Heavy Neutral Leptons searches on SBND

μπ channel

New Perspectives 2024

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SHORT-BASELINE NEAR DETECTOR SBND

UNIVERSIDAD DE GRANADA

The Short-Baseline Neutrino Program

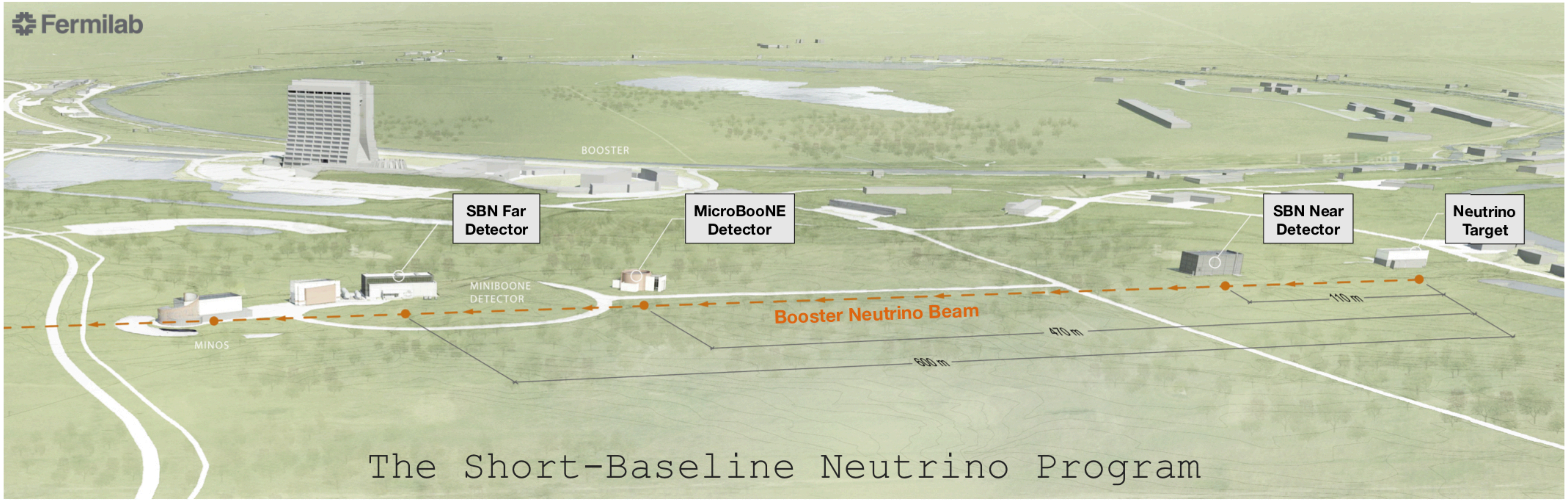
Purpose

Investigate LSND & MiniBoone anomalies in neutrino oscillations: Test the low energy excess under different models

Facilities

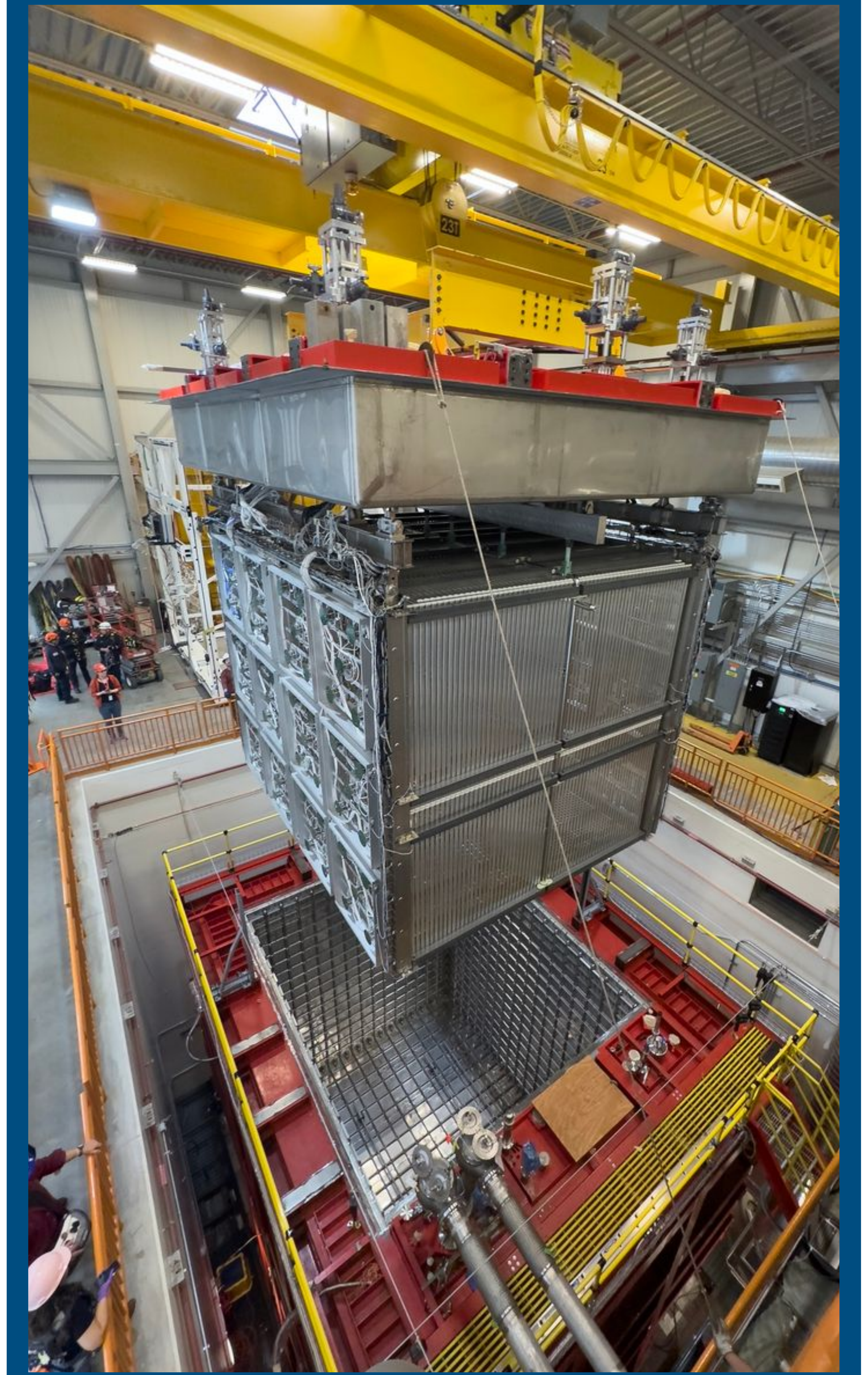
3 Liquid Argon Time-Projection Chambers (LArTPC) along the Booster Neutrino Beam

SBND MicroBooNE ICARUS



SBN Near Detector

The Short Baseline Near Detector (SBND), currently in commissioning, is a 112 ton active volume TPC located 110 m from the BNB target



Rich physics program due to proximity to the target:

- High precision measurement of the unoscillated BNB Flux
- Largest neutrino dataset of neutrino-argon interaction
- Exclusive and Inclusive cross-section measurements
- **Beyond Standard Model (BSM)** searches of particles produced in the neutrino beam

