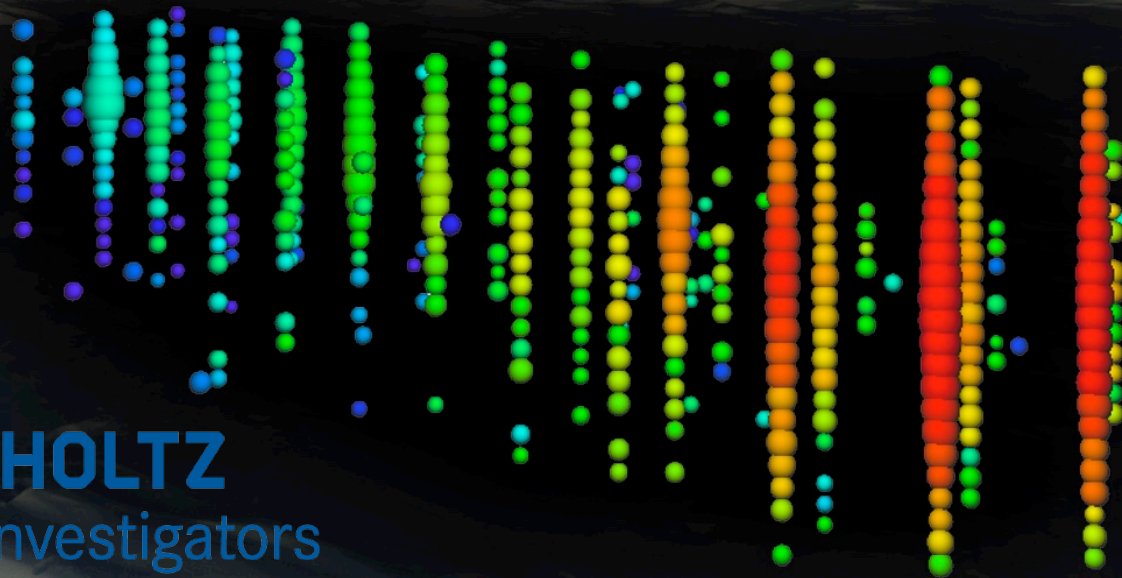
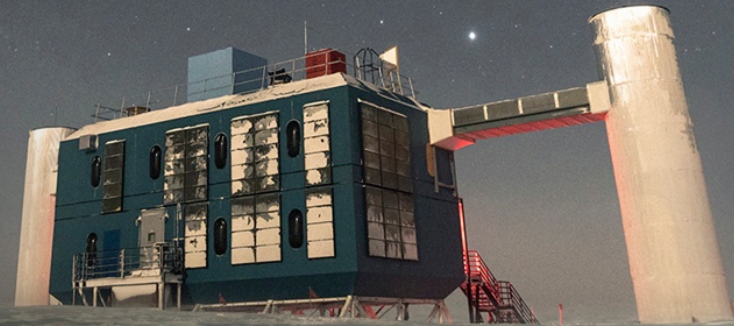


# IceCube Real-time Program

Anna Franckowiak for the  
IceCube Collaboration

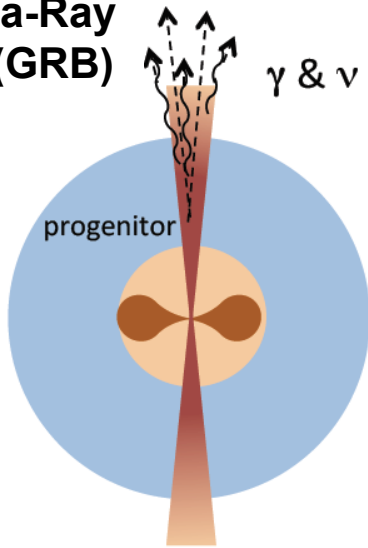


**HELMHOLTZ**  
Young Investigators

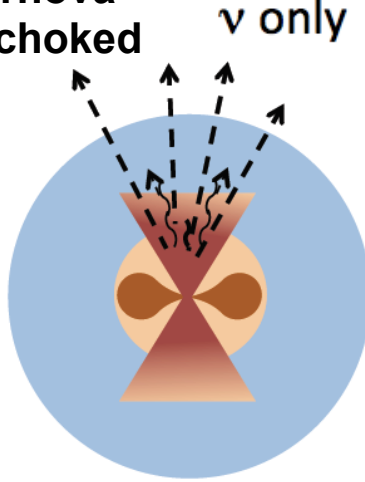
“VLVNT 2018” Dubna, October 3, 2018



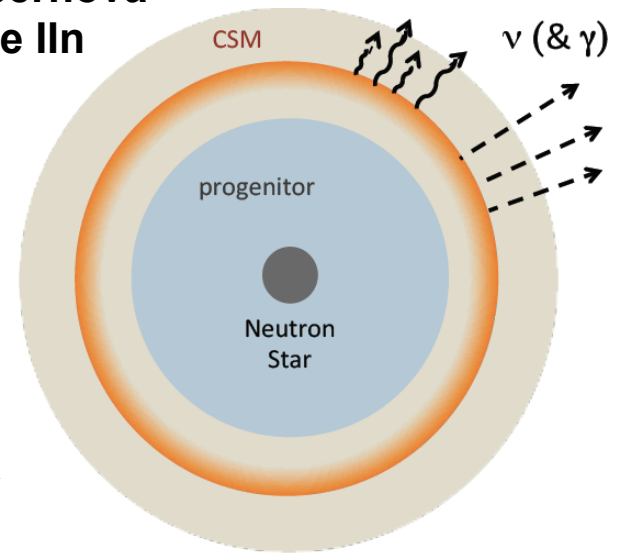
### Gamma-Ray Burst (GRB)



