

## Detector Commissioning

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SBND Operations Readiness Review  
February 21-22, 2024



# Charge Questions Addressed in This Talk



2. What work remains to prepare the experiment to begin physics data-taking?
  - b. Is there a plan for commissioning the detector in preparation for an initial physics run in FY24? Are the roles and responsibilities of members of the collaboration and Fermilab staff clearly defined for this commissioning period?

There is a detailed detector commissioning plan that enables initial physics-quality data-taking in FY24, including BNB beam data before the accelerator summer shutdown.

Detector commissioning is led by the collaboration. We have identified leaders for each subsystem, as well as individual collaborators who will carry out key detector commissioning tasks.

Crucial support is also provided by Fermilab staff, in particular the CSAID artDAQ group and the Neutrino Division TSD operations support and electrical groups.

3. Is there a well-understood run plan for the remainder of FY24, consistent with the planned accelerator schedule and performance? Have adequate resources from the laboratory and the collaboration been identified for an efficient and safe running of the experiment and for maintenance of the detector, and have the responsibilities of the collaboration and Fermilab staff been clearly defined?

Detector commissioning needs will determine the run plan in the first weeks after the cryostat is full of LAr. The commissioning plan prioritizes critical tasks required for taking BNB beam data.

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

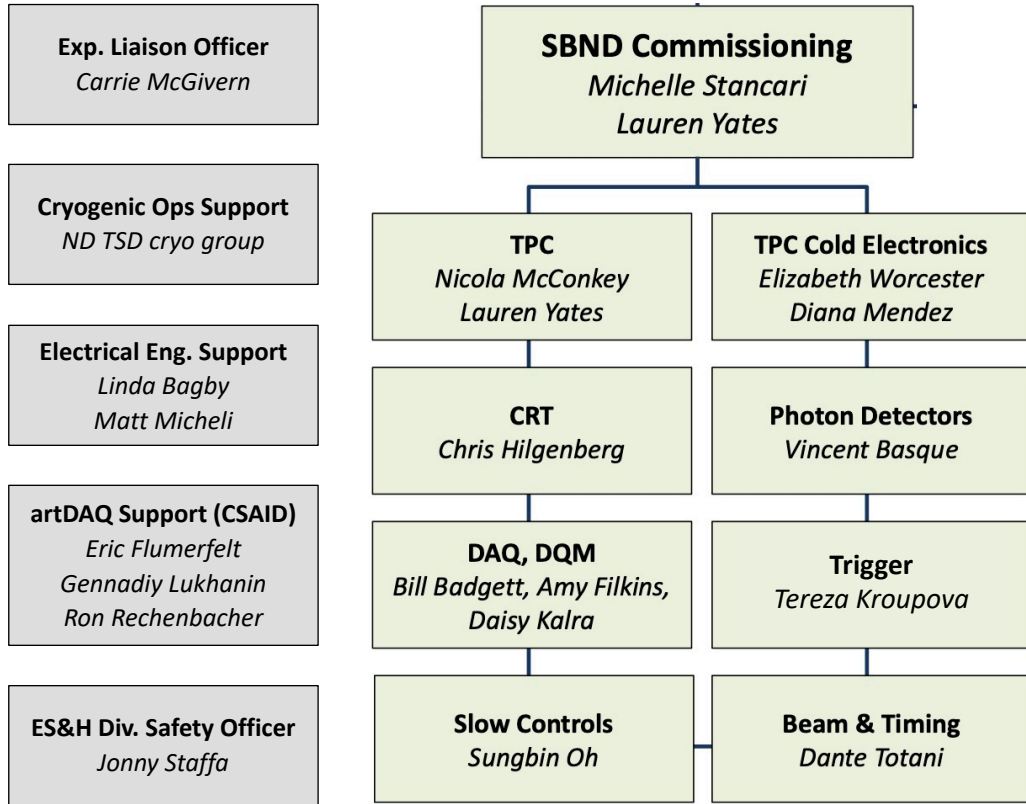
Mitigation already in place for all anticipated hazards during commissioning. Proactive work planning in regular toolbox meetings evaluates each task. Electrical hazards reviewed through ORC process.



# Outline

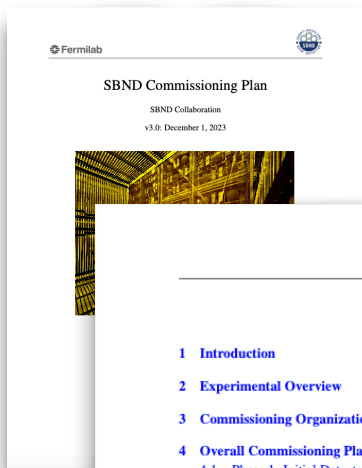
- Detector commissioning organization, plans, and timeline
- Pre-liquid argon detector commissioning work
- Some details of the detector commissioning plan
  - Initial HV ramp-up example: TPC
  - Critical sanity checks examples: noise characterization, PMT synchronization with beam
  - Work in parallel with initial physics run examples: light-based triggering, CRT integration
- ES&H considerations during detector commissioning

# Detector Commissioning Organization



The detector commissioning team has also benefitted from close coordination with the installation team, and now with operations

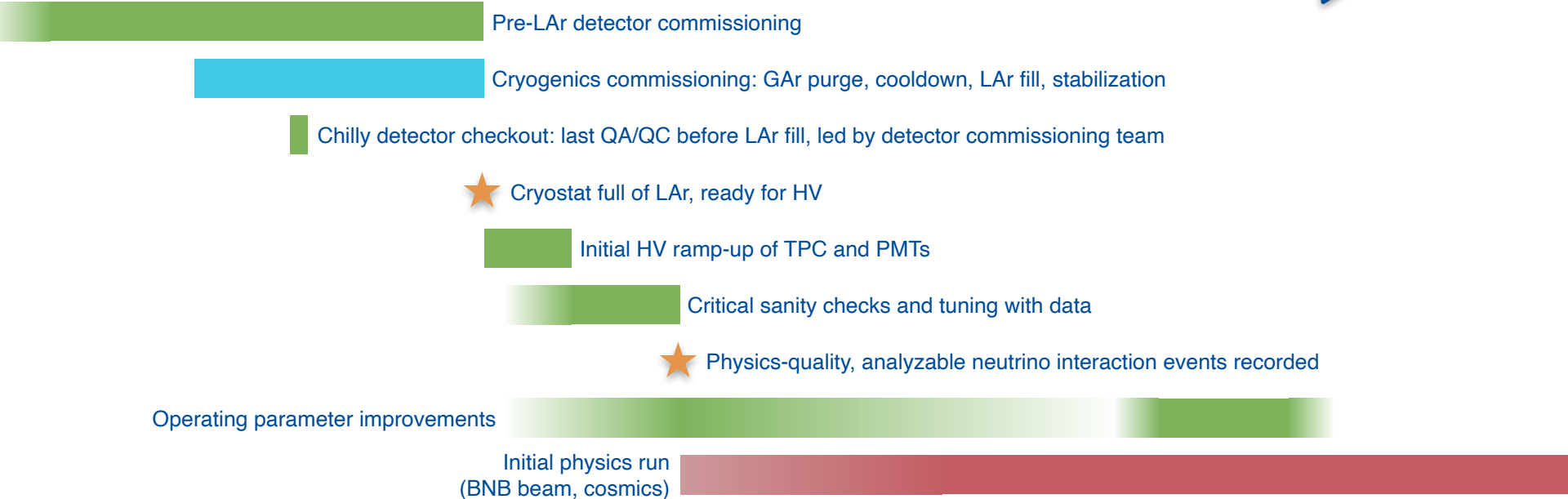
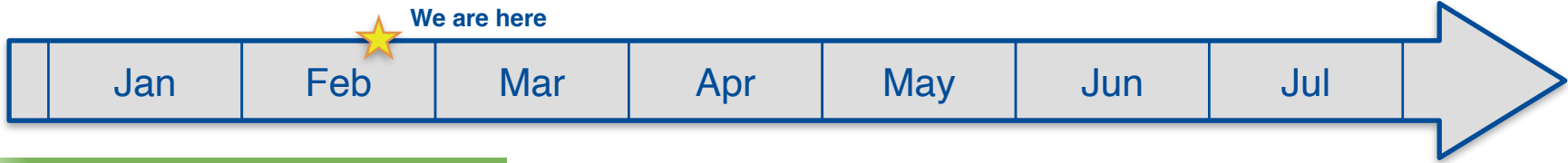
# Detector Commissioning Plan



