SBND
The Short-Baseline Near Detector at Fermilab

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for the SBND Collaboration

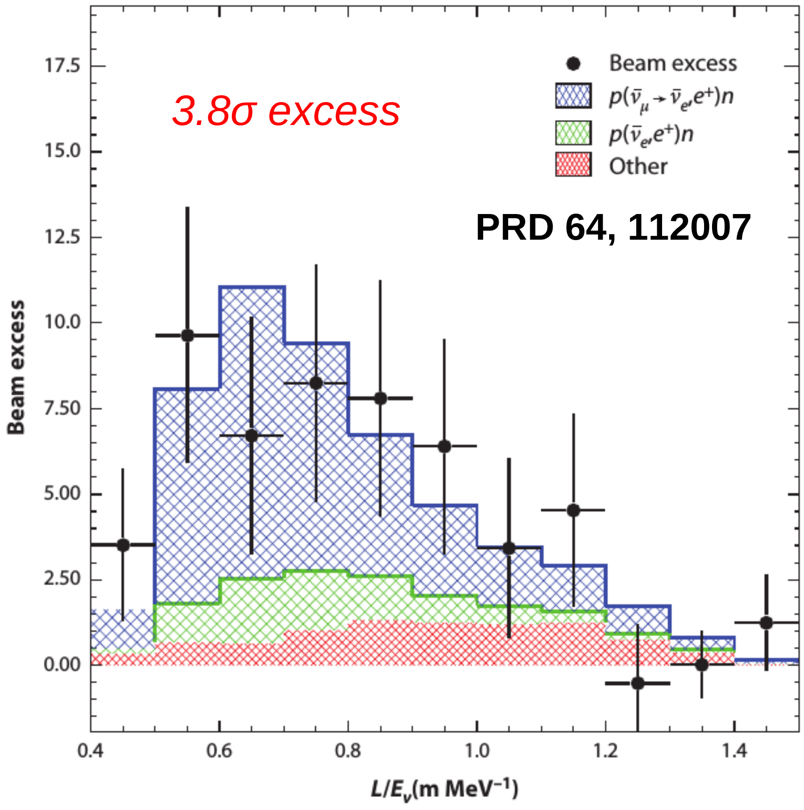
07/31/2017 APS DPF 2017 Meeting

Motivation

Short-Baseline Neutrino Anomalies: LSND & MiniBooNE

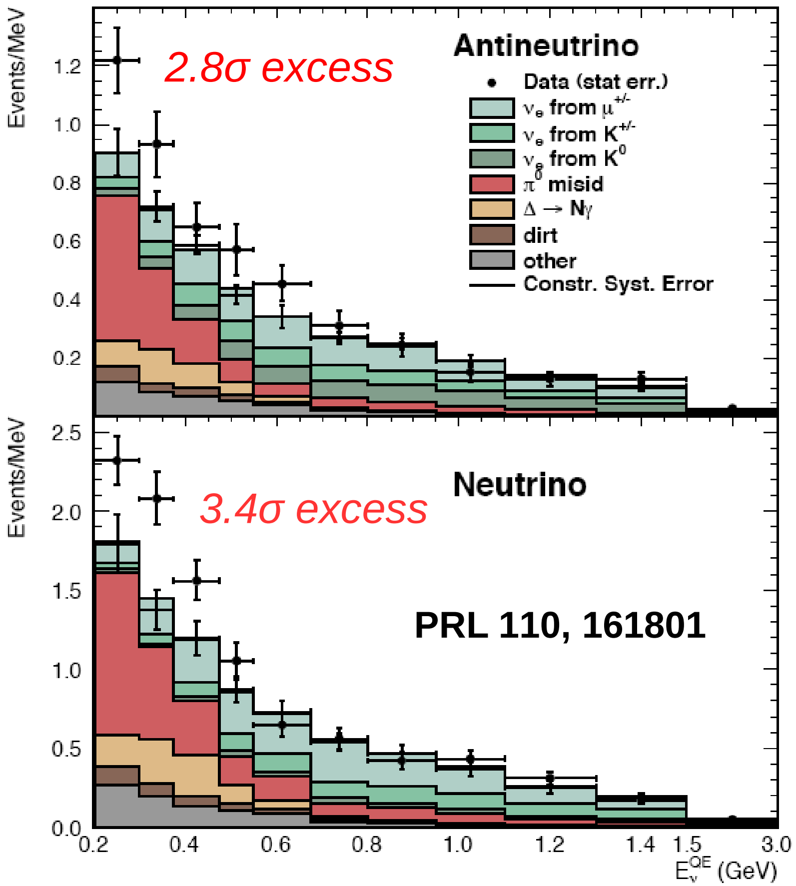
LSND

- Neutrinos from μ^+ decay at rest.
- Liquid scintillator detector.



MiniBooNE

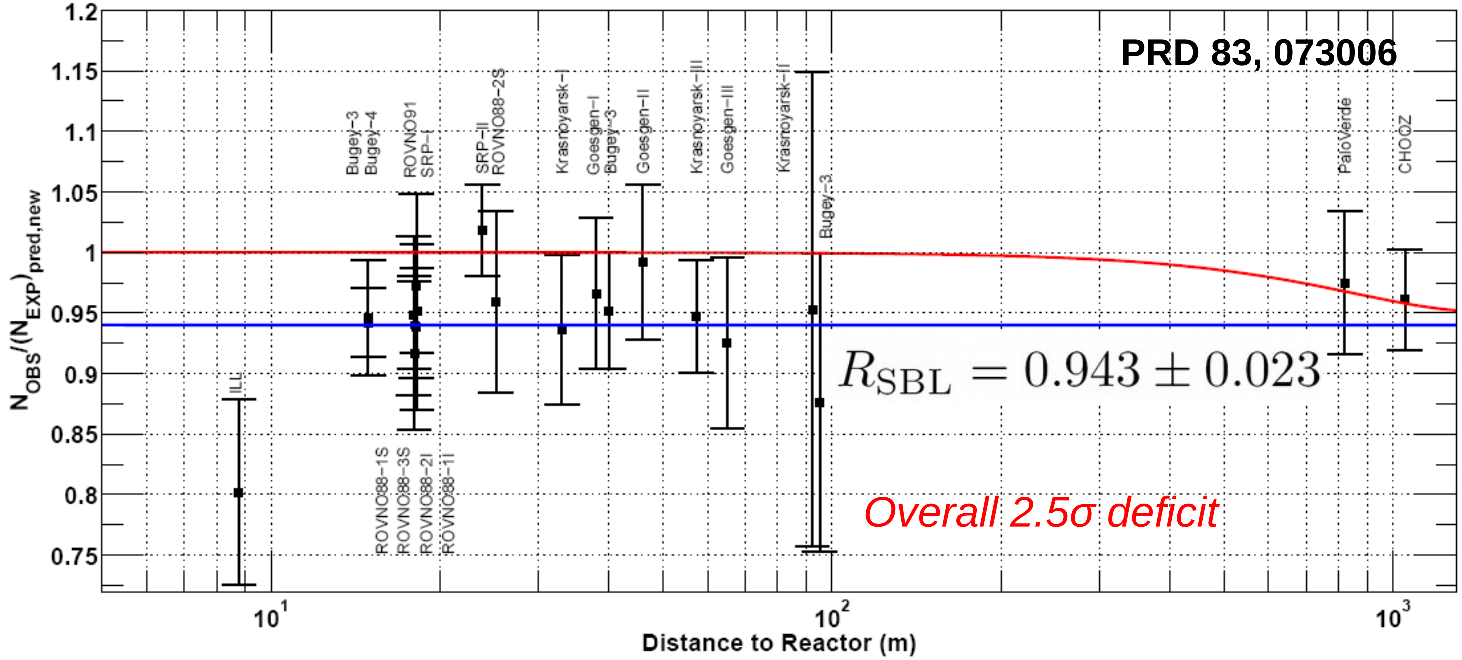
- Neutrinos and antineutrinos from mostly pion decay-in-flight beam.
- Cherenkov detector. Could not distinguish between electron and gamma.
- Different L and E from LSND, but similar L/E.



Short-Baseline Neutrino Anomalies:Reactor and Gallium

Short-Baseline Reactor Experiments

- Electron antineutrinos from β- decay of fission fragments from nuclear reactors.



