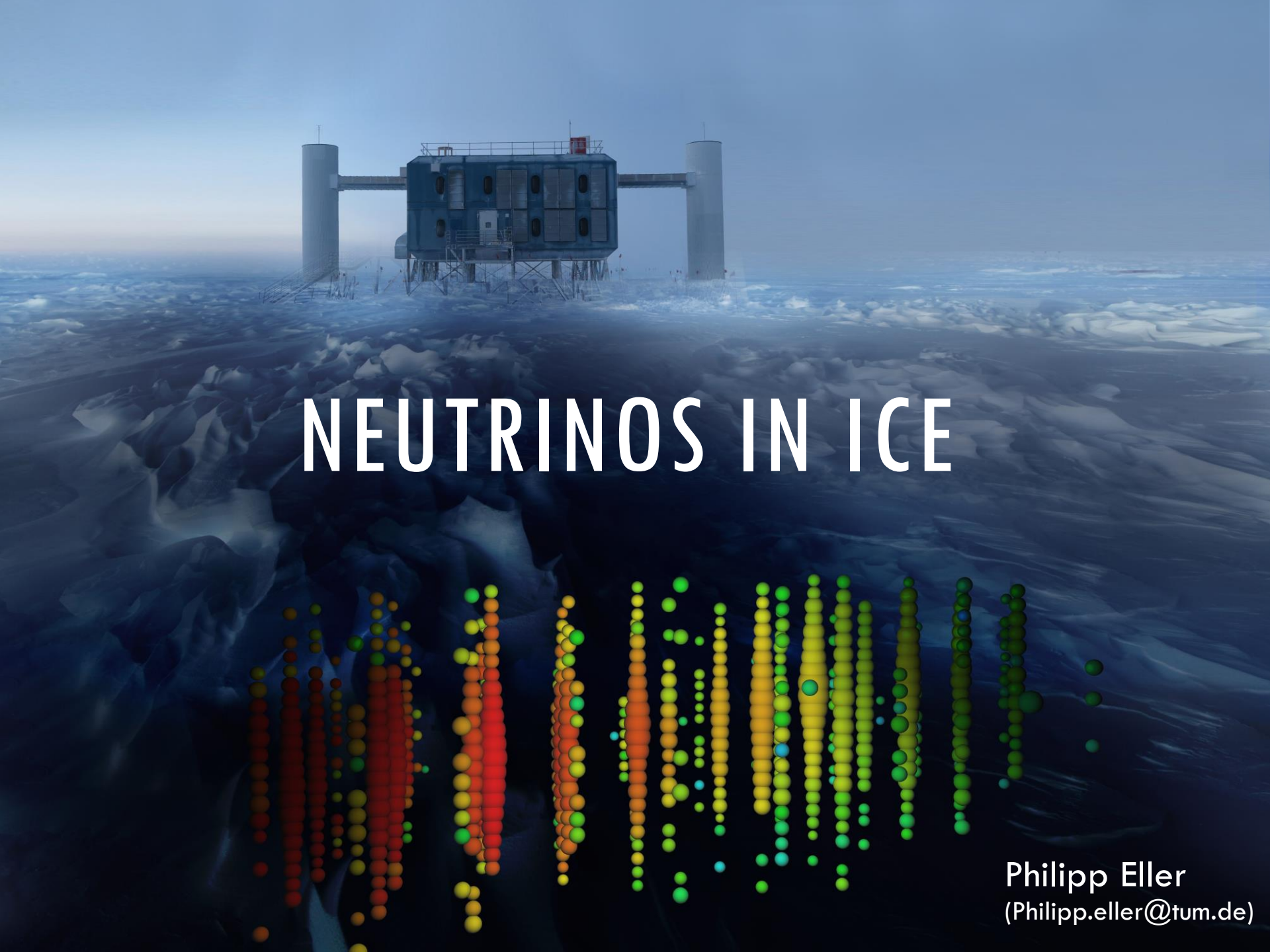


NEUTRINOS IN ICE

Philipp Eller
(Philipp.eller@tum.de)

