IceCube: Detection of optical Cherenkov in-ice at the South Pole

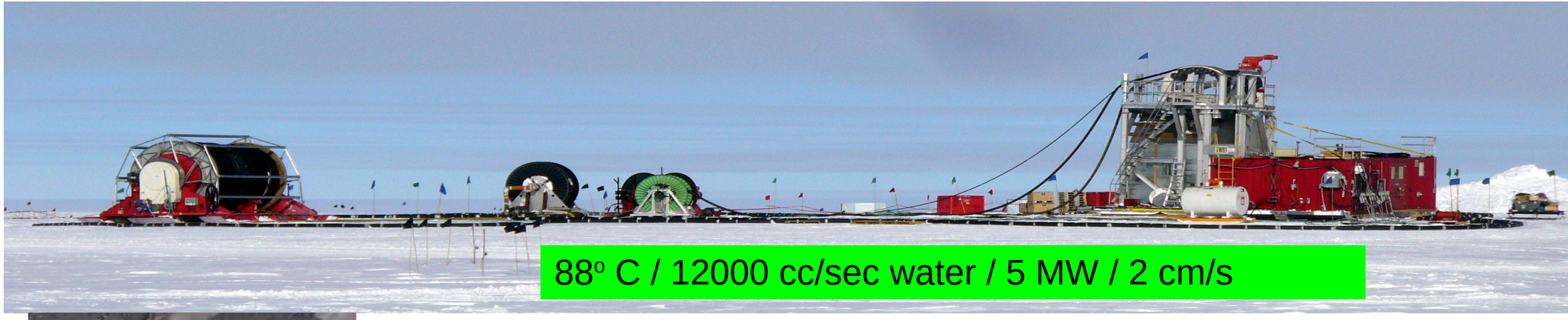
IceCube

Halos

Arrival

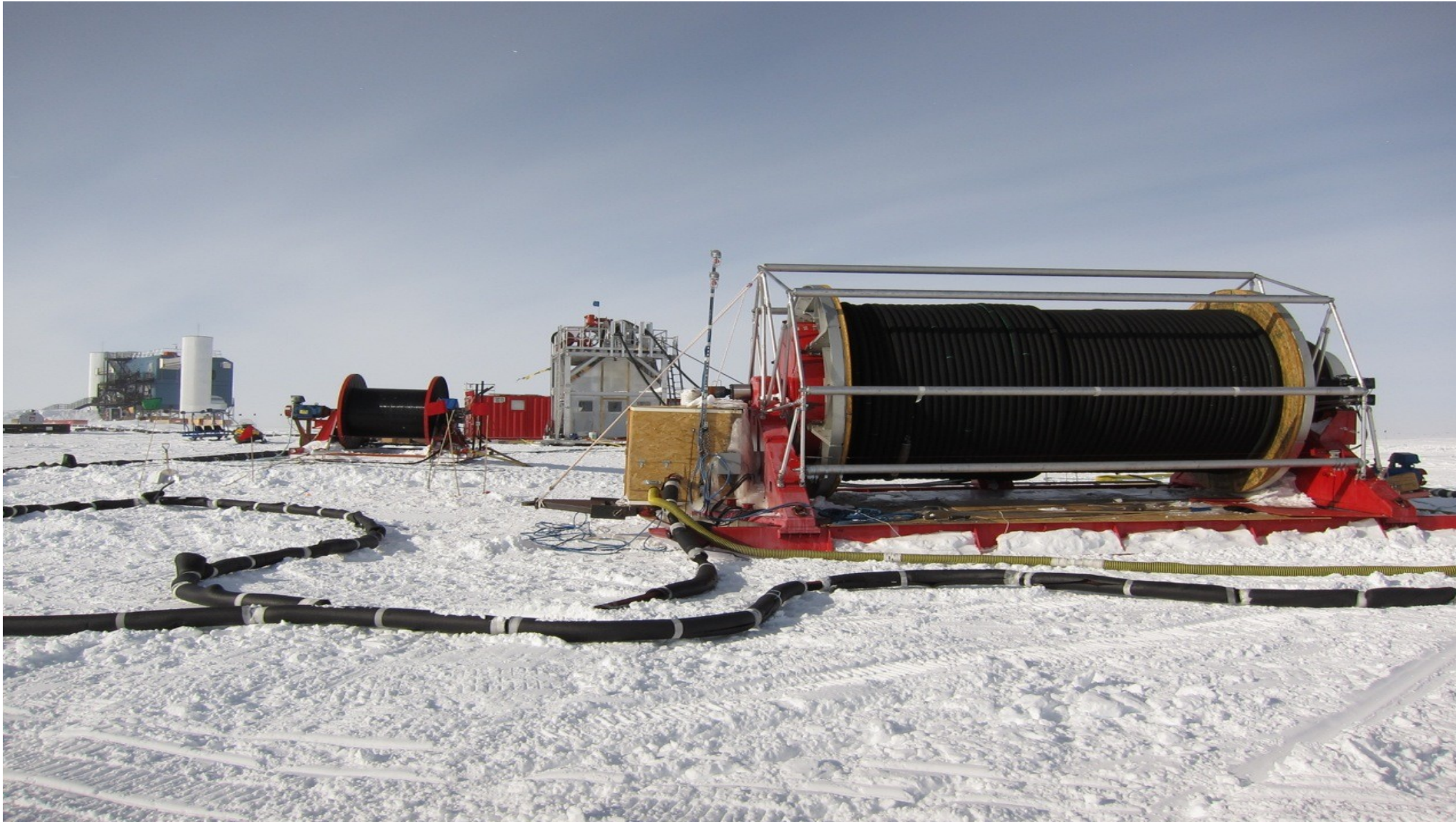
Why is Antarctica a good place to do cosmic ray astronomy?

- Ice is clear: $L_{atten}(\lambda=400\ nm)\sim120\ m$; $L_{scattering}(\lambda=400\ nm)\sim45\ m$ $L_{atten}(\lambda=1\ m)\sim1500\ m$; $L_{scattering}(\lambda=1\ m)\sim10\ km$
- Ice provides a stable pre-made “lab”: The medium is the message



