DUNE
Deep Underground Neutrino Experiment
Technology development for Horizontal and Vertical drift detectors

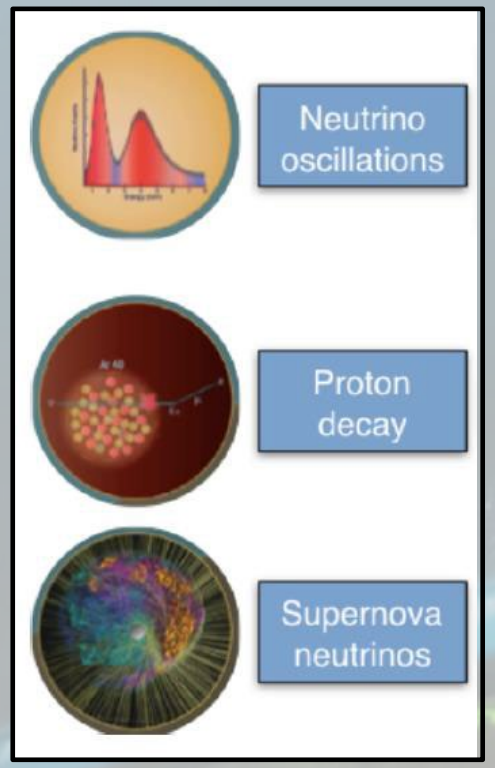
RDG 2026 - LSM
May 6th 2026

JF MURAZ

Outline

- Scientific goal
- LBNF – Long Base Line Facility
- SURF – Sandford Underground Research Facility
- DUNE HD & VD detectors
- HD detector developments (Wire chambers)
- VD detector developments (Stripped PCBs)

Scientific goal



- Neutrinos mass hierarchy
- Charge Parity violation

- Proton decay

- Atmospheric neutrinos
- Solar neutrinos
- Supernova neutrinos

1 300 km

Long-baseline wide-band beam

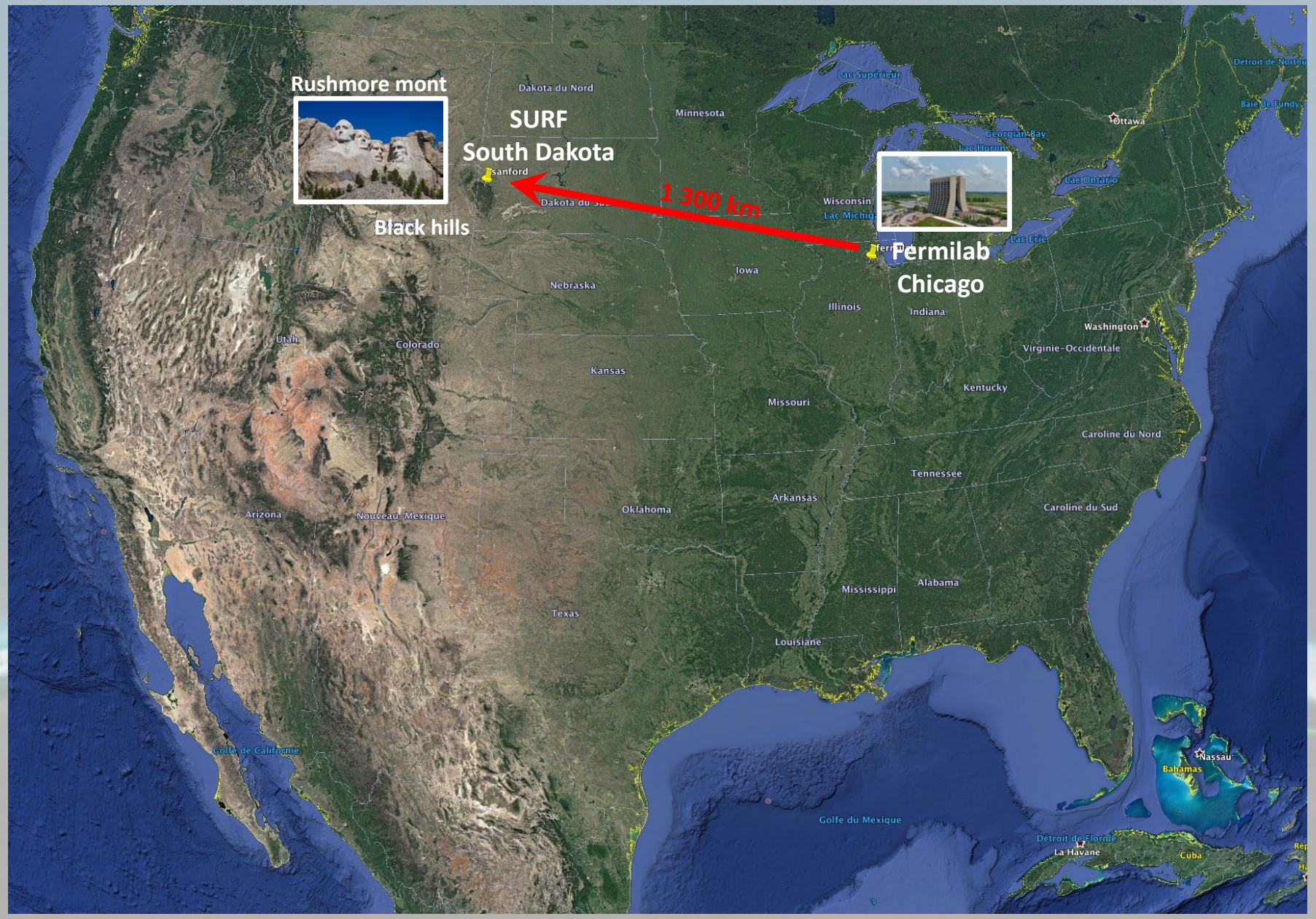
40 kT

Massive detector

1.5 km

Deep underground location

Long Baseline Neutrino Facility

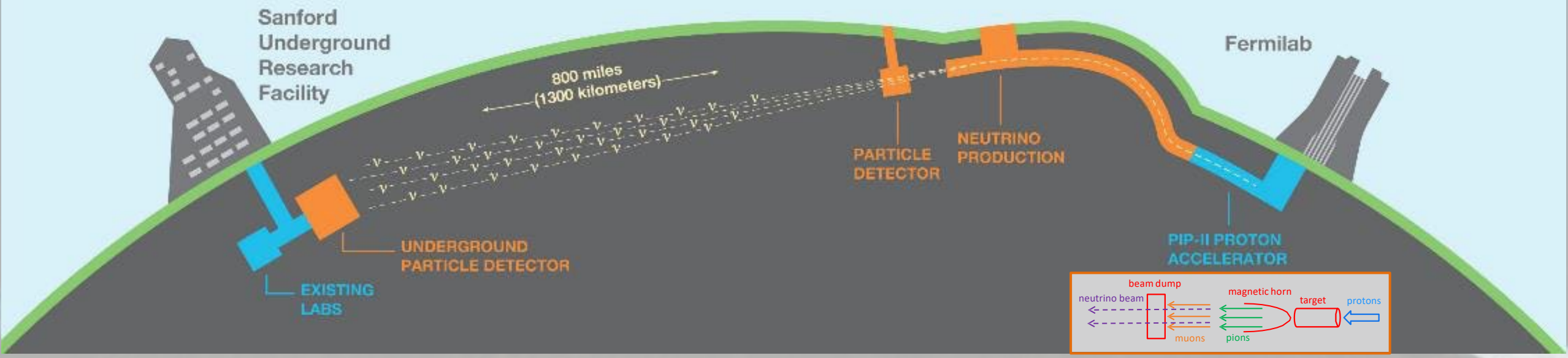


Long Baseline Neutrino Facility

Far Site – SURF in Lead, SD
Facility/Infrastructure and Far Detectors

Near Site – FNAL in Batavia, IL Facility/Infrastructure, Neutrino Beamline, and Near Detectors

1.2 MW (2.4 MW): Protons 2.5 GeV



Long Baseline Neutrino Facility

Far Site – SURF in Lead, SD
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THIS TALK

Near Site – FNAL in Batavia, IL Facility/Infrastructure, Neutrino Beamline, and Near Detectors

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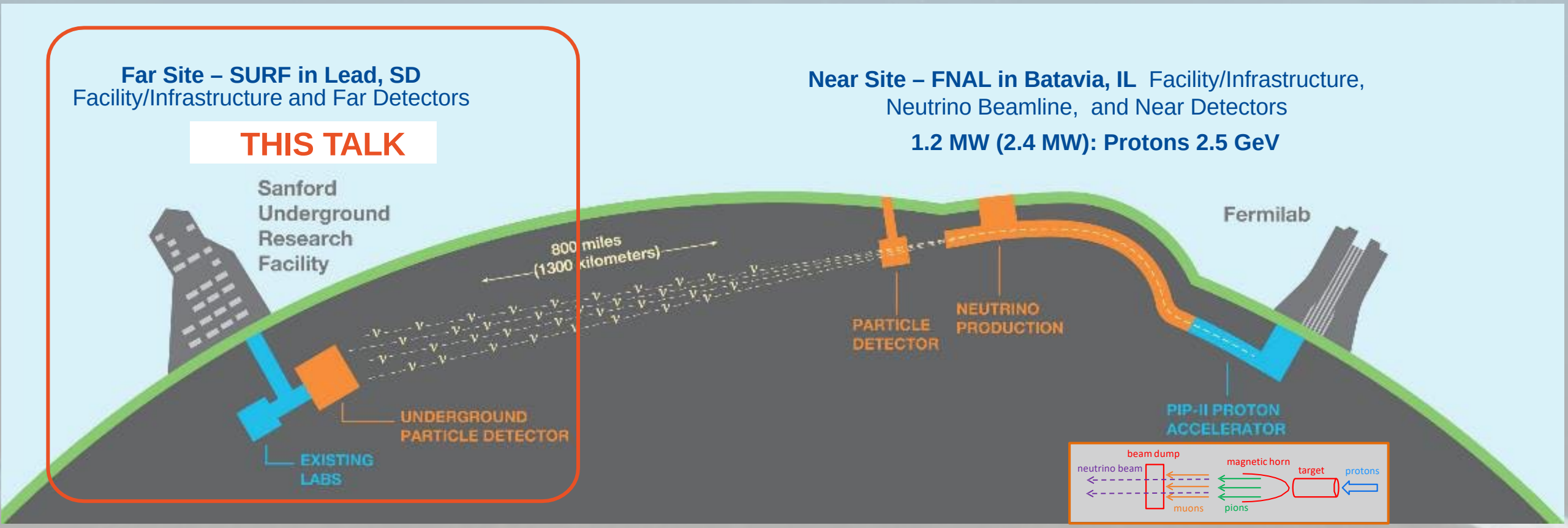
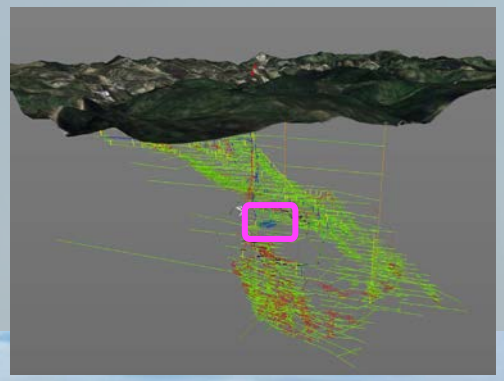


Sandford Underground Research Facility

- Homestake gold mine in the Black Hills *(595 km of galleries, 60 levels down to 2,48 km)*
- Site of the Davis & Bahcall Solar Neutrino Experiment *(1970-94)*
- Donated to South Dakota Science and Technology Authority (SDSTA) in 2006
- Lease agreement in 2016 between SDSTA and US DOE for LBNF/DUNE



Sandford Underground Research Facility

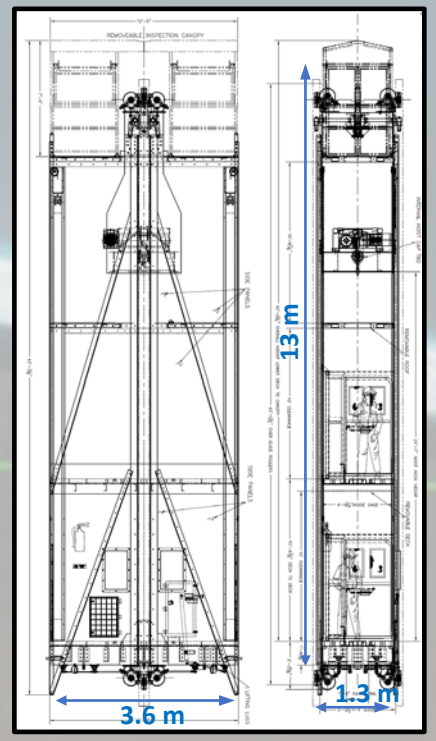
Build in 1930

Machinery

Ross Shaft :

