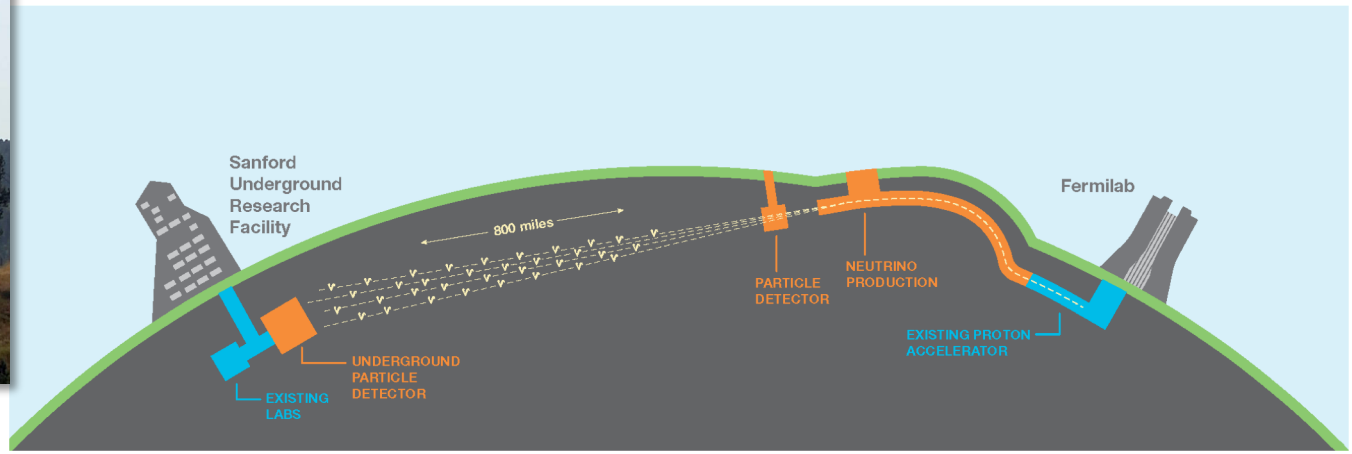


DUNE Status and the Module of Opportunity

Stefan Söldner-Rembold

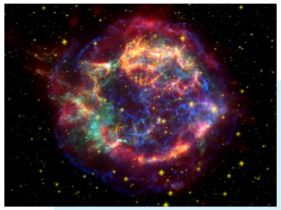
Ed Blucher

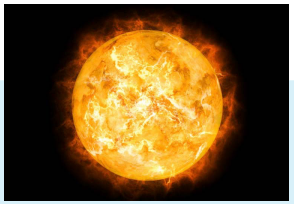
Module of Opportunity Workshop

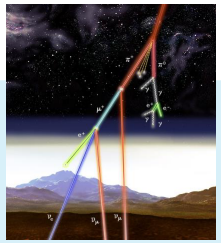
12 Nov 2019

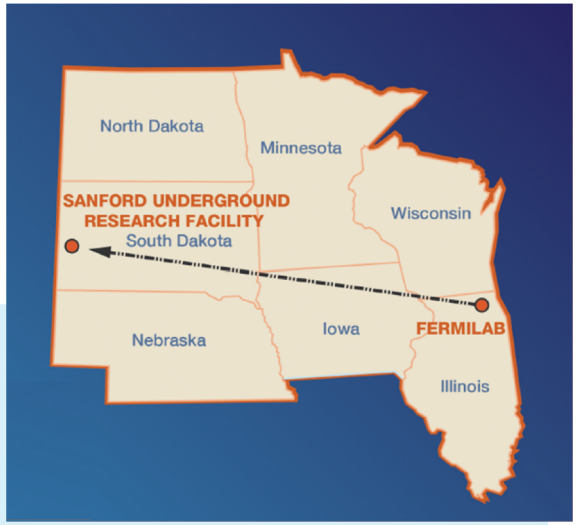
Brookhaven

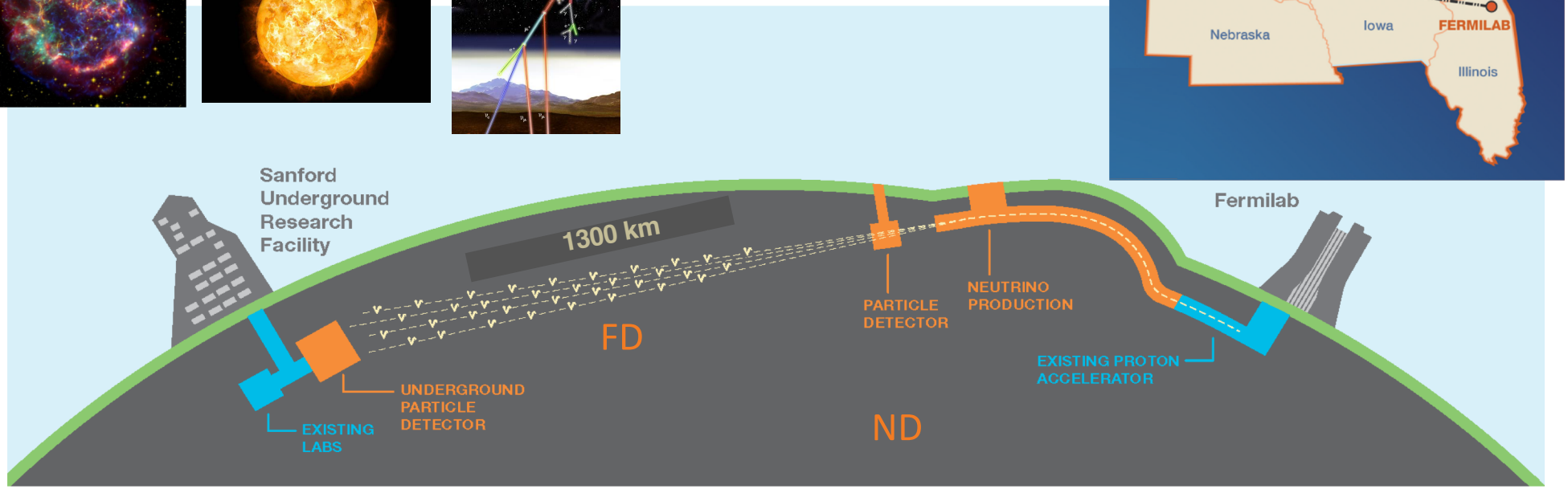
DUNE in a Nutshell





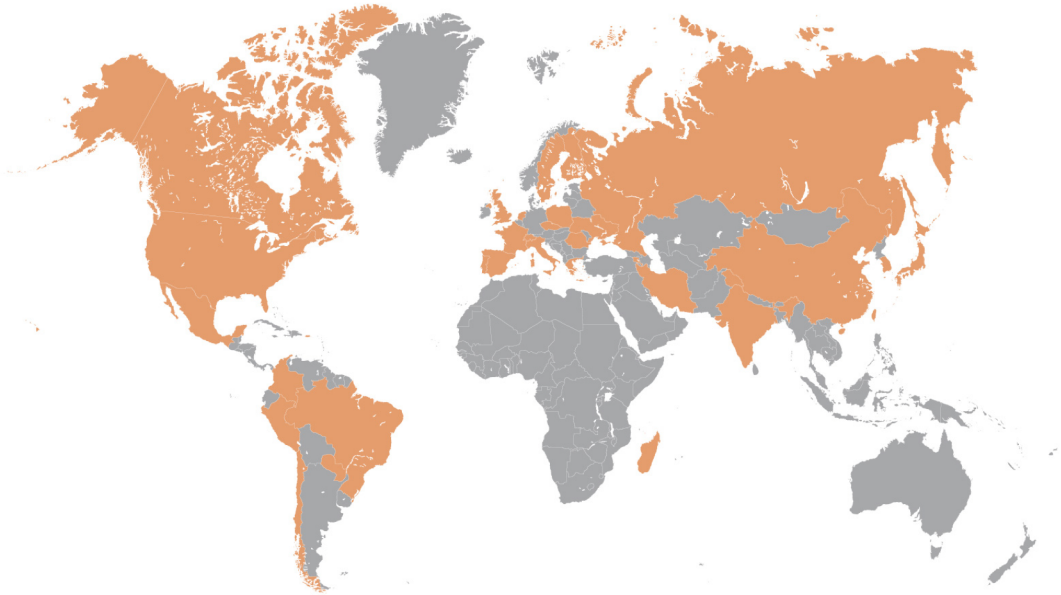






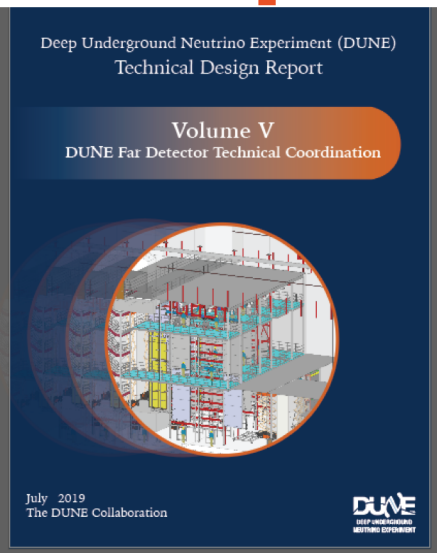
1. A high-power, wide-band neutrino beam (~ GeV energy range).
2. A ≈ 40 kt liquid-argon Far Detector in South Dakota, located 1478 m underground in a former gold mine.
3. A Near Detector located approximately 575 m from the neutrino source at Fermilab close to Chicago.

