Results from IceCube

Dawn Williams, University of Alabama

36th International Cosmic Ray Conference

July 29, 2019

Madison, WI

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FUNDING AGENCIES

Fonds de la Recherche Scientifique (FRS-FNRS)
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University of Wisconsin Alumni Research Foundation (WARF)
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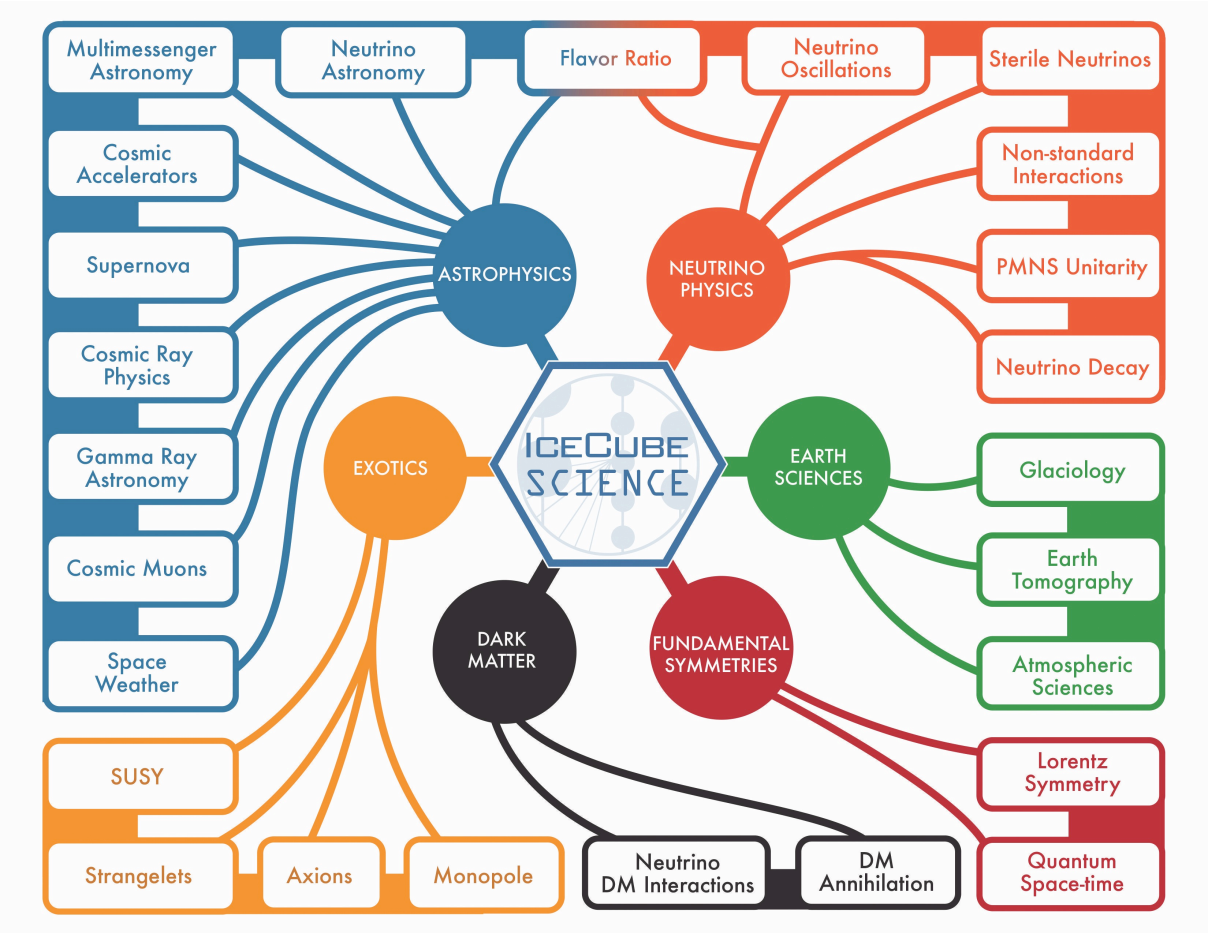
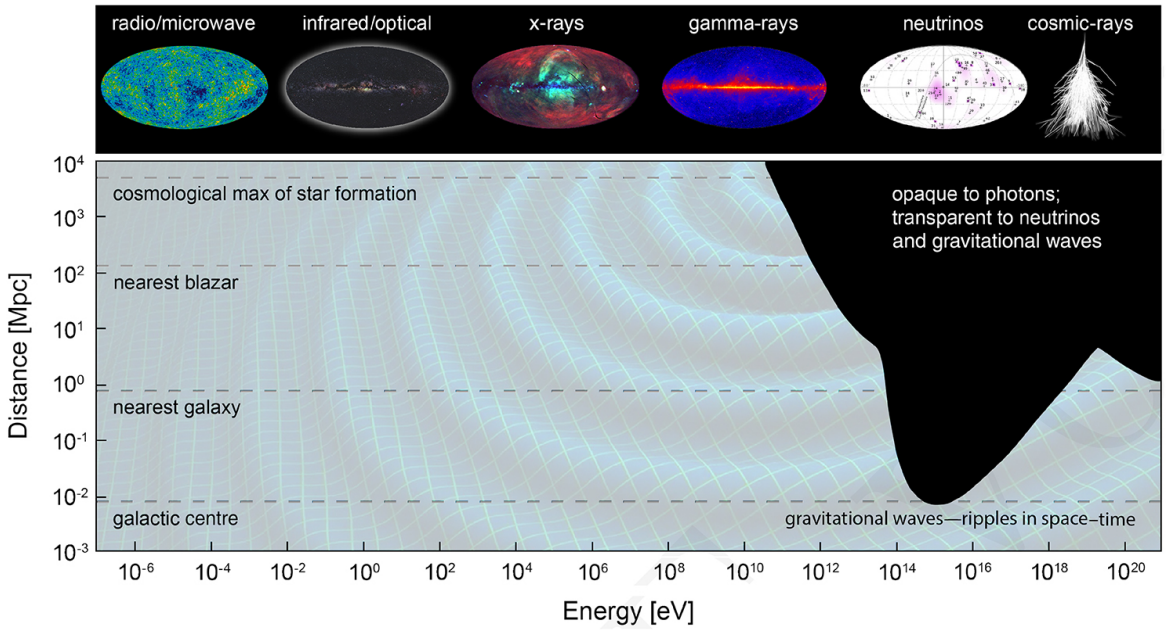
ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY
icecube.wisc.edu

IceCube Science

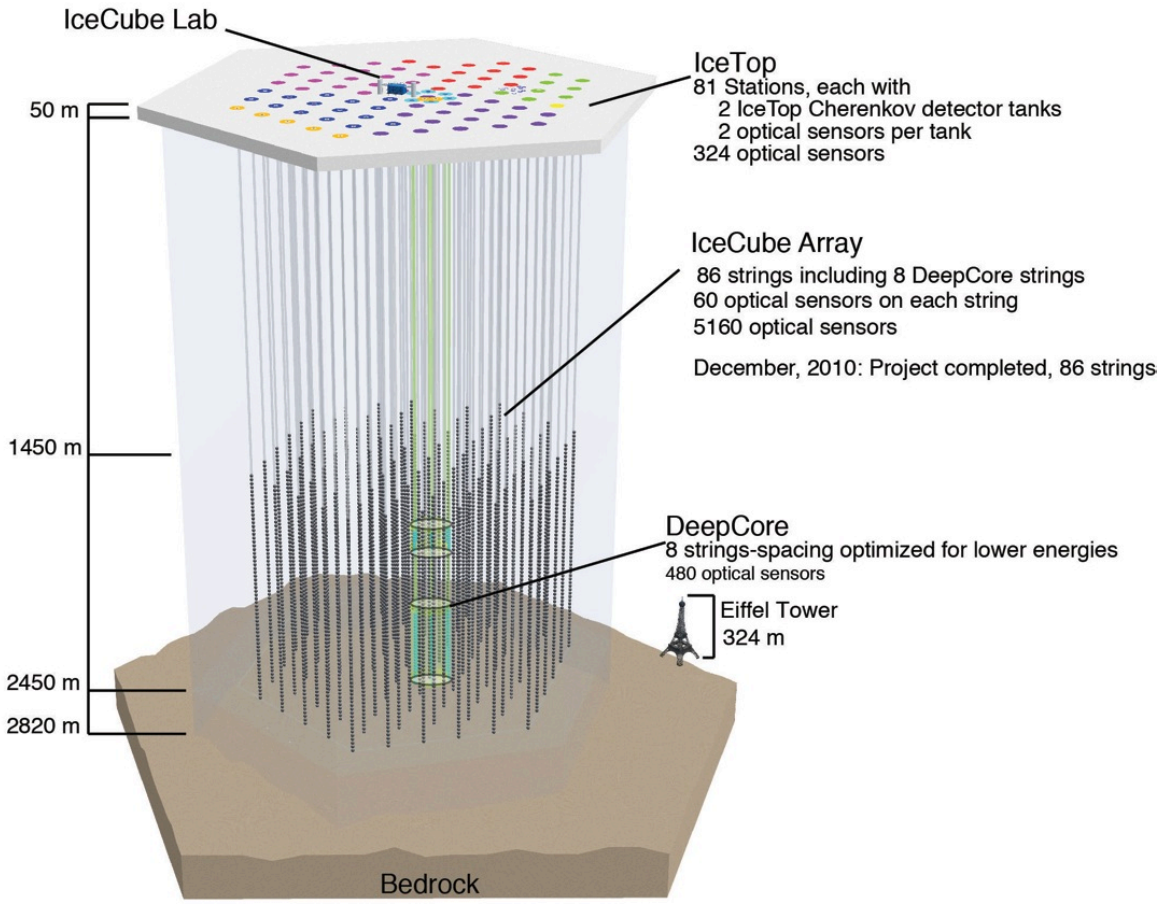


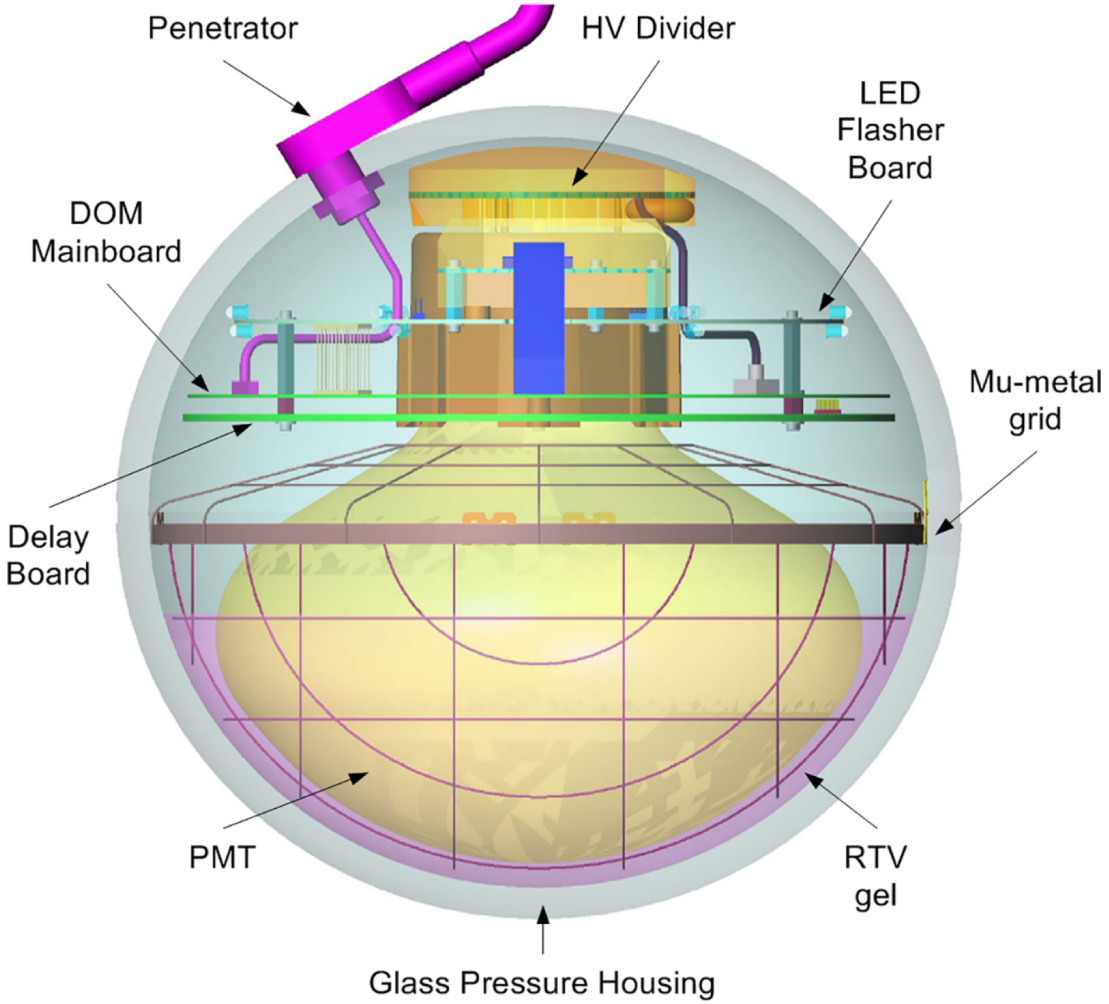
2 Highlight Talks (D. Soldin and D. Williams)
36 parallel talks
43 posters



