

Trigger development for BSM searches in ProtoDUNE

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Long-Lived Particles (LLP) in SM

Long-Lived Particles(LLP) can travel macroscopic distances before decaying

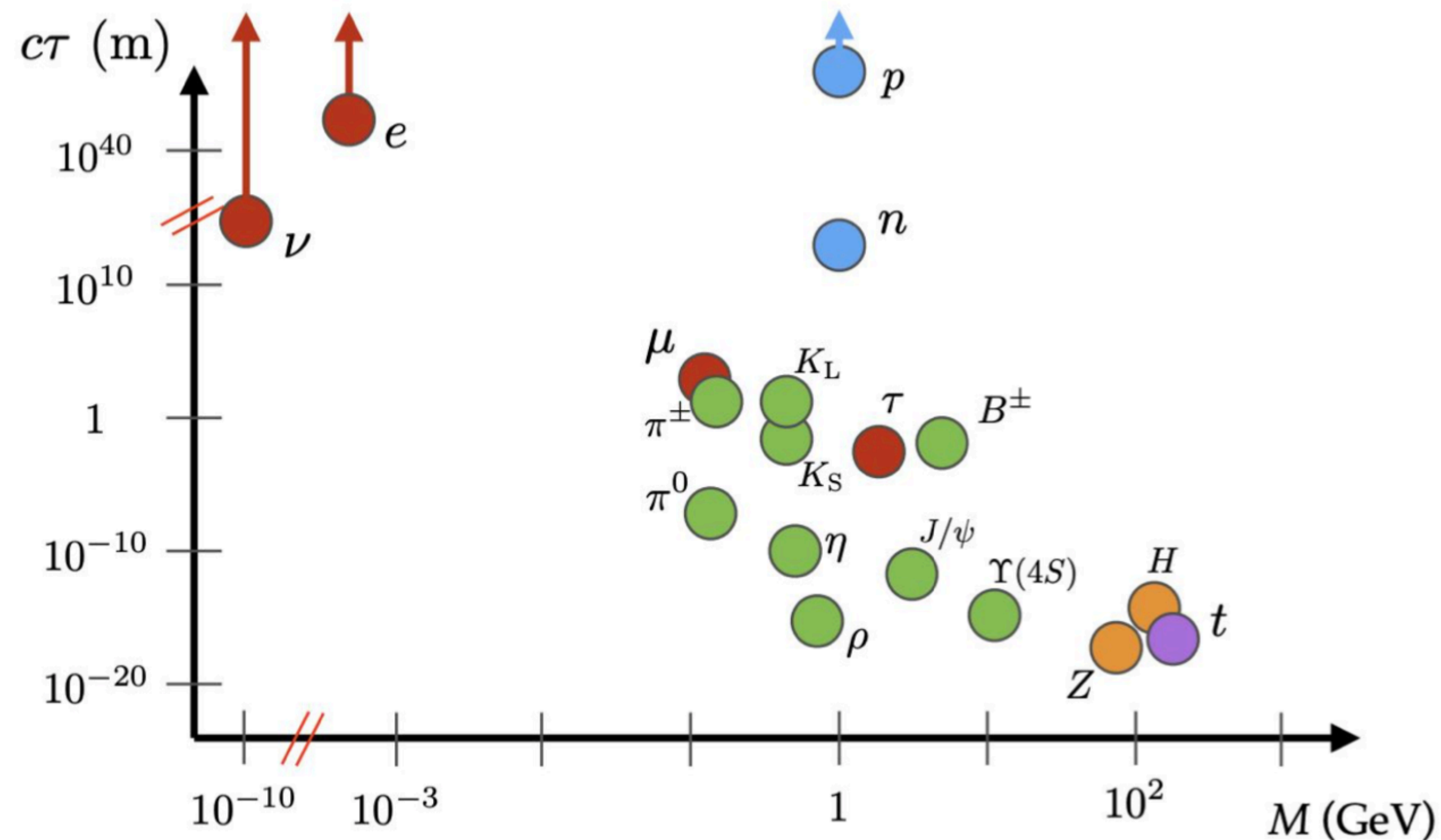


Image taken from arXiv: 1903.04497

Their presence comes from conserved symmetries, feebly couplings, heavy mediators/hierarchy of mass scale, small phase space.

