Particle physics & astrophysics with ice

Ice as an observatory

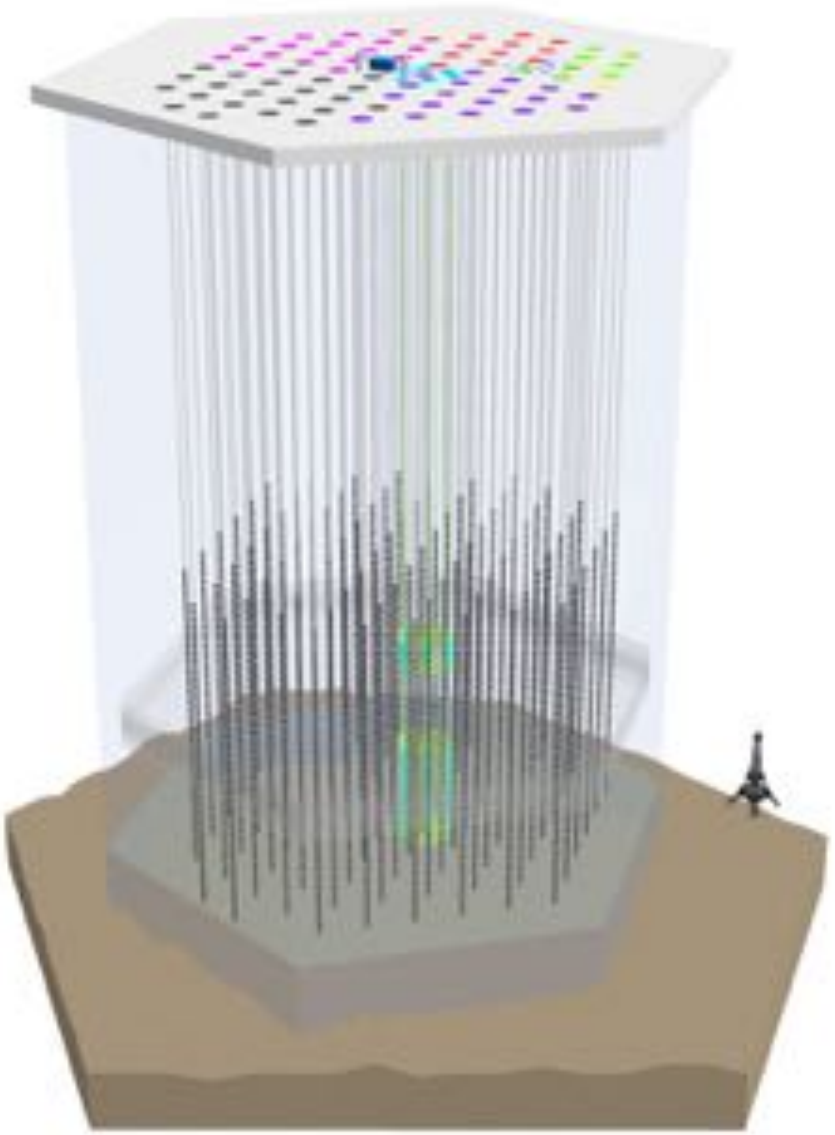
Polar ice for sub-atomic particle detectors:

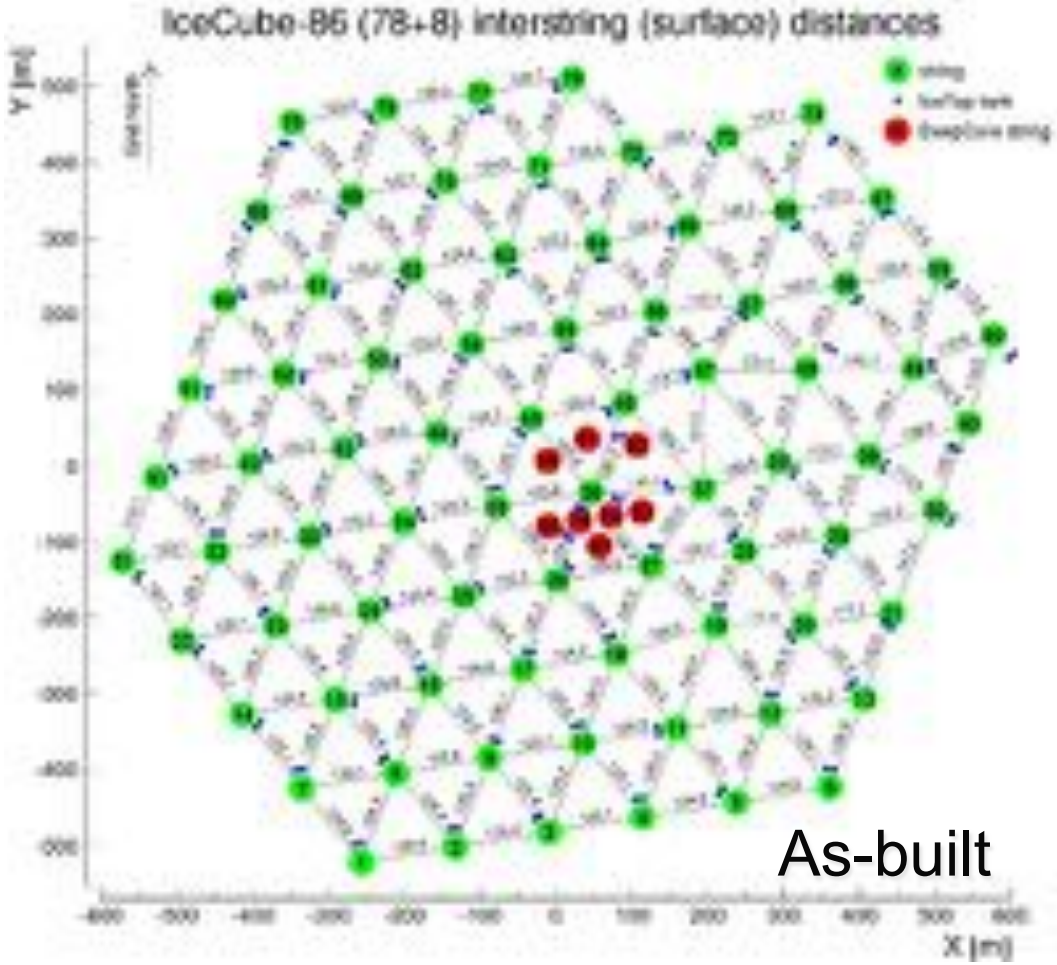
Transparent
Low-noise
Clean
Low-activity
Stable
Abundant

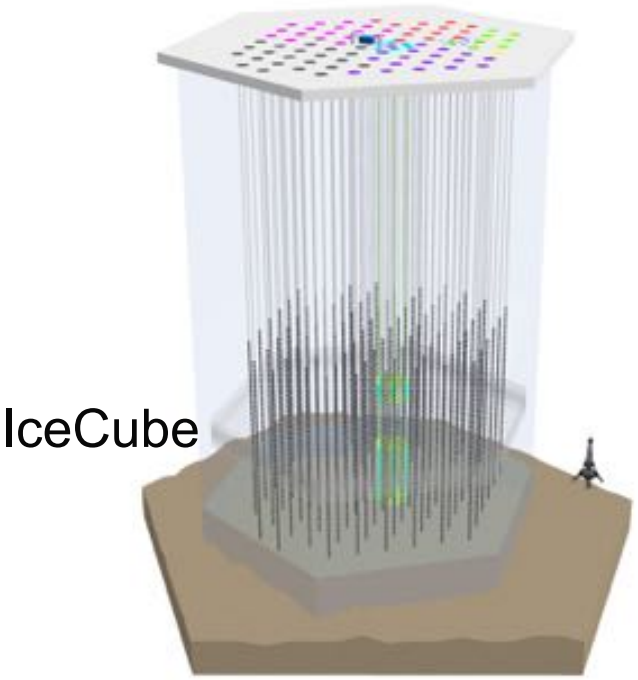
Technologies and drills for:

