IceCube EHE Online Alert

Matt Relich
December 21, 2014
Neutrino Frontier Workshop
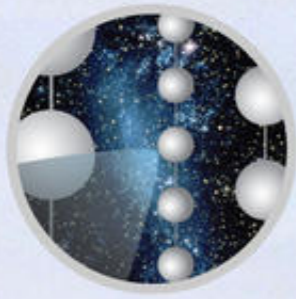
The IceCube Collaboration

Canada
University of Alberta–Edmonton
University of Toronto

USA
Clark Atlanta University
Drexel University
Georgia Institute of Technology
Lawrence Berkeley National Laboratory
Michigan State University
Ohio State University
Pennsylvania State University
South Dakota School of Mines & Technology
Southern University and A&M College
Stony Brook University
University of Alabama
University of Alaska Anchorage
University of California, Berkeley
University of California, Irvine
University of Delaware
University of Kansas
University of Maryland
University of Wisconsin–Madison
University of Wisconsin–River Falls
Yale University

Niels Bohr Institutet, Denmark

Chiba University, Japan

Sungkyunkwan University, Korea

University of Oxford, UK

Belgium
Université Libre de Bruxelles
Université de Mons
Universiteit Gent
Vrije Universiteit Brussel

Sweden
Stockholms universitet
Uppsala universitet

Germany
Deutsches Elektronen-Synchrotron
Friedrich-Alexander-Universität Erlangen-Nürnberg
Humboldt-Universität zu Berlin
Ruhr-Universität Bochum
RWTH Aachen
Technische Universität München
Technische Universität Dortmund
Universität Mainz
Universität Wuppertal

Université de Genève, Switzerland

University of Adelaide, Australia

University of Canterbury, New Zealand

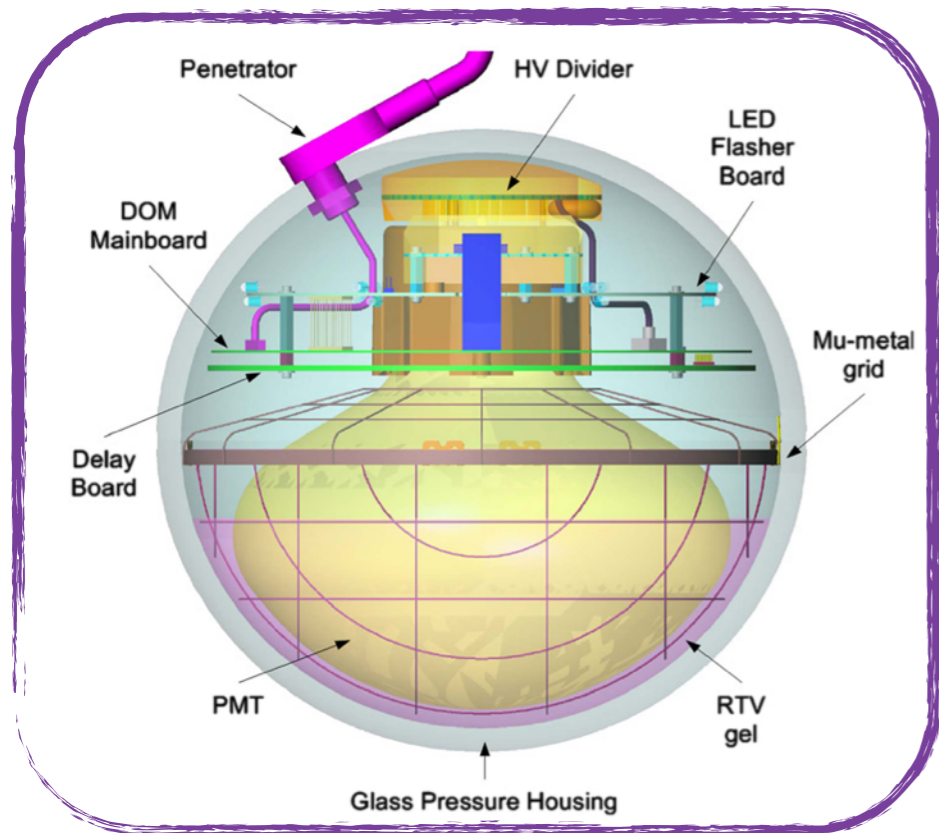## 44 Institutions
12 Countries

Funding Agencies

Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education & Research (BMBF)
German Research Foundation (DFG)

Deutsches Elektronen-Synchrotron (DESY)
Japan Society for the Promotion of Science (JSPS)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
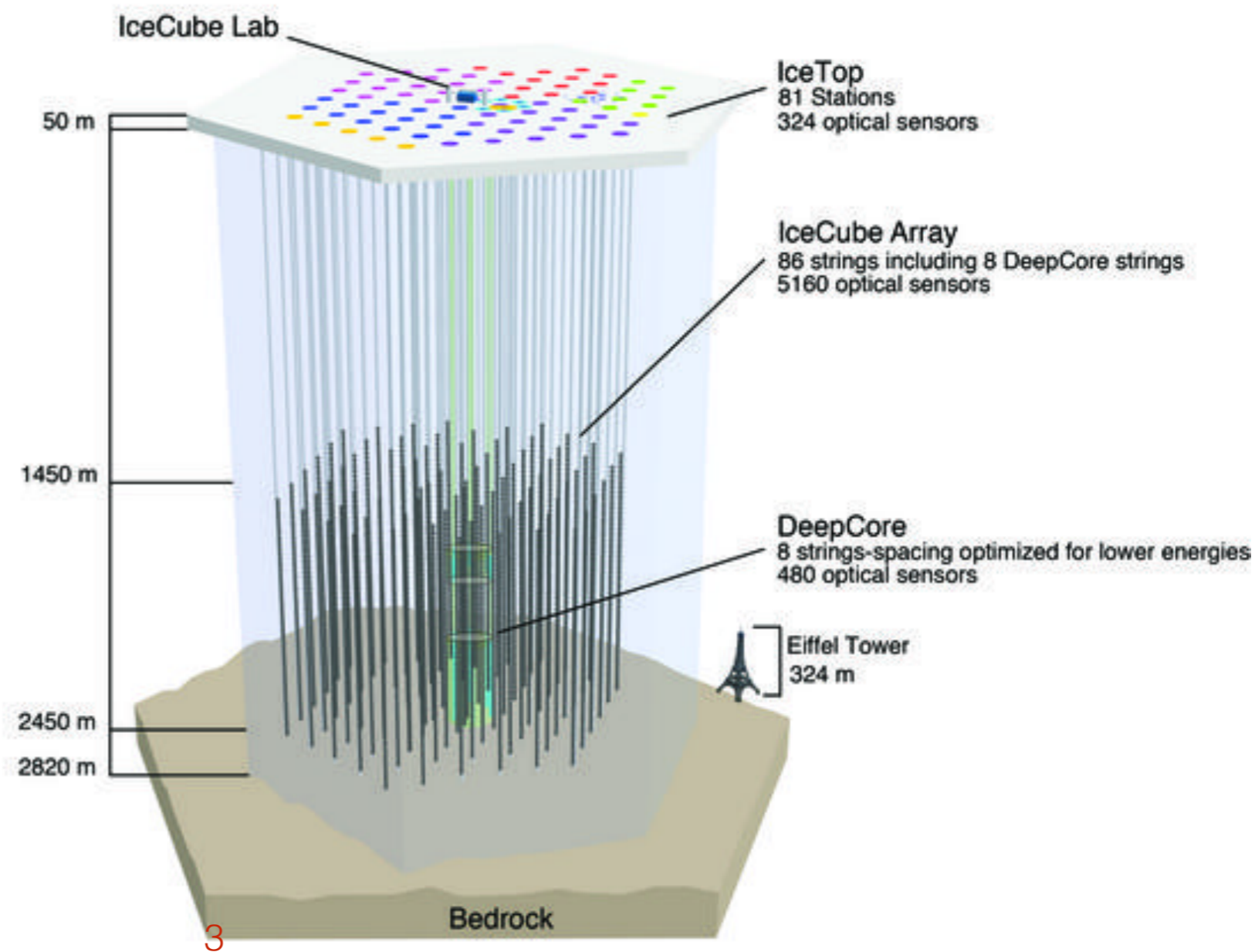The Swedish Research Council (VR)

University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

IceCube Detector

- Consists of 86 strings, each with 60 digital-optical modules (DOMs).

- 4π Detector - measuring neutrinos from all directions.

- Complementary IceTop detector for measuring cosmic ray air showers.
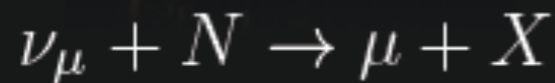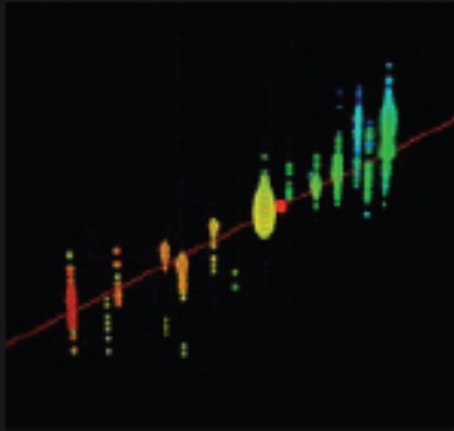

Penetrator · HV Divider · LED Flasher Board · DOM Mainboard · Mu-metal grid · Delay Board · PMT · RTV gel · Glass Pressure Housing

IceCube Lab

IceTop
81 Stations
324 optical sensors

IceCube Array
86 strings including 8 DeepCore strings
5160 optical sensors

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

Eiffel Tower
324 m

50 m

1450 m

2450 m

2820 m

Bedrock

- 125m string spacing

- 17m DOM spacing.

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Event Topologies

CC Muon Neutrino

**Neutral Current /
Electron Neutrino**

CC Tau Neutrino

time

$$\nu_\mu + N \rightarrow \mu + X$$

$$\nu_e + N \rightarrow e + X$$

$$\nu_x + N \rightarrow \nu_x + X$$

$$\nu_\tau + N \rightarrow \tau + X$$

track (data)

factor of ≈ 2 energy resolution

$< 1°$ angular resolution
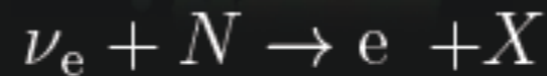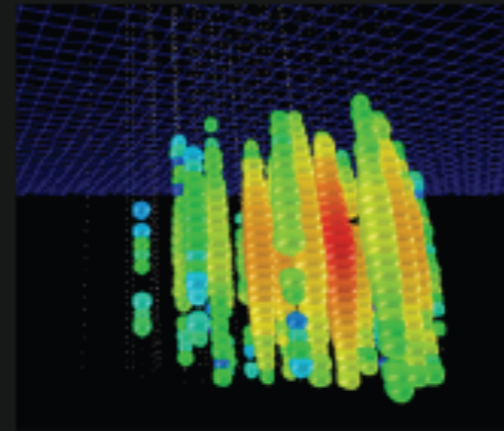
cascade (data)

$\approx \pm 15\%$ deposited energy resolution

$\approx 10°$ angular resolution

(at energies $\gtrsim 100$ TeV)
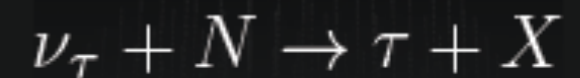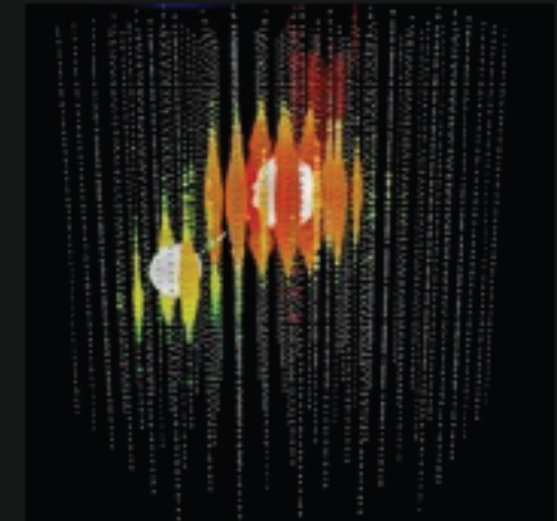
"double-bang" and other
signatures (simulation)

(not observed yet)

Neutrino Frontier

- IceCube sits at the energy frontier for neutrino physics.

