REAL-TIME ALERTS FROM ICECUBE

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FOR THE ICECUBE COLLABORATION

HAP WORKSHOP - THE NON-THERMAL UNIVERSE
2016/09/22, ERLANGEN
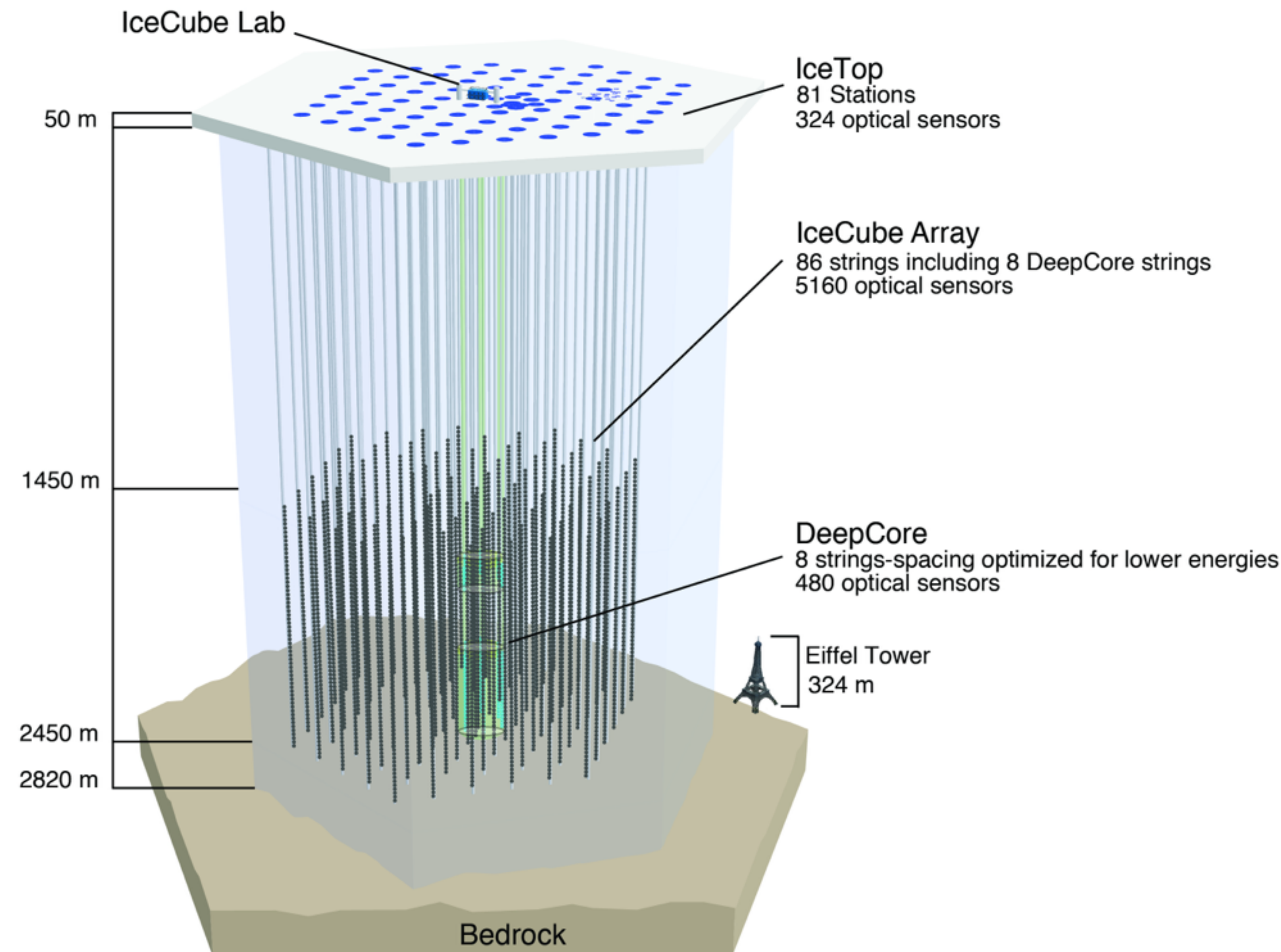
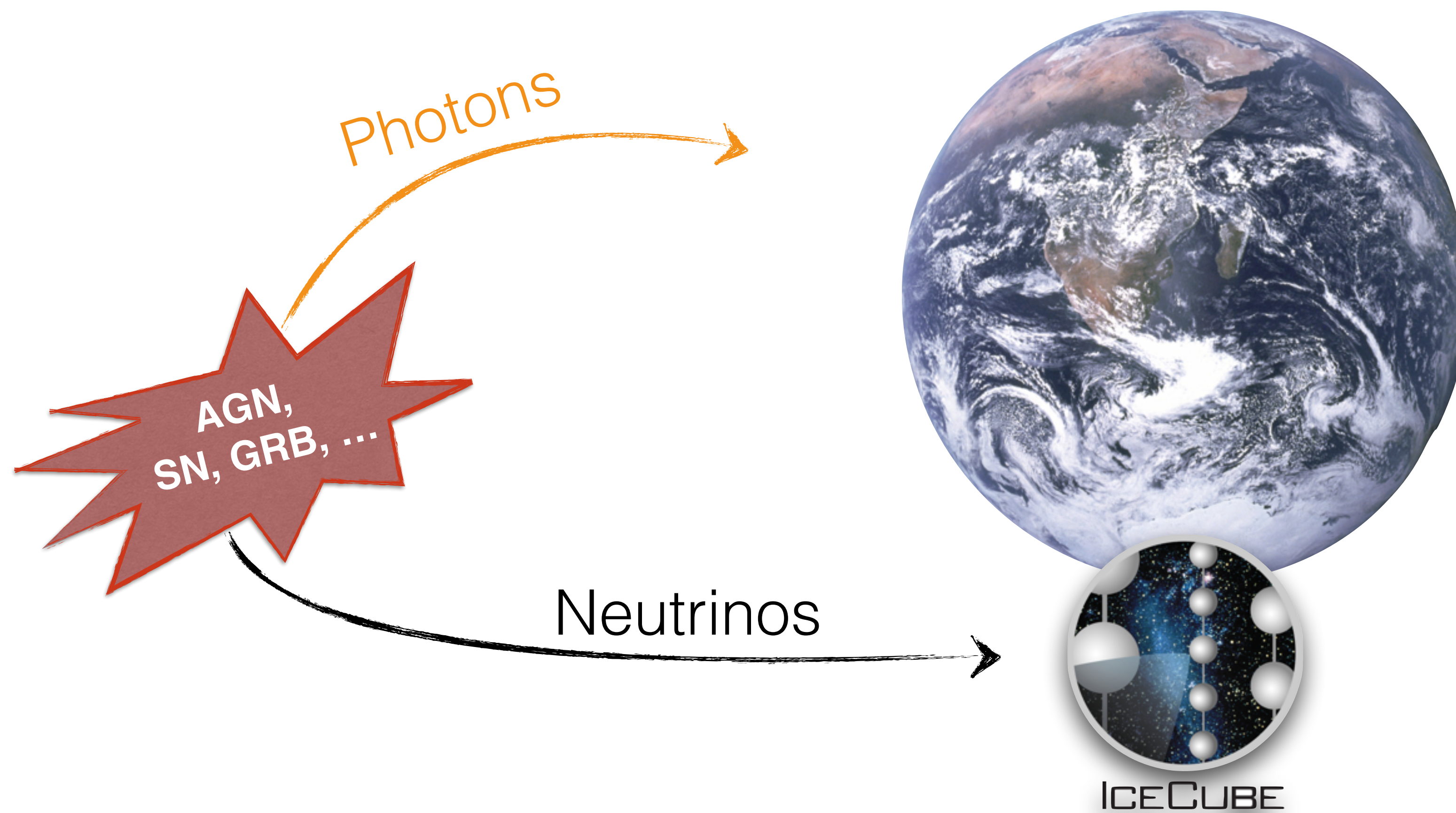# OUTLINE

