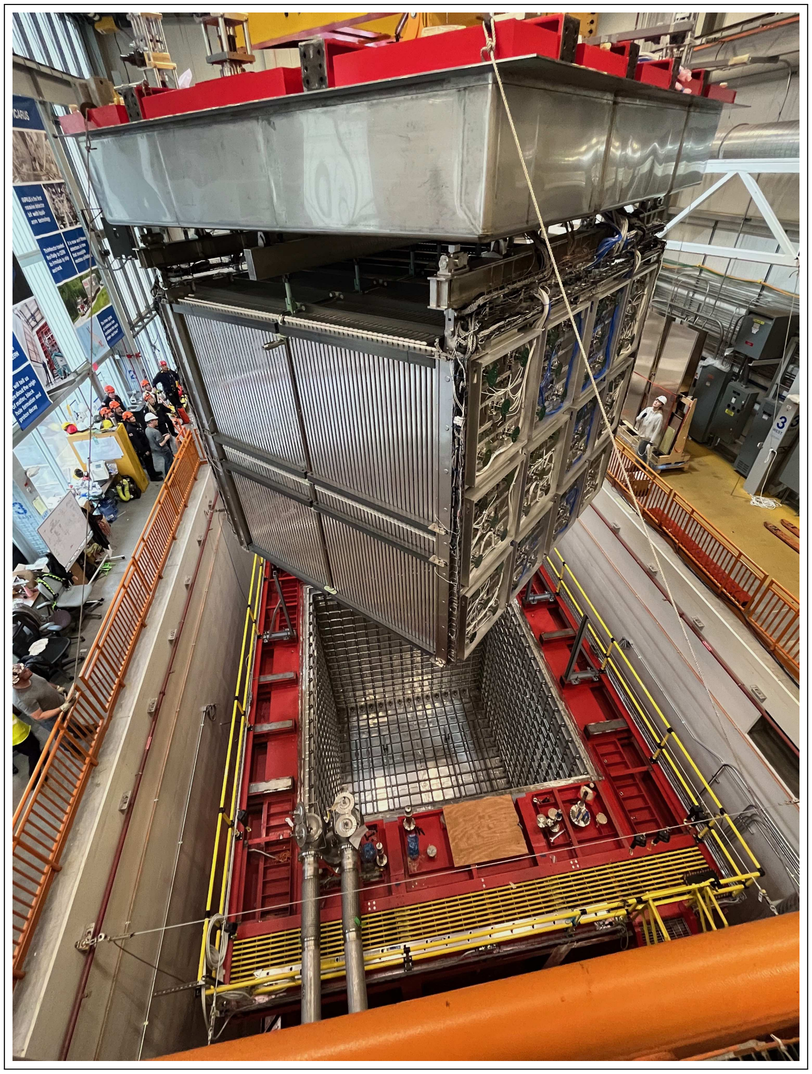
Experimental Operations Plan
SBND Experiment (SBN-ND, T-1053)
Fermi National Accelerator Laboratory

SBND Collaboration

February 17, 2024



1 Introduction

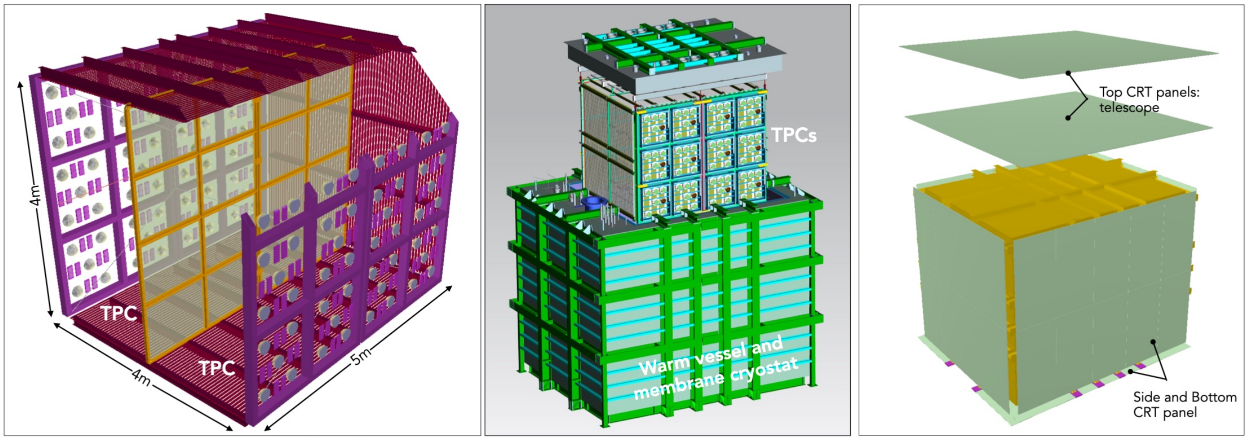
Experiment T-1053, the Short-Baseline Near Detector (SBND), is the newest detector in the Short-Baseline Neutrino (SBN) Program located along the Booster Neutrino Beam (BNB) at Fermilab (see Figure 1). The SBND detector is housed in a new experimental hall that places the detector 110 m from the BNB neutrino production target. The SBN program far detector, ICARUS, sits downstream at 600 m from the BNB target. ICARUS has been collecting physics data since summer 2022. The start of SBND operations will complete the construction phase of SBN and begin the multi-detector SBN science program. The primary science goal of the SBN Program is to test the existence of eV-scale sterile neutrinos through the simultaneous measurement of the rate of muon-neutrinos and electron-neutrinos at different locations along the BNB.

Figure 1: The Fermilab Short-Baseline Neutrino (SBN) Program. The Booster Neutrino Beam (BNB) target sits below the MI-12 building at the top of the image. The SBND detector is located 110 m downstream of the target, and the ICARUS detector is 600 m from the target. Located between, at 470m, is the MicroBooNE detector, no longer in operation.

SBND is a 112-ton active mass liquid argon time-projection chamber (LArTPC) with ionization charge and scintillation light detection for the reconstruction of neutrino interactions. The TPC and photon detectors are housed inside a custom membrane cryostat. The cryostat is surrounded by a cosmic ray tagger (CRT) system made of overlapping layers of plastic scintillators. See Figure 2 for a schematic depiction of the SBND detector systems.

The science goals of SBND mostly fall in three main categories:

- The large mass of the SBND LArTPC detector and its proximity to the beam source enables a broad program of **precision neutrino-nucleus interaction measurements**. SBND will make multi-dimensional differential measurements of many high-rate channels (inclusive,



Two Time Projection Chambers Charge and Light Detection

TPCs lower into membrane cryostat

Cryostat surrounded by a Cosmic Ray Tagger system

Figure 2: The SBND detector. On the left, a cutaway schematic of the TPCs with high voltage cathode in the center flanked by two wire planes. Also shown are the photon detectors (Section 2.3.2) located behind the wire planes, outside the TPC (Section 2.3.1). The beam enters from the left going along the cathode direction. The center image shows how the TPC is supported from the cryostat top and lowered into the membrane cryostat. The right image shows the CRT system (Section 2.3.3) installed on all six sides of the cryostat with a double layer above forming a muon telescope.

single and multi-proton final states, charged/neutral meson production, etc.) with more than an order of magnitude more ν-Ar data than is currently available. The large event rates will also make it possible to explore low-rate neutrino interaction channels (hyperon production, ν-e scattering, etc.) that are not easily studied in smaller data sets.

- The relatively low cosmic backgrounds, the possibility of precision timing measurements with SBND's high-performance photon detection systems, and the large mass and proximity to the beam source will allow the **testing of many Beyond Standard Model scenarios**, including various dark-sector models (e.g., Heavy Neutral Leptons, Higgs portal scalar models, etc.) using multiple possible final-state signatures.
- As the Near Detector in the SBN Program, SBND is the key to mitigating the large neutrino flux and cross-section uncertainties in order to **perform sensitive searches for sterile neutrino oscillations in SBN**. Multiple detectors also enables oscillation searches in both appearance and disappearance channels.

In addition, the SBND detector provides a development platform for the liquid argon time projection chamber neutrino detector technology and creates a primary training ground for an international group of scientists and engineers also working toward the DUNE long-baseline neutrino program in the future.

This document describes the experimental operations plan of the SBND experiment. It includes, in Section 2, a description of the SBND detector systems that will be operated, the tools for control and monitoring of the detectors, and the plans for managing and processing data. In Section 3 we describe the collaboration organization, focusing on operations roles, as well as the plans for shift-taking during operations. Section 4 discusses the run plan and data analysis outlook, both in the near-term during 2024 and over the full SBND run. Section 5 discusses the important roles of the host laboratory, Fermilab, in ensuring the successful and safe operation of SBND. Section 6 summarizes the outcomes of a process the collaboration recently carried out to identify primary risks during operations and how to address those issues, Section 7 lists the available stock of hardware spares, and Section 8 summarizes the expected required budget for operating SBND.

2 Experiment Overview

This Section provides brief descriptions of key elements of the SBND experiment, including: the facility used to produce the neutrinos, the cryostat and cryogenic system that house the detector and maintain the liquid argon, the three main SBND detector sub-systems (TPC, photon detectors, cosmic ray tagger), the data acquisition system and online trigger to initiate readouts, the detector control and online monitoring tools, and the data management and processing procedures.

2.1 Booster Neutrino Beam

The Booster Neutrino Beam (BNB) is the primary source of neutrinos and interactions that the SBND detector will use to execute its physics program. The BNB beamline was originally designed and built to service the MiniBooNE experiment. The beam of neutrinos is created by extracting proton bunches from the Booster accelerator with a mean energy of 8.89 GeV at an average rate of 5 Hz, with a spill duration of 1.6 μs. This 1.6 μs spill of protons is composed of 81 buckets, each 2 ns long, separated by 19 ns. These protons are then impinged onto a 1.7 interaction length beryllium target. The proton-beryllium collisions create secondary hadrons, and charged secondaries are sign selected and focused by a magnetic focusing horn. During nominal operations, positively charged particles are focused toward SBND, though the current can be inverted to focus negative particles. The magnetic focusing field is created by pulsing the horn with 174 ± 1 kA. The resulting stream of particles enter a 50 m long decay pipe where they decay into neutrinos with a mean energy of about 800 MeV. In positive focusing mode, the BNB flux is mostly muon neutrinos (93.6%) and muon anti-neutrinos (5.9%), with only a small (0.5%) contamination of electron neutrinos. This makes the BNB well suited for muon neutrino to electron neutrino oscillation searches.

To monitor the health of the BNB, the proton beamline is instrumented with a number of toroids, position and loss monitors, and a set of multiwire chambers. The Fermilab Accelerator Division, External Beam Delivery Department, maintains these devices. These devices store their outputs through ACNet to a database (IFBeam) which is used to populate a web page that displays the position of the proton beam relative to the target, the intensity of the beam, the current in the focusing horn, and the beam repetition rate. Fermilab experts support this website and the IFBeam database. The collaboration uses the information stored in the IFBeam database to assess the quality of the beam on a spill-by-spill basis and to measure the experiment's total exposure to protons-on-target.

2.2 Cryogenics

To support operation of the SBND LArTPC, a cryogenic plant was designed, built and installed at Fermilab through a scientific collaboration of CERN and Fermilab. The overall cryogenic plant, shown schematically in Figure 3, was divided conceptually into three cryogenic systems: External, Proximity, and Internal.

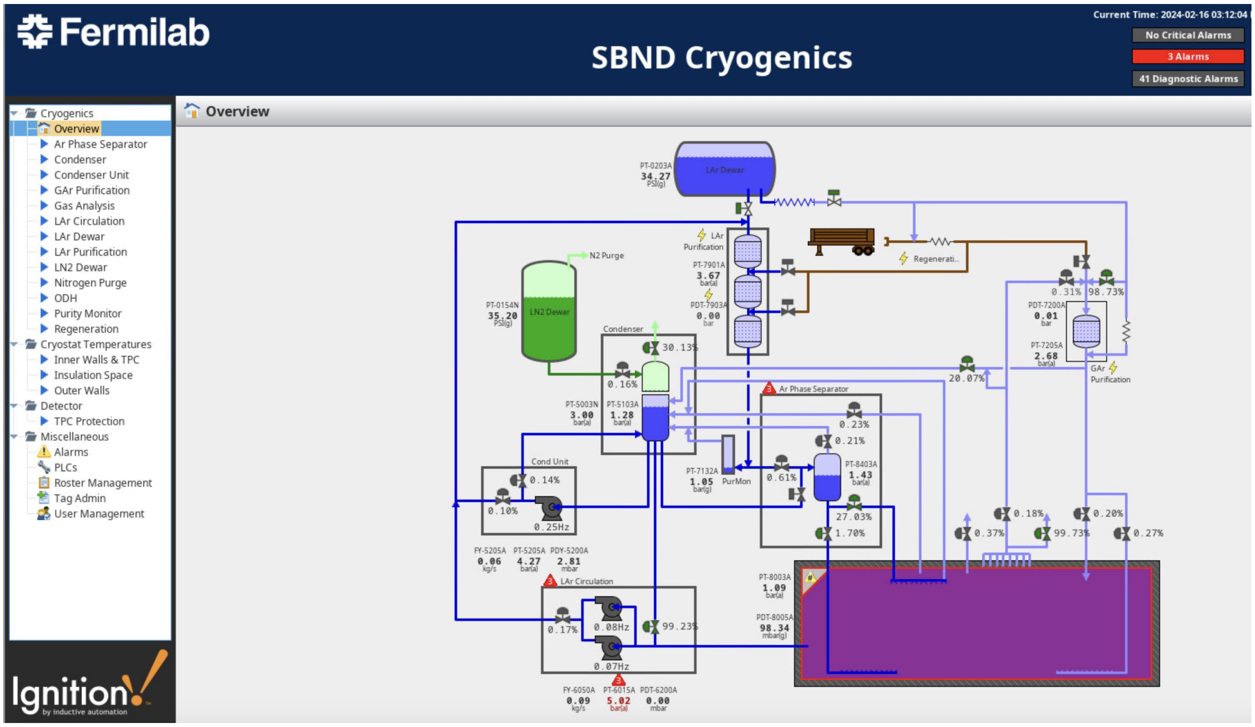


Figure 3: Schematic of the SBND cryogenics system as seen through the Ignition control and monitoring utility.

The External system, delivered by Fermilab, is responsible for storage and supply of cryogens, venting of gases, gas analysis, regeneration of filtration media, electrical power, and the process and safety controls systems. The Proximity system, delivered by CERN, is responsible for all transport and distribution of liquid argon and nitrogen, removal of impurities from argon, and recirculation and filtration of boil-off argon gas. The Internal cryogenic system, delivered by Fermilab, is responsible for interfacing the internal volume of the cryostat with the cryogenic plant and measurement of argon temperatures and levels. Table 1 lists requirements for the cryogenic plant.

Table 1: Requirements for the SBND cryogenic plant.

Requirements for the cryogenics plant	**Value**
Store and supply cryogens	Provide storage of LN2 (up to 75000 L) and LAr (30000 L) and support their uninterrupted supply to the cryogenic plant
LN2 system	Provide circulation of LN2 via gravity for the transfer lines and valve boxes as well as for re-condensing GAr from the cryostat
LAr system	Provide circulation of LAr with Barber Nichols pump via filter up to 10 GPM (2.3 m^3/hr)
GN2 system	Provide purge of the cryostat insulation space
GAr system	Provide collection and re-liquefaction of the GAr boil off
Regeneration system	Provide means of regenerating the filtration media (mol sieve and activated copper) at elevated temperatures and with H2/Ar mix
Control system	Provide process and safety controls with Beckhoff PLCs and Ignition control and data acquisition
Support operations	• Pressurization for qualification tests • Fill cryostat with GAr via piston purge • Circulation of GAr through filter for cleanup • Cool-down by slow transfer of liquid argon into cryostat • Fill with LAr from the LAr storage • Stabilization and normal operations
Control of the argon purity	Maintain purity at $<$100 ppt O^2 equivalent by: • filling the cryostat with purified argon via fill/recirculation filter • circulating LAr via LAr filters up to 10 GPM (2.3 m^3/hr) • removing impurities from condensed ullage gas
Control of the cryostat pressure	Normal operating pressure is 1.070 with ±5% bara maintained with combination of heat removal with condensing of argon gas from the ullage with Ar/N2 condenser. Abnormal operating pressure is managed with vent valves, emergency vent valve (one at 250 mbarg) and magnetic disk reliefs

The cryogenics system is heavily instrumented and monitored using the Ignition control and data acquisition utility. Monitoring panels, alarms, and sensor data are directly accessible to shifters and experts at all times. Figure 3 shows the main display page in Ignition, but one can see on the menu on the left the many other pages available for viewing. The Ignition tools are being used extensively to monitor the cryogenic system during cool down and filling, and this will continue to be a part of routine monitoring throughout operations.

