



Neutrino-Driven Multi-Messenger Astronomy

(and some updated I^3 results)

Shigeru Yoshida

ICEHAP

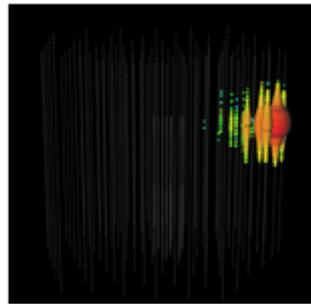
Chiba University

The recently published results from IceCube



EHE analysis updated

Cosmic ν in Ultra-high energy region (10PeV – 10 EeV)



EDITORS' SUGGESTION

Constraints on Ultrahigh-Energy Cosmic-Ray Sources from a Search for Neutrinos above 10 PeV with IceCube

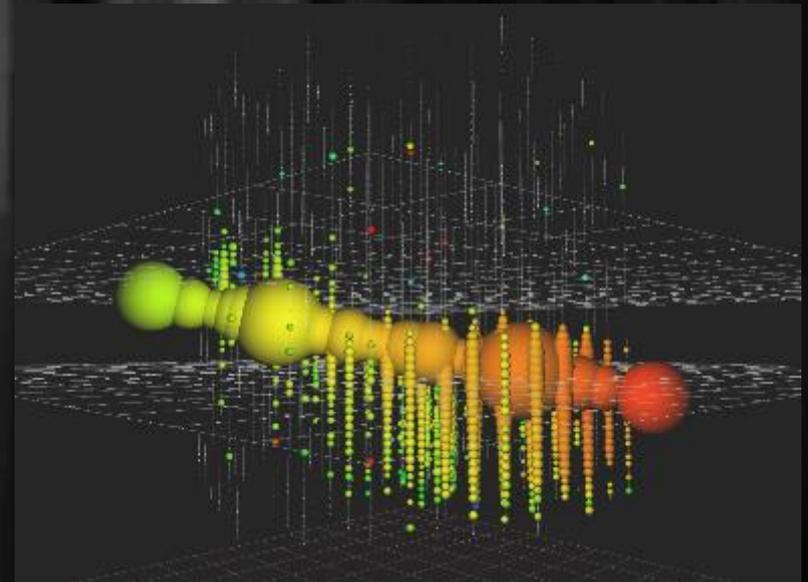
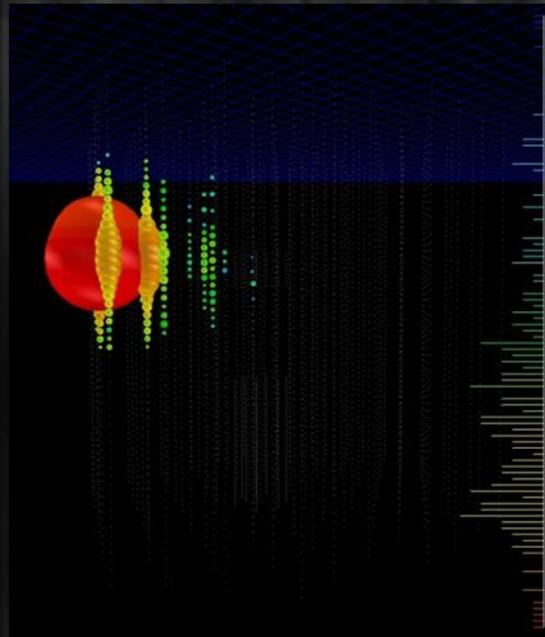
IceCube has put the tightest constraints on the cosmogenic neutrino flux—neutrinos produced when ultrahigh energy cosmic rays scatter from the cosmic microwave background. In the process the collaboration has also detected the highest energy neutrino to date.

M. G. Aartsen *et al.* (IceCube Collaboration)
Phys. Rev. Lett. **117**, 241101 (2016)

UHE events in the 7 years of IceCube data (April 2008 – May 2015)

(2012)
808 TeV

(2014)
2.6 PeV (deposited energy)



They are astrophysical (3.6σ)