LLP in BSM

LLP in BSM can arise from many well motivated classes of theories

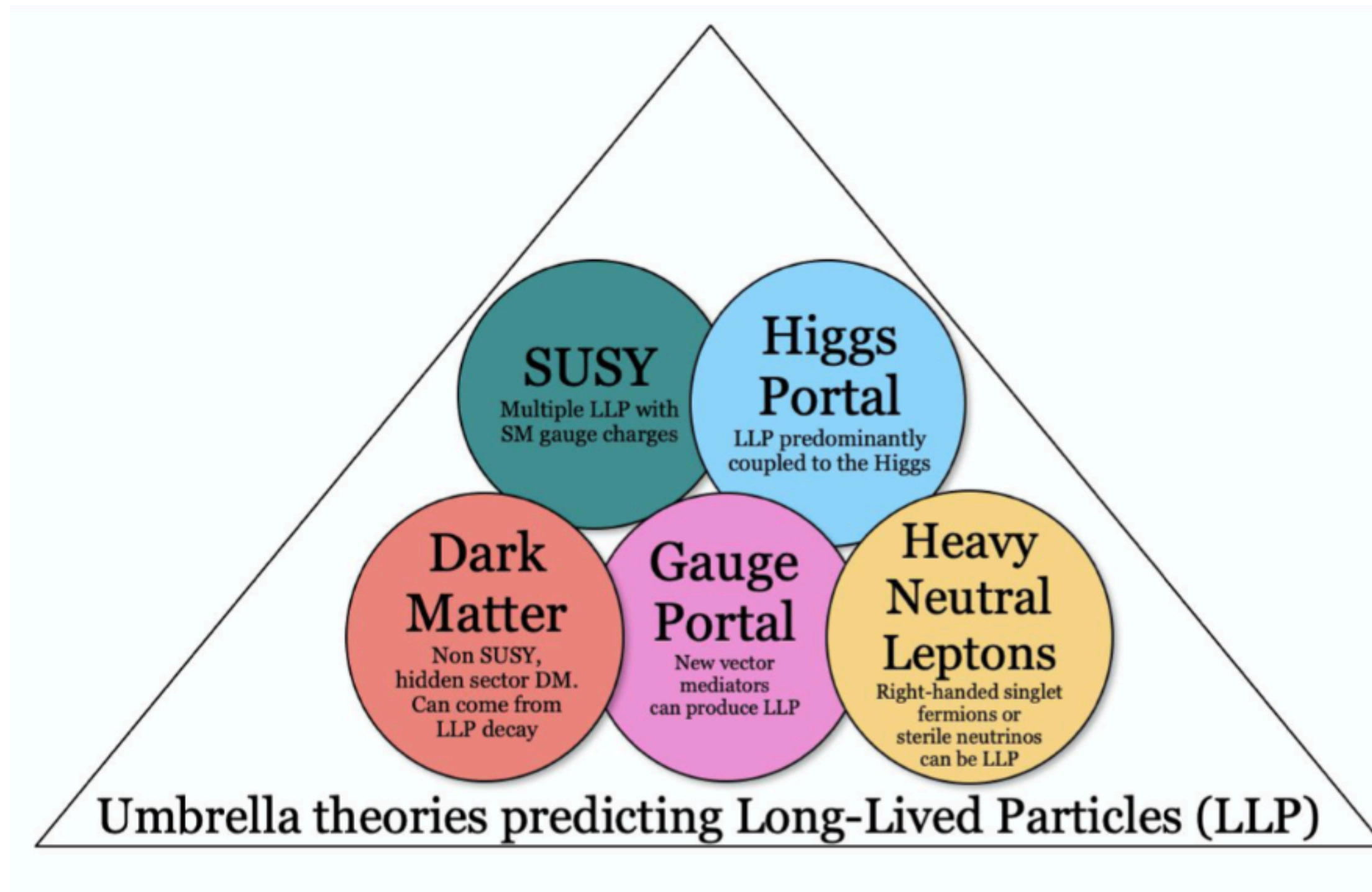


Image from : arXiv:1903.04497, 1806.07396

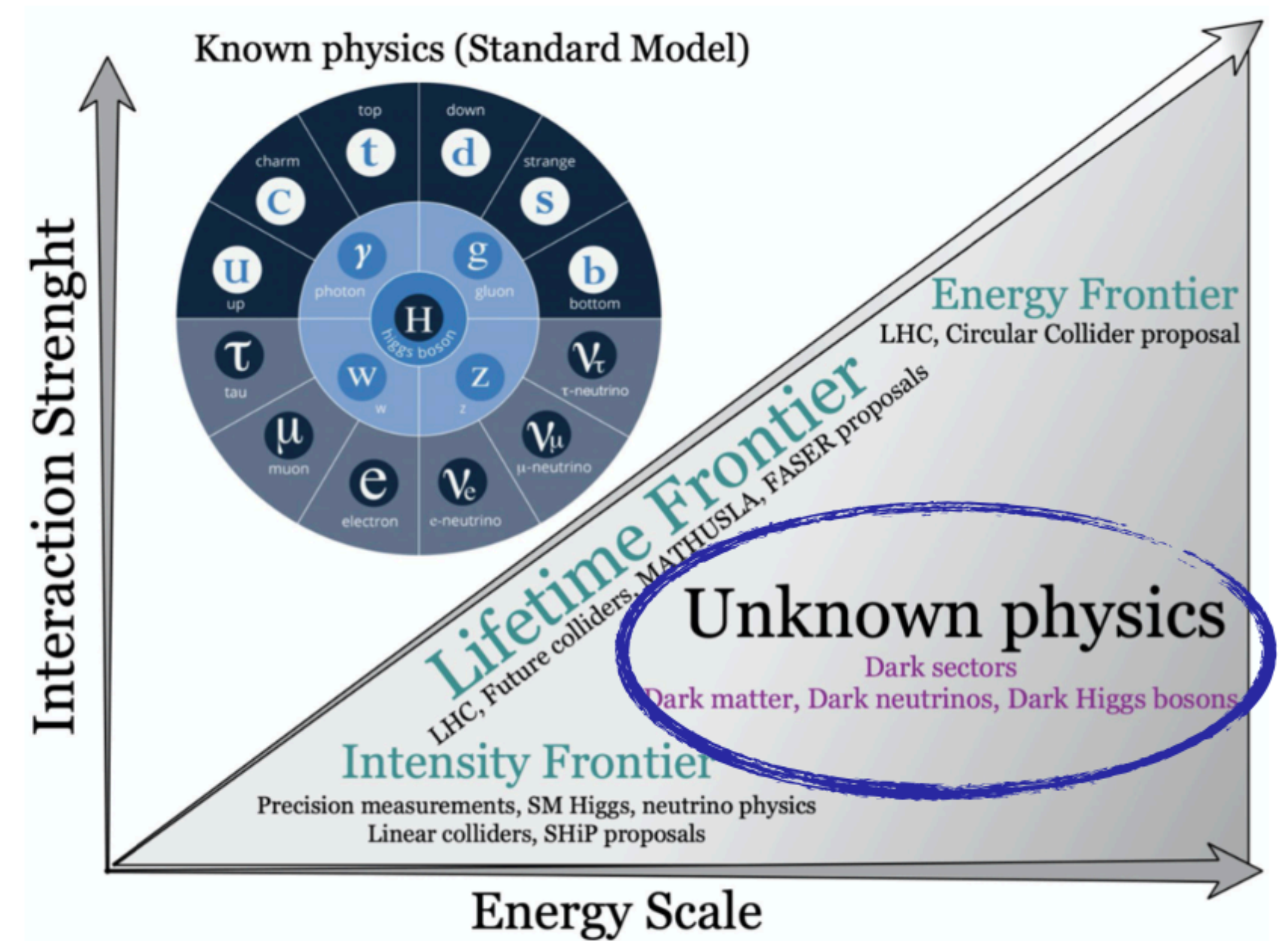


Image @CERN, ATLAS web

Need dedicated experiment to search for the long-lived particles to understand **Unknown physics (BSM)**.

Why BSM ?

WHITE PAPER ON NEW OPPORTUNITIES AT THE
NEXT-GENERATION NEUTRINO EXPERIMENTS