  - Sensitive to neutrino signals from 100s of GeV to EeV!

- First PeV neutrino events detected by IceCube!

"Bert"
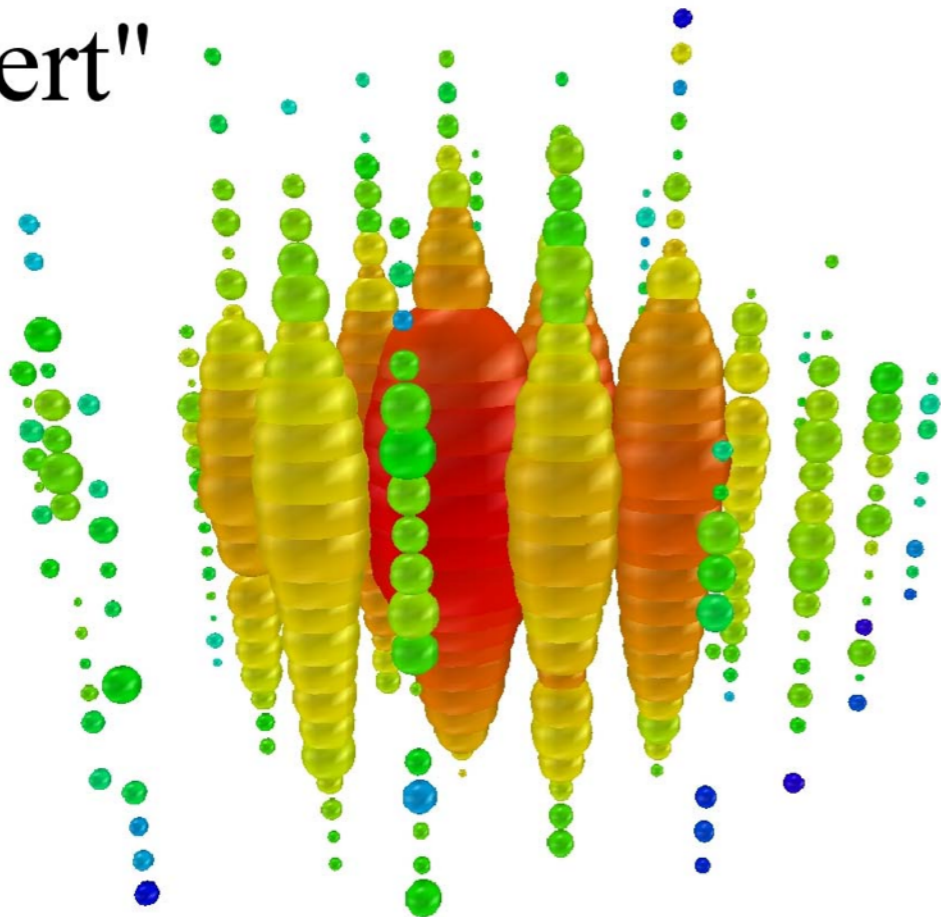
- Now that we have confirmation of these events, we want others help in finding the source.

Multi-messenger Astronomy

Goal of Online Alert

- IceCube has detected Astrophysical neutrinos, and we continue to find them (**H**igh **E**nergy **S**tarting **E**vents).

- Measuring the astrophysical spectrum with better precision is on the horizon for IceCube.

- But we are all kind of impatient. Want results fast! But we also want others to look into them: **Follow-up Program!**

"Bert"
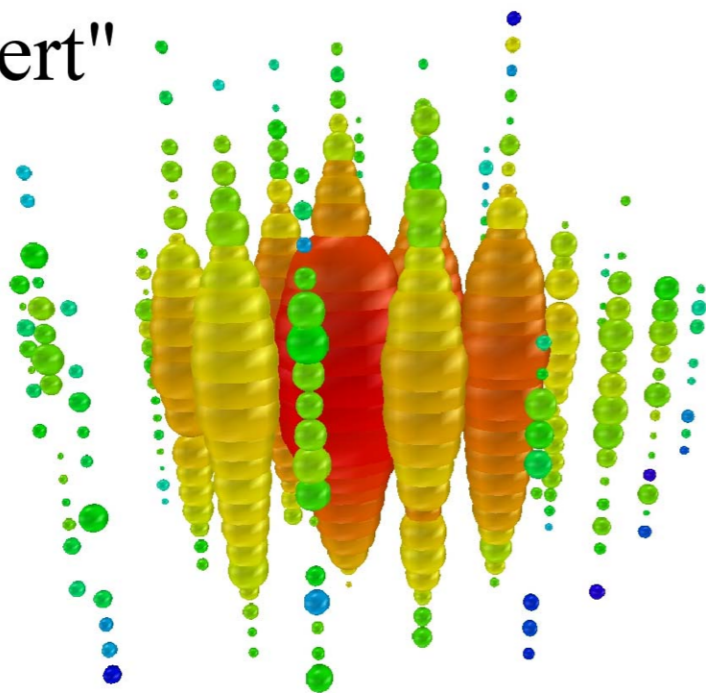
"Ernie"
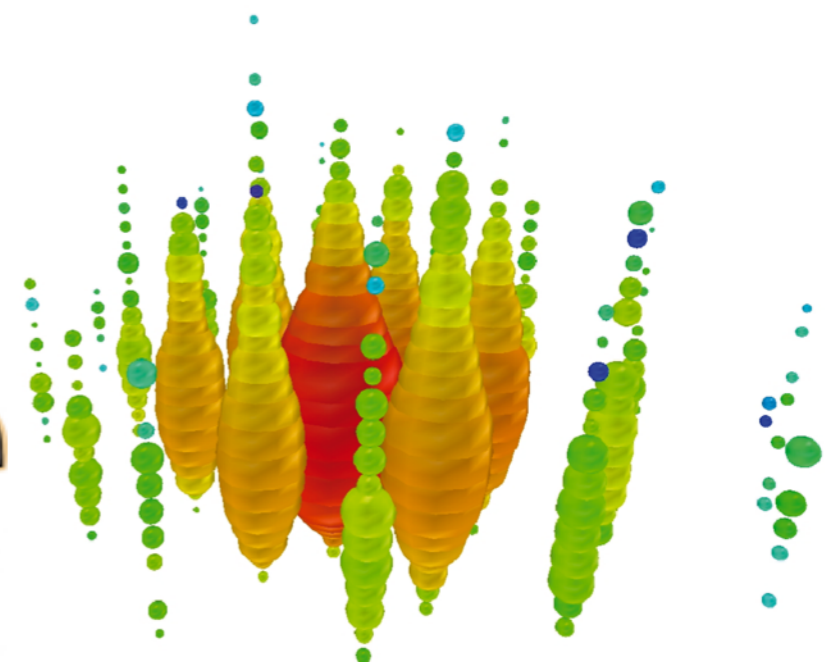
What's the Rush?

- Want to be able to find transient or flaring source which cannot be done offline (might miss it!).

- With optical follow-up, we have the ability to identify the neutrino source with just a single event!

  - Powerful given the rarity of these events and small neutrino cross-section.

How this looks:

IceCube Sees
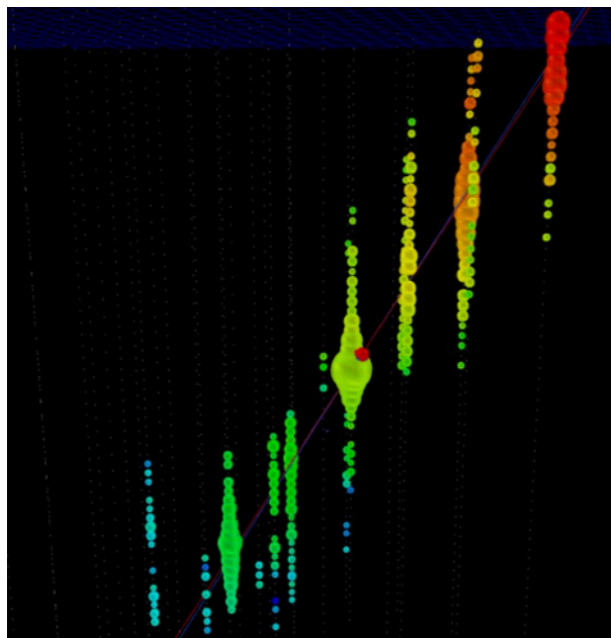
Alert

H.E.S.S. Telescope
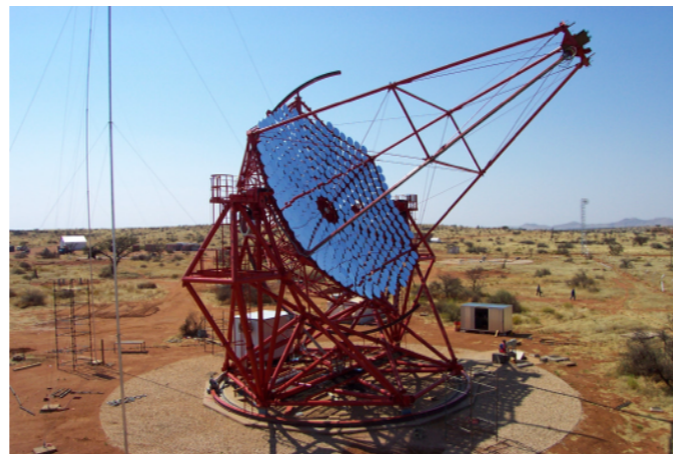
HESS Looks

H.E.S.S. Sees

?

Challenges

IceCube at the South Pole
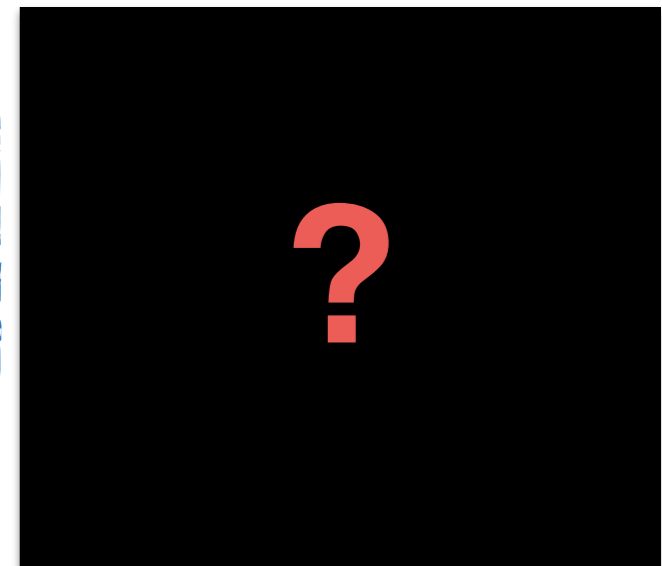
- IceCube is in a pretty remote location!

  - We want to do physics ASAP.

- Raw IceCube trigger rate 3kHz, produces 1TB/day of raw data.