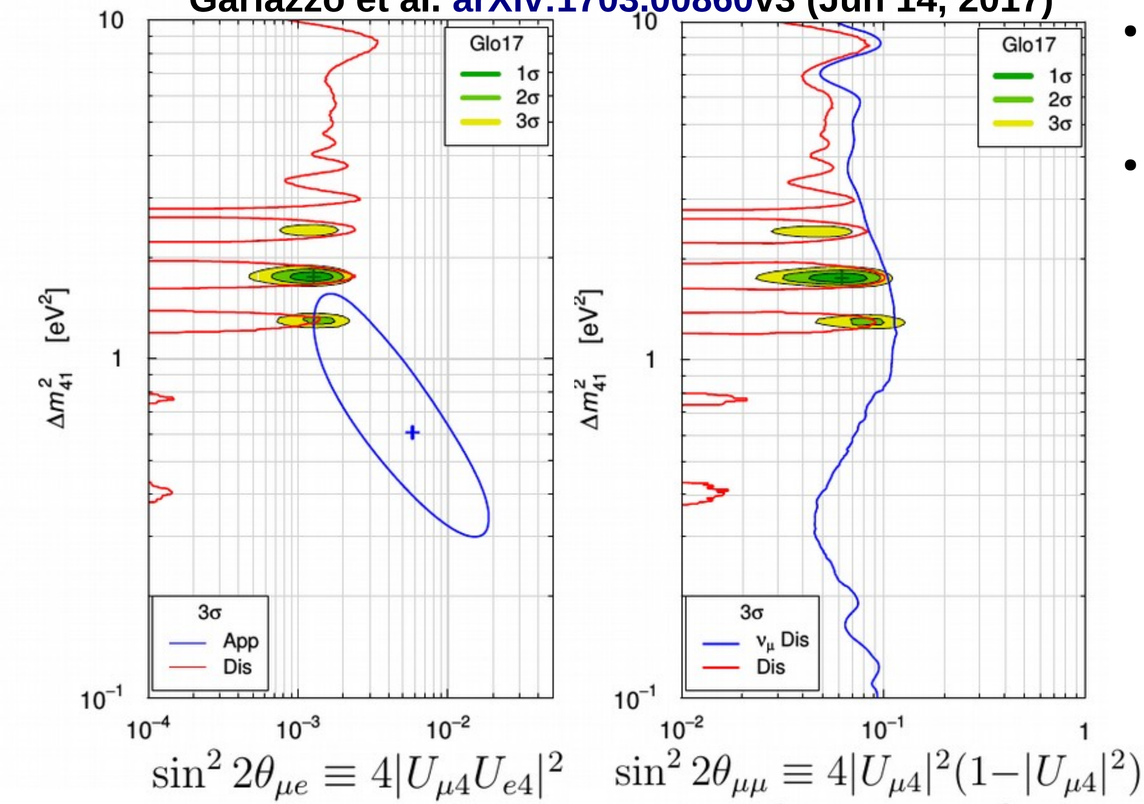
Gallium Experiments

- Electron neutrinos. from decay of calibration sources for solar neutrino experiments GALLEX and SAGE

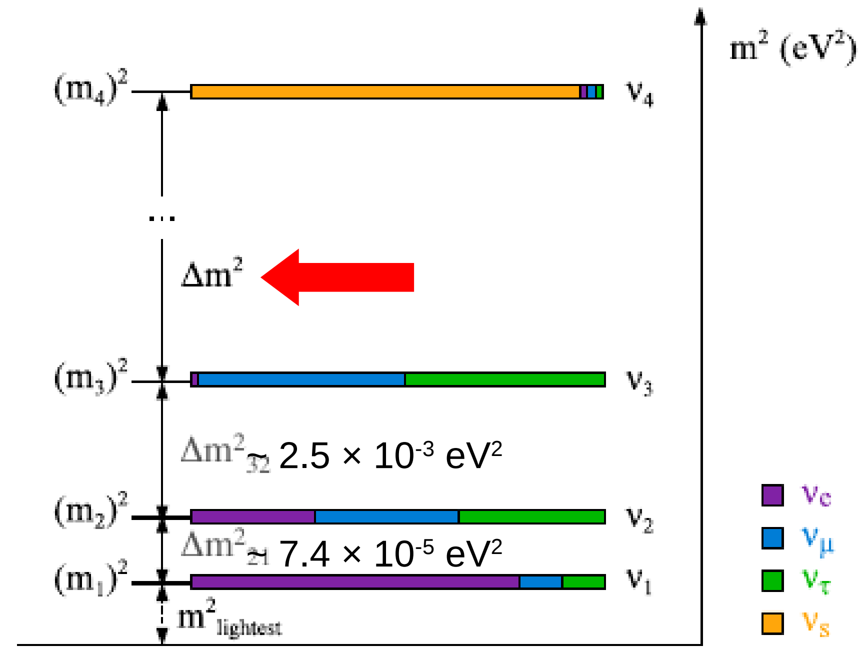
3σ deficit **PRC 83, 065504**

Short-Baseline Neutrino Anomalies

Gariazzo et al. arXiv:1703.00860v3 (Jun 14, 2017)



- All anomalies point to neutrino oscillation with $\Delta m^2 \sim 1$ eV^2.
- Cannot be explained with the 3 Standard Model neutrinos.



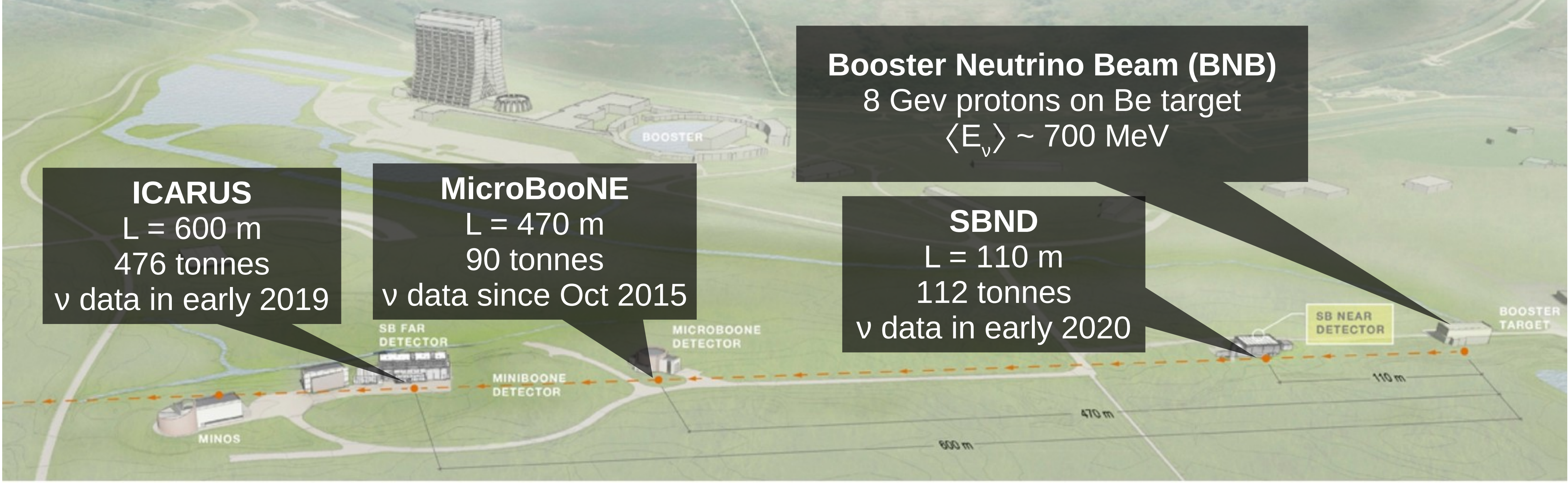
- **Minimal model (3 + 1) requires an additional heavier neutrino mass eigenstate, m_4, mostly sterile.**
- Nevertheless, tension between appearance and disappearance experiments. 3 + 2 or 3 + 3 models do not improve much.
- **Need for definitive confirmation or rejection.**

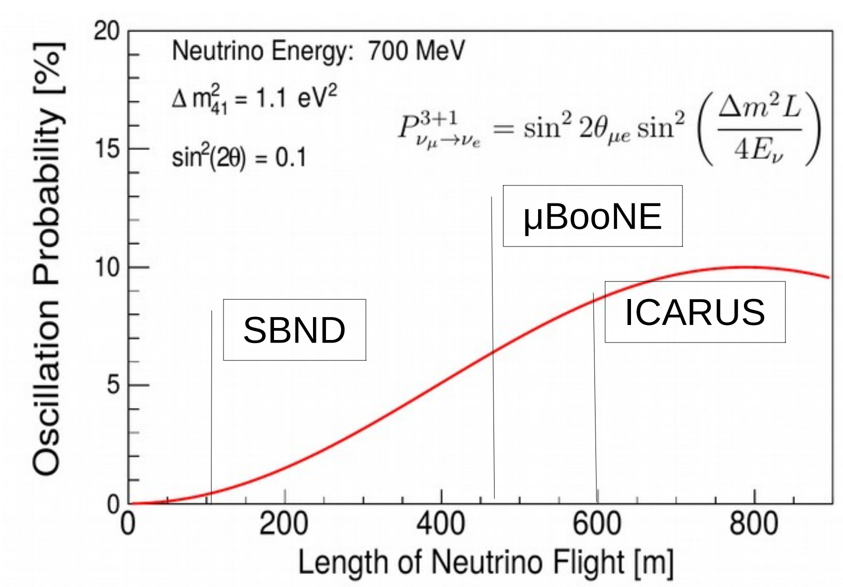
Extended PMNS matrix

$$U_{3+1} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ \vdots & & \vdots & U_{\mu 4} \\ \vdots & & \vdots & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{bmatrix}$$

The Short-Baseline Near Detector & the Short-Baseline Neutrino Program @ Fermilab

The Short-Baseline Neutrino Program at Fermilab





- Neutrino beam from pion decay-in-flight mostly (plus kaon and muon decay).
  - Single horn for focusing charged mesons.
  - Well-known beam, same as MiniBooNE (**PRD 79, 072002**).
- 3 Liquid Argon Time Projection Chamber (LArTPC) detectors.
  - **Same detector technology and target** to reduce systematic uncertainties.
  - **Electron vs gamma discrimination** to investigate MiniBooNE anomaly.

