IceCube Neutrino Alerts



Jon Dumm
EO Meeting
13 Oct 2016

Stockholm University

Oskar Klein centre

IceCube Neutrino Alerts



*Reenactment

Jon Dumm

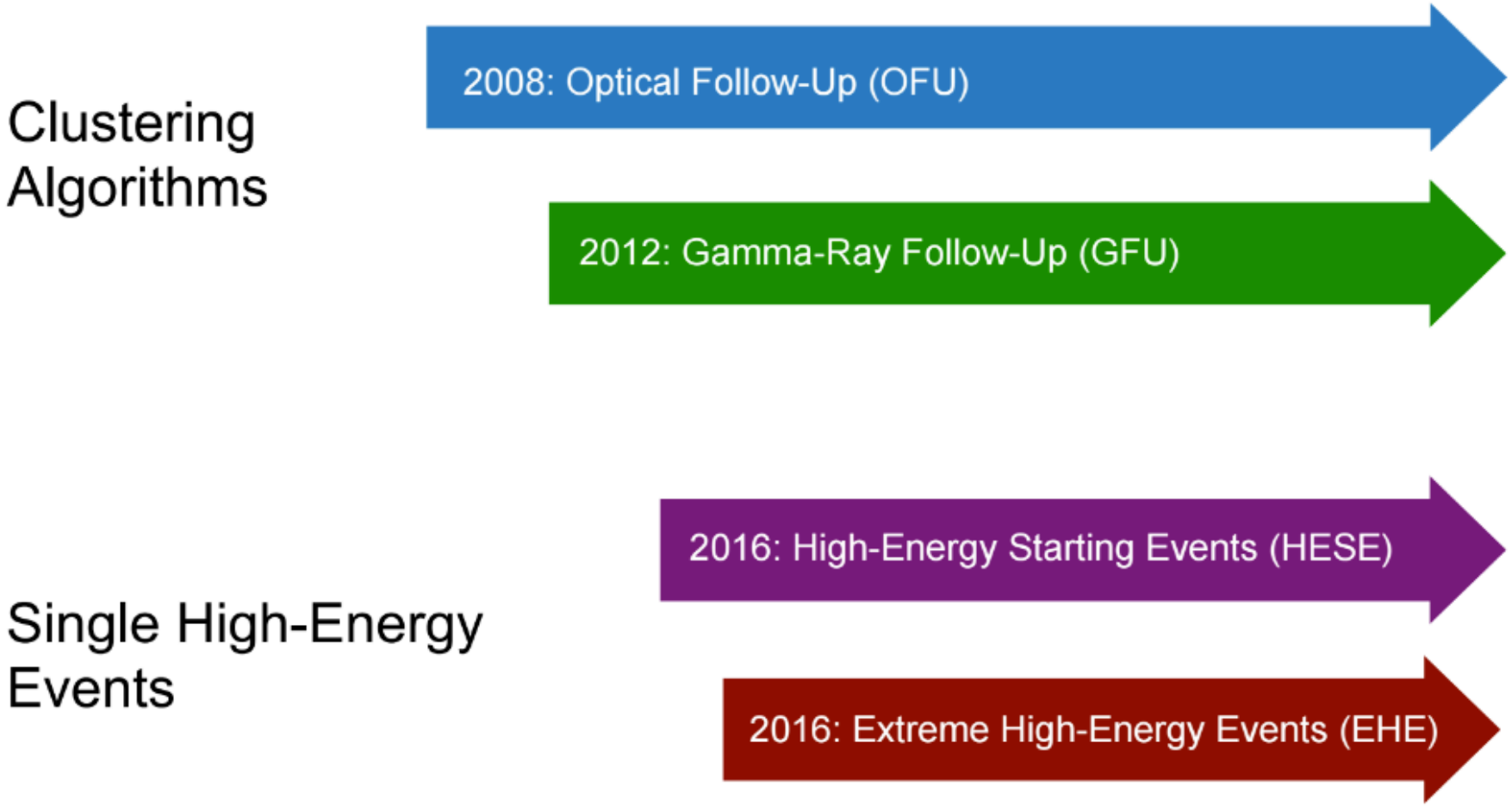
EO Meeting

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IceCube Alert Timeline



IceCube Neutrino Observatory

86 strings

60 Optical Modules per string

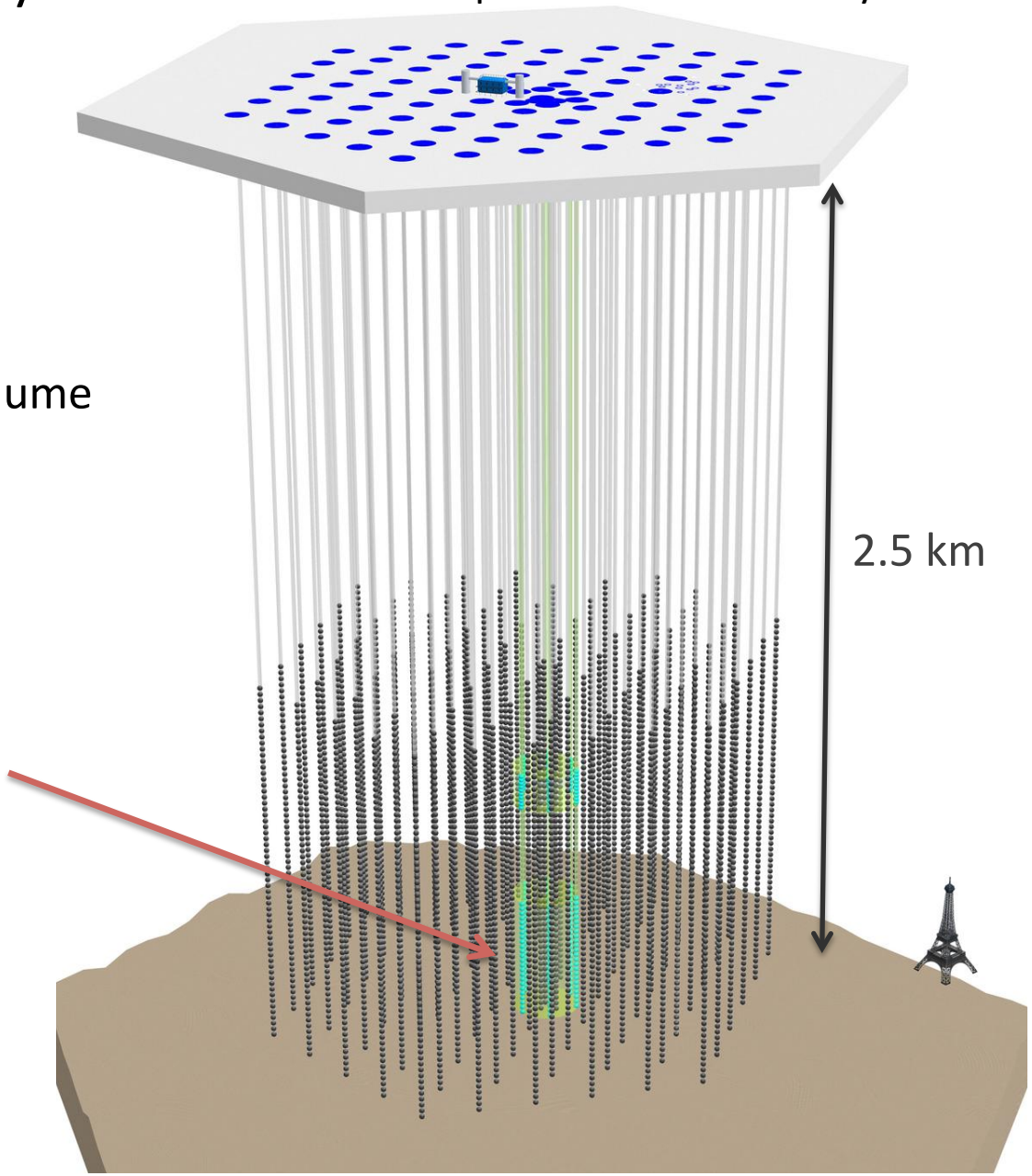
5 160 total modules in Ice

1 km^3 = Gigaton instrumented volume

Began full operations May 2011

DeepCore
Low-energy Extension

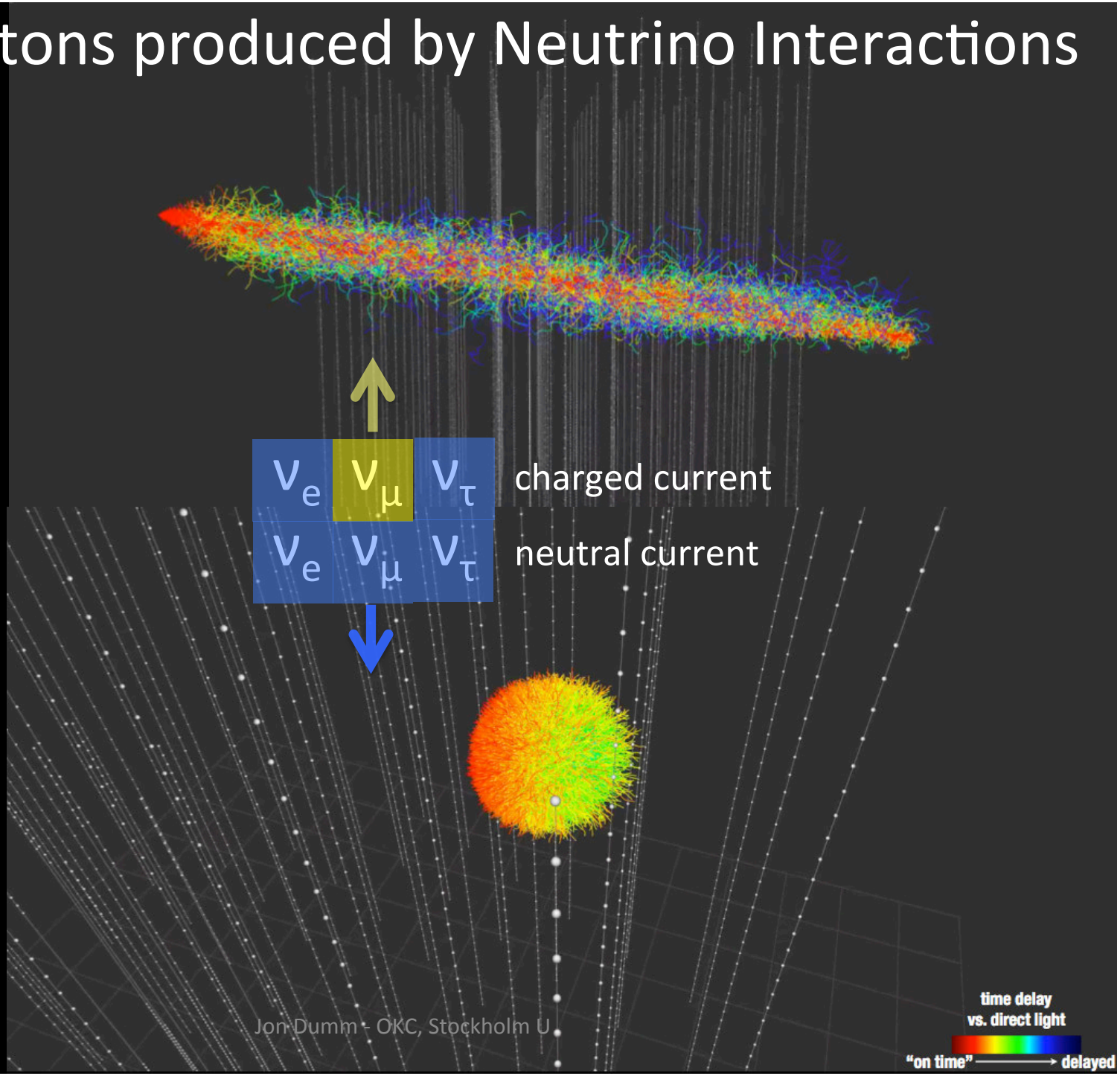
Dark Matter,
Neutrino Oscillations



Photons produced by Neutrino Interactions

Track topology
(e.g. induced by muon neutrino)

Good pointing, 0.1° - 1°
Lower bound on energy

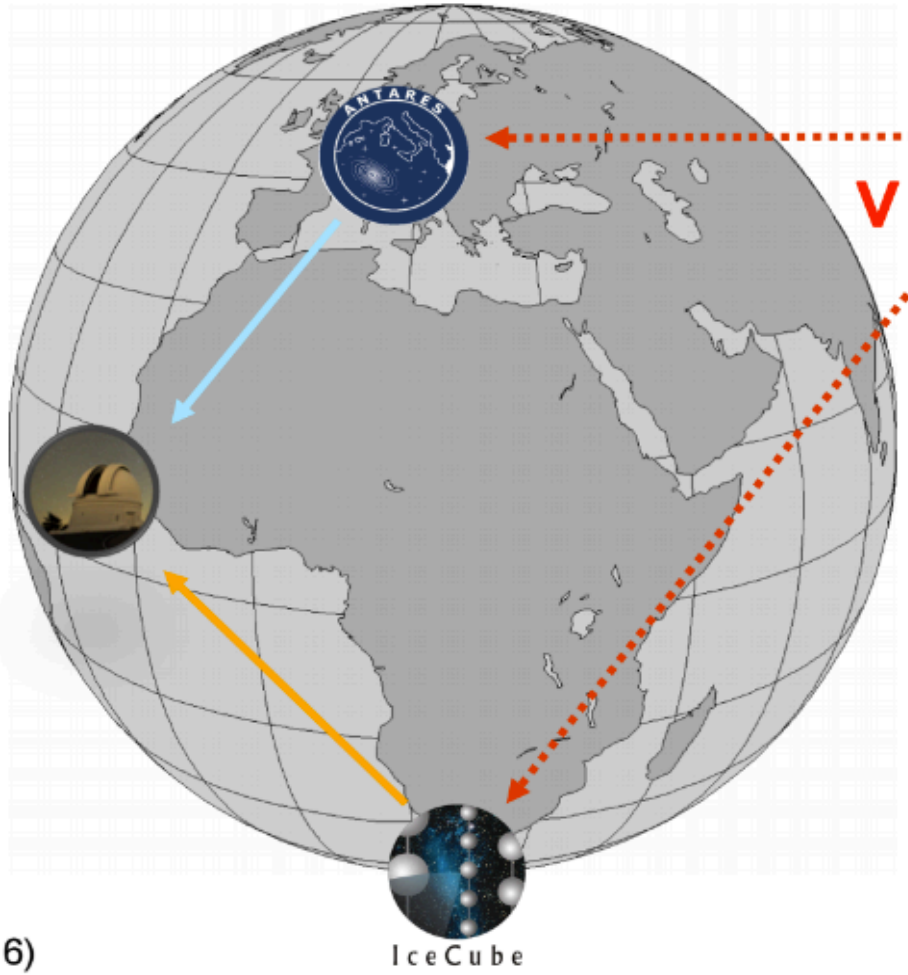


Cascade topology
(e.g. induced by electron neutrino)

Good energy resolution, 15%
Some pointing, 10° - 15°

Optical Followup

Optical Telescopes
(iPTF, MASTER, Tarot, Pan-STARRS, ASAS-SN)



- Online since 2008
- Initially used only robotic telescopes spread around the world
- Only used information available 'online'
- Looked for self-clustering of neutrinos as SN alert

ANTARES JCAP 1602 (2016)
Ackermann et al.arXiv:0709.2640
IceCube A&A 539, A60 (2012)

Thomas Kintscher and IceCube Coll.
2016 *J. Phys.: Conf. Ser.* **718** 062029

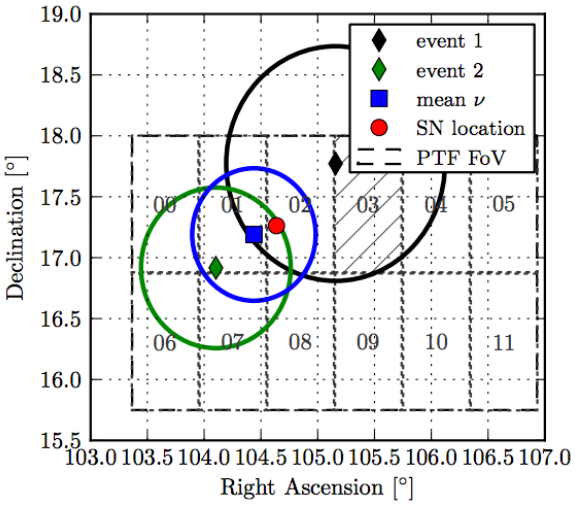
