Cryogenics Commissioning and Installation Completion

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SBND Operations Readiness Review
February 21-22, 2024

Outline

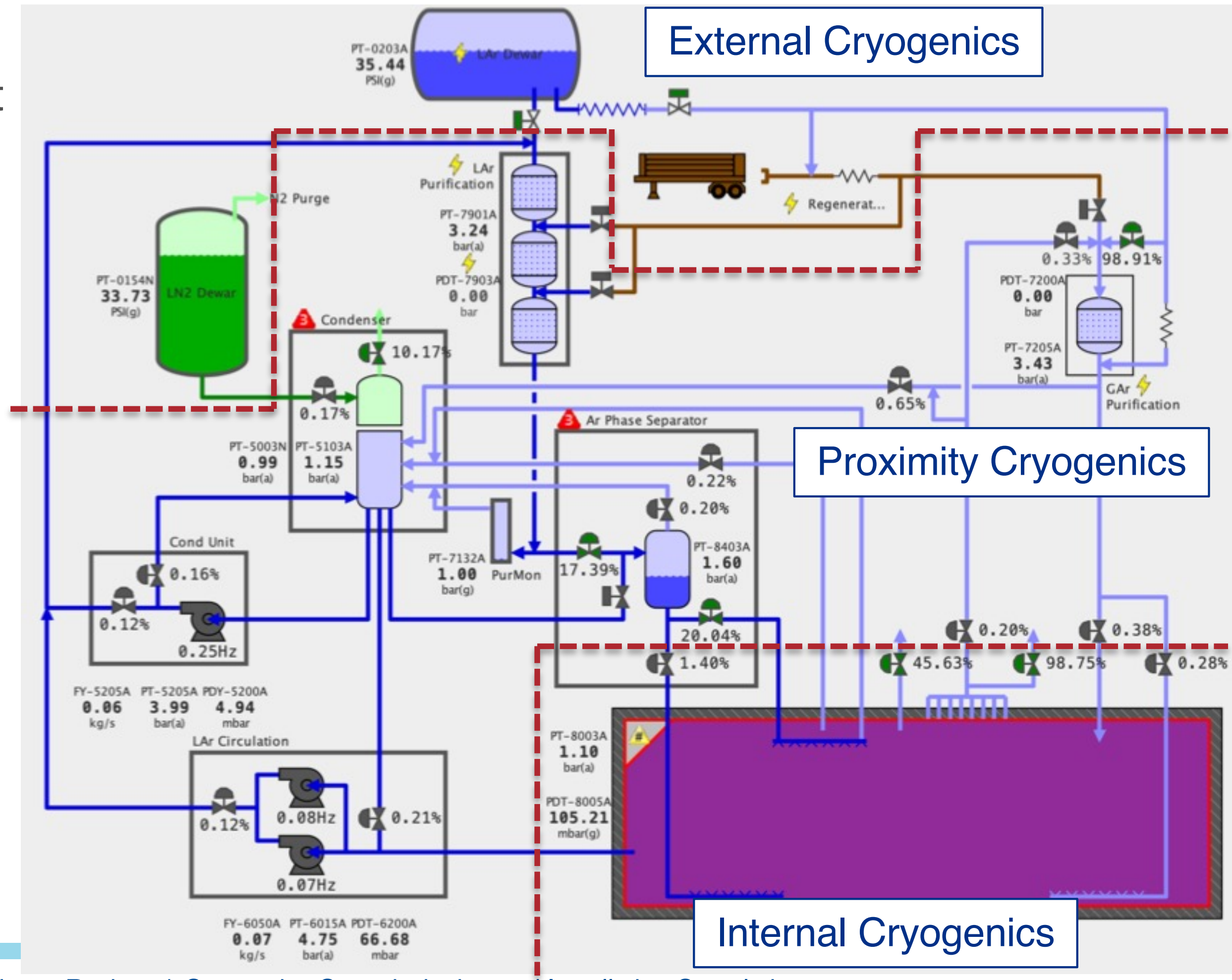
Charge Q2: *What work remains to prepare the experiment to begin physics data-taking*?