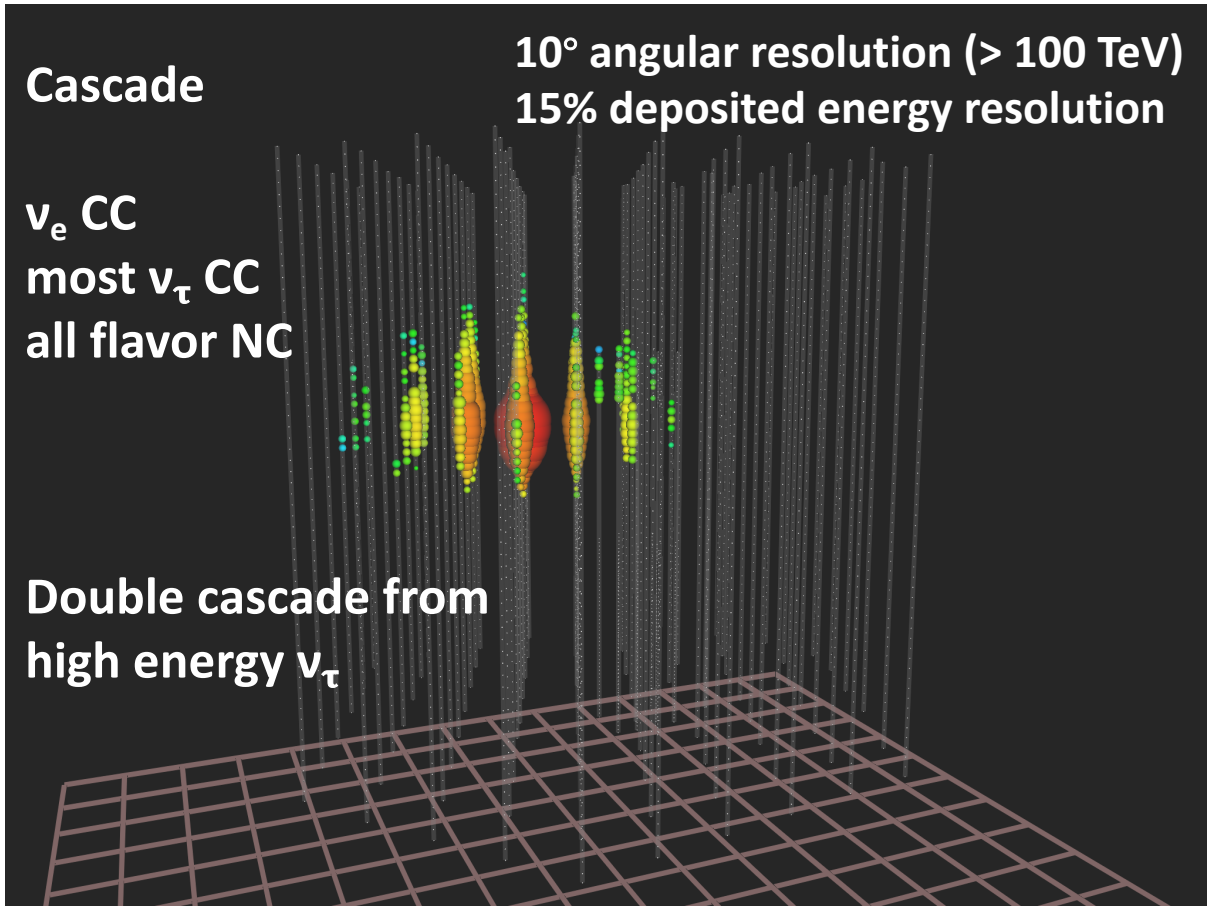
Bartos and Kowalski 2017

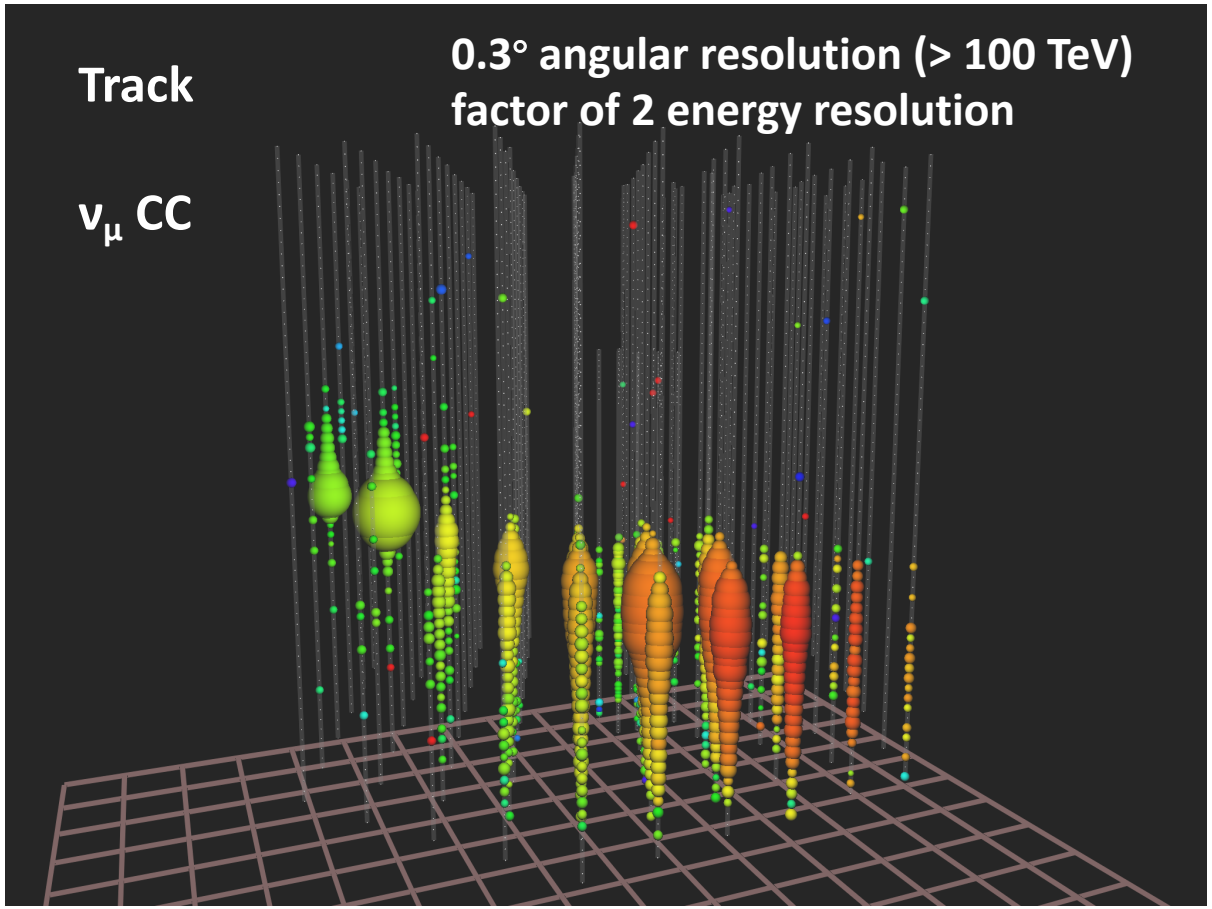
The IceCube Neutrino Observatory



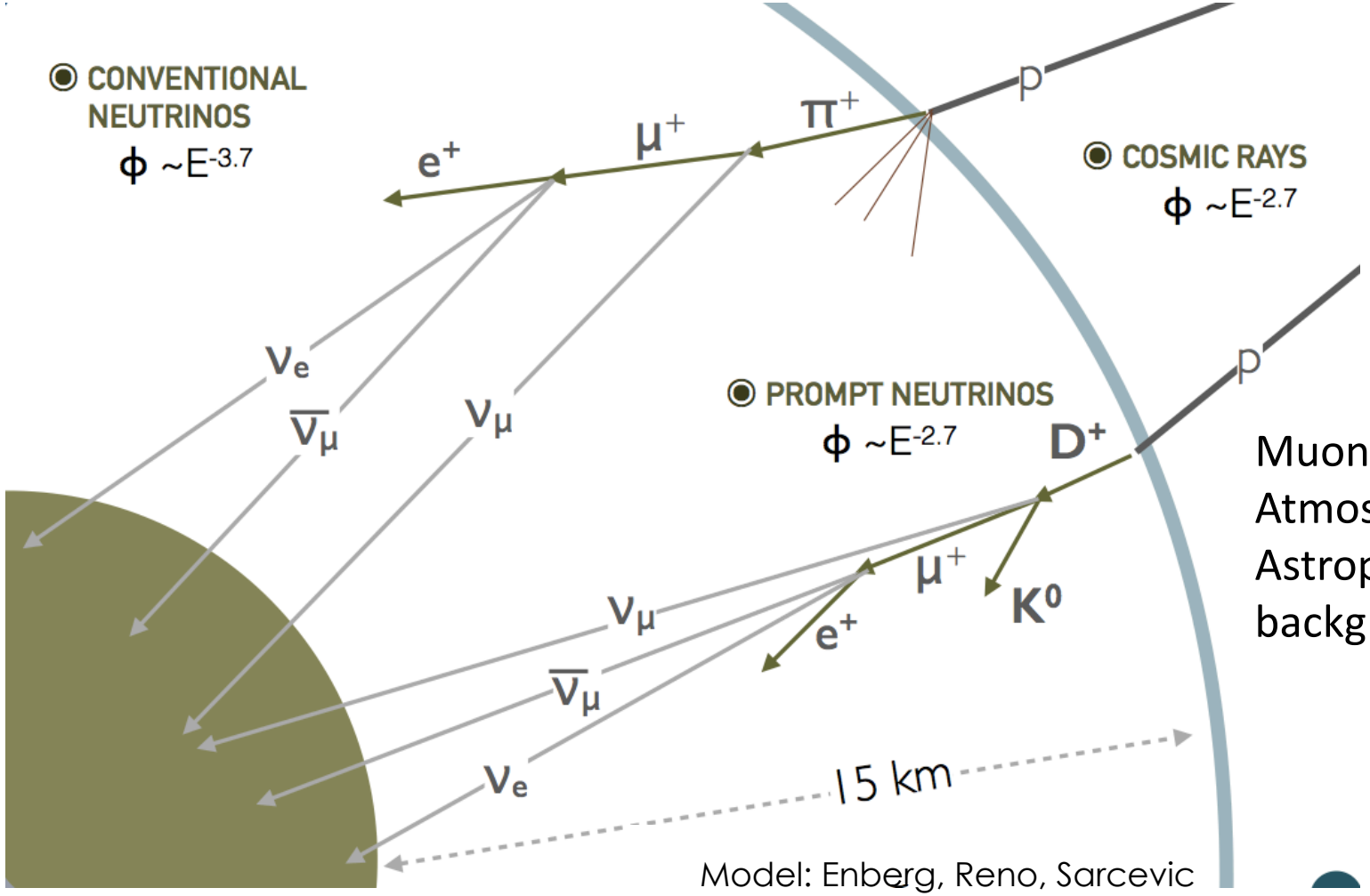


Neutrino Signatures in IceCube



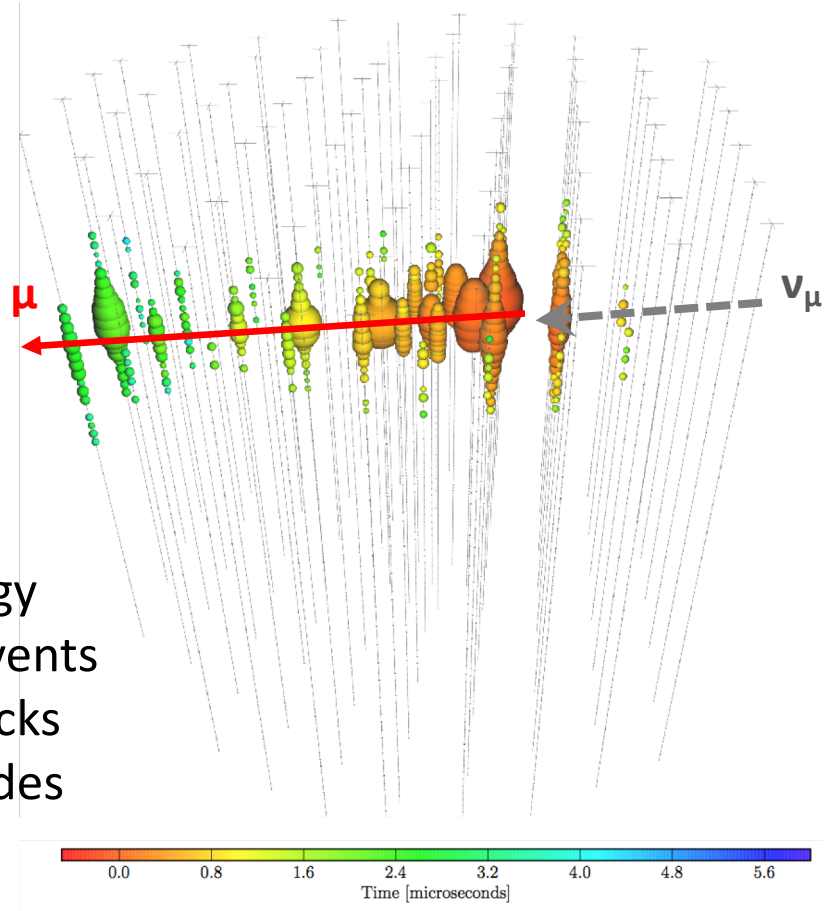


Atmospheric Muons and Neutrinos

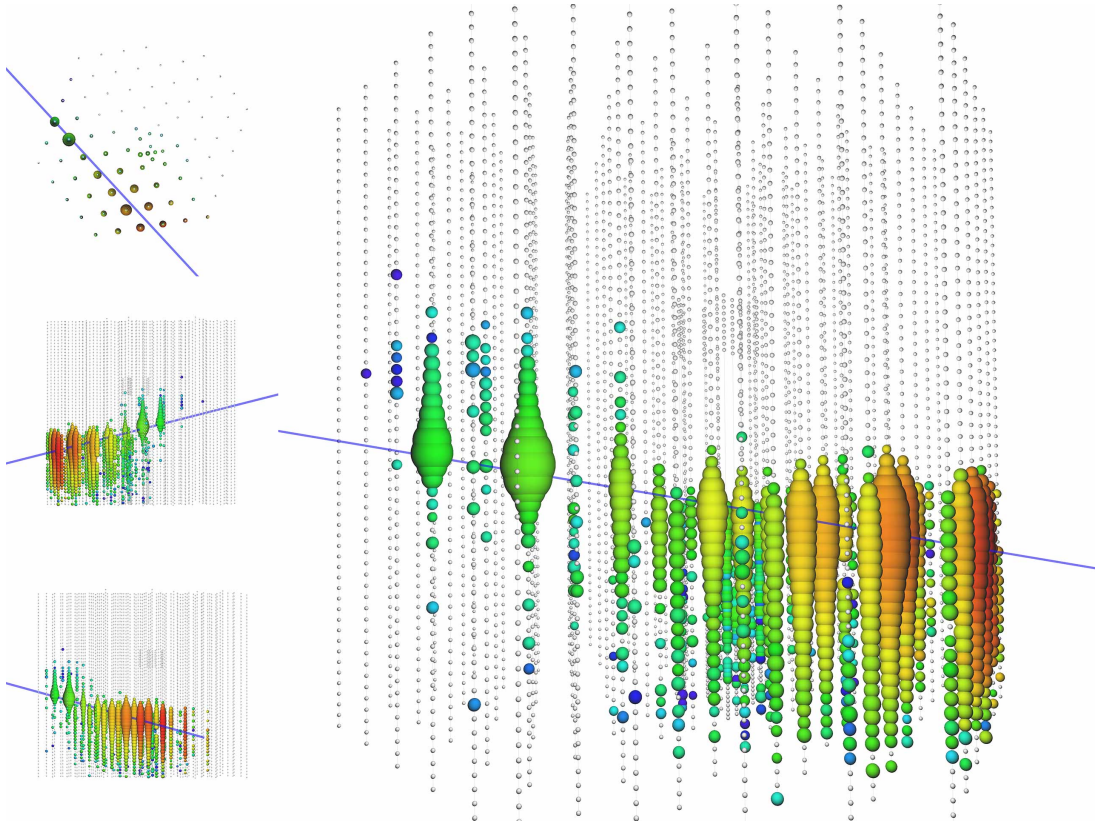


Muons (downgoing): 3 kHz at trigger level
Atmospheric Neutrinos: few hundred per day
Astrophysical Neutrinos: 10-100 per year above background

Astrophysical Neutrinos

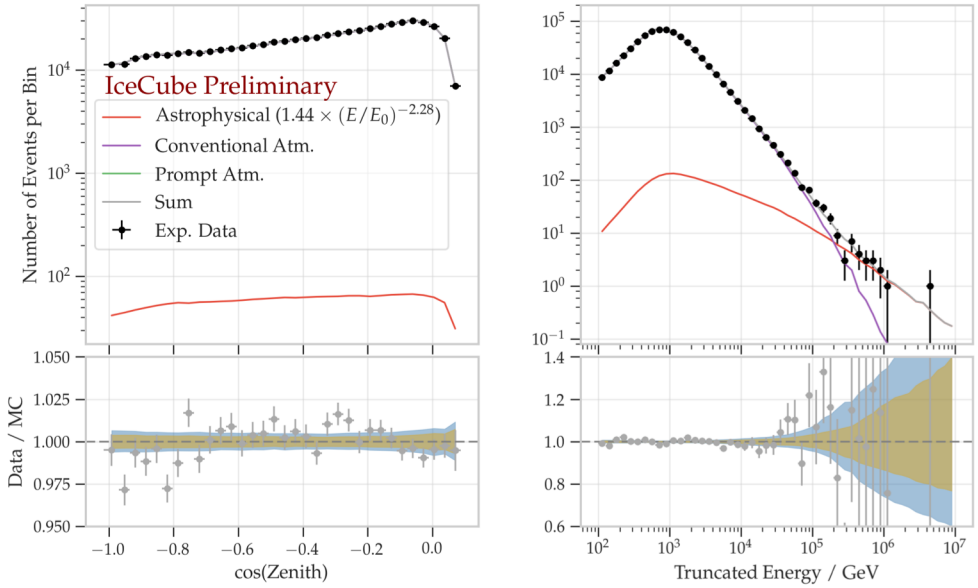


High energy starting events (HESE) tracks and cascades

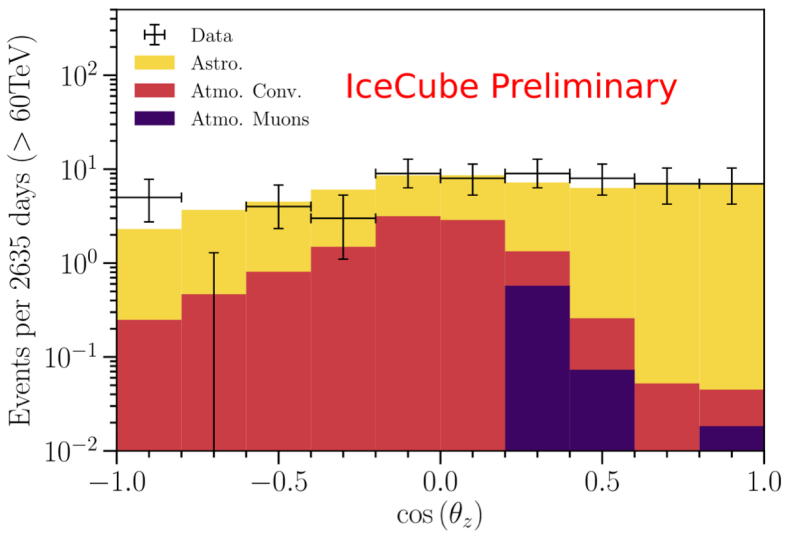


Through-going tracks

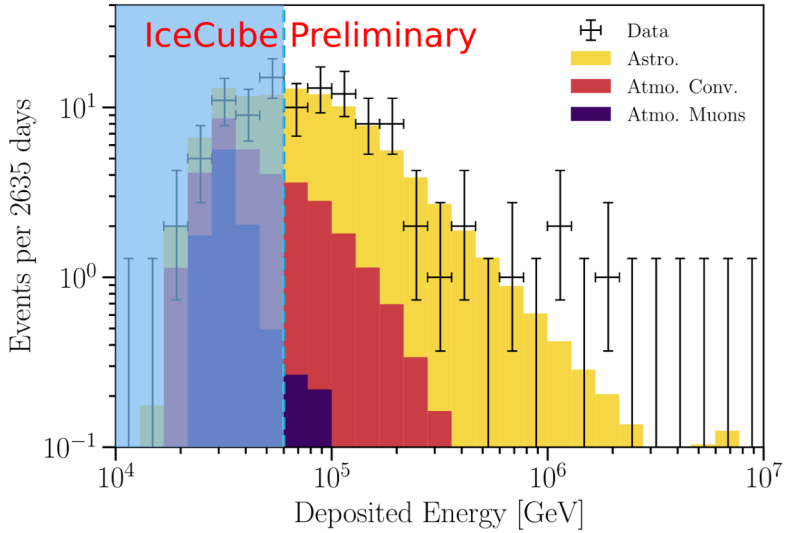
Astrophysical Neutrinos



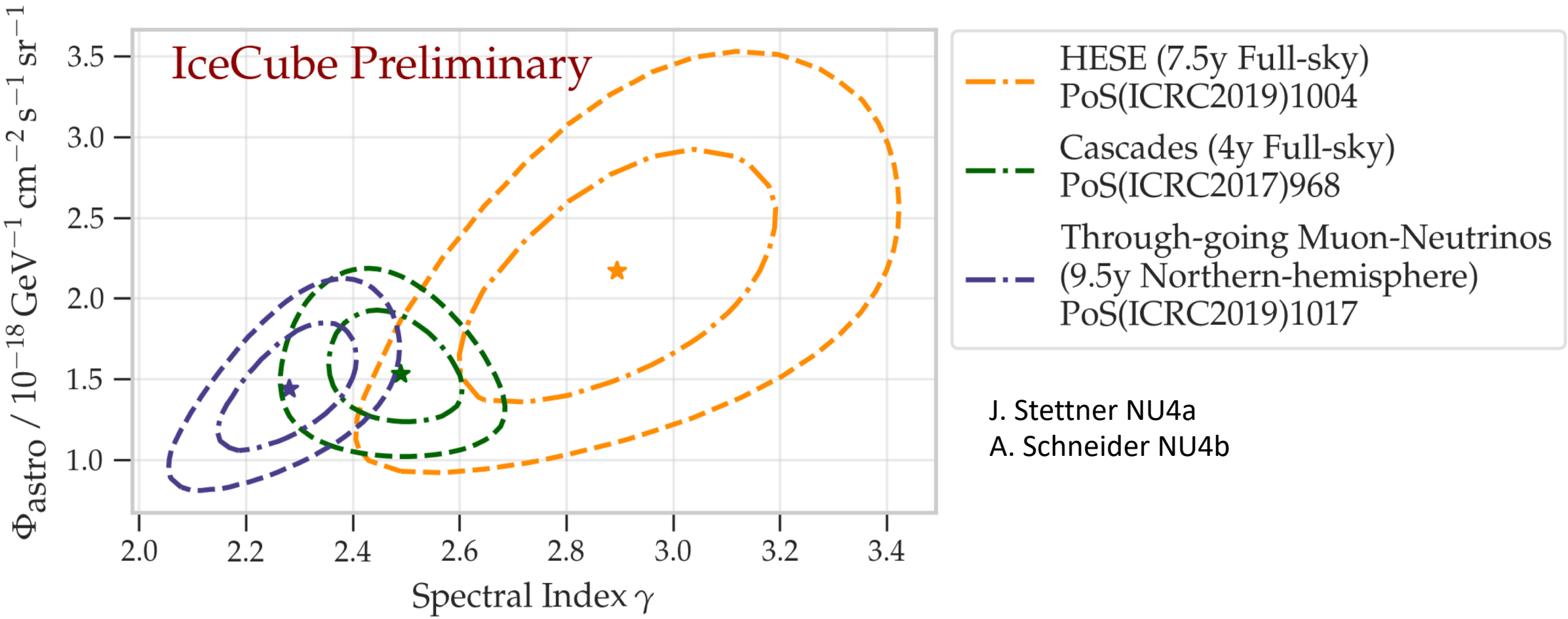
J. Stettner NU4a
A. Schneider NU4b



Through-going 9.5 years	HESE 7.5 years
Updated calibration, updated background modeling and systematics	Updated calibration, updated background modeling and systematics, new double cascade identifier

