

BSM New Physics Searches with SBND

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on behalf of the SBND collaboration

2 August 2022 | NuFACT 2022



SBND Simulation

e^-

SBND event display showing a
simulated light Dark Matter interaction



The SBND time projection chamber

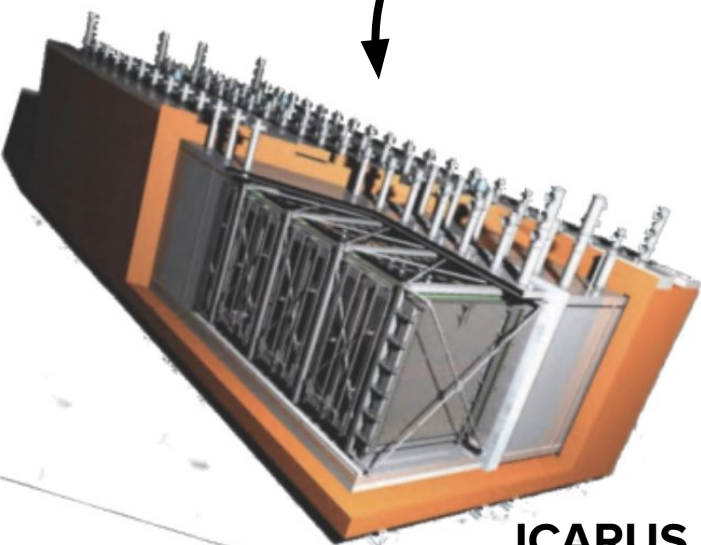
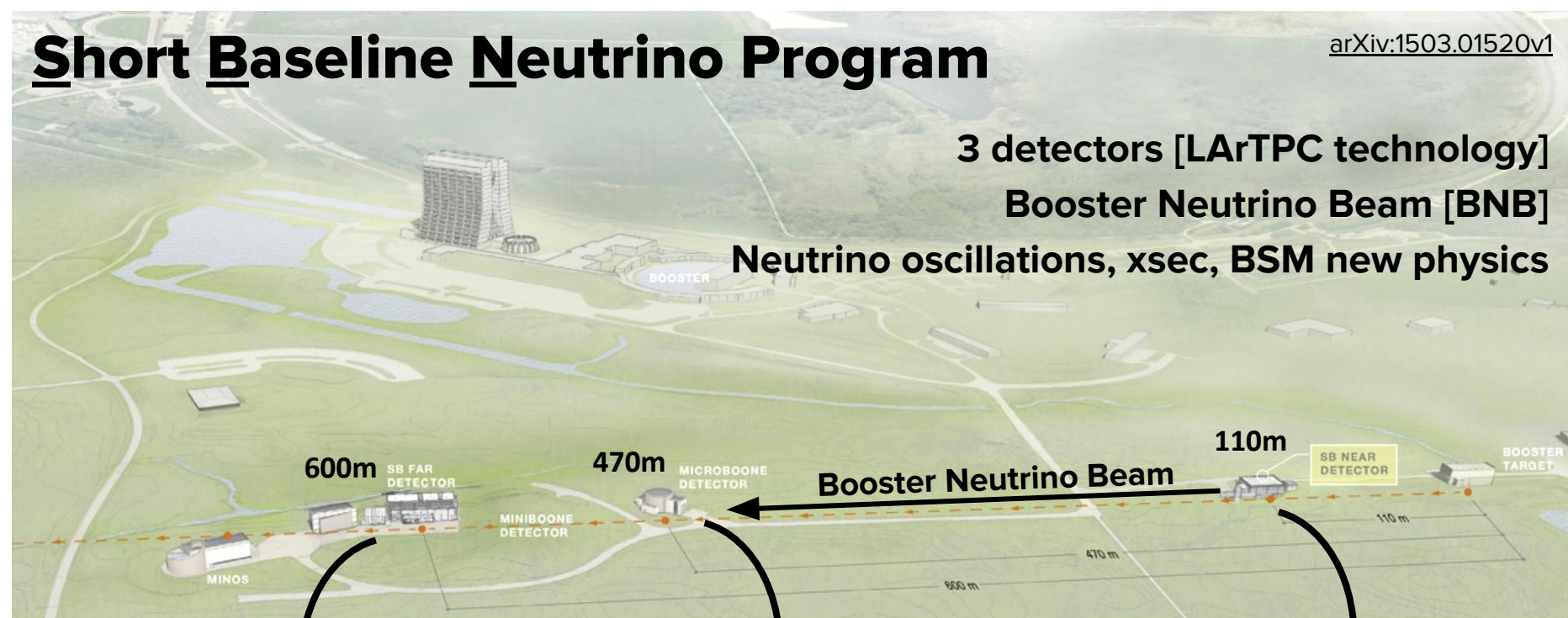
Short Baseline Neutrino Program

arXiv:1503.01520v1

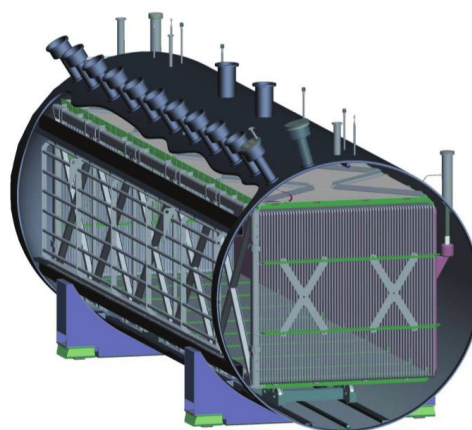
3 detectors [LArTPC technology]

Booster Neutrino Beam [BNB]

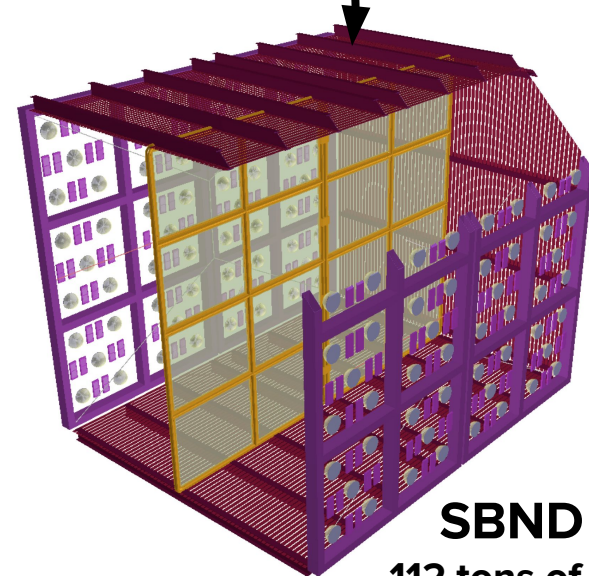
Neutrino oscillations, xsec, BSM new physics



ICARUS
476 tons of Ar



MicroBooNE
89 tons of Ar



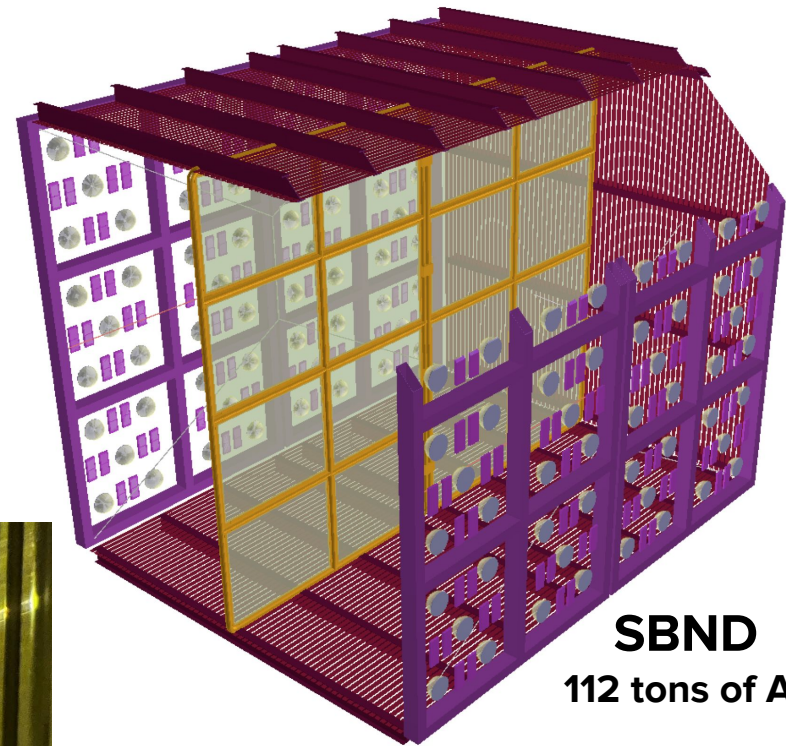
SBND
112 tons of Ar



Short Baseline Near Detector

Near detector of the SBN oscillation program.