(PART 1: BSM NEUTRINO PHYSICS AND DARK MATTER)

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[1907.08311]

* Experimental evidence :

- ☑ Dark matter
- ☑ Neutrino masses
- ☑ Short-baseline anomalies
- ☑ Matter-antimatter asymmetry
- ☑ Gravitational interaction e.t.c.

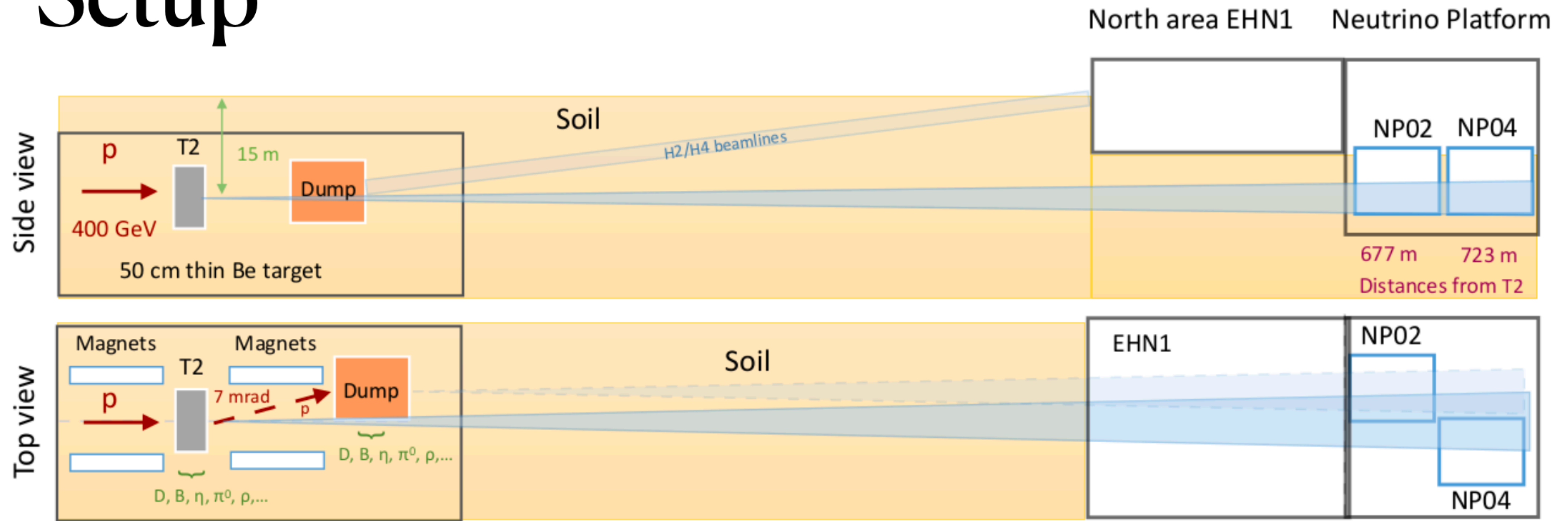
* Theoretical motivation :

- ☑ Hierarchy problem
- ☑ Flavor puzzle
- ☑ Nature of neutrinos (Dirac or Majorana)
- ☑ Strong CP Problem
- ☑ Dark sector e.tc.

