SBND: Short Baseline Near Detector

Marco Del Tutto

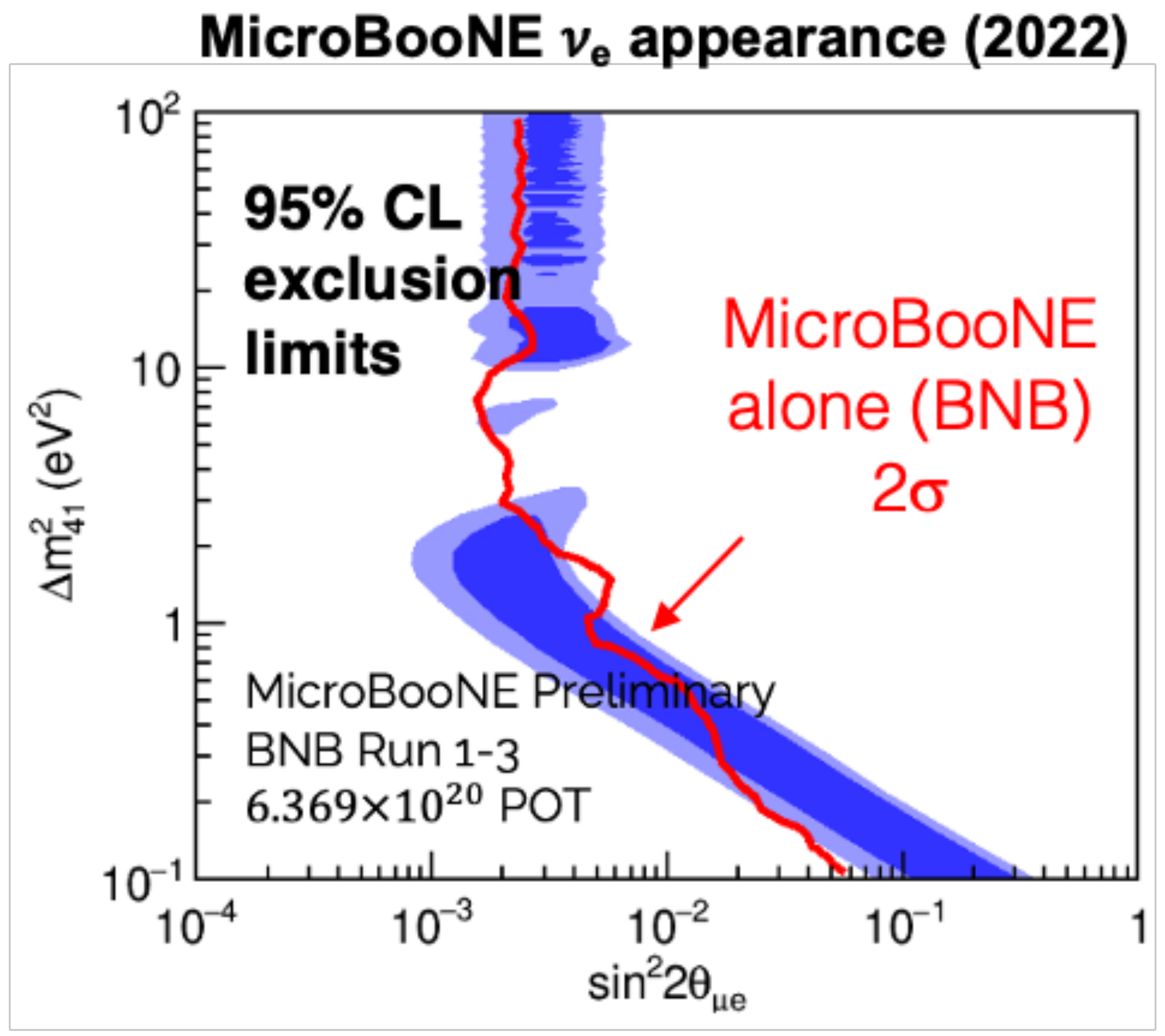
Fermilab Users Meeting

16th June 2022

Introduction

MicroBooNE presented results of their first analyses searching for an excess of low-energy electromagnetic events.

MicroBooNE finds no hints of an electromagnetic event excess but results do not rule out existence of sterile neutrinos.



Entering the next phase of accelerator-based short baseline oscillation searches requires:

- increased exposure through a larger far detector
- a near detector for systematics constraints

The Short Baseline Near Detector (SBND)

SBND is the near detector in the Short Baseline Neutrino (SBN) program at Fermilab

Three Liquid Argon Time Projection Chamber (LArTPC) detectors

located along the Booster Neutrino Beamline (BNB) at Fermilab

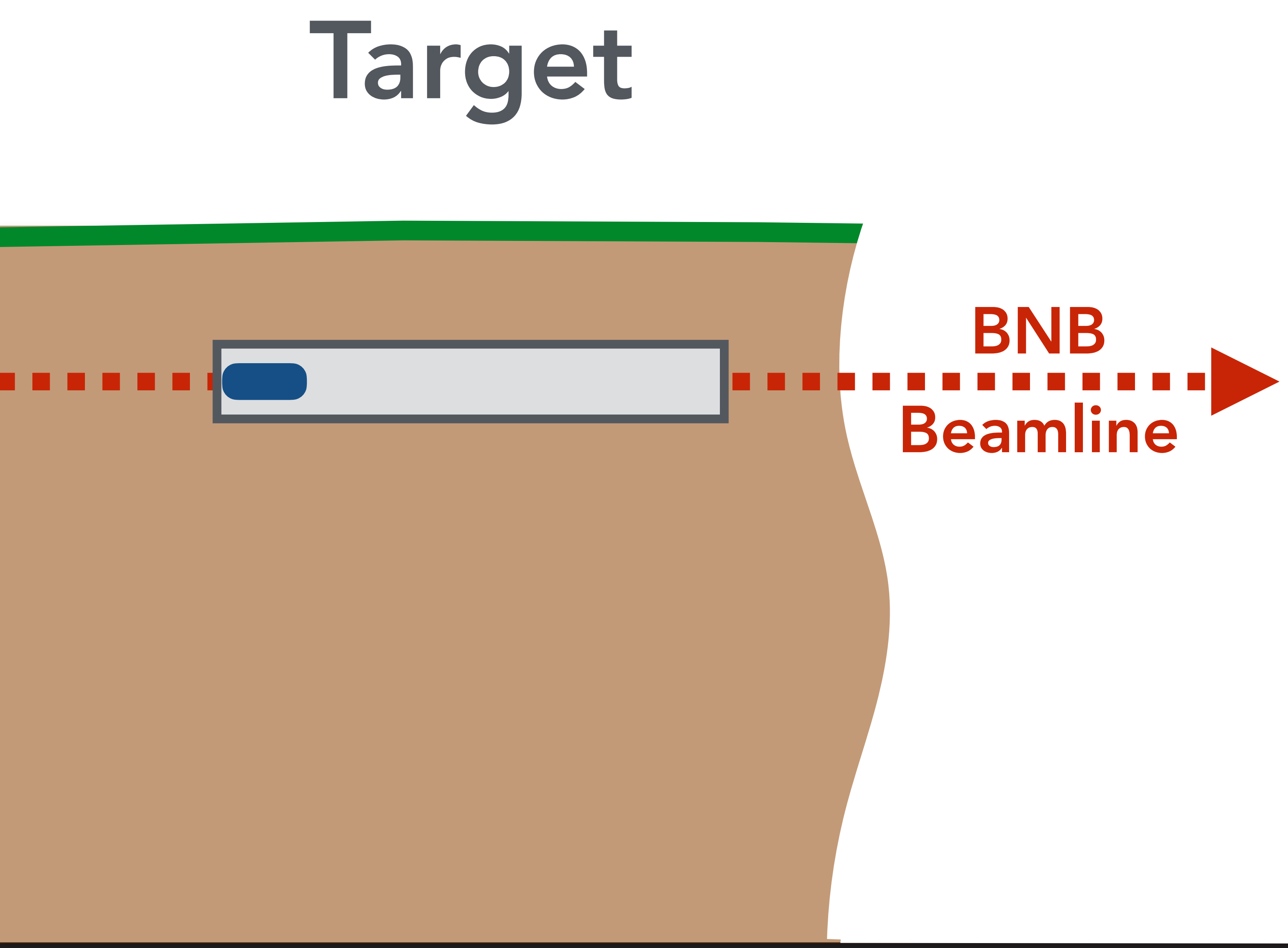
Goals of the SBND:

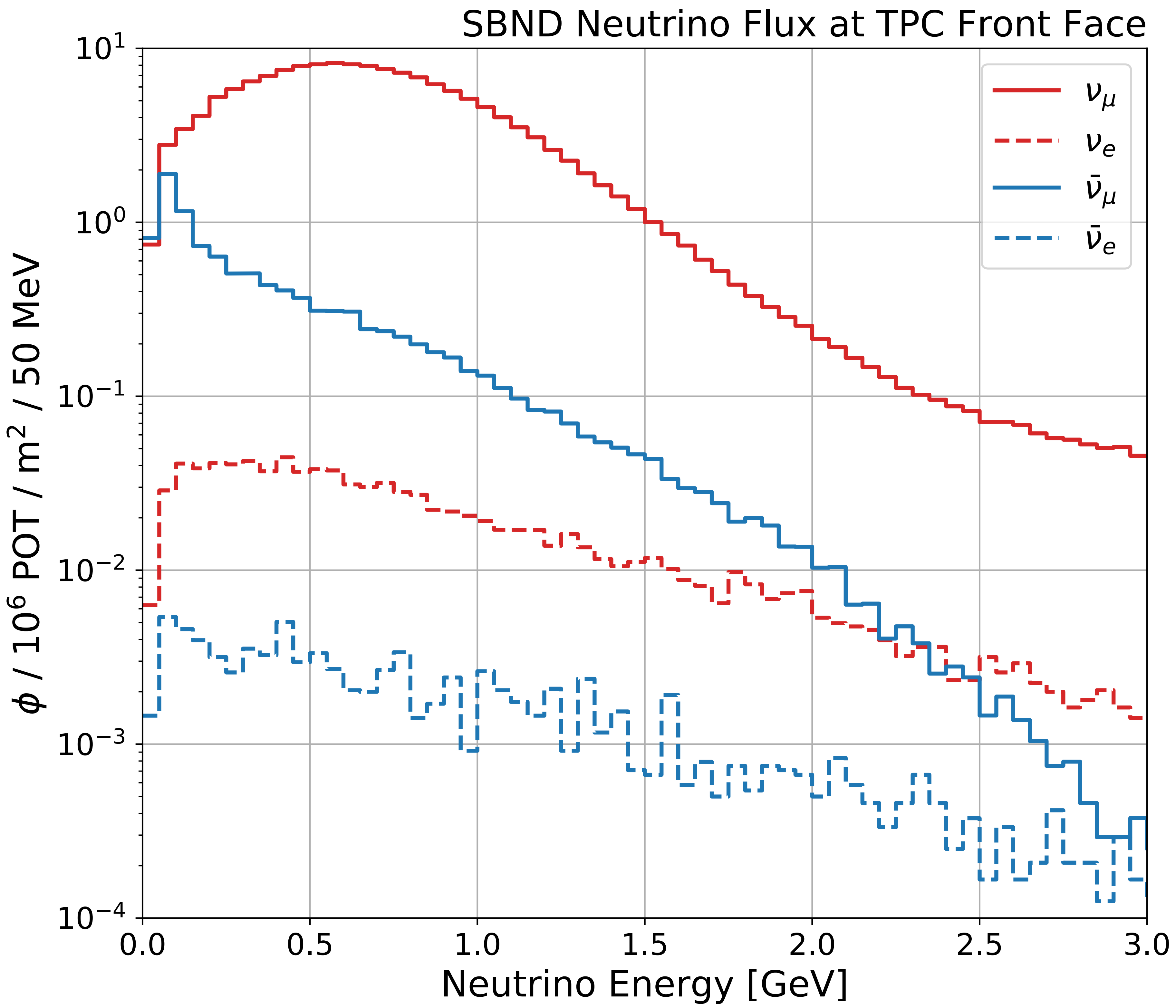
Search for eV mass-scale sterile neutrinos oscillations

Study of neutrino-argon interactions at the GeV energy scale

Search for new/rare physics processes in the neutrino sector and beyond

BNB Flux





Neutrino flux at the SBND front face.

Mean muon-neutrino energy: ~0.8 GeV

Beam composition:

ν_μ (93.6%)

$\bar{\nu}_\mu$ (5.9%)

ν_e+$\bar{\nu}_e$ (0.5%)

SBND

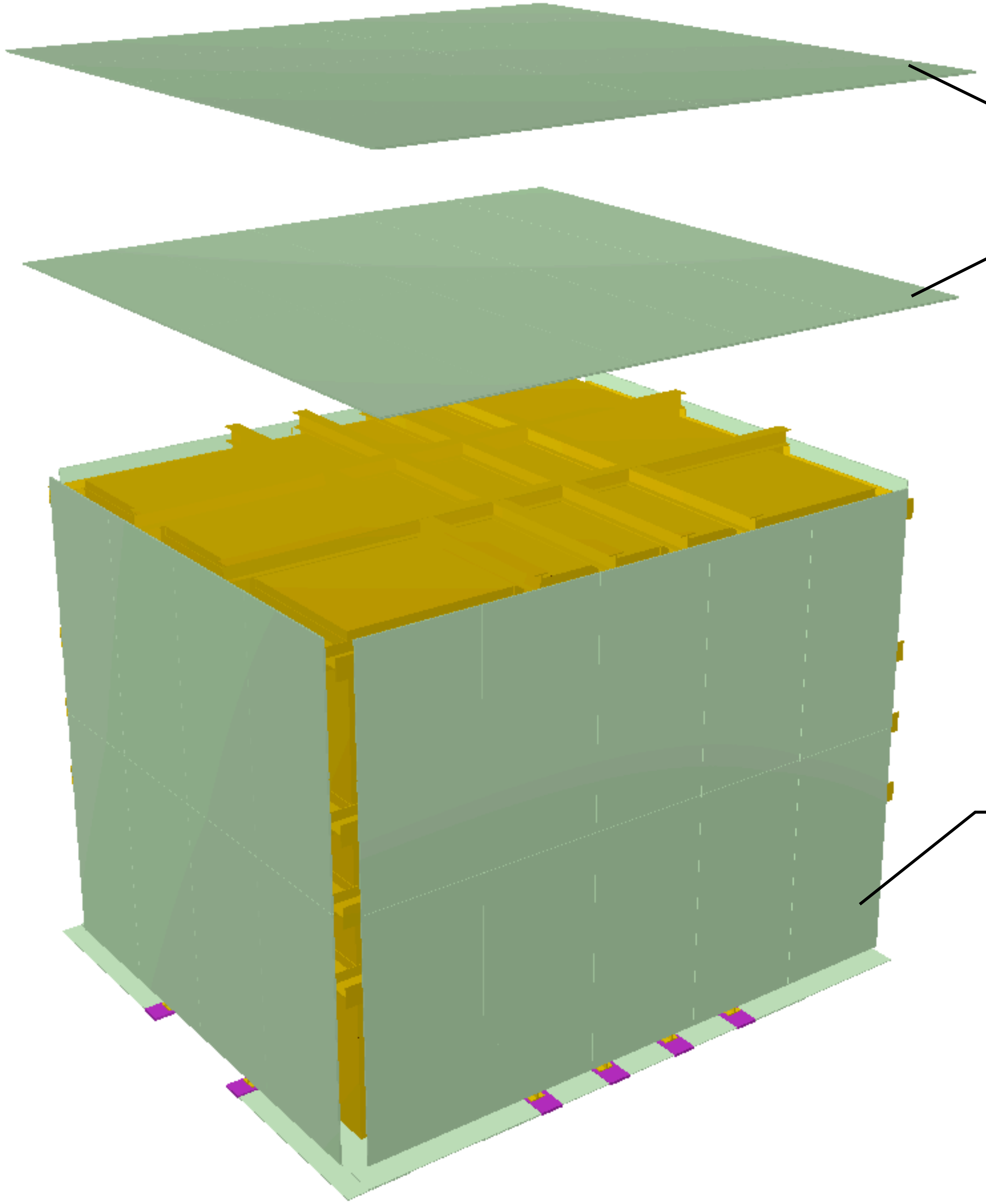

Target
SBND
MicroBooNE
ICARUS
BNB
Beamline
Argon mass: 112 ton
Argon mass: 86.6 ton
Argon mass: 476 ton
0
110 m
470 m
600 m
(Not to scale)

The SBND Detector

Cosmic Ray Tagger

CRT

SBND will be surrounded by scintillator strips to tag cosmic rays



Two top CRT panels: Telescope

CRT panels made of 11 and 6 cm wide scintillator strips

The SBND Detector

2 Time Projection Chambers

for a total of 4m x 4m x 5m

Cathode covered with TPB coated reflectors

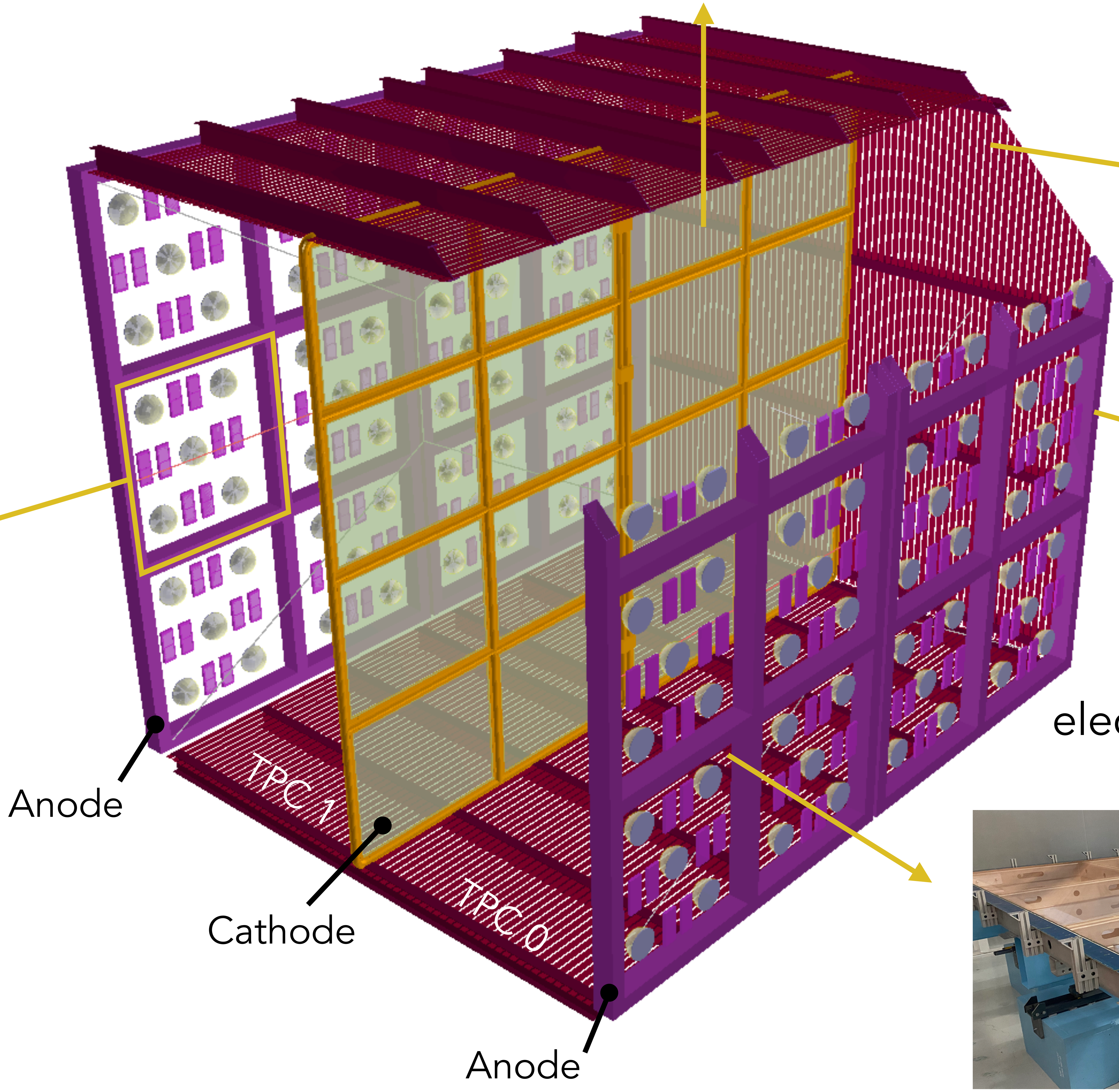
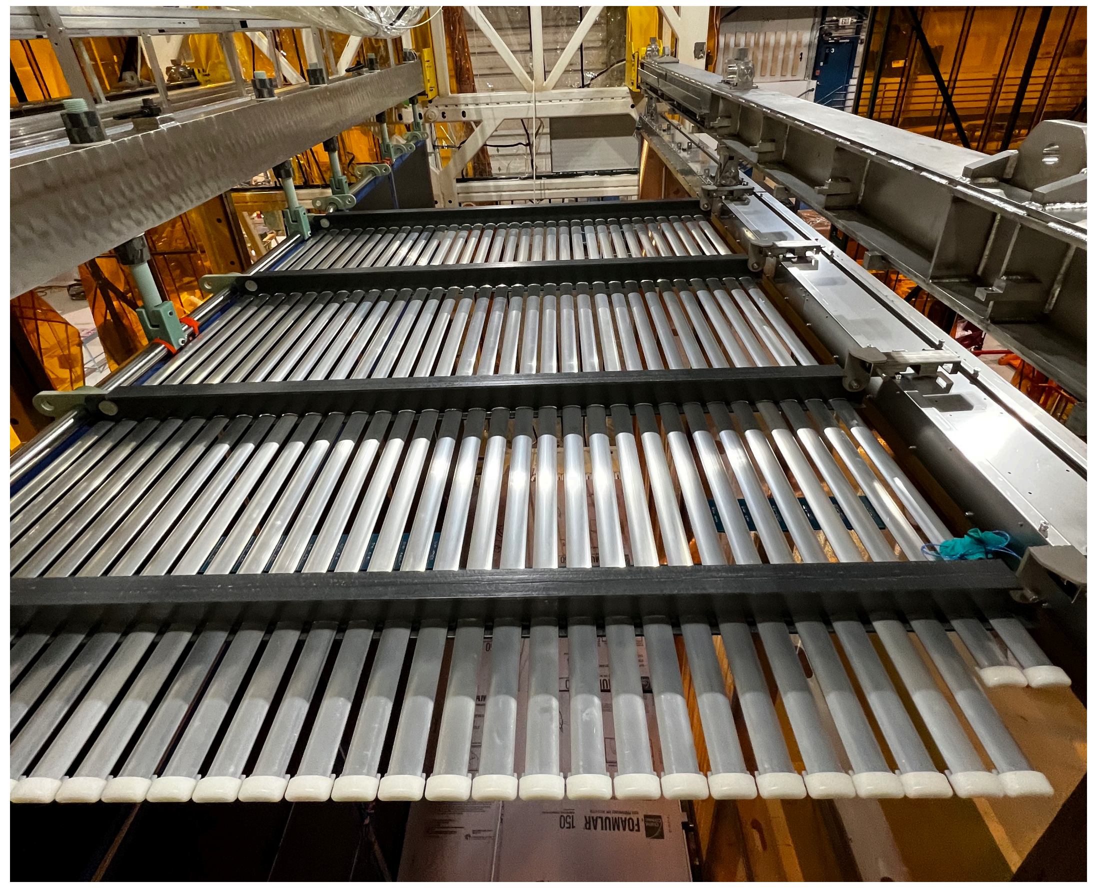


Photo Detection System:

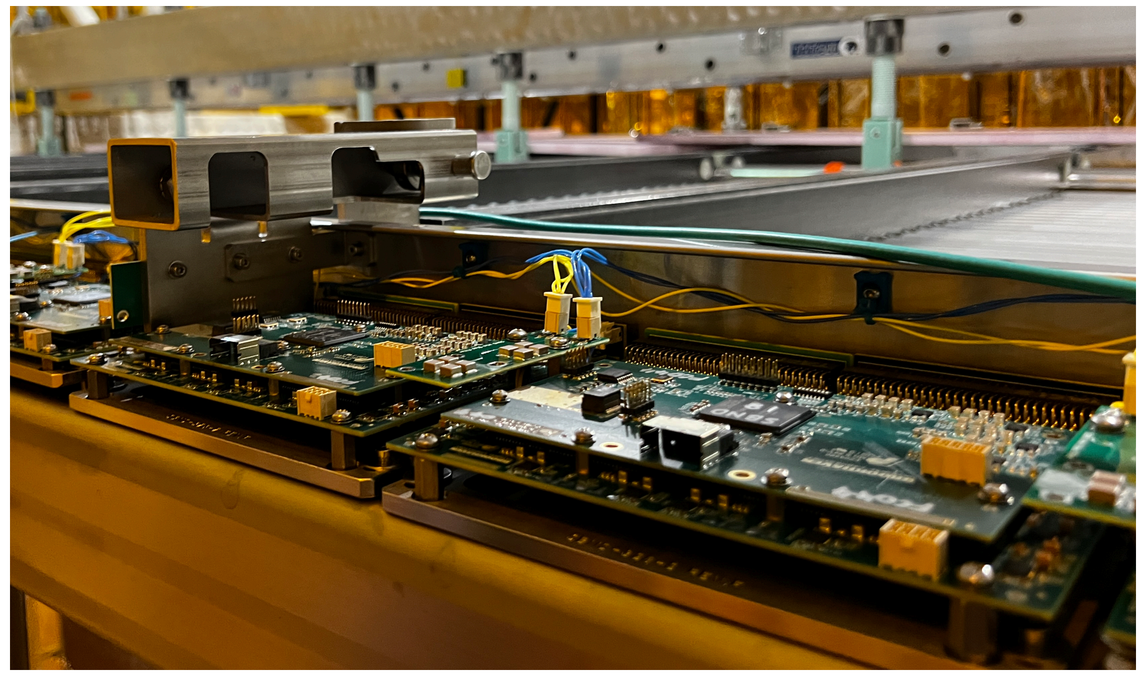
120 PMTs

192 X-Arapucas

Field Cage



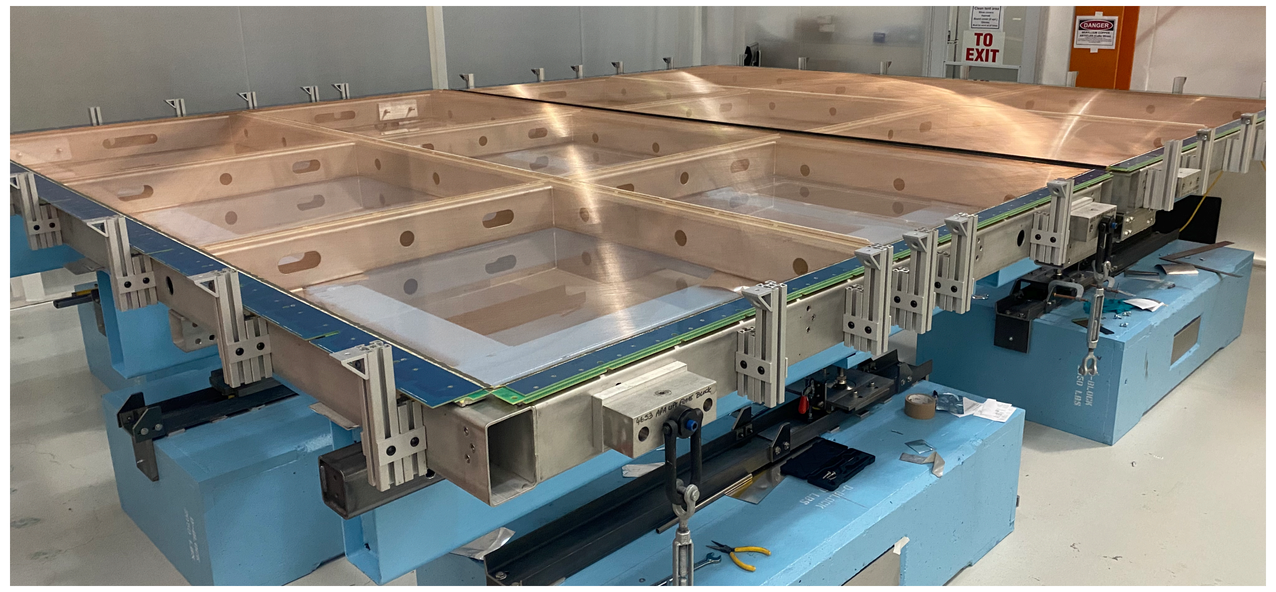
Cold electronics



Wire Plane

3 readout wire planes

~11000 wires

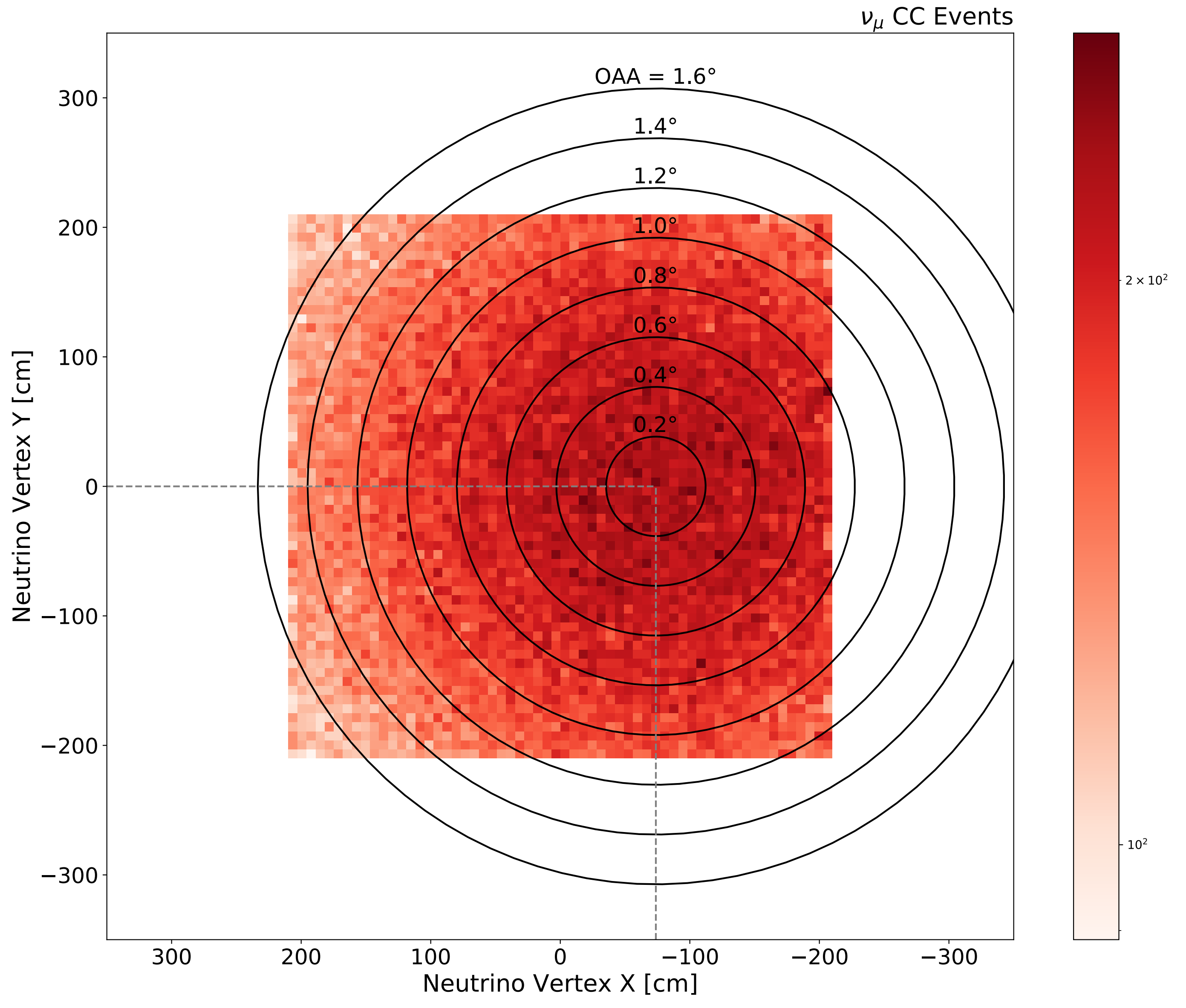


A Slightly Off-Axis Detector

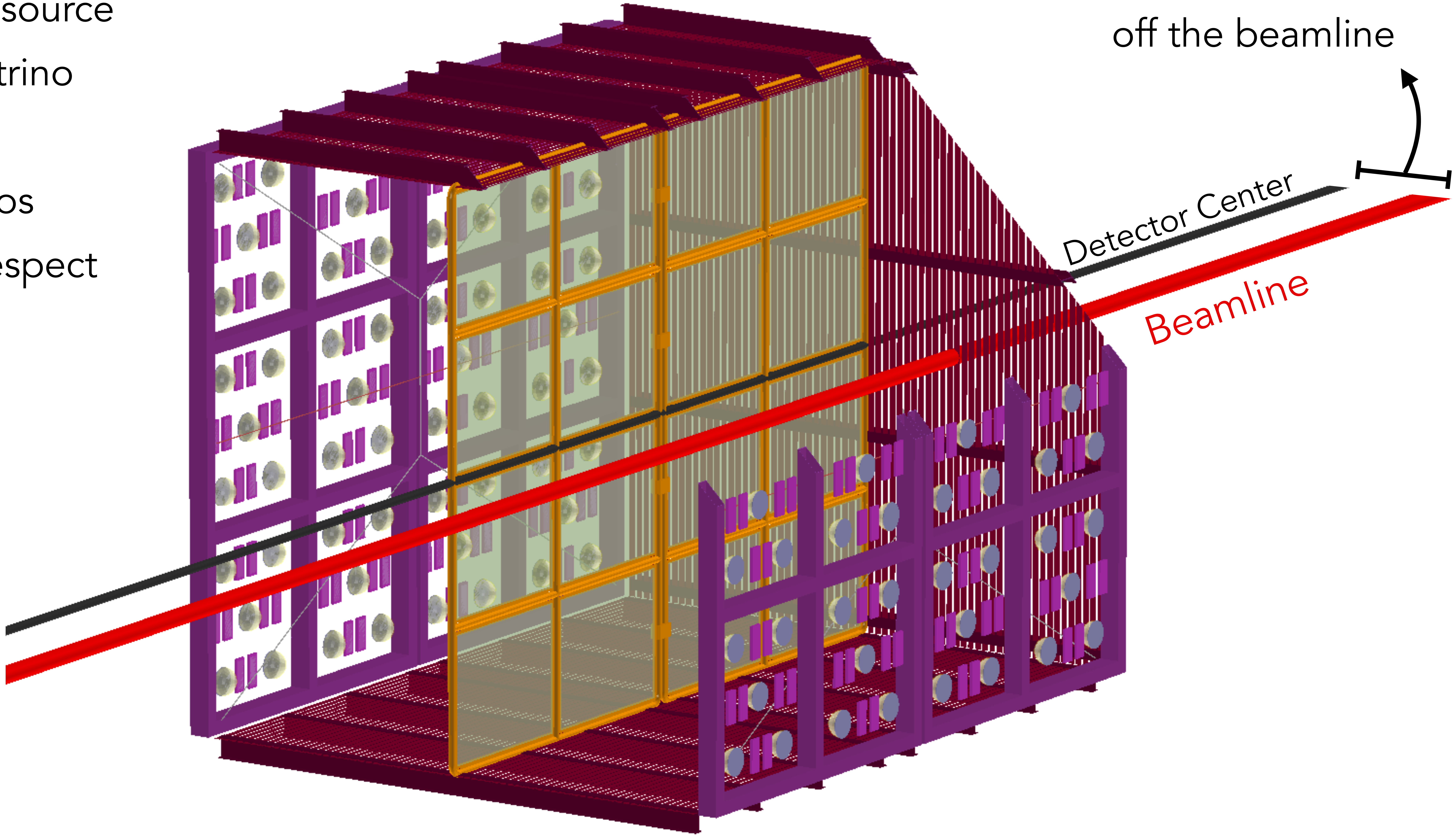
SBND is:

- very close (110 m) to the neutrino source
- not perfectly aligned with the neutrino beamline

The detector is traversed by neutrinos coming from different angles with respect to the beam axis.



The detector is ~74 cm off the beamline



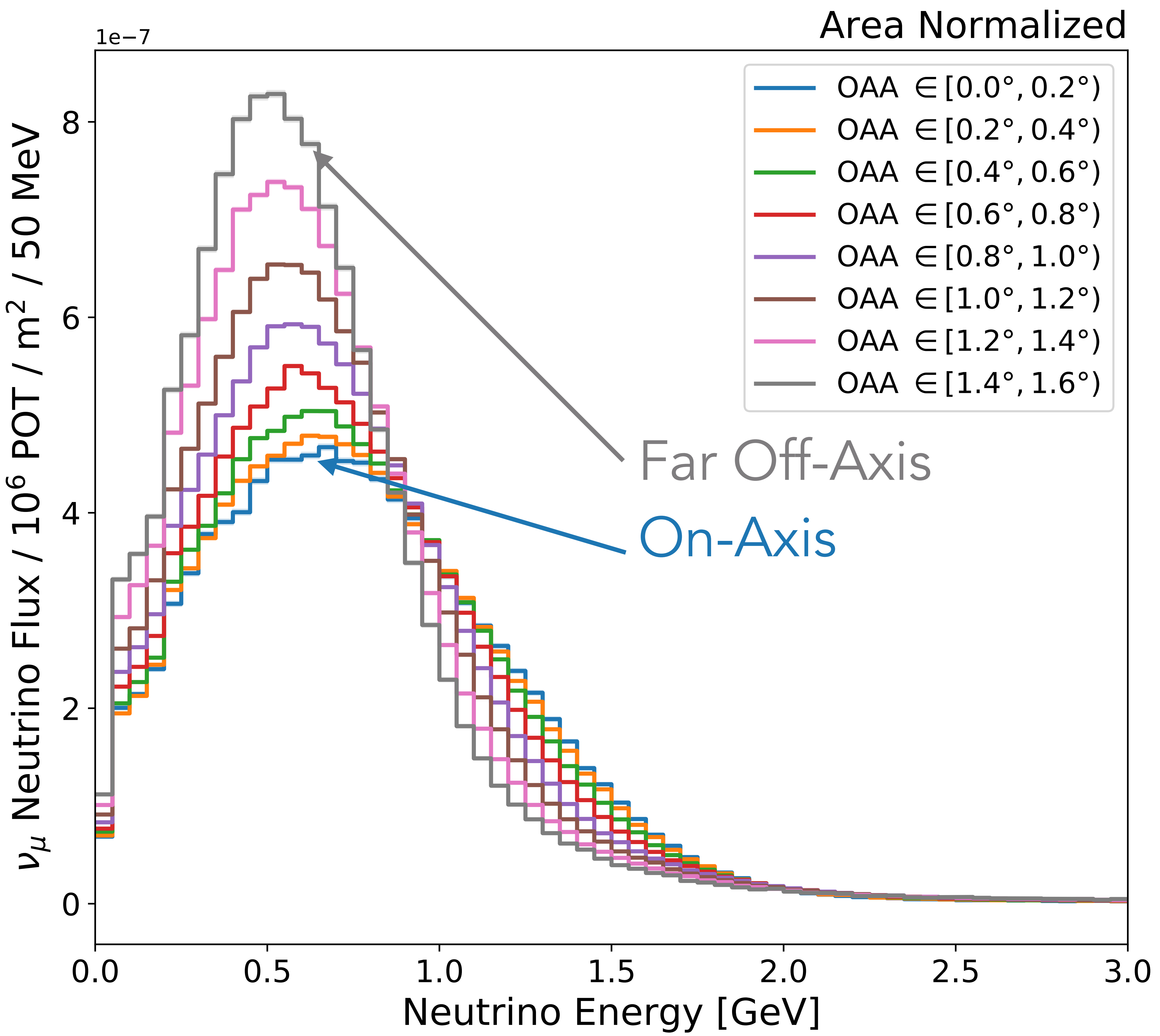
SBND-PRISM Fluxes

This "PRISM" feature of SBND allows sampling of multiple neutrino fluxes using the same SBND detector.

Similar to the nu-PRISM and DUNE-PRISM concepts, but with a fixed detector.

The neutrino energy distributions are affected by the off-axis position

Muon neutrino flux in each of the OAA regions

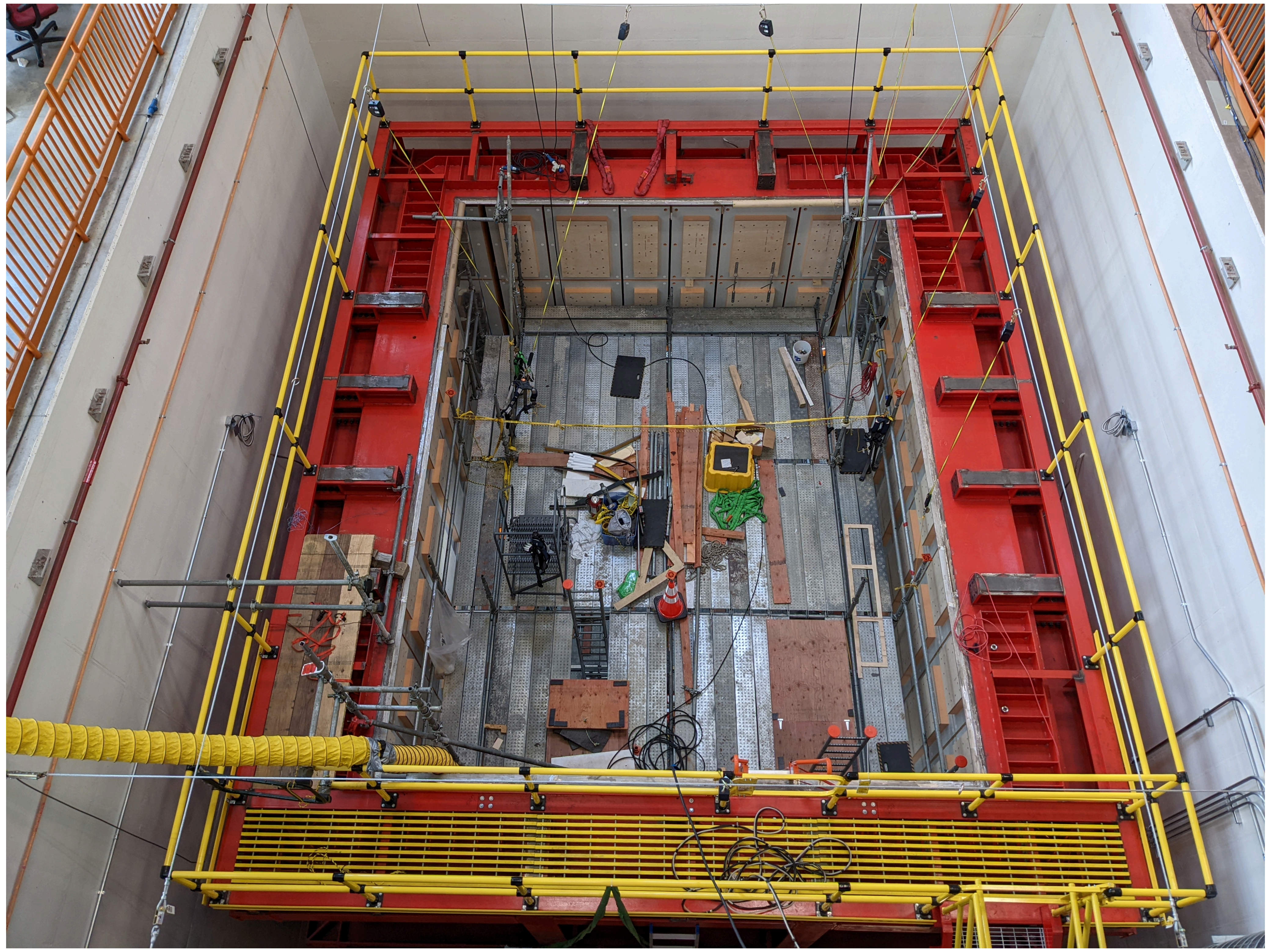


SBND Construction

- SBND TPC construction is now completed (as of this week!)
- Wire planes, field cage, and cold electronics are already installed
- Photon detection system is being installed now

