

# Opportunities for particle physics experiments in salt caverns

Benjamin Monreal, UC Santa Barbara  
[bmonreal@physics.ucsb.edu](mailto:bmonreal@physics.ucsb.edu)  
<http://hep.ucsb.edu/saltcaverns>

- 1) Overview of underground particle physics
- 2) Why I'm interested in salt caverns
- 3) What kind of detector technologies could we install in a salt cavern?

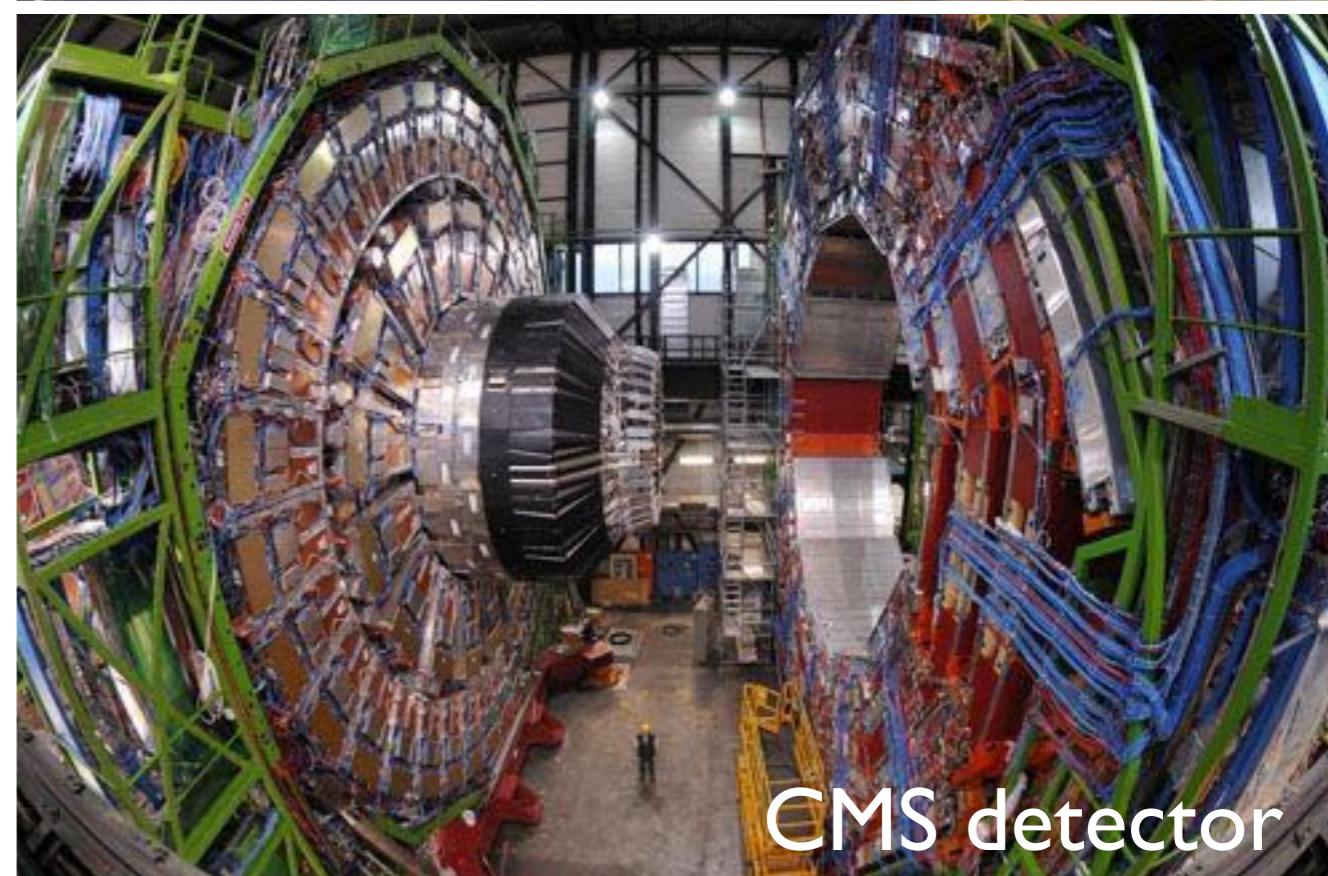
# What do we do aboveground?

- 1) Bring particle beams into violent artificial collisions
- 2) Detect everything that comes out
- 3) Sift through billions of collisions and look for new phenomena

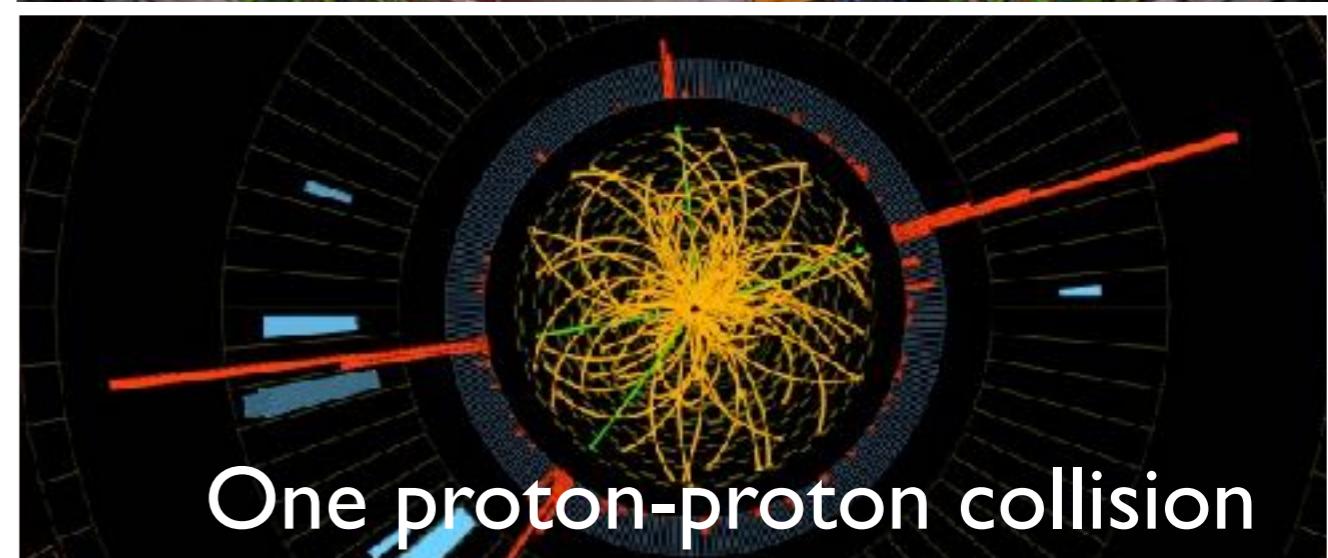
- 2012: Higgs boson
- 1995: Top quark
- 1983: W,Z bosons
- 1975: Tau lepton
- 1974: Charm quark



Large Hadron Collider, CERN



CMS detector

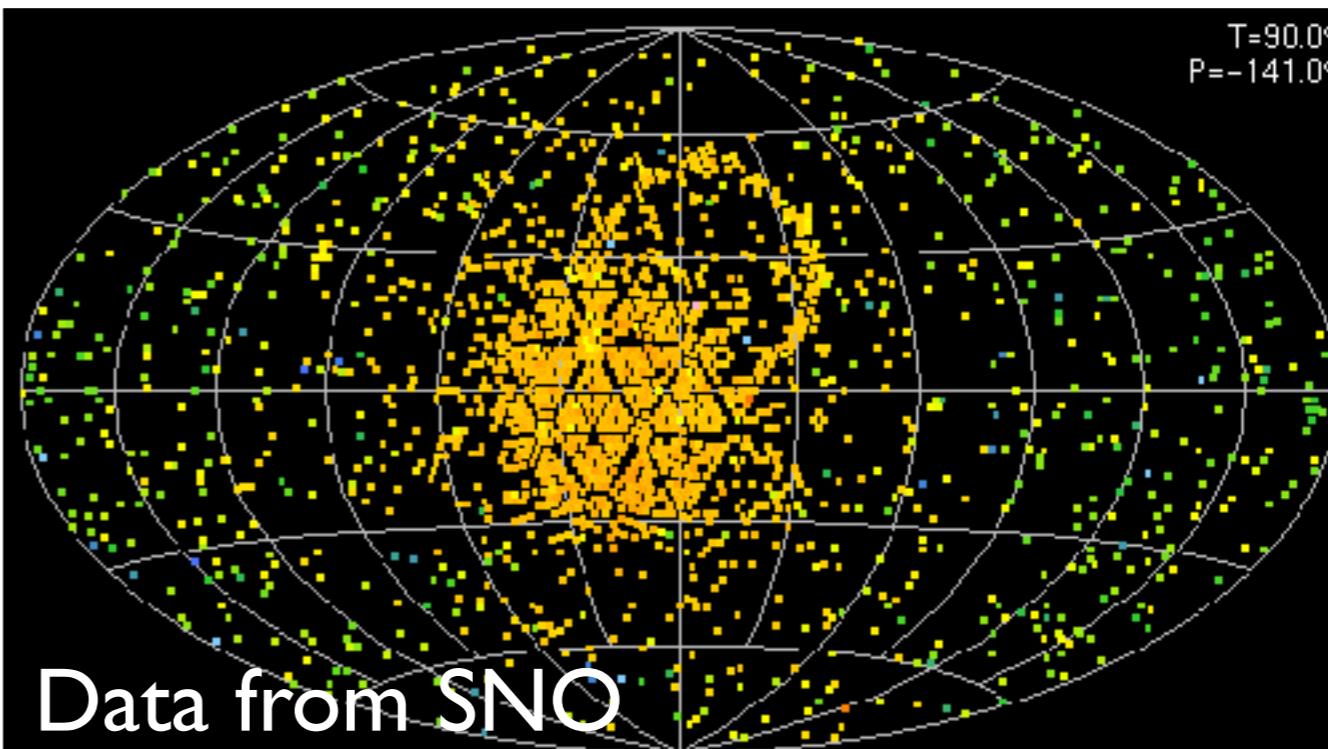


One proton-proton collision

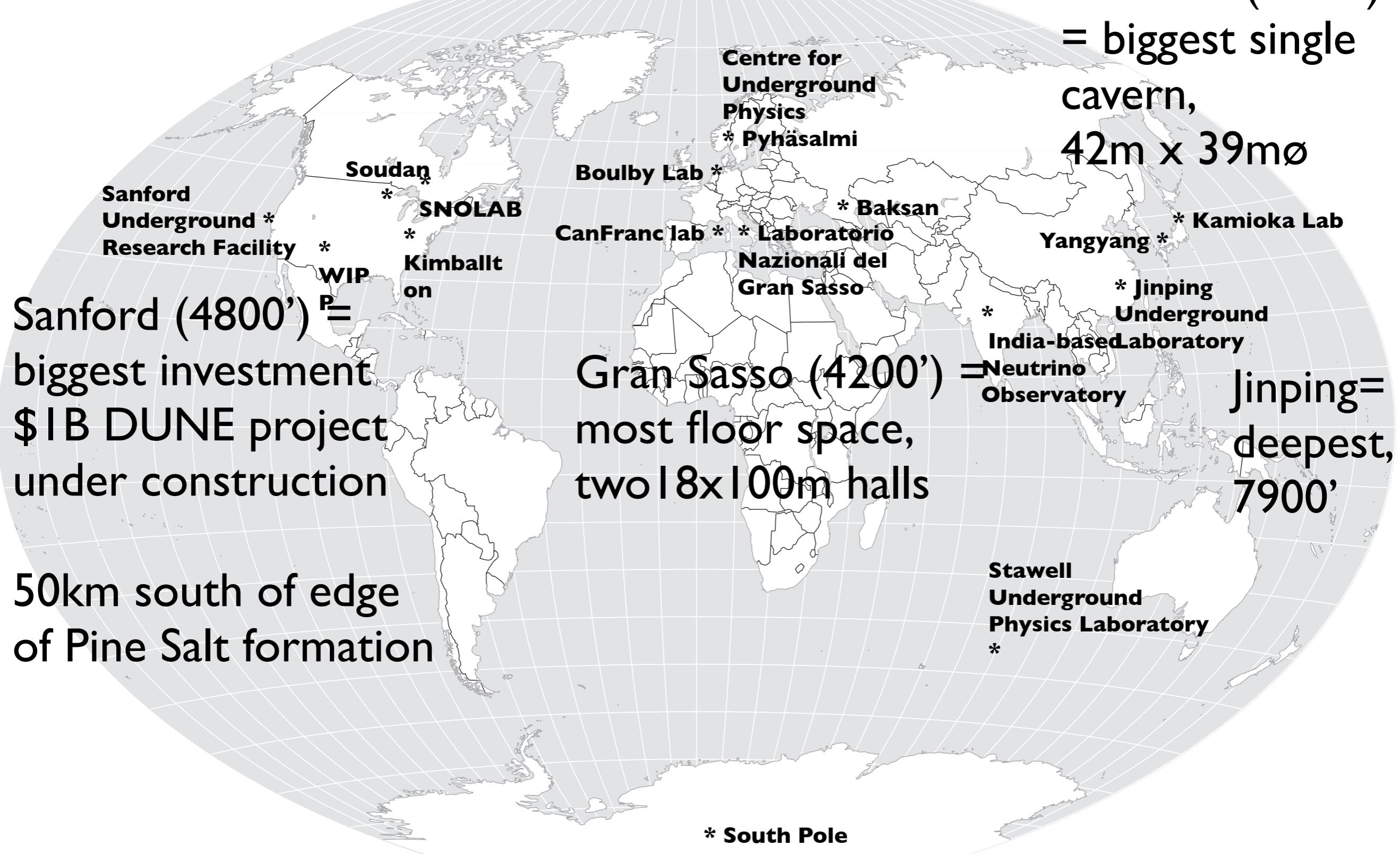
# What do we do underground?