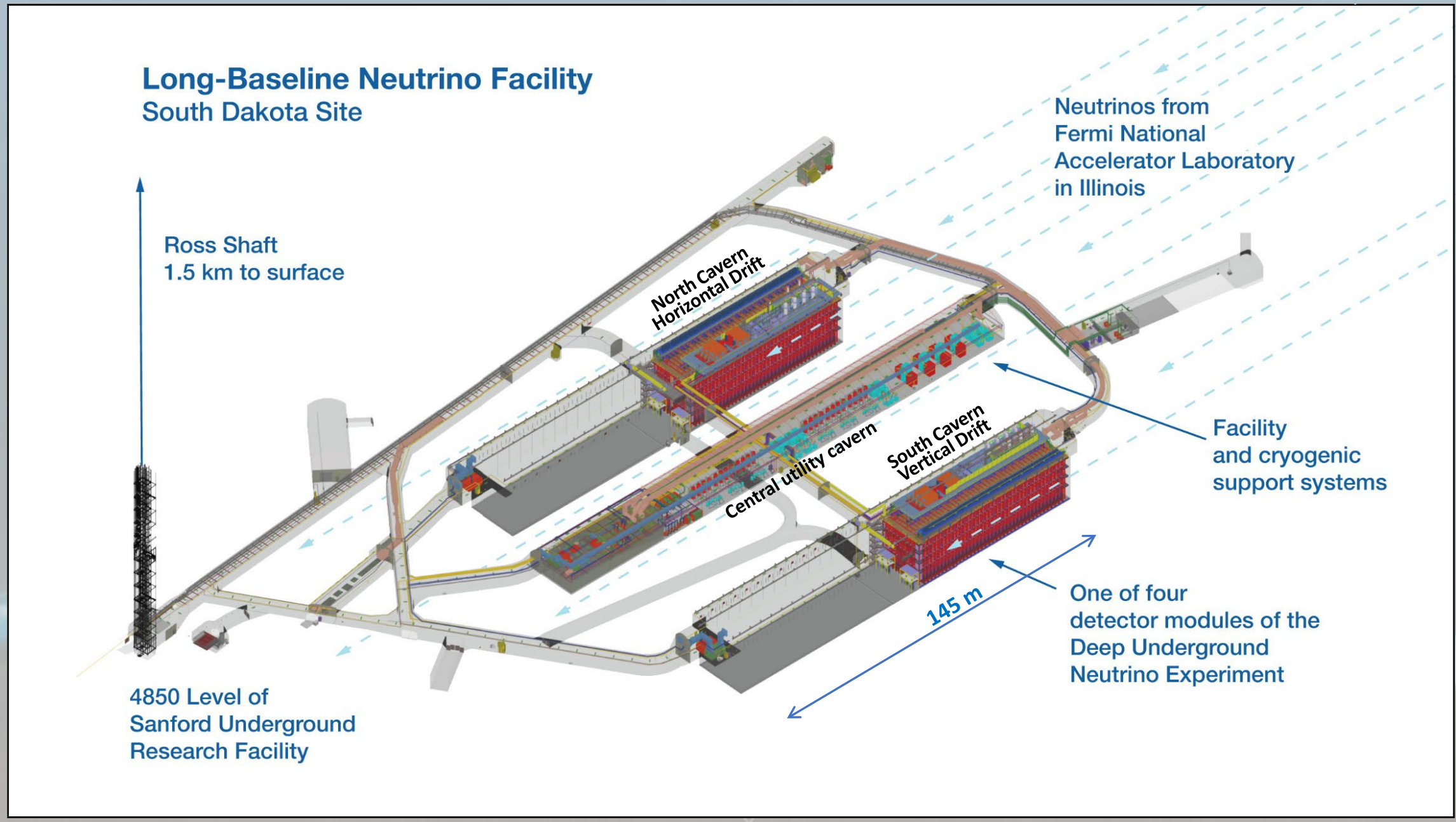
Build in n 1930
Underground: 1.5 km (4850')
Cage speed: 7.8 m/s (1500'/mn)
Time to go underground: ~12 mn
Cage width : 1.3 m !!!

Ross headframe



Ross cage

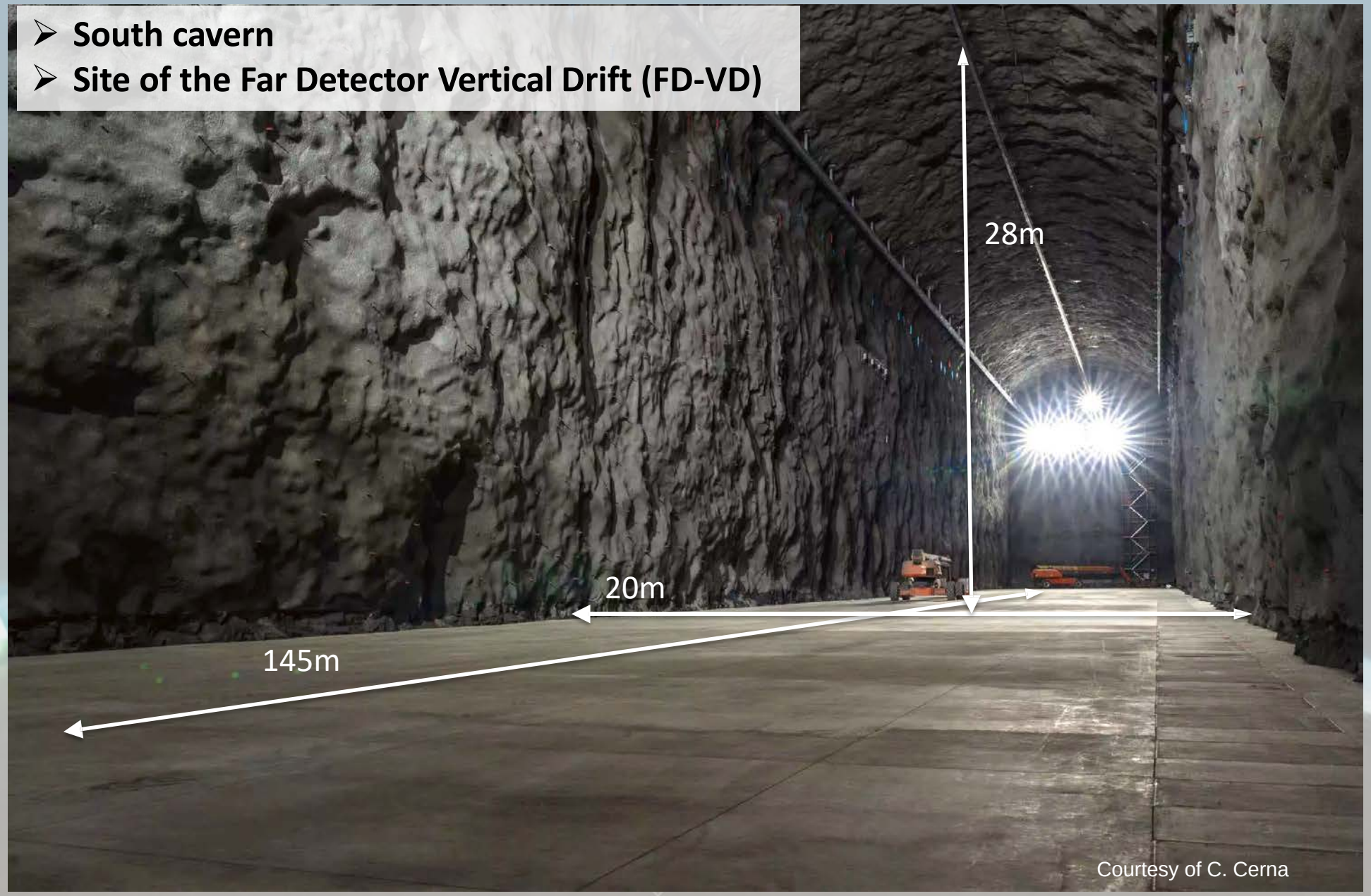
Sandford Underground Research Facility



Sandford Underground Research Facility

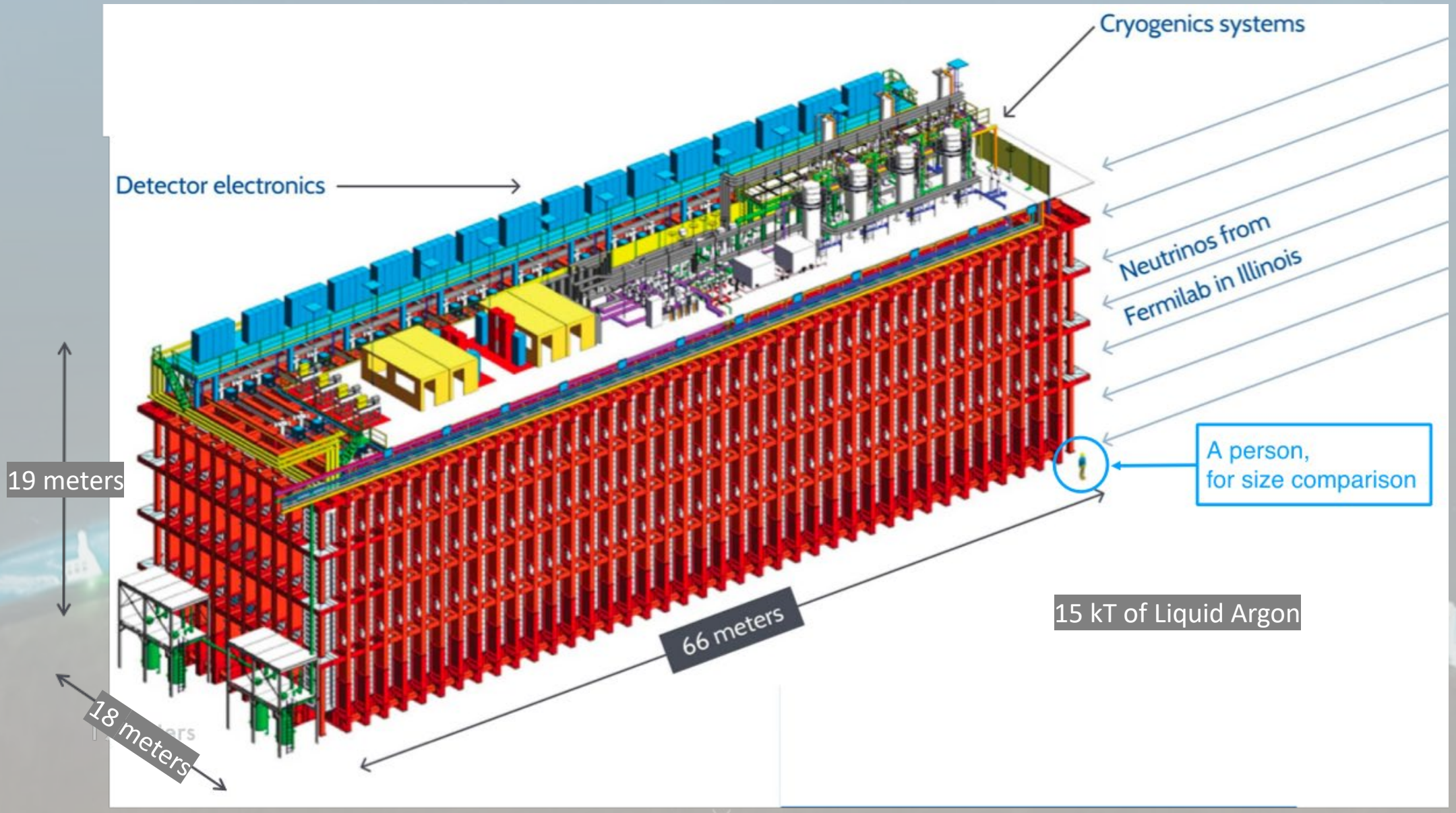
Excavation end in 2024 (800 000 m3)

Sandford Underground Research Facility



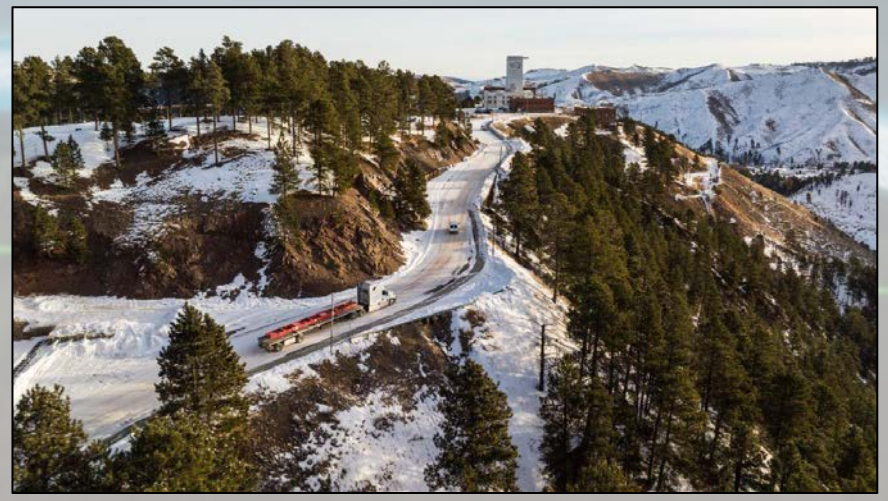
Sandford Underground Research Facility

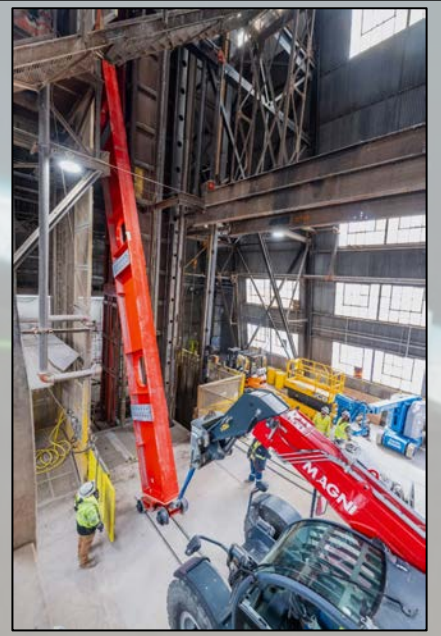
LAr DUNE cryostats (HD & VD)