TPC

TPC



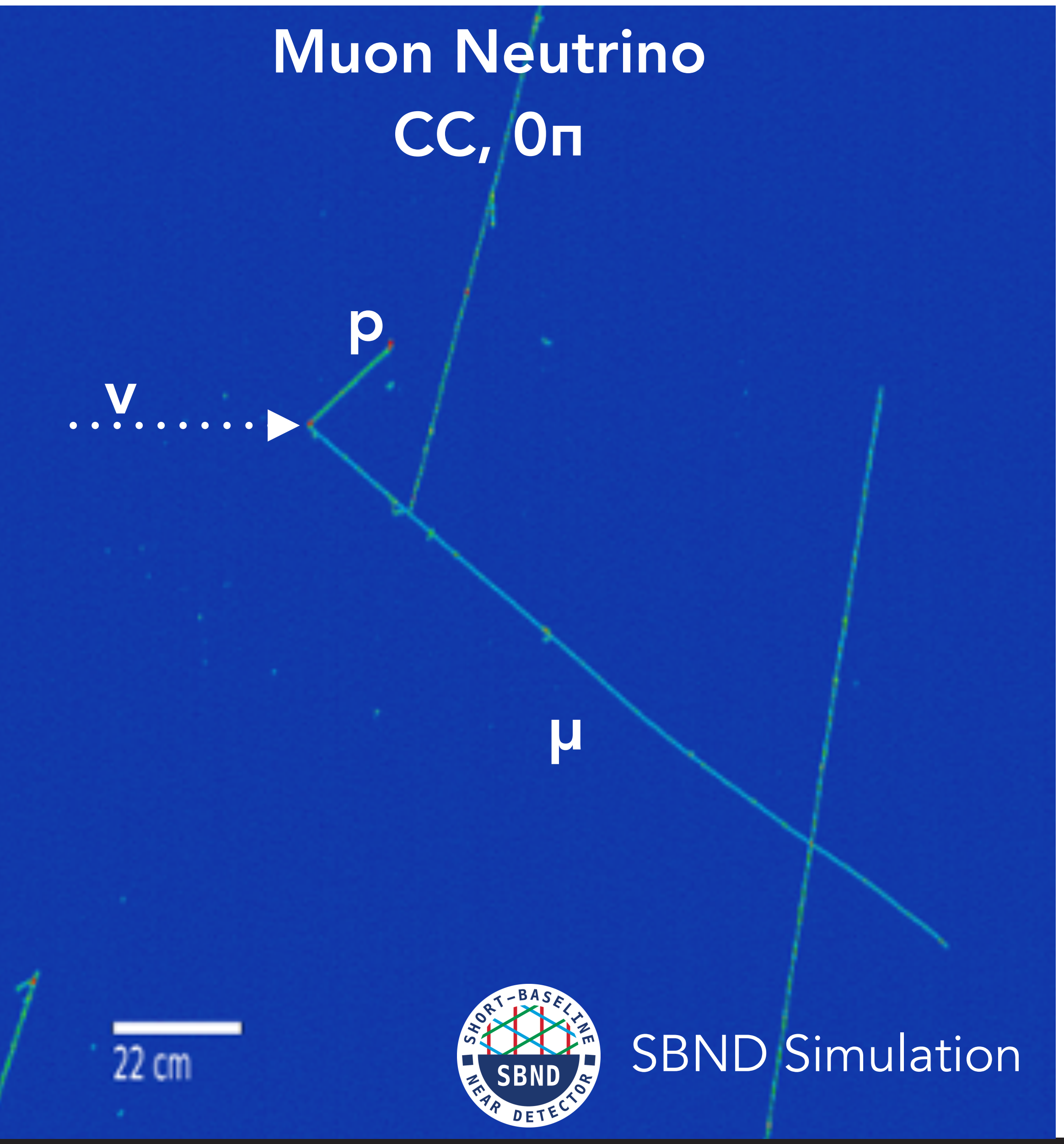
Cryostat construction is in progress

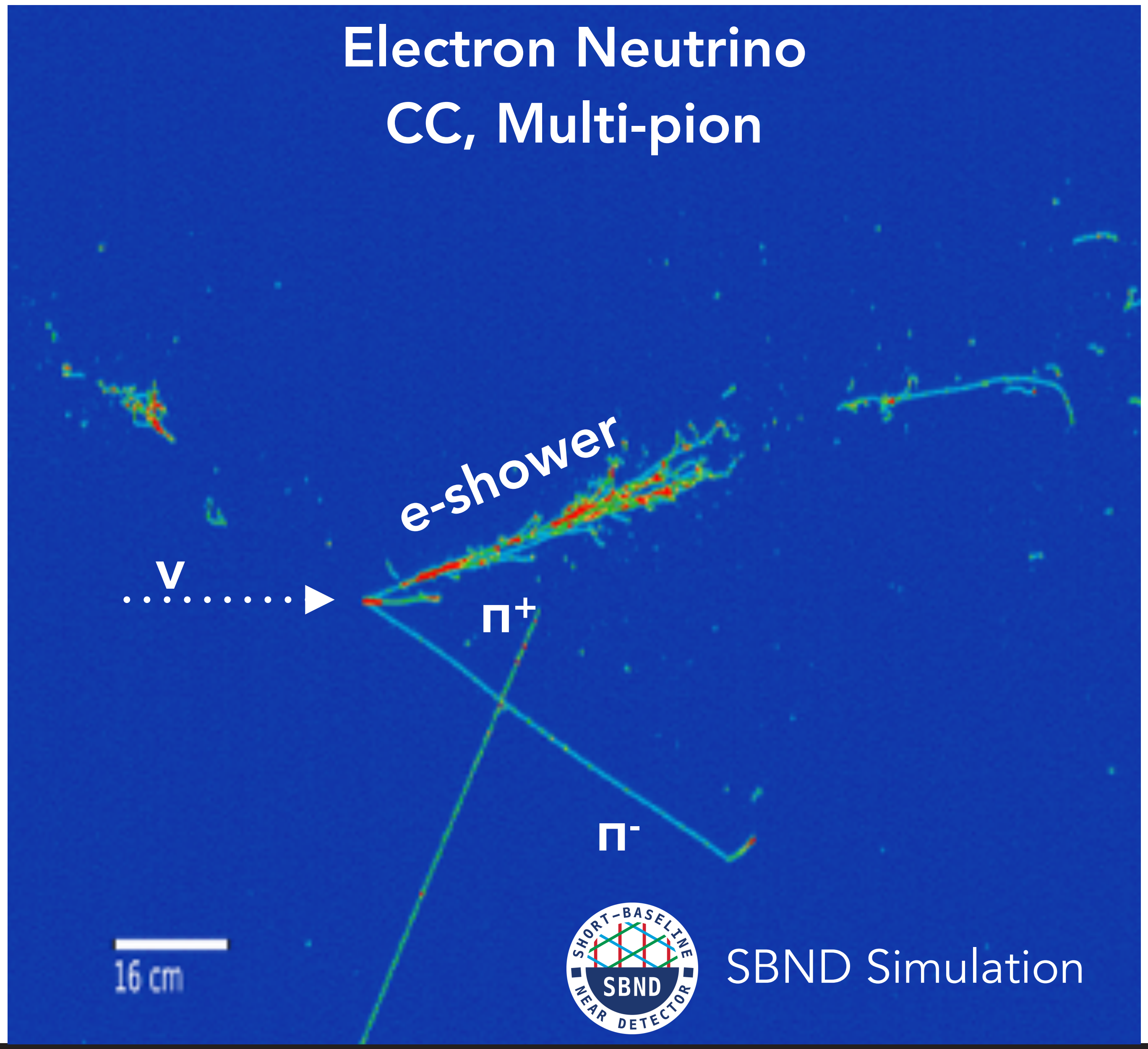
SBND Physics Program

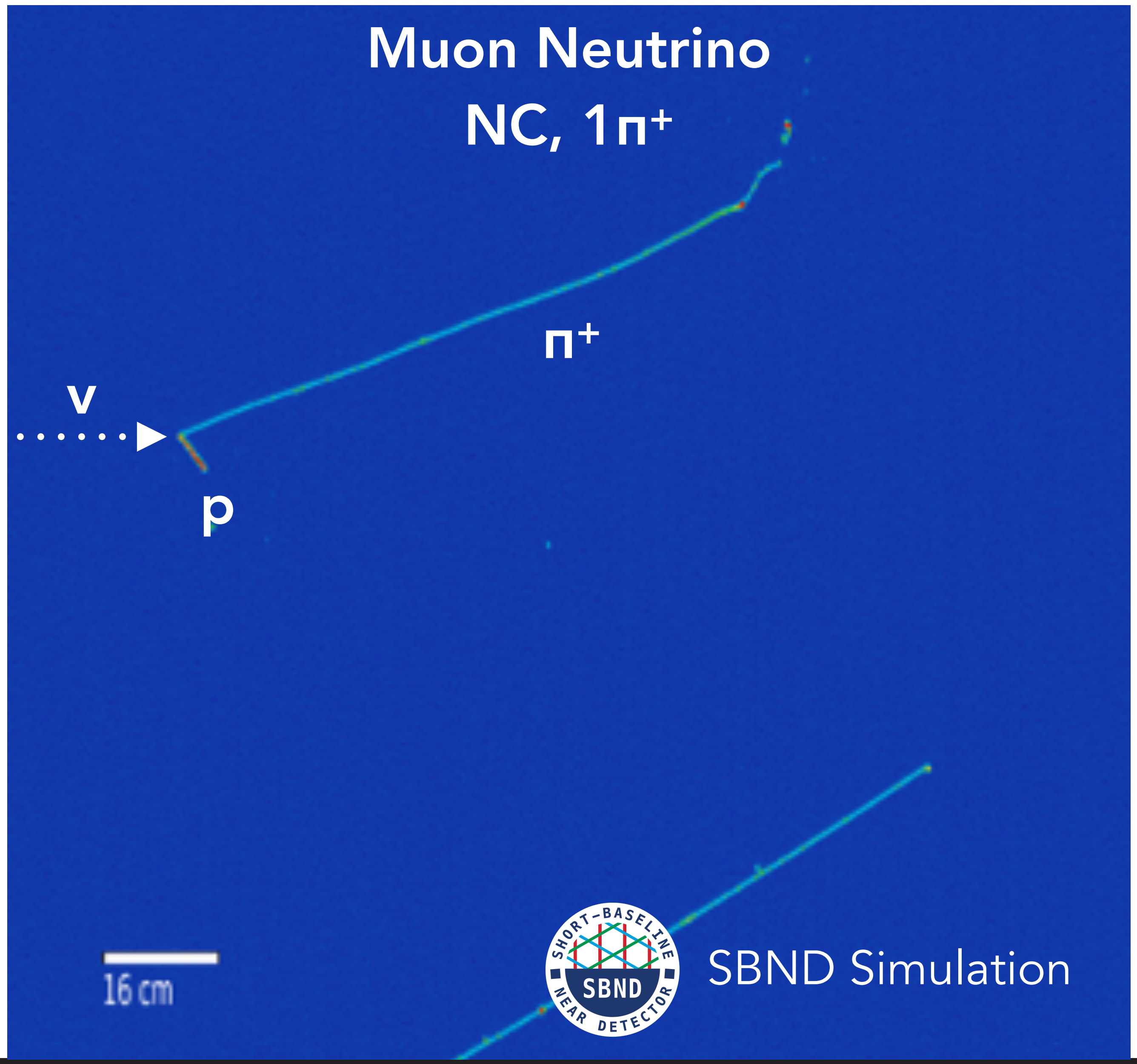
- Neutrino cross-section measurements
- Search for eV mass-scale sterile neutrinos oscillations in the SBN program
- Search for new and exotic physics signals

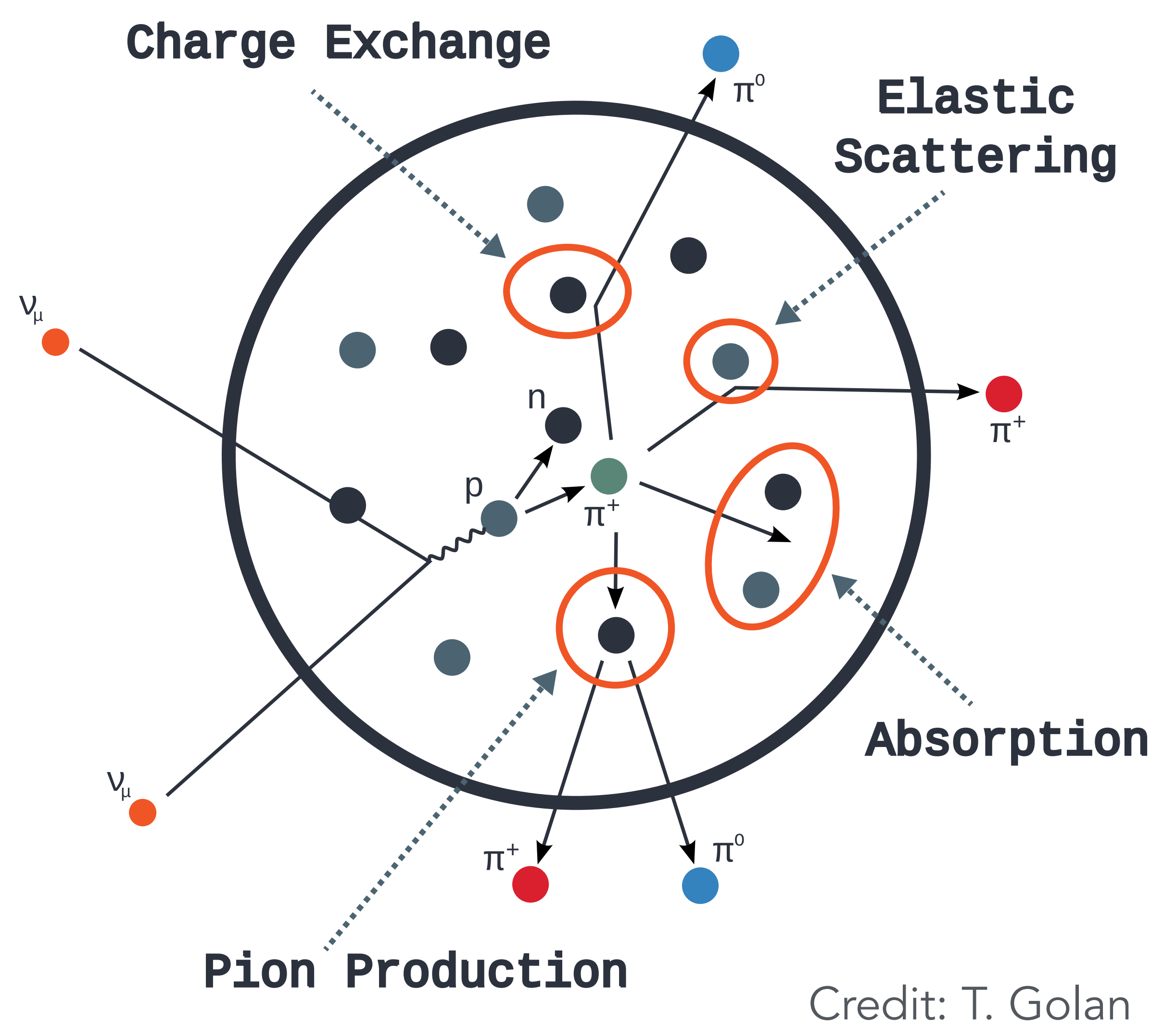
Cross-Section Measurements

- Understanding neutrino interactions with argon is crucial for the success of current and future neutrino experiments.
- Argon has a complex and heavy nucleus and not much data exists to constrain current generators.
- MicroBooNE measurements provide invaluable insights and SBND will be able to expand on those with an incredible large-statistic dataset allowing to make multi-dimensional analyses with high statistics.
- SBND measurements will largely improve DUNE physics as SBND's kinematics cover large parts of DUNE's phase space.









Credit: T. Golan

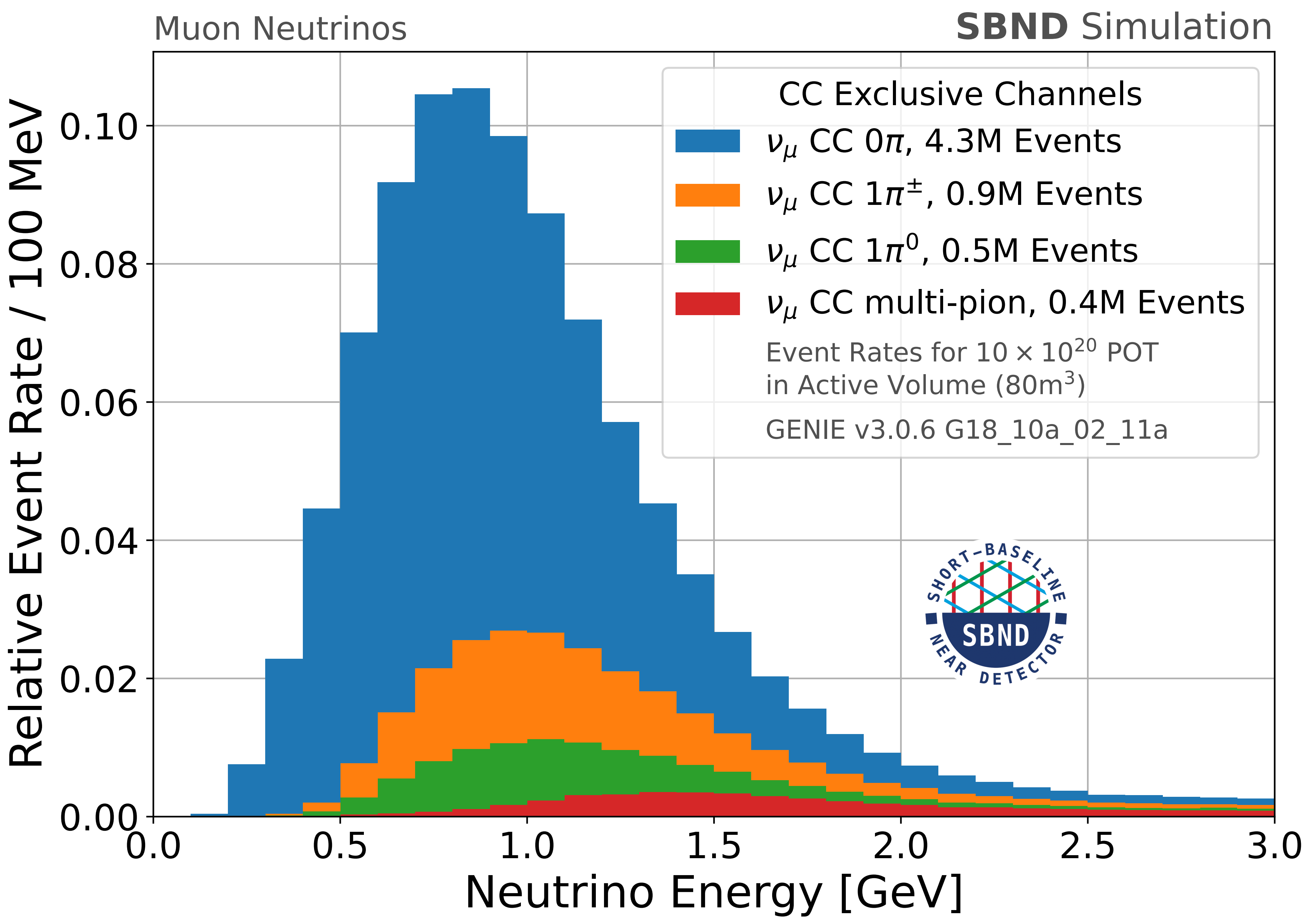
Cross-Section Measurements

SBND data will enable a generational advance in the study of neutrino-argon interactions in the GeV energy range, with low thresholds for particle tracking and calorimetry and enormous statistics.

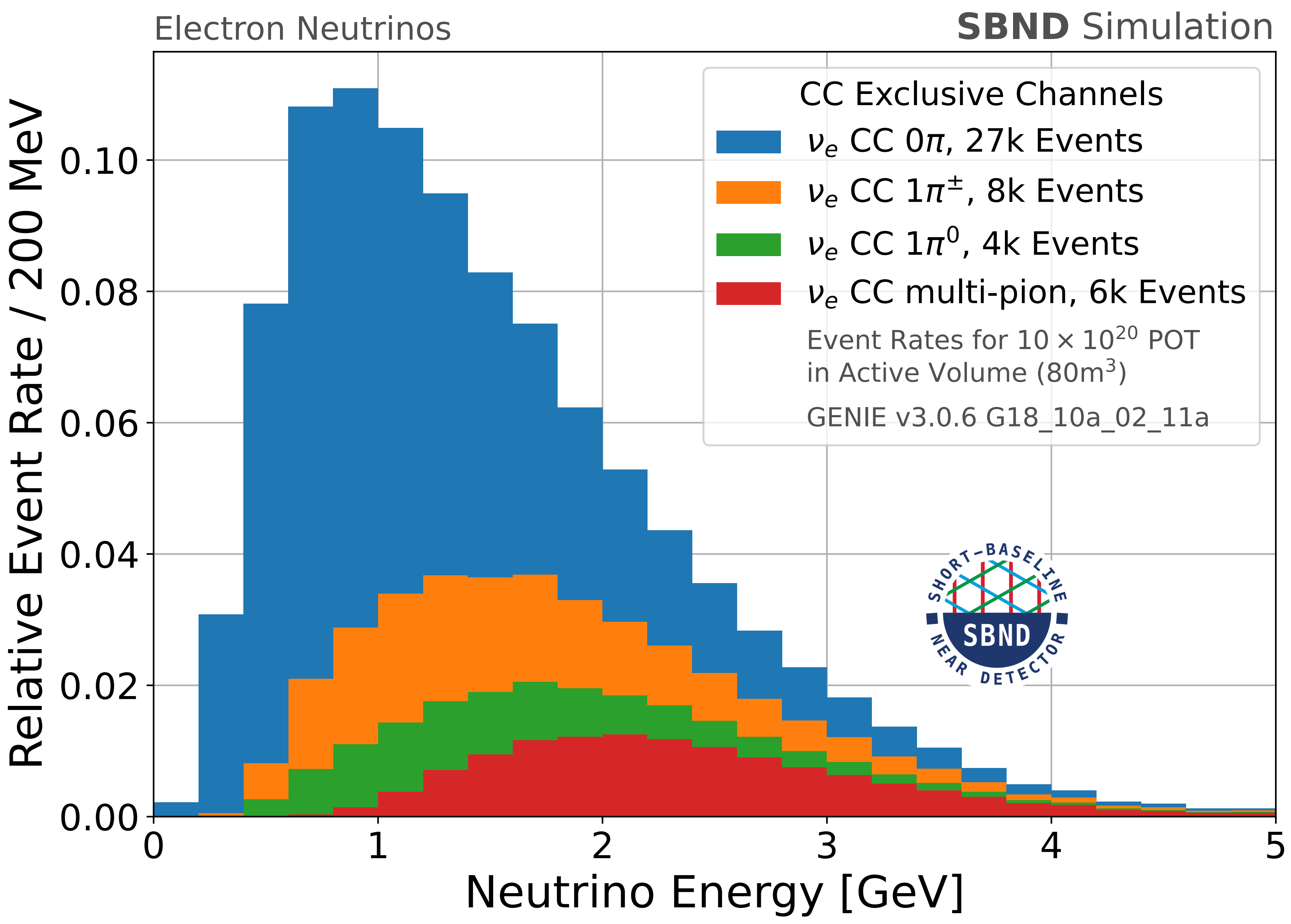
SBND will have the largest dataset of ν-Ar interactions and will do high-statistics measurements of many signatures and can observe rare channels.

SBND will record 20-30x more neutrino-argon interactions than is currently available.

SBND will observe 5000 ν-events/day!

