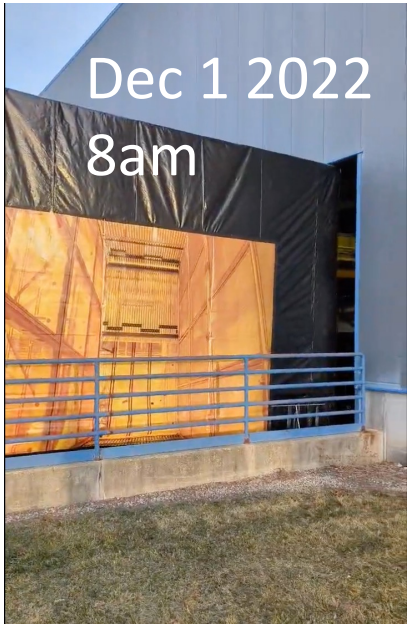
Capabilities of the SBND Trigger

Michelle Stancari (on behalf of the SBND collaboration)

CPAD Workshop 2022



Follow **sbnddetector** on instagram and twitter

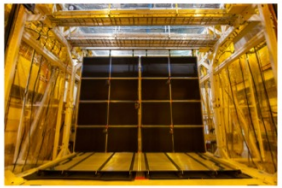
The Short Baseline Neutrino Program at Fermilab

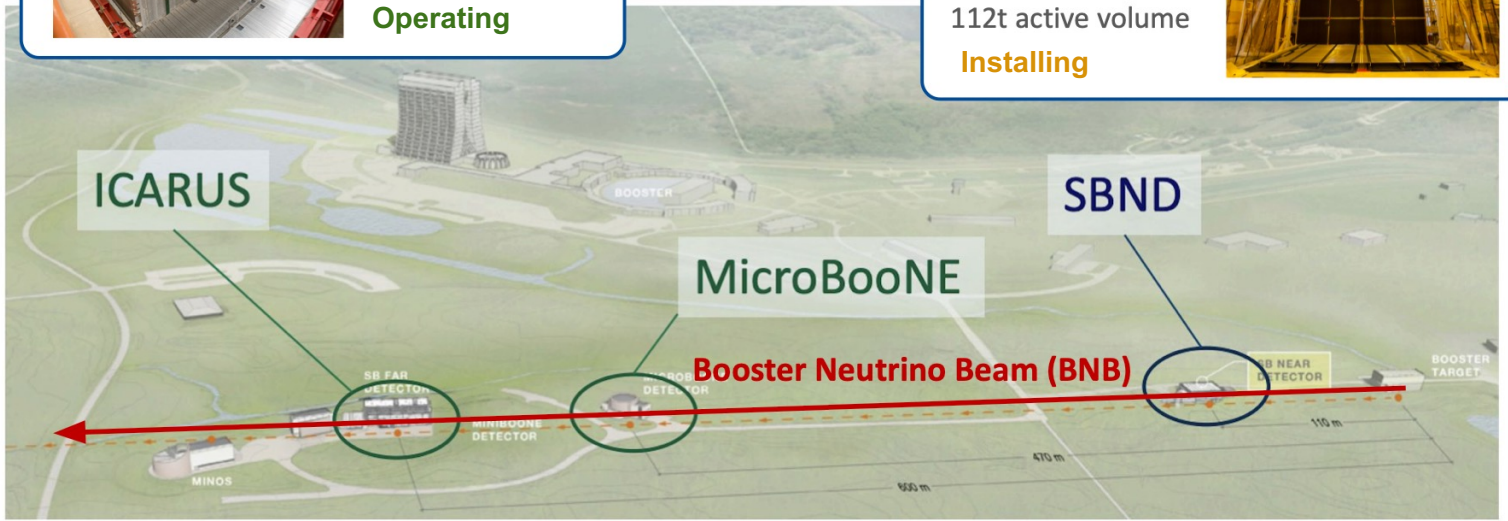
ICARUS

600m baseline
470t active volume
Operating

SBND

110m baseline
112t active volume
Installing





SBN will perform a robust measurement in the search of sterile neutrinos, while also investigating a broad spectrum of other new physics beyond the standard model.

Strategy to reduce uncertainties:

- Three detectors sampling the **same neutrino beam at different distances** (BNB)
- **Same nuclear target** (Ar) and **detector technology** (LArTPC: liquid argon time projection chambers)

SHORT-BASELINE NEAR DETECTOR SBND

Fermilab

Short Baseline Near Detector – only 110 m from the target!

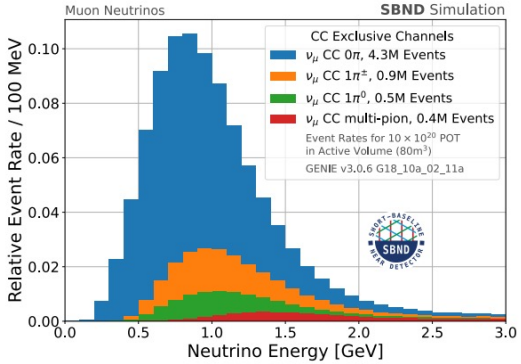
Unique opportunities:

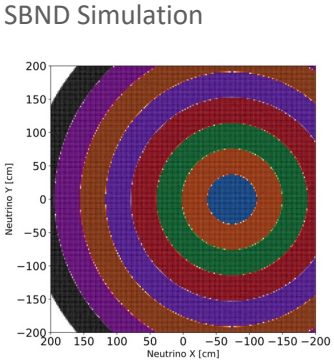
- ~5000 neutrino interactions per day – unprecedented statistics
  - Cross sections, cross sections, cross sections
  - rare process/BSM searches
- Prism effect – sample off axis fluxes

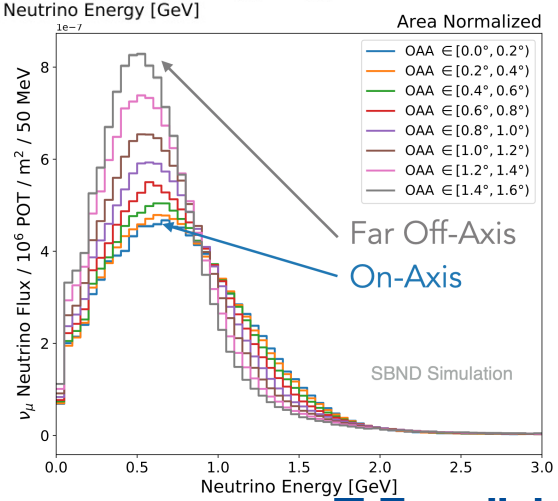
Unique challenges:

- Potential neutrino pile-up
- Sheer data volume ~100 MB/event

3-4 year run corresponding to 10e20-18e20 POT



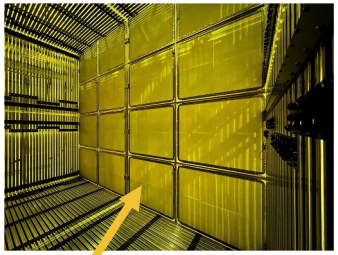




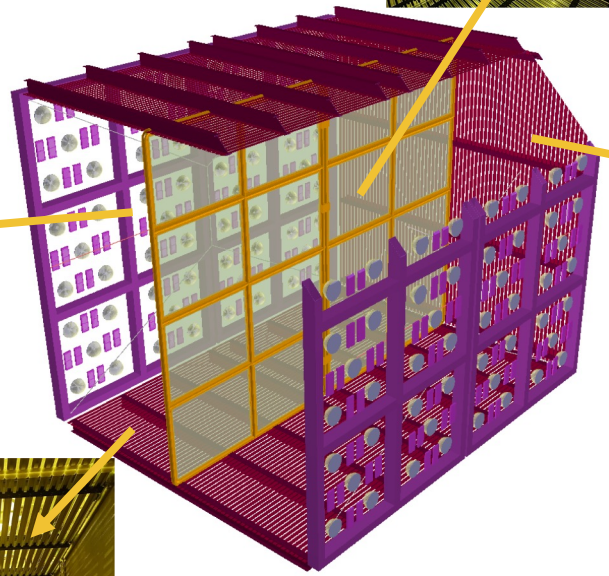
SBND TPC

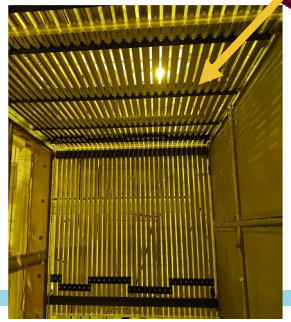
active volume 112t

4 X 4 X 5 m^3



Cathode Plane at -100 kV
divides the detector into 2 drift volumes. Drift distance is 2 m, drift time is 1.25 ms





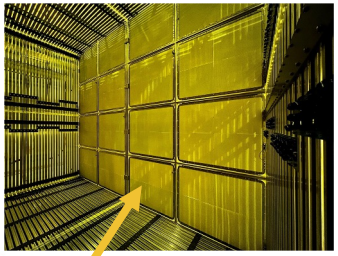
Field Cage
that wraps around the drift volume to step down the voltage & ensure uniform electric field of 500 V/cm.