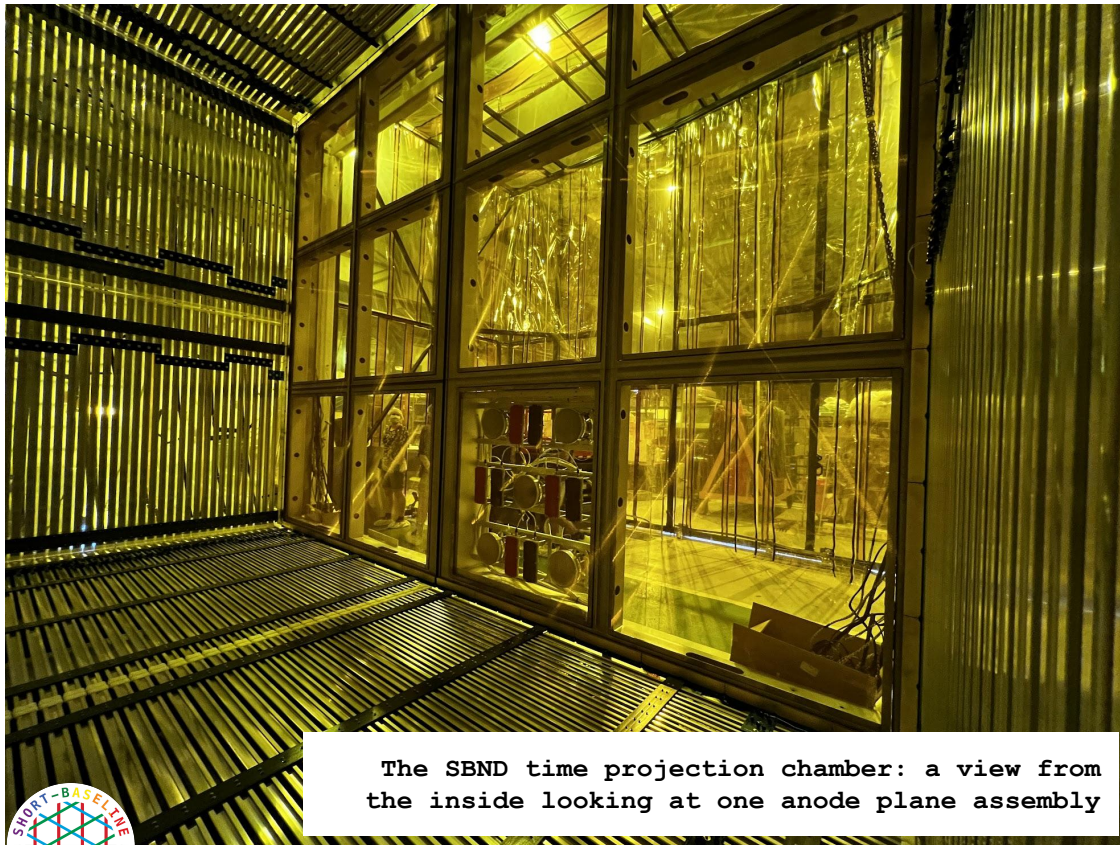
- **High-intensity neutrino beam** from 8 GeV proton beam.
- Proximity to the beam target (110m)
=> **high statistics.**
- Can sample **off-axis fluxes.**



SBND
112 tons of Ar

Current status: TPC fully built, with only the photon detection system remaining to be installed. Cold commissioning expected by **Spring 2023.**

Find more details about SBND in the overview talk given by [Miguel Nebot-Guino](#) (Aug 2, joint session WG1+WG5) & by [Gabriela Vitti Stenico](#) (Aug 4, WG6)



The SBND time projection chamber: a view from the inside looking at one anode plane assembly



Short Baseline Near Detector

Large-mass Liquid Argon Time Projection Chamber (LArTPC)

- 3D reconstruction with **3 mm position resolution**.
- **Fine-granularity** calorimetry.
- Excellent **particle identification** with dE/dx information.
- **Low energy thresholds**, sub-MeV to GeV.

Photon Detection System (PDS)

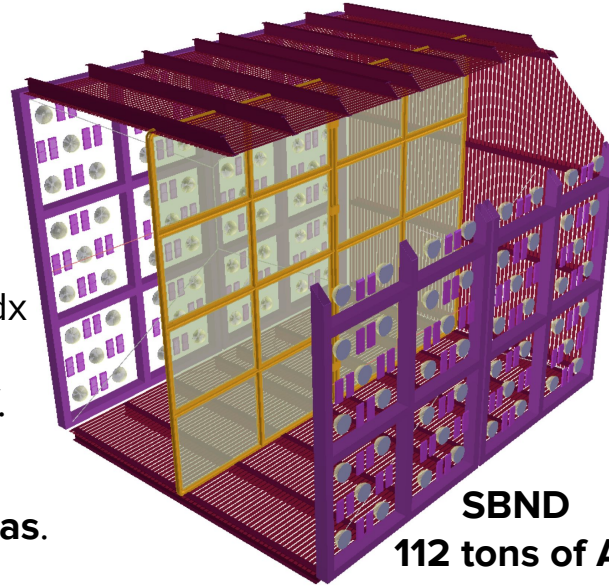
- Novel technology of **PMTs** and **X-Arapucas**.
- Scintillation & reflected light => **high and uniform light yield** and excellent **timing resolution**.

Cosmic Ray Tagger (CRT)

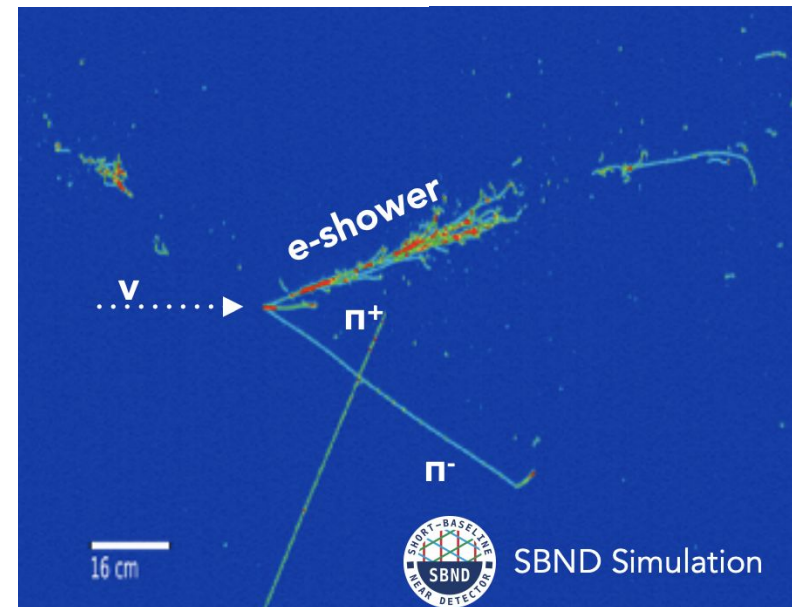
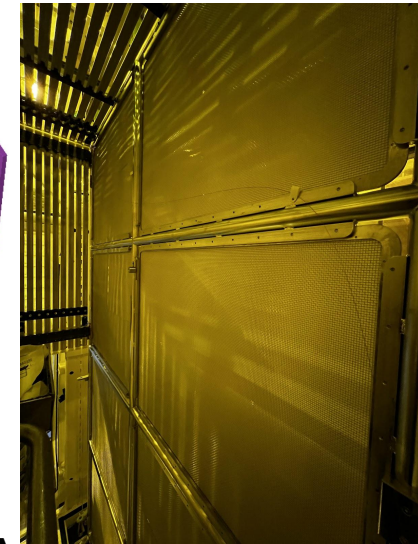
- **Timing and position resolution** allows for triggering on entering/exiting particles.

