DUNE Near Detector LArTPC

Dan Dwyer

5 March 2020

Near Detector Requirements

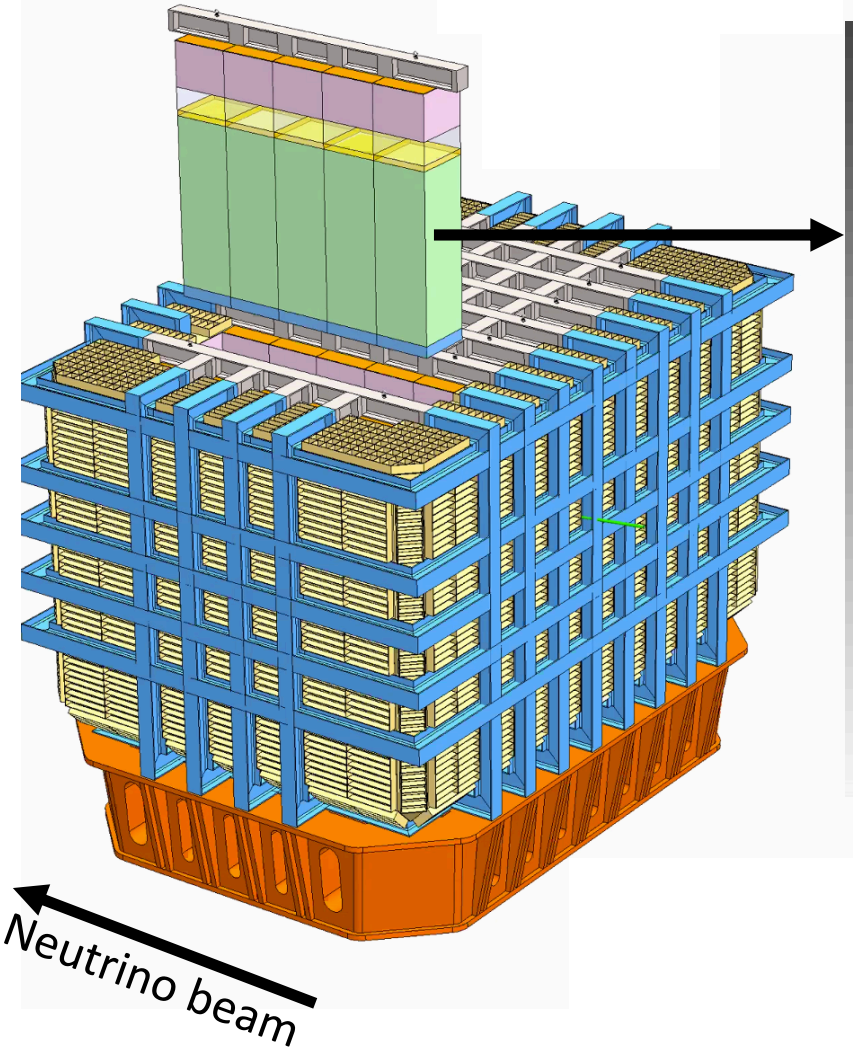
Note: My abridged version.
Requirements under development
by DUNE Near Detector Design Group

Enable precise prediction of DUNE Far Detector neutrino signal. *Precise → ~2% rate, ~4% shape*

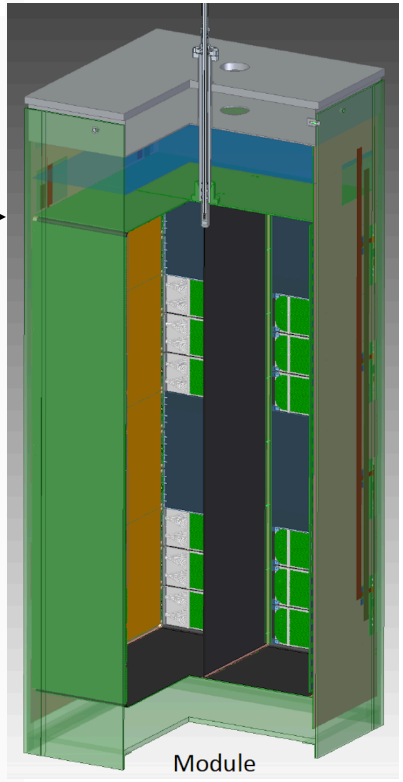
- Measure LBNF flux × cross section (on argon) at Near Site → Active **argon-based detector(s)** at near site
- Precisely characterize FD neutrino interaction, detector response model → *same,better fidelity as FD* → **LArTPC component** of Near Detector System
  - With sufficient signal rate for relevant neutrino interactions → *e.g. e- scat.* → **O(100 ton) active volume** in LArTPC
  - Sufficient acceptance/containment of relevant neutrino interactions → *except for forward-going muons.* → Active LArTPC **3m height, 7m width, 5m depth**, with **downstream muon spectrometer**
  - Cope with signal pileup at Near Site → LArTPC with **pixelated readout**, **optical modularity**
  - Disentangle energy-dependence of cross section and detector response → **Off-axis measurements** with LArTPC
  - Verify beam stability when LArTPC off-axis → Supp. **stationary beam monitor** detector: SAND
  - Precisely constrain LArTPC deficiencies → *Channel accuracy, charge, E vs. p* → Supp. **magnetized low-density Ar detector**: MPD

Near Detector LArTPC Design

ND LArTPC



TPC Module



Key Design Features:

Active size:

5m deep, 7m wide, 3m tall

→ For ν signal containment

Signal rate: ~10 M / yr

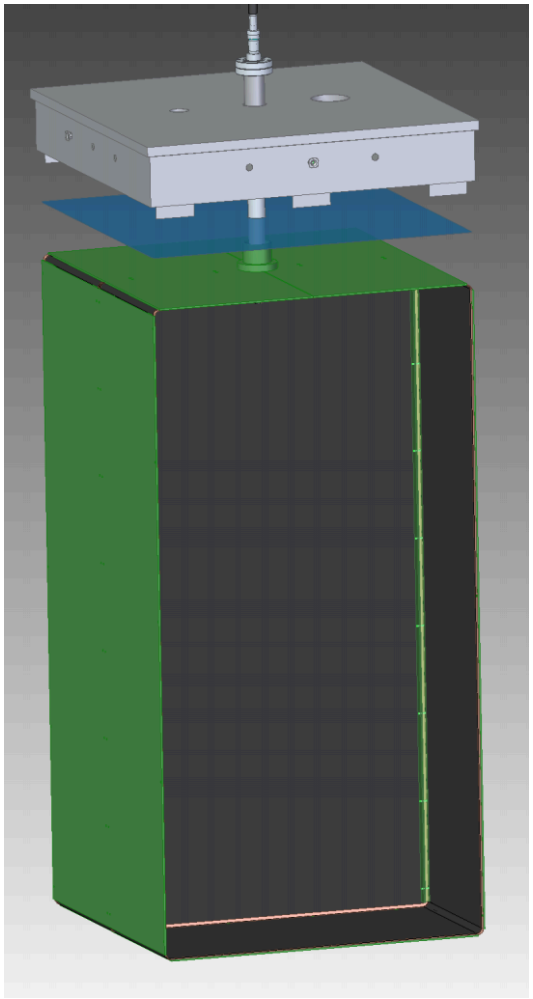
Modular design:

- 5 x 7 hermetic TPC modules
- 3m active height
- Minimal inactive material
- Material density (G10) similar to LAr
- Short drift (50 cm)
- Pixelated charge readout
- Optical segmentation
- High-performance light detection

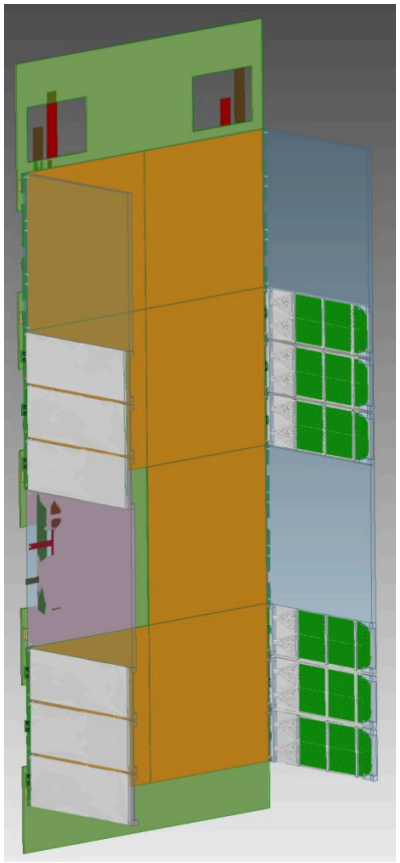
→ *System reliability and capability to operate in high-rate environment*