BSM-Search @protoDUNE : Setup

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Setup



Important features :

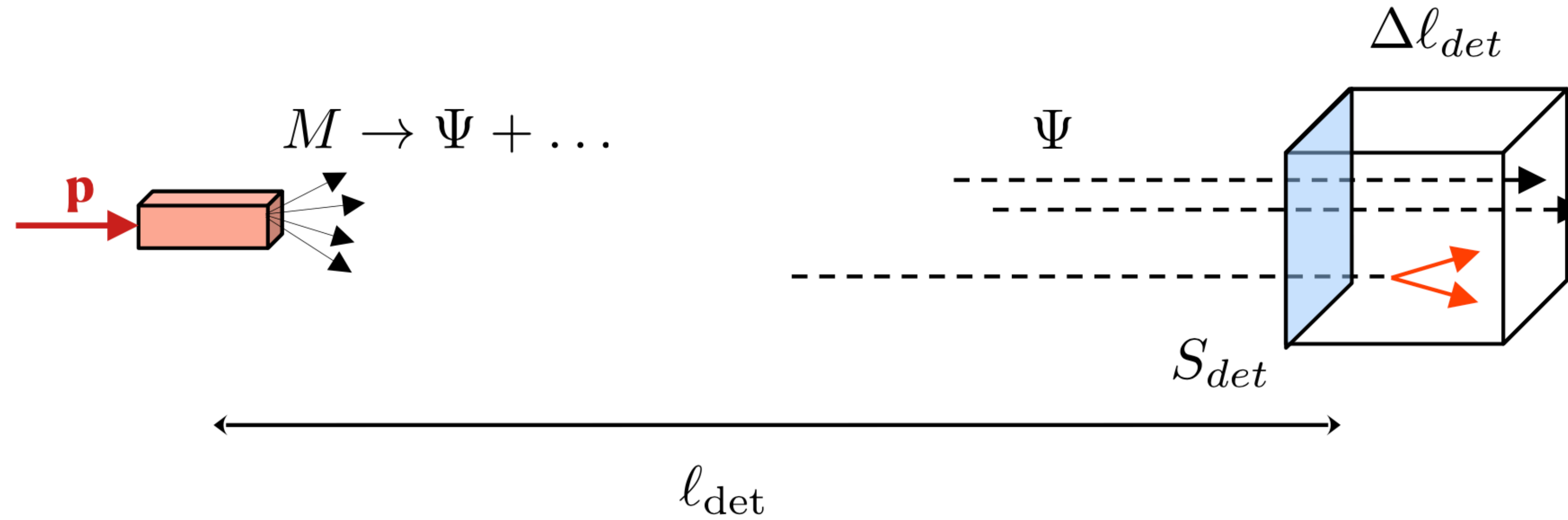
- * No decay volume (no neutrinos!)
- * Very high energy proton

Meson yields* (per PoT):

K_L	π^0	η	η'	D	D_s	τ
0.3	4.03	0.46	0.05	$4.8 \cdot 10^{-4}$	$1.4 \cdot 10^{-4}$	$7.4 \cdot 10^{-6}$
	ρ	ω	ϕ	J/ψ	B	Υ
	0.54	0.53	0.019	$4.4 \cdot 10^{-5}$	$1.2 \cdot 10^{-7}$	$2.3 \cdot 10^{-8}$

Expected number of events: Decay

Pilar Coloma et.al. (JHEP 01 (2024) 134)



$$N_{ev} = N_M \underbrace{\text{BR}(M \rightarrow \Psi) \text{BR}(\Psi \rightarrow \text{Vis})}_{\text{Model-dependent}} \epsilon_{det} \int dS \int dE_\Psi \mathcal{P}(c\tau_\Psi/m_\Psi, E_\Psi, \Omega_\Psi) \frac{dn^{M \rightarrow \Psi}}{dE_\Psi dS}$$

