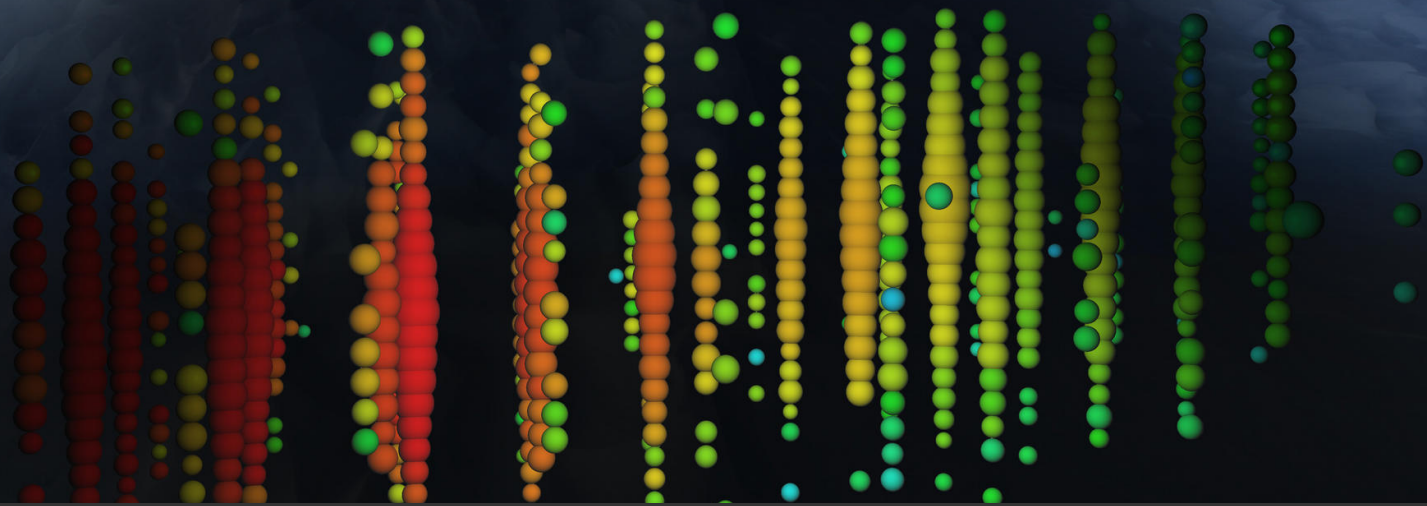
Realtime and Multimessenger Programs using IceCube

Mike Richman

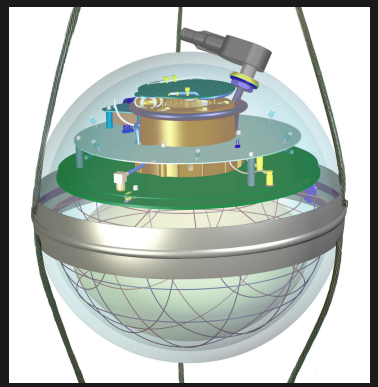
XVIII International Workshop on Neutrino Telescopes
March 19, 2019



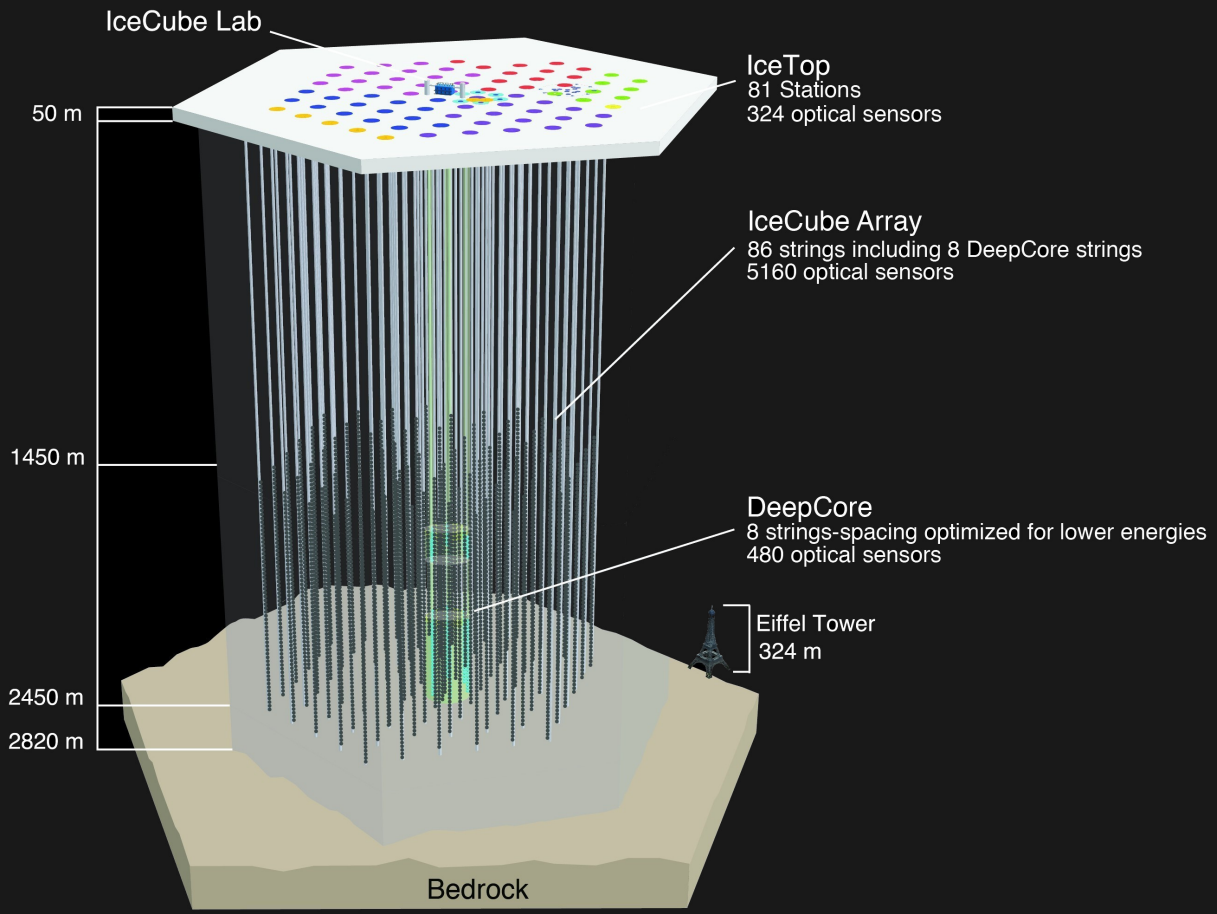
The IceCube Neutrino Observatory

1.5–2.5 km deep in the South Pole glacier

Initial filtering on-site
$> 99\%$ uptime



5160 light sensors
All-sky visibility

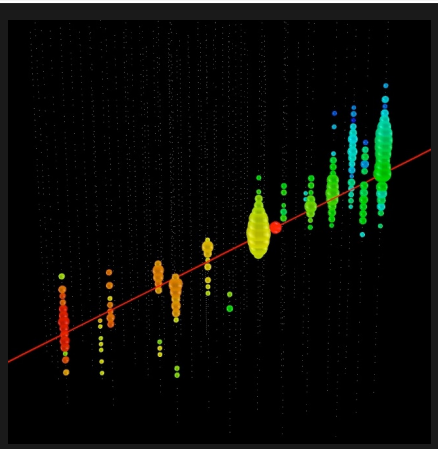
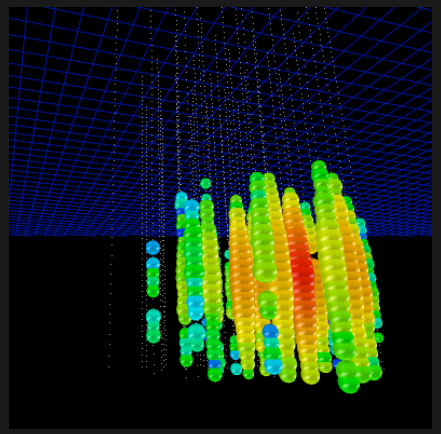
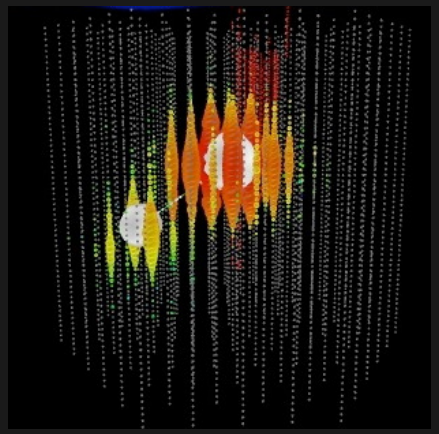