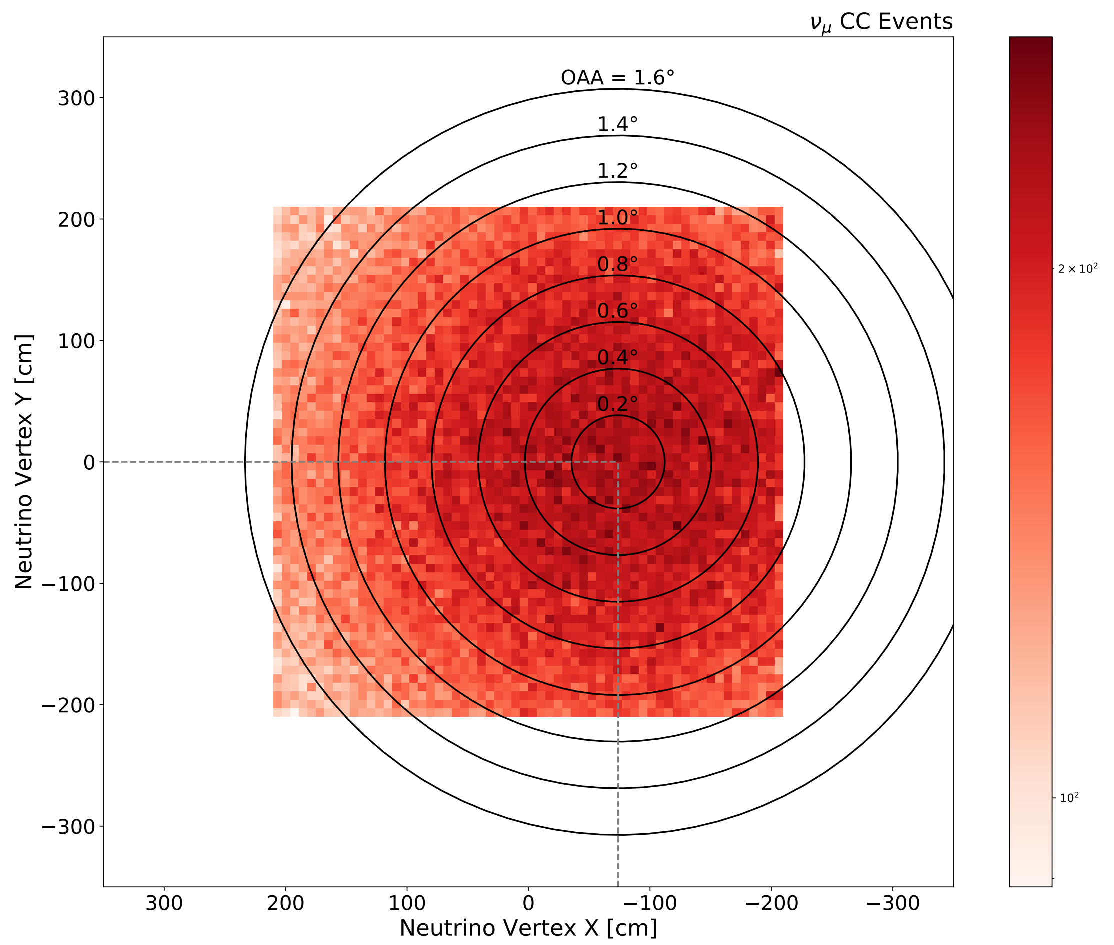


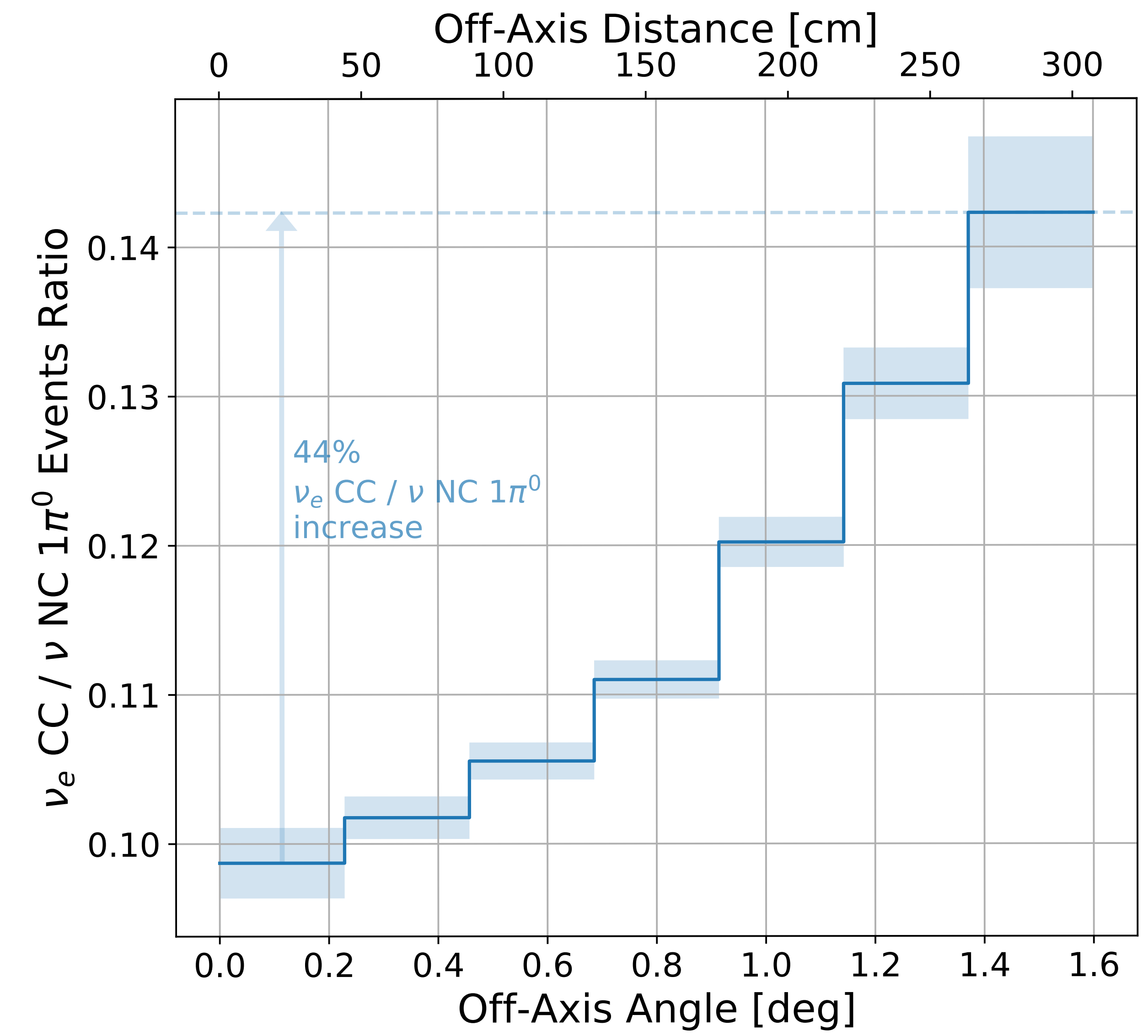
1.5M ν_μ CC events in 1 year

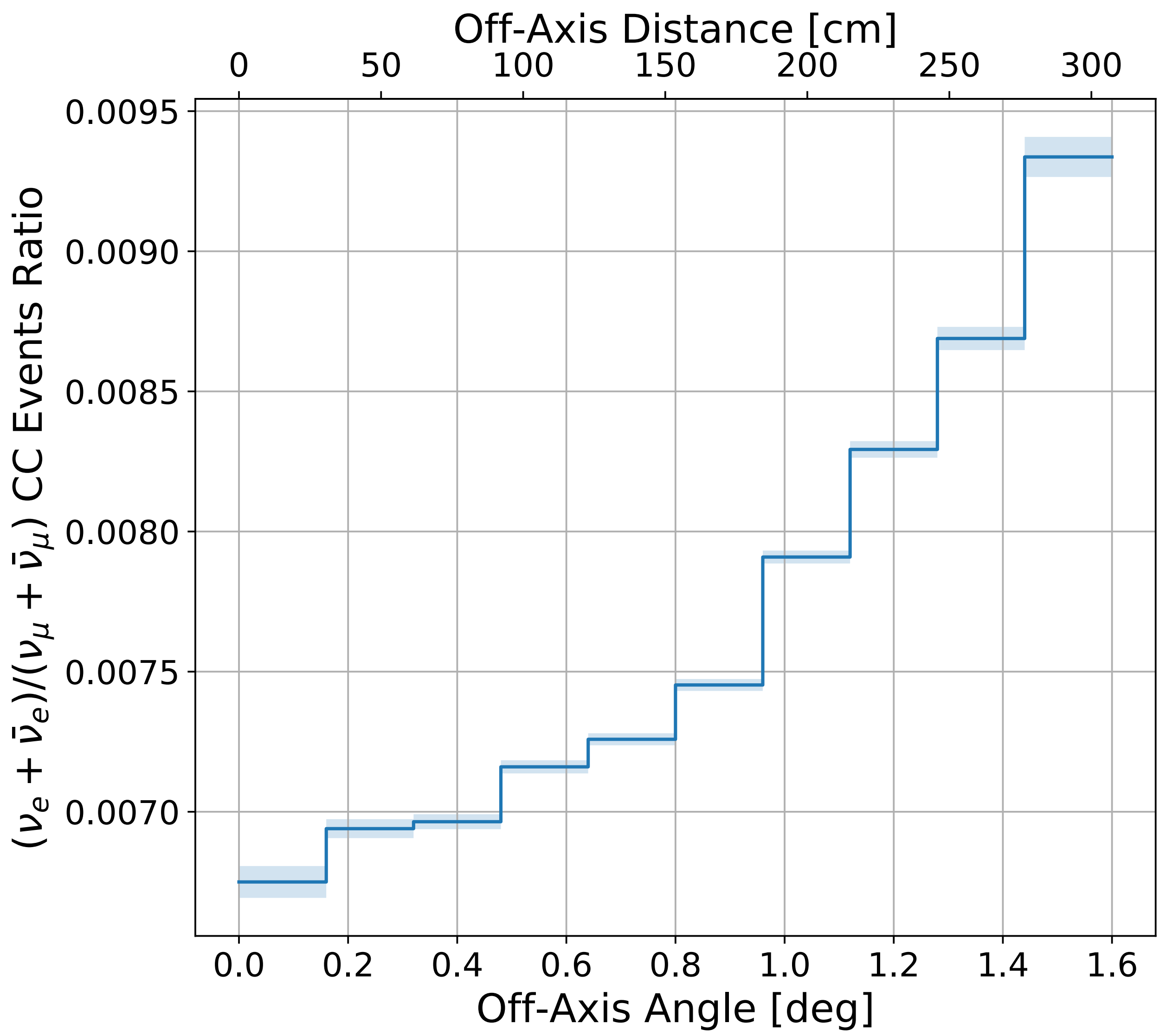


12k ν_e CC events in 1 year

Cross-Section Measurements with SBND-PRISM







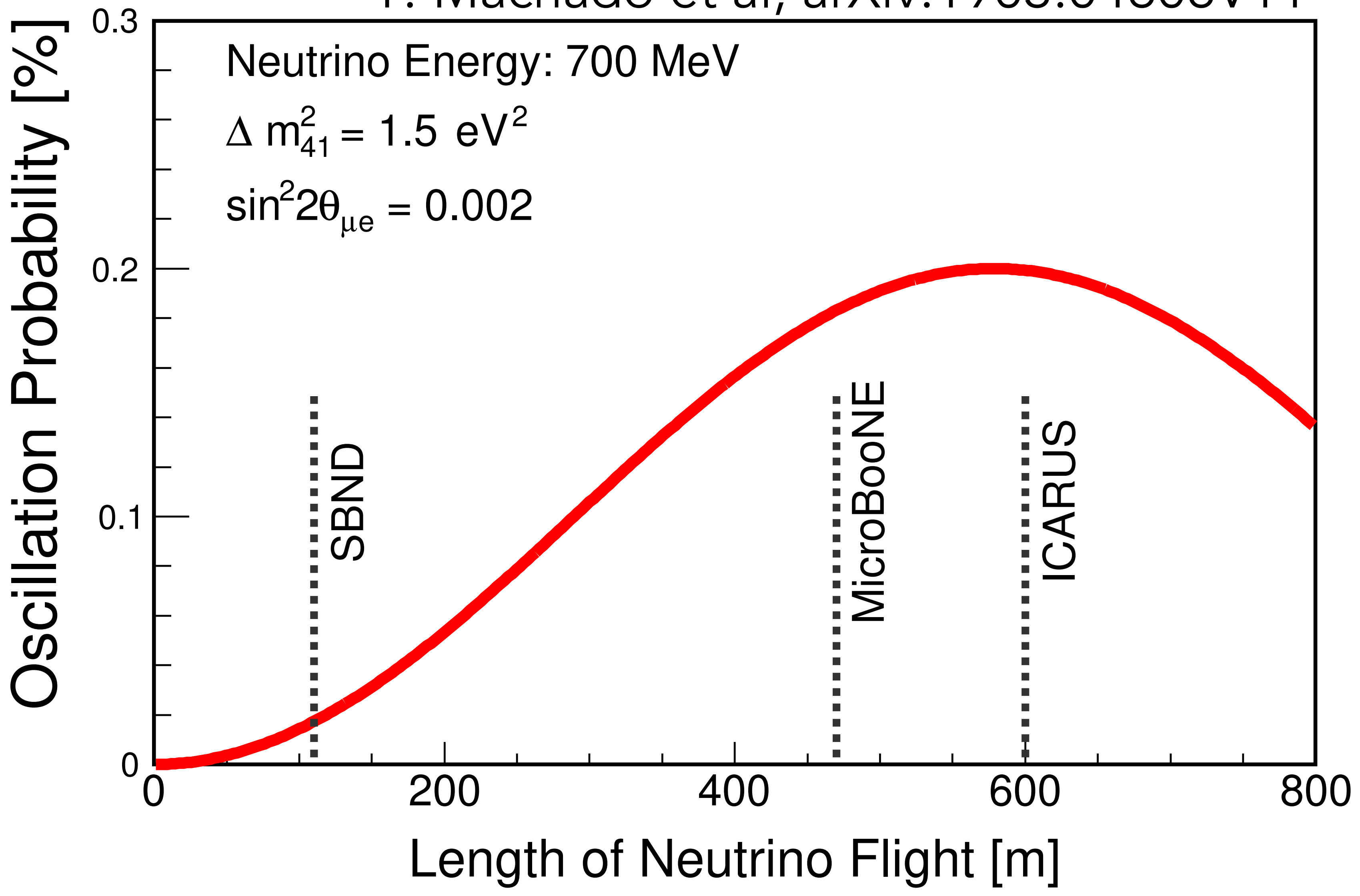
- PRISM provides a natural way to reduce background by moving off-axis.
- Note that we expect high event statistics in all off- axis regions.

- Going off-axis, the increase in ν_e to ν_μ flux ratio combined with a choice of kinematics where ν_e to ν_μ differences are prominent should allow us to measure the ν_e/ν_μ cross section (can study lepton mass effects).

SBN Oscillation Sensitivity

- SBND + ICARUS will test the sterile neutrino hypothesis
- Three detectors sampling the same neutrino beam at different distances.
- Effective systematics constraint through the near detector (SBND) and same detector technology in the near and far detector.

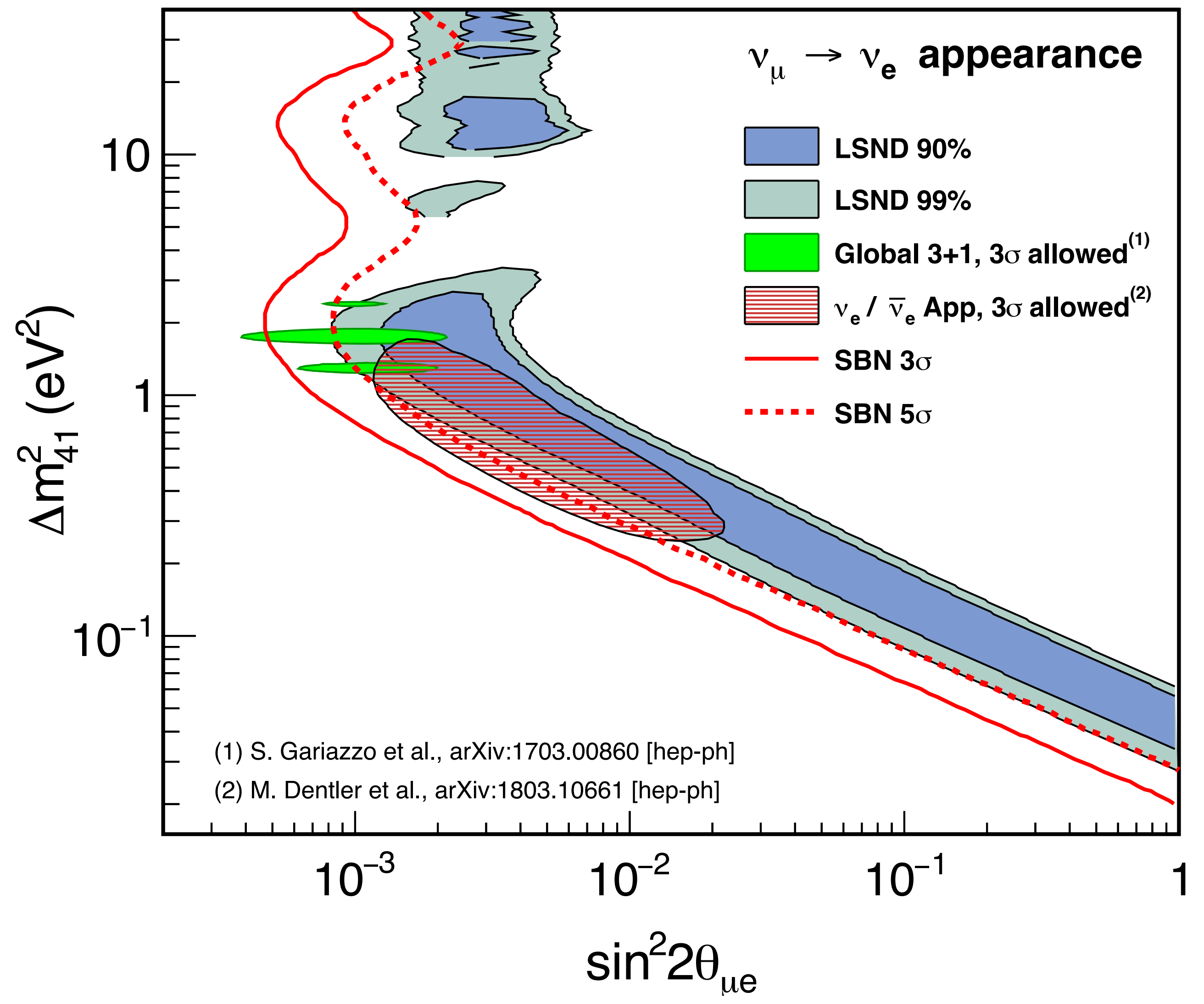
P. Machado et al, arXiv:1903.04608V11

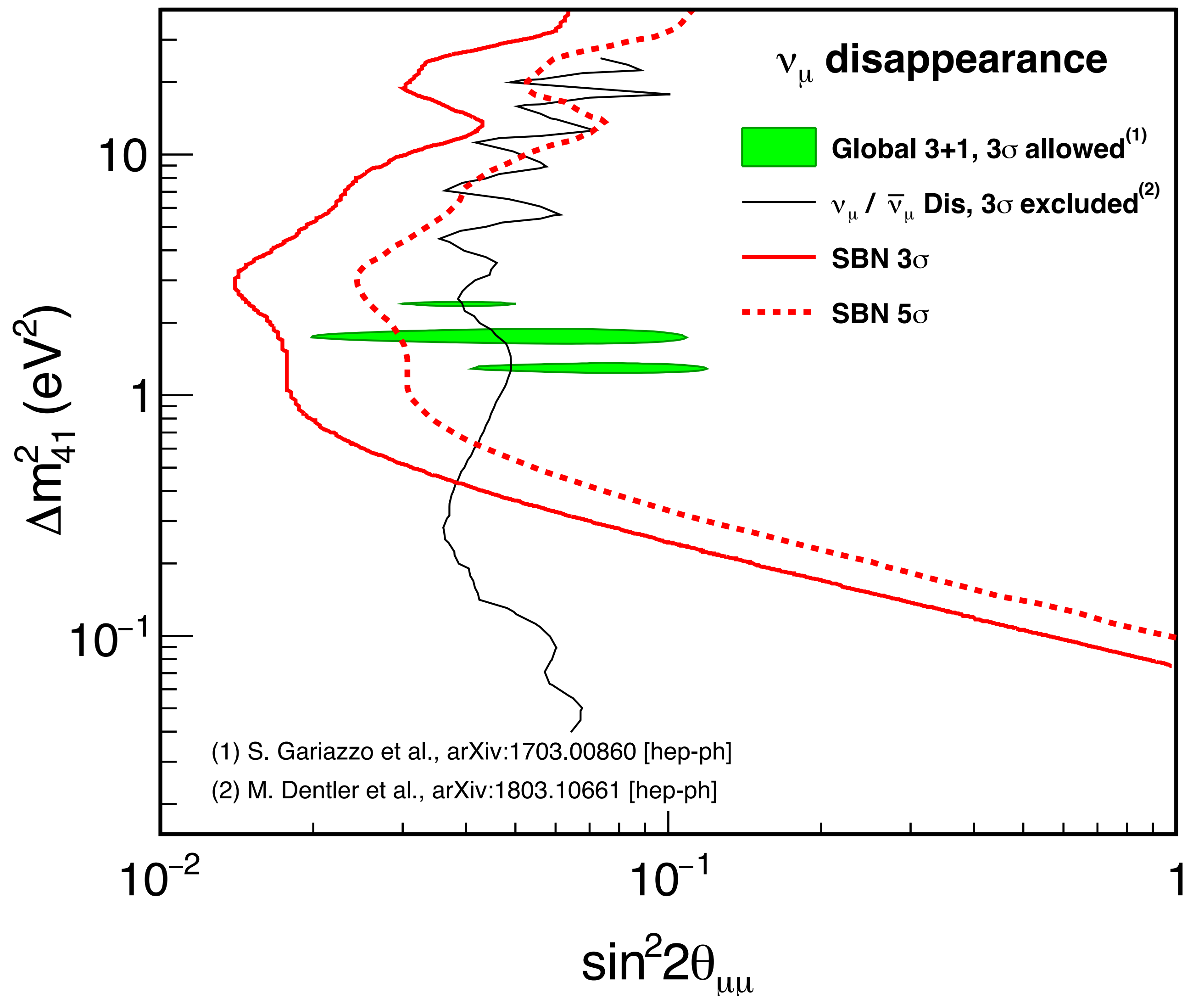


SBN Oscillation Sensitivity

- Search for both ν_e appearance and ν_μ disappearance
- SBND + ICARUS will test the sterile neutrino hypothesis: can cover the parameter space favored by past anomalies with 5σ significance

P. Machado et al, arXiv:1903.04608V11





Alternative Explanations

There is tension when combining ν_e appearance and ν_μ disappearance data.

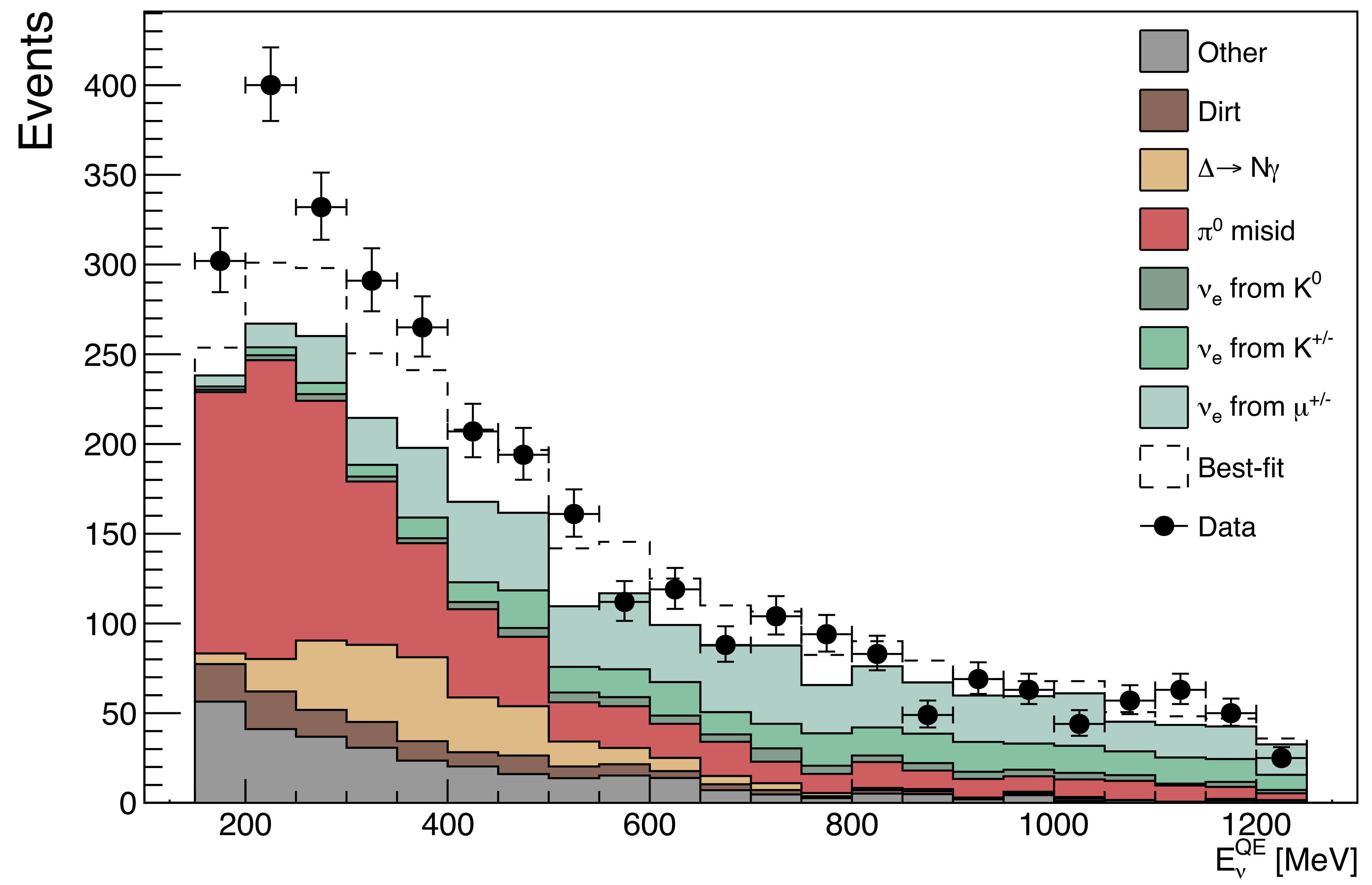
This tension excludes a sterile neutrino

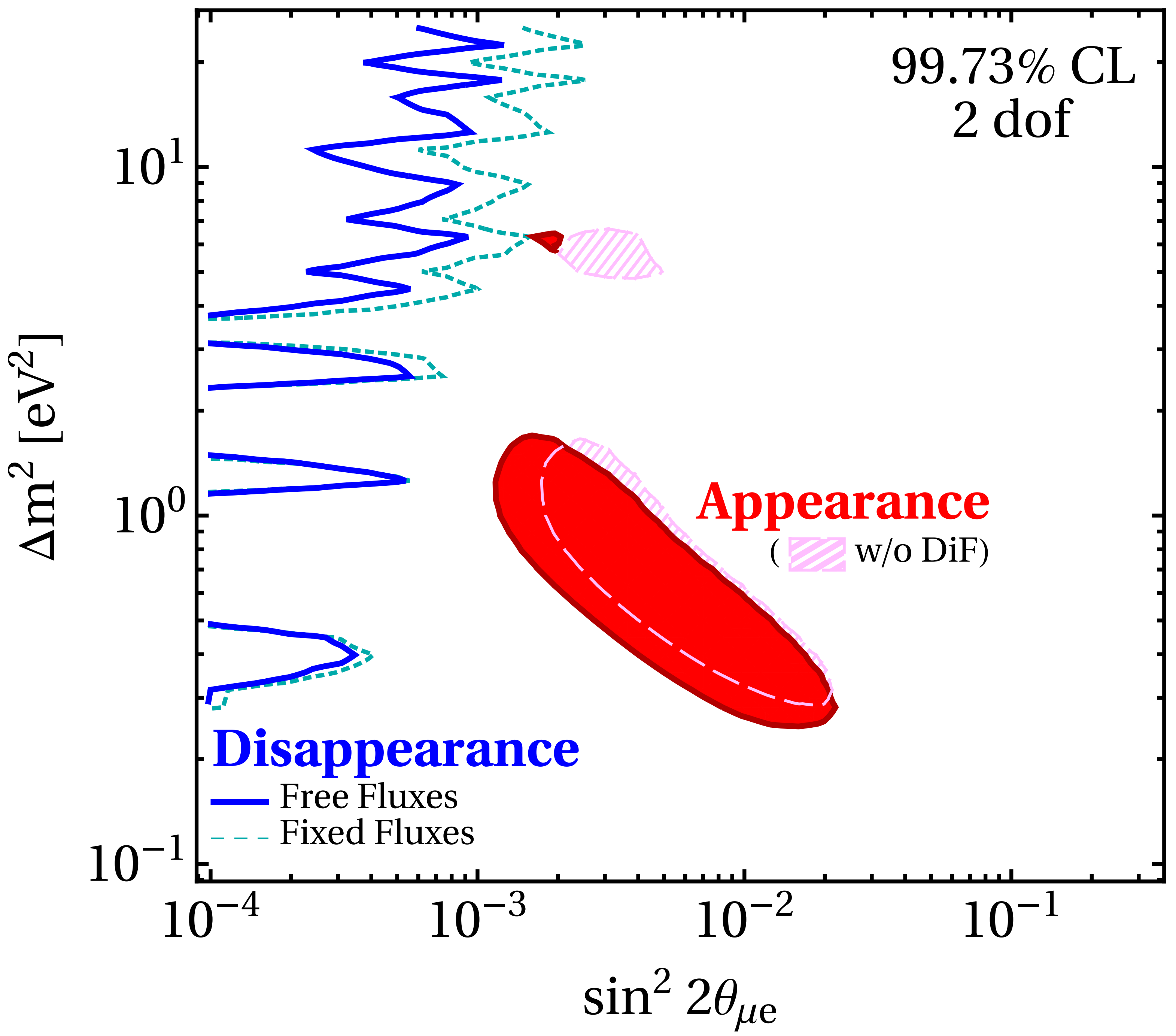
oscillation explanation of the $\nu_\mu \to \nu_e$ anomalies at the 4.7σ level.

Alternative explanations exist that could explain the MiniBooNE excess.