But they are not EeV-energies \rightarrow **Not** originated in UHE Cosmic rays



No Radio-loud AGNs No GRBs

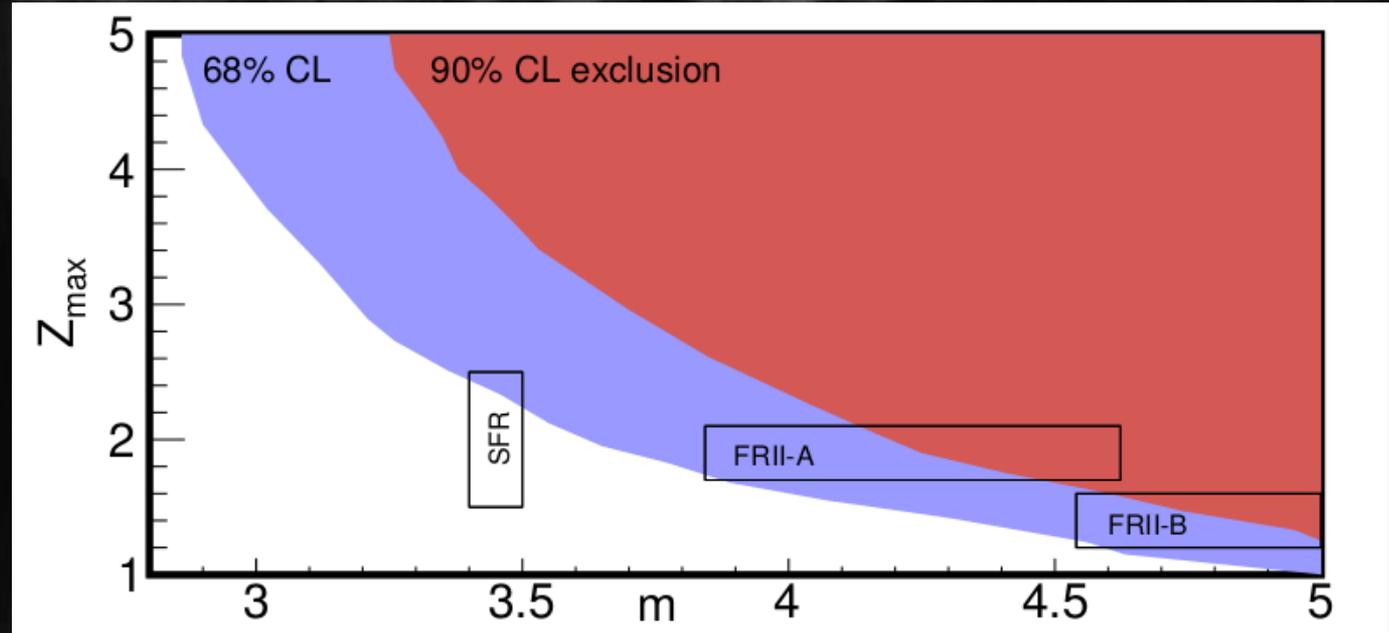


for UHE cosmic-ray sources

ν Model	GZK Y&T <small>m=4,zmax=4</small>	GZK Ahlers <small>Best Fit 10EeV</small>	GZK Ahlers <small>Best Fit 1EeV</small>	GZK Kotera SFR	GZK Aloisio SFR	AGN Murase <small>$\gamma=2.3$ Load.fac 100</small>	Young Pulsar Ke+ SFR
Expect. # of events	7.0	5.3	2.8	3.6	4.8	7.4	5.5
Model Rejection Factor	0.37	0.48	1.17	1.44	1.09	0.96	1.34
p-value	1.0×10^{-3}	7.0×10^{-3}	9.5×10^{-2}	2.2×10^{-1}	7.8×10^{-2}	2.2×10^{-3}	7.8×10^{-2}

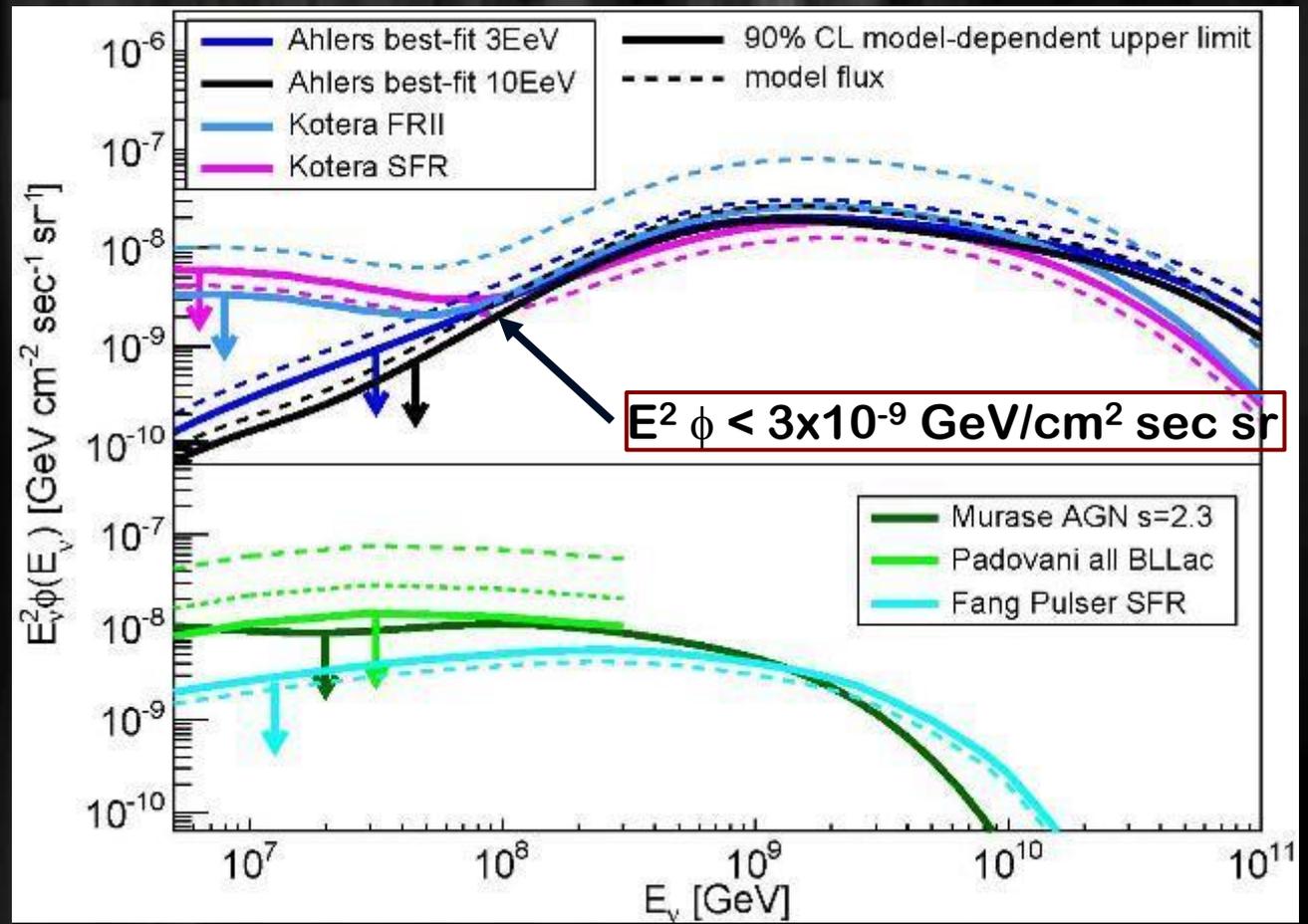
No Radio-loud AGNs No GRBs

for UHE cosmic-ray sources



No Radio-loud AGNs No GRBs

for UHE cosmic-ray sources



The recently published results from IceCube



No neutrinos associated from GRBs

THE ASTROPHYSICAL JOURNAL

AN ALL-SKY SEARCH FOR THREE FLAVORS OF NEUTRINOS FROM GAMMA-RAY BURSTS WITH THE ICECUBE NEUTRINO OBSERVATORY

M. G. Aartsen¹, K. Abraham², M. Ackermann³, J. Adams⁴, J. A. Aguilar⁵, M. Ahlers⁶, M. Ahrens⁷,
D. Altmann⁸, T. Anderson⁹, I. Ansseau⁵ [Show full author list](#)