- Transfer data by satellite? Our allocation is ~100 GB/day so we need to reduce size to 10%

- Remedy: Apply well studied filters to get part of the data north now, and grab the rest when we visit the pole.
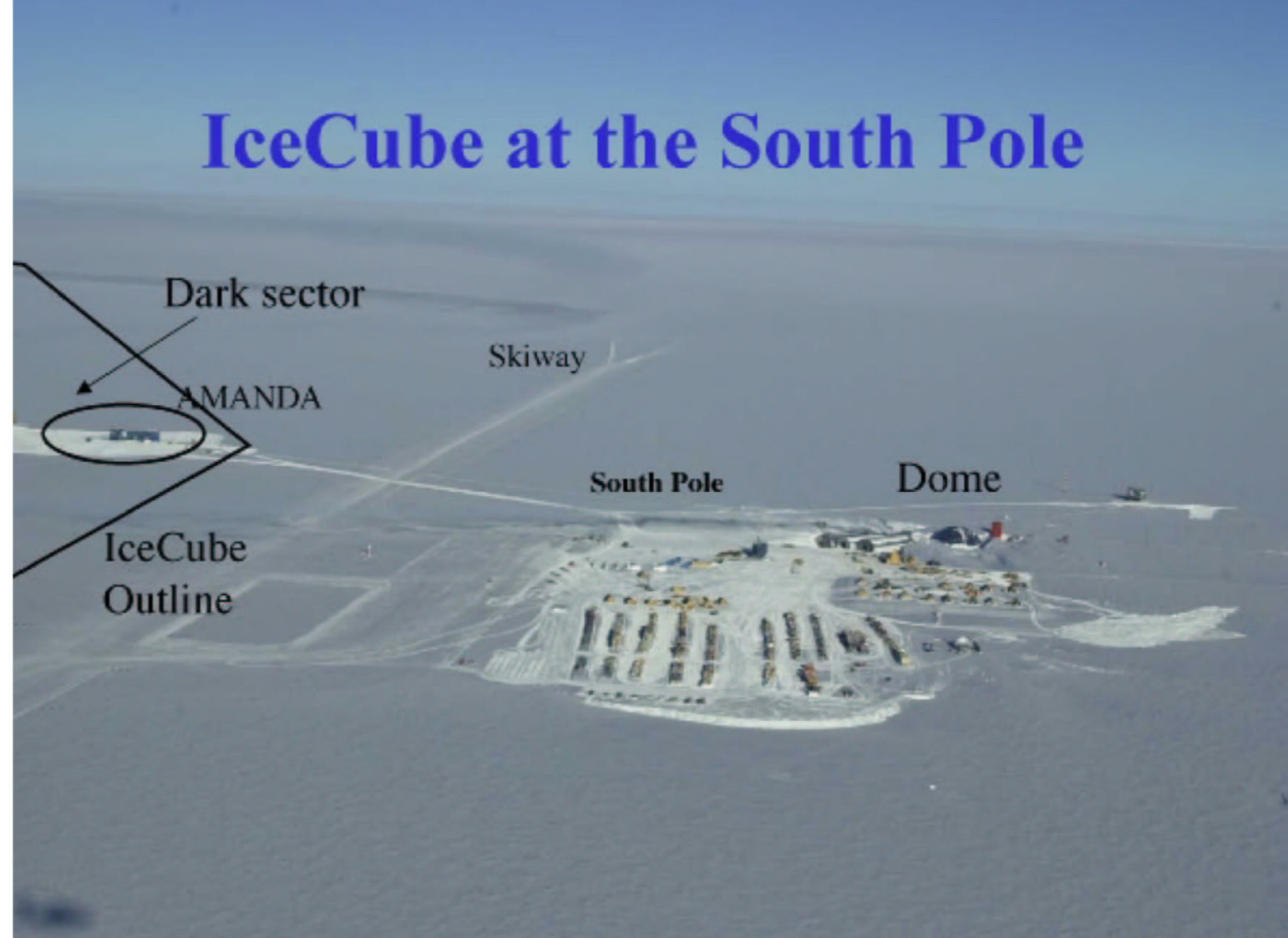
Online Alert Analyses

- Two paths:

  - Online running at the pole — very small latency ~mins

  - Near-realtime follow-up — slightly larger ~2 days

- End goal is to have the alerts running at the pole to reduce the wait time.

- Near-realtime is meant for testing an analyses before deploying.

  - This is currently where the EHE alert is running.

EHE Alert

- Optimize the EHE alert using simulation to select track-like events that follow an E^{-2} spectrum.

- Tried to keep analysis selection as simple as possible.
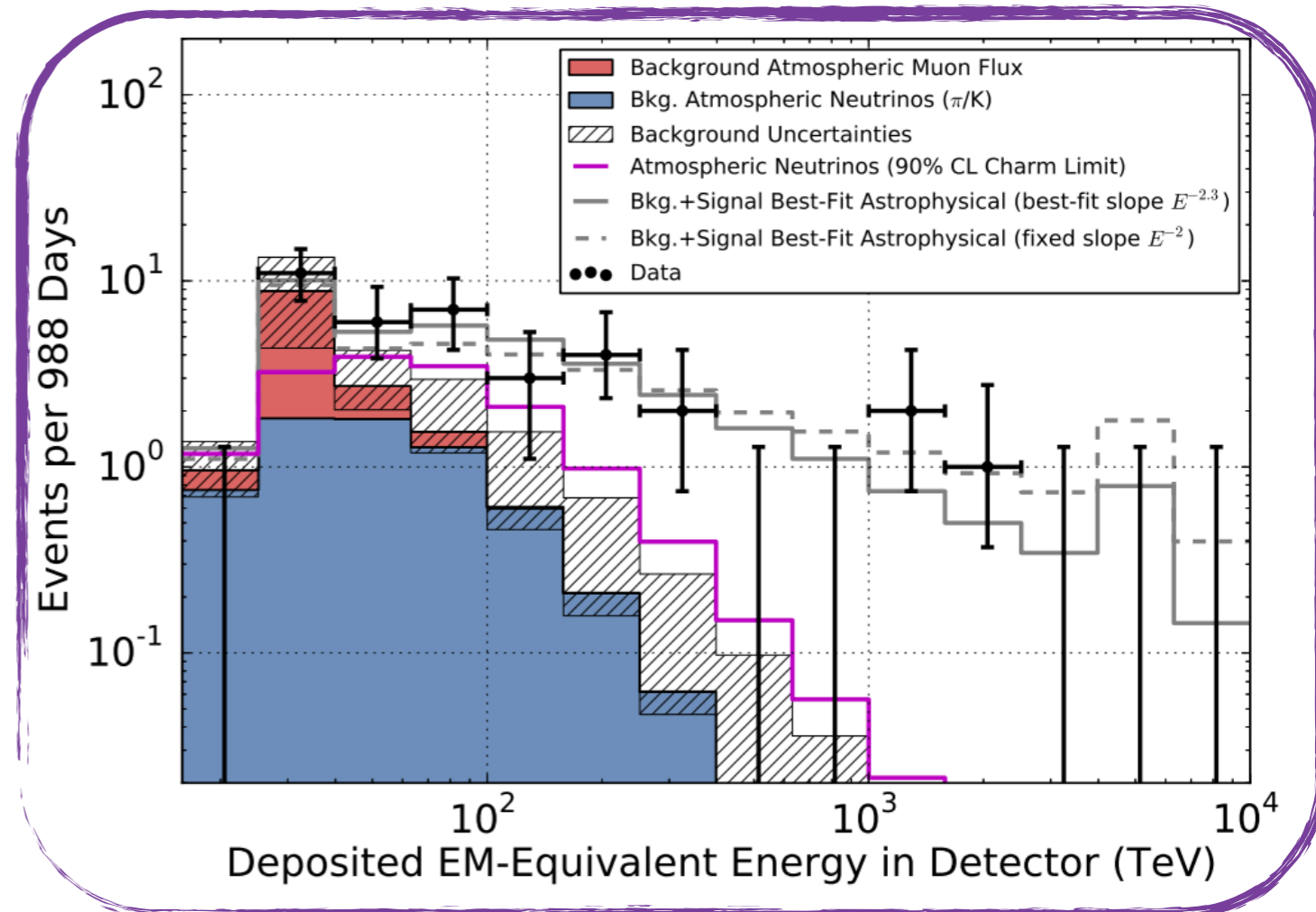
Selection:

1.) Select bright events — Number of photoelectrons (NPE).
2.) Fit for a track and select on fit quality parameter.
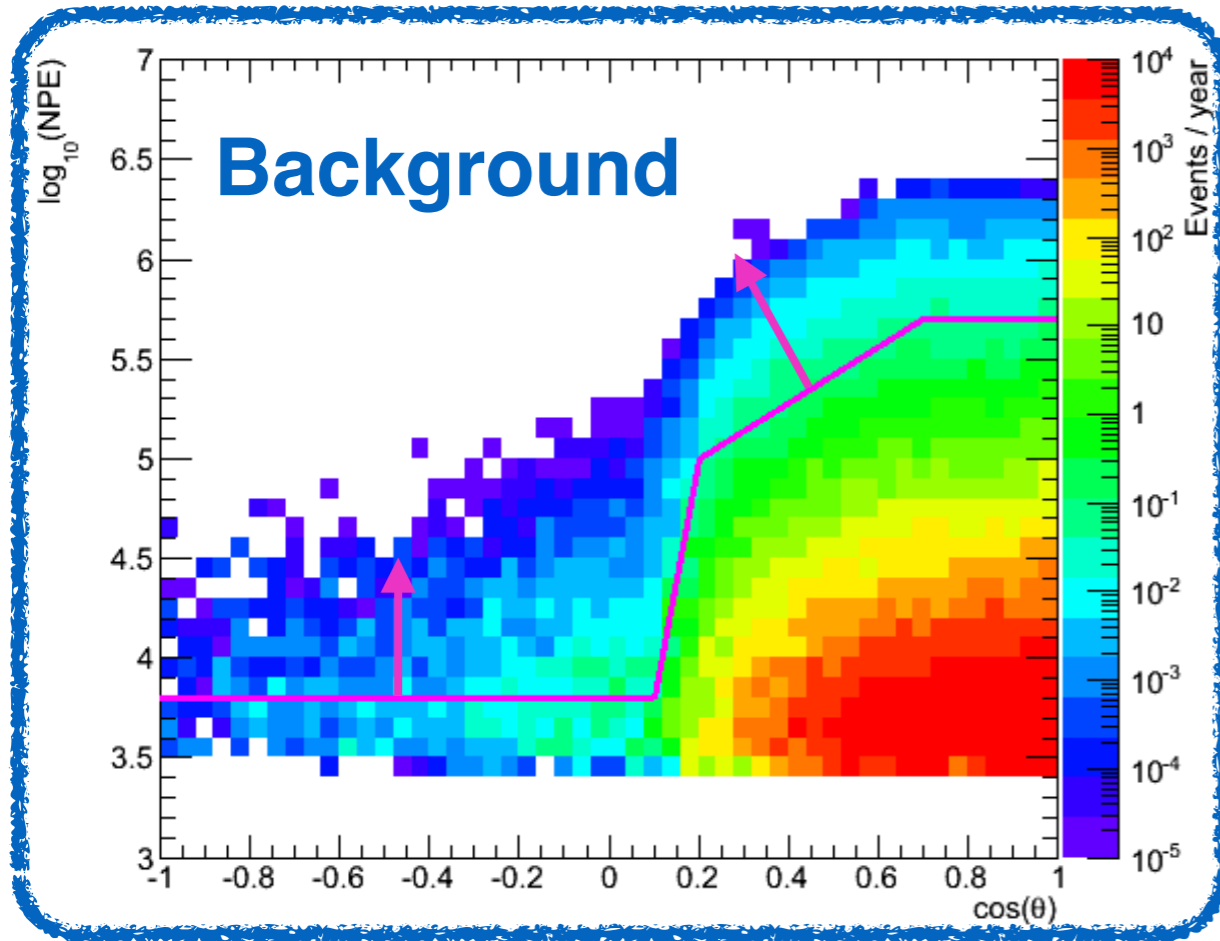**3.) Apply final selection to pick out EHE events (described later)**

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arxiv: 1405.5303

Bright Track-like events

- Tested using a small batch of the data (burn sample).

- Largest background from atmospheric muons.

