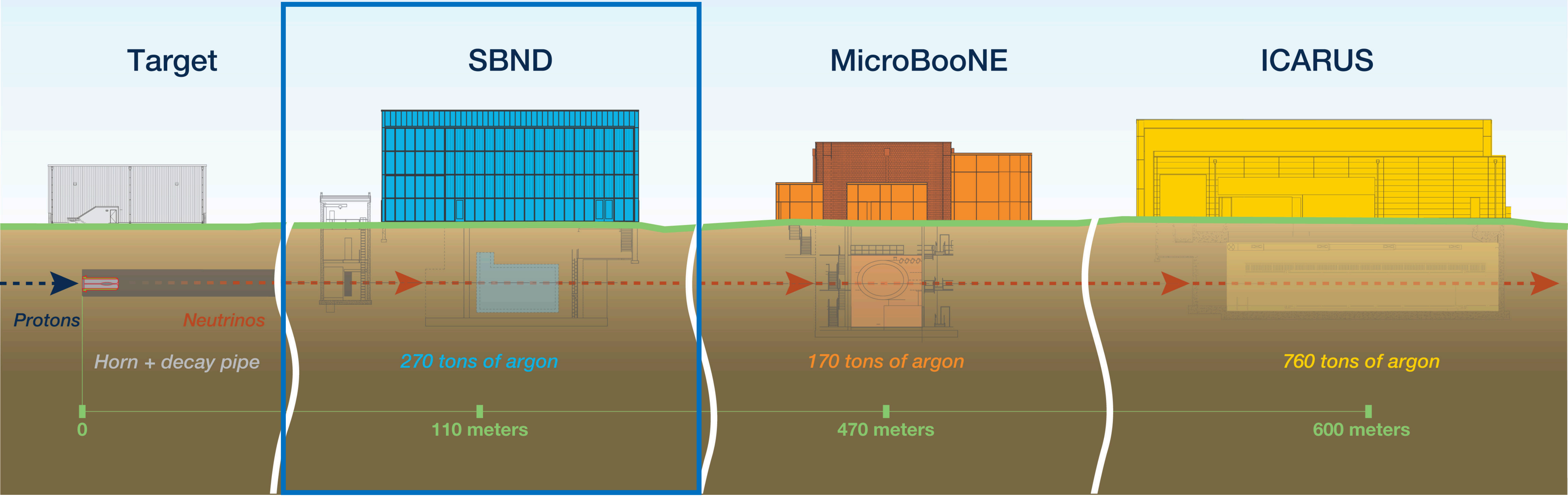
Searches for Beyond Standard Model Physics in the SBND experiment

NuFact 2023

Xiao Luo, University of California Santa Barbara

on behalf of SBND collaboration

Short-Baseline Neutrino Program at Fermilab



SBND General talk by Diana Patricia Mendez Mendez (NuFact23 Tue. 2pm)

Search for eV sterile neutrino

- Consists of 3 Liquid Argon TPC neutrino detectors
- On-axis of intensive GeV neutrino beamline
- O(100) m oscillation baseline

But there is more sub-GeV scale BSM physics than just sterile neutrino

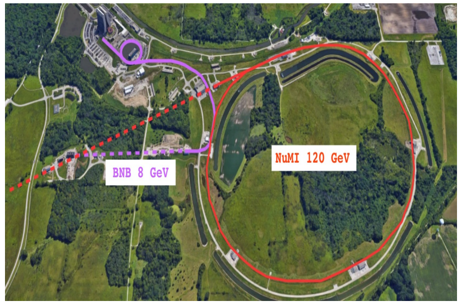
Short Baseline Near Detector (SBND) offers unique opportunity for BSM searches

