Searches for physics Beyond the Standard Model with the Short Baseline Near Detector

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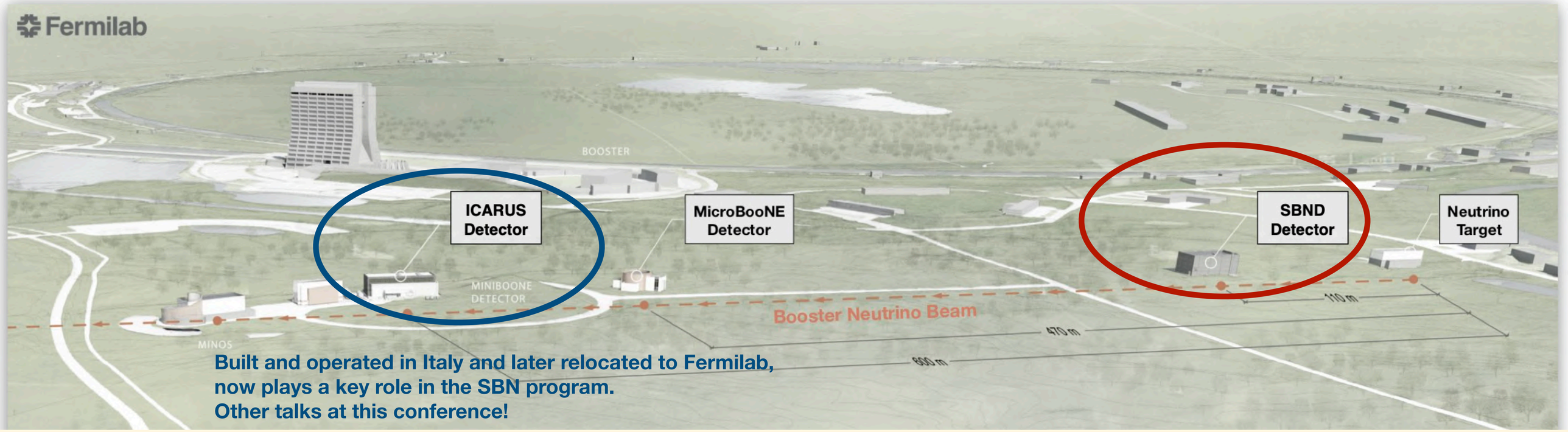
On behalf of the SBND Collaboration

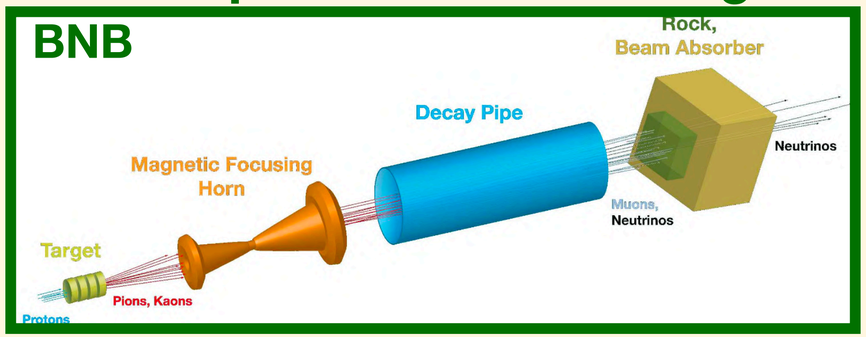
Short Baseline Neutrino Program



Built and operated in Italy and later relocated to Fermilab, now plays a key role in the SBN program.
Other talks at this conference!

