DUNE DAQ Plans

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On behalf of the DUNE DAQ Consortium

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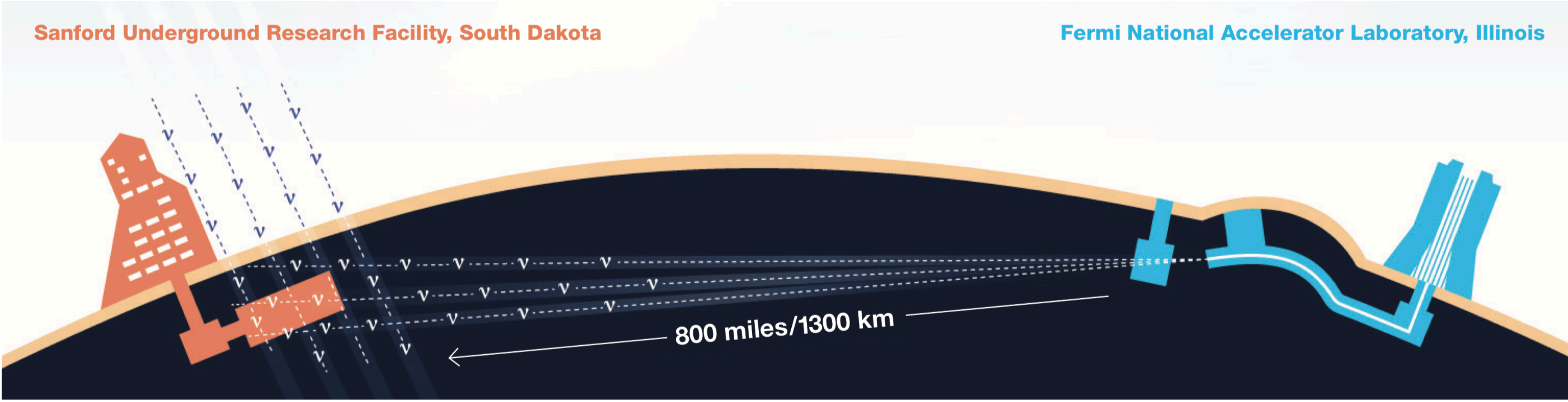
Fermi National Accelerator Laboratory

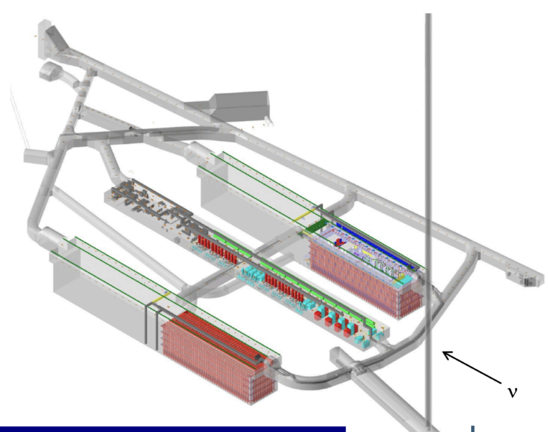
The Deep Underground Neutrino Experiment



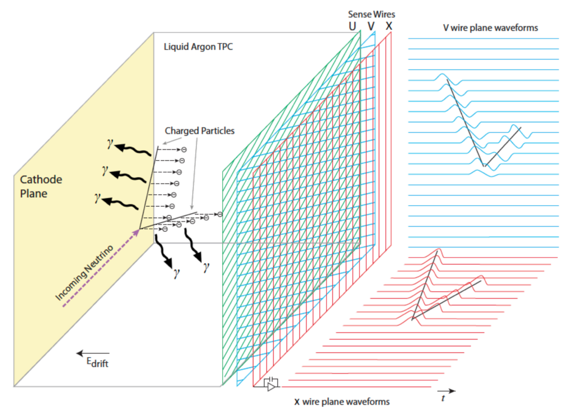
- The DUNE experiment: 1000+ collaborators; 170+ institutions; 30+ countries.
- Physics goals:
  - Search for leptonic CP violation;
  - Search for nucleon decay;
  - Observation of supernova neutrino bursts.
- World's most intense neutrino beam
  - Beam of ν_μ(or $\bar{\nu}_\mu$) produced by 1.0-1.2 MW of proton beam in 60-120GeV from PIP-II at the start of DUNE operations; planned upgrade of 2.4 MW by 2030.
  - Baseline is 1300 km from Fermilab to SURF.

DUNE Far Detector

- Four 10-kt (fiducial) liquid argon time projection chamber (LArTPC) modules;
- Provides excellent 3D imaging and energy measurement capability;
- Integrated photon readout, provides t_0 of each event, crucial for spatial reconstruction.

