Experimental Lecture #7
Telescopes and more

D. Jason Koskinen

NBIA PhD School: Neutrinos Underground and in the Heavens
June 23-27, 2014

Niels Bohr Institutet
The Niels Bohr International Academy
centre for particle physics Discovery

- Neutrino Telescopes and Beyond

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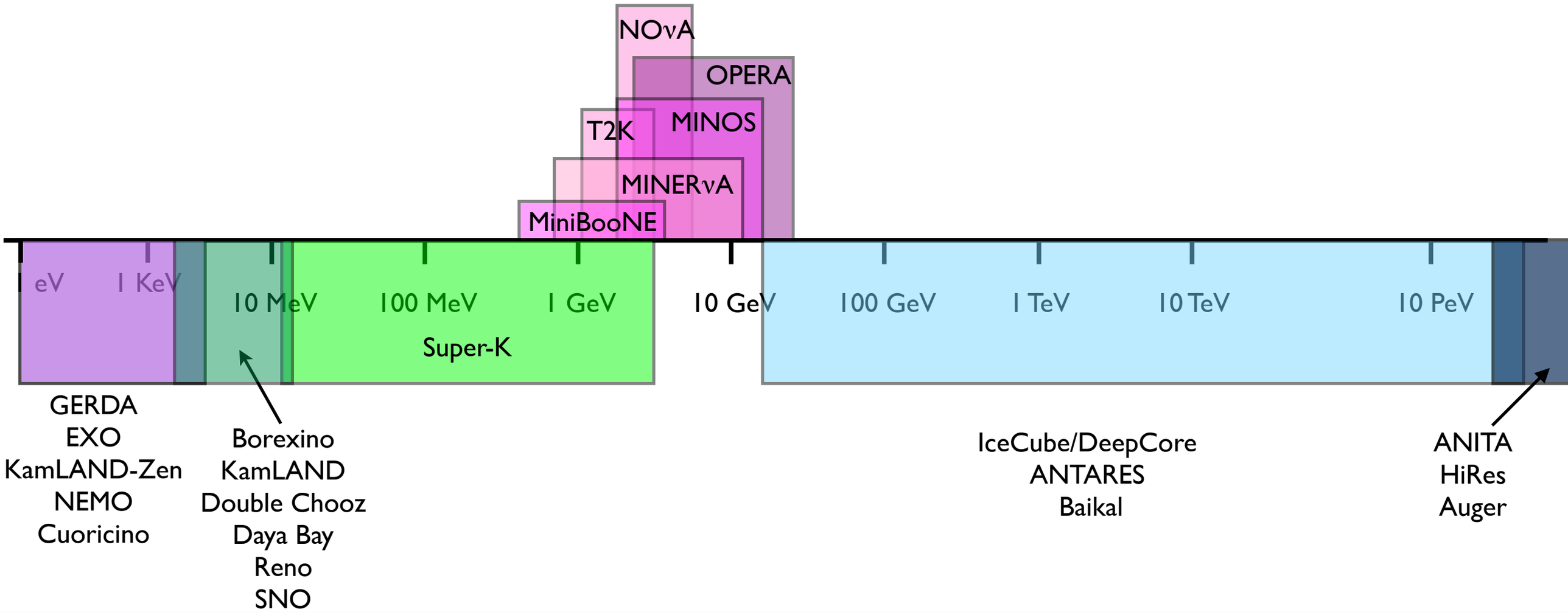
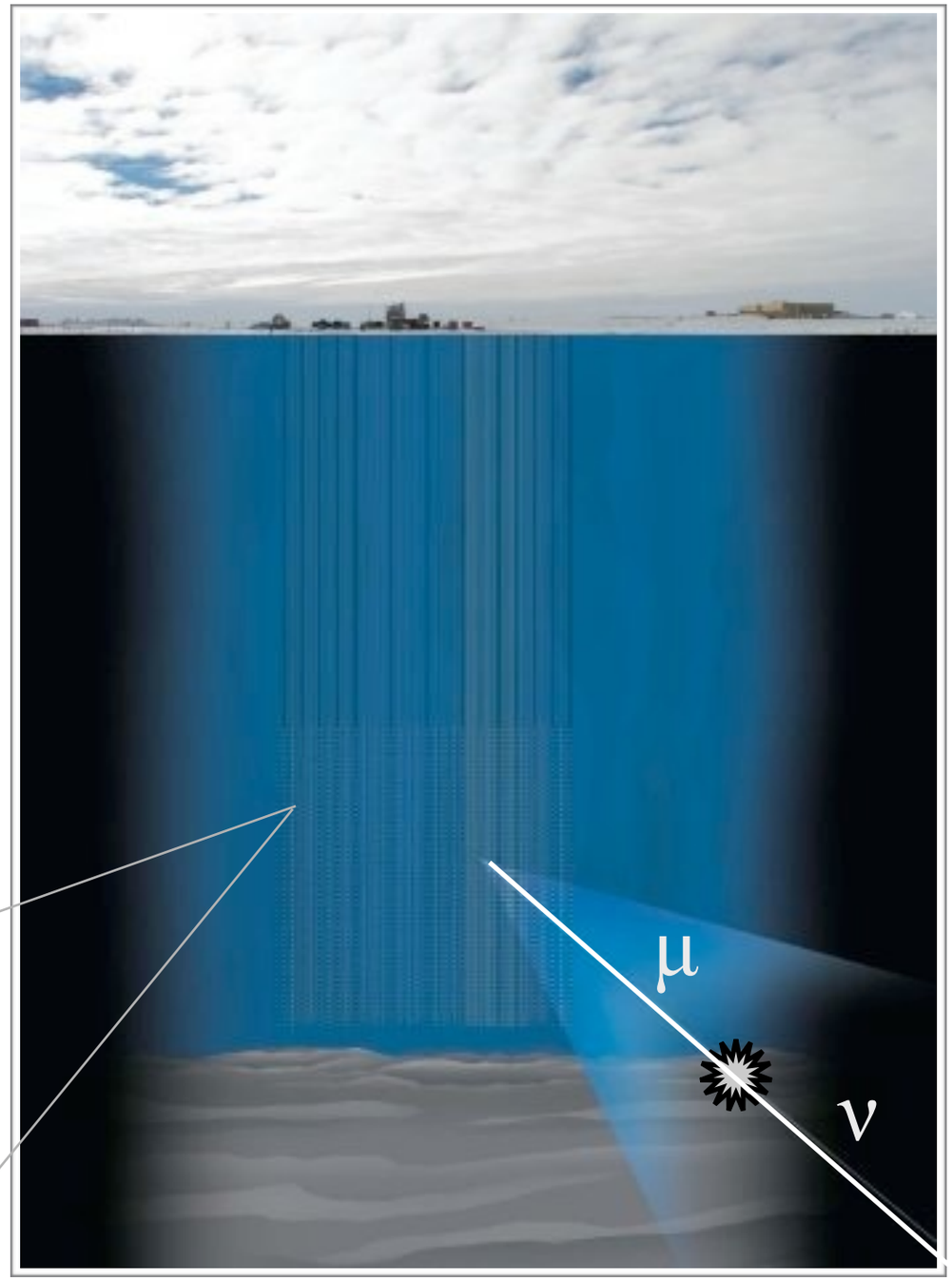
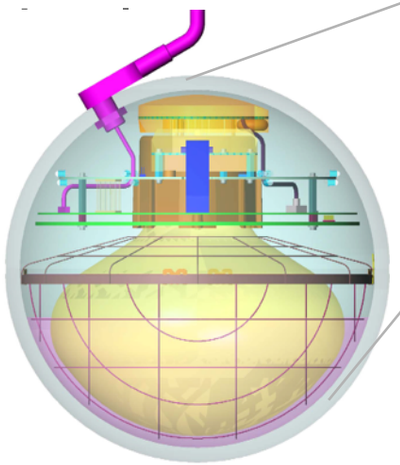


IceCube

- ~1km^3 of instrumented ice
- Uses 5160 Digital Optical Modules (DOMs) across 86 vertical strings to detect Cherenkov radiation
- 160 Cherenkov tank surface array (IceTop)
- Deployed 1.5 - 2.5km the surface





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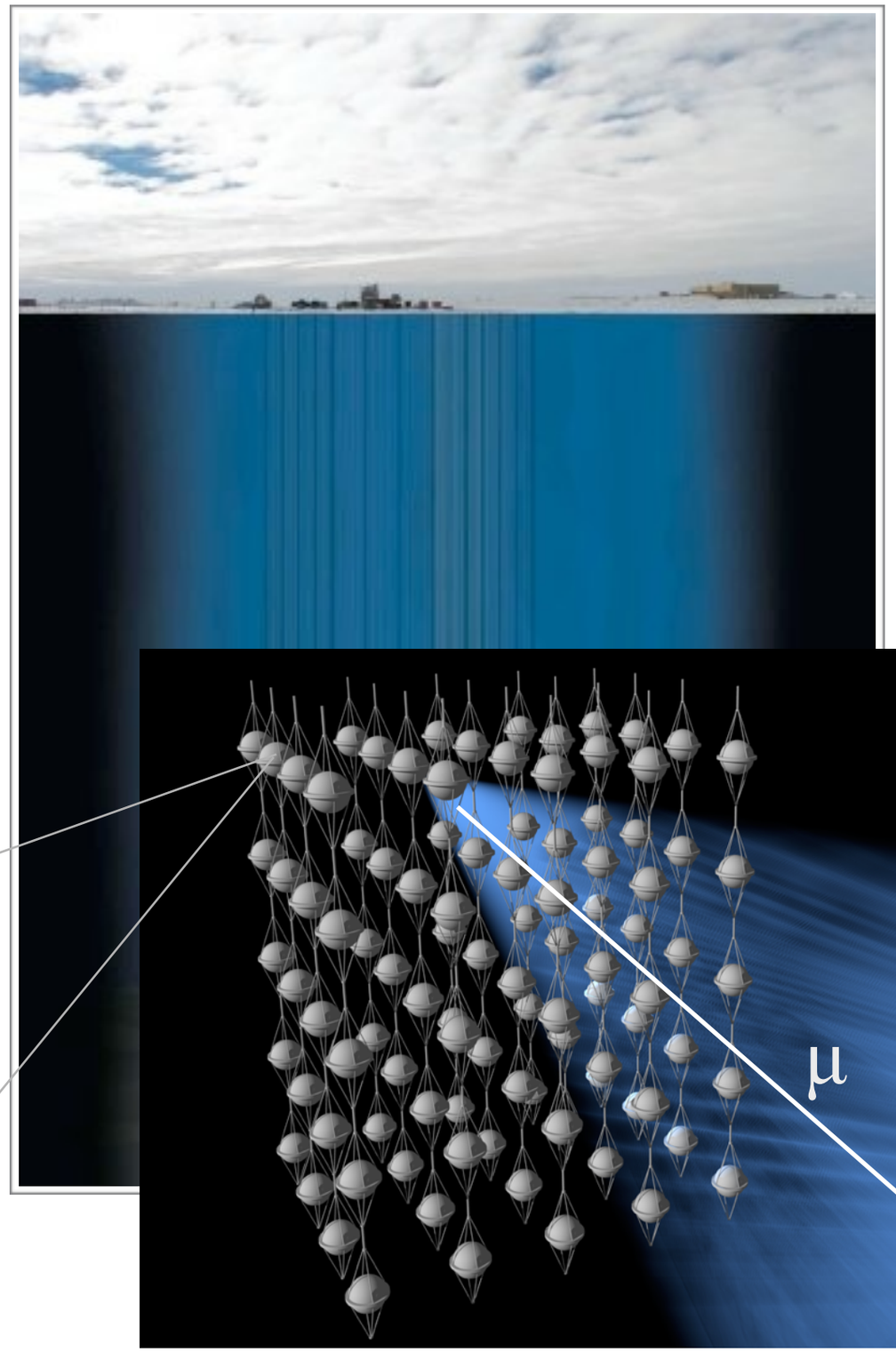
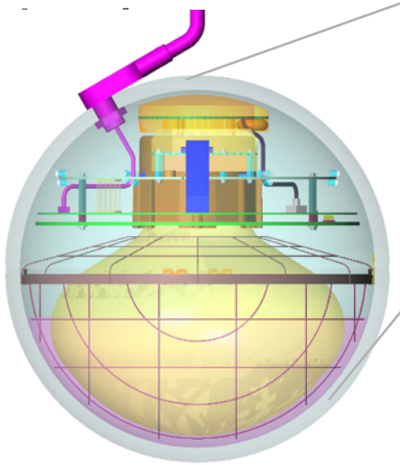
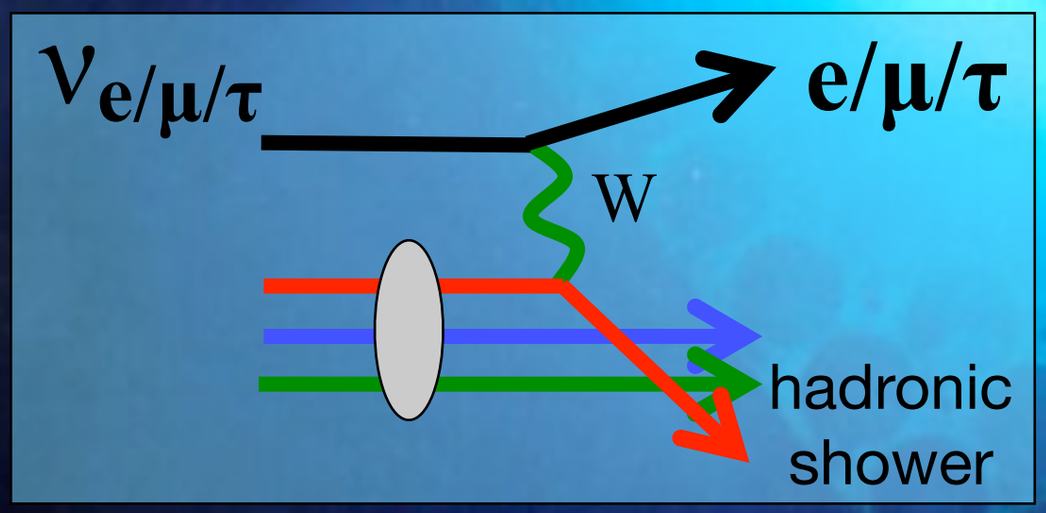




IceCube DOM

Relativistic charged particles traveling through a dielectric medium produce Cherenkov radiation



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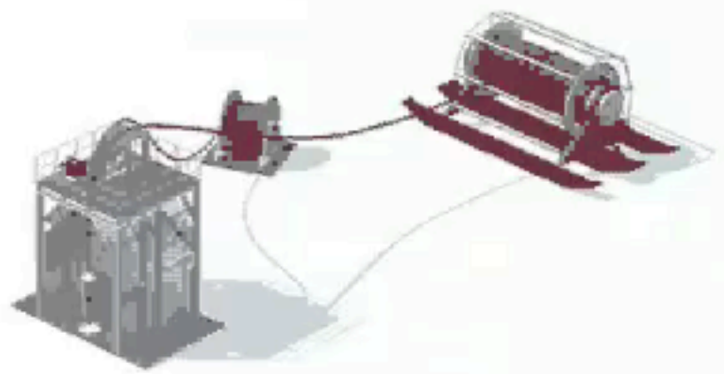
IceCube Hot Water Drill Animation



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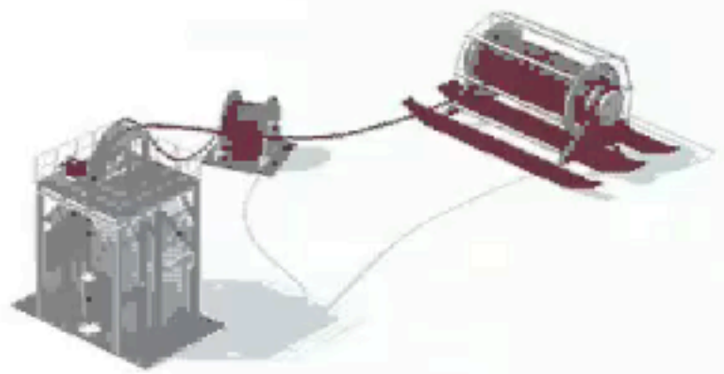
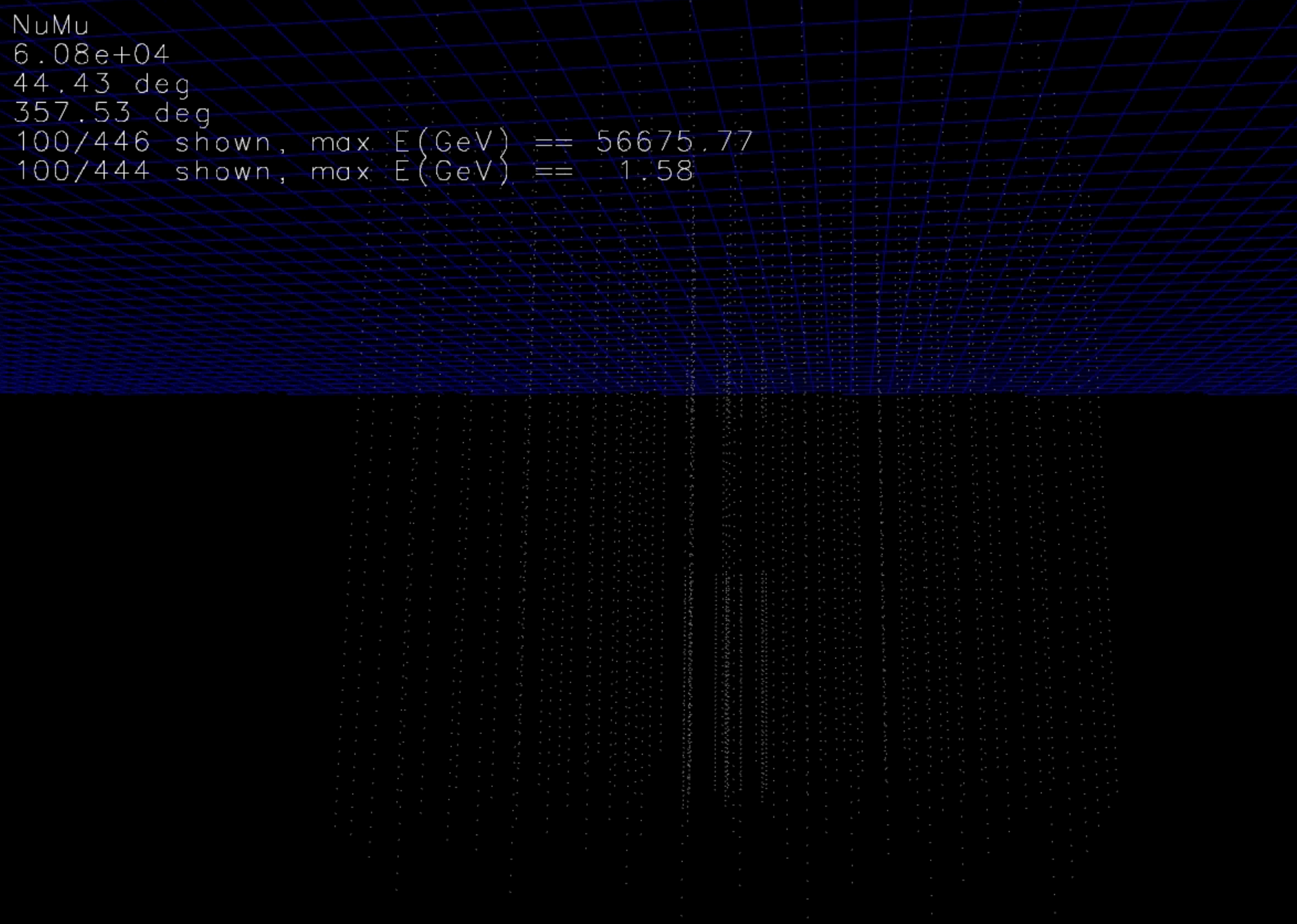
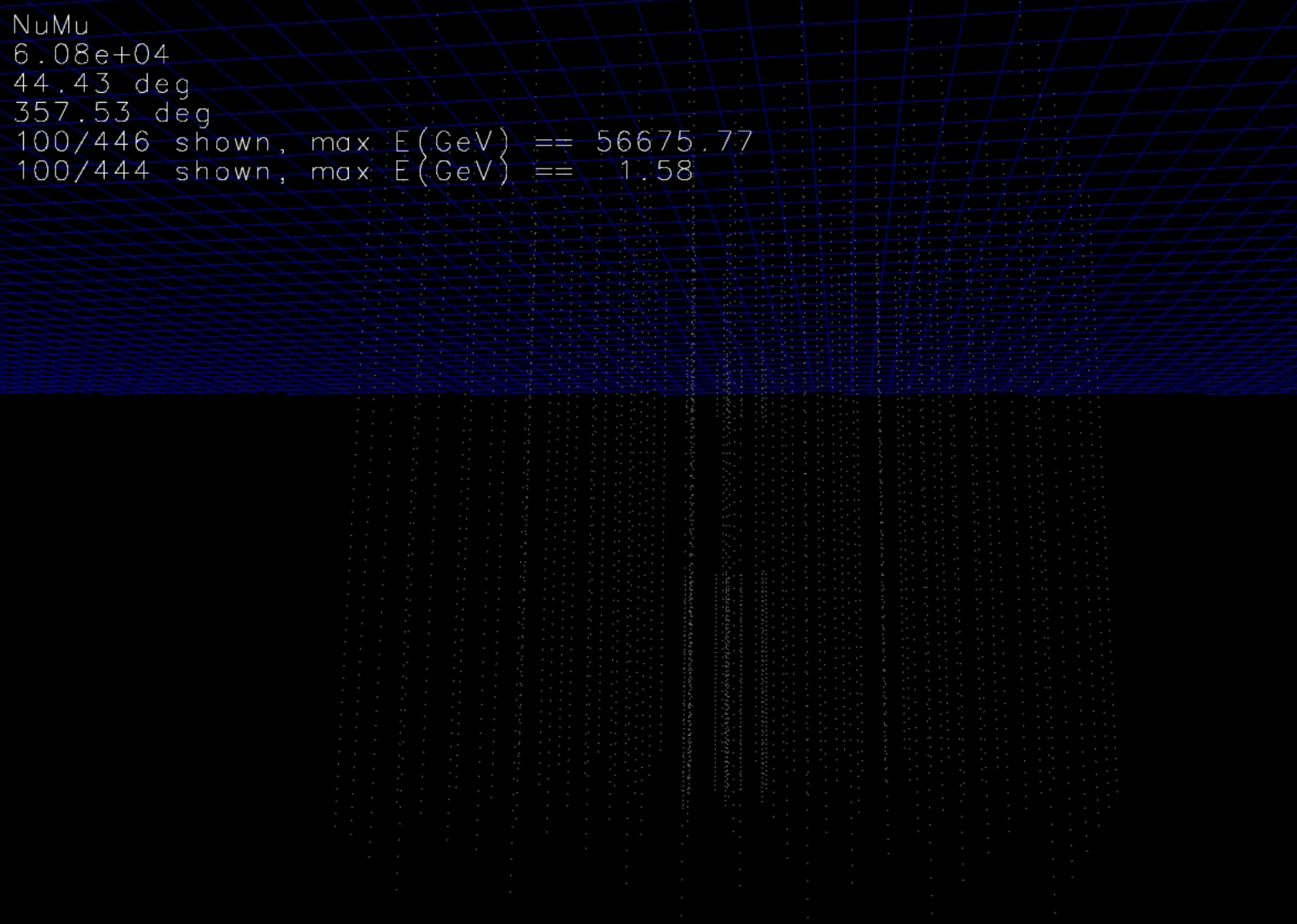



