Status of the Short-Baseline Near Detector (SBND) at Fermilab

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University of Sheffield, UK

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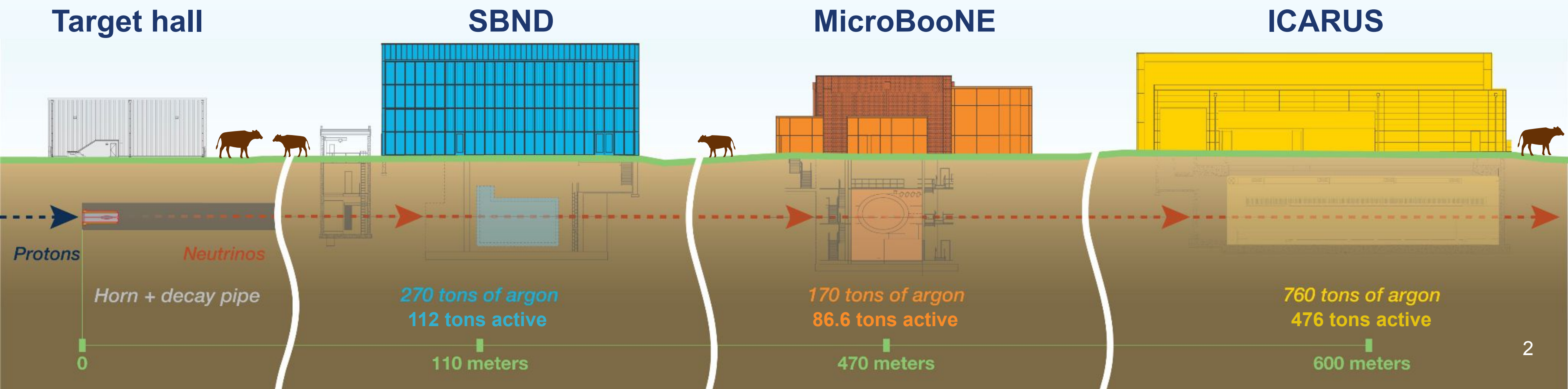
International Conference on High Energy Physics
July 8th 2022

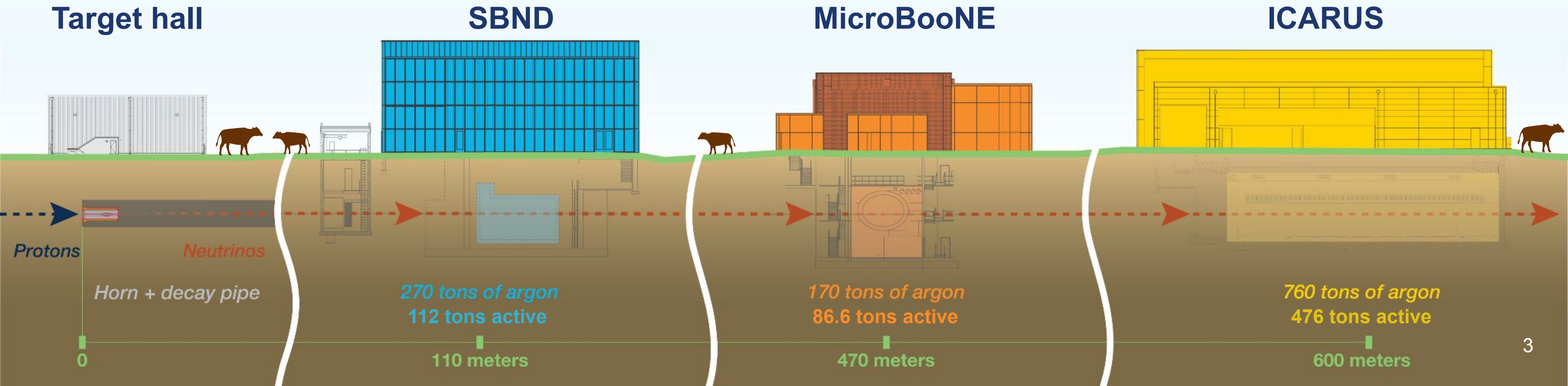
The Short Baseline Near Detector (SBND)

The Short Baseline Neutrino (SBN) program



The Short Baseline Near Detector (SBND)

- The SBN program consists of three liquid argon time projection chamber (LArTPC) detectors in the Booster neutrino beamline (BNB) at Fermilab
- Designed to resolve experimental anomalies in the search for sterile neutrinos
- All detectors will make high-precision neutrino-Argon cross-section measurements
- Each detector will give valuable LArTPC operational experience for DUNE



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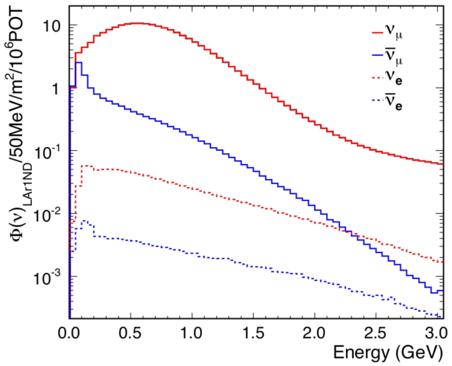
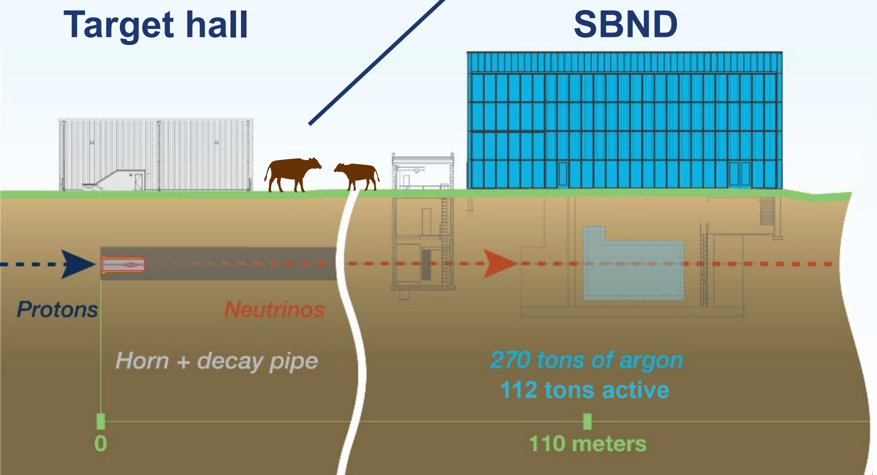


- BNB flux primarily composed of $\mathbf{\nu_\mu}$
- Intrinsic $\bar{\nu}_\mu$,ν_e & $\bar{\nu}_e$ also present, *in decreasing order of prominence*



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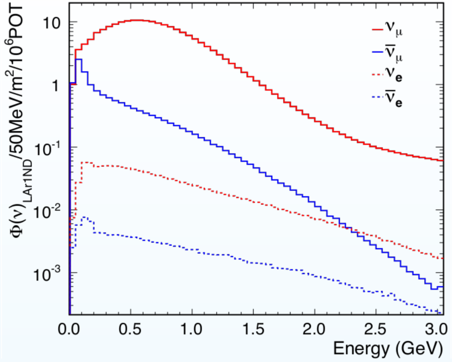