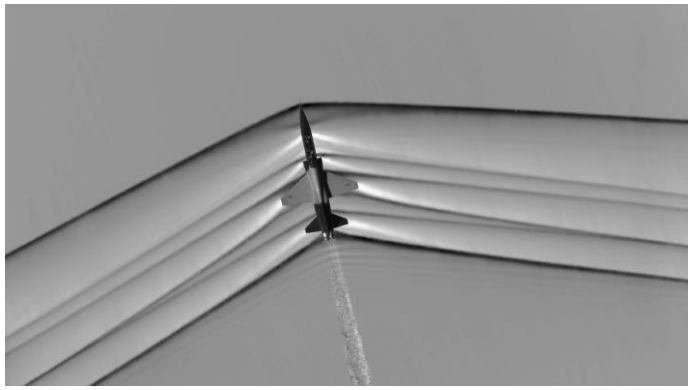
SOUTH POLE

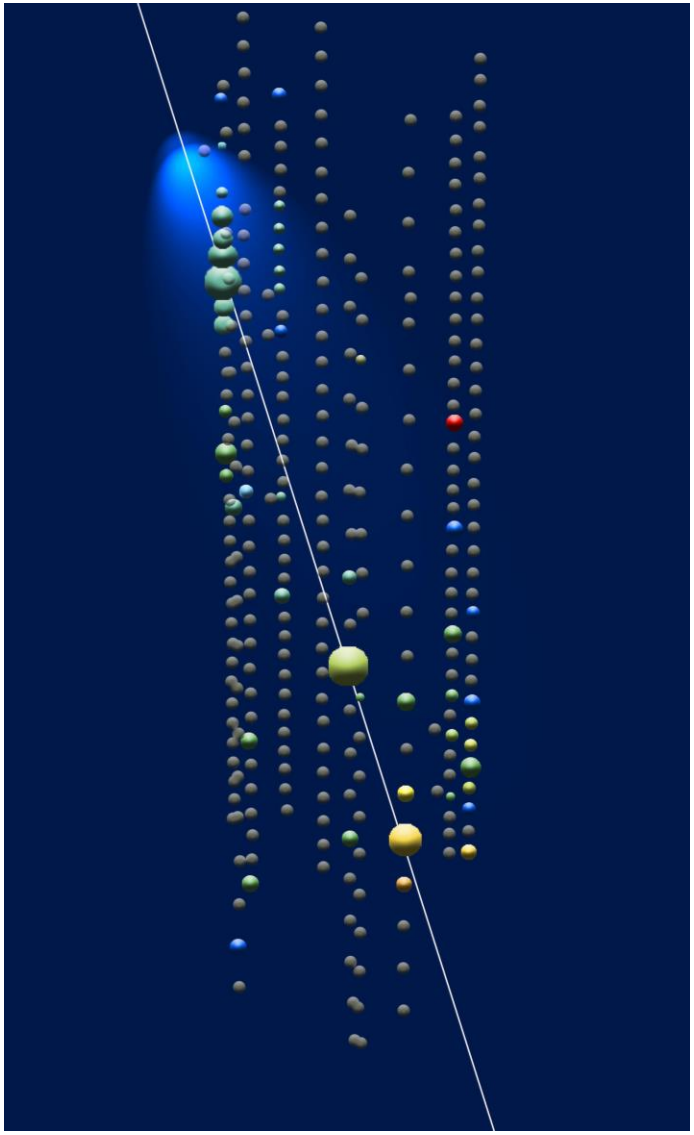
- In 2005, the construction of an unprecedented neutrino detector started at the geographic South Pole
  - An extremely remote and desolate place
  - mean annual temperature of -49.5 degC
  - High altitude (2,835 meters above sea level)
  - Half of year in darkness (winter), station only accessible during a few months in summer
  - Everything needs to be flown in via AirForce
- Construction took 7 years to complete
  - Drilling 2.5 km deep holes into the ice
  - 5 MW enhanced hot water drill, ca. 48h and 21'000 l jet fuel per hole
  - 86 holes in total to deploy detector units
- → **So….why?**