TPC Module Design

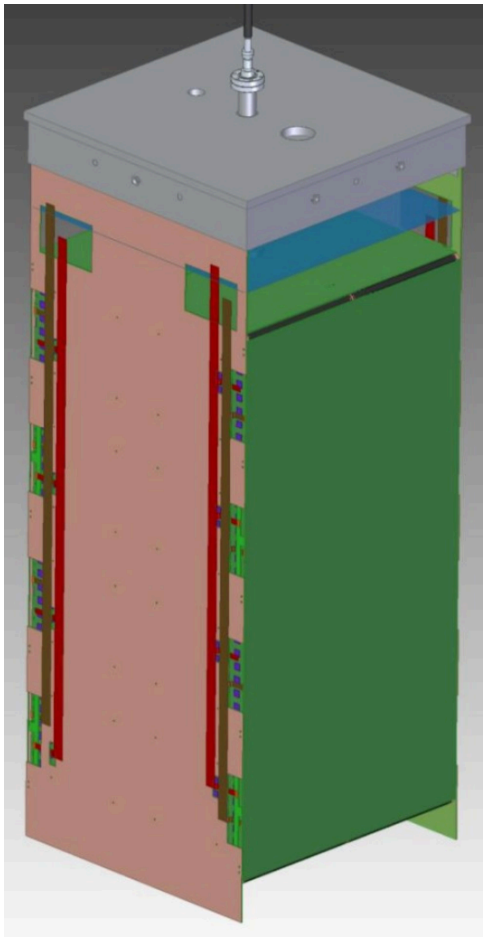
Cathode and Field Cage



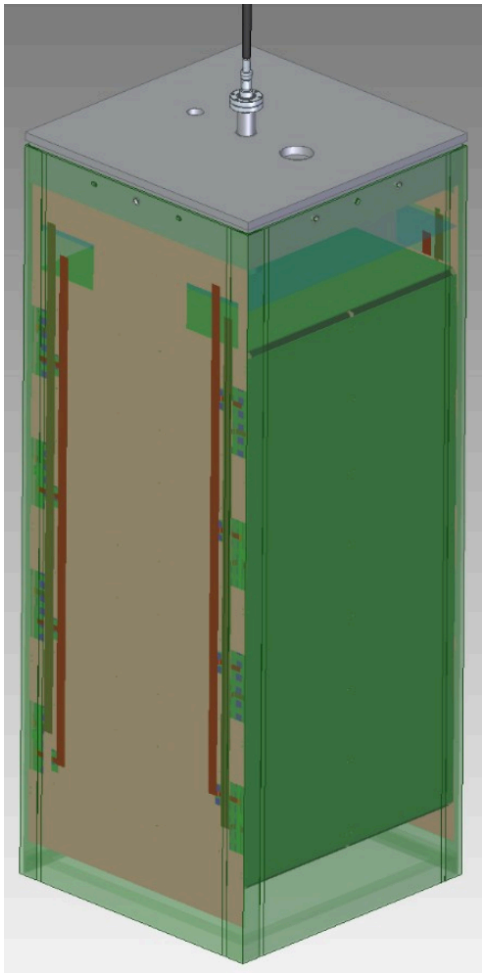
Charge & Light Readout Anode



TPC Assembled (Cath, FC, + 2 Anodes)



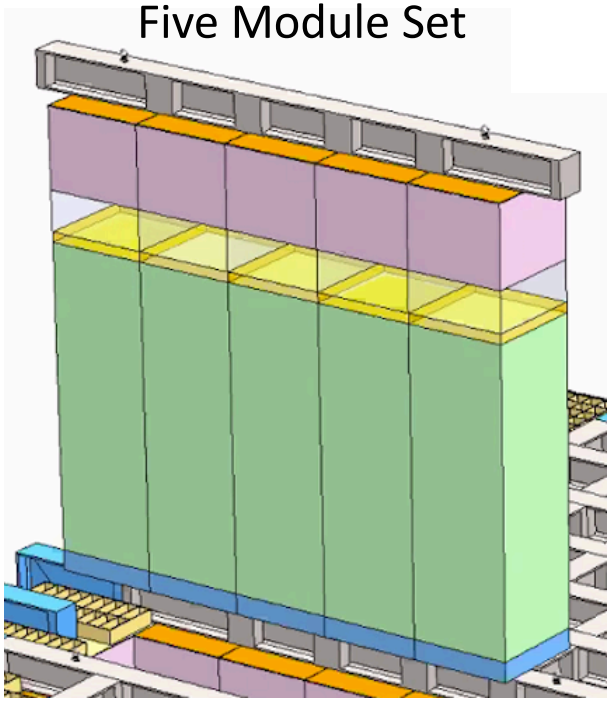
Hermetic Module



Figures show prototype (ArgonCube 2x2 Demonstrator) module. Full ND module has same design, but larger.

Module Structure

Five Module Set



Prototype Module

Key Design Features:

Module structure isolates each TPC
- → *Independent LAr purification cycle, isolated from bath*
- → *Independent HV, to reduce systemwide HV risks*
- → *'Swappable' to simplify repair, upgrades*

Stainless steel top flange
- → *Provides interfaces for cryogenics, HV, instrumentation, detector readout*

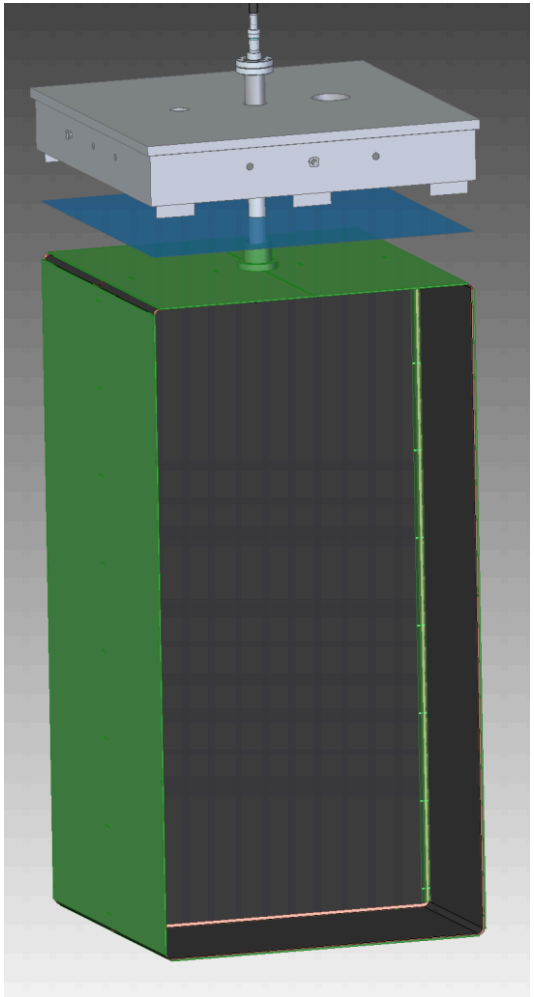
Insulated pillow
- → *Minimize heat leak through cryostat lid*

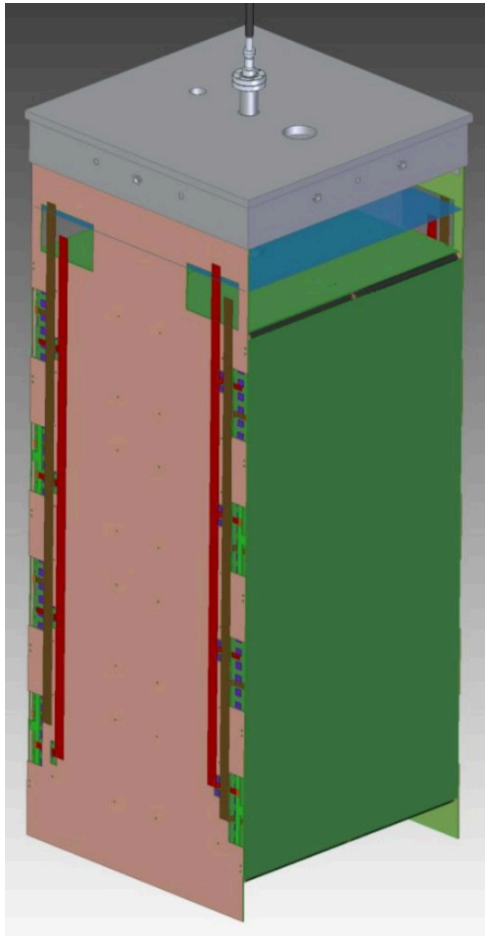
Fiberglass (G10) 'bucket'
- → *Robust seal to pillow in 'warm' region*
- → *Low-profile: maximizes active volume*
- → *Similar density to LAr; reduce signal distortion*

Module instrumentation and fittings
- → *Monitor module LAr level, temp, pressure*
- → *Manage LAr flow through module*