All of these features make SBND a multi-purpose detector that can look for **Beyond the Standard Model new physics**:

- Rare processes
- Low-energy signatures
- Challenging topologies



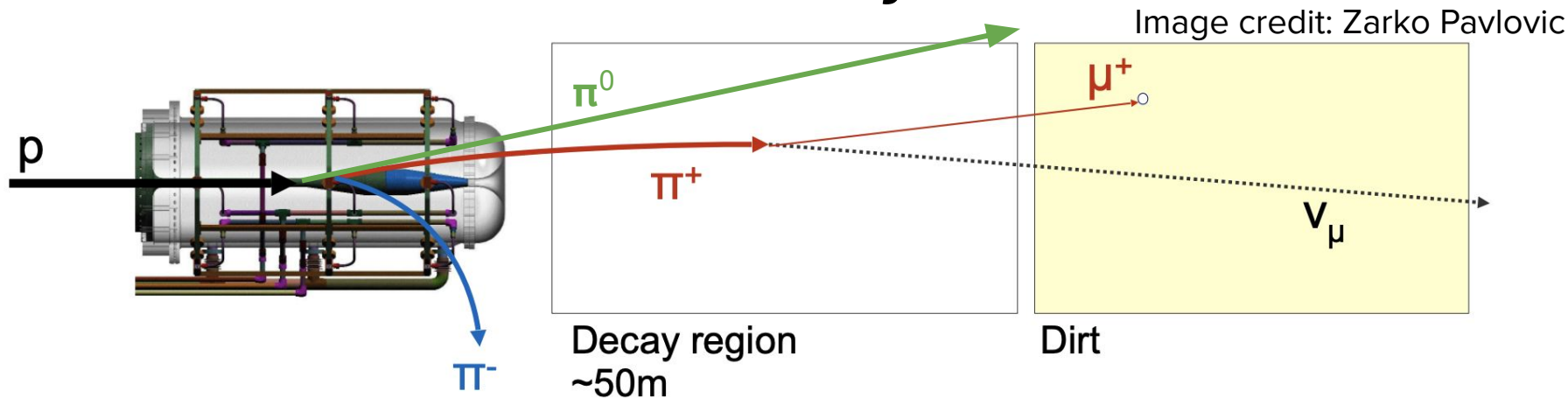
Cathode with reflective foils



SBND event display showing a simulated ν interaction



Booster Neutrino Beam & BSM Physics



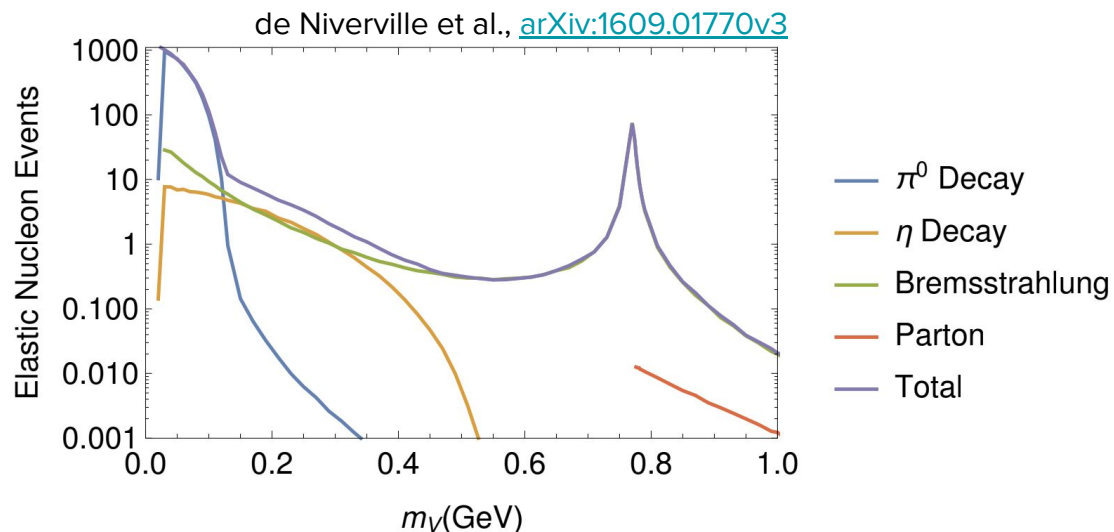
A high-intensity **8-GeV proton beam** is focused on a Beryllium target, producing **charged and neutral mesons**, which decay to produce muons, neutrinos, and potentially a variety of **BSM new physics**.

SBND is particularly close to the beam target (110 m).

BSM new physics with the BNB:

Modifications to the neutrino oscillation paradigm to explain the short-baseline anomalies.

Novel physics produced in the beam (dark matter, heavy neutral leptons, etc).



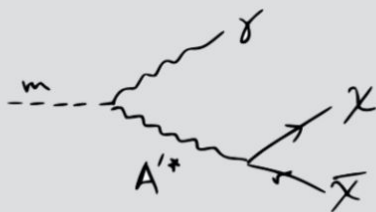
Light Dark Matter production modes in the BNB. The x-axis shows the dark photon mass in this vector portal model.



BSM Production in the Booster Neutrino Beam

A non-exhaustive list of BSM new physics produced in the Booster Neutrino Beam.

Light Dark Matter



Romeri Kelley Machado PRD 2019

Dark Neutrinos



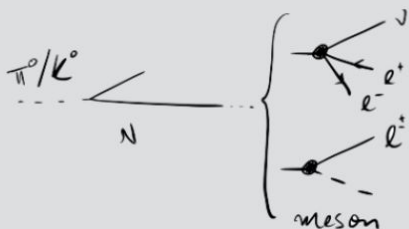
Bertuzzo Jana Machado Zukanovich PRL 2018, PLB 2019
Arguelles Hostert Tsai PRL 2019
Ballett Pascoli Ross-Lonergan PRD 2019
Ballett Hostert Pascoli PRD 2020

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

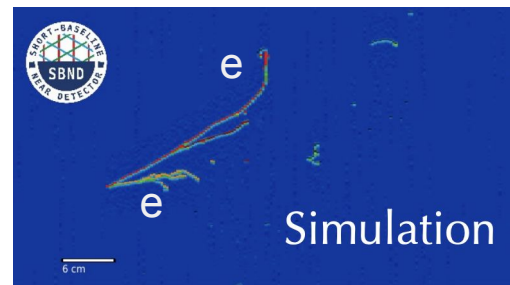
Axion-like Particles



Kelly Kumar Liu PRD 2021
Brdar et al PRL 2021

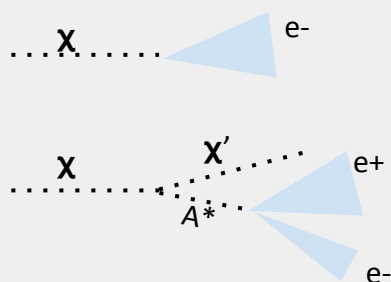
Image credits: Pedro Machado, Marco Del Tutto