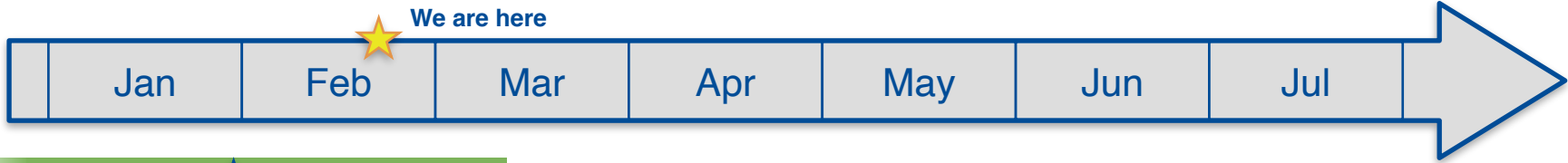
SBND Commissioning Plan	
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- We have developed a detailed commissioning plan and an accompanying resource-loaded schedule
- Our plans consider tasks that can be parallelized or front-loaded to minimize the “ $\Delta t$ ” between when the LAr fill is complete and initial physics-quality data
- Leaders for each subsystem and collaborators who will carry out key tasks have been identified
- A written document on the detector commissioning plan has been reviewed by the collaboration
- Detector commissioning plan was reviewed at the last [SBND Director’s Review](#) (Feb 28–Mar 2, 2023)
- Two recommendations on detector commissioning were closed out at [October SBN PMG](#)

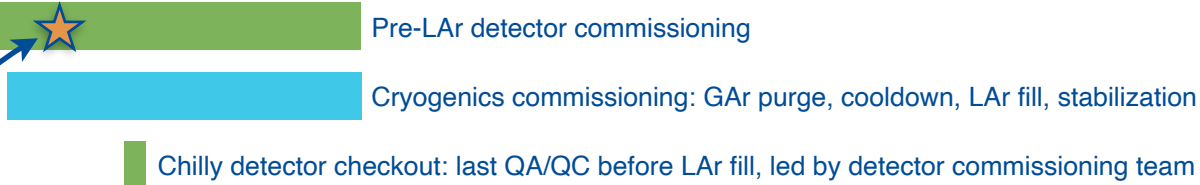
# Detector Commissioning Timeline



# Detector Commissioning Timeline



Bottom and north CRT walls ORC'd on January 30, and we have been regularly taking data with them since then

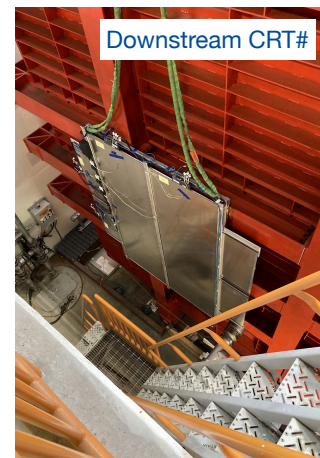
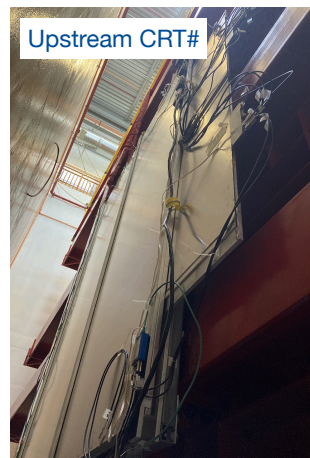
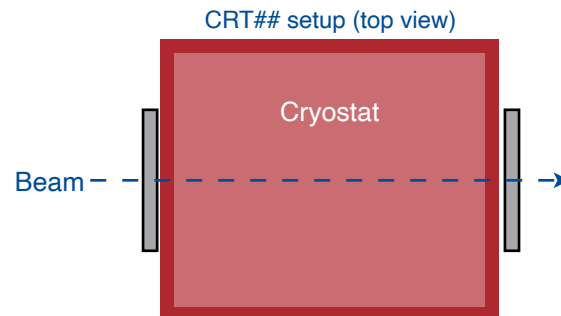


- ★ Cryostat full of LAr, ready for HV
- Initial HV ramp-up of TPC and PMTs
- Critical sanity checks and tuning with data
- ★ Physics-quality, analyzable neutrino interaction events recorded



