

ProtoDUNE's window into Hidden Physics

JOSU HERNANDEZ-GARCIA

XVII CPAN DAYS | Nov 2025



Project CNS2022-136013 funded by MICIU/AEI/10.13039/501100011033
and the European Union NextGenerationEU/PRTR 2025 | Sept 2025



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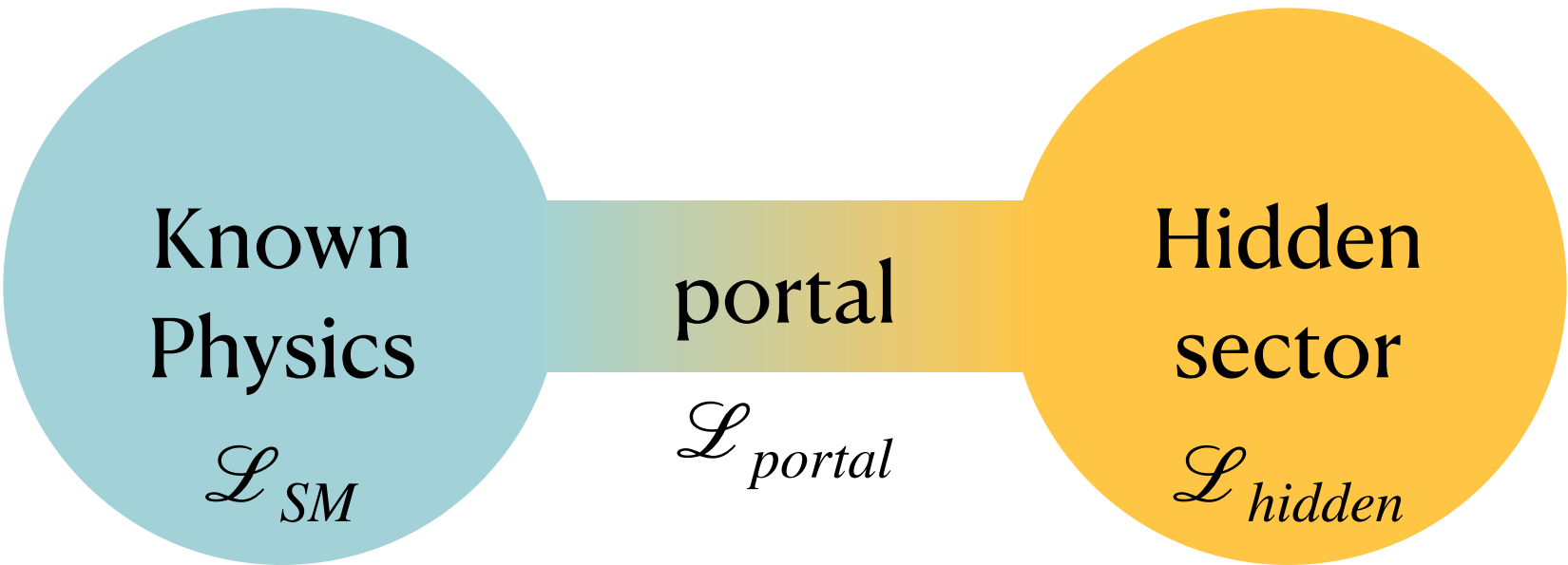
LLPs: Portals to BSM Physics

Long-Lived Particles (LLPs) could be the portal to hidden sectors addressing different Standard Model open problems



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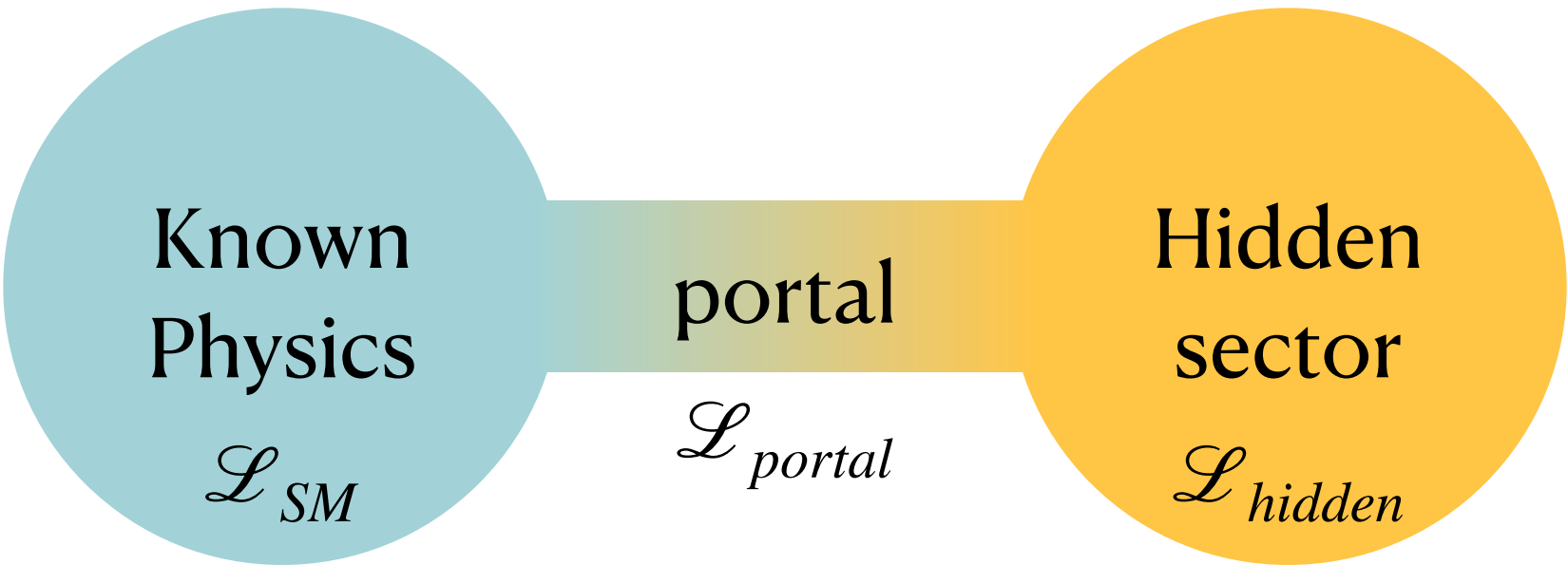


BSM portal	New particle	New parameters	SM open problem
Fermion portal	HNLs – N	$M_N, U_{\alpha N}$	Neutrino masses
Axion portal	ALPs – a	m_a, f_a	Strong CP
Scalar portal	Dark scalar – S	m_S, θ	Vacuum stability
Vector portal	Dark photon – Z'	$m_{Z'}, \epsilon$	DM candidate

Studied in the context of present and near-future beam-dump facilities: T2K, μ BooNE, ICARUS, DUNE ND, SHiP...

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Phenomenology of Heavy Neutral Leptons

Origin of neutrino **masses** and **mixings**

HNL **mixes** with active neutrinos

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

HNL **CC** and **NC** interactions:

$$\mathcal{L}_{N,int} \supset -\frac{m_W}{v} \bar{N} U_{\alpha N}^* \gamma^\mu \ell_{L\alpha} W_\mu^+ - \frac{m_Z}{\sqrt{2}v} \bar{N} U_{\alpha N}^* \gamma^\mu \nu_{L\alpha} Z_\mu$$

Minimal model: 2 HNLs needed.
Phenomenology given by
4 free parameters:

- HNL mass, M_N
- mixing with three ν_α , $U_{\alpha N}$

Heavy Neutral Leptons (HNLs)

$U_{\alpha N} \ll 1 \Rightarrow$ **weaker** than weak interaction

Experimental results shown **single flavor dominance** $\Rightarrow$ HNL coupled to **one flavor** at a time:

$$|U_{eN}|^2 : |U_{\mu N}|^2 : |U_{\tau N}|^2 = 1 : 0 : 0$$

e dominance

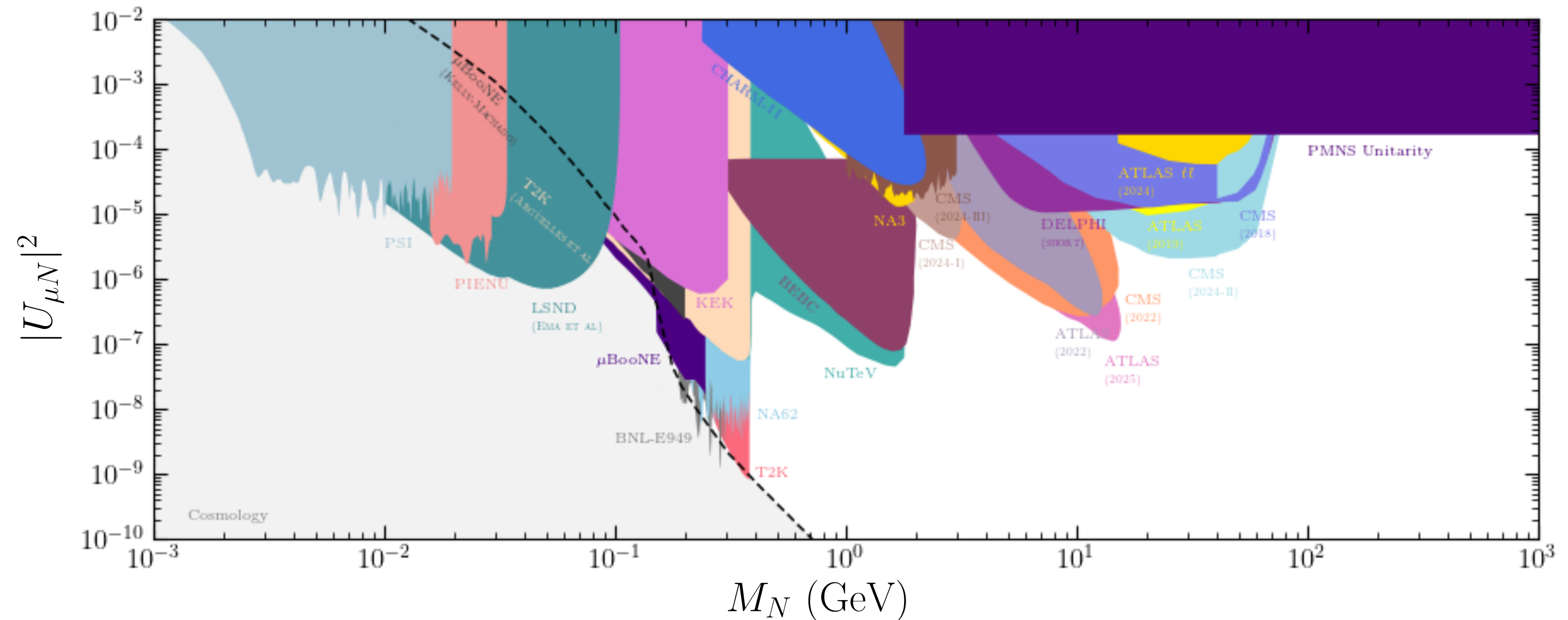
$$|U_{eN}|^2 : |U_{\mu N}|^2 : |U_{\tau N}|^2 = 0 : 1 : 0$$

μ dominance

$$|U_{eN}|^2 : |U_{\mu N}|^2 : |U_{\tau N}|^2 = 0 : 0 : 1$$

τ dominance

Heavy Neutral Leptons: present bounds

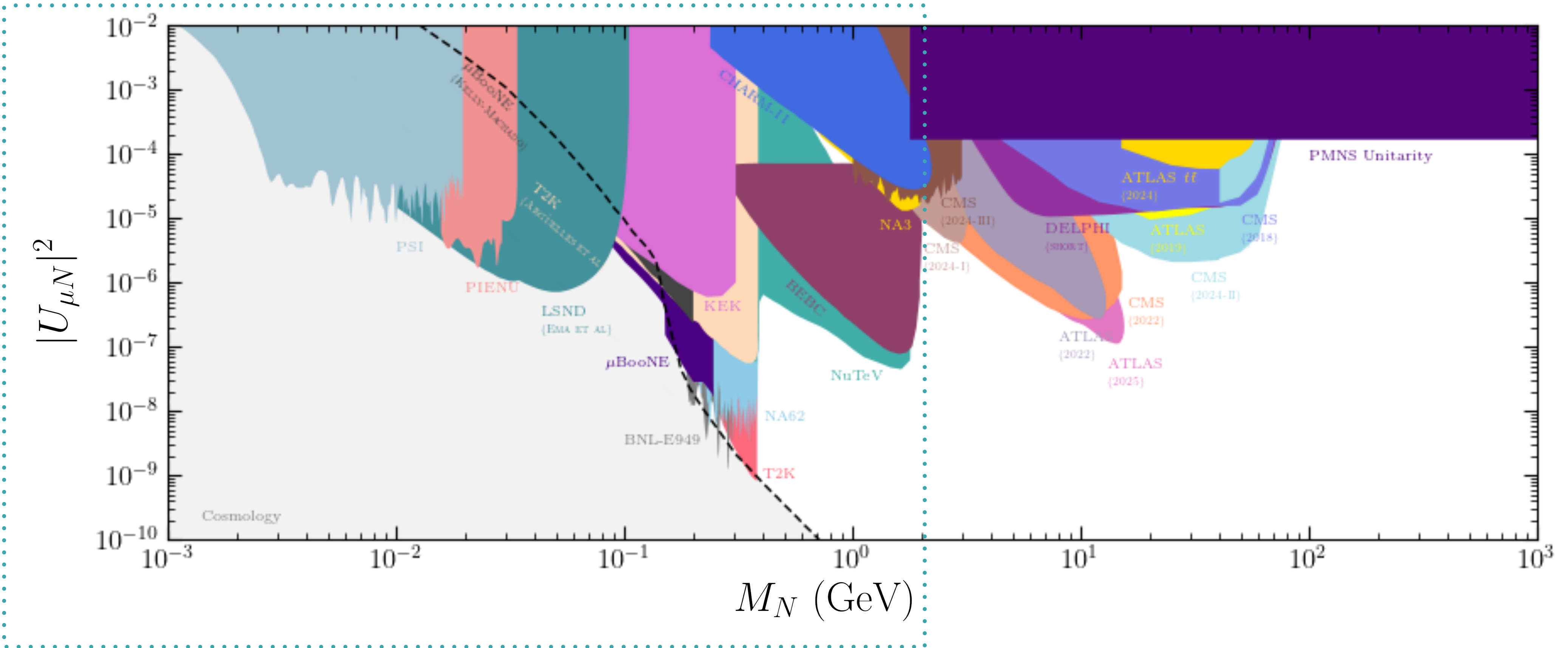


Present bounds on the HNL mixing from ν oscillations, kinks in beta-decay, peaks in meson decays, beam-dumps, colliders, and non-unitarity of the PMNS.

<https://github.com/mhostert/Heavy-Neutrino-Limits>
E. Fernandez-Martinez, M. Gonzalez-Lopez, JHG, M. Hostert, J. Lopez-Pavon. JHEP 09 2023 001



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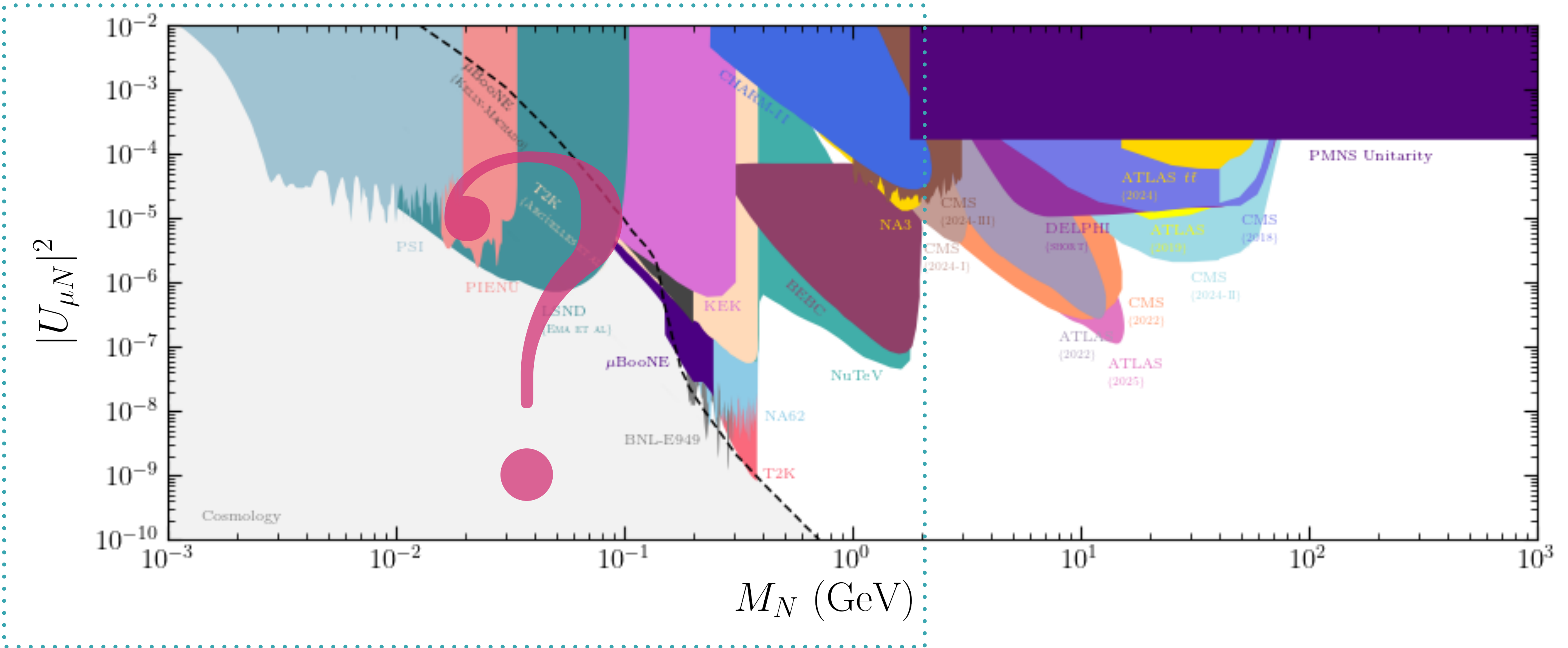


Present bounds in the HNL mass window up to ~ 2 GeV led by peak searches and beam-dump experiments