‣ IceCube Detector

‣ Real-Time Infrastructure

‣ Follow-Up / Alert Programs

  ‣ Gamma-Ray Follow-Up, Optical Follow-Up
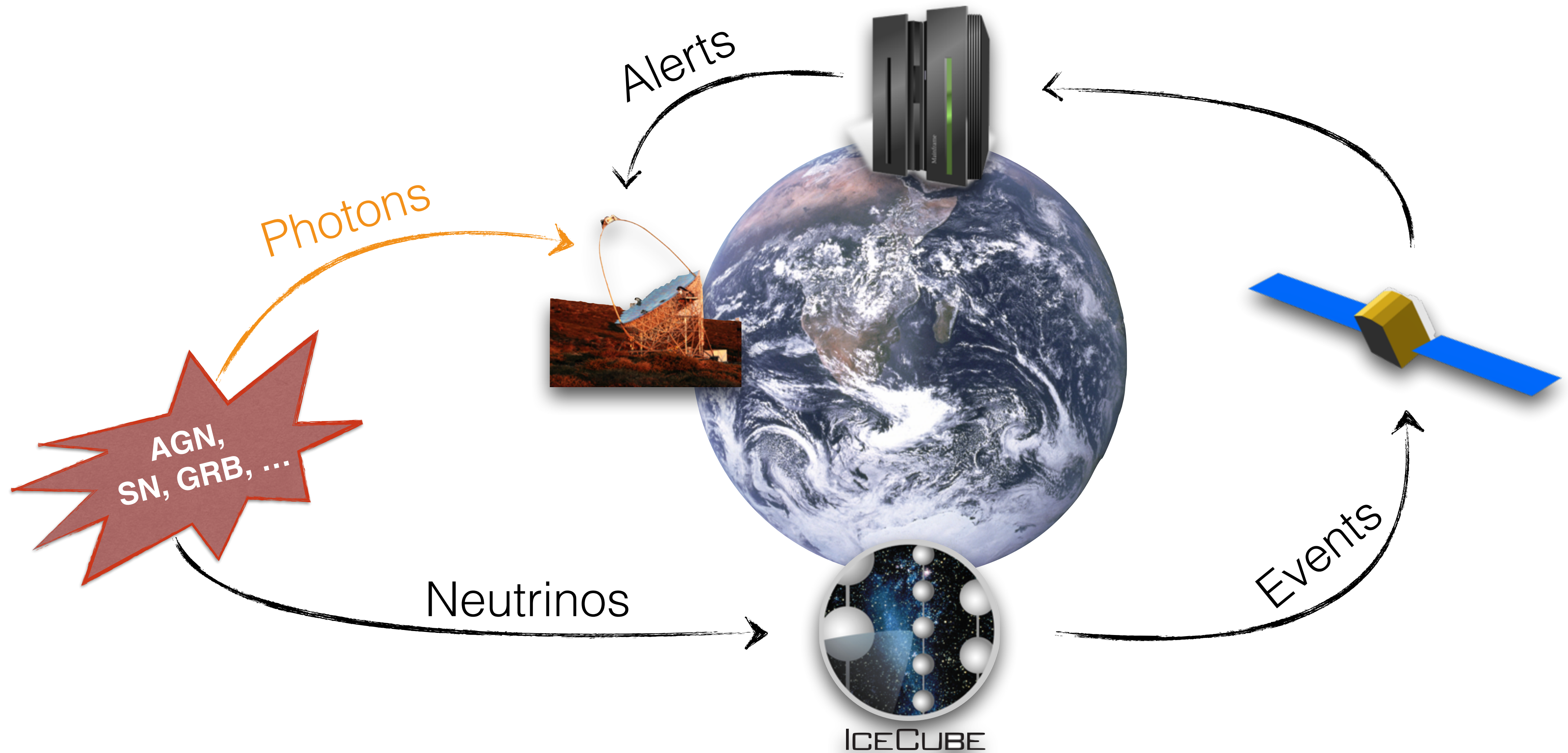
  ‣ HESE and EHE Alerts