SBND TPC

active volume 112t

4 X 4 X 5 m^3

Cold (89K) Electronics to pre-amplify and digitize signals



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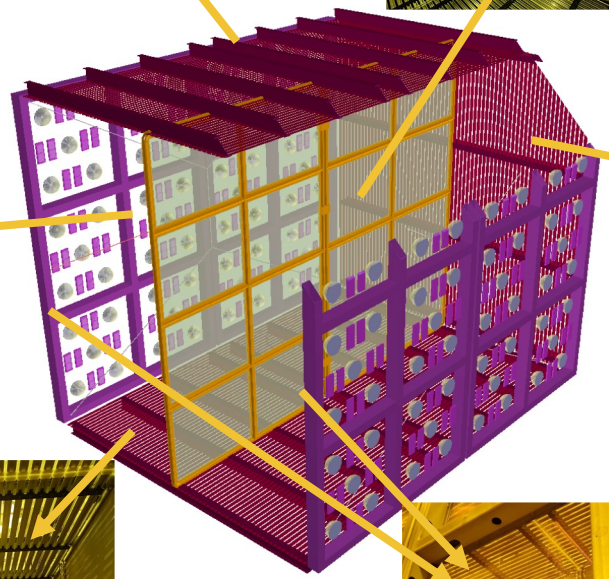
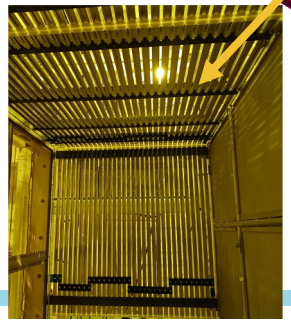
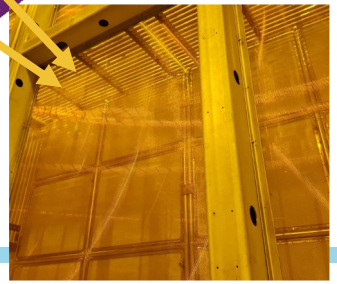


Field Cage that wraps around the 2 LArTPCs to step down the voltage & ensure uniform electric field of 500 V/cm.

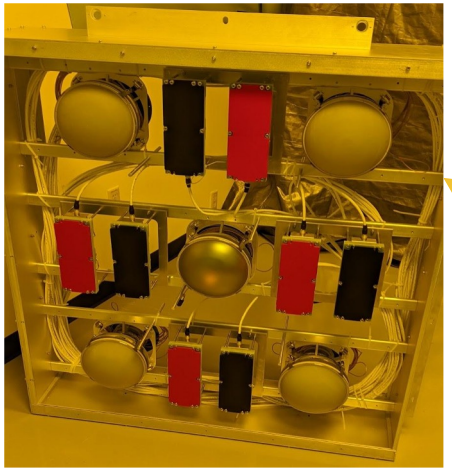


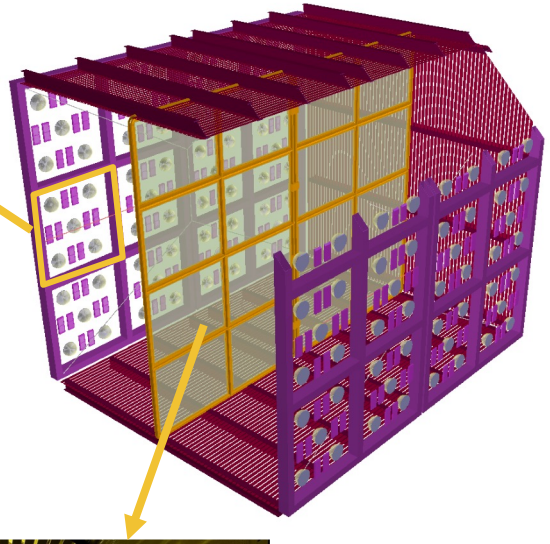


Anode Plane on either side. Each consists of 3 planes of wires with 3 mm spacing and different angle per plane. Total of 11,260 wires

Fermilab

SBND Photon Detection System



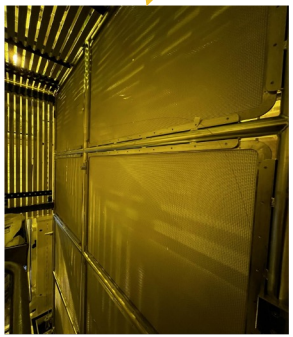


24 Anode Plane boxes

4x24 = 96 **PMTs** (TPB coated)
1X24 = 24 **PMTs** (uncoated)

8x24 = 192 **X-ARAPUCAs***

*sensitive to UV
+ visible light



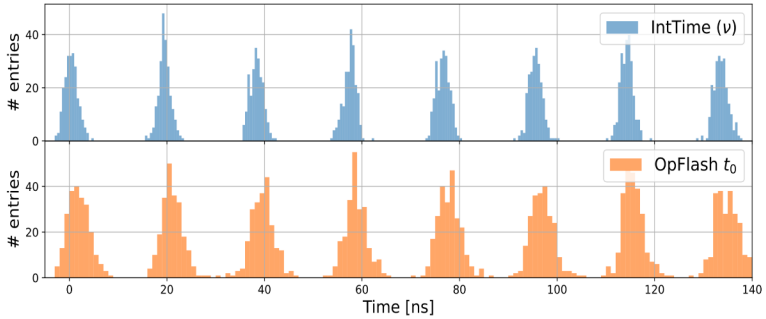
Cathode Plane with TPB coated reflective foils mounted between mesh panels.

While ionization electrons drift slowly at ~1.6 mm/us, scintillation light is fast.

- triggering
- cosmic background rejection

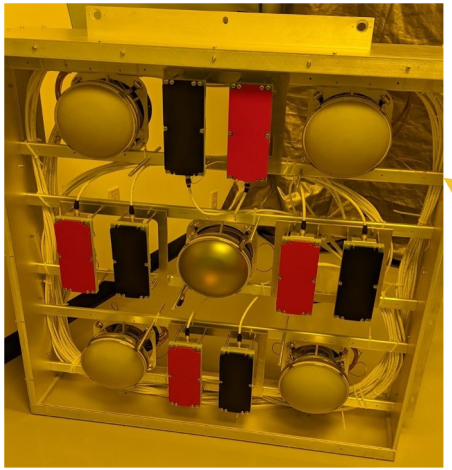
Unprecedented coverage enables SBND to explore using light for calorimetry

Experiment	Average light yield (PE/MeV)	Uniform light collection?
MicroBooNE	~ 5	no
LArIAT	~ 18	yes
pDUNE-SP	1.9 at 3.3m	no
SBND	~ 80 (> 50 min)	yes
DUNE: Vertical Drift	~ 38 (> 16.5 min)	yes



Simulated (top) and reconstructed (bottom) light flashes showing the neutrino beam structure.

SBND Photon Detection System



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See talk by Polina Abratenko yesterday

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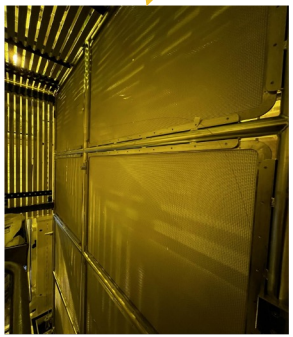

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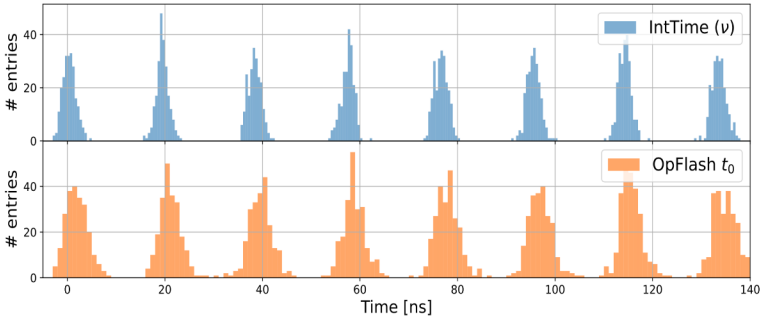
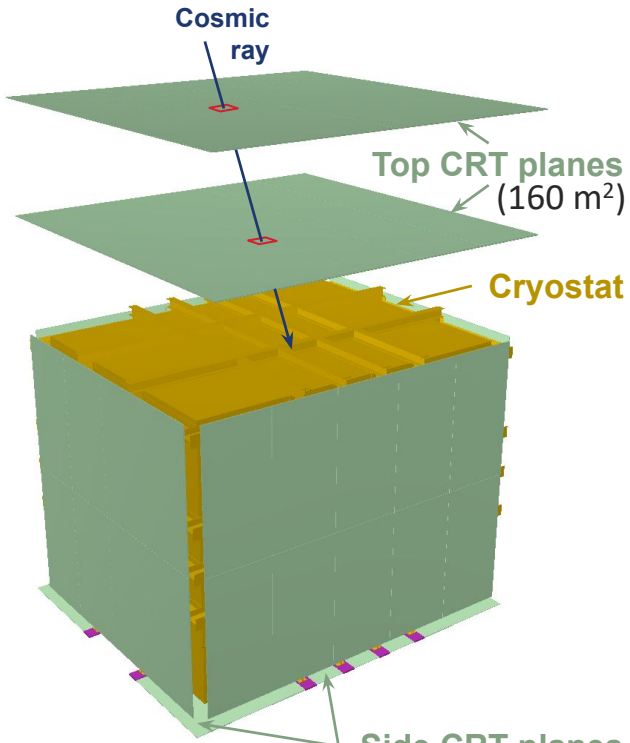
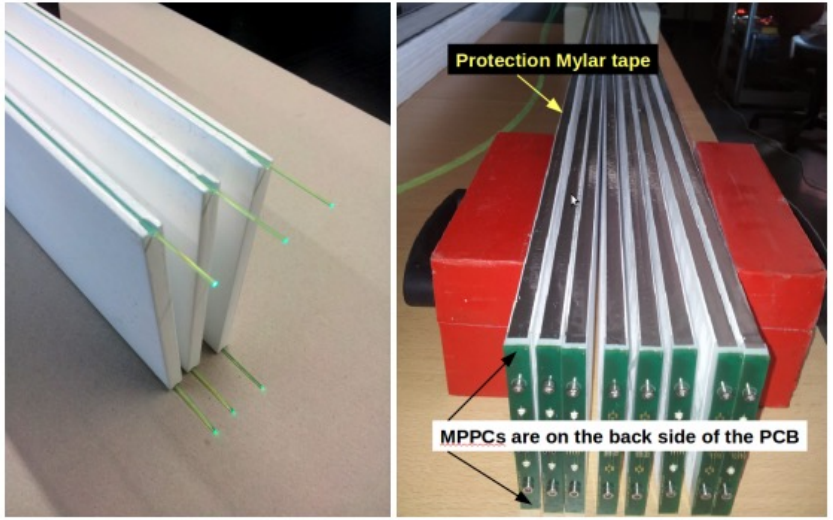


