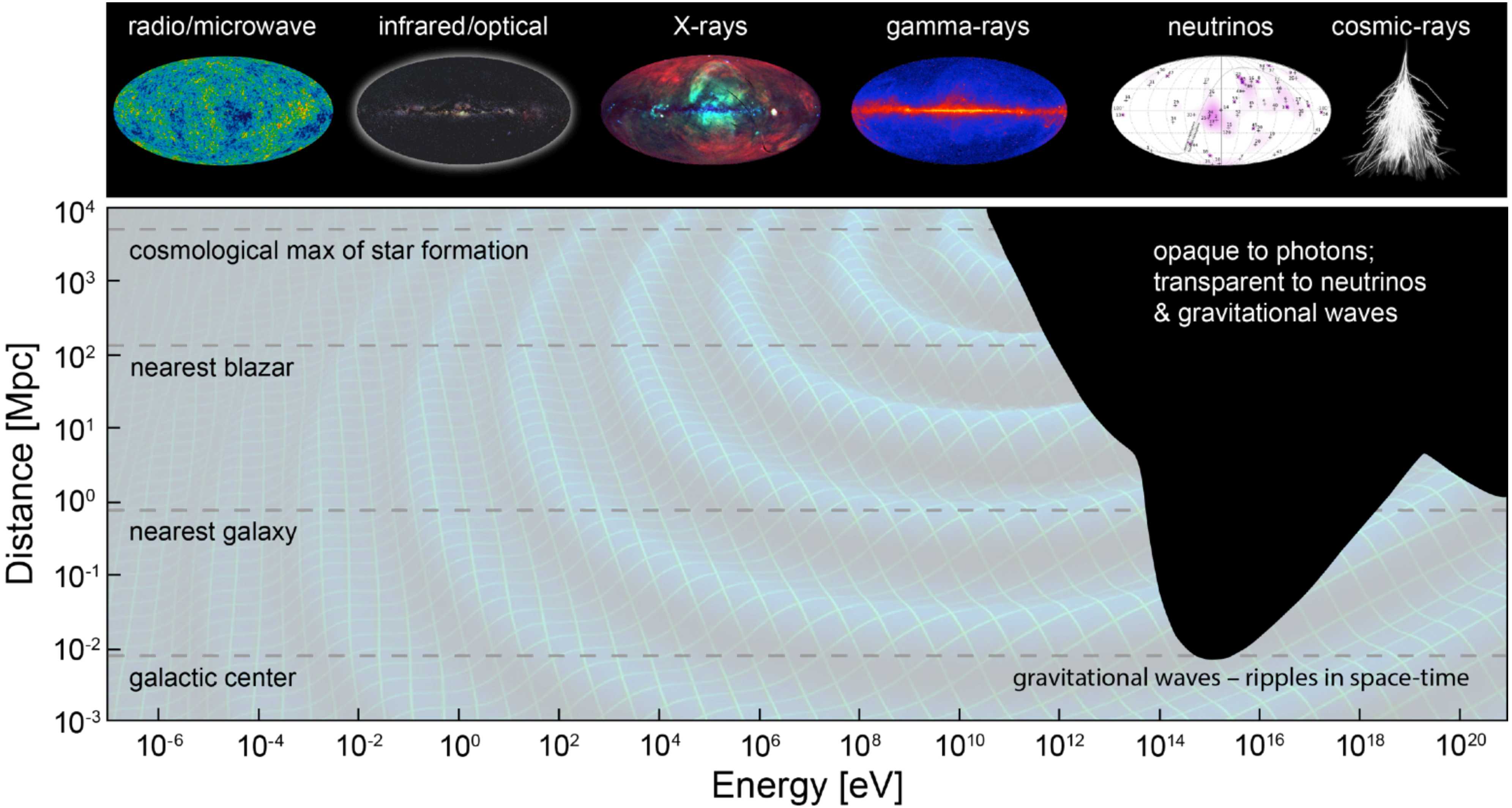
IceCube Generation 2

IceCube Bootcamp 2020

Albrecht Karle
(Univ. of Wisconsin-Madison)

The energy frontier in astronomy



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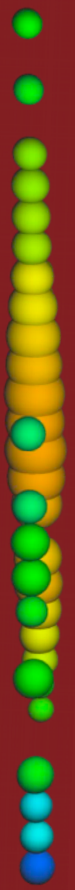
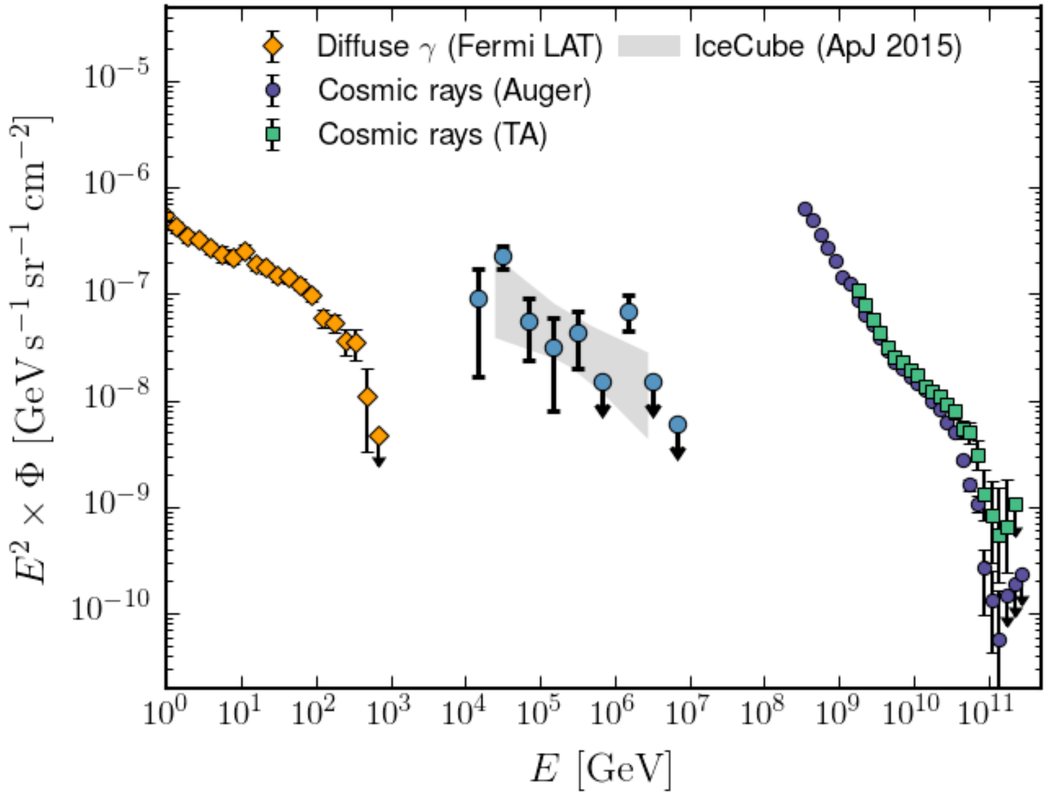
Universe opaque to photons for ¼ of the spectrum

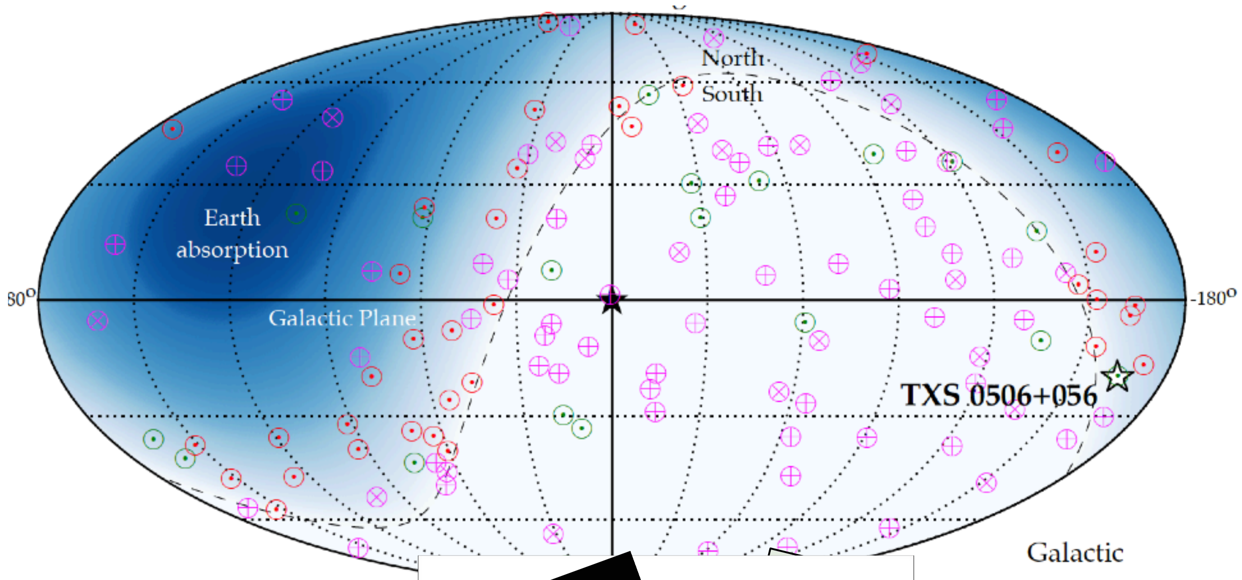


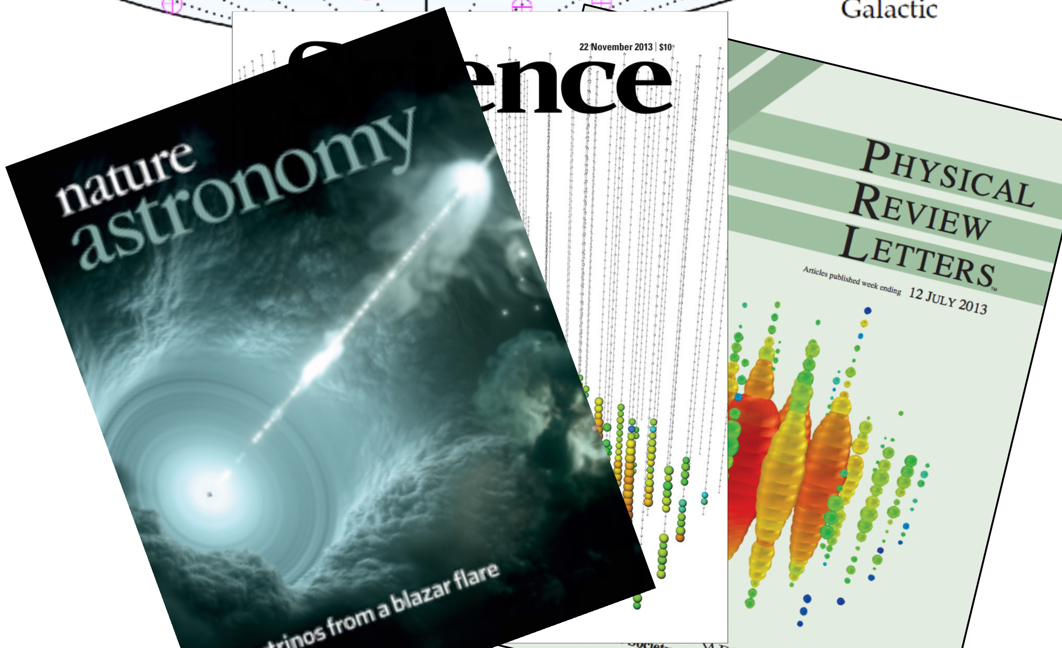
10 yrs of IceCube - a first view on the PeV Universe

Multimessenger spectroscopy



First sky map of cosmic neutrinos





Some highlights:
2013: Discovery of cosmic PeV neutrino flux
2018: Evidence for Blazars as neutrino sources
2019: Observation of first tau neutrino

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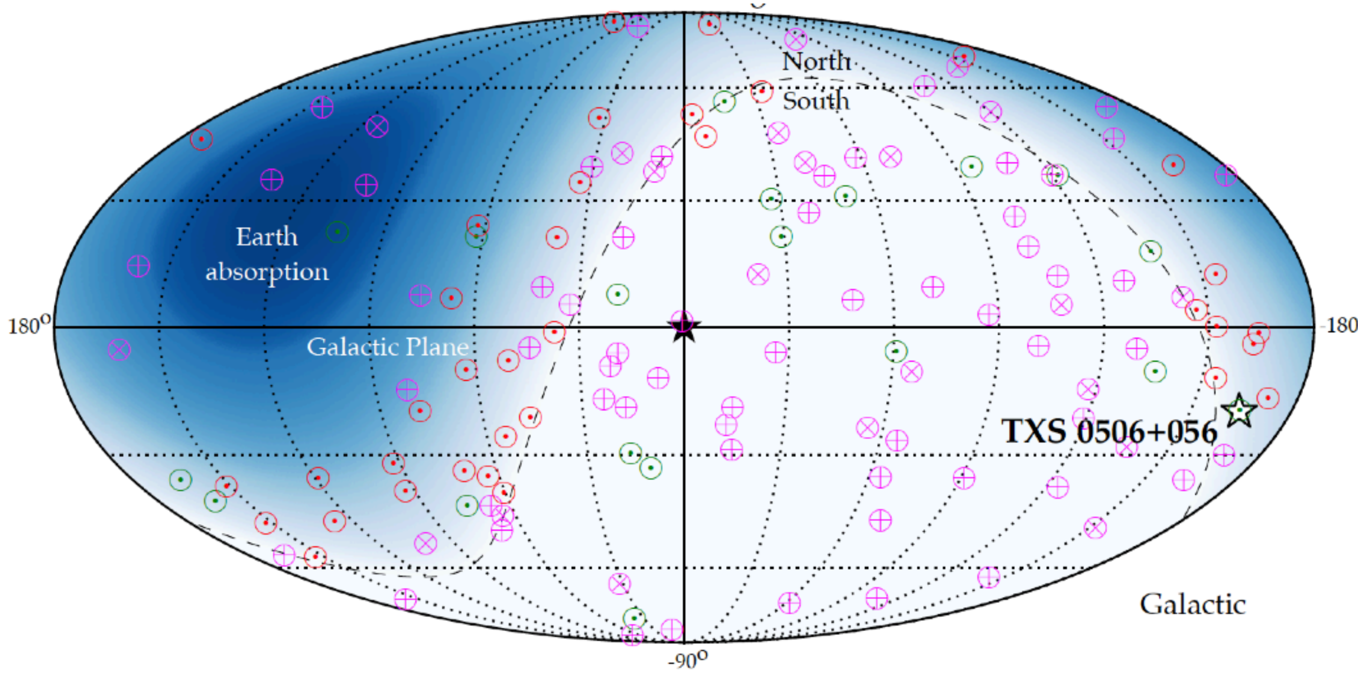
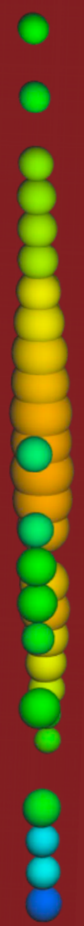
Scientific objectives: building on 10 yrs of IceCube

1. **Resolving the high-energy sky from TeV to EeV energies**



What are the sources of IceCube's high energy neutrinos?