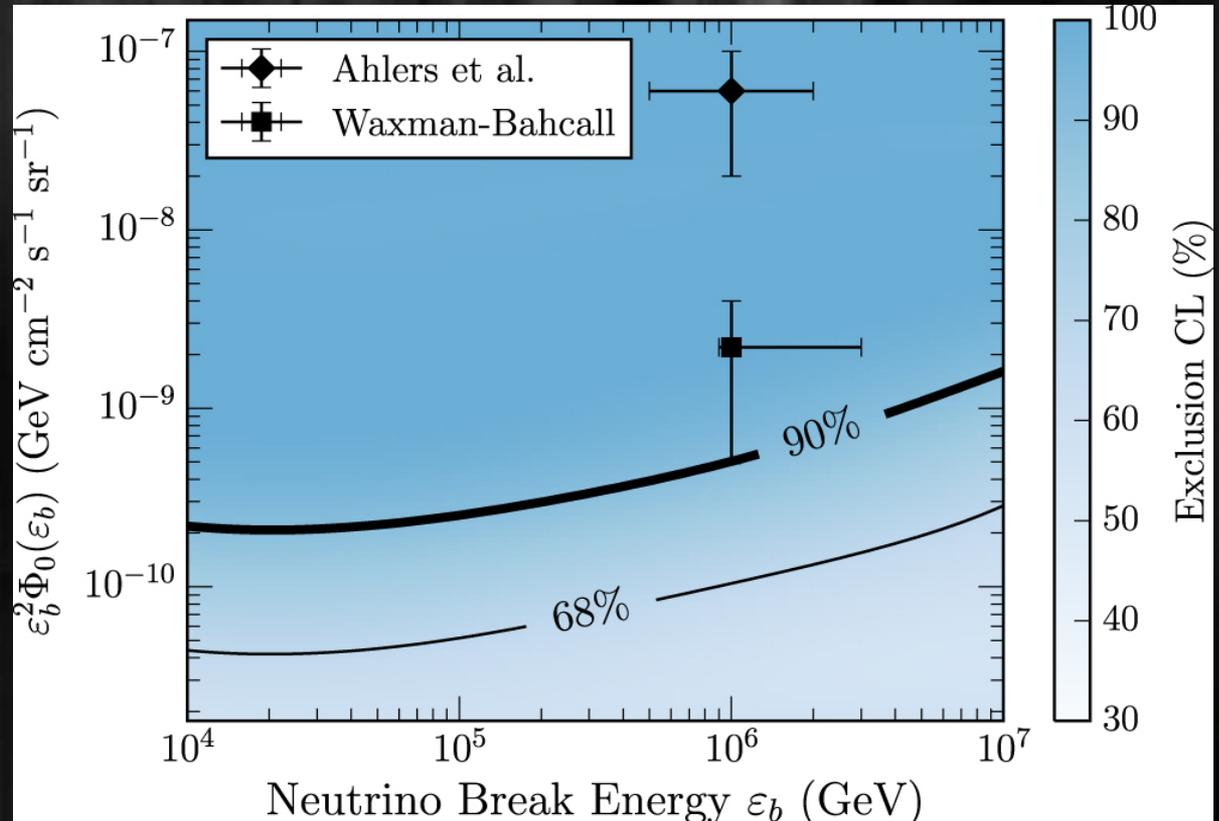
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[The Astrophysical Journal, Volume 824, Number 2](#)

The recently published results from IceCube



No neutrinos associated from GRBs
Based on 807 GRBs



The recently published results from IceCube



100TeV– PeV energy up-going ν_μ measurement
using 6 year data (2009-2015)

THE ASTROPHYSICAL JOURNAL

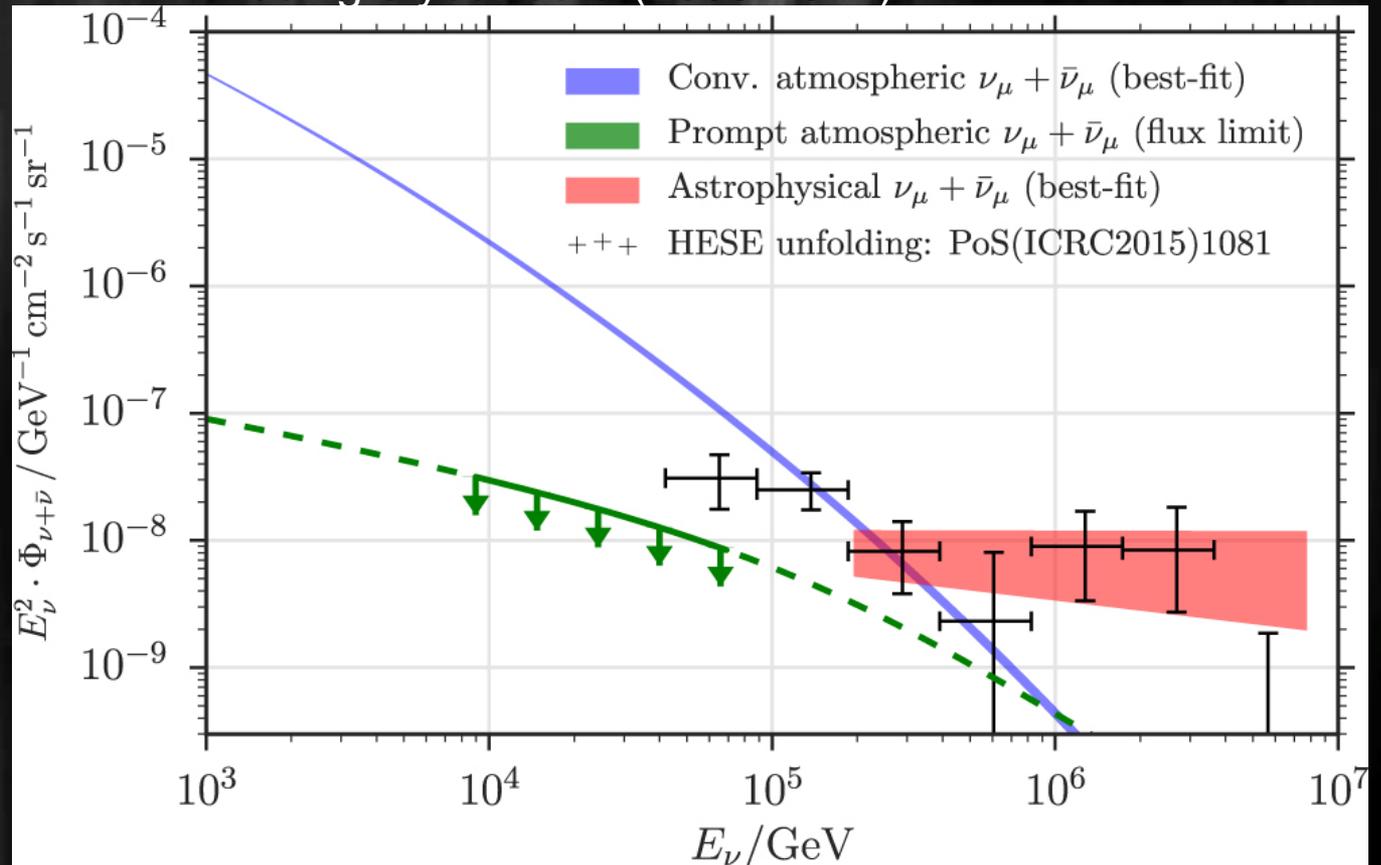
OBSERVATION AND CHARACTERIZATION OF A COSMIC MUON NEUTRINO FLUX FROM THE NORTHERN HEMISPHERE USING SIX YEARS OF ICECUBE DATA