NuMu
6.08e+04
44.43 deg
357.53 deg
100/446 shown, max E(GeV) == 56675.77
100/444 shown, max E(GeV) == 1.58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100/446 shown, max E(GeV) == 56675.77
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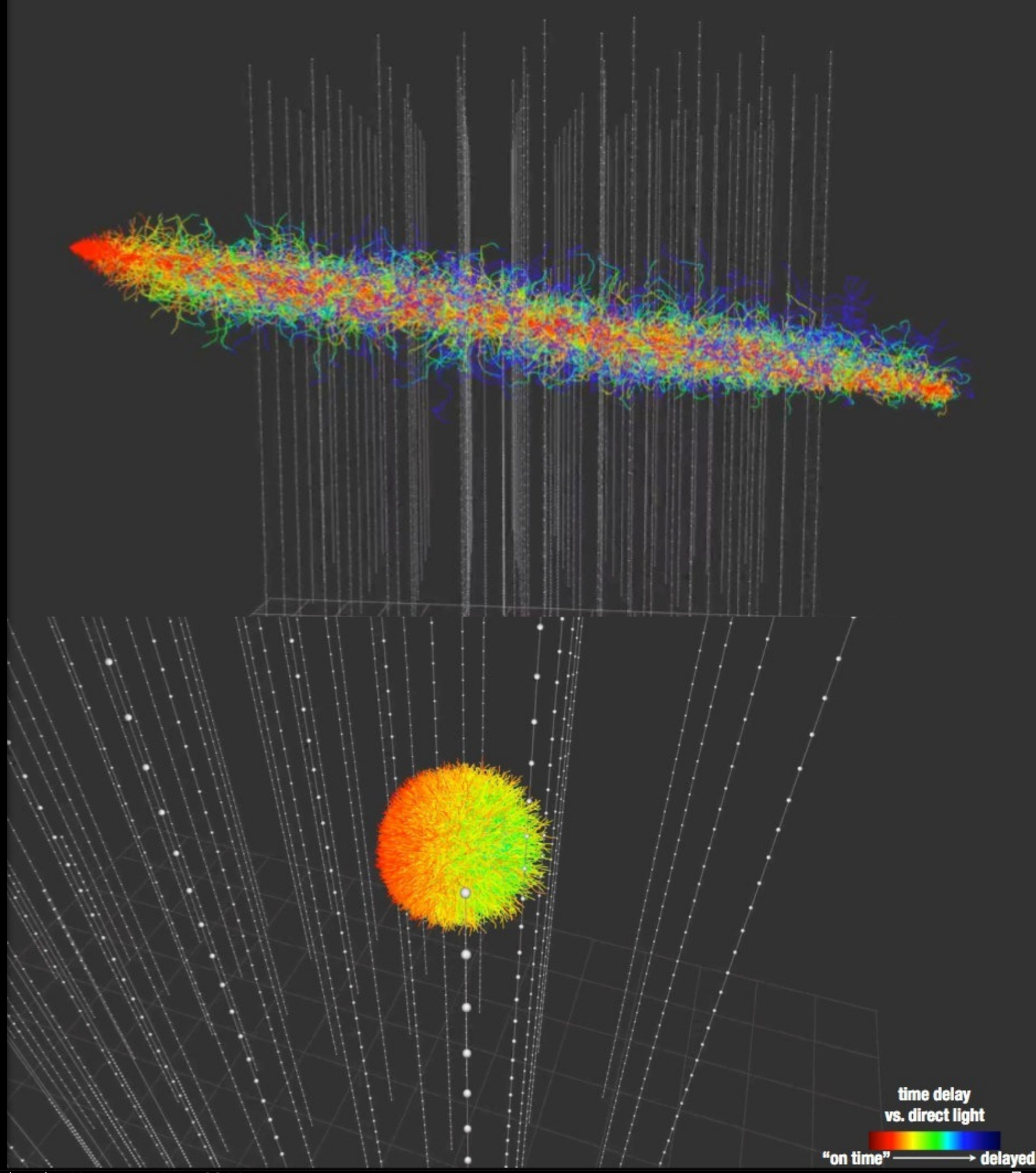
Track topology

(e.g. induced by muon neutrino)

Good pointing,
0.2° - 1°

Lower bound on energy for through-going events



Cascade topology

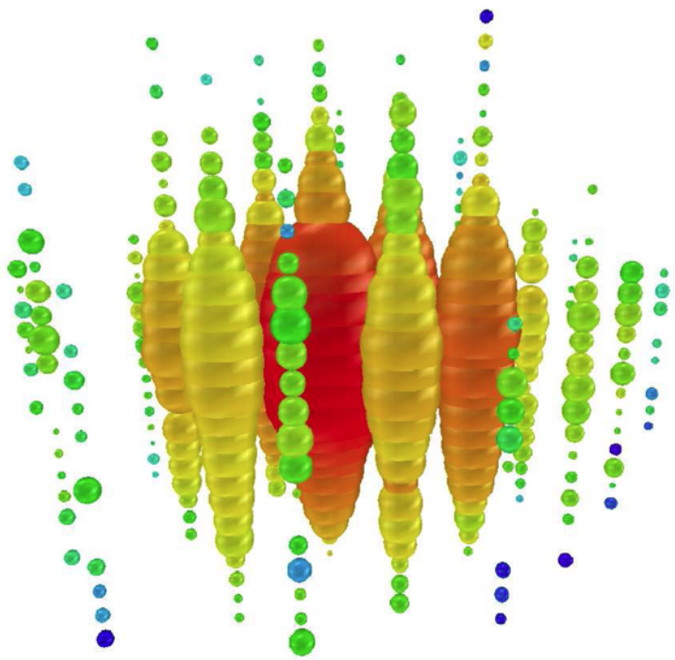
(e.g. induced by electron neutrino)

Good energy resolution, 15%

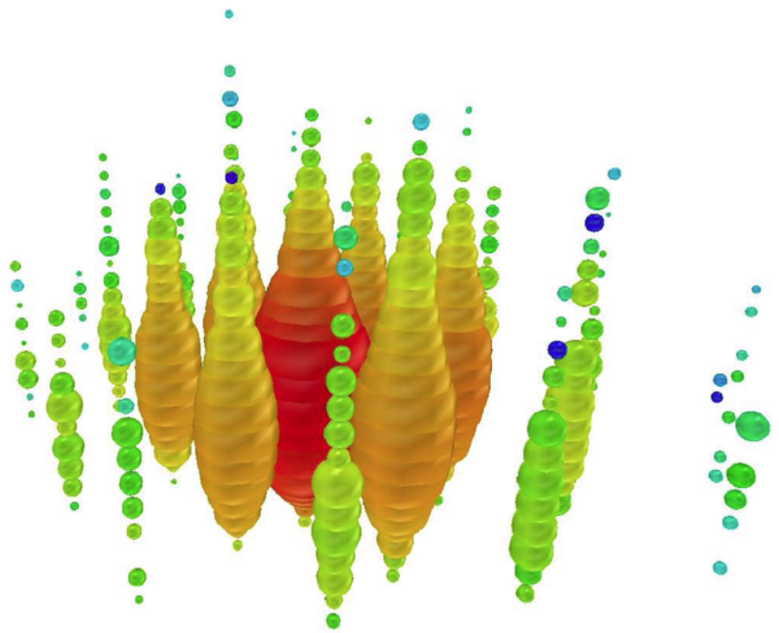
Some pointing,
10° - 15°

Very High Energy

- Very high energy IceCube (GZK) astrophysical search found 2 anomalous background events in 2 years of data



1.04±0.16 PeV



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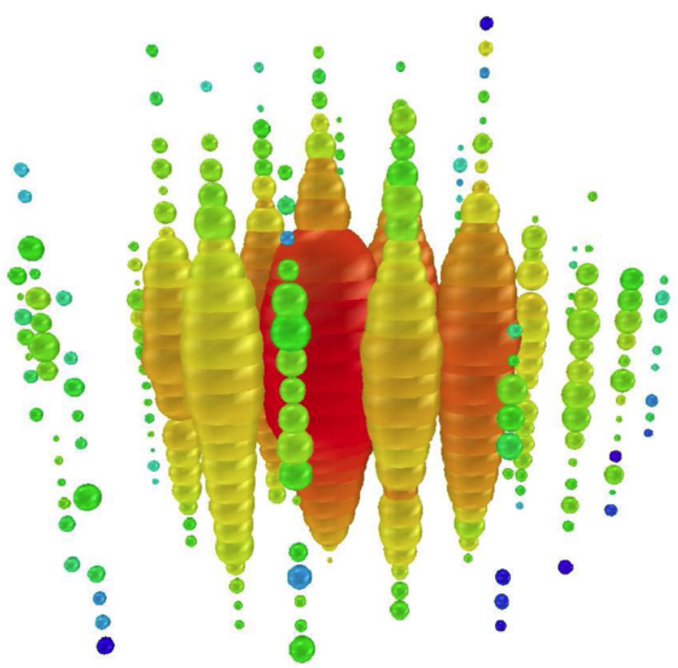

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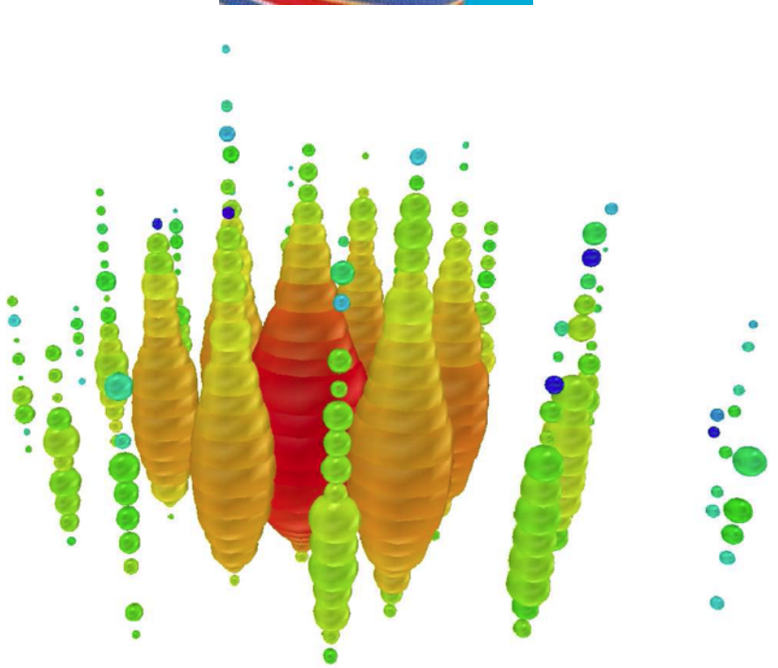

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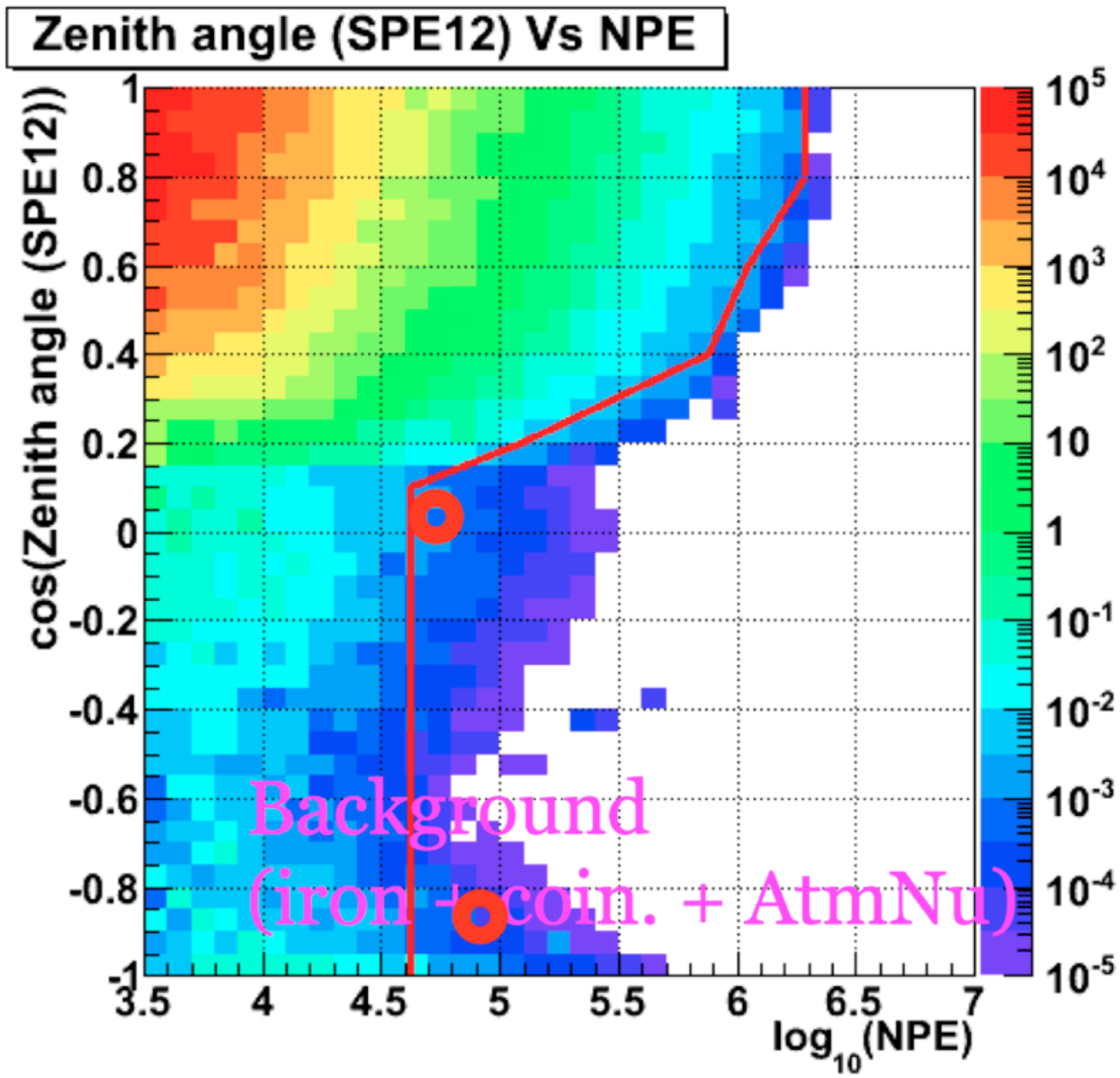
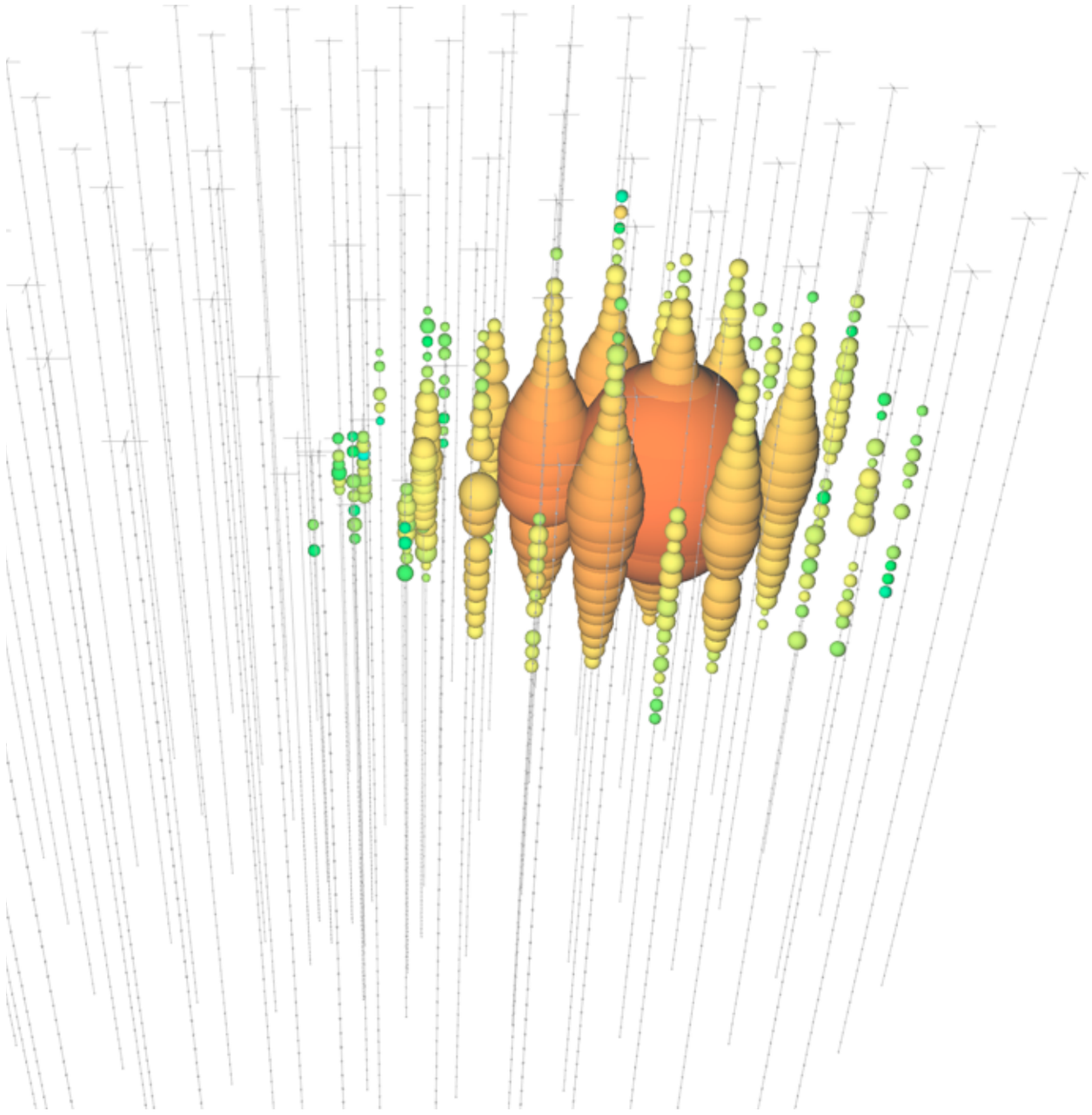
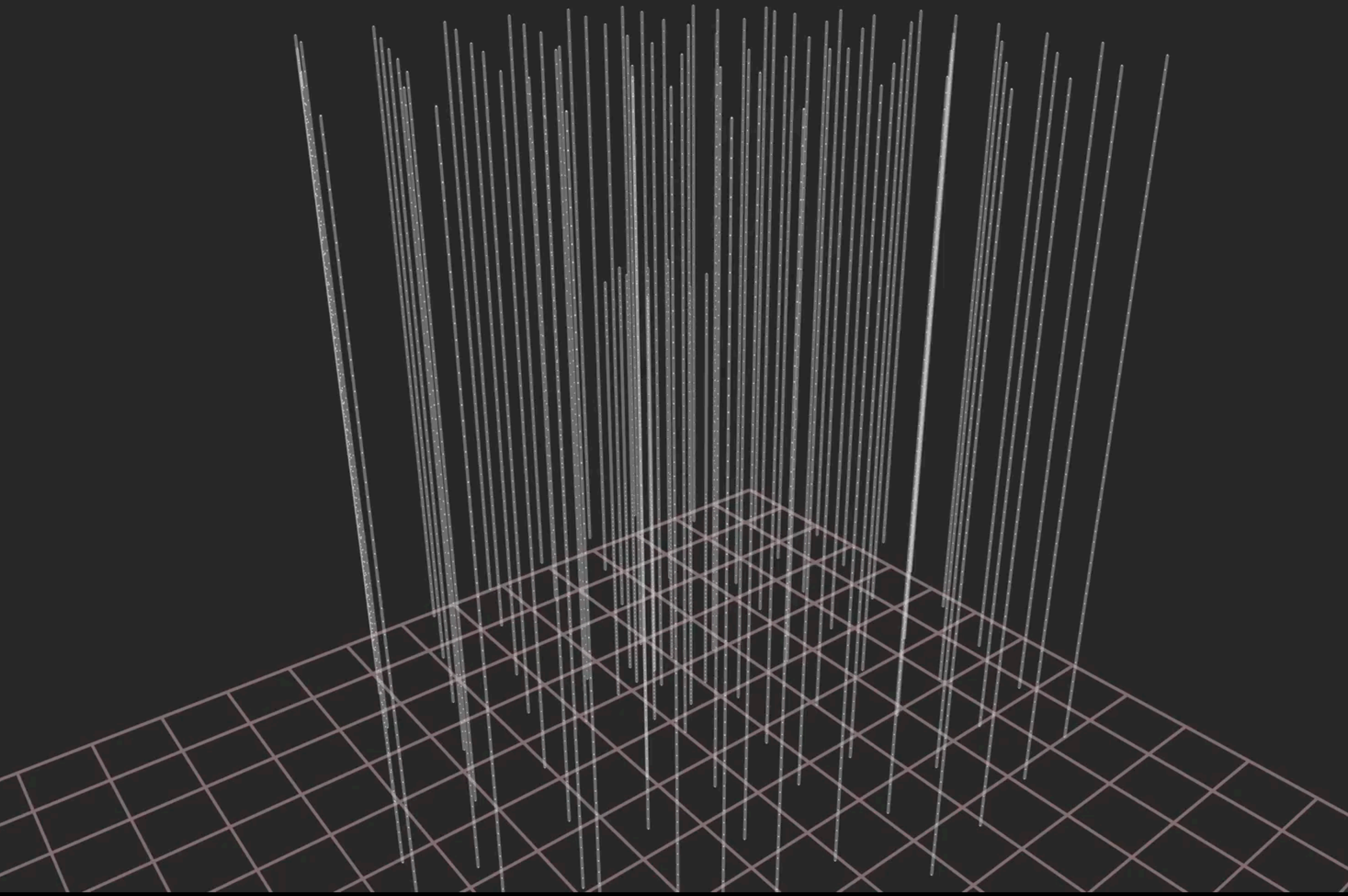
Background Events





