Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Computing for the DUNE Long Baseline Neutrino Oscillation Experiment

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for the DUNE Collaboration

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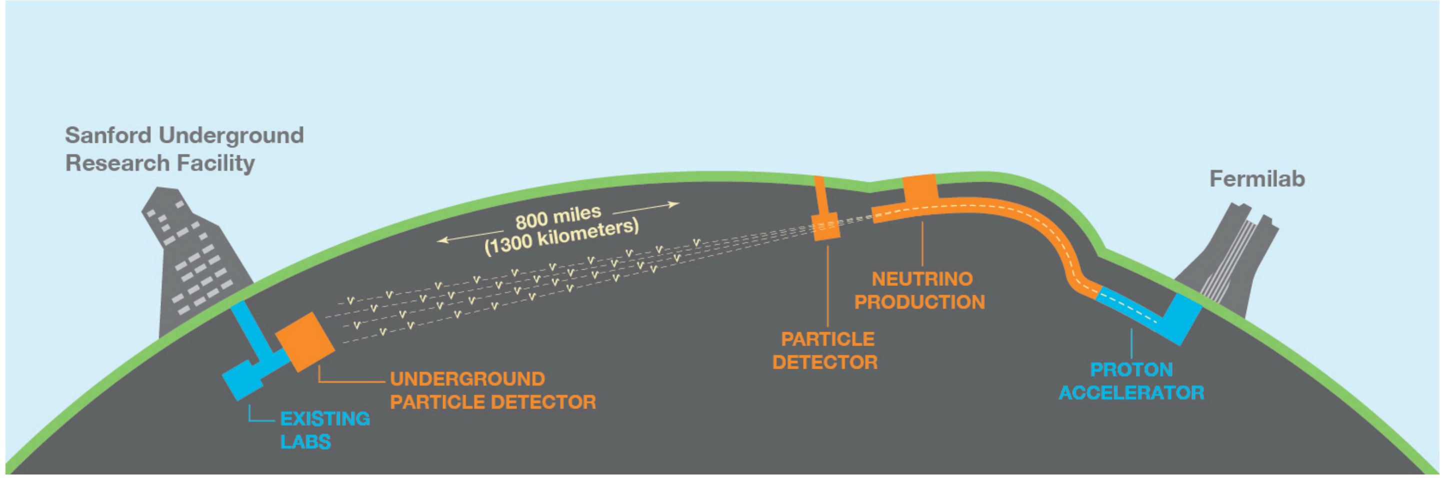
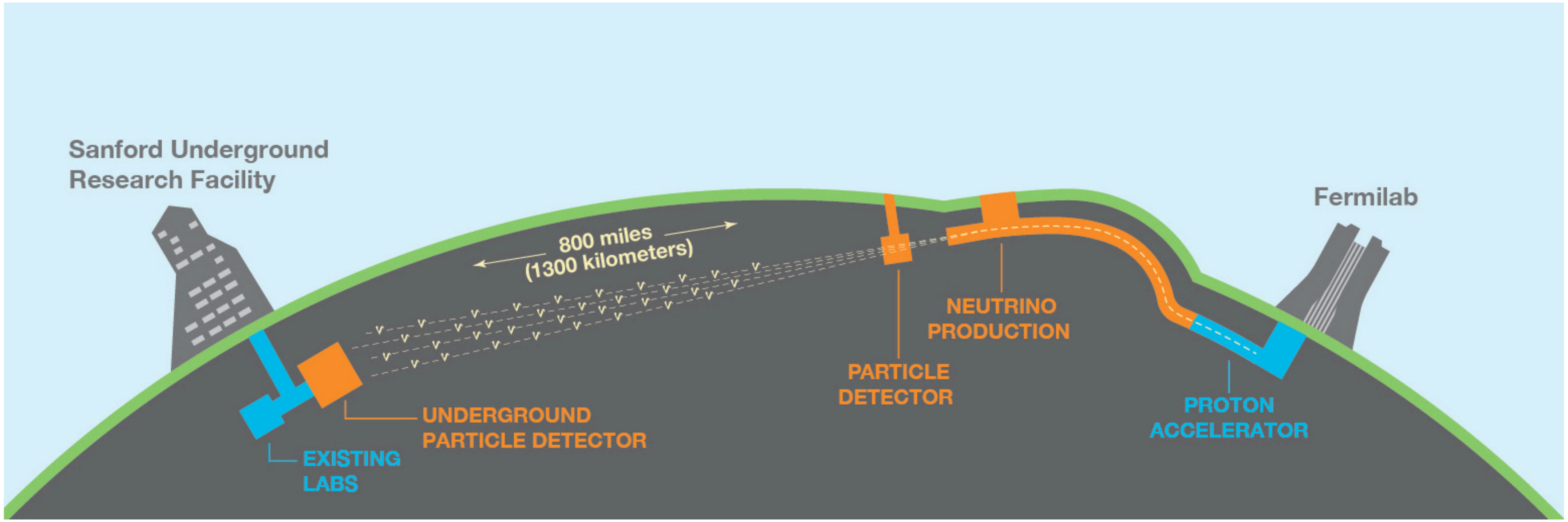
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

Outline Computing for DUNE

- Introduction to the DUNE Experiment and physics goals
- DUNE Near & Far Detectors designs
- ProtoDUNE detectors at CERN
- Unique DUNE computing challenges
- DUNE Computing Model
- Performance on the ProtoDUNE data
- Future prospects

