DRAFT

Multi-messenger Realtime Operations

Erik Blaufuss, University of Maryland

IceCube M&O Review. Jan 8-9, 2019

IceCube

Realtime Oversight Committee

Deliverables

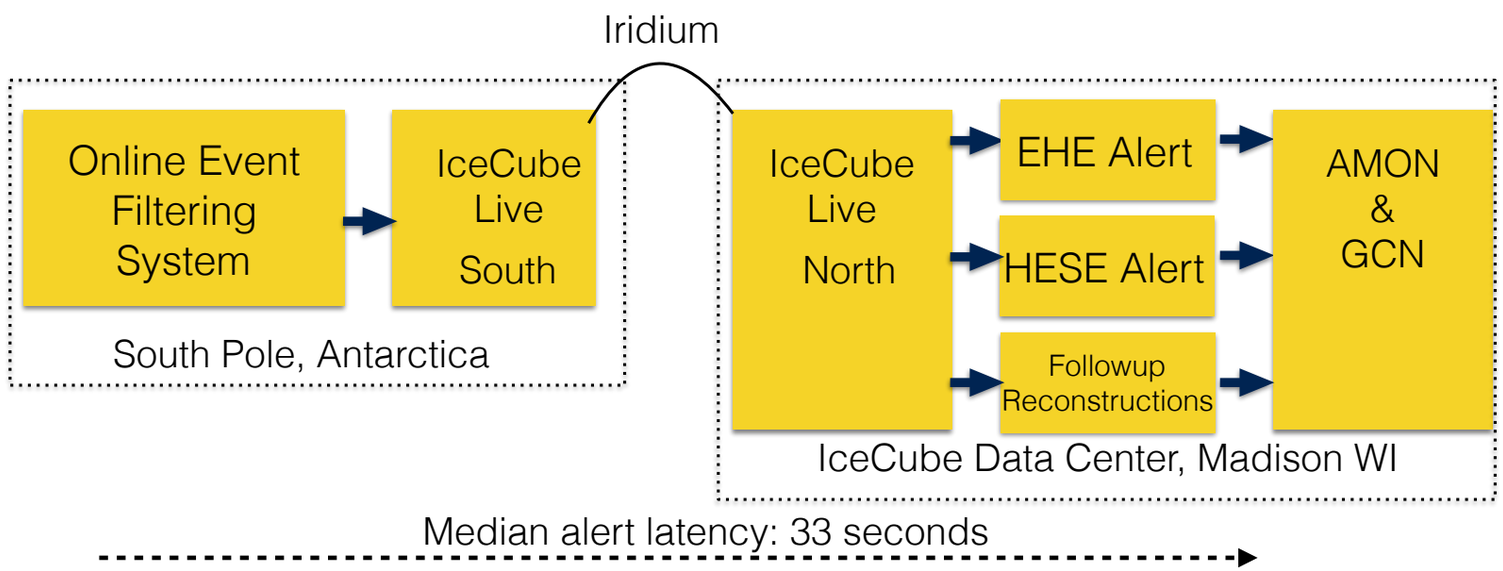
- IceCube is an active participant in multi-messenger observations of the high-energy universe
    - Dedicated partnerships and community-wide participation with photon and gravitational-wave observatories.
- IceCube realtime operations focus on
    - Notifying observational community when we detect neutrino events likely to be of astrophysical origin
    - Perform realtime neutrino point-source searches when community identifies transient objects that are potential neutrino sources.
- Realtime effort made possible by support and targeted additions from IceCube maintenance and operations effort.

Realtime Effort in IceCube

- Realtime activities directed by Realtime Oversight Committee (ROC)
    - Internal IceCube collaboration committee charged with providing oversight of realtime alerts and responses
    - Quickly determine appropriate public response
- Active support from several PhD students in daily activities (realtime shifters)
    - Monitor transient announcements, run fast analyses, developed new toolsets, etc

Realtime
Oversight
Committee

IceCube Neutrino Alerts in Operation

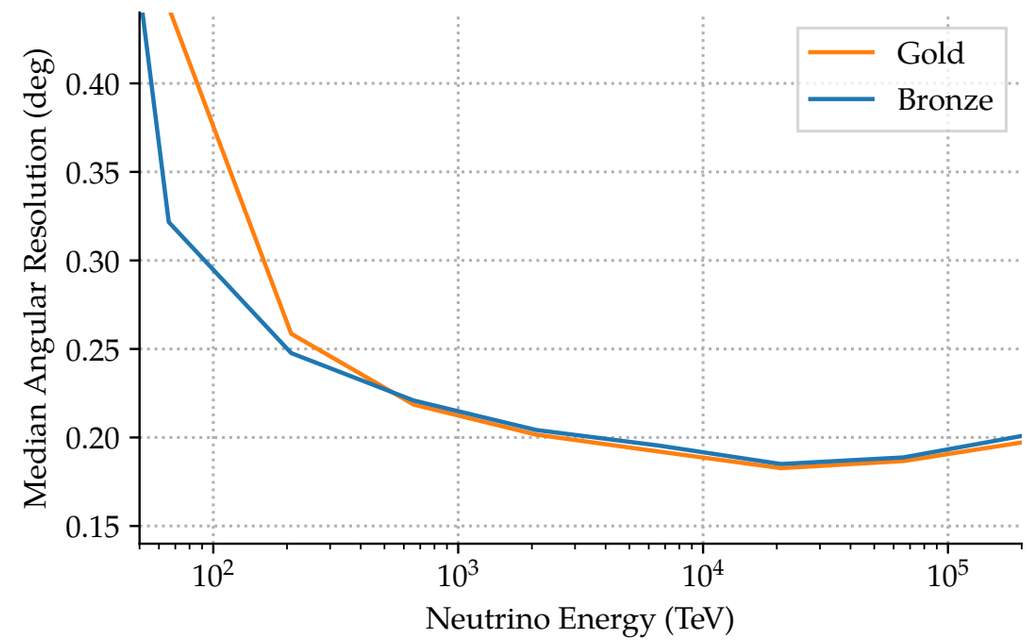


- Select events passing alert criteria in online filter at South Pole
- Transmit event summary north via I3MS Iridium system
  - Include compact DOM hit information for followup reconstructions
- Gamma-Coordinate Network (GCN) notices for track-like events that are likely astrophysical in origin
- Start rapid followup reconstructions, check detector and data quality
  - Issue GCN circular with updated direction from offline reconstructions
- Search online point-source sample for matching signals in our own data

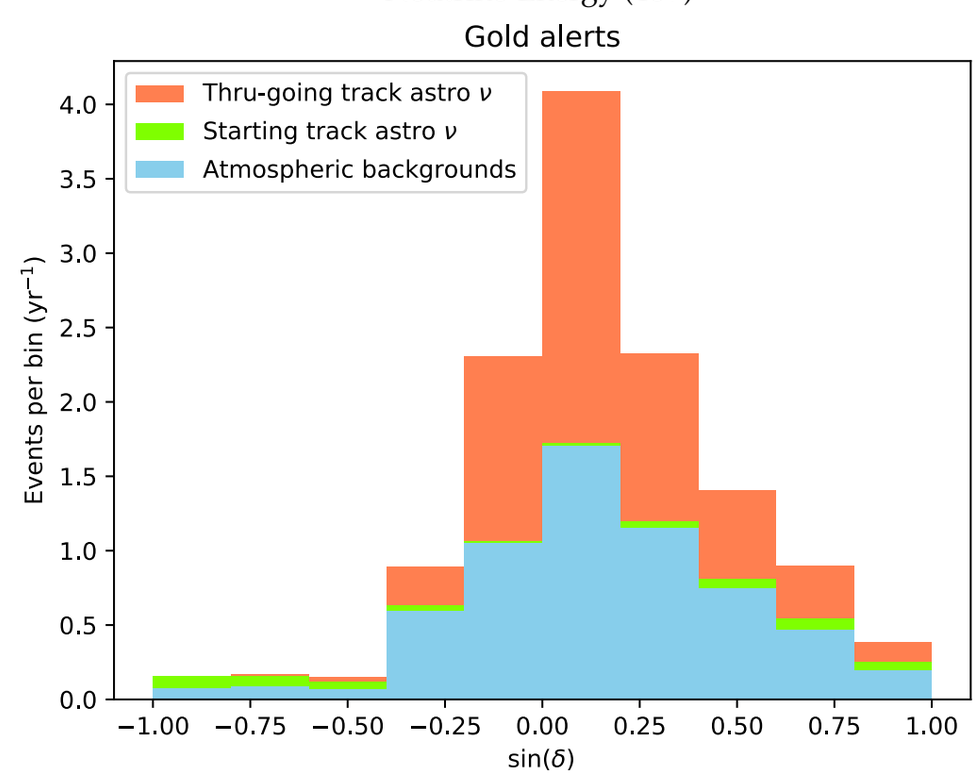
In operation since April 2016 - criteria updated Jan 2019

