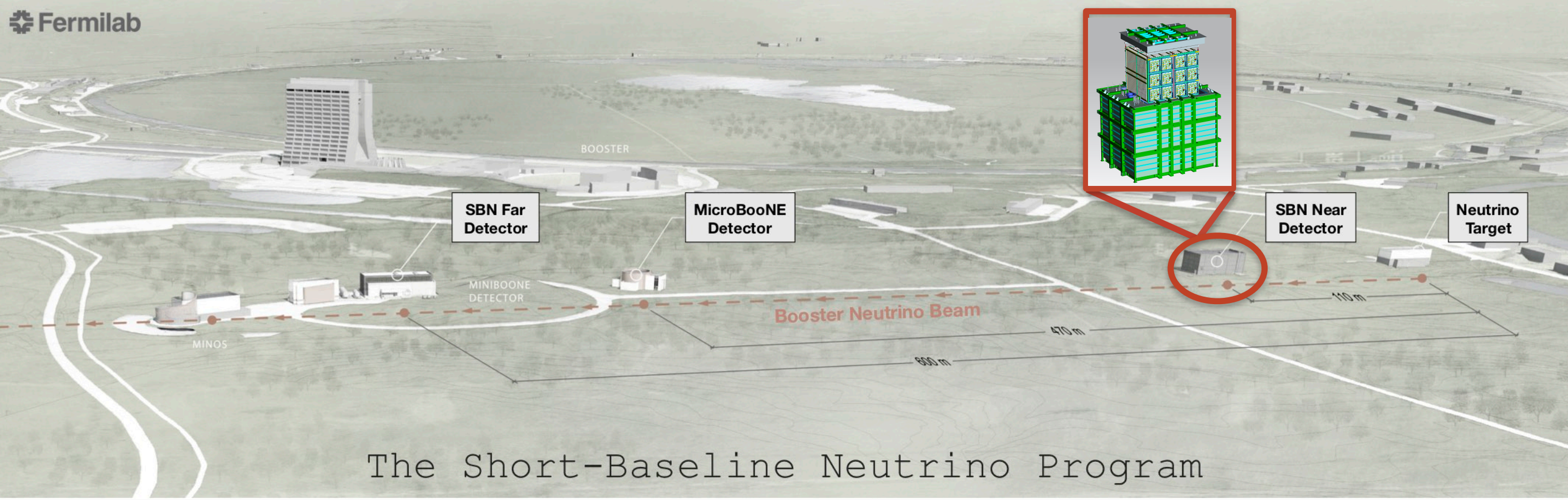


The Short-Baseline Near detector [SBND]

Fermilab PAC Meeting
July 1, 2020

Ornella Palamara (FNAL) & **David Schmitz** (U. of Chicago)

OUTLINE

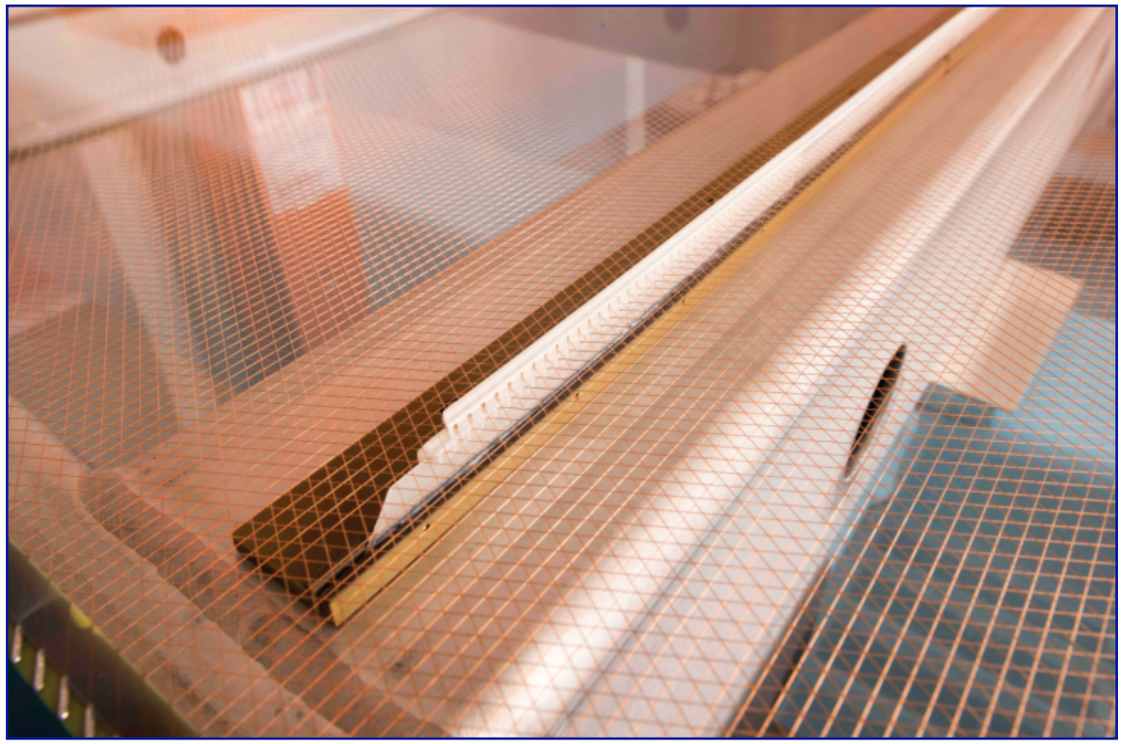
- Brief reminder of the history/timeline of SBND
- SBND physics program
- Overview of the experiment and TPC design
- Status of SBND construction
- Future to completion, operations, and physics

Brief History/Timeline of SBND

- **January 2014 FNAL PAC:** A new LArTPC near detector for the Booster Neutrino Beam (then called **'LAr1-ND'**) was proposed; initially a ND for MicroBooNE.
  - The ICARUS collaboration also proposed to transport the **ICARUS-T600** to Fermilab and build a new 1/4-scale detector for a near detector.
  - The PAC recommended that the two collaborations (+MicroBooNE) work together to develop a coherent FNAL Short-Baseline Neutrino Program.
- **January 2015 FNAL PAC:** Returned with the full **'SBN Proposal'** that detailed the science goals and technical plans for a three-detector LArTPC program on the BNB, including **MicroBooNE, ICARUS, and SBND.**
- Stage 2 approval from FNAL.
- **2015-2016:** Design and construction of a **new experimental hall** at Fermilab.

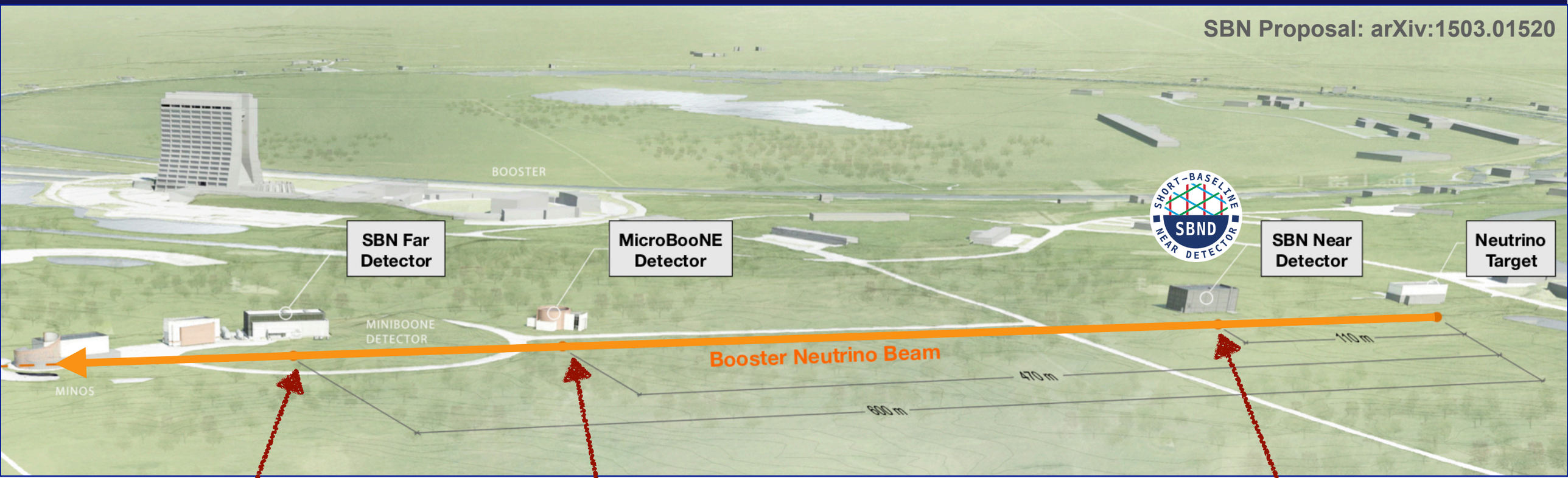
Brief History/Timeline of SBND

- **2015-2019:** Design and construction of the **SBND detector systems**: TPC, photon detectors, cryostat and cryogenics, cosmic ray tagger.
  - Major construction activities in the US (DOE and NSF), UK, Switzerland, Brazil, and CERN.
- **2019-March 2020:** **TPC assembly** at FNAL. **Cryostat** final design and construction at CERN and FNAL.
- **March 2020-Present:** COVID-19 paused all on-site activities at Fermilab in March.
  - TPC assembly most impacted, but work slowly restarting now.
  - Good progress continued in planning procedures and documentation (to be best prepared when work resumes), DAQ software development, and simulation and physics analysis development.



The SBN Program @ Fermilab

SBN Proposal: arXiv:1503.01520

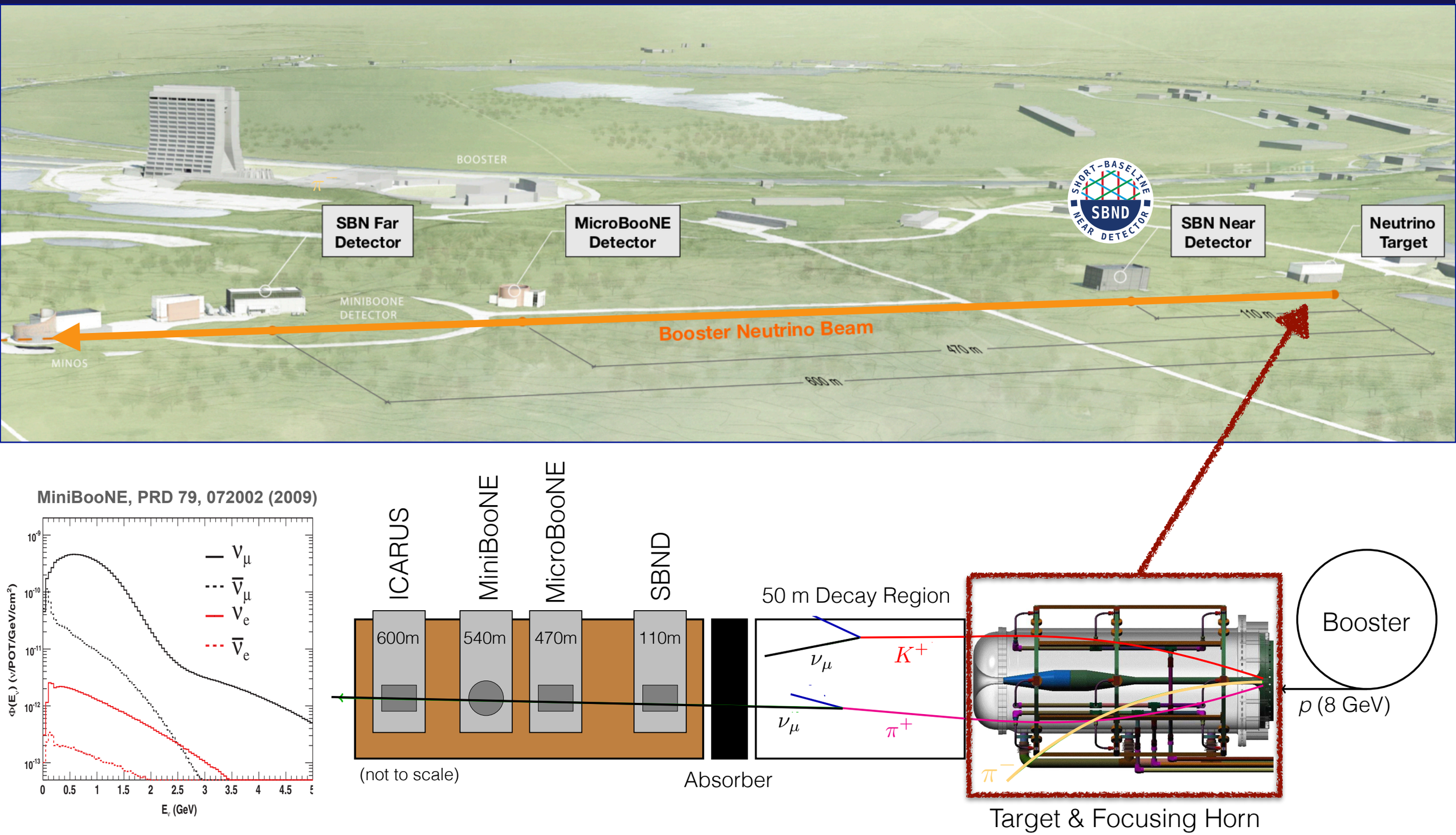


470t LArTPC, 600m from target

89t LArTPC
470m from target

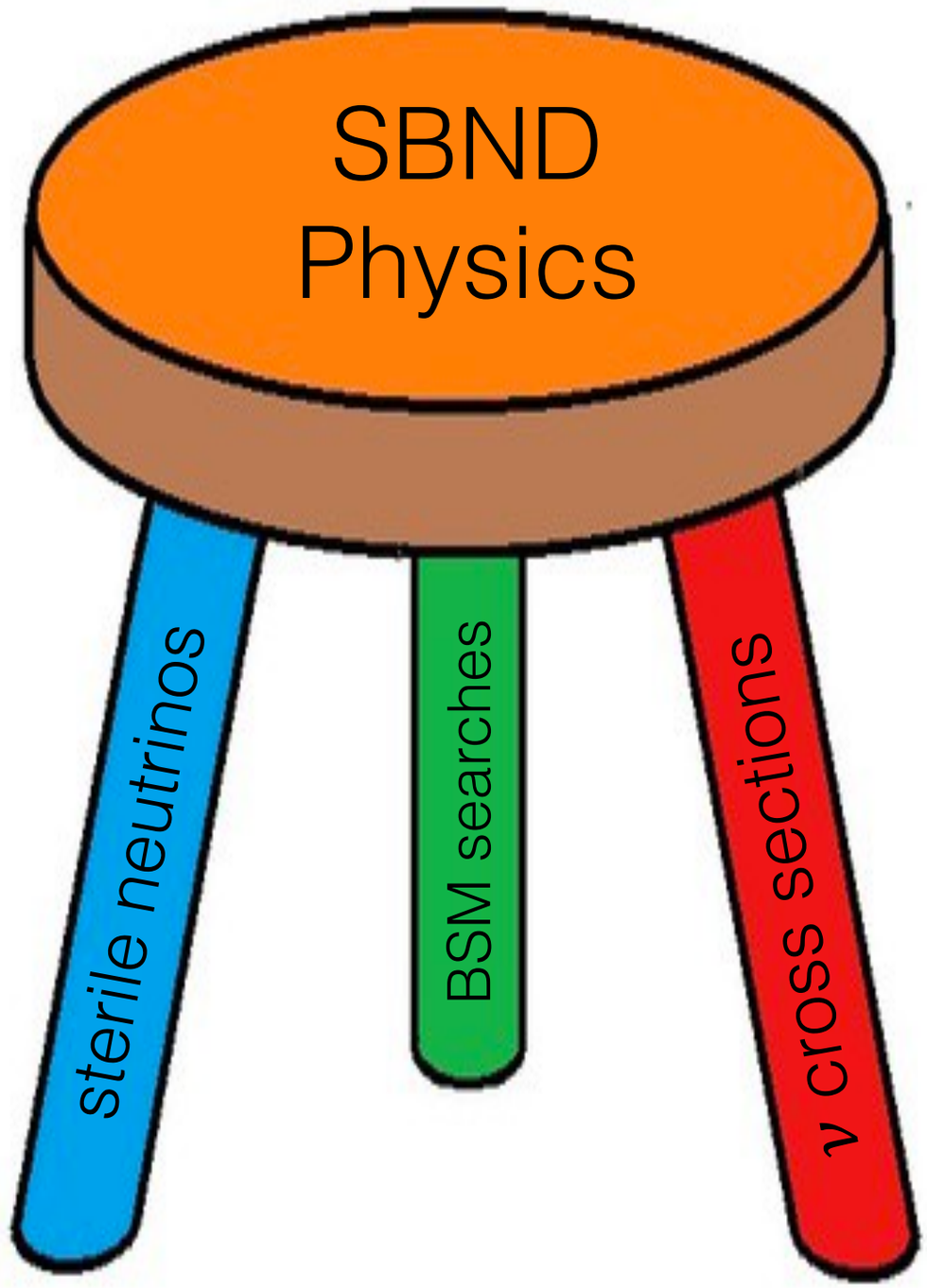
112t LArTPC, 110m from target

The SBN Program @ Fermilab



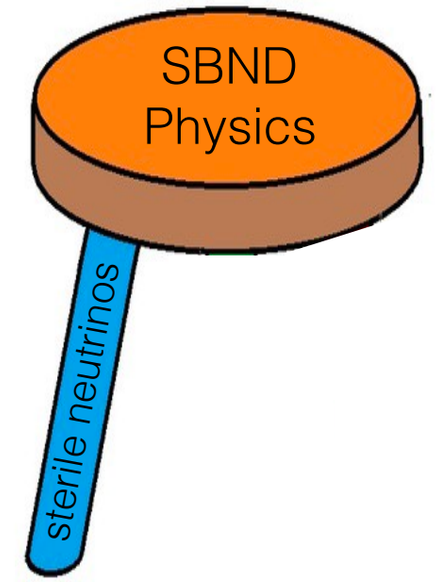
Booster Neutrino Beam (BNB)