SBND Physics Goals

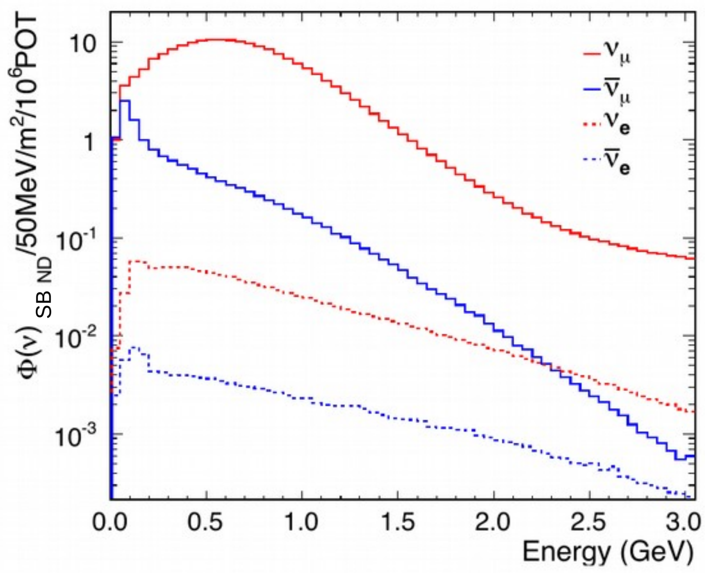
1) Perform a **high-precision measurement of the BNB flux × ν-Ar cross-section before oscillation.**

   The **high degree of correlation between near and far detectors (same beam, same neutrino target, same detector technology)** grants a **reduction on the systematic uncertainties.**

   Boost in the sensitivity for oscillations at $\Delta m^2 \sim 1\ eV^2$ to conclusively address the short-baseline neutrino anomalies.

2) Perform **high-precision measurements of cross-sections of ν_μ and ν_e on Ar to improve our knowledge of neutrino-nucleus interactions and reduce systematic uncertainties on oscillation searches, for both short and long baselines.**

3) Develop further the LArTPC detector technology.

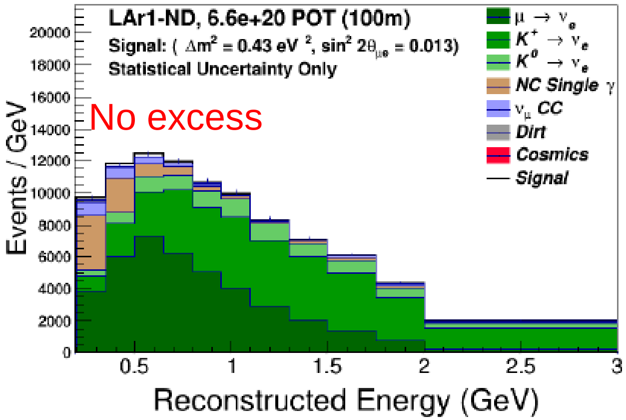


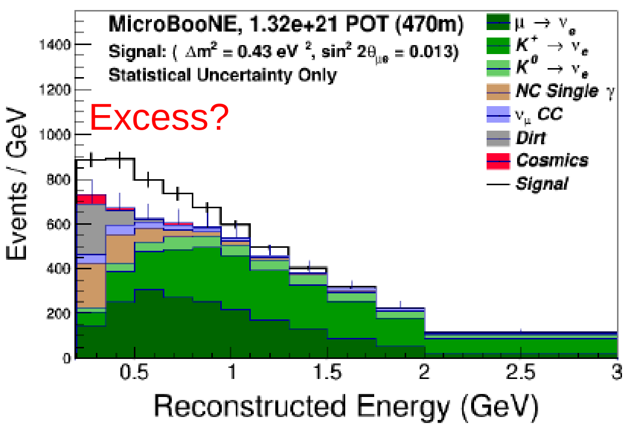
BNB flux by MiniBooNE; PRD 79, 072002

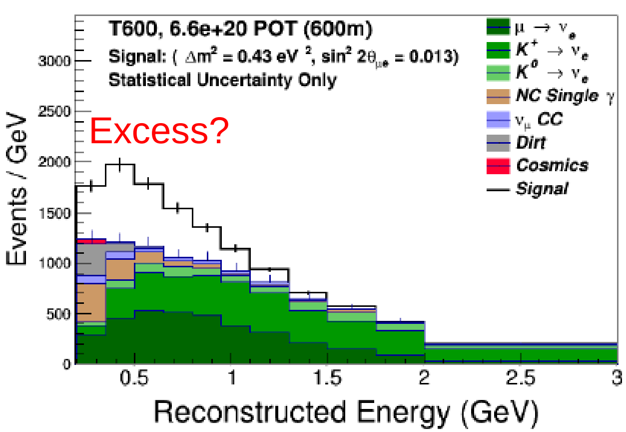
Source of Uncertainty	ν_μ	ν_e
π^+ production	14.7%	9.3%
π^- production	0.0%	0.0%
K^+ production	0.9%	11.5%
K^0 production	0.0%	2.1%
Horn field	2.2%	0.6%
Nucleon cross sections	2.8%	3.3%
Pion cross sections	1.2%	0.8%

