The Short-Baseline Near Detector [SBND] at Fermilab

Supraja Balasubramanian,
on behalf of the
SBND collaboration

26 July 2023

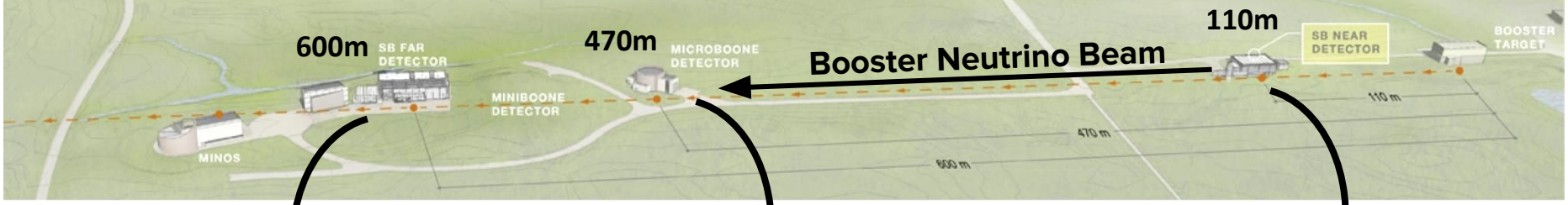
Short Baseline Neutrino Program

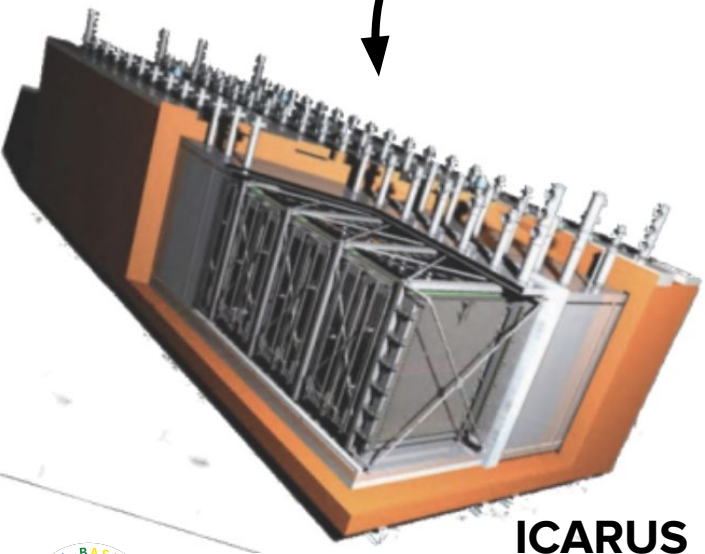
arXiv:1503.01520v1

3 detectors with LArTPC technology

Booster Neutrino Beam

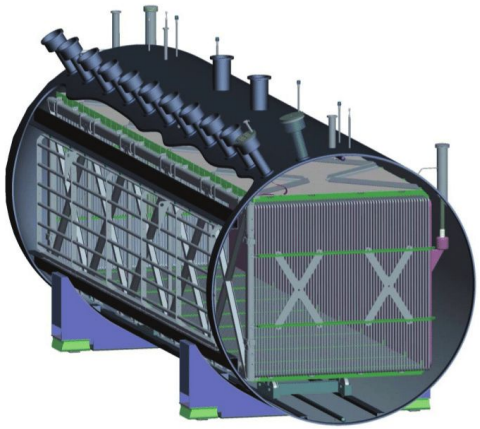
Neutrino oscillations, cross sections, BSM new physics





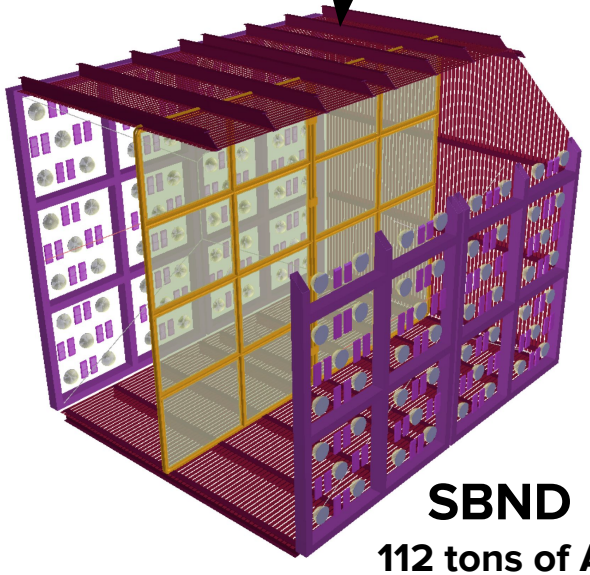
ICARUS

476 tons of Ar



MicroBooNE

89 tons of Ar



SBND

112 tons of Ar

Short Baseline Neutrino Program

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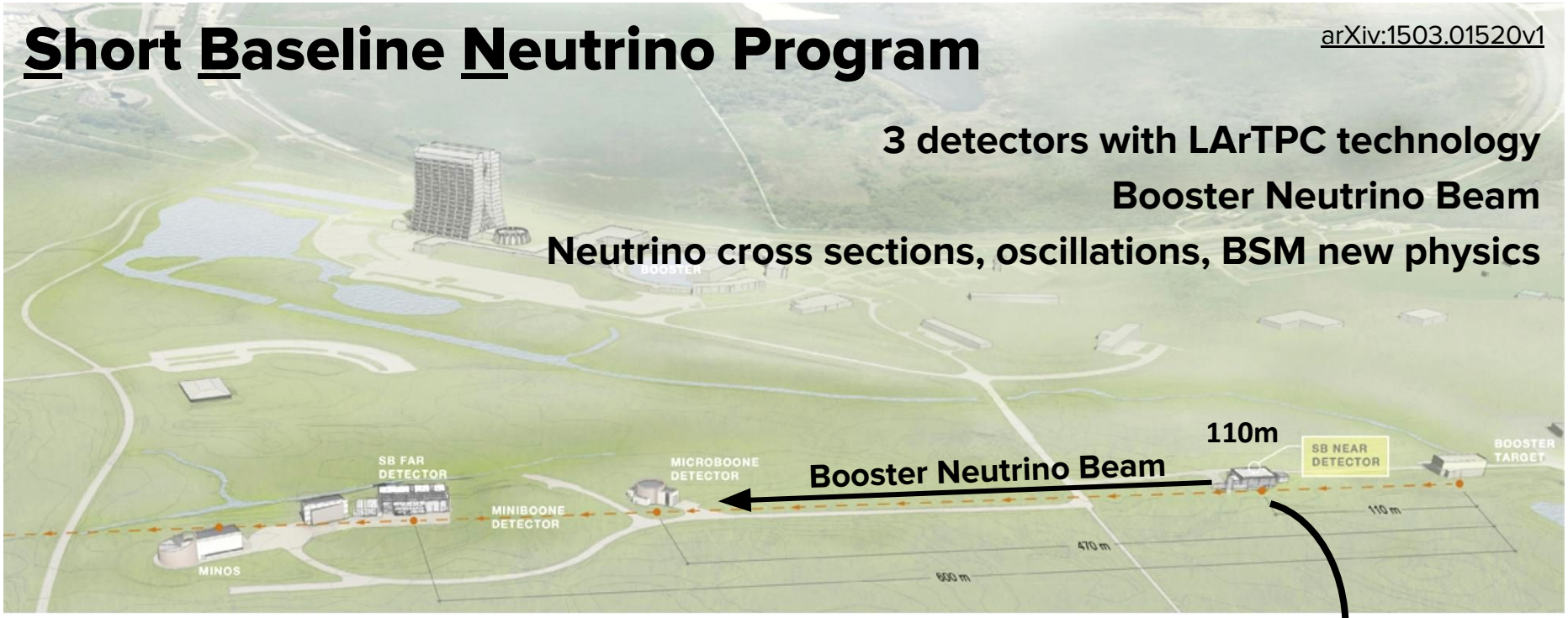
Booster Neutrino Beam

Neutrino cross sections, oscillations, BSM new physics

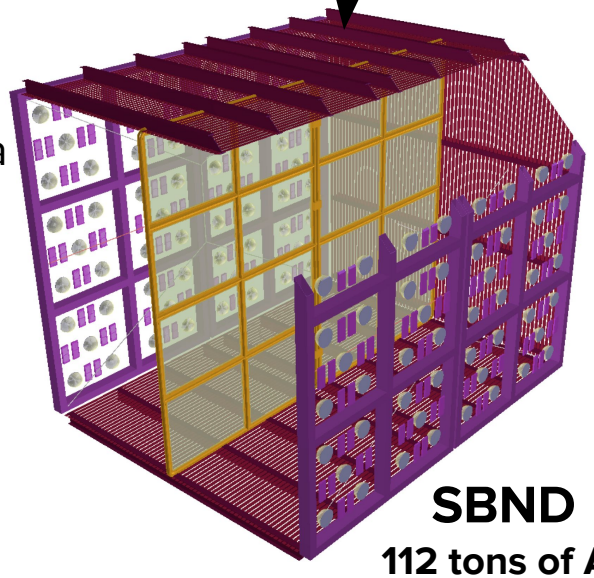


Short Baseline Near Detector

Last LArTPC to begin operating before DUNE
=> last prototype for various design elements, operations, data reconstruction, etc.

High-intensity neutrino beam + proximity to target
=> **large statistics of neutrino-argon interactions, off axis fluxes**.

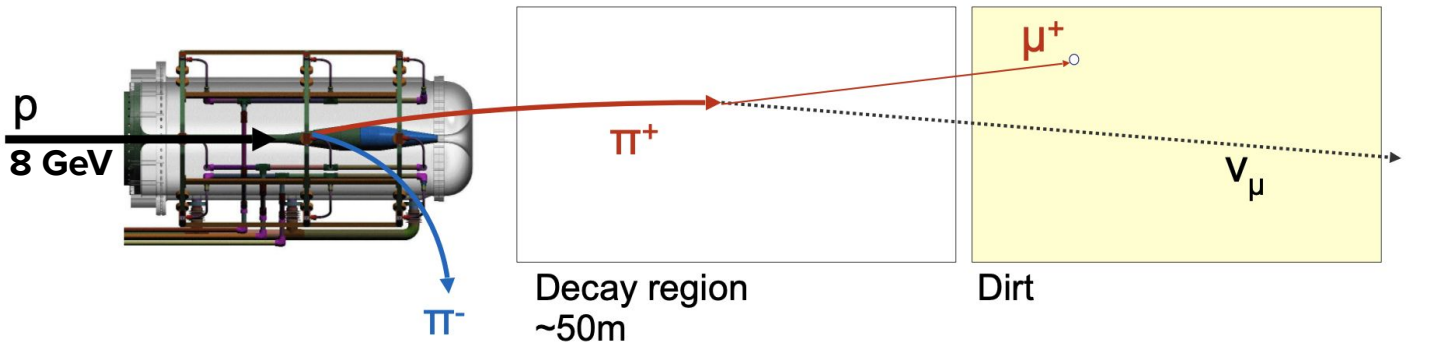
Start of operations planned for **end of 2023/early 2024**.



SBND

112 tons of Ar

The Booster Neutrino Beam @ SBND



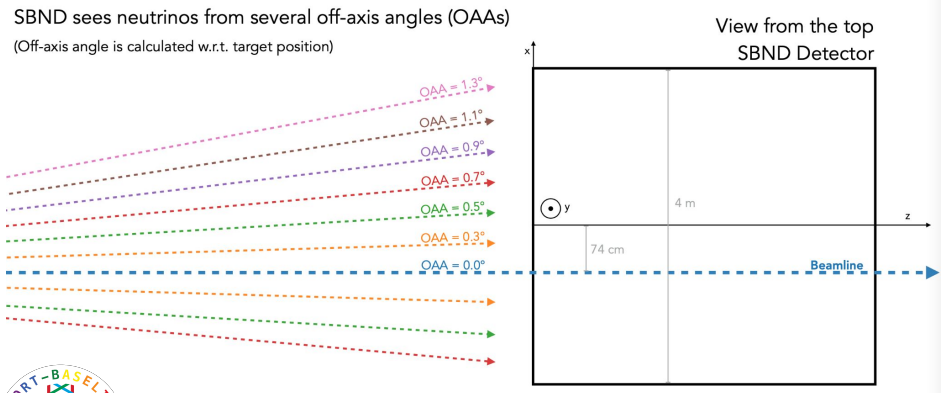
Beam Composition:

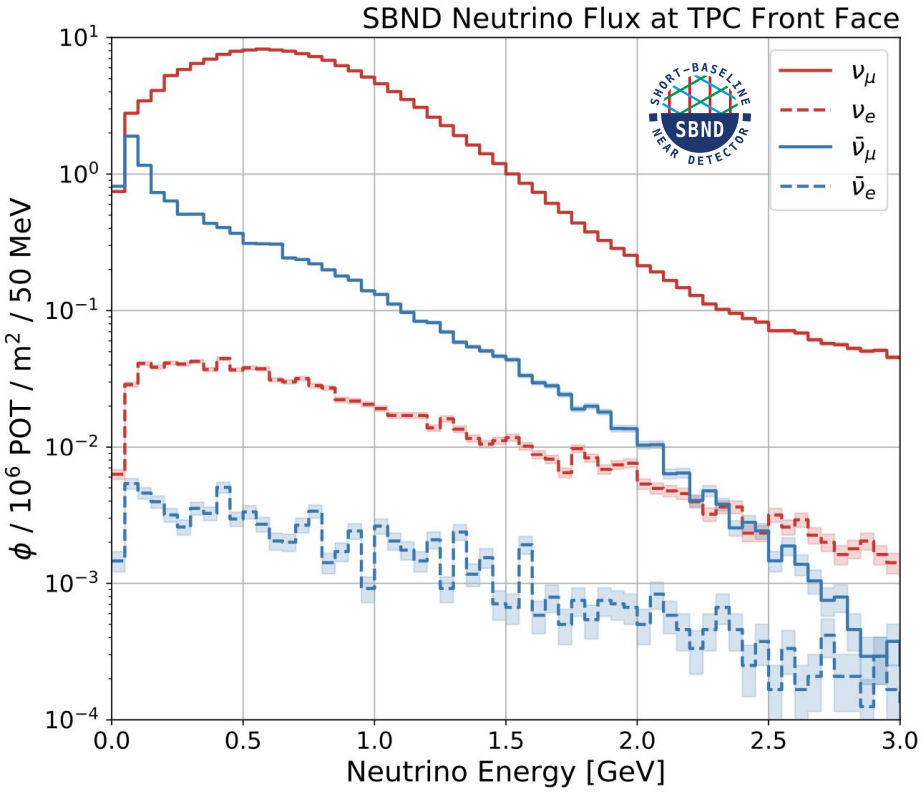
ν_μ = 93.6%

$\bar{\nu}_\mu$ = 5.9%

$\nu_e + \bar{\nu}_e$ = 0.5%

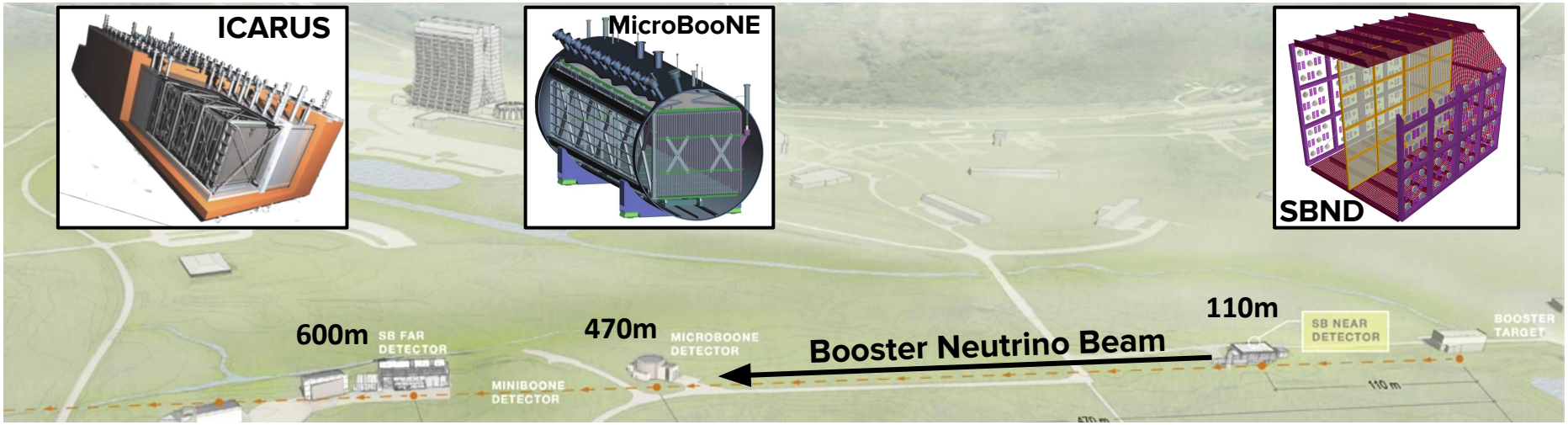
- $\langle E_\nu \rangle$ ~ 800 MeV.
- Projected to take **10-18 X 10^{20} POT** of data in total => large statistics on Argon.
- Close to the target + slightly off-axis => SBND can sample **off-axis fluxes**.





SBND Physics: Neutrino Oscillations

arXiv:1503.01520v1



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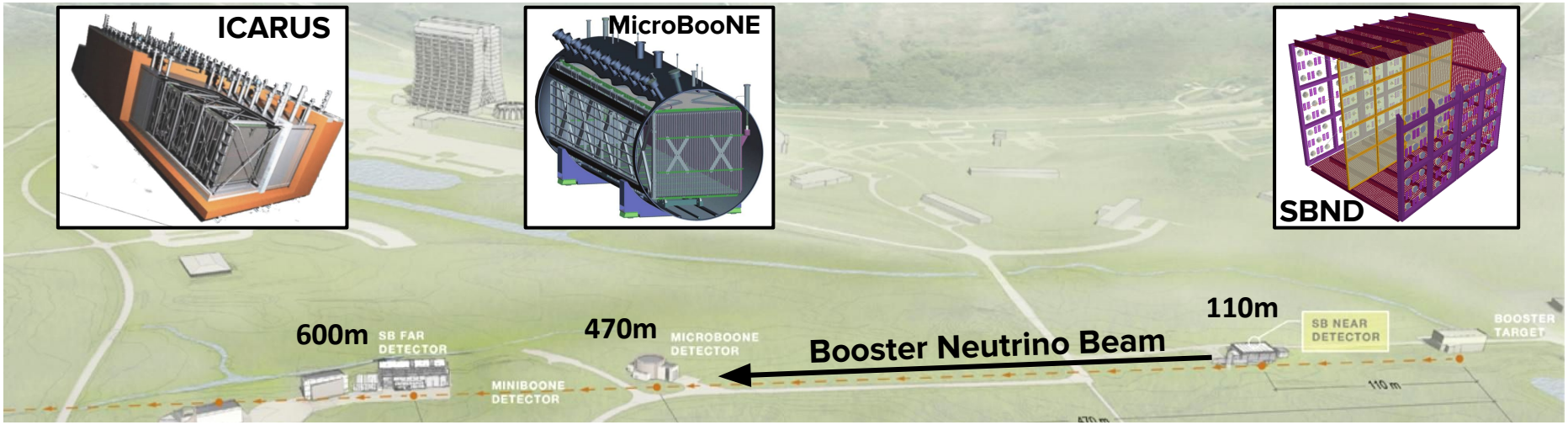
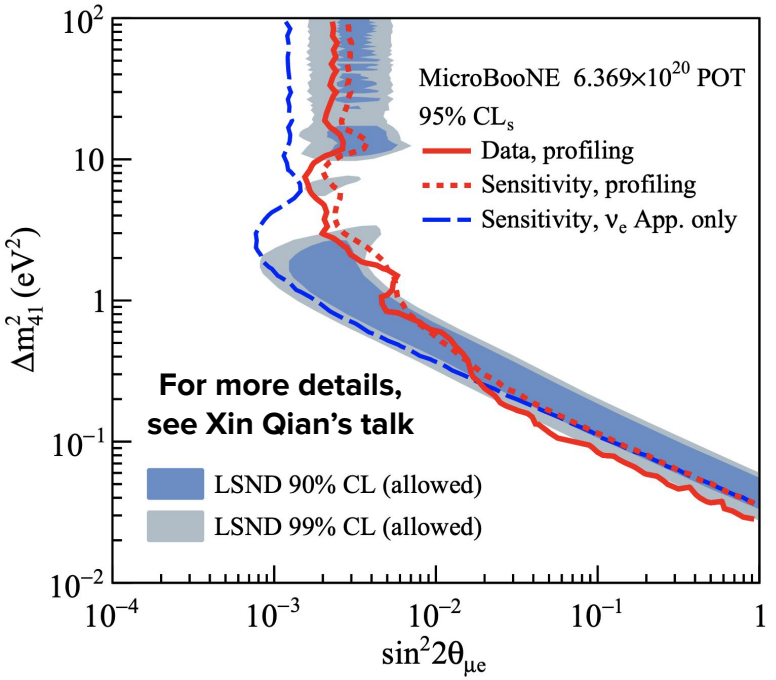


MicroBooNE did not see a “low-energy excess” of electromagnetic events as observed by MiniBooNE, which could have been evidence of sterile neutrino oscillations.

But this does not fully rule out **sterile neutrinos**.

The MicroBooNE Collaboration, arXiv:2210.10216v2



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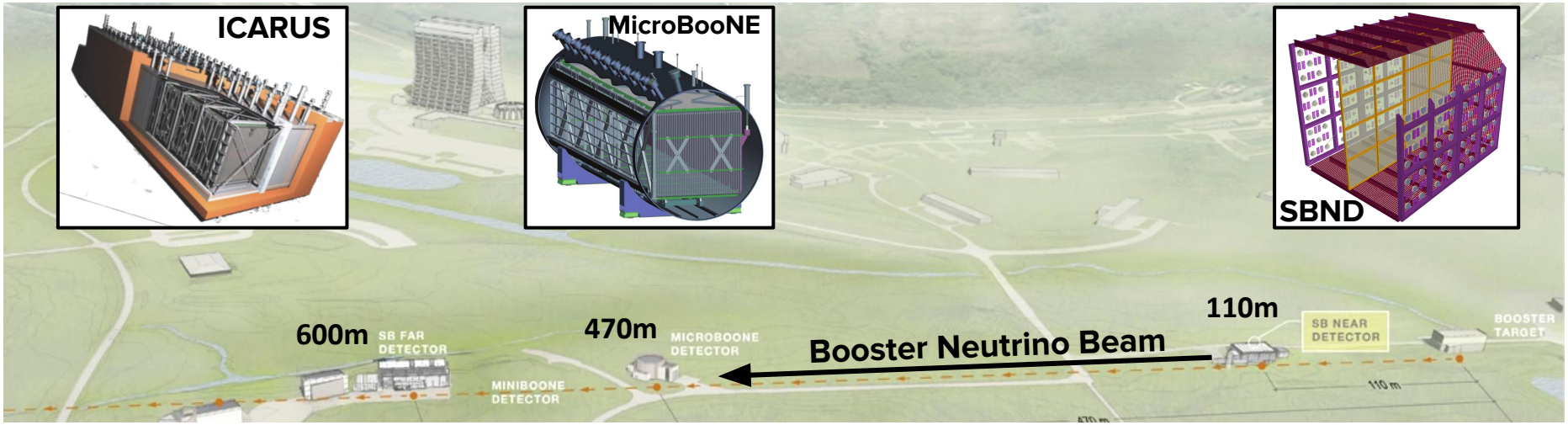

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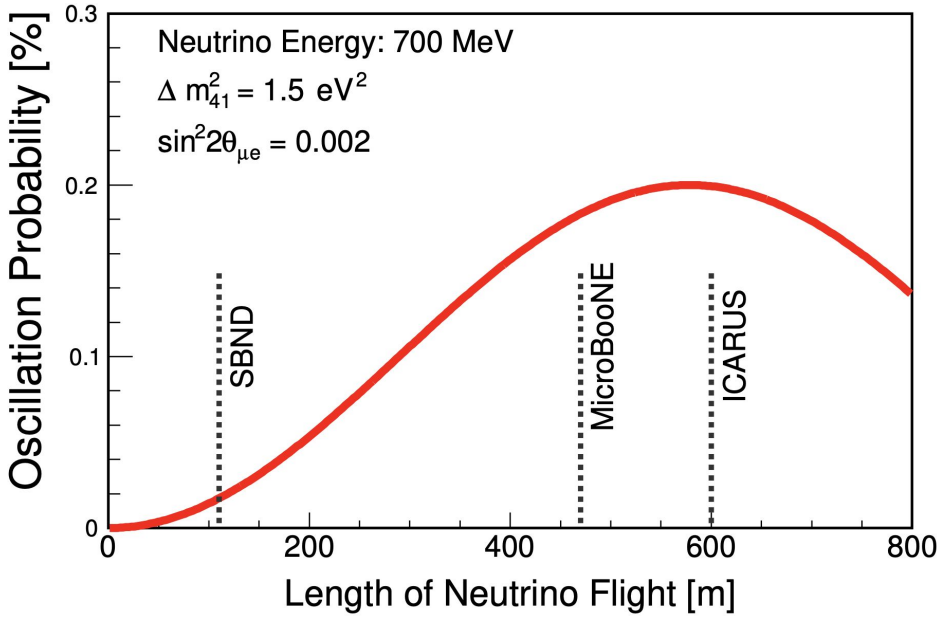
SBN Program:

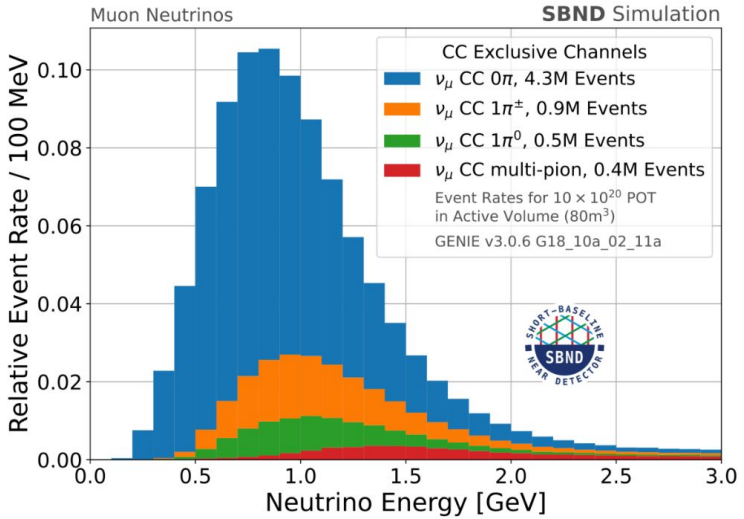
- **Near Detector (SBND) with large statistics to constrain systematics**.
- Far Detector (ICARUS) with large mass for increased exposure.
- The SBN program will probe ν_e appearance, ν_μ disappearance, and ν_e disappearance. Expect 5σ sensitivity.