DUNE – a global Collaboration



~1100 collaborators from
188 institutions in 32 countries

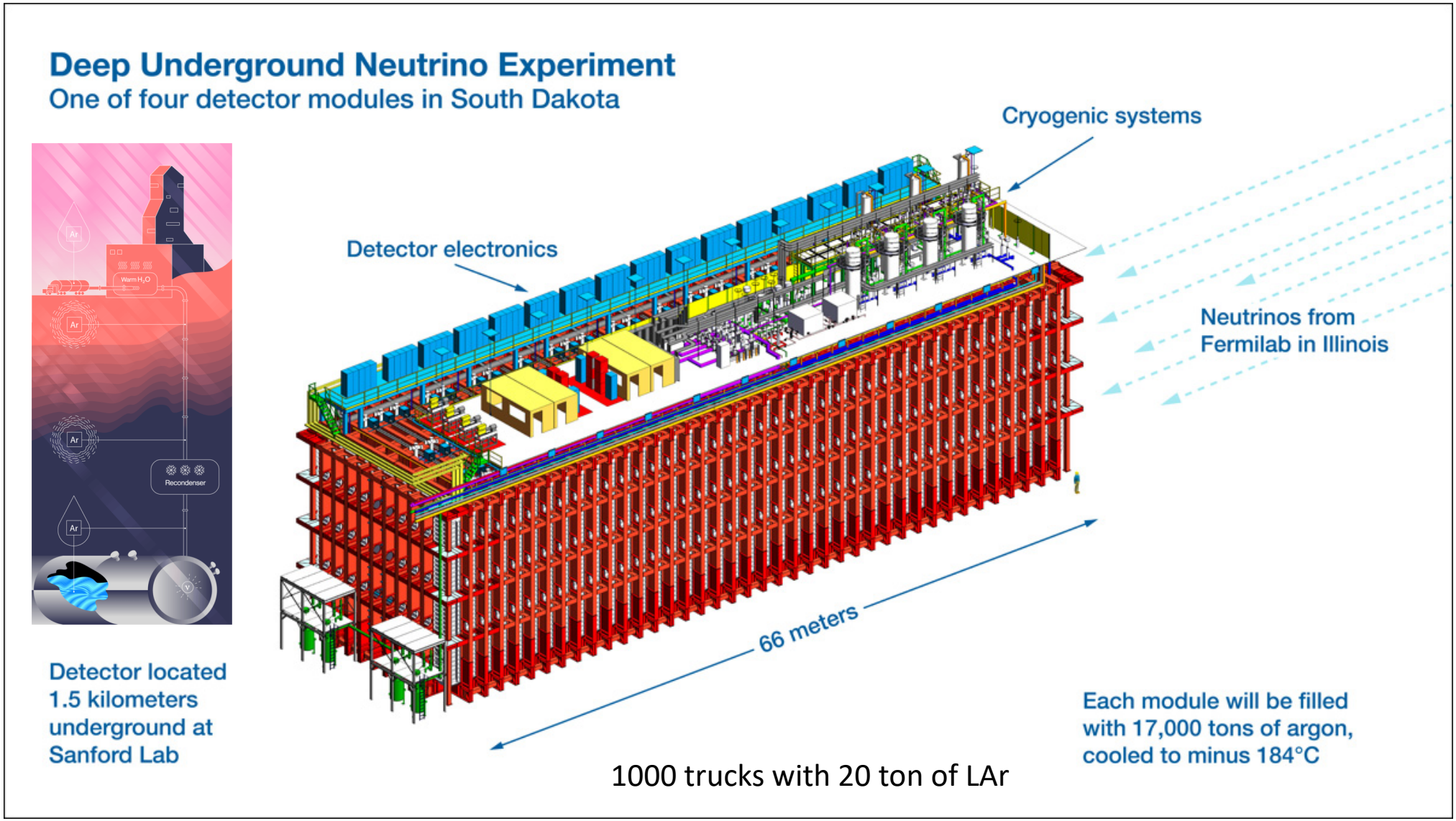
DUNE Technical Design Report



A major milestone for the collaboration

- Publication imminent
- Detector model and physics based on TDR

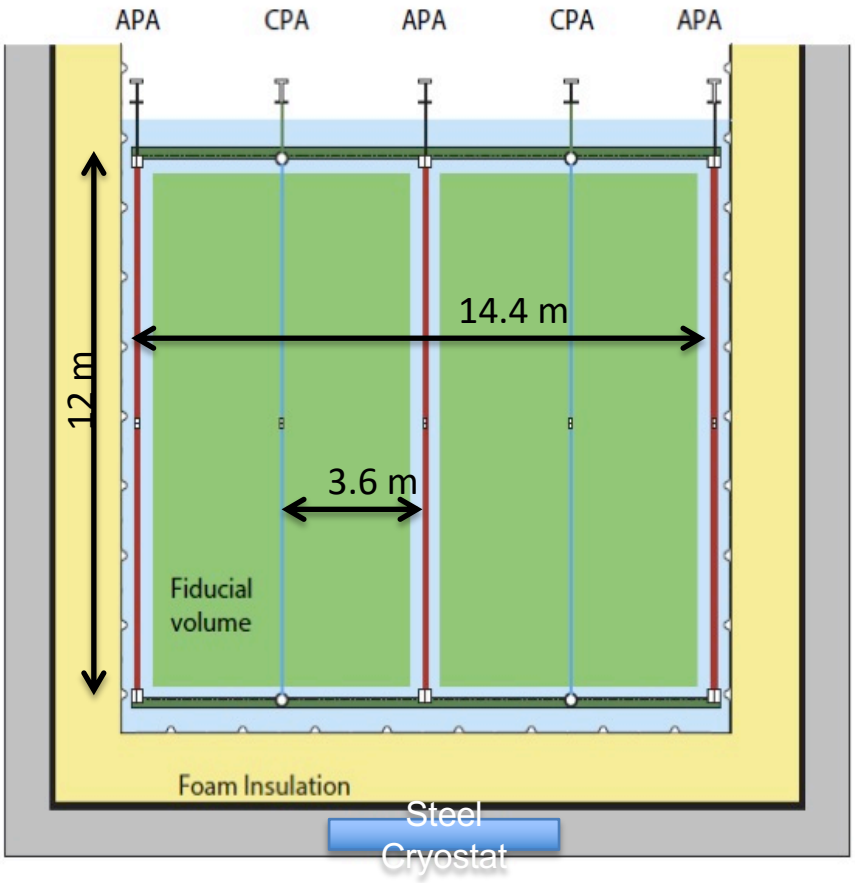
DUNE FD Module

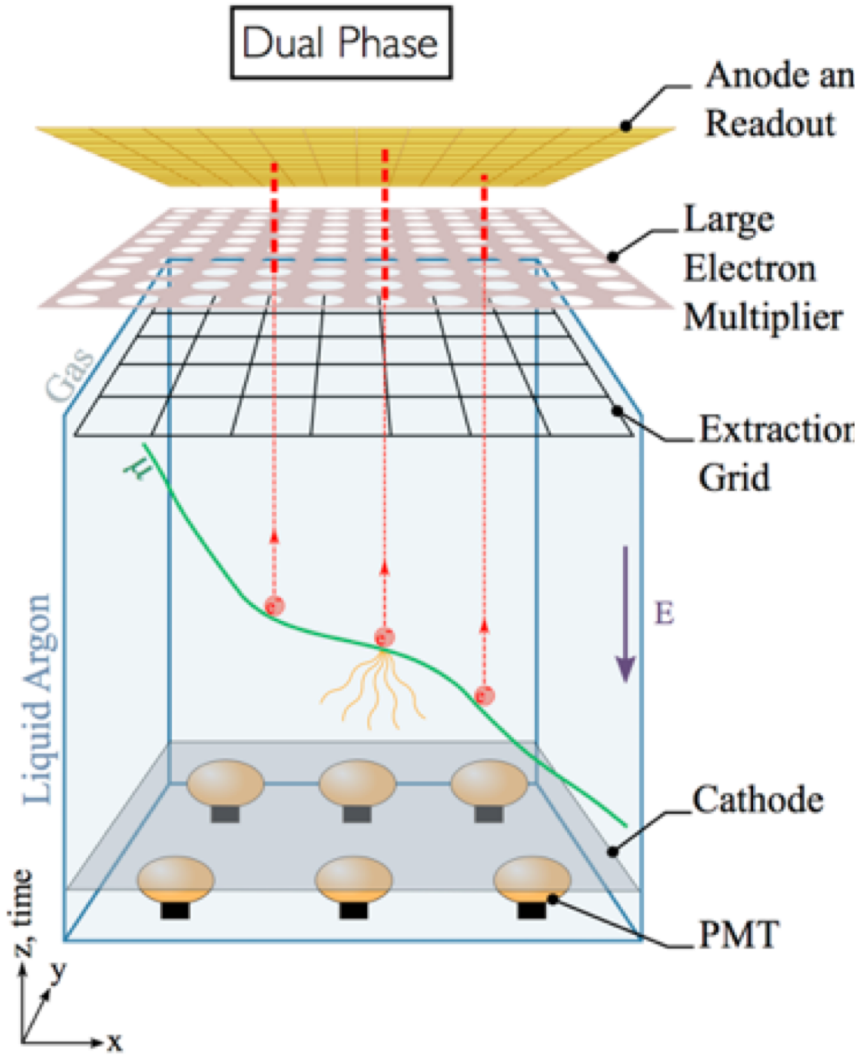


1000 trucks with 20 ton of LAr

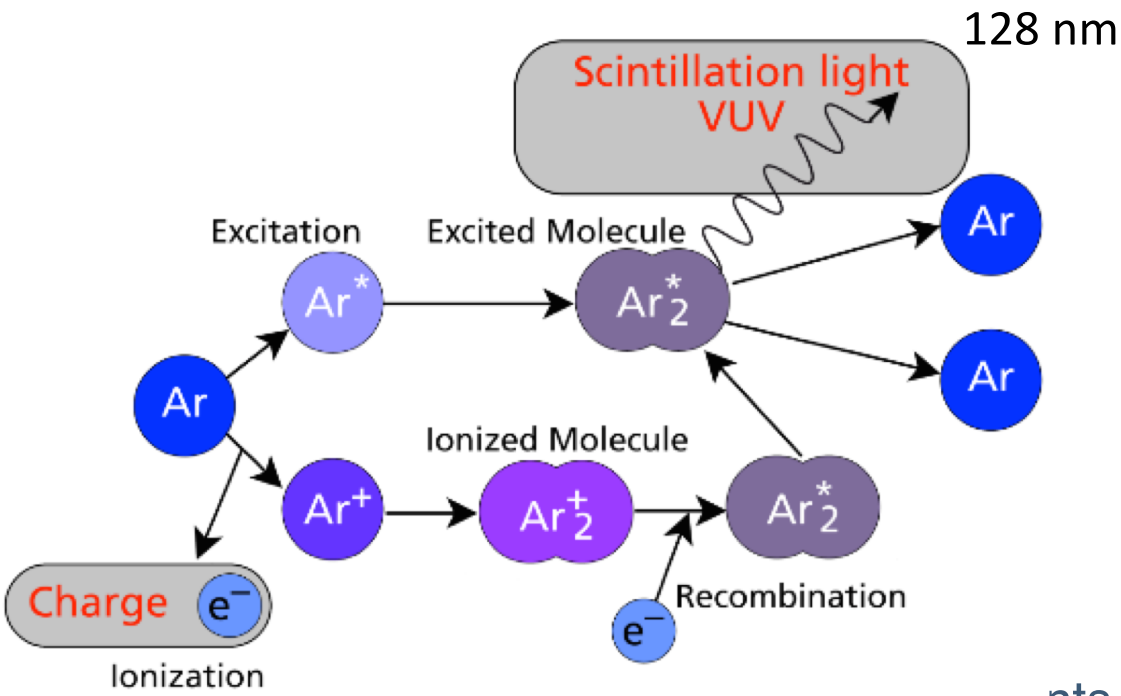
Two Technologies

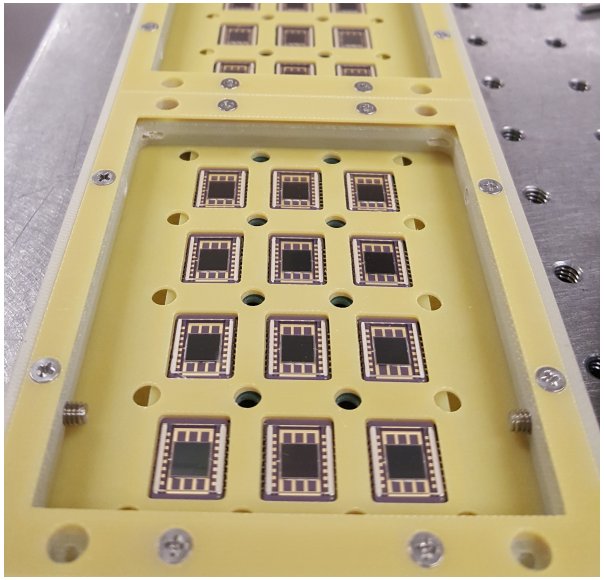
Single Phase





Photon Detection

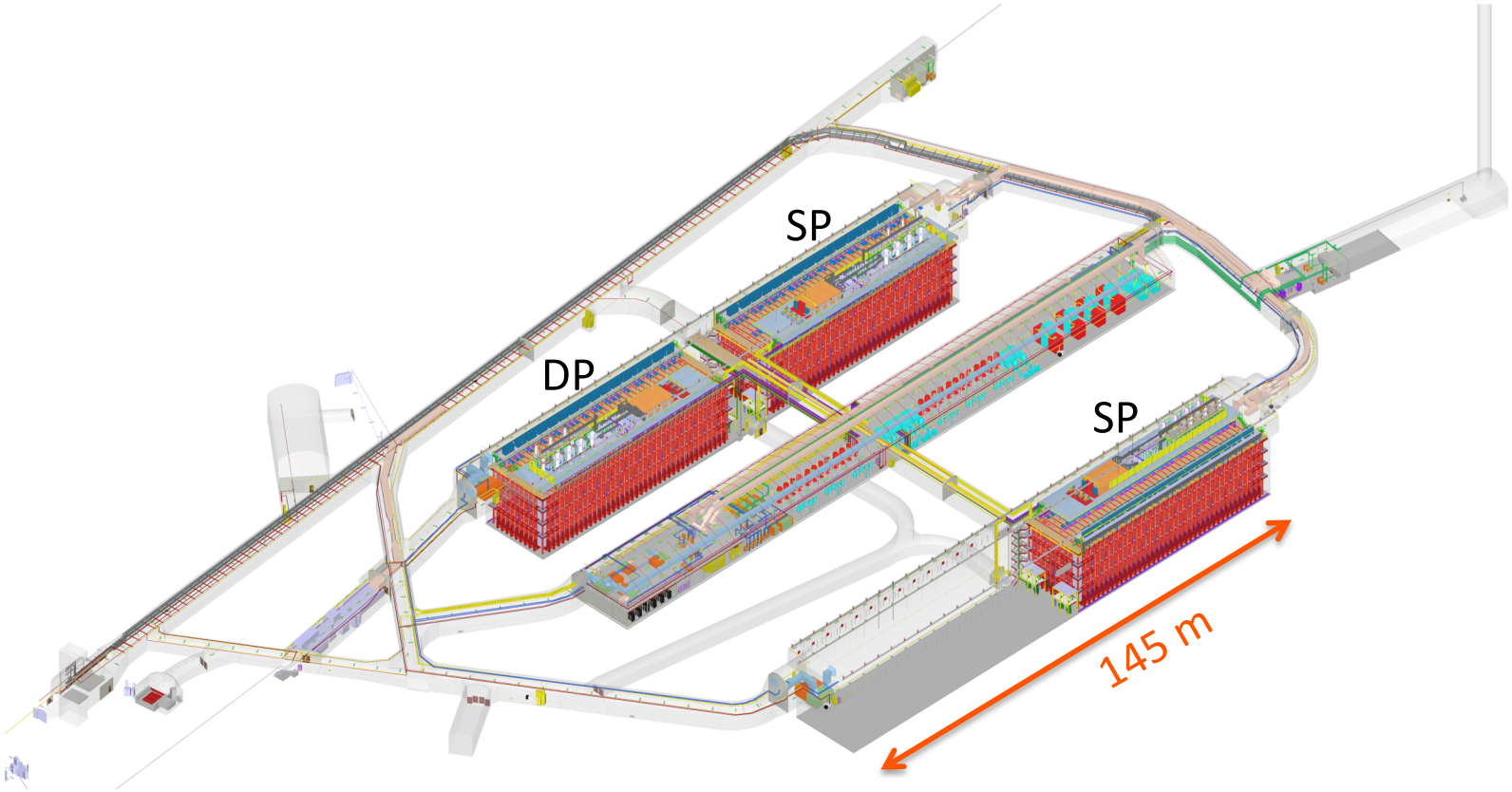




nts

- Need wavelength shifter to shift VUV to visible
- Several technology options under consideration (PMTs, SiPMs….)
- “Arapuca” light trap is the most promising option
- Provides timing and event reconstruction

- 4 identically sized cryostats: 2 single phase (SP) + 1 dual phase (DP) +1 *"opportunity"* ("2+1+1")
- Each cryostat can hold 17 kt (> 10 kt fiducial) of LAr



DUNE Far Detector Strategy

Four chambers hosting four independent FD modules

- Flexibility for staging & evolution of technology design
- We currently assume four nearly “identical” cryostats

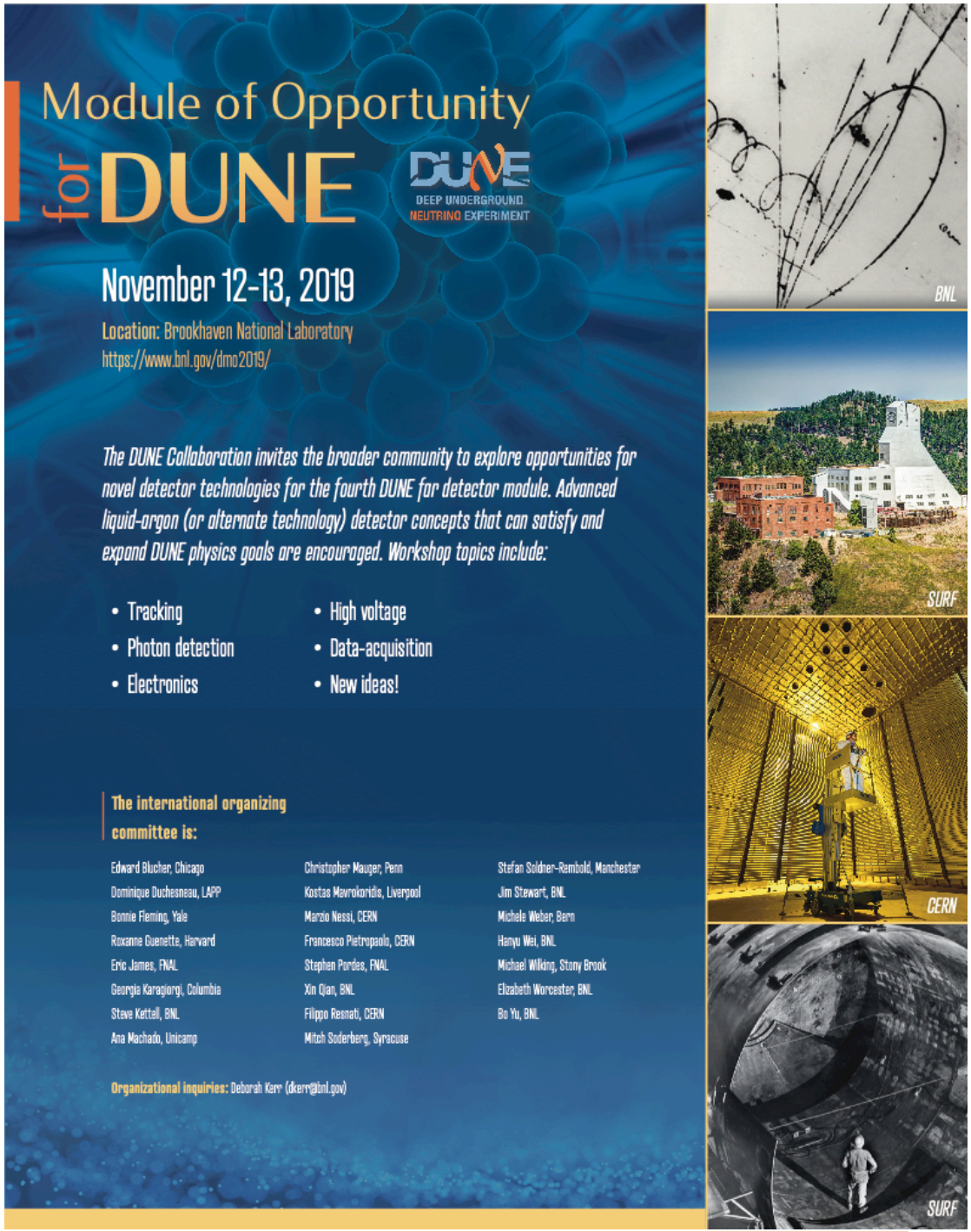
The four modules will not be identical - pursuing (and prototyping) at least two LAr-TPC technologies