Heavy neutral leptons

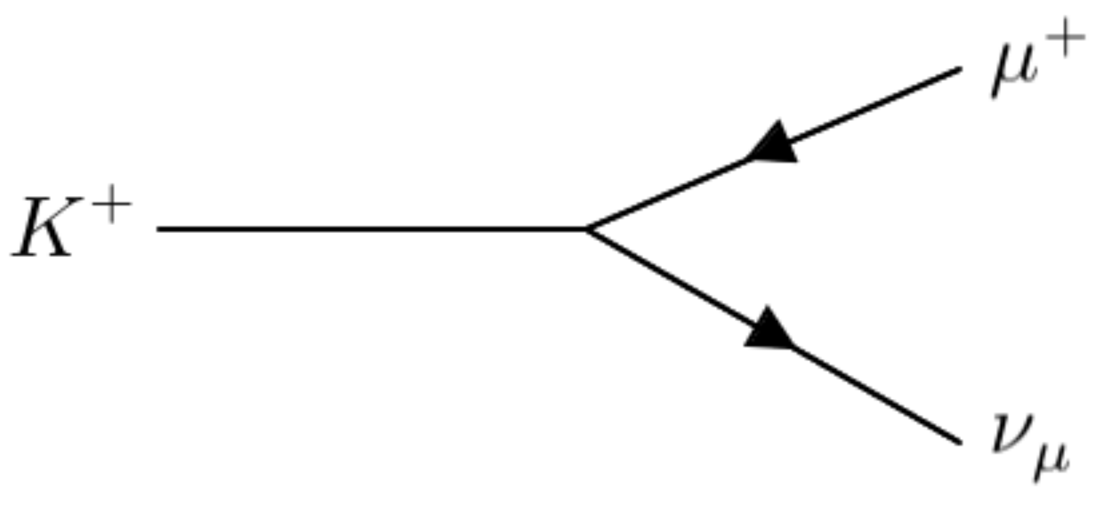
Definition

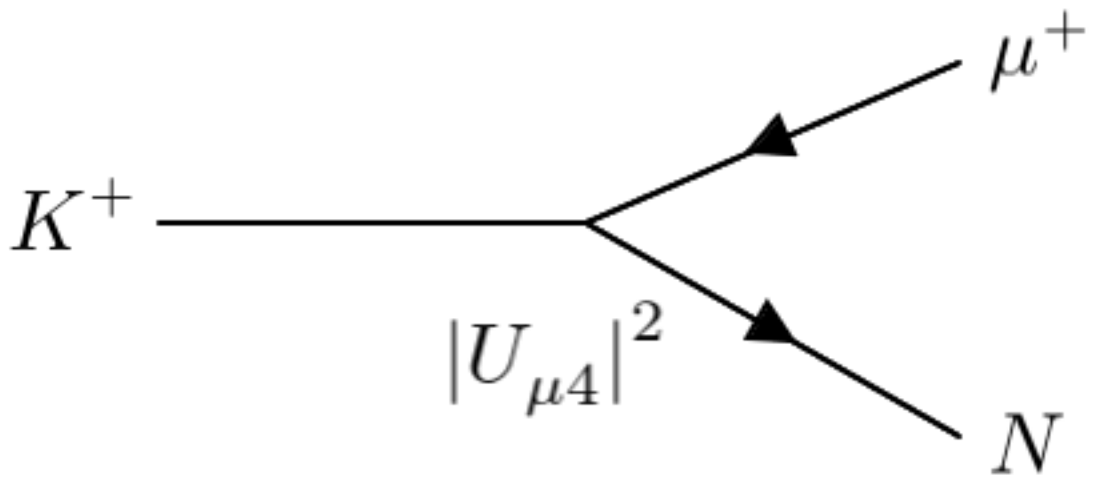
Heavy neutral leptons (HNLs) are right-handed fermions added to the 3 flavour neutrino model to explain the neutrino mass:

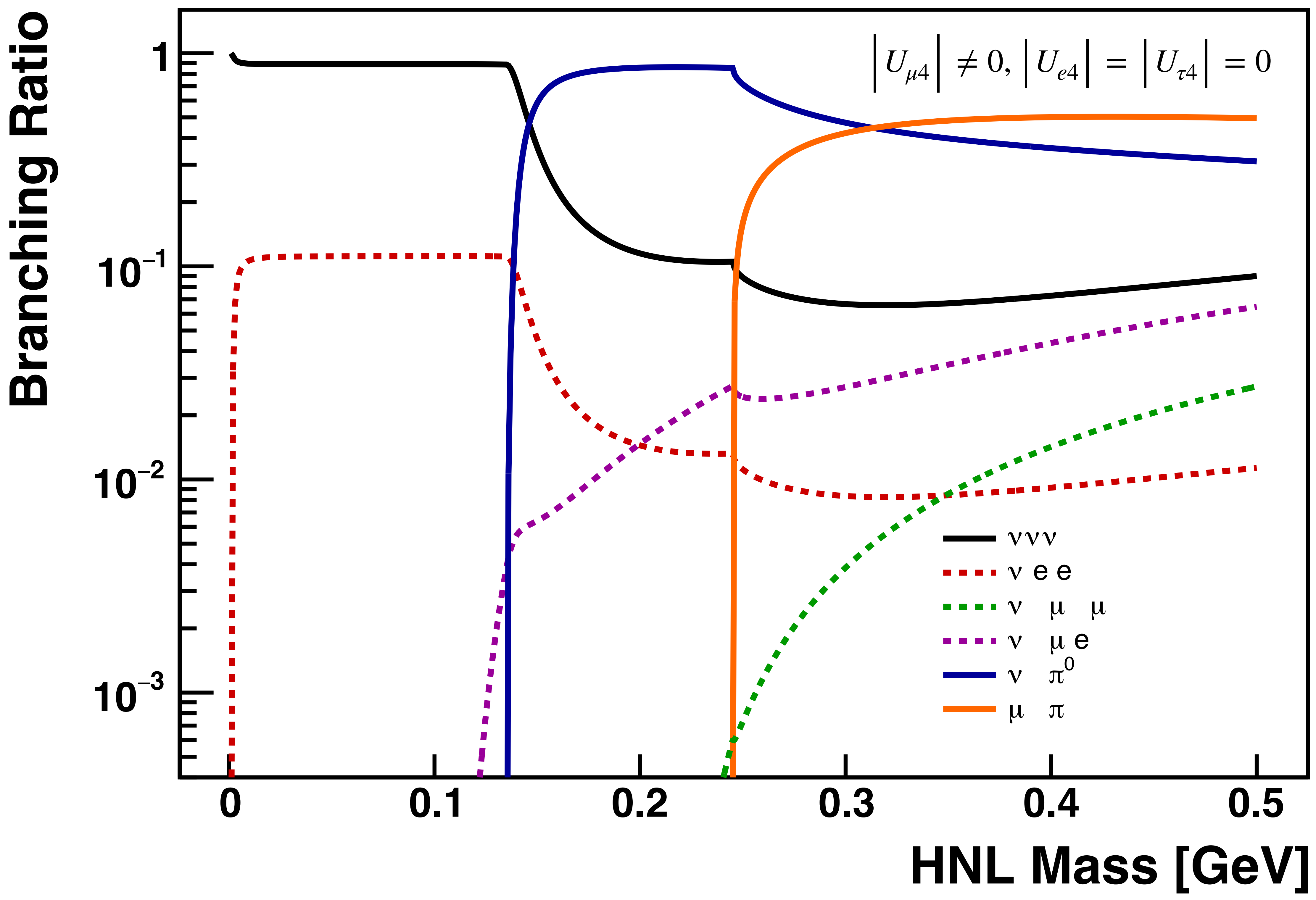
- Can couple to SM neutrinos by an extended PMNS matrix $\left|U_{\alpha 4}\right|, \alpha = \tau, \mu, e$
- Its mass is not constrained
- It can be either Dirac or Majorana
- Do not oscillate with standard model neutrino as its mass is large and coherence is lost