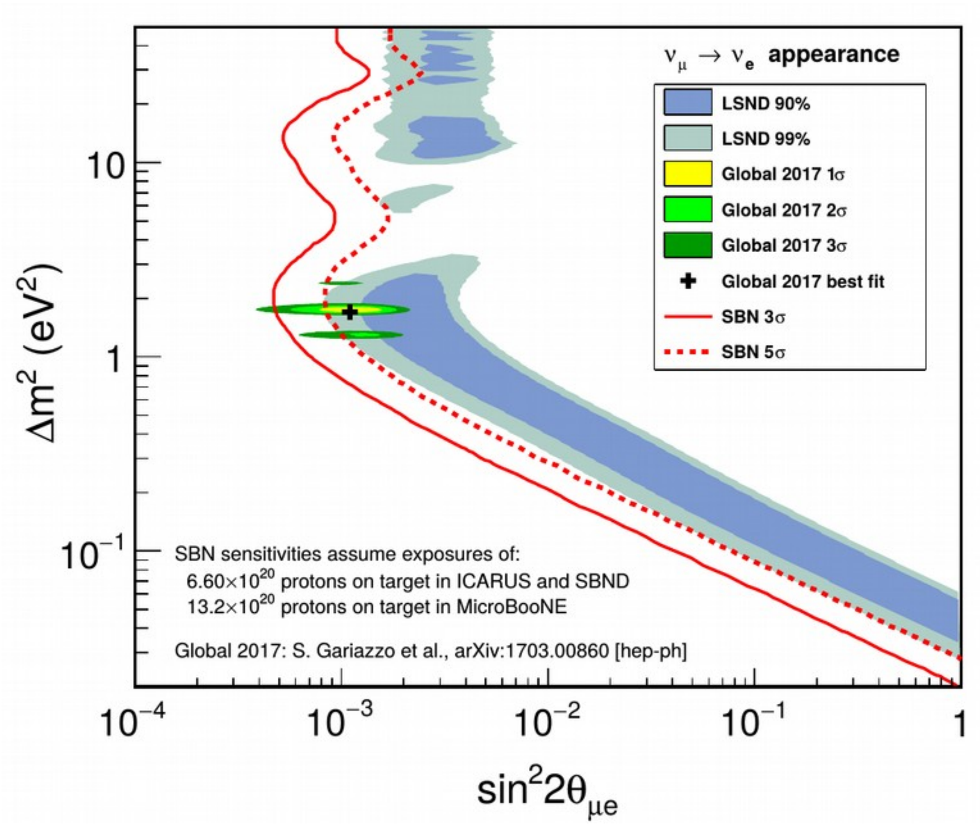
SBND Physics: ν_e appearance

arXiv:1503.01520









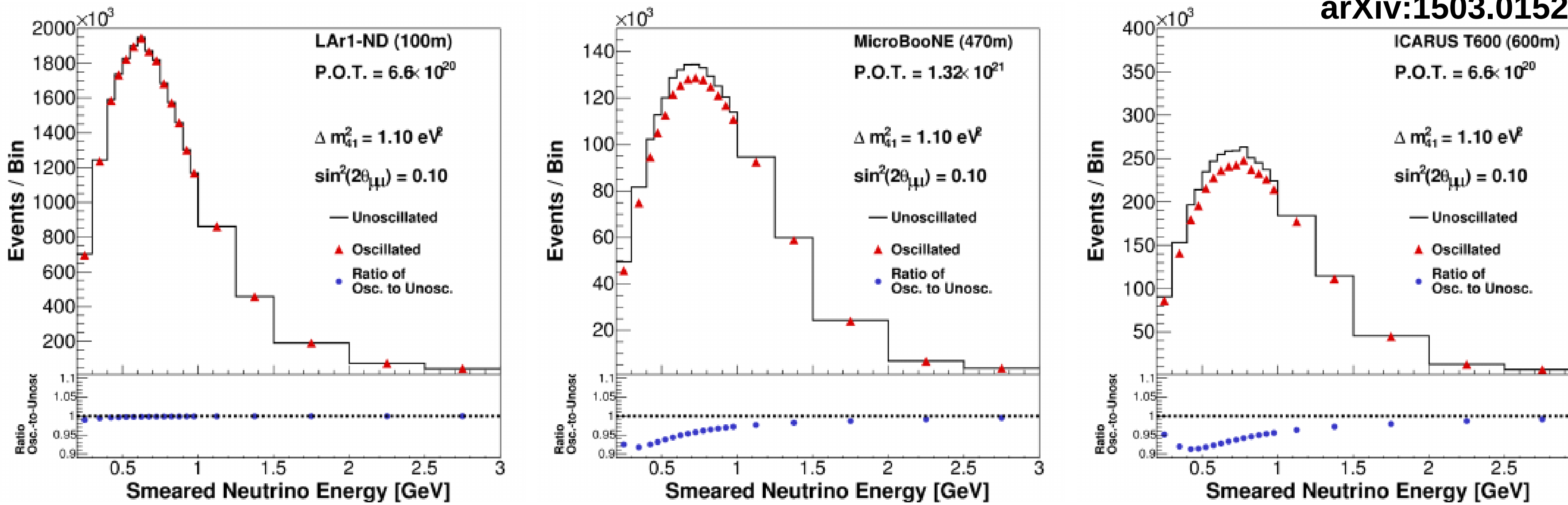
- **SBND will measure the intrinsic ν_e component of the BNB flux with large statistics before any oscillation affects it.**
- MicroBooNE & ICARUS will search for an excess of ν_e using SBND measurement as reference.

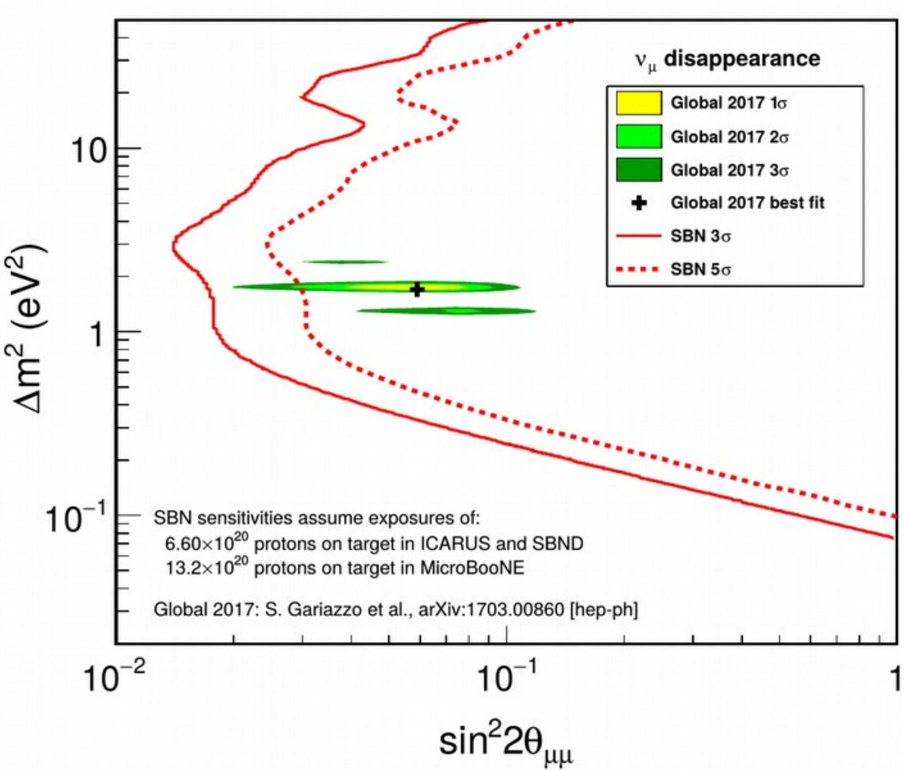
$$P^{3+1}_{\nu_\mu \to \nu_e} = \sin^2 2\theta_{\mu e} \sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right) \qquad \sin^2 2\theta_{\mu e} \equiv 4|U_{\mu 4}U_{e4}|^2$$

- SBN will be able to explore the LSND-favored region with 5σ.

SBND Physics: ν_μ disappearance

arXiv:1503.01520





- ν_e appearance must be accompanied by ν_μ disappearance.

$$\sin^2 2\theta_{\mu e} \equiv 4|U_{\mu 4}U_{e4}|^2$$

$$\sin^2 2\theta_{\mu\mu} \equiv 4|U_{\mu 4}|^2(1-|U_{\mu 4}|^2)$$

$$P^{3+1}_{\nu_\mu\to\nu_\mu} = 1 - \sin^2 2\theta_{\mu\mu}\sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$

- SBND will measure the unoscillated ν_μ flux.
- MicroBooNE & ICARUS will search for a deficit of ν_μ.

Only possible thanks to the reduction on the flux normalization systematic uncertainty brought by SBND.

- SBN covers almost the full allowed region region with 5σ.

SBND Physics: neutrino-argon cross-sections

$\nu_\mu CC$, BNB/FHC, 6.6×10^{20} POT, 112 tonnes active mass ~ 3 years of data taking

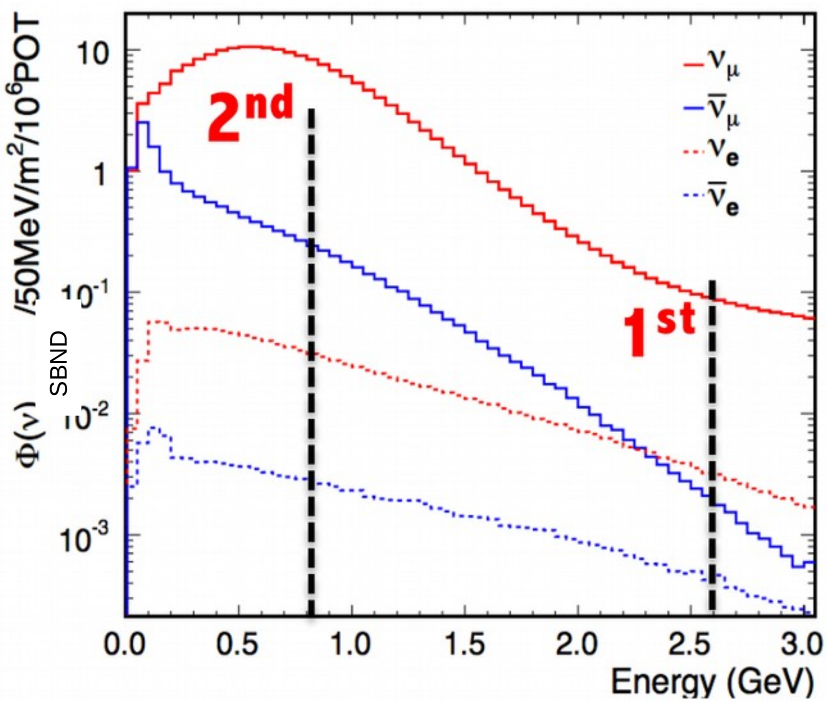
	GENIE Model Configurations	
Hadronic Final State	**G17_01b**	**G17_02a**
Inclusive	5,389,168	5,329,241
$0\ \pi$	3,814,198	3,744,108
$0\ \pi$ + 0p	27,269	34,696
$0\ \pi$ + 1p (> 20 MeV)	1,629,252	2,235,338
$0\ \pi$ + 2p (> 20 MeV)	1,150,368	637,535
$0\ \pi$ + 3p (> 20 MeV)	413,956	229,239
$0\ \pi$ + >3p (> 20 MeV)	396,212	263,727
$1\ \pi^+$ + X	942,555	1,021,212
$1\ \pi^-$ + X	38,012	21,242
$1\ \pi^0$ + X	406,555	370,666
$2\ \pi$ + X	145,336	131,308
$\geqslant 3\pi$ + X	42,510	40,702
Physical Process		
QE	1,569,073	2,827,928
MEC	1,398,773	513,453
RES	1,816,570	1,539,159
DIS	581,905	441,057
Coherent	22,846	7642

G17_01b: Updated empirical model / **G17_02a**: Theory-driven model

C. Andreopoulos, NuInt 17

Also: (per year)
- $\approx$ 350k NCπ^0 events
- $\approx$ 12k ν_eCC events
- $\approx$ 1k charm (QE) events
- $\approx$ 400 $\nu + e^-$ events