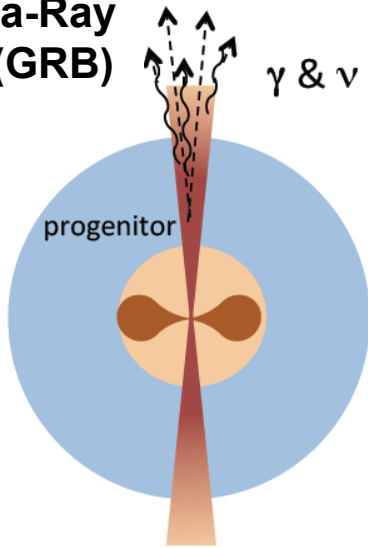
### Supernova with choked jets



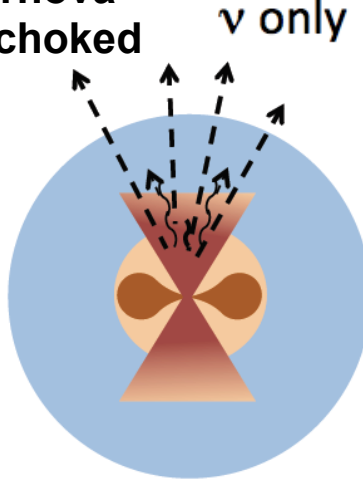
### Supernova Type II<sub>n</sub>



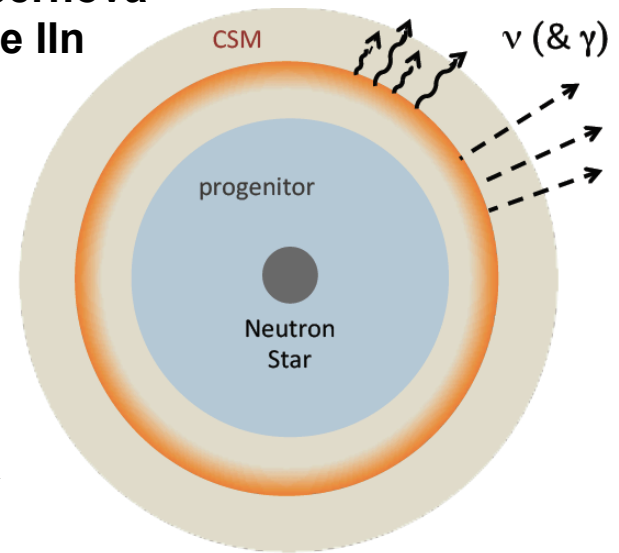
### Gamma-Ray Burst (GRB)