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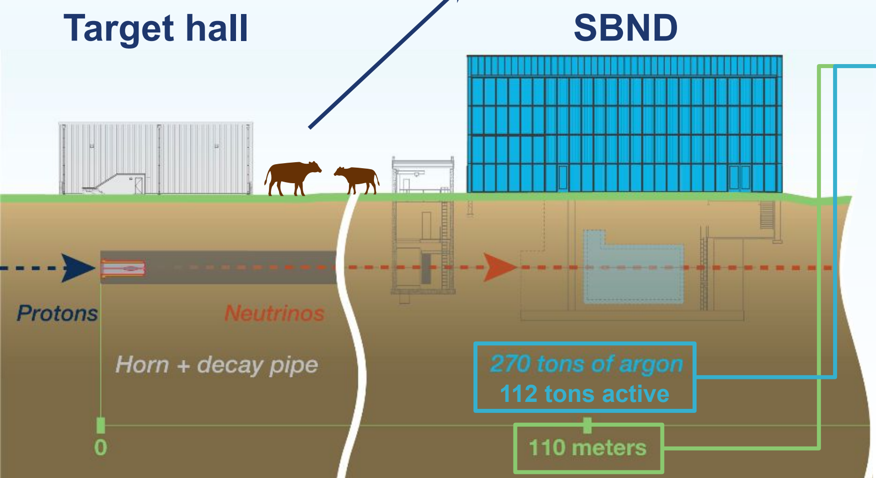
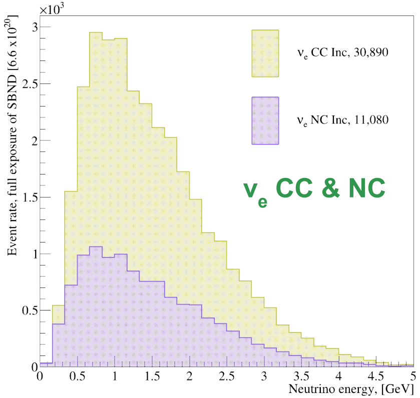
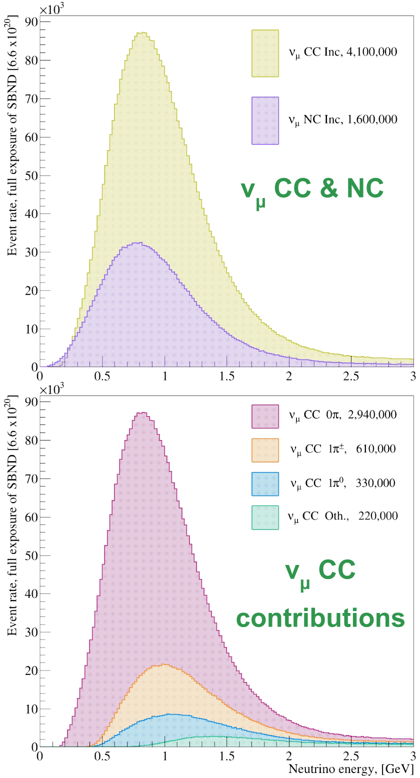
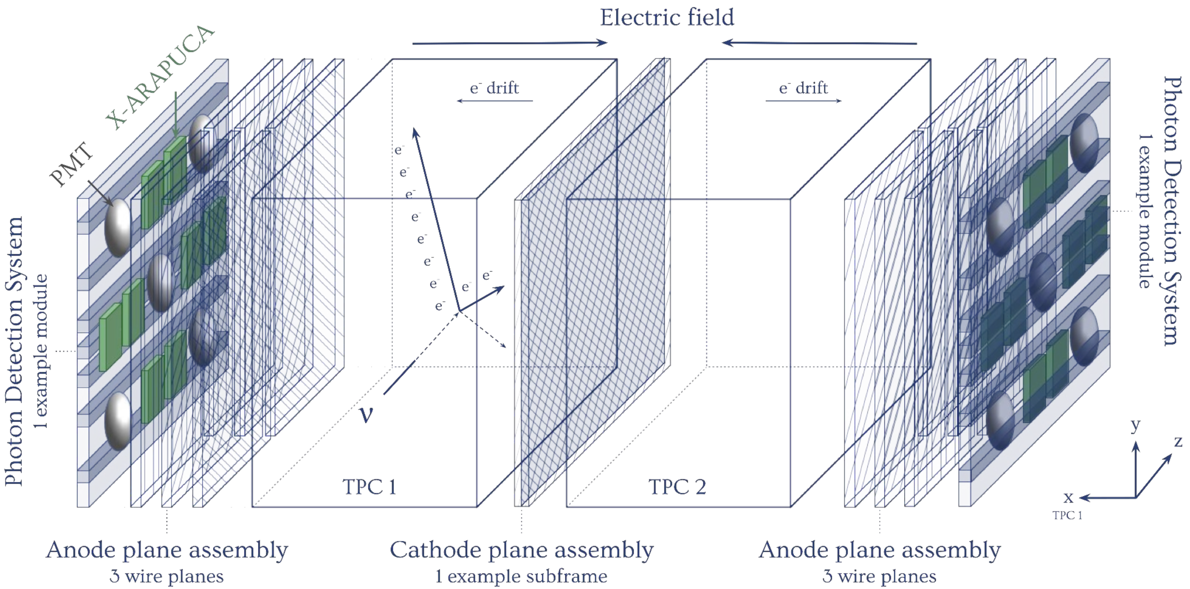


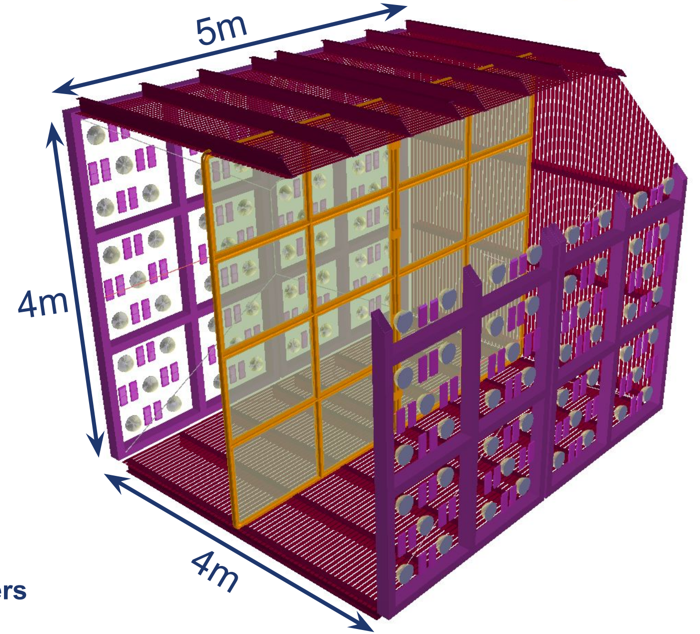




Over **1 million** neutrinos from the BNB will interact within SBND **per year**

The SBND detector systems: LArTPC & PDS





SBND operation principles are similar to that of MicroBooNE, except:

- The CPA is located at the centre of the detector resulting in **two time projection chambers**
- Photon detection system contains **X-Arapucas** as well as PMTs
- **500 V/cm electric field**
- Cold electronics and digitization …

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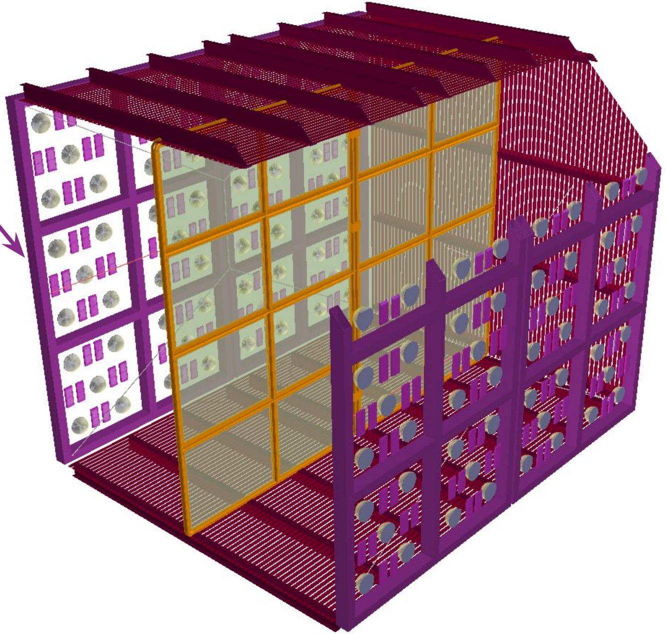
Novel photon detection system (**PDS**). Testing components which will be used in **DUNE.**