Installation of the cryogenic system, including monitoring software, is complete and the system received Operational Readiness Clearance on January 22, 2024. Commissioning of the system started on January 24 with the flow of warm argon gas into the cryostat to purge the air in the cryostat and replace it with argon. Cool down was initiated on February 6 and continued until the cryostat reached approximately 130K on February 9, at which point cooling was paused to perform a set of detector commissioning checks. After completing those checks, cool down recommenced on Monday, February 12. Filling of the cryostat with liquid argon is in progress at the time of the SBND ORR on February 21, 2024.

2.3 Detector Systems

SBND is a 112-ton active mass LArTPC located in the SBN-ND experimental hall along the Booster Neutrino Beam. The detector front face sits 110 m downstream of the BNB target. The main elements of the experiment, the Time Projection Chamber (TPC), the Photon Detector Systems (PDS), and the Cosmic Ray Tagger (CRT), are briefly described in the following sub-sections.

2.3.1 TPC

As seen in the left panel of Figure 2, SBND is composed of two TPCs that share a central high-voltage cathode. Each TPC volume is $5.0\,\mathrm{m}$ (L) $\times$ $4.0\,\mathrm{m}$ (H) $\times$ $2.0\,\mathrm{m}$ (drift distance). Ionization charge readout is wire-based with three layers of wires: a collection plane Y (vertical) and two induction planes U and V ($\pm 60^\circ$ to the vertical). There are a total of 11,264 readout channels between the two TPCs.

The anode wires in each TPC are mounted on two separate, but connected Anode Plane Assemblies (APAs). Each APA consists of a $4.0\,\mathrm{m} \times 2.5\,\mathrm{m}$ steel frame supporting three planes of $150\,\mu m$ copper-beryllium wires at pitch and plane spacing of $3\,\mathrm{mm}$ (see Figure 4). By appropriate voltage biasing, the first two induction planes facing the drift region provide signals in a non-destructive way and the charge is collected on the wires of the collection plane. There is a jumpered interconnect between the two neighboring APA frames so they function as a single wire plane unit and signals can be collected at the outer edges of the TPC volume. The electronics readout is composed of a custom pre-amplifier ASIC, commercial ADCs, and a motherboard with onboard FPGA connected around the perimeter of each wire plane and operating in the liquid argon. The central cathode is a welded, electro-polished assembly composed of a stainless steel tube frame supporting stainless mesh panels which carry the high voltage. The cathode's nominal operating voltage is $-100\,\mathrm{kV}$. A coaxial high voltage feedthrough composed of a stainless steel core and

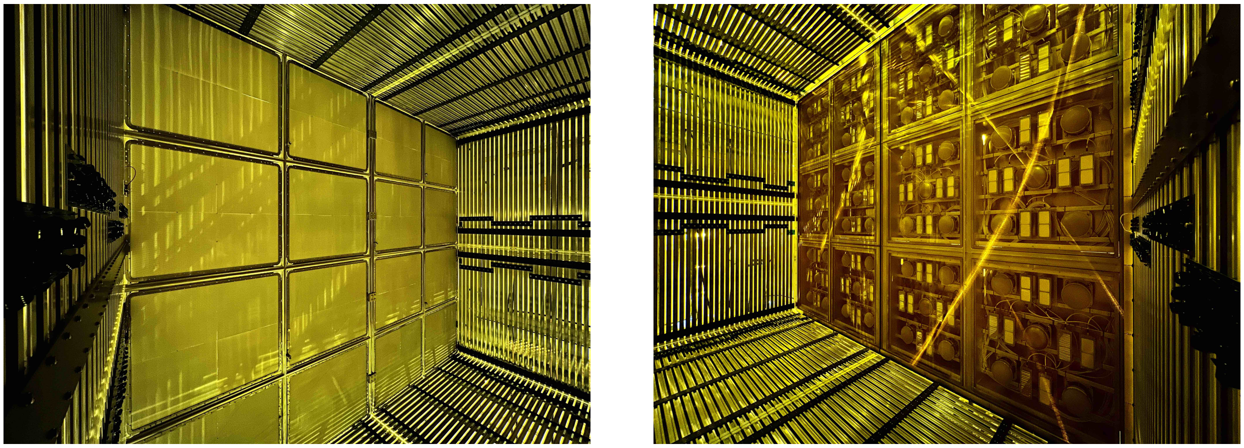


Figure 4: The SBND TPC. visible are the high-voltage cathode with embedded TPB-coated reflector foils (left) and the photon detectors behind the three planes of anode wires (right). The field cage (left and right) steps down the potential uniformly between the cathode and anode.

grounding sheath with polyethylene (PE) insulator brings this bias into the LAr cryostat and contacts the cathode 'donut' through a spring-loaded tip. To maintain a uniform electric field in the drift region, a field cage composed of roll-formed aluminium profiles with PE end caps surrounds the TPC active volume (see Figure 4). The design is the same as the field cage designed for DUNE and used in the single-phase DUNE prototype at CERN, ProtoDUNE-SP.

The entire TPC is housed in a stainless steel membrane cryostat, which is a similar design and serves as a prototype for the cryostat of the DUNE far detectors. The SBND TPC is supported from the cryostat roof, which contains the feedthroughs for all detector cables and the high voltage. Figure 2 (center) shows the TPC attached to the cryostat lid during insertion into the cryostat. See also the photograph on the title page of this document.

2.3.2 Photon Detectors

SBND has a multi-part photon detector system (PDS) that both enhances the amount of light collected and provides an R&D opportunity for scintillation detection in LAr. The PDS in SBND integrates two different optical devices:

- 120 Hamamatsu R5912-mod 8 in. photomultiplier tubes (PMTs) and
- 192 X-ARAPUCA devices composed of a dichroic filter window on a highly internally reflective box instrumented with silicon photomultipliers (SiPMs)

all mounted to the APA frames behind the TPC wire planes (see Figure 2 and 4 - right).

Scintillation photons emitted in liquid argon are in the vacuum ultraviolet (VUV) region of the spectrum rendering them undetectable by most standard devices. Consequently, a wavelength shifting material Tetraphenyl Butadiene (TPB), which absorbs the VUV light and subsequently emits in the visible range, is used. 96 of the PMTs are coated with TPB to wavelength shift

VUV photons before entering the device. In addition, embedded in the TPC cathode wall are large reflective foil panels also coated with TPB (see Figure 4 - left). This design allows photons emitted in the opposite direction to the photon-detection plane (i.e. towards the cathode) to be wavelength-shifted to the visible region and still be detected, thus achieving a higher yield and a significantly more uniform response across the TPC volume. Using different types of dichroic filters, half of the X-ARAPUCAs are built to be sensitive to the VUV light and the other half to the visible light. The PDS will, therefore, see two different light components: (i) a direct component, where the photons arrive with VUV wavelengths to the TPB coated PMT and VUV-sensitive X-ARAPUCA, and (ii) a cathode reflected component, where the photons arrive already with visible wavelengths to PMT and visible-sensitive X-ARAPUCAs. This allows a valuable separation of the two components.

2.3.3 Cosmic Ray Tagger

The Cosmic Ray Tagging system (CRT) detects cosmic muons entering in SBND and measures their crossing time and coordinates relative to interactions internal to the TPC. It is a tool to mitigate the cosmic ray background in SBND physics analyses. From Monte Carlo simulations, an average of five cosmic muon tracks are seen in each recorded TPC readout.

The CRT system is composed of 142 modules. A module contains 16 strips of solid scintillator, each strip with cross-section $10 \times 112\,\text{mm}^2$ (except for the ones beneath the cryostat, where the width of the strips is 59.5 mm). Each strip contains two wavelength-shifting fibers which are routed to the end of the module for readout (See Figure 5). Two layers of modules, oriented perpendicular to each other to provide X and Y coordinates for passing tracks, are assembled into large panels that are mounted outside each side of the SBND cryostat to provide close to 4π solid angle coverage. The side panels, for example, are each $\sim$9 m×7 m; they are pre-assembled onto support frames and then installed around the cryostat as a single unit. Above the cryostat, where the flux of cosmic rays is maximal, two planes will be installed 1.25 m apart. The layout of the seven CRT planes is shown in Figure 2 (right).

WLS fibers are routed to Hamamatsu S12825-050P MPPC photo-diodes at the end of the module. The CRT Front-End Board (FEB) is designed to serve 32 MPPCs from one module (16 scintillating strips). The FEBs provide individually adjustable bias voltages in the range of 40–90 V for each of the 32 MPPCs, amplifies and shapes the MPPC output pulses, discriminates the resulting signal at a configurable level from 0 to 50 photo-electrons, and provides basic signal coincidence from each pair of WLS fibers. This allows digitization of the signal amplitudes and triggering on interactions with sufficient amplitude that happened in coincidence with an interaction in another group of FEBs, while forming the time stamp w.r.t. an input reference pulse with an accuracy of $\sim$1 ns.

2.4 Data Acquisition

The data acquisition (DAQ) system for SBND is responsible for collecting and organizing signals from each of the experiment subsystems. It identifies data from the different subsystems that

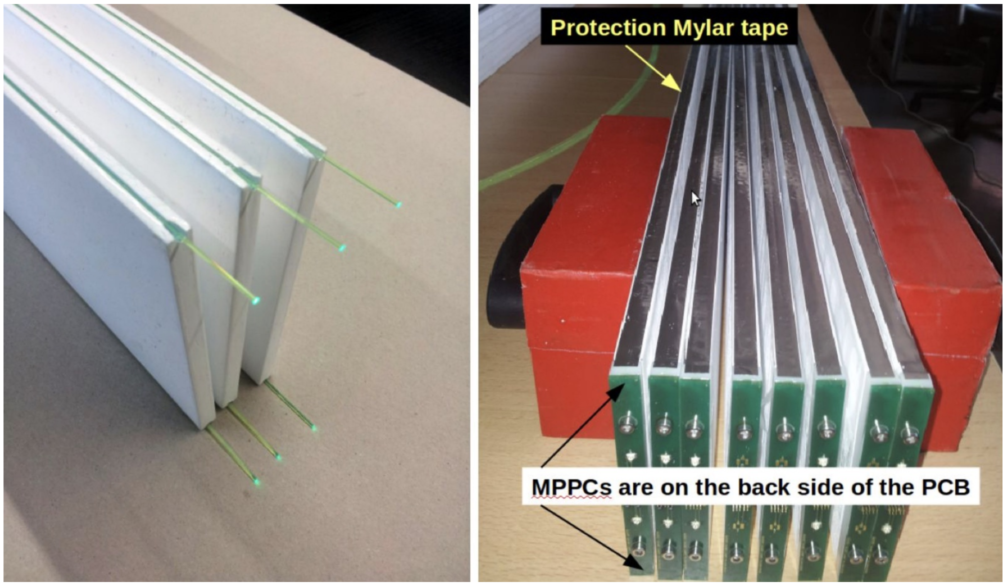


Figure 5: SBND CRT modules are composed of 112 m wide scintillator strips with two wavelength shifting fibers routed to an MPPC at the end of the module.

correspond to activity during a given triggered readout period and assembles these data into a complete "event", which is then written out to disk. These events are the basis used to perform SBND physics analysis. The SBND DAQ system is based on the common Fermilab-supported artDAQ framework, which is shared across several experiments, including the SBN far detector ICARUS.

The artDAQ framework interfaces with the SBND readout electronics for each subsystem through a set of experiment-specific modules, which have been primarily developed by collaborators who have expertise related to their respective electronics, with support from the artDAQ team. These modules configure the electronics and collect data from them, and are each running on one or more dedicated DAQ servers allocated for each subsystem. We have experts for each subsystem within the collaboration who have expertise in the electronics and in implementing and modifying the artDAQ software modules to interface with them.

The flow of data through the system is illustrated in Figure 6. Below, we provide a brief overview of these subsystems from the perspective of the DAQ:

- TPC Cold Electronics (CE) Boards: There are 88 cold front-end motherboards (FEMBs) inside the liquid argon that each read out 128 TPC channels (11,264 total TPC channels). 24 Warm Interface Boards (WIBs) are mounted to the outside of the cryostat feedthrough flanges and are used to configure warm electronics boards by synchronizing them with CE boards. The TPC signals are digitized on the FEMBs at 2 MHz.

- TPC Warm Electronics Boards and Nevis Trigger Board: Warm electronics boards are mounted in 11 TPC readout crates. One of the 11 crates also has the Nevis Trigger Board (NTB), which is responsible for distributing event triggers to all of the TPC readout crates. The TPC warm readout system is responsible for real-time lossless compression of the TPC

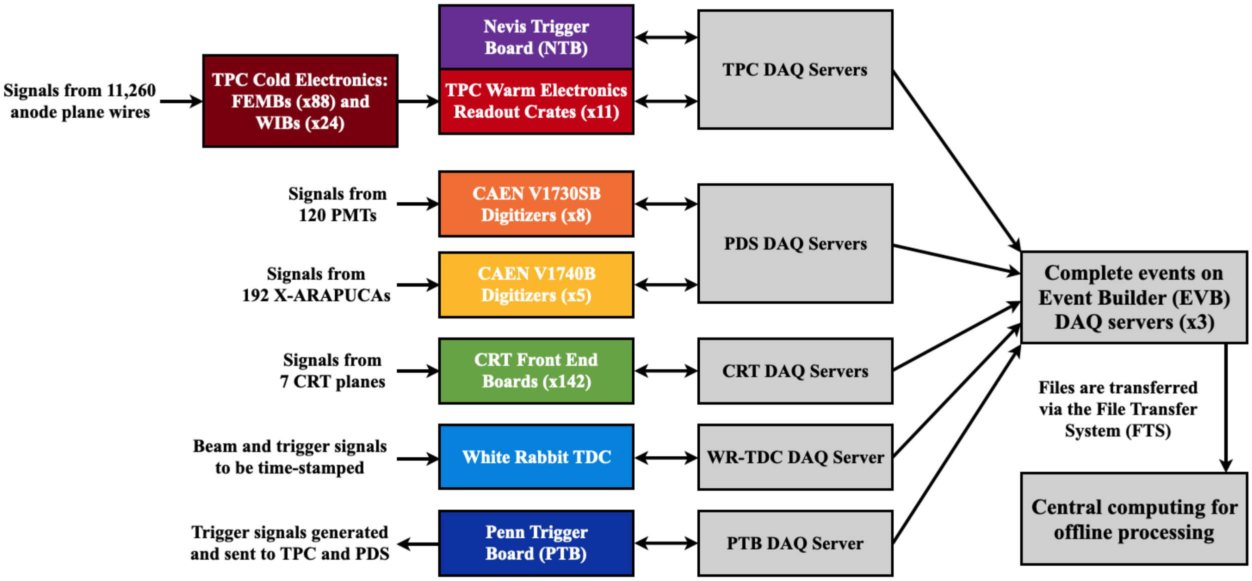


Figure 6: A schematic overview of data flow from the SBND detector to DAQ.

data received from the cold electronics. It also stores the TPC data until a trigger decision can be made. The event data is sent out upon receiving an event trigger from the NTB, which in turn receives an event trigger from the Penn Trigger Board (see Section 2.5).

- Photon Detector Digitizers: As described in Section 2.3.2, the SBND PDS consists of 120 PMTs and 192 X-ARAPUCAs, the signals from which are read out by CAEN V1730 and V1740 boards, respectively. The CAEN readout system digitizes the light signals collected. The PMT CAEN V1730s provide trigger primitives that are inputs to the trigger system. Additionally, the digitized light signals from the PDS are recorded by the DAQ system to construct the complete event. The PMT light signals read out by the V1730 boards are digitized at a rate of 500 MHz, while the X-ARAPUCA light signals read out by the V1740 boards are digitized at a rate of 62.5 MHz.

- Cosmic Ray Tagger FEBs: As described in Section 2.3.3, the 142 CRT FEBs each self-trigger on coincident signals in scintillator strips from CRT modules that may overlap each other in the same CRT panel. The digitized and time-stamped signals are retrieved from the FEB buffers by the CRT DAQ servers.

- Penn Trigger Board (PTB): The PTB sends readout triggers to the TPC and PDS based on logic signals it receives from the beam (indicating the time of the beam arrival), the PDS and the CRT. More details about the PTB are found in Section 2.5.