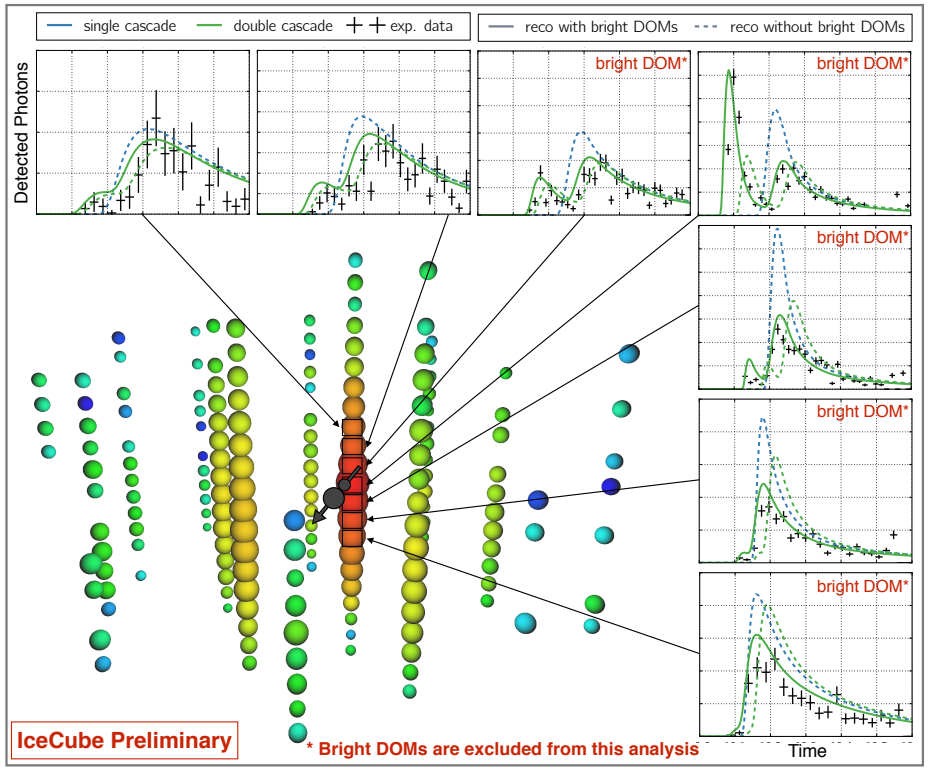


Single power law astrophysical neutrino spectrum

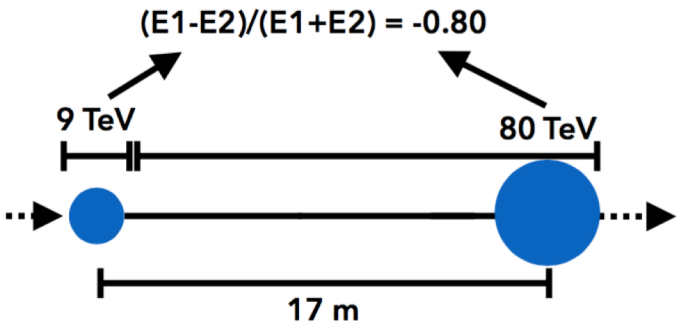


J. Stettner NU4a
A. Schneider NU4b

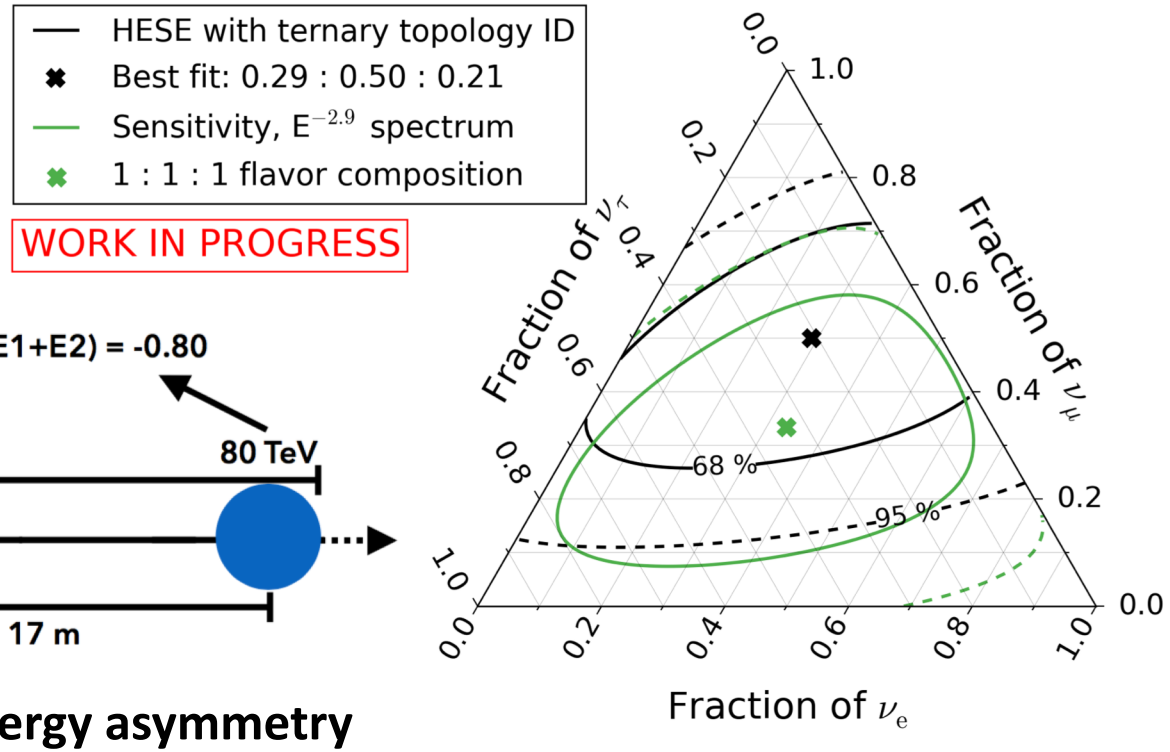
A tau neutrino candidate in the 7.5 year HESE sample: “Double Double”



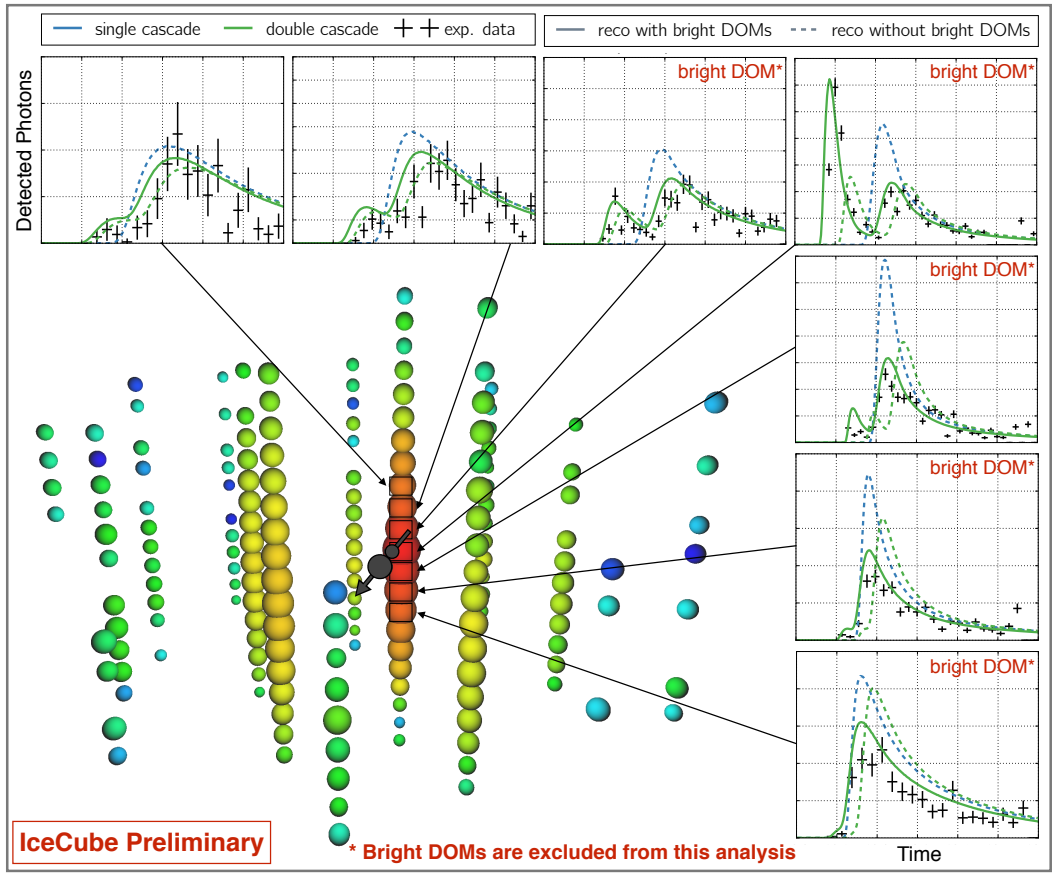
J. Stachurska NU8f



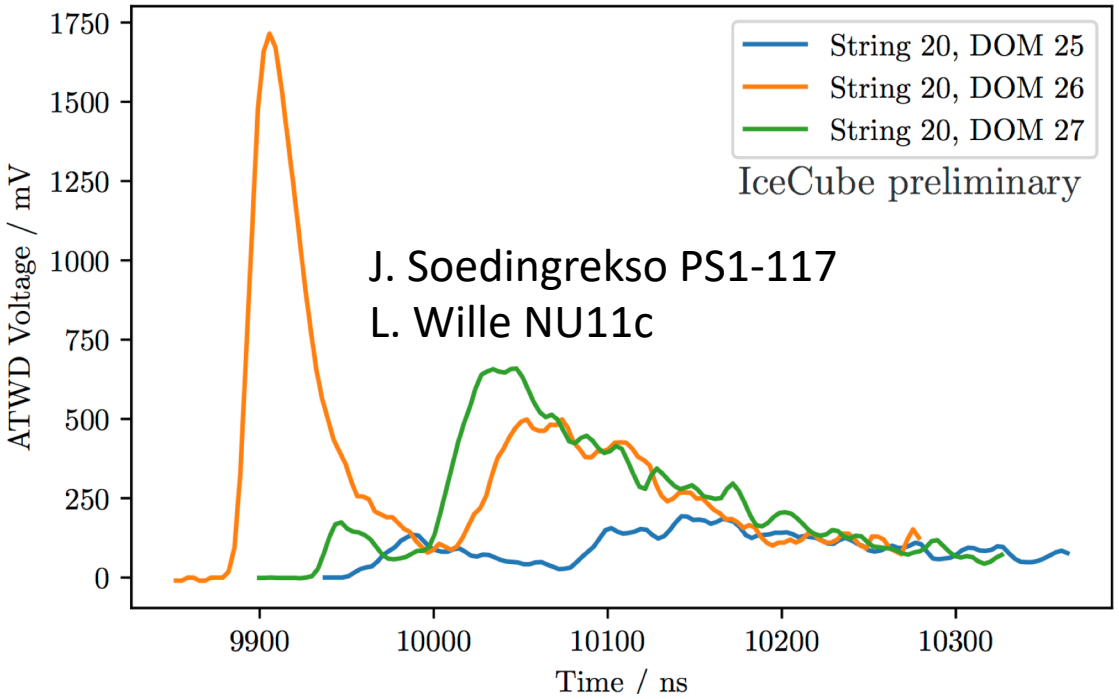
Negative energy asymmetry



Double pulse waveform search

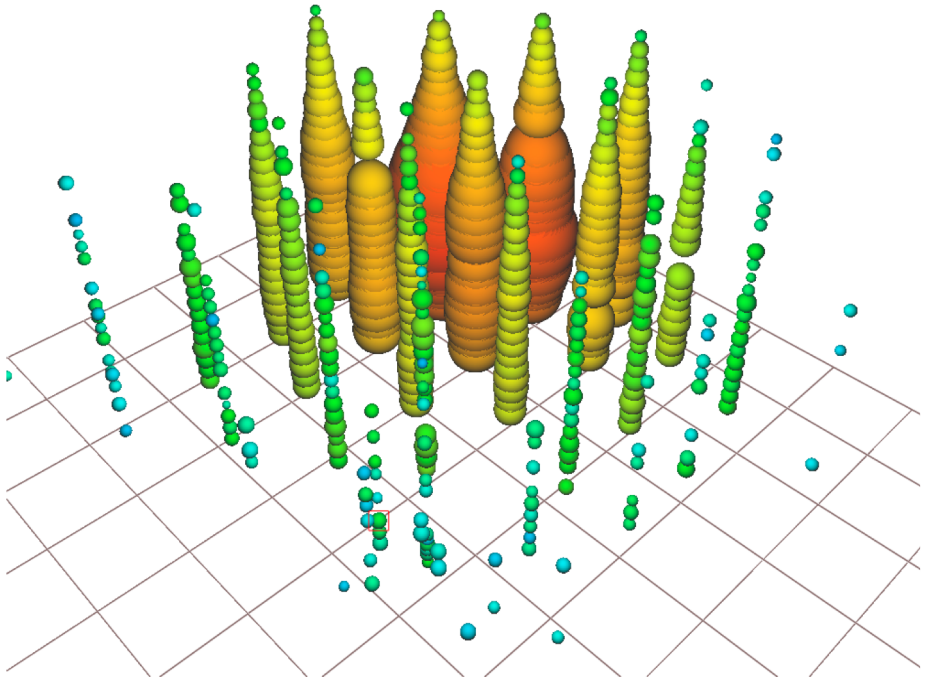


"Double Double" is the only event that passes both the double cascade search and double pulse waveform criteria from two independent searches.