Simulated (top) and reconstructed (bottom) light flashes showing the neutrino beam structure.

SBND Cosmic Ray Tagger





Designed to tag muons . . . low noise, low data volume

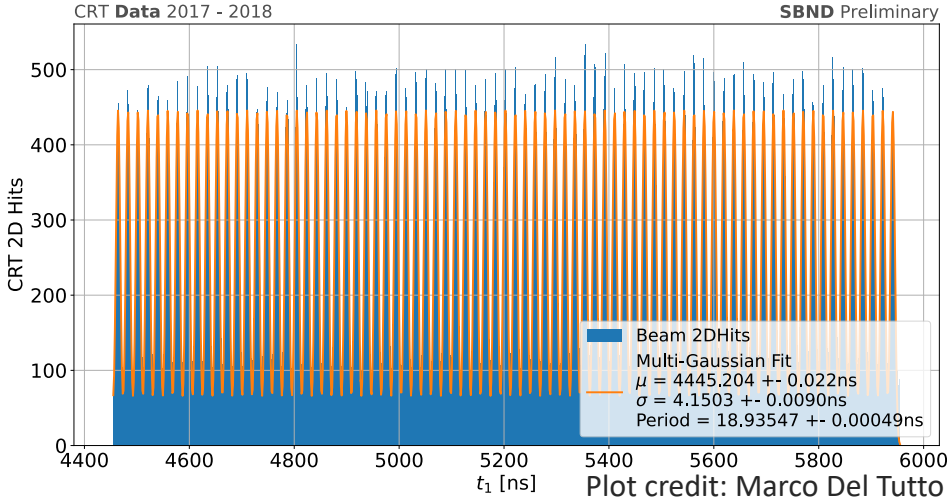
- Each plane has two layers: one “x” strips and one “y” strips
- Each strip has 2 SiPMs, one per fiber
- Single strip (1 cm thick) absorbs radiological decays
- Readout triggered by 4-fold time coincidence of one “x” strip and one “y” strip
- Strips are 1 cm x 11 cm x 2.5-4.5 m
- position resolution: <3 cm
- time resolution: < 2 ns

LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

SHORT-BASELINE NEAR DETECTOR SBND

Fermilab

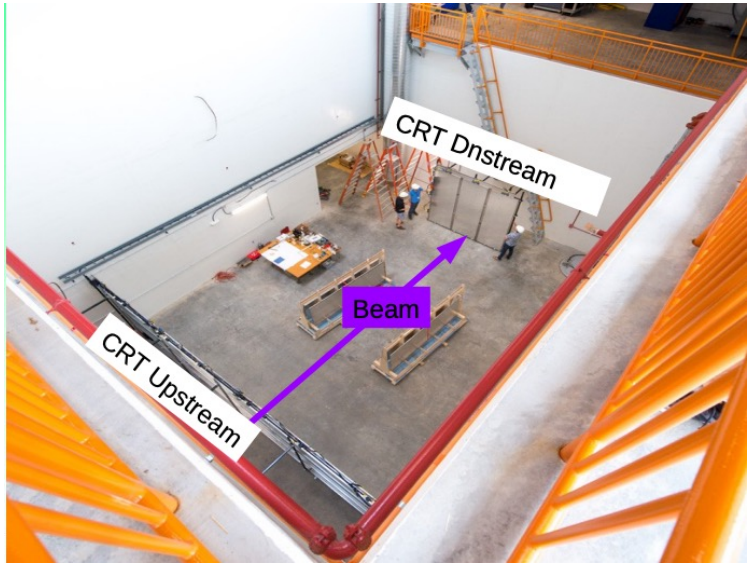
CRT Beam Telescope Run 2017-2018



Plot credit: Marco Del Tutto

Muons from neutrino interactions in the dirt upstream of the pit are detected by the telescope.
The beam spill substructure can be seen

- 81 bunches with 19 ns spacing
- spill duration of 1.6 μs



Pit in SBND hall

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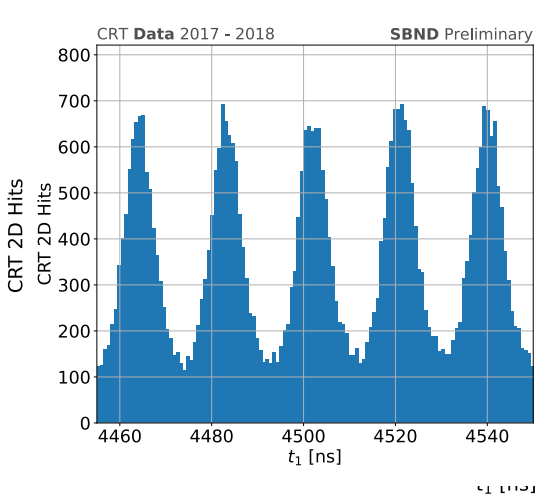

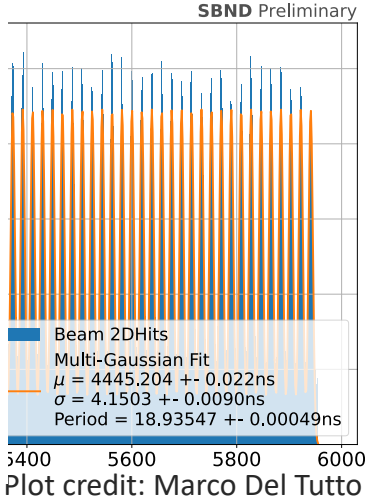

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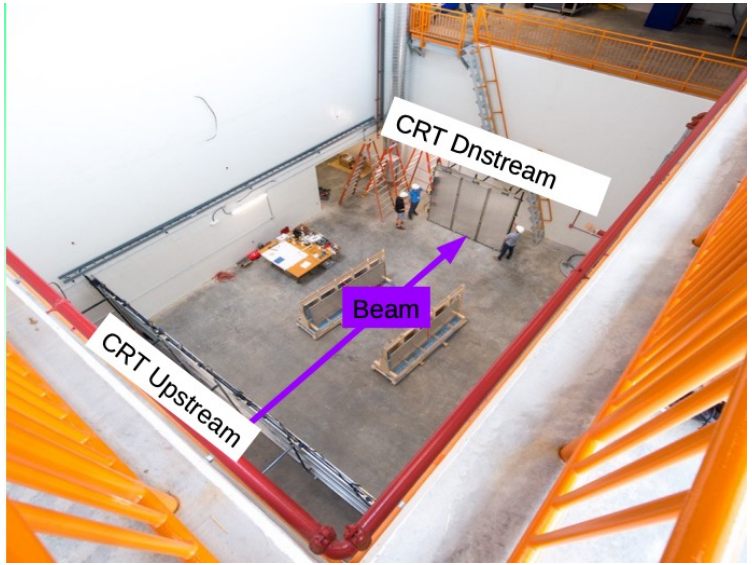
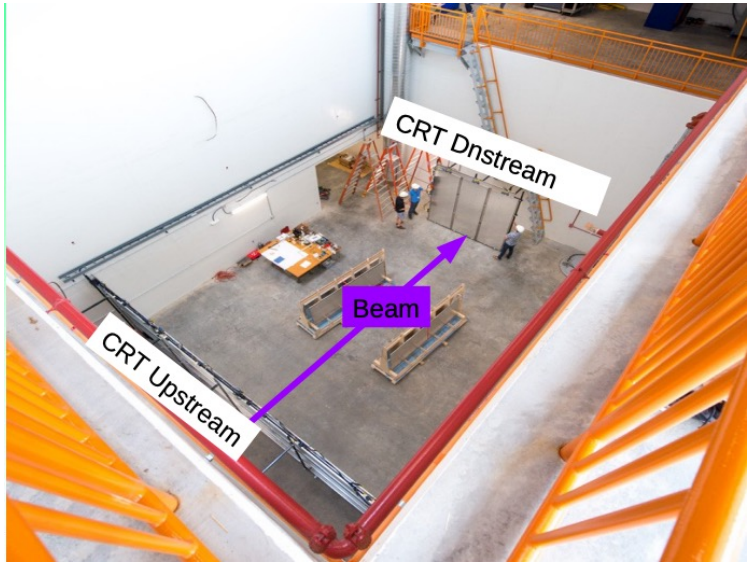