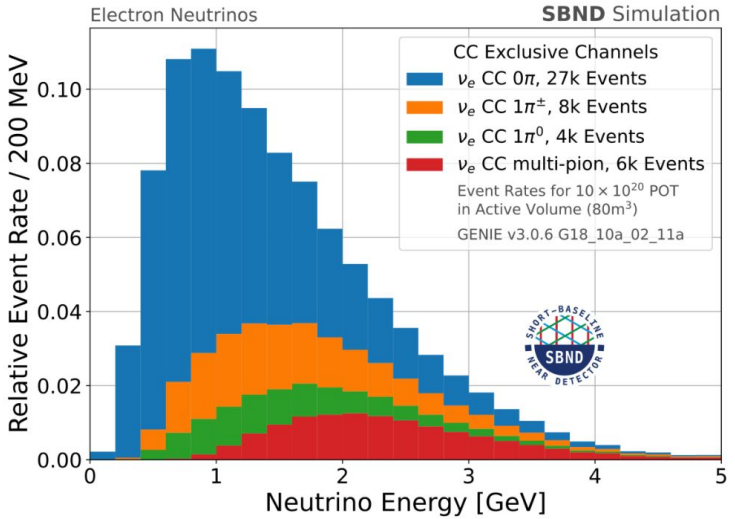
arXiv:1903.04608v1

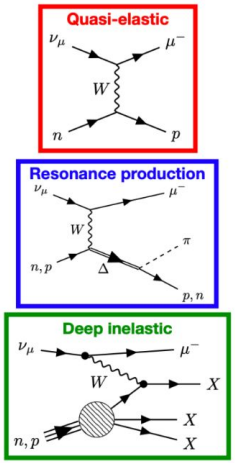


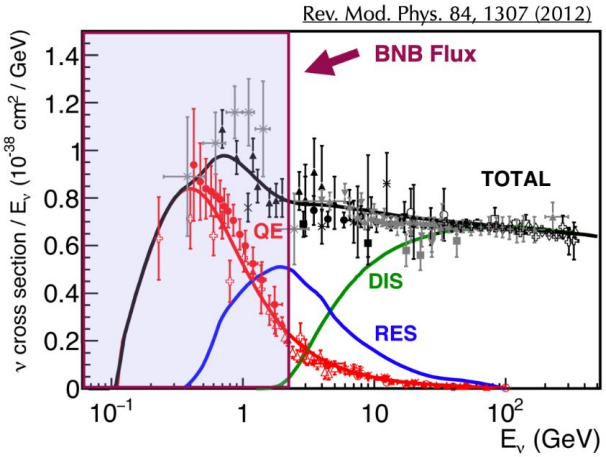
SBND Physics: Neutrino Cross Sections

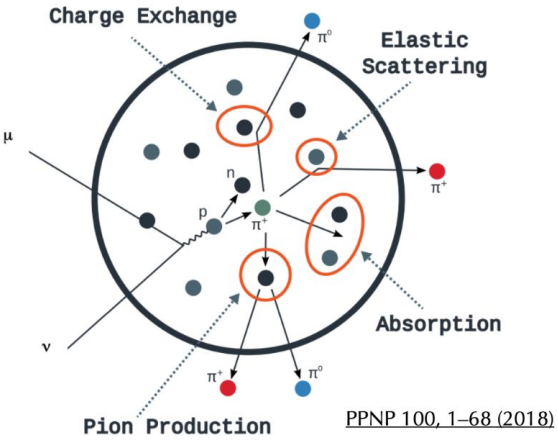
- SBND expects approximately 2 million νμ CC and 15,000 νe CC interactions per year, with around 5,000 total neutrino interactions observed per day.
- Will record ~20–30x more neutrino–argon interactions than is currently available.
- Crucial for probing nuclear structure and constraining systematic uncertainties for DUNE.









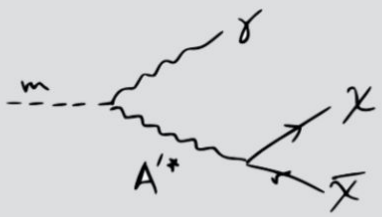


SBND Physics: BSM New Physics

- **High-intensity** proton beam
- **Large-mass** LArTPC
- **3 mm resolution** 3D event reconstruction
- Excellent particle identification with **low thresholds**

=> SBND can search for a variety of BSM phenomena.

Light Dark Matter



Romeri Kelley Machado PRD 2019

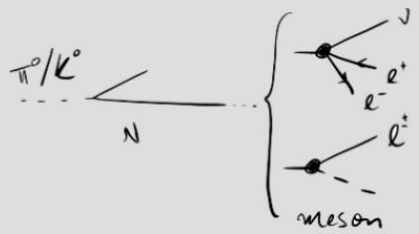
Dark Neutrinos

Bertuzzo Jana Machado Zukanovich PRL 2018, PLB 2019
Arguelles Hostert Tsai PRL 2019
Ballett Pascoli Ross-Lonergan PRD 2019
Ballett Hostert Pascoli PRD 2020

Millicharged Particles

Magill, Plestid, Pospelov, Tsai, PRL 2019
Harnik Liu Palamara, JHEP 2019

Heavy Neutral Leptons

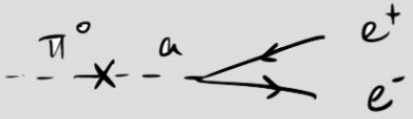


Ballett Pascoli Ross-Lonergan JHEP 2017
Kelly Machado PRD 2021

Higgs Portal Scalar

Pat Wilczek 2006
Batell Berger Ismail PRD 2019
MicroBooNE 2021

Axion-like Particles



Kelly Kumar Liu PRD 2021
Brdar et al PRL 2021

Image credits: Pedro Machado, Marco Del Tutto

SBND Physics: BSM New Physics

We introduce the model into our simulation & run reconstruction.

- **High-intensity** proton beam
- **Large-mass** LArTPC
- **3 mm resolution** 3D event reconstruction
- Excellent particle identification with **low thresholds**

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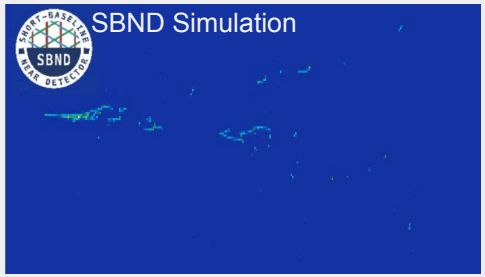
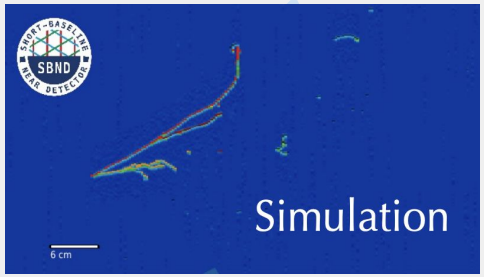


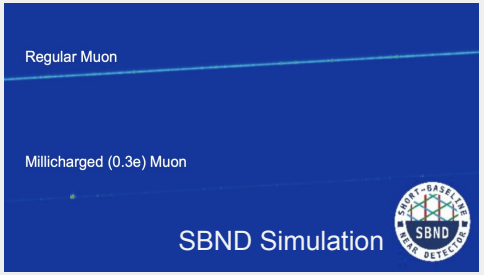
single e^- scattering or e^+e^- pair with no hadronic activity

Dark Neutrinos



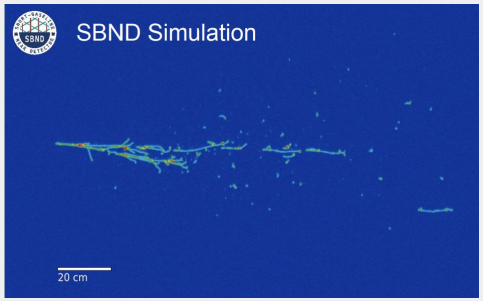
e^+e^- pair with or without hadronic activity

Millicharged Particles



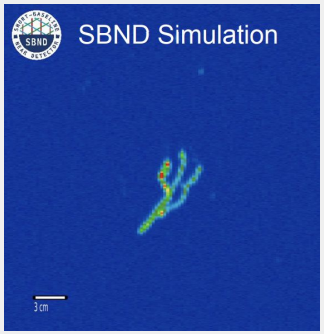
blips or faint tracks

Heavy Neutral Leptons



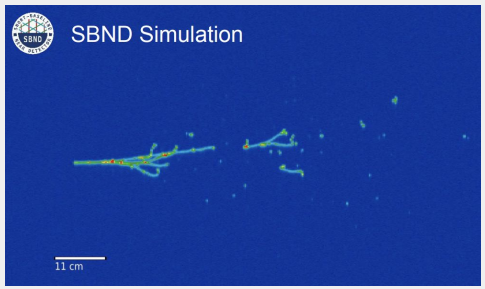
e^+e^-, $\mu^+\mu^-$, or $\mu^\pm\pi^\mp$ pair with no hadronic activity

Higgs Portal Scalar



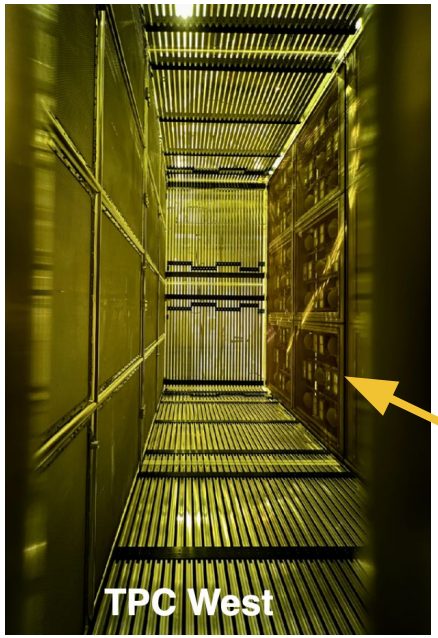
e^+e^- or $\mu^+\mu^-$ pair with no hadronic activity

Axion-Like Particles

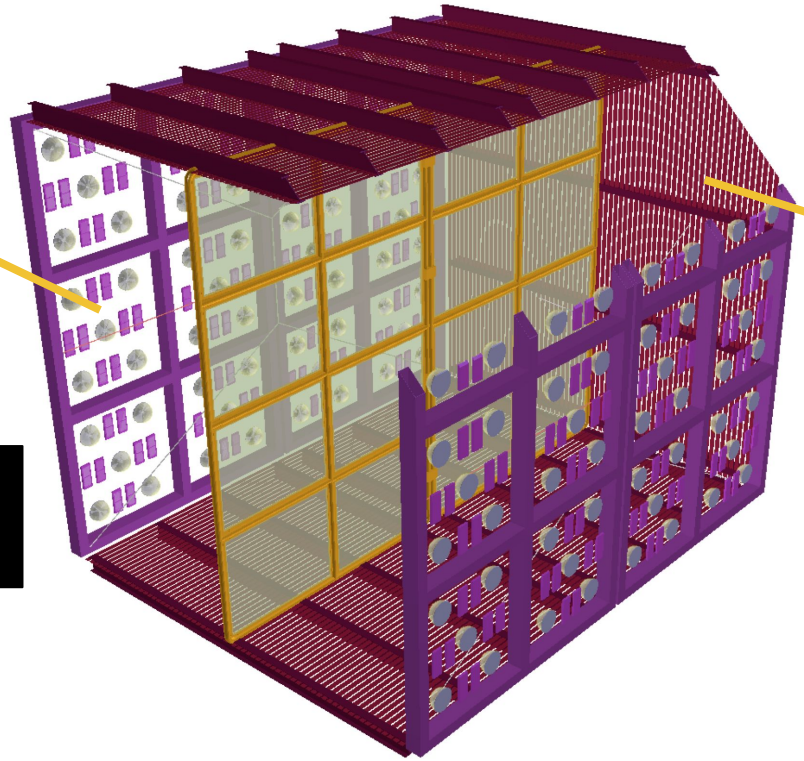


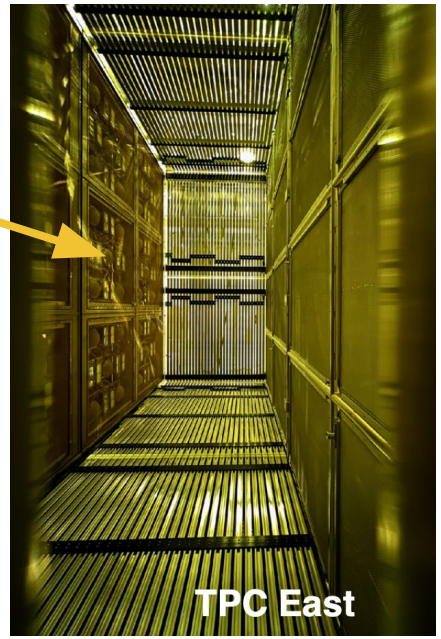
high-energy e^+e^- or $\mu^+\mu^-$ pair

SBND TPC



2 Time Projection Chambers
[total 4 X 4 X 5 m]





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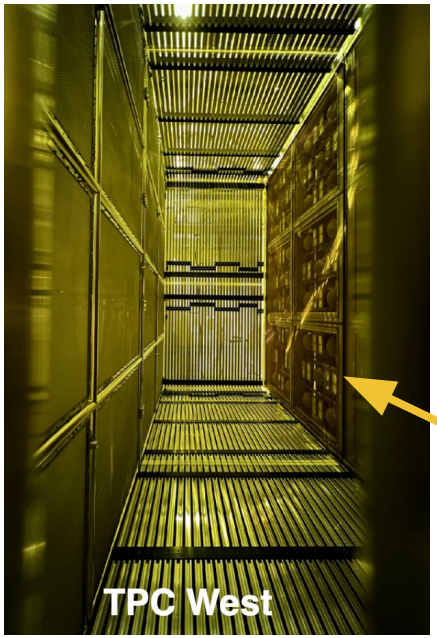

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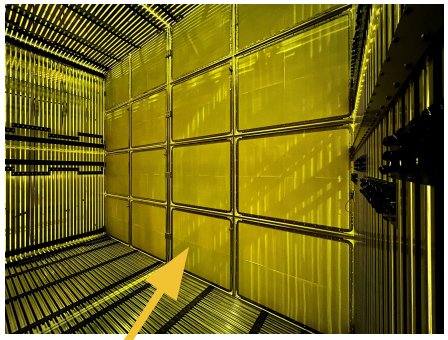
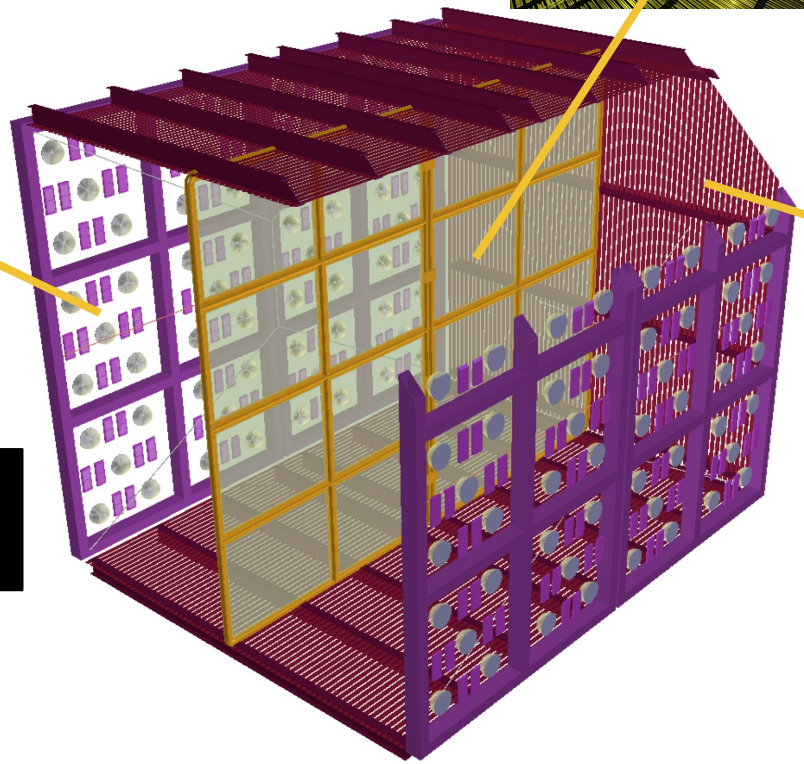
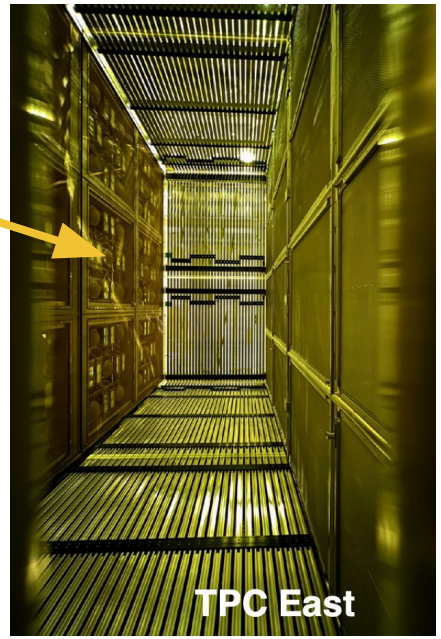


Cathode Plane
in the middle; divides the detector into 2 TPCs. Will be supplied with -100 kV.