- 1) Build particle detectors in heavily shielded places
  - 1) escape cosmic rays
- 2) Detect ultra-rare events from "natural" beams
- 3) Detect ultra-rare radioactive decay modes

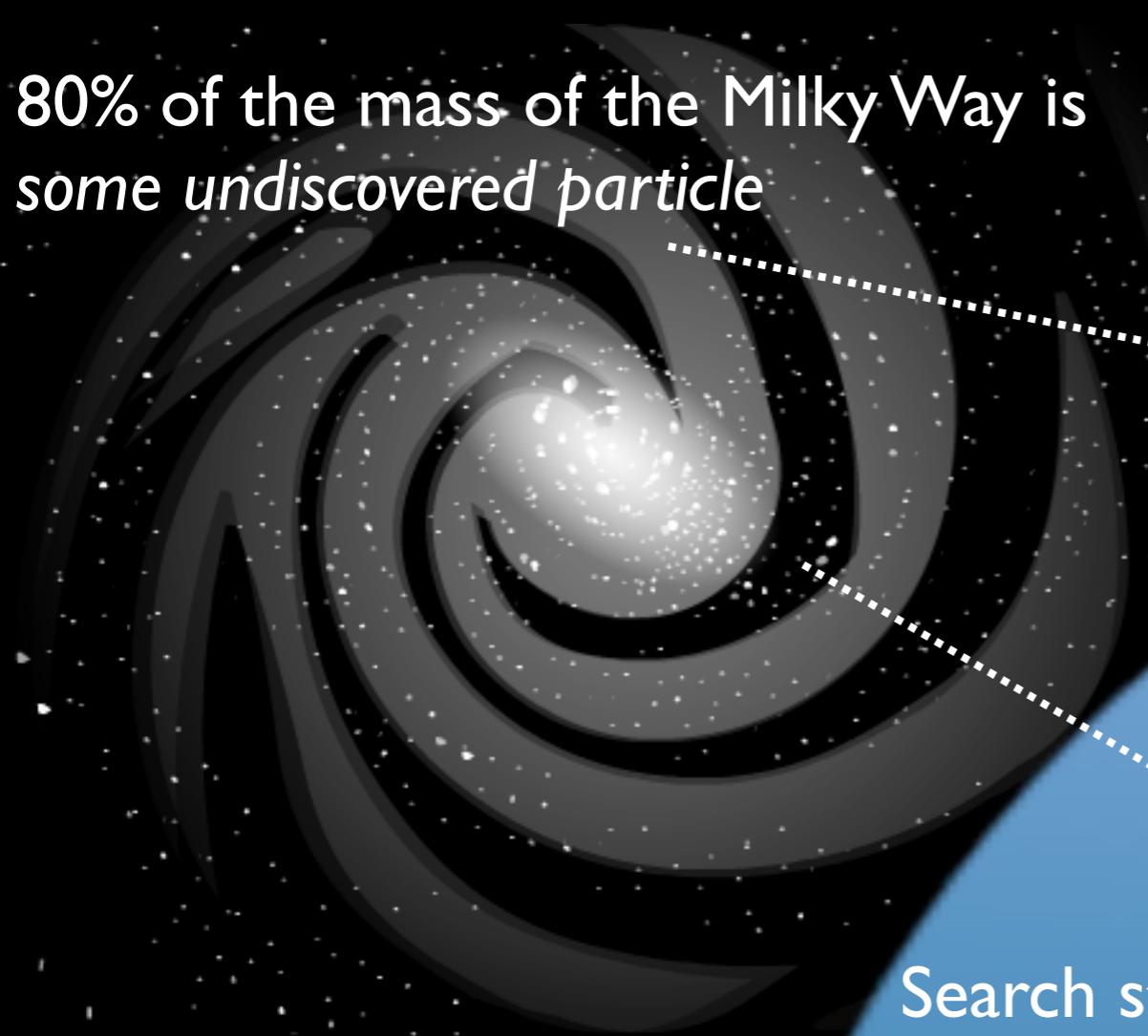
- 2015 Neutrino flavor change
- 2002 Cosmic neutrinos
- 1995 Reactor neutrinos
- 1988 Neutrino beams



# Where does this happen?

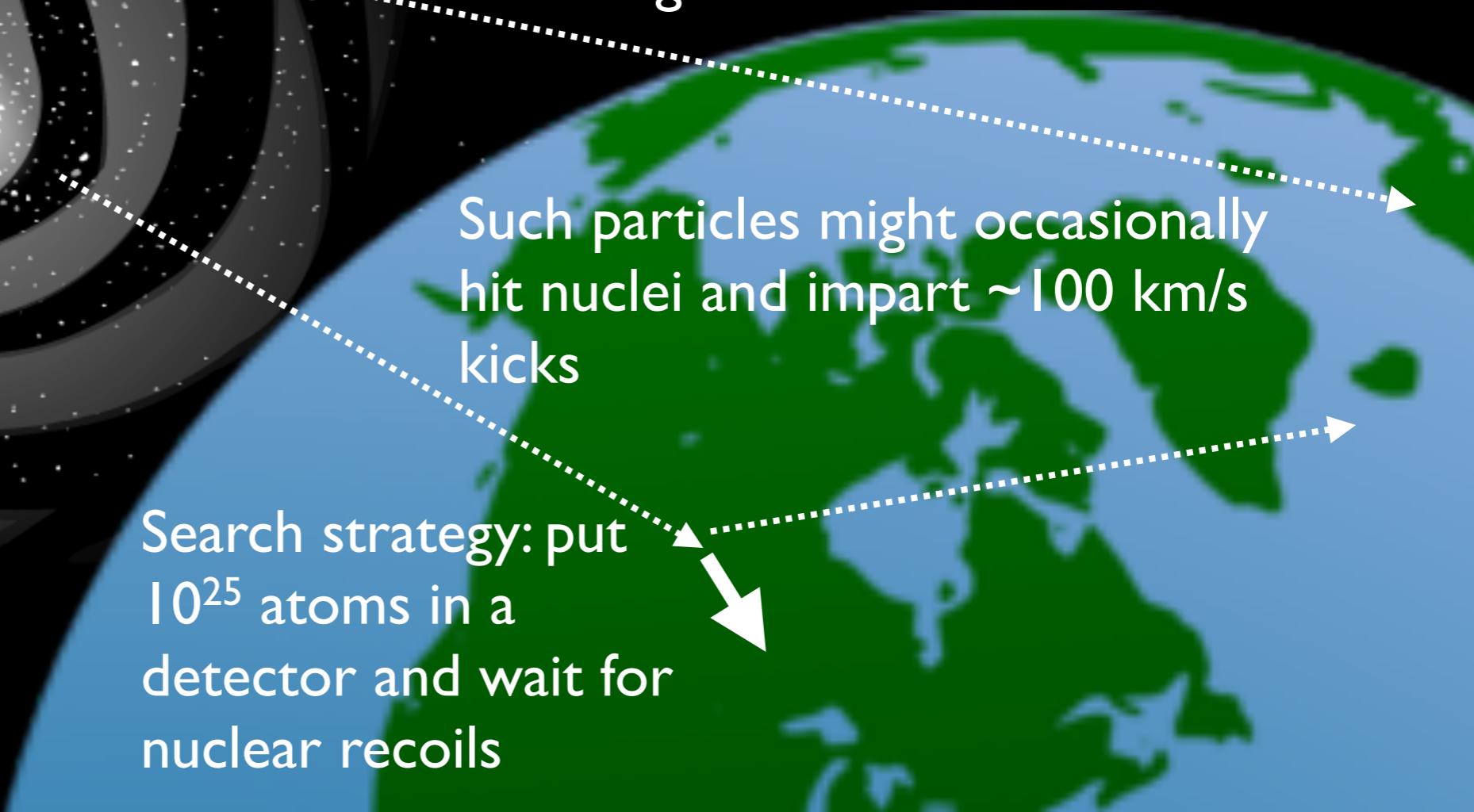


# Dark matter



80% of the mass of the Milky Way is  
*some undiscovered particle*

It may be weakly-interacting  
particles which mostly pass right  
through the Earth at 200 km/s

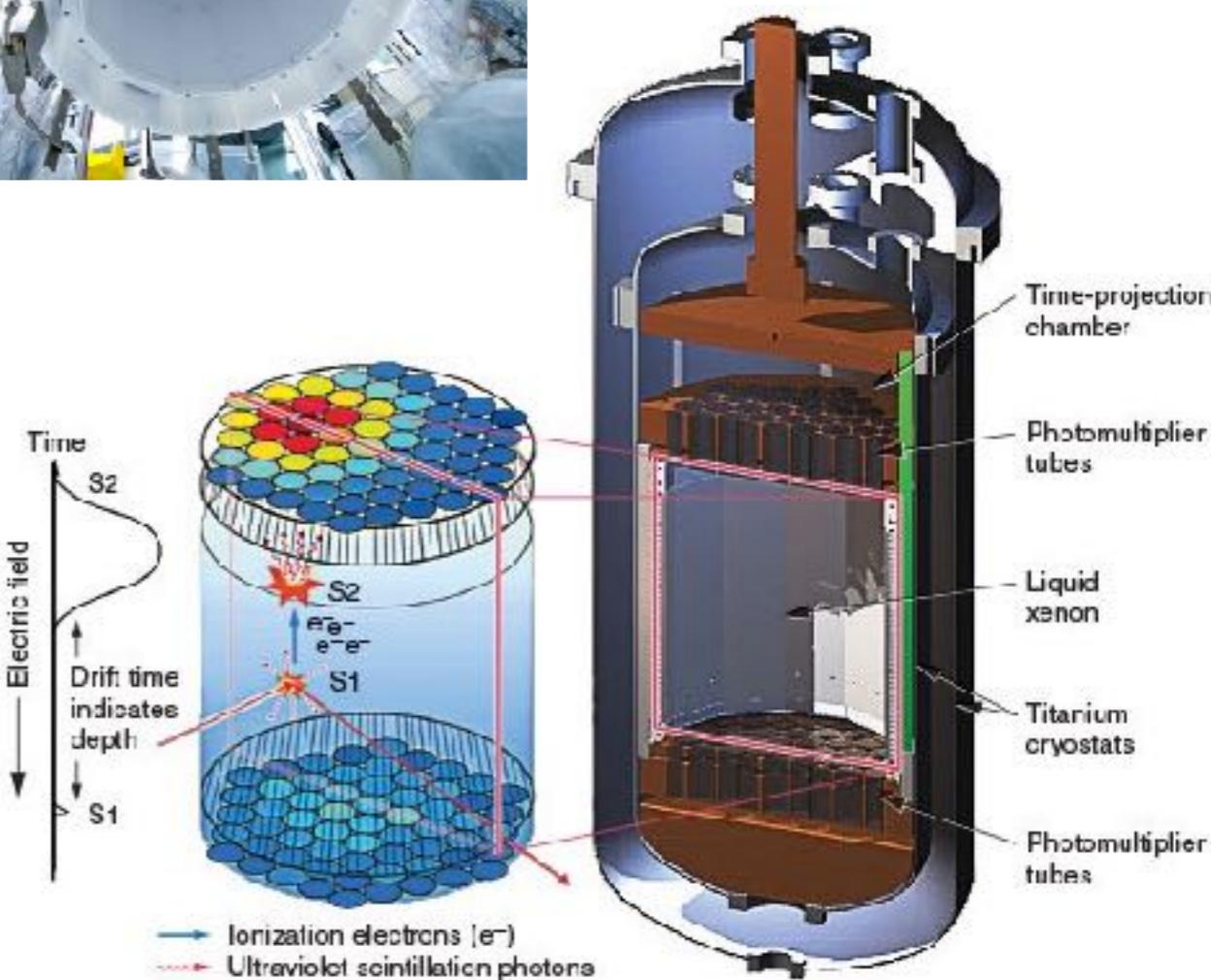
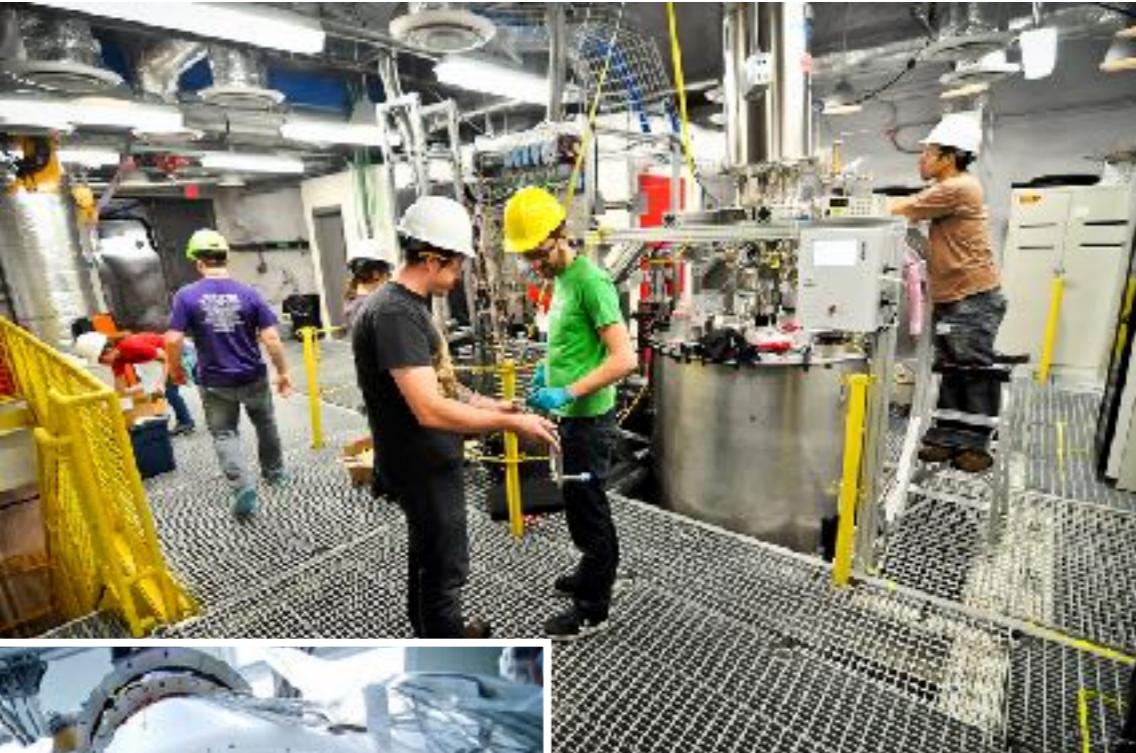