SBND – BSM production

Sub-GeV scale BSM in the intense neutrino beamline

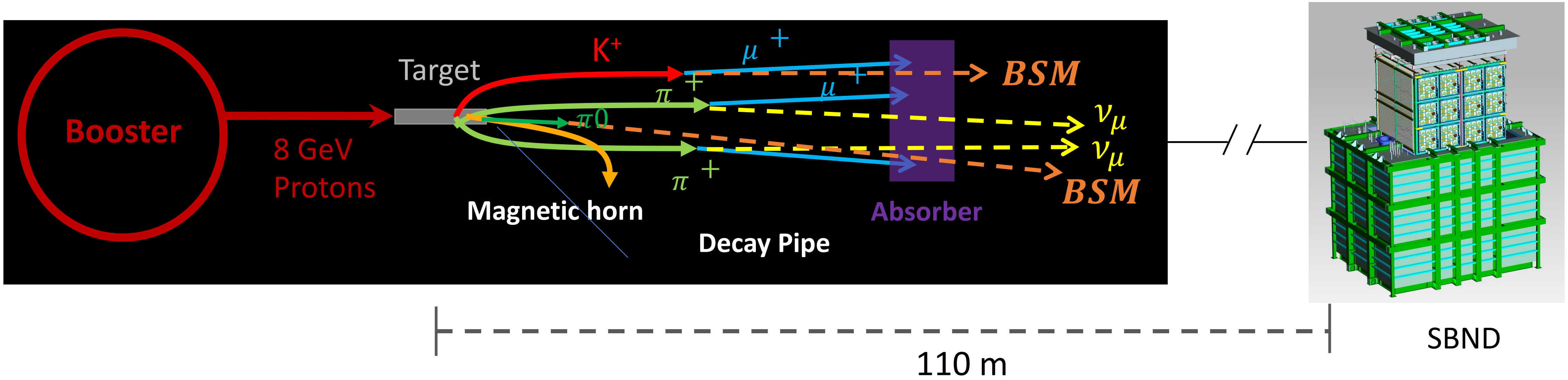
Neutrino experiments energy landscape

Accelerator ν



PTOLEMY **Solar ν** **Collider** **ICECUBE**

...meV eV keV MeV GeV TeV PeV

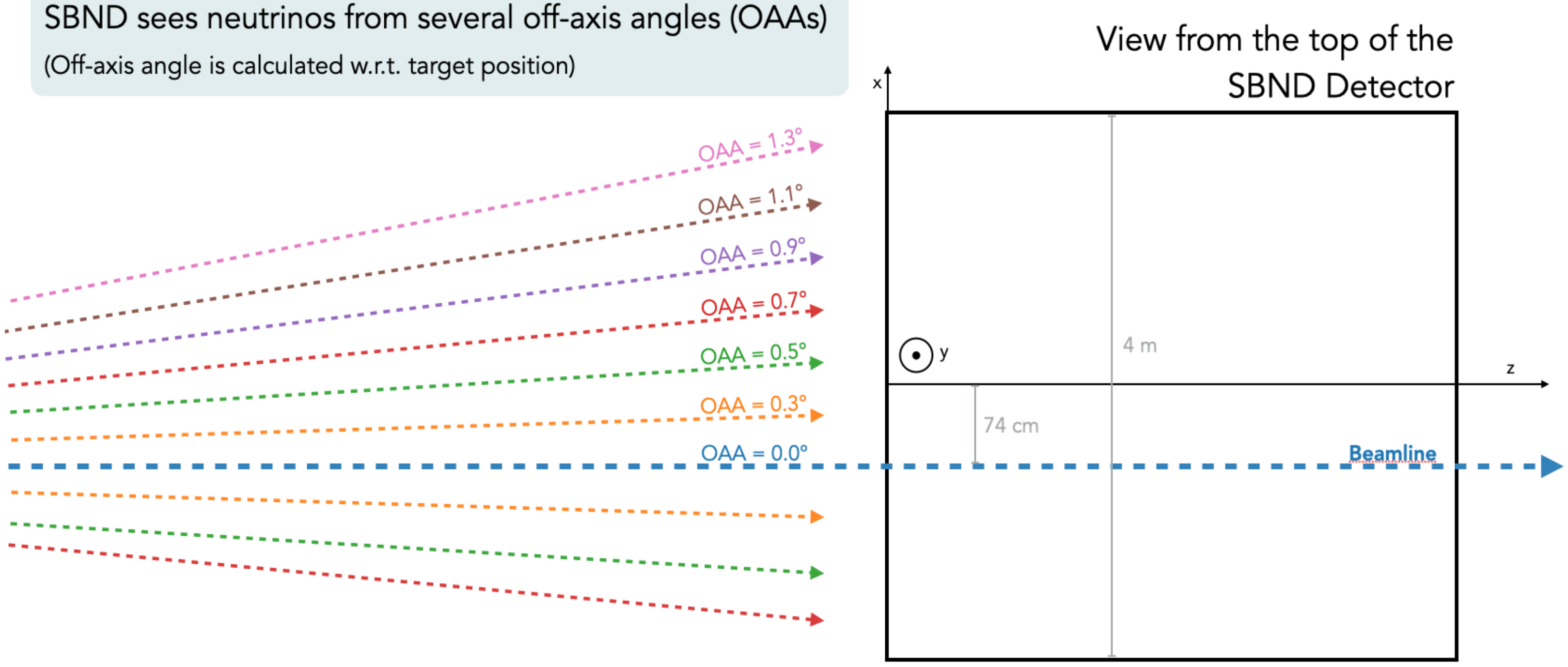


Closest to the beam, high BSM production rate, better for heavier shorter lived BSM particles comparing to the other two SBN experiments.

SBND-PRISM

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

SBND sees neutrinos from several off-axis angles (OAAs)
(Off-axis angle is calculated w.r.t. target position)

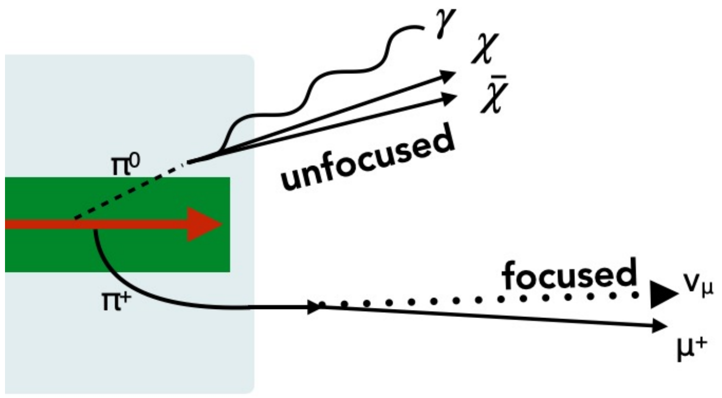


Close proximity to target -> larger solid angle coverage

Off-axis-angle range [0, 1.6°]

Application of SBND-PRISM:

- Constrain flux/xsec systematic uncertainty for SM neutrino background (NuFact 23 Xsec in SBND by A. Furmanski, Fri. 2:30pm)
- Higher BSM Signal / ν bckg. ratio with large off-axis-angle selection.