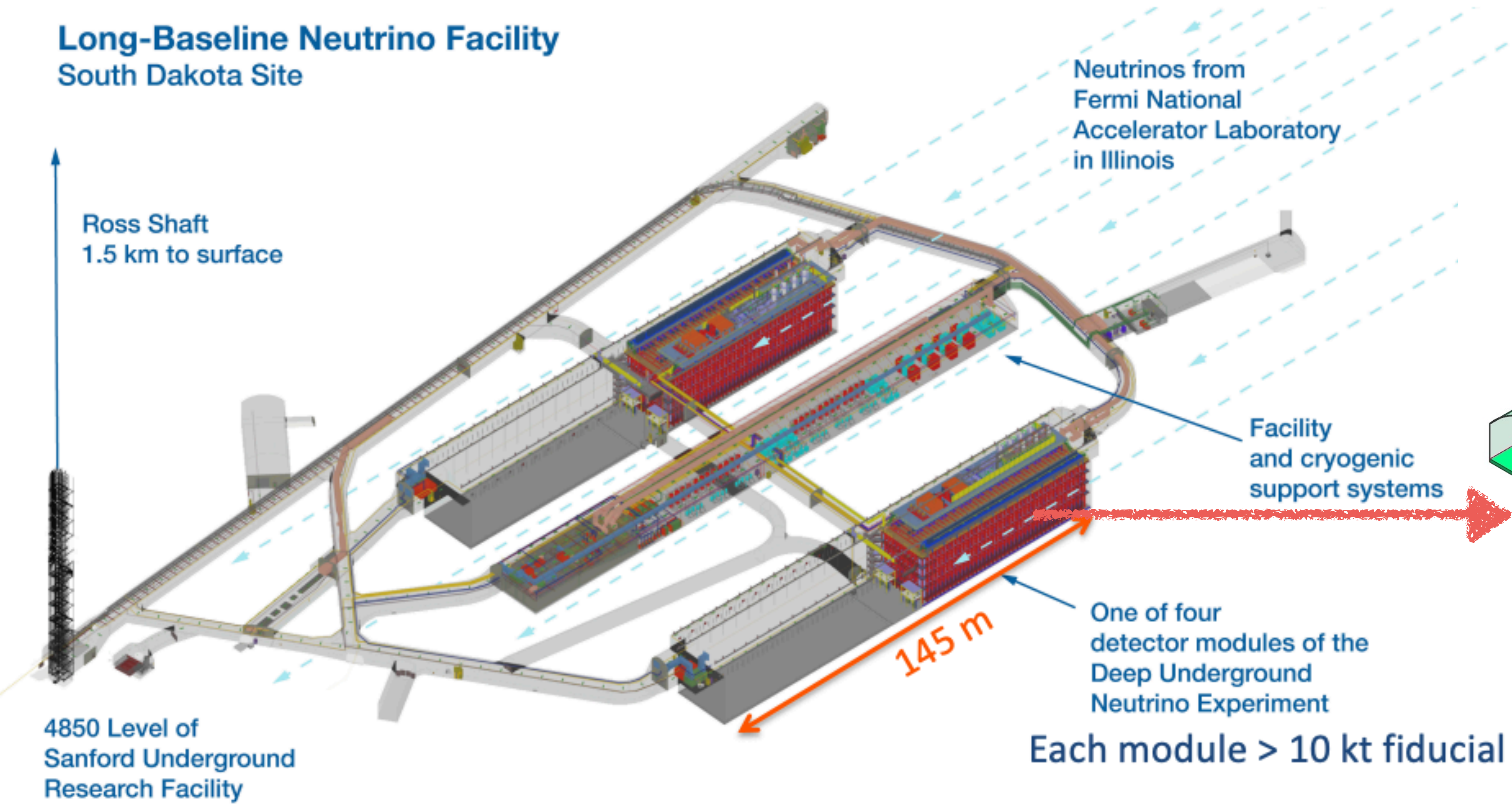


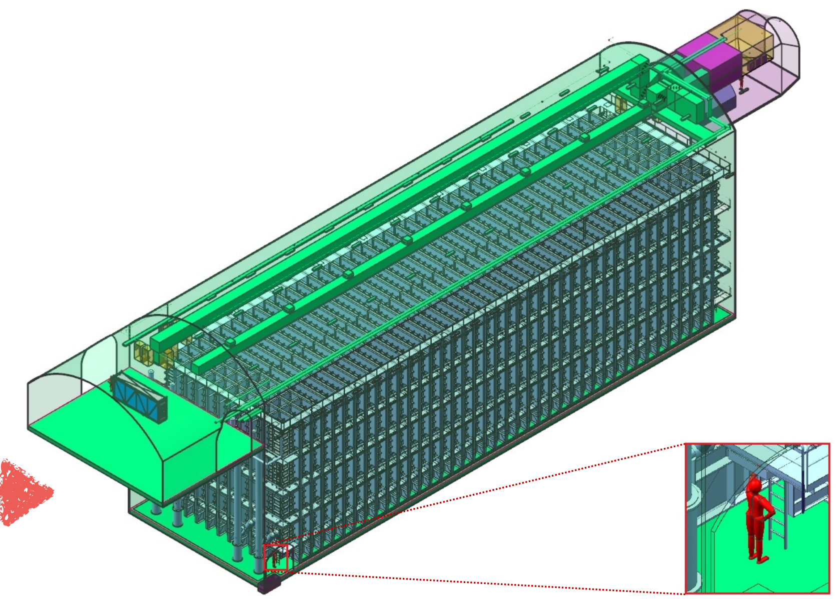
DUNE Experiment Overview



- neutrino experiment measuring neutrino oscillation parameters (mass ordering, matter vs antimatter asymmetry, unitarity), proton decay, supernova neutrinos, and more.
- Far Detector consists of 4 LAr TPC modules at 4850 ft underground in Lead, SD (SURF)
- Near Detector (proposed design) at Fermilab near the neutrino production
- baseline of 1300 km and neutrino beam optimized for oscillation measurement sensitivity
- Two prototypes at CERN - (ProtoDUNE Single Phase - ProtoDUNE Dual Phase)