SCIENCE PROGRAM



SCIENCE PROGRAM

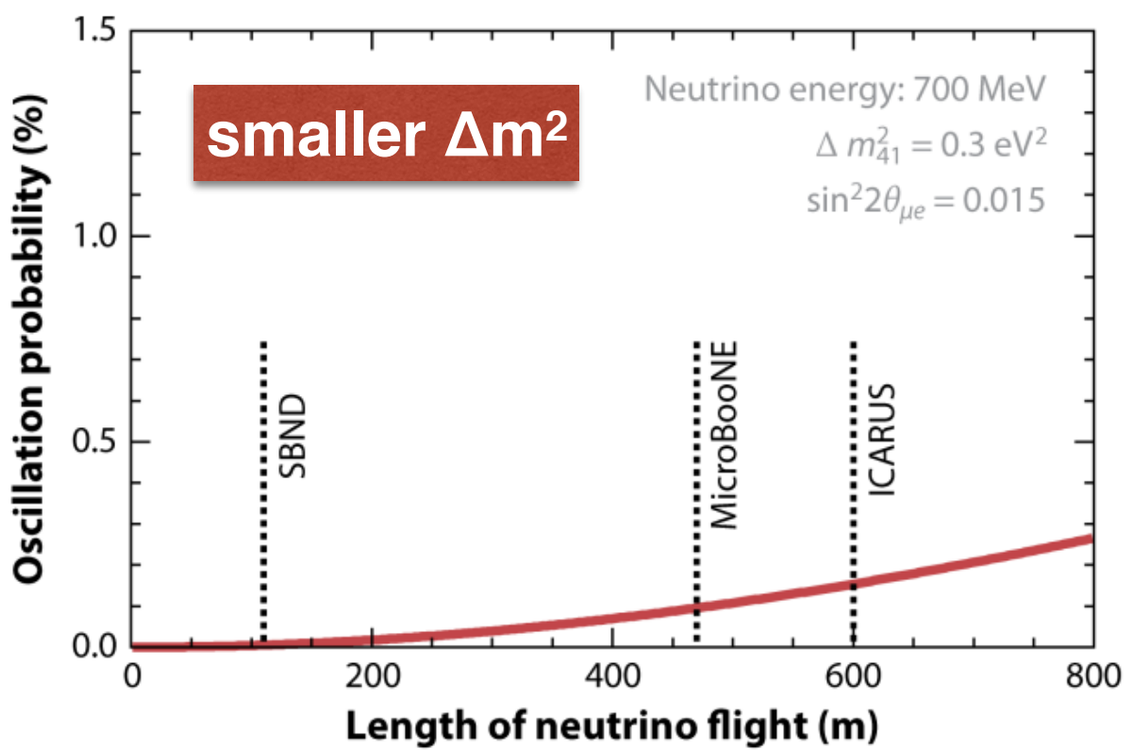
1. SBND, as the Near Detector, plays a unique role in the flagship physics goal of SBN: testing the hypothesis of **light sterile neutrinos.**

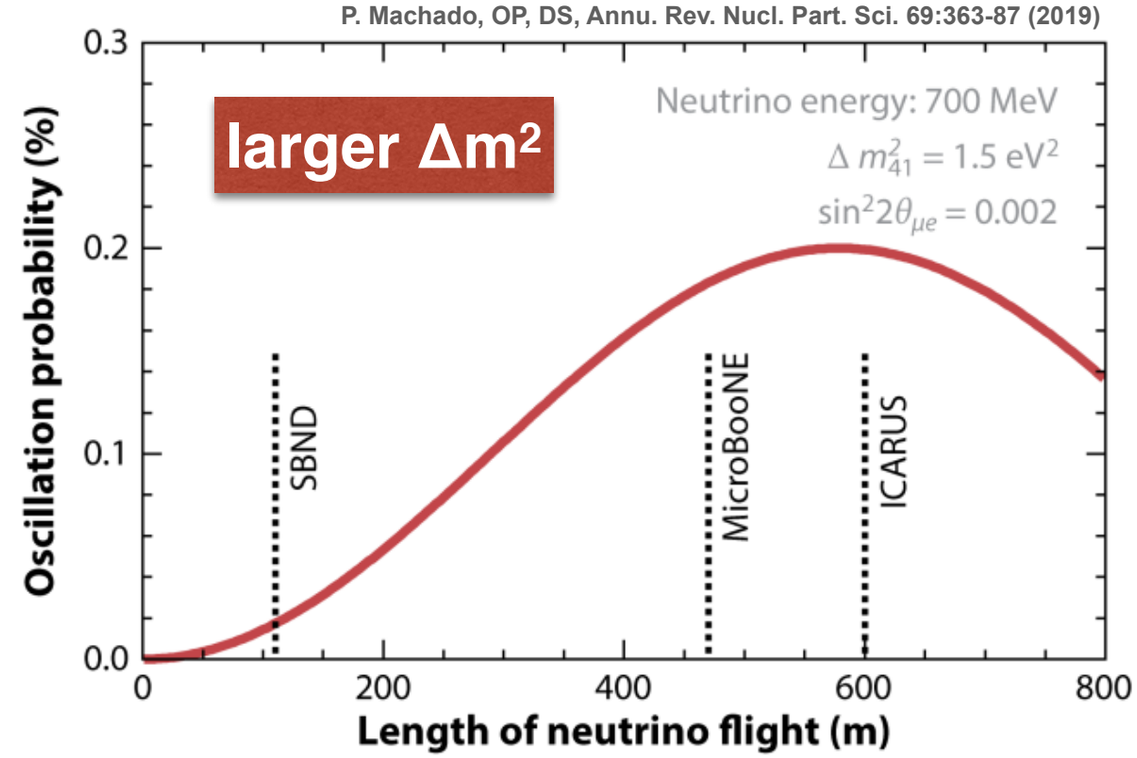


- Sterile ν oscillation searches come down to systematics, and a near detector with the same nuclear target, same detection technology, and located in the same beam is the key.

- Having a ND enables simultaneous tests of ν_e appearance AND ν_μ disappearance in the same experiment.

P. Machado, OP, DS, Annu. Rev. Nucl. Part. Sci. 69:363-87 (2019)





SCIENCE PROGRAM

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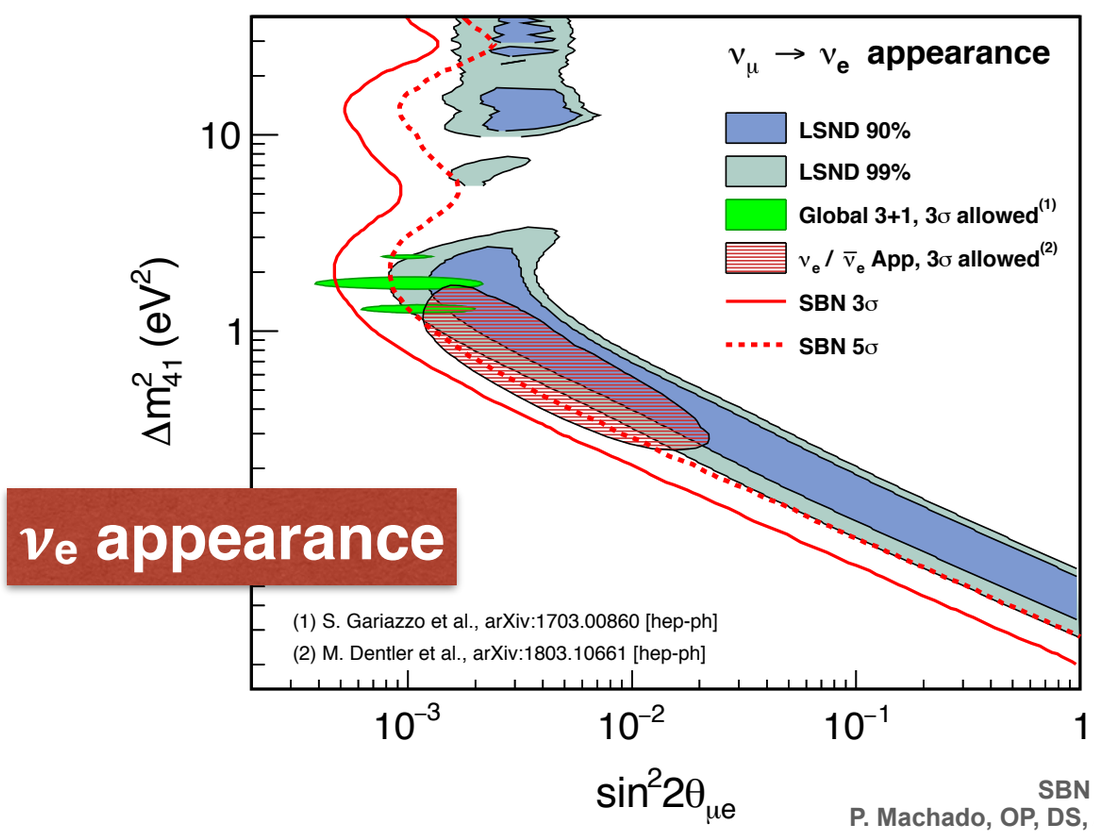
   - Sterile ν oscillation searches come down to systematics, and a near detector with the same nuclear target, same detection technology, and located in the same beam is the key.

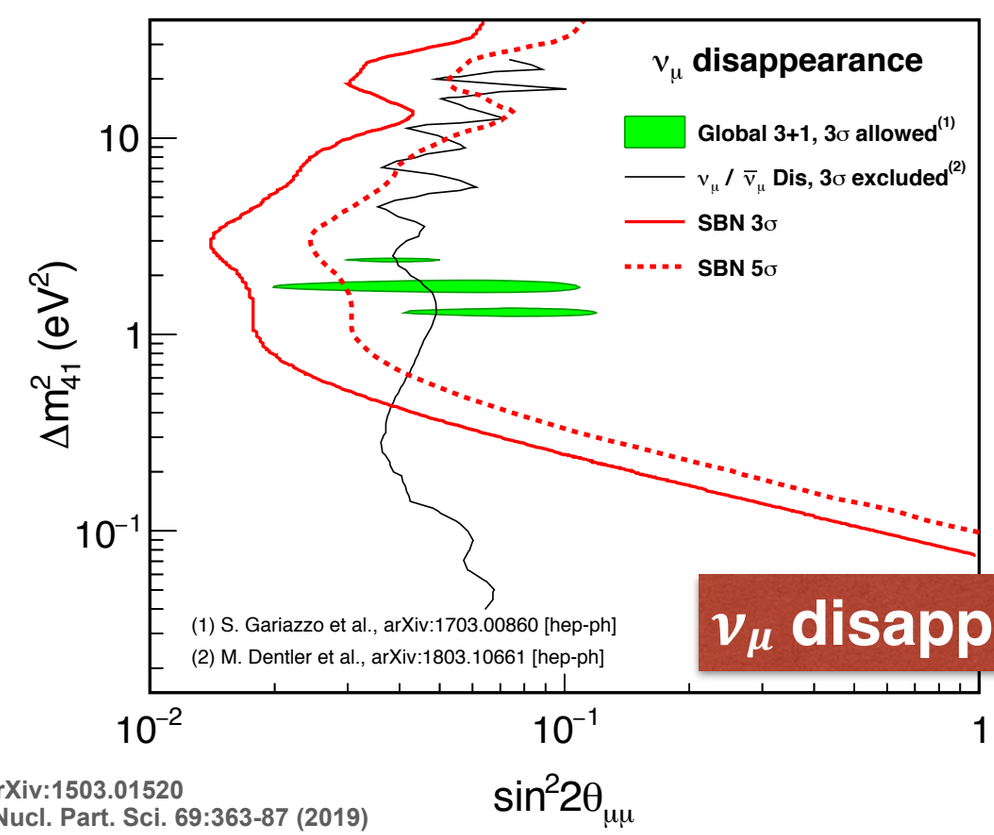
   - Having a ND enables simultaneous tests of ν_e appearance AND ν_μ disappearance in the same experiment.

5σ coverage of global best fits and original LSND 99% CL allowed region in ν_e disappearance.