# Pre-LAr Commissioning

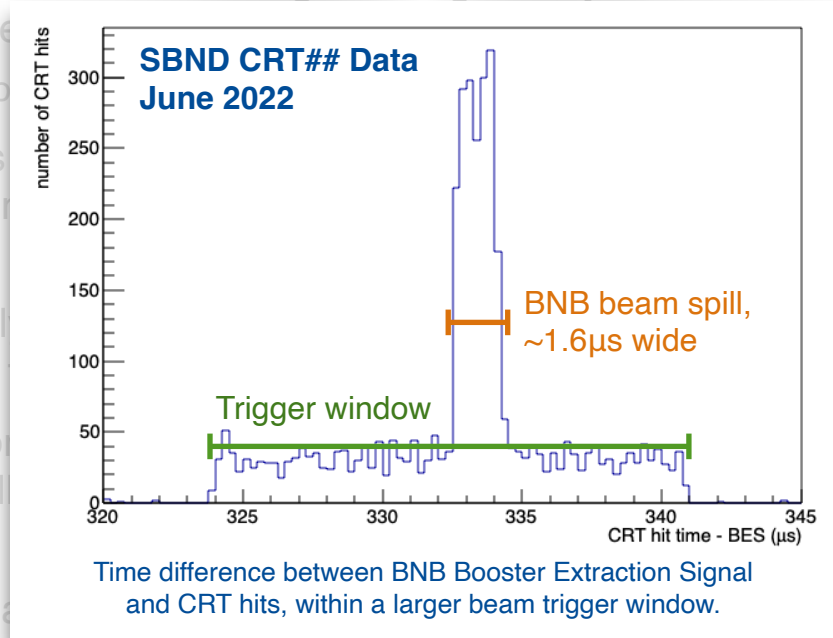
- Pre-LAr commissioning has targeted systems that don't require LAr: CRT, trigger, DAQ, timing, controls, monitoring
  - More on DAQ from Tingjun in the next talk
- Focus has been on integrating different systems and verifying expected performance, as much as is possible
- In early 2022, we hung CRT modules (CRT##) on the sides of the then-empty cryostat and collected some beam data
- Demonstrated some key aspects of trigger and DAQ systems and allowed us to develop important debugging tools
- Have also invested in preparing software and tools for planned post-LAr commissioning tasks





# Pre-LAr Commissioning

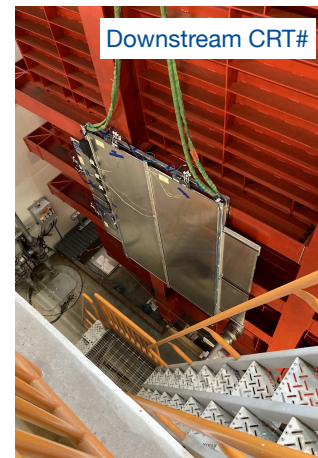
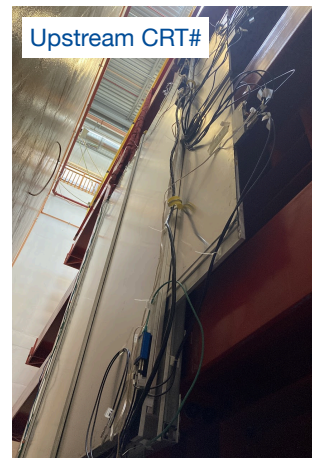
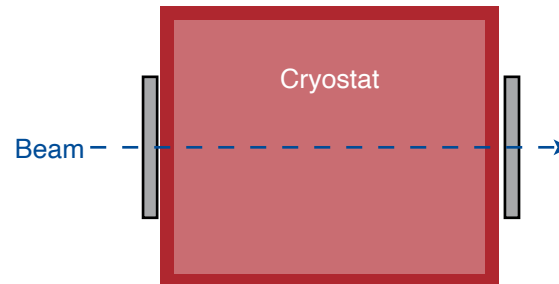
- Pre-LAr commissioning has targeted systems that don't require



- Focus on verifying
- In early of the
- Demonstrate and all
- Have a planned post-LAr commissioning tasks

**We're ready to make a plot like this again with the currently-running CRT walls as soon as BNB returns! And this will help us complete post-LAr commissioning tasks faster**

CRT## setup (top view)

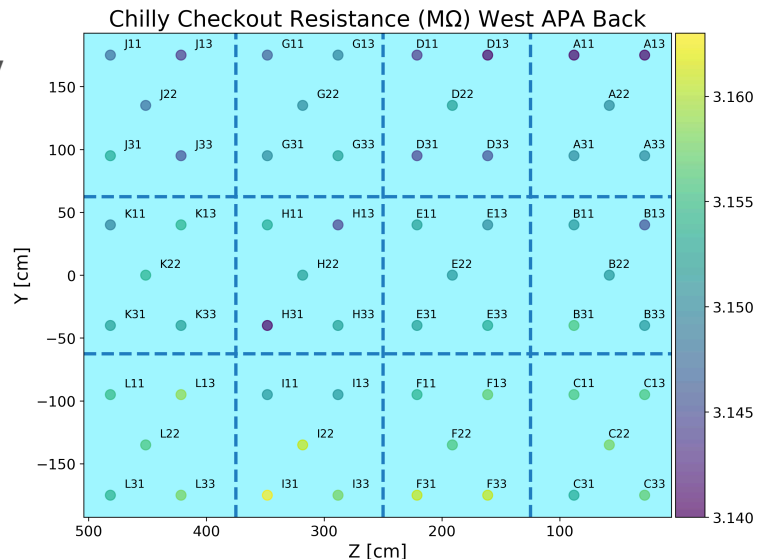


# Chilly Detector Checkout

- Detector commissioning team successfully completed the “chilly detector checkout” on February 9
- Everyone came together to get these tests done efficiently so that we could proceed to filling as soon as possible
- Close coordination with the installation team, who have led previous QA/QC efforts, was invaluable

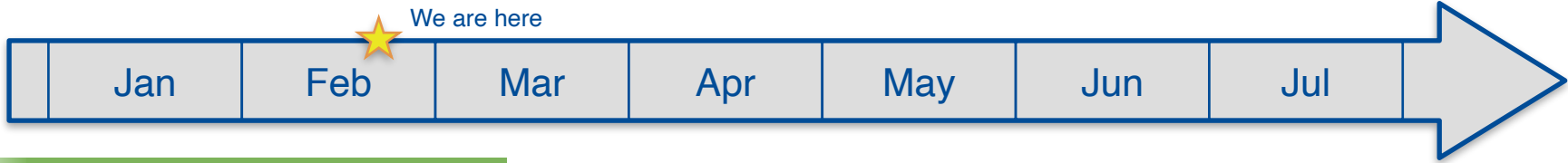


Activities at the SBN-ND building during the chilly detector checkout, February 9.



PMT base impedances for west APA PMTs during the chilly detector checkout. Gradient along y-axis is due to thermal gradient across the APA of  $\sim 14K$ .