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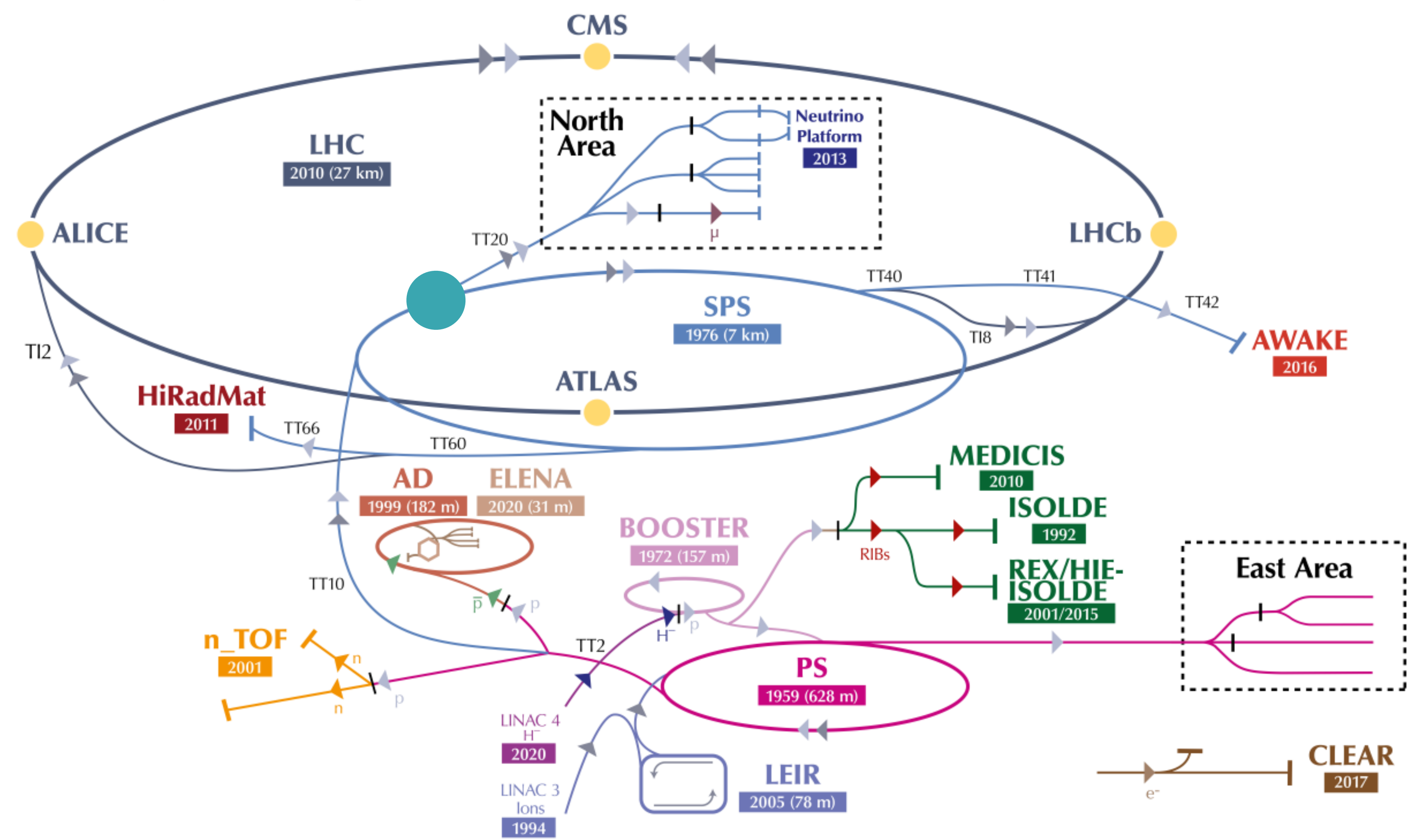
Bounds from on-going and near future experiments.

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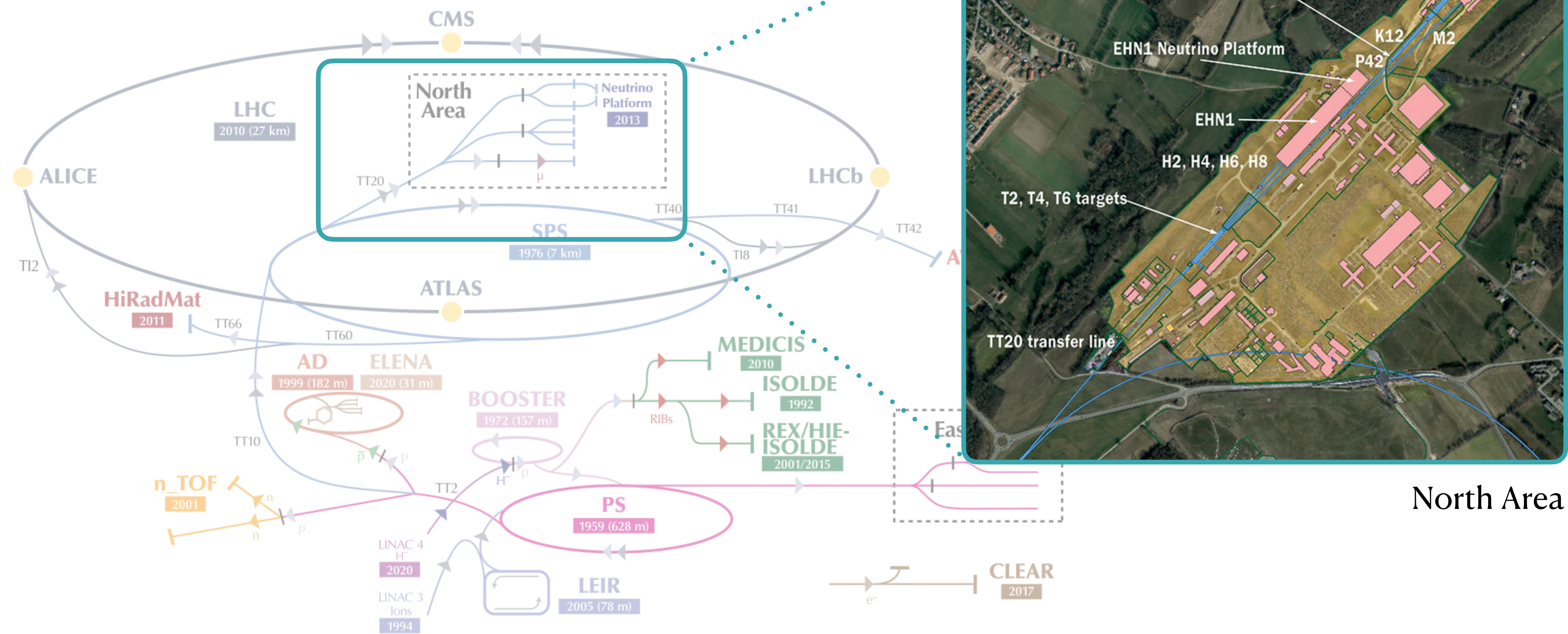
ProtoDUNE setup at SPS

Extracting 400 GeV protons from SPS



ProtoDUNE setup at SPS

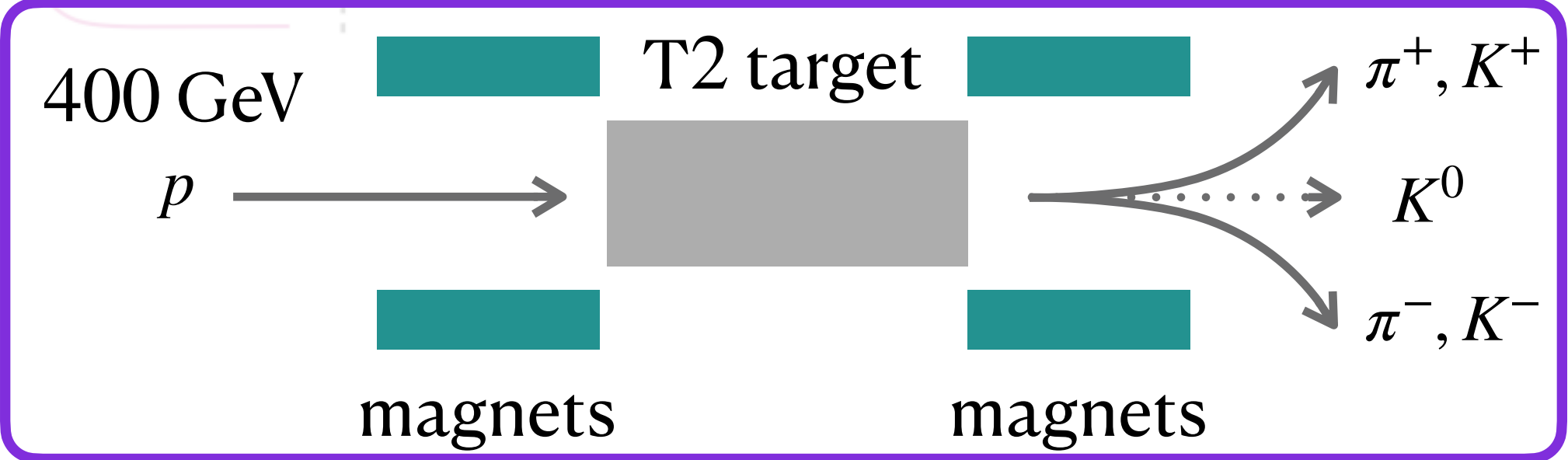
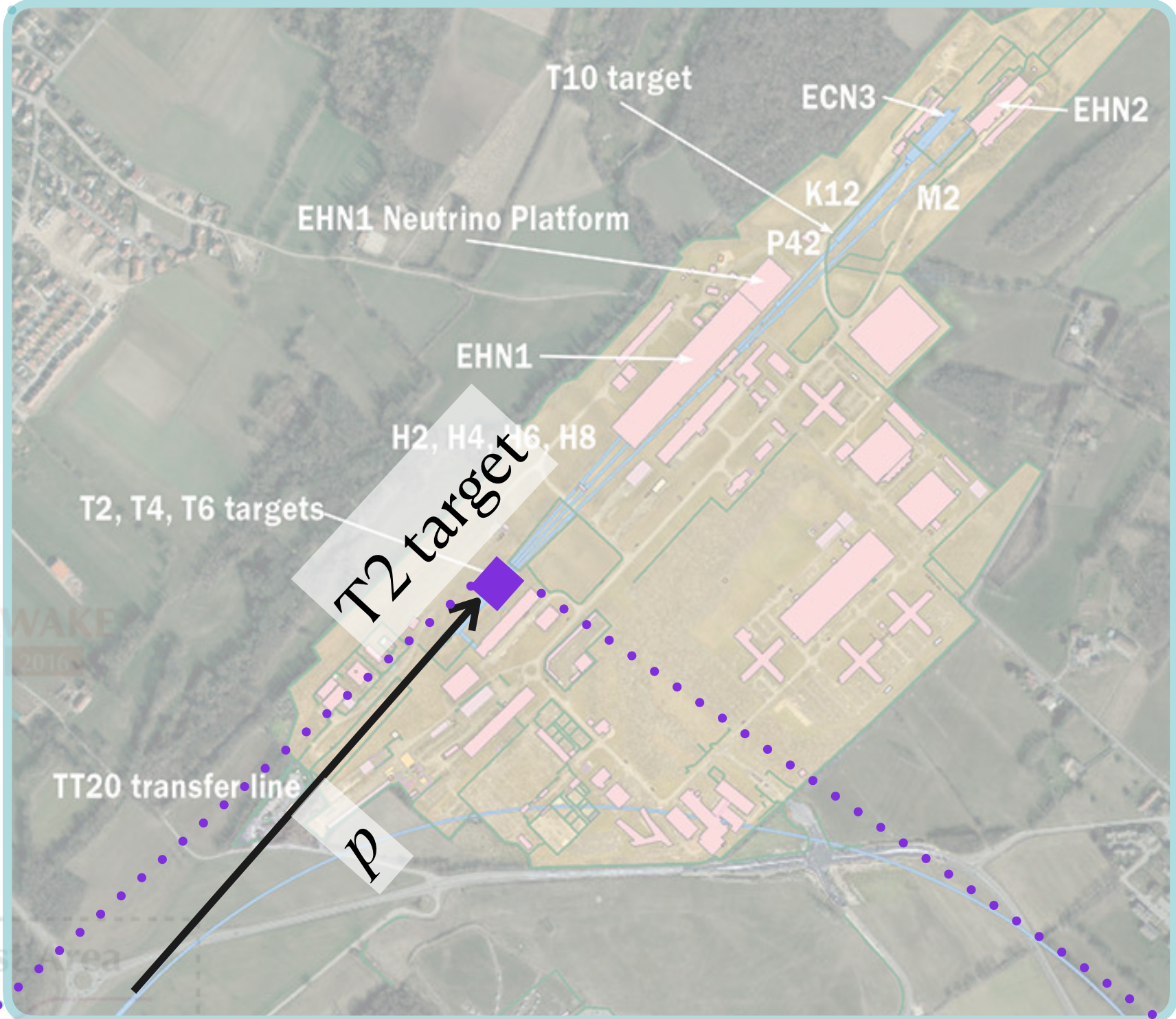
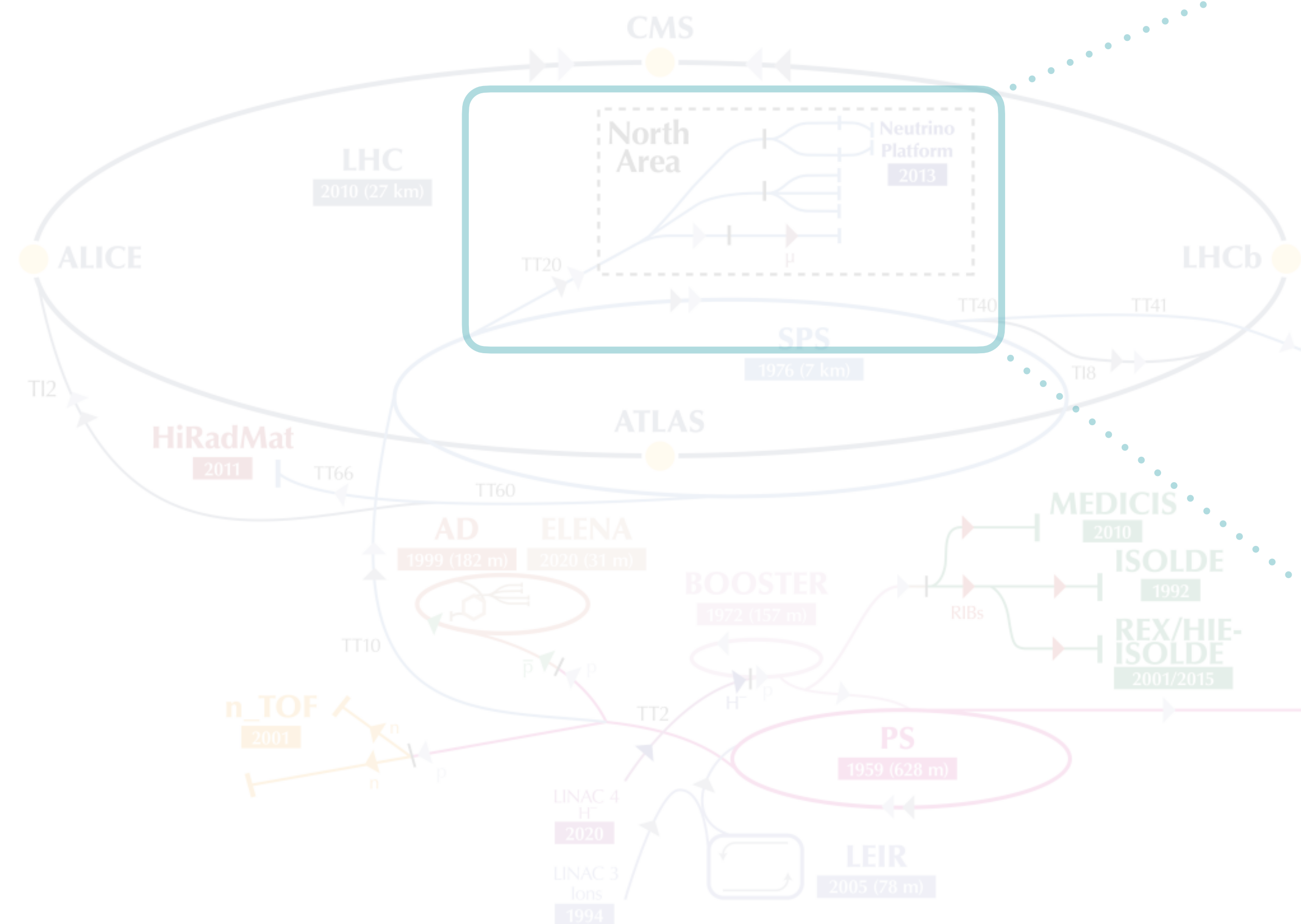
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North Area