- IceCube
- Low energy physics experiments
- Ultra-high energy neutrino astronomy

IceCube Completed – December 18, 2010

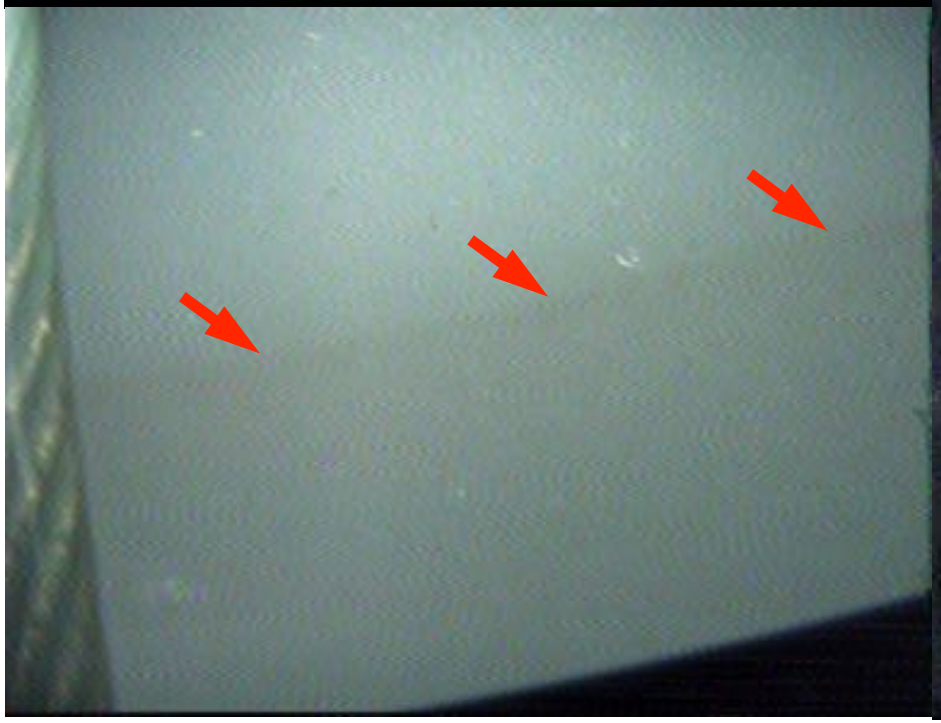




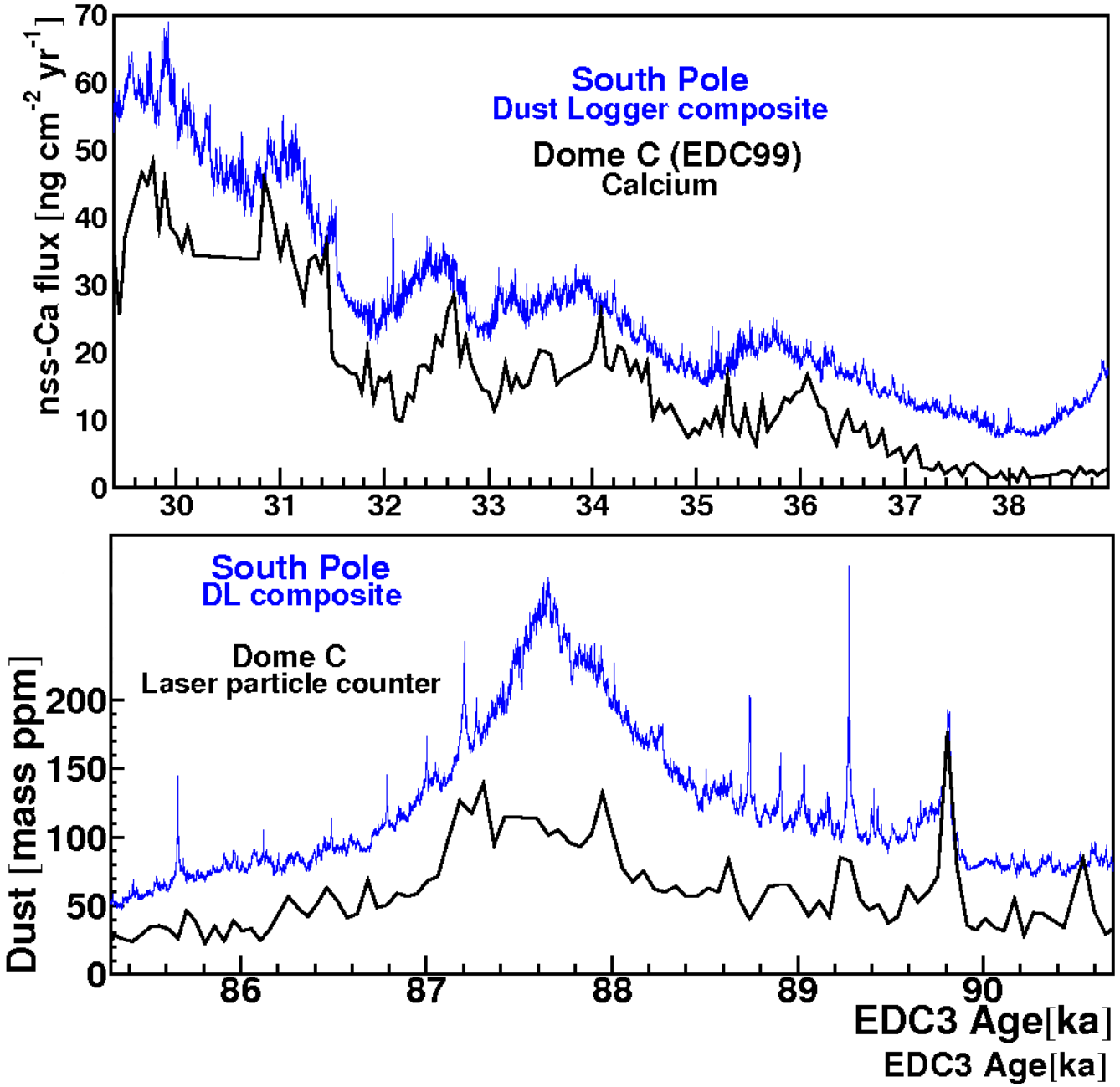


- Power: 5 MW
- 50 cm ⌀ 2500 m ⌀ 30 h holes
- Rate: <48 h per hole
  20 per 2 mo. season
- Personnel: 30 drillers
- Good safety record