Model-dependent

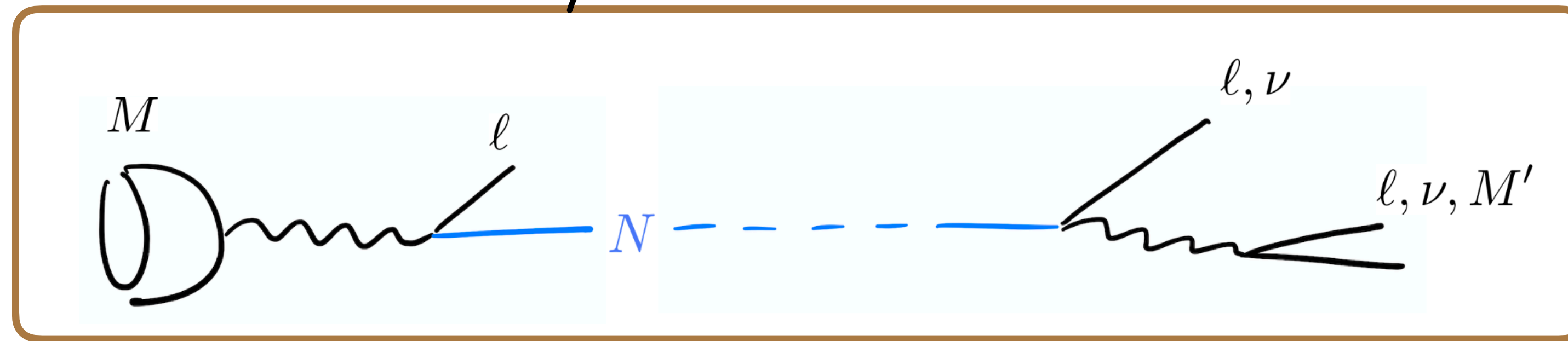
Model-dependent

Benchmark scenario : HNL

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

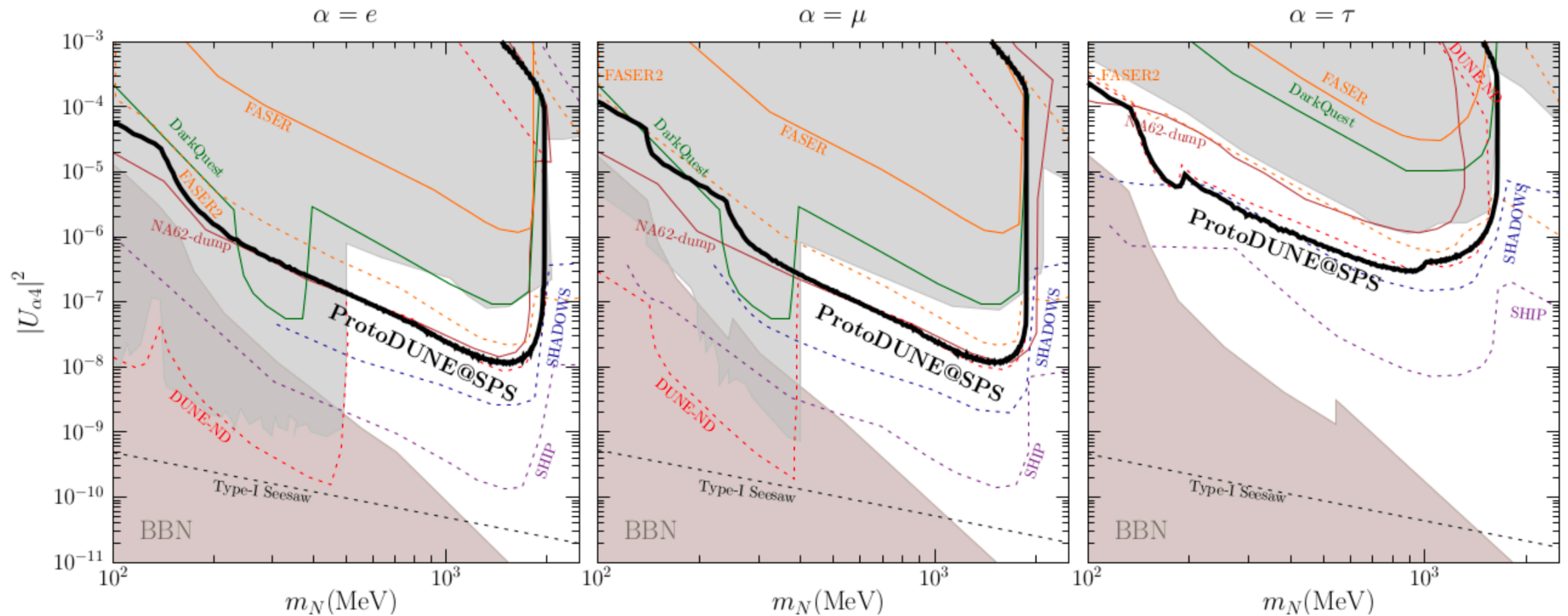
Production and decay :



The best bounds for HNL between $O(100)$ MeV - GeV scale come from fixed targets

Sensitivities to HNL decays

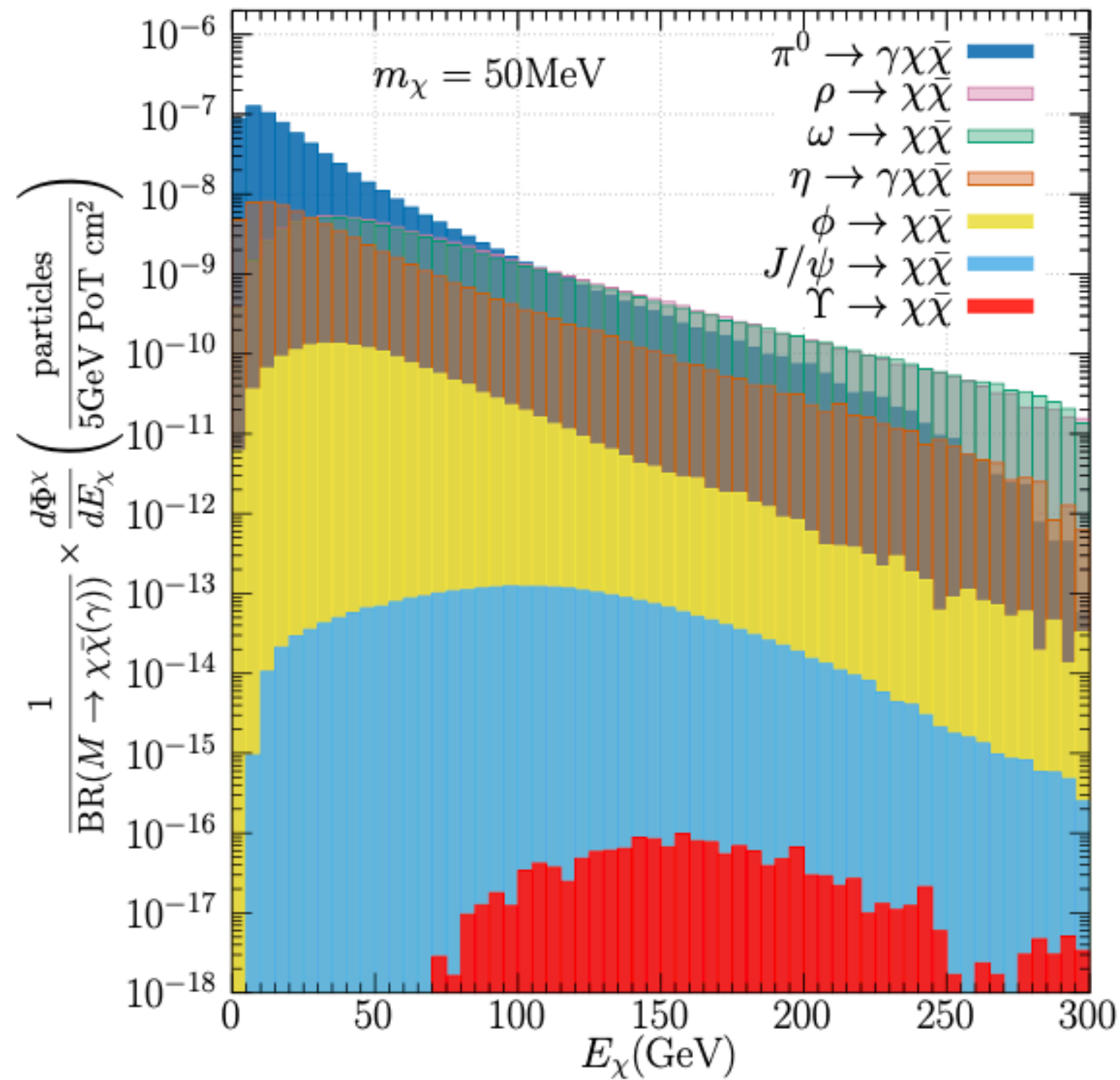
Pilar Coloma et.al. (JHEP 01 (2024) 134)



