ND-LAr (ArgonCube) Consortium: Technical Overview

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Consortium General Meeting

3 Sep. 2020

Requirements and Specifications

- **ND-O0: Predict the observed spectrum of neutrino interactions at FD**

  → **ND-M1: 'The ND must have a LArTPC with reconstruction capabilities comparable/exceeding the far detector'**

→ ND-T1.2: ND LArTPC Active Size: Large enough to fully contain relevant signals	3 m tall x 7 m wide x 5 m in-beam
→ ND-T1.5.1: Electric Field strength: Match the far detector drift field	> 250 V/cm (goal: 500 V/cm)
→ ND-T1.6.1: Pixel Spacing: Match the far detector spatial resolution	< 4.7 mm

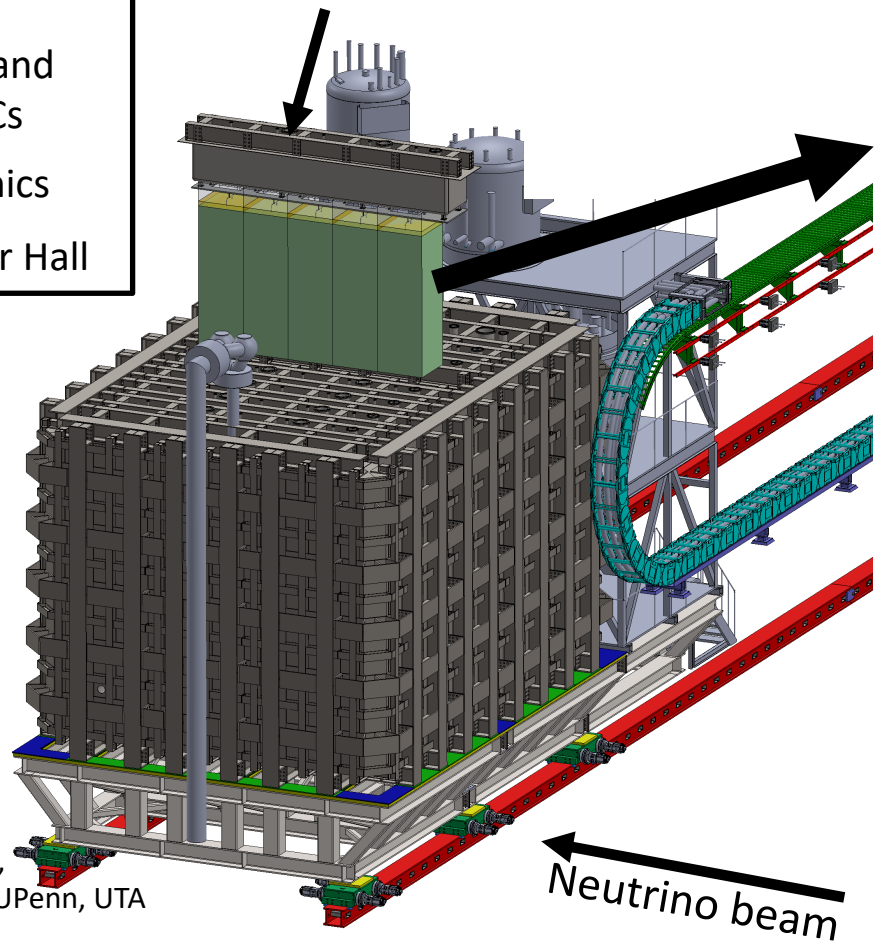
  → **ND-O6: 'Operate in a high-rate environment'**

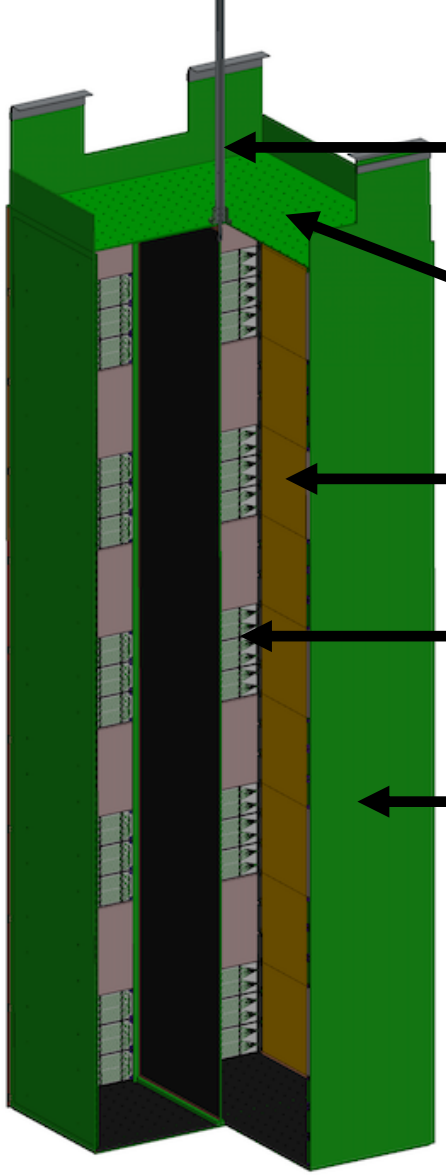
→ ND-T1.6: 3D Pixel Charge Readout: High-accuracy 3D imaging in high-rate env.	-
→ ND-T1.3.3: Detector Modularity: High-accuracy charge-light signal association	< 3 m^3
→ ND-T1.7.1: Photon detection time resolution: High-accuracy charge-light assoc.	< 20 ns

ND-LAr Consortium Scope (131.02.03.02)

Consortium will provide:

- Design, prototyping, production, and testing of 35 (+5) modular LArTPCs
- External HV and detector electronics
- Support during installation in Near Hall





131.02.03.02.02: High Voltage

131.02.03.02.03: Field Structures

131.02.03.02.04: Charge Readout System

131.02.03.02.05: Light Readout System

131.02.03.02.06: Calibration

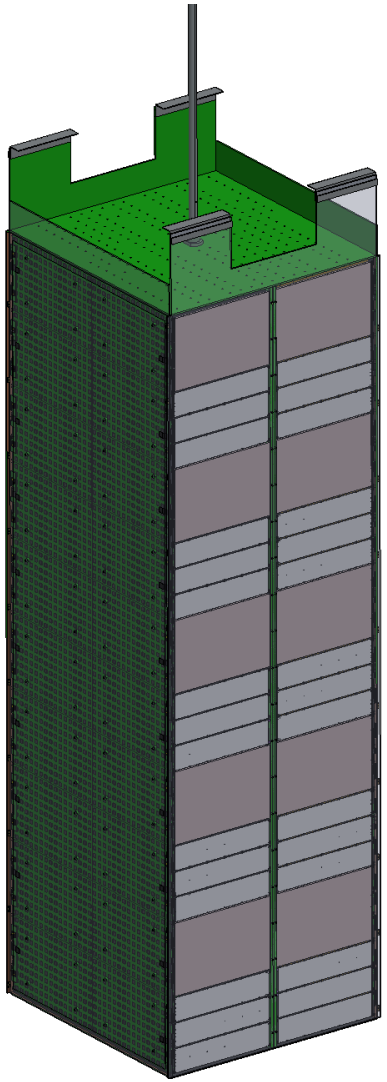
Subsystem	Current Institutions
Module Structure	Univ. of Bern
HV	Univ. of Bern
Field Structure	SLAC, CSU
Charge Readout	LBNL, Caltech, CSU, Rutgers, UC-Davis, UC-Irvine, UCSB, UPenn, UTA
Light Readout	JINR, Univ. of Bern
Calibration	JINR, MSU, UH
TPC Module Integ.	All
TPC Module Install.	All

Others:

131.02.03.03.07: TPC Module Integ. & Testing

131.02.03.03.08: TPC Module Installation

ND LArTPC Module Design



Modular LArTPC Design

Enables accurate signal reconstruction in high pile-up ND environment

Module size

Each 1m x 1m x 3m module has signals from multiple neutrinos (~5) per 10us beam spill at 1.2 MW.