# Detector Commissioning Timeline



Pre-LAr detector commissioning



Cryogenics commissioning: GAr purge, cooldown, LAr fill, stabilization



Chilly detector checkout: last QA/QC before LAr fill, led by detector commissioning team



**Cryostat full of LAr, ready for HV**



Initial HV ramp-up of TPC and PMTs



Critical sanity checks and tuning with data



**Physics-quality, analyzable neutrino interaction events recorded**

Operating parameter improvements

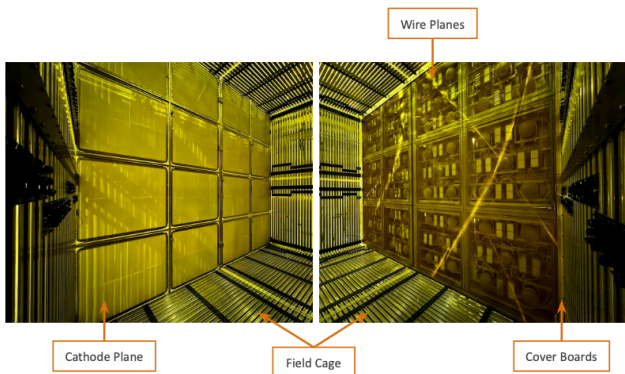


Initial physics run  
(BNB beam, cosmics)



# Initial Detector HV Ramp-Up: TPC

- Have developed a detailed plan to ramp the detector up over three days, with planned pauses to monitor HV stability and verify cold electronics behavior
  - Day 1: 10% of nominal voltages, then 20%, 25%; 2 hour pause; 35%, 45%, 50%
  - Day 2: 60%; 2 hour pause; 70%; 2 hour pause; 80%
  - Day 3: 90%; 2 hour pause; 100%
- Organized an internal technical review focused on the TPC ramp-up plan in August 2023, and got excellent feedback from experts that has been incorporated into the final version of the plan



First ramp: up to 10%

- Ramp CPA (from 1kV)
- Ramp Field cage termination boards
- Ramp APA West U plane
- Ramp APA East U plane
- Ramp APA West Y plane
- Ramp APA East Y plane
- Ramp APA West cover boards
- Ramp APA East cover boards

→ Second ramp up to 20%

→ Third ramp up to 25%

----- Pause point 2h -----

- Monitor stability of I and V for all channels
- Take 5mins TPC data with CE

**Checklist:**

- Are all CE channels responding?
- Is CE noise as expected?
- Are all bias voltages stable
- Are all currents stable at the expected values?

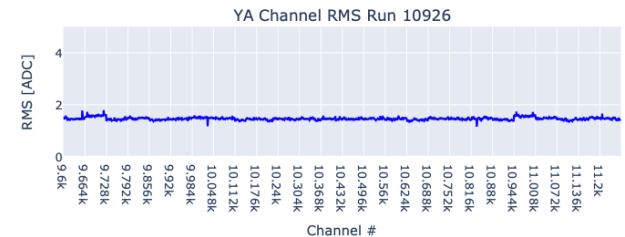
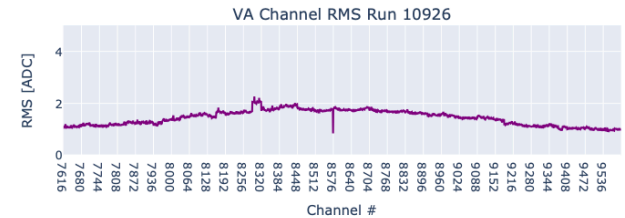
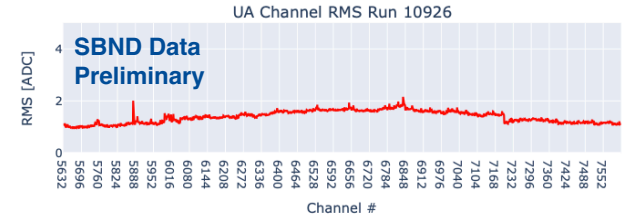
If yes: proceed!

If no: continue to monitor or ramp down

# Critical Sanity Checks and Tuning: Noise Characterization



- TPC cold electronics are quite sensitive noise detectors and will be used to diagnose any external noise sources
- If there are noise sources that can be immediately mitigated, we plan to implement that at this stage
- Work will be led by Linda Bagby (ND TSD Electrical Group) working closely with collaboration experts
- We have been collecting noise data routinely throughout the detector cooldown and the LAr fill, and are already starting to analyze it for insight on external noise sources
- Based on current preliminary measurements, we have an excellent starting point to understand any new sources of external noise as we turn on cryo and detector systems

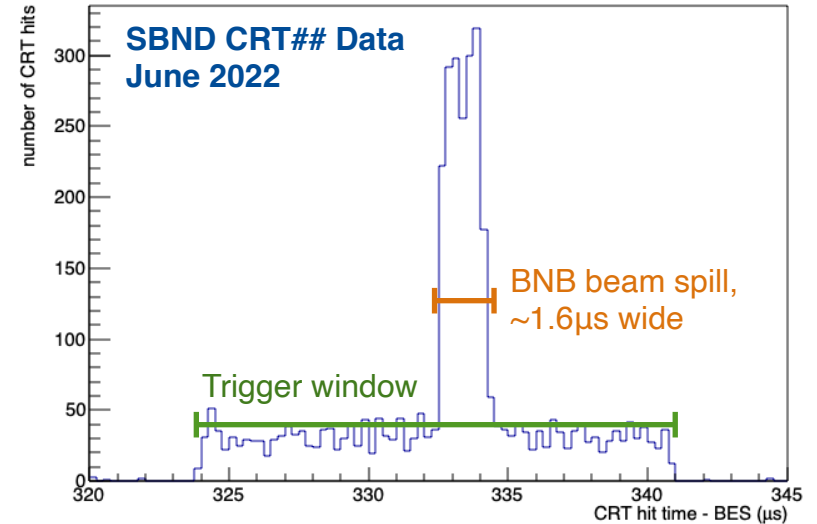


Chilly noise measurements for TPC cold electronics on the west APA. Gain is set to 14 mV/fC, or  $\sim 200$  ENC/ADC. Preliminary measured noise is close to the expected intrinsic noise given SBND's wire lengths.



# Critical Sanity Checks and Tuning: PMT Synchronization

- Another important focus after the PMT HV is ramped up is verifying time synchronization of the trigger system, the PMT readout, and the beam signals
  - This verifies that we can observe and record the light signals during the beam spill, which is key for neutrino selections
- This can be done by plotting the time of light signals in PMTs relative to the beam signals, inside a beam gate determined by the trigger
- We completed the analogous task during the CRT## run in early 2022, so we have a good initial idea for when the beam should be
  - Doing this again with the currently-running CRT walls will also help



Time difference between BNB Booster Extraction Signal and CRT hits, within a larger beam trigger window.