Optical Follow-Up	100 seconds	self-tiggered	Northern sky	straight cuts

Optical Followup - Highlight

- Alert on March 2012: 2 neutrinos within 1.6 sec
  - Expect this once every ~4 years

- Position consistent with PTF12csy
  - Bright supernova type IIn at 300 Mpc
  - Type IIn rare in itself but neutrinos 158 days after t0, much later than a priori 1-day window (p = 1.4% a posteriori)
  - Shows signs of interacting SN ejecta with a dense cirumstellar medium
  - No other signs of neutrinos in longer window (~1yr)
  - Models predictions orders of magnitude too small
  - Interpreted as a chance association





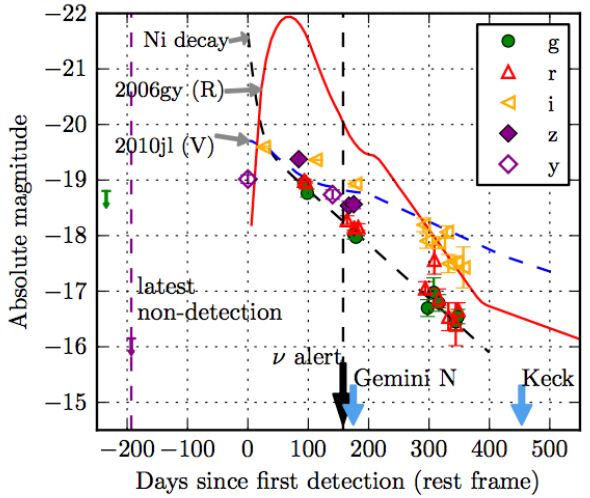
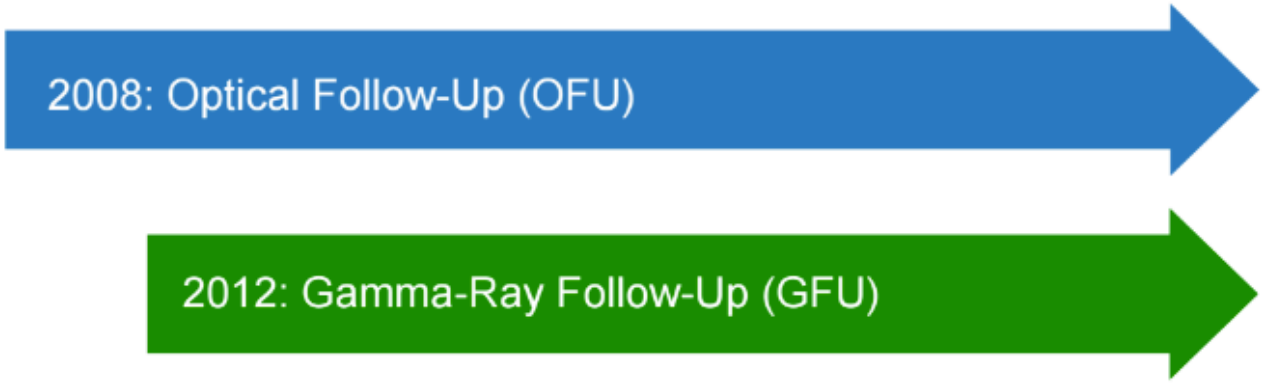


Figure 6. PTF12csy photometry (symbols) in absolute magnitudes, with correction for Galactic extinction, and conversion of P48 Mould R magnitudes to SDSS *r* magnitudes (see Section 5.2.1). The data originate from the following telescopes: *g*: P48, P60, PS1, FTN; *r*: P48, P60, PS1, FTN; *i*: P60, PS1, FTN; *z*: P60, PS1; *y*: PS1. The photometry is averaged over intervals of 10 days. Other absolute SN II light curves (lines) and a theoretical light curve from radioactive decay of nickel (black dashed line) are added for comparison. The comparison light curves are partly not extinction corrected and have different reference dates (see text).