Such particles might occasionally  
hit nuclei and impart  $\sim$ 100 km/s  
kicks

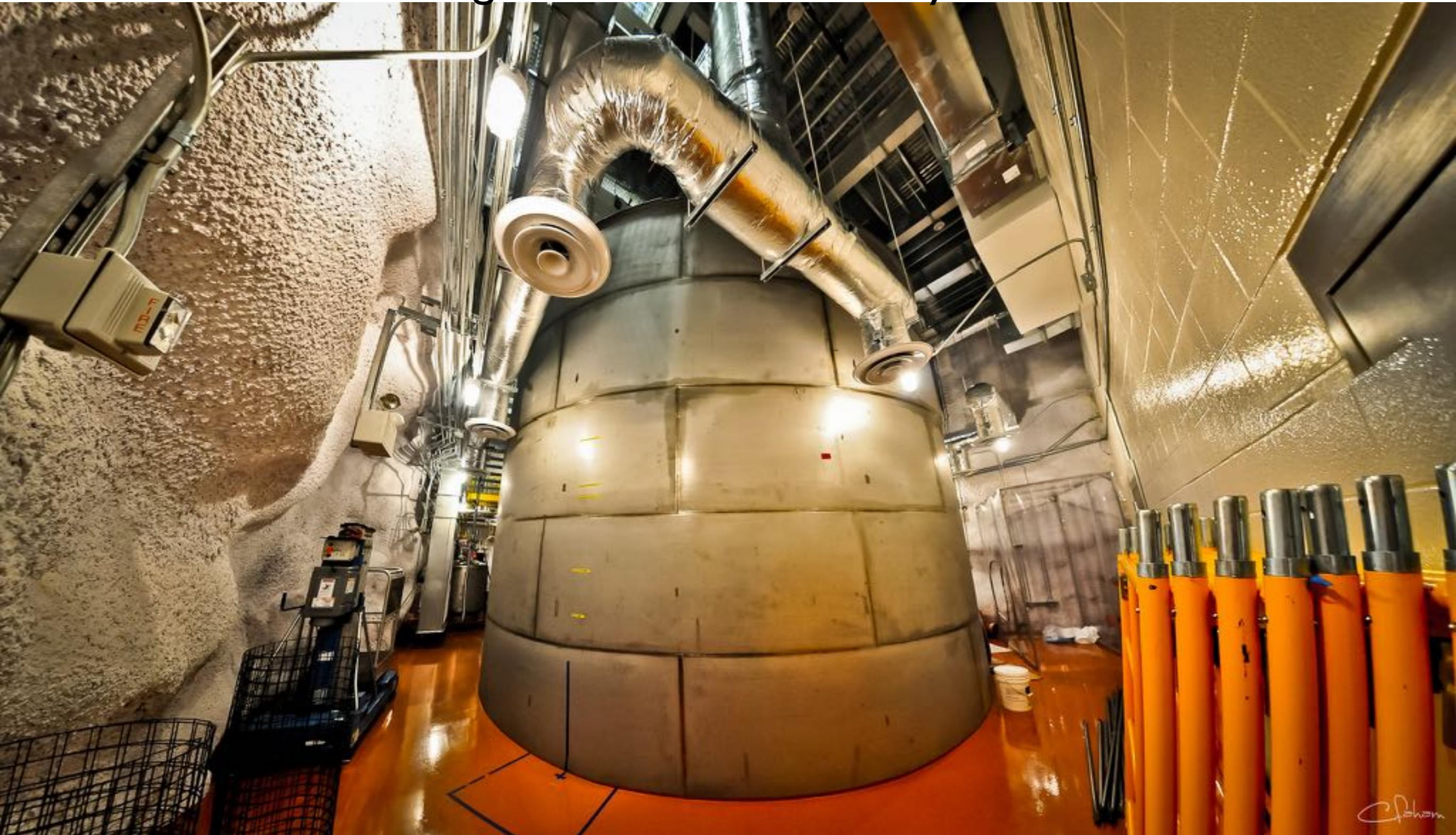
Search strategy: put  
 $10^{25}$  atoms in a  
detector and wait for  
nuclear recoils

# LUX: a typical dark matter search experiment

- 370 kg liquid xenon
- A xenon nucleus, struck by a dark matter particle, would leave a trail of  $\sim 100$  ionized atoms behind
- Made of copper, titanium, quartz, teflon to minimize radioactivity
- 85 day run in 2013 saw zero events; world-record sensitivity



# Sanford Underground Research Facility, 4,850 foot level

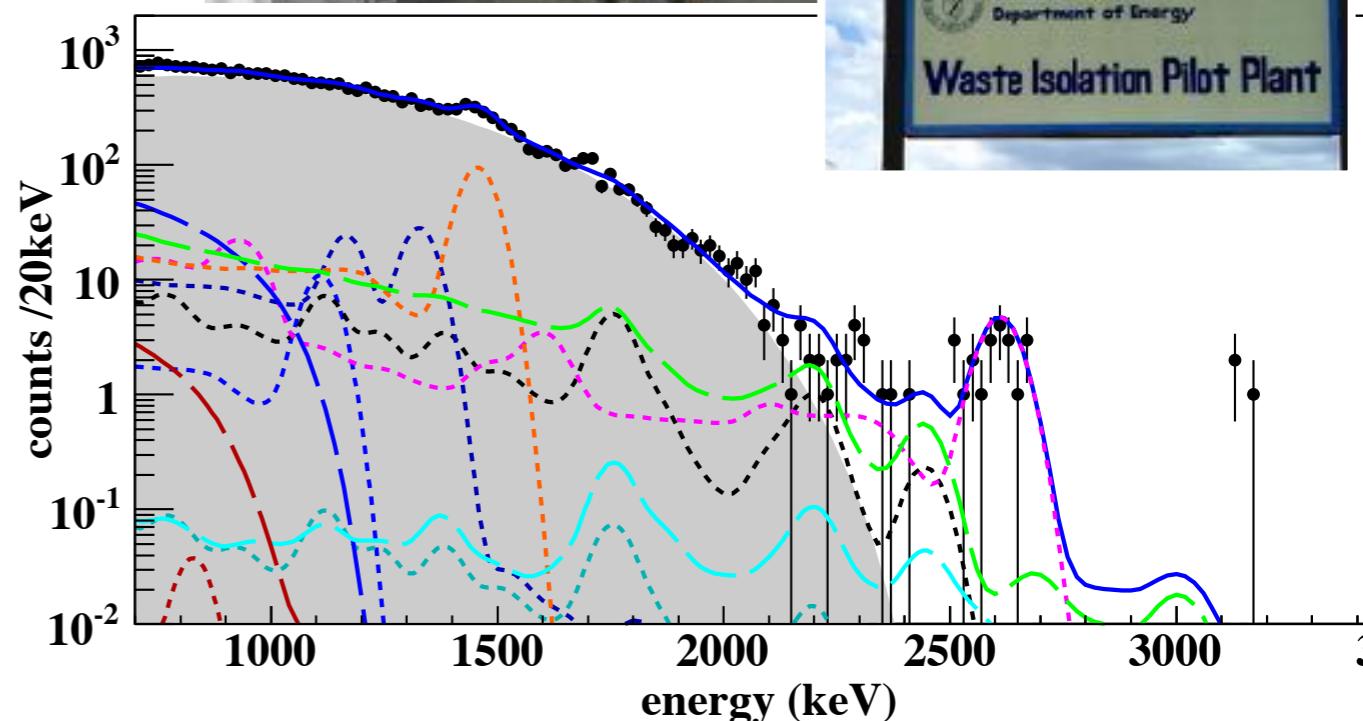
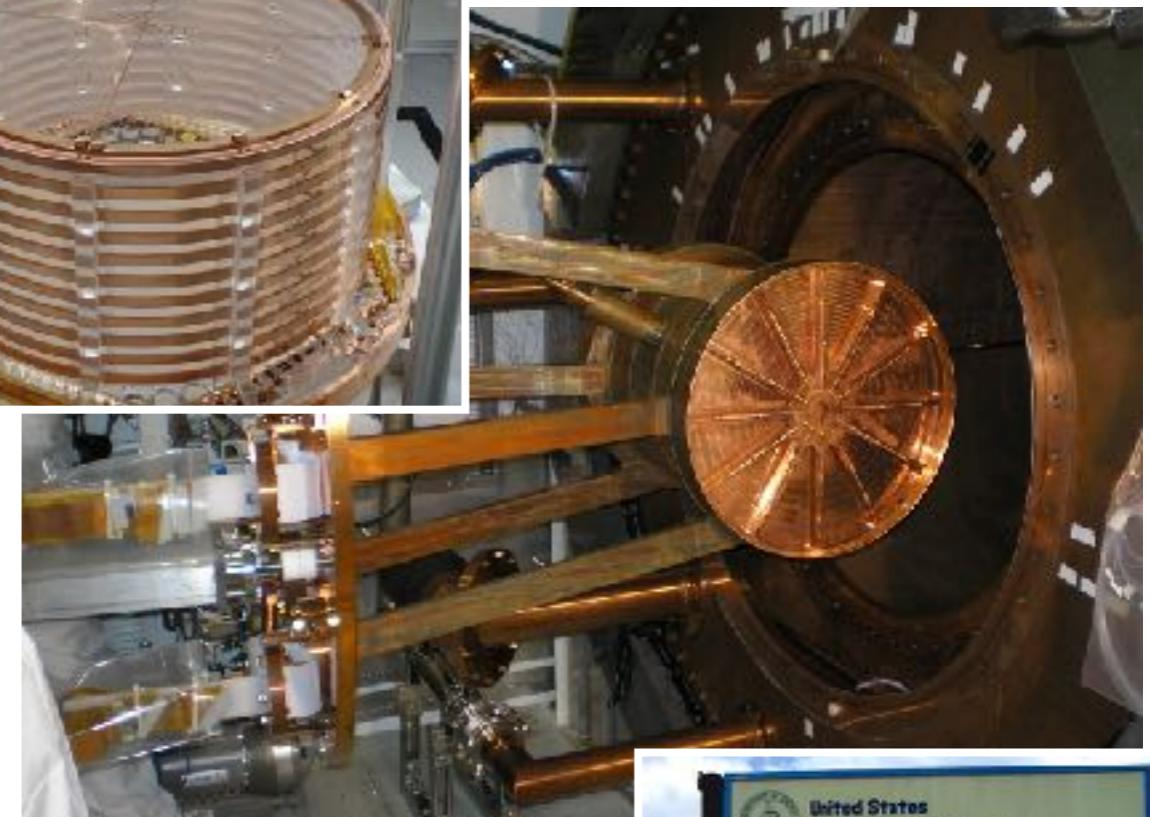


rock, shotcrete  
include lots of  
 $^{40}\text{K}$ ,  $^{238}\text{U}$ ,  $^{232}\text{Th}$