Charge Q6: *Are the ES&H (Environment, Safety, and Health) aspects of all anticipated work properly assessed and managed, with clear roles and responsibilities?*

- Cryogenics commissioning
  - Overview of cryogenics system
  - Cryogenics commissioning plan
  - Status of cryogenics commissioning
  - Transition to cryo operations and operations resources
  - Safety planning for cryogenics – modes of operation
- Remaining installation work
  - CRT assembly and installation plan
  - X-ARAPUCA electronics

Cryogenics System Overview

- Joint FNAL-CERN project
- Very similar to ProtoDUNE design
- External and Internal subsystems designed, procured and installed by FNAL
- Proximity subsystems provided by CERN
  - Same design-build-install contract as ICARUS and ProtoDUNE



Cryogenics System in Pictures

SBND Proximity Cryogenics

SBND Cryostat Top

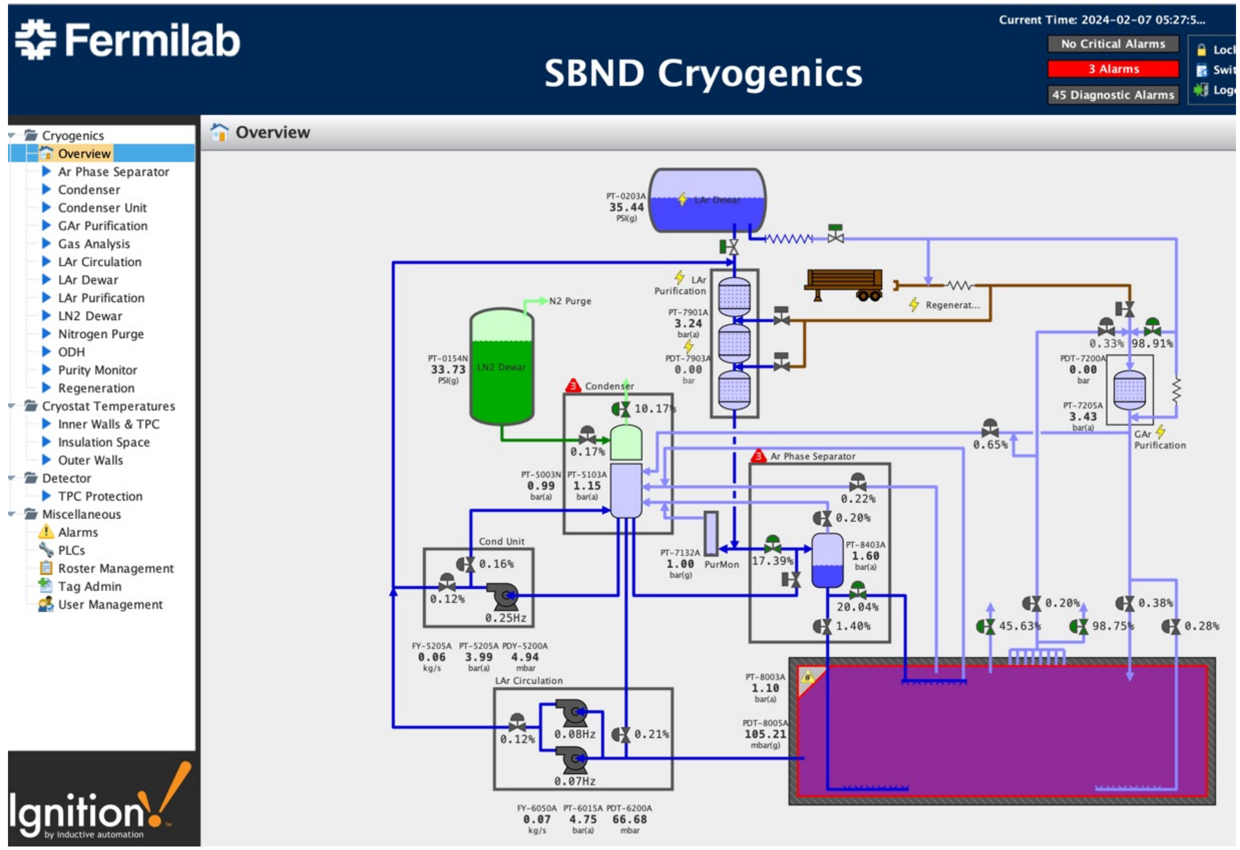
Liquid Argon filter and dewars

Preparing to weld condenser line (last)

Liquid Argon Delivery

Cryogenics System Control

- SBND Cryogenics systems is operated with a process control system using Beckoff PLCs with controls and human interface using Ignition
  - Controls logic specification modeled after CERN protoDUNE and reviewed by ND Cryogenics engineers
  - Provides control and alarms
- Provides both monitoring and control of cryogenics functions
- Most functions have automated feedback response to maintain nominal settings
- Alarms sent to cryo team via autodialer
- Critical alarms (including ODH) sent via FIRUS to Communications Center and Fire Dept (ODH)