LAr DUNE cryostats

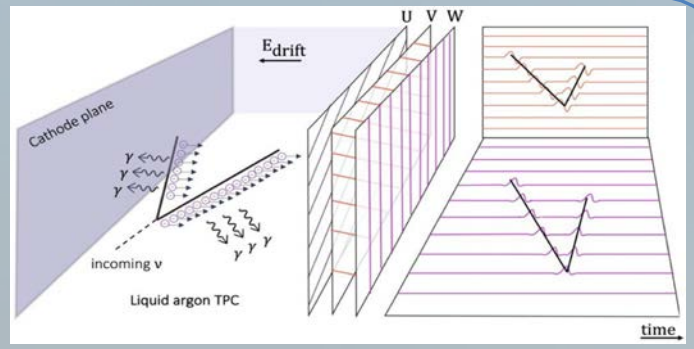
Two cryostats mechanical structure delivered in South Dakota (6 250 tons of Steel - ~800 trucks)

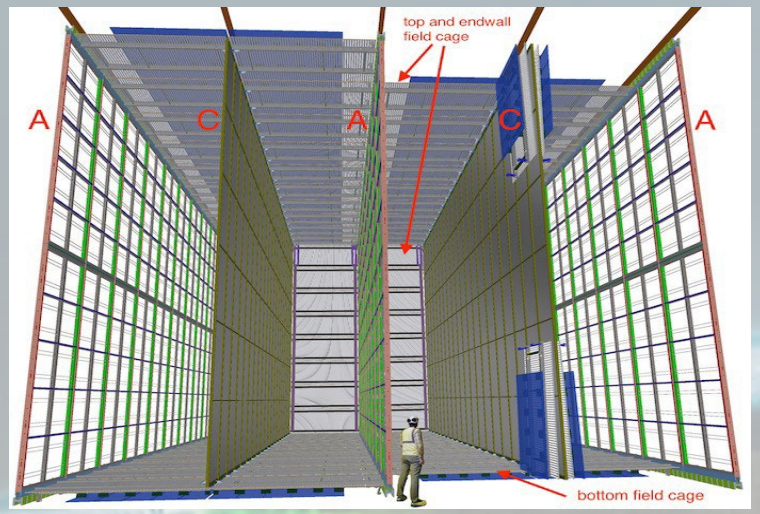




DUNE Far site Detectors

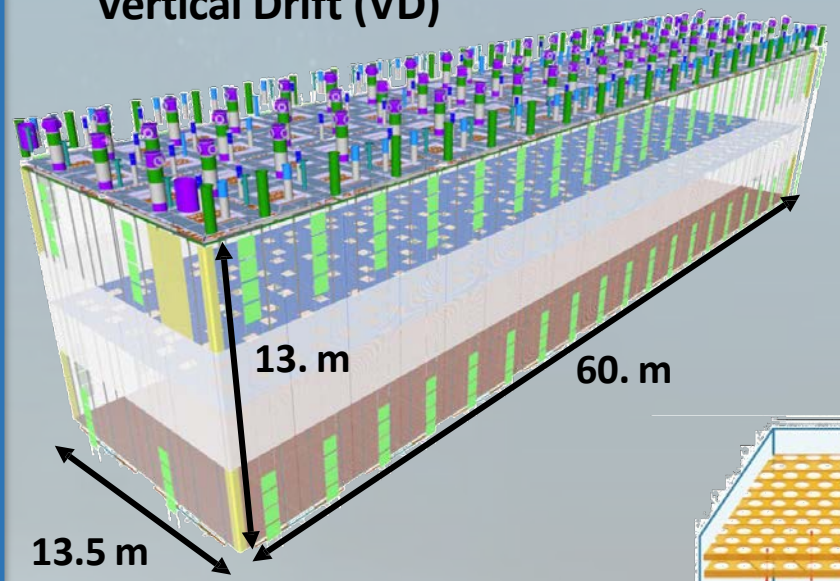
Horizontal Drift (HD)

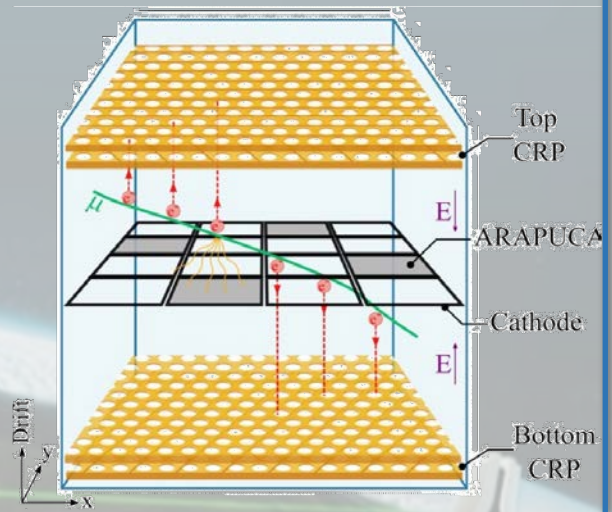




- Drift length ~ 350 cm
  - HV on cathode ~ 180 kV (~510 V/cm)
- Wire readout plane (APA) technology
- Photon detectors integrated in anode planes
- **~ 13.6 kt of Instrumented Volume in LAr**

Vertical Drift (VD)



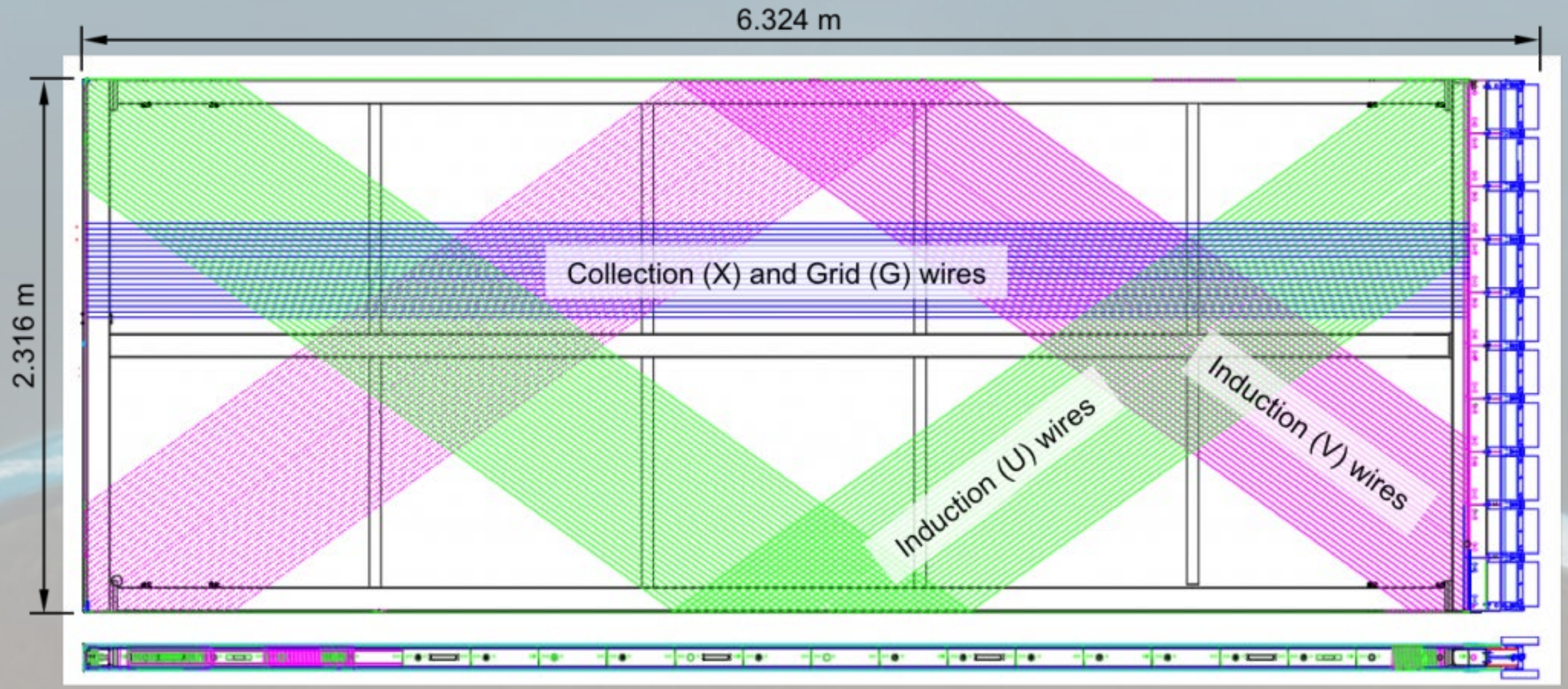


- Drift length ~ 640 cm
  - HV on cathode ~ 300 kV (~470 V/cm)
- Charge readout plane (CRP) technology
- Photon detectors integrated in cathode plane and membrane walls
- **~ 14.7 kt of Instrumented Volume in LAr**