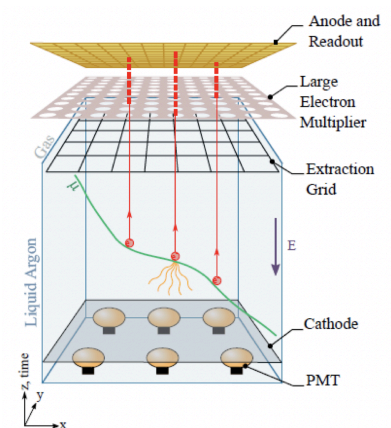


1300 km from Fermilab
~1.5 km underground
Four 10kt LArTPC modules
17.5 kt total mass



Single-Phase

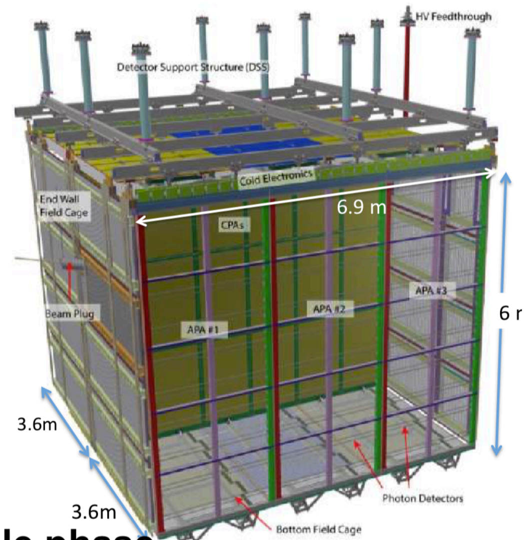
- charges drift horizontally;
- 500 V/cm drift field;
- 3.5m drift length, 180 kV cathode
- 150 Anode Plane Assemblies (APAs)
- 2.3 X 6.0 m2
- 384,000 readout wires



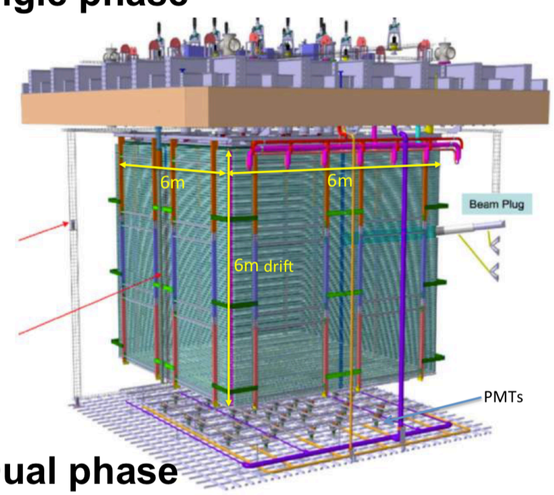
Dual-Phase

- 12.0m drift length, 600 kV cathode
- Charges drift vertically, amplified in gas phase by large electron multipliers (LEMs);
- 80 Charge Readout Planes (CRPs)
- 3.0 X 3.0 m2

ProtoDUNE @ CERN



Single phase



Dual phase

- Single-Phase
  - 6.9 m X 7.2 m X 6 m
  - Used in ICARUS, ArgoNEUT/LArIAT, MicroBooNE
- Dual-Phase
  - 6 m X 6 m X 6 m
  - Being pioneered by the WA105 collaboration
  - If demonstrated, potential advantages over single-phase approach

DAQ

DUNE Requirements

- (some) Requirements
  - Time resolution < 1μs, goal is <100 ns;
  - 1.5 TB/s DAQ readout throughput of TPC and photon detector per single phase module;
  - 10 Gb/s average storage throughput per single phase detector; 100 Gb/s peak;
  - Readout window: 10 μs (calibration) to 100 s (SNB), typically 5.4 ms for triggered interactions;
  - Ability to record 30-100s worth of raw data for a Supernova trigger;
  - High trigger efficiency (99% for particles > 100 MeV; 95% in the first 10s of SNBs)
  - Goals is to get zero dead time (small deadtime would not compromise physics sensitivity);

Supernova

- Despite being extremely rare, the Supernova data are the dominant constraint on the DAQ;
- Signature: lots of low energy deposits in the detector;
- Full Raw Data must be stored for preferably 100 s
- Each SN ~0.5 PB (normal event ~6 GB)
  - 12 triggers expected per year
- Supernova trigger causes data to be sent from NVMe SSD storage and streamed out “slowly” to the data storage.

DUNE SP-LArTPC events at SURF

- Ionized charges drift slowly in LAr, ~2.5 ms for single-phase, ~7.5 ms for dual-phase;
- Leads to:
  - Lower event rate ~100 Hz.
  - With 2MHz digitalization → large event size ~6.22 GB per event (single-phase);

		L0/L1 accept rate
ATLAS/CMS	1-2 MB	100 kHz
LHCb	~50 kB	1 MHz
ProtoDUNE-SP	~250 MB	25 - 100Hz
DUNE	~6.22 GB	~100Hz

