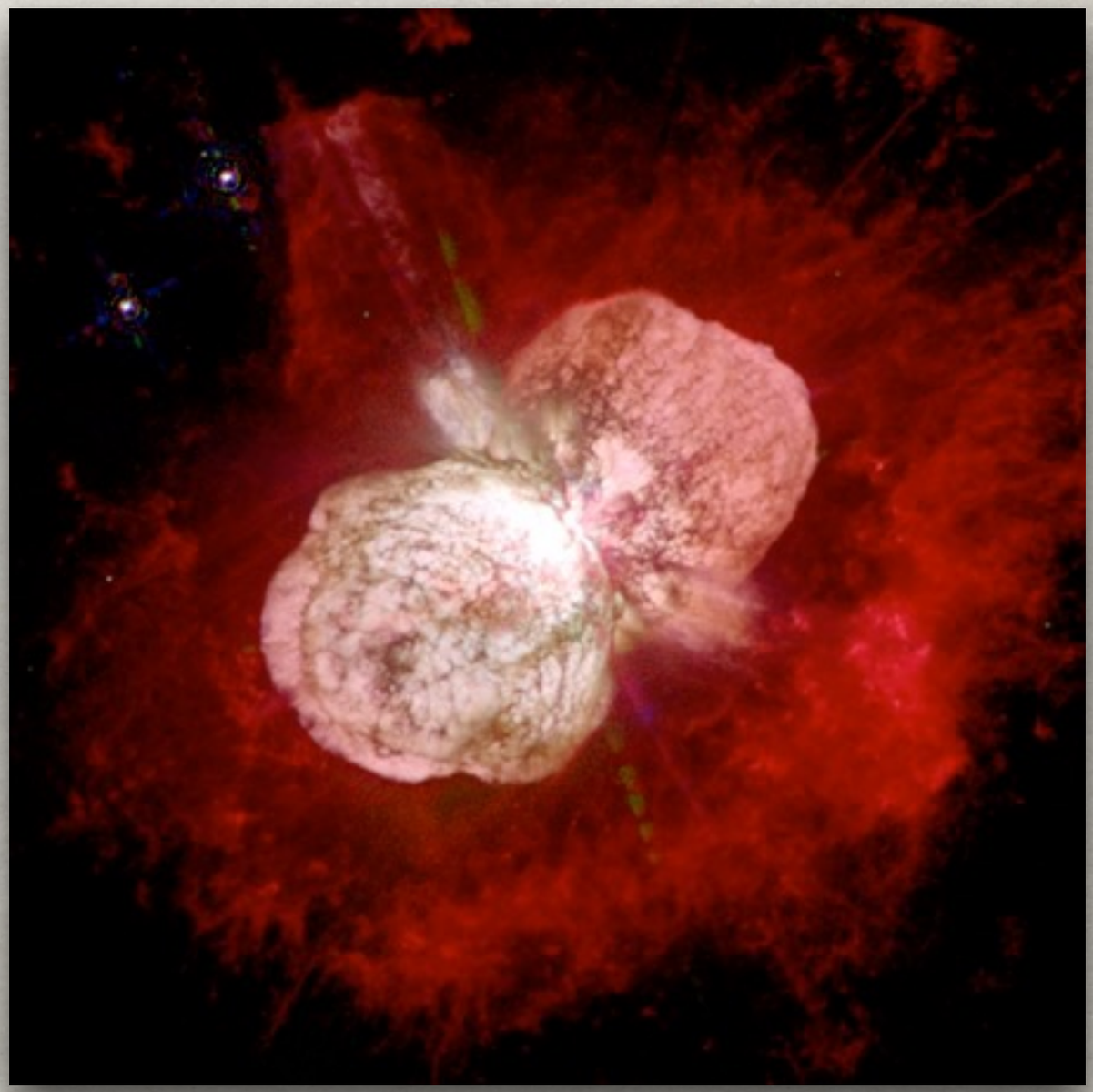

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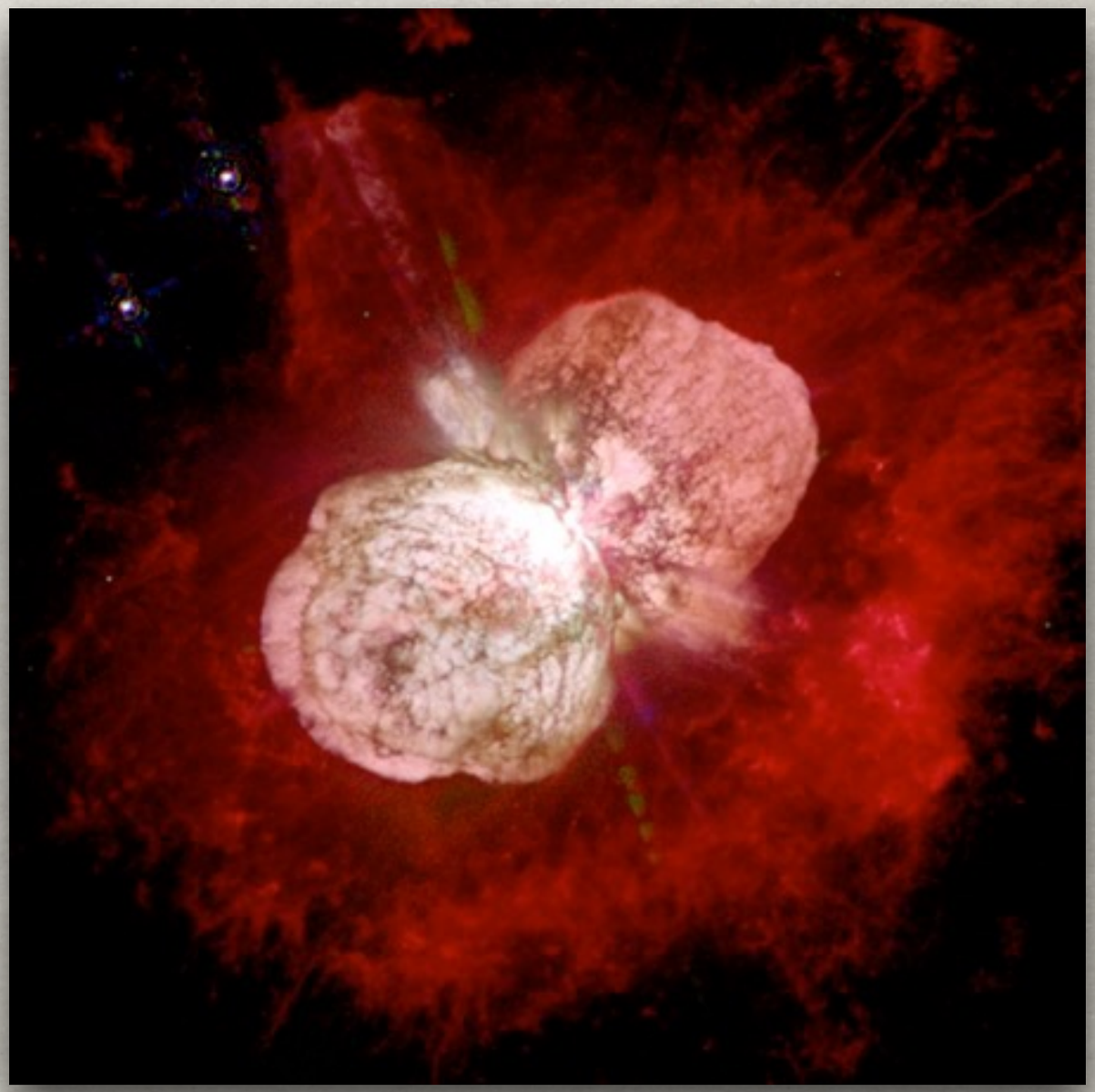
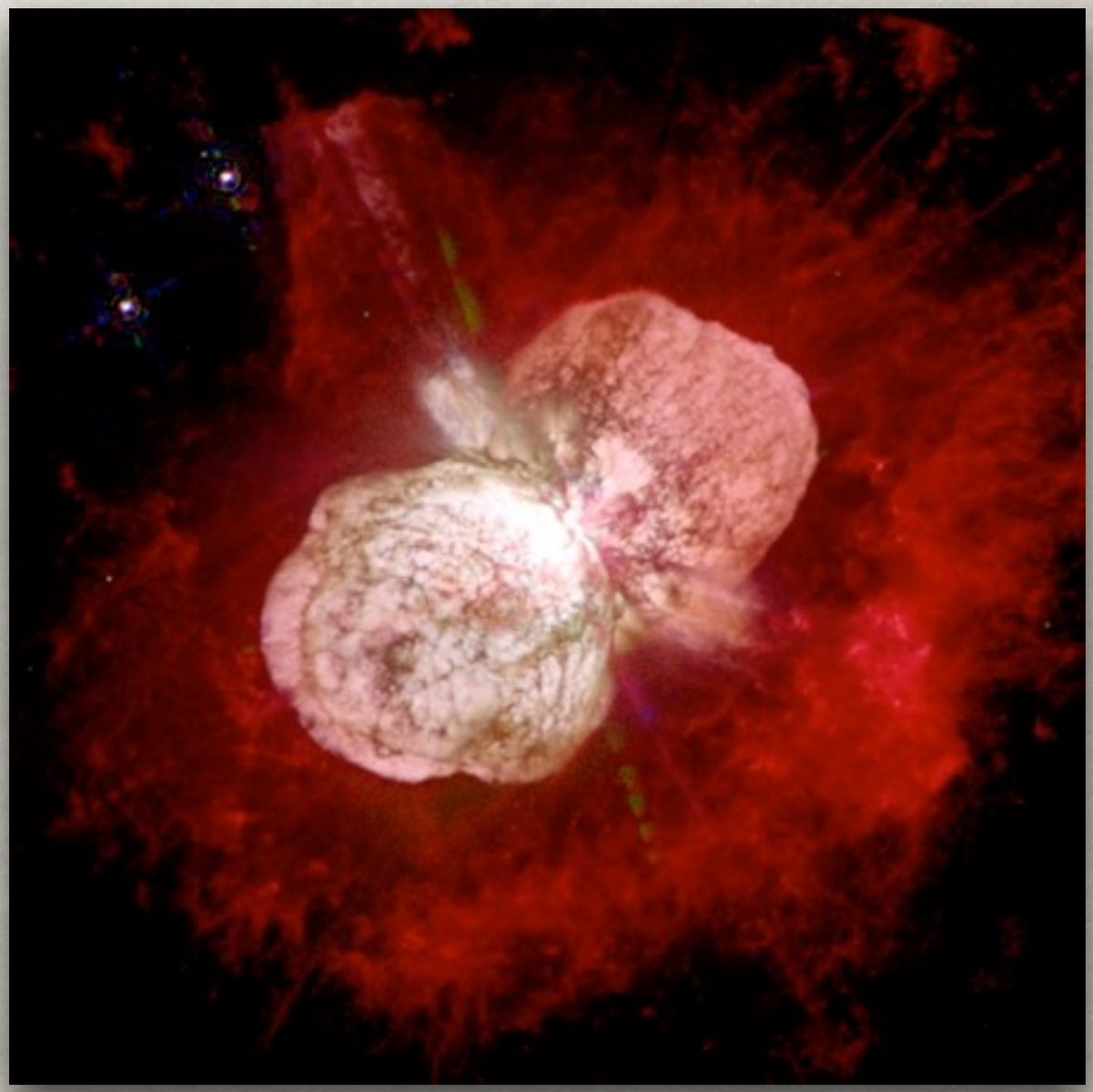
- Track-type events only



Likely-Cosmic Neutrino Alerts

- Discovery report (2013) from archival data
- No real-time follow-up
- **AMON Initiative**: First real-time likely-cosmic neutrino alerts
- Track-type events only
- Installed software to identify, localize, & relay events to GCN



G. Tesic
A. Keivani

AMON_ICECUBE_HESE

AMON ICECUBE_HESE EVENTS

EVENT			OBSERVATION							
EventNum_RunNum	**Date**	**Time UT**	**NoticeType**	**False_Pos**	**Pvalue**	**Charge**	**SignalTr**	**N_Events**	**Stream**	**Comments**
67093193_127853	16/04/27	05:52:32.00	HESE	0.0000e+00	0.0000e+00	18883.62	0.92	1	1	AMON_ICECUBE_HESE.
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- Second alert on 31 July 2016: $p_{\mathrm{cosmic}} \approx 80\% \longrightarrow$ *Swift*

AMON_ICECUBE_HESE

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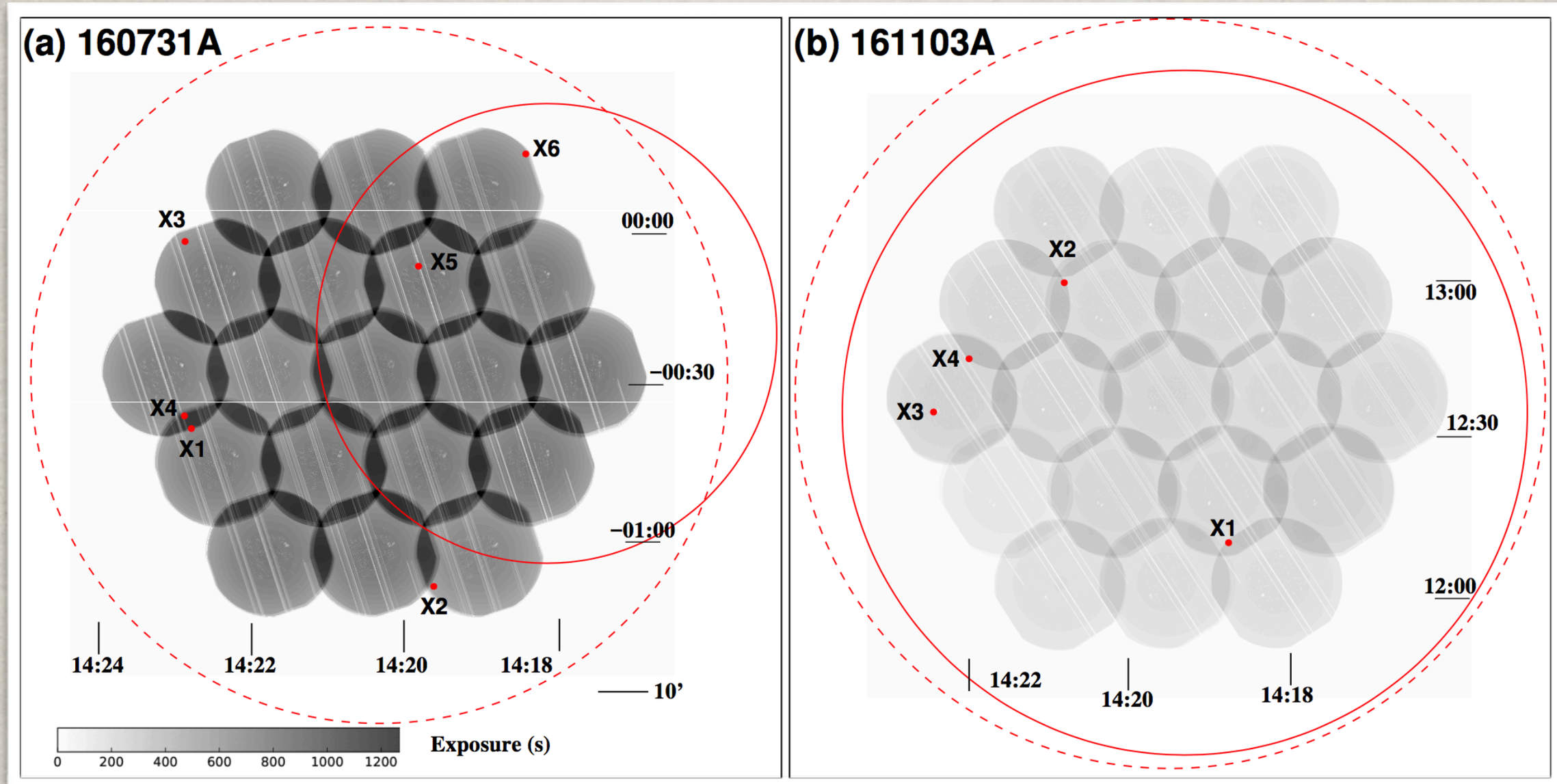
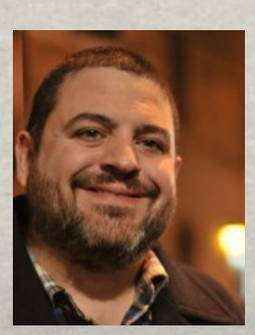
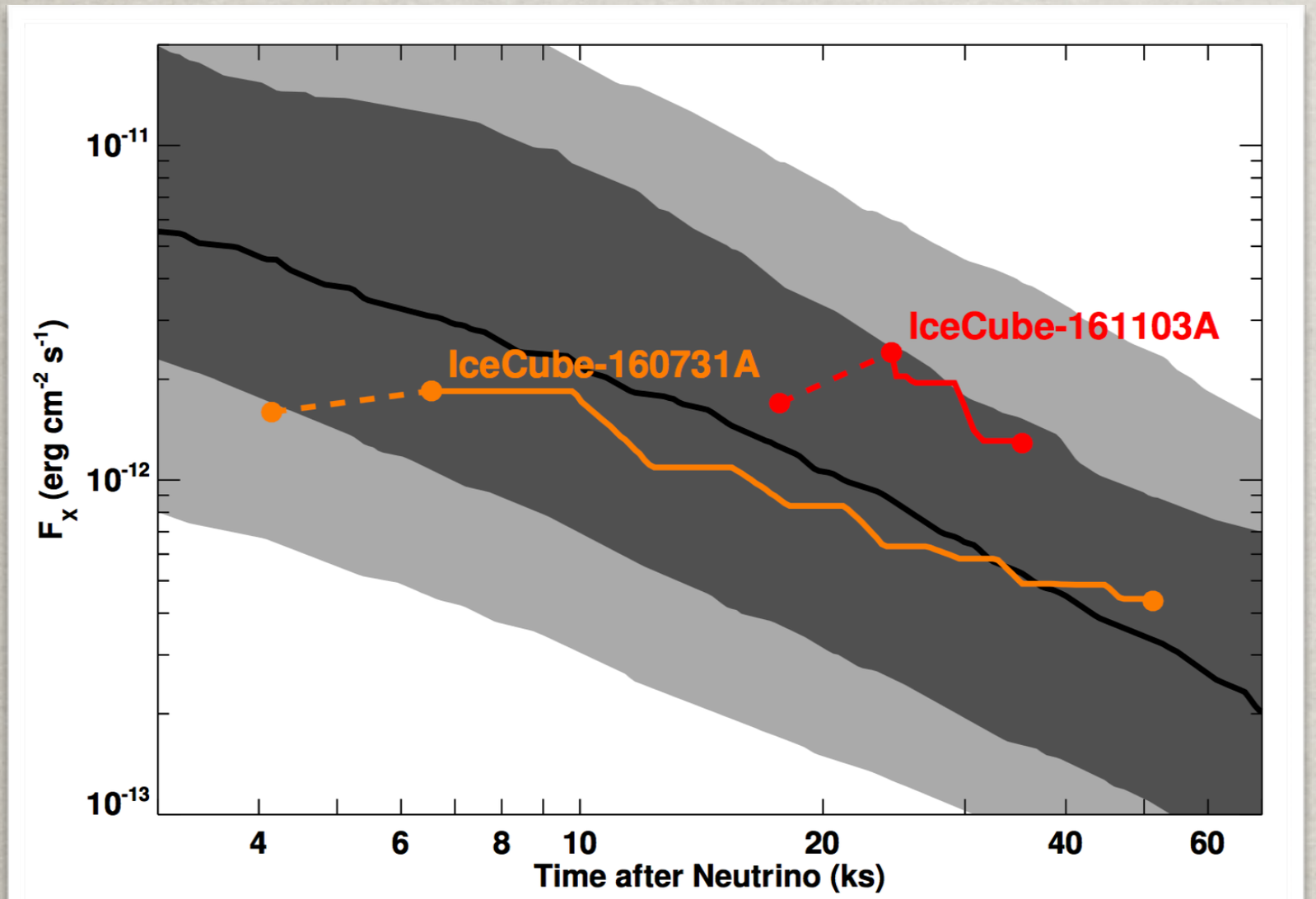
First Swift Campaigns





A. Keivani
J. Kennea
P. Evans

Two Swift Campaigns



Two Swift Campaigns

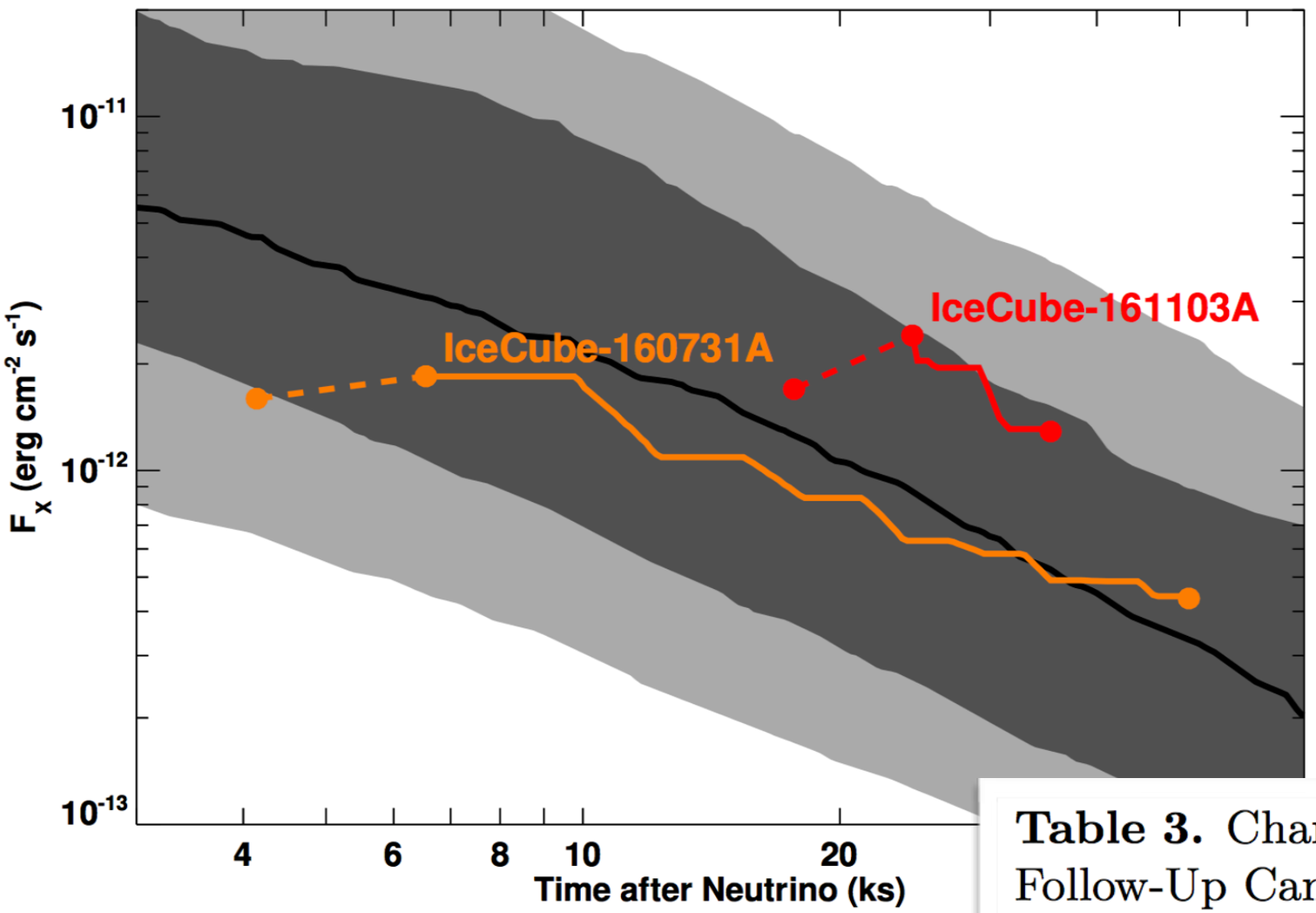
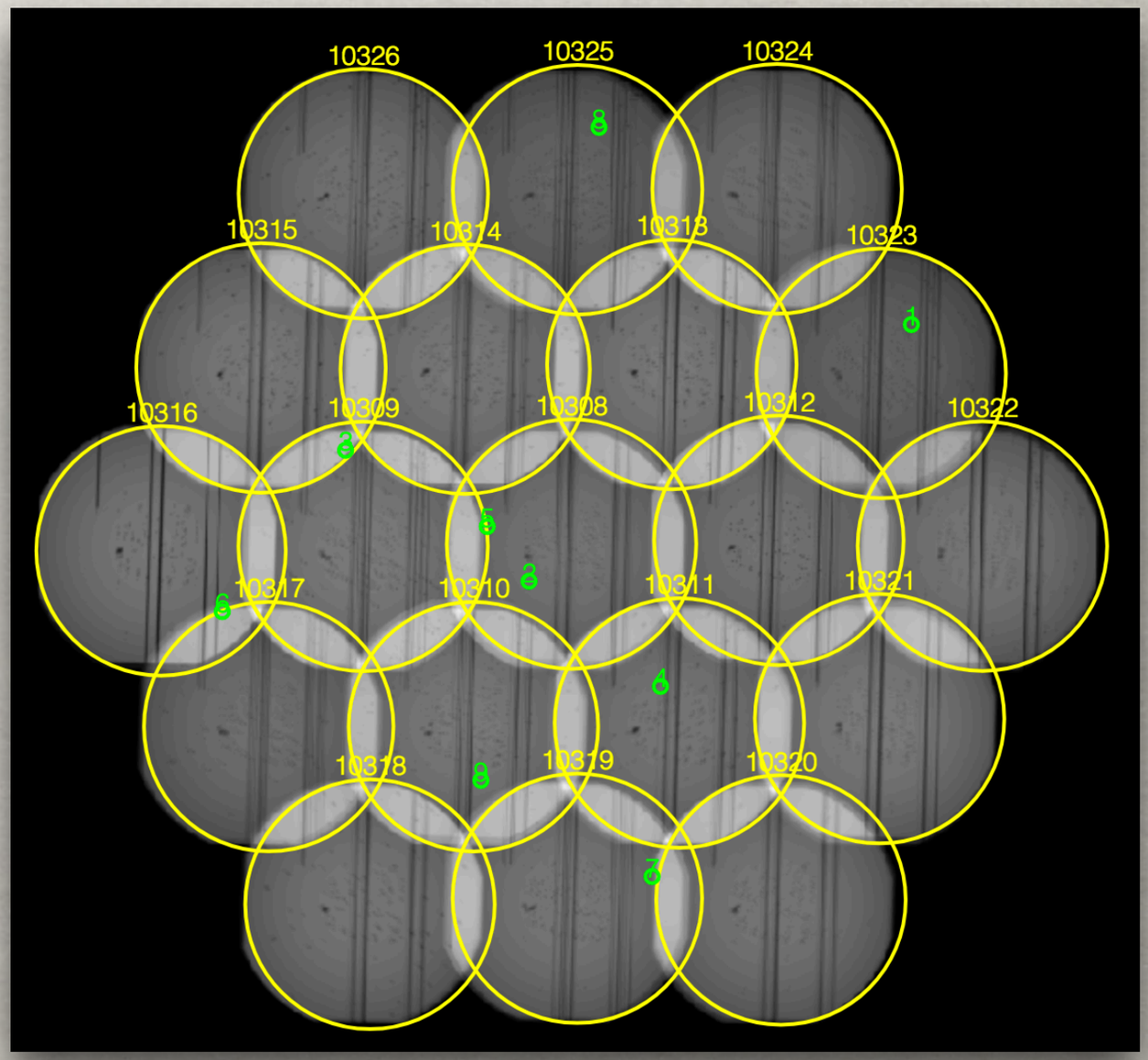


Table 3. Characteristic Probabilities for Neutrino Follow-Up Campaigns

Event	$p_{\mathcal{S}}$	$p_{\Omega,\mathrm{X}}$	$p_{\Delta t,\mathrm{X}}$	p_{total}
IceCube-160731A	91%	64%	65%	38%
IceCube-161103A	30%	68%	30%	6%

IceCube 170922A

- IceCube EHE event of 2017 Sep. 22



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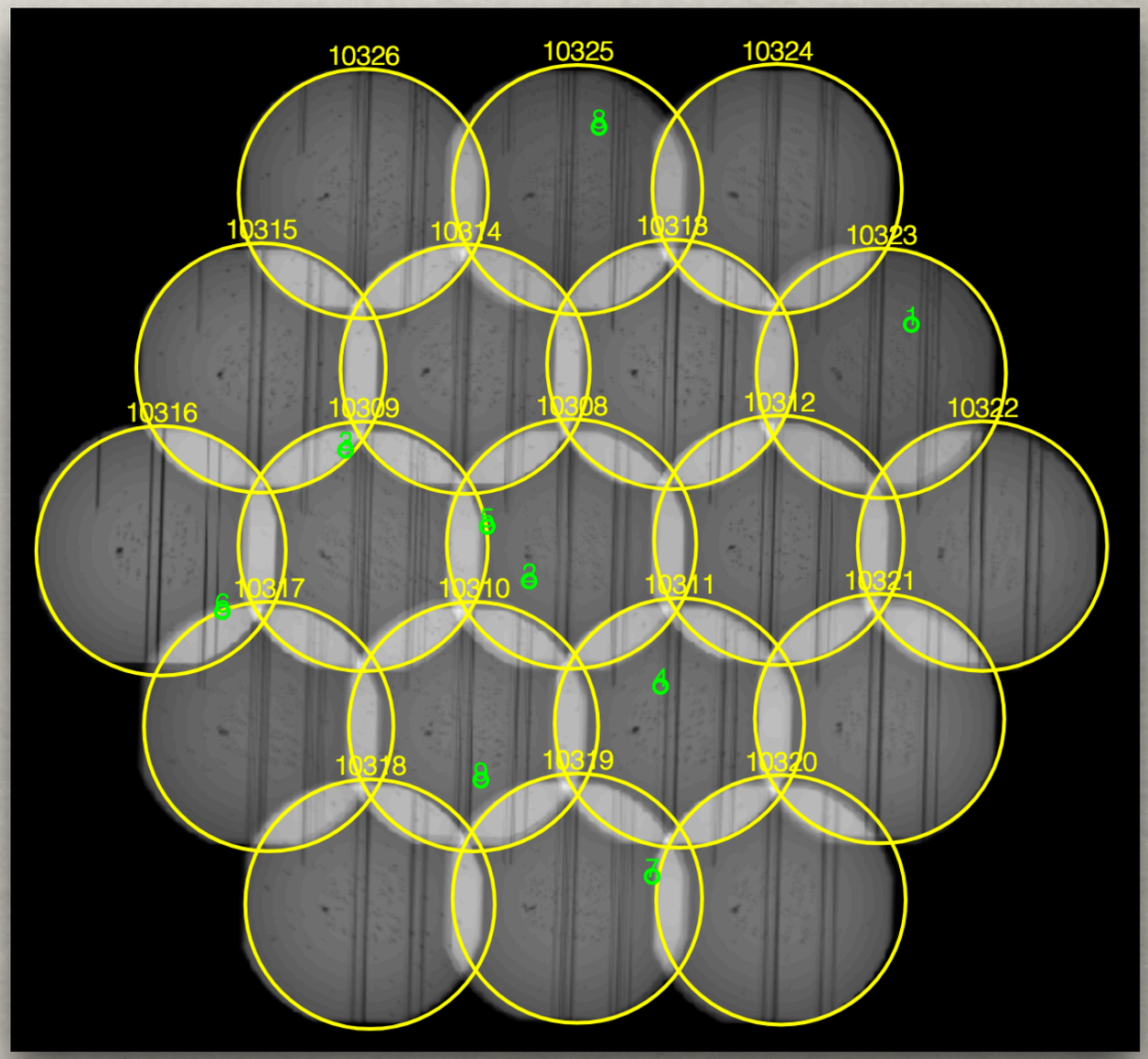

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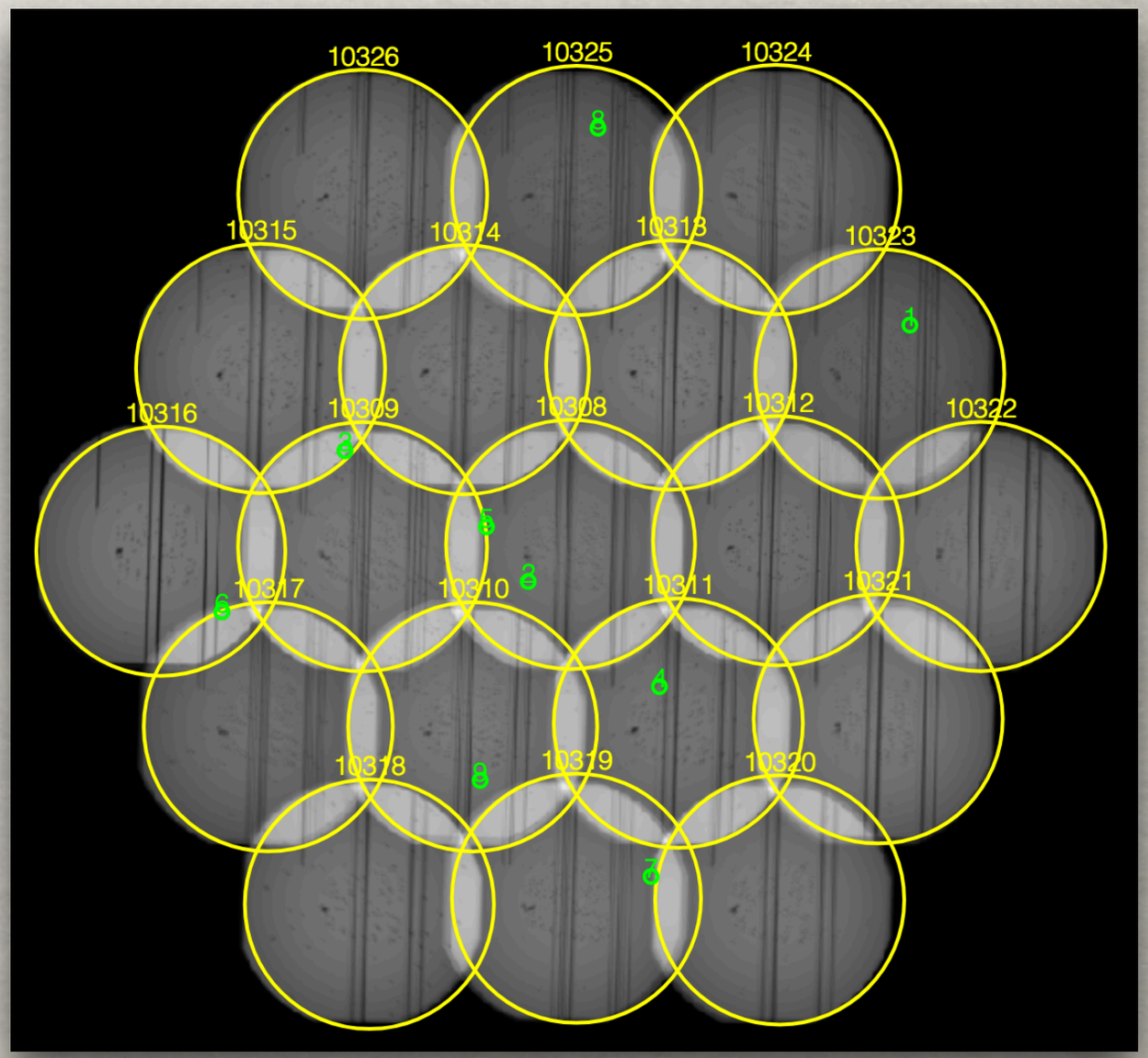

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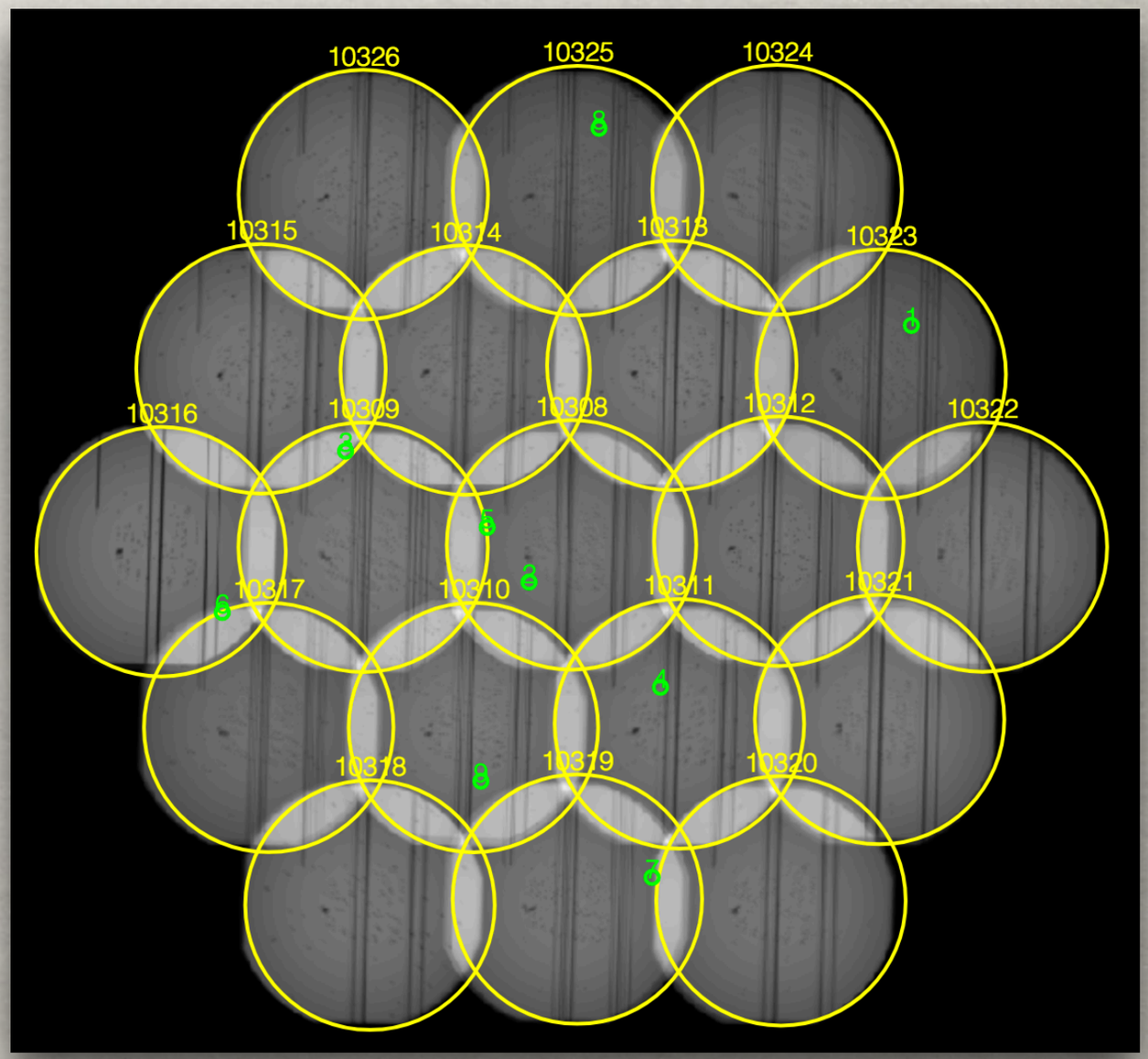

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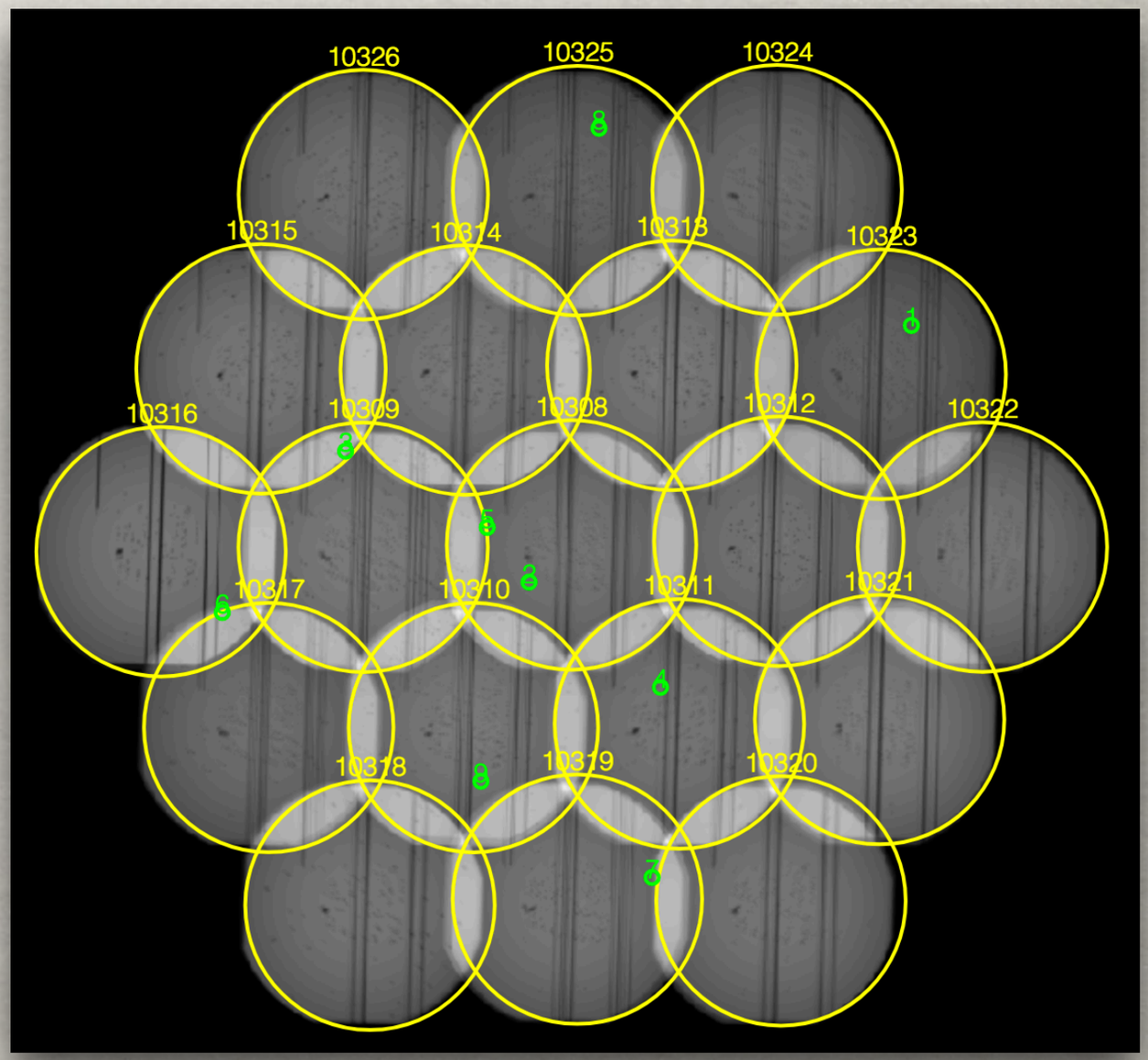

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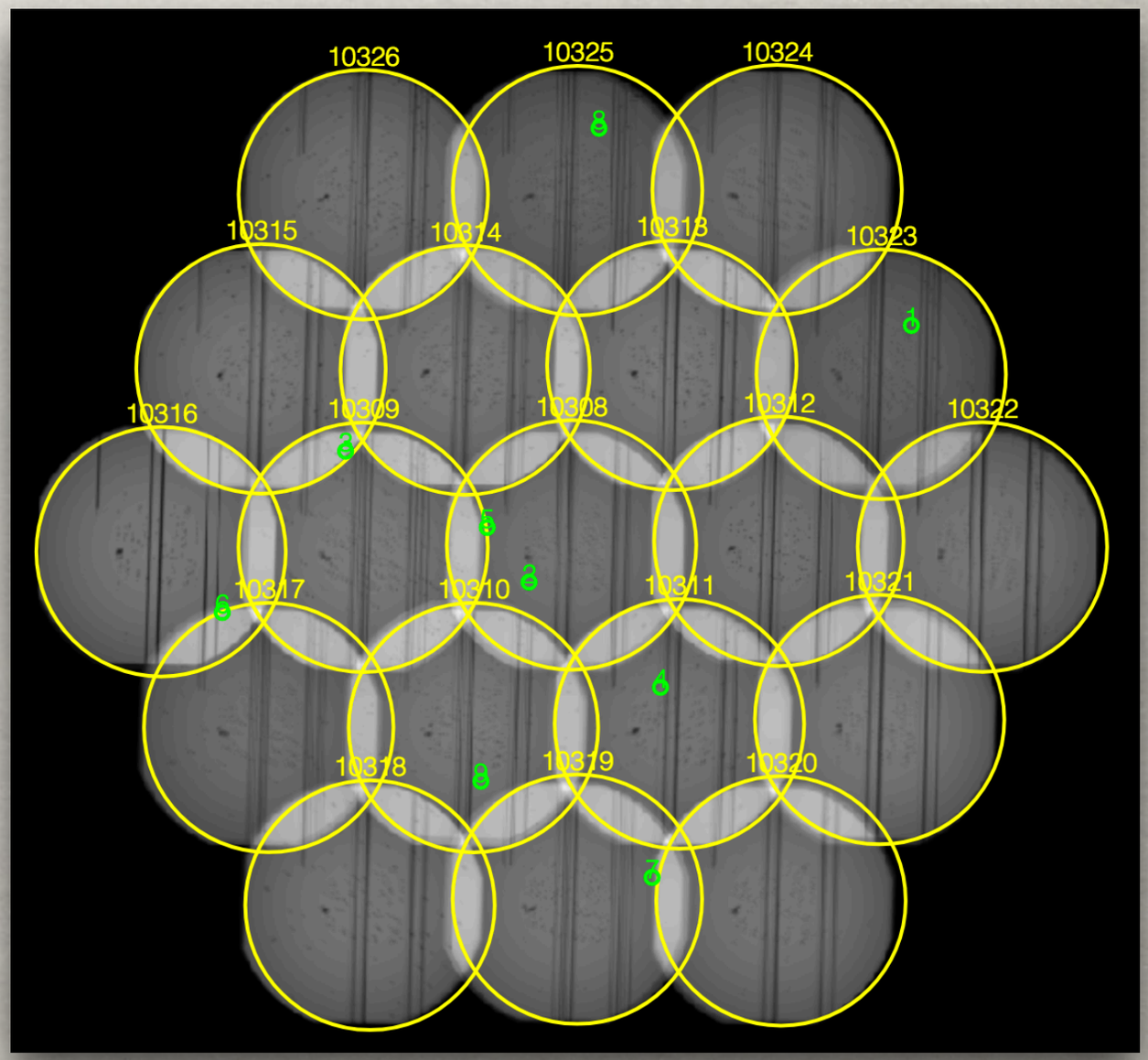
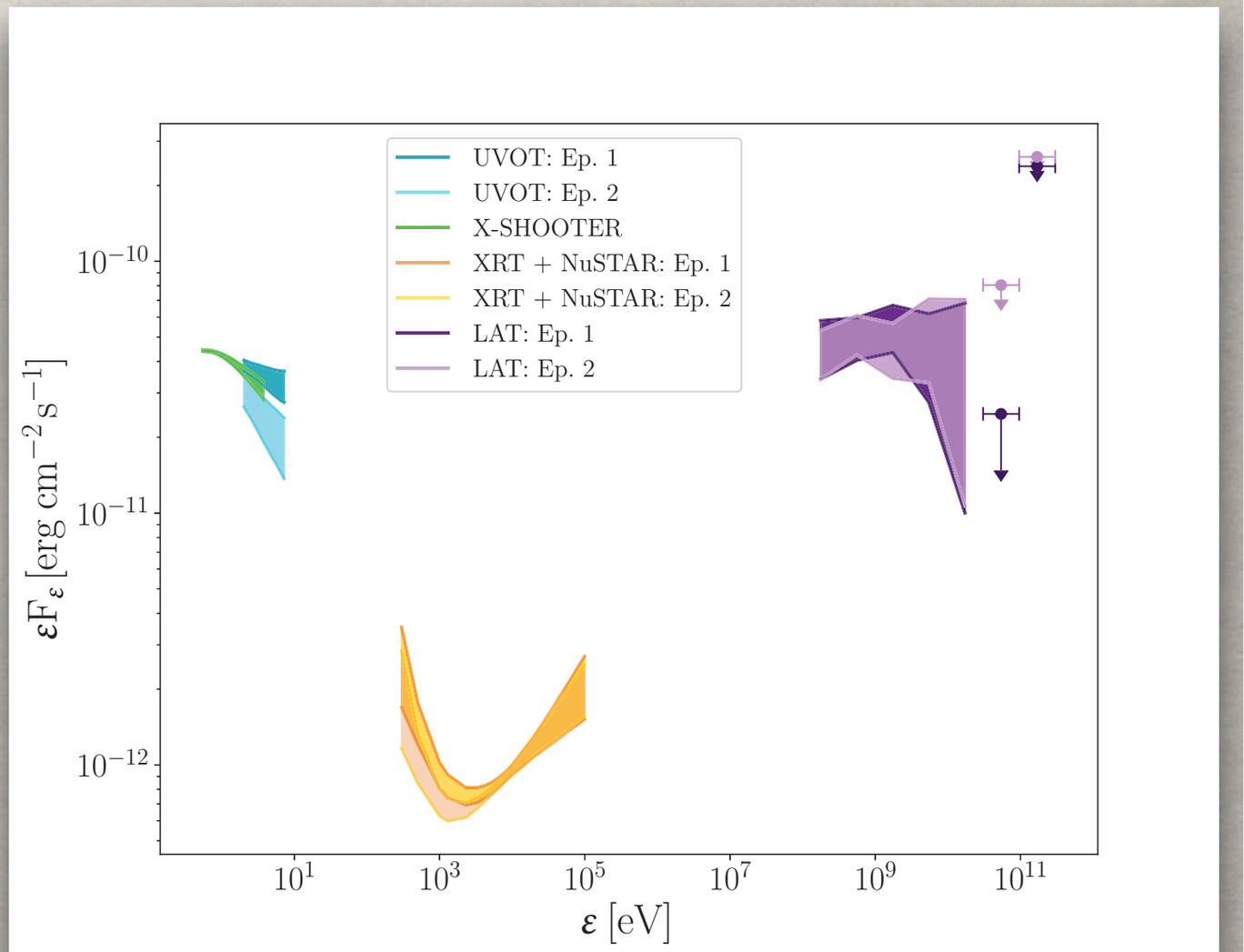
- MAGIC reports first-ever detection at $\varepsilon_\gamma > 100$ GeV



A TXS 0506+056 Neutrino?