- Far from anthropogenic noise
- 3 km elevation
  - close to shower max

Drill Tower side view



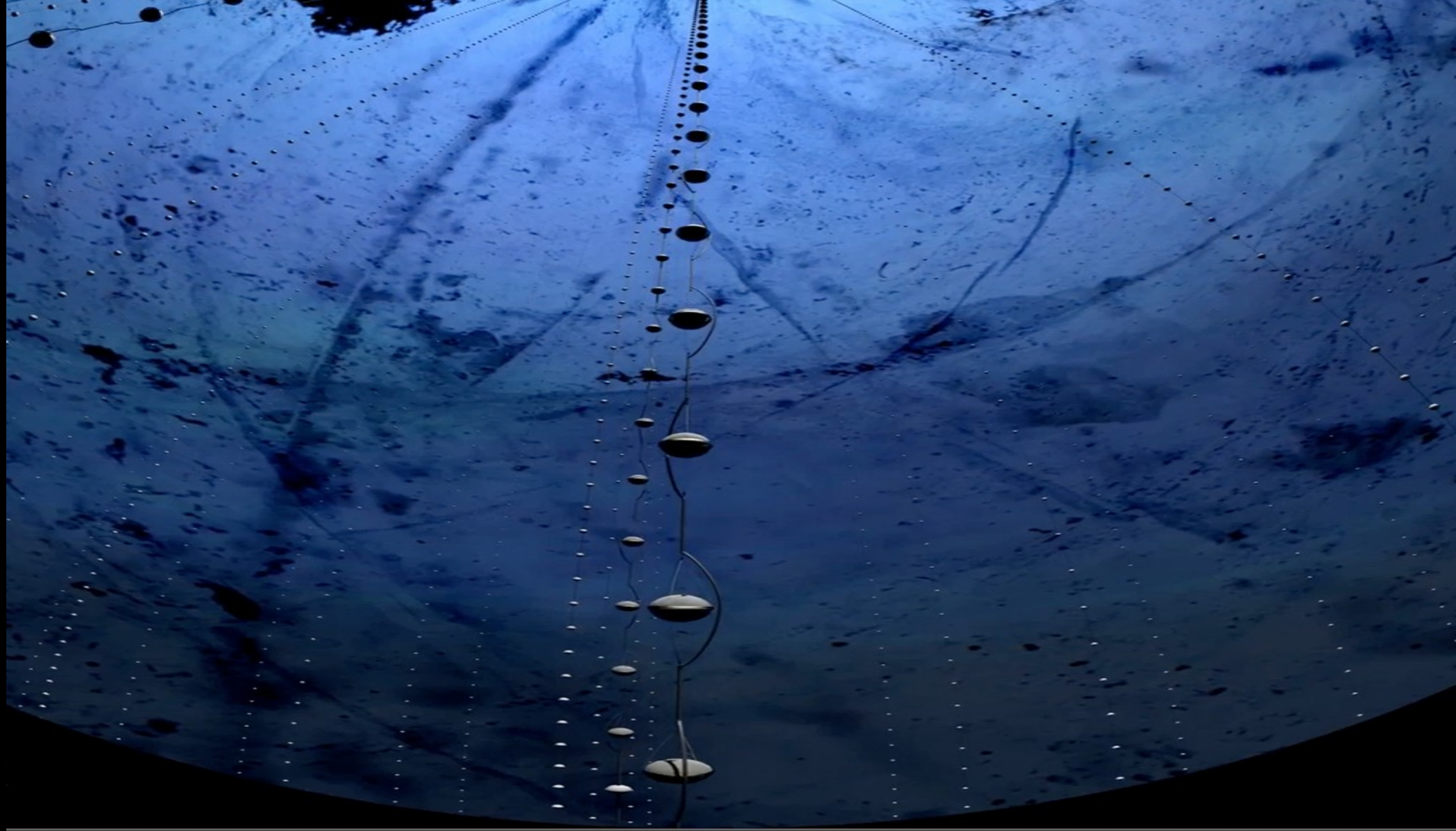
nozzle delivers

- 13 liters/second
- 7 MPa
- 90 degree C

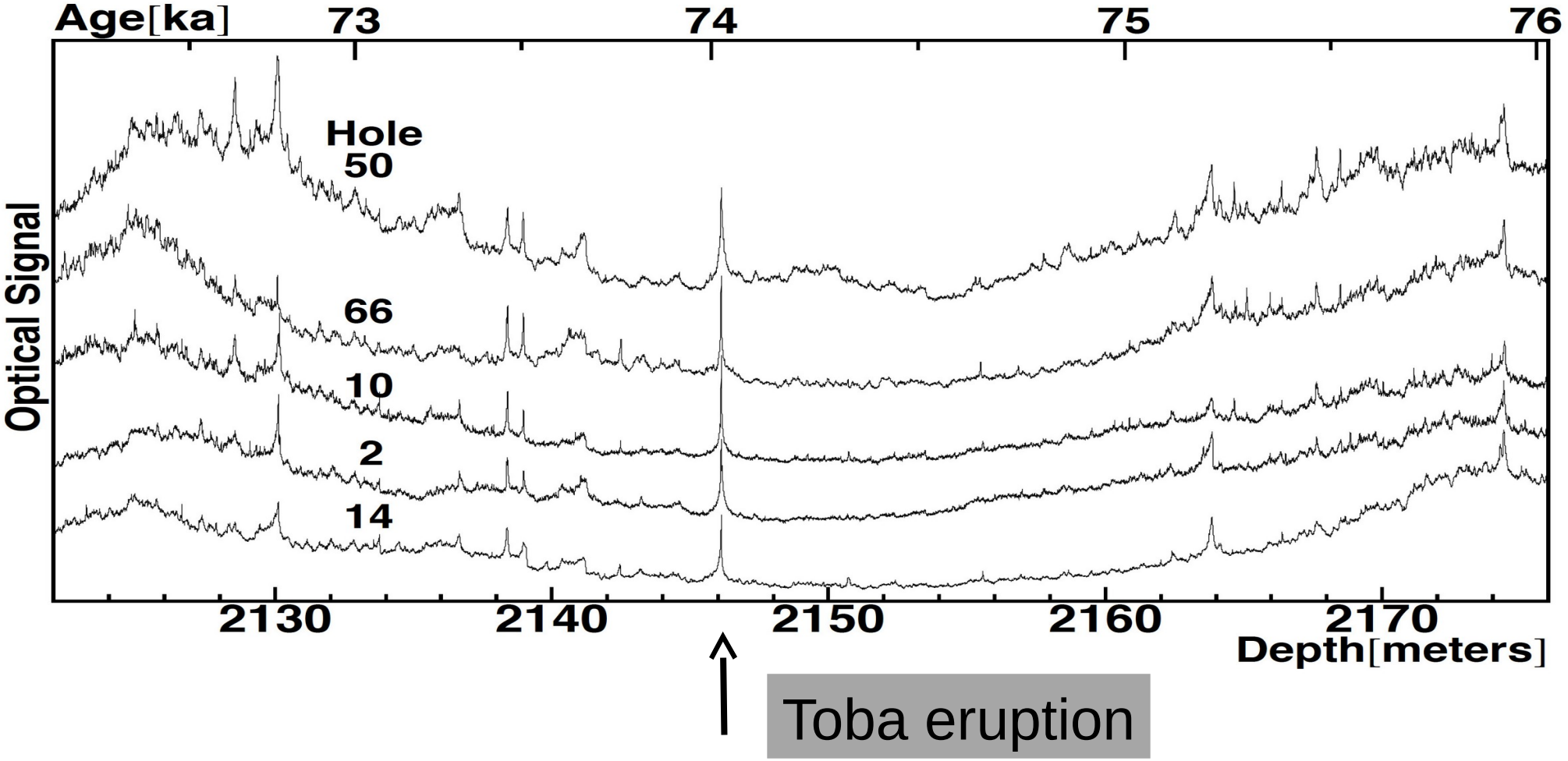
4.8 megawatt heating plant

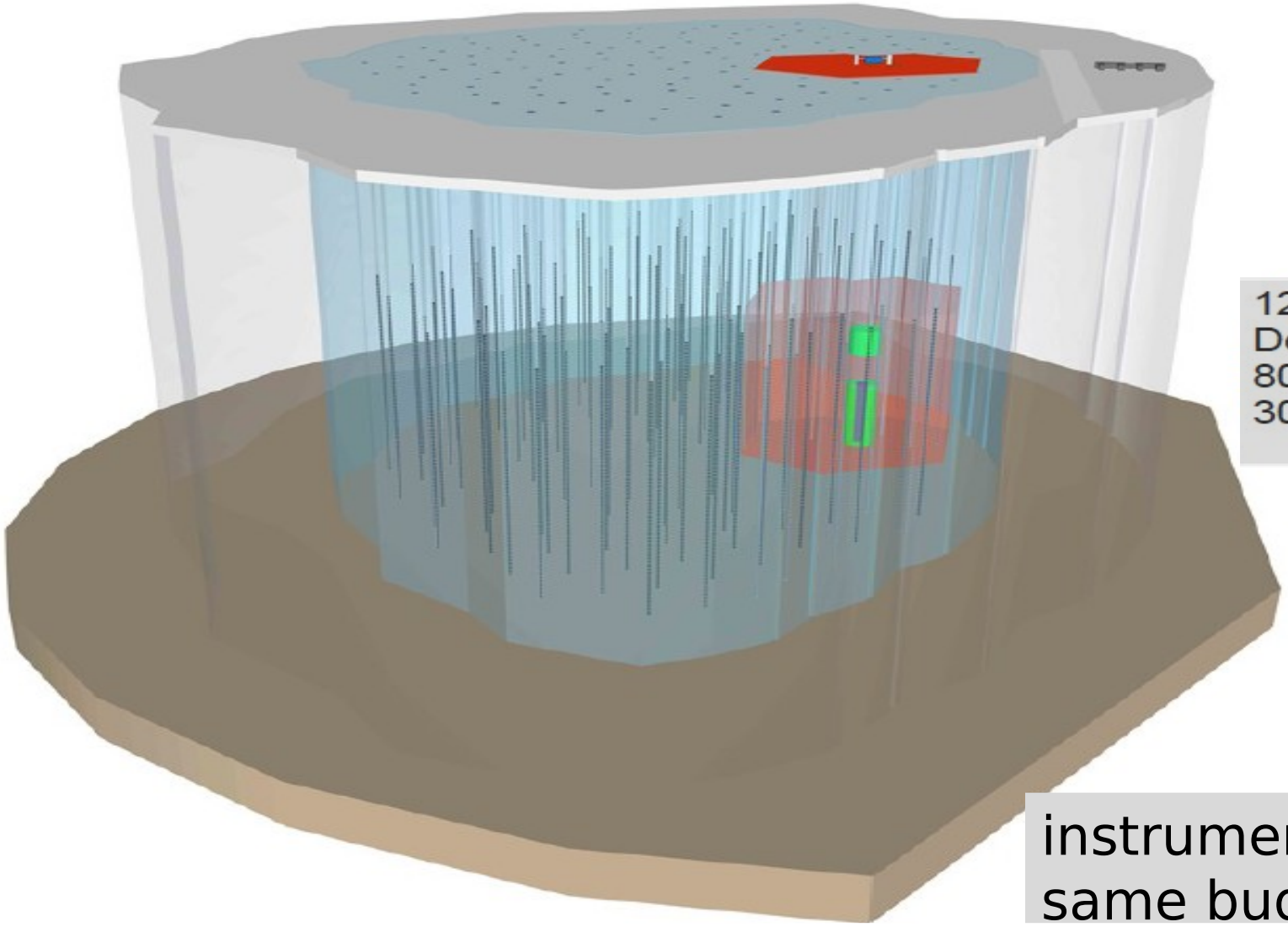
- Drilling in two phases

Hole drilling



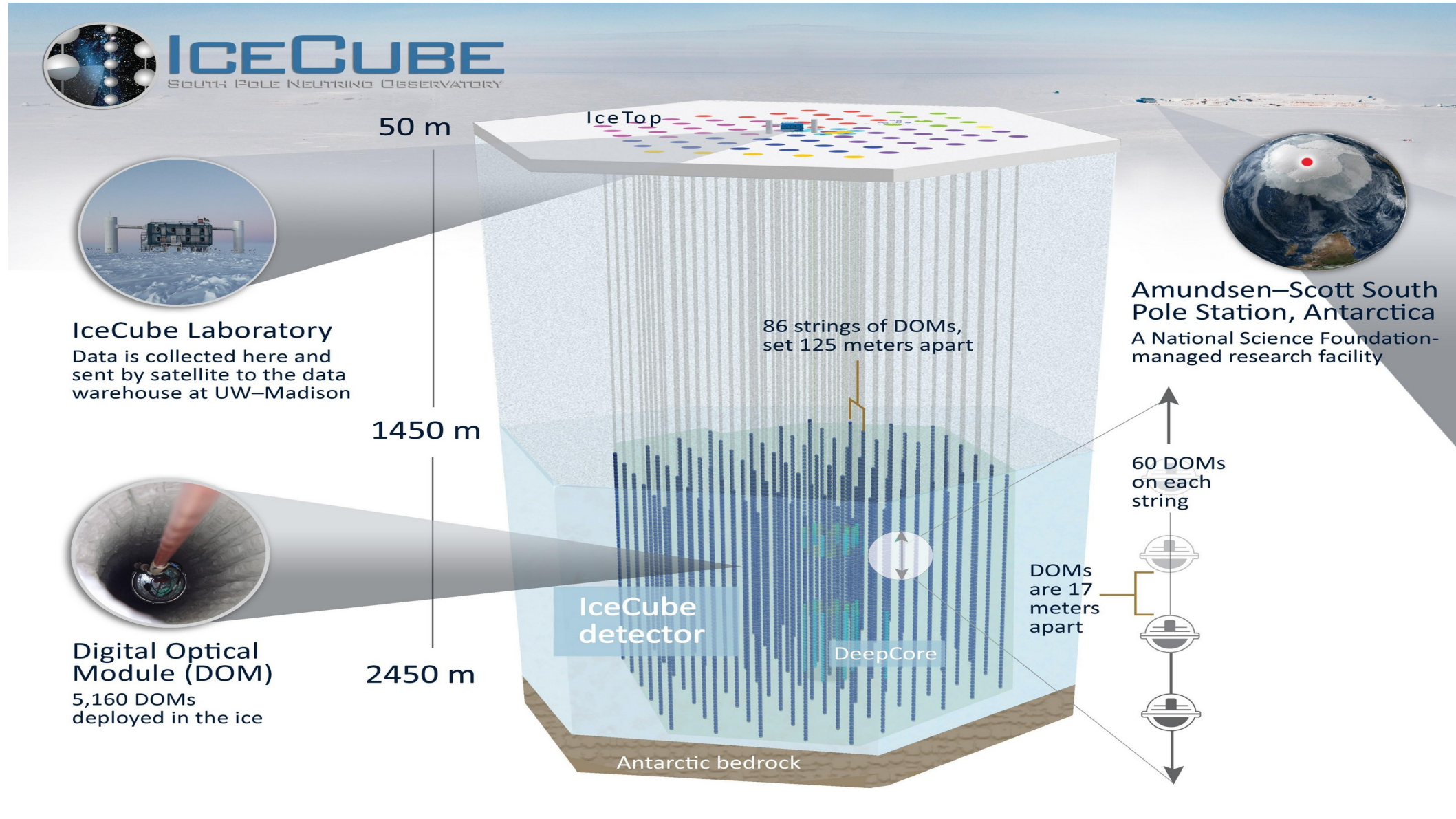
the optics of the ice



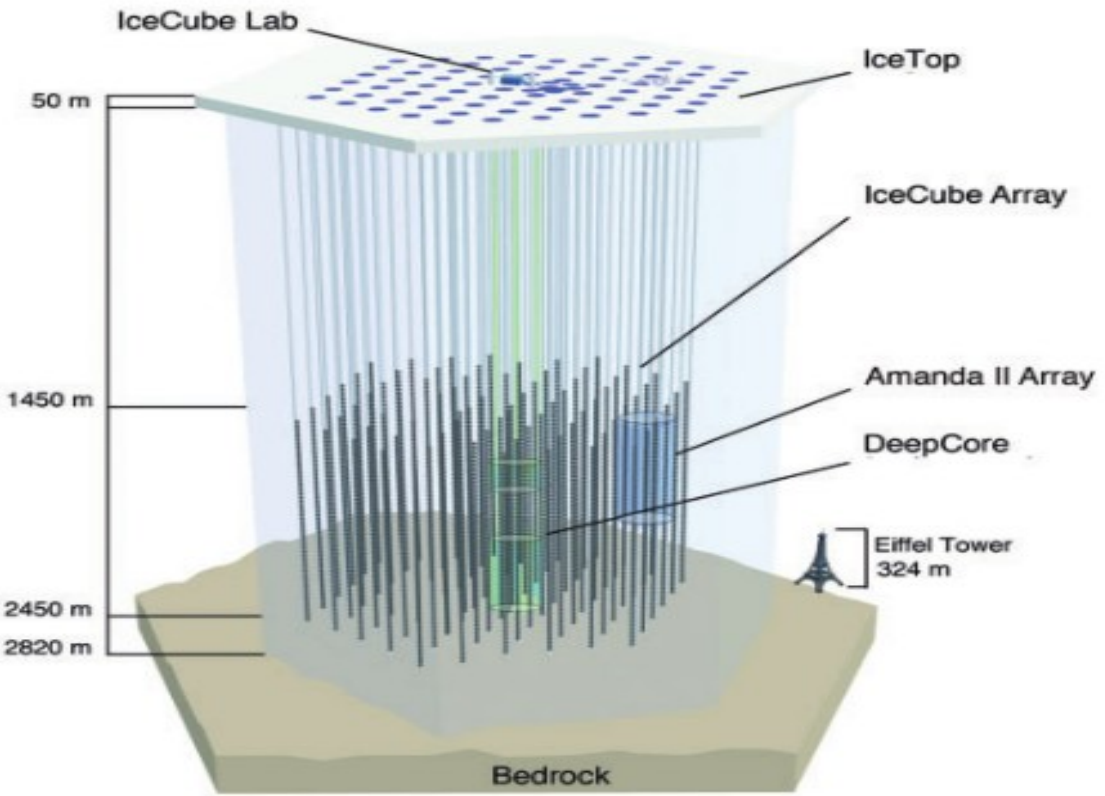


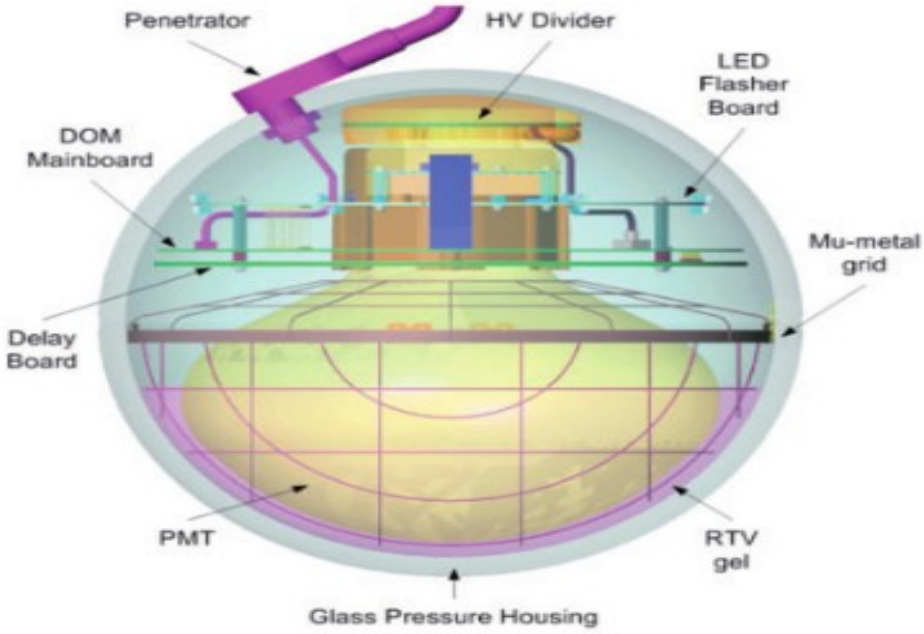
120 strings
Depth 1.35 to 2.7 km
80 DOMs/string
300 m spacing

instrumented volume: x 10
same budget as IceCube


IceCube
South Pole Neutrino Observatory
50 m
IceTop
1450 m
2450 m
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
86 strings of DOMs, set 125 meters apart
IceCube detector
DeepCore
Antarctic bedrock
60 DOMs on each string
DOMs are 17 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility

DOMs=Digital Optical Module



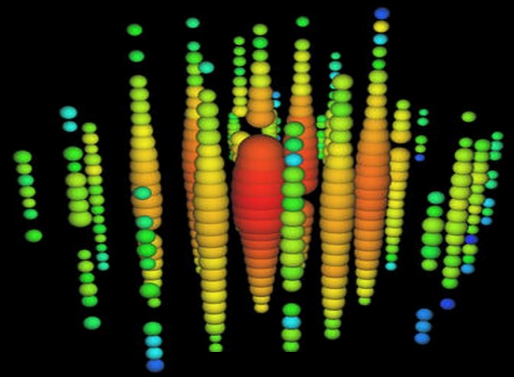


RESEARCH

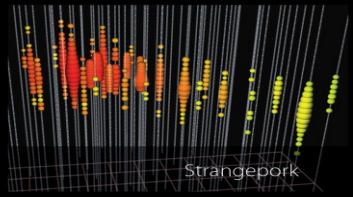
Evidence for High-Energy Extraterrestrial Neutrinos at the IceCube Detector

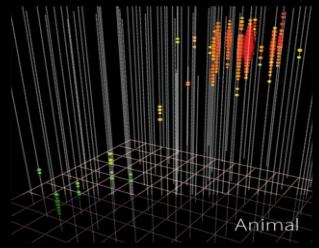
IceCube Collaboration*

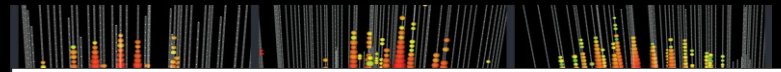
Introduction: Neutrino observations are a unique probe of the universe's highest ene

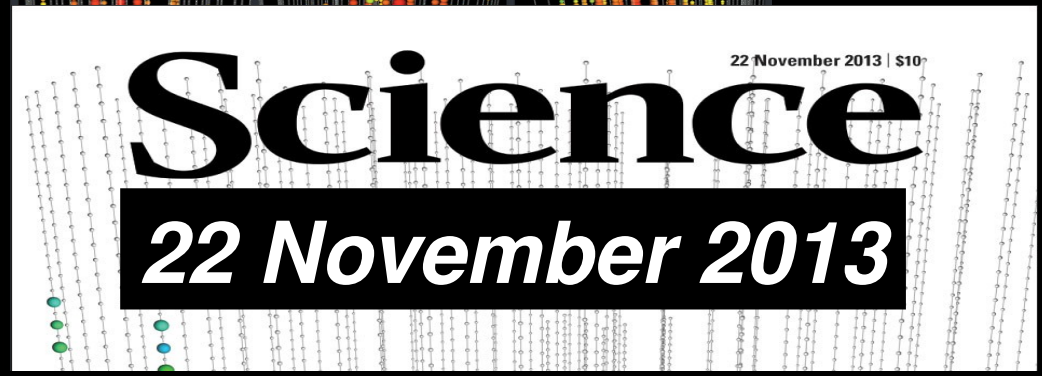


28 High Energy Events





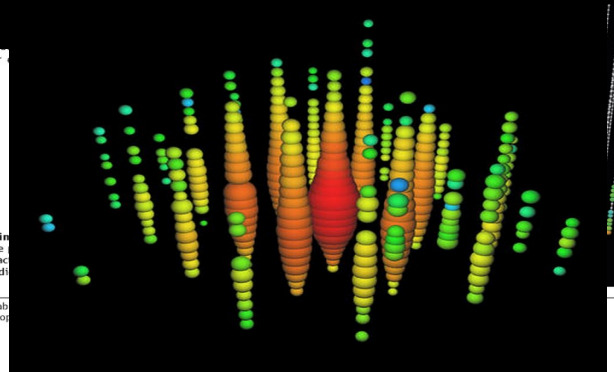


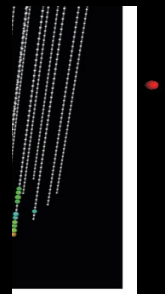


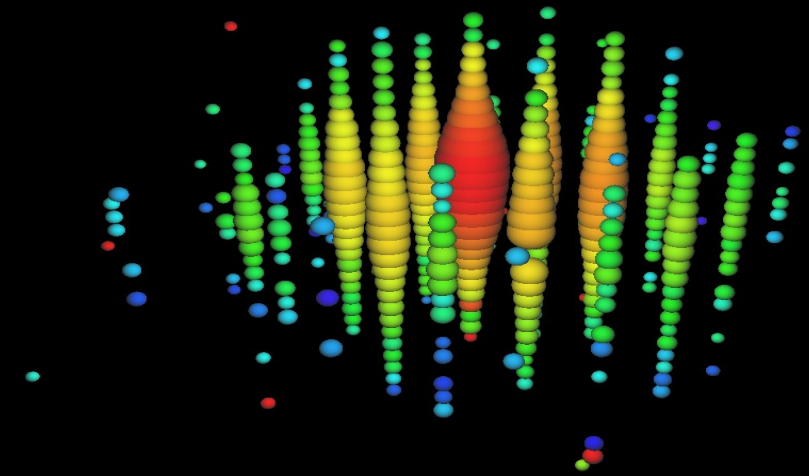
tified high-energy galactic or
accelerators.

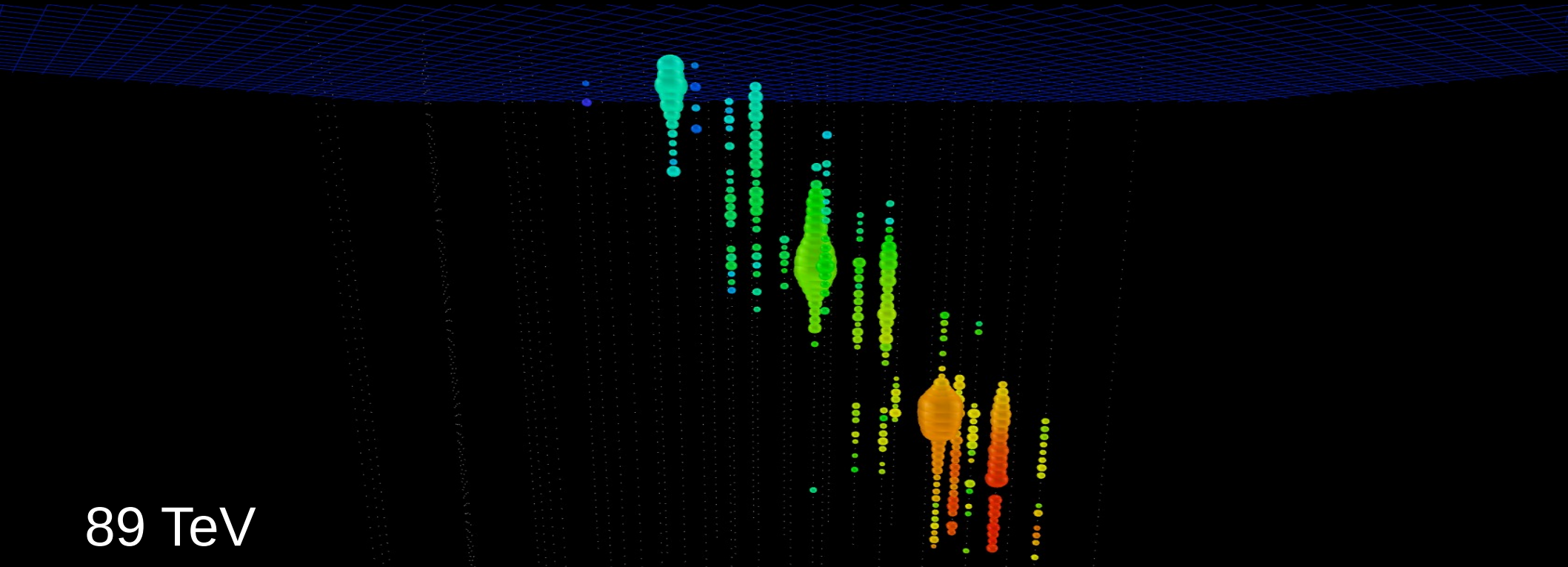
A 250 TeV neutrino interaction in
interaction point (bottom), a large
with a muon produced in the interac
left. The direction of the muon indi
original neutrino.

*The list of author affiliations is availab
Corresponding authors: C. Kopper (ckop









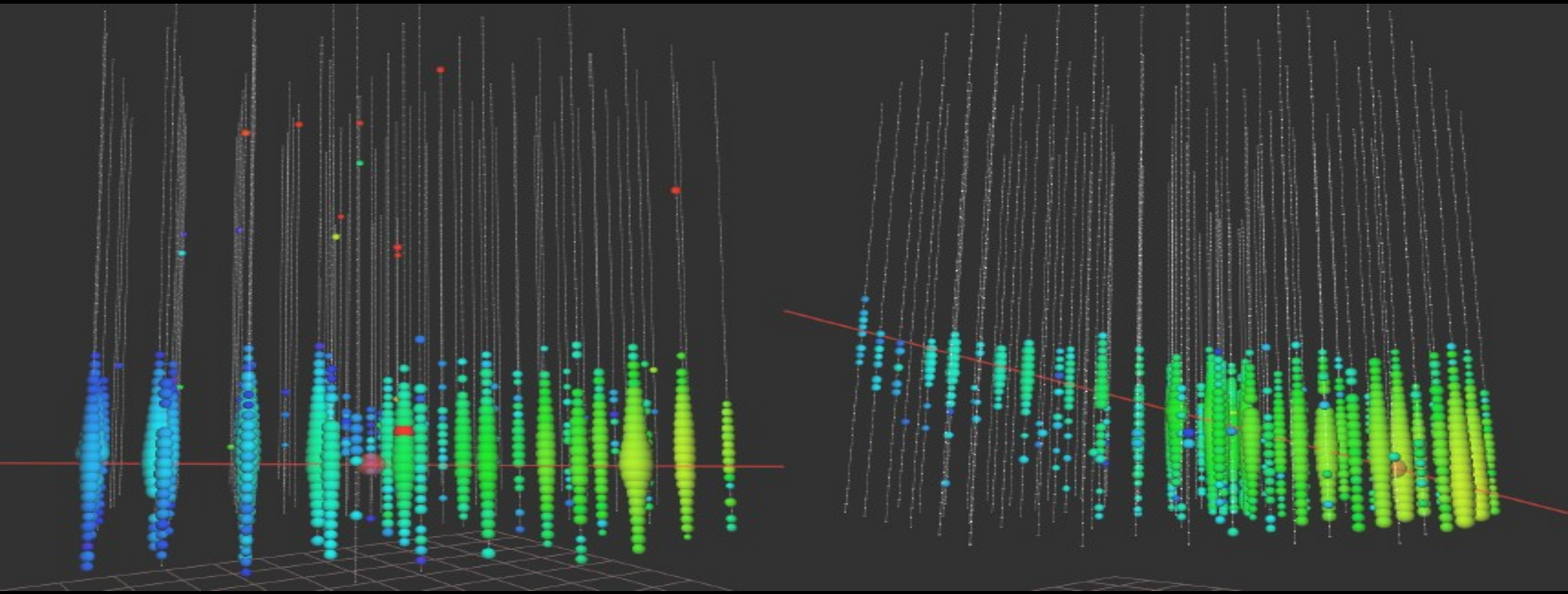
89 TeV

radius ~ number of photons

time ~ red → purple

Run 113641 Event 33553254 [0ns, 16748ns]