$$U_{PMNS}^{Extended} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{41} & U_{42} & U_{43} & U_{44} \end{pmatrix}$$

$$\nu_\alpha = \sum_i U_{\alpha i}\nu_i + U_{\alpha 4}N$$







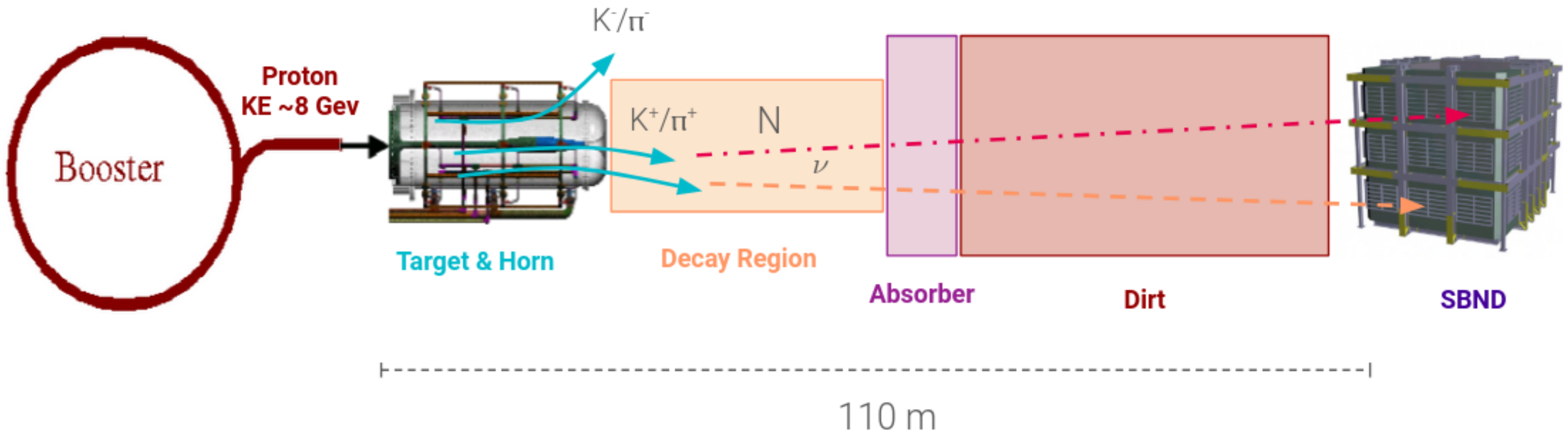
HNLs in SBND

Production and detection:

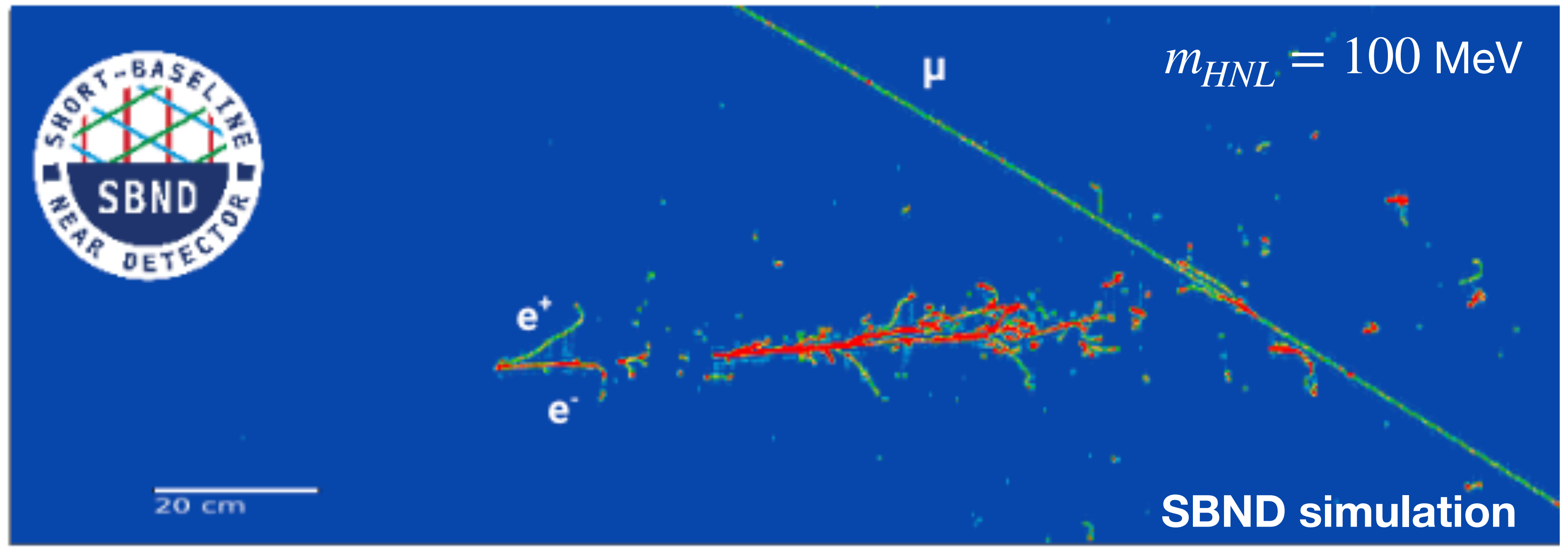
In the given theory HNLs are produced along with neutrinos in K^+ decays, constraining the explorable μ-coupled HNLs mass to < 388 MeV (m_K-m_μ)

HNLs decay inside the detector into standard model particles by three main channels:

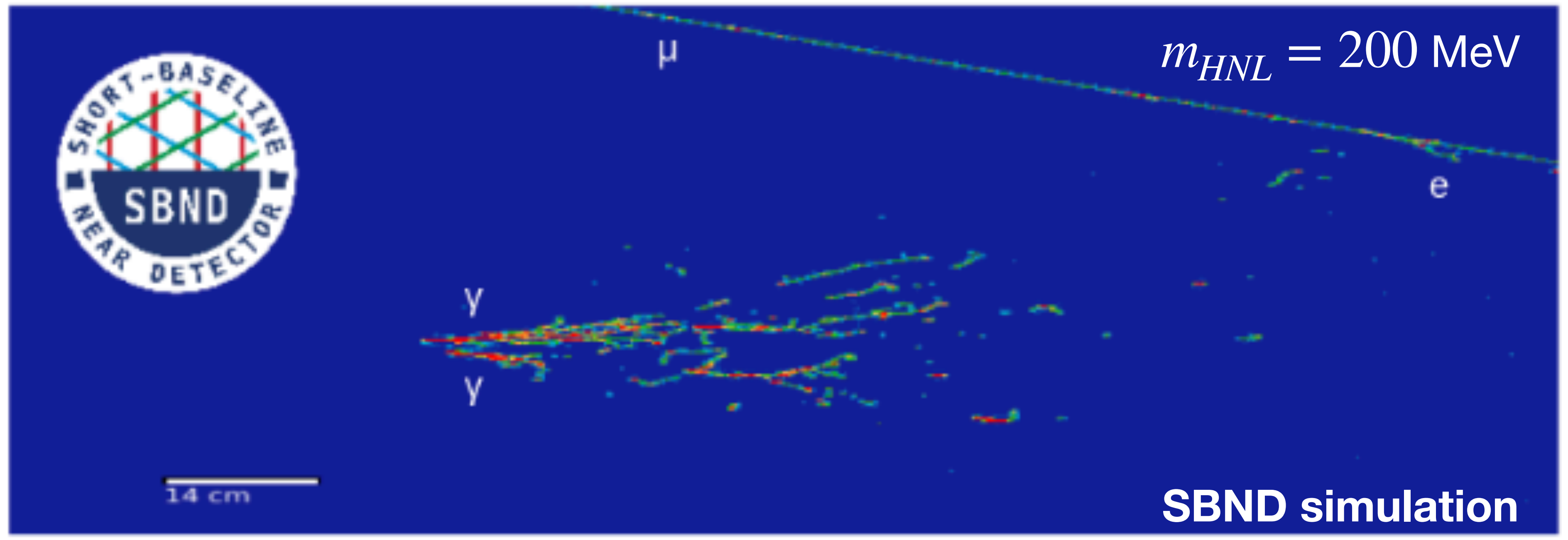
- $\nu e^+e^- \rightarrow m_{HNL} \in$ [1.02, 388] MeV
- $\nu\pi^0 \rightarrow m_{HNL} \in$ [135, 388] MeV
- $\mu\pi \rightarrow m_{HNL} \in$ [240, 388] MeV