1 km^3 instrumented volume

[JINST 12 P03012 (2017)]

Neutrino Detection

interactions and detector signatures

CC ν_μ	CC ν_e / NC ν_*	CC ν_τ
		
$\nu_\mu + N \rightarrow \mu + X$	$\nu_e + N \rightarrow e + X$ $\nu_* + N \rightarrow \nu_* + X$	$\nu_\tau \rightarrow \tau + X$
track	*cascade*	*cascade* (or *double-bang*)

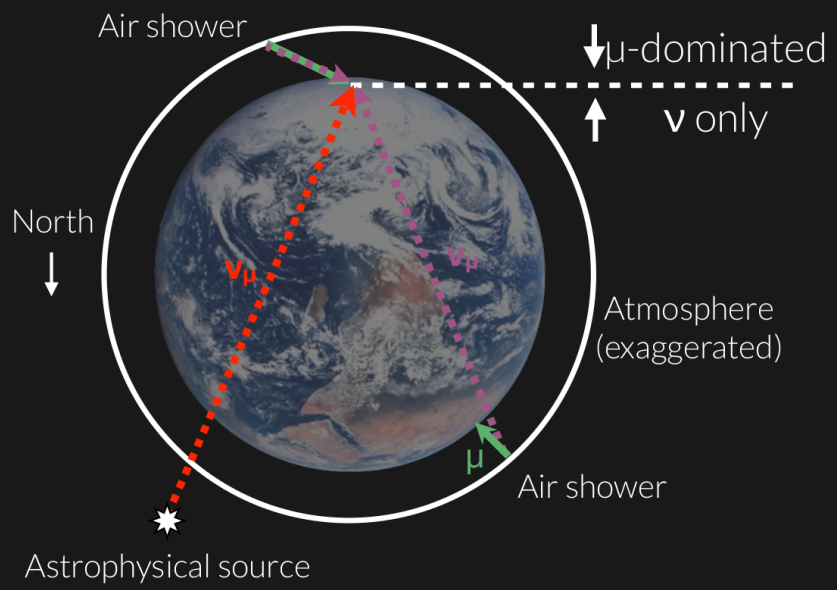
Tracks are far better suited to rapid follow-up.

Event Selection

two approaches to neutrino selection

Classic ν_μ strategy:

- Downgoing cosmic ray muon tracks outnumber neutrinos by $> 10^5\times$
- Earth acts as neutrino filter
- Well-reconstructed northern tracks must be neutrinos



→ North sky and ν_μ only

Both methods used to produce neutrino alerts.

Event Selection

two approaches to neutrino selection

Classic ν_μ strategy:

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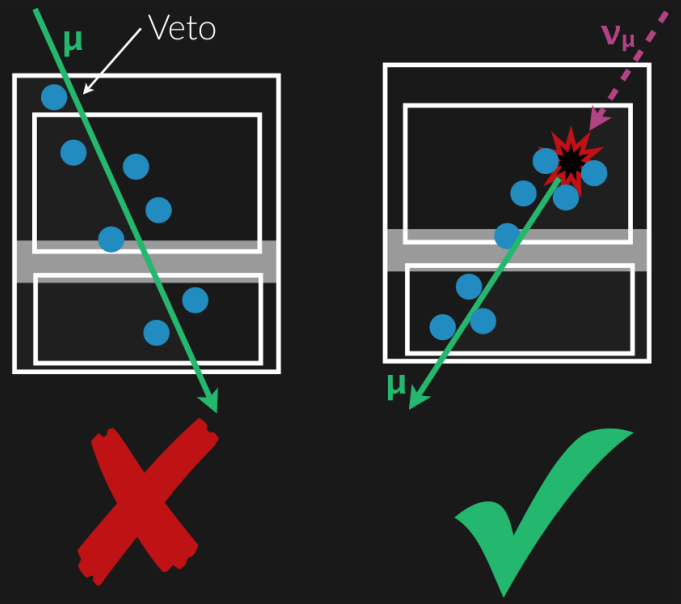
Veto to select starting events:



→ North sky and ν_μ only

→ Very low background

Both methods used to produce neutrino alerts.

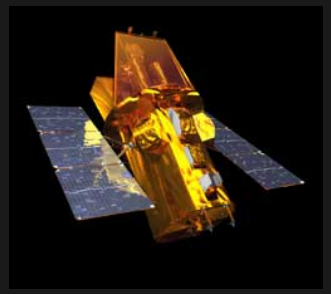
Data Flow Overview

from IceCube to the community

Alerts & data for improved reconstructions transferred via Iridium RUDICS

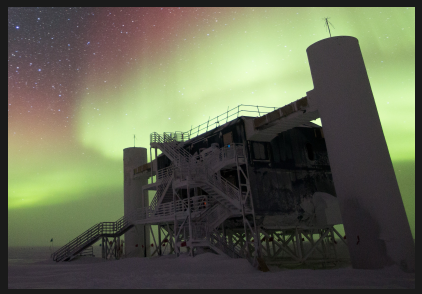
Gamma

X-ray



Iridium Data Transfer to "The North"

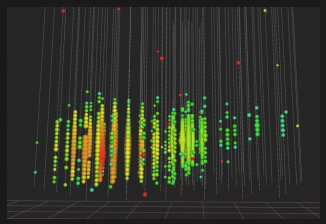
Real-time Processing



Optical

GW

IceCube ν



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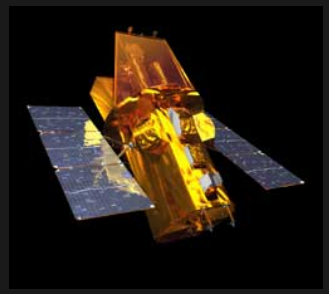

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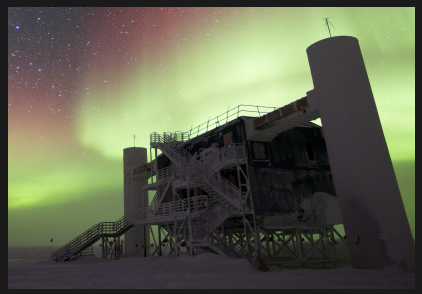

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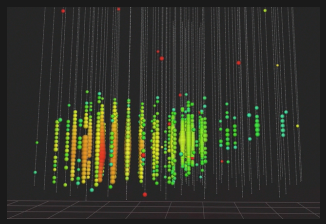


- Private multiplet streams since 2008
- Public singlet streams since 2016
  http://gcn.gsfc.nasa.gov/notices_amon/67093193_127853.amon