- White Rabbit Time-to-Digital Converter (WR TDC): The White Rabbit TDC records the time of TTL input pulses to sub-ns precision. These inputs are: the trigger signals issued by the PTB to the TPC and PDS; the BNB beam signals provided by the accelerator, specifically the BES and RWM; and the timing signal sent to the CRT.

Given the information from each of the subsystems, the DAQ is responsible for integrating this information into complete built events. The process occurs on dedicated event builder DAQ servers. Events are built based on a combination of common trigger number (for TPC data) and data fragment timestamps (for PDS, CRT, PTB, and WR TDC data). Synchronization of the different subsystems is ensured through common distribution of a GPS pulse-per-second signal from the White Rabbit timing system.

The artDAQ framework provides several critical features, including tools for building events with data from the various components, configuring and controlling DAQ runs, monitoring the performance of the DAQ, and sending data events out for analysis as part of online data quality monitoring. The DAQ monitoring (Grafana) and online data quality monitoring (DQM) are described in more detail in Section 2.6.3. Additionally, artDAQ generates raw data that is already in the art ROOT format, which reduces the amount of preprocessing necessary for offline analysis. We rely on support from artDAQ experts at Fermilab to debug any issues that arise during running and to provide ongoing support for the artDAQ framework.

The completed events are written out to files stored on local disk on the SBN-ND event builder servers. They are then transferred to the offline computing system via the common Fermilab-supported File Transfer System (FTS), which is described in Section 2.7. The offline location that files are transferred to is in Fermilab's tape-backed central storage system.

The SBND DAQ is designed to accommodate a 15 Hz instantaneous rate with a 5 Hz average rate, consistent with the maximum BNB beam delivery rate. A typical SBND raw data event is expected to be about 43 MB, although the exact number will depend on the performance of the online TPC and PDS data compression algorithms, which cannot be determined until the detector is turned on. The SBND DAQ event builder servers have a total of 63 TB of local storage, which during normal operations should be sufficient for at least a week's worth of storage should any interruptions in data transfer occur.

Maintenance of the DAQ servers during operations involves both the SBND DAQ team and the SLAM team. SLAM provides 24/7 support in case of server issues, while the vendor (KOI Computers) provides repairs or replacements for any damaged servers that are under warranty. We also have hot spare DAQ servers installed *in situ* at SBN-ND. The experiment will replace DAQ servers as they reach end-of-life status (when the 5-year warranty expires). When a server is replaced, the initial setup of the new servers will be done by the SLAM team, and subsequent testing will be the responsibility of the SBND DAQ team.

2.5 Trigger

The SBND trigger system identifies events of interest and interfaces with the DAQ system to read out and record sub-detector information for the selected events. The primary physics use case is to select events with a neutrino interaction in the TPC, as indicated by light above a noise

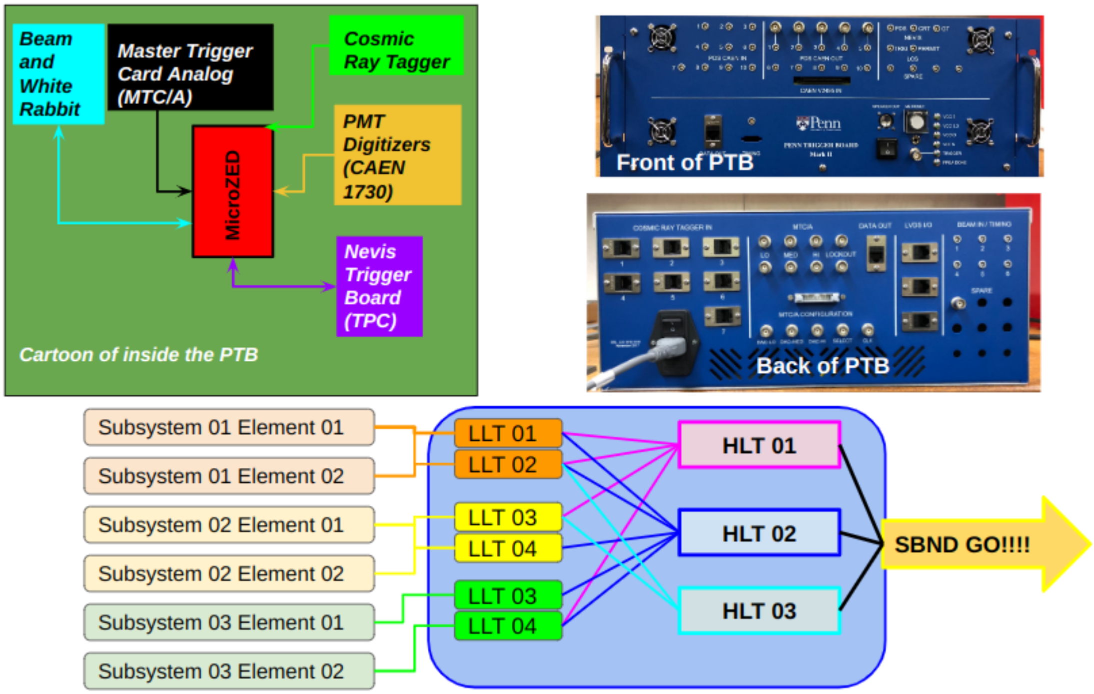


Figure 7: A schematic overview of the PTB (and photographs) highlighting the various hardware inputs and how the Low Level and High Level trigger decisions are made in SBND.

threshold in the PMTs in coincidence with timing signals indicating the presence of the neutrino beam. In SBND, we expect a neutrino interaction inside the detector about 1 in every 20 Booster Neutrino Beam spills. The PMT signals are read out by the CAEN V1730 digitizers which in turn are used as inputs to the MTC/A (Master Trigger Card/Analog) which has settable thresholds (Low, Medium, and High) according to the number of PMT's that are "on" above noise. If an event were to satisfy a trigger in the suite of active triggers for that run, this would initiate the recording of all the detector information for that event: the TPC wire information, the PMTs information, CRT counters informations, etc., thus reducing the overall amount of data relative to the continuous recording of events. The trigger system will also be used for calibration and commissioning (examples would be a muon that crosses the detector leaving hits on each side of the detector, or a cosmic ray trigger that would have a hit in the top and bottom CRT planes, but no beam requirement).

At the heart of the SBND trigger system is the Penn Trigger Board (PTB), which was originally designed to serve as the master trigger and readout of the muon counters for the DUNE 35-ton prototype and later utilized successfully by ProtoDUNE-SP. The conceptual drawing of the PTB can be seen on the left side of Figure 7, where the various hardware inputs are fed to the MicroZED Xilinx ZYNQ 7020, which consists of a powerful FPGA and an embedded processing core. Each subsystem's inputs can be formed into "Low-Level Triggers" (LLTs) via firmware configured on the PTB. LLTs consist of one or more inputs from a single subsystem, and can be combined with

LLTs from other subsystem to form a “High-Level Trigger” (HLT). HLTs are defined in a trigger menu, and if any of the HLT’s are satisfied, the system will initiate a readout by the DAQ.

The PTB receives 102 inputs to the FPGA and provides logical combinations of these to form a master trigger with an associated time stamp and provides 10 trigger outputs and 4 calibration outputs. The hardware also provides a data output over an ethernet connector for downstream event building, which can include whatever header information is needed. Many configurations of the system are possible without firmware changes, but anything that can be done in an FPGA and anything that can be programmed via software (on a simple Linux system) can be handled by this system, with changes to the existing firmware and software. Extensive testing and usage of this trigger system in other experiments gives us confidence that the SBND trigger system provides the desired functionality. During detector operations it will be important to monitor the trigger rates (both LLTs and HLTs), as these will provide not only information about the stability of the trigger system, but also early information about changes in beam conditions or the health of the various detector sub-systems.

2.6 Detector Online Monitoring and Control Systems

The detector control and online monitoring systems of SBND consist of a suite of tools to connect to various components of operation, including the detector systems, experiment control systems, the cryogenics, and the neutrino beam. The organization of the tools is shown in the flowchart of Figure 8. The DAQ retrieves data from the detector subsystems (TPC, PDS, CRT, PTB, and WR TDC) as discussed in Section 2.4; the EPICS software sends and receives information to control and monitor many devices and conditions important to the experiment; the Ignition software is used specifically to control and retrieve data from the SBND cryogenics systems and the HV power supply for the TPC drift electric field. Data collected by these tools can be stored in a variety of formats, as indicated in the blue symbols in the center of Figure 8. Several visualization tools are then available for viewing the data in real-time or for browsing stored, historical data. Together this system provides a number of low-level checks for consumption by shifters and experts for diagnosing the operation status and identifying issues. The monitoring tools operate independently of the systems being monitored. More details about these tools are given in the following subsections.

2.6.1 Auxiliary Instrumentation in the Cryostat

A few different types of devices have been installed in and around the cryostat specifically to monitor the condition of the liquid argon and the detector. These include:

- LAr purity monitors: SBND has three purity monitors to check the electronegative contamination levels of the argon (especially molecules of oxygen and water). The purity monitors are double-gridded ion chambers immersed in the liquid argon, placed outside of the TPC. Figure 9 shows the locations of the three monitors within the experiment. There is one

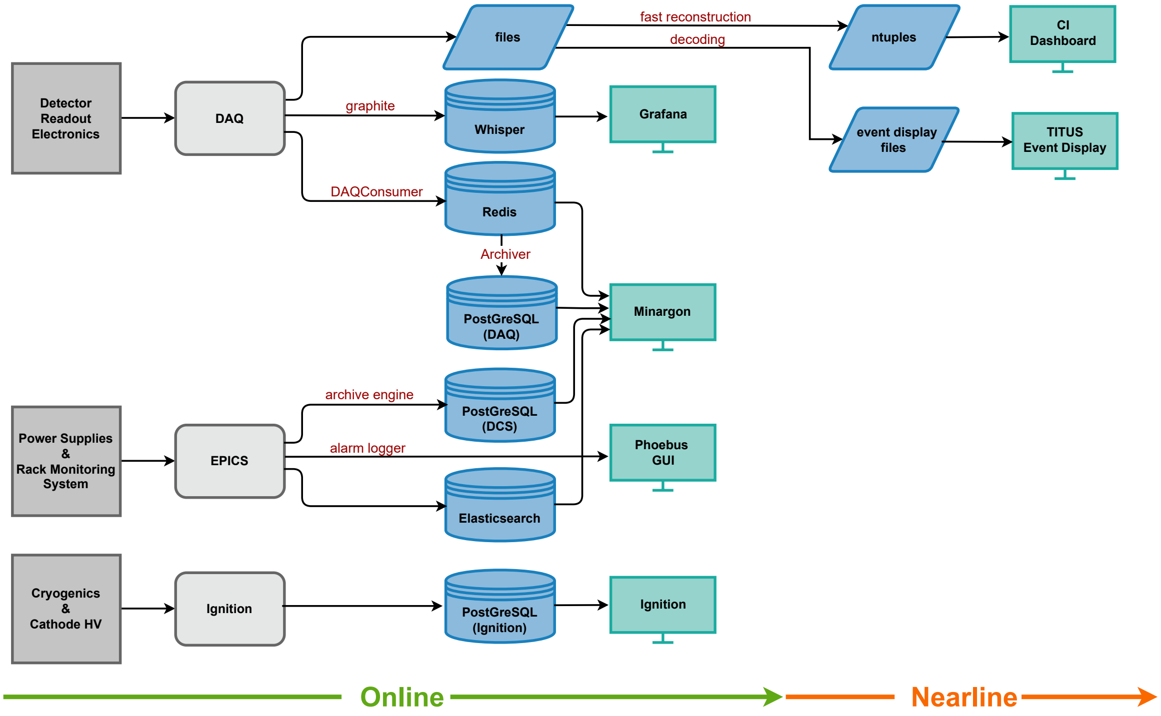


Figure 8: A schematic overview of data flow through the SBND online control and monitoring system.

longer purity monitor along the argon inflow line after the filters and two internal to the cryostat (one long, one short). The purity monitors are especially important during purification, commissioning, and for the first weeks of data, but can also be used during steady operations to monitor the LAr purity. Figure 9 also shows a schematic of a purity monitor. Electrons are liberated from the photocathode by a UV light source, and the amplitude of the charge signal is compared at both ends of a drift region.

- Resistance Temperature Detectors (RTDs): 79 RTDs installed both inside and outside the cryostat will monitor the temperature of the argon and the detector during filling and regular operations: 36 on the cryostat walls, 18 on the TPC, and 25 on the outside of the cryostat. The RTDs are 4-wire PT100 Class A devices from Omega (precision 0.55 K). Figure 10 (left) shows an example of RTDs installed at different heights in one corner of the cryostat.
- Cameras: Five cameras were mounted inside the cryostat that will be able to see several key locations on the detector, including the corners of the TPC (field cage connections to the wire planes), the high voltage feedthrough, the wire planes, and the LAr surface. Figure 10 (right) shows an image captured from one of the cameras during testing.

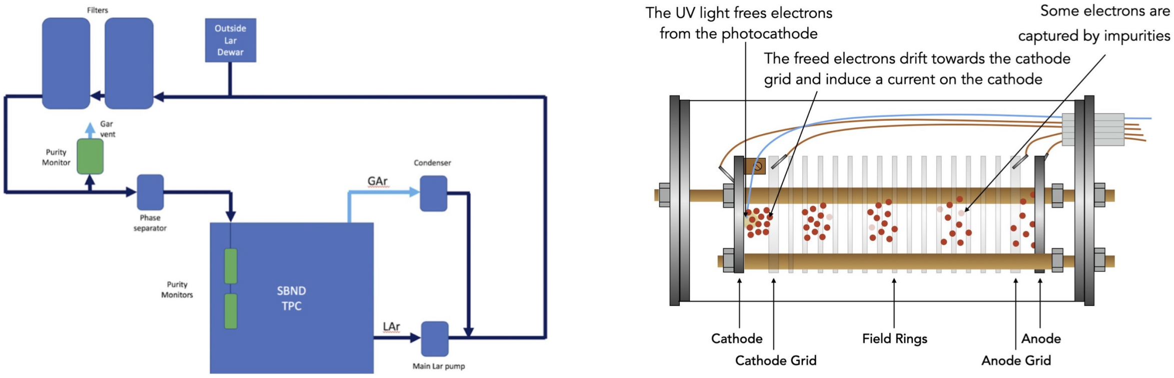


Figure 9: Three purity monitor devices are installed in SBND: two inside the cryostat and one along the inflow line to the cryostat.