Two LArTPC detectors located along the Booster Neutrino Beam (BNB) at Fermilab

8 GeV protons on a Be target

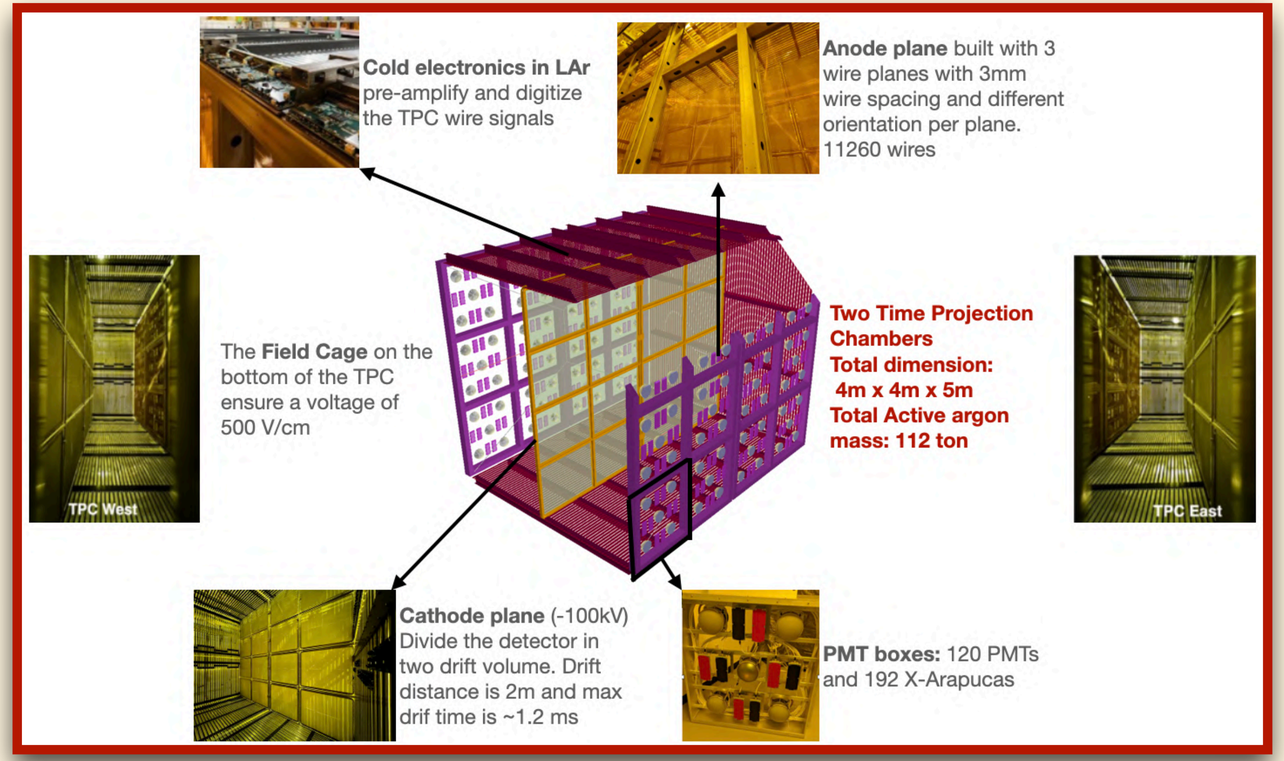


$< E_\nu > \simeq 700\ MeV$

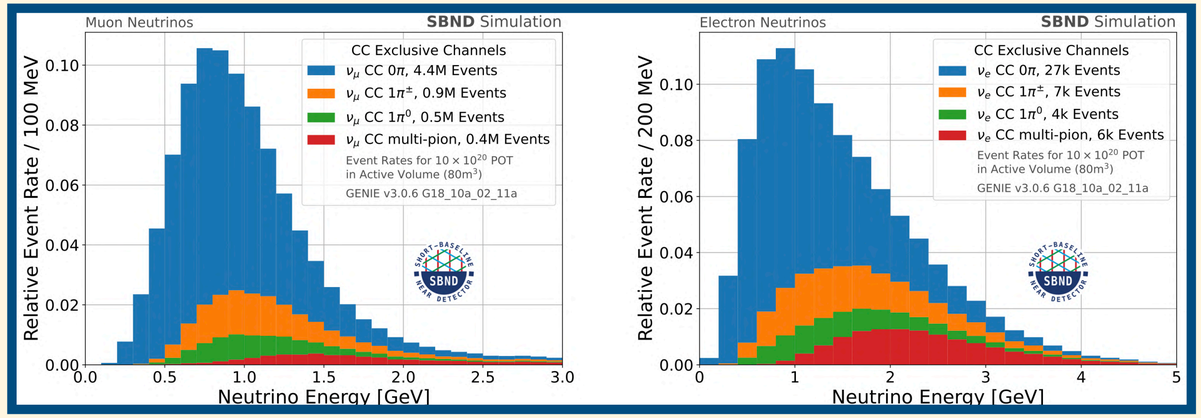
SBND

Topic of this talk!

Short Baseline Near Detector

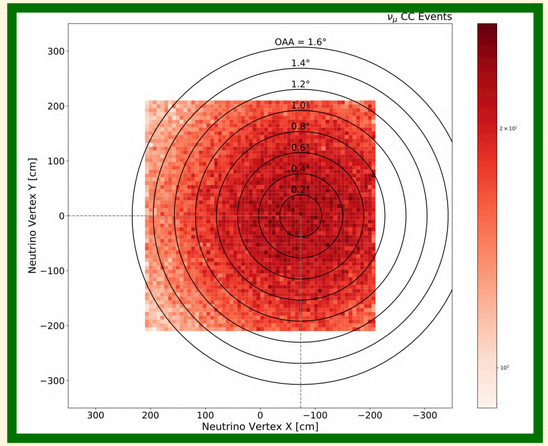


arXiv:2504.00245



6×10^6 *CC* ν_μ *and* 45×10^3 *CC* ν_e **in 3 years**

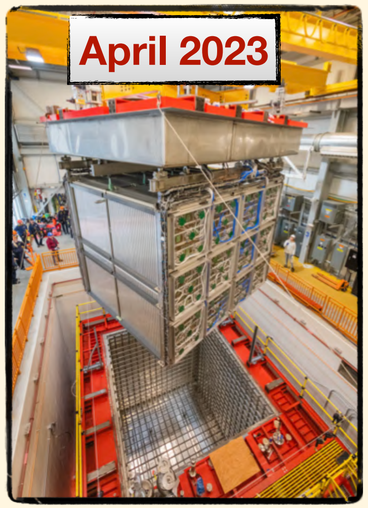
Collects more than 2 million neutrino interactions per year



SBND PRISM
Flux characterization and background rejection

arXiv:2508.20239

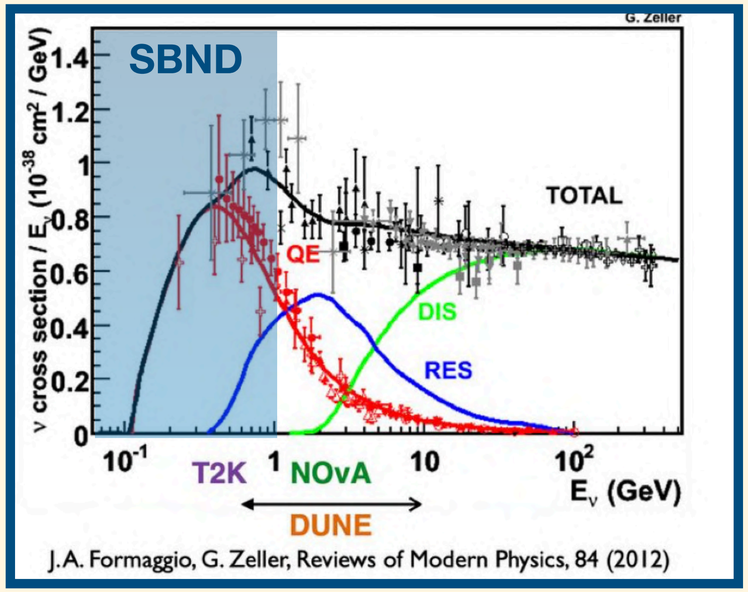
SBND History



RUN 1: February - July 2025
Already collected the largest neutrino-Argon dataset in the world, with 3 million interactions (2.8×10^{20} POT). Two more years of data taking