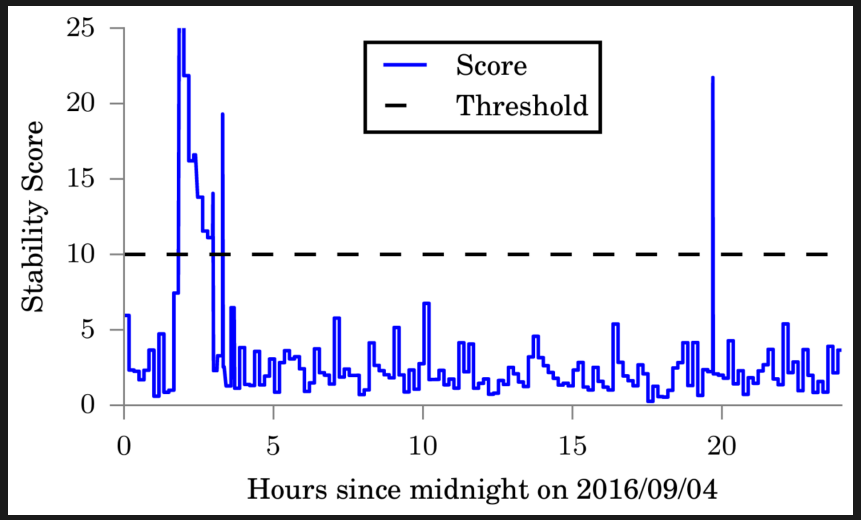
Realtime Detector Performance

low latency, high duty factor

Goal: maximum info $\rightarrow$ minimum latency

Automated stability monitoring ensures data quality

Trigger and filter rates compared to exp.-weighted moving average for stability score



[Astropart. Phys., 92, 30 (2017)]

Realtime Detector Performance

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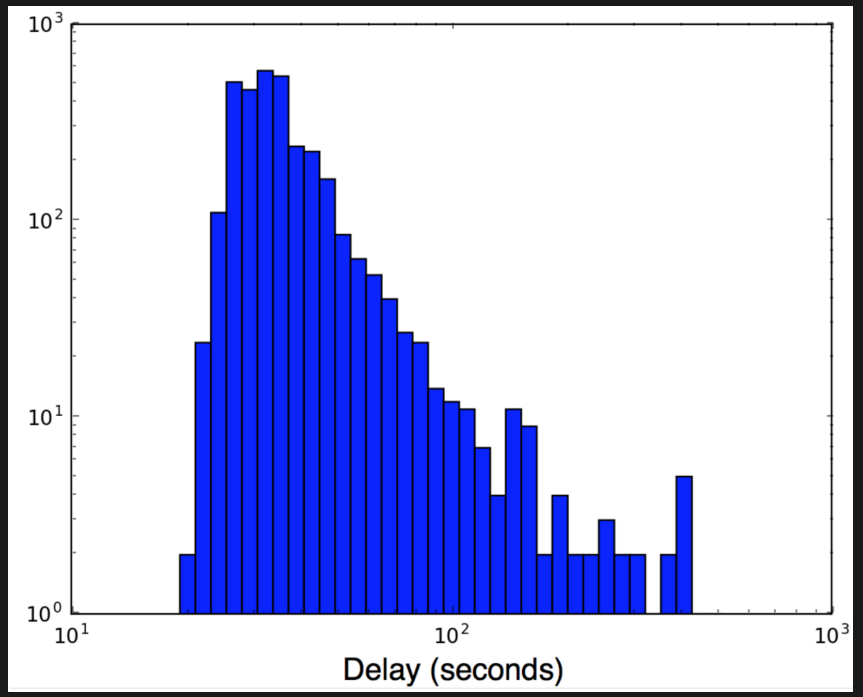
$\sim$ 33 s median delay from detection to received alert



[Astropart. Phys., 92, 30 (2017)]

Throughgoing Tracks

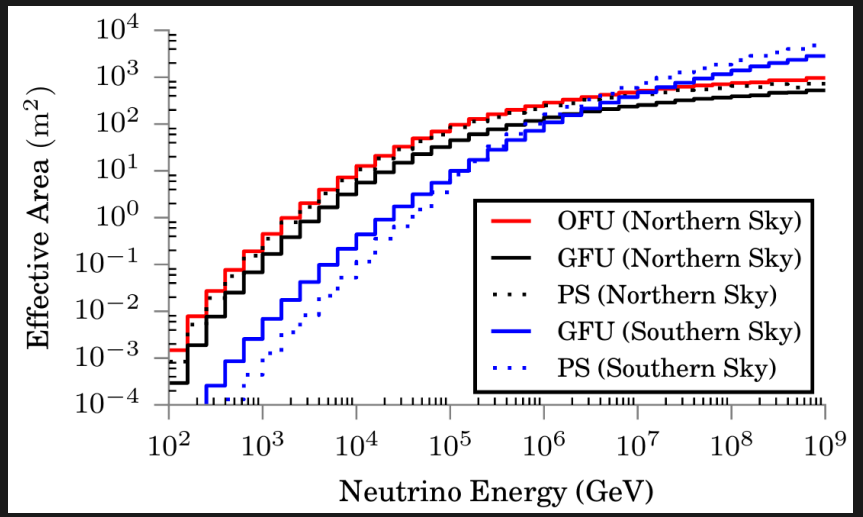
classic muon neutrino strategy

North: well-reconstructed tracks with $\delta > -5^\circ$

South: high E, single muons (try to reject bundles)

Online system requires $< 30\,\mathrm{s}$ processing per event

Performance still comparable to offline analyses



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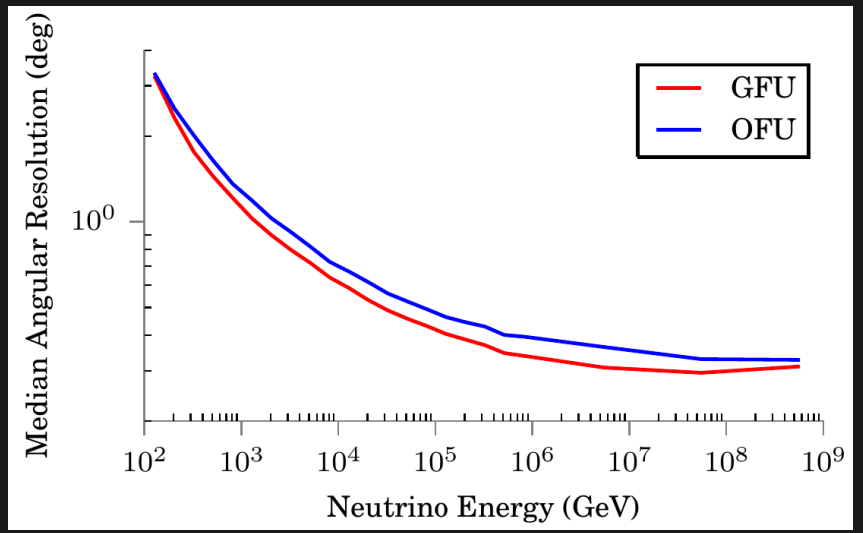


[Astropart. Phys., 92, 30 (2017)]

Gamma-ray Followup

targetting neutrino bursts from known source candidates

Search for point-like, time-clustered emission from predefined subset of *Fermi*-LAT's 3FGL: mostly BL Lacs and FSRQs

Considers range of timescales up to 180 days

Northern sky operational since 2012; southern sky added 2015

Catalog favors variable sources visible to MAGIC, VERITAS, HESS

[JINST 11 (2016) no.11, P11009]

Optical and X-ray Followup

targetting short bursts of neutrinos

Search for northern multiplets within 3.5° and 100 s

Signal candidates include GRBs or supernovae with choked jets

Operational since 2008, with partners PTF, MASTER, ASAS-SN, LCOGT, *Swift*-XRT

Doublets: per-telescope cut depending on angular+temporal separation and telescope FoV