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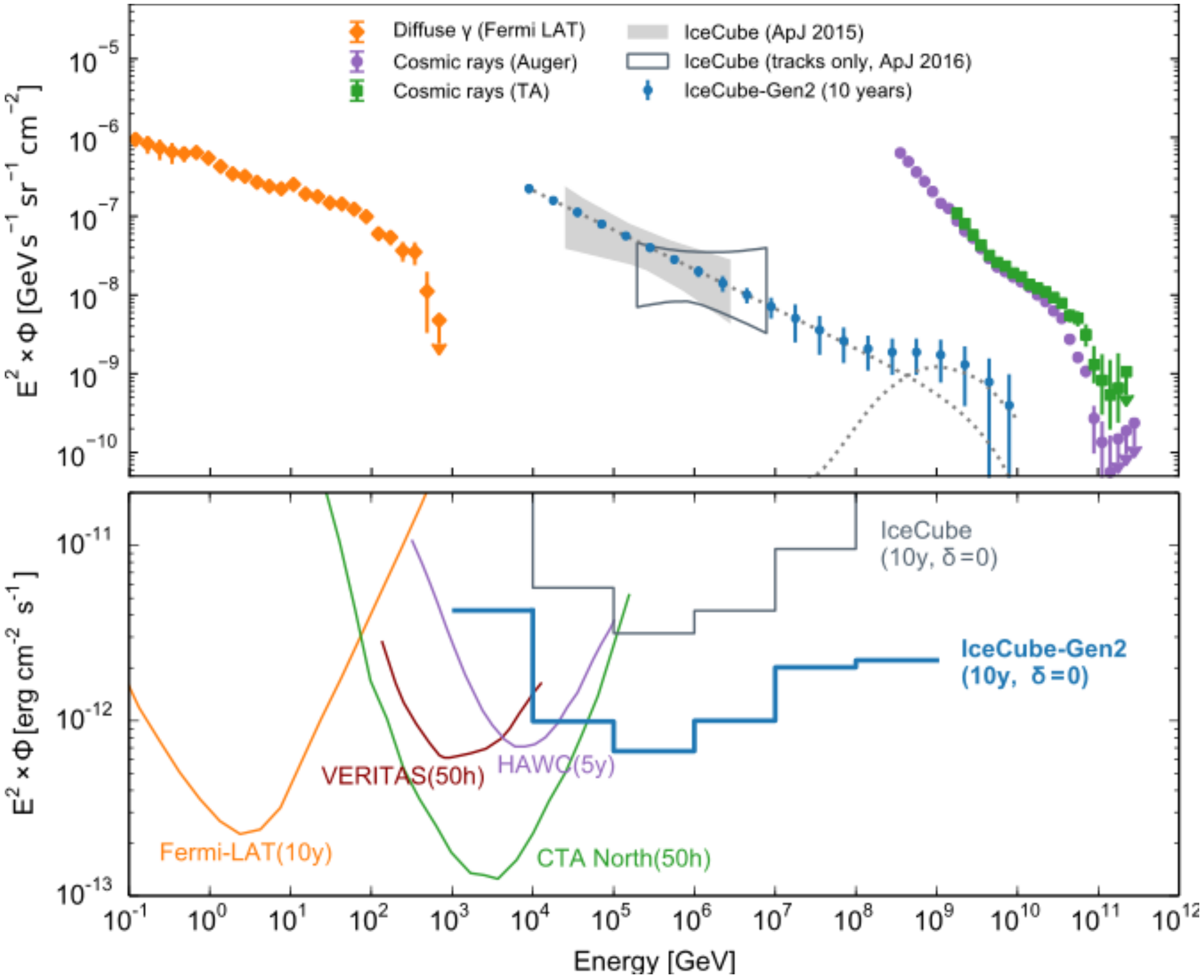
Scientific objectives: building on 10 yrs of IceCube

2. **Understanding cosmic particle acceleration through multimessenger observation**



Completing the multi-wavelength view of the Universe

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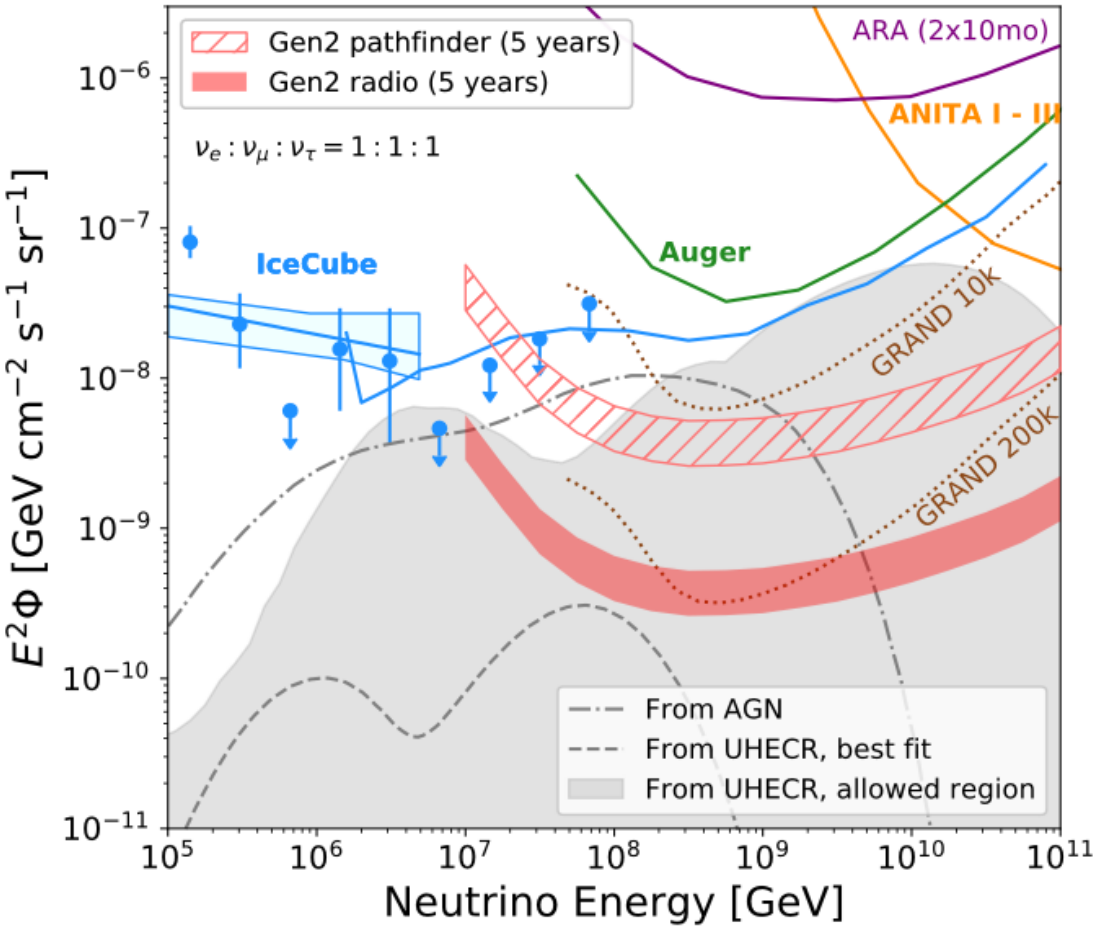
Scientific objectives: building on 10 yrs of IceCube

3. **Revealing the sources and propagation of the highest energy particles in the universe**



Probing source populations and composition of highest energy cosmic rays

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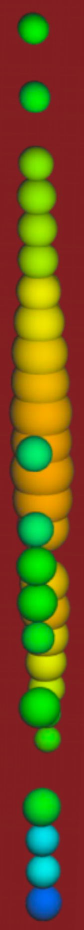
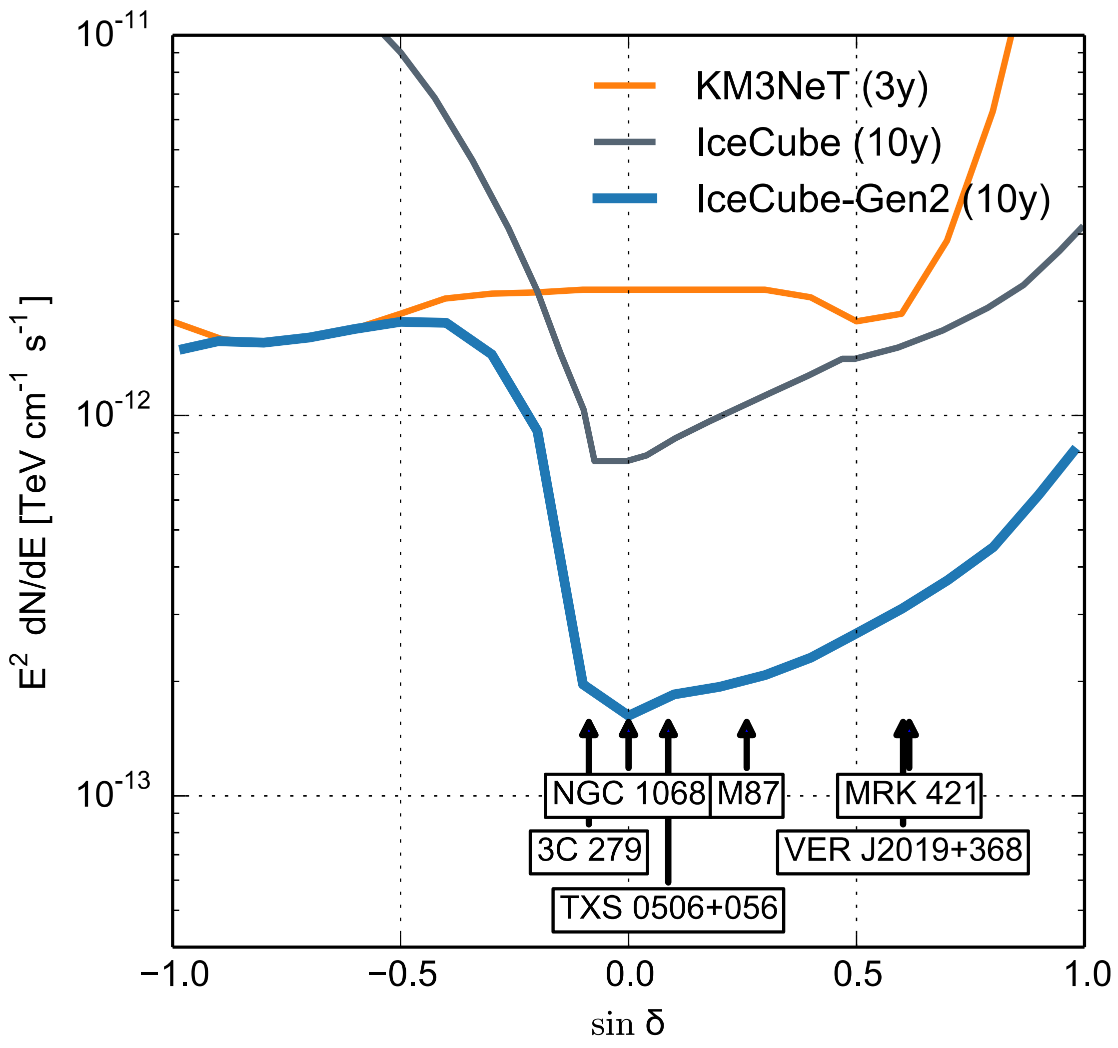
Requirements for IceCube-Gen2



1. Increase the neutrino point source sensitivity at least 5 times over the current IceCube array

Sensitivity to all realistic source populations (steady and transient) explaining the diffuse flux



Requirements for IceCube-Gen2

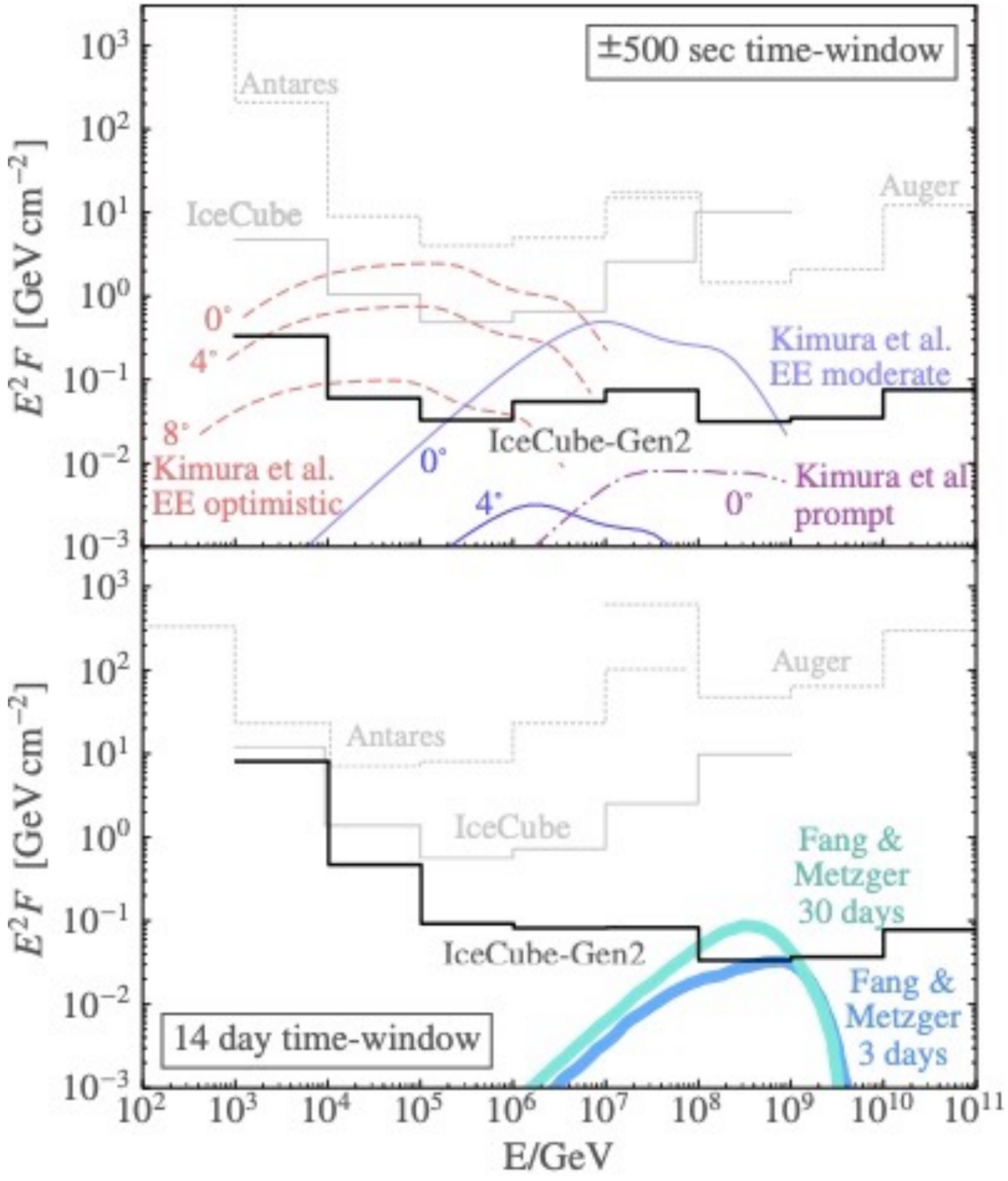
2. Enable multimessenger astronomy with individual, high-energy neutrinos

Transient events, example:

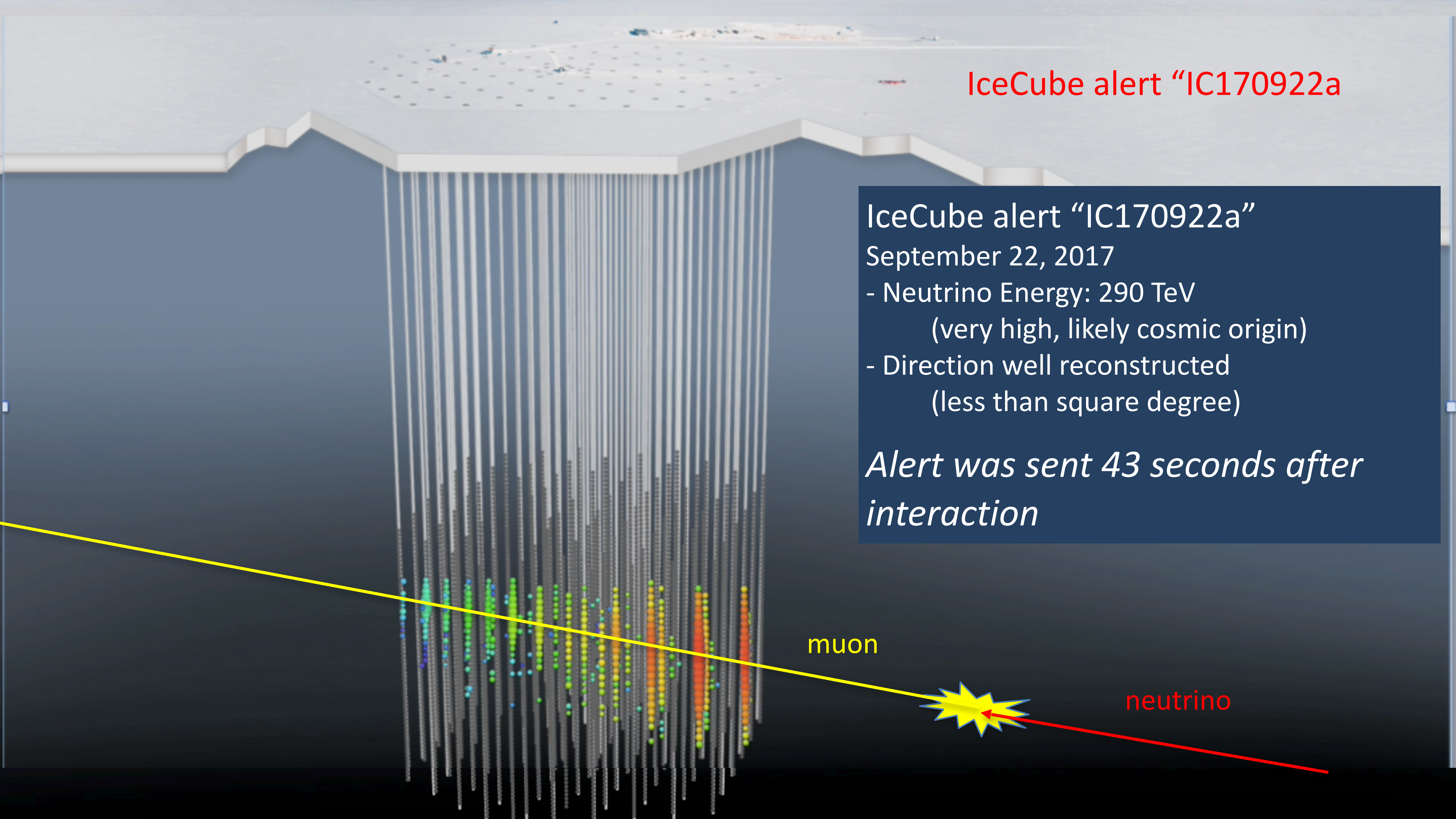
Neutrino alert IC170922A pointing to TXS 0506+056