Pit in SBND hall



Pit in SBND hall in 2017

Pit in SBND hall
November 2022

Why do we need a trigger? (the beam spill rate is only 5 Hz)

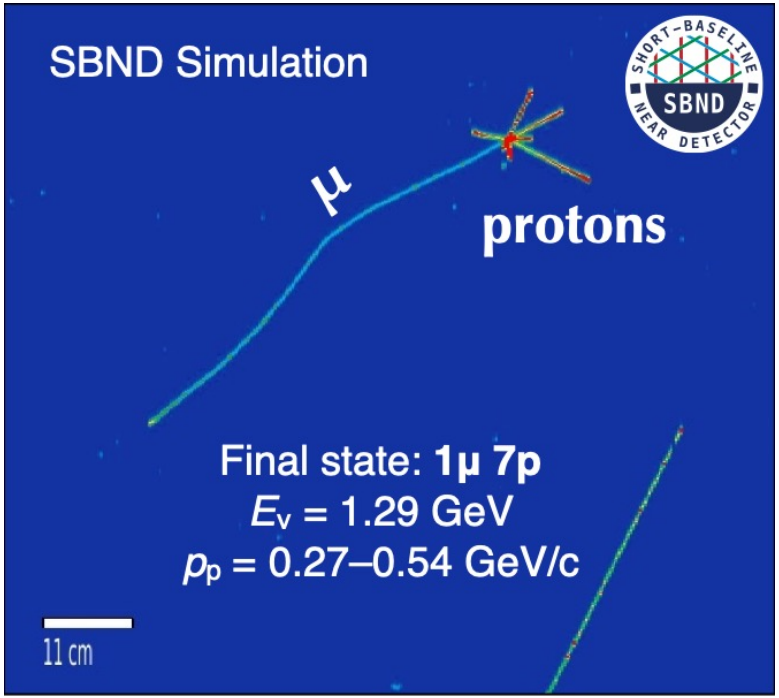
- There is 1 neutrino interaction every ~20 beam spills at SBND
- Events are large, processing the data offline isn't trivial.

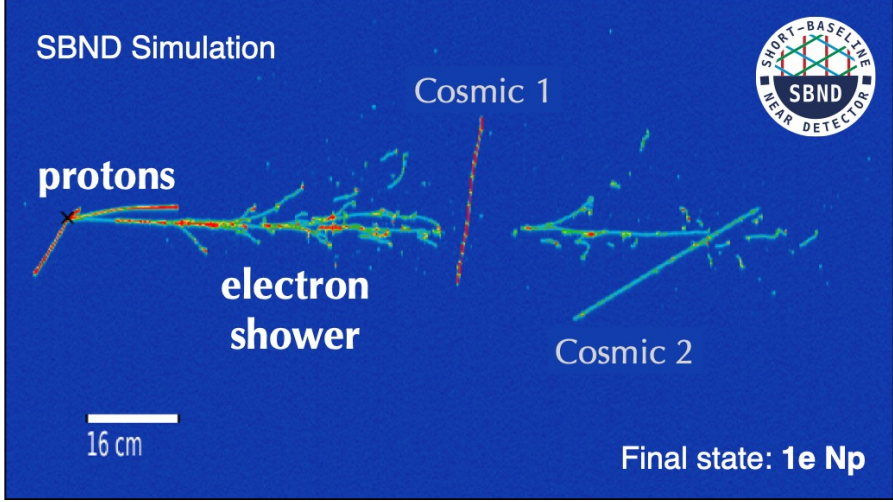
Only save events when scintillation light is detected during the beam spill

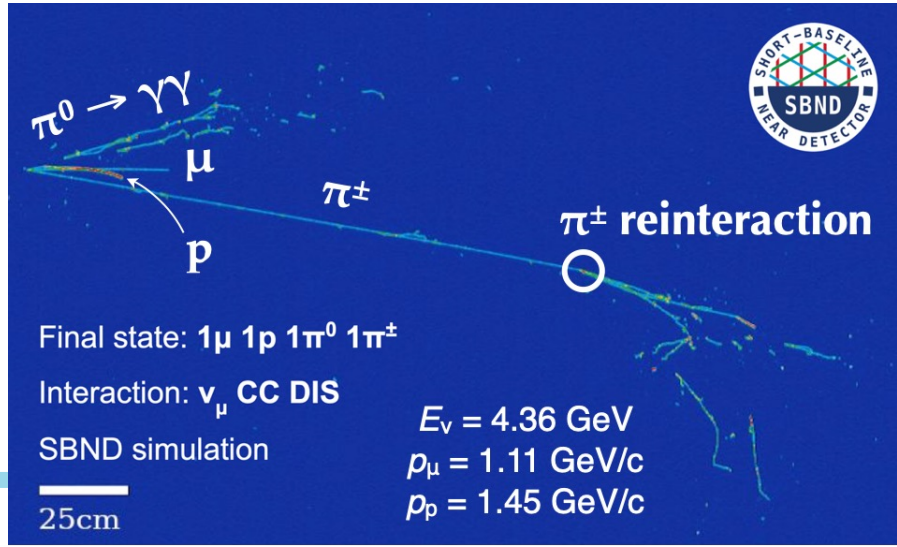
Aside on why events are so large . . .

- The detailed 3D image is a lot of numbers. The 1.75 ms TPC waveforms are sampled at 2 MHz, 11k channels
- Precision calorimetry without electron multiplication requires signal processing on raw waveforms.
  - with 3mm wire spacing, MIP muons deposit only 25,000 collectable electrons per wire in 1-2 us -> O(10) nA signals!!
- New tools such as real time signal processing and ROI finding are in development across the community . . . exciting!

LArTPC images







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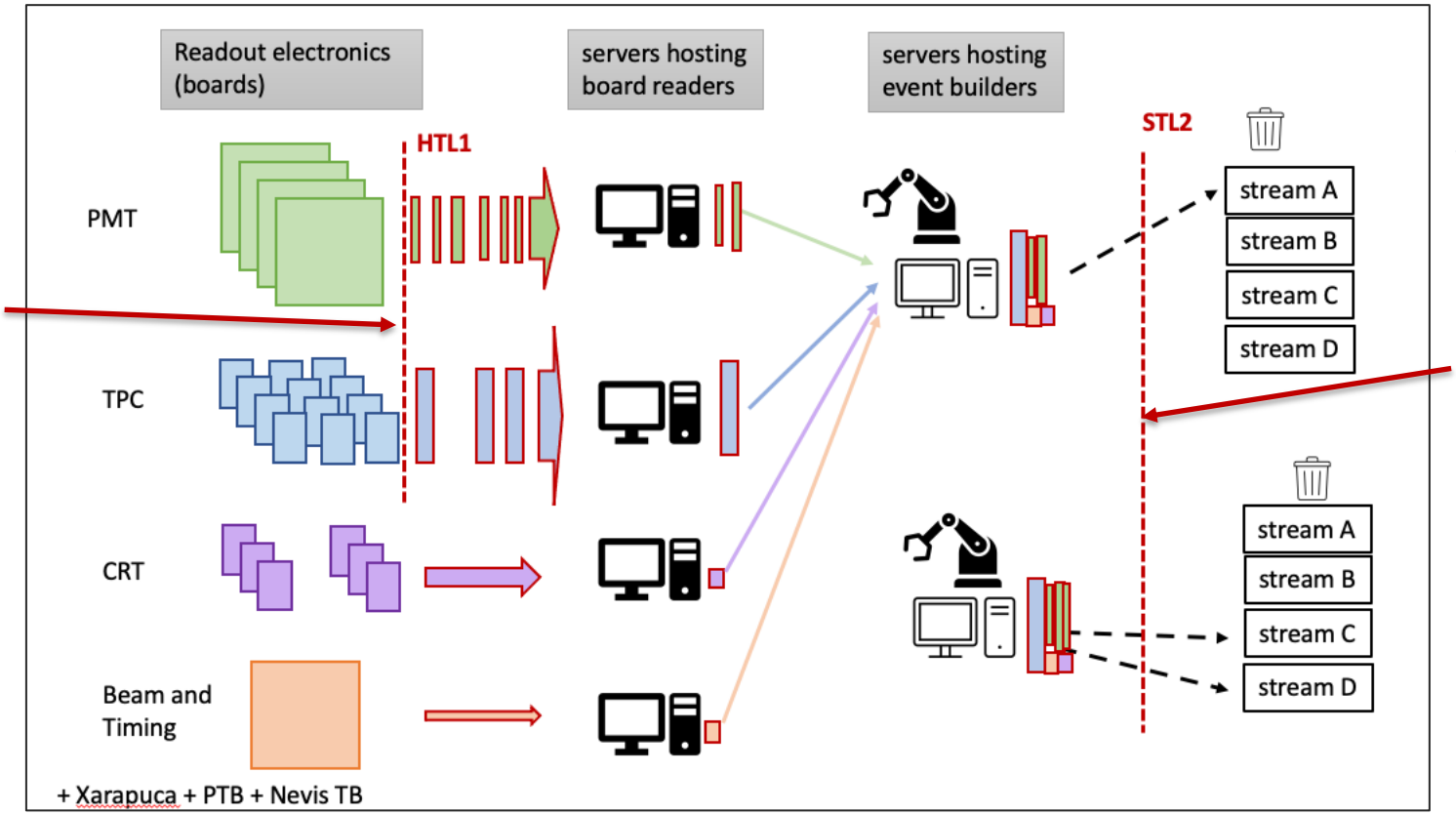
Multi-level, multi-prong triggering

Hardware "Level 1" trigger activates the PDS and TPC readout for short windows.