IceCube Alert Timeline

Clustering Algorithms



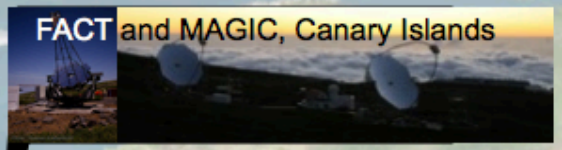
- Monitored only VHE-detected targets
- Private alerts to MAGIC, HESS, VERITAS, and now FACT

Participating IACTs



★ First light in 2007
★ 4x12m Davies-Cotton IACTs
★ Energy threshold: ~80 GeV
★ Camera FoV: 5° (PMTs)
★ 0.1° angular resolution > 1 TeV

★ Operational since Oct 2011
★ 9.5m^2 mirror area
★ Camera FoV: 4.5° (SiPM)
★ Energy threshold ~750 GeV
★ Long-term monitoring of blazars at TeV energies,
★Quick-Look Analysis (publicly available): http://fact-project.org/monitoring



★ MAGIC-I (17m) in operation since 2004, MAGIC-II (stereo mode) since 2009
★ Camera FoV: 3.5° (LV PMT)
★ Energy threshold: ~50 GeV (25 GeV with SumTrigger)

★ HESS-I in operation since 2004, HESS-II since 2012
★ HESS-I (4x12m), camera FoV: 5° (PMT)
★ HESS-II (23m), camera FoV: 3.5° (PMT)
★ Energy threshold: ~100 GeV (~30 GeV HESS-II)



IceCube Alert Timeline

Clustering Algorithms

2008: Optical Follow-Up (OFU)

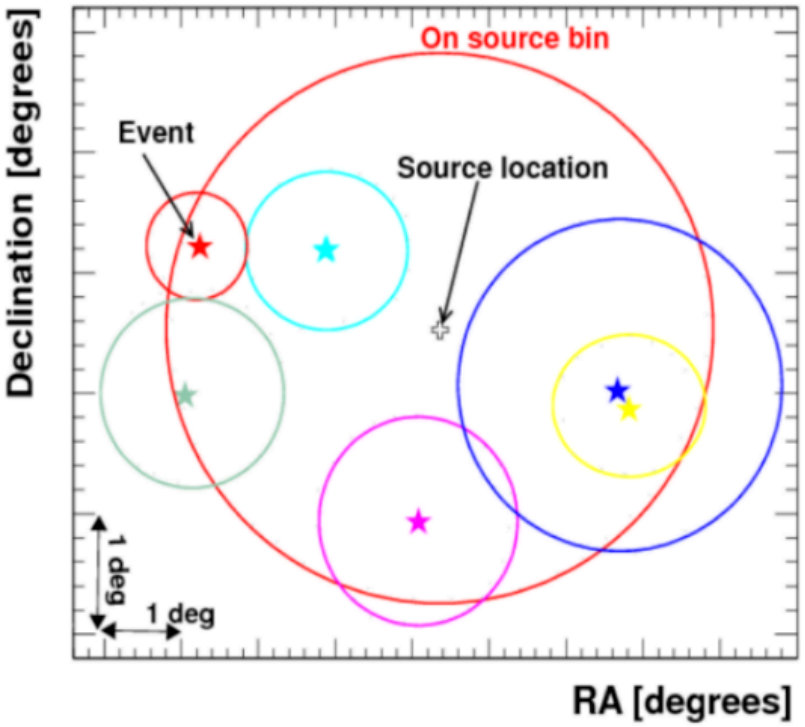
2012: Gamma-Ray Follow-Up (GFU)

- Monitored only VHE-detected targets
- Private alerts to MAGIC, HESS, VERITAS, and now FACT
- Much more advanced computing/recos in use
- Looking to upgrade event selection to use BDTs

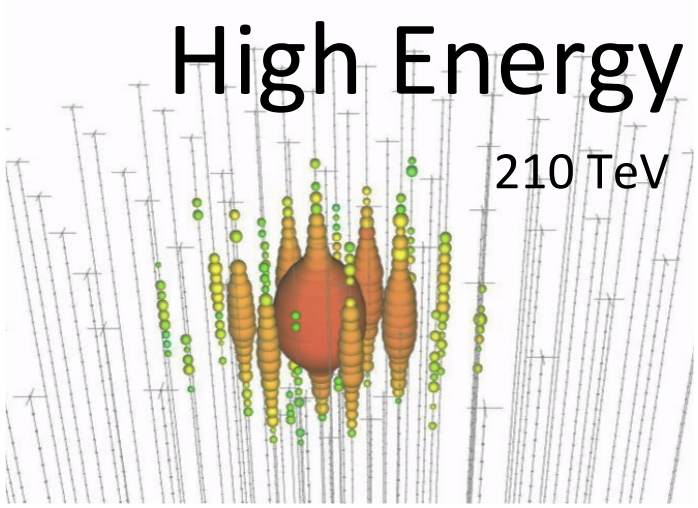
Optical Follow-Up	100 seconds	self-tiggered	Northern sky	straight cuts
Gamma Follow-Up	21 days	source list	All sky*	time-clustering llh
All-Sky Clustering	to be optimized	self-tiggered	All sky	time-clustering llh

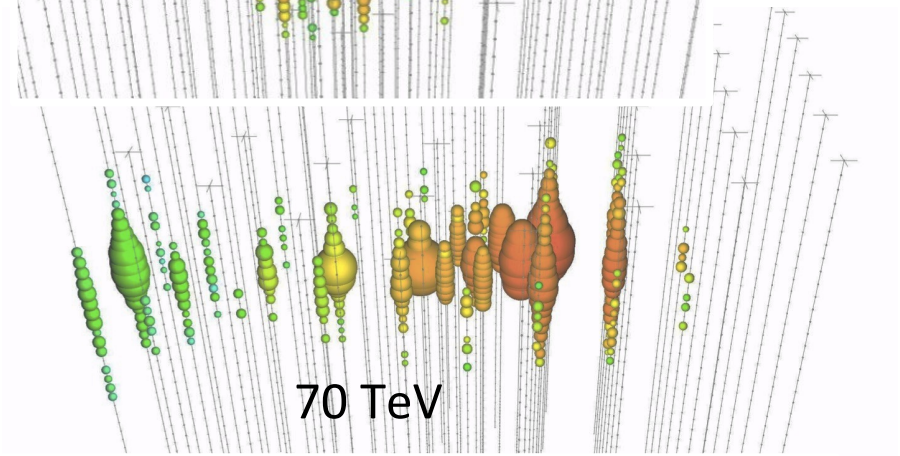
Most Significant GFU Alert

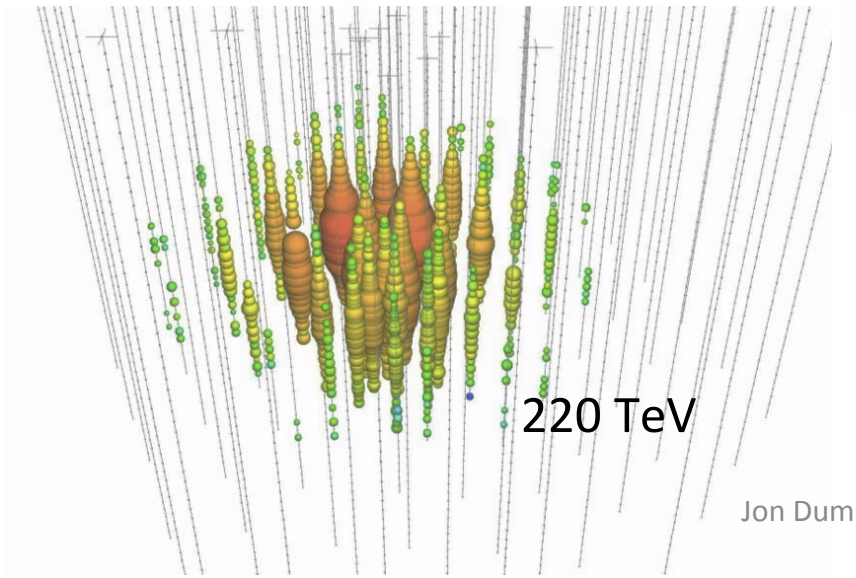
- Nov. 9th 2012
- 6 events in 4.2 days from blazar 1ES2344+514 at z=0.044
- Small chance prob of seeing 6 events during the period: p = 0.2%
- Alert forwarded to VERITAS
  - No detection but limited observations