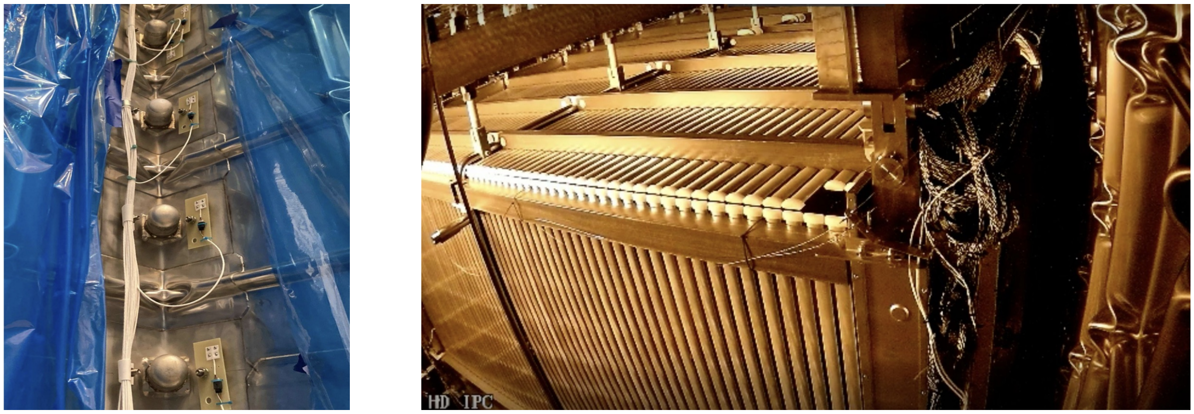
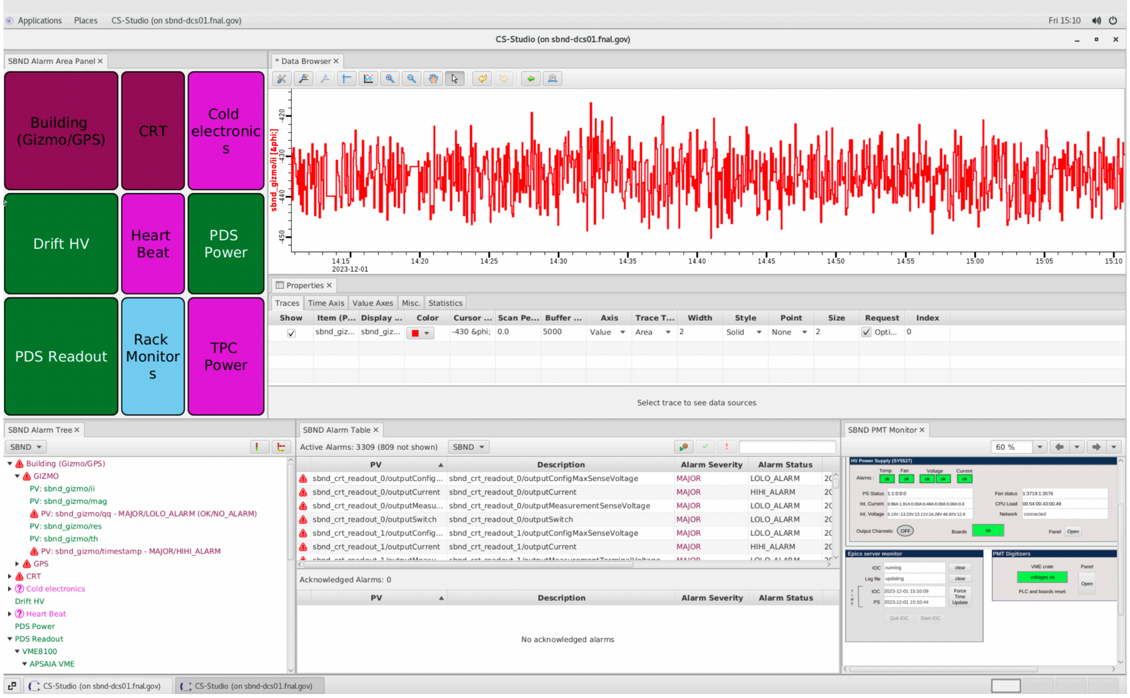


Figure 10: 79 RTDs are installed in and around the SBND TPC for monitoring the temperature - on the left are shown RTDs installed in the corner of the cryostat at different levels. Five cameras are mounted inside the cryostat for viewing the detector - on the right is shown the view of one of the cameras.

2.6.2 Detector Control and Monitoring with EPICS

The Detector Control System (DCS) of SBND uses EPICS (Experimental Physics and Industrial Control System) for controlling and monitoring many devices and conditions important to the experiment. These include power supply and readout crates/modules controls, rack temperatures, fan speeds, rack protection interlock status, and various environmental conditions. Applications from the "Phoebus" Control System Studio (CS-Studio) are used for providing displays, alarm notifications, and data archiving. For examples, Figure 11 shows a summary page for shifters and Figure 12 shows a window for TPC experts for monitoring and controlling wire bias power supplies.



Show	Item (P...	Display ...	Color	Cursor ...	Scan Pe...	Buffer ...	Axis	Trace T...	Width	Style	Point	Size	Request	Index
☑	sbnd_giz...	sbnd_giz...	🟥	-430 φ	0.0	5000	Value	Area	2	Solid	None	2	☑ Opti...	0

Select trace to see data sources

- Building (Gizmo/GPS)
  - GIZMO
    - PV: sbnd_gizmo/ii
    - PV: sbnd_gizmo/mag
    - PV: sbnd_gizmo/qq - MAJOR/LOLO_ALARM (OK/NO_ALARM)
    - PV: sbnd_gizmo/res
    - PV: sbnd_gizmo/th
    - PV: sbnd_gizmo/timestamp - MAJOR/HIHI_ALARM
  - GPS
- CRT
- Cold electronics
- Drift HV
- Heart Beat
- PDS Power
- PDS Readout
  - VME8100
    - APSAIA VME

Active Alarms: 3309 (809 not shown) SBND

PV	Description	Alarm Severity	Alarm Status
sbnd_crt_readout_0/outputConfig...	sbnd_crt_readout_0/outputConfigMaxSenseVoltage	MAJOR	LOLO_ALARM
sbnd_crt_readout_0/outputCurrent	sbnd_crt_readout_0/outputCurrent	MAJOR	HIHI_ALARM
sbnd_crt_readout_0/outputMeasu...	sbnd_crt_readout_0/outputMeasurementSenseVoltage	MAJOR	LOLO_ALARM
sbnd_crt_readout_0/outputSwitch	sbnd_crt_readout_0/outputSwitch	MAJOR	LOLO_ALARM
sbnd_crt_readout_1/outputConfig...	sbnd_crt_readout_1/outputConfigMaxSenseVoltage	MAJOR	LOLO_ALARM
sbnd_crt_readout_1/outputCurrent	sbnd_crt_readout_1/outputCurrent	MAJOR	HIHI_ALARM

Acknowledged Alarms: 0

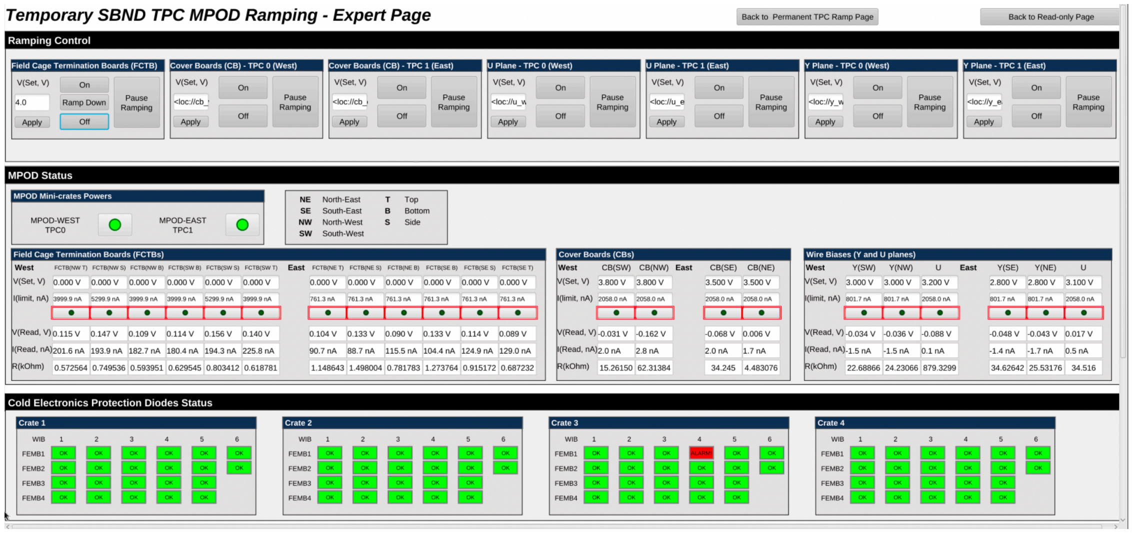
PV	Description	Alarm Severity	Alarm Status

No acknowledged alarms

Figure 11: A detecor control system summary page for shifters. Alarm status is summarized in top-left panel. Top-right panel shows data browser for real time monitoring on a certain variable. Bottom-left and bottom-center panels show alarm tree and alarm table, respectively. Bottom-right panel summarizes photon detection system status.

EPICS architecture: An EPICS system consists of any number of server programs implementing the EPICS Channel Access (CA) protocol to provide client programs access to any number of process variables (PVs), where each process variable represents a quantity being controlled (an output) or measured (an input). The EPICS base distribution provides a standard type of channel access server called an Input/Output Controller (IOC), which can be extended to support specific hardware as desired.

Power supply controls: Power supplies for readouts, field cage termination boards, cover boards, and wire biases are controllable over the network through the NetSNMP protocol. Several EPICS driver modules are available for SNMP, and SBND utilizes one written at NSCL. An IOC



Panel	V(Set, V)
Field Cage Termination Boards (FCTB)	4.0
Cover Boards (CB) - TPC 0 (West)	<loc://cb_
Cover Boards (CB) - TPC 1 (East)	<loc://cb_
U Plane - TPC 0 (West)	<loc://u_w
U Plane - TPC 1 (East)	<loc://u_e
Y Plane - TPC 0 (West)	<loc://y_w
Y Plane - TPC 1 (East)	<loc://y_e

NE	North-East	T	Top
SE	South-East	B	Bottom
NW	North-West	S	Side
SW	South-West		

Field Cage Termination Boards (FCTBs)

West	FCTB(NW T)	FCTB(NW S)	FCTB(NW B)	FCTB(SW B)	FCTB(SW S)	FCTB(SW T)	East	FCTB(NE T)	FCTB(NE S)	FCTB(NE B)	FCTB(SE B)	FCTB(SE S)	FCTB(SE T)
V(Set, V)	0.000 V	0.000 V	0.000 V	0.000 V	0.000 V	0.000 V		0.000 V	0.000 V	0.000 V	0.000 V	0.000 V	0.000 V
I(limit, nA)	3999.9 nA	5299.9 nA	3999.9 nA	3999.9 nA	5299.9 nA	3999.9 nA		761.3 nA	761.3 nA	761.3 nA	761.3 nA	761.3 nA	761.3 nA
	●	●	●	●	●	●		●	●	●	●	●	●
V(Read, V)	0.115 V	0.147 V	0.109 V	0.114 V	0.156 V	0.140 V		0.104 V	0.133 V	0.090 V	0.133 V	0.114 V	0.089 V
I(Read, nA)	201.6 nA	193.9 nA	182.7 nA	180.4 nA	194.3 nA	225.8 nA		90.7 nA	88.7 nA	115.5 nA	104.4 nA	124.9 nA	129.0 nA
R(kOhm)	0.572564	0.749536	0.593951	0.629545	0.803412	0.618781		1.148643	1.498004	0.781783	1.273764	0.915172	0.687232

Cover Boards (CBs)

West	CB(SW)	CB(NW)	East	CB(SE)	CB(NE)
V(Set, V)	3.800 V	3.800 V		3.500 V	3.500 V
I(limit, nA)	2058.0 nA	2058.0 nA		2058.0 nA	2058.0 nA
	●	●		●	●
V(Read, V)	-0.031 V	-0.162 V		-0.068 V	0.006 V
I(Read, nA)	2.0 nA	2.8 nA		2.0 nA	1.7 nA
R(kOhm)	15.26150	62.31384		34.245	4.483076

Wire Biases (Y and U planes)

West	Y(SW)	Y(NW)	U	East	Y(SE)	Y(NE)	U
V(Set, V)	3.000 V	3.000 V	3.200 V		2.800 V	2.800 V	3.100 V
I(limit, nA)	801.7 nA	801.7 nA	2058.0 nA		801.7 nA	801.7 nA	2058.0 nA
	●	●	●		●	●	●
V(Read, V)	-0.034 V	-0.036 V	-0.088 V		-0.048 V	-0.043 V	0.017 V
I(Read, nA)	-1.5 nA	-1.5 nA	0.1 nA		-1.4 nA	-1.7 nA	0.5 nA
R(kOhm)	22.68866	24.23066	879.3299		34.62642	25.53176	34.516

Crate 1

WIB	1	2	3	4	5	6
FEMB1	OK	OK	OK	OK	OK	OK
FEMB2	OK	OK	OK	OK	OK	OK
FEMB3	OK	OK	OK	OK	OK	
FEMB4	OK	OK	OK	OK	OK	

Crate 2

WIB	1	2	3	4	5	6
FEMB1	OK	OK	OK	OK	OK	OK
FEMB2	OK	OK	OK	OK	OK	OK
FEMB3	OK	OK	OK	OK	OK	
FEMB4	OK	OK	OK	OK	OK	

Crate 3

WIB	1	2	3	4	5	6
FEMB1	OK	OK	OK	ALARM!	OK	OK
FEMB2	OK	OK	OK	OK	OK	OK
FEMB3	OK	OK	OK	OK	OK	
FEMB4	OK	OK	OK	OK	OK	

Crate 4

WIB	1	2	3	4	5	6
FEMB1	OK	OK	OK	OK	OK	OK
FEMB2	OK	OK	OK	OK	OK	OK
FEMB3	OK	OK	OK	OK	OK	
FEMB4	OK	OK	OK	OK	OK	

Figure 12: TPC ramping page is shown as an example for expert pages. Top panel is for setting voltages and ramping up/down each layer. Center panel shows status of all power supply channels together with control for each channel. Last panel summarizes status of cold electronics protection didoes.

with this SNMP module runs on a central computer and contacts the power supplies over a private network for monitoring and control. The PMT power supplies have custom IOCs running in their own controllers.

Stream devices: Devices with private communication protocols are also monitored and controlled using the EPICS by providing protocol definitions to the EPICS. PDS readout crates are such devices.

Slow control boxes: SBND has a number of racks in various positions at the mezzanine level and above the detector. Each is equipped with a rack-protection system including a smoke detector and multiple digital temperature sensors, and most contain one or two fan packs, each containing 3 fans. Each rack has a 1U rack-mount enclosure containing a single-board computer (Beaglebone Black, BBB) running Debian GNU/Linux 8 and a custom interface board, collectively known as a "slow controls box". A custom PCB which is powered from the BBB interfaces for rack protection system (RPS), six temperature probe channels, four fan pack channels, and hardware interlocks for power supply modules. A 5V interlock signal is provided only if BBB is running, no smoke detection, and no over temperatures.

External data sources: Data are imported into EPICS channels from a number of external sources. The primary reason for duplicating these data in EPICS is to integrate displays and warnings into one system for the experiment operators, and to provide integrated archiving for sampled data in the archived database. An IOC running on a central computer provides "soft" process-variables channels for these data. Cold electronics status, building ground current and impedance monitor (GIZMO), and GPS are examples. Baseline monitoring of Master Trigger Card Analog (MTC/A) will be added.

Archiving and alarm: All PVs are archived into a Postgres database (DB) by the EPICS archive engine following pre-defined sampling rates and sampling variations. Alarm ranges for important PVs are defined inside IOCs. The alarm-server package summarizes alarms of all PVs and presents status for each sub-system. Detailed alarm information for each PV can be also visited using the alarm tree and table feature of the alarm-server package. It will be helpful for experts and shifters for recognizing if there is any problem with a certain sub-system. The alarm-logger package archives history of alarms into an Elasticsearch DB. Both the Postgres DB for PV histories and the Elasticsearch DB for alarm histories are also accessible from the online monitoring page which is described next.

2.6.3 Online Monitoring

DAQ Monitoring: SBND uses the Grafana monitoring system to monitor the DAQ. Grafana uses the graphite program to send time-series data from the DAQ to the Whisper DB. Data stored in the DB can be pulled and displayed on the Grafana webpage, which is hosted locally on a DAQ machine. The hosting machine is typically an event-builder: the server “evb04.fnal.gov” was used for commissioning. To view the web page, local forwarding or a DAQ machine VNC session is used. Roughly 24 to 48 hours worth of live data can be stored in the Whisper DB. Older data is then averaged with an increasing level of time intervals such as over a day, couple of days, and a week to stay in the DB for a couple of months.

All systems and software being run as parts of the DAQ can be monitored through Grafana. This includes the run number, DAQ server time, and memory metrics. It also includes event-building metrics (such as the number of empty or missing fragments, the time taken waiting for a process or to build events), board-reader metrics, the status of various memory buffers, and trigger and event rate metrics. All metrics are sent to the Whisper DB and are displayed on the Grafana webpage as long as the relevant piece of the DAQ is running, regardless of whether the information is part of a built event or not.

The Grafana web page allows for the DAQ metric data to be displayed in a variety of configurable ways, such as tables, timeline plots, bar graphs, and more. One set of data can be displayed multiple ways on the same page. Some display settings allow for color-coding with configurable thresholds, so that certain displays can “alarm” (turn red) with undesirable metric values. Additionally, multiple Grafana pages can be hosted on the same machine. This allows for the existence of a general “shifter” page as well as a number of different “expert” pages.