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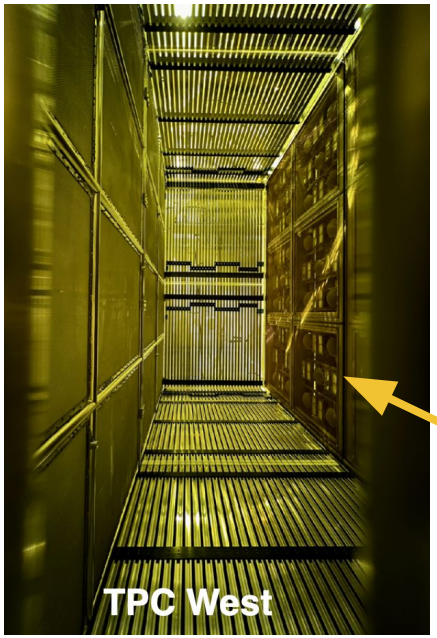

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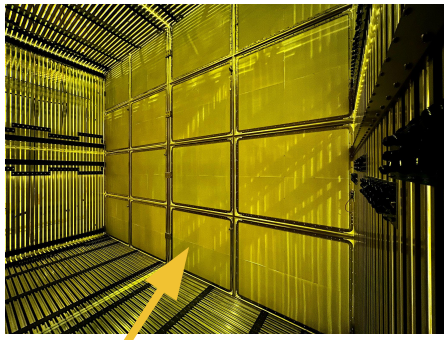

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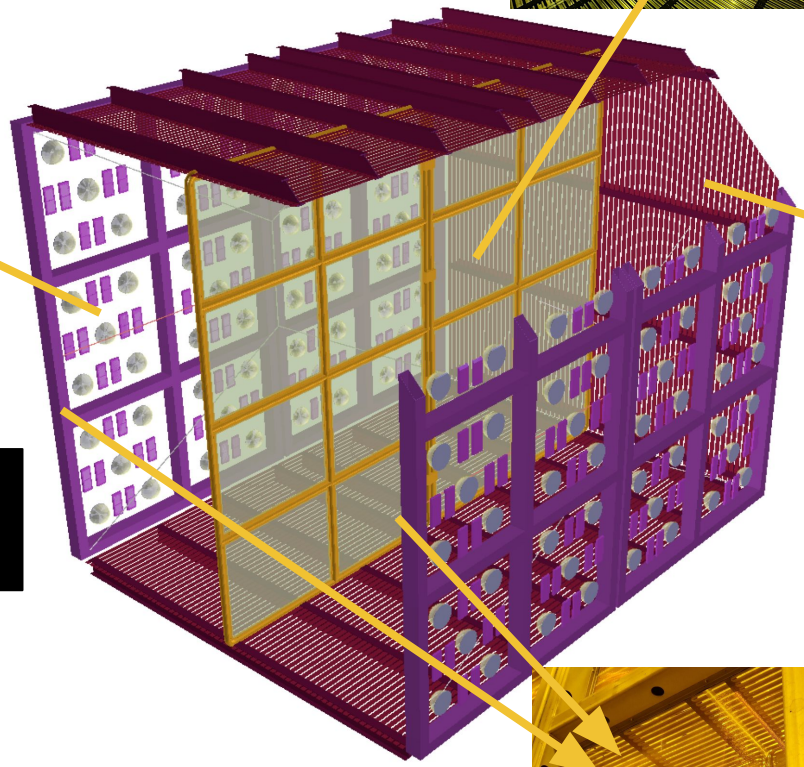
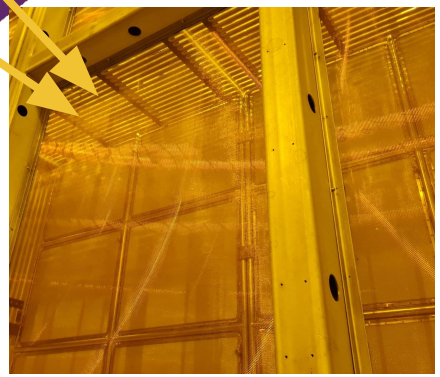
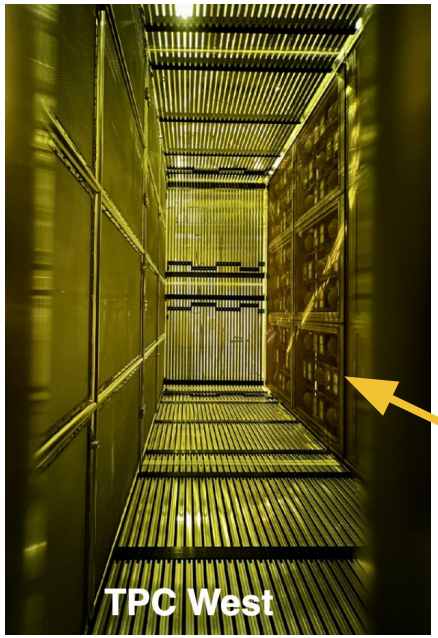
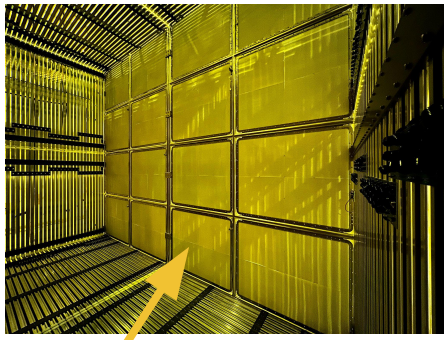




Anode Plane
on either side. Each consists of 3 planes of wires with 3 mm spacing and different angle per plane.

SBND TPC





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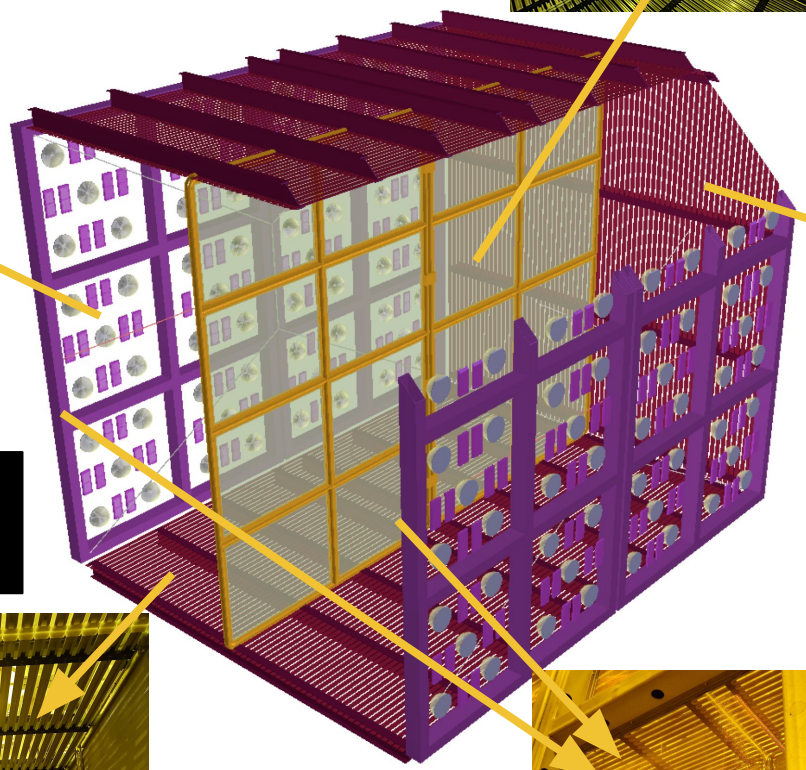

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Field Cage
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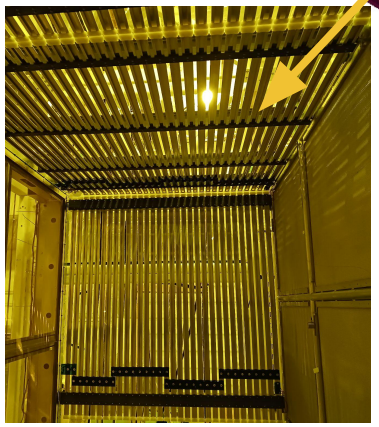

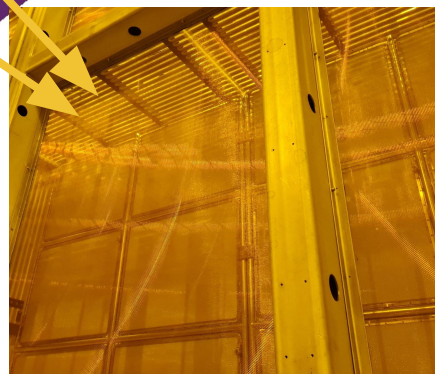

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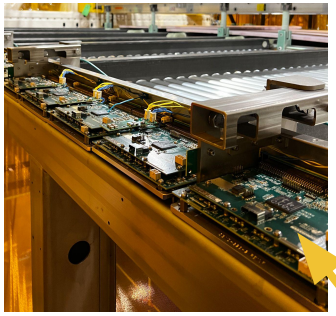
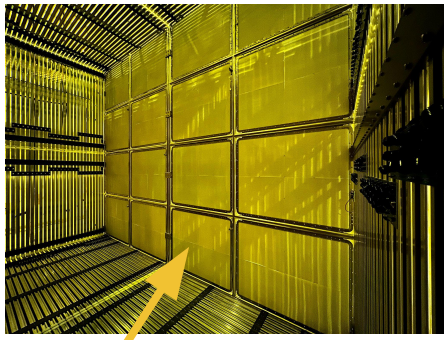


Cold Electronics to pre-amplify & digitize signals in the cold



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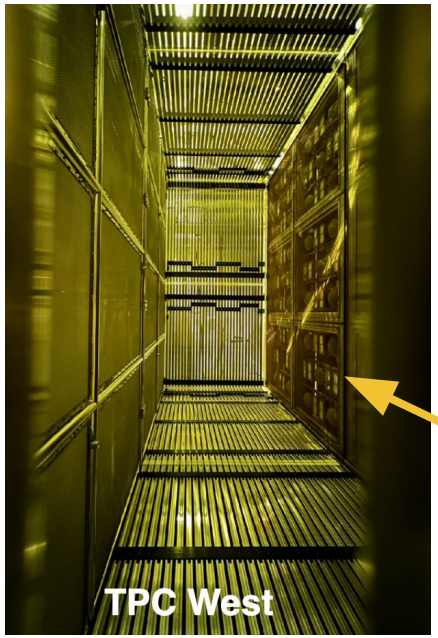

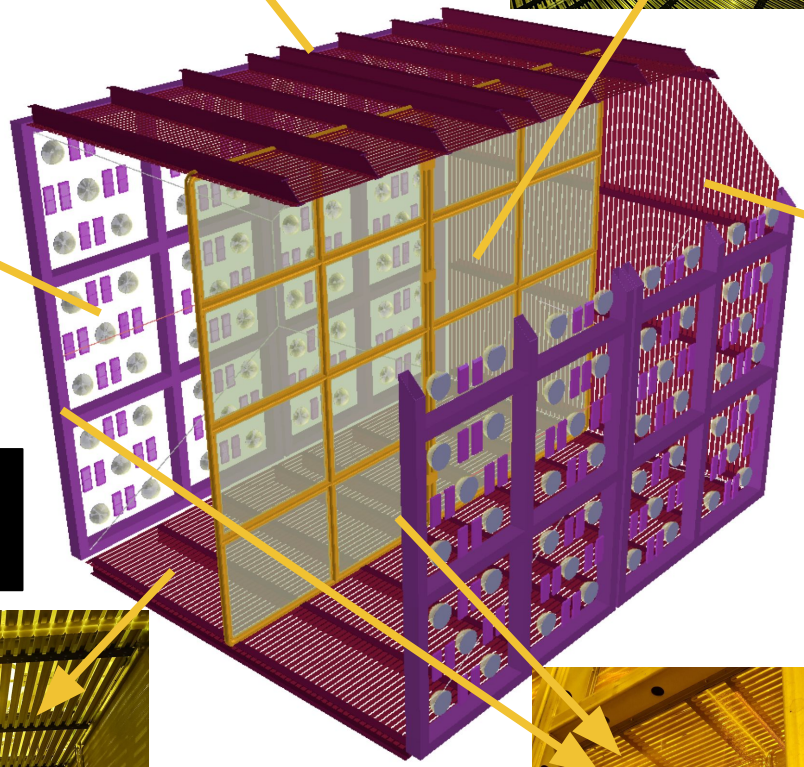

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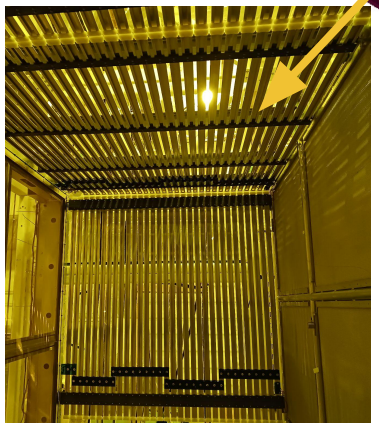
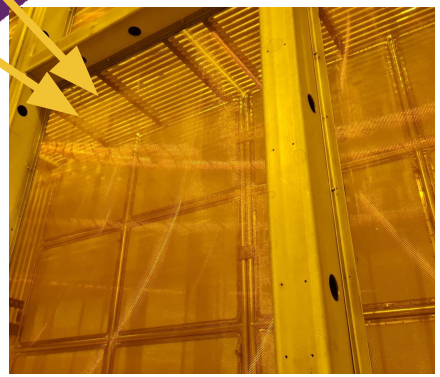
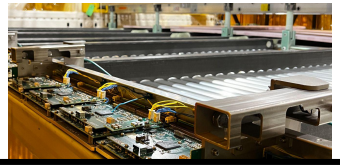


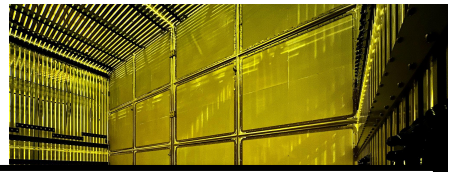


Anode Plane on either side. Each consists of 3 planes of wires with 3 mm spacing and different angle per plane.