- IceCube-led Science paper: Focused on Fermi+MAGIC coincidence, ~3σ



Keivani+2018

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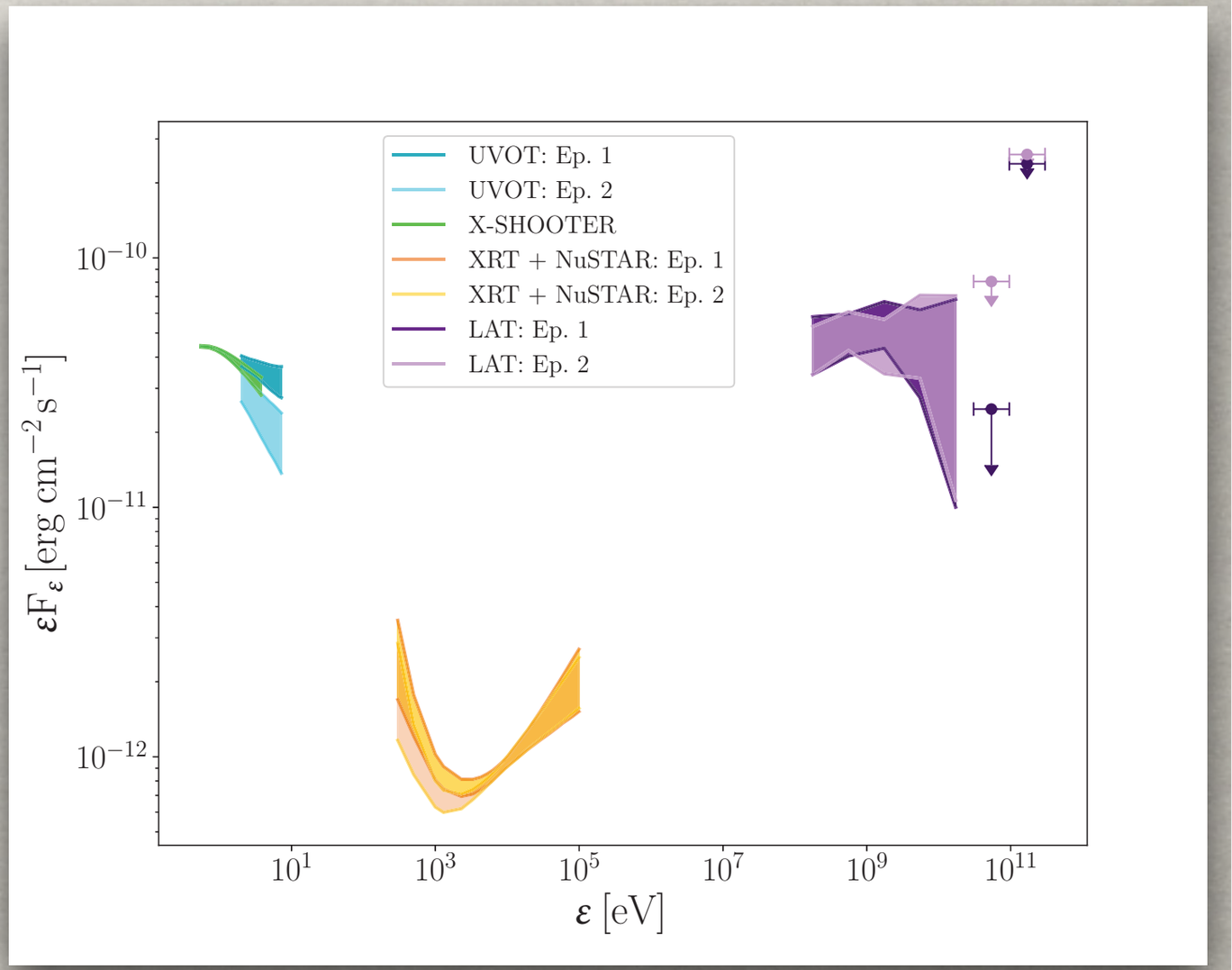

Keivani+2018

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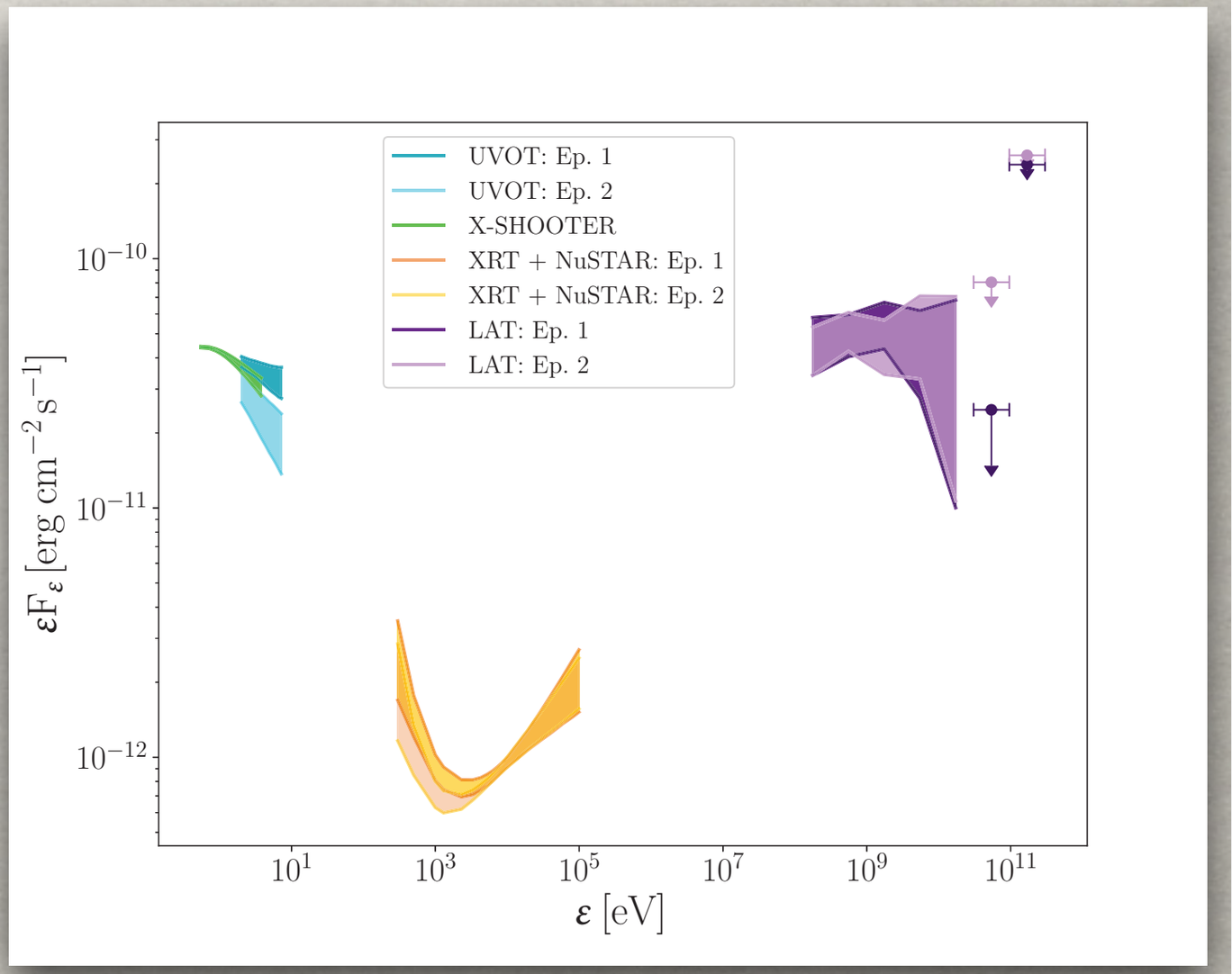

Keivani+2018

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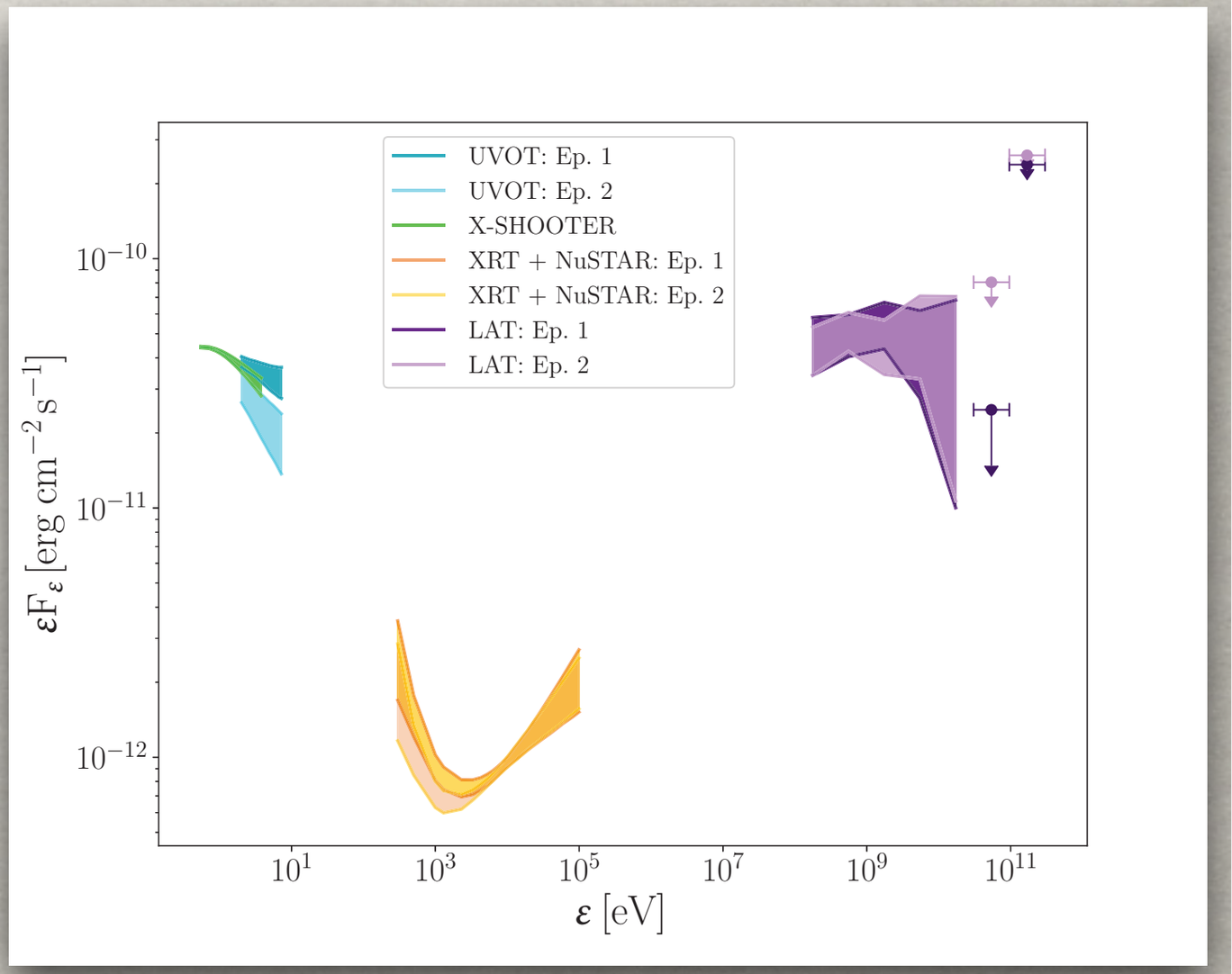
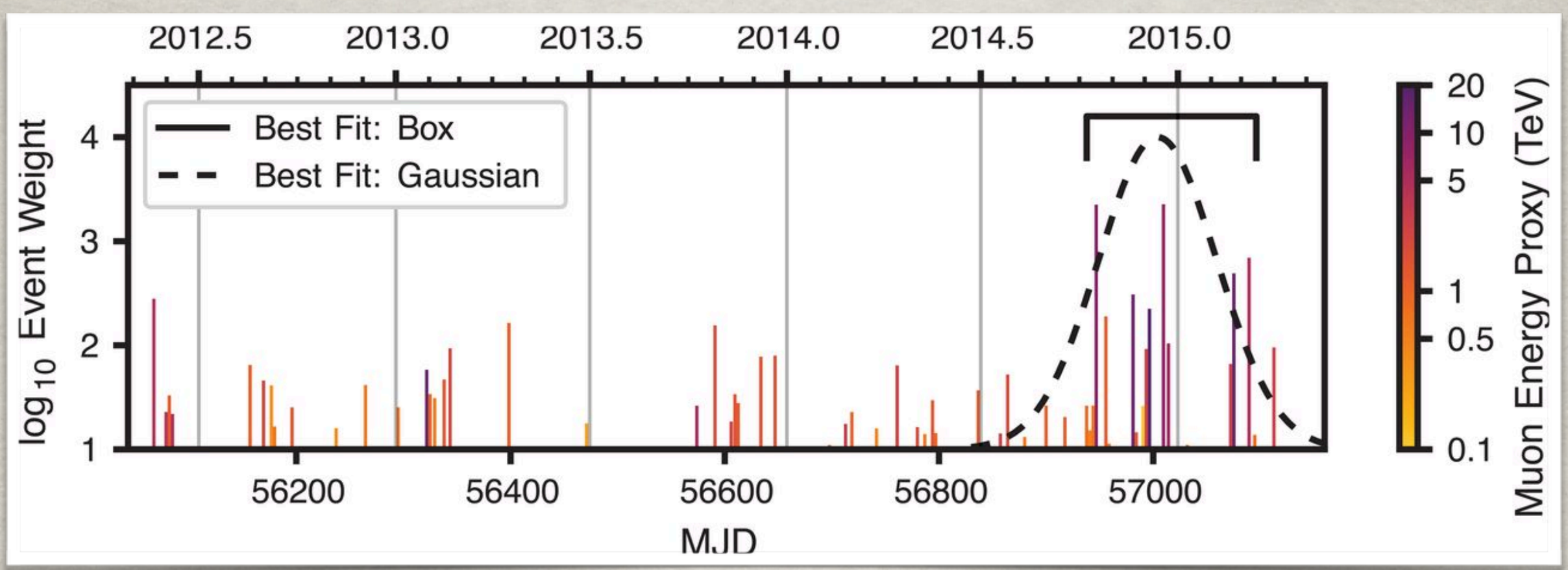
- Strongest limits via deep "dip" in the source SED at X-ray energies (Swift + NuSTAR)



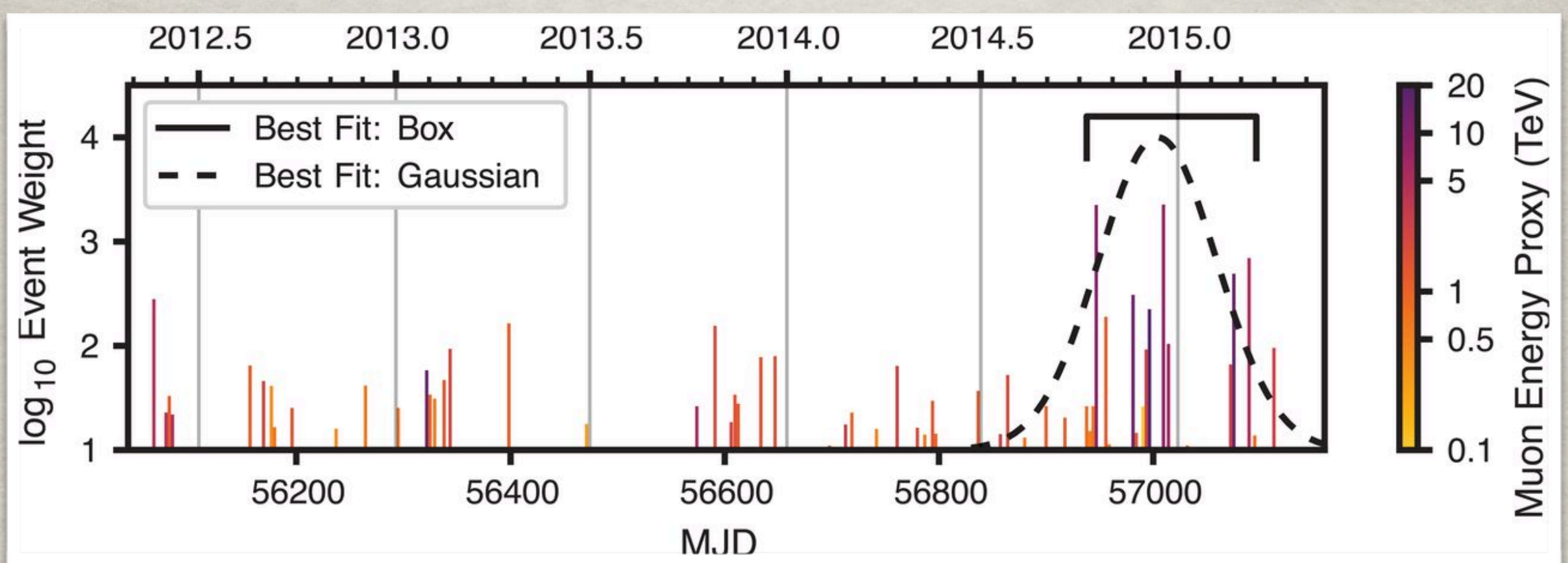
Keivani+2018

Blazar Neutrinos!



IceCube 2018b

Blazar Neutrinos!



IceCube 2018b

- IceCube's ***second*** Science paper in 12 July 2018 issue

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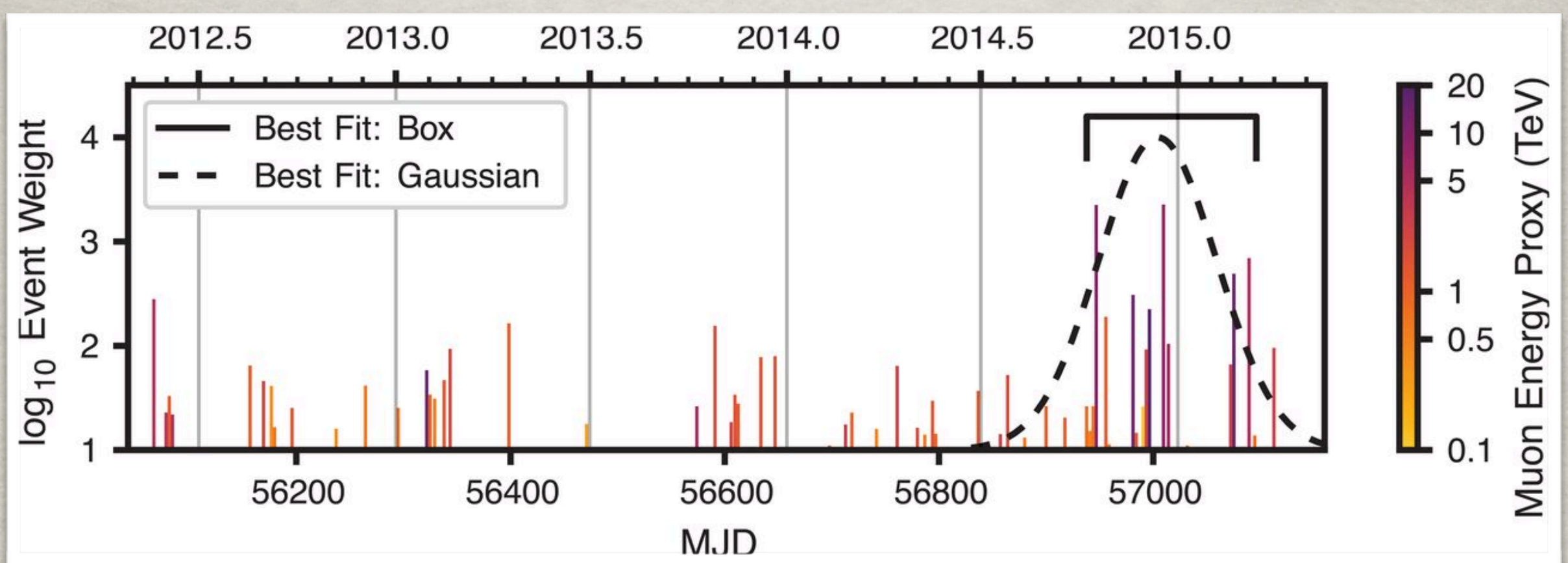

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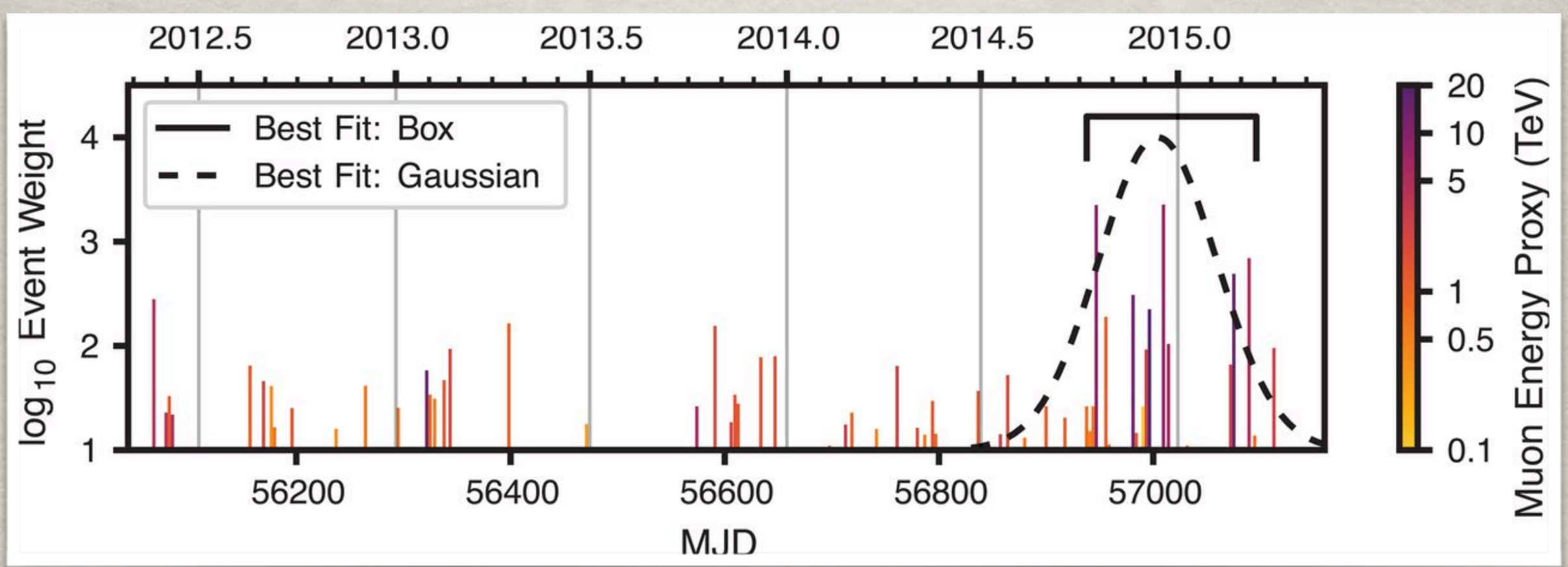

IceCube 2018b

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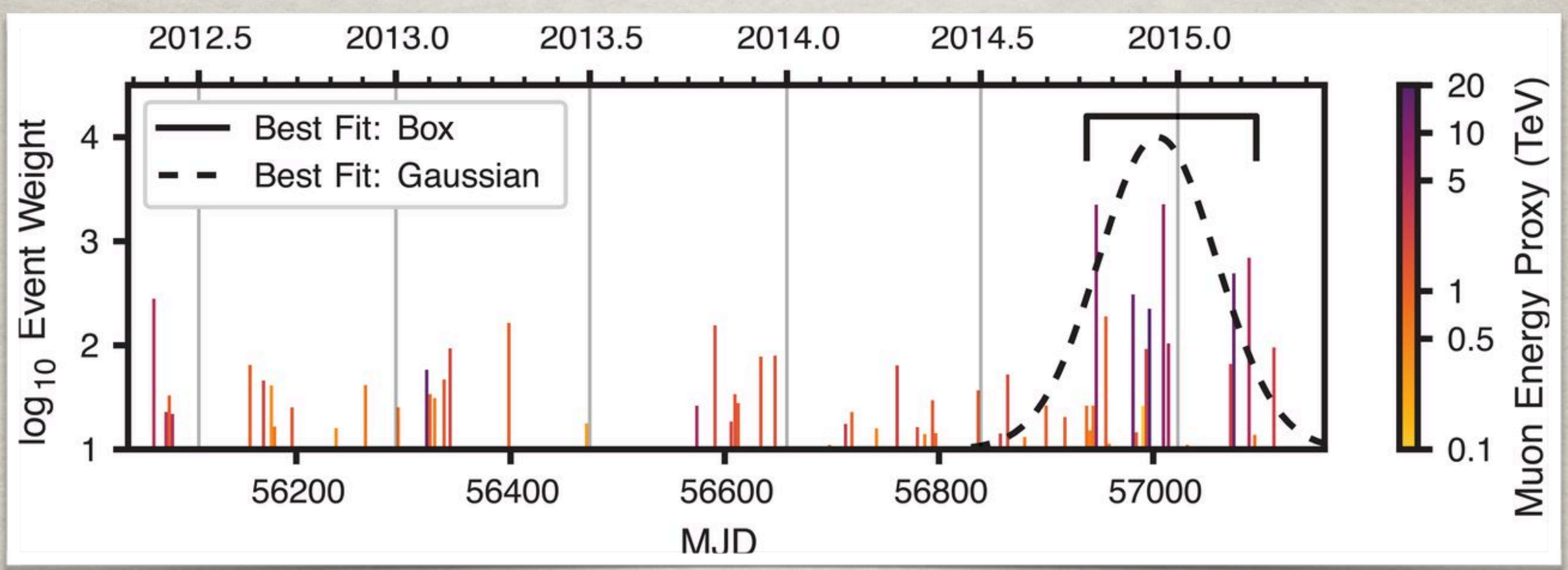
- 3.5σ + statistically independent of IceCube-170922A

Blazar Neutrinos!



IceCube 2018b

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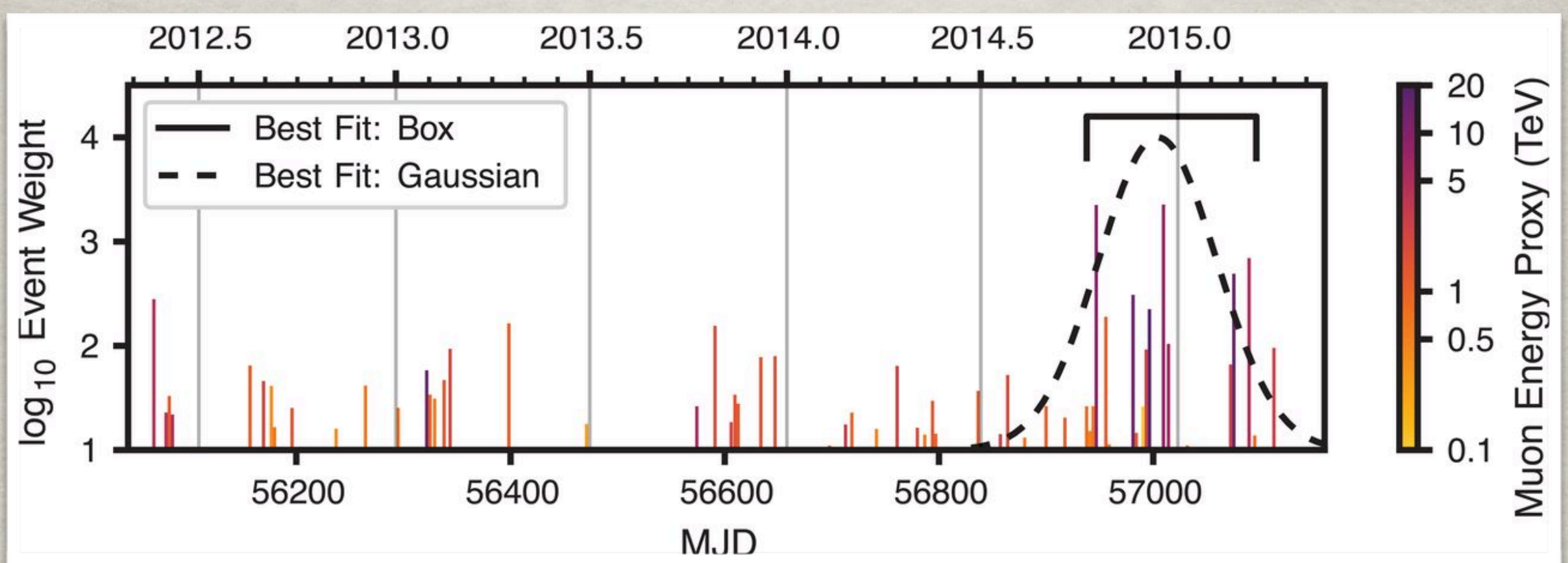
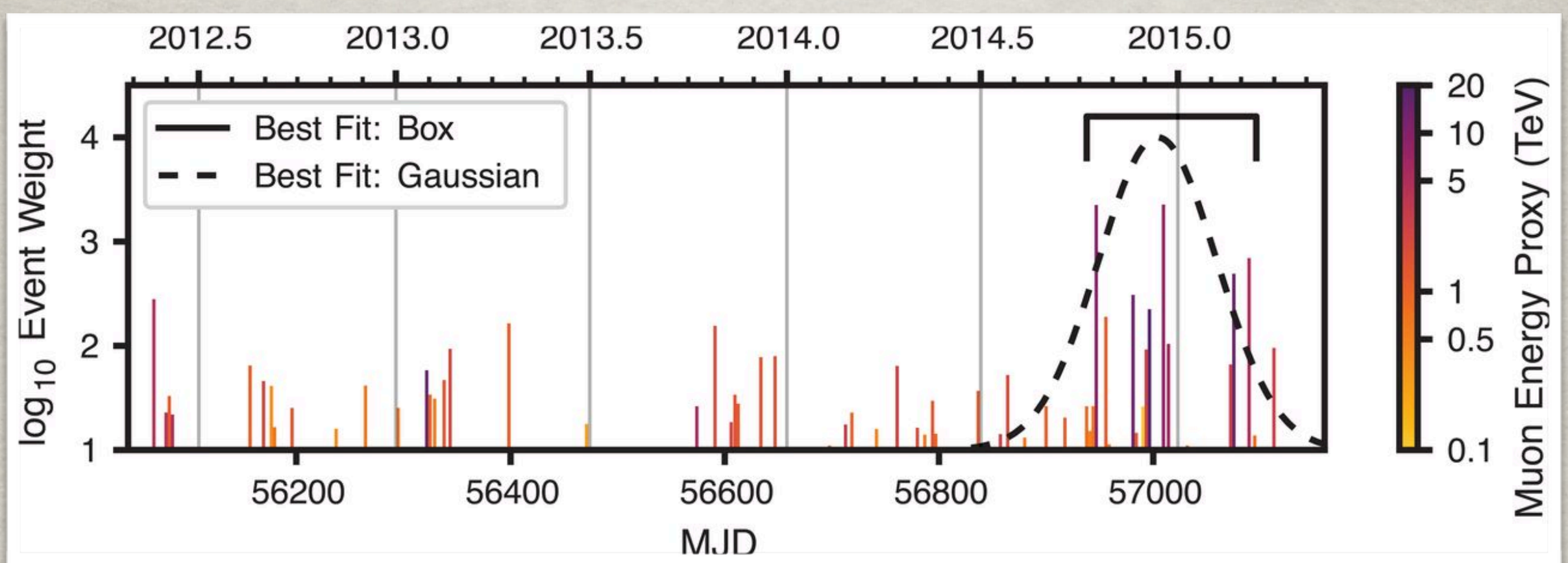


IceCube 2018b

- First identified source of high-energy neutrinos

Blazar Neutrinos!



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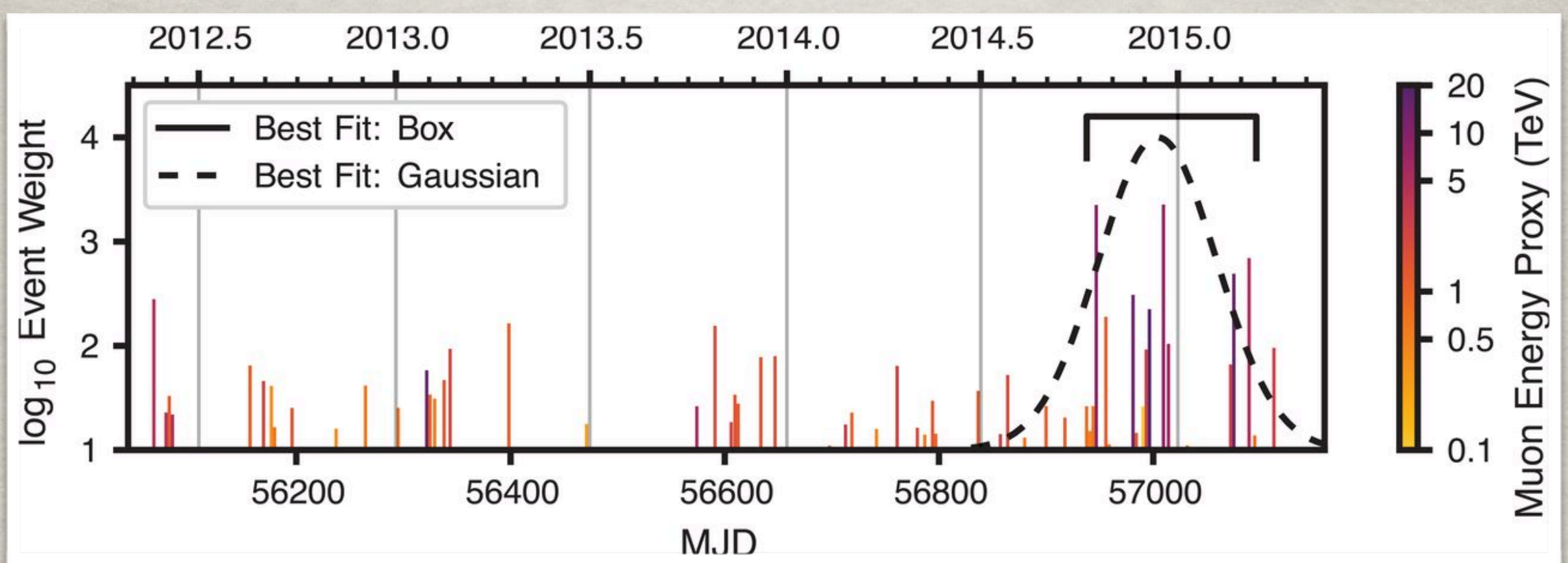

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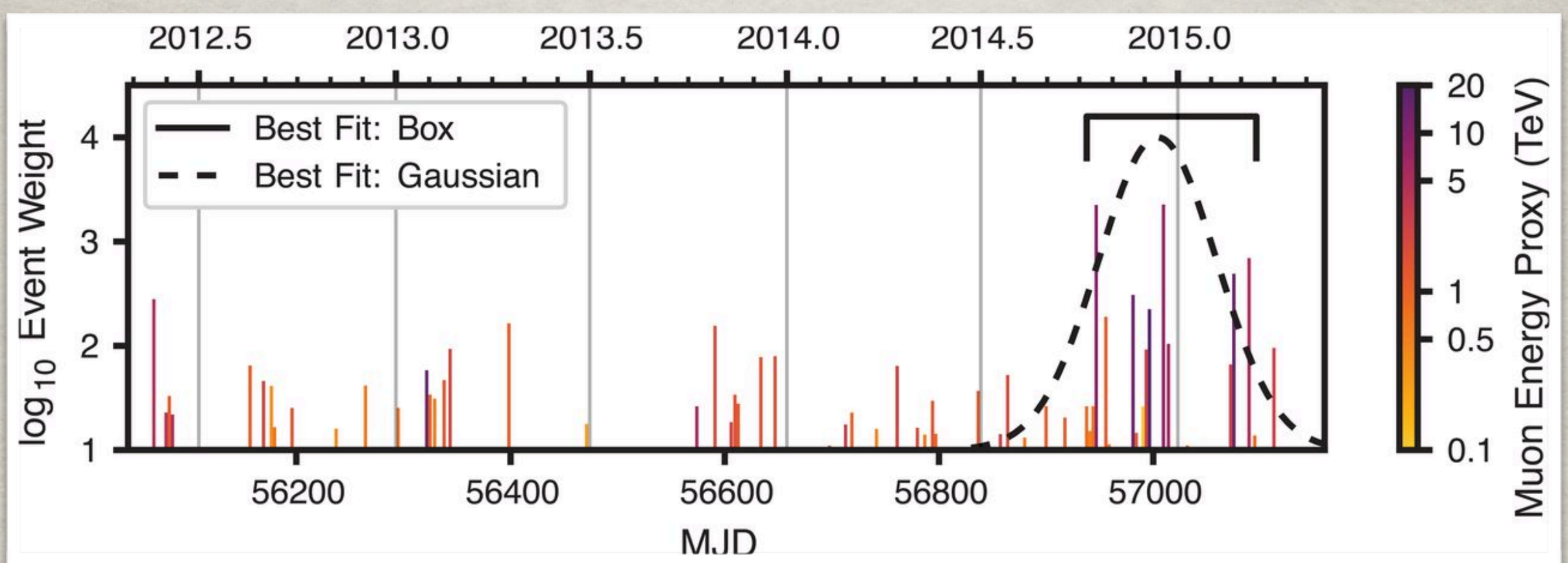

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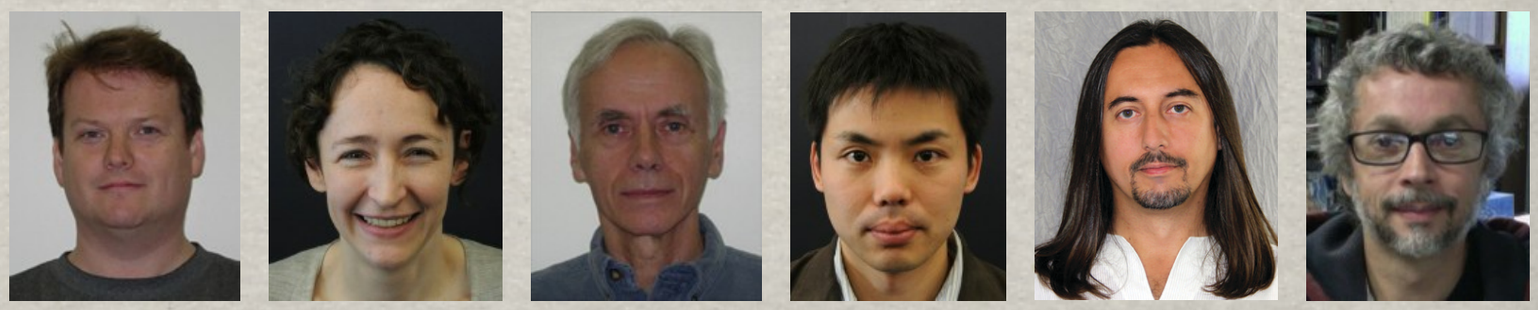
- But: Hard to explain 100% of IceCube neutrinos with blazars

2. ANITA Anomalous Events

DBF &
S. Sigurdsson, S. Shandera,
P. Meszárós, K. Murase,
M. Mostafá, S. Coutu



ArXiv:1809.09615

What is ANITA?