MiniBooNE electron-like excess

Phys. Rev. D 103, 052002 (2021)





Limits from the disappearance and allowed appearance regions

M. Dentler et al., JHEP 08:010 (2018)

Beyond Standard Model Searches

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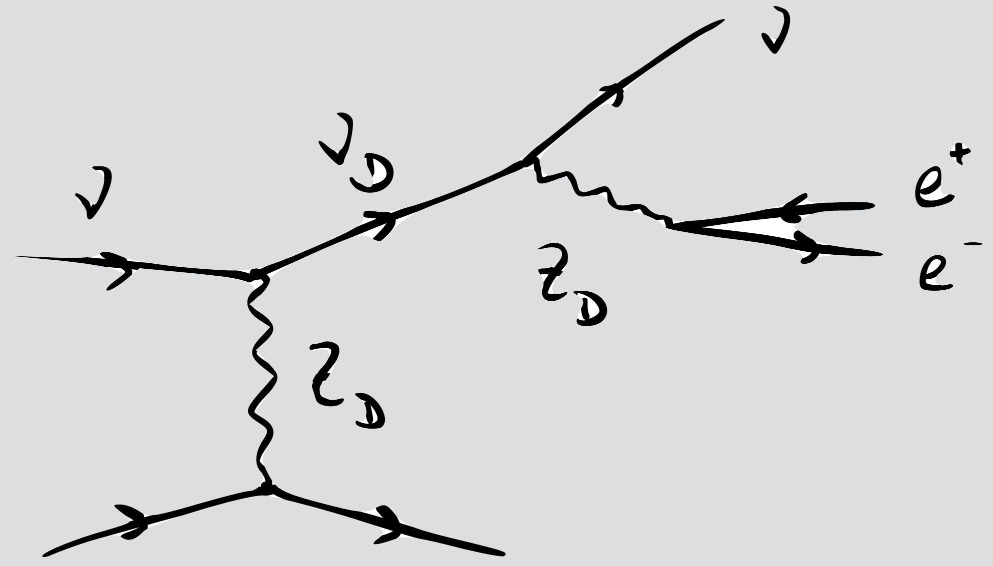
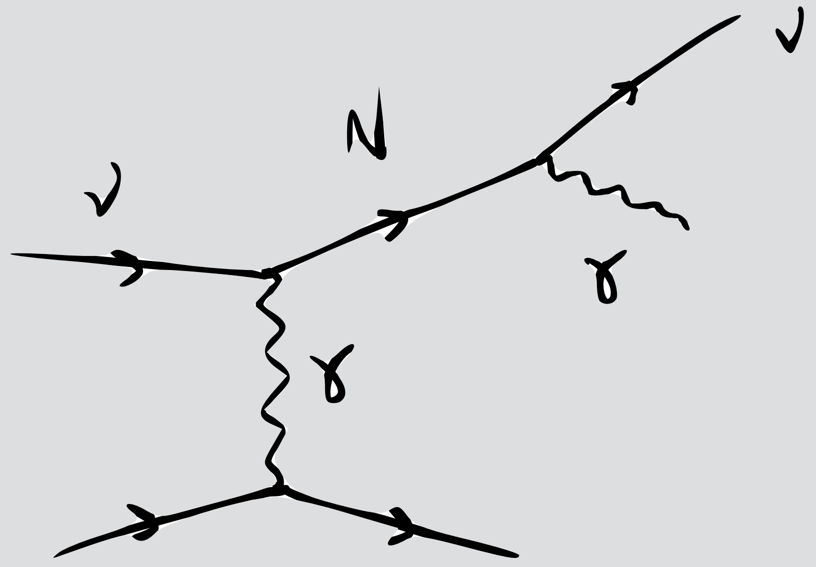
Dark Neutrinos



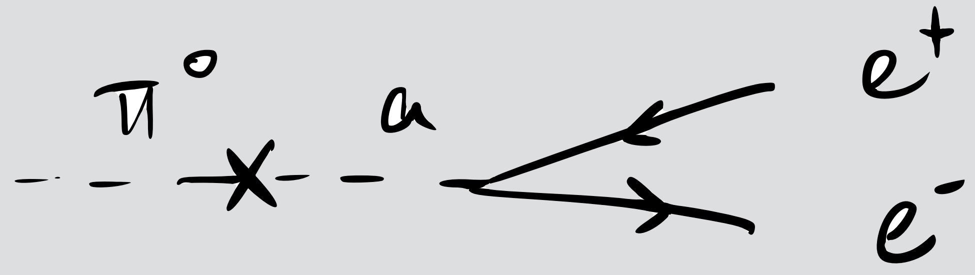
Bertuzzo Jana Machado Zukanovich PRL 2018, PLB 2019
Arguelles Hostert Tsai PRL 2019
Ballett Pascoli Ross-Lonergan PRD 2019
Ballett Hostert Pascoli PRD 2020

Transition Magnetic Moment



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

Axion-like Particles



Kelly Kumar Liu PRD 2021
Brdar et al PRL 2021

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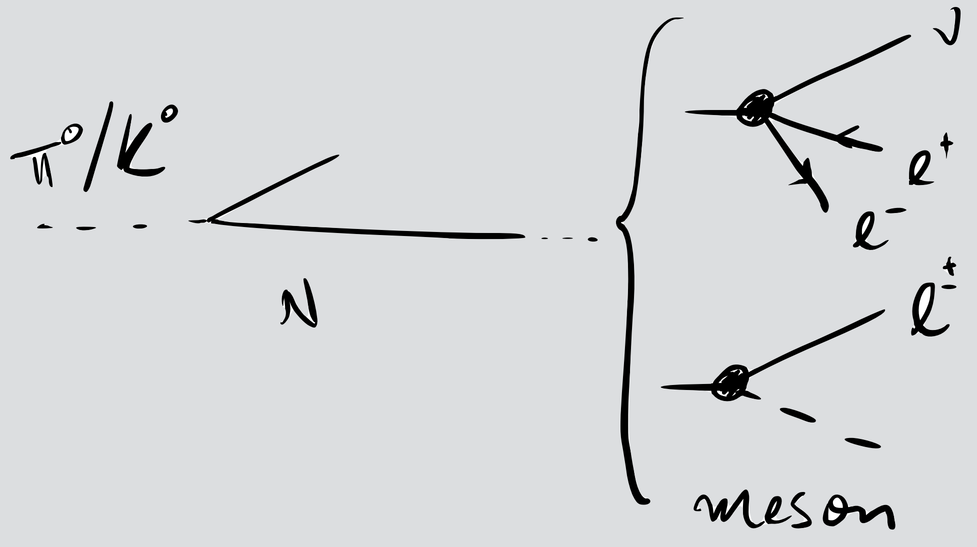

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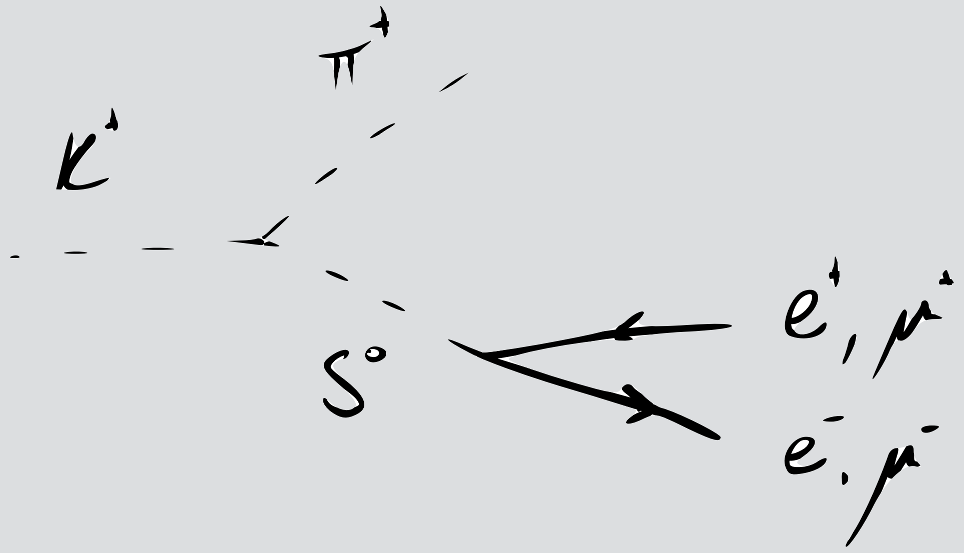

Pat Wilczek 2006
Batell Berger Ismail PRD 2019
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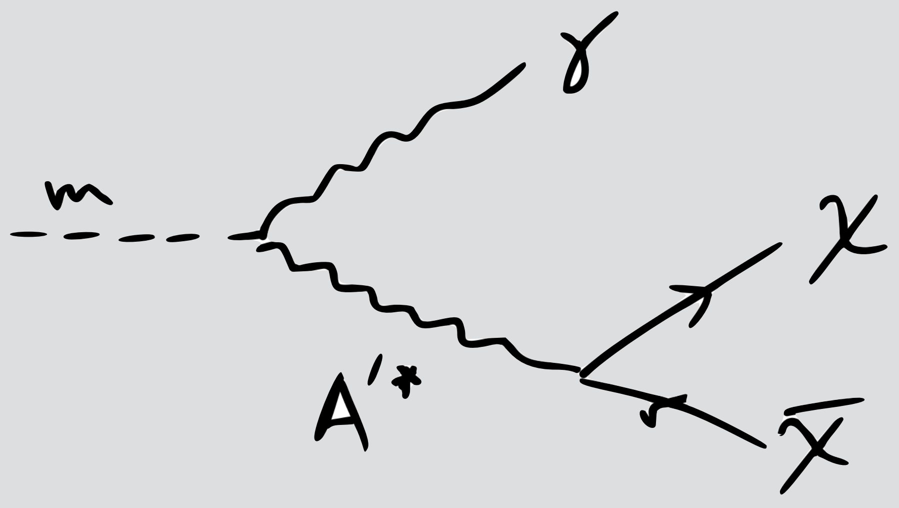
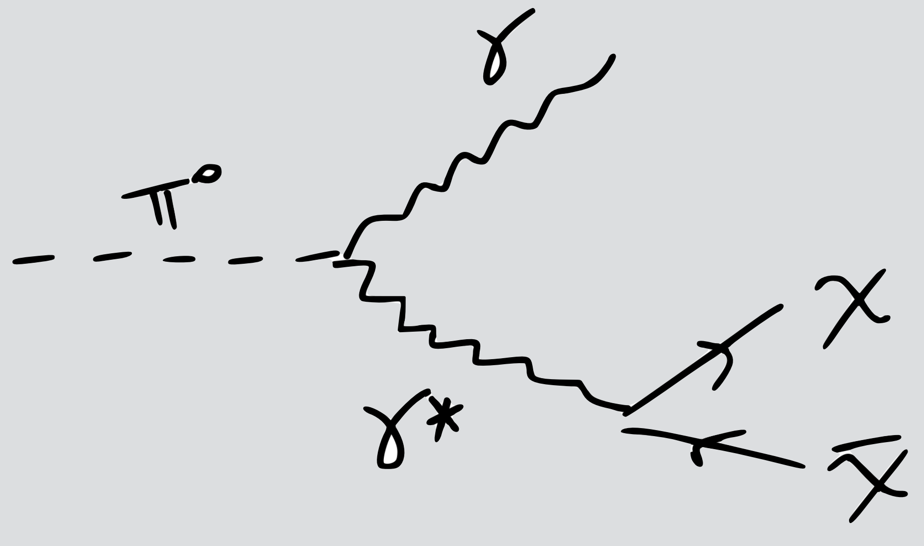


Romeri Kelley Machado PRD 2019

Millicharged Particles



Magill, Plestid, Pospelov, Tsai, PRL 2019
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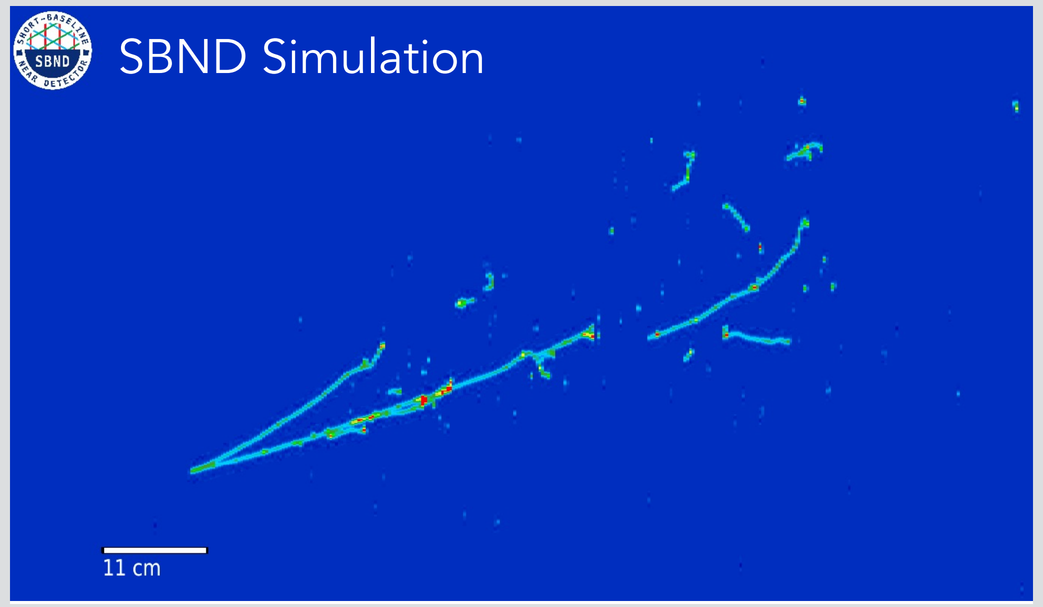

e+e- pair w/ or w/o hadronic activity

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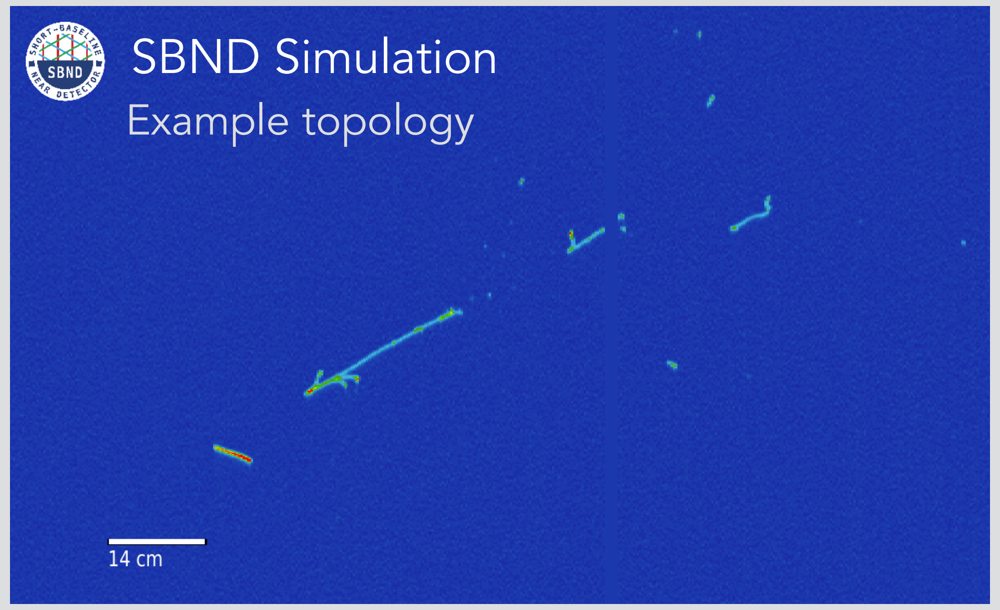

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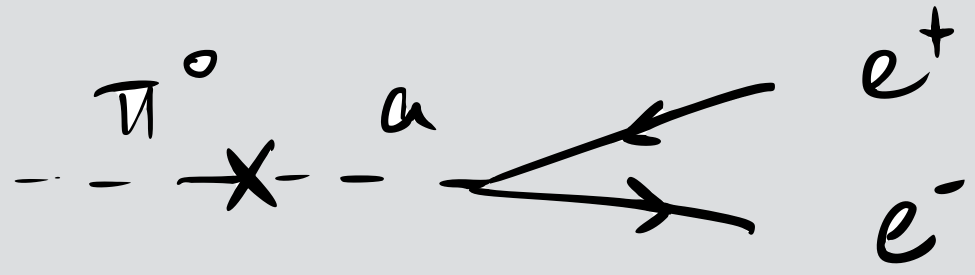

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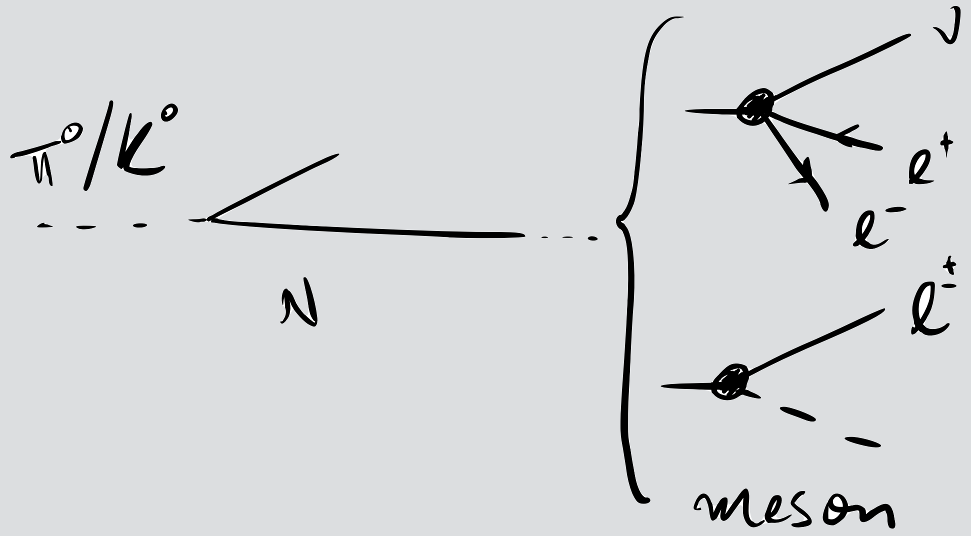

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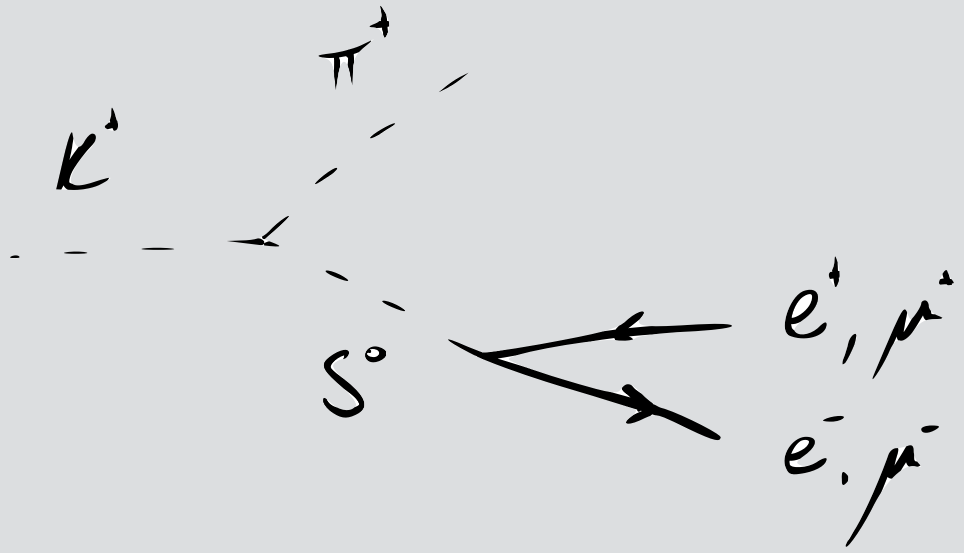

Pat Wilczek 2006
Batell Berger Ismail PRD 2019
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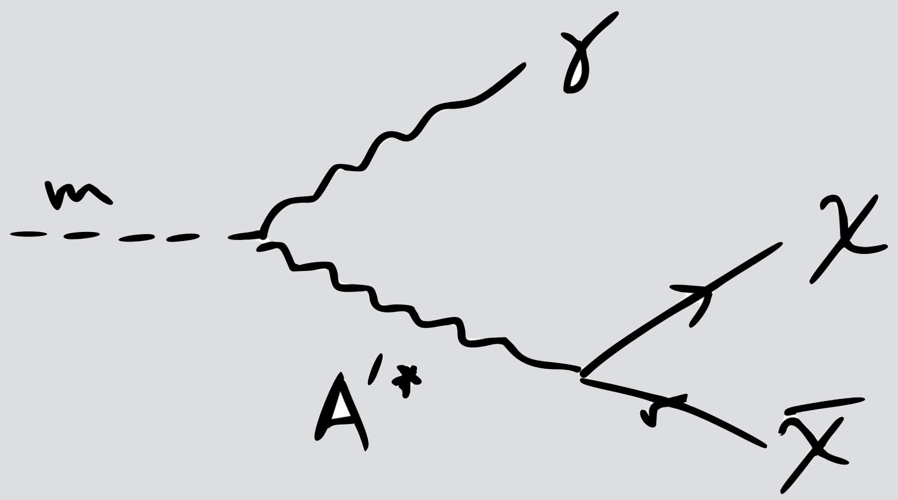

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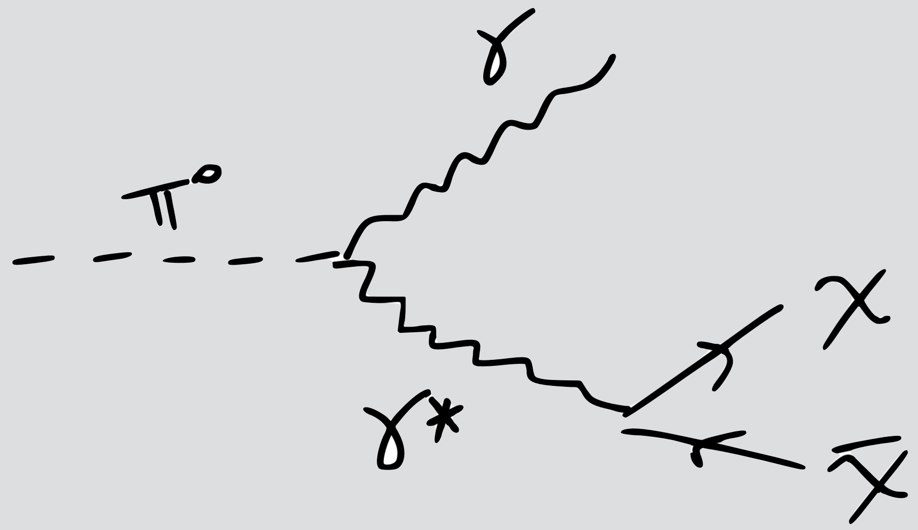

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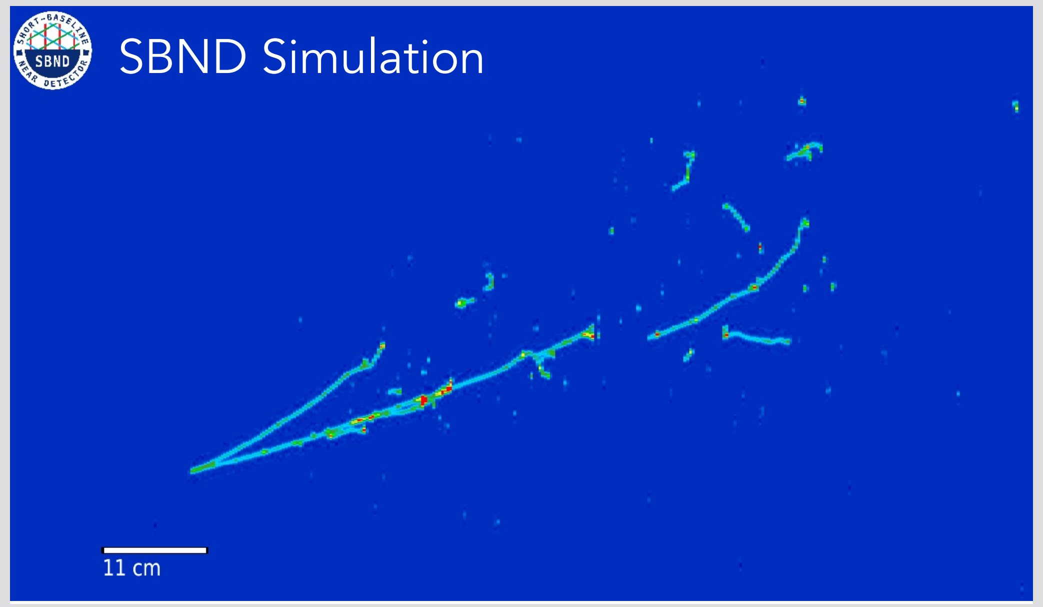

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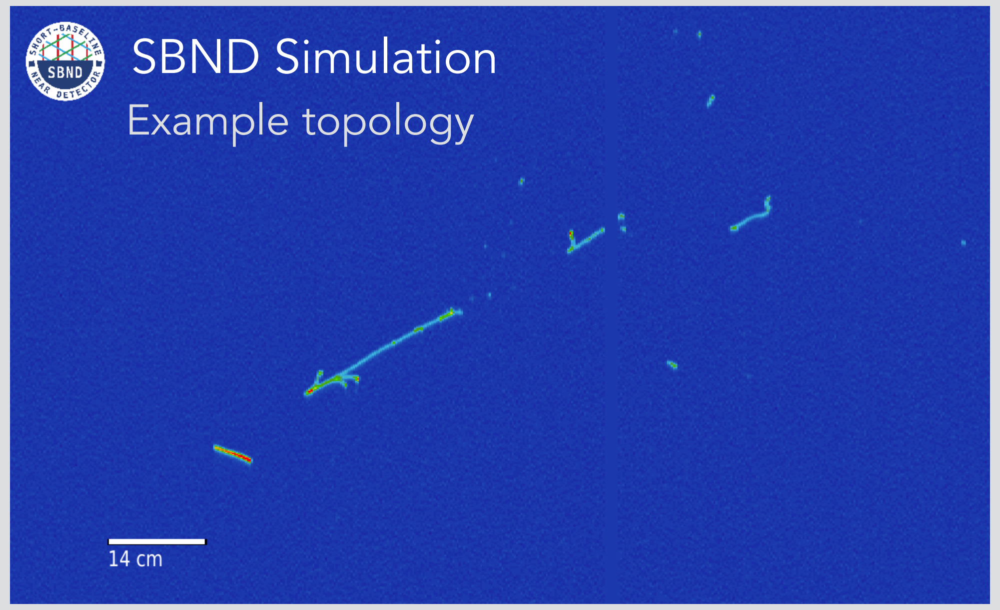