Institutions: Univ. Of Bern

Field Structures



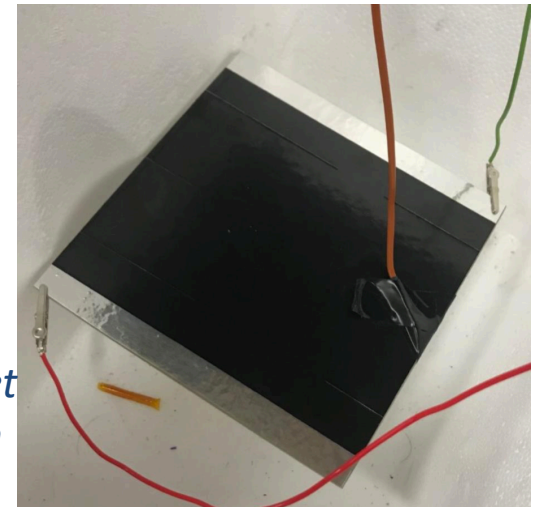


Key Design Features:

Central cathode, dual anode with 50cm drift regions
→ *Short drift reduces required HV and assoc. risks*

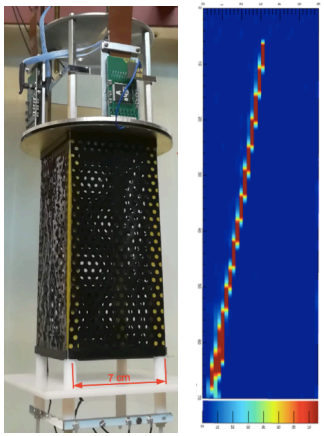
Resistive polyamide sheet laminated on G10 panels
→ *Reduces risks from accidental HV discharge*
→ *No resistor chain; reduce single-point failure risk*
→ *Low-profile: maximizes active volume*

All G10 construction
→ *Similar density to LAr; reduce signal distortion*
→ *Compatible thermal contraction at LAr temp*



Cryogenic test of resistive sheet (GOhm / square) laminated on G10 panel @ SLAC

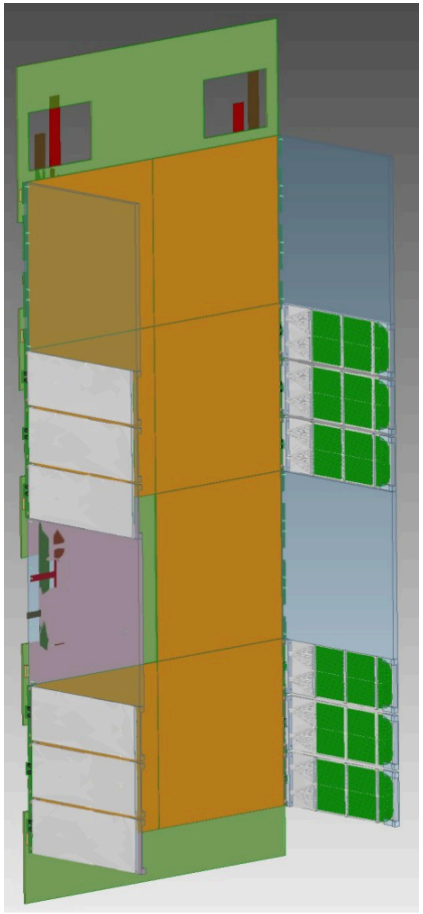
Resistive sheet LArTPC @ BERN



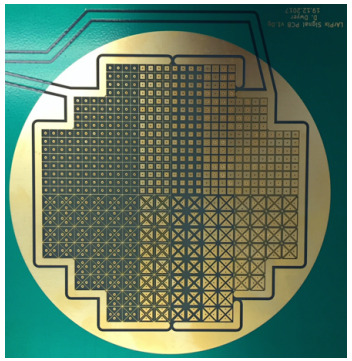
Institutions:
Bern, SLAC

Pixelated Charge Readout

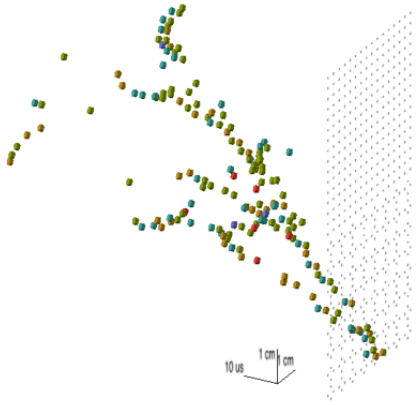
Pixelated Anode for ArgonCube 2x2 Demonstrator



Prototype pixel tile, O(1k) channel



Small shower imaged using LArPix-v1 system



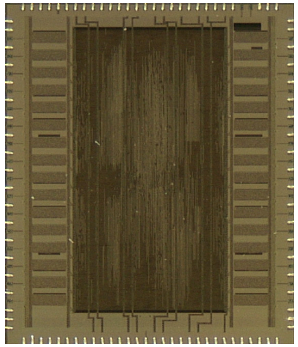
Key Design Features:

Pixelated charge readout tiles, ~4mm pitch
- → *True 3D imaging; no projective ambiguities*
- → *Overcomes signal pileup at DUNE Near Site*
- → *Mechanically robust, less sensitive to noise pickup*
- → *Scalable design leverages commercial production*

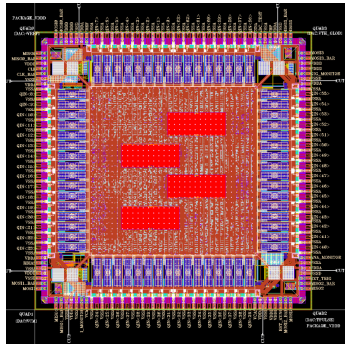
LArPix: Custom pixel readout ASIC
- → *Provides low-noise, low-power, cryogenic readout*
- → *SOC: amplification, digitization, triggering, readout*
- → *Implements highly-scalable control, I/O architecture*

LArPix Controller System
- → *Leverages commercial Zynq (CPU+FPGA) system with simple custom interface PCB to control large-scale pixel system (~1 controller per 50k pixel channels)*

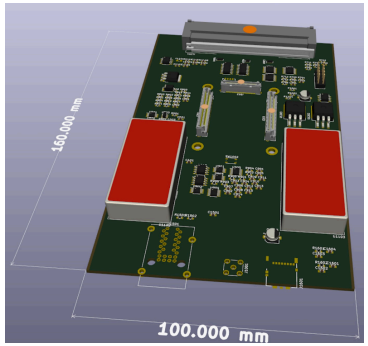
LArPix-v1 ASIC



LArPix-v2 ASIC



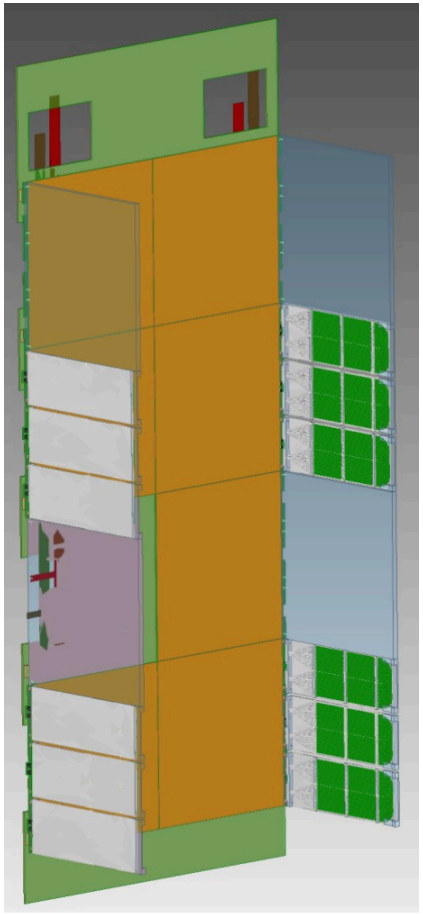
LArPix-v2 Controller



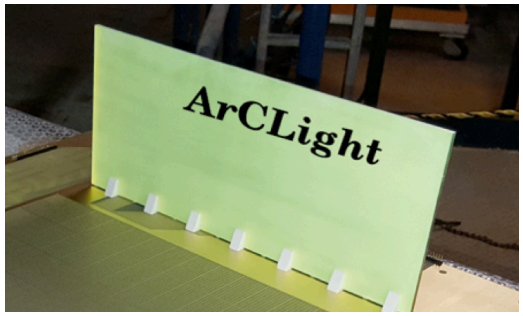
Institutions: LBNL, Caltech, CSU, Rutgers, UC-Davis, UCSB, UPenn, UTA

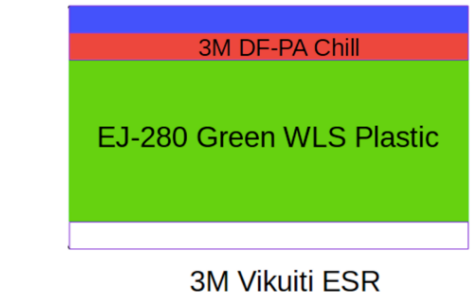
Advanced Light Readout

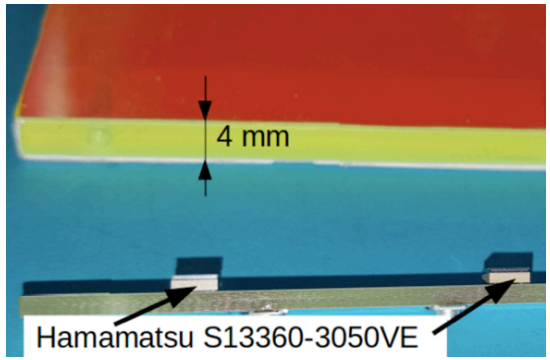
Pixelated Anode for ArgonCube 2x2 Demonstrator



