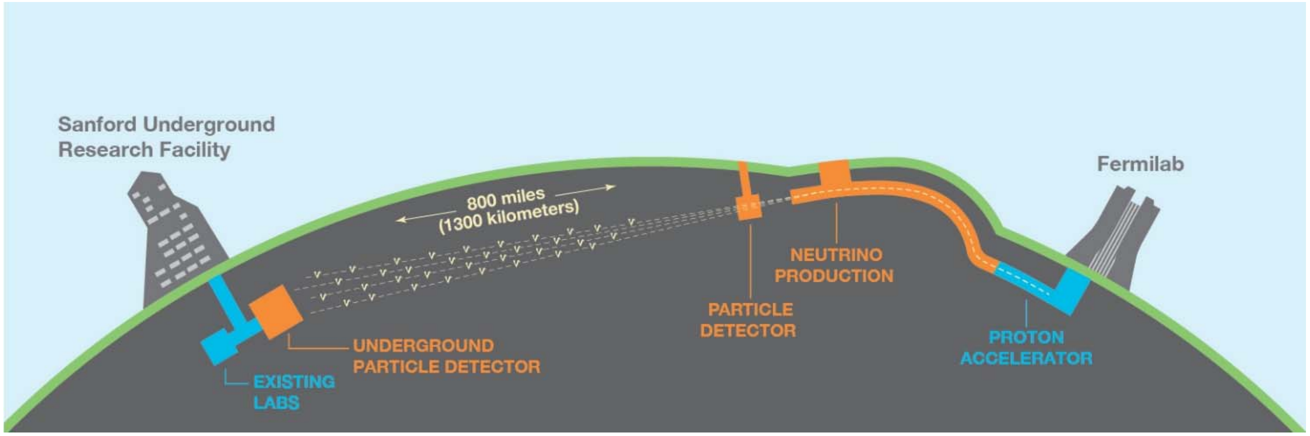
The Long-Baseline Neutrino Facility: Supporting a Global Neutrino Experiment

C. J. Mossey, Deputy Director for LBNF, Fermi National Accelerator Laboratory
09 October 2018

World-Class Facility supporting World-Class Experiment



- The **Deep Underground Neutrino Experiment** will be a **game-changing experiment for neutrino science**, potentially transforming our understanding of why the universe exists as it does.
- The **Long-Baseline Neutrino Facility** is the **infrastructure** necessary to send a powerful beam of neutrinos 800 miles through the earth, and measure them deep underground at South Dakota's Sanford Underground Research Facility.
- The **Proton Improvement Project – Phase II** will provide the most intense neutrino beam in the work
- The DUNE/LBNF project will be the **first internationally conceived, constructed, and operated mega-science project** hosted by the Department of Energy in the U.S.

LBNF will drive neutrino science forward the way CERN's Large Hadron Collider drove Nobel Prize-winning Higgs discovery

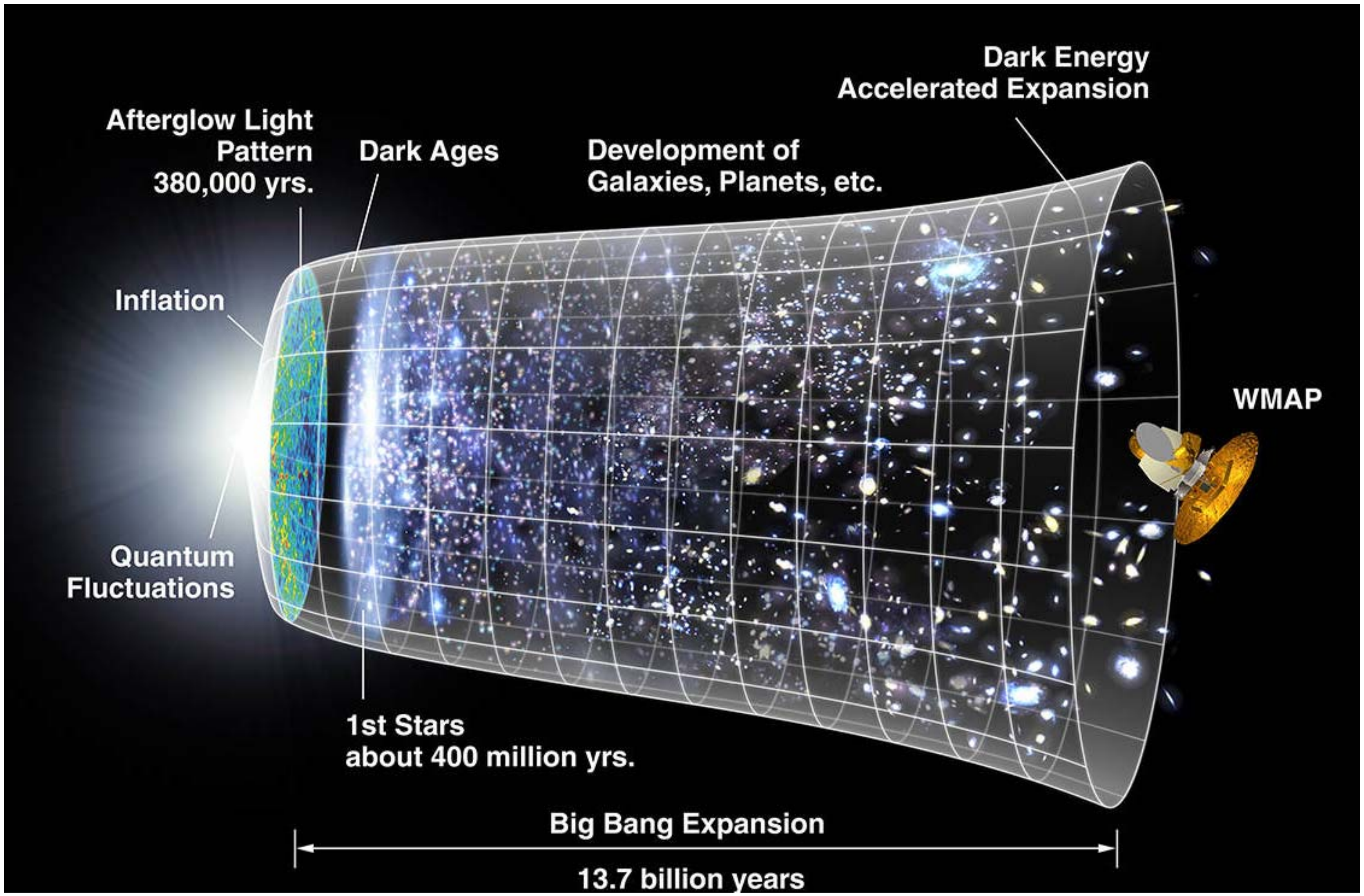
What are Neutrinos?

- **Ever present**
  - One of Mother Nature's handful of fundamental matter particles
  - More neutrinos in the Universe than any other matter particle
  - ~65 billion pass through every cm2 every second
- **Mysterious and surprising**
  - Almost massless
  - Almost always pass straight through matter without interacting

- **Important**
  - Pivotal role in the evolution of the Universe
  - May hold the key to why there is so little anti-matter (i.e. why we exist)
- **Experimentally Challenging**
  - Need different approach than CERN's Large Hadron Collider
  - Need powerful beams (many, many neutrinos)
  - Need very large detectors to observe rare interactions

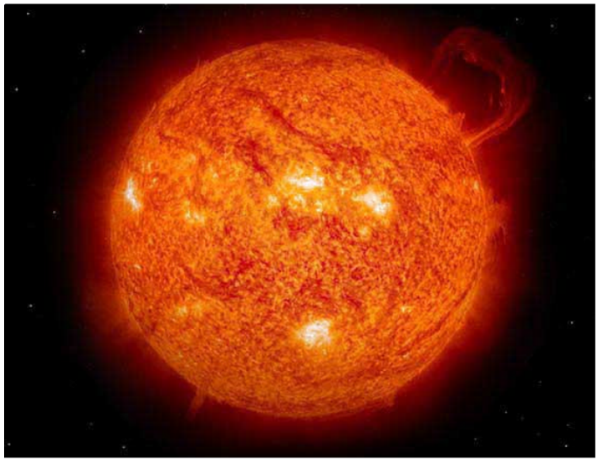
Where do neutrinos come from?

The Big Bang: neutrinos are by far the most abundant form of known matter in the universe



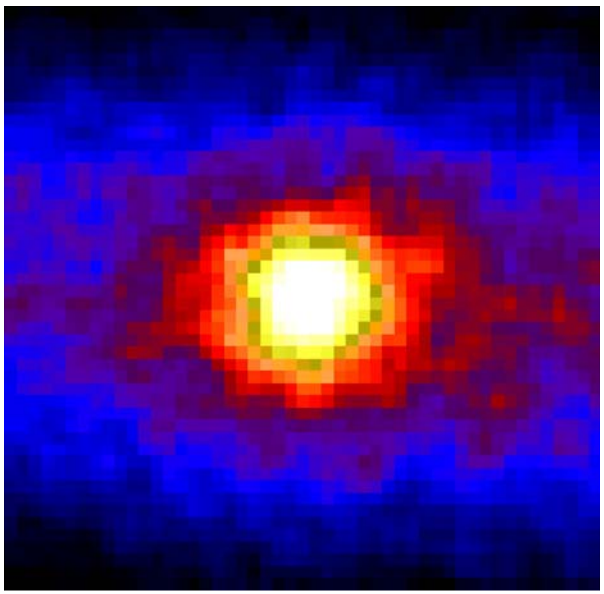
(Courtesy of Dr. Joe Lykken, Deputy Director of Fermilab for Research)

Where do neutrinos come from?



The Sun:

The nuclear fusion reactions that power the sun produce neutrinos



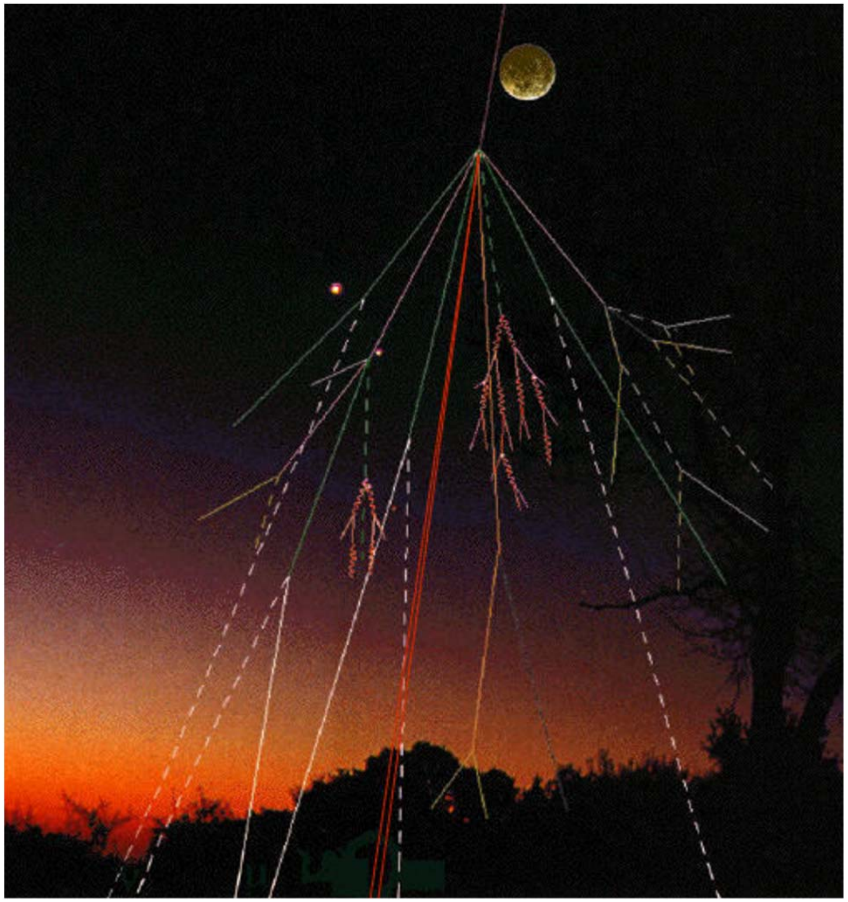
The sun shines almost as brightly in neutrinos as it does in light

(Courtesy of Dr. Joe Lykken, Deputy Director of Fermilab for Research)

Where do neutrinos come from?