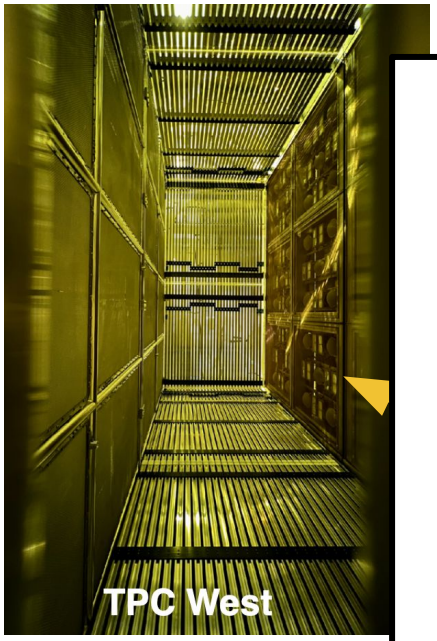
SBND TPC



Cold Electronics to pre-amplify &



Cathode Plane in the middle; divides the detector into 2 TPCs. Will be supplied with -100 kV.



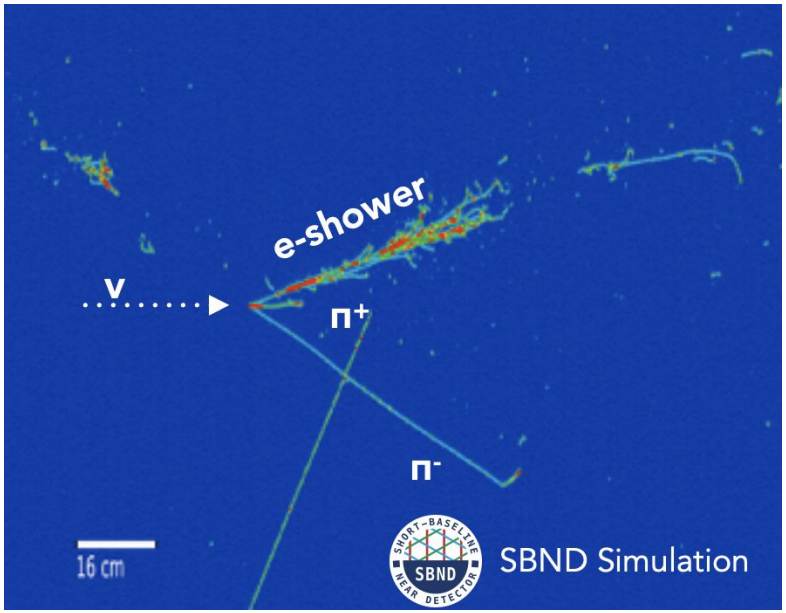
2 Time Projection C
[total 4 X 4 X 5

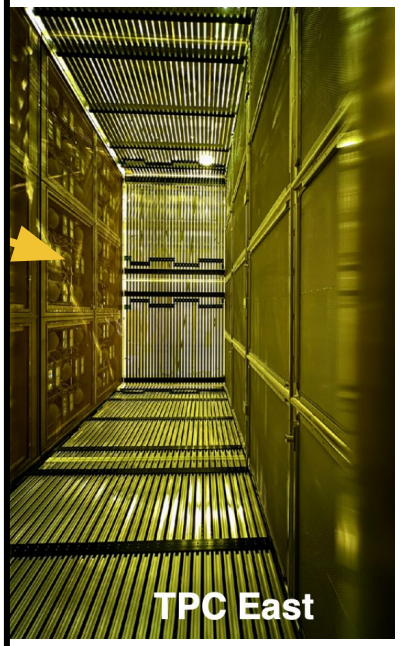
3D event reconstruction.

3 mm position resolution.

Low momentum thresholds.

Particle ID: e/**γ** separation
μ, **π**, p,etc identification.

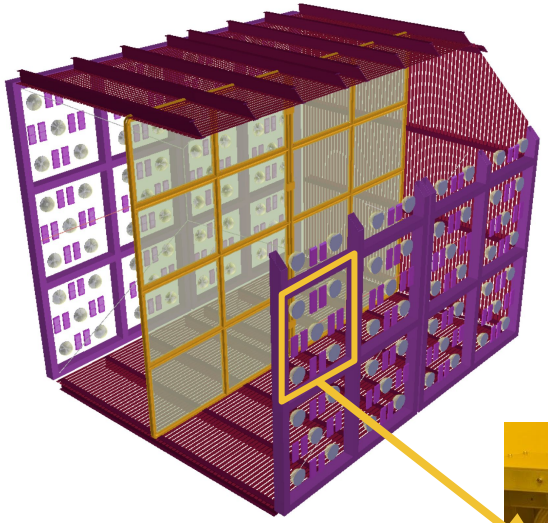




Field Cage that wraps around the 2 LArTPCs to step down the voltage & ensure uniform electric field of 500 V/cm.

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

SBND Photon Detection System

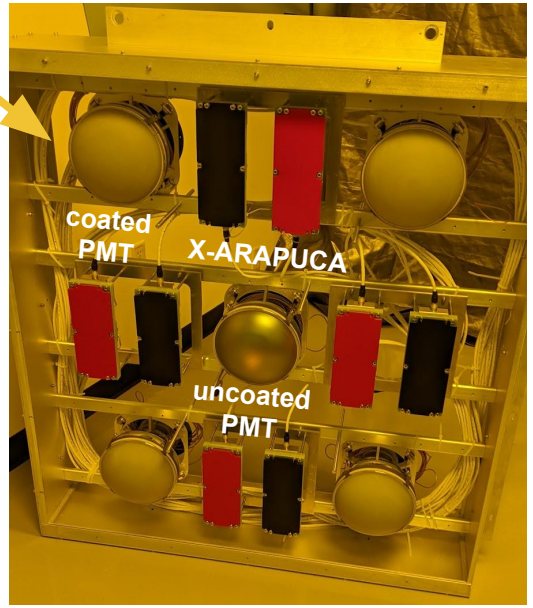


24 Anode Plane boxes

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

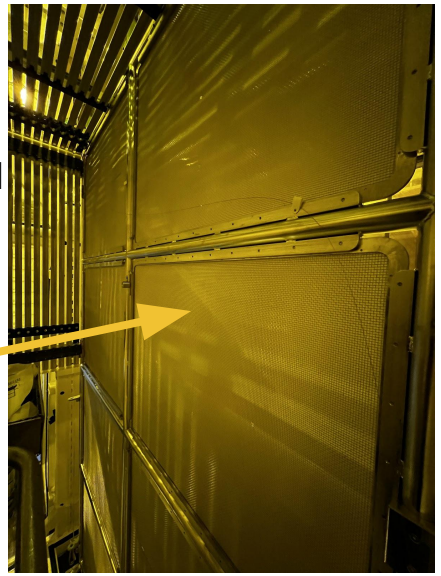
8x24 = 192
X-ARAPUCAs*

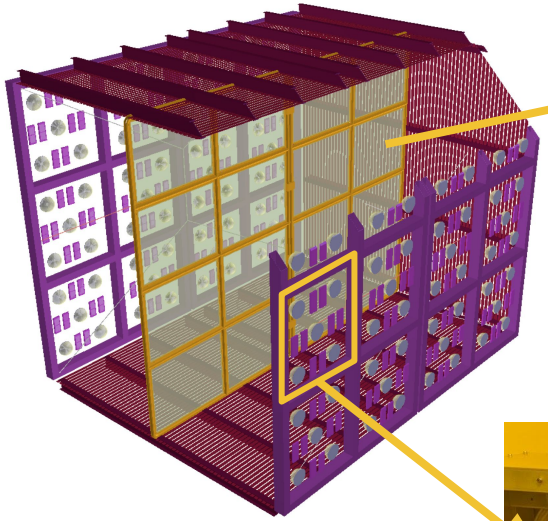
*sensitive to UV
+ visible light



SBND Photon Detection System

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





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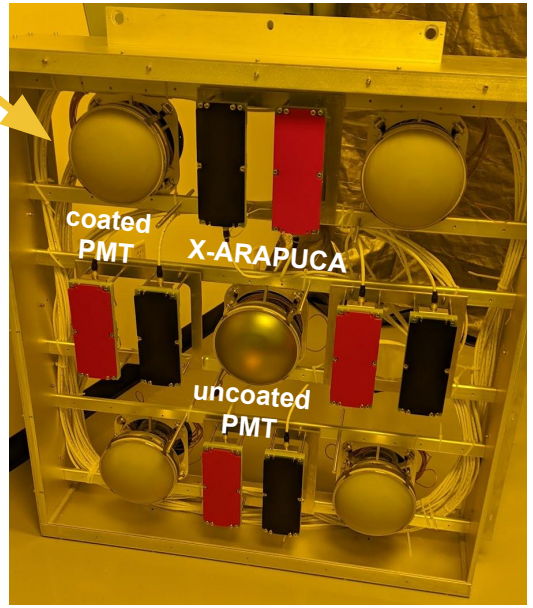
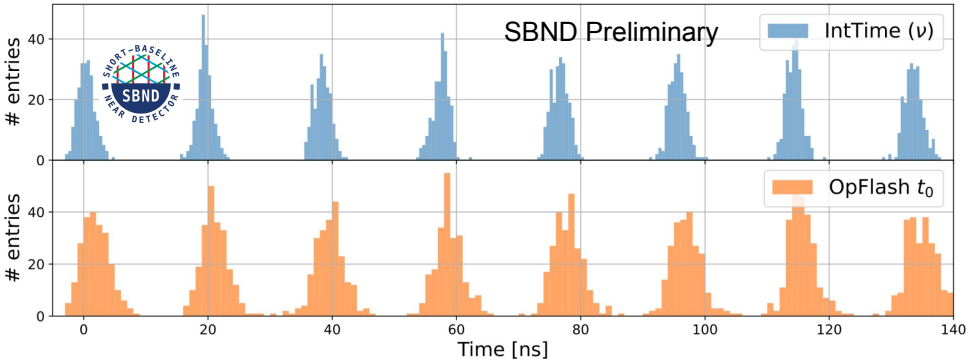


SBND Photon Detection System

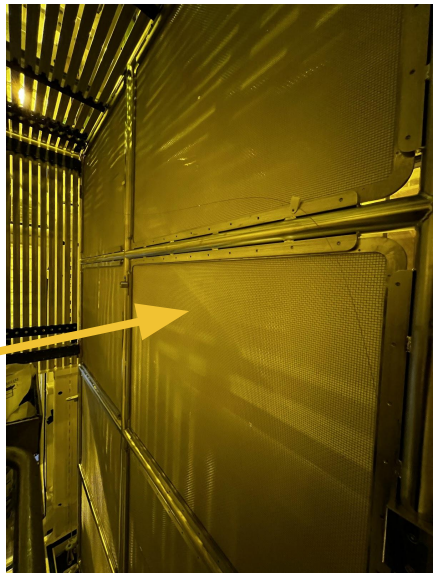
- **Primary scintillation and reflected light:** improved and more uniform total light yield.
- **Triggering :** recent improvements in timing resolution to resolve the beam structure & identify interaction time.
- **Cosmic background tagging**: based on amount of light + 3D position reconstruction.
- **Calorimetry:** light information can supplement TPC information. arXiv:2203.00740

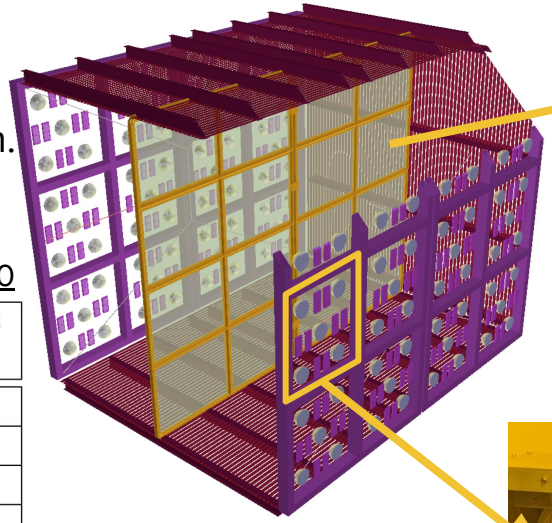
Experiment	Average light yield (PE/MeV)	Uniform light collection?
MicroBooNE	~ 5	no
LArIAT	~ 18	yes
pDUNE-SP	1.9 at 3.3m	no
SBND	~ 80 (> 50 min)	yes
DUNE: Vertical Drift	~ 38 (> 16.5 min)	yes



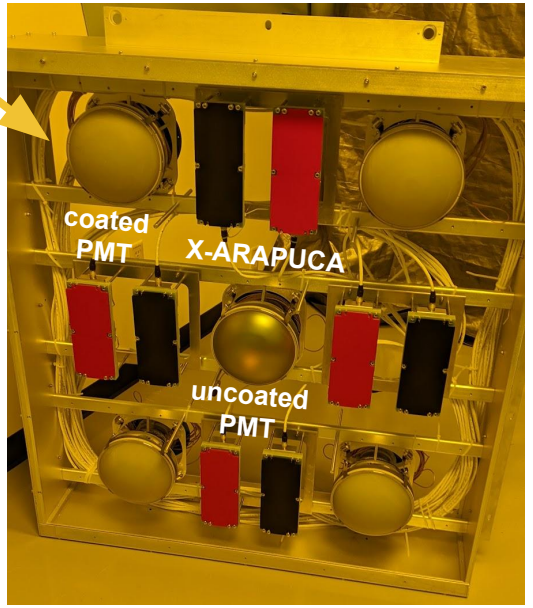
Simulated (top) and reconstructed (bottom) light flashes showing the neutrino beam structure.