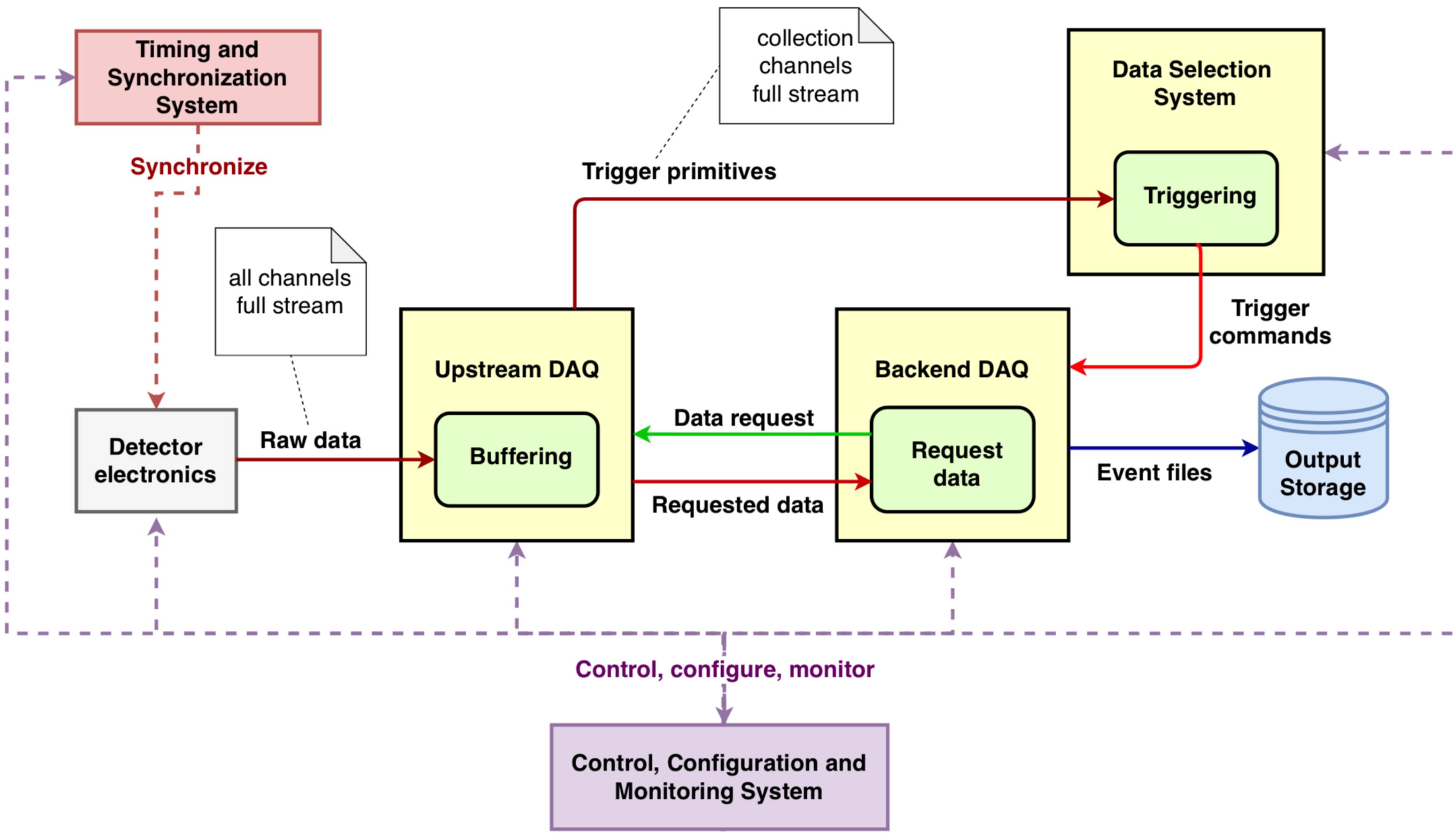
- Big challenges on dataflow management, storage etc.

DAQ Overview

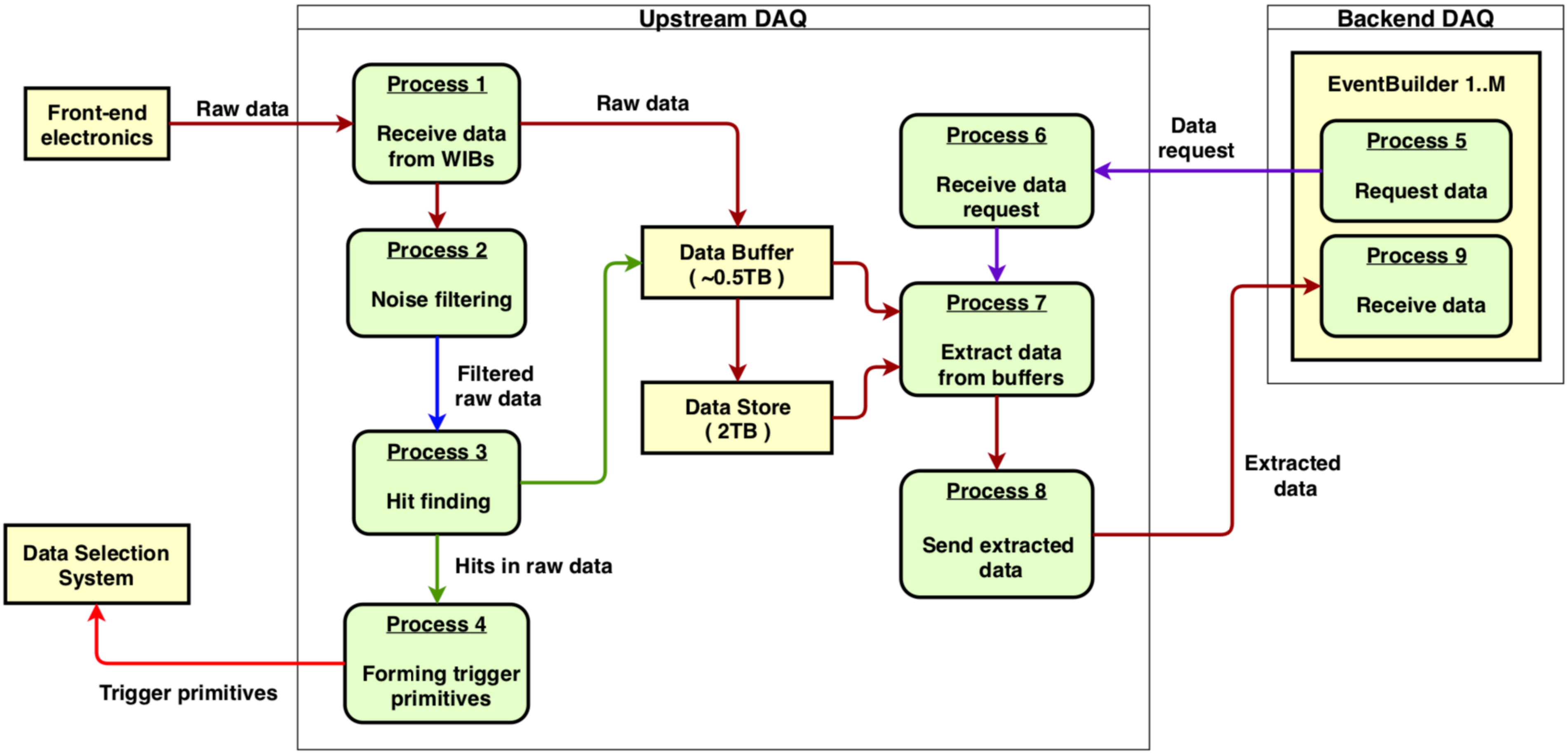
1. **Upstream DAQ** – Front-end readout and software based low-level trigger primitives;
2. Data Selection – Higher level trigger processing;
3. **Back-end** – dataflow management;
4. **Timing and synchronization;**
5. Control, configuration and monitoring.