Software "Level 2" trigger applied after event building.

Sorts the data into output streams, one of which may be a trash can

Hardware/Level 1

Information available:

- PMT multiplicity
  - how many PMTs are above threshold
  - +/- 40 ns due to differences in light path length and production time
- CRT activity
  - Readout trigger for each plane separately
  - +/-100 ns from cable lengths
- Beam signals from accelerator complex

The Penn/Photon Trigger Board receives inputs above and issues triggers to TPC and PDS readout

- See talk by D. Rivera at CPAD 2019

Analog Master Trigger Cards (MTC/A)

The Penn/Photon Trigger Board (PTB)

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- See talk by D. Rivera at CPAD 2019

ards (MTC/A)

This is the first LArTPC in a neutrino beam to use CRT information at the trigger level!

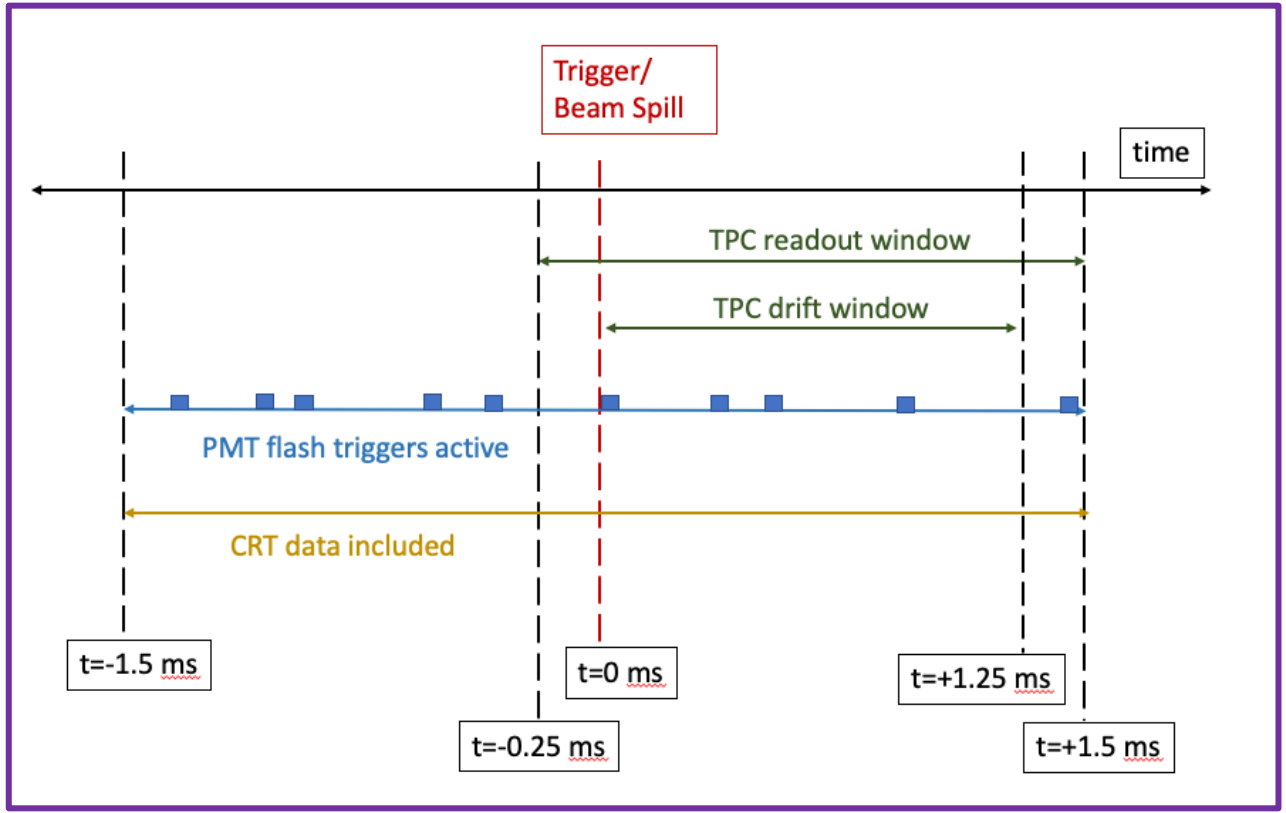
The Penn/Photon Trigger Board (PTB)

Software/Level 2

- last stage of the event building process in the DAQ (server)
- classifies events into different output streams, one of which may be a trash can

What information does it use?

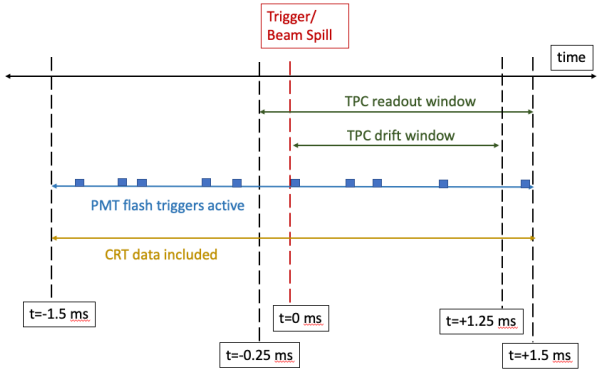
- CRT hits from the beam spill
- PMT waveforms from the beam spill
- Trigger category from PTB (BNB physics, Minimum bias, ”off-beam”, etc)
- Does not yet use TPC information – this requires expanding the DAQ to include more processing power and/or a circular buffer to store events

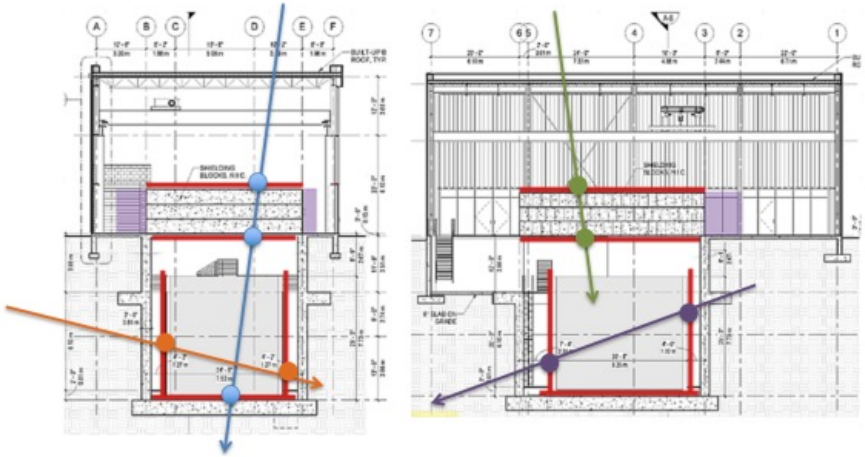


CRT based triggers

Long muon tracks are a critical commissioning tool and the basis of many calibration measurements.

The ability to trigger on the presence of muon tracks means that pure calibration samples can be acquired quickly and/or written to separate data streams. The calibration process is considerably faster when processing calibration data is decoupled from processing physics data





- CRT-Beam: Stopping beam muons (not shown)
- CRT-A: Vertical through-going
- CRT-B: Stopping muons (Michel sample)
- CRT-C: Horiz. through-going Anode-Cathode crossing muons
- CRT-D: Horiz. through-going “parallel” muons

All triggers shown here also require high PMT multiplicity to ensure the muon track enters the active TPC volume

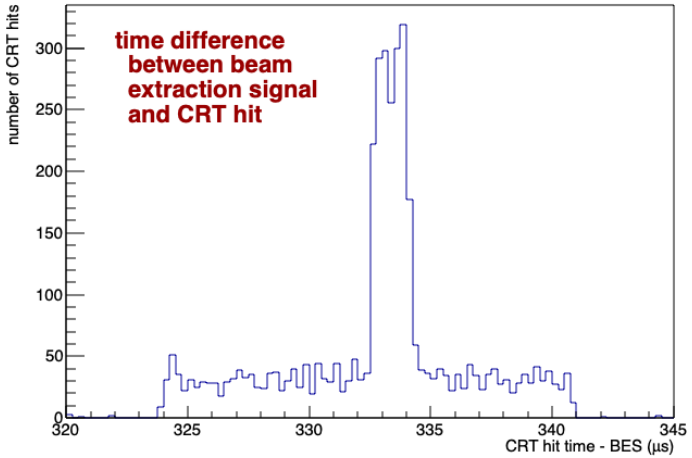
For dedicated runs, a subset of the CRT strips can be activated, restricting the trigger to certain track angles/topologies

CRT crossing muon trigger in action

Early trigger commissioning:

Temporary installation of 4 CRT modules in # configuration on both the upstream and downstream side of the cryostat.