Pixelated charge readout

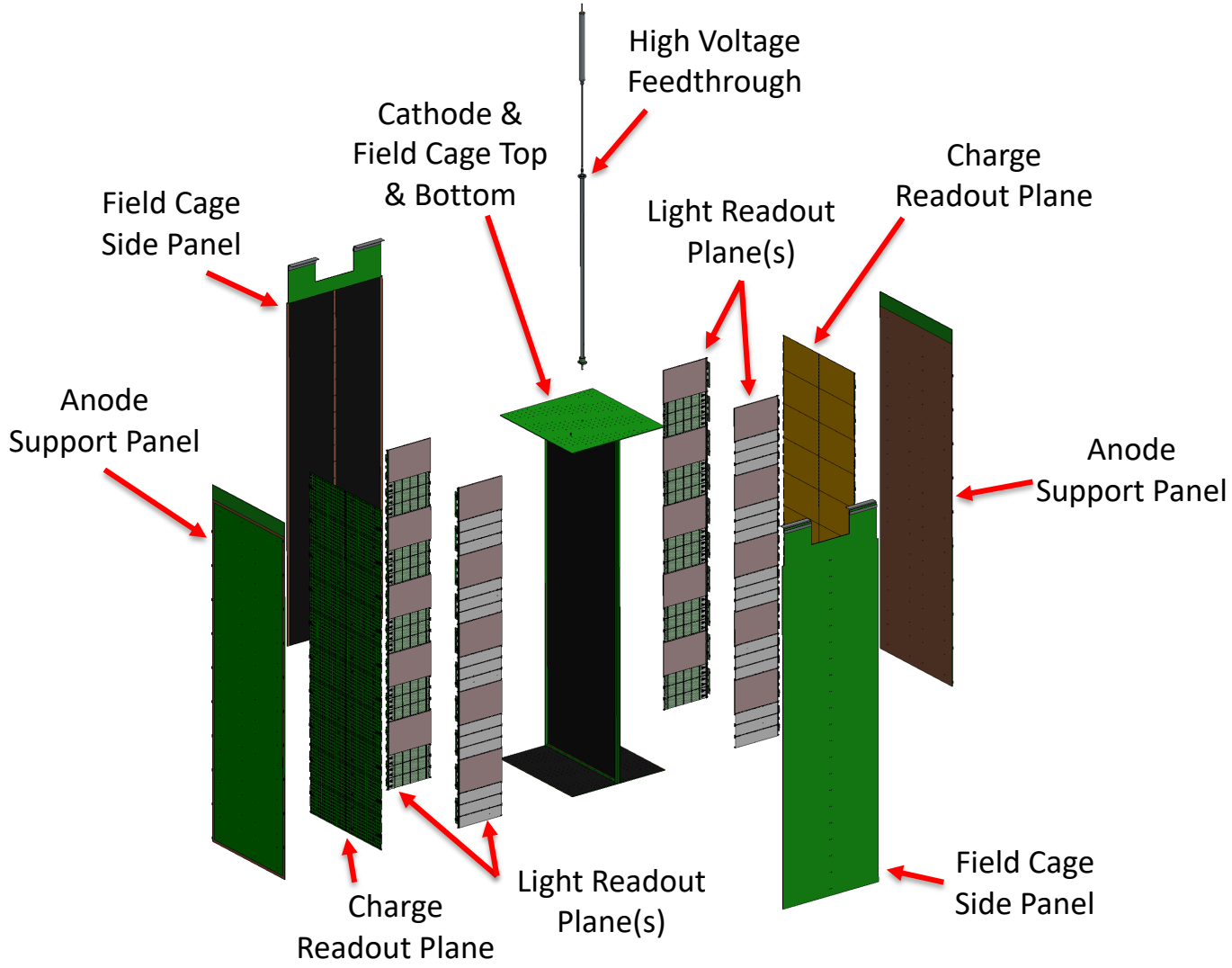
Provides true 3D imaging of ionization

Low-profile field cage

Maximizes instrumented region
Provides optical segmentation

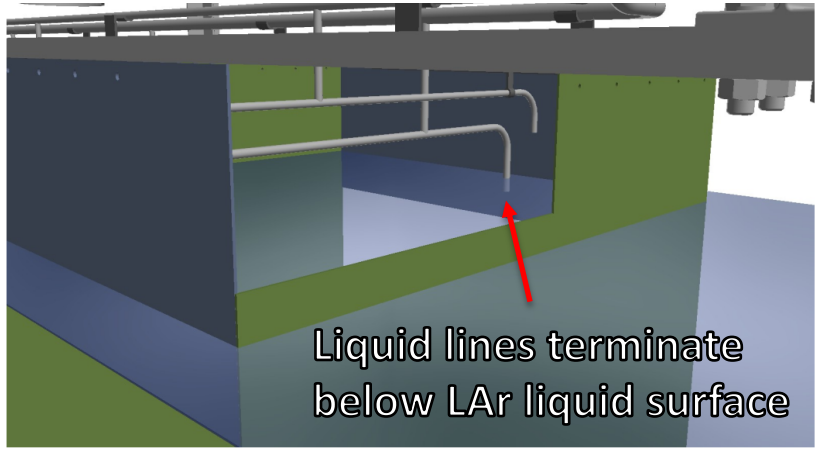
High-performance light readout

Enables accurate charge-light signal matching within each module to overcome pile-up.

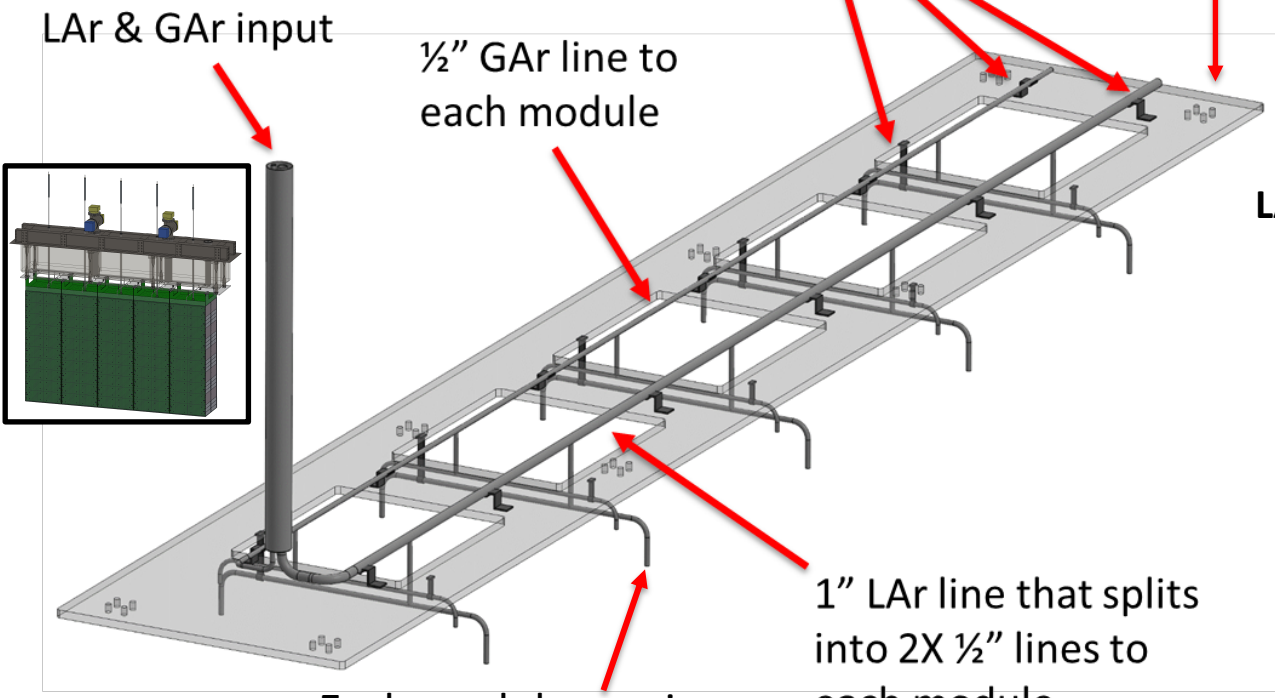


Module Structure (131.02.03.02.01)

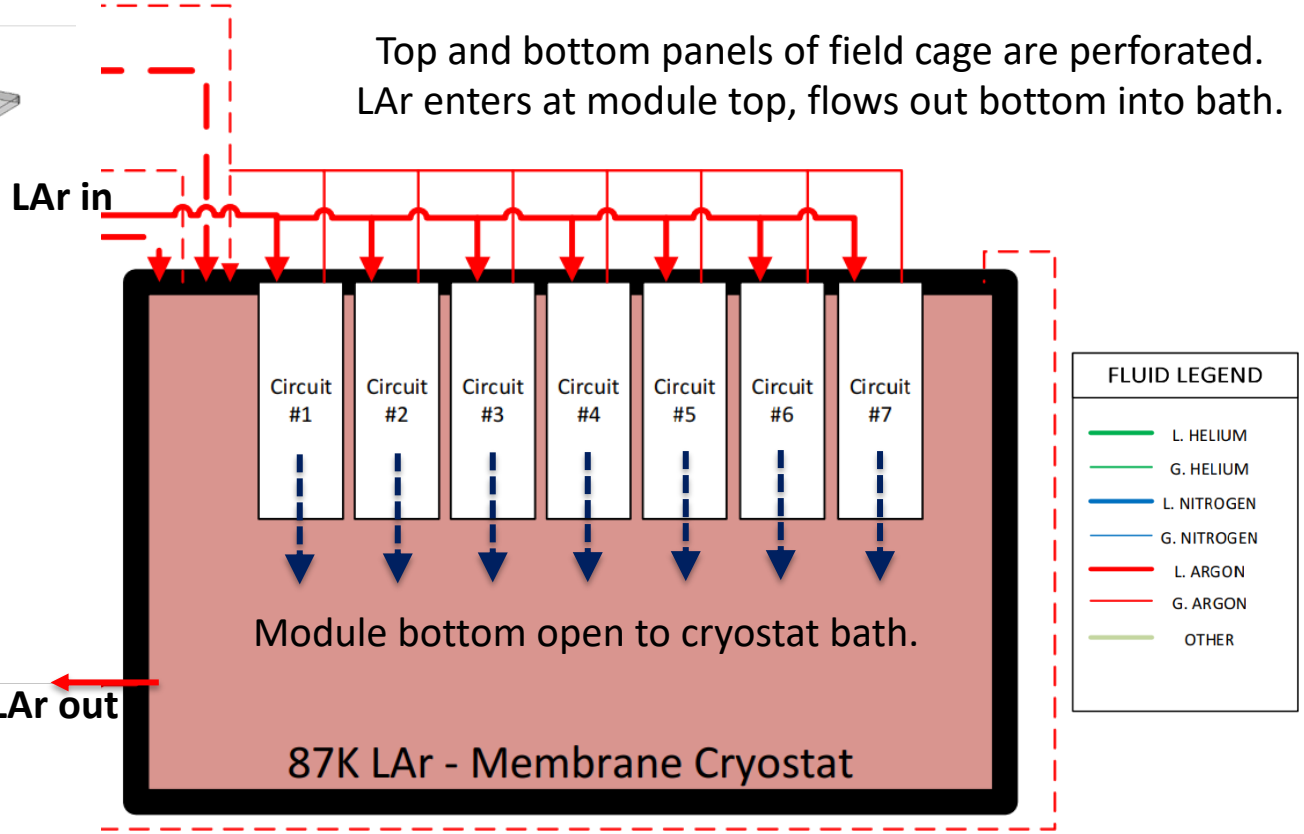
Interfaces between detector & cryostat
- 5-module row mechanical interface plate
- Internal LAr/GAr routing
- Monitoring instrumentation



Support plate for module attachment as well for mounting clips for cryo-line routing or electronics routing



Top and bottom panels of field cage are perforated. LAr enters at module top, flows out bottom into bath.