DUNE Far Detector at Sanford Underground Research Facility

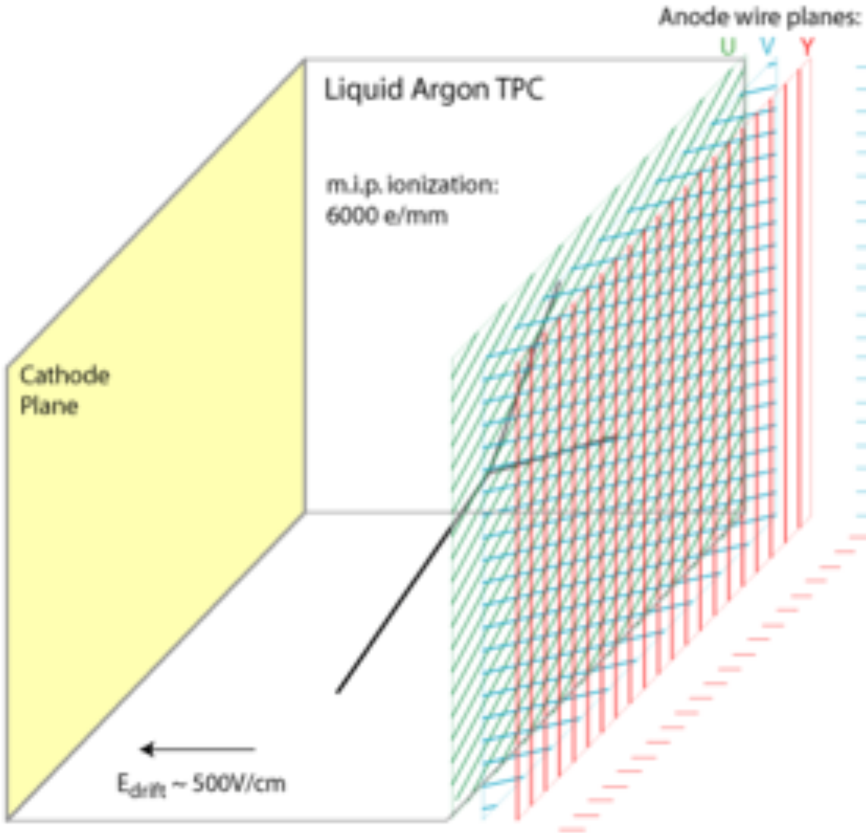


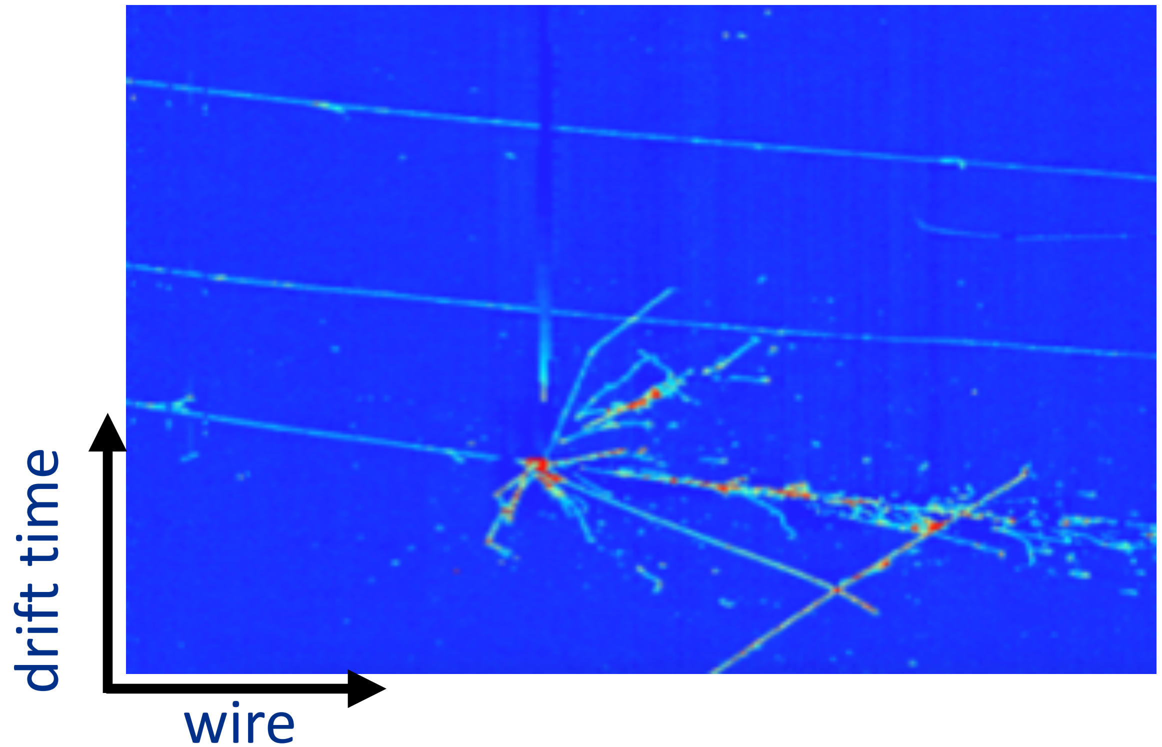


Each module > 10 kt fiducial

Slide: Ed Blucher

Single Phase Liquid Argon Time Projection Chamber



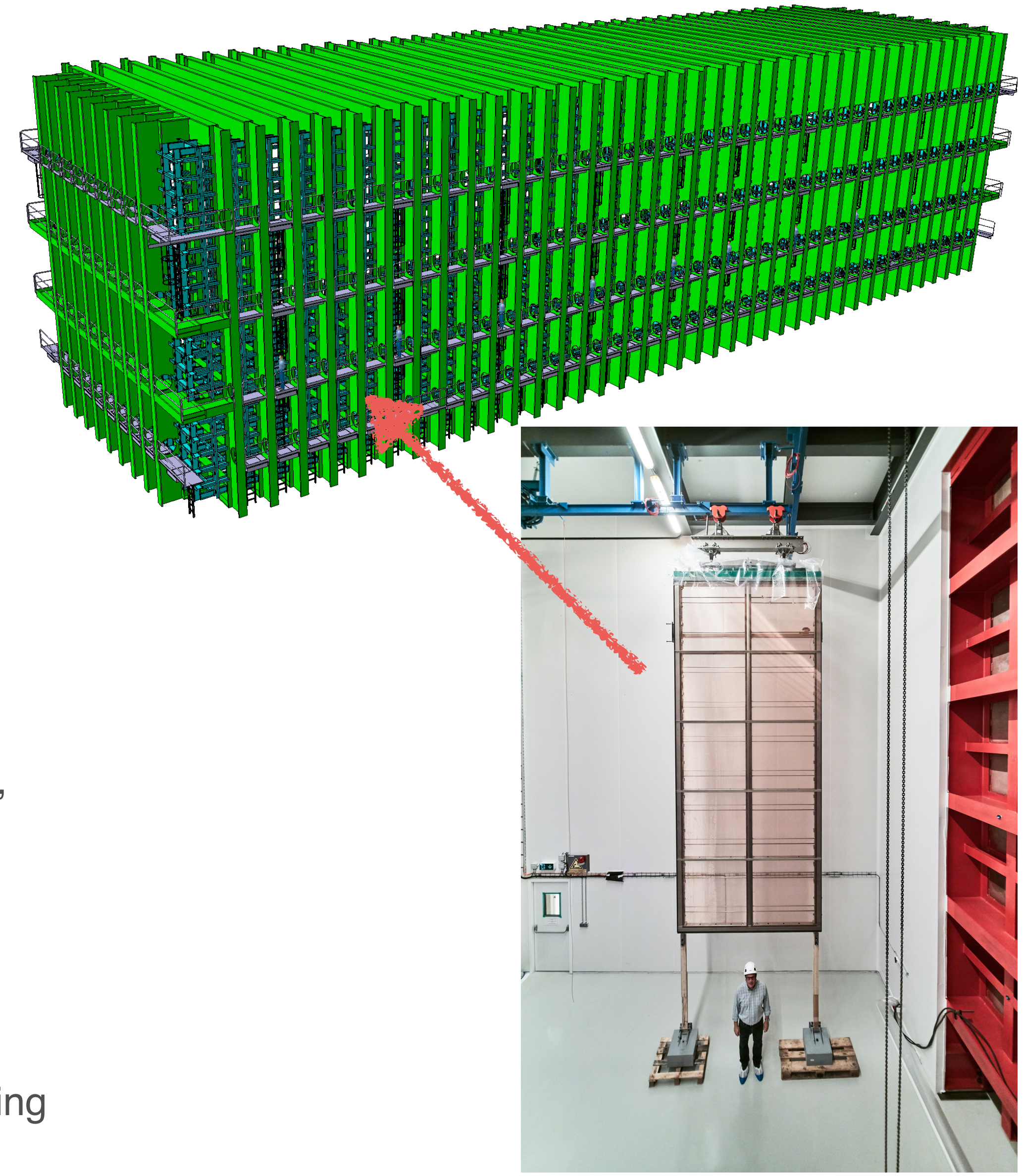


- High spatial and calorimetric resolution - necessary for particle ID, ν-energy measurement
- drift time set by electric field, sampling rate and ADC precision set by physics goals and cost
- two induction planes and one collection plane for the DUNE single-phase Far Detector modules
- dual-phase LAr TPC will be the second Far Detector module

DUNE Far Detector Design

- First Far Detector build will be a single phase LAr TPC
  - 17 kT of liquid Argon
  - 150 Anode Plane Assemblies tiled on center and walls
  - 180 kV electric field across each drift volume -> 5.4 ms drift time
- Beam timing triggered readout for oscillations physics analysis
  - normal neutrino-beam trigger record is 5.4 ms
  - 12-bit ADC sampled every 0.5 μs
  - 2560 channels per APA
  - 6 GB uncompressed or 2-3 GB compressed
- time-extended readout window of far detector module varies greatly
  - continuous readout (SuperNova), calibrations, etc
  - DAQ designed with greater bandwidth, but reduced with trigger, zero suppression, and compressed data format
- reconstruction of signals and hits spatially independent within an Anode-Plane Assembly, but 2D deconvolution and FFT require time stitching
- processing of a single trigger record can generate multiple “events” - consider these events to be causally separable regions of interest
- creation of analysis events to minimize data volume and facilitate additional processing

Far Detector SP Module



Single APA

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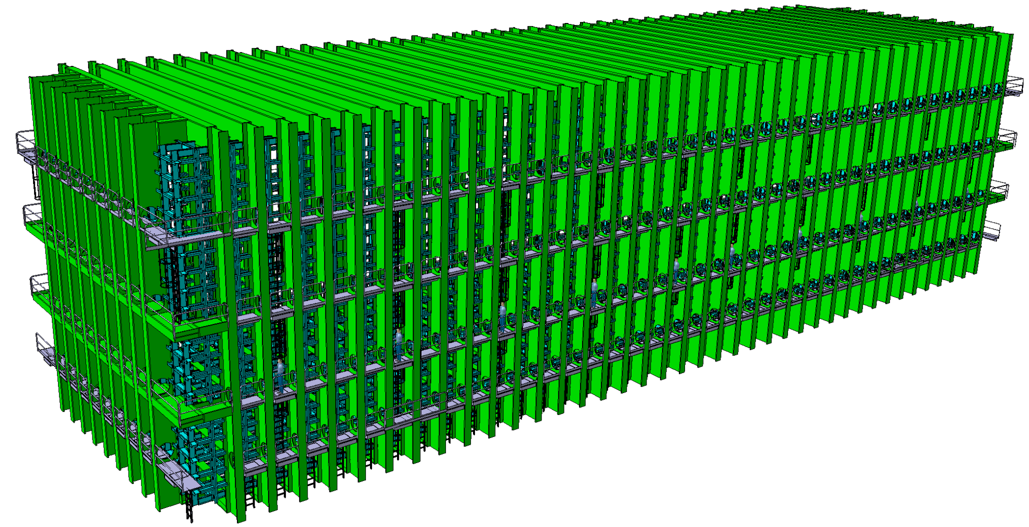
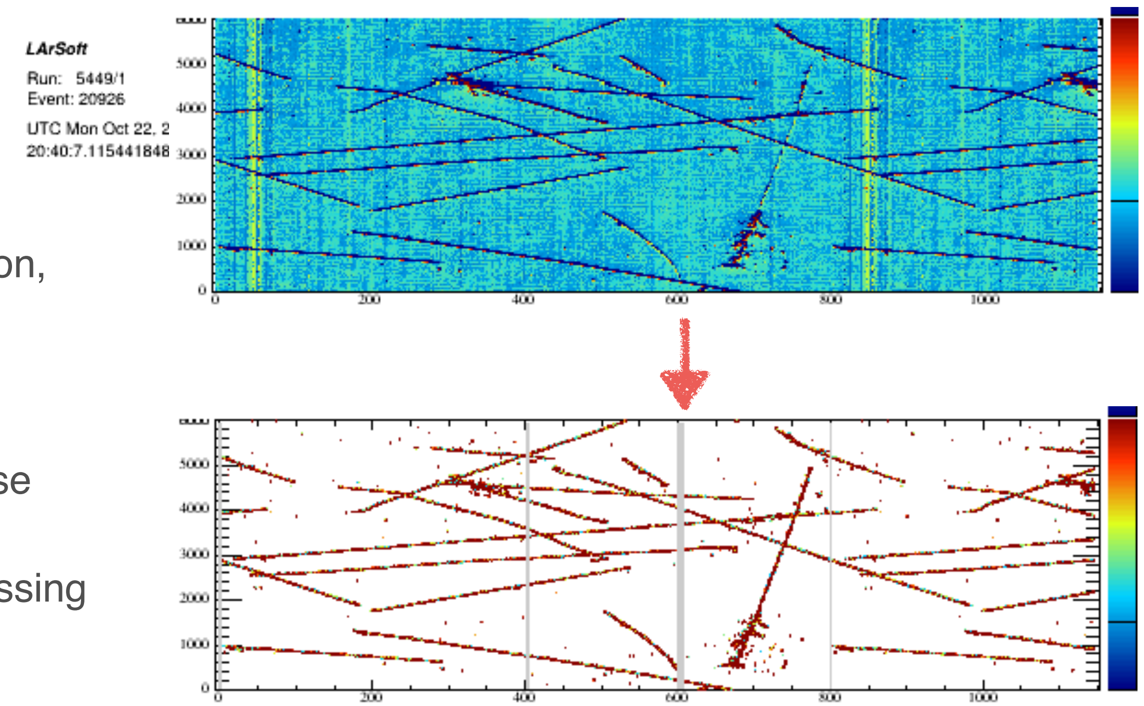
Far Detector SP Module





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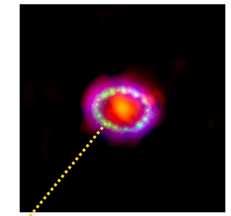
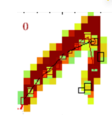
DUNE Far Detector Supernovae Detection

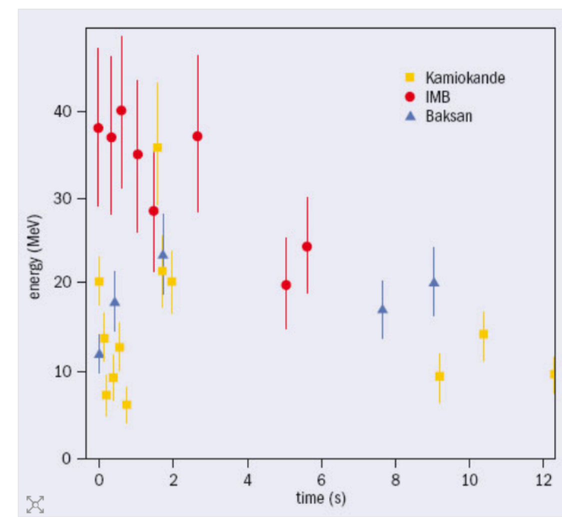
- FD designed to be sensitive to nearby (Milky Way neighborhood) supernovae events
- estimated to occur every 30-200 years, but a false alarm possibly once a month
- 100 sec readout implies
  – 1 channel = 300 MB uncompressed
  – 1 APA = 768 GB uncompressed
  – 1 module = 115 TB uncompressed
  – 4 SP modules = 180 TB compressed
  – takes 4-5 hrs to transfer at 100 Gb/s
- Need to detect and process the data quickly for multi-messenger observations can follow