6m water tank to  
block neutron and  
gamma radiation

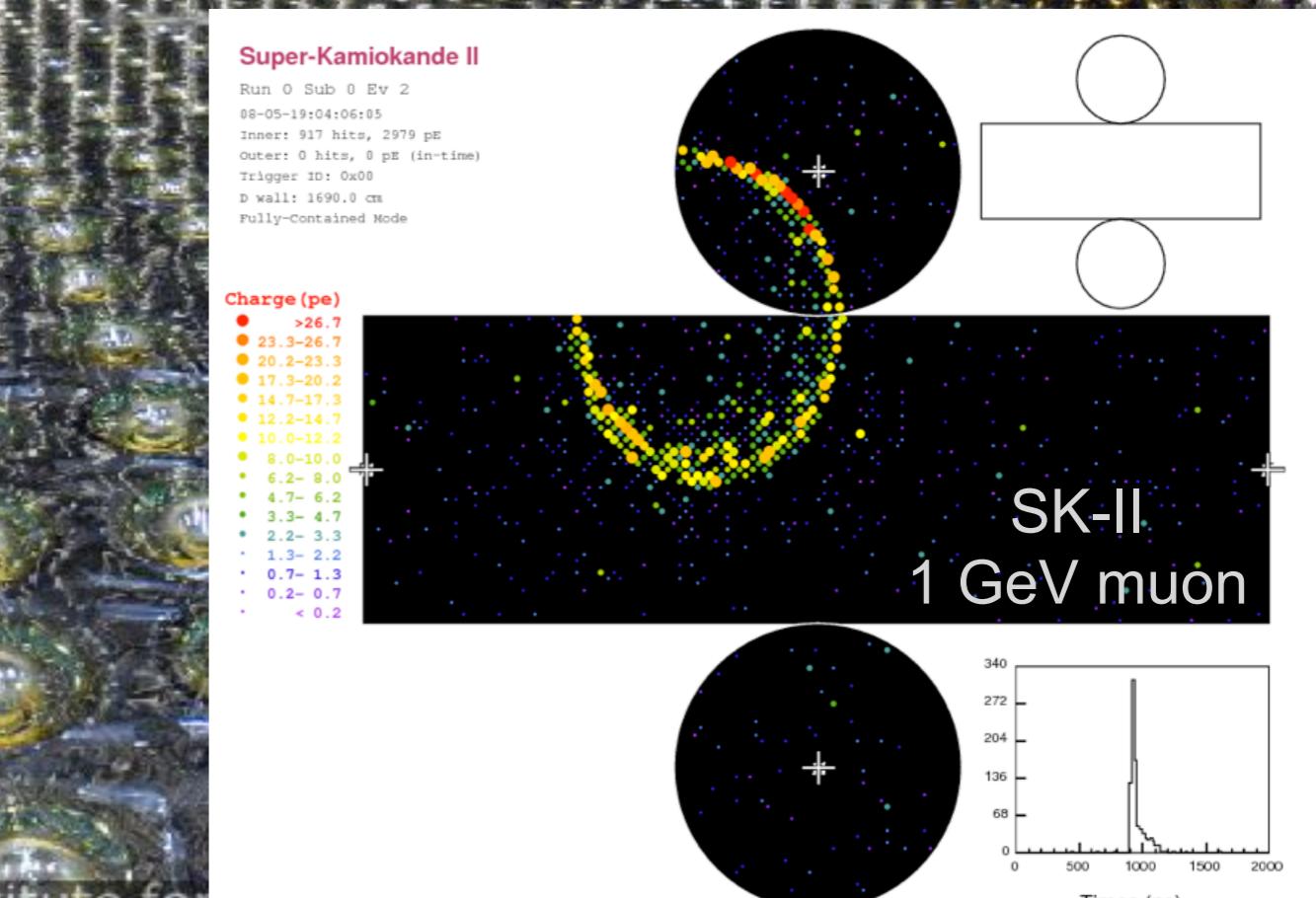
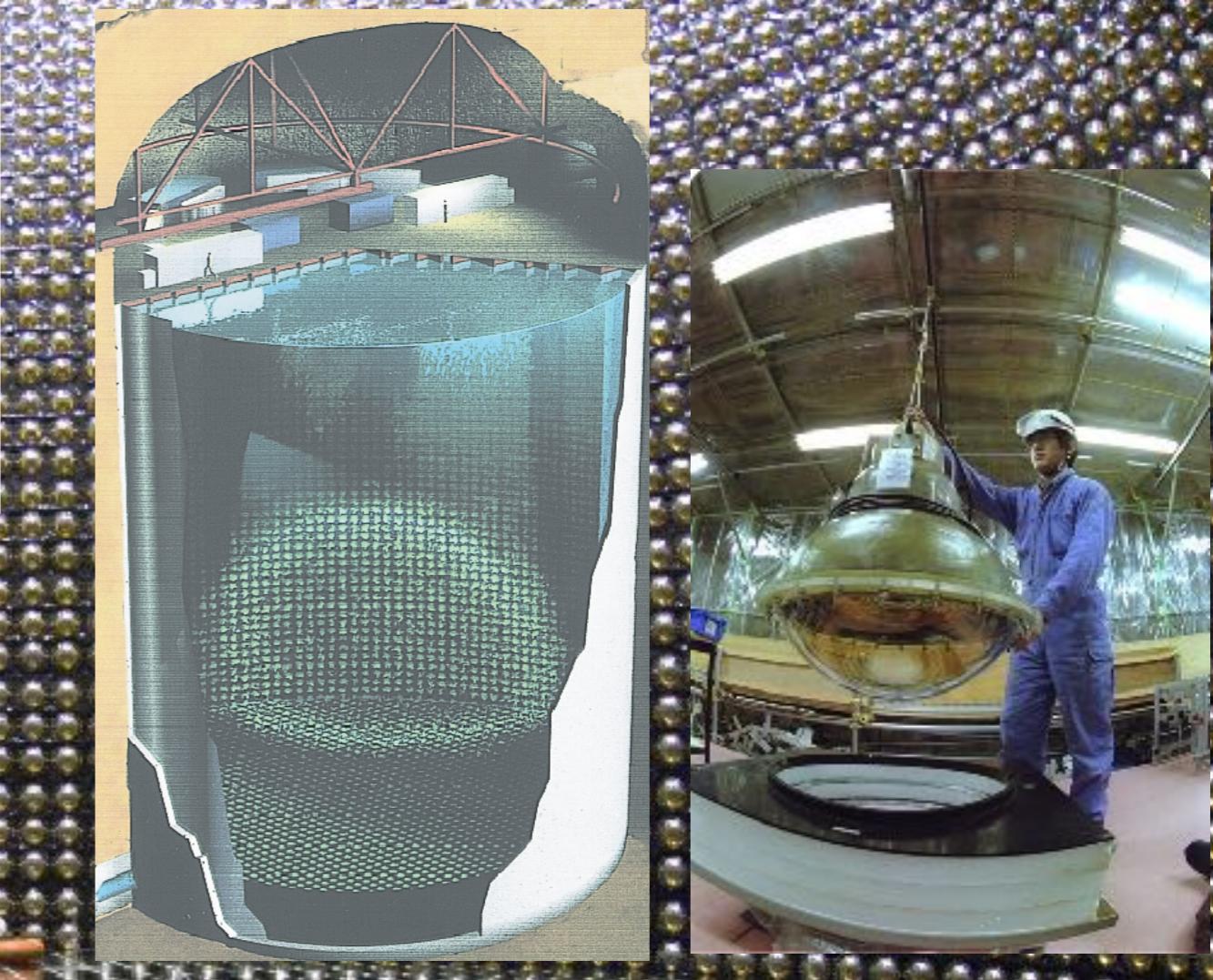
# EXO: Searching for the rarest nuclear decays

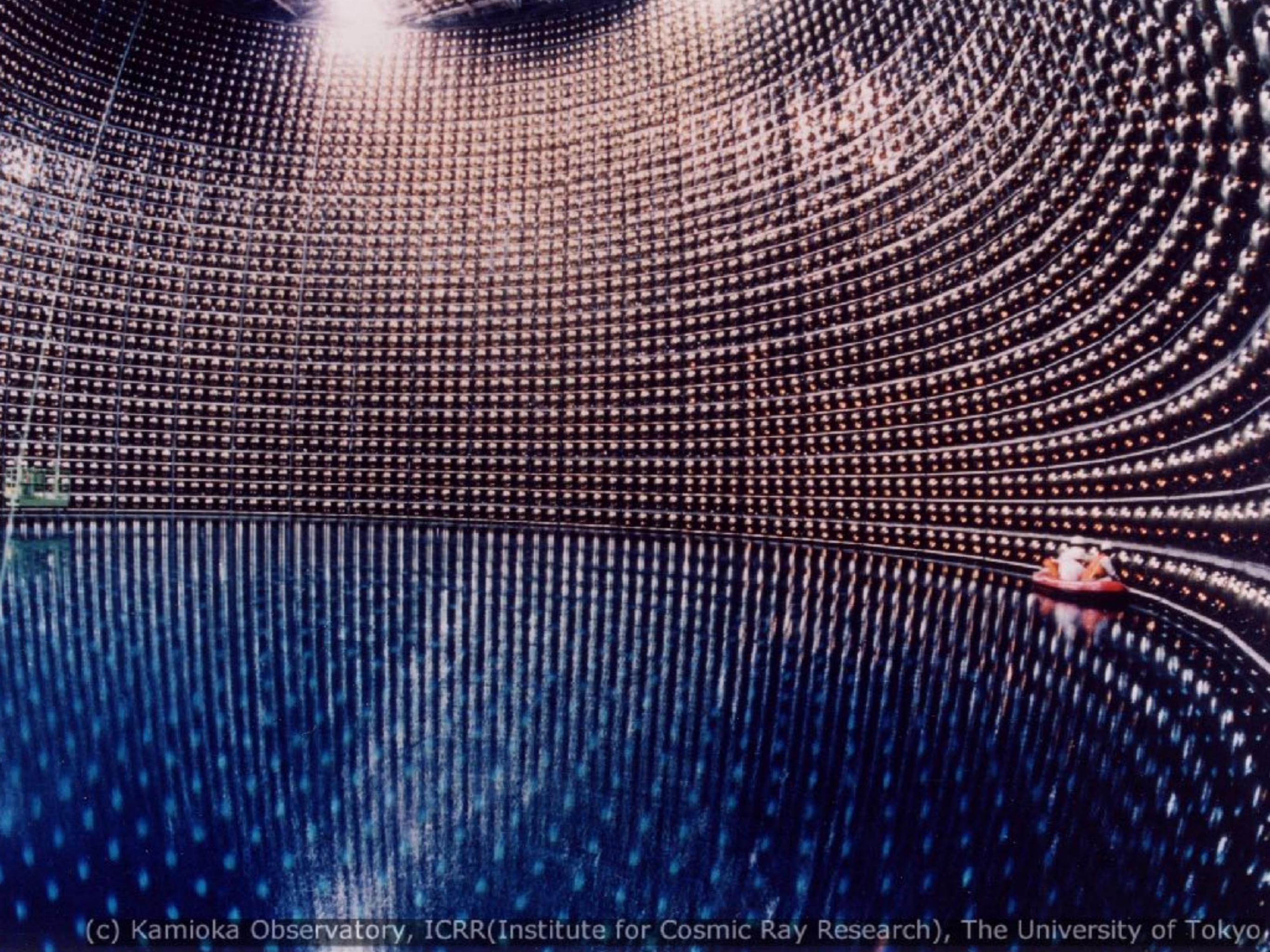
- 200 kg isotope-enriched liquid xenon-136
- "neutrinoless double beta decay" has not yet been observed:  
 $^{136}\text{Xe} \rightarrow ^{136}\text{Ba}^{++} + 2\text{e}^-$
- Easily mistaken for gamma ray
- Huge effort to minimize radioactive materials, maximize shielding ... but that's hard to do in a cryostat.



# Super-Kamiokande: a large neutrino experiment

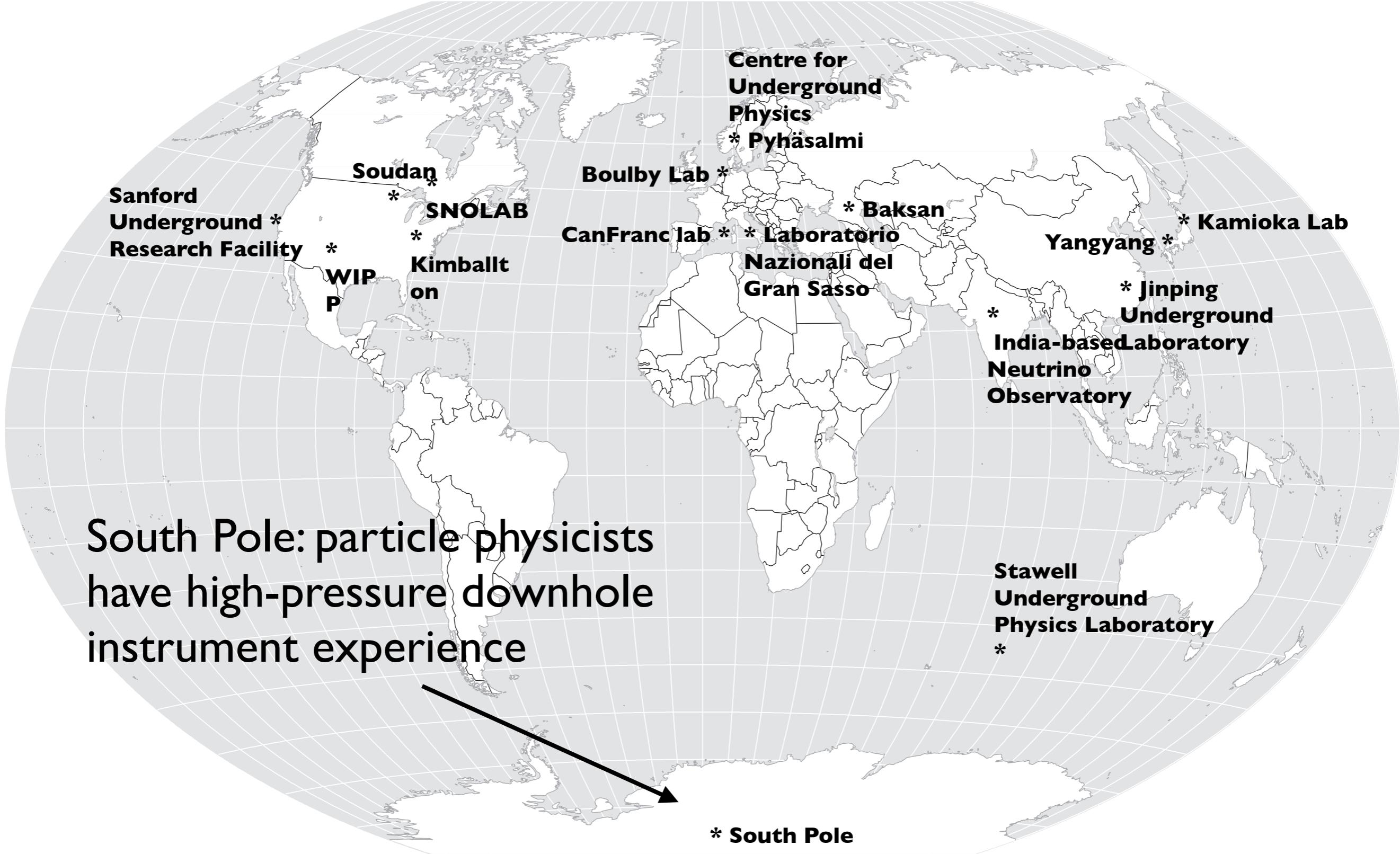
- 50 kT water tank  $39\varnothing \times 42\text{m}$
- Neutrino from cosmic source collides with water and become a muon; muon track emits cone of light
- 11,000 photomultiplier tubes detect light
- Only  $\sim 10$  a day
- Neutrino arrival direction and flavor counts revealed new physics (oscillations)