LC-130 Hercules

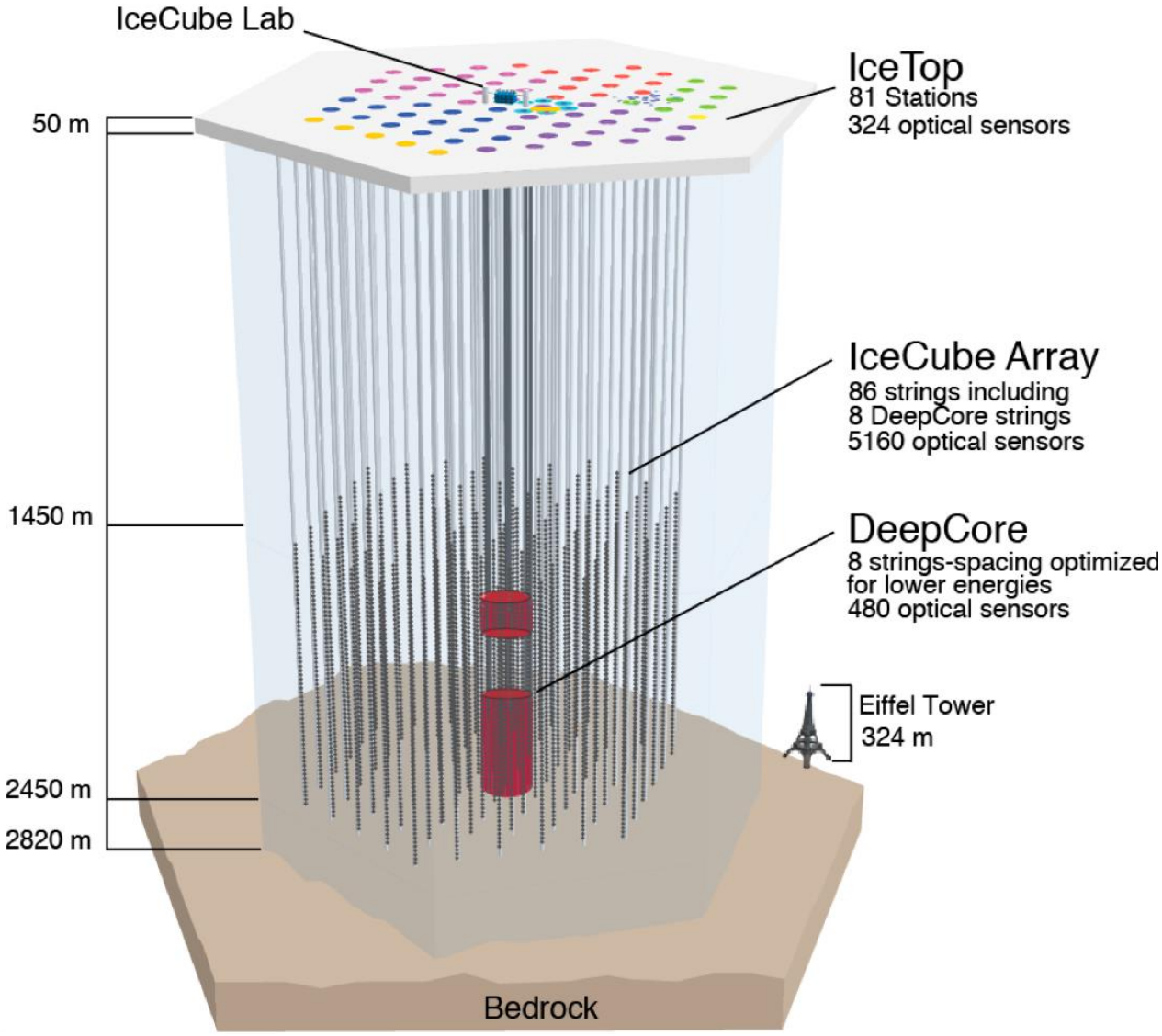
DETECTION PRINCIPLE

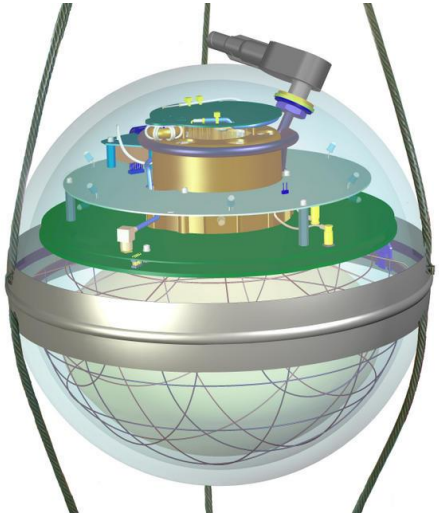
- Neutrino interactions are a) very rare, and b) very large for high energies
  - → want a large (huge!) detector
- A neutrino interaction will usually create a number of charged particles
  - When these travel through the ice faster than light, they emit *Cherenkov* radiation
- South pole ice some of the world's most optically transparent and radio pure medium
- allowing this light to reach photosensitive sensors