‣ Summary

THE ICECUBE DETECTOR

- ‣ 1 km^3 detector for Cherenkov light at the South Pole

- ‣ 5160 optical modules on 86 strings

- ‣ Scope of this talk:
  Muons from CC ν_μ interaction

- ‣ Angular resolution:
  typically better than 1 deg

IceCube Lab

50 m

IceTop
81 Stations
324 optical sensors

IceCube Array
86 strings including 8 DeepCore strings
5160 optical sensors

1450 m

DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors

Eiffel Tower
324 m

2450 m
2820 m

Bedrock

REAL-TIME ALERT SYSTEM

Photons

AGN,
SN, GRB, …

Neutrinos

ICECUBE

REAL-TIME ALERT SYSTEM

Alerts

Photons

AGN, SN, GRB, …

Neutrinos

Events

ICECUBE

REAL-TIME OPERATIONS

‣ Limited computing resources
    at the South Pole

‣ Limited connectivity
    Iridium: low latency, low bandwidth
    TDRSS: high latency, high bandwidth

‣ Limited detector monitoring
    (i.e. no „Good Run List")

‣ Fast/specialized event selections

‣ Basic event information first
    for quick generation of alerts

‣ Full event later
    for improved reconstruction

‣ Conservative online monitoring

REAL-TIME ANALYSES IN ICECUBE

Clustering Searches

2008: Optical Follow-Up (OFU)

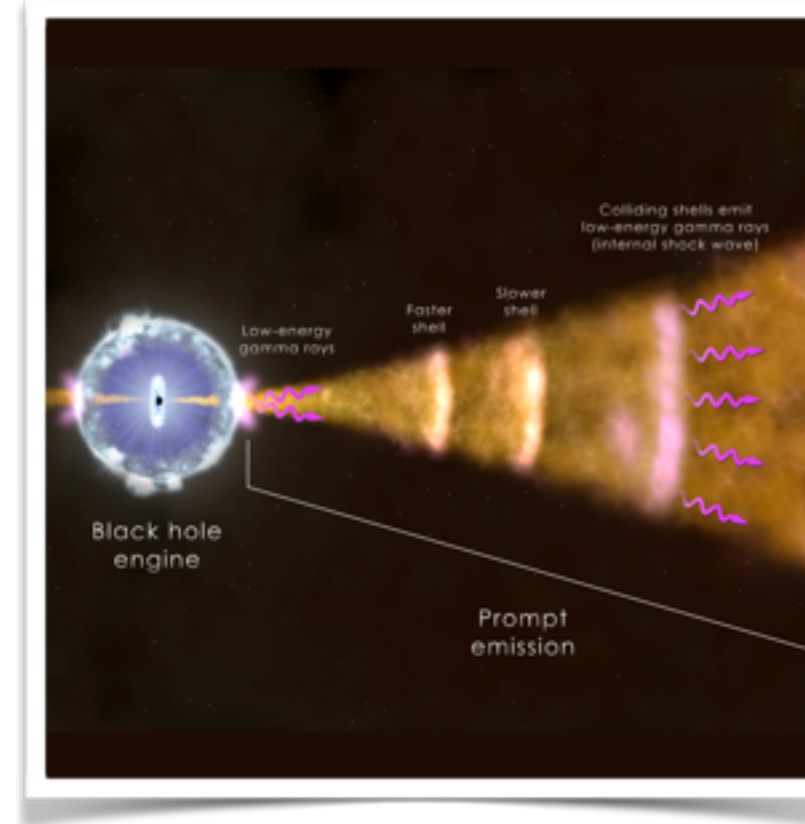**2012: Gamma-Ray Follow-Up (GFU)**

Individual Events

2015: High-Energy Starting Events (HESE)