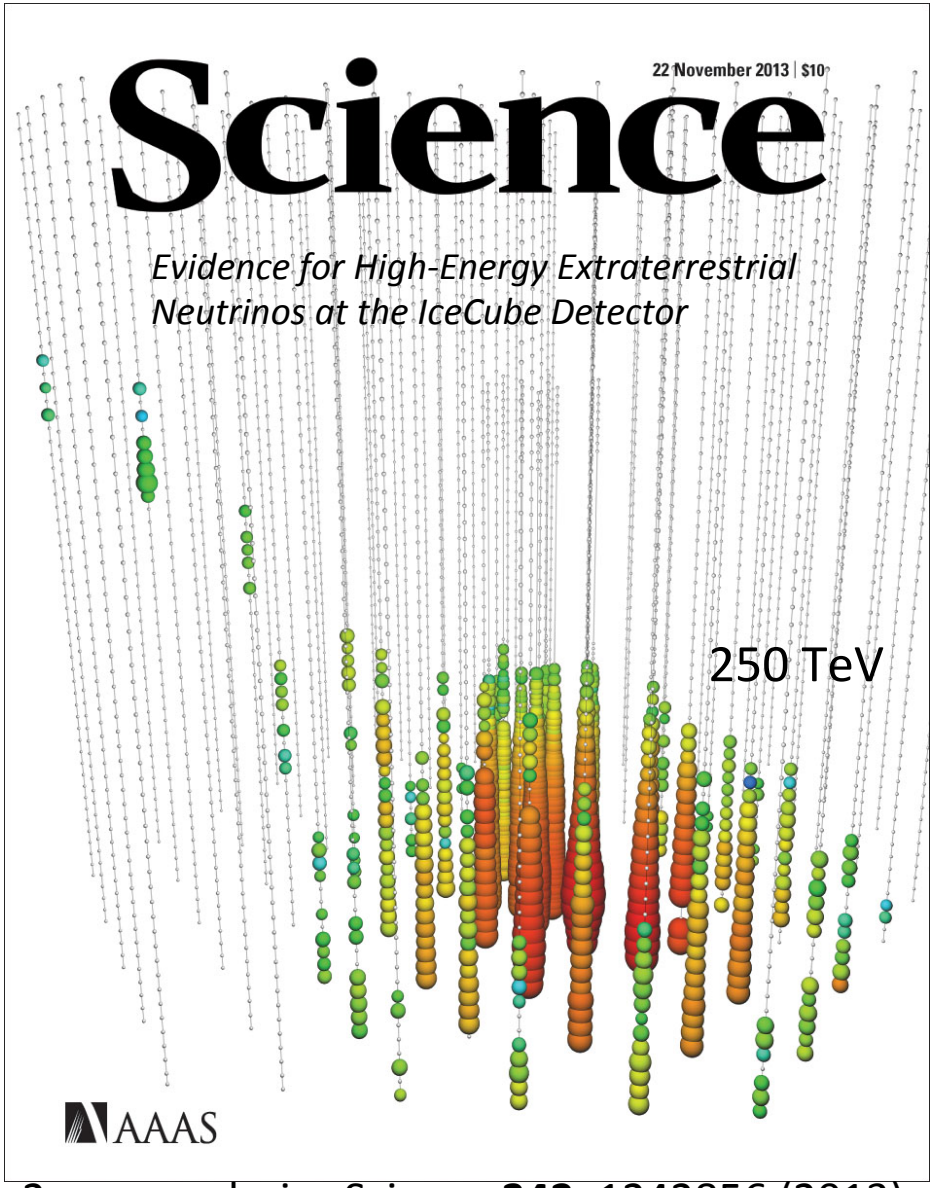


High Energy Starting Event Analysis



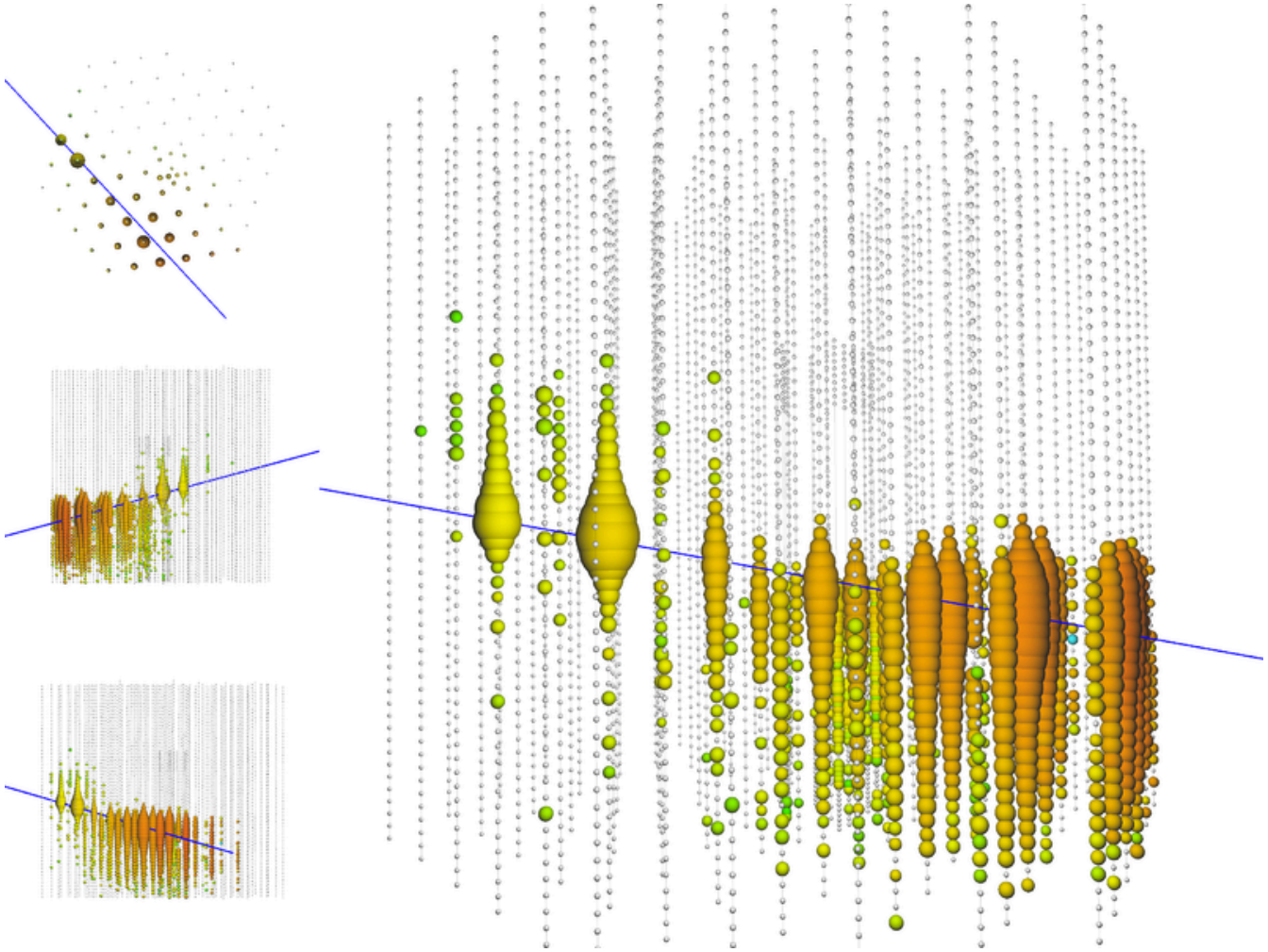






2-year analysis: Science **342**, 1242856 (2013)

Multi-PeV Muon Track



Almost a discovery in itself! p = 0.005% from atmos. background

IceCube Alert Timeline

Clustering Algorithms

2008: Optical Follow-Up (OFU)

2012: Gamma-Ray Follow-Up (GFU)

Single High-Energy Events

2016: High-Energy Starting Events (HESE)

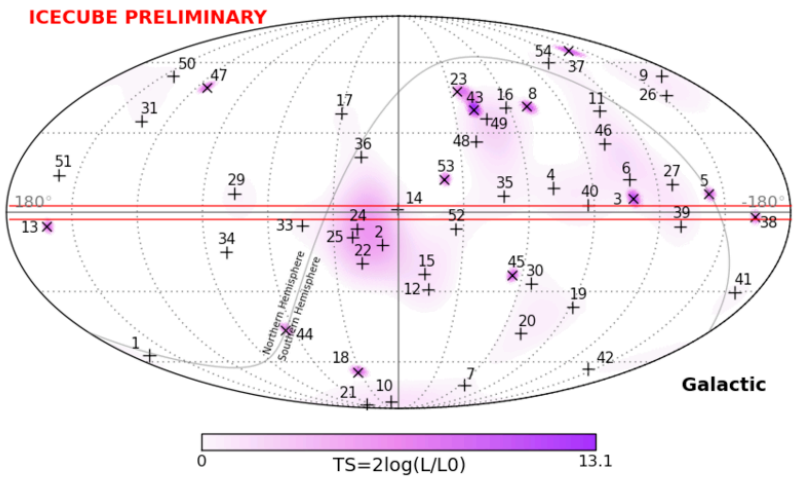
2016: Extreme High-Energy Events (EHE)

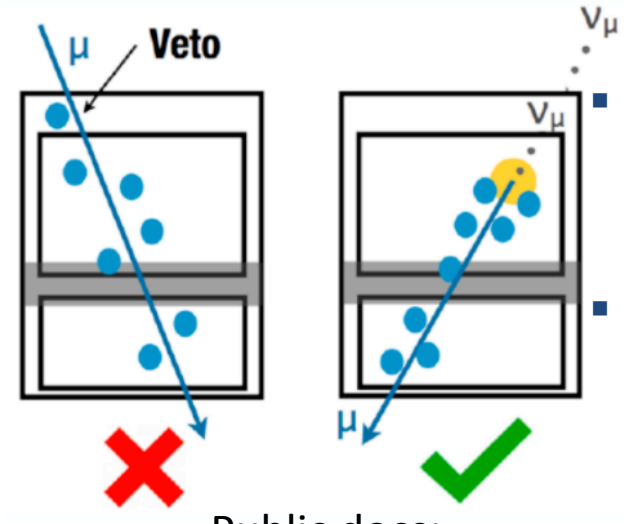
Public GCN Alerts!