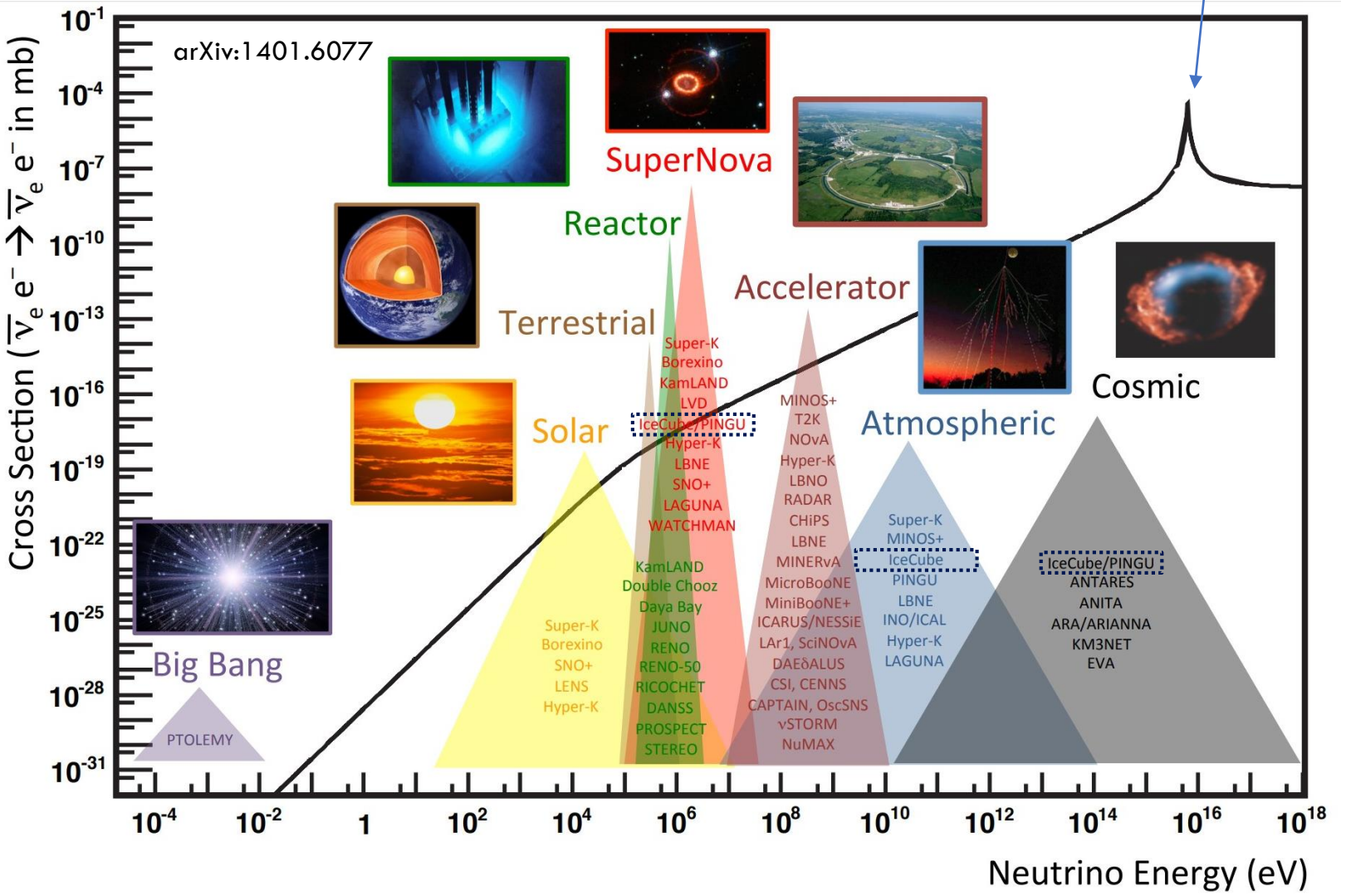


ICECUBE DETECTOR





NEUTRINO SOURCES

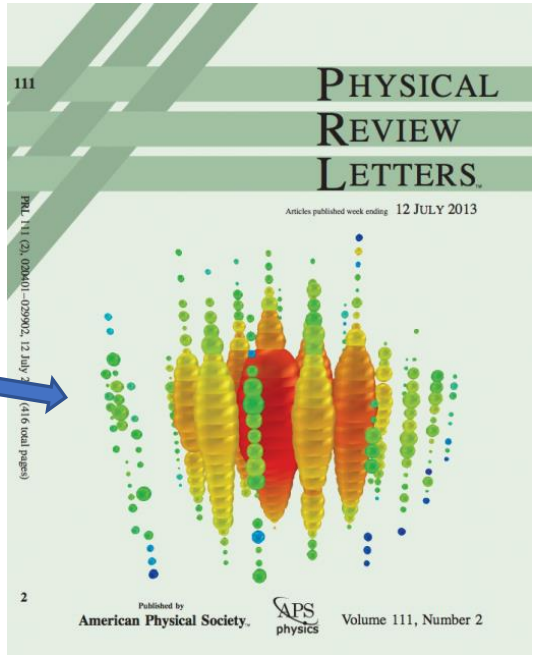


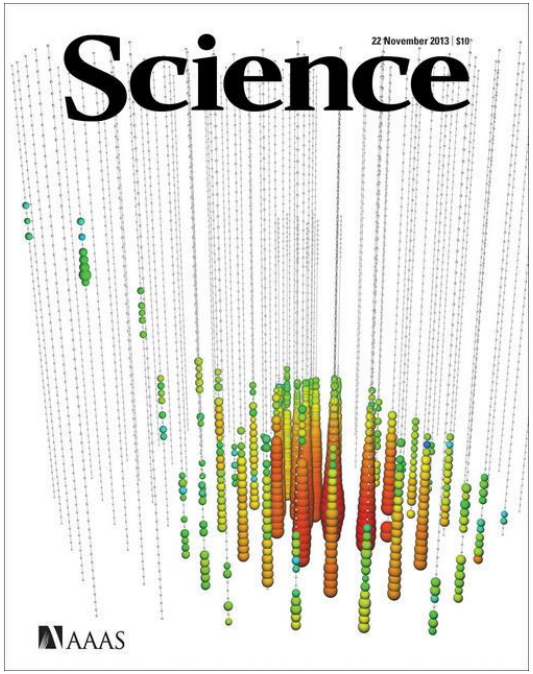
EVENTS IN ICECUBE

- Every DOM gets around ~500-800 hits per second, mainly from dark noise
  - Hits from physics events are ~1 order of magnitude fewer
- Most of this is suppressed by trigger conditions
- Per year, we read out roughly:
  - **10^{10}** events caused by atmospheric muons
  - **10^{9}** events caused by noise
  - **100'000** events from atmospheric neutrinos
  - A **handful** of very high energy events likely to be of astrophysical origin
- Special triggers exist for example looking for supernovae, they monitor the overall hit rate, where a correlated increase could indicate a nearby supernova

HIGH ENERGY EVENTS

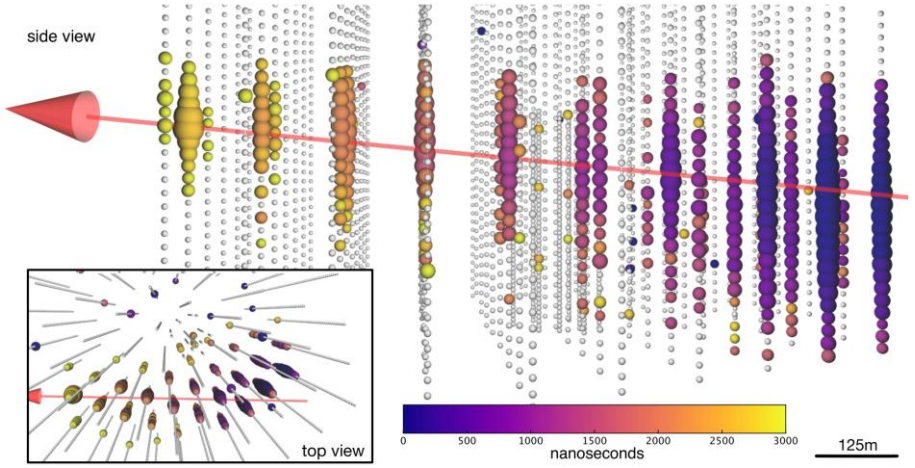
- *Really* high energy!
- Here for example “Big Bird”, ~2 PeV
- Very rare events, but very likely to be of astrophysical origin
- Led to the **observation** of a flux of **astrophysical neutrinos**!
- Have observed until today > 100 high energy events (albeit not all are as high as PeV)
- Can do interesting physics:
  - Flux energy distribution
  - Flavour composition
  - Source search
  - …

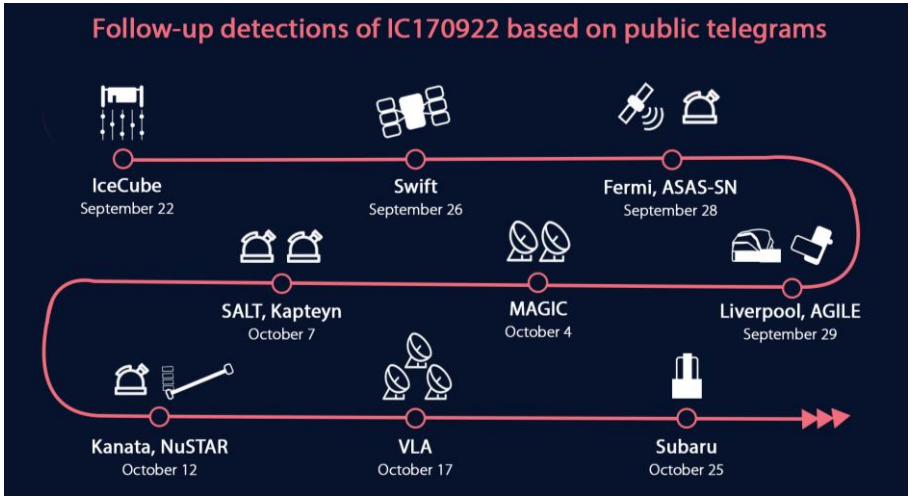




ICECUBE ALERT IC170922A

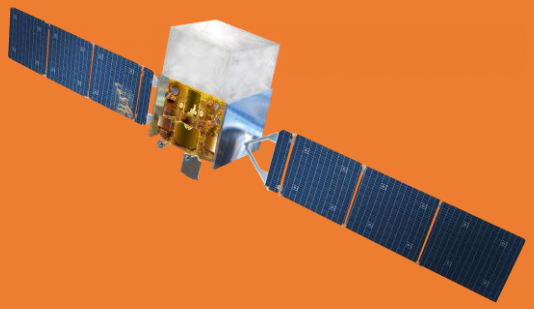
- On September 22, 2017 an extremely high energy neutrino interacted in IceCube
- An event with estimated energy of around 290 TeV and high "signalness"
- A global follow-up campaign of the event by many different observatories happened over the following weeks…