- Note: Background expected to be near or more than data.
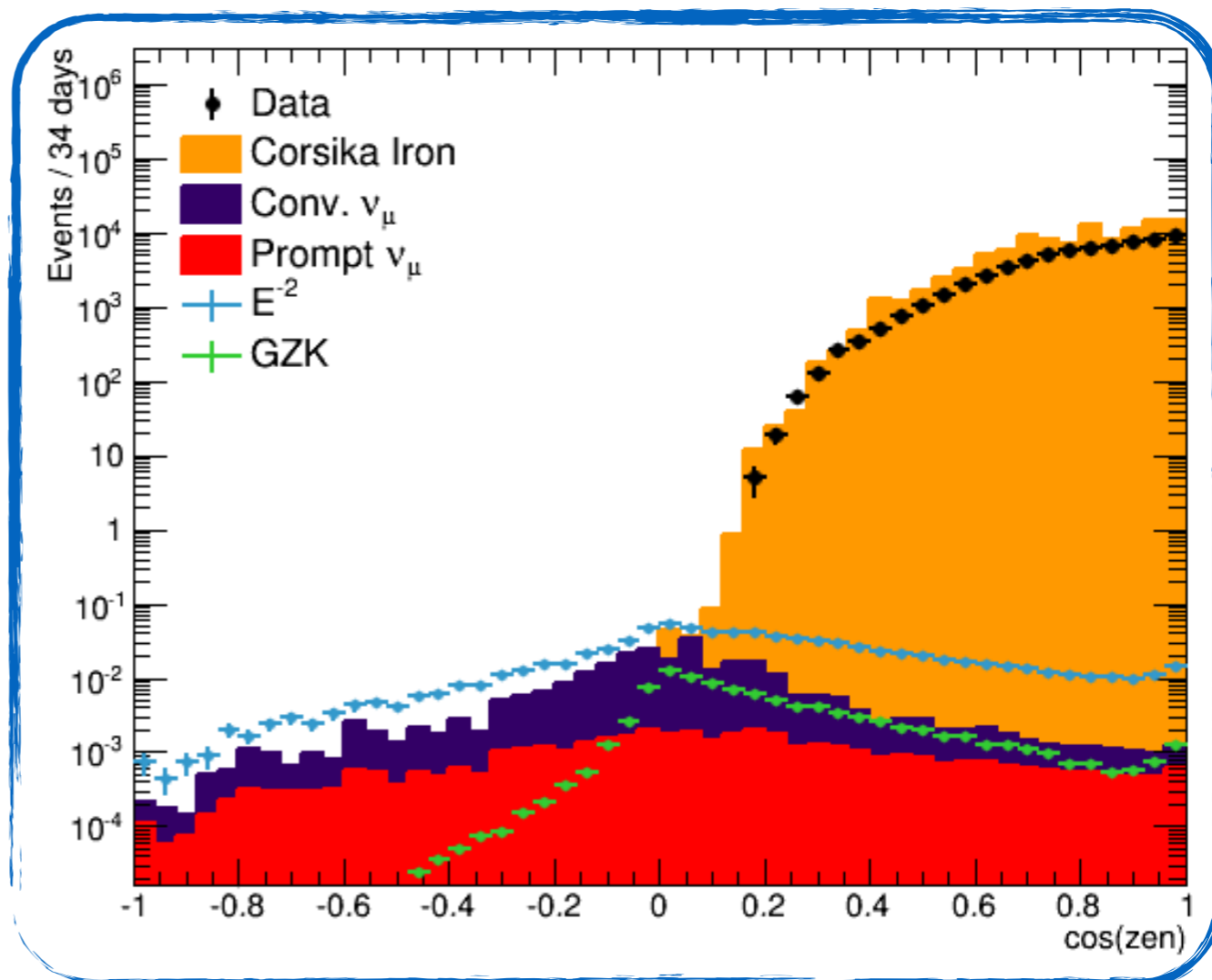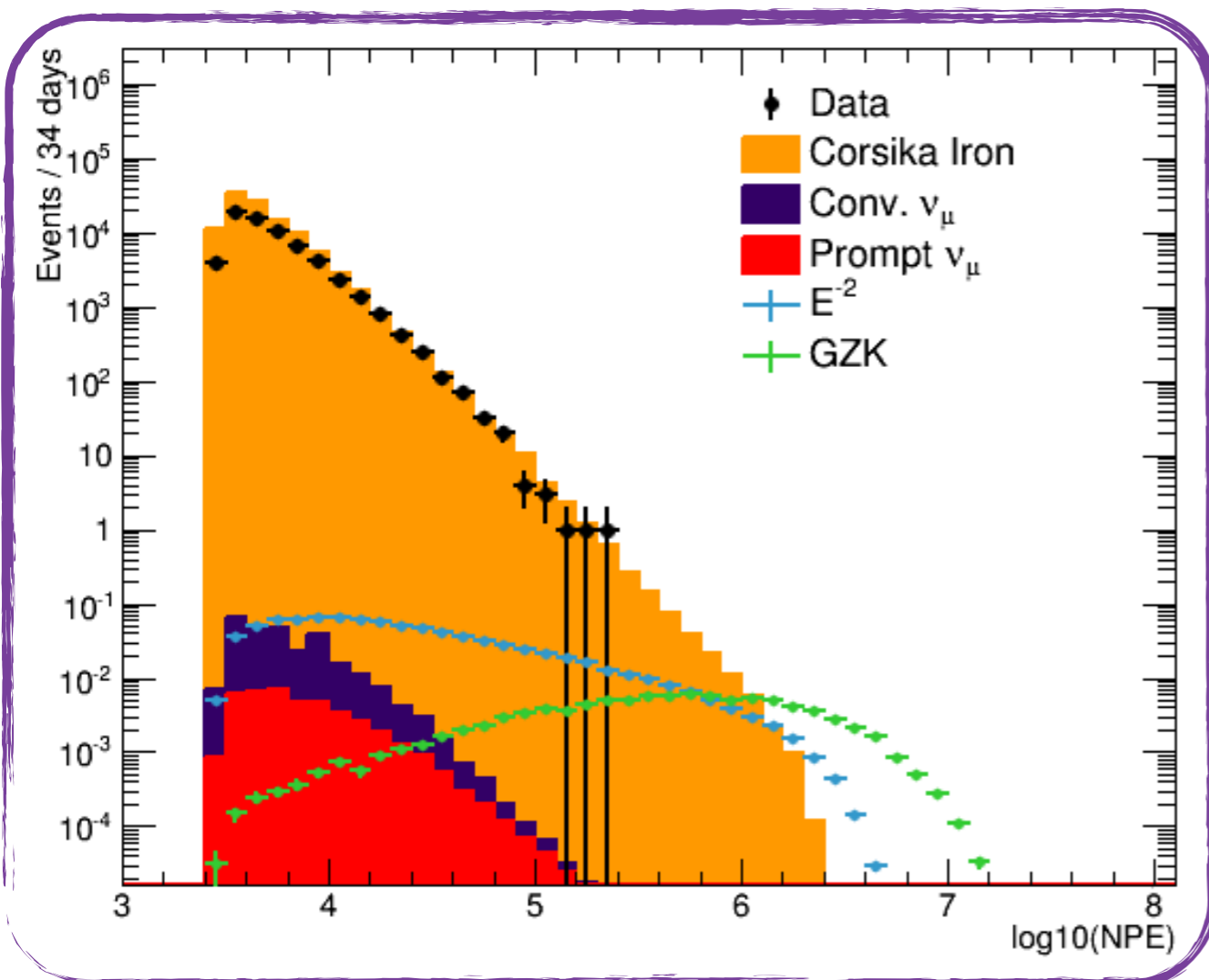
Signal Region

- Two dimensional requirement on brightness (NPE) and directional information.
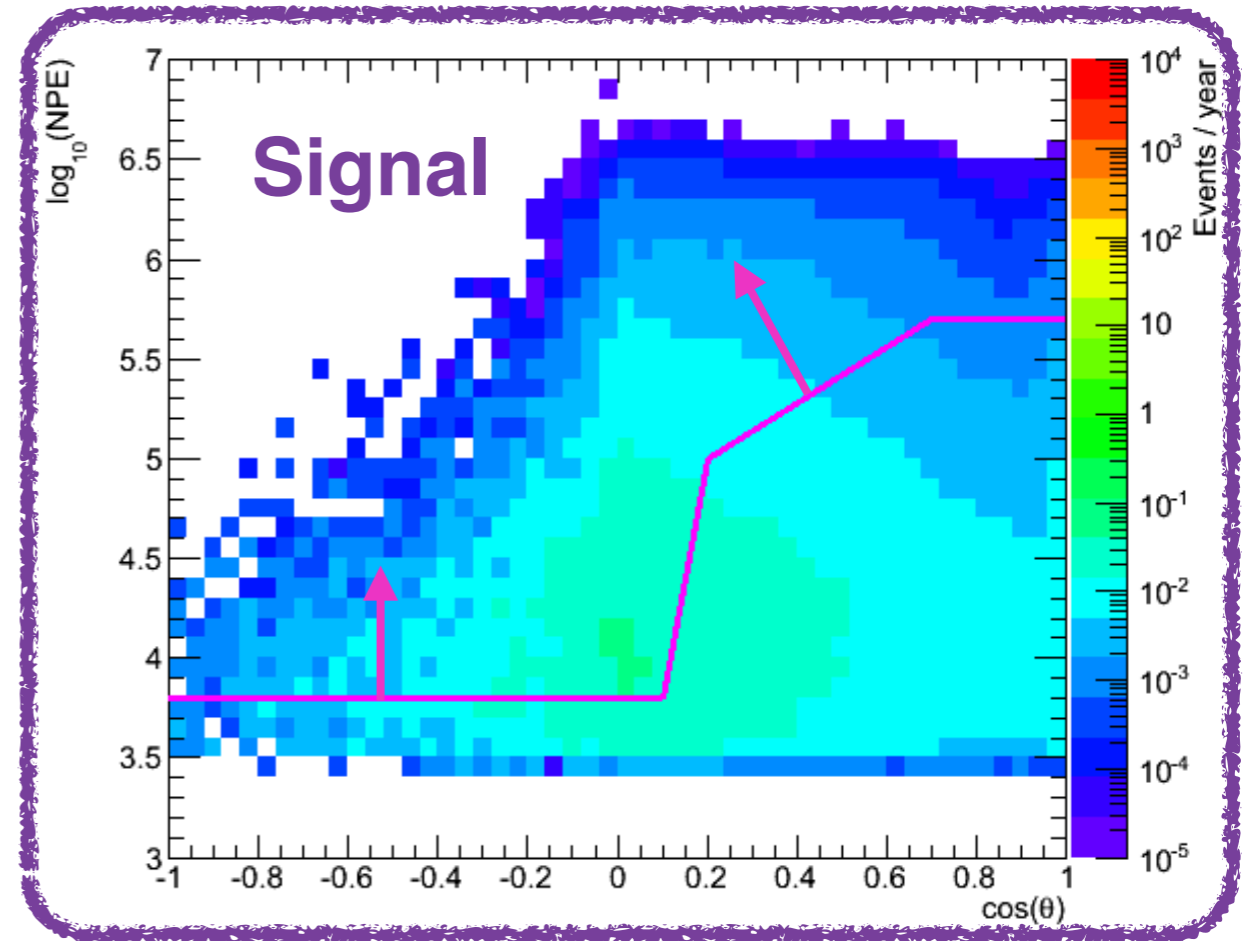
| Sample	yield
Corsika Iron	2.489
Conv. Atm. ν_μ	0.649
Prompt Atm. ν_μ	0.117
Total Bkg.	3.254
E^{-2}	3.854

~7 Events / year

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Angular Resolution

- Look at simulated events and define the opening angle as angle between reconstructed and true neutrino direction.

- Resolution defined as median opening angle.

Simulated ν_μ Events

Resolution = 0.25 [deg]
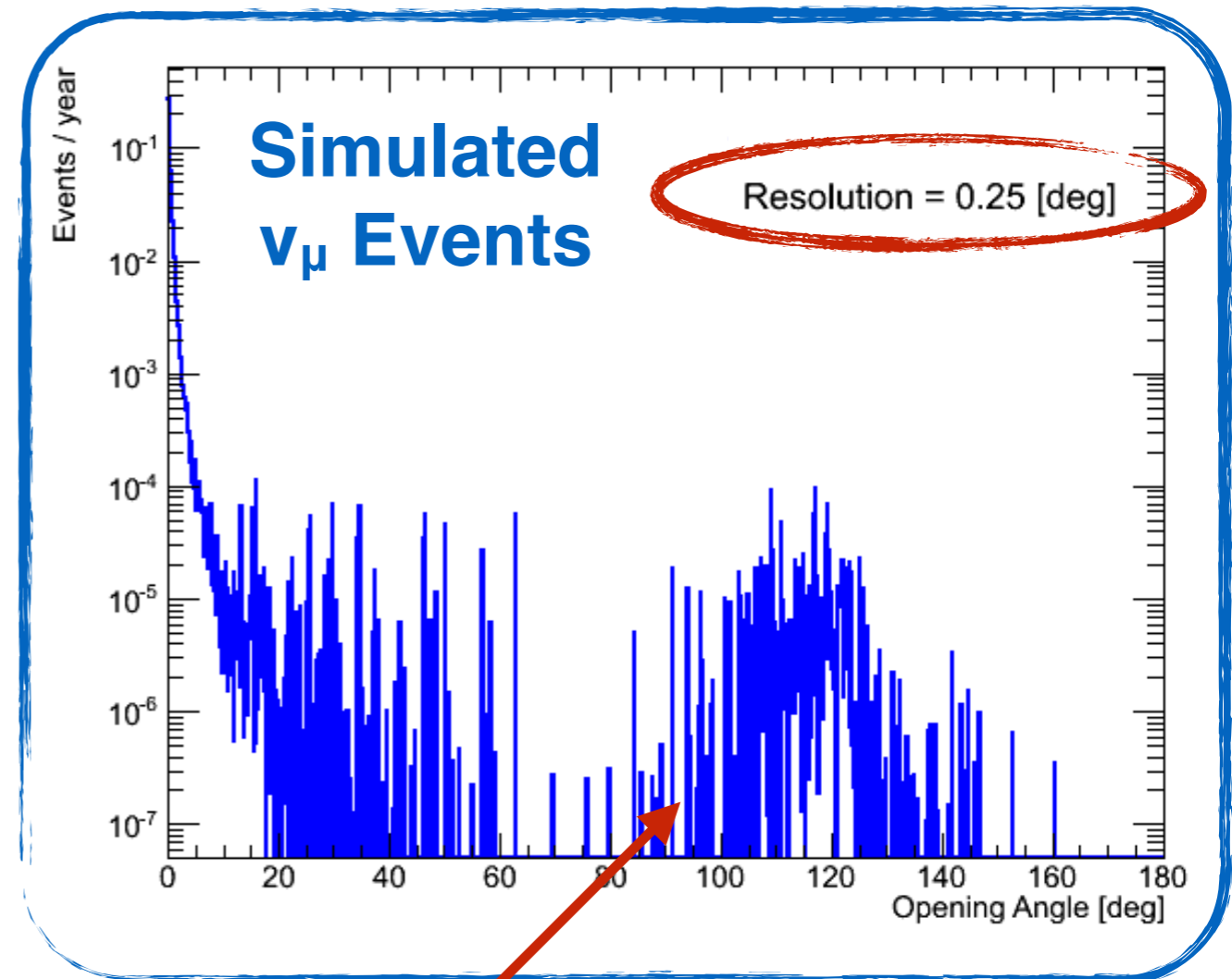
Mis-reconstructed direction (flipped) Rate is < 1%.