IceCube Neutrino Track Alert Selections

- Alerts focus on finding tracks
  - Best potential source localization
- Two categories of track alerts
  - Gold - 50% signal-rich
  - Bronze - 30% signal-rich



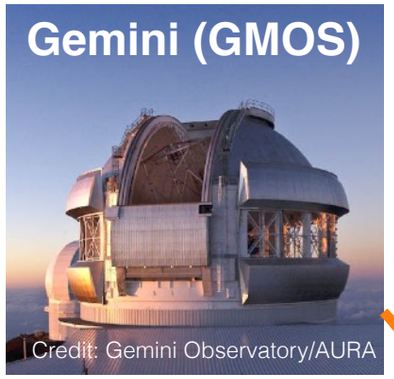
	Gold events	Bronze Events
Signal ($E^{-2.19}$)	6.6 (Total) 5.1 (GFU) 0.5 (HESE) 2.1 (EHE)	8.4 (Total) 7.6 (GFU) 0.8 (HESE)
Atmospheric Backgrounds	6.1 (Total) 4.7 (GFU) 0.4 (HESE) 1.9 (EHE)	19.8 (Total) 18.5 (GFU) 1.3 (HESE)
Observed historical rate	9.9 (Total) 7.8 (GFU) 1.1 (HESE) 4.3 (EHE)	28.2 (Total)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

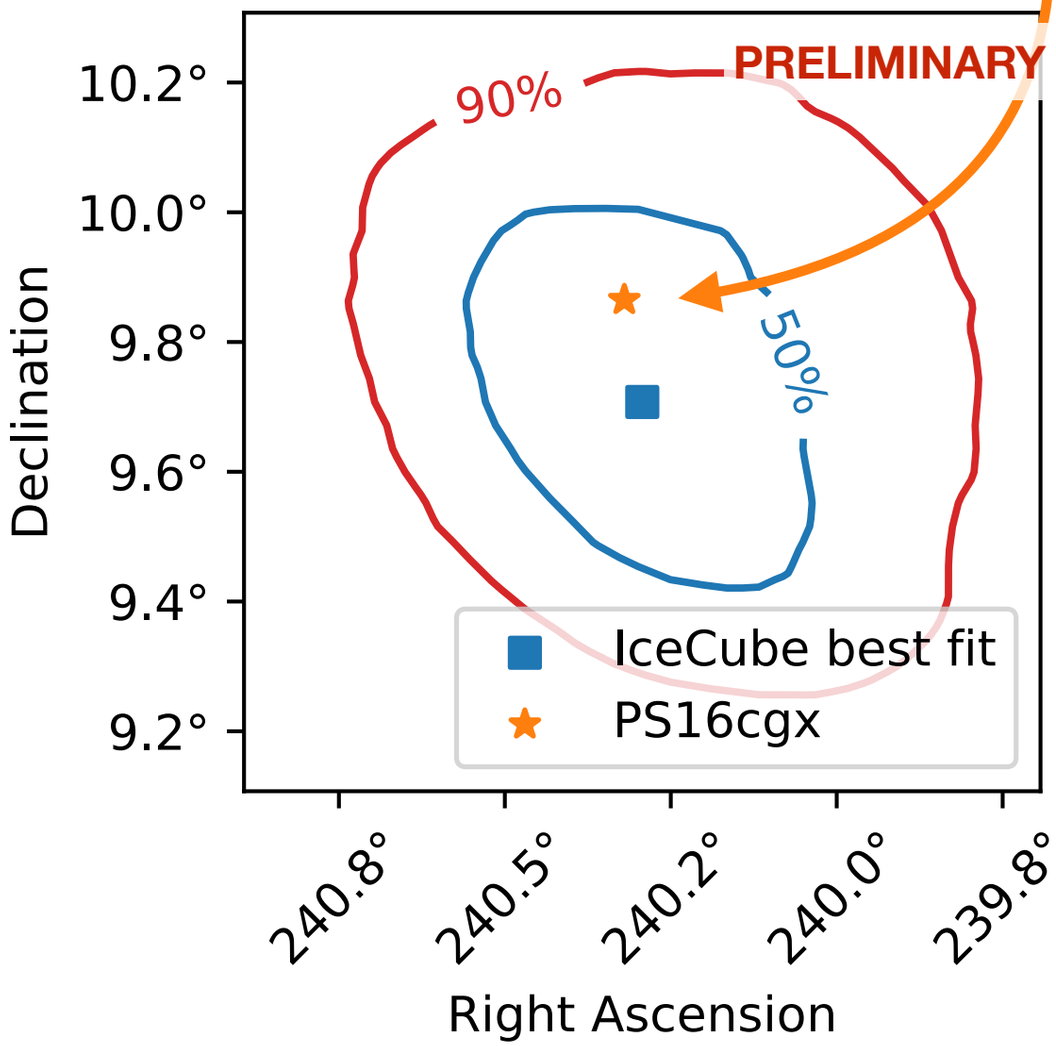


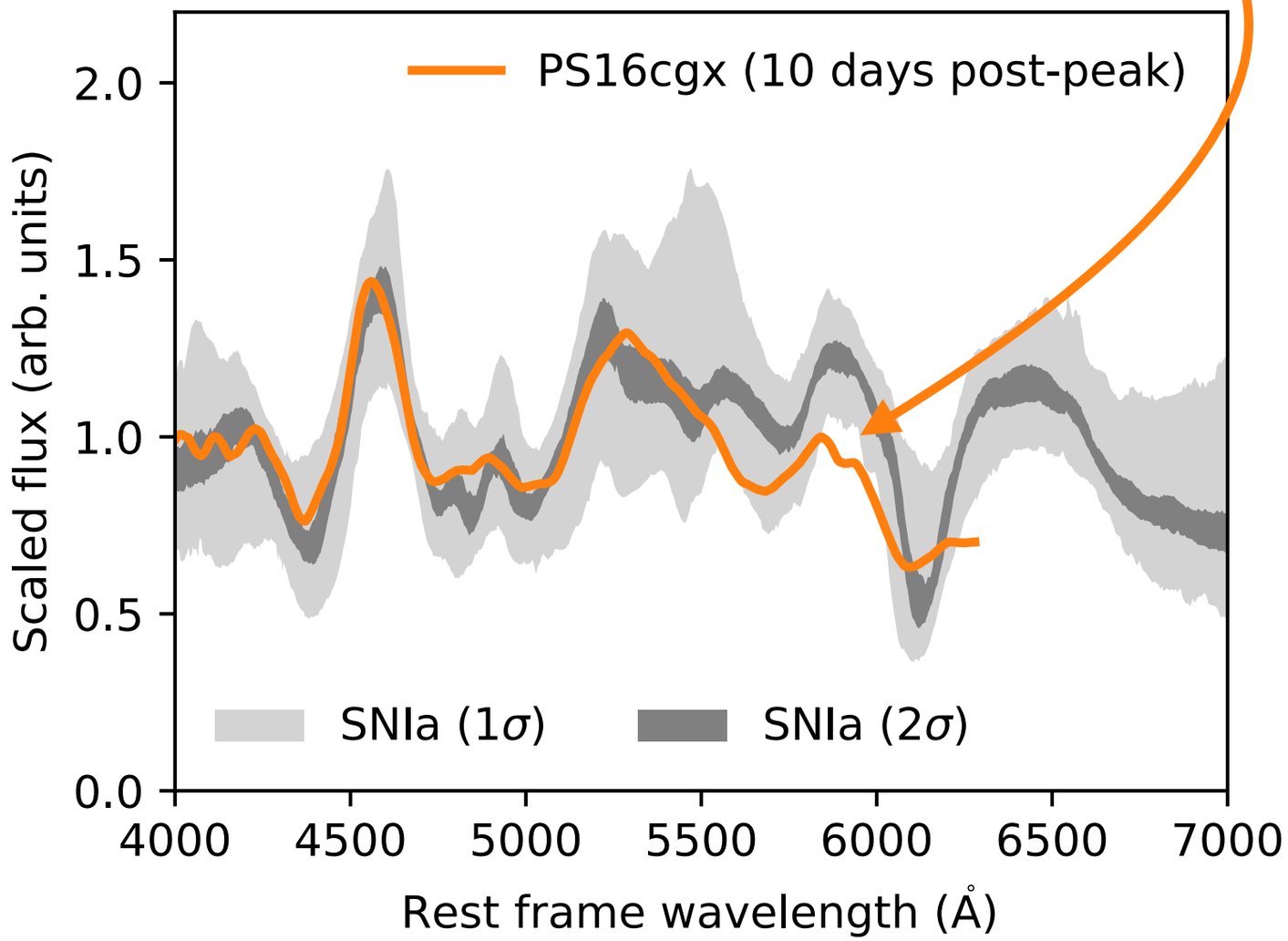
PS16cgx: a young supernova in the field of a HESE neutrino