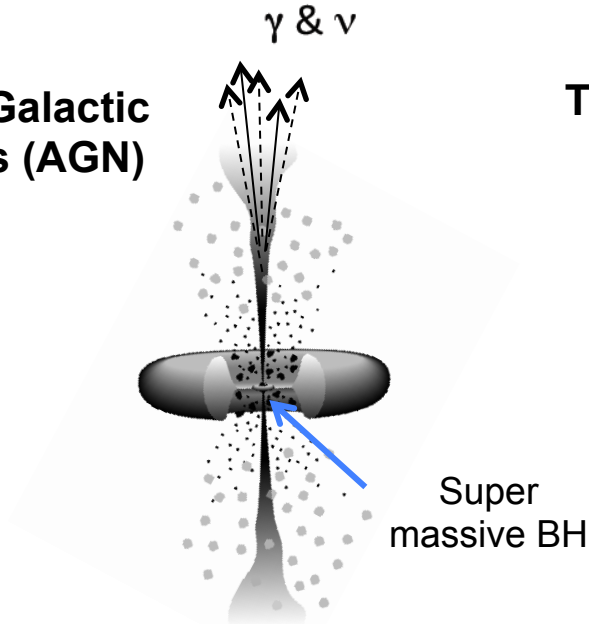
### Supernova with choked jets



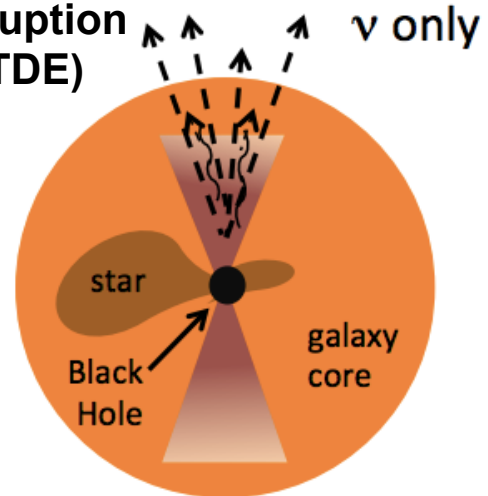
### Supernova Type II<sub>n</sub>



### Active Galactic Nucleus (AGN)



### Tidal Disruption event (TDE)



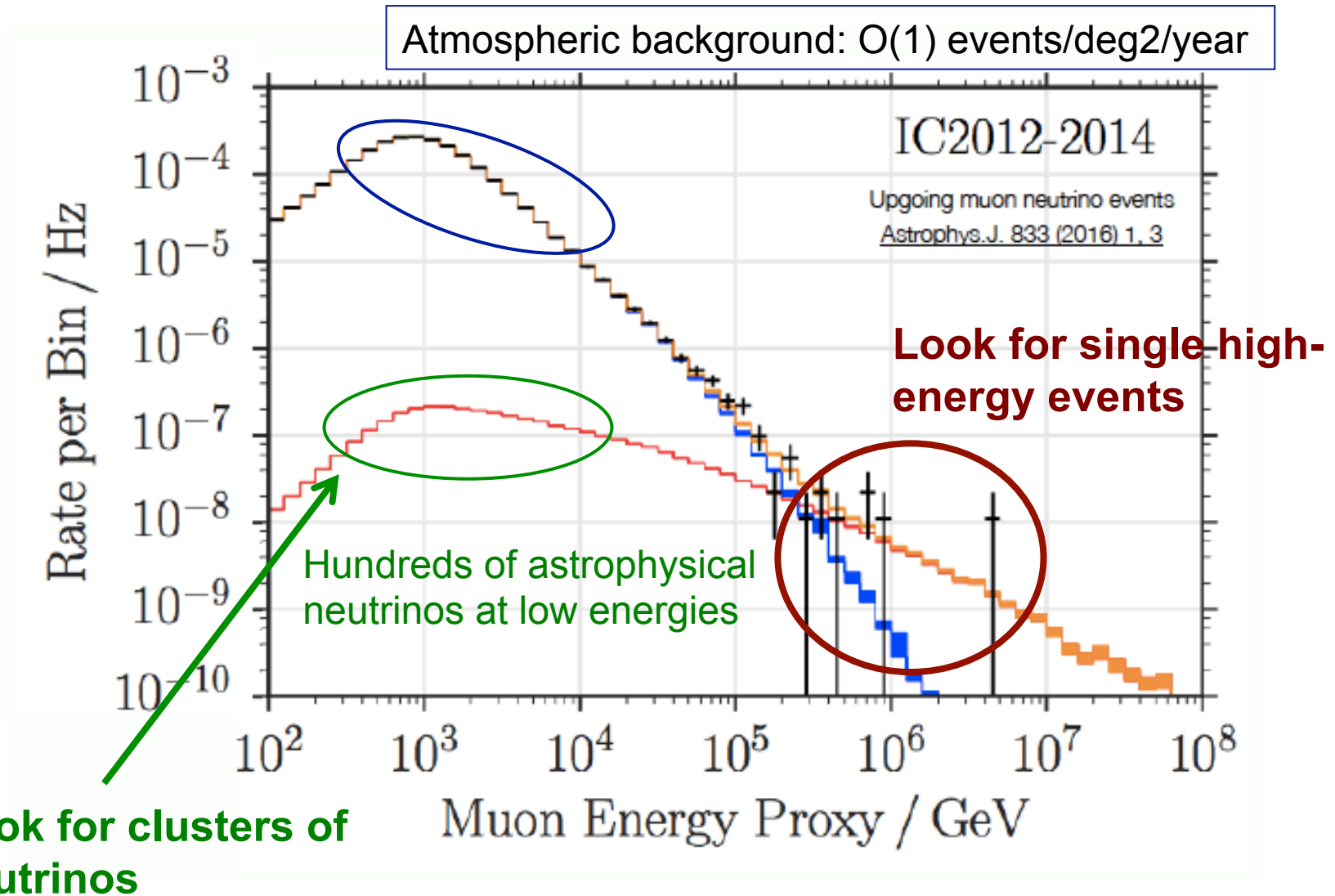


# IceCube Target of Opportunity Program



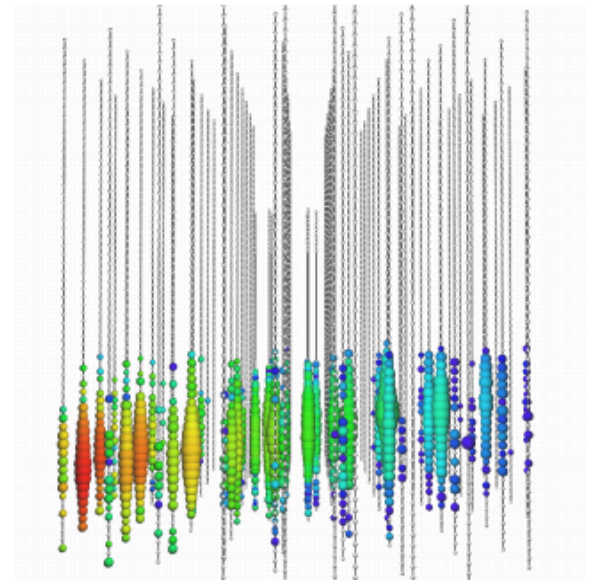
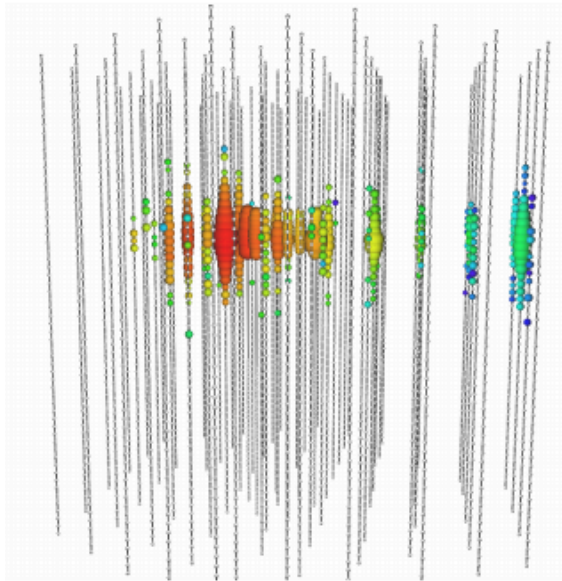


# Two Strategies



# High-energy Single Events – Two Streams

- High-energy starting tracks (HESE)
- Veto against atmospheric muons by outer detector layer
- 4 events / year (1 signal/y)
- Through going high-energy events (EHE)
- 4 events / year (2 signal/y)
- Better angular resolution compared to HESE

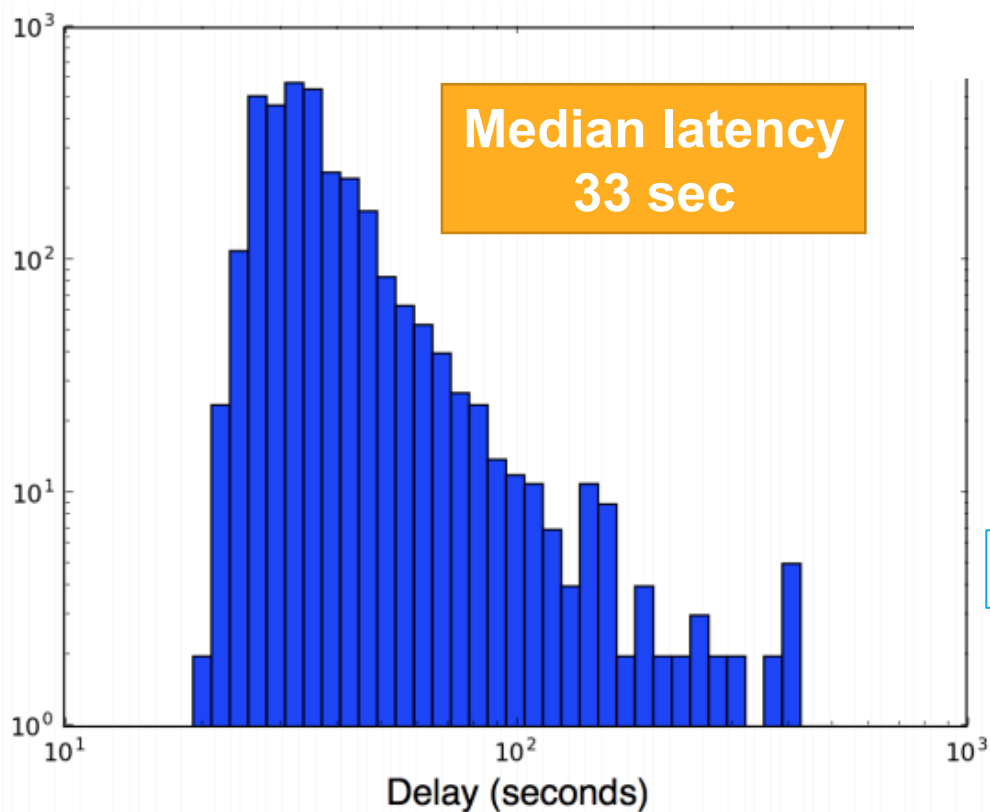


Will be unified into ONE stream in the near future

# High-energy Single Events – Public GCN

Public alerts since April 2016

Distribution through Gamma-ray Coordinate Network (GCN) via AMON



See AMON talk by Jimmy DeLaunay.