- Fortuitous scenario where the events were mis-reconstructed too high in energy

“Ernie” - 2nd highest energy neutrino ever



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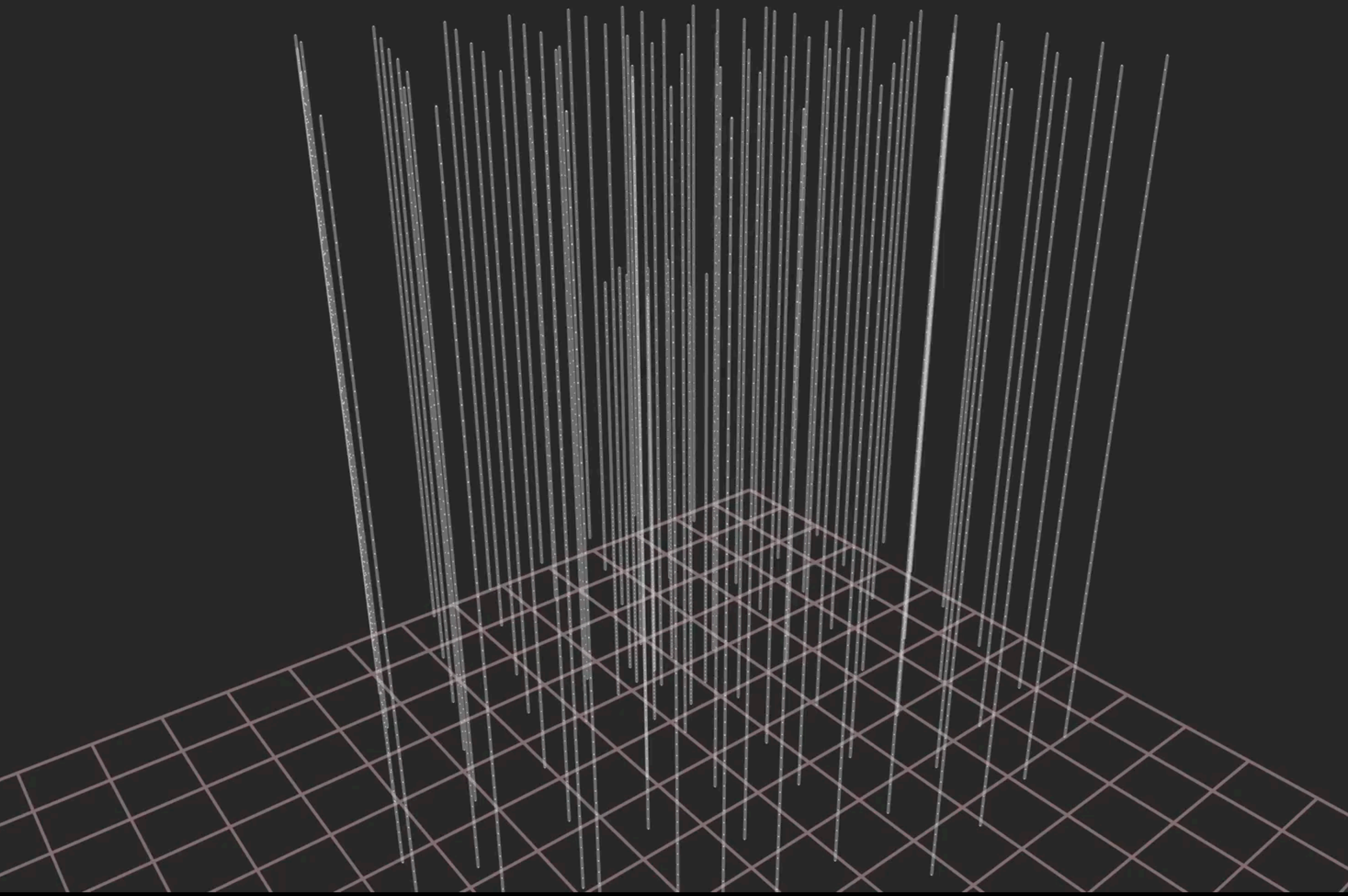
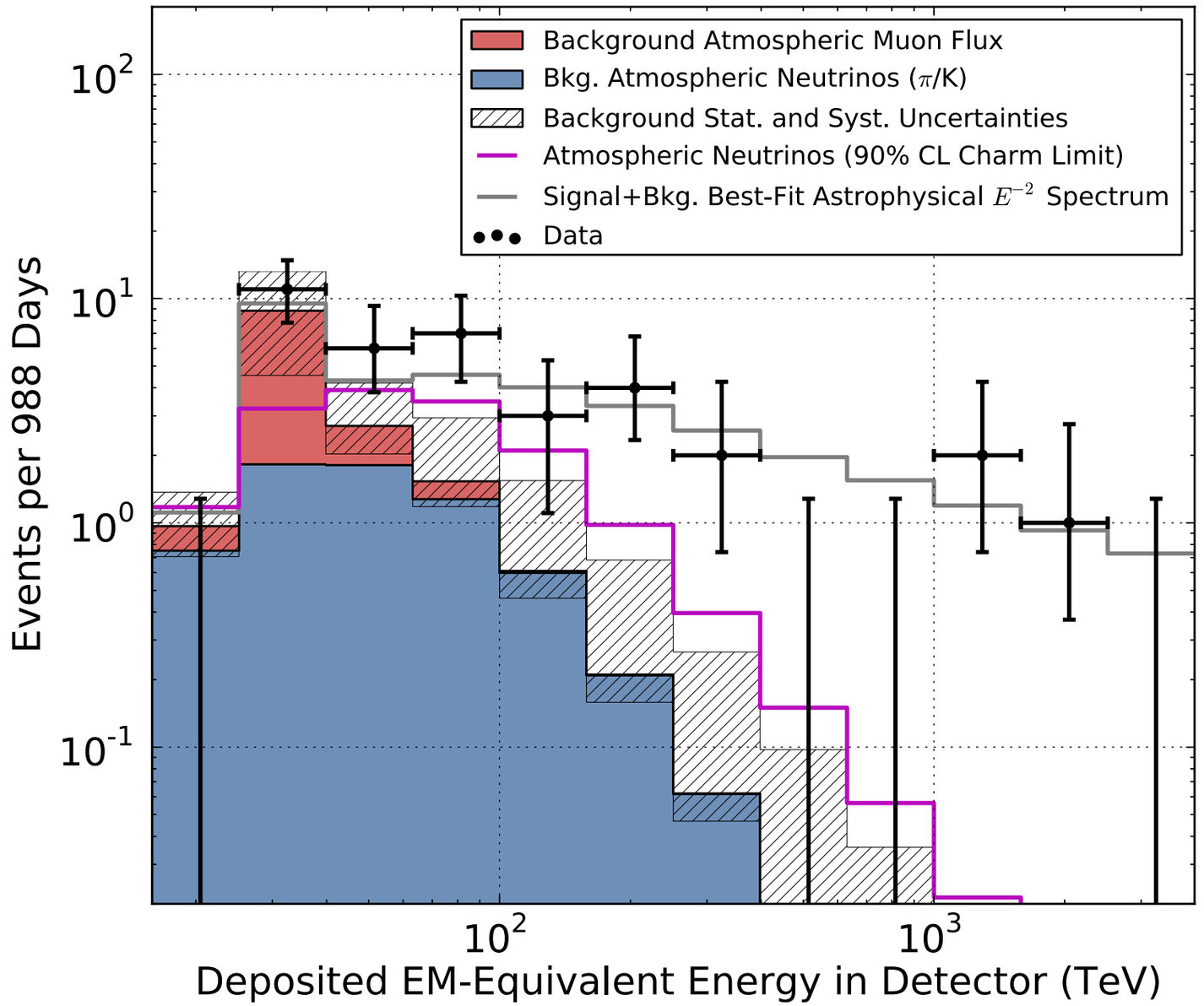
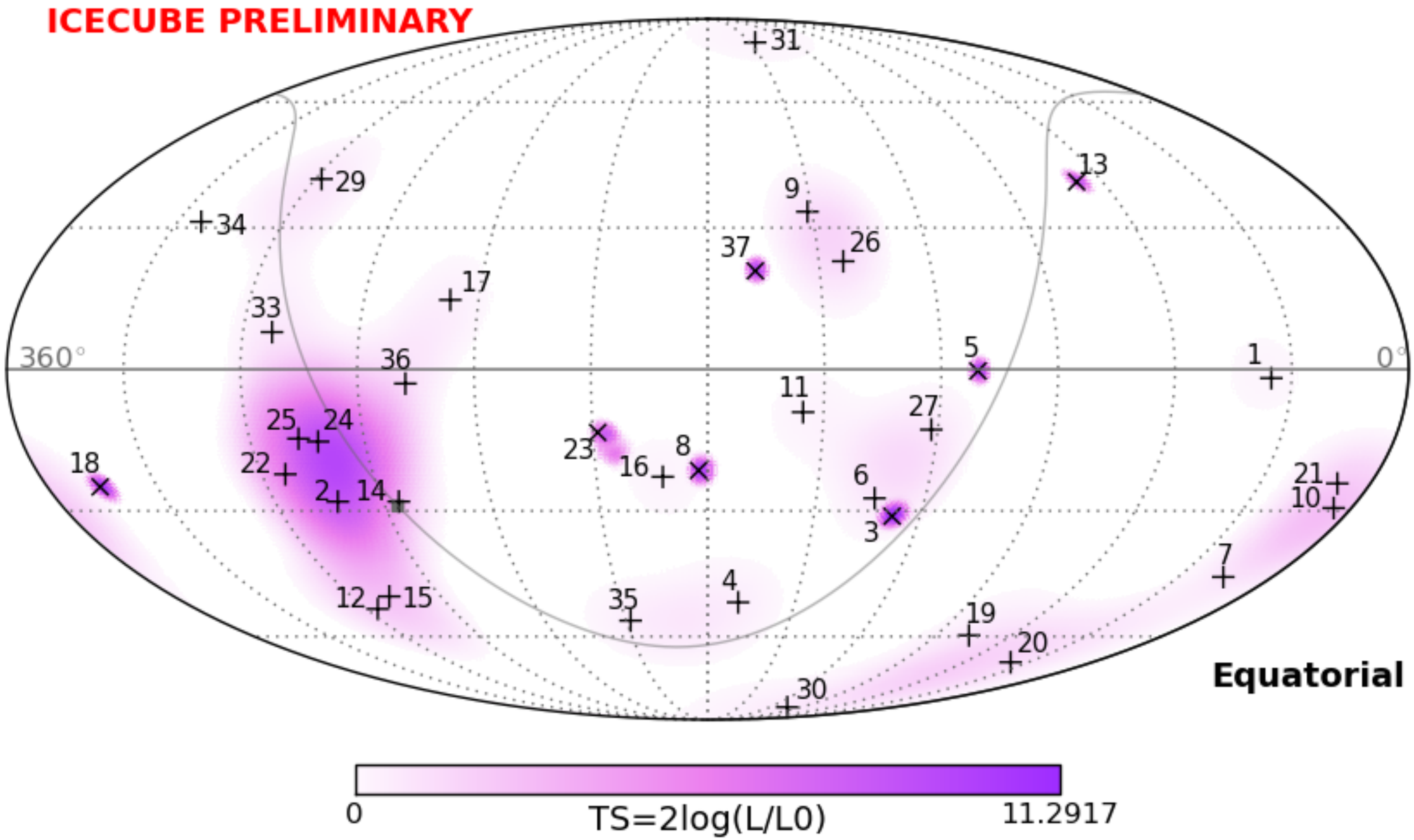


3-year HESE Result

- 36(+1) events total
  - 8.4 ± 4.2 atm. muons
  - $6.6^{+5.9}_{-1.6}$ atm. neutrinos
- 5.7σ rejection of only atmospheric neutrino flux



HESE-III Sky Map

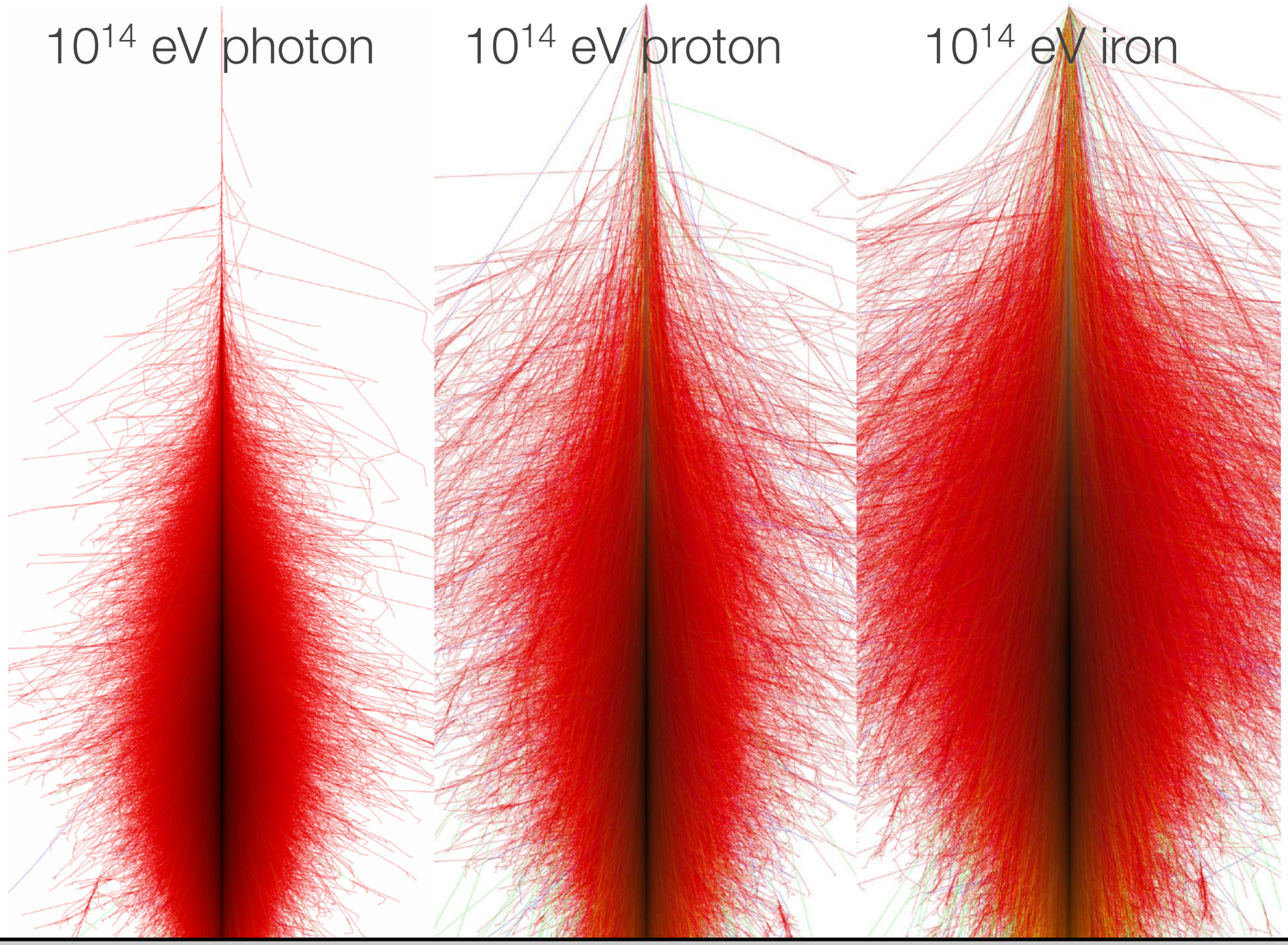


- No significant evidence for clustering

Monte Carlo

- High Energy Starting Event analysis is simple and serendipitous
  - Easy cuts
  - Signal would, and has been, found by dedicated analysis that use more sophisticated methods
- Analysis which found the 2 ‘background’ events
  - Developed on Monte Carlo
  - 2 backgrounds were statistically significant