- System with capability of being partitioned:
  - Operate in independent DAQ instances;
  - Each executed across all DAQ subsystems;
  - Each uniquely mapped among subsystem components.

DAQ Overview

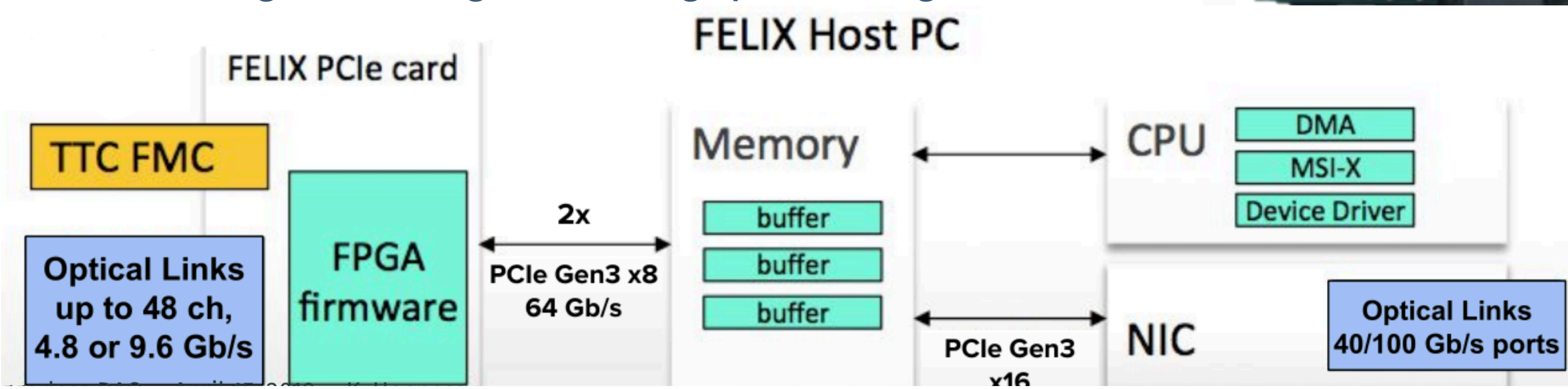


Upstream DAQ (I)



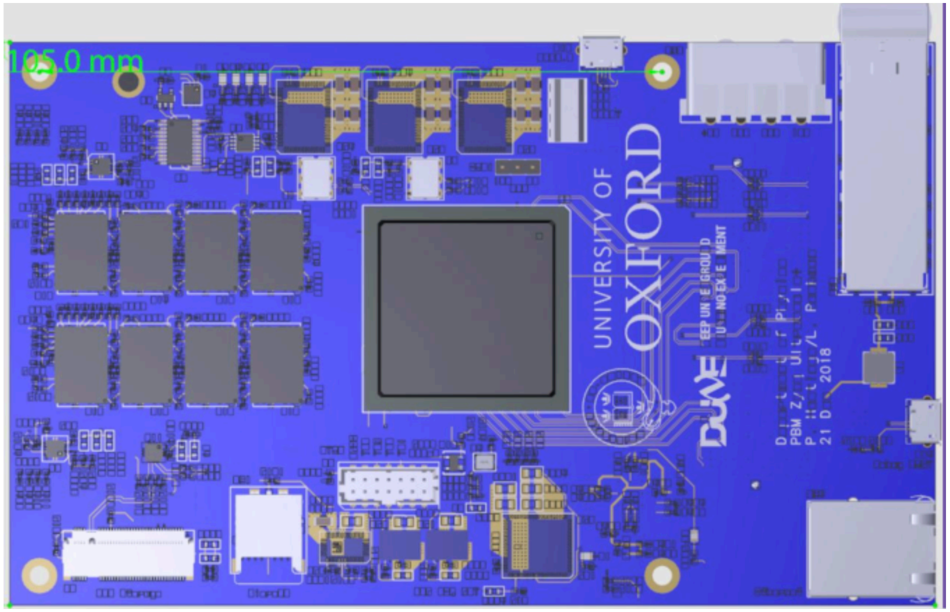
Upstream DAQ (III)

- FELIX @ ProtoDUNE-SP
  - PCIe card on host computer;
  - P-to-p link throughput;
  - 10 links to host memory over 1 FELIX card;
  - HW aided data compression using Intel's QAT;
  - Full I/O over InfiniBand for ProtoDUNE;
  - Need much less network I/O for DUNE;
  - Need longer and higher throughput storage for DUNE.