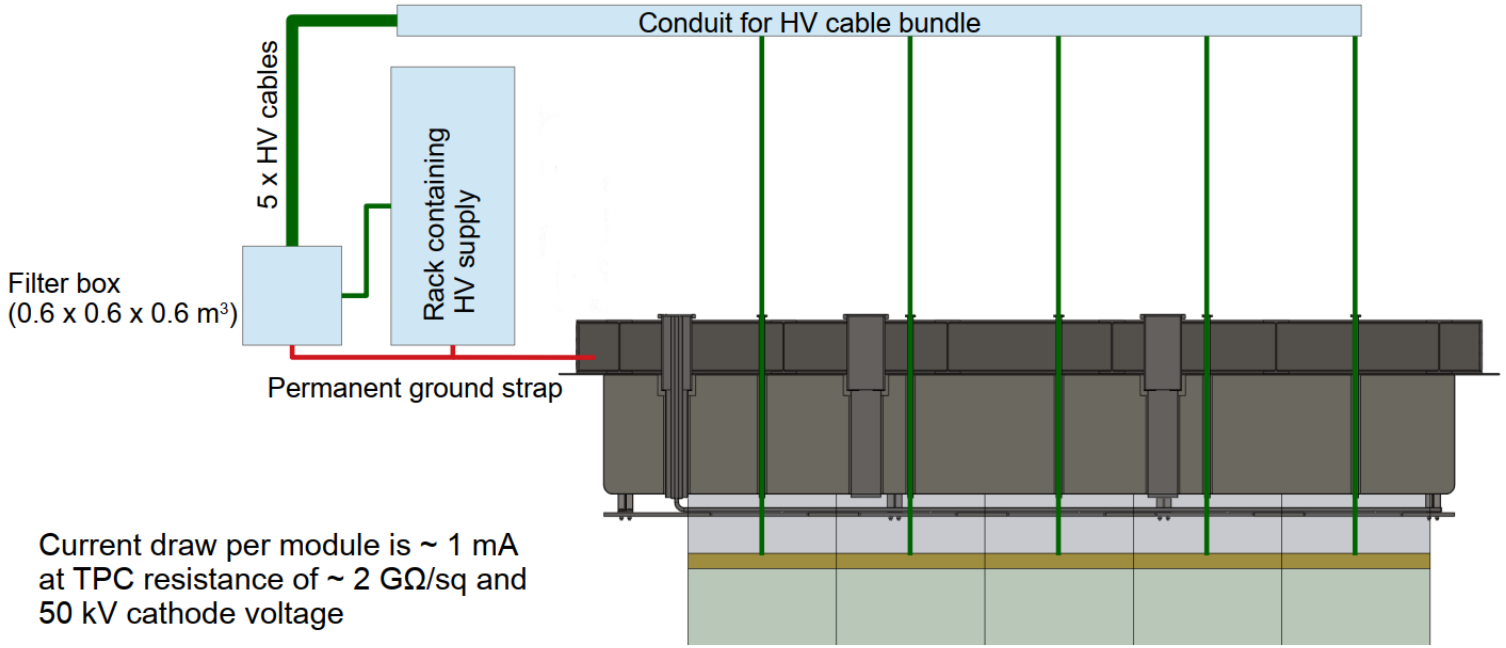


Institutions: Univ. of Bern

High Voltage (131.02.03.02.02)

- One power supply serves a row of 5 modules
- The power supply is connected to the modules by a single low-pass filter
- After the filter 5 resistive cables connect to the HV feedthrough/cathode
- The variations in length of the 5 cables are accounted for by adding a resistor for each cable after the filter
- For safety and to reduce ground loops, cables are bundled together in conduit until they reach their feedthrough
- The jacket of all cables (HV→filter & filter→detector) must share common ground with the filter and detector
- The detector and rack grounding must be permanent dedicated lines, regardless of ground loops

Module Row High Voltage Distribution Schematic



HV Cable
- Produced by Dielectric Sciences, INC.
- Application in nEXO
- Resistance: 8.4 kΩ/m
- Capacitance: 90 pF/m

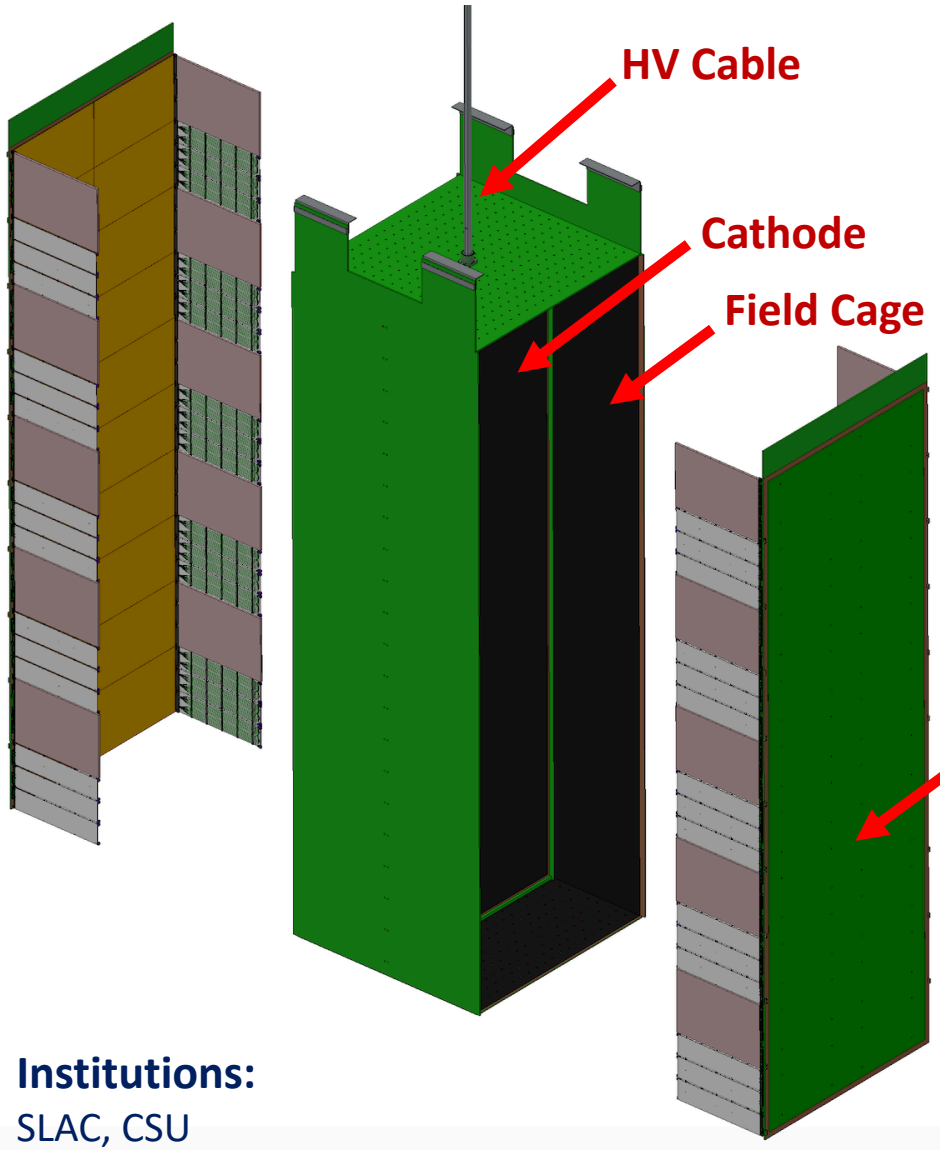
HV Filter
- Low-pass filter with large capacitor & small resistor to prevent voltage drop
- Additional resistors at outlet set to match cathode voltages

HV Supply
- Provide 60kV and 5 mA
- Within range of standard power supplies
- ProtoDUNE recommendation Heinzinger or Fug-Elektronik

HV Breakdown
- Monitor current draw
- In event of, power supply is cut
- Manual feedthrough replacement

Institutions: Univ. of Bern

ND LArTPC: Field Structures (131.02.03.02.03)

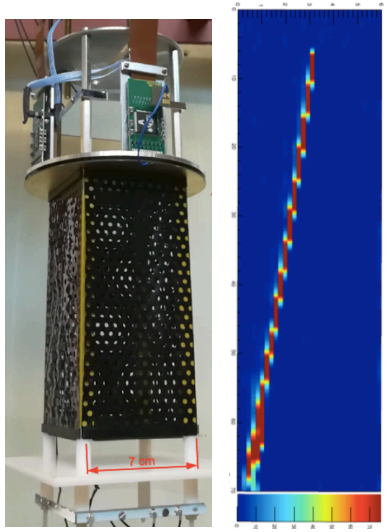


Key Design Features:

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

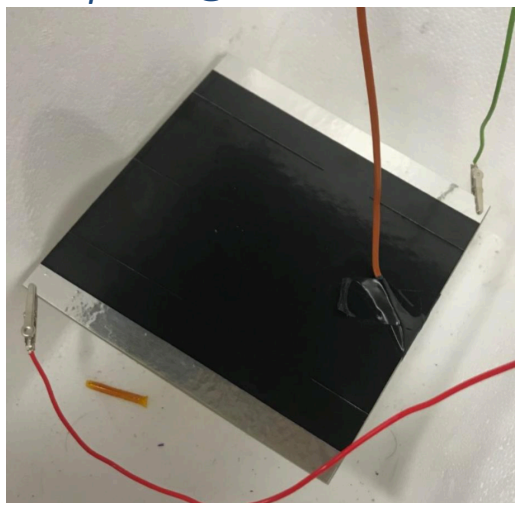
Resistive polyamide sheet laminated on G10 panels
→ *Reduces risks from accidental HV discharge*
→ *No resistor chain; reduce single-point failure risk*
→ *Low-profile: maximizes active volume*

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

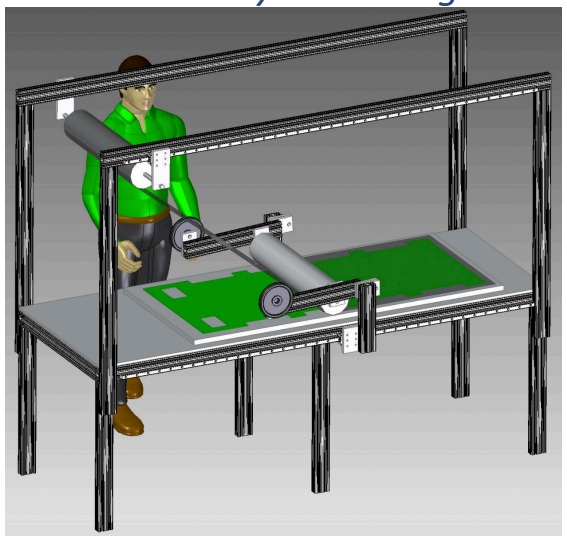


Resistive sheet LArTPC @ BERN

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



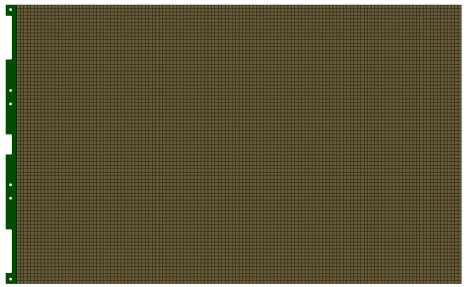
Lamination system design



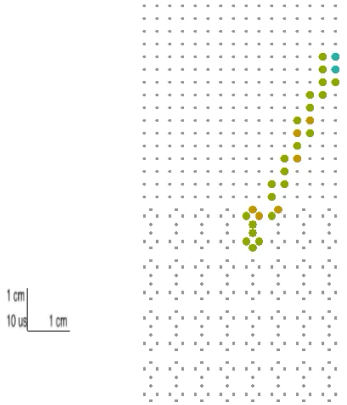
Institutions:
SLAC, CSU

Pixelated Charge Readout (131.02.03.02.04)

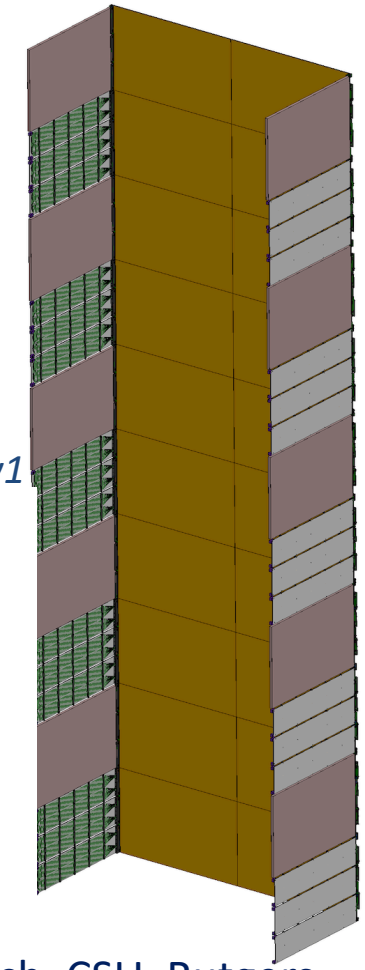
ND pixel tile design, 10,240 pixels



3D cosmic data from LArPix-v1



Pixelated Anode Design



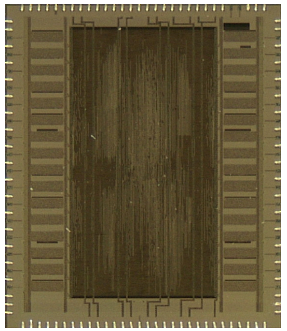
Key Design Features:

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*

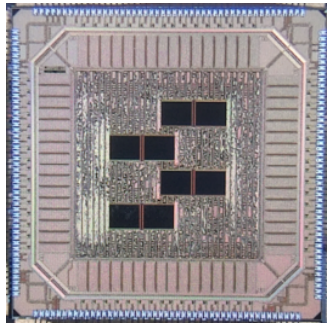
LArPix: Custom pixel readout ASIC
- → *Provides low-noise, low-power, cryogenic readout*
- → *SOC: amplification, digitization, triggering, readout*
- → *Implements highly-scalable control, I/O architecture*

LArPix Controller System: Pac-Man
- → *Leverages commercial Zynq (CPU+FPGA) system with simple custom interface PCB to control large-scale pixel system, ~1 controller per O(100k) pixel channels*

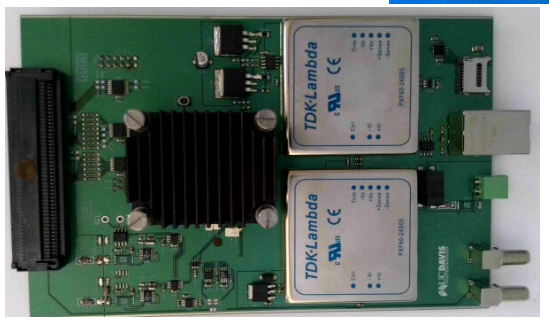
LArPix-v1 ASIC



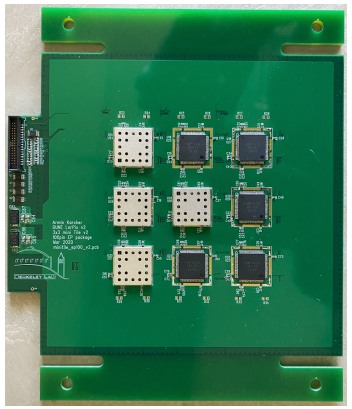
LArPix-v2 ASIC

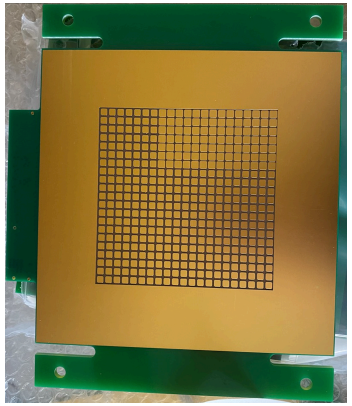


LArPix-v2 Controller

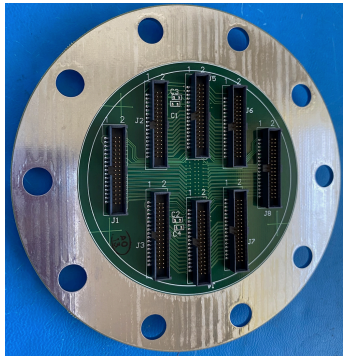


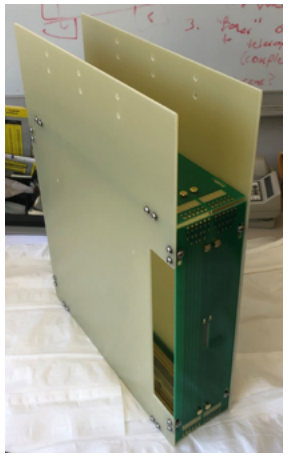
'Industrialized' Pixel Tile (v2)





Pixel Tile (v2) cable feedthrough

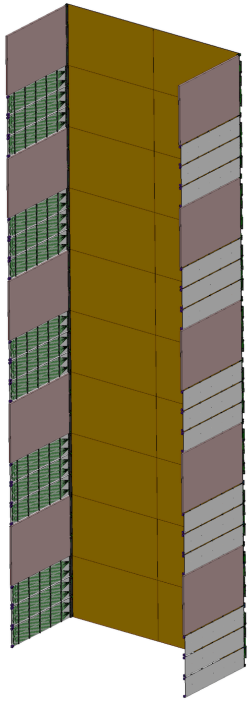




QC Test TPC for Pixel Tiles

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

Light Readout (131.02.03.02.05)



LCM Modules

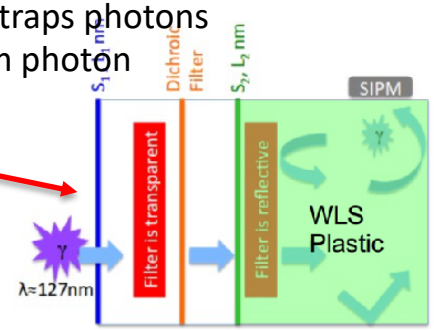
Shifts UV light (128 nm) into visible light (510nm)

- TPB on fibers shift 128 nm to 425 nm -> wavelength shifting fibers shift 425 nm to 510 nm -> Silicon Photomultipliers (SiPMs) detect 510 nm light
- Easy to scale -> fibers have long attenuation
- High detection efficiency, PDE ~ 1-2 %