120 PMTs
192 X-Arapucas



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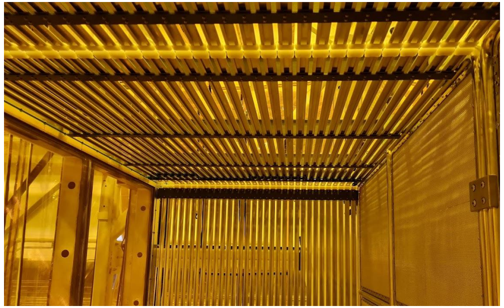

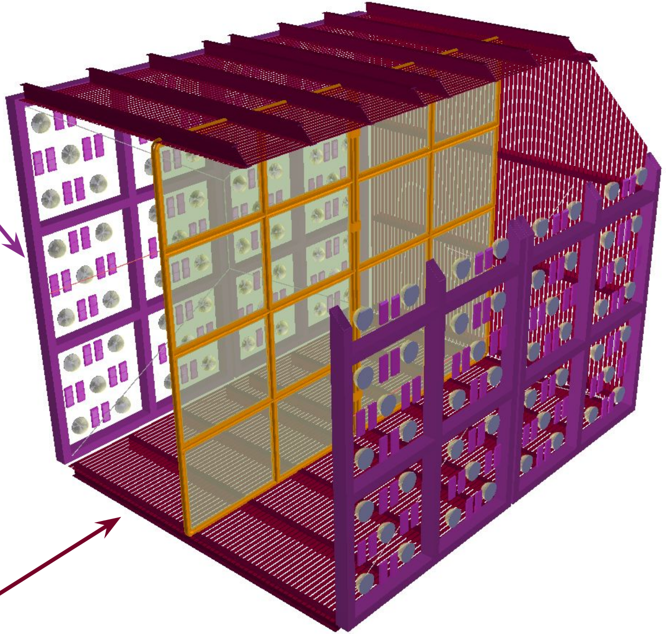

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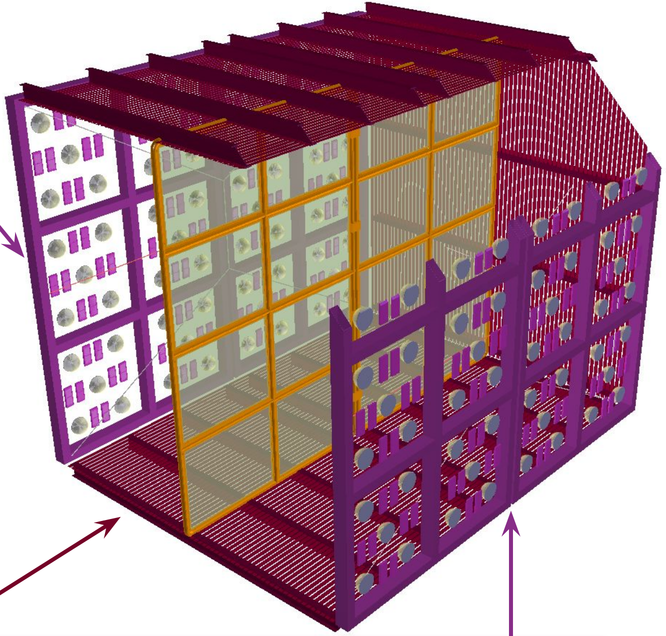

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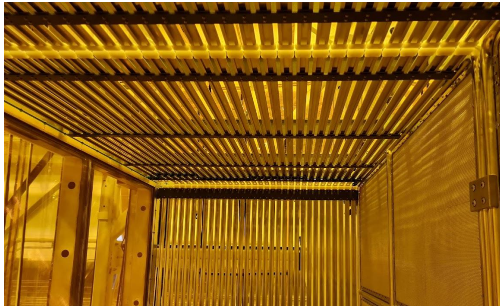

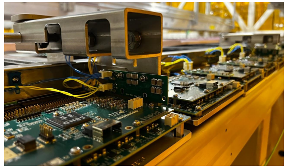

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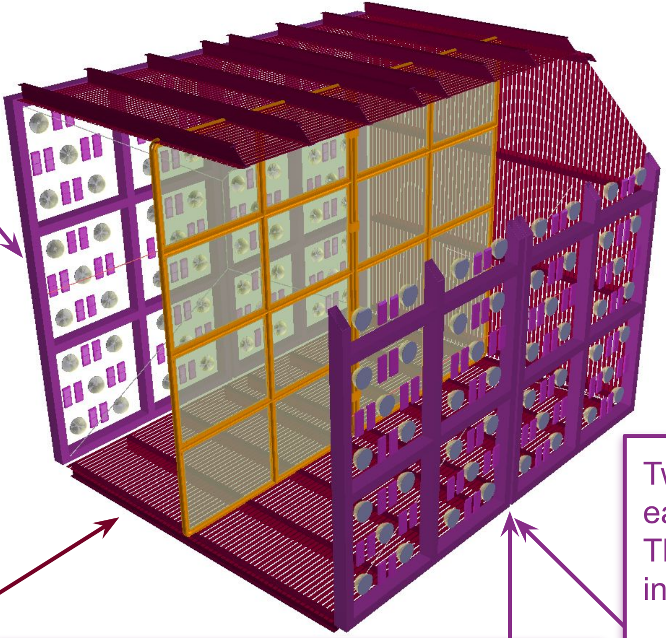

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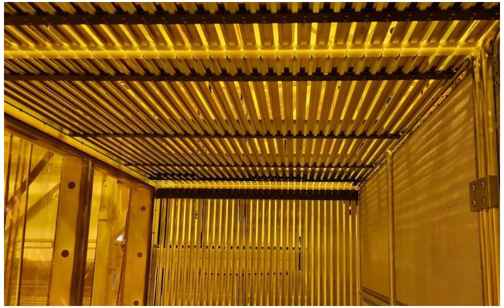

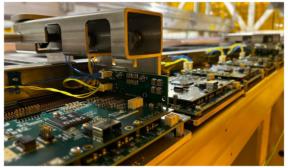

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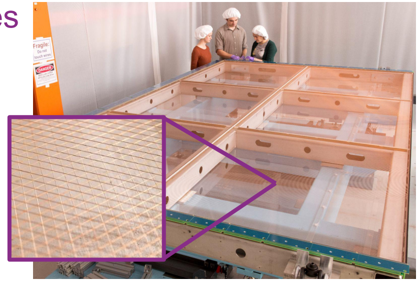
Two anode plane assemblies (**APAs**) on each side of the detector in front of the PDS. Three wire planes in each APA.