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





24 Anode Plane boxes



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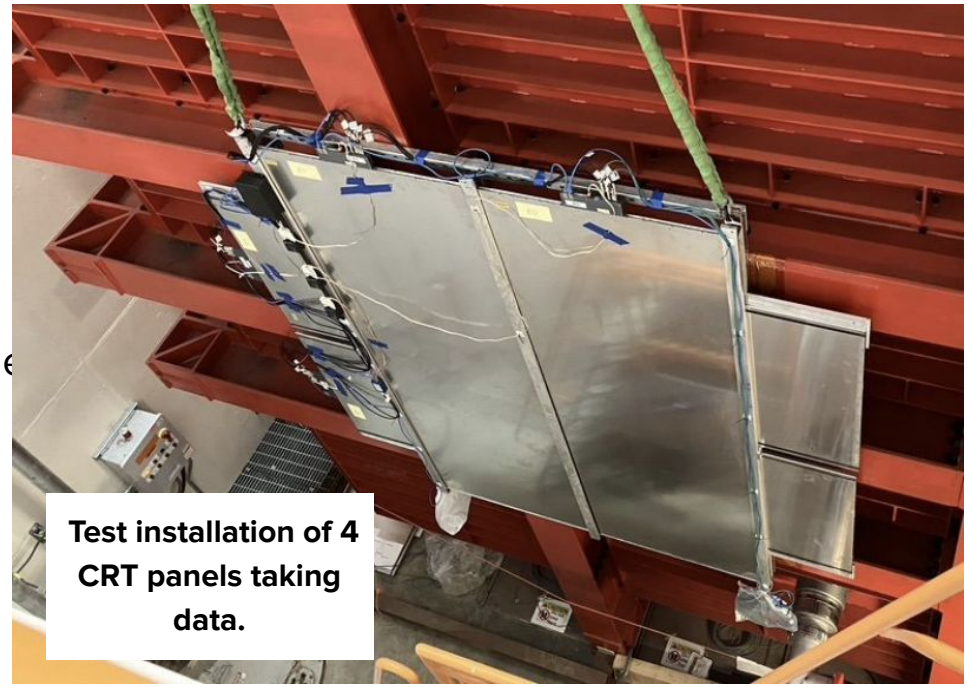
8x24 = 192 **X-ARAPUCAs***

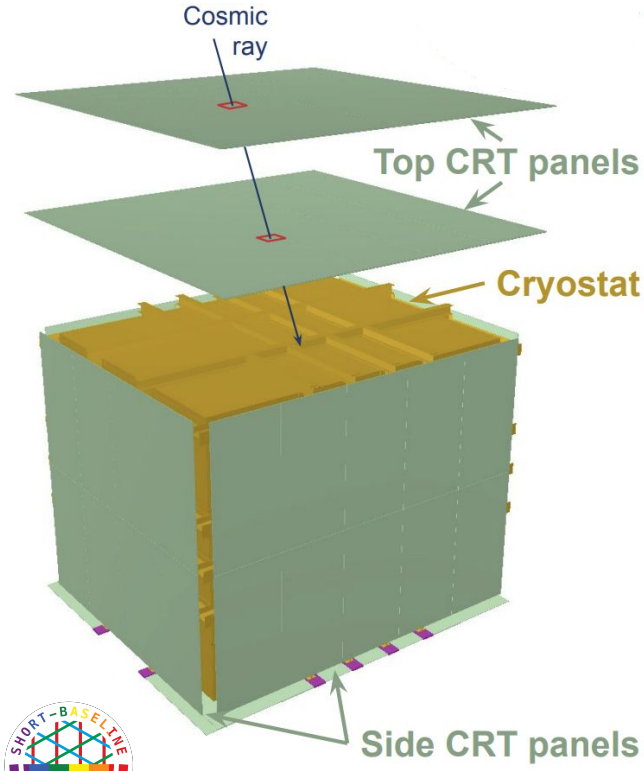
*sensitive to UV + visible light

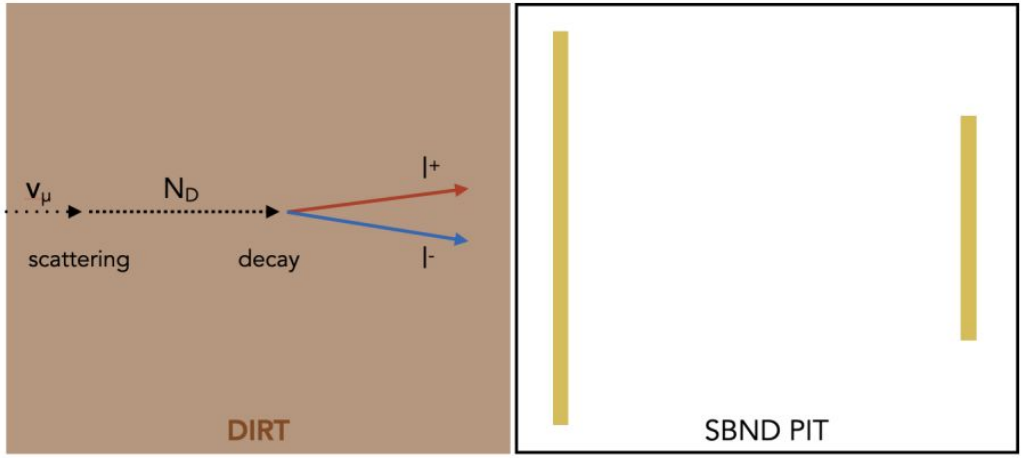
SBND Cosmic Ray Tagger

- 3-4 cosmic muons in TPC per readout window.
- **4π coverage** important for surface detectors
- Can act as a "**beam telescope**," e.g. to look for BSM new physics particles decaying in the dirt around SBND (dark neutrino analysis development underway).



Test installation of 4 CRT panels taking data.

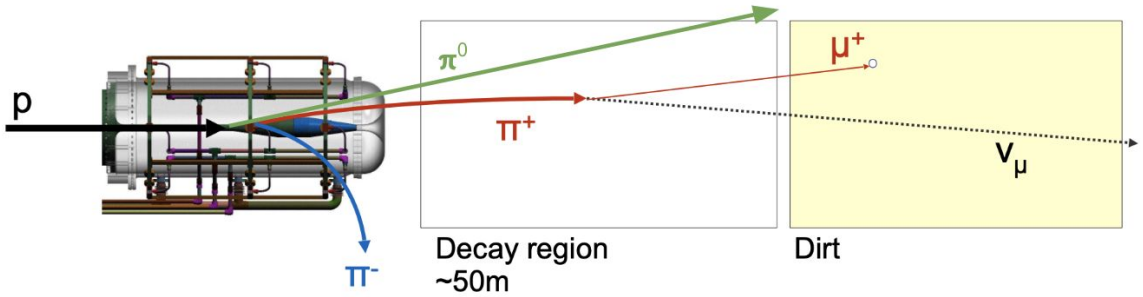


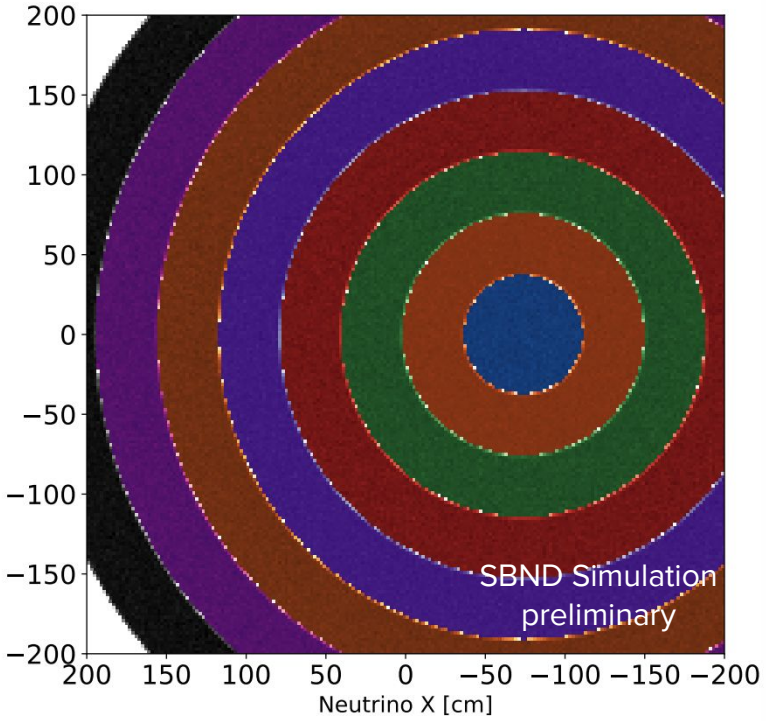


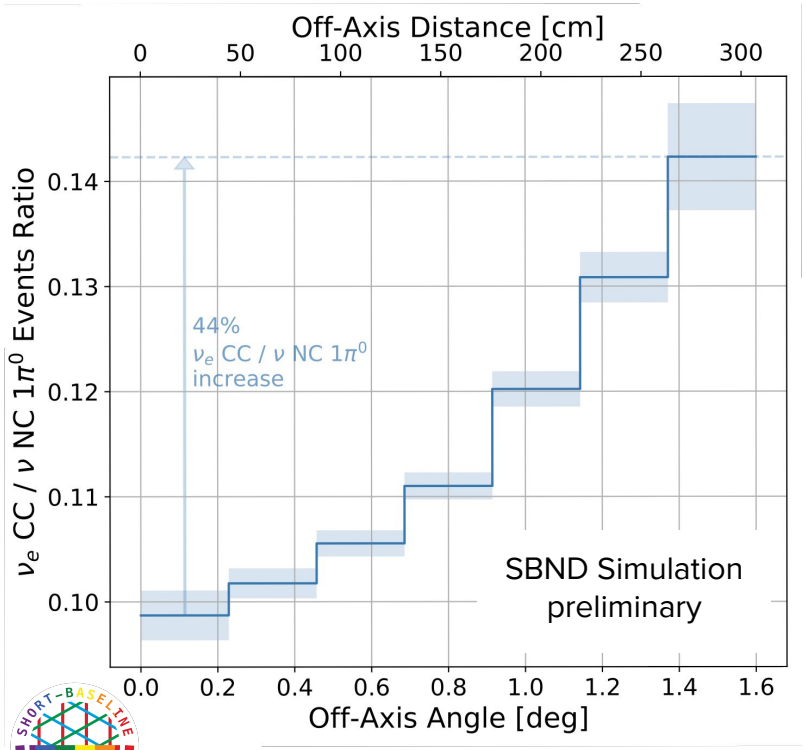
SBND PRISM

* nuPRISM

Precision **R**eaction **I**ndependent **S**pectrum **M**easurement (*)