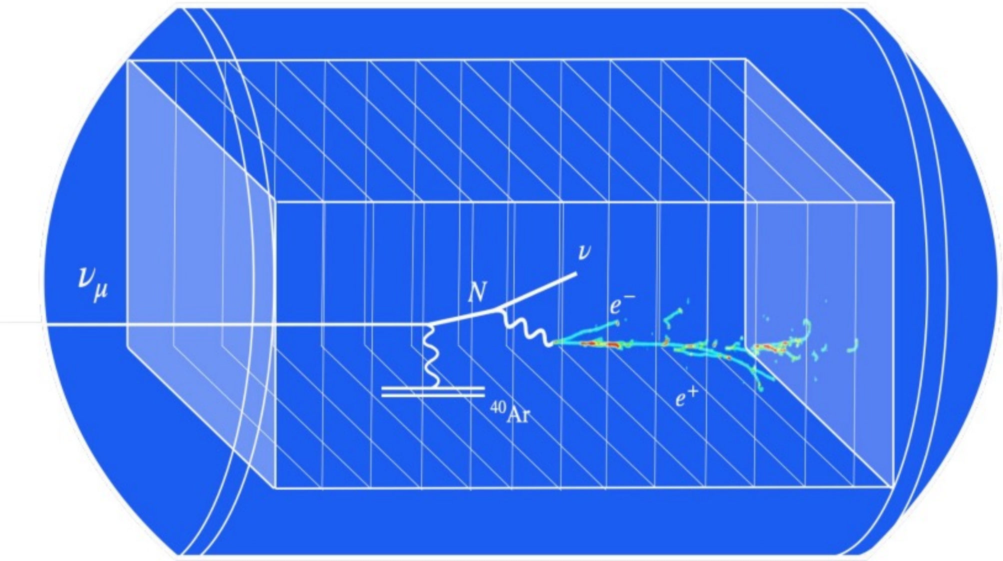
SIGNAL

Dark matter (signal) events come from **unfocused** neutral mesons

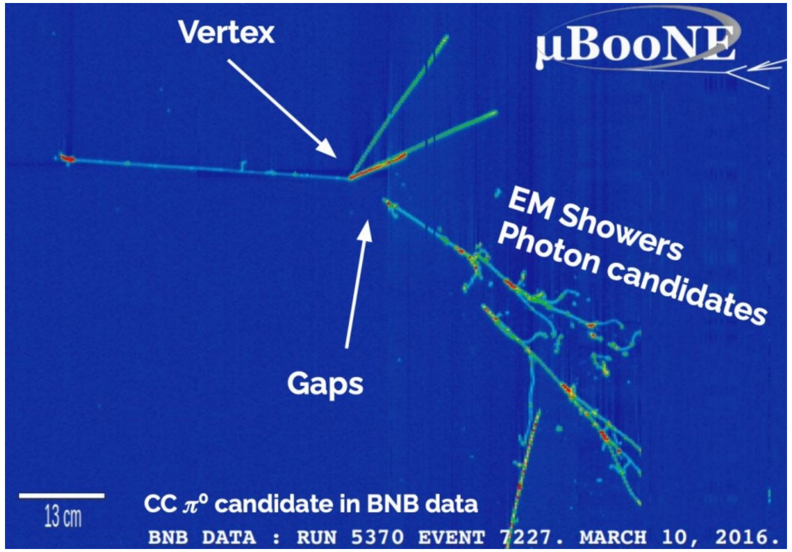
BACKGROUND

SBND-PRISM: Neutrinos (background events) **decrease** with the off axis angle

SBND - LArTPC detector



Example of BNB data from MicroBooNE LArTPC.



LArTPCs are like HD camara that captures the 3D images of the particle interactions


The rigging of the detector attached to the cryostat top cap into the cryostat, on April 25th, 2023.

SBND detector is currently under commissioning.
Expect argon filling later this year followed by calibration data taking. Physics data is expected in 2024

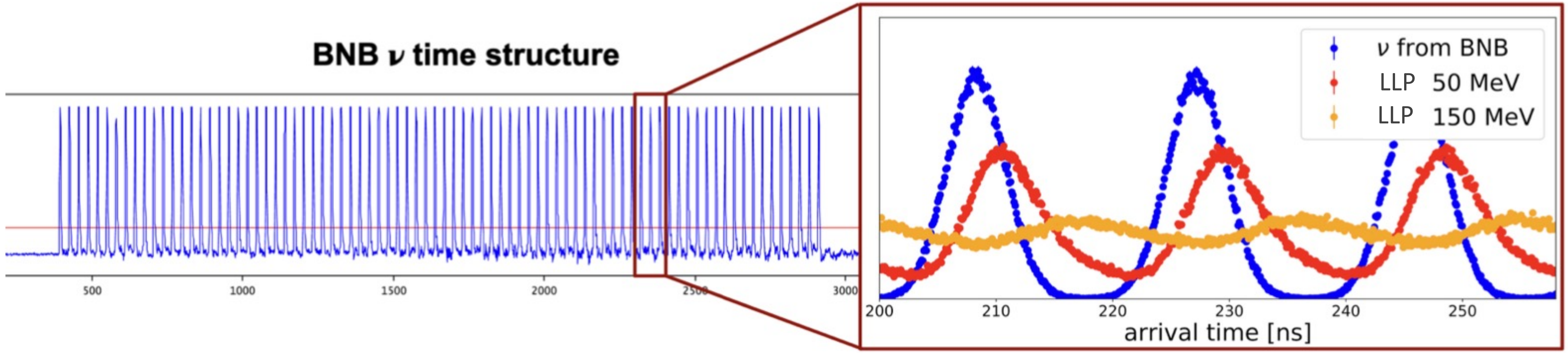
SBND General talk by Diana Patricia Mendez Mendez (NuFact23 Tue. 2pm)

SBND – Precise Timing

Bunched structure of ν beamlines
2ns ν bucket separate by ~18 ns gaps

~500 m

Heavier BSM particles arrived at detector later than ν

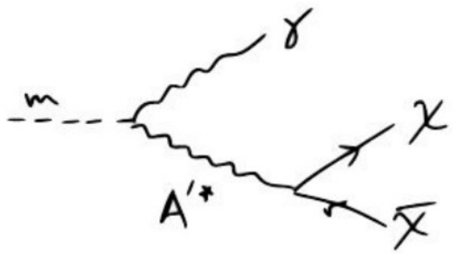


Time-of-Flight measurement with nanosecond precision offers a unique **model-independent** handle for any massive Long-Lived Particle

O(1) ns timing measurement achieved for the 1st time with a LArTPC detector in MicroBooNE
arxiv.2304.02076

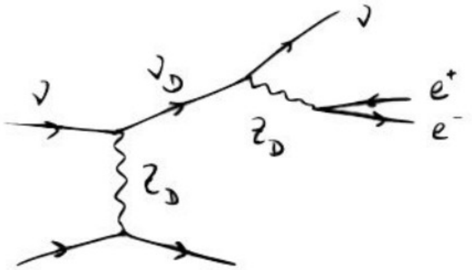
What BSM physics?