Courtesy of C. Cerna

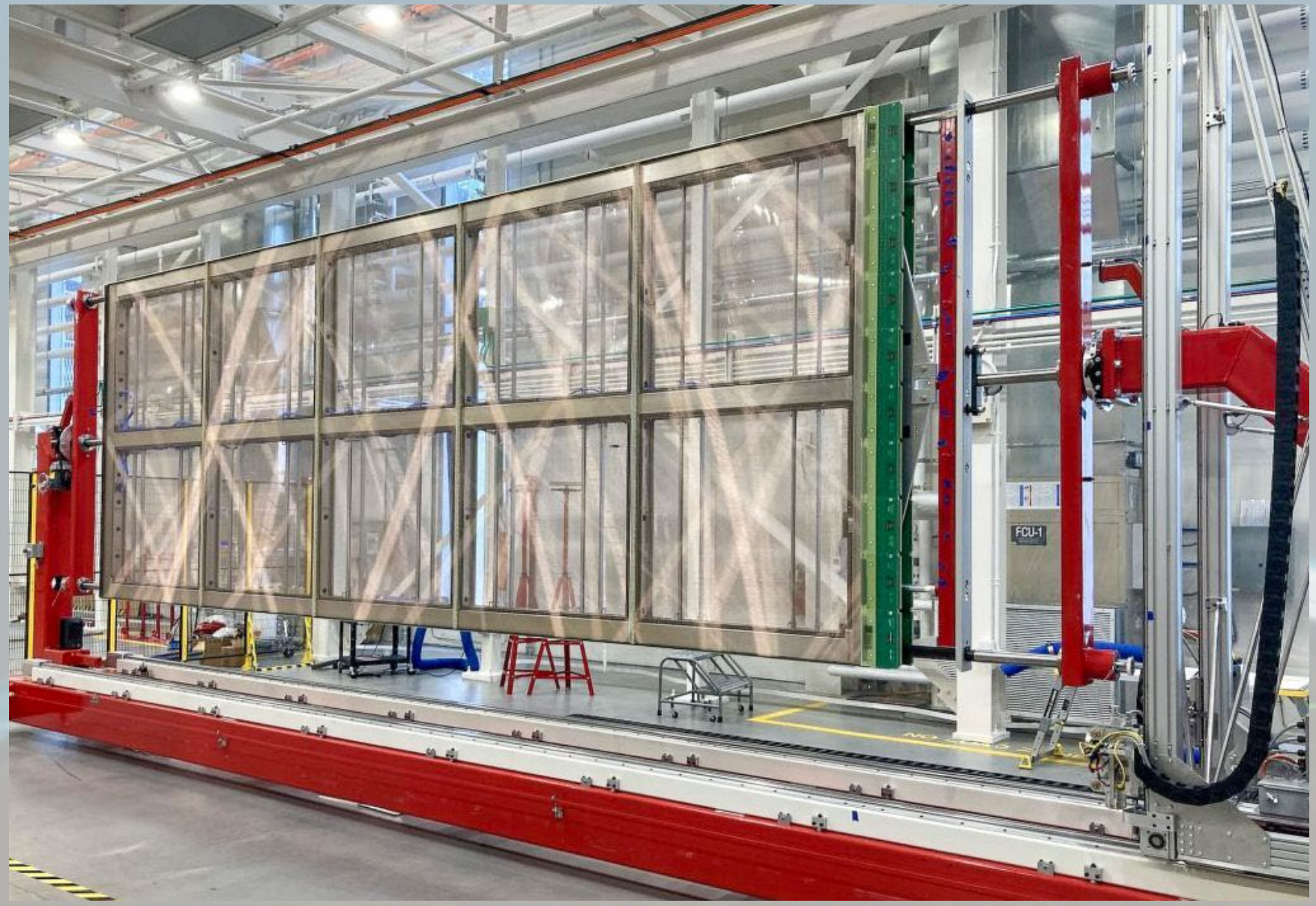
DUNE Horizontal Drift detector

150 APA (136 UK, 14 US) (APA= Anode Panel Assembly)
3 520 wires per APA (24 km)
150 µm CuBe wires

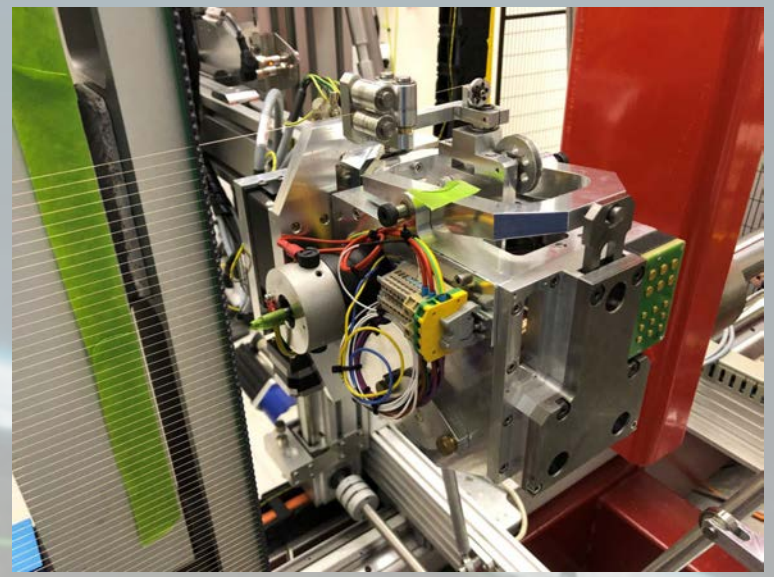


DUNE Horizontal Drift detector

APA winding machine (University of Chicago)

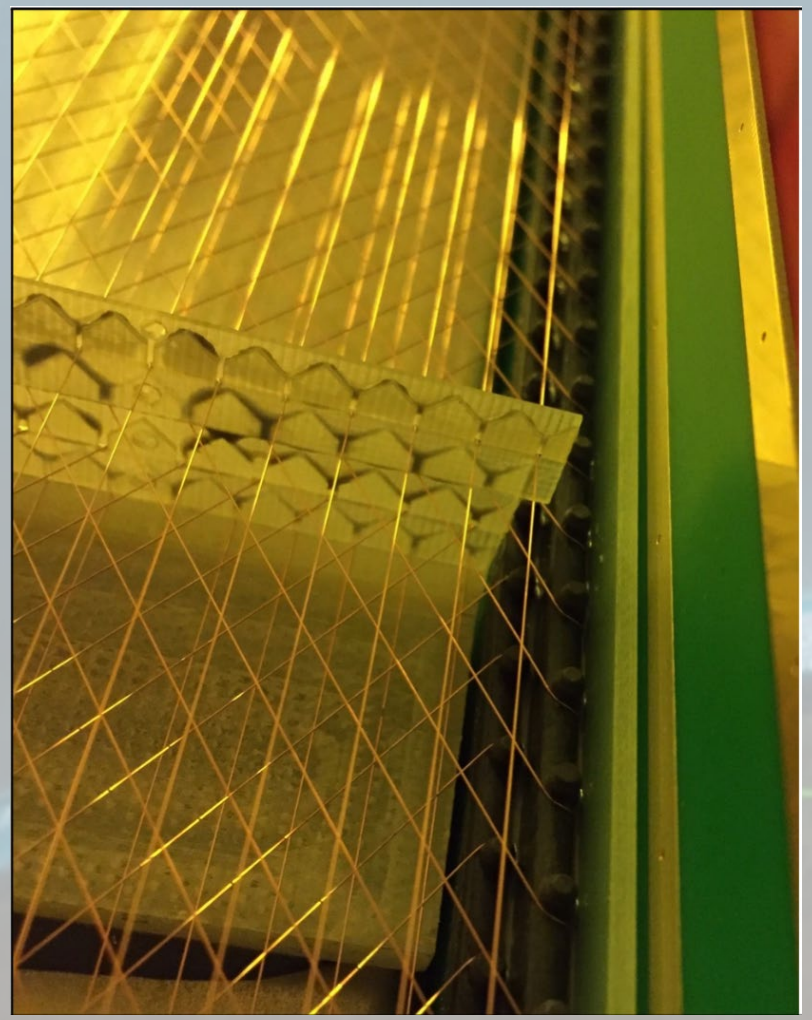


Winding head (Daresbury Laboratory)



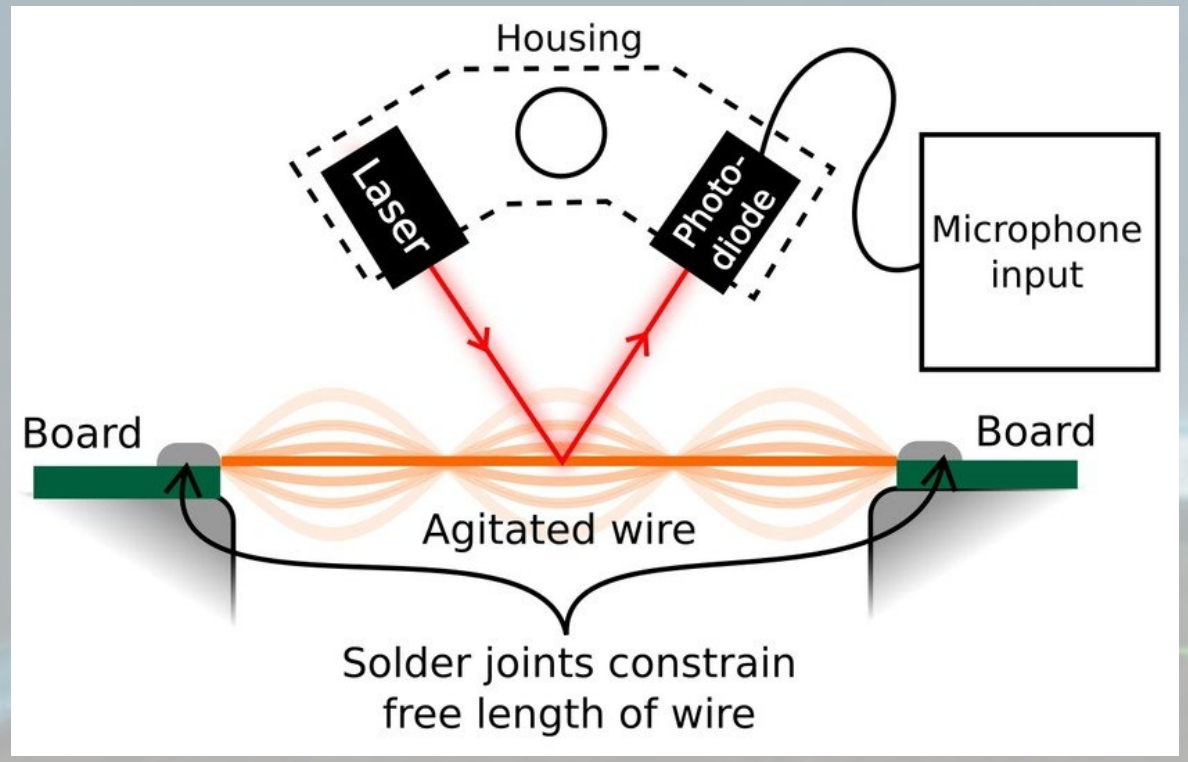
DUNE Horizontal Drift detector

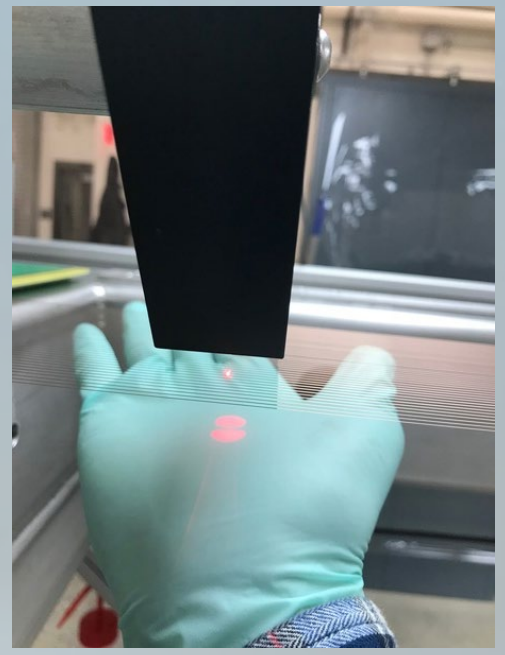
Wire soldering



DUNE Horizontal Drift detector

Wire tension QC : Laser acoustic exitation
Cons: Only one wire tested at a time



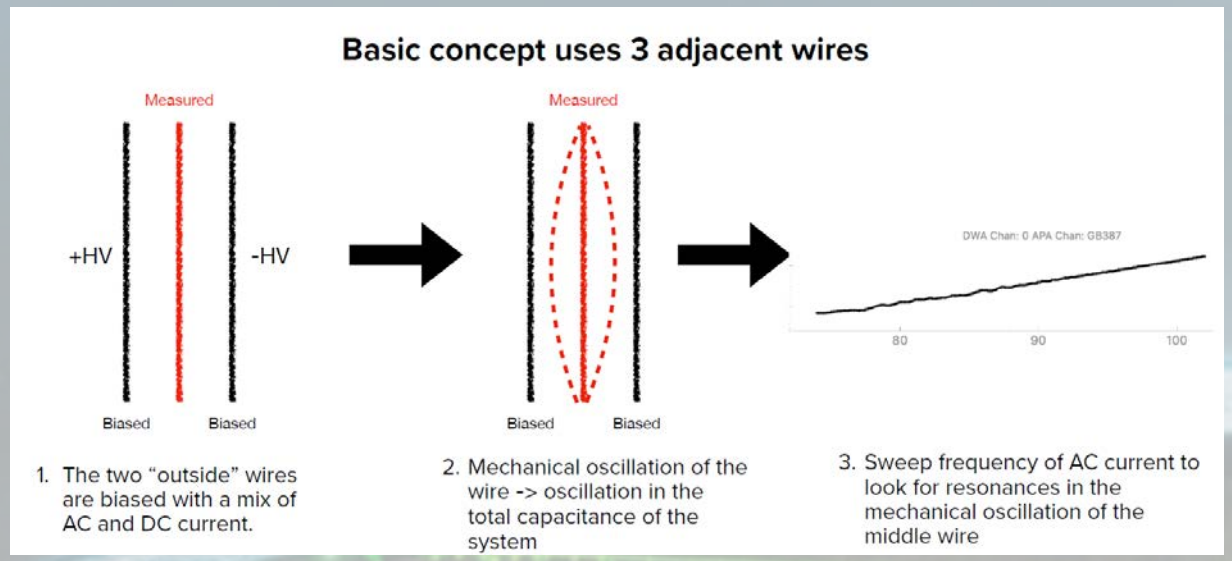


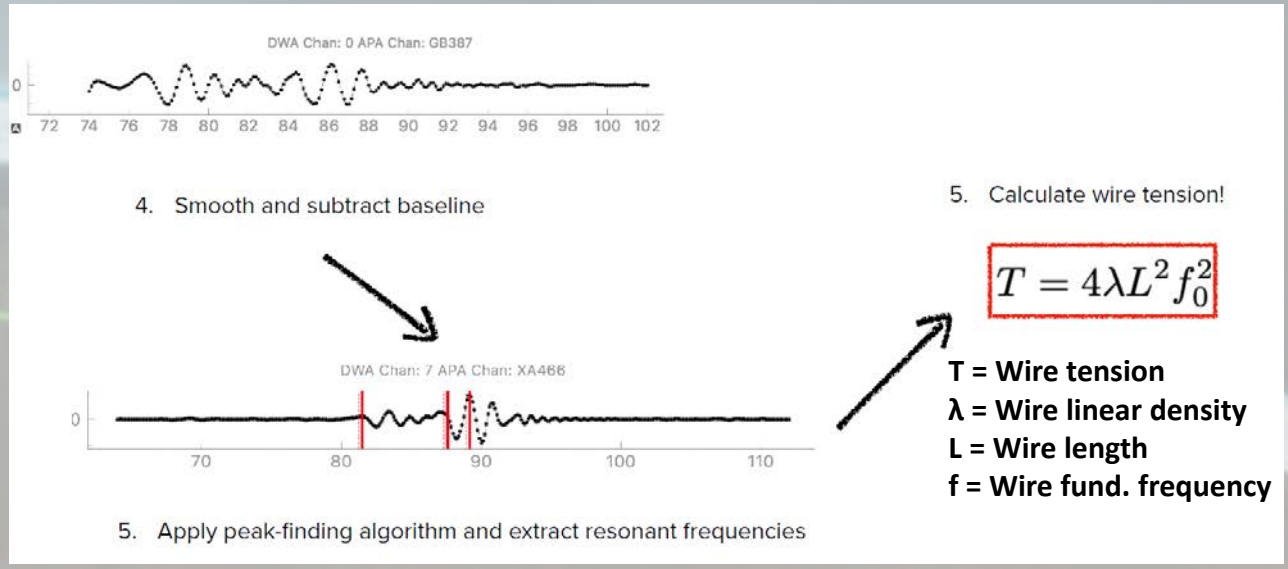
DUNE Horizontal Drift detector

Wire tension QC: Digital Wire Analyzer (DWA)
Pro : Up to 128 wires tested at a time by a group of 8
No need to have access to the wires