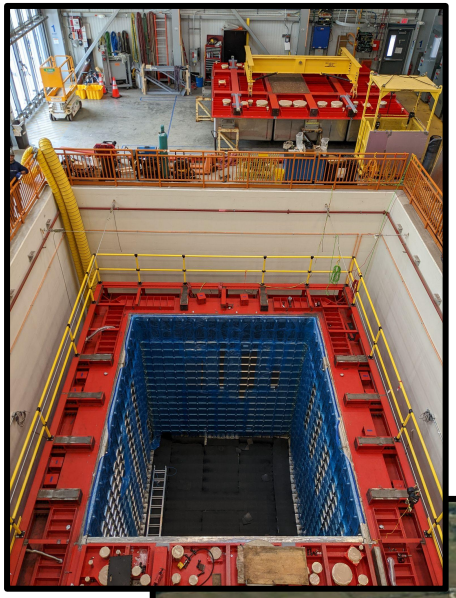


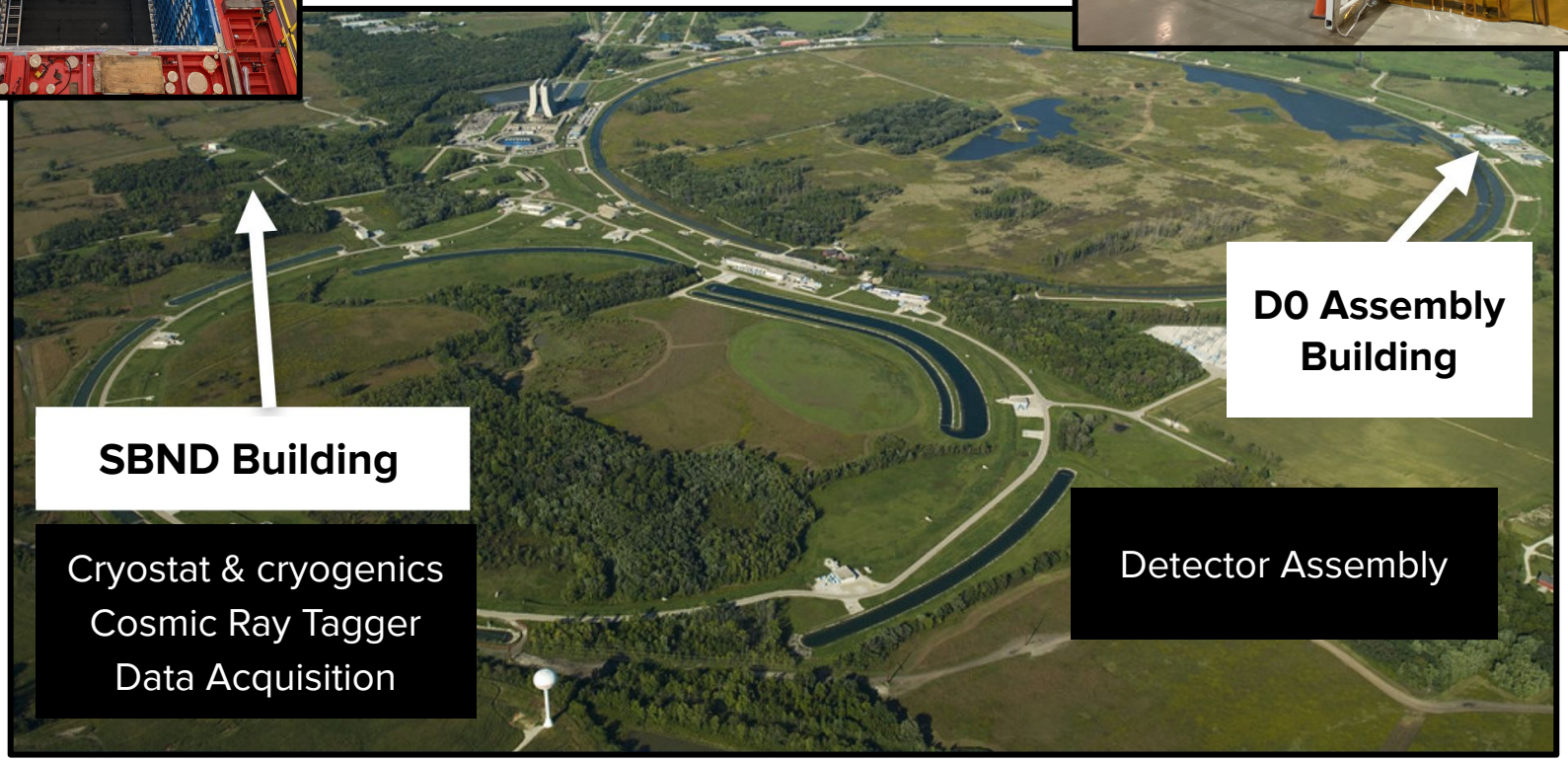


Can sample **multiple off-axis fluxes** with the same detector, due to proximity of SBND to the beam source.

The beam composition changes with respect to off-axis angle. E.g. ν_e's tend to be produced more off-axis compared to ν_μ's => can use for **preferentially selecting ν_e events** over ν_μ neutral current π^0 background events.

Detector Construction at Two Sites





SBND Building

Cryostat & cryogenics
Cosmic Ray Tagger
Data Acquisition

D0 Assembly Building

Detector Assembly

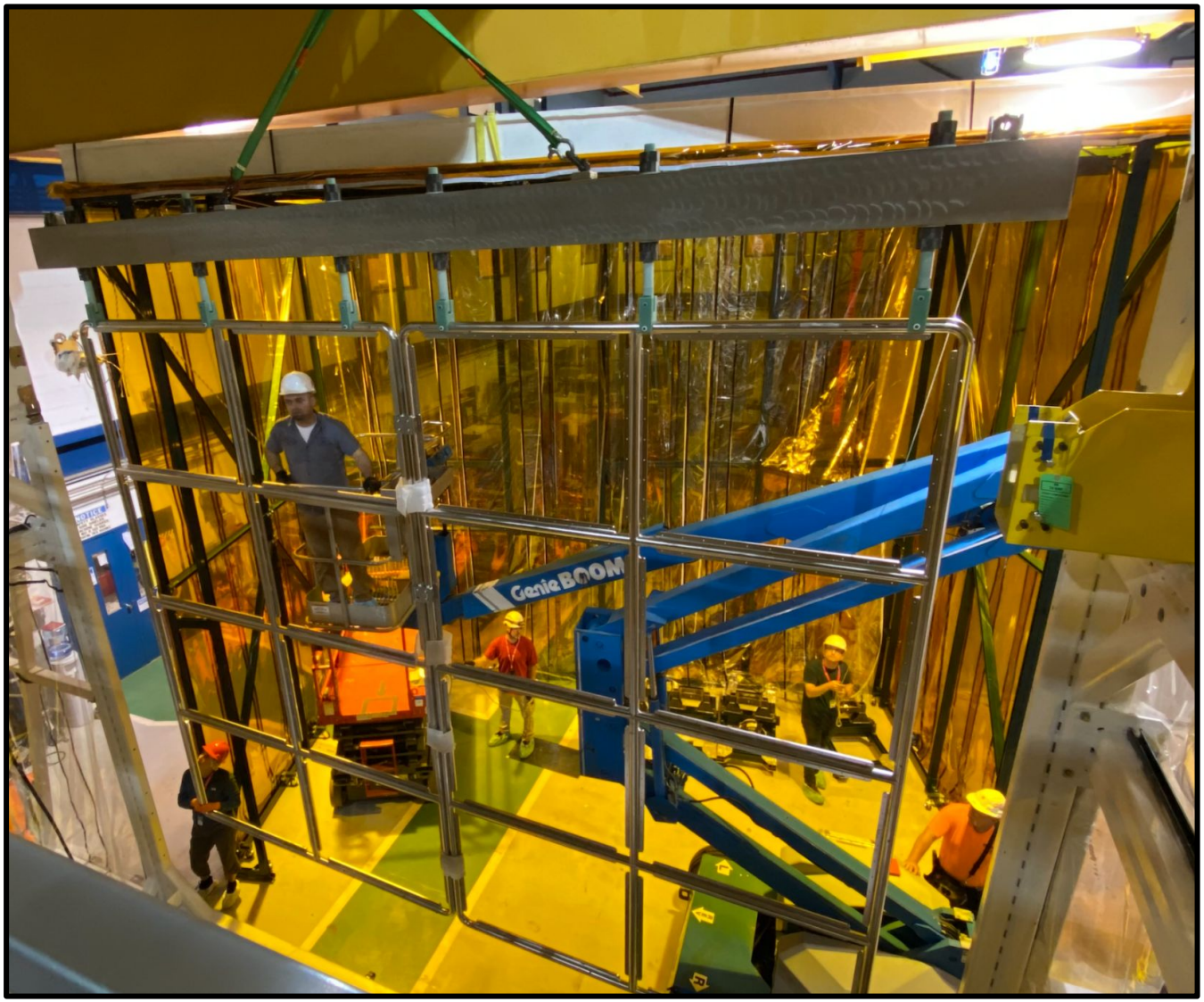
Detector Assembly

Empty Assembly Transport Frame, December 2019

Detector Assembly

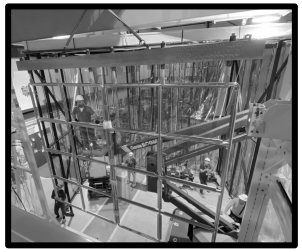
Clean tent with UV filters fully constructed,
April 2021

Detector Assembly



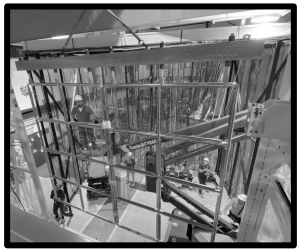
Cathode Plane structure being installed,
July 2021

Detector Assembly



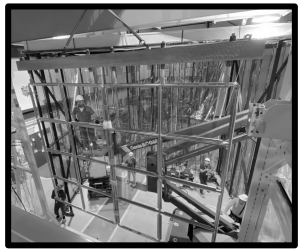
Anode Plane Assembly with wires being brought into place, October 2021