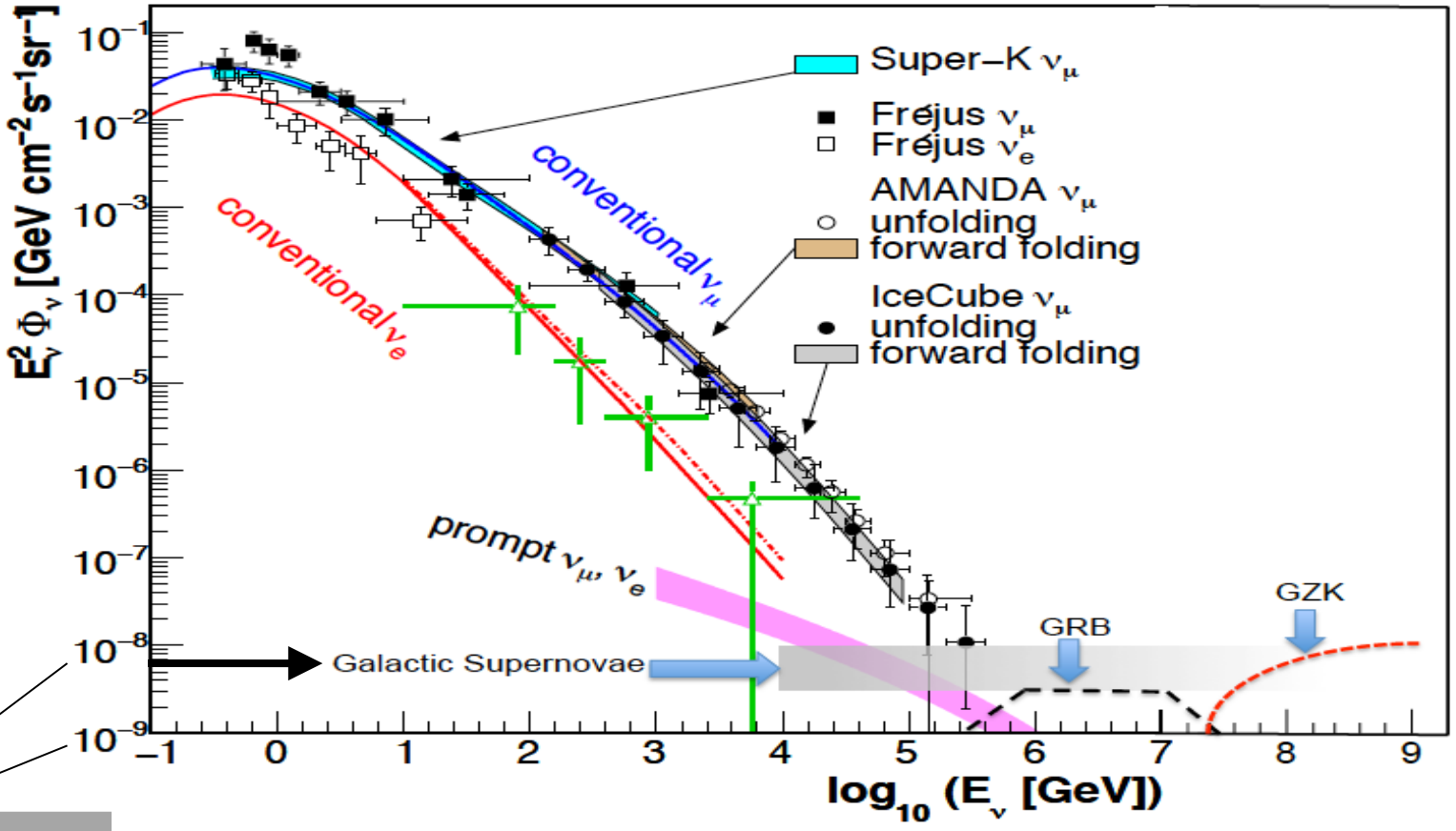
2 events, including highest energy muon energy observed: 560 TeV
=> PeV energy neutrino



above 100 TeV

- cosmic neutrinos:
- atmospheric background disappears

$$dN/dE \sim E^{-2}$$



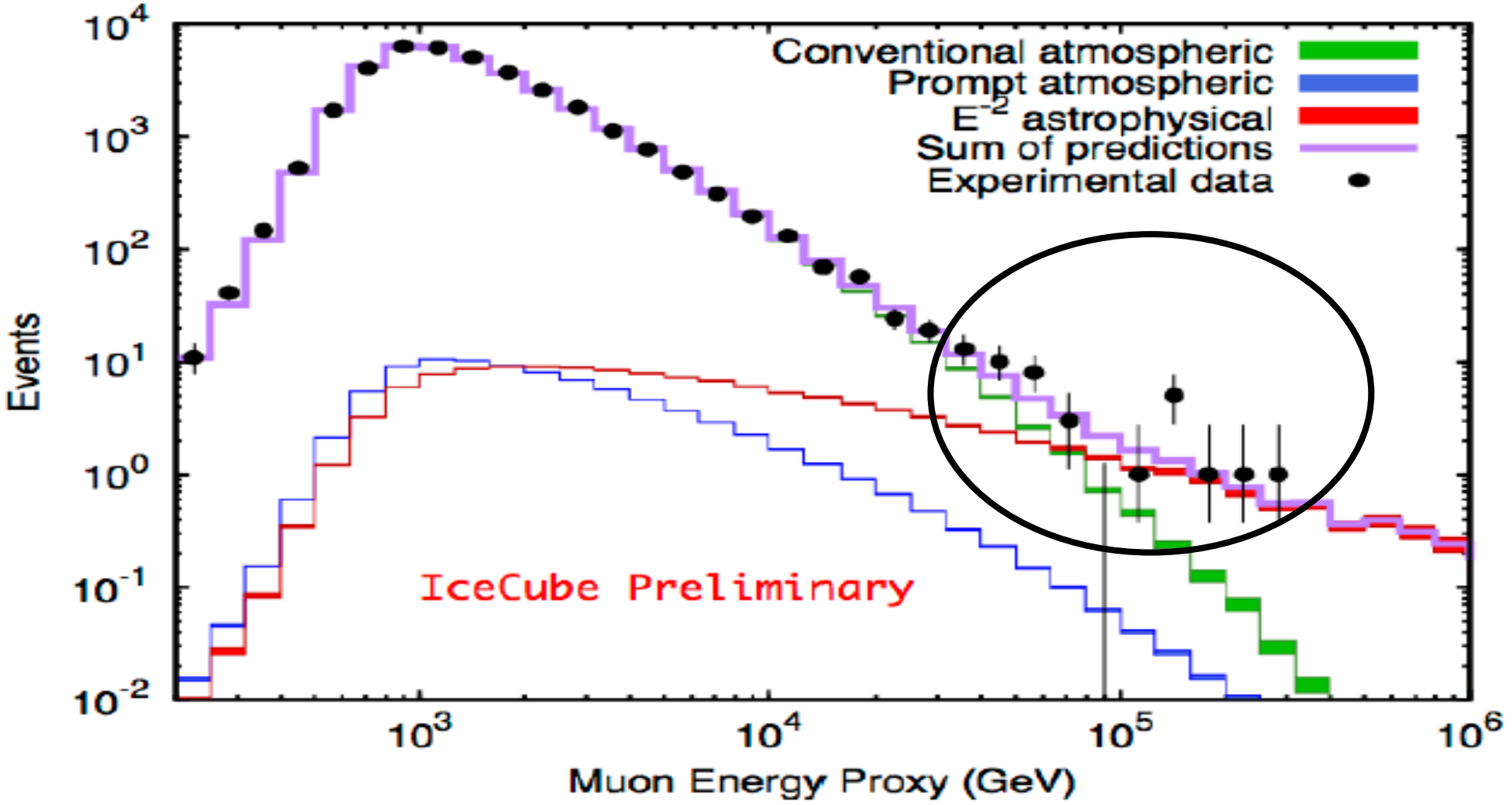
10—100 events per year for fully efficient detector

atmospheric

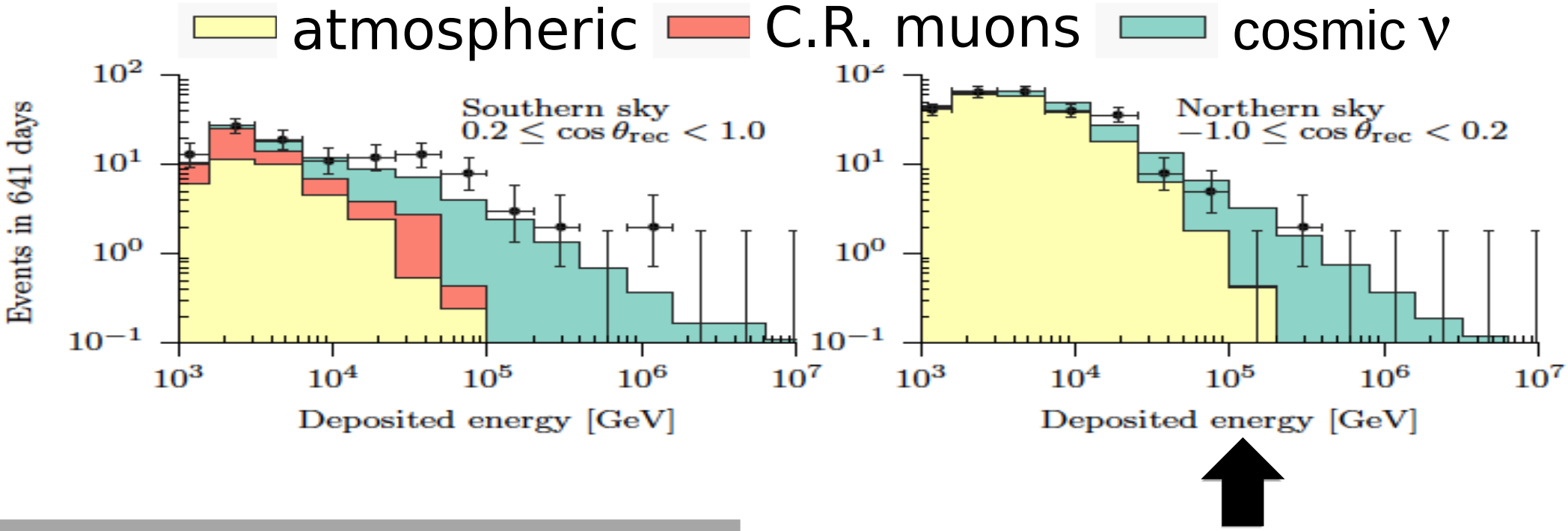
cosmic

100 TeV

cosmic neutrinos in 2 years of data at 3.7 sigma



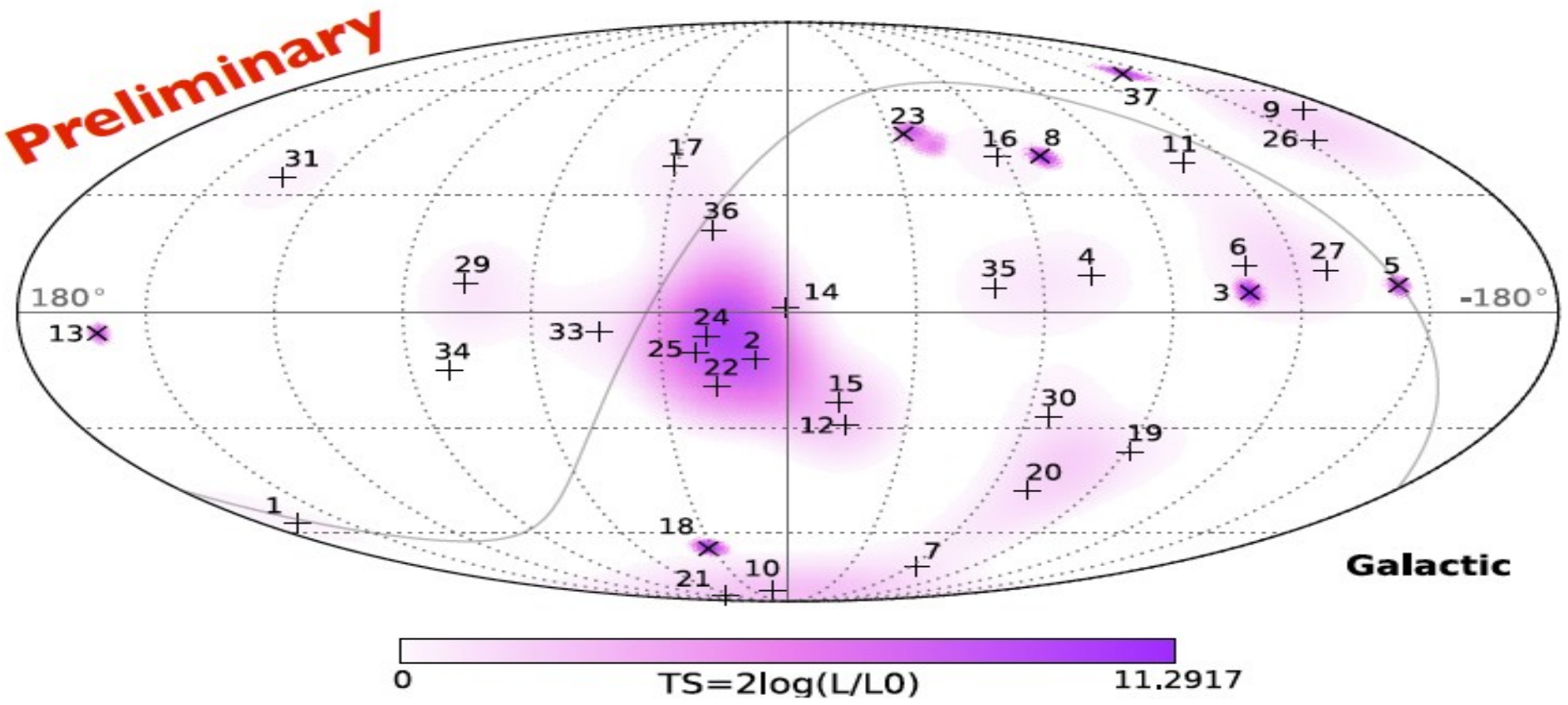
starting events; towards lower energies



warning:
- spectrum may not be a power law
- slope depends on energy range fitted