Supernova 1987A





30 MeV ν_e CC

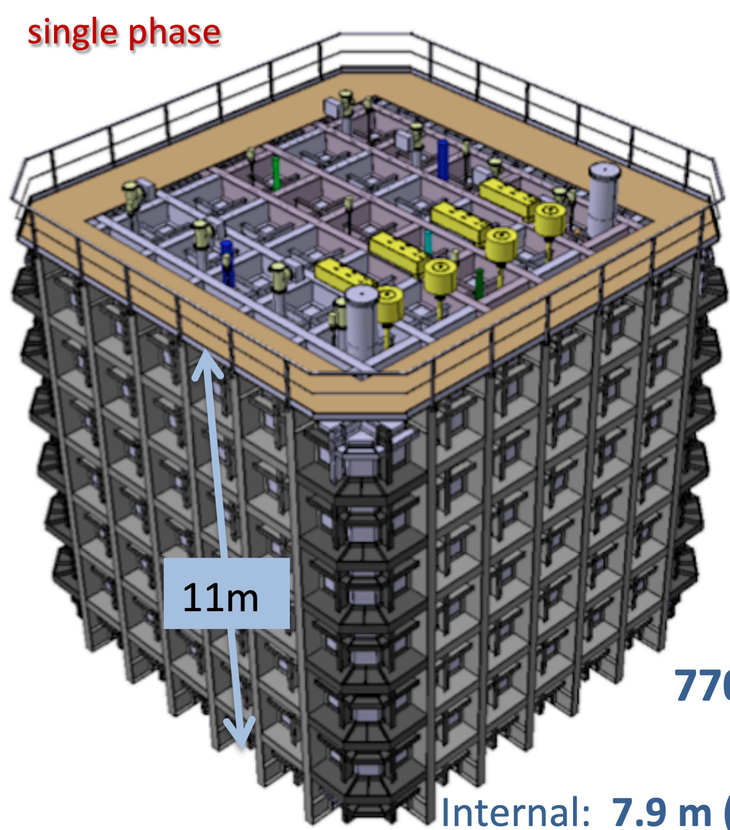


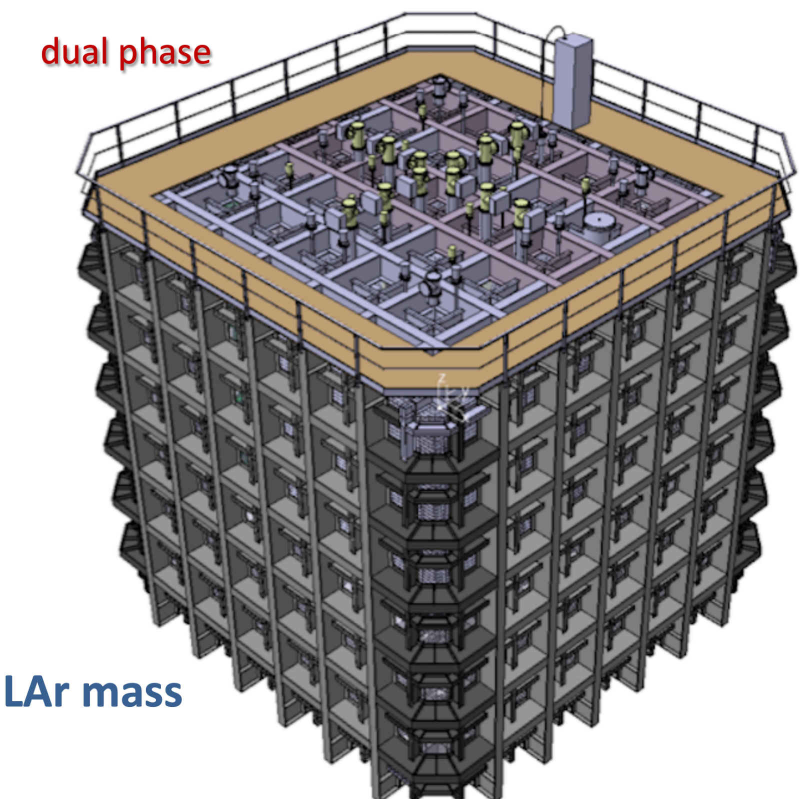
SN1987A neutrino events observed by Kamiokande, IMB and Baksan showed that the neutrino burst lasted about 13 s.

CERN Courier, Jan 2007

ProtoDUNE Detectors at CERN

- Construct small single-phase and dual-phase LAr TPC (~770 tonnes LAr)
- Single-phase constructed with 6 APAs (instead of 150)
- Dual-phase constructed with 4 Charge Readout Planes





770 t total LAr mass

Internal: **7.9 m (Transv) x 8.5 m (Parallel) x 8.1 m (Height)**

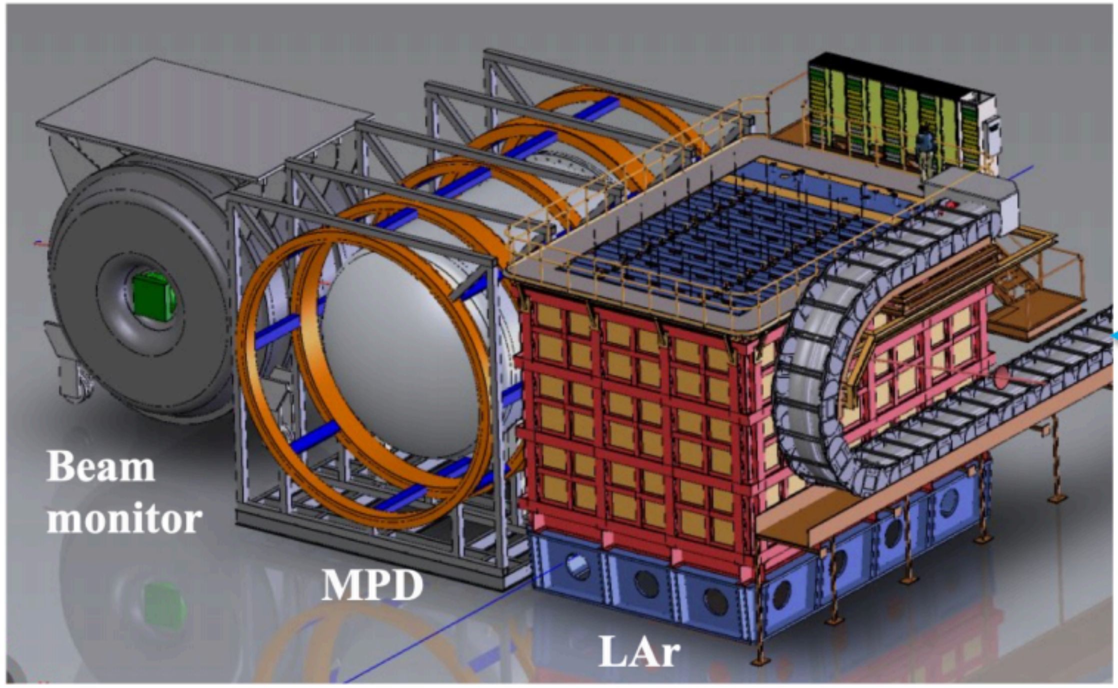
External: **10.8m (Transv) x 11.4 m (Parallel) x 11.0 m (Height).**

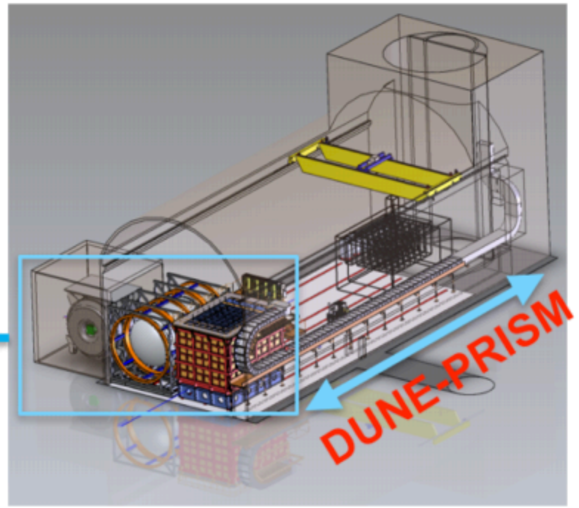
Figure by Thomas Kutter

(Proposed) Near Detector Design

Slide: Ed Blucher

- critical part of the oscillation analysis
- precise cross section measurements to improve modeling
- anticipate high occupancy with proximity to beam source and lower overburden
- readout rate ~1 Hz
- at least 1 PB/year but likely much larger
- greater simulation complexity and statistics compared to modeling of Far Detector





- LAr: Highly segmented LAr TPC (ArgonCube)
- MPD (Multi-purpose detector): High Pressure Gas Argon TPC, Calorimeter, and muon system magnetized by superconducting coils
- Beam monitor: High density plastic scintillator detector with tracking chambers and calorimetry in KLOE magnet
- DUNE-PRISM: Movement of LAr+MPD transverse to the beam, sampling different E_ν