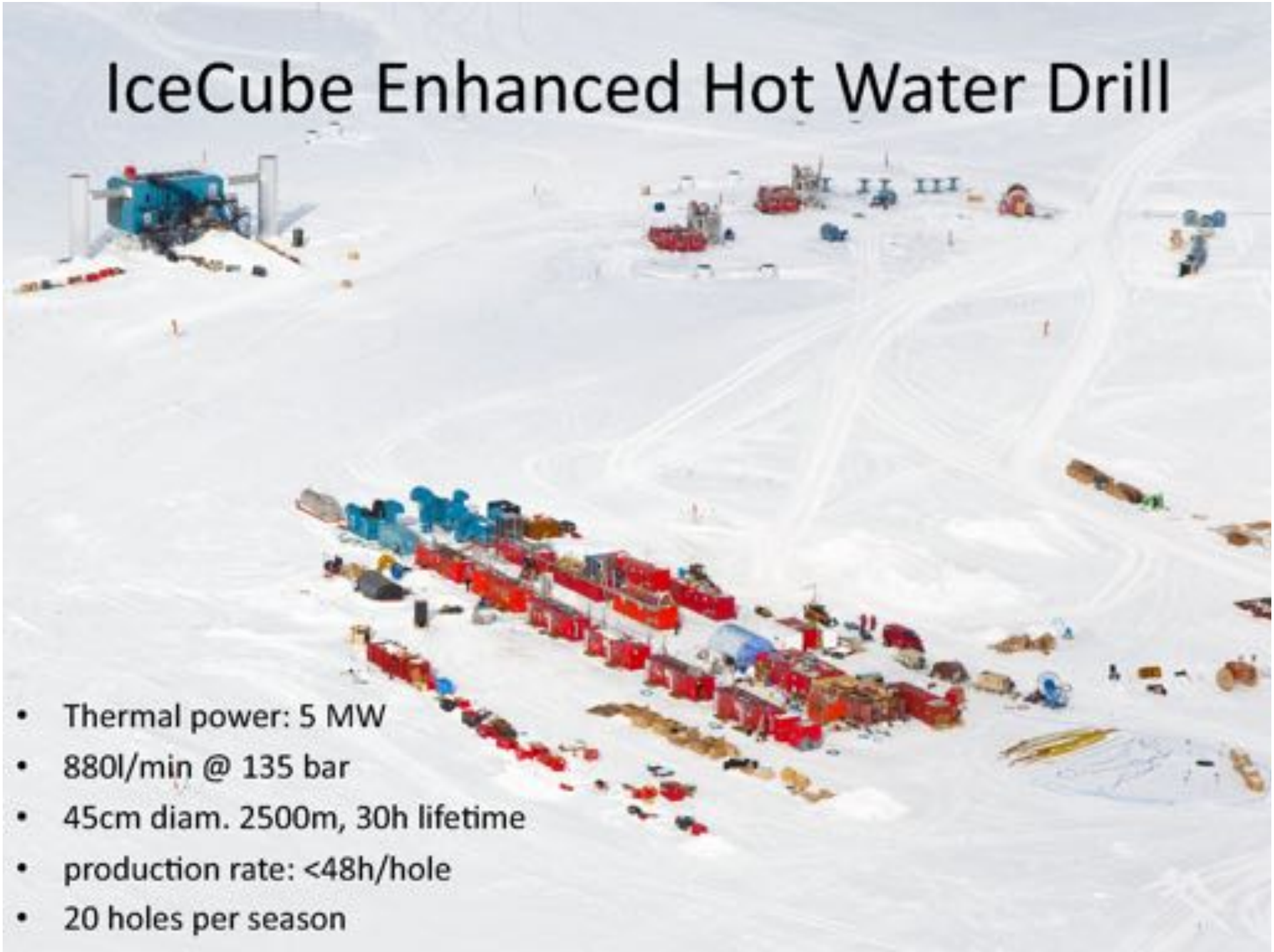
100,000 year snow pits



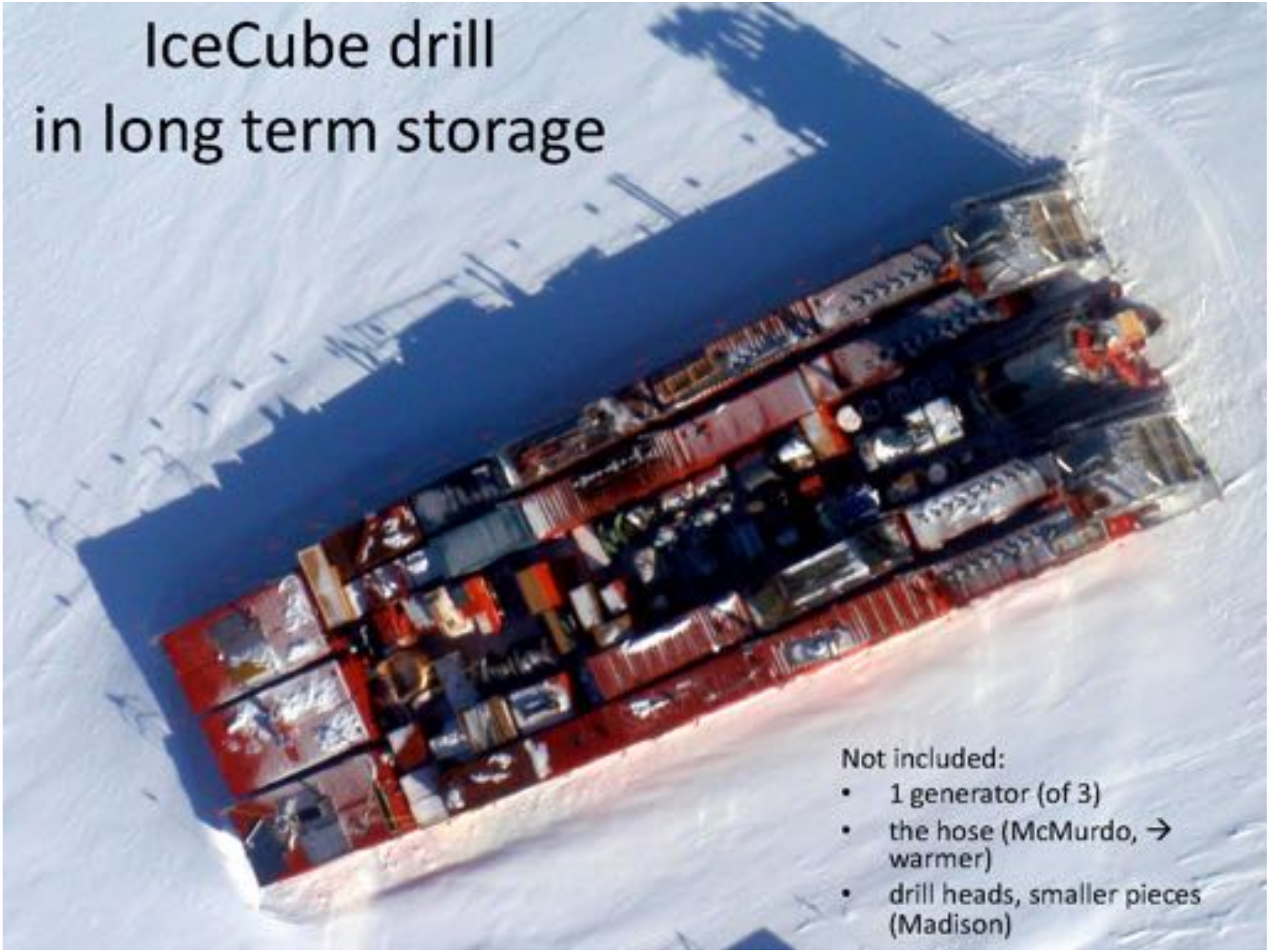
Laser particulate stratigraphy



IceCube Enhanced Hot Water Drill



- Thermal power: 5 MW
- 880l/min @ 135 bar
- 45cm diam. 2500m, 30h lifetime
- production rate: <48h/hole
- 20 holes per season


IceCube drill
in long term storage
Not included:
• 1 generator (of 3)
• the hose (McMurdo, → warmer)
• drill heads, smaller pieces (Madison)