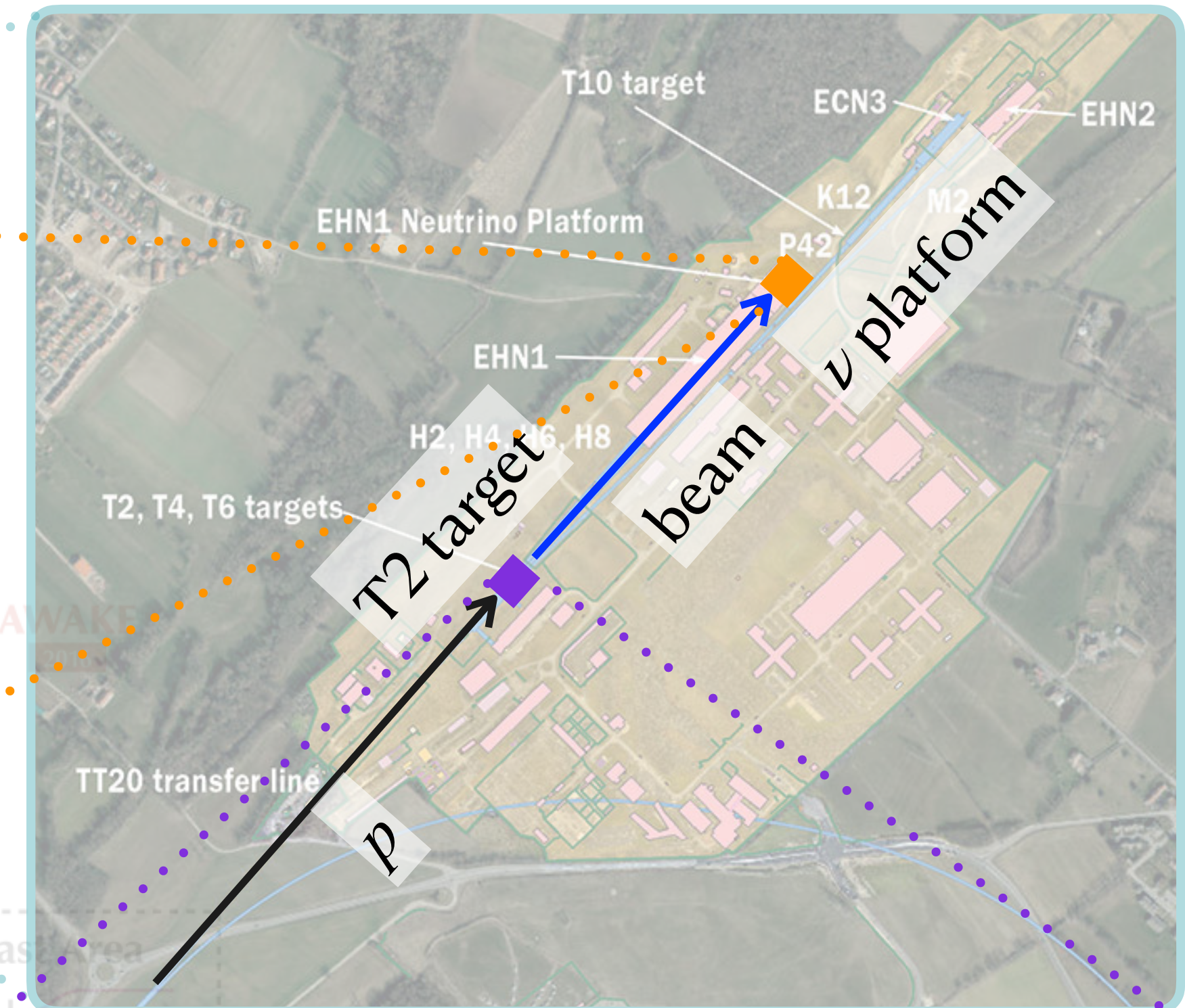
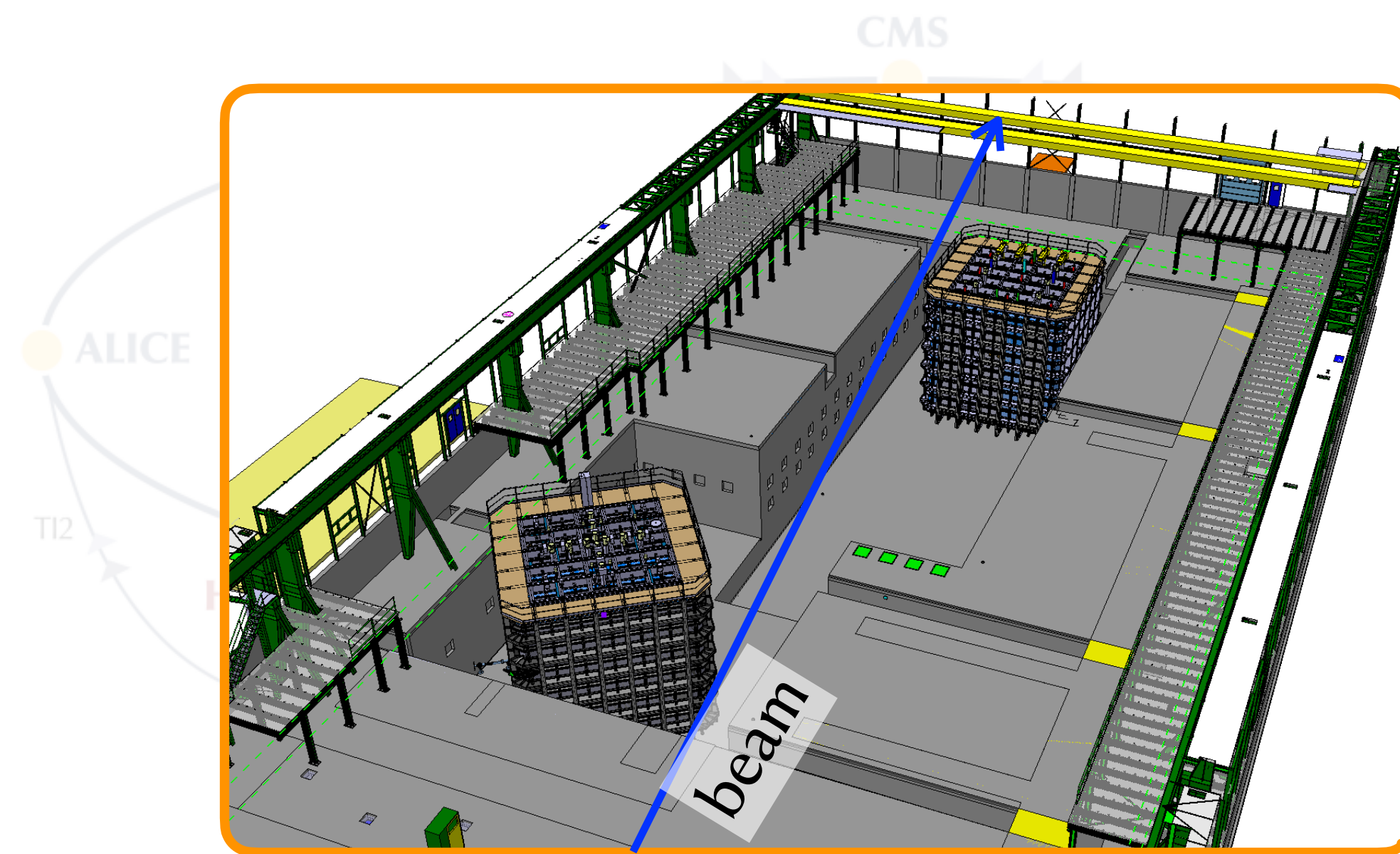
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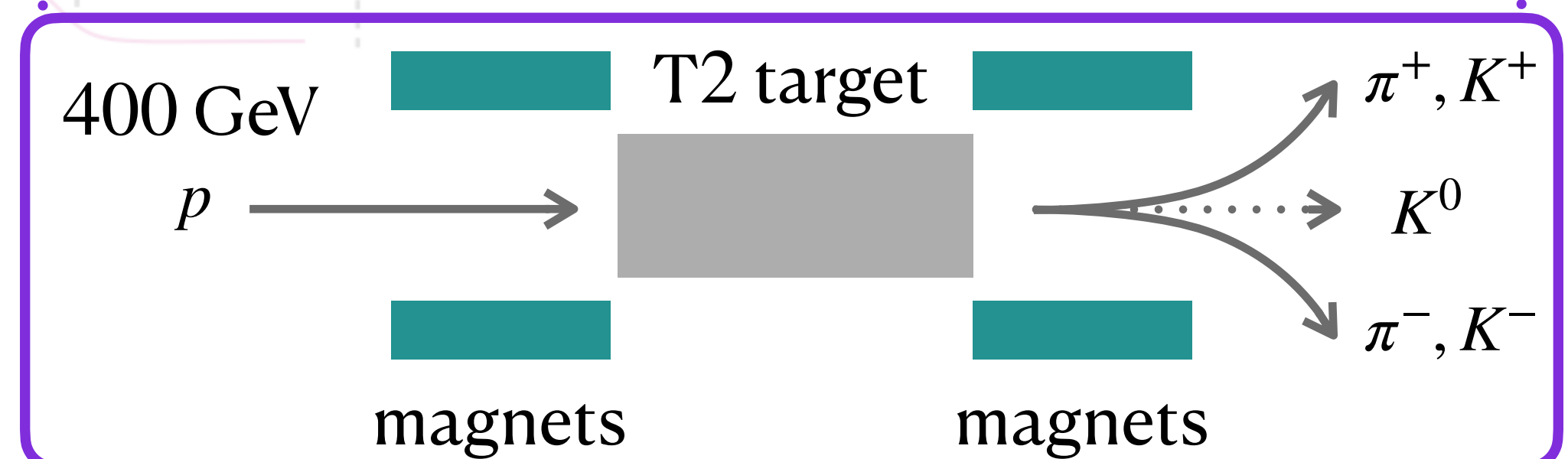
Extracting 400 GeV protons from SPS



Two ProtoDUNE detectors at Neutrino Platform

- NP04 LAr horizontal drift (HD) TPC
- NP02 LAr vertical drift (VD) TPC

See talk by A. Roche



BSM at ProtoDUNE: the original idea

Can we use the existing ProtoDUNE detectors as a beam-dump to search for LLPs?

[Pheno study](#) showing promising results: P. Coloma, J. López-Pavón, L. Molina-Bueno and S. Urrea, [JHEP 01 \(2024\)](#)

Several approximations:

- beam simulation: Pythia8 T2 + TAX, but not all the light mesons included
- sensitivity results at level of number of events
 - No bkg considered. ν flux expected to be negligible due to magnets after T2
 - No trigger and reconstruction efficiencies

BSM at ProtoDUNE: feasibility study

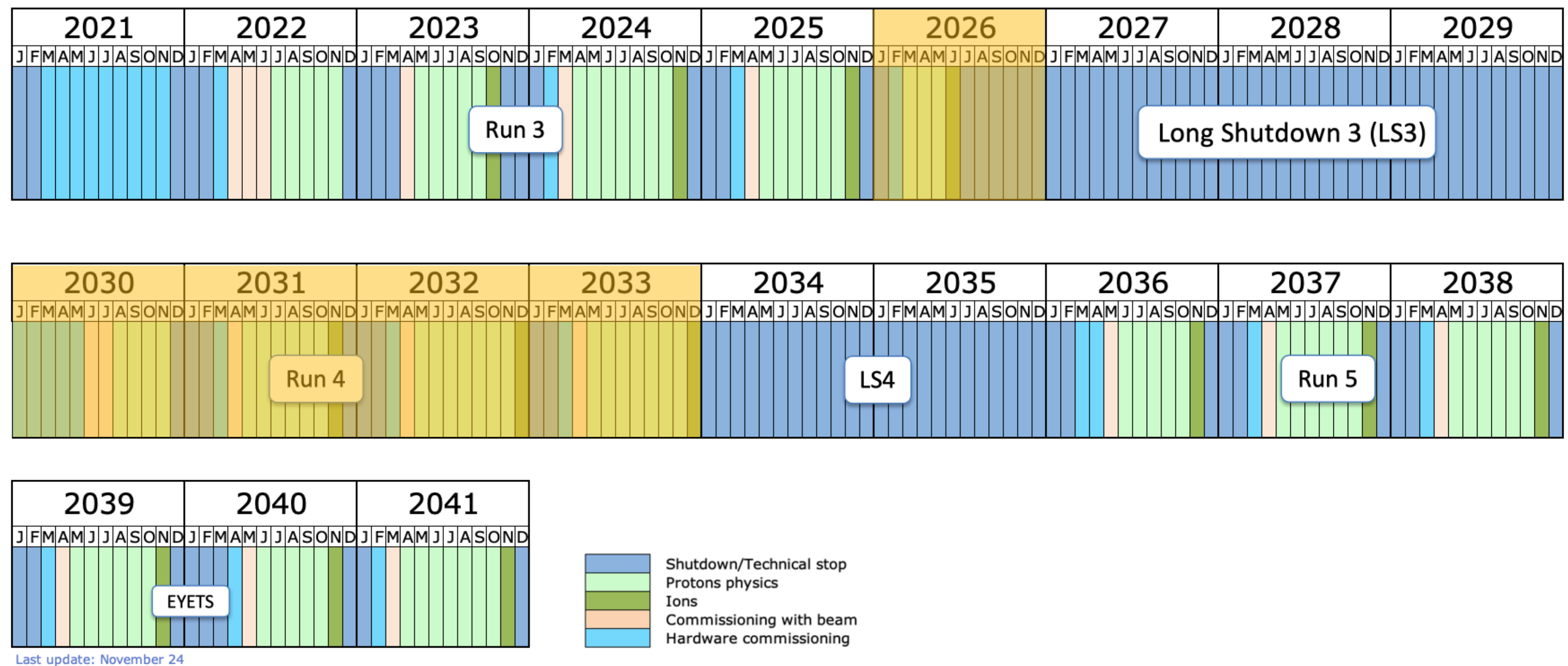
Working group formed 2023 December to study the feasibility of the proposal and demonstrate the proof-of-principle at NP02 and NP04

Challenges:

- Detector at the surface: can we reject cosmics?
- Full bkg estimation: Are there other beam-related sources?
- Can we trigger on the events coming from the T2 target?
- Which topologies are we able to reconstruct and with which efficiency?

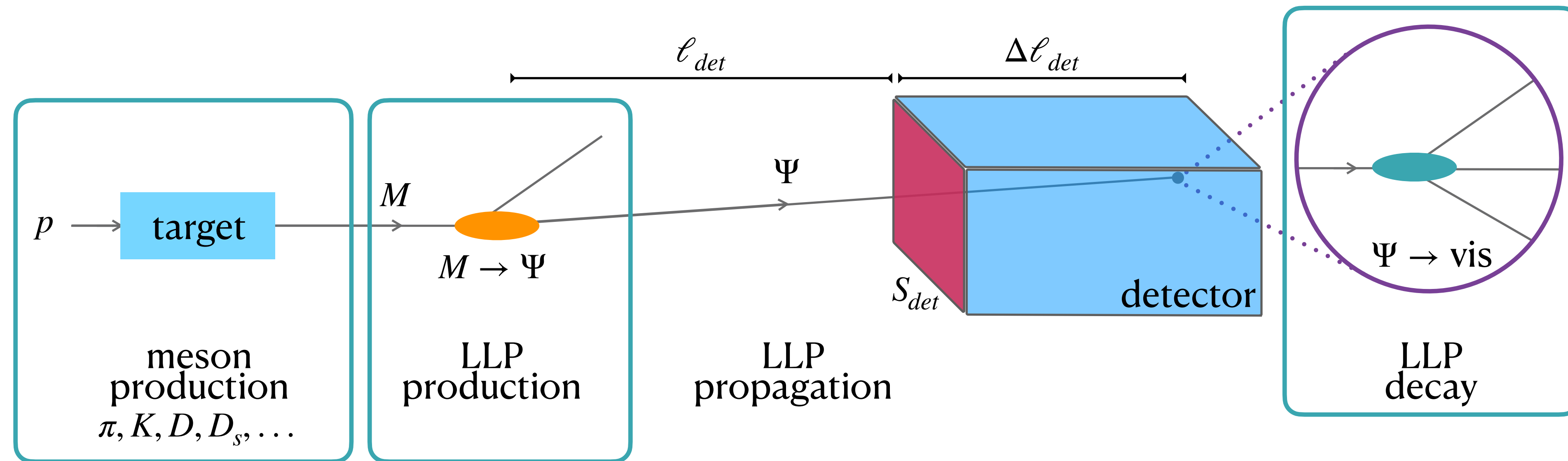
Timescale considered

- Run parasitically at SPS (not interfering with other experiments at H4/H2)
- Proton run at SPS can be up to 6 months depending on the year
- We consider 5 years to collect $1.75 \cdot 10^{19}$ PoT



Simulating LLP decays at ProtoDUNE

LLPs could be produced via meson decay at the beam-dump experiment beam



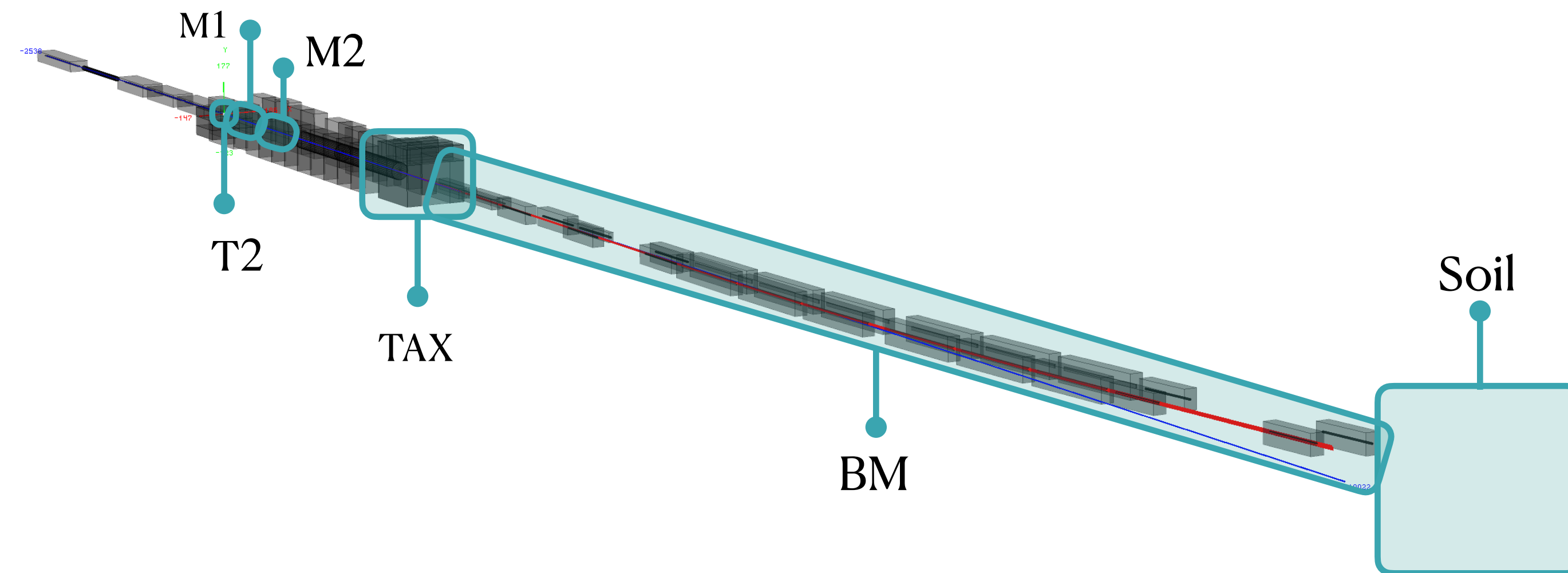
Three sets of simulations are needed:

- Meson production at T2: we consider the mesons with relevant branching fraction to LLPs
- LLP production
- LLP decay

Meson production

- Meson production at the target station: we consider the mesons with relevant branching fraction to neutrinos
 - $\pi^\pm, K^\pm, K_L^0$ & K_S^0

Full GEANT4 based simulation including the main T2 target area elements



- Meson fluxes produced with exact magnetic field settings for 3 configurations: w000, w133 and wNP04
- Results validated against Pythia8 considering only the initial proton interaction