Higher multiplicity: alerts forwarded immediately

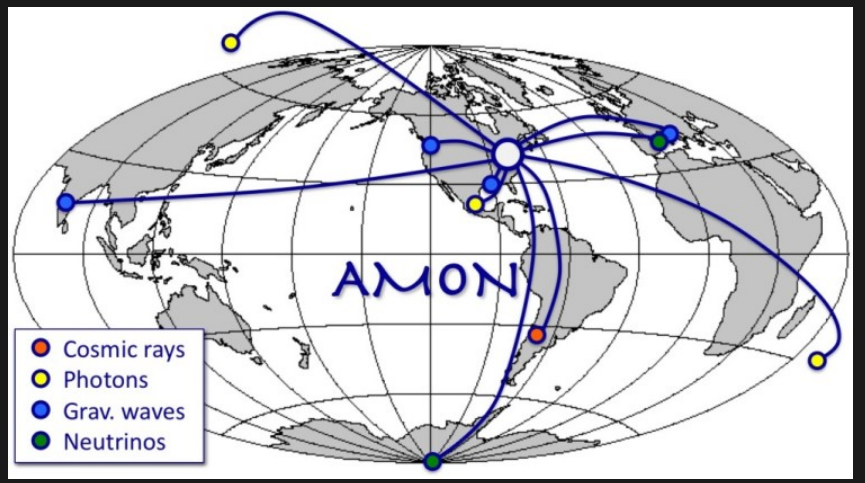
Partners through AMON

Astrophysical Multimessenger Observatory Network

Facilitates sharing as agreed upon by participants

Alerts from AMON coincidence analyses under development

Partners include FACT, VERITAS, MASTER, LMT, ASAS-SN, LCOGT



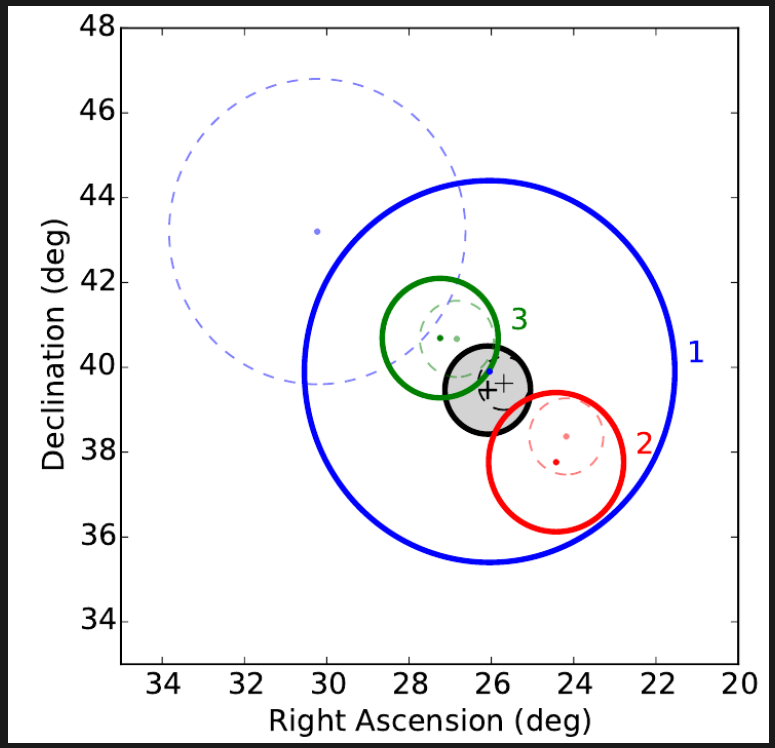
[Astropart.Phys. 45 (2013) 56-70]

A Rare IceCube Multiplet

three neutrinos within 100 s

Two doublets sharing an event on 2016-02-17

($\Delta T < 100\,\mathrm{s}$, $\Delta\Psi = 3.6°$)



[A&A 607, A115 (2017)]

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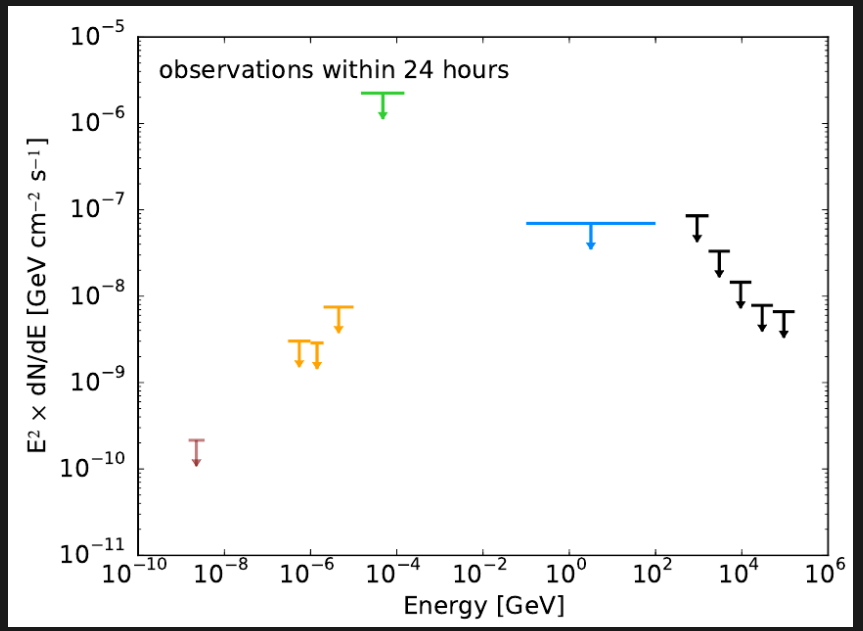
Manual alert at $+22\,\mathrm{hrs} \rightarrow$

- VERITAS, *Swift* XRT+BAT
- ASAS-SN, LCO, MASTER
- Later: *Fermi*-LAT, HAWC



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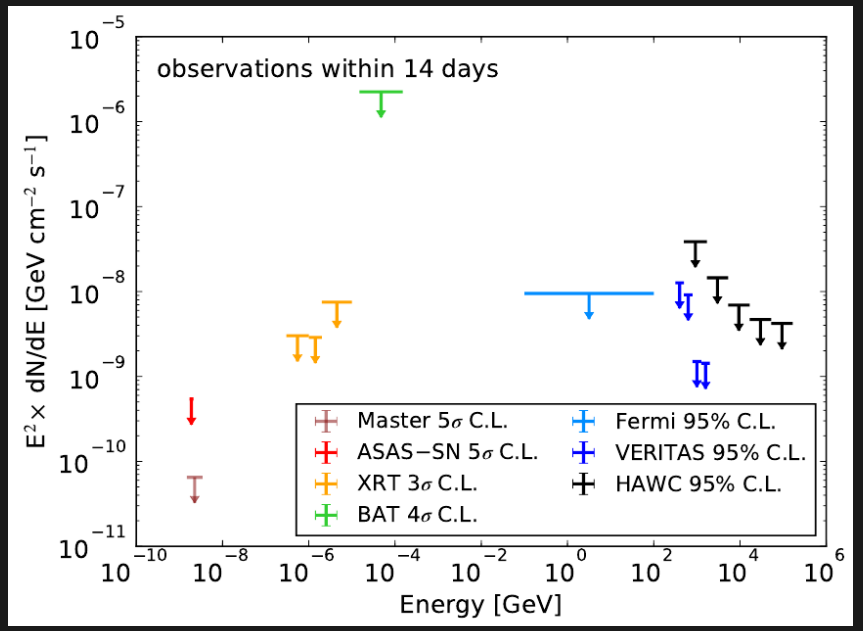

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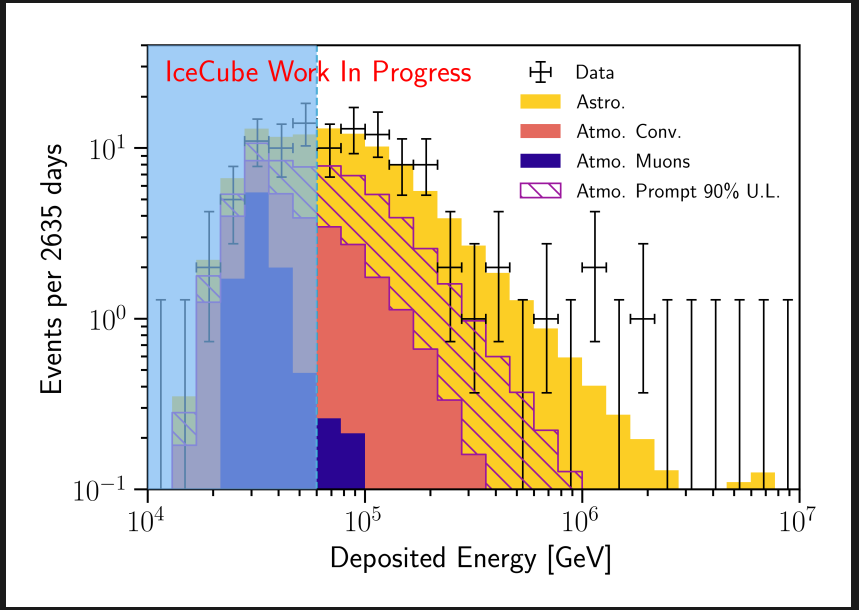
Singlet Alerts

individual astrophysical neutrino candidates

High Energy Starting Events (HESE): first $> 5\sigma$ astrophysical flux observation



[Neutrino 2018]

Public alerts for EHE or high quality HESE tracks issued to GCN via AMON.