Wire θ_Y: **0, ± 60°**

Wire & plane spacing: **3 mm**

JINST 15, P06033 (2020)



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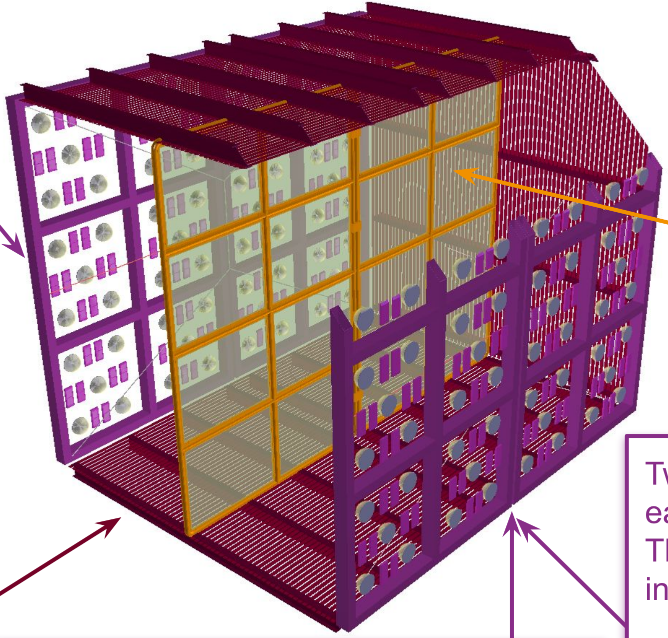
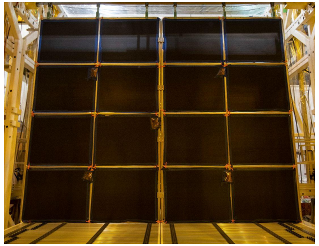


The cathode plane assembly (**CPA**) splits the detector into **two TPCs.**

TPB-coated reflective foils to convert VUV into visible light for the PDS.



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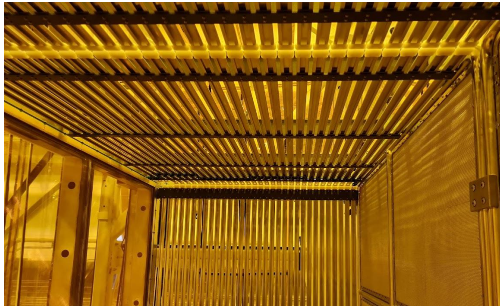

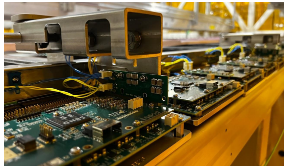

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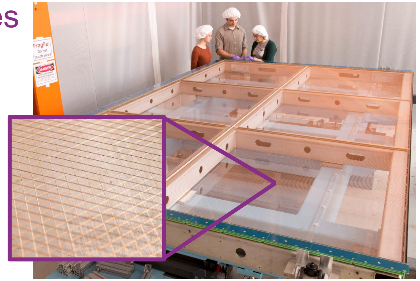
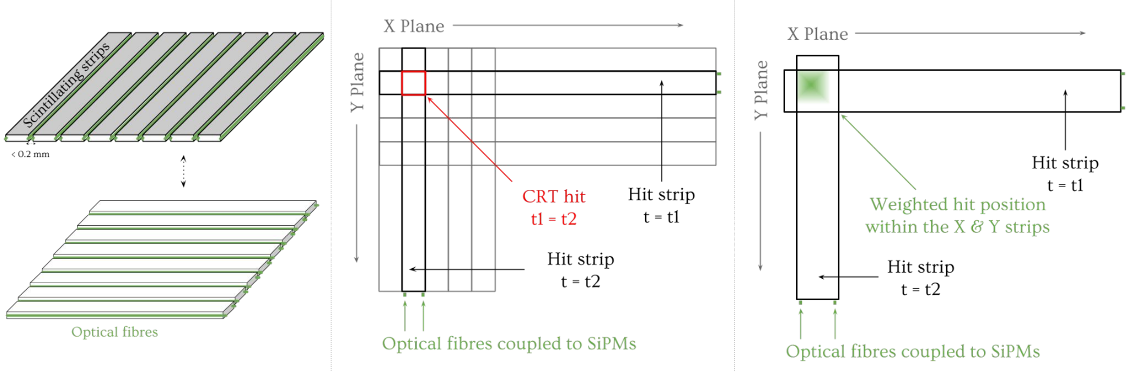
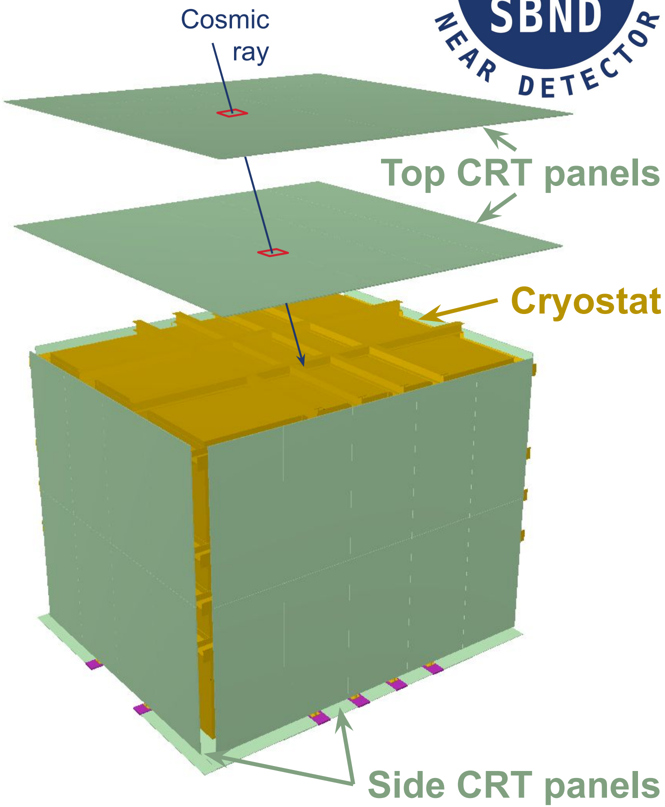


The SBND detector systems: CRT

- The SBND will be entirely surrounded by planes of cosmic ray taggers (**CRTs**)
    - 4π coverage important for surface detectors
    - Two panels on top for telescopic tagging

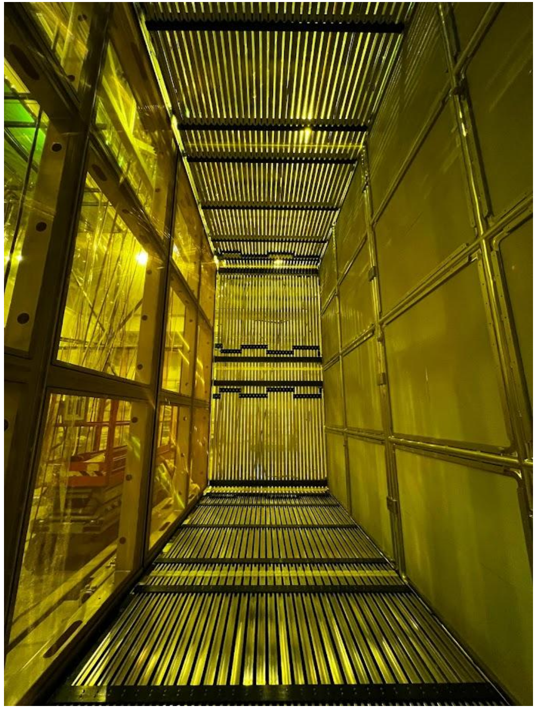
Each CRT plane comprises panels of scintillator strips in a cross formation for precise hit reconstruction





Breaking news!

As of 13th June 2022: **The SBND TPC is complete**



Breaking news!