ArCLight Modules

Shifts UV light (128 nm) into visible light (425nm)

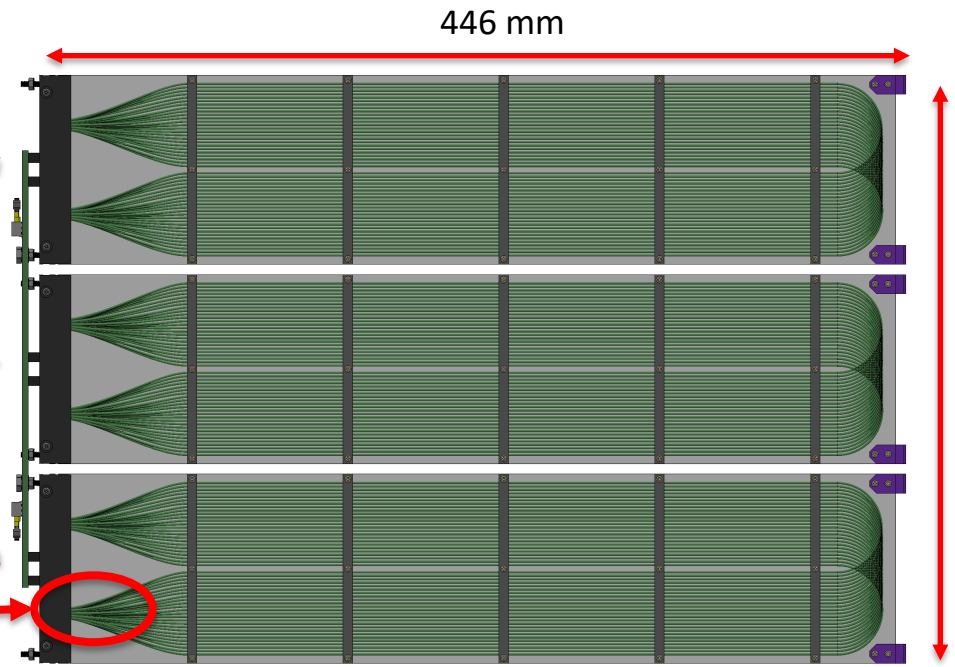
- Wavelength shifting plastic (WLS) traps photons that pass through filters -> random photon movement until capture in Silicon Photomultipliers (SiPMs)
- Rigid construction
- Good spatial resolution

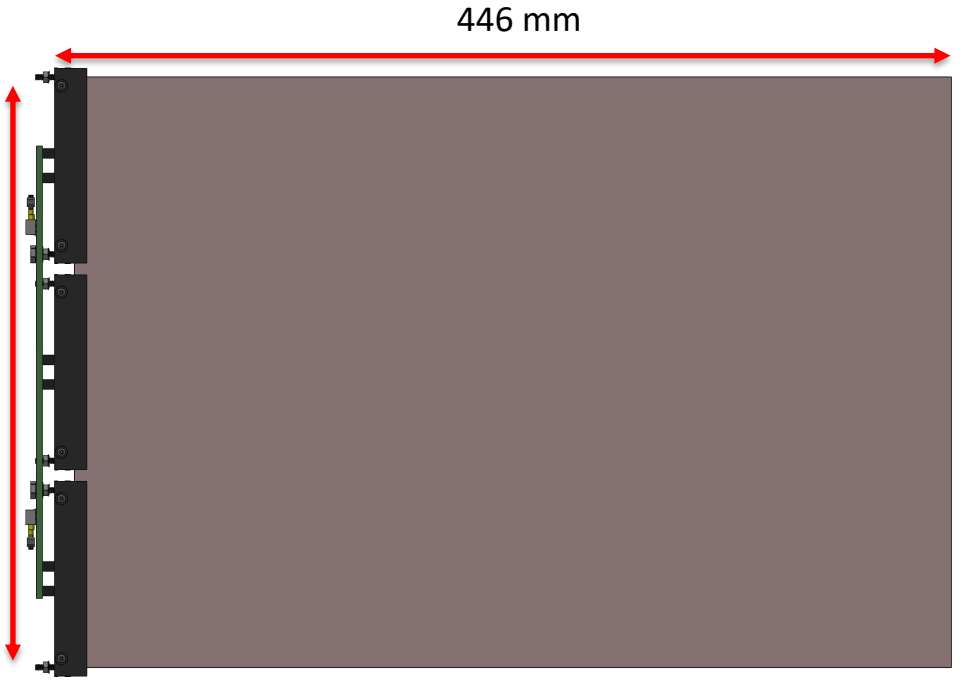


One SiPM PCB per LCM

- Three LCMs per LRO array
- Six SiPMs per LCM array

Bundle goes to SiPM





Institutions: JINR, Univ. of Bern

Calibration (131.02.03.02.06)

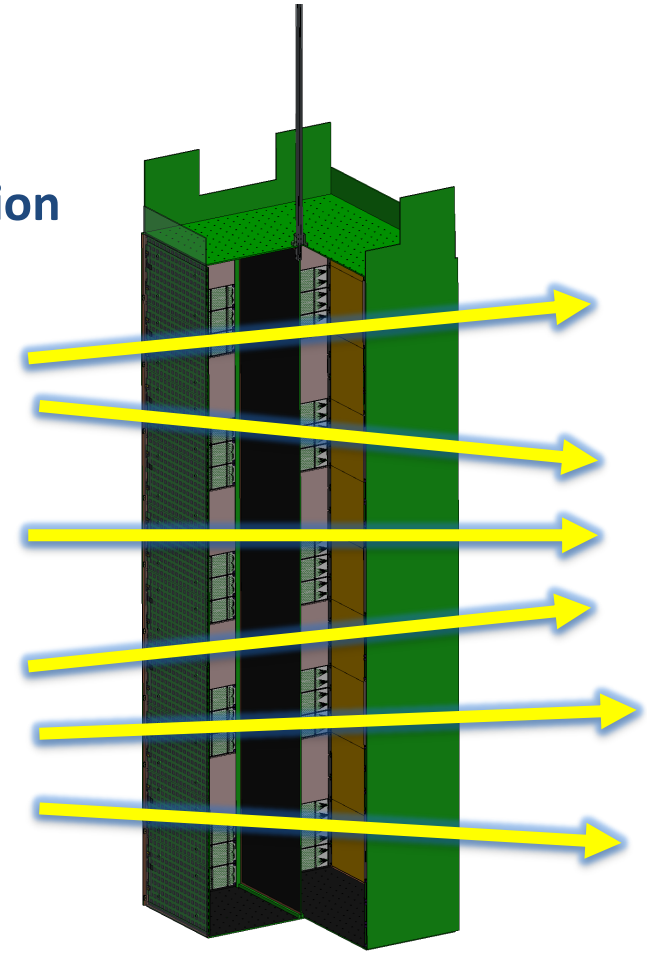
Charge and Field Calibration

Rock Muons

- Plentiful source in Near Site

Ionization sources:

- Exploring potential, based on FD studies

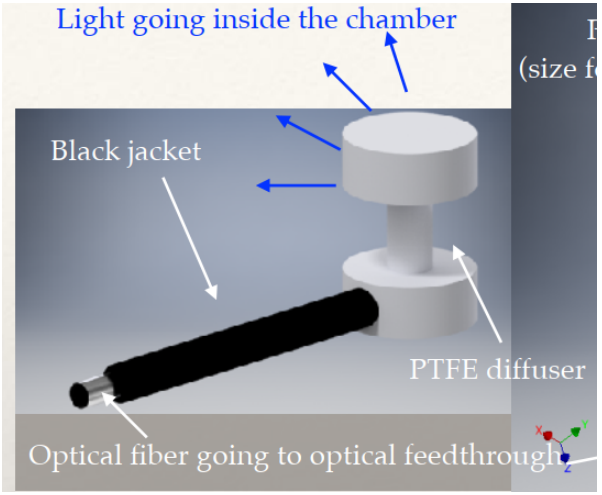


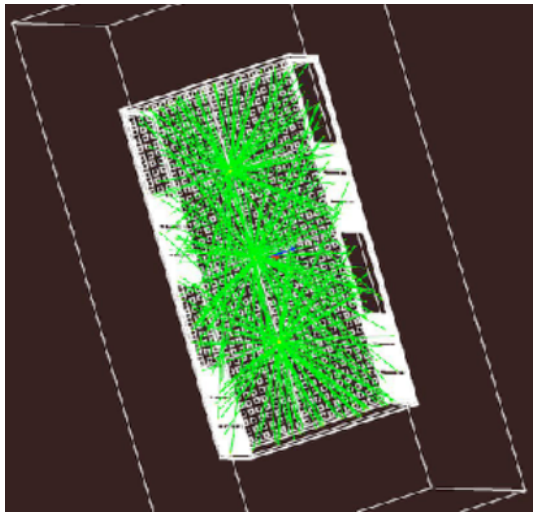
Rock Muons

Light Calibration

UV pulsers with diffusers

- Light input via optical fiber that is routed to warm feedthrough
- Location TBD based on simulation



