DUNE ArgonCube ND LArTPC

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CDR review, 7-8-9 July 2020

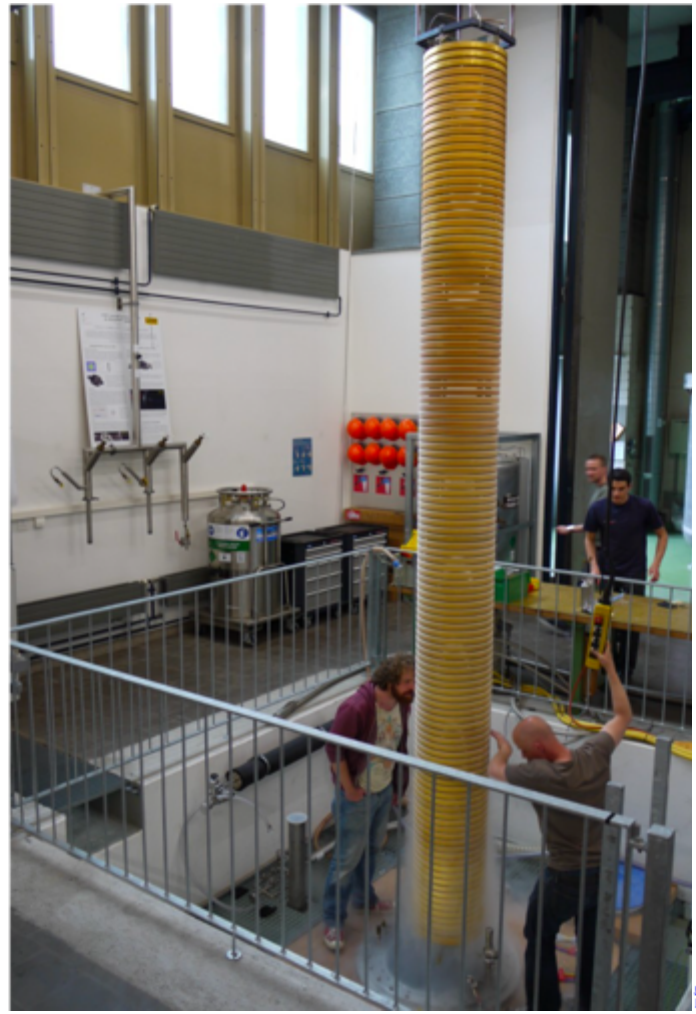
Near Detector Requirements

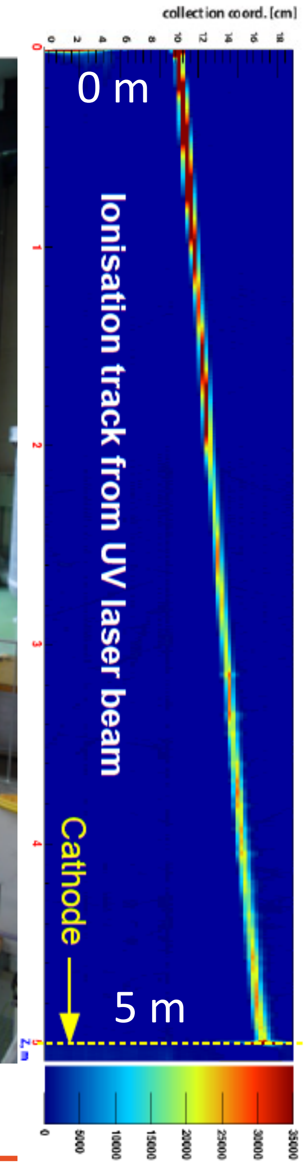
Predict the observed neutrino spectrum at the FD
Transfer measurements to FD (xsec, flux)

- Measure ν beam fluxes $\times$ cross section (on argon) at Near Site including nu_e → **LAr TPC**
- Classify FD neutrino interaction with LAr TPC Measure → **LAr TPC**
  - With sufficient signal rate for relevant neutrino interactions and fiducial mass → **O(100 ton) active volume** in LArTPC
  - Sufficient LAr acceptance/containment of relevant neutrino interactions; nu_mu and nu_e identification → Active LArTPC **3m height, 7m width, 5m depth**, with **downstream muon spectrometer**
  - Electron energy and angular resolution, thresholds → LArTPC with **pixelated readout**, **optical modularity, E-Field, Purity**
  - Cope with signal pileup at Near Site → LArTPC with **pixelated readout**, **optical modularity timing <20 ns**
  - Timing for matching among modules and externally → **Timing <20 ns**
  - Disentangle energy-dependence of cross section and detector response → **Off-axis measurements** with LArTPC

History: ArgonTube

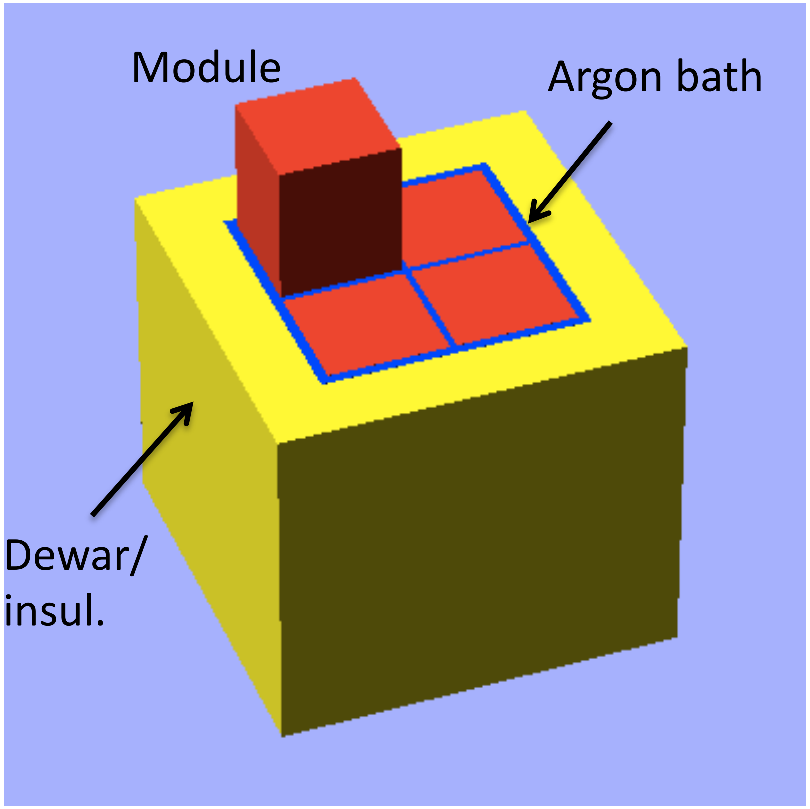
- Longest possible drifts for largest masses of LAr
- 5m ionization electron drift achieved
- Studied the physics of voltage breakdowns in LAr and identified limitations of field
  (40 kV/cm).
  Identified possible mitigation.
- Achieved >350 kV with in-situ generation of HV





Modular approach (2014)

- Short horizontal drift, “low” HV, less stringent purity requirement (robust, low risk)
- Independent modules
- Common bath to all modules
- Thin walls separating modules
- Modules can be removed for maintenance and upgrade
- Distributed production
- Cold electronics, pixels ?



-> The right concept for the ND,
for these and other reasons (e.g. light containment) !

Near Detector Requirements

Predict the observed neutrino spectrum at the FD
Transfer measurements to FD (xsec, flux)