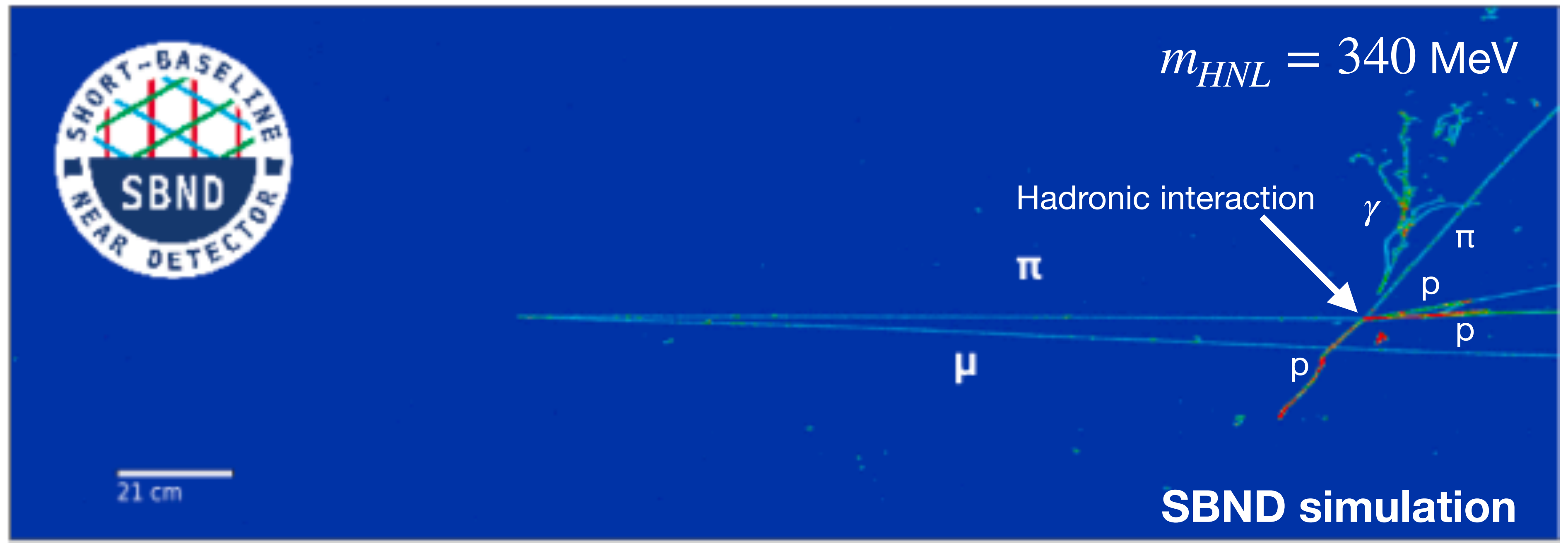
Event display for vee



Event display for νπ⁰



Event display for μπ



μπ HNL decays on SBND

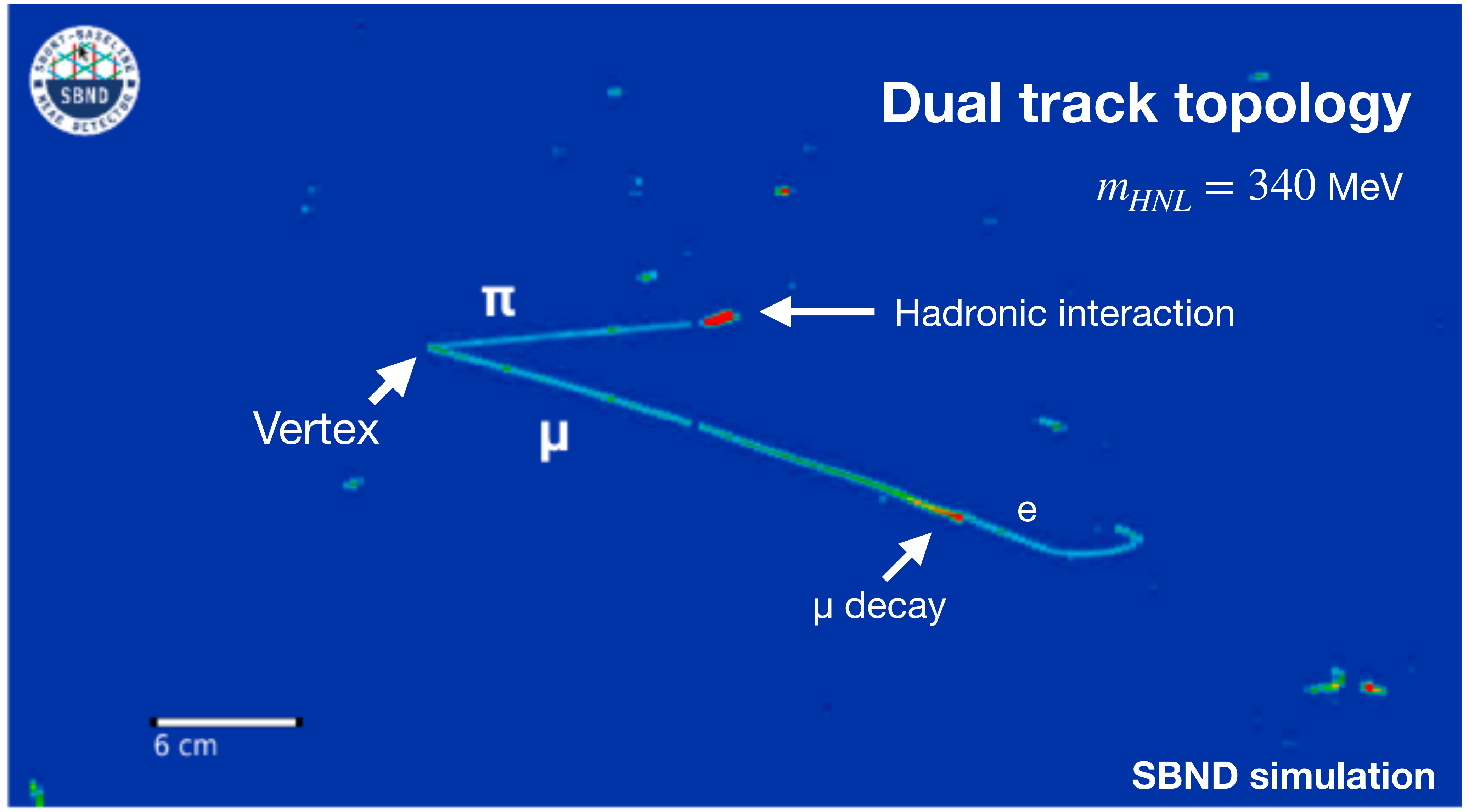
Most important channel at $m_{HNL} \in [245, 388]$ MeV