M. G. Aartsen¹, K. Abraham², M. Ackermann³, J. Adams⁴, J. A. Aguilar⁵, M. Ahlers⁶, M. Ahrens⁷,
D. Altmann⁸, K. Andeen⁹, T. Anderson¹⁰, I. Anseau⁵, G. Anton⁸, M. Archinger¹¹, C. Argüelles¹²,
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A. Bernhard², D. Z. Besson²⁴, G. Binder^{16,25}, D. Bindig²⁰, M. Bissok¹³, E. Blaufuss²³, S. Blot³,
C. Boehm⁷, M. Börner²⁶, F. Bos¹⁹, D. Bose²⁷, S. Böser¹¹, O. Botner²⁸, J. Braun⁶, L. Brayeur²⁹,
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M. Day⁶, J. P. A. M. de André³⁴, C. De Clercq²⁹, E. del Pino Rosendo¹¹, H. Dembinski³⁵,
S. De Ridder³⁶, P. Desiati⁶, K. D. de Vries²⁹, G. de Wasseige²⁹, M. de With³⁷, T. DeYoung³⁴

The recently published results from IceCube



100TeV– PeV energy up-going ν_μ measurement
using 6 year data (2009-2014)



$$E^2 \phi(E) \approx 8 \times 10^{-9} \text{ GeV/cm}^2 \text{sec sr}$$

The recently published results from IceCube



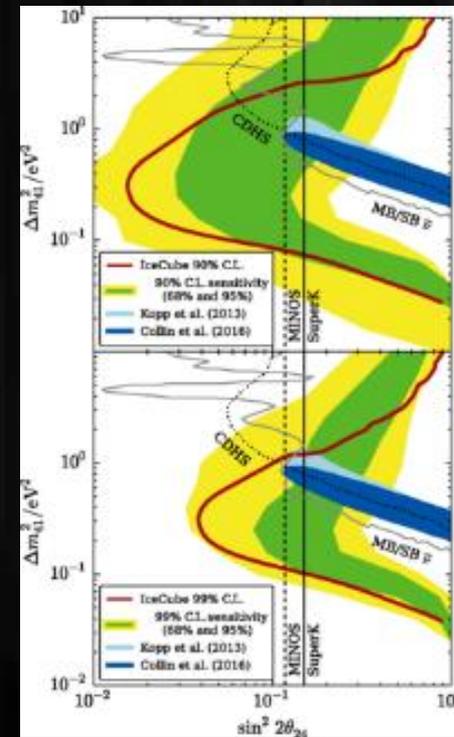
Sterile Neutrinos? *May be better to forget it*

Featured in Physics Editors' Suggestion

Searches for Sterile Neutrinos with the IceCube Detector

M. G. Aartsen *et al.* (IceCube Collaboration)

Phys. Rev. Lett. **117**, 071801 (2016) – Published 8 August 2016



Multi-Messenger



South Pole



Northern Hemisphere



< 3 minutes time lag

GCN-TAN

IceCube Realtime Analysis Chain



muon multiplet for Gamma-ray/Optical follow-up

TeV

PeV

EeV

muon neutrino sensitive
good angular resolutions
large background chance

veto-based
HESE

TeV

PeV

EeV

all neutrino flavor sensitive
high chance of real cosmic neutrino signals
angular resolutions so-so

High cosmic ν purity samples.
Launched in 2016!

EHE (Ultra-High Energies)

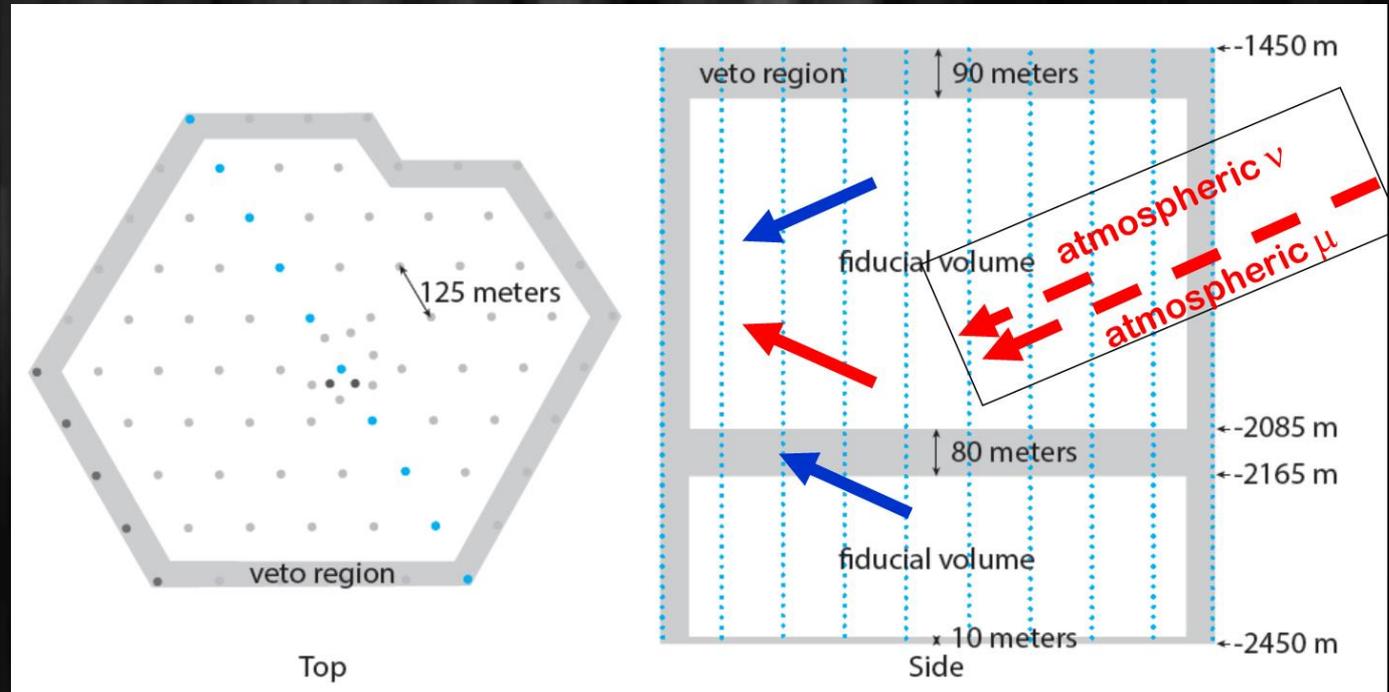
TeV

PeV

EeV

all neutrino flavor sensitive
high chance of real cosmic neutrino signals
good angular resolutions
signal flux highly uncertain