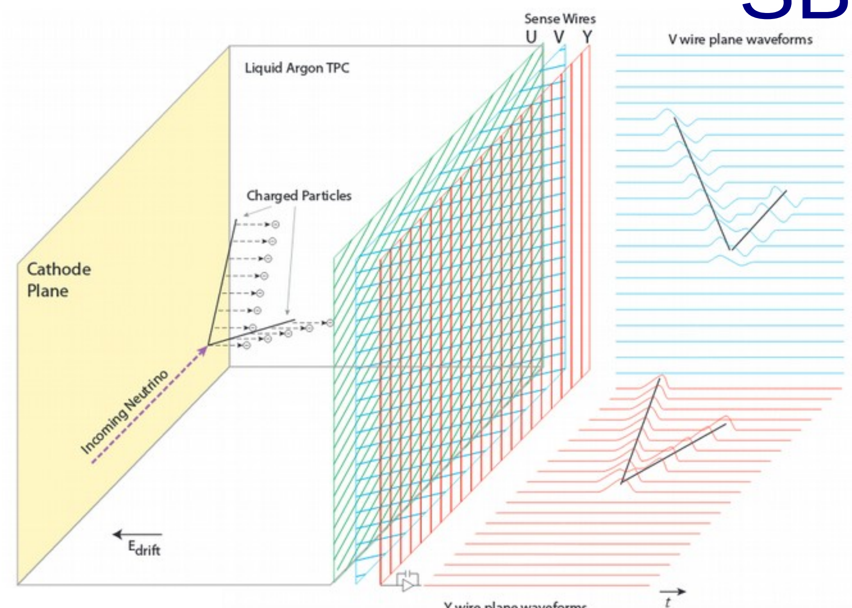
DUNE oscillation maxima

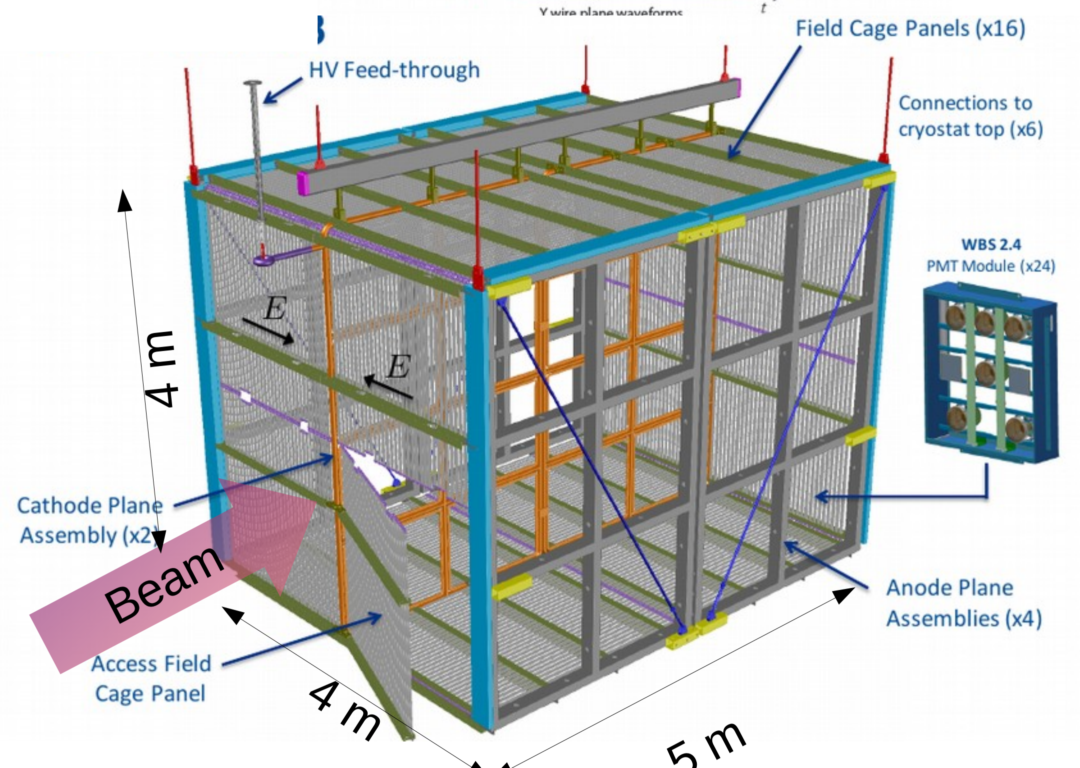


- Large statistics of ν-Ar interactions. *3-year MicroBooNE dataset in 2 months!*
- **Discriminate between models**, **tune MC generators** and **reduce systematic uncertainties for oscillation analysis**.