Ability to observe ν_μ disappearance is essential to the interpretation of any electron neutrino excess as being due to the existence of sterile neutrinos



ν_e appearance

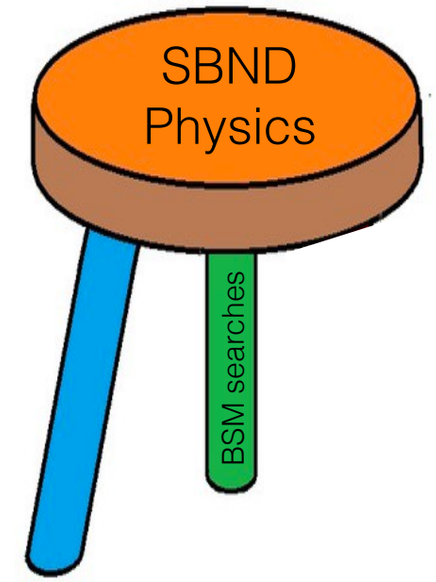


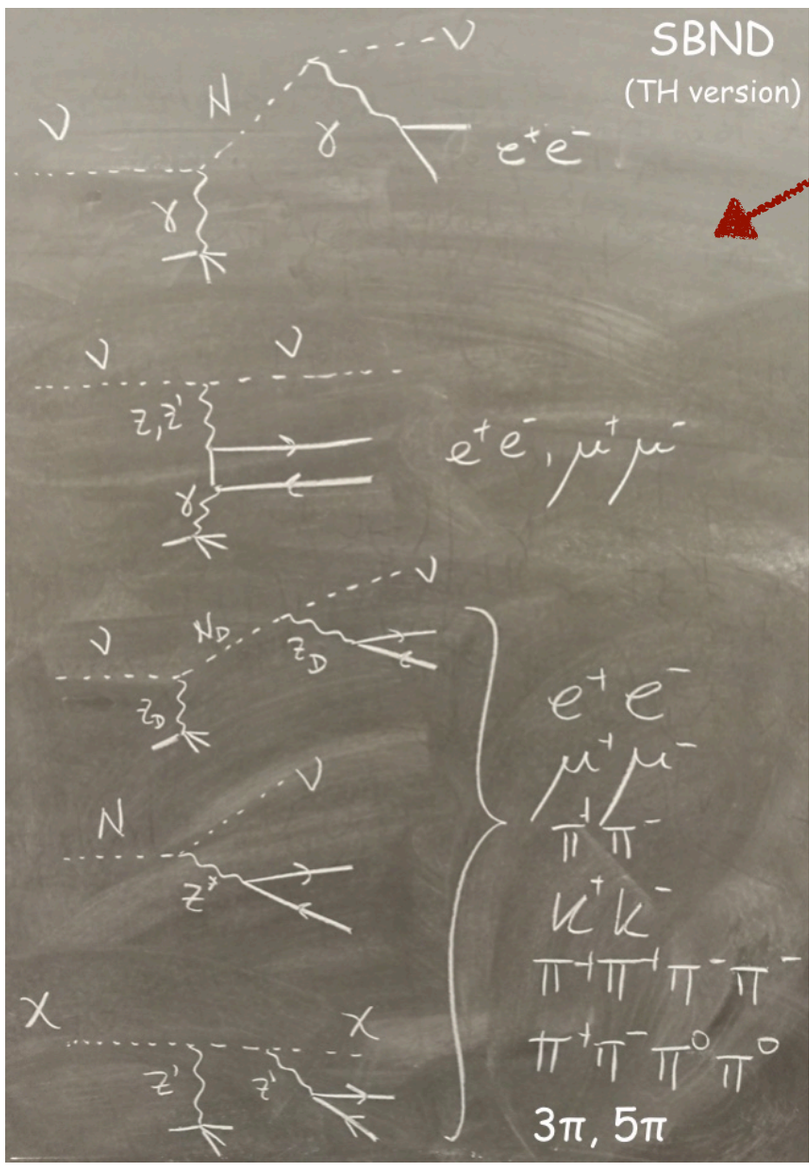
ν_μ disappearance

SBN Proposal: arXiv:1503.01520
P. Machado, OP, DS, Annu. Rev. Nucl. Part. Sci. 69:363-87 (2019)

SCIENCE PROGRAM

2. The large detector mass, precision reconstruction capabilities, and proximity to the neutrino source have caught the attention of the theory community for other **BSM searches** that SBND can perform.





Courtesy P. Machado (FNAL Theory Department)

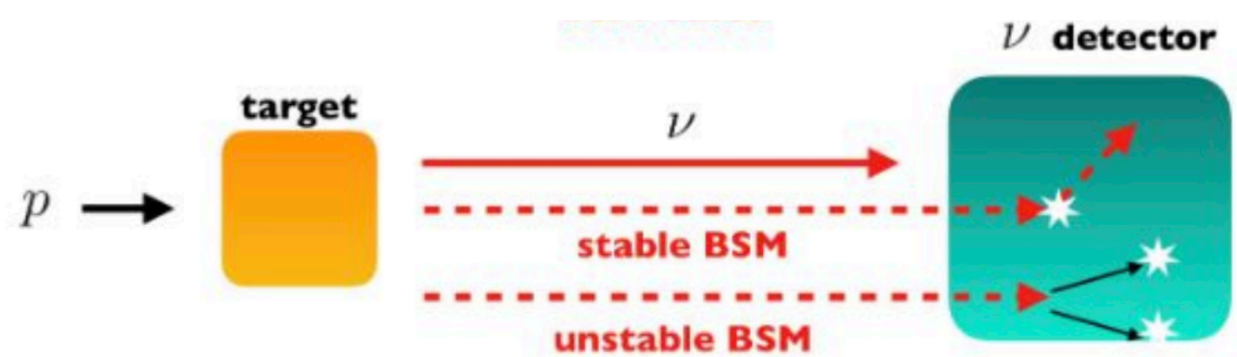
This is SBND from a theorist's perspective!

Two general categories of phenomena:

Modifications to neutrino oscillations (large extra dimensions, decaying sterile neutrinos, ...)

New states produced in the beam target (dark matter, heavy neutrinos, millicharged particles, ...)

P. Machado, OP, DS, Annu. Rev. Nucl. Part. Sci. 69:363-87 (2019) and many references therein

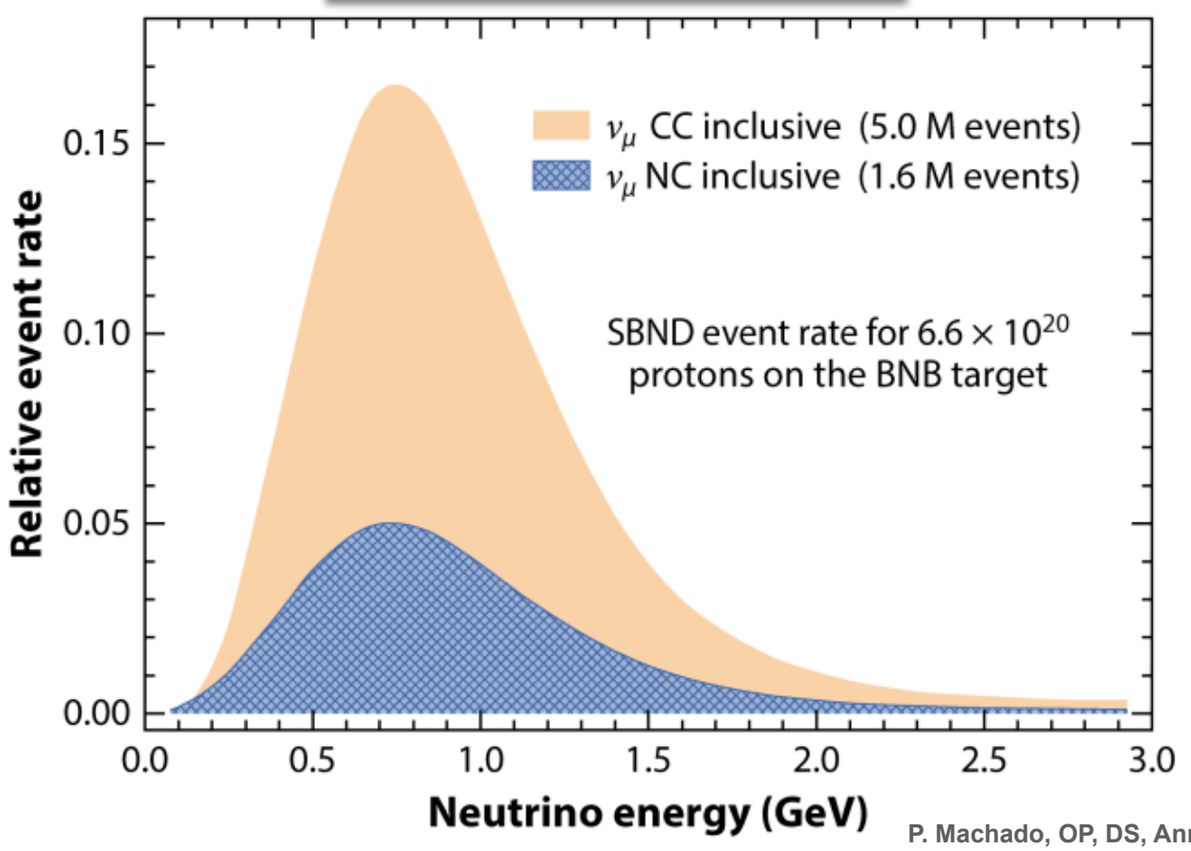


SCIENCE PROGRAM

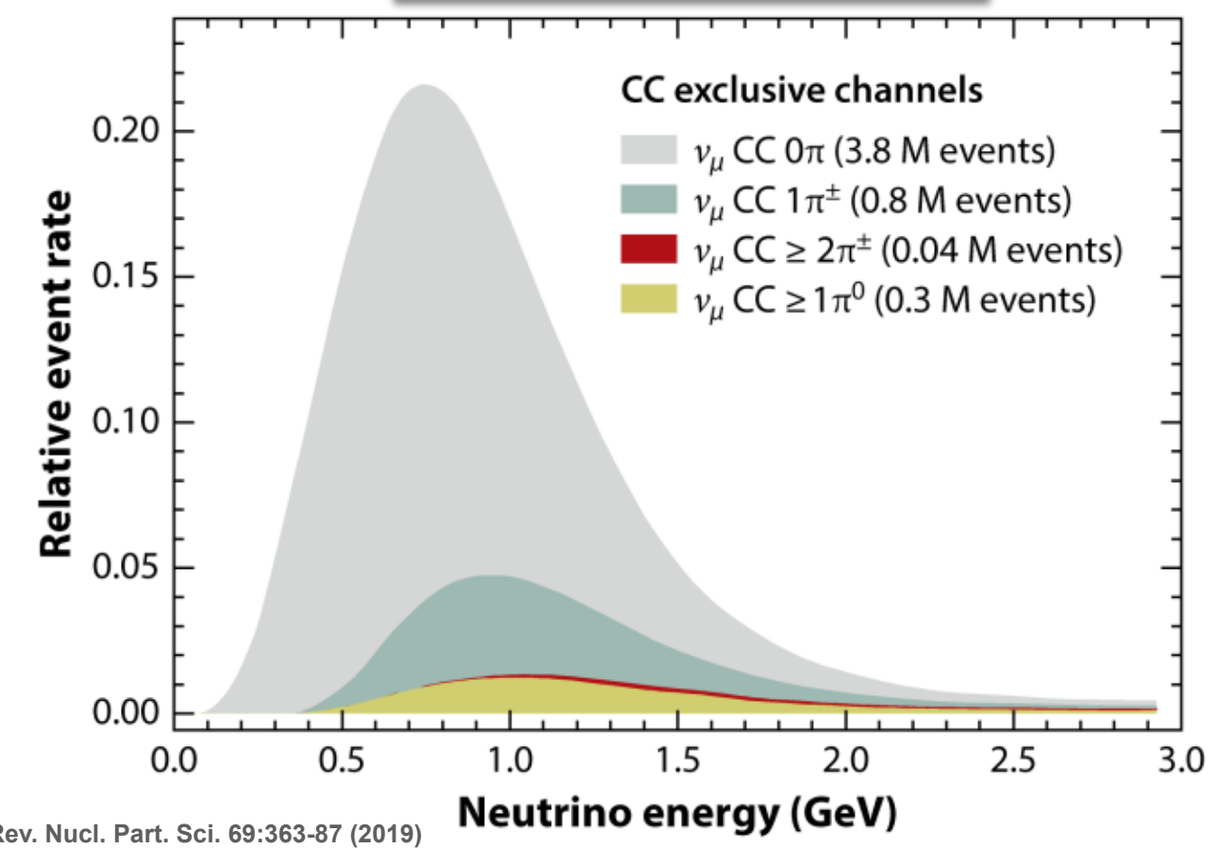
3. SBND will have the largest sample of **GeV-scale neutrino interactions on argon** before DUNE.
   - ~**7 million ν_μ interactions** (0.2-3 GeV) in 6.6e20 POT run
   - Also **50,000 ν_e interactions**
   - Reproduce a full MicroBooNE data set every 2-3 months

Large data set will enable differential measurements in multiple kinematic dimensions, the exploration of small-rate channels not accessible to other experiments, and the disentangling of aspects of neutrino-argon interaction phenomenology through measurements in many exclusive channels.

inclusive statistics



exclusive channels



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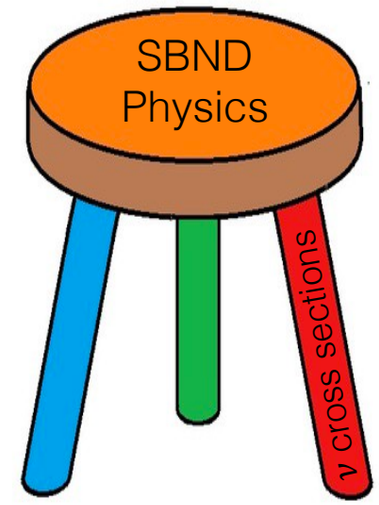
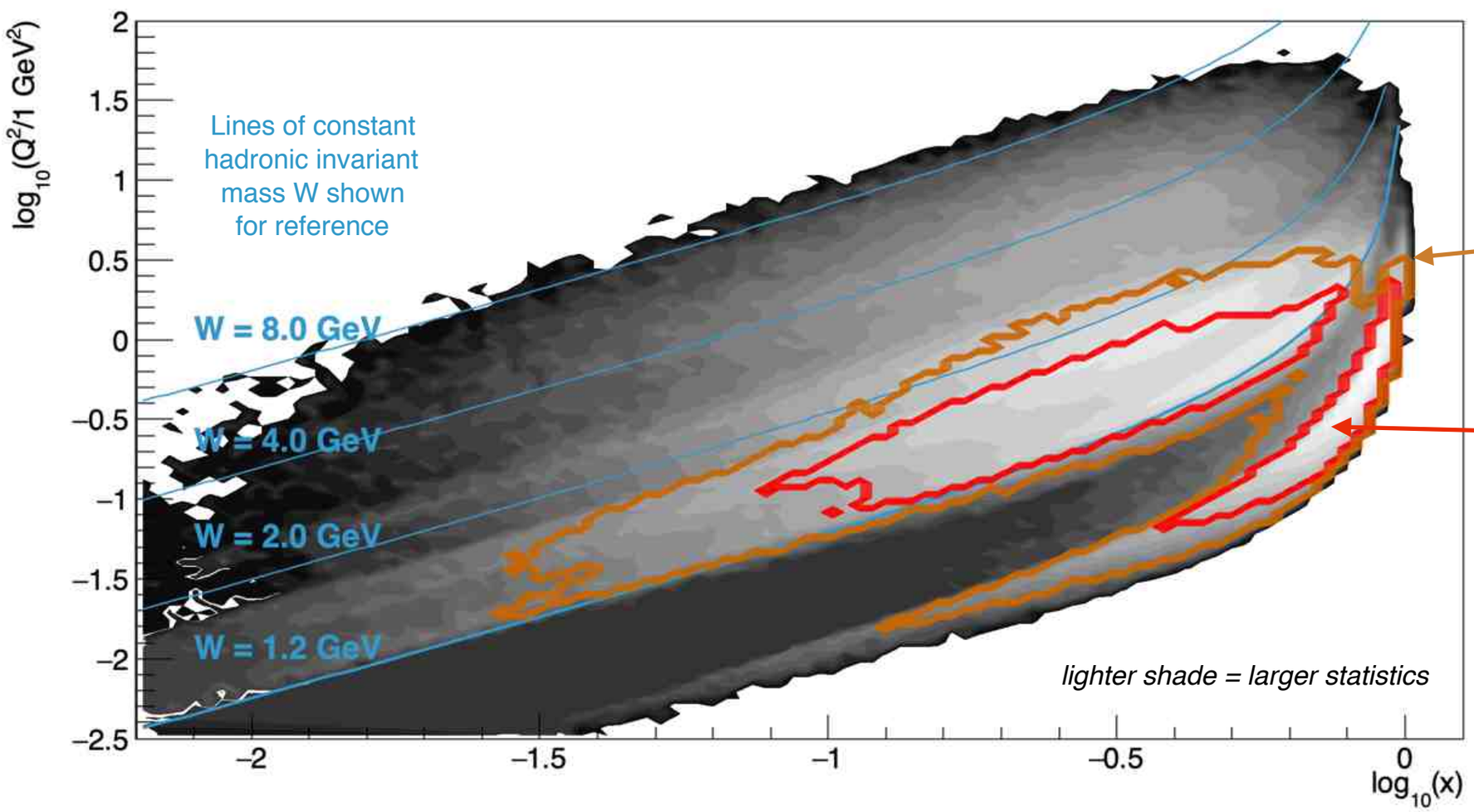