Measure ν beam fluxes × cross section (on argon) at Near Site including nu_e	**LAr TPC**
Classify FD neutrino interaction with LAr TPC Measure	**LAr TPC**
With sufficient signal rate for relevant neutrino interactions and fiducial mass	**O(100 ton) active volume** in LArTPC
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Electron energy and angular resolution, thresholds	LArTPC with **pixelated readout**, **optical modularity, E-Field, Purity**
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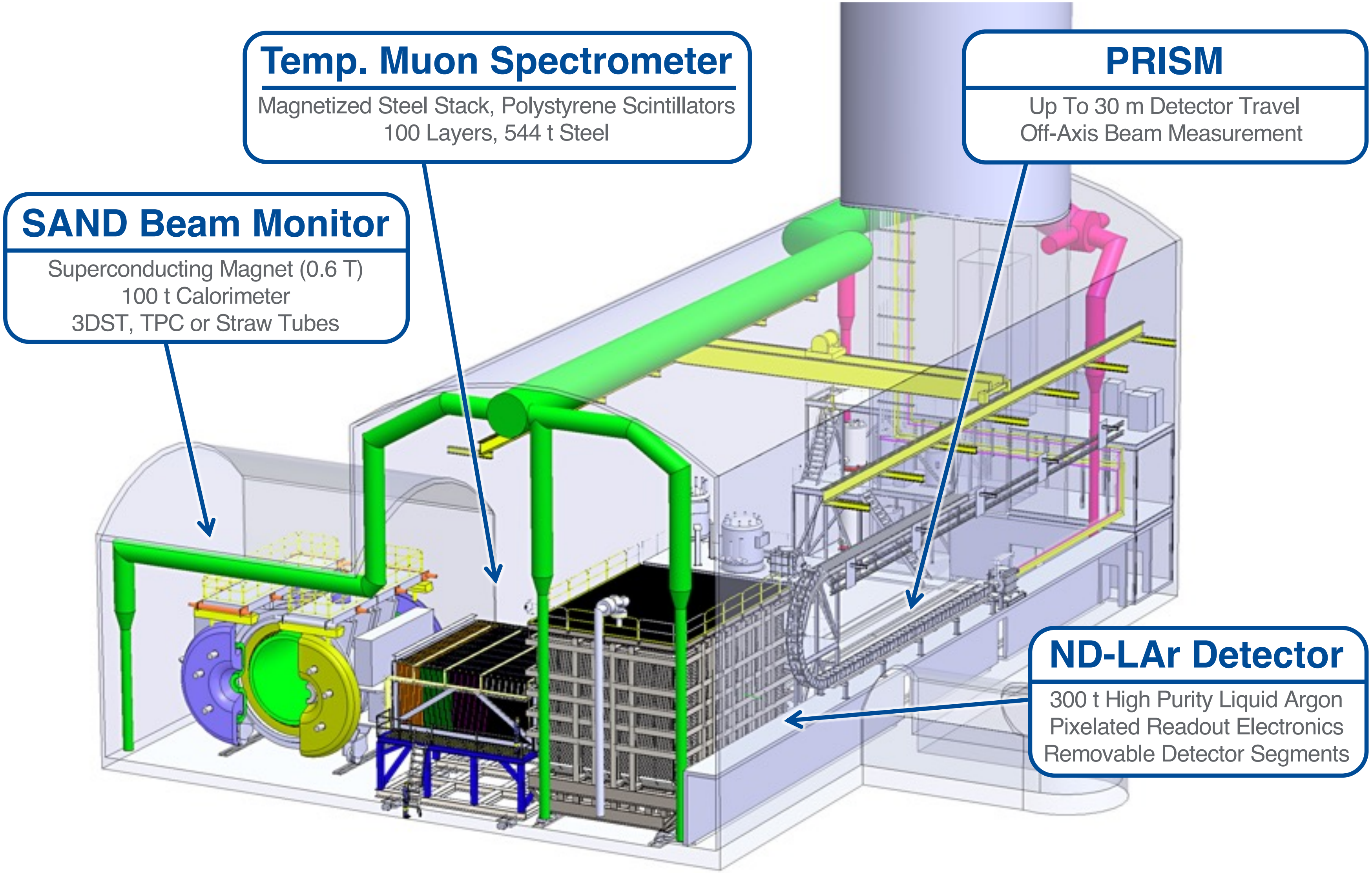
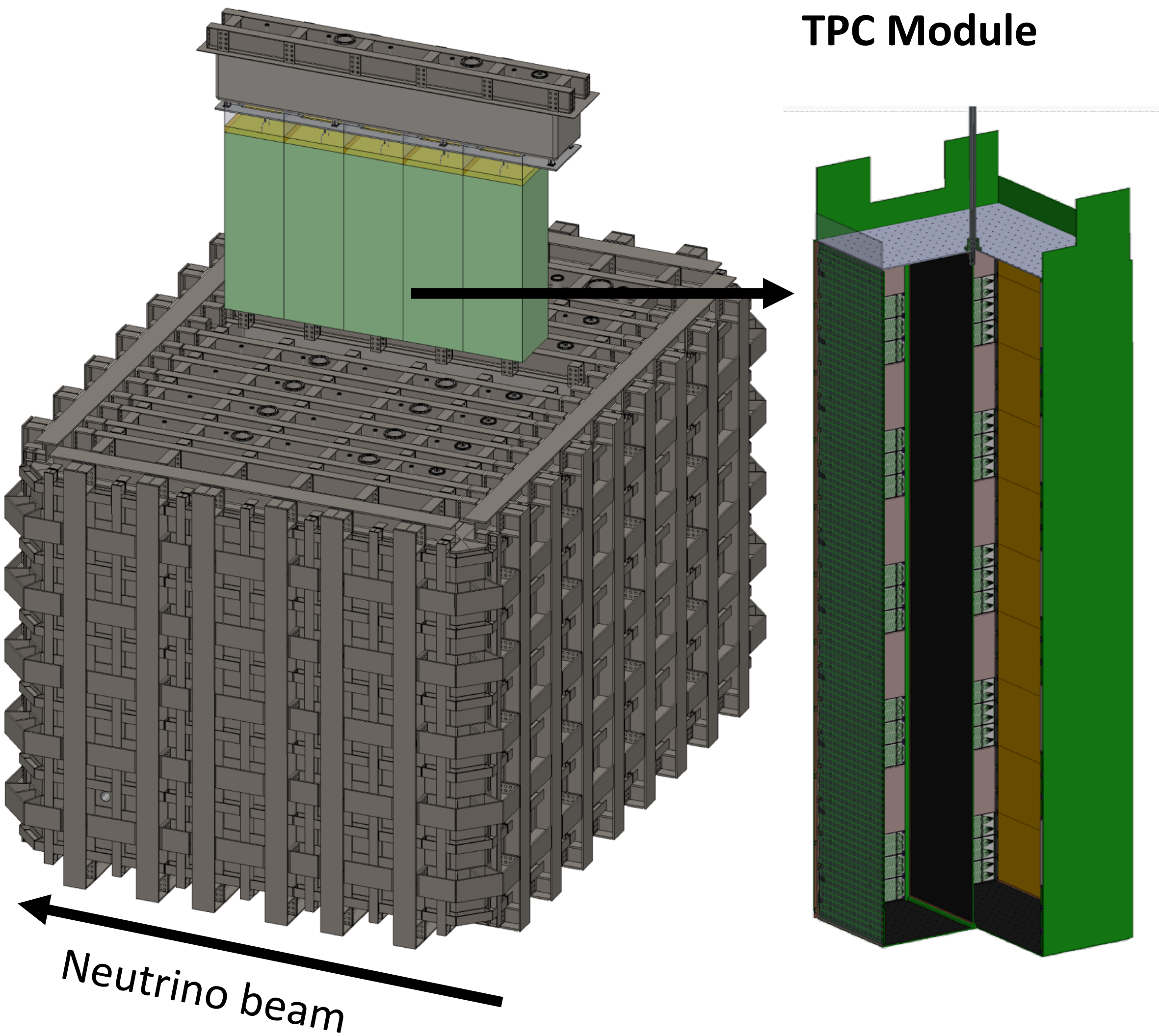
Timing for matching among modules and externally	**Timing <20 ns**
Disentangle energy-dependence of cross section and detector response	**Off-axis measurements** with LArTPC

DUNE ‘Day-one’ Near Detector System



Near Detector LArTPC Design



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*

- Operation for 10-20 year with accessibilty for repair / upgrades

Height and length for hadronic containment

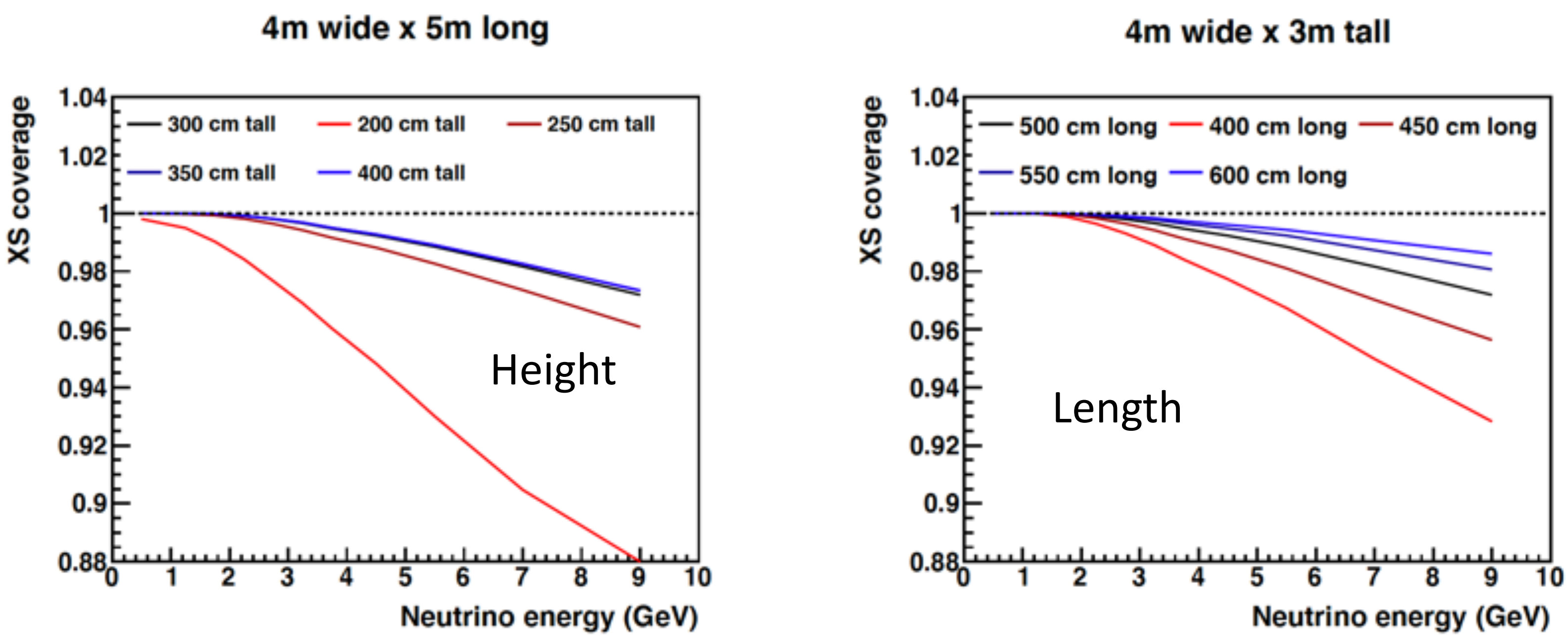


Figure 2.22: The cross section coverage, defined in the text, is shown for various LArTPC heights (left) and widths (right) as a function of true neutrino energy. In each plot, the other two dimensions are held constant at the baseline values while the third is varied. The optimal dimensions for hadron containment are determined to be 4 m × 3 m × 5 m.

Width determined by the muon

- To contain muons emitted at large angles with respect to the beam, a width of 7m is required.

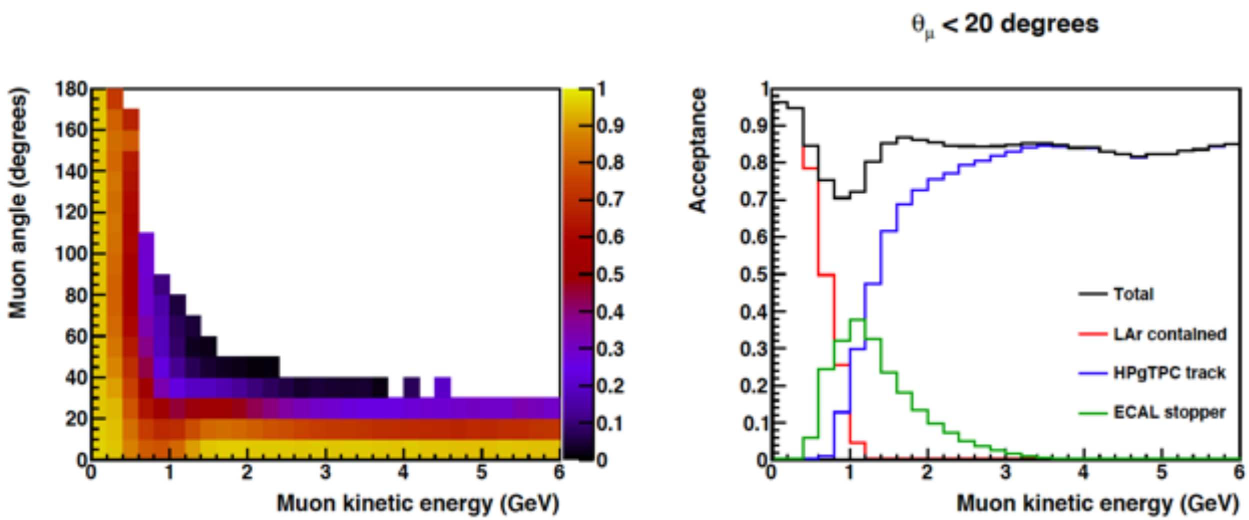
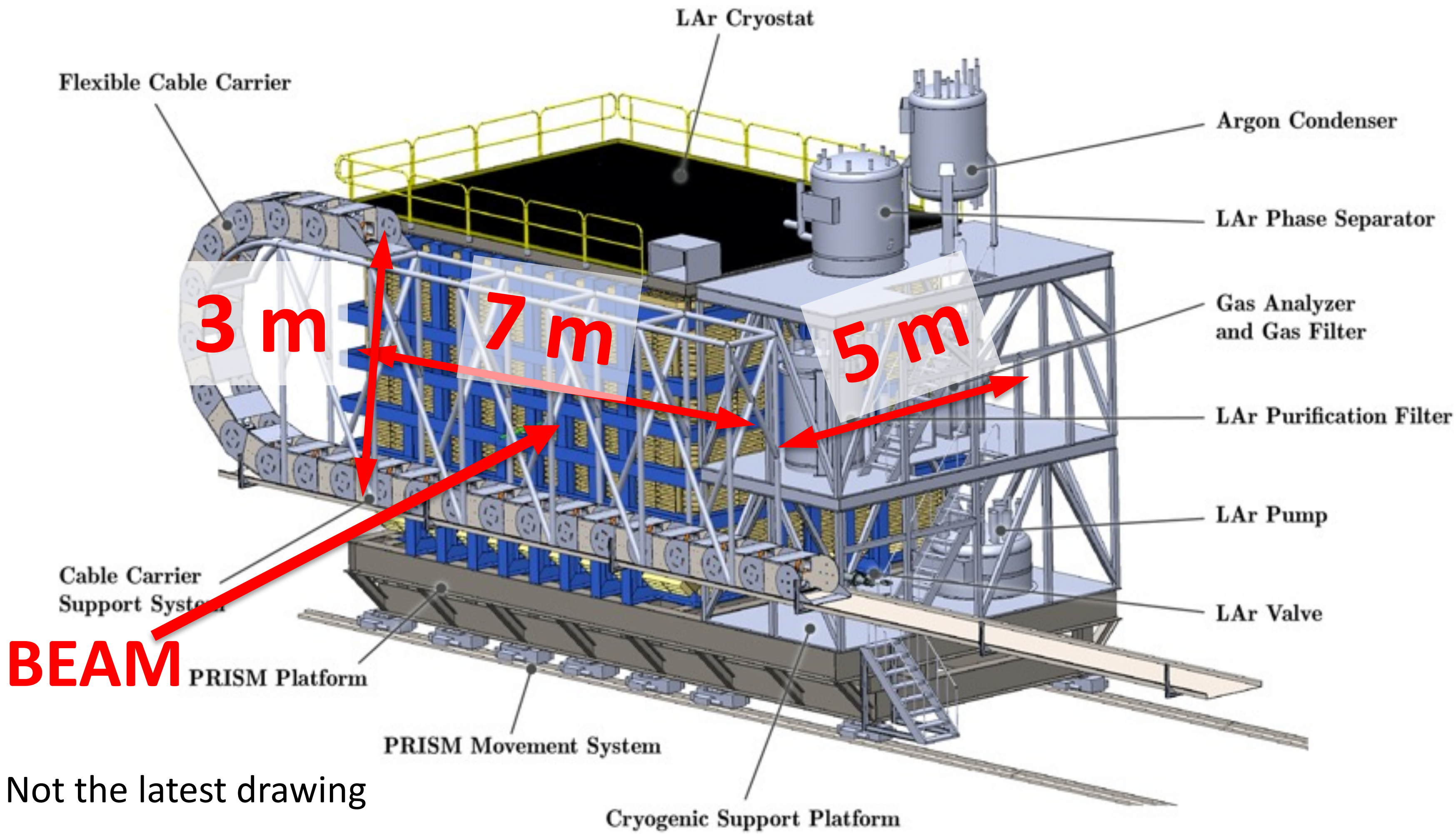