Short Baseline Neutrino

Cryogenics commissioning team

- Built on experienced team that commissioned ICARUS in 2020
- Led by the Michael Geynisman (SBN Lead Cryo Engineer) and Fritz Schwartz (ND/TSD Cryo group leader and SBND co-L2 for Cryogenics)
  - ND/TSD engineers: Roza Doubnik, Trevor Nichols (Controls), Bill Scofield, Zack West
  - ND/TSD technicians: Tony Alfaro and Andy Scherf
- Claudio Montanari (ICARUS Technical Coordinator) in daily consultation with cryogenics team
- CERN is engaged in a consulting and monitoring roles
  - Johan Bremer (Head of CERN cryogenics group) in near daily consultation with Michael Geynisman; at FNAL for 1 week to test Proximity Cryo
  - Monitoring strain gauges on cryostat during filling by Olga Belatramello and Gianluigi Buccino as part of cryostat qualification and validation for DUNE FD cryostats
- Daily toolbox meeting: review results of previous day and plan actions for the coming day
  - Frequently hold a smaller 8pm Zoom call to define overnight configuration

Cryogenics commissioning plan

- Set of steps to systematically qualify and bring into operation the cryogenics system and cryostat
- Same as sequence used for MicroBooNE and ProtoDUNE
- Divide into phases:
  - ✓ Pre-Commissioning tests that lead up to partial Operational Readiness Clearance (pORC)
    - Test components (valves, gauges, pumps etc) and subsystems
    - Leak tests, pressure tests, valve operations via process controls system…
    - Lasted several months as each subsystem was completed
  - ✓ Gaseous argon (GAr) purge of cryostat (Planned for 1-2 weeks, actual Jan 23 - Feb 5)
    - Push ultra pure GAr into cryostat from bottom forcing air (lighter) out vents
  - ✓ GAr cooldown (Planned for 1-2 weeks, actual Feb 6-9)
    - Cool the detector and interior of cryostat from 298^{o}K to ~130^{o}K (LAr ~87^{o}K) for "Chilly Checkout"
  - – LAr fill (2-3 weeks, started Feb 12)
    - Need 15-16 tanker trucks at about 1/day
    - 3 trucks last week, daily starting Sunday Feb 18
  - – Start LAr recirculation pumps and optimize/stabilize operations

See talk by Lauren Yates

Purge – gas purity

- Cryostat started with ~100% N_2
- Measure compositions with high resolution gas analyzers
- End of purge – cryostat well below specification for purge
  - N_2 and O2 both < 200ppb
  - H_2O about 5-6ppm
- After cooldown H_2O freezes out – currently
  - N_2 ~100ppb
  - O_2 ~ 150ppb
  - H_2O < 200ppb
- After startup of the LAr recirculation through the filter, will use purity monitors to monitor purity until TPC is turned on and tracks can be used to measure purity

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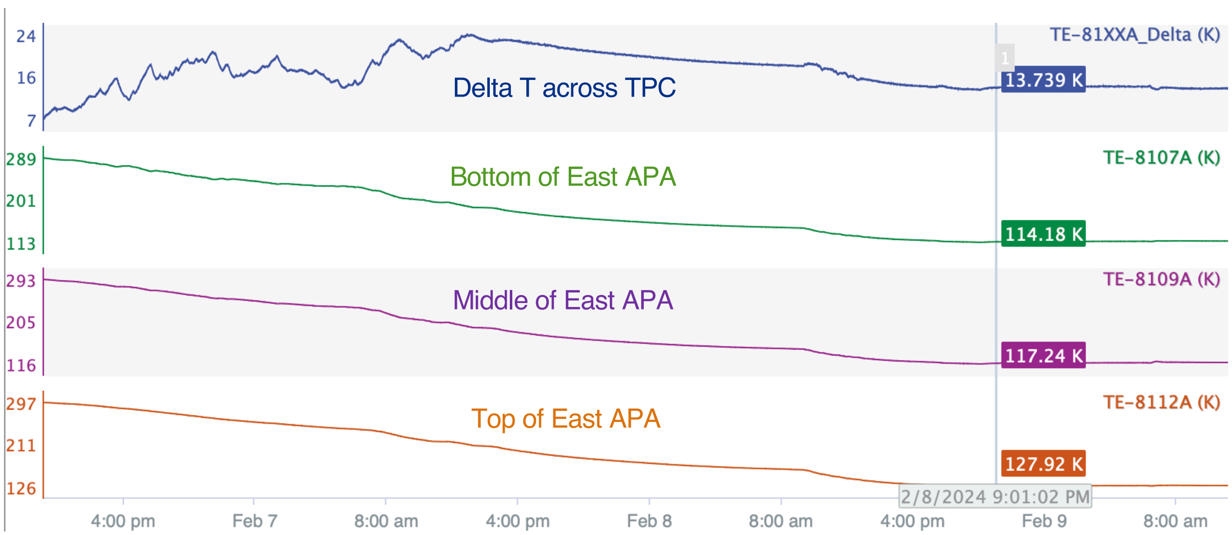
Cool Down