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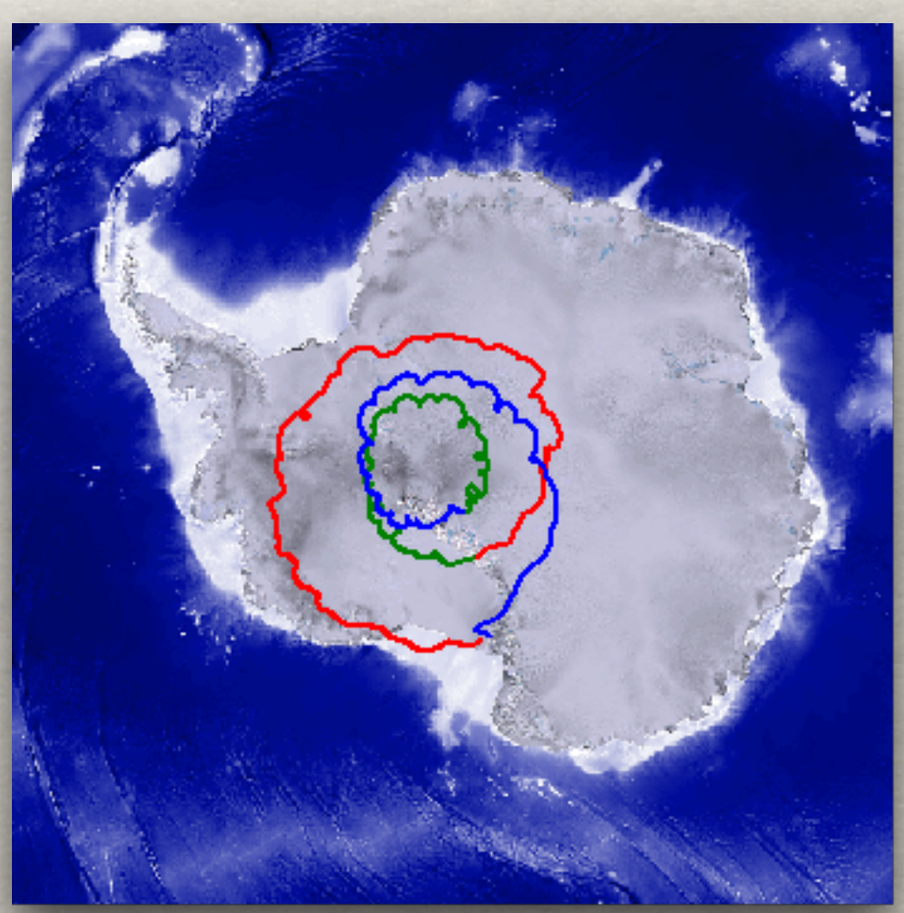

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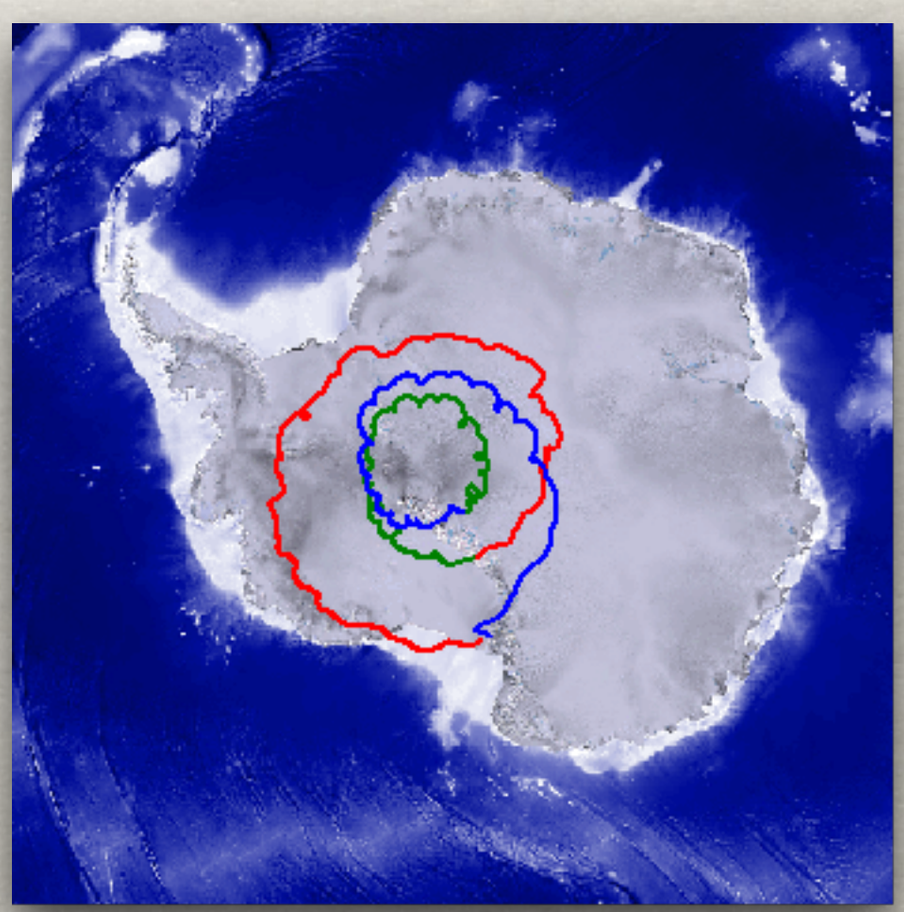
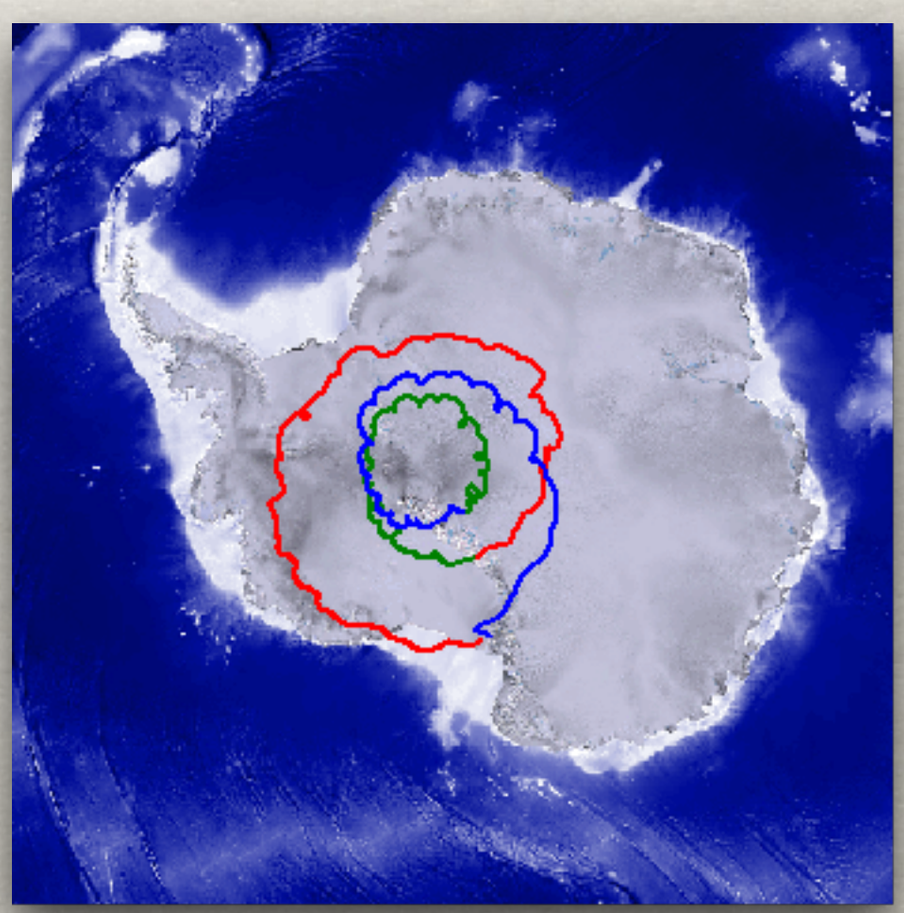
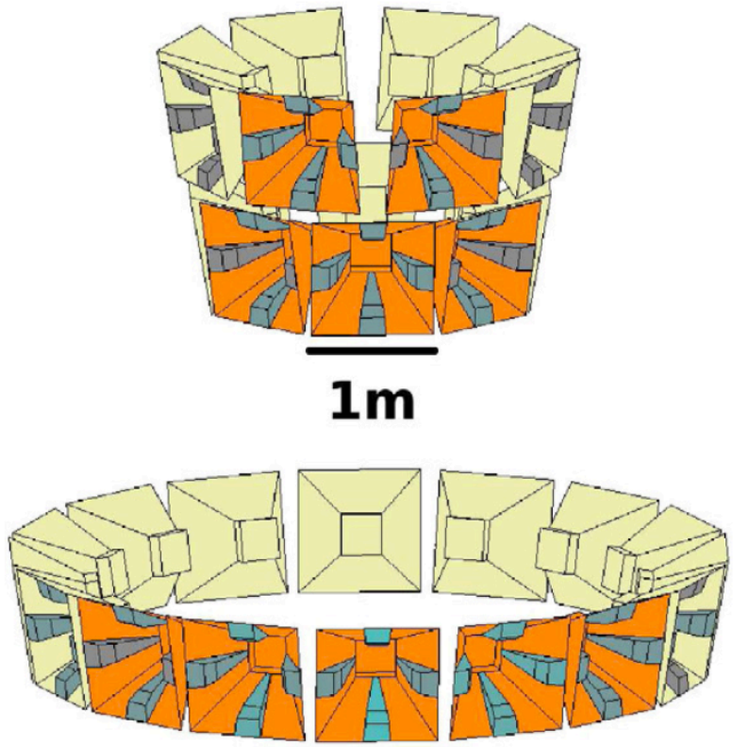
- NASA "Ultra Long Duration Balloon" experiment
- Seeking radio signature of UHE Earth-skimming neutrino interactions in ice (Askaryan)
- Months-long flights "orbiting" Antarctica
- 4 flights to-date, 3 flights published

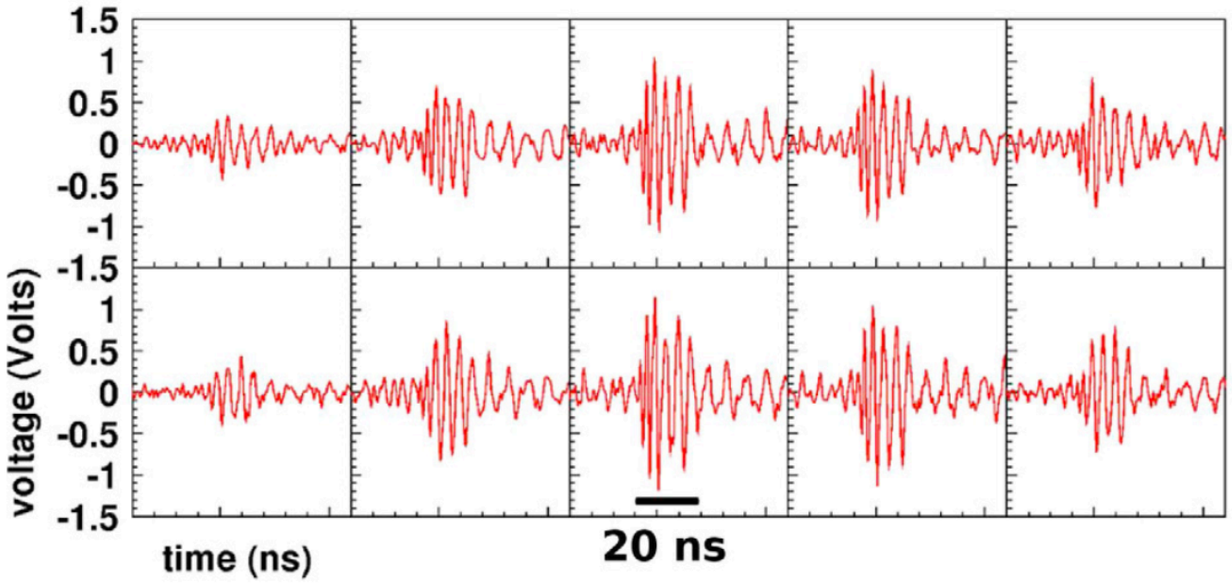


What is ANITA?

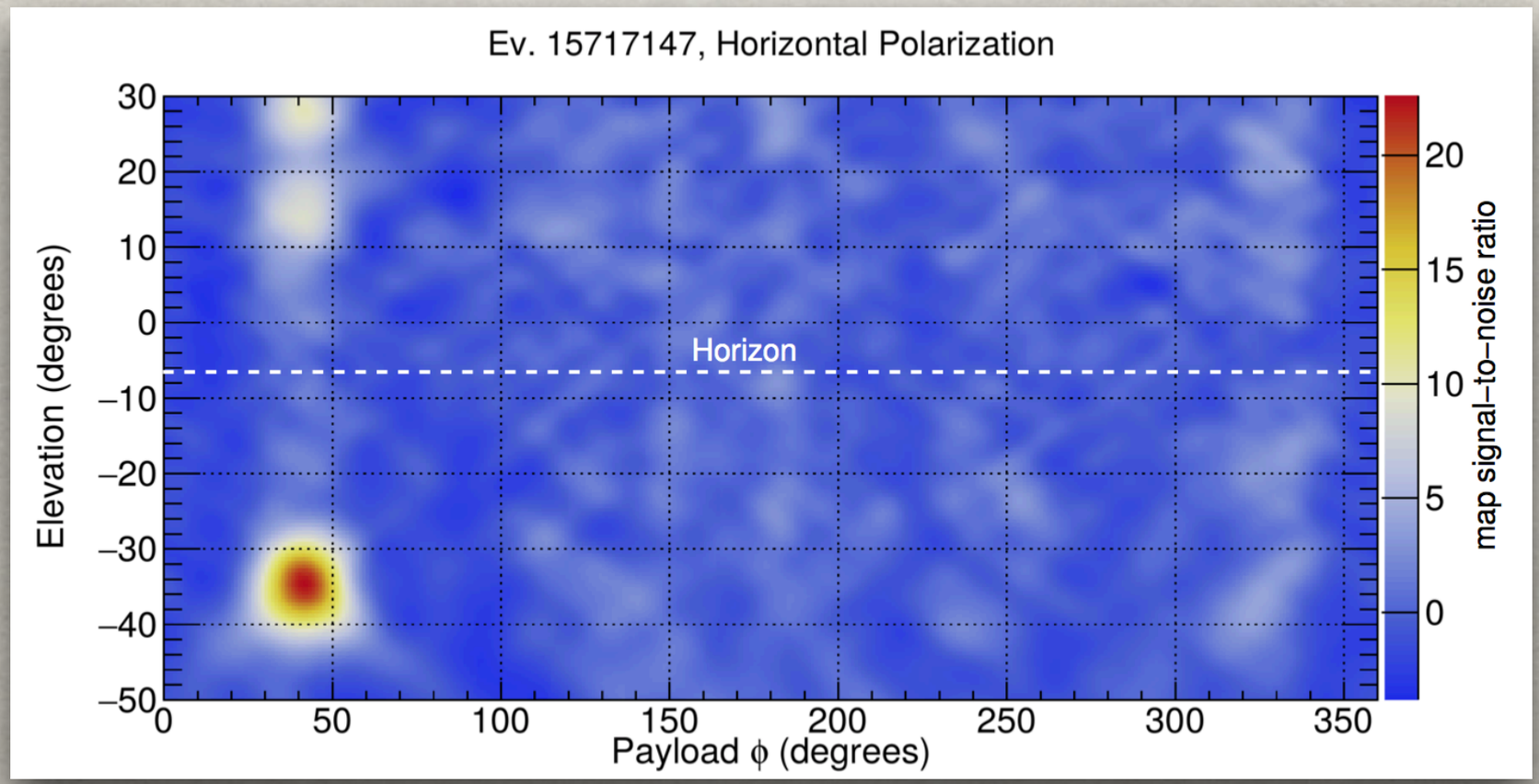
- NASA "Ultra Long Duration Balloon" experiment
- Seeking radio signature of UHE Earth-skimming neutrino interactions in ice (Askaryan)
- Months-long flights "orbiting" Antarctica
- *4* flights to-date, 3 flights published
- One candidate Askaryan event (p=0.7, conservatively)





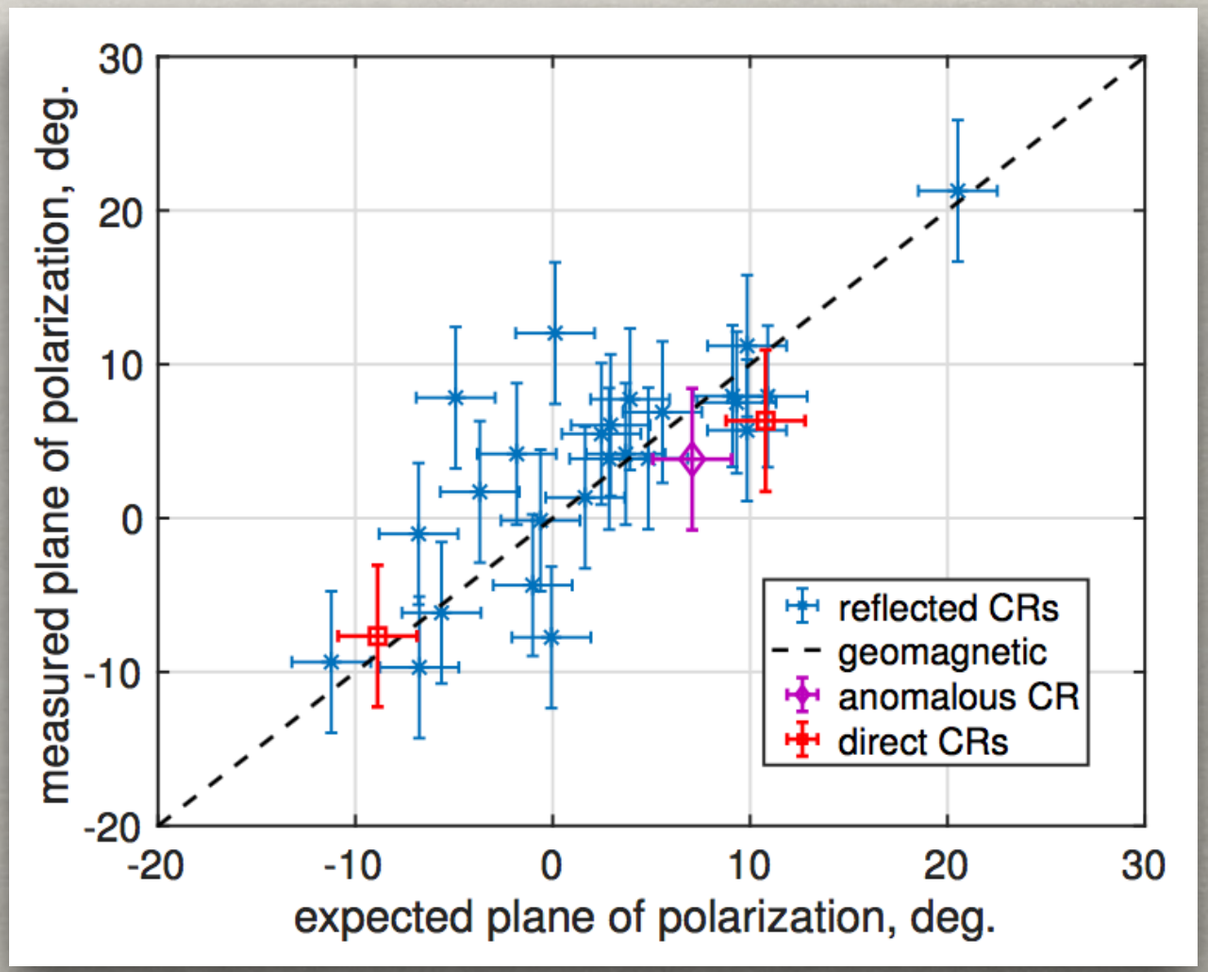


Romero-Wolf+15



Gorham+18

ANITA Anomalous Events



Gorham+18

ANITA Anomalous Events

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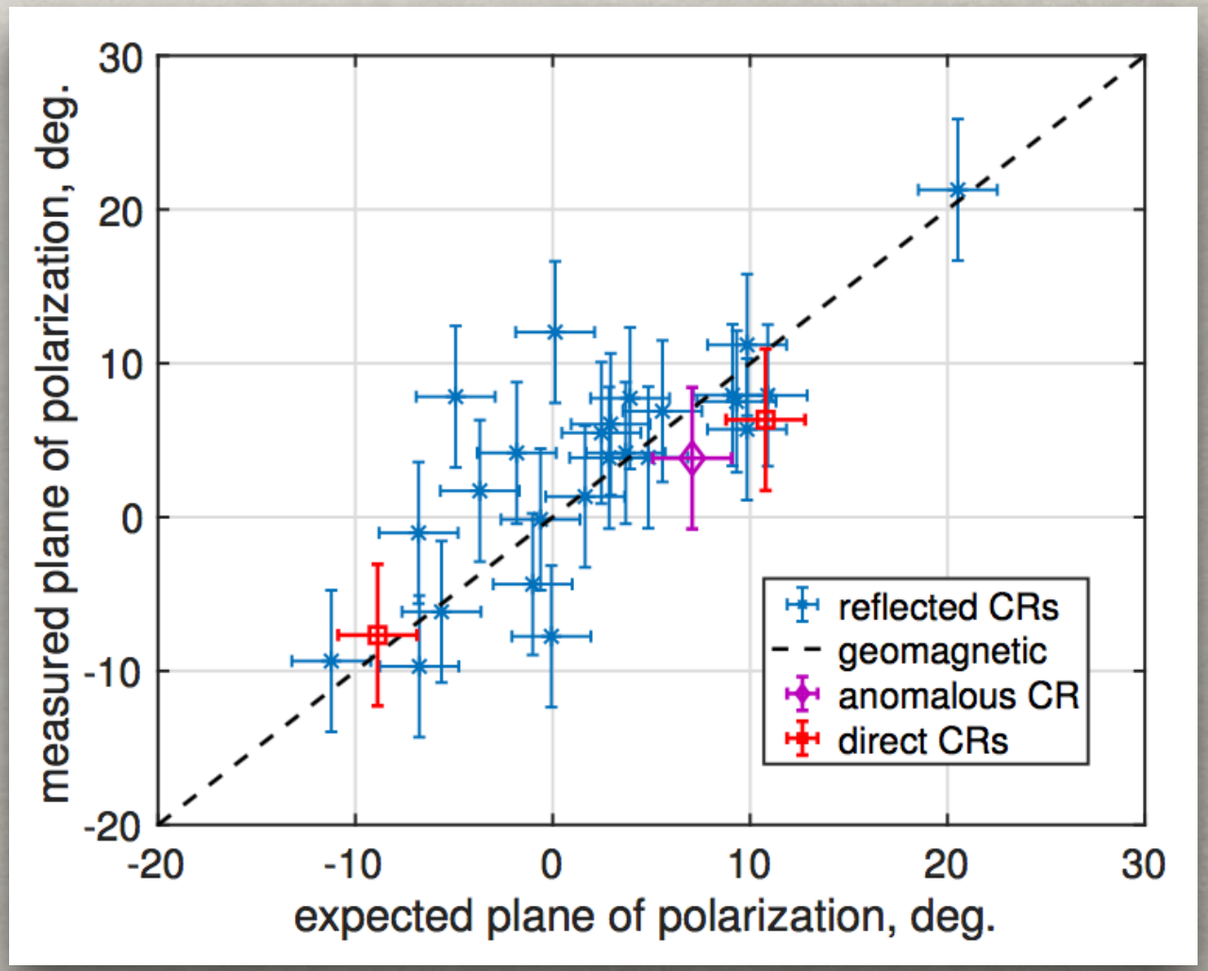

Gorham+18

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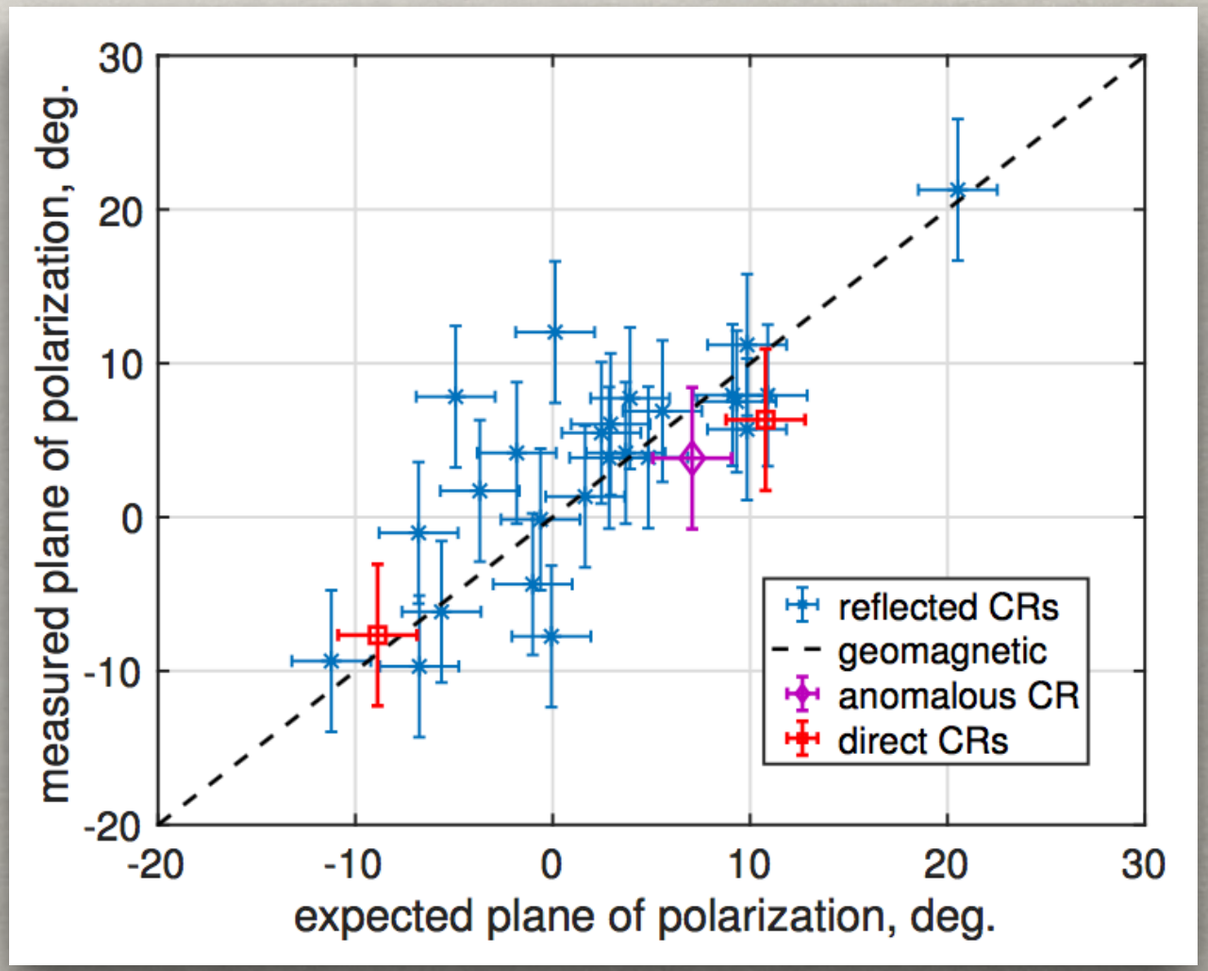
- …and directly-observed CRs just above Earth limb (red)



Gorham+18

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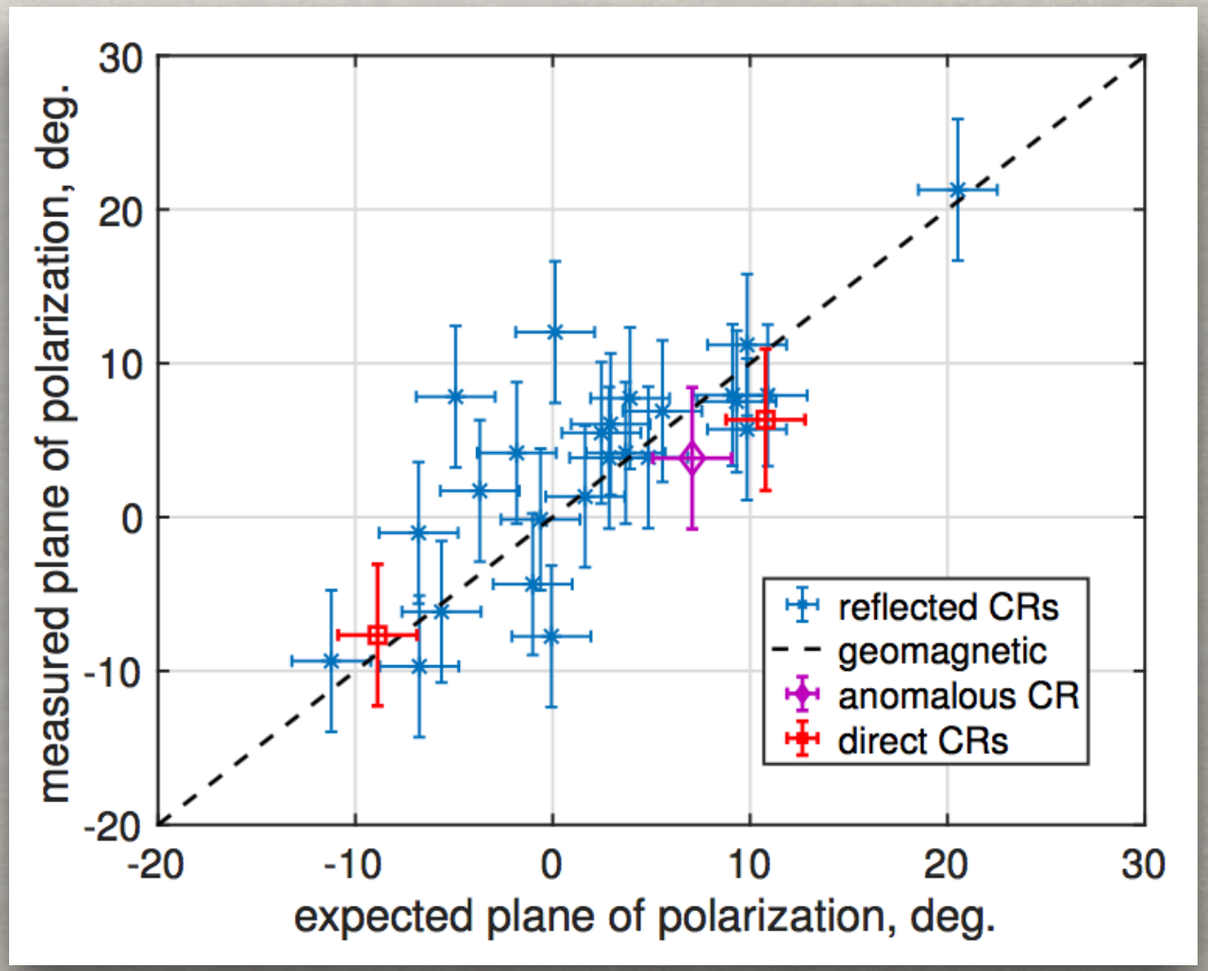

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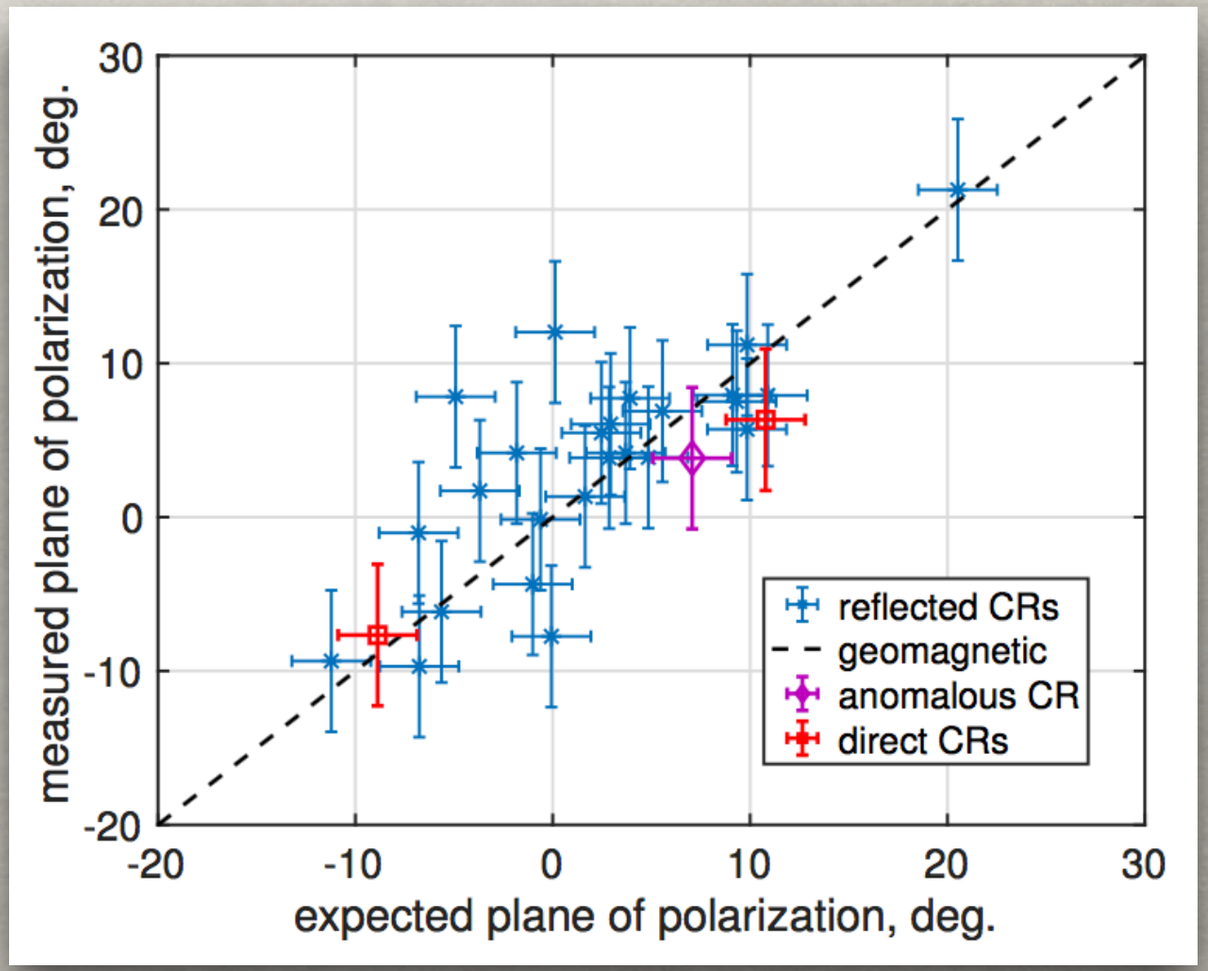

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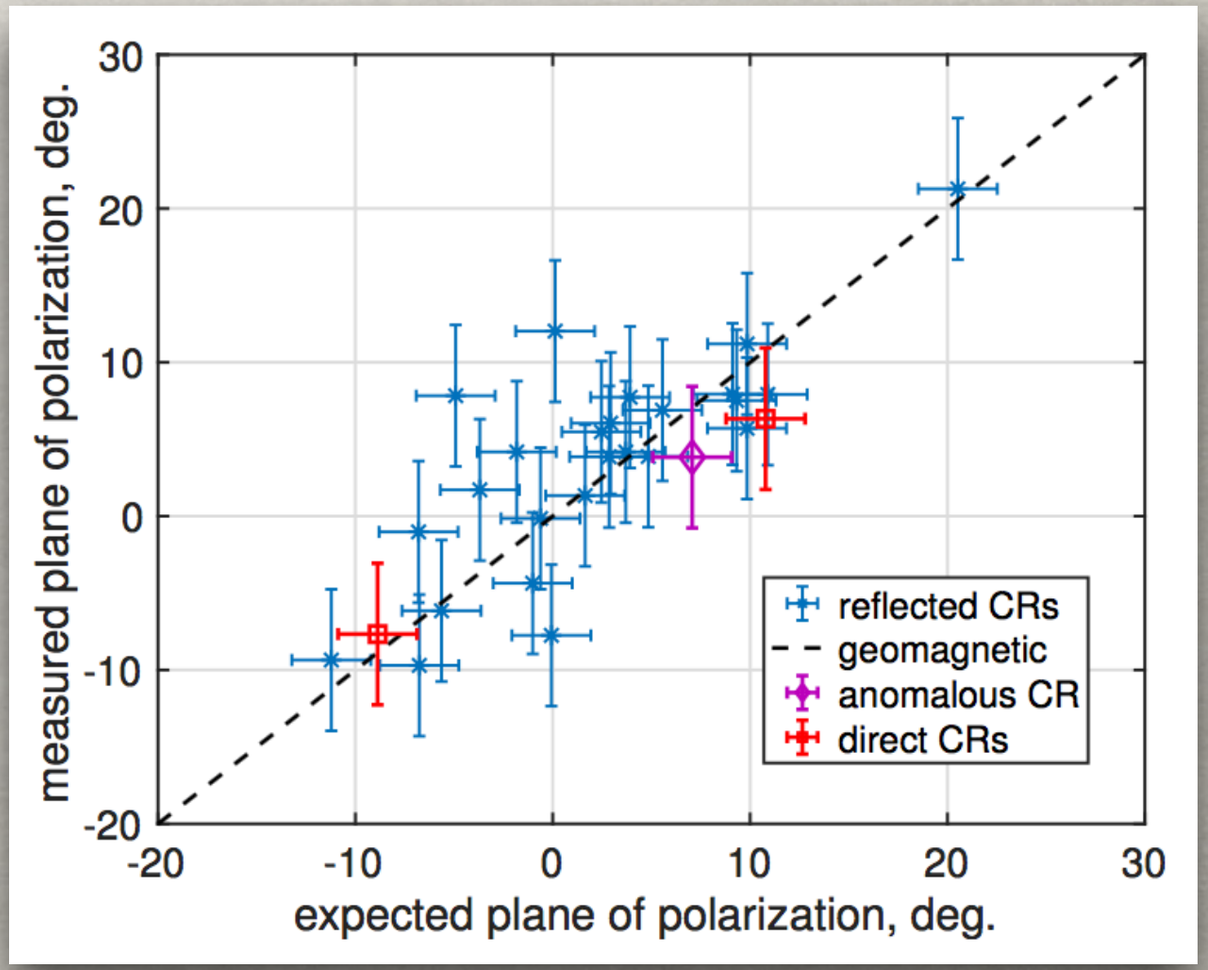

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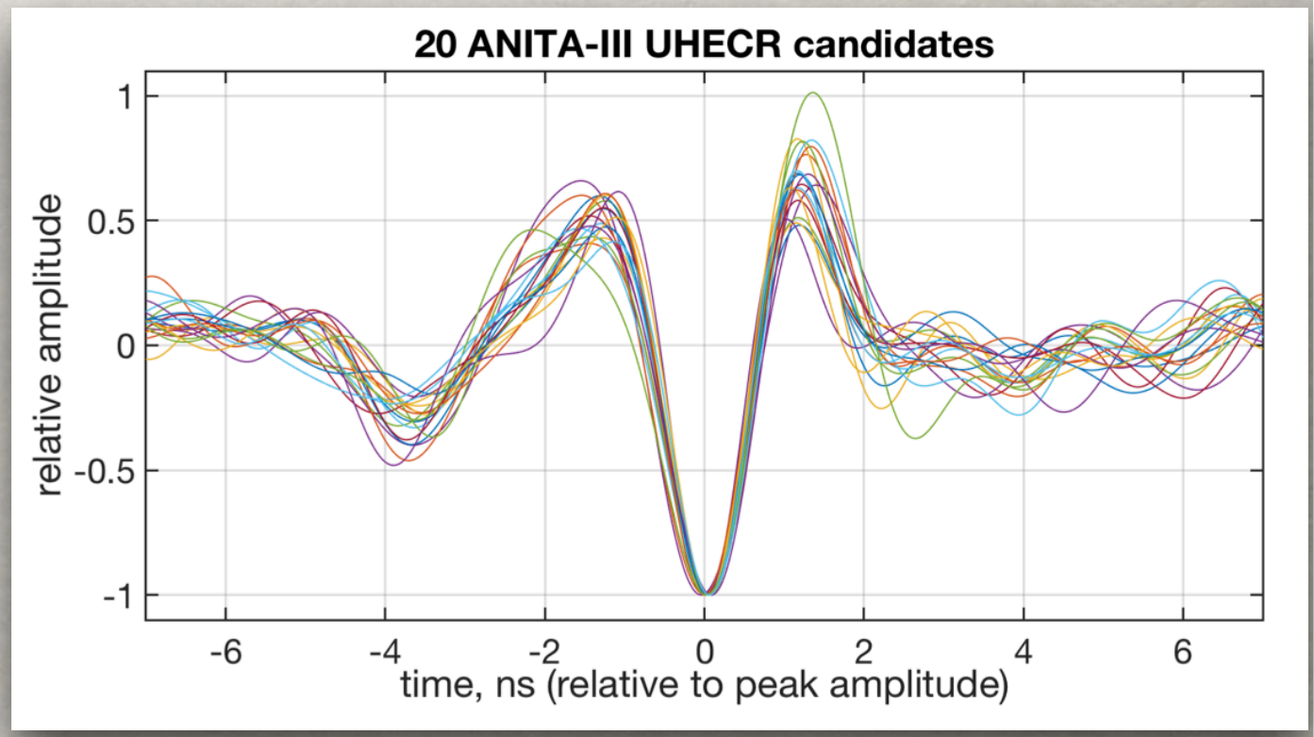
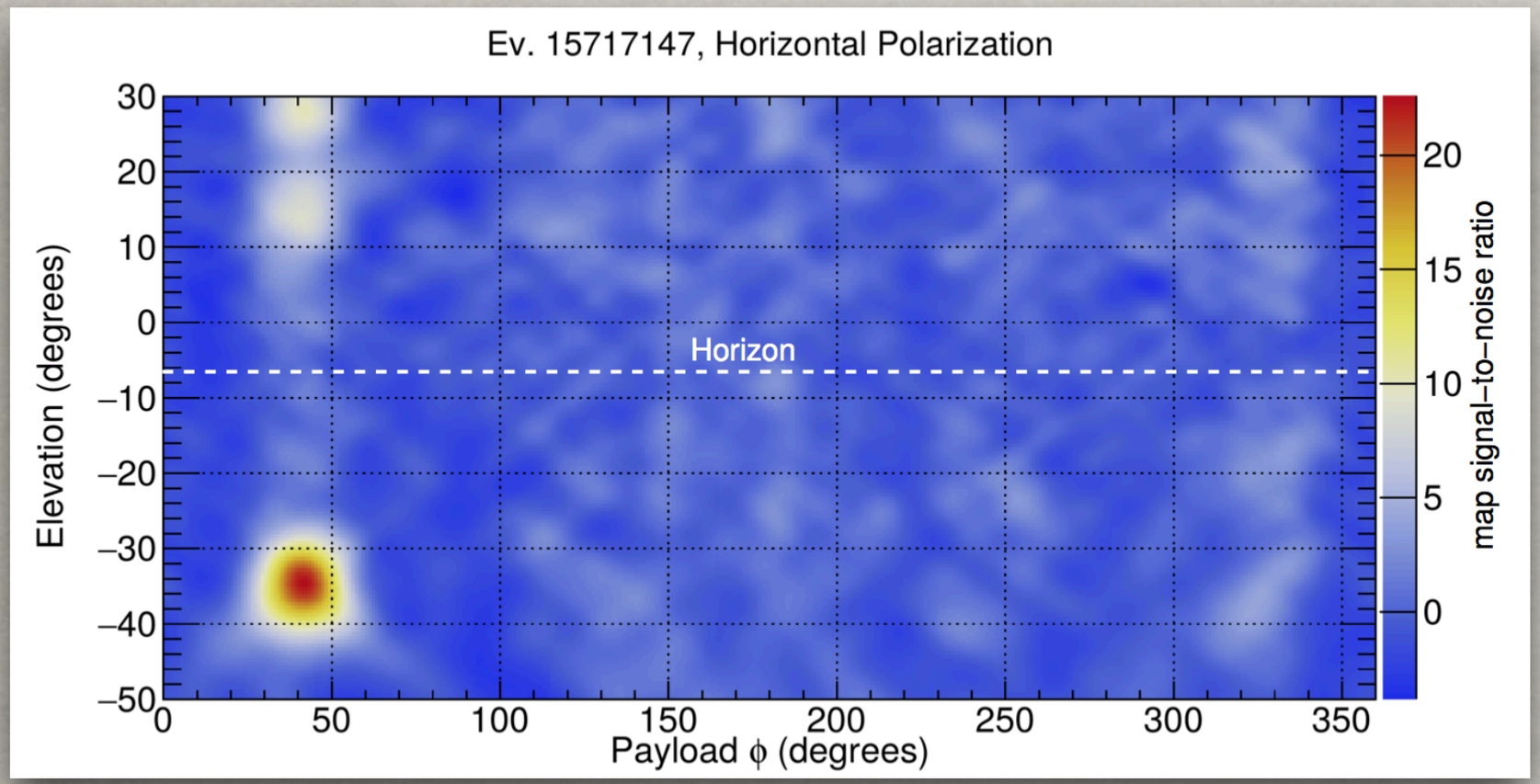
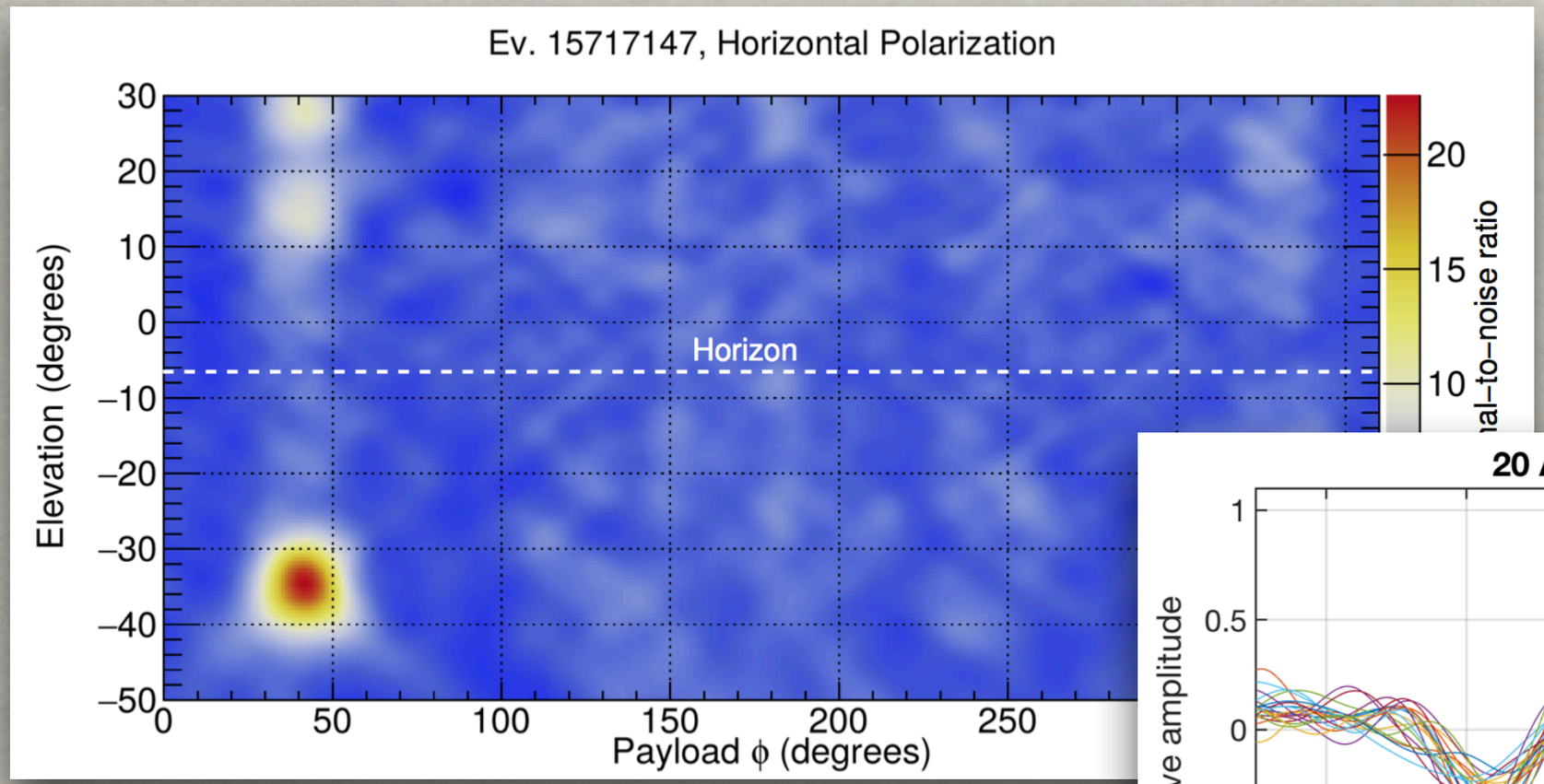