Future projects using IceCube drill

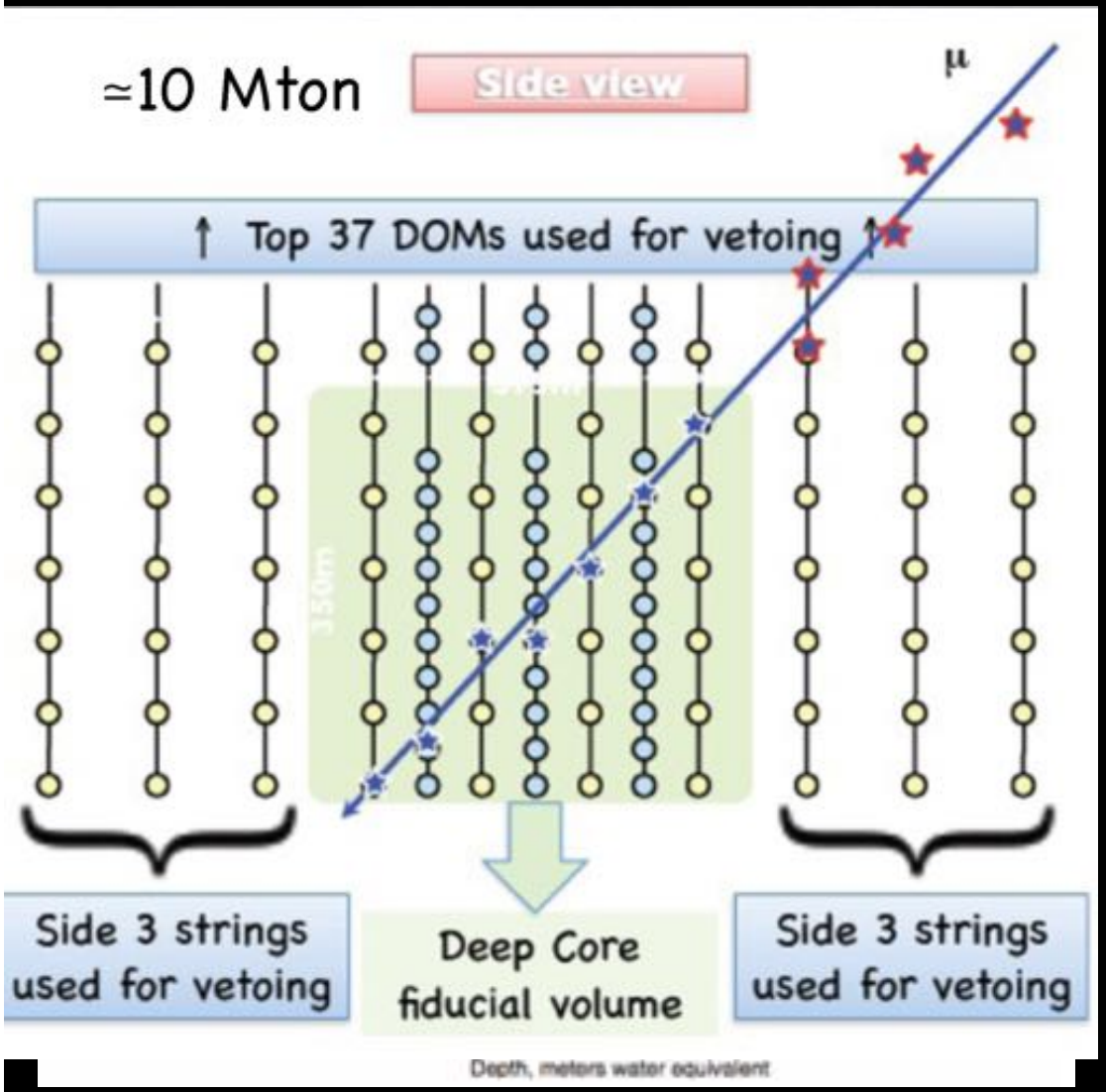
- IceCube DEEPCORE upgrade - PINGU phase I
  ~20 strings
- Low energy detector – PINGU phase II
  ~100 strings
- DM-ICE
- IceCube high-energy upgrade