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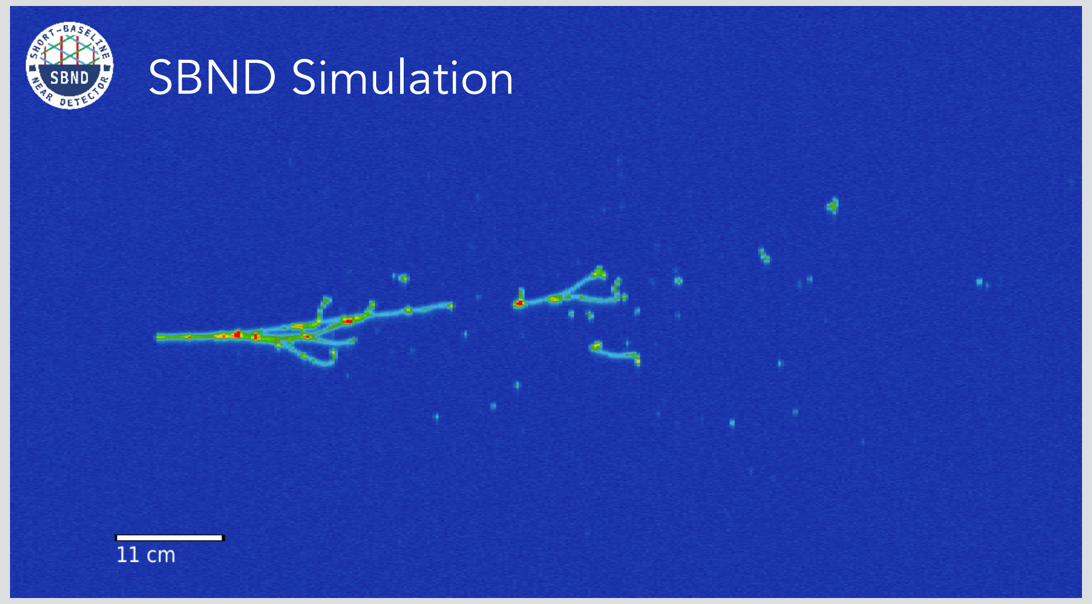

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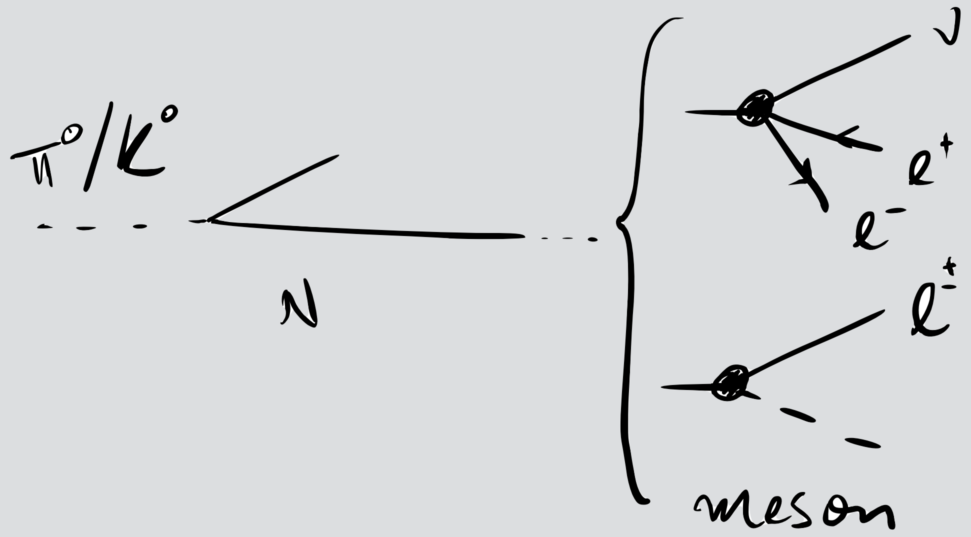

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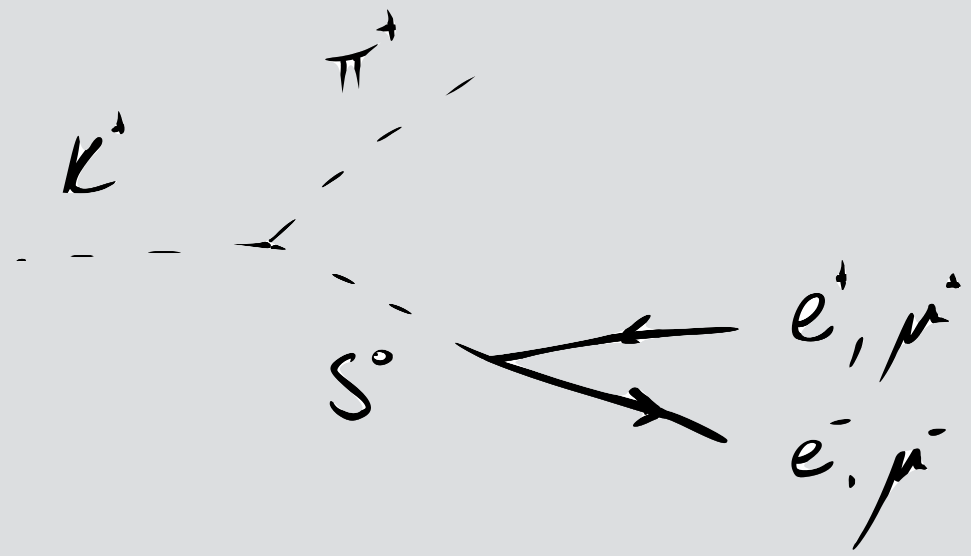

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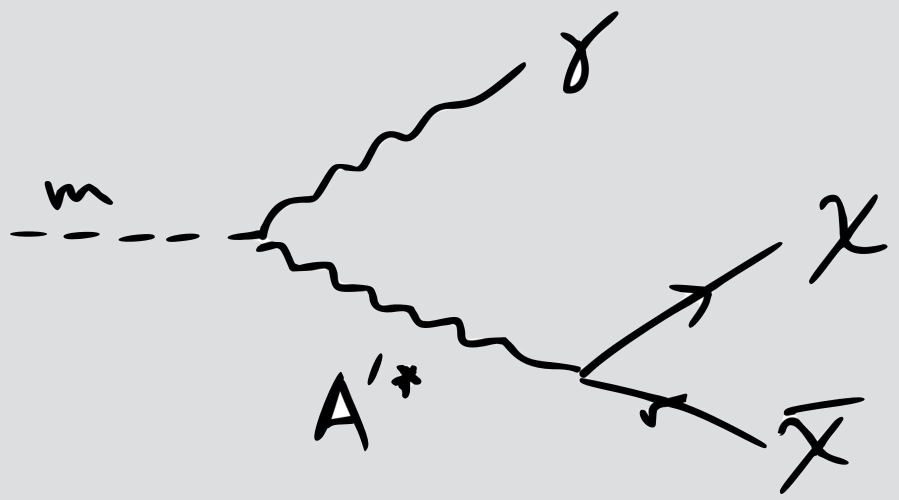

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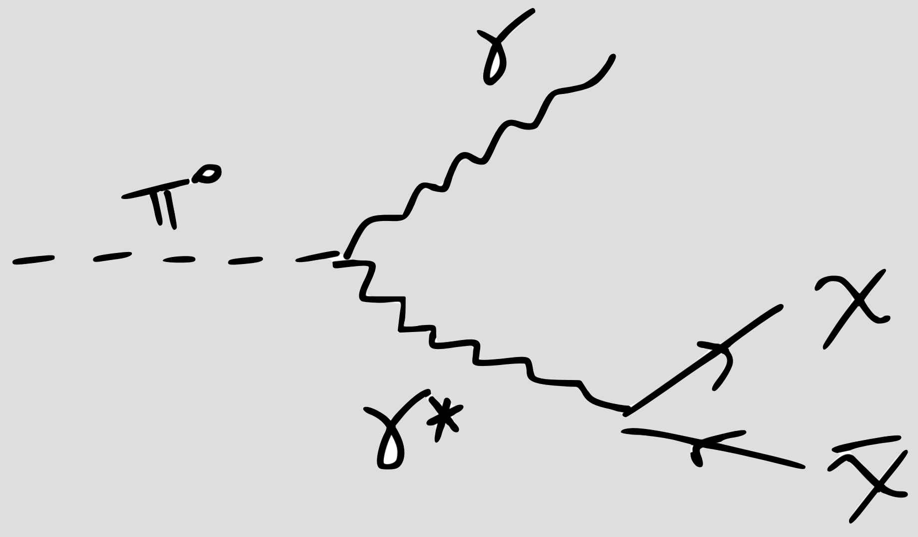

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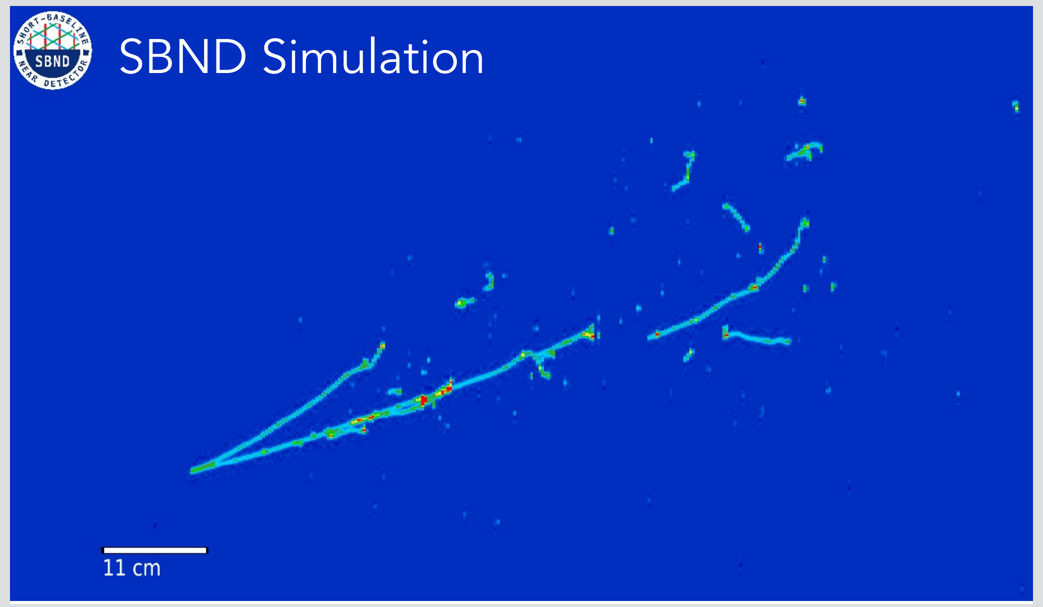

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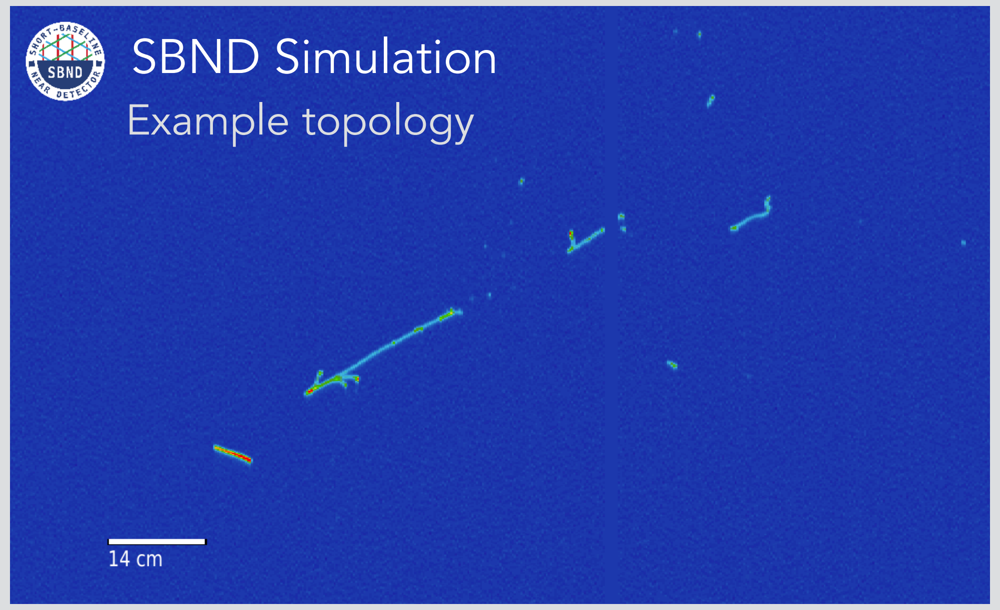

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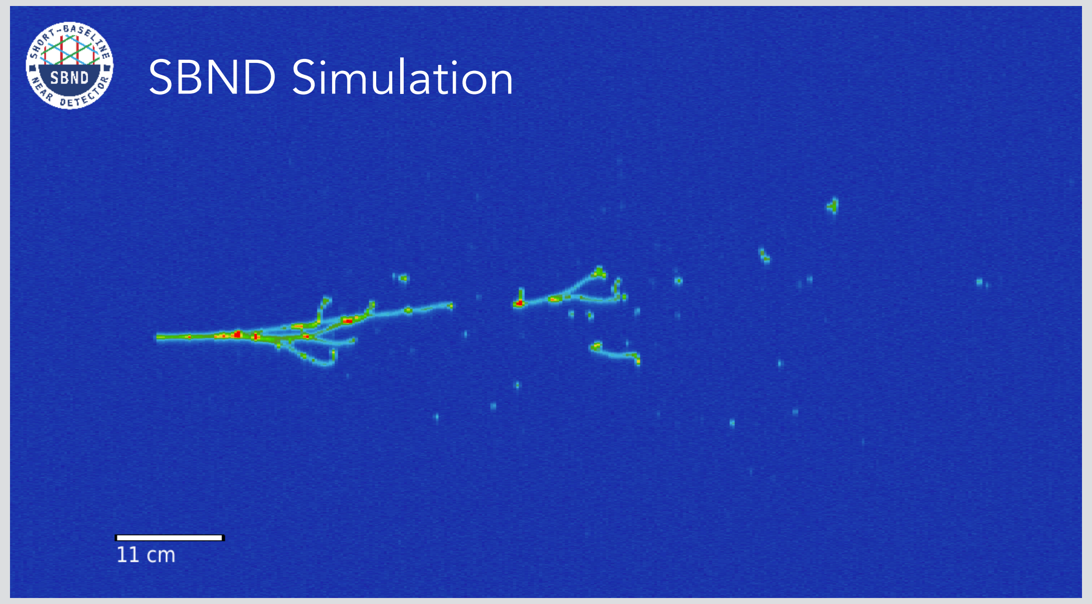

high-energy e^+e^-, $\mu^+\mu^-$

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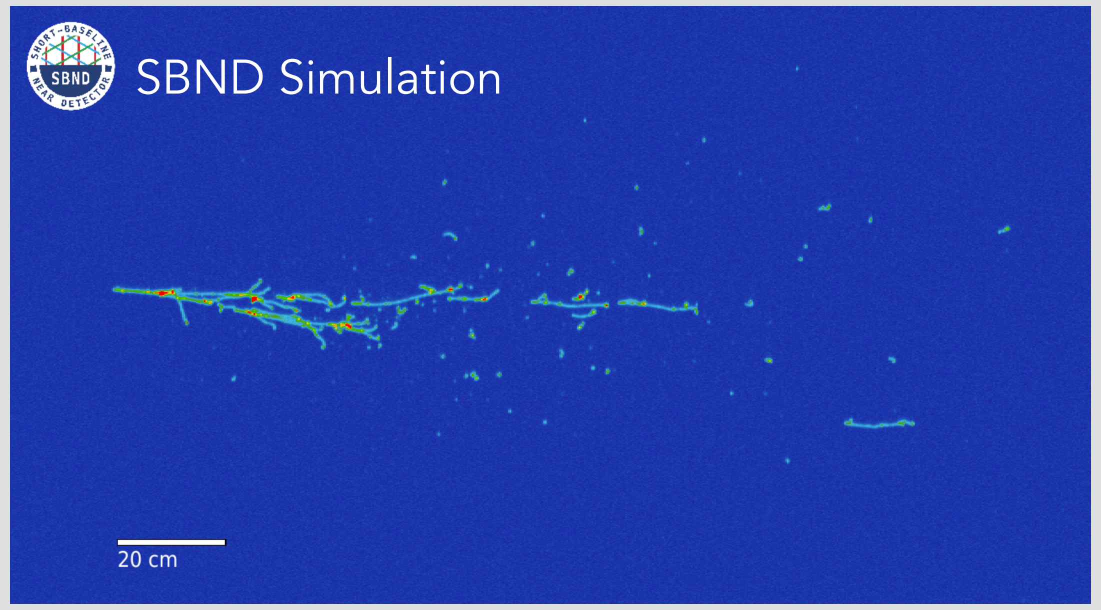
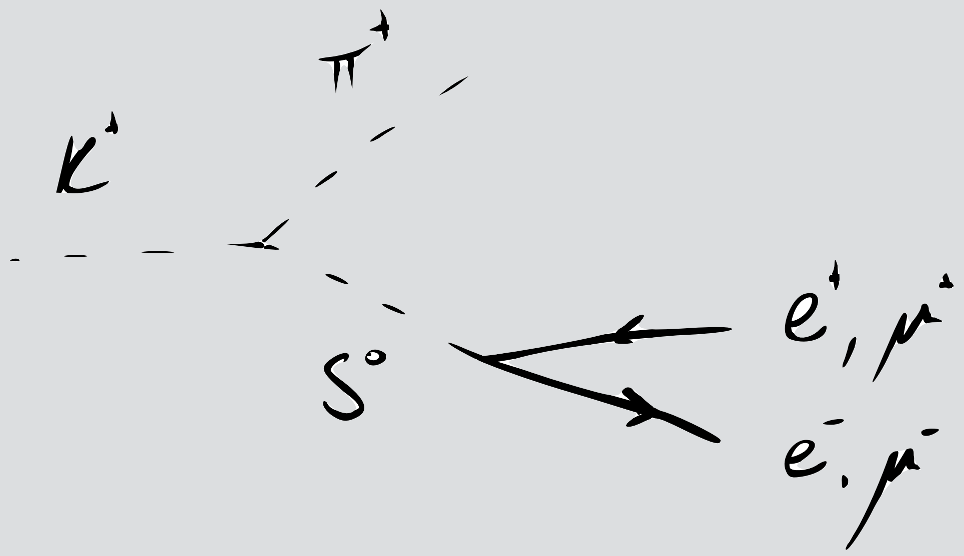


e^+e^-, $\mu^+\mu^-$, $\mu\pi$

Higgs Portal Scalar



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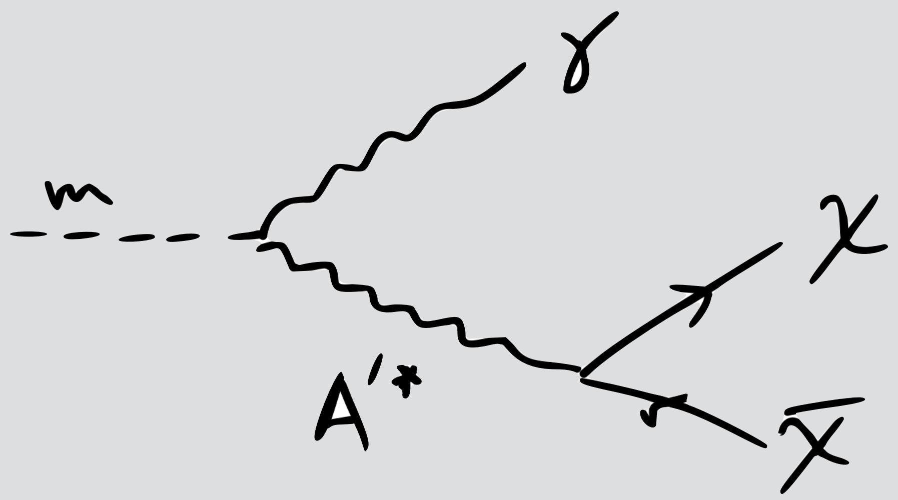

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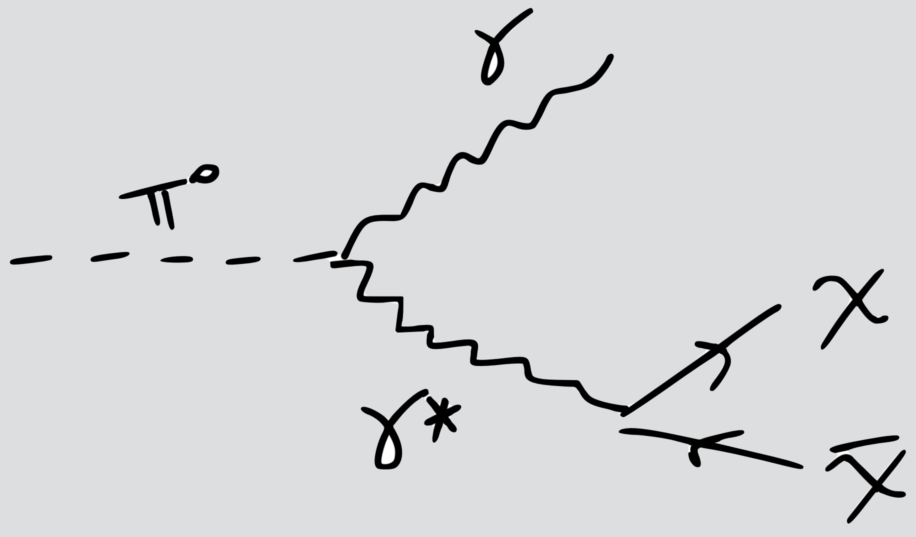

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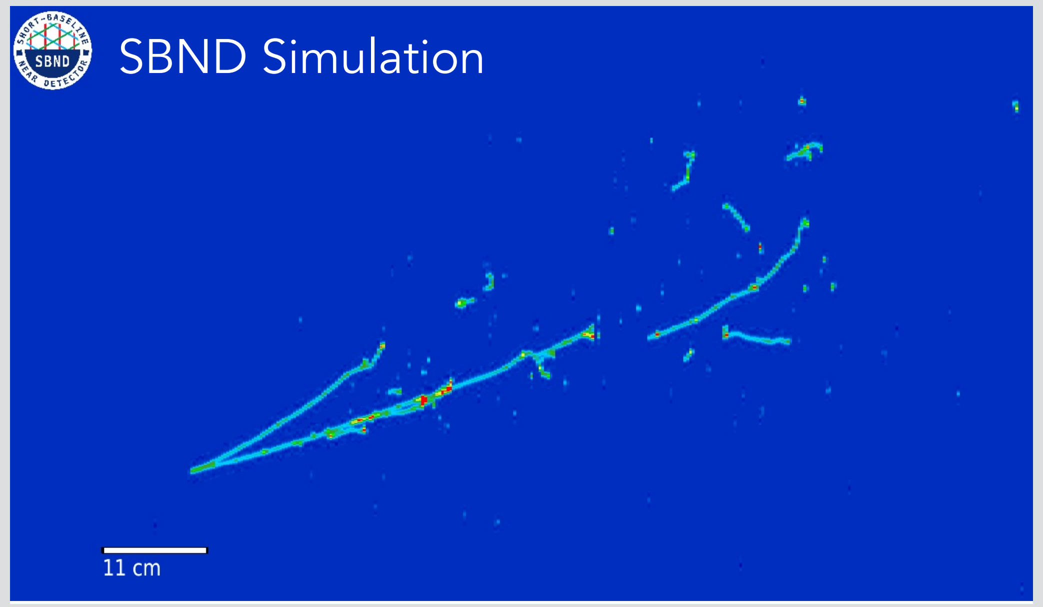