PAN-Starrs followed up IceCube HESE alert on 2016-04-27 and found a recent supernova at z=0.3:

- Optical spectroscopy 10, 20 days post-peak
- Features atypical for SNIa, but not sufficient to exclude







Chance probability { if **Ic** (associated with GRBs): **<1%**
if **Ia** (no HE neutrinos expected): **<10%**

Neutrino track alert IC-170922A: TXS 0506+056

TITLE: GCN CIRCULAR
NUMBER: 21916
SUBJECT: IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE: 17/09/23 01:09:
FROM: Erik Blaufuss at

Claudio Kopper (Universit
Maryland) report on beha
icecube.wisc.edu/).

On 22 Sep, 2017 IceCube
high probability of being
the Extremely High Ener
was in a normal operating
interaction vertex that is
the detector volume, and

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration*
on 28 Sep 2017; 10:10 UT
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Referred to by ATel #: 10792, 10794, 10799, 10801, 10817, 10830, 10831, 10833, 10838, 10840, 10844, 10845, 10861, 10890, 10942, 11419, 11430, 11489

Tweet Recommend 3

We searched for Fermi
neutrino event error r
10787) with all-sky surv
ray Space Telescope. W
and also included in the
located inside the IceCu
at energies abo
(https://fermi.gsfc.nasa.
Indeed, the LAT 0.1--3
cm-2 s-1 (errors are sta
nearly the same power-l
of this source. We also
unknown. According to
175, 97). Radio observ
http://www.astro.caltech
http://www.physics.purd

Because Fermi operates
region will continue.
(ytanaka@astro.hiroshi
the energy band from
collaboration between
Italy, Japan and Sweden

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

ATel #10817; *Razmik Mirzoyan for the MAGIC Collaboration*
on 4 Oct 2017; 17:17 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Optical, Gamma Ray, >GeV, TeV, VHE, UHE, Neutrinos, AGN, Blazar

Referred to by ATel #: 10830, 10833, 10838, 10840, 10844, 10845, 10942

Tweet Recommend 448

After the IceCube neutrino event EHE 170922A detected on 22/09/2017 (GCN circular #21916), Fermi-LAT measured enhanced gamma-ray emission from the blazar TXS 0506+056 (05 09 25.96370, +05 41 35.3279 (J2000), [Lani et al., Astron. J., 139, 1695-1712 (2010)]), located 6 arcmin from the EHE 170922A estimated direction (ATel #10791). MAGIC observed this source under good weather conditions and a 5 sigma detection above 100 GeV was achieved after 12 h of observations from September 28th till October 3rd. This is the first time that VHE gamma rays are measured from a direction consistent with a detected neutrino event. Several follow up observations from other observatories have been reported in ATels: #10773, #10787, #10791, #10792, #10794, #10799, #10801, GCN: #21941, #21930, #21924, #21923, #21917, #21916. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) E. Bernardini (elisa.bernardini@desy.de), K.Satalecka (konstancja.satalecka@desy.de). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

On September 22, 2017, IceCube issued a neutrino alert:

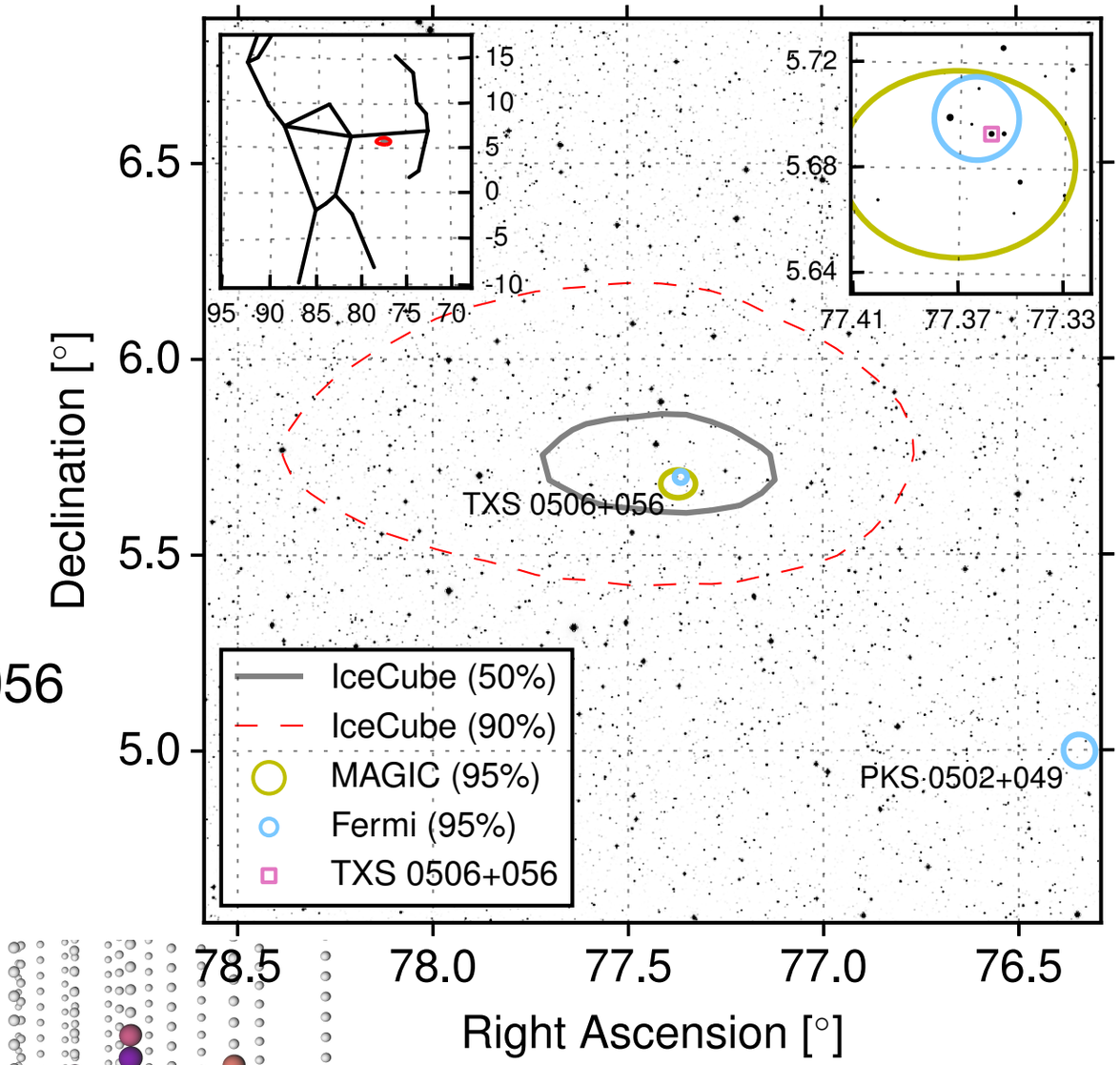
- A muon neutrino track event created by a ~290 TeV neutrino (IceCube-170922A)
- Found to be spatially coincident with a known blazar (TXS 0506+056) that was in a flaring state
- Blazar was also detected by the MAGIC air-Cherenkov telescope in the days after the alert, with γ-rays up to 400 GeV.
- This launched a very active multi-messenger follow-up campaign that included observations from radio to γ-rays.