ArcLight: Dichroic light-trap design







Key Design Features:

Fully-dielectric SiPM-based light collectors, two designs

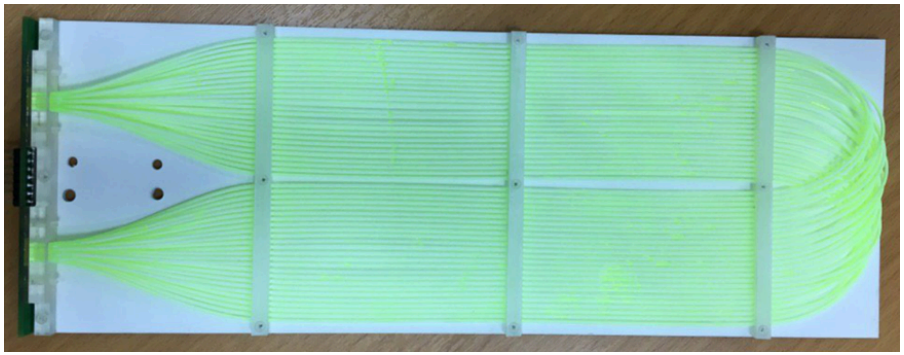
→ *Dielectric: tolerant of high field gradients*

→ *High-coverage: covers ~75% of field cage*

→ *Enables localization of light signals, correlation to charge*

→ *Combined with optical modularity, improves discrimination of pileup at DUNE Near Site*

LCM: Fiber-bundle based light collection module



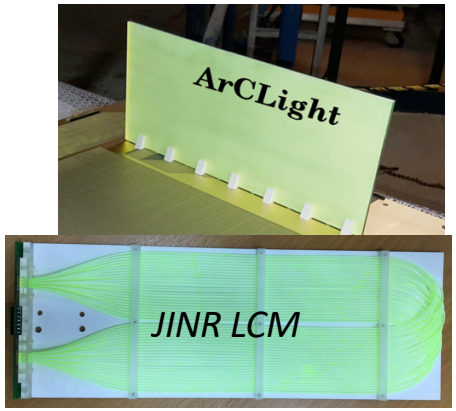
Institutions:

Bern, JINR

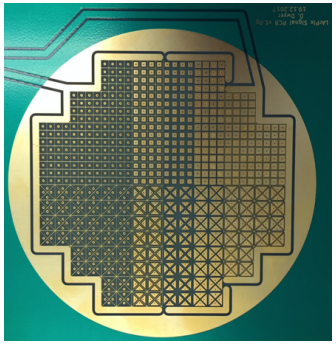
ArgonCube Collaboration: LArTPC Technology R&D

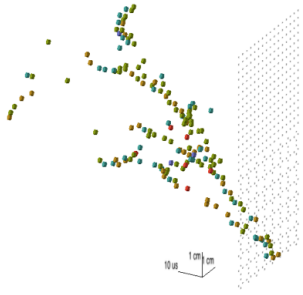
Technology Prototypes (2016-2018)

Enhanced Light Readout

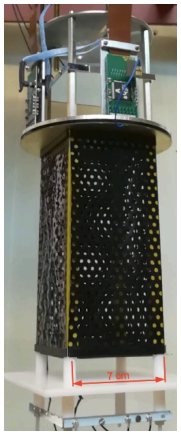


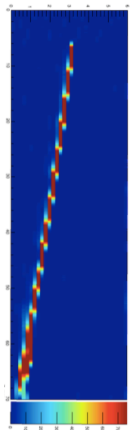
Pixel Charge Readout



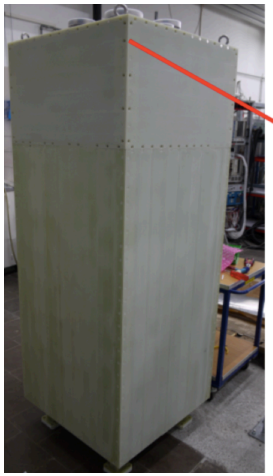


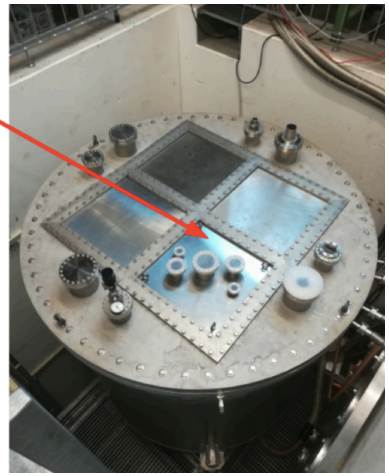
Resistive Field Cage and Cathode





Modular TPC Design



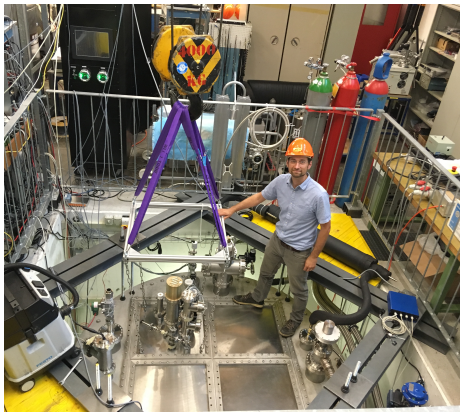


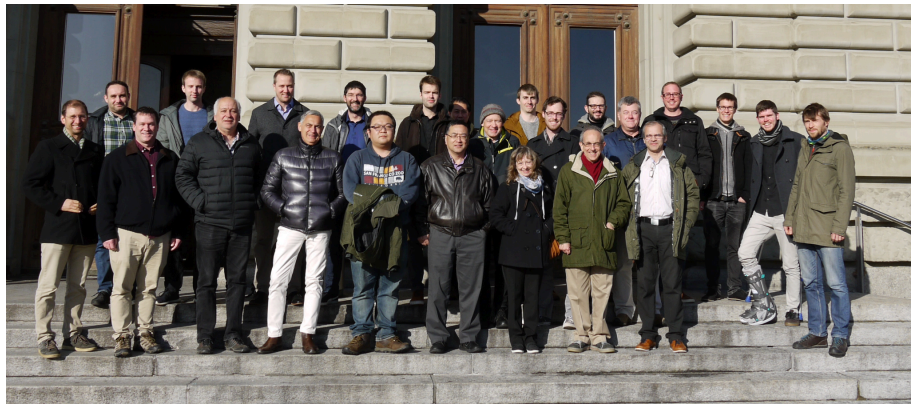
Near Detector Prototype (2019-2021)

ArgonCube 2x2 Demonstrator

→ 4 LArTPC modules, 3-tons active volume

Operate at Bern in late 2020, then in NuMI Neutrino beam in 2021

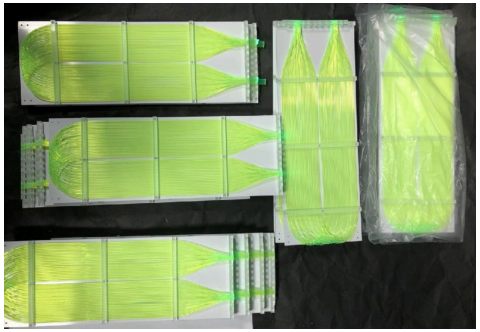




ArgonCube 2x2 Demonstrator: Recent Progress

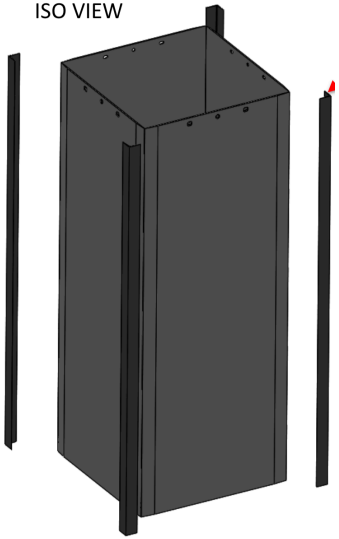
Cryogenics and Purity Testing System Bern