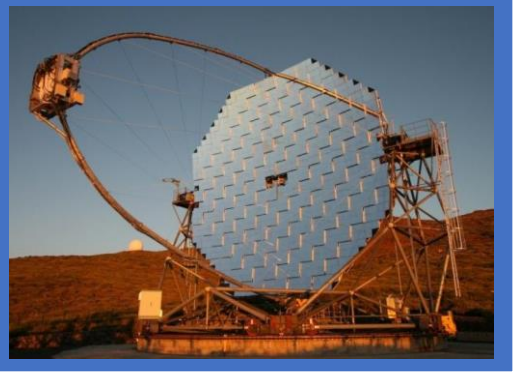


COINCIDENCE WITH FLARING BLAZAR

FERMI LAT detected a Blazar in this area to be in a state of high gamma-ray activity (flaring)

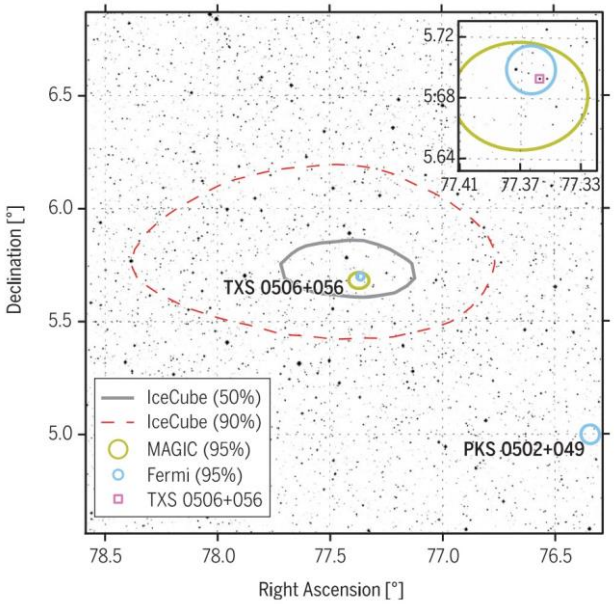


The Major Atmospheric Gamma Imaging Cherenkov (MAGIC) telescope detected gamma-ray flux from this location of up to 400 GeV



In ~10 years of IceCube archival data, we went back an searched for any clustering of (lower energy) events coming from the same location

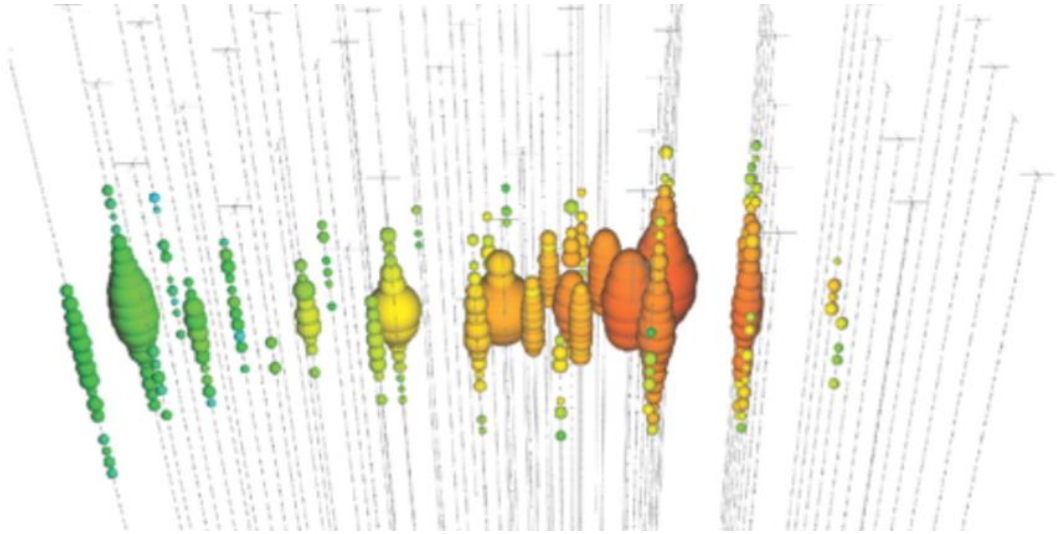
Found 13 ± 5 events above background around December 13 2014



This blazar is situated in the night sky just off the left shoulder of the constellation Orion and is about 4 billion light years from Earth.

GOING LOWER IN ENERGY

~100m

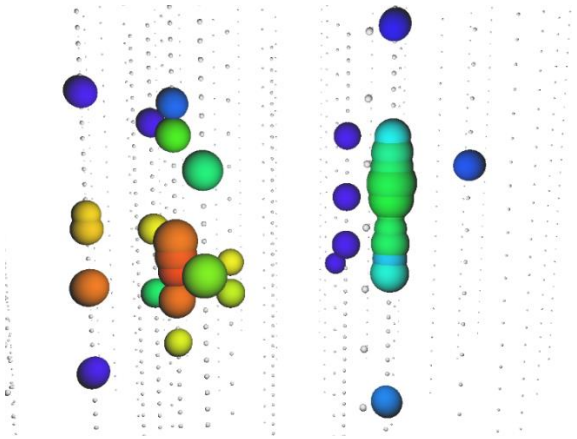


The typical TeV-PeV IceCube event:

- Photons from secondary particles arriving in many strings and modules
- Very clear, extended signature

The typical GeV DeepCore event:

- Photons from secondary particles arriving in few strings, tens of sensors
- Almost impossible to see “by eye” what event it was



~35m

NEUTRINO OSCILLATIONS

- Neutrinos oscillate their flavor while travelling (Due to the flavor and mass eigenstates not being aligned)