CRT sees muons from neutrino interactions in the dirt just upstream of the cryostat



- Trigger requires a hit in either CRT # (each 4 m^2 active area) during a 16 μs window around the 1.6 μs long beam spill
- ~12 hours of data
- Rough extrapolation: side CRT cosmic rate roughly ~50 hits per second per m^2 of active area, or 10 hits per millisecond in all 4 modules

What can SBND do with this multi-level multi-pronged trigger?

Information available

Hardware/ Level 1

- PMT multiplicity
- CRT activity per plane
- Beam signals from accelerator complex

Software/ Level 2

- PMT primitives (work in progress)
  - total PE in the beam flash
  - size of the flash
  - coated/uncoated PE ratio
- CRT primitives (work in progress)
  - number of hits total or per panel during the beam spill
  - rough position of hits from strip crossing
  - +/- 5 ns timing after cable delay corrections
- Trigger category/stream from PTB

Things that are in place already

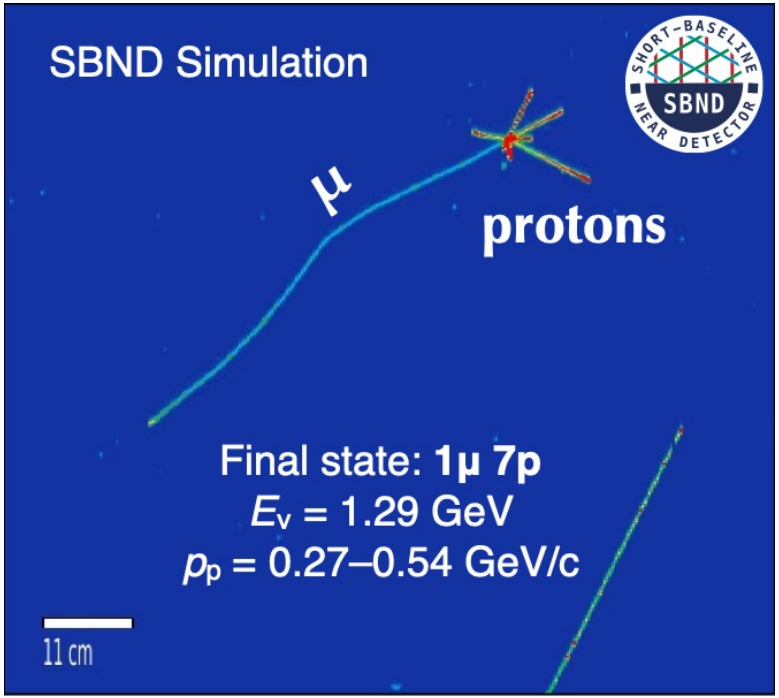
- Identify (and trash) “empty” beam spills – standard light+beam trigger used in MicroBooNE and ICARUS
- CRT-based triggers for commissioning and calibration measurements

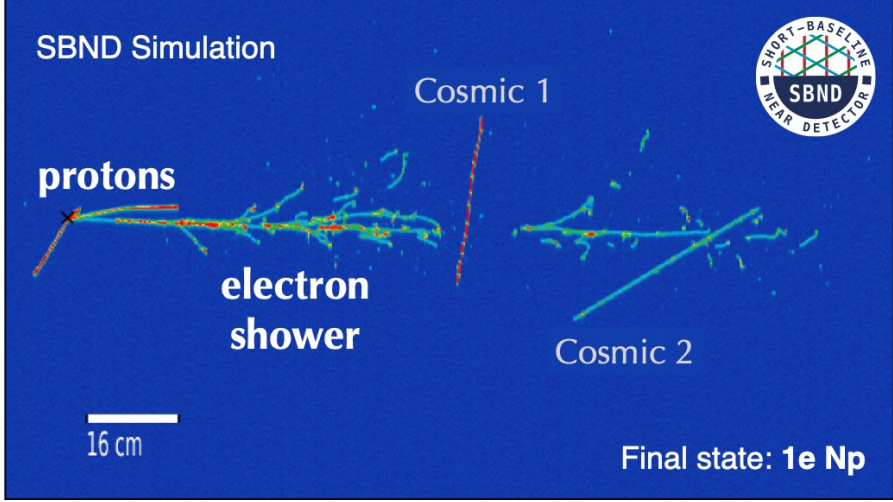
Ideas we will explore

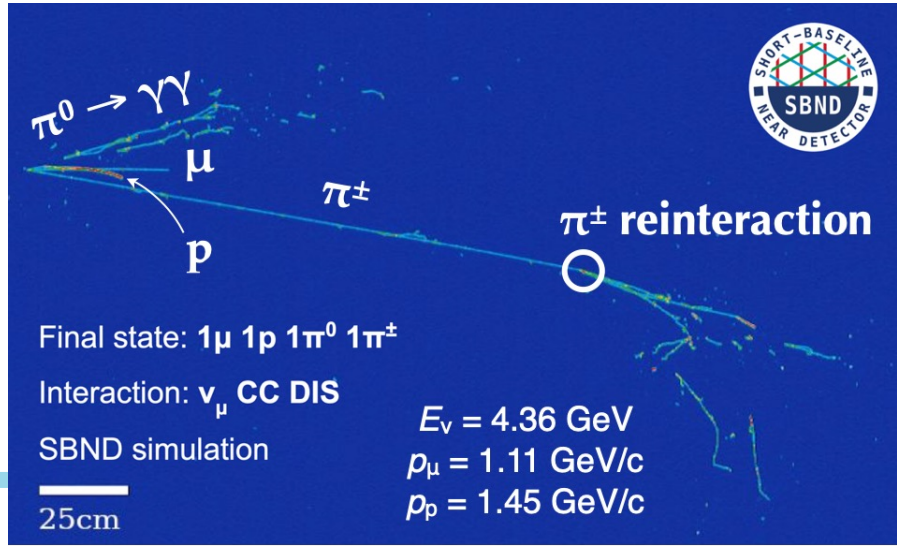
- Additional “contained” physics stream (veto on CRT activity) with a much lower light threshold for this stream only
- Analyze PMT waveforms to identify the delayed Michel flash
- ”golden neutrino stream” – low efficiency, high purity ν_μ CC selection for monitoring purposes

stay tuned !

LArTPC images







SBND as an R&D platform for triggering

- The SBND “day-1” DAQ is flexible and expandable
- 3-year physics run before the long shutdown provides opportunities for trigger R&D during beam downtimes and for parasitic running with beam
- Ideas for “SBND phase 2” after the long shutdown are being discussed
- Proximity to the target makes SBND a unique place to search for beam-produced BSM candidates

SBND already has plans for R&D on tpc-based triggering, project lead by Georgia Karagiorgi at Columbia University/NEVIS CPAD talk 2021 by Daisy Kalra

- TPC-based triggering is essential to the DUNE-FD low energy physics program (proton decay, supernova, atmospheric neutrinos, annihilation processes and much more)
- SBND TPC readout already has a supernova data stream – a duplicate continuous stream of TPC data that is subject to “lossy compression” and stored short-term while waiting for a SNEWS alert.
- This R&D also utilizes a duplicate continuous stream of TPC data

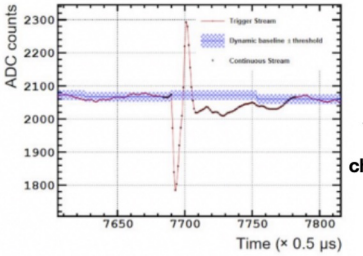
Why a TPC-based trigger?

- **Recording every beam trigger** to search for beam-based signatures or **saving continuous stream data** (expected data rates without compression: 45GB/s) to search for non-beam signatures can be **computationally very challenging**.
- Current strategy has two key components

  Reduce the TPC raw data to a set of **trigger primitives** (TPs) that is stored short-term.
  A trigger decision is made on-the-fly by looking for patterns in the TPs
  Offline analysis is done on the TPs and not on the raw data, which is not saved.
- **Example use case:** millicharge particles (mCP) Phys. Rev. Lett 124 (2020)13, 131801
  - These interactions generate little/no scintillation light and are contained in the TPC, so triggering on light or CRT activity is not possible
  - We can perform a search for mCP from decay of neutral mesons produced in beam interactions and cosmic interactions

Trigger Primitive generation

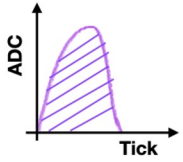
- Use TPC information (ROI waveforms from Continuous data stream) and summarize ionizations per channel per time to generate trigger primitives (TP)
- TP generation has already been tested in real-time with Nevis test stand and offline from MicroBooNE data



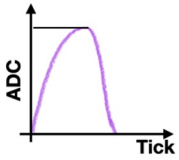
Zero-Suppressed waveform

Trigger Primitives

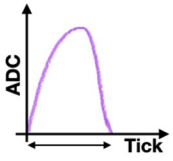
Summary of ionization charges per channel per time