Light Collection Module Production and Testing JINR

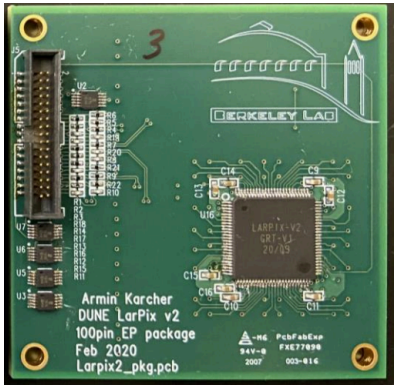


Hermetic Module Assembly Bern

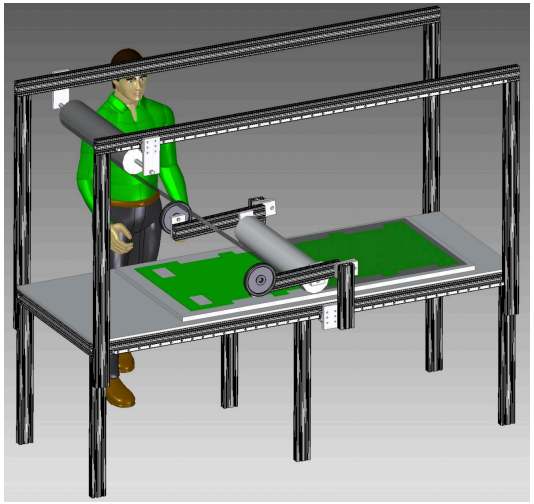
ISO VIEW

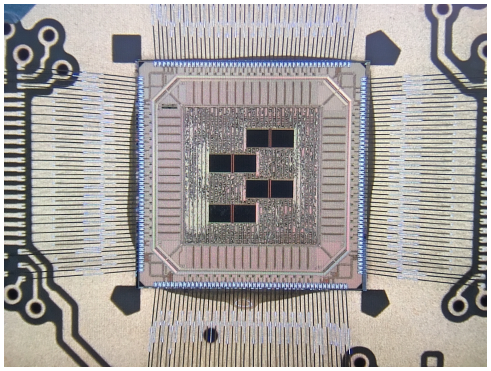


LArPix-v2 Charge Readout Testing LBNL



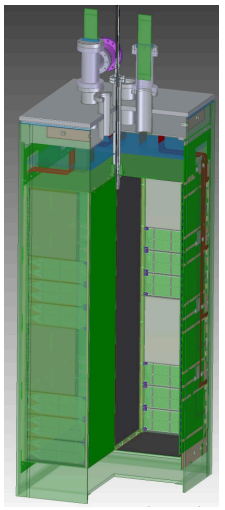
Field Cage Lamination SLAC





Tests of Module Assembly and Cryo-robustness CSU

ArgonCube 2x2 Demonstrator: Schedule & Goals

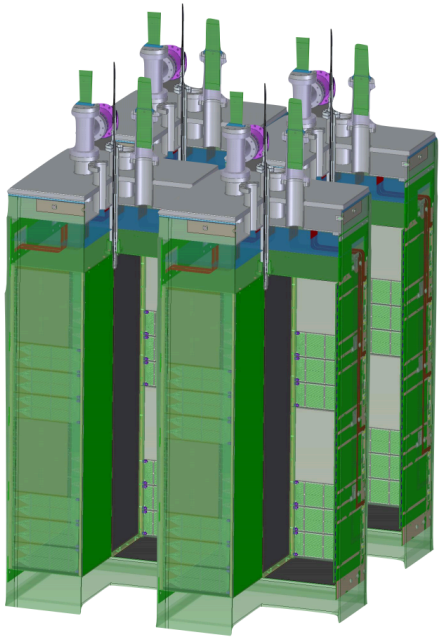


Module 0 @ Bern:

Now-May: Production, validation of components for Module 0
Commissioning of LAr cryogenics/purification system
May: Commissioning of single-module cryostat
June: Integration of Module 0
July-Sep.: Operation of Module 0

Goals:

→ *Integrated technical demonstration of LArTPC module design*
→ *Assessment of LArTPC performance using cosmic rays*
→ *Development and benchmarking of pixel LArTPC simulation/reconstruction*



Modules 1-4 @ Bern:

Now-Oct.: Production, validation of components for Module 1-4
Nov.: Integration of Modules 1-4
Dec.: Operation of Modules 1-4 (Complete ArgonCube 2x2 Demonstrator)

Goals:

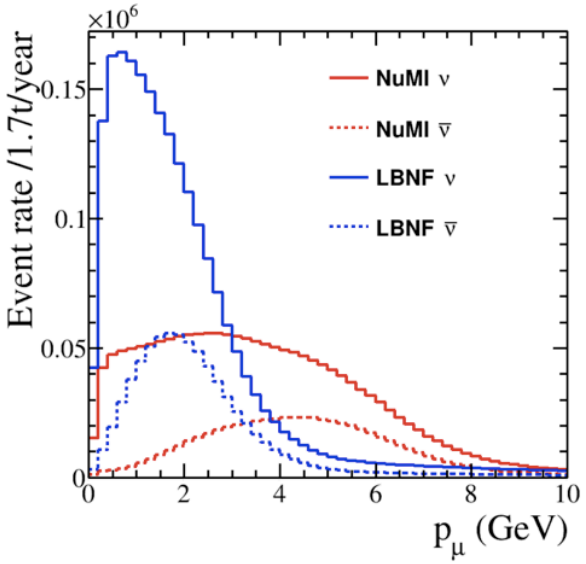
→ *Technical demonstration of multiple independent LArTPC modules*
→ *Cosmic ray reconstruction across module boundaries*

→ *2021: Operation in FNAL Neutrino Beam (a.k.a. ProtoDUNE-ND)*

ProtoDUNE-ND: ArgonCube 2x2 @ NuMI

Stepping-stone to Near Detector

NuMI neutrino rates and energy spectrum similar to planned DUNE LBNF beam

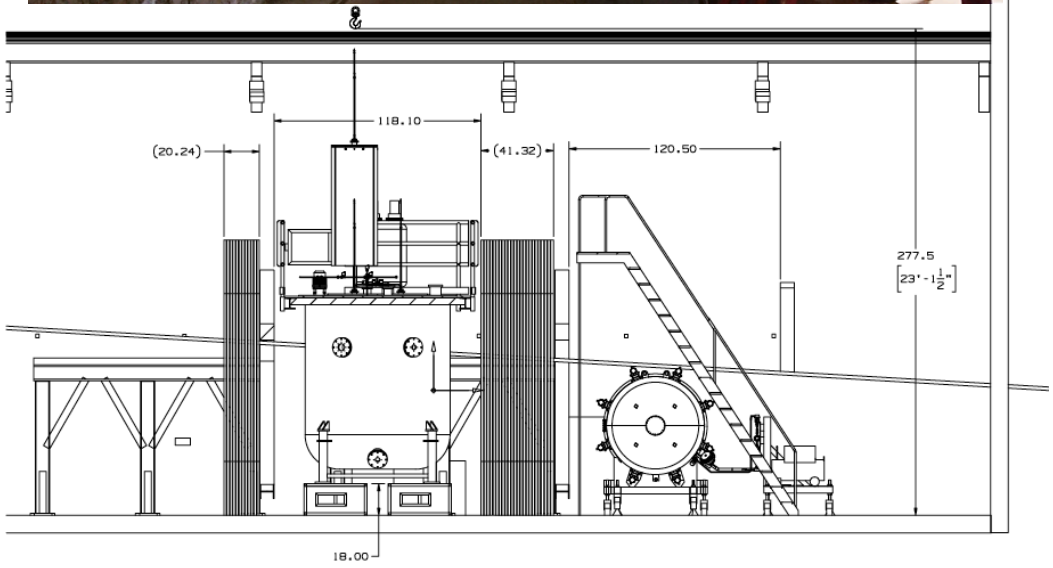


Goals:

→ Underground integration, operation
→ Neutrino signal identification and reconstruction
→ Pileup rejection
→ Track matching with tracking detector (Minerva)

Aiming for operation in 2021

NuMI Near Underground Hall



TPC Module Integration and Testing

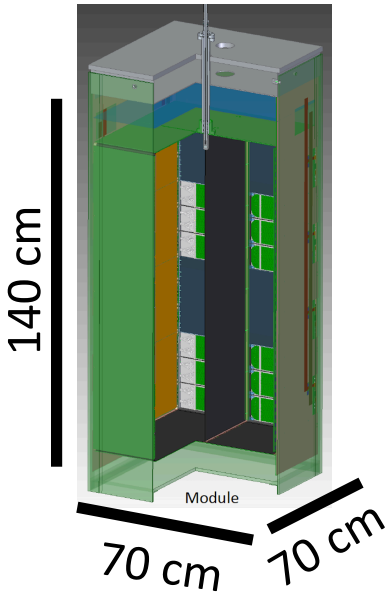
Institutions: Bern, CSU, UTA, LBNL, SLAC, +others

2019-2021
ArgonCube 2x2 Demonstrator

4 (+1) modules

Operated in existing cryostat at Bern, then FNAL (NuMI)