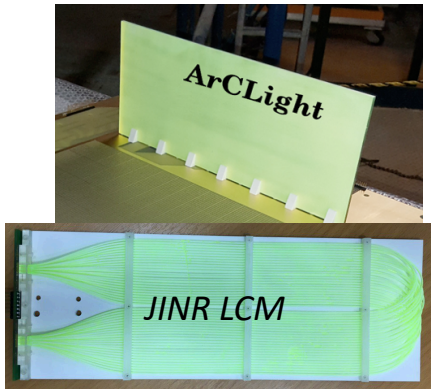


Institutions: JINR, MSU, UH

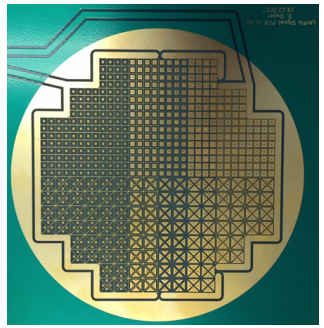
ND LArTPC Prototyping / ArgonCube 2x2 Demonstrator

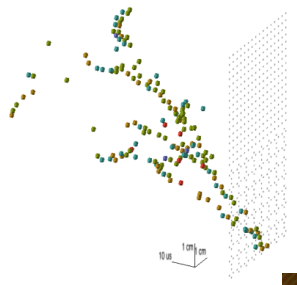
Technology Prototypes (2016-2018)

Advanced Light Readout

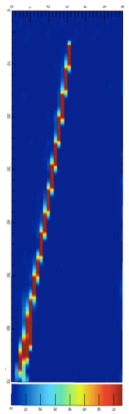


Pixel Charge Readout

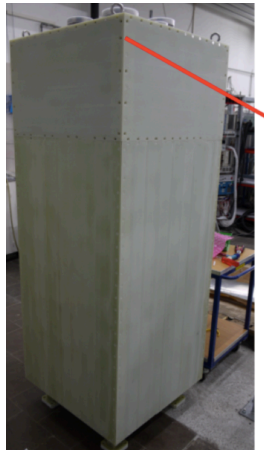


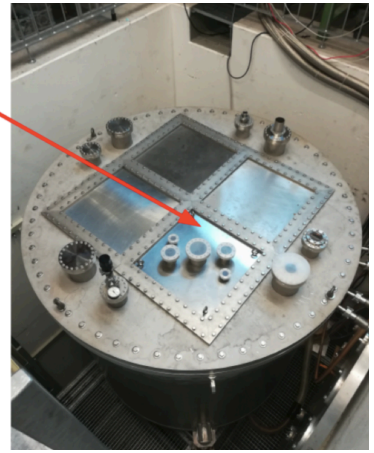


Resistive Field Cage



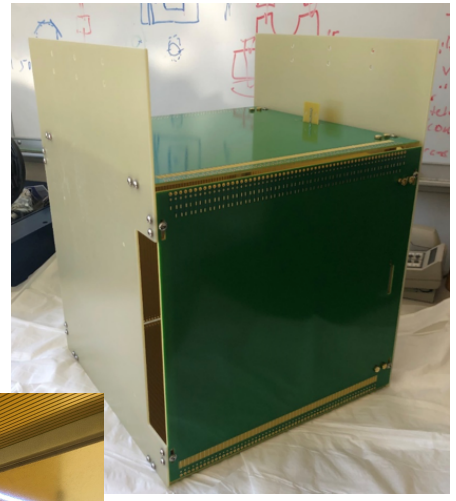
Modular TPC Design

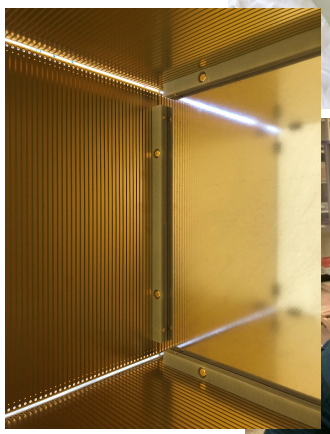


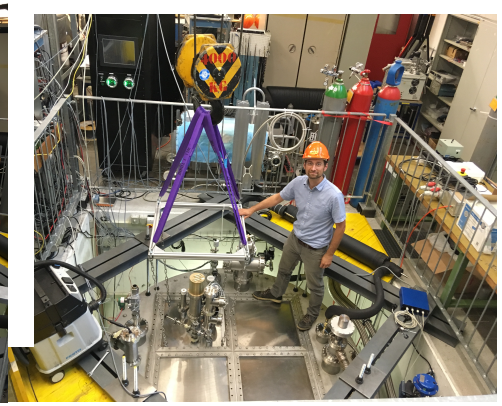


Near Detector Prototype (2019-2021)

1. *SingleCube:* Small-scale test of ArgonCube design
2. *Module 0:* First 2x2-scale detector module test
3. *ArgonCube 2x2 Demonstrator*
   4 LArTPC modules, 3-tons active volume







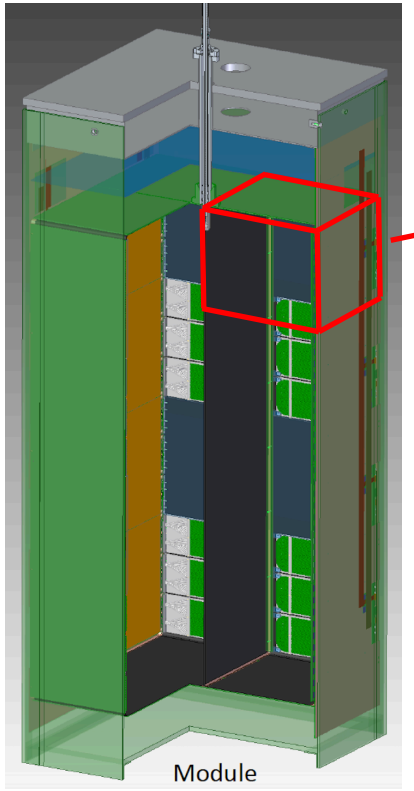
LBNF/DUNE

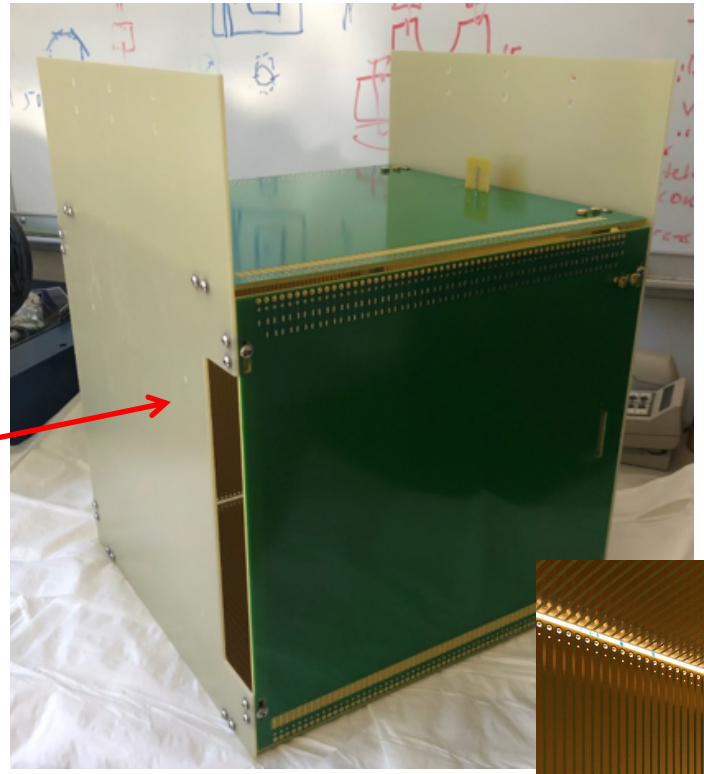
Adapting to COVID-19: SingleCube

COVID-19:
- Delays in production of 2x2 components
- Travel restrictions to 2x2 site @ Bern

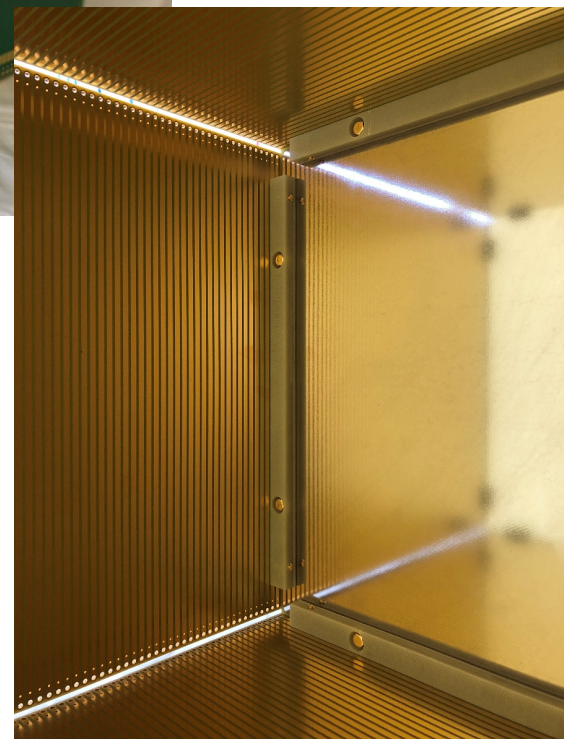
Strategy response:
- Minor adjustment of LBNL pixel tile test TPC enables distributed 2x2 prototyping

SingleCube TPC:
- Scaled 2x2 design to smallest 'quanta': 1/16th
- Supports single 2x2 Pixel Tile and Light Module
- Same drift distance as 2x2
- Same materials and fixtures as 2x2





SingleCube TPC assembly @ LBNL



Interior view of SingleCube TPC

Status:
- Produced all parts commercially during lab/university shutdowns
- Distributed SingleCube TPC kits to partners: Bern, CSU, UTA, SLAC
- Issue: delays in production of multiple charge & light readout systems