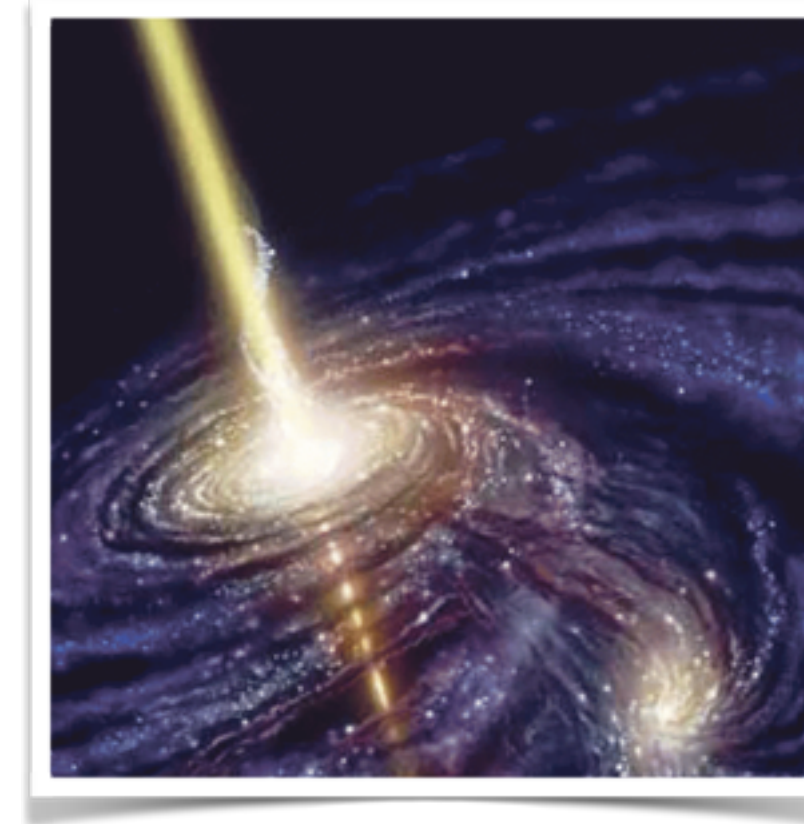**2016: Extreme High Energy Events (EHE)**

GAMMA, OPTICAL AND X-RAY FOLLOW-UP

Target:
transient and
variable sources

GRB: 10–100 s

AGN: ~ 10 d

SN: ~ 100 d

Time-dependent analyses:
- Optical/X-ray Follow-Up: Multiplets within 100 seconds
- Gamma-Ray Follow-Up: Cluster search for up to 21 days

GAMMA-RAY FOLLOW-UP

Event Selection
- ‣ Fast, BDT-based
- ‣ Picking well-reconstructed, through-going muon tracks
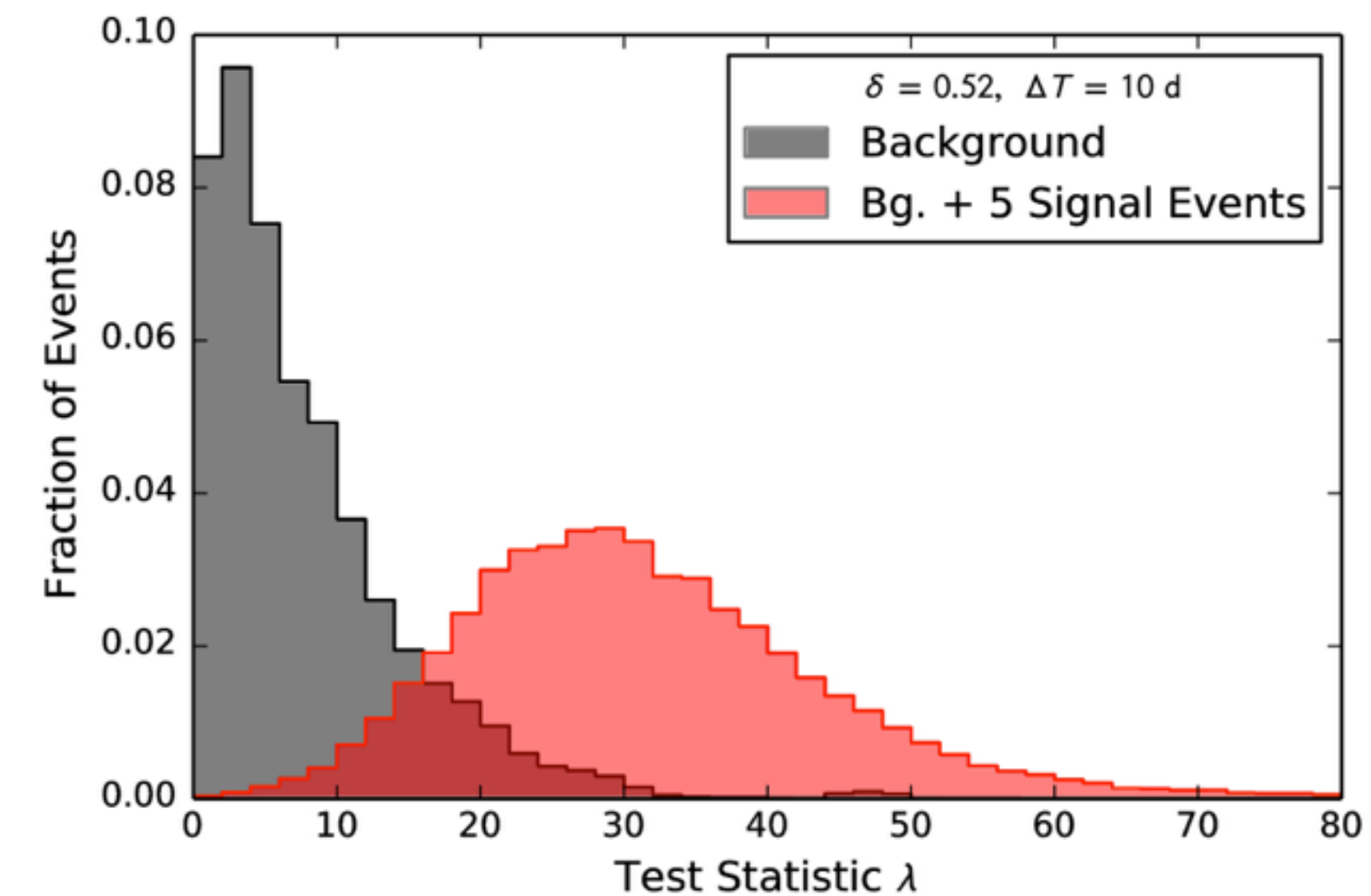
Sending to the North
- ‣ Basic information: direction, energy, uncertainty