High-Energy Starting Events - HESE

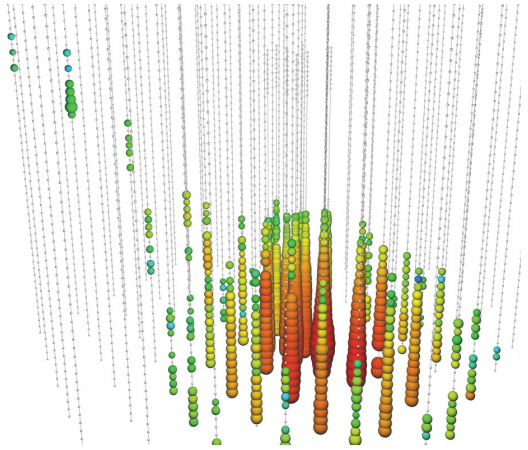
- Outer-layer veto against atmospheric muons
- Starting tracks with >6000 photoelectrons
- Short lever arms for recon
- Time-consuming offline recon

54 events in 4 years





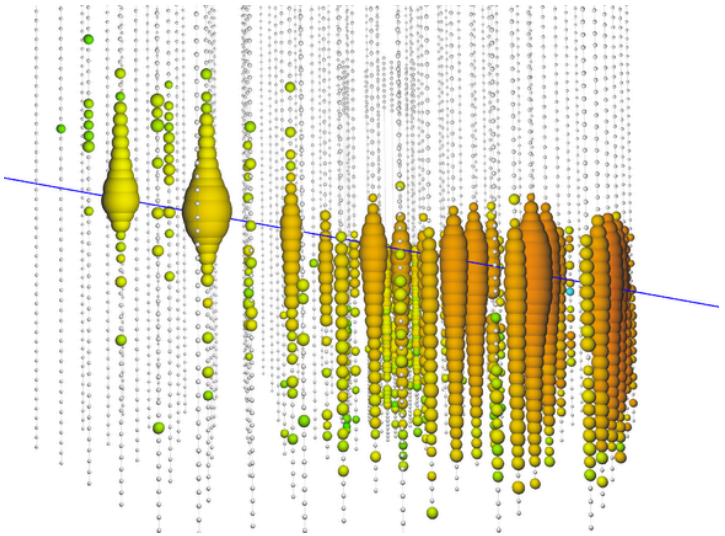
- Expectation: 3.6 alerts/yr
  (25% chance astrophysical)
- Pointing is 0.4° to 1.6° (50%)
  1.2° to 9.0° (90%)

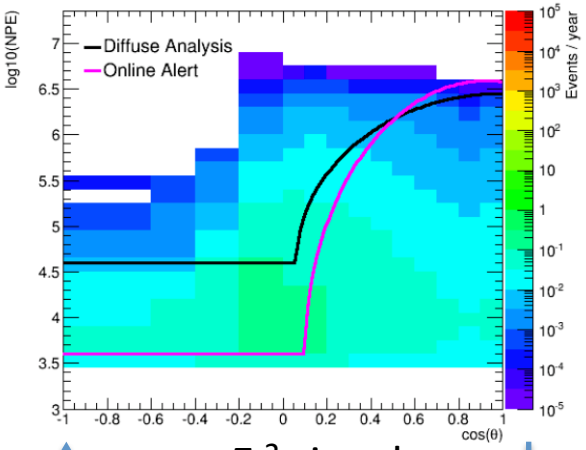


Public docs:
http://gcn.gsfc.nasa.gov/doc/Public_Doc_AMON_IceCube_GCN_Alerts_v2.pdf

Extremely High Energy - EHE

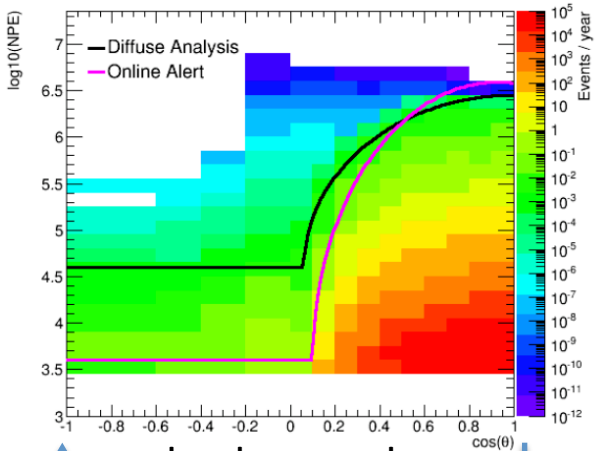
- High-quality through-going muon tracks
- Energy cuts reduce background
- Tracks with >4000 photoelectrons or higher
- Large lever arms for recon, less variation
- Still time-consuming offline recon





E^{-2} signal

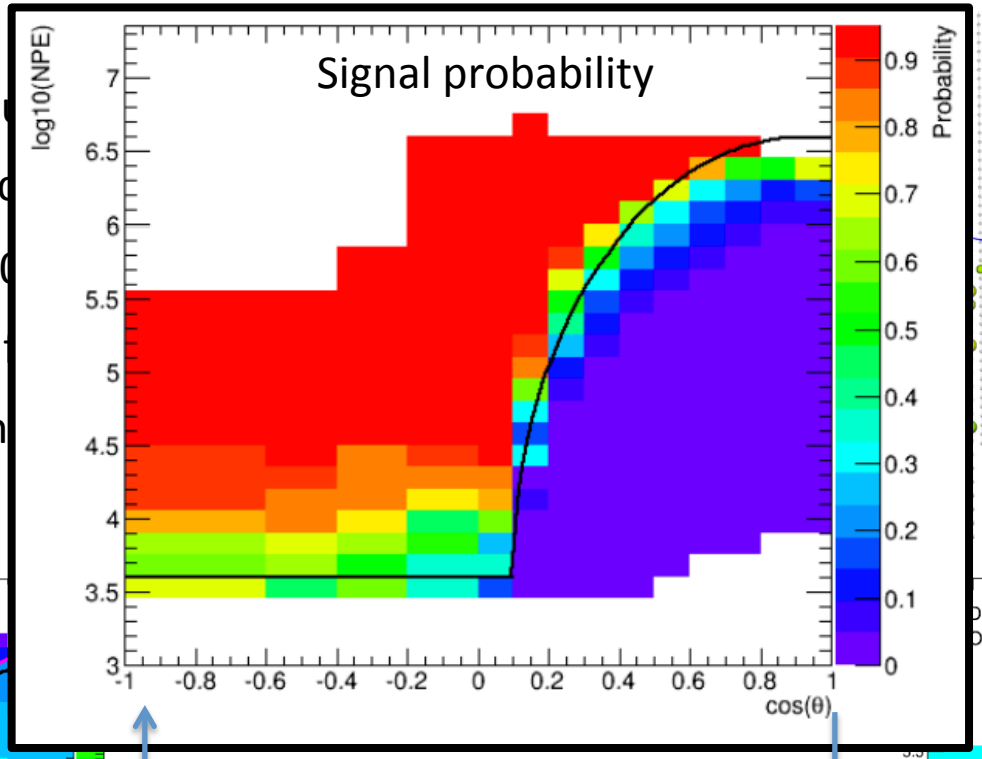
- Expectation: 4.4 alerts/yr
  (50% chance astrophysical)
- Pointing is 0.22° (50%)
  0.81° (90%)

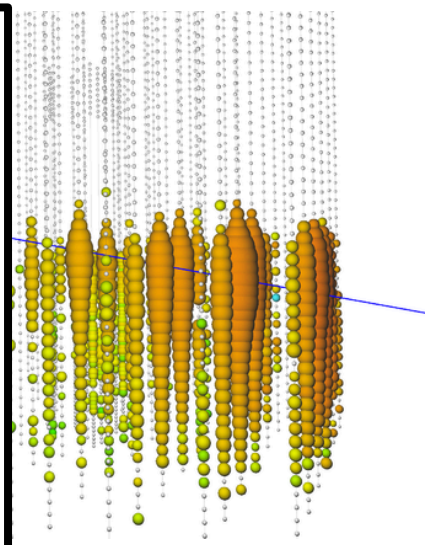


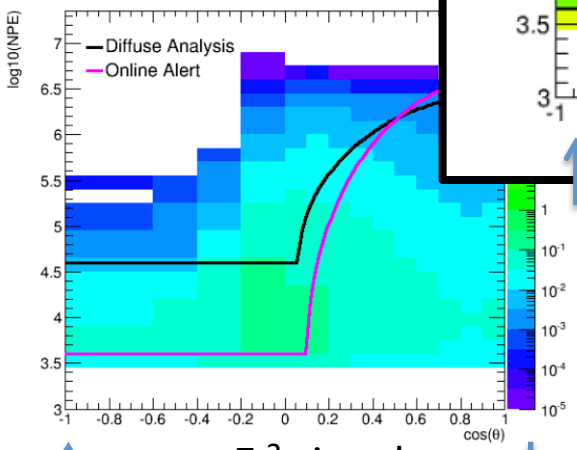
background

Extremely High Energy - EHE

- High-quality throu
- Energy cuts reduc
- Tracks with >4000
- Large lever arms
- Still time-consum