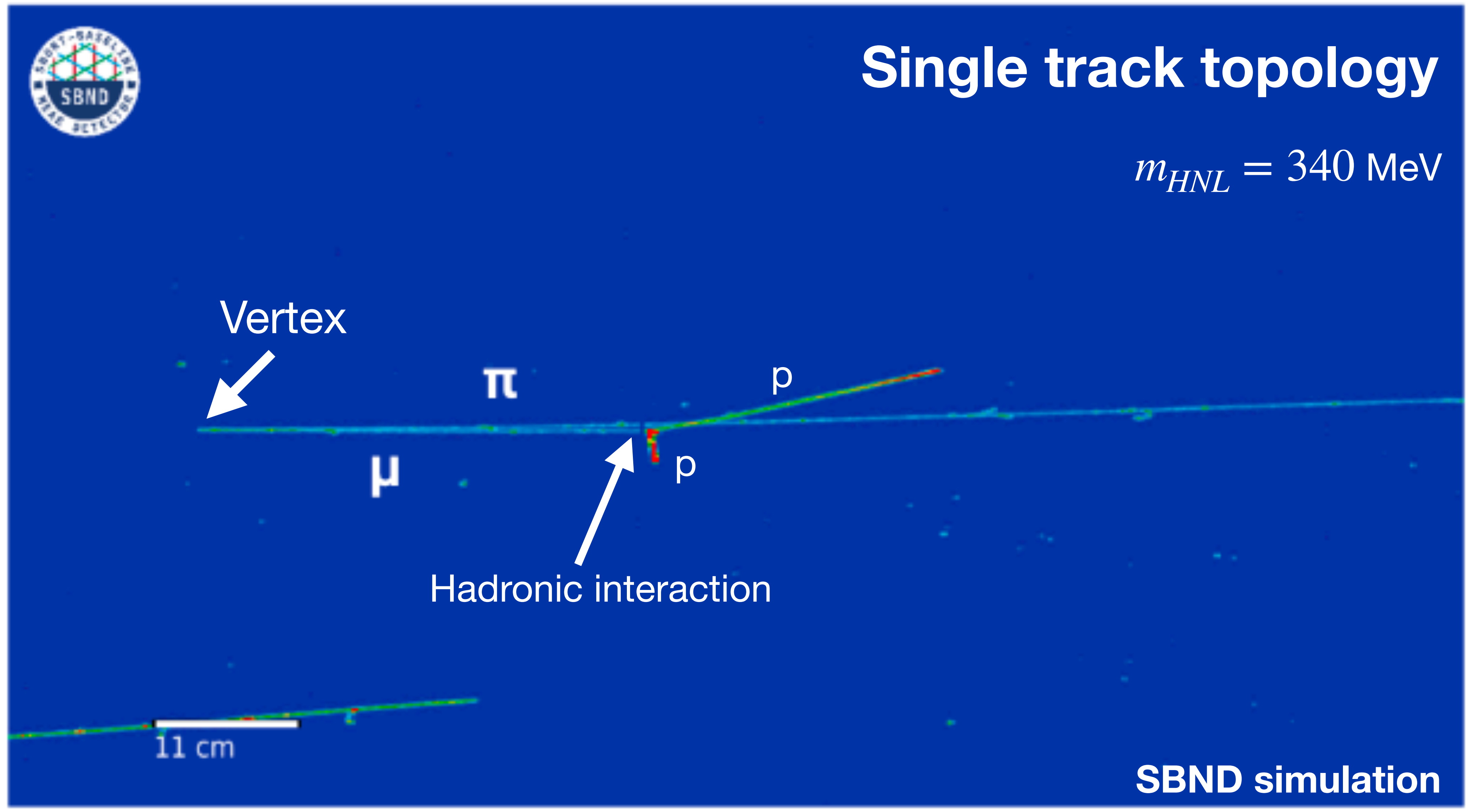
Signal definition

Two boosted muon-like tracks with a common vertex
Delayed compared to a SM neutrino interaction

Current workflow working with full beam and detector Monte Carlo simulations. Due to detector resolution the reconstruction of this signal can be split in 2 cases:

- 1 track case: Some tracks appear merged near the vertex ($\theta_{\mu\pi}$ ~ 5º), when $\theta_{\mu\pi} \simeq 180º$ some tracks are also merged. More relevant at lower mass ranges
- 2 track case: The tracks can be resolved by our reconstruction algorithms





Selection strategy

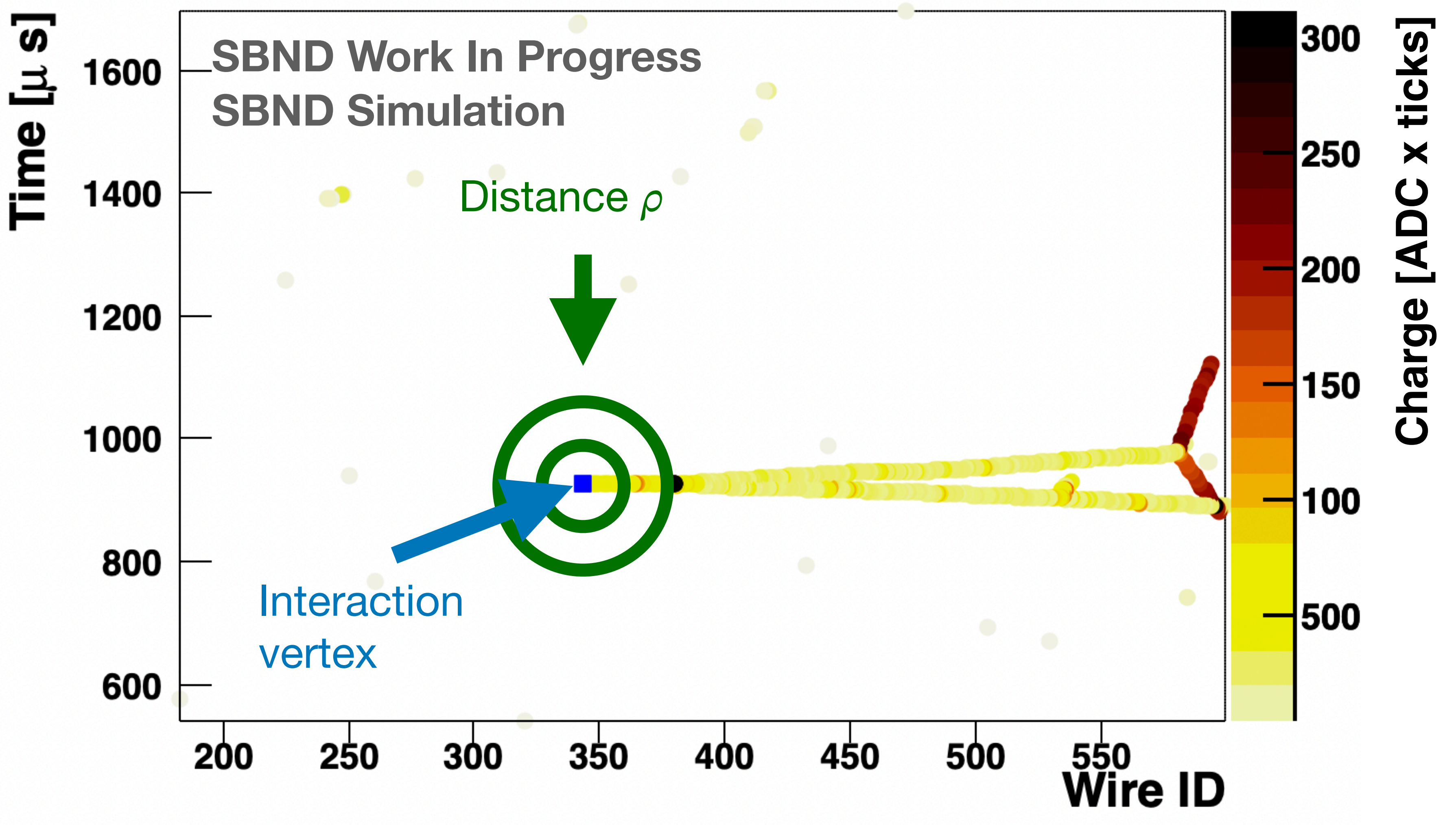
1	**Pre-selection & Cosmic rejection**	Reject cosmic-like events and those outside the fiducial volume or the neutrino window
2	**Particle Identification (PID) Cut**	Reject any event with showers or protons
3	**Charge deposition (dQdx) Cut**	Use Charge deposition around the vertex to distinguish boosted 1μ1π signatures