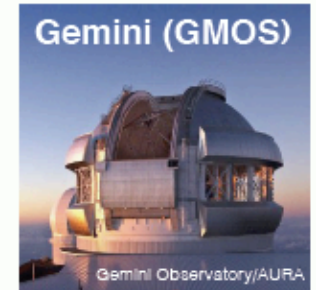


# High-energy Single Events

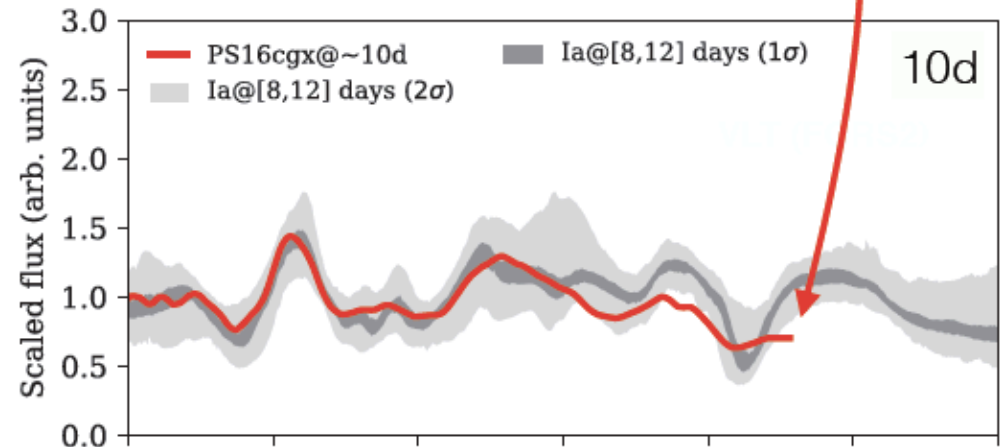
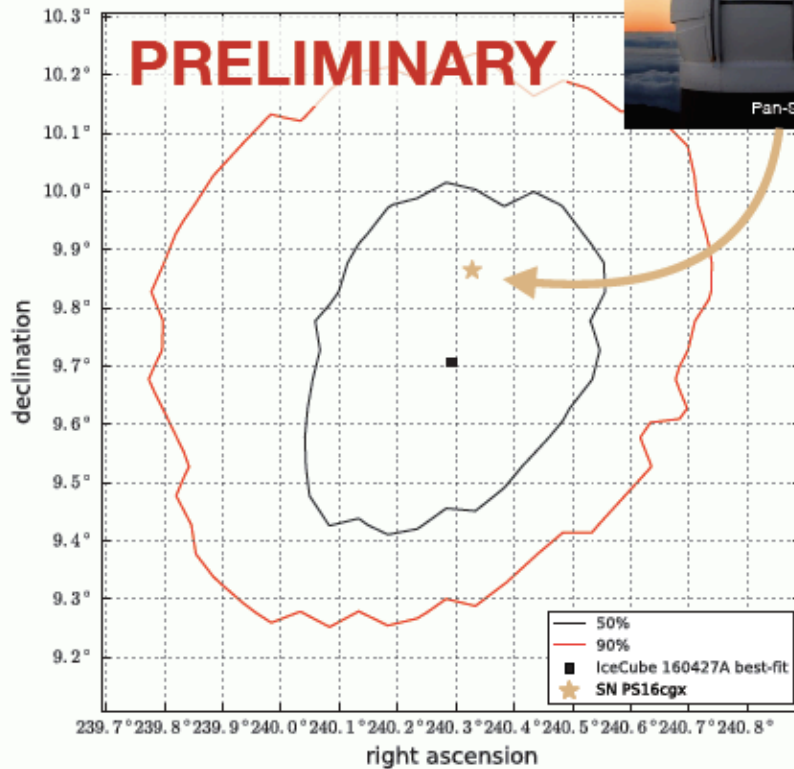
## Interesting Candidate – Pan-STARRS Supernova

IceCube, ICRC 2017

recent supernova at  $z=0.3$   
in coincidence with HESE  
alert on 2016-04-27:



Optical spectroscopy  
taken 10, 20 days  
post peak



Features atypical for SNIa but  
not sufficient to exclude

Light curve consistent  
with explosion days  
before neutrino alert

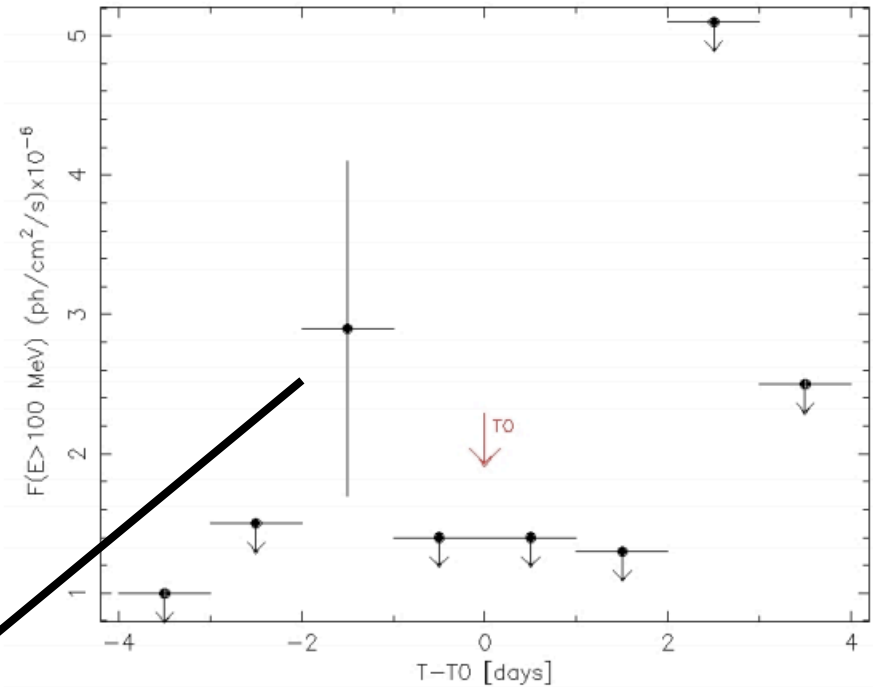
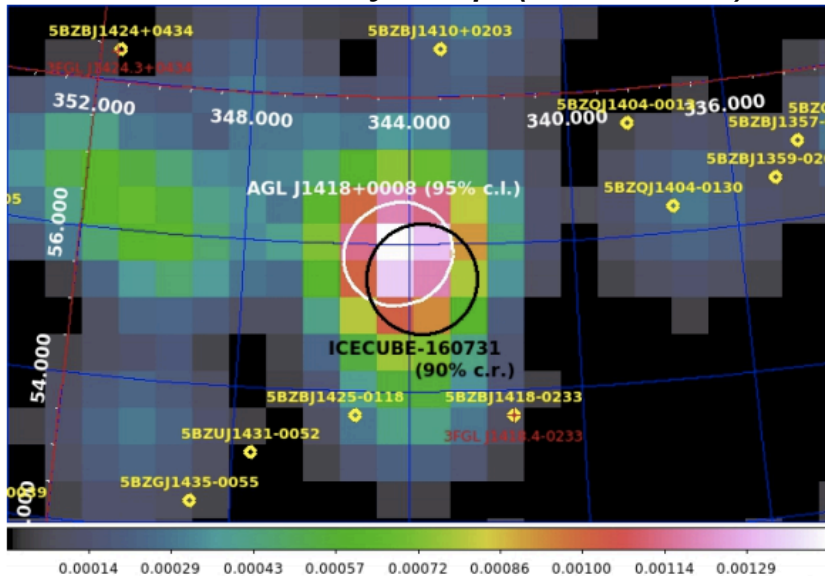
Chance probability { if Ic (associated with GRBs):  $<1\%$   
if Ia (no HE neutrinos exp.):  $<10\%$