Figure 2.23: Muon acceptance shown as a function of true muon kinetic energy and angle with respect to the neutrino beam (left), and projected onto the muon kinetic energy axis for small angles (right). The acceptance includes muons contained in the LArTPC as well as those that stop in the MPD electromagnetic calorimeter (ECAL) or match to tracks in the high-pressure gaseous argon TPC (HPgTPC).



Not the latest drawing

Event rate

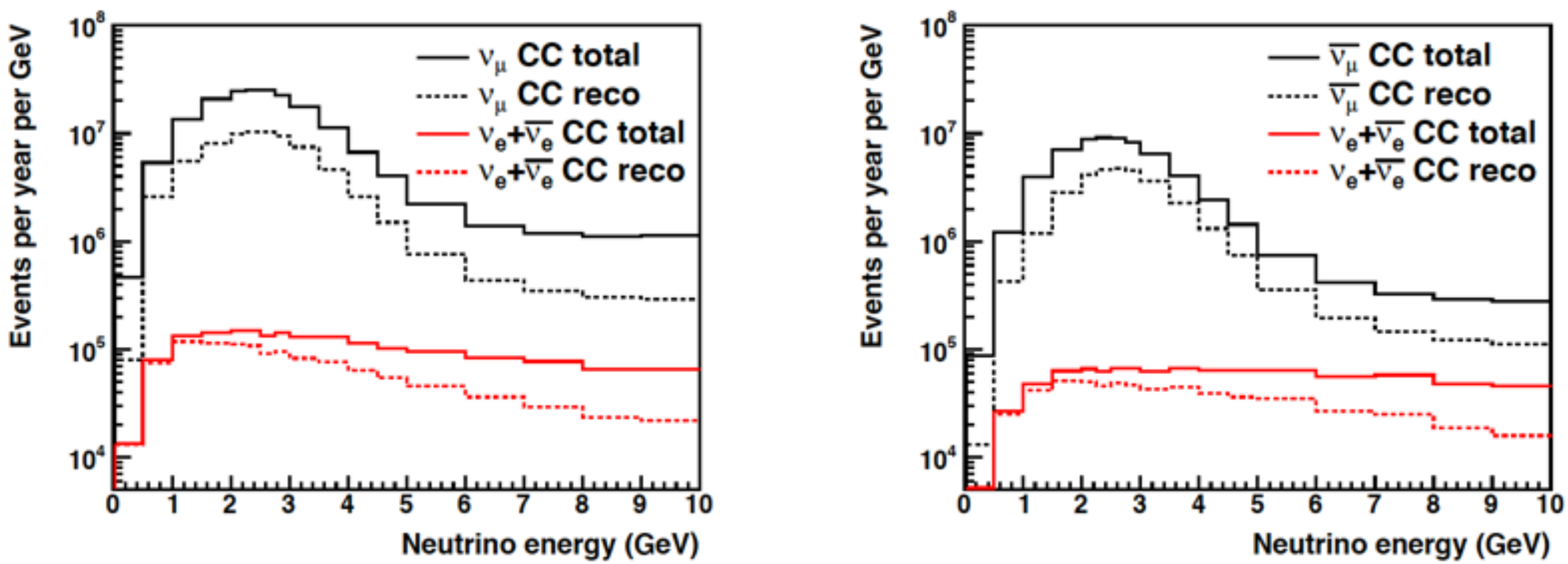
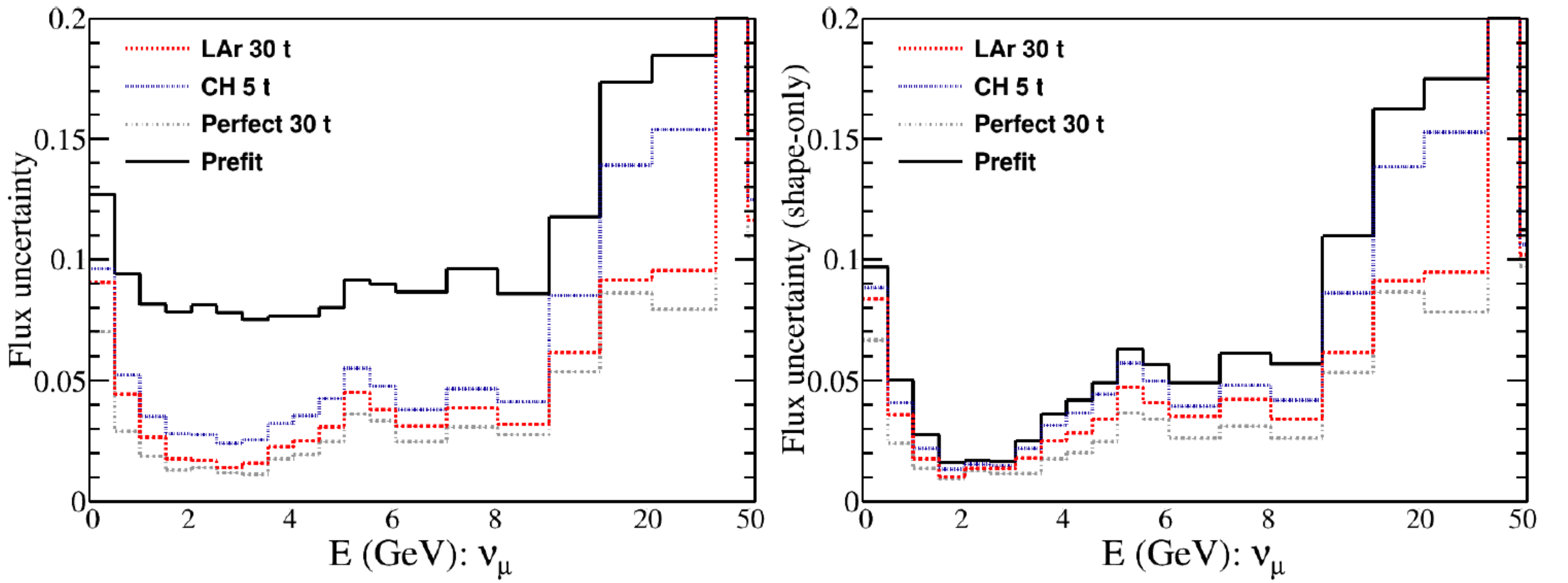


Figure 2.27: The rate of CC interactions in the fiducial volume of ArgonCube as a function of true neutrino energy, expressed per year of exposure assuming 1.2 MW beam intensity in FHC (left) and RHC (right) beam polarity.