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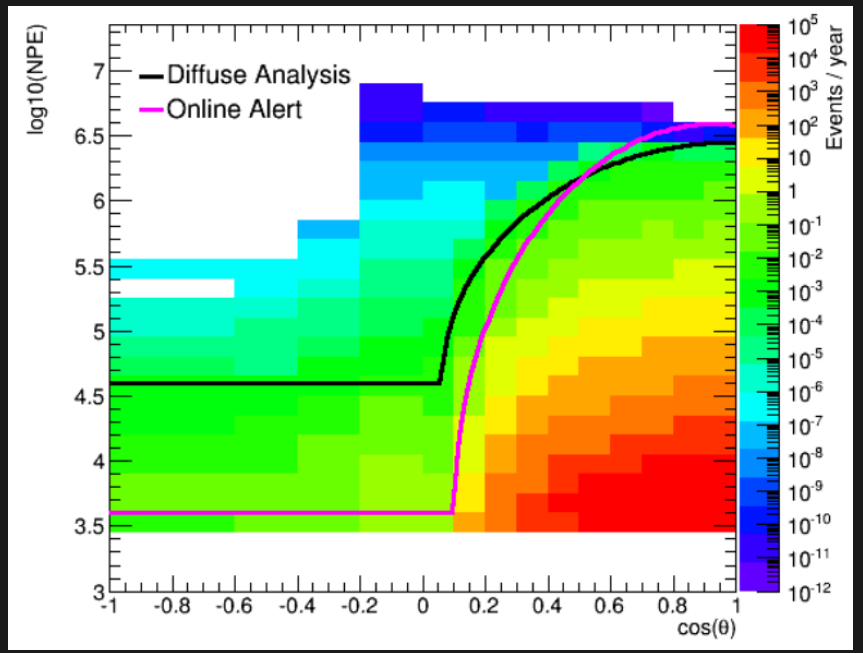

(atmospheric backgrounds)
[Astropart. Phys., 92, 30 (2017)]

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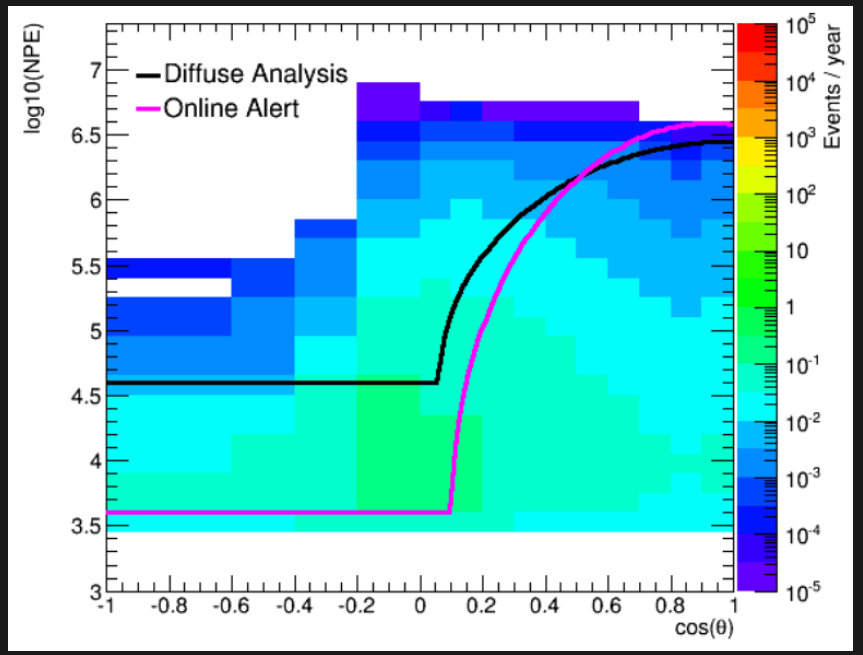


(E^{-2} neutrinos)
[Astropart. Phys., 92, 30 (2017)]

Singlet Alerts — Upgrade

improved performance, simplified alerts, coming very soon

Unified track selection based on signalness $S = N_{\text{sig}}/(N_{\text{sig}} + N_{\text{bg}})$

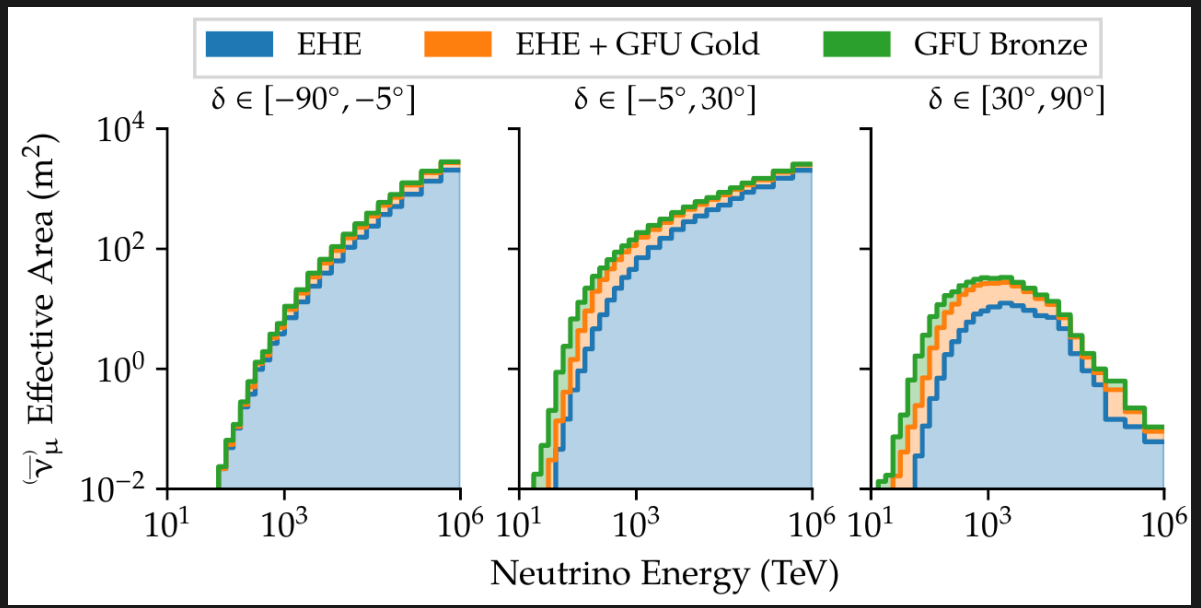
Two categories:

- Gold: EHE|GFU|HESE, $S > 50\%$
- Bronze: GFU|HESE, $S > 30\%$

Improved cuts
reduce HESE 90%
angular errors

counts per year

	Gold events	Bronze Events
Signal ($E^{-2.19}$)	6.6 (Total) 5.1 (GFU) 0.5 (HESE) 2.1 (EHE)	8.4 (Total) 7.6 (GFU) 0.8 (HESE)
Atmospheric Backgrounds	6.1 (Total) 4.7 (GFU) 0.4 (HESE) 1.9 (EHE)	19.8 (Total) 18.5 (GFU) 1.3 (HESE)
Observed historical rate	9.9 (Total) 7.8 (GFU) 1.1 (HESE) 4.3 (EHE)	28.2 (Total) 26.2 (GFU) 2.0 (HESE)