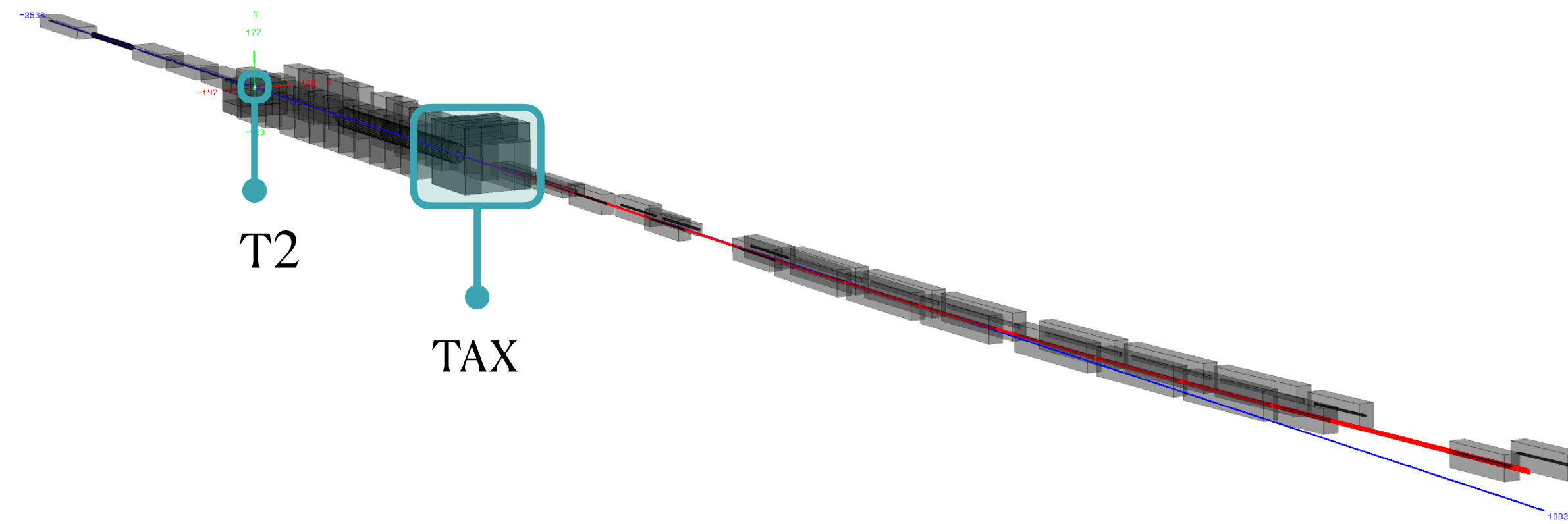
Meson production

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Full GEANT4 based simulation including the main T2 target area elements

- $D^\pm, D_s^\pm$ & $\tau^\pm$

Heavy mesons simulated with Pythia8 considering only the initial proton interaction



P. Coloma, J. López-Pavón, L. Molina-Bueno and S. Urrea, JHEP 01 (2024)

Heavy Neutral Leptons: production and decay

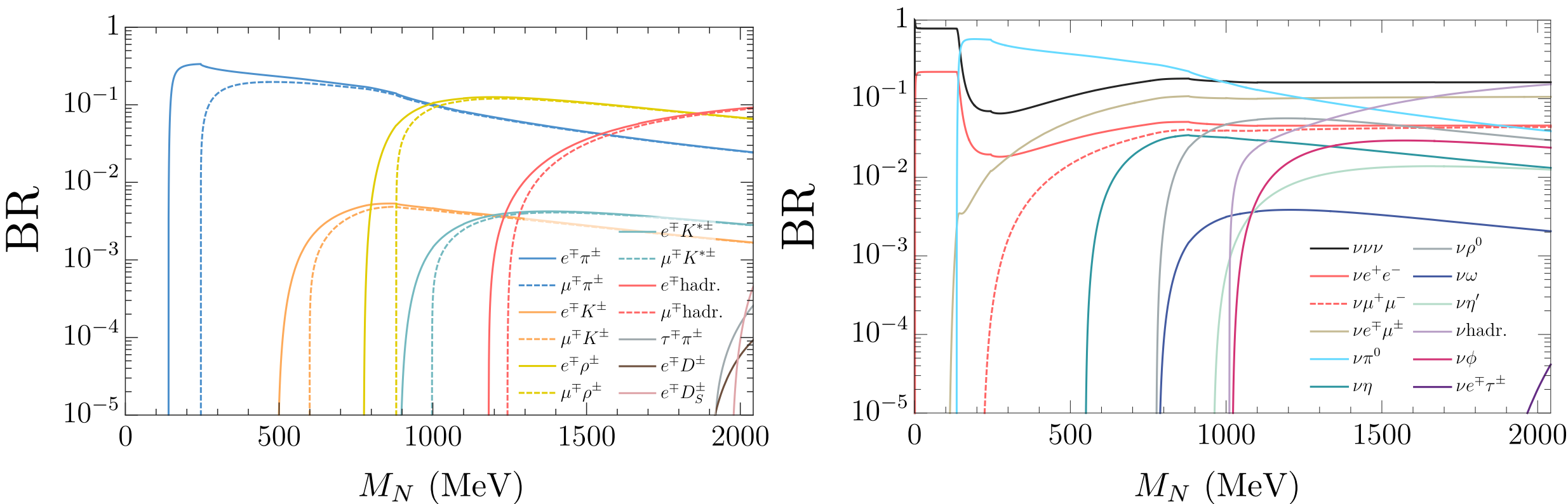
- HNL production

Leptonic and semileptonic meson decays

	$\pi \rightarrow$	$K^0 \rightarrow$	$K \rightarrow$	$D \rightarrow$	$D_s \rightarrow$	$\tau \rightarrow$
$ U_{eN} ^2$	eN	—	eN	eN	eN	—
	—	$\pi^0 eN$	πeN	$K^0 eN$	—	—
$ U_{\mu N} ^2$	μN	—	μN	μN	μN	—
	—	$\pi^0 \mu N$	$\pi \mu N$	$K^0 \mu N$	—	—
$ U_{\tau N} ^2$	—	—	—	τN	τN	πN
	—	—	—	—	—	$\pi \pi^0 N$
	—	—	—	—	—	$e \nu N$
	—	—	—	—	—	$\mu \nu N$

- HNL decay

2-body and 3-body HNL decays



Heavy Neutral Leptons: production and decay

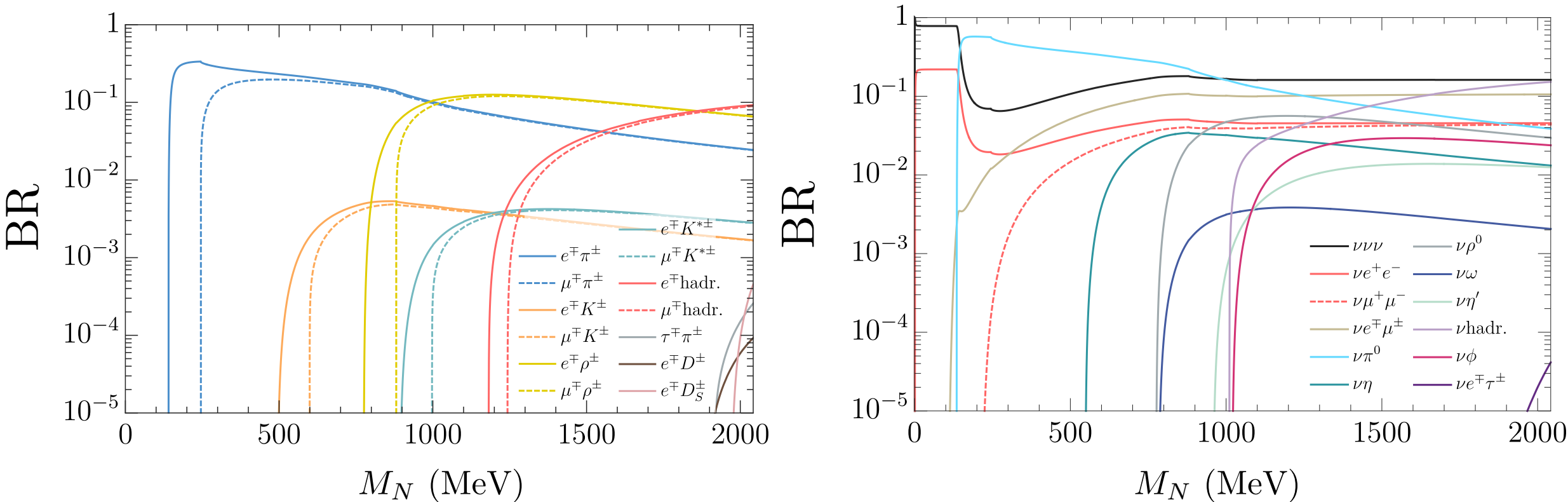
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	—	$\pi^0 eN$	πeN	$K^0 eN$	—	—
$ U_{\mu N} ^2$	μN	—	μN	μN	μN	—
	—	$\pi^0 \mu N$	$\pi \mu N$	$K^0 \mu N$	—	—
$ U_{\tau N} ^2$	—	—	—	τN	τN	πN
	—	—	—	—	—	$\pi \pi^0 N$
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2-body and 3-body HNL decays

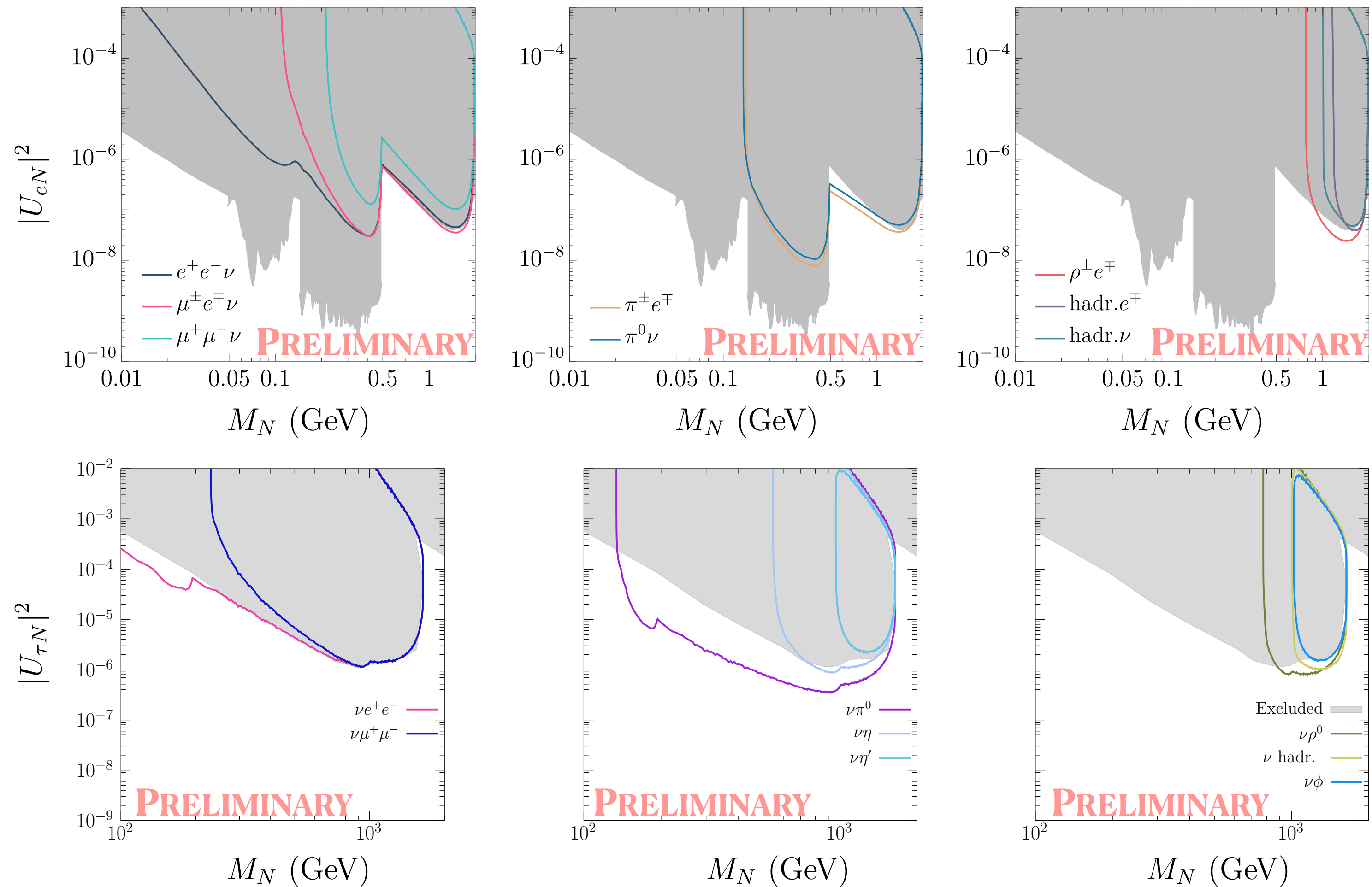


Effective operators describing interactions between light mesons and HNL included in a FeynRules model file

Interfacing the model file with an event generator allows for the simulation of fully differential event distributions.

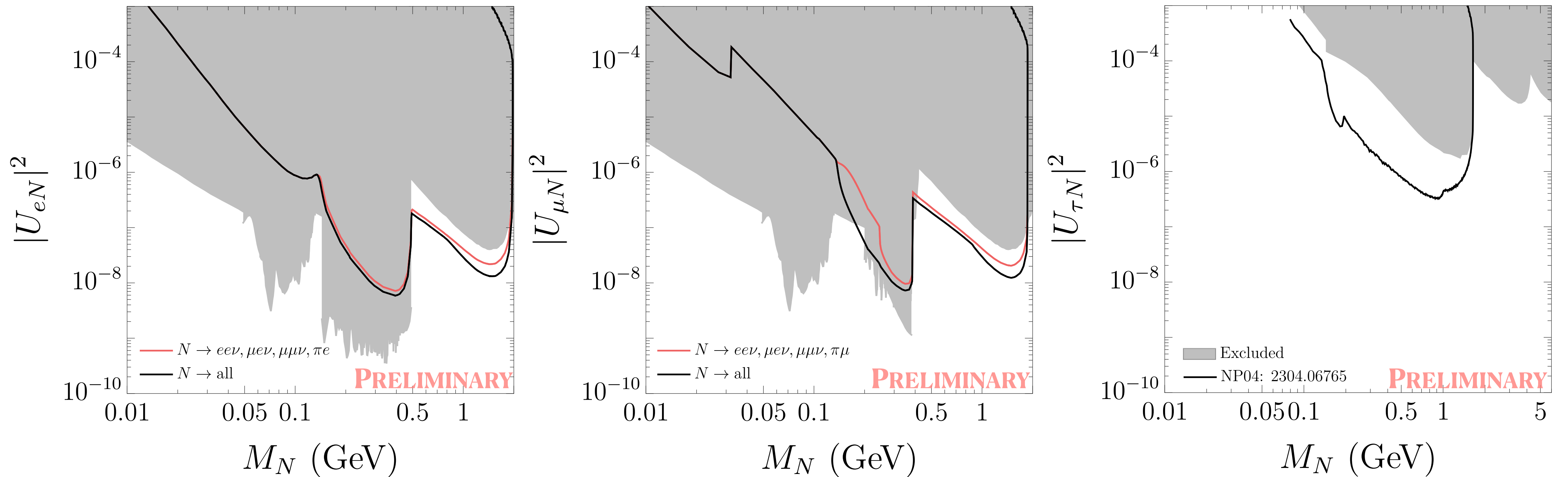
Heavy Neutral Leptons: signal sensitivity

Following the Feldman and Cousins prescription for a Poisson distribution with no background: $N_{ev}^{ex} < 2.3 \Rightarrow 90\% \text{ CL}$



Heavy Neutral Leptons: signal sensitivity

Combining the HNL decay channels:



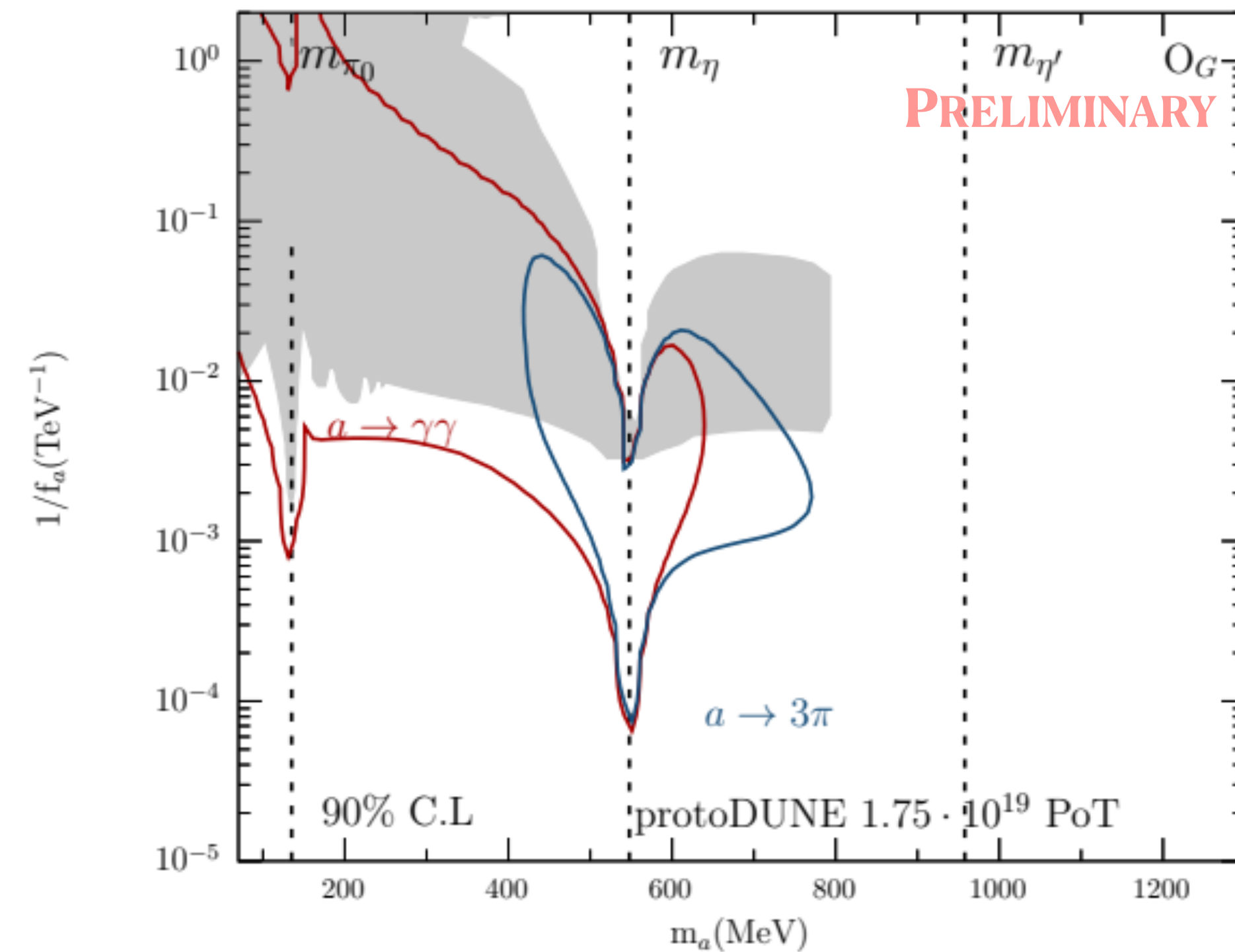
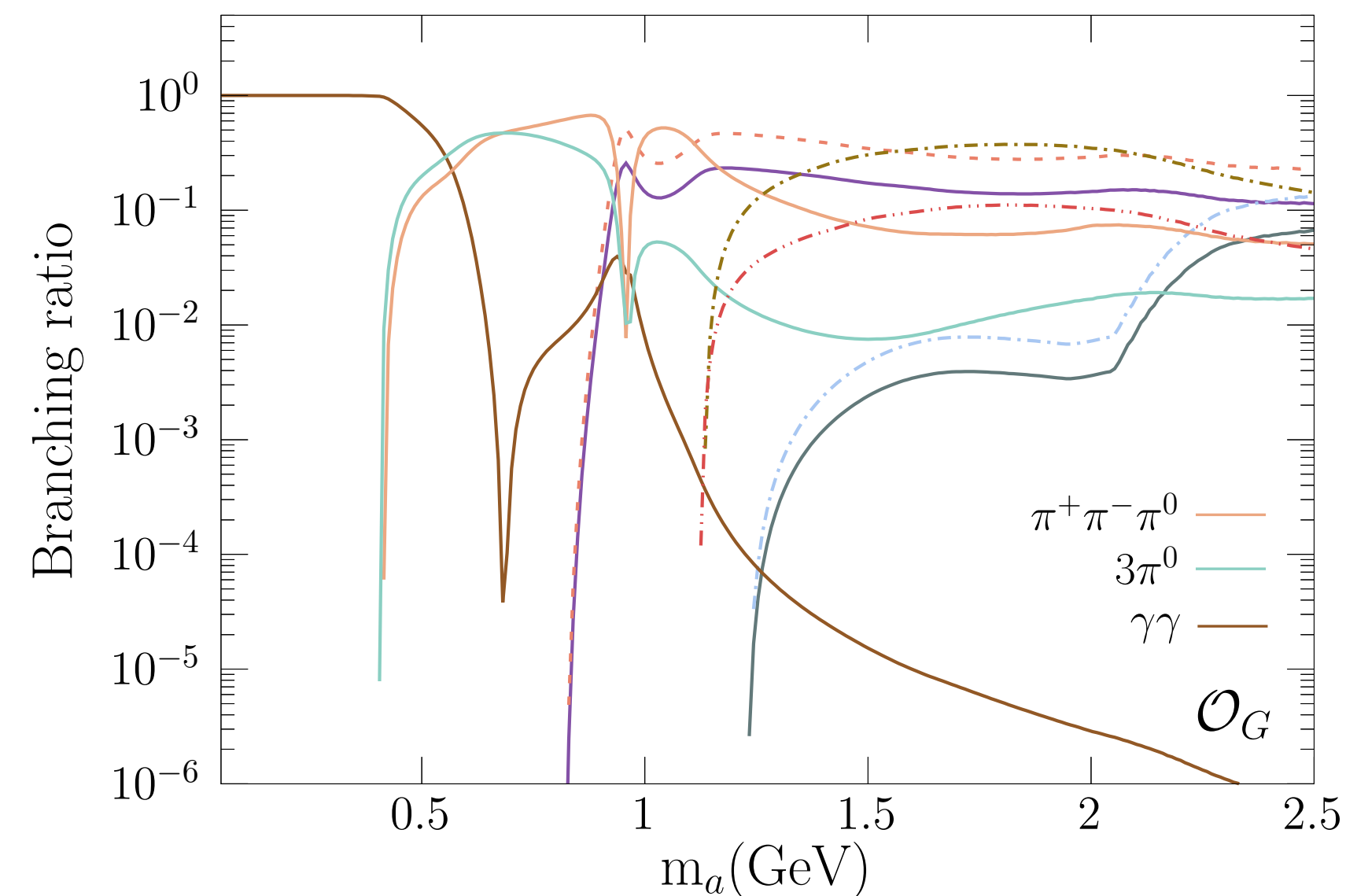
- 5 years of data taking $\Rightarrow 1.75 \cdot 10^{19}$ PoT from SPS $\Rightarrow \sim$ by end of 2033
- 90 % CL assuming no background and 100 % signal efficiency

Axion Like Particles: signal sensitivity

ALPs could be coupled to the SM via different sets of effective operators. **Gluon dominance** scenario:

$$\delta\mathcal{L}_{a,int} = \frac{\alpha_S}{8\pi f_a} a G_{\mu\nu}^b \tilde{G}^{b\mu\nu}$$

- ALP production via π^0, η, η' mixing
- ALP decay



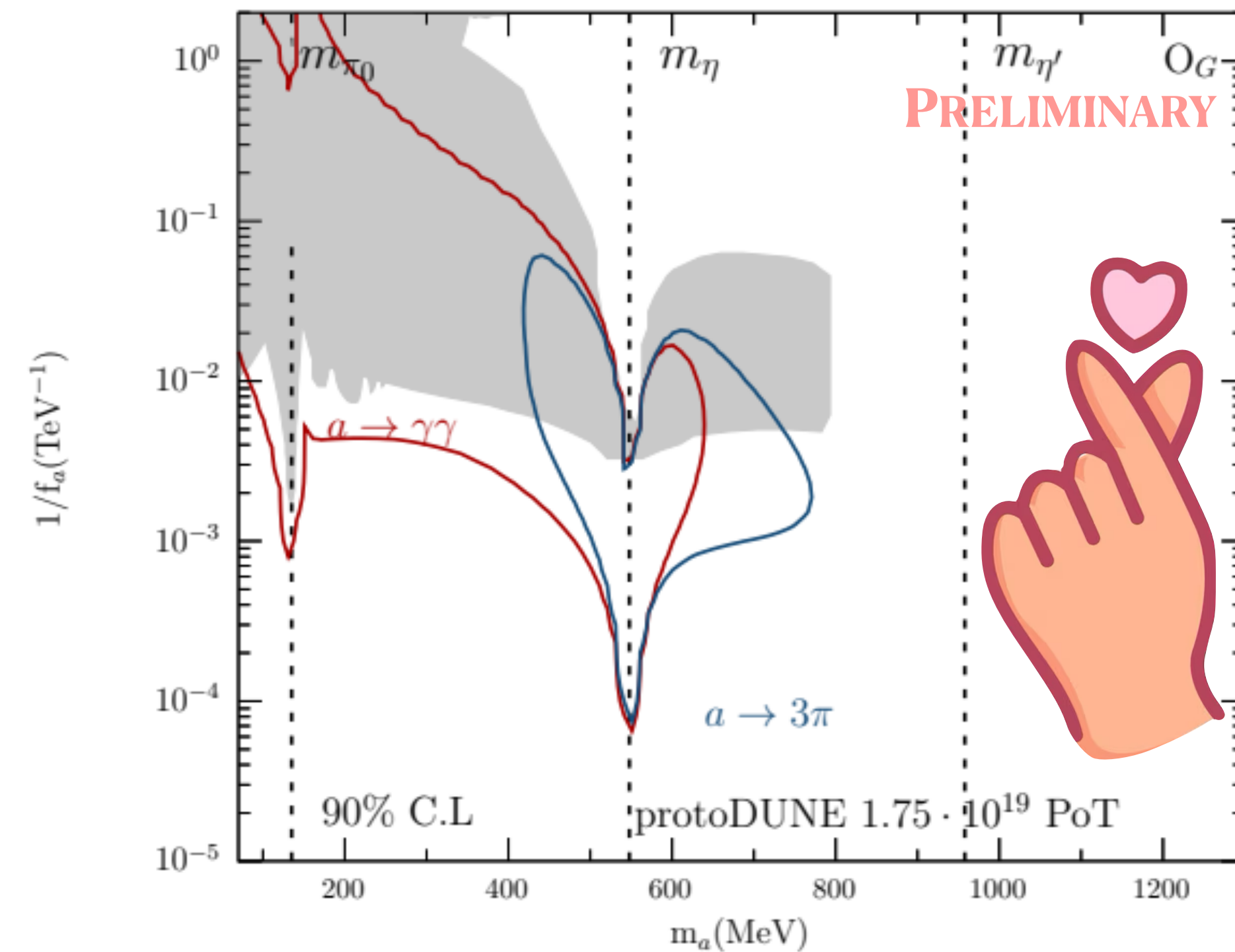
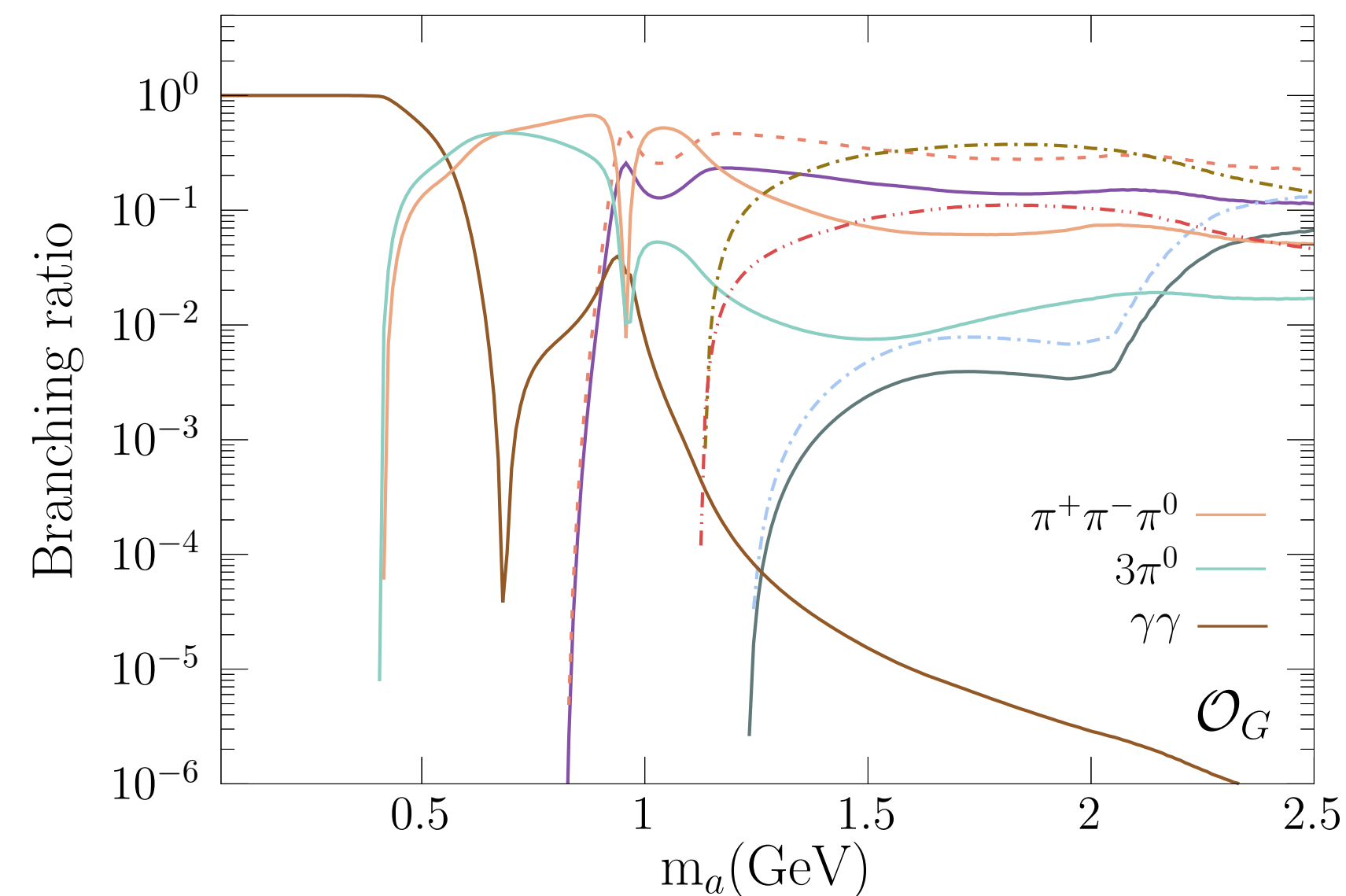
See talk by J. Lopez-Pavon

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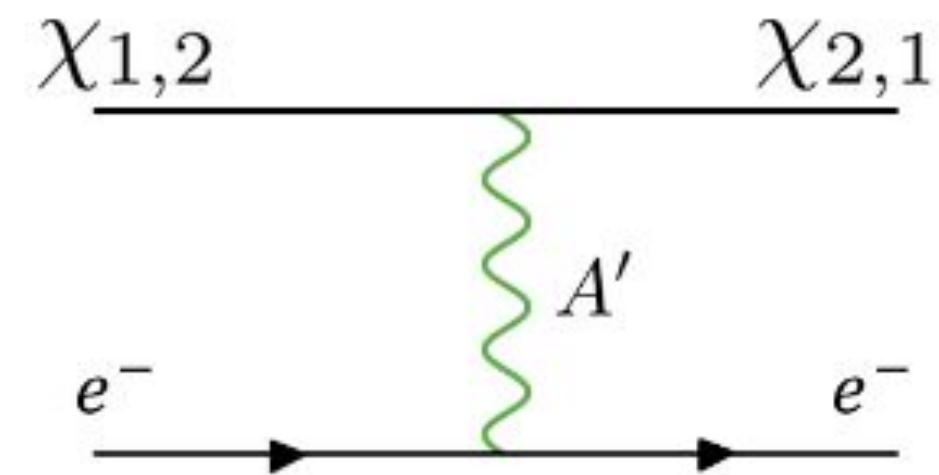
Inelastic Dark Matter: signal sensitivity

Extend the SM with a dark U(1) and two Majorana fermions. After **diagonalizing** the kinetic mixing term:

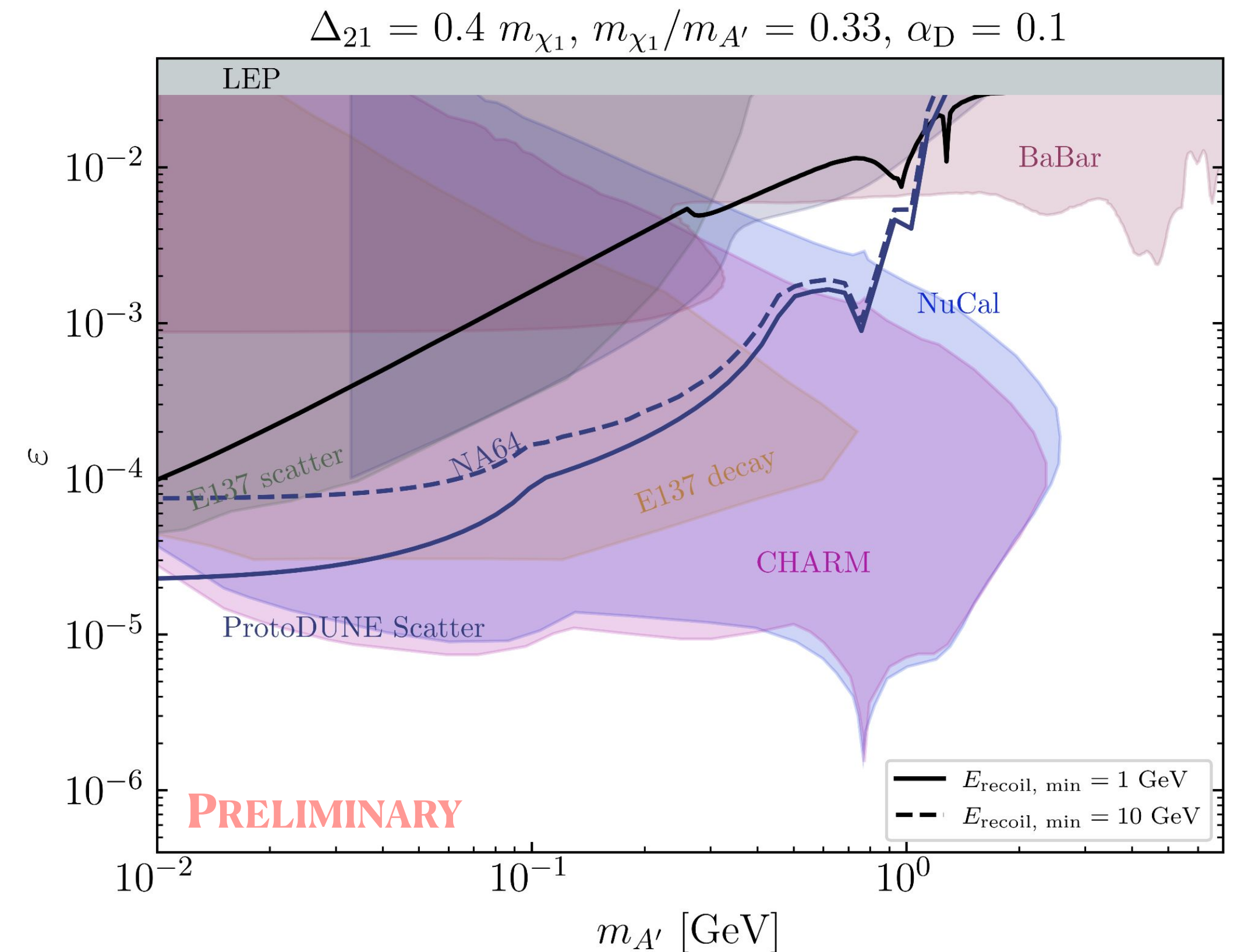
$$\mathcal{L}_{int} \supset A'_\mu \left(g_D \mathcal{J}_{iDM}^\mu - e\epsilon \mathcal{J}_{EM}^\mu \right)$$

• $\bar{\chi}_1 \gamma^\mu \chi_2 + \text{h.c.}$ purely **off-diagonal**

- iDM production via pseudoscalar & vector meson decay
- iDM detection
 - Scattering inside detector