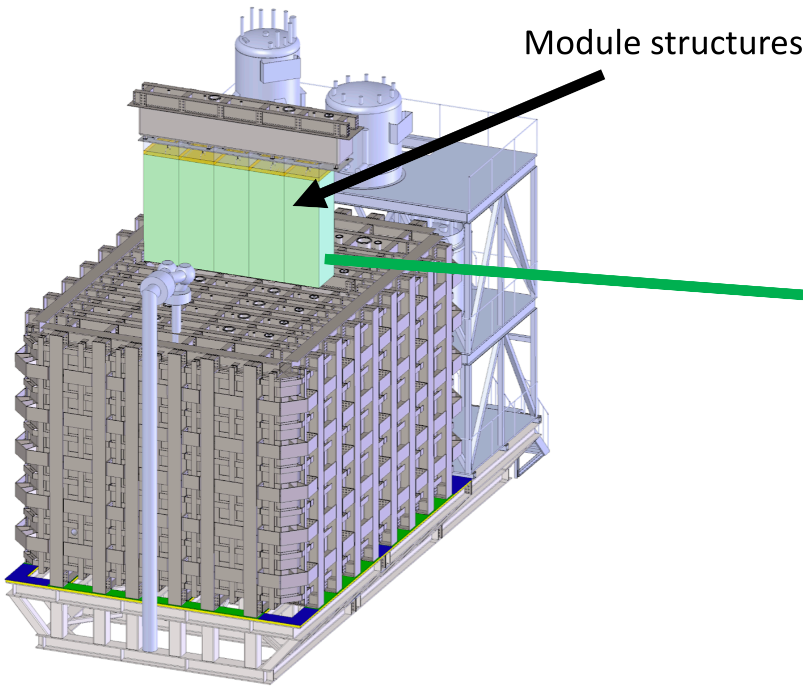
Flux constraint



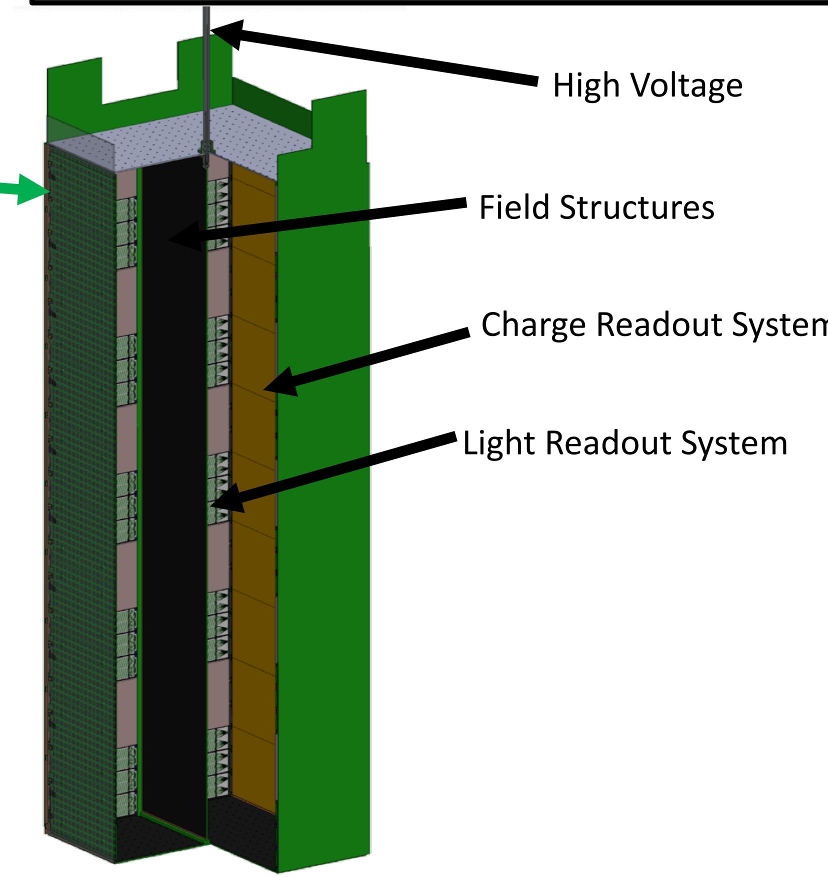
(a) Rate+shape (b) Shape-only

Figure 2.29: Rate+shape and shape-only bin-by-bin flux uncertainties as a function of neutrino energy for a five year exposure of the baseline 1.2 MW beam, with various detector options, compared with the input flux covariance matrix before constraint.

ArgonCube ND LArTPC Consortium



Design, prototyping, production, installation and commissioning of the ND LAr TPC for DUNE

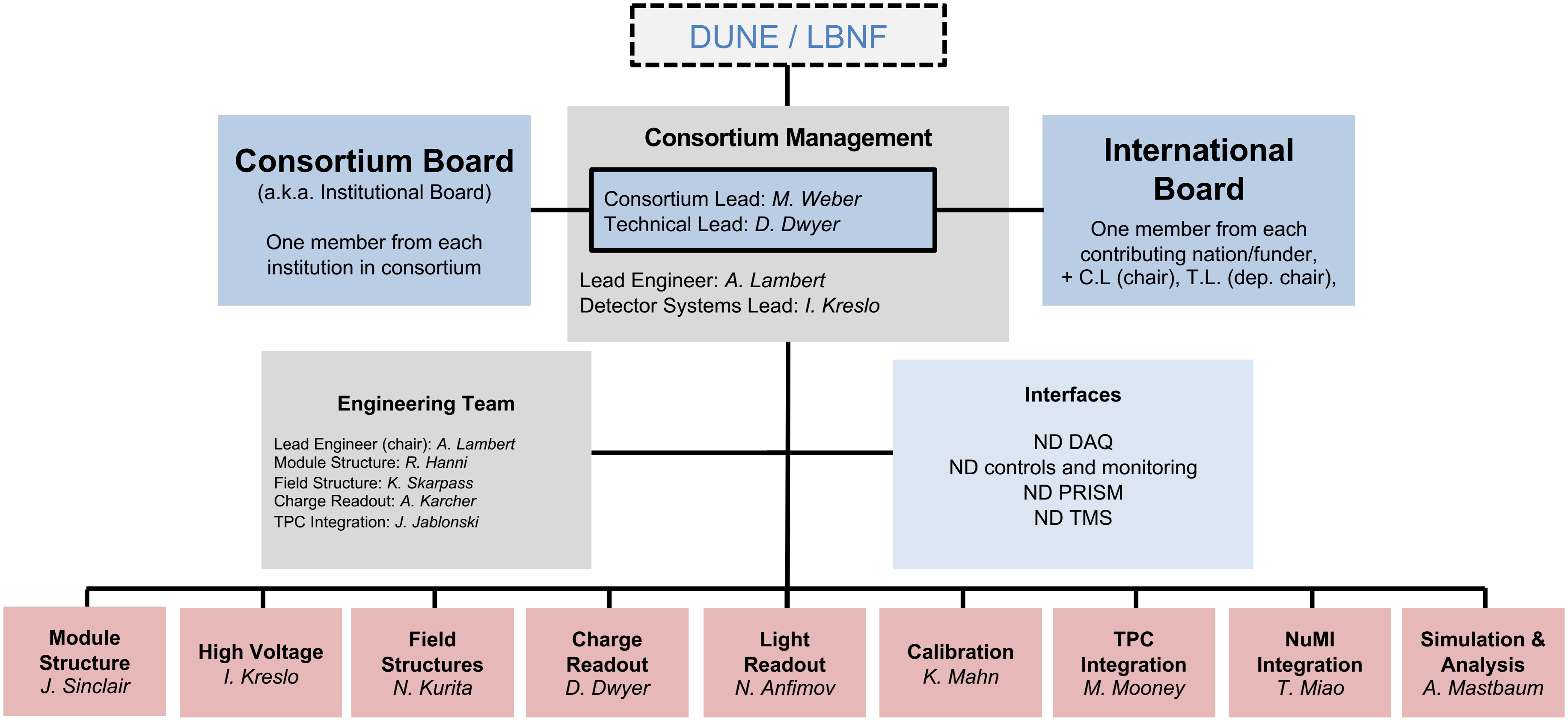


Subsystem	Institutions
Module Structure	Univ. of Bern
HV	Univ. of Bern
Field Structure	SLAC, CSU,
Charge Readout	LBNL, Caltech, CSU, Rutgers, UC-Davis, UCSB, UPenn, UTA
Light Readout	JINR, Univ. of Bern
Calibration	MSU, JINR, Univ. of Bern
TPC Module Integ.	LBNL, CSU, Univ. of Bern
TPC Module Install.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

ArgonCube ND LAr Consortium

- LBNL
- RAL
- U Rochester
- U Pennsylvania
- ANL
- Rutgers U
- U Iowa
- U Minnesota
- U Oxford
- Fermilab
- UCSB
- Wichita State U
- William and Mary
- U Bern
- Caltech
- CSU
- SLAC
- UC Irvine
- UC Berkleley
- U Sheffield
- U Manchester
- York U
- JINR
- U Lancaster
- ANL
- Tufts U
- UC Davis
- U Cambridge
- UTA

Organization: DUNE ND LArTPC ArgonCube Consortium



Interfaces

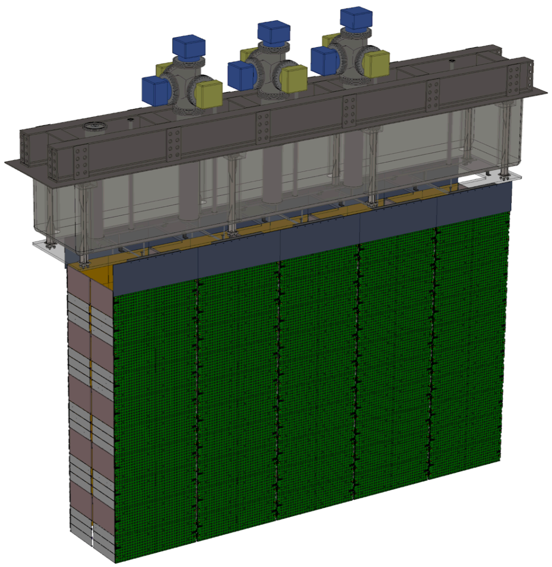
- DUNE Near Detector Consortia
  - International bodies responsible for delivering detector systems
- ND LArTPC Cryostat
  - Multiple interfaces: Mechanical, electrical, cryo, etc.
  - Cryostat engineer is also ND LArTPC Lead Engineer
- LBNF Cryogenics
  - Provides LAr cryogenic system for ND LArTPC
- 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

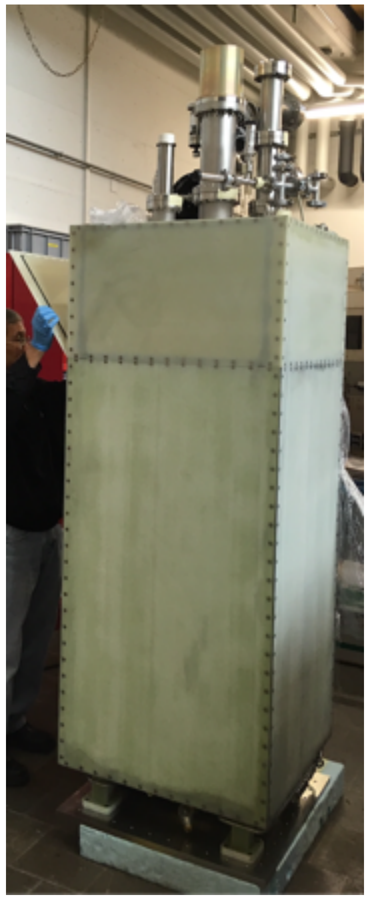
	LArTPC Cryostat	LArTPC	DAQ	LBNF	NSI&I	MPD	PRISM	SAND
LArTPC Cryostat		1 3	1	1 2	1 3	1	1 3	1
LArTPC	1		1 4	1 2				
DAQ	1	1 4			1			
LBNF	1 2 3	1 2 3			1 2			
NSI&I	1		1	1 2		1	1	1
MPD	1				1			
PRISM	1				1			
SAND	1				1			

Module Structure

Five Module Set



Prototype Module



U Bern

Key Design Features:

Module structure optically isolates each TPC
→ *Containment/localization of scintillation light*
→ *Helps LAr purification cycle*
→ *HV per module/set, to reduce systemwide HV risks*
→ *'Swappable' to simplify repair, upgrades*

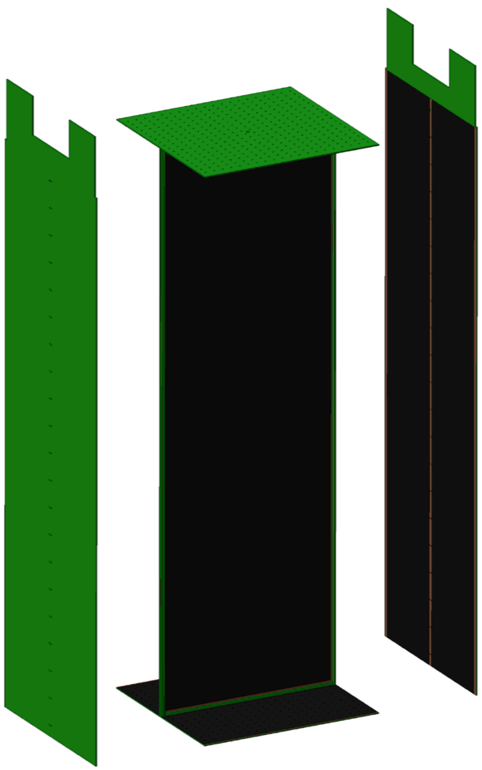
Stainless steel top flange
→ *Provides interfaces for cryogenics, HV, instrumentation, detector readout*