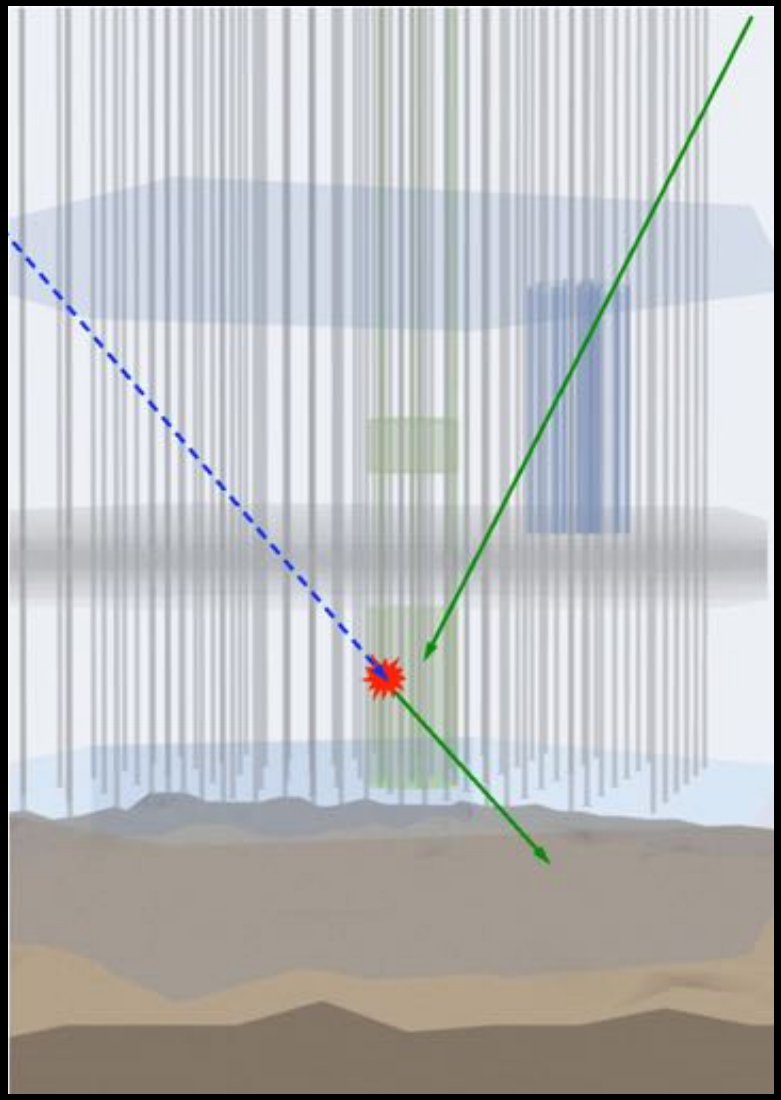
Drill currently stored at Pole

NSF will decide based on expected future needs

Mobilization cost: $3M

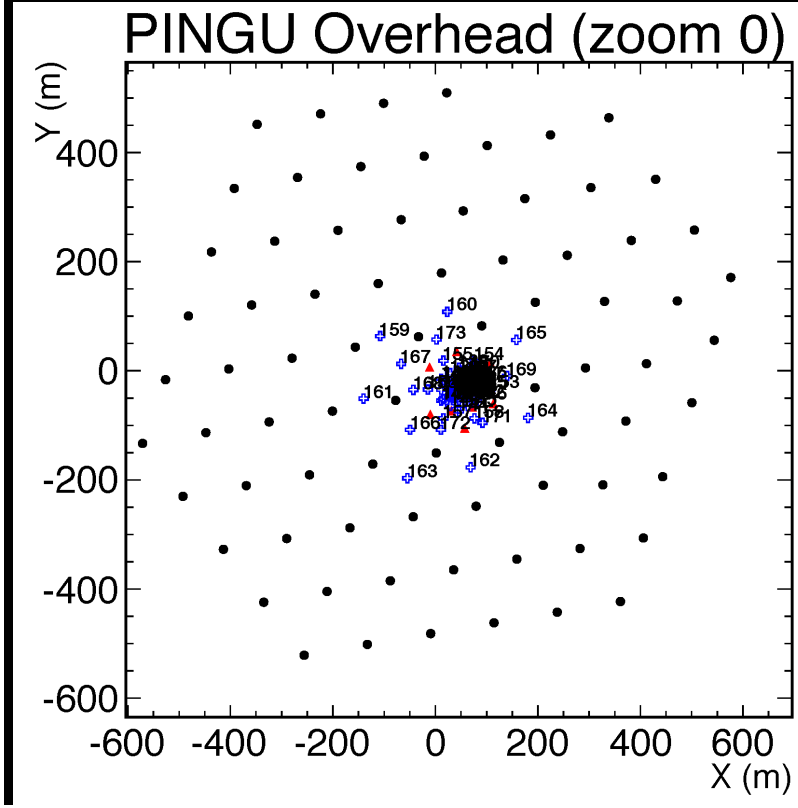
Future Low Energy physics in IceCube

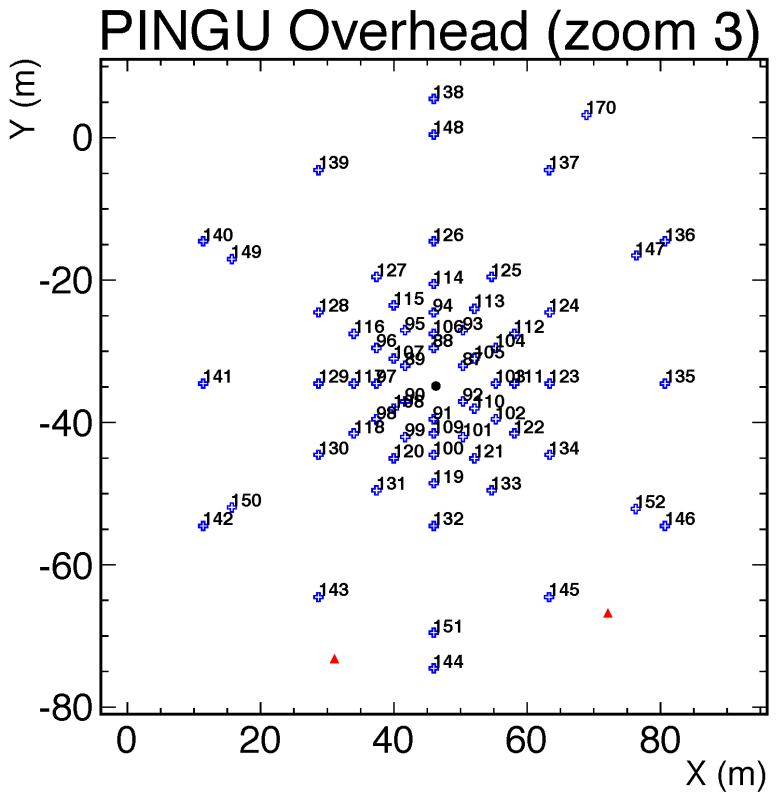




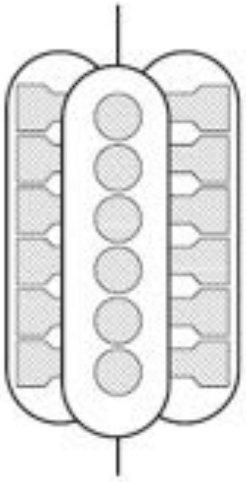
Future Low Energy physics in IceCube

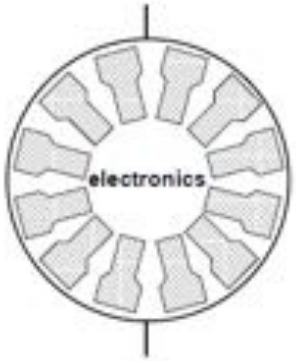
- *Backfilling* a core within IceCube
- Physics:
  - Neutrino oscillations
  - Proton decay
  - Neutrino beams
  - Dark Matter
  - Supernovae detection
  - Geo-neutrinos

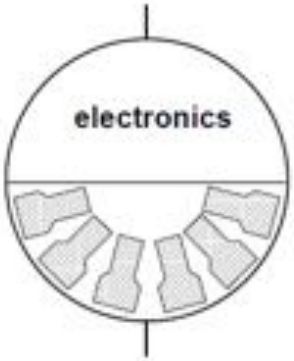


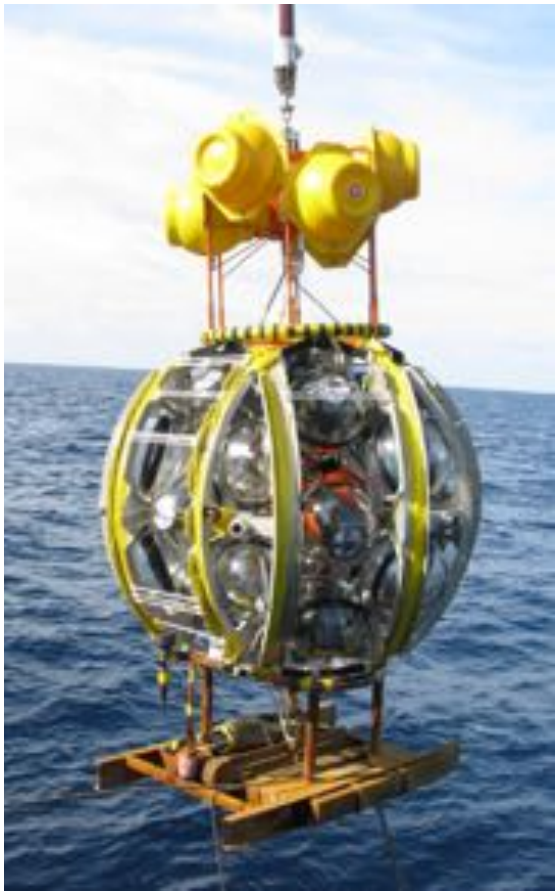


Multi-PMT Imaging Systems (KM3NeT)





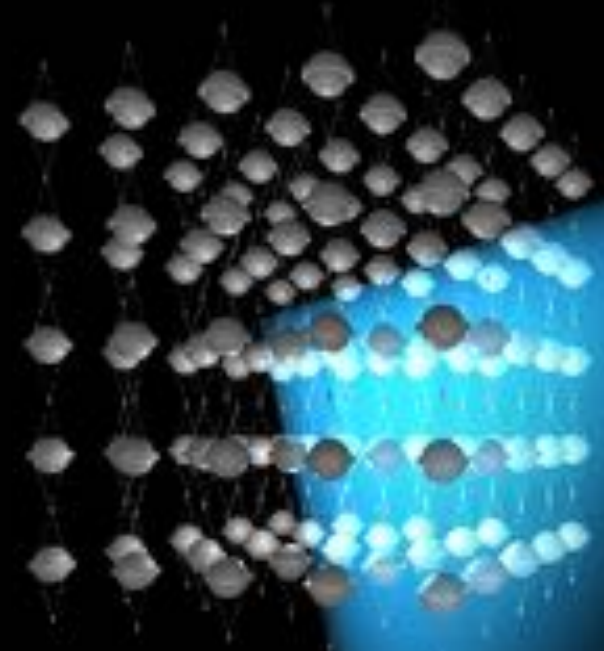




Discriminate signal vs. background

But PMTs are expensive…

Alternative optical detectors / amplifiers / concentrators:



Hybrid Photon Detectors (HPDs)

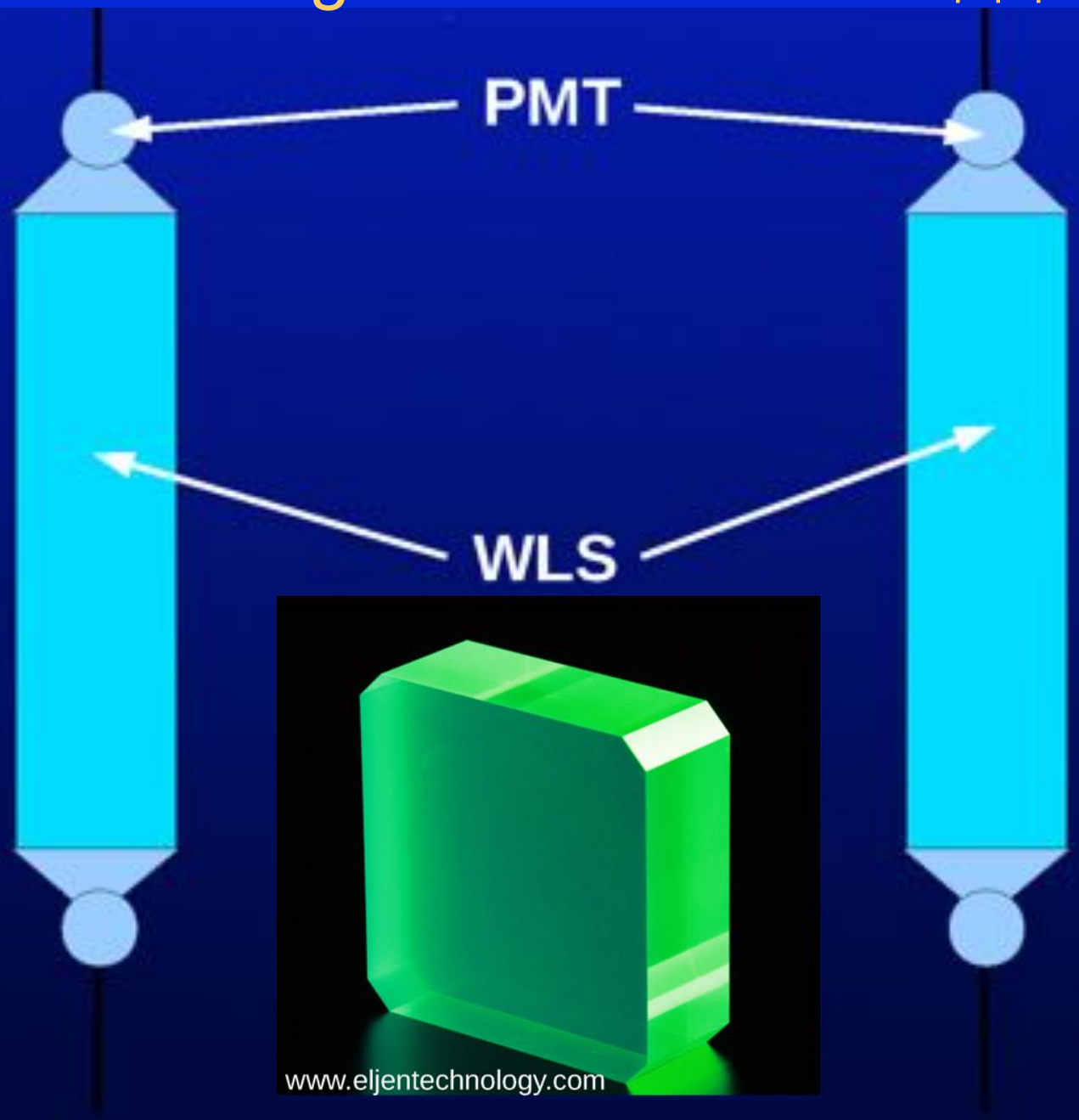
- photocathode + APD
- scintillator + Geiger-mode APD

Flat-panel photocathodes

- Transmission-mode
- Reflection-mode

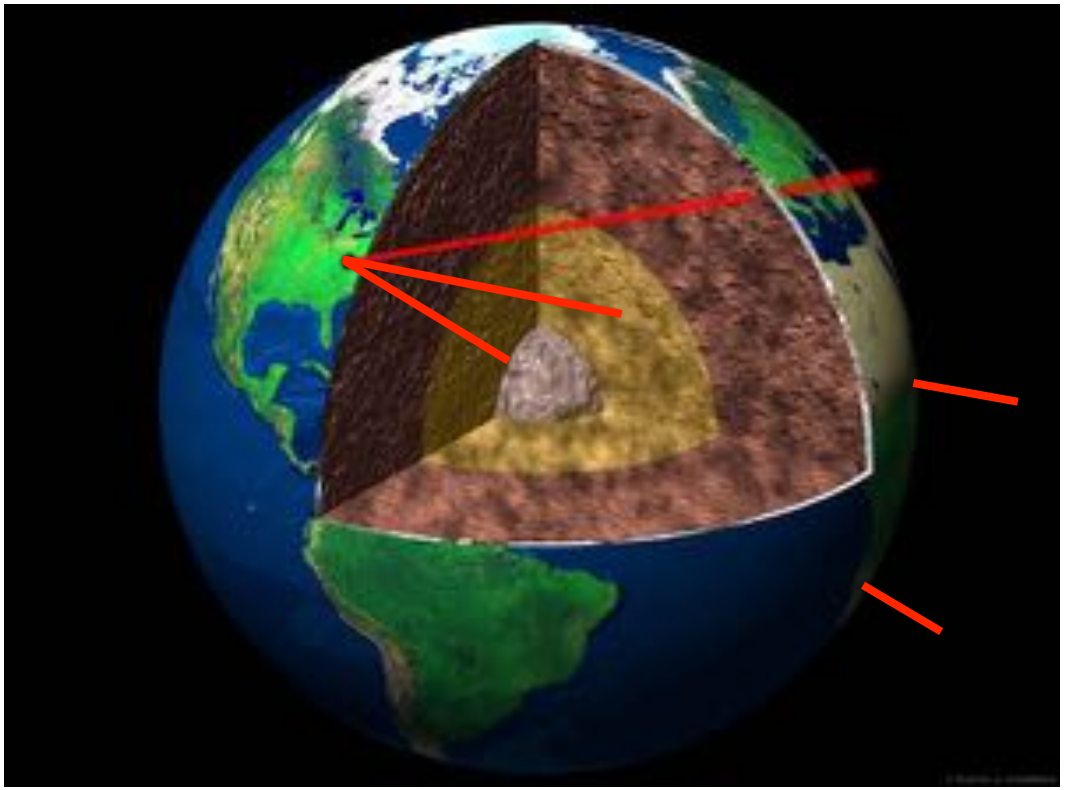
Significant progress over last 2-3 years…