Supernovae

Cosmic rays



(Courtesy of Dr. Joe Lykken, Deputy Director of Fermilab for Research)

Where do neutrinos come from?

Nuclear reactors

The Earth's crust

(Courtesy of Dr. Joe Lykken, Deputy Director of Fermilab for Research)

Where do neutrinos come from?

Bananas

A banana emits about one million neutrinos per day from the radioactive decay of potassium 40

(Courtesy of Dr. Joe Lykken, Deputy Director of Fermilab for Research)

Science Objectives

Neutrinos – most ubiquitous matter particle in the universe, yet the least understood. Opportunities for game changing physics discoveries:

- **Origin of matter**
  Investigate leptonic CP violation, mass hierarchy, and precision oscillation physics
  - Discover what happened after the big bang: Are neutrinos the reason the universe is made of matter?

- **Neutron Star and Black hole formation**
  Ability to observe supernovae events
  - Use neutrinos to look into the cosmos and watch the formation of neutron stars and black holes in real time

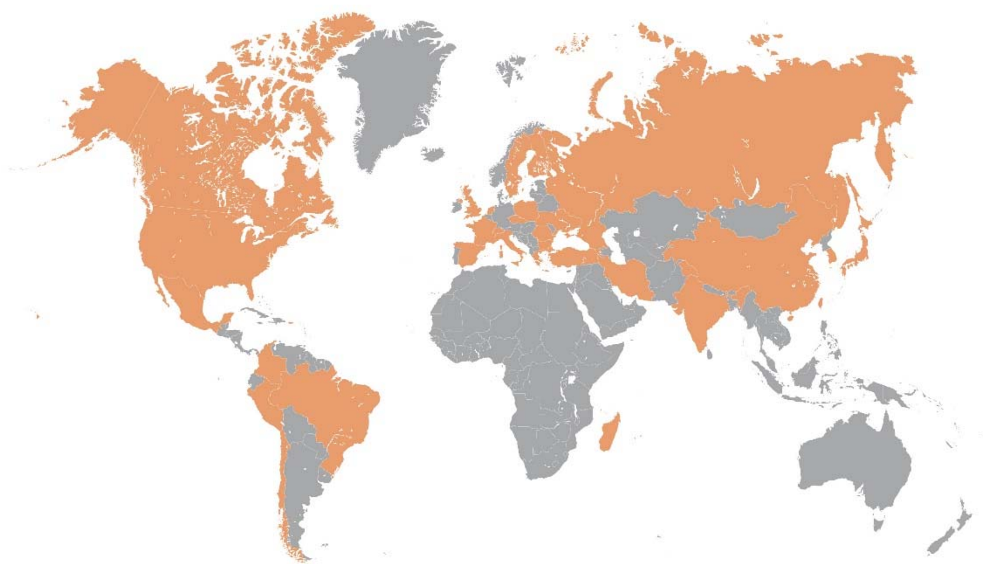
- **Unification of forces**
  Investigate nucleon decay targeting SUSY-favored modes
  - Move closer to realizing Einstein’s dream of a unified theory of matter and energy

DUNE experiment is managed by the DUNE Collaboration

60 % non-US

1143 collaborators from 178 institutions in 32 nations

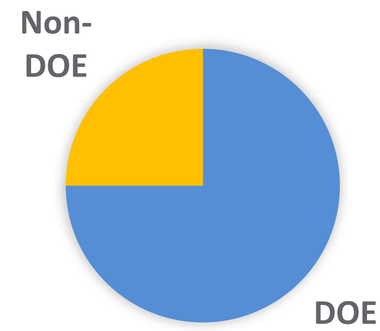
Armenia, Brazil, Bulgaria, Canada, CERN, Chile, China, Colombia, Czech Republic, Spain, Finland, France, Greece, India, Iran, Italy, Japan, Madagascar, Mexico, Netherlands, Paraguay, Peru, Poland, Romania, Russia, South Korea, Spain, Sweden, Switzerland, Turkey, UK, Ukraine, USA



DUNE is still growing: dN/dt > 100 collaborators/year!

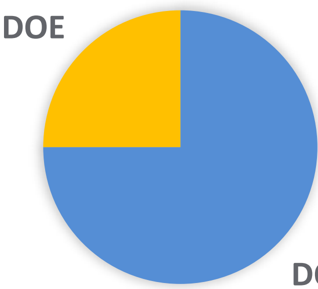
International In-kind Contributions – 1 of 2

Approximate LBNF Funding Breakdown



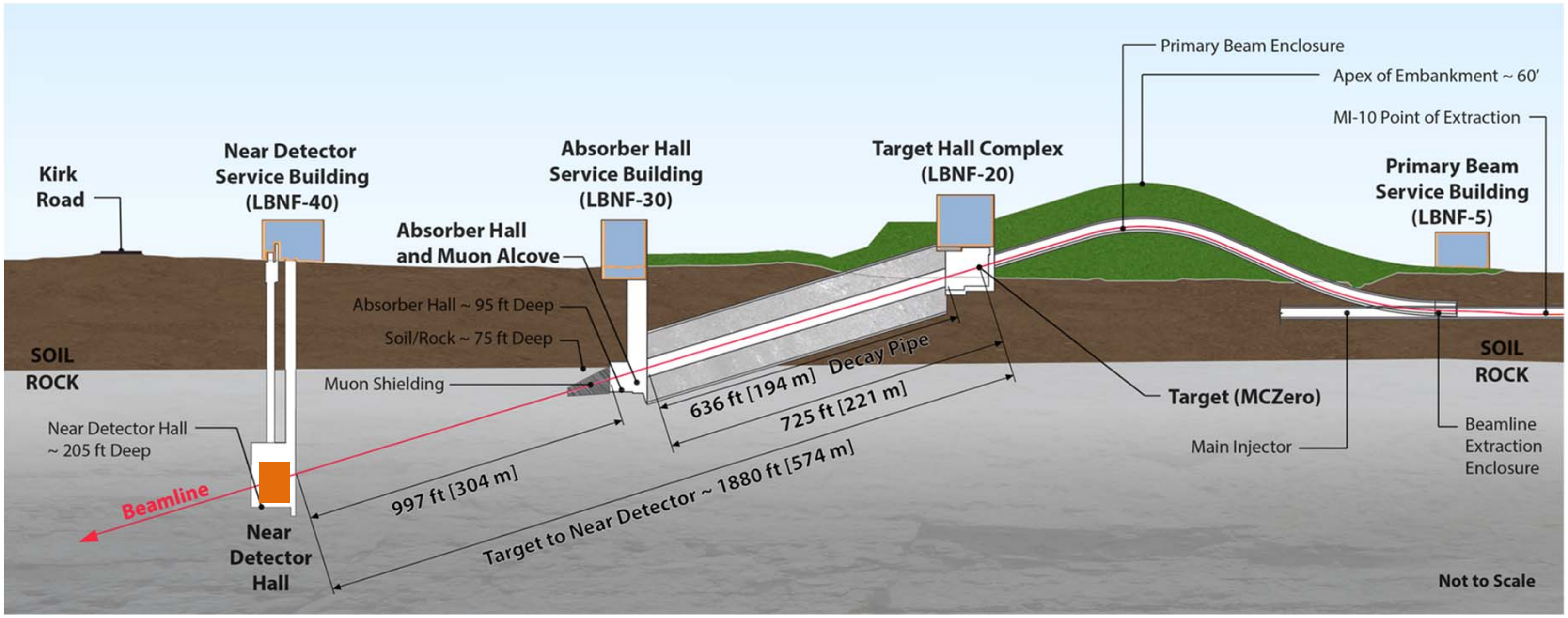
- International groups are making important contributions for key components of LBNF and DUNE. With respect to LBNF:
  - CERN is designing and building the first membrane cryostat.
  - UK/RAL is conducting target R&D, target design and production, and an associated package for target support systems.
  - IHEP China has provided a prototype corrector magnet and has started production of 23 magnets. Also, working on FEA analysis for the decay pipe windows and performing a welding experiment of Al/Be for the prototype of the upstream window.
  - KEK Japan is planning to prototype the seals of the target shield pile's hatch covers and sealed feed-throughs for horn striplines. Ongoing discussions on additional opportunities.

International In-kind Contributions – 2 of 2



- Canadian science community has submitted a proposal to TRIUMF requesting to be in their next five year plan for LBNF neutrino beamline and PIP-II components.
- India has expressed interest in fabricating for primary beam magnets. Further discussions under way.
- Swiss have expressed interest in a cryo infrastructure contribution. Proposal moving through system.
- Discussions are underway with other potential partners.

Overview - “Near Site” – LBNF/DUNE at Fermilab, Batavia, IL

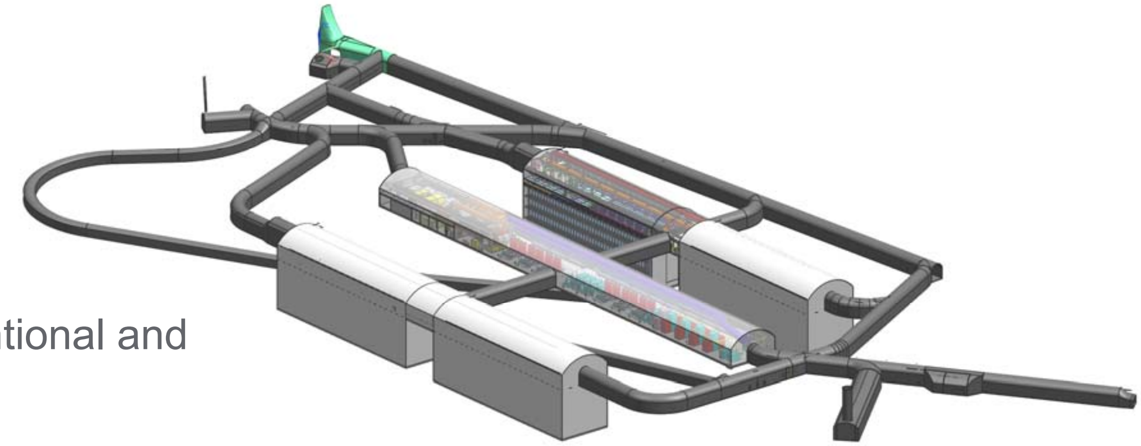


- Primary proton beam @ 60-120GeV extracted from Main Injector
- Initial 1.2 MW beam power, upgradable to 2.4 MW
- Embankment allows target complex to be at grade and neutrino beam to be aimed to SURF
- Decay region followed by absorber
- Four surface support buildings
- Near Detector facility
- DUNE Near Detector

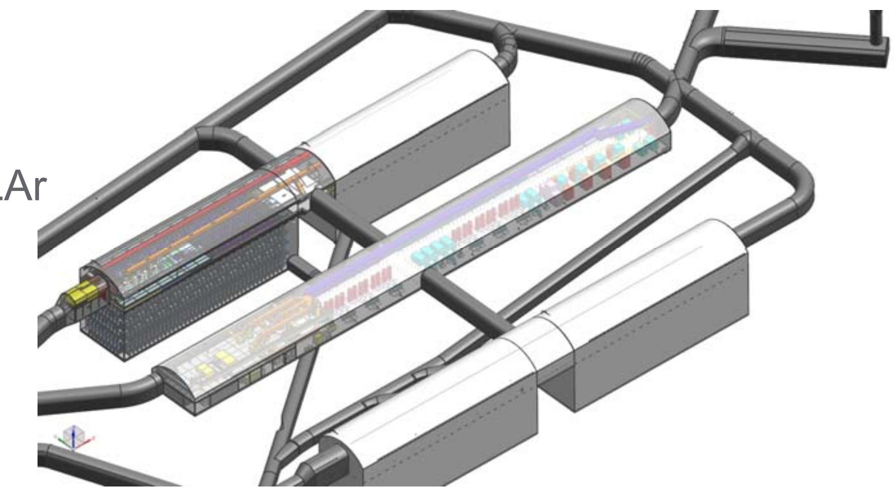
Optimized beamline provides significantly more physics reach over NUMI based reference design

Overview – "Far Site" – LBNF/DUNE at Sanford Lab, Lead, SD

- **Conventional Facilities**:
  - Surface and shaft Infrastructure including utilities
  - Drifts and two caverns for detectors
  - Central utility cavern for conventional and cryogenic equipment
- **Cryostats**:
  - Four membrane cryostats supported by external steel frames
- **Cryogenic Systems**:
  - LN2 refrigeration system for cooling and re-condensing gaseous Argon
  - Systems for purification and recirculation of LAr
- **Argon:**
  - 70kt LAr (~40kt "fiducial" mass)
- **DUNE Detectors**
  - Four 10kt fiducial mass LAr TPC detectors



4850L caverns and drift layout



Single cryostat and central utility cavern

Overview - the PIP-II Project

Mission

PIP-II will deliver the world's most intense beam of neutrinos to the international LBNF/DUNE project, and enable a broad physics research program, powering new discoveries for decades to come.