Digital Wire Analyzer of Mechanical Tension, Electrical Continuity, and Isolation : https://arxiv.org/abs/2206.00125

The wire tension is determined with an accuracy of 1% by measuring the fundamental frequency of the wire



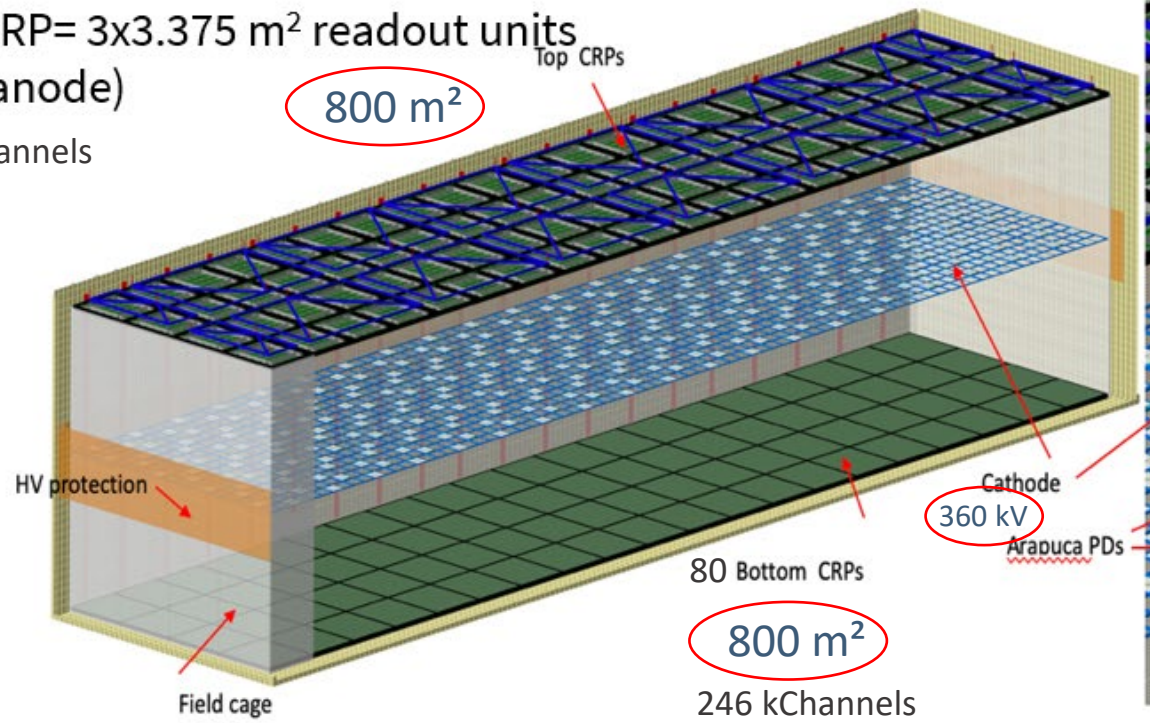


DUNE Vertical Drift detector

80 TOP CRP= 3x3.375 m² readout units (anode)

246 kChannels

800 m²



800 m²

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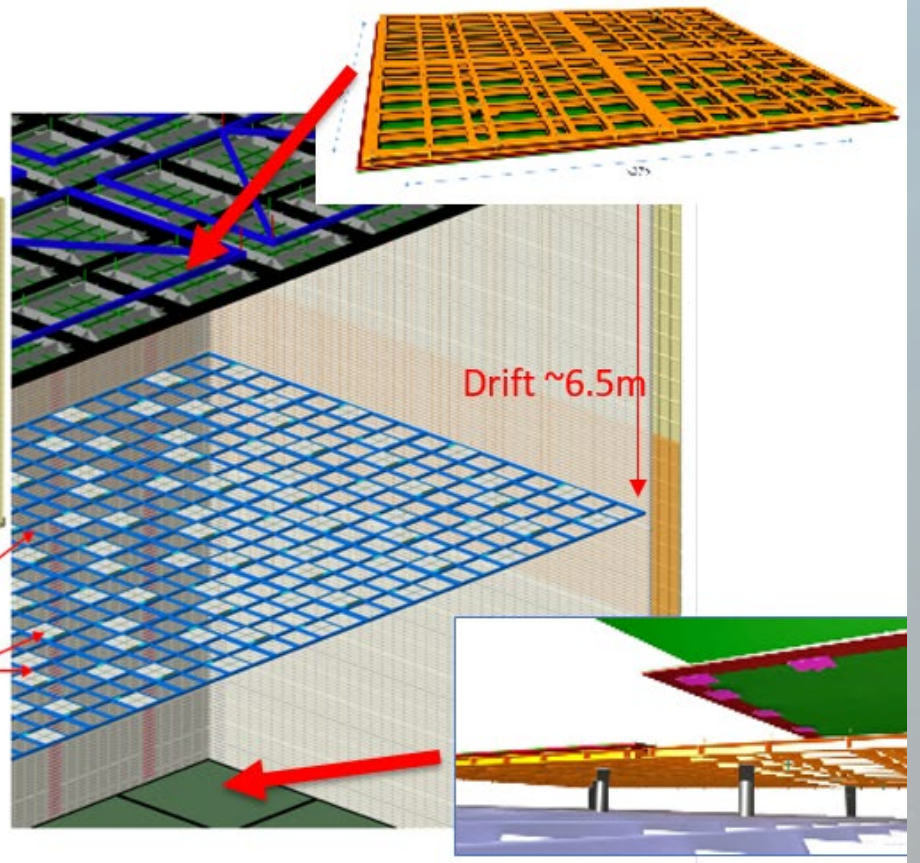
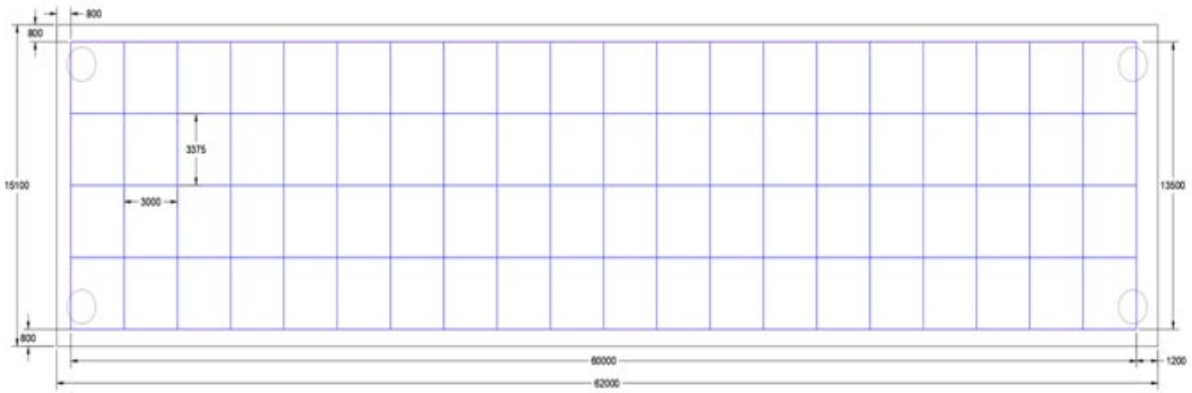
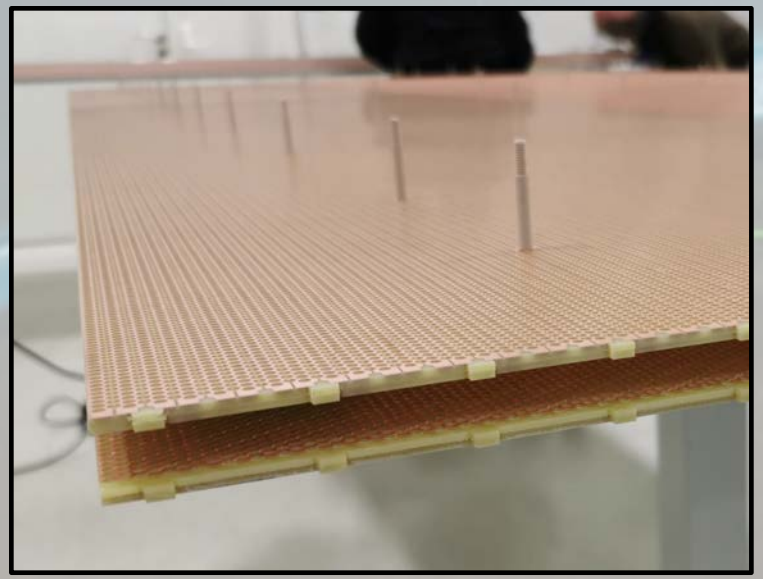




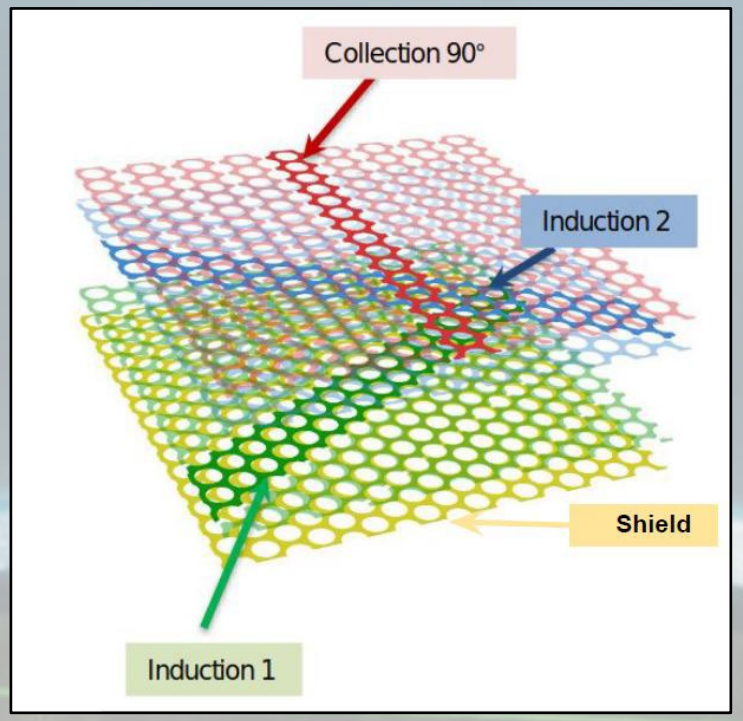
- ✓ 160 CRP units (80+80 on top/bottom, readout with DP/SP electronics)
- ✓ Drift active volumes 2*5'265 m^3 = LAr 14.74 kton

DUNE Vertical Drift detector

Anodes



Anode strips



Charged Readout Unit :