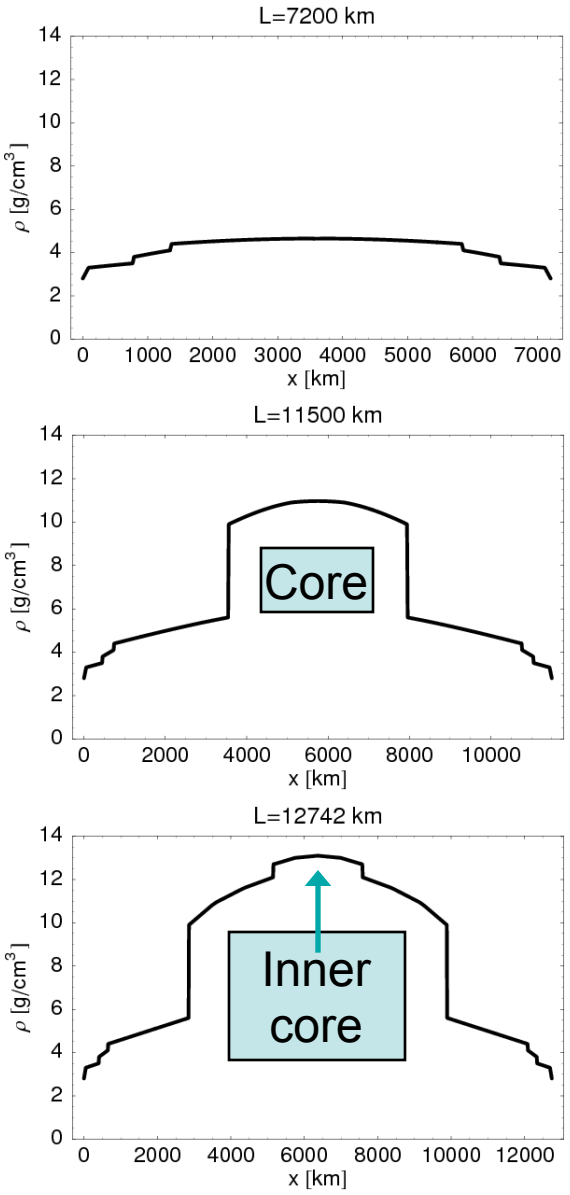
Wavelength shifters to save $$$?



Neutrino profiling of the Earth

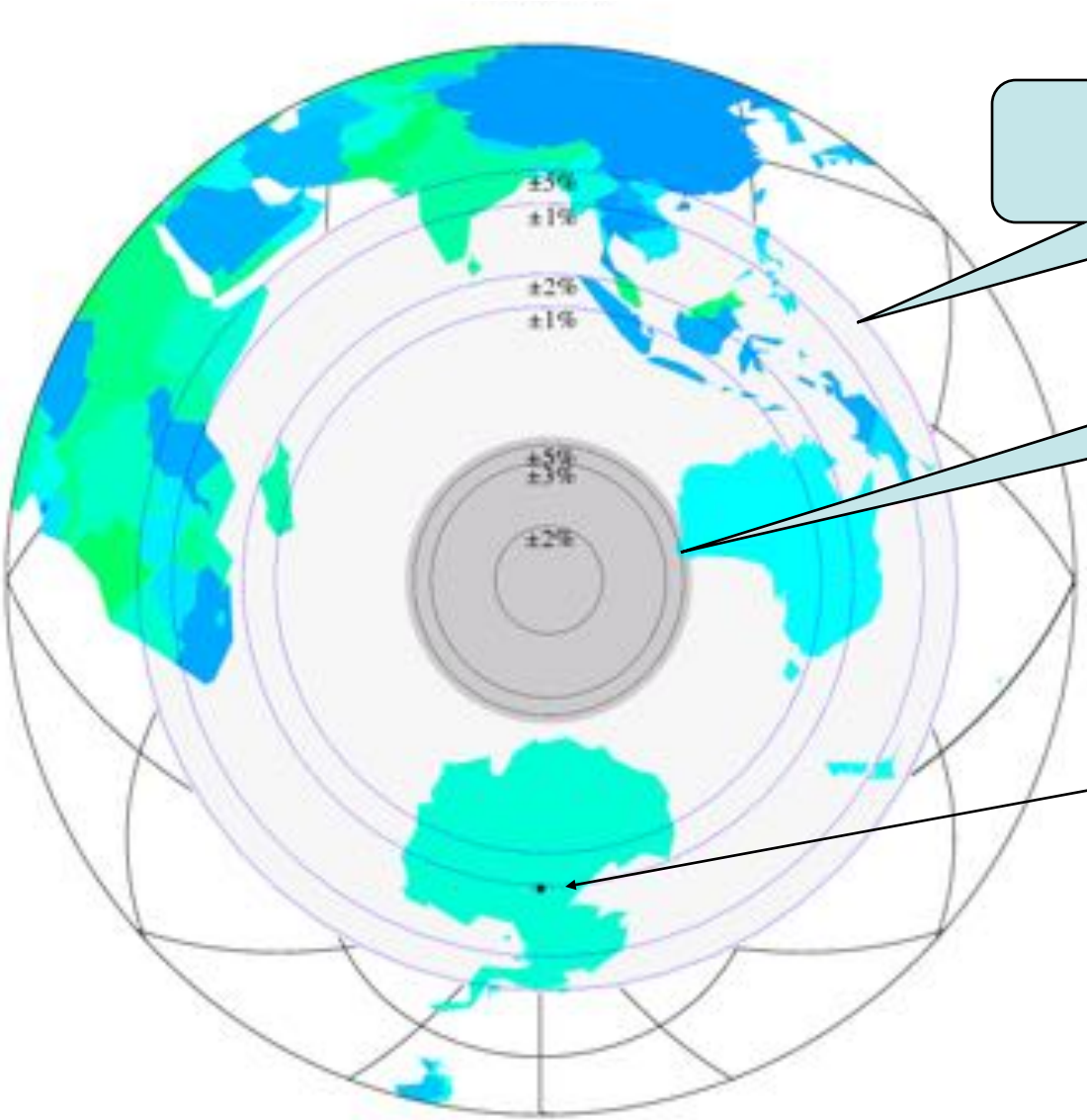
Source: Neutrino factory from Fermilab





(PREM: Preliminary Reference Earth Model)

Neutrino profiling of the Earth



Outer core shadow

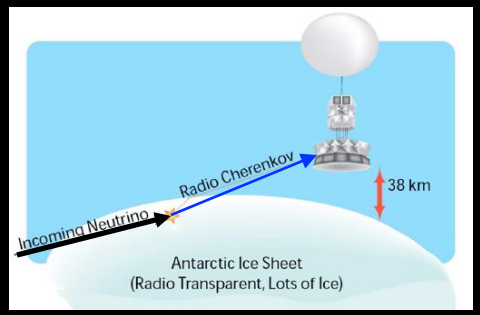
Inner core shadow

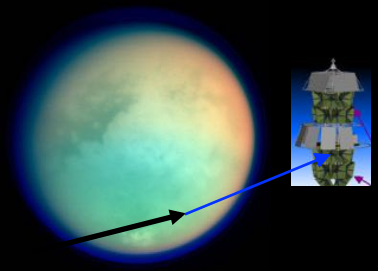
Measure density of Earth‘s core to 1%

Very High Energy ("GZK") Neutrino Detectors

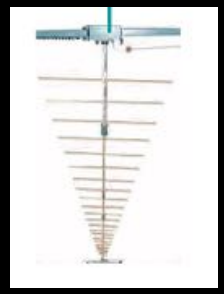
- Long distance experiments (no drilling):