SBND Physics Goals

Search for eV Sterile Neutrino with ICARUS

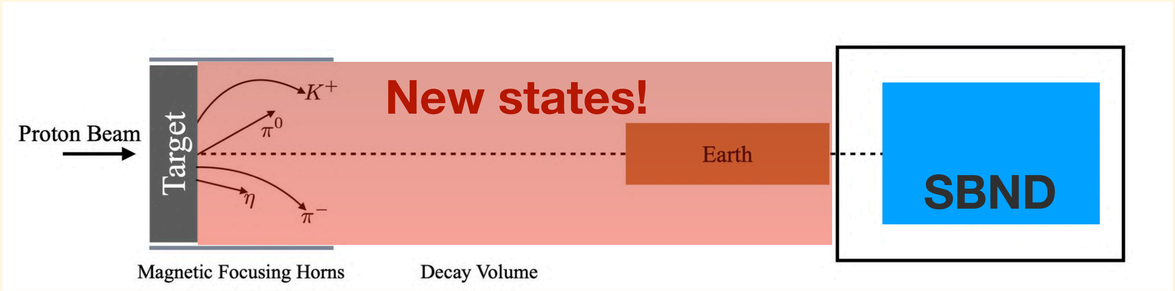


Measure neutrino cross sections with LAr

Beyond the Standard Model Physics

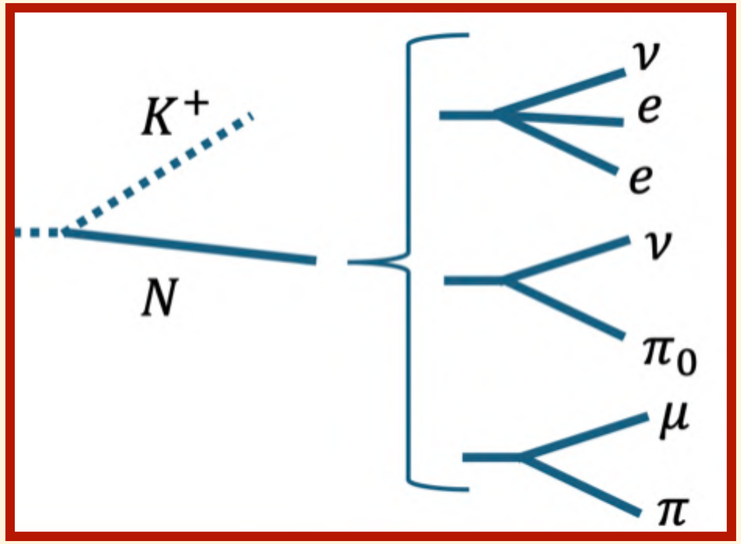
Given its proximity to the target and its excellent spatial, temporal, and energy resolution, SBND provides ideal conditions to search for new states produced in the BNB that decay inside its volume, thereby opening the door to dark sector investigations.

Topic of this talk!

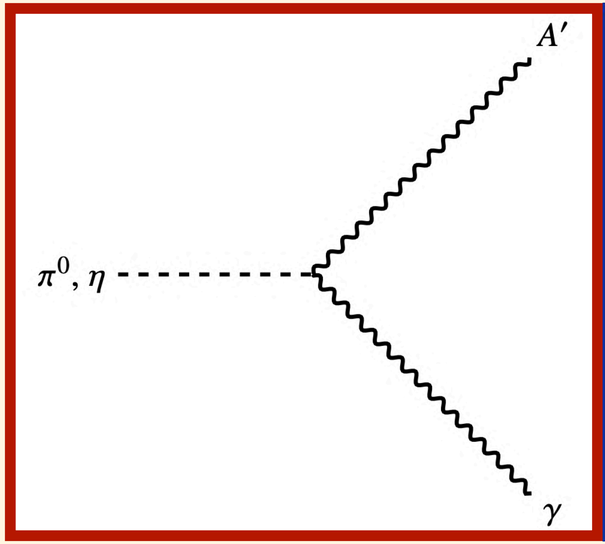


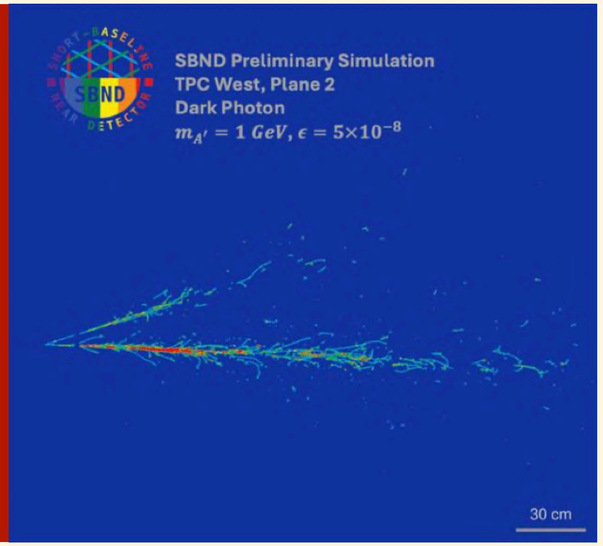
Some of the BSM Models in SBND

Heavy Neutral Lepton

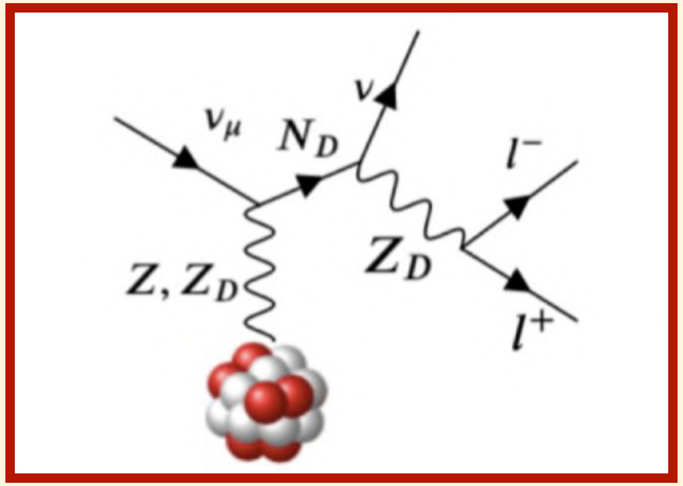


Dark Photons

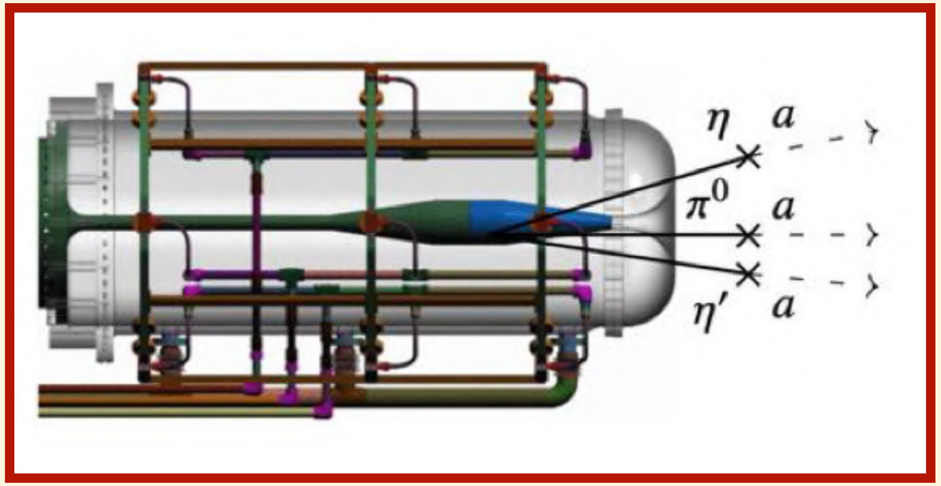




Generic Long-Lived Particles



Heavy QCD Axions



…To be continued!