The Short-Baseline Near Detector

SBND TPC

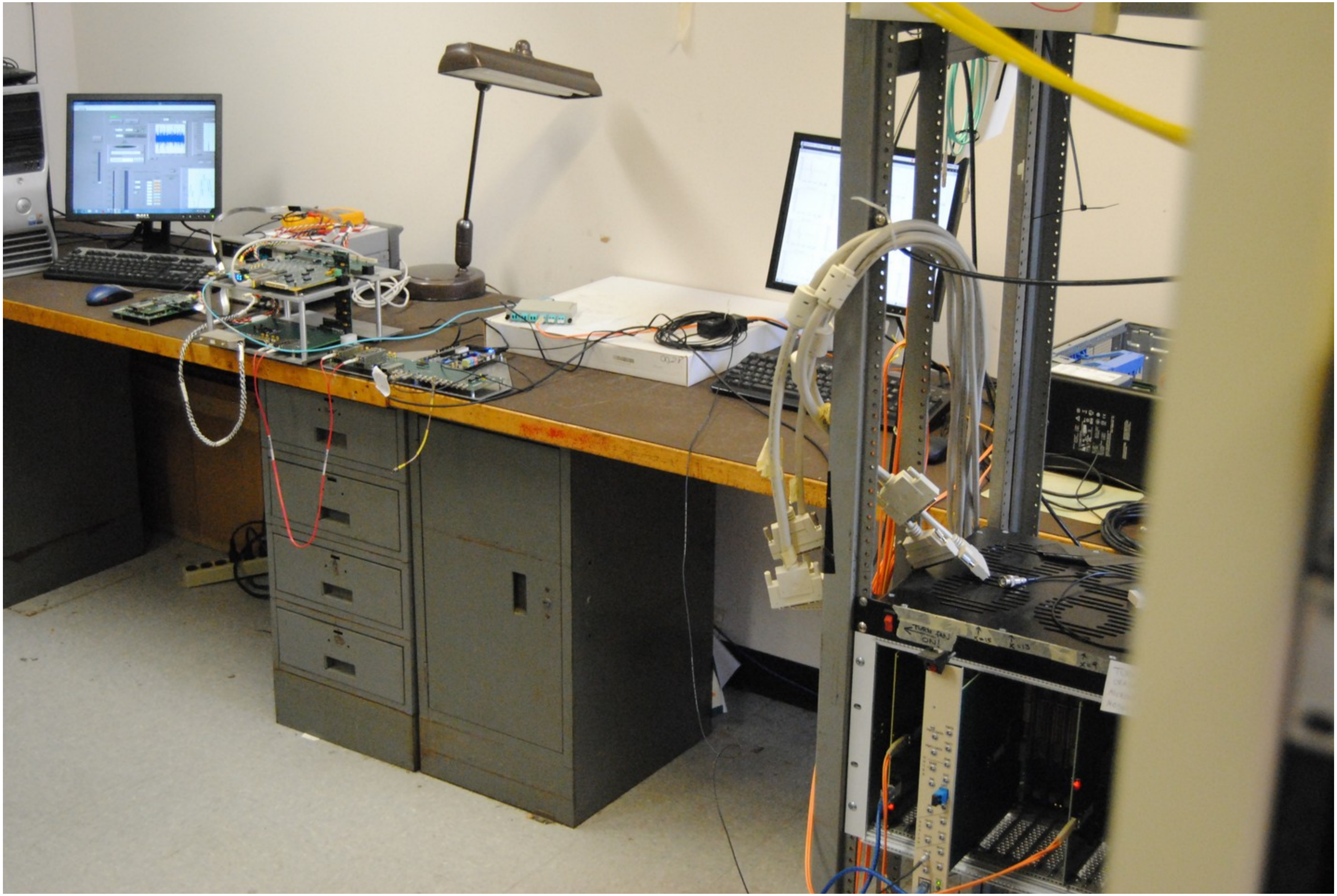




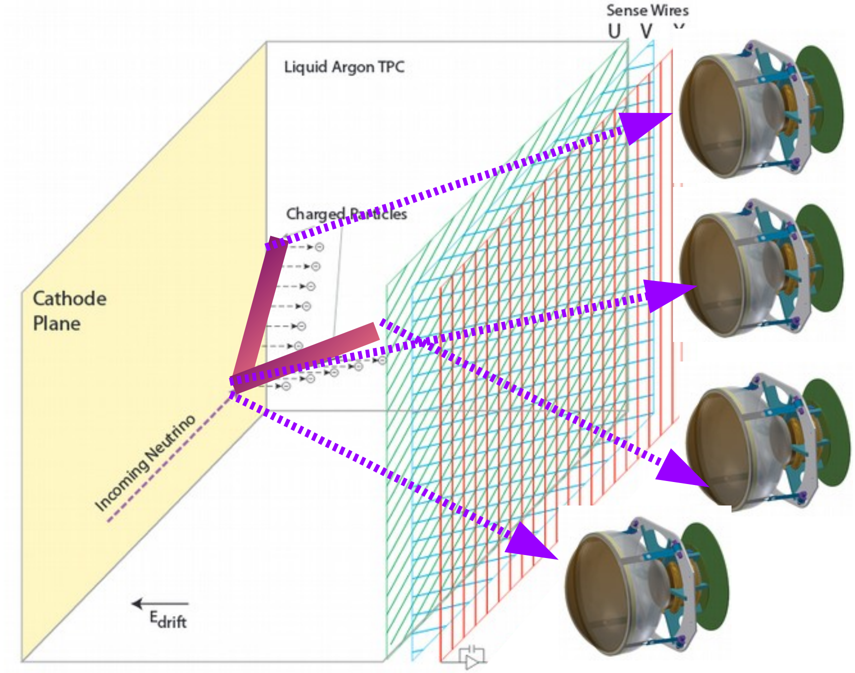
- 112 tonnes of liquid argon (active).
- Charged particles ionize Ar. Electrons are drifted towards wires using an electric field

  E_{drift} = 500 V/cm.
- Cathode Plane Assembly in the middle of the TPC at -100 kV.
- **2 drift volumes. Maximum drift length: 2 m. Maximum drift time: 1.28 ms.**
- On both sides, three wire planes to reconstruct 3D interaction.
  - Two induction planes with wires at ± 60º from vertical. One collection plane with vertical wires.
  - 3 mm wire pitch. **11264 channels.**
- Cold front-end electronics by Brookhaven National Laboratory.
  - 2 MHz digitization. On-going study to select cold or warm ADC electronics.
- Custom back-end electronics by Columbia University Nevis Laboratories.

First end-to-end test of TPC readout electronics



SBND PMT system



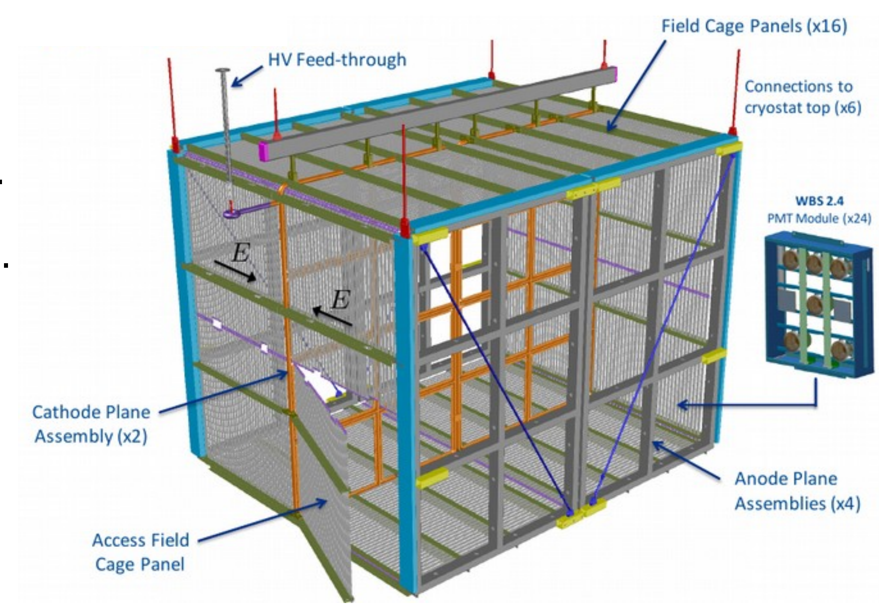
- Charged particles excite Ar, causing scintillation.
  - ~ 40000 photons/MeV (at 0 V/cm).
  - UV light (~ 128 nm). Wavelength shifter required: TPB.
- Online: trigger on ν events.
- Offline: determine t_0 of interactions.

- 160 8” Hamamatsu R5912 Cryogenic PMTs mounted behind the wire planes.

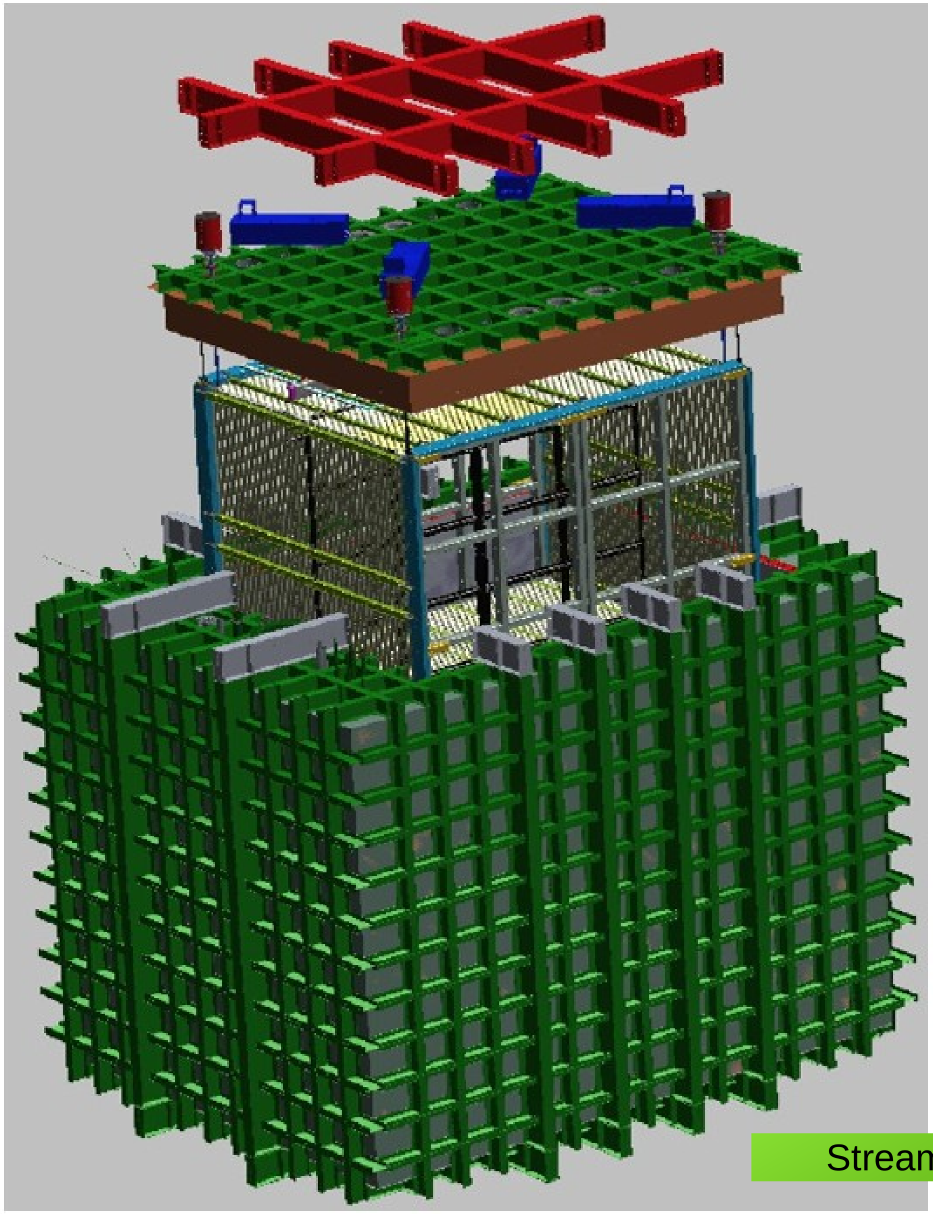
  (≥ 24 not TPB-coated to detect Cherenkov light).
- CAEN flash-ADC (500 MHz) readout electronics.
- R&D opportunities:

  Possibility to use wavelength-shifting reflector foils to increase collected light.

  Additional photon detection systems: light guide bars and photon traps.