Background - CORSIKA



Produces neutrinos too

Neutrino

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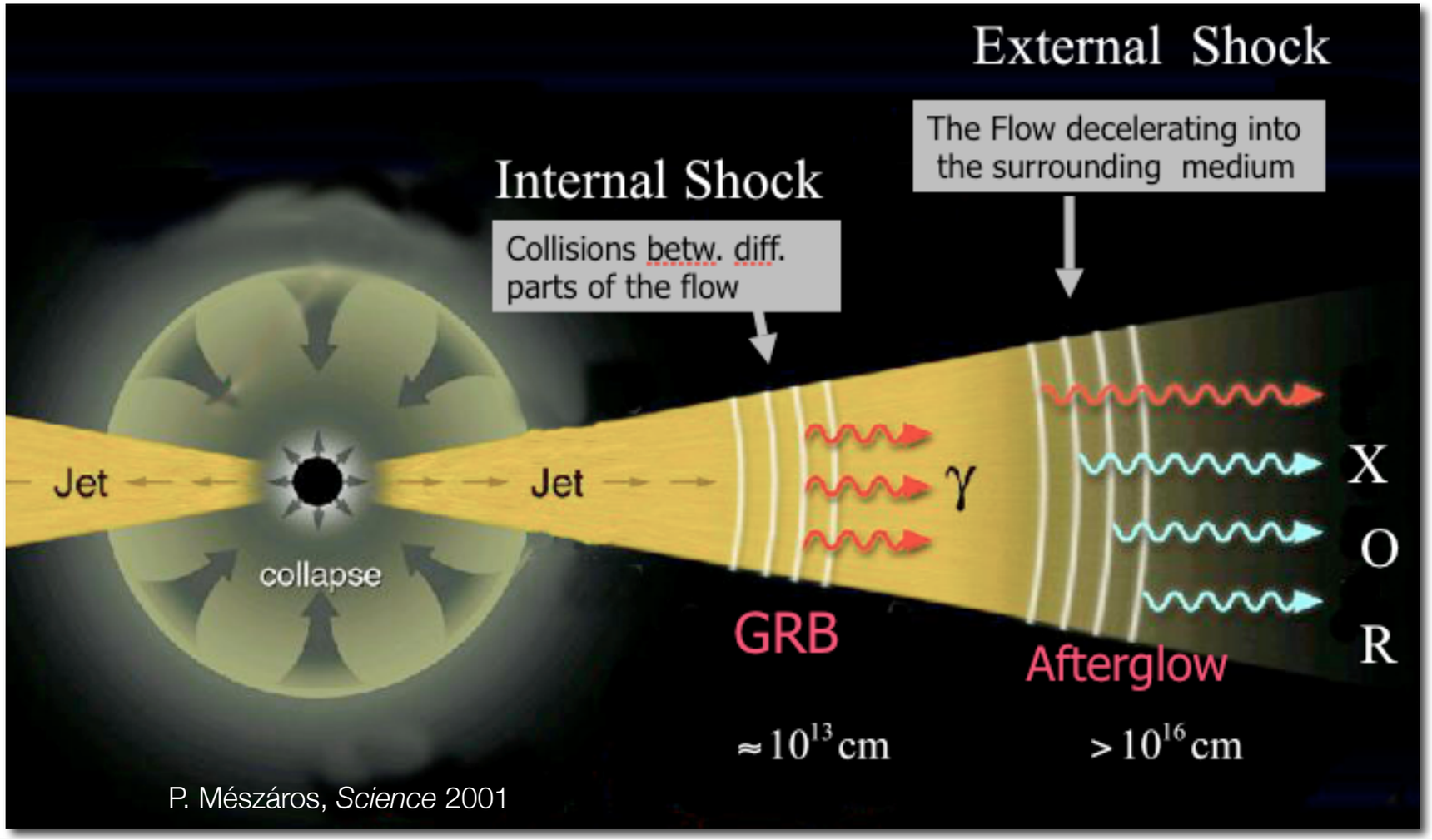
    - Modify spectral index
    - Modify energy range

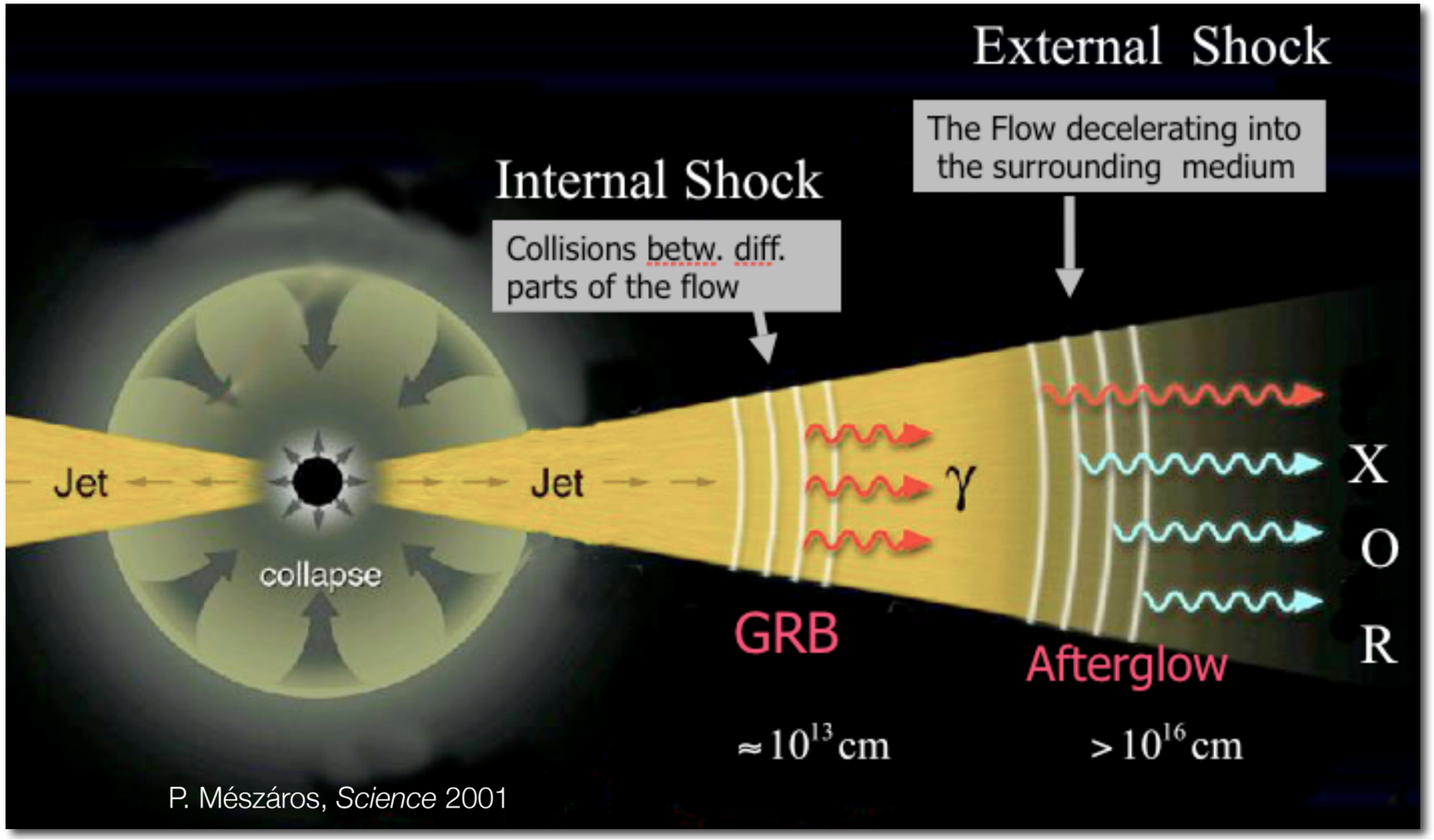
Gamma Ray Bursts



P. Mészáros, *Science* 2001

Gamma Ray Bursts

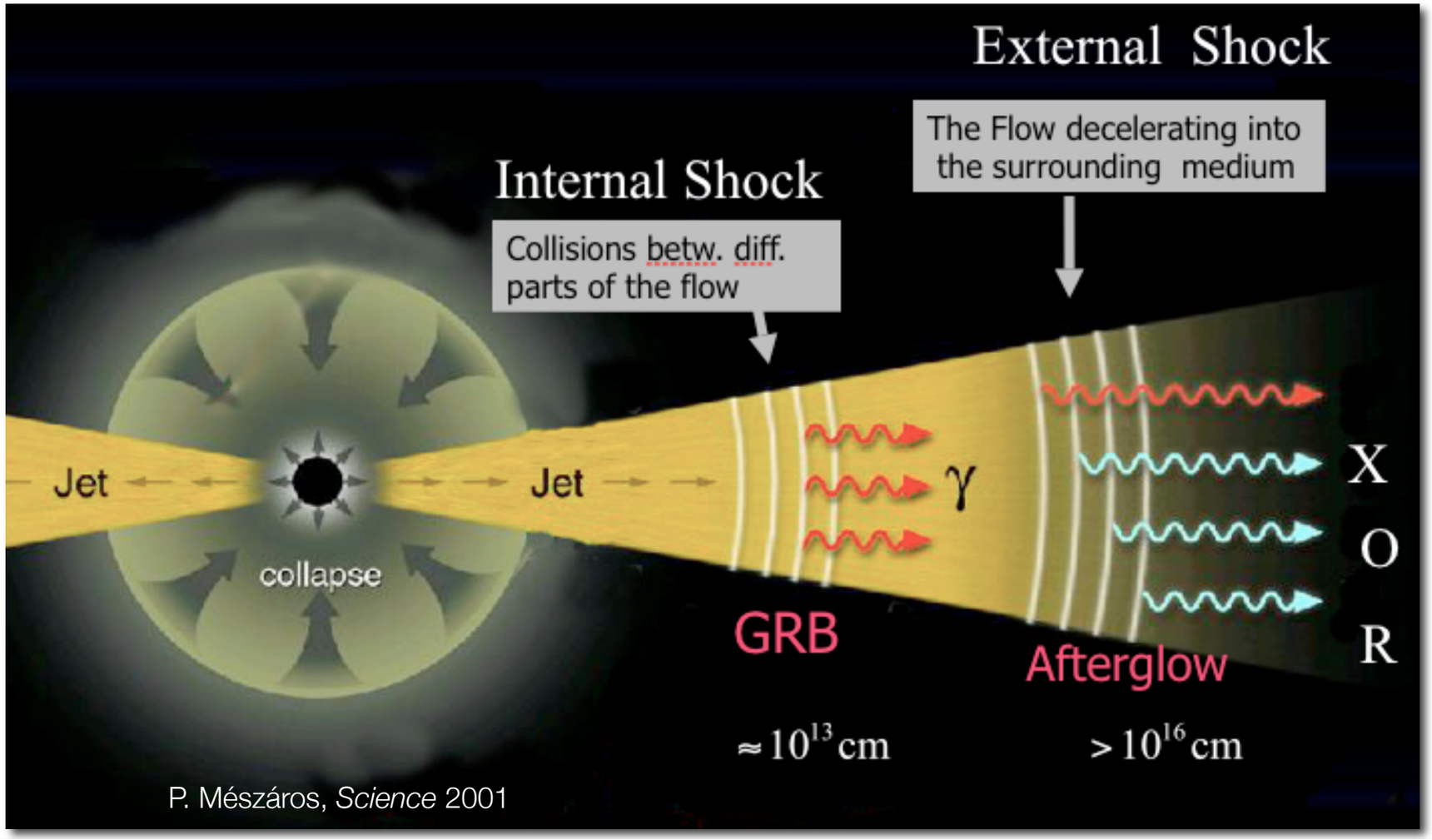
- Gamma-ray satellites identify time and location of GRB



P. Mészáros, *Science* 2001

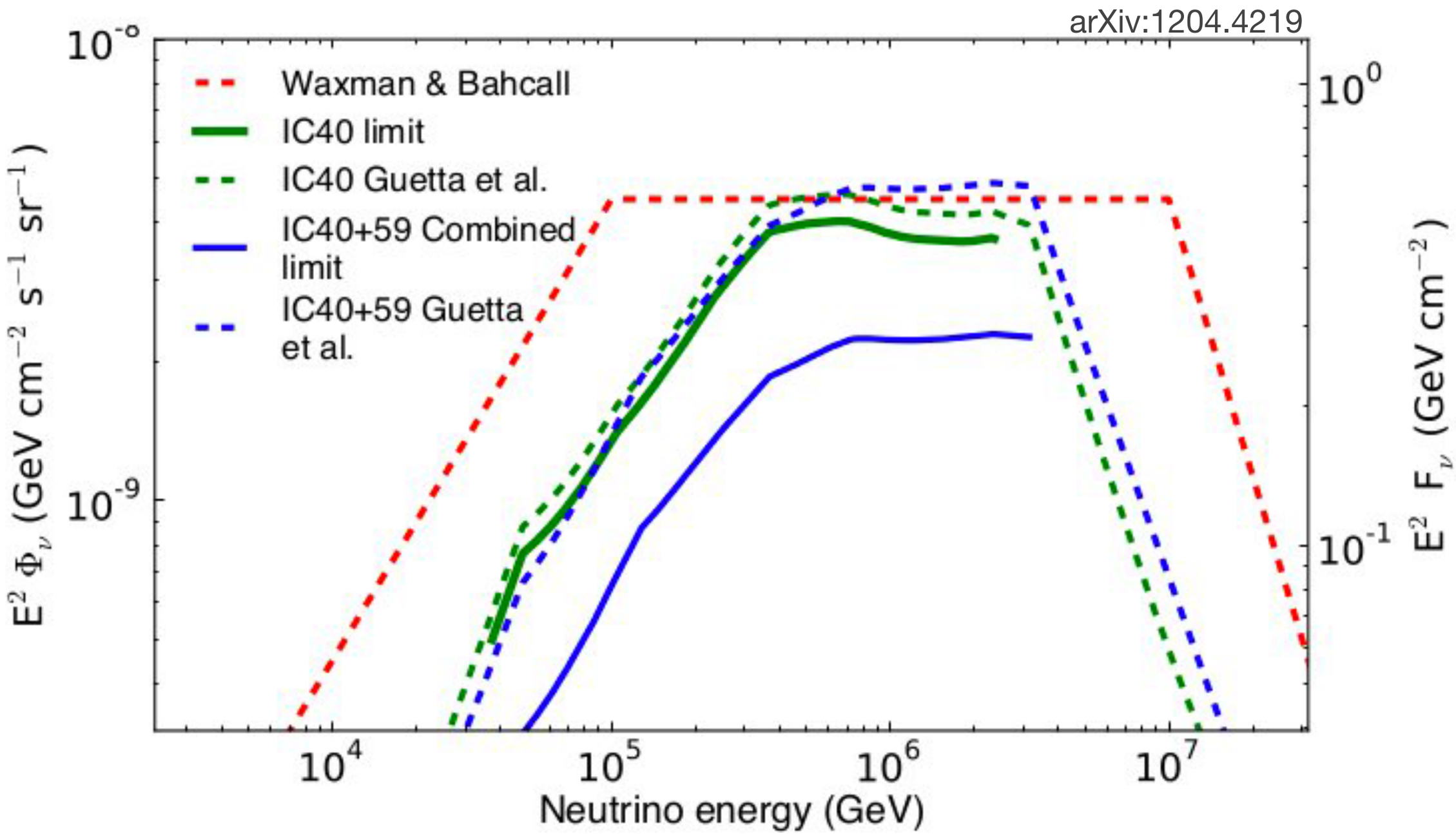
Gamma Ray Bursts

- Gamma-ray satellites identify time and location of GRB
- Search for neutrinos produced by p+γ interactions
    1. Fireball GRB models, i.e. gamma-rays produced from high temperature plasma
    2. Model Independent



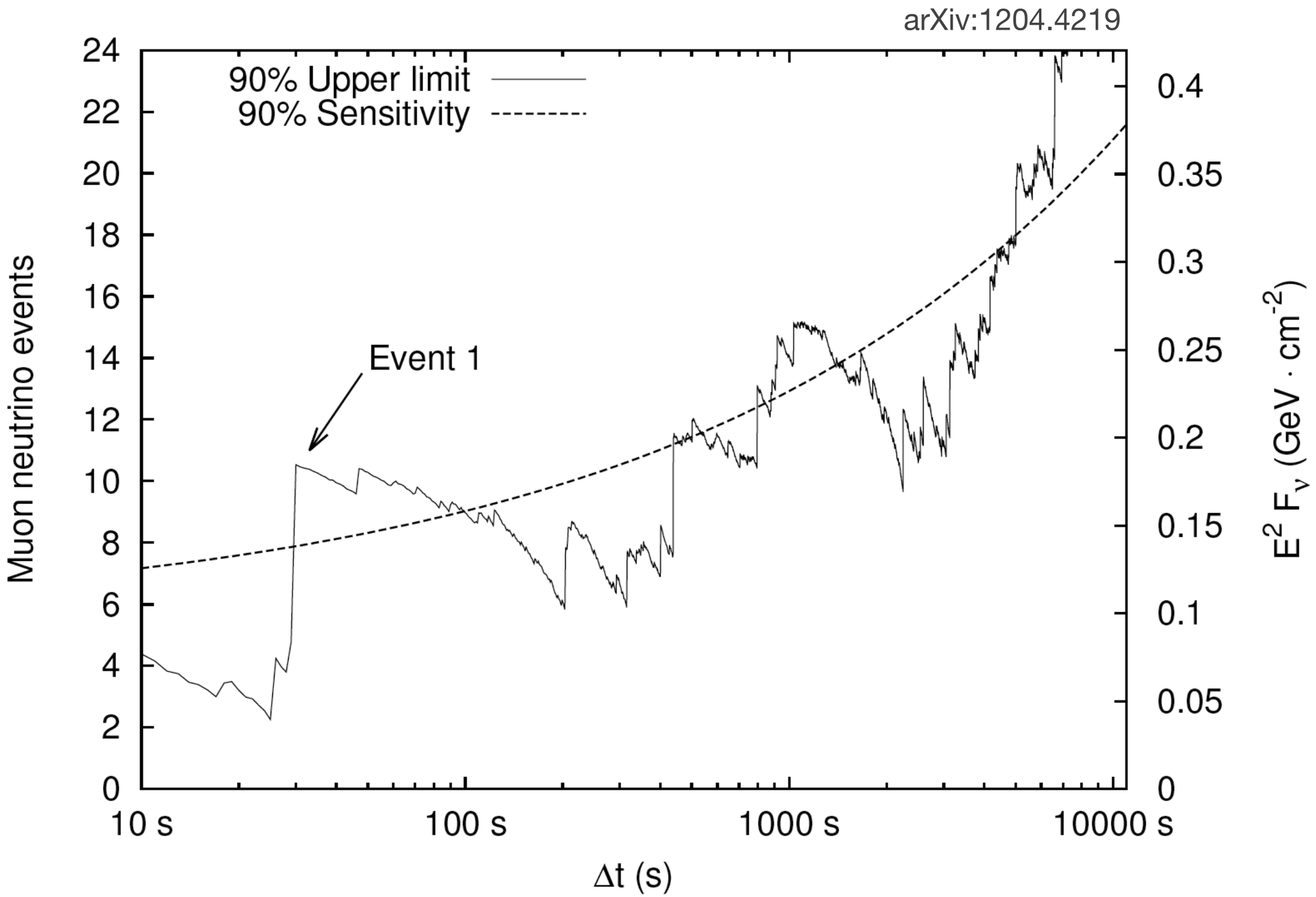
P. Mészáros, *Science* 2001

GRB Fireball Model



- Data provides an upper limit that is 3.7x lower than fireball prediction
- Model independent search also shows no events associated with GRBs

Model Independent

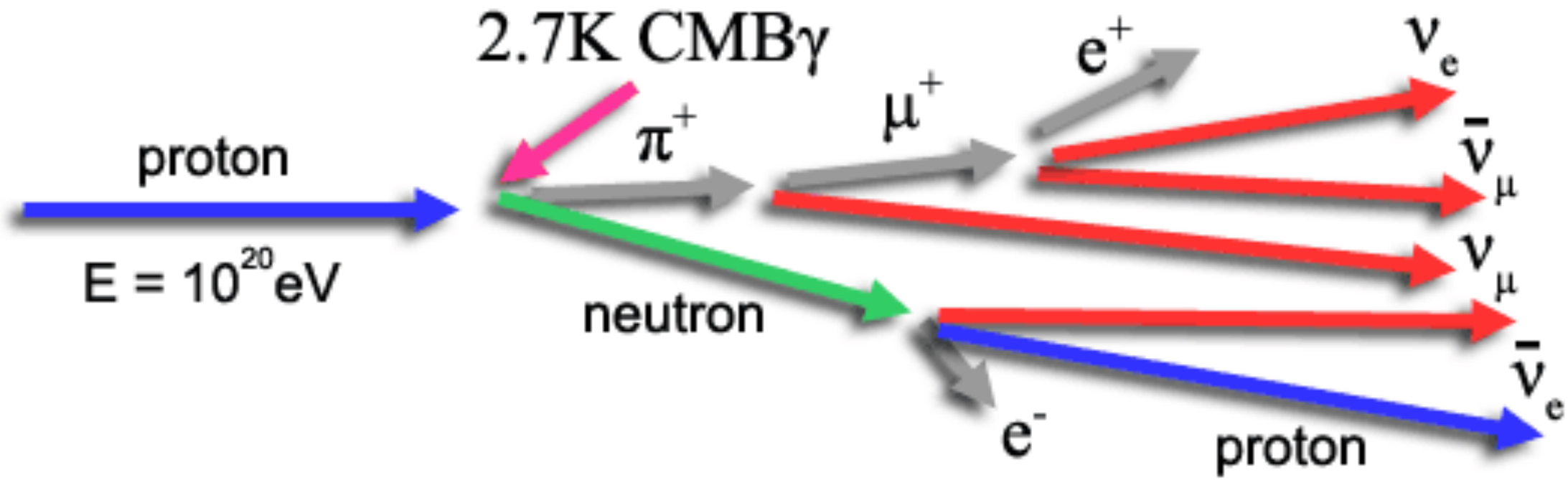


KM3NeT

- Possible neutrino telescope in Mediterranean

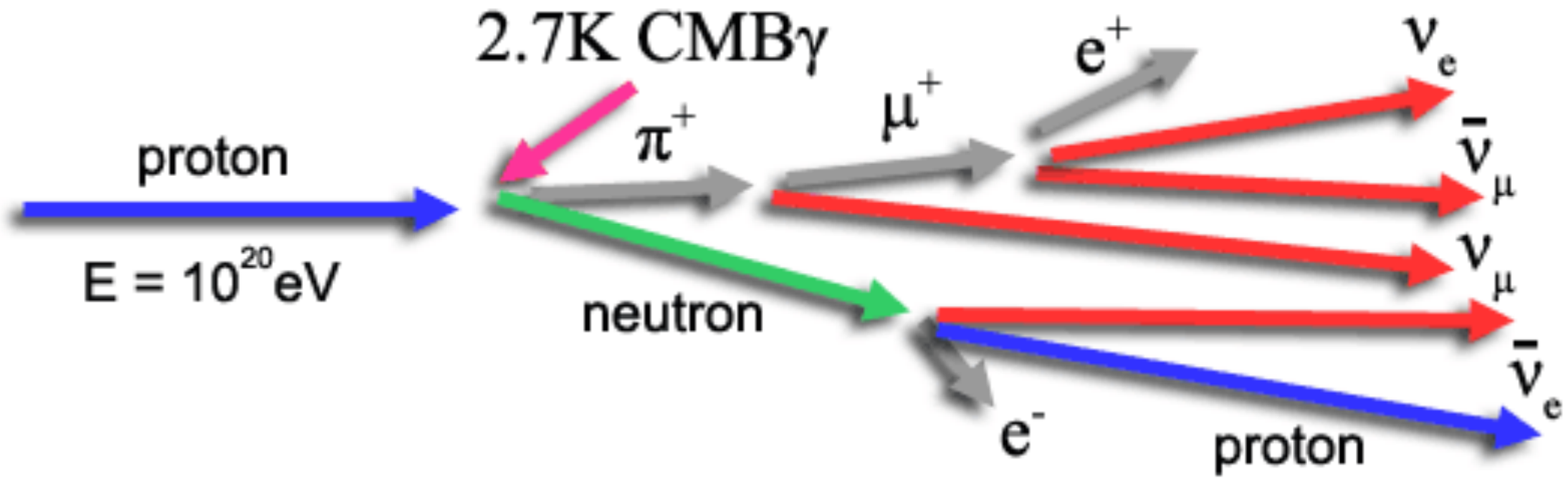
Radio

GZK Reminder



GZK Reminder

- Neutrinos break high energy cosmic ray degeneracy in why no high energy cosmic rays are detected:



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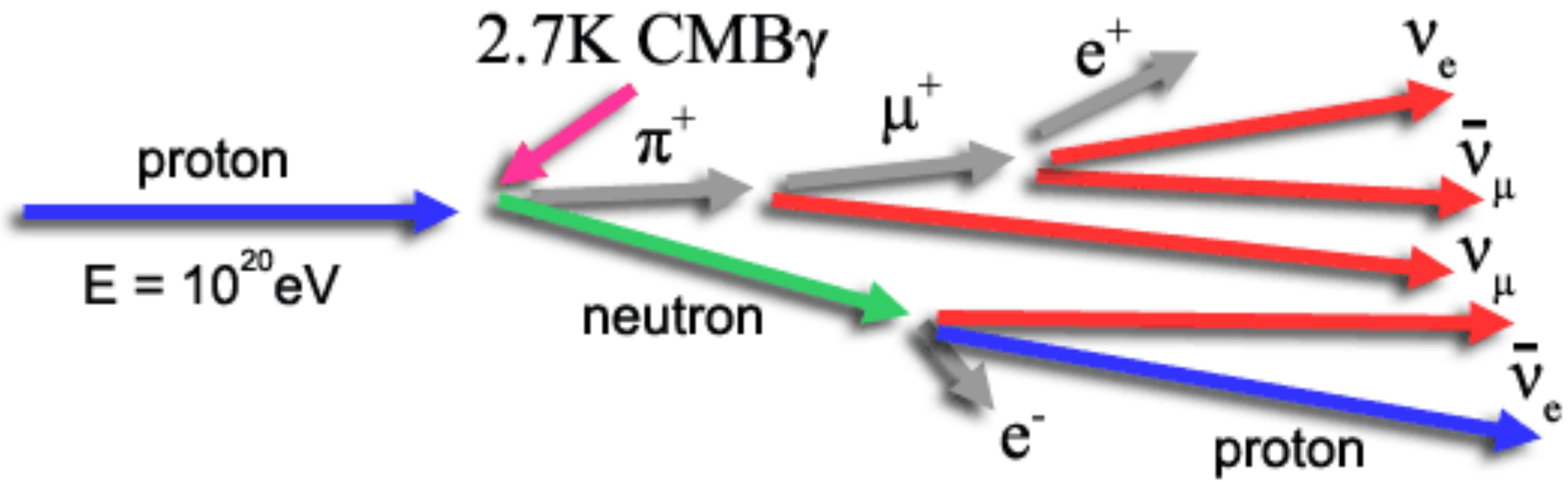
    1. Cosmic ray accelerators do **NOT** produce particles at $5x10^{19}$ eV, i.e. no observation of neutrinos near $5x10^{19}$ eV



GZK Reminder

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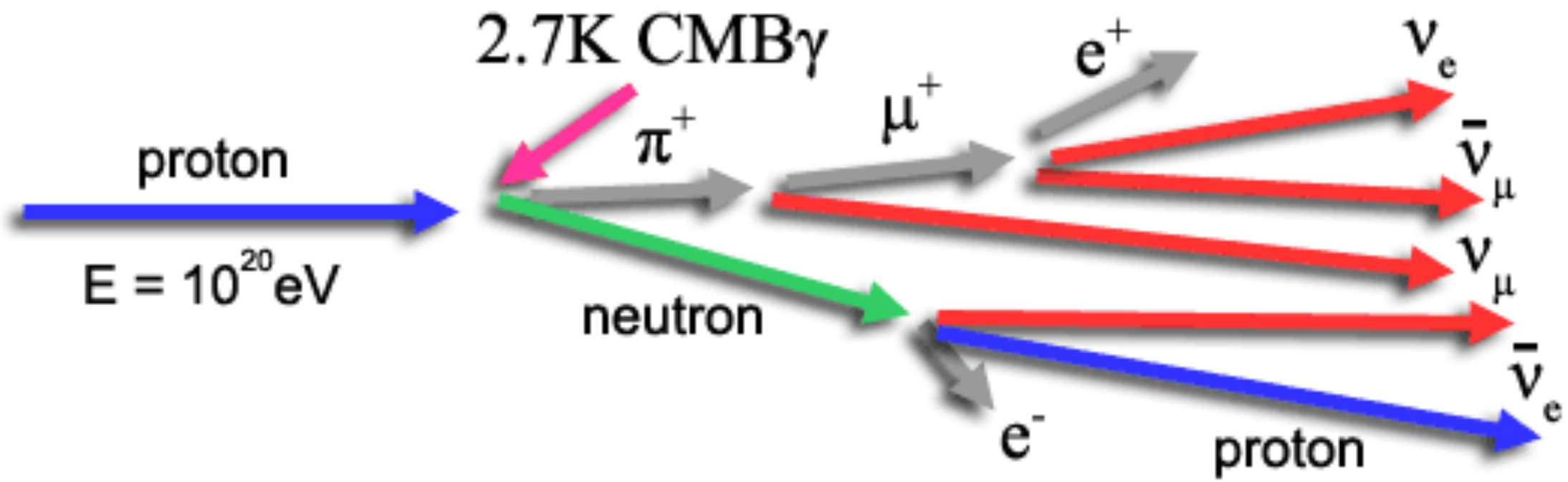
    1. Cosmic ray accelerators do **NOT** produce particles at $5x10^{19}$ eV, i.e. no observation of neutrinos near $5x10^{19}$ eV
    2. Cosmic ray accelerators **DO** produce particles at $5x10^{19}$ eV, i.e. positive observation of neutrinos near $5x10^{19}$ eV



ANITA

- Askaryan effect is where high energy particle in a dense medium produces coherent (polarized) radio emission

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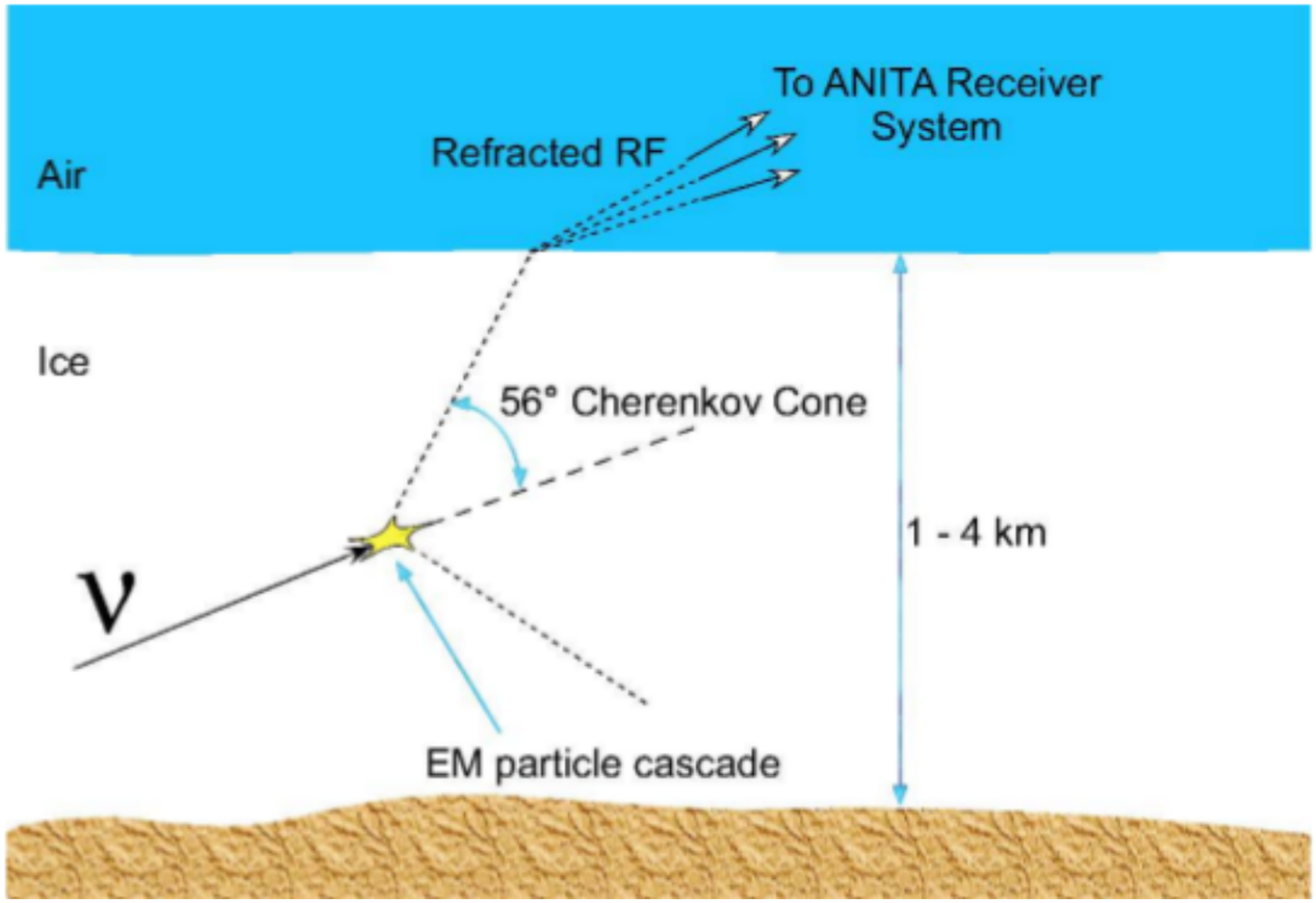
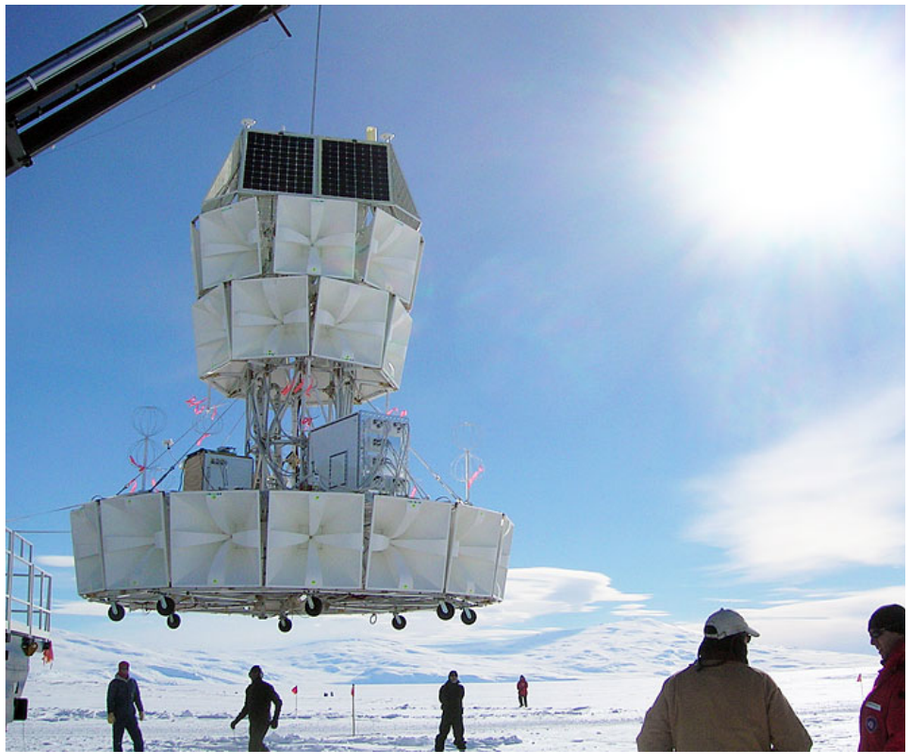
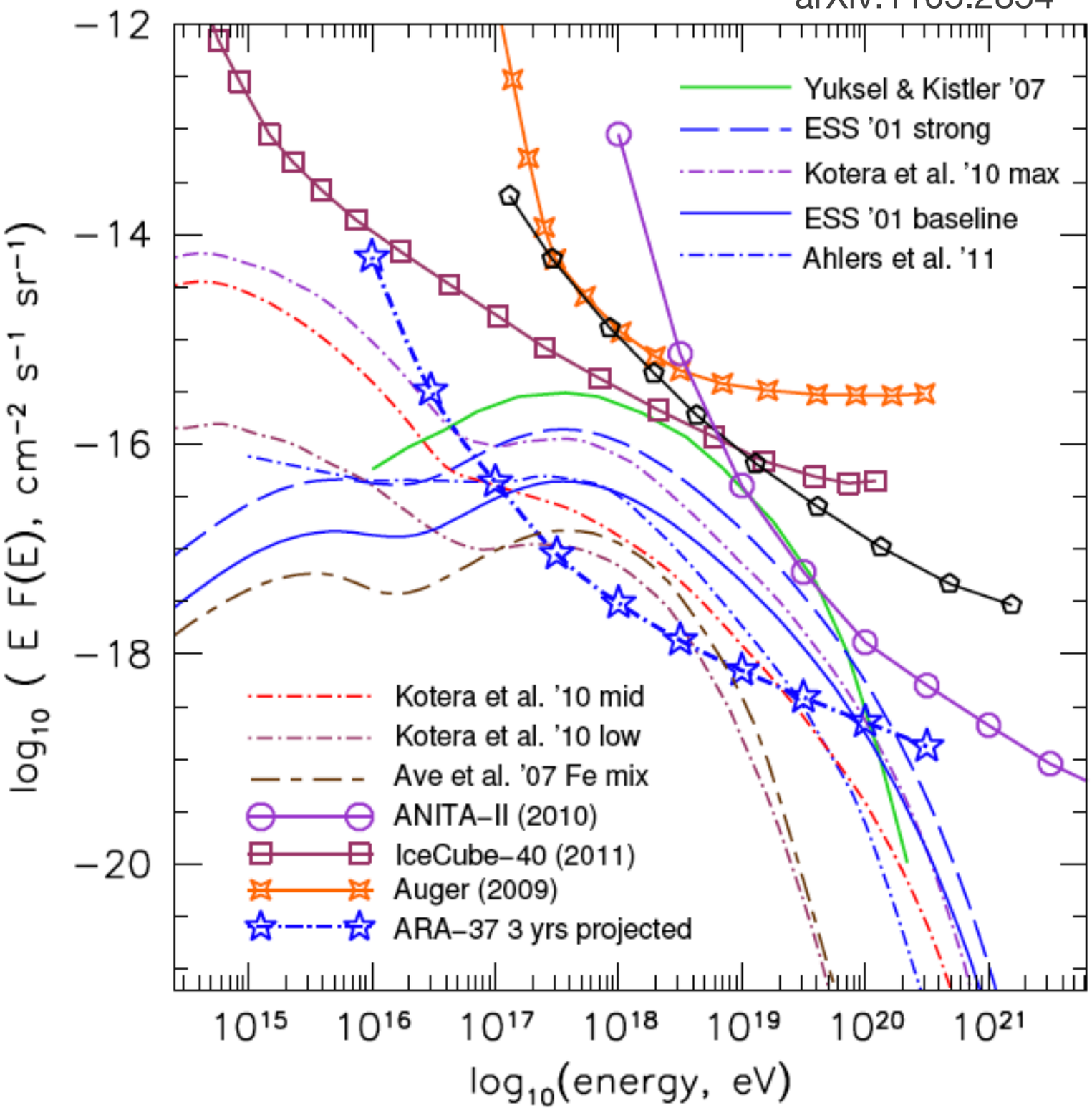