Goals

- Deliver 1.2 MW of proton beam power from the Main Injector over the energy range 60 – 120 GeV, at the start of LBNF ops
  - Establish a platform for future upgrades to multi-MW capability
- Provide a flexible platform for extension of capability to high duty factor/higher beam power, multiple users and reliable operations

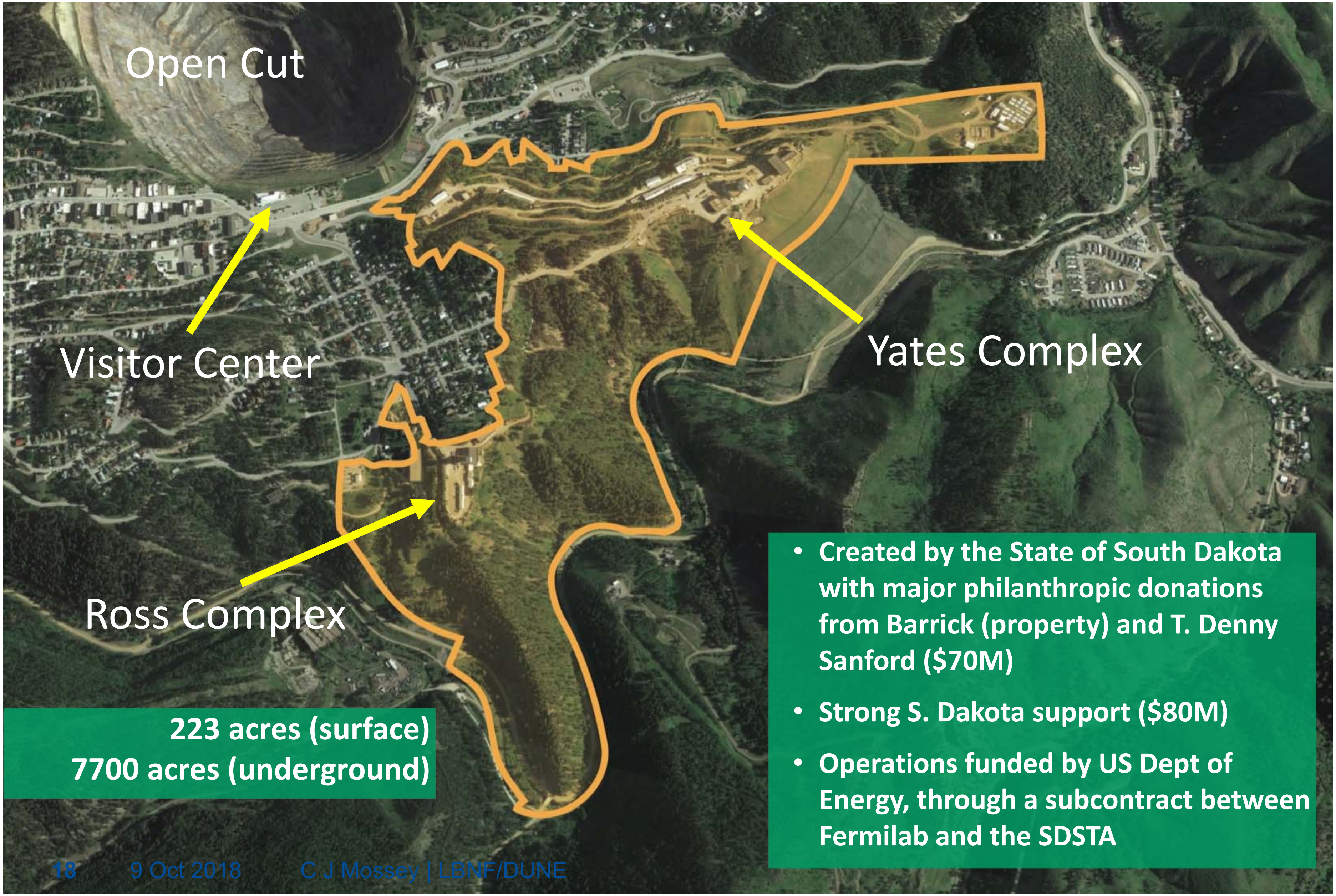
Plan

- **CD-1 approval achieved July 2018; CD-2 planned ~April 2019**

DUNE/LBNF/PIP-II

DUNE/LBNF/PIP-II

Far Site – Sanford Lab in Lead, SD

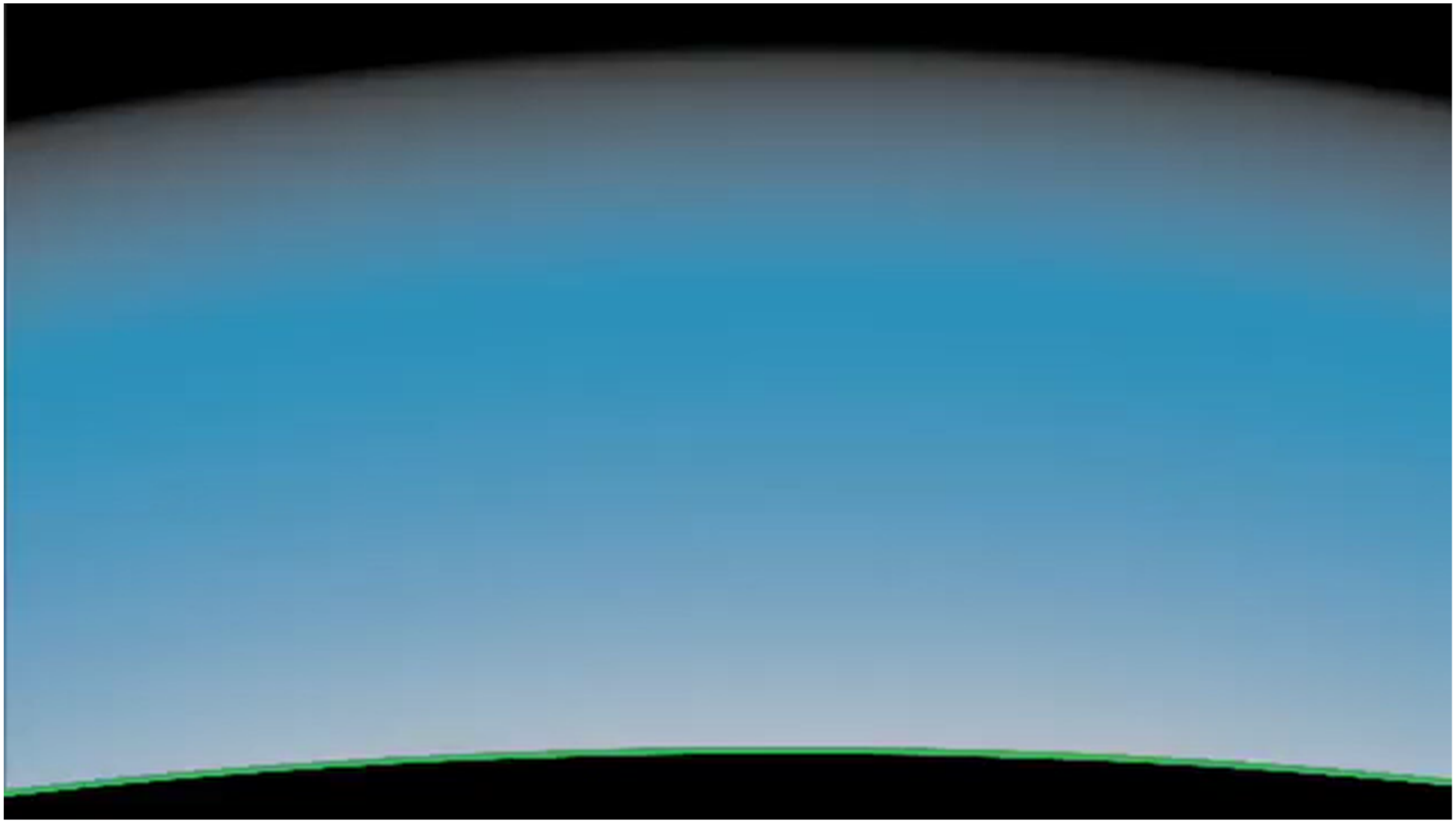


223 acres (surface)
7700 acres (underground)

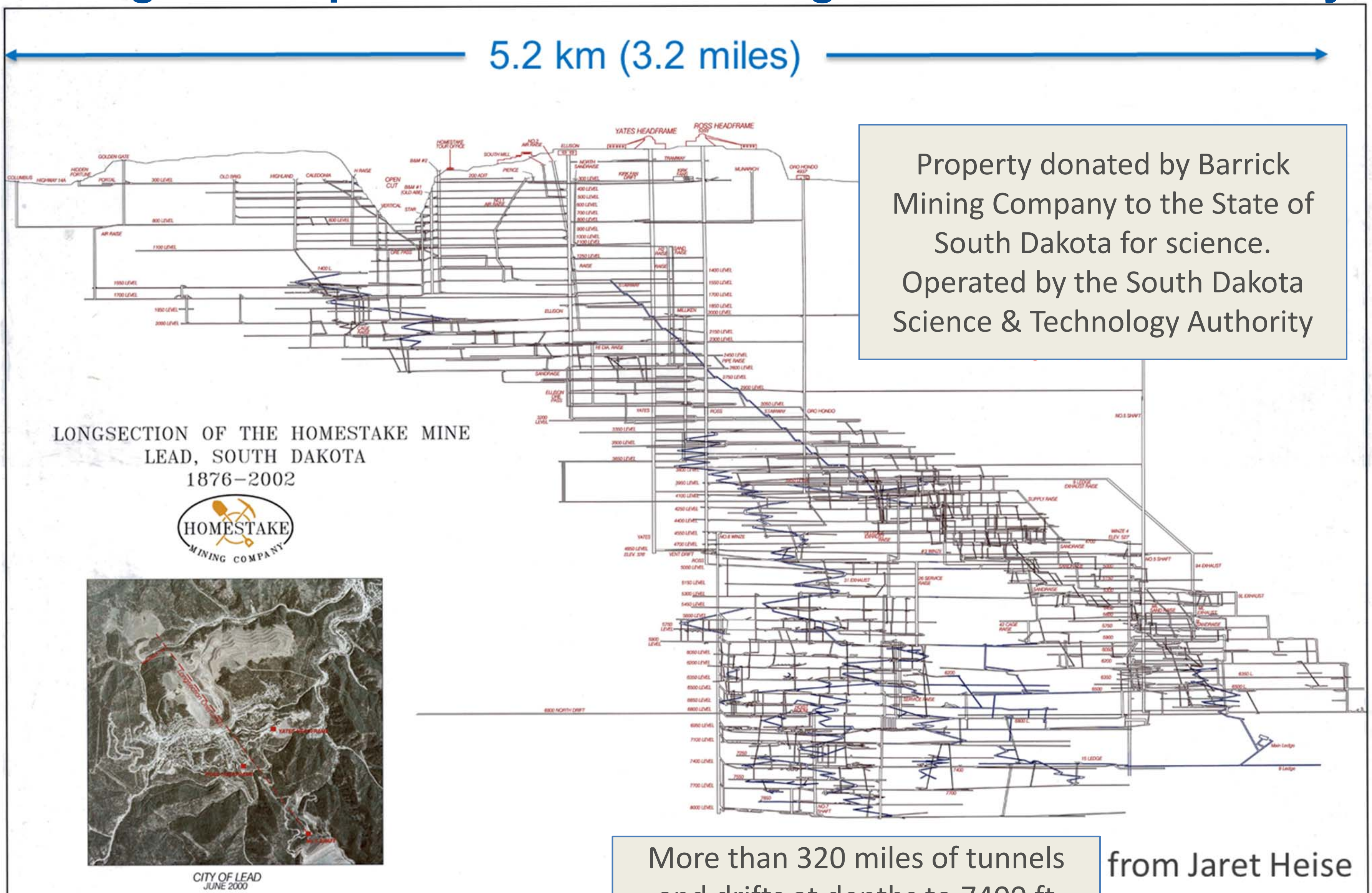
- **Created by the State of South Dakota with major philanthropic donations from Barrick (property) and T. Denny Sanford ($70M)**
- **Strong S. Dakota support ($80M)**
- **Operations funded by US Dept of Energy, through a subcontract between Fermilab and the SDSTA**

Why underground? It's a "quiet" place.