As of 13th June 2022: **The SBND TPC is complete**

- ✓ APAs installed
- ✓ CPAs installed
- ✓ FC installed
- ✓ Cold-electronics installed
- ✓ **TPC is CLOSED**

Next steps

PDS installation, **TPC transport to SBN-ND building**, **installation in cryostat**

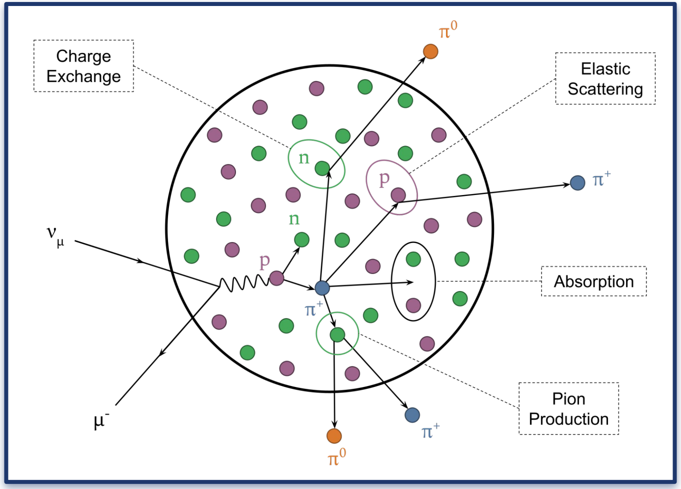
Physics with the near detector

- SBND will provide the largest dataset of neutrino-Argon cross-section measurements in the few-GeV energy range

Interaction cross-section measurements

Argon has a **heavy nucleus** which facilitates final state interactions (**FSI**) following the initial neutrino interaction

- These FSIs modify the observed final state of the neutrino interaction
- This makes reconstructing the initial neutrino interaction challenging



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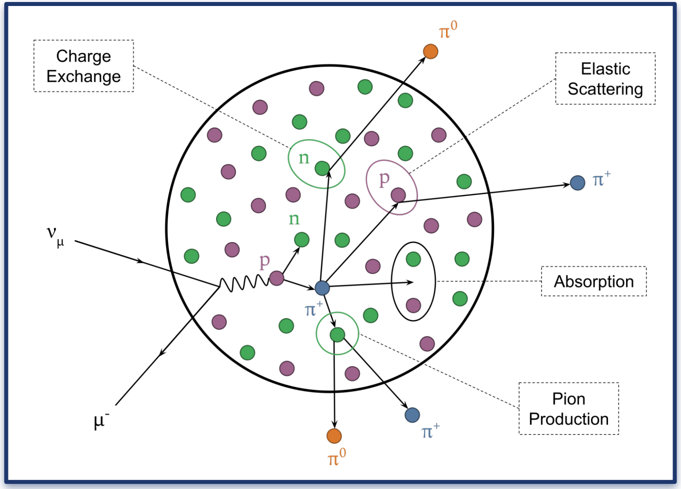

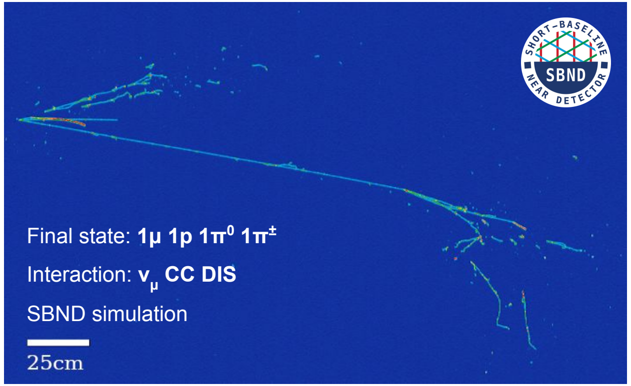

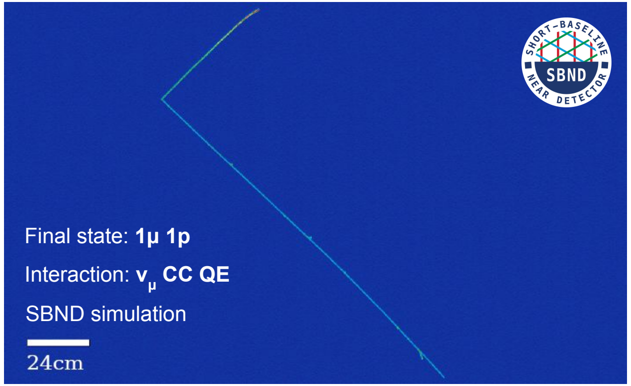

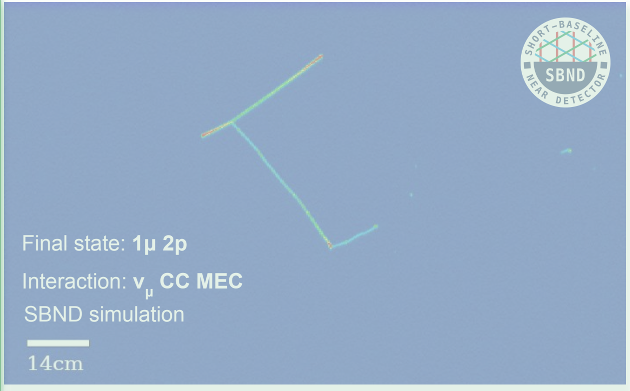

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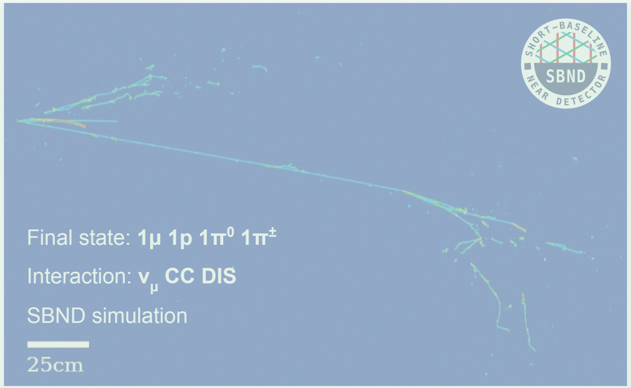
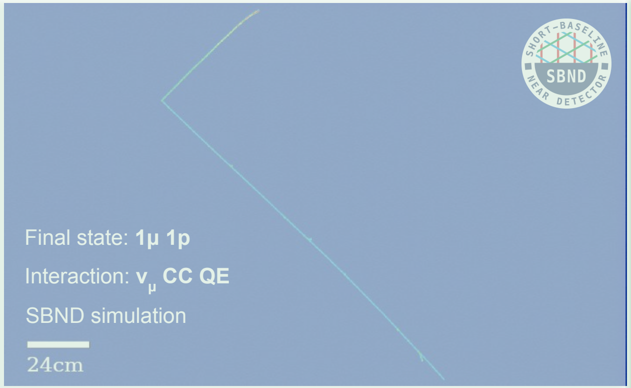
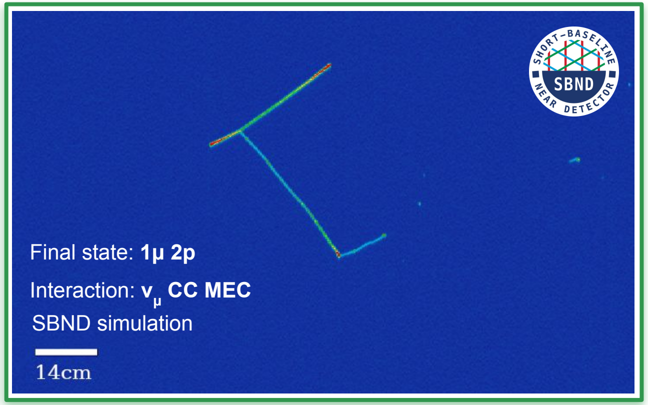
SBND will record **over 5000 ν/day** providing unprecedented precision for cross-section measurements on argon

- Enables searches for **rare** and exotic processes with statistical significance
- Expand on invaluable cross-section data from MicroBooNE, ProtoDUNE & ArgoNeuT
- Lots of kinematic phase-space overlap with DUNE
- Update generators for the next generation of physics