Large background expected



See talk by S. Bianco

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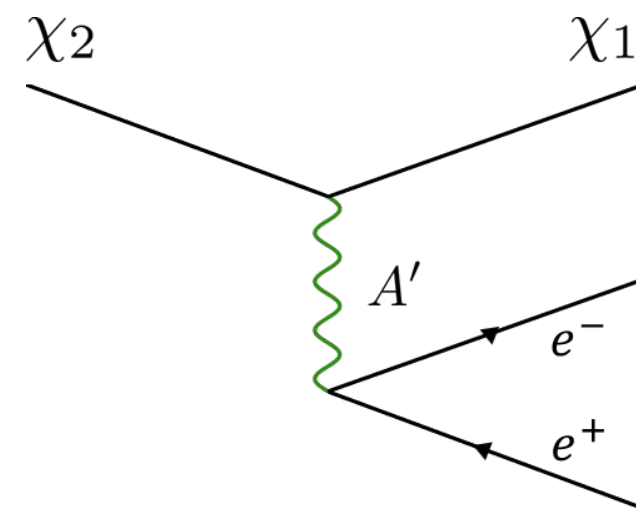
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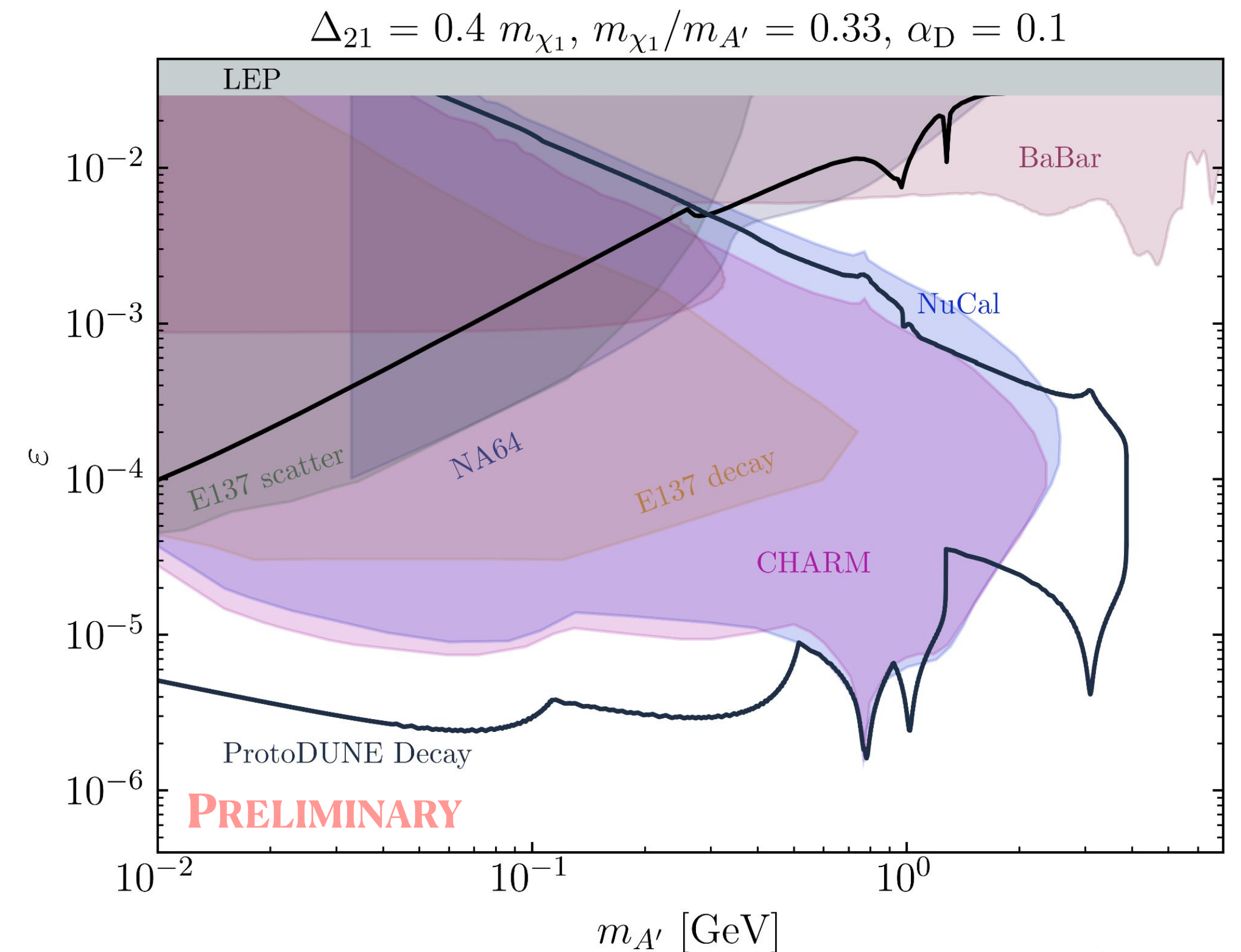
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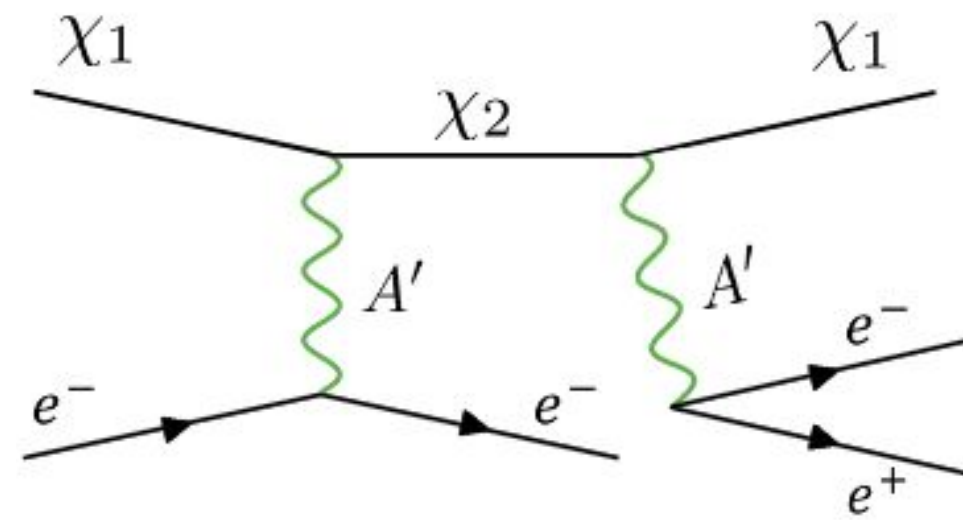
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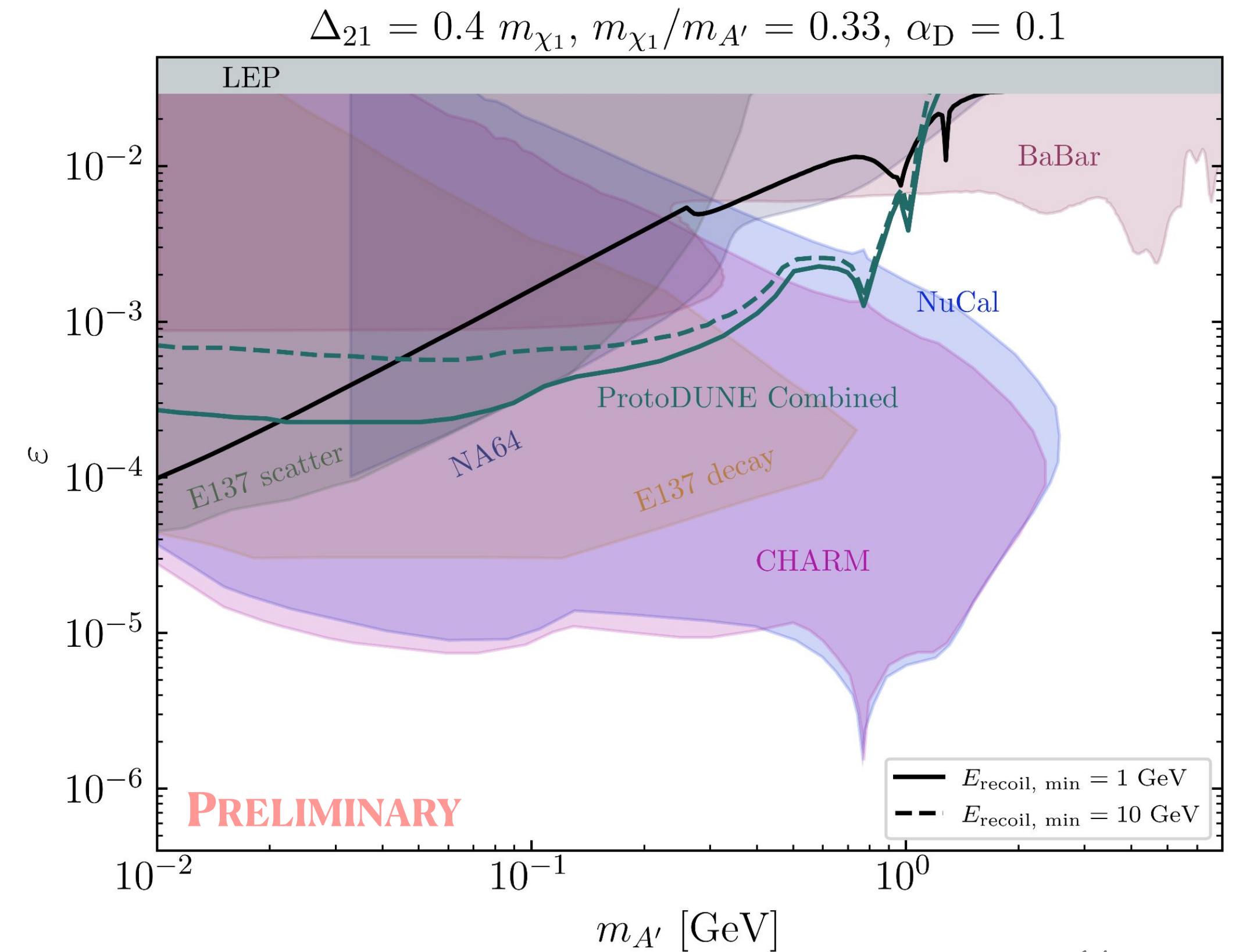
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- iDM production via pseudoscalar & vector meson decay
- iDM detection
 - Scattering + decay inside detector (**double bang**)



Background free?



See talk by S. Bianco

Impact of the background

The impact of the background on the sensitivity has to be considered

- Background from cosmics:

Preliminary results show that by filtering events that are not horizontal, we reject most cosmics at the trigger level

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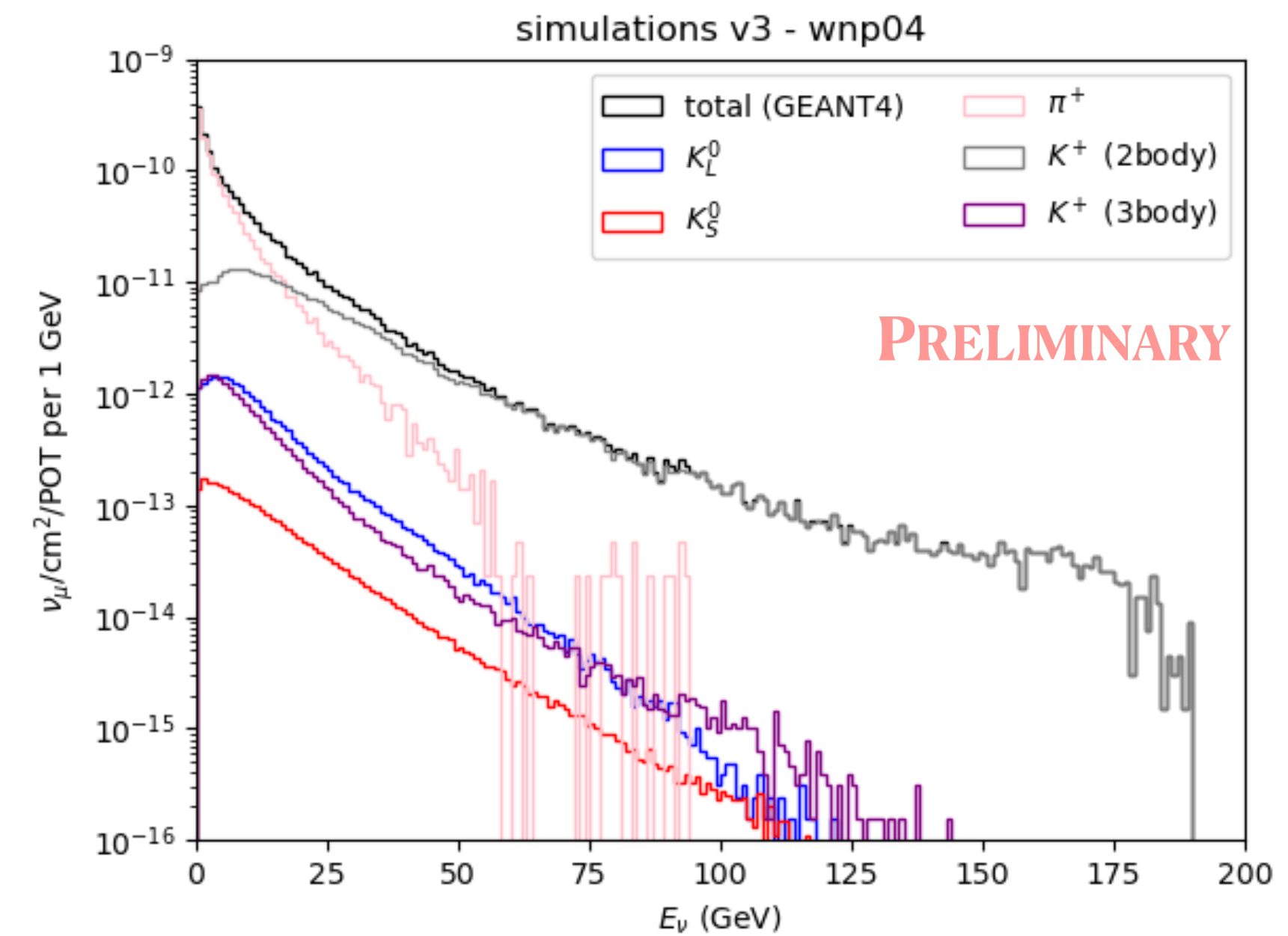
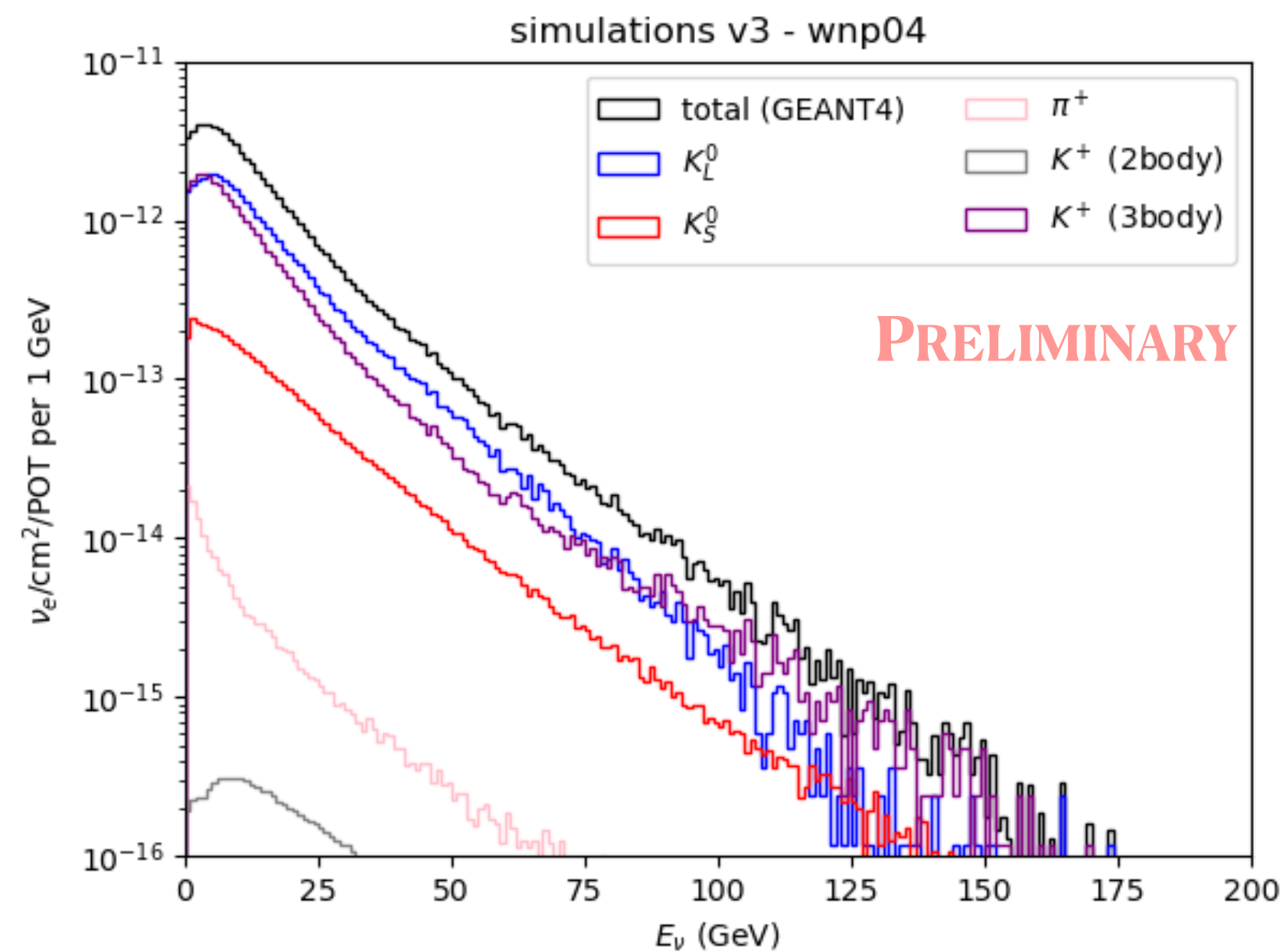
- Beam related: ν flux

ν interactions with Ar of the TPC produce particles in the final state that mimic the decay products of the HNL signal
 $\Rightarrow$ dominant background. For instance:

$$\begin{aligned} N \rightarrow \pi\mu \text{ vs CC interaction } \nu_\mu\text{-Ar}^{40} &\rightarrow \pi\mu \\ N \rightarrow \pi^0\nu_\mu \text{ vs NC interaction } \nu_\mu\text{-Ar}^{40} &\rightarrow \pi^0\nu_\mu \end{aligned}$$