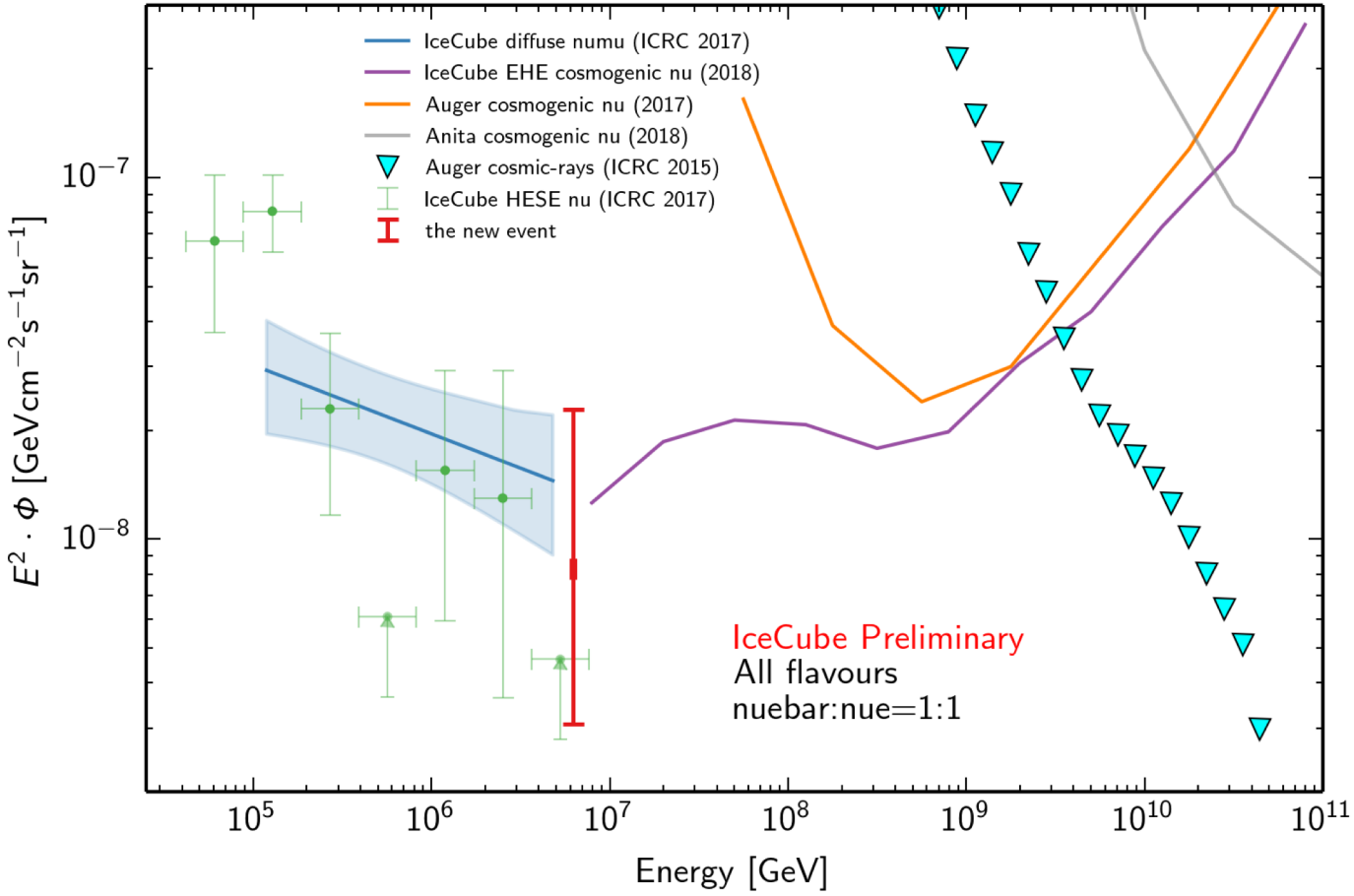


Search for partially contained cascades

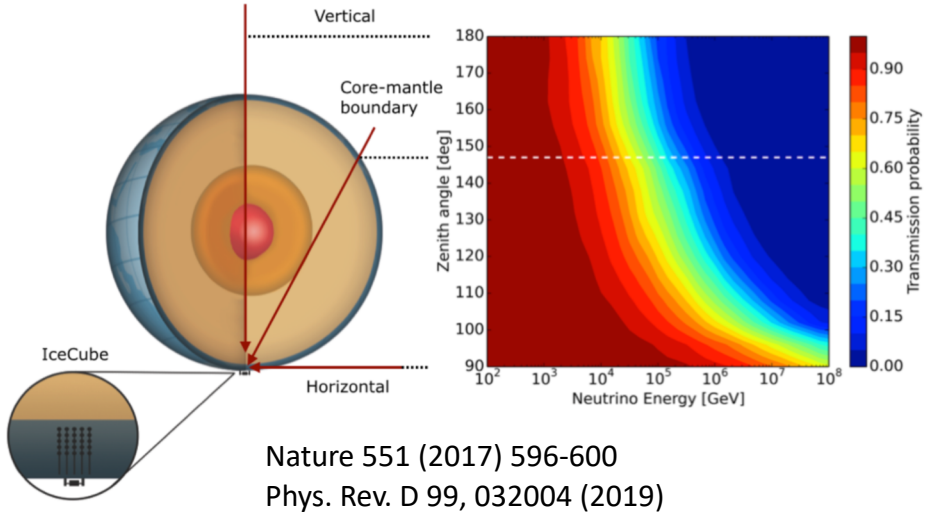
Glashow resonance candidate



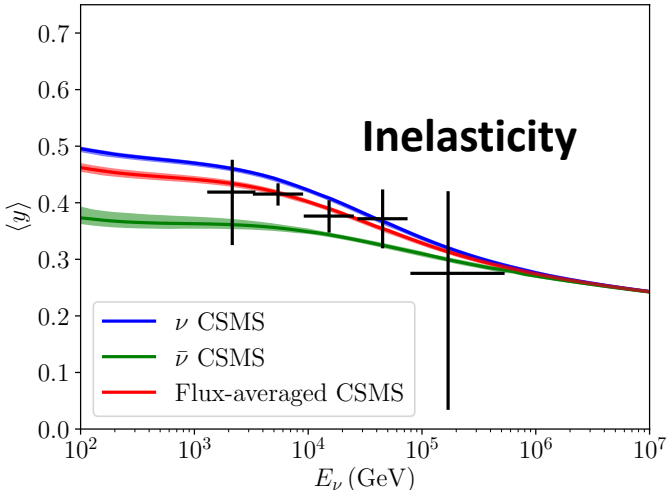
L. Lu PS1-115

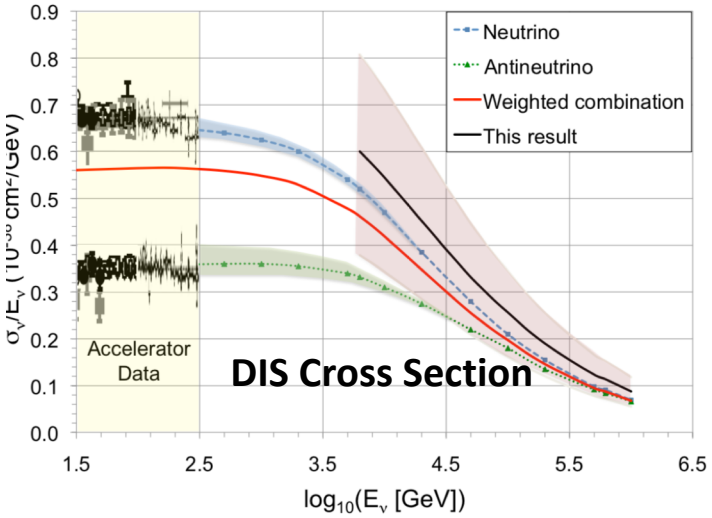


High energy neutrino physics

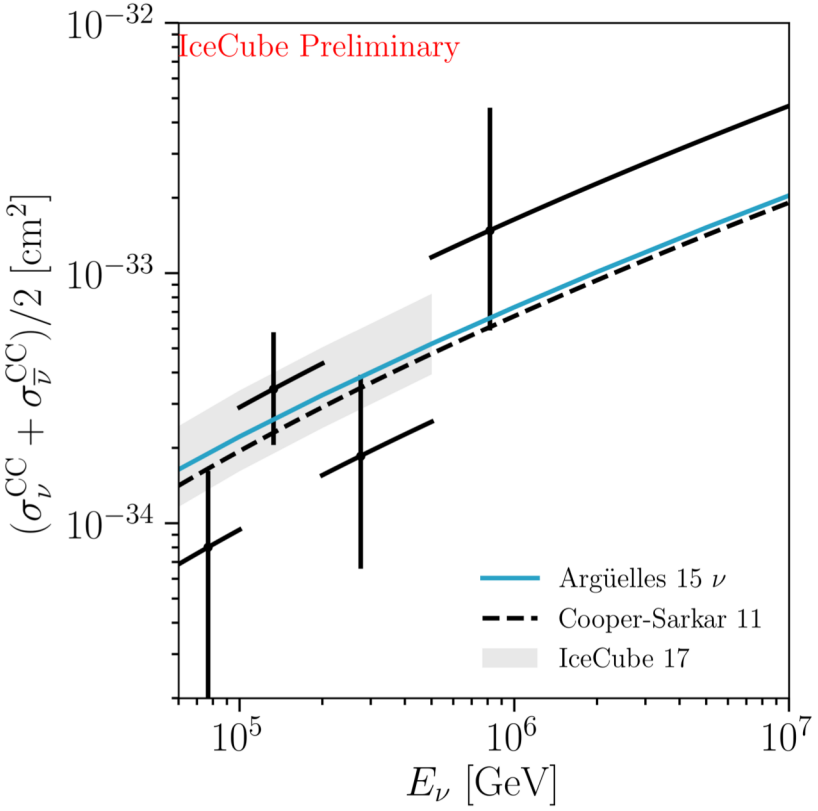


Nature 551 (2017) 596-600
Phys. Rev. D 99, 032004 (2019)





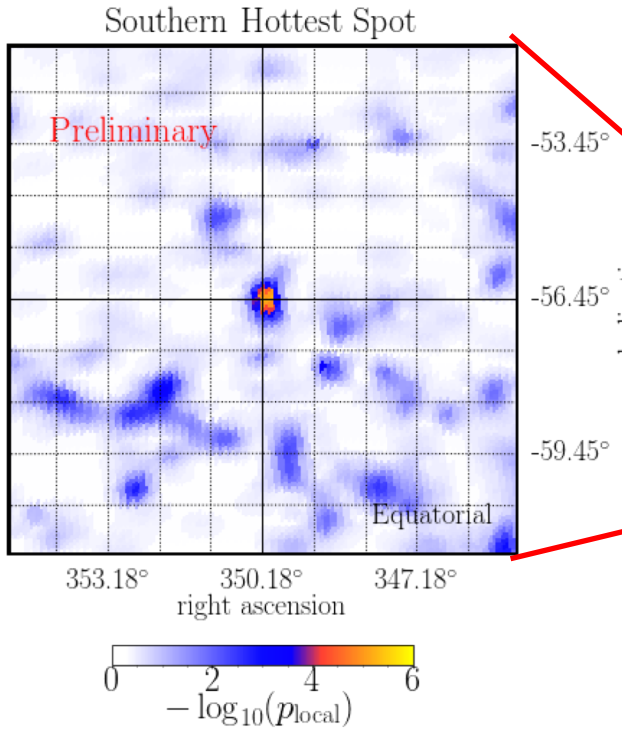
Neutrino DIS Cross Section measurement with the 7.5 year HESE sample

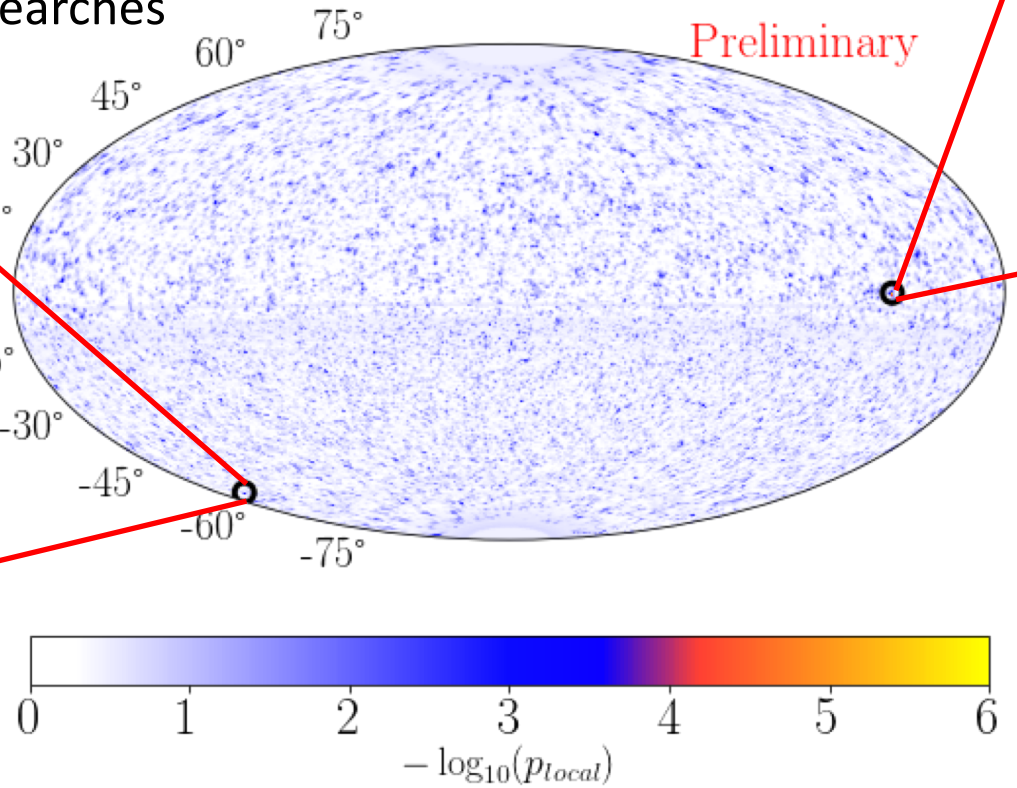


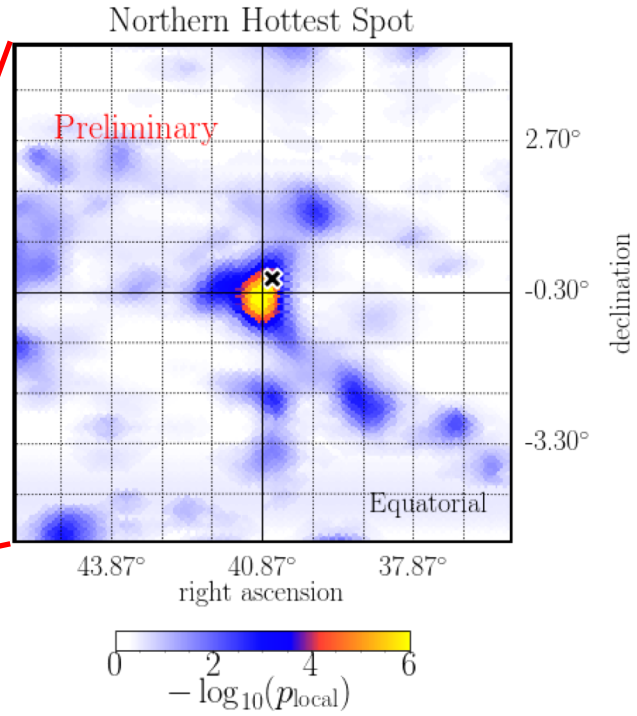
T. Yuan NU2h
Also see S. Robertson PS2-65

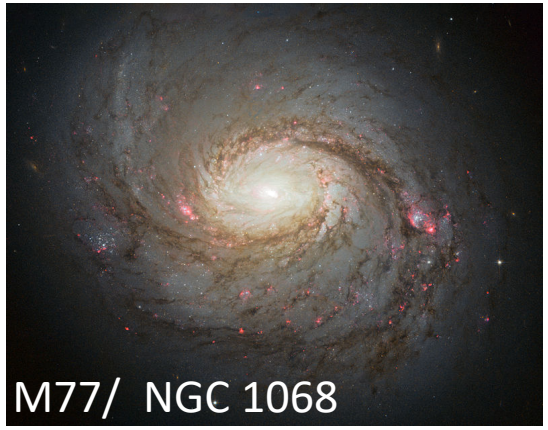
All sky combined 10 year search

Using high energy through-going tracks and tracks optimized for point source searches







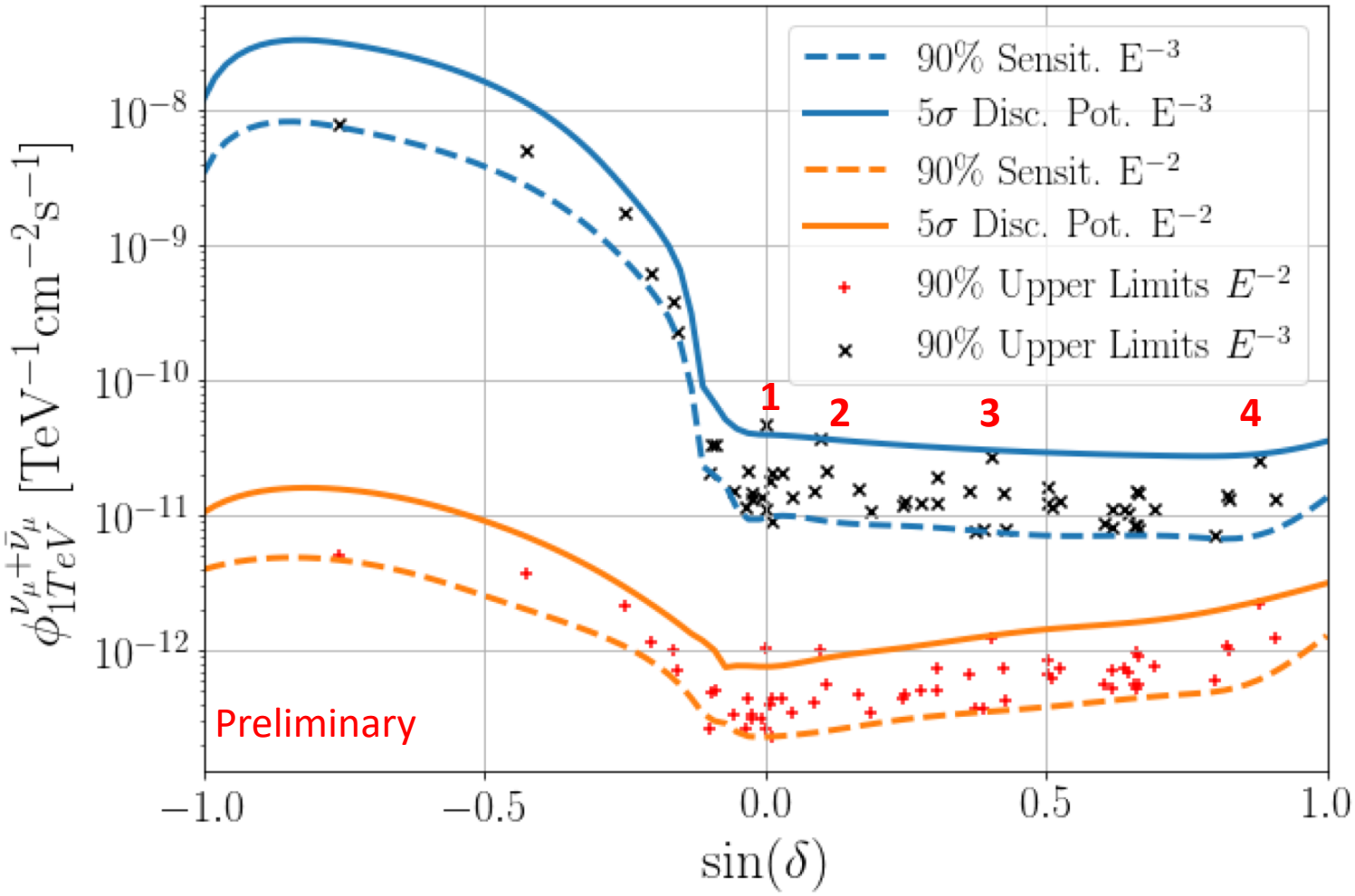


NASA, ESA & A. van der Hoeven

T. Carver NU5c

New source list of 110 Galactic and Extragalactic objects
Hottest spot in Northern Hemisphere coincides with 2.9σ excess at the position of NGC 1068

All sky combined 10 year search



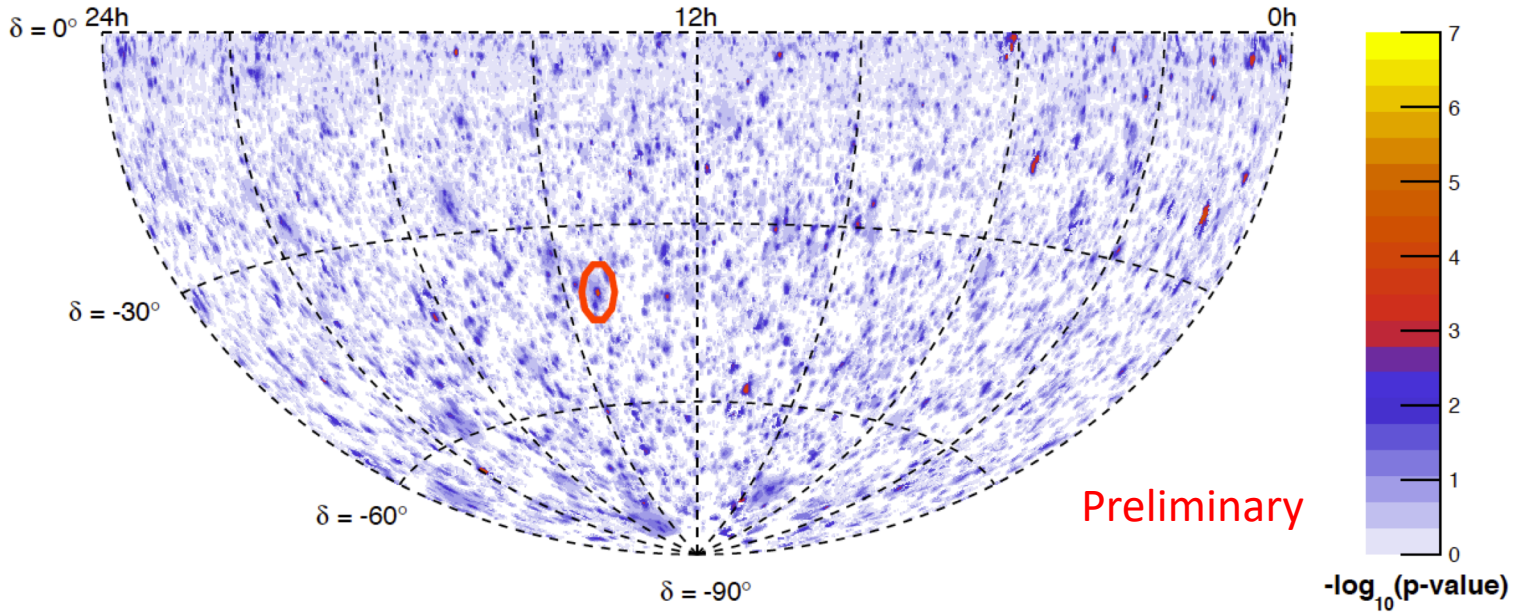
1. **NGC 1068**
2. **TXS 0506 + 056**
3. **PKS 1424 + 240**
4. **GB6 J1542+6129**