- Single-Phase
  - Technology is mature, e.g., ICARUS, MicroBooNE, SBND, ProtoDUNE-SP
- Dual-Phase
  - Lower technical readiness
  - A number of potential advantages & challenges (WA105, ProtoDUNE-DP)

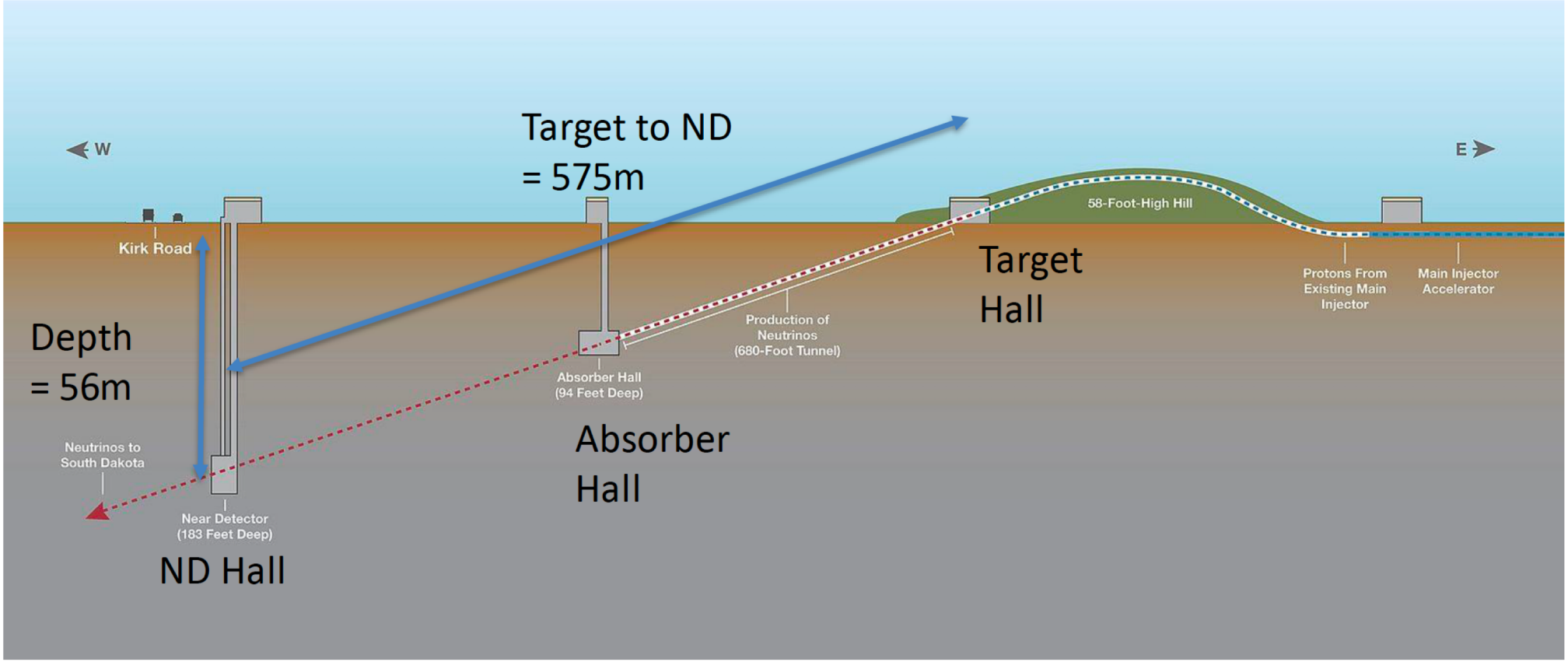
Decision on staging sequence will depend on installation requirements, ProtoDUNE results, funding – currently no funding model for 4th module

Module of Opportunity

- Technology for 4th module not yet defined
- Consider advanced liquid-argon (or alternate) technologies
- This Workshop could form basis for “EoI”s.

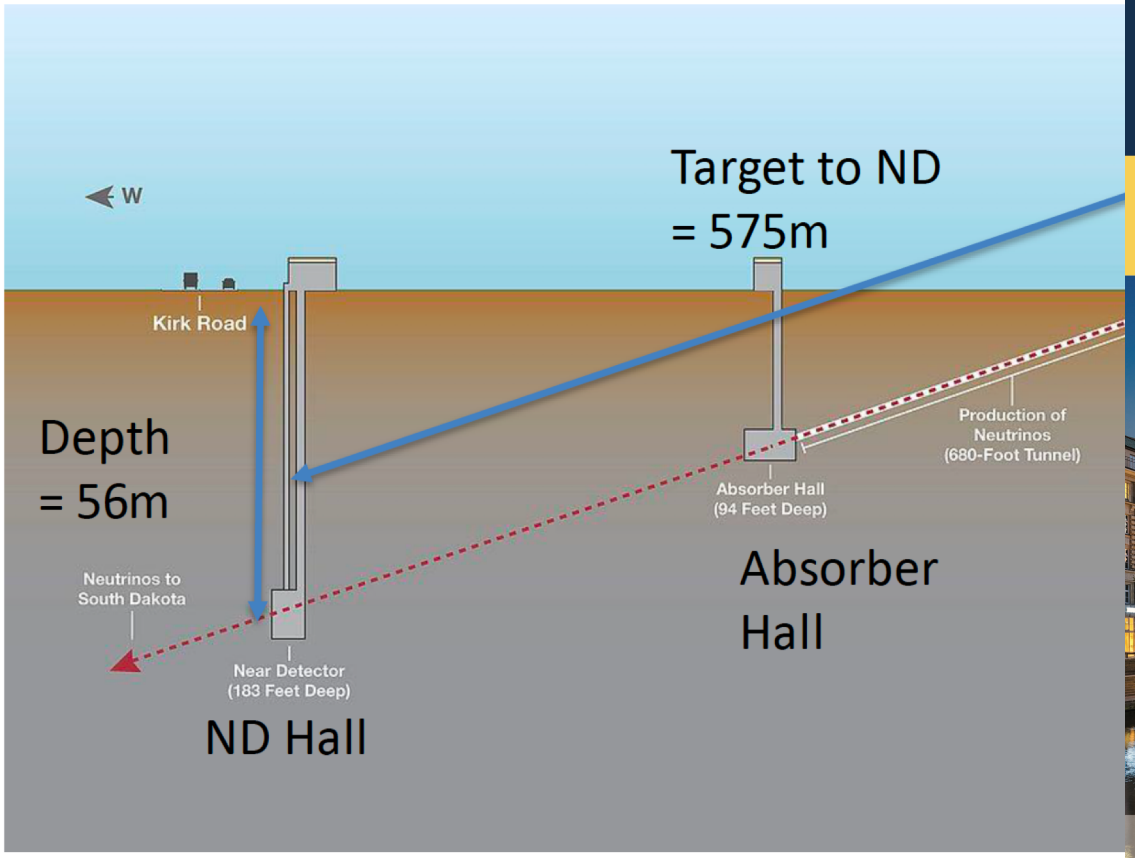


Near Detector Complex



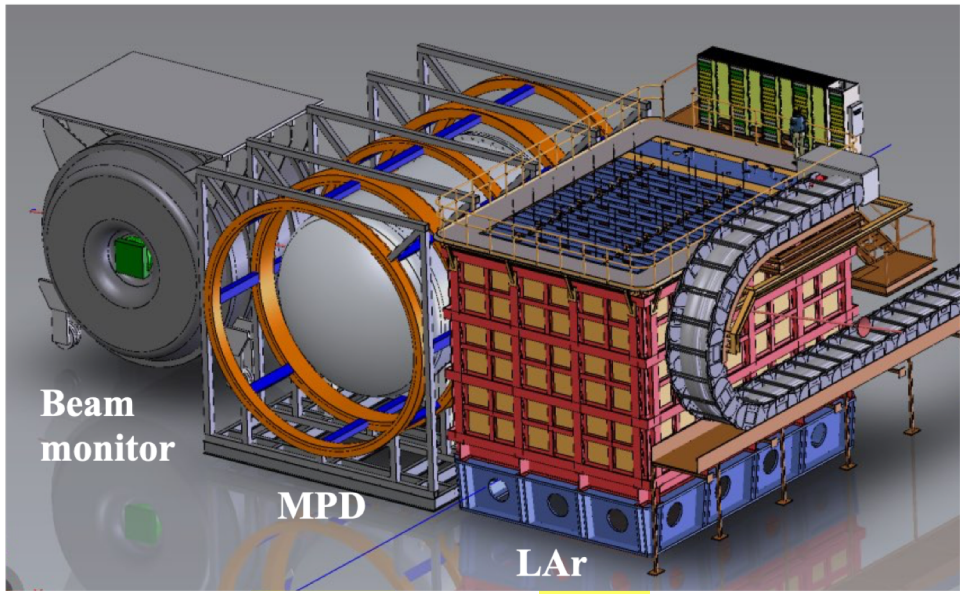
- Constrain systematic uncertainties for long-baseline oscillation analysis
  - Neutrino flux & cross-section, and detector systematics
- In addition, >100 million interactions will also enable a rich non-oscillation physics programme

Near Detector Complex



- Constrain systematic uncertainties for lo
  - Neutrino flux & cross-section, and de
- In addition, >100 million interactions will
  physics programme

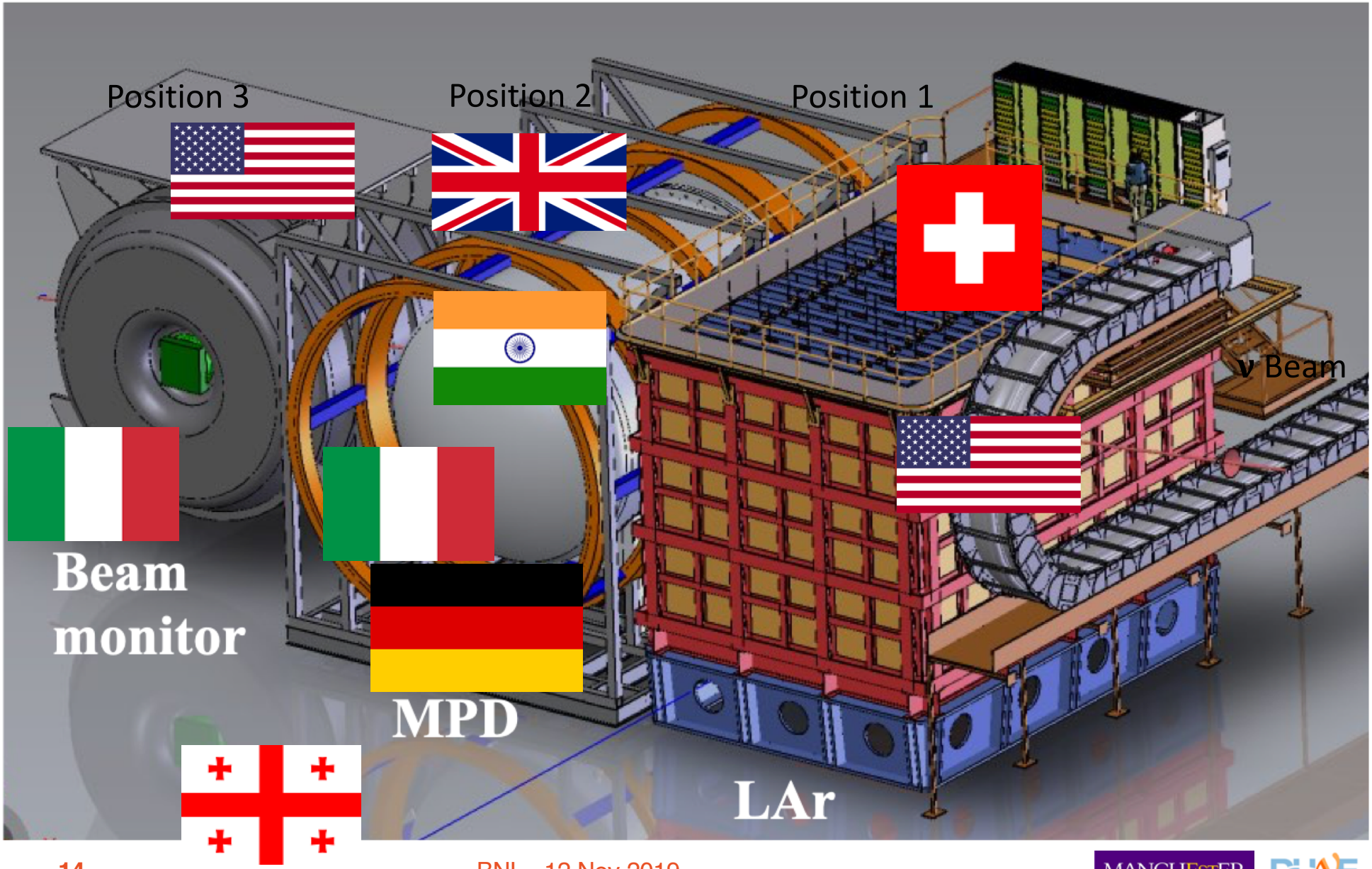
Near Detector Reference Design



Three sub-systems:

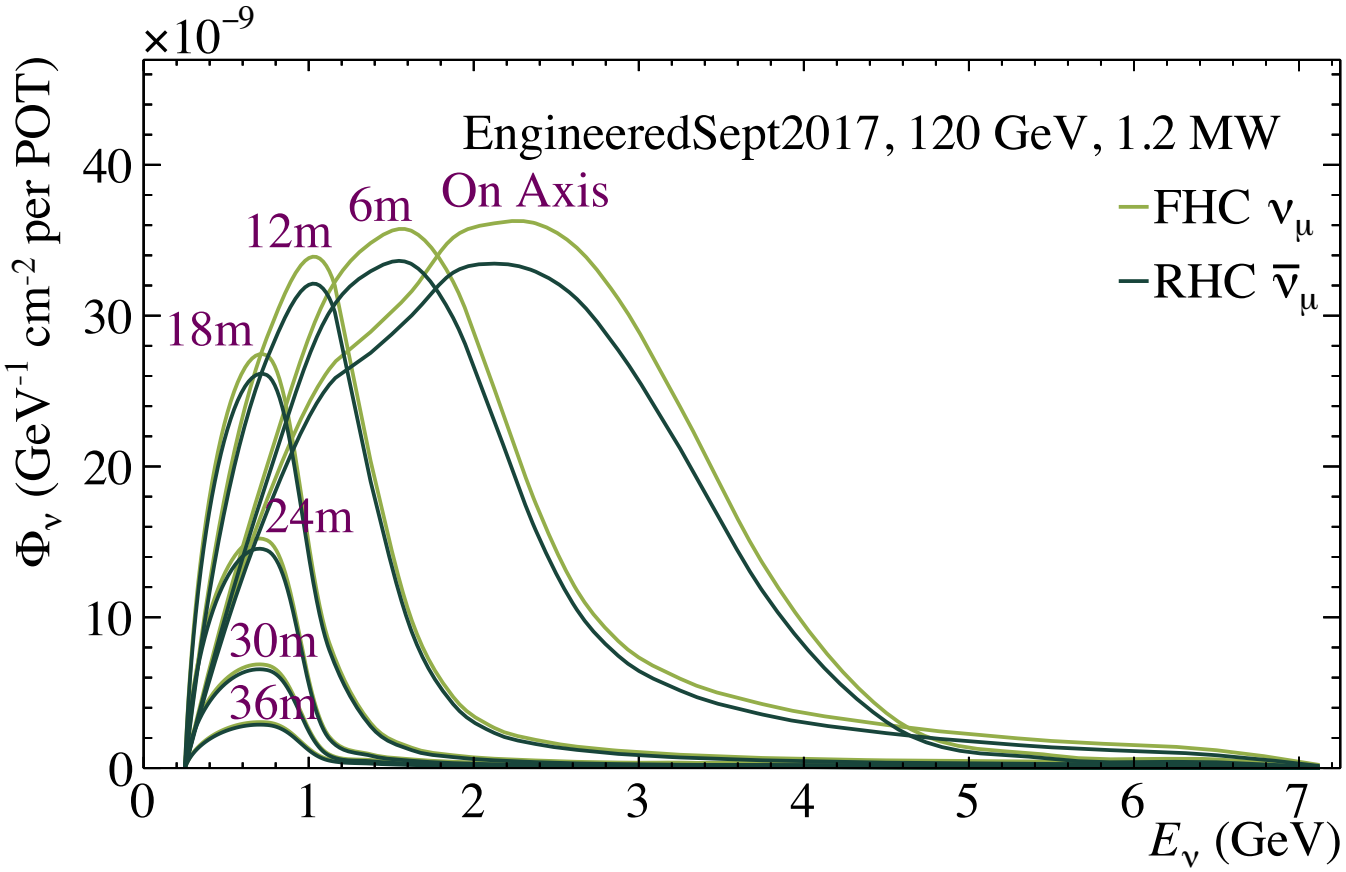
1. Highly segmented liquid-argon TPC (ArgonCube)
2. Multipurpose Detector (MPD)
   - Magnetized High Pressure Gas Argon TPC
   - Electromagnetic calorimeter/Muon Chambers
   - Superconducting magnet
3. On-axis beam monitor (KLOE magnet+tracking/calorimeter)

DUNE Near Detector



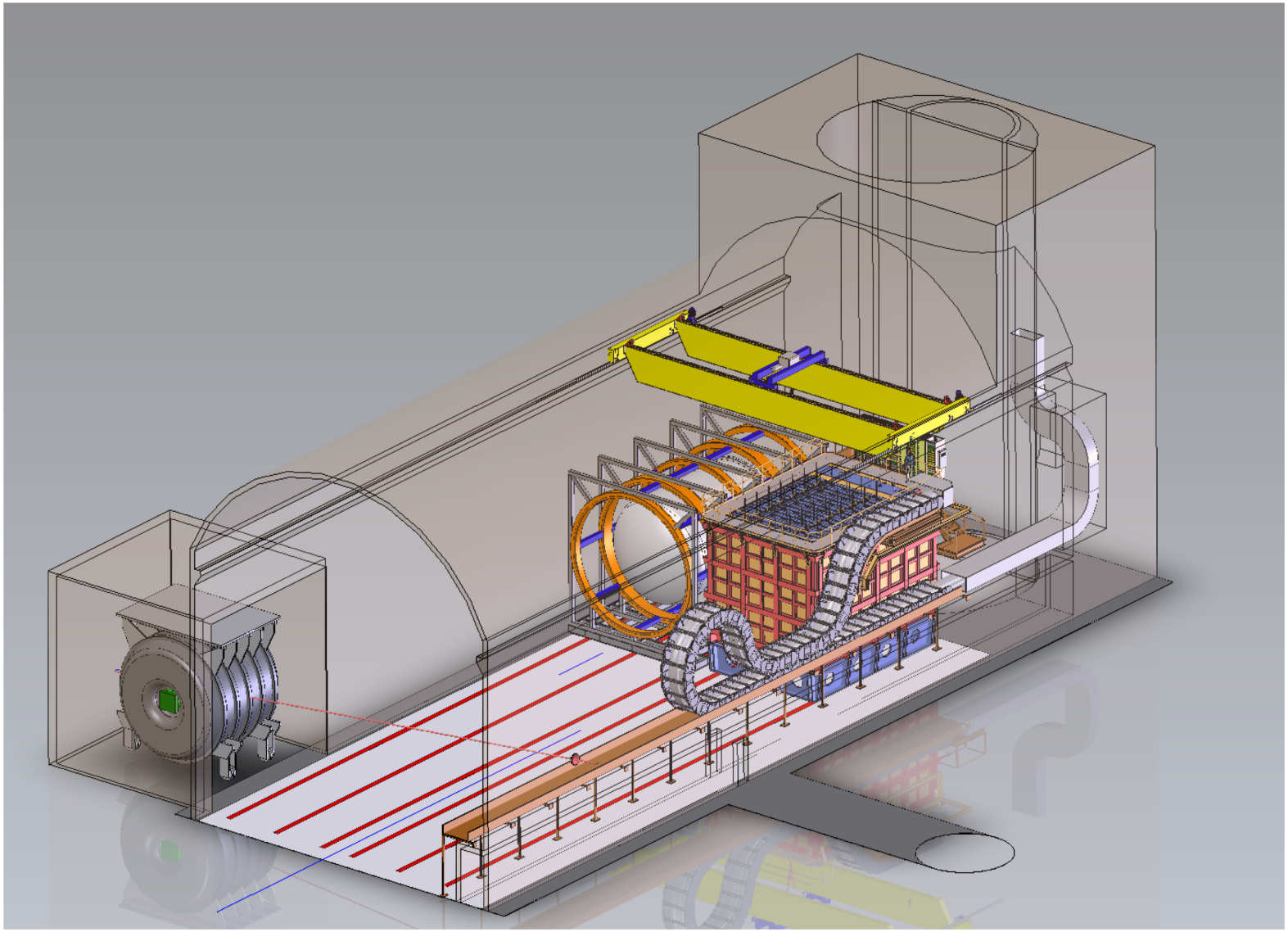
The DUNE Near Detector

Capability to move ND for off-axis measurements (DUNE-Prism)

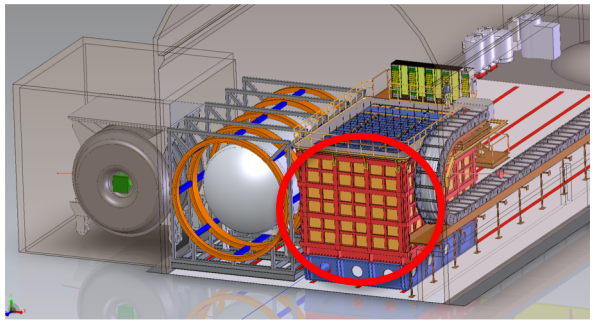


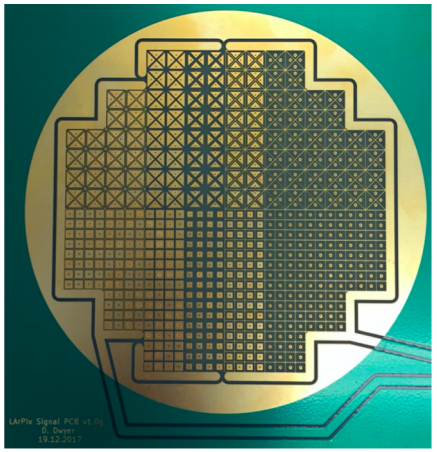
Gives us the ability to change neutrino energy in a controlled way