Current Status: Loose Selection

- Relax the cuts such that we can test to see if the alert is running properly.

- Designed on burn sample data.

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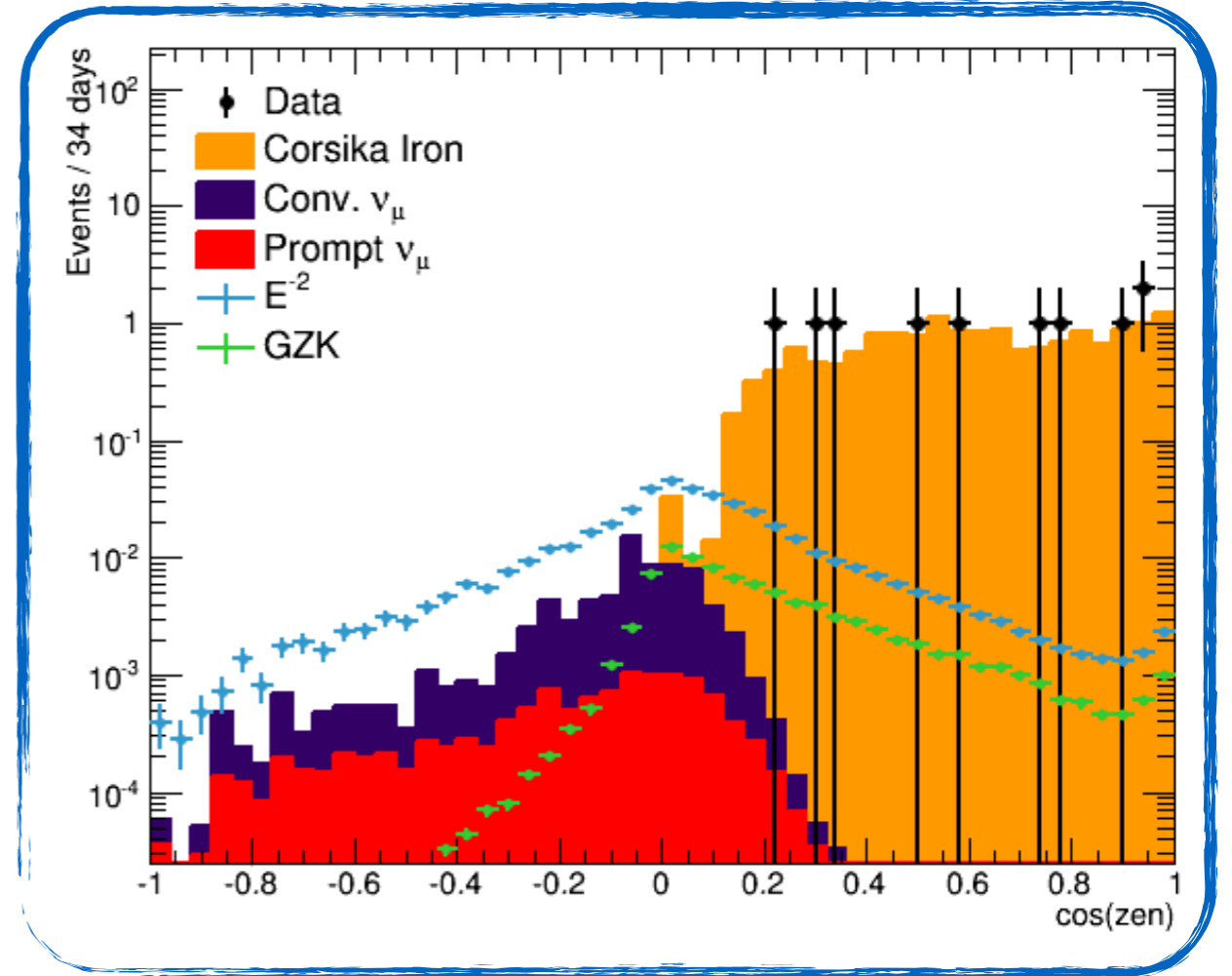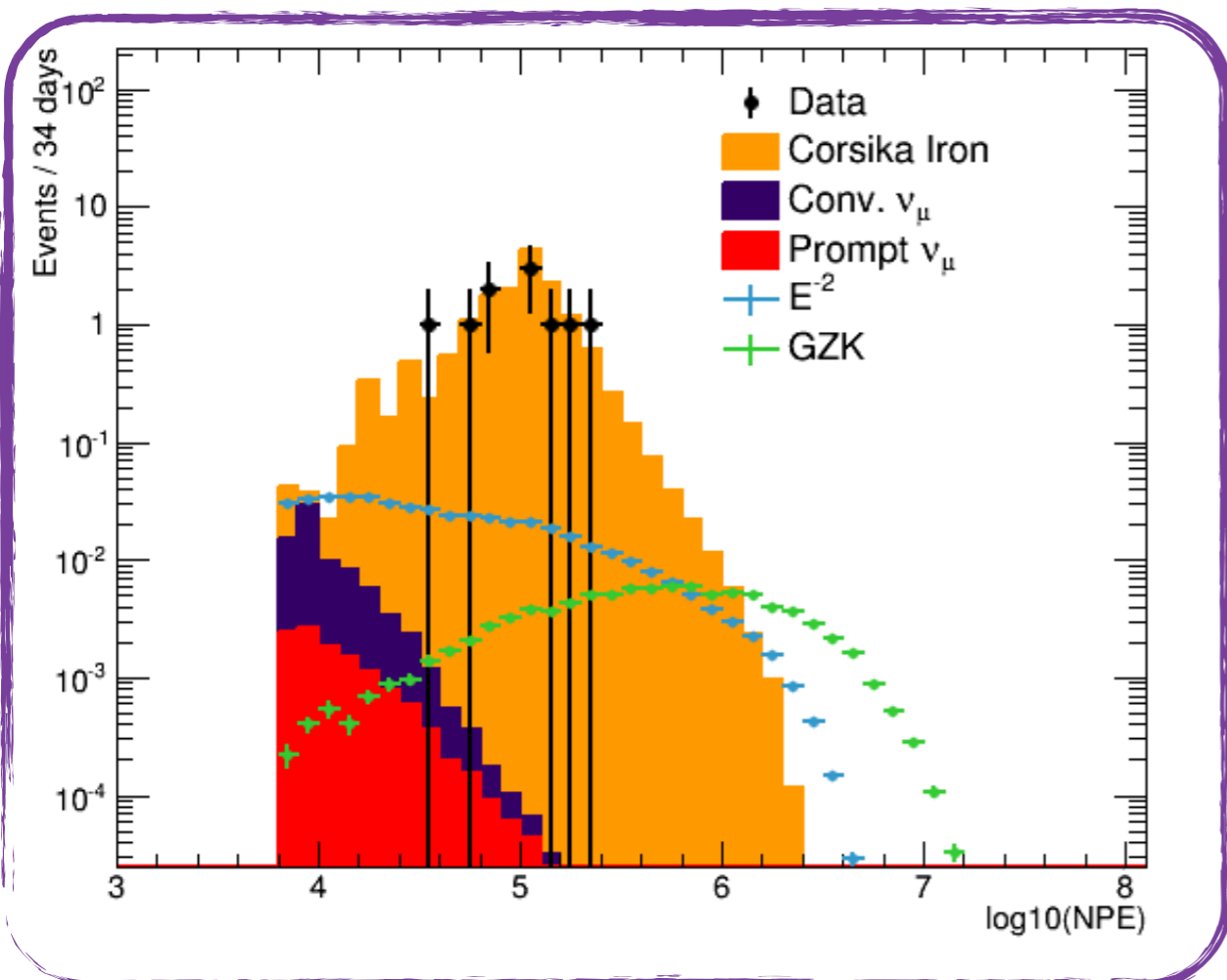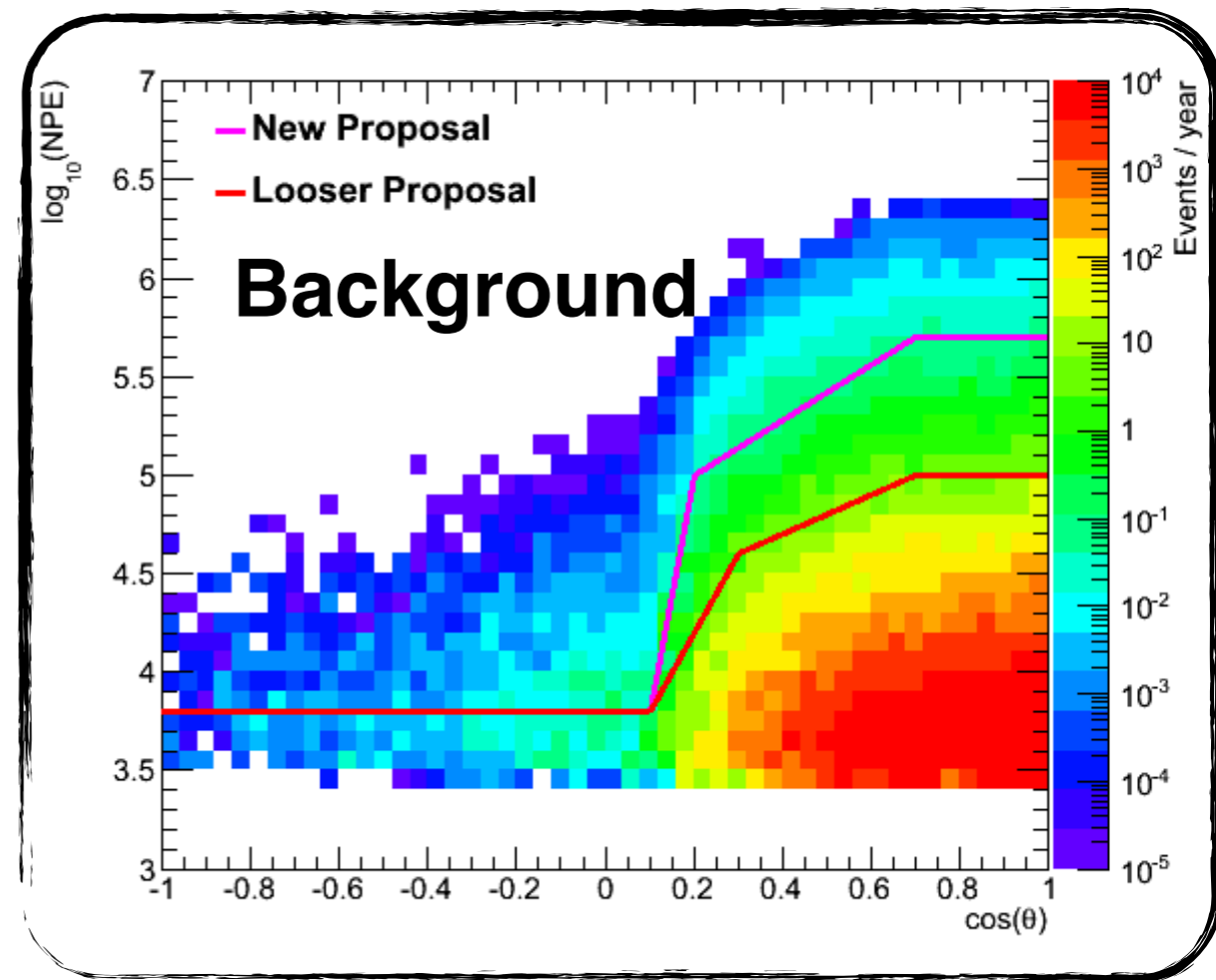
Sample Email

IceCube EHE Track-Like Alert   Chiba x

mrelich@hepburn.s.chiba-u.ac.jp   Nov 1
to me, jwfelde

This is an automated alert sent on behalf of the IceCube Neutrino Observatory.