http://www.thespectrumofriemannium.com/2012/10/17/log047-the-askaryan-effect/

ANITA

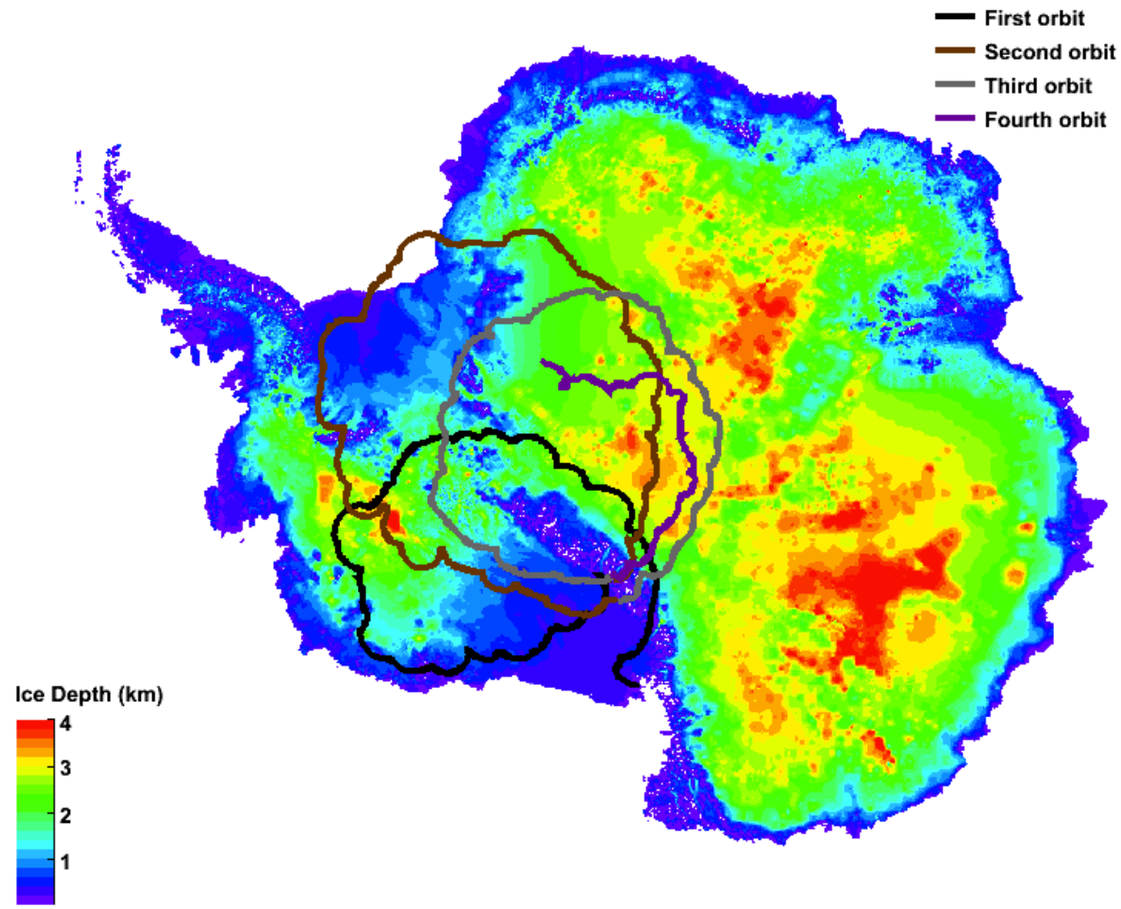


arXiv:1105.2854



ANITA

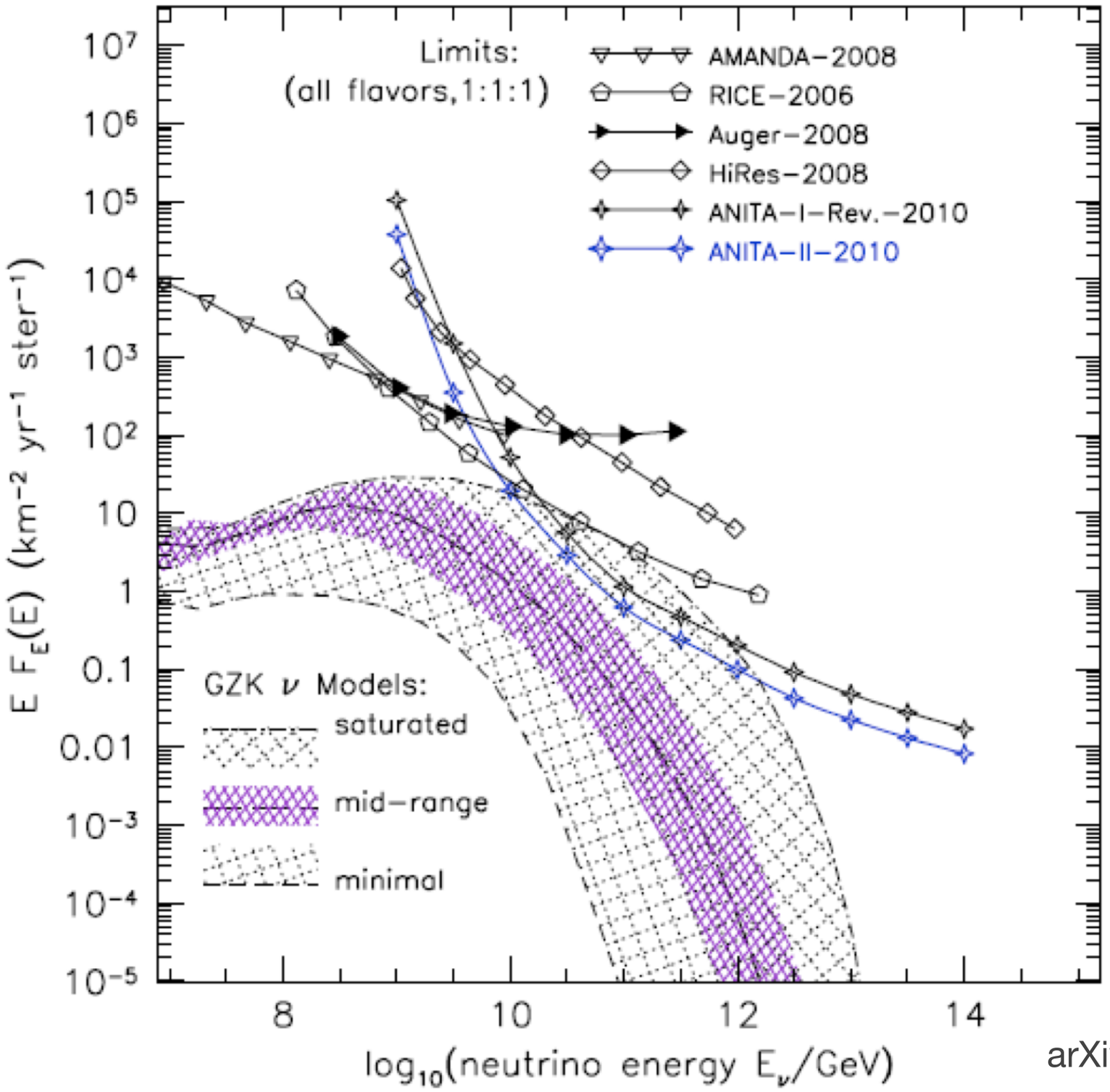
- First two flights are done
- ANITA-III
  - 5x improvement in sensitivity
  - Planned flight in Dec. 2014



	ANITA-I	ANITA-II
Neutrino Candidate Events	1	1
Expected Background	1.1	0.97 +/- 0.42

*A. Vieregg, Harvard CfA 2013

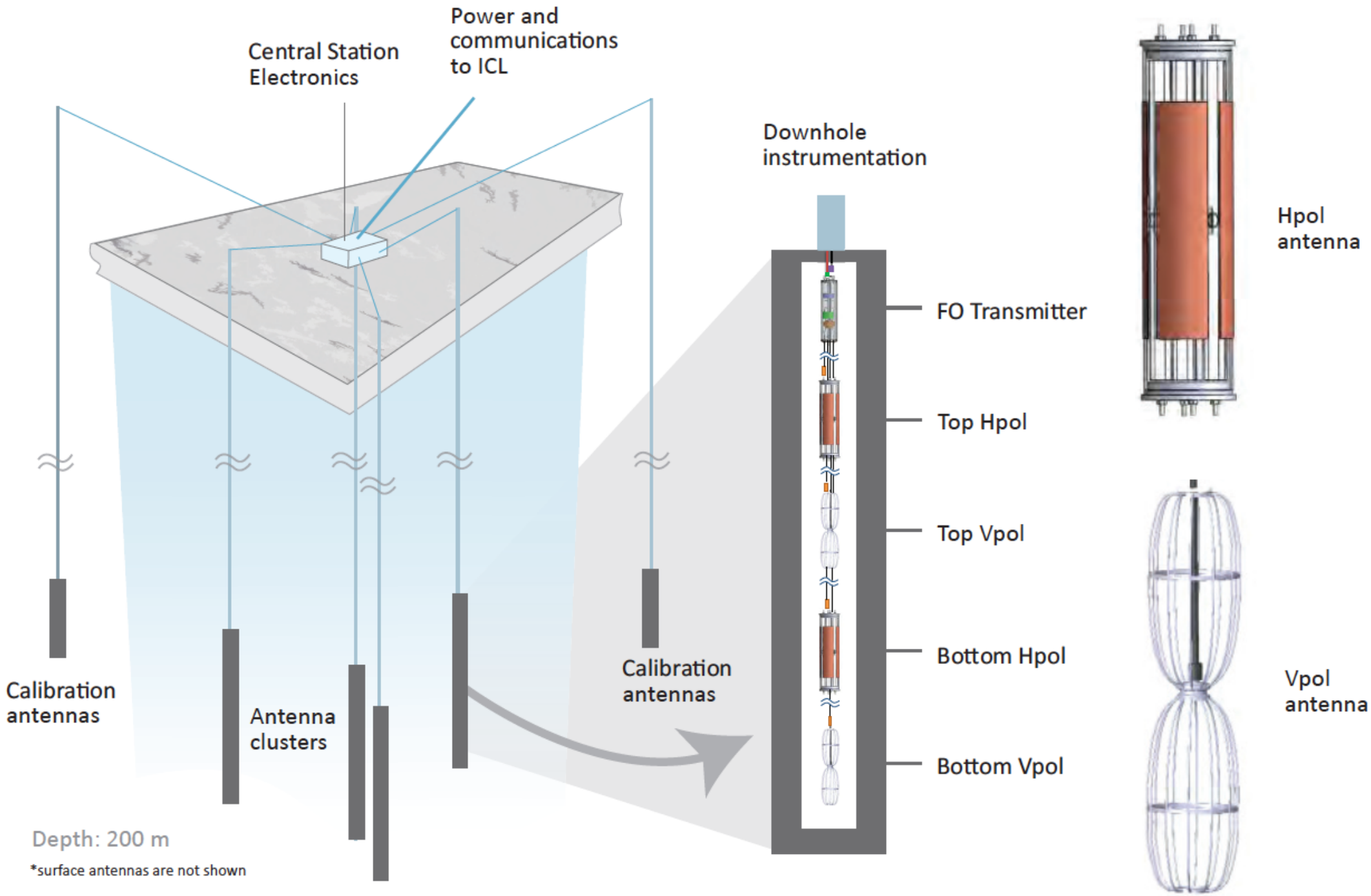
Low Coverage for GZK



arXiv:1207.3846

ARA

- Askaryan Radio Array



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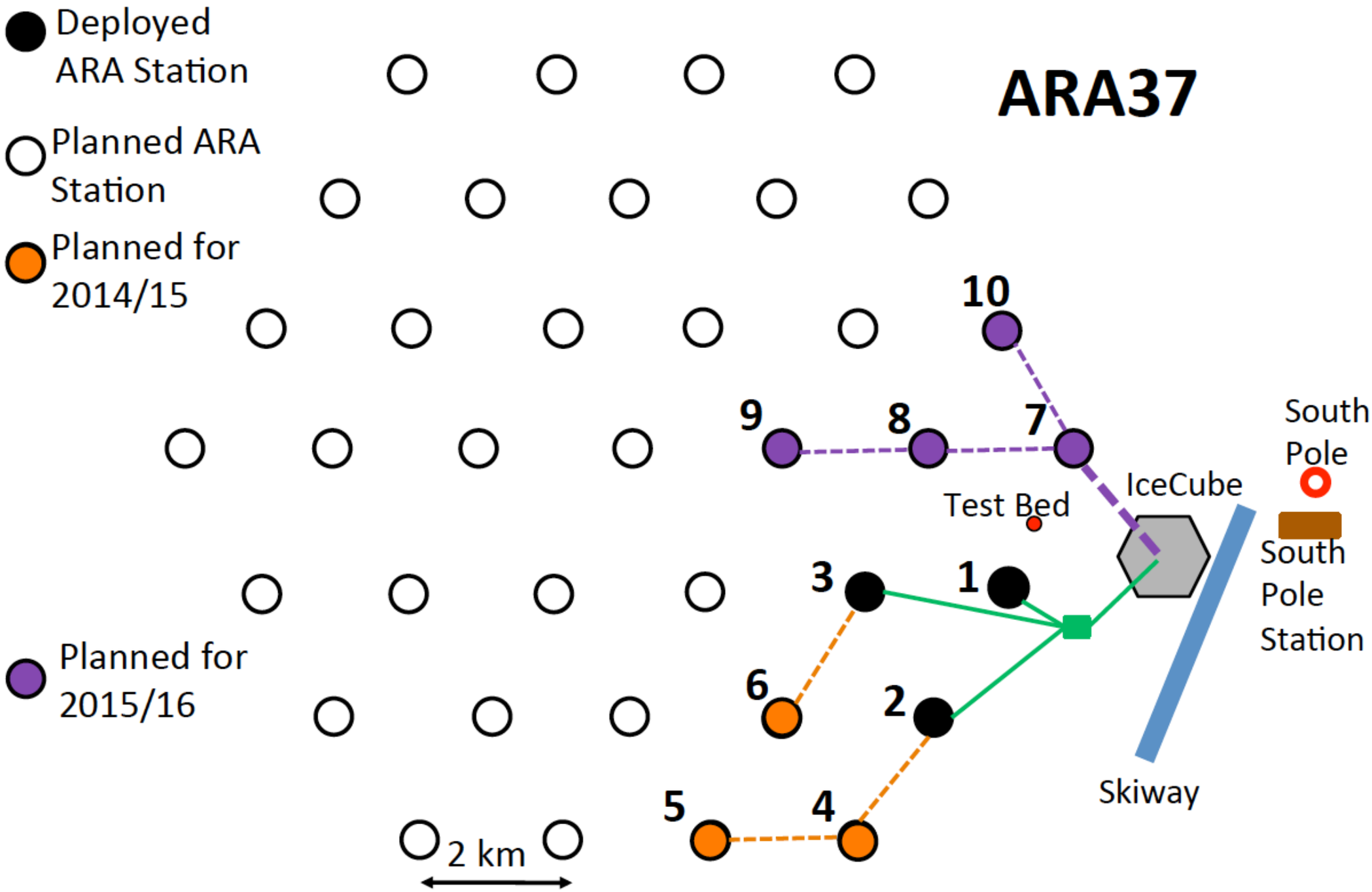
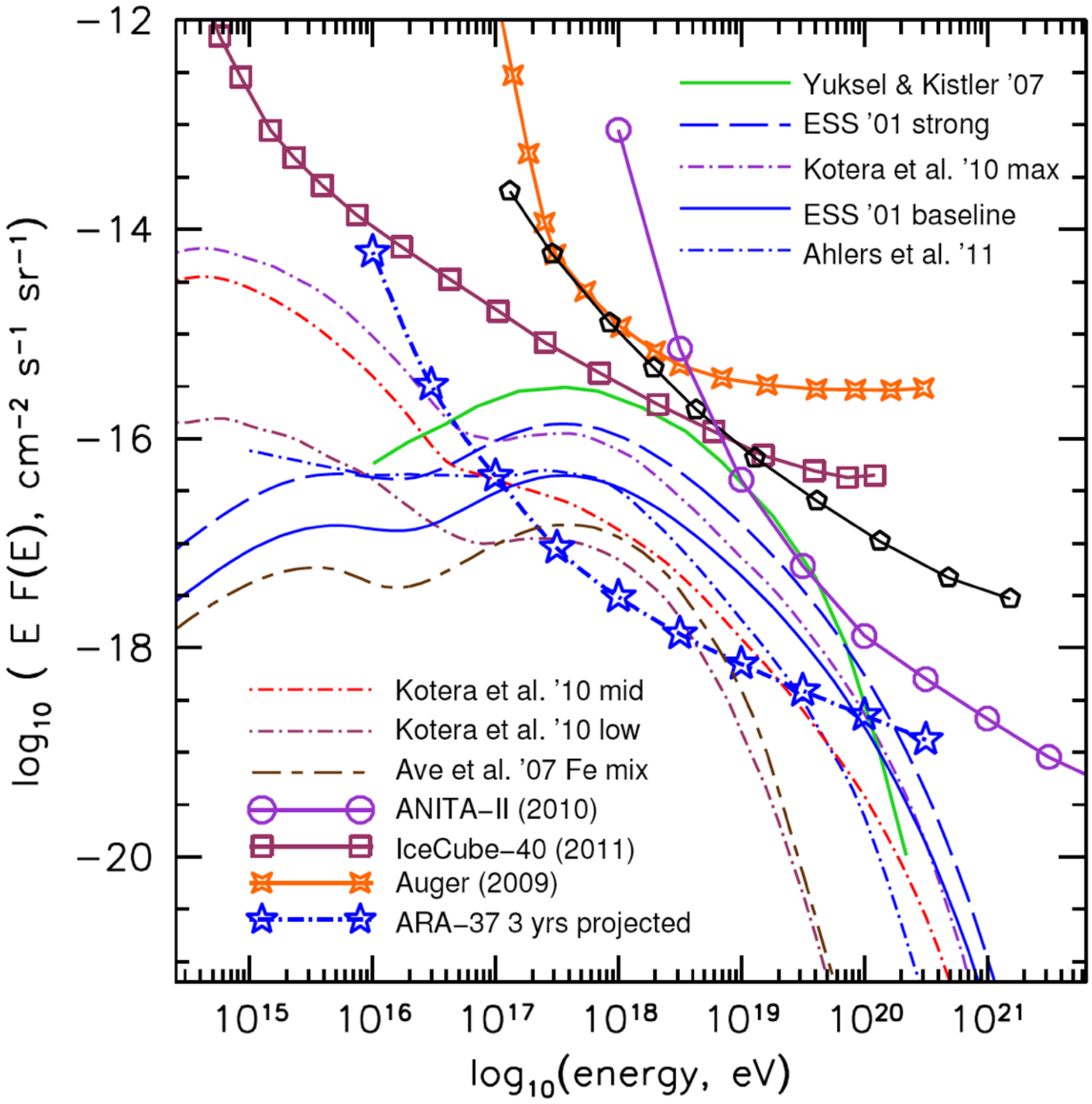

Deployed ARA Station
Planned ARA Station
Planned for 2014/15
Planned for 2015/16
ARA37
10
9
8
7
3
1
6
2
5
4
2 km
IceCube
Test Bed
South Pole
South Pole Station
Skiway

ARA Projected Sensitivity



arXiv:1105.2845

ARIANNA on the Ross Ice Shelf

78° 44.523' S, 165° 02.414' E

Antarctic **R**oss **I**ce Shelf **An**tenna **N**eutrino **A**rray

Dry Valleys

Wireless Internet Link

Ross Island and McMurdo Station
(~120 km from array)

Minna Bluff
(radio barrier)

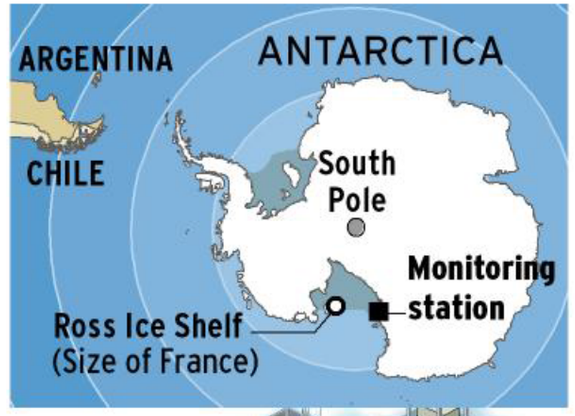
S

30 x 30 km, 900-station grid

ARIANNA

Counting neutrinos

A high-energy neutrinos constantly stream through all objects on Earth. Occasionally, a neutrino hits the nucleus of atoms and generates a blast of particles, generating a pulse of radio emissions that can be recorded. Here is a look at why the antarctic is a good place to monitor those radio emissions:



NEUTRINOS ENTER ICE

1 Countless neutrinos enter the ice, a few occasionally strike hydrogen and oxygen atoms in the ice.

COLLISION IN ICE

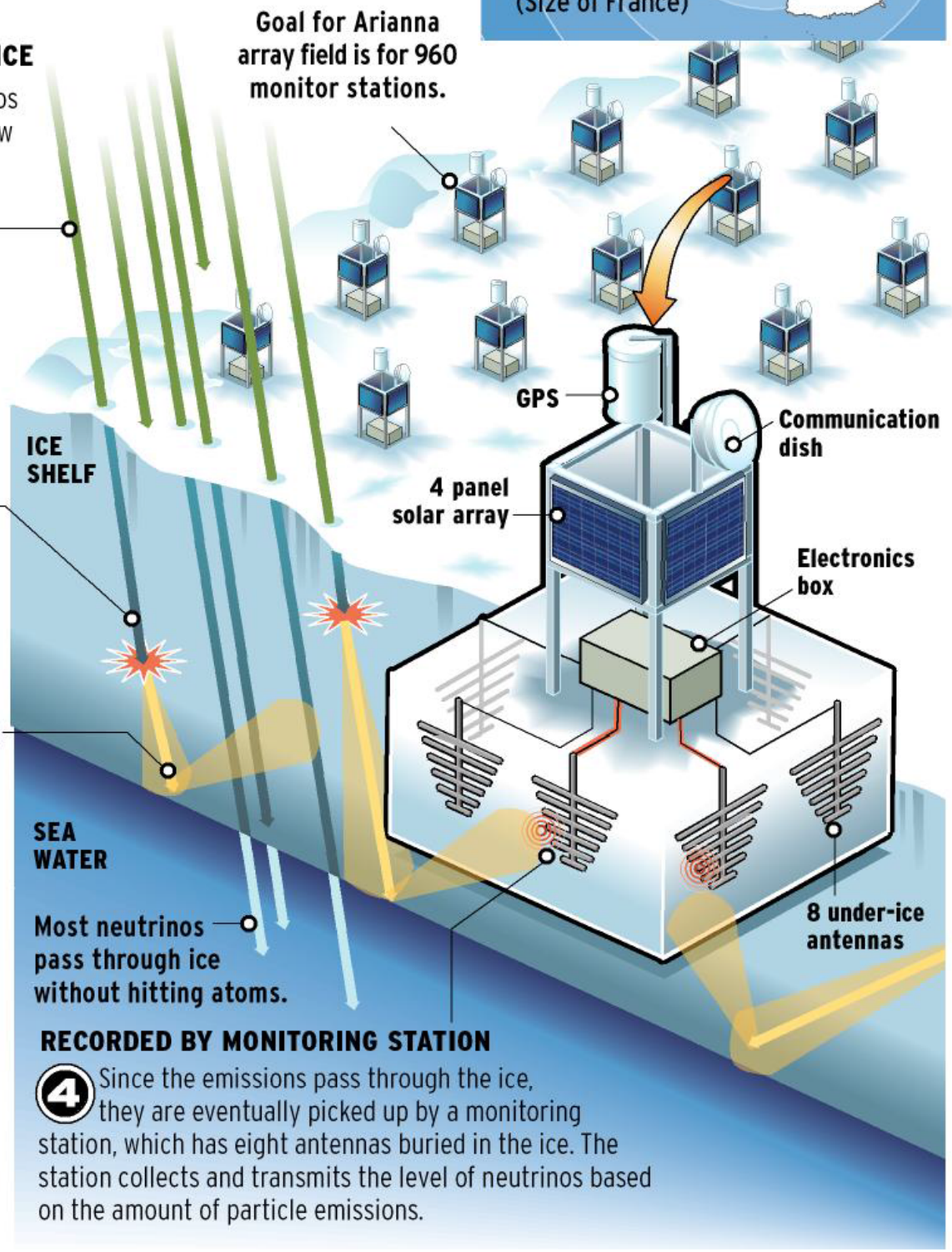
2 The force of the collision blasts particles from the nucleus of the atoms. The spray of particles emit radio waves in the form of a "cone" that points in the same direction that the neutrino was moving.