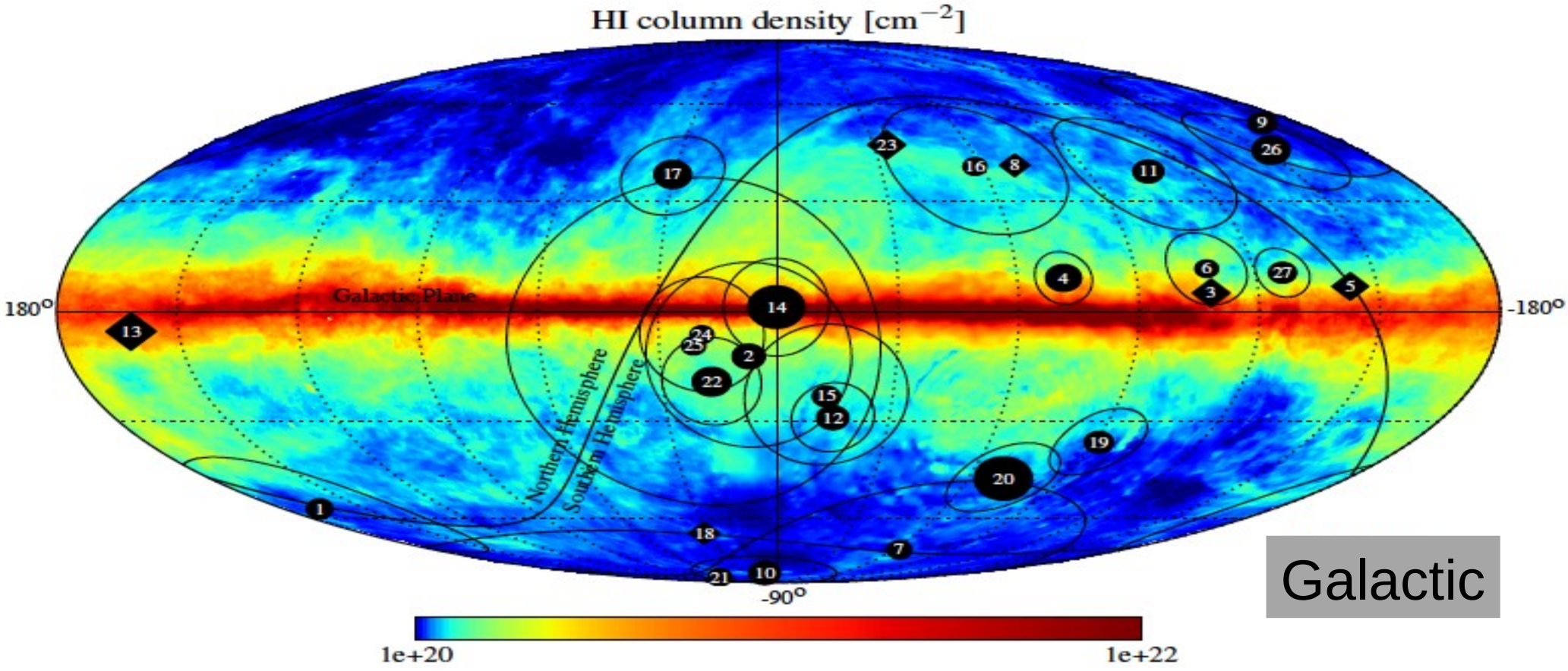
PeV neutrinos absorbed in the Earth

where do they come from (3 year data)?



hottest spot 7.2%: consistent with diffuse flux with fllavor 1:1:1?

correlation with Galactic plane: TS of 2.8% for a width of 7.5 deg



Galactic

hadronic gamma rays ?