# Detector Commissioning Timeline



Pre-LAr detector commissioning

Cryogenics commissioning: GAr purge, cooldown, LAr fill, stabilization

Chilly detector checkout: last QA/QC before LAr fill, led by detector commissioning team

★ Cryostat full of LAr, ready for HV

Initial HV ramp-up of TPC and PMTs

Critical sanity checks and tuning with data

★ **Physics-quality, analyzable neutrino interaction events recorded**

Operating parameter improvements

Initial physics run  
(BNB beam, cosmics)



# Light-Based Trigger Commissioning

- Although SBND sees a relatively high rate of neutrino interactions, still only  $\sim 1/20$  beam spills is expected to produce a neutrino interaction in the active volume of the TPC
- A light-based trigger will be used to reject beam spills with no neutrino interaction and thus reduce the data rate to a digestible level
  - Not critical for initial data-taking where we could record every beam spill, but essential for achieving the experiment's goals over the longer term
  - Also improves the efficiency of offline data storage and processing
- This is one of the main drivers of ongoing detector commissioning work after we are able to record our first complete BNB neutrino interactions





# Light-Based Trigger Commissioning

- Pre-LAr trigger commissioning has focused on building out functionality for a commissioning trigger menu, including the beam+light trigger
- First step post-LAr is an initial equalization of PMT gains, so the trigger response is uniform
- In parallel with the above, can take some data with very high (safe) trigger thresholds to verify basic functionality of the light-based trigger
- Then will take zero-bias data with PMTs and analyze it to determine expected trigger rate for given thresholds, explore how this would change for different threshold choices
  - Protects the trigger hardware against unintended excessively high trigger rates



# CRT Integration & Commissioning



- Bottom and north CRT walls are already installed, ORC'd, and running
- Remaining side and top CRTs will be installed in parallel with detector commissioning, and we will want to integrate them as soon as possible
- Significant work has already been done on pre-installation testing and characterization using a test stand setup at DAB (summer 2023)
  - This will give us initial settings to equalize CRT module response
- DAQ integration and data validity checks are well underway for the bottom and north CRT walls, and are starting for the east side CRT wall
  - East wall is assembled in SBN-ND high bay, waiting for installation
  - We are ready to observe beam in these CRTs as soon as BNB comes back
- Further CRT commissioning will continue once the walls are installed, for example fine-tuning the equalization of the module response

East CRT wall assembled in the high bay at SBN-ND. The wall is ORC'd and routinely running alongside the bottom and north.



# ES&H Considerations during Detector Commissioning

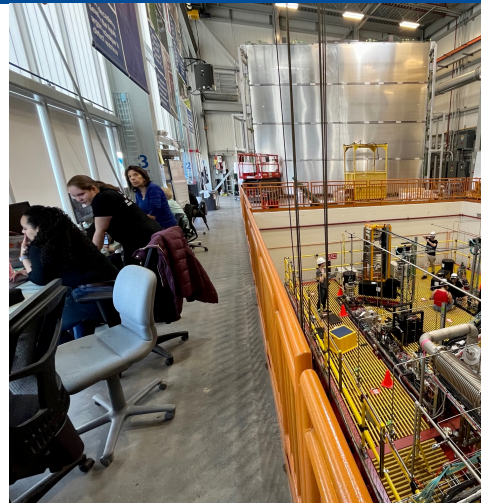
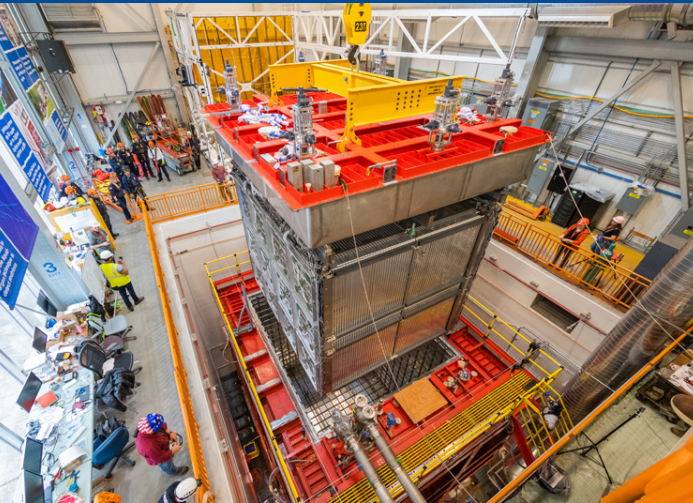
- Work Planning - twice weekly toolbox meetings (daily when needed)
- Coordinate with ongoing installation activities (CRT)
- Coordinate with cryogenics commissioning/operations
- Hazards we are acutely aware of:
  - ODH
  - Confined space (in the pit)
  - Work at heights (railings)
  - High voltage
- Written work plans and hazard analyses (as needed) will be shepherded by Carrie McGivern (ELO), Rob Acciarri (Installation Coordinator), or Monica Nunes (Operations Coordinator) during commissioning



# Summary



- We have a mature detector commissioning plan that has been reviewed already, both at the Director's Review in February/March 2023 and internally by the collaboration
- Our plan identifies tasks that can be parallelized or front-loaded to minimize the “ $\Delta t$ ” between when LAr fill is complete and initial physics-quality data
- Substantial pre-LAr detector commissioning work has already happened and is continuing, including commissioning of systems that don't rely on LAr and preparations for post-LAr work
  - This has included work on DAQ commissioning covered in Tingjun's talk, up next
- We expect to be able to take an initial BNB physics run during FY24, in parallel with ongoing detector commissioning work that will enable improvements to data quality
- We look forward to completing detector commissioning, and SBND physics!

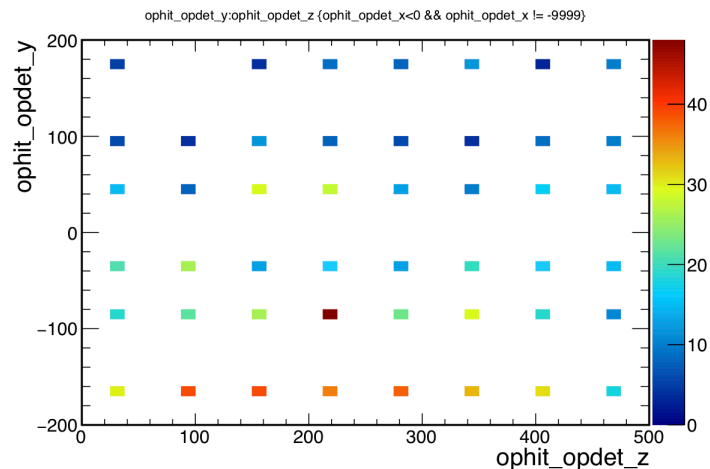
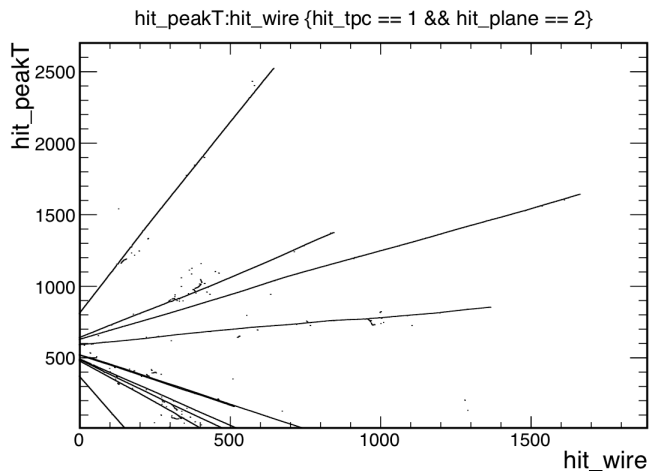