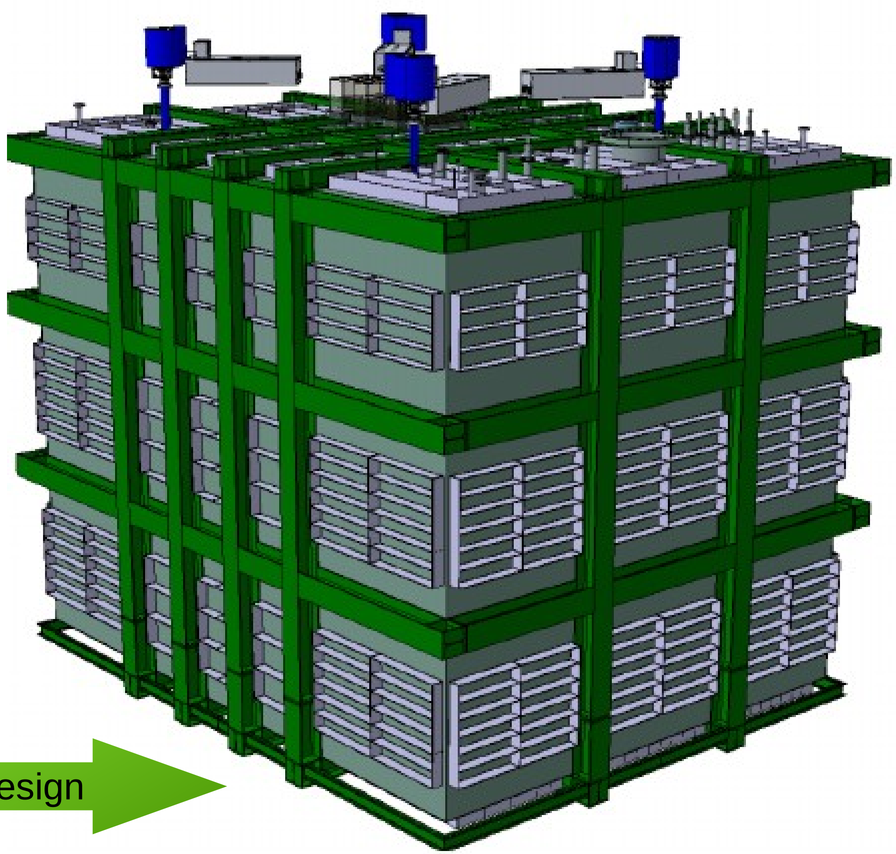


SBND cryostat



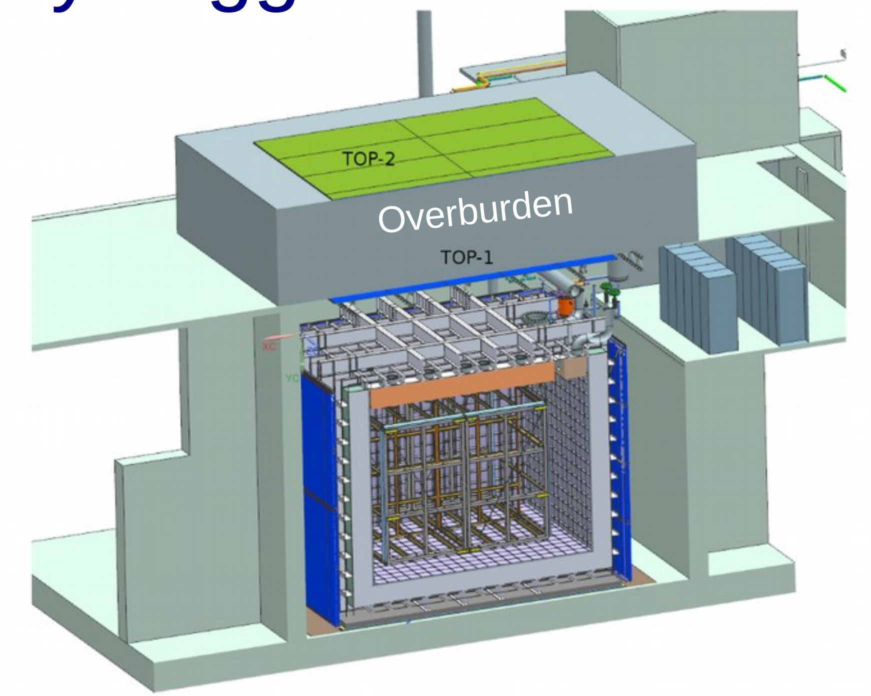
- Membrane cryostat.
- Design by CERN.
- 3rd generation prototype for DUNE.