—> next slide

Gen2 sensitivity to NS-NS mergers



IceCube alert “IC170922a



IceCube alert “IC170922a”

September 22, 2017

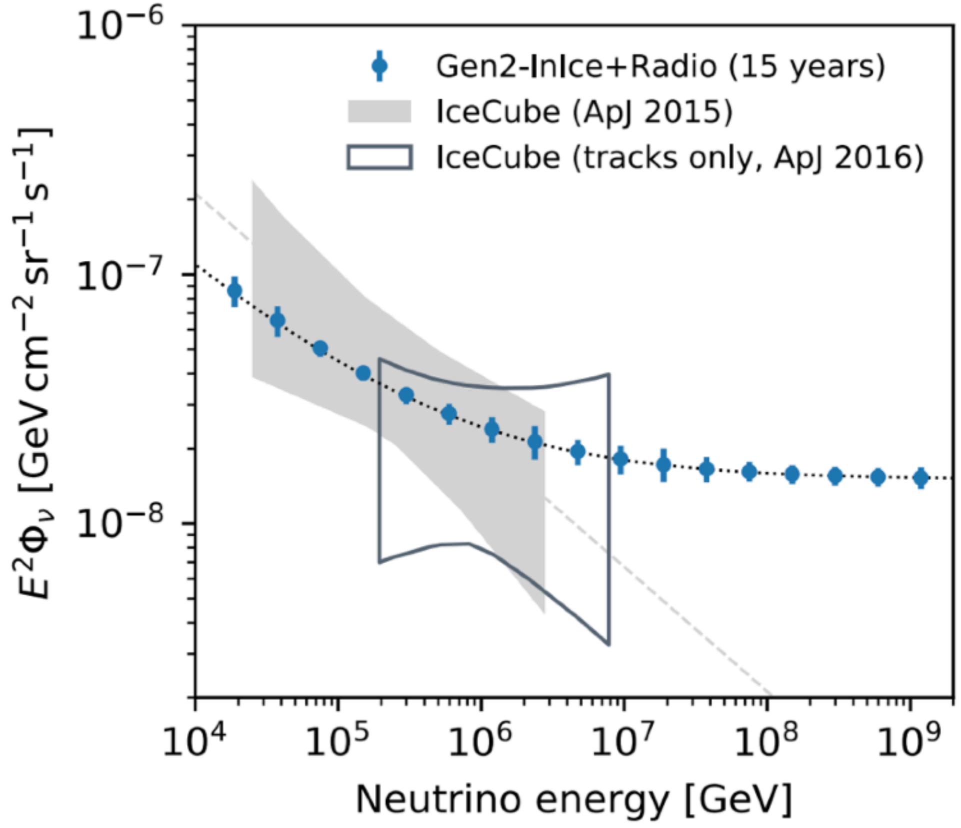
- Neutrino Energy: 290 TeV
  (very high, likely cosmic origin)
- Direction well reconstructed
  (less than square degree)

Alert was sent 43 seconds after interaction

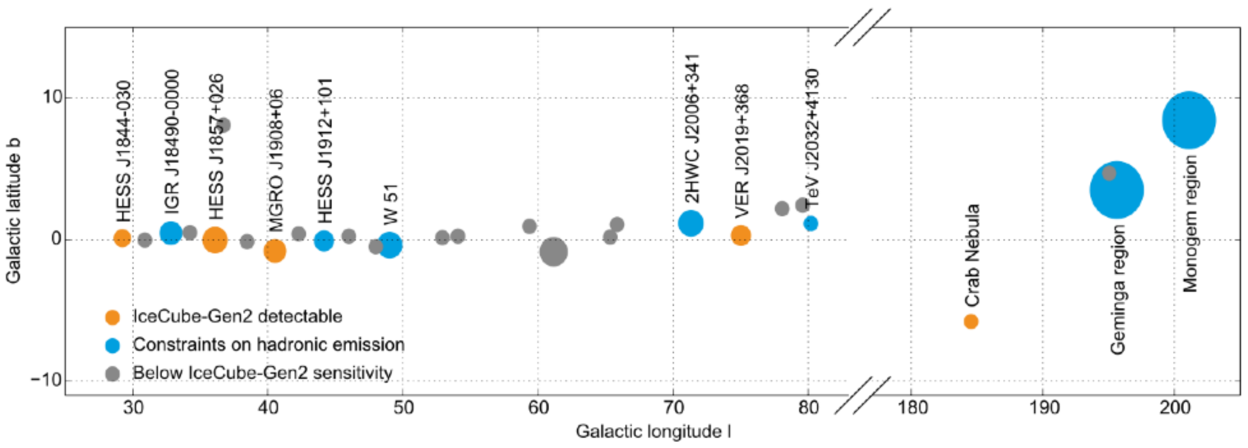
Requirements for IceCube-Gen2

3. Collect 10 times more neutrinos per year than the current IceCube array in the energy range 100 TeV to 10 PeV

Projected spectral measurement uncertainties



Sensitivity to galactic sources



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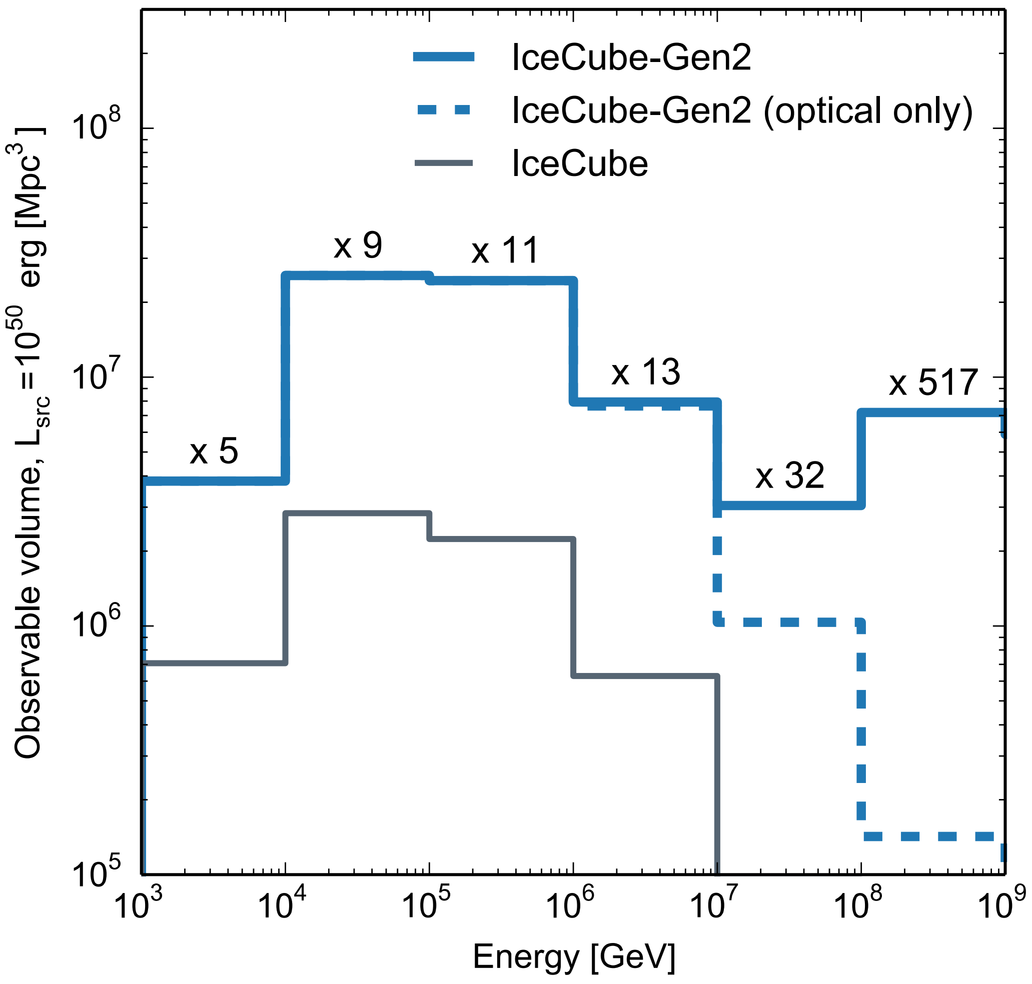
Requirements for IceCube-Gen2

4. Expand energy range to beyond 10^{18} eV with sensitivity improved by two orders of magnitude

Uniform sensitivity over large energy range over more than 6 orders of mag energies.



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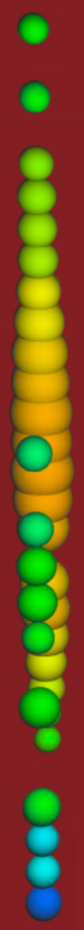
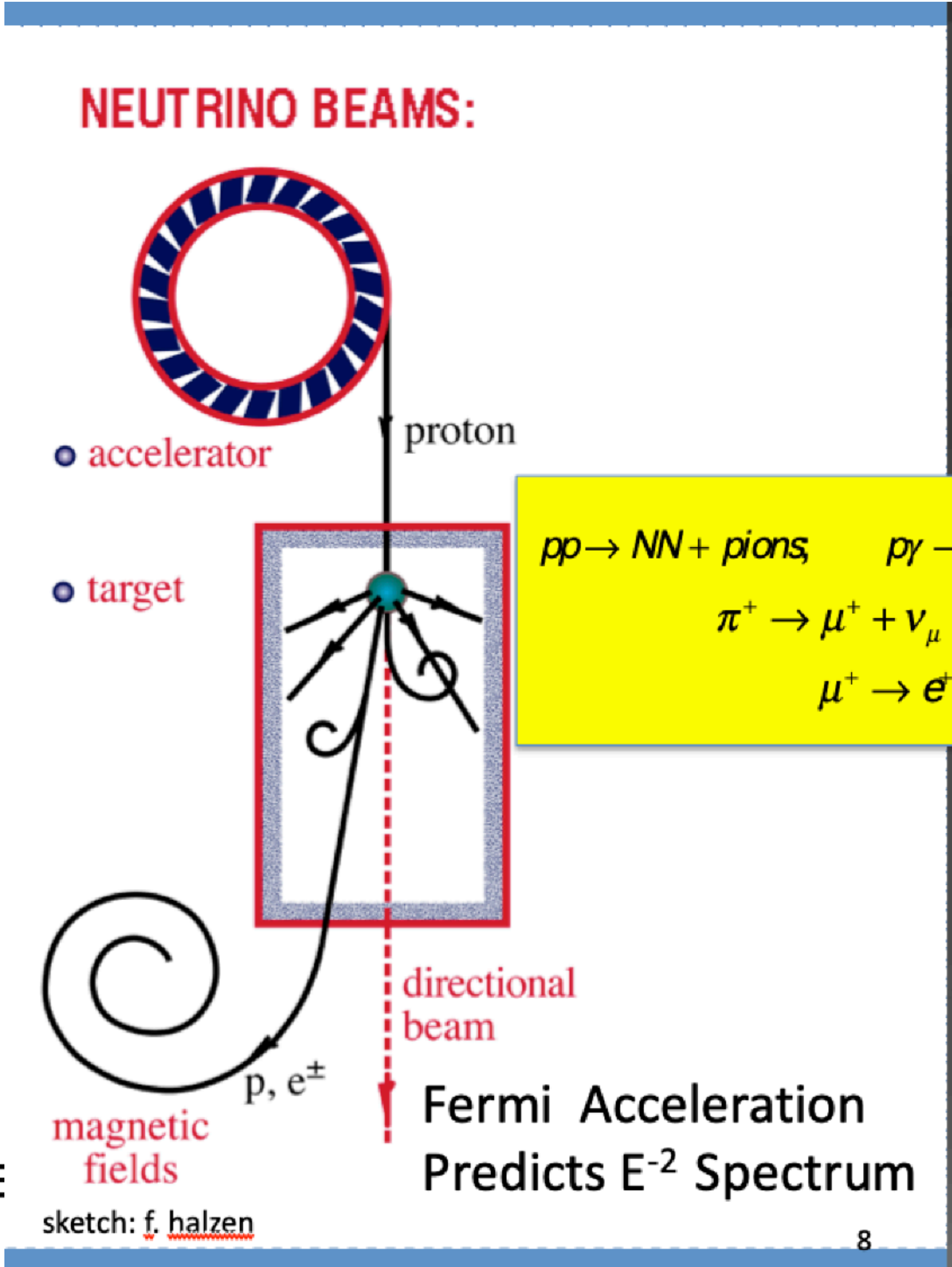
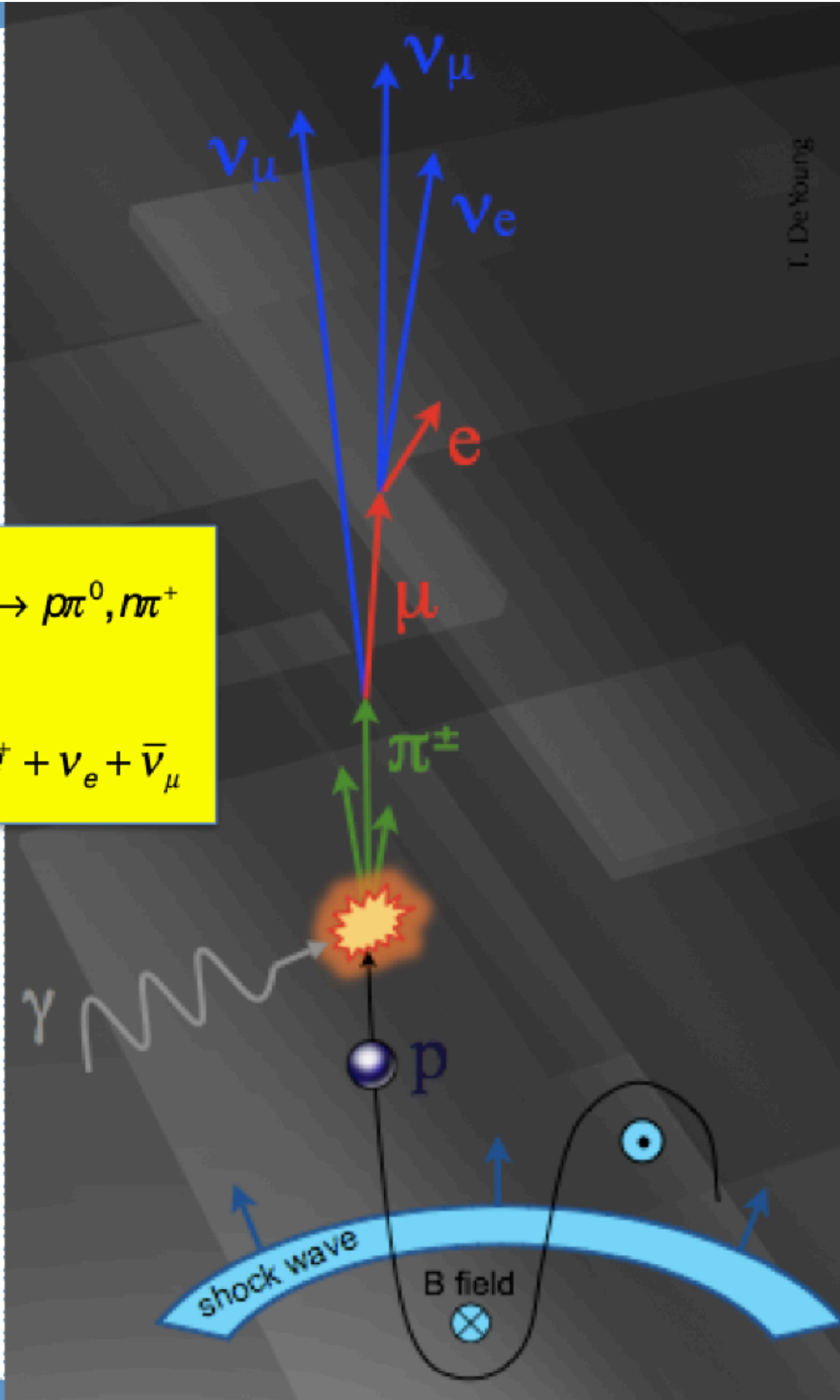
Neutrino production and flavor ratio





$$pp \to NN + pions, \qquad p\gamma \to p\pi^0, n\pi^+$$
$$\pi^+ \to \mu^+ + \nu_\mu$$
$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$$