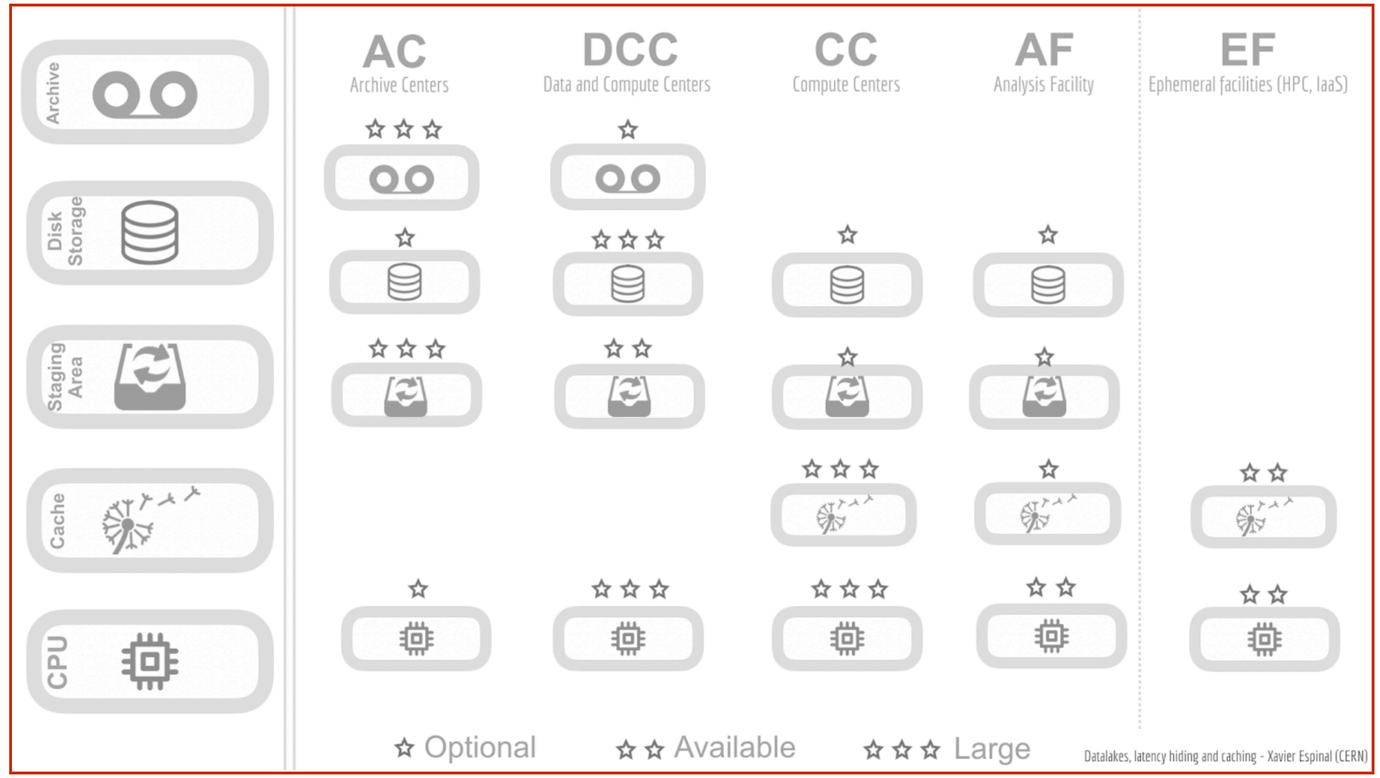
DUNE Computing Challenges Summary

- Need to transfer and store 30 PB/year from Far Detector at SURF
- Handle burst transfer and processing of time-extended trigger records (Supernovae)
  - 180 TB compressed data from 100 s of streaming data - 4 hours to FNAL @ 100 Gb/s
  - 30,000 CPUs to analyze data within 4 hours and provide 5º pointing
- Creation of ROI after signal processing and noise removal
  - reduce data volume from 6 GB/evt
- Calibration data on similar scale as Supernovae
- Near Detector data volume potentially comparable to Far Detector (trigger rate, occupancy)
- Detector Simulation challenging for 1 MeV scale at FD and occupancy at ND

DUNE Computing Model

DEEP UNDERGROUND NEUTRINO EXPERIMENT
COMPUTING CONSORTIUM

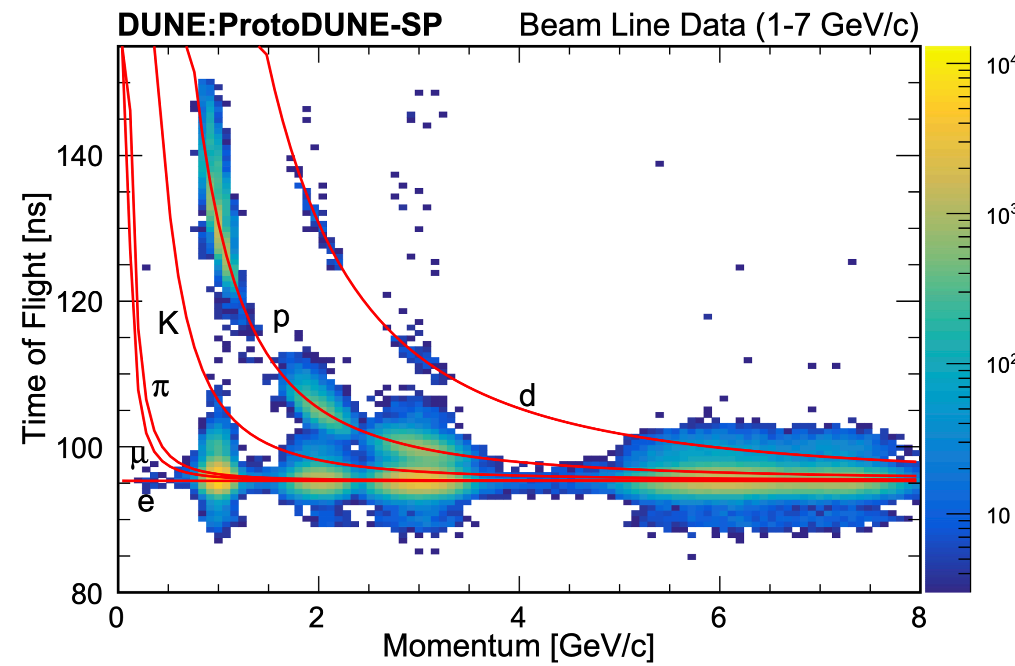
- Working from HSF DOMA model for sites
  - Archive Center - tape/staging
  - Data Center - disk + CPU
  - Compute Center - CPU + cache
  - Analysis Facility - cpu + cache
  - HPC - (HPC, IaaS)
- Goal is to have resource split between FNAL and other institutions - 25%/75%
- FNAL has some custodial responsibilities from the Dept of Energy that make this not possible for archival storage
- additional resources potentially available from cloud resources

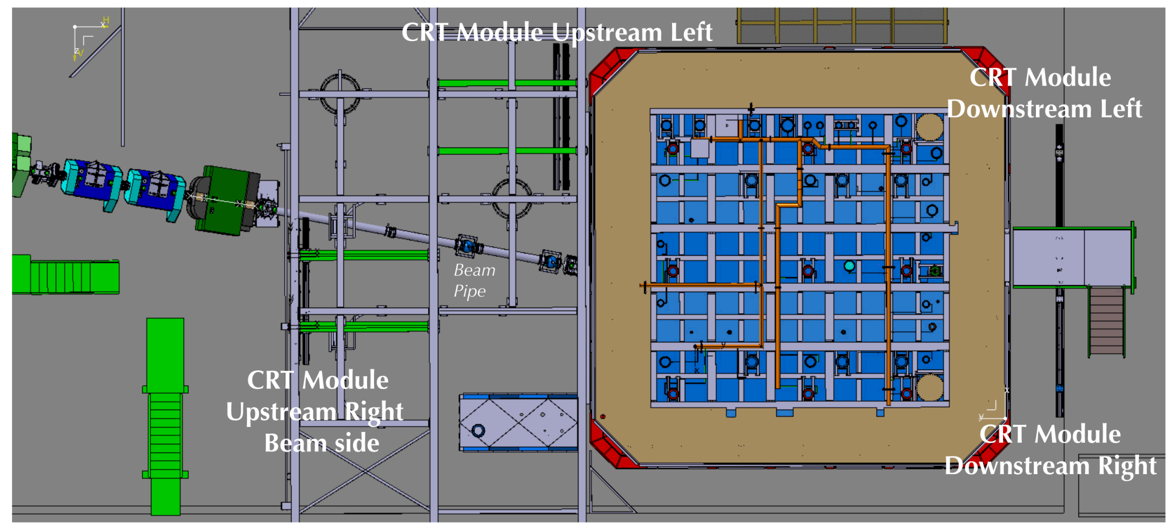


Data Access in DOMA, HSF/OSG/WLCG Joint Workshop J-LAB Newport News, VA 19-23 March 2019

Implementation of Computing Model with Data from ProtoDUNE - SP

- ProtoDUNE Single Phase beam Oct - Nov 2018
- Time-of-Flight and Cherenkov tagged events
  - 300k π - Momentum 1, 2, 3, 6-7 GeV/c
  - additional e, p, K events
  - 8M total beam events - 600 TB raw data
- Additional > 50M cosmic events
  - 2 PB raw data
  - varying the purity, HV, Xenon doping
- utilize this large sample of data to test the Computing Model for DUNE
- See next talk by Steve Timm - “DUNE Data Management Experience with Rucio”