How to search for BSM Models in SBND

Kinematic analyses

Energy, momentum, invariant mass, and angular distributions — are essential to separate BSM signals from background

Background

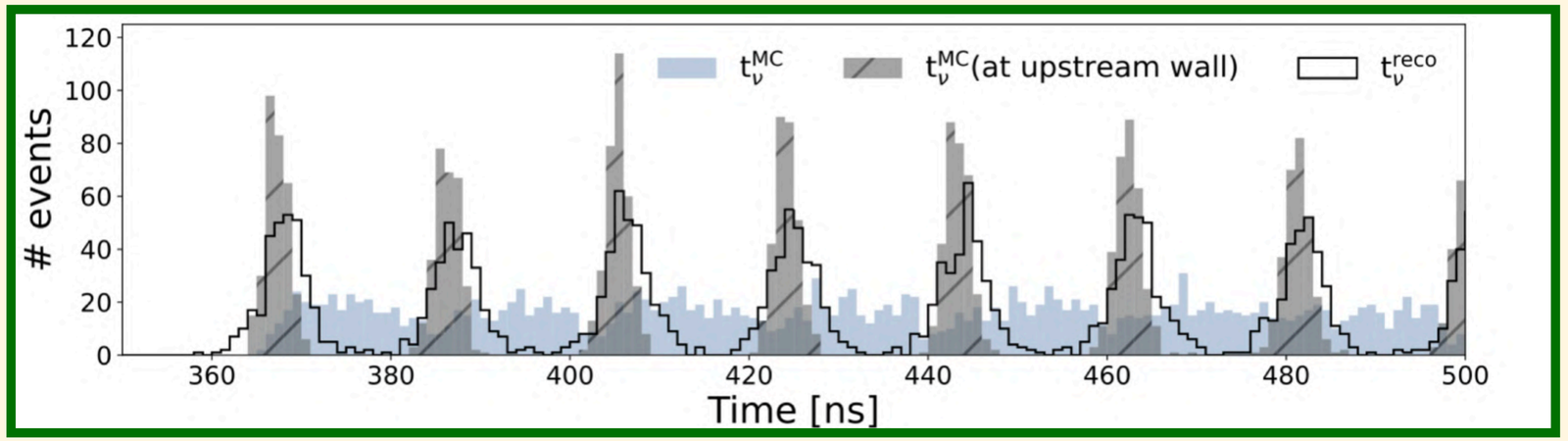
Beam-induced $NC\pi^0$events and generic cosmic-ray induced ones

Timing analyses

Protons arrive in ~2 ns bunches spaced by ~19 ns.
The PDS provides O(ns) timing resolution

BSM decays may be outside neutrino bunches

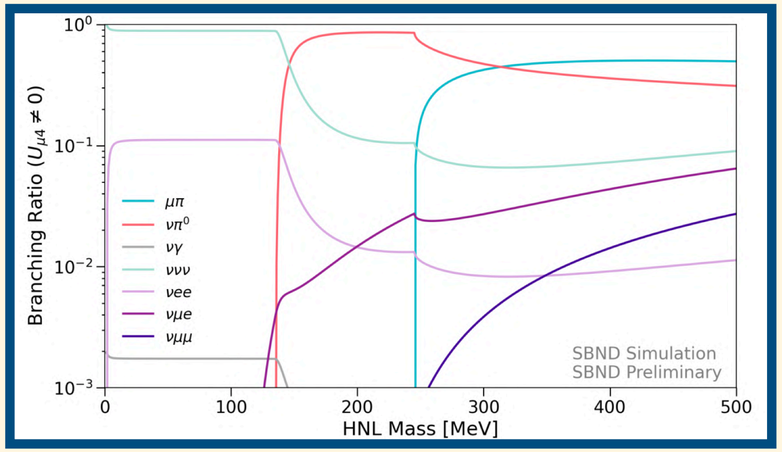
arXiv:2406.07514



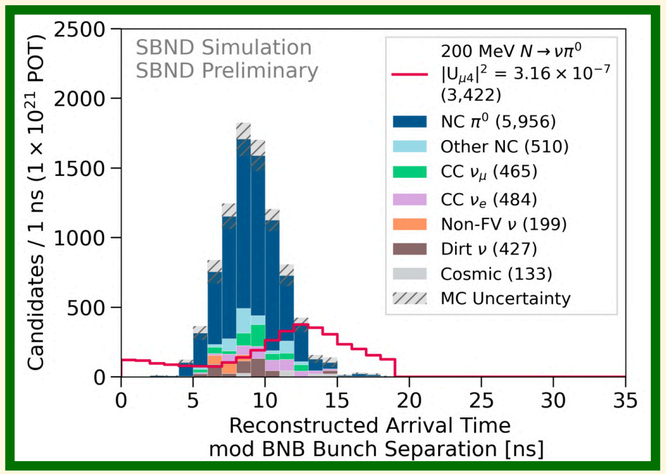
Heavy Neutral Lepton

Proposed as right-handed fermion coupled to the standard neutrinos via an extended PMNS matrix. Assumed as Majorana one for this analysis

Production and decay

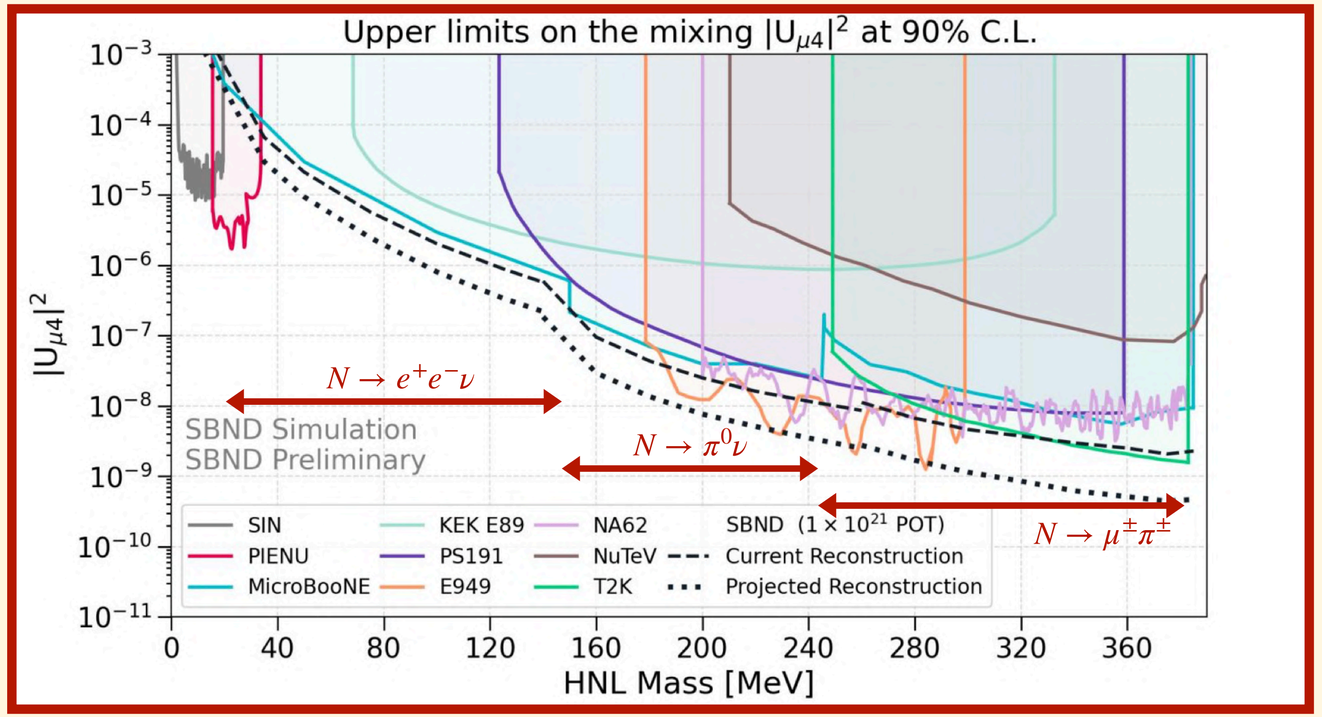


MeVPrtl simulation



Exploiting time delays relative to neutrinos (arrival time)