HESE channel

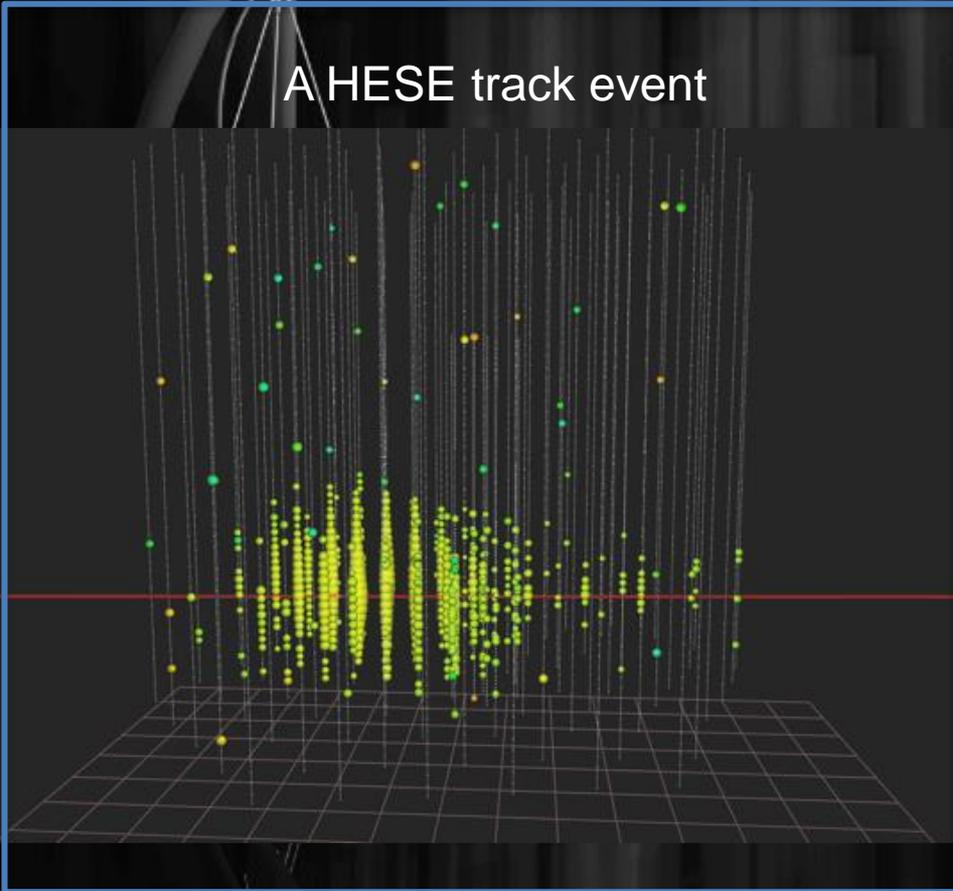


Cosmic ν \sim 1.09 event/year
Atmospheric BG \sim 3.73 event/year

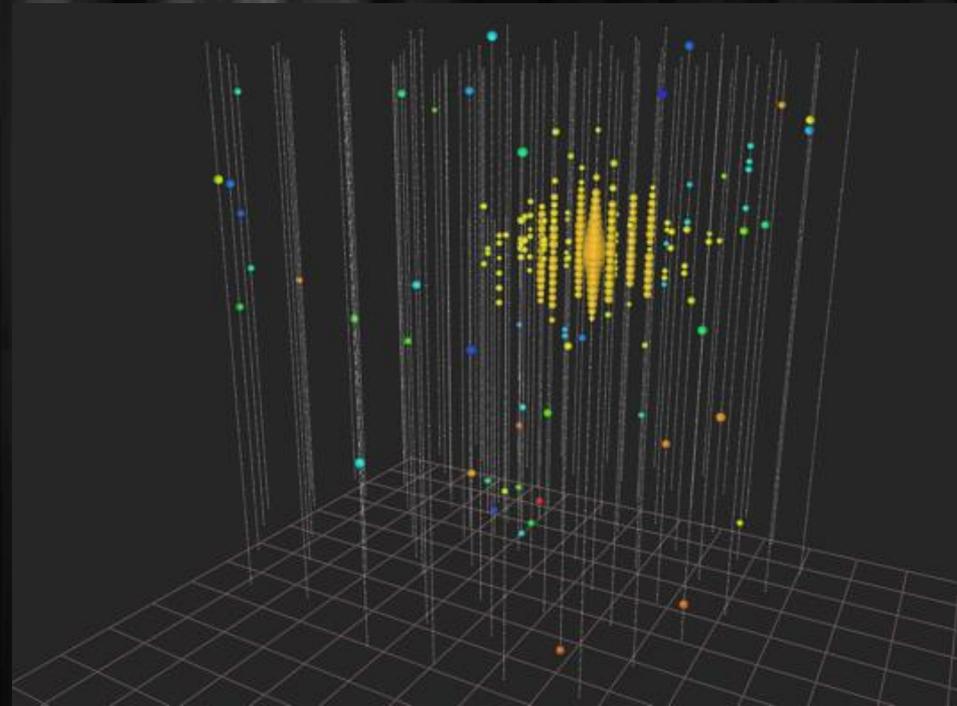
HESE channel

Additional cut to only pick up track-like events

A HESE track event



A HESE cascade (shower) event



angular error 0.6~1.6 deg (median)