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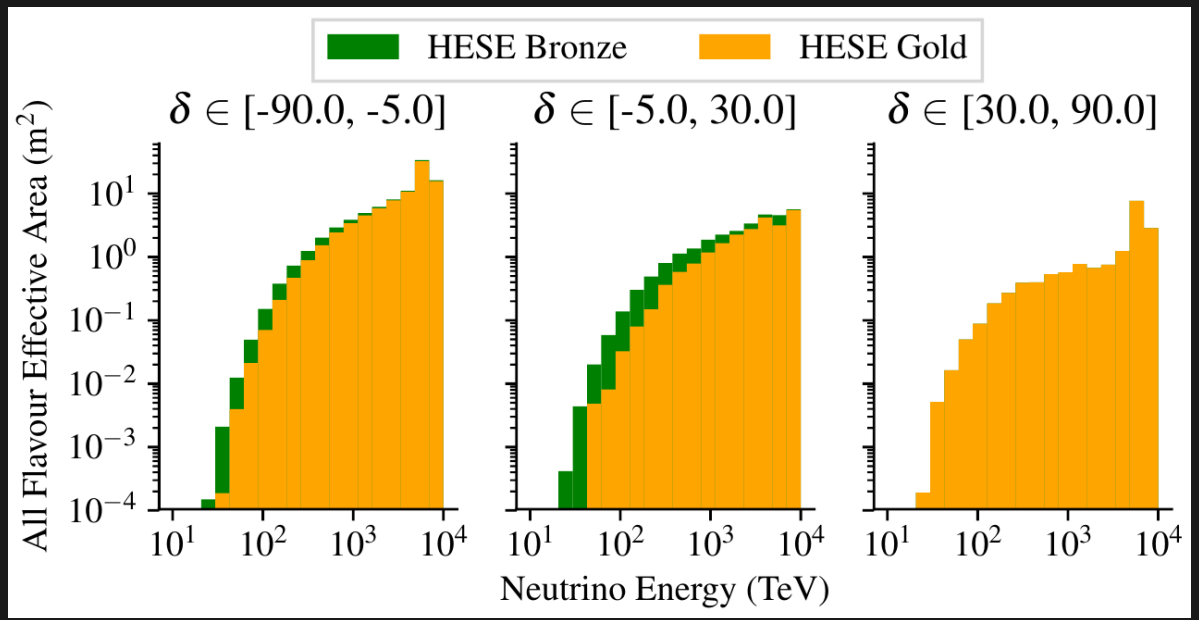
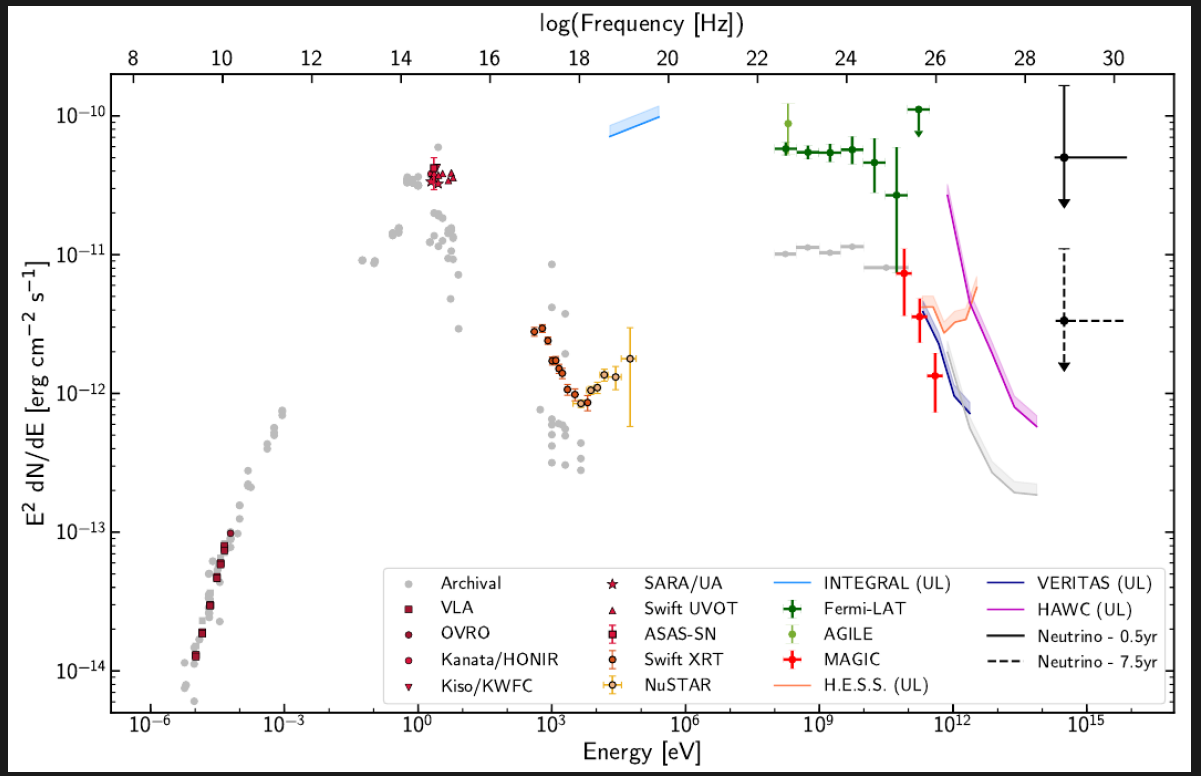


Some Interesting Singlet Alerts

TXS 0506+056 and SN PS16cgx

IC-170922A → TXS 0506+056

Detailed spectral measurements within 14 days



[Science 361, eaat1378 (2018)]

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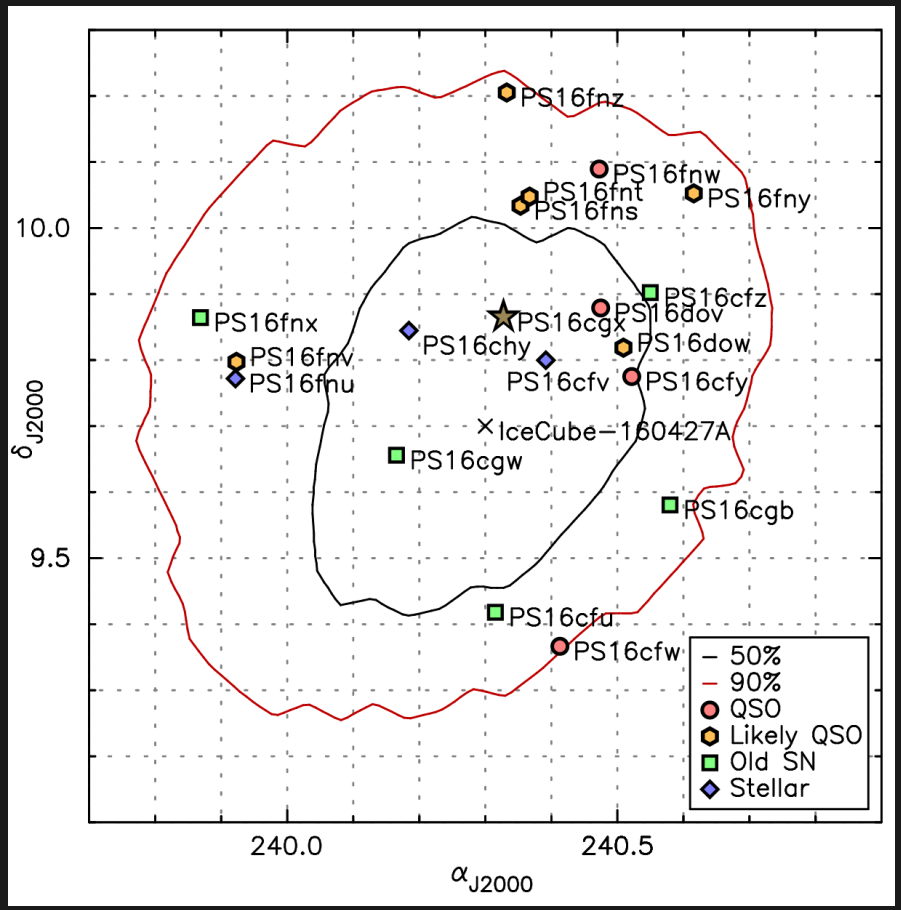
Pan-STARRS1 found SN PS16cgx near IC-160427A (likely Type Ia)