Additional Slides



# Commissioning Trees (Data Processing for Commissioning)

- Simple root trees with hit level quantities for the first look at data from TPC, PDS, CRT
- Infrastructure in use in SBND for 5 years (used for summer student projects on simulation)
- No signal processing, no 3D reconstruction or other algorithms that might not work on Day 1
- Allows a crude evaluation of detector performance metrics quickly for sanity checks



# SBND Operational Parameters



## TPC and TPC CE

- Cathode HV (1)
- Wire bias and cover board voltages (3×4)
- Field cage termination board voltages (1×4)
- TPC readout — 11,264 channels
  - CE gain, **shaping time**, and baseline

## CRT

- **SiPM voltages** (142×32)
- **SiPM readout thresholds** (142×32)

## Trigger

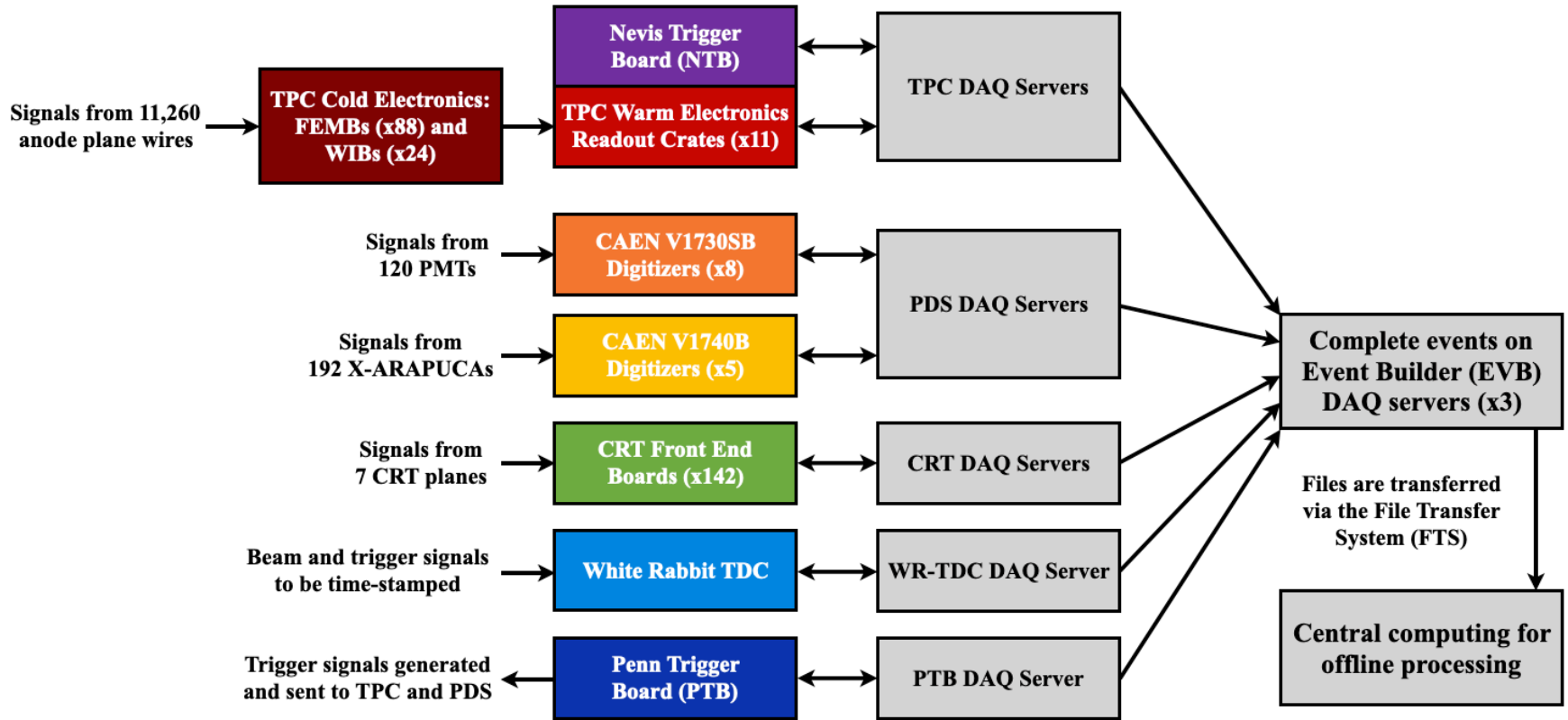
- **Individual PMT thresholds** (120)
- **PMT multiplicity thresholds** (3)
- **Timing offsets** (several)

## PDS

- **PMT voltages** (120)
- **X-ARAPUCA voltages** (208)
- Time delays to electronics for trigger (120)

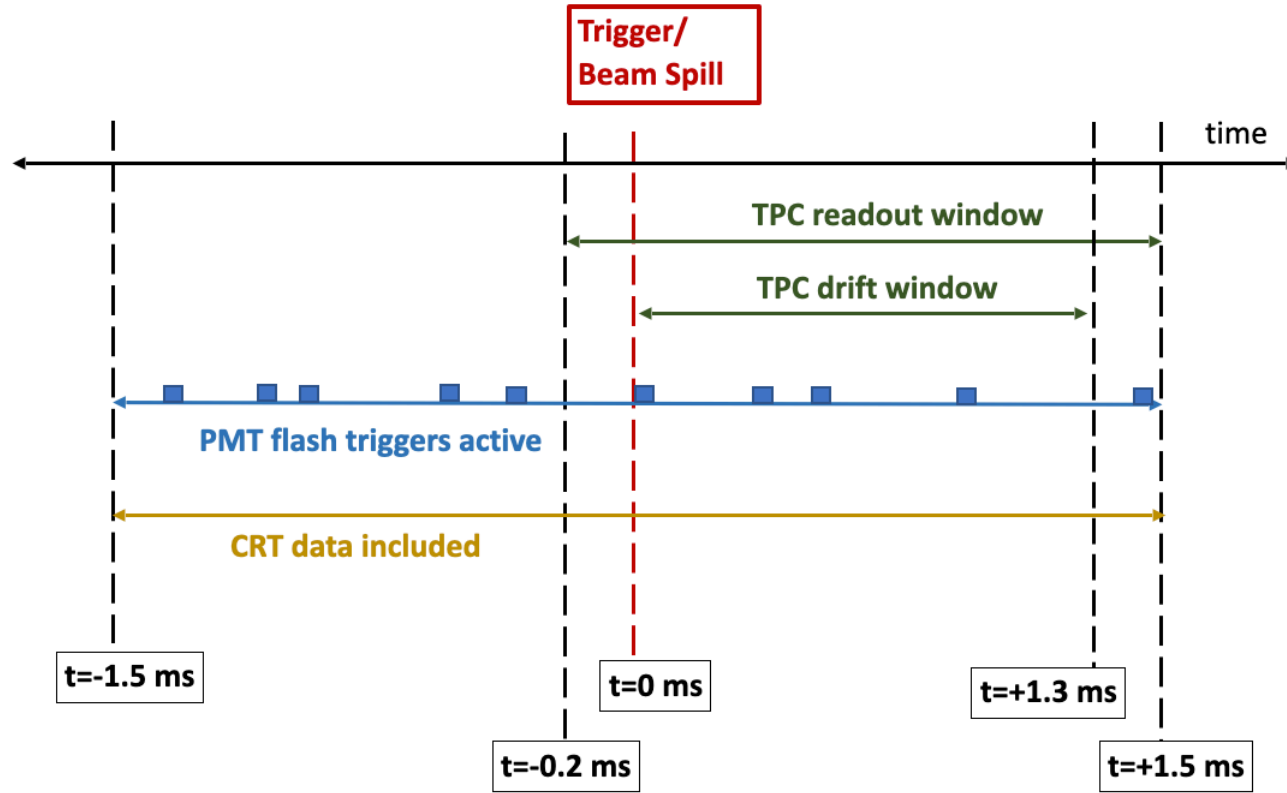
Has nominal setting, not expected to change  
**Has nominal setting, needs confirmation with data**  
Setting must be determined based on data