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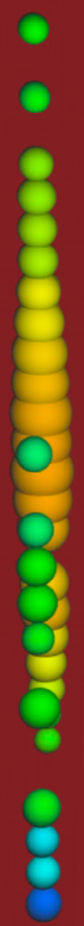
Requirements for IceCube-Gen2



5. Enhanced sensitivity to neutrino flavors and the ability for flavor identification.

Neutrino flavor at the source: key information about production mechanism

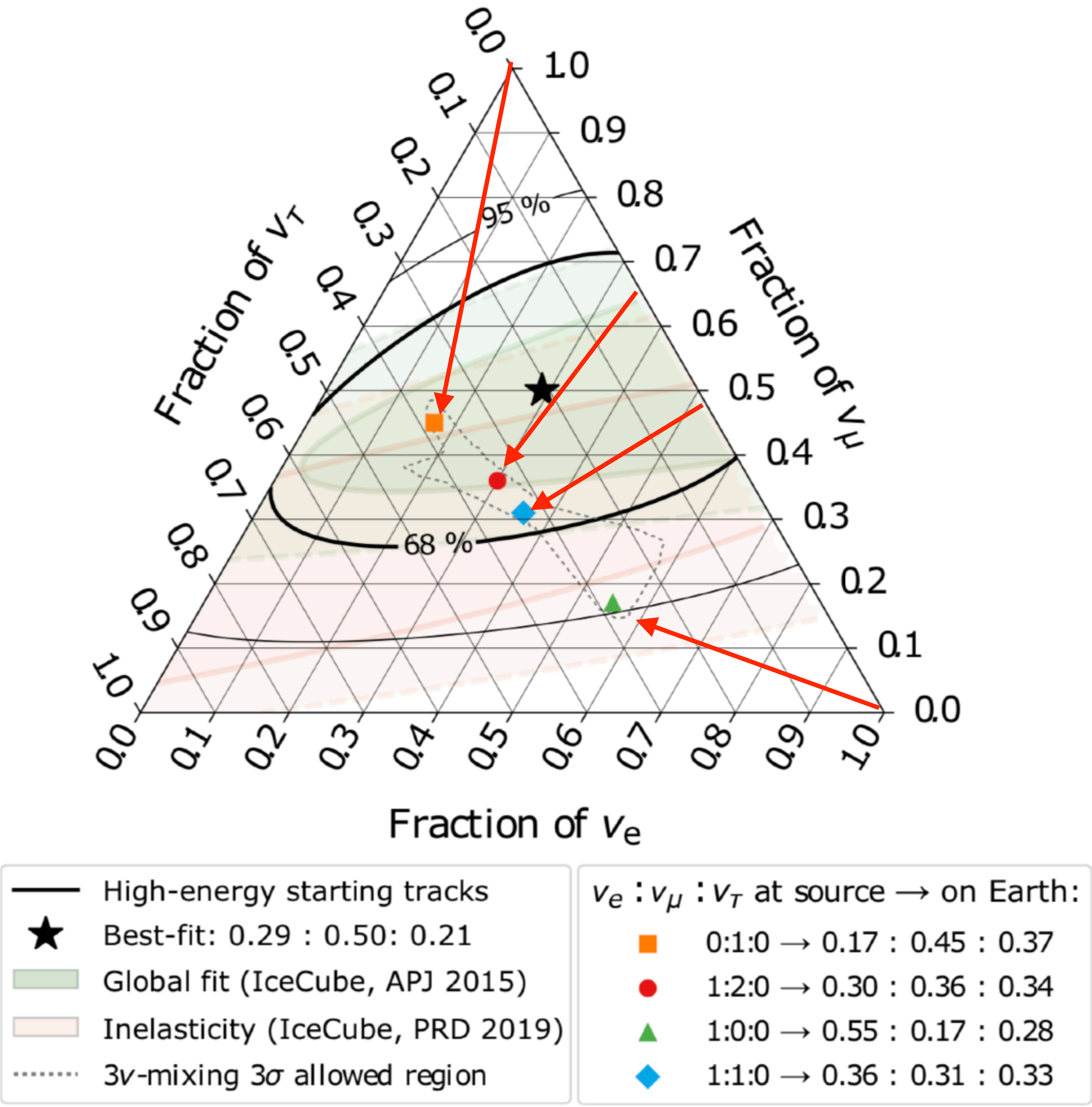
Reminder of basic neutrino production

$$pp \to NN + pions; \qquad p\gamma \to p\pi^0, n\pi^+$$

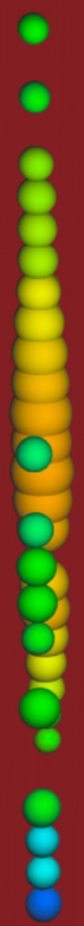
$$\pi^+ \to \mu^+ + \nu_\mu$$

$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$$

IceCube GEN2



Requirements for IceCube-Gen2



Neutrino flavor at the source: key information about production mechanism.

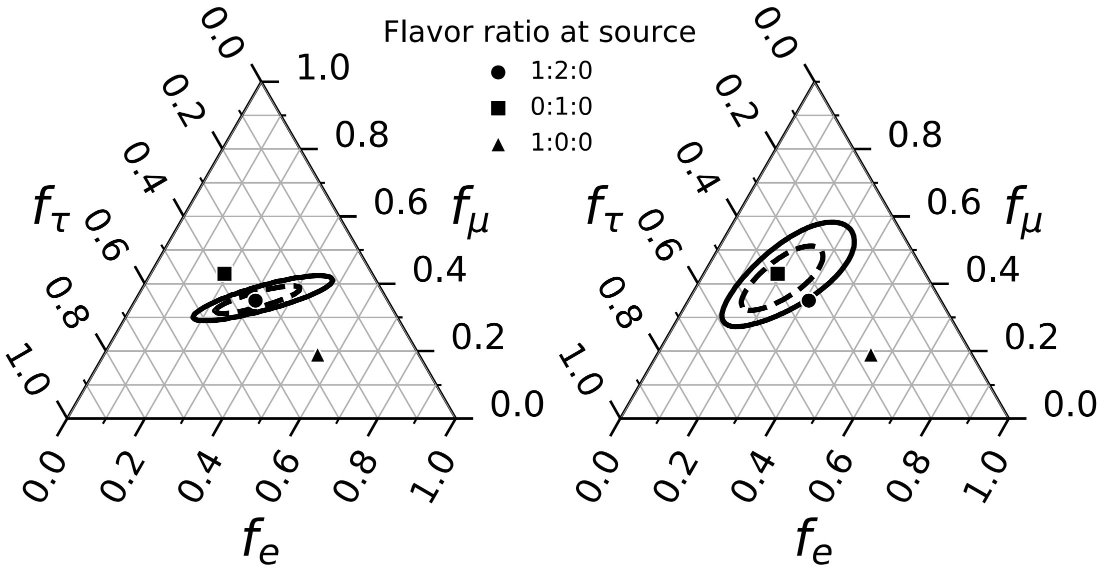
Example:

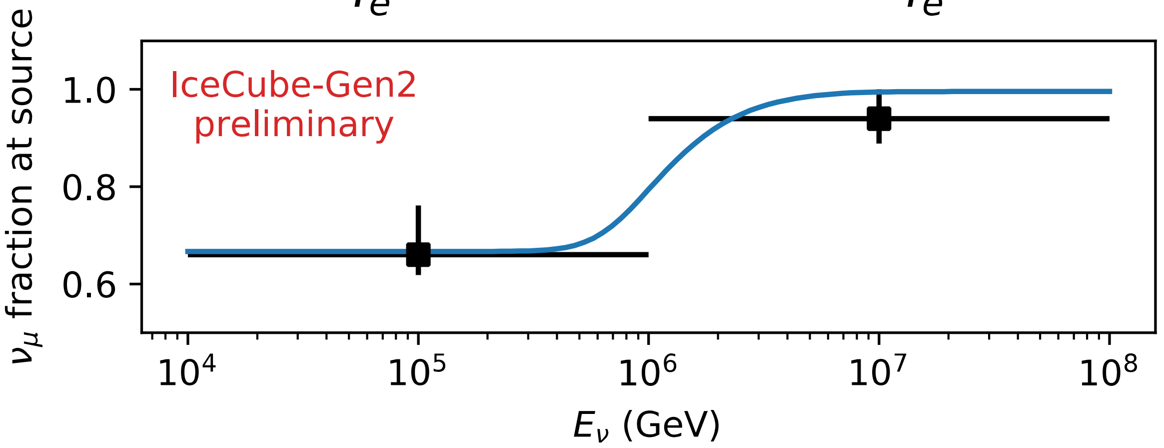
$$pp \rightarrow NN + pions; \qquad p\gamma \rightarrow p\pi^0, n\pi^+$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

In a strong magnetic field the decay of muons could be effectively suppressed. Muons may loose energy before they can decay.





Measuring energy dependent neutrino flavor ratios (→BSM physics and nature of source)

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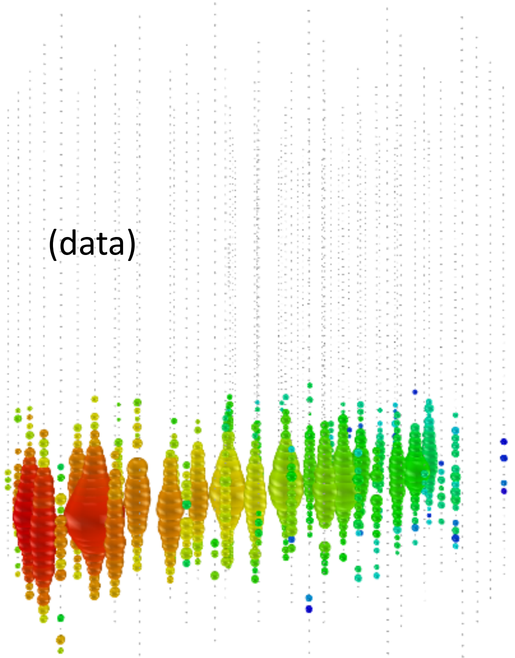
Types of events and interactions

Charged-current ν_μ

(data)



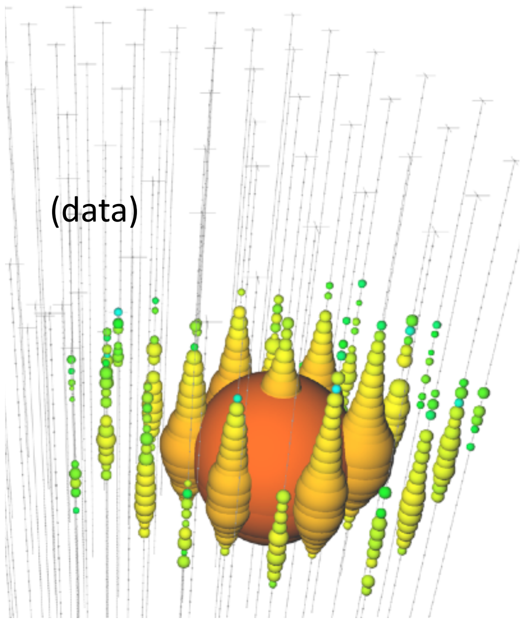
Up-going (throughgoing) track

Factor of ~2 energy resolution
~ 0.5° angular resolution

0.3° above 100 TeV

Neutral-current / ν_e

(data)



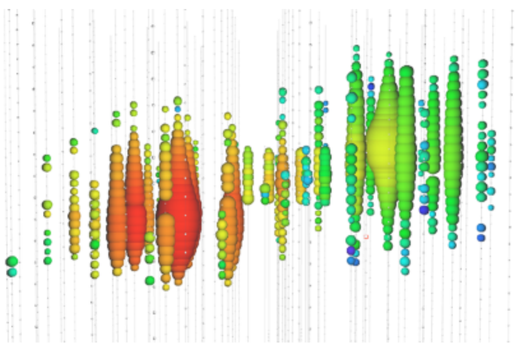
Isolated energy deposition (cascade) with no track

15% deposited energy resolution
10-15° angular resolution (above 100 TeV)
Working on improving that.

Early  Late

Charged-current ν_τ

(simulation)



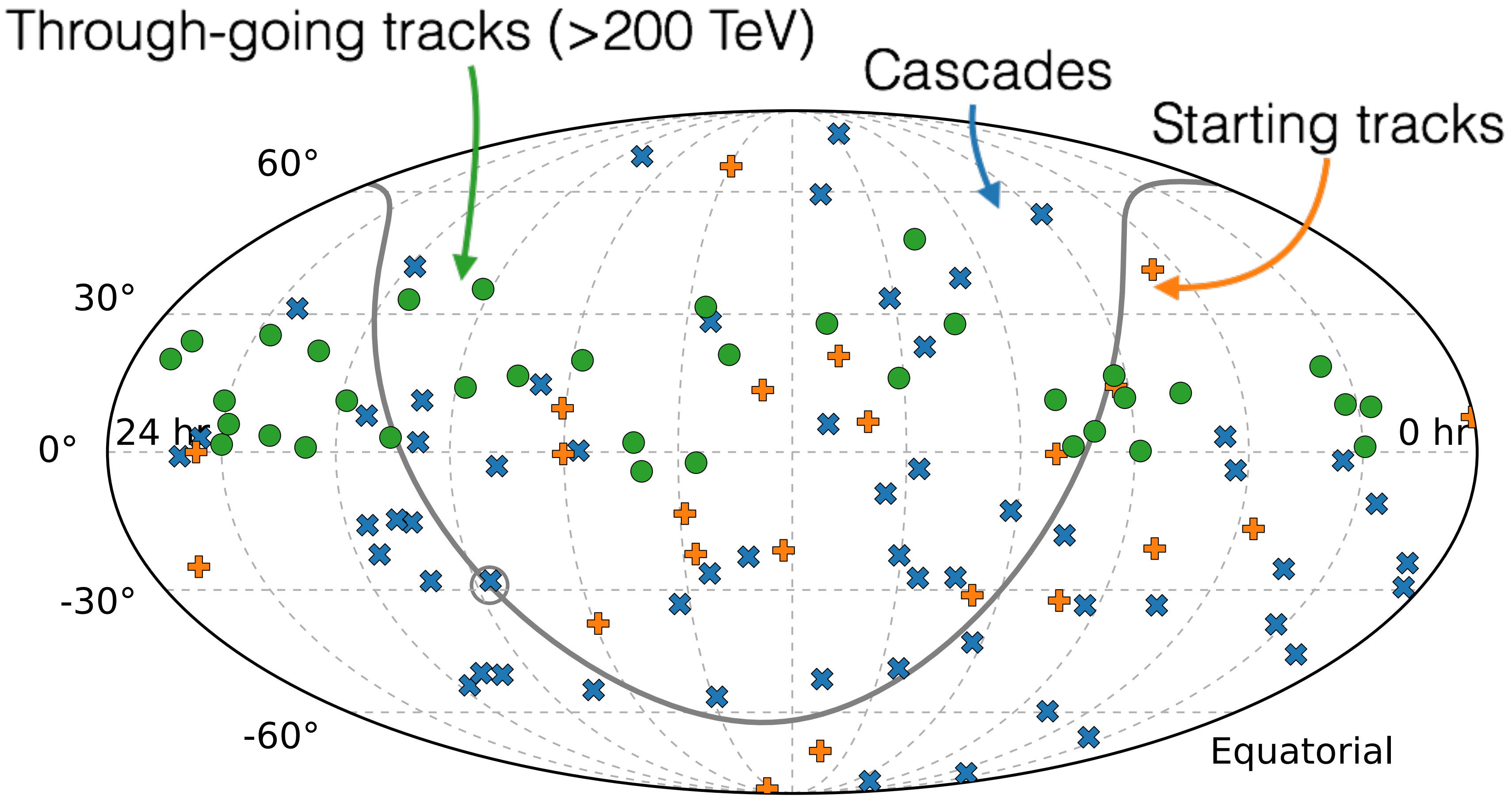
"Double-bang"

(none observed yet: τ decay length is 50 m/ PeV)

ID: above~ 100 TeV (two methods)

Events with reconstructed energy > 200 TeV (more than 50% of events are astrophysical)

Events from above event selections with energy cut.