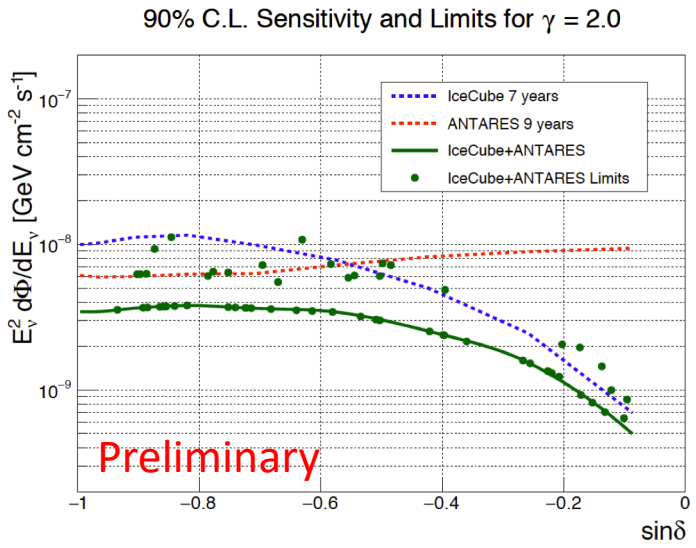
Source list search is incompatible with background at 3.3σ (2.25σ without TXS 0506)

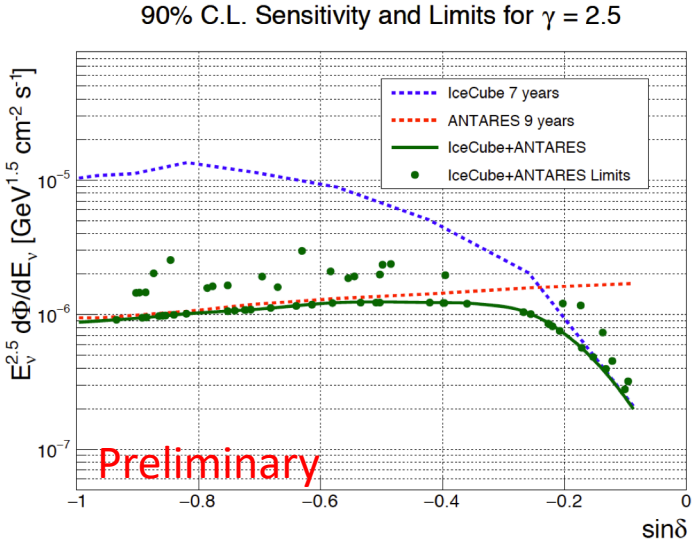
T. Carver NU5c

Joint Southern Sky Search with ANTARES

Up to a factor of 2 improvement in point source sensitivity compared to individual analyses



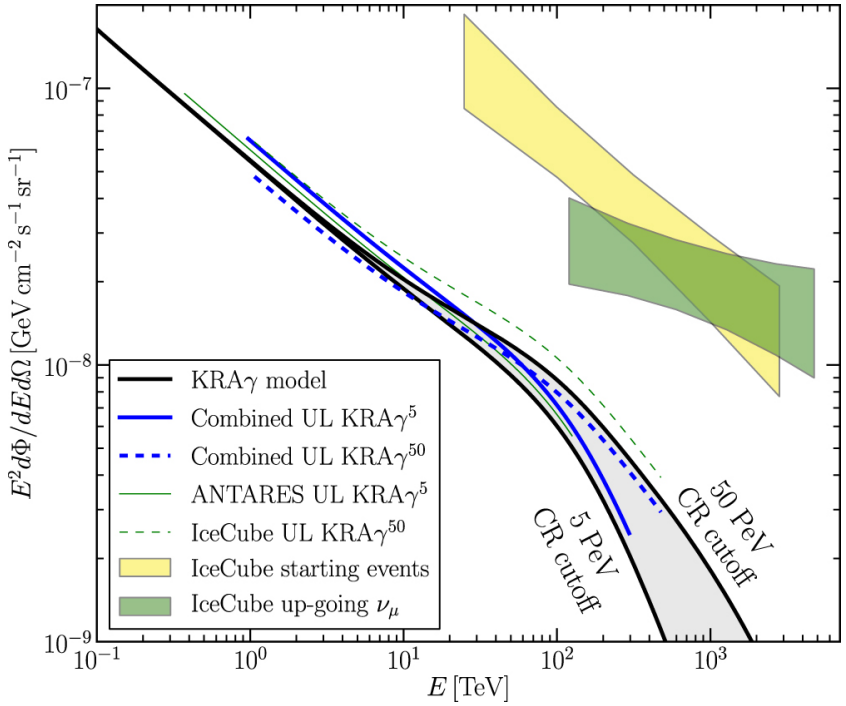




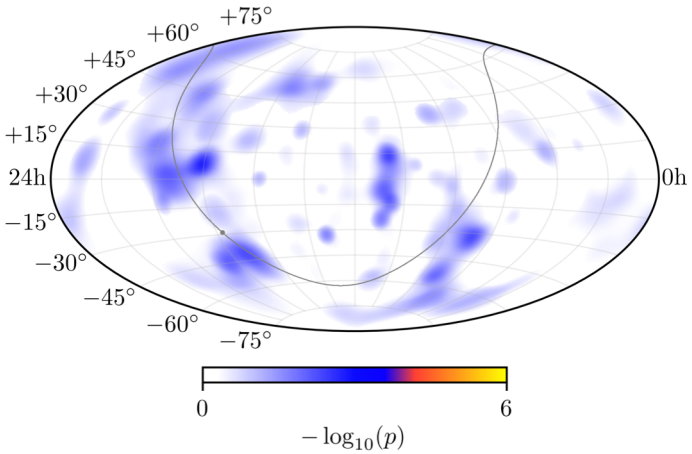
G. Illuminati (NU5b)

Source Searches with IceCube Cascades (7yr)

Joint search for Galactic diffuse neutrino emission with IceCube tracks and ANTARES cascades + tracks

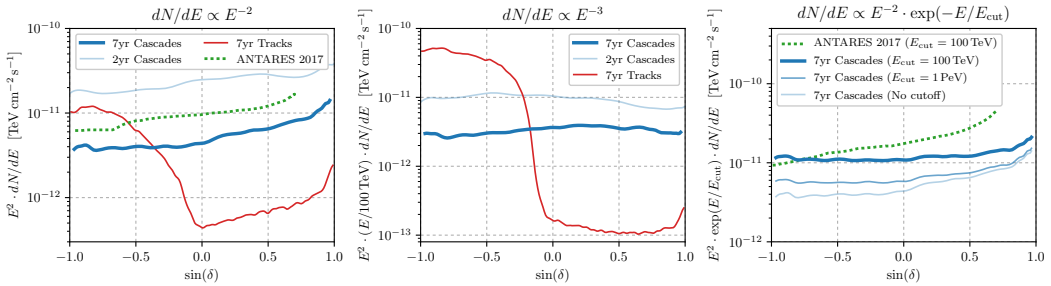


ApJ Letters 868 (2018) no. 2, L20



Median cascade resolution < 10° above 40 TeV with deep learning

P-value for KRAγ with 5 PeV cutoff is 2$\boldsymbol{\sigma}$

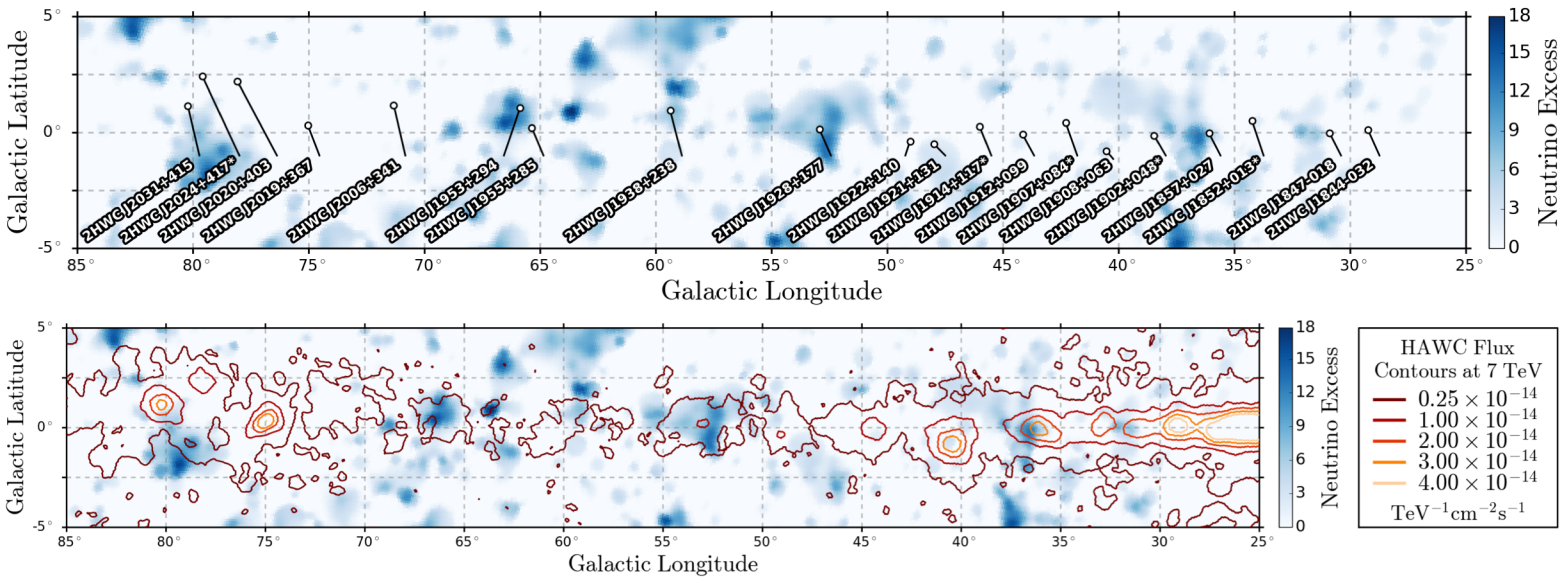


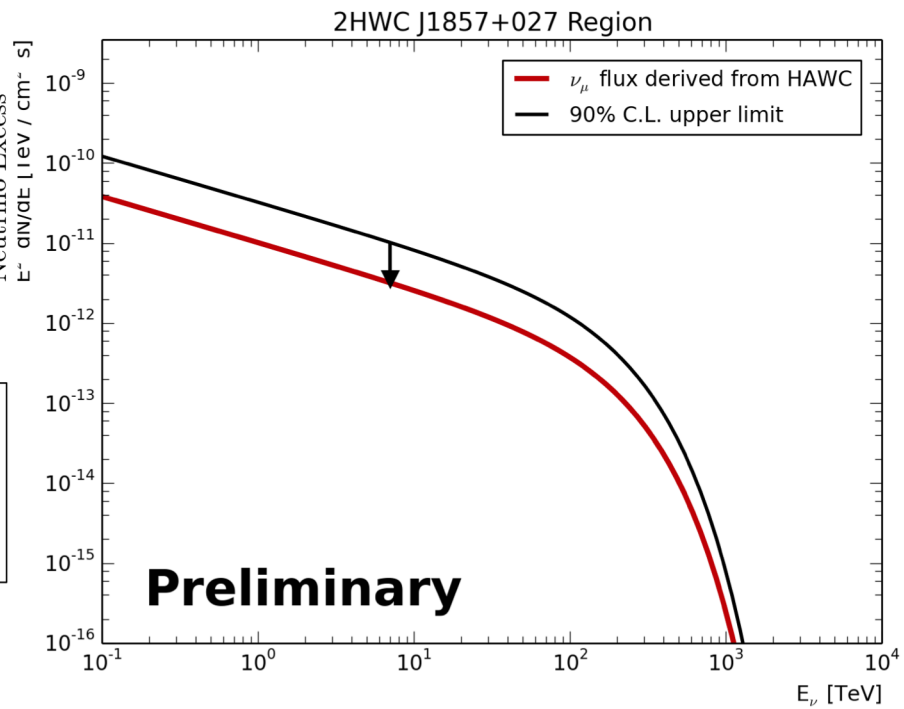
Template	7yr Cascades p-value	7yr Cascades Sensitivity	7yr Cascades Fitted Flux	7yr Cascades UL	Previous Work p-value	Previous Work Sensitivity	Previous Work Fitted Flux	Previous Work UL
KRA$_\gamma^5$	0.021	0.58	0.85	1.7	0.29	0.81	0.47	1.19
KRA$_\gamma^{50}$	0.022	0.35	0.65	0.97	0.26	0.57	0.37	0.90
Fermi-LAT π^0	0.030	2.5	3.3	6.6	0.37	2.97	1.28	3.83

arXiv:1907.06714 [astro-ph.HE]

Galactic Neutrino Source Search with IceCube and HAWC

A. Kheirandish NU6b





Stacked search for neutrino emission from HAWC 2HWC catalog

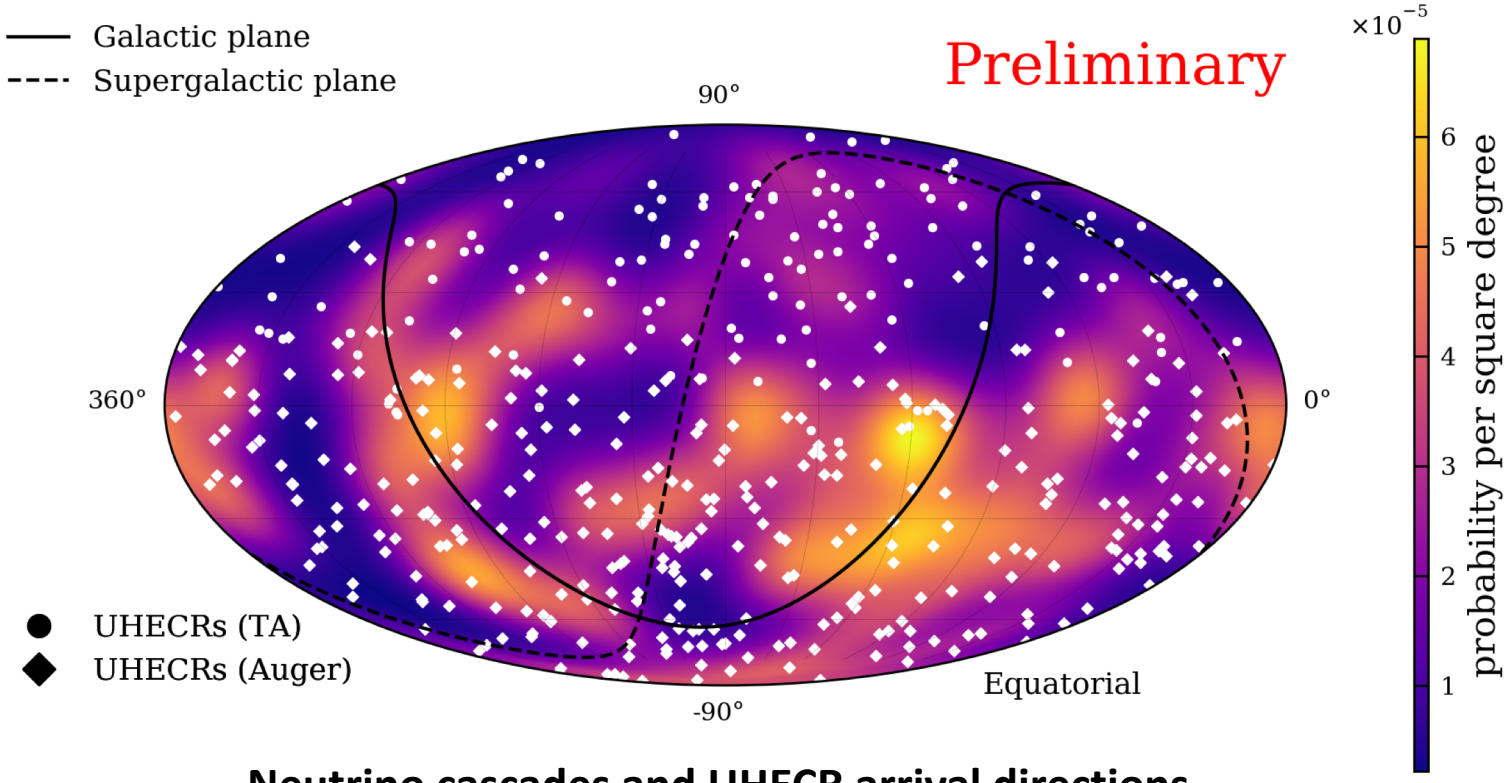
Template analysis for neutrino emission from Galactic plane and certain source regions

Most significant result is for J1857+027 (p value 0.02 before trials correction)

Coincident search with UHECR and neutrinos

A. Barbano NU6c

Combined ANTARES, IceCube, PAO and TA search for common origin of high energy neutrinos and cosmic rays