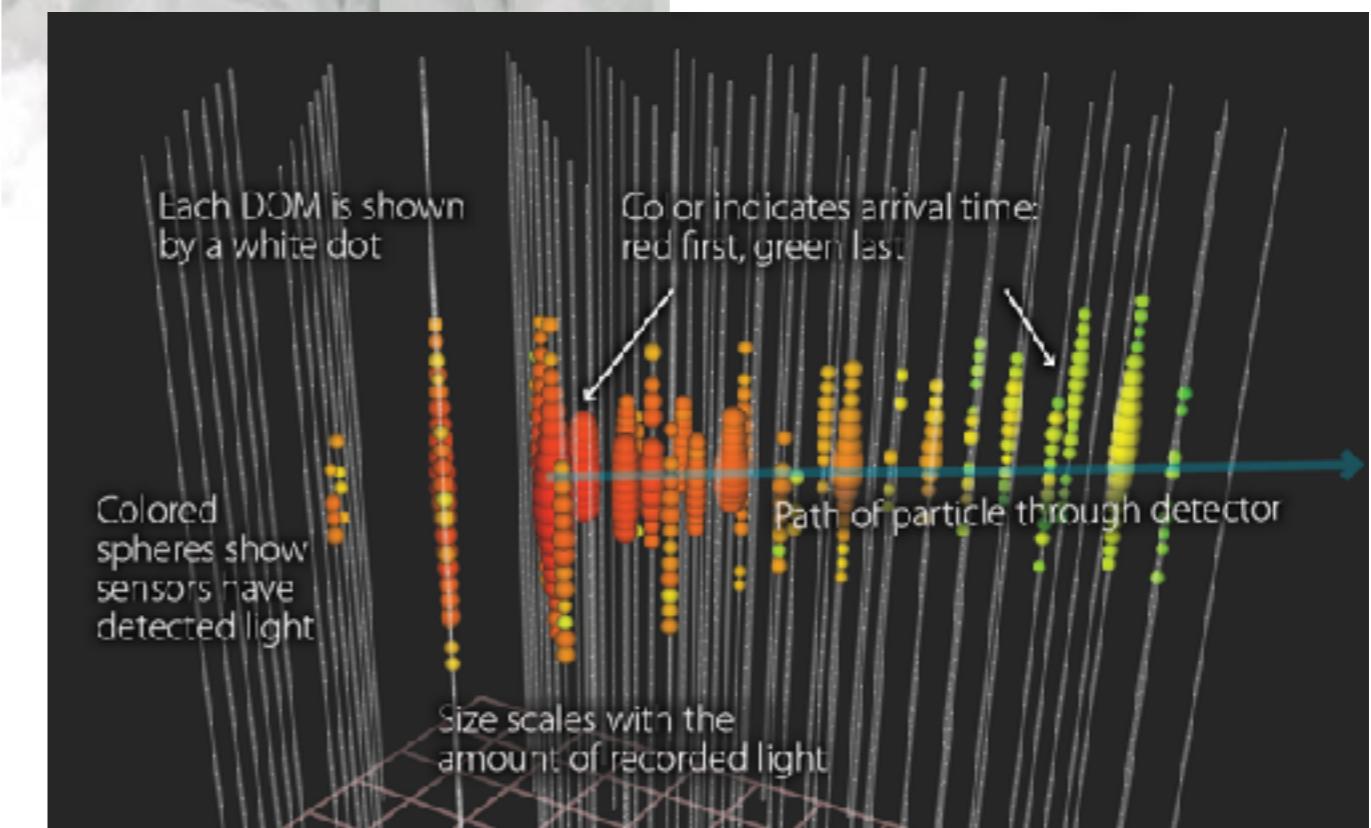
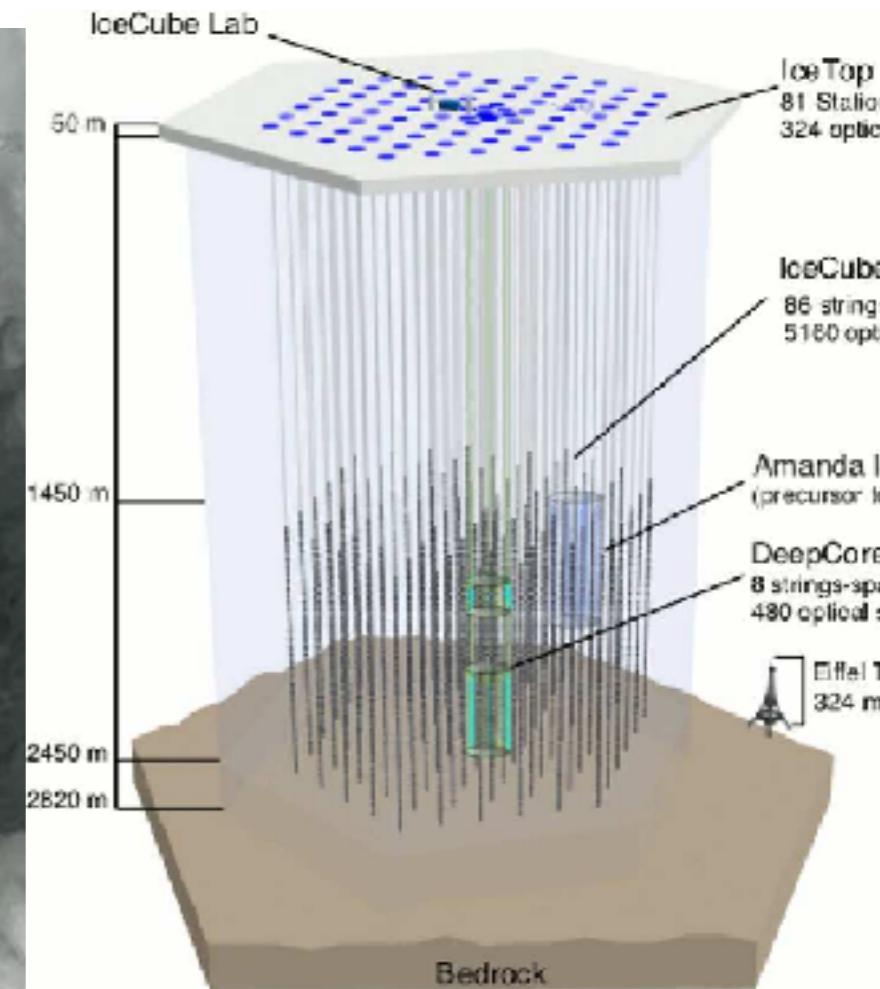
(c) Kamioka Observatory, ICRR(Institute for Cosmic Ray Research), The University of Tokyo,

# Where does this happen?



# IceCube

- Antarctic ice cap is incredibly pure, transparent ice. Turn  $1\text{ km}^3$  block into a detector
- Custom hot-water drill bores holes to 2450m
- "String": 60 photosensors in Benthos pressure vessels on a cable
- ~ \$300M project cost
- Science goal: neutrinos from distant galaxies



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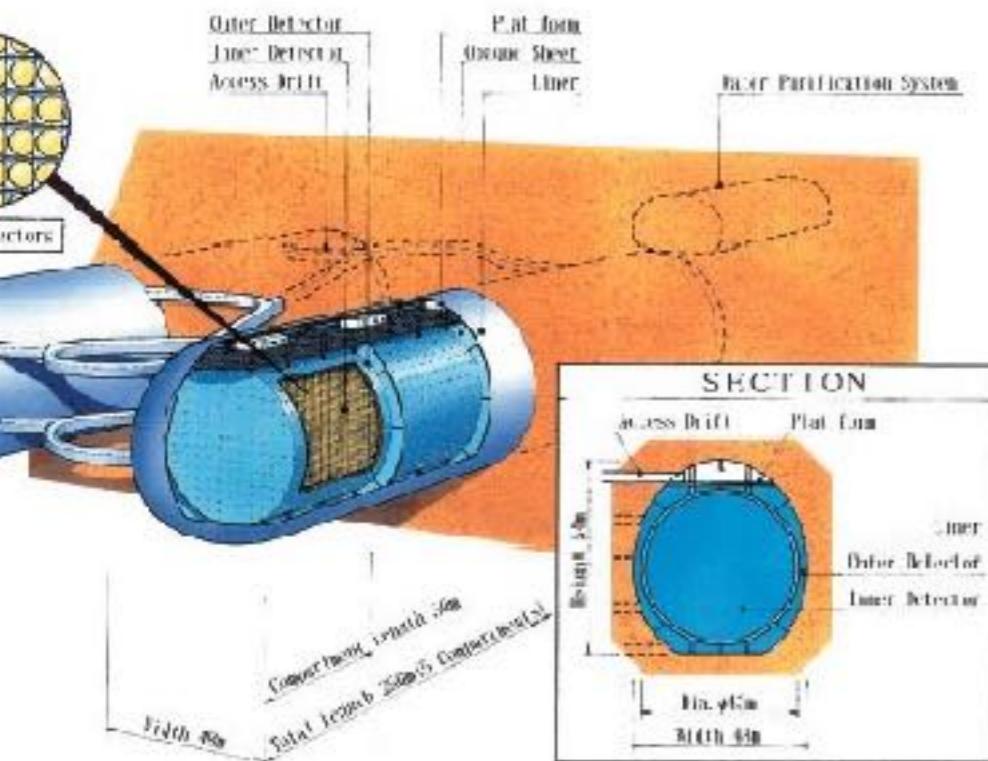
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# Why I'm interested in salt caverns

Affordable space:

- 1) Small experiments want thicker water shielding
- 2) Some physics goals demand megaton targets
- 3) Mine development costs \$1000/m<sup>3</sup> in the US



\$900M Hyper-Kamiokande proposal  
500 kT water in two large halls

High pressure:

- 1) High-pressure xenon is often a better ionization medium than liquid xenon
- 2) Pressure-vessel engineering is too hard (mass, cost, radioactivity)



Access to flammable gases:

- 1) CH<sub>4</sub> and H<sub>2</sub> targets for antineutrino experiments
- 2)  $\bar{\nu} + H \rightarrow e^+ + n$
- 3) Prohibitive safety issues in conventional labs



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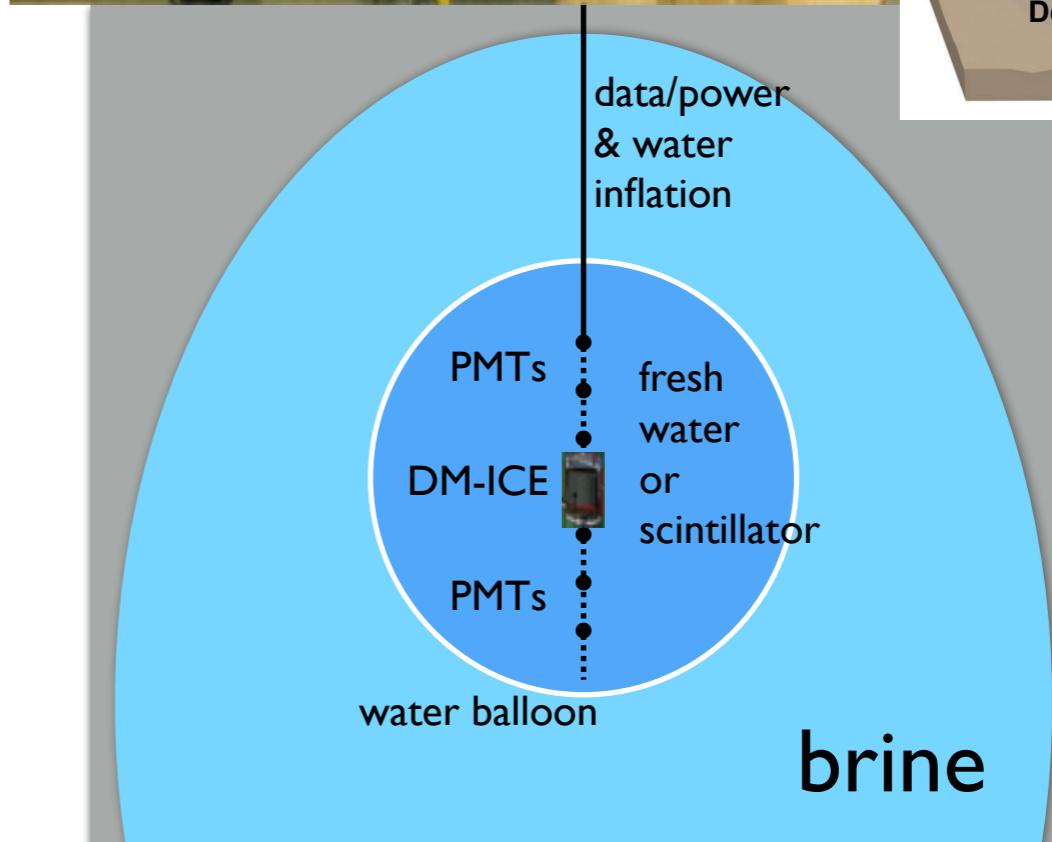
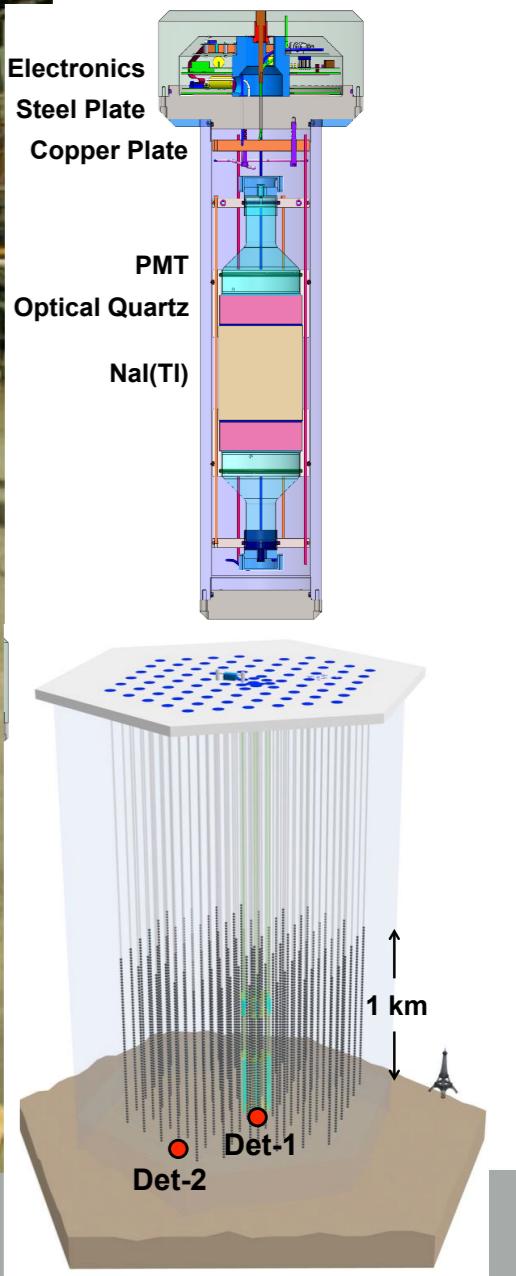
# What kind of detector technologies could we install in a salt cavern?