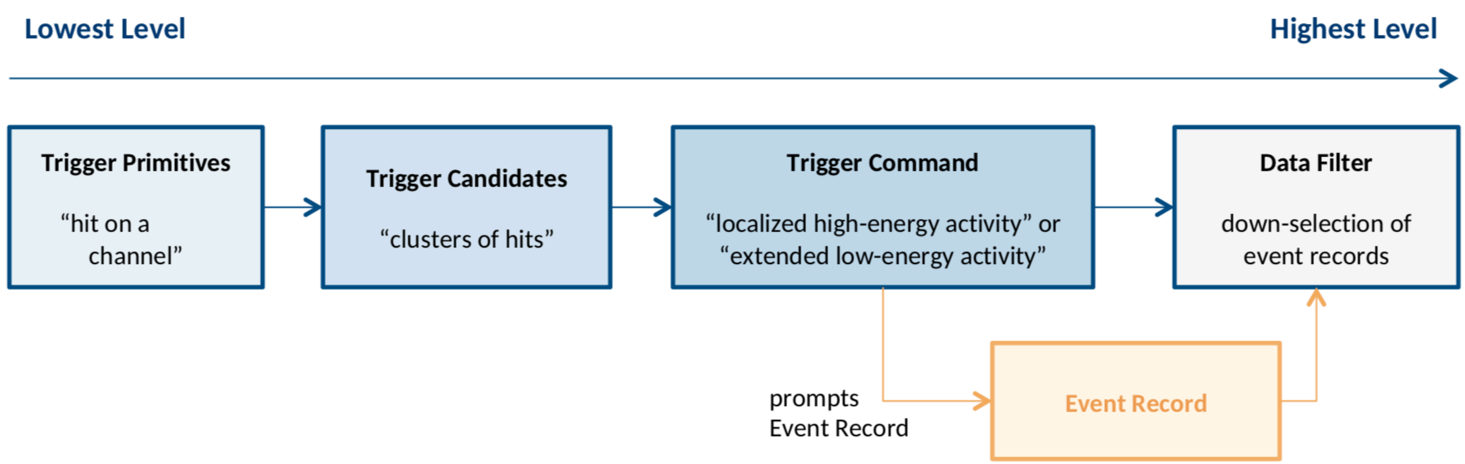
Upstream DAQ (III)

- Co-processor
  - Companion processor board for FELIX;
  - 24 FMC+ links to FELIX;
  - Quad-core ARM Cortex™-A53 MOCore™ up to 1.5GHz
  - 16GB DDR4 memory;
  - 512GB M.2 NVMe on board storage;
  - Acts as processing and buffering module.