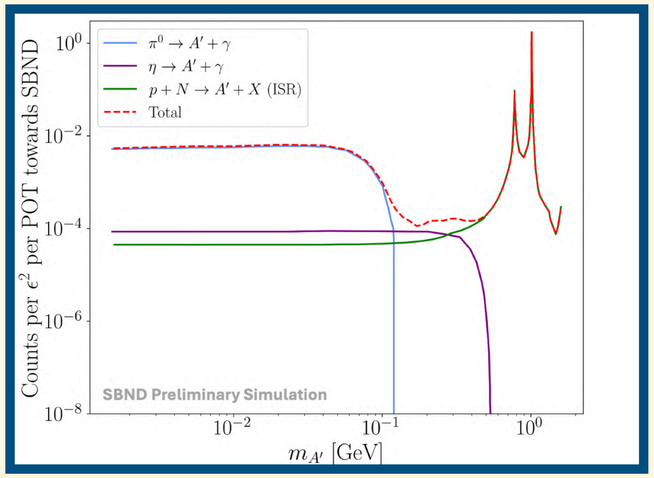
Sensitivity



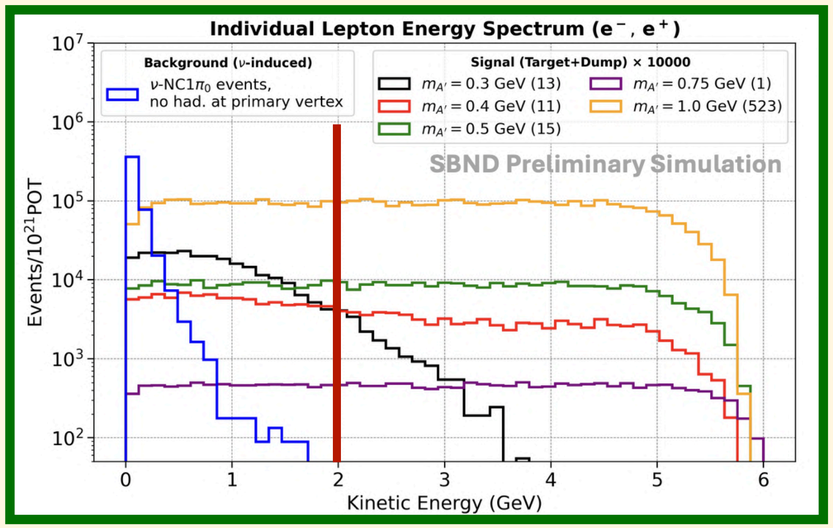
Ability to place competitive, world-leading bounds on the HNL parameter space

Dark Photon

U(1) gauge boson coupling to the SM via ϵ, kinetic mixing $\mathscr{L} \supset \frac{m_{A'}^2}{2} A'_\mu A'^\mu + e\epsilon \sum_f q_f \bar{f}\gamma^\mu f A'_\mu$

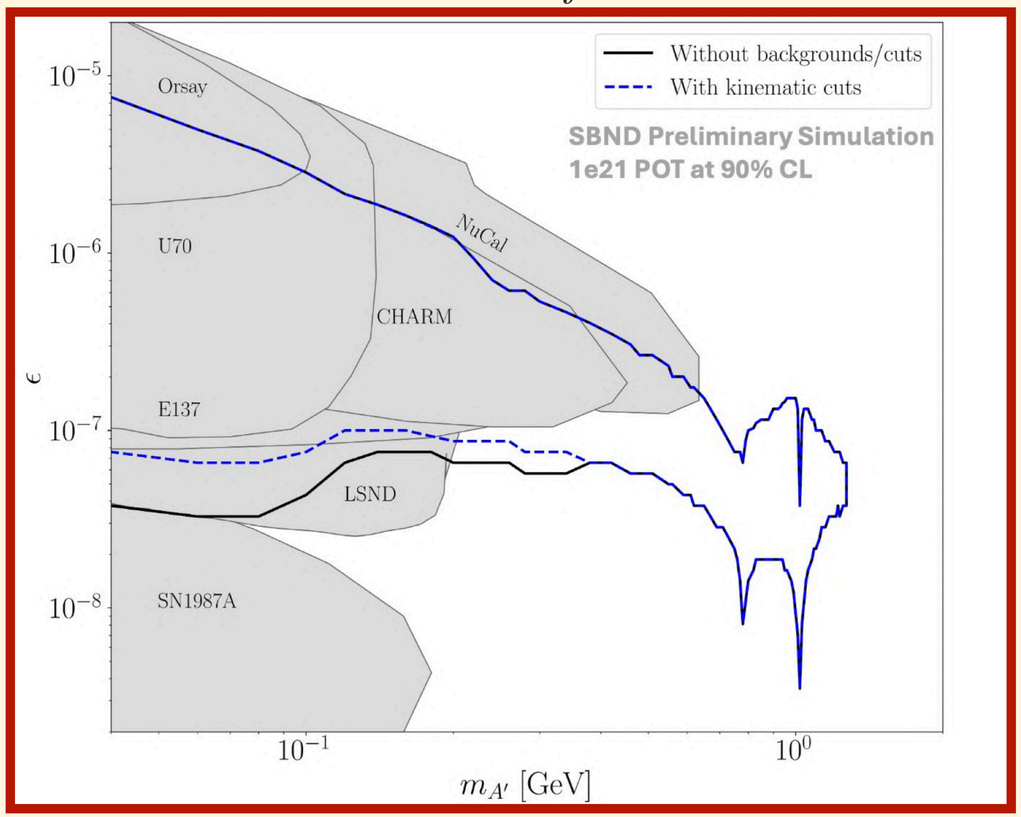


Production



The higher kinetic energy of electromagnetic showers induced by Dark Photons can be exploited by applying a 2 GeV cut