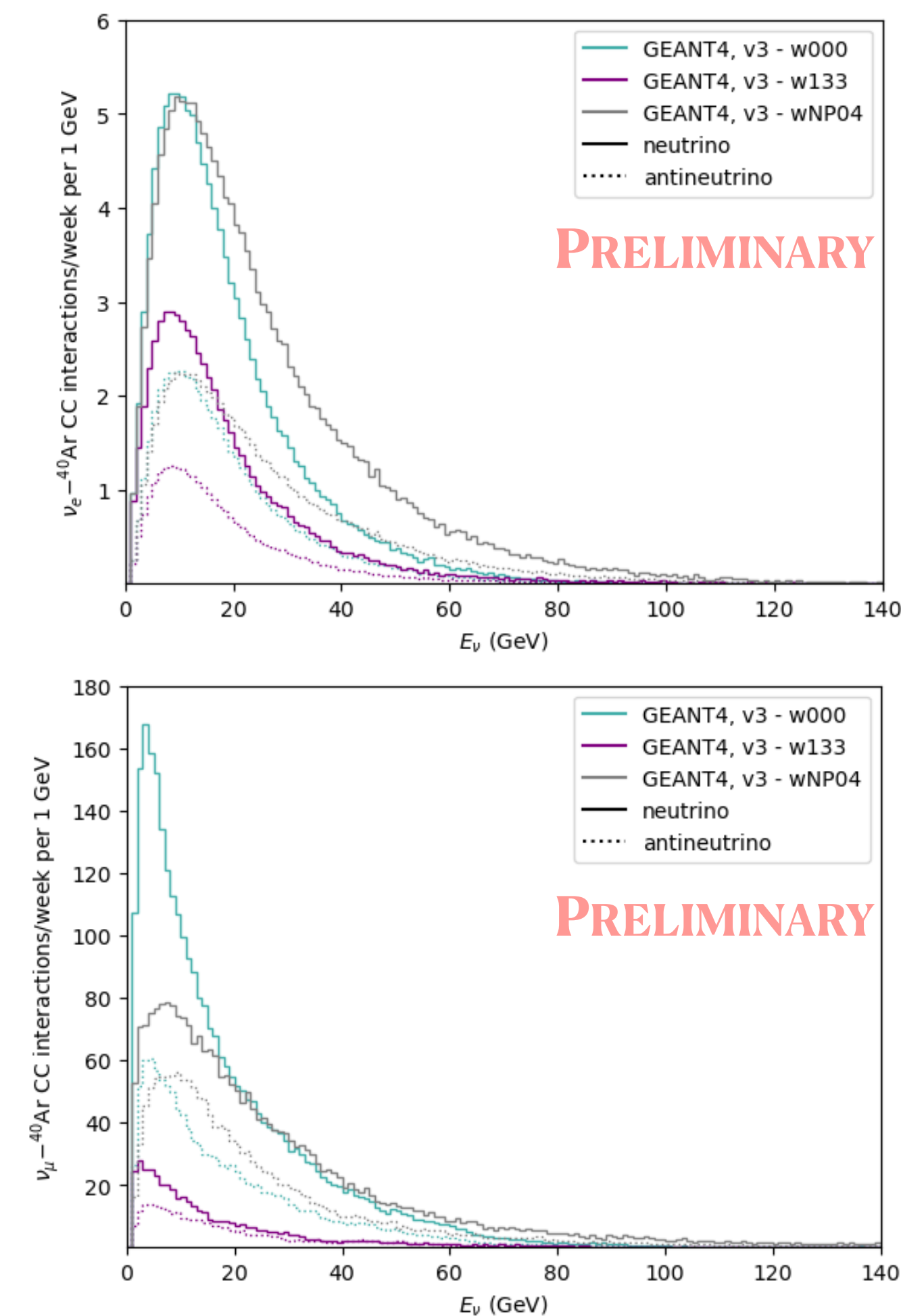
Light neutrino bkg: energy distribution

Expected energy distribution of the light neutrinos crossing NP04



Light neutrino bkg: interactions

These fluxes can be passed to GENIE to simulate the ν - ^{40}Ar interactions in NP04.



expected weekly

of ν interactions

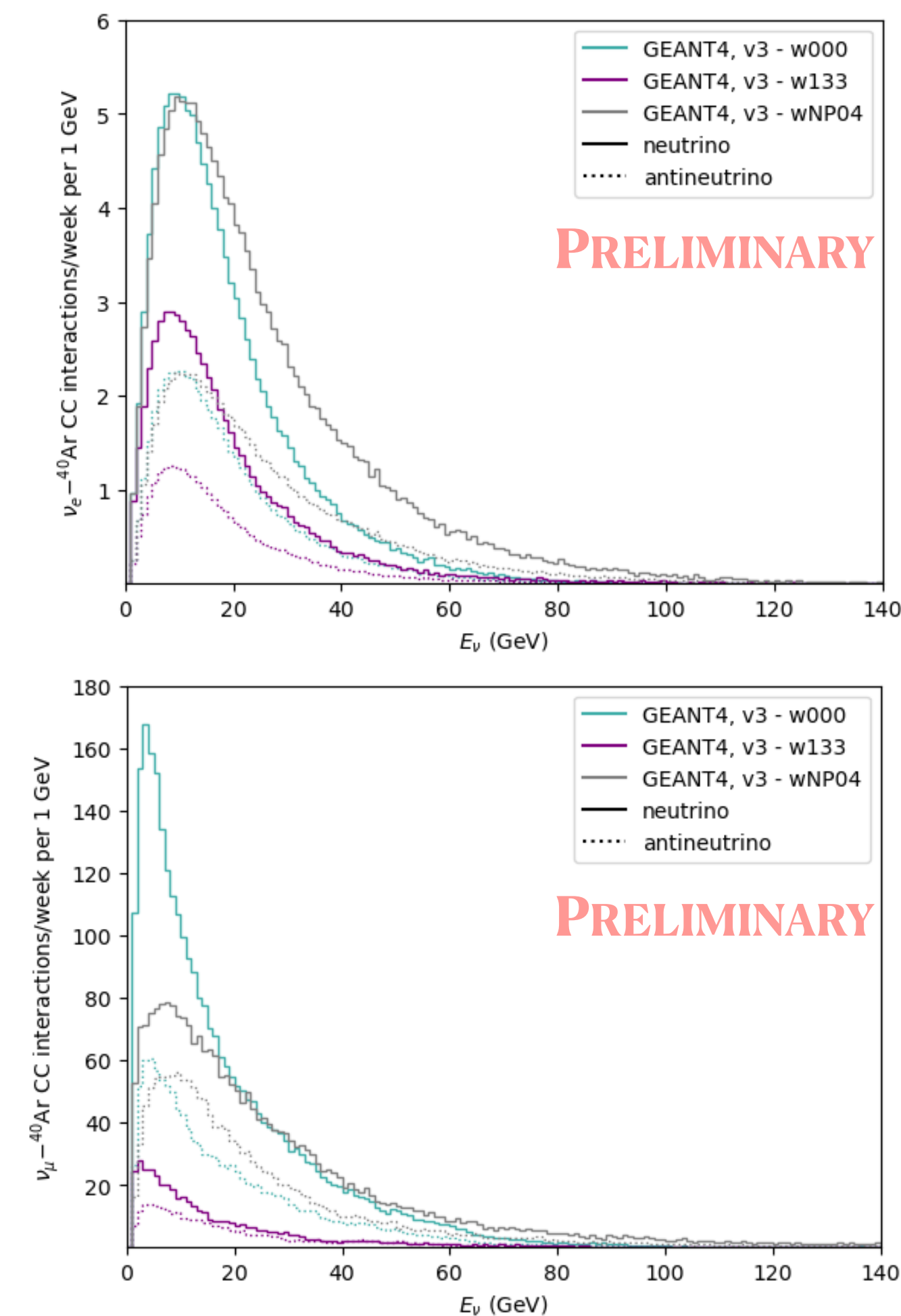
PRELIMINARY	Weekly interactions		
	w000	w133	wNP04
ν_e - ^{40}Ar - CC	120	65	162
ν_e - ^{40}Ar - NC	38	21	51
$\bar{\nu}_e$ - ^{40}Ar - CC	52	28	71
$\bar{\nu}_e$ - ^{40}Ar - NC	20	11	27
Total	230	125	311

PRELIMINARY	Weekly interactions		
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ν_μ - ^{40}Ar - CC	2983	464	2597
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$\bar{\nu}_\mu$ - ^{40}Ar - NC	495	121	615
Total	5681	1040	5609

Bad news for BSM searches, but...

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Bad news for BSM
searches, but...
could we detect them?

Proof-of-Principle

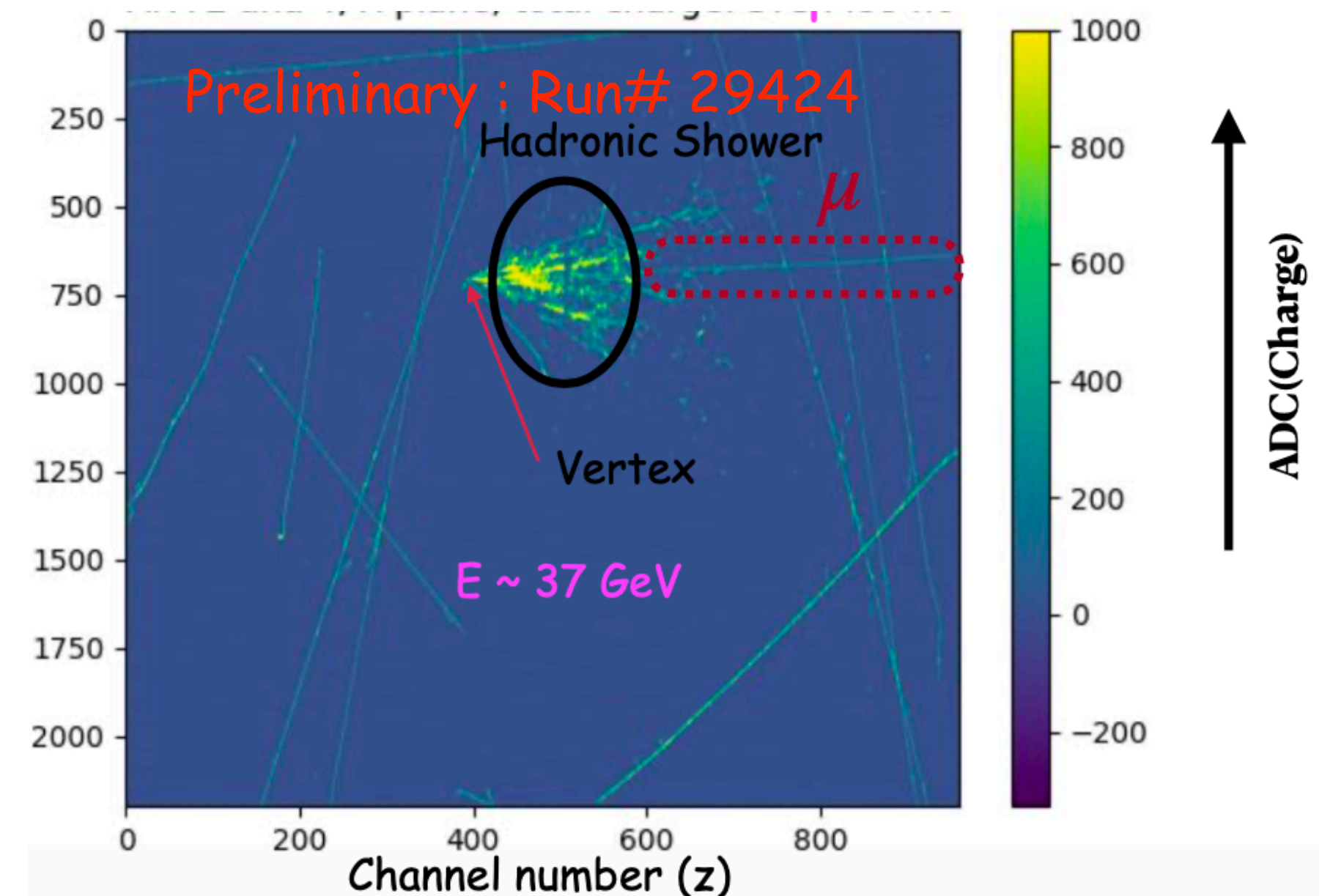
Their observation can be the proof-of-principle and the opportunity to study neutrinos at DUNE prototypes.

8 small (1 week) runs collected at different beam configurations including also **no beam** at SPS. Only one configuration and the one without beam currently under analysis:

- Interesting sample of events to train DUNE simulations.
- Several neutrino-like candidate events at NP04 under investigation

Event scanning:

- Select event only when spill ON
- Events filtered to reject cosmic and any event which are not horizontal
- Fiducial cut : remove any interaction from the surroundings.



See talk by D. Pullia

Summary

- The excellent imaging capabilities and large fiducial volume of the ProtoDUNE detectors make them ideal for searching for LLP particles in BSM scenarios without interfering with CERN's current program.
- Currently, we are focused on carrying out the feasibility study to demonstrate the proof-of-principle and search for HNLs as benchmark process:
 - A test was carried out at NP04 to understand the expected rate and validate the simulations: Preliminary neutrino-like events observed but further studies and a full analysis chain are ongoing to understand them and their source. Their observation can be the proof-of-principle and the opportunity to study neutrinos at DUNE prototypes.
 - We are currently developing all analysis tools for signal and background selection and to validate our Monte Carlo simulations with the collected data.
- Many other LLP scenarios can be exploited: already explored and calculated the sensitivity to ALPs, inelastic dark matter, dark scalar,...

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This research is also supported by the EU H2020 research and innovation programme under the MSC grant agreement No 860881-11 HIDDDeN, as well as by the Spanish Ministerio de Ciencia e Innovación project PID2020-113644GB-I00, the Spanish Research Agency (Agencia Estatal de Investigación) through the project CNS2022-136013, and Severo Ochoa Excellence Program CEX2023-001292-S.

Back-up

ProtoDUNE-BSM group

ProtoDUNE-BSM group: H. Amar, C. Andreopoulos, A. Chatterjee, S. Bianco, E. Campenhout, P. Coloma, A. De Roeck, G. Gurung, C. Hasnip, J. Hernandez-Garcia, W. Ketchum, F. Lanni, J. López-Pavón, J. Martin-Albo, L. Molina-Bueno, O. Palamara, J. K. Plows, F. Pietropaolo, D. Pullia, F. Resnati, P. Sajitha, H. Sieber, C. Touramanis, S. Urrea

LLPs signals at neutrino experiments

Neutrinos are feebly-interacting particles

- intense sources needed
- large detectors needed

Interactions $\rightarrow$ scale with detector **mass**

LLPs decays $\rightarrow$ scale with detector **volume**

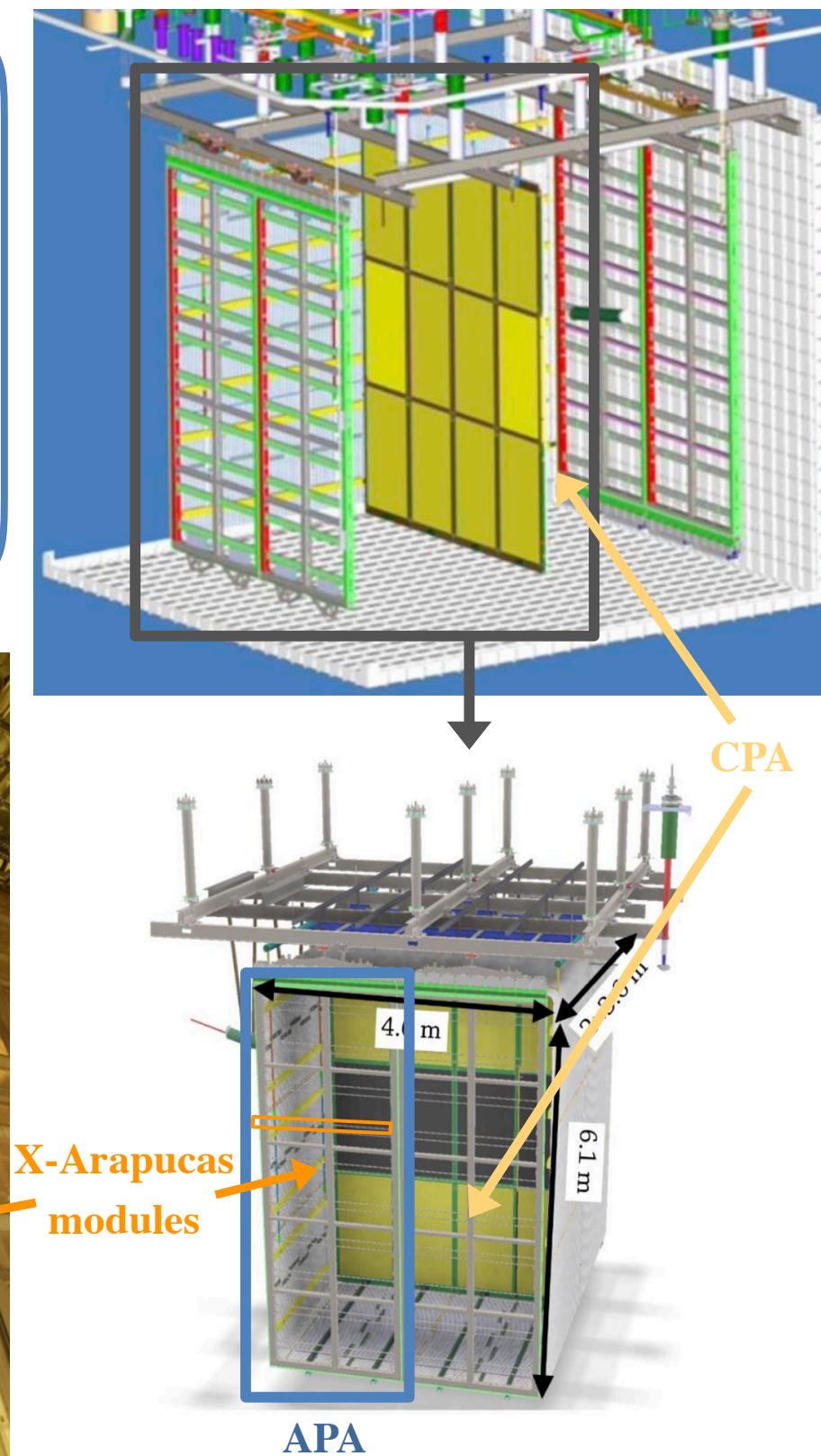
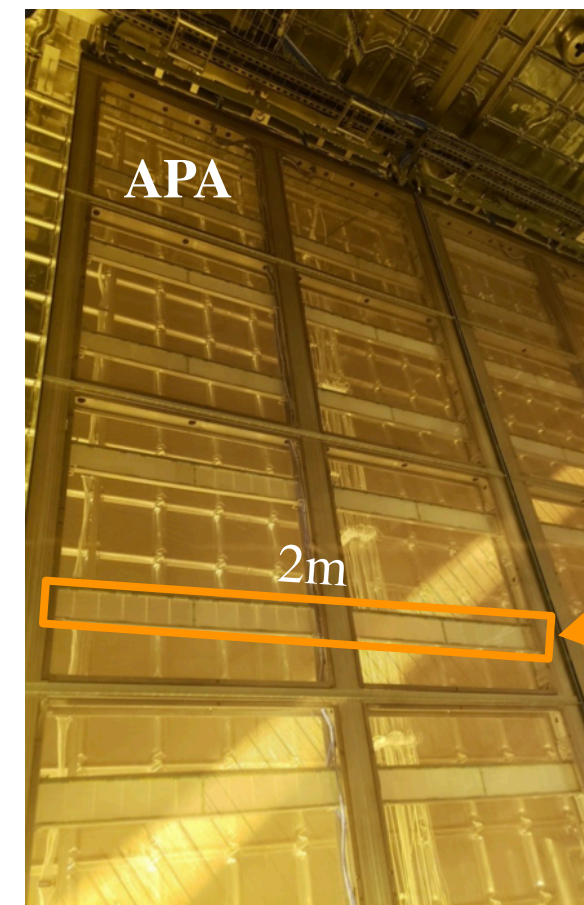
Generally lower backgrounds if

- Detector has low density/mass
- decays can be fully reconstructed $\Rightarrow$
instrumented detector (ECAL, magnetic field, ...)