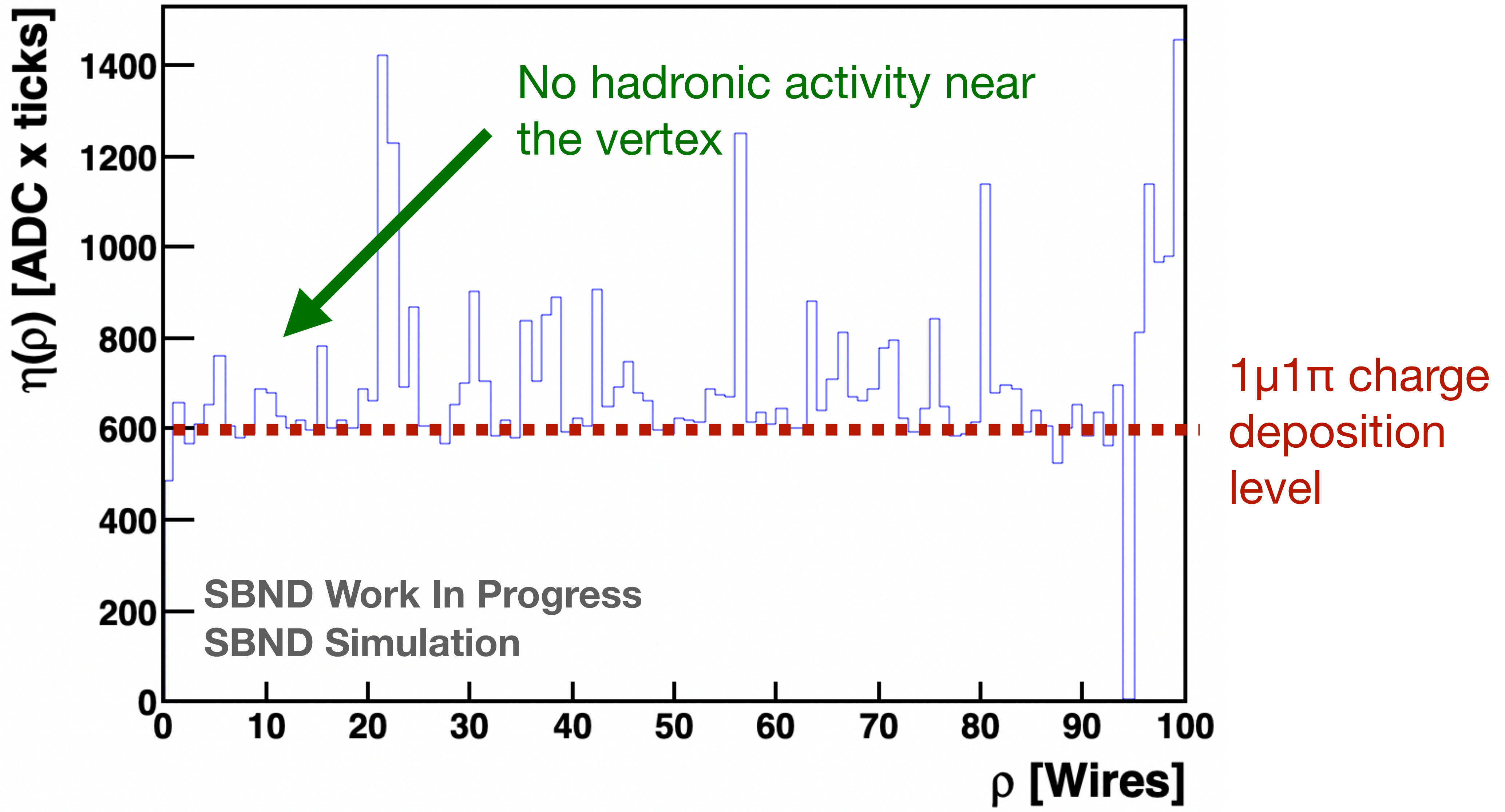
Cuts independent on HNL Mass

4	**Muon candidate and topology cut**	Select events with 2 muon-like tracks or 1/2 muon-like tracks for masses below 320 MeV
5	**Kinematic Cuts**	Cuts on higher level reconstructed variables (Invariant mass, transverse momentum…)