Xilinx Zynq: XCZU15EG

Data Selection

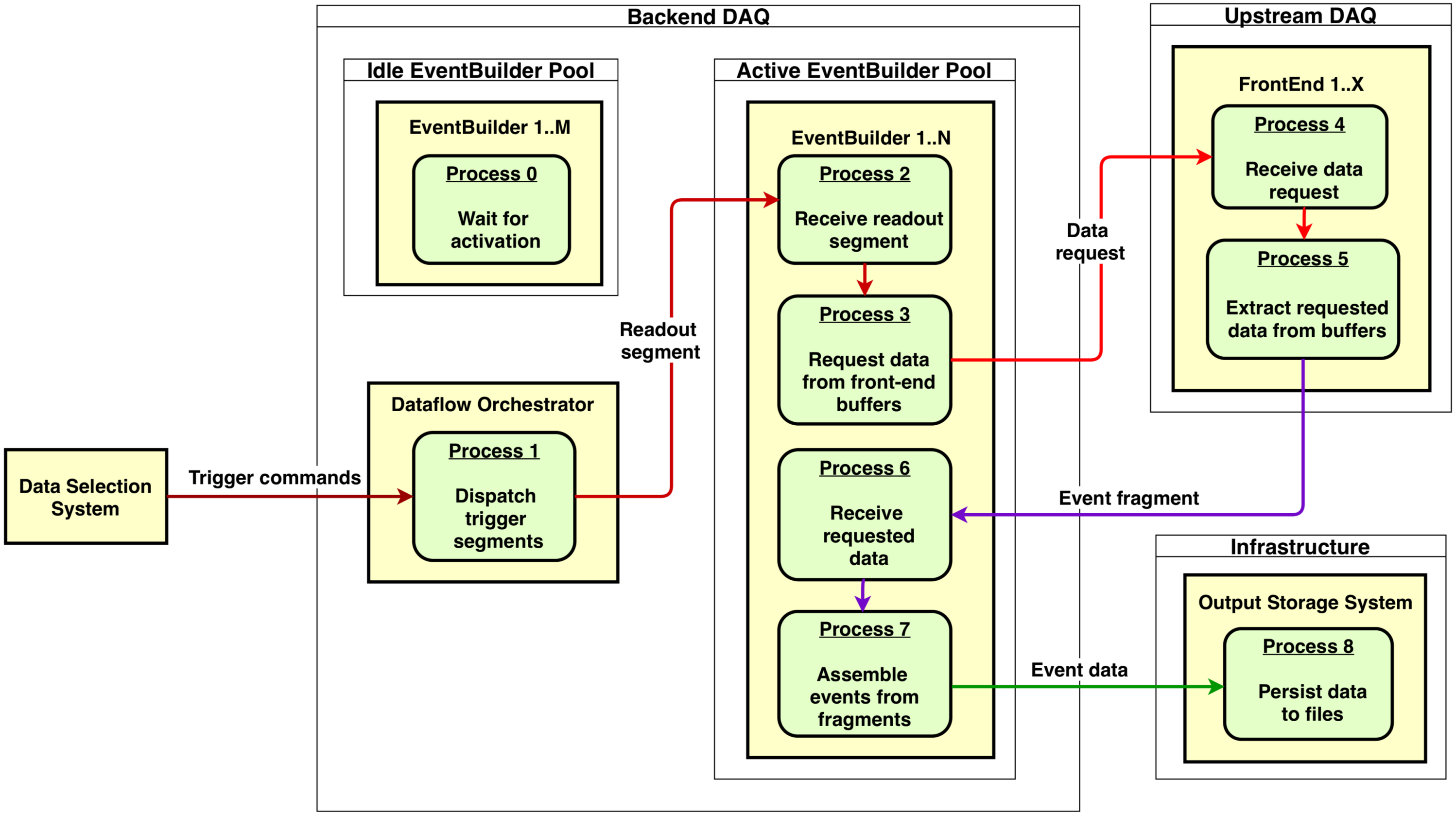


- Hierarchical, online, software-based system;
- Trigger primitives – on a per channel basis;
- Trigger candidate – on a per APA basis;
- Trigger command – on a per module basis.

Back-End DAQ (I)

- Back-end DAQ is all about moving data across the network…
- Based on Fermilab's artdaq framework;
- artdaq has been used by many experiments:
  - NOvA Test Beam, Mu2e (tracker, calorimeter, CRV), many LArTPC experiments (SBND, ICARUS etc).
- artdaq features:
  - Provide a common framework for back-end DAQ;
  - Highly configurable, can deal with wide range of event rate and size;
  - Experiments put most efforts on implementing hardware specific code in the form of BoradReader;
  - artdaq provides subsequent data transfer, event building, file I/O etc;
  - also provides system configuration, process management, monitoring etc.

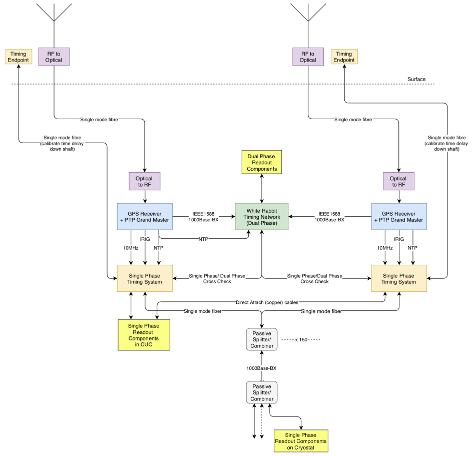
Back-end DAQ (II)