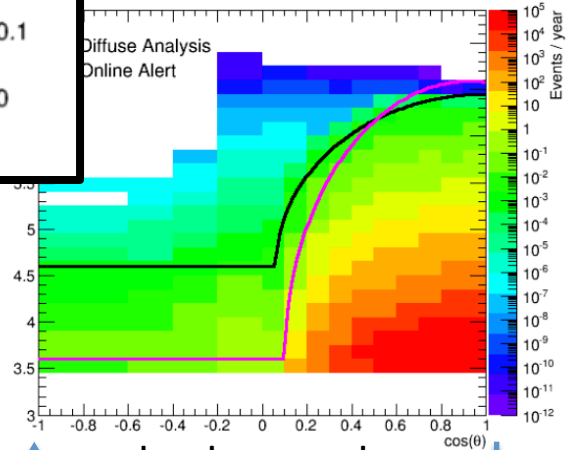






E^{-2} signal

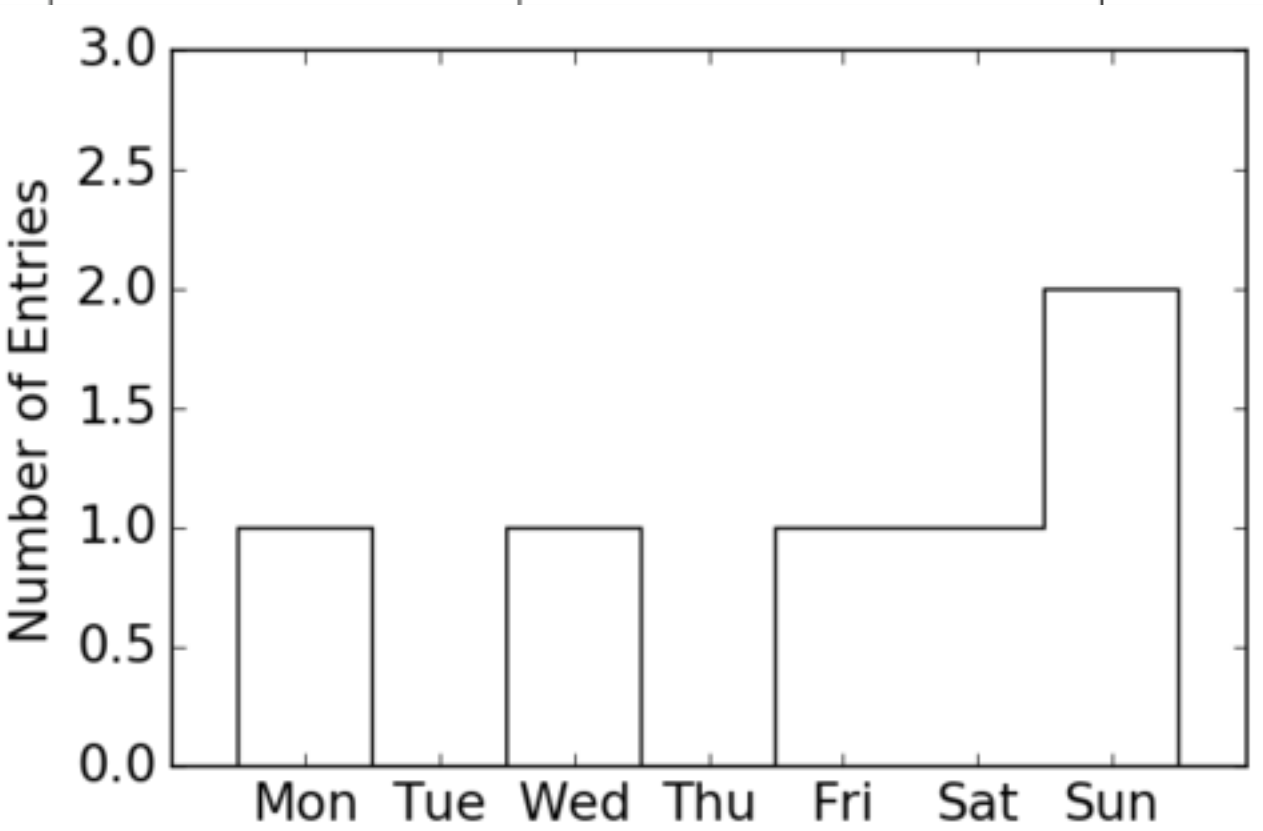
- Pointing is 0.22° (50%)
  0.81° (90%)



background

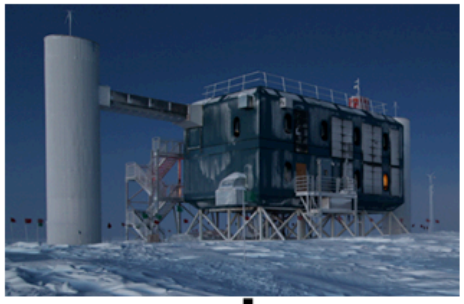
Parameter	Description	Format / Unit	Comments
TITLE	"GCN/AMON Notice"		
NOTICE_DATE	"GCN Notice Time"	UT	
SRC_RA	Right Ascension of the event	[deg]	
SRC_DEC	Declination of the event	[deg]	
SRC_ERROR	Angular uncertainty of the event	[deg]	
DISCOVERY_DATE	Event arrival time	TJD and DOY and (yy/mm/dd)	
DISCOVERY_TIME	Event arrival time	SOD and UT	
SIGNALNESS	The probability of the event being an astrophysical neutrino as estimated from simulation.	N/A	Values range from 0 to 0.95. If an event in data falls outside of the simulation coverage, the signalness value is set to -1. See the description below and Figure 4.
REVISION	Revision number of this EHE alert		The default value will be 0. See Section 2.5 for more information.
SRC_ID_NUM	Unique ID Number		
STREAM	Stream Number (AMON)		AMON stream number (=2 for EHE)
COMMENTS	"AMON_ICECUBE_EHE"		
SUN_POSTN	(RA, Dec) of the sun	[deg] and ([h,m,s],[d,,])	
SUN_DIST	Angular distance of the event relative to the Sun	[deg]	Also Sun_angle in [hr] (East of Sun)
MOON_POSTN	(RA, Dec) of the moon	[deg] and ([h,m,s],[d,,])	
MOON_DIST	Angular distance of the event relative to the Moon	[deg]	

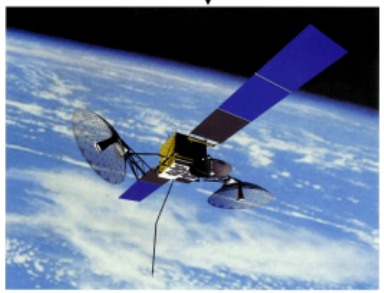
Parameter	Description	Format / Unit	Comments
TITLE	"GCN/AMON Notice"		
NOTICE_DATE	"GCN Notice Time"	UT	
SRC_RA	Right Ascension of the event	[deg]	
SRC_DEC			
SRC_ERROR			
DISCOVERY_DAT			
DISCOVERY_TIM			
SIGNALNESS			ange from 0 to an event in data ide of the simula- erage, the signal- e is set to -1. See iption below and
REVISION			ult value will be ction 2.5 for more ion.
SRC_ID_NUM			
STREAM			stream number EHE)
COMMENTS			
SUN_POSTN	(RA, Dec) of the sun	[deg] and ([h,m,s],[d,,])	
SUN_DIST	Angular distance of the event relative to the Sun	[deg]	Also Sun_angle in [hr] (East of Sun)
MOON_POSTN	(RA, Dec) of the moon	[deg] and ([h,m,s],[d,,])	
MOON_DIST	Angular distance of the event relative to the Moon	[deg]	



Revisions

- Full likelihood scans now fully automated
  - Refined position now available within 1 to 2 hours