BLOCKED BY WATER

3 The Ross Ice Shelf is ideal for monitoring these emissions due to the water below the ice blocking the radio emissions. They bounce off the water and travel back through the ice.

Source: UCI Professor Steven Barwick

Graphic by Scott Brown / The Register

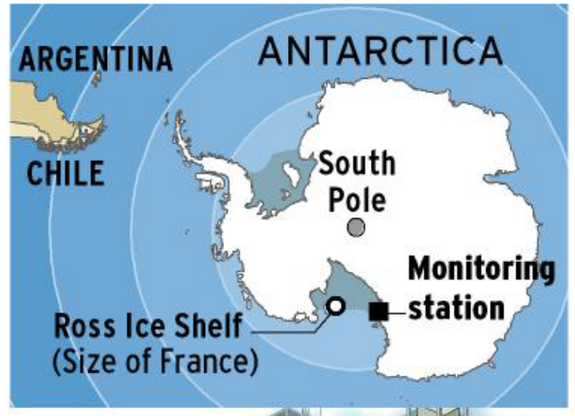


ARIANNA

- Passive stations

Counting neutrinos

A high-energy neutrinos constantly stream through all objects on Earth. Occasionally, a neutrino hits the nucleus of atoms and generates a blast of particles, generating a pulse of radio emissions that can be recorded. Here is a look at why the antarctic is a good place to monitor those radio emissions:



NEUTRINOS ENTER ICE

1 Countless neutrinos enter the ice, a few occasionally strike hydrogen and oxygen atoms in the ice.

COLLISION IN ICE

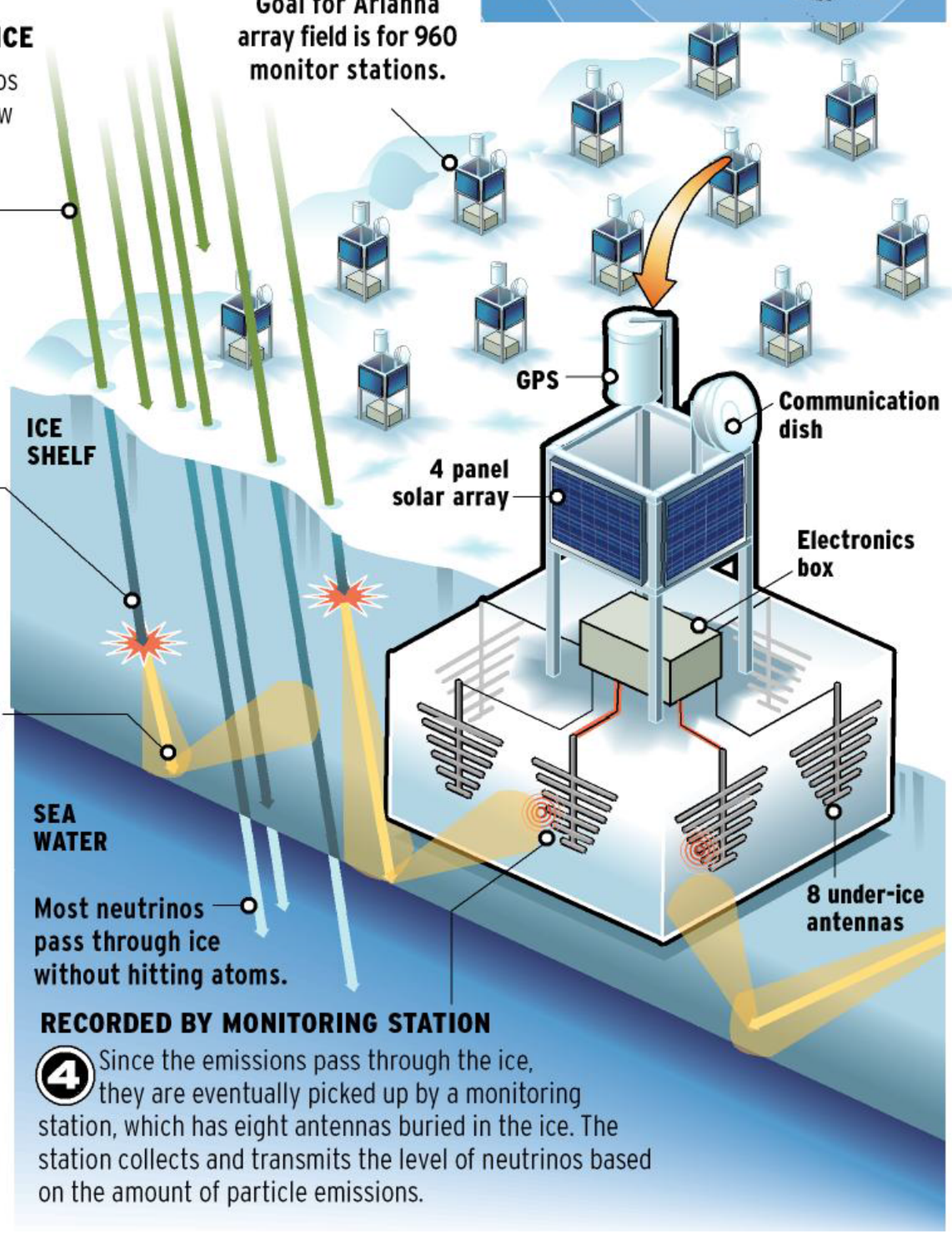
2 The force of the collision blasts particles from the nucleus of the atoms. The spray of particles emit radio waves in the form of a "cone" that points in the same direction that the neutrino was moving.

BLOCKED BY WATER

3 The Ross Ice Shelf is ideal for monitoring these emissions due to the water below the ice blocking the radio emissions. They bounce off the water and travel back through the ice.

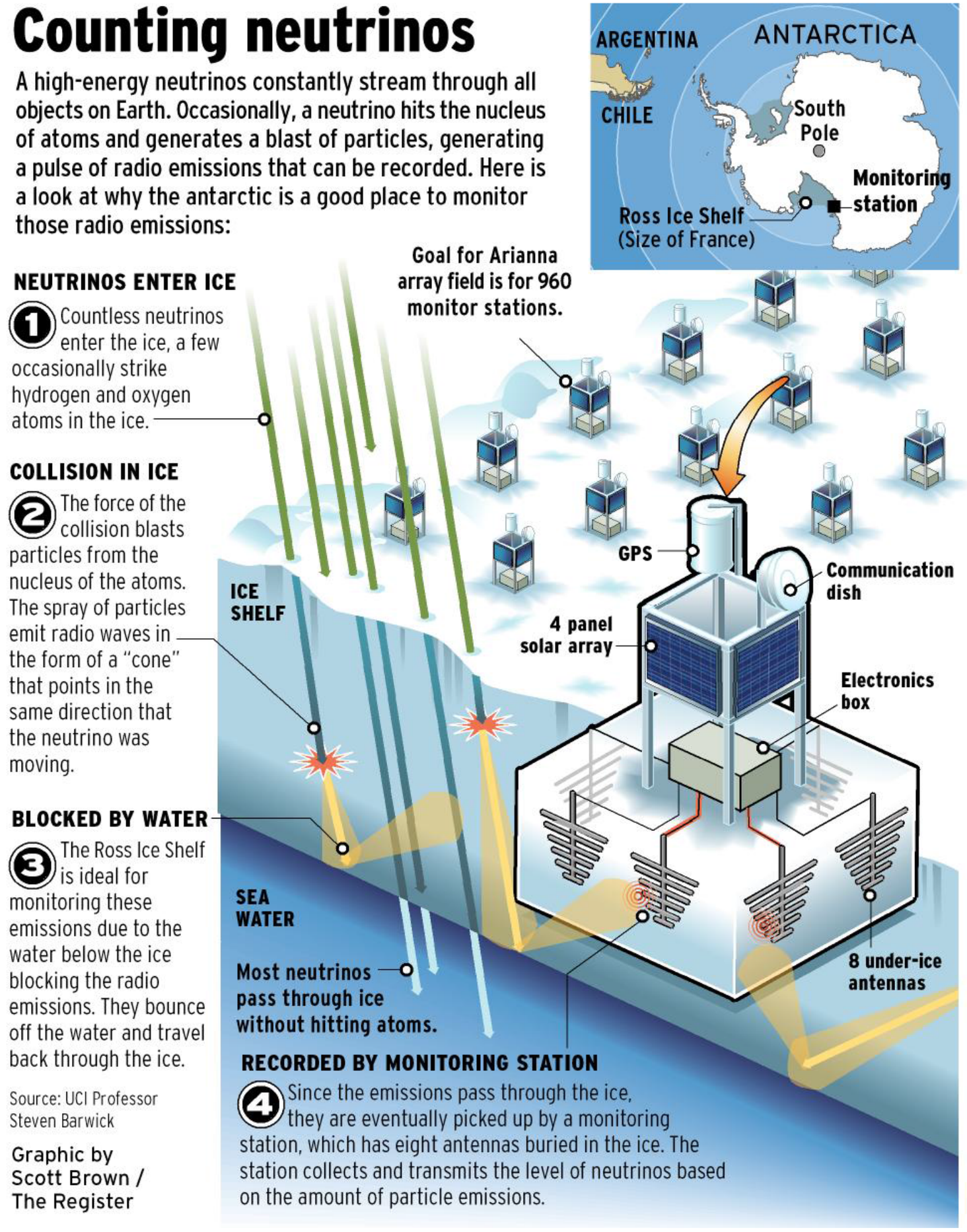
Source: UCI Professor Steven Barwick

Graphic by Scott Brown / The Register



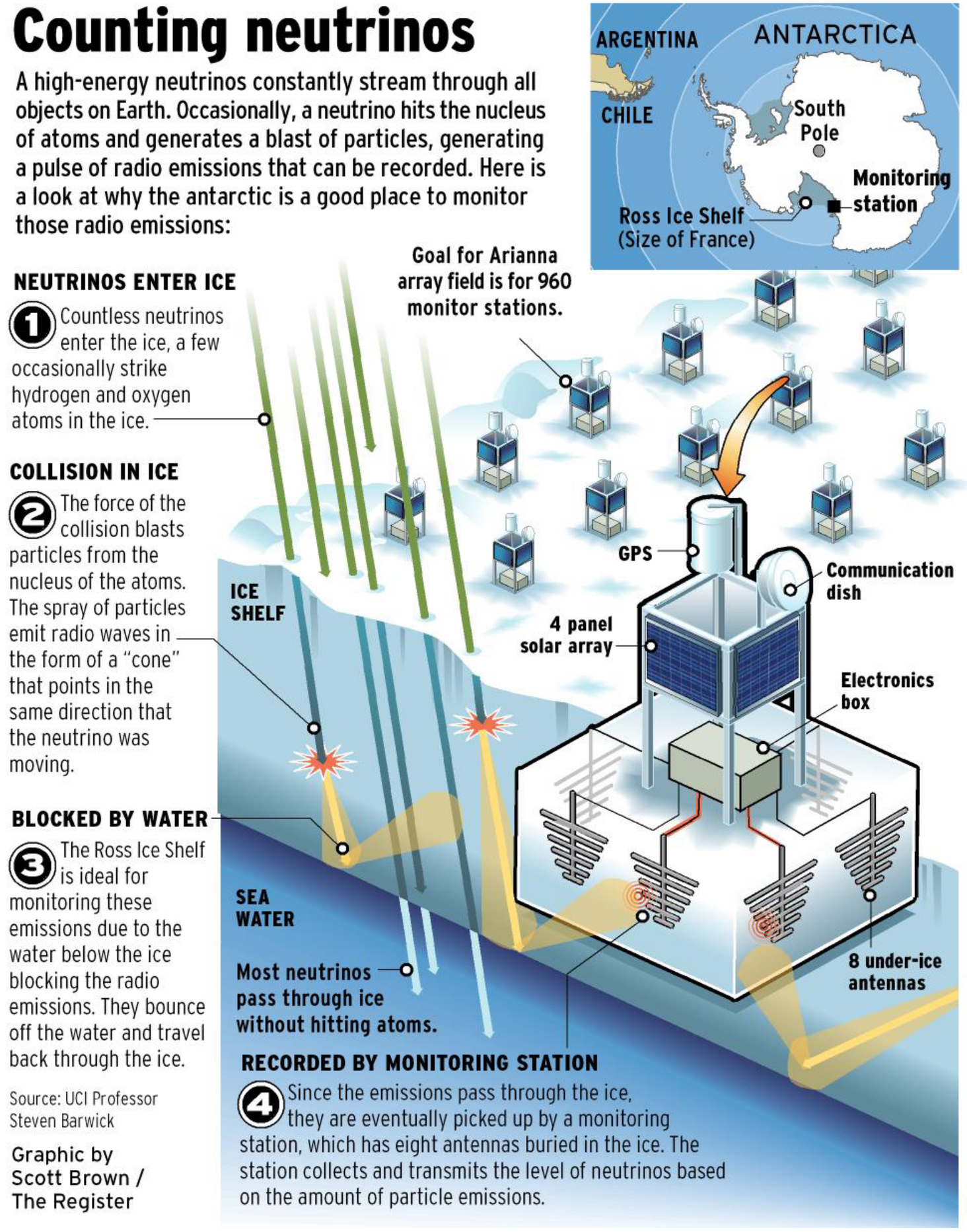
ARIANNA

- Passive stations
- Large
  - 31x31 array
  - 30km x 30km



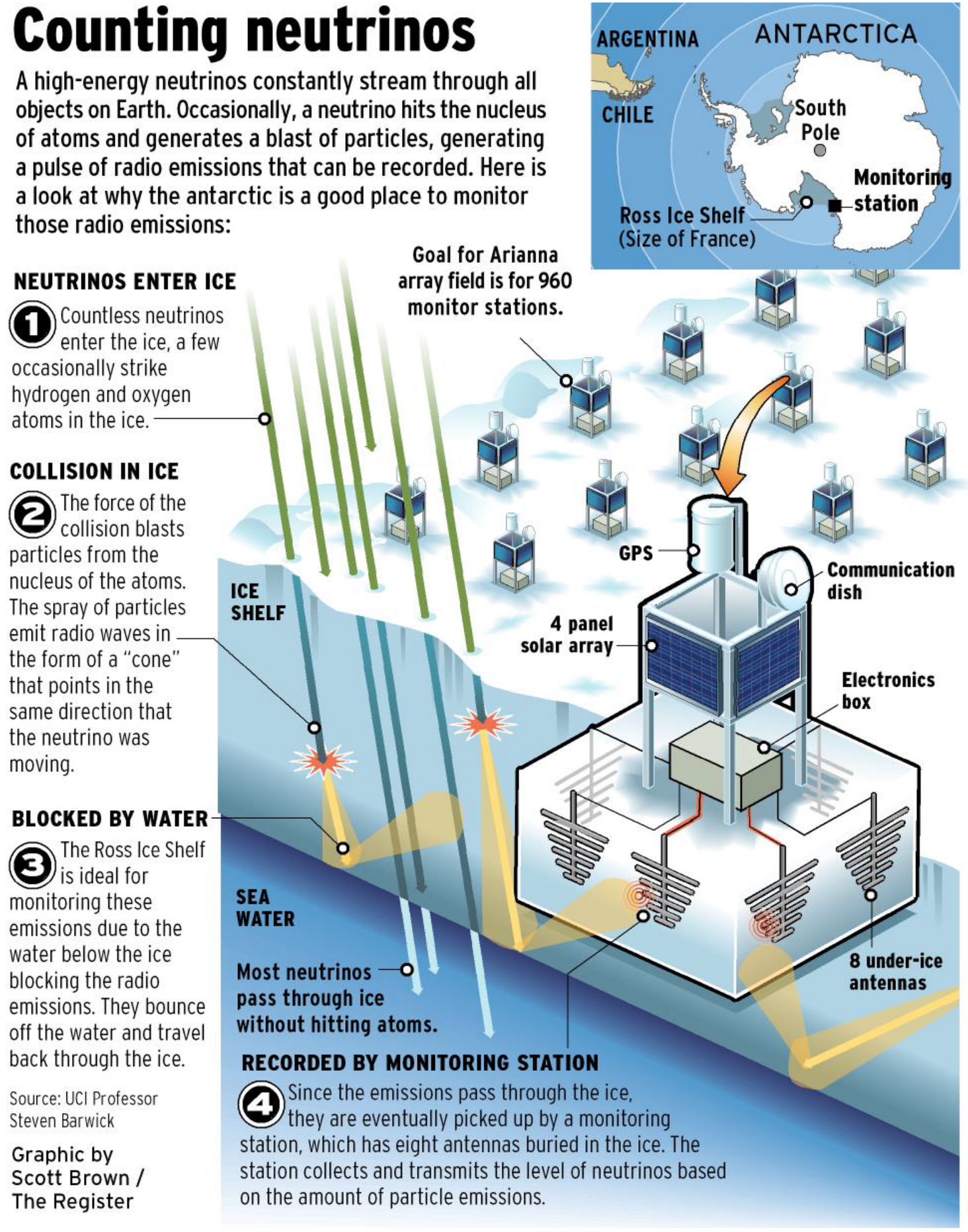
ARIANNA

- Passive stations
- Large
  - 31x31 array
  - 30km x 30km
- Economical



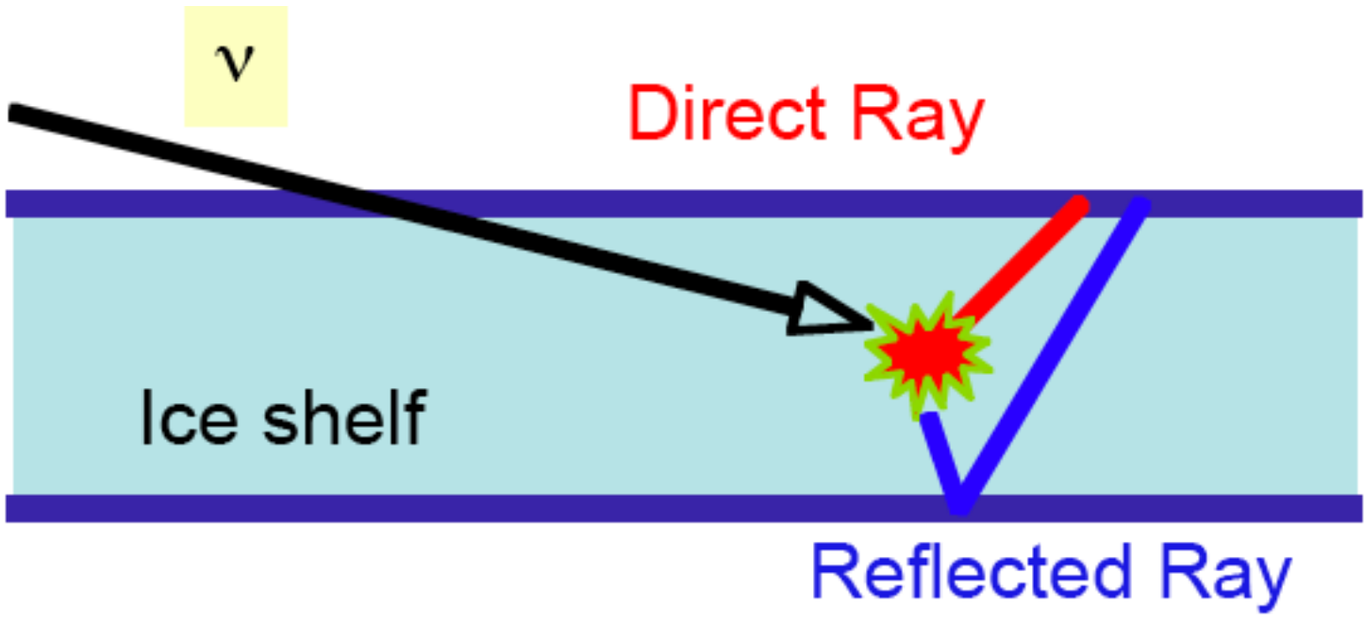
ARIANNA

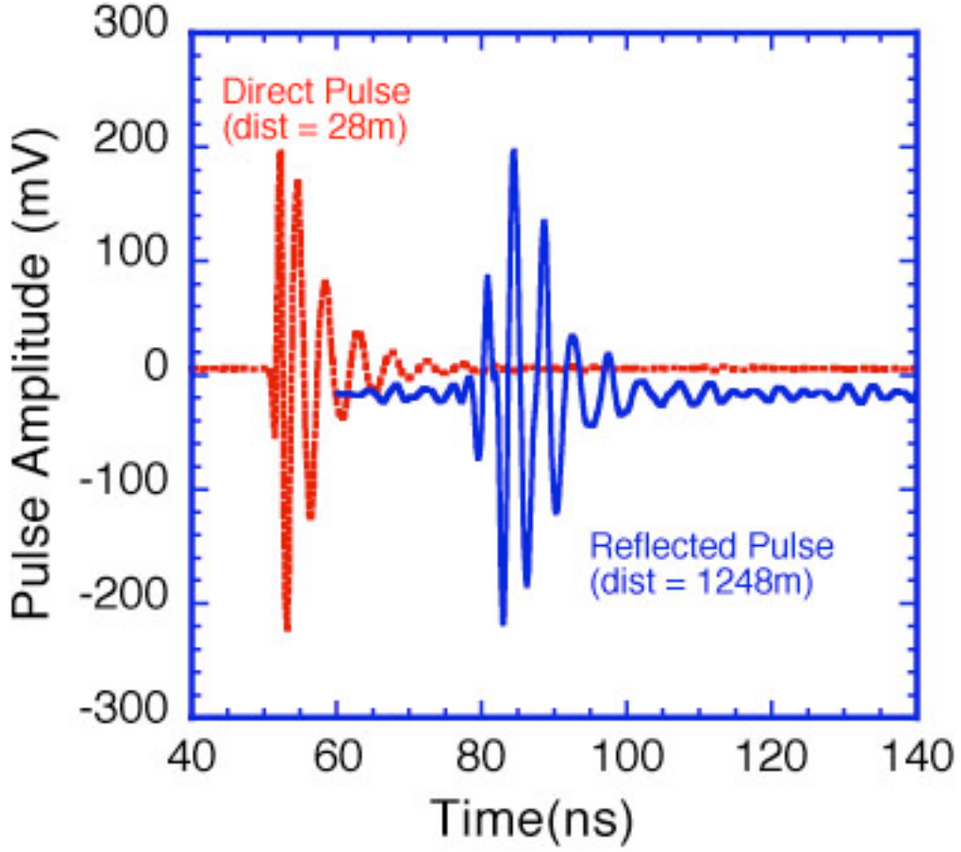
- Passive stations
- Large
  - 31x31 array
  - 30km x 30km
- Economical
- Redeployable