- Cool with LAr sprayed from top and onto cryostat floor
- Keep ΔT(TPC) < 50°K (alarm in controls + monitoring)
- LAr starts to pool on floor



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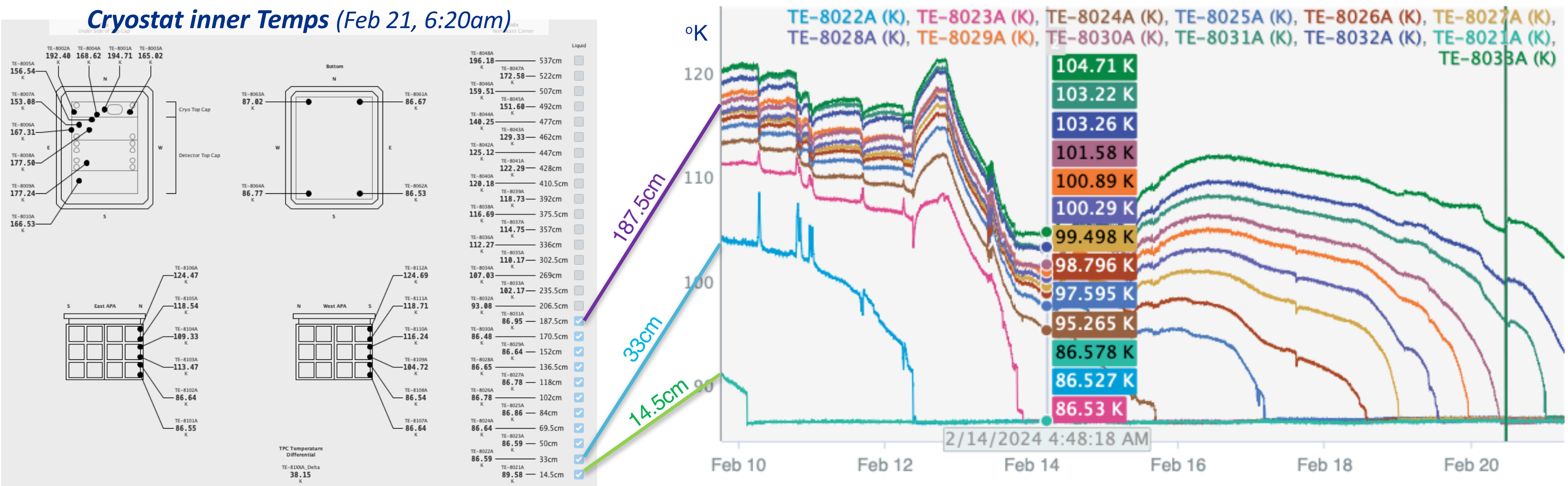
LAr fill status

Cryostat inner Temps (Feb 21, 6:20am)

Cryostat NE Wall Temps vs Time



- Filling rate increasing with higher efficiency and more frequent deliveries
- Project completion of fill around March 1

Cryogenics Transition to Operations

- After cryostat filling is complete there are steps before being ready to turn on the detector and further steps to move cryogenics to operations
- Prior to detector turn-on (~1 week):
  1. Ullage pressure test (1 day with full building exclusion)
  2. Commission Condenser (if not already commissioned)
  3. Commission re-circulation (through LAr filter) pumps (if not already commissioned)
  4. Stabilize operation
- In parallel with detector turn-on, prior to CRT installation (~4-8 weeks):
  1. Argon purification (~4 weeks) to reach >3ms lifetime
  2. Establish stable operation points for full system including LAr pump, condenser, GAr filter, etc
  3. Verify thermal performance of cryostat (thermal imaging of exterior); leads to final cryostat acceptance