# High-energy Single Events

## Interesting Candidate

- **AGILE gamma-ray signal**
  - No prompt emission in +/-1000 sec
  - Gamma-ray signal 2 days before the neutrino event ( $\sim 4\sigma$  post-trial significance)
  - Not a known gamma-ray source, possibly HBL blazar

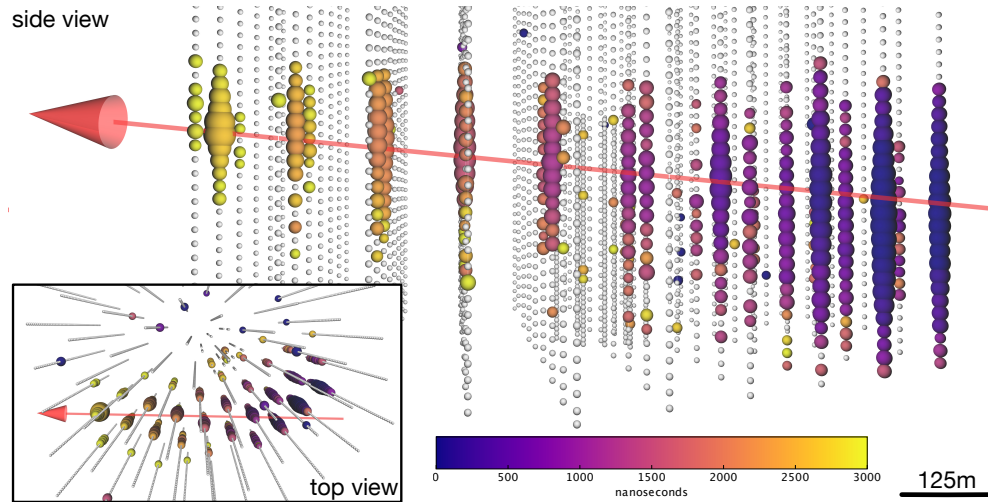
AGILE intensity map ( $>100\text{MeV}$ )



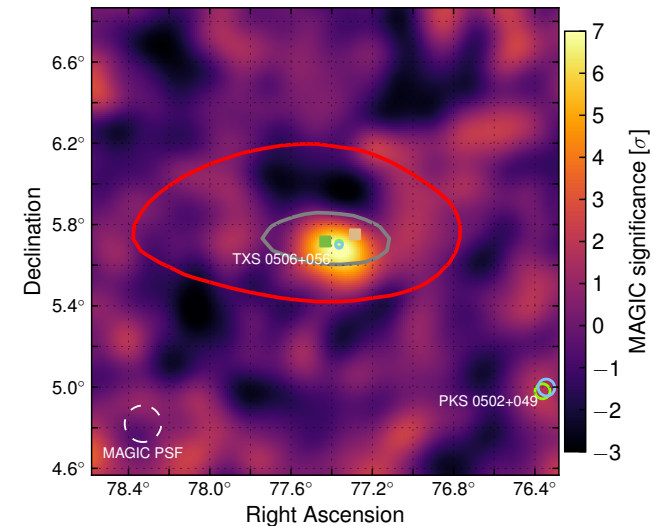
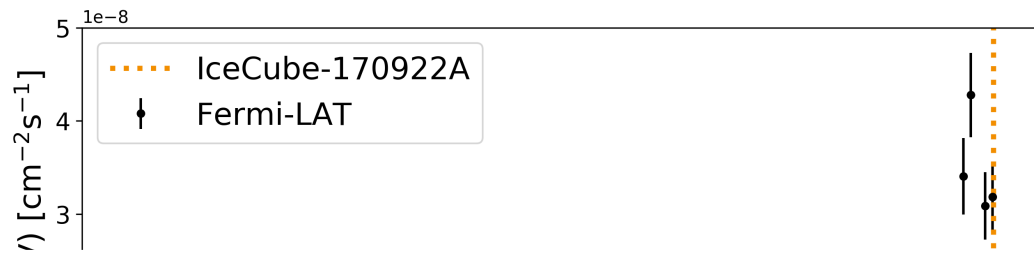
F. Lucarelli et al, ApJ 846, Vol. 2, p. 121 (2017)