- Example: simplest 2-flavor, vacuum oscillation probability:

$$P_{\nu_\mu \to \nu_e} = \sin^2 2\theta \sin^2 \frac{m_2^2 - m_1^2}{4E_\nu} L$$

Mass eigenstates

Length

From mixing matrix

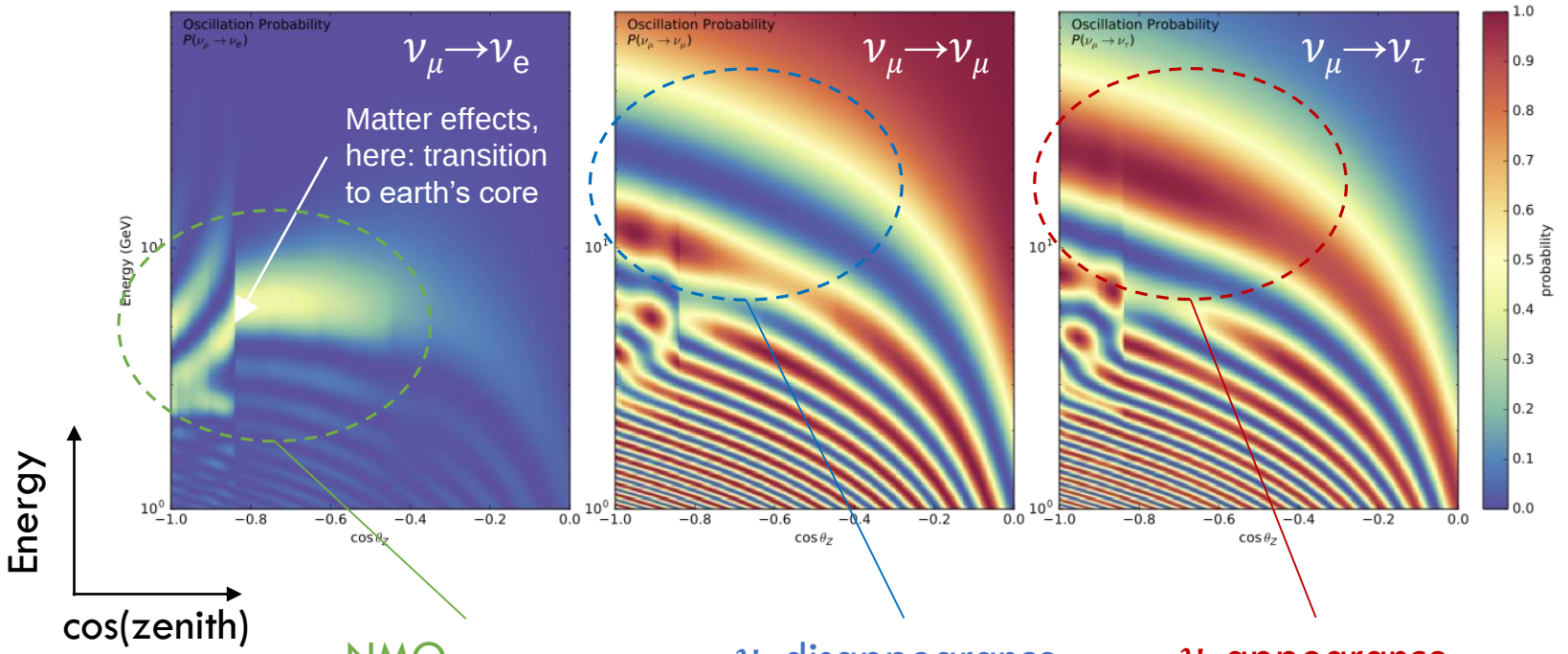
Energy

- → Observing oscillation implies that neutrinos must have non-zero, and different masses

LOW ENERGY ATMOSPHERIC NEUTRINOS

- For O(10) GeV neutrinos and below, earth diameter provides perfect L/E
- We can look at oscillations in the energy-cos(zenith) ($\propto$ E-L) plane