BSM Signatures in SBND



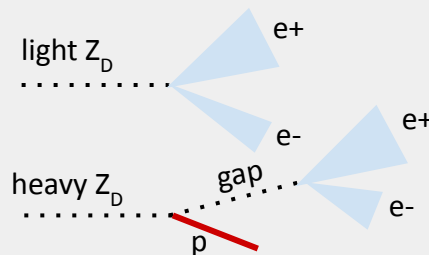
An SBND event display of a simulated dark neutrino event producing e^+e^- showers

Light Dark Matter



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

Dark Neutrinos



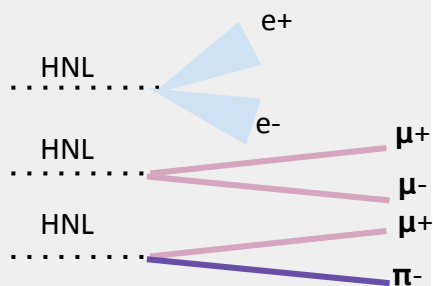
e^+e^- pair with or without hadronic activity

Millicharged Particles



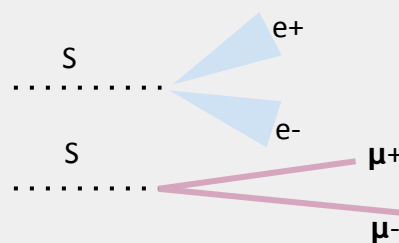
blips or faint tracks

Heavy Neutral Leptons



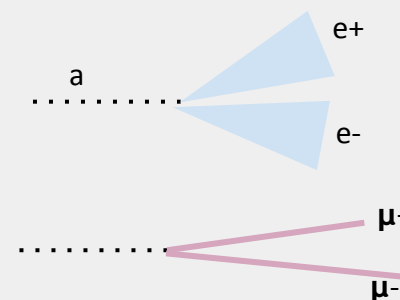
e^+e^- , $\mu^+\mu^-$, or $\mu^\pm\pi^\mp$ pair with no hadronic activity

Higgs Portal Scalar



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

Axion-Like Particles



high-energy e^+e^- pair

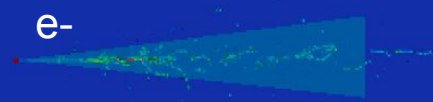
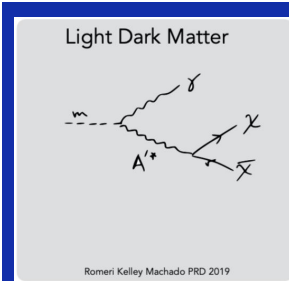


Light Dark Matter

SBND can probe **sub-GeV DM** postulated by “thermal relic” models, compared to WIMP searches restricted to higher masses.

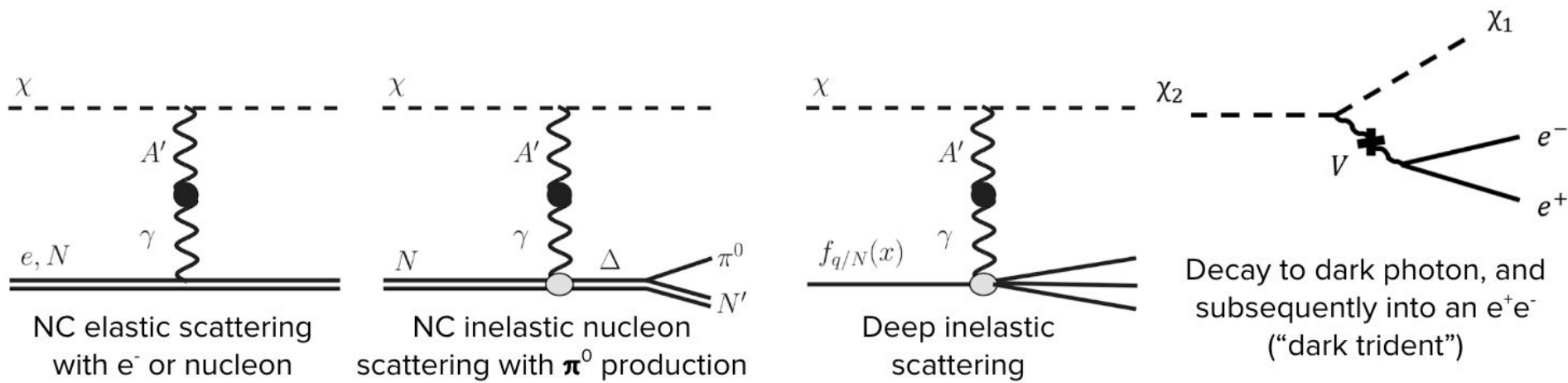
Vector portal DM models: light DM can be produced via **neutral meson decay** or **proton bremsstrahlung** in the Booster Neutrino Beam.

The light DM can subsequently **scatter or decay** in the SBND TPC, producing **electromagnetic showers** (scatter e^- or e^+e^-) and no other hadronic activity.



$$M_{\text{DM}} = 0.01 \text{ GeV}, \alpha_D = 0.5, \epsilon = 10^{-3}$$

SBND event display showing a simulated light Dark Matter interaction in TPC 0, with Pandora shower reconstruction depicted with the light green cone.



Light Dark Matter interaction modes in SBND

Light DM-e⁻ Scattering

Signature: a single highly forward-going electron with no other hadronic activity.

Dominant backgrounds:

- **ν -electron scattering**
- **ν -nucleon neutral current interactions with electrons/photons, and hadrons below thresholds.**

SBND tools being developed:

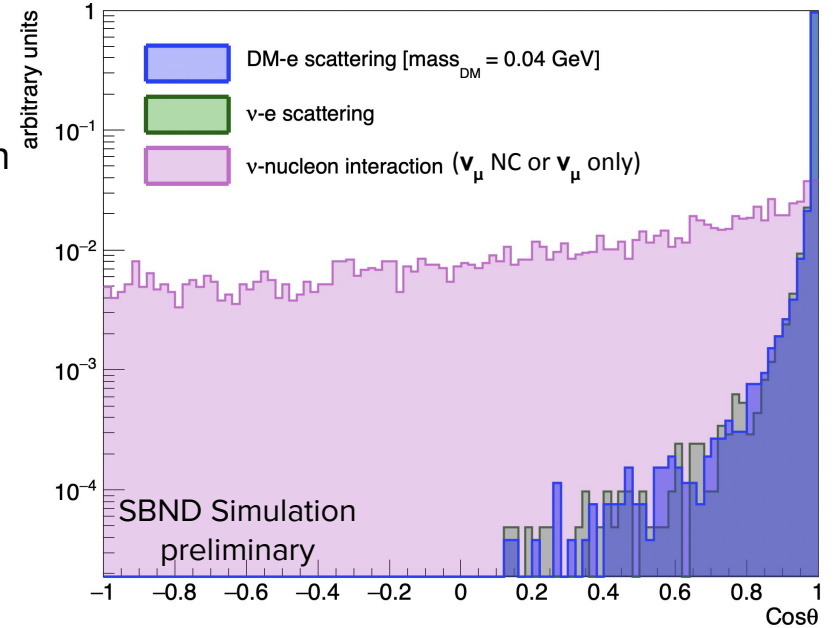
- low-energy shower reconstruction
- low-energy proton veto
- off-axis sampling to reduce **ν -electron scattering** backgrounds.
- machine-learning techniques for cosmic ray rejection... and others.

The plots on the right are area-normalized, and do not have any event selection applied.