Cryogenics Operations Plan and Resources

- Daily operation of SBND cryogenics will follow the same model as ICARUS (and previously MicroBooNE)
  - Primary responsibility with ND/TSD/Cryogenics Group (CERN only consulted occasionally)
  - Daily checks by cryo engineers on status
  - Regular system walkthroughs
  - SBN Cryo Coordinator phone rotates through the group for 24/7 response to critical alarms
  - SBND collaboration shifters monitor key items (eg critical alarms, cryostat pressure) on hourly basis, provide backup response
- Routine maintenance provided by technicians in Cryogenics Group ND/TSD/Electrical Group (for controls)
- Steady state resource estimates based on actual ICARUS usage in FY23
  - Note: SBND has <½ the number of valves/instruments/pumps as ICARUS => expect it will take less effort to operate in steady state
  - We have not taken any credit in our labor estimate

Cryogenics Safety

- Planning for cryogenics safety started with building design and has continued up through system design, installation, and commissioning.
- System safety analysis defines building occupancy rules by mode of cryo operation
  - Example: 3. during fill only Cryo authorized personnel and tasks allowed in building.
- Daily toolbox meetings address work plan and any special hazards
  - Discuss previous day performance and issues
  - Plan for the coming day, require concurrence prior to actions

SBND Cryo Modes of operation and restrictions

	MODE OF TEST OR OPERATION	TYPE OF EXCLUSION FOR PERSONNEL	PERSONNEL ACCESS AND RESTRICTED ACTIVITIES (TO SPECIFIED AREAS)
1	QC BEFORE PURGES BY PRESSURIZATION TO 250 mbarg	TOTAL EXCLUSION	NOT ALLOWED TO ENTIRE BUILDING
2	PURGES (OPEN AND CLOSED)	NO ADDITIONAL RESTRICTIONS	ALLOWED (ODH QUALIFIED AND TRAINED OR SBN-ND) ONLY CRYO PERSONNEL IS ALLOWED TO PIT (TBD IN ODH)
	COOLDOWN WITH LIQUID ARGON SPRAY	NO ADDITIONAL RESTRICTIONS	ALLOWED (ODH QUALIFIED AND TRAINED OR SBN-ND) ONLY CRYO PERSONNEL IS ALLOWED TO PIT (TBD IN ODH)
3	FILL OF CRYOSTAT WITH LIQUID ARGON	LIMITED RESTRICTIONS	NOT ALLOWED, EXCEPT FOR CRYO PERSONNEL FOR DURATION NEEDED FOR INSPECTION WHILE STABLE CONDITIONS ARE VERIFIED AND IN DIRECT COMMUNICATION WITH CRYO OPERATORS MONITORING THE SYSTEM. NON-CRYO PERSONNEL NEED TO BE ACCOMPANIED BY CRYO PERSONNEL LIFTING LOADS WTH CRANE OVER CRYOGENIC EQUIPMENT SHALL BE "SPECIAL LIFT" PER FESHM 10100
1	QC AFTER FILL BY PRESSURIZATION TO 250 mbarg	TOTAL EXCLUSION	NOT ALLOWED TO ENTIRE BUILDING
4	STEADY STATE OPERATIONS	NO ADDITIONAL RESTRICTIONS	ALLOWED (ODH QUALIFIED AND TRAINED OR SBN-ND) ONLY CRYO PERSONNEL IS ALLOWED TO PIT (TBD IN ODH) CRYO AREAS ARE LIMITED ACCESS ONLY LIFTING LOADS WTH CRANE OVER CRYOGENIC EQUIPMENT SHALL BE "CRITICAL LIFT" PER FESHM 10100

SBND Modes of Operations – QC – Risk Assessment for SBN-ND Cryostat at Fermilab (Team Center ED0012607)