The Earth is constantly bombarded by cosmic rays.
On the surface, you have about three cosmic rays go through your hand every minute
A mile underground, roughly one cosmic ray goes through your hand every month



Underground Space at Sanford Underground Research Facility

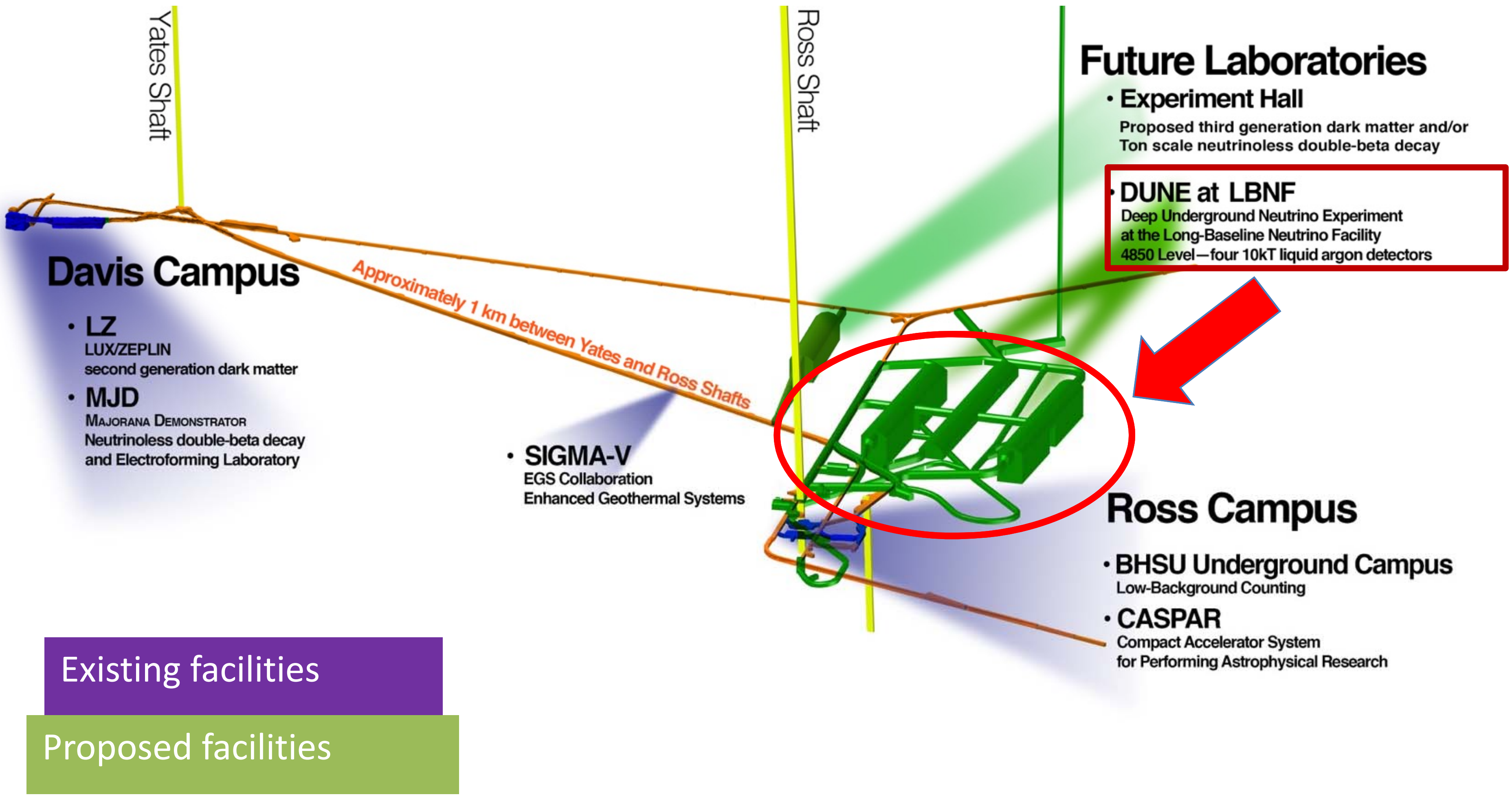


Property donated by Barrick Mining Company to the State of South Dakota for science. Operated by the South Dakota Science & Technology Authority

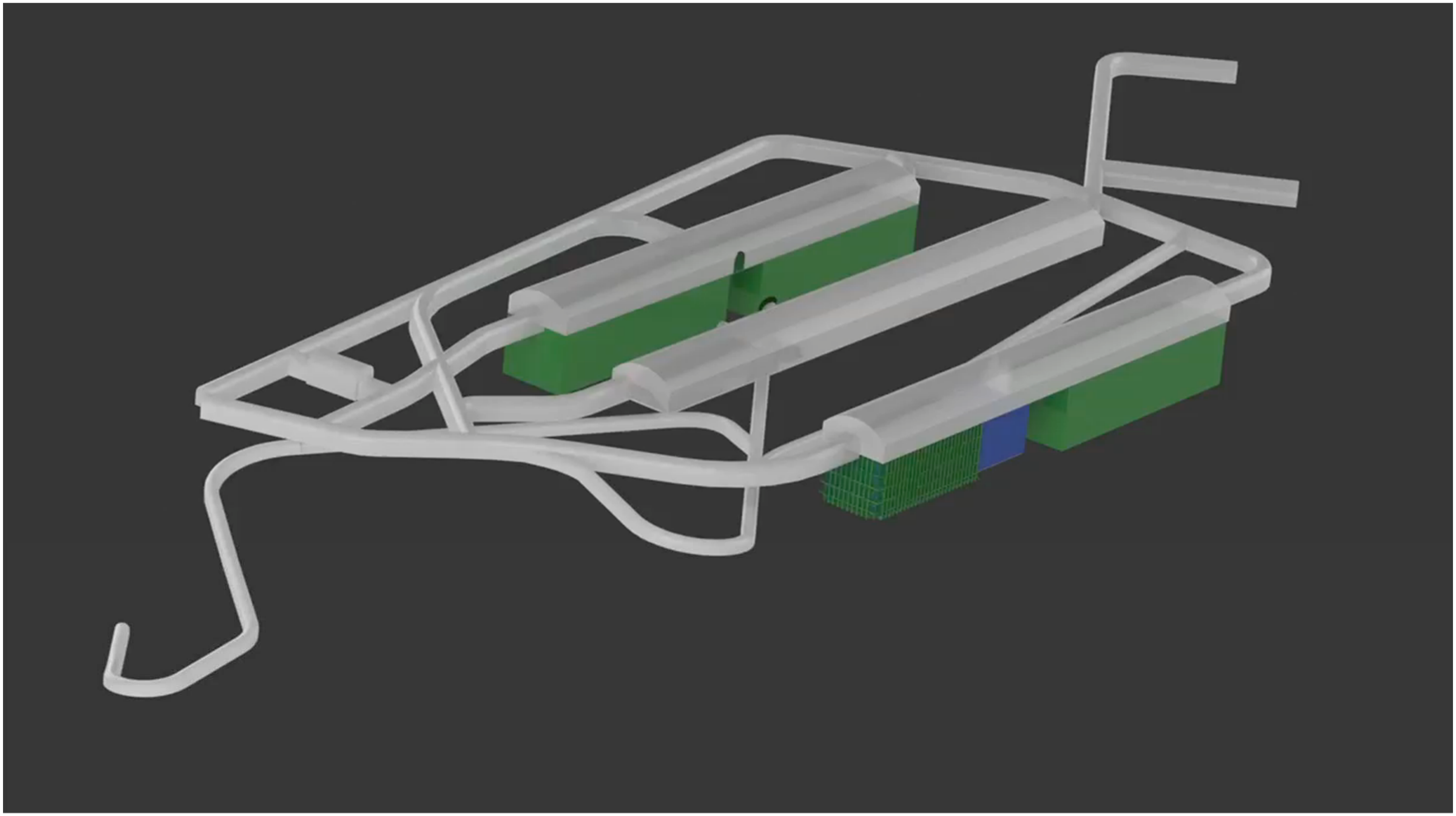
More than 320 miles of tunnels and drifts at depths to 7400 ft

from Jaret Heise

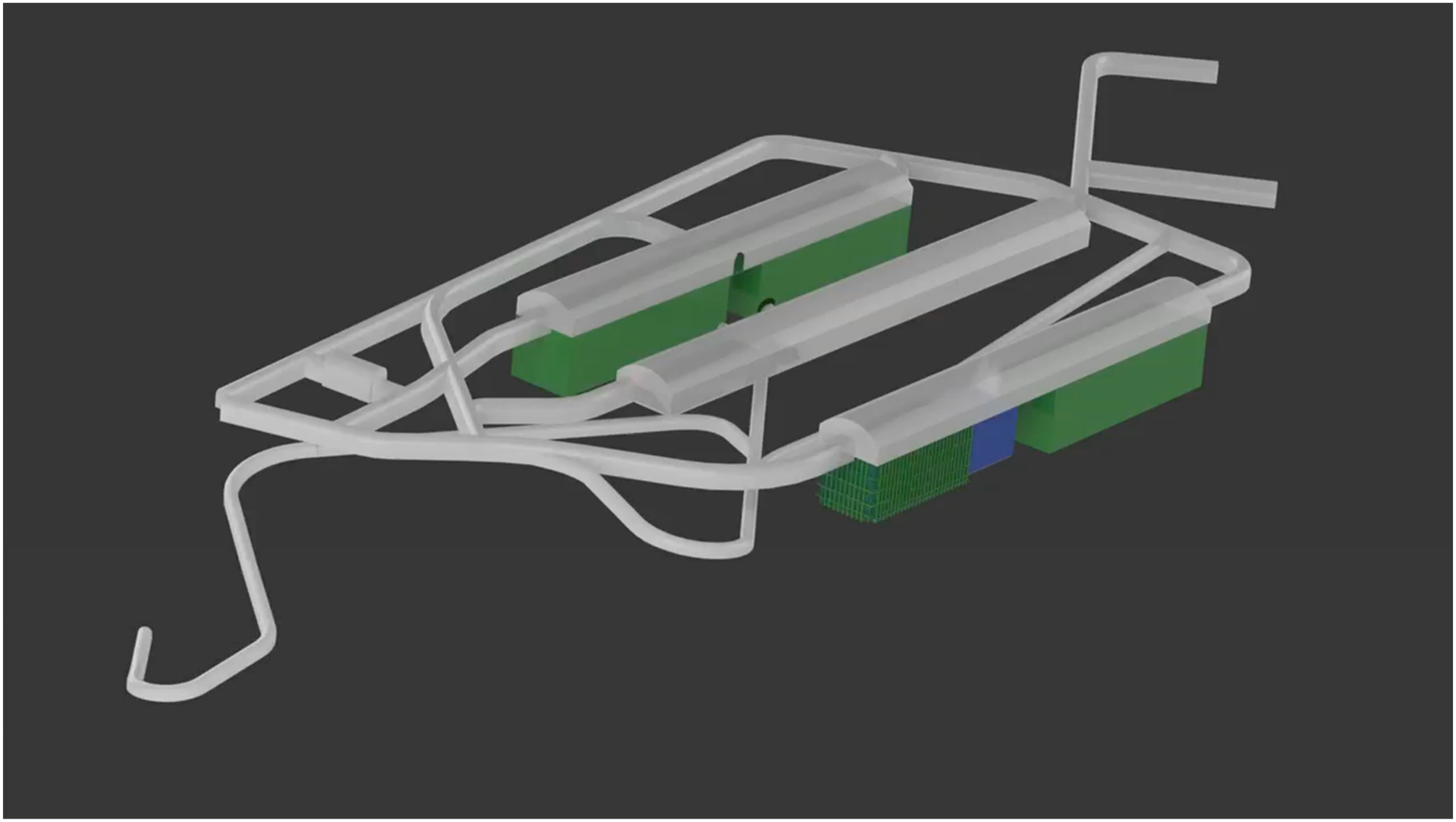
Far Site Context – part of an Underground Campus