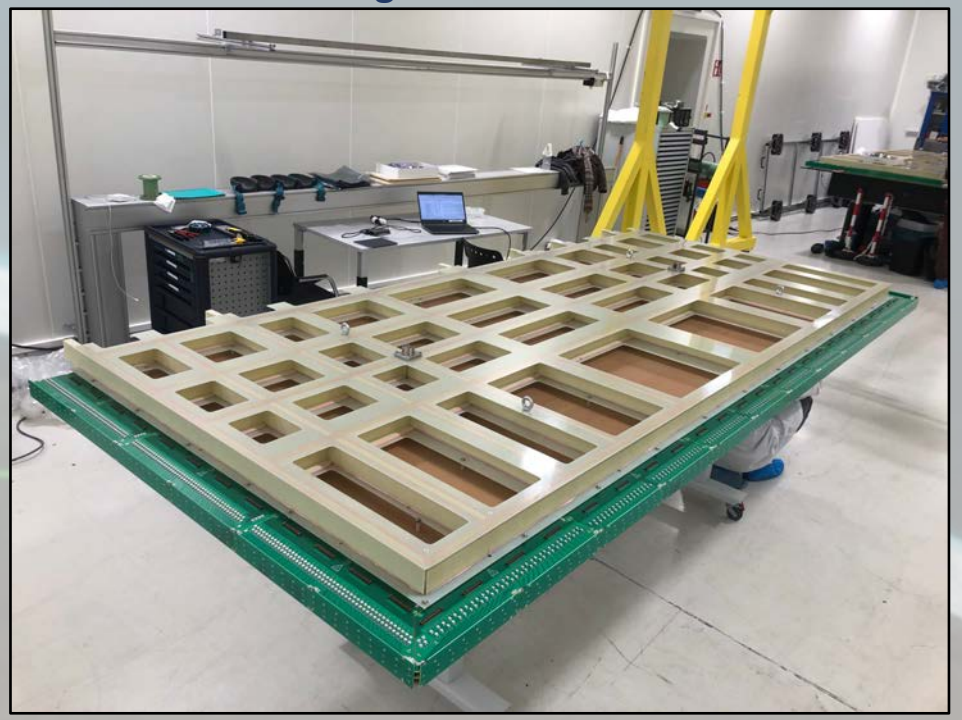
3 400 x 1 500 mm

1536 channels

160 Top CRU (+ spares)

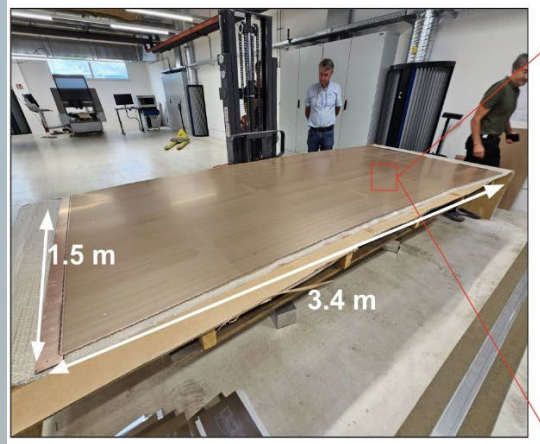
160 Bottom CRU (+ spares)

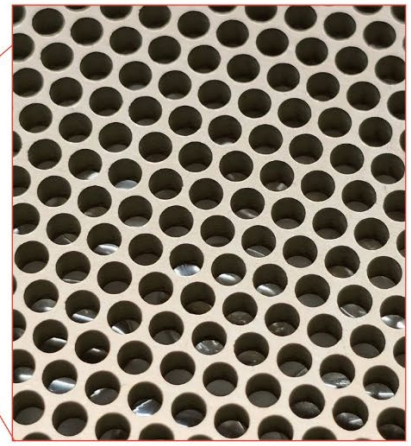
Charge Readout Unit



DUNE Vertical Drift detector

Anode production (700 anodes in total, CERN responsability)

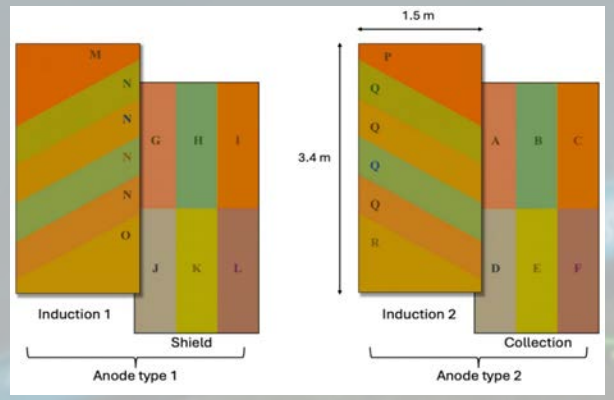


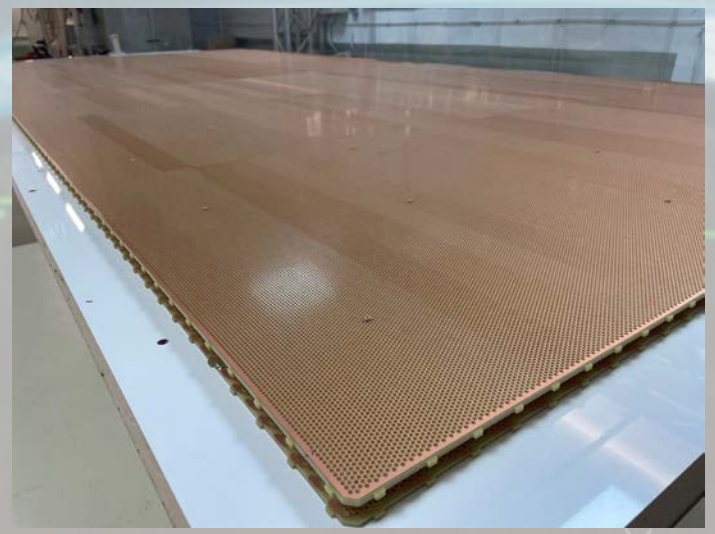


CRP Anode
= **large PCB** (1.5 m x 3.4 m x 3.2 mm)
= **perforated** with about 600 000 signal holes (2.4 mm) and about 60 alignment/structural holes (4 mm)
→ And requiring **exceptional precision** (tolerances under 100 µm)

★ Particularly challenging for the PCB industry

Segment PCB gluing



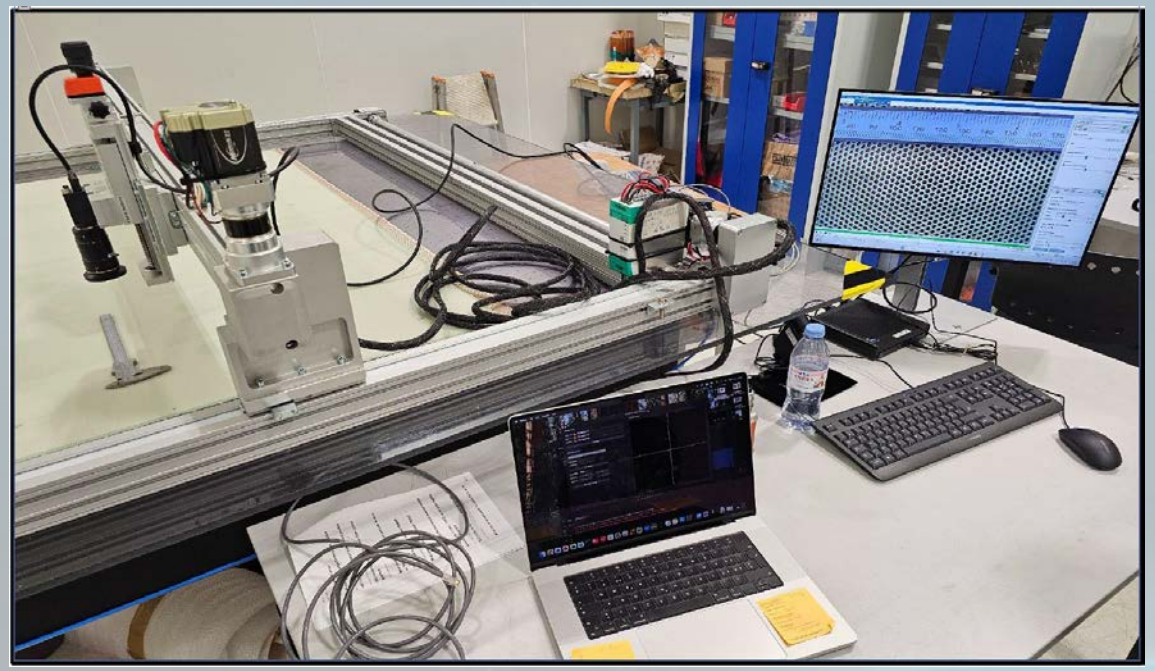


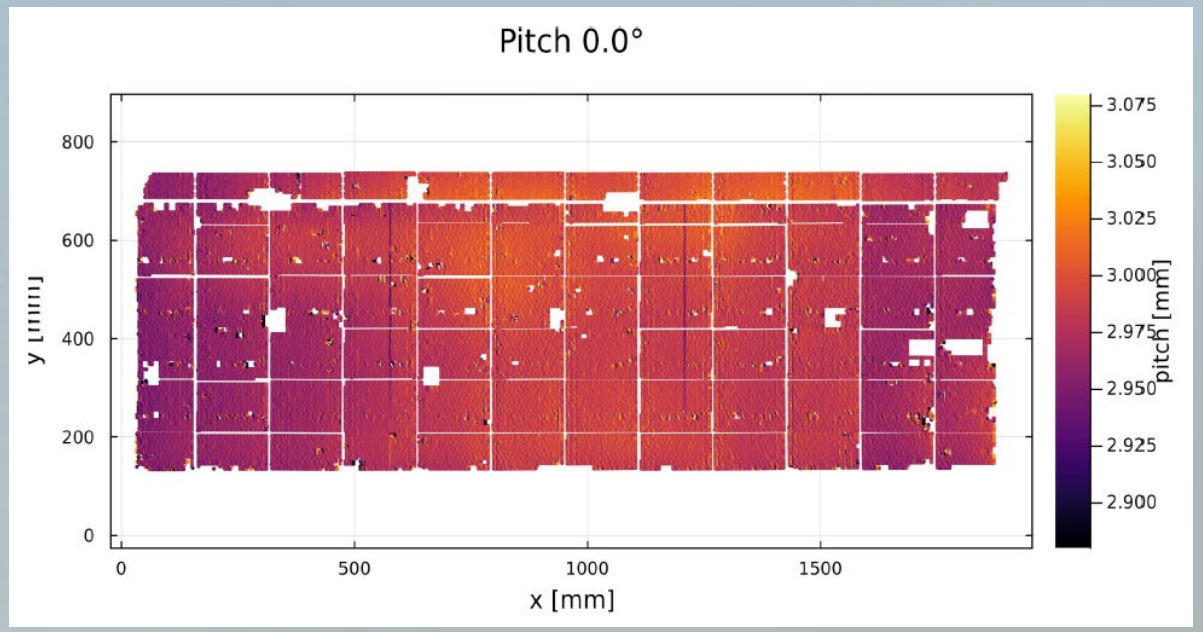
Anode drilling

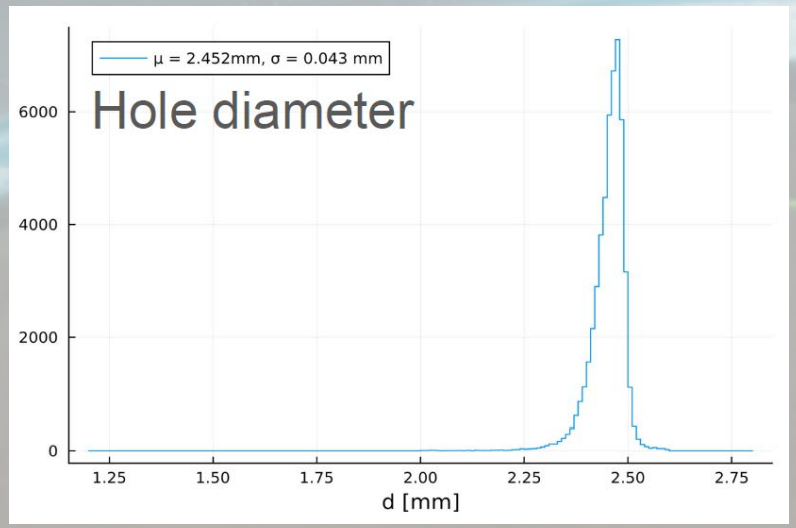
Courtesy of J. Merlin

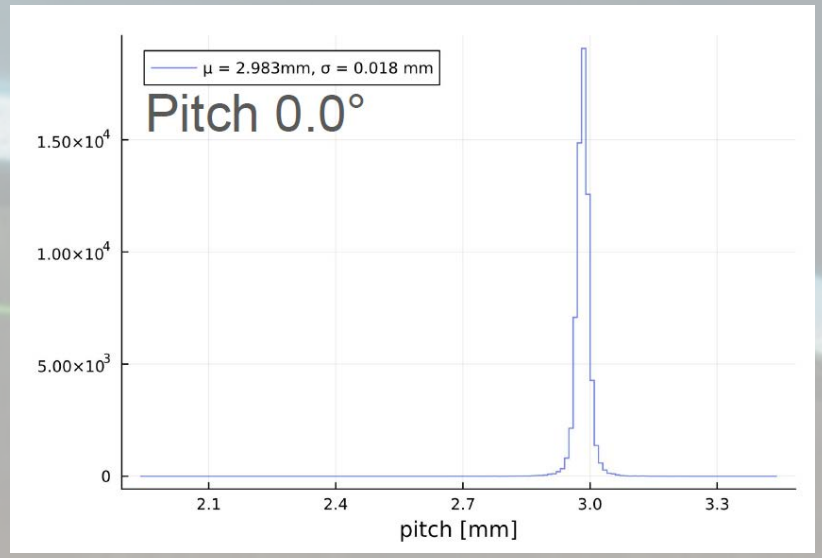
DUNE Vertical Drift detector

Anodes QC @CERN









Courtesy of J. Merlin

DUNE Vertical Drift detector

LPSC-Grenoble CRP Factory : Assembly of 90% of the TOP CRPs (144/160 CRU + 4 spares)