Light Dark Matter



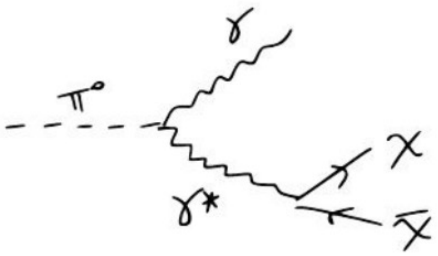
Romeri Kelley Machado PRD 2019

Dark Neutrinos



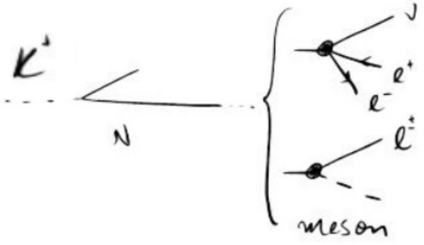
Bertuzzo Jana Machado Zukanovich PRL 2018, PLB 2019
Arguelles Hostert Tsai PRL 2019
Ballett Pascoli Ross-Lonergan PRD 2019
Ballett Hostert Pascoli PRD 2020

Millicharged Particles



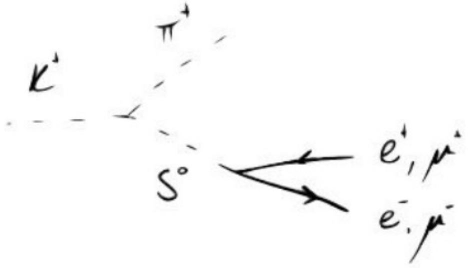
Magill, Plestid, Pospelov, Tsai, PRL 2019
Harnik Liu Palamara, JHEP 2019

Heavy Neutral Leptons



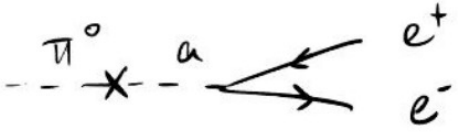
Ballett Pascoli Ross-Lonergan JHEP 2017
Kelly Machado PRD 2021

Higgs Scalar Portal



Pat Wilczek 2006
Batell Berger Ismail PRD 2019
MicroBooNE 2021

Axion-like Particles



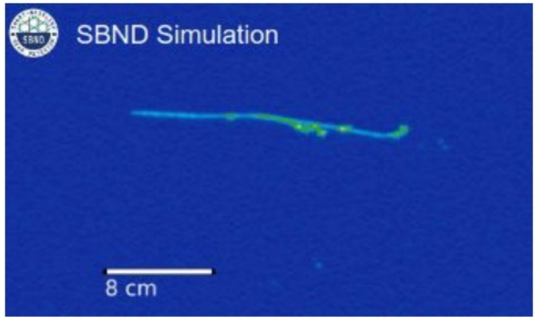
Kelly Kumar Liu PRD 2021
Brdar et al PRL 2021

A non-exhaustive list of BSM particles produced at the Booster Neutrino Beam

Image credit: Pedro Machado, Marco Del Tutto

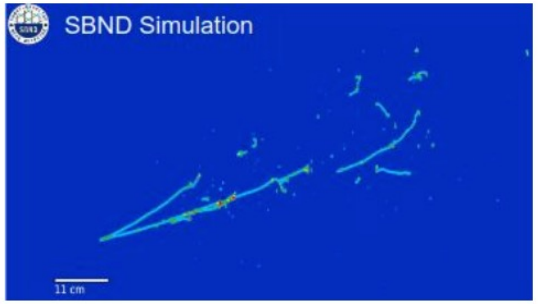
BSM events @ SBND

Light Dark Matter



Single e- scattering
Pair of e+e- and γγ
No hadronic activity

Dark Neutrinos

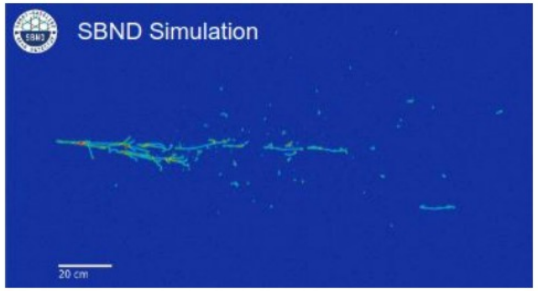


Pair of e+e- and μ+μ-
With or without hadronic activity

Millicharged Particles

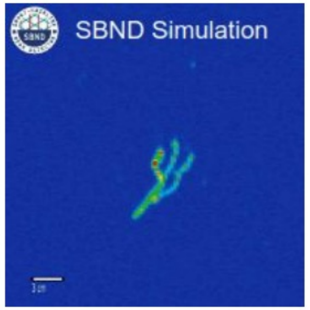
Blip or faint tracks

Heavy Neutral Leptons



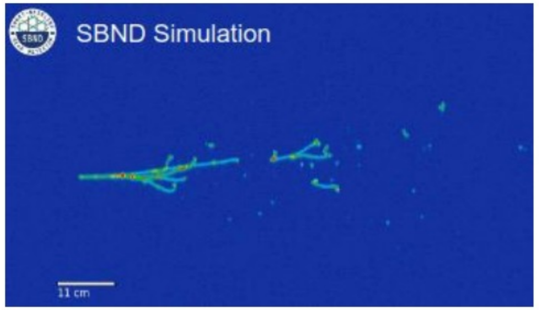
Single lepton + π
High energy pair of e+e-, μ+μ- and γγ
No hadronic activity

Higgs Scalar Portal



Pair e+e- and μ+μ-
No hadronic activity

Axion-like Particles



High energy pair of e+e- , μ+μ- and γγ
No hadronic activity

Long-Lived-Particle decay:
- Final states with lepton pairs or photon(s) without hadronic activity

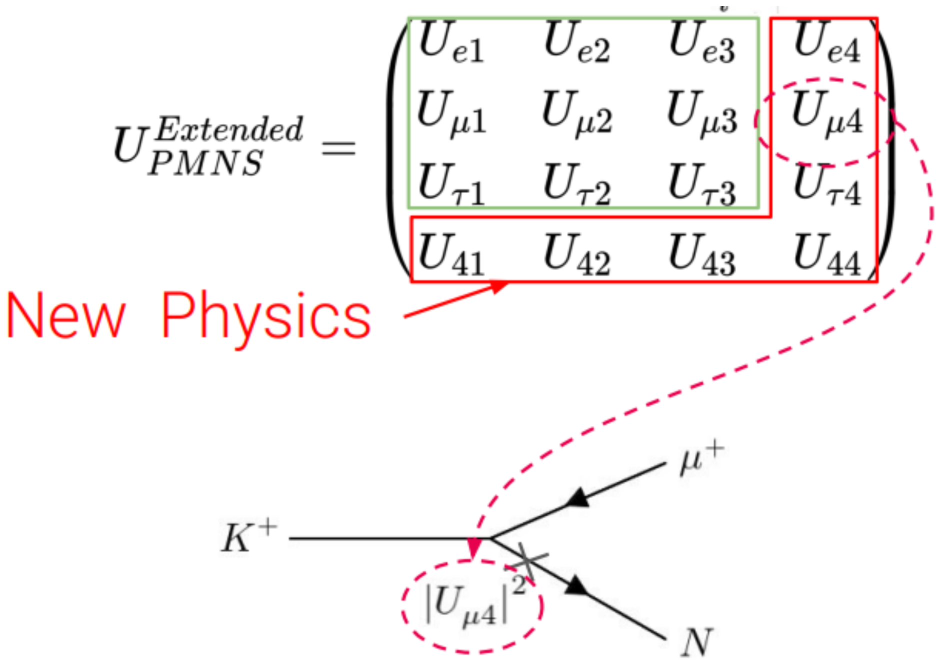
BSM particle scattering:
- Electron or nuclear recoil