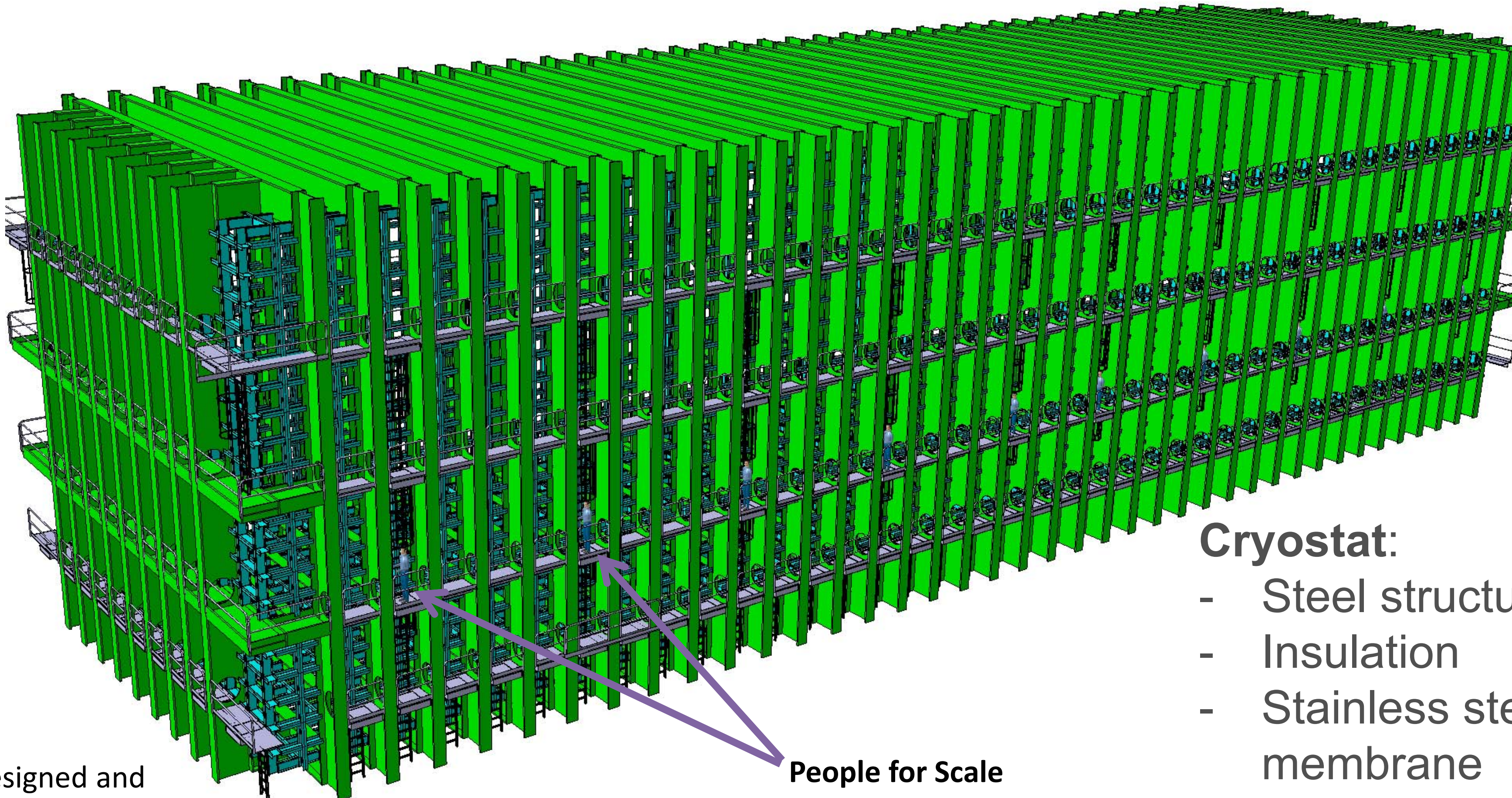
LBNF / DUNE Far Site



LBNF / DUNE Far Site



Free-Standing Steel Cryostat Design

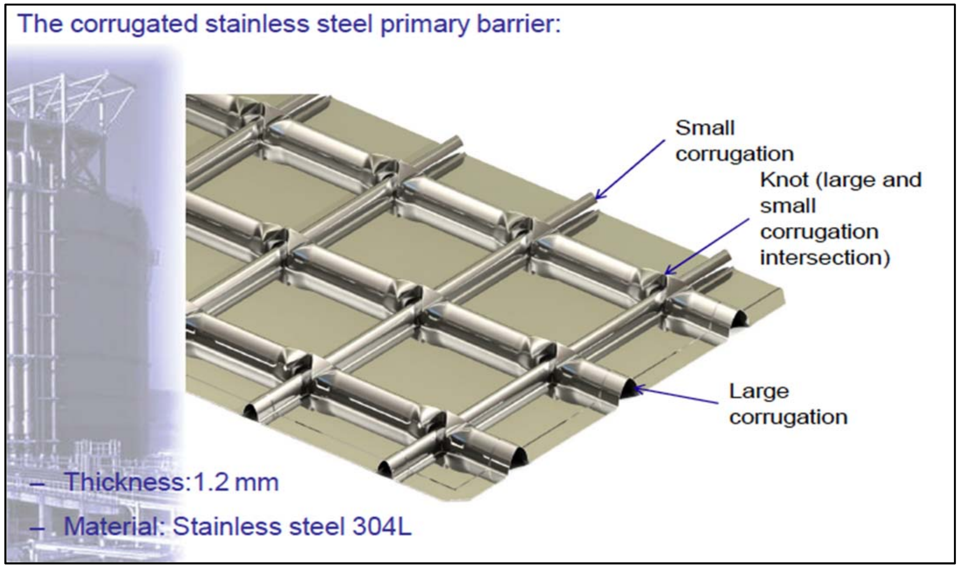


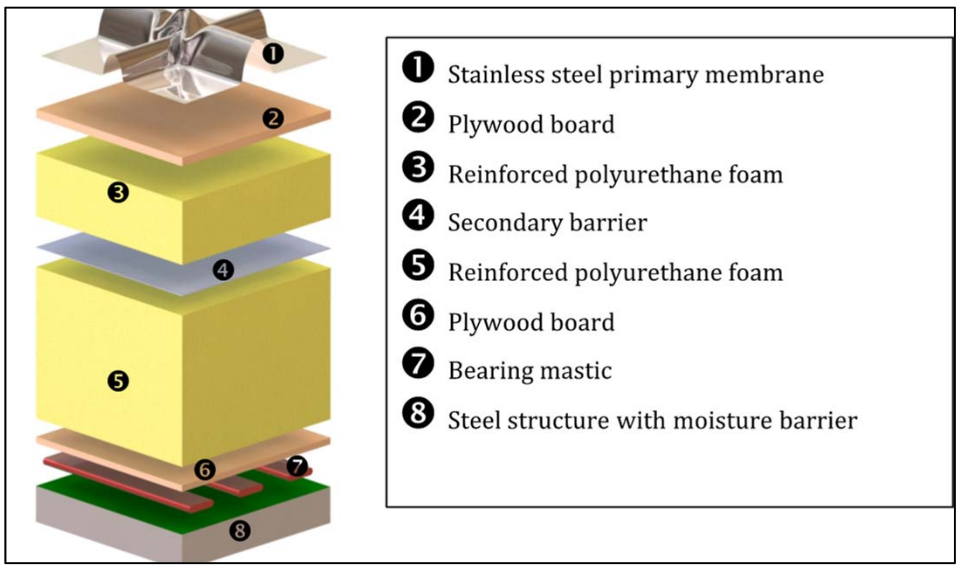
Cryostat:
- Steel structure
- Insulation
- Stainless steel membrane
- Holds the liquid argon

Designed and engineered by CERN

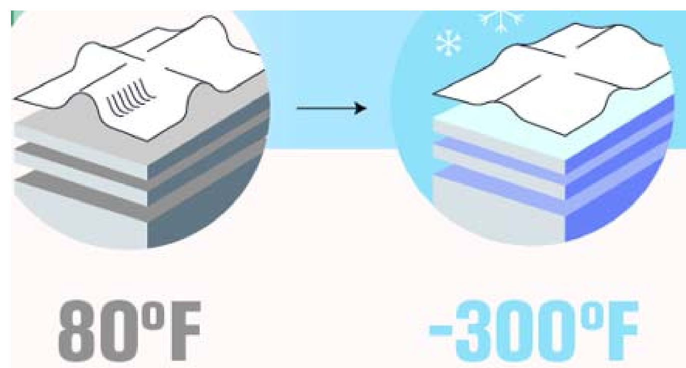
<u>External Dimensions</u>
62.7’ W x 59’ H x 216.5’ L (19.1m W x 18.0m H x 66.0m L)