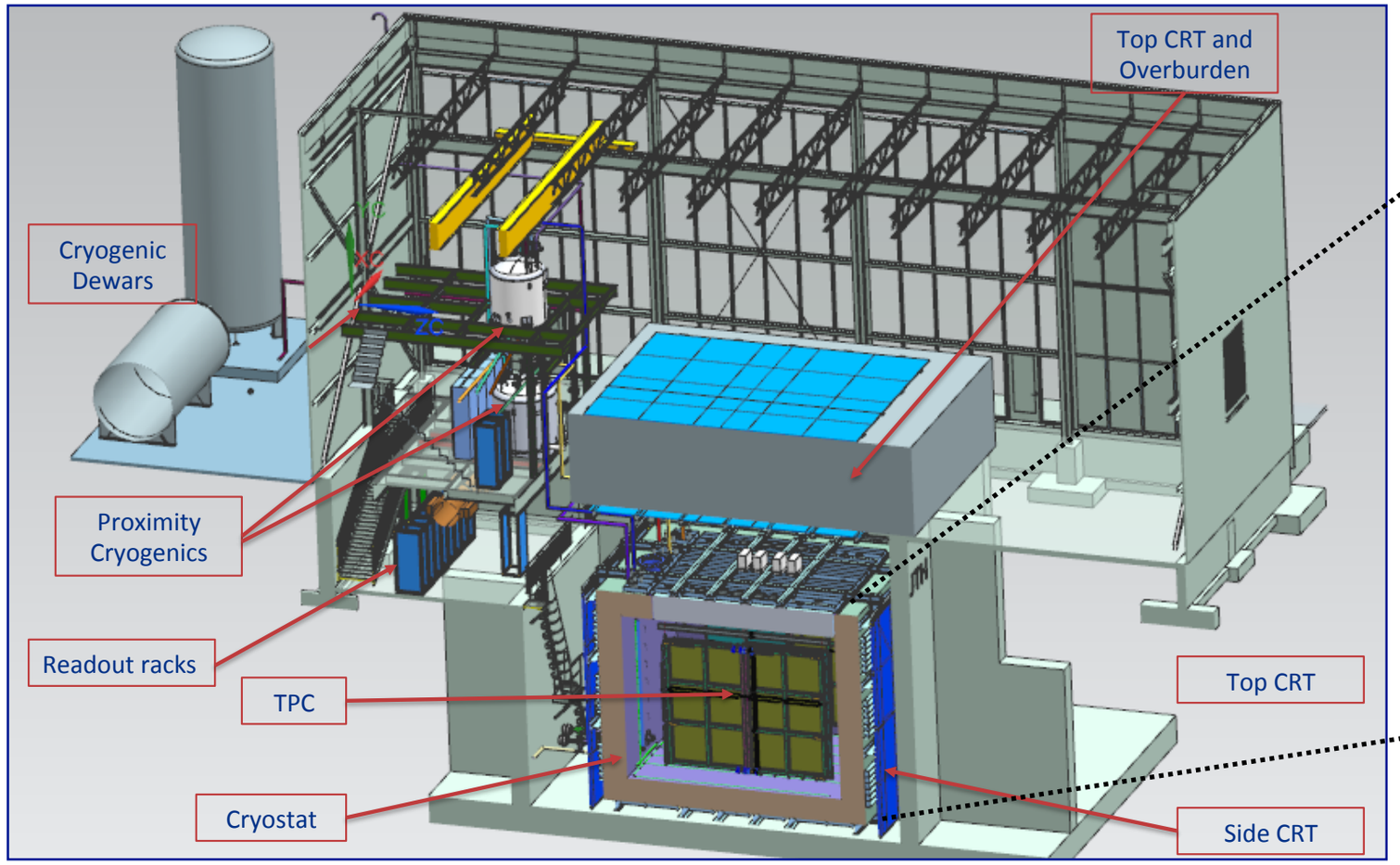
Even though DUNE is at higher energy, SBND covers kinematic regions most relevant for DUNE

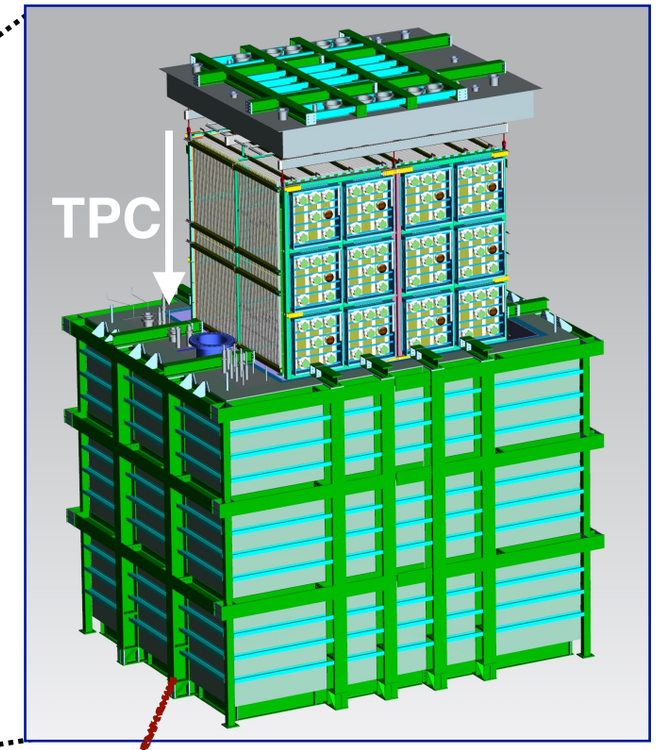
Areas where SBND statistical error is < 5%

Areas where SBND statistical error is < 2%

Gray-scale shows kinematical coverage of the LBNF beam for **DUNE** in (Q^2, $x_{Bjorken}$) space.

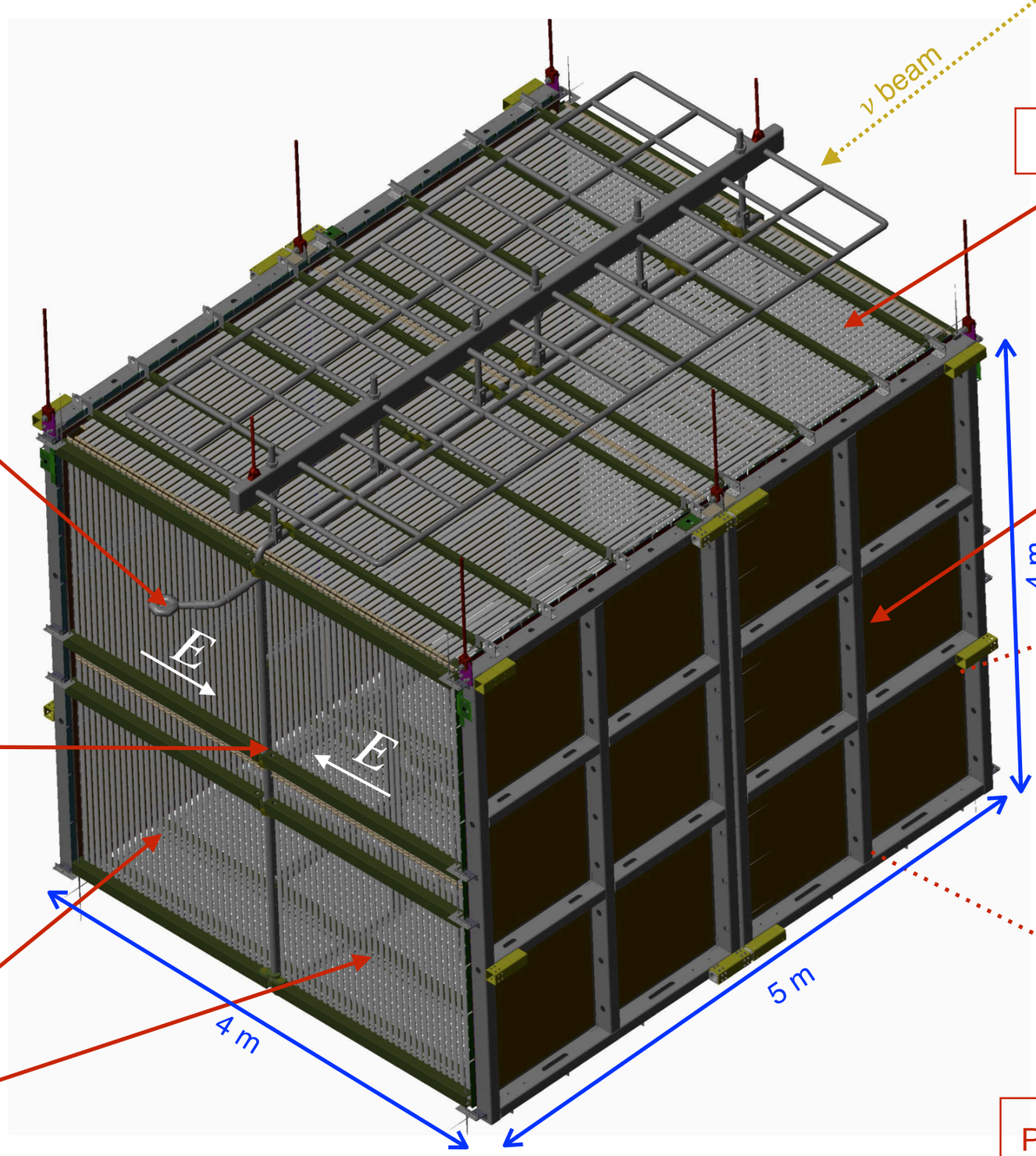
SBND Experiment

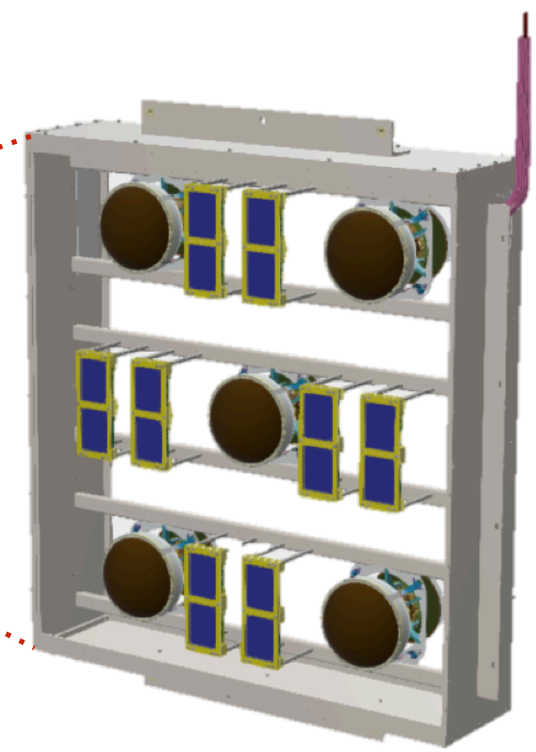




Membrane cryostat constructed inside an outer warm steel structure, with the TPC supported from the cryostat top.

THE SBND TPC





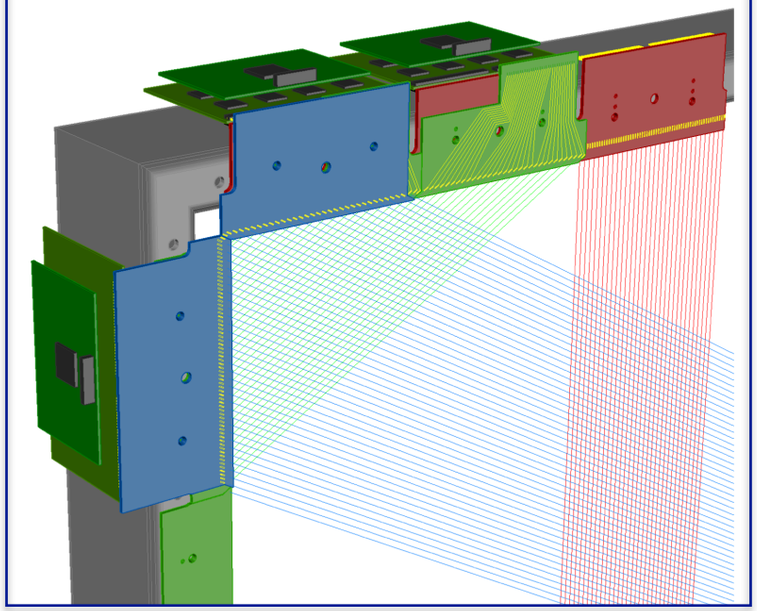
Photon Detection System module (x24)
(PMTs and ARAPUCAs)

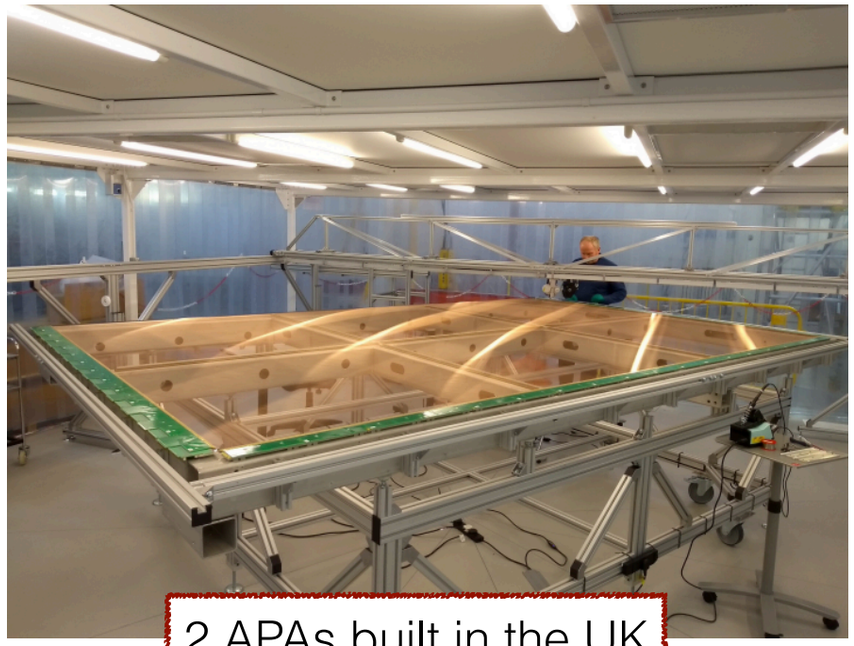
Construction Status Overview

- All TPC components (anode, cathode, field cage, HV) were constructed at collaborating institutions and are now at FNAL for assembly.
- All PMTs successfully tested in LAr, now ready to ship to FNAL.
- ARAPUCA final testing and assembly ongoing.
- TPC electronics all tested and at FNAL for installation.
- Electronics for photon detection systems (PDS) also available and integrated into DAQ.
- DAQ operational at SBND hall; test stand at DAB.
- CRT (cosmic ray tagger) panels and electronics mostly at FNAL. Bottom already installed.
- Warm cryostat installed at SBND building. Cryostat top under construction at CERN. Membrane cryostat materials ordered.