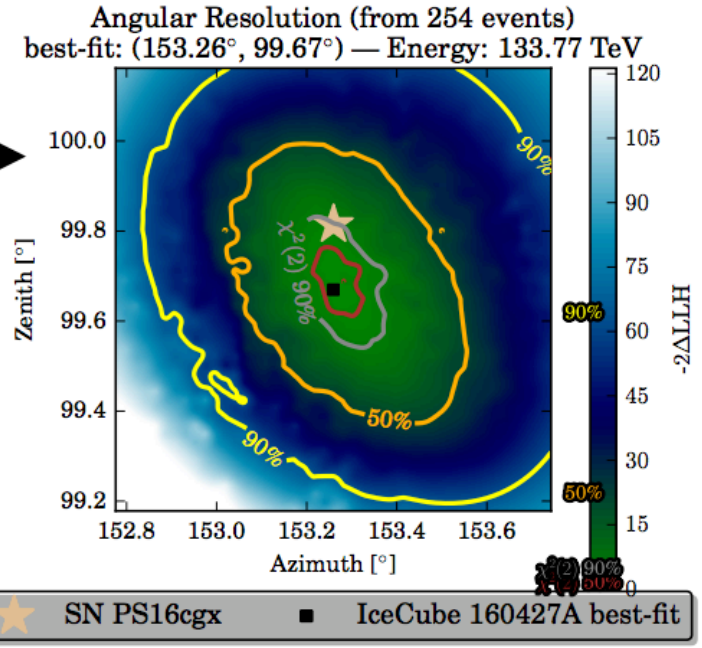




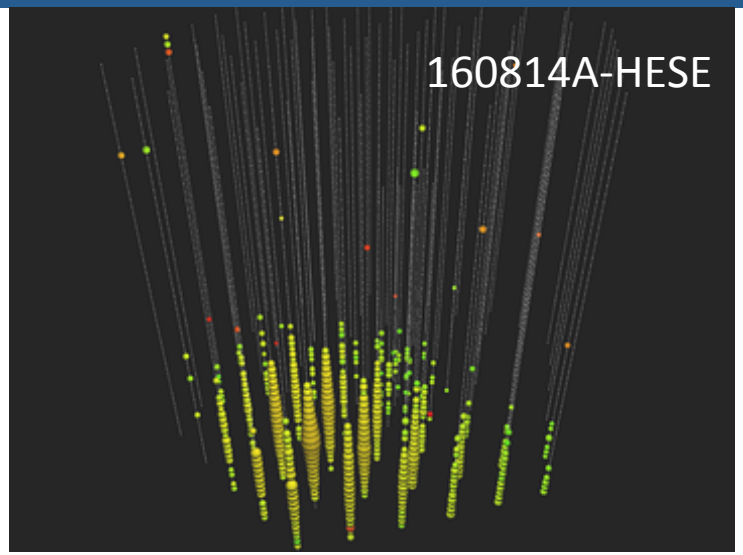
~1000-core cluster
automated scripts

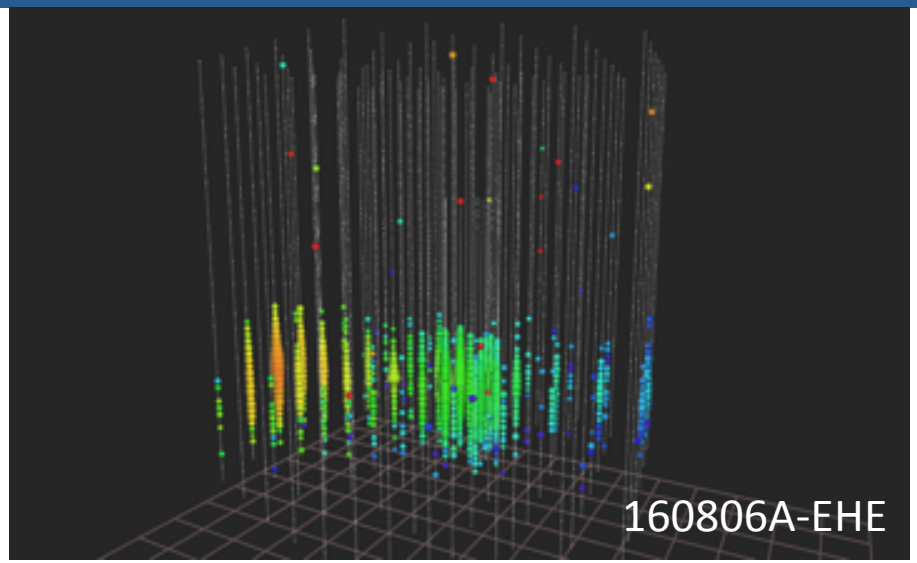
grad student

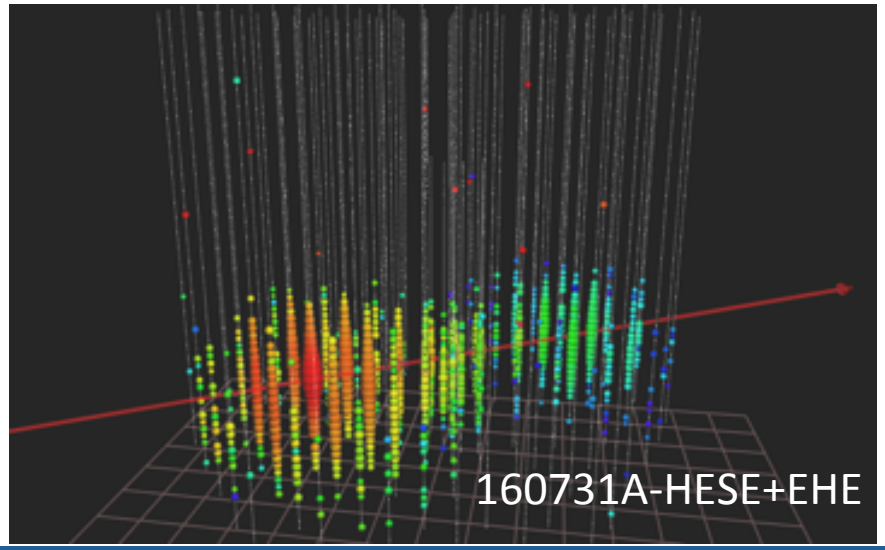
IceCube Live

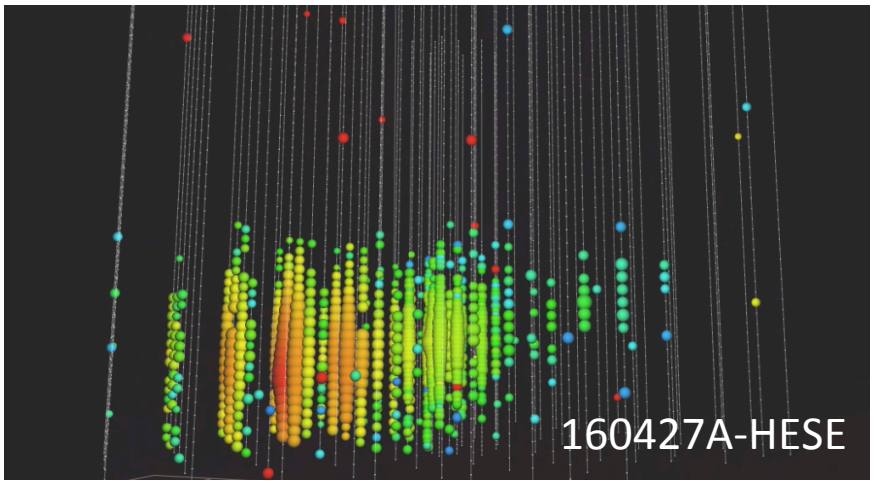


Four EHE/HESE Alerts to Date









Four EHE/HESE Alerts to Date

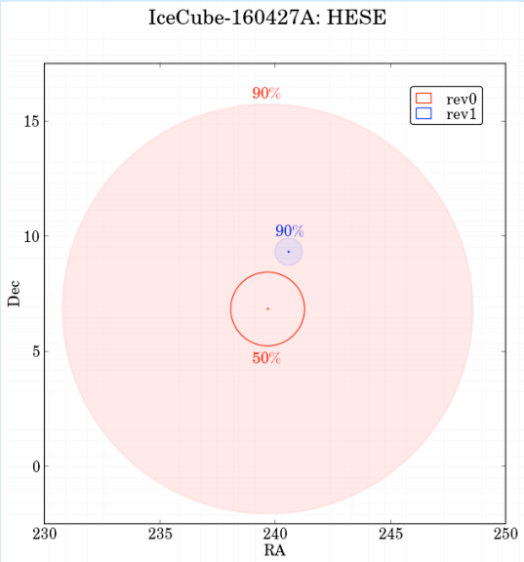
Same Neutrino!

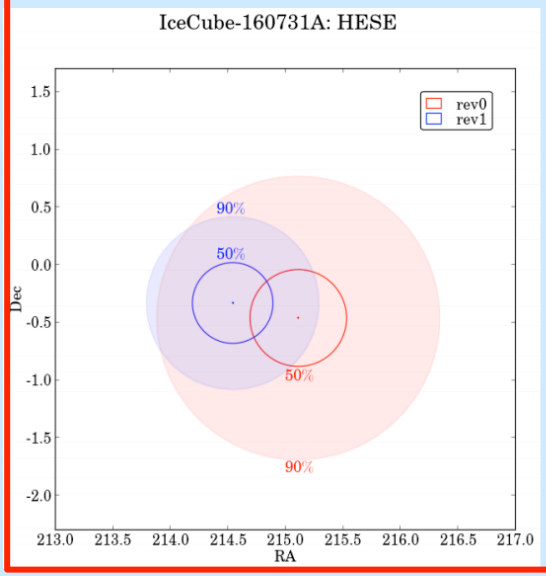
Alert name/type	160814A/HESE	160806A/EHE	160731A/HESE	160731A/EHE	160427A/HESE
RA/DEC (rev1) RA/DEC (rev2)	[199.31°, -32.02°] [200.25°, -32.35°]	[122.80°, -0.73°] [122.81°, -0.81°]	[215.11°, -0.46°] [214.54°, -0.33°]	[215.09°, -0.42°] [214.54°, -0.33°]	[239.66°, +6.85°] [240.57°, +9.34°]
θ/φ (rev1)	180.68° / 57.89°	89.21° / 107.85°	89.47° / 212.57°	89.51° / 212.59°	153.43° / 96.82°
Resolution	0.48° (50%), 1.49° (90%)	0.11° (50%)	0.42° (50%), 1.23° (90%) 0.35° (50%), 0.75° (90%)	0.17° (50%), ~0.8° (90%) 0.35° (50%), 0.75° (90%)	1.6° (50%), 8.9° (90%) 0.6° (90%)
Energy	?	~62 TeV	~130 TeV	~130 TeV	~150 TeV
ST or Signalness	0.12	0.28	0.91	0.85	0.92
Latency: Event t0 to GCN alert sending	42 s	37 s	41 s	54 s	81 s
Followups					
GCN Notices	http://gcn.gsfc.nasa.gov/notices_amon/58537957_128340.amon	http://gcn.gsfc.nasa.gov/notices_amon/26552458_128311.amon	http://gcn.gsfc.nasa.gov/notices_amon/6888376_128290.amon	http://gcn.gsfc.nasa.gov/notices_amon/6888376_128290.amon	http://gcn.gsfc.nasa.gov/notices_amon/67093193_127853.amon

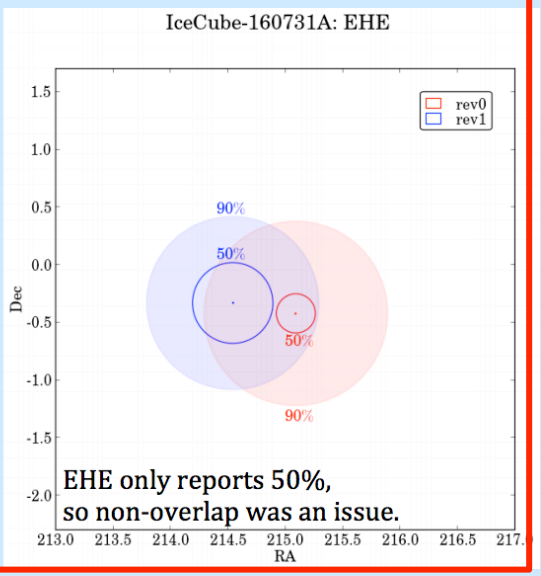
AGILE, ANTARES, FACT, Fermi GBM, Fermi LAT, HAWC, H.E.S.S, INTEGRAL, IPN, Konus-Wind, LCOGT, MAGIC, MASTER, Maxi/GSC, Pan-STARRS, PTF, Swift, VERITAS

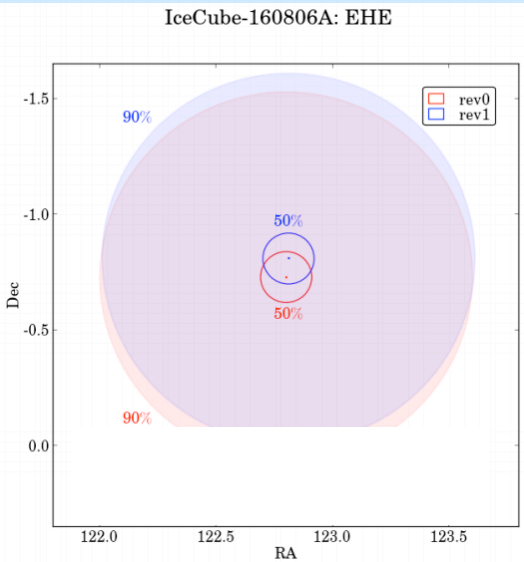
Four EHE/HESE Alerts to Date

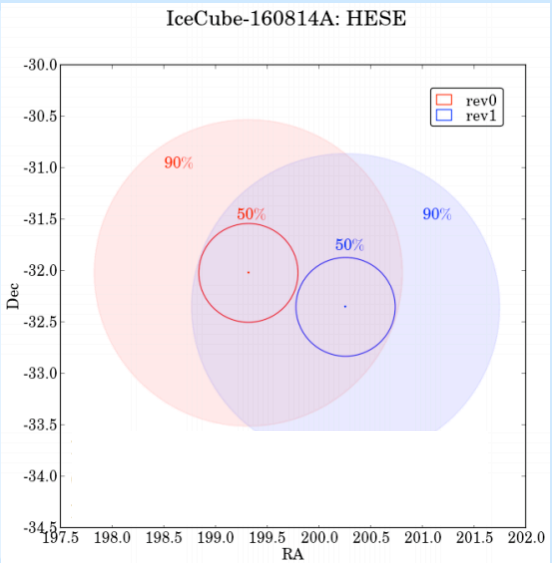
Same Neutrino!