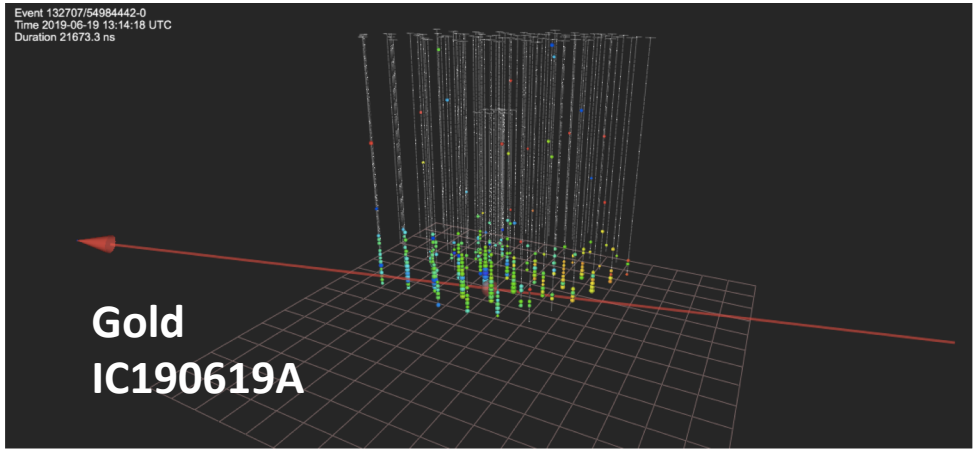
Neutrino cascades and UHECR arrival directions

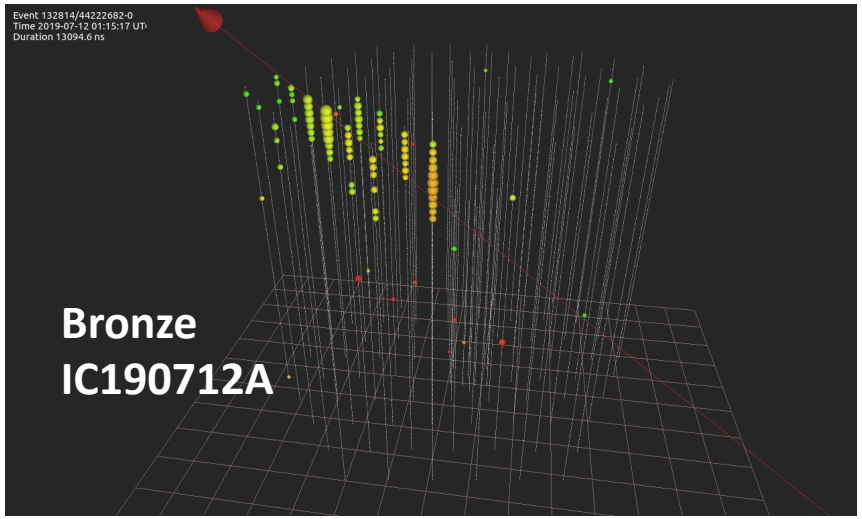
Three searches:

1. Neutrino/UHECR cross-correlation
2. Search for neutrino clusters in direction of UHECR
3. Search for UHECR clusters in direction of neutrinos

No significant correlations seen

IceCube Realtime Alerts



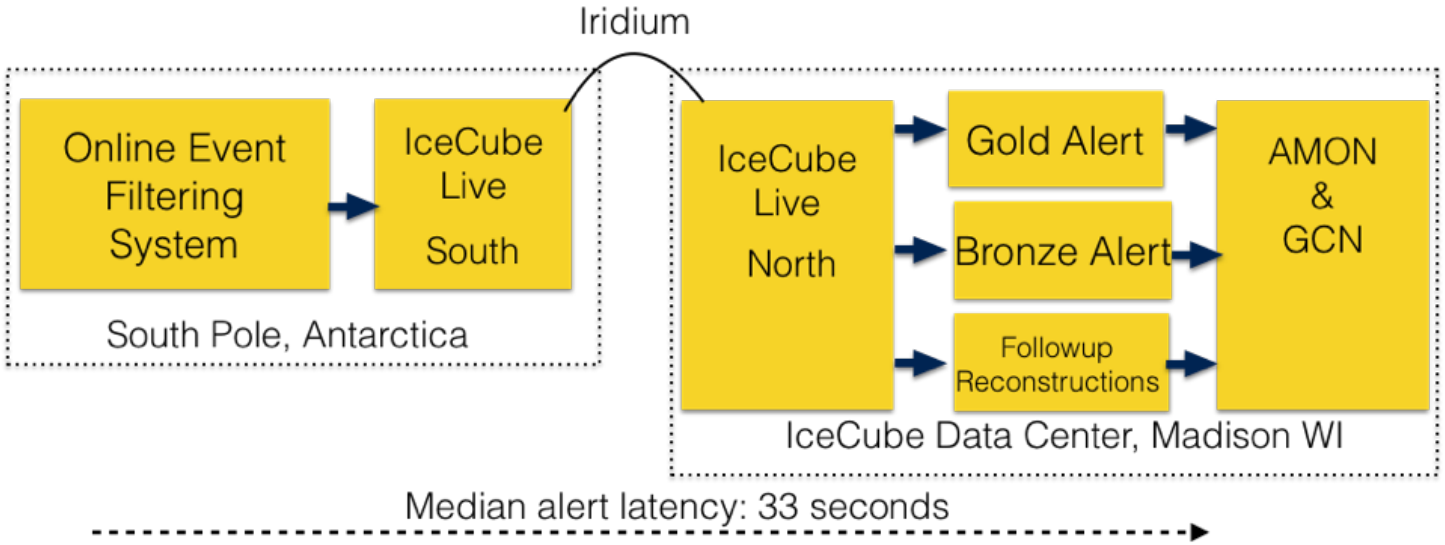


IceCube sending alerts since April 2016
Updated alerts as of June 2019

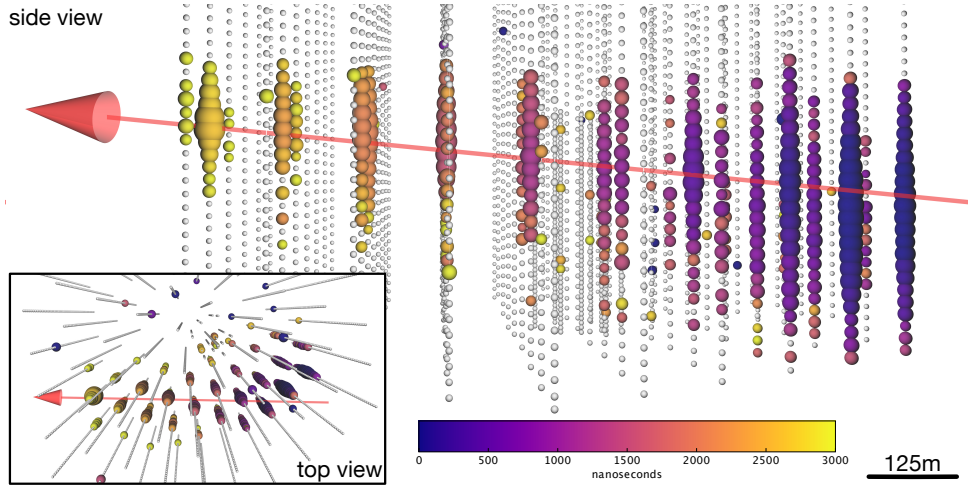
Initial GCN Notice followed by GCN Circular with updated reconstruction

C. Tung NU9b

Updated alerts	Gold	Bronze
Signalness	> 50%	>30%
Expected signal/yr	6.6	2.8
Expected bkgd/yr	6.1	14.7



A high energy neutrino in coincidence with a flaring blazar



Science 13 Jul 2018: Vol. 361, Issue 6398

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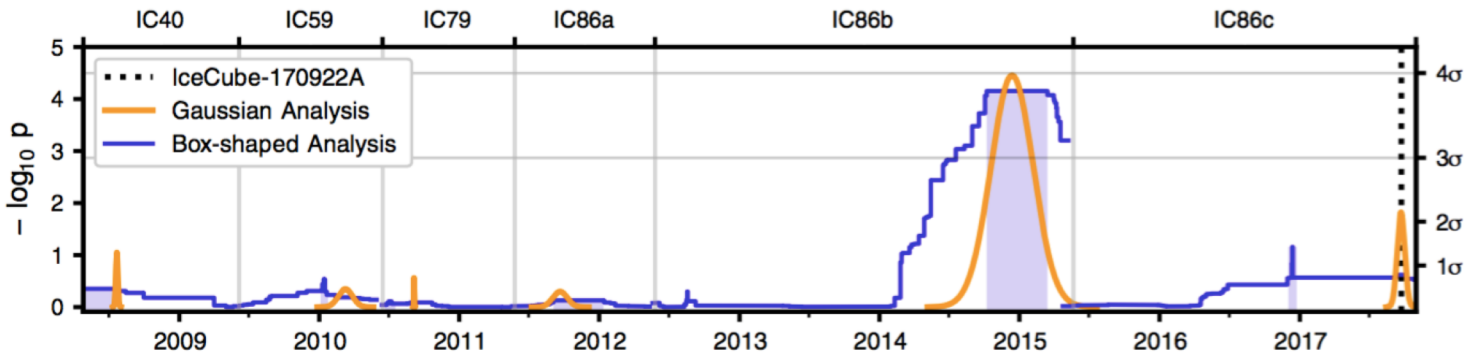
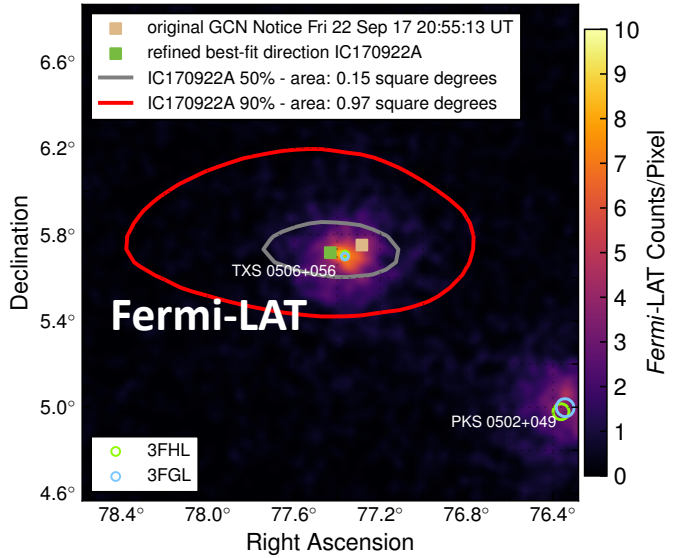
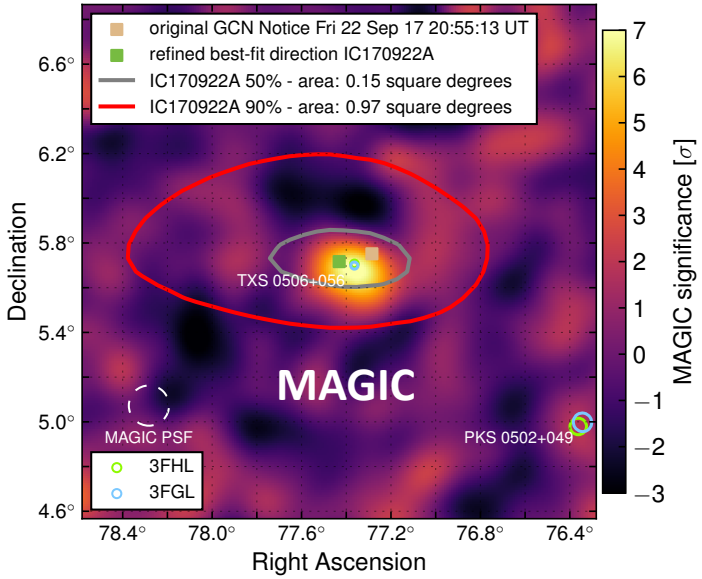


Excess of neutrinos observed between September 2014 and March 2015
Background only hypothesis rejected at 3.5σ

Correlation of IC170922A with TXS 0506+056 preferred to chance at 3σ level

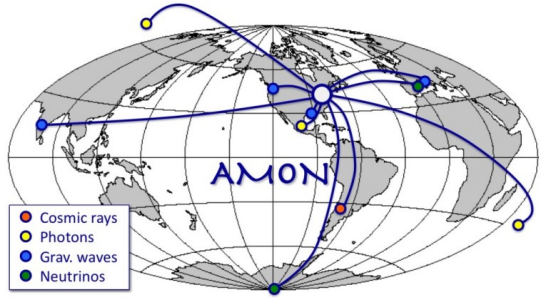


Blazar redshift 0.3365 +/0.0010 (Paiano *et al.*)



AMON: IceCube+HAWC Sub-threshold Coincident Analysis

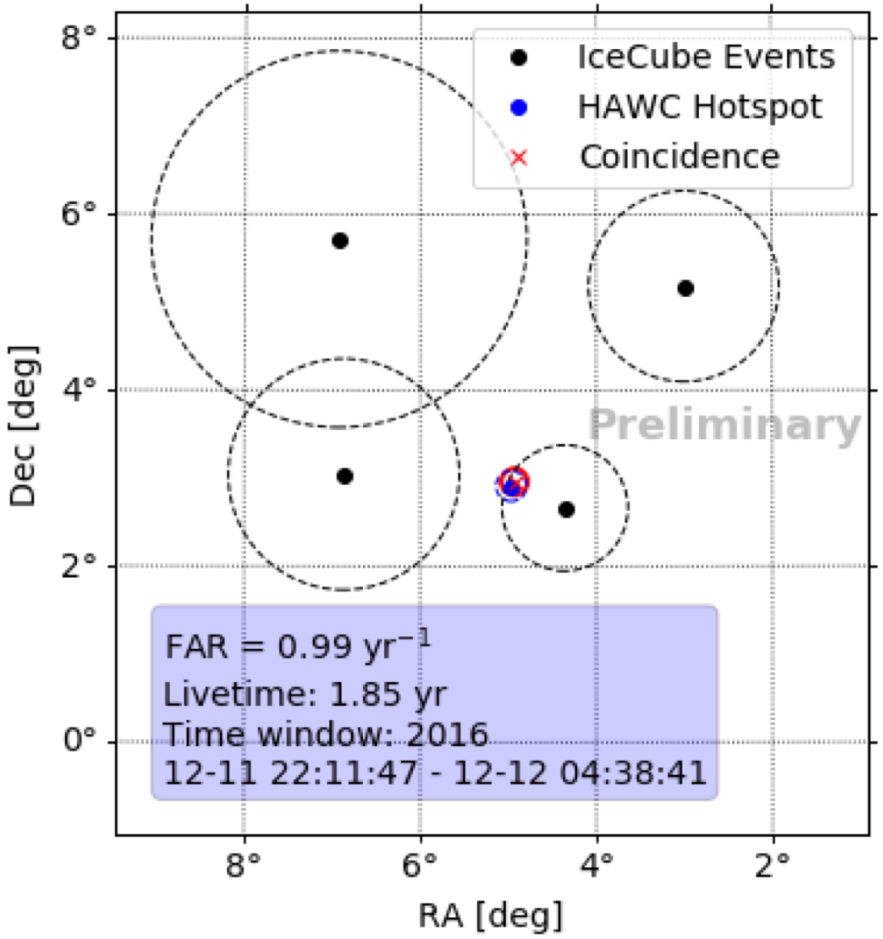
H. Ayala NU9f

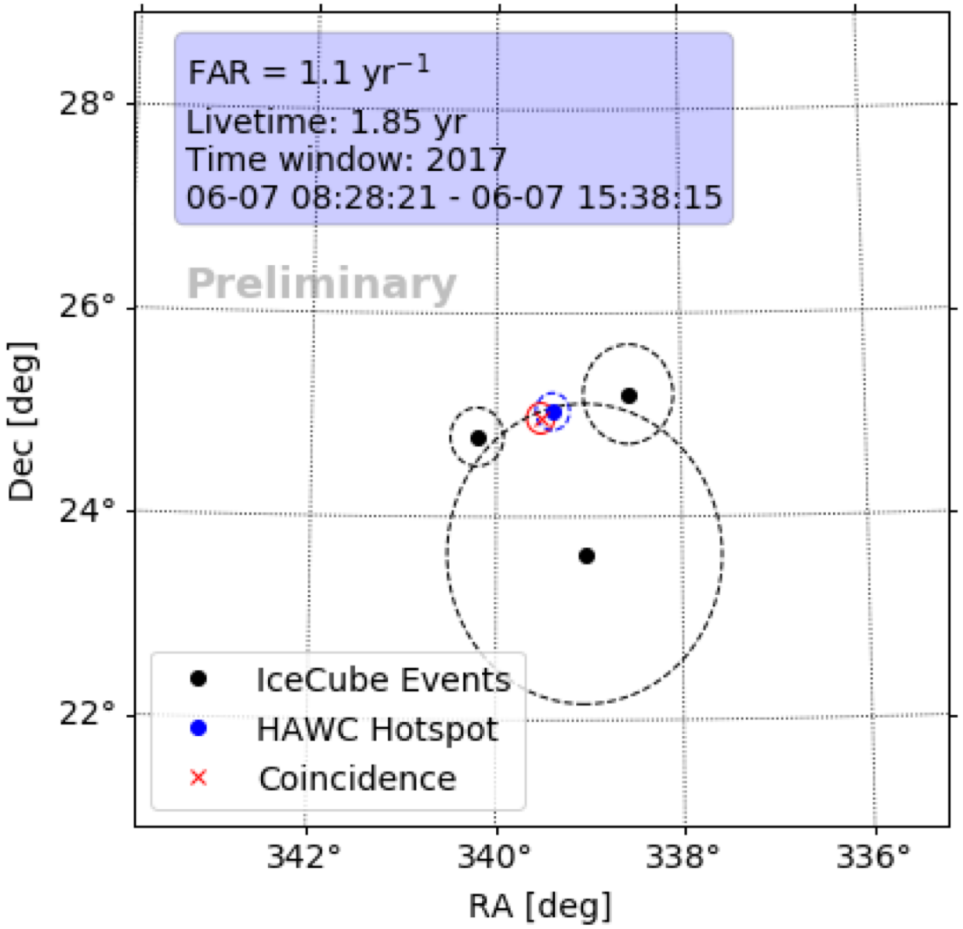


Goal: enhance sensitivity to transient events with search for coincidences between sub-threshold events in AMON and HAWC