Integral

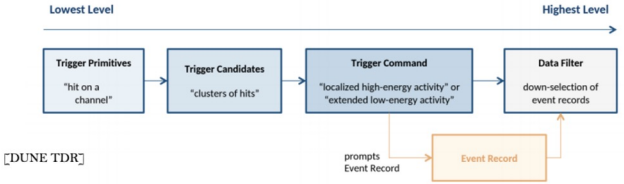


Amplitude



Time over threshold

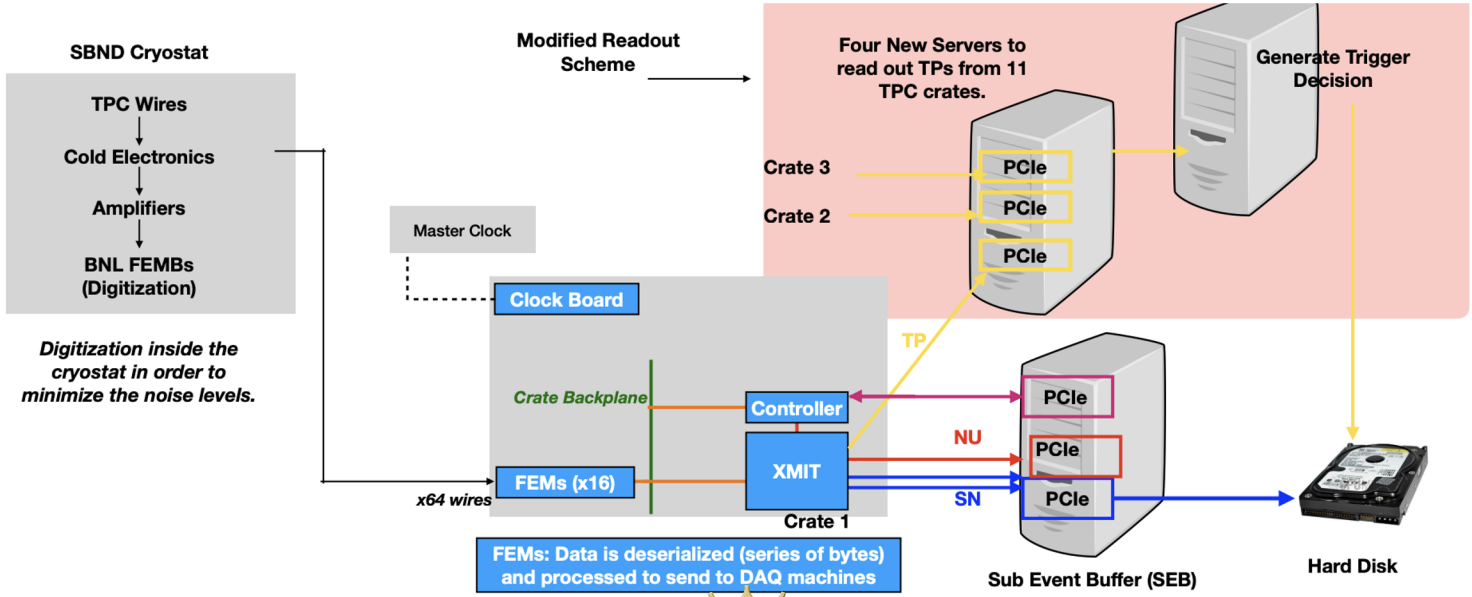
Trigger Strategy



[DUNE TDR]

What additional hardware is needed?

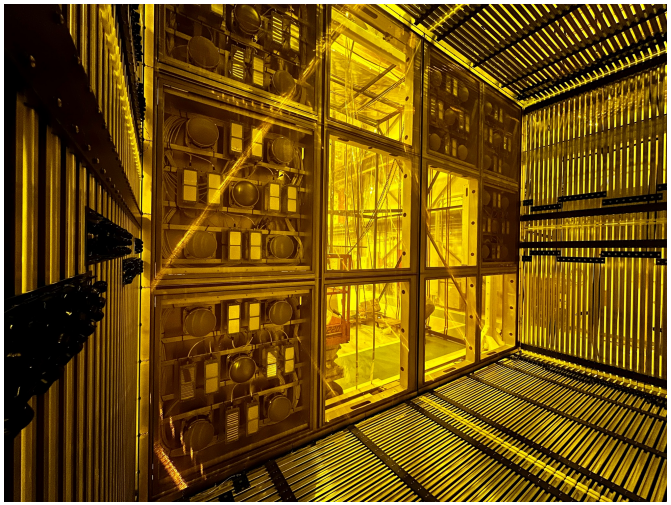
To read out TP stream independent of neutrino stream (without affecting our nominal physics run/data collection), we need additional 5 servers, 4 servers to collect TPs from hardware and 1 server to generate trigger decision.

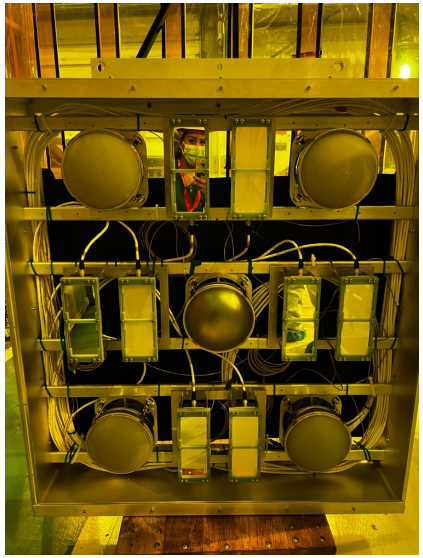


Conclusions

- SBND is looking forward to commissioning in 2023
- Unprecedented statistics for high precision cross section measurements and BSM searches with rare signatures
- CRT information available at the triggering stage will both expand the physics we can do and get it done faster
- SBND is a unique platform for future trigger R&D

Backup slides

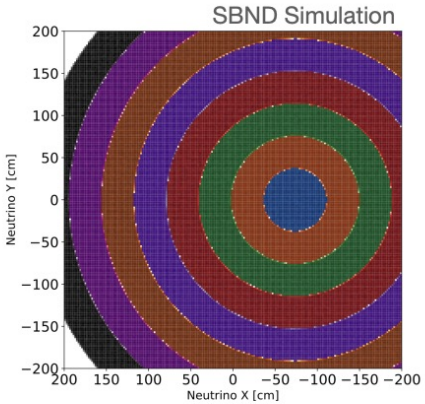


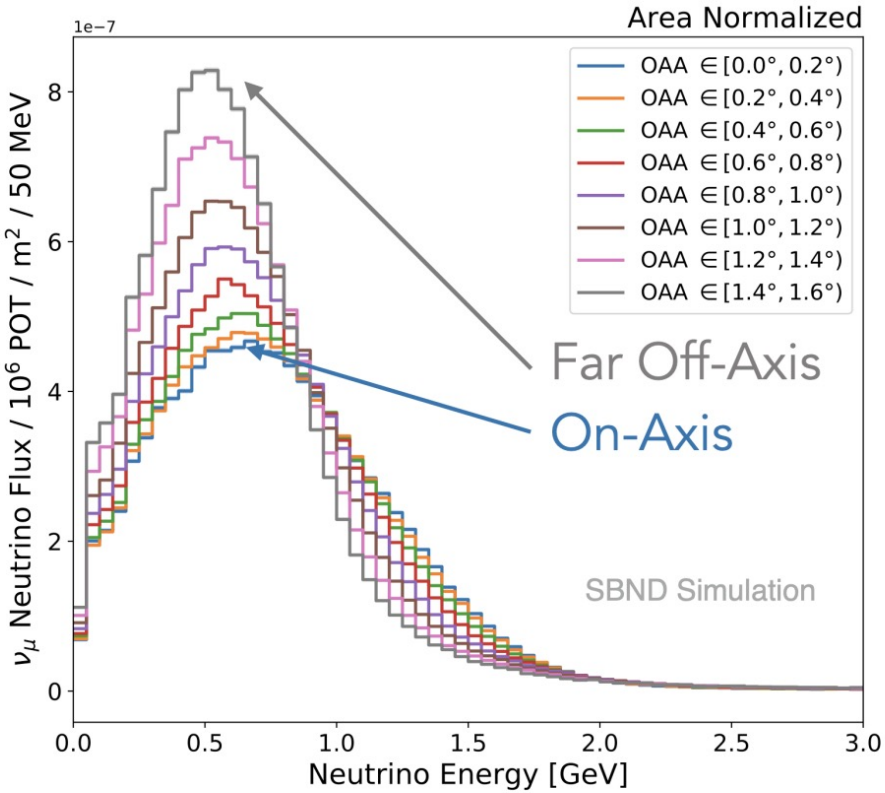


SBND-PRISM

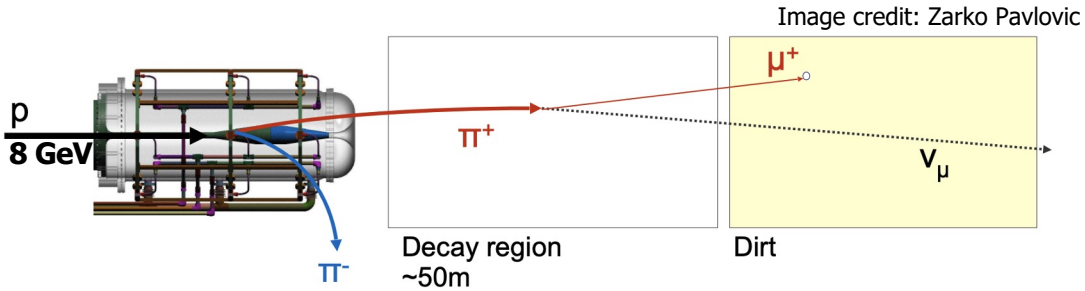
nuPRISM proposal:
arXiv:1412.3086

- Off-axis angle directly corresponds to the neutrino interaction vertex position
- The flux spectrum evolves as a function of the off-axis angle
  - Further off-axis fluxes peak lower and tighter
- Allows SBND to leverage PRISM concept