# SBND DAQ Schematic

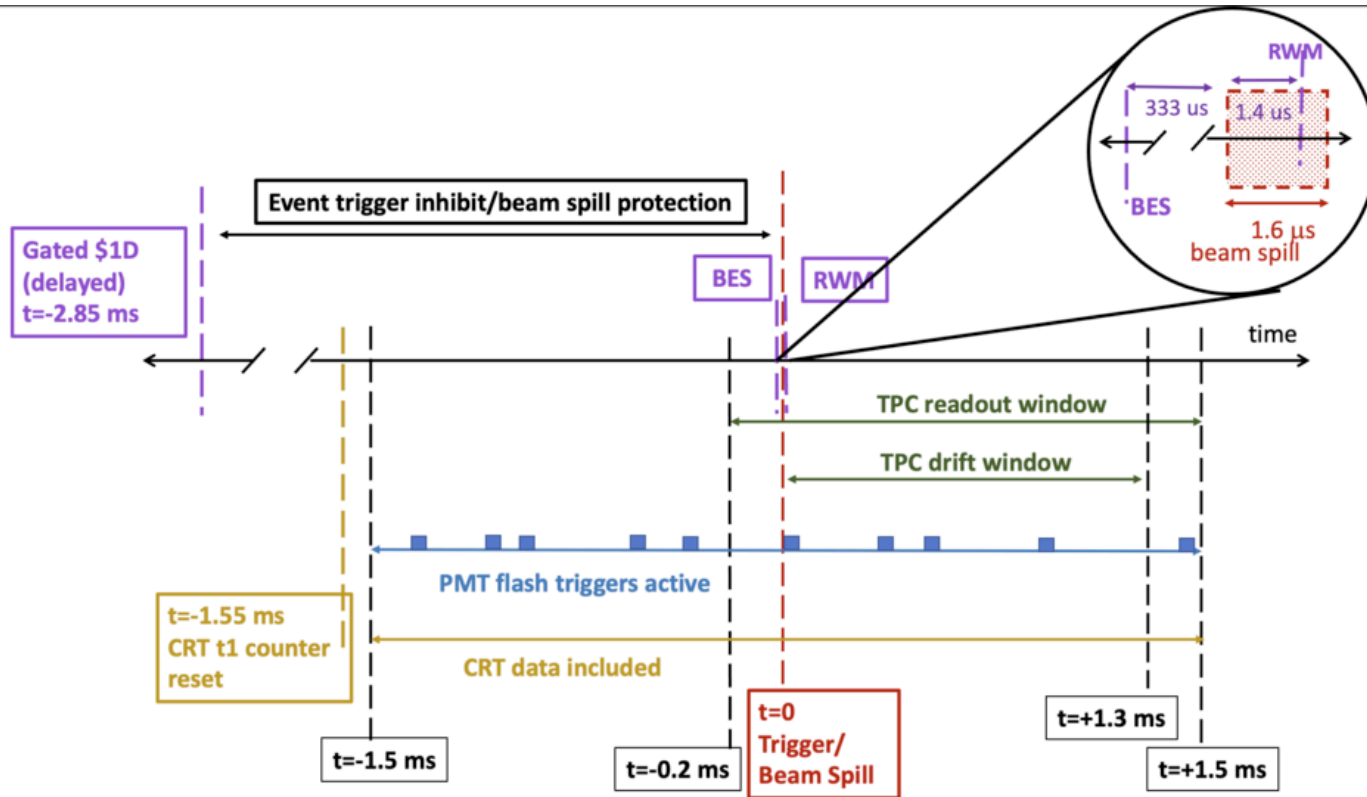




# SBND Event Schematic



# SBND Event Schematic (Beam Events)



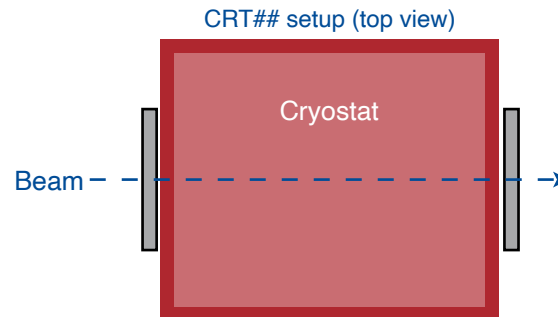
# Commissioning Trigger Menu



	Description	Purpose
<b>BNB + light</b>	beam+light	neutrino interactions
<b>off-beam + light</b>	strobe+light (not during beam spill)	measure cosmic background in BNB+light stream
<b>BNB zero bias</b>	every beam spill (prescaled)	trigger efficiency, commissioning
<b>off-beam zero bias</b>	strobe (prescaled, not during beam spill)	data/MC comparison, cosmic data overlays
<b>crossing muon</b>	two CRT walls (+light) (prescaled)	commissioning, calibrations

# Pre-LAr Commissioning with CRT##: DAQ Integration

- 4 m<sup>2</sup> active area each # module
- Centered on beam axis
- Systems integrated
  - PTB
    - beam+CRT trigger
    - CRT+CRT crossing muon trigger
  - PMT digitizers (CAEN 1730)
    - record beam signal (RWM)
    - record CRT inputs to PTB
  - WR-TDC
    - record BES, RWM
    - CRT clock reset and event trigger
  - CRT readout stream