A lot of insulation and a stainless steel membrane – Inside the Warm Structure

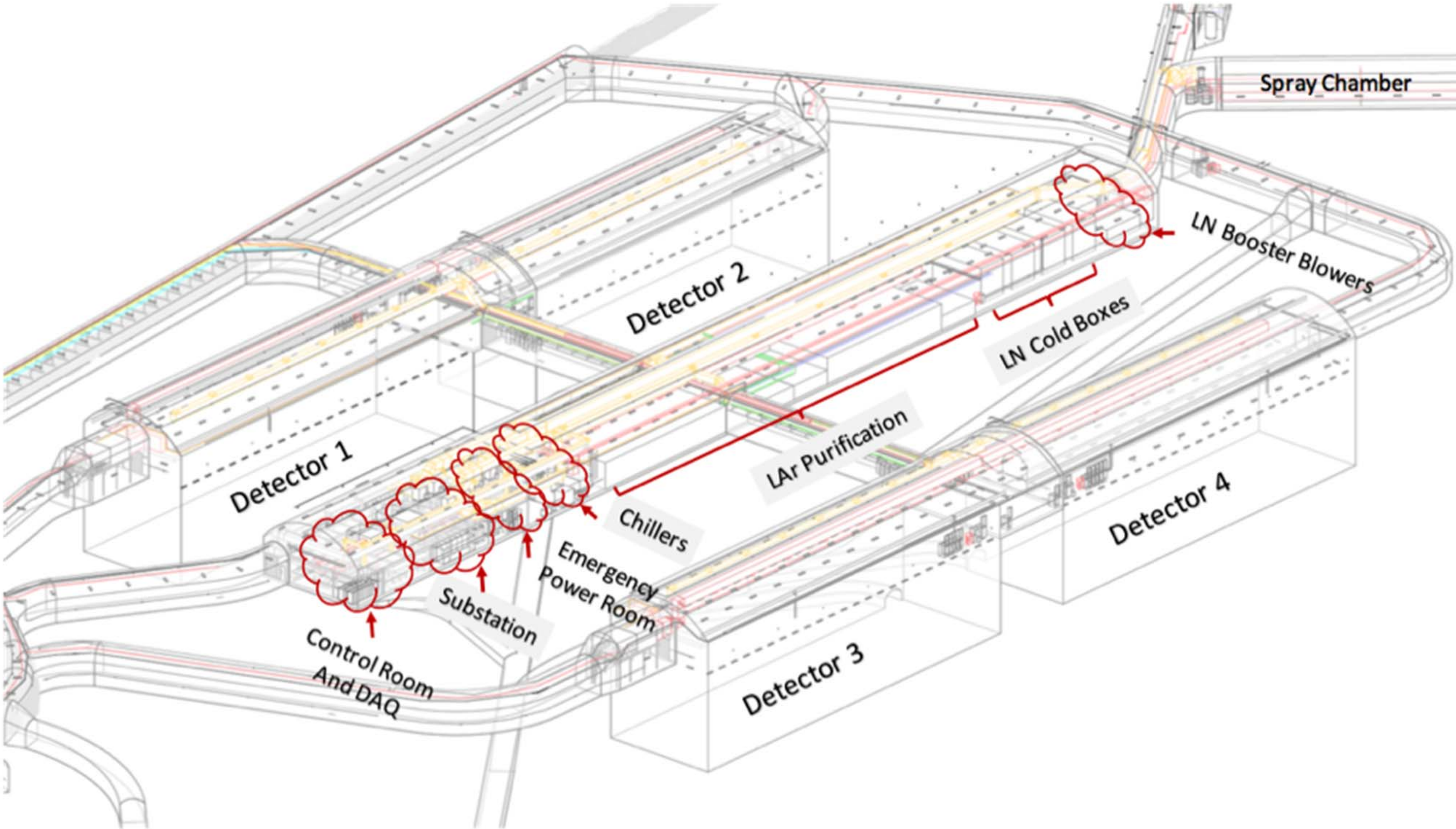




- Same technology used for LNG transport ships
- The DUNE detector modules will shrink by about 16.5 cm (half a foot) when filled with liquid argon at -300 F

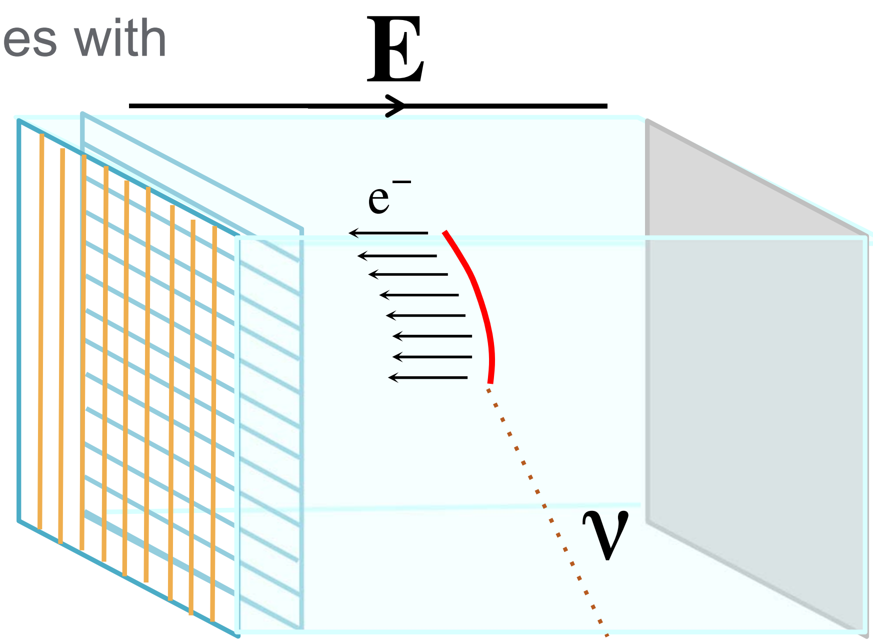


Cryogenic Systems to support detectors– Central Utility Cavern

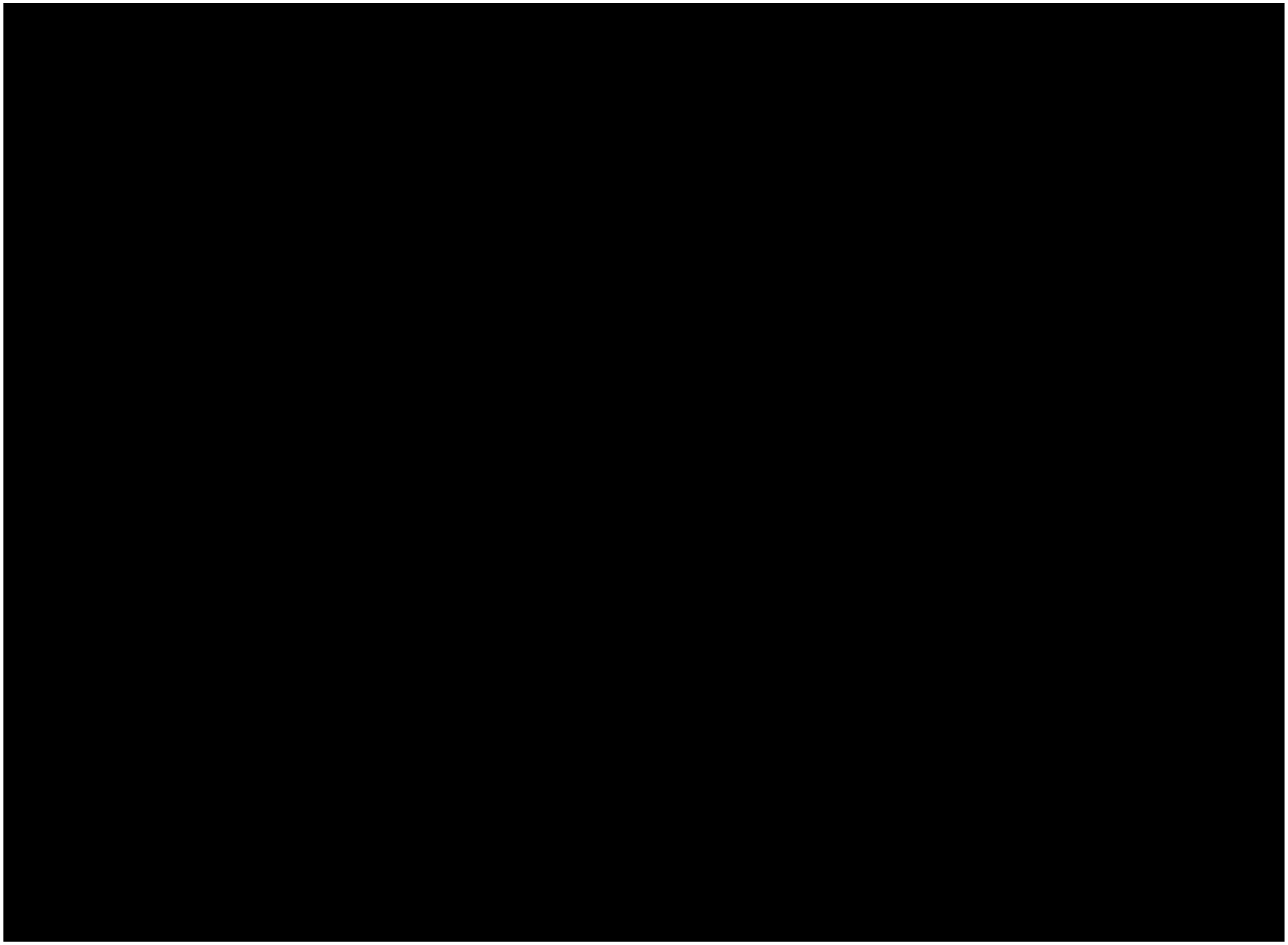


Cryostats will hold large, sensitive detectors

- Why very big? To see as many neutrino interactions as possible
- Why very sensitive? To see subatomic processes is great detail
- Basic Idea:
  - Build a large tank of liquid argon (-300 degrees F)
    - Why argon? Dense, condensed noble gas
  - Apply a very strong electric field across the tank
  - When a neutrino (occasionally) collides with an Argon nucleus, electrons are caused to “drift” towards the large planes of wires
  - Detect when the electrons contact the wire
  - Figure out what happened – reconstruct the interaction by “decoding” the signals on the wires.



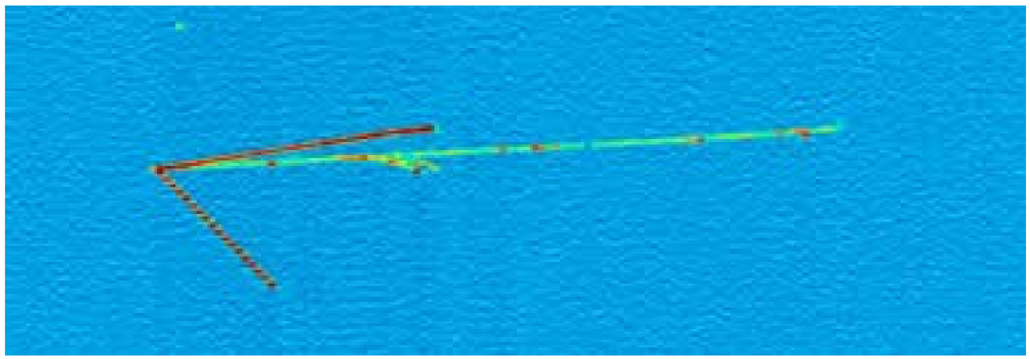
How “drifting” electrons paint the picture of a neutrino collision



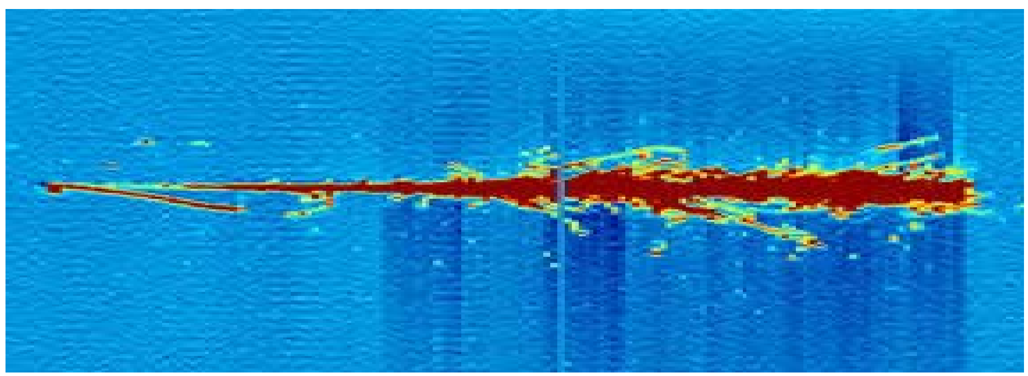
What you get from the LAr detectors…

- 3D image of particles anywhere inside a ***very*** large volume (~70,000 tons of liquid argon)
- Clear detection of neutrino "flavor," for example:

ν_μ →



ν_e →

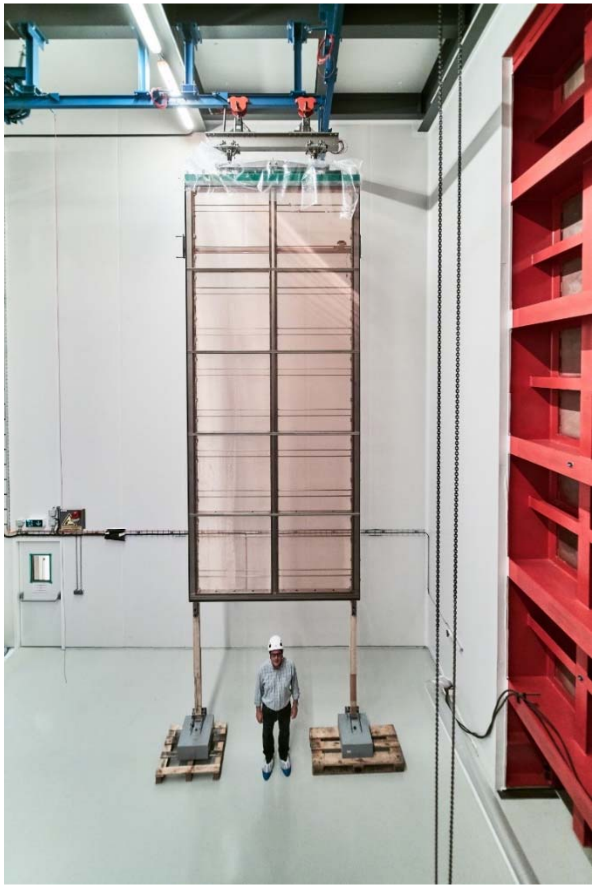


How do you know it will all work?