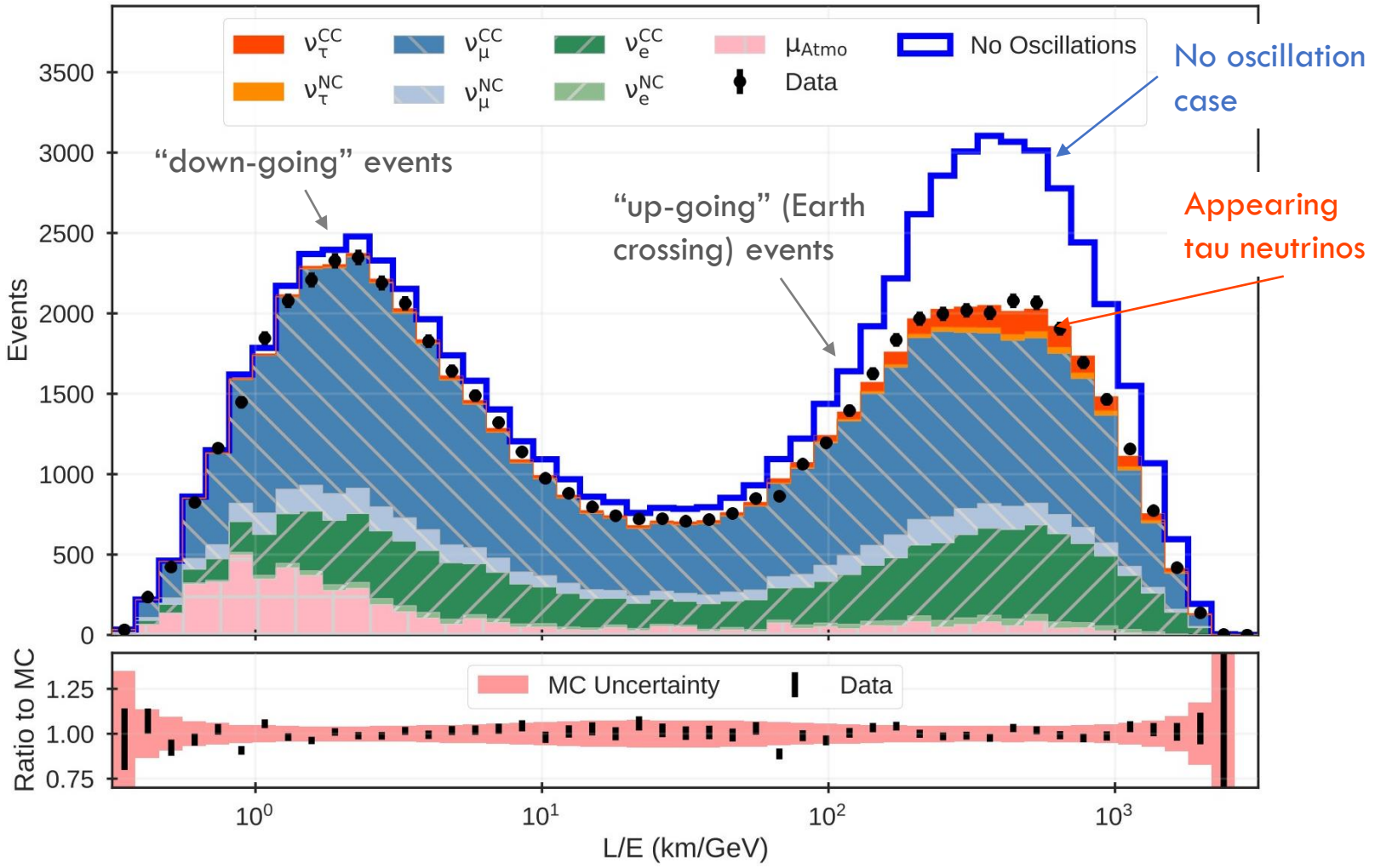
$$P_{\nu_\mu \to \nu_e} = \sin^2 2\theta \sin^2 \frac{m_2^2 - m_1^2}{4E_\nu} L$$



EVENT DISTRIBUTIONS

$$P_{\nu_\mu \to \nu_e} = \sin^2 2\theta \sin^2 \frac{m_2^2 - m_1^2}{4E_\nu} L$$

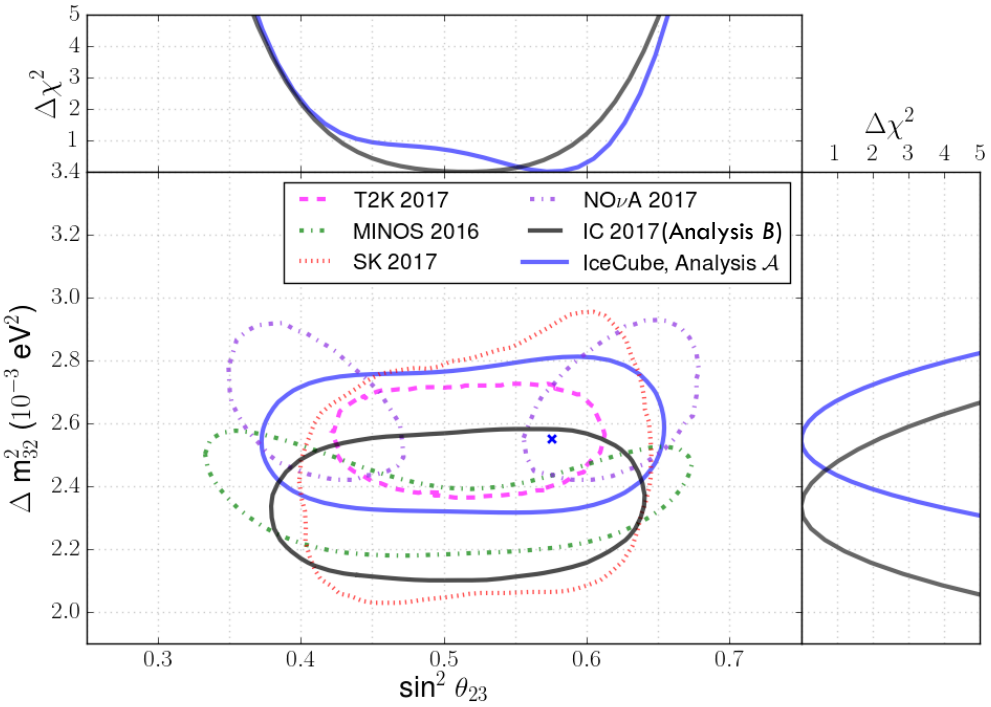
- Projection of events onto the L/E axis