Data Quality Monitoring: SBND uses a data quality monitoring (DQM) infrastructure that was developed for the Short-Baseline Neutrino (SBN) program and is currently in routine use for operations at ICARUS. At SBND, the monitored detector systems are as follows:

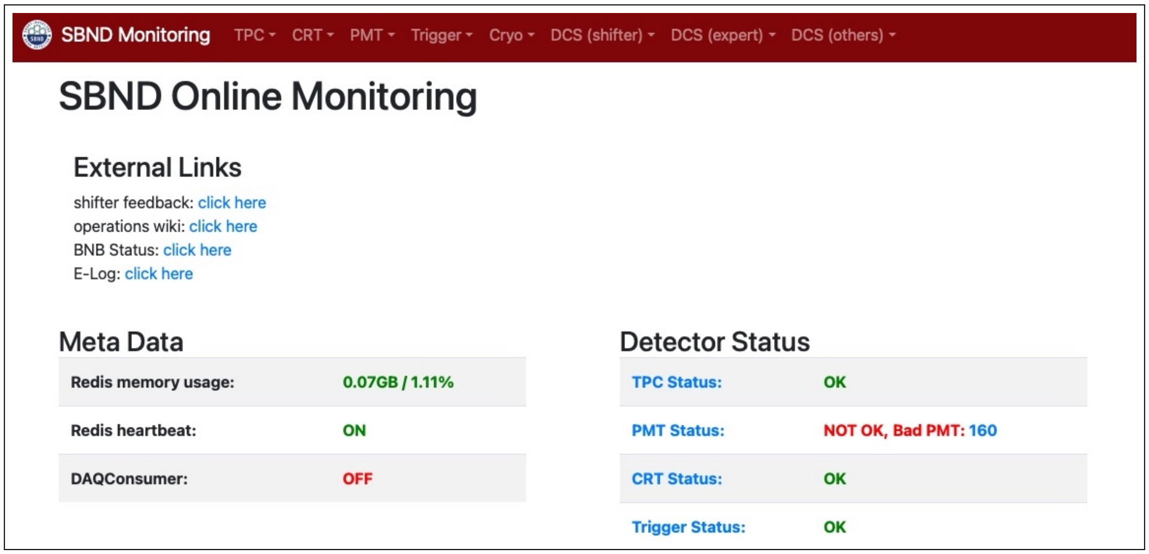
- TPC: Channel waveforms and FFTs will be monitored, along with computed metrics such as noise RMS, baseline, hit occupancy and mean peak height. The values will be compared to reference values from stable operation.

- PDS: Computed metrics such as noise RMS, baseline, hit occupancy and mean peak height will be monitored per photon detector (PD), and the values will be compared to reference values from stable operation.

- CRT: Computed metrics such as baseline, hit time, and maximum ADC value will be monitored per board, and the values will be compared to reference values from stable operation.
- WR TDC: Timestamps of the different signals that are inputs to the White Rabbit TDC will be monitored and compared to ensure stable time alignment between beam, timing, and trigger signals.
- Trigger system: Low- and high-level trigger (LLT and HLT) production and analog sum of the MTC/A will be monitored.

The low-level monitoring metrics listed above can be summarized into high-level information for shifters to monitor.

The infrastructure enables running the DQM analyses online and displaying data on the front-end monitoring website (“Minargon”) immediately. The DAQ raw data is dispatched directly to the analysis modules, and the modules compute data quality metrics such as noise RMS and baseline. Then the computed metrics are sent to and stored in DBs, and Minargon queries and displays these data.



SBND Online Monitoring

External Links

shifter feedback: click here
operations wiki: click here
BNB Status: click here
E-Log: click here

Meta Data

Redis memory usage:	0.07GB / 1.11%
Redis heartbeat:	ON
DAQConsumer:	OFF

Detector Status

TPC Status:	OK
PMT Status:	NOT OK, Bad PMT: 160
CRT Status:	OK
Trigger Status:	OK

Figure 13: Front page of the SBND Online Monitoring website Minargon. On display here are high-level subdetector status summaries, as well as key links to other monitoring pages. At the top are the Minargon menus that allows users to easily navigate into more detailed monitoring pages for various subsystems.

The primary output data format for the online monitoring is time-series data (as opposed to event-by-event data), along with other assorted types of data such as waveforms and histograms. These are initially stored in the Redis DB, which is an in-memory temporary DB that saves time-series data for days and waveforms for minutes. Important metrics are saved by the Data-Quality

Archiver to permanent storage provided by the PostgreSQL DB, which can be looked up afterwards from Minargon.

Minargon allows for the data to be displayed in multiple tiers, such as high-level shifter information and more detailed per-subsystem expert pages. Shifter pages display the overall system operation status determined by predefined alarm levels, and help shifters spot any issues in operation. More detailed pages provide channel/PD/board-level metric status and history to help experts understand any observed issues.

Slow Monitoring EPICS data and Cryogenic Monitoring: In addition to displaying data quality metrics of the detector systems, Minargon can display data from other sources internal and external to SBND by connecting to the DBs in which the relevant data is stored. For example, Minargon allows browsing of archived histories of PVs and alarms of the slow monitoring EPICS data, and provides specialized displays. Similarly, archived values and errors of the cryostat PVs are also accessible to view and browse through the connection with the Ignition DB to monitor pressures and temperatures from the cryogenic system. In addition, a health check of the monitoring system itself is provided, displaying information such as the on/off status of the DQM and Archiver, and DB memory usage.

Booster Neutrino Beamline Monitoring The neutrino beam is monitored using tools from Fermilab Beams Division and available through a web display[1]. The monitoring includes proton intensity, BNB repetition rate, horn current, position of the proton beam along the BNB beam line and beam profile versus time.

Nearline Monitoring: Nearline monitoring will monitor higher-level metrics to ensure collection of quality neutrino interaction data and spot critical issues before full data processing. This system is currently being developed, but the plan is that a fast, lightweight reconstruction will be performed on data to create ntuples, which are then processed through the continuous integration (CI) system to compare metrics with those from a reference run. Monitored metrics will include neutrino rates, distributions of track length, start positions, dQ/dx, ADC, flash times, and timing and positions of hits from the cosmic ray tagger. CRT hit positions during the beam spill can also serve as a fairly sensitive BNB beam monitor.

2.7 Data Management and Processing

Data collected by the detector are highly valuable and the prompt use of them in calibrations and analyses is essential to the success of the experiment. Data from events are collected into event records by the event builder and written to *art*-formatted ROOT files on disks managed by the DAQ group. Metadata sufficient for identifying files in the file catalog are extracted from the file contents and the running conditions at the time the file was written. File sizes and checksums are written to the metadata. The files and metadata are moved to a FTS dropbox on the DAQ disks. FTS then transfers the files to dCache disks managed by CSAID, and at the same time, registers the metadata in SAM. Files in dCache are copied to tape in enstore as tape drives become available, and they are

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[1] https://dbweb9.fnal.gov:8443/ifbeam/bmon/bnbmon/Display

accessible on disk, though the copies on disk are subject to a least-recently-used eviction policy.

Only after a successful transfer with a validated checksum is complete, and DQM processes no longer require access to files, can files be deleted from the disk buffer. A small number of recent files is kept on the DAQ disks for debugging and inspection purposes. Run configuration information and conditions are stored in a time-dependent run history database. This database will be replicated for convenient offline use by batch jobs and interactive queries.

Files are divided into file families based on the run configuration and trigger type. File families “commissioning”, “test”, “cosmics”, “minbias”, “beam”, and “calibration” capture the expected running conditions. Files are stored on tape by file family, optimizing the access to similar data, and facilitating the re-use of tapes when large amounts of similar data can be discarded.

Approximately 4 PB of raw data are expected to be collected per calendar year, assuming 75% accelerator uptime and negligible detector downtime. Early data will consist of commissioning, test, and calibration data samples. Valuable calibration data for the TPC and PDS systems will be taken early on, and additional calibration data will be taken throughout stable operations to enable time-dependent calibration analyses. Approximately 30 TB of calibration data are expected to be collected per year. Beam and cosmic data, once transferred to dCache, will be scheduled for keepup reconstruction processing. The first round of keepup reconstruction will be used as input to calibration steps, such as determining the response of the TPC and characterizing the detector noise. These calibrations will be uploaded to the calibration database and the keepup processing rerun on the initial data. Subsequent data processing will benefit from the initial calibrations, though monitoring and re-calibrations will be necessary at intervals. Furthermore, algorithmic improvements will require the reprocessing of the data at intervals during the lifetime of the experiment. In addition to keepup processing, standard ntupling jobs, such as the production of CAFs, will be included in the regularly-scheduled processing. Raw and processed data samples will be cataloged in SAM and the dataset names published on SBND internal wiki pages so that analysts have easy access to the processed data and ntuples.

The estimated computing resources required are summarized for 2024 in Section 5.3 and subject to annual updates reported by the SBN Analysis Infrastructure conveners to the Fermilab Computing Resource Scrutiny Group (FCRSG). The latest presentation to FCRSG can be found here[2].

Data are to be divided into exposure blocks for ease of reference to large portions of the data sample, and to facilitate dividing the data into portions that may have different operational characteristics, such as a major planned or unplanned change to the beam or the detector performance.

3 Operations Planning

The detector commissioning process begins once the cryogenic team certifies that there is stable liquid argon level and pressure at the full operational capacity. A detailed commissioning plan, including sequencing for powering up of systems, quality control checks, and procedures for tuning

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[2] https://indico.fnal.gov/event/57596/contributions/258367/attachments/163819/217051/FCRSG%20FY23%20SBN.pdf

detector configurations is in place. The detector commissioning concludes with stable operation of all detector subsystems, DAQ, trigger, slow controls, online monitoring, and data storage, allowing steady operations with physics quality data. For a time, Commissioning activities and Operations (shifts) will run simultaneously.

An Operations Planning Task Force (OPTF) was formed by the SBND spokespersons in May 2023 to prepare all systems, procedures, policies, and documentation needed for the operations phase of the experiment. A key purpose of the OPTF is to facilitate communication across different activities that are critical to operations, and therefore the task force is composed of representatives from efforts ranging from commissioning, to detector monitoring, to data management, to reconstruction, calibration, and analysis. There are 15 members in total, and the spokepersons chair the Task Force. The charge for the OPTF include:

- Establish an SBND control room station at FNAL and ensure it is ready for shift-taking
- Establish remote shifting capabilities
- Generate documentation needed for shifters to safely operate the detector
- Ensure ability to control and monitor all detector systems as needed for operations
- Ensure ability to monitor and QC the data being collected during operations
- Ensure trigger system capable of recording data needed for calibration and physics goals in early running
- Ensure readiness to handle and process data as required for operations
- Ensure availability of all beam information required for offline analysis of data
- Ensure ability to process and analyze data offline as needed for calibration and physics goals in early running

Much of the work needed to achieve these goals is done within various collaboration working groups (see next section), so a key purpose of the OPTF has been to facilitate communication across the full range of activities – from shift-taking to physics analysis.

This chapter provides a description of the Collaboration organization and includes details on the Operations group in Section 3.1.1. Section 3.2 and 3.3 discuss the plans and the facilities and procedures for shift-taking during operations.

3.1 Collaboration Organization

The SBND Collaboration consists of 200 physicists (including Ph.D. students) and about 40 engineers and technicians from 38 institutions in 5 countries (Brazil, Spain, Switzerland, UK, and US).

Currently, the SBND Collaboration is organized into three main groups: a Commissioning group, an Operations group, and a Physics group. The Organization Chart of the collaboration is shown in Figure 14. Since SBND is part of the SBN program, in addition to the internal organization, the figure also highlights connections to relevant SBN Boards, Committees and Working Groups. The construction and installation of the detector and cryogenic system were coordinated by the SBN Program Office and led by the SBND Technical Coordinator, leading a large Project Team (the details of which are not shown in the figure).

The Commissioning group is in charge of commissioning the detector, which is the process of activating all components and validating that the system produces physics-quality data and is capable of stable running. The commissioning procedures include activities that take place both before and after the cryostat has been filled with liquid argon, depending on the needs of each subsystem.

The Operations group (described in the next Section) is in charge of ensuring smooth operations of the experiment during the entire duration of the data taking.

The Physics group (described in Section 4) is in charge of coordinating the different physics analyses and preparing the tools to perform detector calibrations, to simulate the experiment, and to reconstruct events. To ensure connection and coordination within SBN, the SBND Physics group is directly linked to the SBN Analysis working group (in charge of SBN oscillation analyses) and to the SBN Analysis Infrastructure working group, in charge of data management and processing within SBN (see Section 2.7).

Other Committees and Boards that have different roles within the Collaboration are also shown in Figure 14 (light blue boxes).

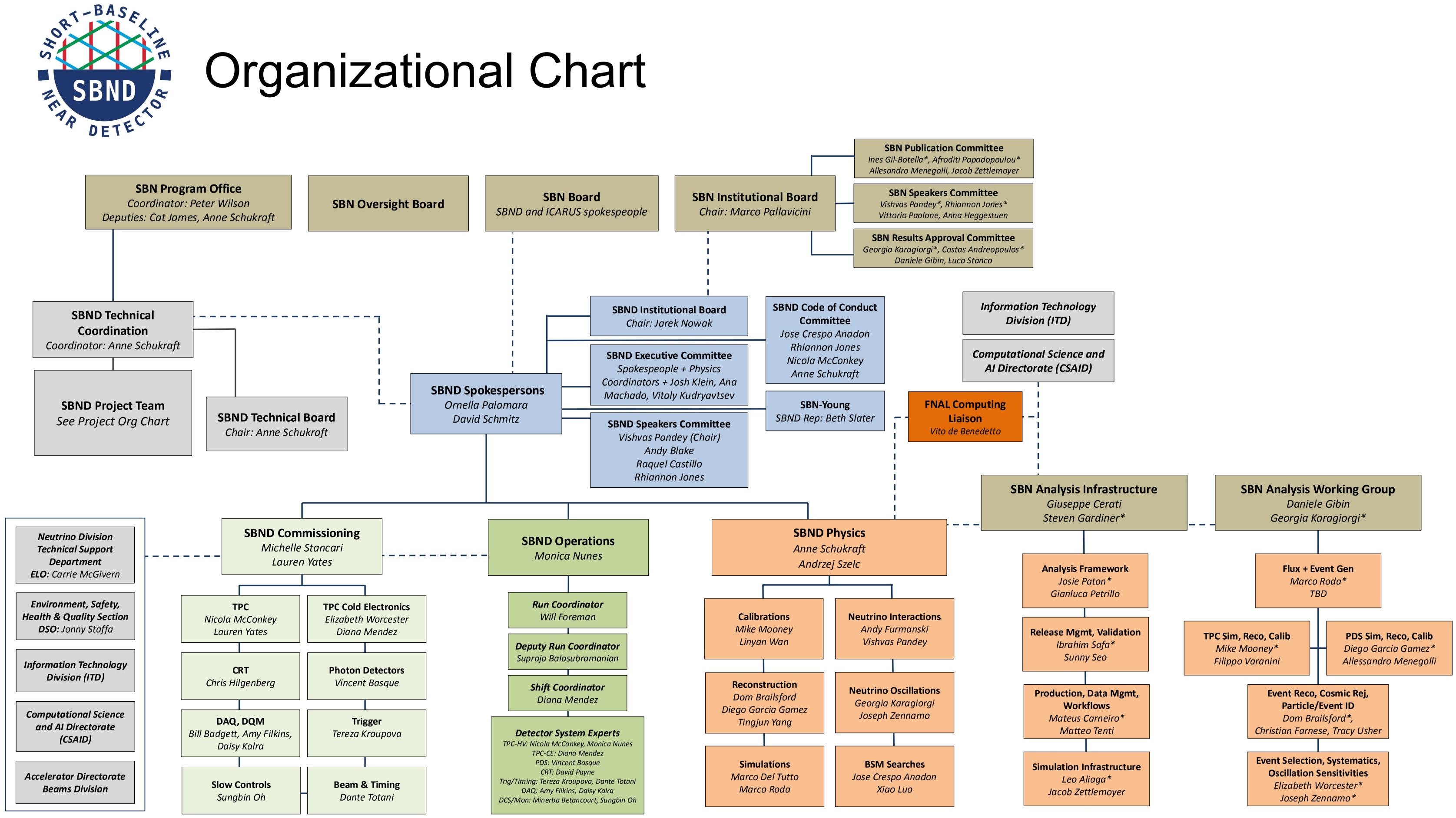

Figure 14: SBND Collaboration Organization Chart

3.1.1 Operations Group

The SBND Operations group includes (see Figure14):

- **Operations Coordinator** - charged with optimizing efficient operation of the detector to meet the physics goals of the experiment, with the main tasks of:
  - Respond quickly to system failures that impact efficient detector operations.
  - Report detector failures that interfere with smooth detector operation to Spokespersons.
  - Direct and decide the priority and scheduling of detector systems development and maintenance, in consultation with the Spokespersons.
  - Serve as member of the SBND Technical Board.
  - Maintain the Detector Systems Experts lists.
- **Run Coordinator** and **Deputy Run Coordinator** - in charge of day-to-day management of the detector data taking, with the main tasks of:
  - Maintaining shift procedures.
  - Being the primary contact between the experiment and the Fermilab Main Control Room and responsible for reporting at FNAL Experimenters' Meetings.
- **Detector System Experts** - lists maintained by the Operations Coordinator - who share the responsibility for:
  - Maintenance and trouble-shooting of their respective detector subsystem.
  - Staffing on-call expert shifts to provide real-time assistance when problems arise that are beyond the expertise of the regular shifters.
- **Shift Coordinator** - in charge of allocating detector monitoring shifts according to an IB approved shift assignment scheme. The shift coordinator maintains records of the assigned and completed shifts.