Build two 1/20th scale prototypes at CERN

ProtoDUNE detectors at CERN

- Prototypes are 1/20 scale full size detectors to be installed at Sanford Lab
- Each prototype holds 770 tons of liquid argon vs. 17,700 tons that each full size detector module will hold.

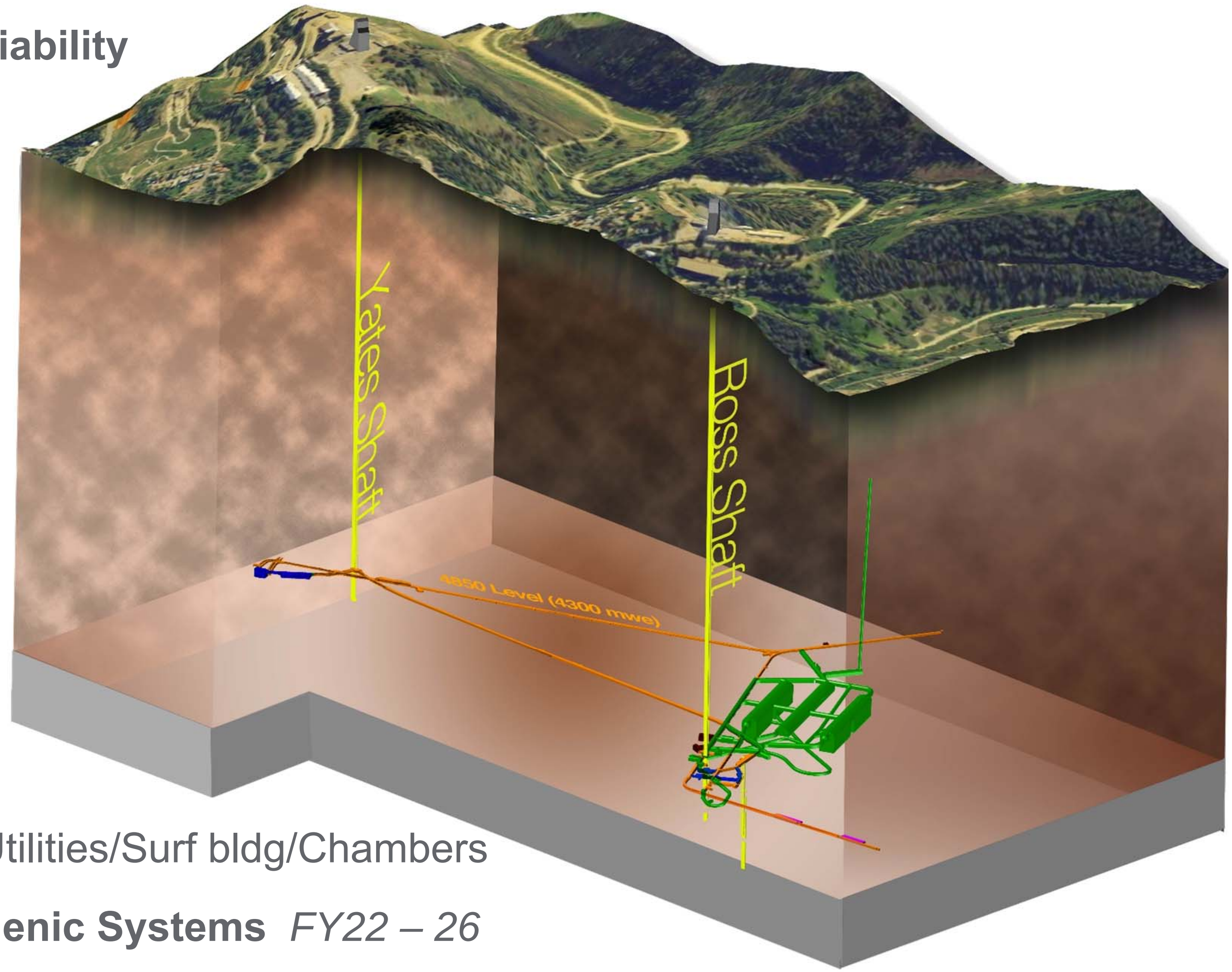


- The SP prototype detector has 6 wire plane panels; full size detector will hold 150 panels.
- Each panel has 15 miles of wire!

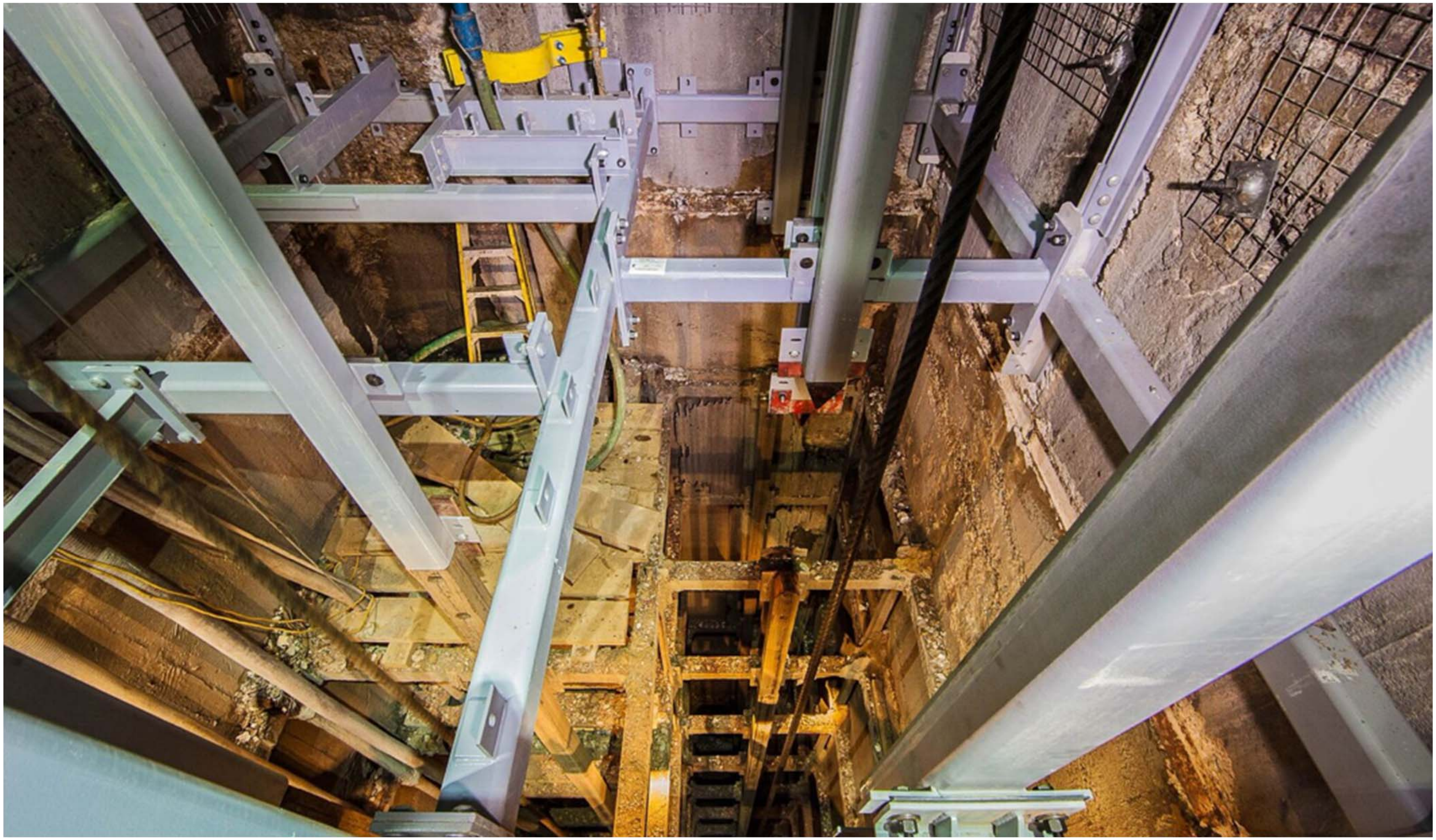
ProtoDUNE progress

Far Site - Phases of Work

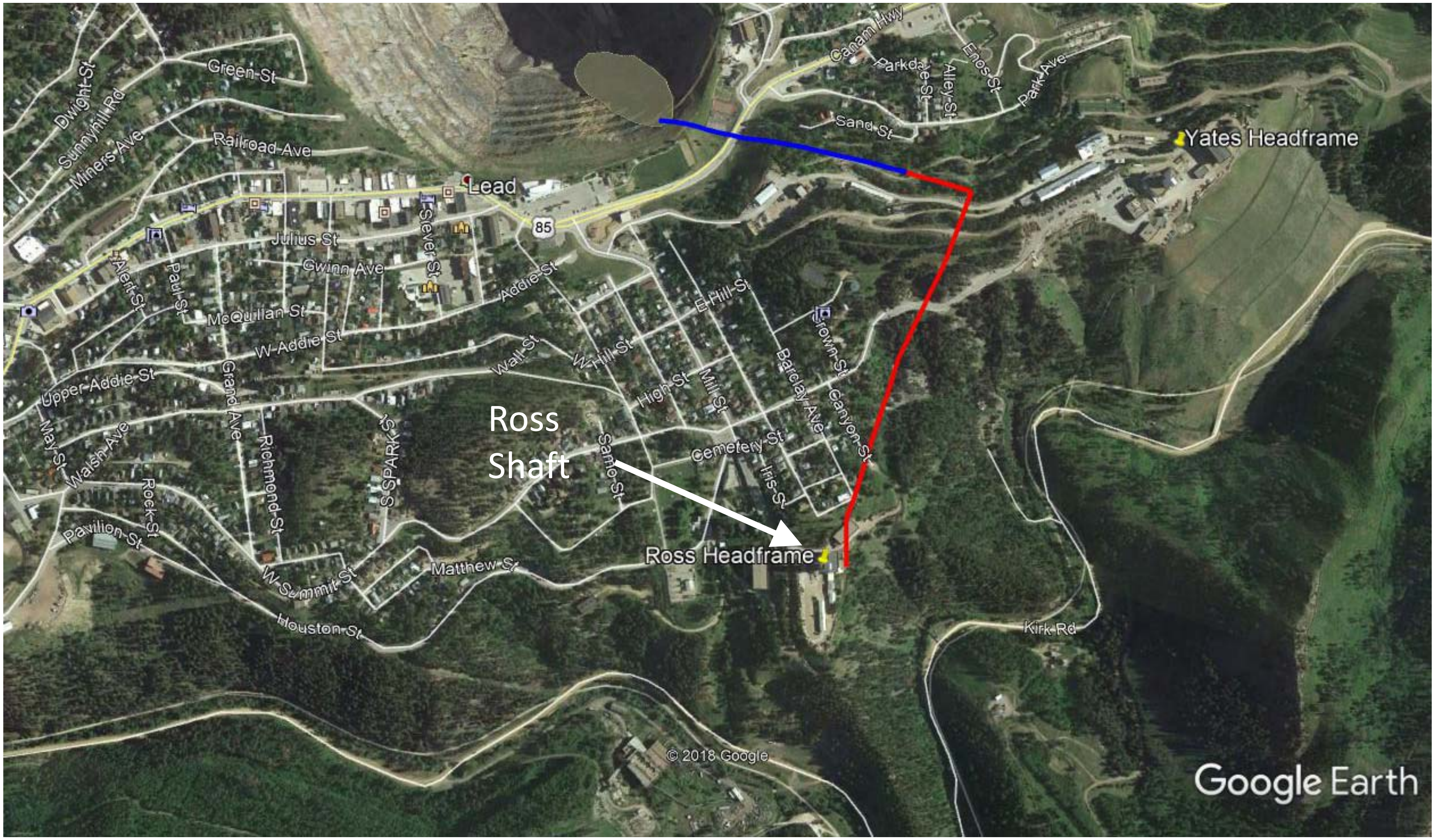
1. **Sanford Lab Reliability Projects**
   FY16 – 19
   - Ross shaft rehab
   - Hoist motor rebuilds, more…
2. **Pre-Exec Const**
   FY17 - 20
   - Rock disposal systems
   - Ross headframe upgrade, more…
3. **Exec & Surface Construction**
   FY21 – 24
   - Brow/CUC/Drifts/Utilities/Surf bldg/Chambers
4. **Cryostats/Cryogenic Systems** *FY22 – 26*