# High-energy Single Events

## Most Interesting Candidate – TXS 0506+056

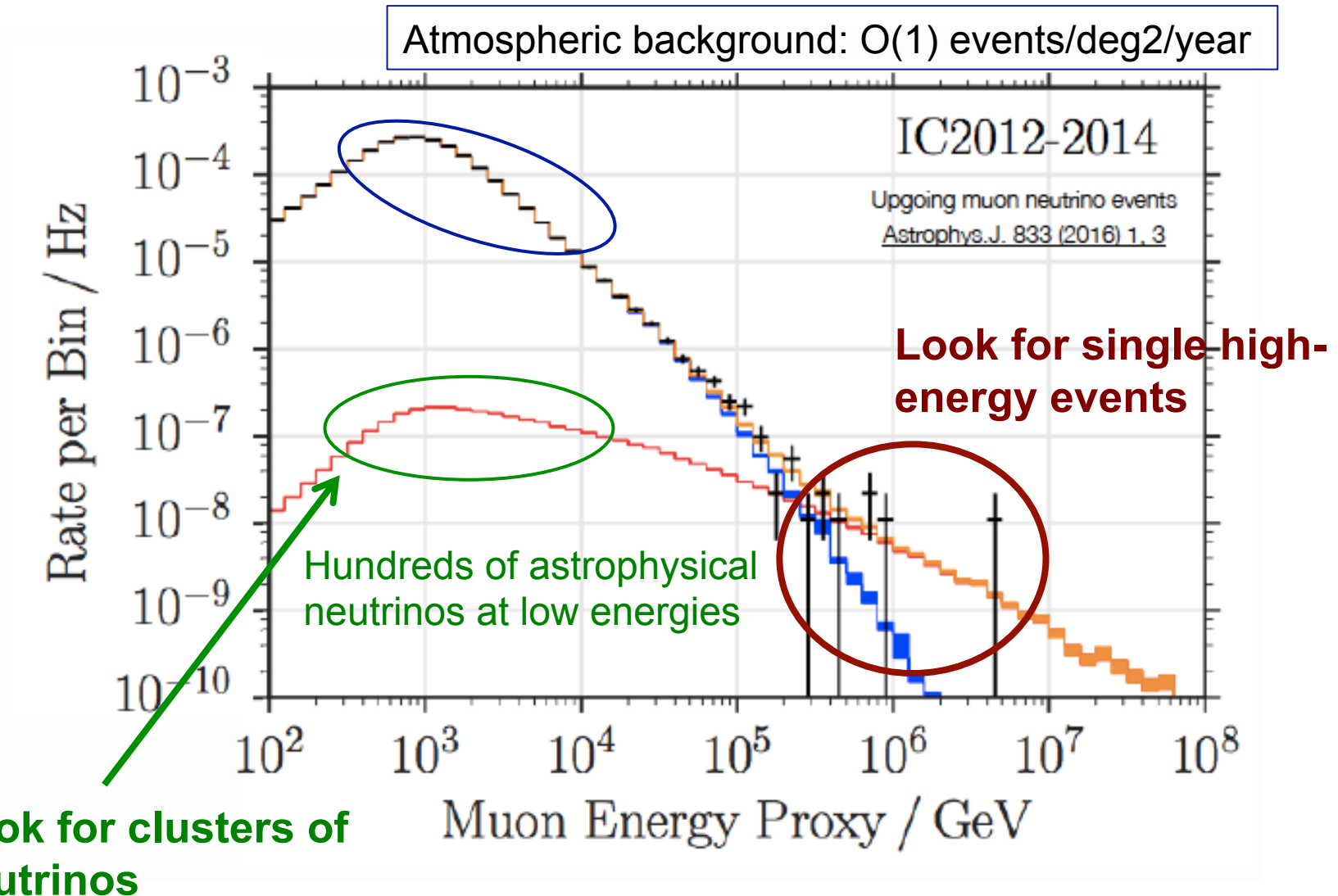


See talks on Oct. 2nd





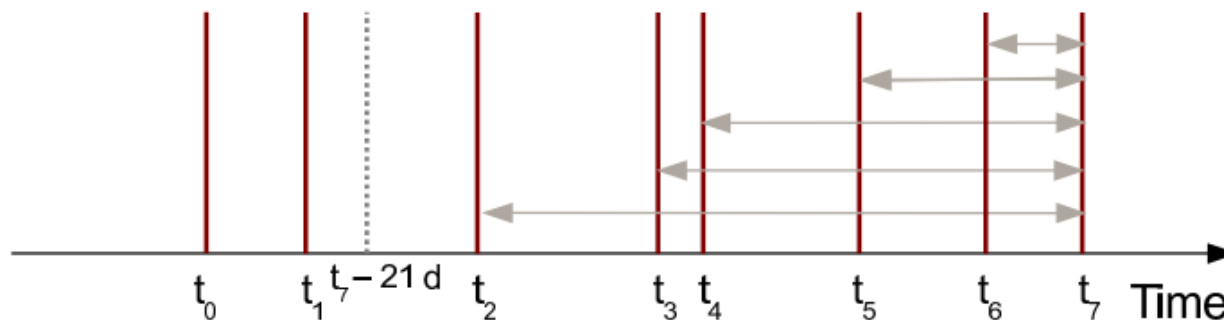
# Two Strategies



# Neutrino Clusters from pre-defined sources

## Monitoring blazars in neutrinos

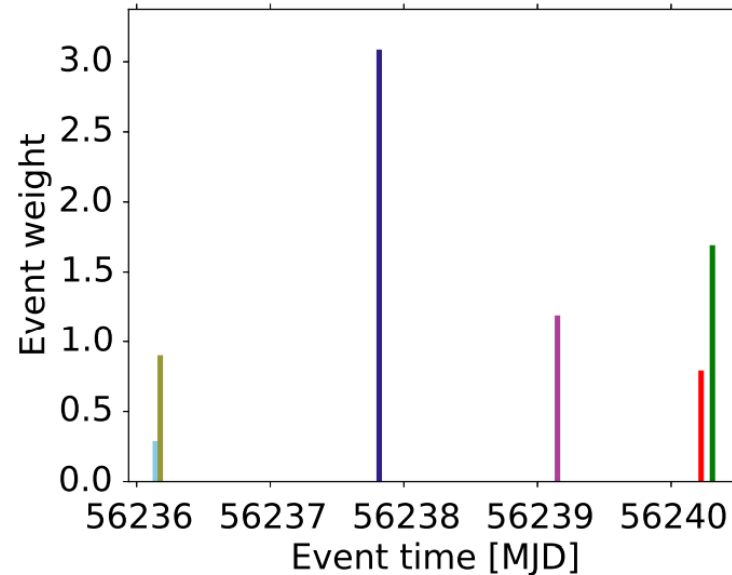
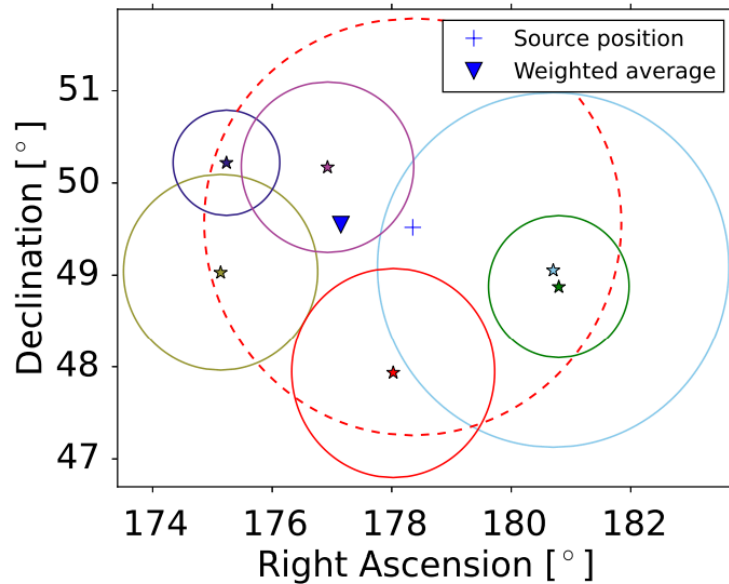
- Input stream: all-sky muon-neutrino candidates **above few 100 GeV**
- Clusters from predefined source list
  - Bright, hard and variable GeV  $\gamma$ -ray sources
  - 180 sources: mostly blazars
  - Clusters on all time scales up to 3 weeks
  - p-value calculated for clusters, if threshold is reached alert is sent
- Forwarded to MAGIC, VERITAS and HESS ( $\sim 2/\text{yr}$ )