3.2 Collaboration Shift Policies

Shifts for running the experiment are the responsibility of the SBND scientific collaborators. The shifters' responsibilities are to follow a Run Plan set out by the Operations Coordinator and Run Coordinator, monitor various aspects of detector operation to ensure systems are running properly, and check that the data being collected is of high quality, as determined from diagnostic online monitoring tools. Shifters make extensive use of the control and monitoring tools described in detail in Section 2.6.

The SBND Collaboration Shift Policy was approved by the SBND Institutional Board in December 2023 and contains the following main elements:

- Shift quotas are assigned per institution and based on the number of author-eligible collaborators at that institution during the coming shift period for which shifts are being scheduled. Shifts are scheduled in 6-month periods.

- Different shift roles are considered within the same shift-credit accounting system, including: Control Room Shifts, Run Coordinator Shifts, and Detector System Expert On-call Shifts.

- Control Room Shifts are 8 hours long (0:00-8:00, 8:00-16:00, 16:00-24:00), with a small overlap time before and after each shift to allow for a smooth transition. Shifts are grouped into blocks of 4 days (“weekday”) and 3 days (“weekend”).

- The Shift Coordinator is in charge of scheduling shifts. We use the same software tools being used by ICARUS (and previously developed by NOvA) to schedule shifts. Collaborators submit preferences for the upcoming shift period, and the Shift Coordinator creates a schedule based on those preferences and the current institutional shift-point quotas.

24/7 detector monitoring Control Room shifts started on January 29, 2024, during the phase of cryostat purging with gas argon. Table 2 shows the list of SBND Collaboration institutions and the number of shifters/authors from each for the initial shift period running from January through June 2024. We currently have 193 shifters, meaning on average one shift block assigned to every collaborator every six months.

To ensure stable operations, we must maintain a group of “Detector System Experts” to continuously monitor the different systems and provide troubleshooting and repairs in case of issues. “Detector System Experts” will take turns being on-call 24/7 to provide immediate assistance when problems arise that are beyond the expertise of the regular control room shifters. Table 3 lists the detector subsystems and the collaborating institutions with members who are currently experts for that system. For each subsystem, one or two “Lead Experts” are identified who work directly with the Operations Group for coordination and planning purposes. The lead experts are indicated on the organizational chart in Figure 14. Lead experts also ensure that new members are properly trained when joining a detector expert group.

3.3 Shifter Facilities and Procedures

During periods of regular operation, SBND is anticipated to maintain 24/7 detector monitoring shifts. For this, it is important to maintain a set of connections and web pages which provide interactivity with detector tools and monitoring software and documentation and instructions on procedures. The SBND shift system is set up to allow shifts to take place from the ROC-West control room at Fermilab or remotely. A shift station is available in ROC-West (Remote Operations Center, Wilson Hall) at Fermilab where availability of multiple machines/screens provides a shifter with real-estate to display and interact with multiple tools in unison. The current shift setup involves a number of specific connections, for example a VNC server to control and interact with

Table 2: SBND collaboration institutions and the number of Authors/Shifters for the shift period running from January 2024 through June 2024.

Institution	Location	No. of Shifters (1/2024)
Argonne National Laboratory	USA	3
Universität Bern	Switzerland	1
Brookhaven National Laboratory	USA	10
University of California, Santa Barbara	USA	6
Universidade Estadual de Campinas	Brazil	5
University of Chicago	USA	12
CIEMAT	Spain	4
Colorado State University	USA	3
Columbia University	USA	8
University of Edinburgh	UK	7
Universidade Federal do ABC	Brazil	2
Universidade Federal de Alfenas	Brazil	1
Fermi National Accelerator Laboratory	USA	33
University of Florida	USA	6
Universidad de Granada	Spain	8
Illinois Institute of Technology	USA	4
Imperial College London	UK	3
Lancaster University	UK	7
University of Liverpool	UK	8
Los Alamos National Laboratory	USA	5
Louisiana State University	USA	2
University of Manchester	UK	9
University of Michigan	USA	2
University of Minnesota	USA	3
University of Oxford	UK	2
University of Pennsylvania	USA	3
Queen Mary University of London	UK	1
Rutgers University	USA	2
São José dos Campos	Brazil	1
University of Sheffield	UK	7
University of Sussex	UK	2
Syracuse University	USA	3
Texas A&M University	USA	1
University of Texas at Arlington	USA	8
Tufts University	USA	5
University College London	UK	2
Virginia Tech	USA	4
38		193

Table 3: Detector System Expert categories and collaborating institutions with members who are currently experts for each detector system.

Detector Subsystem	Institutions with committed experts
TPC high voltage	Fermilab, Queen Mary, Chicago
TPC cold electronics	BNL, Fermilab, Florida
Photon Detectors	Fermilab, Florida, Michigan, Unicamp, CIEMAT, Tufts
Cosmic Ray Tagger	Fermilab, Liverpool, Syracuse
Trigger/Timing/Beam	Penn, Liverpool, UCSB
DAQ	Fermilab, Columbia, Syracuse
Slow Controls & Online Mon.	Fermilab, Chicago, UCL

the DAQ and a VNC server for detector slow controls. However, because the ROC-West setup involves connecting to these servers in another location (the SBND building) and other tools are available remotely and/or on the web, the activities needed to take a shift can also be performed remotely, either from an institutional ROC or their own computer, once the shifter (or their computer) is granted access to the machines used for shift. Many of the connections needed for shifts are detailed in Figure 15.

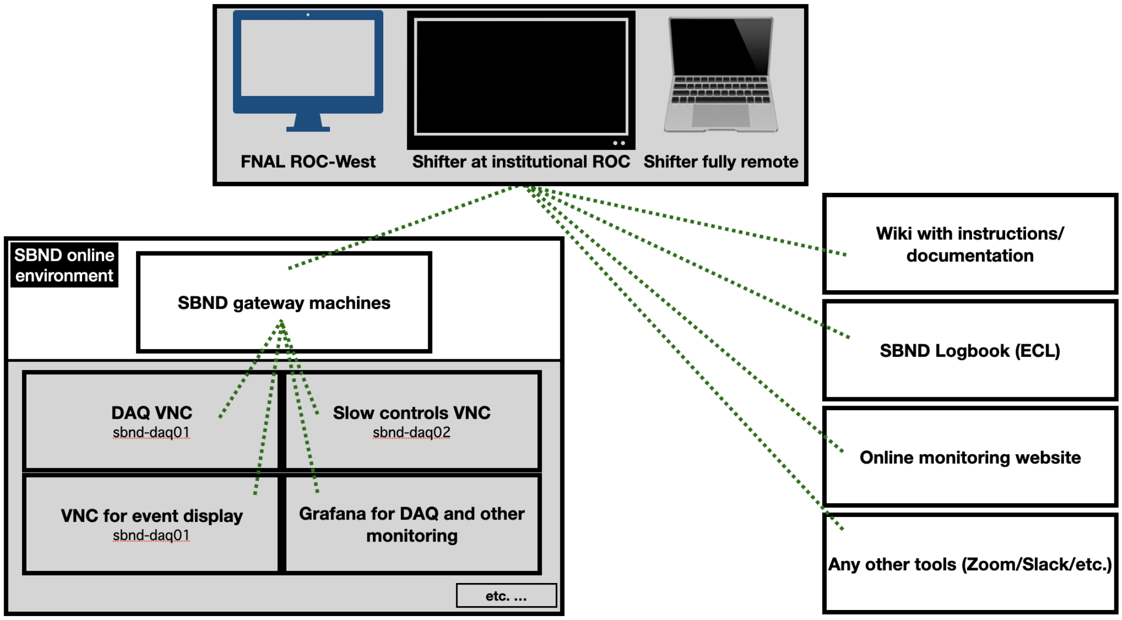

Figure 15: Diagram of connections used by shifters to monitor and control the SBND detector, either from Fermilab's ROC-West shift station or from remote locations. Servers in the online environment which are needed directly for shifting — many listed in the figure — are connected to by an ssh tunnel with port-forwarding using the SBND gateway machines.

The shifter and on-call experts will have access to a set of documentation and instructions, largely available in wiki formats[3]. A set of forms and checklists to confirm the starting or ending of shifts, check subsystems, and guide monitoring will be filled out by the shifter on the SBND Electronic Collaboration Logbook (ECL), similar to other FNAL experiments. Detector Monitoring Shifts, both from ROC-West and international remote locations, have been successfully running since January 29, 2024.

4 Run Plan and Analysis Outlook

SBND will register an unprecedented number of neutrino interactions on LAr and provide a unique opportunity to perform single-detector physics measurements ranging from high-precision and rare-process cross-section measurements to searches for beyond the standard model physics. In parallel, SBND's role in the SBN program is to provide a high precision constraint of the neutrino event rate in the Booster Neutrino Beam to perform sensitive searches for neutrino oscillations in conjunction with the SBN far detector, ICARUS.

Commissioning of the detector will begin once the cryostat will be full with LAr and in stable cryogenic conditions. The presence of the neutrino beam during commissioning will be extremely important, especially for the DAQ, timing, and trigger systems. The commissioning team is aiming to achieve stable operation within a few months from detector filling, enabling the collection of some physics data during the spring/summer of the FY24 run. We are aiming to be ready for fully optimized physics data taking for the return of the beam in the fall of 2024.

4.1 Analysis and Tool Preparations

The SBND Physics group (see Figure 14) is divided into several subgroups in charge of the various aspects of the physics program: "Neutrino Interactions", "BSM Searches" and "Neutrino Oscillations" for the three main areas of physics measurements, and "Simulations", "Calibrations" and "Reconstruction" for developing the tools and techniques needed to analyze the data collected by the experiment. The SBND physics groups operate in coordination with the SBN Analysis and the SBN Analysis Infrastructure working groups.

The SBND off-line software code is organized within the LArSoft package, the common framework for the simulation and data reconstruction/analysis of LAr-based experiments at Fermilab. SBND and ICARUS share a common code base: sbncode, residing within LArSoft. sbncode contains common tools for simulation and reconstruction, that will build the basis for joint analyses. Development work on sbncode is coordinated at the SBN Analysis and Analysis Infrastructure group level. Several workshops have been held in the past with analyzers from both experiments. SBND-specific code resides in a dedicated github repository (sbndcode). The standard simulation path of neutrino events currently consists of: the GENIE neutrino generator combined with CORSIKA for cosmic rays, Geant4 simulation of particle propagation in the detector and cryostat,

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[3] these are currently maintained at `https://cdcvs.fnal.gov/redmine/projects/sbnd-operations/wiki` and `https://cdcvs.fnal.gov/redmine/projects/sbn-online/wiki`.

and electronics simulation of the various detector components (TPC, PDS, CRT). All of these elements are currently functional, including the 2-dimensional WireCell signal simulation, with minor, known corrections to the detector geometry in progress. Reconstruction applies 2-dimensional deconvolution pioneered by MicroBooNE, runs a hit-finder algorithm and sends the results to the Pandora reconstruction package, which produces high-level reconstructed objects: tracks and showers with corresponding calorimetric information. Tools to simulate and reconstruct the light signals in two PDS systems (PMTs and X-ARAPUCAs) are also in place and their performance has been estimated on Monte Carlo. After waveform deconvolution, the signals are reconstructed as Optical Hits and Optical Flashes (a group of correlated Optical Hits), and the result is used to obtain timing information on events with a resolution of 2 ns (PMTs) as well as position reconstruction in all three dimensions, and potentially for light-based calorimetry. A CRT reconstruction chain is also in place and has been exercised with first data from a temporary test installation of several CRT modules around the cryostat during the installation. The timing between the CRT system and the beam has been demonstrated using that test installation. Reconstructed information from all three systems is then stored in Common Analysis Framework (CAF) files, allowing for high-level analyses utilizing all subsystems. Figure 16 illustrates how the information recorded by the TPC, PDS and CRT systems combined can inform the reconstruction and interpretation of an event.

Currently, the entire reconstruction chain has been demonstrated to work, and a few mature selections have been developed on simulation files. Work is ongoing on finalizing the final systematics calculation tools, some of which will only be possible once the detector is in operation.

SBND can also pioneer and demonstrate several new analysis and reconstruction techniques, e.g.:

- The PRISM concept: The dependence of neutrino energies on the off-axis angle at which they arrive in the detector enables the construction of datasets corresponding to narrow bands of neutrino energy and advanced background reduction methods. This is taking advantage of the close proximity of SBND to the BNB target.
- Novel applications of scintillation light: The SBND light collection system is unique in that it employs passive elements of light collection (reflective, wavelength-shifter coated, foils on the cathode), which will enable new techniques to enhance neutrino and low-energy event reconstruction.
- Multi-system event identification: SBND will pioneer the simultaneous use of the CRT, PDS and TPC to identify neutrino interactions and reject cosmic ray backgrounds.

4.2 Plan for First Physics Run (Spring 2024)

Initial data-taking at SBND will be a blend of commissioning, calibration, and early analysis. After ramp up of the detector systems, the focus will be to obtain data using dedicated run configurations to further commission all subsystems. This will include specifically dedicated runs

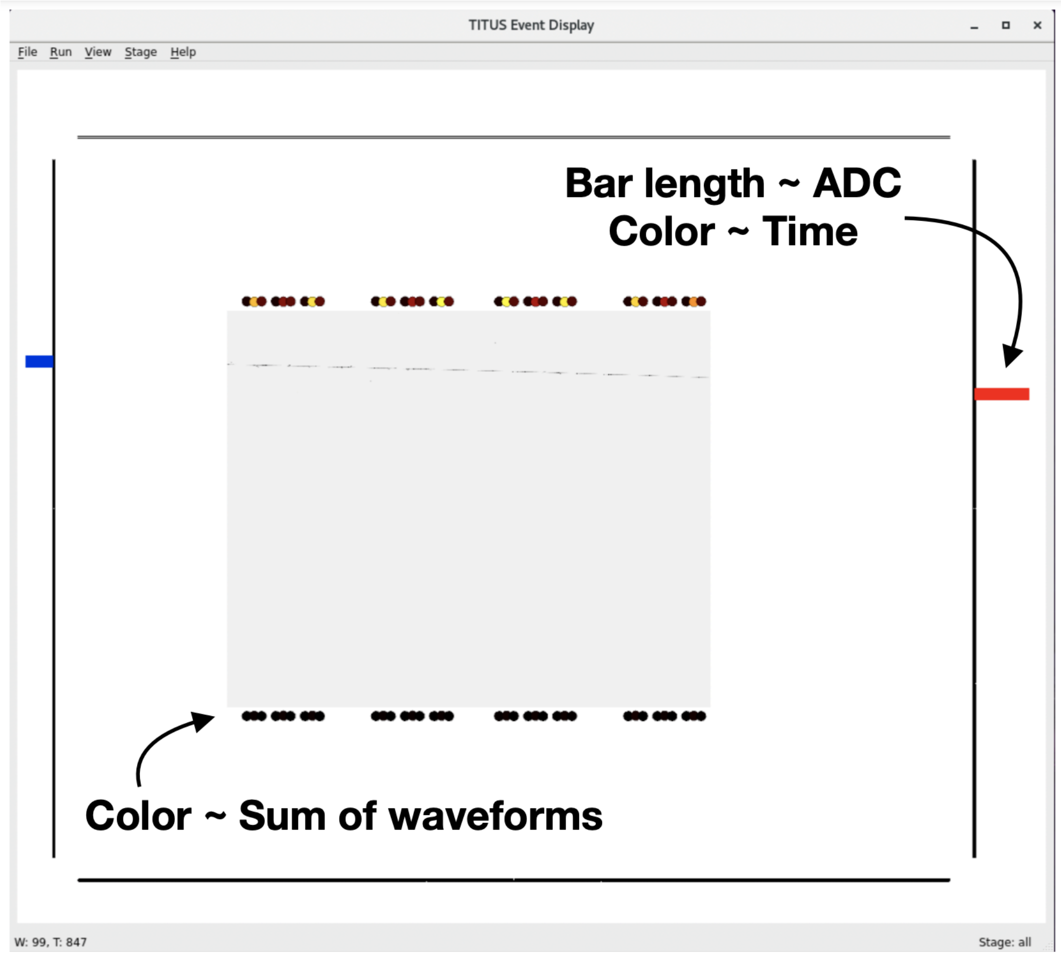

Figure 16: TITUS event display of a muon track showing signals in the TPC, PMT and CRT system. The graphic is a top view of a muon crossing the detector. The TPC track is shown in the grey shaded area. The PMTs are located behind both anode planes and their signal is indicated by the colored circles. As the track is entering and exiting it leaves signals in the upstream and downstram walls of the side CRT.

to characterize and mitigate any observed noise on the TPC and PMT systems. The next major phase will focus on obtaining and verifying timing synchronization of the detector systems with the beam, and an initial gain calibration of the PMTs in order to develop a light-based trigger that can henceforth be used to reduce the on-beam data stream. During this first running period, the remaining CRT walls (East, West and South) as well as the two CRT top layers will be installed and commissioned. As the early operation of the detector reaches stability, data taking will shift towards calibrations and early analysis. These calibrations include:

- TPC electronics calibrations such as ensuring matching between data and simulation with respect to channel-to-channel variations in the gain and noise level, as well as ensuring the wire electronics and field response is understood and well modeled in simulation;
- other TPC calibrations that ensure charge position/magnitude is accurately and precisely

reconstructed, such as estimation of electron lifetime, electron-ion recombination, diffusion, and electric field distortions such as space charge effects;

- PDS (including both PMTs and X-ARAPUCAs) calibrations such as capturing channel-to-channel variations in gain, timing, and single photoelectron response shape, as well as light yield variations across the detector; and
- calibrations of the CRT, including channel-to-channel variations in gain and timing.