LArTPC's powerful particle identification capability is ideal for observing these similar final states with different kinematics, and differentiate among the BSM models

Heavy Neutral Lepton

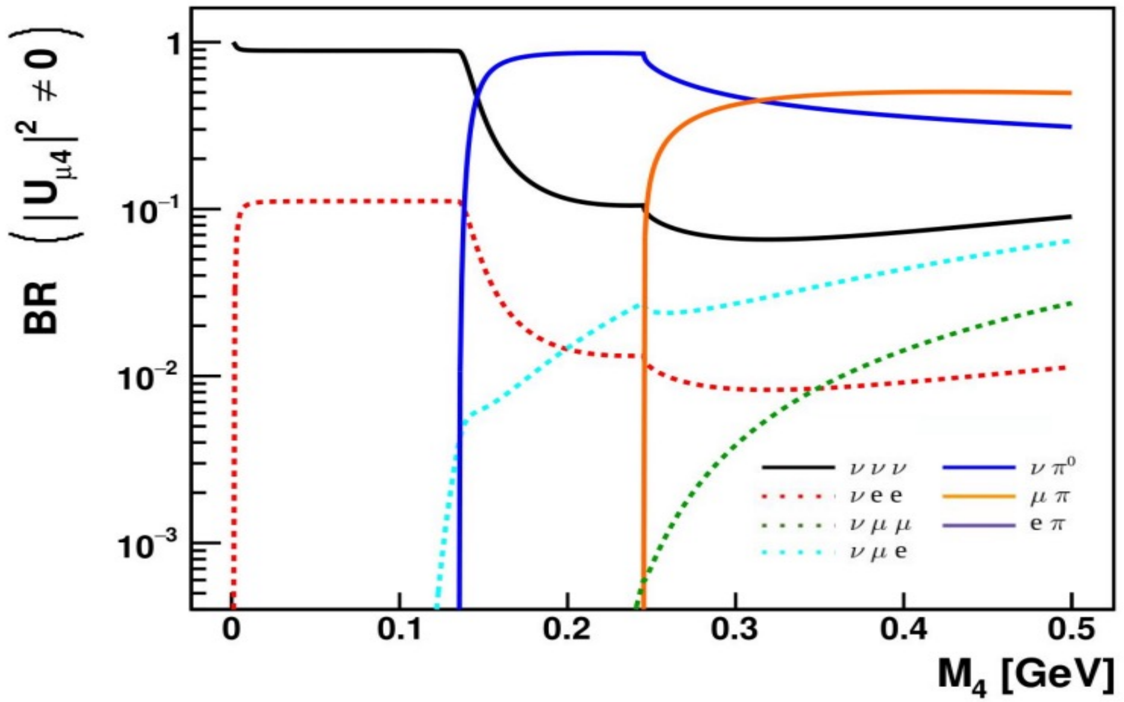
JHEP 04 (2017) 102
JHEP 02 (2020) 174
EPJC 81 (2021) 1, 78
PRD 104, 015038 (2021)

Production



At Booster Neutrino Beamline, HNL can be produced from K+ decay up to ~500 MeV

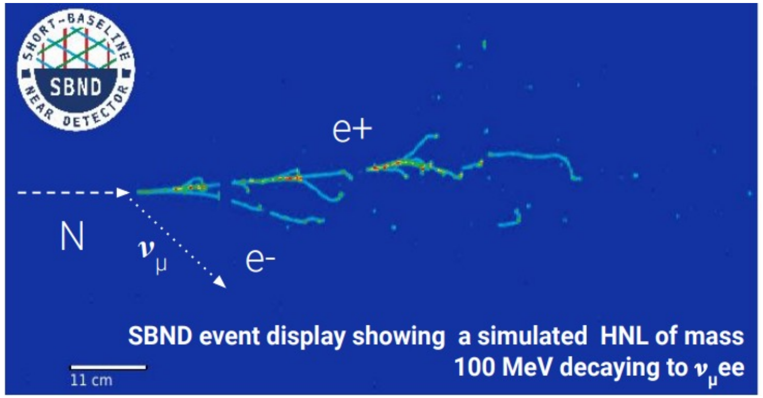
Decay



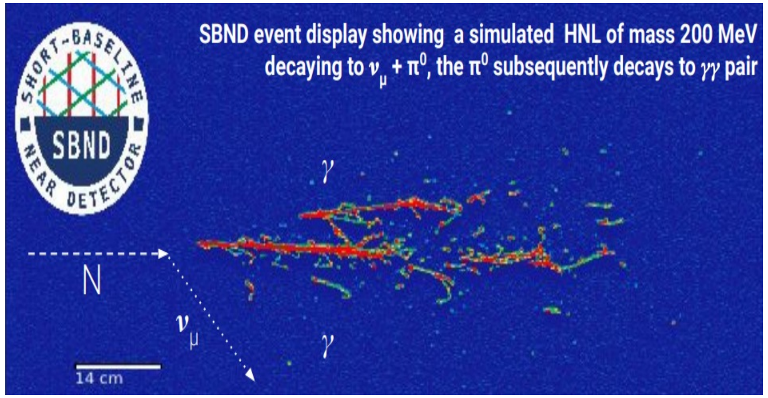
HNL then decays to SM particles with rate $\propto |U_{\alpha4}|^4$