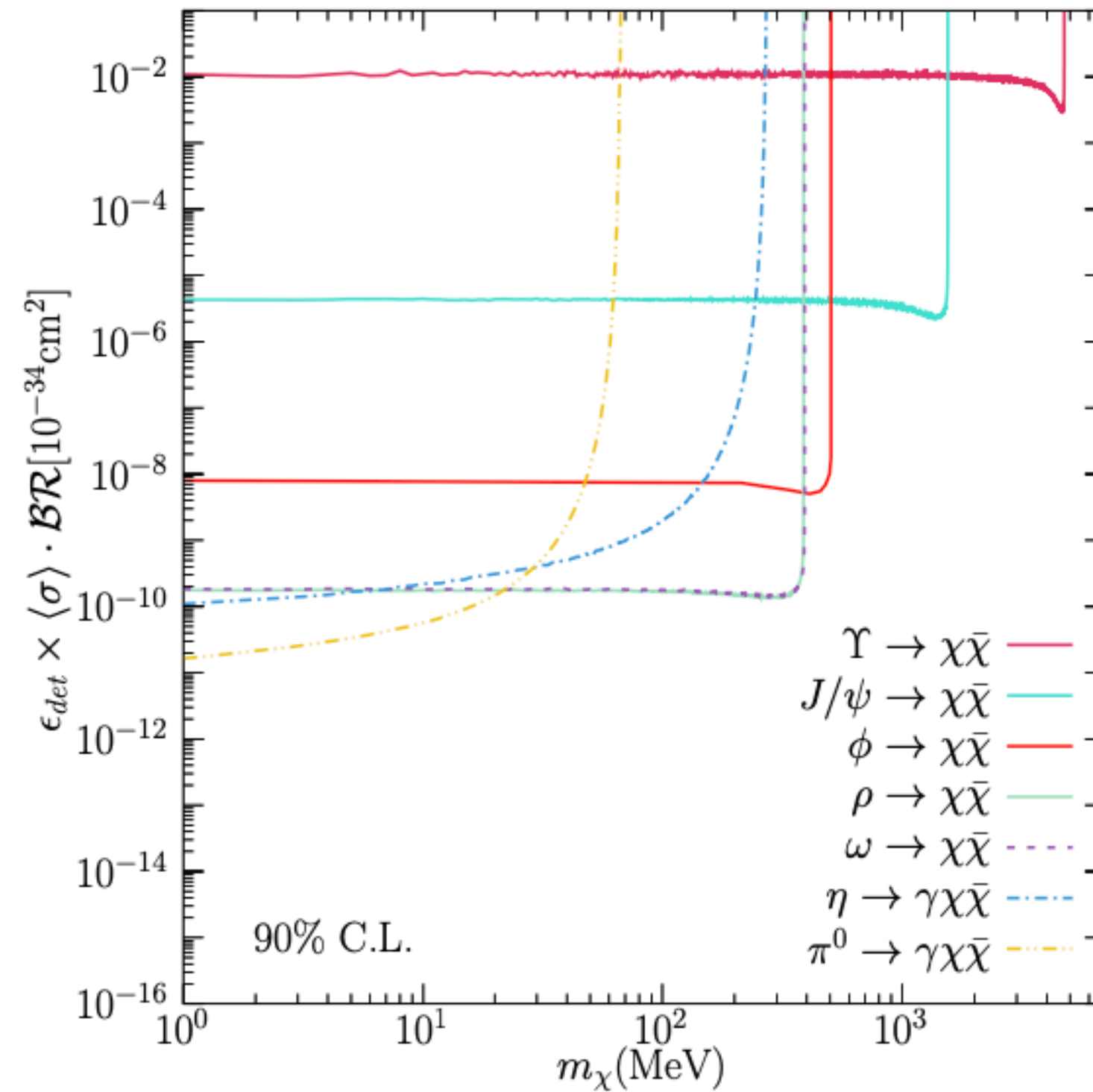
Other Model independent searches

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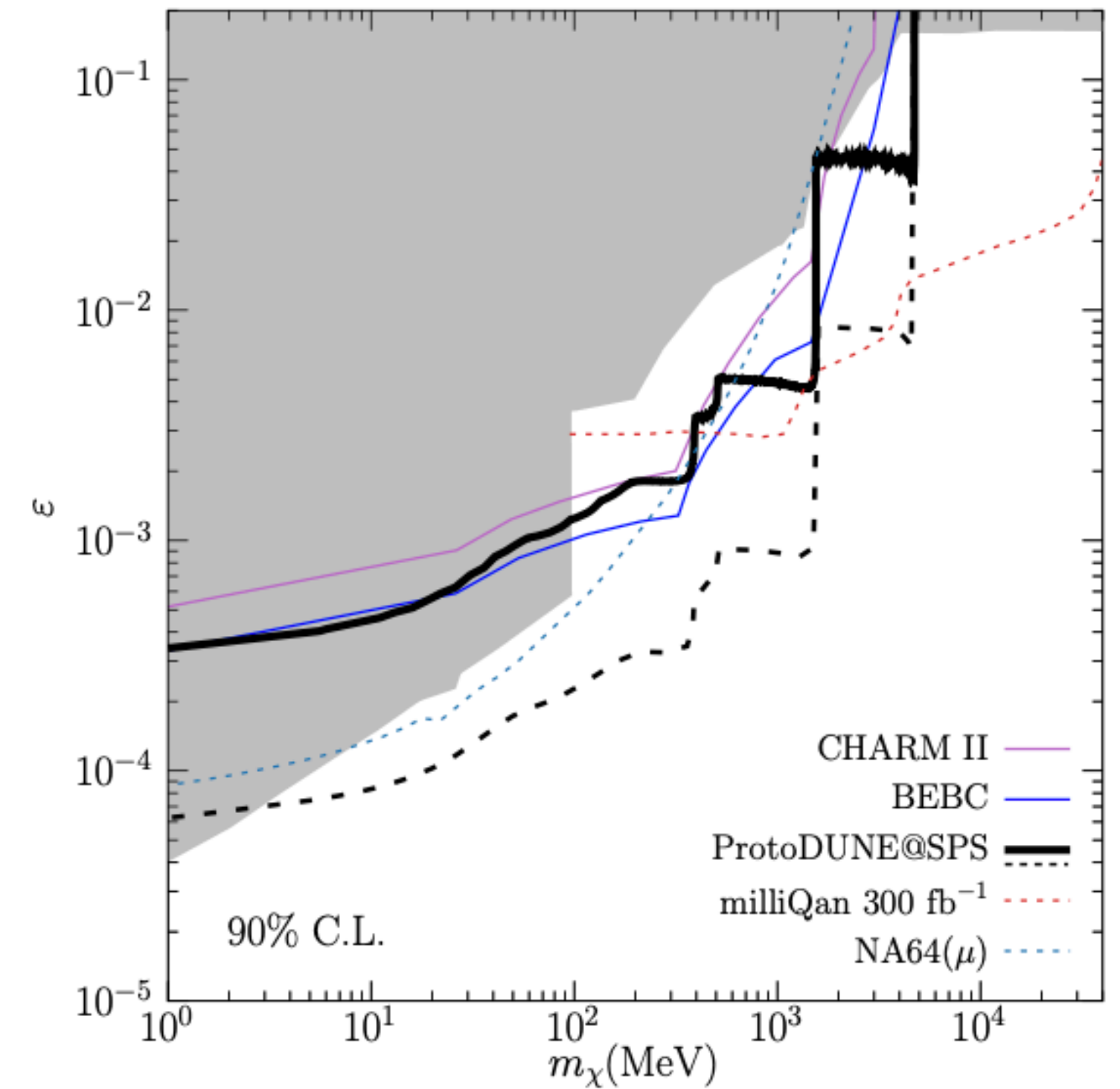
Flux @protoDUNE



Sensitivity: WIMP



Sensitivity :Millicharged



Other phenomenological studies (Axion like, dark scalar) are ongoing

Trigger algorithms for BSM searches

To develop a suitable trigger algorithm based on directionality. What we need as a first step is:

- ☑ Definition of a fiducial volume.
- ☑ Identification of the incoming direction of particles.
- ☑ Implementation of angular cuts.
- ☑ Use of adjacency algorithm could be also complementary to improve the reconstruction efficiency.

Trigger algorithms for BSM searches

To test the performance of the algorithm we will proceed as:

- ☑ Estimation of the reconstructed cosmic ray rate coming from the beam halo direction.
- ☑ Calculate the **Efficiency** for selecting muons from a particular direction:
 - From the algorithm output, a variable **Purity** can be retrieved as the fraction of events that corresponds to muons signatures with the intended direction.
 - If there is a CRT trigger, the BSM trigger will not acquire data when CRT trigger turns on.

First step:

- ☑ Modify the current algorithm that selects muons to select muons coming from a particular direction.
- ☑ Tested with VD Coldbox data and later, when NP04 is filled.
- ☑ Timeline: 2 weeks.

Outlook and requirement of special trigger

- ☑ protoDUNE@SPS is ideal facilities for BSM searches as detectors are in place and will start data taking soon!
- ☑ Sensitivity to HNL and other physics cases look promising.
- ☑ We have recently formed a group (Theorist and Experimentalist) to understand all the related issues
- ☑ In process of developing beam line simulation, detector simulation and background.
- ☑ One of the key aspect will be to develop a special trigger to acquire these kind of decay signature, to remove large cosmic and other background events.