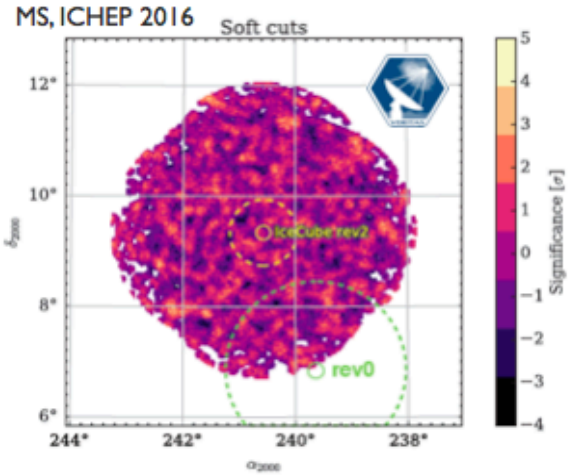




IceCube-160427A-HESE GFU

H.E.S.S.

★ automatic **follow-up < 2 min**
★ duration: 2h (full H.E.S.S.-II array)
2016-04-28: 18min (first position)
2016-04-29: 1.5h (updated position)
2016-04-30: 0.5h (updated position)
★ analysis in progress



VERITAS

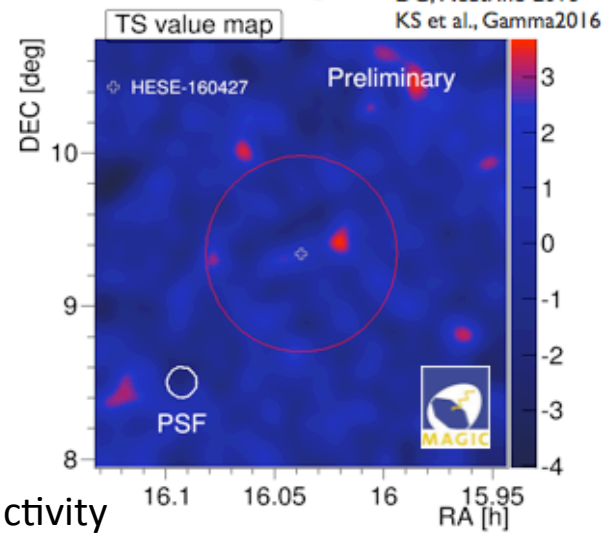
★ automatic **follow-up in 112s**
★ duration: 1.2 h (first) + 2 h (updated)
★ moonlight settings - reduced high-voltage
★ UL ~ few % C.U.

FACT

★ observed updated position
★ duration: 4.24 h
2016-04-28 2:00 – 4:32 UTC
2016-04-29 1:32 – 3:33 UTC
★ zd: 19 – 30°
★ moderate moon light
★ some clouds in the 1st night
★ weather fine in the 2nd night
★ no signal found

MAGIC

★ 2h data taken on 29/04/2016 with moderate moon (updated position)
★ night 27/28 Apr not possible - Moon too bright
★ zenith range: 18-26 deg
★ E threshold ~120 GeV
★ hot spot 0.3 deg away, significance: ~ 3.6 sigma (2.1 sigma after trials)
★ UL - analysis ongoing...



Fermi-LAT saw 5 blazars within error circle – no activity

IceCube-160427A-HESE Pan-STARRS

- GCN 19381
- No bright transient source found, but several dim candidates
- Eight variable AGN in error circle
- Seven supernova candidates (mags 20.5 < i < 22.1)
  - PS16cgx at z = 0.29 rose by 0.4 mag over 2 days following alert
  - Rise time consistent with explosion time around the neutrino arrival time
  - Supernova could be either type Ia or type Ic
    - Models say only CCSN interesting for neutrino production
    - If type Ic chance probability quite low: p~1%
    - If type Ia chance probability not as striking: p~10%
    - Spectroscopic followup inconclusive

Summary

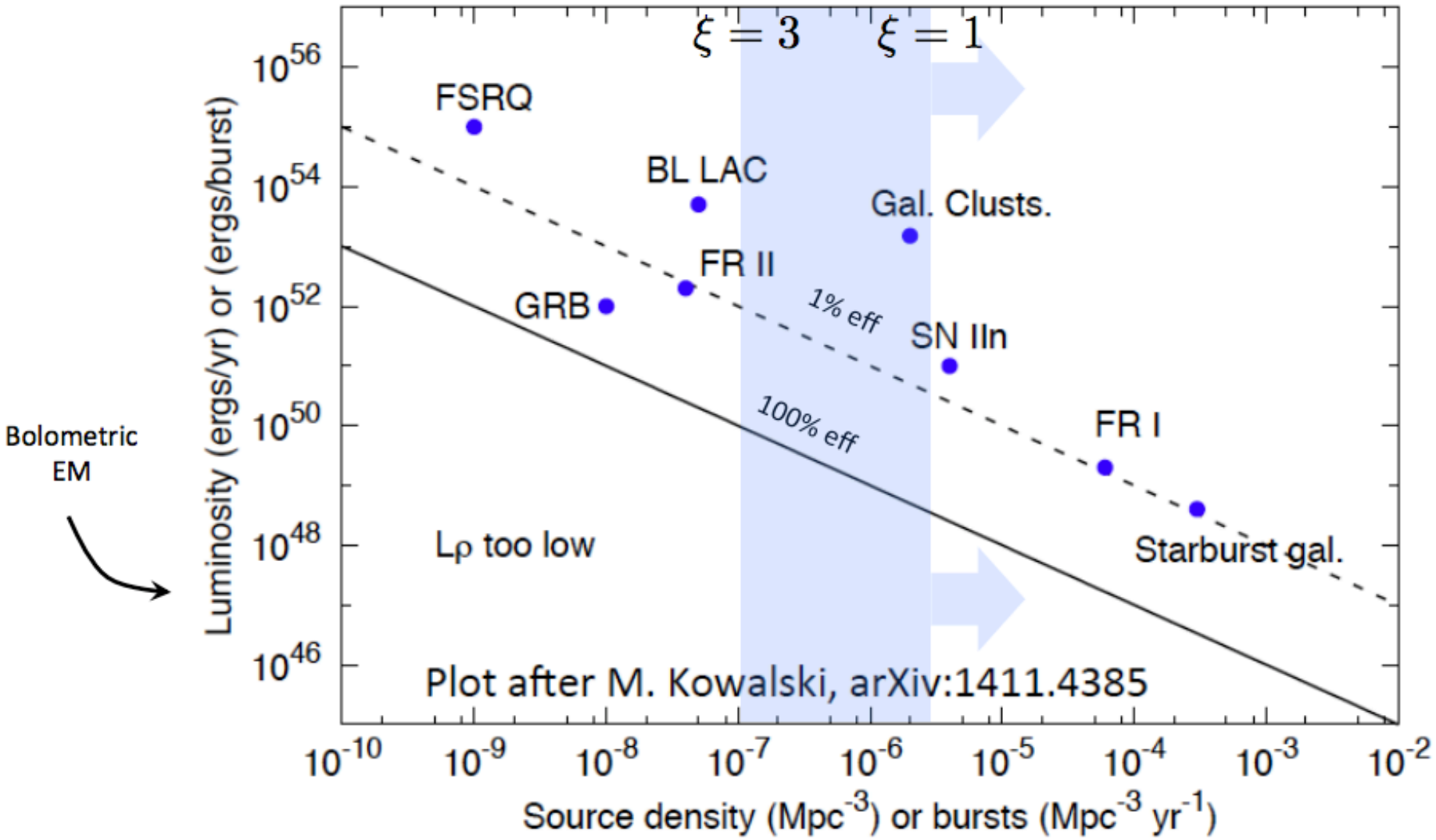
- Realtime alerts from IceCube have seen steady upgrades through the years
  - Current focus**: Single high-energy events** distributed to the public through GCN
  - New organizational structure in place to respond quickly and efficiently
  - Will start using GCN Circulars to provide status updates to the community

- Some (likely coincidental) associations with **supernova**:
  - OFU: medium-energy neutrino duplet
    - Type IIn rare in itself but neutrinos 158 days after t0, much later than a priori 1-day window (p = 1.4% a posteriori)
  - HESE: high-energy neutrino singlet
    - Possibly type Ic and arrived within t0 uncertainty
    - p = 1% if Ic, 10% if Ia
    - Stay tuned for more details in the publication

- We have sent **just 4 HESE/EHE** 'signal-rich' alerts
  - Likely only 1 or 2 are astrophysical (i.e. not background)
  - Still venturing into uncharted waters...

Backup

Potential neutrino sources – Kowalski plot



Back of the envelope disfavors : FSRQs, BL LACs, GRBs, FR II

Other work: Ahlers and Halzen, PRD 2014. Murase and Waxman arXiv:1607.01601