Sensitivity



Ability to place world-leading bounds on Dark Photon parameter space

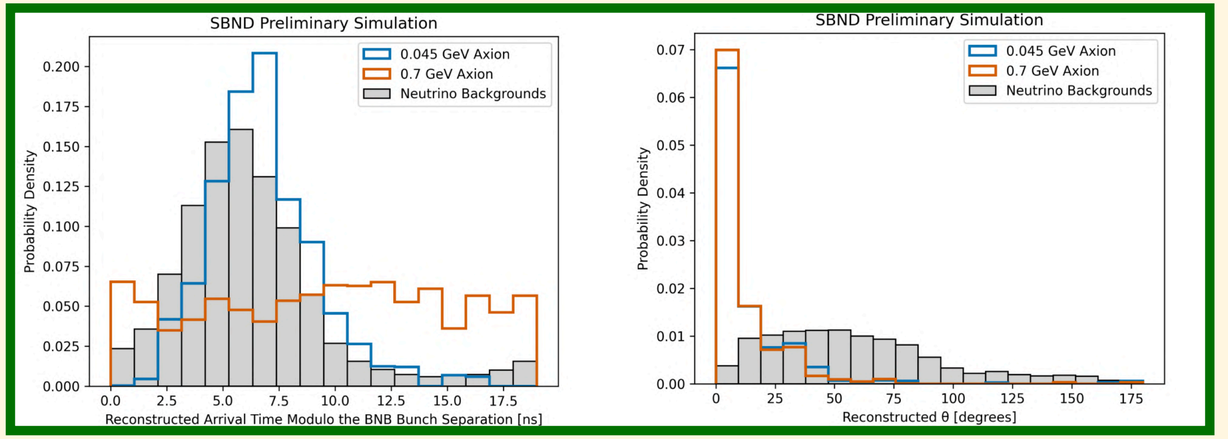
Heavy QCD Axion

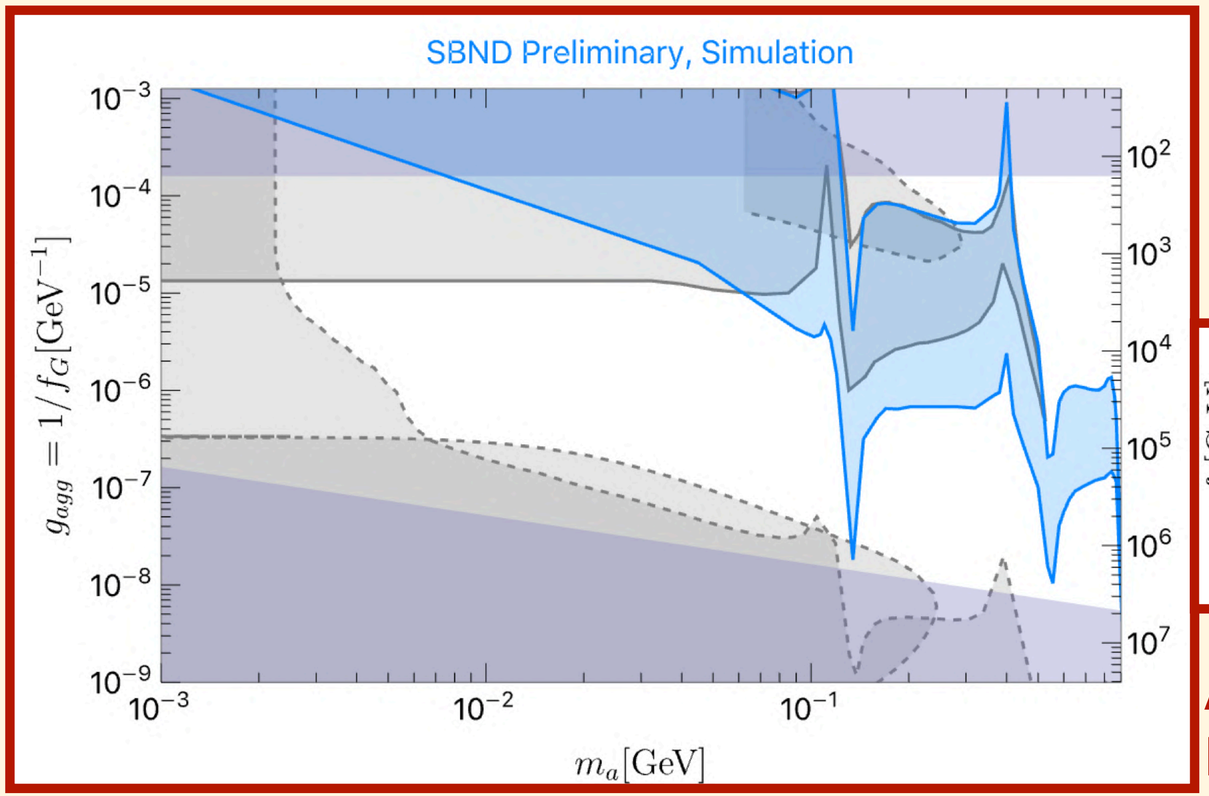
Proposed solution to the Strong CP problem $\mathscr{L}_{eff} = \frac{a}{8\pi f_a}\left(c_3\alpha_3 G\tilde{G} + c_2\alpha_2 W\tilde{W} + c_1\alpha_1 B\tilde{B}\right)$

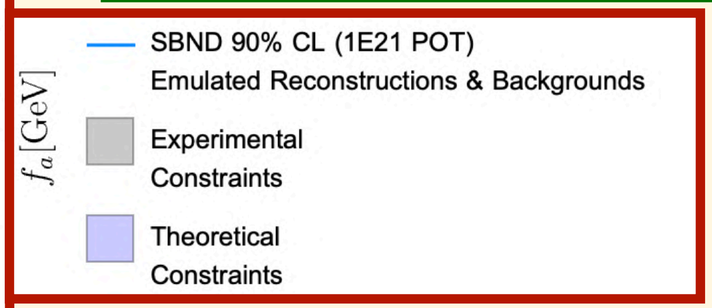
Produced by neutral mesons in the BNB

Same neutral mesons simulation as Dark photon

Exploiting time delays and angular distribution





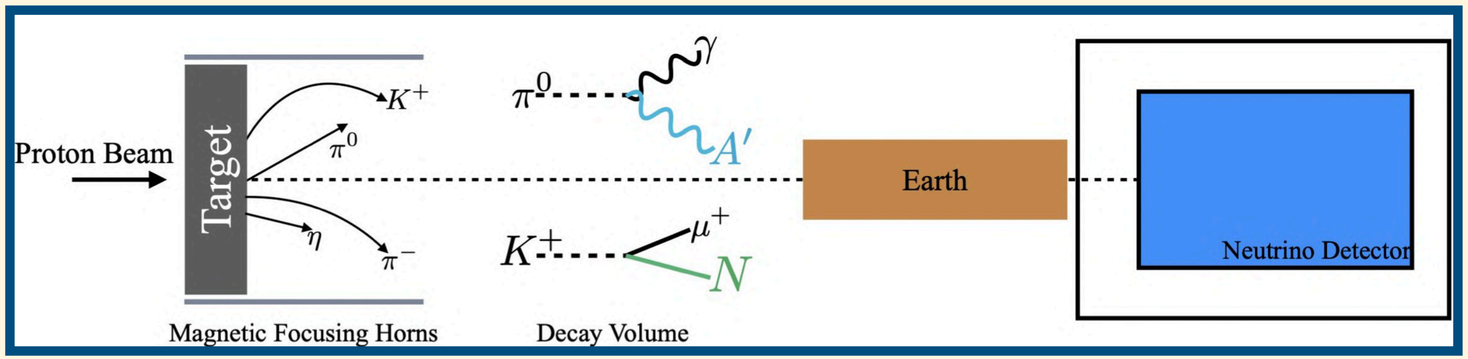


Ability to place world-leading bounds on Heavy QCD axions parameter space

Generic Long-Lived Particles

Model-independent search for exotic particles produced in the BNB and decaying in SBND