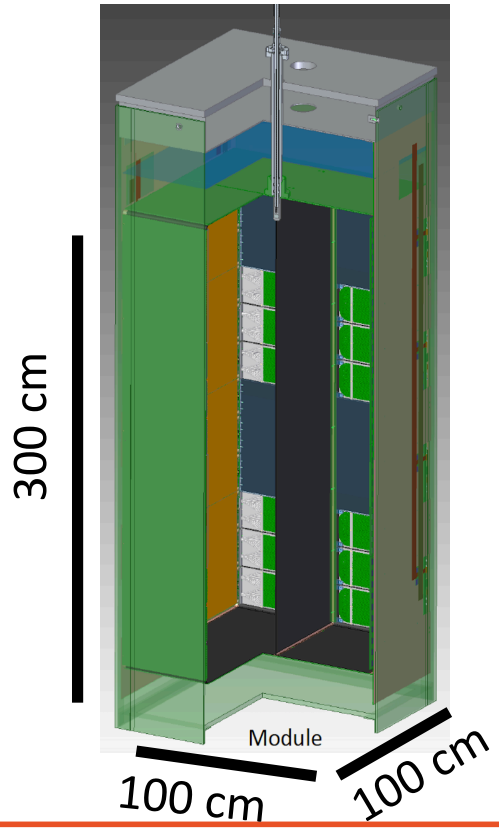
Technical demonstrator



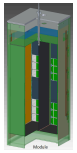
2021-2023
Full-scale ND Demonstrator

1 Full-scale ND module

Operated in single-module cryostat



2024-2026
Production



1 production ‘first article’

35 (+5) Production modules

Each fully tested in single-module cryostat

Deliverable: modules packed and ready for installation underground

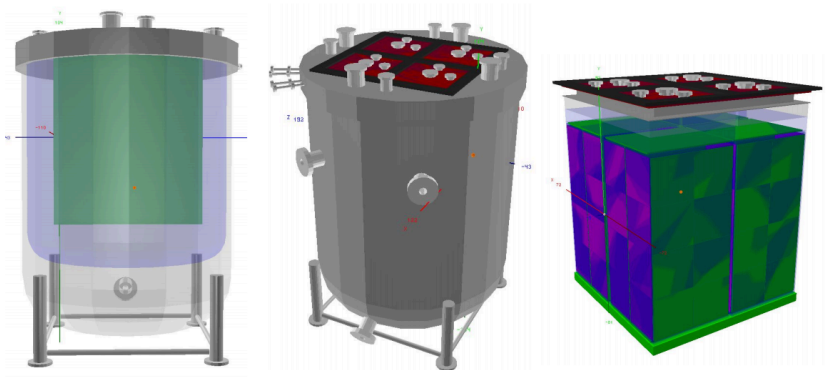
Near Detector LArTPC: Simulation and Analysis

Dedicated ND LArTPC analysis effort:

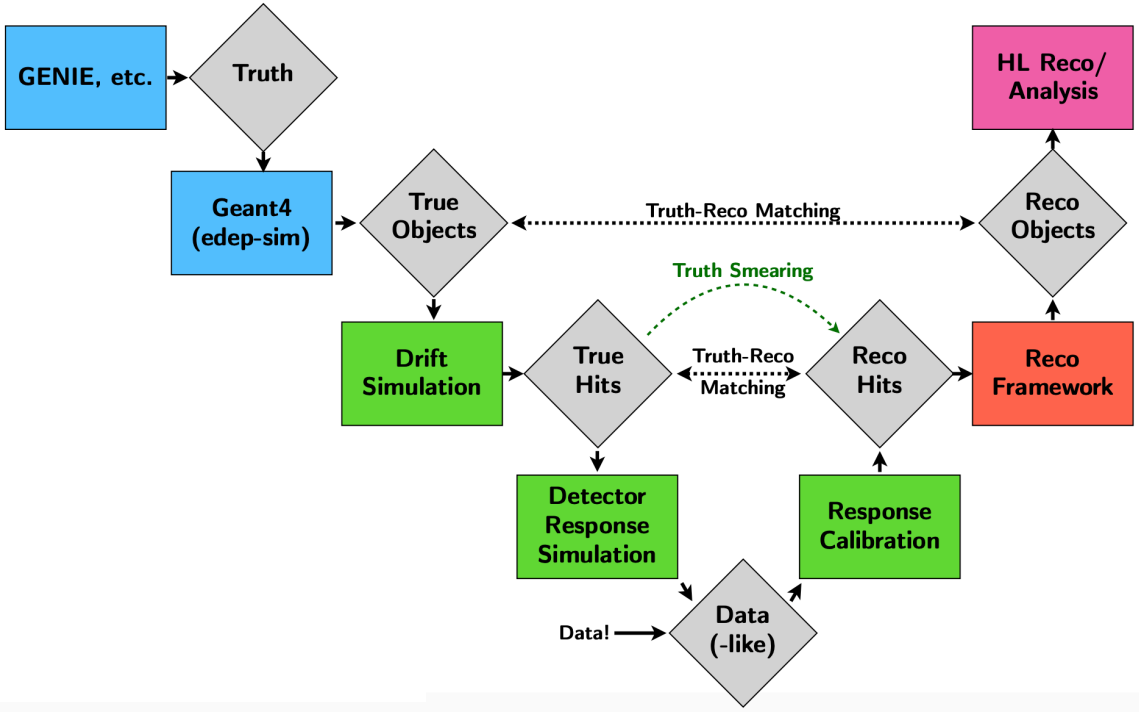
Coordinator: A. Mastbaum (Rutgers)
Email: lar-nd-analysis@fnal.gov
slack: #lar_nd_analysis

ArgonCube 2x2 GDML Geometry

P. Koller (Bern), H. Sullivan (UTA)

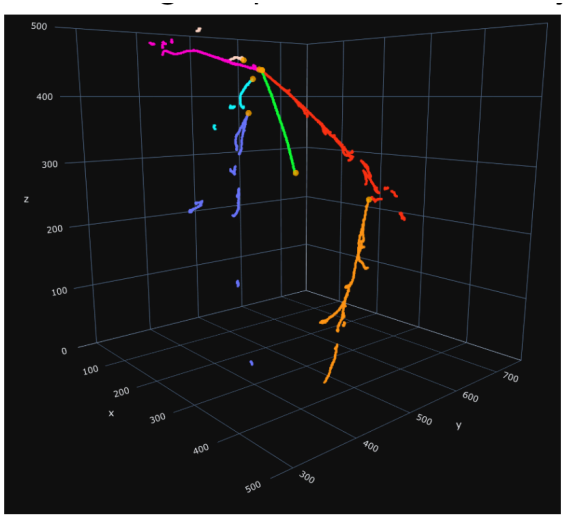


Analysis Workflow and Data Model (in development)