Clustering Analysis
- ‣ Likelihood analysis: 21 day point-source search
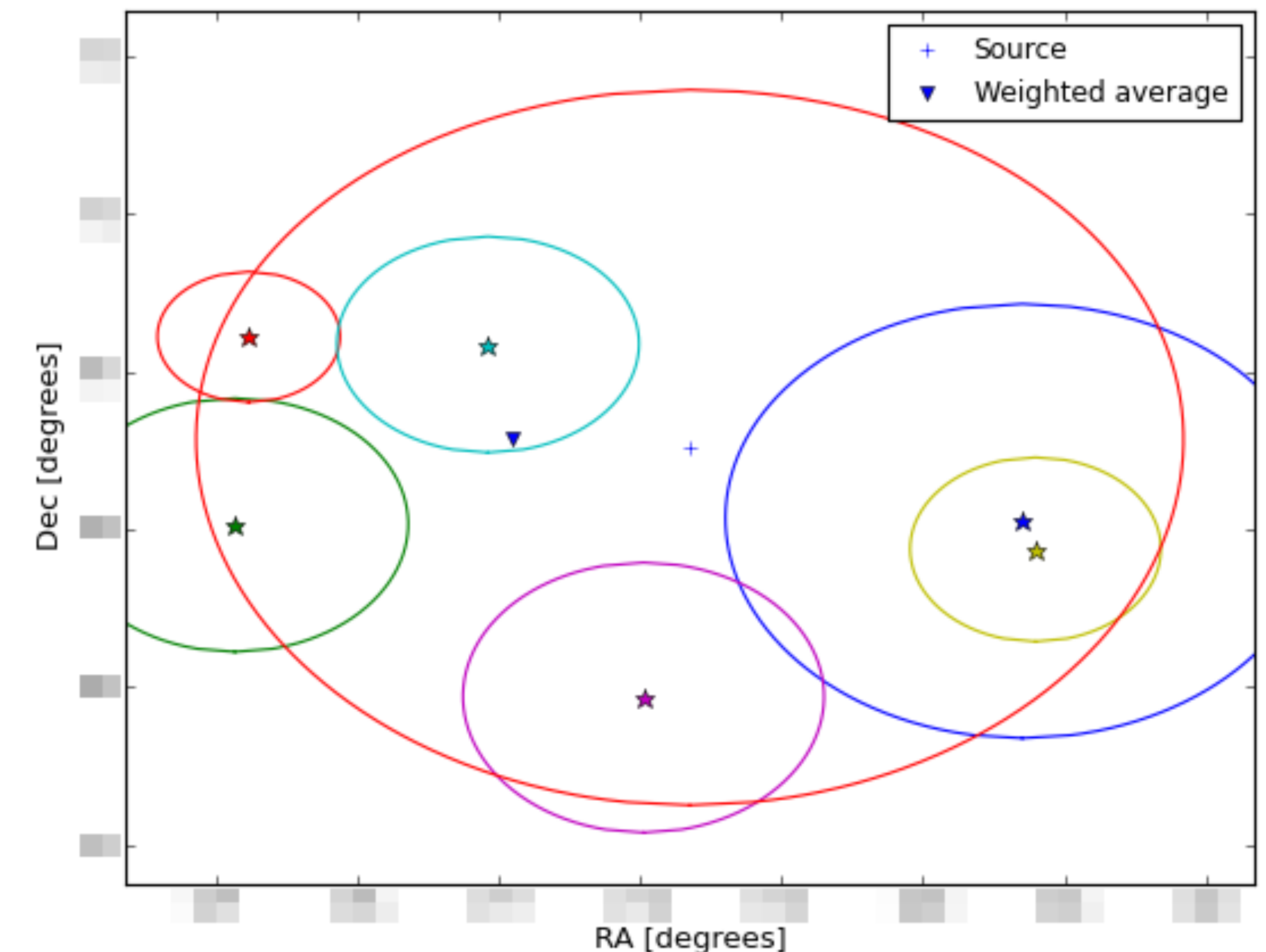- ‣ Pre-agreed upon list of sources

Alerts
- ‣ 2 alerts/year to MAGIC and VERITAS

- ‣ Most significant alert: 2012/11/09
  - 6 events within 4.2 days
  - p-Value: 0.002% (pre-trial)

- ‣ Alert forwarded to VERITAS
- ‣ No significant evidence for gamma-ray emission seen

Future plan: Addition of a
generic clustering search on the whole sky

RESULTS FROM THE OFU PROGRAM

- ‣ Straight cuts for multiplets
  - … in space (3.5 deg)
  - … and time (100 s)

- ‣ Most significant doublet: 2012/03/30
  - two neutrinos within 1.7 s
  - 0.14 deg away from CCSN PTF12csy
  - p-Value: 0.014
  - neutrinos likely unrelated to SN

- ‣ Growing list of follow-up observatories:

  ~~ROTSE~~, PTF, MASTER, SWIFT, (ASAS-SN, LCOGT)
  in preparation
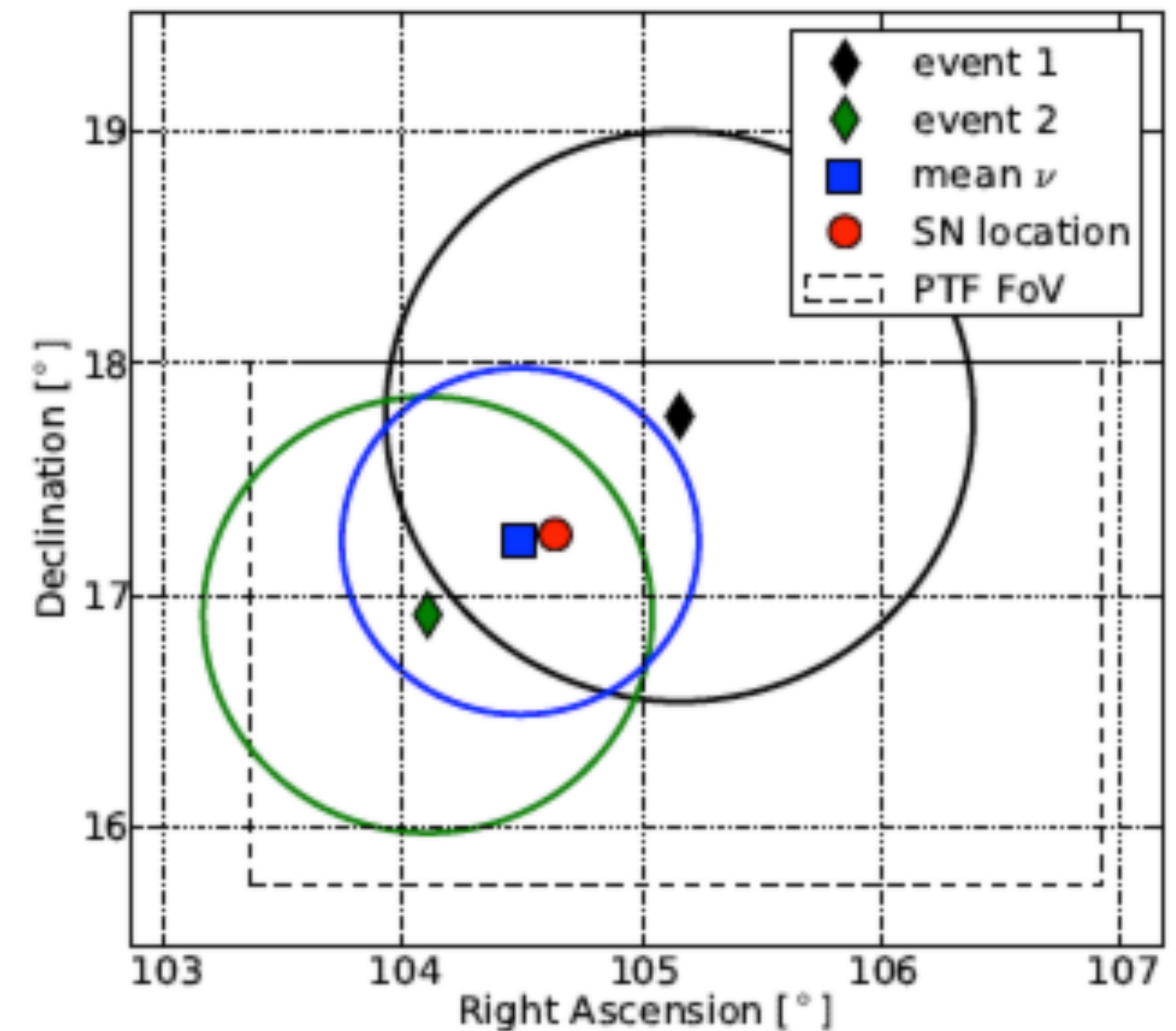
HIGH ENERGY STARTING EVENTS