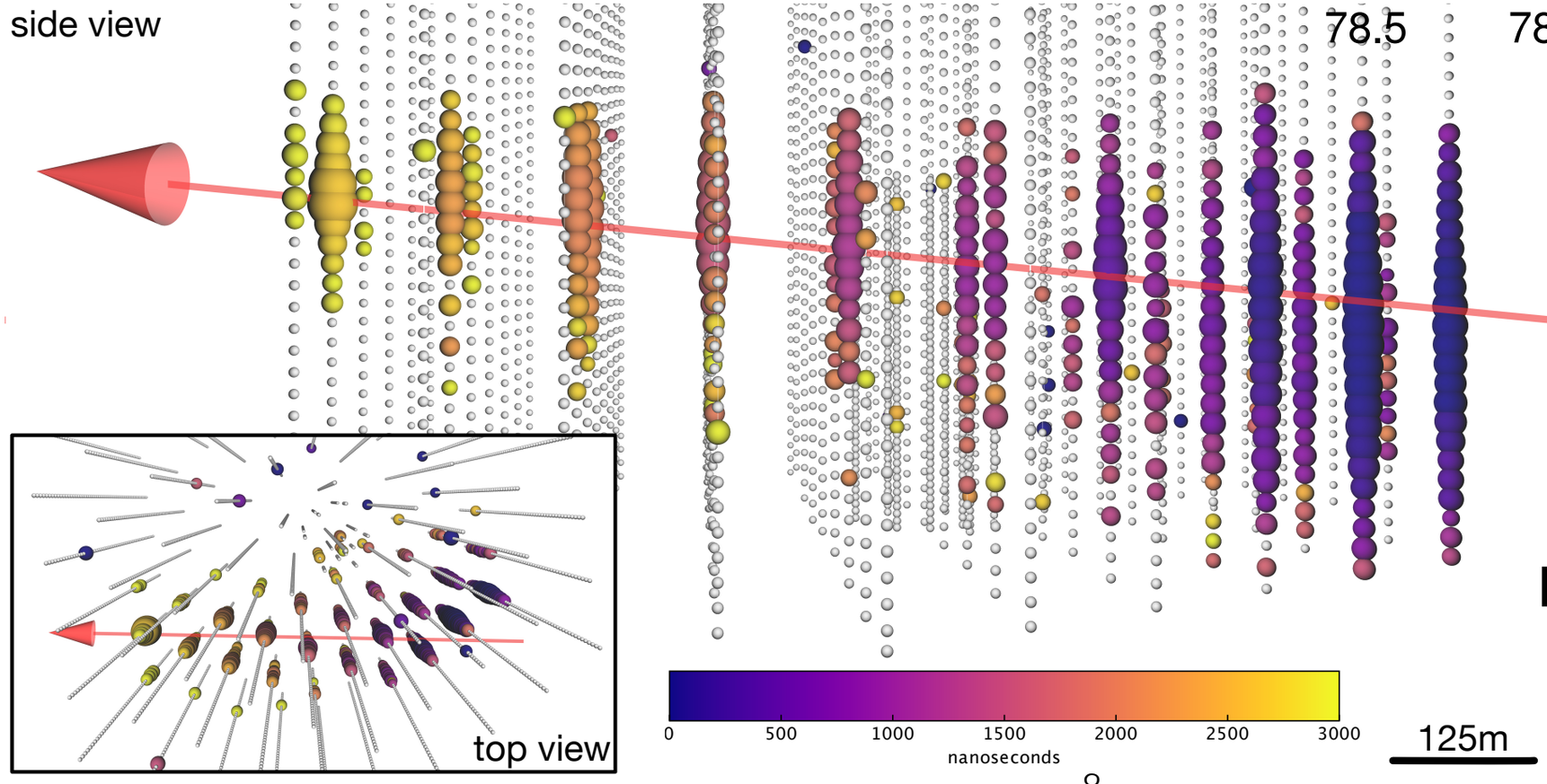
Recently published in Science:
IceCube Coll. et al., Science 361 (2018)

Multi-messenger alerts: TXS 0506+056

Neutrino direction was well reconstructed

- Uncertainty of less than 1 sq. deg at 90% CL
- Positionally consistent with blazar TXS 0506+056
- ~290 TeV estimated neutrino energy