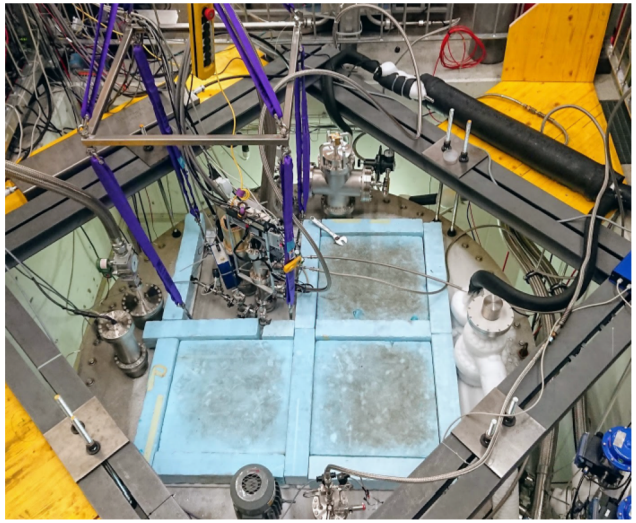
The DUNE Near Detector

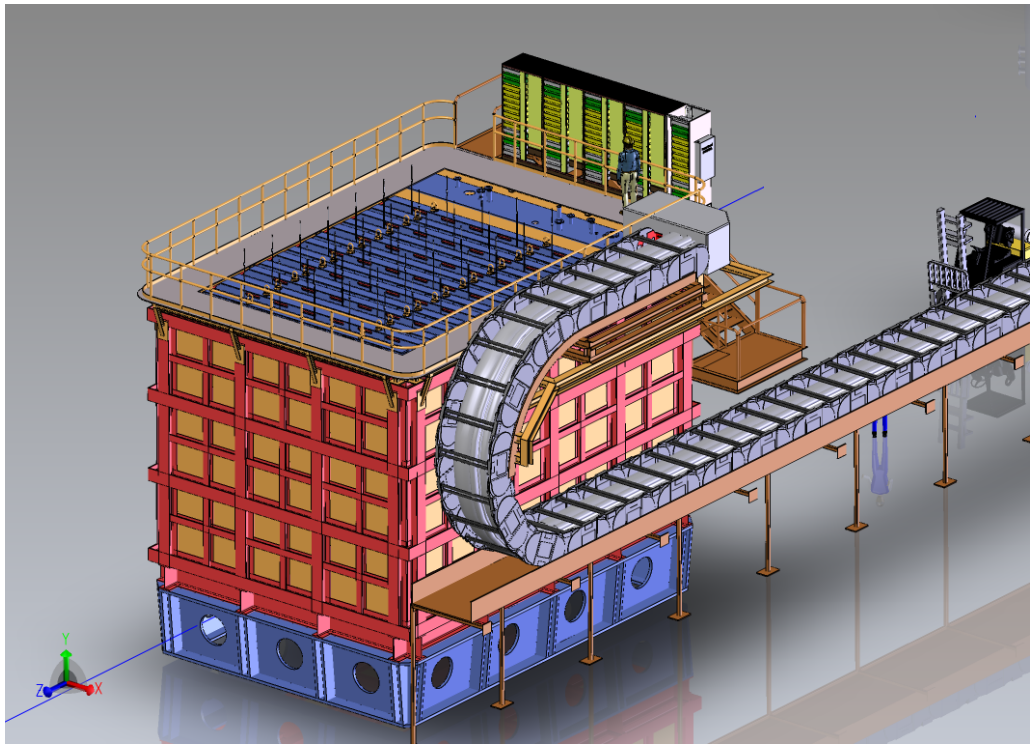


ArgonCube



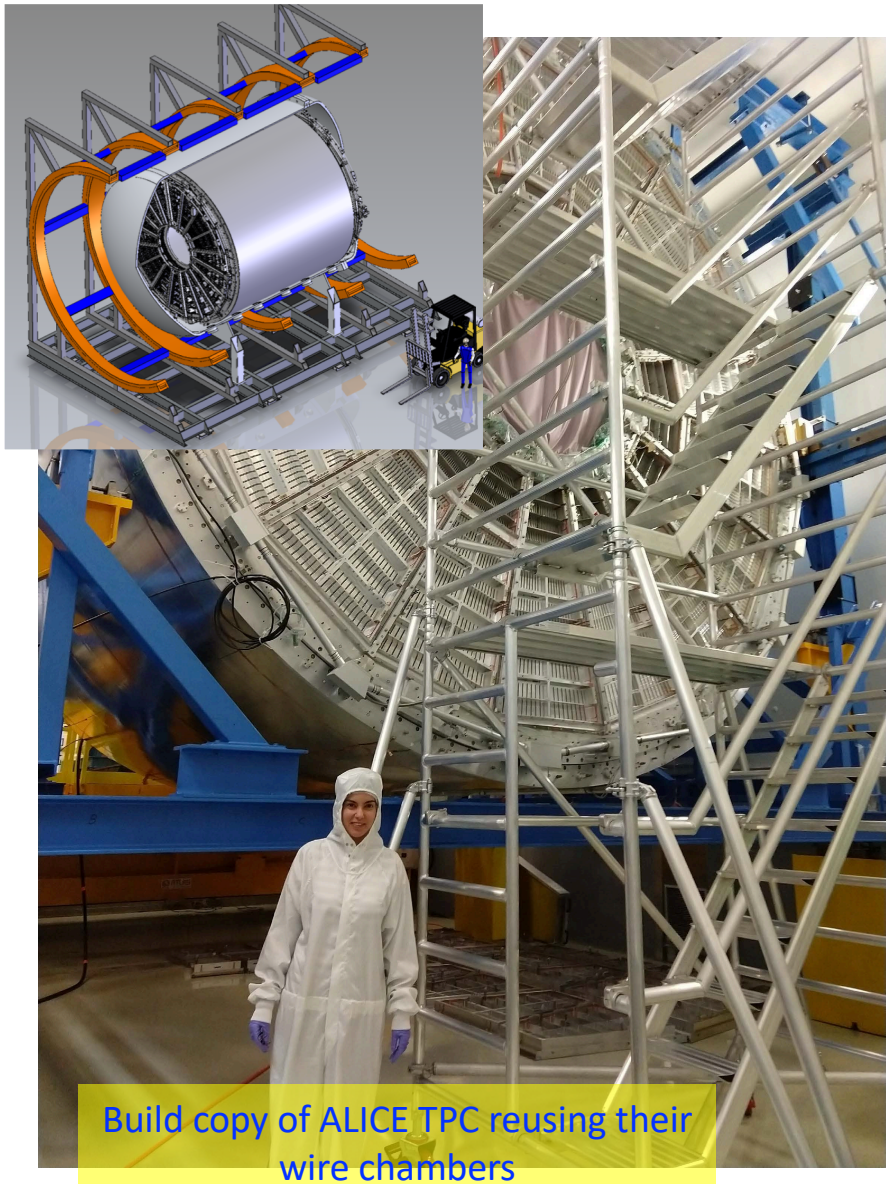






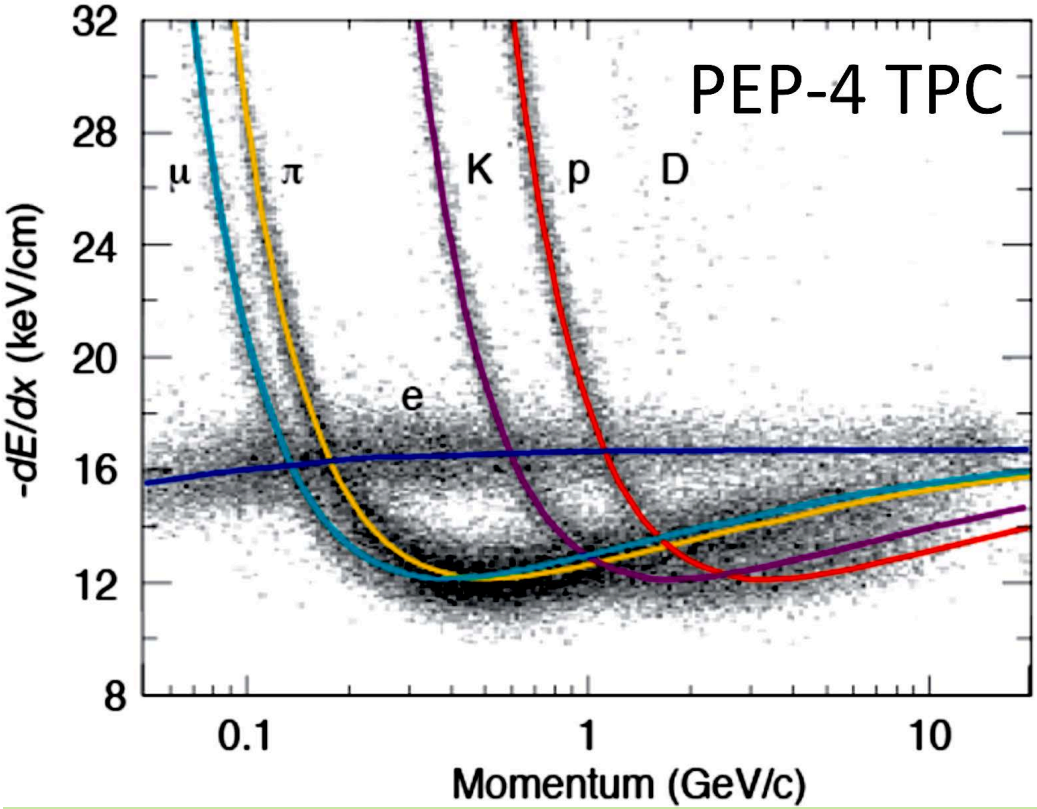
- Pixelated readout to accommodate high rate (>5 evts/spill)
- Active mass ~ 150 t
- Prototype at Bern

High-pressure gas TPC (HPgTPC)



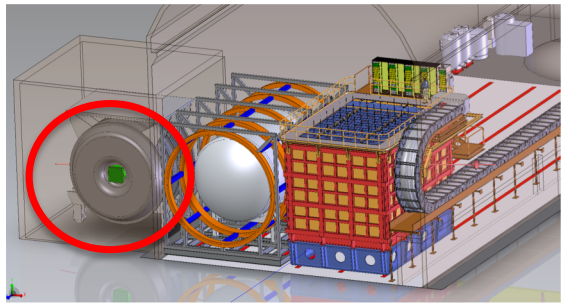
Build copy of ALICE TPC reusing their wire chambers

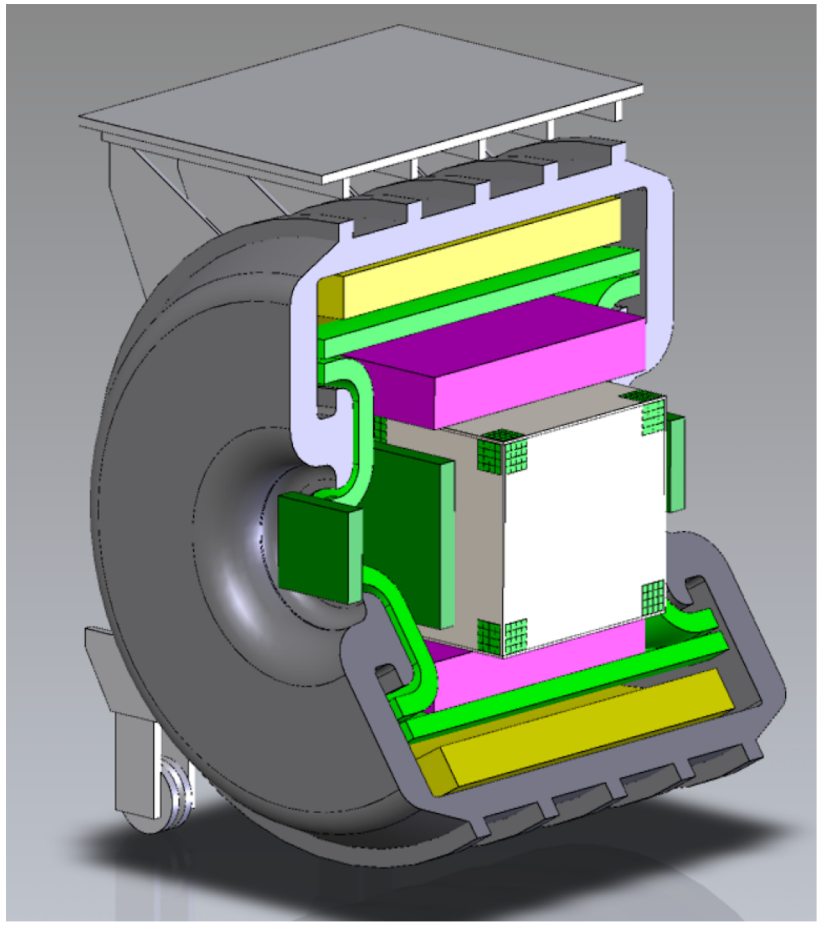
Well established technology
Vetted detector design



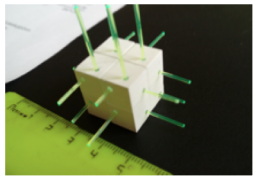
We expect ~ 2% dE/dx resolution based on PEP4
ALICE obtains 5-6%

On-axis Beam Monitor





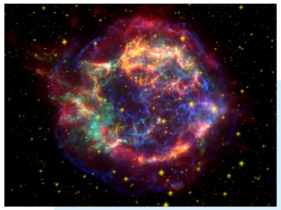
- Provides precision on-axis monitoring of neutrino beam through rate, profile, and spectrum measurements
- Consists of
  - 3-dimensional scintillator tracker active target (8t)
  - Tracking
    - 1 atm TPCs <u>or</u>
    - Straw tube tracker
  - KLOE EM calorimeter
    - Scintillator fiber + lead
  - KLOE magnet system
    - 0.6T central field (SC magnet)

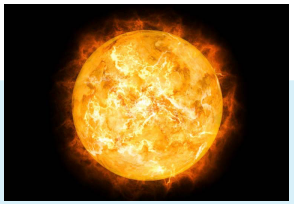


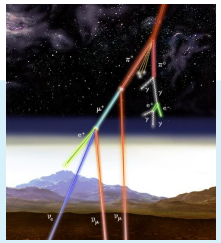
DUNE Near Detector

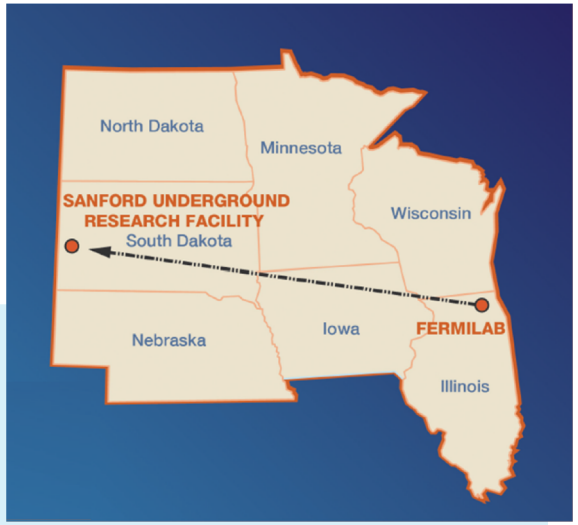
- Near Detector using both gaseous and liquid argon – crucial for systematics.
- Excellent progress over the last year, leading to reference design
  - LBNC: “The LBNC believes that the proposed suite of ND elements will allow DUNE to achieve its physics goals for CP violation sensitivity. “
- Next steps
  - ND CDR at end of 2019
  - ND preliminary design late in 2020, as required for Near Site CD-2

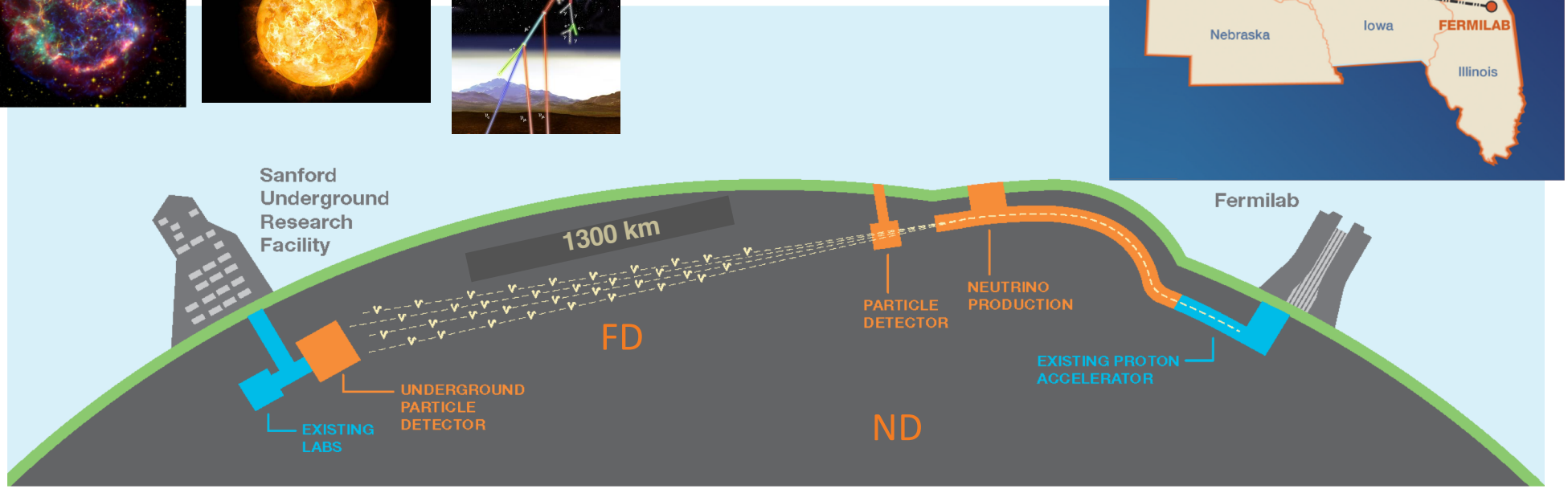
DUNE in a Nutshell









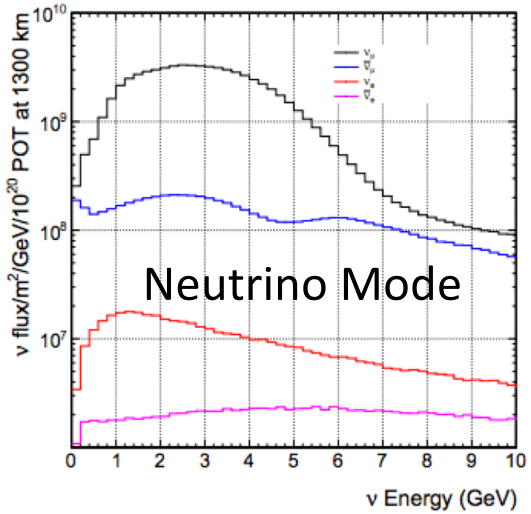


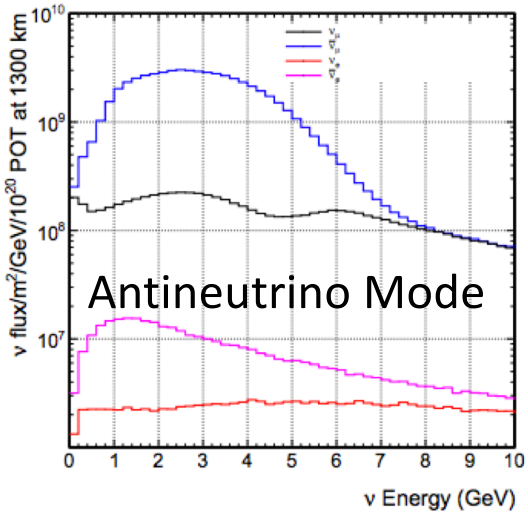
1. A high-power, wide-band neutrino beam (~ GeV energy range).
2. A ≈ 40 kt liquid-argon Far Detector in South Dakota, located 1478 m underground in a former gold mine.
3. A Near Detector located approximately 575 m from the neutrino source at Fermilab close to Chicago.