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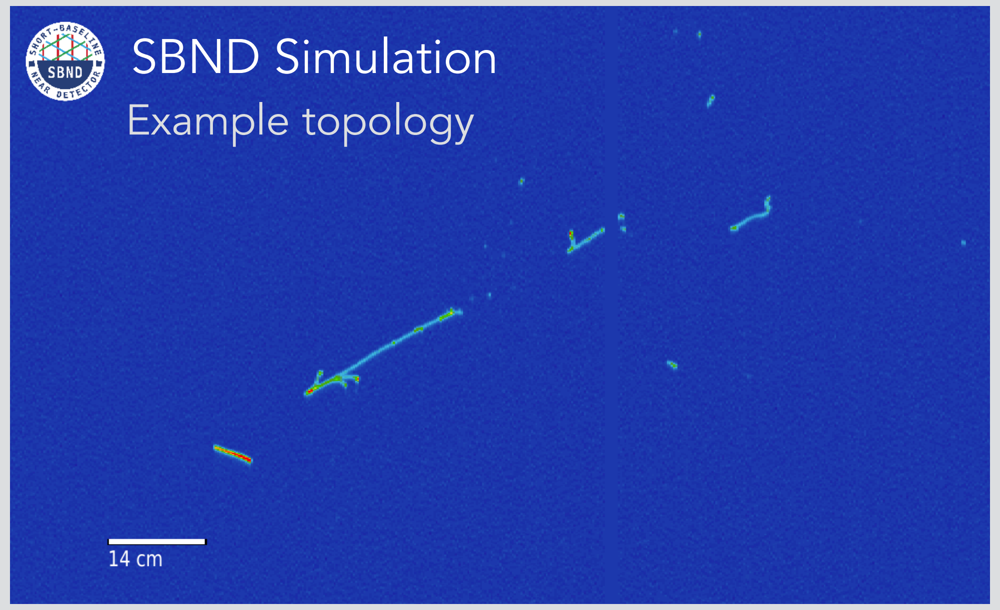
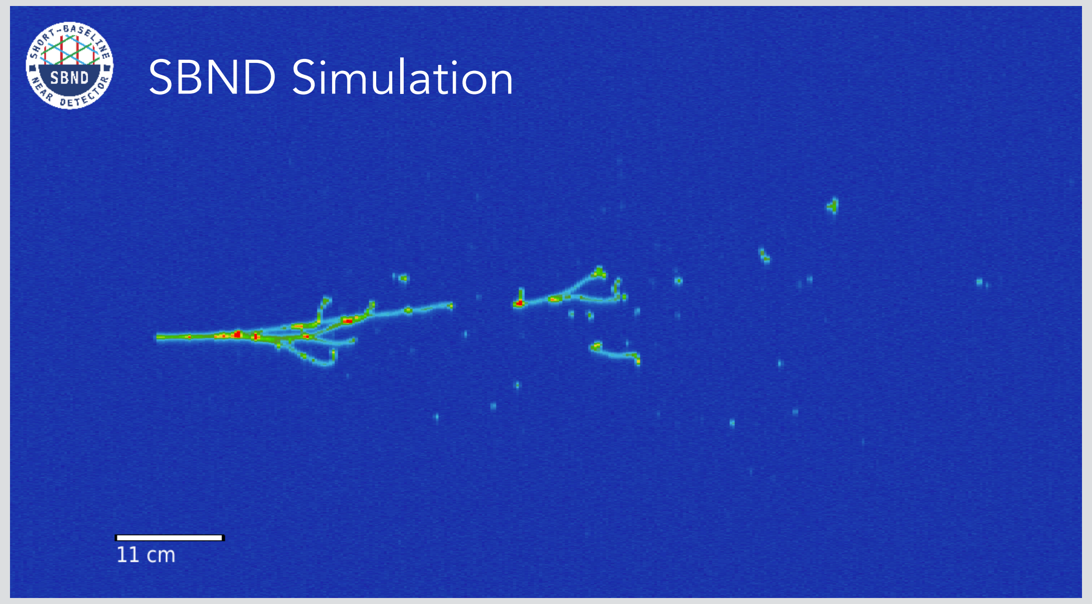


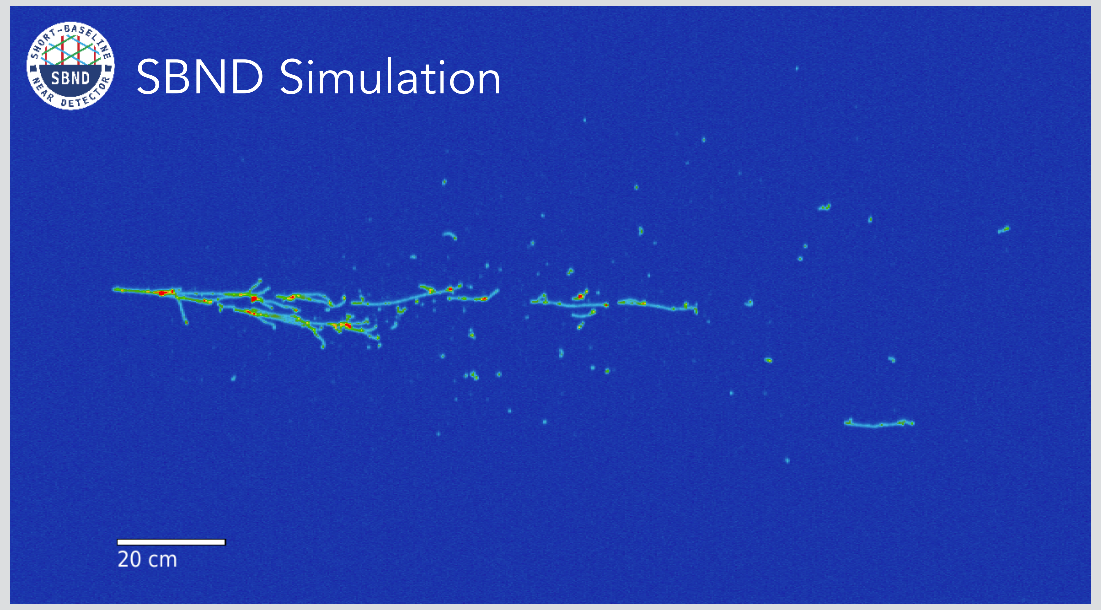
photon shower and hadronic activity

Axion-like Particles



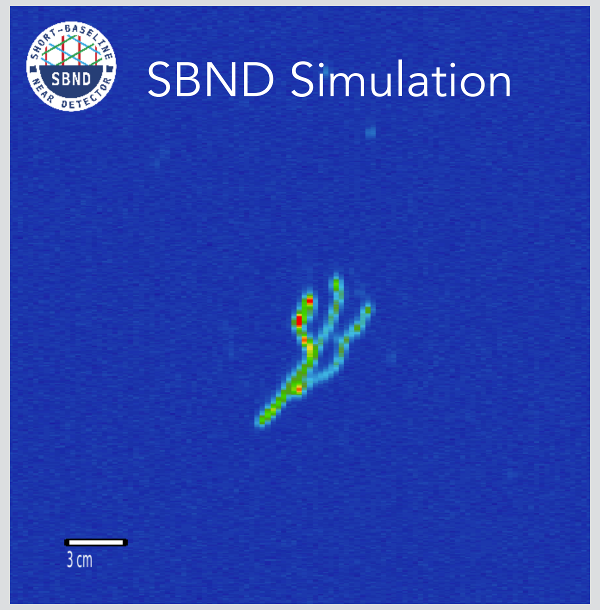
high-energy e^+e^-, $\mu^+\mu^-$

Heavy Neutral Leptons



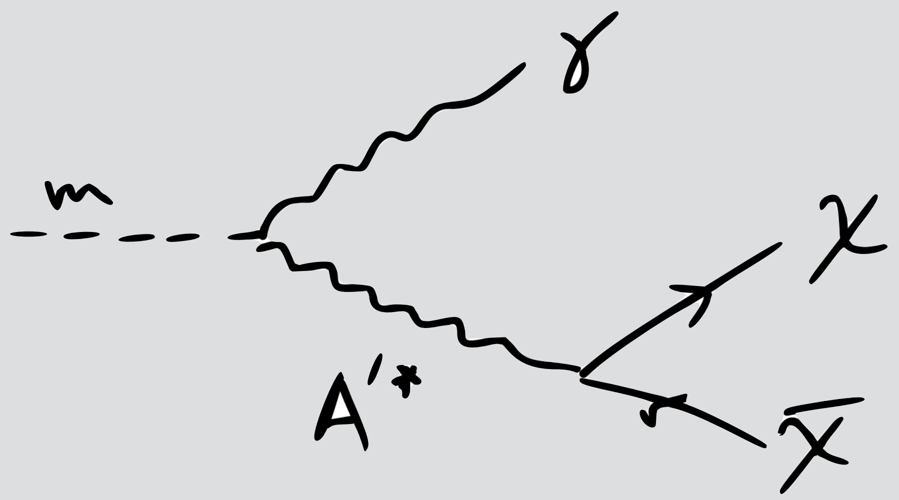
e^+e^-, $\mu^+\mu^-$, $\mu\pi$

Higgs Portal Scalar



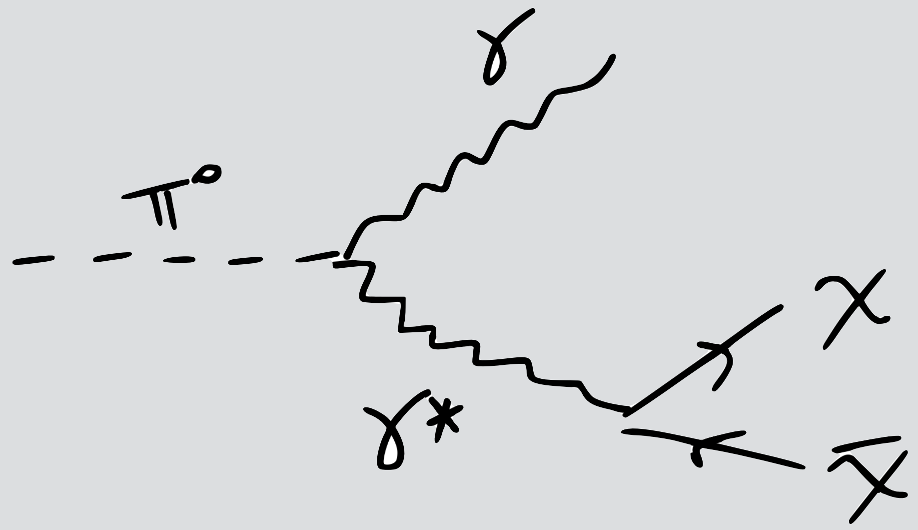
e^+e^-, $\mu^+\mu^-$, no hadronic activity

Light Dark Matter



Romeri Kelley Machado PRD 2019

Millicharged Particles



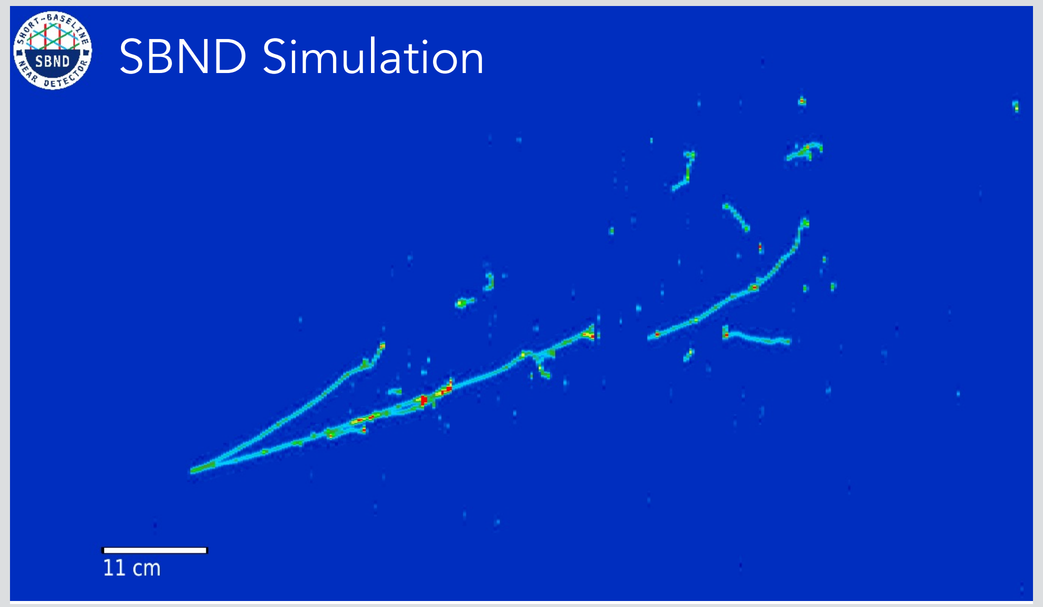
Magill, Plestid, Pospelov, Tsai, PRL 2019
Harnik Liu Palamara, JHEP 2019

Beyond Standard Model Searches

Alternative explanations to the MiniBooNE excess and other BSM scenarios

Not an exhaustive list

Dark Neutrinos



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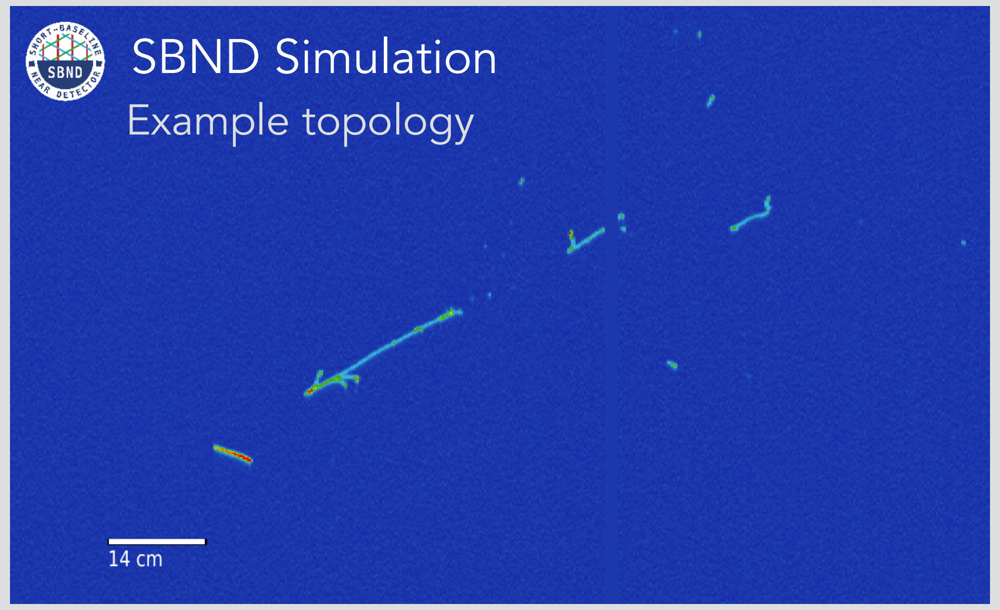

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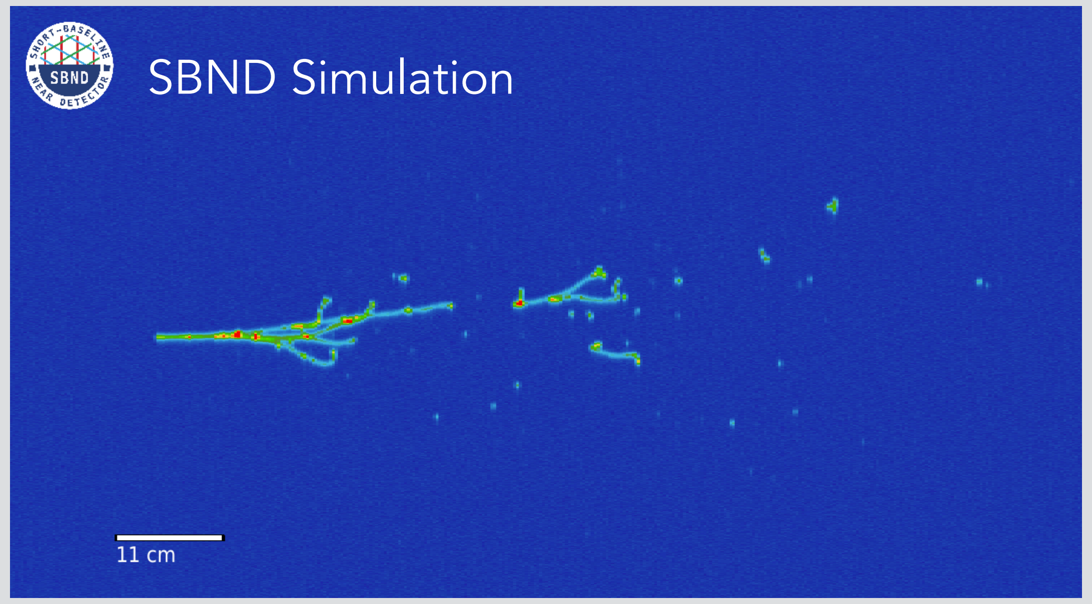

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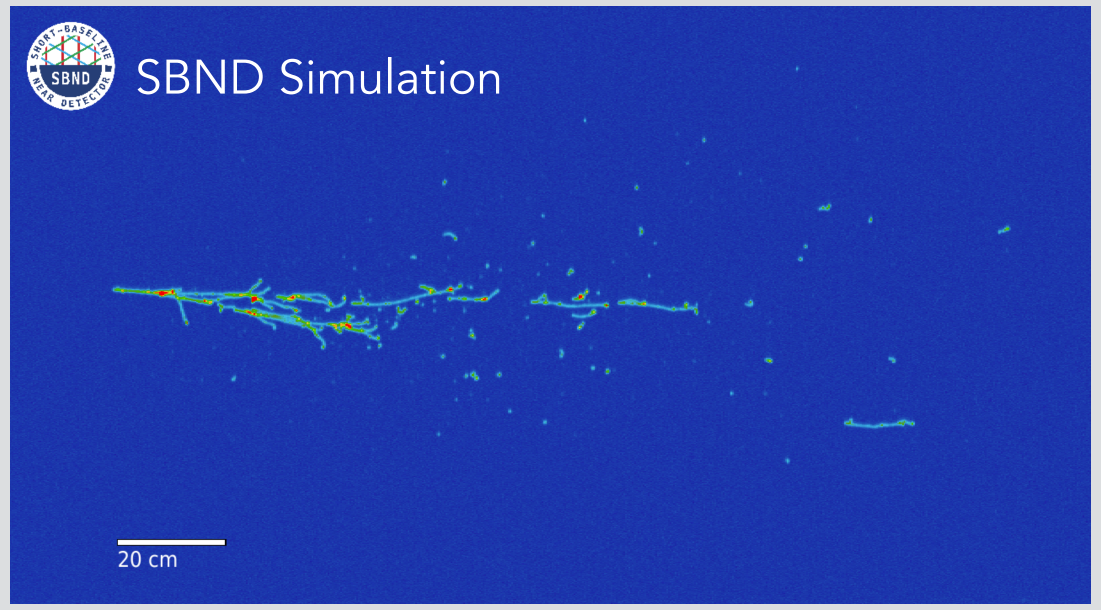

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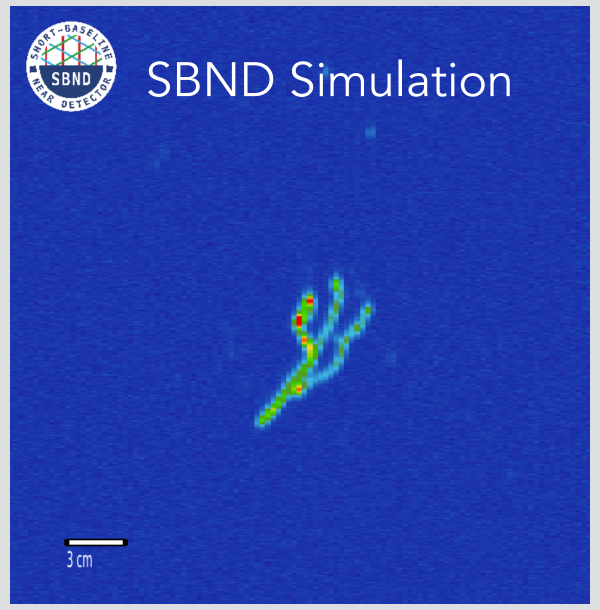

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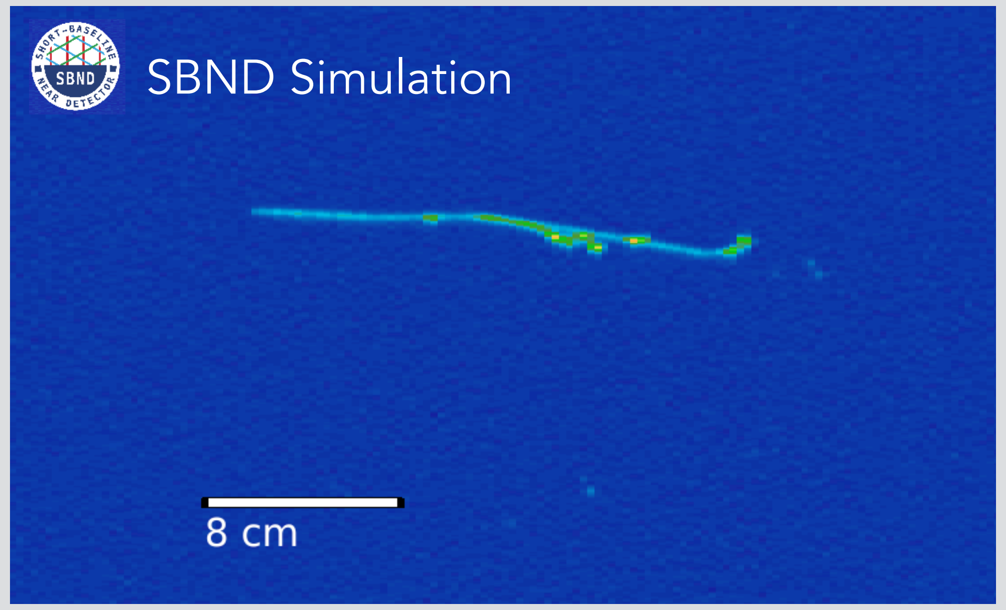
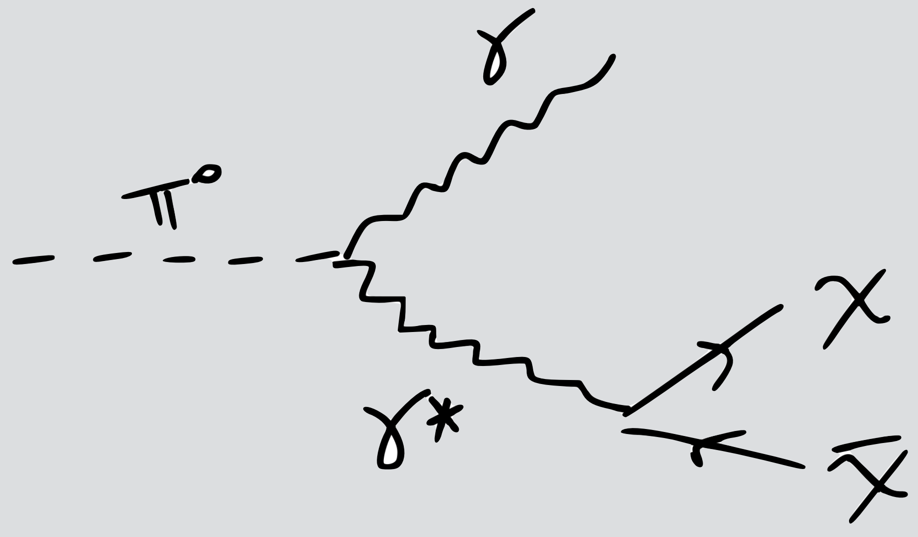


electron scattering

Millicharged Particles



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Beyond Standard Model Searches

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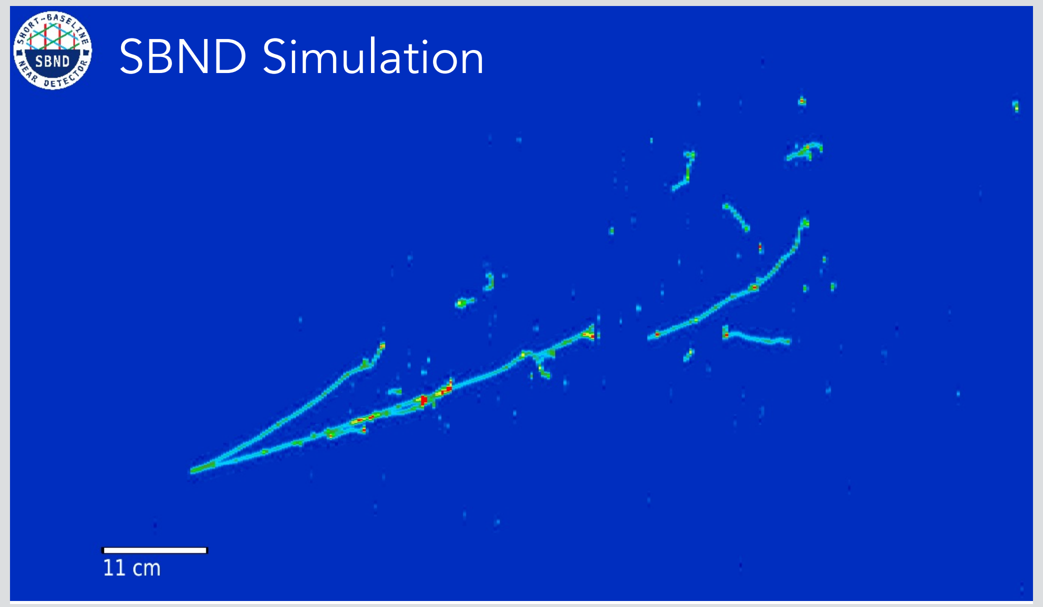