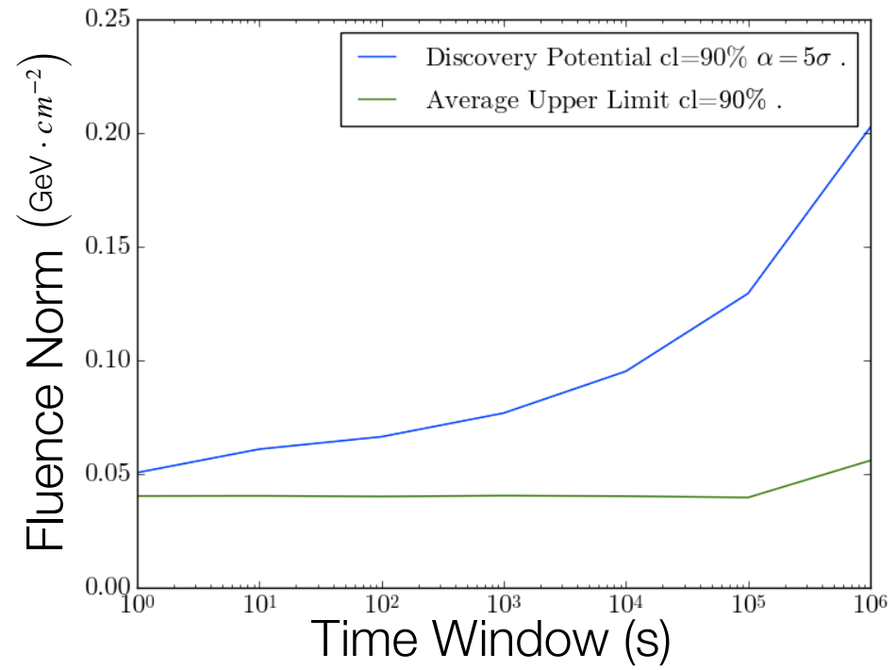


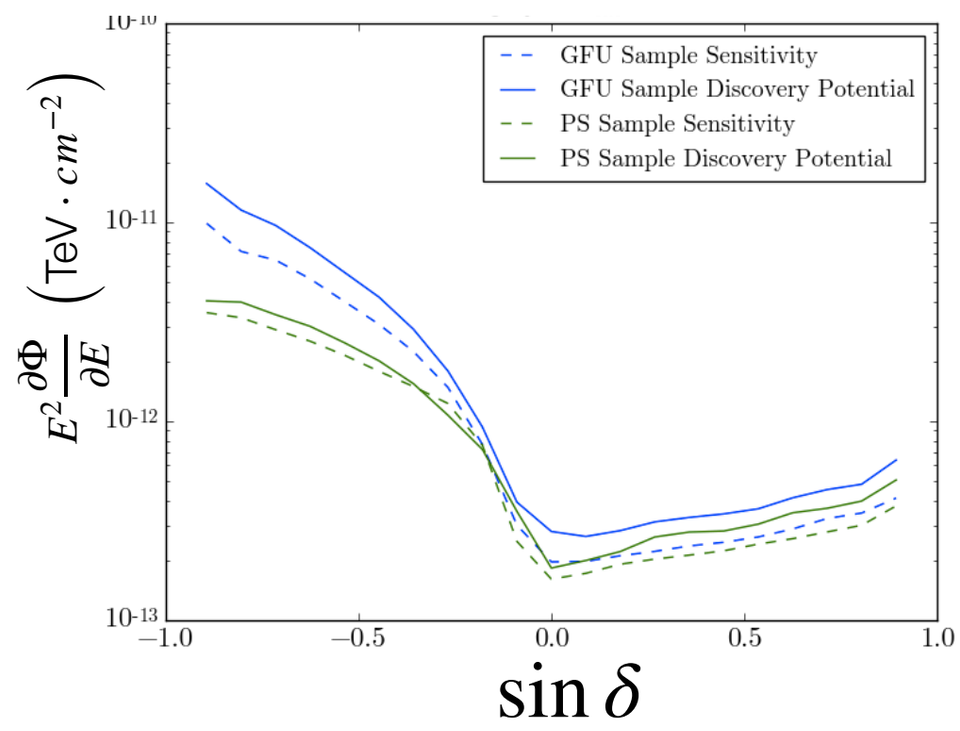
More than 2000 known Blazars from Fermi catalogs

Just be chance? Unlikely probability of chance overlap is < 0.2%

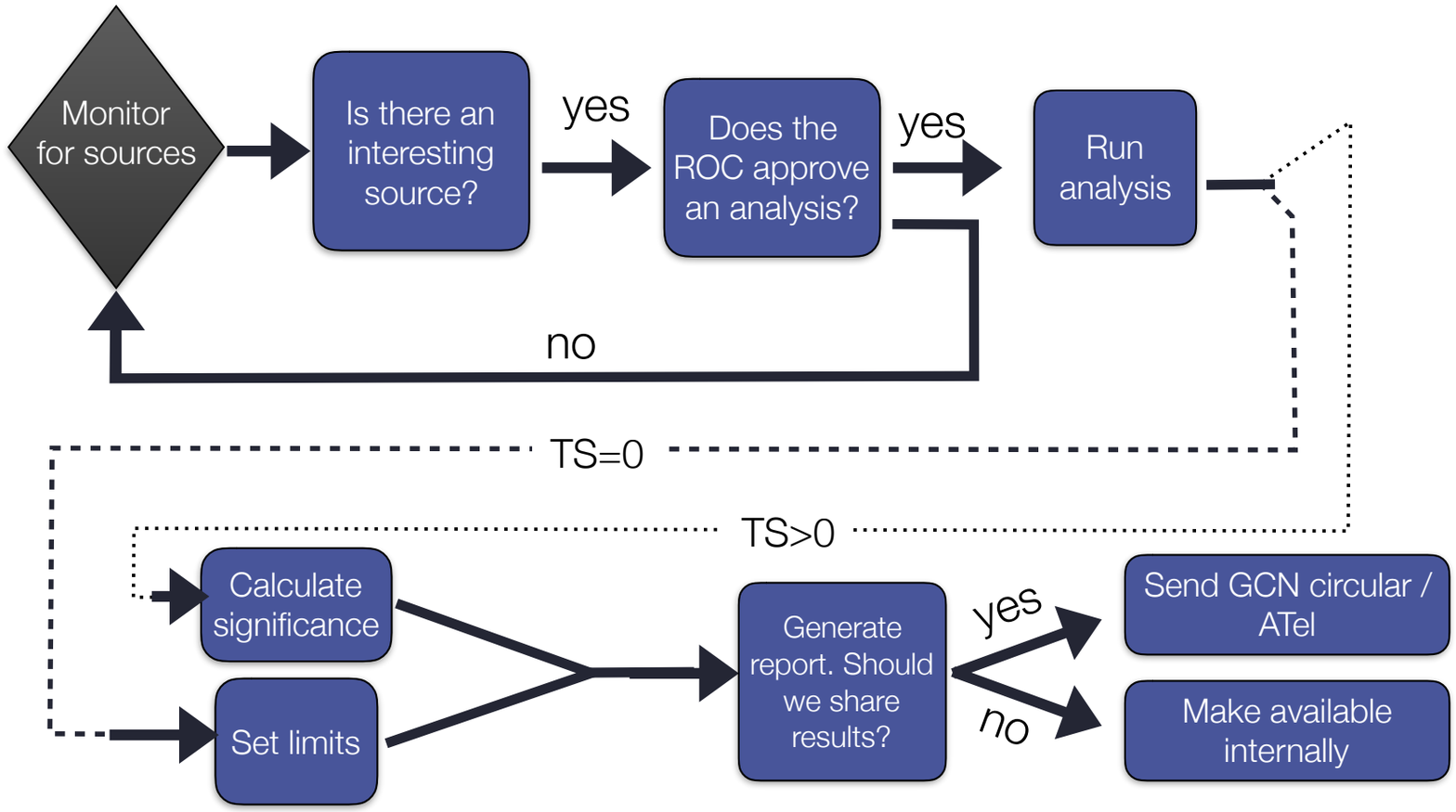
Realtime Point Source Searches

- Online point-source sample
  - Search for statistically significant excess of neutrino track events
  - Events identified in realtime, transmitted North via I3MS Iridium
- Median angular error < 1°
- Optimized for transient sources
  - Most sensitive in Northern Sky
  - Broad sensitivity over several timescales