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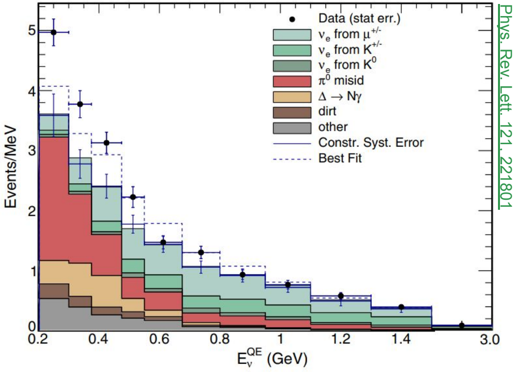
SBN oscillations: Motivation

MiniBooNE Low Energy Excess



- Gallium, reactor and accelerator neutrino experiments have all reported anomalous results in some of their oscillation data
- LSND & MiniBooNE observed an excess of low-energy electron-like signals
  - Known as the ‘Low Energy Excess’ (**LEE**) anomaly
  - **Is this caused by sterile neutrinos oscillating into active neutrinos?**
- MicroBooNE was built in order to better-characterise this excess
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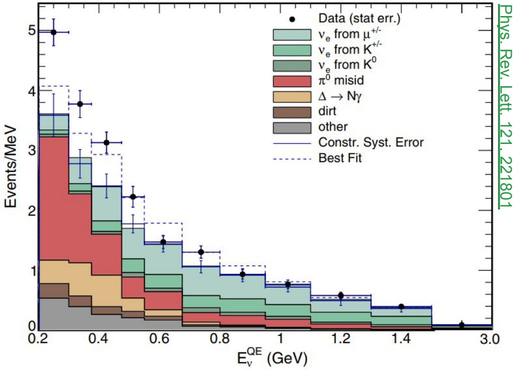

Phys. Rev. Lett. 121, 221801

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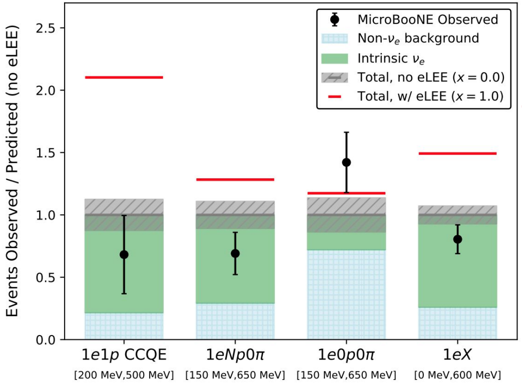

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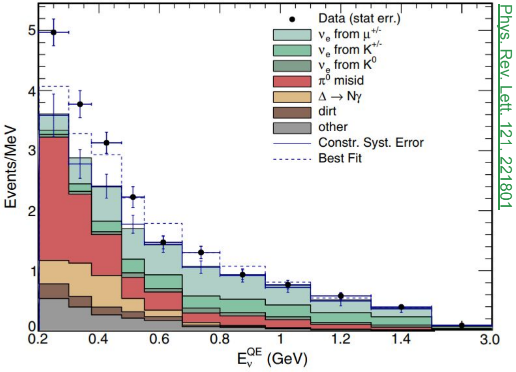

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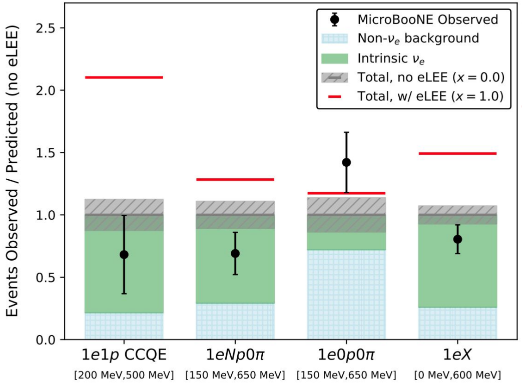

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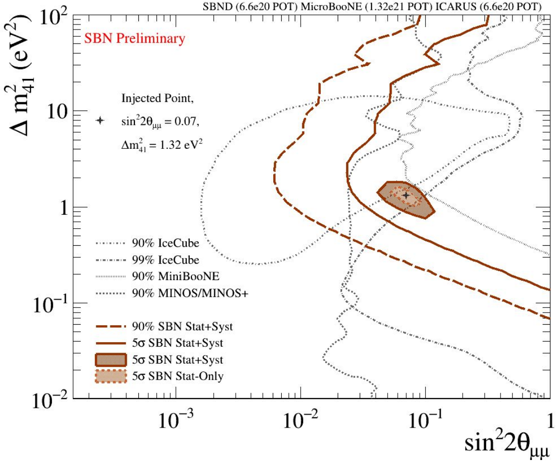
- MicroBooNE **did not observe the same LEE signal**
  - This result alone doesn’t rule out the existence of sterile neutrinos
- The SBN program will probe all three sterile neutrino oscillation channels

ν_e appearance and ν_μ & ν_e disappearance

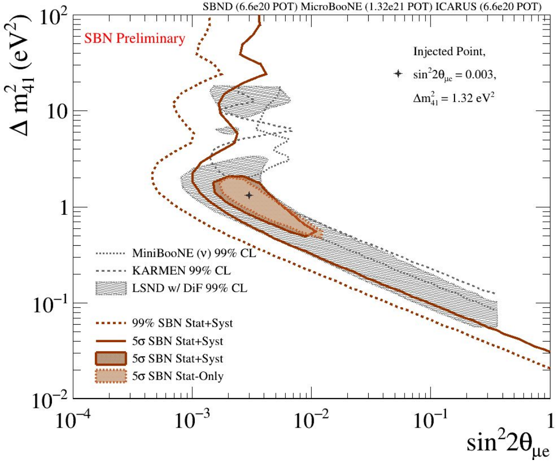
The multi-detector SBN oscillation analysis will substantially improve the global dataset and our confidence in whether sterile neutrinos exist

SBN oscillations: Sensitivities

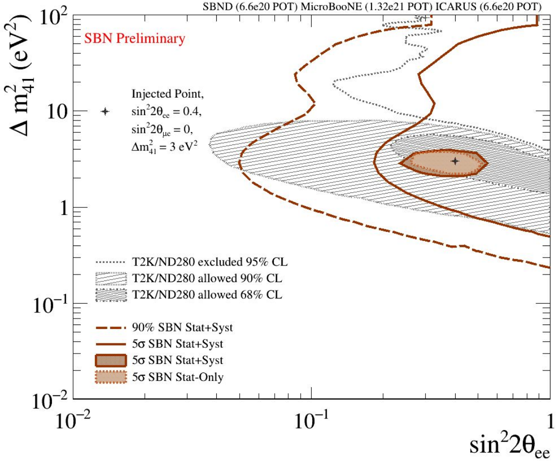
ν_μ disappearance



ν_e appearance



ν_e disappearance (New!)