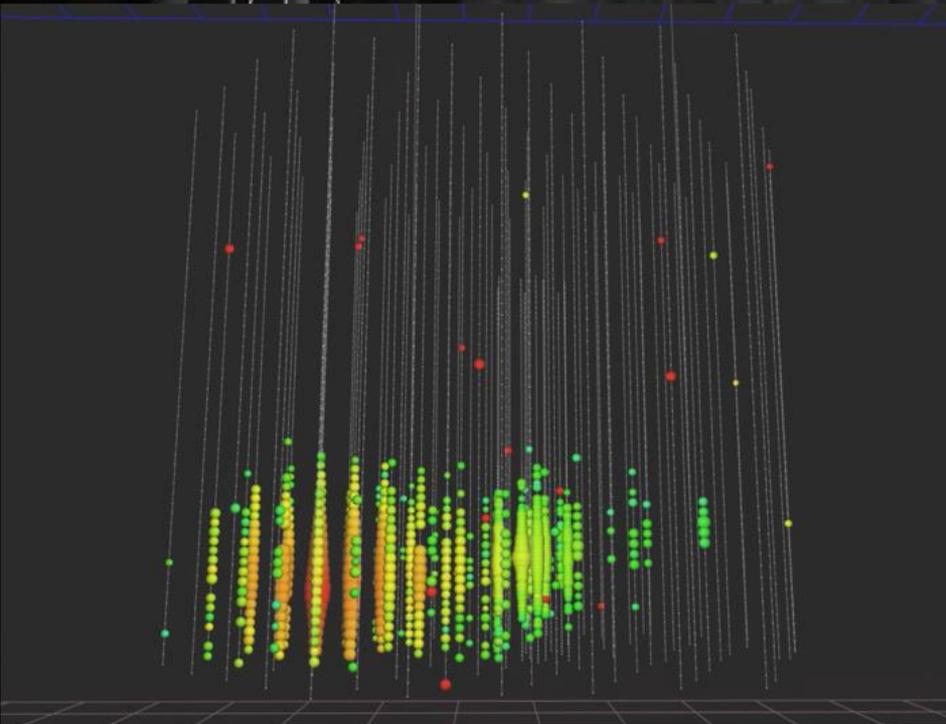
First GCN event from HESE



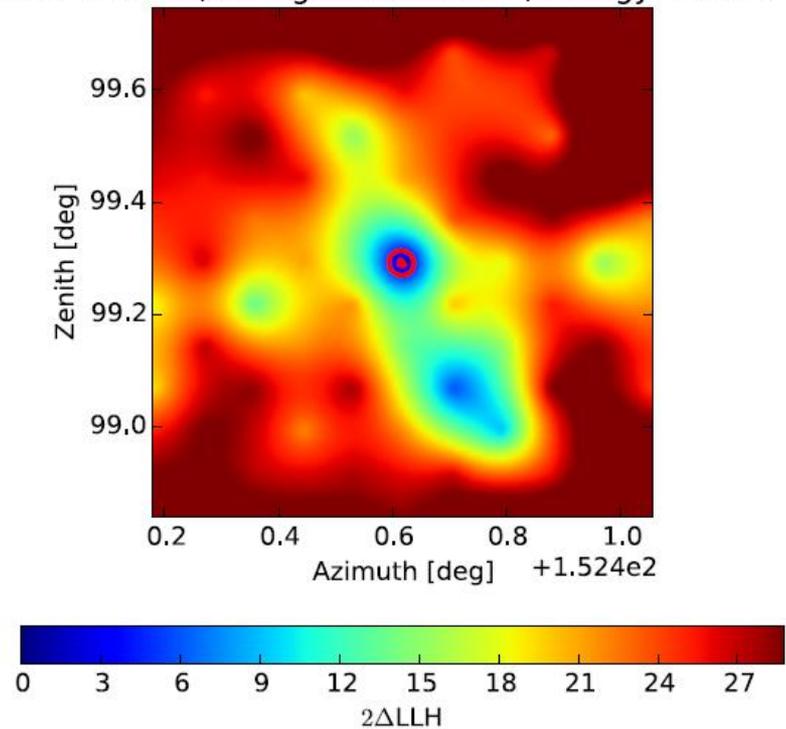
~ 150 TeV

~0.6 deg uncert.

April 27, 2016 at 5:52 UTC



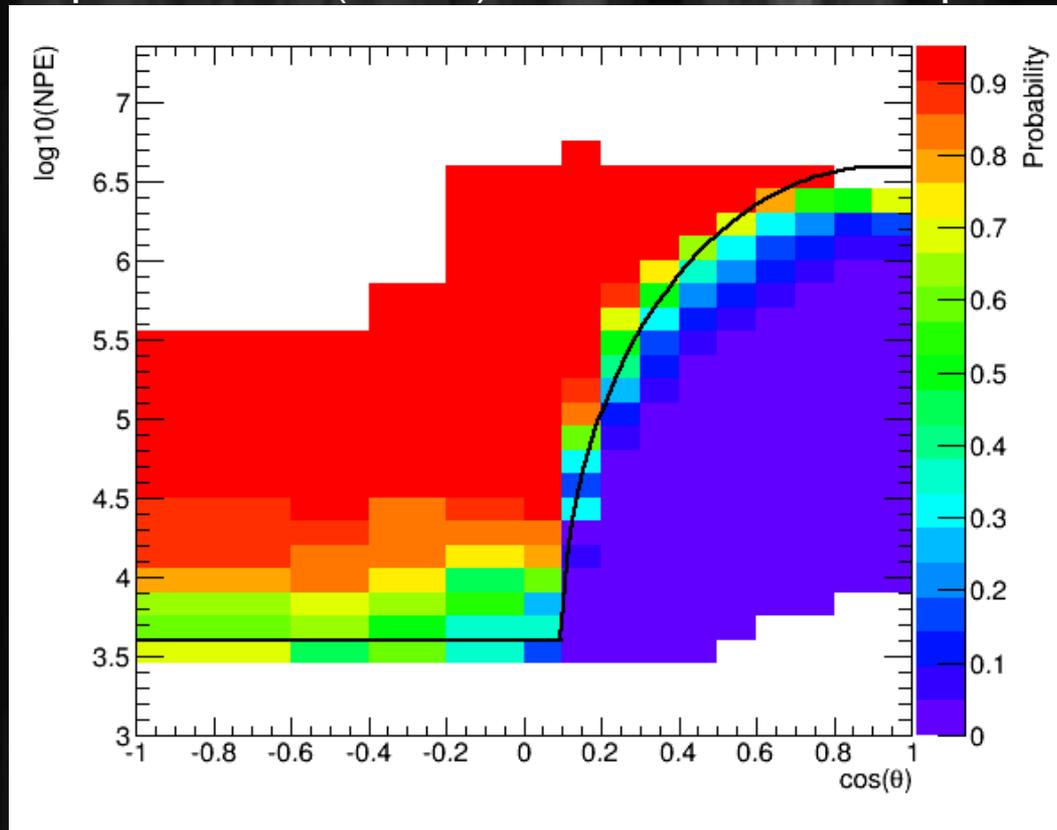
RunID: 127853, Charge: 18883.6 PE, Energy: 146.37 TeV