Gorham+18


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


Ev. 15717147, Horizontal Polarization
Horizon
Elevation (degrees)
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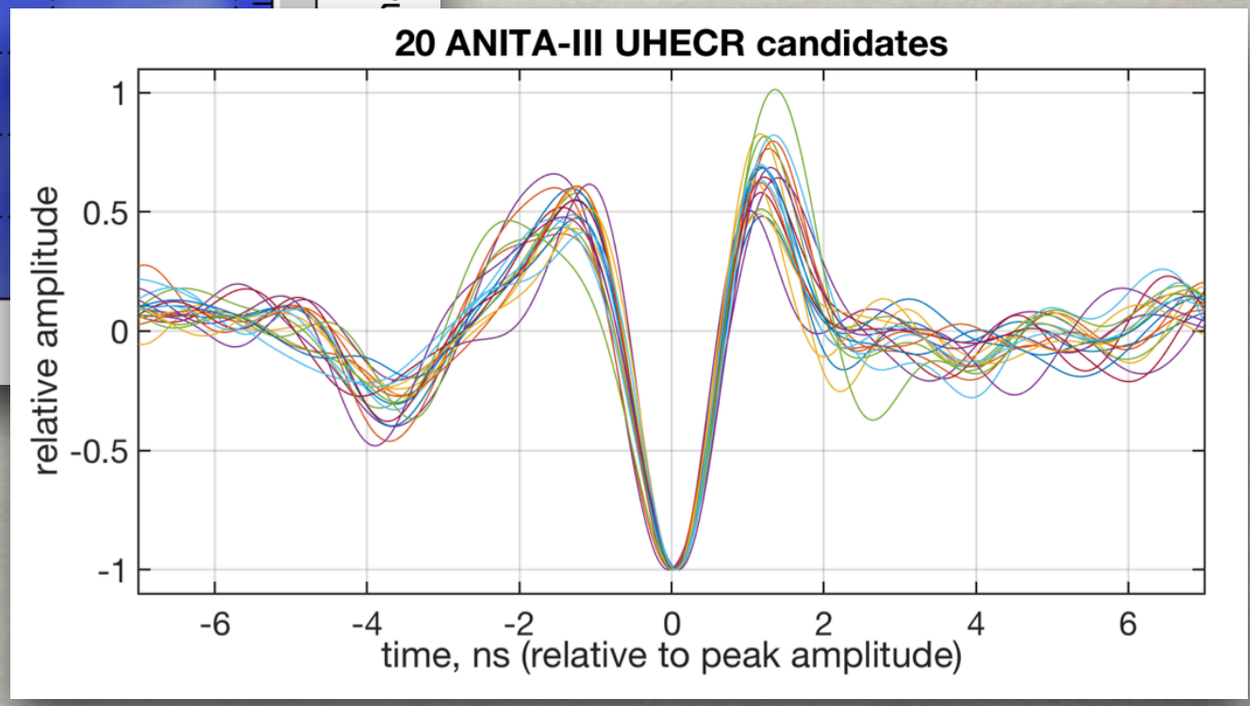
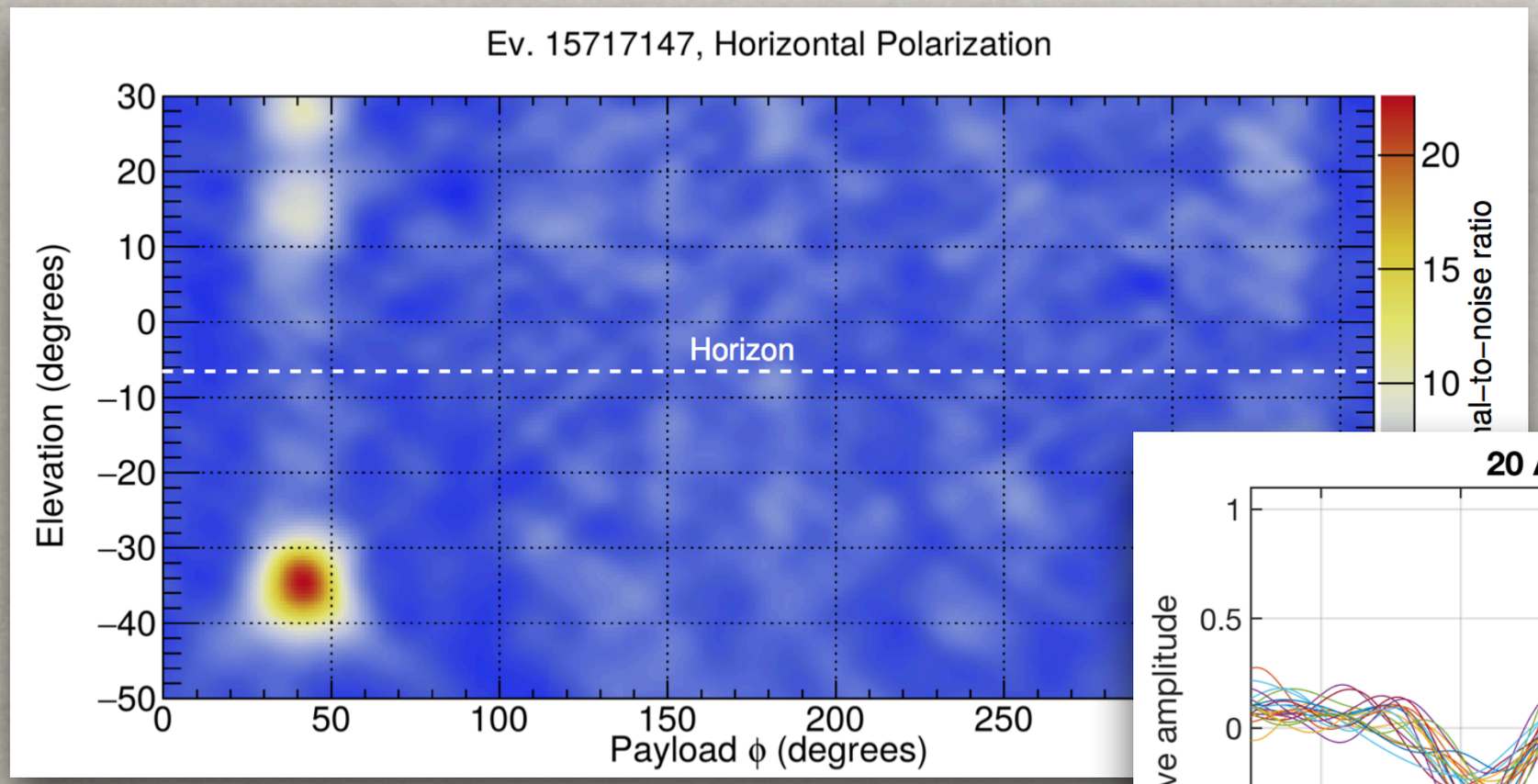

20 ANITA-III UHECR candidates
relative amplitude
time, ns (relative to peak amplitude)
1
0.5
0
-0.5
-1
-6
-4
-2
0
2
4
6

Gorham+18


Ev. 15717147, Horizontal Polarization
Horizon
Elevation (degrees)
Payload ϕ (degrees)
30
20
10
0
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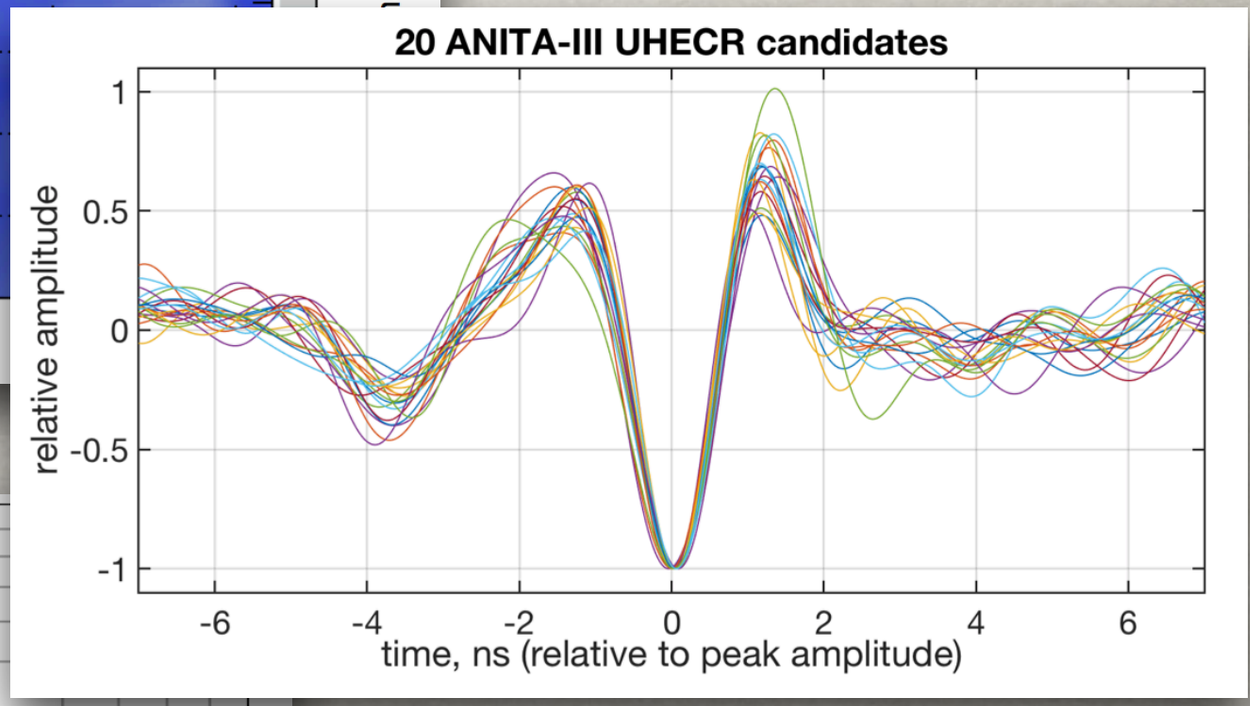
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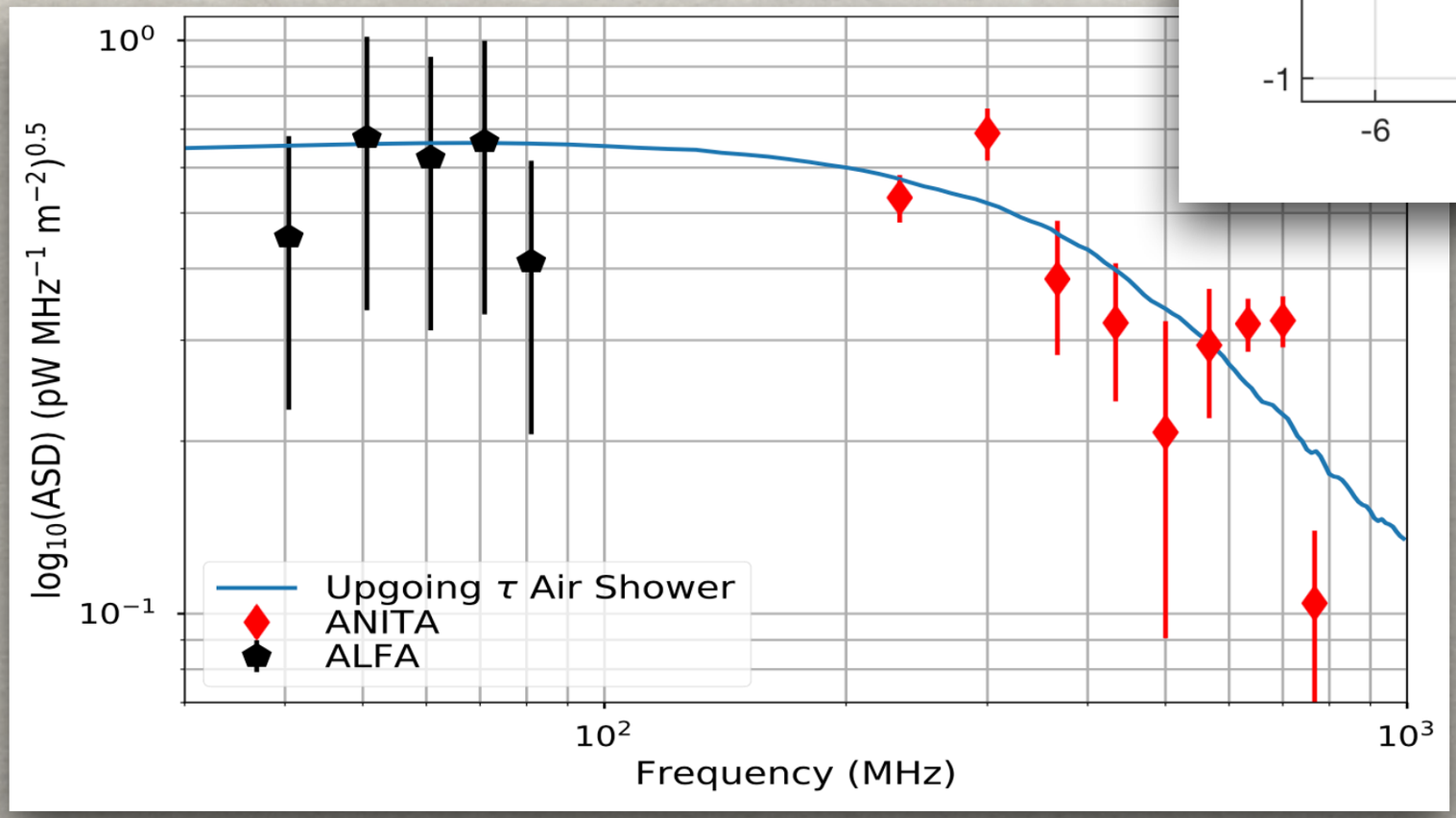
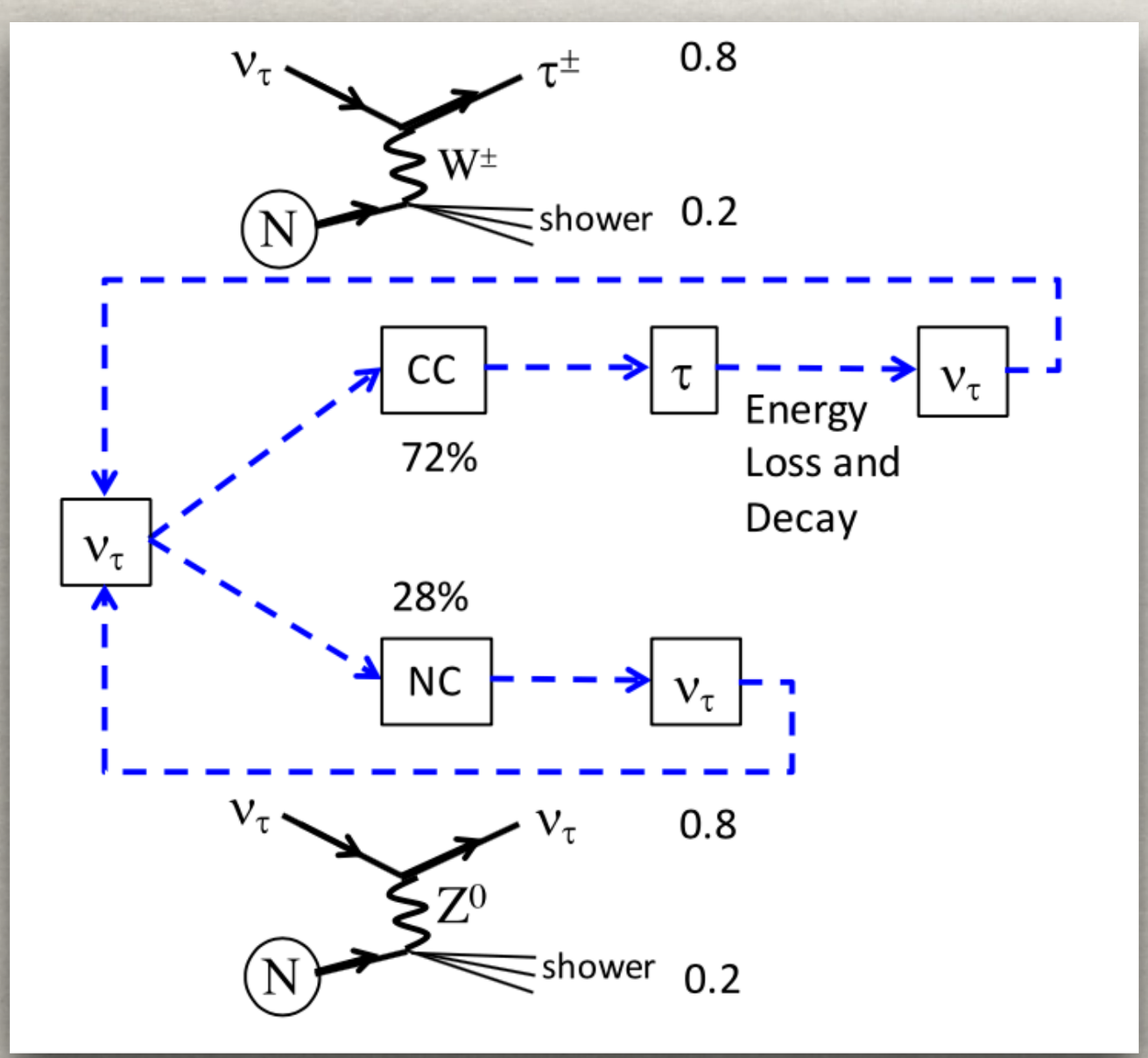
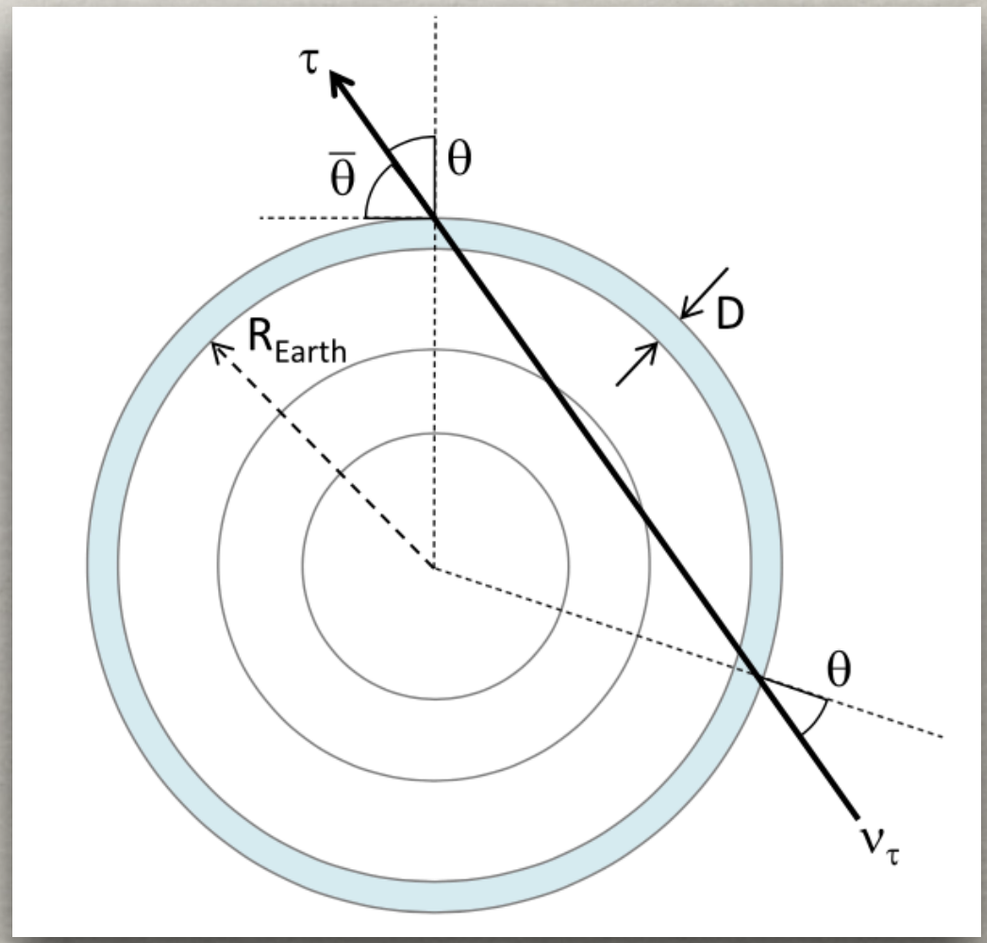

log10(ASD) (pW MHz−1 m−2)0.5
Frequency (MHz)
Upgoing τ Air Shower
ANITA
ALFA
10^0
10^−1
10^2
10^3

Gorham+18

AAEs in the Standard Model

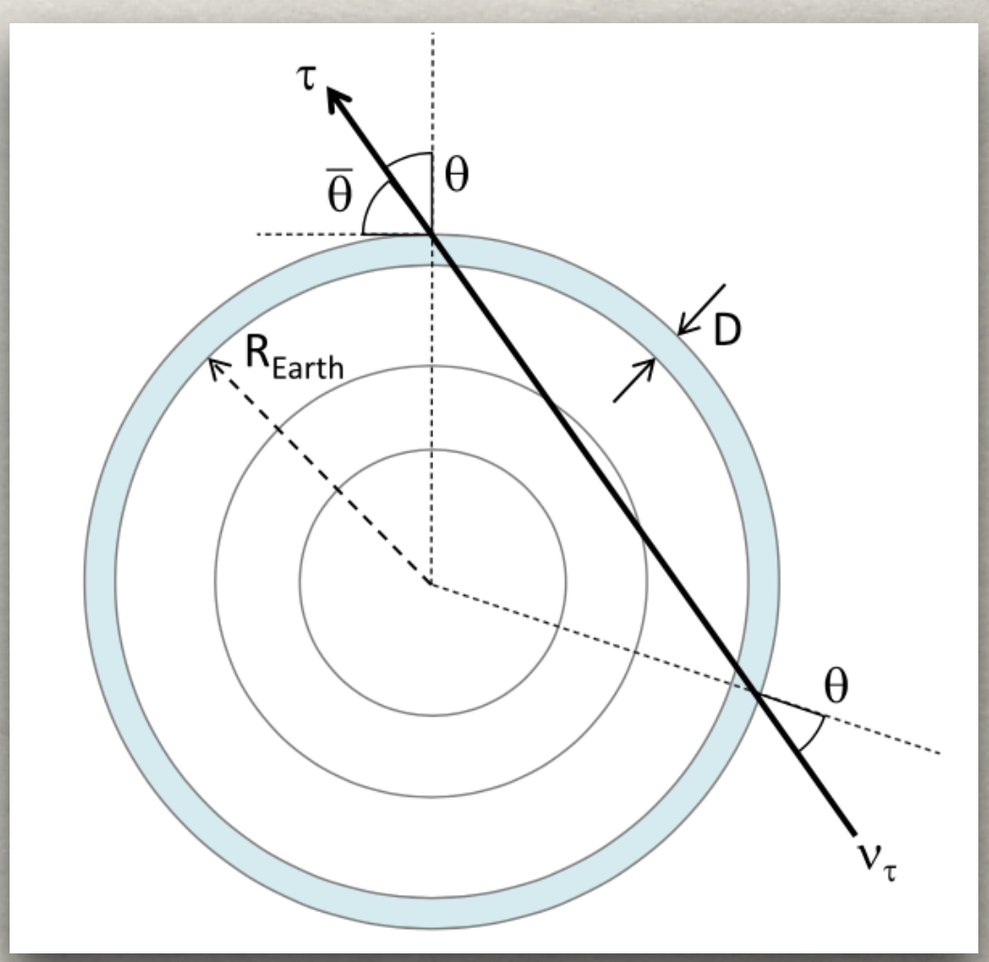


Alvarez-Muniz+18



Alvarez-Muniz+18

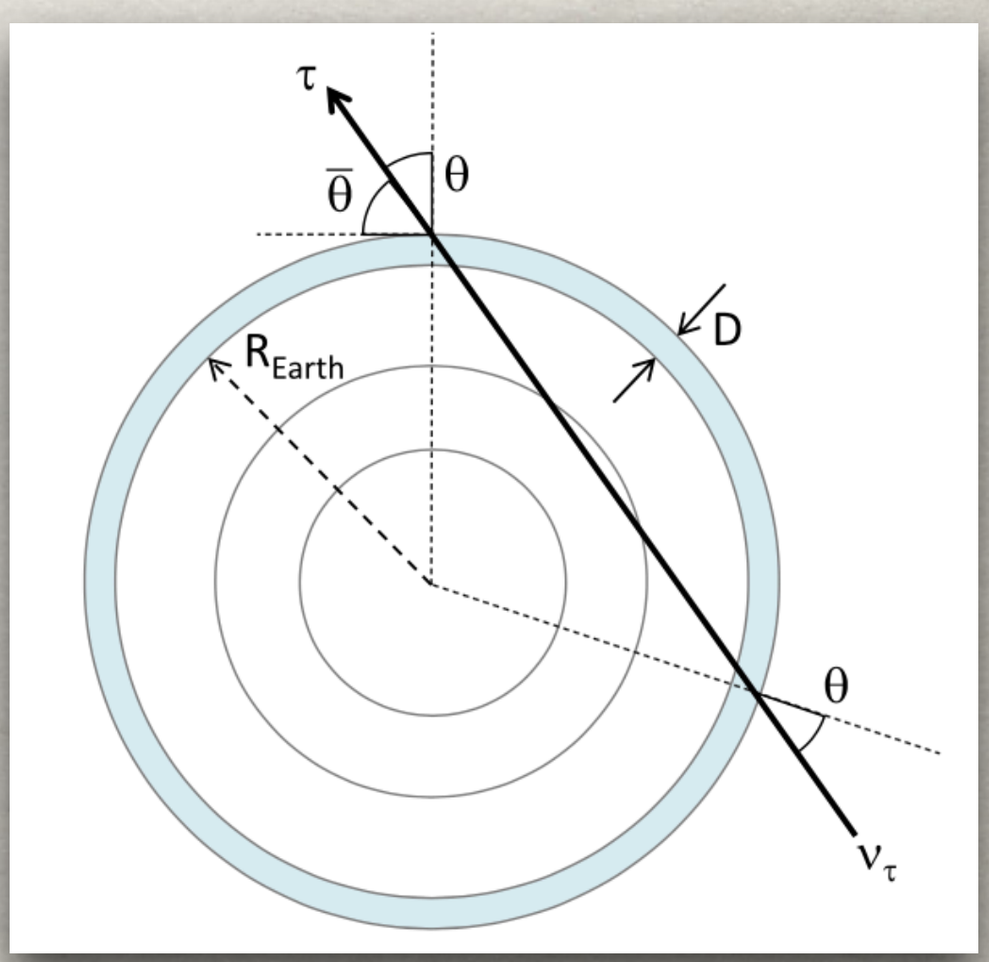
AAEs in the SM



Alvarez-Muniz+18

AAEs in the SM

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



Alvarez-Muniz+18

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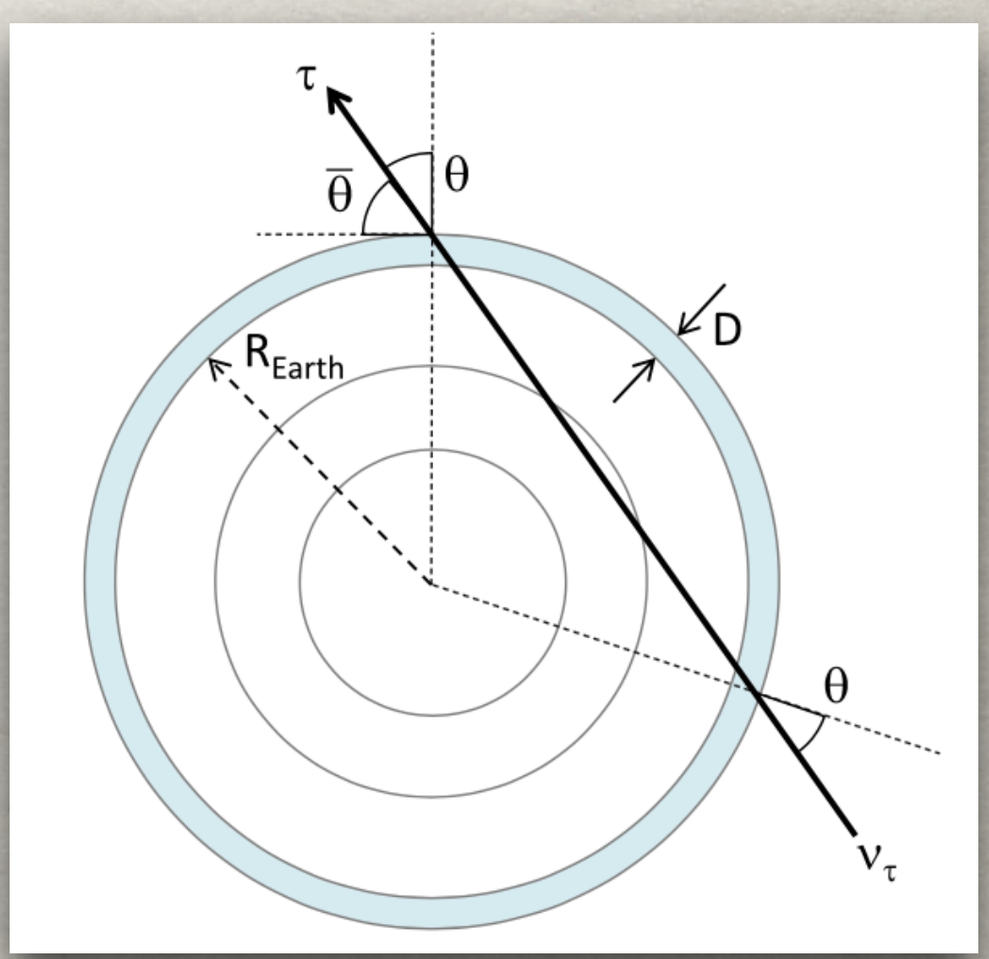

Alvarez-Muniz+18

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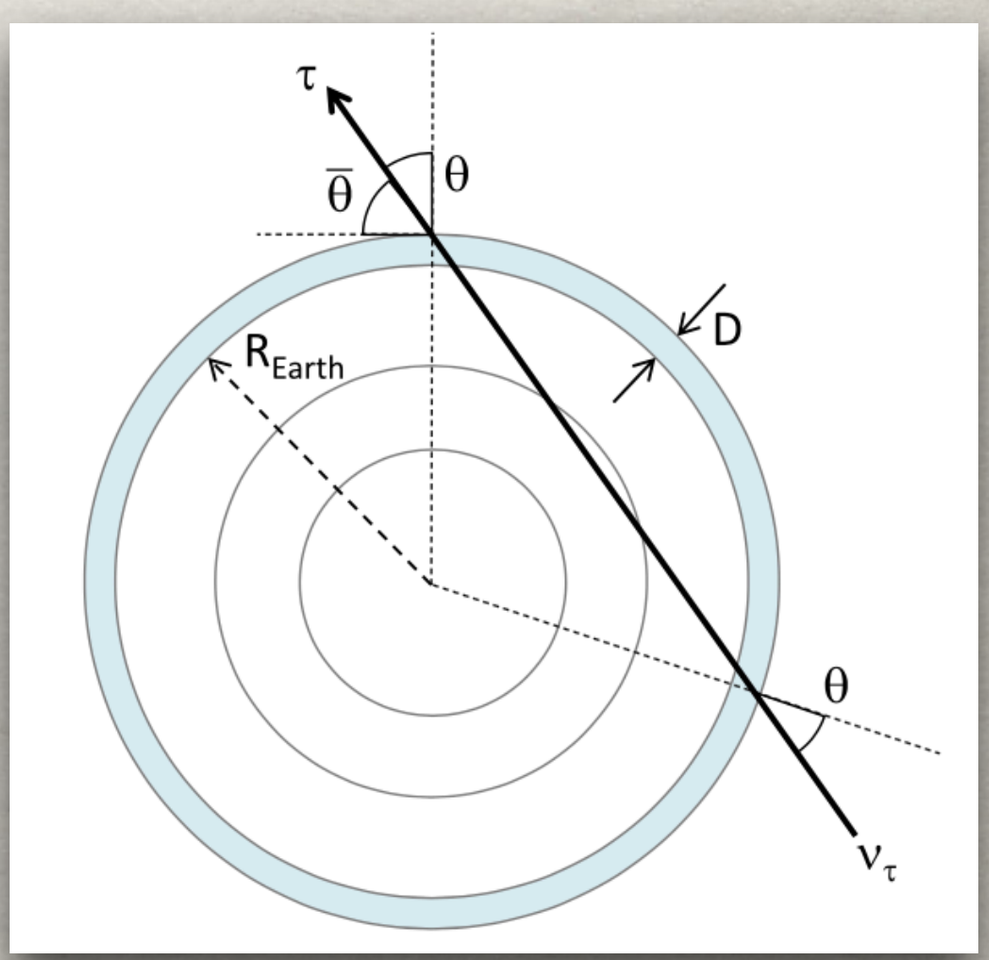

Alvarez-Muniz+18

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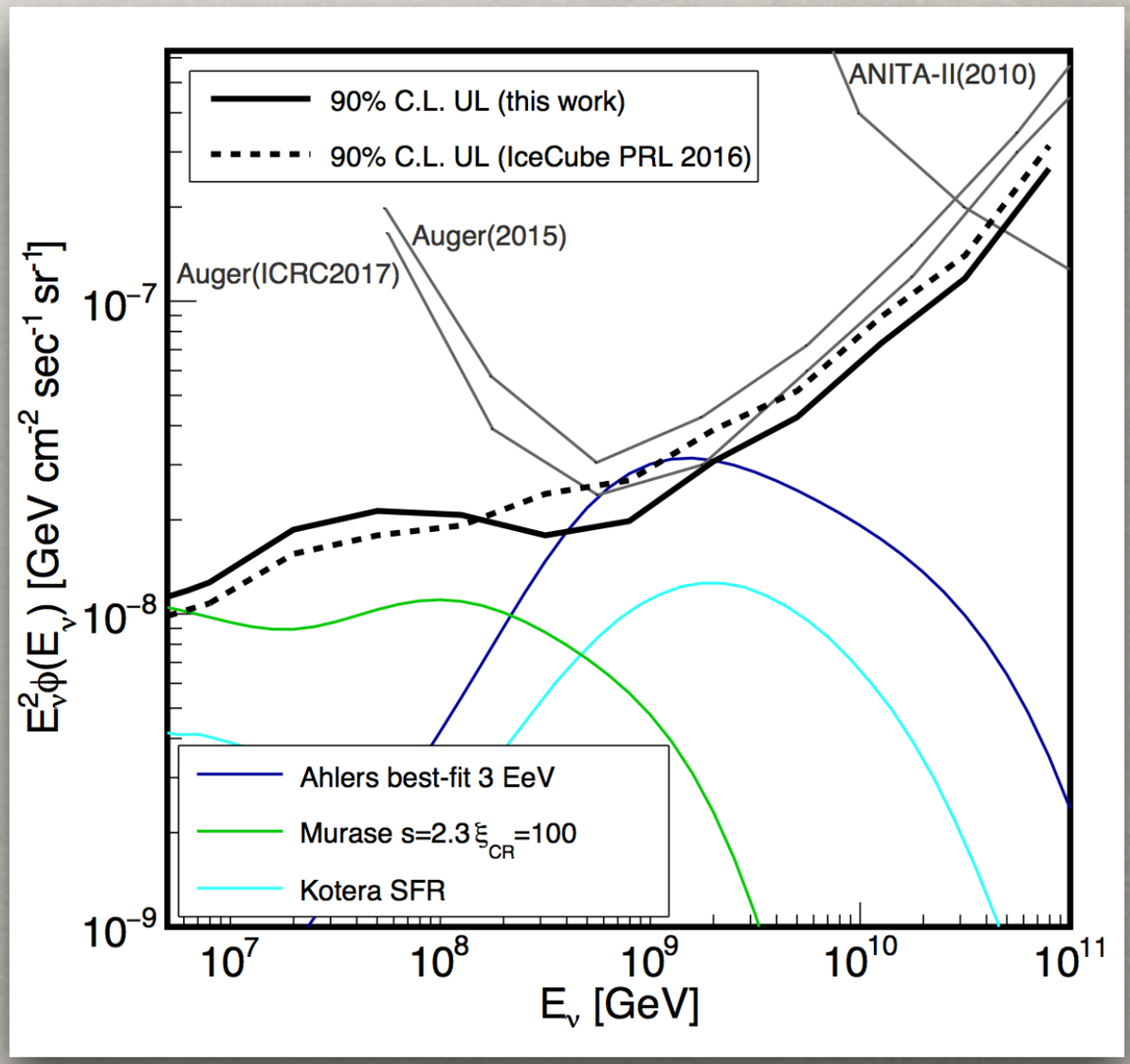
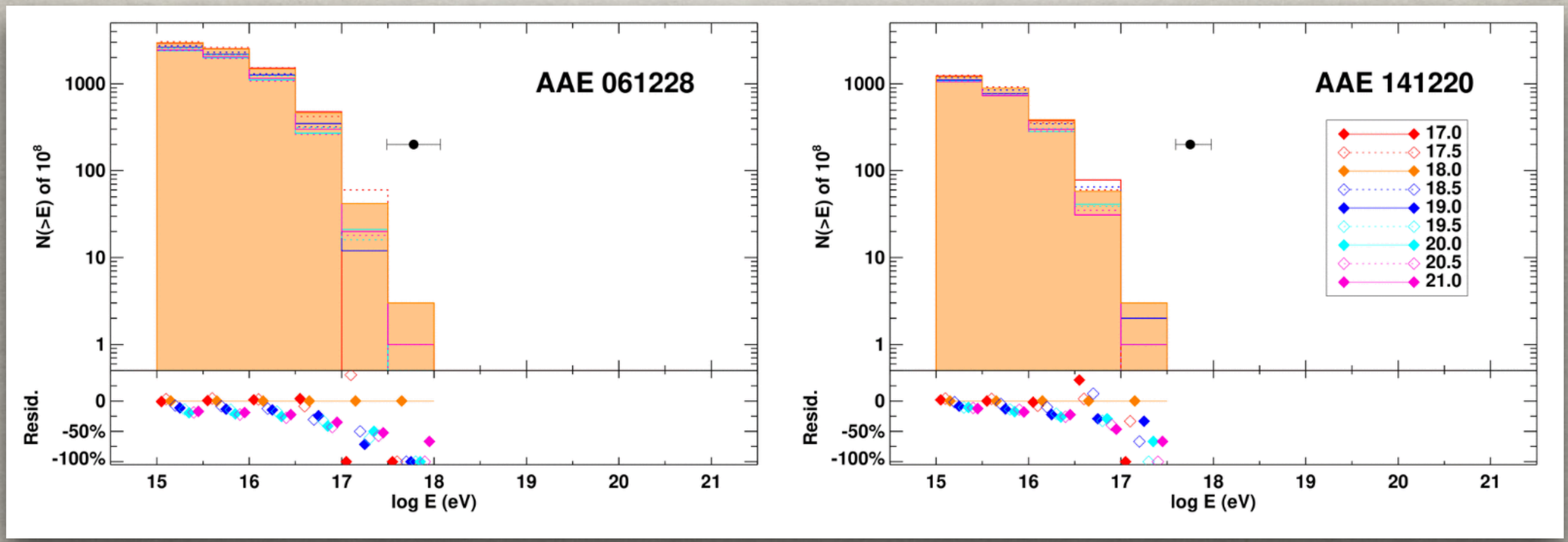


IceCube 2018

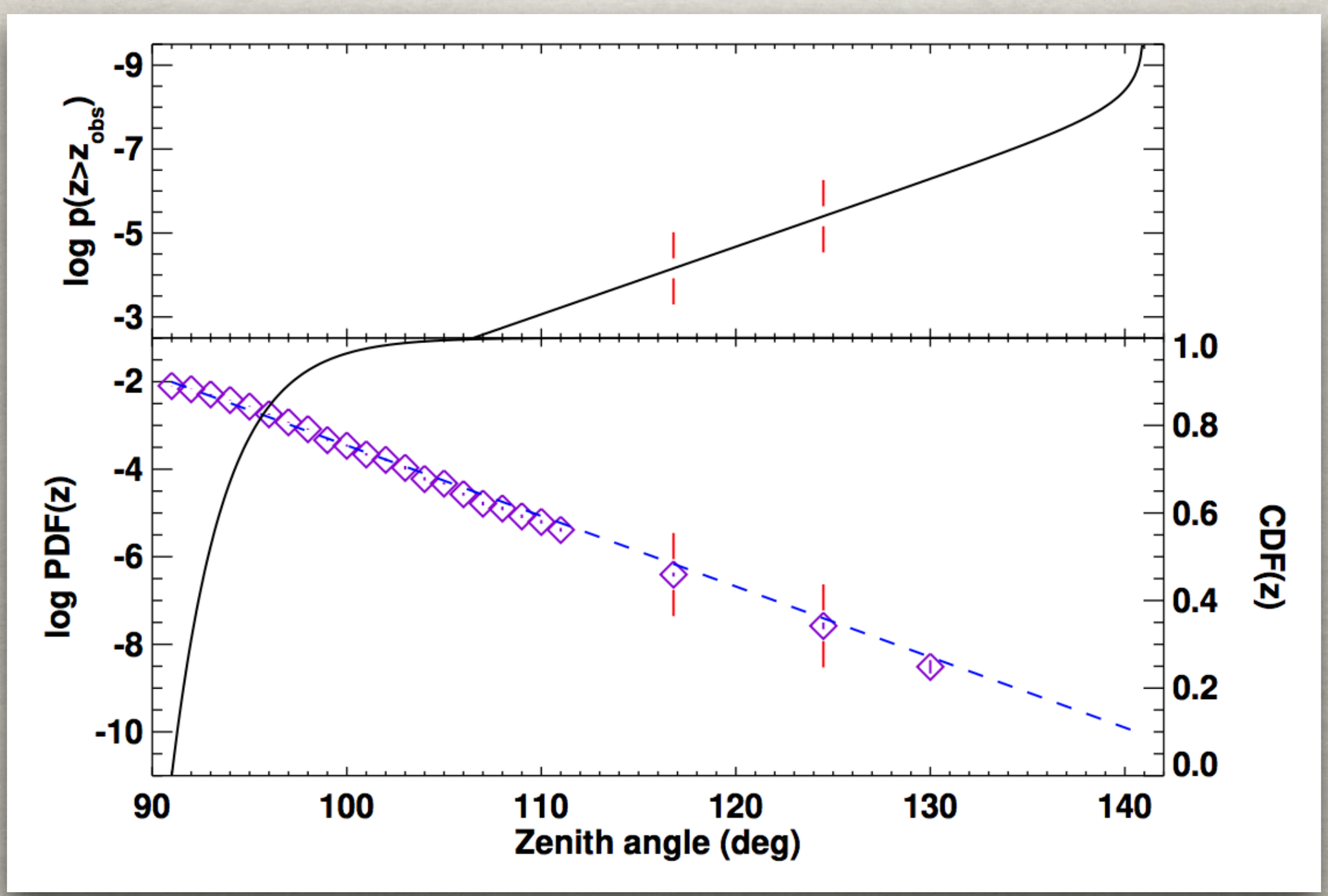
TABLE I. Properties of the ANITA Anomalous Events

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. $282.^{\circ}14064$, Dec. $+20.^{\circ}33043$	R.A. $50.^{\circ}78203$, Dec. $+38.^{\circ}65498$
Energy $\varepsilon_{\rm cr}$	$0.6 \pm 0.4\,{\rm EeV}$	$0.56^{+0.30}_{-0.20}\,{\rm EeV}$
Zenith angle z'/z	$117.^{\circ}4$ / $116.^{\circ}8 \pm 0.^{\circ}3$	$125.^{\circ}0$ / $124.^{\circ}5 \pm 0.^{\circ}3$
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