External data:

IceCube ν_μ 2020
MiniBooNE ν_μ 2011
MINOS/MINOS+ ν_μ 2017

MiniBooNE ν_e 2013
KARMEN ν_e 2002
LSND ν_e 2001

T2K ν_e 2014

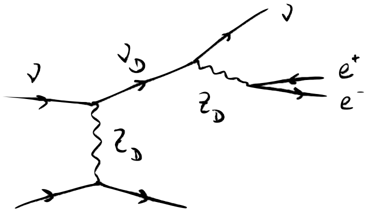
- New, *preliminary*, sensitivity plots from SBN using up-to-date models, systematics and geometries with respect to the SBN proposal (2015)
- **As the near detector, SBND will carefully constrain the interaction and flux systematics**
- In **two/three sterile oscillation channels**, SBN will be sensitive to the parameter space favoured by previous measurements at the **5σ confidence level**
- Directly address existing tensions observed in the combined appearance and disappearance data

Physics with the near detector

- SBND will provide the largest dataset of neutrino-Argon cross-section measurements in the few-GeV energy range
- As the near detector in the SBN program, SBND will constrain the unoscillated component of the neutrino flux in the search for sterile neutrinos
- Some statistical significance in many rare and exotic interaction channels for probing beyond the Standard Model (**BSM**) physics searches

Beyond the Standard Model

Dark Neutrinos



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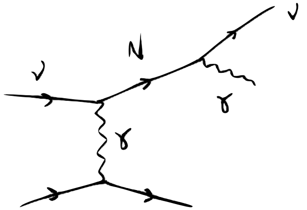
Transition Magnetic Moment



Gninenko PRL 2009
Coloma Machado Soler Shoemaker PRL 2017
Atkinson et al 2021 Vergani et al 2021

Alternative explanations to the MiniBooNE excess and other BSM scenarios

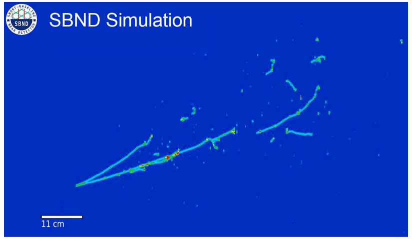
Not an exhaustive list

Some diagram credit: Pedro Machado

Slide credit: Marco Del Tutto

BSM signatures in SBND

Dark Neutrinos



e^+e^- pair with or w/o hadronic activity

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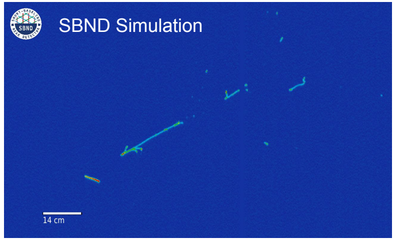

Photon shower and hadronic activity

Example signatures and event displays for alternative explanations to the MiniBooNE excess

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Beyond the Standard Model

SHORT-BASELINE NEAR DETECTOR SBND

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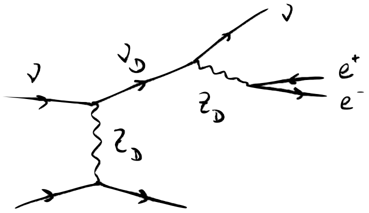

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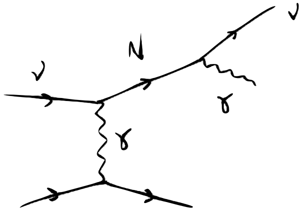

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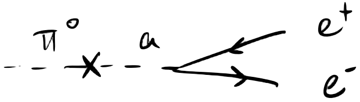
Axion-like Particles



Kelly Kumar Liu PRD 2021
Brdar et al PRL 2021

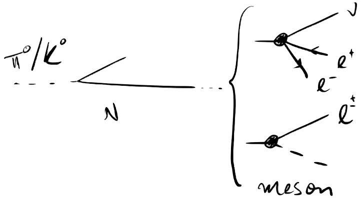
Alternative explanations to the MiniBooNE excess and other BSM scenarios

Not an exhaustive list

Some diagram credit: Pedro Machado

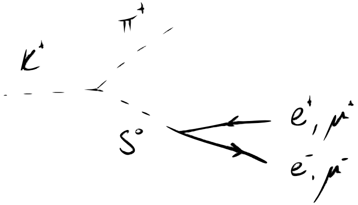
Slide credit: Marco Del Tutto

Heavy Neutral Leptons



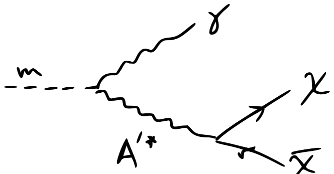
Ballett Pascoli Ross-Lonergan JHEP 2017
Kelly Machado PRD 2021

Higgs Portal Scalar



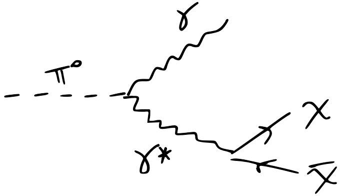
Pat Wilczek 2006
Batell Berger Ismail PRD 2019
MicroBooNE 2021

Light Dark Matter



Romeri Kelley Machado PRD 2019

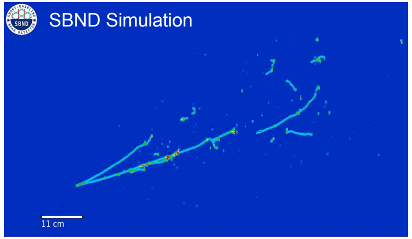
Millicharged Particles



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

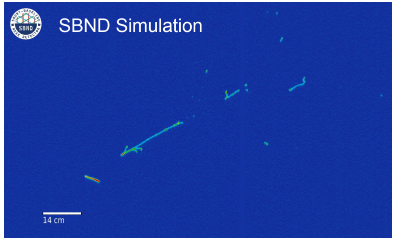
BSM signatures in SBND

Dark Neutrinos



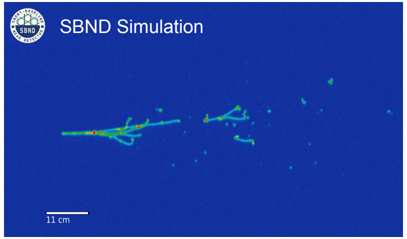
e^+e^- pair with or w/o hadronic activity

Transition Magnetic Moment



Photon shower and hadronic activity

Axion-like Particles



High-energy e^+e^- or $\mu^+\mu^-$

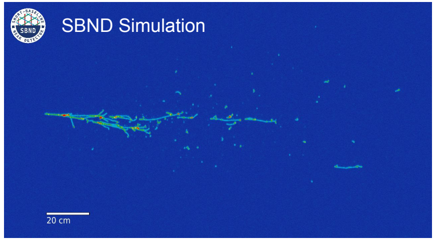
Example signatures and event displays for various BSM scenarios

Not an exhaustive list

Some diagram credit: Pedro Machado

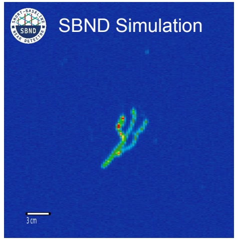
Slide credit: Marco Del Tutto

Heavy Neutral Leptons



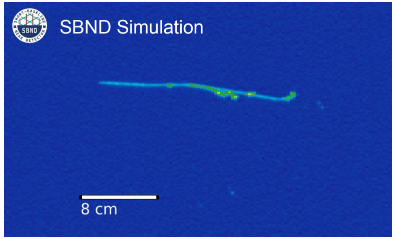
e^+e^-, $\mu^+\mu^-$ or $\mu\pi$

Higgs Portal Scalar



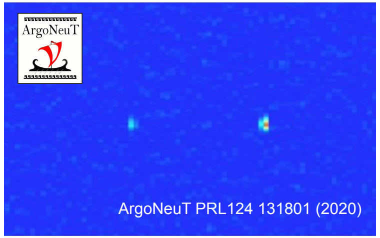
e^+e^- or $\mu^+\mu^-$, no hadronic activity