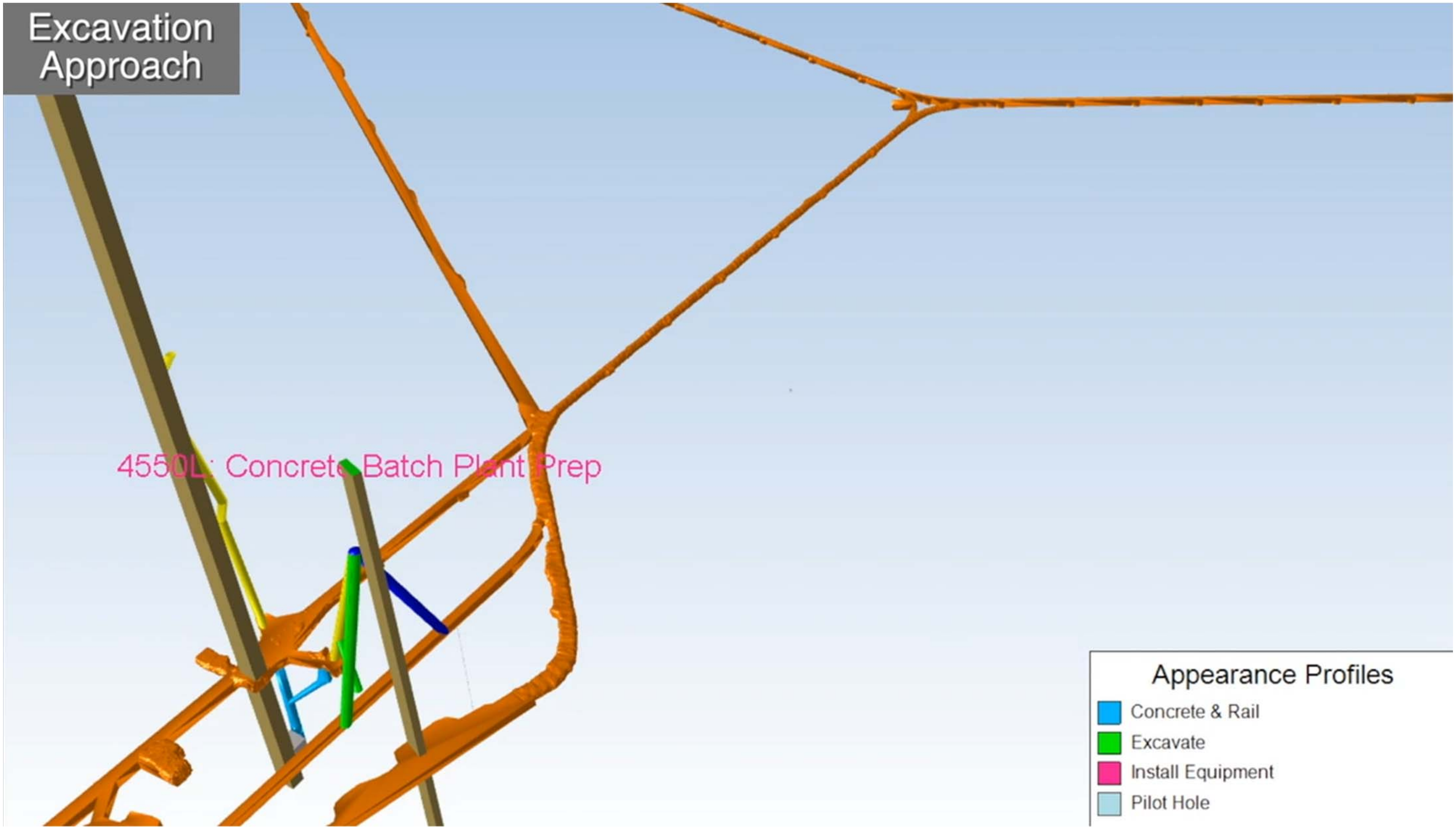
Ross Shaft Refurbishment



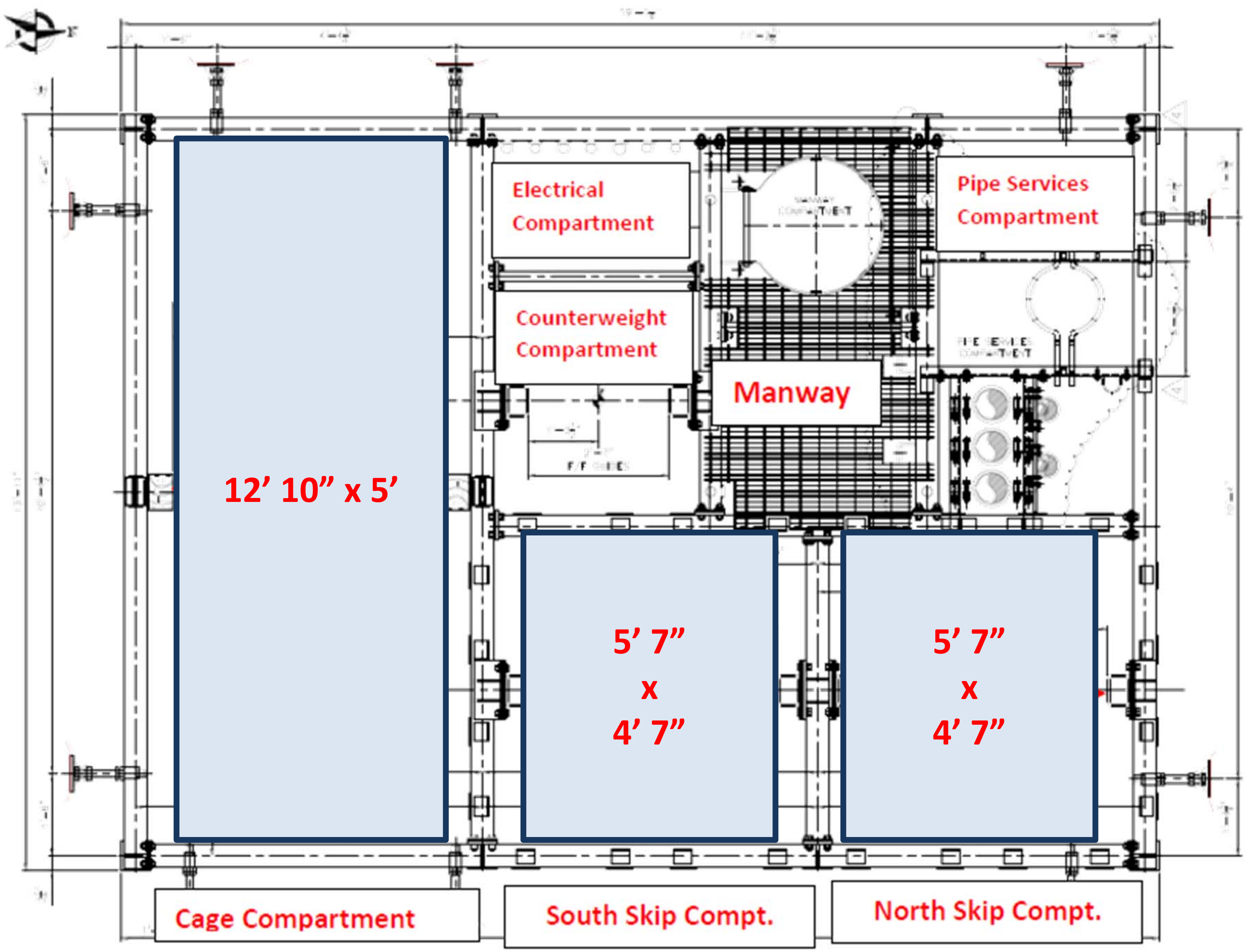
875,000 tons of rock will be transported to the surface and deposited in the Open Cut using a conveyor system



30% Final Design – Excavation Sequencing



The Ross Shaft

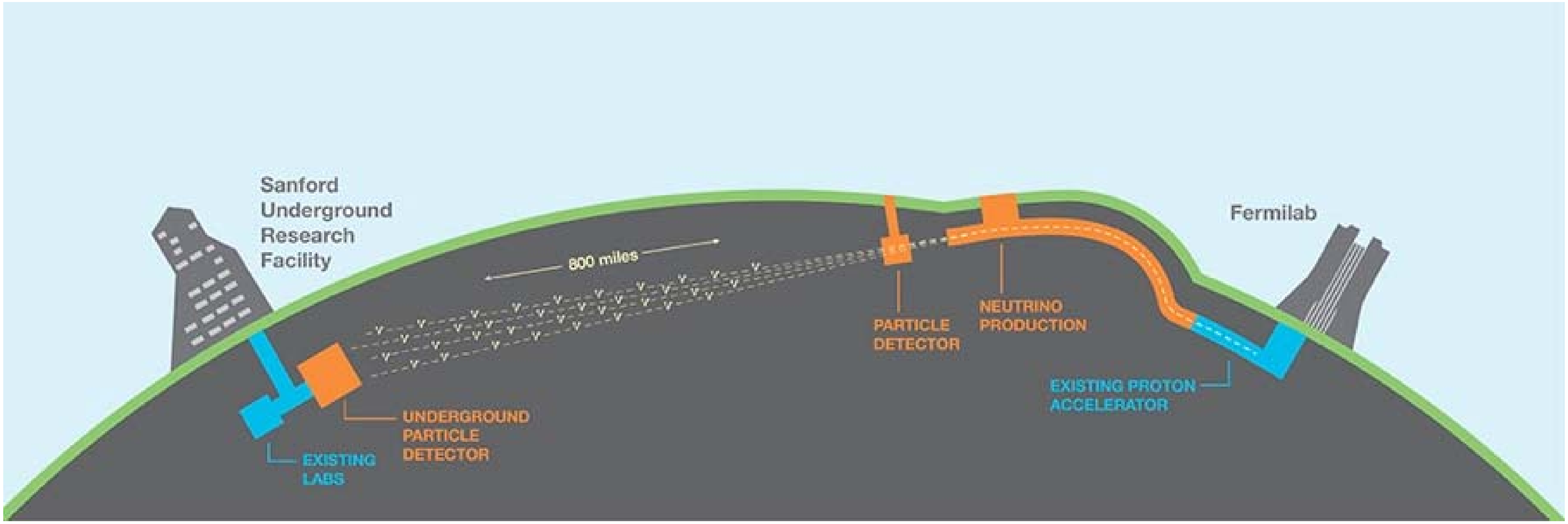


Summary

- LBNF continues to receive extraordinary support from DOE leadership, Congress, administration, and international partners.

- Opportunity to advance understanding of fundamental particle thought to hold the key to why matter exists. Also provides opportunity to advance unified theory of energy and matter by looking for proton decay.

Questions?


Sanford
Underground
Research
Facility
800 miles
Fermilab
PARTICLE
DETECTOR
NEUTRINO
PRODUCTION
EXISTING PROTON
ACCELERATOR
UNDERGROUND
PARTICLE
DETECTOR
EXISTING
LABS