An event was seen in the near real-time data processing system that has passed the EHE track-like event selection. Below are some basic information about this event. Please reply to this mail for more information on accessing the near real-time data stream.

EHE Track-like Event:
Run: classified
Event:
Time:

log(NPE): 5.626
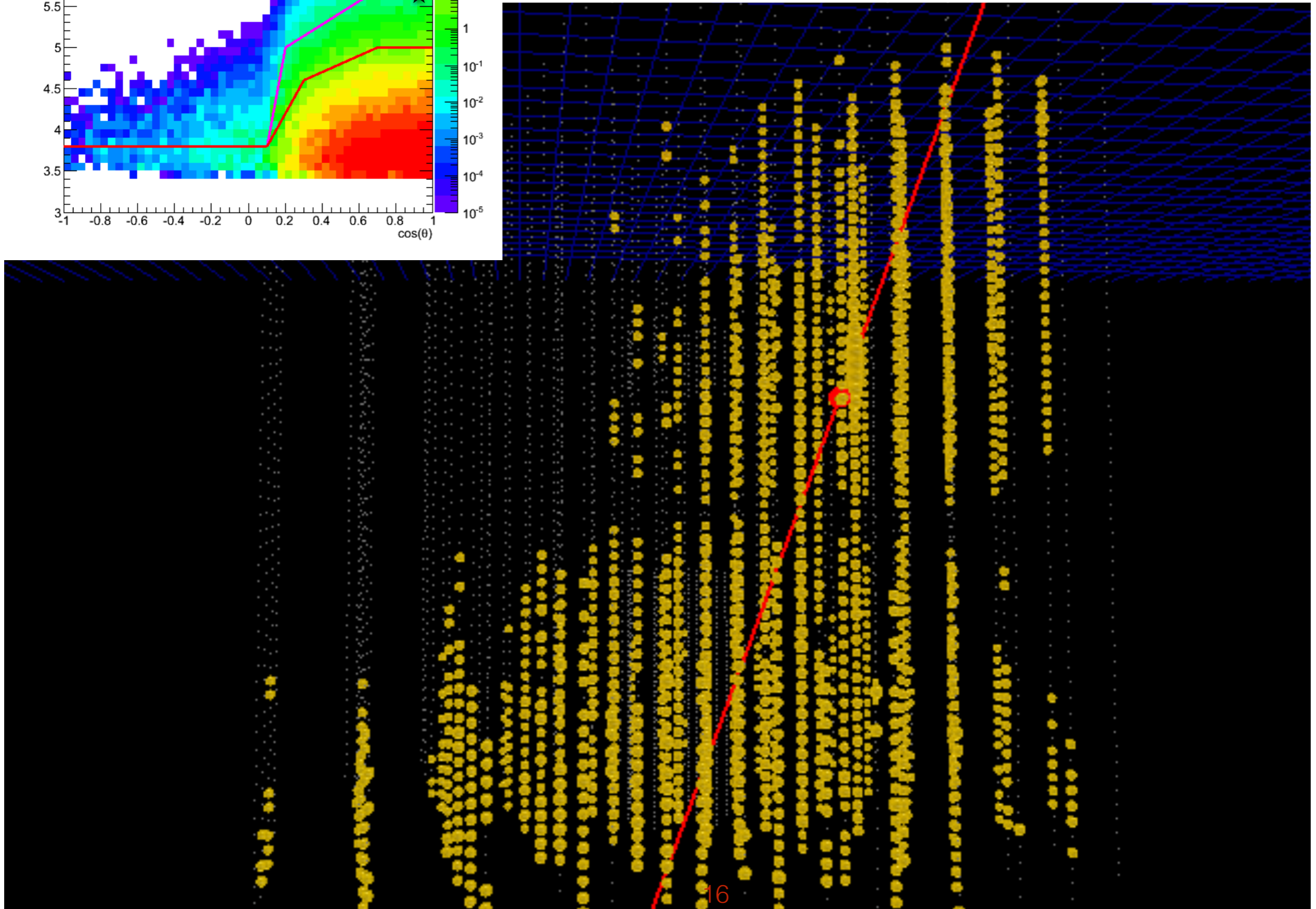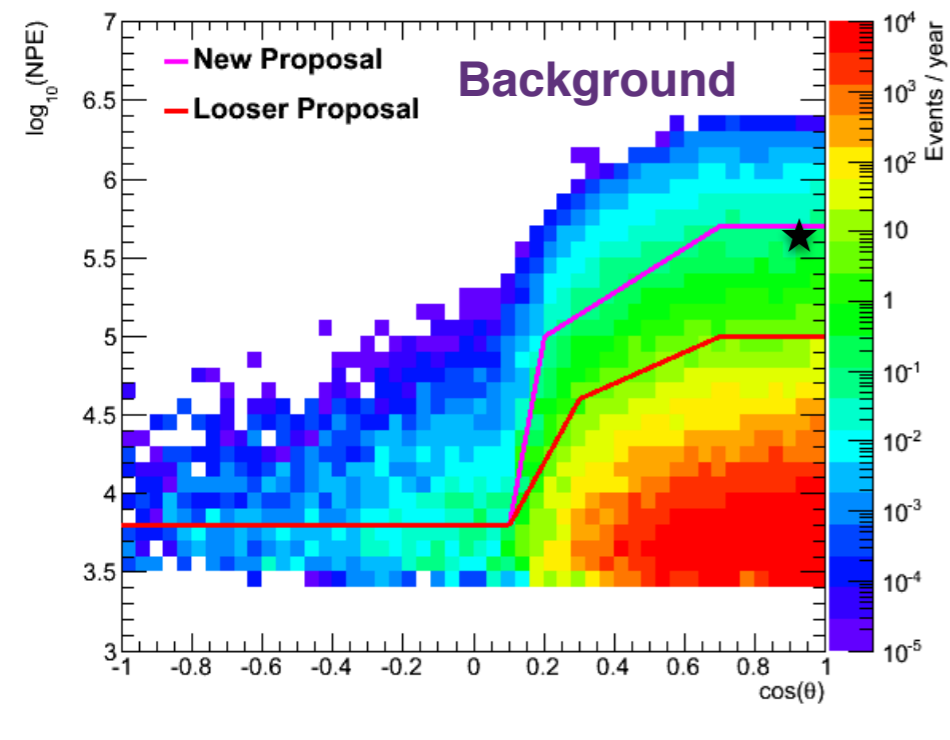cos(zen): 0.928

SPE zen:
SPE azi: classified
MPE zen:
MPE azi:

Lat:
Lon: classified

P(sig):

Not Included in Email

New Proposal
Looser Proposal
Background
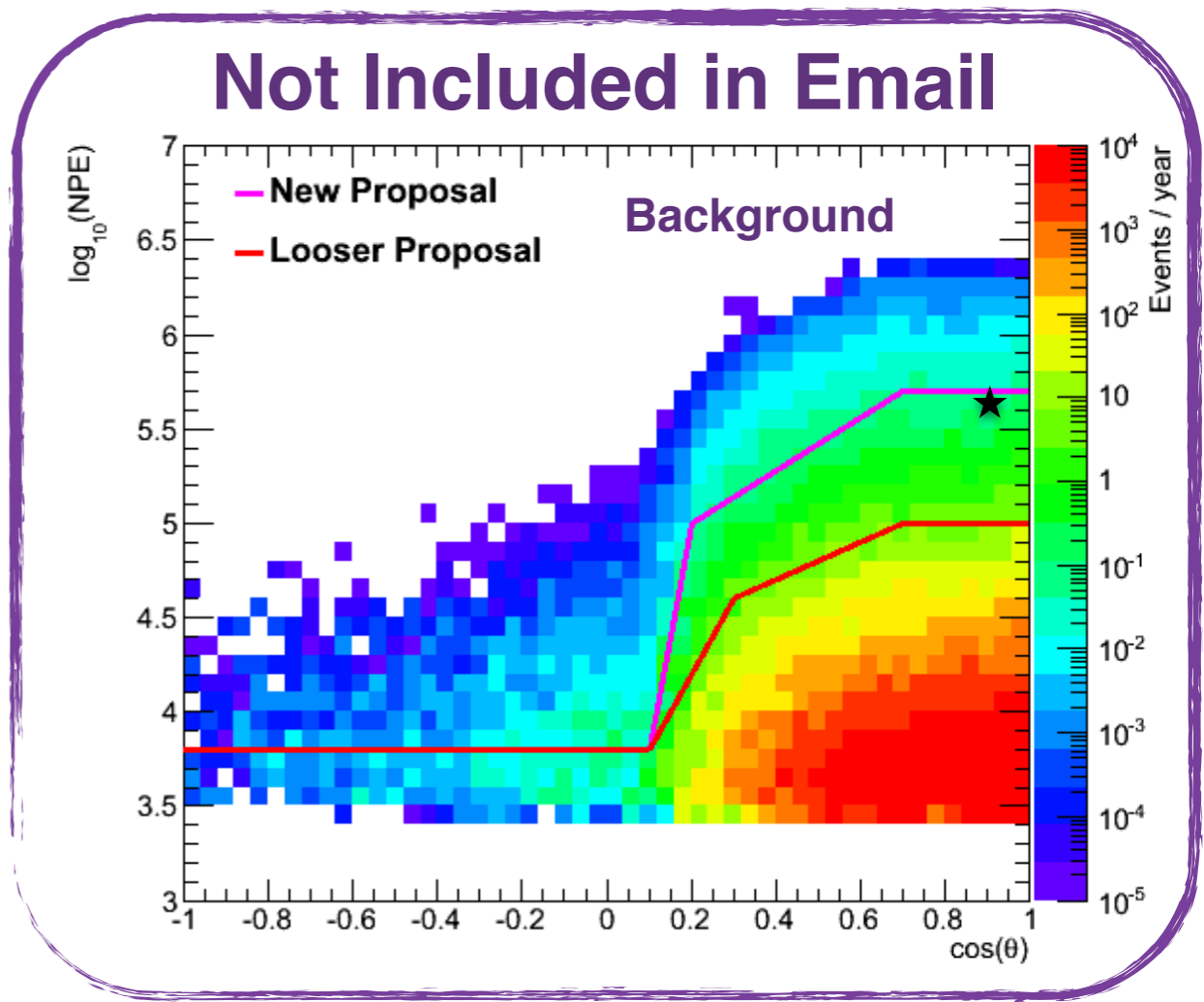
Event Display

Event Display

IceTop lights up beautifully for this event!