Light Dark Matter



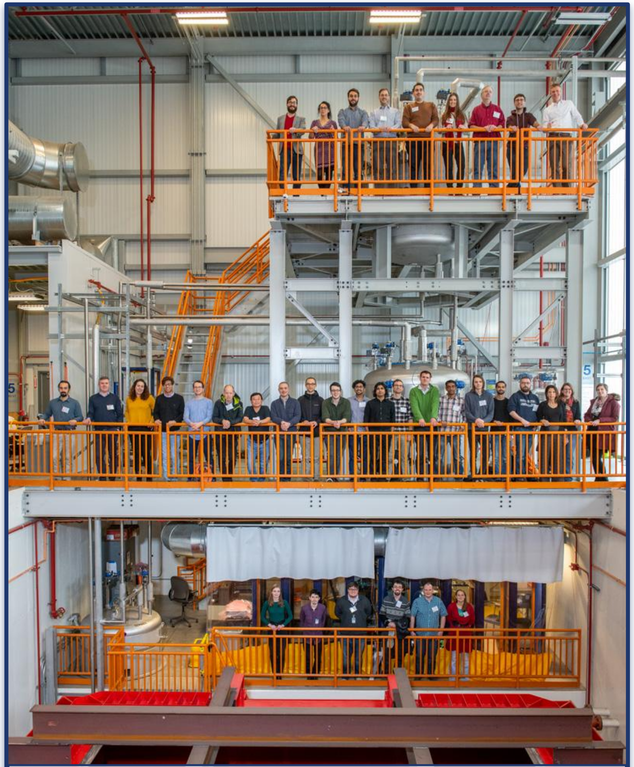
Electron scattering

Millicharged Particles



Blips/faint tracks

Summary and conclusions



SBND collaboration, SBN-ND building, December 2019

The SBND TPC is complete!

- The TPC will be transported to the SBN-ND building later this summer
- Detector operations will commence in 2023
- The SBND physics program boasts a wide variety of exciting opportunities
  - Unprecedentedly-precise cross-section measurements
  - Multi-channel search for eV-scale sterile neutrinos
  - Searches for rare and exotic **BSM** physics
- The extremely interesting concept of **SBND Prism** will be discussed by **Marco Del Tutto** in the next talk

Thank you!

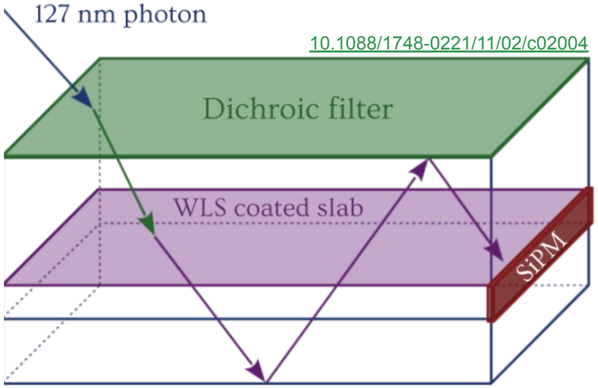
ν

SBND collaboration, SBN-ND building, June 2022

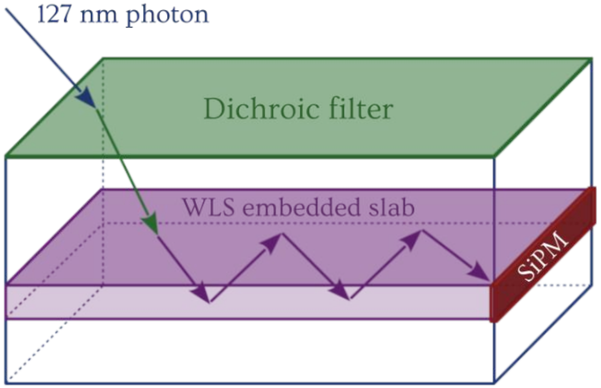
X-Arapuca operation principles

The ARAPUCA concept aims to record scintillation photons with extremely high efficiency by trapping them within a box that has highly reflective internal surfaces without the need for a large active photon detection system.

10.1088/1748-0221/11/02/c02004

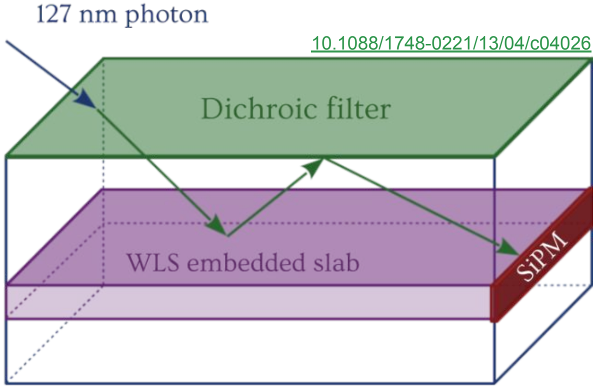


Original ARAPUCA



X-ARAPUCA: Total internal reflection

10.1088/1748-0221/13/04/c04026



X-ARAPUCA: High incident angles

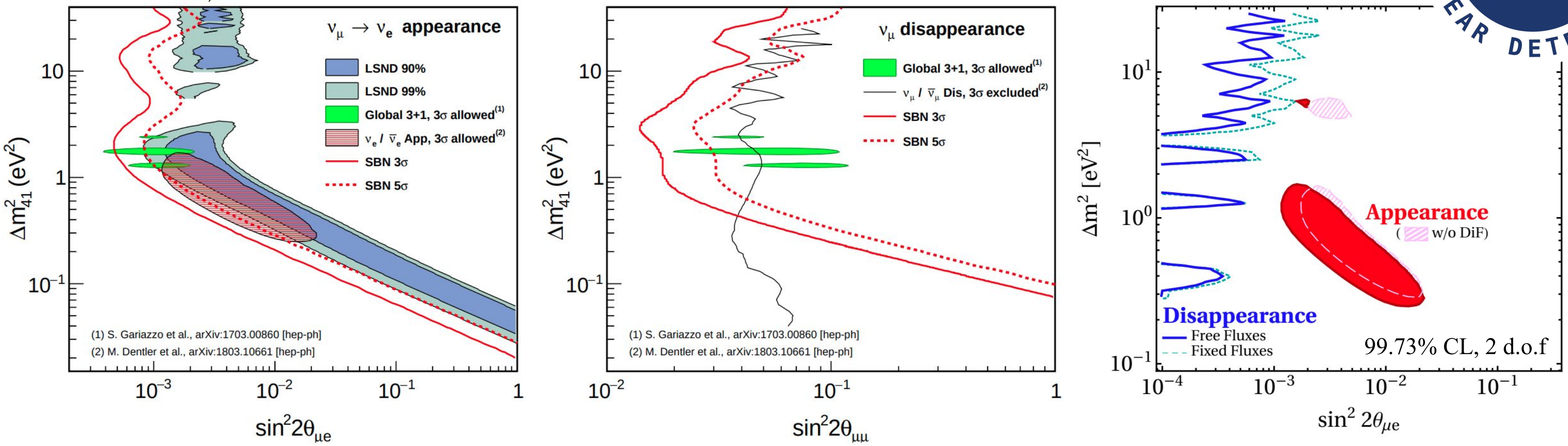
Photons enter the light box, are wavelength shifted when travelling through the coated slab and are then reflected internally until they reach and are detected by the SiPM.

The main idea behind the X-ARAPUCA, in which the photons are totally internally reflected inside the wavelength shifting slab until they reach the SiPM.

Photons with high incident angles will be reflected by the slab. These photons remain trapped in the upper part of the ARAPUCA and are reflected internally until they reach the SiPM

SBN oscillations: Sensitivities

P. Machado et al, arXiv:1903.04608V11



- The SBN program will search for sterile neutrinos with three detectors utilising the same technology in the same beamline
- **As the near detector, SBND will carefully constrain the interaction and flux systematics**
- In **two of the sterile oscillation channels**, SBN will be sensitive to the parameter space favoured by previous measurements at the **5σ confidence level**
- Directly address **existing tensions** observed in the combined appearance and disappearance data