Fox+2018

AAE Zenith Angles



Fox+2018

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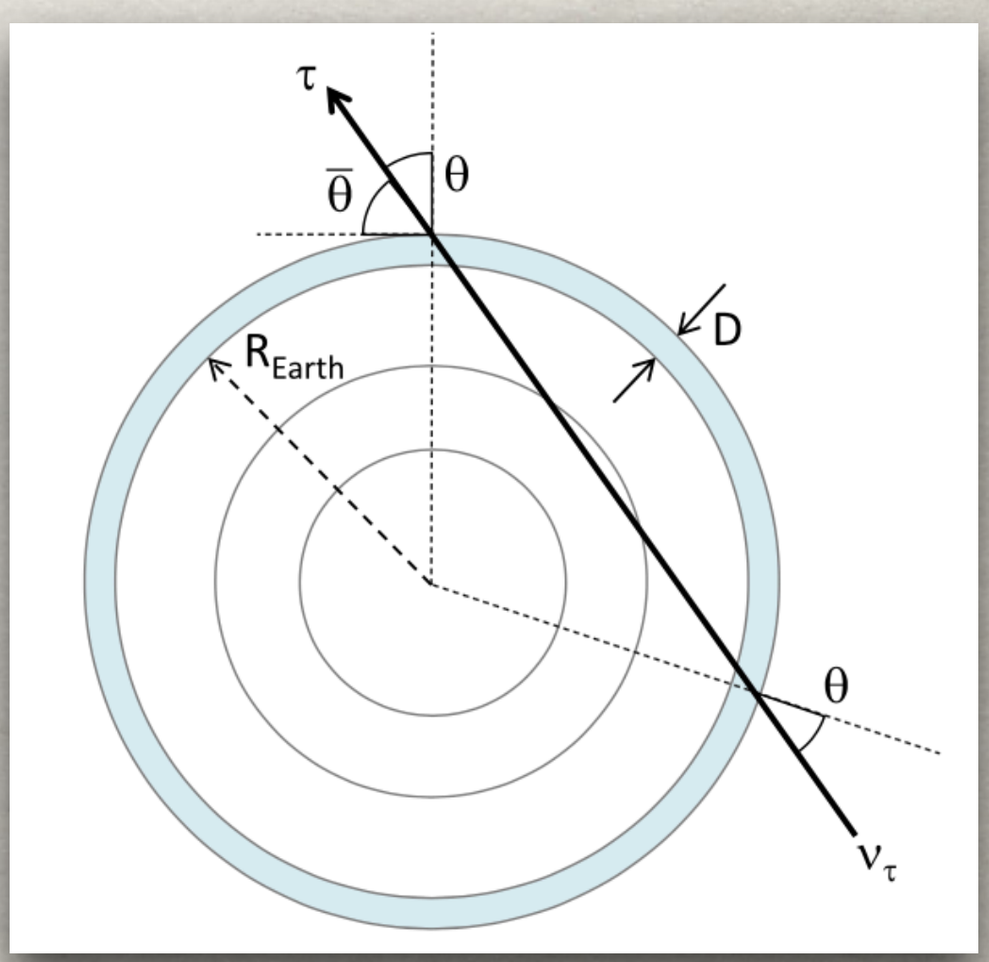

Alvarez-Muniz+18

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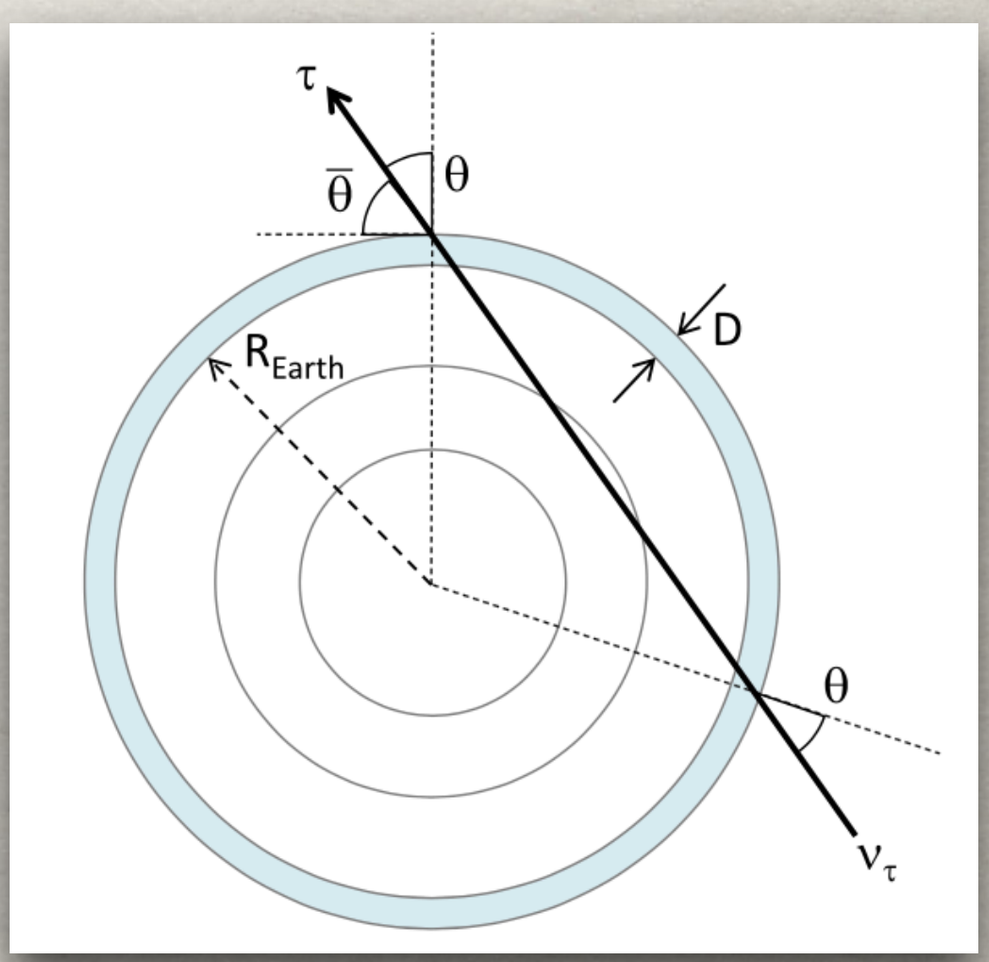

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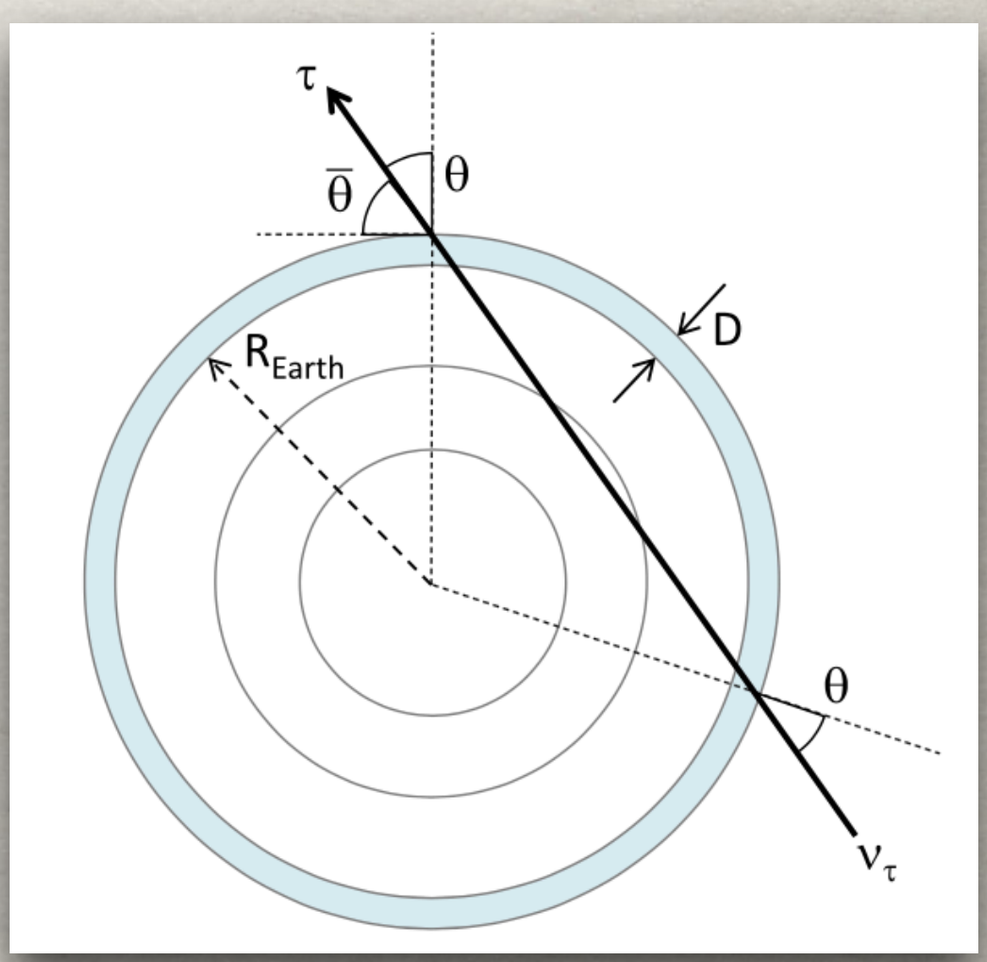

Alvarez-Muniz+18

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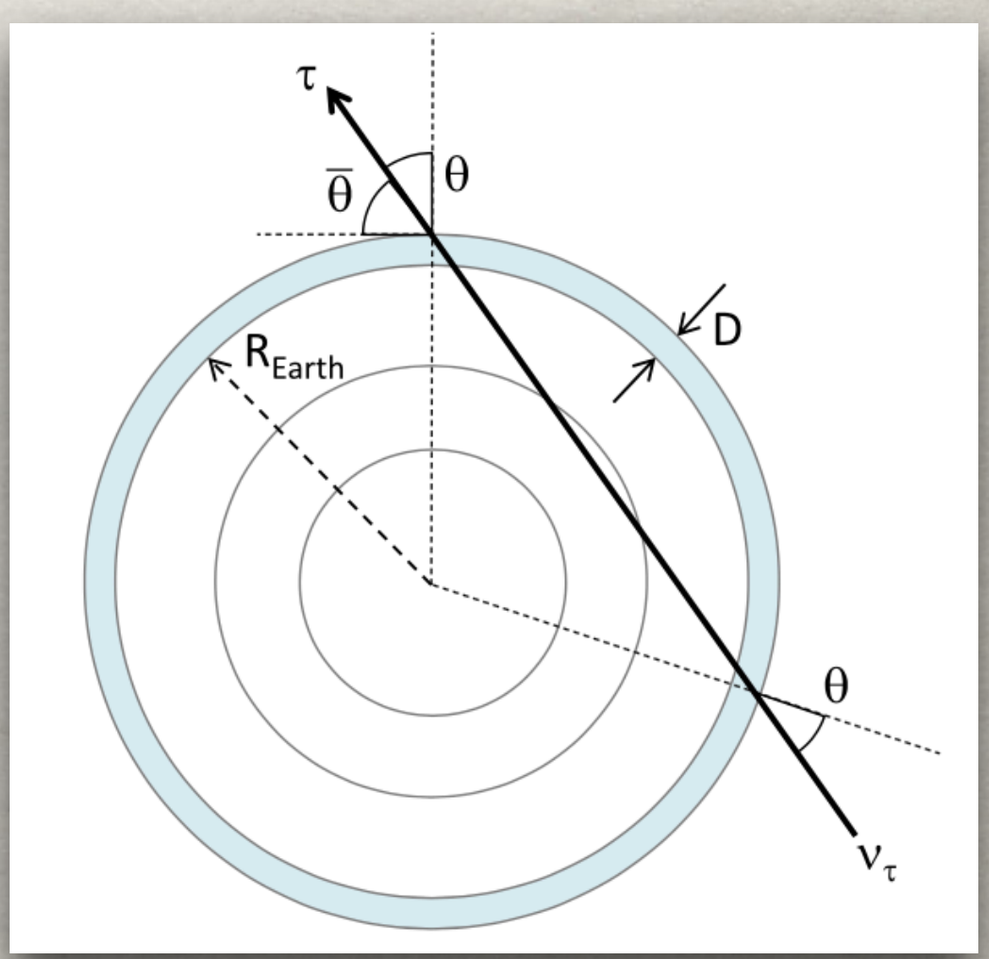

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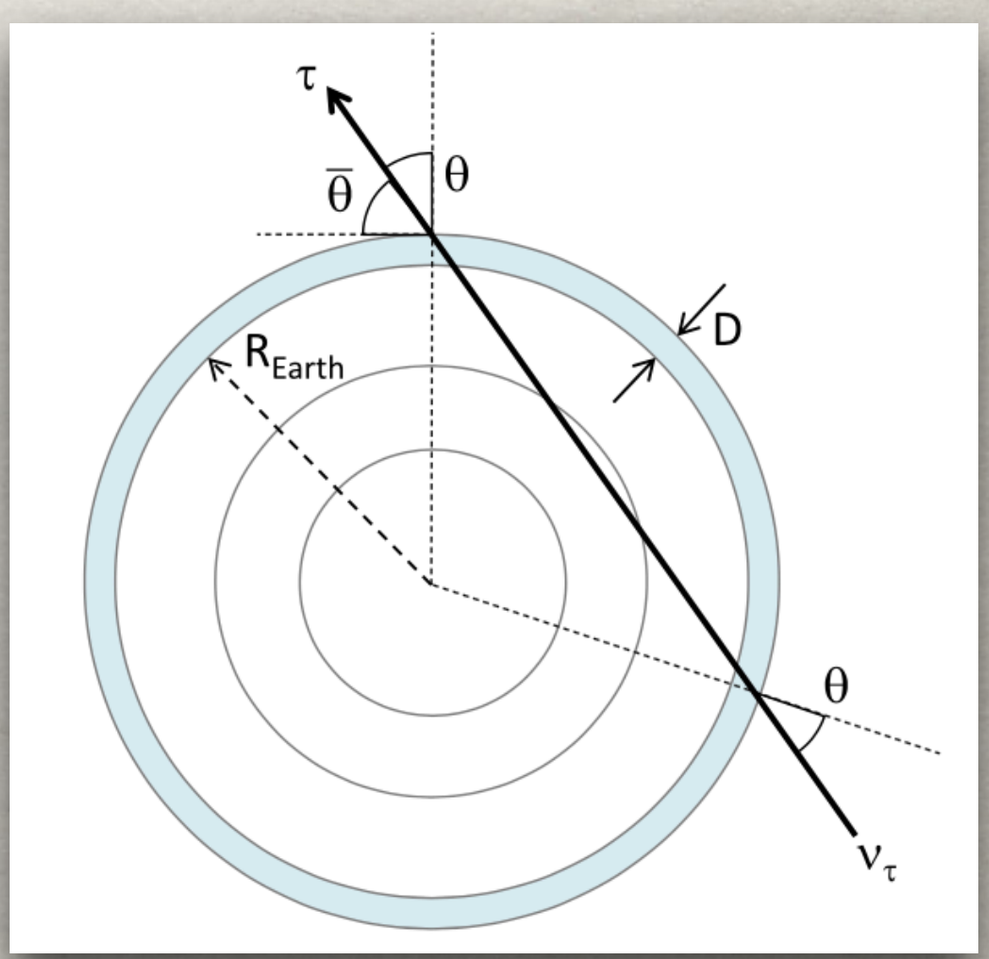

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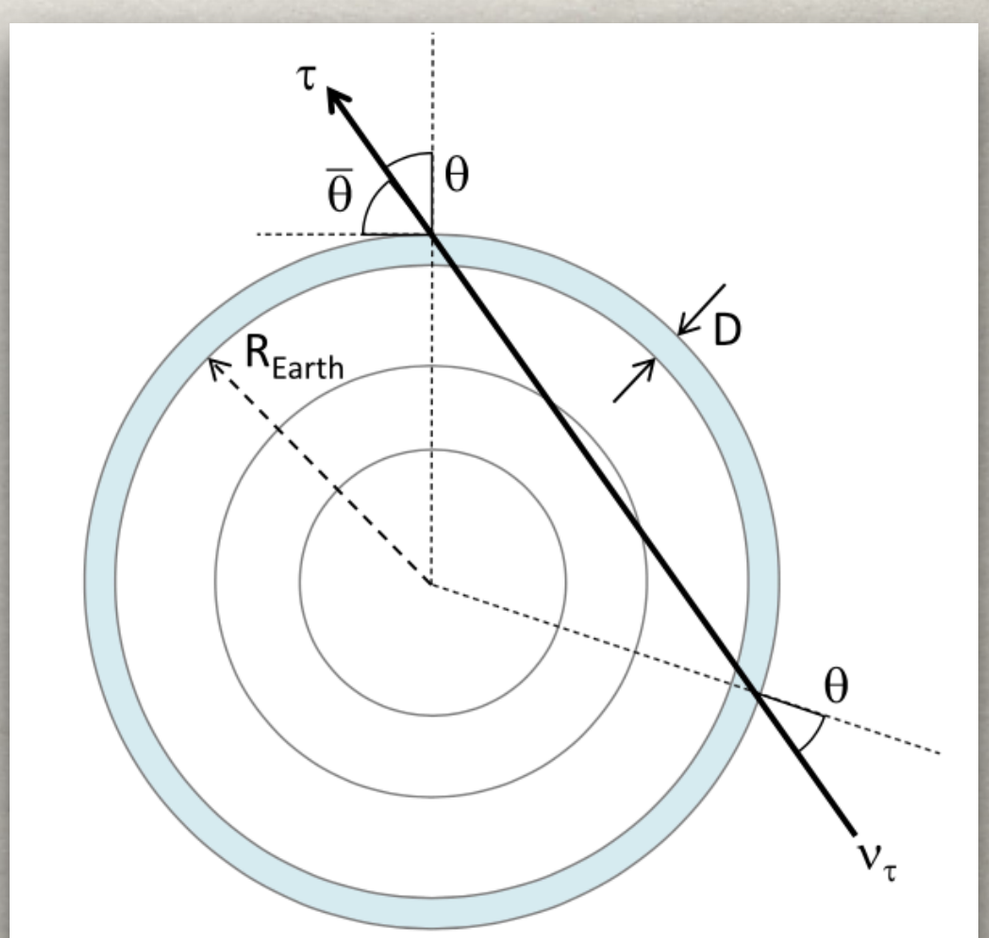

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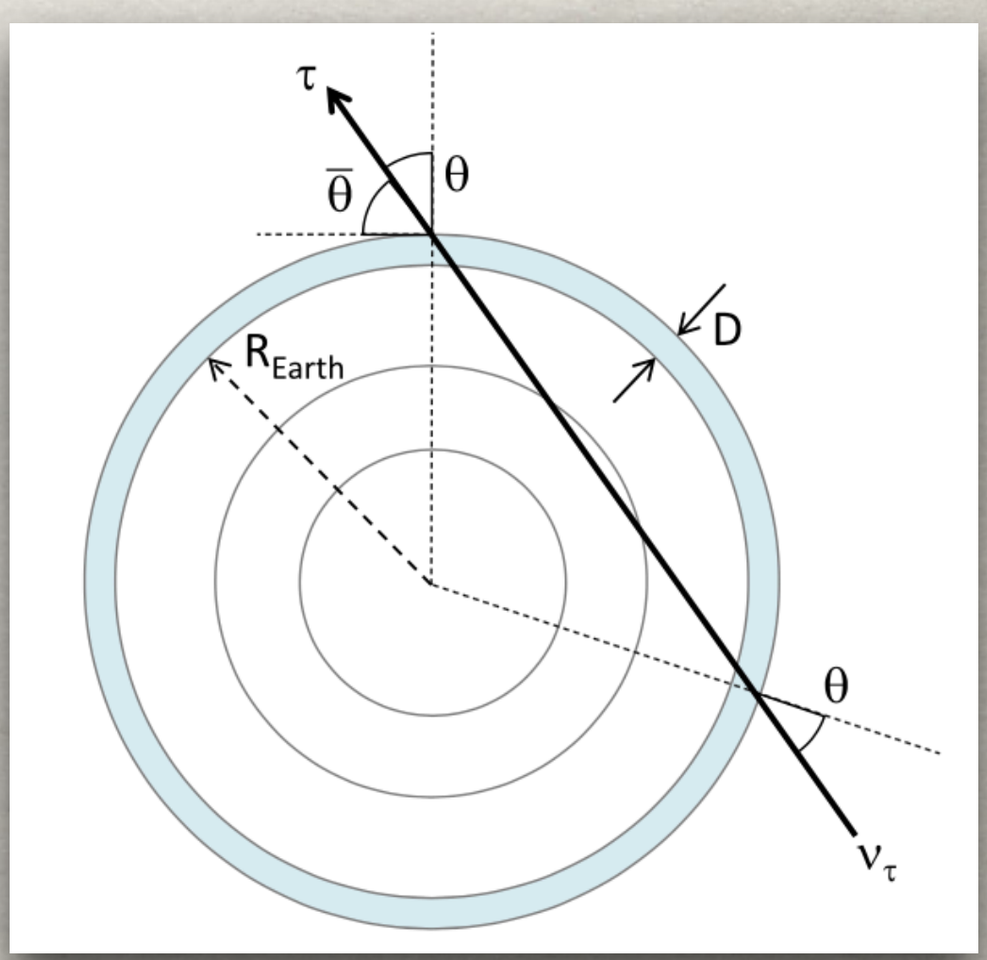

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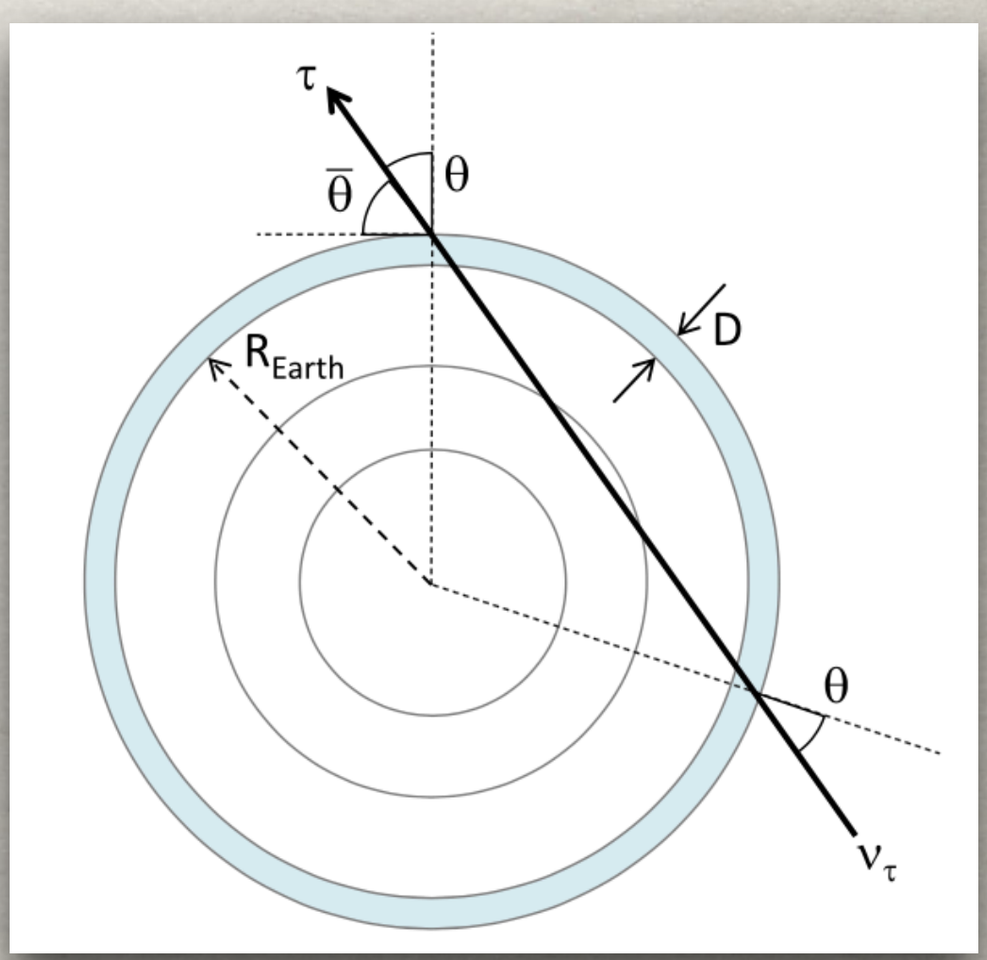
  - $\boldsymbol{\tau}$ / $\boldsymbol{\nu_\tau}$ regeneration over final $\lesssim$ 1000 km



Alvarez-Muniz+18

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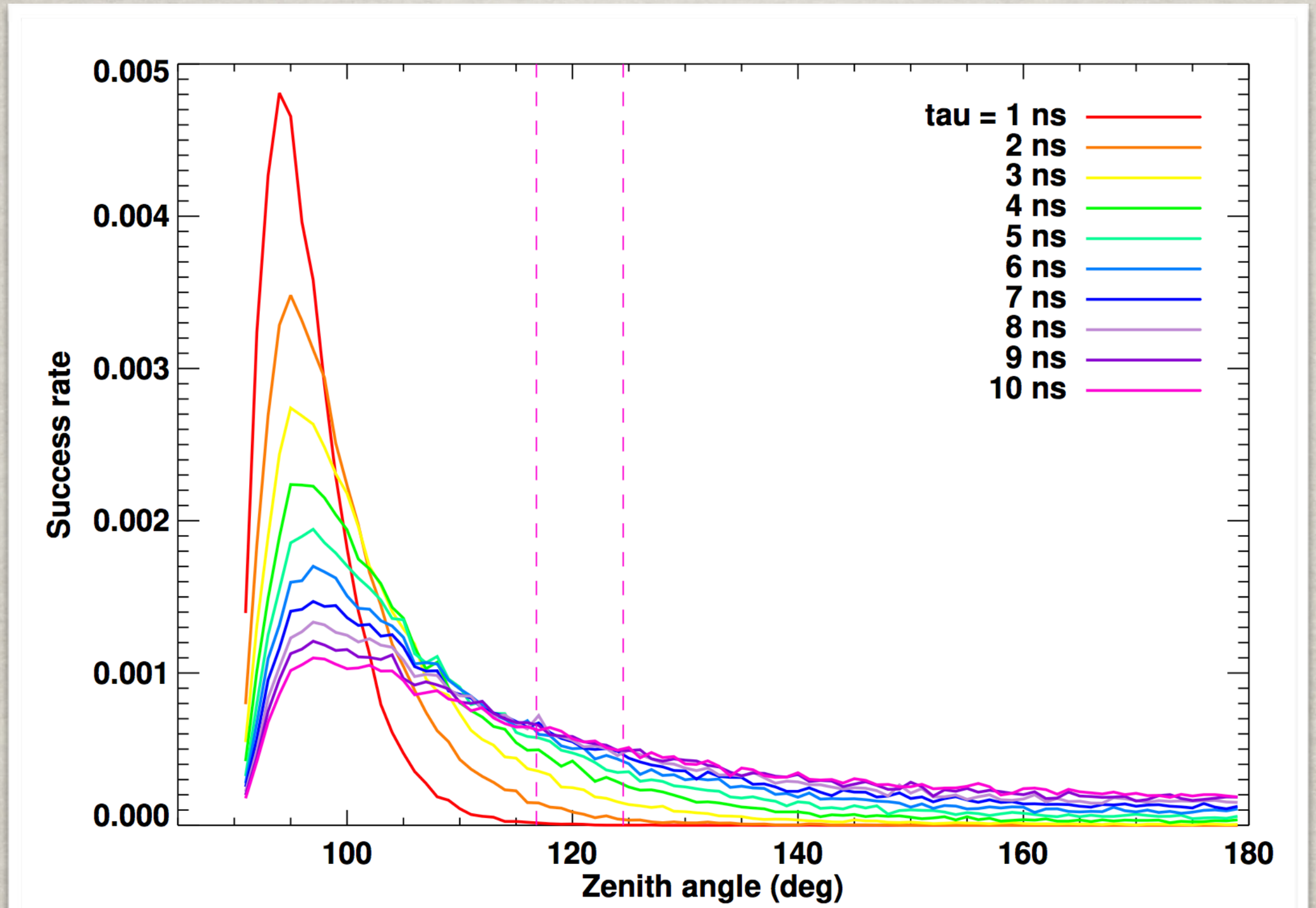

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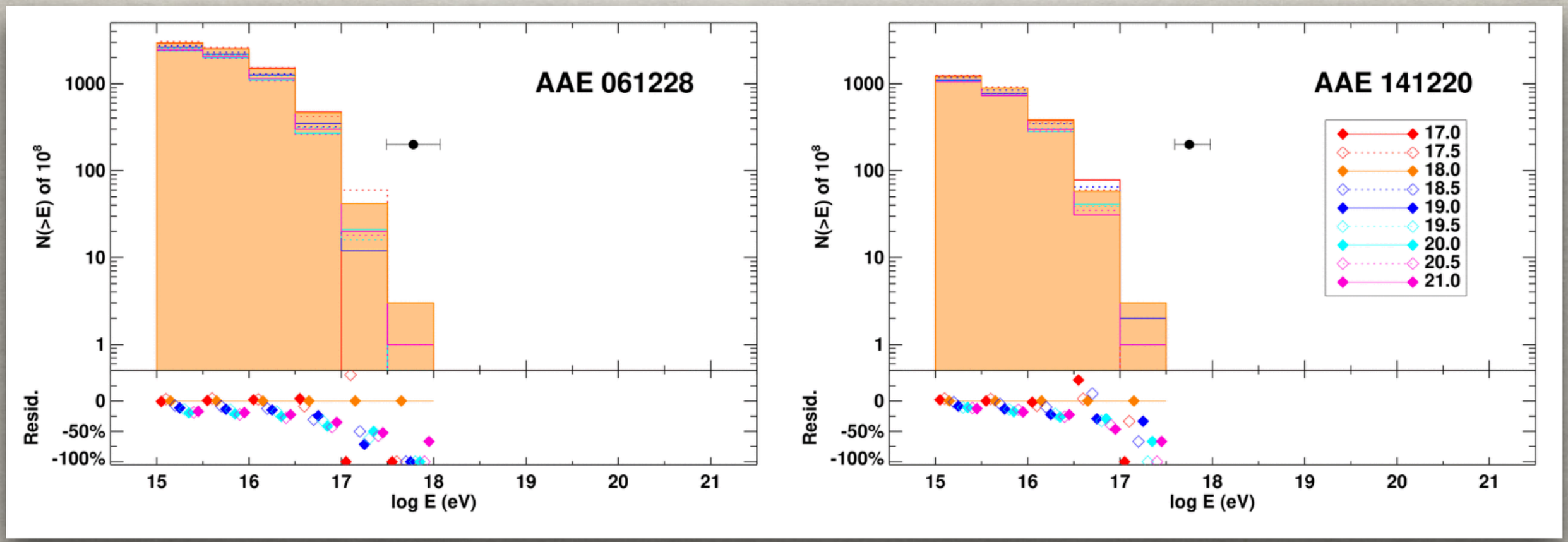
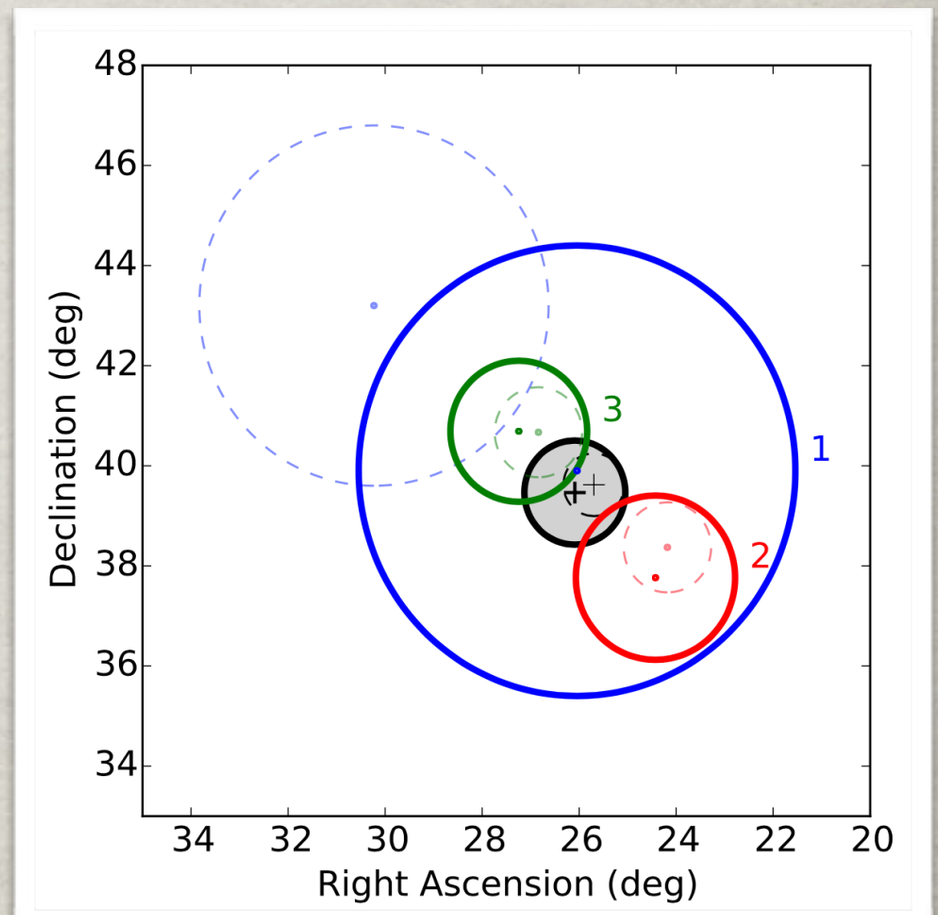


Fox+2018

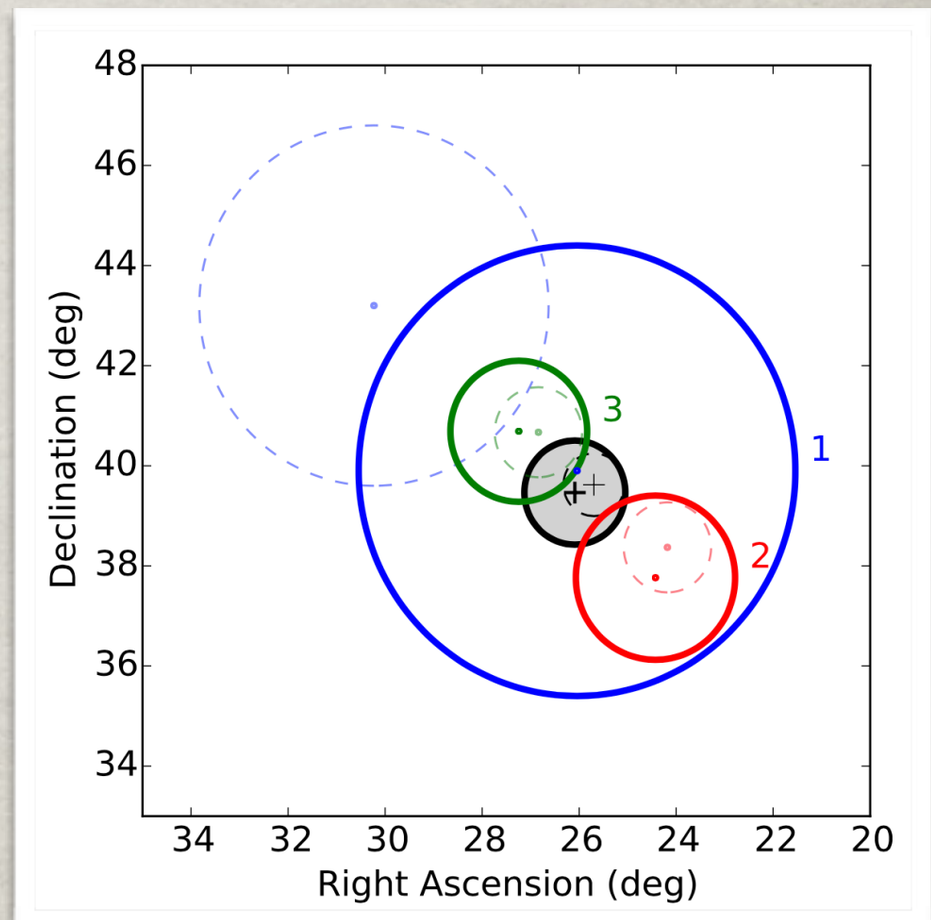
“It’s Not Transients”



IceCube+2017

"It's Not Transients"

- Evade diffuse UHE neutrino flux bounds via transients



IceCube+2017

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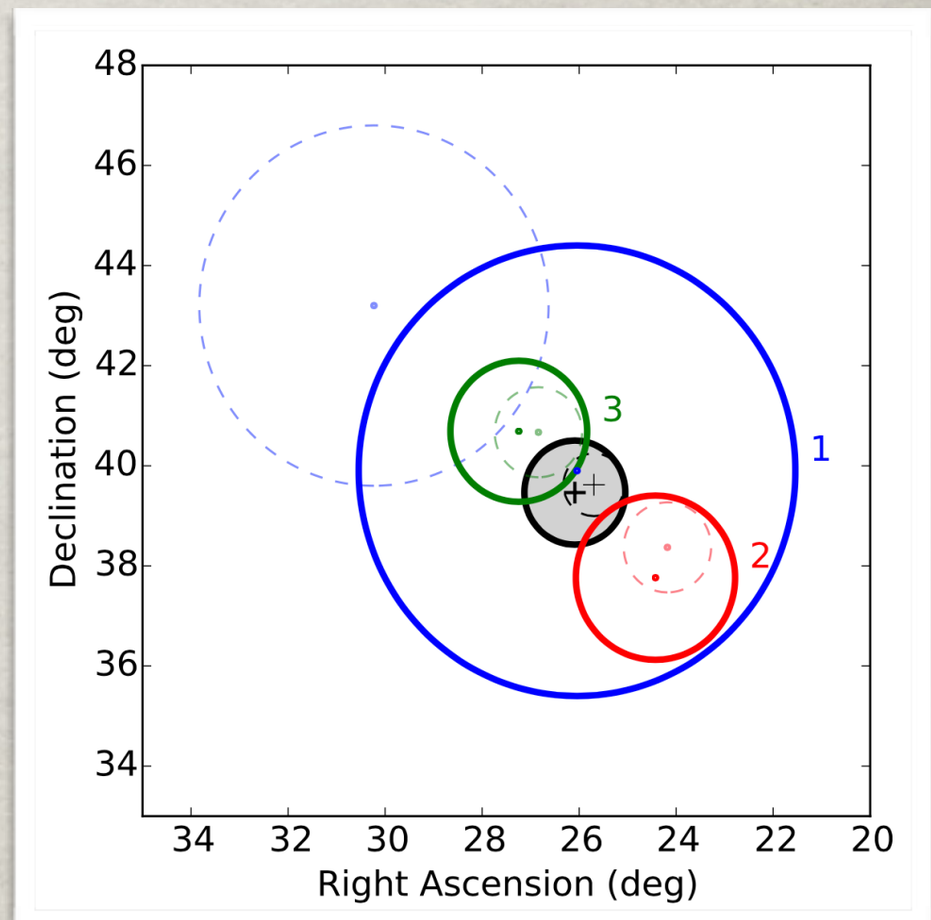

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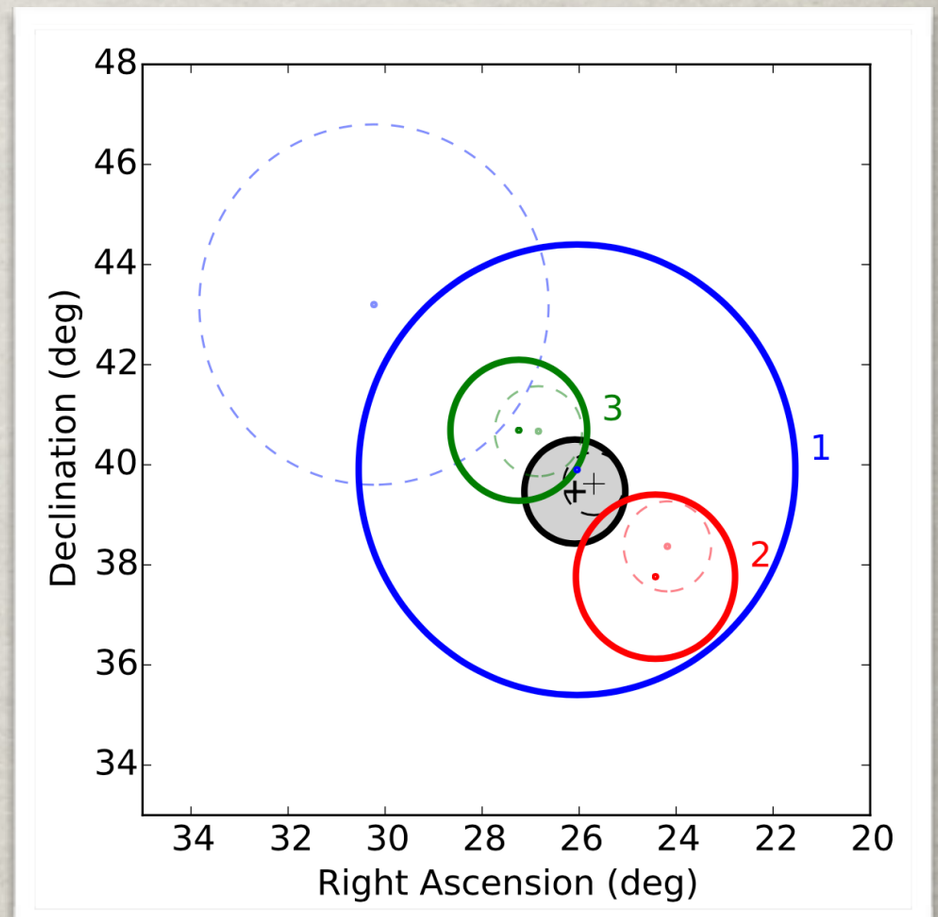

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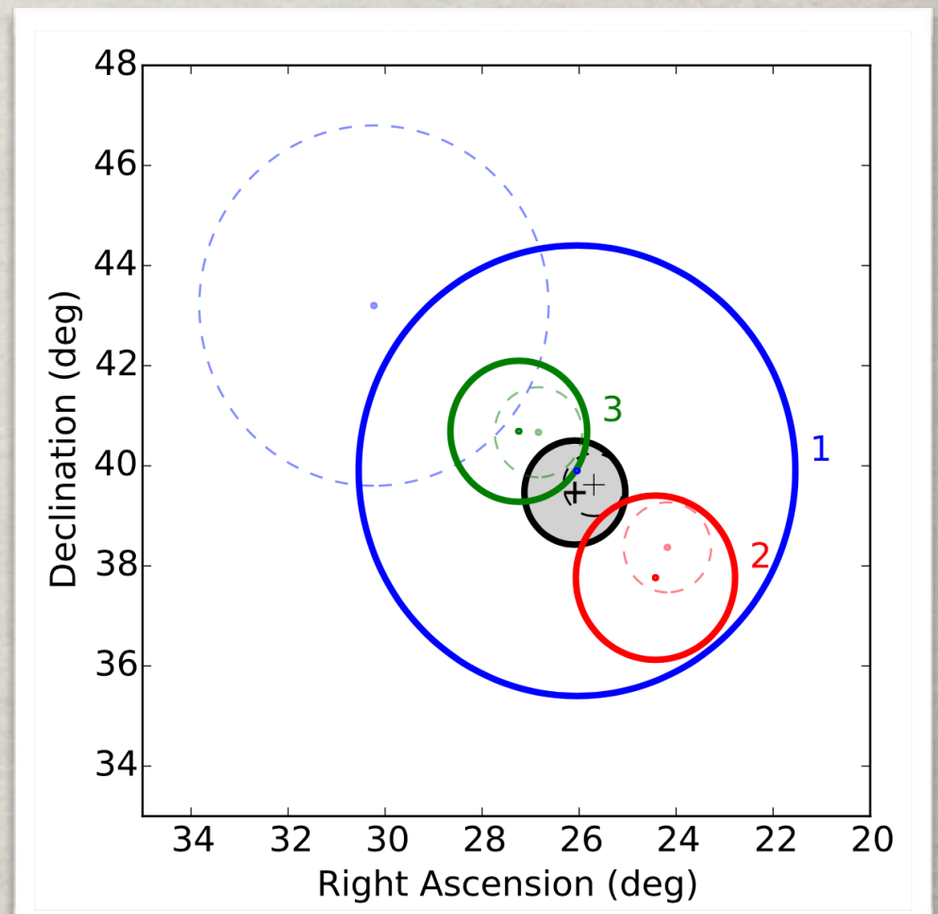

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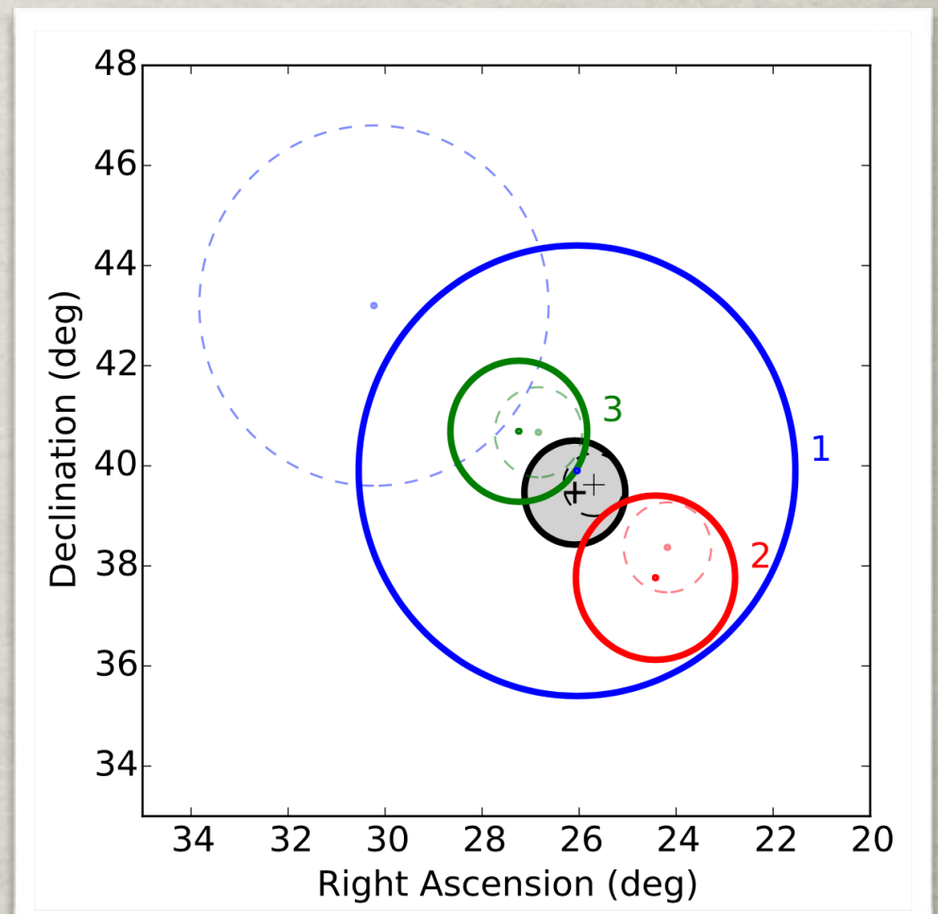