- We have brainstorming-level ideas, not real engineering designs
- Some of these ideas are probably unrealistic
- That's part of why I am here

# Simple: DM-ICE

- 17kg scintillating crystal, sensitive to dark matter
- Pressure-hardened! Two units already using deep polar ice as low-background environment
- Salt cavern with some muon veto = lower background, easier logistics
- Existing hardware fits down 14" borehole
- Design studies for 250kg upgrade with 27" bore

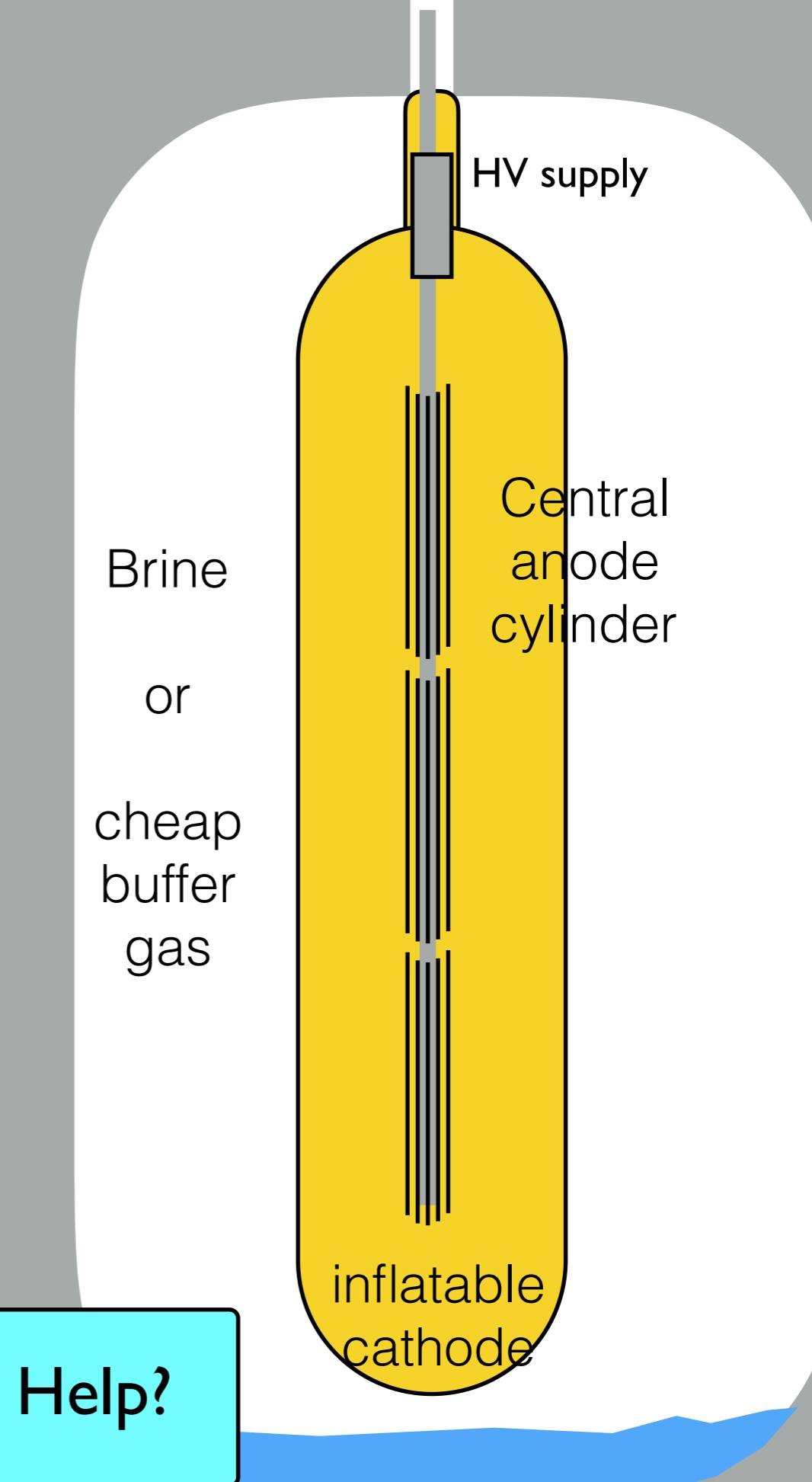
Question #1: what constrains bore diameters?



# Medium complexity: inflatable drift chamber

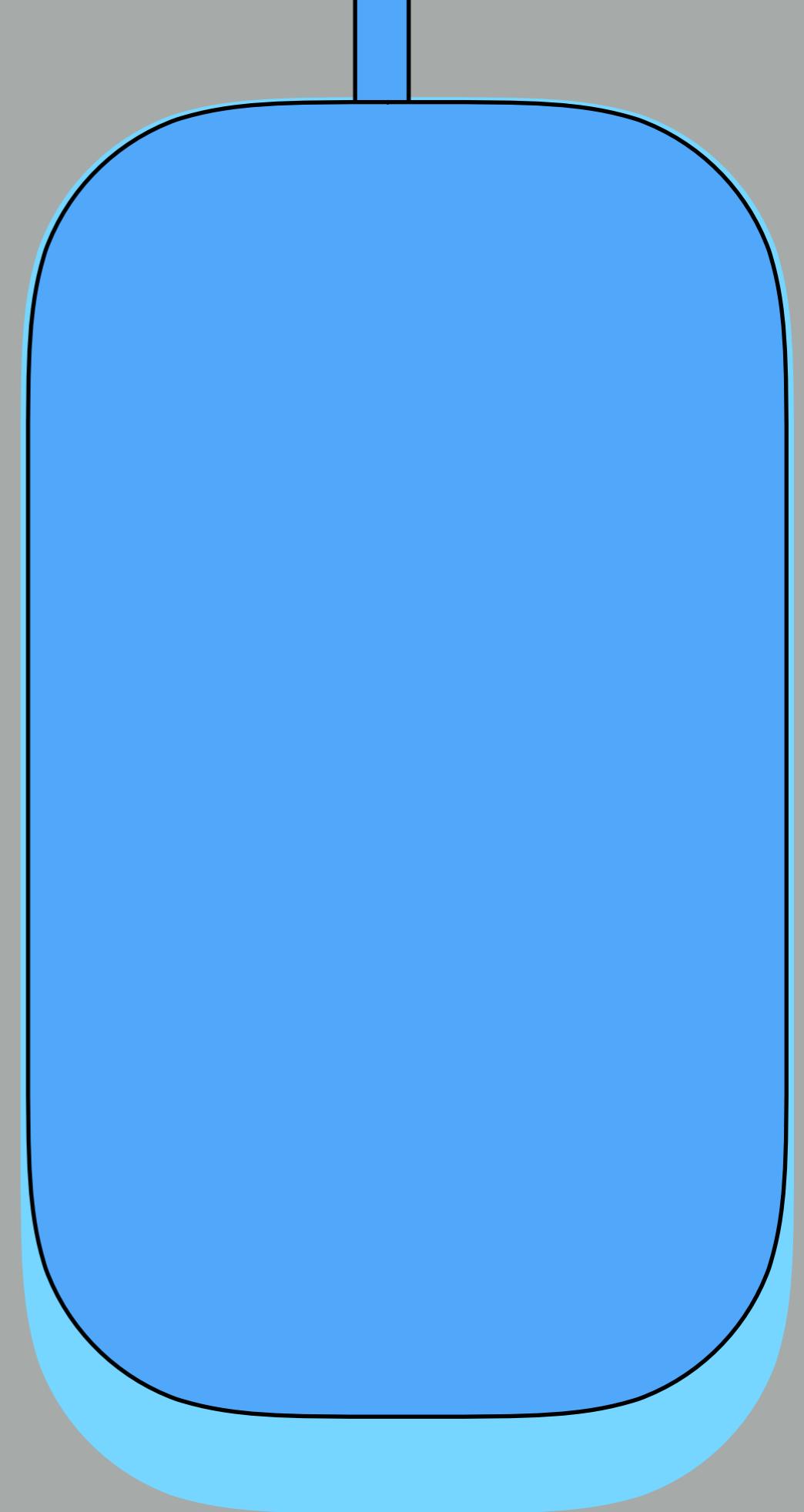
- How do we use cavern volume at diameters larger than the borehole?
- "inflatable" drift chamber
  - cylindrical balloon w/ conductive surface
  - (complex) anode cylinder in center at +100 kV
  - Particle events in gas lead to signals on anode
- $R_{\text{cathode}} < 20 \times R_{\text{anode}}$
- Brine fill: hydrostatic gradient along balloon
- Gas fill: more complicated string, shoe, plug? Rockfall?

Help?



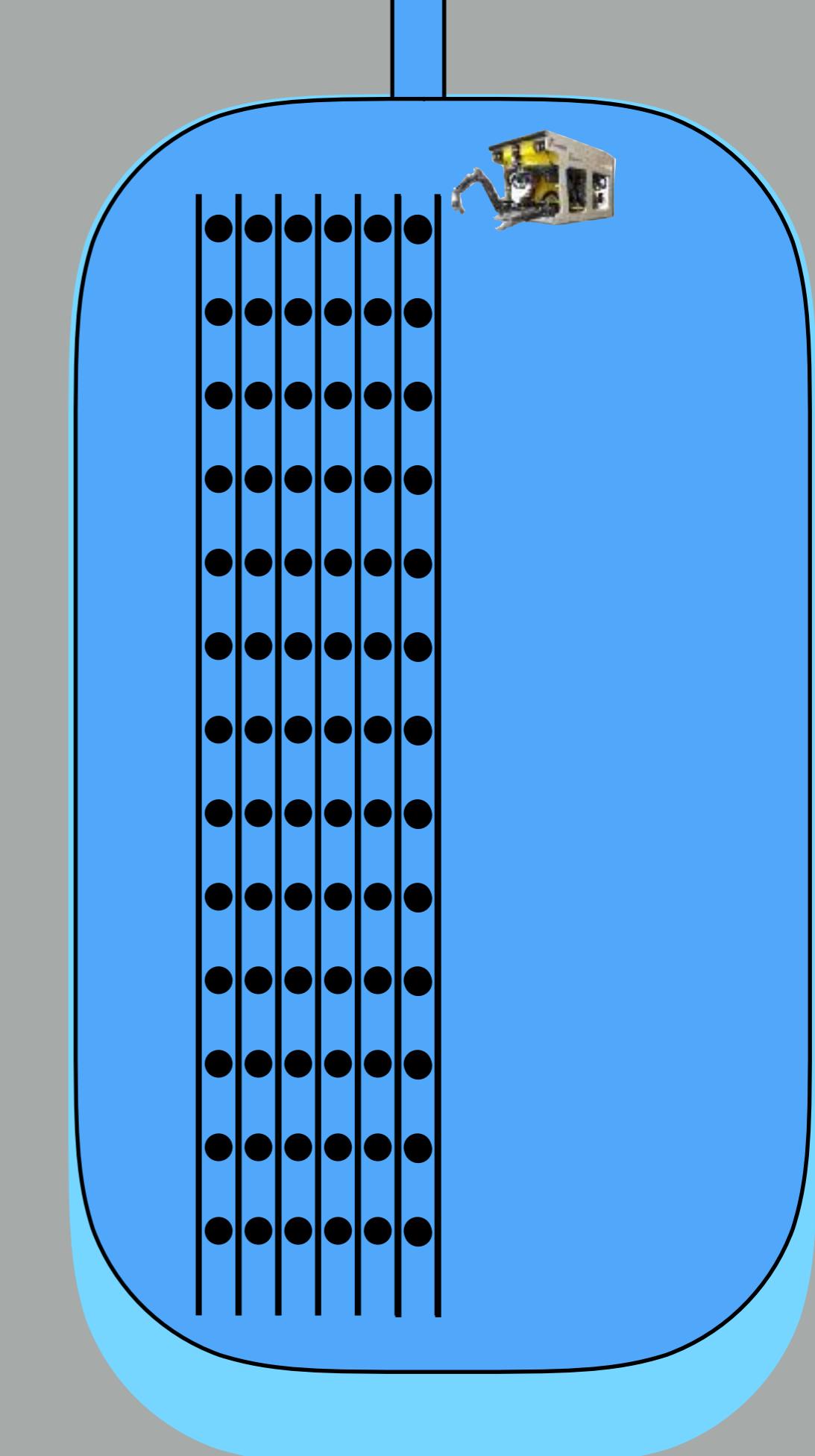
# High complexity: Fully lined cavern, in-cavern construction

- Can we instrument megaton-scale volumes?