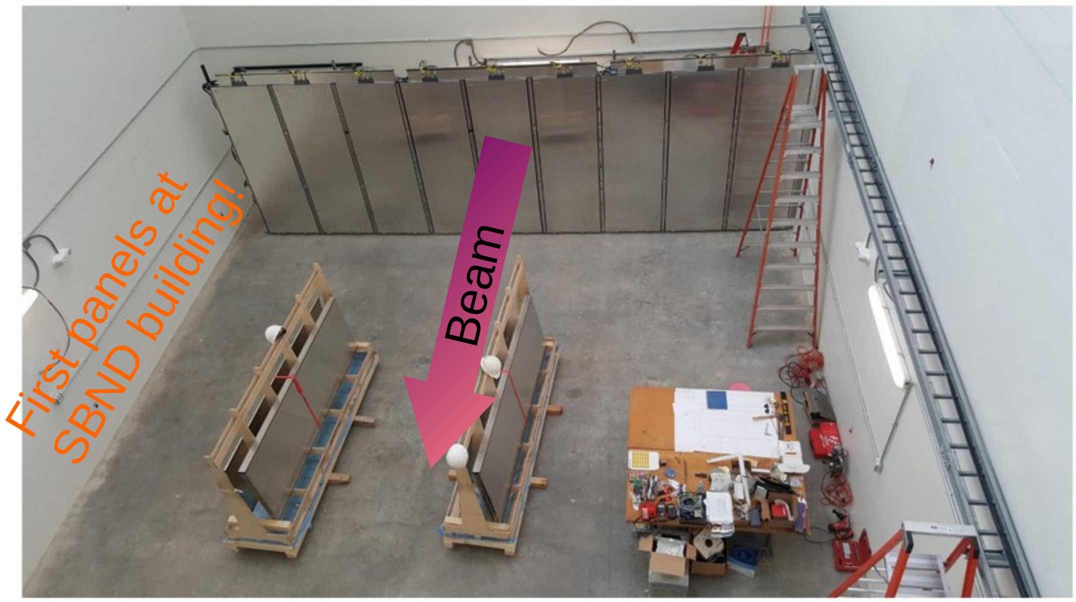
Streamlined design

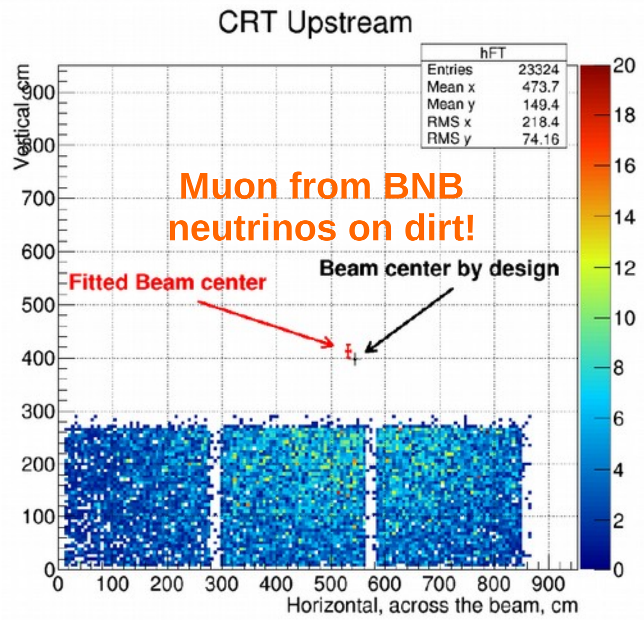


SBND Cosmic Ray Tagger

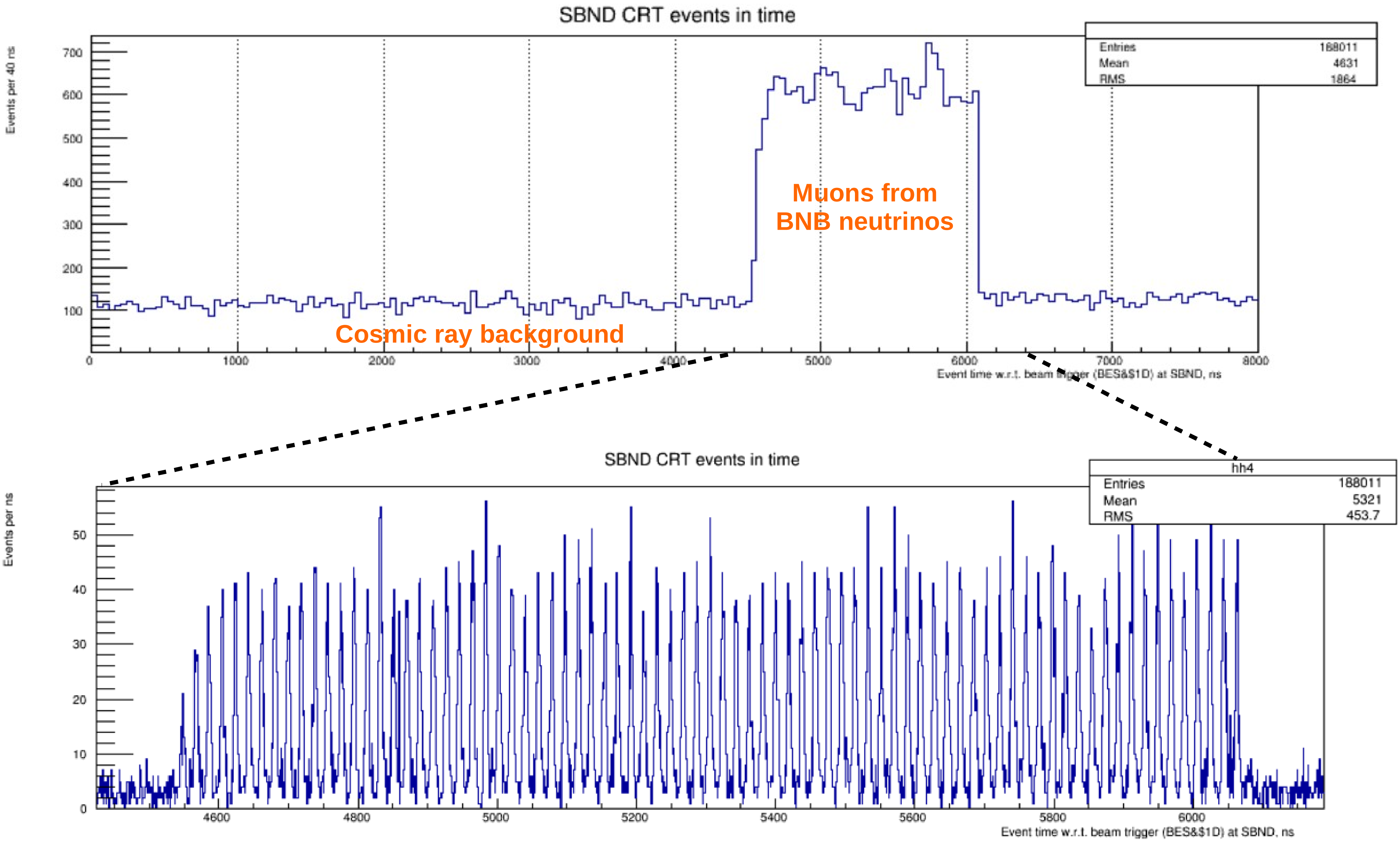
- **Detector at surface.** Only 3 m of concrete overburden.
- **Identify cosmic rays entering the detector.**
- Plastic scintillator strips arranged in planes with two layers for x-y coincidence.
- Readout by Hamamatsu S12825-050P SiPMs + custom electronics made by Universität Bern.
- 94% coverage of cosmic ray flux.



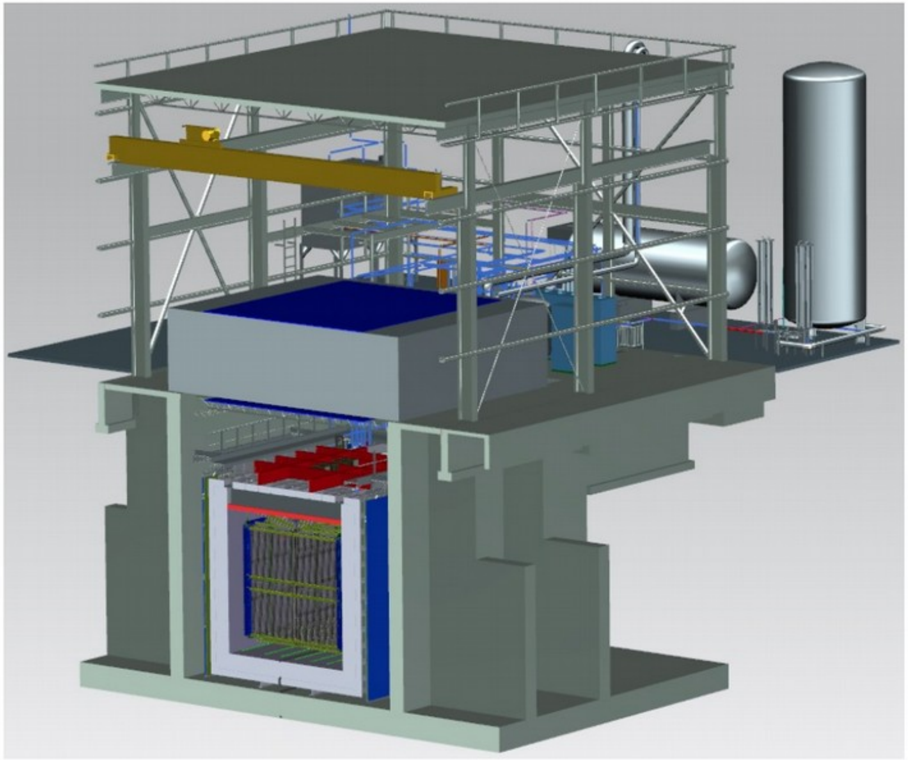


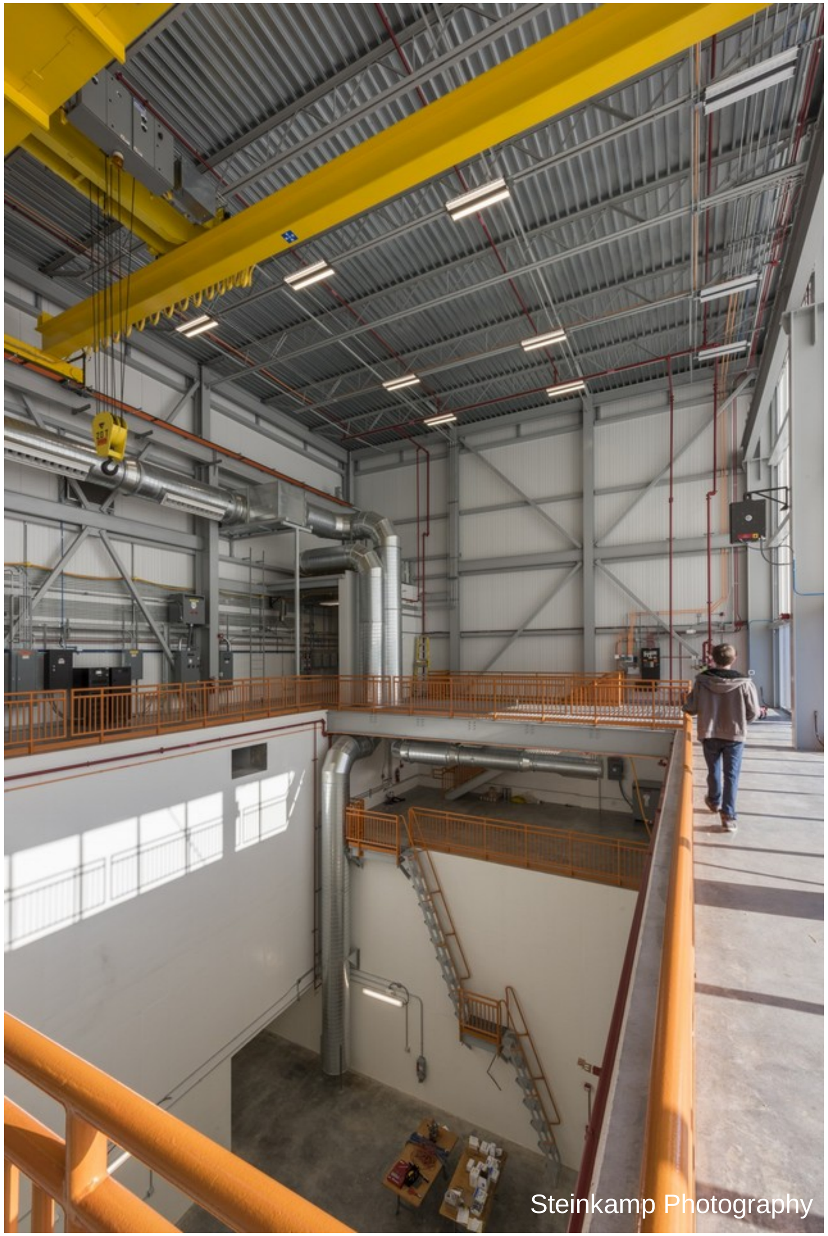


SBND Cosmic Ray Tagger



SBND Building





Conclusions

- Short-baseline neutrino program using the Booster Neutrino Beam at Fermilab to **conclusively address anomalies potentially caused by sterile neutrinos at $\Delta m^2 \sim 1$ eV^2**.
- 3 LArTPC detectors: **SBND**, MicroBooNE, ICARUS.
- SBND will **measure the neutrino beam with high statistics before oscillation develops**, reducing systematic uncertainties for oscillation analysis.
- SBND will accumulate an **unprecedented number of ν-Ar interactions**, enabling a high-precision cross-section program, useful for SBN and DUNE.
- SBND construction is on-going. **Neutrino run in early 2020!**

The SBND Collaboration

Updated June 2017

Including both scientific and technical personnel

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30 graduate students

Backup

Electron vs gamma discrimination with LArTPC