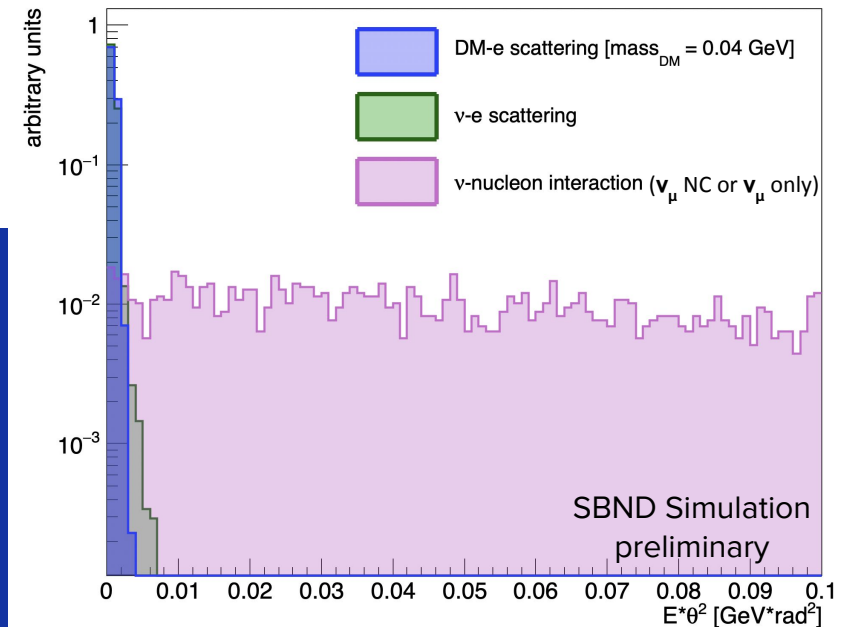
Event display showing a simulated light DM-electron scattering event

e⁻

SBND Simulation



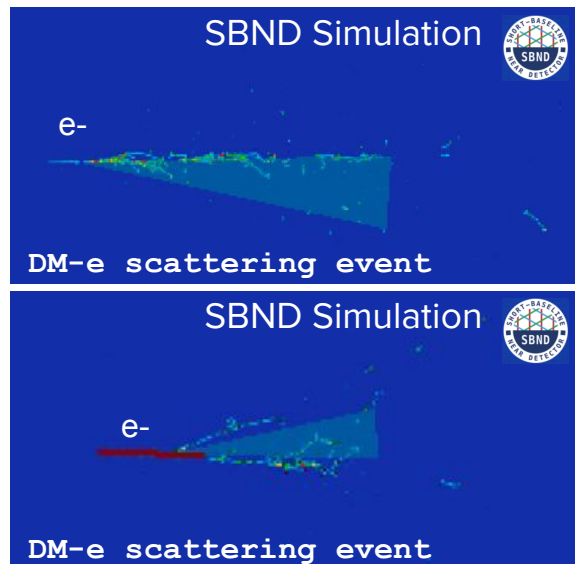
Distribution of events with respect to the beam direction



A commonly-used variable for BSM searches.

Examples of Reconstruction Tools for BSM Physics**

**not exhaustive, by any measure.



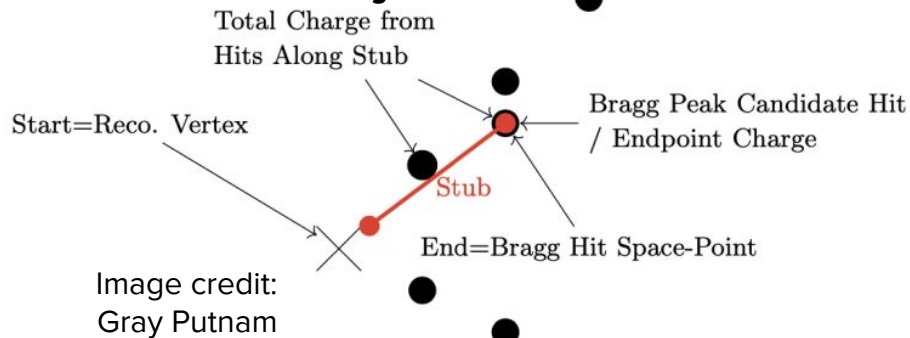
Many BSM signatures produce electromagnetic activity.

In this case, the DM scatter electron is reconstructed $\sim 91\%$ of the time: 54% as a single shower, 10% as a shower+track, 8% as a single track, 8% as two showers, 9% not at all, and the rest as multiple tracks and/or showers.

Efforts to improve reconstruction completeness, purity and resolution are ongoing.

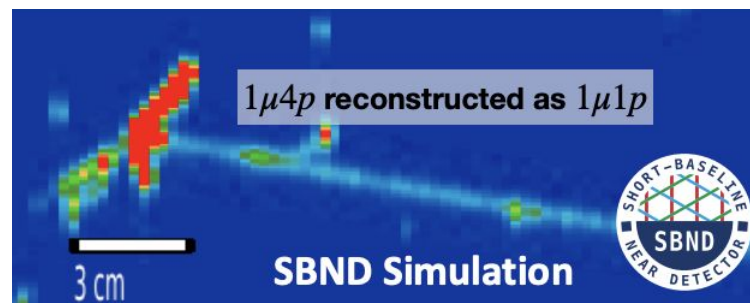
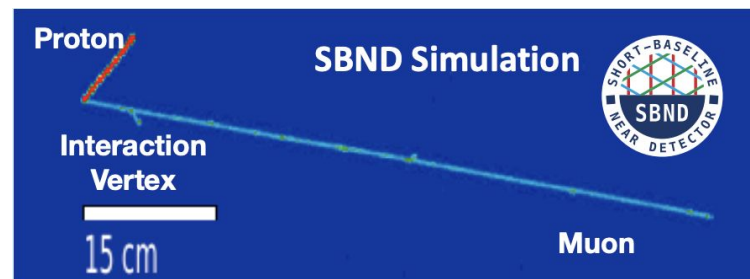
Electromagnetic Activity Reconstruction

Proton “Stub” Rejection



Tags and rejects low-energy stub-like charge depositions around a vertex that fail standard track reconstruction.

[[MicroBooNE](#) threshold: 100 keV, SBND projected: 50 keV]