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

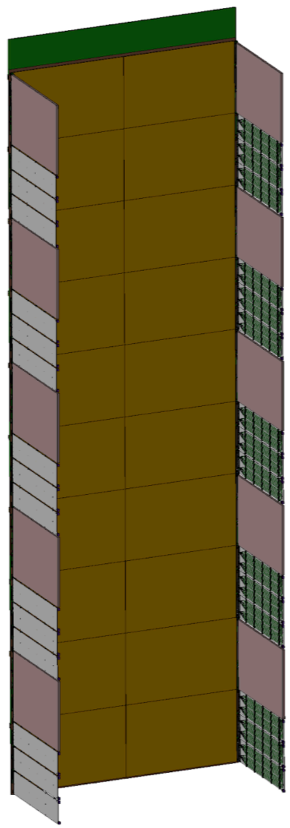
Module instrumentation and fittings
→ *Monitor module LAr level, temp, pressure*
→ *Manage LAr flow through module*

TPC Module Concept

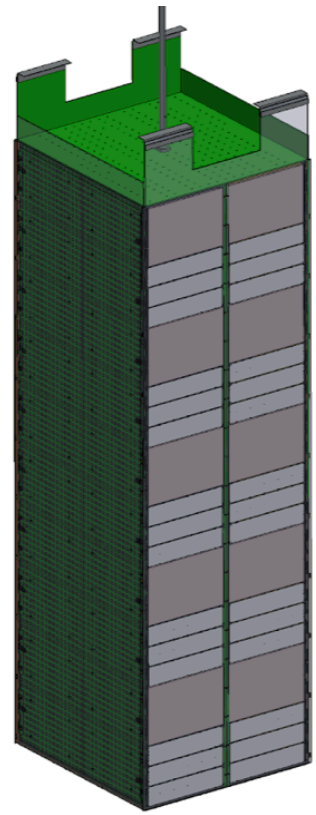
Cathode and Field Cage



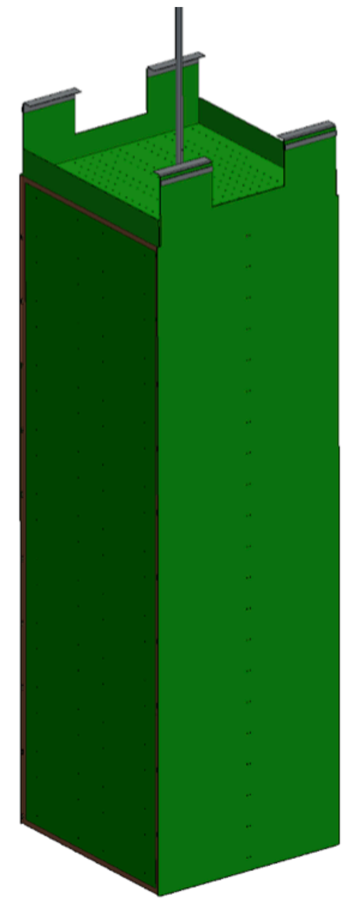
Charge & Light
Readout Anode



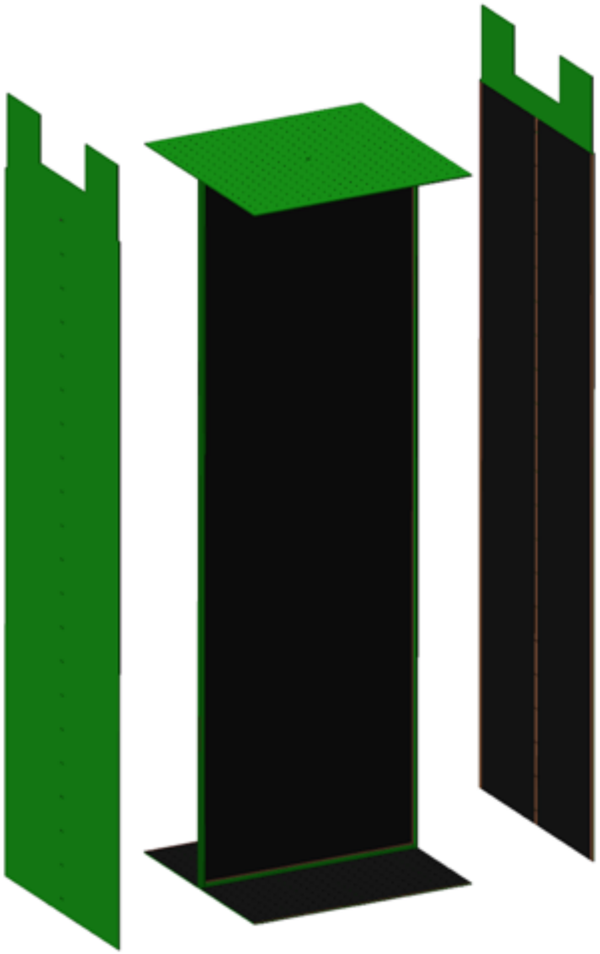
TPC Assembled
(Cath, FC, + 2 Anodes)



Module



Field Structures



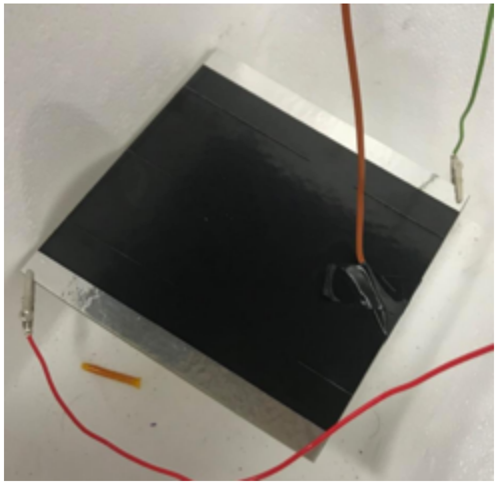
Key Design Features:

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

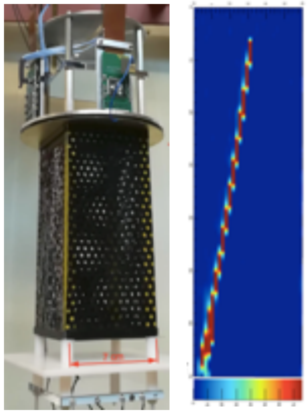
Resistive polyamide sheet laminated on G10 panels
→ *Reduces risks from accidental HV discharge*
→ *No resistor chain; reduce single-point failure risk*
→ *Low-profile: maximizes active volume*

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

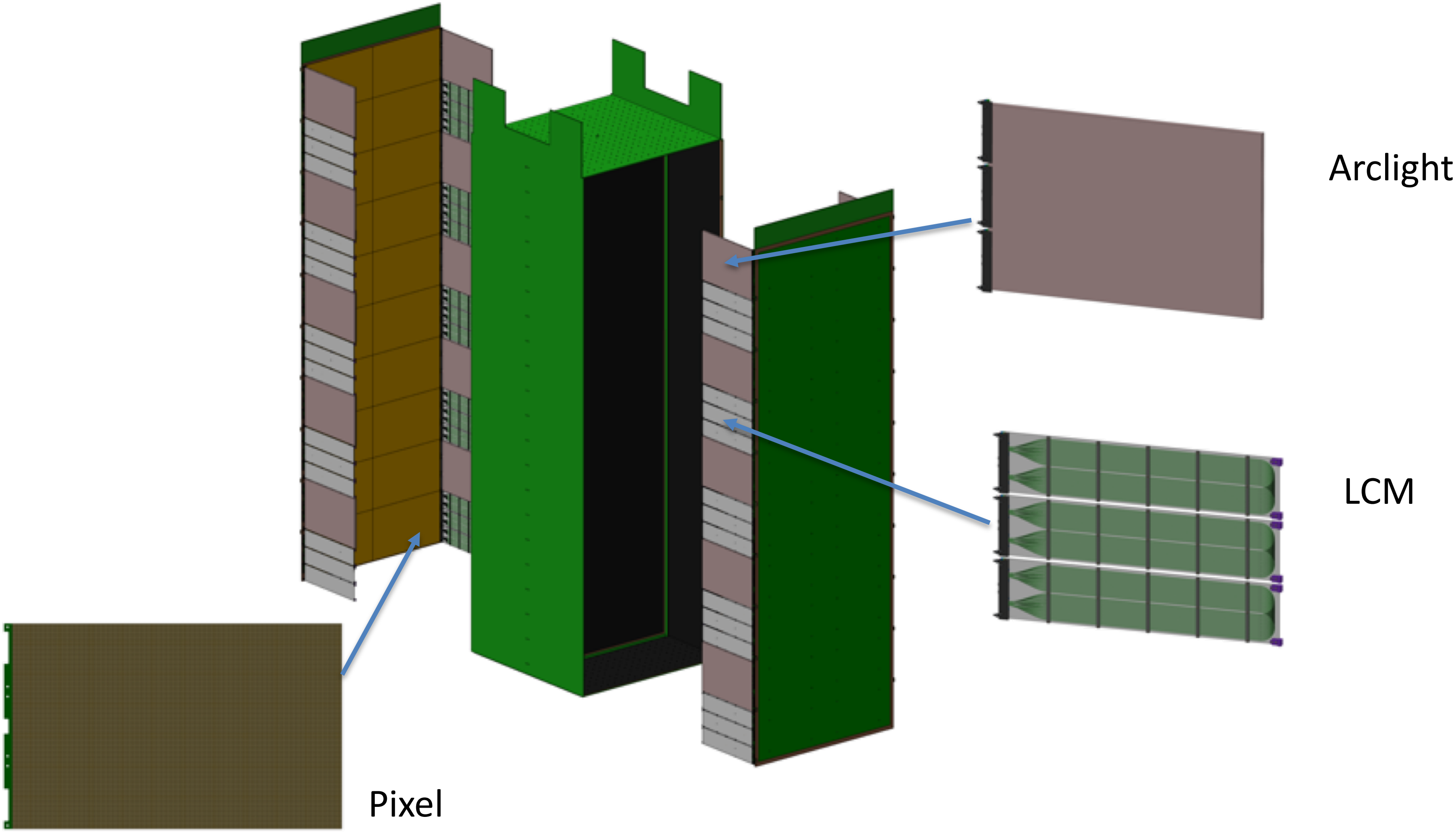
Cryogenic test of resistive sheet (GOhm / square) laminated on G10 panel @ SLAC



Resistive sheet LArTPC @ BERN



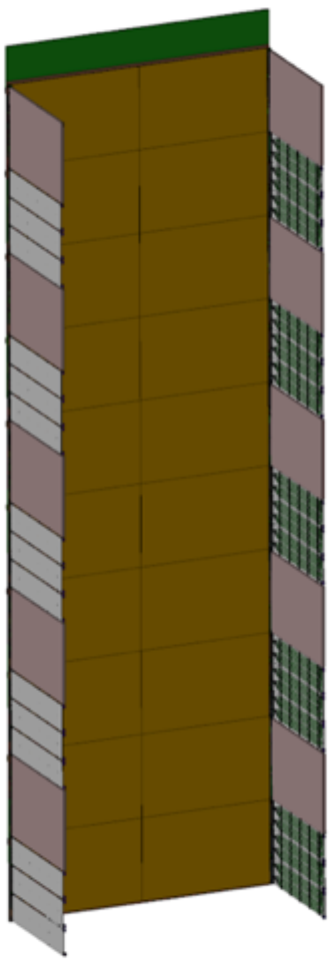
Module with charge and light readout



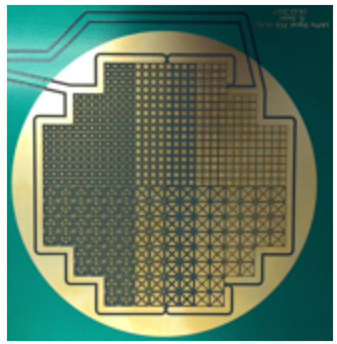
Dedicated engineering talk for details

Pixelated Charge Readout

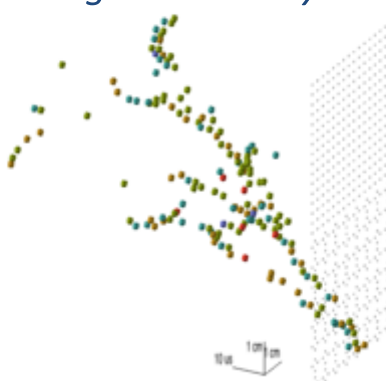
Pixelated Anode



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

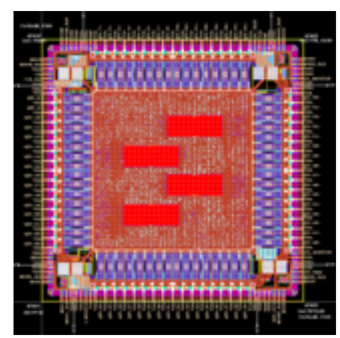
→ *Provides low-noise, low-power, cryogenic readout*
→ *SOC: amplification, digitization, triggering, readout*
→ *Implements highly-scalable control, I/O architecture*