These calibrations will largely rely on use of cosmic muons from both on-beam and off-beam triggers, necessitating roughly 100k triggered events for a first pass in Spring 2024 and roughly 1M triggered events on the timescale of Summer 2024. For measurements requiring a precise timing of the tracks, samples of anode- or cathode-crossing tracks will be used. SBND can use the CRT in combination with the TPC for t_0 tagging to increase the angular coverage of our calibration samples. We also aim to pioneer the use of CRT information in the readout trigger, which could greatly increase the efficiency with which we collect data useful for calibration.

A simple data format has been developed for this work, namely flat ROOT ntuples referred to as “calibration ntuples” that are used at both SBND and ICARUS; students and postdocs are being trained on how to use them for producing first SBND detector calibrations. Additional data from pulsing the TPC front-end electronics with a known amount of charge will provide the inputs for the rest of the calibrations listed above, which can be taken on the timescale of a few hours.

Precise measurements of detector effects and calibration constants are necessary to improve the understanding of detector response and energy resolution, which in turn are crucial for reaching better physics sensitivity. The precision of these measurements and calibrations will increase as data taking progresses resulting from iterative processes and an improving understanding of the detector.

If detector commissioning goes as planned and we are able to achieve an intermediate steady-state configuration for the detector, we will be able to take good quality data in FY24, and use them for first measurements/demonstrations. Depending on the configuration of the accelerator complex, the BNB can delivery between 3.5e19 and 5.2e19 protons on target per month (a main difference being whether NuMI is also running or not). Given the closeness to the neutrino target, even a run of a few weeks or months would result in a large initial sample of neutrino interactions. An exposure of $\sim$6e19 POT is already comparable to MicroBooNE’s full data set. A sample of that size in SBND would contain approximately 260k ν_μ CC 0π interactions, 54k ν_μ CC $1\pi^\pm$ interactions, and 2400 ν_e CC interactions.

Given our advanced reconstruction chain and very mature selections, proven on Monte Carlo simulations, we aim to demonstrate first physics results using this initial data set. The planning and prioritization among first data analysis efforts is currently in progress. Natural candidates are the observation of first neutrino events in the detector, measurements of cosmic ray spectra, and ν_μ-CC and ν_e-CC topologies. Tuning and evaluating the performance of our reconstruction algorithms for the various detector systems, as well as studies of particle ID and event kinematics will enable a variety of thesis projects for students who have been preparing these tools over the past years.

Data taking will continue during the Summer shutdown to collect cosmic ray data to study the cosmic background and perform more accurate calibrations.

4.3 Longer-Term Plans (1–3 years of data)

The SBND experiment data taking will continue in the following years, running until the Fermilab accelerator long-shutdown in 2027. In this time SBND is expected to collect $6-12 \times 10^{20}$ protons on target (POT) from the Booster Neutrino Beam (BNB), depending on beam delivery to the BNB, which will result in the largest sample of neutrino interactions on argon by a factor of 10–20.

Detector calibrations first developed during commissioning and early operations will be integrated into a semi-automated workflow that will be maintained for the entire lifetime of the experiment. This includes continual taking of cosmic data through both off-beam and on-beam triggers and production of calibration ntuples for use in measurements of detector quantities that may change over time. The primary detector physics quantities to measure over time include TPC electronics noise levels, electron lifetime, electric field distortions such as space charge effects, PDS gain, and light yield; however, a broader set of measurables (such as non-uniformities in charge scale across the detector that are unrelated to expected variations in electron lifetime over time) will be checked regularly to ensure that unexpected changes in detector condition are not left unobserved.

The data acquired during the first year of running will already enable many important measurements, starting from inclusive and exclusive ν_μ and ν_e-CC cross sections with and without pions in the final state, as well as NC-π^0 production, where the selection chains are already quite mature. In parallel, a few BSM models predict SBND should be sensitive to signals already with the first year of running - here we primarily expect to focus on Heavy Neutral Leptons, where the selection chains are mature. Collaborations with various theorist groups have developed, which are exploring opportunities for SBND. Additionally, the first year of data will already enable first ν_μ-disappearance and ν_e-appearance oscillation searches together with ICARUS, using both near and far detector data and benefiting from the very mature work that has been done within ICARUS and the joint SBN Oscillations working group to date. With the full three year data set, we will be able to perform a multi-channel oscillation analysis including also all-active-flavor (NC) disappearance and utilizing the PRISM concept to further reduce uncertainties significantly. The statistics of a 3-year data set will enable SBND to perform several first measurements of low-cross-section interaction channels on argon, e.g. hyperon production, neutrino-electron elastic scattering; as well as perform multi-dimensional measurements, including using transverse kinematic imbalance variables, to pin down the interaction models of neutrinos with argon. Finally, the full 3-year dataset will allow us to probe a class of BSM models inaccessible to other detectors with lower interaction rates.

5 Fermilab Roles and Resources

This Section describes the Fermilab roles and resources to support the operations of the SBND experiment. A short description of the procedures for safe operations of the experiment is also included.

5.1 Accelerator Directorate

The Beams Division within the Accelerator Directorate (AD) is responsible for the commissioning, operation, and maintenance of the BNB proton beam line, target, horn, and decay pipe. AD is responsible for the maintenance of all existing standard beamline elements, instrumentation, controls, and power supplies. AD also provides the online monitoring of the intensity and beam quality of the primary proton beam. The Fermilab Office of Program Planning sets the number of protons routed to each neutrino production target.

The External Beam Delivery Department provides the necessary beam timing signals. This includes interfaces in the MI-12 and the SBN-ND building. The External Beam Delivery Department will provide support in delivering the beam signals, via the AD network, from the sending locations (MI-12) to the experiment hall. The setting up of AD timing signals at the experiment hall is up to the experiment, but the External Beam Delivery experts are available for consultation and help. The replacement of broken modules (at the experiment's site) will be done by the AD Controls Department, contacted by the External Beam Delivery Department upon the experiment's notification.

5.2 Neutrino Division

The Neutrino Division (ND) within the Particle Physics Directorate (PPD) is the primary source of technical assistance to the SBND collaboration and provides oversight of experiment operations. Figure 17 shows the current ND organization chart.

ND provides an administrative organization for the Fermilab staff working on SBND as well as administrative support to the SBND collaboration. ND provides office space for both resident and visiting SBND collaborators.

The Neutrino Division provides funds for the operation and maintenance needs of the SBND detector and the SBN Near Detector (SBN-ND) facility including cryogenics systems. See Section 8 for the estimated SBND operations budget.

5.2.1 Technical Support Department

The Neutrino Division Technical Support Department (TSD) provides the primary operations support by Fermilab for the SBND detector and SBN-ND facility. The TSD provides an Experiment Liaison Officer (ELO), currently Carrie McGivern, who works with the SBND Operations Coordinator to identify necessary resources to support the experiment. The ELO will work with

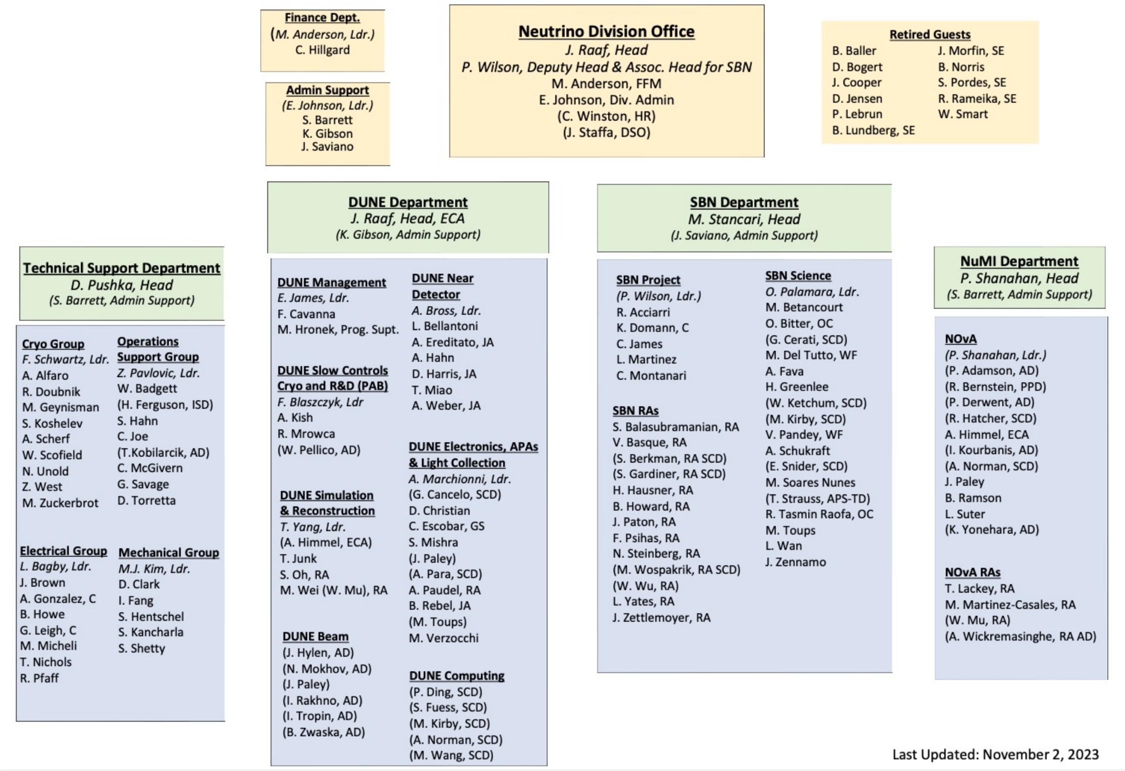

Figure 17: Fermilab Neutrino Division organization chart.

the SBND Operations Coordinator to ensure all work in the SBN-ND facility is coordinated with required work planning, scheduling, and safety procedures.

In addition to the ELO, the Operations Support Group (OSG) provides technical support for various online and DAQ systems both as primary experts and through general online system expertise. The Electrical Group provides support for electronics infrastructure such as detector AC power distribution, rack protection systems, and the ground impedance monitor (GIZMO).

The TSD Cryogenics group has primary responsibility for operational support of the SBND cryogenics systems. The group provides 24/7 emergency response through on-call expert engineers. The group performs daily monitoring checks of the cryogenic system performance. They also arrange for scheduled maintenance such as LAr pump rebuilds. Primary support of the cryogenics controls system is provided by the TSD Electrical group. The SBND cryogenics support is provided as part of an overall SBN cryogenics support plan described in SBN DocDB-13981 .

The TSD provides electrical and mechanical technician support on an as-needed basis. The leaders of the groups work with the ELO to identify additional technician resources from other divisions if needed.

Table 4: Listing of services provided by Fermilab's Information Technology Division (ITD) in support of SBND operations

Authentication and Directory Services	Standard KCA and DNS services provided.
Central Web Hosting	Support for the SBN central web server, including the SBN online portal, and SBN DocDB and FNAL Indico.
Database Hosting	Database hosting and database infrastructure used by SBND.
Desktop Services	Windows and Mac desktop support for the computers covered by the Managed Services contract.
Fermilab (Data Center) Facilities	Support for laboratory space for DAQ test stands and collaboration common computing nodes.
Network Services	Standard support for detector facilities. Essential SBND network devices are supported for 24x7 service.
Networked Storage Hosting	Support for home areas and NAS attached data disks
Service Desk	Issue and notification reporting, handling and tracking.

5.3 Computing Organizations

Fermilab's computing organizations, including the Information Technology Division (ITD) and the Computational Science and Artificial Intelligence Directorate (CSAID), support the needs of the SBN program, including SBND-specific needs, through provision, maintenance and support of common, and in some cases experiment-specific, core and scientific services and software.

CSAID assigns a Liaison to the SBND experiment (currently Vito Di Benedetto) whose responsibilities include maintaining communication between the experiment and the computing organizations, as well as ensuring that the computing needs, agreements, issues and any other relevant items between the experiment and Fermilab are addressed in a timely and mutually agreed upon manner. For example, CSAID contributes to SBND operations by providing user support for the common `artdaq` software framework, and also by system administrative support of SBND's DAQ and control room computers. Tables 4 and 5 outline many of the services provided by ITD and CSAID that are important for the collection and timely analysis of SBND data as well as general operation of the experiment.

Each year, ICARUS and SBND present a yearly assessment of scientific computing needs to the Fermilab Computing Resource Scrutiny Group (FCRSG). This assessment is conducted by the conveners of the SBN Analysis Infrastructure group (currently Giuseppe Cerati and Steven Gardiner) in consultation with technical experts and management of both experiments. Estimated SBND needs for 2024, which were included in the totals presented at the last FCRSG meeting, are shown in Table 6. These estimates include resources for both simulation and processing of data collected by the experiments.

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[3] Shared with ICARUS

Table 5: Listing of services provided by Fermilab's Computational Science and Artificial Intelligence Directorate (CSAID) in support of SBND operations

Grid and Cloud Computing	Batch processing on Grid accessible systems at Fermilab as well as offsite through the Open Science Grid and HEPCloud. Jobsub, GlideinWMS, CVMFS, "POMS" production software, and other software for enabling processing and analysis.
Scientific Collaboration Tools	SBN code repositories hosted through cdcvs.fnal.gov, redmine, GitHub, and the electronic log-book application.
Scientific Computing Systems	Support for control room and SBND computing systems and workstation administrative support. Support for interactive, batch processing, simulation and analysis computing systems at Fermilab.
Data Acquisition Servers	Maintenance and repairs provided by the SLAM team
Scientific Data Management	SAM, IFDH, FTS, RUCIO, and other data handling software and systems that are essential to online data transfer.
Scientific Data Storage and Access	Enstore-based tape storage services. Tape handling and curation. dCache-based data disk services and systems.
Scientific Databases	Applications and database infrastructure for identified SBND online and offline databases, including hardware mapping database, calibration database, run history database, and the IFBEAM database.
Scientific Software	Support for LArSoft, artdaq, art, ROOT, and other software tools.
Simulation Software	Support for Geant4, GENIE, and other simulation codes.

Table 6: SBND computing resource estimates for 2024

Grid time (CPU hours)	21 M
Persistent disk	2.9 PB
Dedicated write (shared with ICARUS)	2 PB
Tape	4.3 PB
`/exp/sbnd/app` storage	8 TB
`/exp/sbnd/data` storage	35 TB

5.4 Environment, Safety, Health & Quality Section

Safe operations of SBND is a top priority. The Operations Coordinator is responsible, in consultation with the Division Safety Officer (DSO), currently Jonny Staffa, with making sure that all operations on the detector are conducted according to the Fermilab safety rules.