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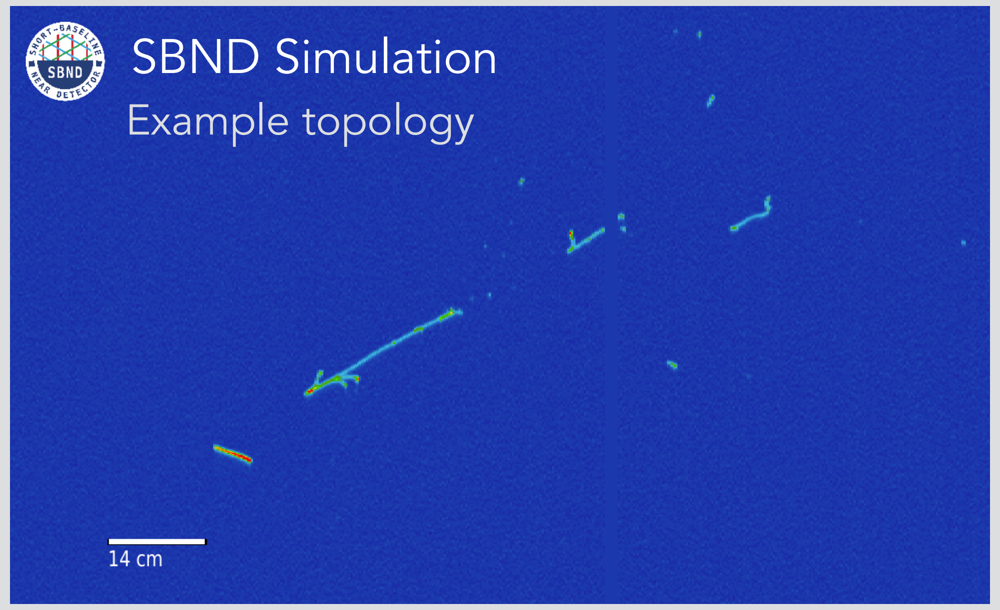

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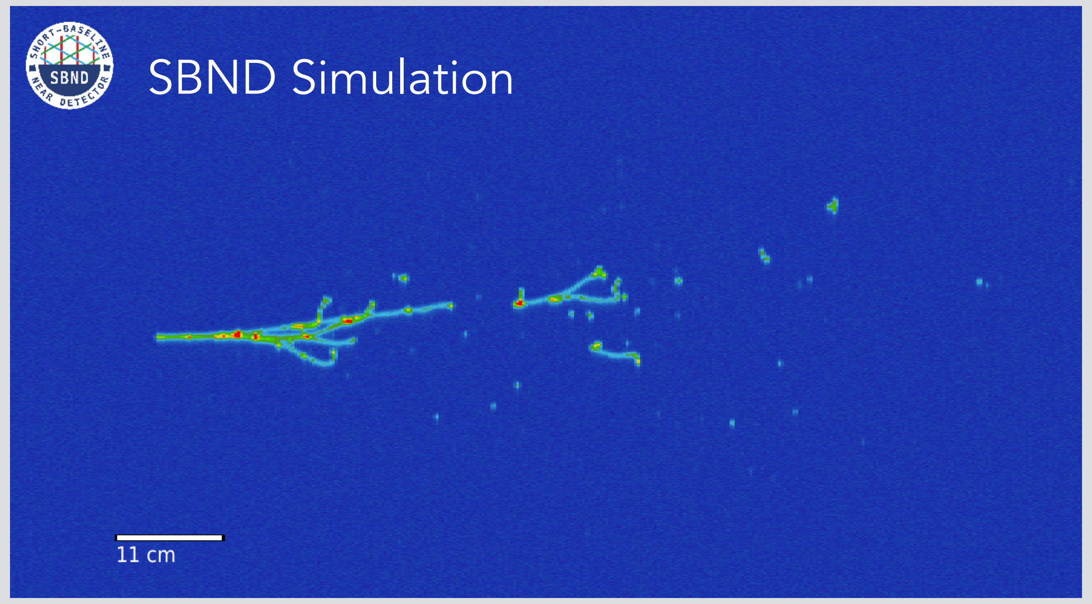

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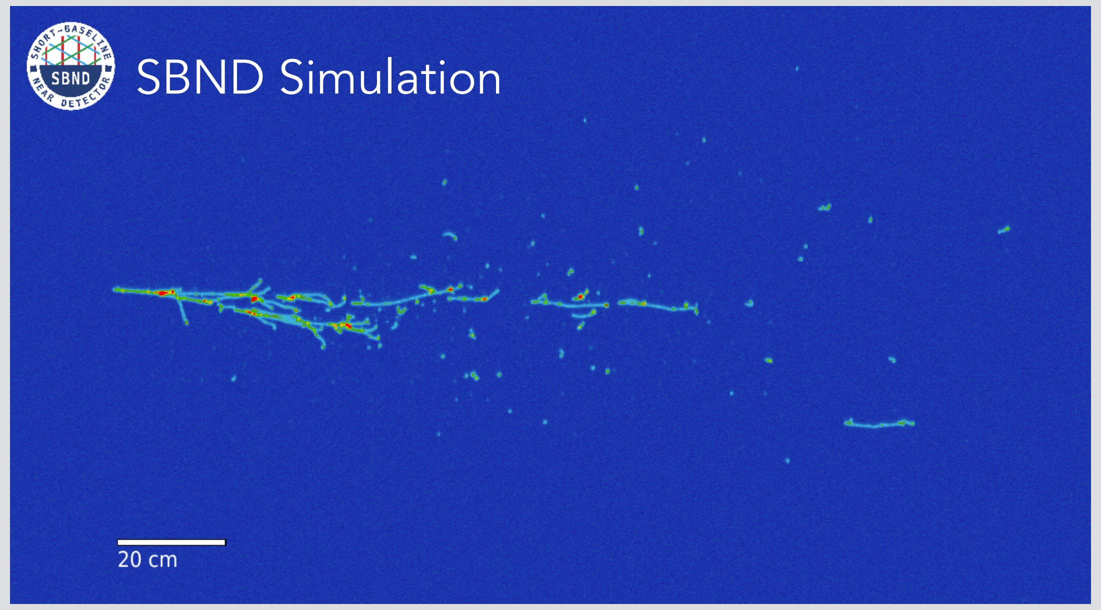

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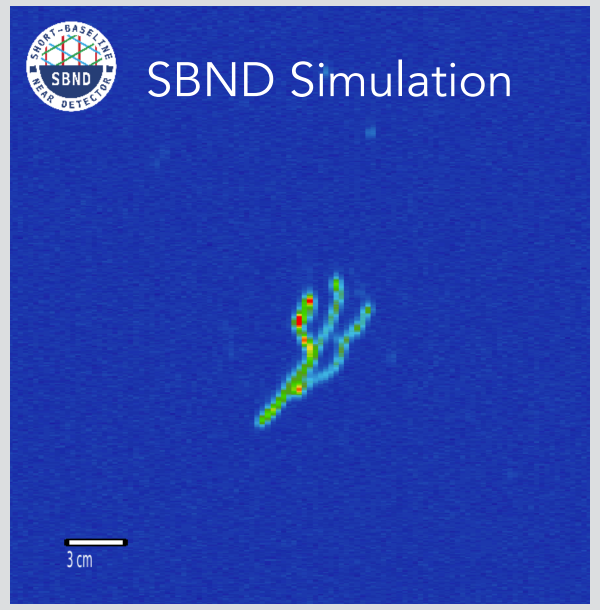

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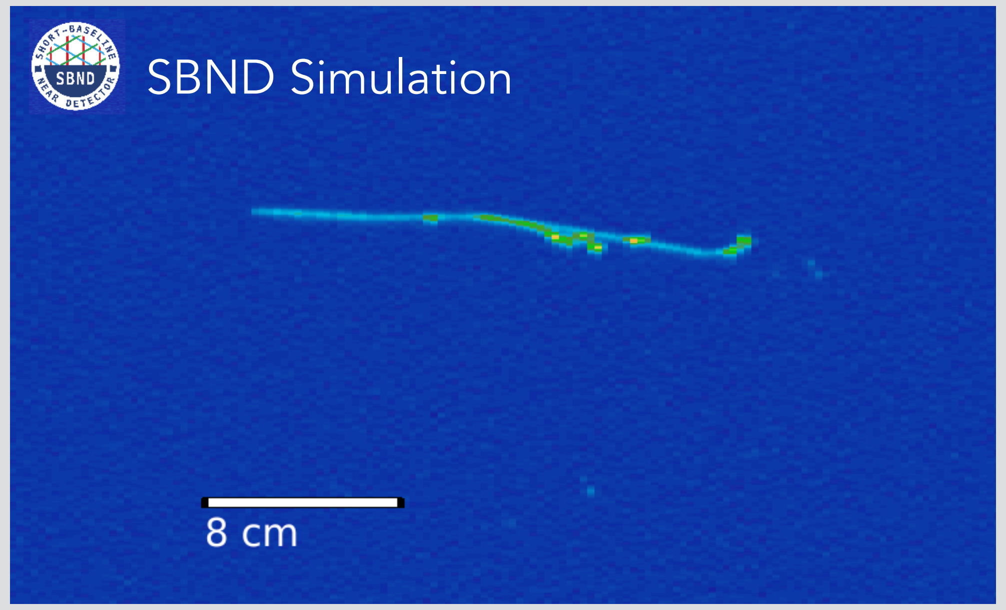
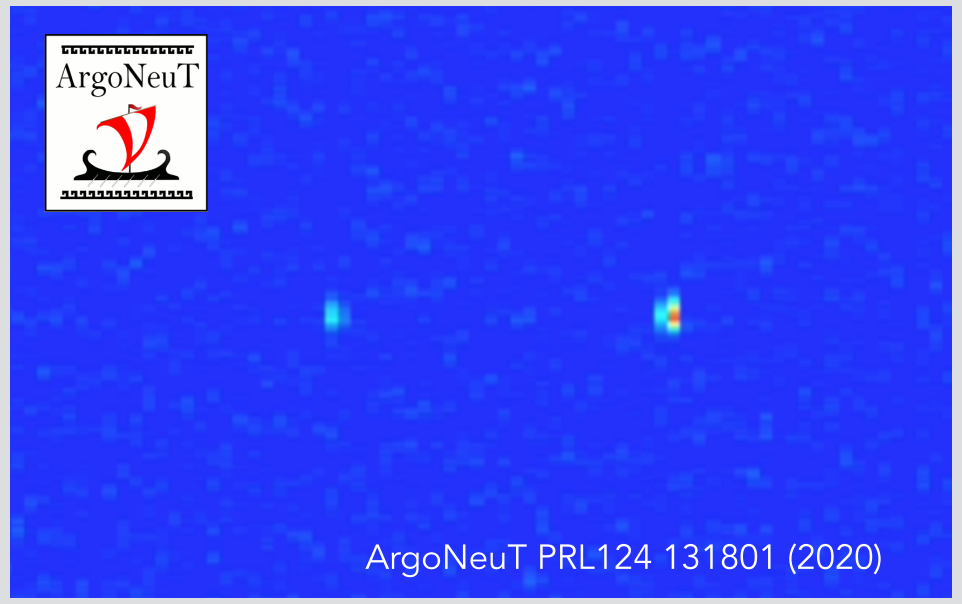
Light Dark Matter



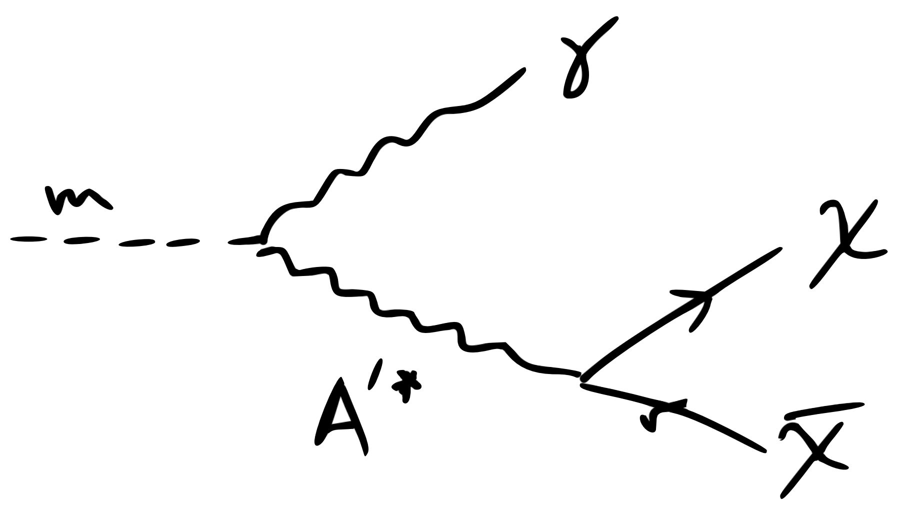
electron scattering

Millicharged Particles

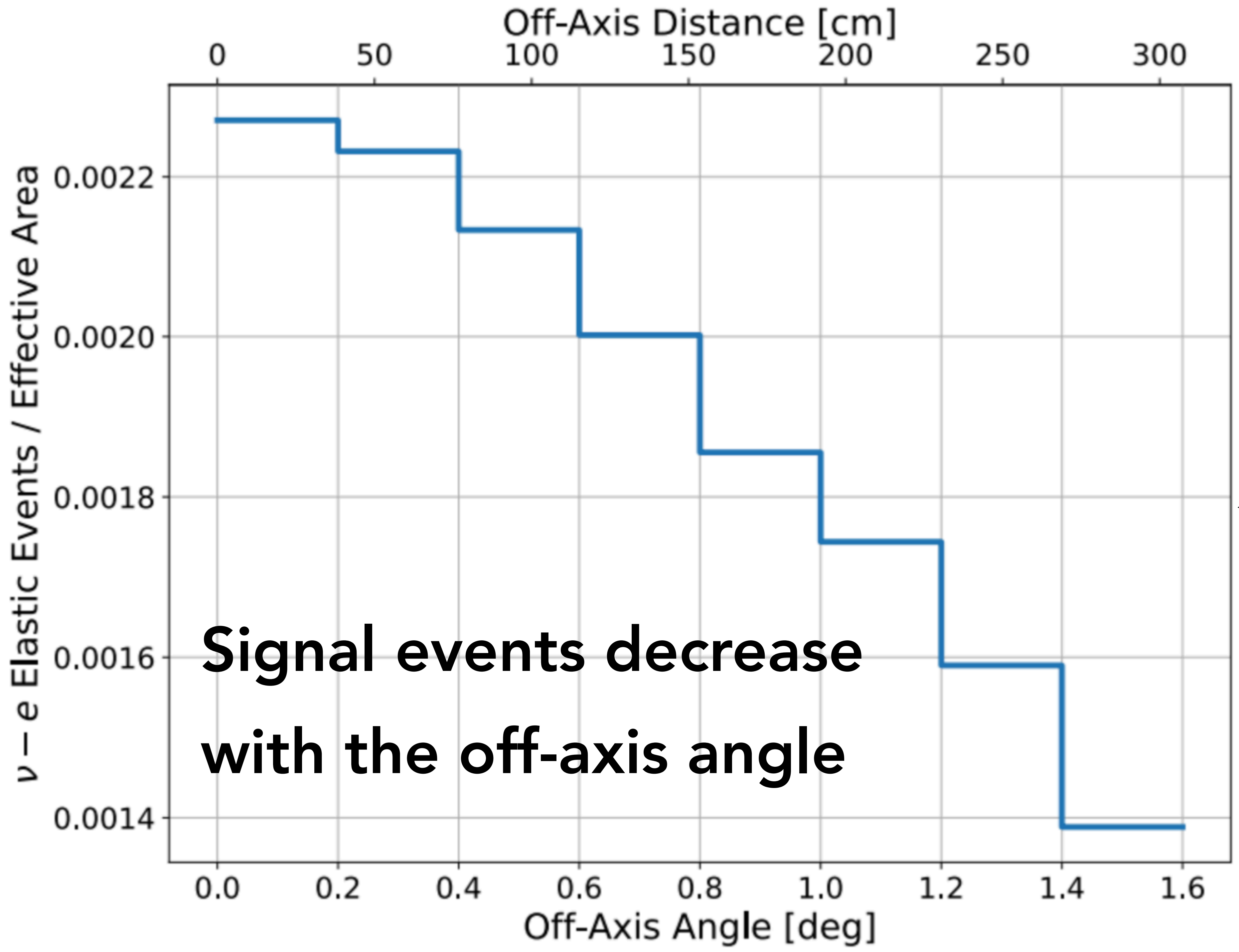


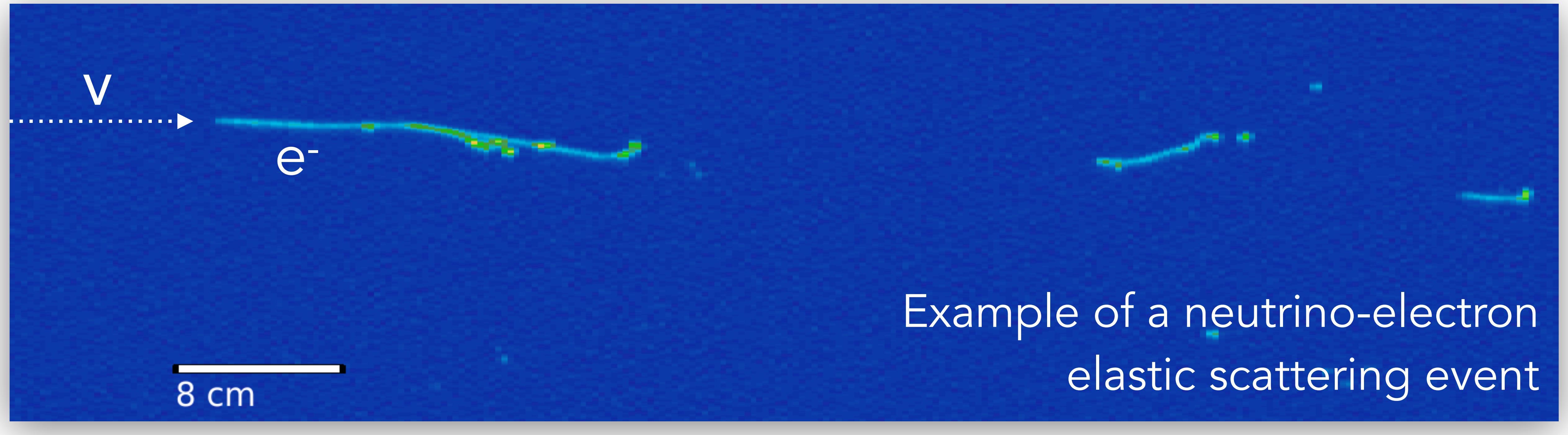
blips/faint tracks

Dark Matter Searches: Light Dark Matter



One example: **light dark matter** (sub-GeV) coupled to the Standard Model via a dark photon. The dark photons can be produced by neutral meson decays (pions, etas) in the target, and then decay to dark matter. The dark matter can then travel to SBND and, through the dark photon, **scatter off electrons in the detector**.





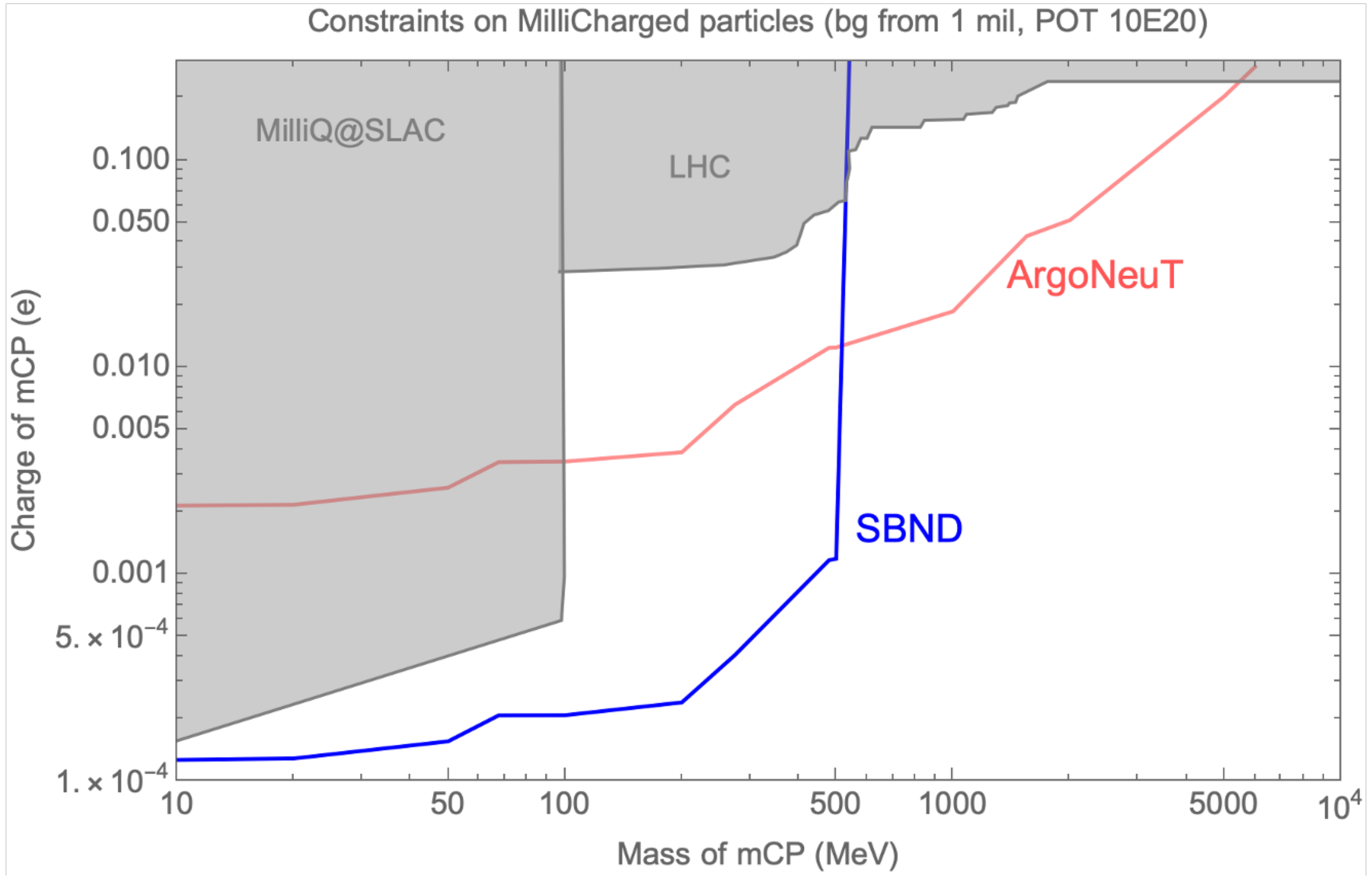
- **Background**: neutrino-electron elastic scattering. Neutrinos come from two-body decays of charged (focused) mesons.
- **Signal**: elastic scattering electron events. Dark matter comes from three-body decays of neutral (unfocused) mesons.
  - **Neutrino flux drops off more sharply as a function of radius!**

See also https://arxiv.org/abs/1903.10505

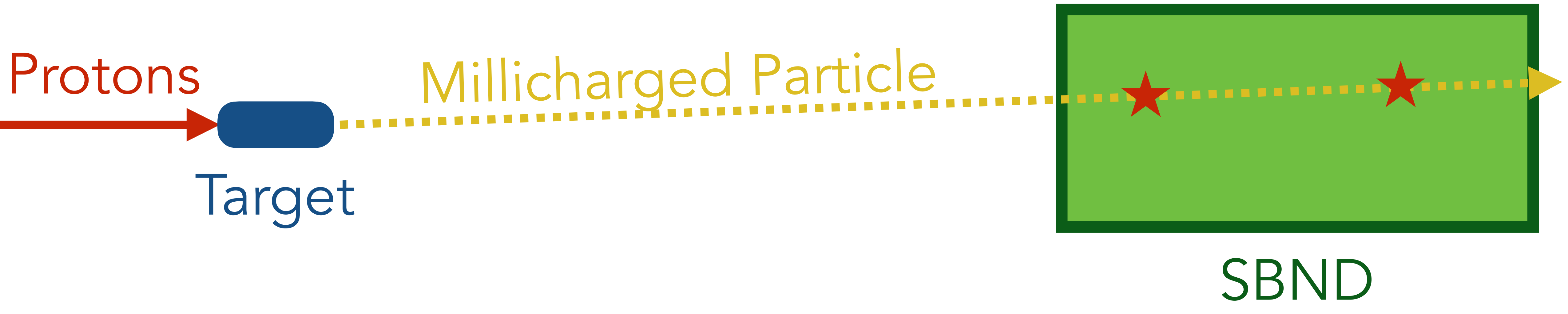
Dark Matter Searches: Millicharged Particles

- **Millicharged particles**: hypothetical new particles with fractional charge.
- Neutral mesons produced from proton collisions with the target could decay into millicharged particles.
- Millicharged particles will produce low-energy depositions (small hits or faint tracks) that point back to the target.
- **SBND could provide a promising new search for millicharged particles.**

Argoneut method: R. Acciarri et al., PRL124 131801 (2020)



Preliminary results from simulation



Conclusions

- SBND detector construction and installation are progressing very well
- We expect to begin detector operations next year
- SBND will have an extensive physics program including:
  - search for eV mass-scale sterile neutrinos oscillations in the SBN program
  - neutrino cross-section measurements
  - search for new and exotic physics signals