Anode Plane Assemblies (APA)

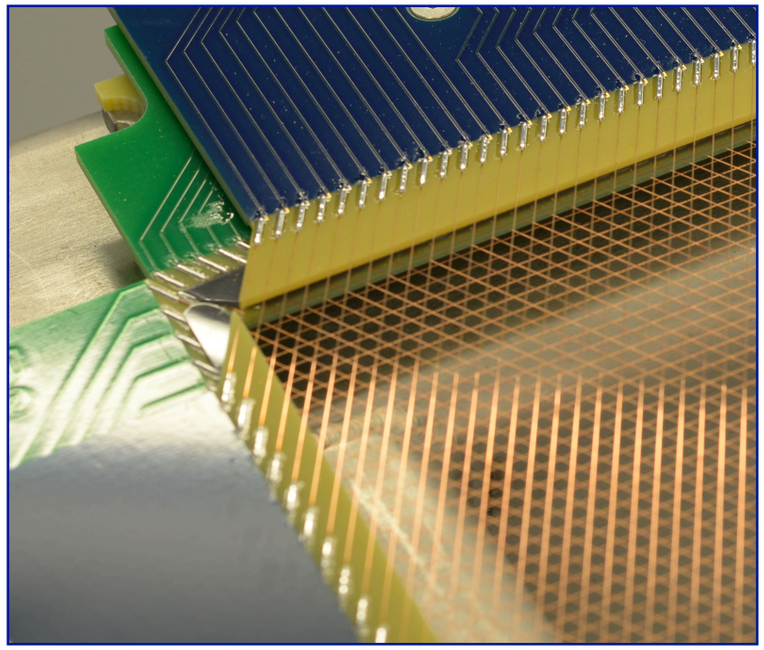
4 APAs: steel frame supporting
150 μm CuBe wires, 3mm pitch.
vertical collection (Y-plane)
± 60° induction (U-plane, V-plane)



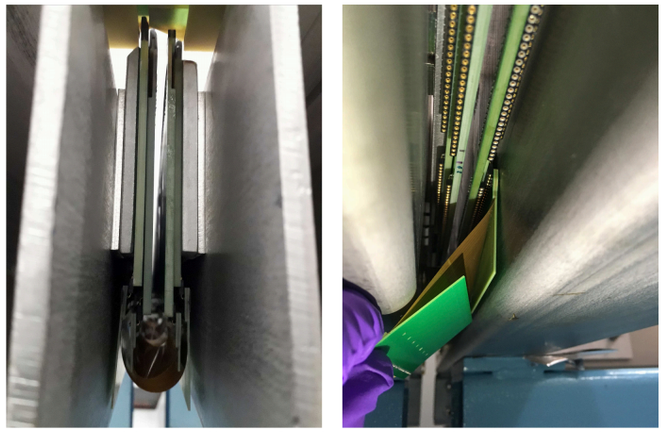


2 APAs built in the UK

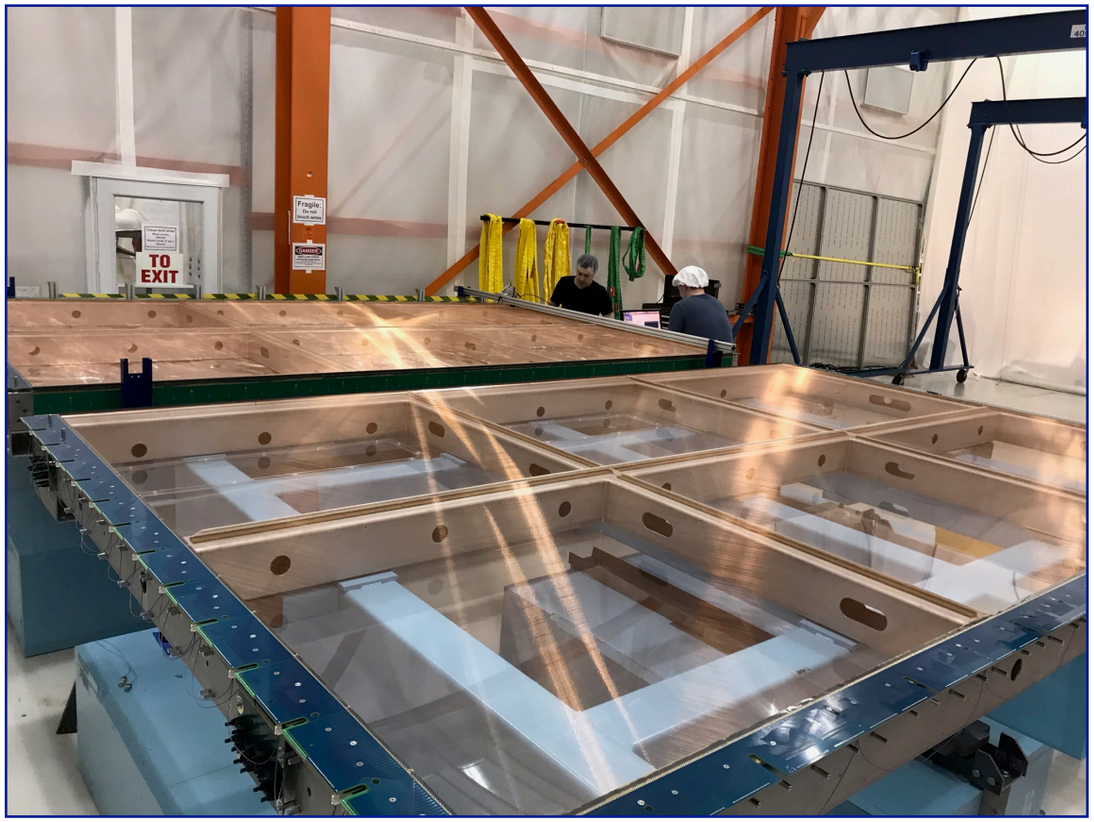
2 APAs built in the US



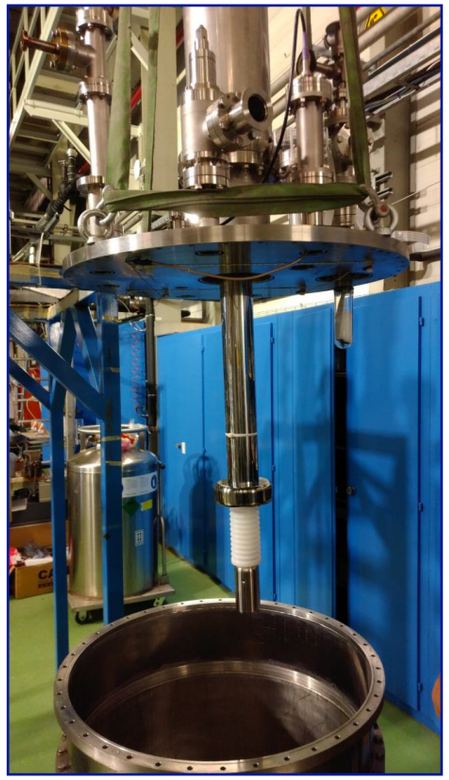
Aligned, mechanically and electrically connected in clean tent at DAB, Fermilab.



Jumper cable installation for electrical coupling between planes



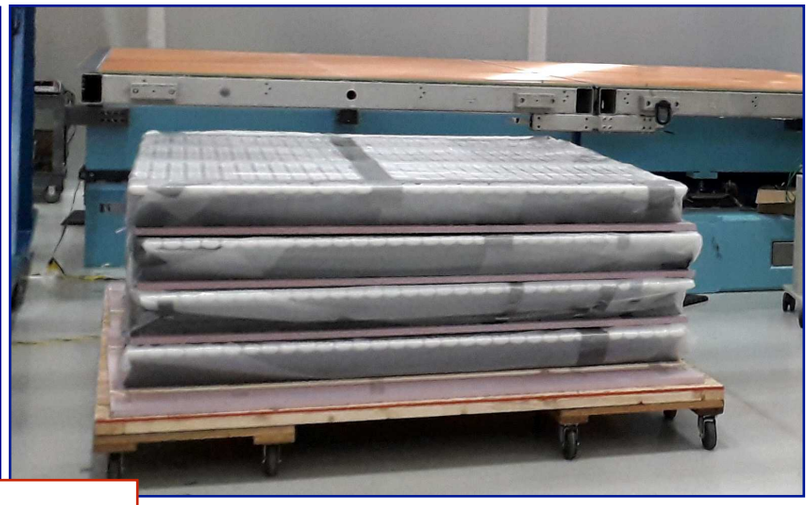
Cathode Plane, Field Cage, HV



Coaxial FT: a stainless steel core and grounding sheath with polyethylene insulator.

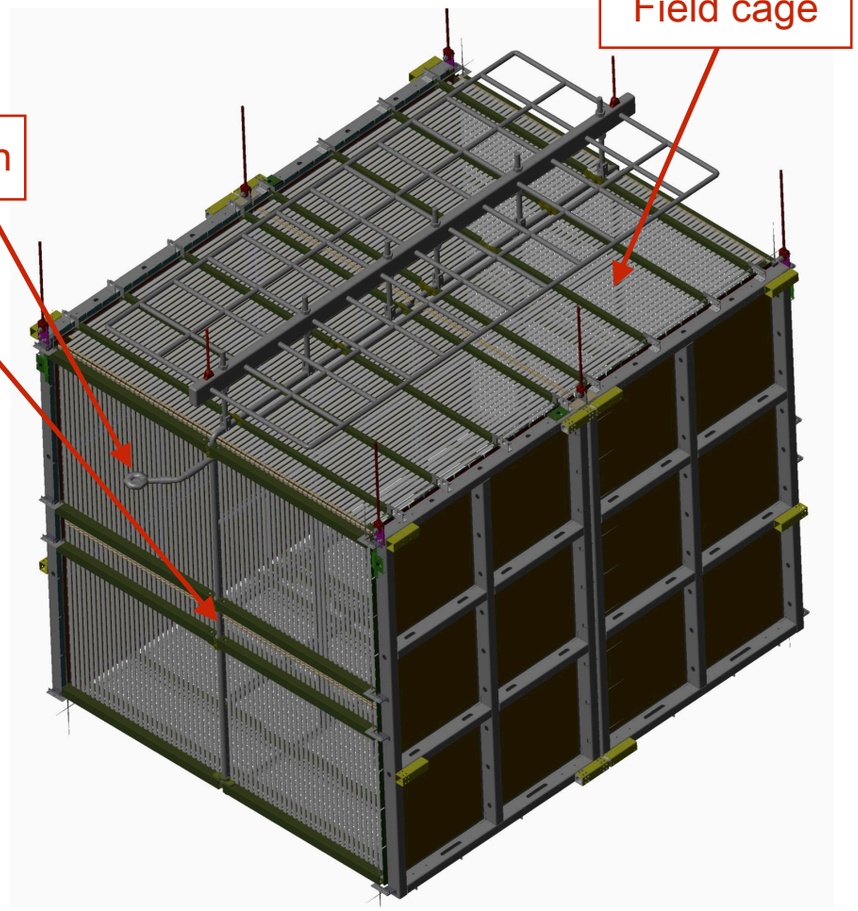
Same design as ProtoDUNE-SP

Contact with cathode via spring-loaded tip into a donut.



Roll-formed aluminum profiles with polyethylene end caps.

Same design as ProtoDUNE-SP



Cathode assembled upright at DAB

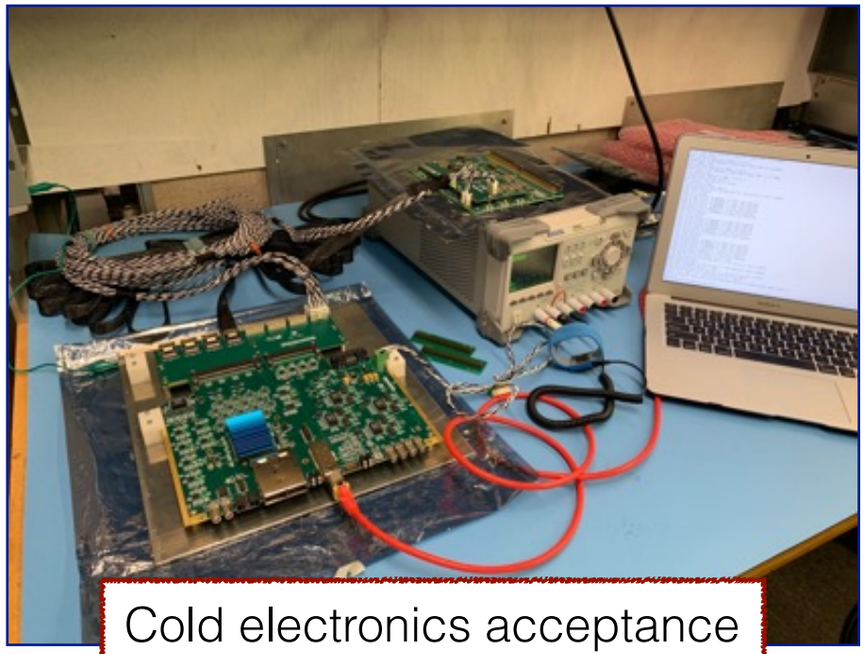
Welded, electropolished assembly composed of a stainless steel tube frame supporting stainless mesh panels

Successful operation of ProtoDUNE-SP at 180kV represents a valuable test for SBND, which shares the design for HV and field cage.

SBND nominal = 100kV

TPC ELECTRONICS

- **11,263 TPC channels**
- **Cold Electronics (front end)**
  - FE ASIC (amplifier and shaper) + commercial ADC (AD7274)
  - FEMB production and testing completed. Delivered to Fermilab and acceptance tested.
  - All cold electronics are ready for installation.
  - Signal feed-throughs at FNAL and leak tested.
- **TPC Readout Electronics (back end)**
  - 4 TPC readout racks and all 11 warm readout crates installed at SBND building.
  - Passed pORC and racks powered-up on March 11, 2020.



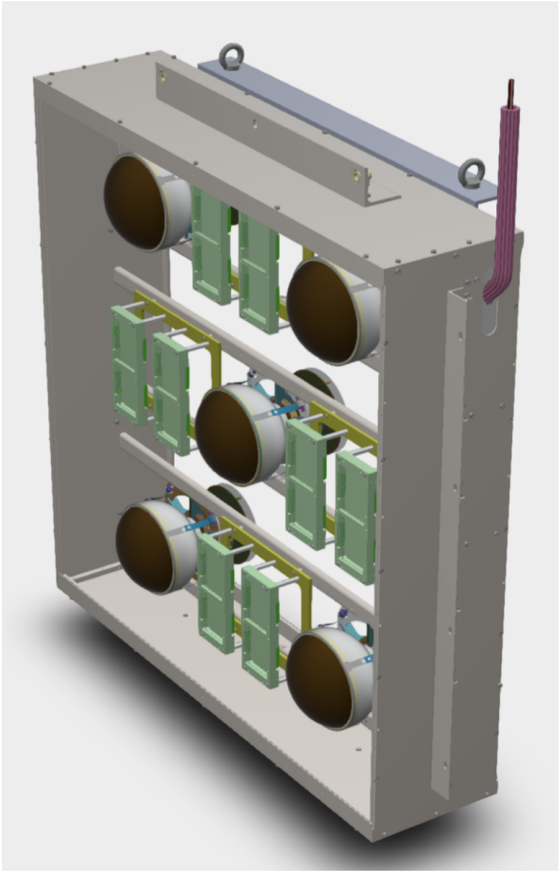
Cold electronics acceptance testing at DAB, Fermilab

Warm readout installed and operational at SBND hall.