- ‣ Veto against atmospheric muons by outer detector layer

- ‣ Starting tracks with Q > 6000 pe, but short lever arm

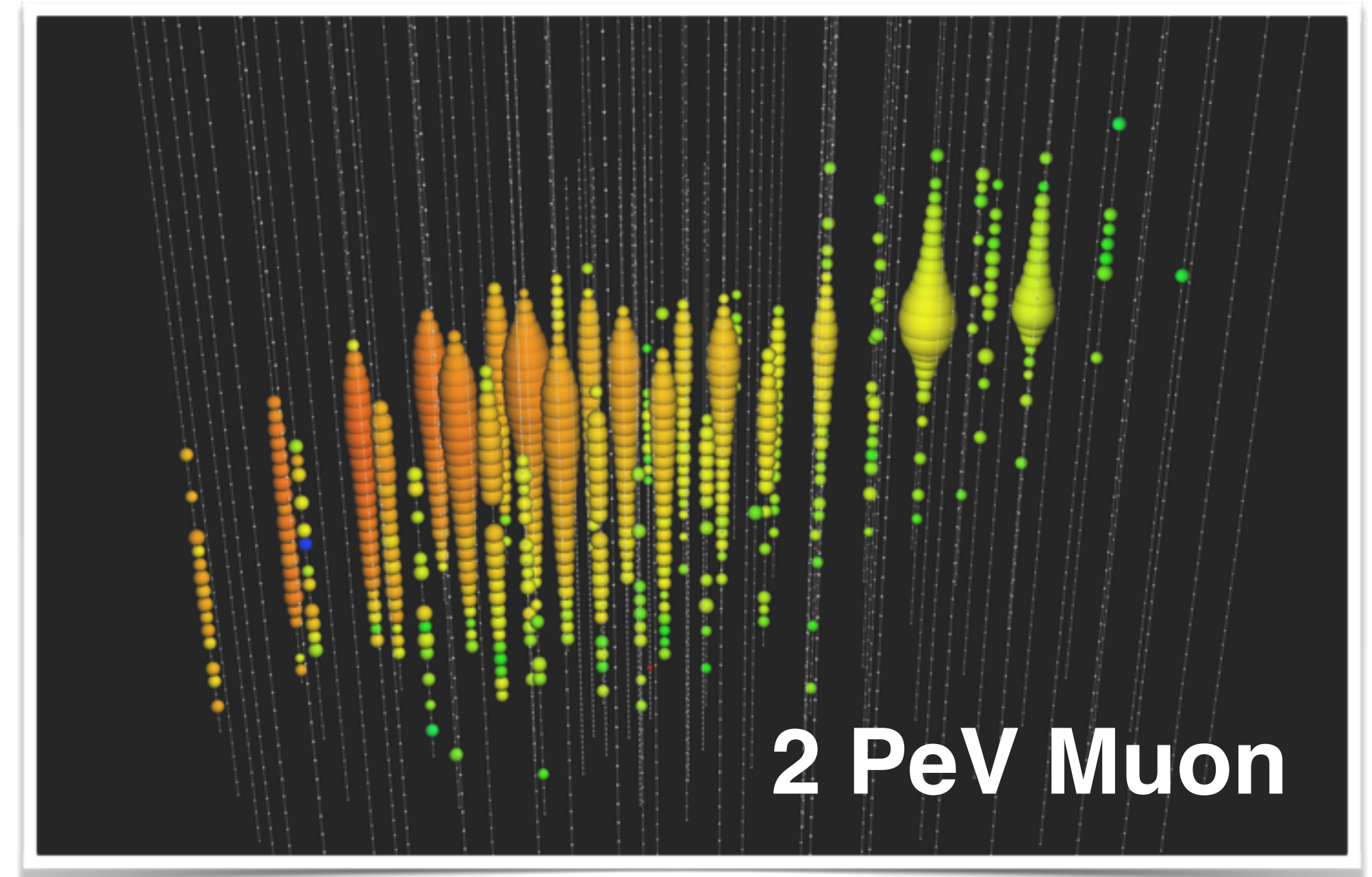- ‣ Expensive reconstruction (→revised alerts)
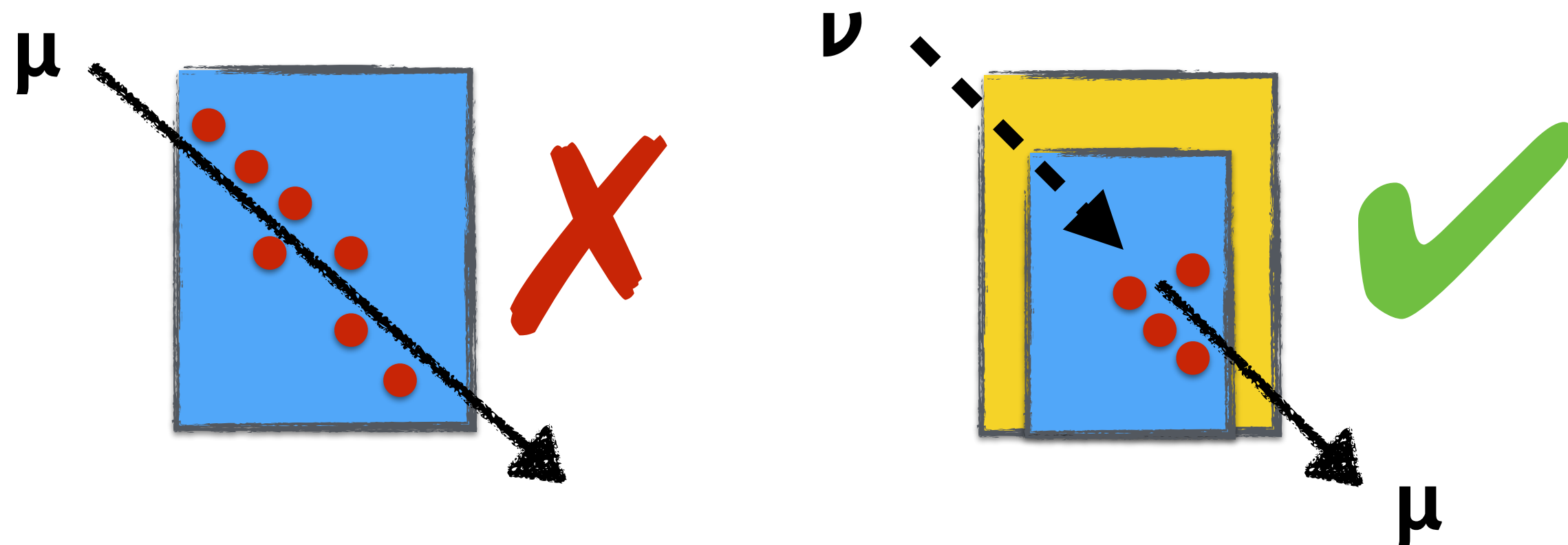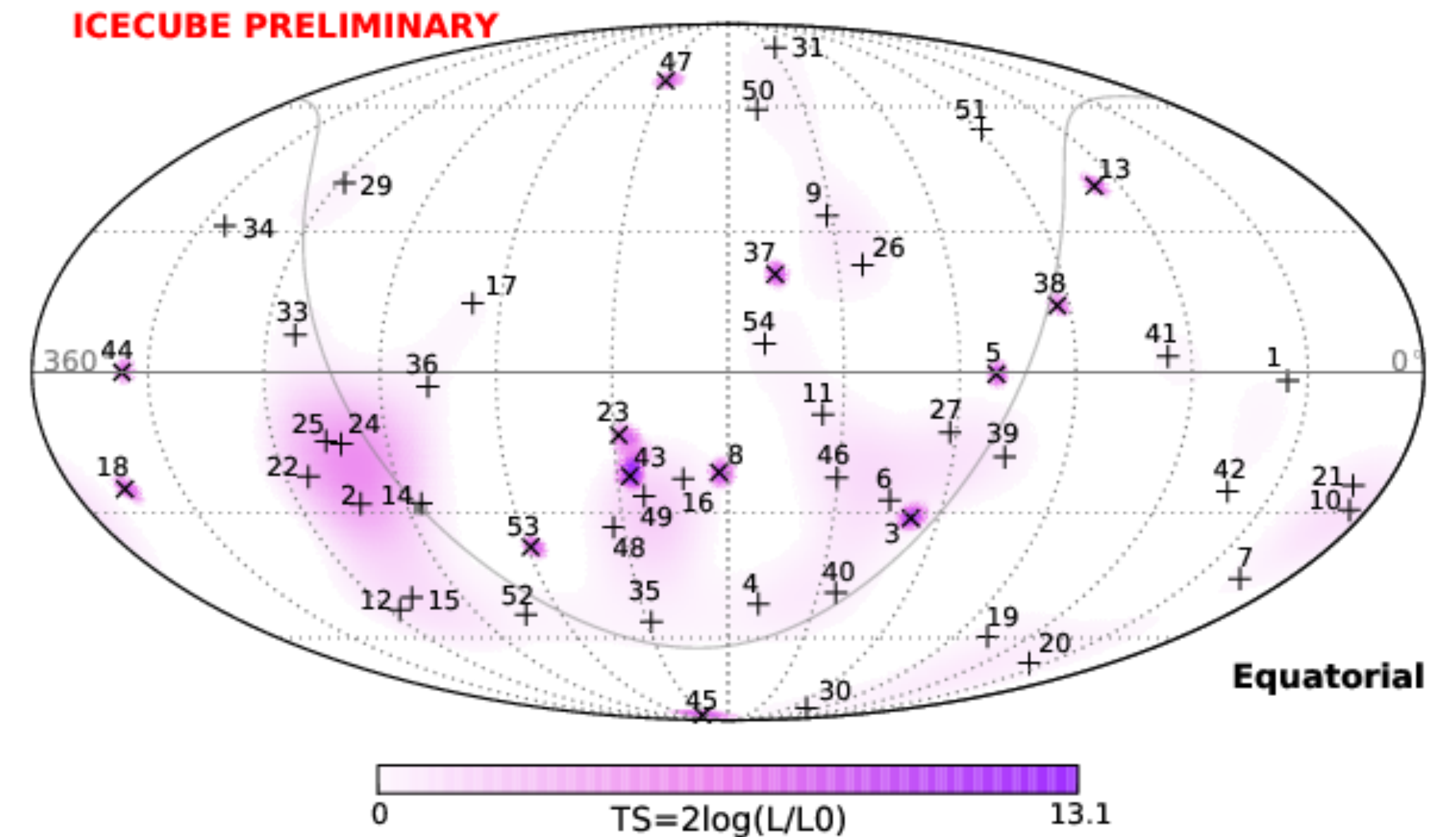
Public events (GCN)
~ 4 alerts / year