Heavy Neutral Lepton continued

HNL → vee

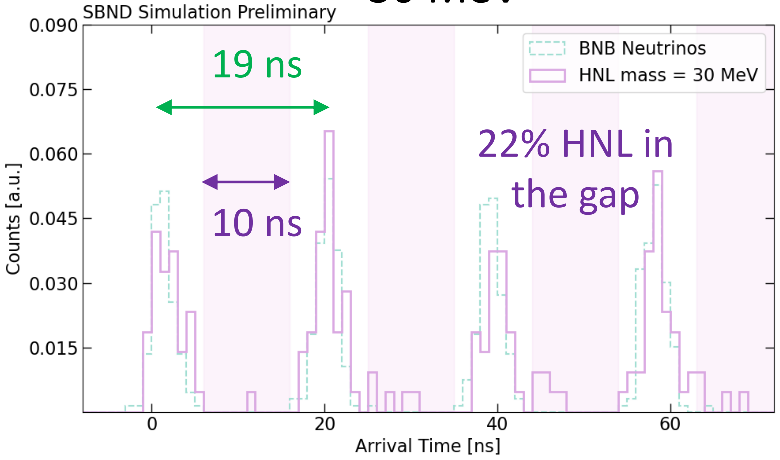


HNL → $\nu\pi^0$

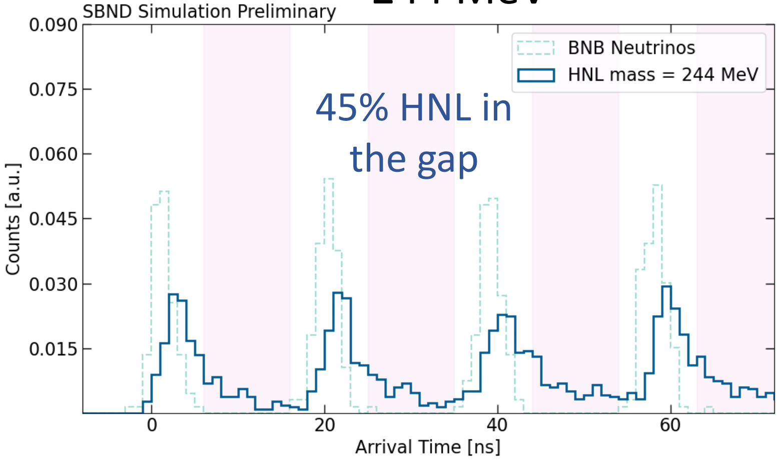


Two final states channels are under investigation

30 MeV

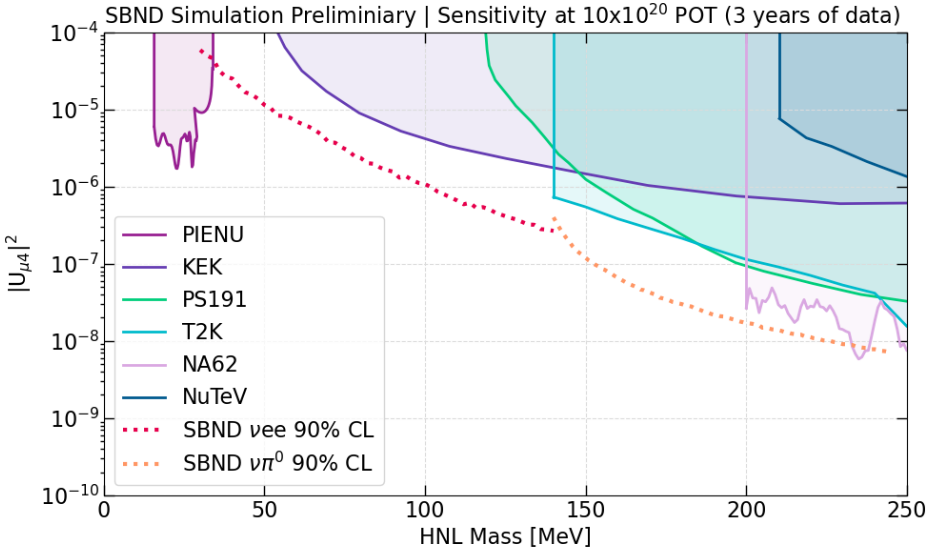


244 MeV



Use ToF to find HNL in between neutrino beam bucket

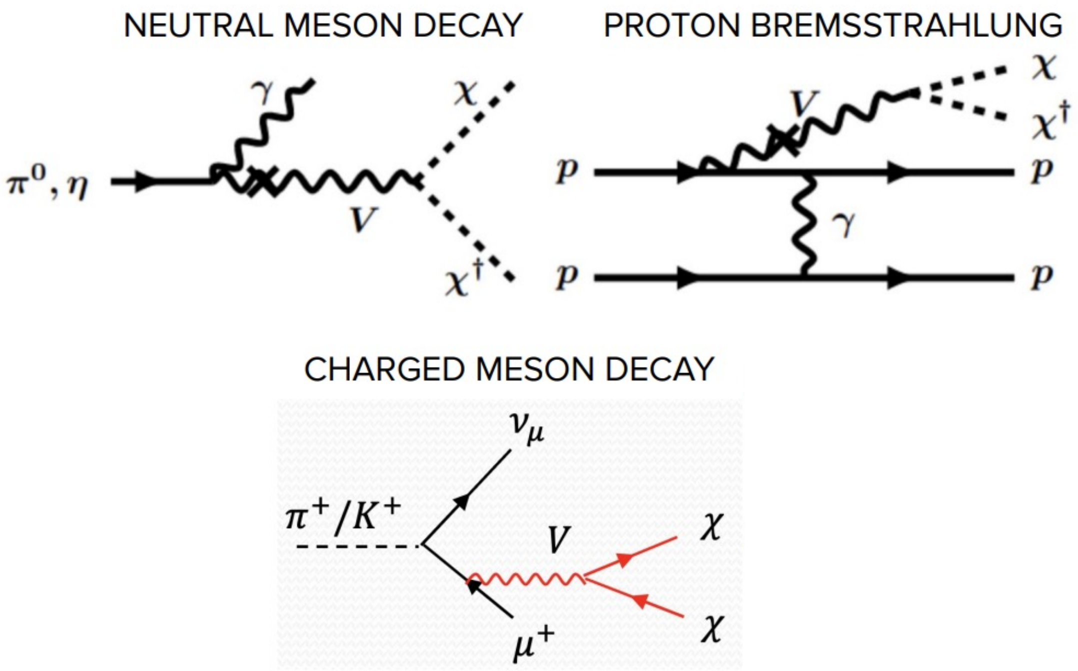
HNL sensitivity estimate Competitave up to 250 MeV mass range



Disclaimer: this sensitivity estimate assumes no background, applies the between bucket event selection, and 20% reconstruction efficiency.