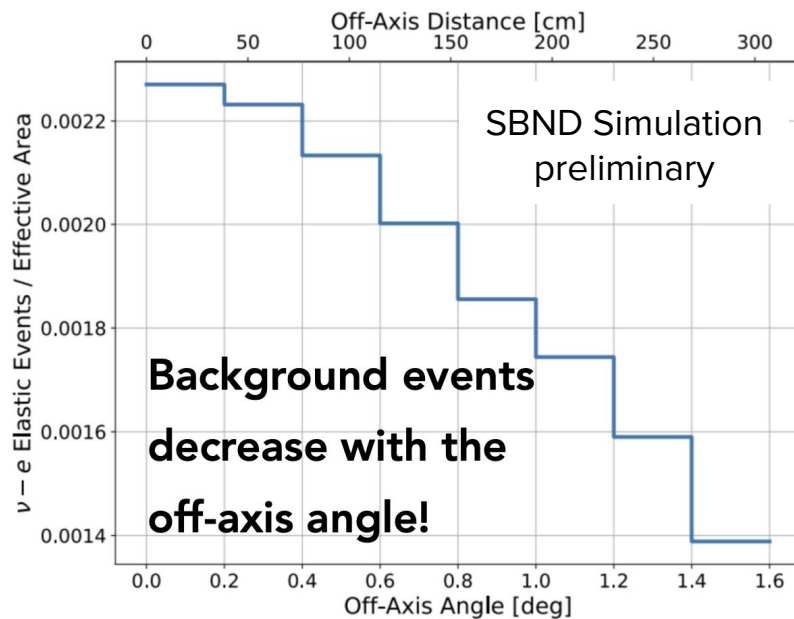
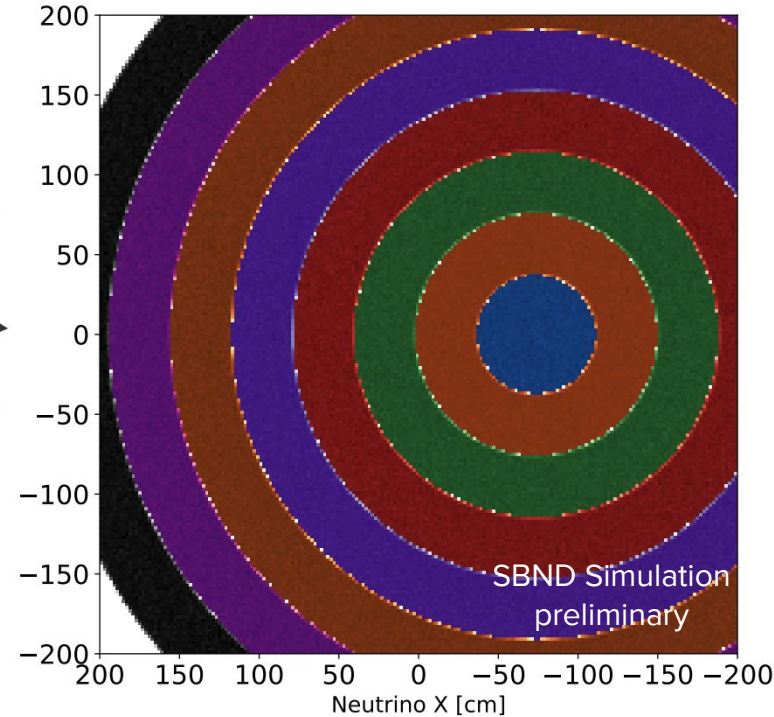
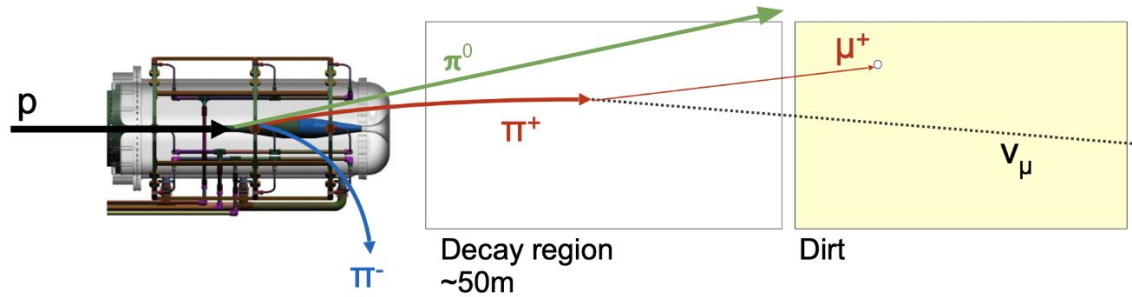


SBND PRISM

* [nuPRISM](#)

Find more details SBND PRISM in the talk given by [Marco Del Tutto](#) (Aug 4, WG1)

Precision Reaction Independent Spectrum Measurement (*)



ν -e scattering event rate as a function of off-axis angle (background for DM-e scattering)

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

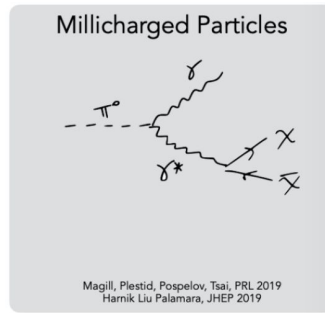
Neutral mesons in the BNB = less focused
can produce a variety of BSM: HNL, light DM, axion-like particles, millicharged particles.

Charged mesons in the BNB = more focused
produce SM neutrinos.

=> **Background reduction of SM neutrinos at off-axis angles for BSM new physics searches.**



Millicharged Particles



Hypothesized particles with **fractional electronic charge**, motivated by a cosmological anomaly (EDGES).

Could be a constituent of **Dark Matter**.
Produced by **neutral meson decay** in the BNB.

They would appear as **blips** or **faint tracks** pointing back to the target in SBND.

Projected SBND threshold: 50 keV
[MicroBooNE threshold: [100 keV](#)]

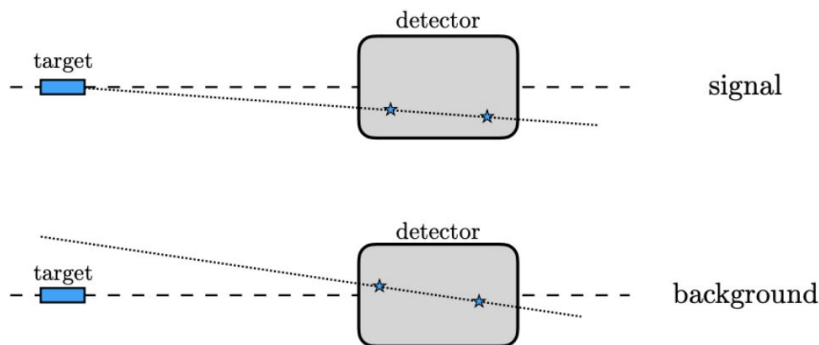
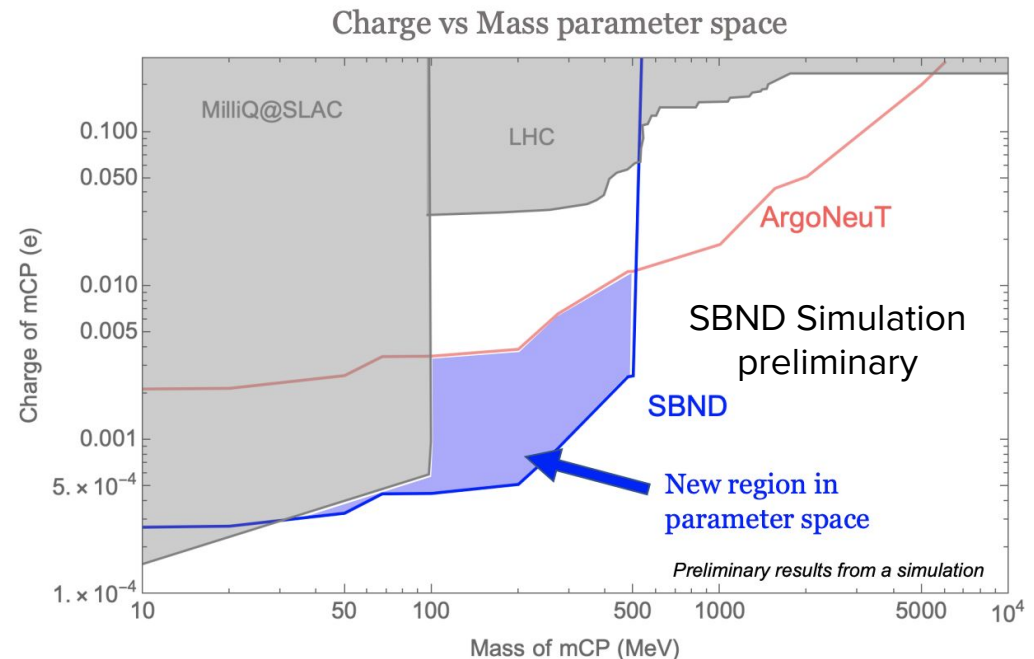


Image credit: ArgoNeuT,
[arXiv:1902.03246v2](#)