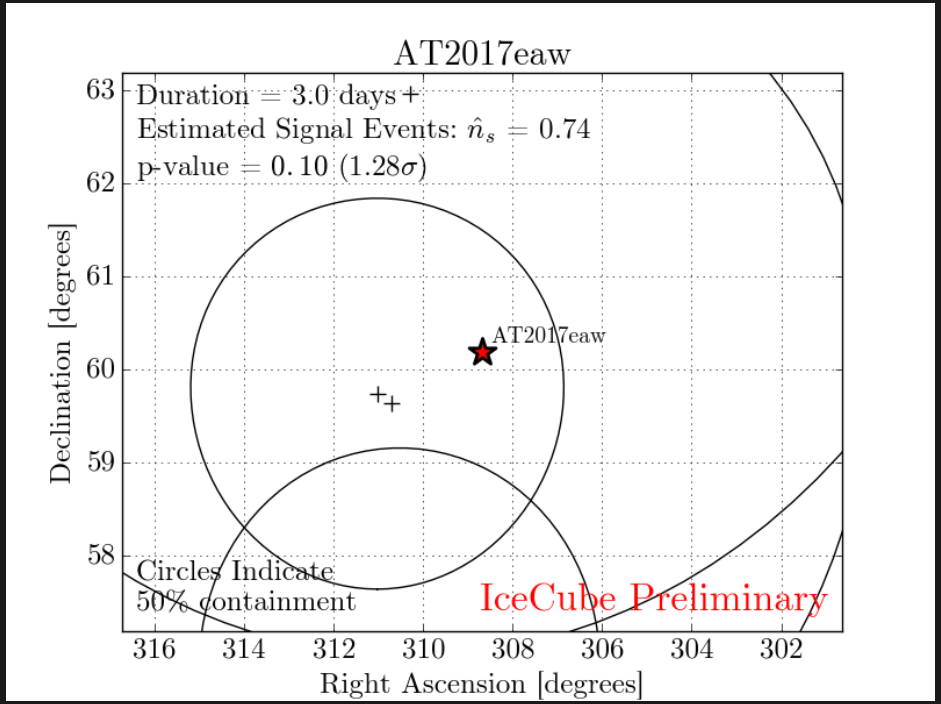


[arXiv:1901.11080 (sub. to A&A)]

Fast Response Analysis

. . . what did IceCube see?

Pre-set transient analysis



[followup of ATel 10372]

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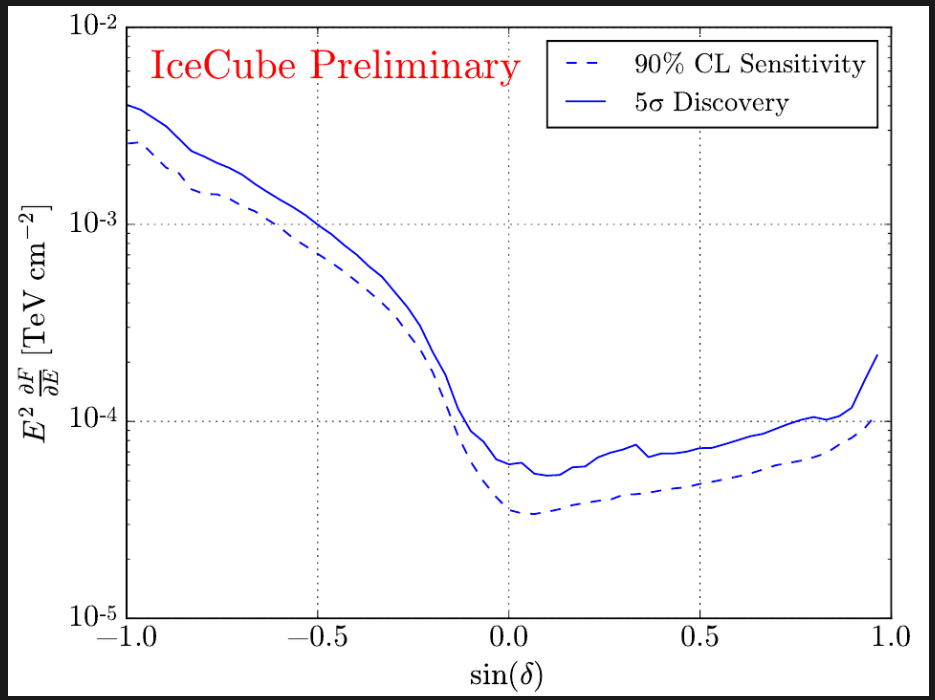
Search for neutrinos given direction, duration, and angular extent of "something interesting"



[PoS(ICRC2017)1007]

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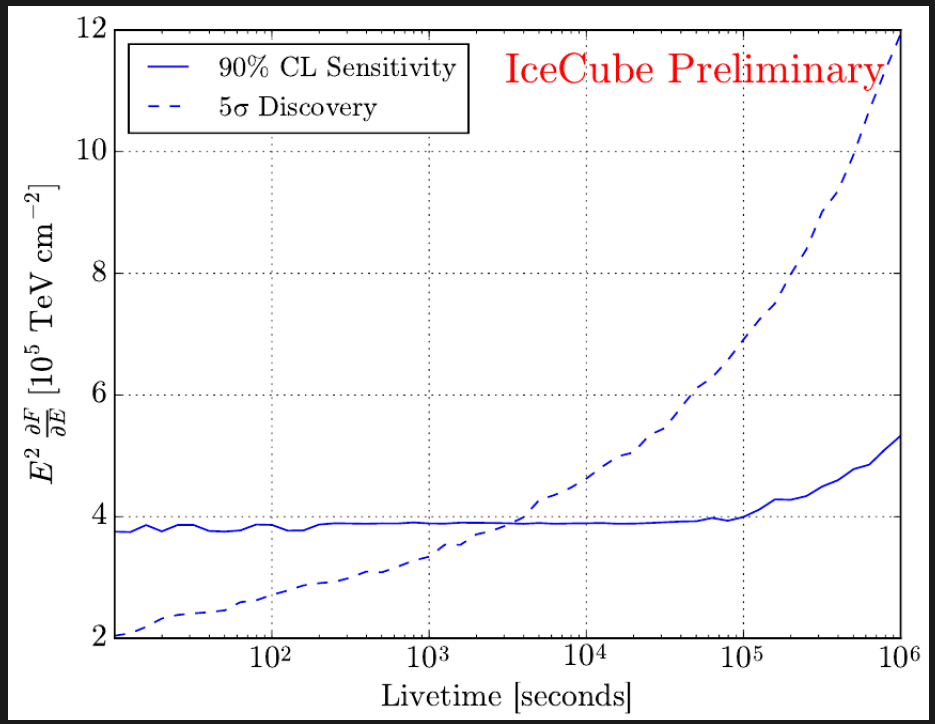

[PoS(ICRC2017)1007]