Indicates there is an accompanying air-shower
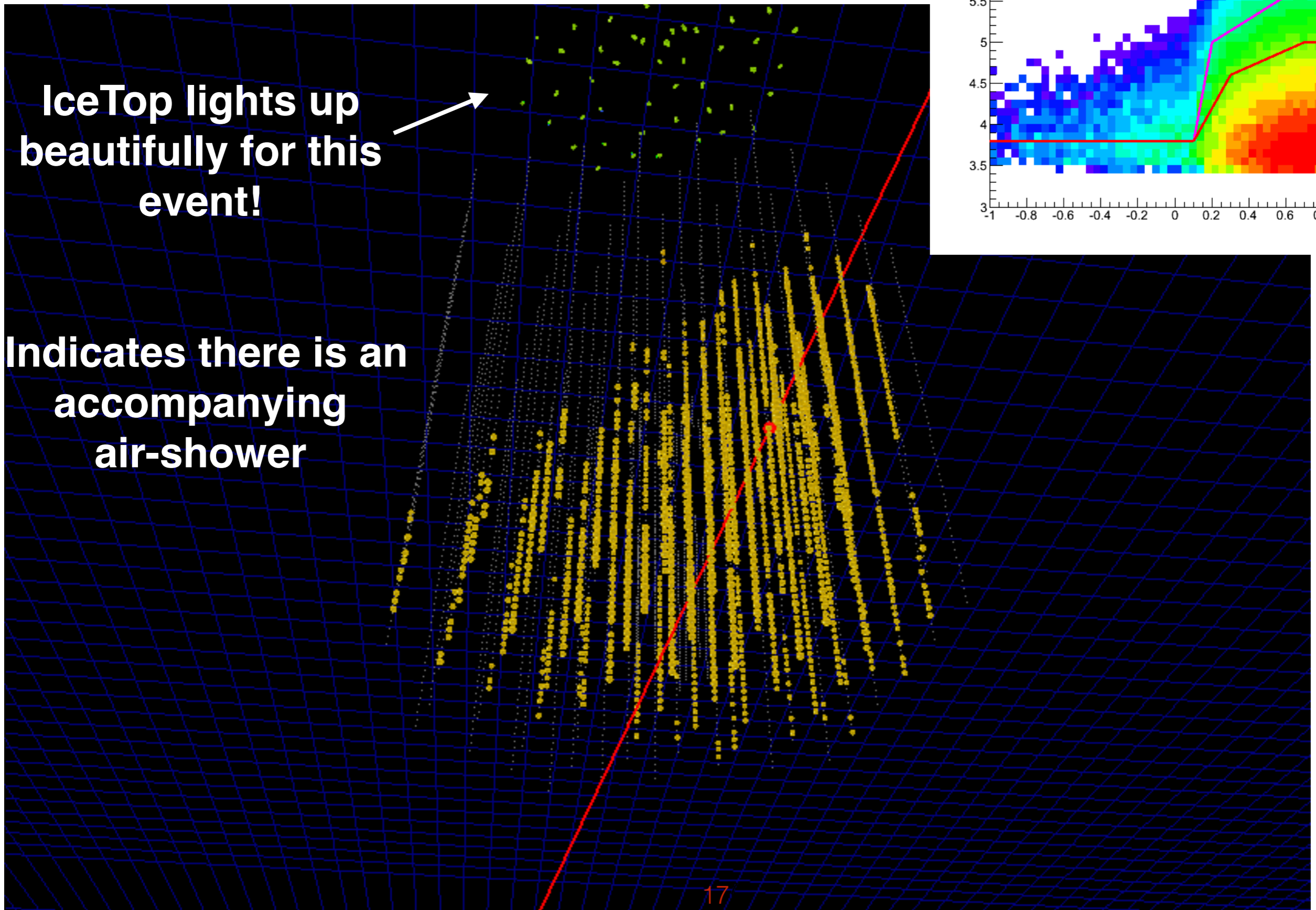
I know what you're thinking…
Wow! How can I get these Alerts!?

1.) Join experiment where you have ability to follow-up on these types of events. Either looking for coincidences between experiments (eg. HAWC) or optical follow-up (eg. HESS)

2.) Encourage your experiment to join AMON network*.

*Still undecided if we will do this or single MoUs

Advertisement: AMON
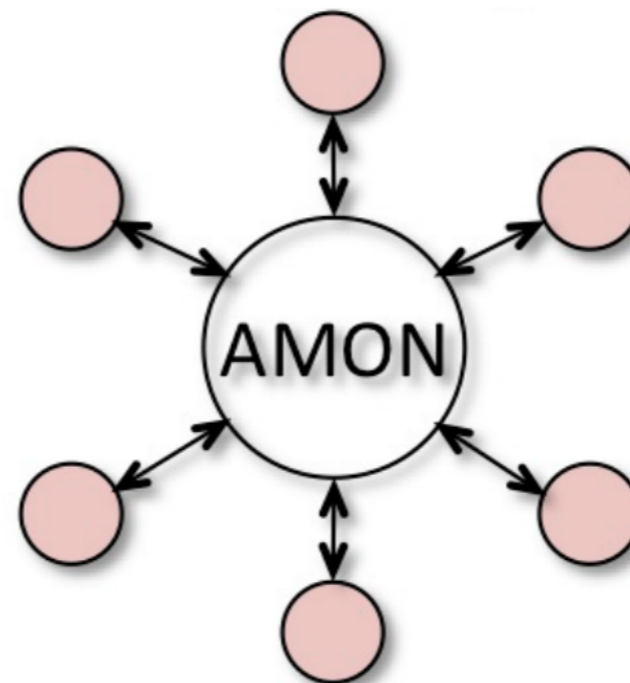Astrophysical Multimessenger Observatory Network

- AMON framework is a great idea to centralize and coordinate astro/astro-particle community in sharing of data.

  - Website: http://amon.gravity.psu.edu/amon_system.shtml

  - Not it's own experiment, merely a service for experiments.

Current Setup

Future!

Courtesy of Gordana Tesic (PSU)
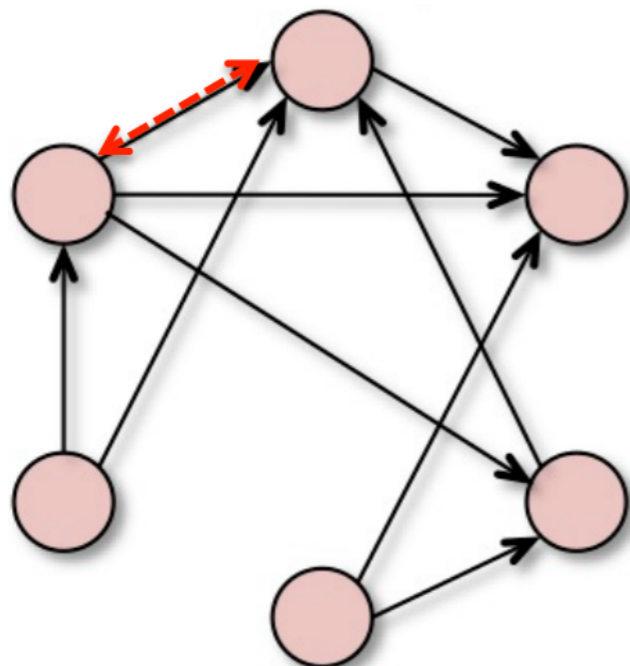
Conclusions/Summary

- The online alert for EHE like events has been developed and is currently being tested in the north.

- Resolution ~ 0.25 degrees which provides good pointing.

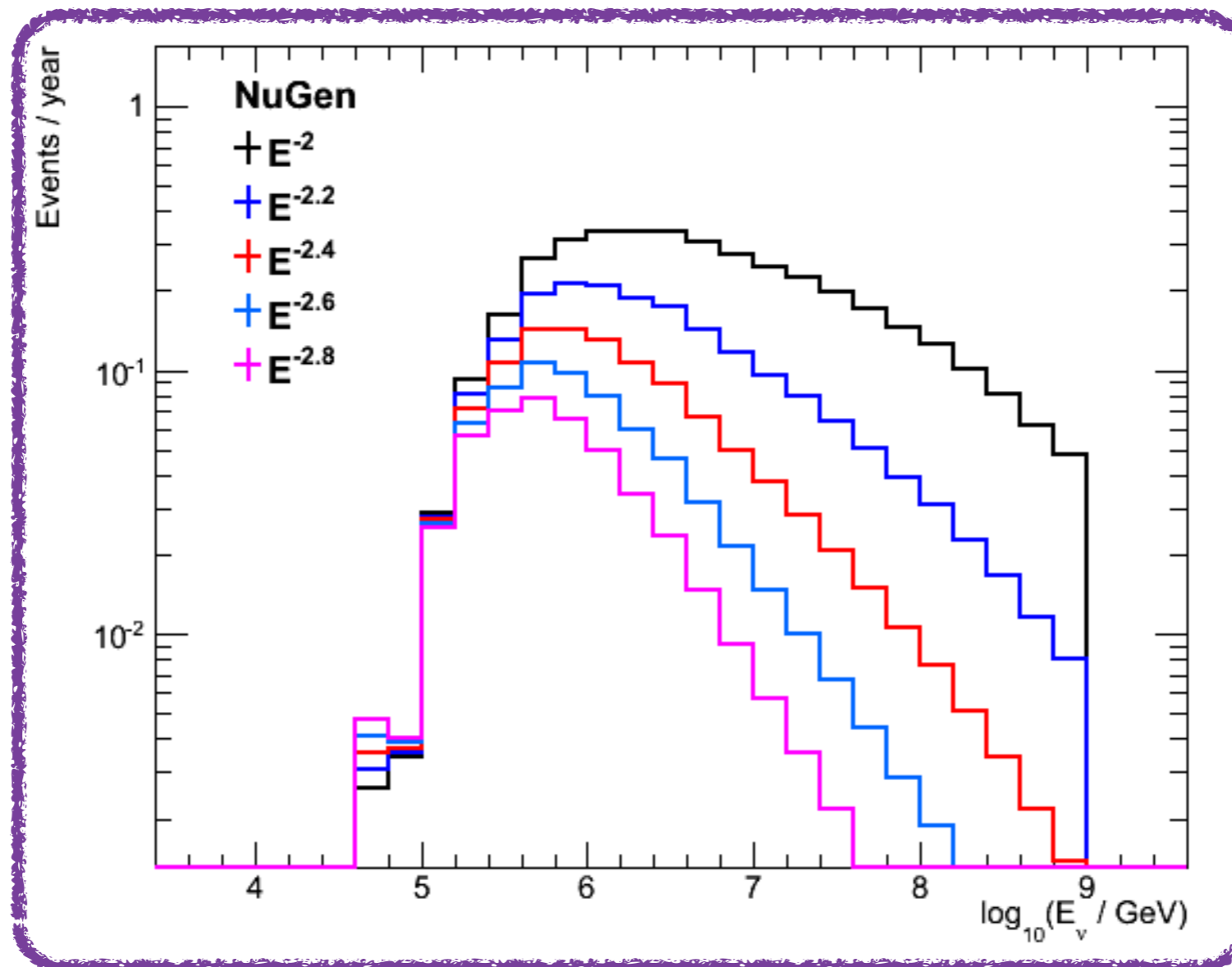- If neutrino energy spectrum is E^{-2} we should have ~7 events per year, with 3 being of astrophysical origin.
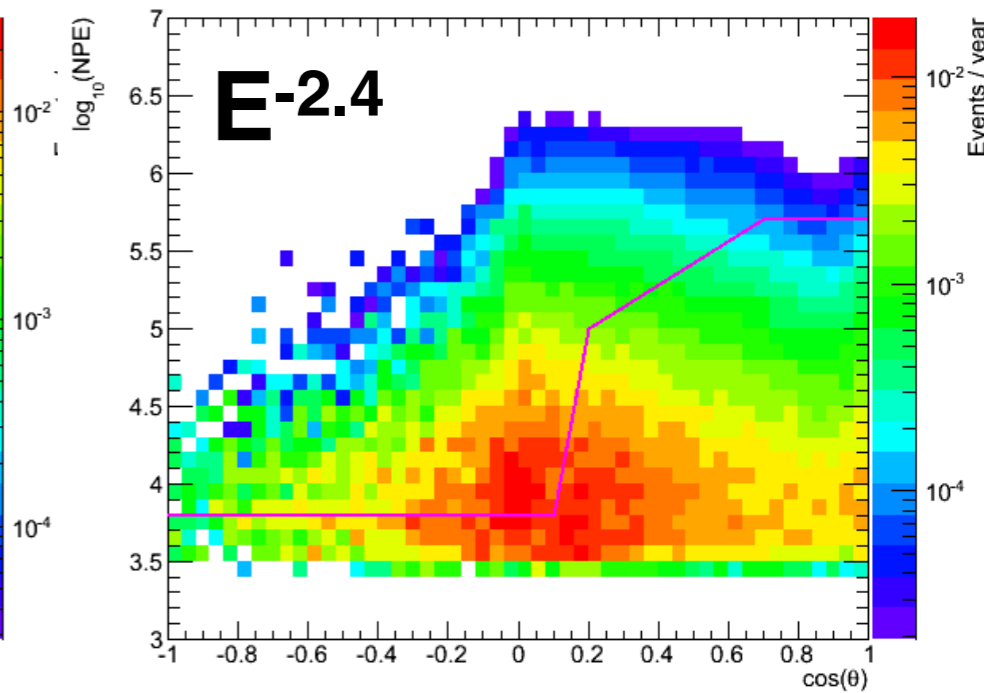
Let's hunt some neutrinos!
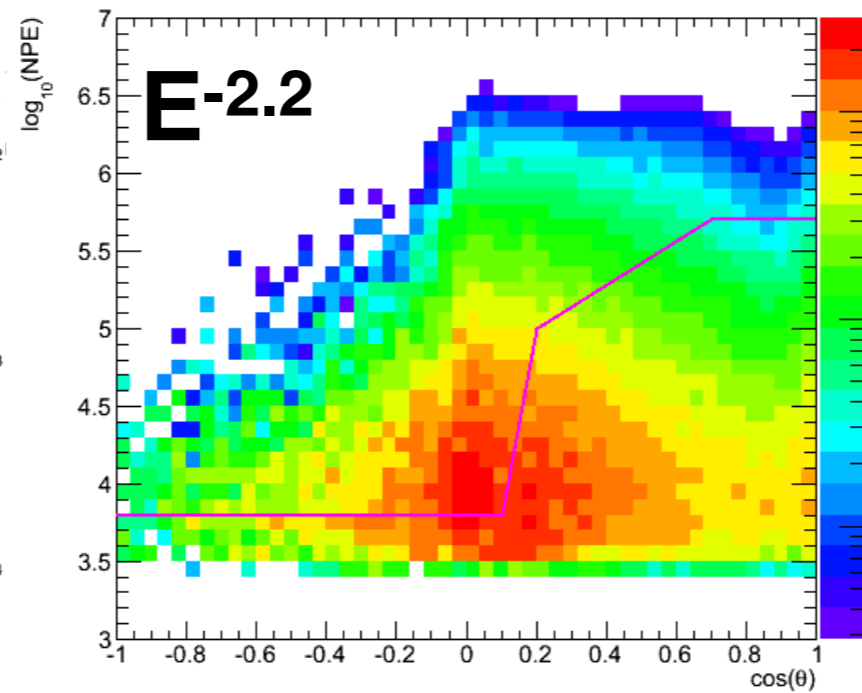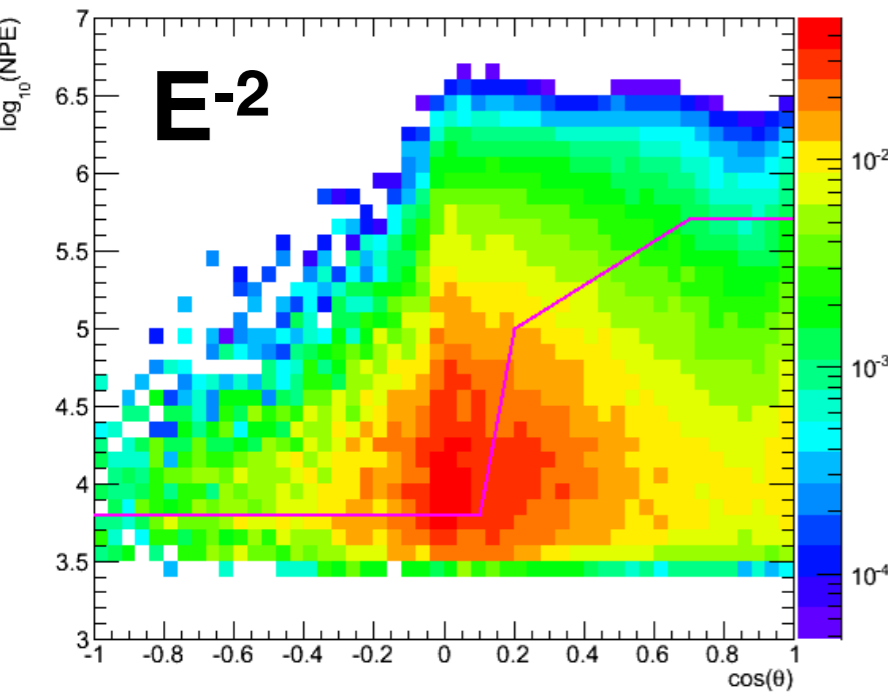
NEUTRINO