Primary DUNE Physics Goals

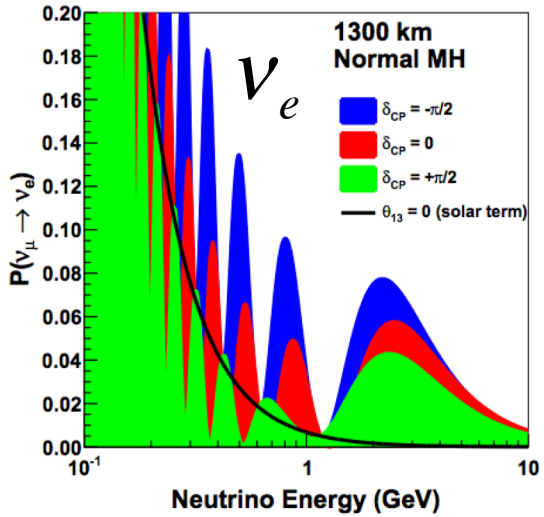
- …carry out a **comprehensive program of neutrino oscillation measurements** using ν_μ and $\bar{\nu}_\mu$ beams from Fermilab:
  - search for *CP* violation in neutrinos
  - precision measurements of the phase δ and mixing angle θ_{23}
  - determination of the neutrino mass ordering
  - tests of the three-neutrino paradigm.
- …detect and characterize the ν_e **flux from a core-collapse supernova** within our galaxy, should one occur during the lifetime of the experiment.
- …search for **Physics beyond the Standard Model** in a broad range of important channels, including proton decay

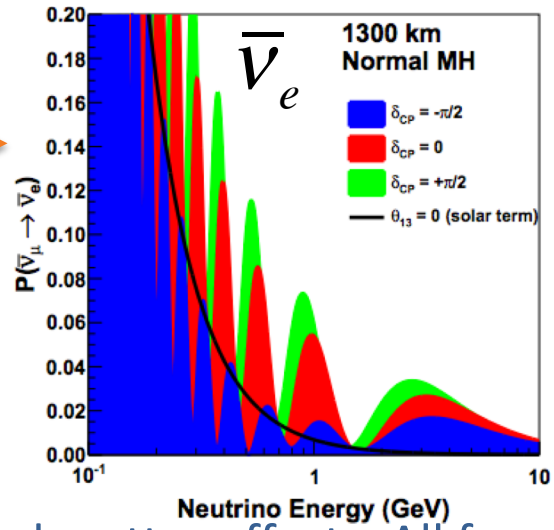
Additional physics enabled by the Far Detector includes measurements with atmospheric neutrinos and potential low-energy astrophysical measurements (solar neutrinos, DSNB)





Initial neutrino energy spectra (left) will be modified by neutrino oscillation probabilities (right)

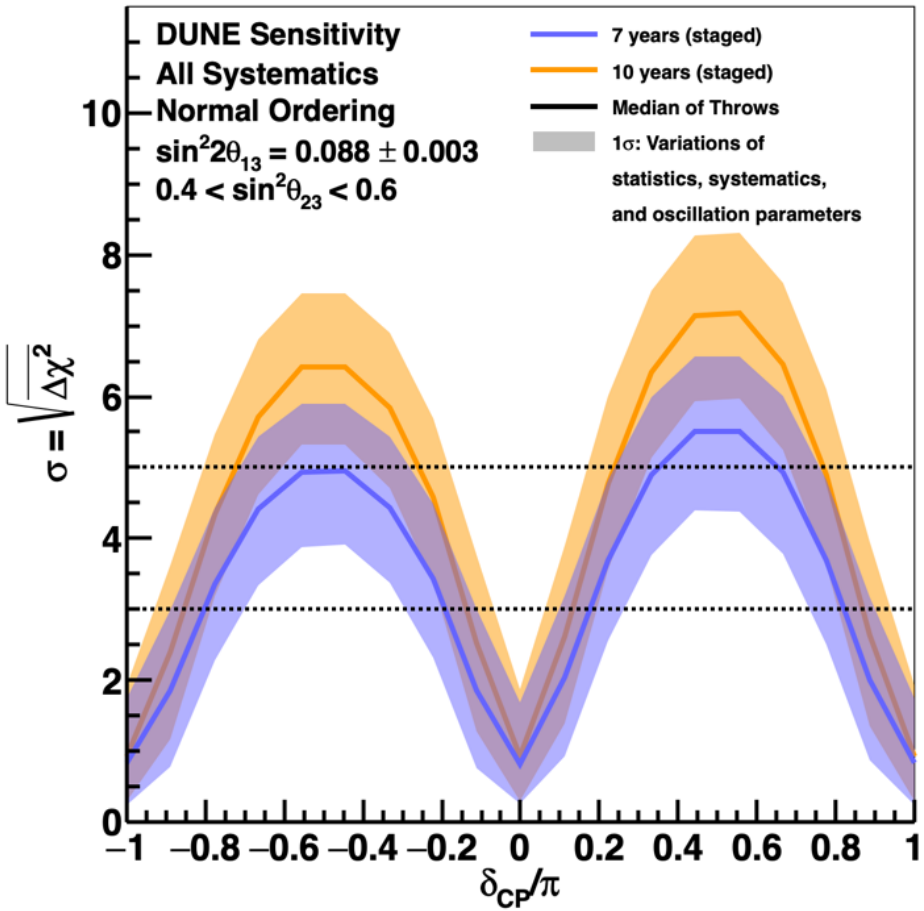




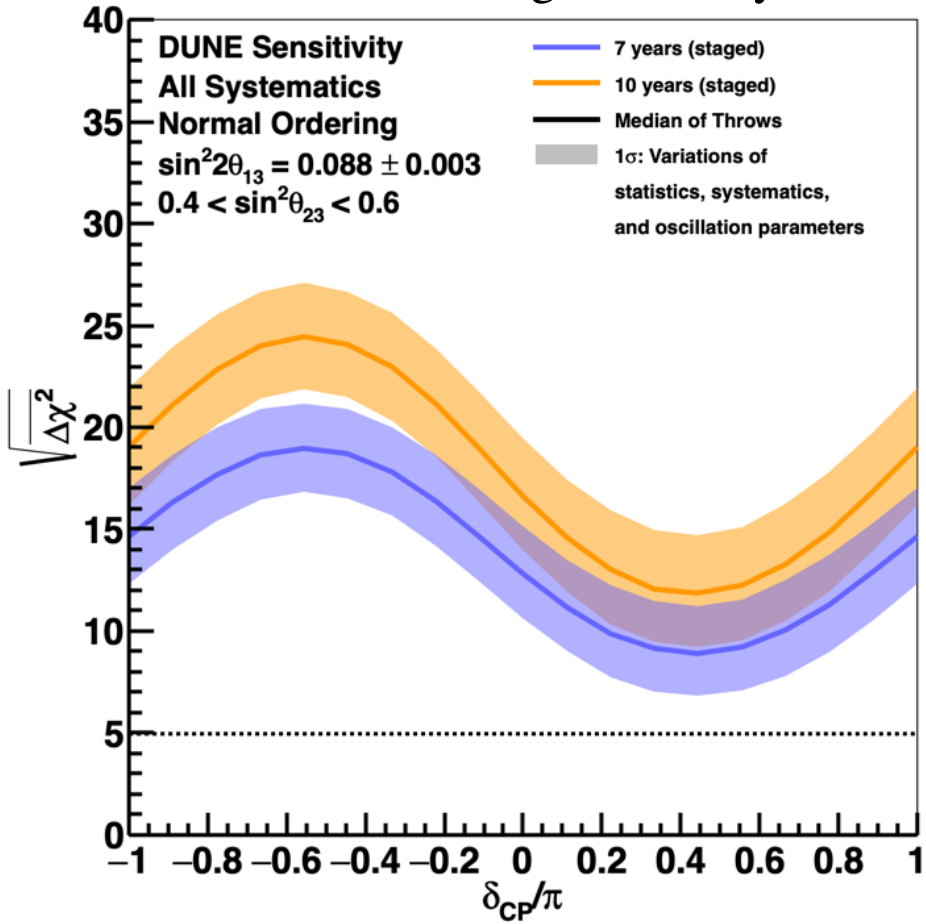
- ν_e appearance probability depends on θ_{13}, θ_{23}, δ_{CP}, and matter effects. All four can be measured in a single experiment.
- Wide-band beam, precise energy reconstruction, and long baseline break the degeneracy between CP violation and matter effects.

Mass ordering and CPV

*CP*ν sensitivity

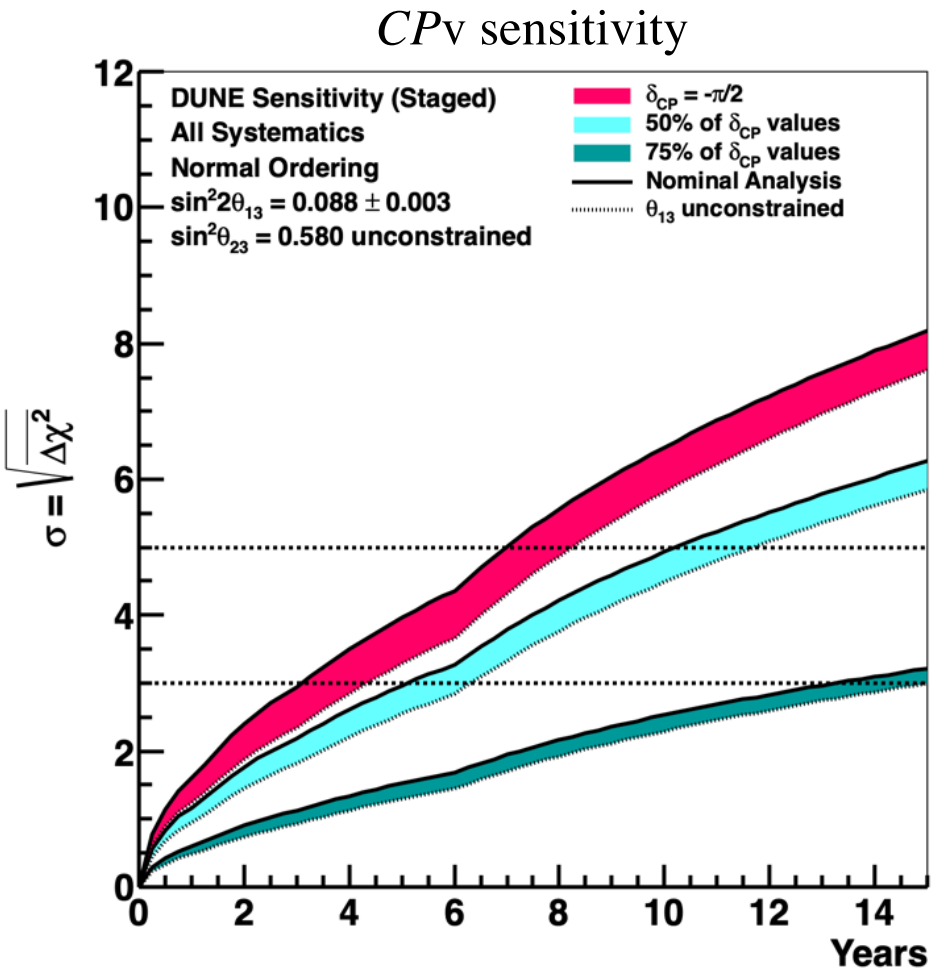


Mass ordering sensitivity



Moving quickly towards CPV discovery!

Sensitivity versus time

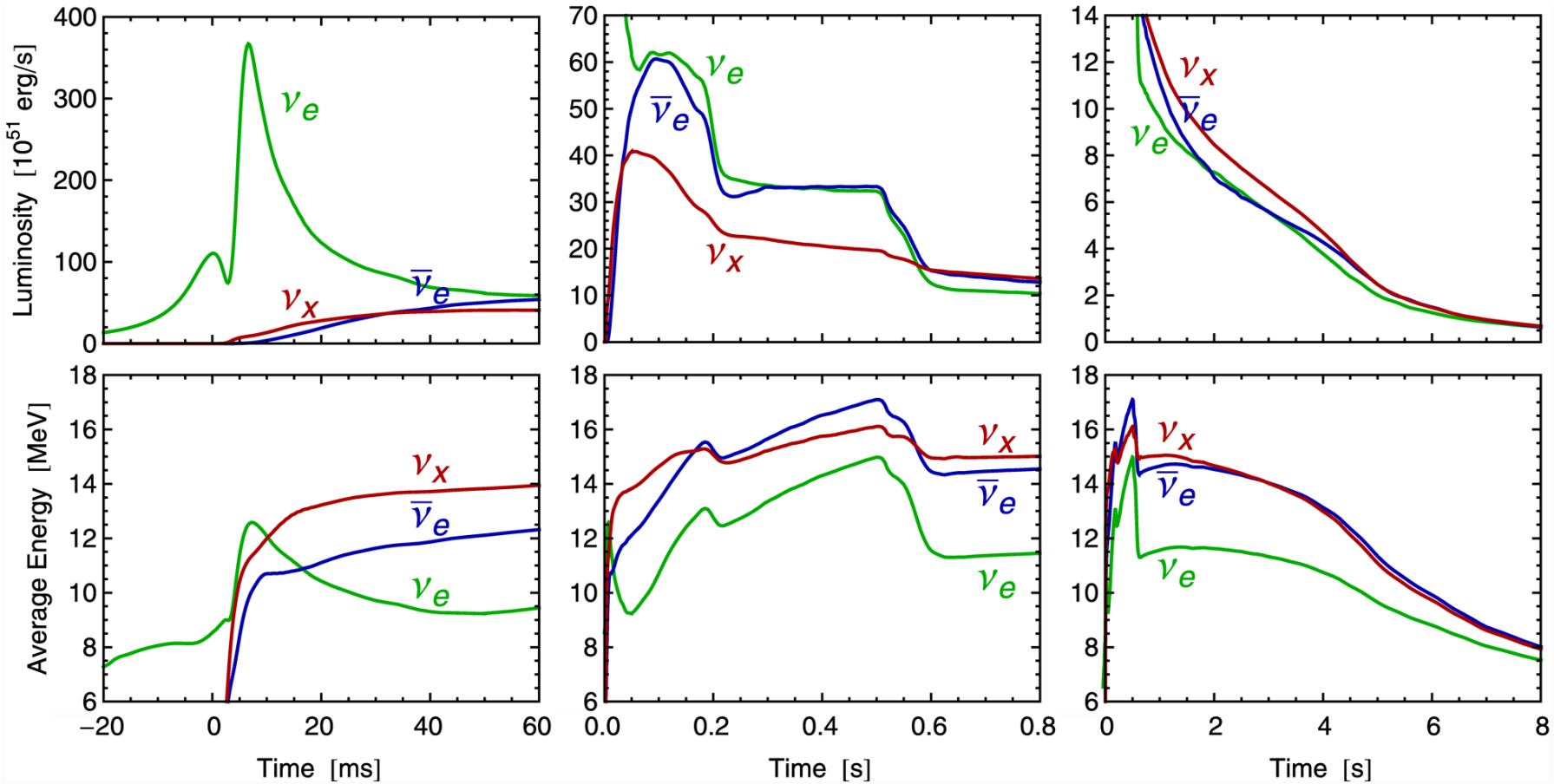


Staging assumptions:

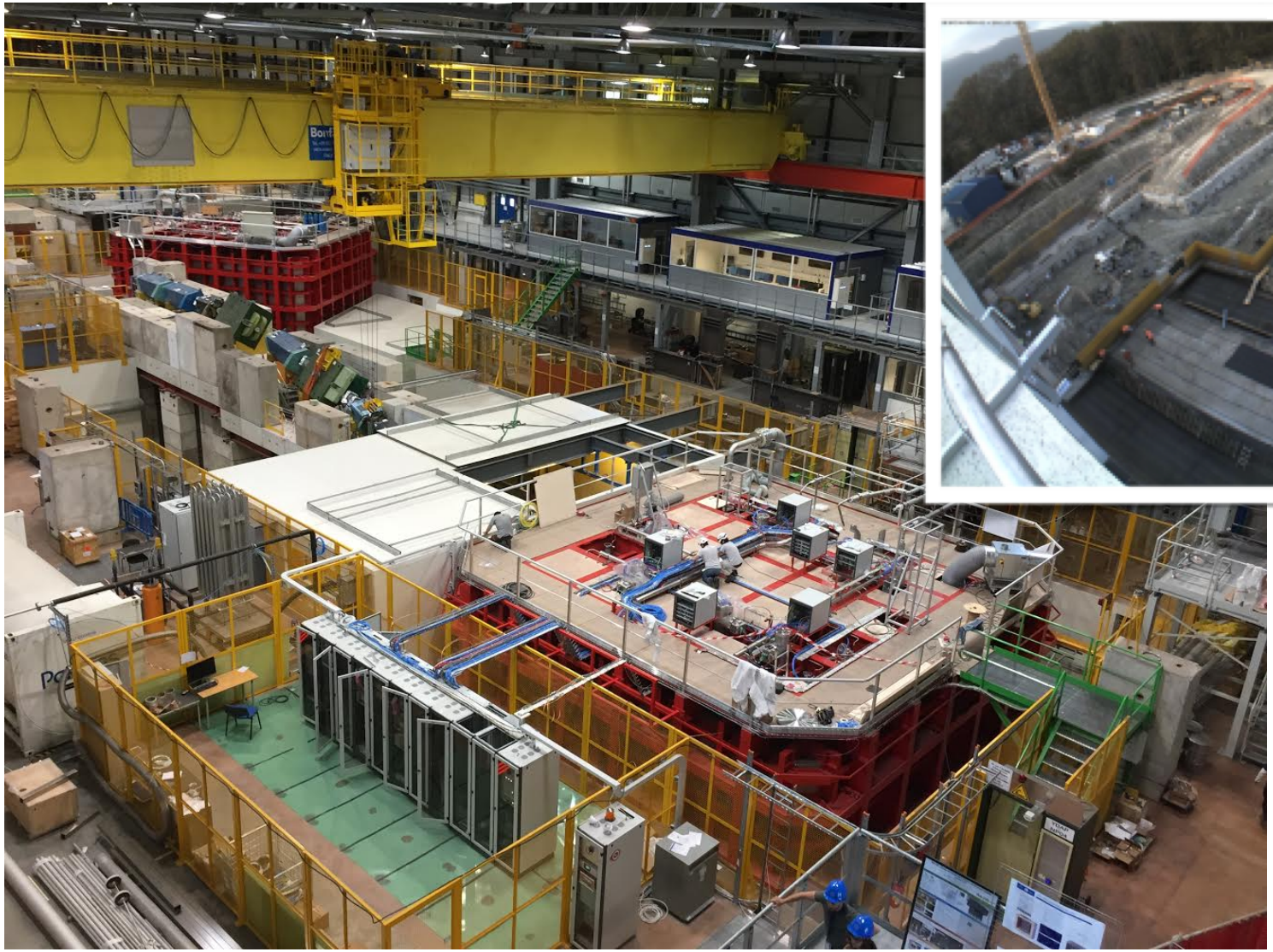
- Start of beam run: Two far detector (FD) module volumes for total fiducial mass of 20 kt, 1.2 MW beam
- After one year: Add one FD module volume for total fiducial mass of 30 kt
- After three years: Add one FD module volume for total fiducial mass of 40 kt
- After six years: Upgrade to 2.4 MW beam
- Year 0 will be defined after baselining of project in 2020.

Supernova Neutrinos

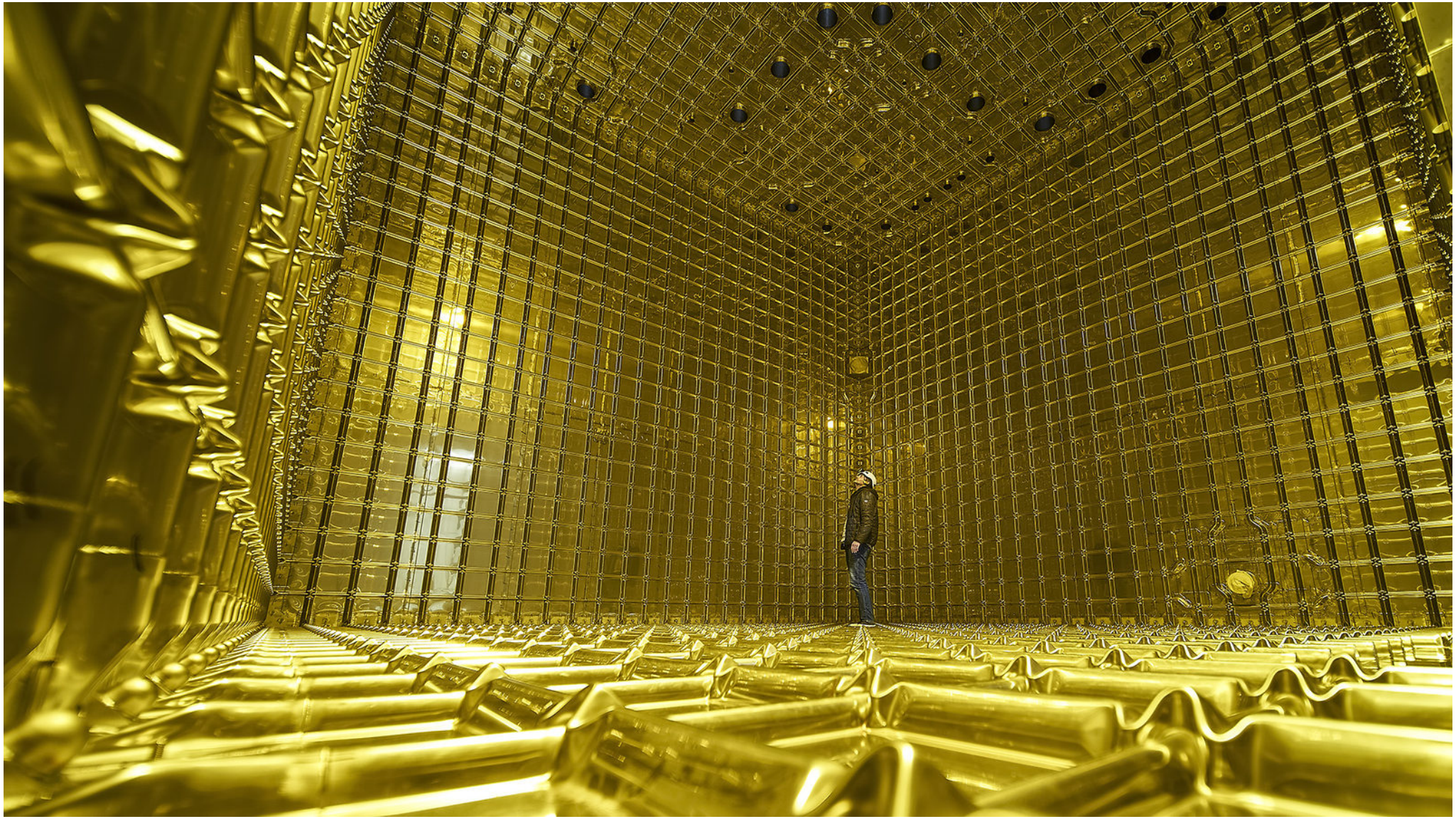
- LAr also provides unique sensitivity to ν_e: $\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$
- About 3000 ν_e events in 10 sec from SN at 10 kpc