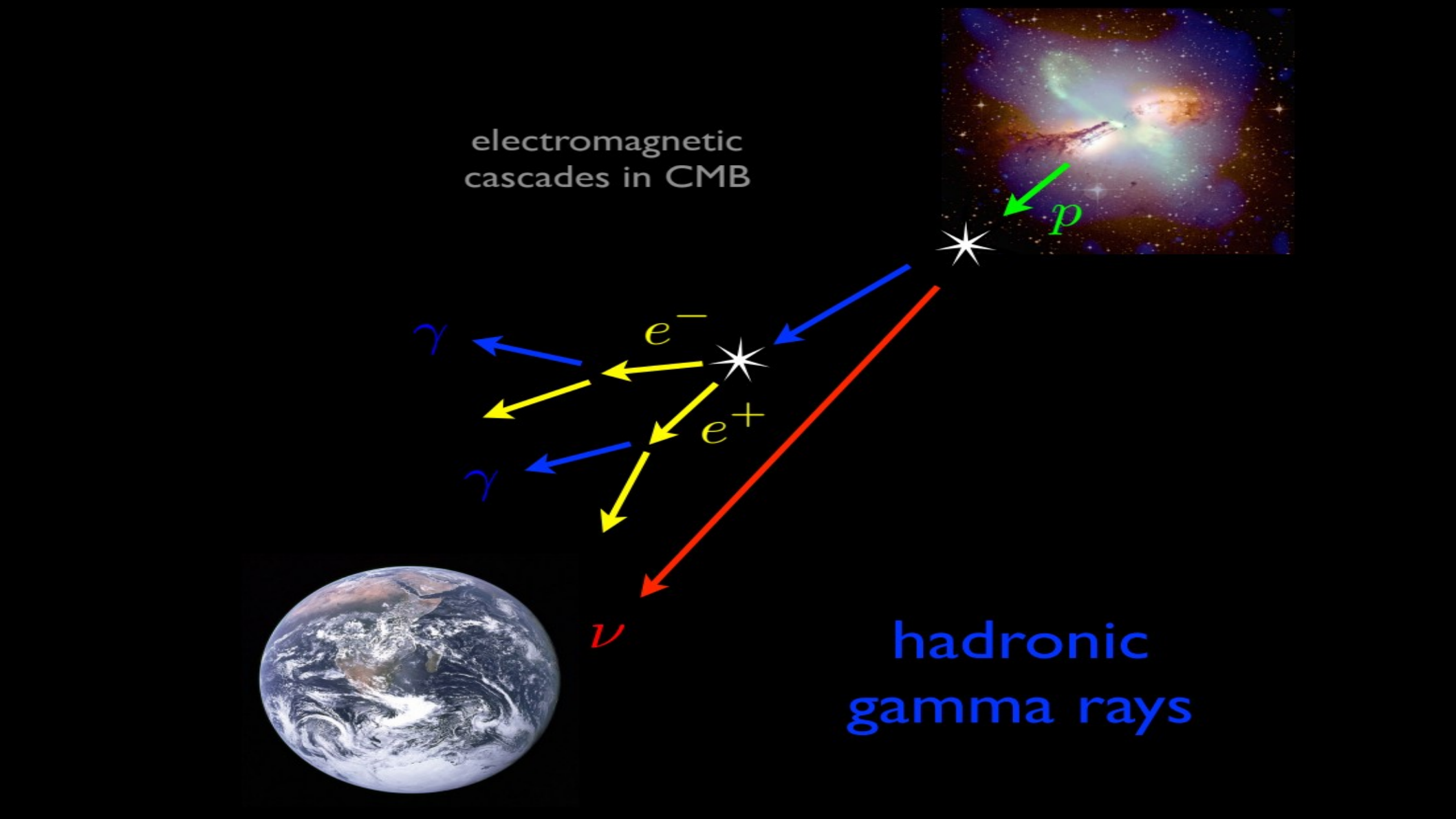
$\pi^+ = \pi^- = \pi^0$

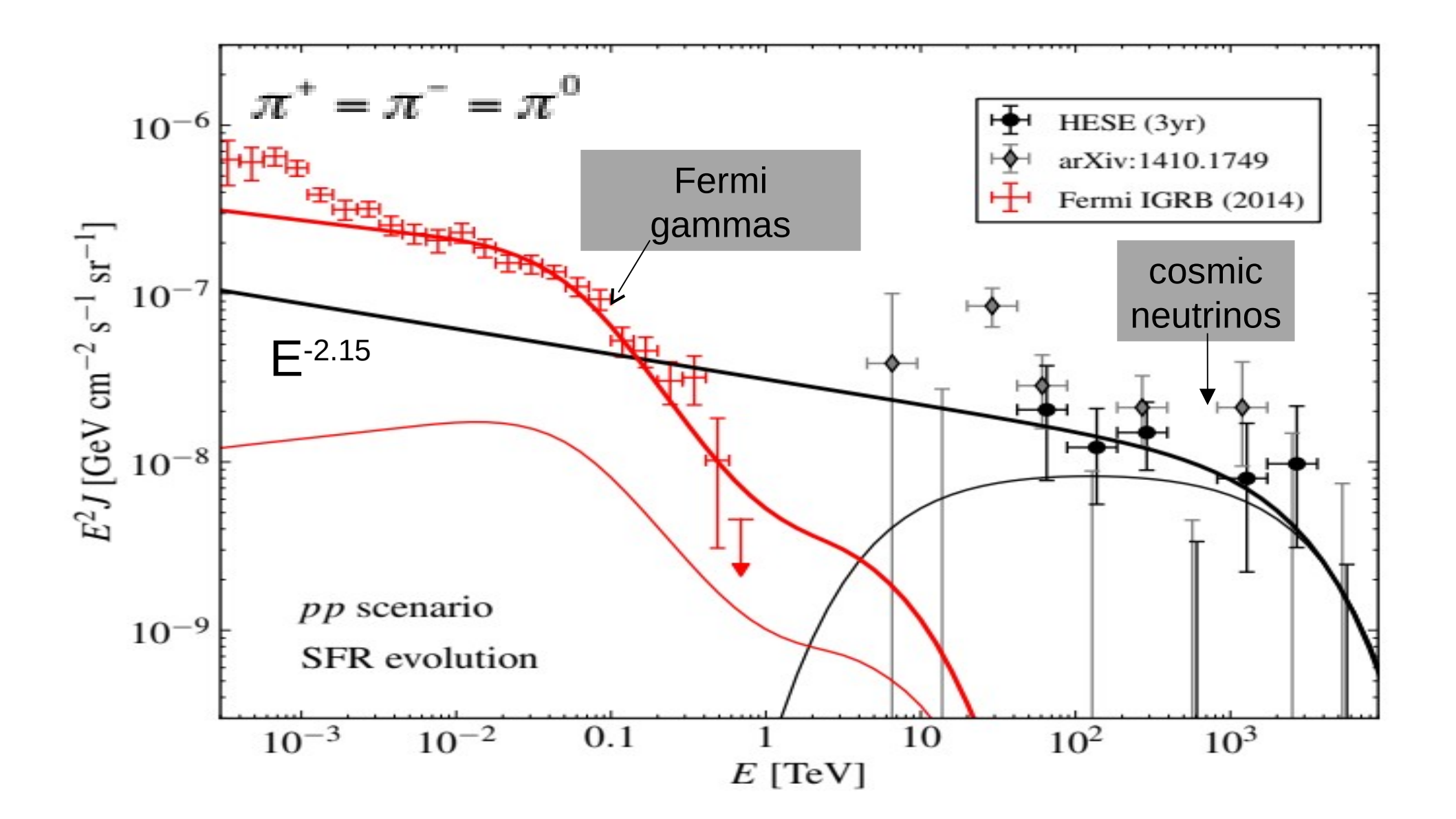
p

γ

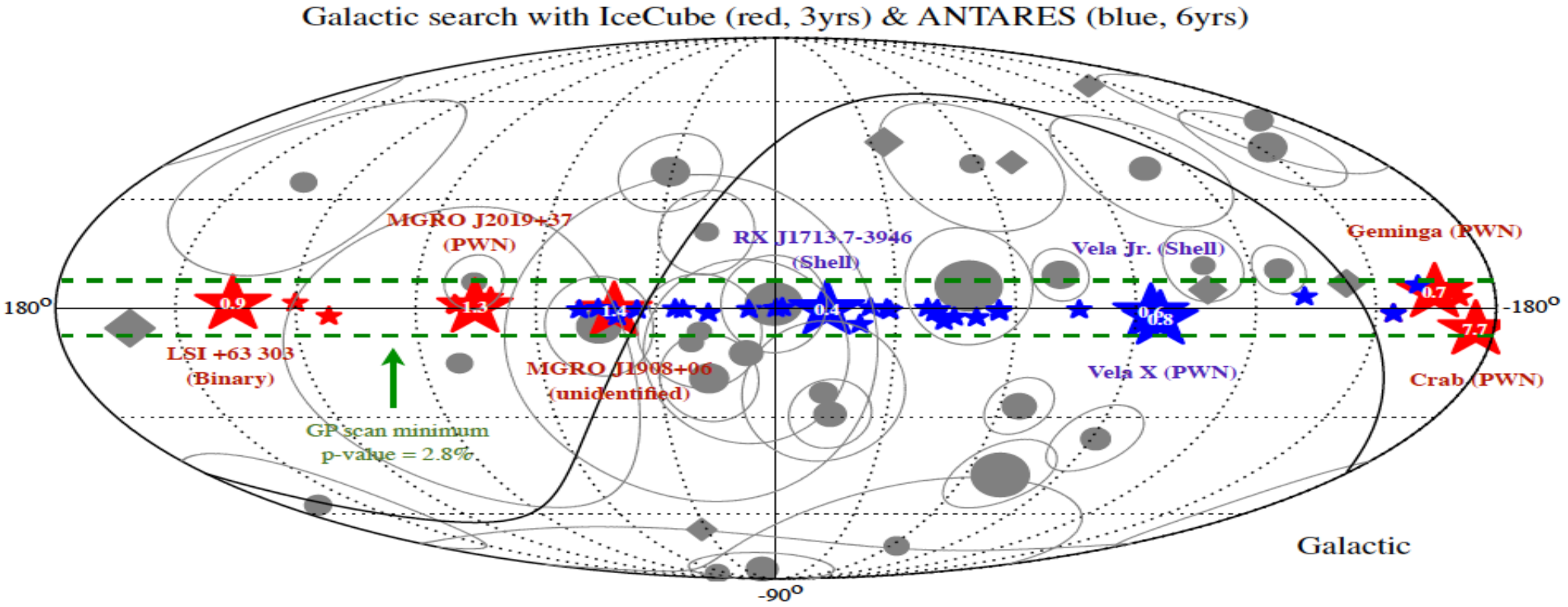
ν

hadronic
gamma rays


electromagnetic
cascades in CMB
p
γ
e^-
e^+
γ
ν
hadronic
gamma rays

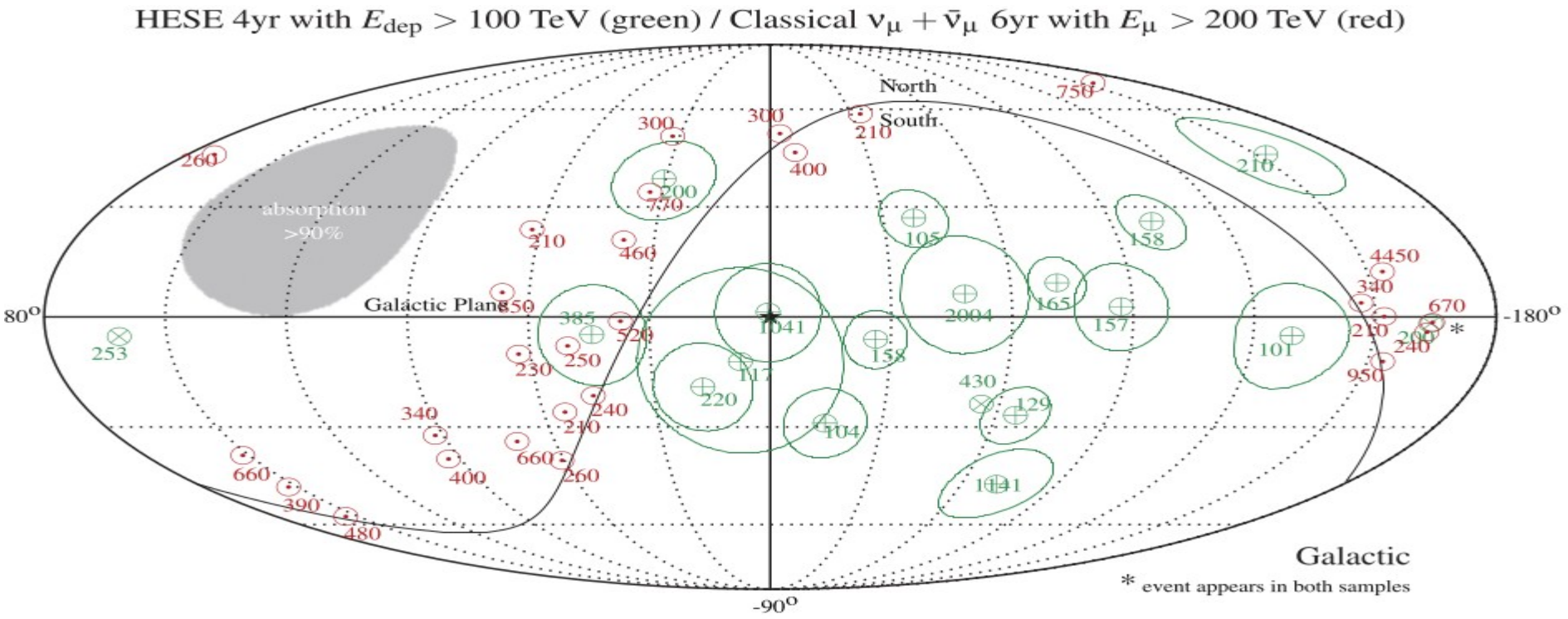

$\pi^+ = \pi^- = \pi^0$
HESE (3yr)
arXiv:1410.1749
Fermi IGRB (2014)
Fermi gammas
cosmic neutrinos
$E^{-2.15}$
pp scenario
SFR evolution
$E^2 J$ [GeV cm^{-2} s^{-1} sr^{-1}]
E [TeV]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-3}
10^{-2}
0.1
1
10
10^2
10^3

neutrino event rates from gamma ray sources

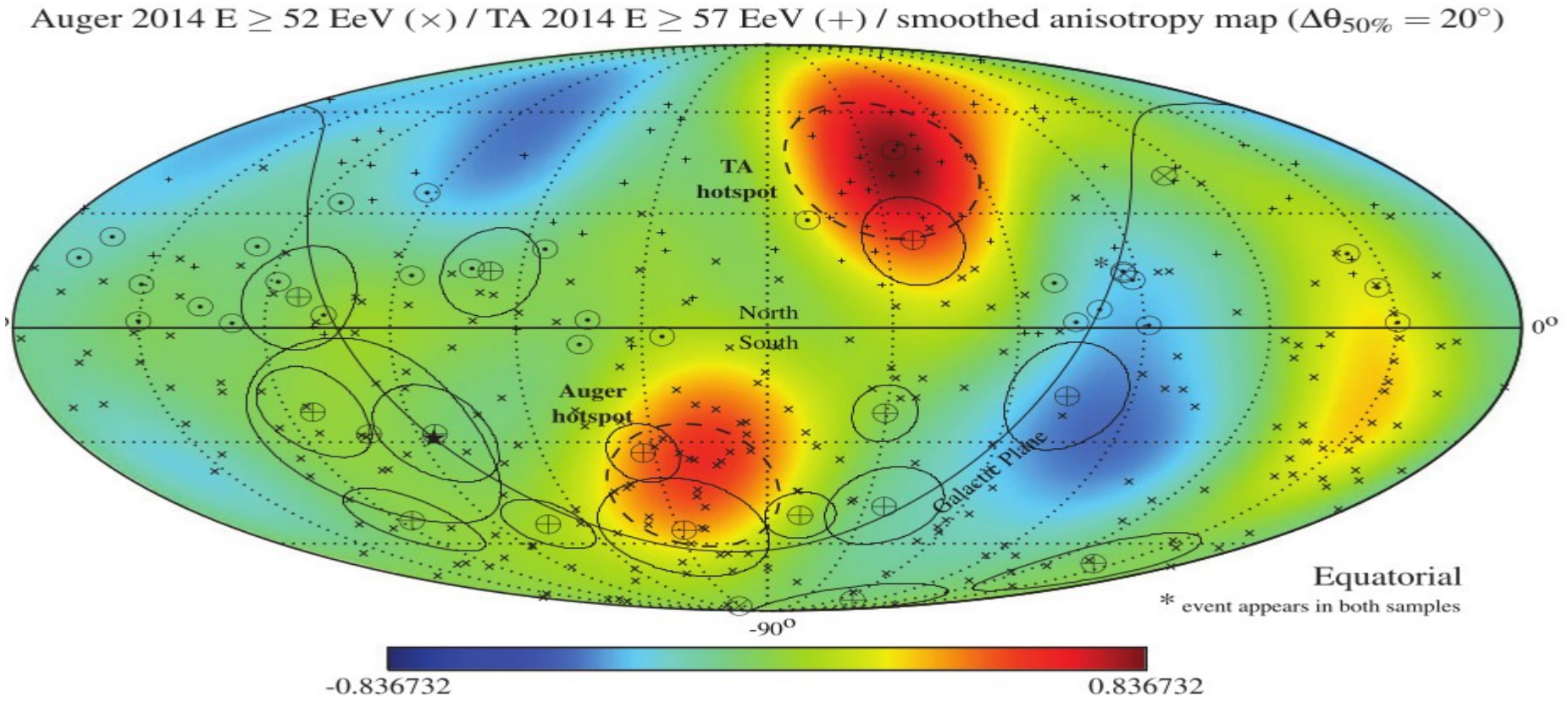


as some (all?) gamma ray sources produce neutrinos, we are close to detecting neutrinos from known high energy gamma ray emitters (one neutrino per photon)