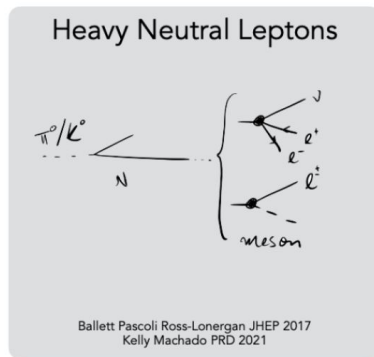


Preliminary SBND sensitivity projection from simulation



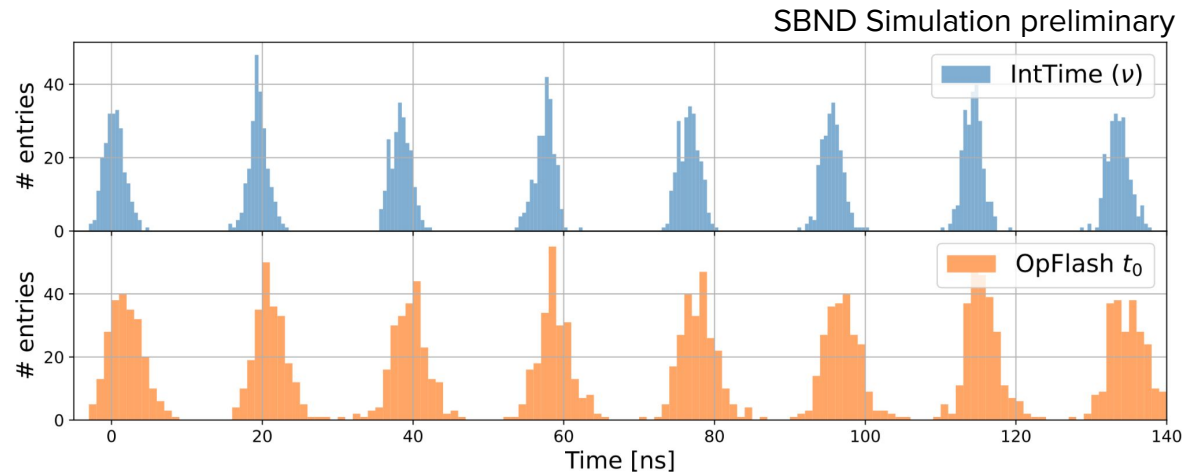
Heavy Neutral Leptons

Hypothesized heavy neutrinos as an addition to the 3-flavour paradigm; they can decay into e^+e^- , $\mu^+\mu^-$, or $\mu^+\pi^\mp$ pairs in SBND. Heavy particles are expected to reach SBND **later** than neutrinos.

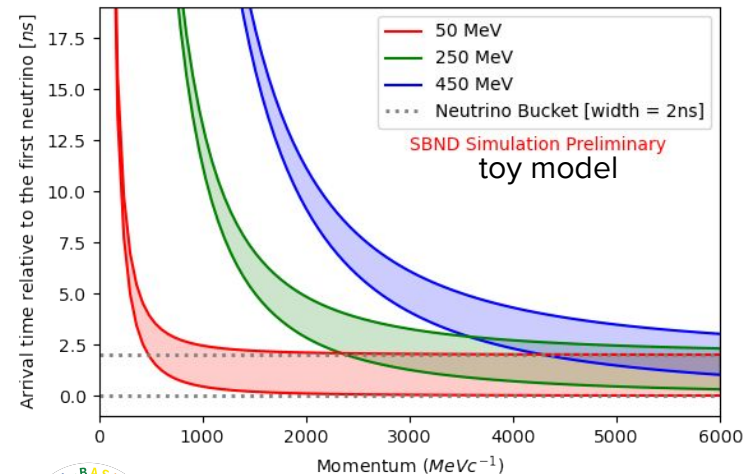


Main idea: use SBND's **excellent timing resolution** to **trigger** on them at the end of the beam spill *and* in between “buckets” of neutrinos.

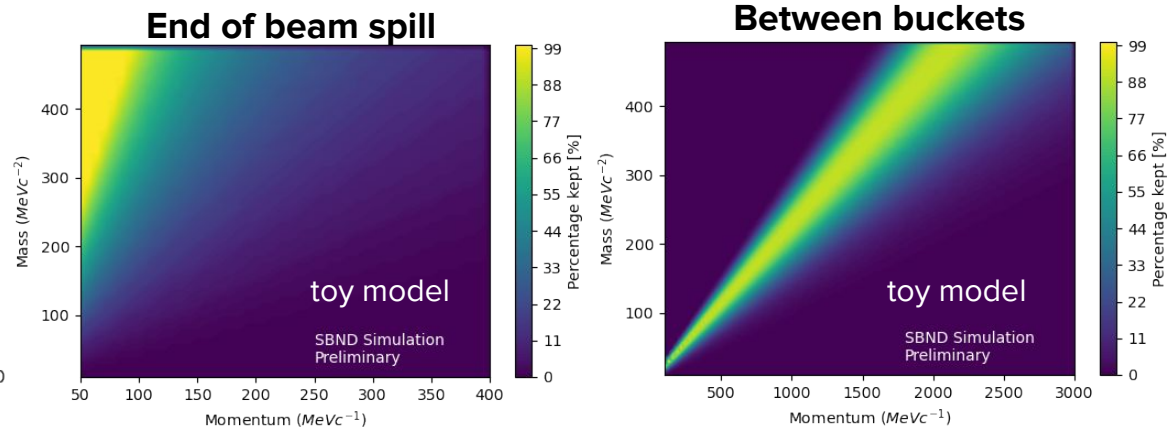
The two different types of triggers could grant access to **different areas of HNL phase space**.