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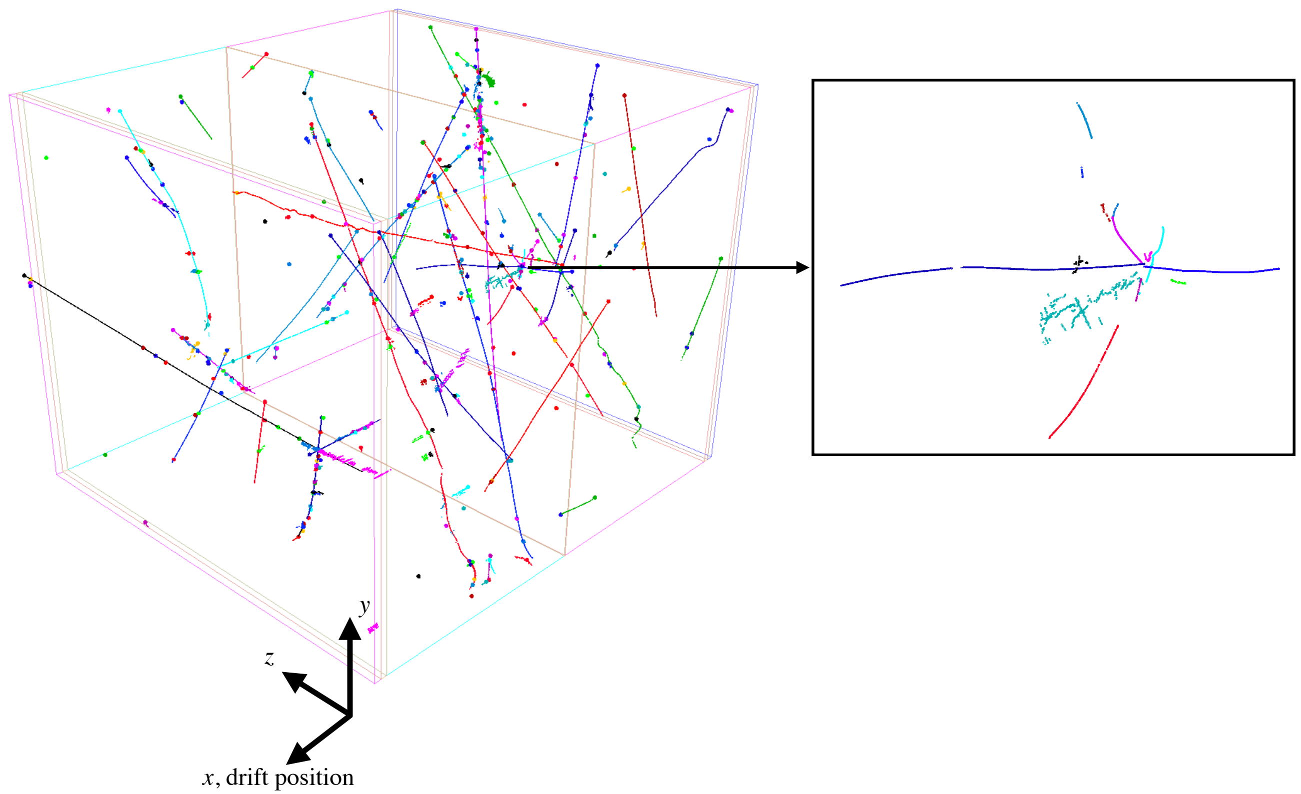
ProtoDUNE Reconstruction Processing

- Based on art framework and LArSoft physics software with ProtoDUNE specific modules
  - WireCell, Pandora libraries utilized extensively
- Processing a 100 event 8 GB file takes ~500 sec/event (80 sec/APA)
  - Signal processing is < 2 GB memory
  - Pattern recognition is < 3 GB memory
  - ProtoDUNE SP event is 75 MB/evt
- reduction to 20 MB/evt - 2 GB files
- with 25 Hz trigger rate is equivalent to DUNE Far Detector beam trigger stream
- "First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform" https://arxiv.org/abs/2007.06722



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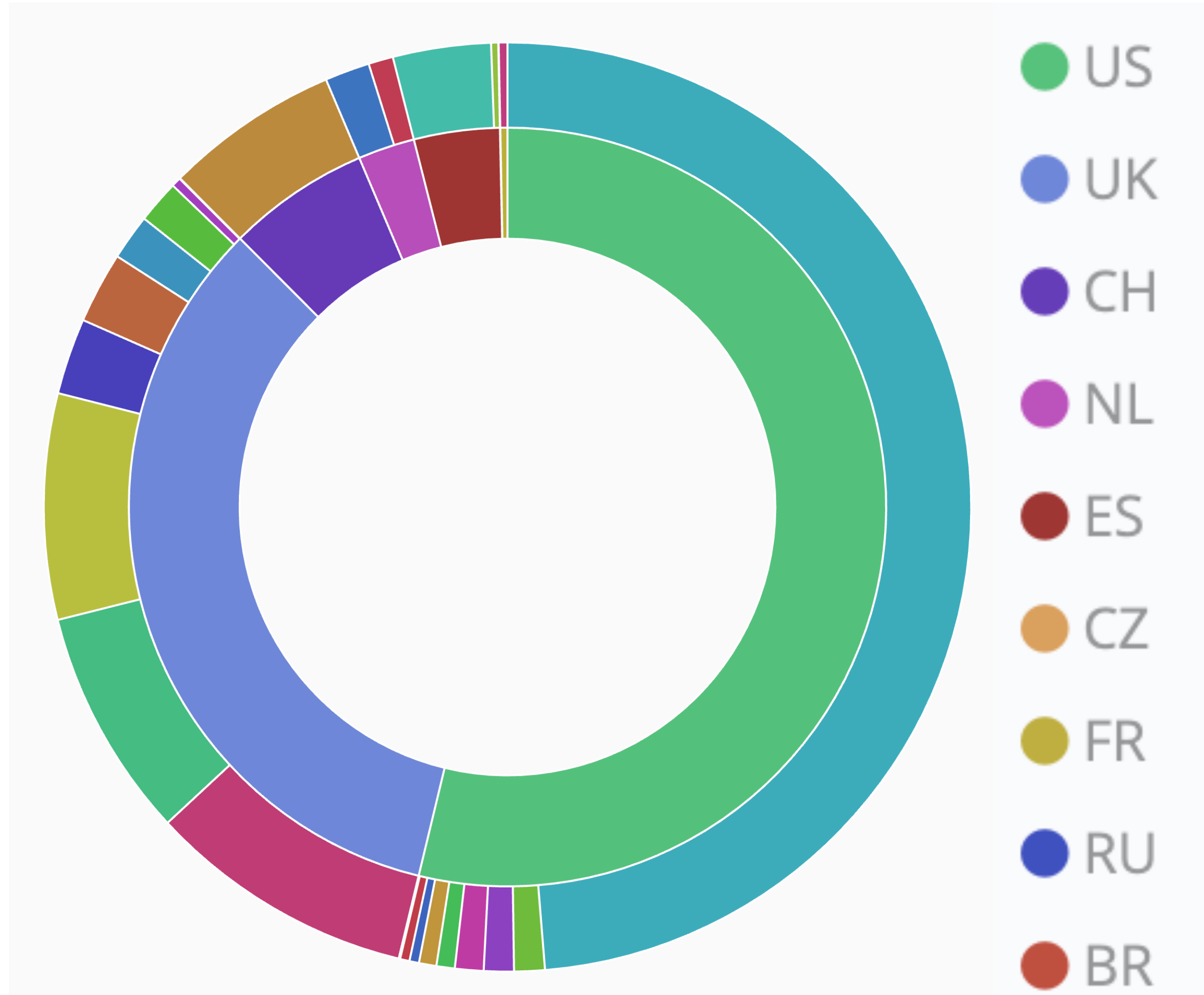
ProtoDUNE Production Processing

- DUNE Site working group doing excellent job incorporating new Compute Elements (CE) and Storage Elements (SE)
  - Continue to add resources from sites around the world - 36 sites
  - Addition of Storage Elements continues - 13
- Soon undertake ProtoDUNE Single Phase Production version 3 (PD-SPProd3)
- Data processing on distributed computing
  - (FNAL ~50% similar to previous usage)
- Utilizing NERSC SuperComputer Cori allocation for simulation generation (10000 simultaneous jobs running ~40% of total DUNE CPU hours)
- Anticipate using 80 - 100 M CPU hours/year in during ProtoDUNE II operations

CPU Hour fraction Feb 1 - May 20



Inner Circle is country

Thanks to Ken Herner for plots

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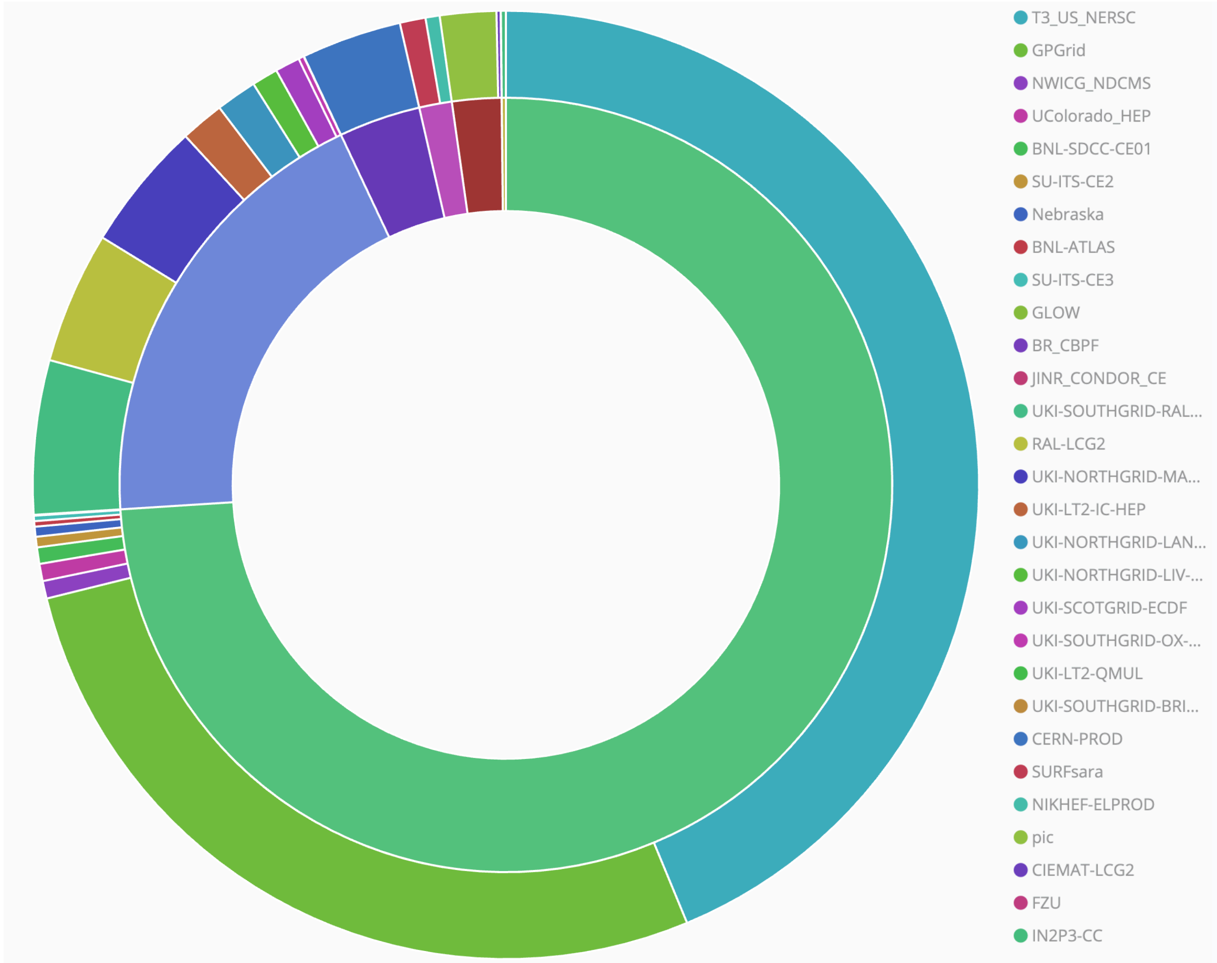