DUNE Vertical Drift detector

CRP QC : Continuity, shorts, HV bias

→ Capacitance measurement between two adjacent strips *(1536 channels read in 1 mn)*

Capacity ∝ strip length

Capacitance measured with AD7746

ANALOG DEVICES

24-Bit Capacitance-to-Digital Converter with Temperature Sensor

AD7745/AD7746

FEATURES

Capacitance-to-digital converter
- New standard in single chip solutions
- Interfaces to single or differential floating sensors
- Resolution down to 4 aF (that is, up to 21 ENOB)
- Accuracy: 4 fF
- Linearity: 0.01%
- Common-mode (not changing) capacitance up to 17 pF
- Full-scale (changing) capacitance range: ±4 pF
- Tolerant of parasitic capacitance to ground up to 60 pF
- Update rate: 10 Hz to 90 Hz
- Simultaneous 50 Hz and 60 Hz rejection at 16 Hz

Temperature sensor on-chip
- Resolution: 0.1°C, accuracy: ±2°C

Voltage input channel

Internal clock oscillator

2-wire serial interface (I²C®-compatible)

Power
- 2.7 V to 5.25 V single-supply operation
- 0.7 mA current consumption

Operating temperature: −40°C to +125°C

16-lead TSSOP package

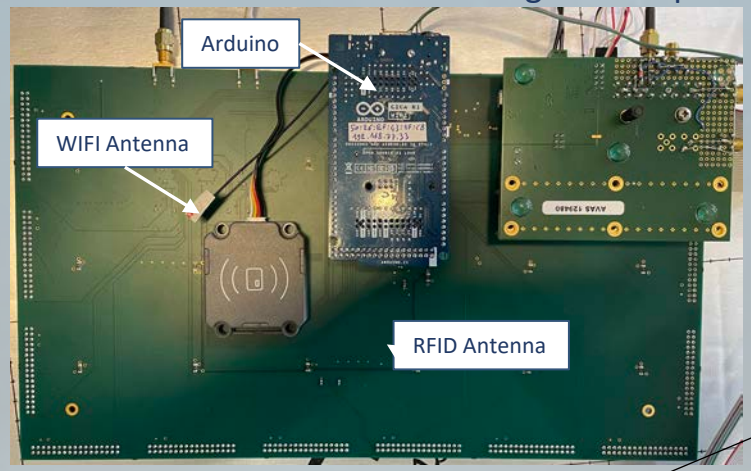
GENERAL DESCRIPTION

The AD7745/AD7746 are a high resolution, Σ-Δ capacitance-to-digital converter (CDC). The capacitance to be measured is connected directly to the device inputs. The architecture features inherent high resolution (24-bit no missing codes, up to 21-bit effective resolution), high linearity (±0.01%), and high accuracy (±4 fF factory calibrated). The AD7745/AD7746 capacitance input range is ±4 pF (changing), while it can accept up to 17 pF common-mode capacitance (not changing), which can be balanced by a programmable on-chip, digital-to-capacitance converter (CAPDAC).

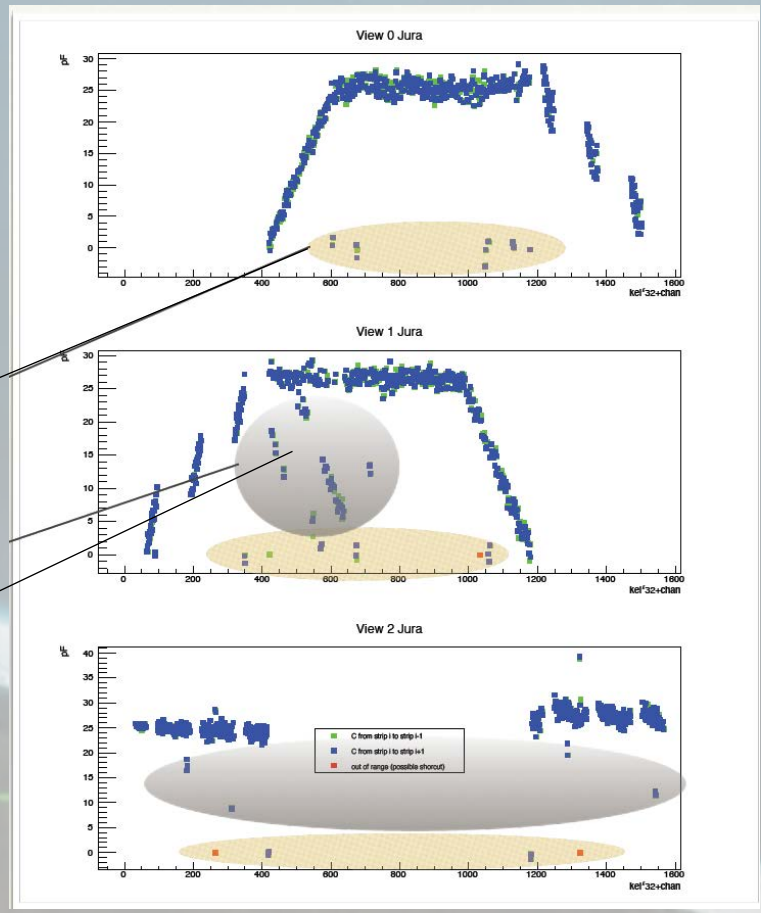
The AD7745 has one capacitance input channel, while the AD7746 has two channels. Each channel can be configured as single-ended or differential. The AD7745/AD7746 are designed for floating capacitive sensors. For capacitive sensors with one plate connected to ground, the AD7747 is recommended.

The parts have an on-chip temperature sensor with a resolution of 0.1°C and accuracy of ±2°C. The on-chip voltage reference and the on-chip clock generator eliminate the need for any external components in capacitive sensor applications. The

CRU self-identification using RFID chip

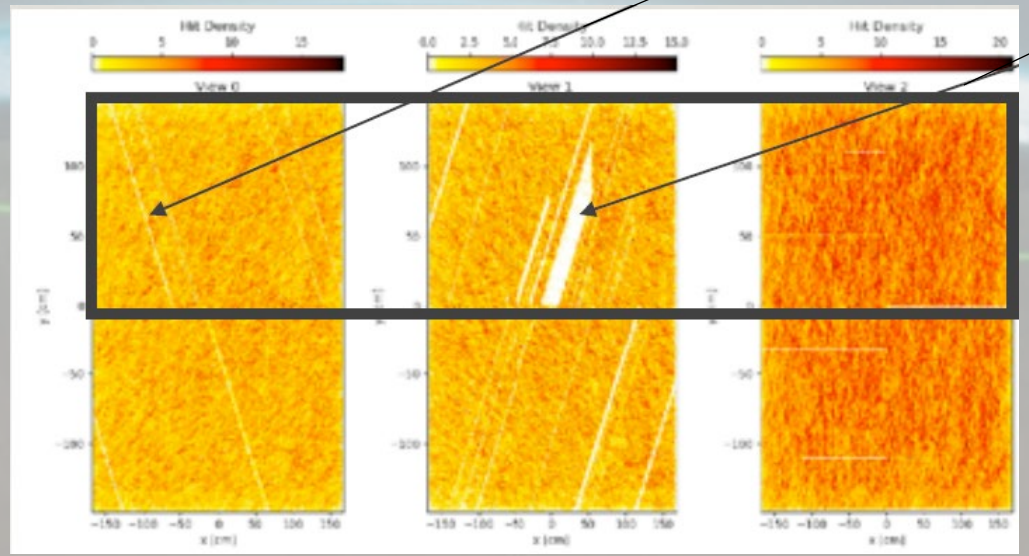


Capacitance datas



CRU7-2 capacitance measurement @Grenoble

LAr Coldbox cosmic datas

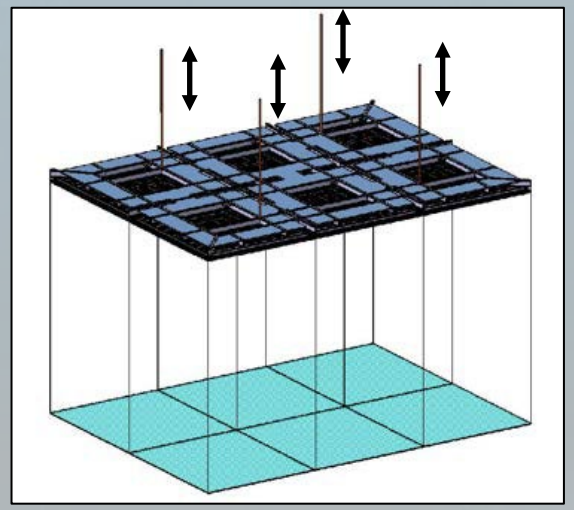


DUNE Vertical Drift detector

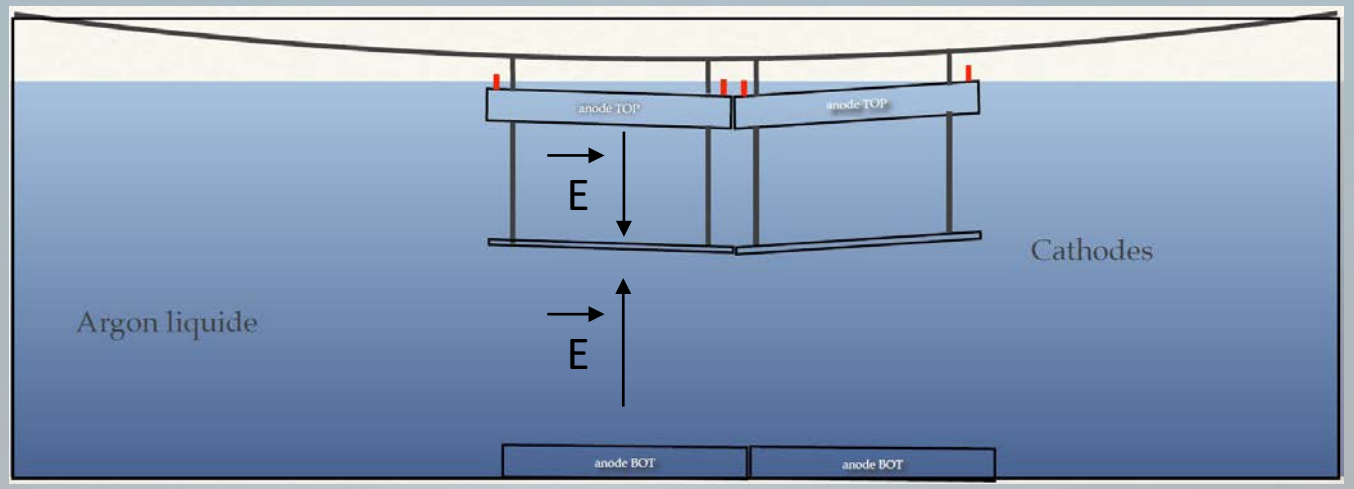
Aim: Positionning the Top CRPs and cathodes parallel to Bottom CRPs

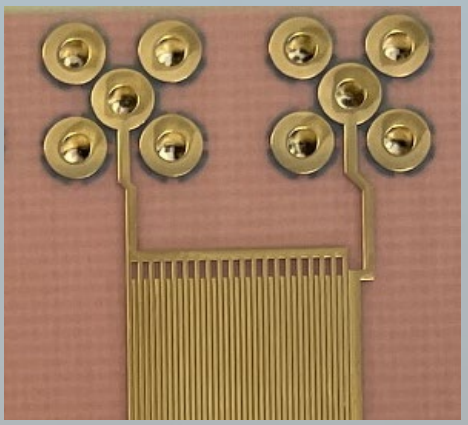
Capacitance measured using AD7746
Capacity ∝ LAr level
Précision ~ 500 µm

4 motorised cables suspension system

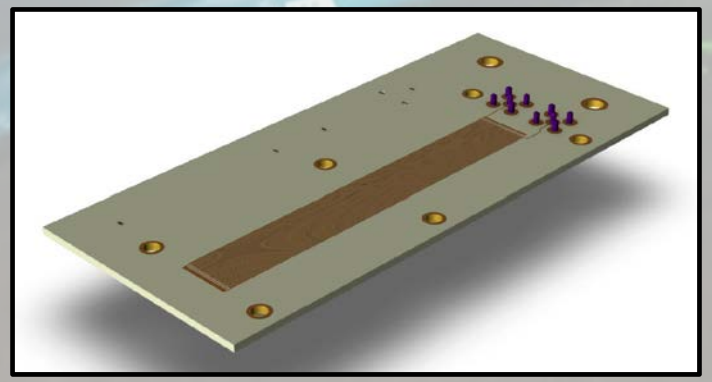


Cryostat roof deformation

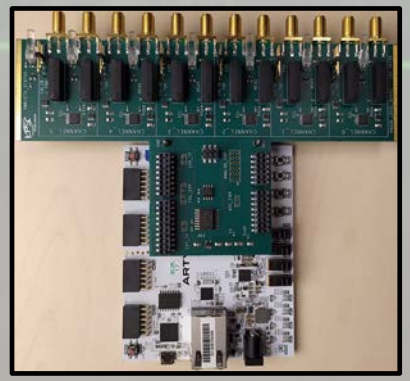




Capacitance sensor (8 cm)