Remaining Detector Installation Activities

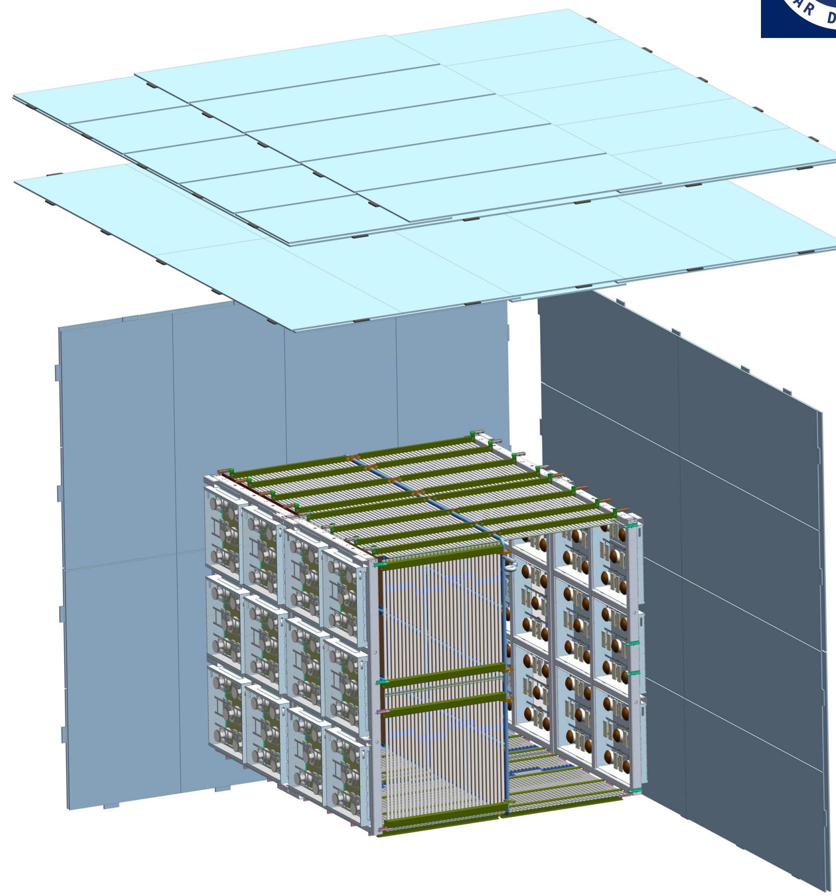
Charge Question 2a: *The installation of the CRT is not expected to be complete at the start of the commissioning period. Is any other work required to complete the assembly of the detector? When will assembly of the full detector be complete? How will this impact the first physics run?*

- Two systems remain to be completed to achieve the full detector scope:
  - The Cosmic Ray Tagger (CRT) consists of bottom (installed, pORCed), four side walls (north installed and pORCed) and two top layers. Completion of this installation is final scope of the SBN project.
    - Installation of remaining components after cryogenics/cryostat is stable after filling
  - The X-ARAPUCA light detection system is a collaboration provided enhancement to the Photon Detection System (PMTs are baseline PDS system for the project).
    - Two different readout systems: APSAIA (16 channels), ARARA (176 channels)
    - Most of APSAIA system is in hand and ready to install, ARARA system nearing production
- Initial physics goals can be achieved while these systems are being completed

See talk by Andrzej Szelc

SBND Cosmic Ray Tagger (CRT) System

- Modules on 6 sides cryostat to identify tracks external to cryostat.
  - Timing to differentiate in-going vs out-going
- Modules designed and built by Univ of Bern
- Bottom modules installed before cryostat warm vessel in 2019
  - A few repurposed MINOS modules due to space constraints
- North wall installed in May 2023 before cryogenics piping blocked installation
- Install remainder after cryostat is full, allows for thermal qualification of the cryostat with an infrared camera



CRT Modules

- All of wall CRT modules and ½ of top modules built specifically for SBND and delivered several years ago
  – All tested at DAB using cosmic rays in 2023
  – Stored ready for delivery to SBN ND when needed

- Remainder of top will use repurposed CRT modules from MicroBooNE
  – Same design as SBND modules (strip width, SiPM, readout electronics), different external dimensions
  – Built by Univ of Bern before the SBND modules
  – Demounting by PPD rigging group started last week.
    - Work Plan/HA created by Roberto Acciarri
  – Modules with be tested with a source at LArTF after demounting
    - Plan confirmed with Rad Safety

CRT Wall Assembly and Installation

- Assemble one wall at a time on the loading dock then install:
  1. Assemble frame
  2. Test rigging frame into pit, adjust rigging plan
  3. Install modules
  4. Install electronics and cables
  5. Test on loading dock, pORC
  6. Install into pit
  7. Connect cabling, test, commission
  - Steps 1-3,6 done by FNAL technicians
  - Steps 4,5,7 done by collaborators
  - Work plans for all rigging steps developed by Roberto Acciarri

- Status:
  - North wall completed steps 1-7
  - East wall completed steps 1-5; Install after cryostat qualification complete
  - West assembly starts as soon as East rigged