Adding in HPC @ NERSC Cori

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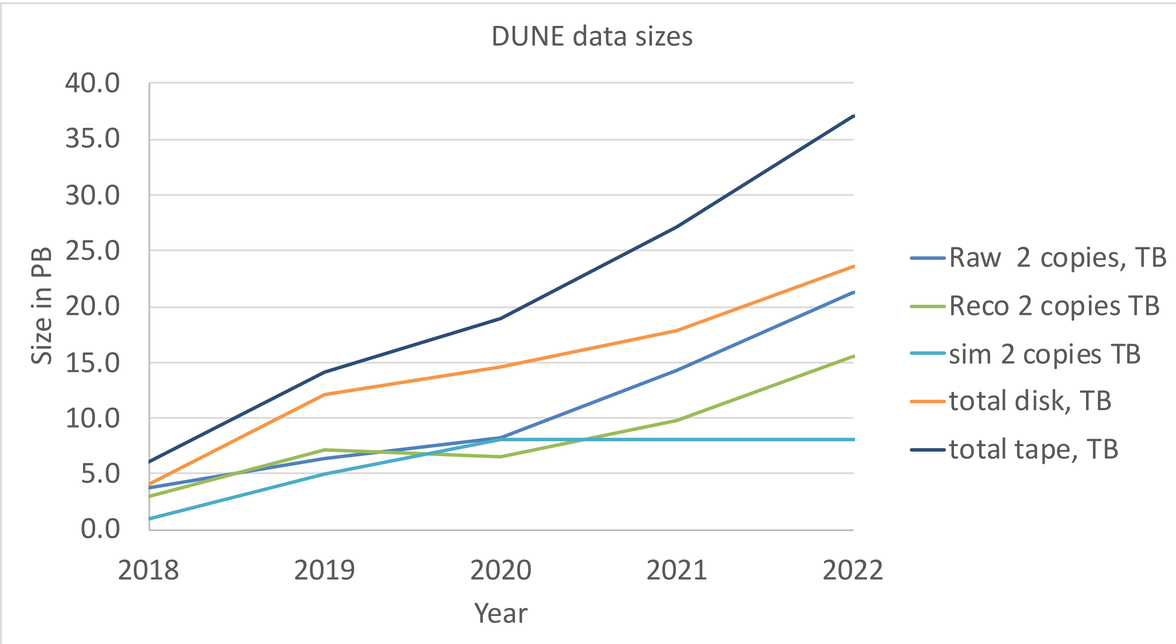
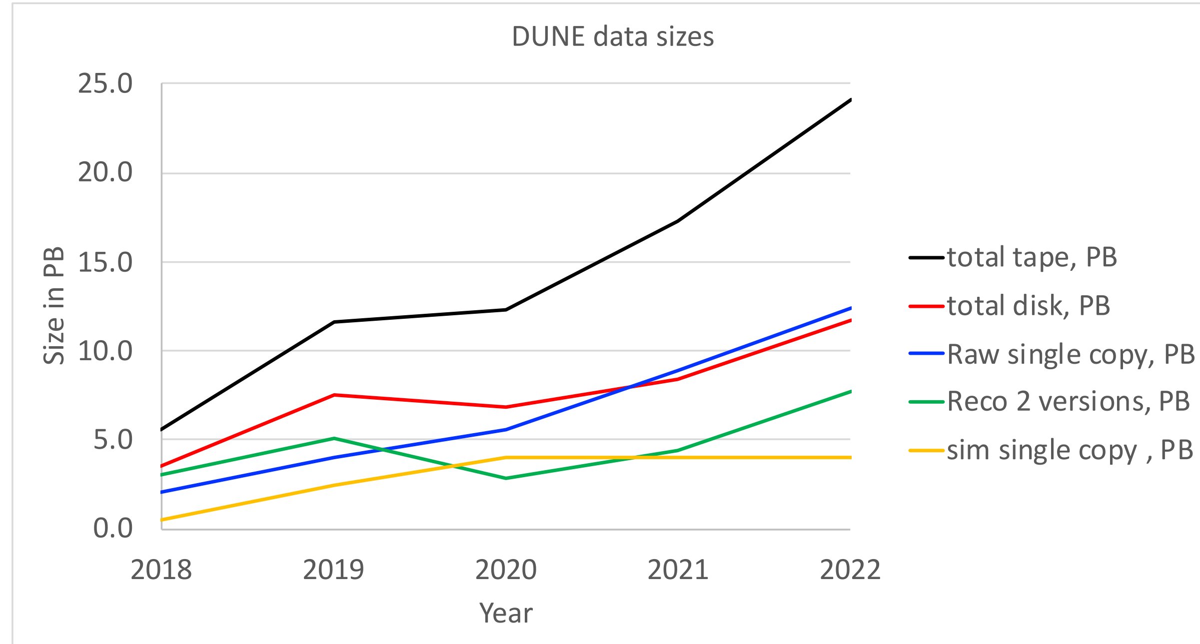
Tape and disk storage 2018-2022

Total DUNE Storage



FNAL DUNE Storage



- Computing Model for DUNE Storage
  - 2 archival copies of raw, derived, and simulated data - 1 copy at FNAL, second copy distributed institutions
  - production processing of SP and DP data and matching simulation twice per year
  - 2 or 3 copies of active derived and simulated datasets on disk - dataset stays active for 1 year

Computing Infrastructure Work

- Working to incorporate additional tools for tracking, accounting, and real-time monitoring status of the collective DUNE infrastructure
- Transition to a Global Pool for universal submission from around the world - HTCondor
- working with WLCG and OSG to evaluate, adapt, and incorporate pre-existing tools
- Computing Resource Information Catalogue - CRIC
- WLCG Experiment Test Framework - ETF
- Networking - LHCONE, perfSONAR (**perf**ormance **S**ervice-**O**riented **N**etwork monitoring **AR**chitecture)

Future Prospects

- Continue to expand the global nature of DUNE Computing - adopt new site structure, contribution agreements, and support
- Event Data Model poses potential challenge - 6 GB/evt -> analysis format
  - numerous Machine Learning techniques being developed based on close to raw data
  - need to capitalize on APA/wire plane/channel parallelism
  - promising new results in Inference as a Service (Cloud GPU) suggest excellent potential
- Continue to collaborate with OSG/HSF/WLCG to test, integrate, and develop features for infrastructure/middleware software
- Data Management and workflow management will be important focus of Computing Model in the near future
- Federated Storage and Federated Identity seen as important part of development going forward with increased international collaboration

backup

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- ProtoDUNE Single Phase beam Oct - Nov 2018
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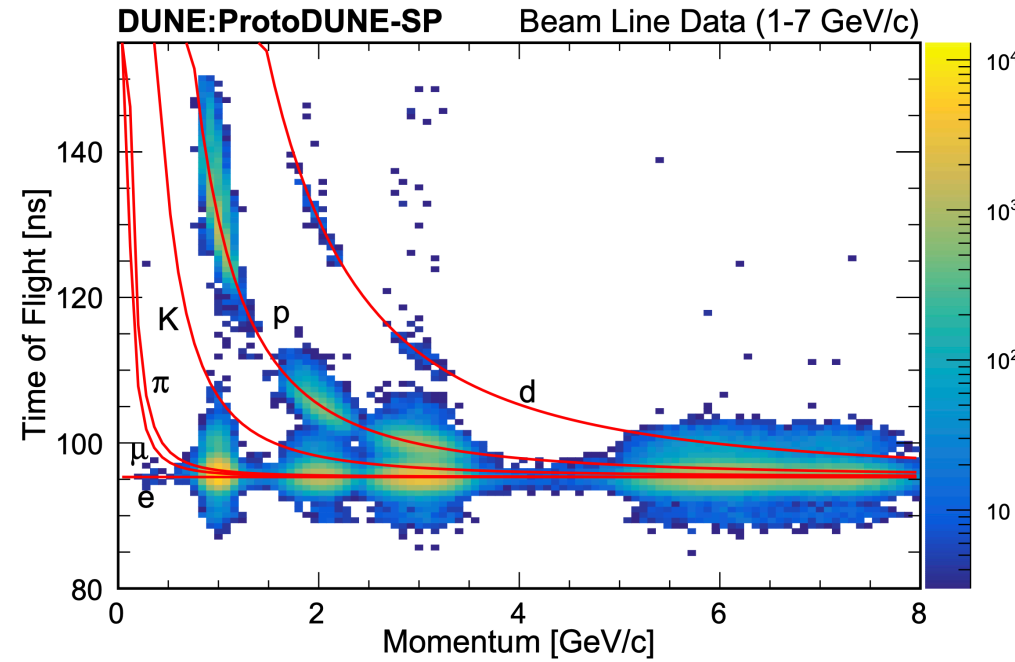
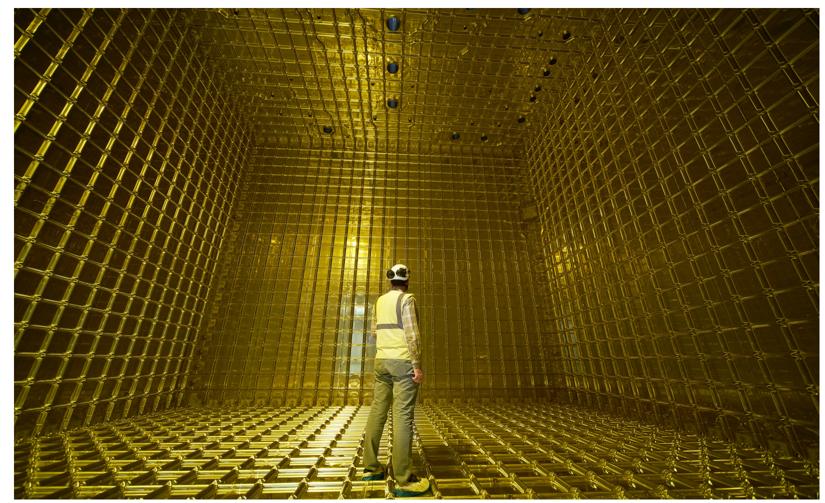