Collaborators making access to the SBN Near Detector building (SBN-ND) are required to take the SBN Near Building Hazard Awareness Training (NDSBNND1/CB) which describes the hazards and training requirements for working in the building. We briefly describe those hazards and work practices. Everyone working in the building is expected to have completed ODH training since all below grade areas (mezzanine, cryostat top and pit) are classified ODH 1 due to the presence of large volume of liquid argon. In the below grade areas, personnel are required to carry an oxygen monitor and wear a hard hat. The pit area is classified as a confined space due to more limited access using the ships-ladder type stair. In the pit, an oxygen rescue pack is also required.

A two-person rule is enforced for ODH areas at SBN-ND, requiring either more than one person with ODH training to be present for any work on the mezzanine or cryostat top cap, or one person in continuous visual and auditory contact (from the top level) with an ODH-trained person working on the detector. In the pit, the two person rule requires that both must be in visual contact in the pit.

The collaboration requires that all work occurring in the SBN-ND building be discussed in one of the regular toolbox meetings to ensure compliance with FESHM 2060 – Work Planning and Hazard Analysis. Work that is considered high risk requires written hazard analyses and work plans using the lab IMPACT tool. These work plans are reviewed by the SBND Installation Coordinator or Operations Coordinator as appropriate and by Subject Matter Experts and approved by the DSO.

Collaborators are required to be up-to-date on safety training at Fermilab and all shifters are encouraged to have ODH training. The Run Coordinator must have ODH training and is encouraged to have Confined Space training. ITNAs are created or updated for new collaborators when they join the experiment. Shifters have access to an emergency call list that lists at least two experts for each system.

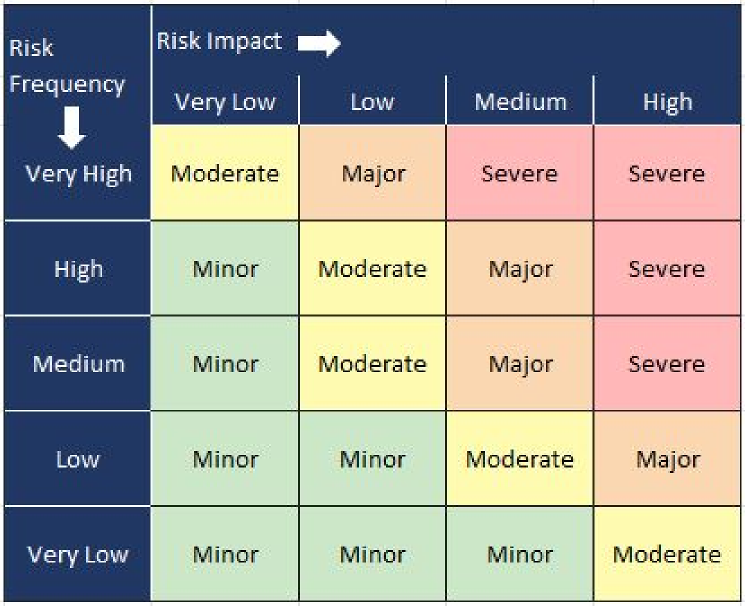
Additional safety hazards present at SBND (UV laser, high voltage power supplies) and the necessary safety training are outlined in the SBN Safety Assessment Document (SAD). The Neutrino Division Safety Officer (DSO) oversees any SBN activities where there are safety concerns. Any new equipment installed in the SBN-ND building must undergo Operational Readiness Clearance (ORC) review prior to being put into full operation. The SBN ORC committee, currently chaired by Michael Crisler, is responsible for ORC reviews. The DSO and ELO must both approve ORCs prior to approval by the Neutrino Division head.

6 Operations Risk Analysis

Risks to operations are future events that may negatively impact the data-taking capabilities of the detector which in turn may impact the scientific goals of the experiment. The Operations

Task Force created an Operations Risk Management Plan (SBN DocDB-33674) to identify and assess such risks and specify mitigation and response plans to blunt the impact of these potential events. Descriptions of the risks and mitigations are collected in risk assessment documents (SBN DocDB-34054). The results of the risk assessment process is a table, the Operations Risk Register (SBN DocDB-34066). This section summarizes the assessment process and results.

Risks were scored using a risk ranking matrix. The ranking matrix combines four levels of the risk impact to data-taking capability (Very Low, Low, Medium, and High) with five levels of the risk frequency (a non-linear spread, from Very High being weekly to Very Low being less than once per year). Each level of risk impact to data-taking capability combined multiple factors: the effect of the risk on data collection rate, the effect on data quality compared to nominal, and the time duration of these effects before a response plan returns data-taking to nominal condition.



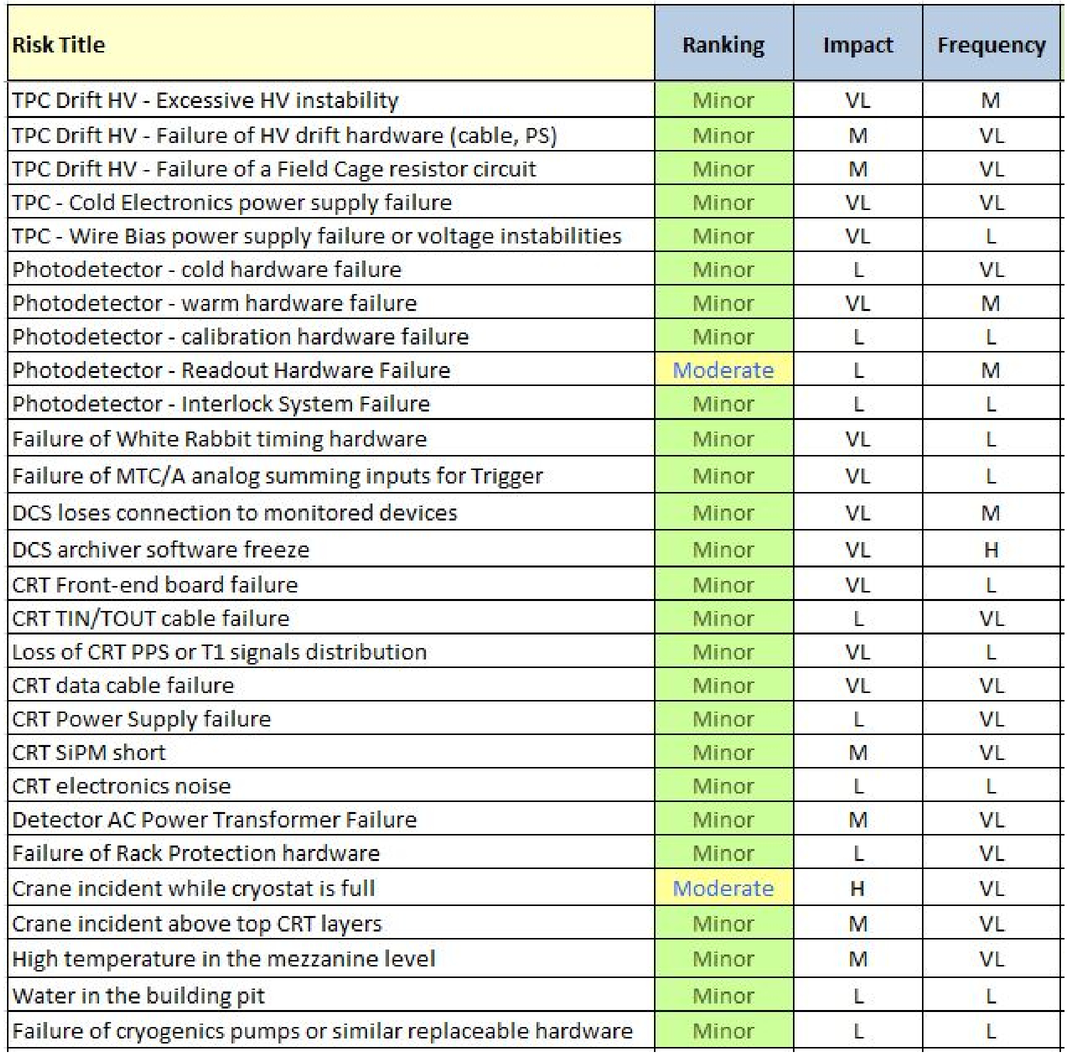
Risk Frequency ↓	Risk Impact →			
	Very Low	Low	Medium	High
Very High	Moderate	Major	Severe	Severe
High	Minor	Moderate	Major	Severe
Medium	Minor	Moderate	Major	Severe
Low	Minor	Minor	Moderate	Major
Very Low	Minor	Minor	Minor	Moderate

Figure 18: Operations Risk Scoring Matrix.

The matrix provides the resulting risk score from crossing the risk impact with risk frequency. For example, a risk with a Minor ranking may be an event which occurs once per month (glitch in a readout board) but the response plan requires less than an hour to implement (reset the board or swap with a spare). On the other hand, a risk with a Major ranking may also occur once per month, but requires a few days to implement the response and during that time all data-taking is halted. The boundaries between the risk rankings are not precise, but overall the Minor and Moderate risks have a less than 10% effect on detector up-time with respect to delivery of beam from the BNB, while the Major and Severe risks have greater than 10% effect.

Figure 18 provides a compact view of the risk scoring matrix; the Operations Risk Management Plan holds the same matrix but with more detailed headings and text explanation.

The experts for each detector sub-system described earlier in this document evaluated their



Risk Title	Ranking	Impact	Frequency
TPC Drift HV - Excessive HV instability	Minor	VL	M
TPC Drift HV - Failure of HV drift hardware (cable, PS)	Minor	M	VL
TPC Drift HV - Failure of a Field Cage resistor circuit	Minor	M	VL
TPC - Cold Electronics power supply failure	Minor	VL	VL
TPC - Wire Bias power supply failure or voltage instabilities	Minor	VL	L
Photodetector - cold hardware failure	Minor	L	VL
Photodetector - warm hardware failure	Minor	VL	M
Photodetector - calibration hardware failure	Minor	L	L
Photodetector - Readout Hardware Failure	Moderate	L	M
Photodetector - Interlock System Failure	Minor	L	L
Failure of White Rabbit timing hardware	Minor	VL	L
Failure of MTC/A analog summing inputs for Trigger	Minor	VL	L
DCS loses connection to monitored devices	Minor	VL	M
DCS archiver software freeze	Minor	VL	H
CRT Front-end board failure	Minor	VL	L
CRT TIN/TOUT cable failure	Minor	L	VL
Loss of CRT PPS or T1 signals distribution	Minor	VL	L
CRT data cable failure	Minor	VL	VL
CRT Power Supply failure	Minor	L	VL
CRT SiPM short	Minor	M	VL
CRT electronics noise	Minor	L	L
Detector AC Power Transformer Failure	Minor	M	VL
Failure of Rack Protection hardware	Minor	L	VL
Crane incident while cryostat is full	Moderate	H	VL
Crane incident above top CRT layers	Minor	M	VL
High temperature in the mezzanine level	Minor	M	VL
Water in the building pit	Minor	L	L
Failure of cryogenics pumps or similar replaceable hardware	Minor	L	L

Figure 19: A compact view of the Operations Risk Register, listing the identified risks with their assessed Impact, Frequency, and Ranking.

operations risks and provided their mitigation plans through the use of a risk assessment form; the assessment process is also briefly described in the Risk Management Plan. The risk assessment forms are collected in SBN DocDB-34054; there is one file per sub-system and each file holds one or more risk assessments for that sub-system. The goal of the operations risk assessment process was to demonstrate that all identified risks have mitigation plans and result in a residual risk of either Minor or Moderate ranking. The outcome of the risk assessment process shows that most identified risks to operations are caused by hardware failures, and most mitigation plans are having sufficient spares on hand so a situation of reduced data quality does not persist for very long. The Operations Risk Register (SBN DocDB-34066) provides a summary of the risks, rankings, and mitigation response plans. A condensed version of this Register is provided in Figure 19.

7 Spares

Table 7 contains a list of installed components and the available stock of hardware spares for each detector subsystem.

Table 7: List of SBND spares, by subsystem

Subsystem	Component	Installed	Spares
TPC Cold Electronics			
	WIB crates/feedthroughs	4	2
	WIB cards	24	12
	Magic Blue Box	1	2
TPC Warm Electronics			
	NIM clock distribution module	1	1
	Front end modules	176	2
	Crate controllers	11	1
	Crate power supplies	4	1
	XMIT	11	1
	Phenix PCIe cards	33	6
	NEVIS trigger board	1	1
TPC Cathode HV			
	Drift HV power supply (Heinzinger)	1	0
	Drift HV monitor (Beckhoff 3702)	1	0
TPC Wire Bias			
	Power supply modules	6	0
	Power supply crates	2	0
PDS Readout			
	PMT signal cables	120	7
	PMT breakout boxes	3	1
	CAEN V1730SB digitizers	8	2
	CAEN VME8100 crates	2	1
	CAEN V1740B digitizers	5	0
	CAEN A3818 PCI-e card	4	2
	X-ARAPUCA A amplifier cards	1	0
	X-ARAPUCA B amplifier cards	8	1
PDS Power			
	PMT warm HV cables	120	2

	PMT HV crate	1	1
	PMT HV crate controller	1	1[4]
	PMT primary power	1	1
	PMT HV modules	3	1
	X-ARAPUCA A power card (VME)	1	0
	X-ARAPUCA B power cards	4	0
	X-ARAPUCA B MPOD crate	1	0
CRT			
	CRT timing TTL fanout	1	1[5]
	Front end boards (Bern)	140	15
	Front end boards (CAEN)	2	1
	Trigger Blue Box	7	3
	Optical isolaters	2 pair	2 pair[6]
	Power supply	2	0
Timing System			
	CAEN V1730S digitizer	1	1
	White Rabbit switch	1	1
	White Rabbit SVEC	2	4
	White Rabbit Fine Delay card	2	4
	White Rabbit TDC card	1	1
	White Rabbit SPEC	1	3
	White Rabbit A25 crate contoller	1	1
	Axcen SFPs	4 pair	1 pair
	VME crate	1	1
	GPS antenna	1	0
	GPS receiver	1	1
	TTL fanout	1	1[7]
	VME clock distribution card	2	2
	Optical isolaters	4 pair	2 pair[8]
Trigger			
	Penn Trigger Board	1	2
	MTC-A Chassis	1	1
	MTC-A Cards	2	2
DAQ Servers			

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[4] No interlock feature installed on spare

[5] Spare shared with timing system

[6] Spares shared with timing system

[7] Spare shared with CRT

[8] Spares shared with CRT

	TPC	12	1
	PDS/PTB/WIB	6	1
	Database	1	1
	NFS	1	1
	Gateway	1	1
	Event builder	3	1
	CRT	3	1
	General purpose	2	0
	Timing/DCS	2	0
Rack Infrastructure			
	RPS boxes (smoke detectors)	20	6
	ACS boxes (interlocker)	20	6
	Rack Monitor boxes	20	0
	Horizontal PDUs	14	2
	Vertical PDUs	6	2

8 Budget

The projected annual cost of steady state operations is broken down in the table below (M&S only). The costs are informed by MicroBooNE and ICARUS detector operations and adjusted to current pricing.

Cryogenic system maintenance	$ 43K
Liquid Nitrogen	$ 112K
Misc. Operations Expenses	$ 50K
Replacements for end-of-life DAQ servers	$ 70K

The cryogenic system annual maintenance costs include LAr recirculation pump maintenance, Ignition software license, network switch software license, ODH head replacements and compressor skid maintenance. The heat load assumed to estimate the liquid nitrogen cost has large uncertainties, and this cost will be updated once the system is operating stably. It is assumed that the annual LAr consumption is negligible. There is a schedule for replacing end-of-life DAQ servers for FY25-FY27 with roughly balanced annual cost.

The misc expenses includes expenses related to the detector, cryo system and SBN-ND facility. Not included in this table are any one time expenses to address issues that might arise during commissioning of the cryogenic system or detector that can be mitigated with non-trivial interventions, such as low argon purity or excess detector noise.

A breakdown of the projected annual technical personnel support needed from the Particle Physics Directorate is tabulated below and is informed by the ICARUS effort reporting over the last two years. Currently most of the technical support comes from personnel in the Neutrino Division Technical Support Department.

Cryo Engineering support	0.30 FTE
Electrical Engineering support	0.15 FTE
Technician support (electrical and mechanical)	0.40 FTE
Online computing support	0.50 FTE
Experiment Liaison Officer	0.20 FTE

The online computing support from the Particle Physics Directorate does not include ARTDAQ support and SLAM team support, which are provided by CSAID. It does include coordinating OS upgrades and end-of-life server replacements, as well as general support for online infrastructure such as databases, slow controls, networking, etc.