Photon Detection Systems

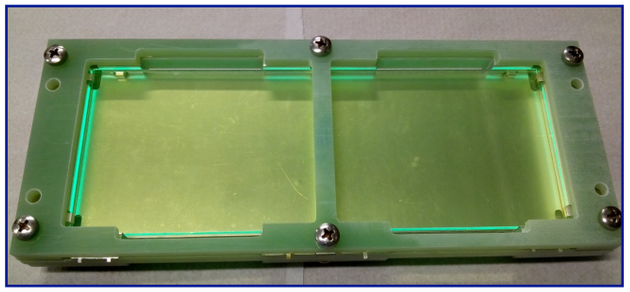
- Composite photon detection system that enhances the amount of light collected and provides R&D opportunities
  - Detect both direct scintillation light (VUV) and visible light (Cherenkov or reflected)
- 24 photon detector modules mounted behind the Anode Planes
  - **120 8" Hamamatsu PMTs**
    - 96 coated with wavelength-shifting Tetraphenyl Butadiene (TPB)
    - 24 uncoated for seeing visible light
  - **192 ARAPUCA light collectors**
    - 8 ARAPUCA + 8 X-ARAPUCA read out by CAEN SiPM readout electronics
    - 176 X-ARAPUCA + DAPHNE SiPM readout electronics, adapted from Mu2e cosmic veto system

Prototype system for DUNE



SBND PDS module
5 PMTs + 8 ARAPUCAs

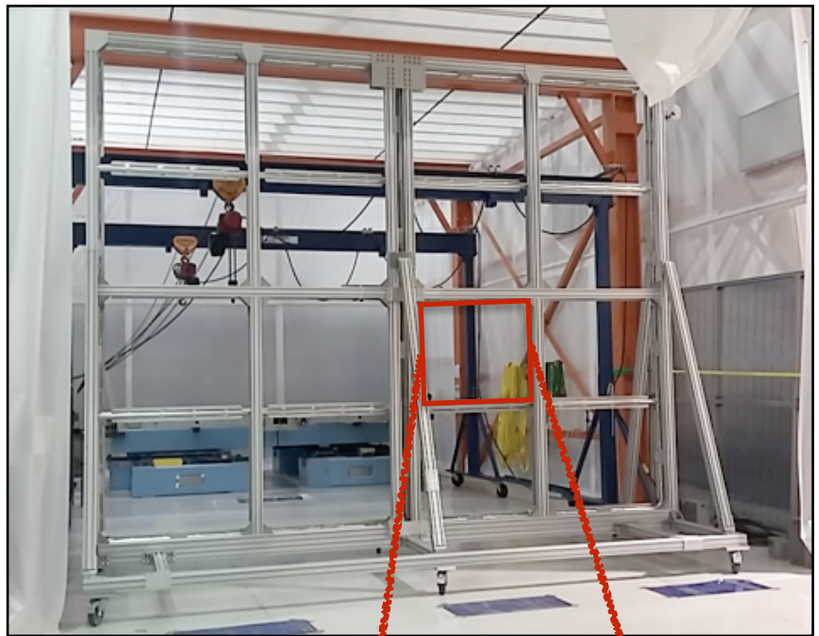
PMTs being tested in Coherent Captain Mills (CCM) detector at LANL

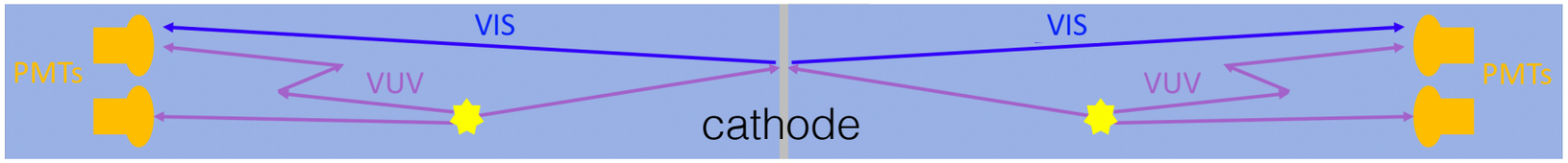


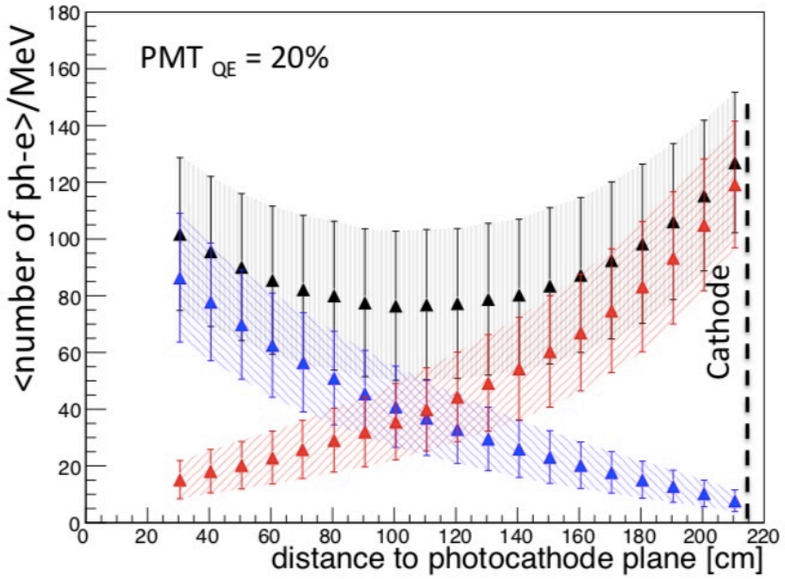
ARAPUCA: Trap photon with highly reflecting surface. Device composed of dichroic filter windows and a highly internally reflective box instrumented with silicon SiPMs

X-ARAPUCA: additional layer of light guide

Boosting Light Collection



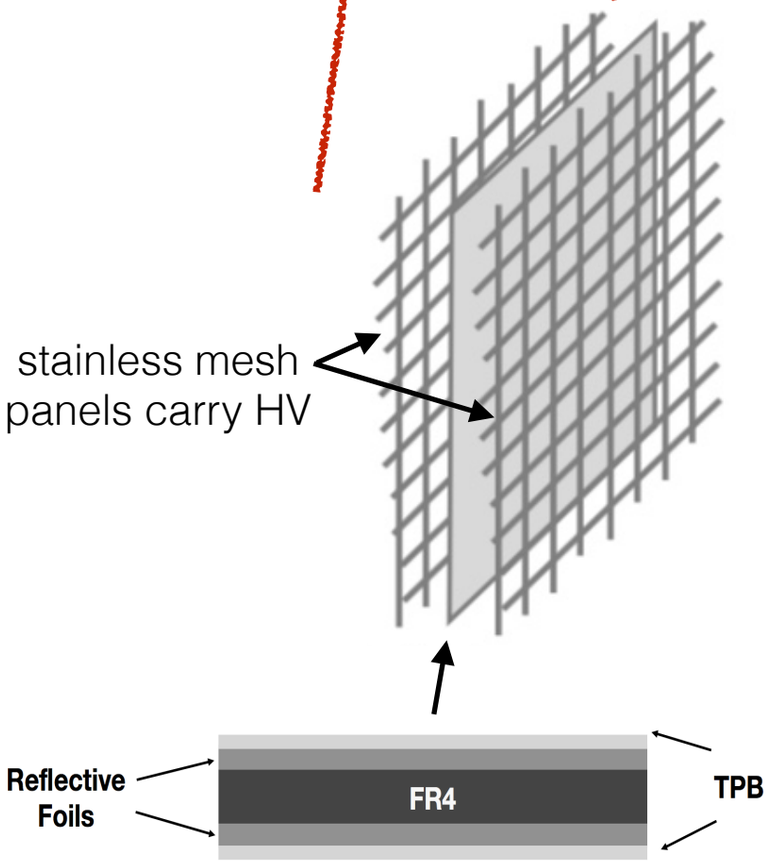


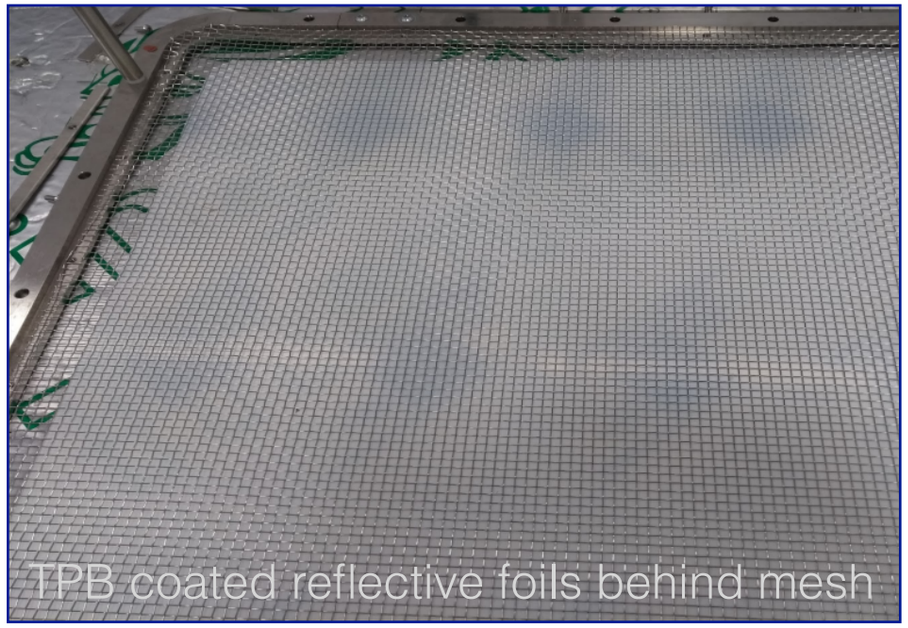


- **VUV direct**
- **Visible reflected**
- **Total light**

100 photoelectrons per MeV when combining direct and reflected light!

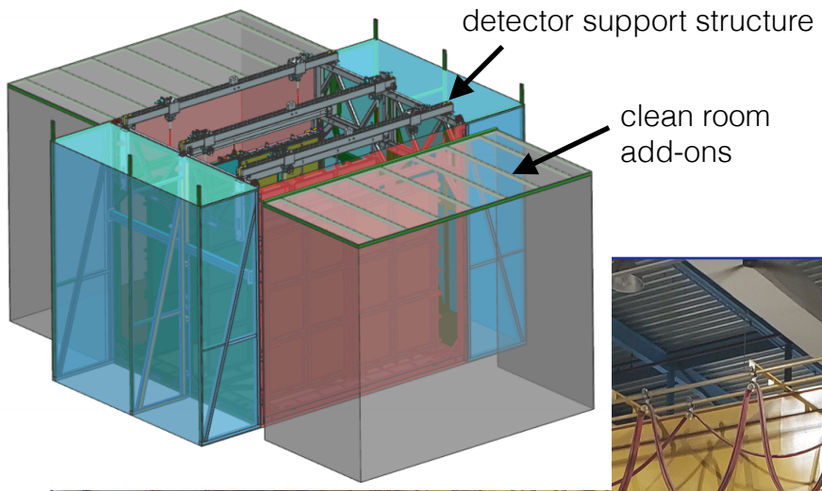
PMTs only





Foils installed in 16 cathode panels at DAB last year, ready for install.

TPC Assembly



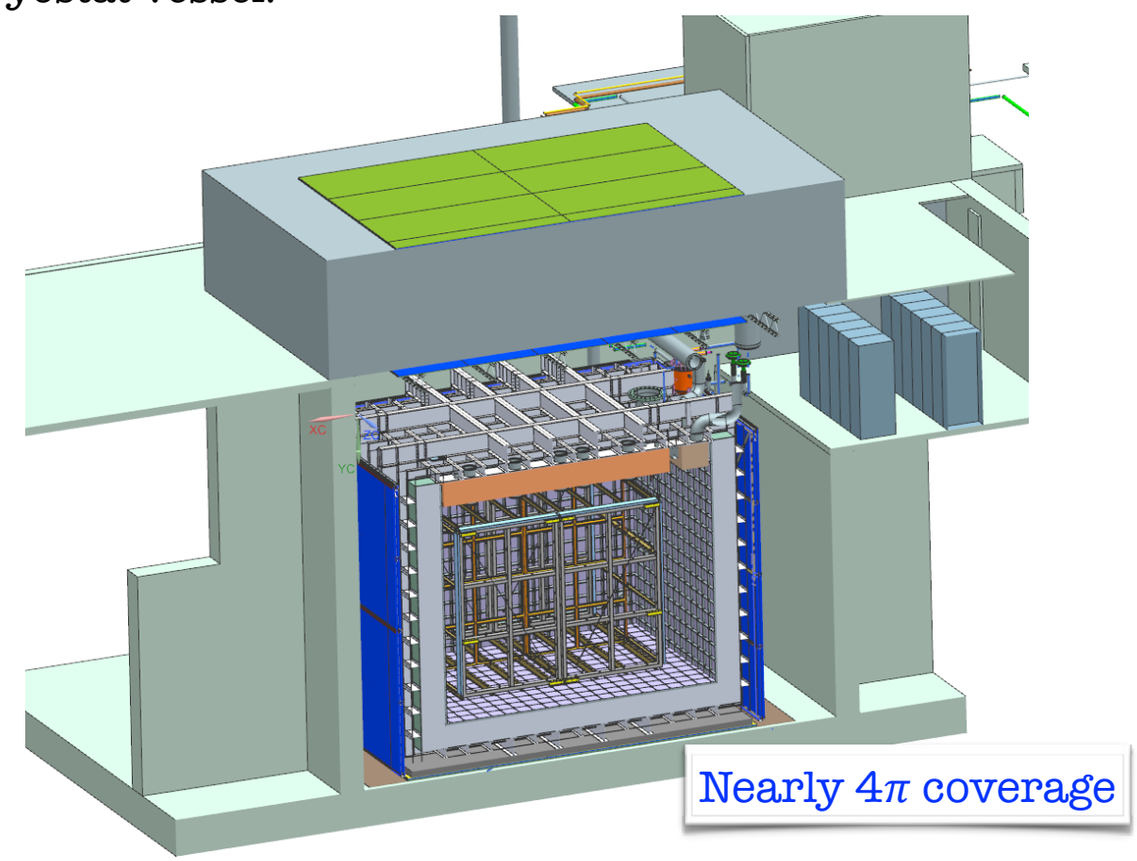
The Assembly Transport Frame (atf) supports the entire detector during assembly and for transport to the SBND building from DAB.

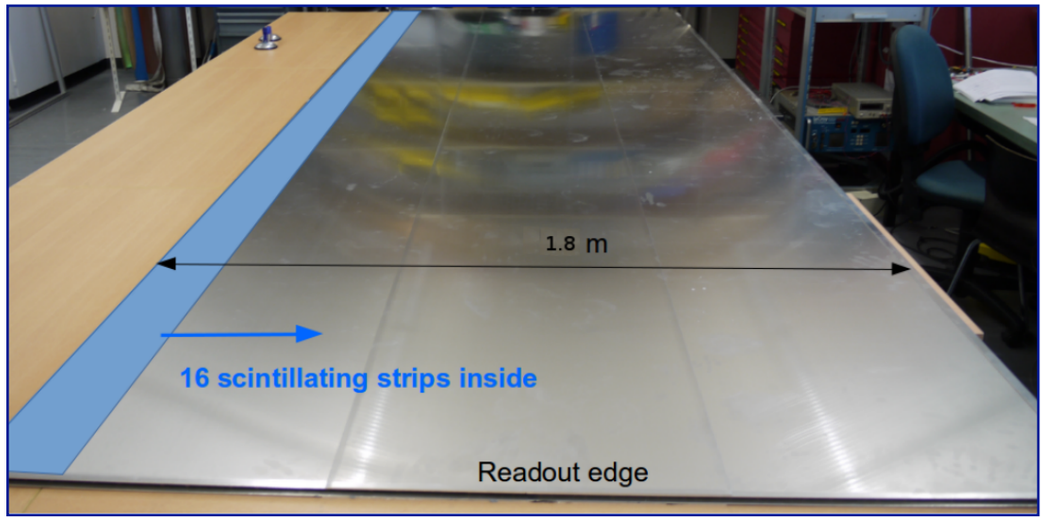
atf rolled outside DAB for load test in December 2019

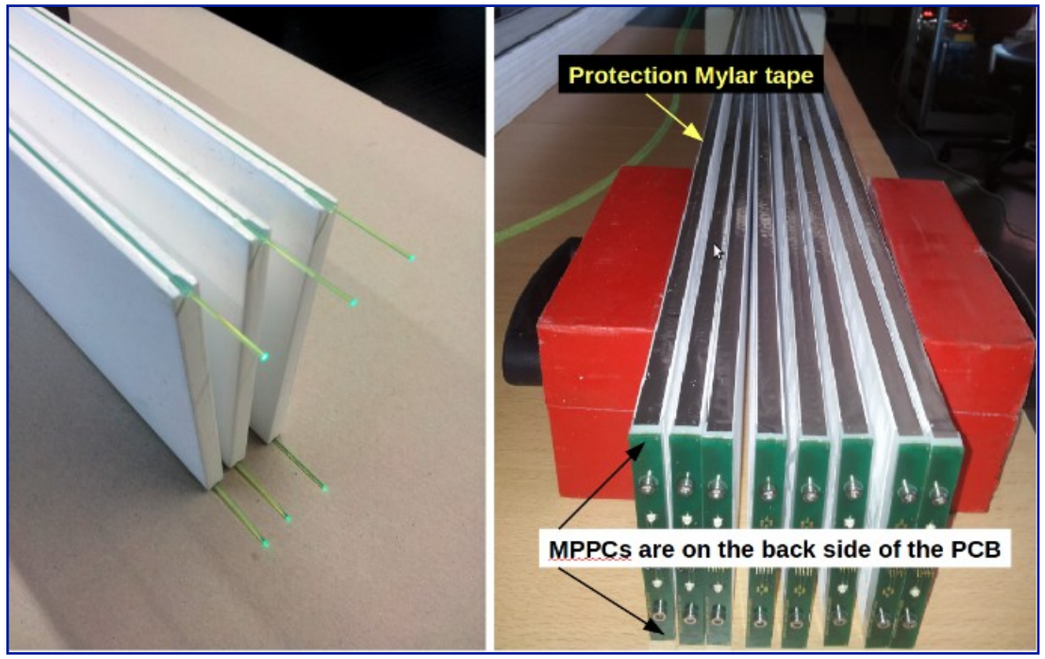
The atf represents a substantial engineering effort in 2019-2020. COVID-19 interrupted construction, but resuming now with technicians returning to activities in DAB. Will be completed very soon.