Production

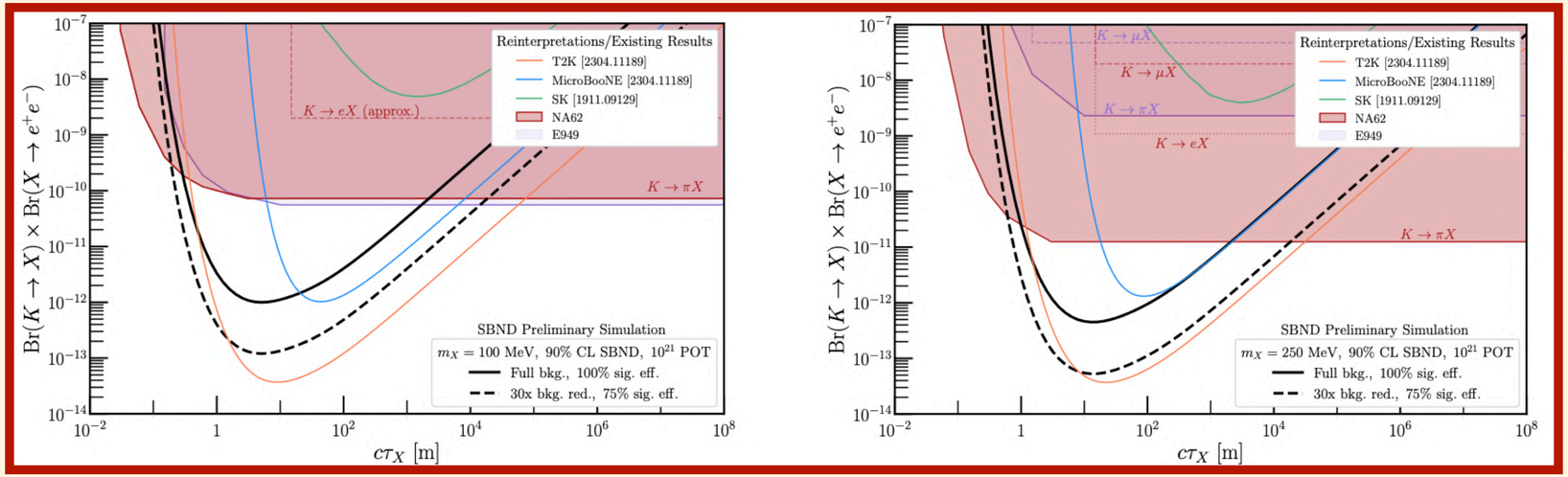


For this analysis we consider the production channels

$$K^+ \to \pi^+ + X$$

$$K^+ \to \mu^+ + X$$

Sensitivity



A model-independent search also has the potential to set world-leading limits

Summary and Outlook

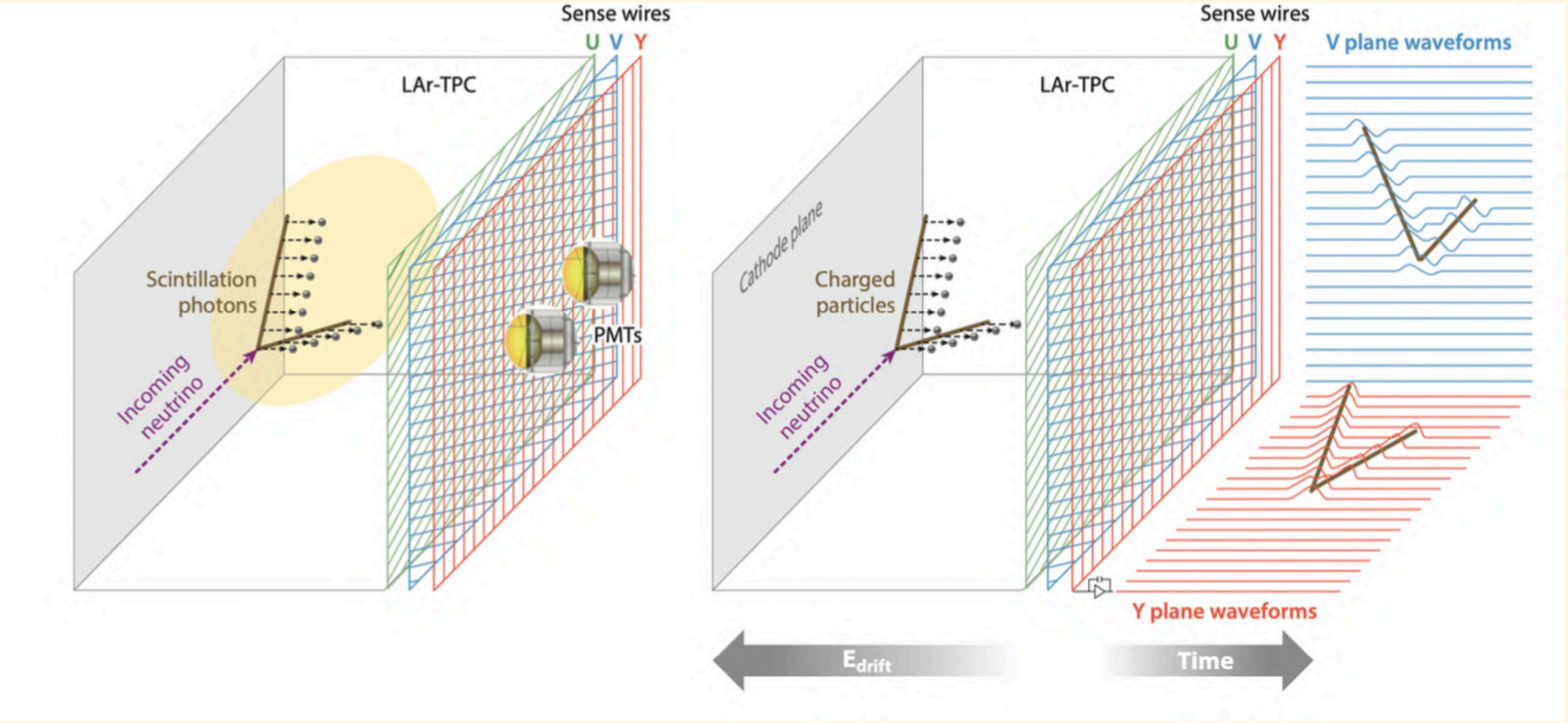
- SBND has capability to probe many BSM models — a publication is under preparation!
  - LArTPC and PDS provide excellent spatial and timing resolution
  - Timing and kinematic analyses offer the potential for world-leading searches
- Ongoing SBND data analyses are expected to produce exciting new insights — stay tuned!