ARIANNA

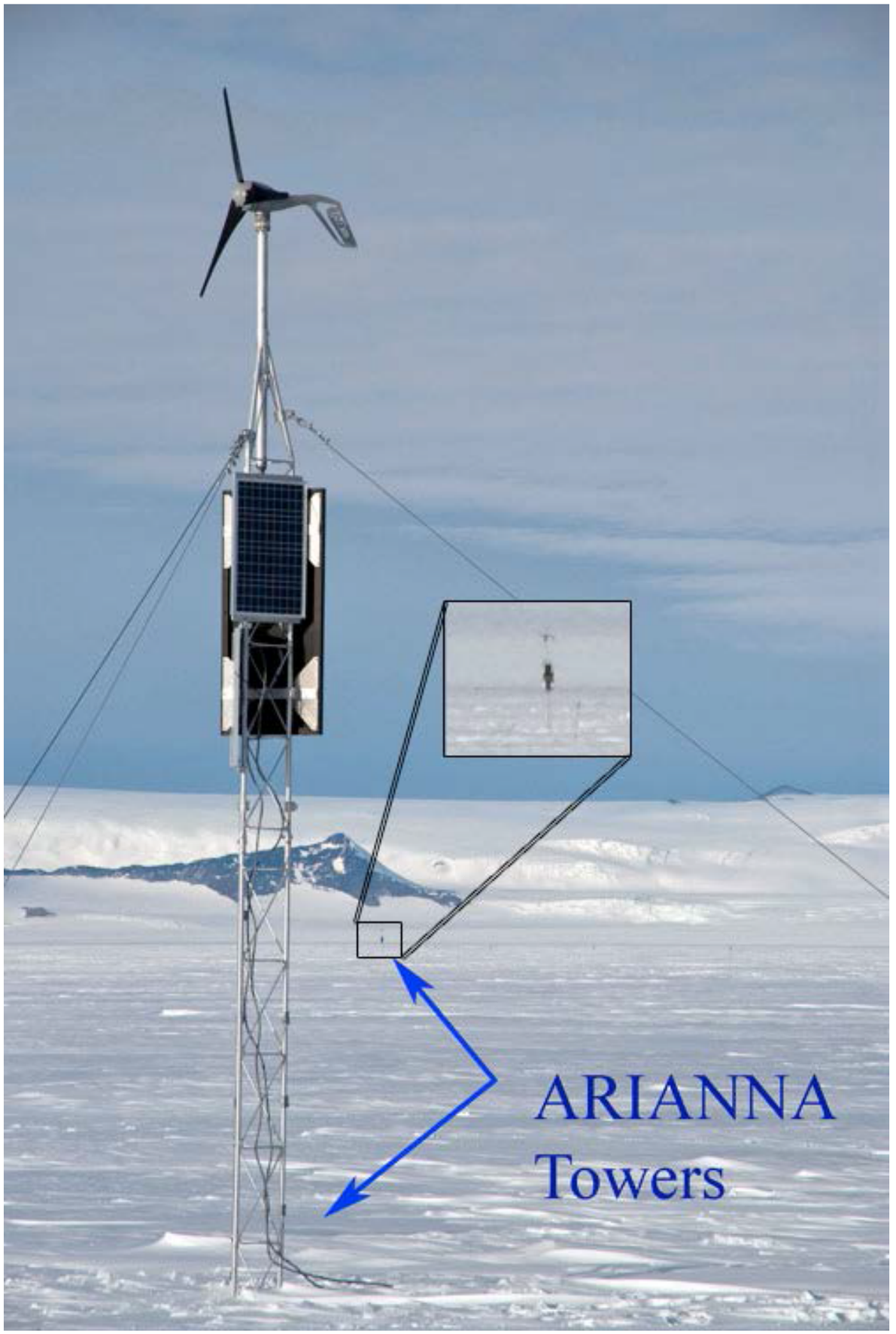
- Reflected pulse very similar to direct pulse
- Free from RF interference
- Enhanced signal from reflection





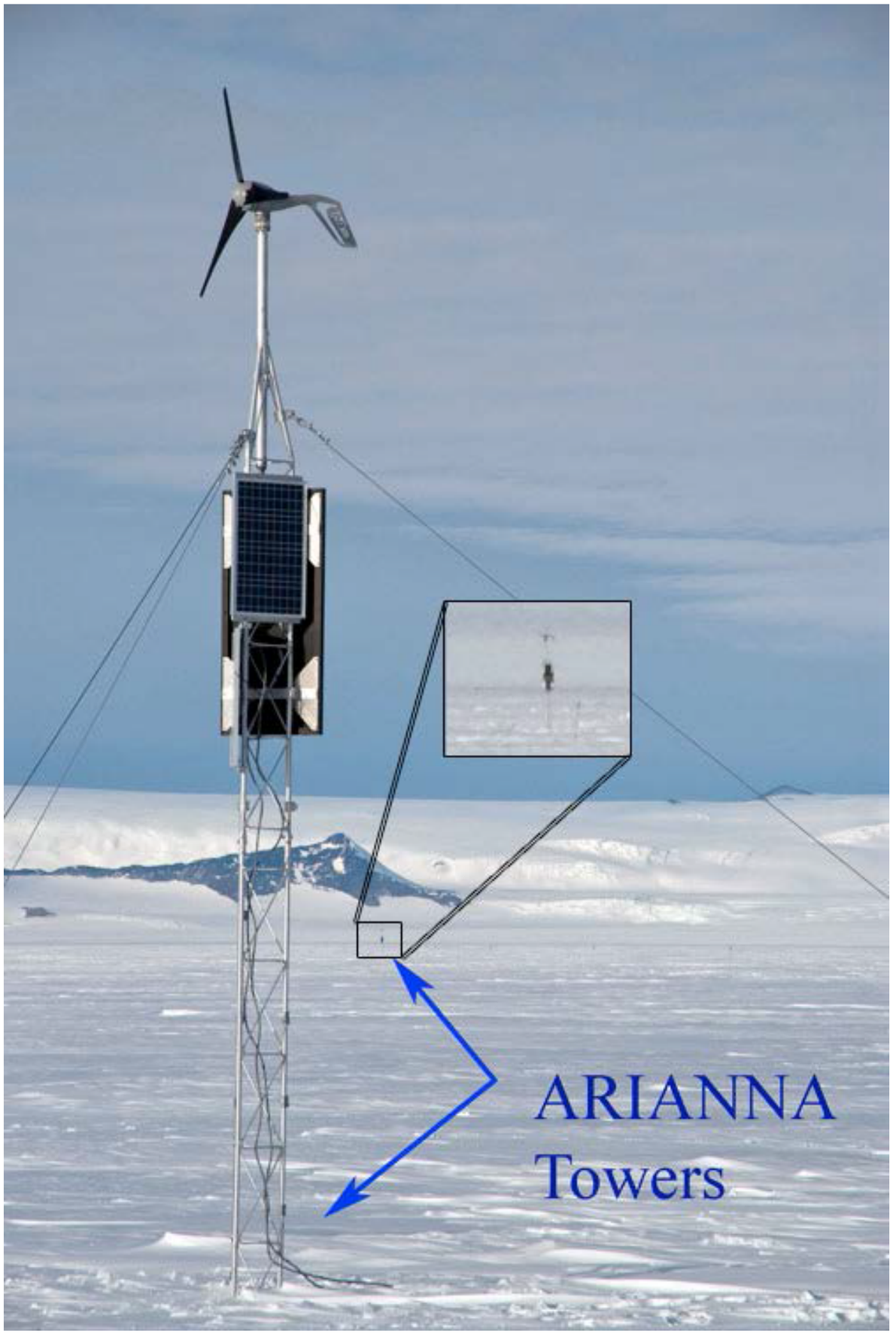
*S. Barwick, UCI

Power



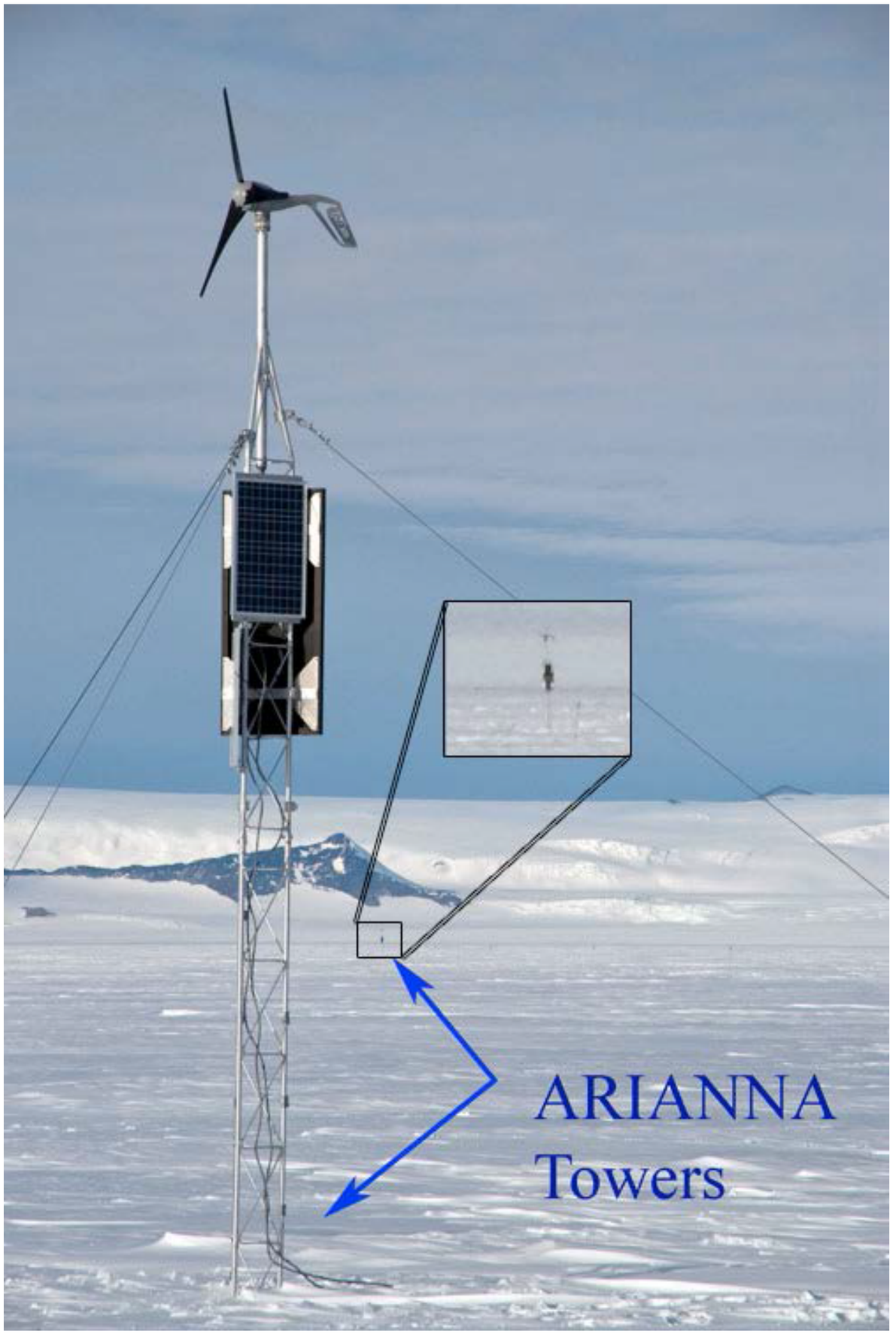
Power

- Summer tests showed 1.45A from tower



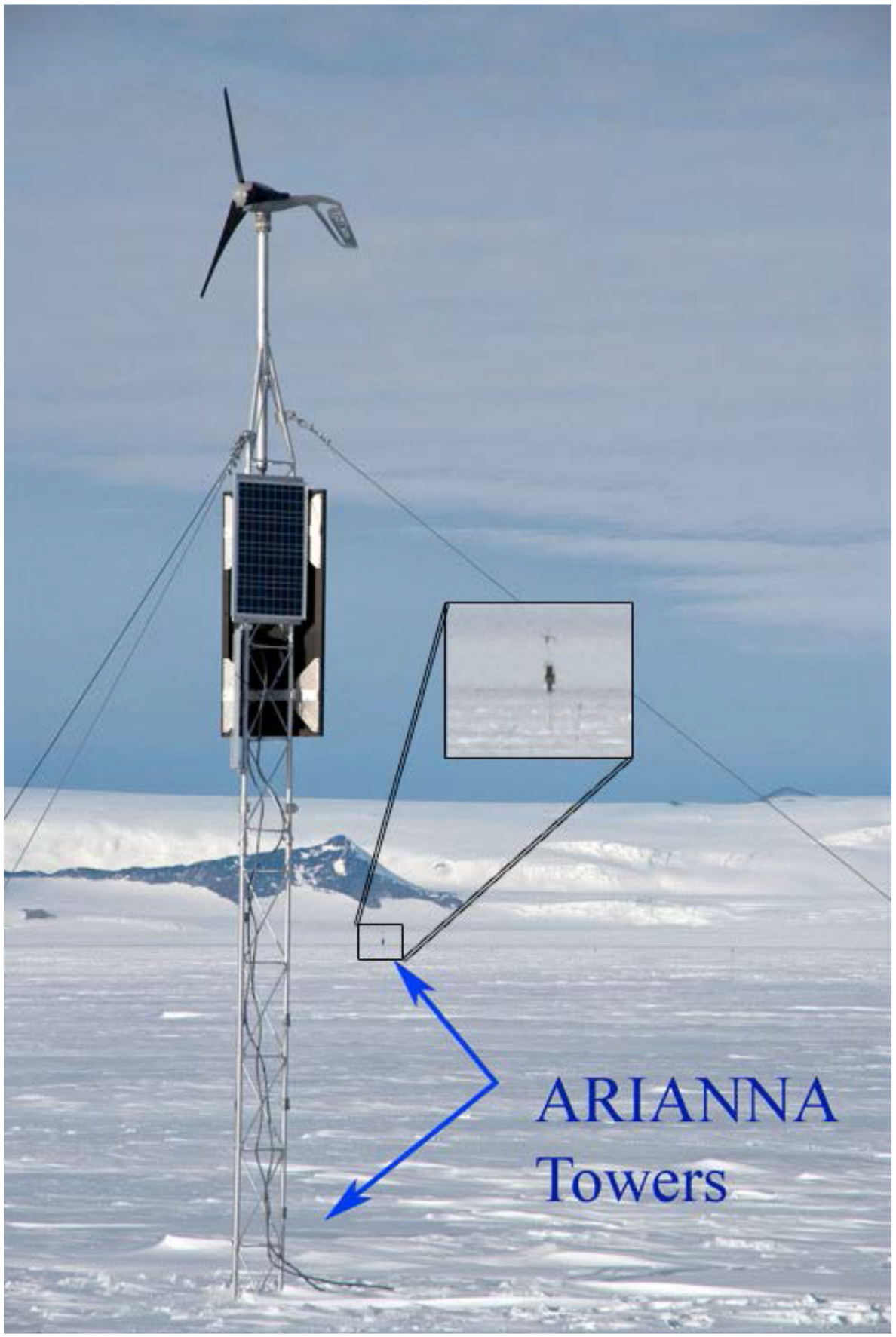
Power

- Summer tests showed 1.45A from tower
- Station requires 0.9A



Power

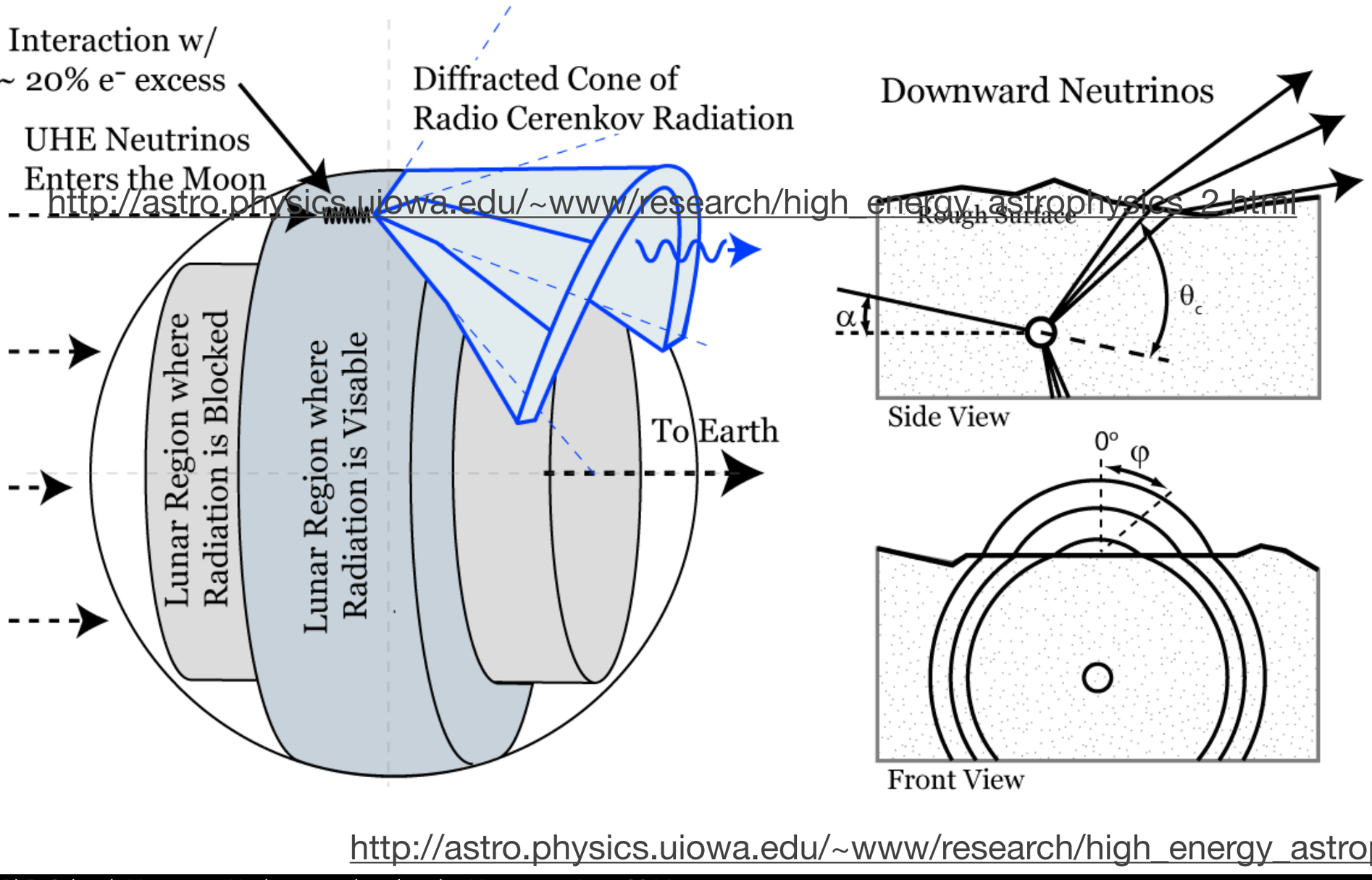
- Summer tests showed 1.45A from tower
- Station requires 0.9A
- Issues
  - Winter reduces efficiency due to cold
  - Low wind contingency



Other Options

Other Options

- Neutrino interaction in dielectric regolith of the moon



http://astro.physics.uiowa.edu/~www/research/high_energy_astrophysics_2.html

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Square Kilometre Array

Very Large Array

High Energies

- IceCube

- Neutrinos at PeV+ energies produce polarized radio emission (Askaryan) for which antennae detectors are well-suited