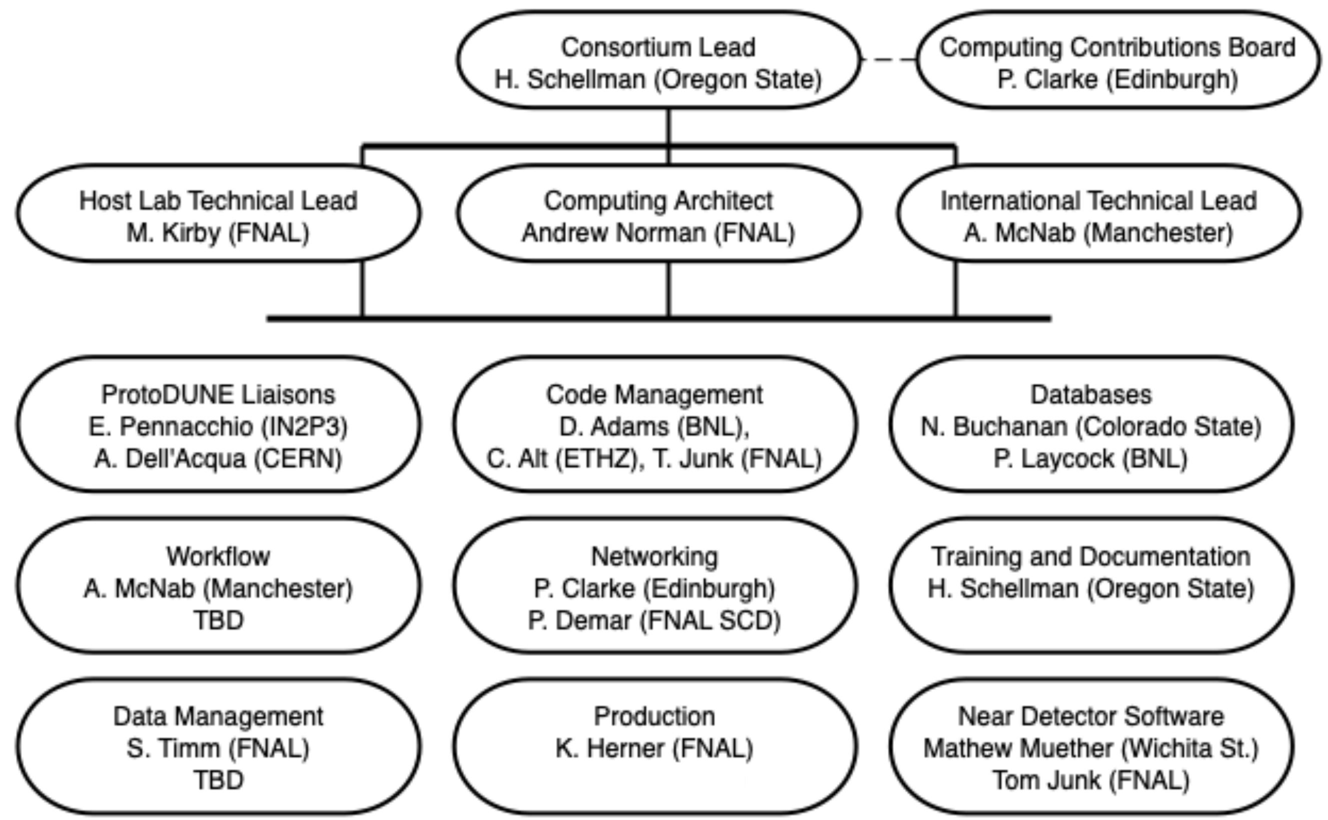
Computing Model Policies

- Tape Storage
  - two copies of all raw data for security
  - FNAL provides storage for an archival copy of all raw data for DUNE (ND, FD, protoDUNE)
  - Rucio Storage Elements (RSEs) around world provide storage for 2nd copy
  - FNAL provides storage of derived datasets with lifetime of 2 years
  - FNAL provides storage for single copy of simulated data
  - RSEs around the world provide storage for second copy of simulated data
- Disk Storage
  - two or three copies of every active derived dataset on disk at any time
  - two derived datasets will be active at any one time
  - latest two active derived dataset staged to disk at FNAL
  - two or three copies of every active simulated dataset on disk at any time
  - two simulated datasets will be active at any one time (matching active derived dataset)
- From these policies can development estimates for resource needs

DUNE Computing Outline

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT COMPUTING CONSORTIUM

- Computing Consortium Activity
- Grid Operations and Production Campaigns
  - ProtoDUNE-SP Reprocessing
  - ProtoDUNE-DP Processing
- Data Management
- Fermilab Computing Resource Scrutiny Group
- Computing Infrastructure Work
  - CRIC
  - ETF
  - Networking
- Future plans for Computing CDR and TDR
- Database progress and updates
- Analysis Framework Task Force update



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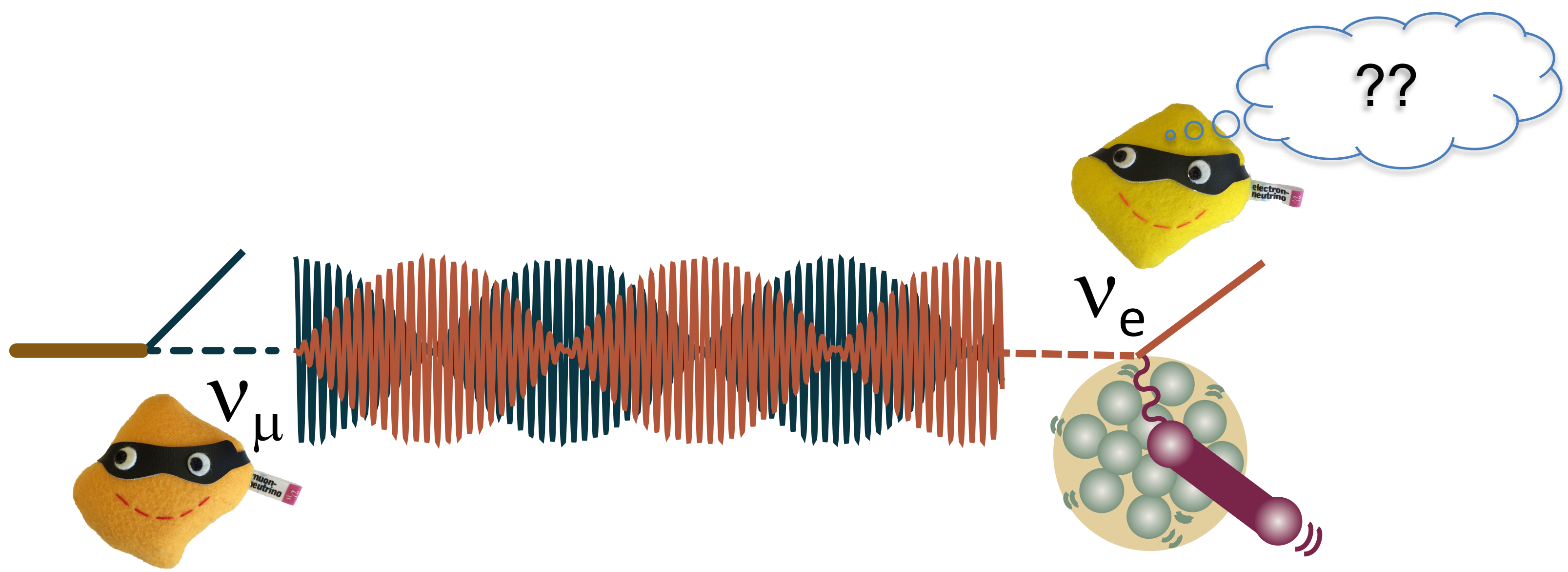
DUNE Experiment Physics Goals

The quantum wavelength of a 2 GeV muon neutrino is ~ 10^{-16} m
But it is actually a superposition of the 3 mass types of neutrinos which have slightly different wavelengths – the beat wavelength between the types is about 2000 km.

Bottom line – propagation can change a muon type neutrino 
into an electron type neutrino 



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Slide courtesy of Heidi Schellman