Cuts dependent on HNL Mass

Charge deposition example

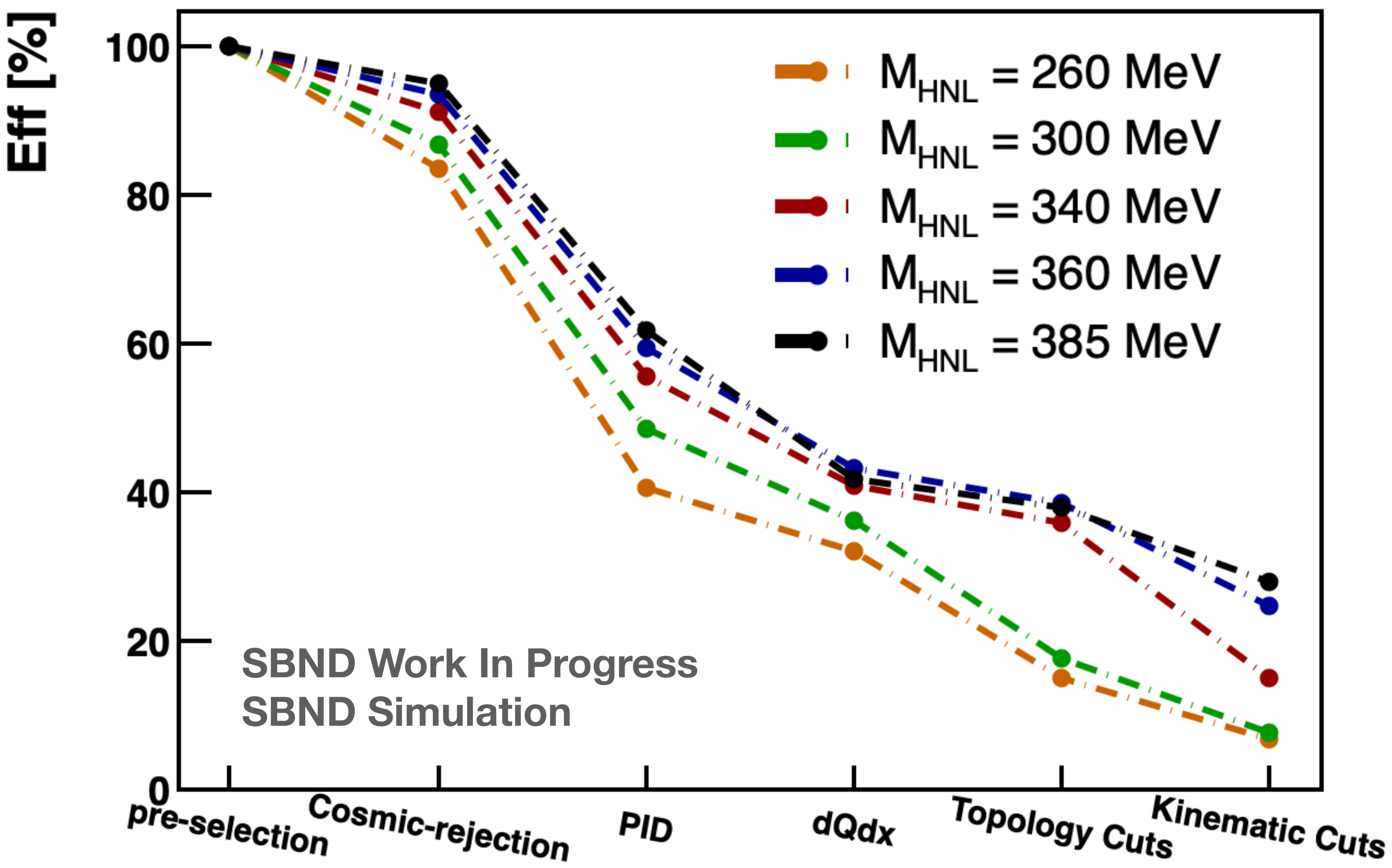




μπ selection

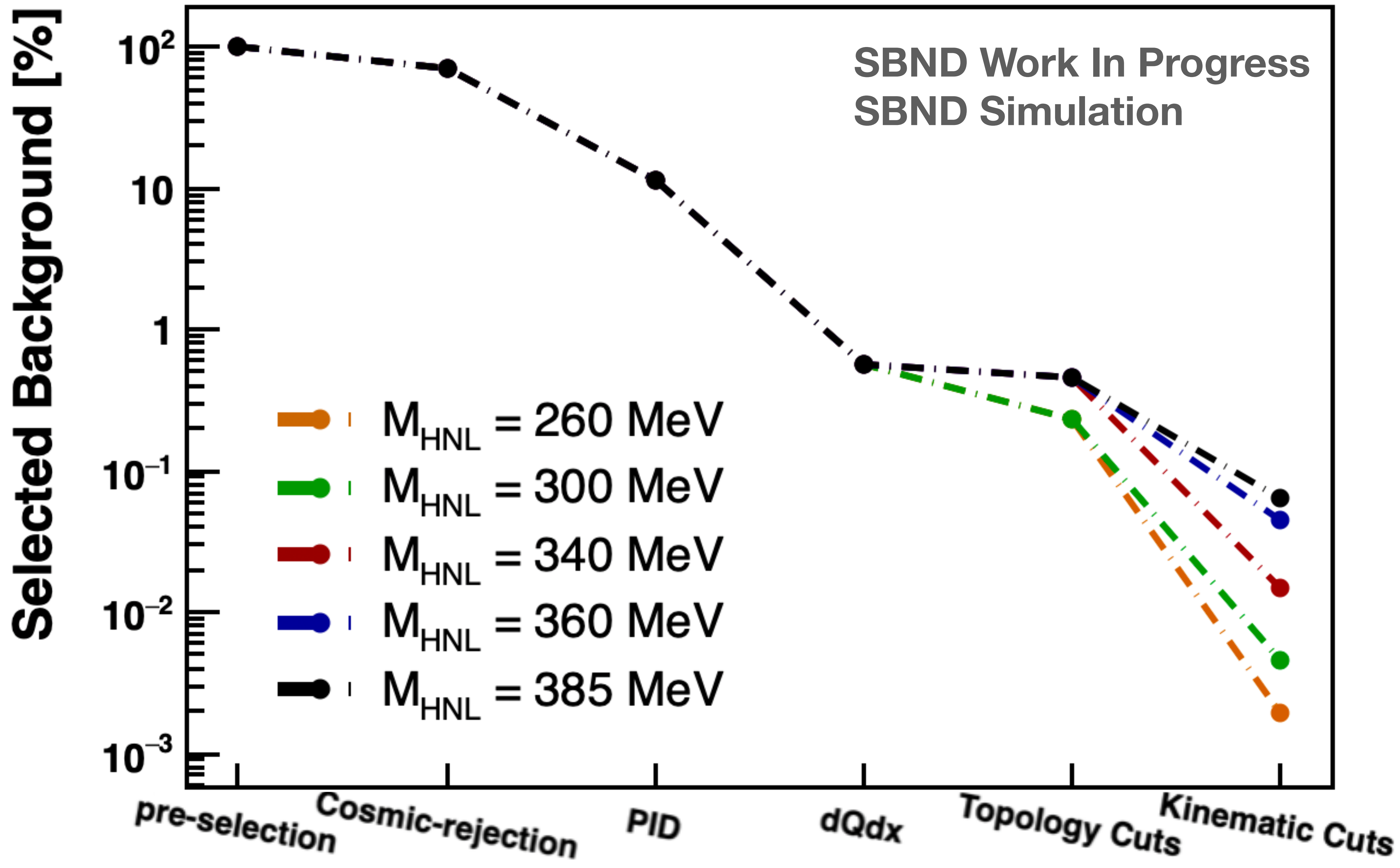
Results

- Background reduction ranges from 3 to 5 orders of magnitude with no timing information
- Between 6.7% and 28% selection efficiency



Most effective Cuts

- dQdx Cut: Reduces background by 2 orders of magnitude
- Kinematic Cuts: Increases the background rejection at lower masses



Setting HNL sensitivity

PYHF

PYHF is a python-interface of HistFactory, a statistical modelling tool built by LHC experiments

Using it we test two different hypothesis:

- Null hypothesis: signal + background
- Test hypothesis: background only

Using a multibinned histogram a likelihood function is created and an exclusion limit at 90% Confidence Level is found by varying model parameters

$$L(\mu, \boldsymbol{\theta}) = \prod_{i=1}^{N} \frac{(\mu s_i + b_i)^{n_i}}{n_i!} e^{-(\mu s_i + b_i)} \prod_{\theta \in \boldsymbol{\theta}} c_\theta(a_\theta|\theta)$$