LArPix Controller System

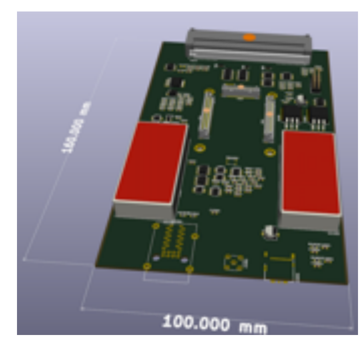
→ *Leverages commercial Zynq (CPU+FPGA) system with simple custom interface PCB to control large-scale pixel system (~1 controller per 50k pixel channels)*

LArPix-v1 ASIC

LArPix-v2 ASIC

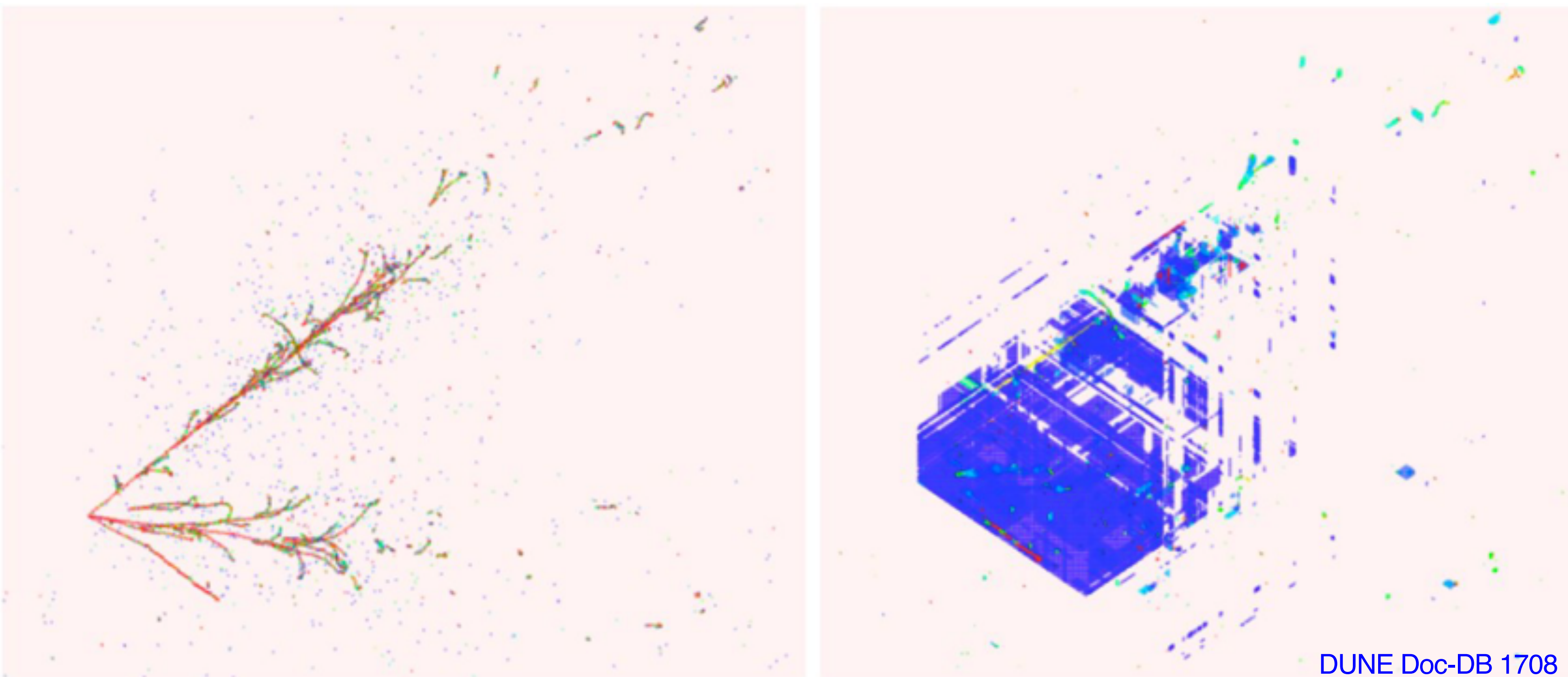


LArPix-v2 Controller



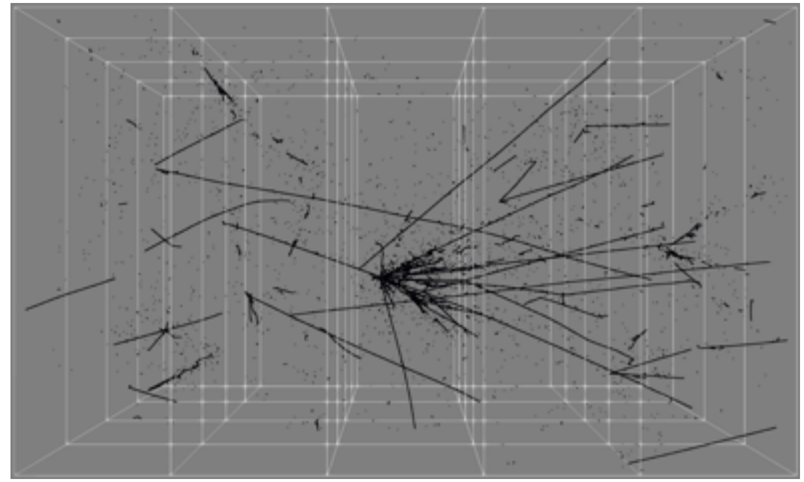
Unambiguous readout

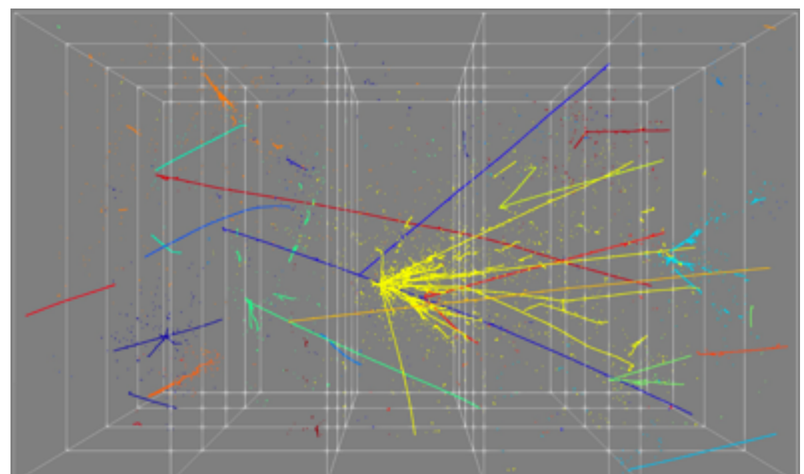
3 GeV ve simulated in BNL's Wire-Cell



Timing / Light

- Unambiguous charge R/O allows to reconstruct "busy" events
- Still difficulties due to pile-up:
  - Spill (10 µs) < Drift window (250 µs)
- Use light info to associate isolated/detached deposits to the correct vertex – fast neutrons
  - Contained prompt scintillation
  - <20 ns resolution

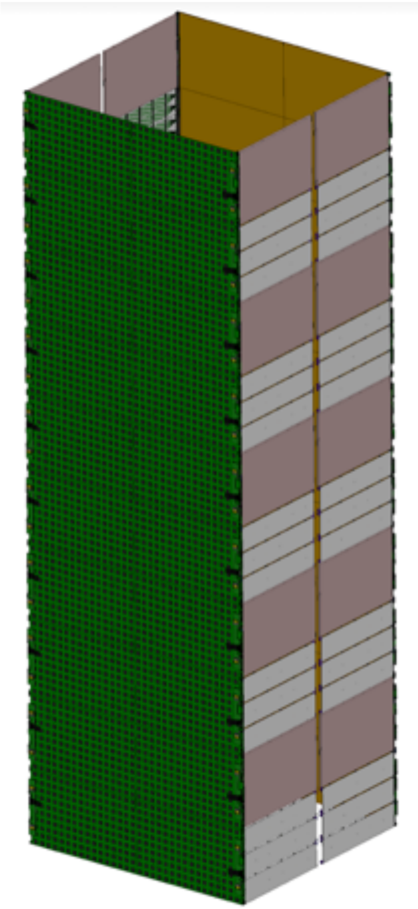




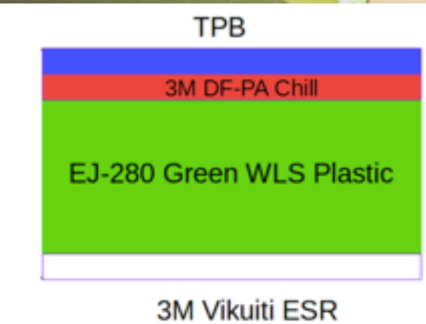
1 MW 3 horn optimised spill, FHC, including rock. Colouring by charge R/O.