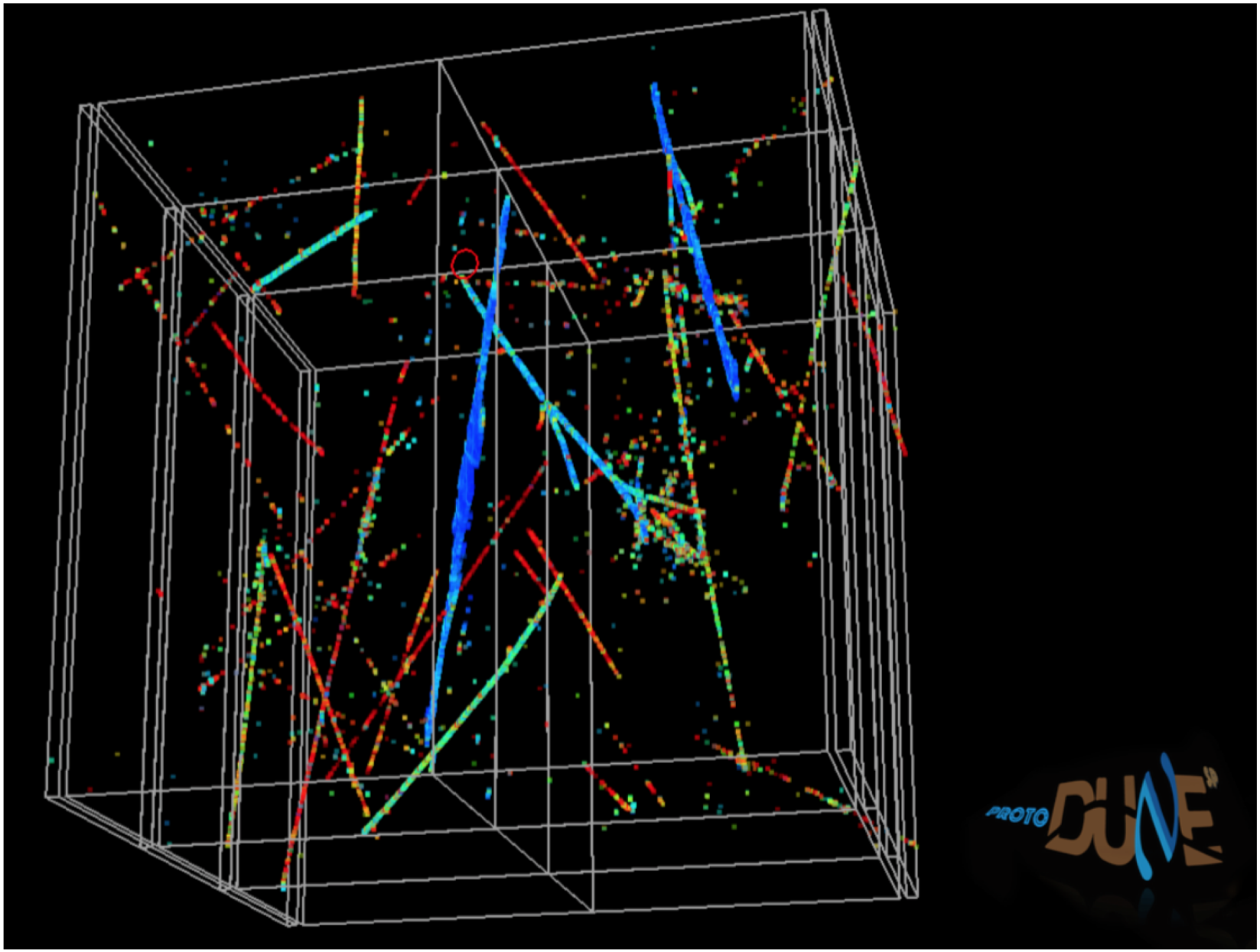


ProtoDUNEs

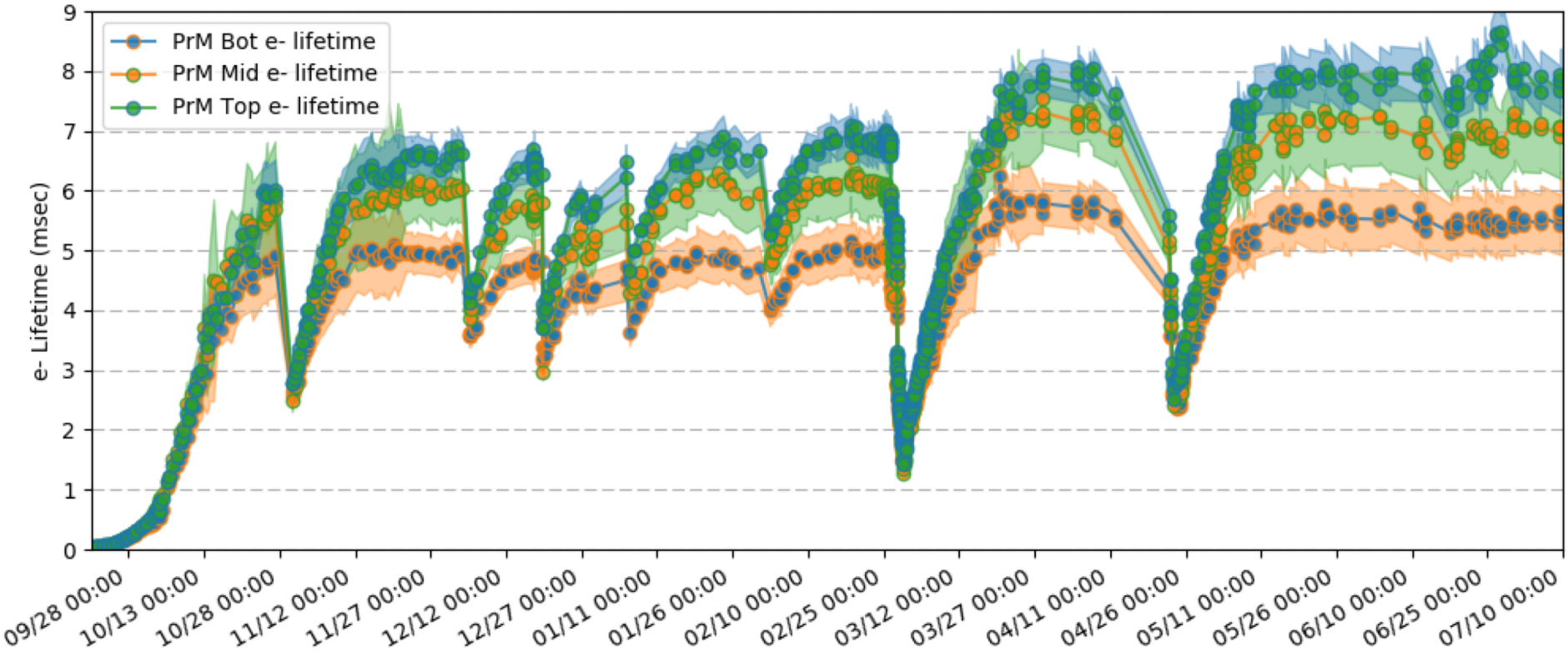


Dec 2015



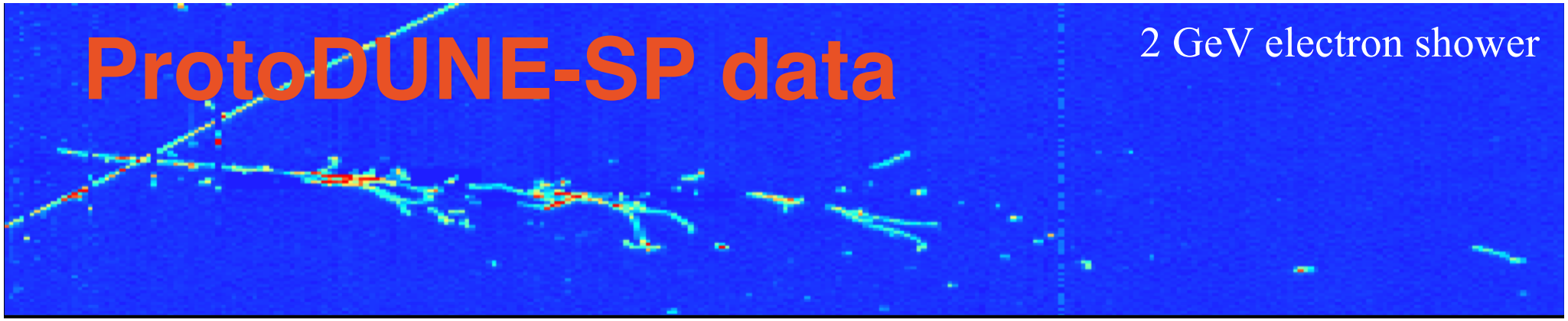

PROTO DUNE

Argon purity/electron lifetime

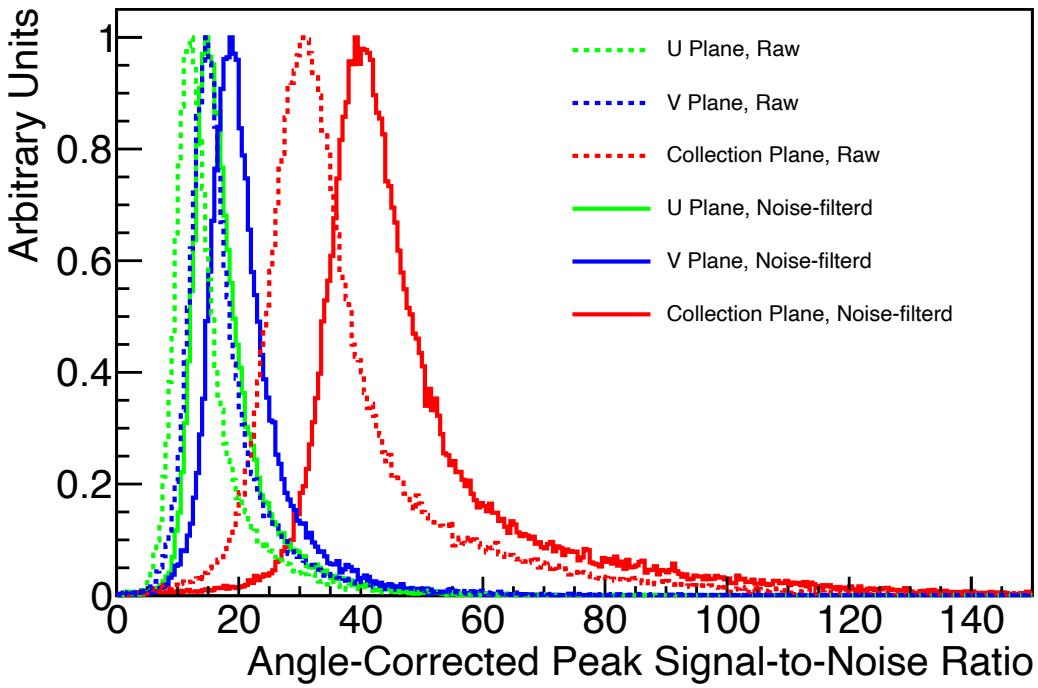


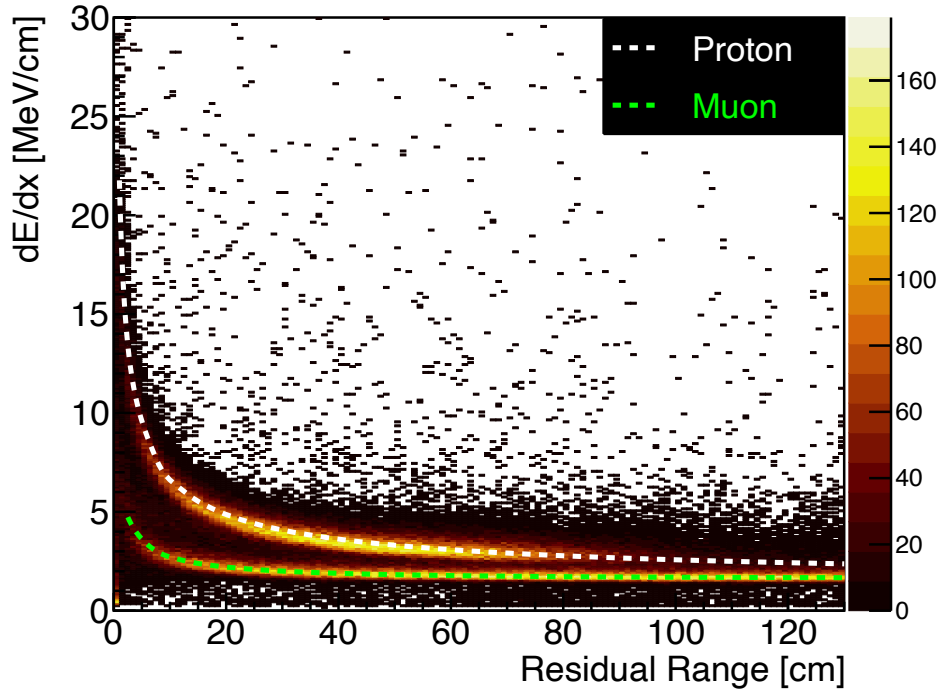
Purities of 6 ms (in electron lifetime) correspond to about 10 m drift

ProtoDUNE-SP data



- One year of data taking, including 2 months of beam data
- Excellent performance: HV, liquid argon purity, and signal-to-noise
- First publication in preparation

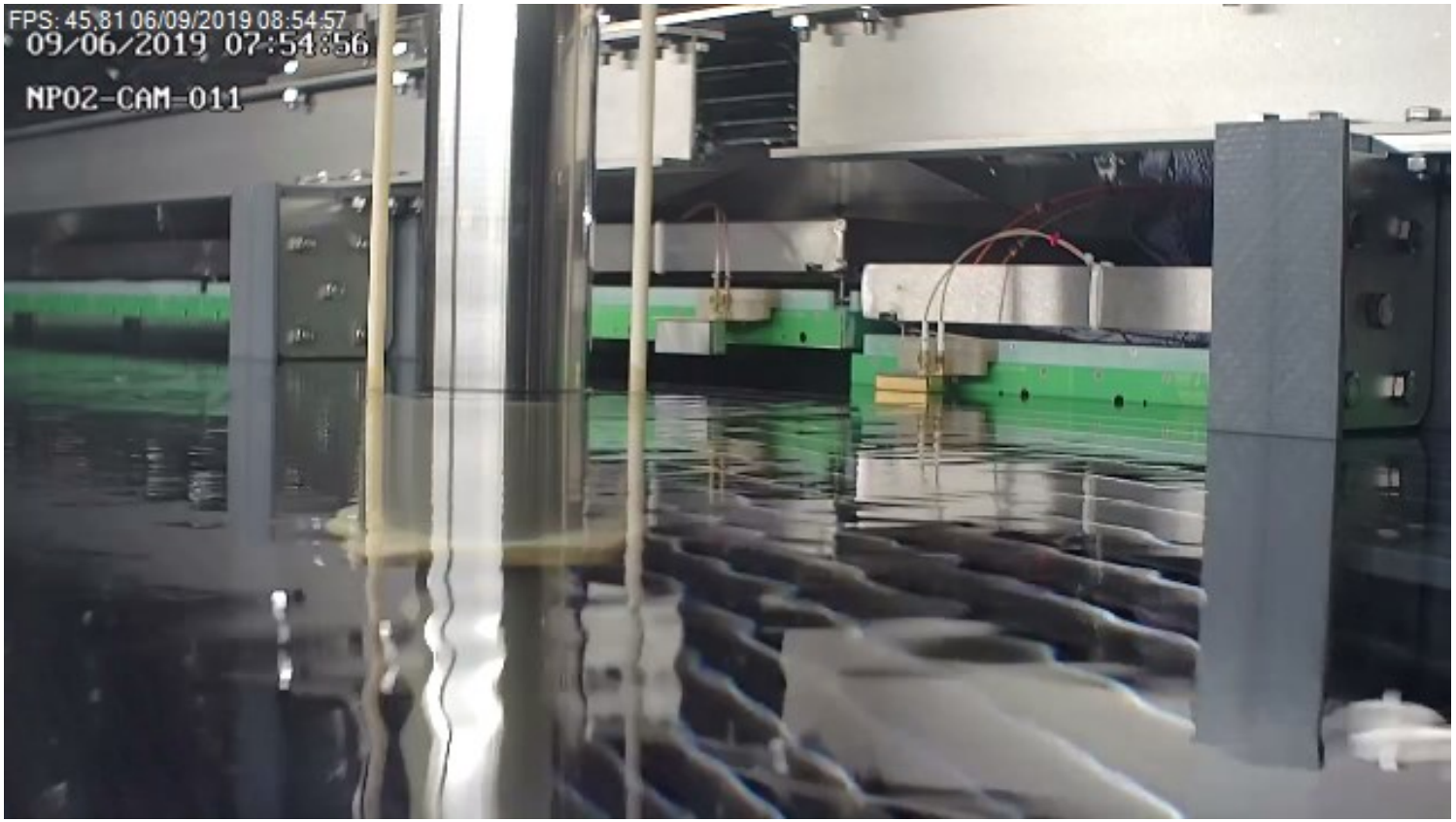




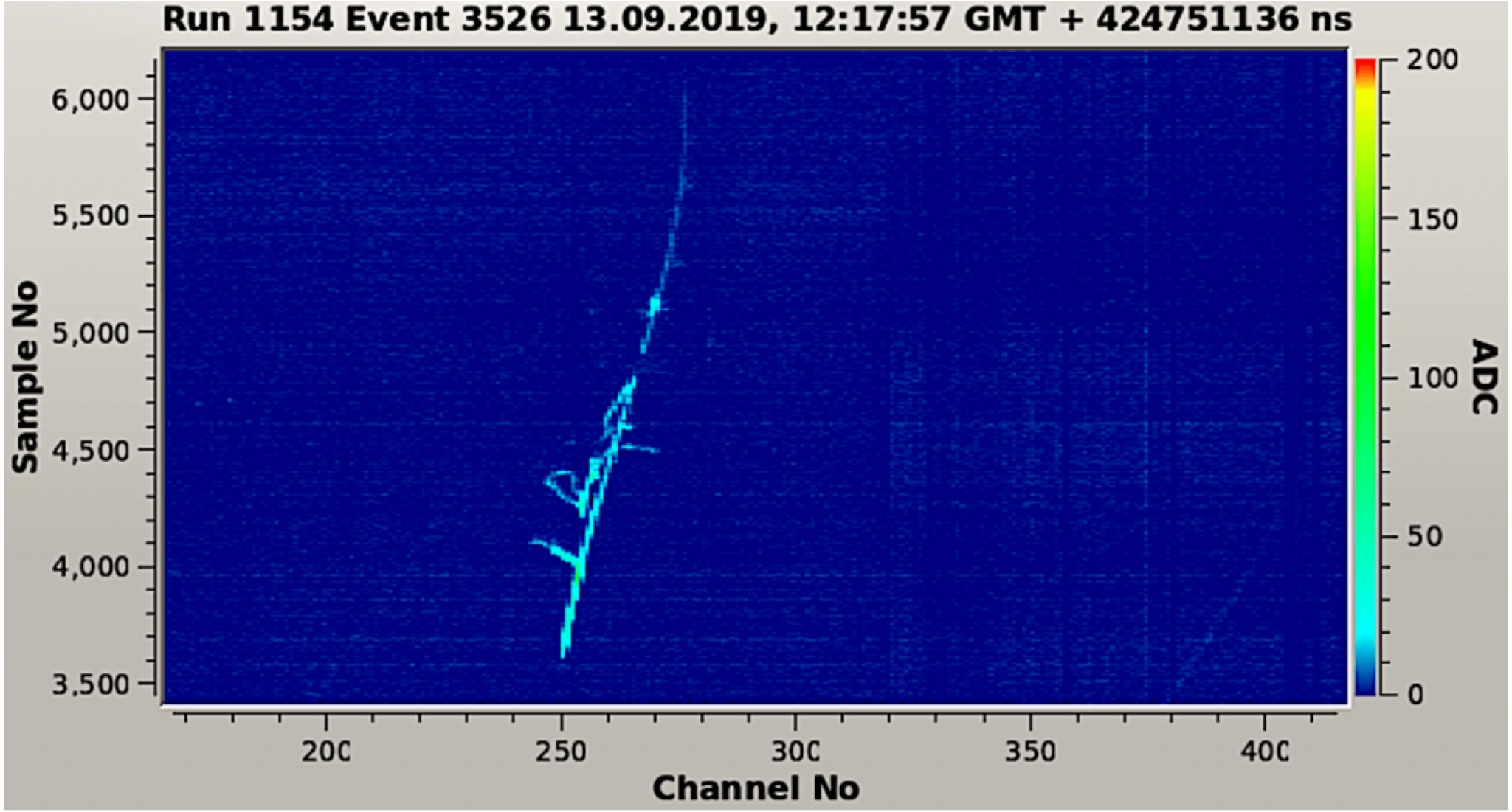
ProtoDUNE Dual-Phase

Now filled with liquid-argon and operating

ProtoDUNE Dual-Phase



First tracks seen by ProtoDUNE-DP



ProtoDUNE program has been a great success

- Construction and stable operation of ProtoDUNE-SP has validated DUNE's SP design, and demonstrated the Collaboration's ability to execute a complex construction project on schedule.
- ProtoDUNE-DP has observed first tracks and is making important progress towards demonstrating stable operations with a challenging technology.
- Detectors use full-scale elements designed for DUNE
  - test of engineering solutions, quality control protocols, and installation procedures
  - mitigate technical and cost risks for far detector
  - establish design maturity for DUNE far detector
- ProtoDUNE Phase II planned after LS2 (21/22) with final detector designs (including, e.g., calibration systems)

4th module technology will have to demonstrate equivalent level of readiness

The 4th DUNE FD module should support the primary physics program

Questions to consider for the 4th module

- **Long-baseline oscillations:**
  - Would the DUNE Near Detector adequately constrain cross section uncertainties to fully utilize the FD neutrino event sample?
  - How would detector uncertainties (acceptance, energy response, etc.) be mitigated? *E.g.,* well-established technology, ND measurements
  - Are there novel opportunities with the technology (*e.g.*, sign-selection)?

- **Supernova neutrinos:**
  - Does the technology offer appropriate energy thresholds and resolutions? Are the intrinsic backgrounds tolerable (*e.g.*, for practical triggering)?
  - Does the technology provide unique neutrino flavor or interaction channel tagging, perhaps in complementarity to the other FD modules?

- **BSM searches and potential new scope**
  - Does the technology provide competitive or novel background rejection for baryon number violation searches (*e.g.*, $p \rightarrow K\bar{\nu}$)
  - Does the technology open up avenues for discovery that are not currently in DUNE's science portfolio?