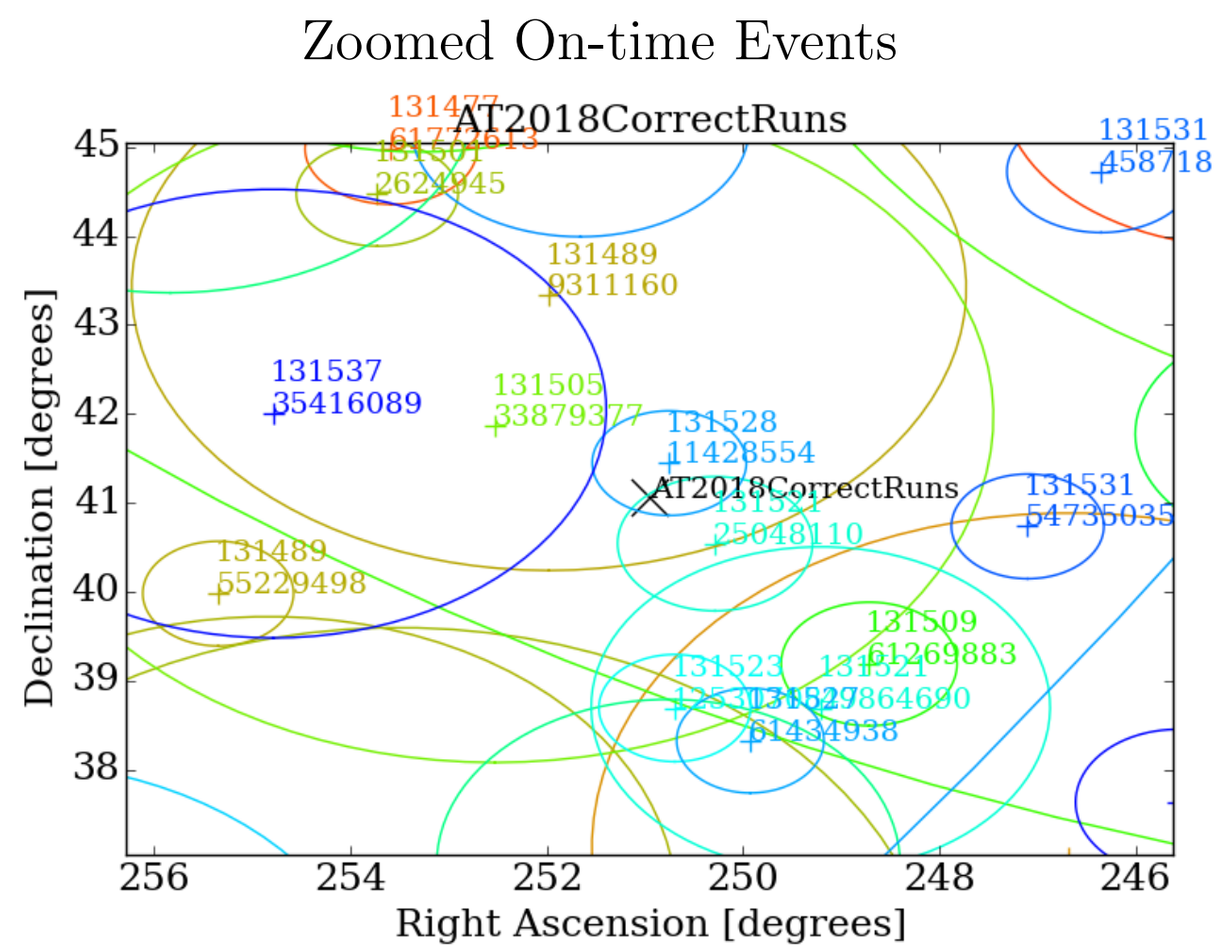
Realtime Point Source Analysis



- ROC oversees approval of realtime point source searches
  - Focus on transient objects identified in other messengers that are potential neutrino sources
  - Public response for results for p-values < 0.1 or cases where null results and upper limits are astrophysically interesting.
    - Planning a public website where ALL searches performed will be cataloged.

Recent realtime point source searches

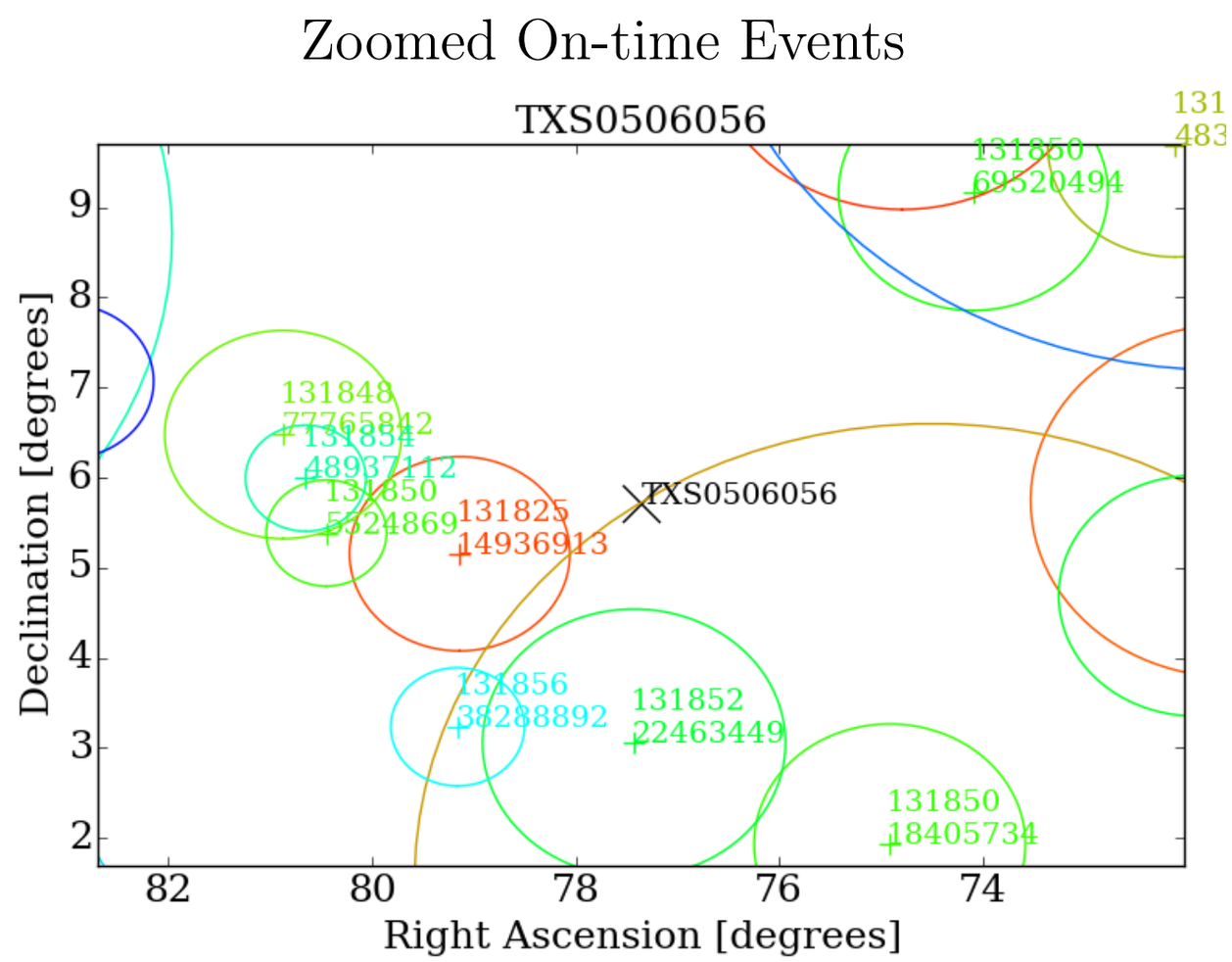
- ZTF18abukavn (AT2018gep)
  - Super-luminous SN candidate
  - Potential Type Ic
  - very close, z~0.03
- Performed a search for tracks over the ~2 week period since detection
  - p=0.04 (1.8 sigma)
- Fast response report generated (Sept 24, 2018)
- Issued ATel (Sept 25, 2018)



Realtime point source searches available since April 2017
To date: 47 analysis performed (10 publicly reported)

Recent realtime point source searches

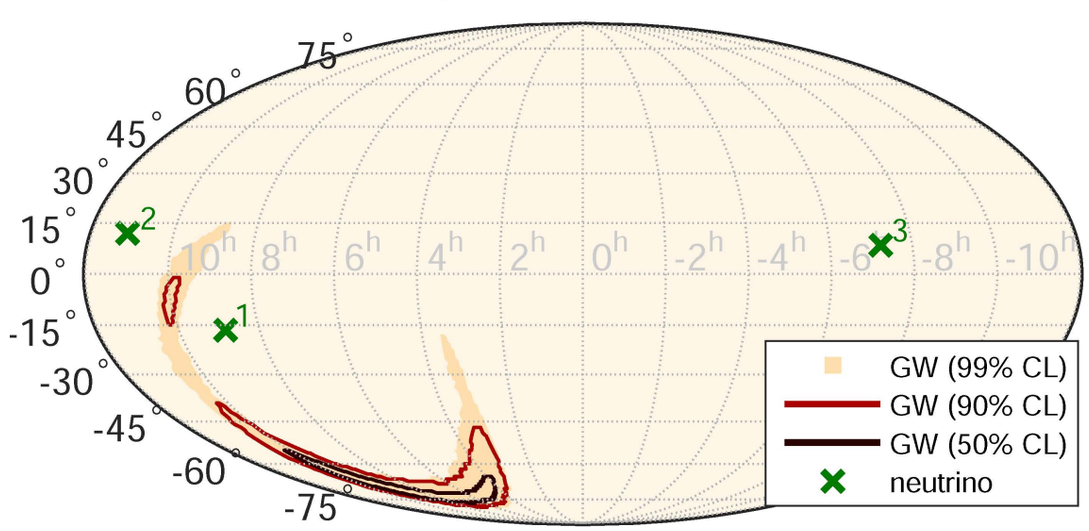
- TXS 0506+056
  - Detected as flaring in VHE gamma-rays by MAGIC
  - Performed search for tracks 1 week around MAGIC flare detection
  - No evidence for neutrino emission found
  - ATel with flux upper limits published (ATEL 12267)