BET YOU CAN'T CATCH ME!

BONUS SLIDES!

Neutrino Energy

- After placing the signal region requirements in the 2-D plane of cos(zenith angle) and NPE the peak energy for E^{-2} flux is ~ 1 PeV and slightly decreases for various others.
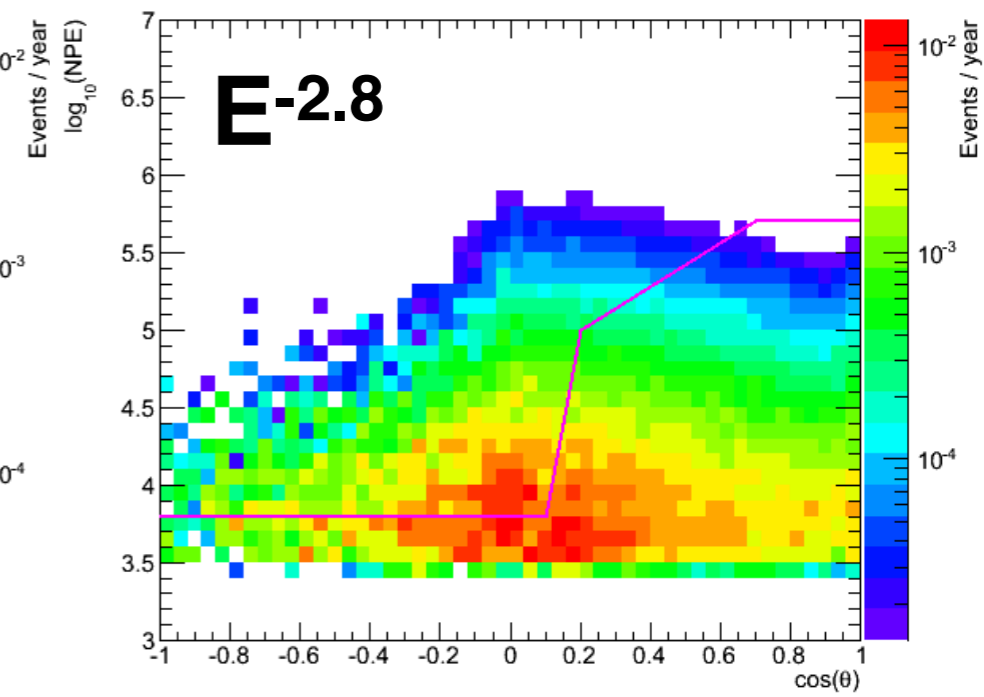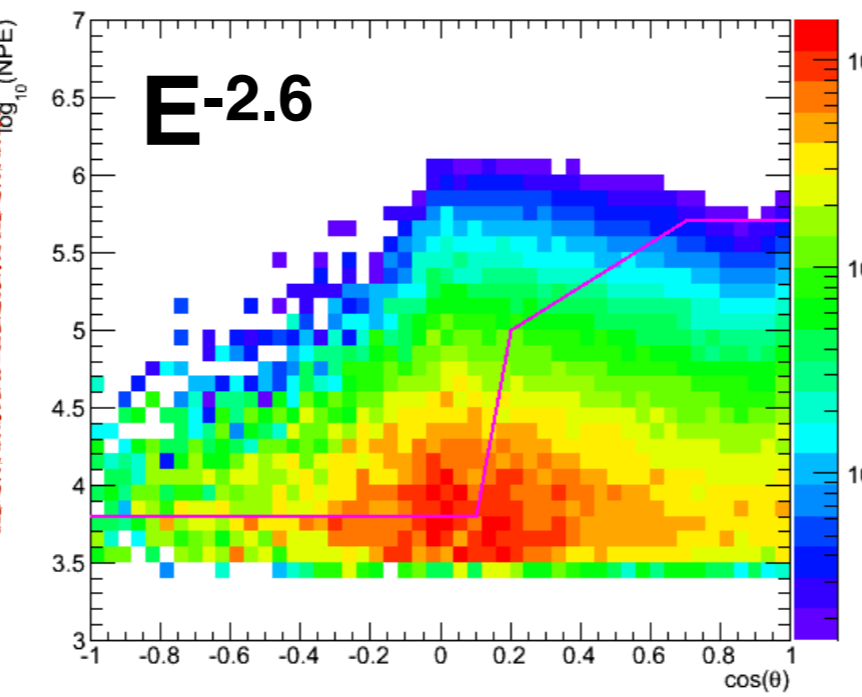
Change Spectrum

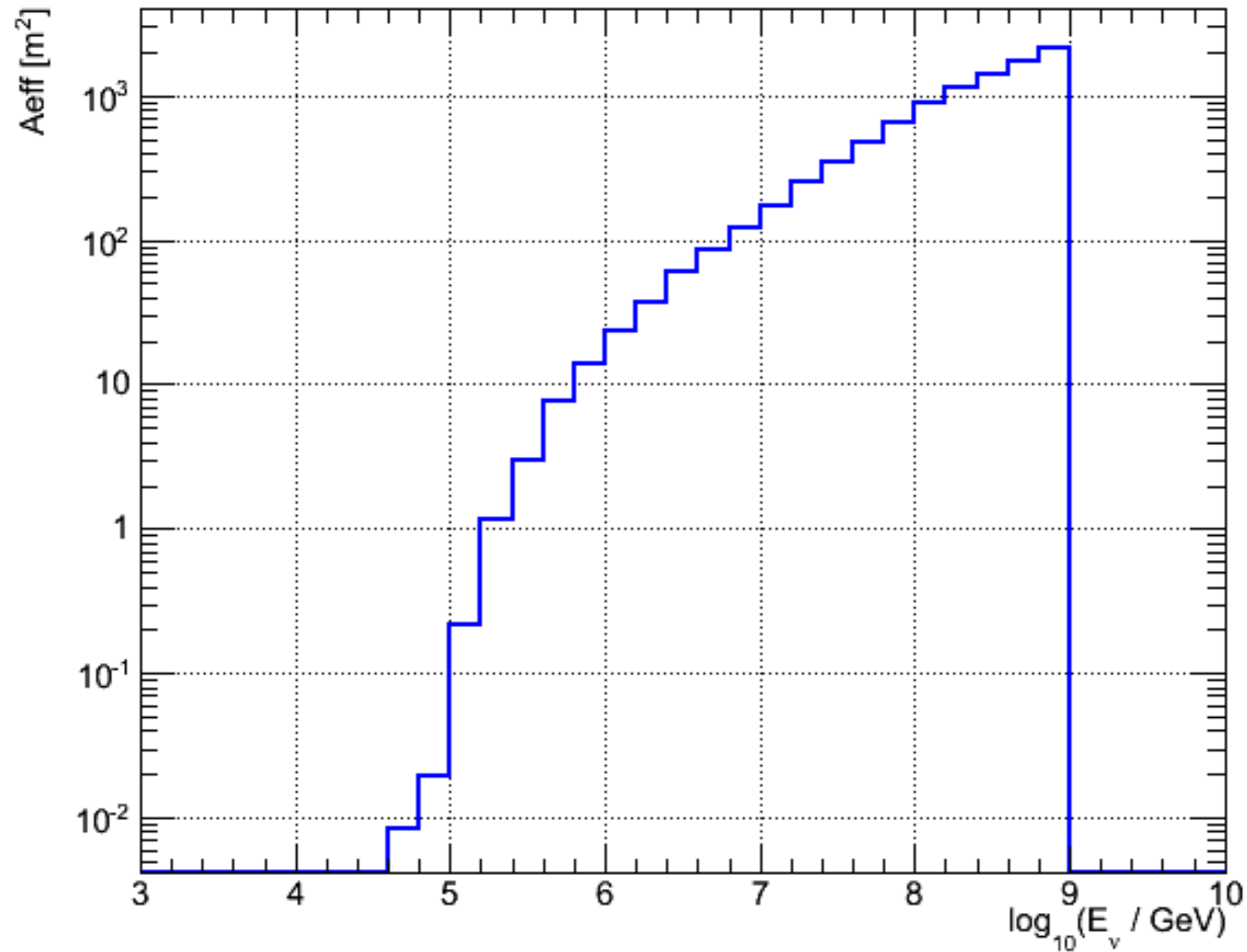- Check softer spectrum (indicated form current fits).

Specturm	Yield /	f (nHz)
E^{-2}	3.85	220
$E^{-2.2}$	1.90	60
$E^{-2.4}$	1.07	34
$E^{-2.6}$	0.668	21
$E^{-2.8}$	0.450	14

Astro. Norm = 1e-8 @ 100 TeV

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Effective Area

GZK Prospects

- Also checked GZK prospects with updated Signal Region

- Expected Signal: 0.88 Events (for $\nu_e + \nu_\mu + \nu_\tau$)