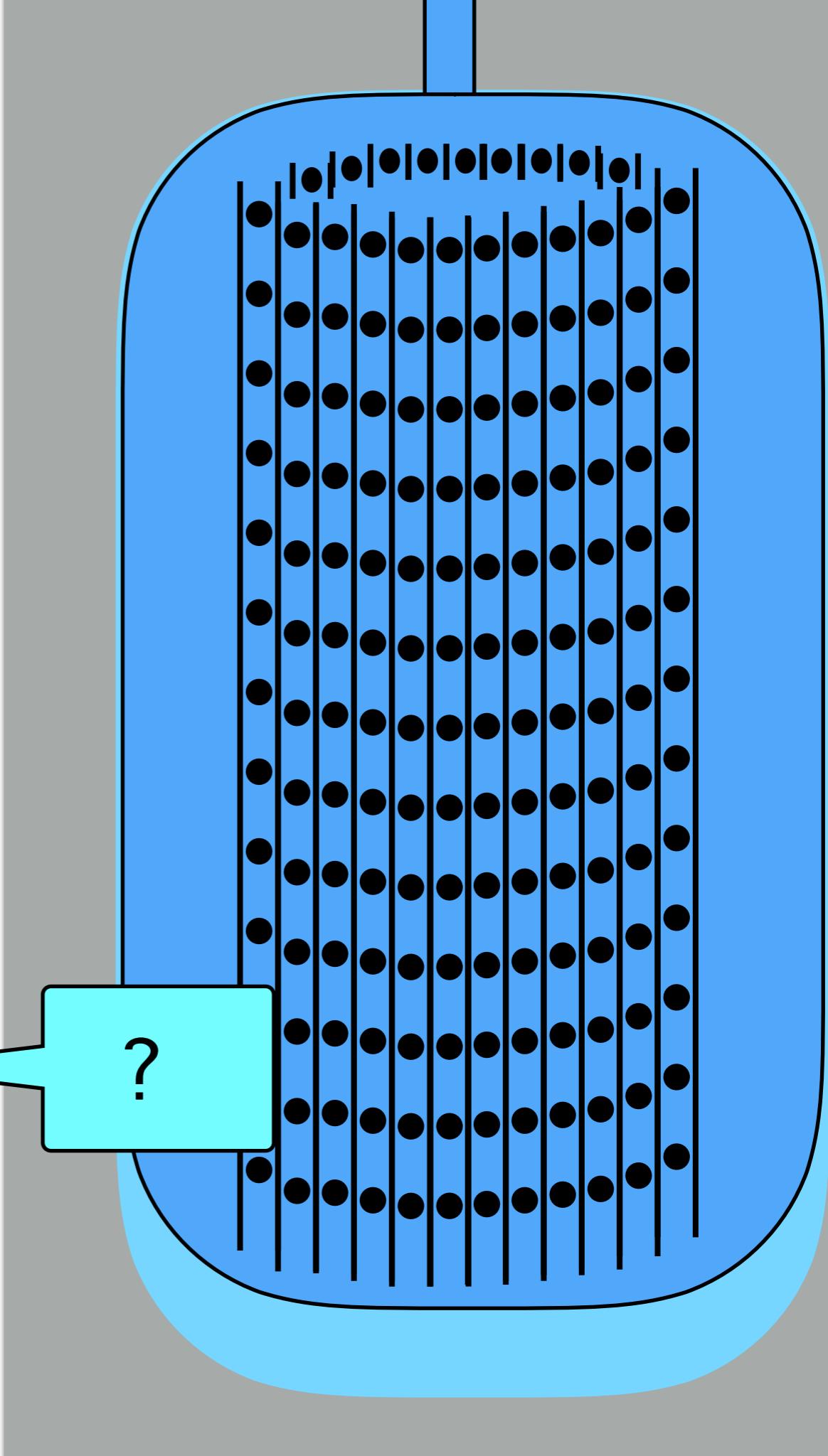
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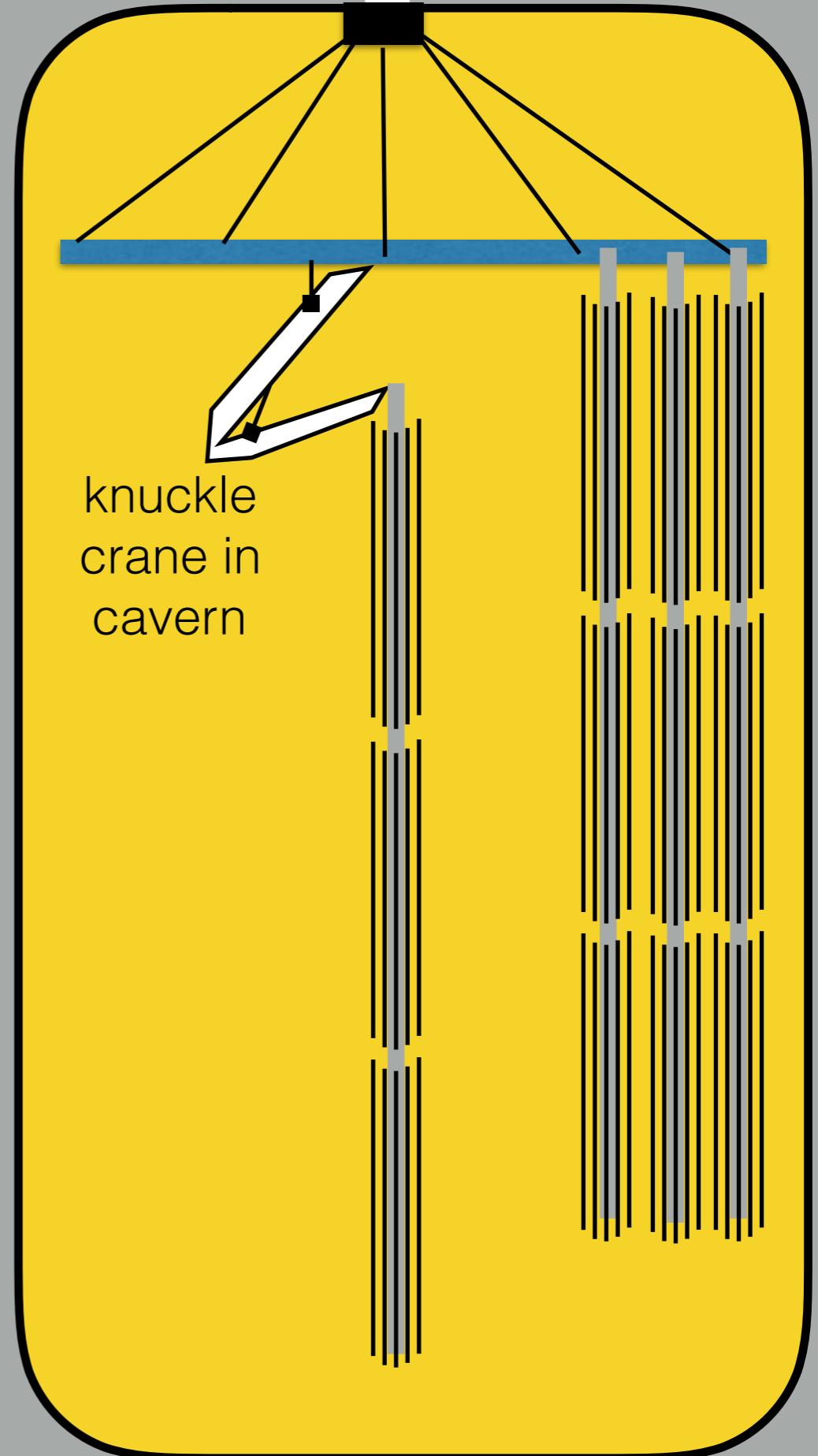
# High complexity: Fully lined cavern, in-cavern construction

- Standard-ish tech
  - PMT strings in pressure hulls = "standard" detector tech from IceCube
  - Remote sub/crane operations
- Low-risk cavern design: open well, halmostatic pressure, well diameter not critical
- Biggest novelty: cavern lining
- If this sounds hard remember that we are accustomed to \$1B project estimates for facilities half this size



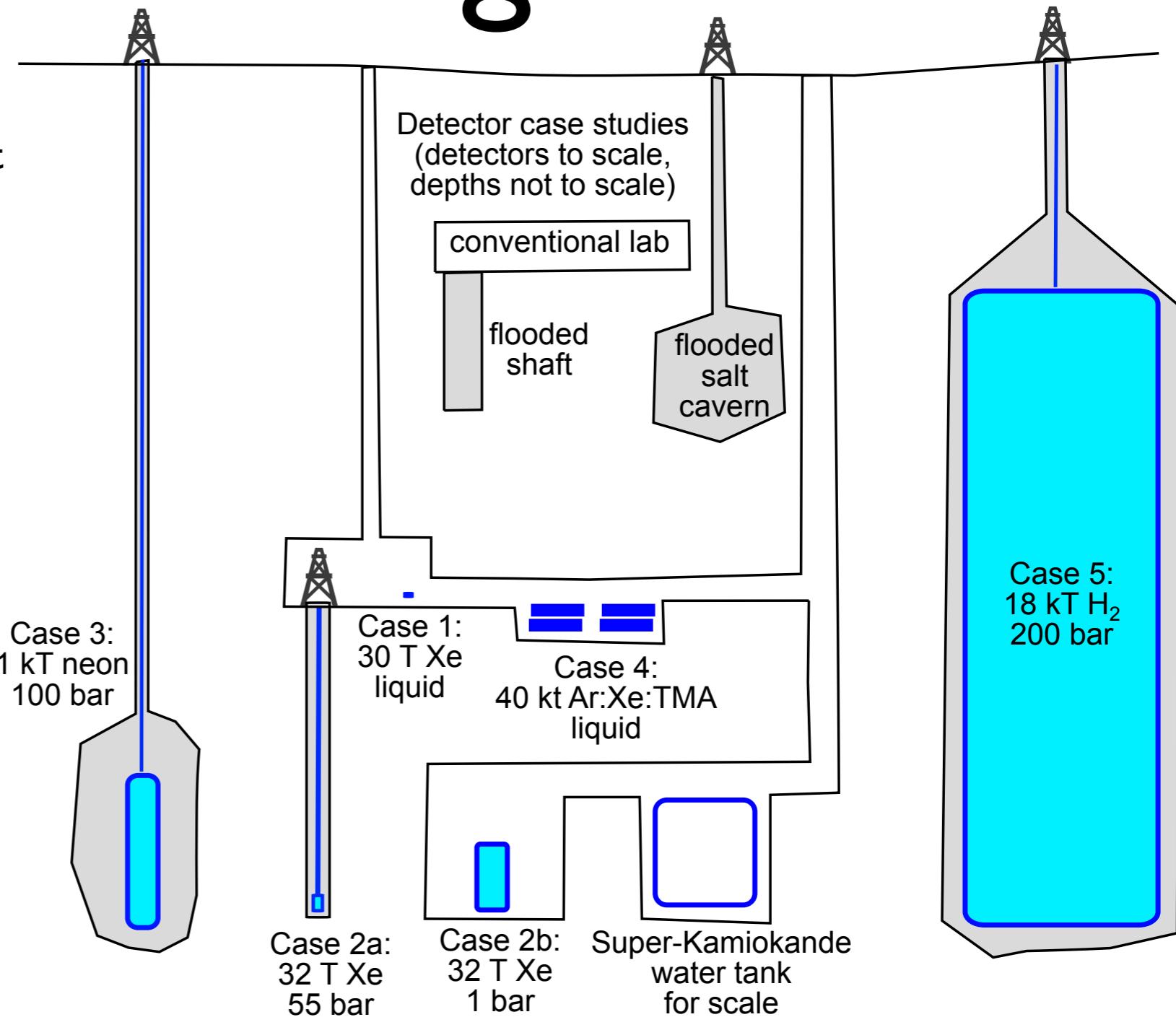
# How far can we push?

- Can we imagine a cavern-spanning gas ionization detectors?
  - Ar, CO<sub>2</sub>, or CH<sub>4</sub> based
  - 100-200 bar
  - Elaborate mech. eng.
- Speculative mining tech:
  - Stringent materials specs on huge liner
  - Assemble under 1 bar air?
  - Hang 1000 t weight from casing?
- At stake: at 500kT scale, factor of 100 boost in search for proton decay and "grand unified theory"



# What scales are interesting?

- Solid-state detectors < 1 t
- Xenon at 1—30 tons, especially with  $P < 50$  atm
- Neon at 1 kT
- Argon at > 20 kT
- $H_2$  at >10 kT
- Water at 200—1000 kT



# Questions

## From physicists

- "Can't we send miners in? Or divers? Wait, no."
- "Is such a cavern predictable/stable enough to entrust \$100M worth of detector hardware to it?"
- They're used to scaled, bolted, shotcreted roofs

## From me

- "How would you build a cavern if it was required to spend 2y at zero pressure?"
- "How big a borehole can we get?"
- "What would plug/BOP/DHSV operations look like?"
- "When/where do we start?"

# What's next

- UCSB engineer working on design of inflatable-cylinder detector
- In contact with DM-ICE collaborators who have quickly-deployable hardware
- Would like to open discussion/collaboration with engineers, owners, etc.
- Visit [hep.ucsb.edu/saltcaverns](http://hep.ucsb.edu/saltcaverns) and join a discussion group

Funded by DOE Office of High Energy Physics  
under DE-SC0013892.



SNOLAB

# Salt Cavern Detector Interest Group

We are a group of physicists interested in solution-mined salt caverns as deployment sites for future experiments in nuclear and particle physics.

## Internal site

Our [internal discussion forum](#) is hosted on Basecamp. Please join us! Students, postdocs, PIs, engineers all welcome. Site access requires an invitation, so email [scdig\\_request@hep.ucsb.edu](mailto:scdig_request@hep.ucsb.edu) to get one. (Doing so is not a commitment to anything---work, email, teleconferences, etc. You'll just get an invitation email from Basecamp.)