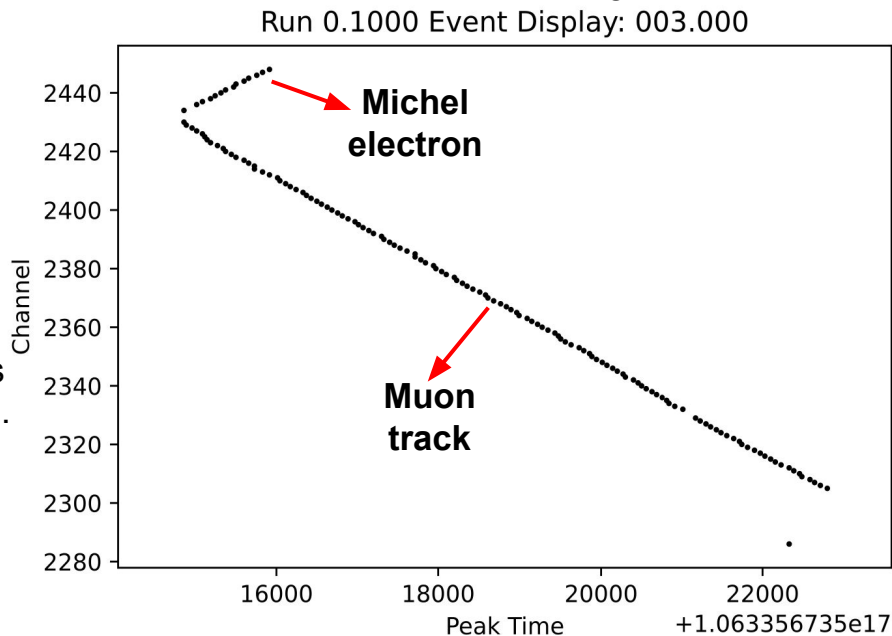
Backup

Trigger algorithms for BSM

Currently the work is focused on developing a *Trigger Activity* (TA) algorithm to select muons with a given direction to test the trigger algorithms for BSM searches:

- *Trigger Primitives* (TPs) with real data from the VD Coldbox are used to test the algorithm.
- **Current trigger algorithm is based on adjacency.** If TPs adjacency is above a threshold then a TA is generated.
- **Most of the selected muons are stopping muons.**
- To select muons with a specific direction is needed to develop a new trigger algorithm.

**Directionality filter algorithm,
essential for beam events.**



Trigger algorithms for BSM

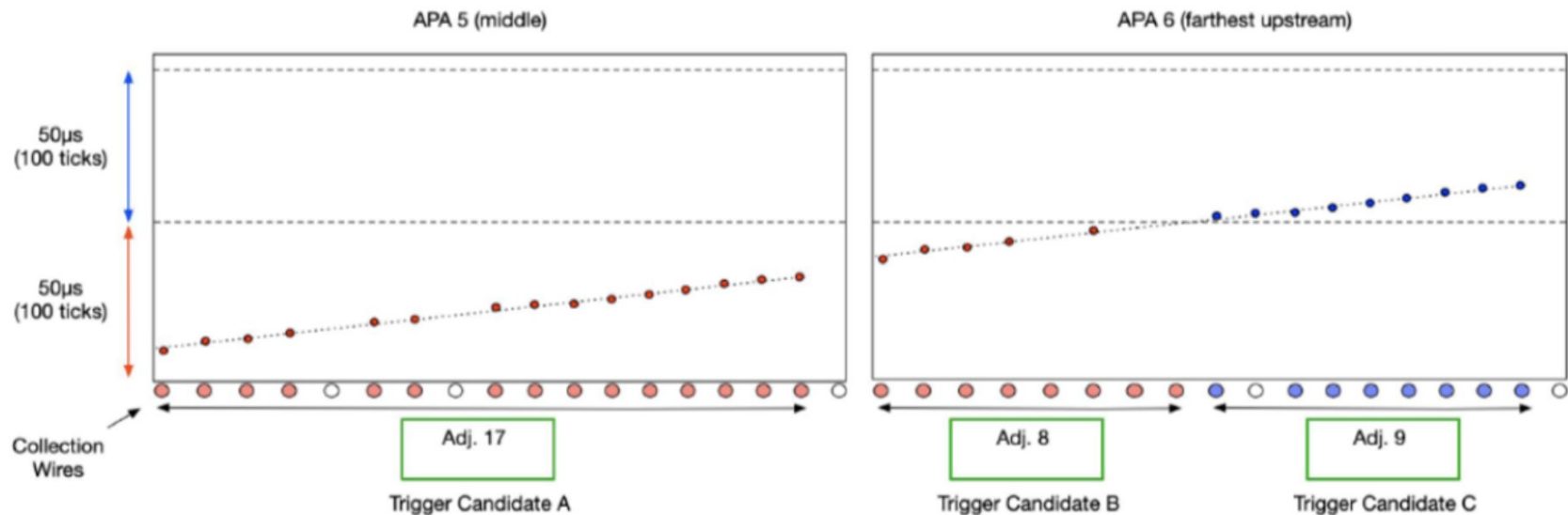


Figure 4.53: Horizontal muon triggered via early implementation of TriggerPrimitive \rightarrow TriggerCandidate chain during ProtoDUNE-I.