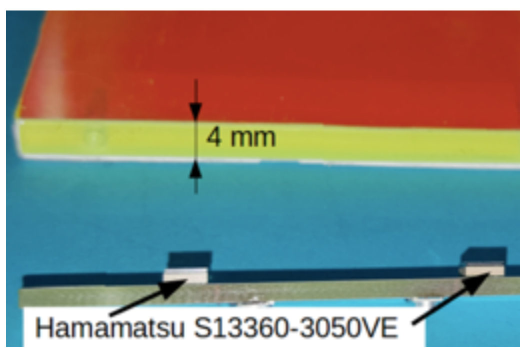
Advanced Light Readouts

Large area light collection



ArcLight: Dichroic light-trap design





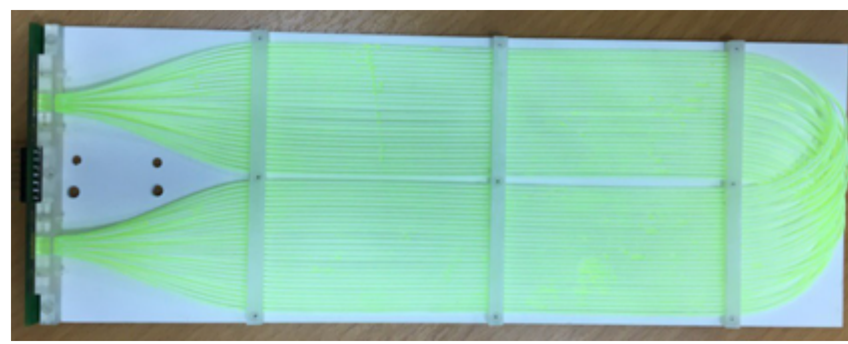
Key Design Features:

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*

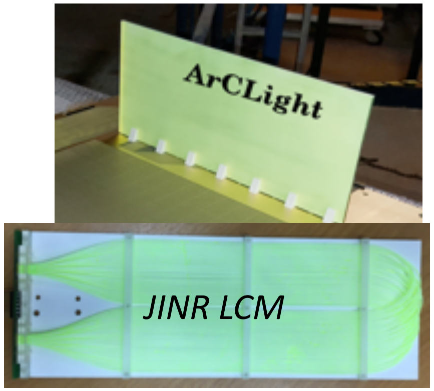
LCM: Fiber-bundle based light collection module



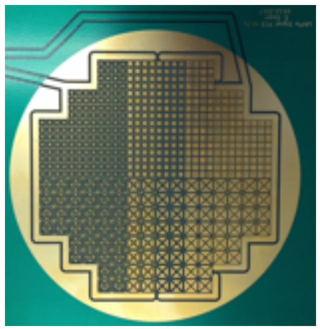
ND LArTPC ArgonCube Technology R&D

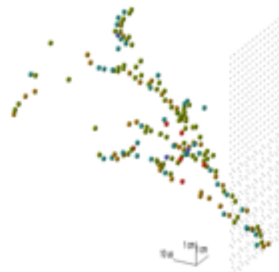
Technology Prototypes (2016-2018)

Enhanced Light Readout

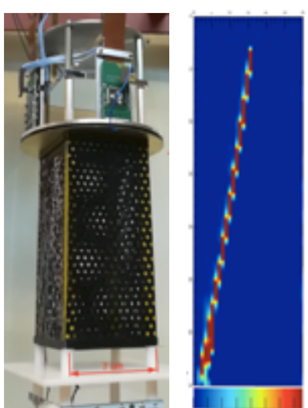


Pixel Charge Readout

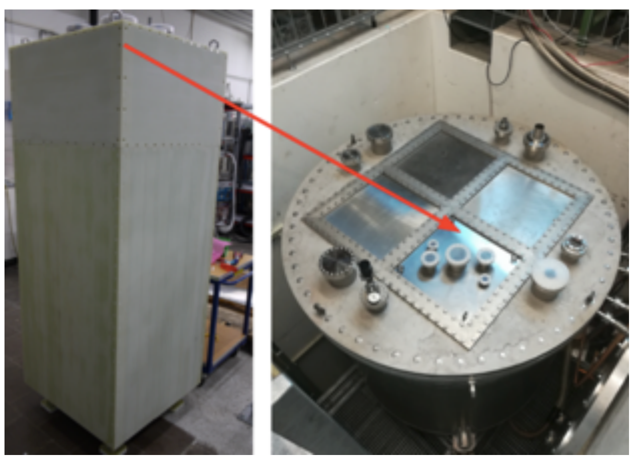




Resistive Field Cage and Cathode



Modular TPC Design

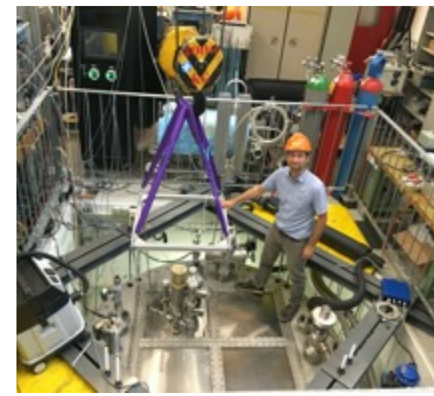


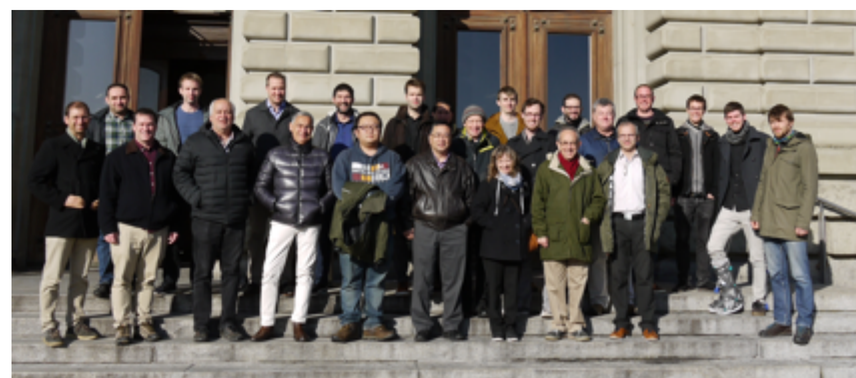
Near Detector Prototype (2019-2021)

ArgonCube 2x2 Demonstrator

→ 4 LArTPC modules, 3-tons active volume

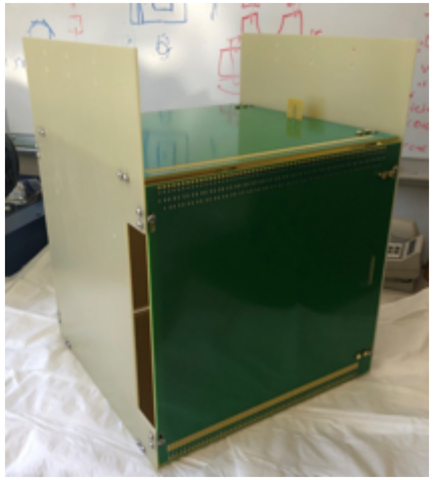
Operate at Bern in late 2020, then in NuMI Neutrino beam in 2021



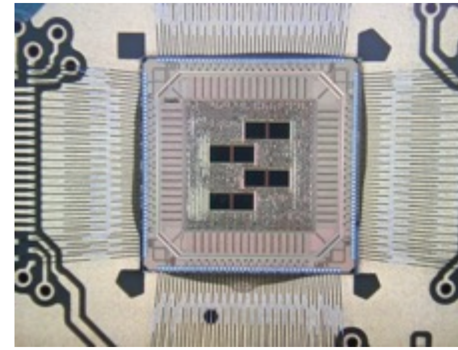


ArgonCube 2x2 Demonstrator: Recent Progress

Single Cube



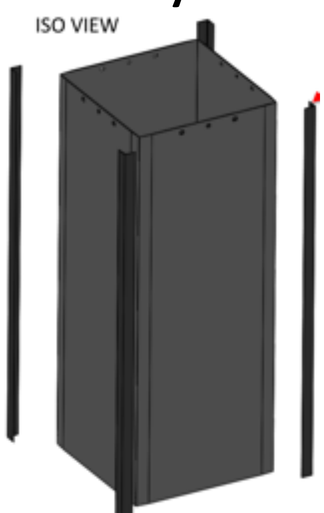
LArPix-v2 Charge Readout Testing LBNL



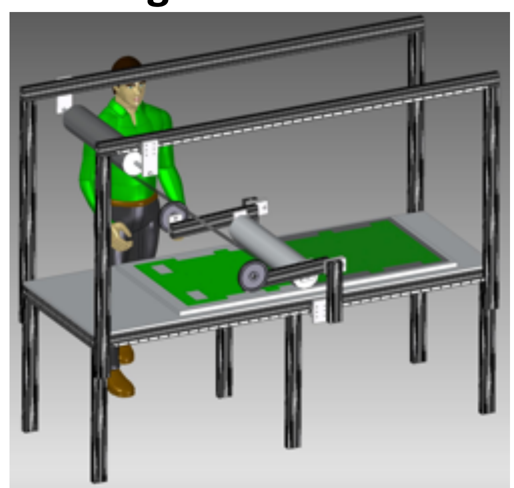
Cryogenics and Purity Testing System Bern

Tests of Module Assembly and Cryo-robustness CSU

Hermetic Module Assembly Bern



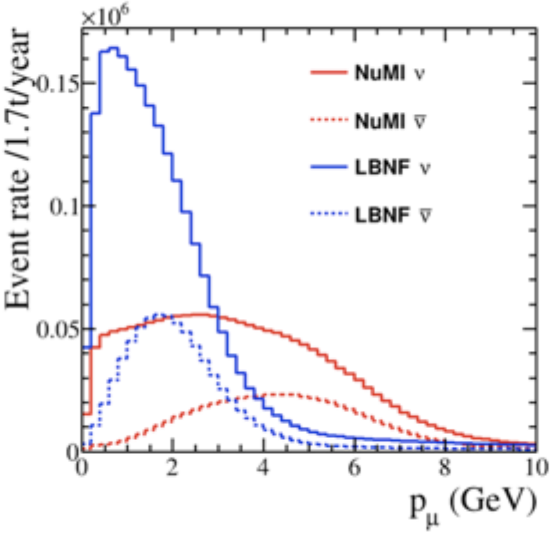
Field Cage Lamination SLAC



ProtoDUNE-ND: ArgonCube 2x2 @ NuMI

Stepping-stone to Near Detector

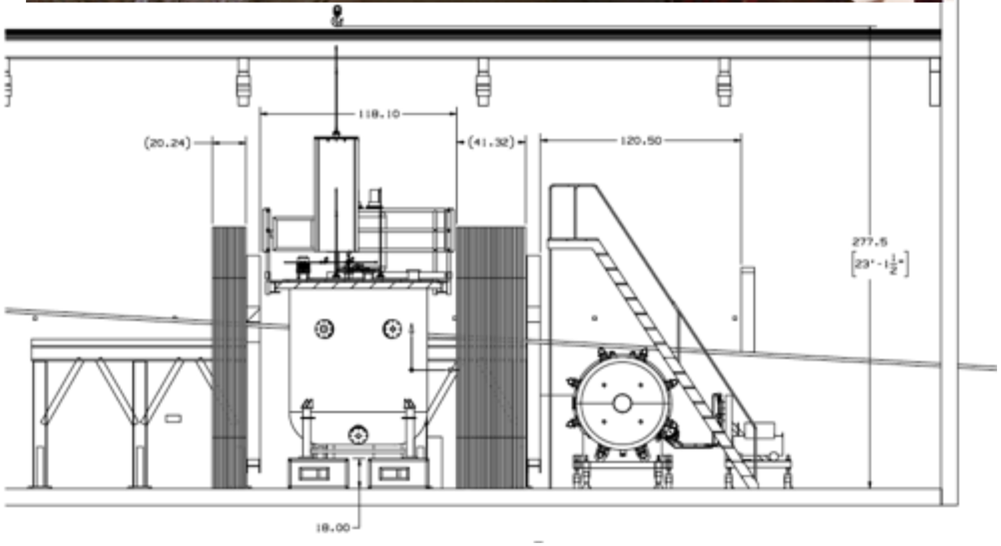
NuMI neutrino rates and energy spectrum similar to planned DUNE LBNF beam