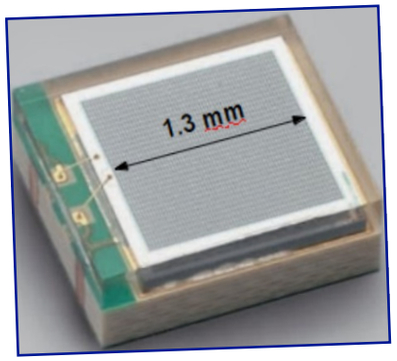
Cosmic Background Mitigation

- SBND is on the surface. To mitigate cosmic induced backgrounds, it is equipped with a **Cosmic Ray Tagger system (CRT).**
- All sides of the cryostat are covered by **planes of extruded scintillator strips read out by SiPMs.**
  - 135 modules ranging from (1.8m x 1.8m) to (4.5m x 1.8m)
  - 100% Bottom and Side CRT panels constructed at University of Bern and delivered to FNAL. Production of Top CRT >50% complete.
  - Bottom CRT panels installed in final position under the warm cryostat vessel.







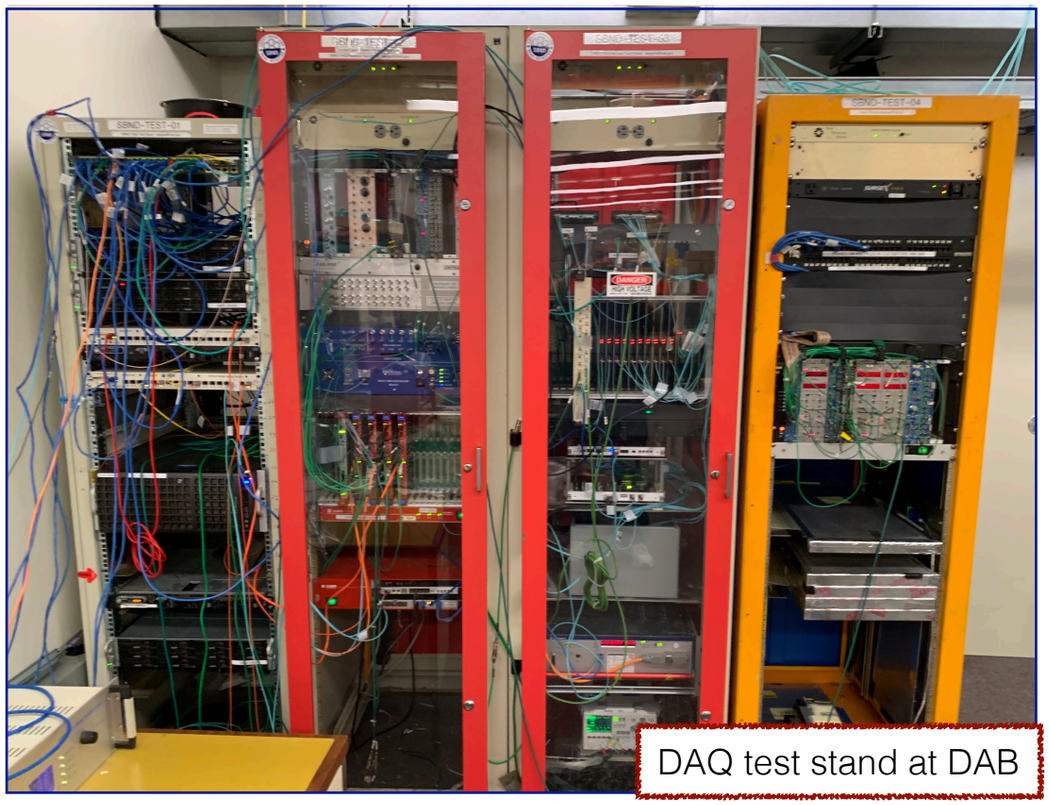


2 MPPCs per strip

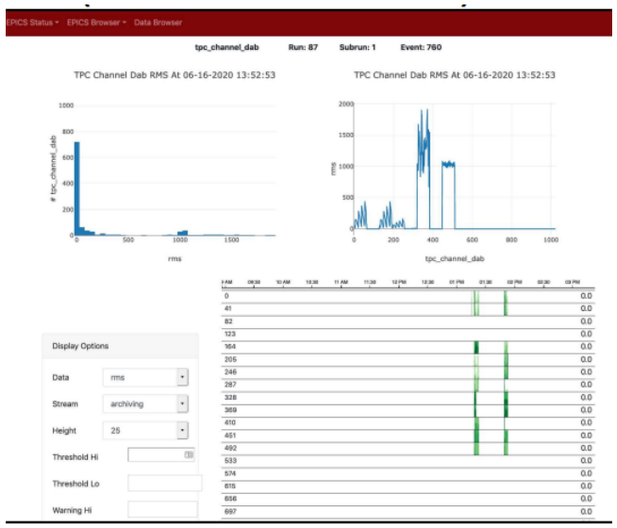
Each module is read out by one front end board (CAEN)

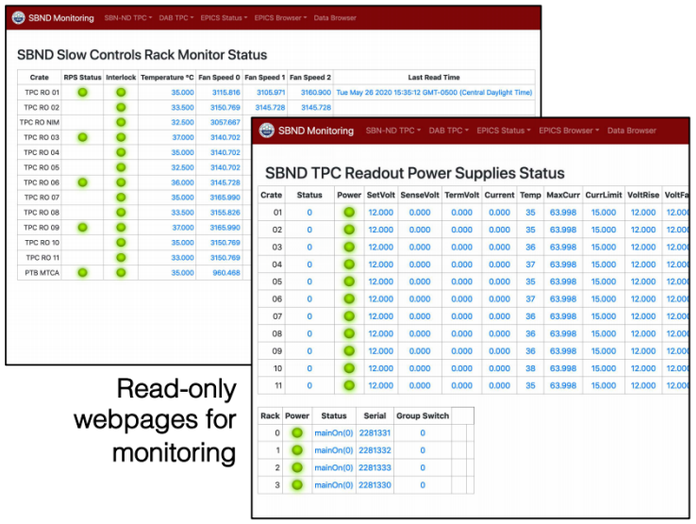
DAQ and Online Monitoring

- **Readout Test Stand at DAB**
  - Porting readout code & control and monitoring code from ProtoDUNE and previous SBND test stand to sbndaq.
  - Work in progress for synchronization of data readout across subsystems: TPC, PMT, CRT and trigger.
  - Developing Run Control GUI
  - Developing Online Monitoring tools
- **Installation at SBND building**
  - Using portable test stand to feed data to readout, first data acquisition runs taken April 22, 2020.

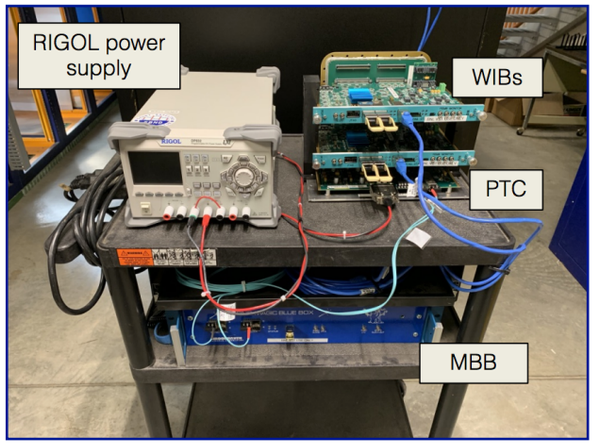


DAQ test stand at DAB



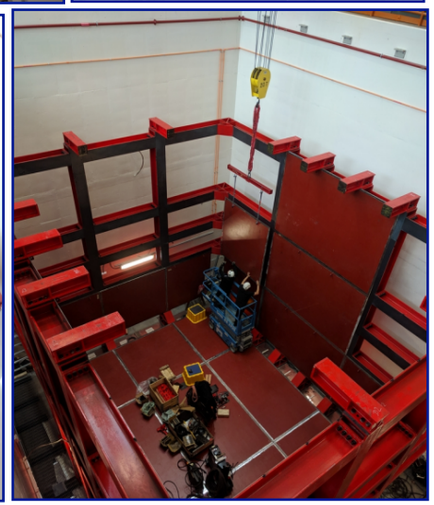


Read-only webpages for monitoring

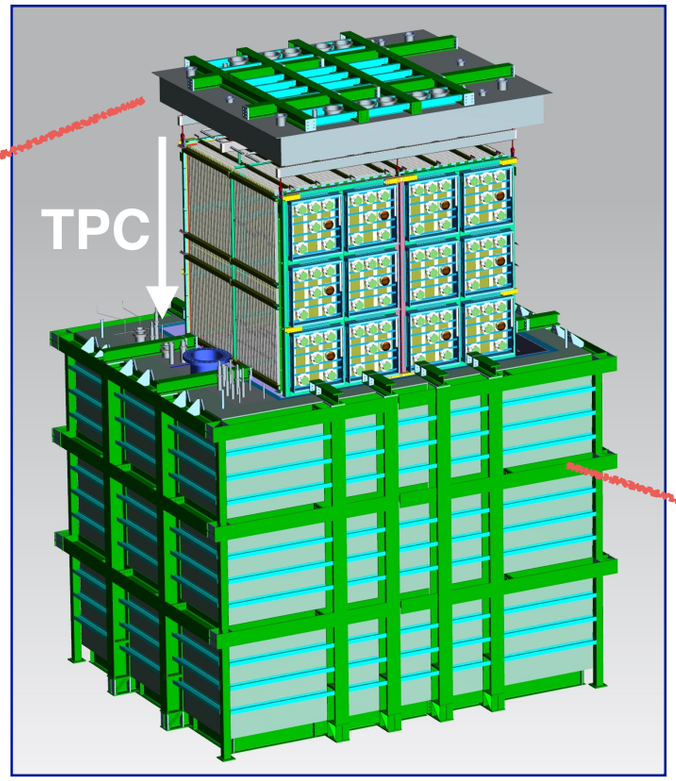


CRYOSTAT CONSTRUCTION

- SBND membrane cryostat is a **3rd generation prototype for DUNE** (WA105, ProtoDUNE, SBND).
- Warm outer vessel installed in SBND building last year.
- Membrane materials order placed by CERN in March with manufacturer in South Korea. Delivery expected end of December.
- Cryostat top cap fabrication at CERN. Work paused due to COVID-19.



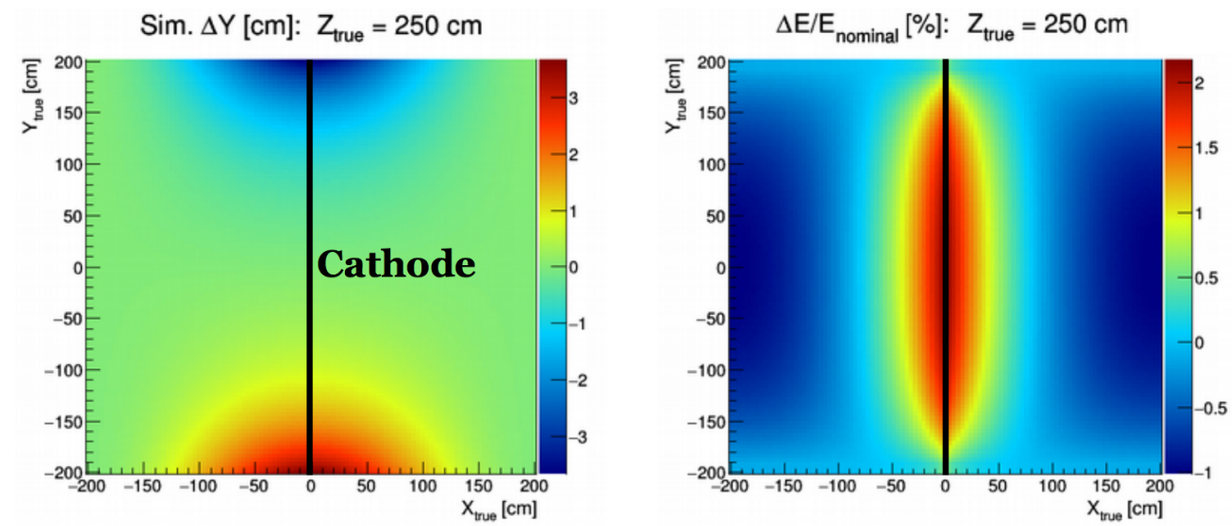
Cryostat Top Cap fabrication at CERN



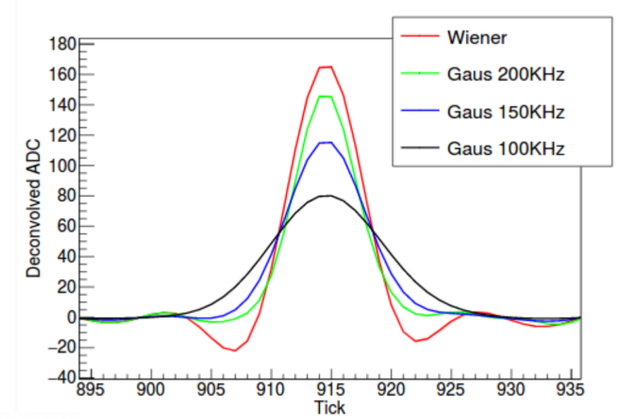
Warm vessel in SBND building

SIMULATION AND ANALYSIS

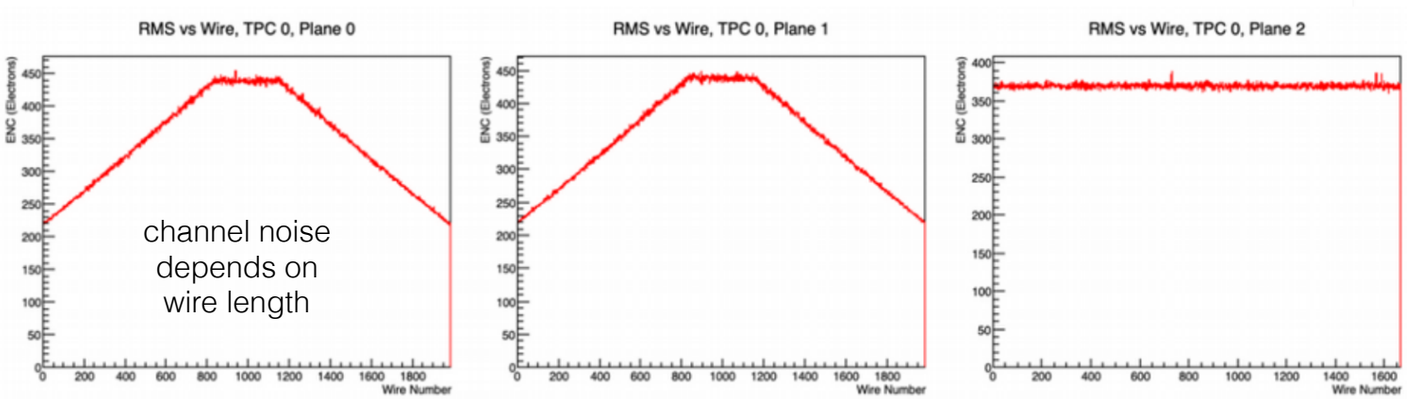
- Including **realistic effects in SBND detector simulation** well in advance of data taking.
  - Based on lessons learned by the community on other detectors (MicroBooNE, ProtoDUNE-SP) as well as SBND test stand measurements.
- Lots of **progress in physics analysis** in all three areas: SBN oscillations, BSM searches, and neutrino-argon interactions.
  - Analysis using full reconstruction and realistic simulation is already 'the norm'.