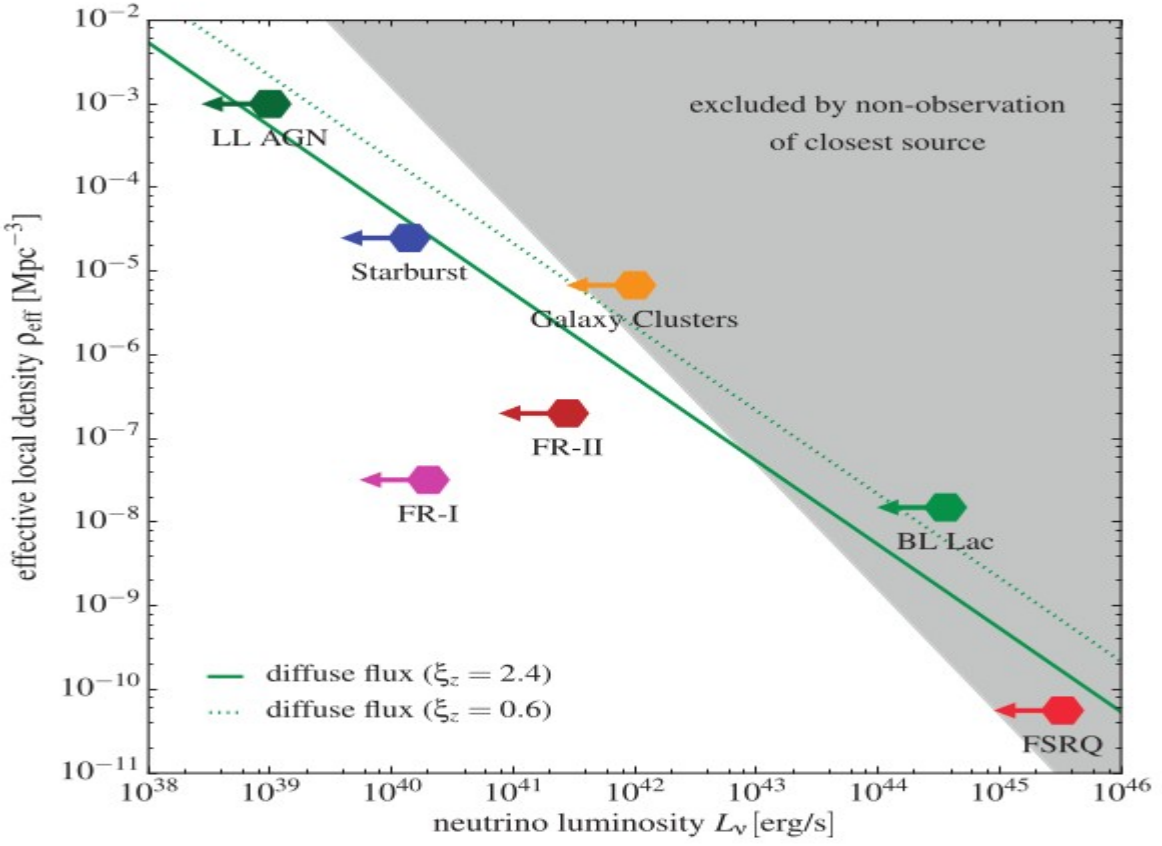
Overlay with gamma-ray catalog

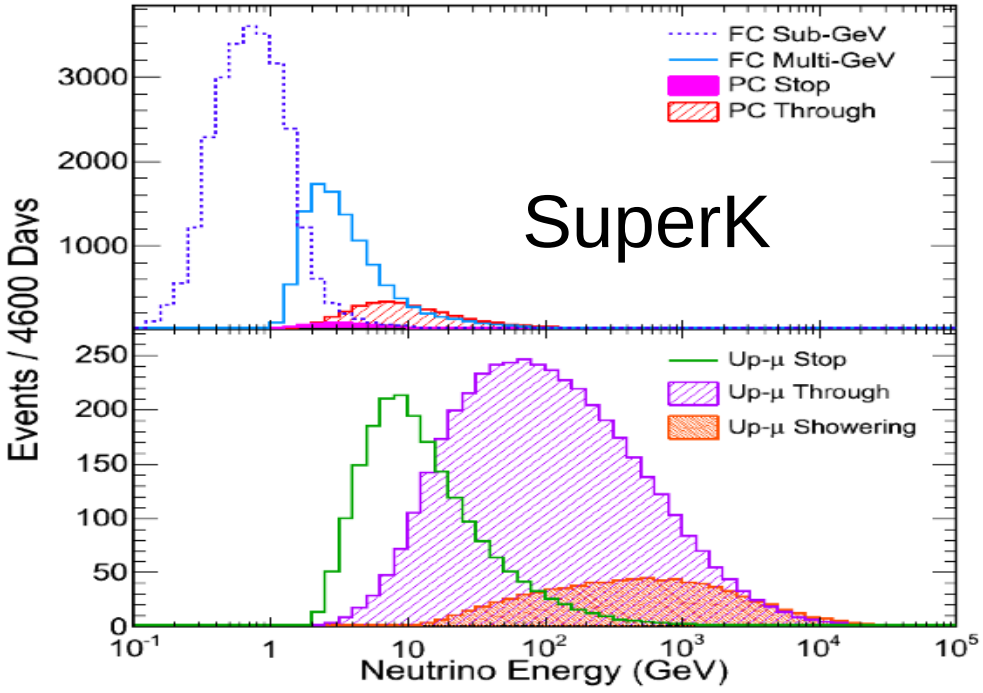


And overlay with TA/Auger

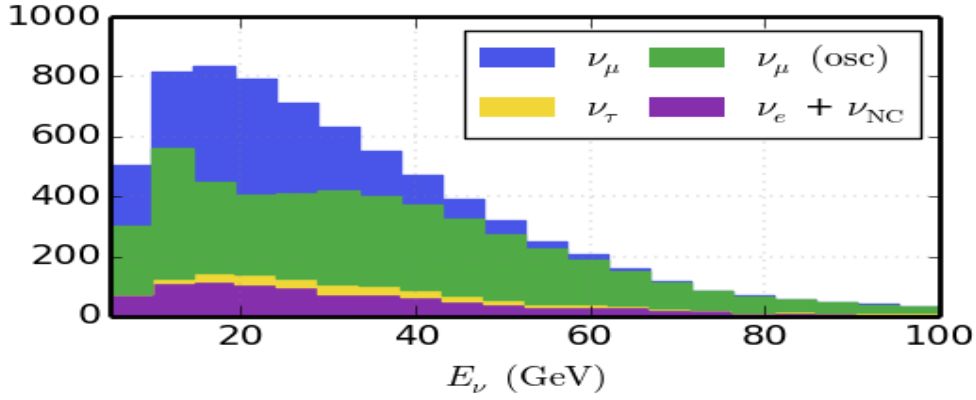


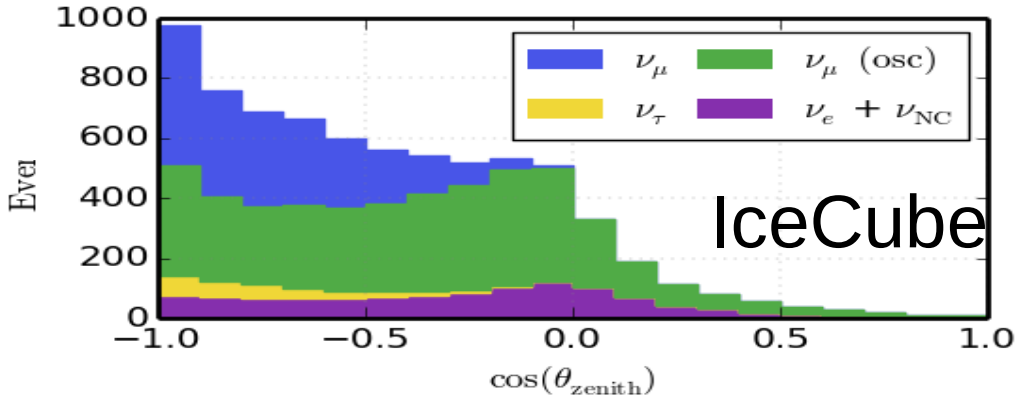
Place limits on neutrino source fluence





- Average energies
  - FC: ~1 GeV , PC: ~10 GeV, UpMu:~ 100 GeV

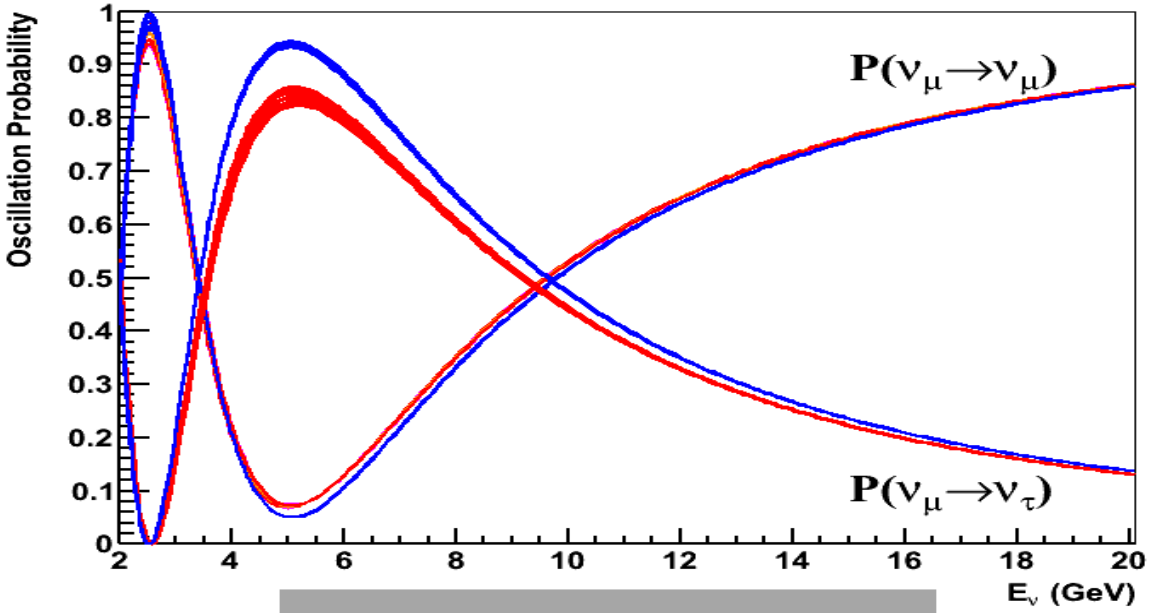




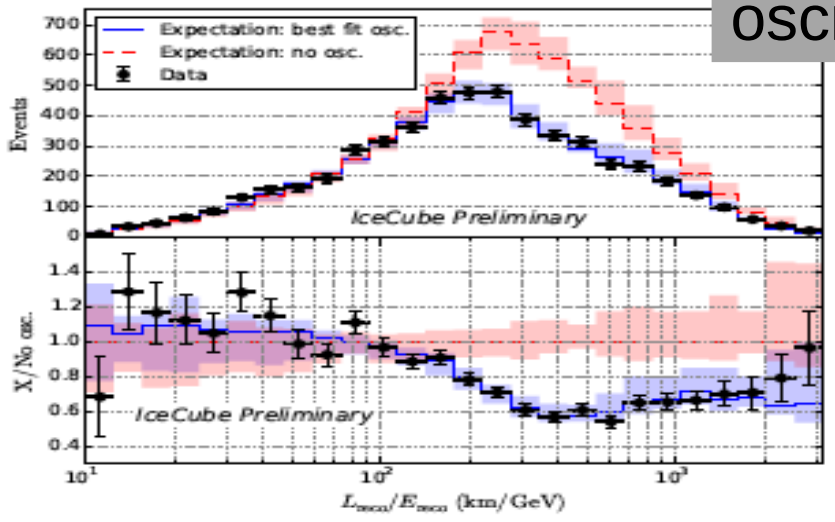
IceCube

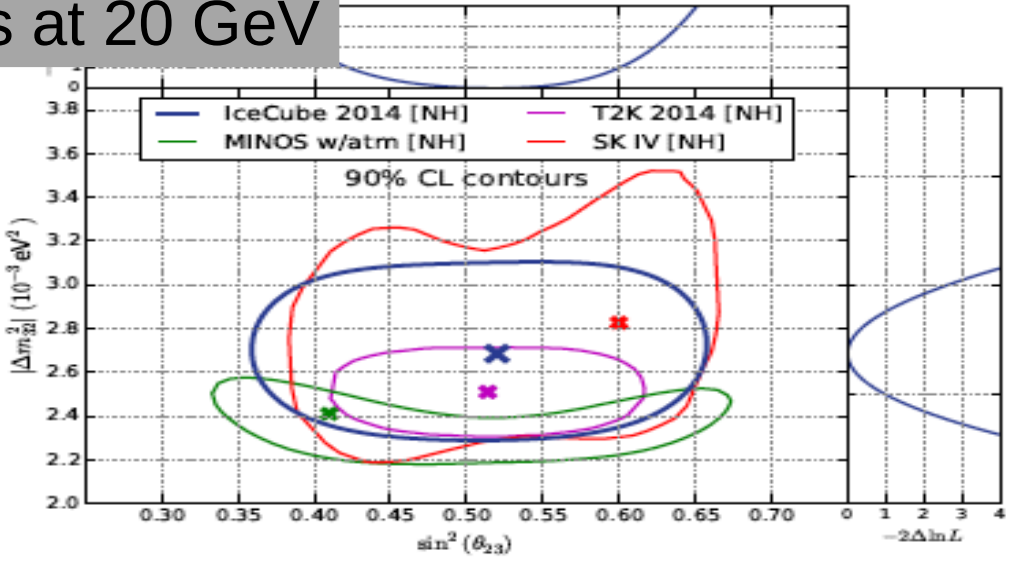
DeepCore

PINGU

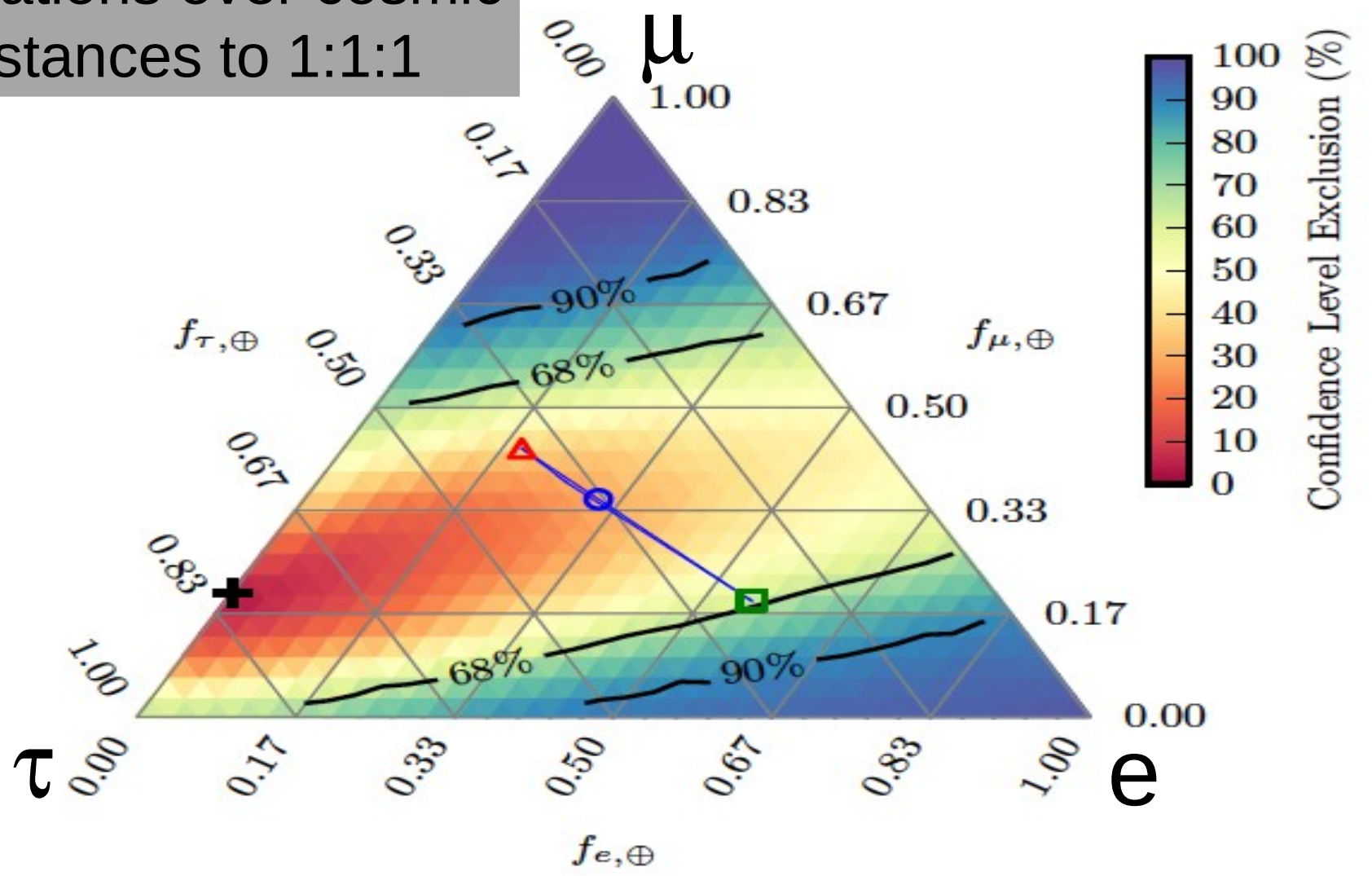


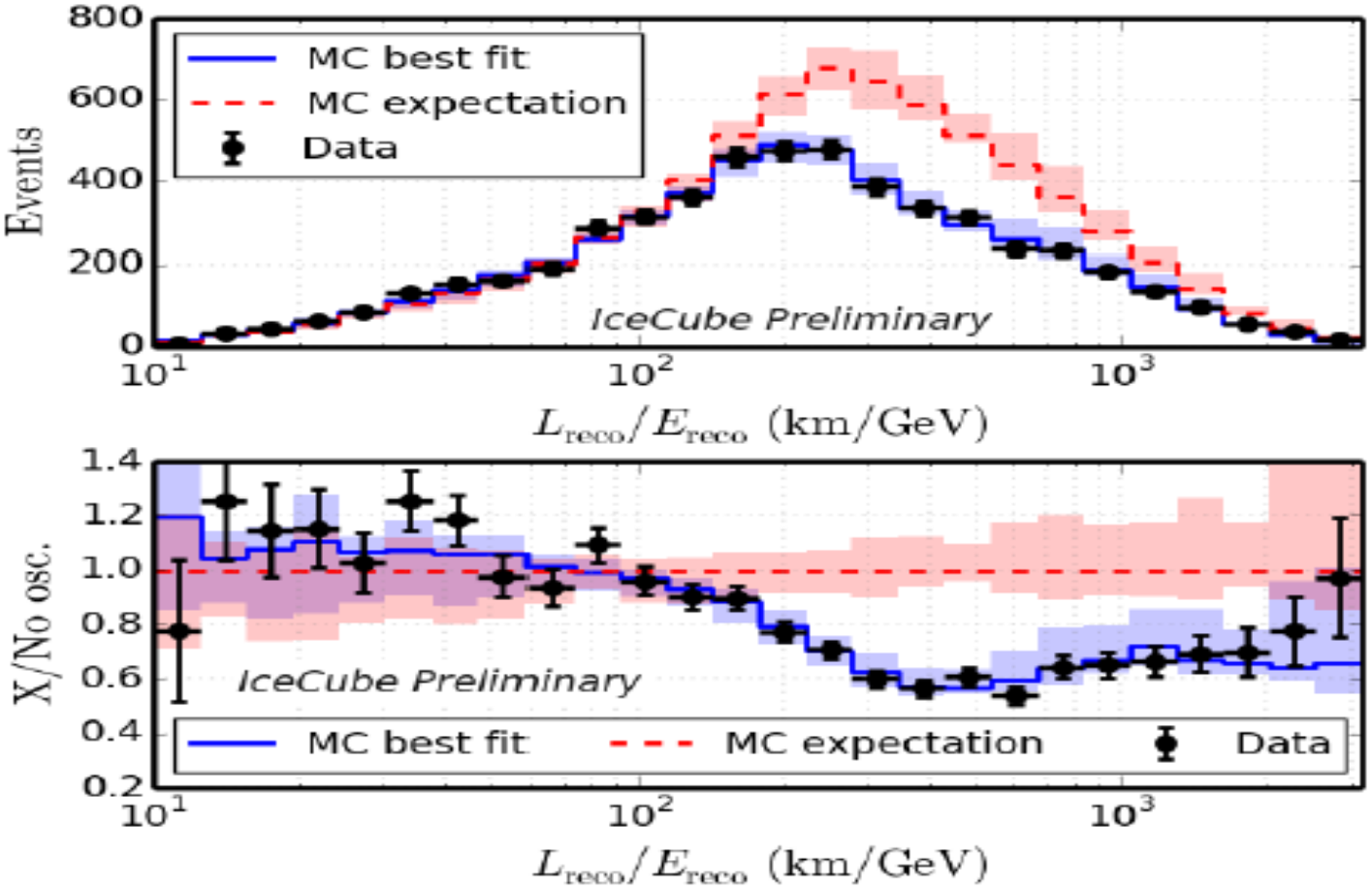
oscillations at 20 GeV





oscillations over cosmic distances to 1:1:1




800
600
400
200
0
Events
MC best fit
MC expectation
Data
IceCube Preliminary
10^1
10^2
10^3
$L_{\mathrm{reco}}/E_{\mathrm{reco}}$ (km/GeV)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
X/No osc.
IceCube Preliminary
MC best fit
MC expectation
Data
10^1
10^2
10^3
$L_{\mathrm{reco}}/E_{\mathrm{reco}}$ (km/GeV)

290 TeV (22Sep17) neutrino!

TXS 0506+056

From Wikipedia, the free encyclopedia Coordi

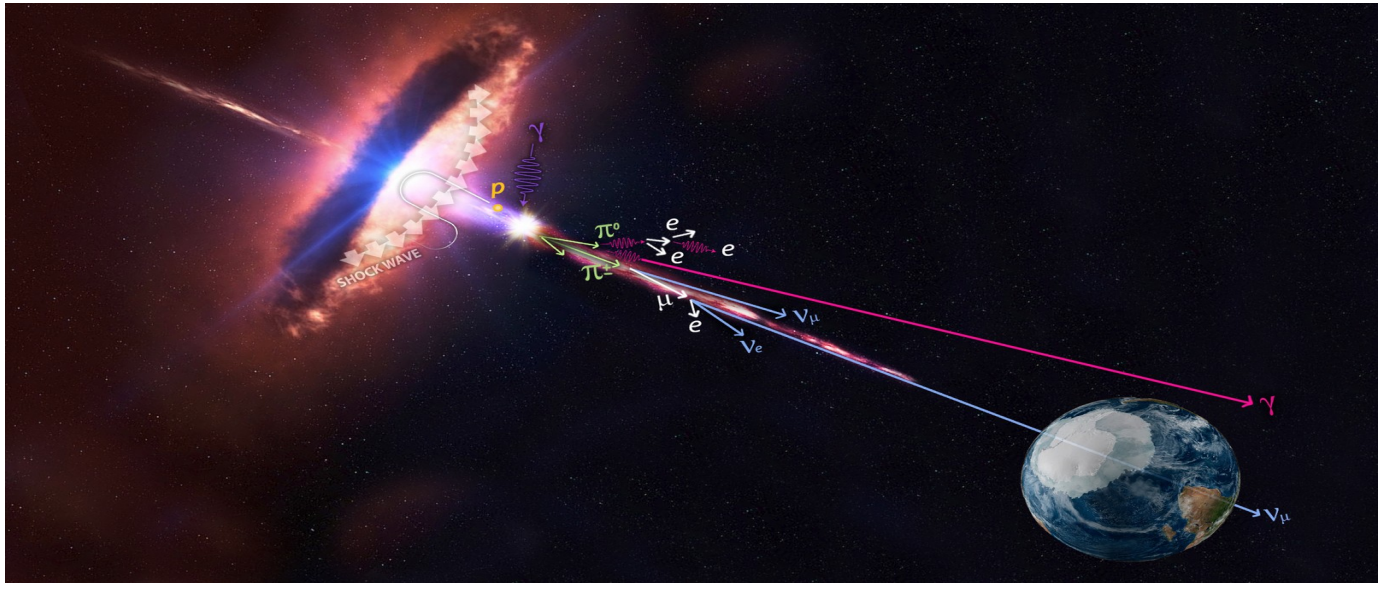
TXS 0506+056 is a very high energy blazar – a quasar with a relativistic jet pointing directly towards Earth – of BL Lac-type.[3] With a redshift of 0.3365 ± 0.0010,[3] it is about 1.75 gigaparsecs (5.7 billion light-years) from Earth.[4] Its approximate location on the sky is off the left shoulder of the constellation Orion.[5] Discovered as a radio source in 1983, the blazar has since been observed across the entire electromagnetic spectrum.

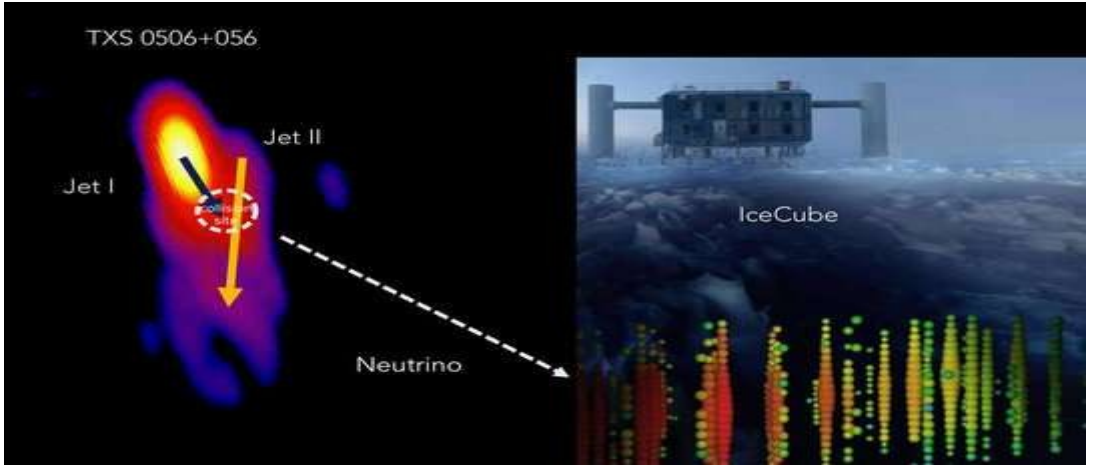