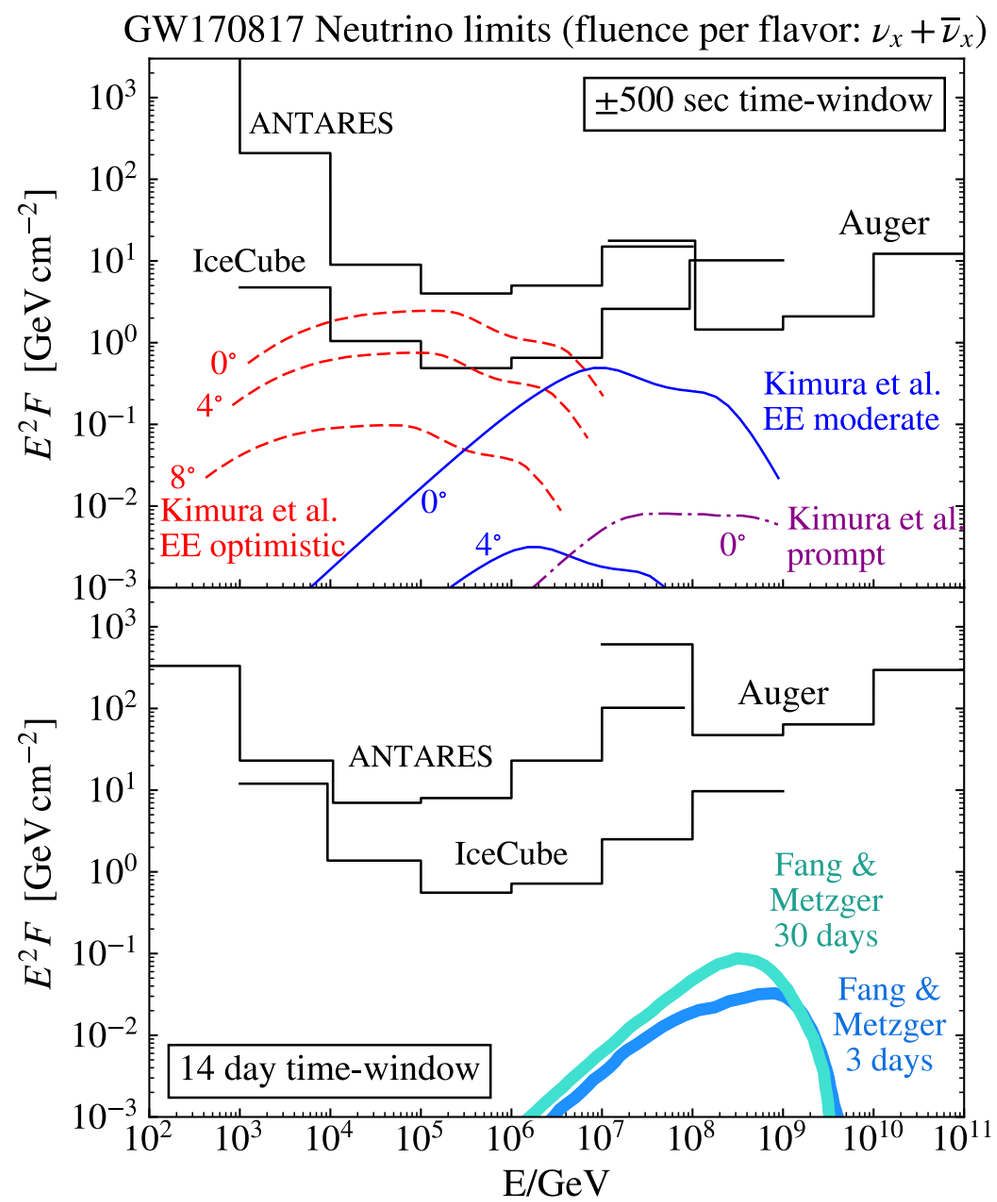


Neutrinos from gravitational wave events with IceCube

- High-energy neutrinos can provide important information:
  - Coincident detection could reduce localization uncertainty and aid followup observations
  - Provide understanding of particle acceleration and high-energy emission from compact objects
- Finalizing preparations for rapid responses in O3!

GW150904



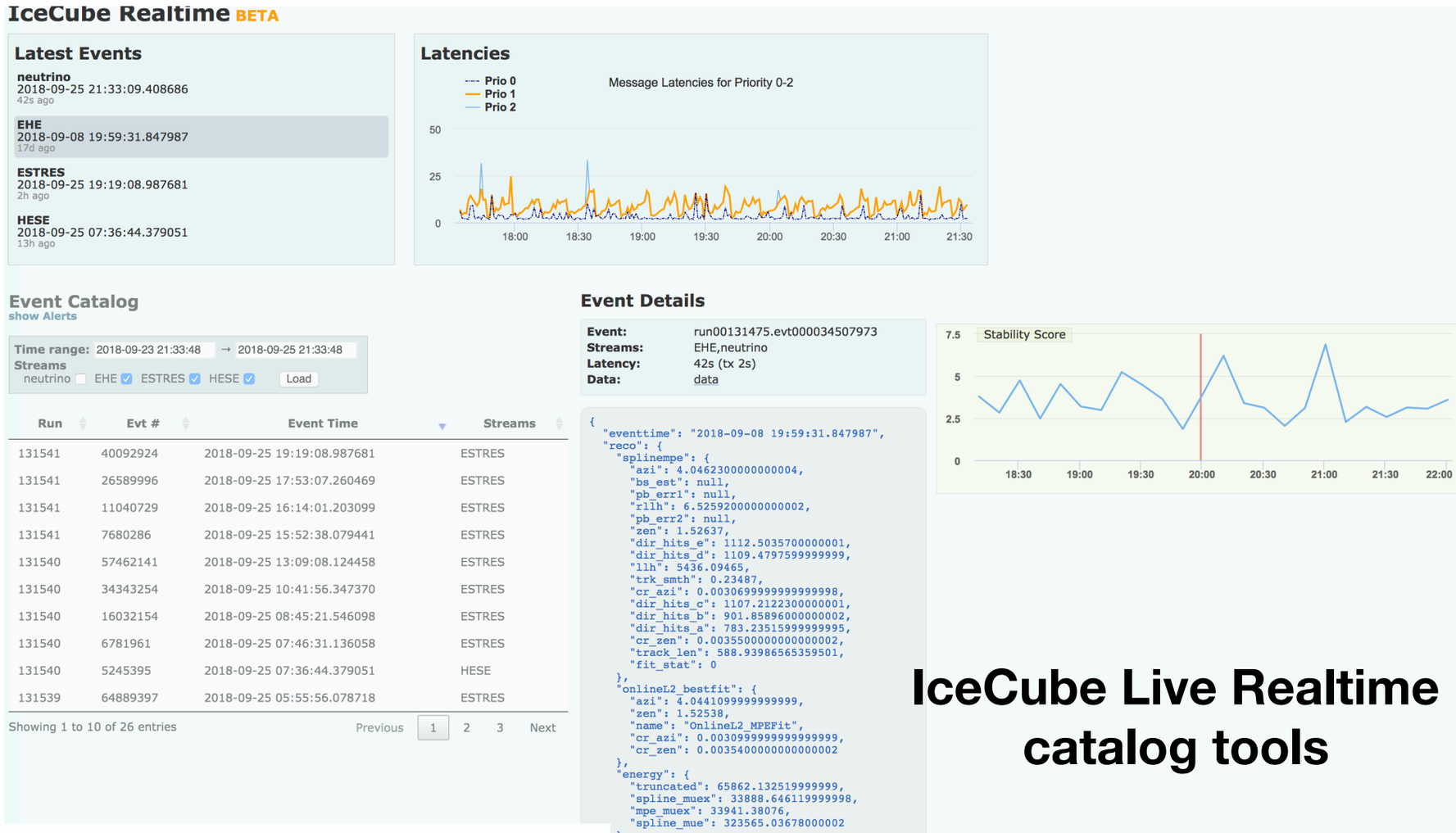


Astrophys.J. 850 (2017)