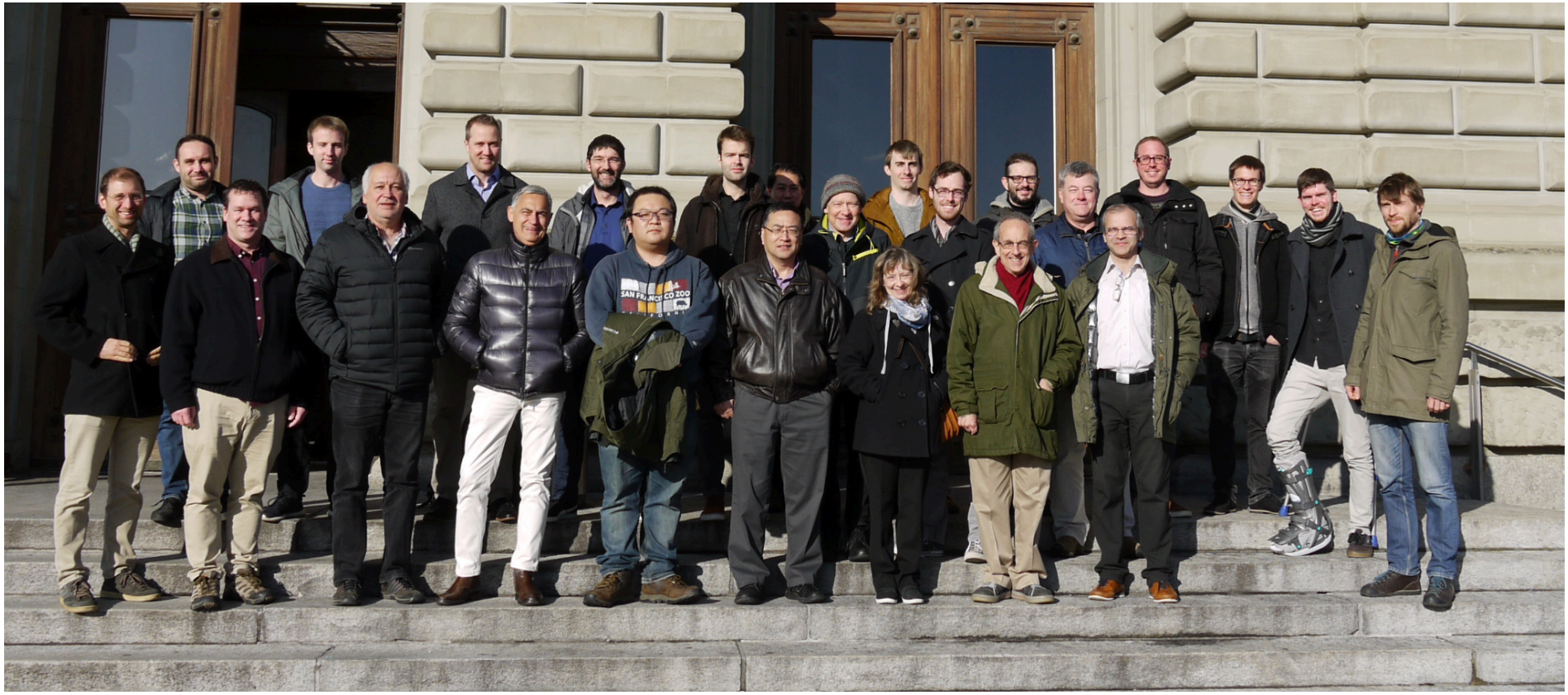


Intrinsic 3D Reconstruction Tools

K. Terao (SLAC)

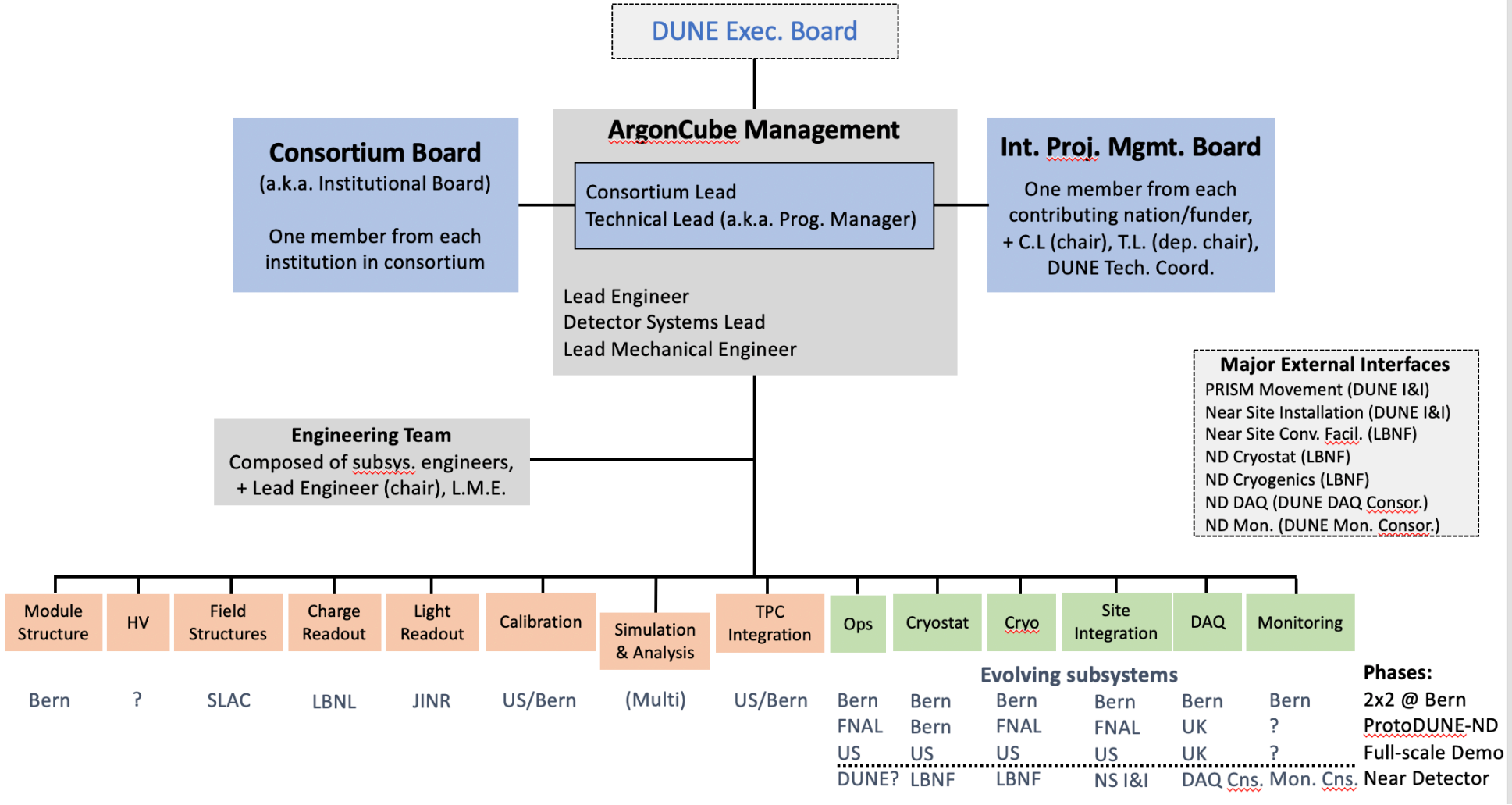


ArgonCube Collaboration



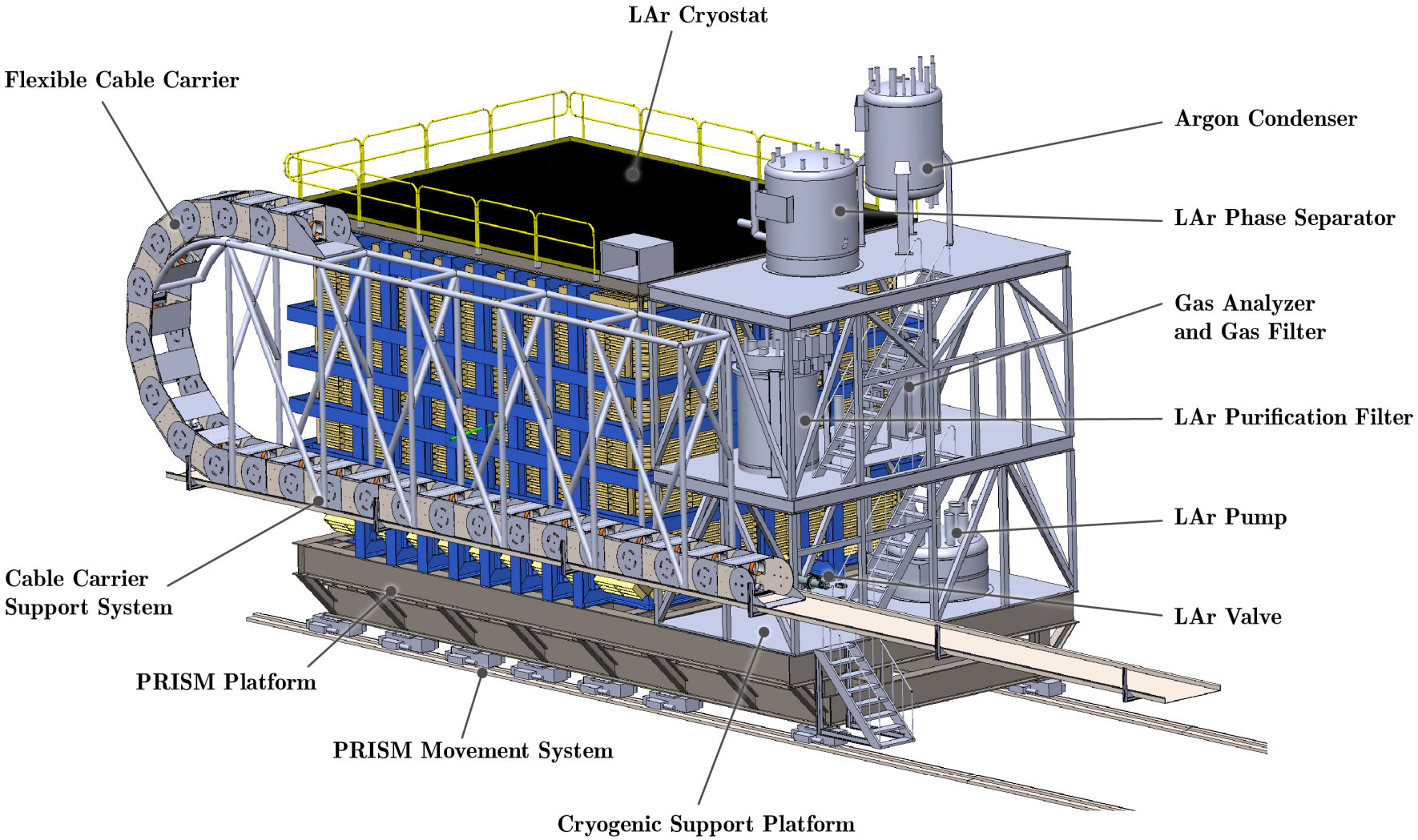
ArgonCube Consortium

Now transitioning from Independent R&D Collaboration to DUNE Near Detector Consortium



Near Detector: Cryostat, Cryogenics, and PRISM

Substantial progress in associated system development (outside of ArgonCube Consortium)