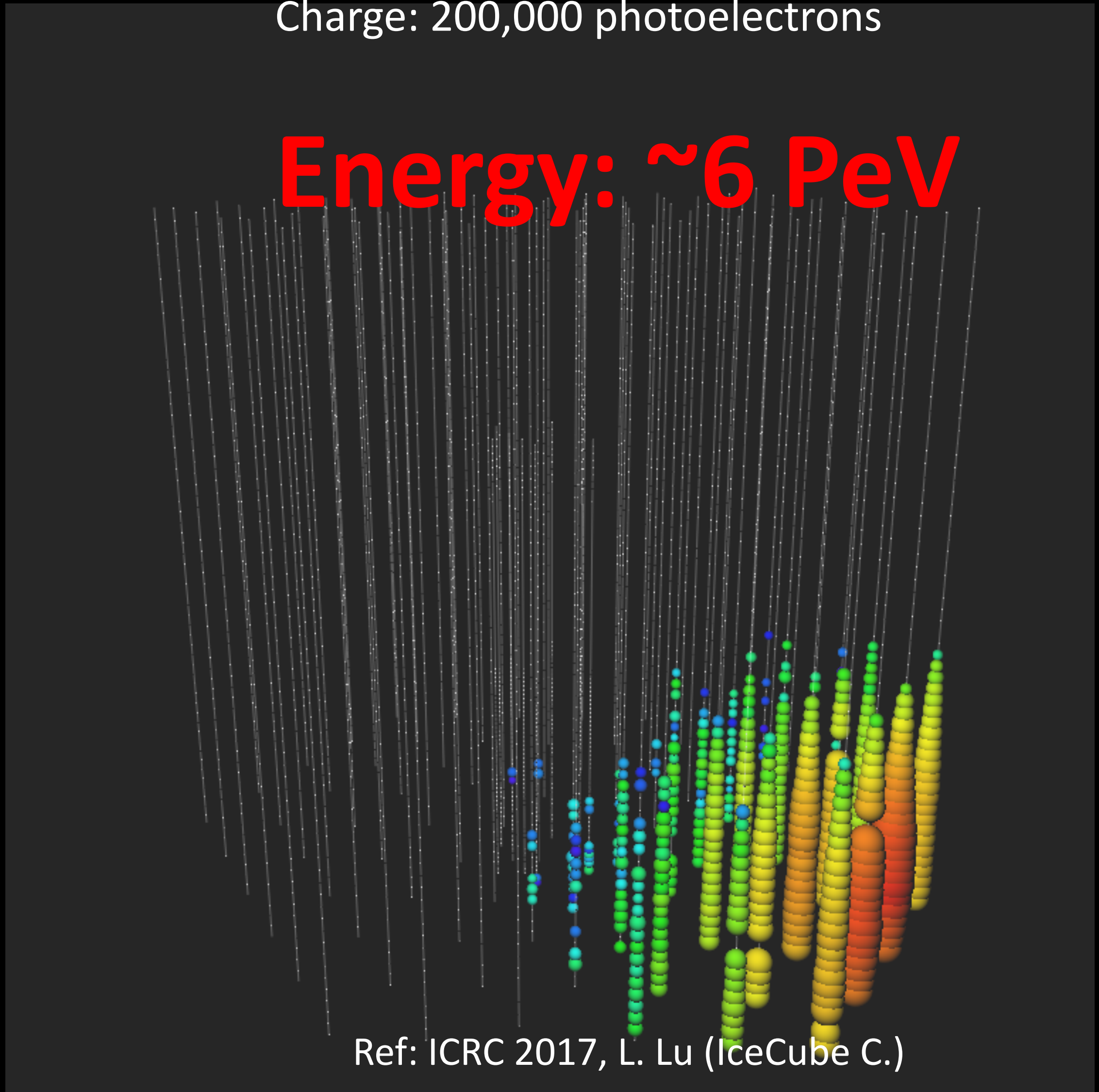
6 years of data (ICRC 17)

A neutrino event near Glashow resonance?

Interesting event found in expanded search.

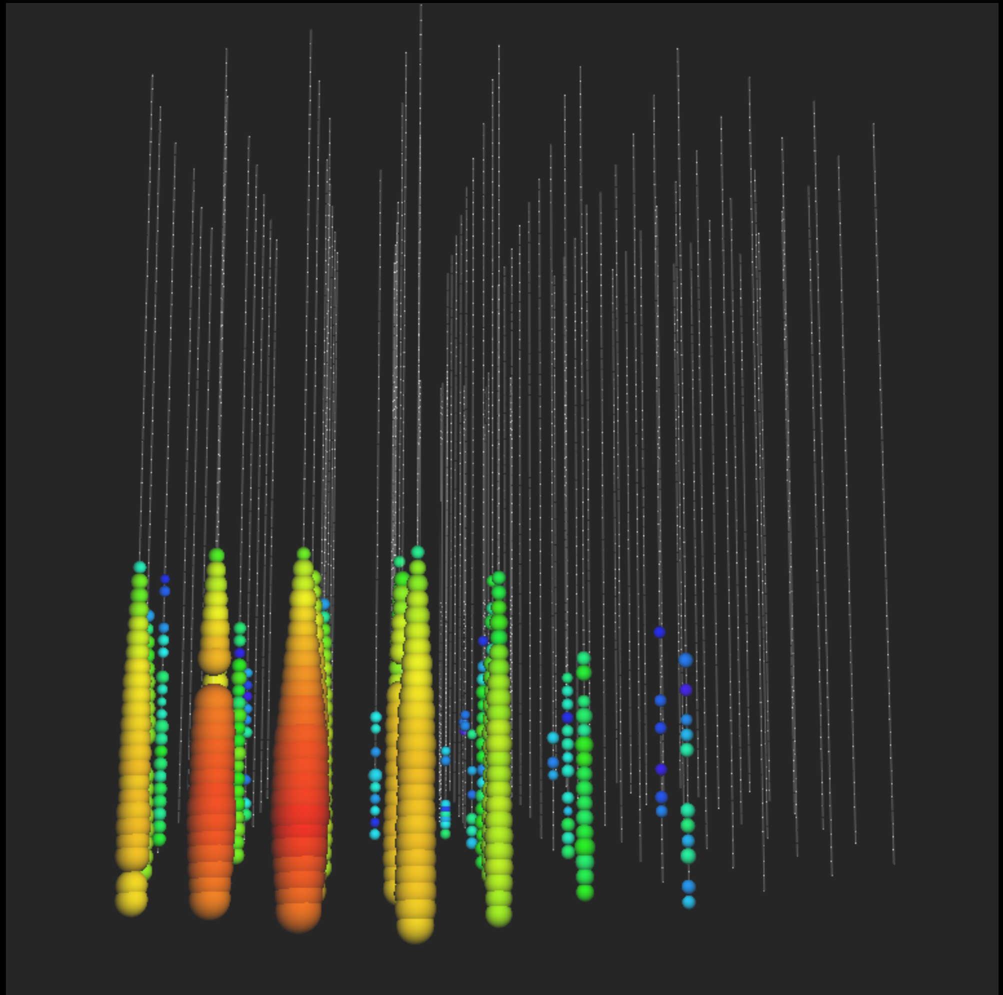
Charge: 200,000 photoelectrons

Energy: ~6 PeV



Ref: ICRC 2017, L. Lu (IceCube C.)

First observation of this interaction



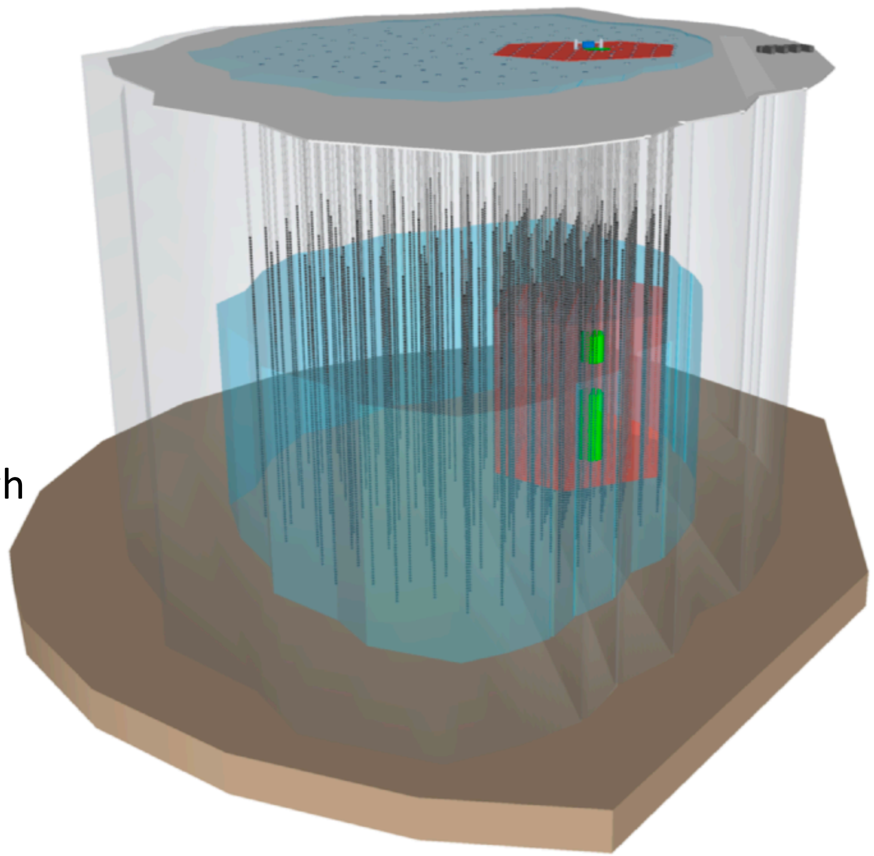
IceCube-Gen2

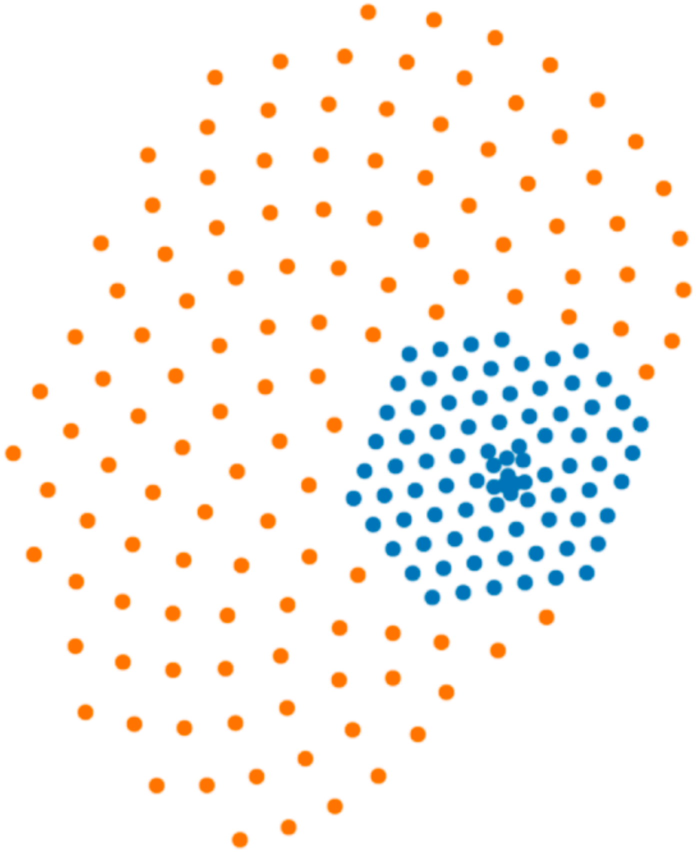
A Vision for the Future of Neutrino Astronomy in Antarctica (arXiv:1412.5106)

Surface Area: ~6.5km^2 (0.9)
Instrumented depth: 1.26 km (1.0)

Instrumented Volume: 8 km^3

Order of magnitude increase of contained event rate at high energies.





Artist's conception
120 strings at 240 m spacing

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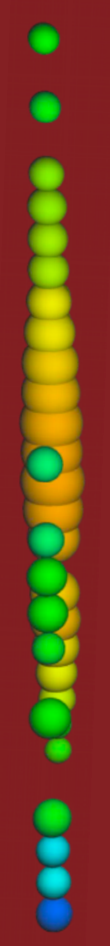
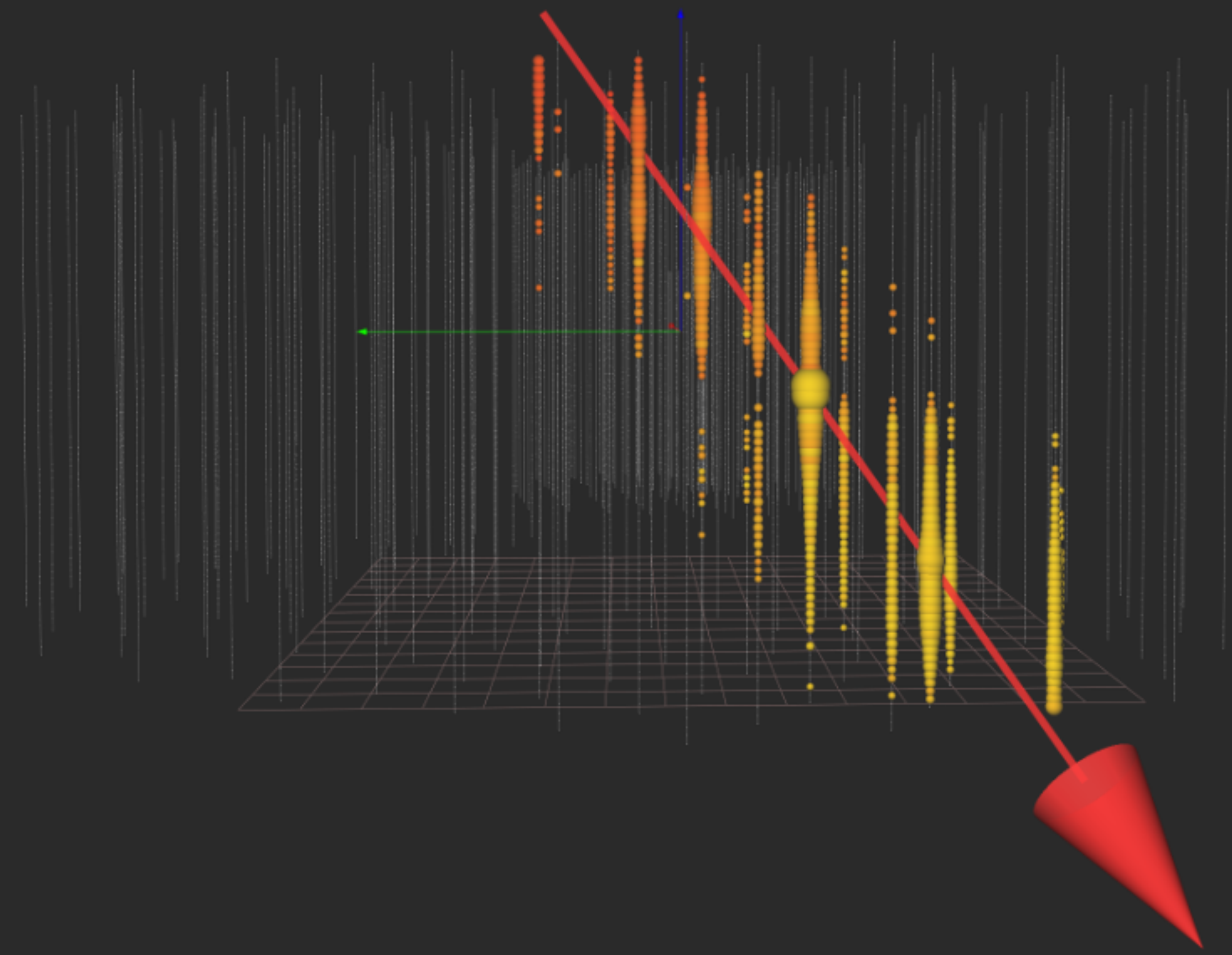
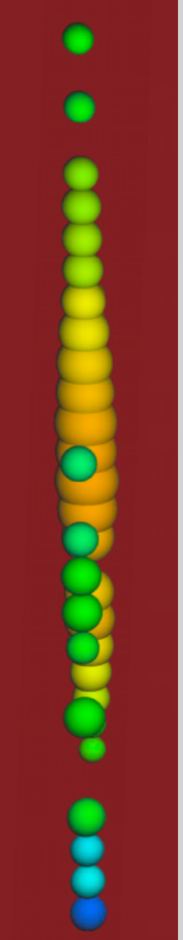
The next-generation IceCube: from discovery to astronomy