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



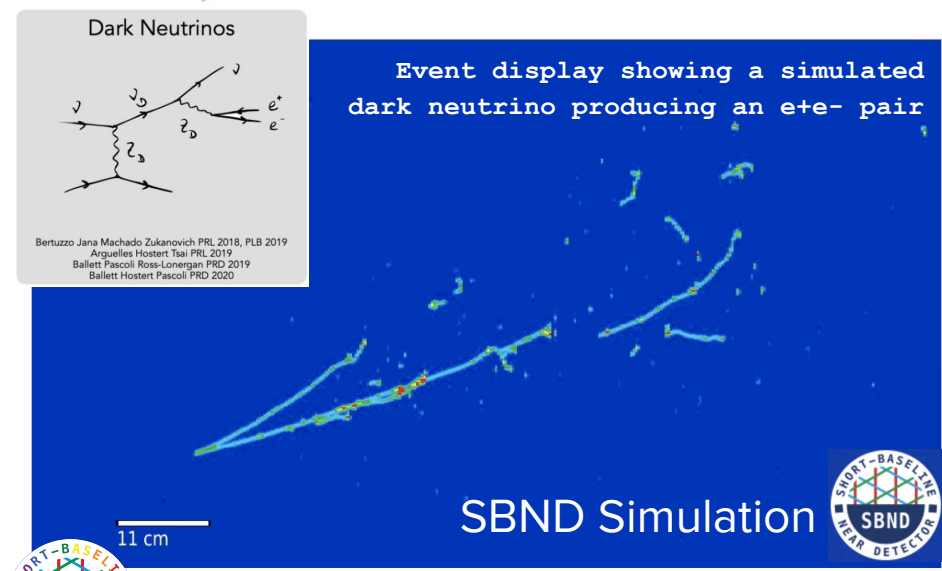
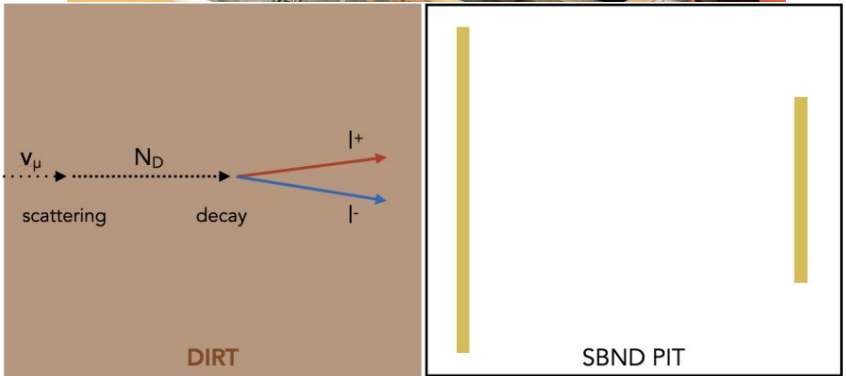
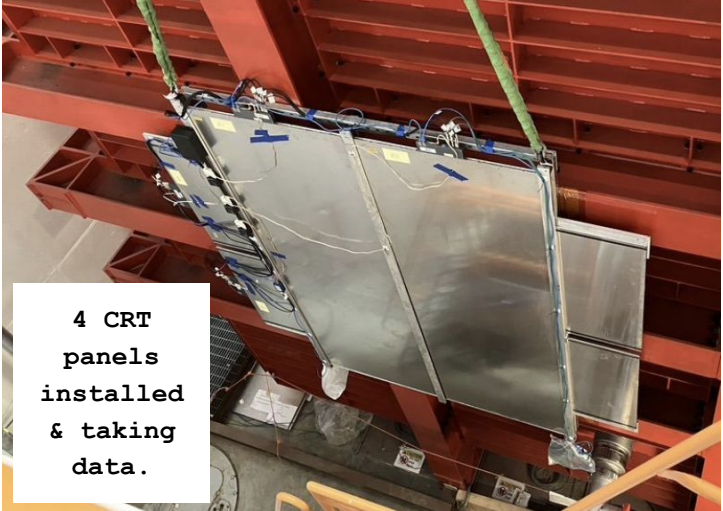
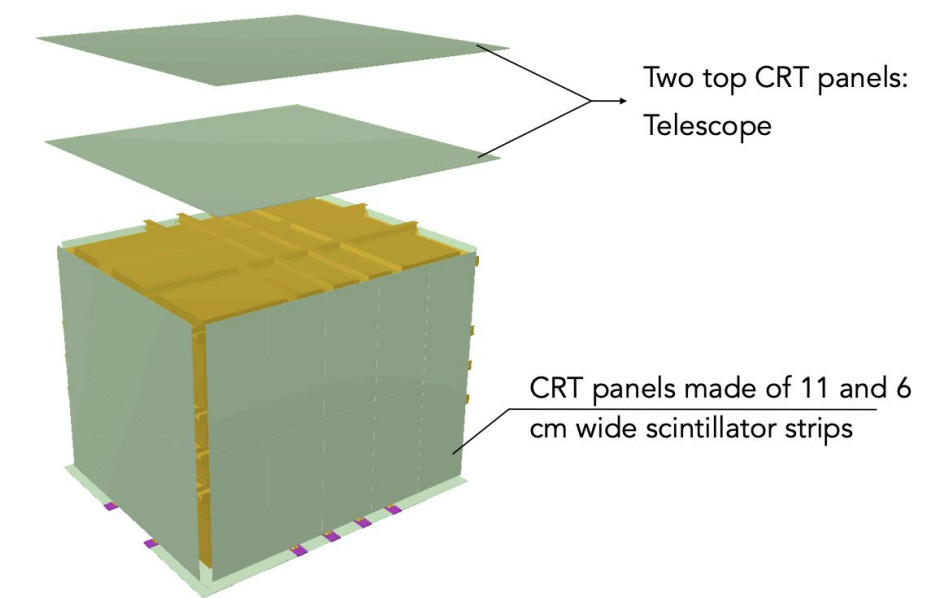
HNL time of flight w.r.t momentum



Preliminary sensitivity to HNL phase space for different triggering modes



SBND Cosmic Ray Tagger Beam Telescope



The SBND **cosmic ray tagger** can be used to tag BSM new physics particles that could decay in the dirt around SBND or in the cavern.

One example: **dark neutrinos** (a possible BSM explanation for the MiniBooNE low-energy excess) can be produced via upscattering of SM neutrinos in the dirt, decaying to dilepton pairs. These can be tagged by the **CRT upstream or downstream panels**.





Summary

- SBND is a large-mass 2-LArTPC system with proximity to the Booster Neutrino Beam target and high-intensity neutrino beam source
=> **large statistics, off-axis fluxes.**
- 3 detection subsystems: LArTPC + Photon Detection System + Cosmic Ray Tagger
=> **excellent spatial, timing and energy resolution, low energy thresholds.**
- A variety of new physics can be produced in the Booster Neutrino Beam
=> **BSM new physics detection opportunities at SBND.**
- Work has begun for estimating sensitivities and developing event selections:
dark neutrinos, heavy neutral leptons, millicharged particles, light dark matter, etc.
- **SBND is scheduled to start data-taking in late Fall 2023.**



Thank you!



Backup



SBND Light Collection & Triggering

Three-part Photon Detection System (PDS):

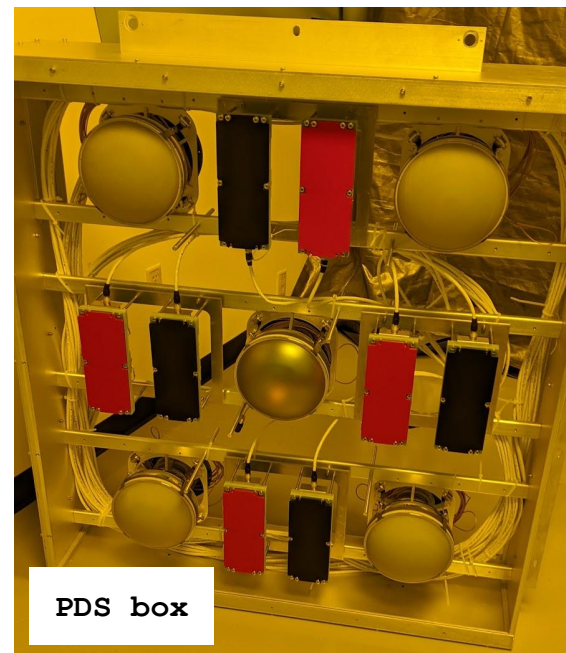
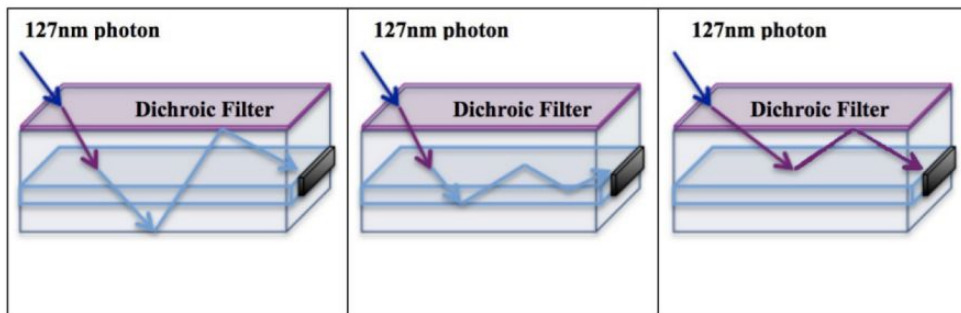
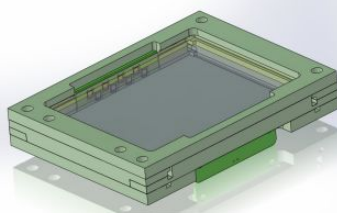
- Photomultiplier tubes (coated + uncoated)
- X-Arapuca devices (sensitive to UV + visible)
- Cathode covered with wavelength-shifting reflective foils

Primary scintillation and reflected light: improved and more uniform total light yield.

Energy reconstruction: can supplement LArTPC charge information with light for calorimetry.

Triggering: Recent improvements in timing resolution => can resolve the beam structure, and trigger on non-neutrino content in the beam.

X-Arapuca technology
uses dichroic filters
and waveguides to
guide photons to SiPM



PDS box



CPA mesh panels with
reflective foils

Expected # of BSM particles