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Since mid-2018, issuing ATels, GCN circulars more frequently

```
TITLE:   GCN CIRCULAR
NUMBER:  23926
SUBJECT: Search for additional neutrino events from the direction of IceCube-
190221A with IceCube
DATE:    19/02/22 20:57:41 GMT
FROM:    Alex Pizzuto at ICECUBE/U of Wisconsin  <pizzuto@wisc.edu>

The IceCube Collaboration (http://icecube.wisc.edu/) reports:

IceCube has performed a search for additional track-like muon neutrino events
arriving from the direction of IceCube-190221A (https://gcn.gsfc.nasa.gov
/gcn3/23918.gcn3) in a time range of 2 days centered on the alert event time
(2019-02-20 08:25:40.00 UTC to 2019-02-22 08:25:40.00 UTC) during which IceCube
was collecting good quality data. Excluding the event that prompted the alert,
2 additional track-like events are found in spatial coincidence with the 90%
PSF containment of IceCube-190221A. We find that these 2 additional events are
well described by atmospheric background expectations, with a p-value of 0.08.
Accordingly, these data would represent a time-integrated muon-neutrino flux
upper limit assuming an E^-2 spectrum (E^2 dN/dE) at the 90% CL of 2.71 x 10^-4
TeV cm^-2 for this observation period.

A subsequent search was performed to include the previous month of data
(2019-01-21 08:25:40.00 UTC to 2019-02-22 08:25:40.00 UTC). In this case, we
report a p-value of 1.0, consistent with no significant excess of track events,
and a corresponding time-integrated muon-neutrino flux upper limit assuming an
E^-2 spectrum (E^2 dN/dE) at the 90% CL of 3.5 x 10^-4 TeV cm^-2.

The IceCube Neutrino Observatory is a cubic-kilometer neutrino detector
operating at the geographic South Pole, Antarctica. The IceCube realtime alert
point of contact can be reached at
roc@icecube.wisc.edu<mailto:roc@icecube.wisc.edu>
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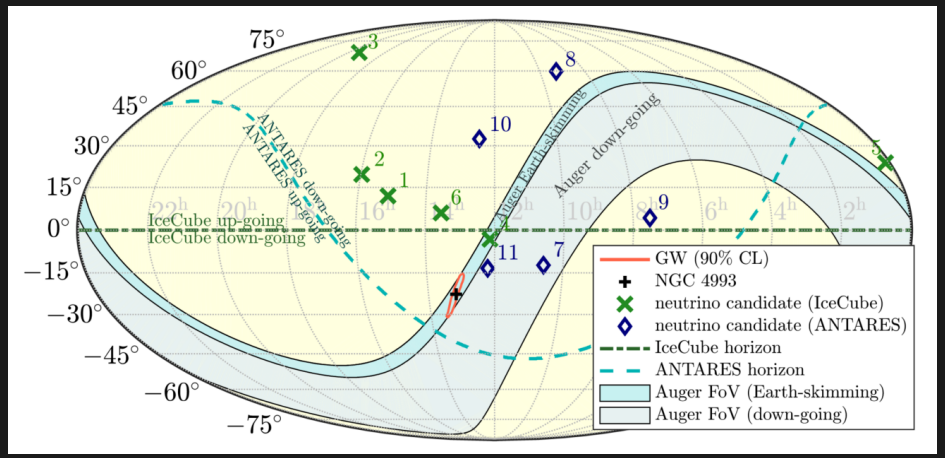
[GCN Circular 23926]

Gravitational Waves

working up to LIGO+Virgo O3 run

So far, simple all-sky $\pm 500\,\mathrm{s}$ search upon GW observations



[ApJL 850 (2017) no.2, L35]

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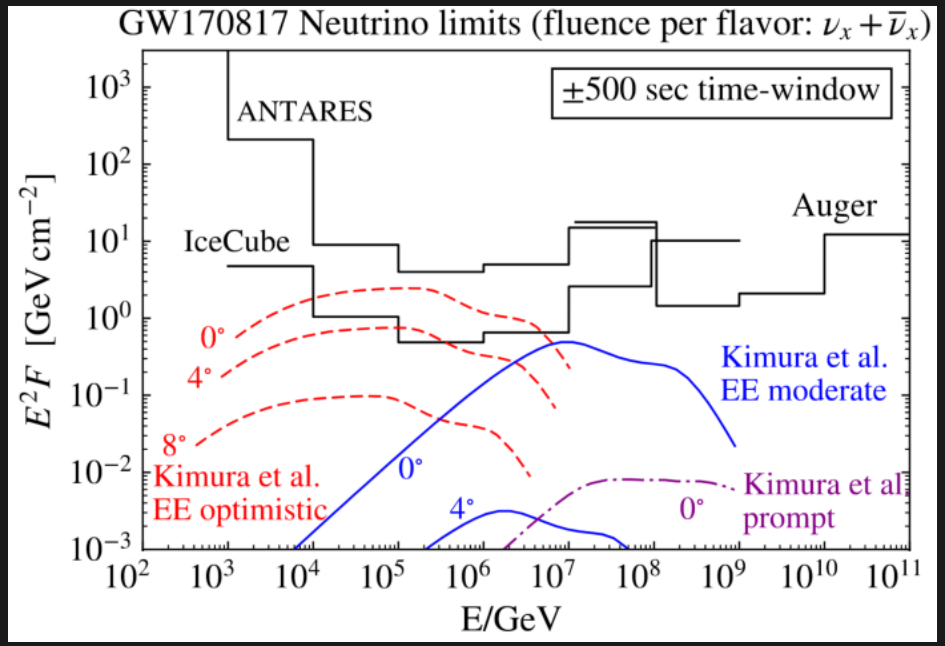
New, more sensitive "GW as spatial prior" analysis ready for O3 rapid followup



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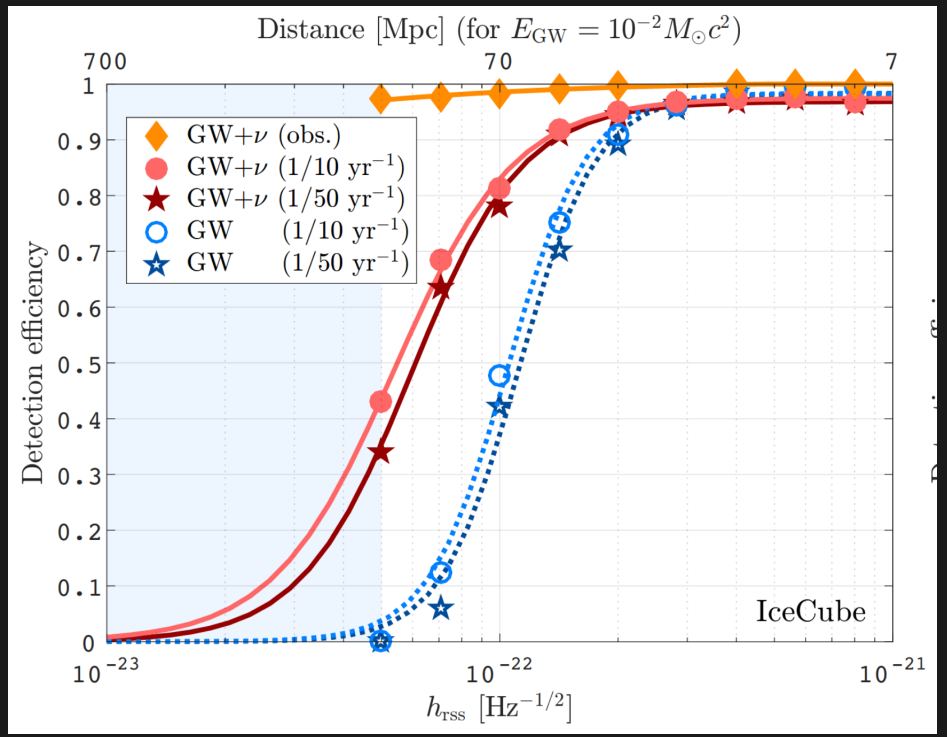
Related method for lowering GW threshold also under development



[ApJ 870 (2019) no.2, 134]

Summary

"Multimessenger studies are essential for identification of [neutrino] sources" — A. Kheirandish, last session

IceCube is working closely with EM and GW partners to maximize opportunities for detailed time-dependent studies

Ongoing work seeks to improve alert and followup systems in response to community needs — talk to us!