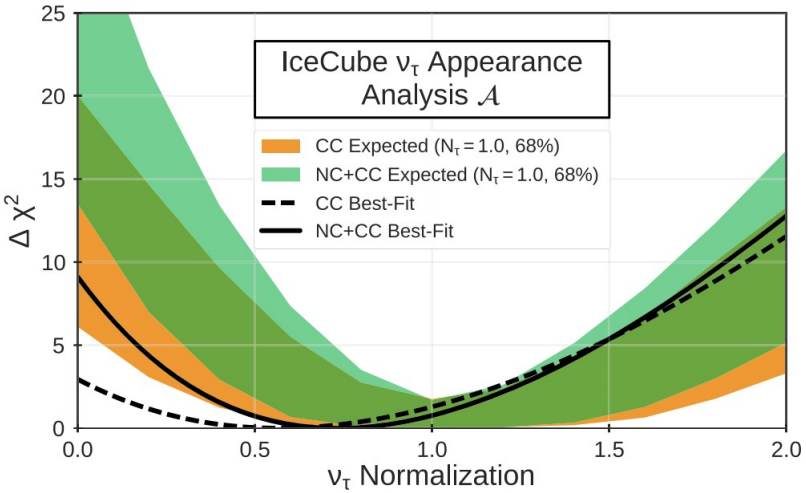


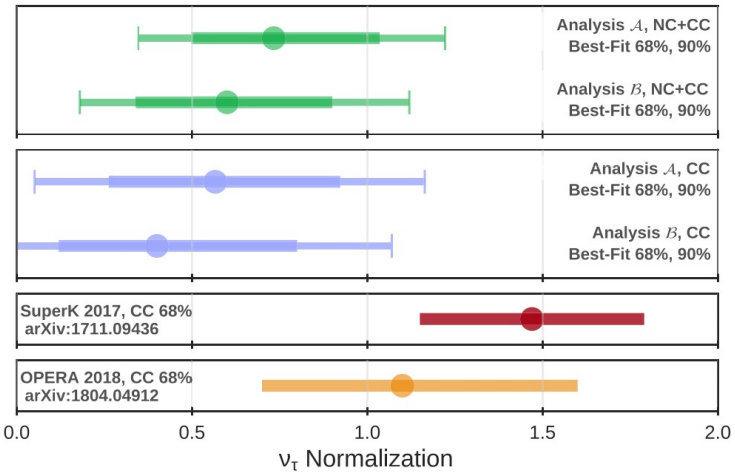
OSCILLATION RESULTS

- atmospheric mixing parameters theta$_{23}$ and dm$^2_{32}$
- tau neutrino normalization

→ Insight on validity of standard mixing paradigm

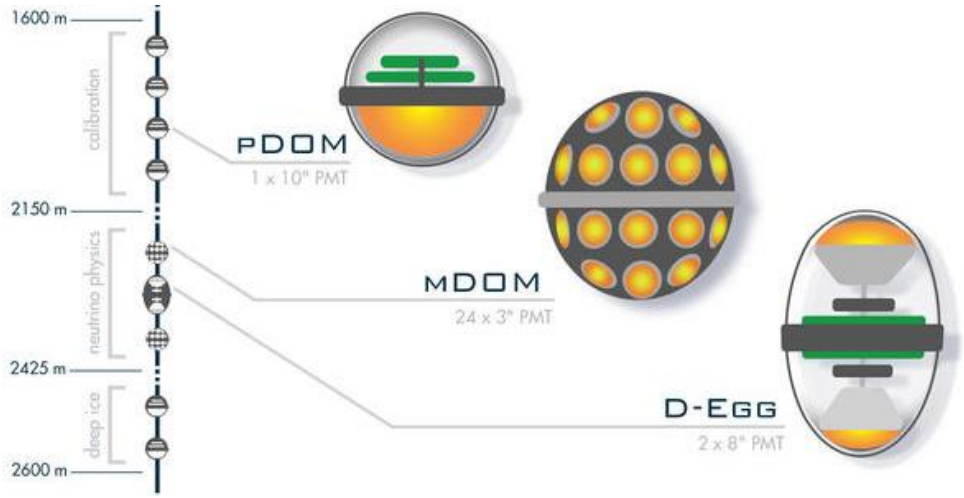




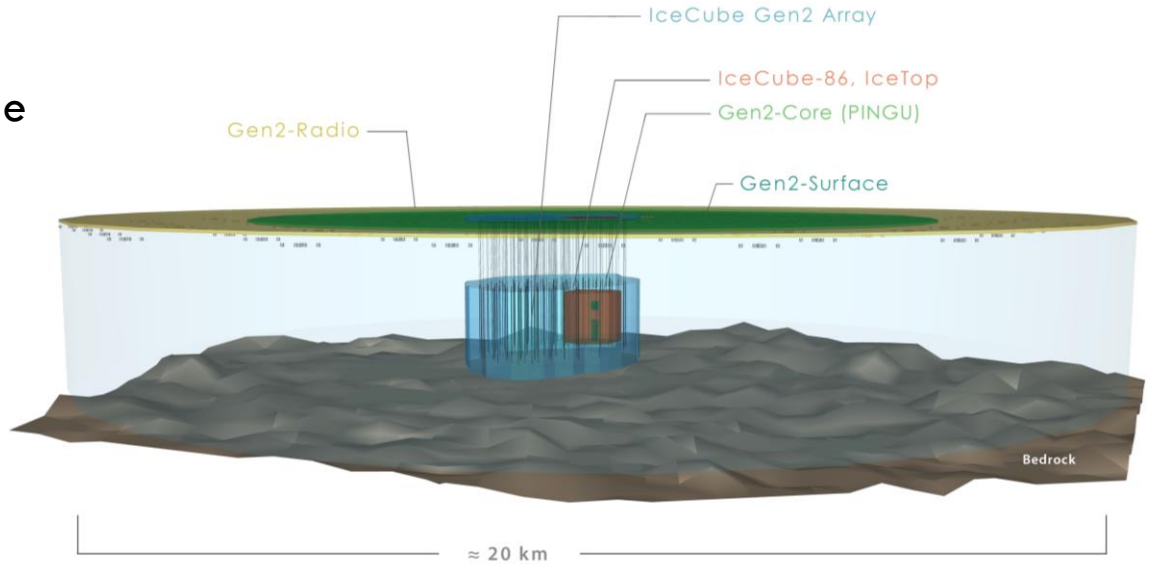


FUTURE DETECTORS

- IceCube "Upgrade"
  - 7 more strings in the very center
  - Advanced detector concepts
  - New calibration devices
  - Optimized for oscillation physics
  - Fully funded, deployment 2022/23



- IceCube Gen2
  - Very large detector upgrade
  - optimized for high energies
  - 10x larger Volume
  - Radio array
  - Cherenkov telescopes
  - In proposal stage



- IceCube has a diverse science program
  - Neutrinos over a broad range of energies
  - Recording data since > 10y and still going strong
- Astrophysics using high energy neutrinos
  - Observation of astrophysical neutrinos
  - Observation of neutrinos in coincidence with flaring blazar
- Particle physics using low energy neutrinos
  - Atmospheric neutrinos can be used for precision oscillation measurements
- New and exciting extensions for IceCube observatory underway

Warmest day, -31 °C

Thank you!