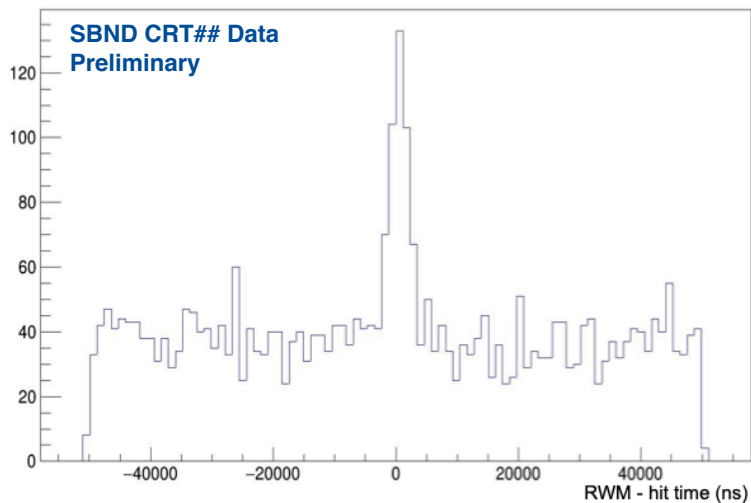


# Pre-LAr Commissioning with CRT##: DAQ Integration

- We compared the time of CRT hits to the BNB RWM signal in the CAEN 1730SB digitizers (for PMT signals), and saw the beam peak
  - From docdb-26770

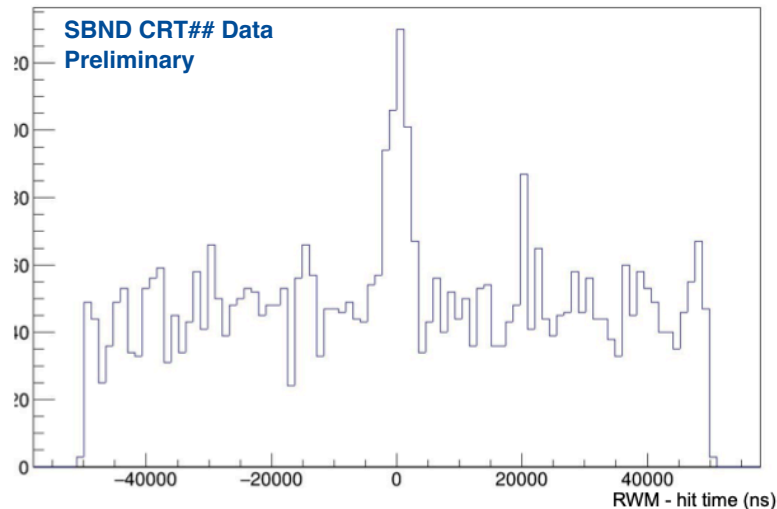
upstream

CRT Hits w.r.t PDS Digitizer Trigger Time

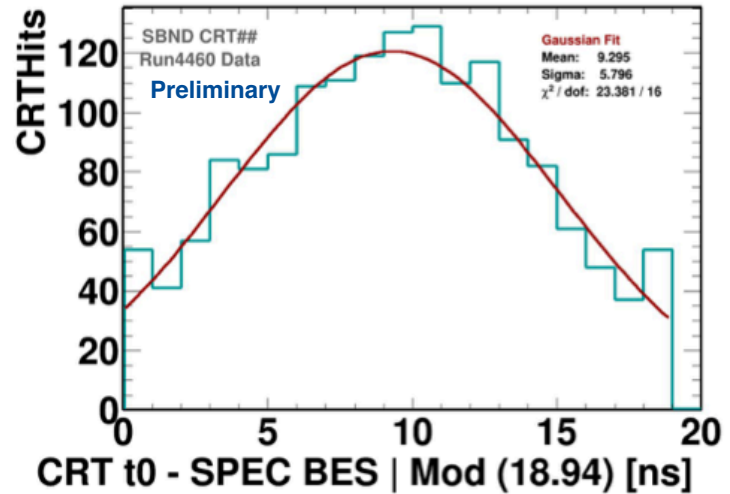
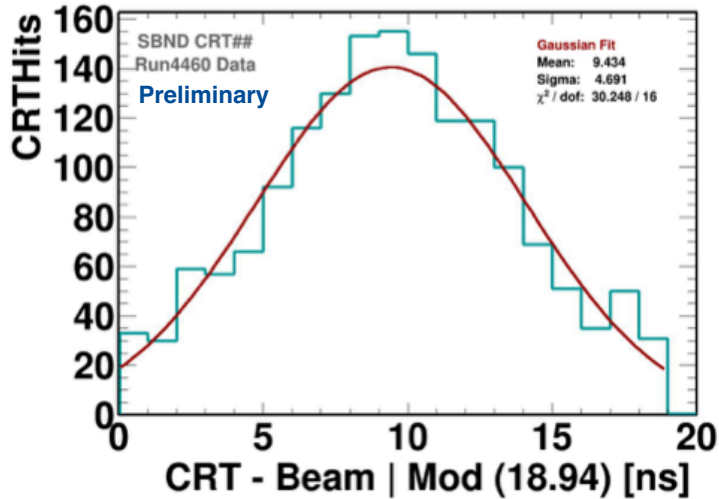


downstream

CRT Hits w.r.t PDS Digitizer Trigger Time

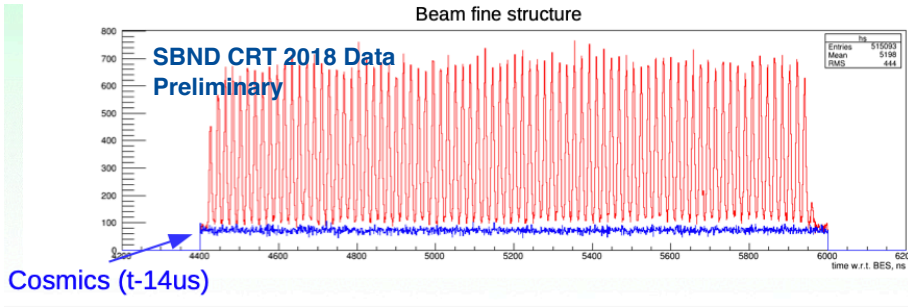


# Pre-LAr Commissioning with CRT##: Beam & WR-TDC Integration



Above: Time difference between beginning of the beam spill and CRT hits, modulo the 18.94ns of the bucket structure. Left: Using the beam signal sent to the CRT. Right: Using the PPS signal sent to the CRT and the WR-TDC.

Right: Fine structure of the BNB, from the SBND 2018 CRT running.



Top plots from docdb-29151  
Bottom plot from docdb-8523



## Pre-LAr Commissioning: Chilly Detector Checkout

- Current on cathode at 1kV — continuously since start of cool-down
- Currents in TPC HV bias voltages (wire bias, cover board, FCTB)
- TPC cold electronics functionality — before, during, and after TPC HV tests
- TPC cold electronics noise
- PMT base impedance
- X-ARAPUCA impedance