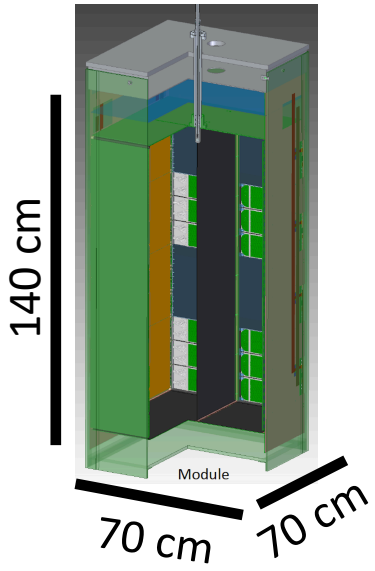
→ Enable more "shots-on-goal" for prototyping effort during COVID-19 pandemic

ND LArTPC: From Prototyping to Production to Installation

2019-2021
ArgonCube 2x2 Demonstrator 'ProtoDUNE-ND'

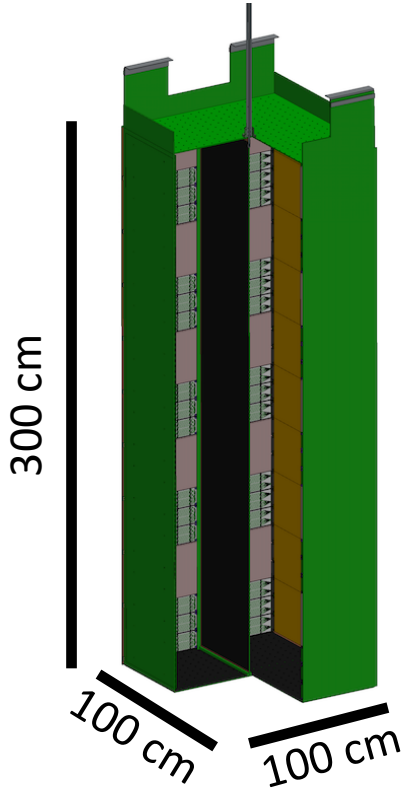
SingleCube,
then 1 module (Module 0),
then 4 modules (2x2)

Operated in cryostat at Bern,
then FNAL in NuMI beam

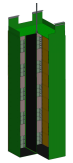


2021-2023
Full-scale ND Demonstrator

1 Full-scale ND module
Operated in single-module cryostat



2024-2026
Production



1 production 'first article'

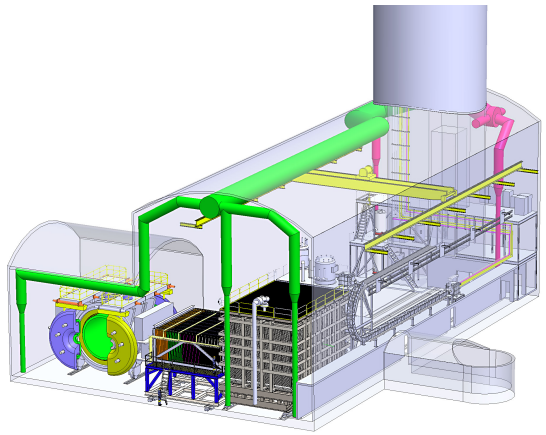
35 (+5) Production modules
Each fully tested in single-module cryostat

Deliverable: modules packed and ready for installation underground

2027-2029
Installation

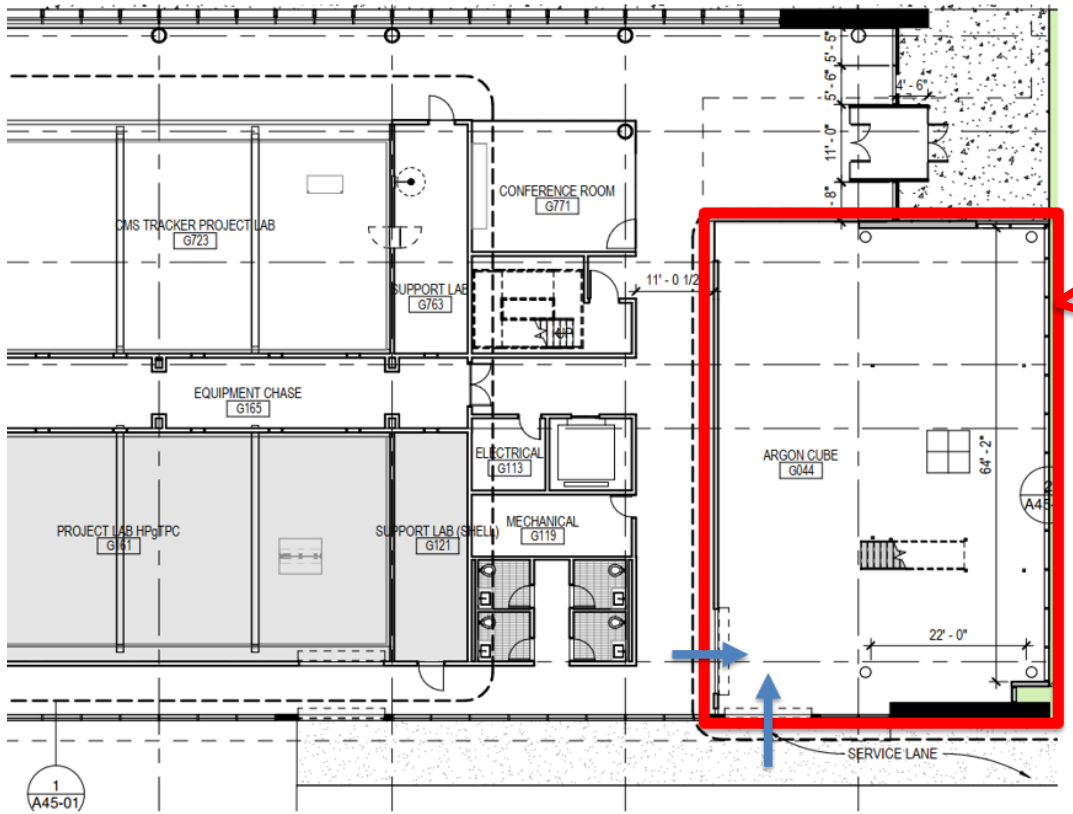
Support of TPC module installation in Near Site

Activity driven by Near Site Integration (NSI)

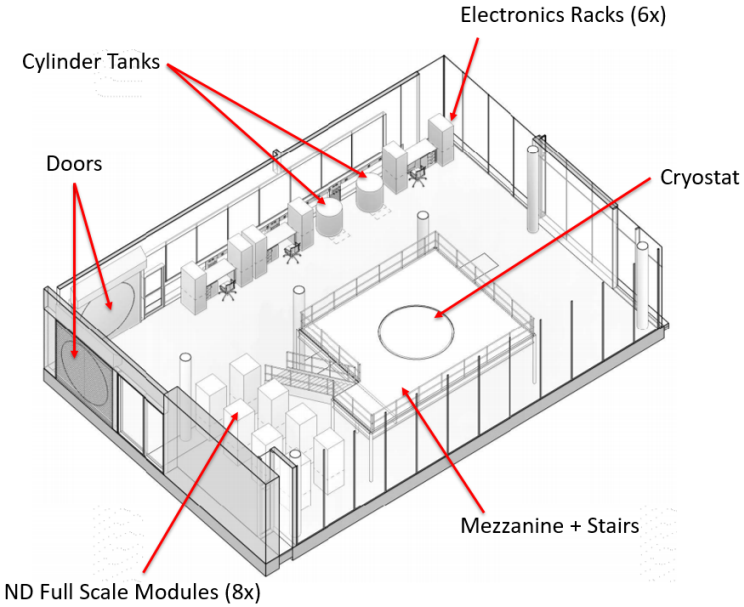


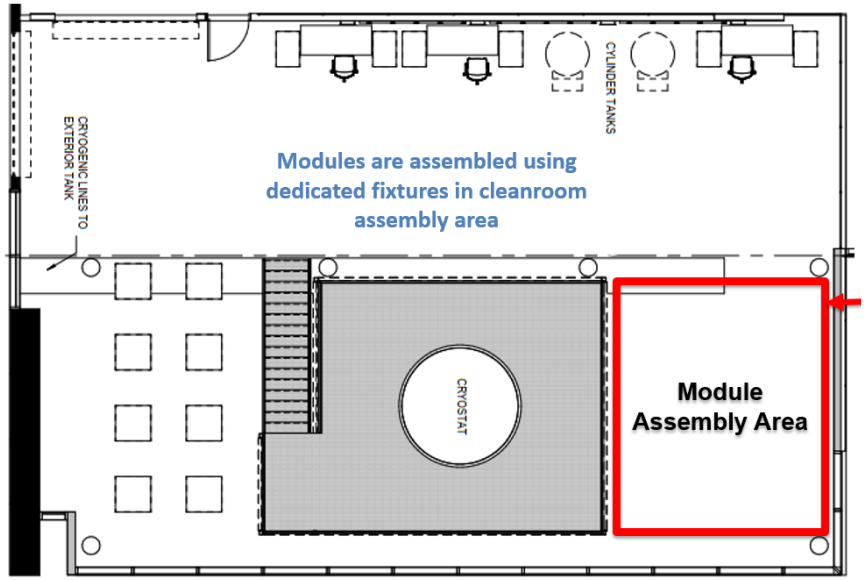
Module Integration Facility @ IERC

- ✓ High-bay sufficient for ~4m-tall module assembly
- ✓ **Cryostat(s) capable of hosting ~4m x 1m x 1m module**
- ✓ Crane with ~4m clearance above cryostat for module installation/removal
- ✓ **System for LAr purification, recirculation, and cooling**
- ✓ **Cleanroom for module assembly**