## References

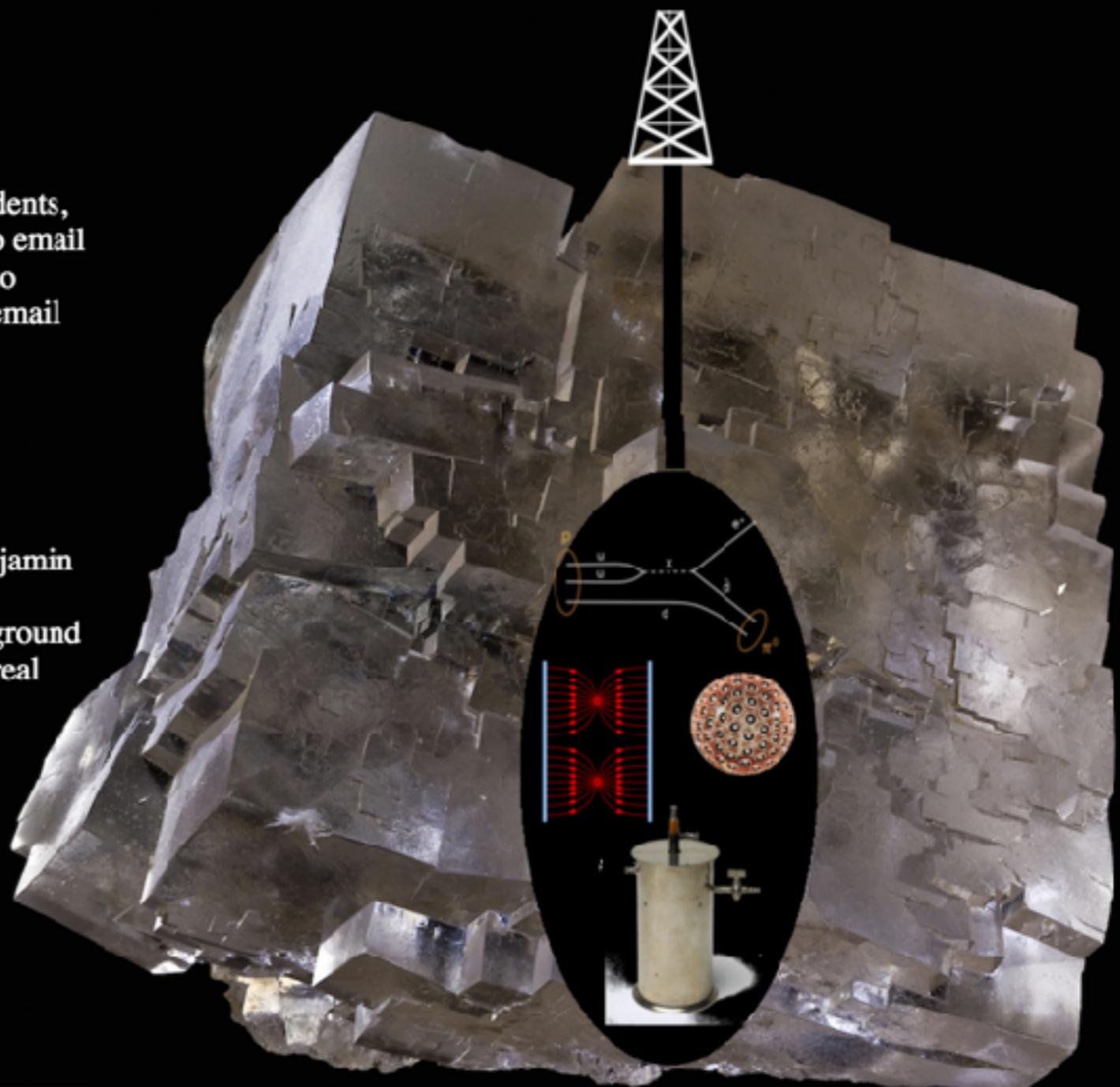
1. <http://arxiv.org/abs/1512.04926> Sub-Penning gas mixtures: new possibilities for ton- to kiloton-scale time projection chambers. Benjamin Montreal, Luiz de Viveiros, William Luszczak
2. <http://arxiv.org/abs/1410.0076> Underground physics without underground labs: large detectors in solution-mined salt caverns. Benjamin Montreal

## Contact

All interest is welcome! Contact Ben Montreal via [scdig@hep.ucsb.edu](mailto:scdig@hep.ucsb.edu).

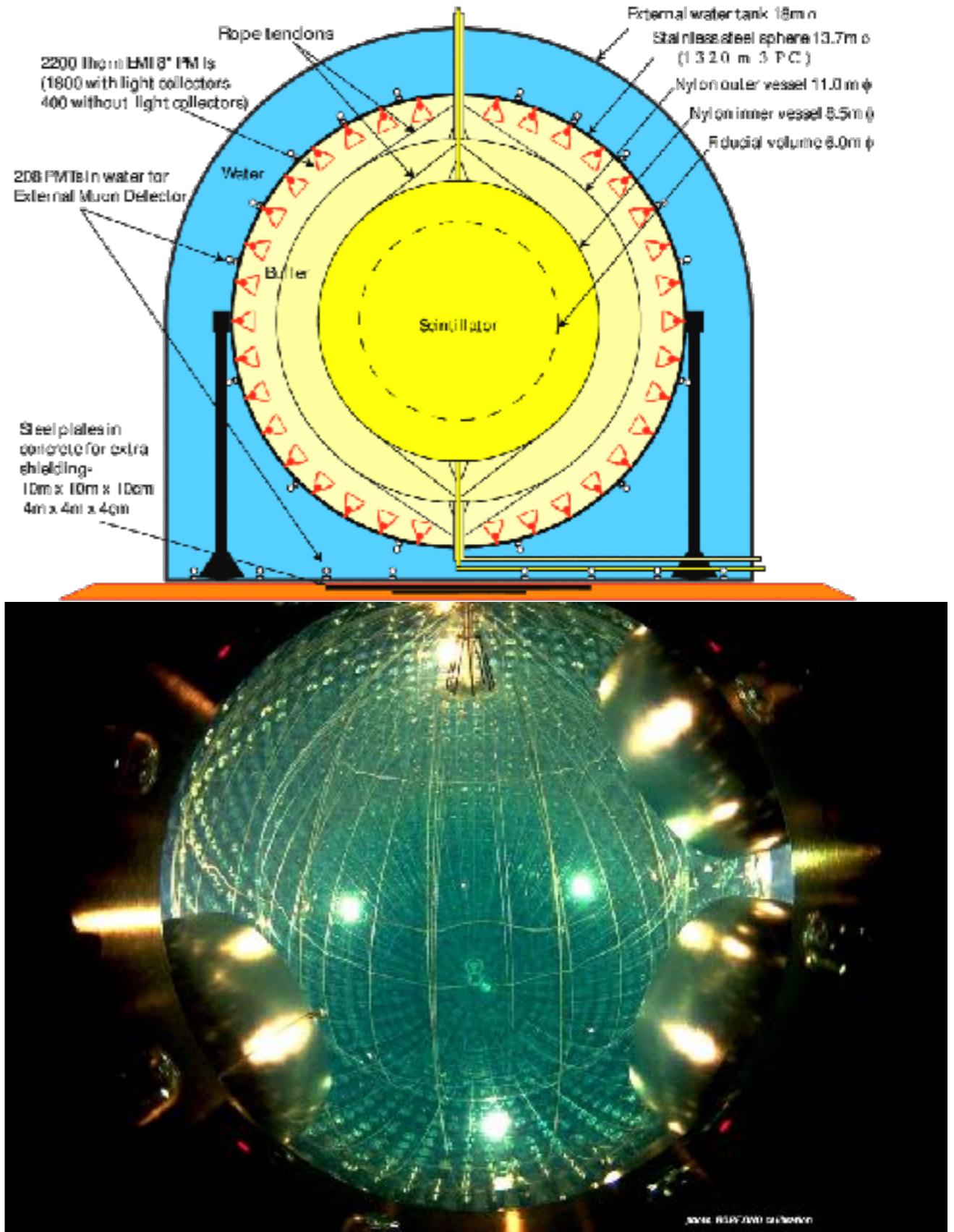
## Credit

This research is funded by the Department of Energy under grant DE-SC0013892. Salt crystal and detector images from Wikimedia Commons.



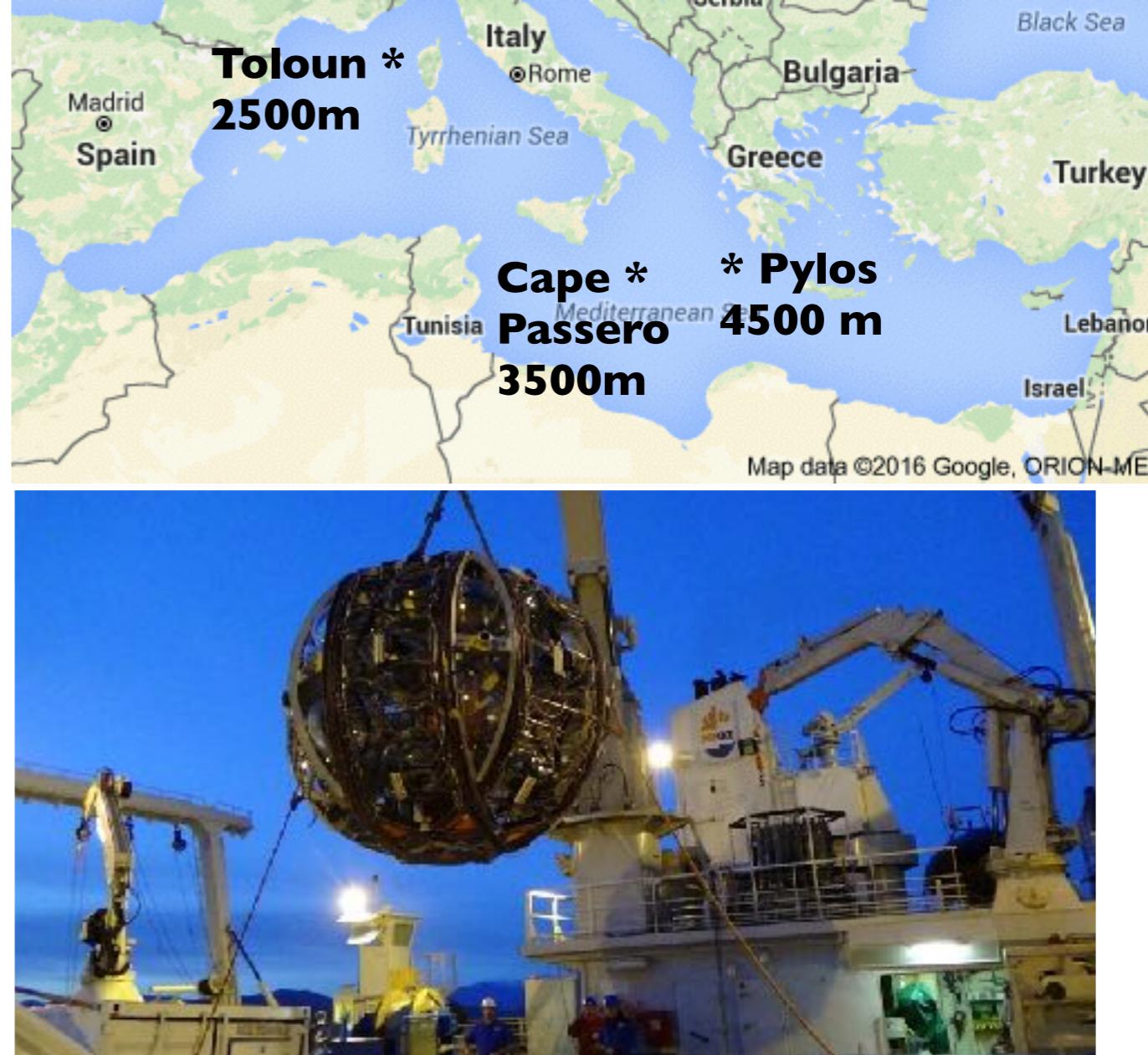
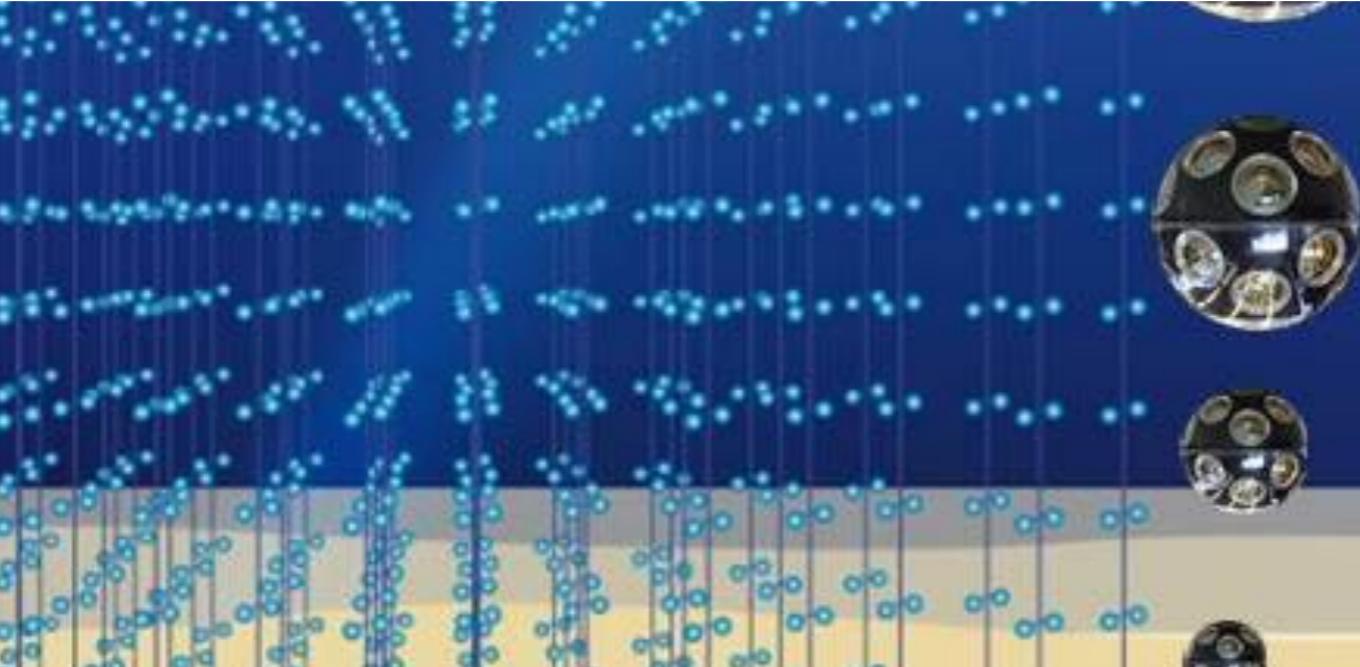
# Borexino: a onion-like scintillator detector

- Nested spheres:
  - 18m: water tank
  - 14m: photodetector sphere
  - 11m: high-purity oil balloon
  - 8.5m: particle-sensitive scintillator balloon
- Complex inflation, calibration sequence controlled through "neck"
- Observables:
  - 200/y neutrinos from Sun
  - 5/y antineutrinos from Earth



# KM3NeT

- Like IceCube, but in the deep Mediterranean
- Buoyant strings deployed and cabled by ROV
- Three sites under construction



# DUNE

- 30 kT liquid argon target in membrane cryostats
- High-energy neutrino beam travels 1300km Fermilab - SD