# Neutrino Clusters from pre-defined sources

## Most interesting flare

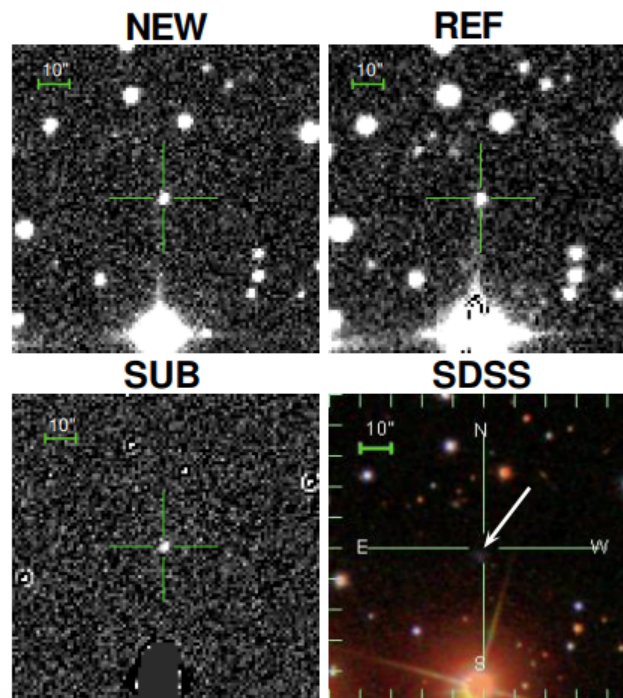
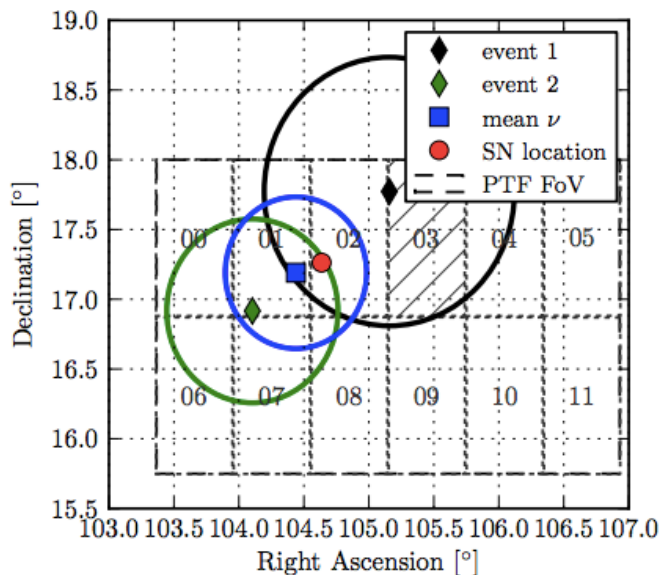
- **Most significant alert:** Nov. 9<sup>th</sup> 2012
- 6 events in 4.2 days, followed up by VERITAS, no counterpart found
- $\text{Log}_{10}(\text{p-value}) = -4.64$  (0.2% after trials correction)