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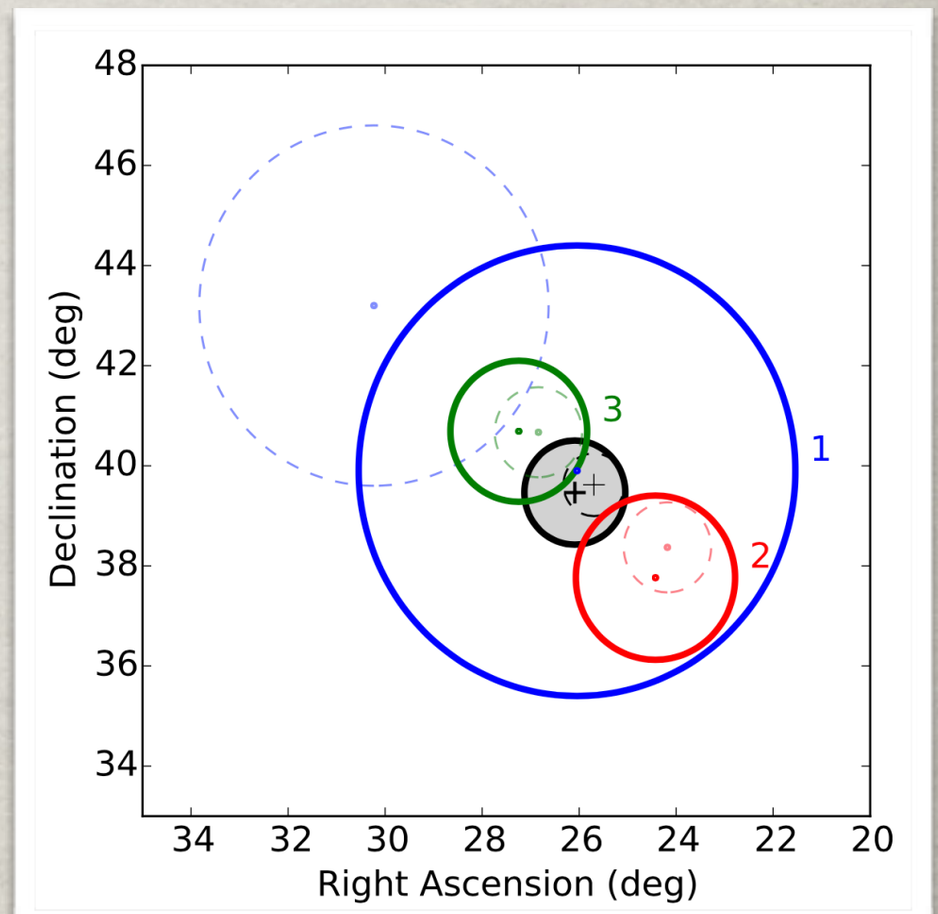

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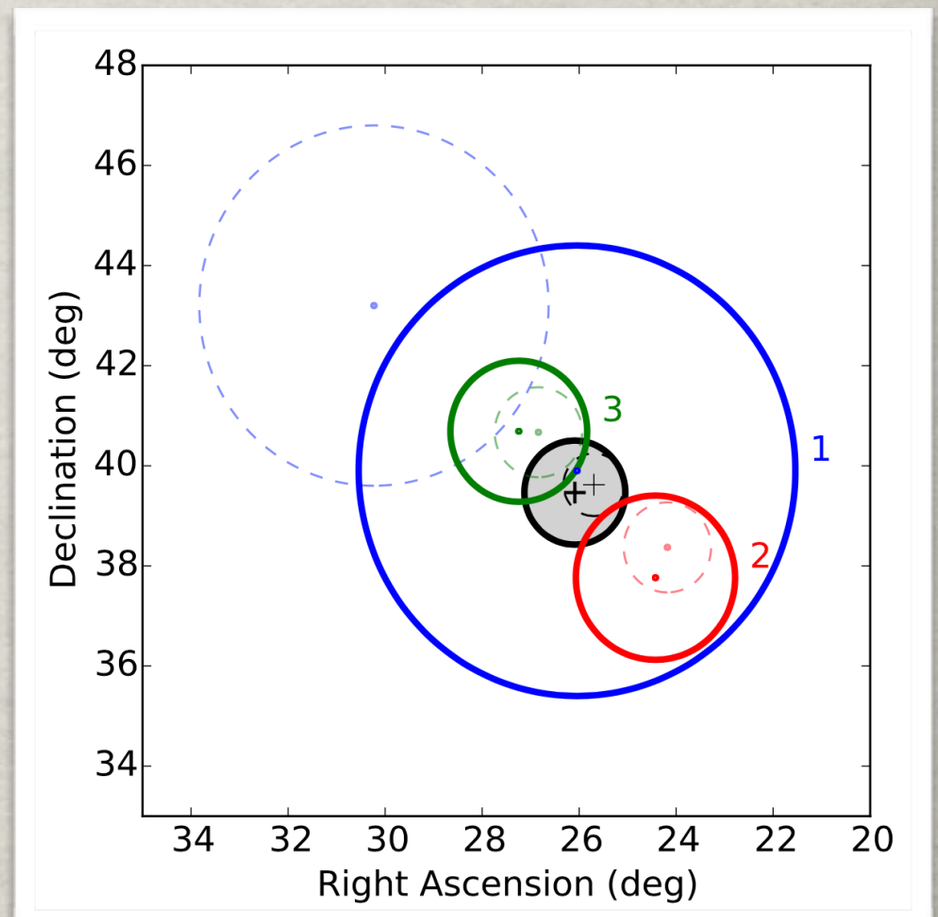

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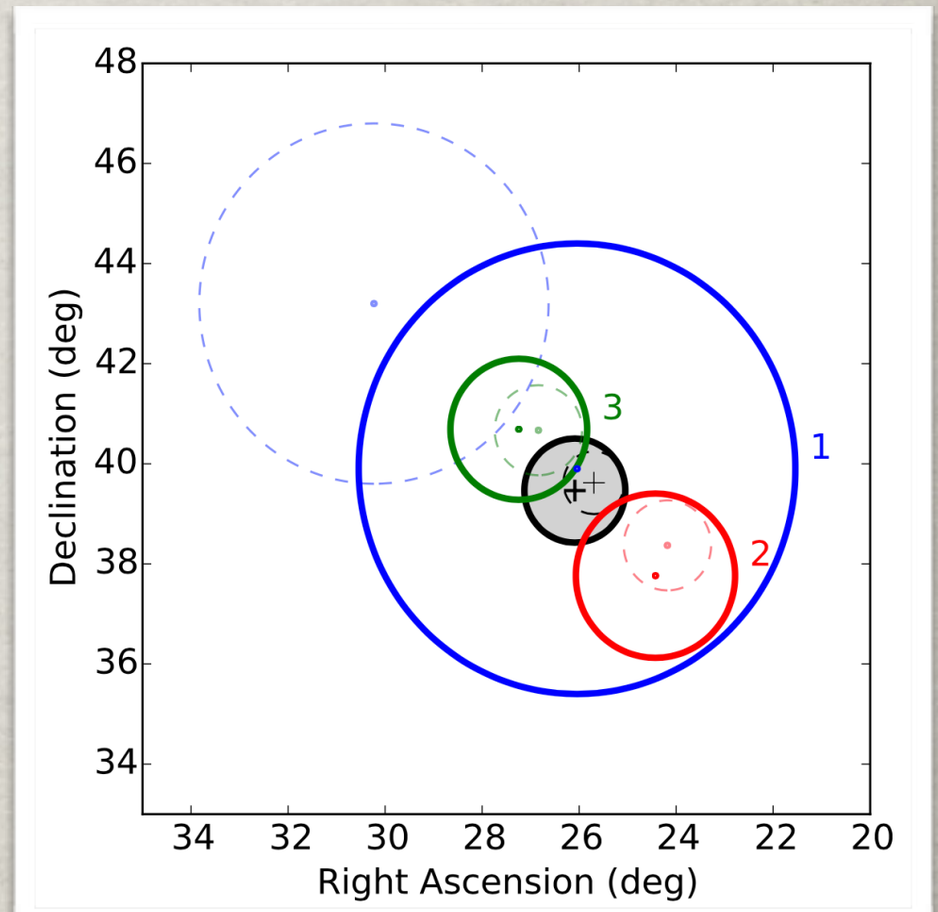

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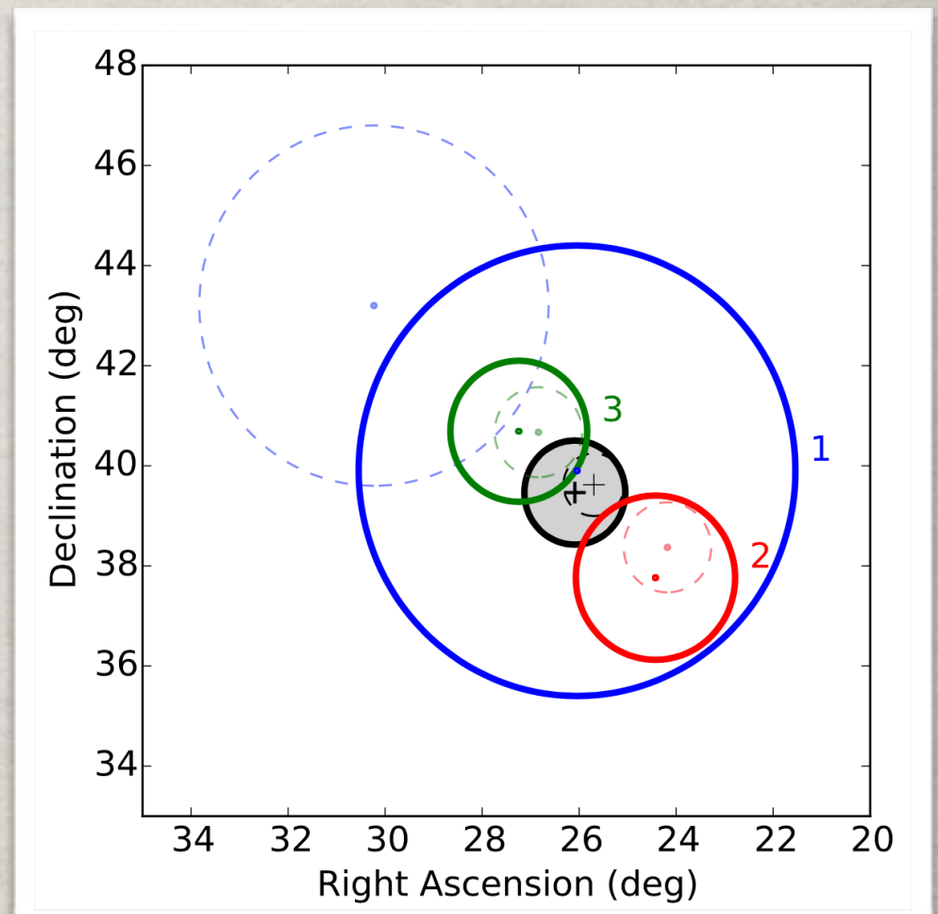

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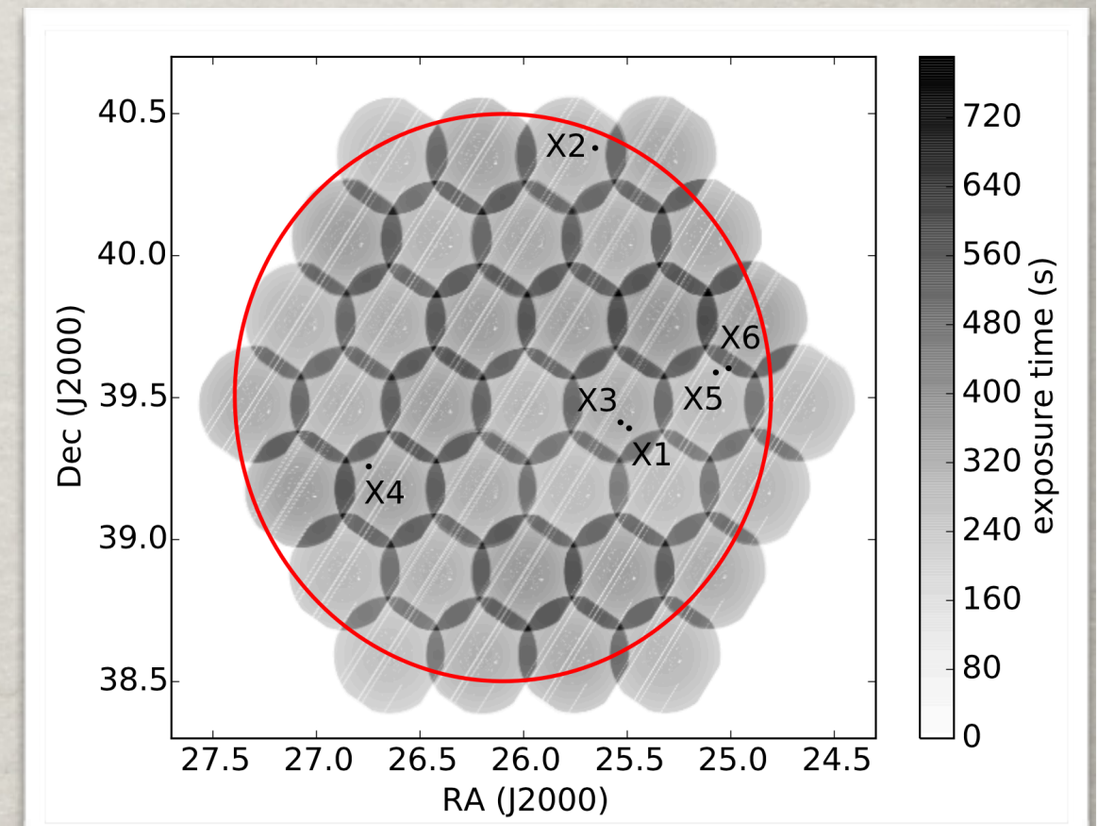

IceCube+2017

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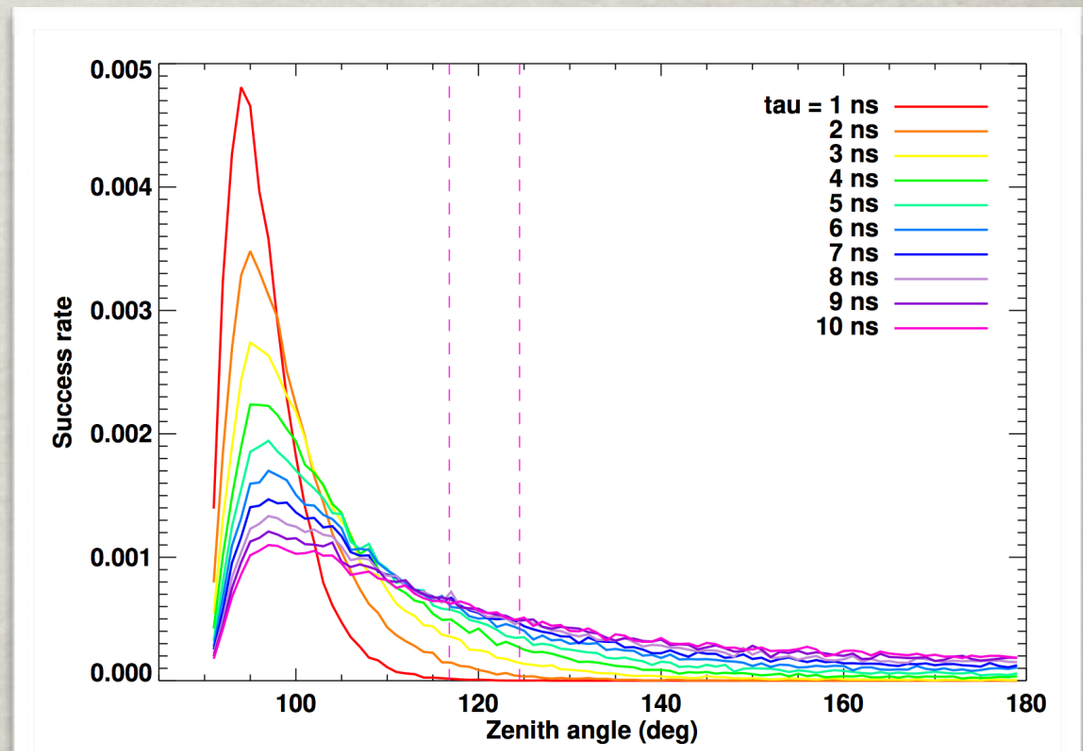

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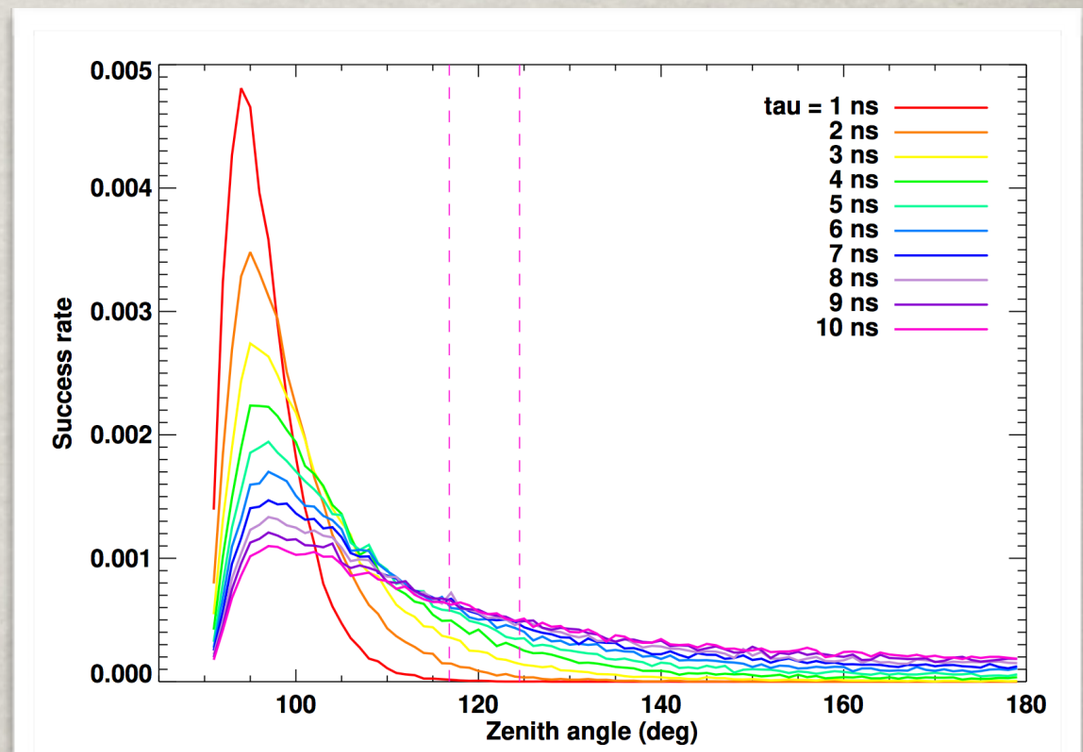

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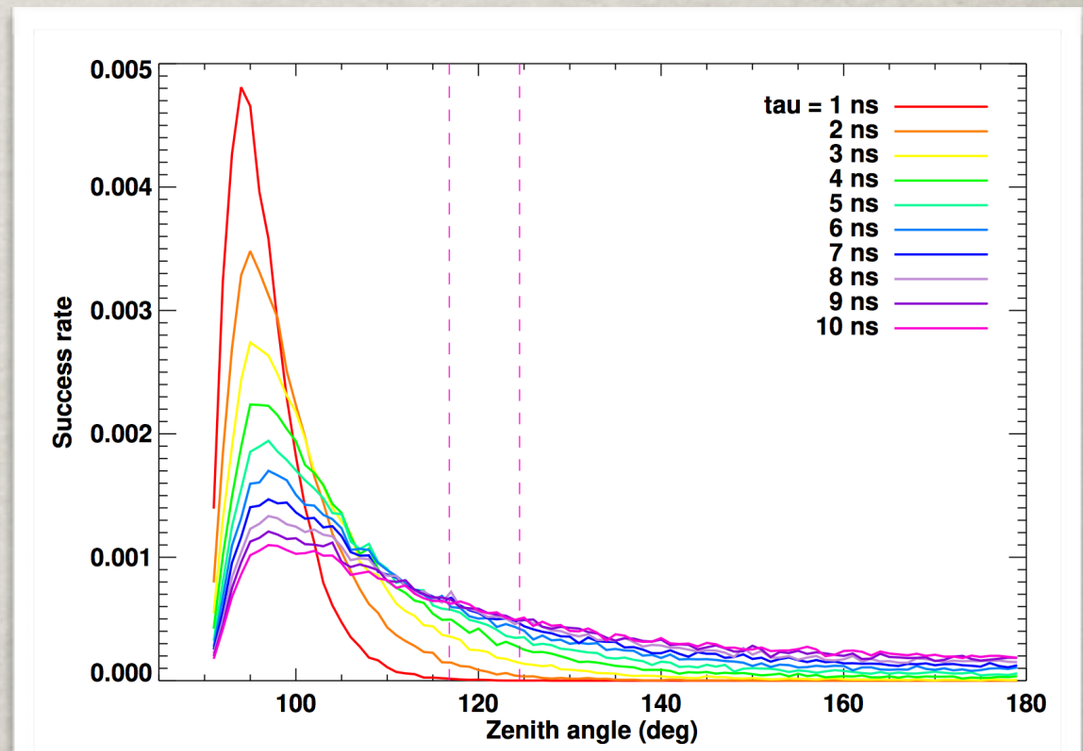

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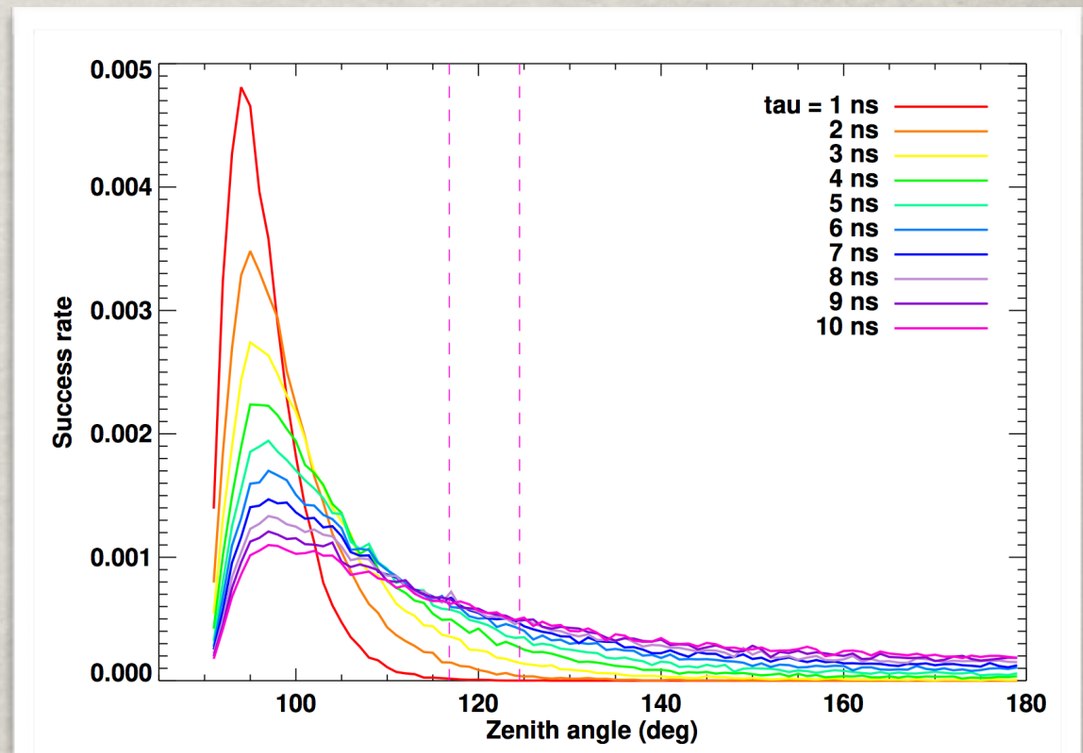

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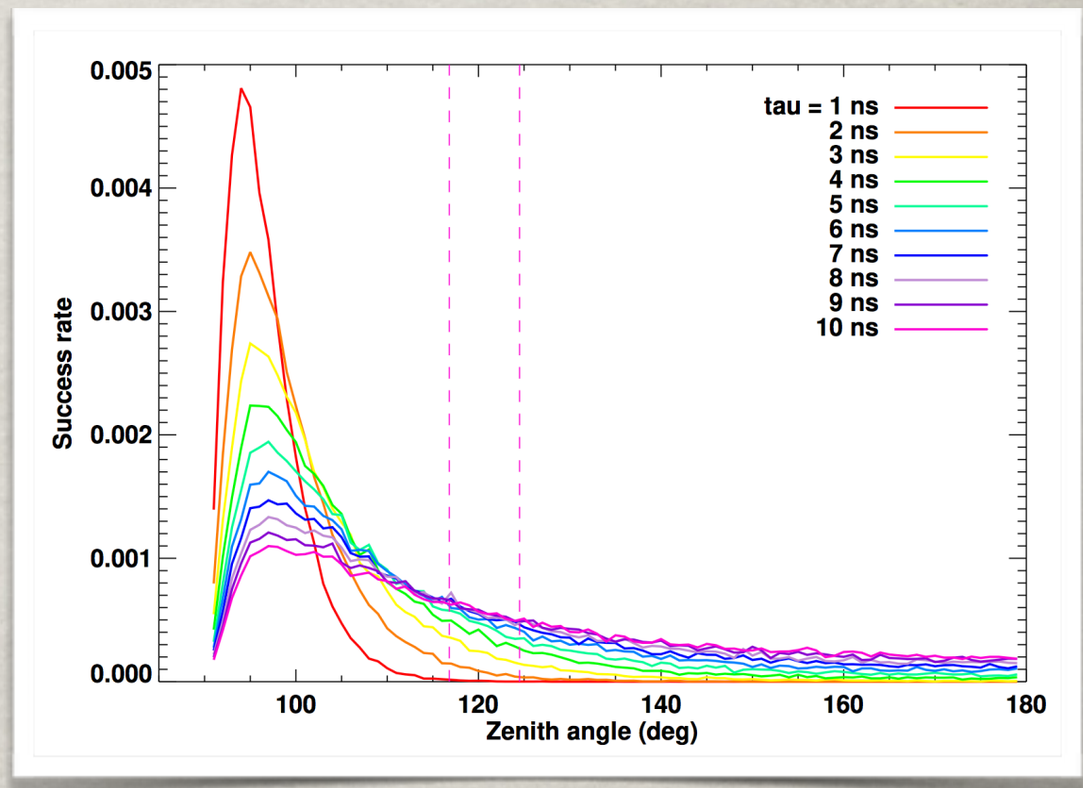

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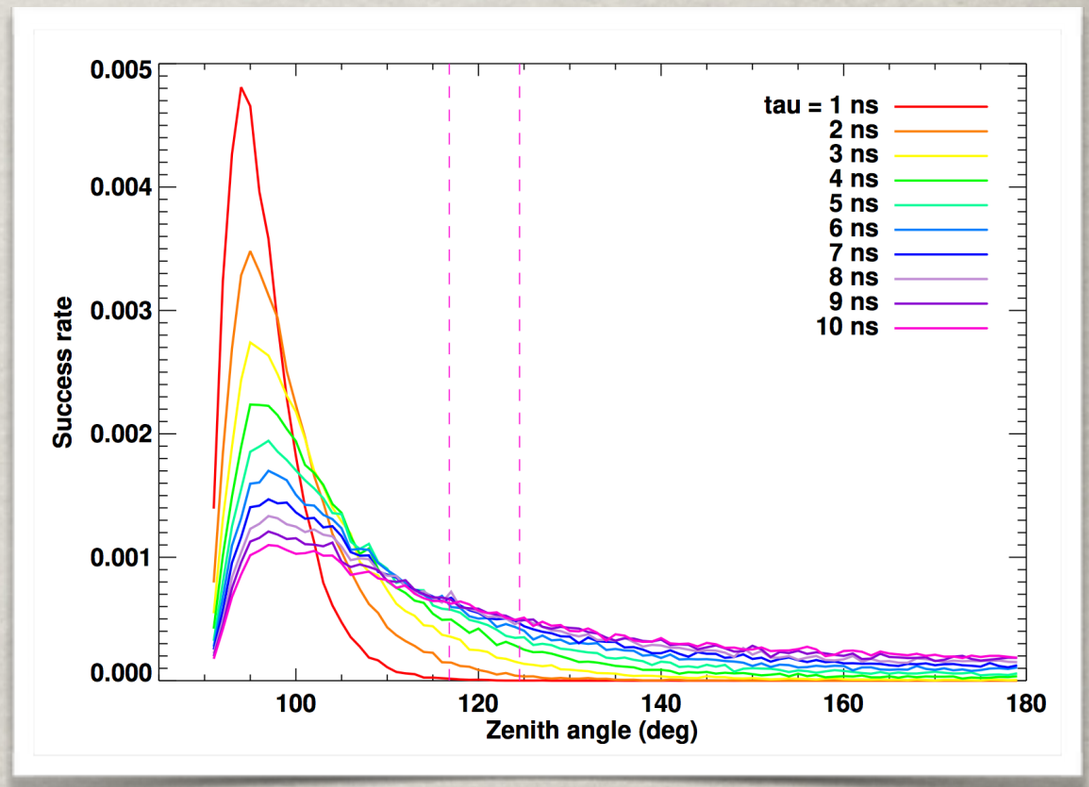

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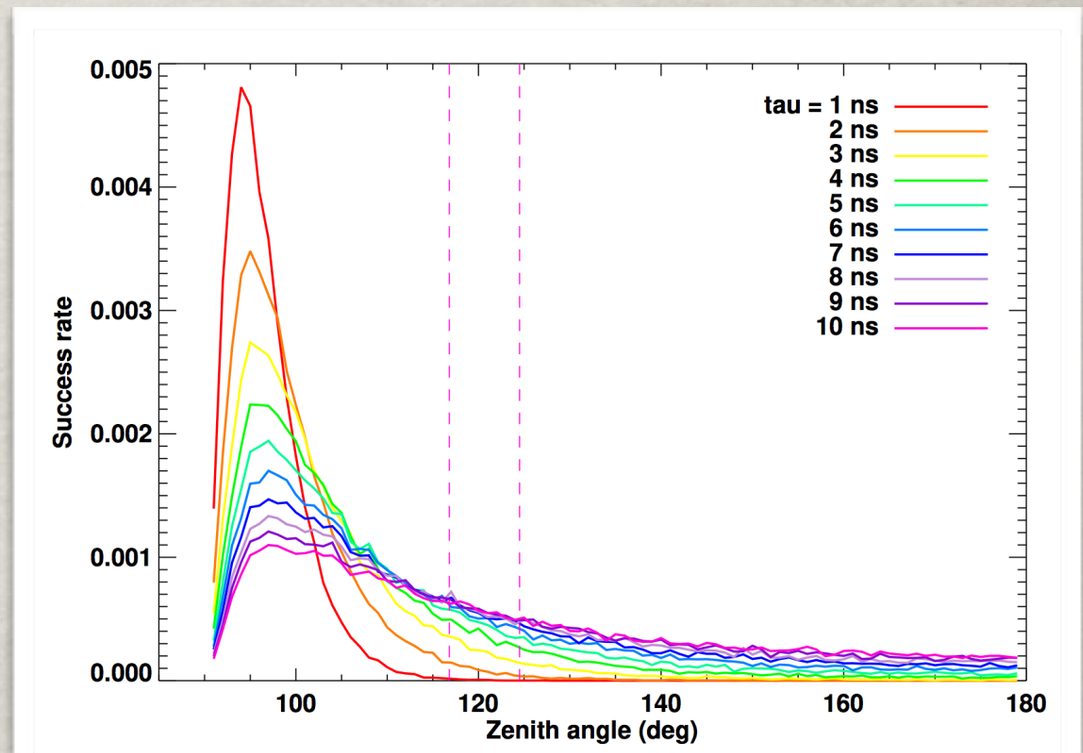

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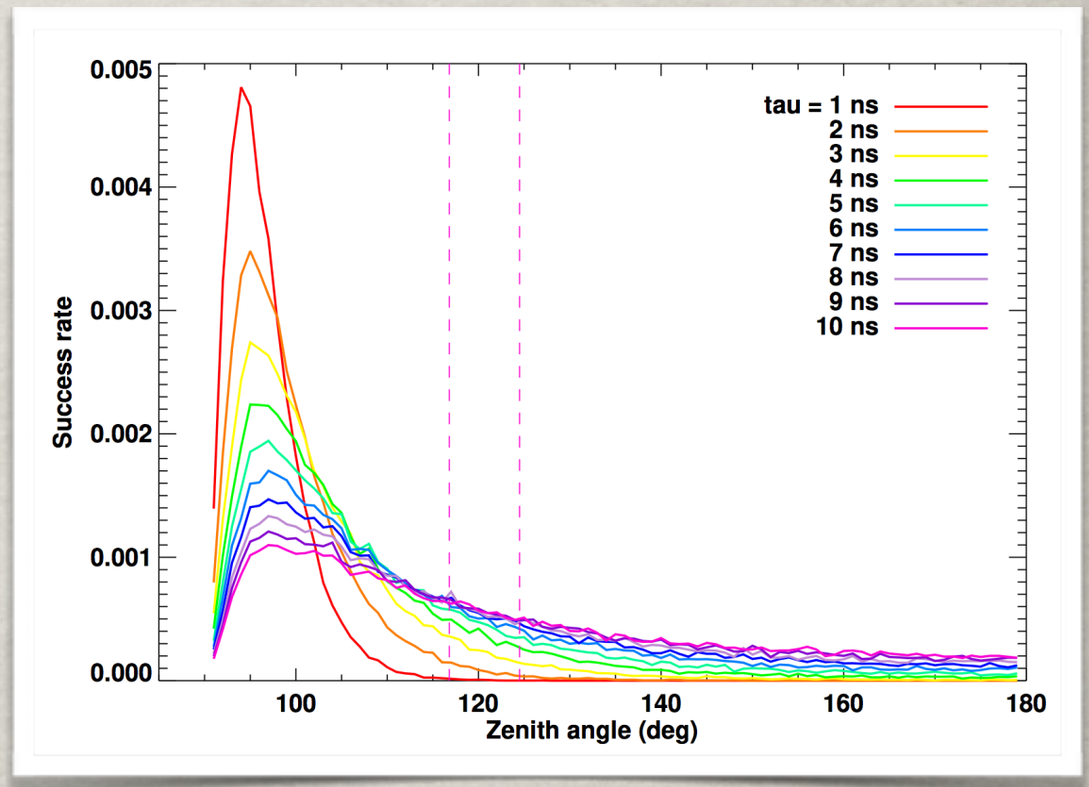

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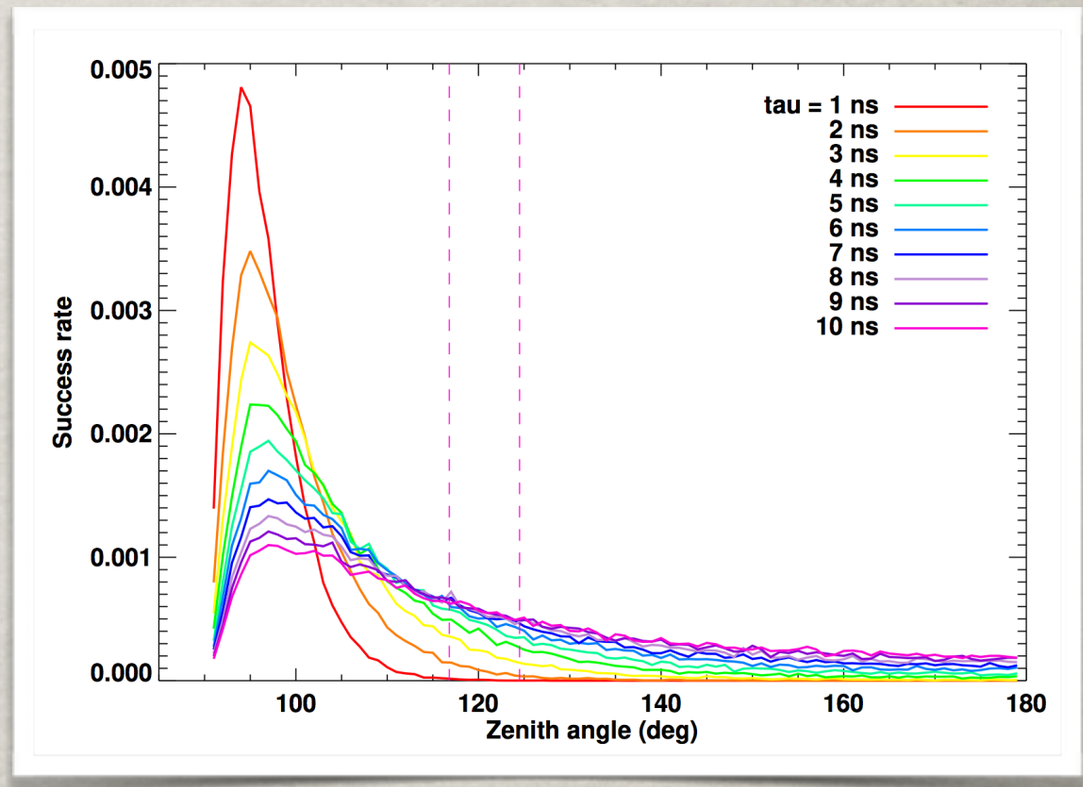

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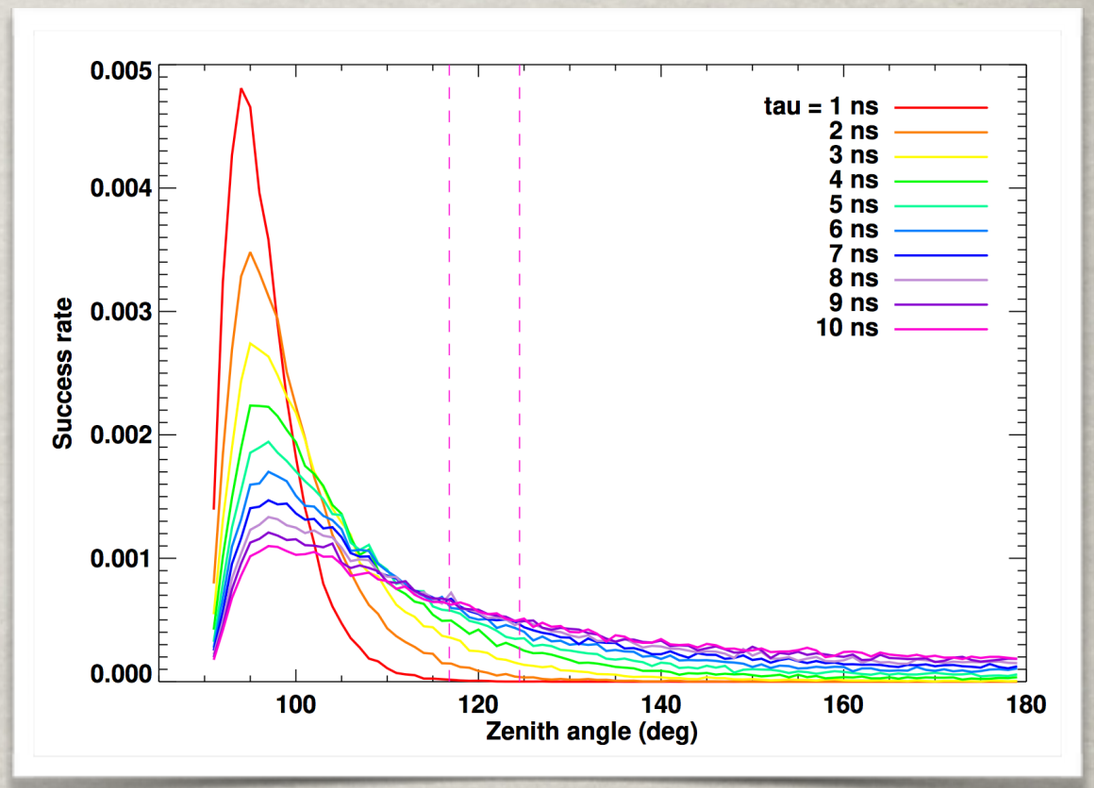
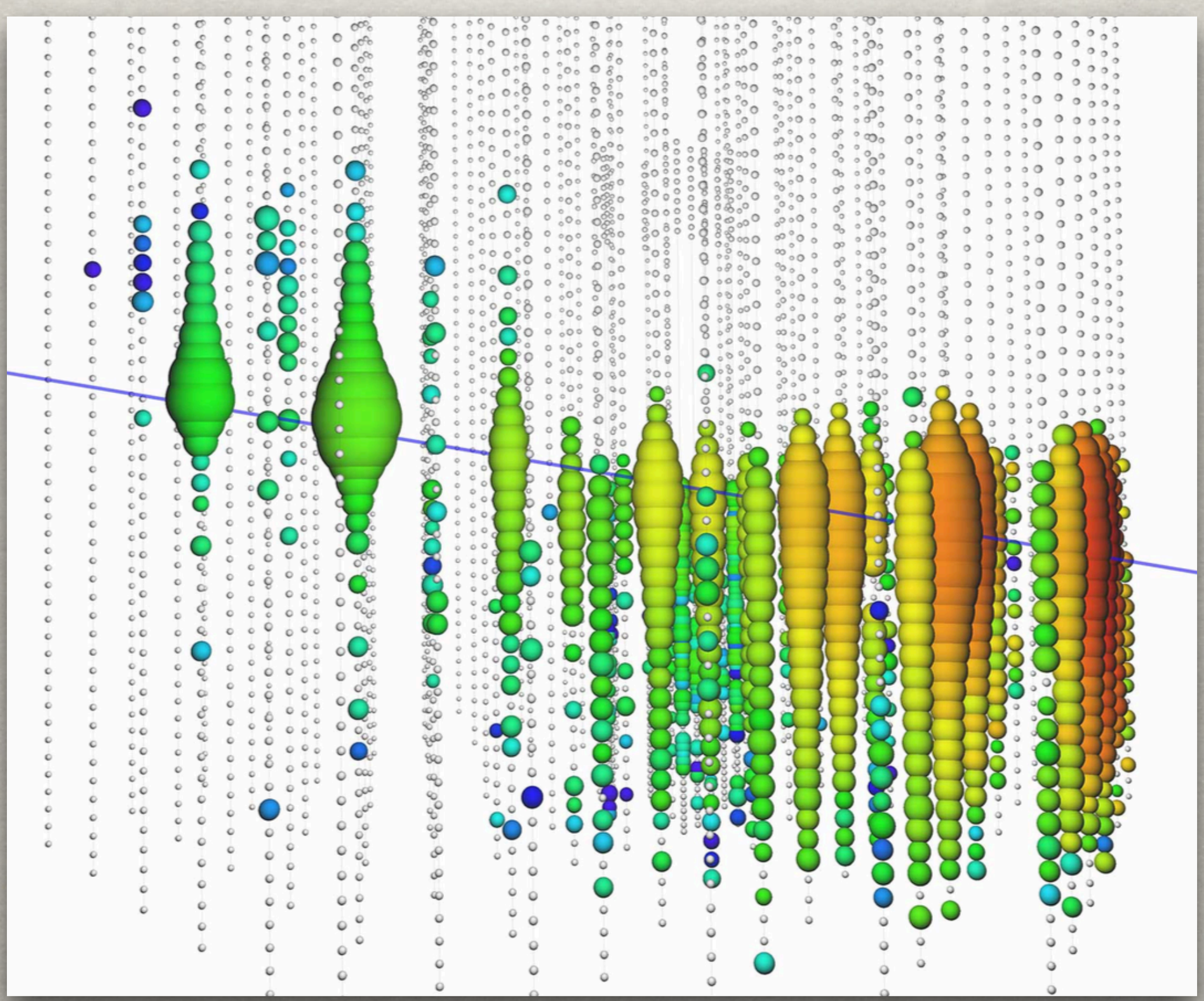


3. The Pieces of the Puzzle



"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,†]

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

(Dated: June 27, 2018)