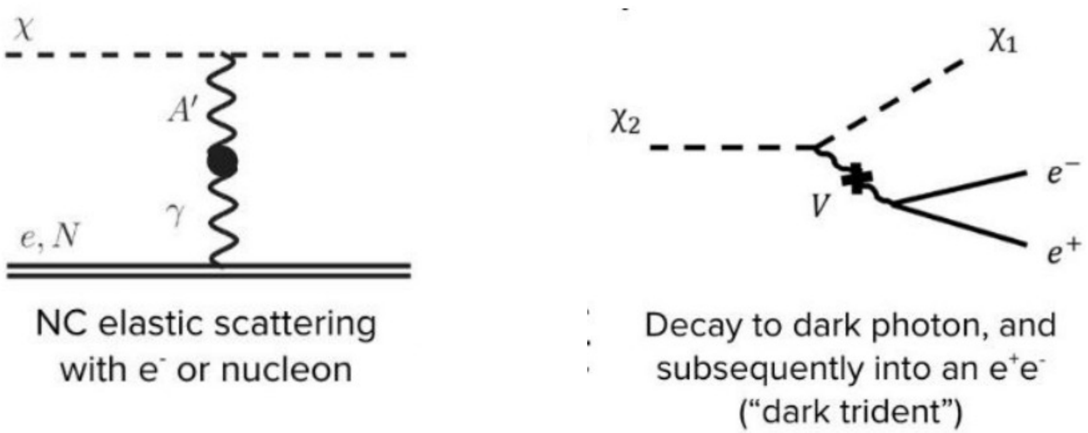
Light Dark Matter

[PRD 95, 035006 (2017)]

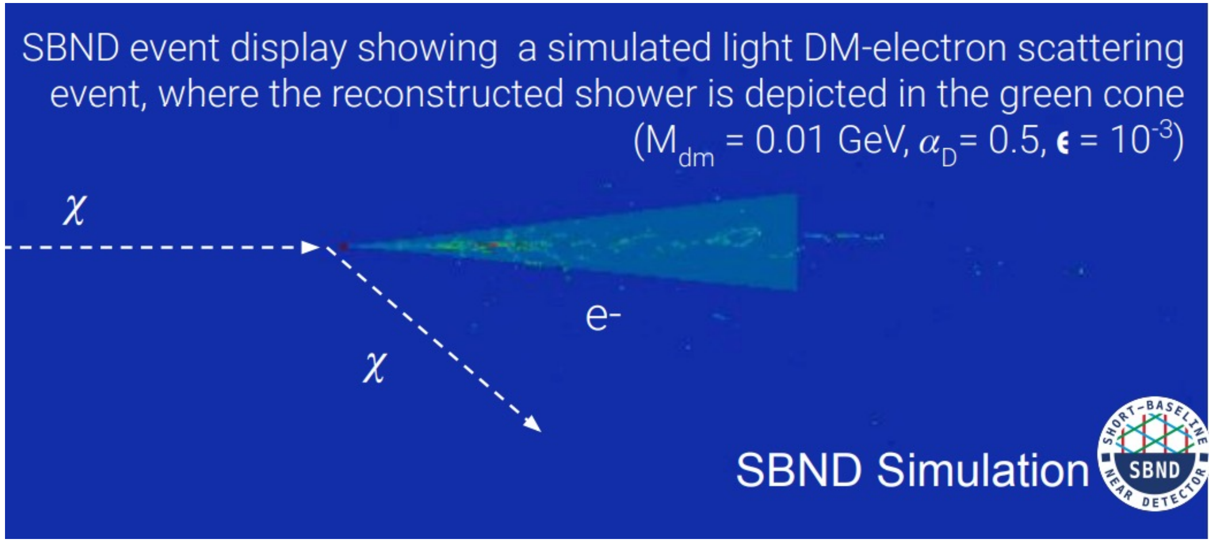


In the Booster neutrino beamline, Sub-GeV Dark Matter can be produced from neutral/charge meson decay and proton Bremsstrahlung

Light DM can scatter or decay inside SBND



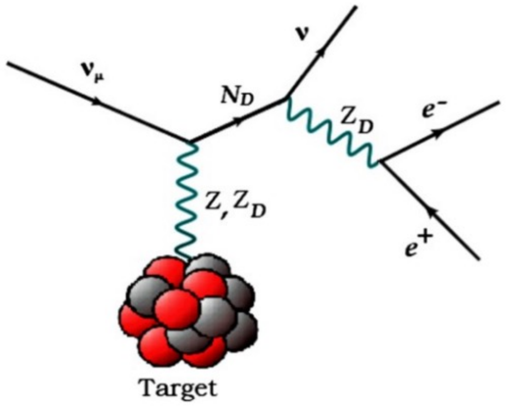
Both channels are being explored in SBND, search for signature with EM showers without hadronic activity



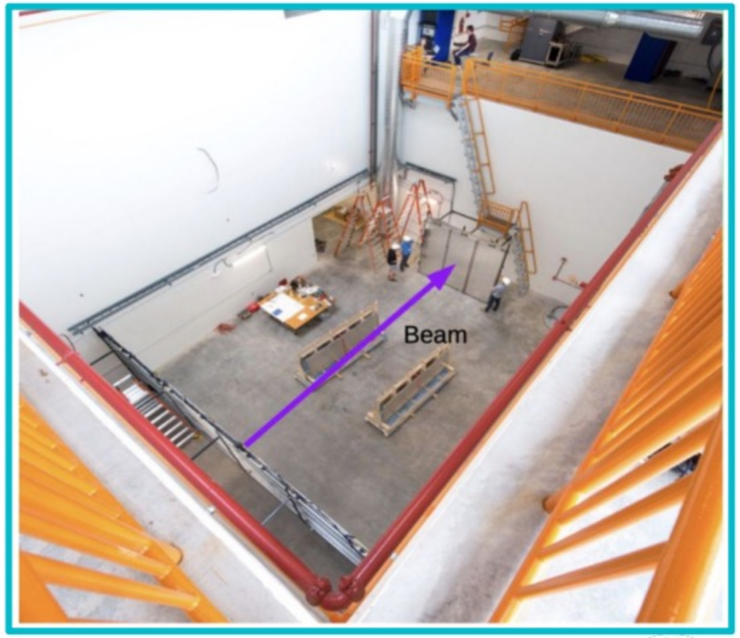
Dark Neutrino

Produced via nu-nucleon scattering, then decay to dark gauge boson, which decays to dilepton