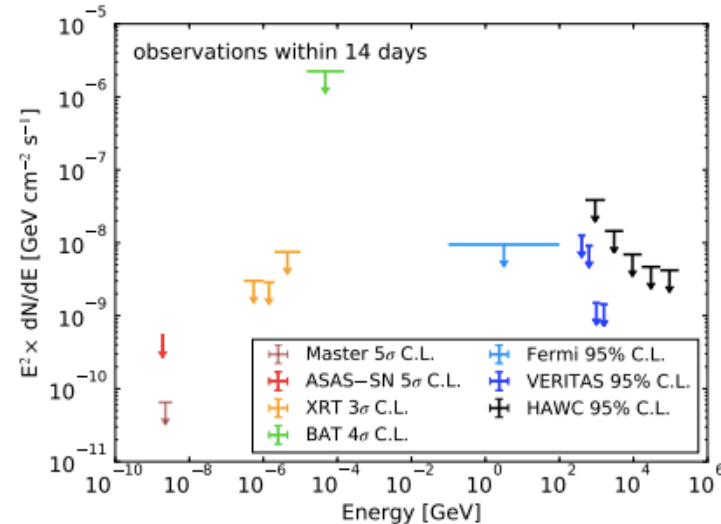
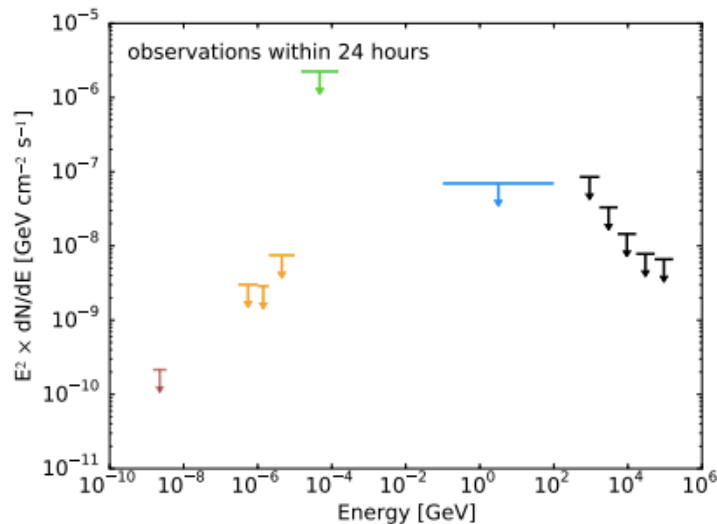
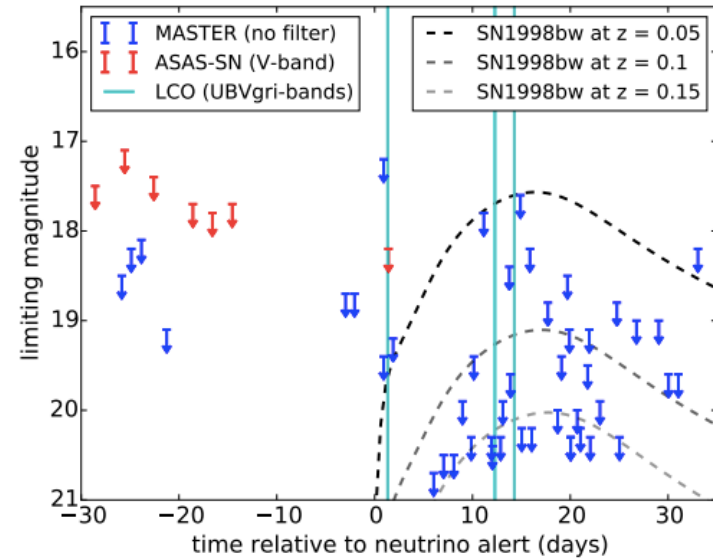
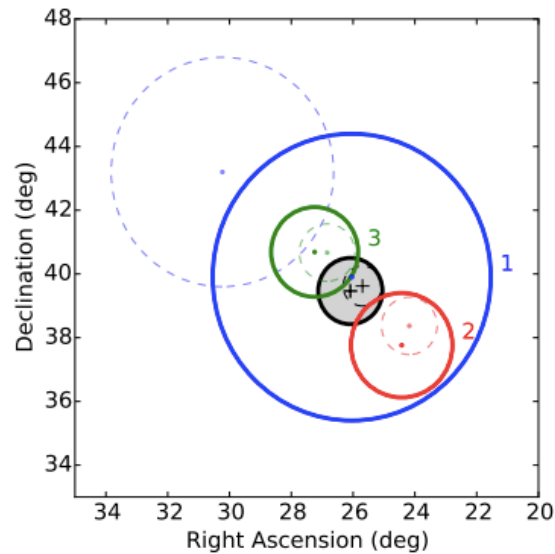
# Short Neutrino Transients

- Input stream: Northern hemisphere muon-neutrino stream **above few 100 GeV**
- Two or more events within 100 sec
  - Likelihood term selects most interesting multiplets
- Triggers optical (MASTER, ZTF, ASAS-SN) and X-ray (Swift-XRT) observations



# Short Neutrino Transients

## First triplet with extensive multi-wavelength follow-up



(a) Limits on short transients.

(b) Limits on longer lasting transients.

# IceCube Fast Response Analysis

## What did IceCube see?

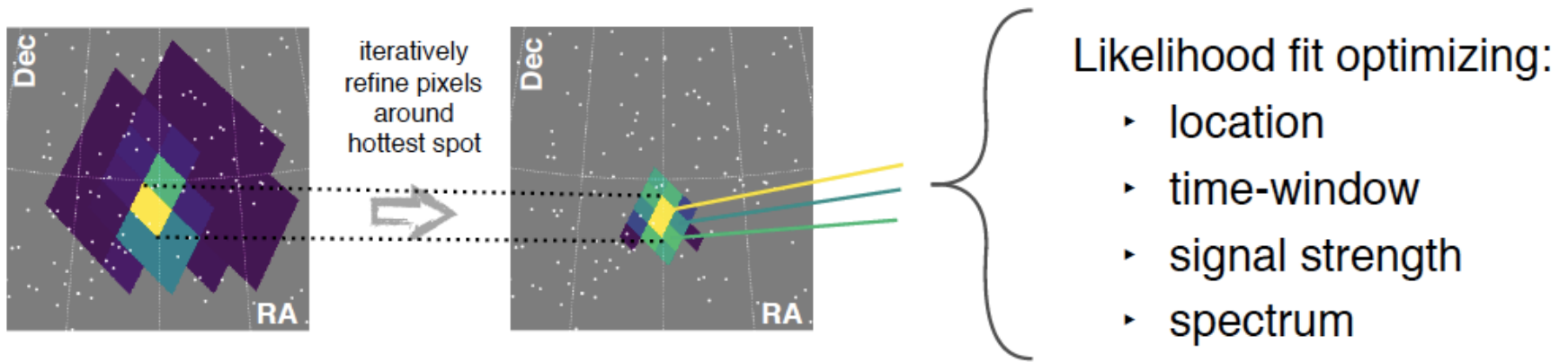
- Externally triggered
- All-sky muon-track neutrino stream
- Search for neutrino emission in time window <2 week
- Approval by IceCube Realtime Oversight Committee (ROC)

Source	Start Time [UTC]	Duration [D:H:M:S]	RA	Dec	Extension
PS16cgx	2016-04-26 15:59:12	1:03:46:40	240.33°	+09.86°	0.0°
Cygnus X-3	2017-04-03 00:00:00	1:00:00:00	308.11°	+40.96°	0.0°
GRB 170405A	2017-04-05 18:35:49	0:00:20:02	219.83°	-25.24°	0.0°
AGL J0523+0646	2017-04-15 11:50:00	2:00:00:00	080.86°	+06.78°	0.6°
IceCube 170506A	2017-05-06 00:36:55	1:00:00:00	221.80°	-26.00°	1.0°
AT2017eaw	2017-05-10 12:00:00	3:00:00:00	308.68°	+60.19°	0.0°

# Soon: Longer Time-Scale Neutrino Clusters

## Real-time all-sky search

Scan pixels around most-recent event with time-clustering analysis



Identify hotspots as they grow and notify community within one minute of neutrino observation at the South Pole

Expected public alert rate: 1 alert / year

# Summary

- Multi-messenger studies are crucial to identify the origin of high-energy neutrinos
- IceCube has several analysis in place
  - Follow-up of single high-energy events
  - Follow-up of neutrino clusters
- First interesting candidates identified
- Improvements in the future will hopefully provide more interesting multi-messenger events!