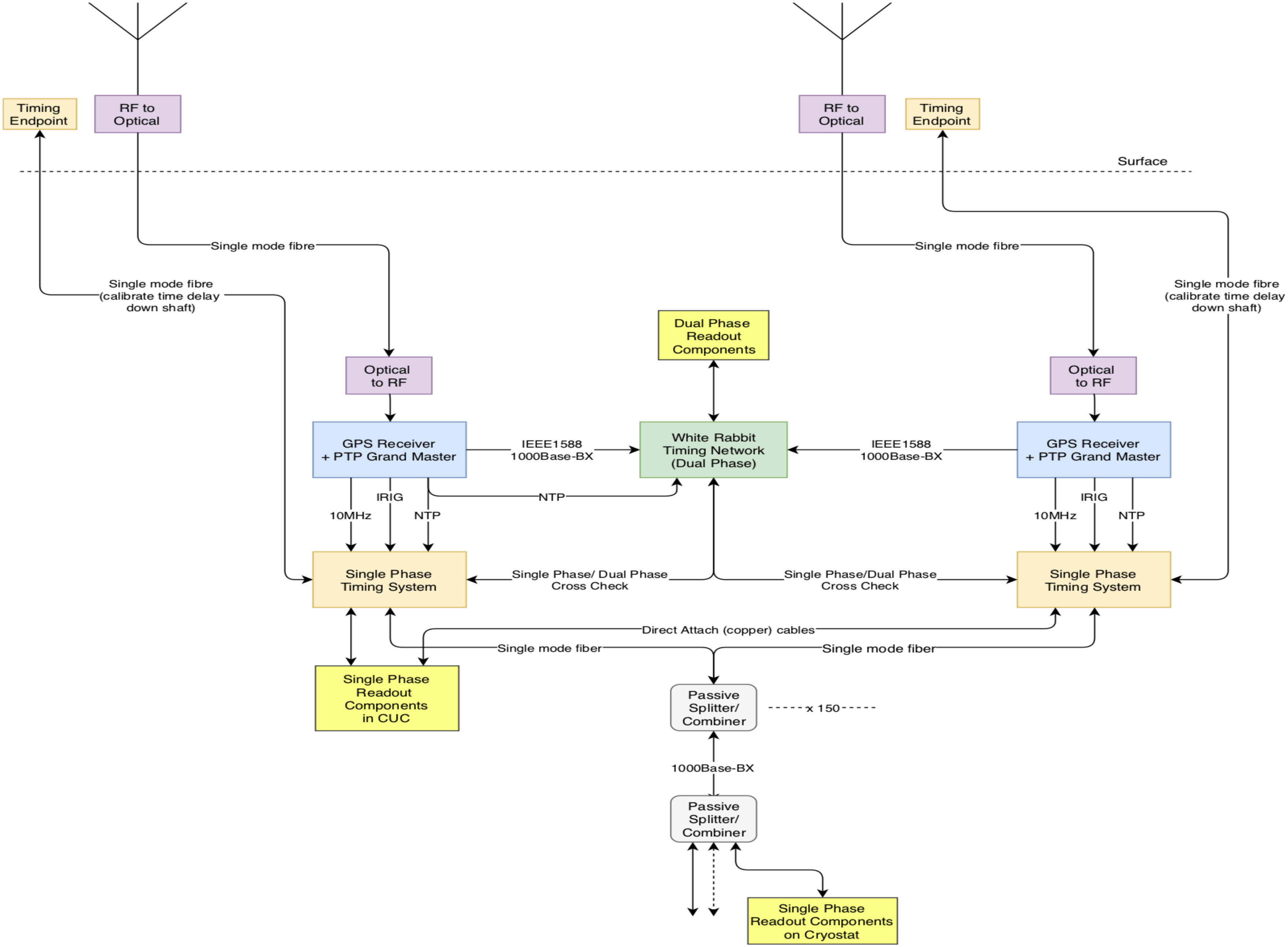
- Plan to have process awareness to tolerate dead event builders

Timing System (I)

- Dual Phase: White Rabbit implementation of the IEEE1588-2008 timing distribution standard.
- Single Phase: improved version of a custom protocol/solution developed for ProtoDUNE-SP;



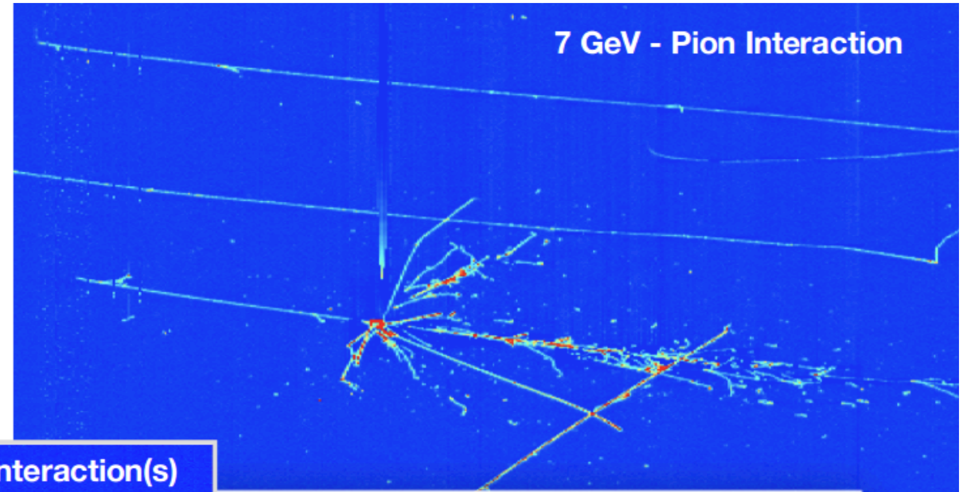
- Plan for DUNE Far Detectors:
  - Redundant antennae in both mine shafts;
  - Two GPS receivers;
  - Can hot-swap between the two;
  - Signals provided to Front-end electronics and calibration systems;
  - In each module, components synchronized to a common 62.5MHz clock (1ns precision);
  - Also acts at the clock source for the computing.