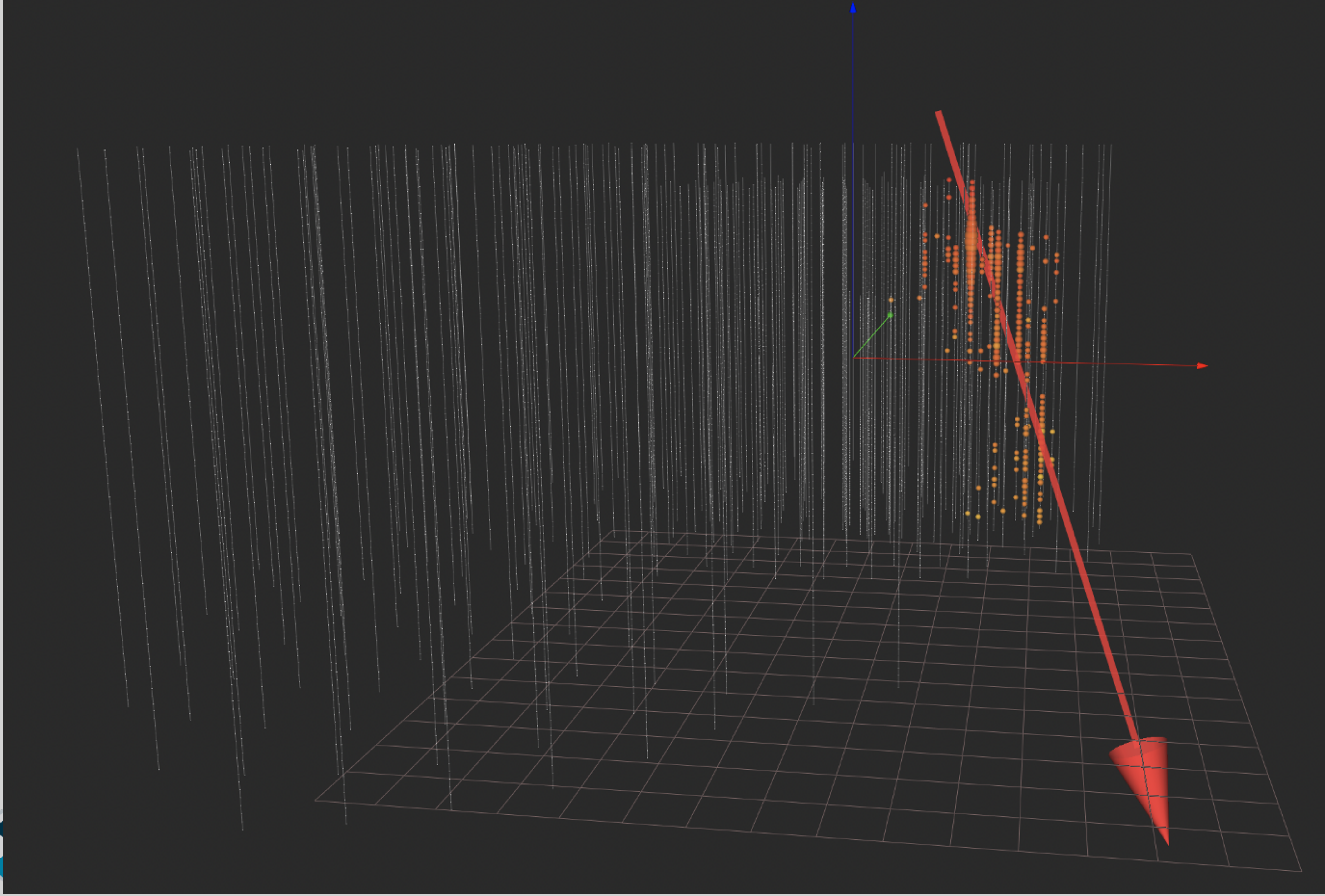


10 PeV



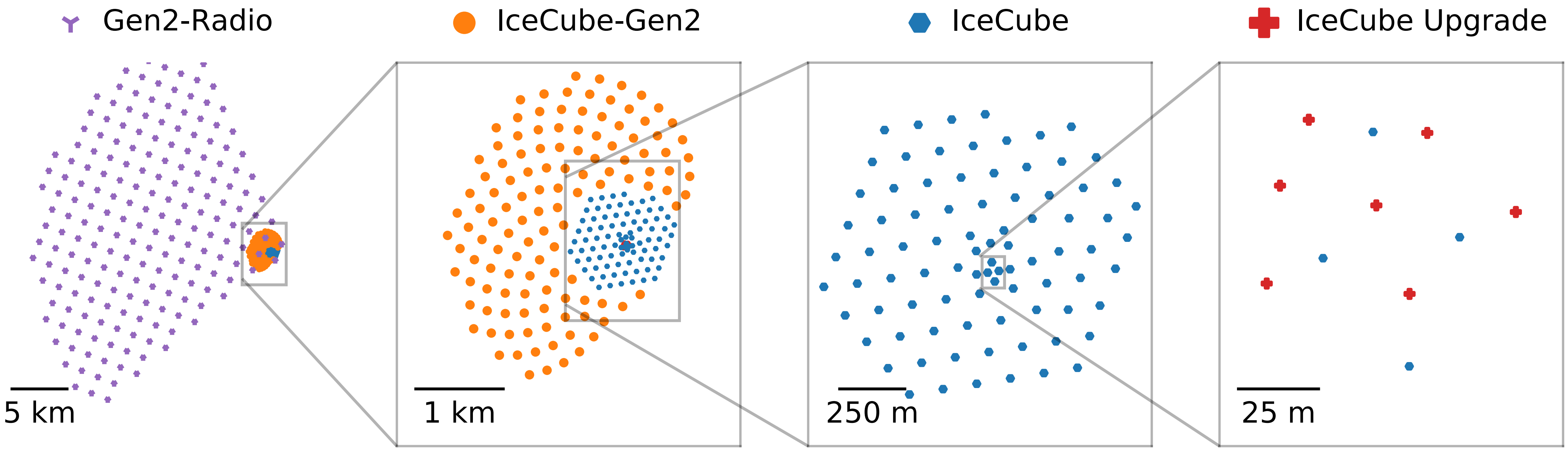
96 TeV





IceCube-Gen2 — scales and energies

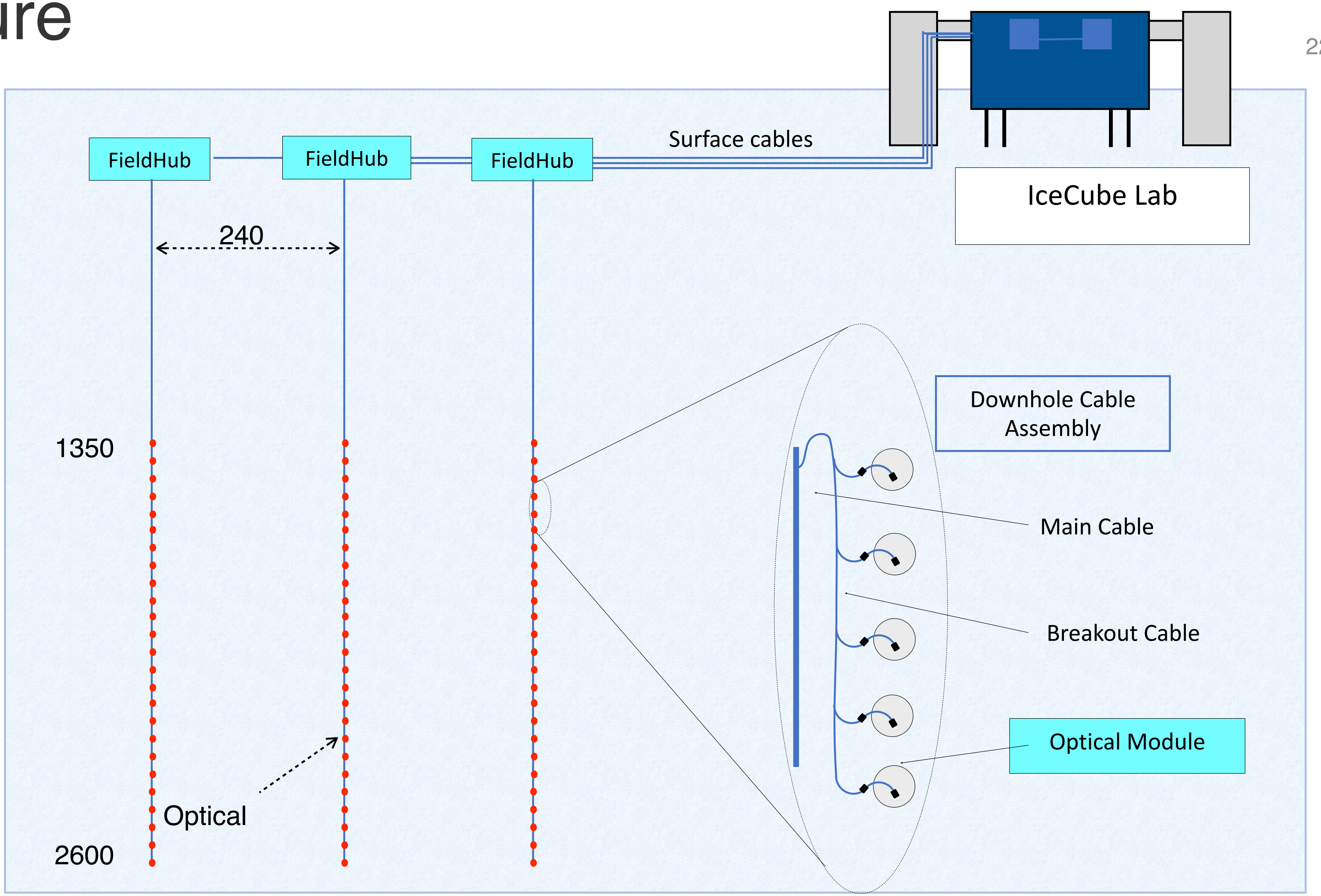
IceCube and Gen2 on different scales reflecting different energies



10 PeV **10 TeV** **1 TeV** **few GeV**

Architecture

- Power and communications architecture: simplified requirements for cable hardware.



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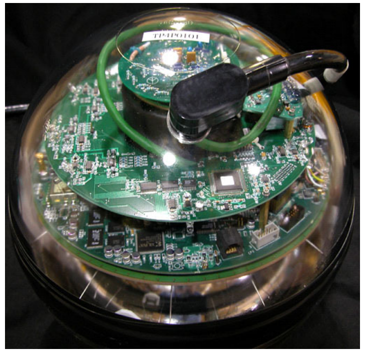
Optical sensors

IceCube Upgrade (under construction) primary sensors

Gen2 sensor design studies:
MDOM with smaller diameter,
Development briefly discussed.

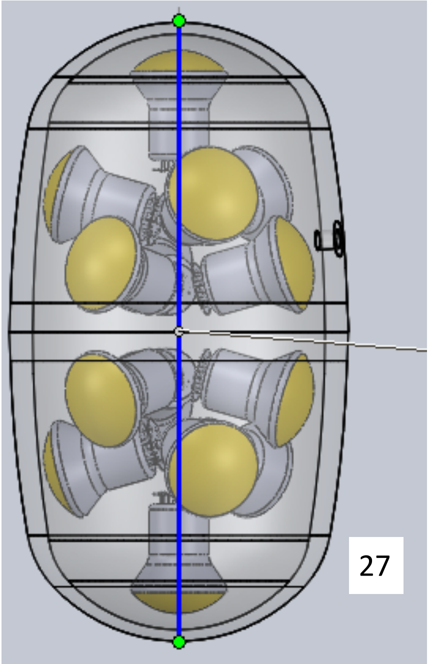
IceCube DOM



Diameter 33 cm
10 inch PMT

Directional information
24 x 3 inch PMT
Diameter 36 cm

2 x 8 inch PMT
Smaller diameter 30 cm



12 x 4 inch PMT
Smaller diameter 30 cm

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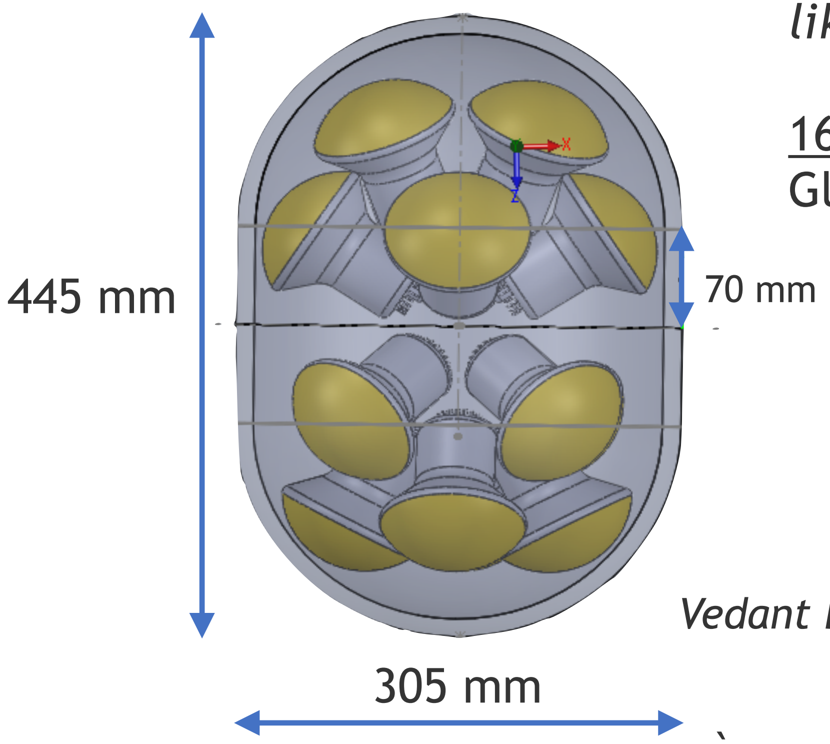
4” PMTs Fitting in Vessels

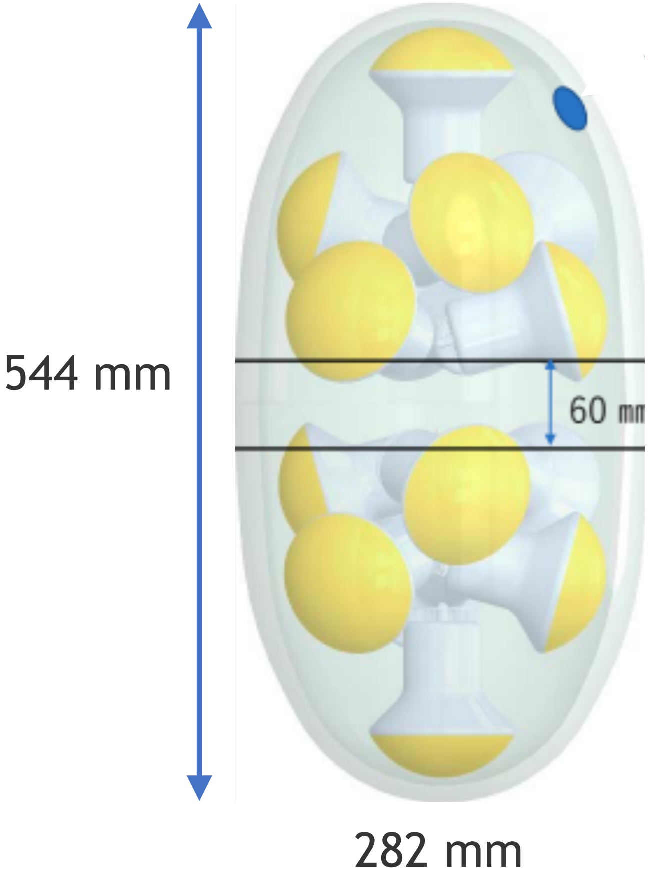
- PMTs do fit with proposed (shorter) length
- Many arrangements require tilting PMT axis relative to normal vector, up to 30°
- Areas to be compared with 14” MDOM (24x 3”PMT), 1140 cm² if calculated in the same way
- Reflectors not shown here, detailed choices and shaping require GEANT study