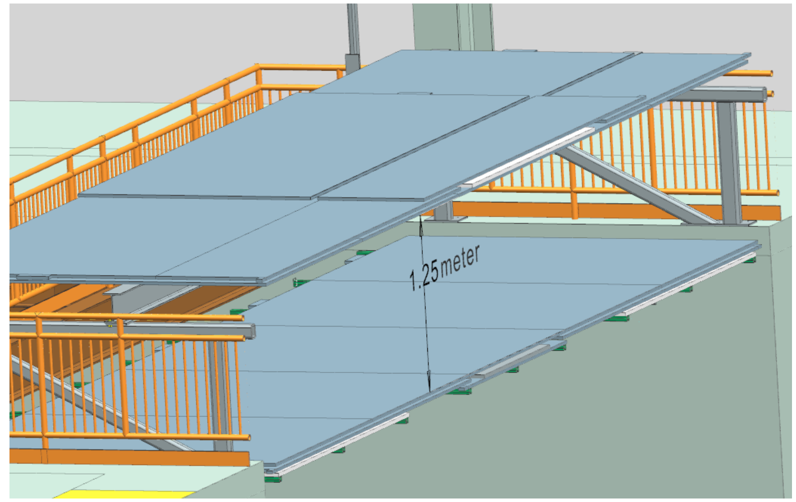
Test rigging of CRT frame

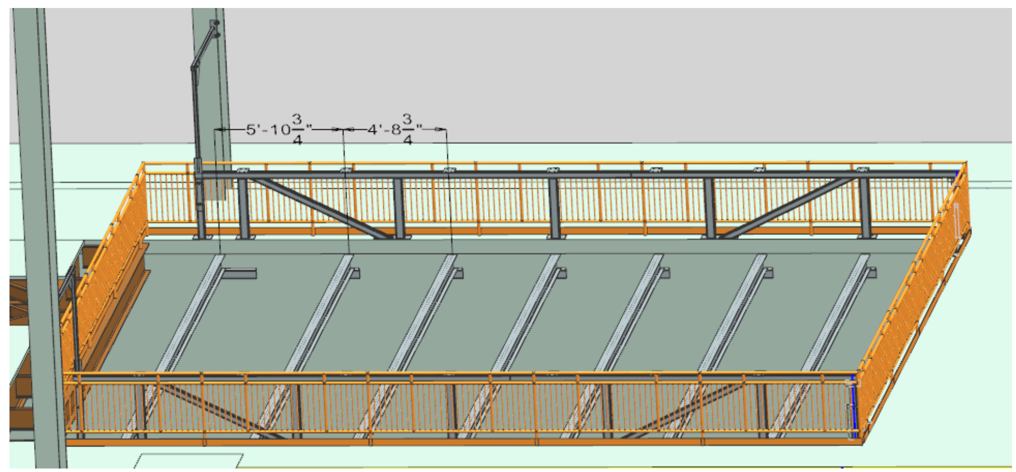
Module installation on CRT frame by ND &PPD techs

Top CRT Design

- Top CRT will consist of 2 layers separated by about 1.25m
  - 1st layer installed on existing I-beams that mount off the pit wall just below the surface
    - All materials in hand
  - 2nd layer installed on newly designed structure that mounts to ground floor inside the existing pit guardrail
    - Completed final design review in January
    - Structure ready for fabrication using off the shelf materials

- Cabling plan and installation work plan to be developed over next 2 months





CRT Installation Timeline and Resources

Installation Timeline:

- Side installation starts within 6-8 weeks after cryostat filling (before end of April)
- Side installation expected to take about one month (complete by end of May)
- Installation of top I-beams and modules will follow south wall and should complete by end of June

Resources:

- Joint ND/PPD technician team assembles and installs walls, installs top structure and top modules
- Collaboration scientists, postdocs, and students install electronics and cables; perform tests and DAQ integration
- Teams already practiced on north and east walls

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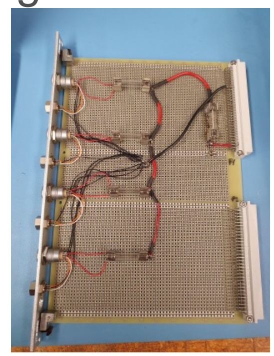
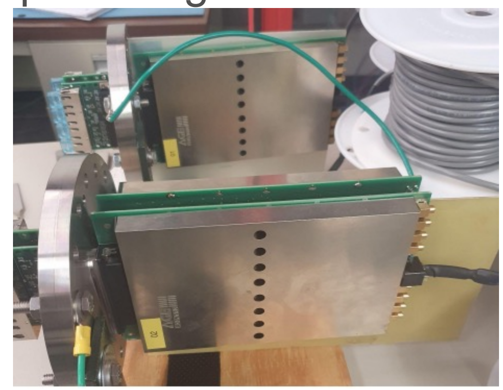
X-ARAPUCA – APSAIA Status