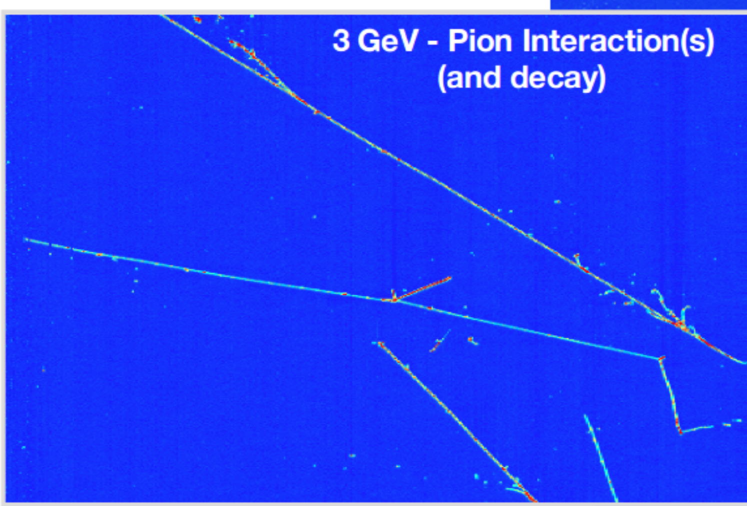


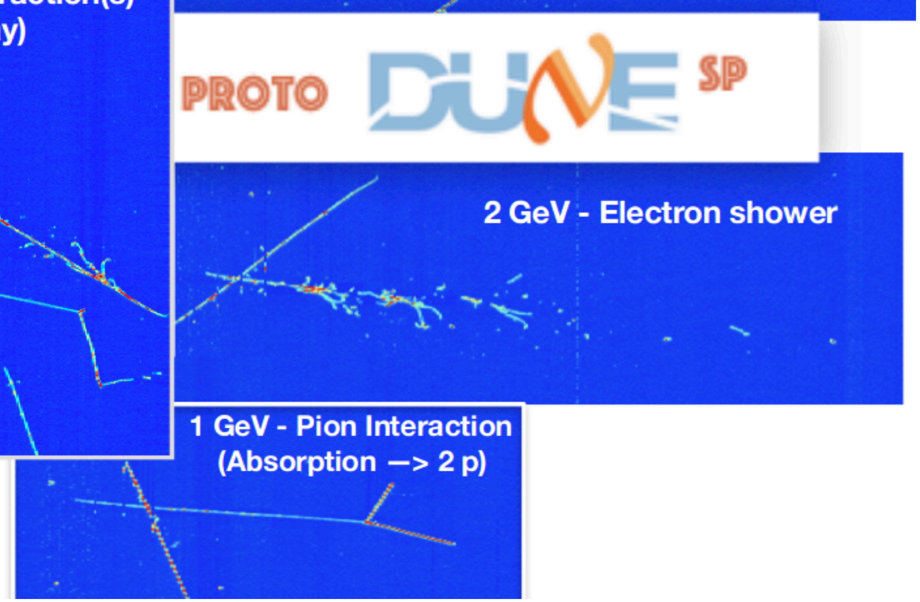
Timing Endpoint
RF to Optical
RF to Optical
Timing Endpoint
Surface
Single mode fibre
Single mode fibre (calibrate time delay down shaft)
Single mode fibre
Single mode fibre (calibrate time delay down shaft)
Dual Phase Readout Components
Optical to RF
Optical to RF
GPS Receiver + PTP Grand Master
IEEE1588 1000Base-BX
White Rabbit Timing Network (Dual Phase)
IEEE1588 1000Base-BX
GPS Receiver + PTP Grand Master
IRIG
10MHz
NTP
NTP
IRIG
10MHz
NTP
Single Phase Timing System
Single Phase/ Dual Phase Cross Check
Single Phase/Dual Phase Cross Check
Single Phase Timing System
Direct Attach (copper) cables
Single mode fiber
Single mode fiber
Single Phase Readout Components in CUC
Passive Splitter/ Combiner
x 150
1000Base-BX
Passive Splitter/ Combiner
Single Phase Readout Components on Cryostat

Testing @ protoDUNE

- Data taking with beam from Sep. 21st, 2018;
- Saw events in data from charged beams of $\mu\ \pi\ \mathrm{K}\ p\ e$.



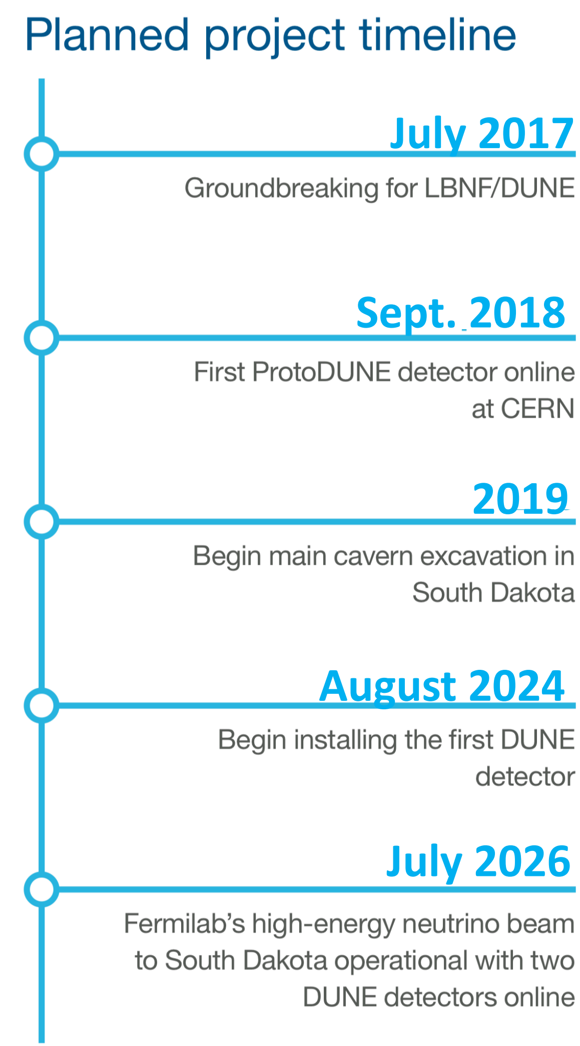




Timeline

- Start of 1st FD detector module installation in August 2024;
- Start of 2nd FD detector module installation in August 2025;
- 1st FD detector module in operations in July 2026.

- ProtoDUNE-SP-II installation in March 2021;
- ProtoDUNE-DP-II installation in March 2022.



Thanks for listening!