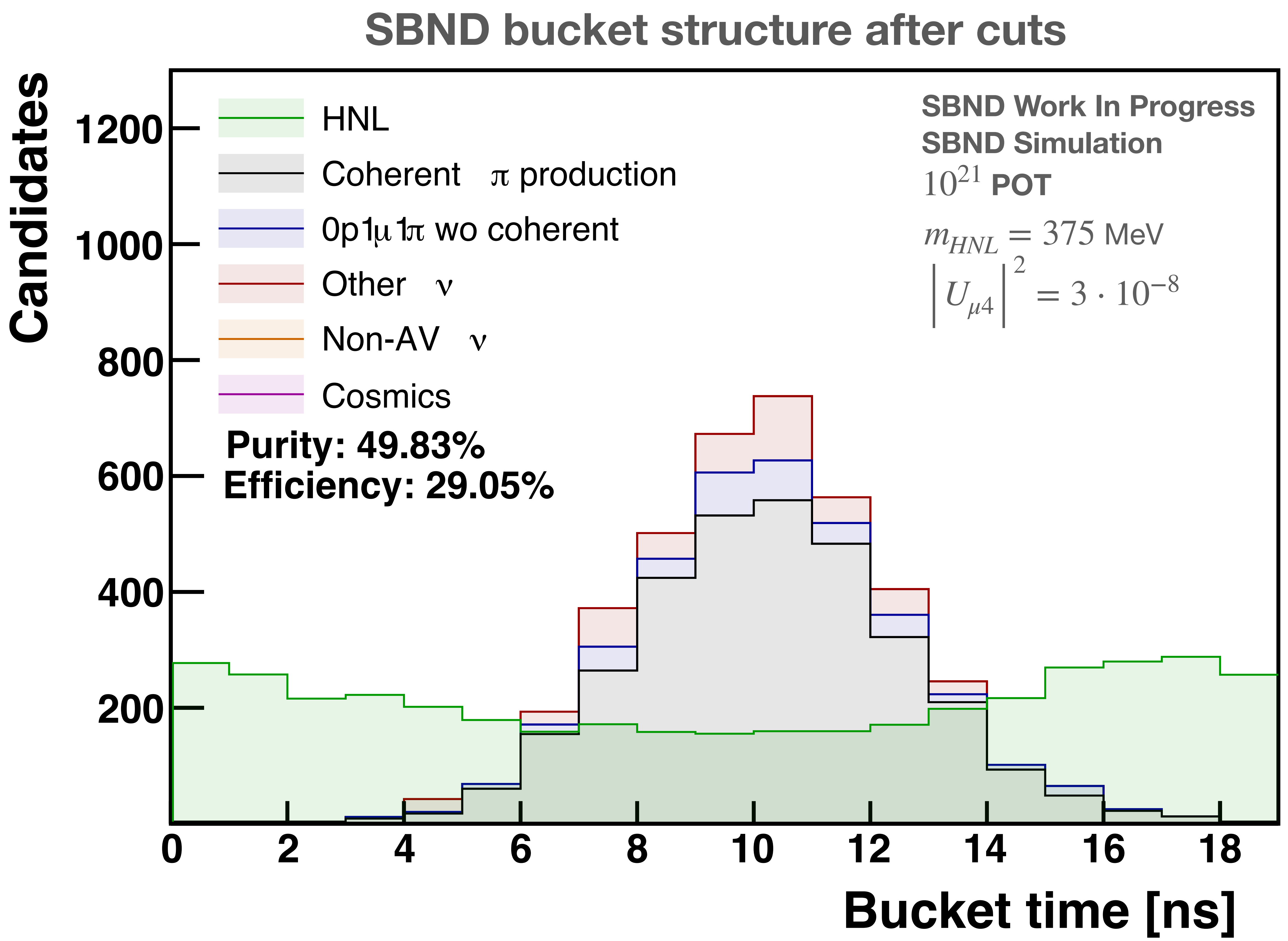
Product of Poisson probability bin by bin s = signal, b = background, μ = signal normalisation

Constrain on how much signal or background can fluctuate i.e. statistical uncertainty, etc.

https://pyhf.readthedocs.io/en/v0.7.6/
https://arxiv.org/abs/1007.1727
https://inspirehep.net/literature/532313

HNL timing as PYHF input

As HNL are slower than neutrinos the arrival time can be used as a good input for PYHF

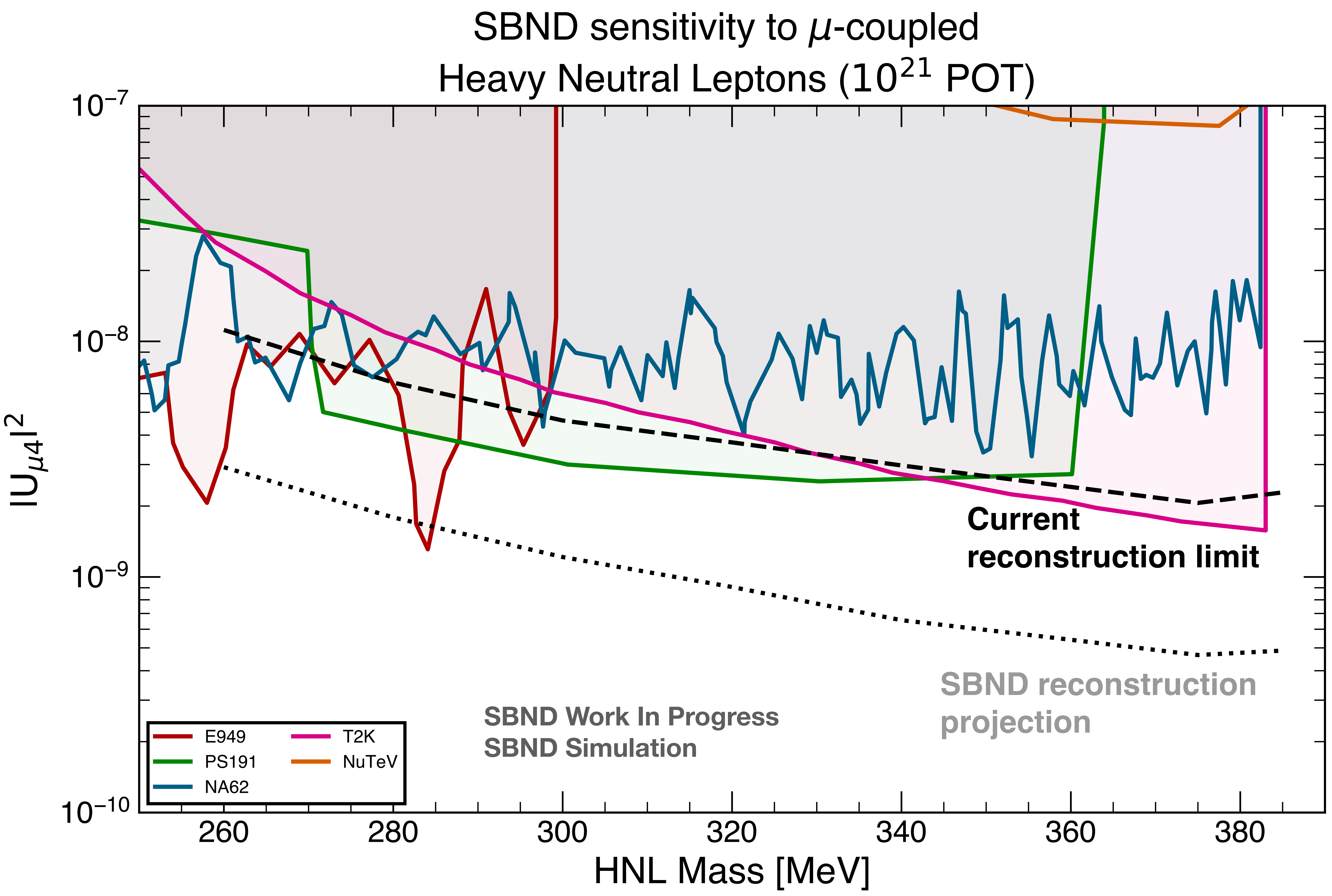


Current sensitivity predictions for SBND

Current and future sensitivity projection

Limit given for two cases:

- Current reconstruction limit: Ongoing development on improving SBND reconstruction tools
- SBND limit projection: Limit calculated by assuming the same efficiency and background rejection as current limit but better S/N ratio linked to an improved timing resolution of ~1.73 ns



¡¡¡Muchas Gracias!!!

SBND Collaboration Meeting, Fermilab, July 2024