1 event with FAR < 1/year found in 1.85 years

Eventually run this search in real time





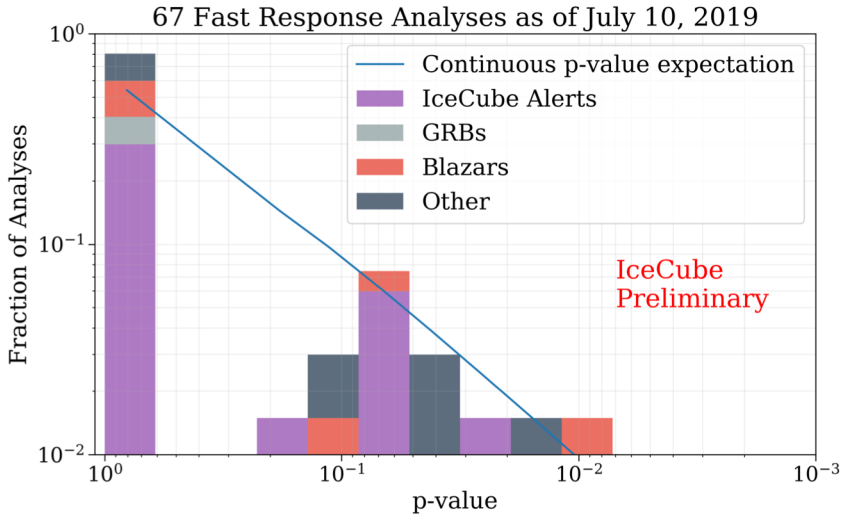
IceCube Follow-up of External Triggers

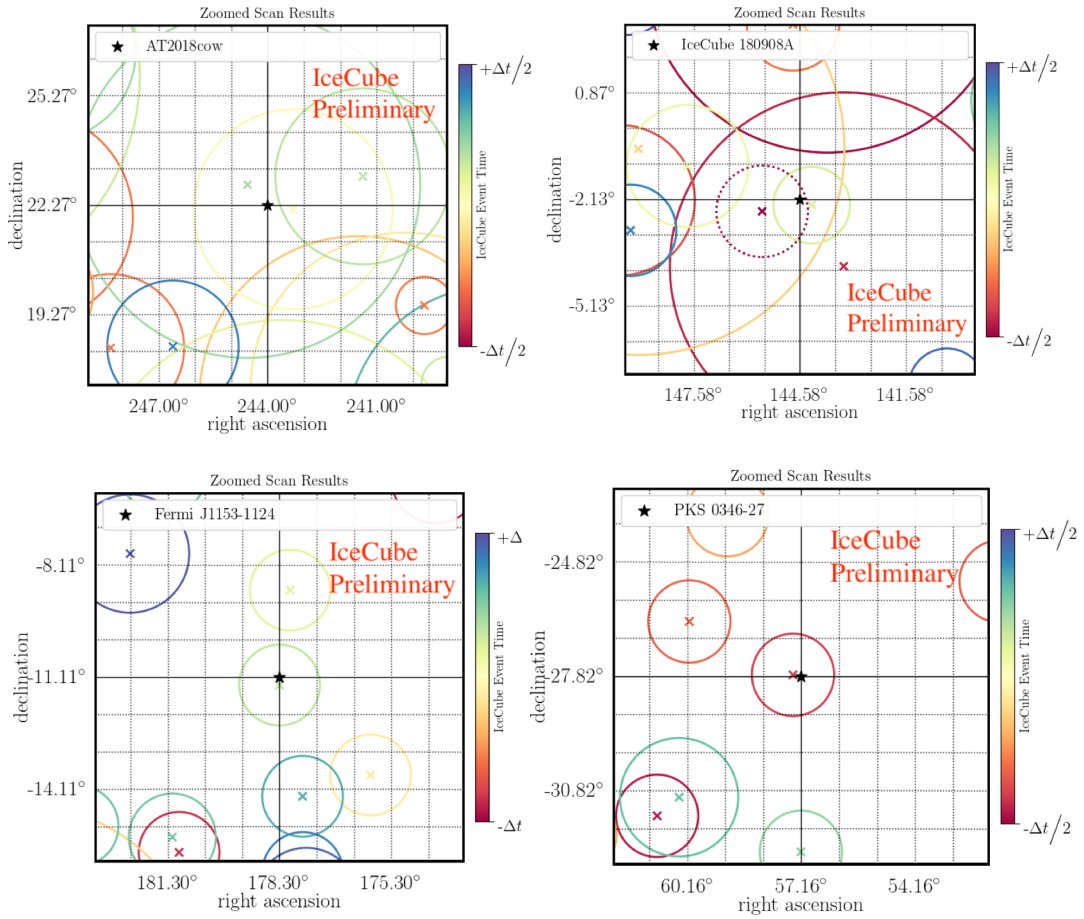
IceCube observes the whole sky with > 99% uptime

Follow up on internal and external triggers

67 analyses performed as of July 10, 2019

No statistically significant results

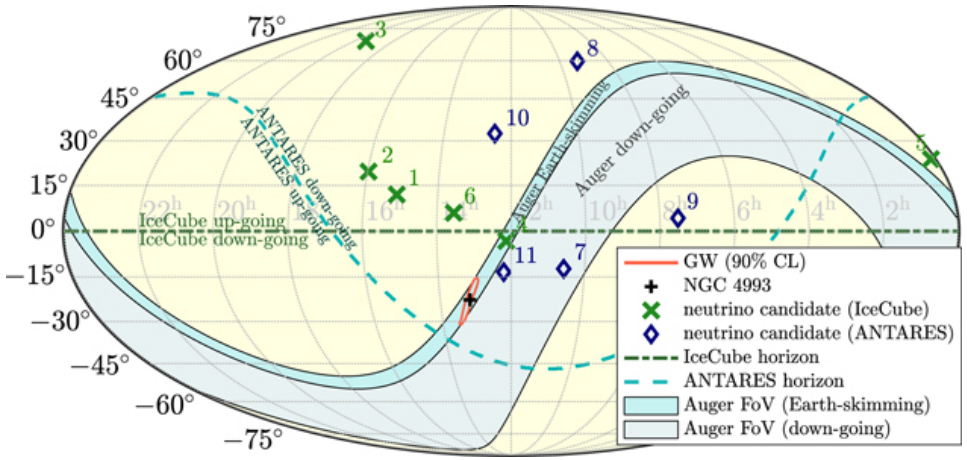


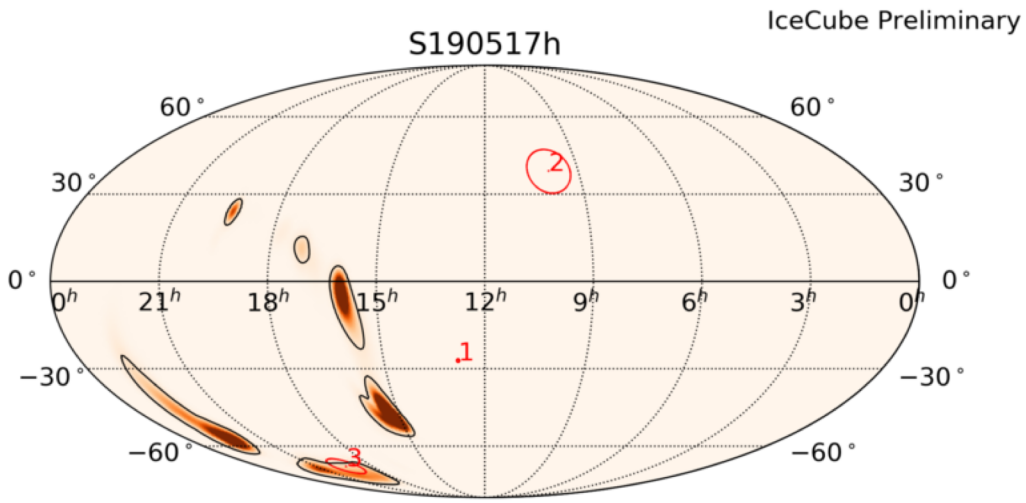


J. Vandenbroucke NU9g

IceCube Follow-up of Gravitational Wave Events

ANTARES, IceCube, Auger search for neutrinos from BNS merger GW170817
Astrophys.J. 850 (2017) no.2, L35



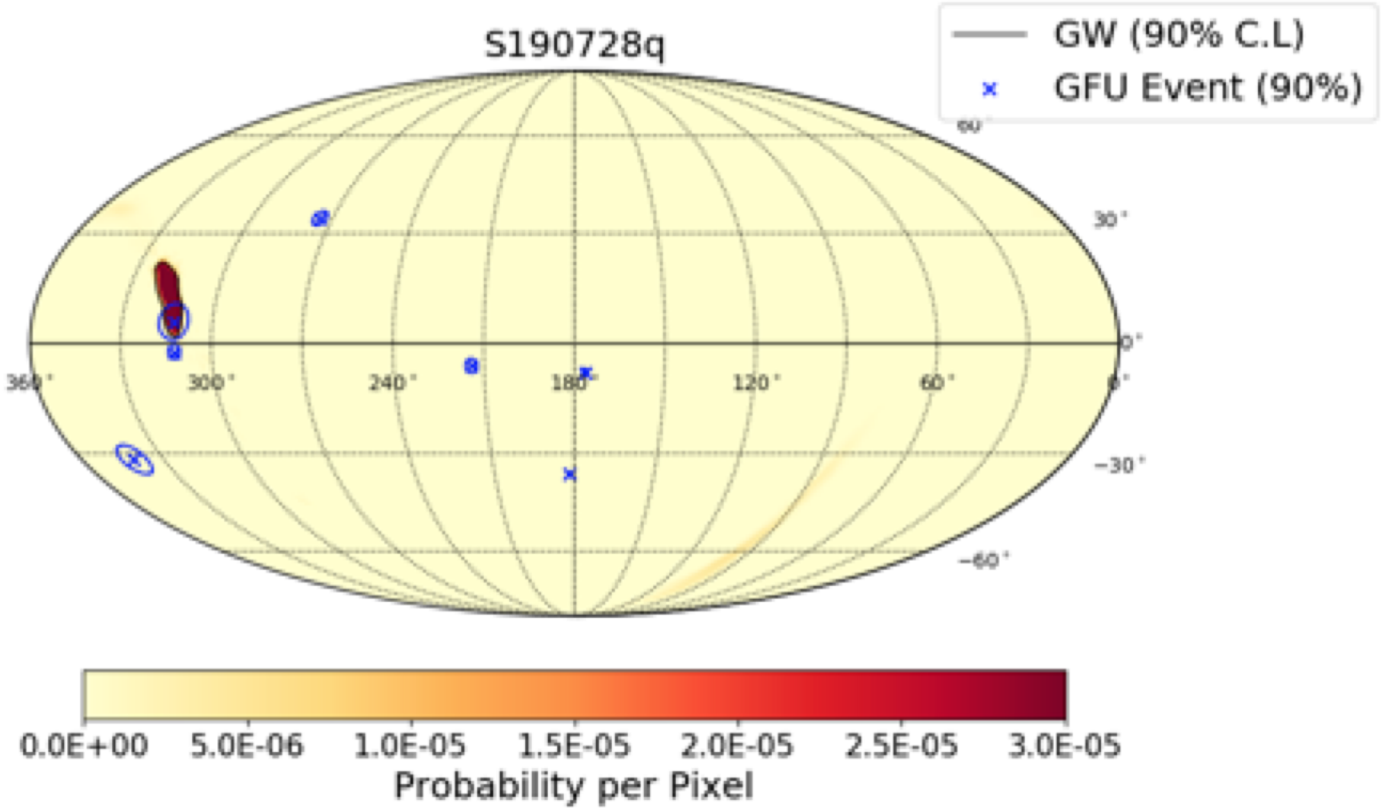


Two analyses in LVC O3 run:

1. A search for point-like neutrino sources coincident with the reported LVC alert skymap.
2. A Bayesian search considering the combined GW + neutrino joint significance with astrophysical priors such as distance.

A. Keivani NU6a
R. Hussain NU9d
Also see G. de Wasseige (NU6e) for low energy neutrino search from compact binary mergers

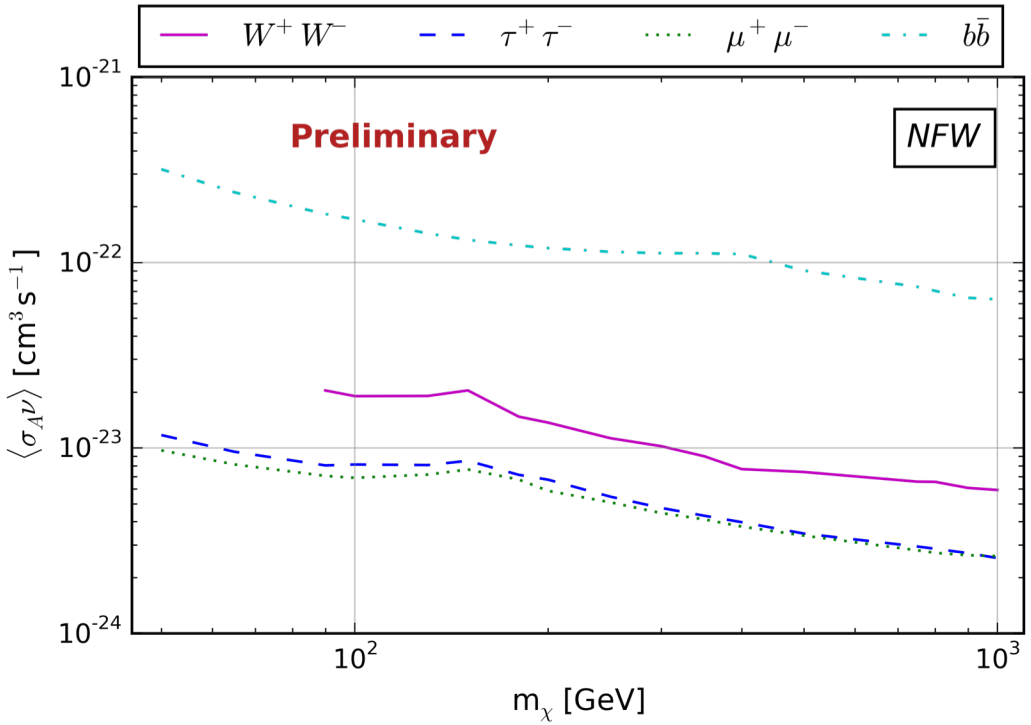
Search for Neutrinos from S190728q



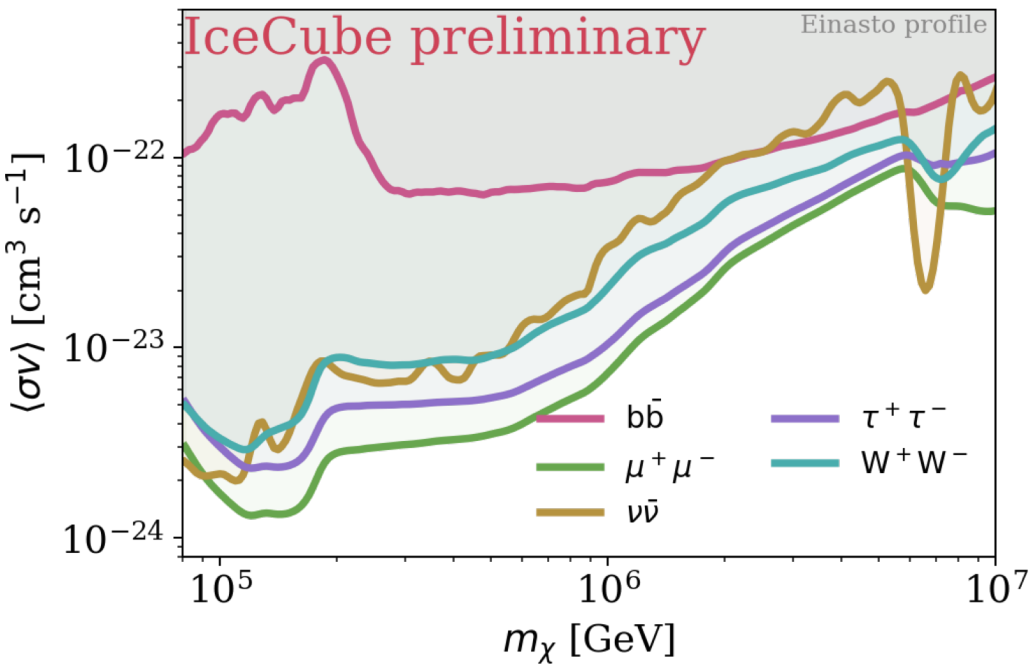
See A. Keivani, NU6a (Saturday) for Bayesian search, R. Hussain, NU9d (Tuesday) for generic transient search

dt (ns)	RA (deg)	Dec (deg)	Ang. Uncert. (deg)	P-value (Bayesian)	P-value (generic transient)
-360	312.87	5.85	4.81	0.010 (2.33 σ)	0.016 (2.21 σ)

Searches for Dark Matter

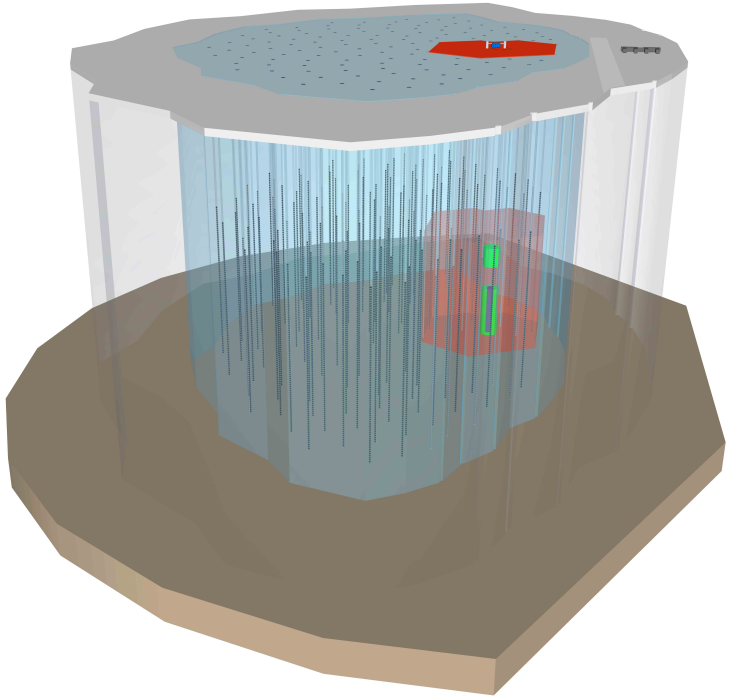


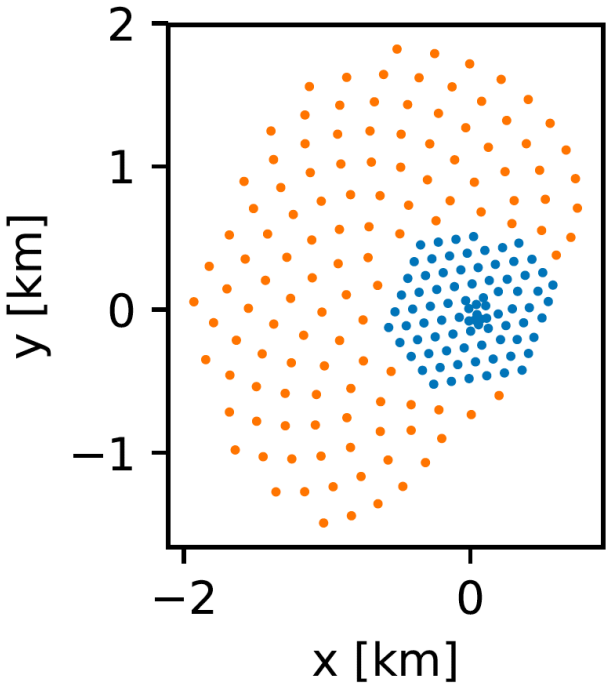
Combined limits from ANTARES and IceCube
N. Iovine DM2f