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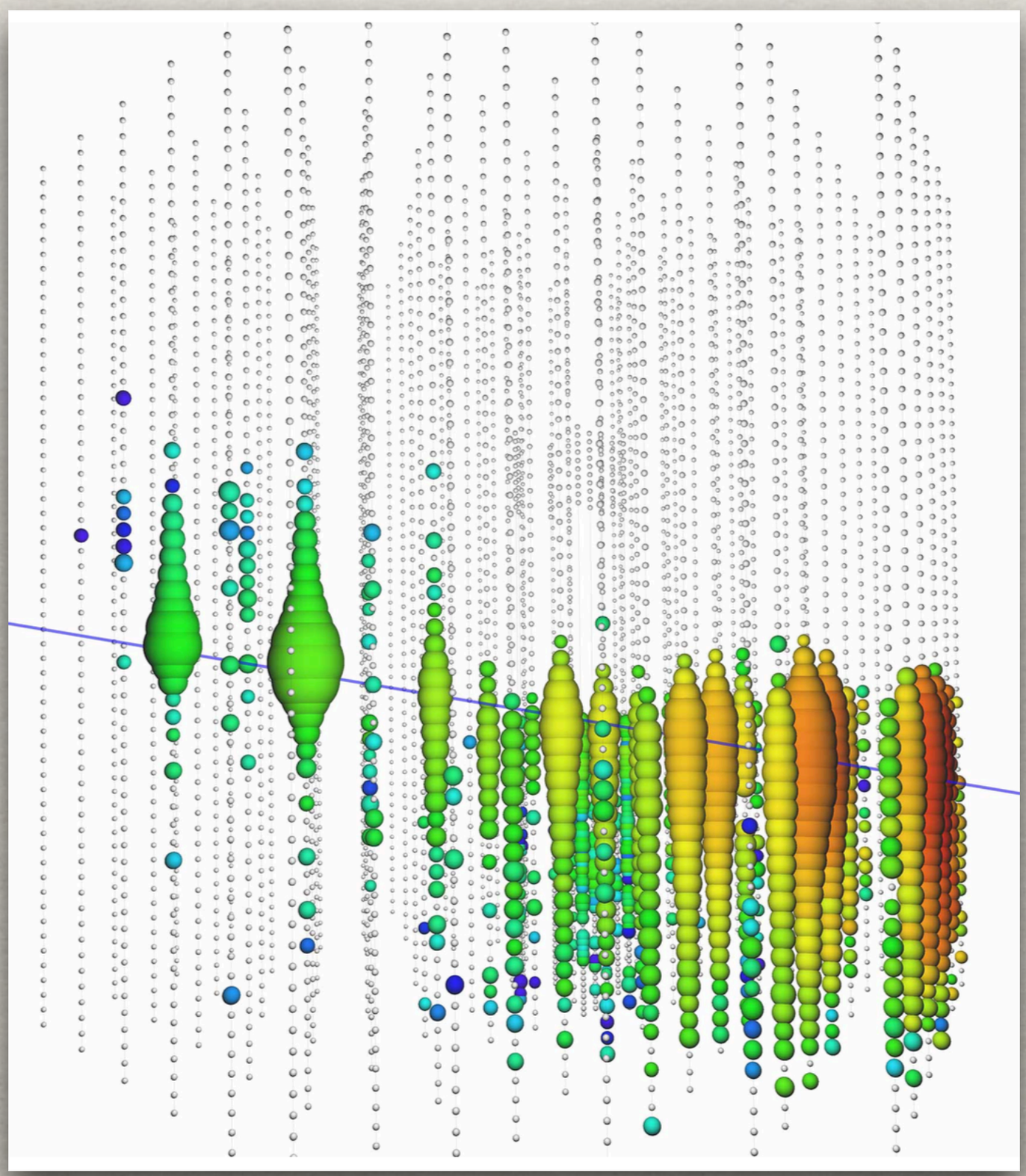
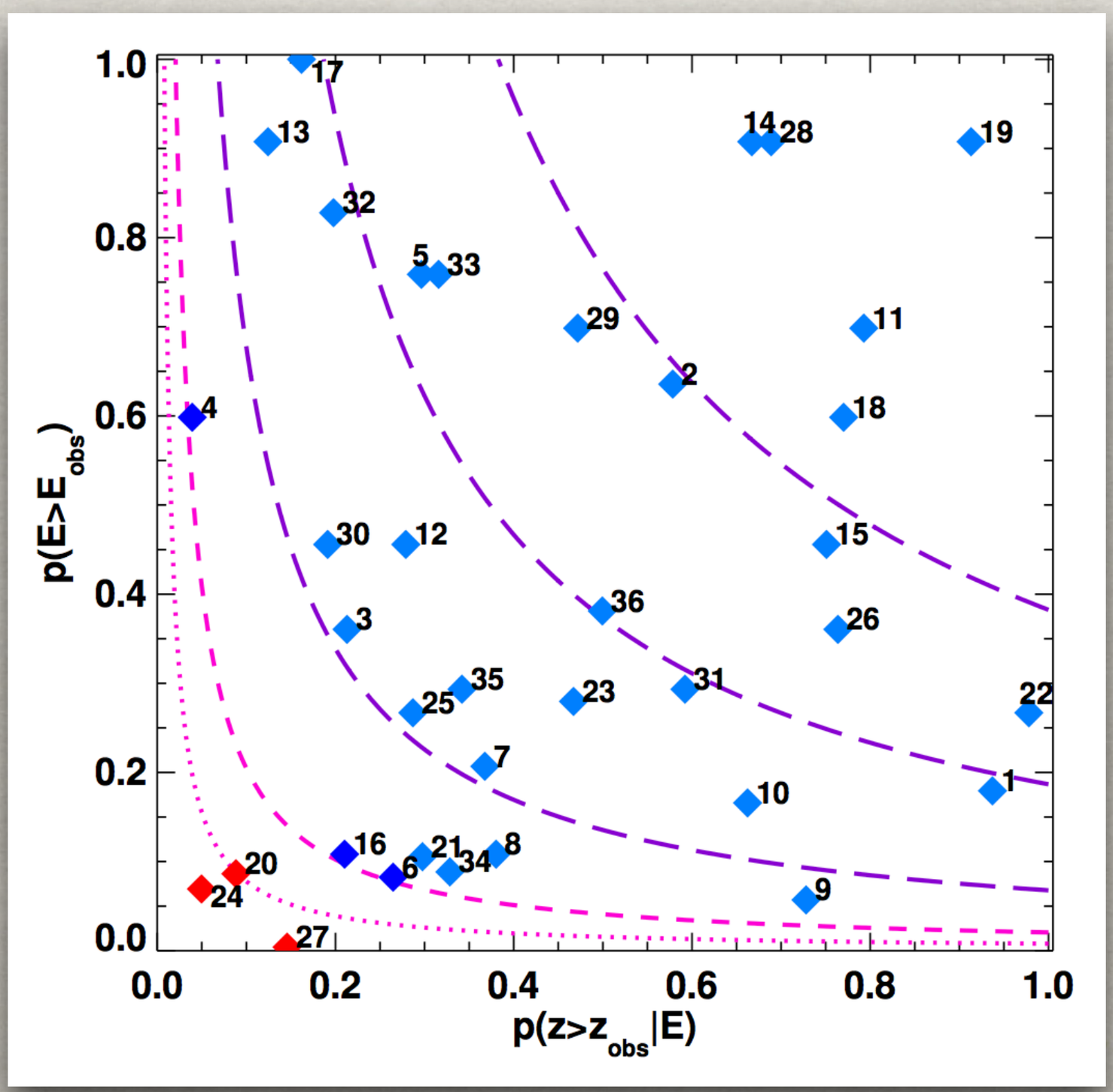
Kistler & Laha 2018

IceCube-140611



IceCube 2016

Candidate Analog Events from IceCube



Fox+18, ArXiv:1809.09615

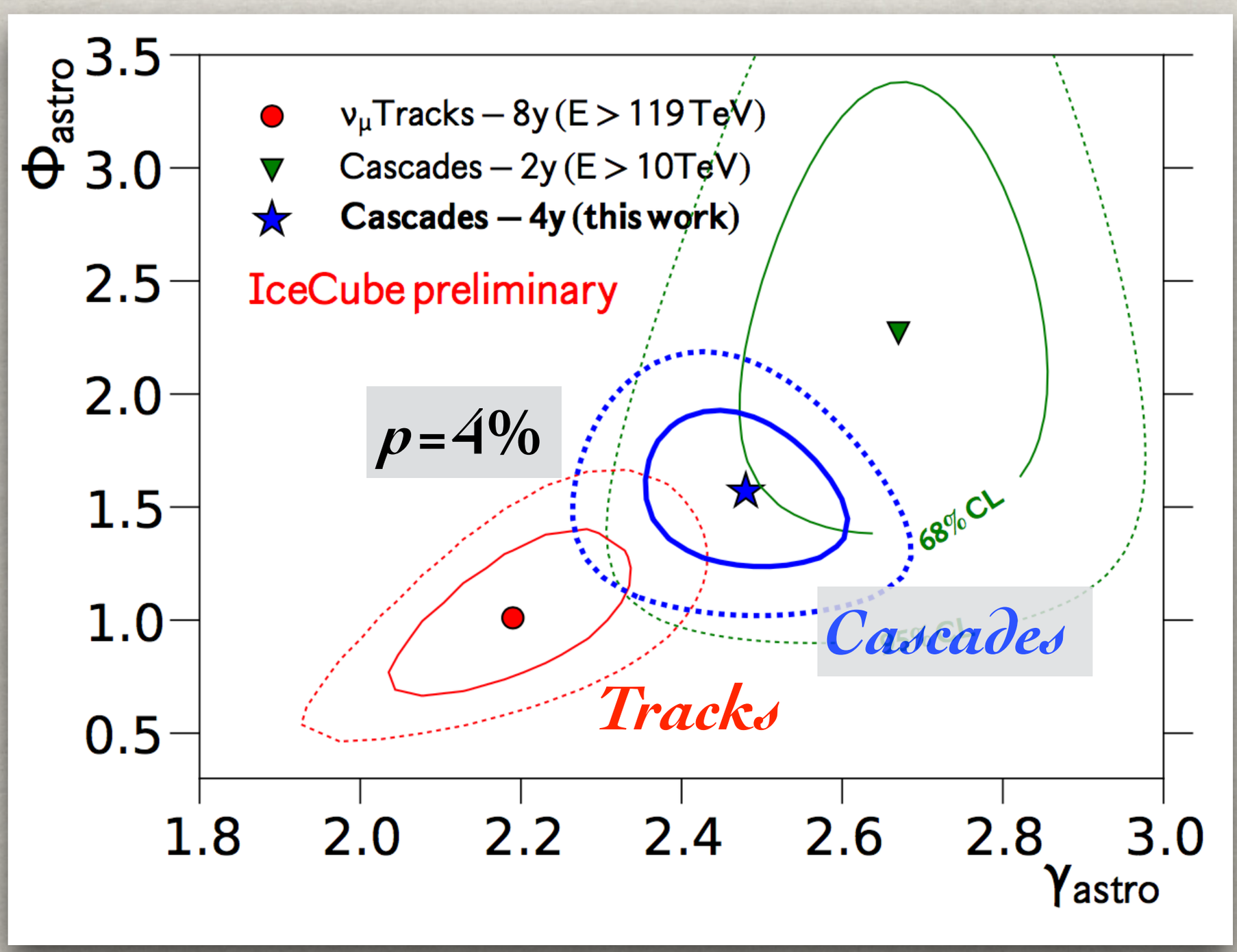
IceCube Anomalous Event Candidates

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. $110.^\circ34 \pm 0.^\circ22$, Dec. $+11.^\circ42 \pm 0.^\circ08$	R.A. $293.^\circ29$, Dec. $+32.^\circ82$	R.A. $169.^\circ61$, Dec. $+28.^\circ04$
Zenith angle z	$101.^\circ42$	$122.^\circ82$	$118.^\circ04$
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 $\varepsilon_\nu = 1$ EeV	340 km	270 km	285 km
$p_{\mathrm{SM}}(\varepsilon_\tau > \varepsilon_{\tau,\mathrm{obs}})$ for $\varepsilon_\nu = 1$ EeV	2.2×10^{-4}	3.8×10^{-6}	1.0×10^{-5}
$p_{\mathrm{SM}}(z > z_{\mathrm{obs}})$ for $\varepsilon_\nu = 1$ EeV, $\varepsilon_\tau > \varepsilon_{\tau,\mathrm{obs}}$	5.0×10^{-3}	4.5×10^{-5}	1.8×10^{-4}

Fox+2018

Cascades v. Tracks



IceCube 2018

Theoretical Precedents

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$$c\tau = \left(\frac{\sqrt{F}}{10^7\ \mathrm{GeV}}\right)^4 \left(\frac{100\ \mathrm{GeV}}{m_{\tilde{\tau}_R}}\right)^5 10\,\mathrm{km}$$

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LHC Run 1:
$m \gtrsim 300$ GeV

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(aiming for ~1 $R_\oplus$)

AAEs ~1 EeV

$$\gamma c\tau = \left(\frac{10^9\ \mathrm{GeV}}{500\ \mathrm{GeV}}\right) \left(\frac{\sqrt{F}}{10^7\ \mathrm{GeV}}\right)^4 \left(\frac{100\ \mathrm{GeV}}{500\ \mathrm{GeV}}\right)^5 10\,\mathrm{km}$$

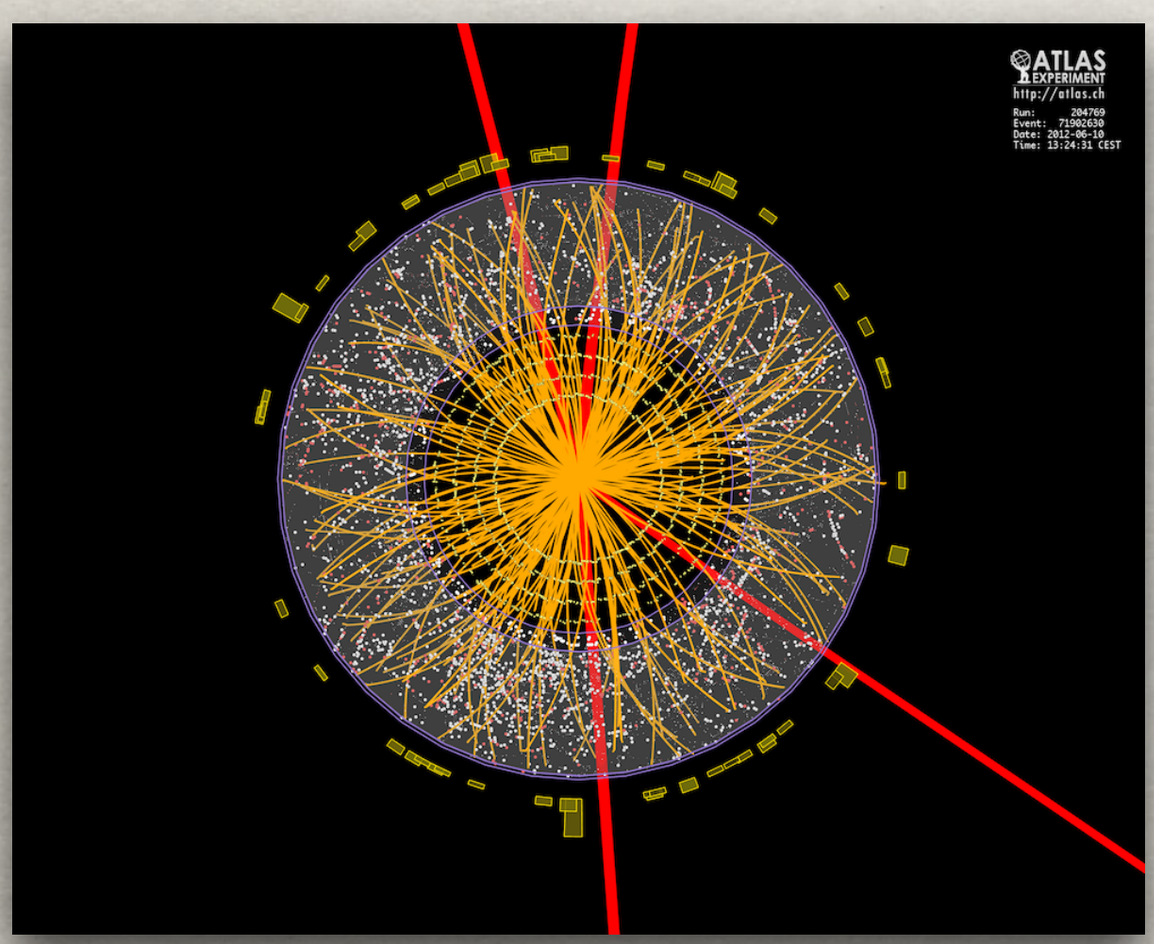
LHC Run 1: $m \gtrsim 300$ GeV

$$\gamma c\tau = \left(\frac{2\times 10^6}{3125}\right) \left(\frac{\sqrt{F}}{10^7\ \mathrm{GeV}}\right)^4 \left(\frac{500\ \mathrm{GeV}}{m_{\tilde{\tau}_R}}\right)^6 10\,\mathrm{km}$$

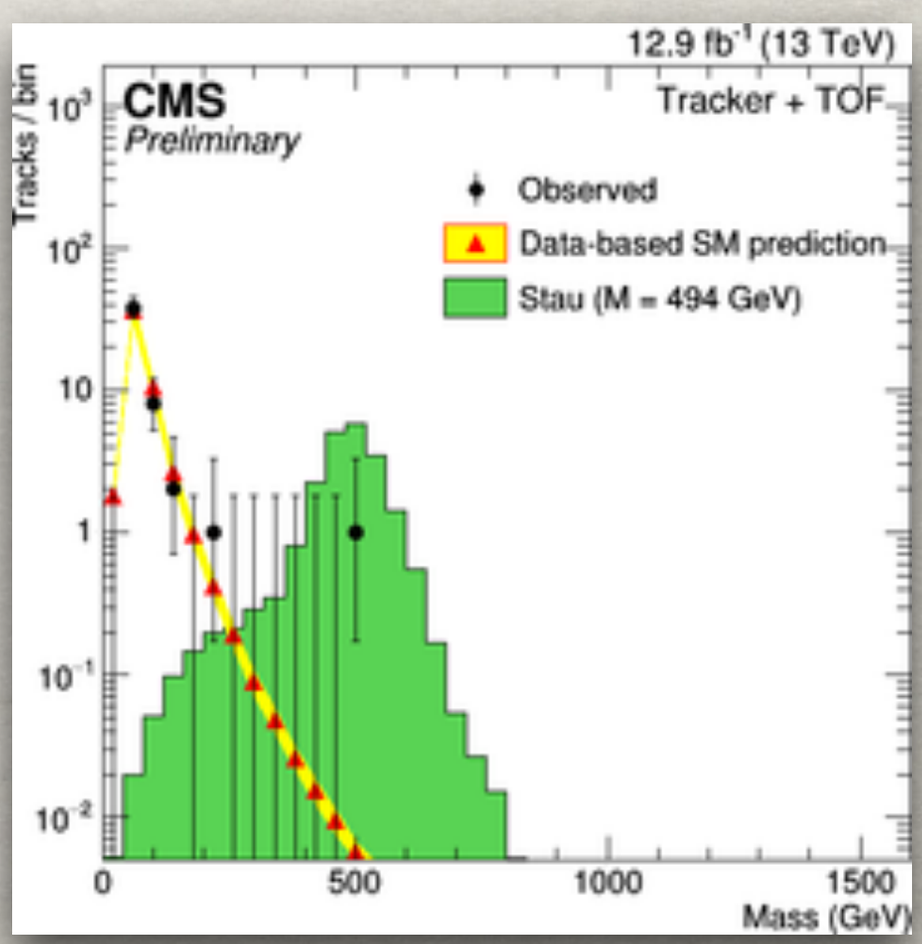
$$\gamma c\tau = \left(\frac{\sqrt{F}}{10^7\ \mathrm{GeV}}\right)^4 \left(\frac{500\ \mathrm{GeV}}{m_{\tilde{\tau}_R}}\right)^6 6400\,\mathrm{km}$$

(= 1.0 $R_\oplus$)

4. What Lies Ahead

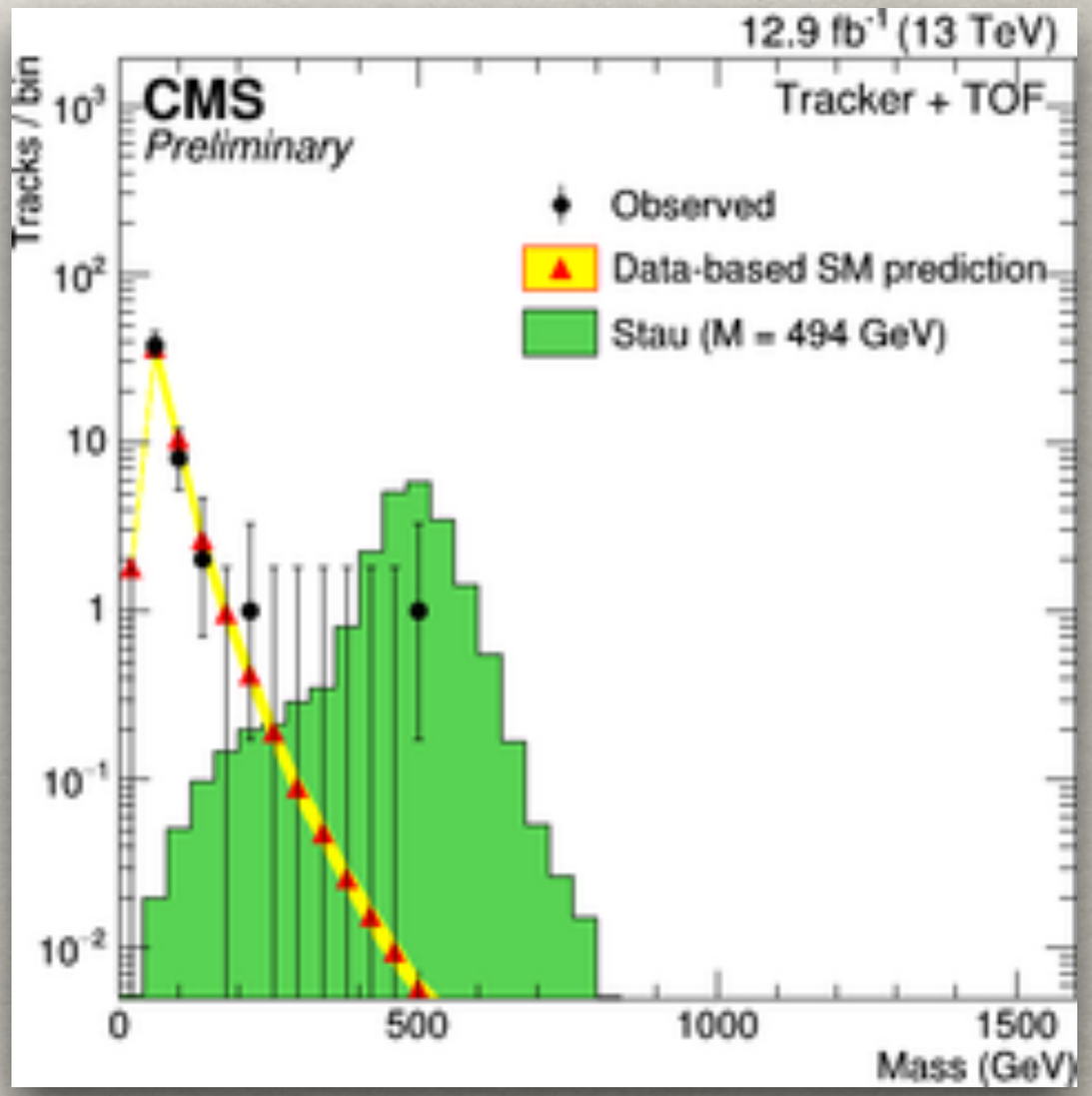


ATLAS 2013



CMS 2016

CMS 2016 LLP Search



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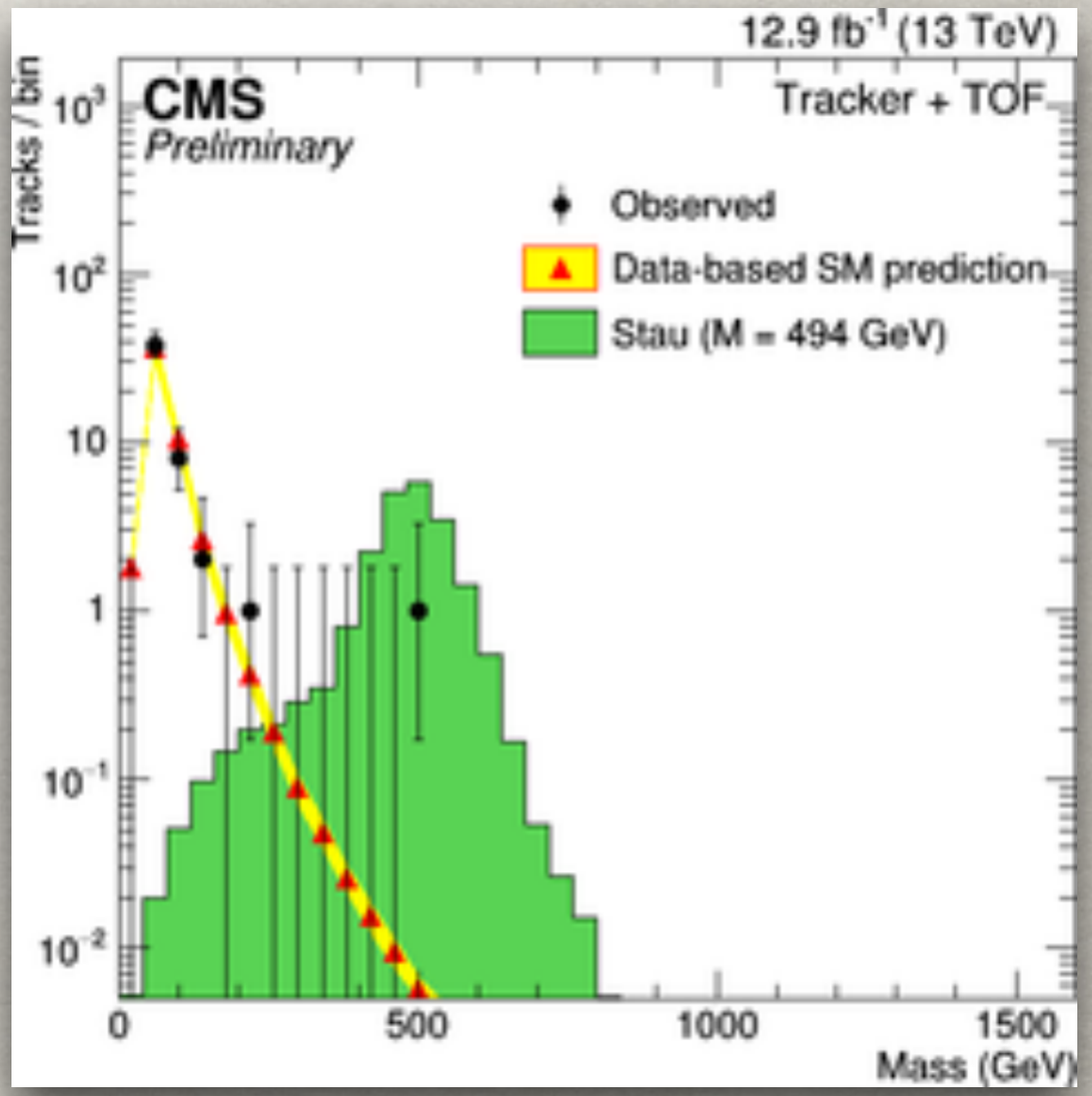

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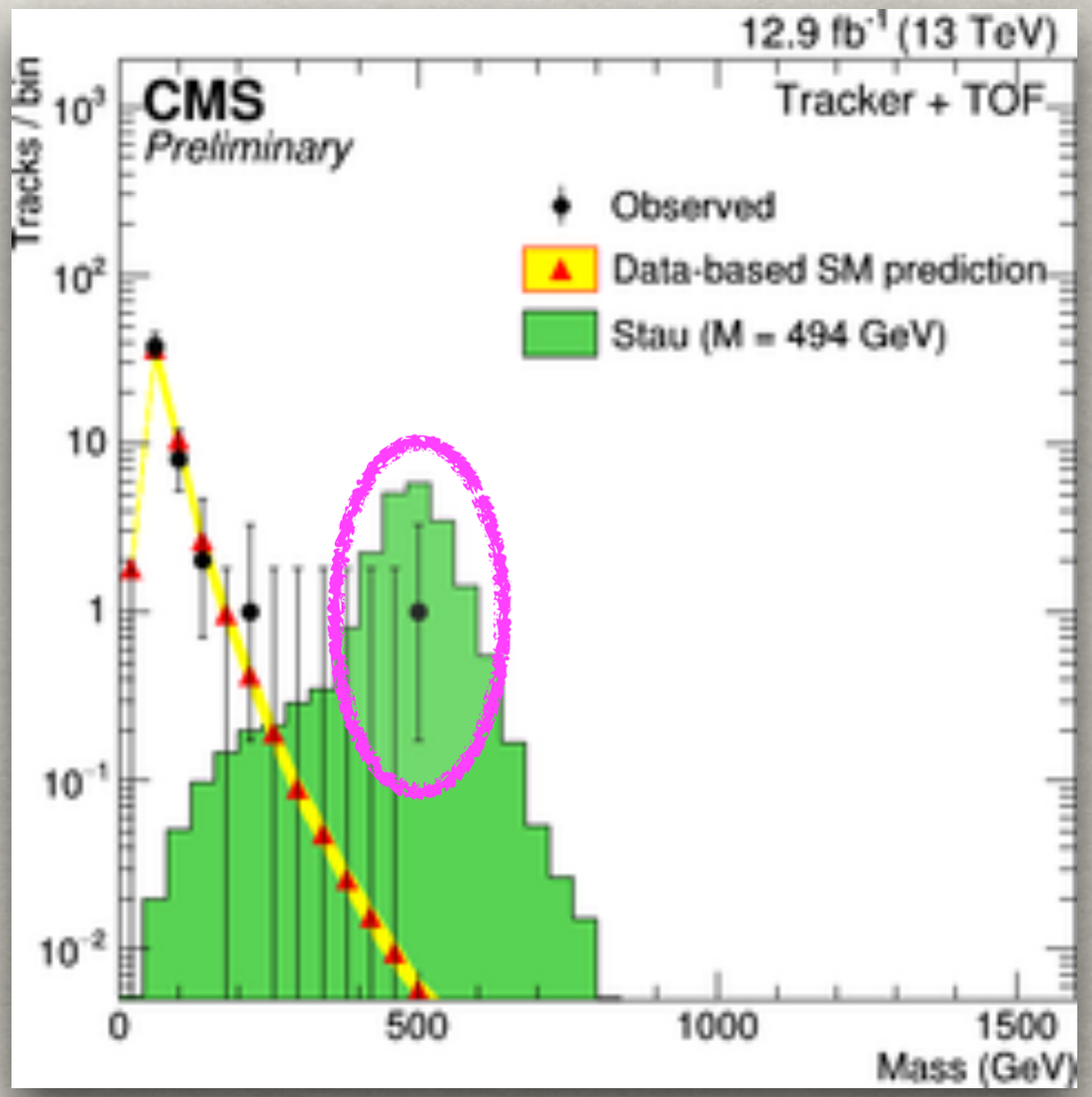

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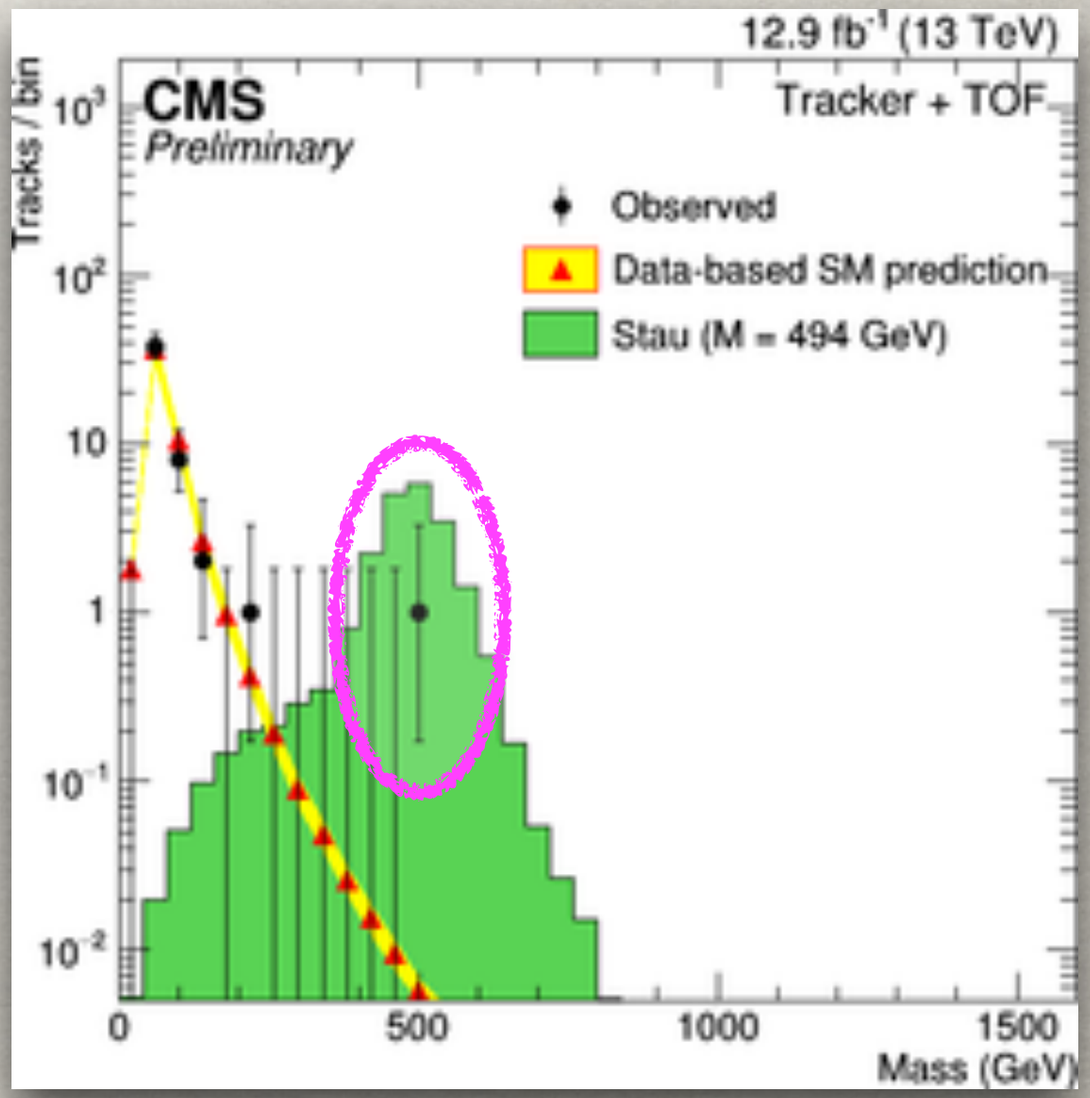

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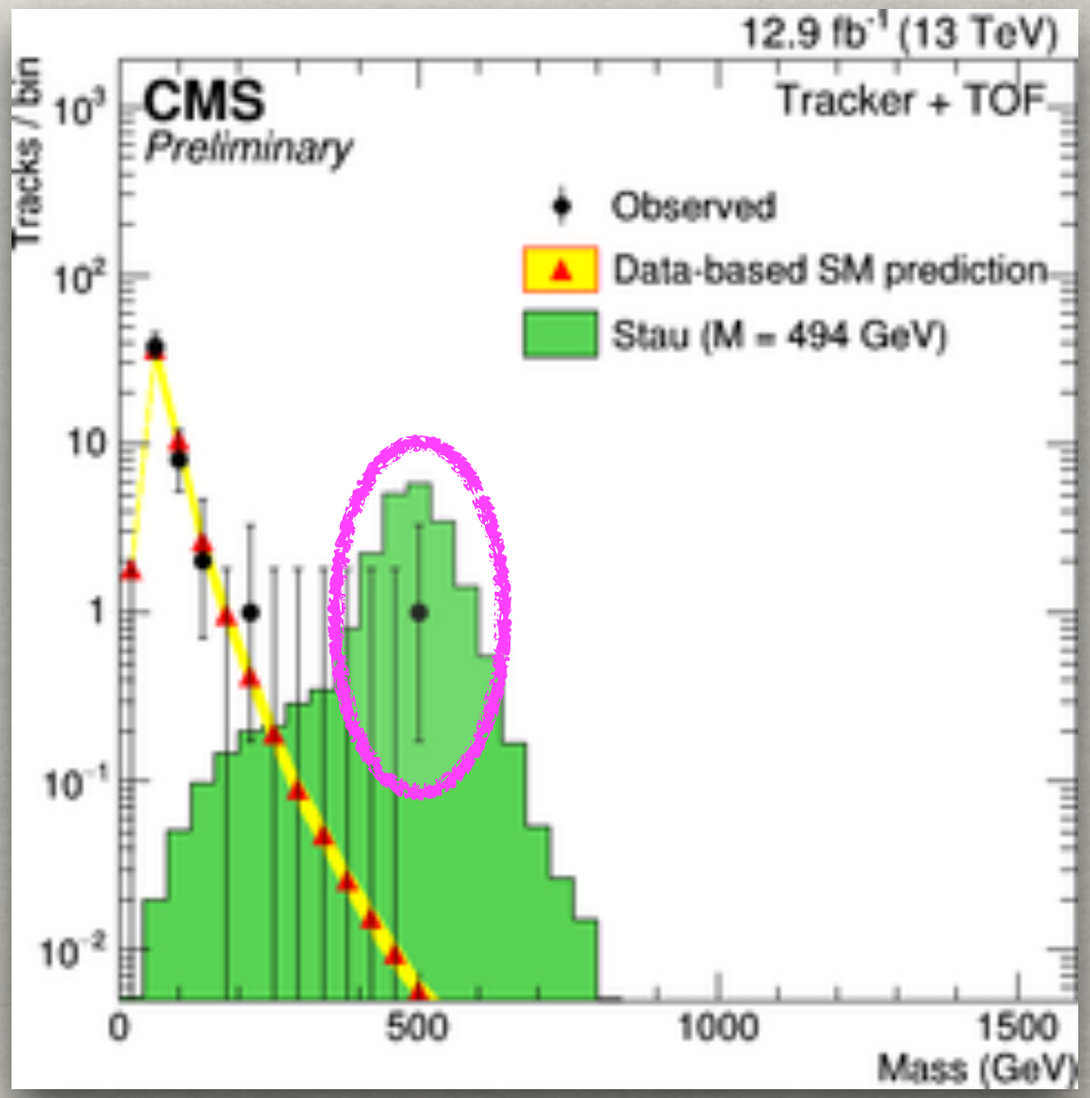

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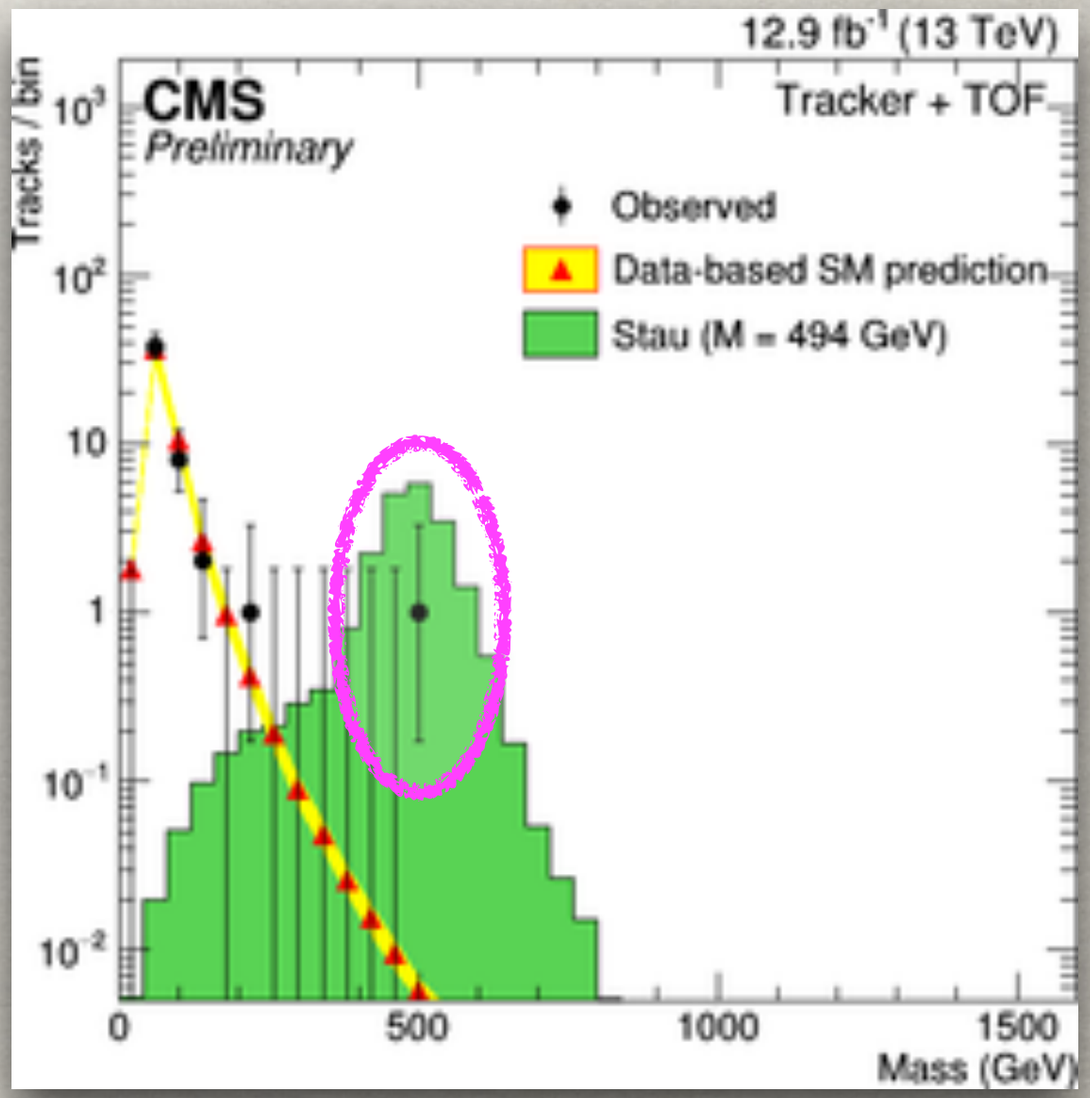

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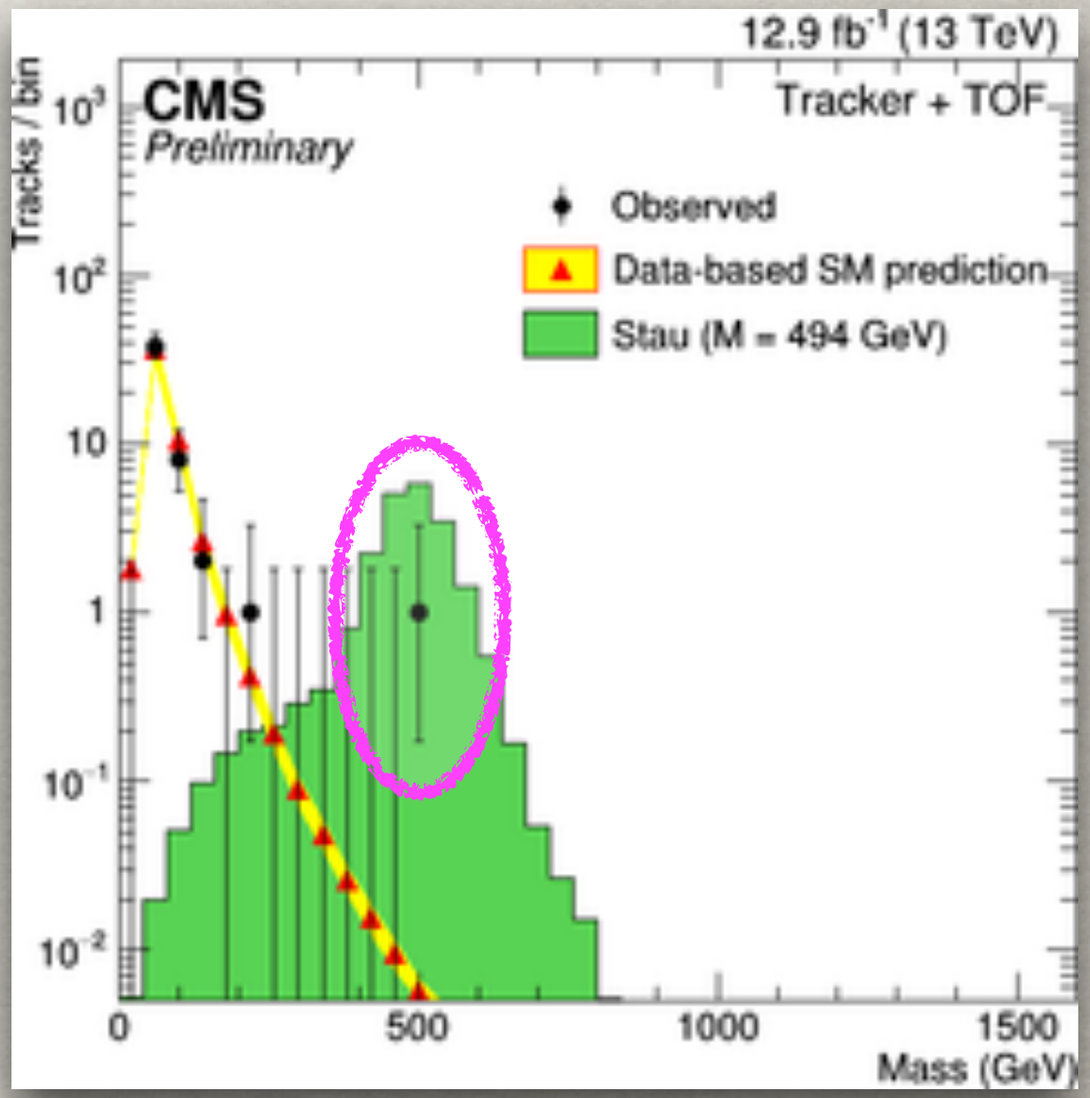
- 3 events for >3σ (5 for >5σ)