12” Nautilus housing like DESY proposal

16x 4”PMTs, 1352cm²
Glass Vessel 12kg

Vedant Basu @ UW-Mad



Redesign from DEgg, only 71% glass weight

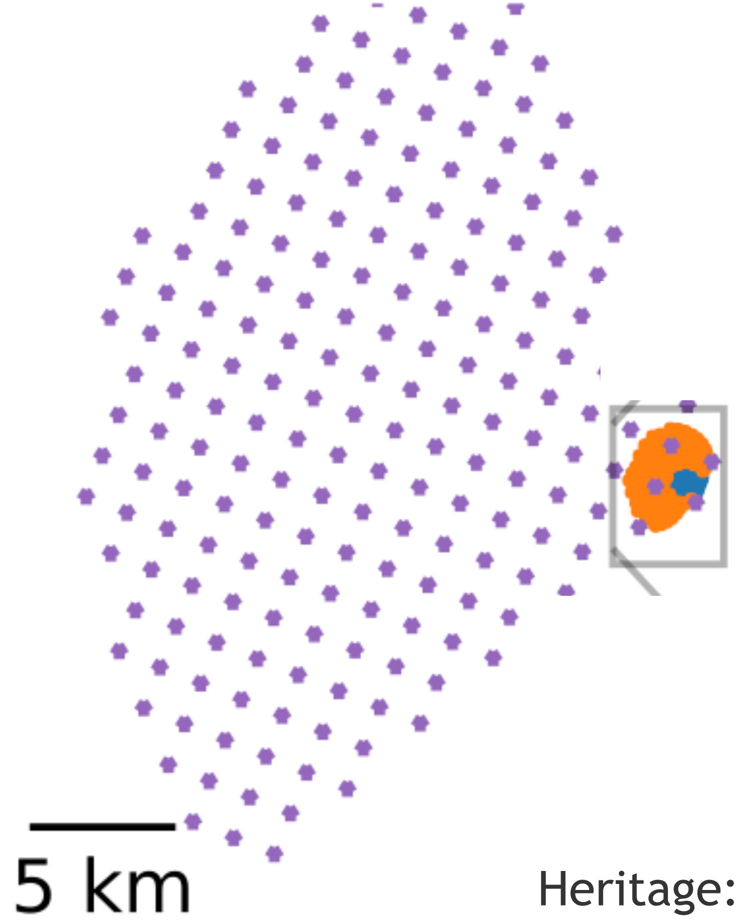
14x 4”PMTs, 1183cm²
Glass Vessel 13kg

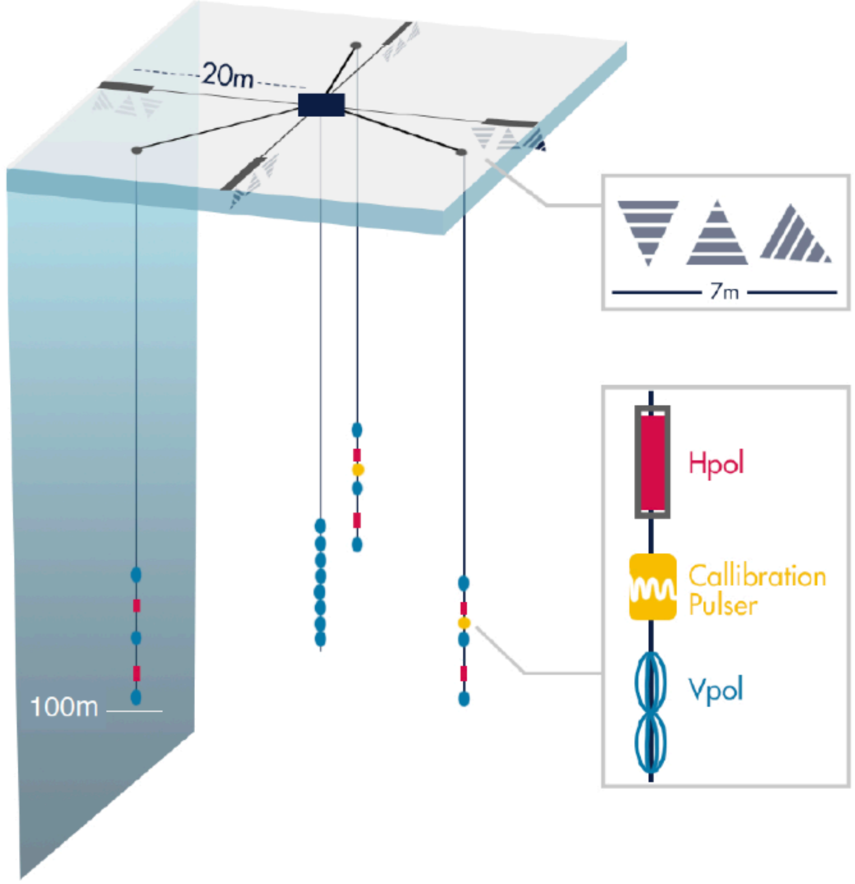
Satoshi Shimizu @ NME
Aya Ishihara @ Chiba Univ.

The Gen2 radio array

200 stations
~500 km^2

- A daunting scale! Impact on Gen2 deployment.
- Highly efficient deployment will be critical.





Heritage:
RICE, ARA, ARIANNA

RNO-G (Greenland) first deployment summer 2020

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Optimization criteria

Effective area (volume): how many events?

Background rejection

Quality of events: (angular, energy resolution)

Particle ID? Very hard. may be not so important.

Cost

Other limitations?

Risk?

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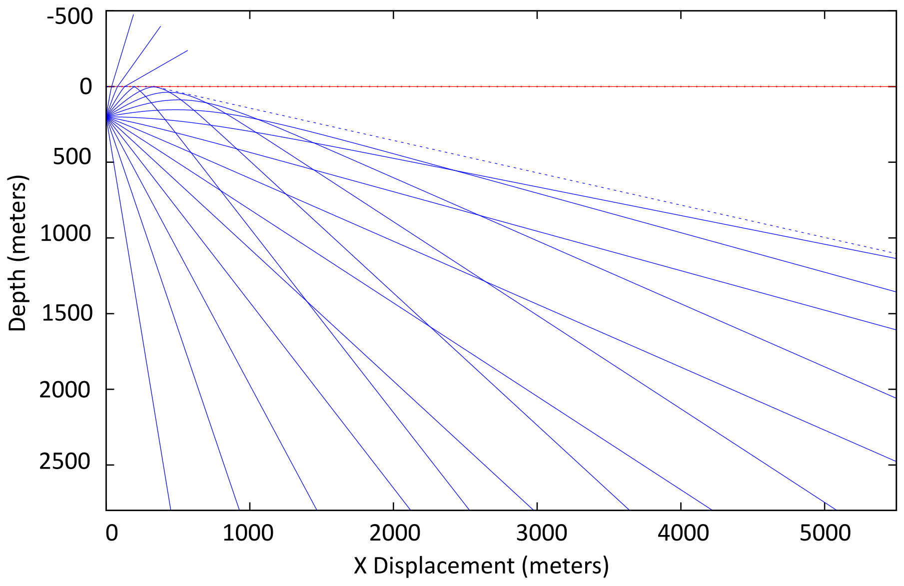
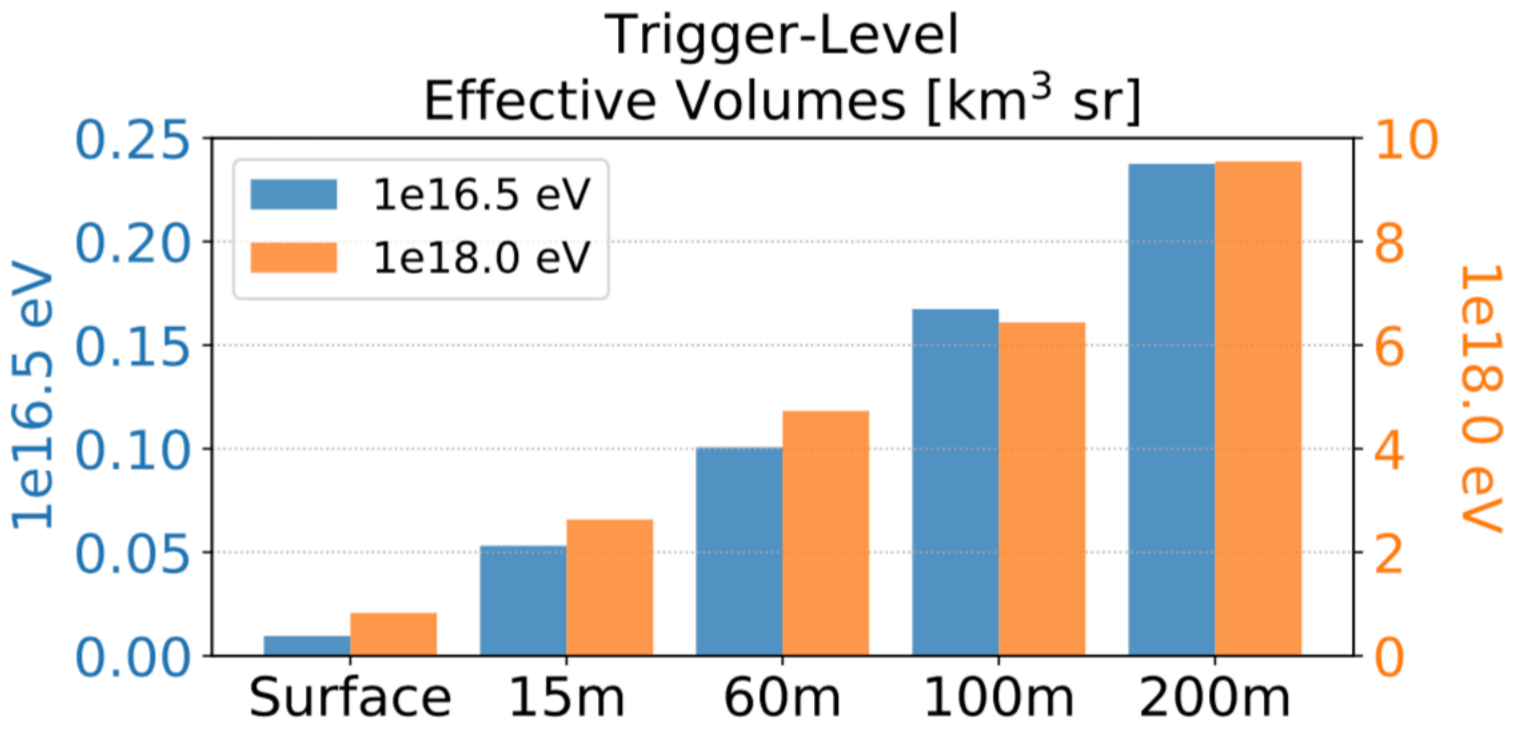
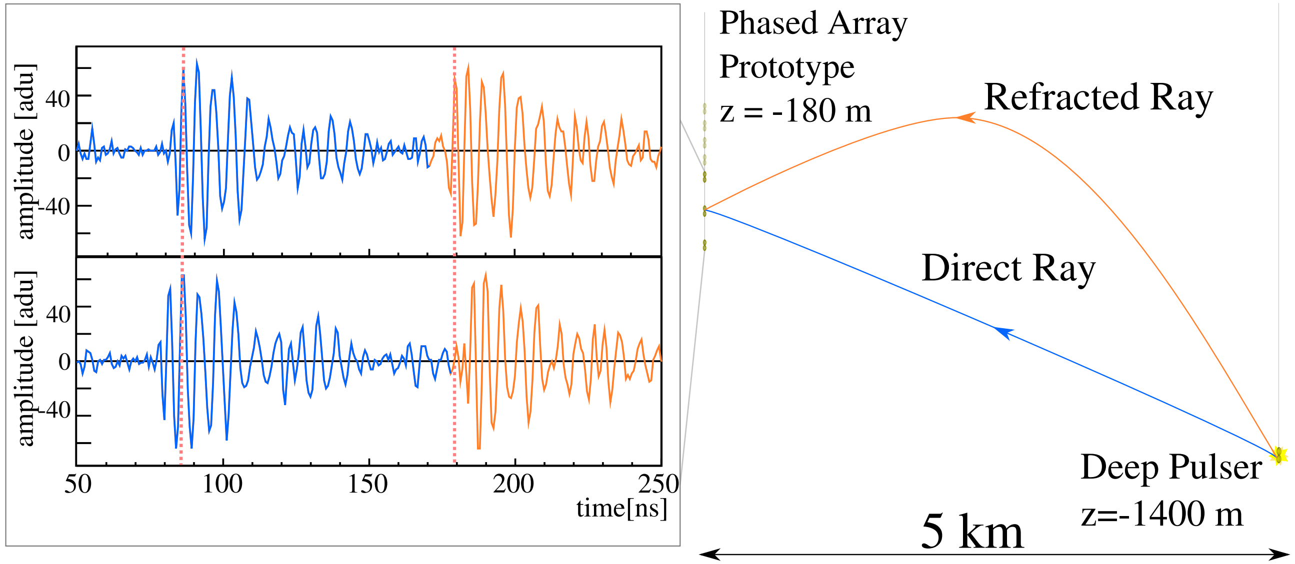
A deeper detector can see more events!

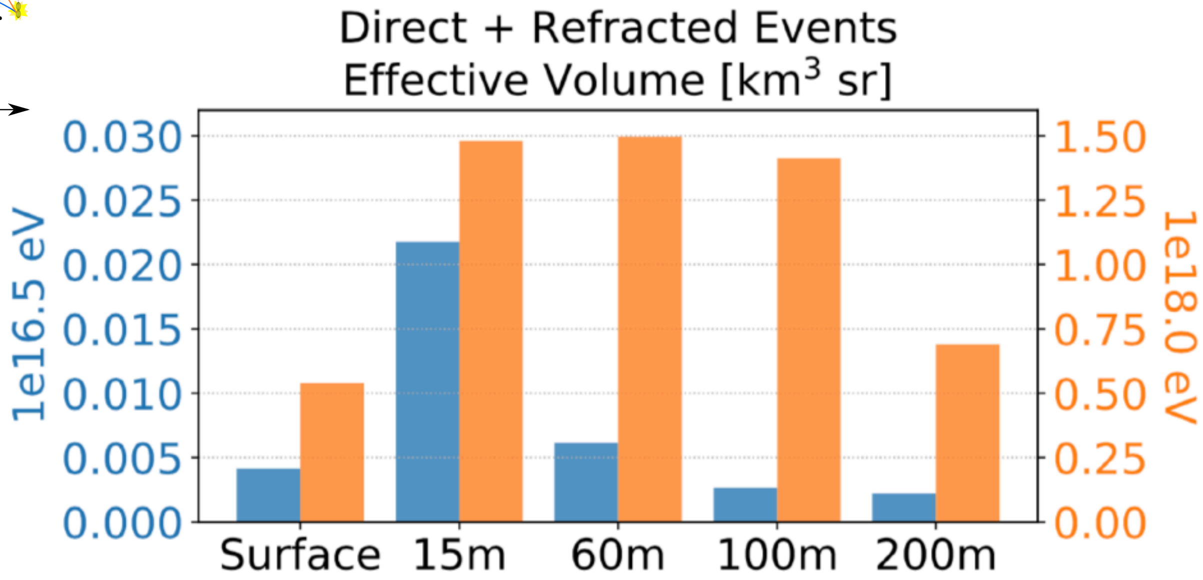




A shallow detector can compensate a little by using larger antennas which may be of higher quality and more gain.