Limits from HESE 7.5
Also set limits on DM decay and DM-neutrino scattering
C. Arguelles PS1-95

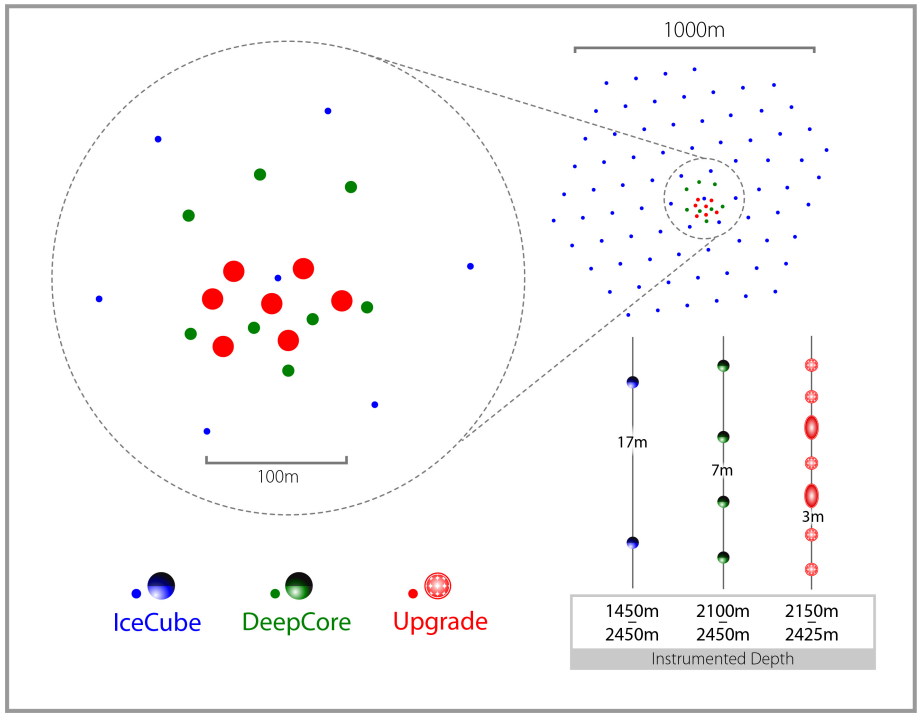
Planning the Future of IceCube

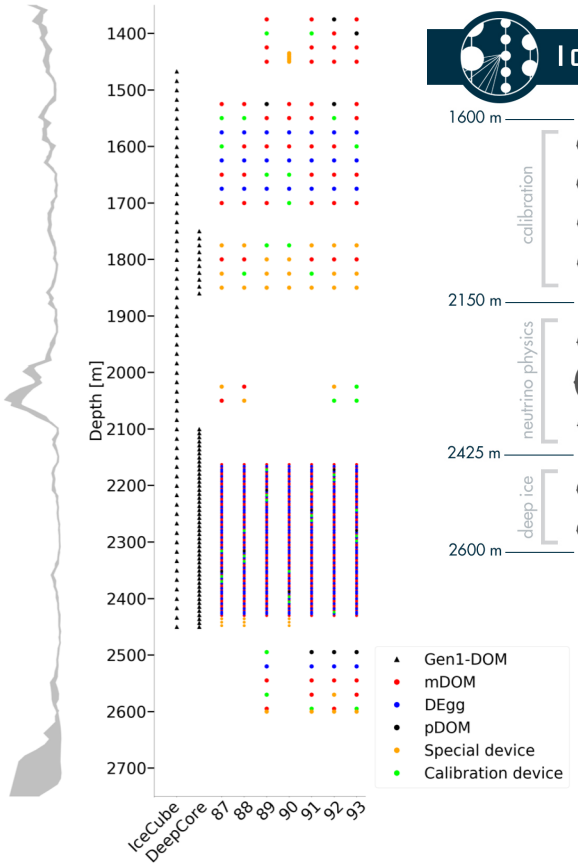


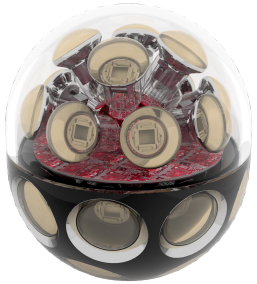


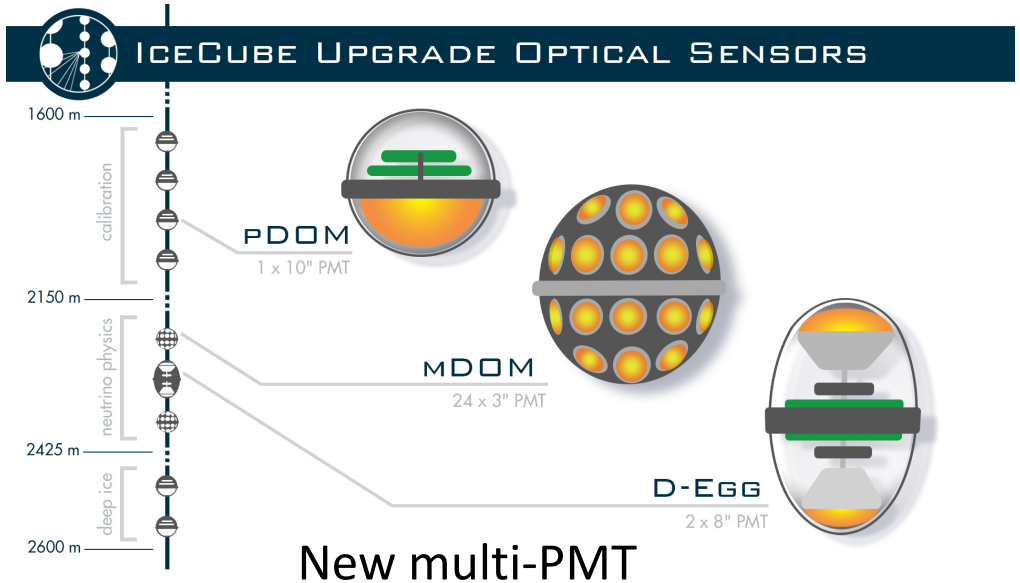
- The origin of astrophysical neutrinos is largely unresolved
- IceCube-Gen2 is a proposed multi-cubic-kilometer neutrino detector designed to be sensitive to 5x fainter sources
- Wide-band neutrino observatory with optical and radio detectors, surface array

The IceCube Upgrade









Approved by NSF, planned to deploy in 2022-23
7 new strings near the center of IceCube

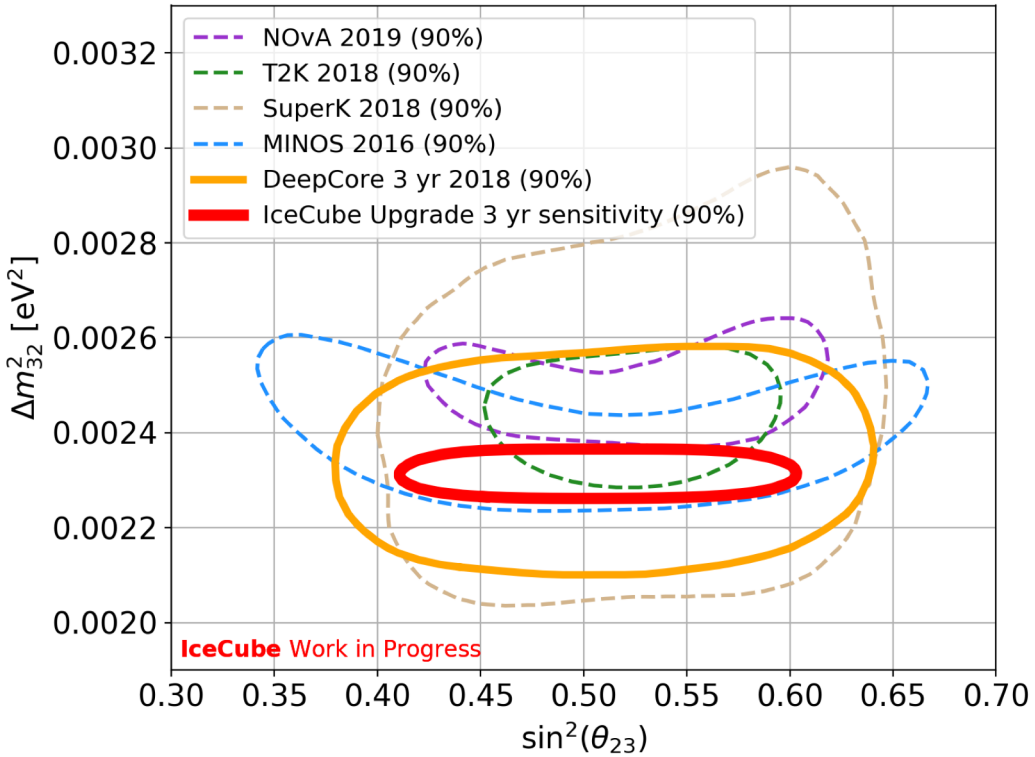
A. Ishihara NU7a

New multi-PMT sensors

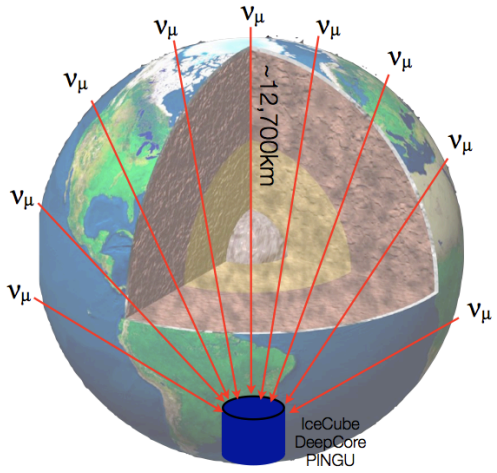
New calibration devices

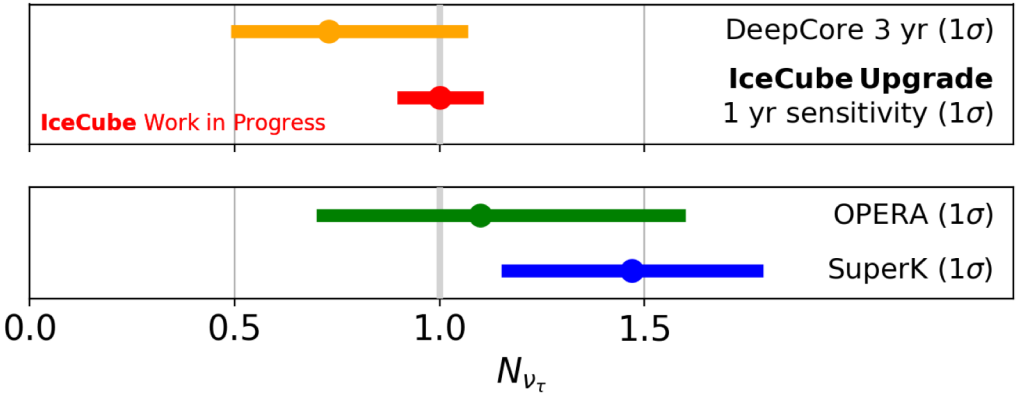
L. Classen PS3-98
A. Ishihara PS3-123
D. Van Eijk PS3-130

IceCube Upgrade: Neutrino Oscillation Physics



A. Ishihara NU7a

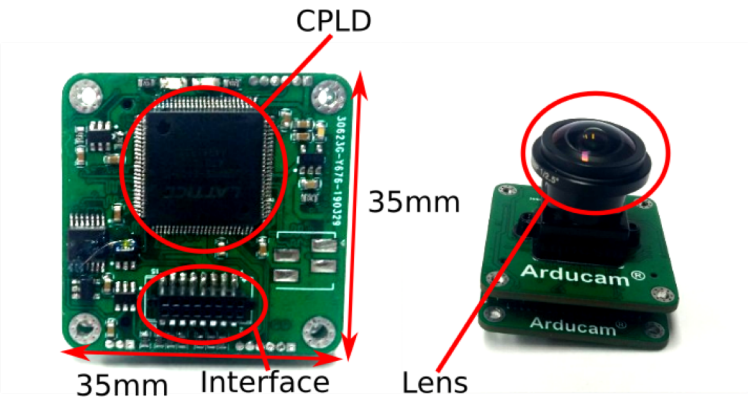




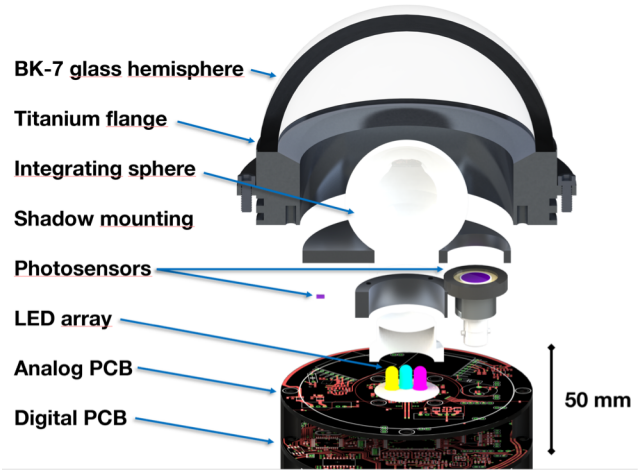
The IceCube Upgrade will have world-leading sensitivity to atmospheric tau neutrino appearance

Calibration in the IceCube Upgrade

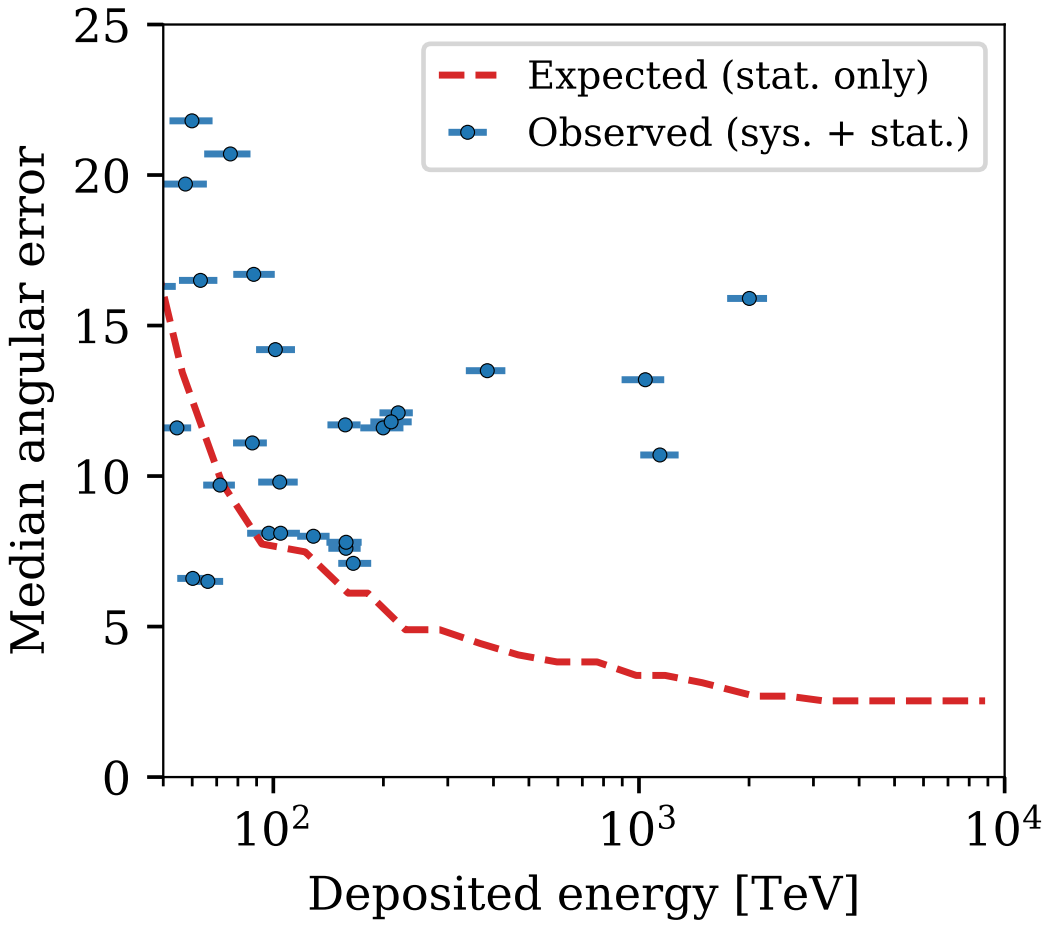
C. Fruck PS3-114
A. Ishihara PS3-117
C. Tonnis PS3-118
J. Auffenberg PS3-131



Camera system



Precision Optical Calibration Module (POCAM)



Summary

- IceCube has observed astrophysical neutrinos in multiple channels
- The first tau neutrino candidate has been detected
- IceCube plays a major role in multi-messenger astronomy and has seen the first indications of astrophysical neutrino sources
- The IceCube Upgrade has been approved, inaugurating the next phase of discovery in IceCube

Backup

430 TeV inside detector
PeV ν_μ
no air shower

all cosmic neutrinos are isolated by self-veto