EHE channel

Selects energetic (i.e., *bright*) events

cosmic ν signalness map
in the plane of $\cos(\text{zenith})$ and # of Cherenkov photons



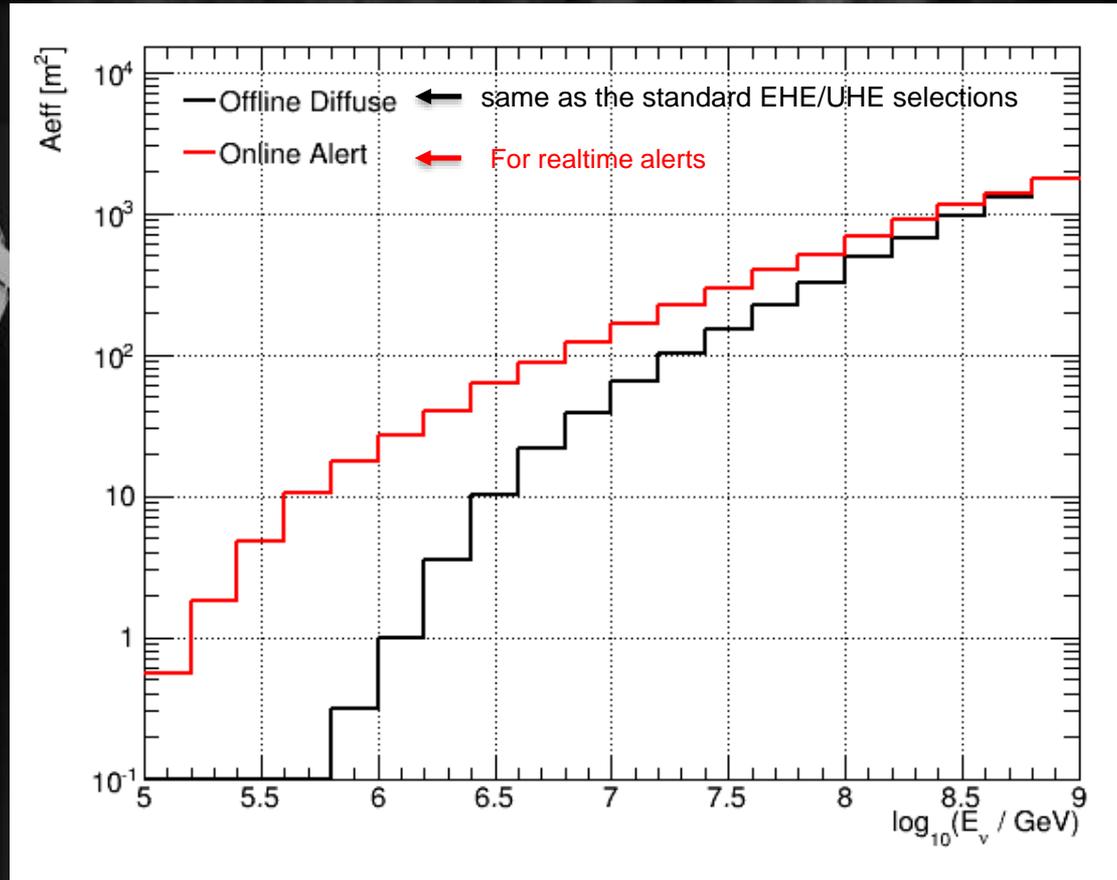
events above
the black curve
retains

Cosmic ν \sim 2.5 event/year
Atmospheric BG \sim 1.91 event/year

EHE channel

Selects energetic (i.e., *bright*) events

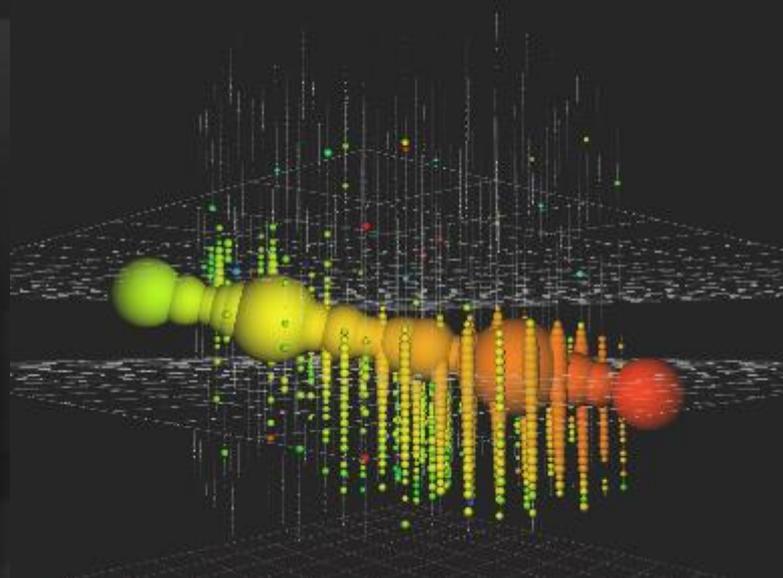
effective area : most efficient channel for energies above PeV