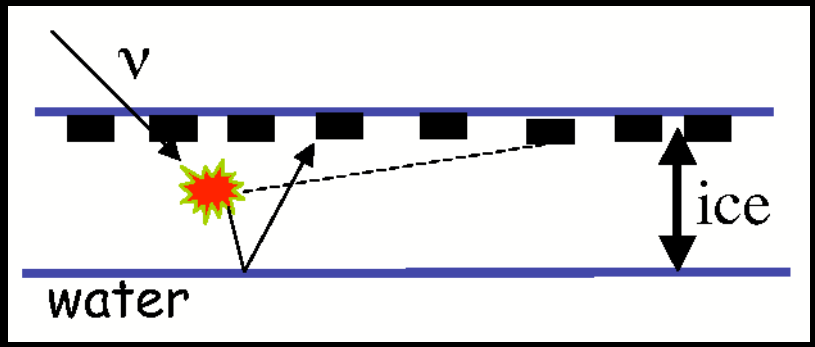
ANITA-like





ARIANNA-like



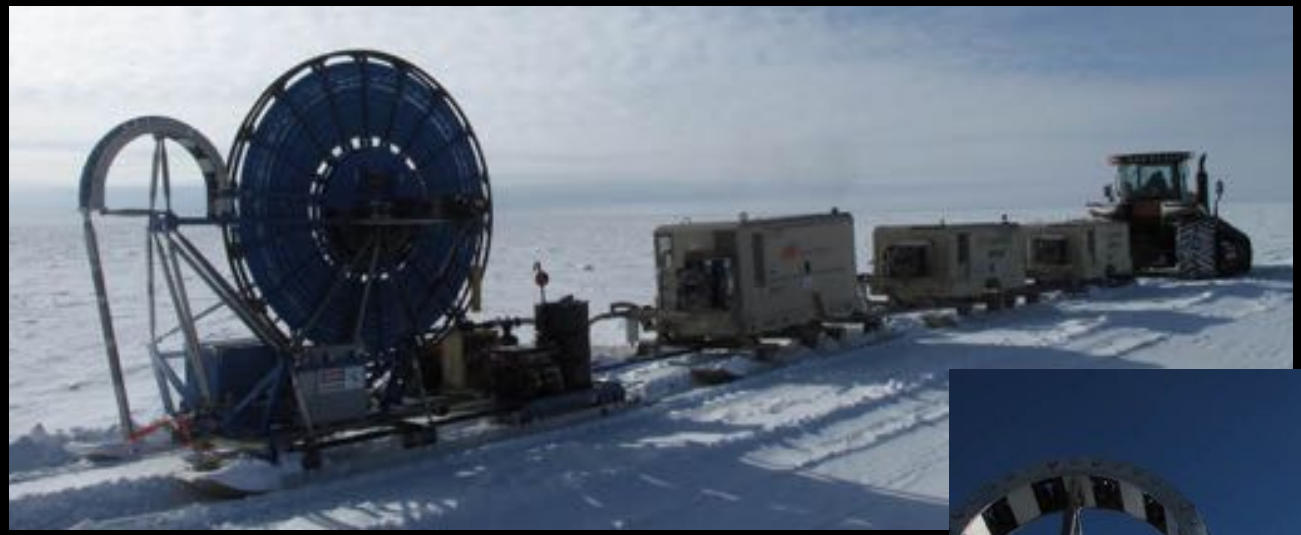


- Askaryan Radio Array (ARA)

Askarayan Radio Array (ARA)

- Radio Cherenkov (Askarayan) radiation
- 10^{16}-10^{17} eV threshold ᛉ sensors *in ice*
- Need **100** km^3 to detect 100 events in 3-5 years
- Imaging Askarayan cone ᛉ 100m detector spacing
- Full (constant) density ice ᛉ deeper than 150 m
- Sensitivity ≥150 MHz ᛉ 15 cm holes, antennas

South Pole RAM drilling 2010-11

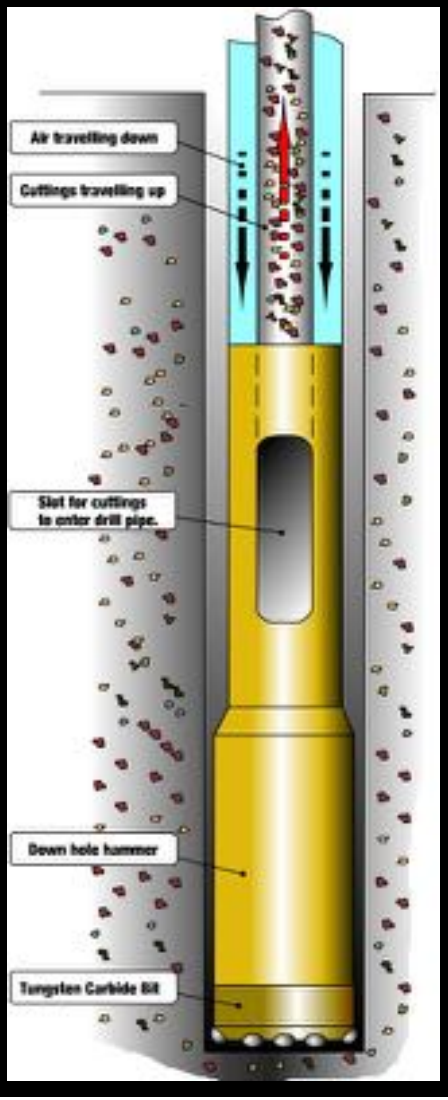


As expected, firn air loss is a serious problem

RAM has potential, probably not suitable for ARA

Drilling technology for ARA

- For now, mini-hot-water drilling



- Future: Reverse circulation drilling →

Beacons & Standard Candles

- High Power Radio Beacon (Bob Morse, U. Hawaii)

  Minimum 1 km deep to illuminate ARA
  (200 m array  5 km radius)

  Passive downhole electronics
  - low-loss cable 100 MHz – 1 GHz
  - 20 year service life

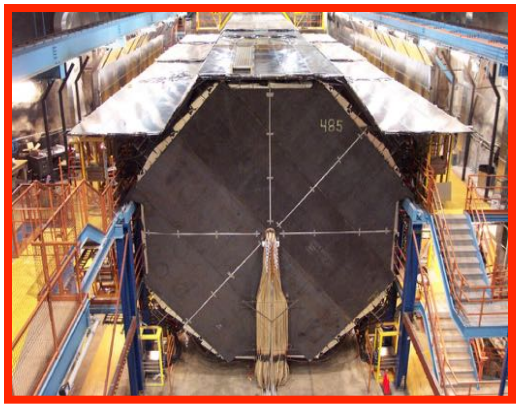
- ***South Pole ice core***

  Core: radio / optical / acoustic ice characterization

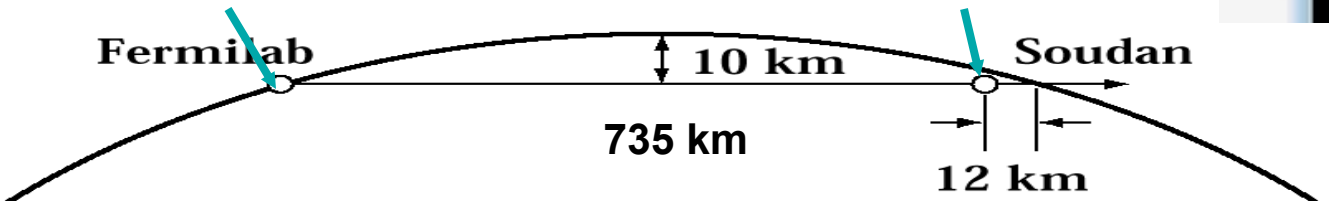
  Borehole: access point for beacons

Neutrino Beams

Near detector: 980 ton



Far detector: 5400 ton



Source: MINOS

Borehole laser dating