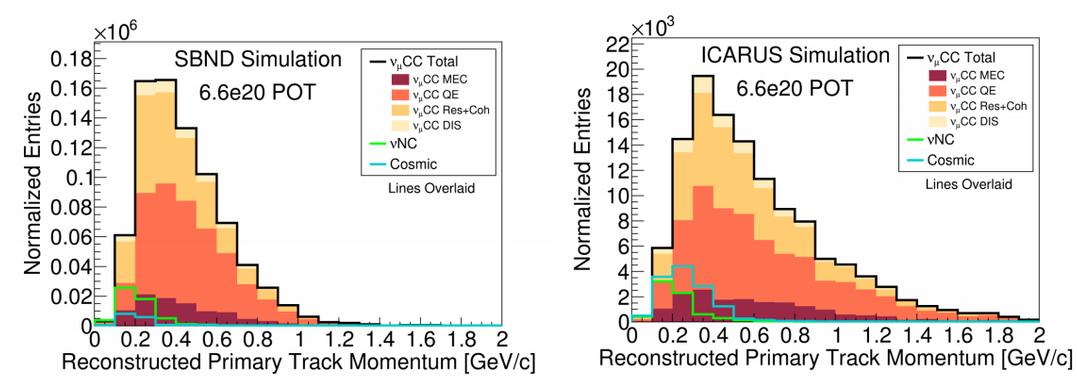
Space charge effects recently implemented in SBND TPC simulation



Detailed studies of the choice of signal deconvolution filter on hit efficiency and calorimetry measurements



Recently changed from white noise to data-driven noise model using SBND FEMB test stand data

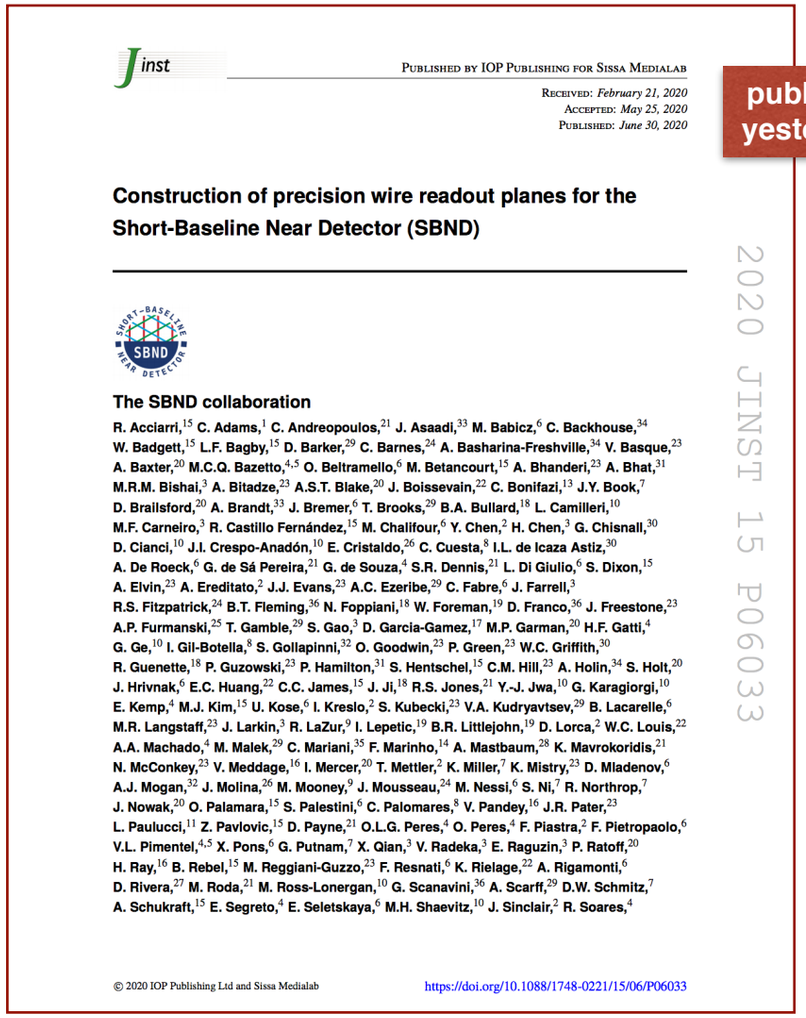


Example of common selection of ν_μ-CC interactions in SBND and ICARUS for ν_μ disappearance analysis
(will be shown tomorrow in SBN talk at Neutrino 2020)

PUBLICATIONS

- **First two Physics PhDs** based on SBND work!
  1. Tom Brooks, U. of Sheffield, "Selecting Charged Current Muon Neutrino Interactions on Argon with the Short-Baseline Near Detector", submitted June 2020.
  2. Dom Barker, U. of Sheffield, on selecting electron neutrino interactions, writing now.
- **First two SBND Publications:**
  1. SBND Collaboration, "Construction of precision wire readout planes for the Short-Baseline Near Detector (SBND)", 2020 JINST 15 P06033.
  2. SBND Collaboration, "Cosmic Background Removal with Deep Neural Networks in SBND", now in collaboration review.

https://doi.org/10.1088/1748-0221/15/06/P06033



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Construction of precision wire readout planes for the Short-Baseline Near Detector (SBND)

The SBND collaboration

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2020 JINST 15 P06033

published yesterday!

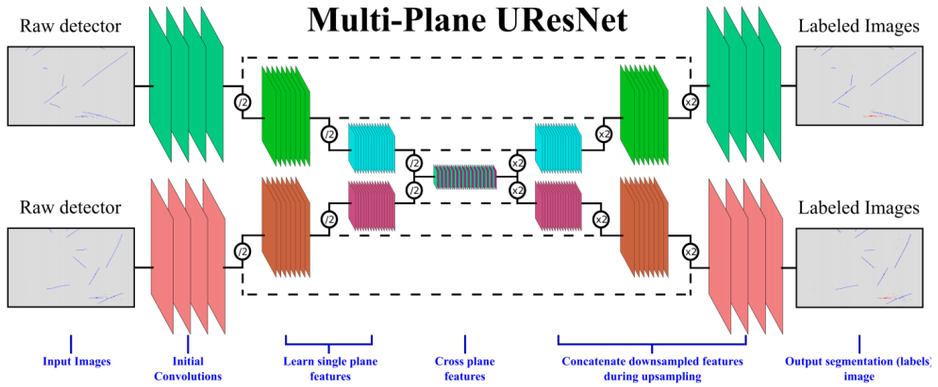


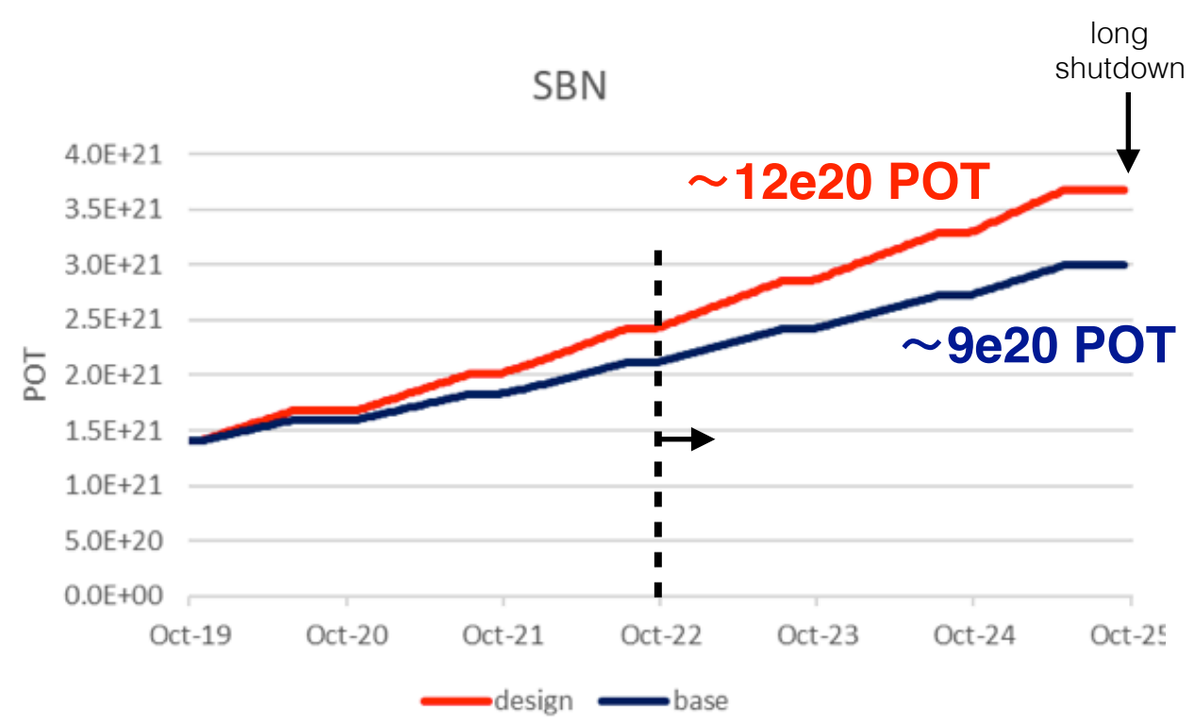
Figure 6: A representation of the multi-plane UResNet architecture. Shown here are just two of the three planes for clarity.

Looking Ahead

- **Project schedule recently reviewed and updated** by entire project team
  - Externally reviewed at February 2020 Director's Review
  - Mini-review planned for September/October to check on progress
  - COVID-19 impacts not included in that analysis
- **Major Milestones:**
  - TPC assembly scheduled complete in early 2021 (including cold electronics installation).
  - Detector ready-to-fill projected for October 2021.
  - Detector commissioning and operation in first half of 2022.
- SBND will record beam data at approximately **7 times the rate of ICARUS** and 24 times the rate of MicroBooNE.

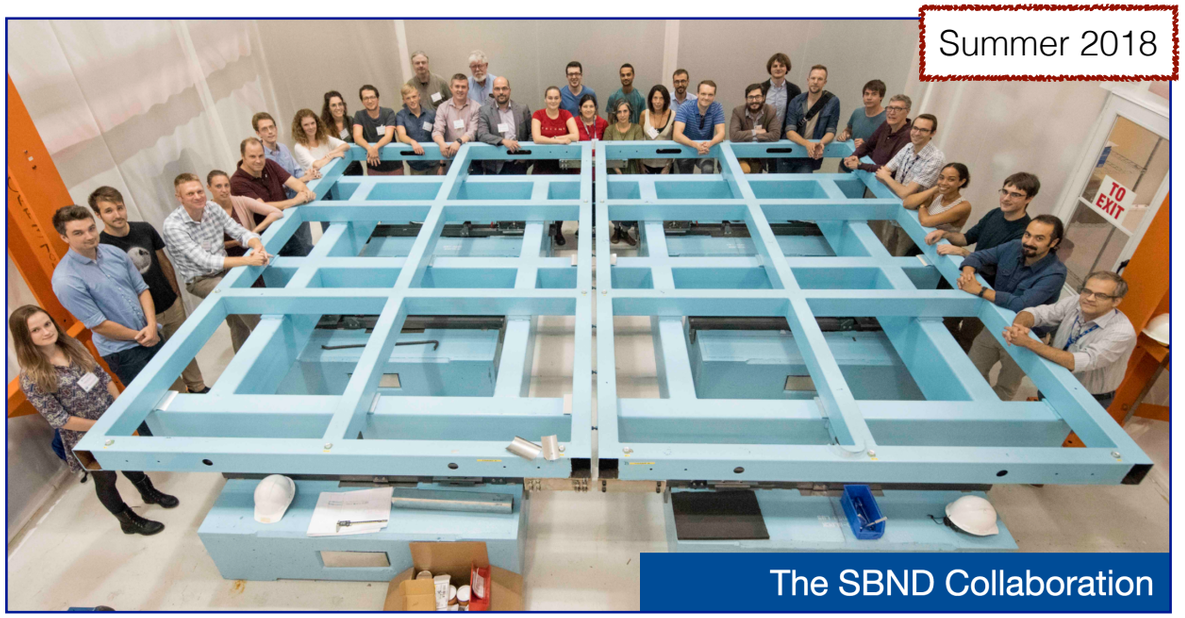
Fermilab
Fermi National Accelerator Laboratory

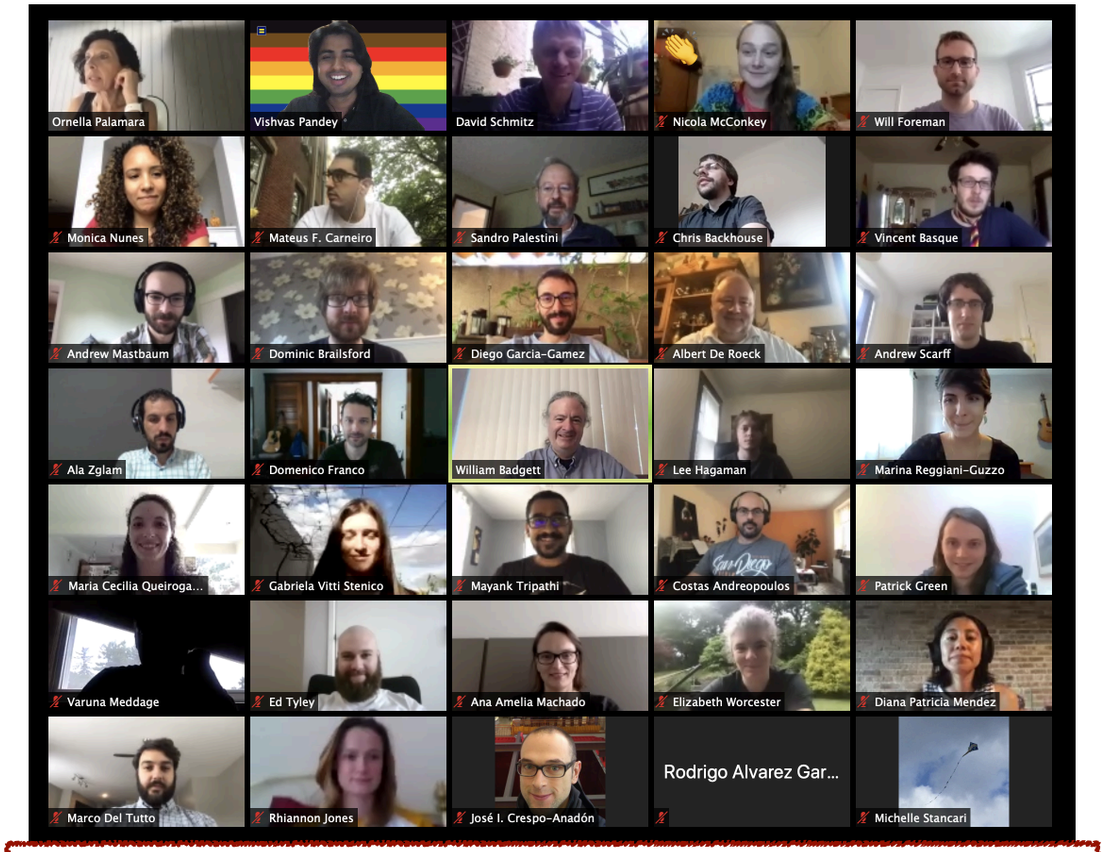
Accelerator Operations Plan to Meet Experiments' Physics Objectives
November 2019



SUMMARY

- **Great progress has been made toward the construction of SBND**
  - Most major detector system components are at FNAL for assembly. Cryostat materials ordered. Fermilab is the new center of construction activity.
  - Support from Neutrino Division, Fermilab, and DOE has been strong and is greatly appreciated by the 39 institutions of the SBND Collaboration.
  - As everywhere, SBND has suffered setbacks due to COVID-19, but interrupted work is starting to resume.
- **The Collaboration is very excited to get to the start of physics with SBND**
  - **High performance experiment:** LArTPC detector with 3mm wire pitch and 2GHz low-noise readout, complimentary high-performance photon systems (resulting in 100s of pe/MeV), full-coverage CRT system for minimizing backgrounds (high-purity analysis samples).
  - Detector mass and proximity to source make for an incredible neutrino rate: ~ 2M events per year or more than **7,000 events per day**.





SBND Collaboration meeting social gathering, June 2020

The SBND Collaboration

Updated June 2020

Including both scientific and technical personnel

*Spokespeople

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