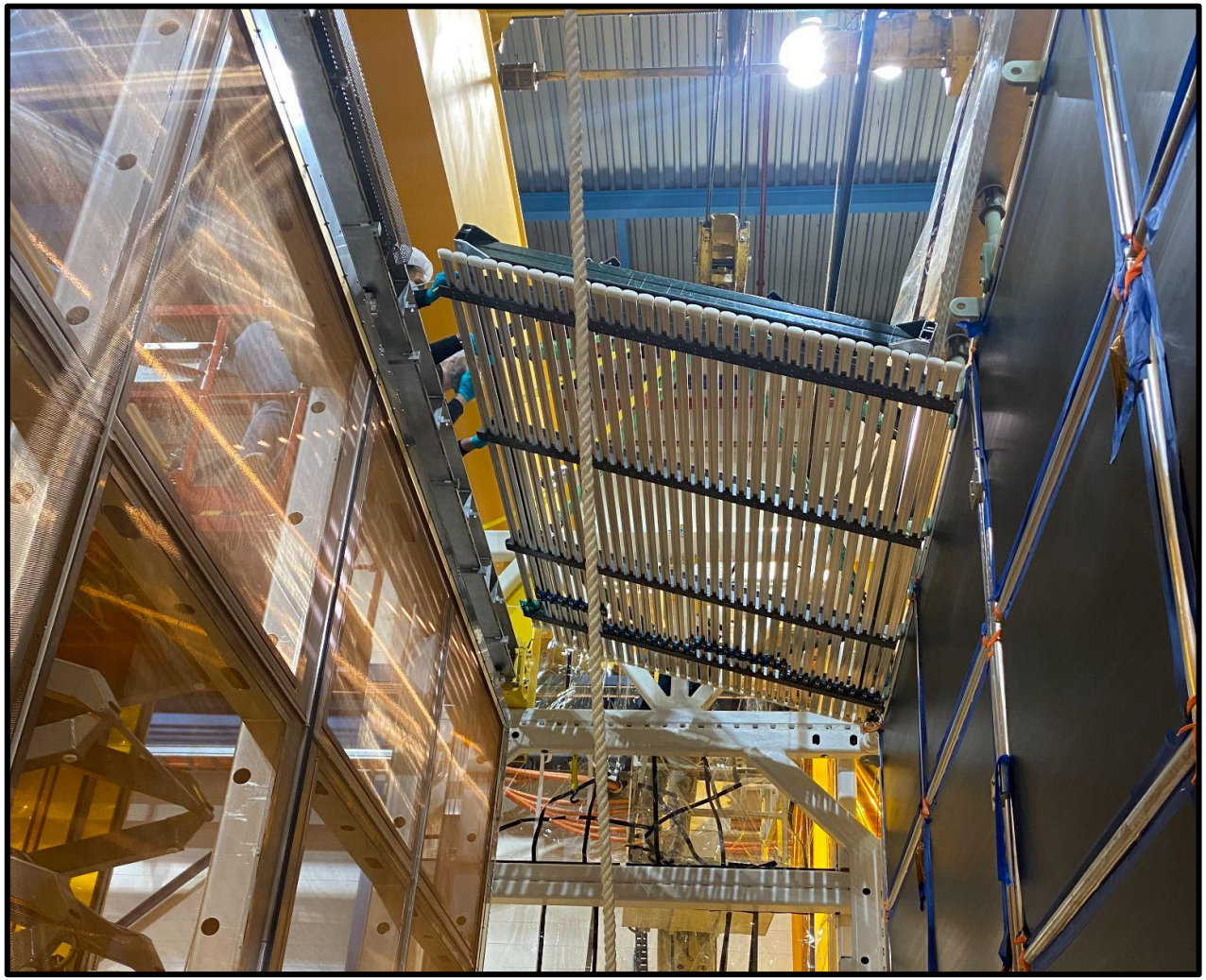
Detector Assembly



Installation of Cold Electronics,
December 2021 & May 2022

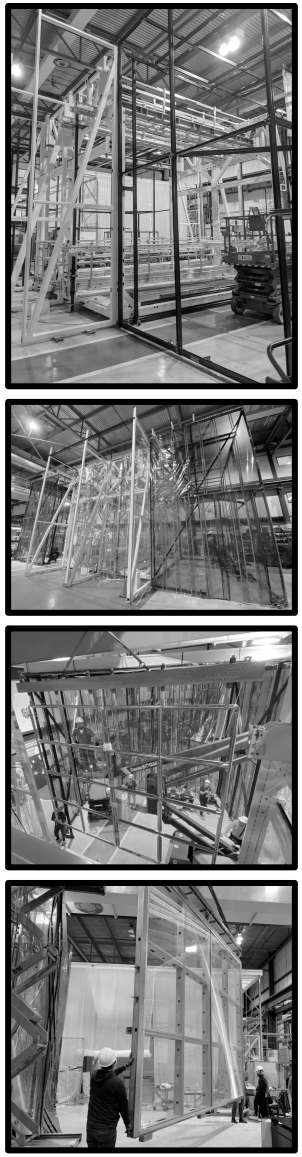
Detector Assembly

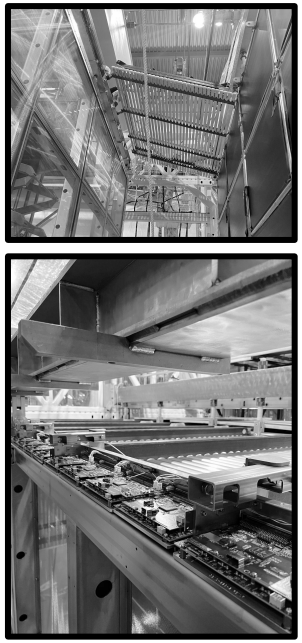


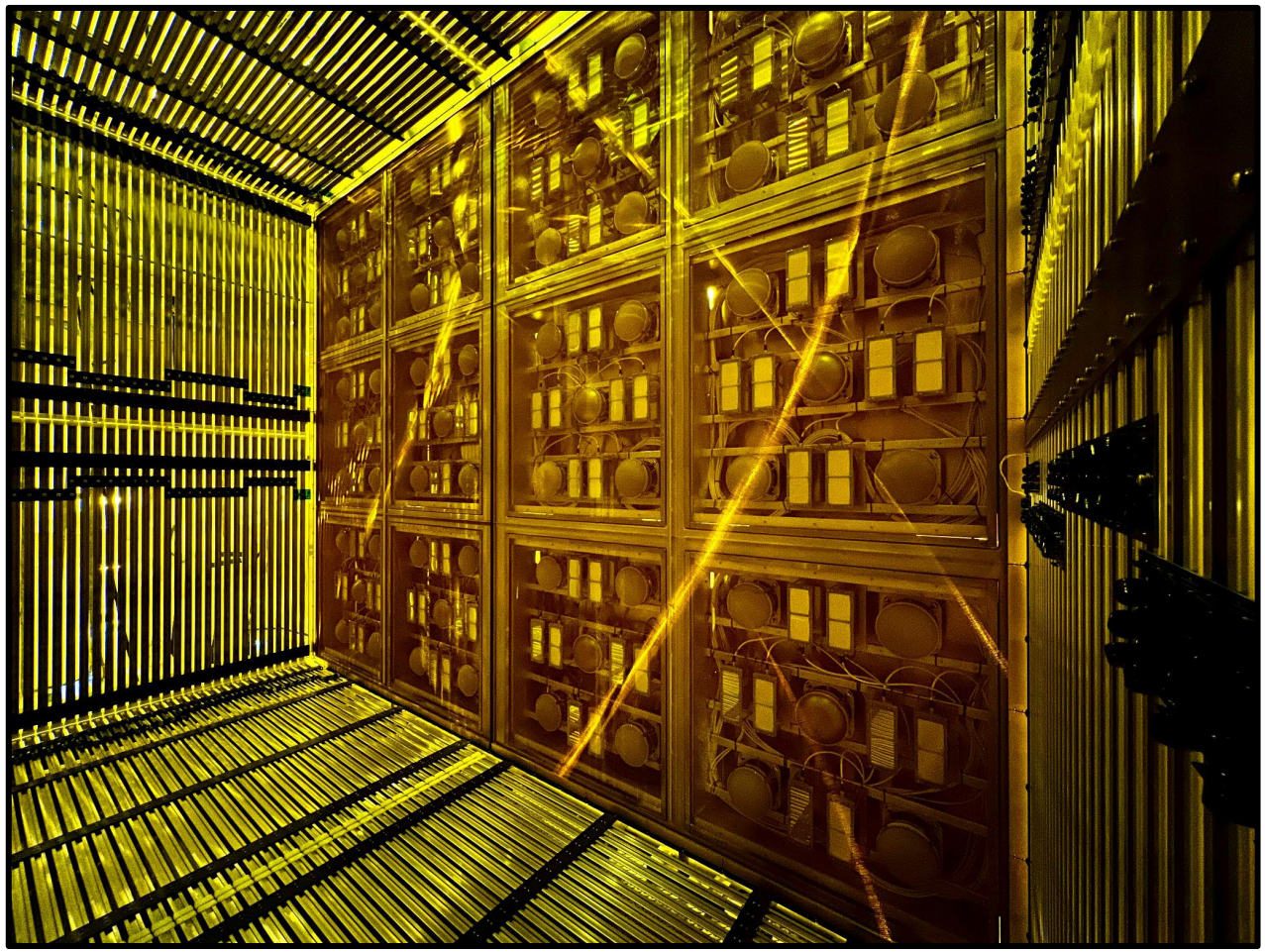


Field Cage top module being lowered,
January 2022

Detector Assembly

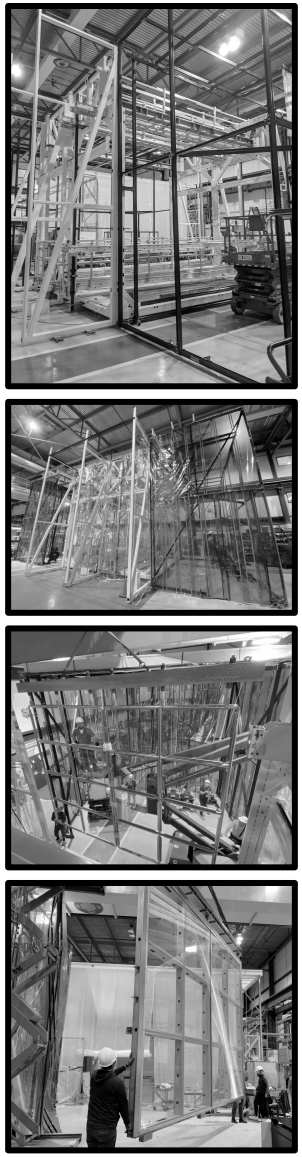






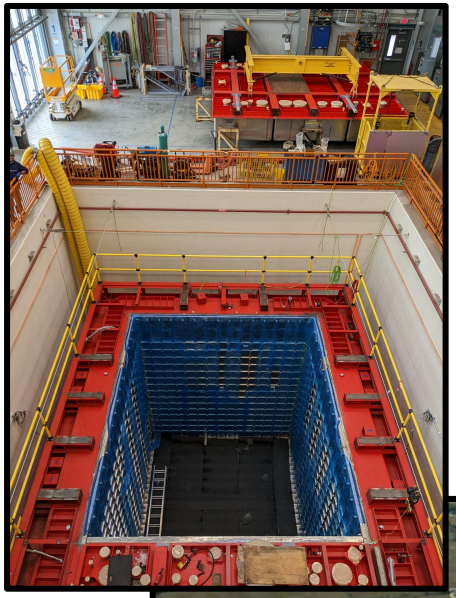
Photon Detection System boxes fully installed behind anode wire planes, September 2022

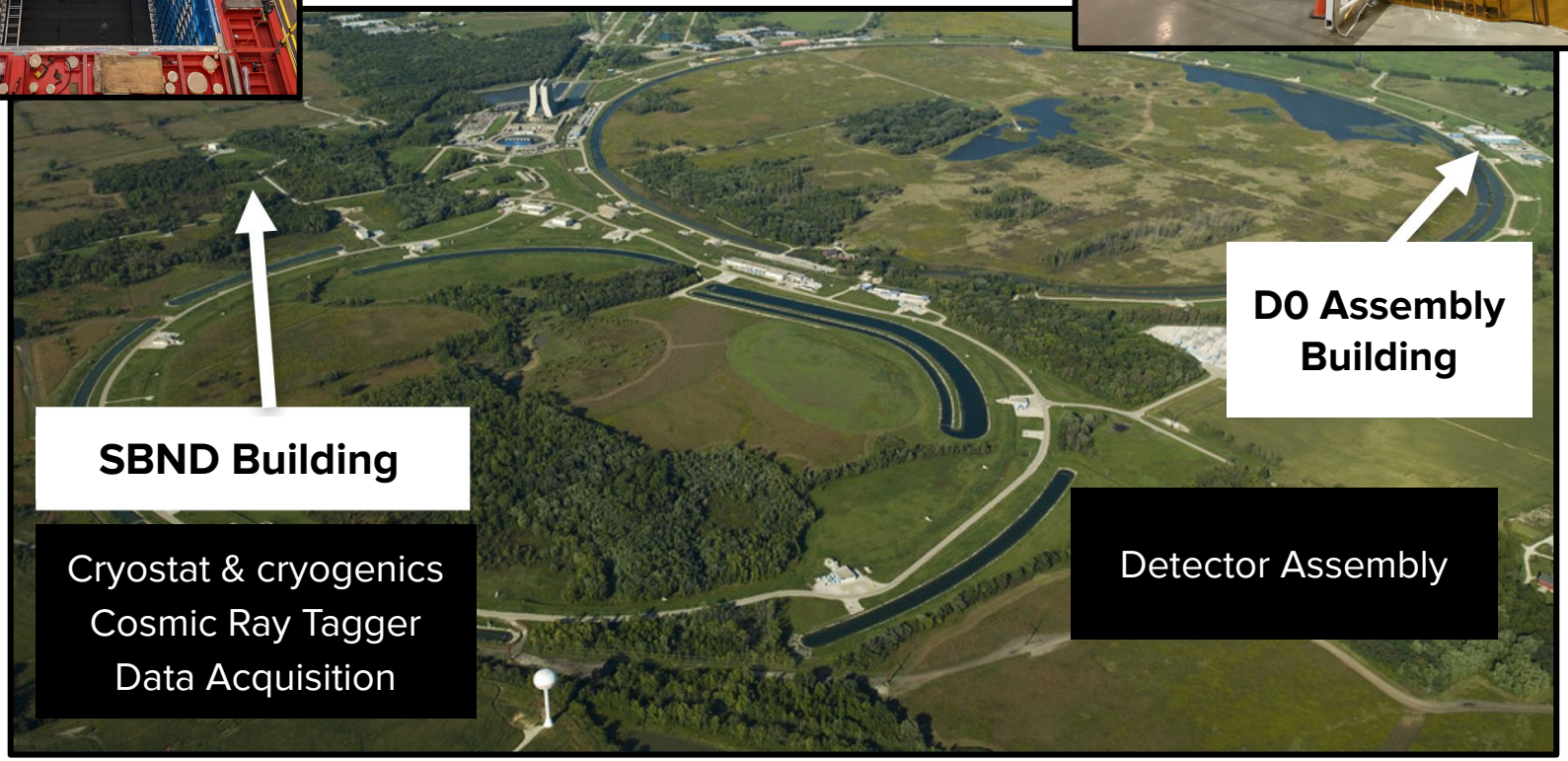
Detector Assembly



Fully completed assembly of 2 TPCS + Photon Detection System, September 2022

Detector Construction at Two Sites





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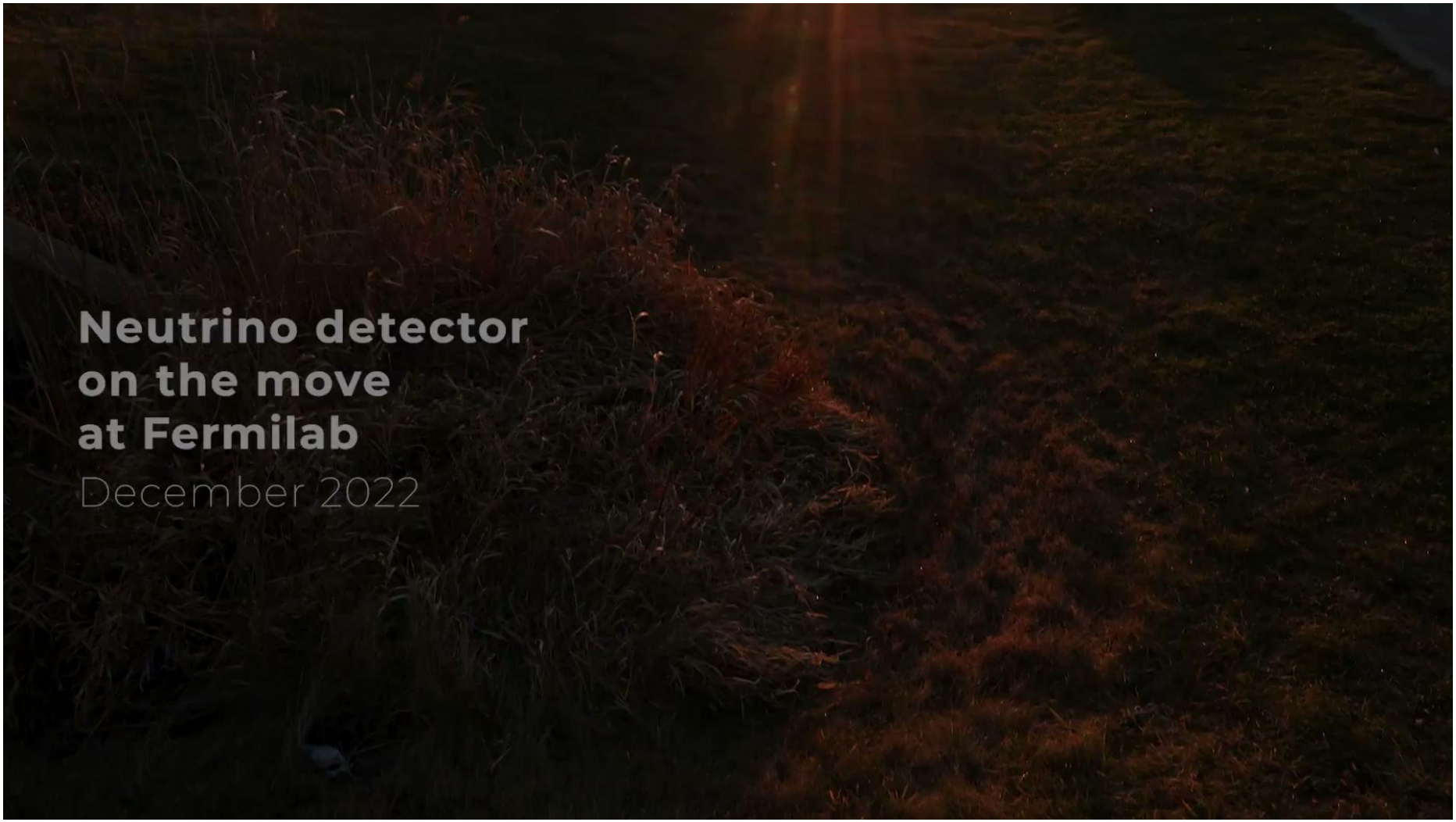
Detector Assembly


Neutrino detector
on the move
at Fermilab
December 2022


How many types exist?
Scientists from around the world work together to build detectors
It took decades to develop the liquid-argon technique to detect neutrinos

Summary & The Road to Physics

- SBND will record the **largest statistics of neutrino-Argon interactions to date** (before DUNE) due to proximity to the beam target and a high-intensity neutrino beam source.
- 3 detection subsystems: LArTPC + Photon Detection System + Cosmic Ray Tagger
  => **excellent spatial, timing and energy resolution, low energy thresholds**.
- SBND physics has 3 goals: neutrino oscillation studies, measure neutrino-argon cross sections, and look for BSM new physics.
- Remaining preparations before operations: finish installing all instrumentation and cabling, cryogenic tests, cooldown and filling with liquid argon
- **SBND plans to start cold commissioning and data-taking in the start of 2024.**