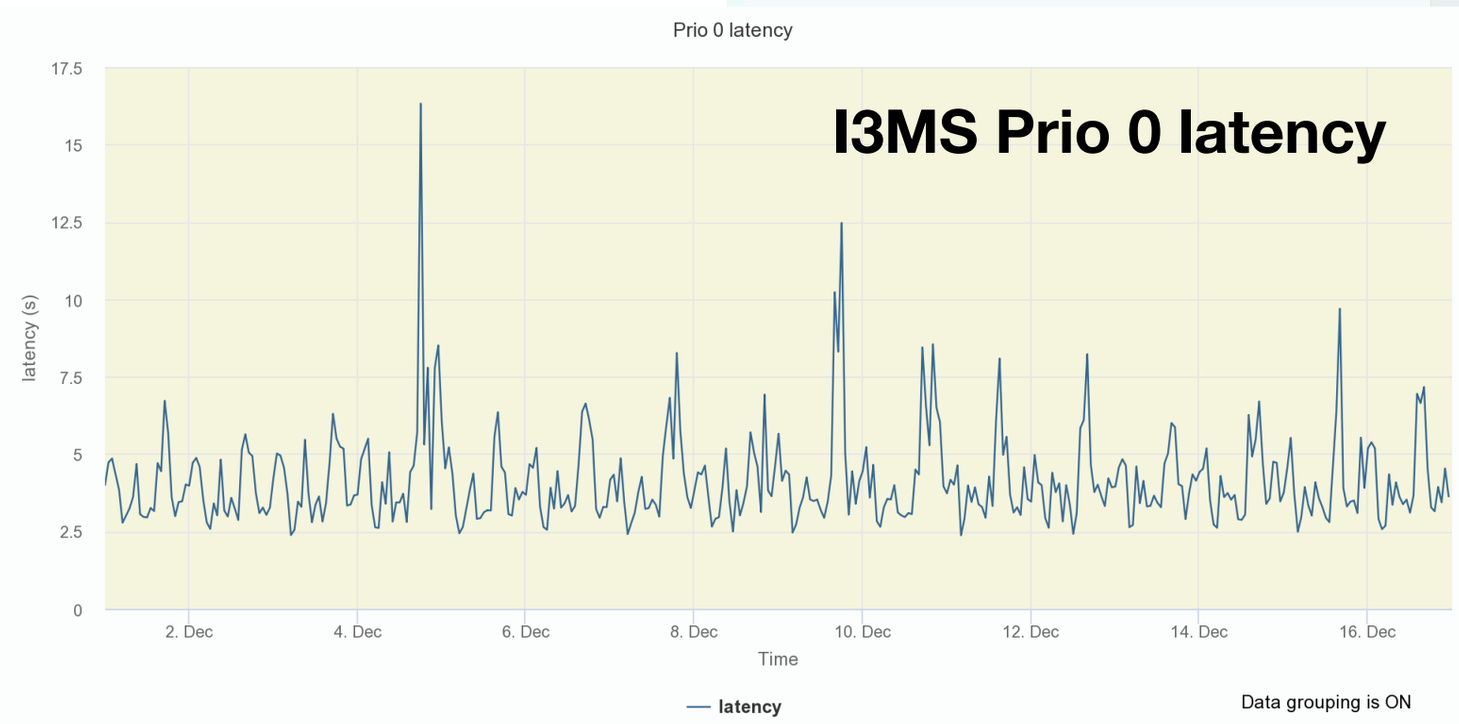
Realtime operations in M&O

- Maintenance and Operations provide critical infrastructure and support that make realtime operations possible.
  - High duty factor (>99%)
    - Neutrino data available during transient events
  - Realtime event filtering to support alert event detection
  - IceCube Live reporting and messaging
    - Realtime knowledge of detector status
    - Immediate transmission of alert data to the North
  - Followup in the North
    - Prioritized reconstruction processing in IceCube computing
    - IceCube Live realtime data and alert catalog tools

IceCube Realtime Tools

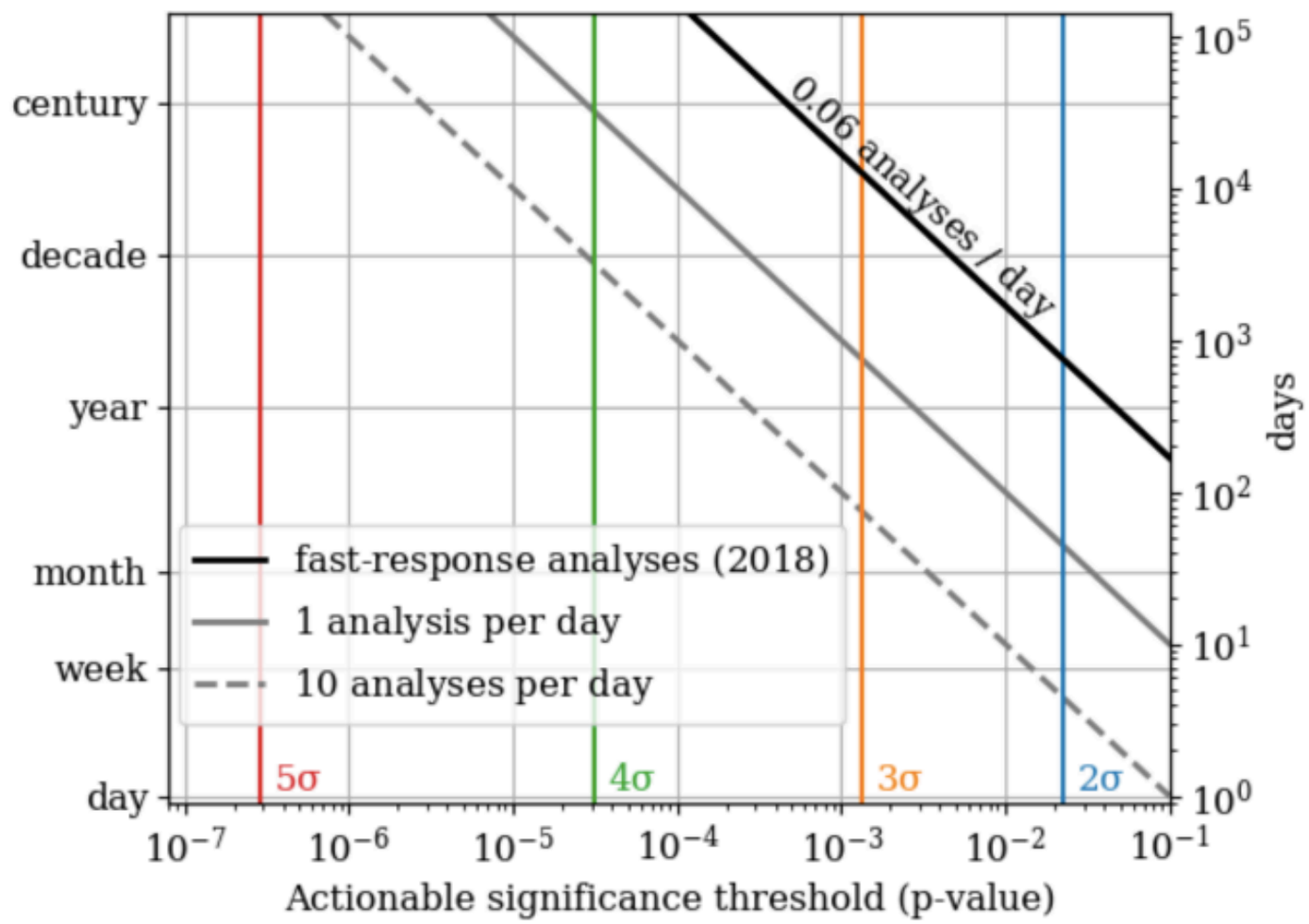


IceCube Live Realtime catalog tools



Summary

- IceCube Realtime operations enabled by new systems and ongoing support from Maintenance and Operations
  - Excellent synergy between collaboration and operation teams
- Realtime alerts continue and are evolving as we improve our online event selections
  - TXS 0506+056 results directly derived from the realtime alert
- IceCube is an active member of global multi-messenger discovery effort.
  - Prompt followup of transient discoveries in other messengers searching for neutrinos.
- Future is bright for IceCube realtime neutrino science!

Backup Material

Rate of false alarms