- 16 of192 X-ARAPUCA modules are being readout by the “APSAIA readout”.
- **APSAIA** (**A**RAPUCA **P**ower **S**upply **A**nd **I**nput **A**mplifier) will be installed on the X-ARAPUCA flanges on the warm side to reduce the propagation length of non-amplified signals.
- Already installed/completed:
  - ✓ Power and signal cables + power supply in VME crate.
  - ✓ Slow controls are ready.
- Remains to be installed:
  - Digitizer (CAEN V1740B) -> procured by Unicamp. Expected next month.
  - APSAIA amplifier modules -> All in hand and tested, currently building a protective cage before installing
  - MCX to ERNI convertor board -> being designed by U. Michigan now (simple).
- After convertor board is delivered to FNAL: full chain test and installation.





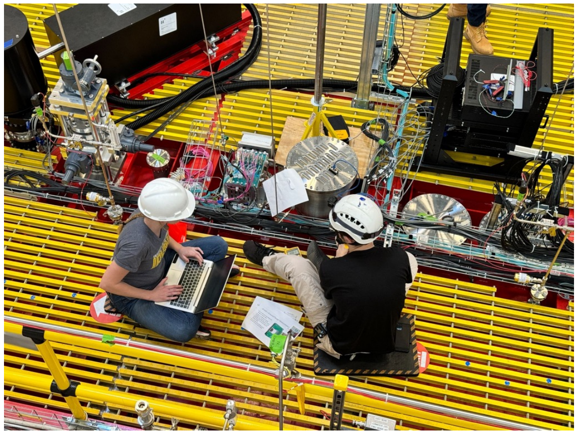
ARARA Status

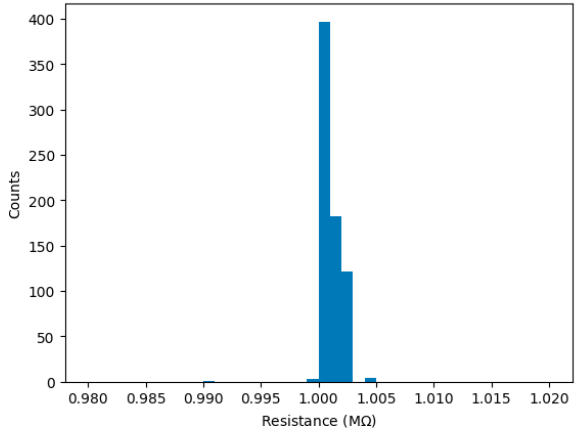
Chilly detector checkout of all installed X-ARAPUCAs:

- Passed resistance and electrical isolation measurements

The ARARA system will gang sets of 4 X-ARAPUCA SiPMs into single pre-amplifier mounted close to the flange (similar to APSAIA).

- A single-channel prototype pre-amplifier board is designed and sent out for fabrication
  - Power distribution circuit also included in design
  - Will be tested by U. Michigan in the coming weeks
- Production will follow testing and a Production Readiness Review
- CAEN V1740 digitizers have been received at CIEMAT; readout testing and code development is underway





Summary

Charge Q2: *What work remains to prepare the experiment to begin physics data-taking*?

- Cryogenics commissioning is progressing well with hand-off to detector commissioning expected in early March,
- CRT installation will resume once cryostat is qualified in April, and
- X-APAPUCA electronics will be installed during the spring-summer.

Initial data taking can continue in parallel

Charge Q6: *Are the ES&H (Environment, Safety, and Health) aspects of all anticipated work properly assessed and managed, with clear roles and responsibilities? Yes,*

- ES&H needs of cryogenics commissioning and operations planned starting from original design,
- All installation activities are planned, with the Installation Coordinator, to follow FESHM 2060 work planning using IMPACT (see sbn docDB 14697 and 14700), and
- All new equipment undergoes ORC process before operation.

Backup

Instrumentation for monitoring

- The SBND cryostat, cryogenics and detector are instrumented with a large array of instruments to ensure successful commissioning
  - Pressure transducers throughout cryogenics system
  - High precision gas analyzers that can be configured to sample many points: LAr delivery prior to offloading, LAr leaving filter, GAr venting from the cryostat..
  - Purity monitors in the cryostat (2) and in cryogenics system (1) to actively monitor electron lifetime
  - Temperature sensors (RTDs) on the detector, inside cryostat, in cryostat insulation and exterior
  - Strain gauges and deflection sensors on cryostat exterior to measure deflection during pressure test and LAr fill
  - Cameras inside cryostat to monitor LAr fill

SBND TPC inside Cryostat