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



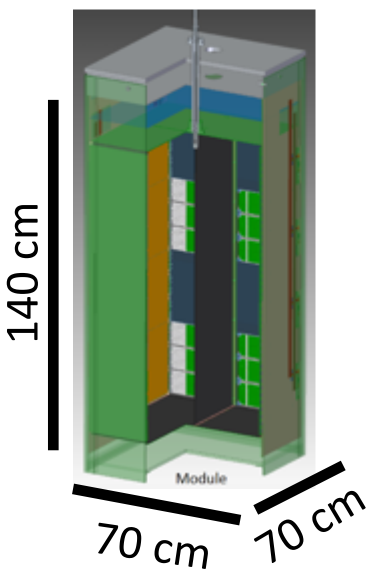
TPC Module Integration and Testing

2019-2021
ArgonCube 2x2 Demonstrator

4 (+1) modules

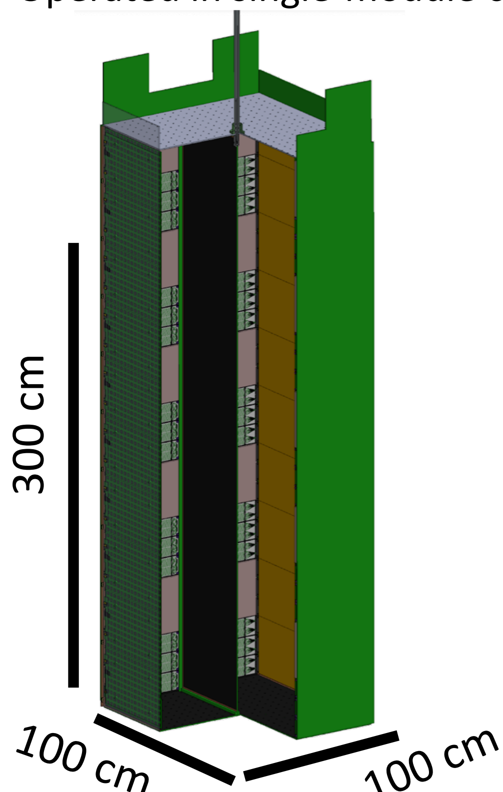
Operated in existing cryostat at Bern, then FNAL (NuMI)

Technical demonstrator

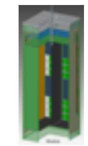


2021-2023
Full-scale ND Demonstrator

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



2024-2026
Production



1 production 'first article'

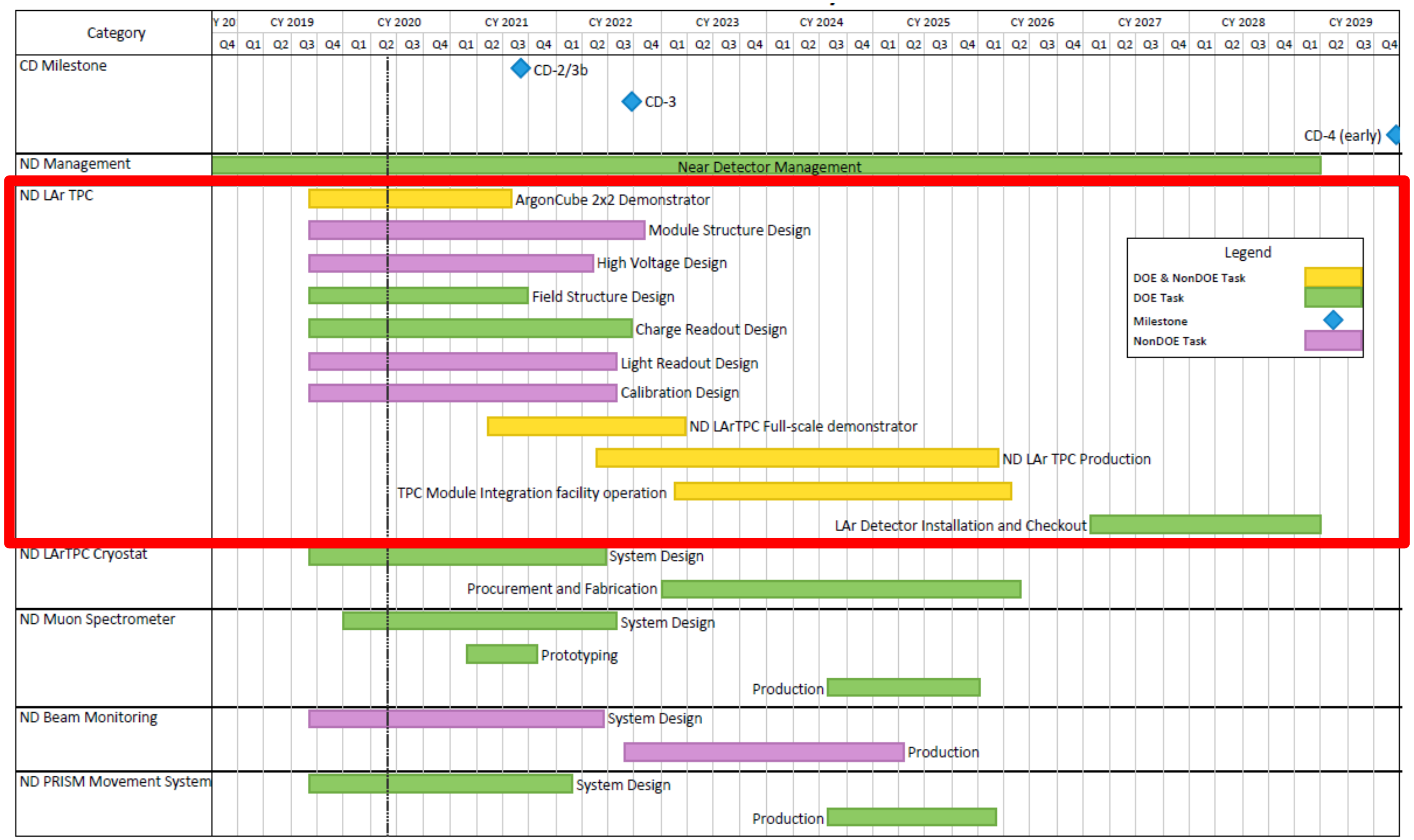
35 (+5) Production modules
Each fully tested in single-module cryostat

Deliverable: modules packed and ready for installation underground

Costs

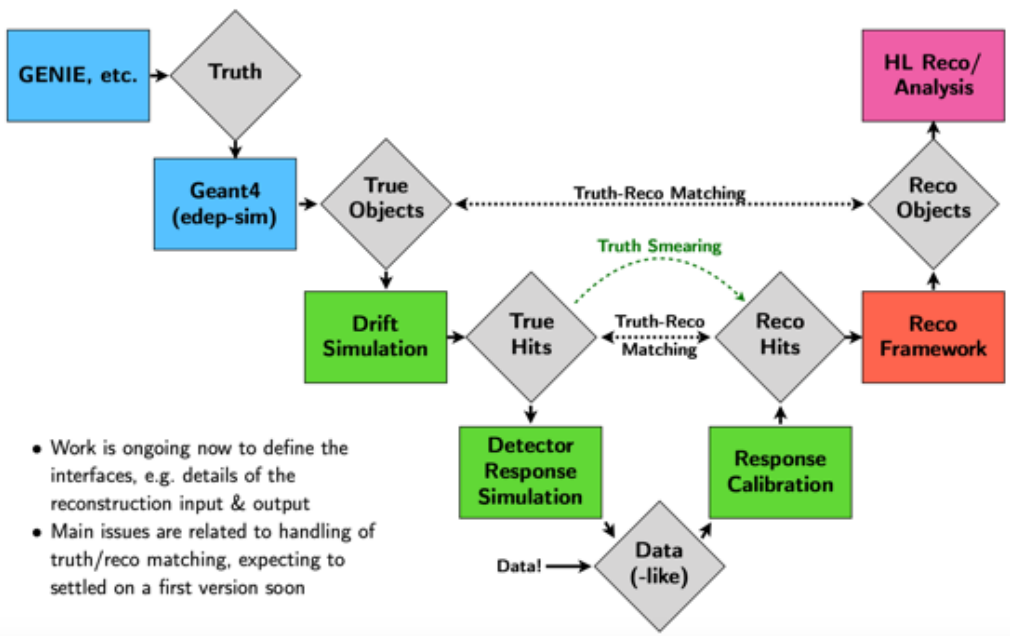
- BoE cost estimates available
- Detailed costing exercise planned after CDR review
- ArgonCube ND LAr TPC 131.02.03.02,
  CORE / M&S ONLY:
  - 01 Module structure: 2.4 M$ (Switzerland)
  - 02 High Voltage: 0.8 M$ (Switzerland
  - 03 Field Structures: 2.7 M$ (USA)
  - 04 Charge Readout: 1.7 M$ (USA)
  - 05 Light readout: 3 M$ + 2.4 M$ (JINR + Switzerland)
  - 06 Calibration: >0.2 M$ (not all systems defined)
  - 07 Module integration and testing: 1.8 M$ (USA + Switzerland)
  - 08 TPC module installation: no core

Summary schedule



Near Detector LArTPC: Simulation and Analysis

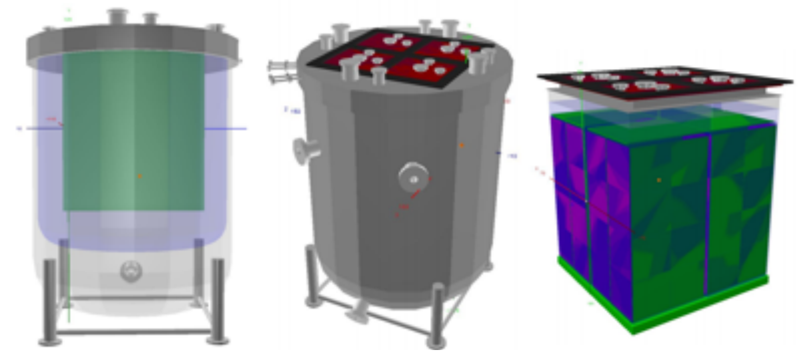
Dedicated ND LArTPC simulation and analysis effort:



B. Russell, R. Soleti, Z.Vallari (LBNF, Caltech)

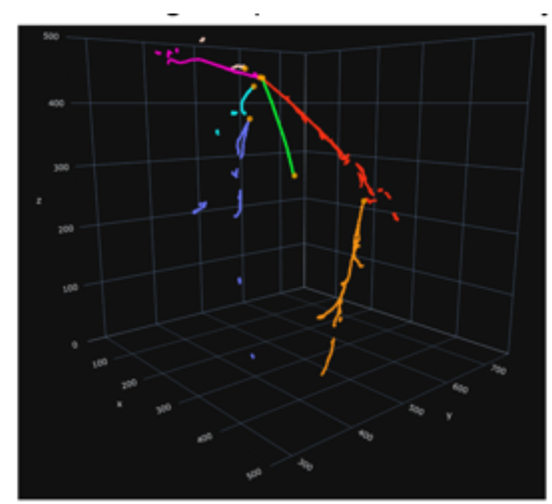
ArgonCube 2x2 GDML Geometry

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



Intrinsic 3D Reconstruction Tools

K. Terao (SLAC)



Near Detector LArTPC ArgonCube

Critical Component of Near Detector System

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

Strong international partnership

- DUNE ND Lar ArgonCube consortium

Mature concept

- ArgonCube R&D program
- Detector elements demonstrated
- Advanced design stage, beyond concept

Prototyping program (dedicated talk)

- Successes with 3D pixel readout, novel light readout, resistive field cage, modular TPCs
- ArgonCube 2x2 Demonstrator in the NuMI beam at Fermilab
- Full-scale ND Module Demonstrator

Corresponding progress in design of associated systems:

- Cryostat, Cryogenics, PRISM, Near Site Infrastructure