Dark neutrino portal
[PRL 121, 241801 (2019); PRD 99, 071701 (2019)]

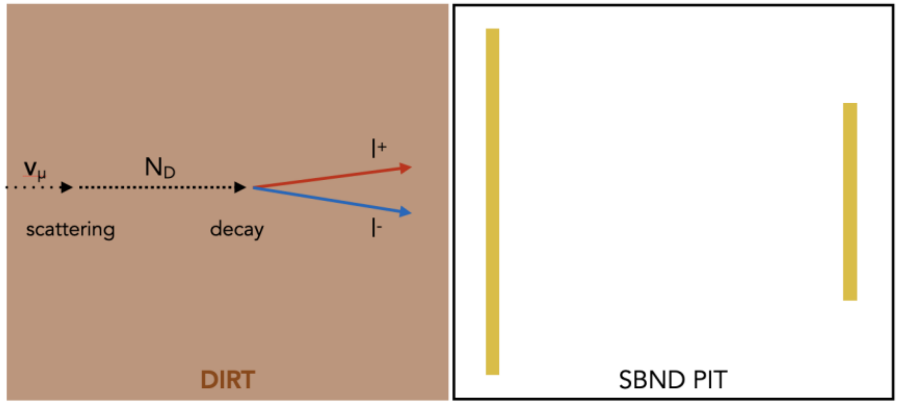


SBND installed Cosmic Ray Tagger panels at up & downstream of the detector. Lepton pairs from the dark neutrinos can be tagged by these CRT detector



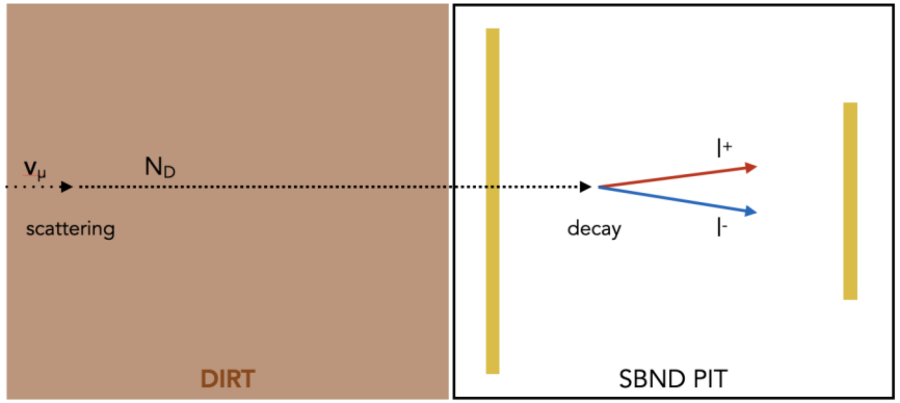
Short-lived dark neutrinos

- Electrons are hard to study as they will shower in the dirt (unless we focus on the last region of dirt only)
- Muons can be studied.



Long-lived dark neutrinos

- Both muons and electrons can be studied.
- Upstream layer can be used as a veto to reject dirt muons.



Dark neutrinos searching using real data collected by CRT from 2017-18 data is currently ongoing.

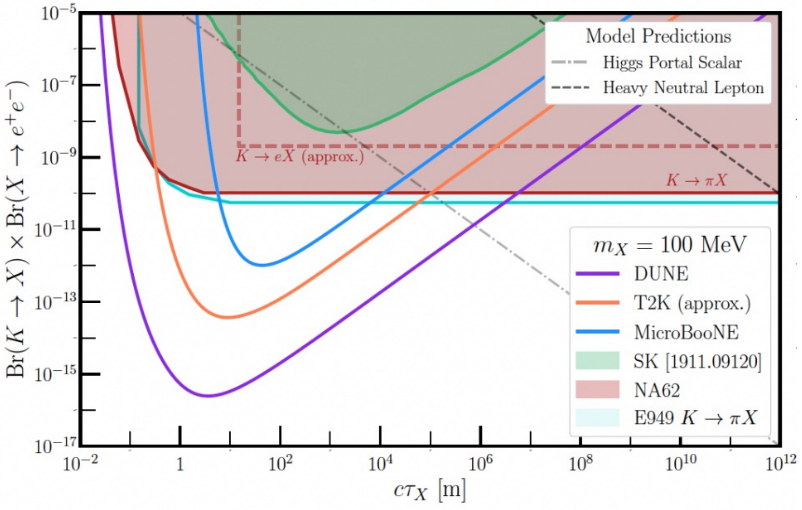
Model independent BSM search

Search driven by experimental observables

BSM models	Dark v light Z_d	Dark v heavy Z_d	QCD Axion	HNL	Dark matter
Delayed timing	no	no	yes	yes	maybe
Final states	e+e-	e+e-	γγ, ee, μμ	e+e-, μπ	e, ee, γγ
Opening angle	small	small	tiny	large	?
Proton	no	yes	no	no	no

Different experiments can report their sensitivity in a uniformed way based on experimental observables (ie. event rates at different final-state) and general BSM parameters, e.g. branch ratio, mass

B. Batell’s talk @ PDSD



This limits can then be interpretated for any specific models

Advantage

- Simplified, unified sensitivity defined by experimental observables
- Maximize discovery potential, needed for BSM field

Summary

- Short Baseline Neutrino Detector (SBND) is in a unique position to search for **sub-GeV BSM** physics
  - High BSM production rate
  - SBND – PRISM for systematic constraints and S/B optimization
  - **Bunched nu beam + O(1) ns ToF** for low background
- Vibrant BSM search program
  - Model dependent, e.g. HNL, Dark Matter, Dark ν...
  - Model-independent to maximize discovery potential, enable comparisons across experiments
- SBND will start data taking in 2024. Stay tuned for BSM sensitivity estimate before data search

Thank you


Photo taken at SBND Collaboration Meeting at Arlington, June 2023
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