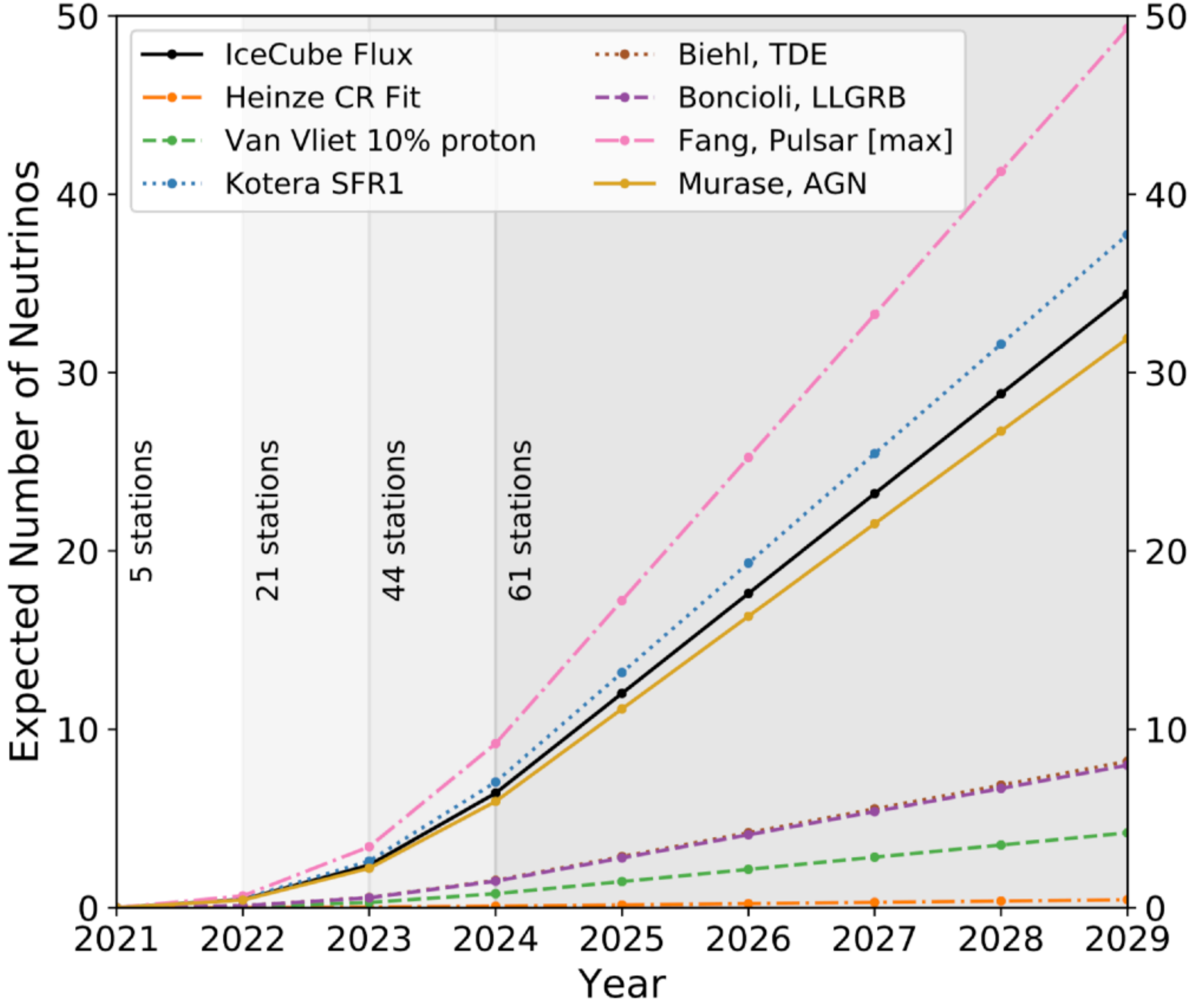
A shallow detector will more often see double pulses
(substantial information gain: vertex and energy)





Number of events for a detector of 61 stations
- proposed Radio Neutrino Observatory in Greenland

Gen2 would be
3 to 5 times larger



Construction

Production of DOMs

Drilling and deployment

South Pole logistics

ICECUBE GEN2

IceCube-Gen2 - Challenges: Radio array deployment

Drilling

1. Drilling 600 holes for radio while a challenge, is conceptually straightforward.
2. Scalable solutions exist. ASIG drill is current reference. Requires to people to operate. can be turned on and off.
3. For production, a conceptually similar but more automated design of the British Antarctic Survey may be employed..

Population: 2 - 3 people/hole/day

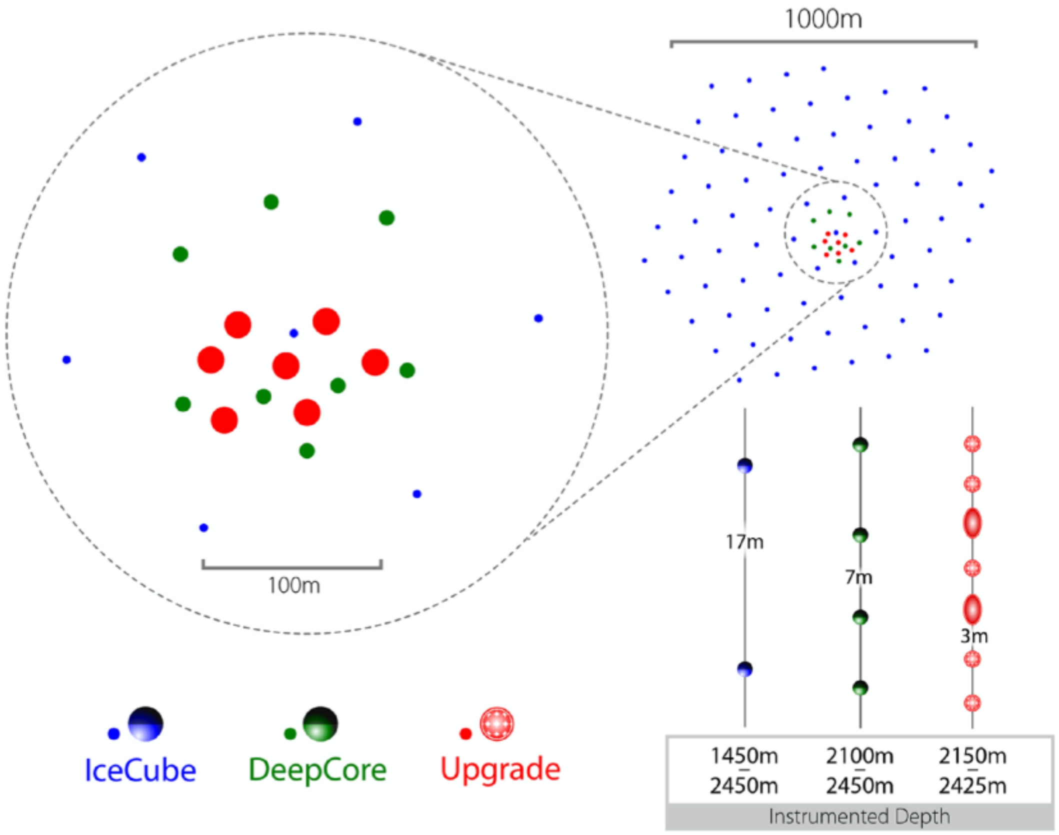
Deployment

1. Deployment takes most of the labor. about 2/3 of the population will be needed for deployment.
2. Long distances require special safety considerations.
3. Good equipment for transportation: Field shelters, Arctic trucks.

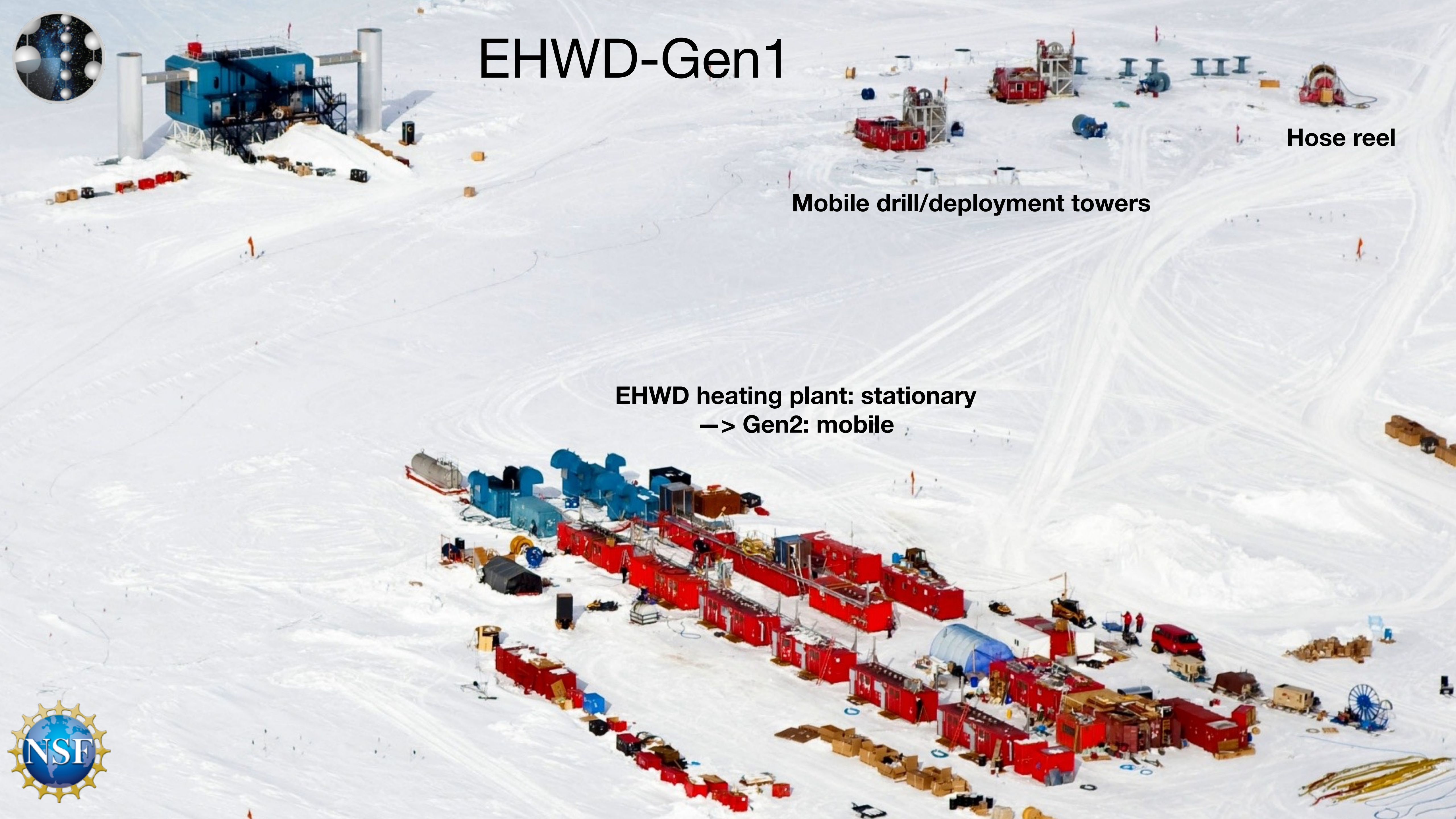
ASIG drill
https://icedrill.org/equipment/agile-sub-ice-geological-drill.shtml

IceCube-Upgrade (Gen2 Phase 1)

- 7 new strings instrumented with more than 700 advanced sensors
- Improvements to precision measurements of neutrino properties at low energies - O(10 GeV); extensive calibration program is expected to more than double the current IceCube high-energy neutrino sample
- Fully funded $36M project (~65% NSF/35% partner agencies and institution)
- Deployment completion January 2023.

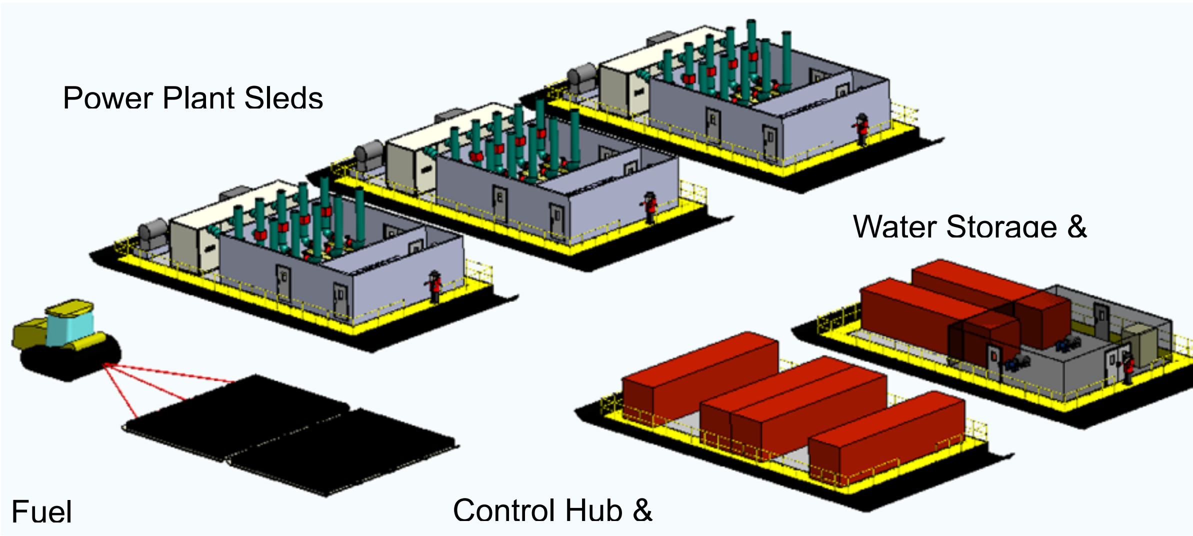


EHWD-Gen1


Hose reel
Mobile drill/deployment towers
EHWD heating plant: stationary
—> Gen2: mobile

Gen2 hot water drill - changes in requirements

- Mobility: IceCube drill was stationary per season. Gen2 string spacing requires a mobile drill. WDrill will be moved multiple times per season.
- Improved efficiency and lower maintenance technology
- Aim for higher drill speed. (Gen1: 2.1 m/min, Gen2 target close to 3 m/min)



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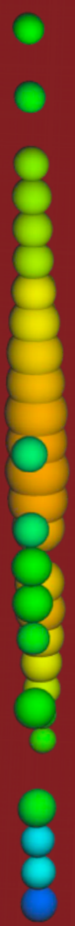
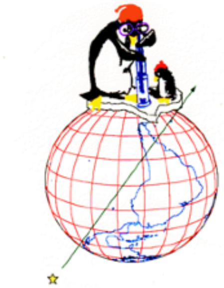
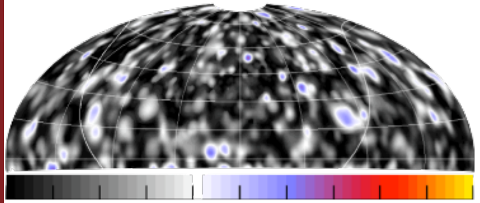
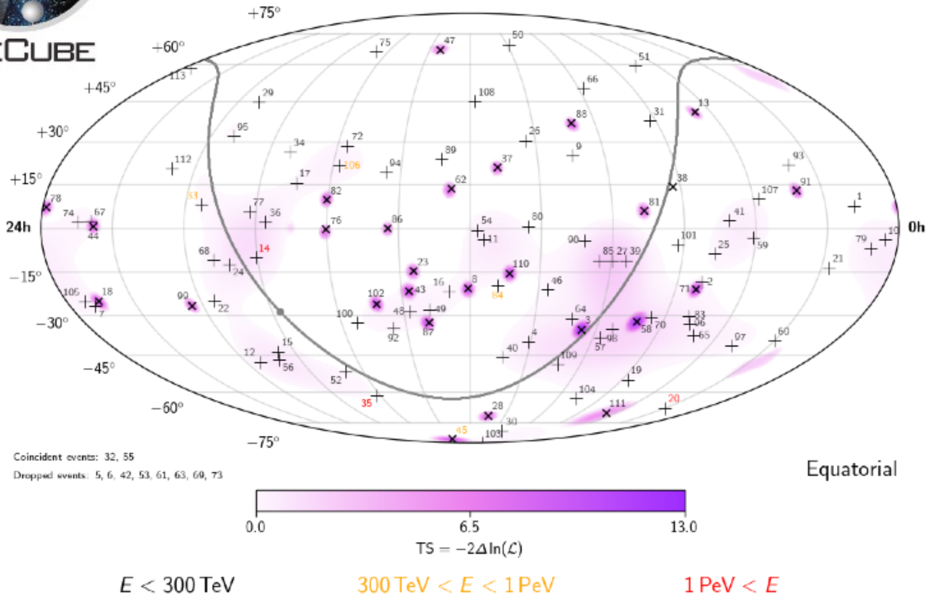
IceCube-Gen2: *From Discovery to Astronomy*

…building the future of a new field









Gen2 Phase 1 (Upgrade) drill camp; January 29, 2020