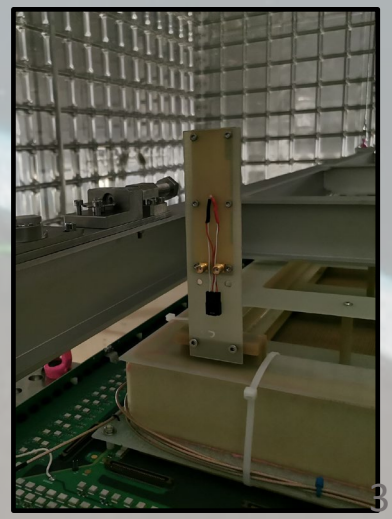
Electronic readout
Capacitance measurement



Calibration bench

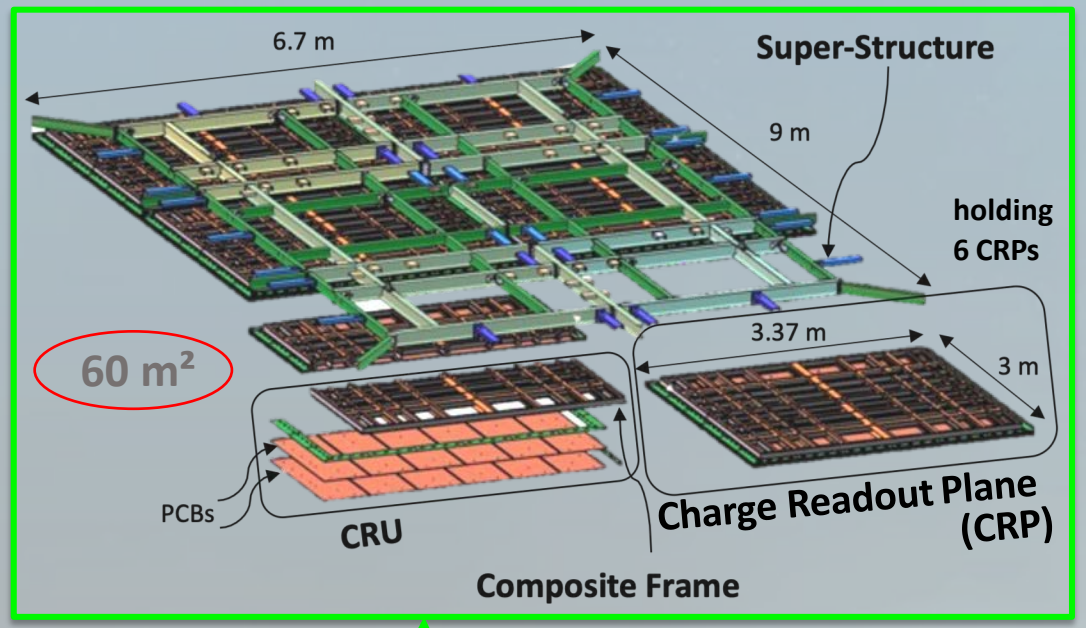
Module 0 production

Module 0 installation



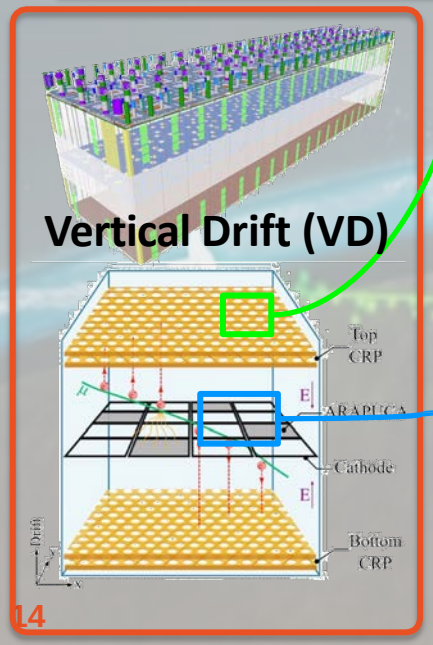

Thank you for your attention

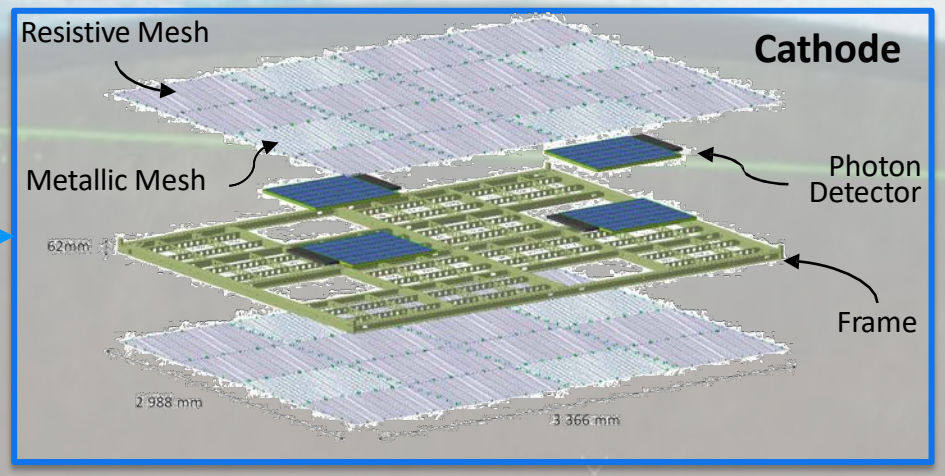
DUNE Vertical Drift detector

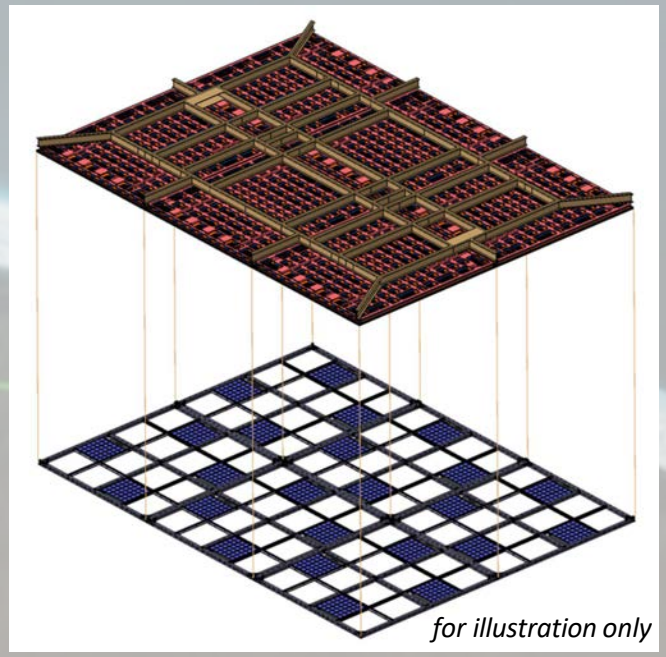


CRP7 @Grenoble

6 cathodes supermodule suspended from a CRP superstructure







for illustration only

CERN Neutrino Platform

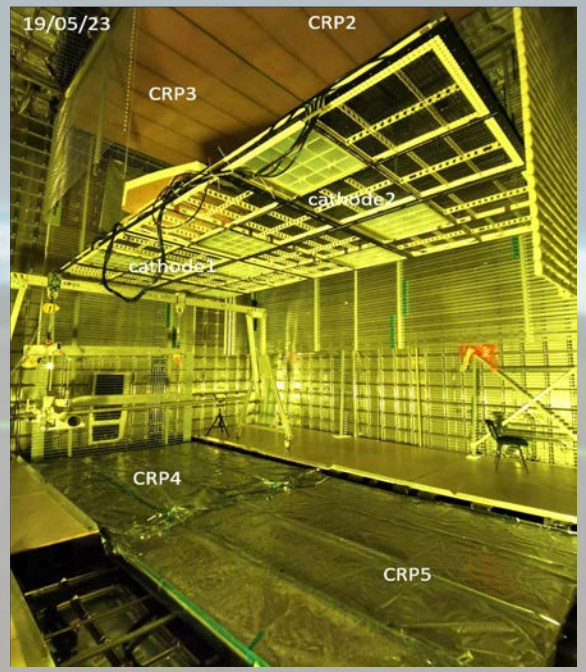
CERN Neutrino Platform

Cold Box TPC

- 1 CRPs at a time
- Cathode + PDS
- ~ 0.3 m drift

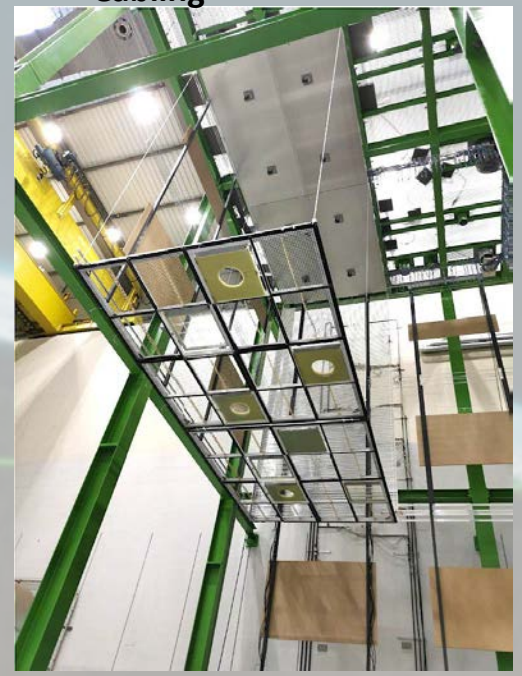
ProtoDUNE NP02

- 1/40 DUNE Vertical slice Top + Bottom CRP + Cathode + Field cage + PDS + TDE + BDE + DAQ
- 2 x ~ 3.4 m vertical drift



Installation Mockup 1:1

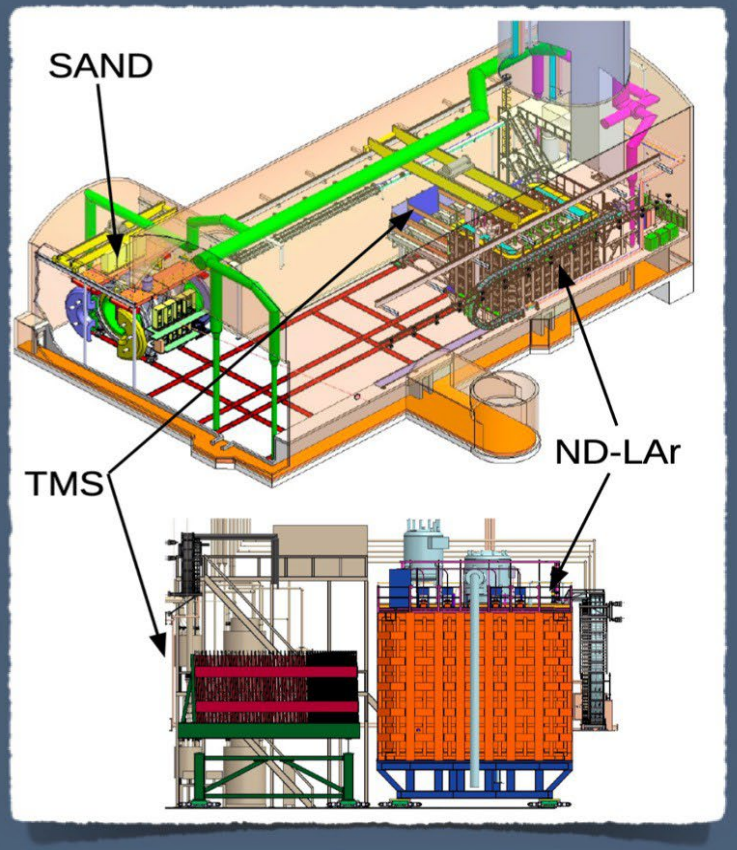
- Mechanical Model
- Size 1:1
- 13 m high
- Installation / Interfaces / Training
- Top + Bottom CRP + Cathode + Field cage + PDS + Chimney interface + Cabling



Near Detectors

DUNE ND

- DUNE will have a ***Near Detector complex critical starting from early physics goals*** to reduce flux and cross sections uncertainties and have the most accurate prediction of neutrino spectrum at the Far Detector.
- ***System for on-Axis Neutrino Detection (SAND):*** On-axis magnetized low-density tracker and calorimeter to control and monitor the neutrino beam on axis.
- ***Near Detector Liquid Argon (NDLAr):*** Liquid Argon Detector (50t fiducial) with the same target and technology as FD.
- ***The Muon Spectrometer (TMS):*** detector to measure muons escaping from NDLAr.
- ***NDLAr+TMS*** are a ***movable*** detector and exploit the ***PRISM technique***: they measure neutrino flux at different angles (i.e. different energies) for a ***better extrapolation at the FD reducing the dependency on the accuracy of interaction models***.



Cryostat installtion

- Cryostats will be erected using a 35-ton mobile crane and 20-ton central beam hoist