EHE channel

Selects energetic (i.e., *bright*) events

This is THE event in EHE channel – detected in 2014 sample

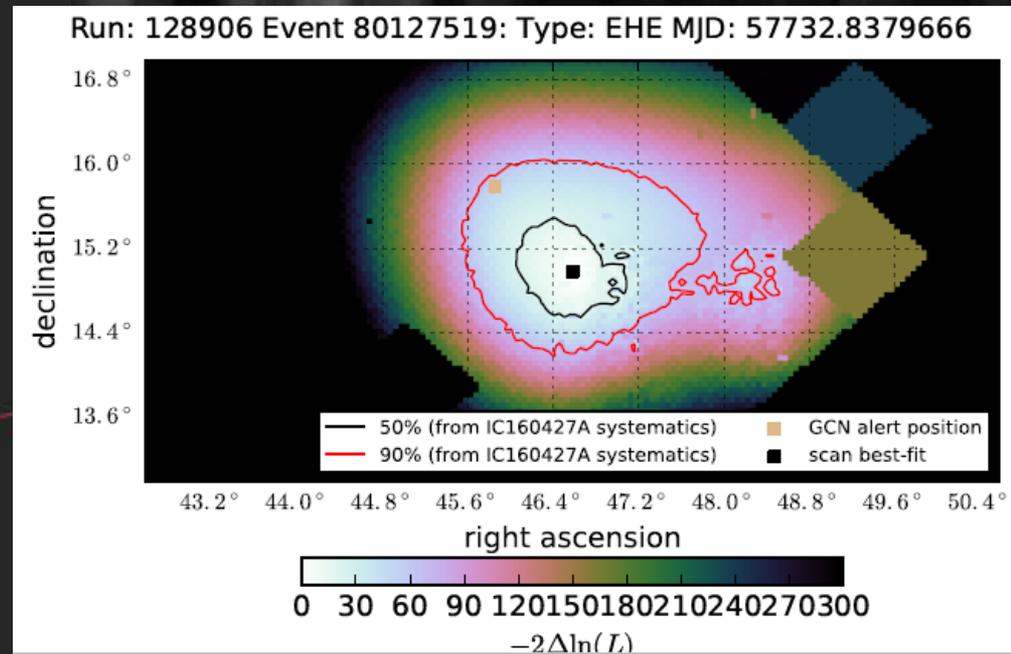
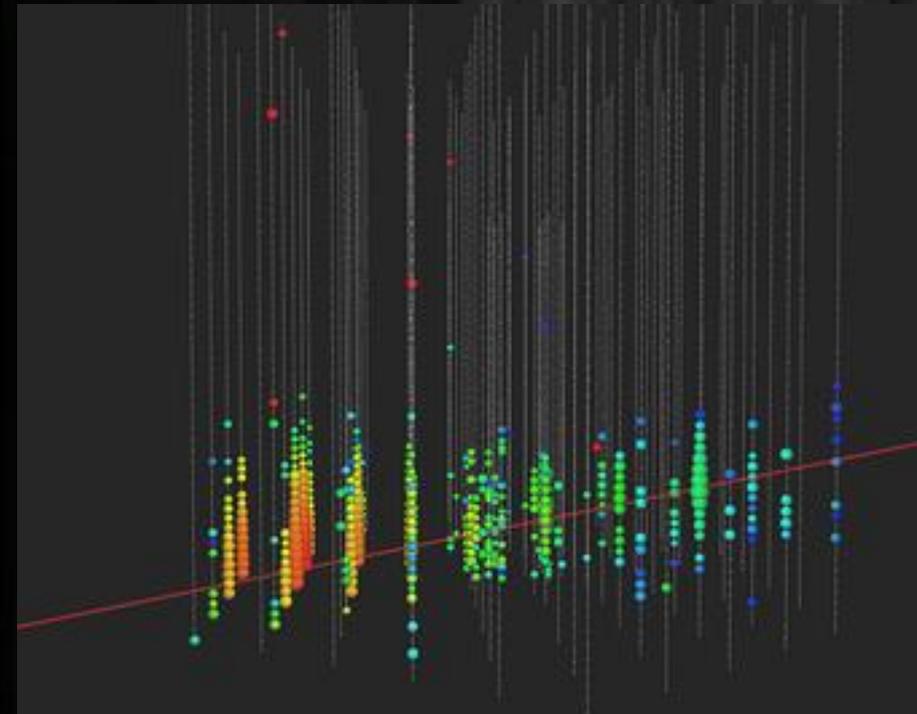


EHE channel

Selects energetic (i.e., *bright*) events



Detected last Sunday morning (in JST)



IceCube alerts are found in GCN-AMON notice

<http://gcn.gsfc.nasa.gov/amon.html>

AMON ICECUBE_EHE EVENTS

EVENT			OBSERVATION							
EventNum_RunNum	Date	Time UT	NoticeType	RA	Dec	Error	Signalness	N_Events	Stream	Comments
80127519_128906	16/12/10	20:06:40.31	EHE	46.5799	+14.9800	60.00	4.9023e-01	1	2	AMON_ICECUBE_EHE.
80127519_128906	16/12/10	20:06:40.31	EHE	45.8549	+15.7851	14.99	4.9023e-01	1	2	AMON_ICECUBE_EHE.
26552458_128311	16/08/06	12:21:33.00	EHE	122.7980	-0.7331	6.67	2.8016e-01	1	2	AMON_ICECUBE_EHE.
6888376_128290	16/07/31	01:55:04.00	EHE	214.5440	-0.3347	20.99	8.4879e-01	1	2	AMON_ICECUBE_EHE.
6888376_128290	16/07/31	01:55:04.00	EHE	215.0929	-0.4191	10.31	8.4879e-01	1	2	AMON_ICECUBE_EHE.

AMON ICECUBE_HESE EVENTS

EVENT			OBSERVATION									
EventNum_RunNum	Date	Time UT	NoticeType	RA	Dec	Error	False_Pos	Pvalue	Charge	SignalTr	N_Events	Stream
38561326_128672	16/11/03	09:07:31.12	HESE	40.8252	+12.5592	66.00	0.0000e+00	0.0000e+00	7546.05	0.30	1	1
38561326_128672	16/11/03	09:07:31.12	HESE	40.8740	+12.6159	73.79	0.0000e+00	0.0000e+00	7546.05	0.30	1	1
58537957_128340	16/08/14	21:45:54.00	HESE	199.3100	-32.0165	89.39	n/a	n/a	10431.02	0.12	1	1
6888376_128290	16/07/31	01:55:04.00	HESE	215.1090	-0.4581	73.79	n/a	n/a	15814.74	0.91	1	1
6888376_128290	16/07/31	01:55:04.00	HESE	214.5440	-0.3347	45.00	n/a	n/a	15814.74	0.91	1	1
67093193_127853	16/04/27	05:52:32.00	HESE	240.5683	+9.3417	35.99	n/a	n/a	18883.62	0.92	1	1
67093193_127853	16/04/27	05:52:32.00	HESE	239.6639	+6.8528	534.00	n/a	n/a	18883.62	0.92	1	1
67093193_127853	16/04/27	05:52:32.00	HESE	239.6639	+6.8528	534.00	n/a	n/a	18883.62	-1.00	1	1
67093193_127853	16/04/27	05:52:32.00	HESE	239.6639	+6.8528	534.00	n/a	n/a	18883.62	-1.00	1	1

References for IceCube follow-up observers

IceCube HESE channel

http://gcn.gsfc.nasa.gov/amon_hese_events.html
public document

http://gcn.gsfc.nasa.gov/doc/Public_Doc_AMON_IceCube_GCNAAlerts_Oct2016_v7.pdf

IceCube EHE channel

http://gcn.gsfc.nasa.gov/amon_ehe_events.html
public document

http://gcn.gsfc.nasa.gov/doc/AMON_IceCube_EHE_alerts_Oct31_2016.pdf

We will also publish a paper on “IceCube Realtime Alert system”
(to be submitted to Astroparticle Physics)