TXS 0506+056 is the first known source of high energy astrophysical neutrinos[6], identified following the **IceCube-170922A** neutrino event[7] in an early example of multi-messenger astronomy.[12] The only astronomical sources previously observed by neutrino detectors were the Sun and supernova 1987A, which were detected decades earlier at much lower neutrino energies.[6]

On September 22, 2017, the IceCube Neutrino Observatory detected a high energy muon neutrino, dubbed **IceCube-170922A**.[7] The neutrino carried an energy of ~290 tera–electronvolts (TeV); for comparison, the Large Hadron Collider can generate a maximum energy of 13 TeV.[24] Within one minute of the neutrino detection, IceCube sent an automated alert to astronomers around the world with coordinates to search for a possible source.[7]

A search of this region in the sky, 1.33 degrees across, yielded only one likely source: TXS 0506+056, was found to be in a flaring state of high gamma ray emission.[7][6] It was subsequently observed at o the electromagnetic spectrum, including radio, infrared, optical, X-rays and gamma-rays.[7][25] The de

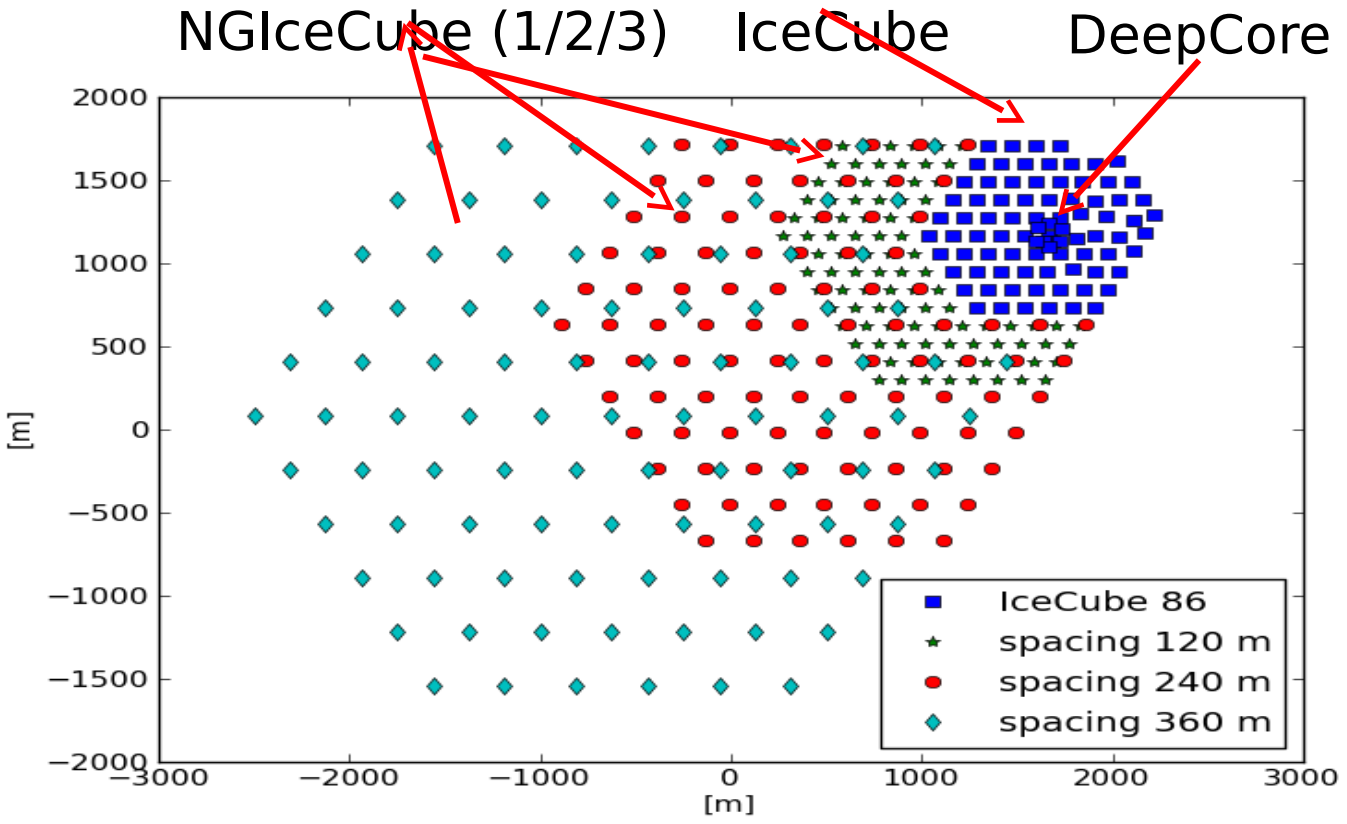
TXS 0506+056


SHOCK WAVE
p
γ
π°
π±
e
e
e
μ
e
νμ
νe
γ
νμ


TXS 0506+056
Jet II
Jet I
Neutrino
IceCube

Possible future expansion scenarios

(increase in threshold not important: only eliminates energies where the atmospheric background dominates)



Spacing 1 (120m):
IceCube (1 km³)
+ 98 strings (1,3 km³)
= 2,3 km³

Spacing 2 (240m):
IceCube (1 km³)
+ 99 strings (5,3 km³)
= 6,3 km³

Spacing 3 (360m):
IceCube (1 km³)
+ 95 strings (11,6 km³)
= 12,6 km³