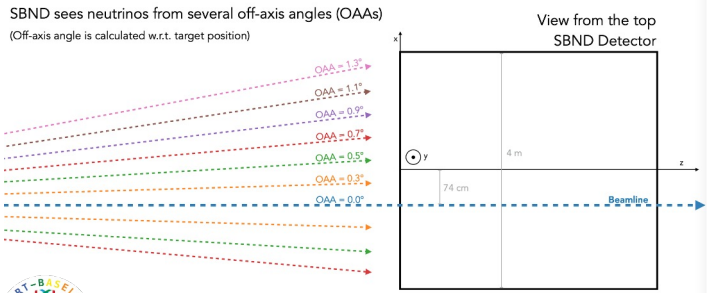
The Booster Neutrino Beam @ SBND

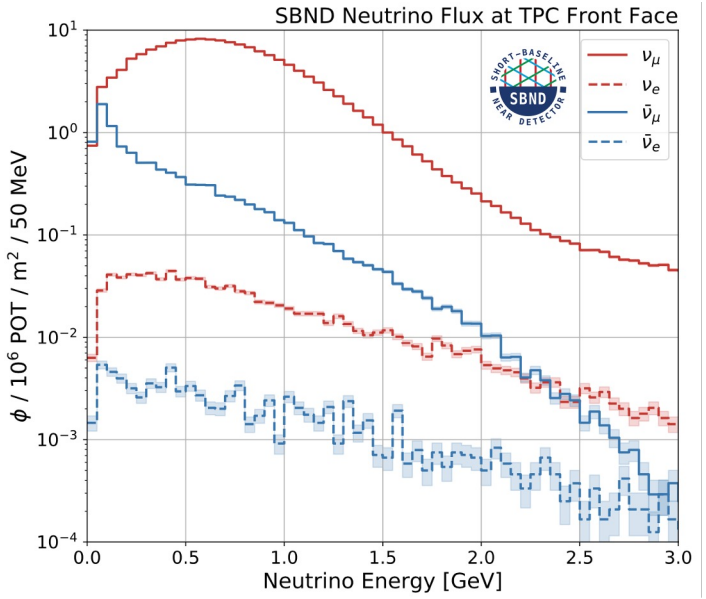


Beam Composition :

$\bar{\nu}_\mu$ = 93.6%
ν_μ = 5.9%
$\nu_e + \nu_e$ = 0.5%

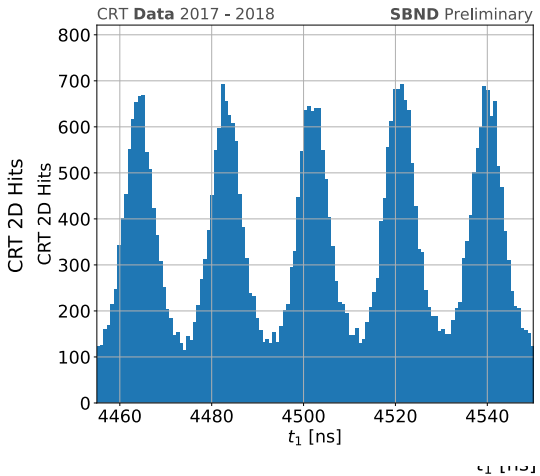
- $\langle E_\nu \rangle$ ~ 800 MeV.
- Projected to take **10-18 X 10^{20} POT** of data in total => large statistics on Argon.
- Close to the target + slightly off-axis => SBND can sample **off-axis fluxes** (hear more about this in the next talk by Lauren Yates).

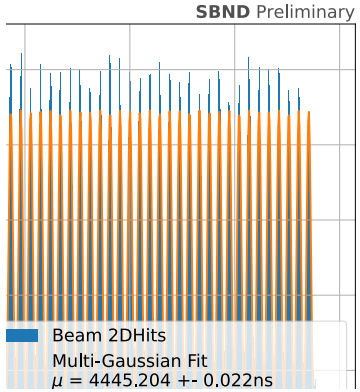




CRT Beam Telescope Run 2017-2018

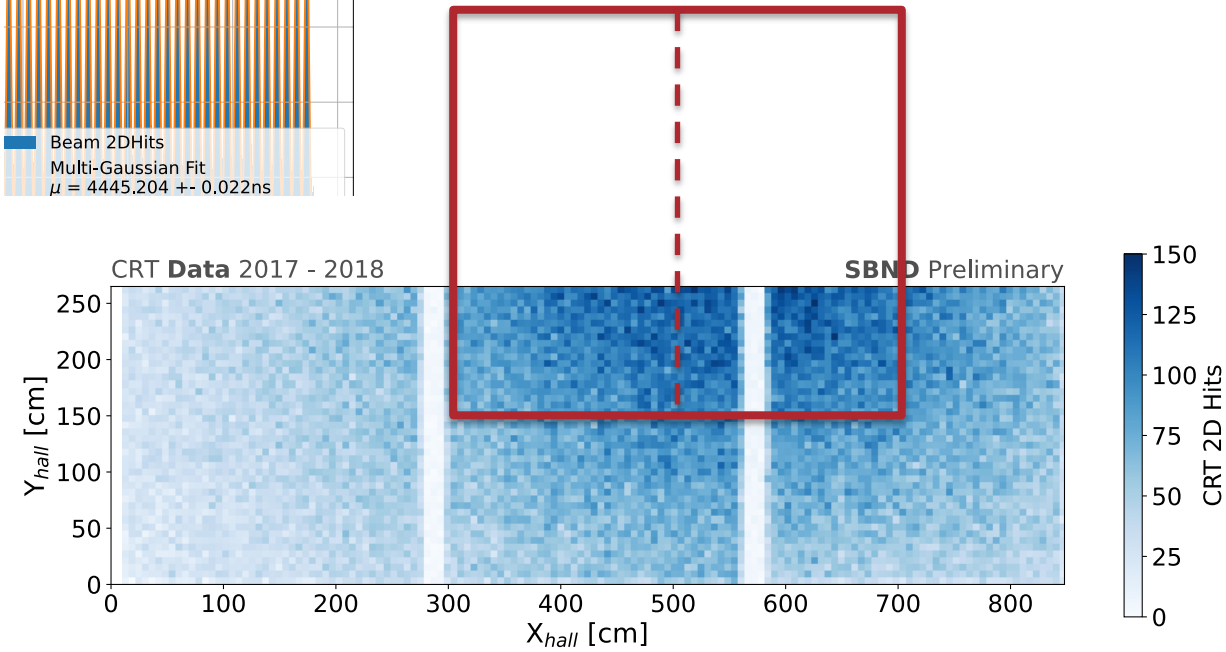
move to backup



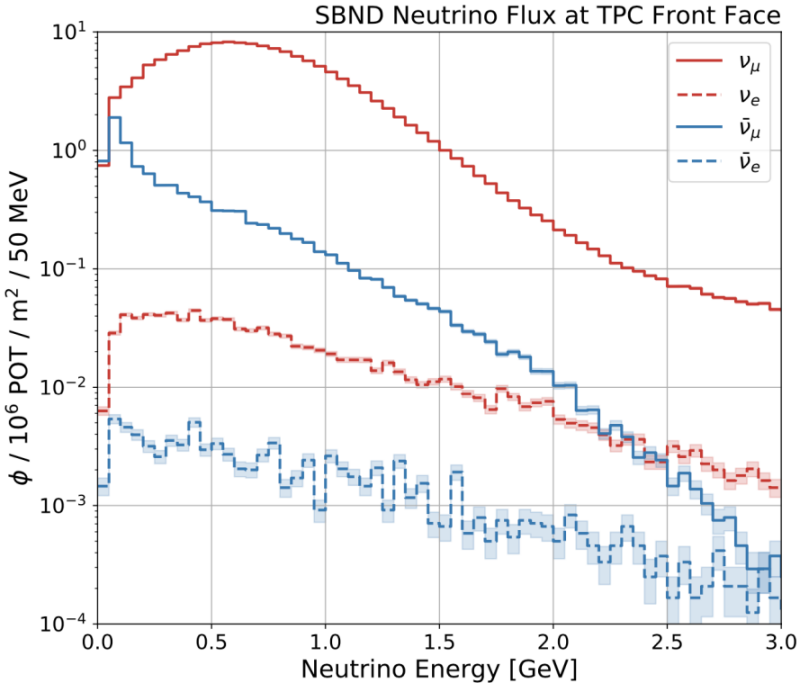


Muons from neutrino interac
of the pit are detected by the
The beam spill substructure c

- 81 bunches with 19 ns spa
- spill duration of 1.6 µs



Booster Neutrino Beam Flux at SBND



- The primary beam of interest at SBND is the Booster Neutrino Beam (BNB)
- The mean energy for muon neutrinos is about 0.8 GeV
- Beam composition by neutrino flavor:
  - 93.6% ν_μ
  - 5.9% $\bar{\nu}_\mu$
  - 0.5% ν_e+$\bar{\nu}_e$
- Plan to collect data corresponding to 10e20–18e20 protons on target (POT) over the course of a 3–4 year run

Concept for 4-SiPM/2-strip requirement on CRT readout