SBND Collaboration Meeting at Sheffield University, UK June 2025

Thank you!

Backup Slides

Liquid Argon Time Projection Chamber



Digitized signals from the wire are collected [time of the wire pulse gives the drift coordinate of the track and the amplitude gives the deposited charge]

Charged particles produce ionization electrons and scintillation light (event time)

Ionization charges drift in a uniform electric field towards the readout wire planes. Electron drift time ~ ms

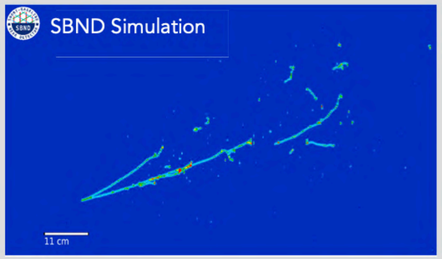
MIP at 500 V/cm:
~60,000 e/cm
~50,000 photons/cm

Other BSM models and event display

Alternative explanations to the MiniBooNE excess and other BSM scenarios

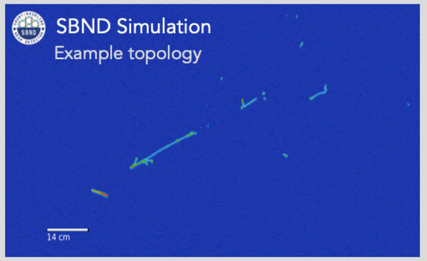
Not an exhaustive list

Dark Neutrinos



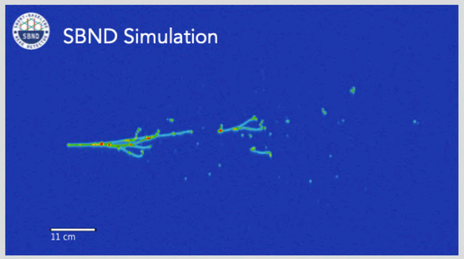
e+e- pair w/ or w/o hadronic activity

Transition Magnetic Moment



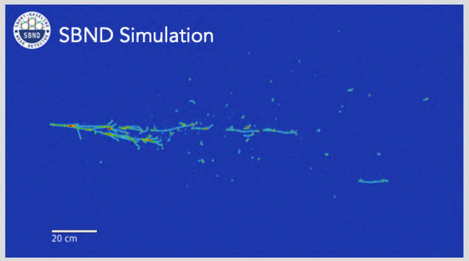
photon shower and hadronic activity

Axion-like Particles



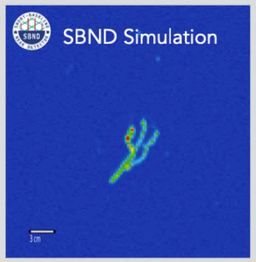
high-energy e^+e^-, $\mu^+\mu^-$

Heavy Neutral Leptons



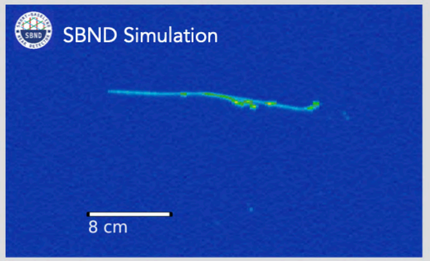
e^+e^-, $\mu^+\mu^-$, $\mu\pi$

Higgs Portal Scalar



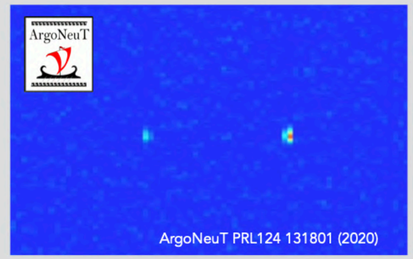
e^+e^-, $\mu^+\mu^-$, no hadronic activity

Light Dark Matter



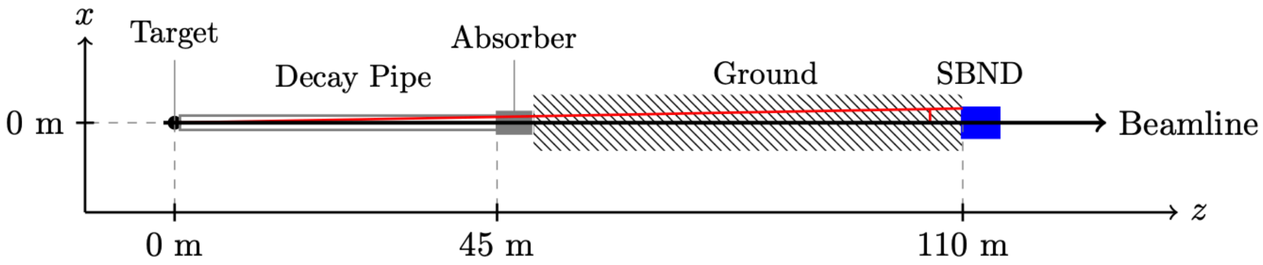
electron scattering

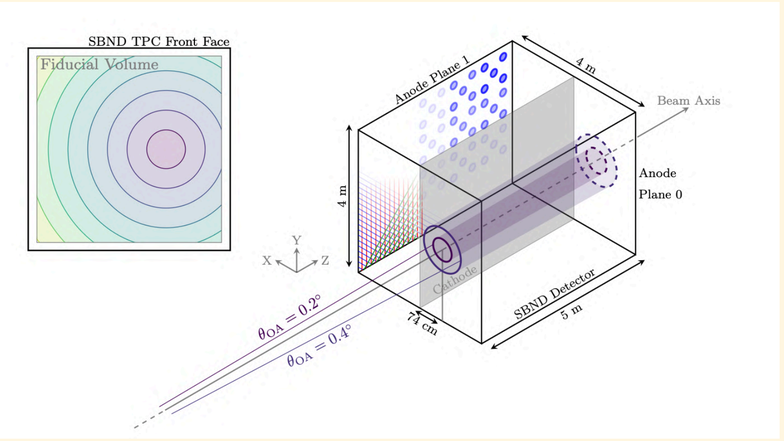
Millicharged Particles



blips/faint tracks

PRISM





$$\pi^+ \to \mu^+ + \nu_\mu,$$
$$K^+ \to \mu^+ + \nu_\mu,$$
$$K^+ \to \pi^0 + e^+ + \nu_e,$$
$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu.$$