Near Detector LArTPC

Important Component of Near Detector System

- Key design features (size, fidelity, modularity) driven by LBL physics needs
- Growing analysis team focus on physics needs and technical design development

Mature prototyping program

- Successes with 3D pixel readout, novel light readout, resistive field cage, modular TPCs
- ArgonCube 2x2 Demonstrator:
  - → integrated demonstration of TPC design in 2020
  - → operation in NuMI beam in 2021
- Next Step: Full-scale ND Module Demonstrator

Strong international partnership

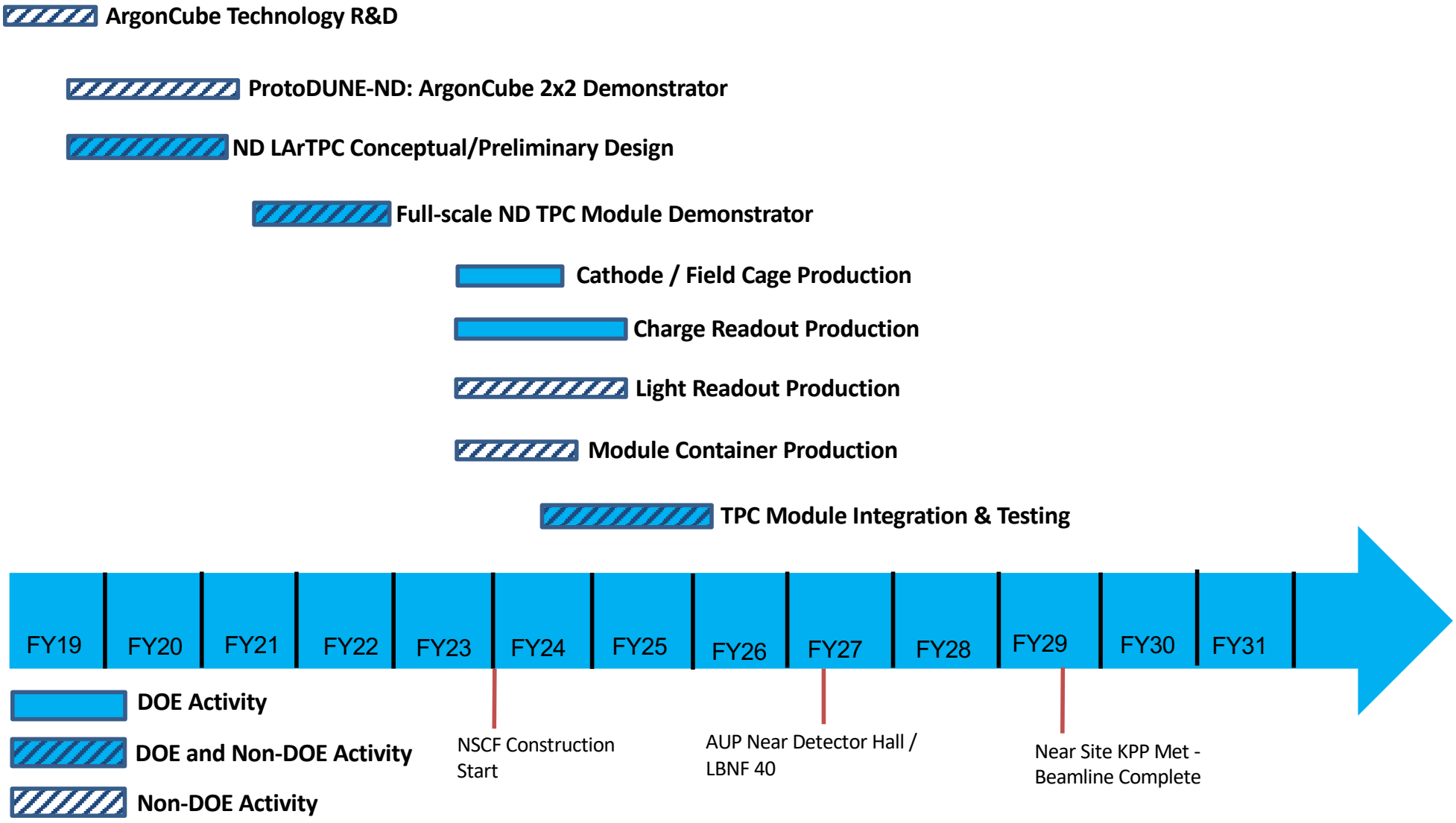
- Currently in transition from ArgonCube Collaboration to DUNE Near Detector Consortium

Corresponding progress in design of associated systems:

- Cryostat, Cryogenics, PRISM, Near Site Infrastructure

Backup

ArgonCube Schedule



Near Detector Reference Design

Reference Design:

- Defined by DUNE Collaboration
- Broad international effort
- Achieves complete DUNE physics program

LAr Detector (ArgonCube)

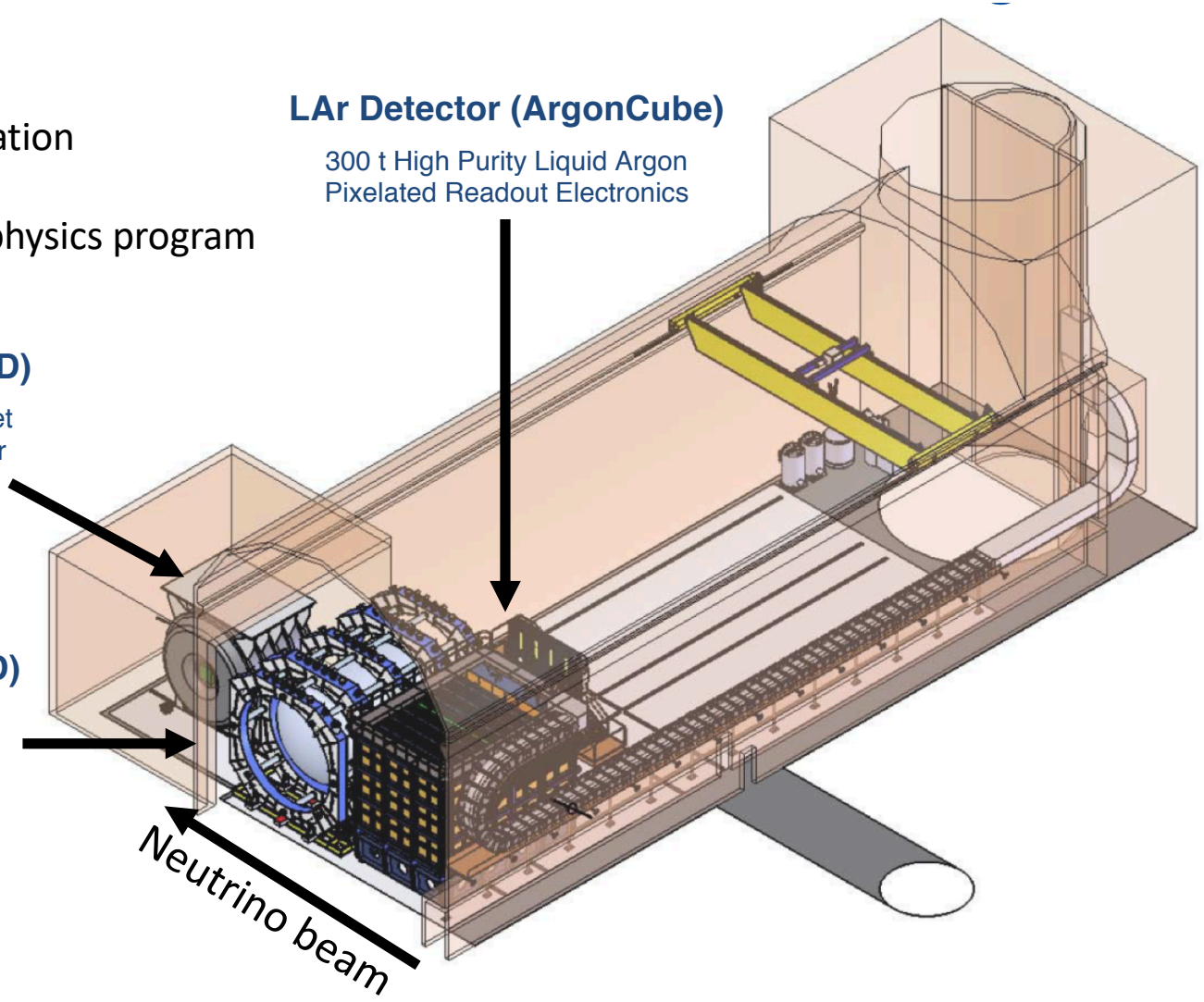
300 t High Purity Liquid Argon
Pixelated Readout Electronics

Beam Monitor (SAND)

Repurposed KLOE magnet and calorimeter, new inner trackers (3DST + straws)

Multi-purpose Detector (MPD)

1 t High-pressure gas Argon TPC
Calorimeter, Muon ID system,
SC magnet



DUNE Is Currently Developing A Risk Mitigation Strategy For A Possible Late Availability Of An MPD Detector