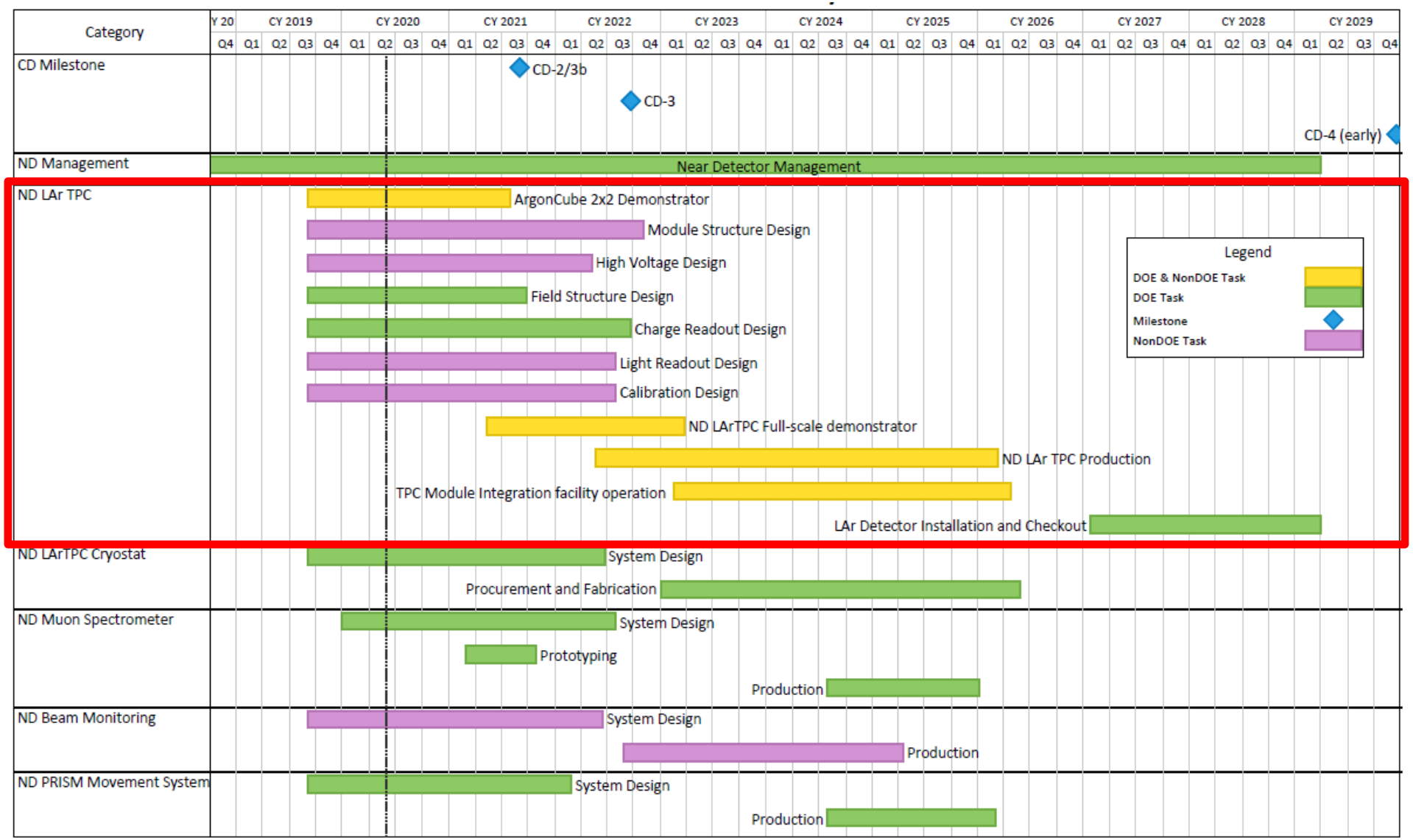
- Specs
  - 3167 ft^2
  - 12' X 12' Door Size
  - Temperature = 74°F +/- 2°F
  - Rel. Humidity = 50% +/- 10%
  - O_2 sensors
  - Vent for ODH purge
  - Sprinkler system
  - Power & ground @ walls every 11'
  - Data outlets @ walls every 11'
  - 25-ton gantry crane w/hook @ 25' (7.62 meters)
  - Services:
    - CDA
    - Vacuum
    - Nitrogen
    - Other: Local use Ar, LAr, LN2





Institutions: All

Summary schedule



Key Dates:

May 2021:
Preliminary Design Review

July 2022:
Final Design Review(s)

~2023:
Production Readiness Reviews

2026:
Completion of LArTPC module production & testing

2029:
Completion of installation & testing

Major Design Concerns

Identify and address any outstanding concerns with the existing design

Goal:

Rapidly address any major design concerns before we progress too far into the preliminary design

Today:

Requesting input from full Consortium. Please review/enter in the shared spreadsheet by next Thursday (Sep. 10):
https://docs.google.com/spreadsheets/d/11L_lNb8Jsgv6g3gW8x4JVjG3Mgt7q3aMzV4E1kbZpks

In 1 Week:

Discuss with the team of subsystem leads, and propose a plan for addressing each item.

In 4 Weeks:

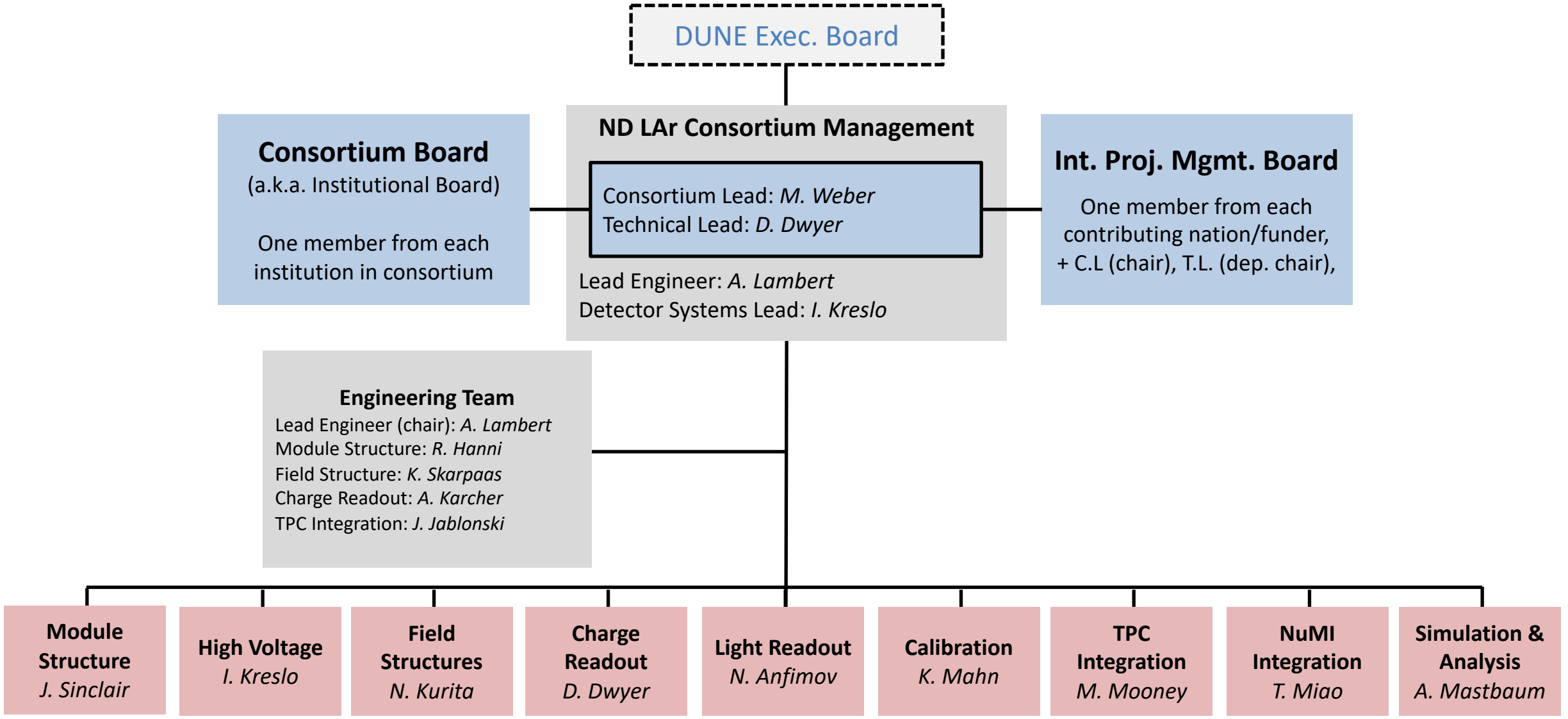
Report status to the full Consortium.

Summary

- Substantial work for our Consortium to perform, both near-term and long-term
- Many potential roles for new partners
- Activities in need of near-term help:
  - Simulation studies to help inform preliminary design
  - Analysis of prototype data to understand system performance, unexpected issues

Backup

Organization: ND-LAr (ArgonCube) Consortium



Interfaces

- DUNE Near Detector Consortia
  - International bodies responsible for delivering detector systems
- ND LArTPC Cryostat
  - Multiple interfaces: Mechanical, electrical, cryo, etc.
  - Cryostat engineer is also Consortium Lead Engineer (A. Lambert)
- LBNF Cryogenics
  - Provides LAr cryogenic system for ND LArTPC
- Near Site Integration
  - Manages interface between Near Detector and NSCF
  - Installation of Near Detector System
    - NSI provides coordination: installation engineer, general technician team
    - ND provides support: scientific labor and technical experts

ND Interface Matrix *A. Lambert*