EXTREME HIGH ENERGY EVENTS

‣ High-energy, throughgoing events
‣ $N_{pe} > 3000$
‣ Very good resolution (<0.2 deg)

‣ Public alerts (GCN)

‣ Expected yield (S+B):
  • 4+2 events/year (E^{-2})
  • 2+2 events/year ($E^{-2.5}$)

2 PeV Muon

FIRST HESE/EHE ALERTS

Date	Type	RA	Dec	50% Error
2016/04/27	HESE	240.6 deg	9.3 deg	0.6 deg
2016/07/31	EHE + HESE	214.5 deg	-0.3 deg	0.35 deg
2016/08/06	EHE	122.8 deg	-0.7 deg	0.11 deg
2016/08/14	HESE	200.3 deg	-32.4 deg	0.48 deg

‣ all alerts published as GCN (via AMON)

‣ responses from observers also via GCN

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Gamma-Rays

Observer	Result
IPN	no detection
Fermi-LAT	5 unrelated blazars
Fermi-GBM	no detection
FACT	no detection
VERITAS	no detection
HAWC	no detection
MAGIC	no detection?

Optical

Observer	Result
iPTF	3 transients, all AGN
MASTER	no detection
PanSTARRS	7 SN candidates

SUMMARY

‣ **Long-standing experience in realtime analyses**
  Clustering searches
  Single events

‣ **Successful exchange of alerts** with
  MAGIC, VERITAS, HESS, ROTSE, PTF, SWIFT, MASTER, …

‣ **Alerts are shared**…
  … directly through MoU with partners
  … through AMON / GCN