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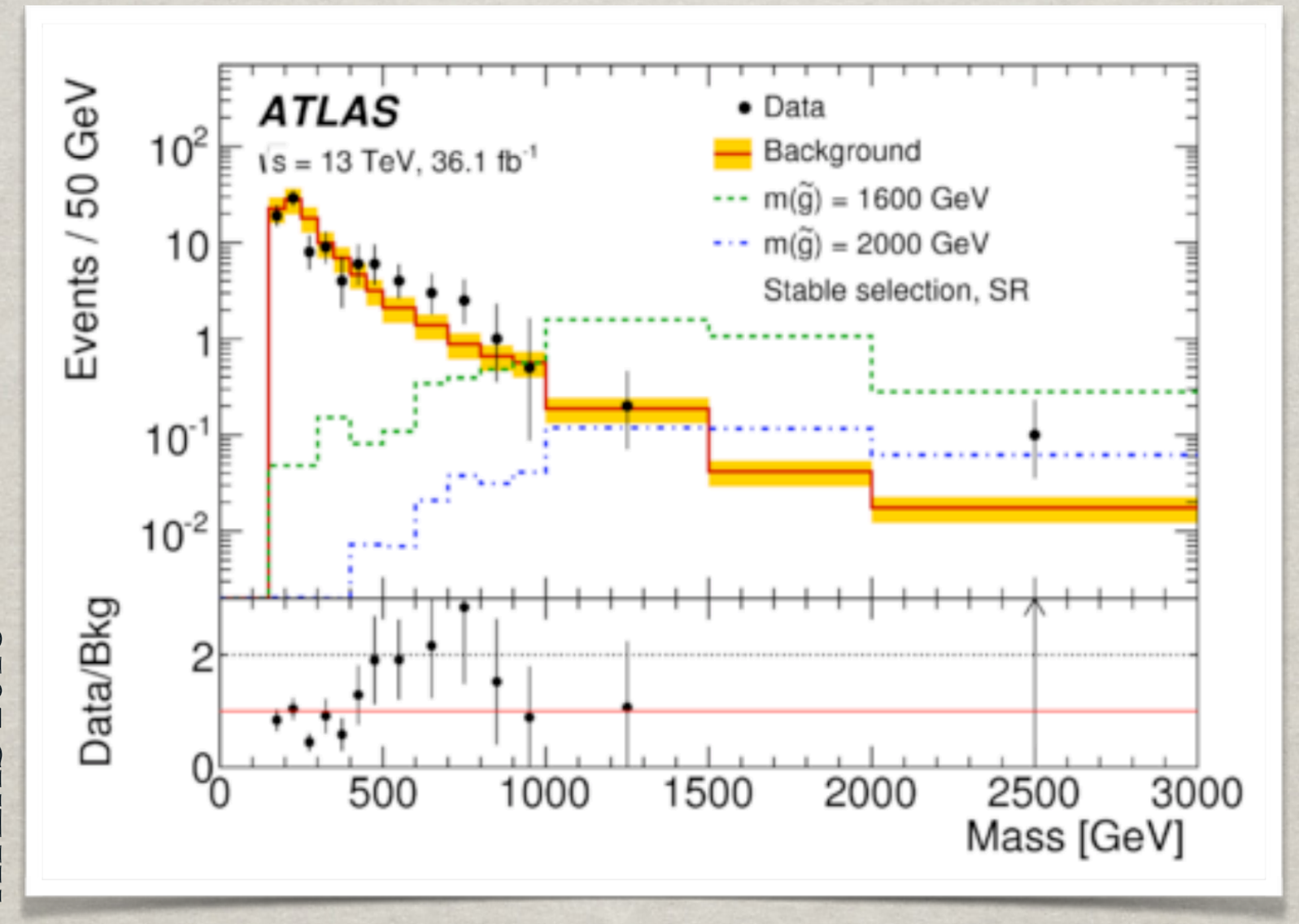

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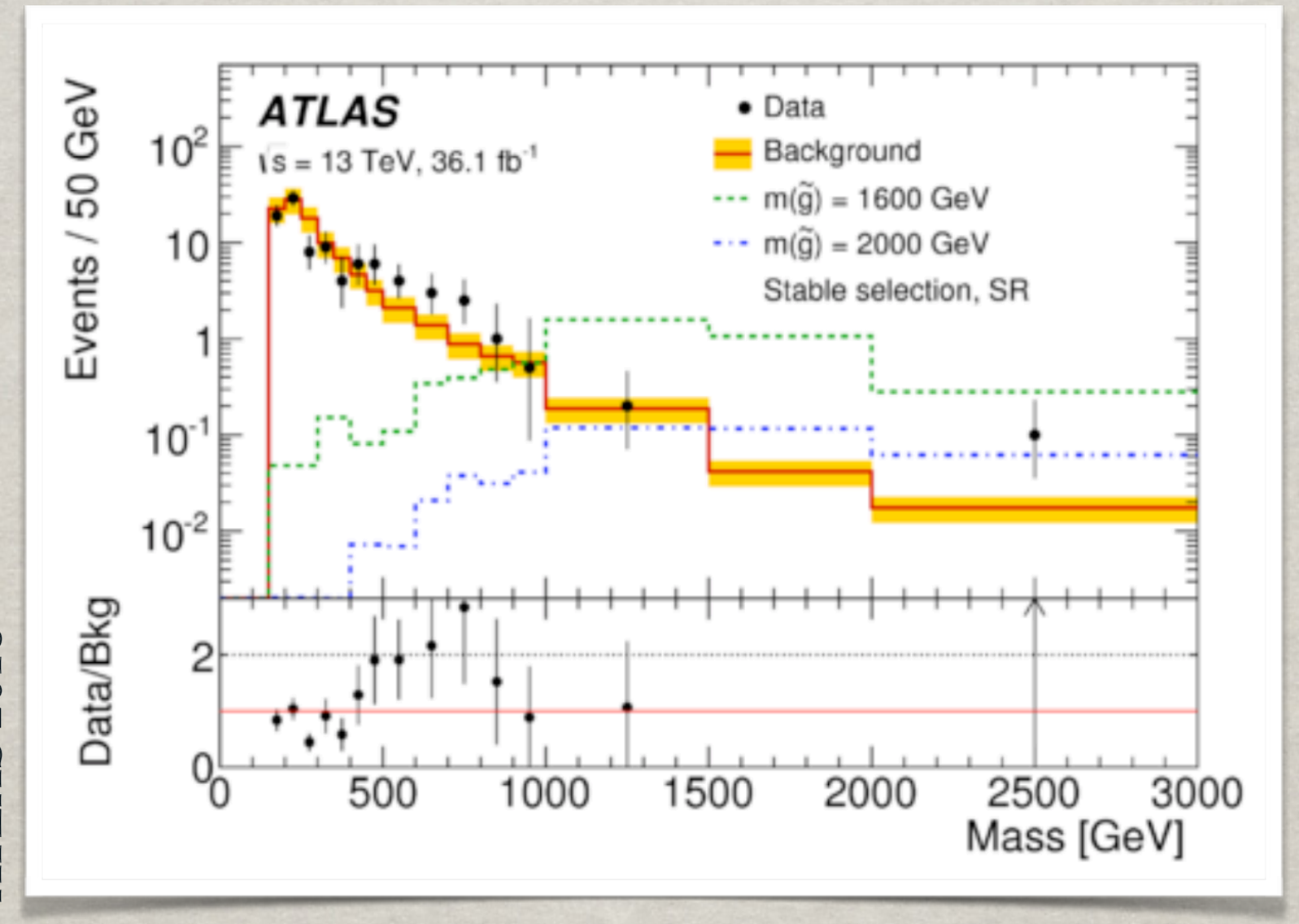

- ATLAS gluino targeted search for heavy stable charged particles with 36.1 fb^{-1} of data

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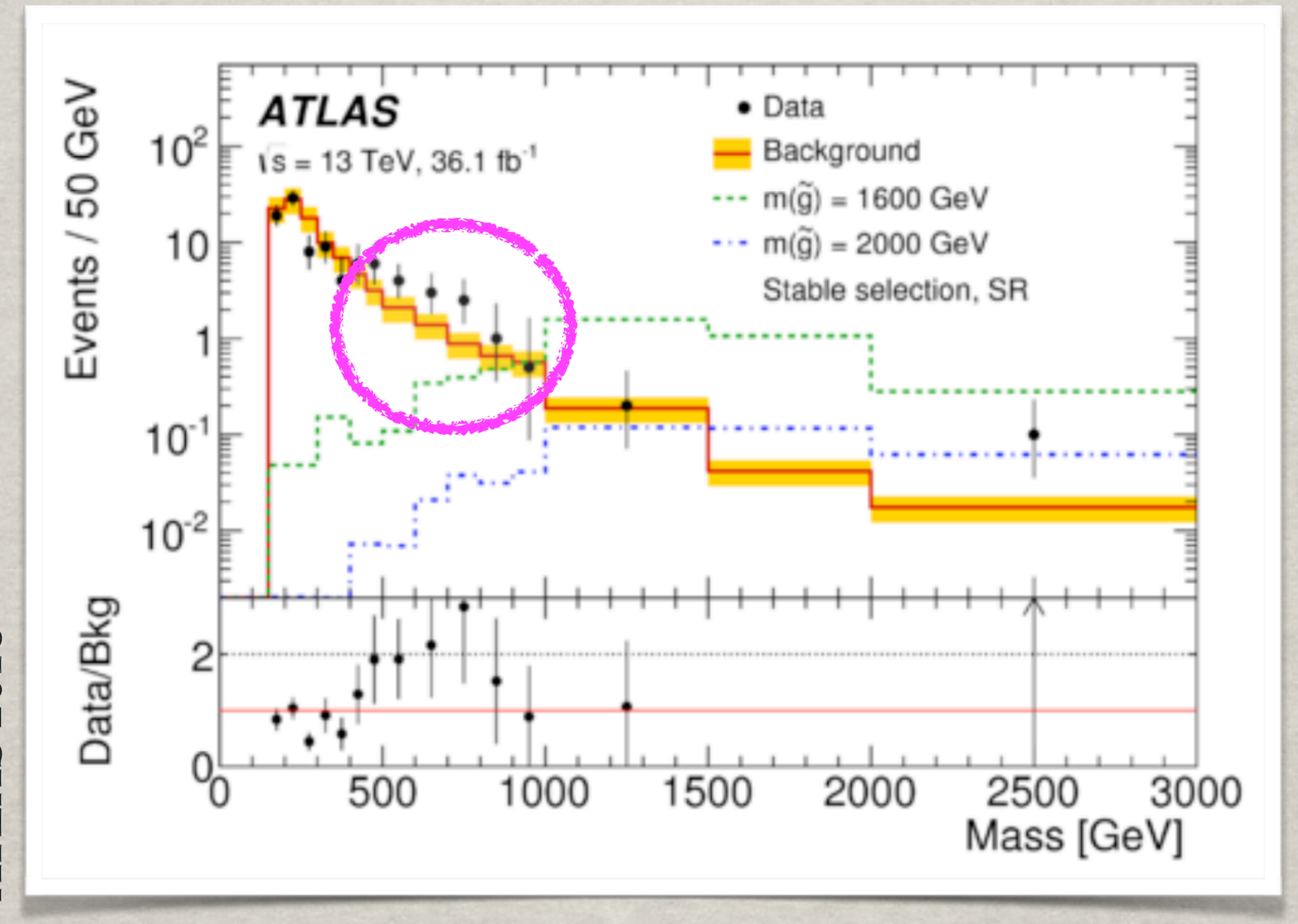
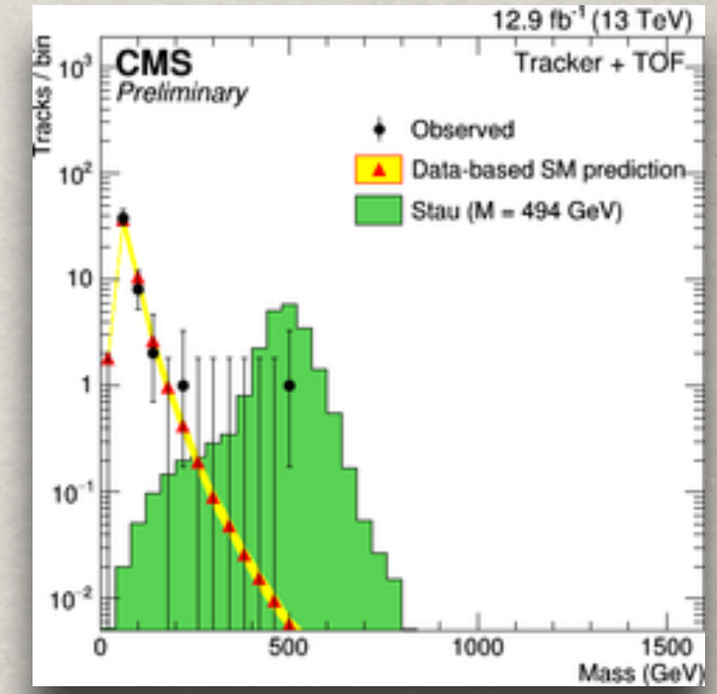
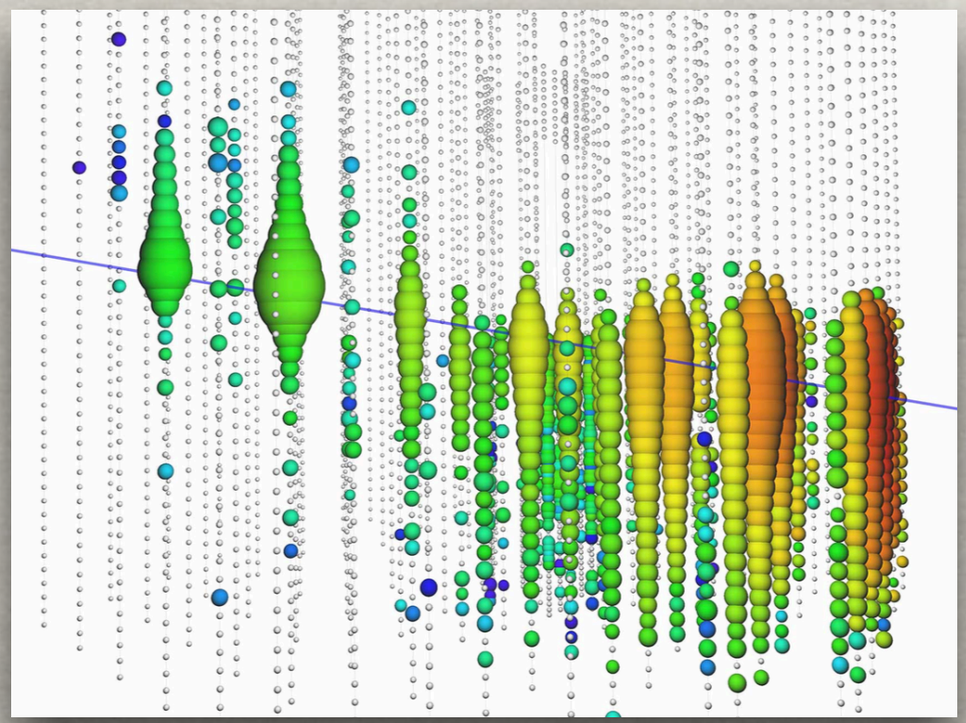


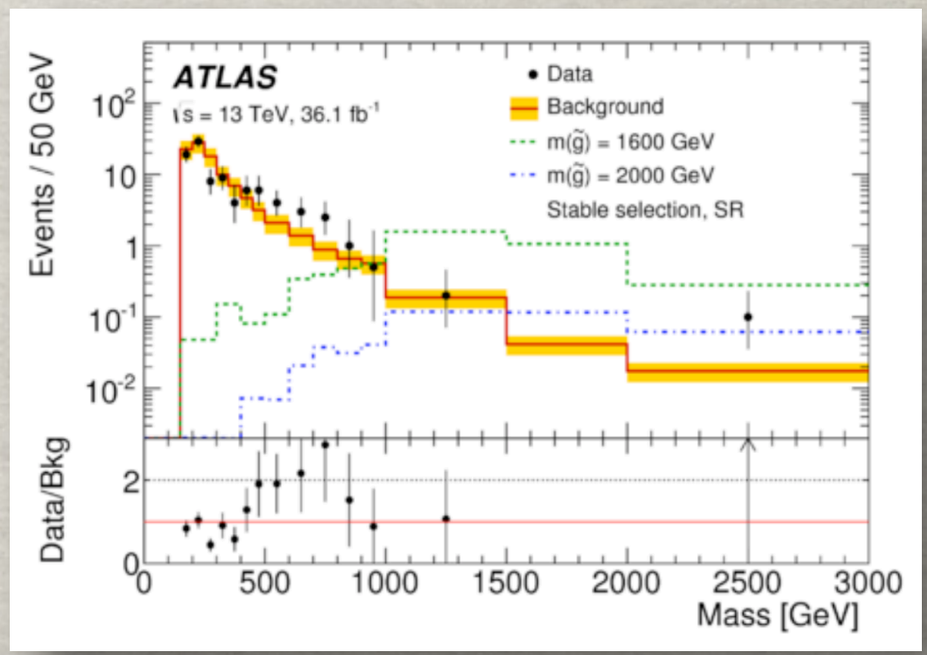
- ATLAS gluino targeted search for heavy stable charged particles with 36.1 fb^{-1} of data
- "2.4σ excess in stable region" over masses 500 GeV to 800 GeV

Breaking the Standard Model

- IceCube lepton mass discrimination analysis







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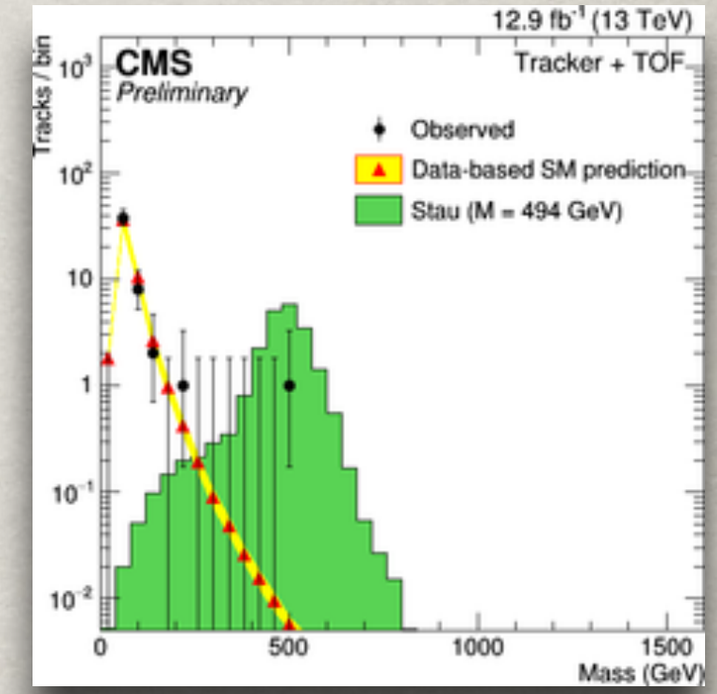

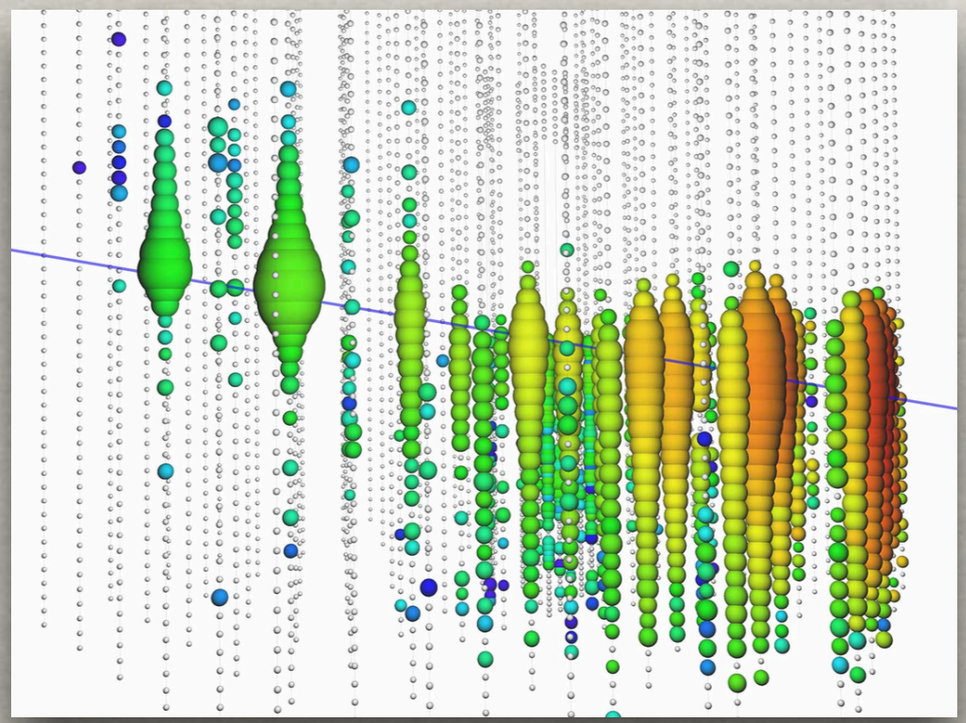

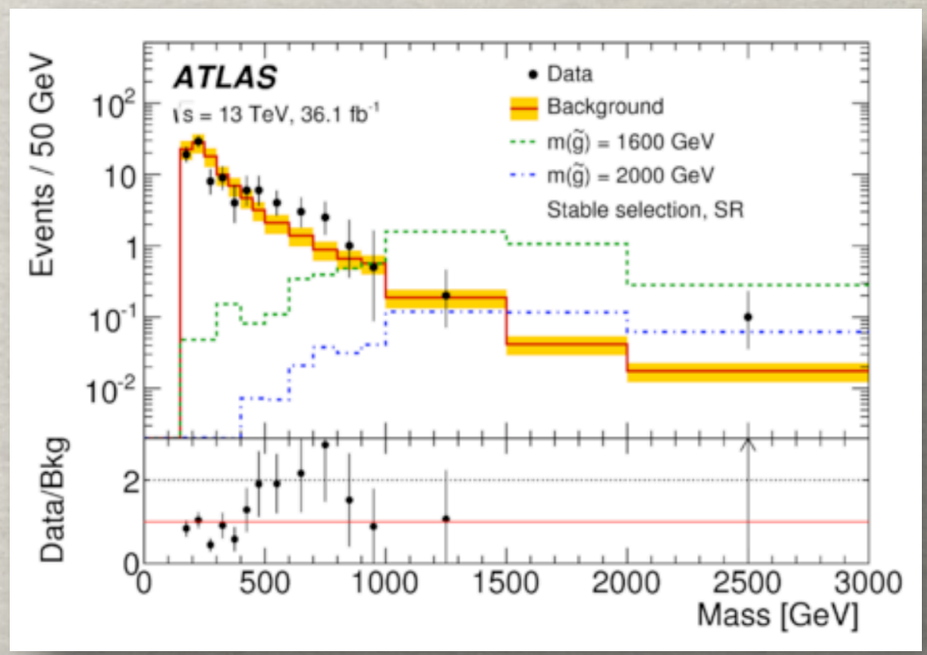

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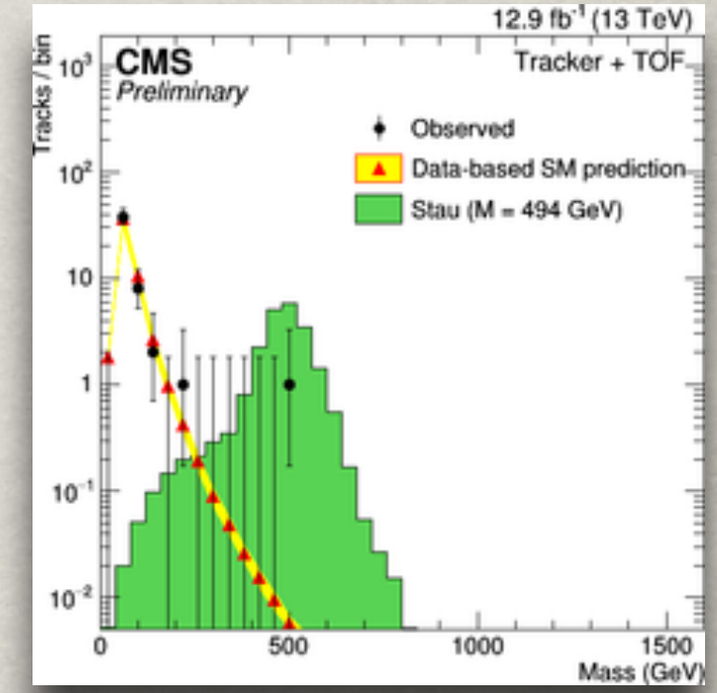

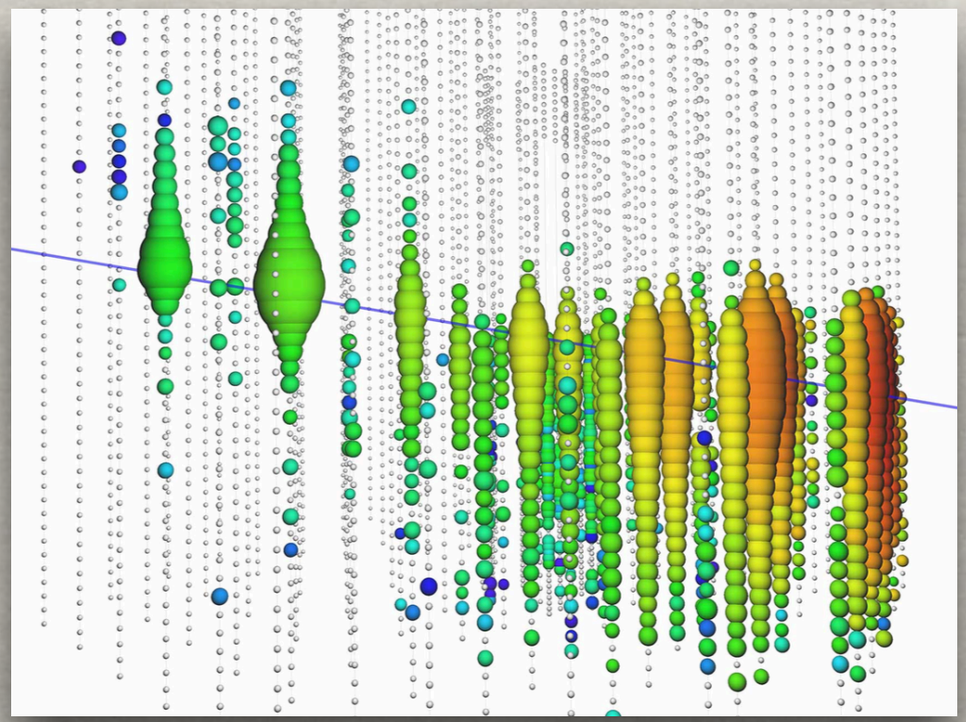

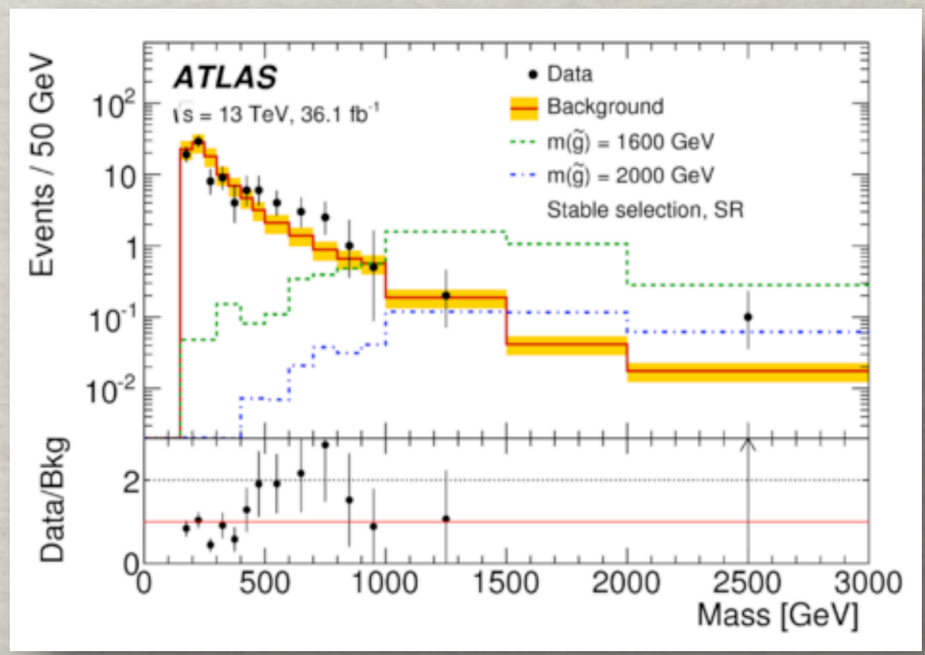

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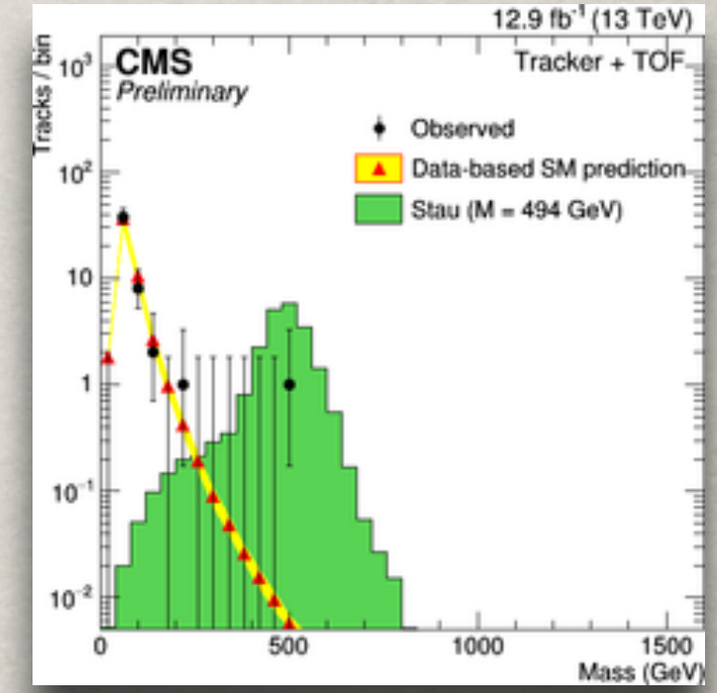

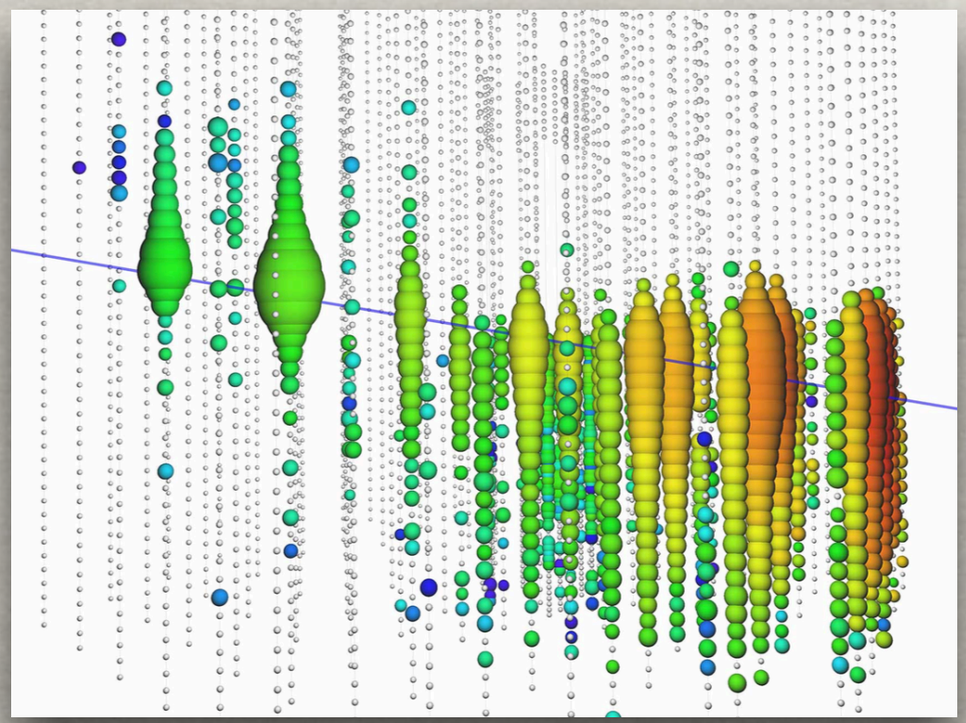

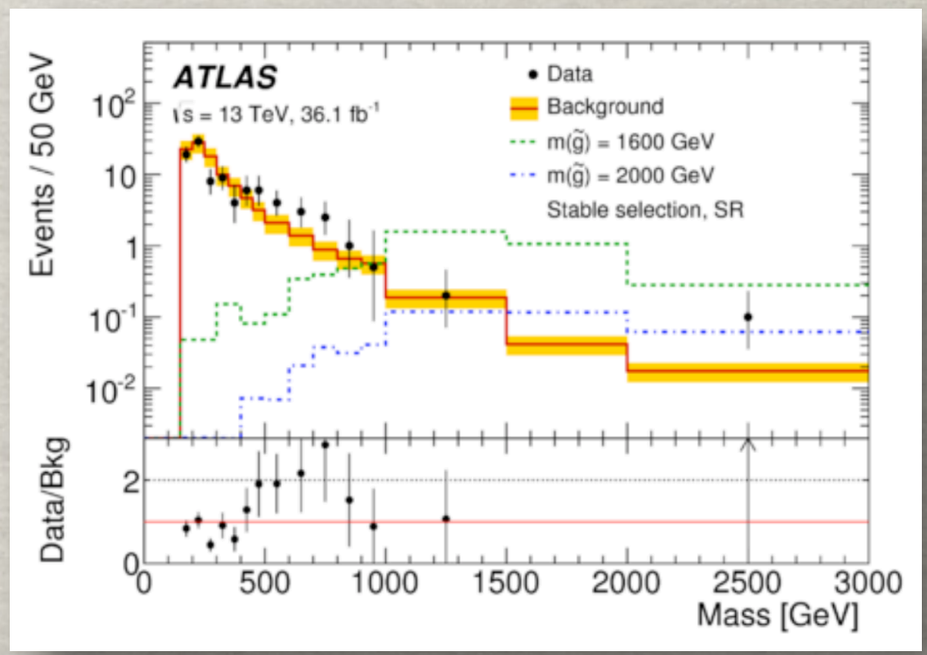

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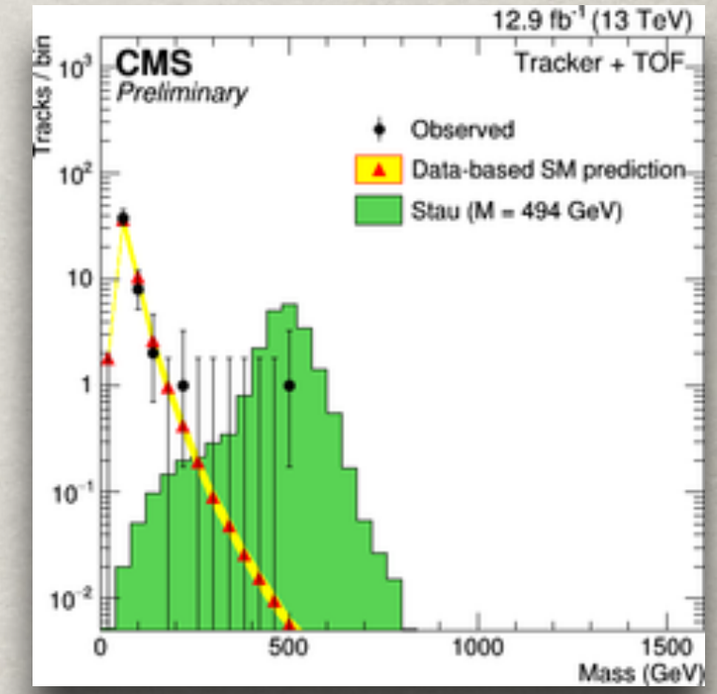
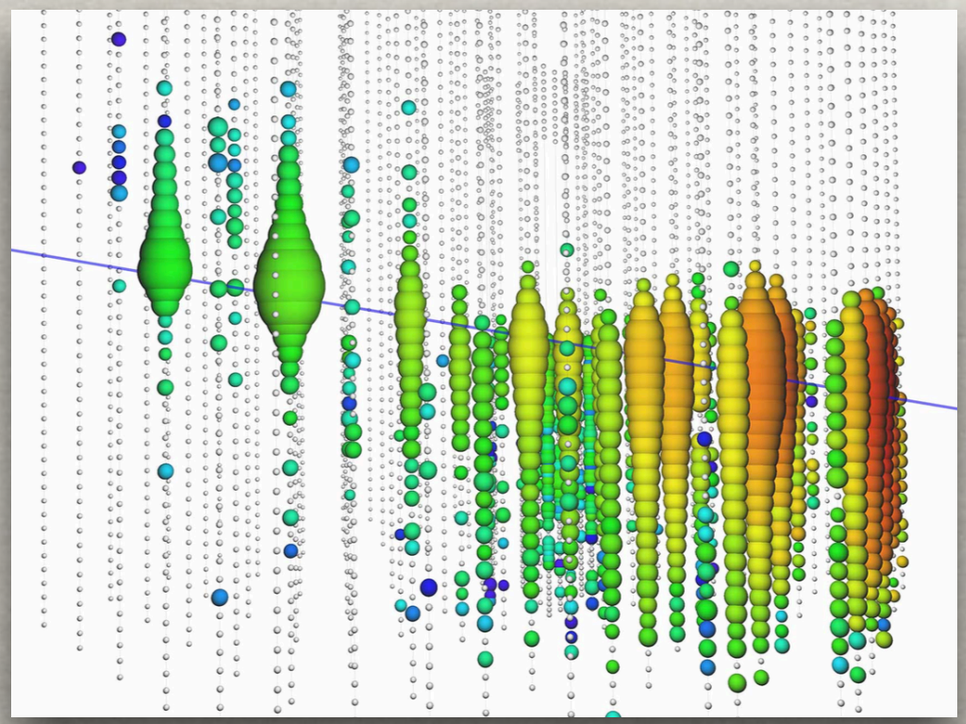
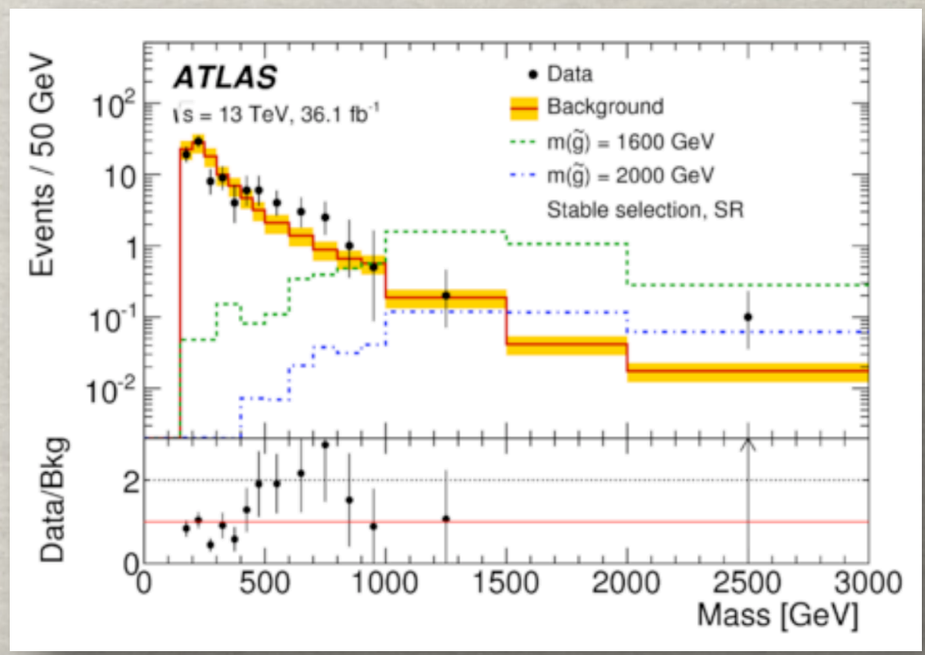
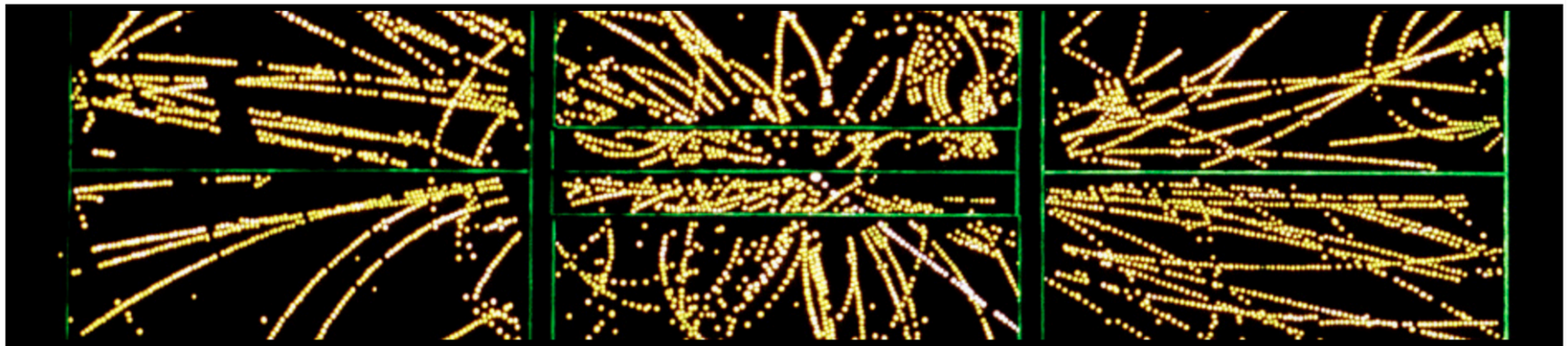






SUSY Bets

Not Even Wrong



← Use the Moment Map, not Noether's Theorem

Quick Links →

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Posted on September 3, 2014 by woit

The LHC long shutdown (LS1) seems to be progressing on schedule, with physics collisions at 13 TeV planned for early April 2015. I'd guess the earliest 13 TeV results might appear at the summer 2015 conferences. The long term plan is to accumulate up to about 50 fb^{-1} of data per year for about 3 years of data-taking, ending in mid-2018. There will then be a year and a half shutdown (LS2), followed by data-taking at 14 TeV from 2020-2022. The plan is to end up with about 300 fb^{-1} before a long shutdown (LS3) starting in 2023.

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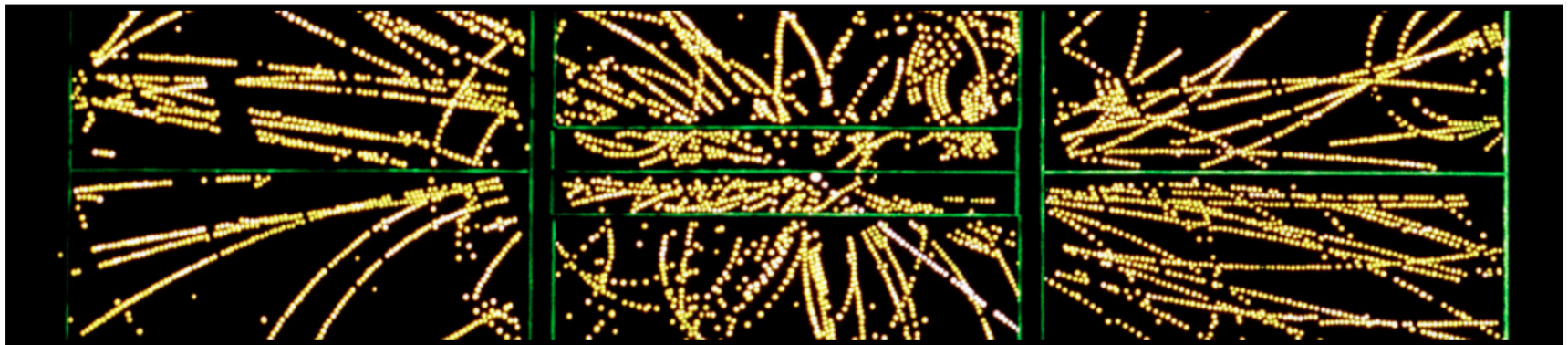

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About

Peter Woit's Home Page

Quantum Theory, Groups and Representations

- Peter Woit "SUSY Bets" page at Not Even Wrong (3 Sep 2014)

SUSY Bets

Not Even Wrong

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> *To have a meaningful bet the LHC has to work at an appropriate energy and luminosity. It is expected to take integrated luminosity of order 300 fb^{-1} at a total energy near 13 TeV in the next run, in less than two years after turning on in early 2015. Assuming those results, signals for gluinos and/or light neutralinos and/or charginos are expected, and that's the appropriate bet.*

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- Garrett Lisi [announced on Twitter](#) back in 2009 that:

  Frank Wilczek just bet me $1000 that superparticles will be detected by July 8, 2015. Max Tegmark will arbitrate.

At this point it seems that Wilczek is likely out $1000, since this date will only be 3 months into the run with results available for only a small amount of data if any.

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Breaking the SM with ANITA + IceCube + Others

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- LHC Run 2 data now under analysis may be highly relevant

FAQs

- Could the ANITA events be fake?
  - 3 years since first publication
  - Recent ANITA team papers confirm SM exclusion
  - Not instrumental – definitely at least atmospheric
  - RFI seems wildly unlikely
  - Hypothetical “double bounce” / reimaged events never seen from pulser
- How can we confirm SEECR interpretation?
  - IceCube particle mass diagnostics
  - Pierre Auger fluorescence detector data
  - UHE neutrino sources
  - LHC Run 2 or Run 3
  - Other?

The End