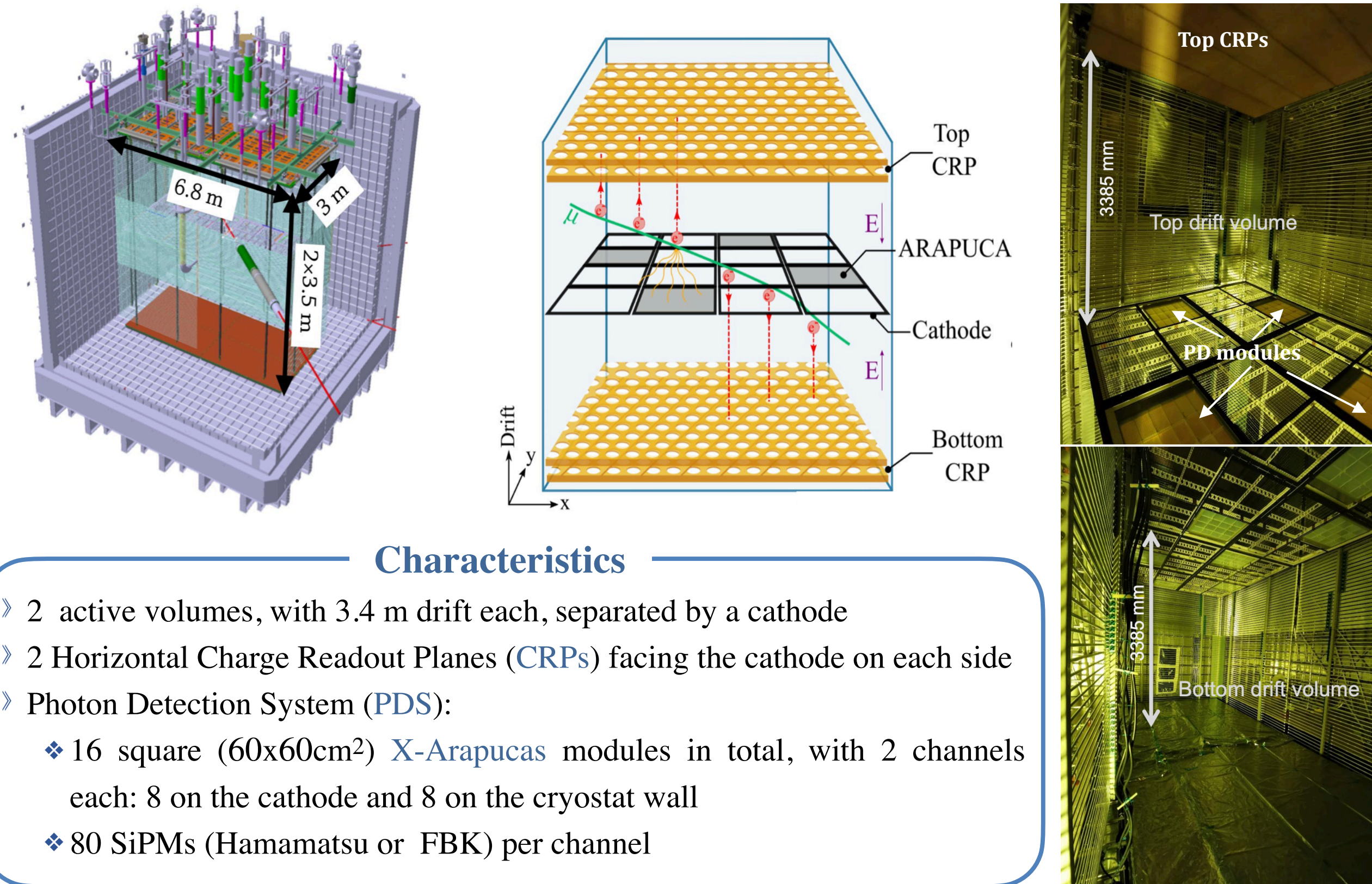
ProtoDUNE Horizontal Drift (PD-HD)

Characteristics

- » 2 active volumes, with 3.6 m drift each, separated with a cathode
- » 2 anode plane assemblies (APAs), facing the cathode plane assembly (CPA) on each side
- » Photon Detection System (PDS) modules, integrated in the APAs:
 - ❖ 40 rectangular (2m length) X-Arapucas modules in total, with 4 channels each
 - ❖ 48 SiPMs (Hamamatsu or FBK) per channel

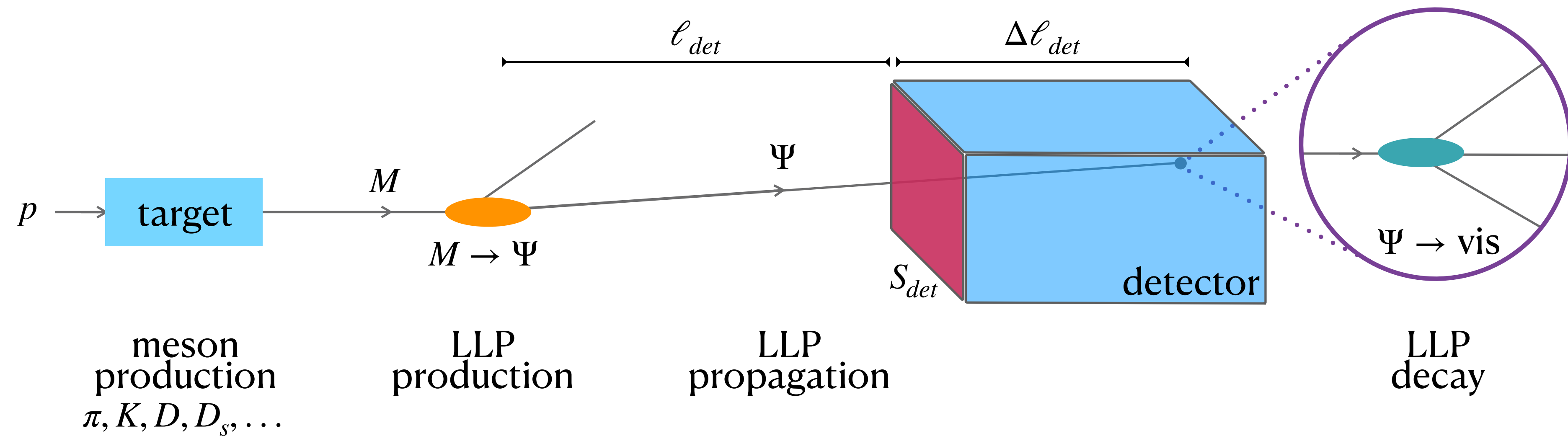


ProtoDUNE Vertical Drift (PD-VD)



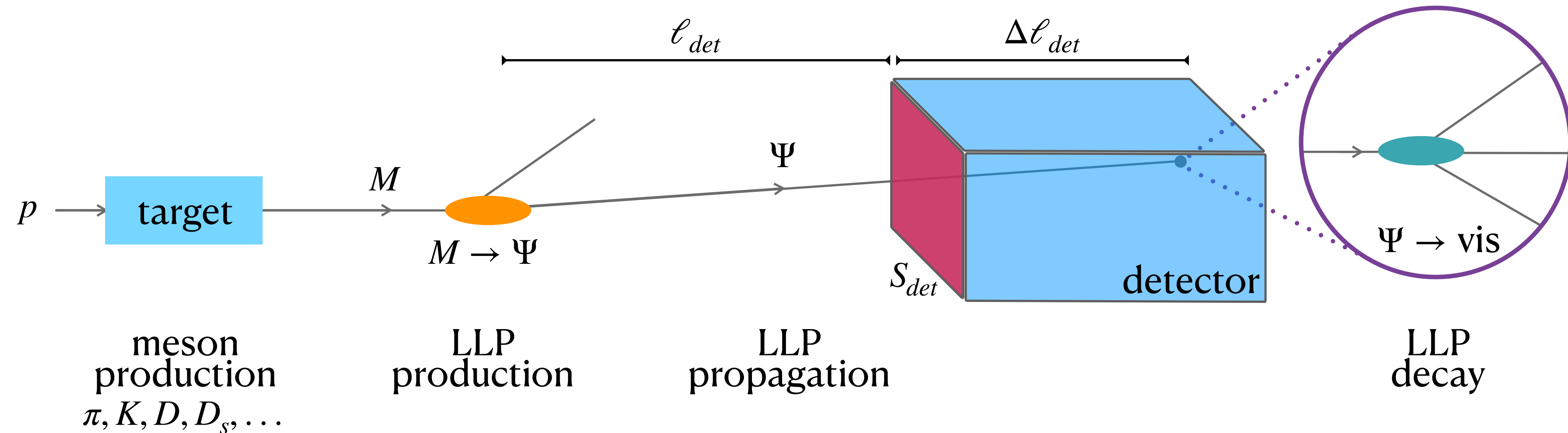
LLP at beam-dump experiments

LLPs could be produced via meson decay at the beam-dump experiment beam



LLP at beam-dump experiments

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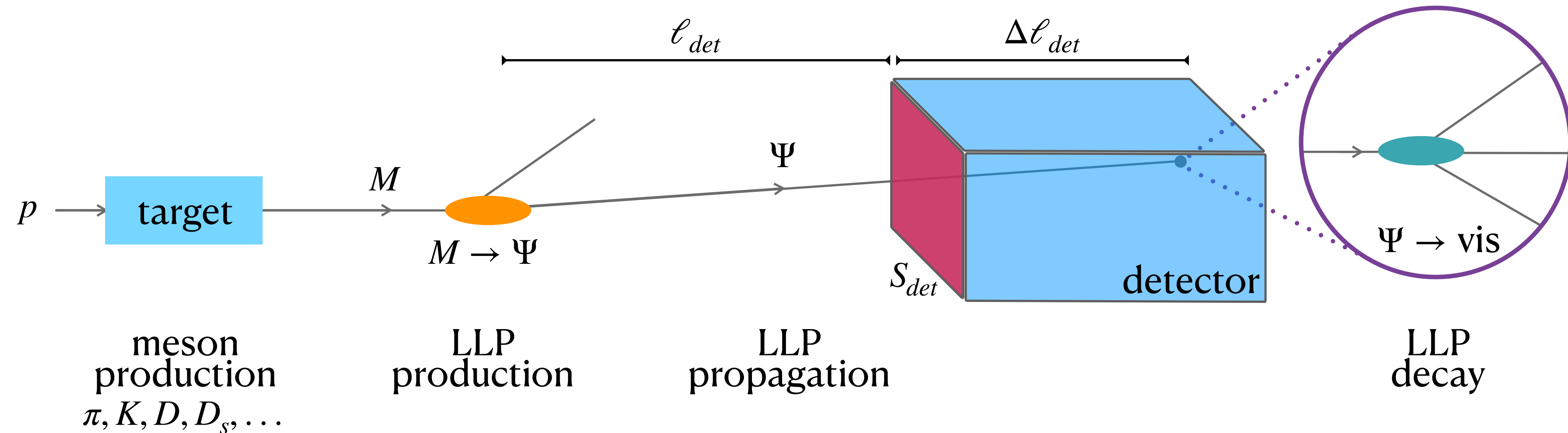


The number of decay events

$$N_{ev} = N_M \text{BR}(M \rightarrow \Psi) \text{BR}(\Psi \rightarrow \text{vis}) \epsilon_{det} \int dS \int dE_\Psi P(c\tau_\Psi/m_\Psi, E_\Psi, \Omega_\Psi) \frac{dn^{M \rightarrow \Psi}}{dS dE_\Psi}$$

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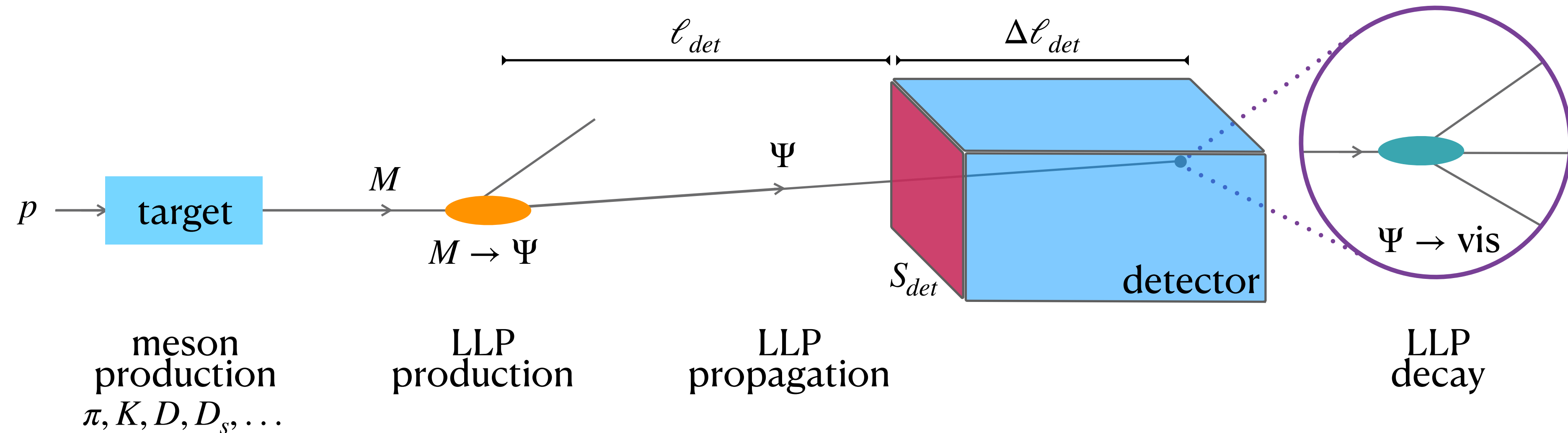
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experiment-dependent
quantities

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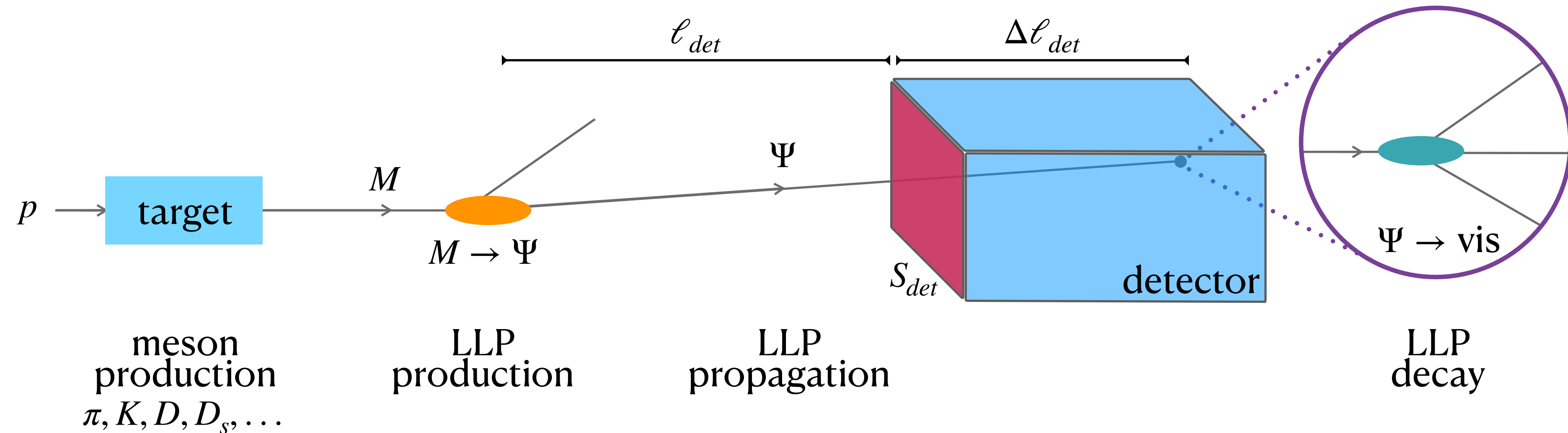


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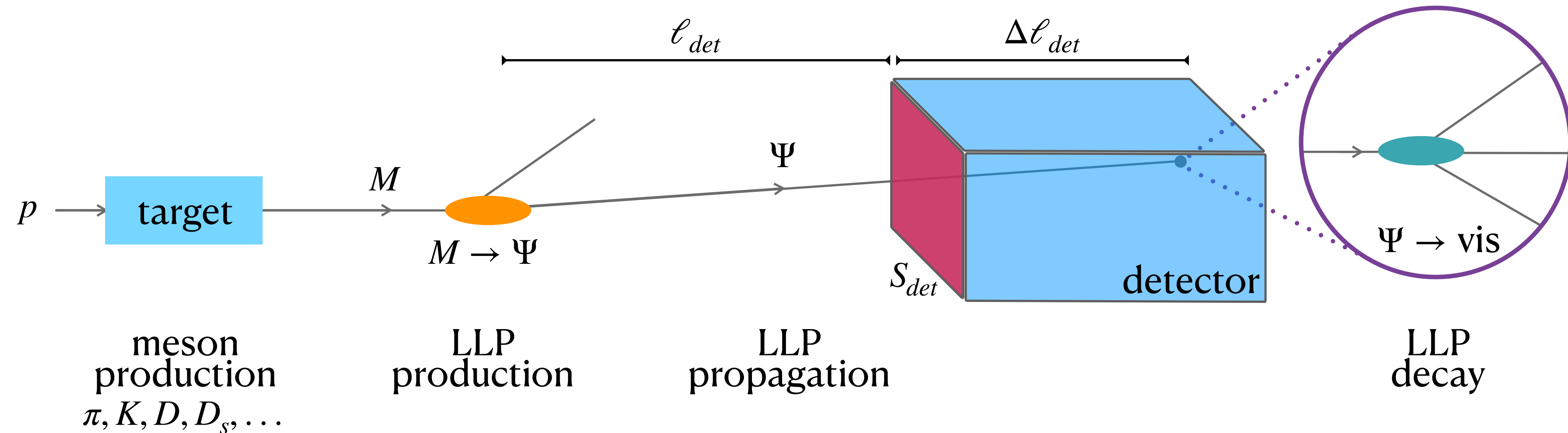


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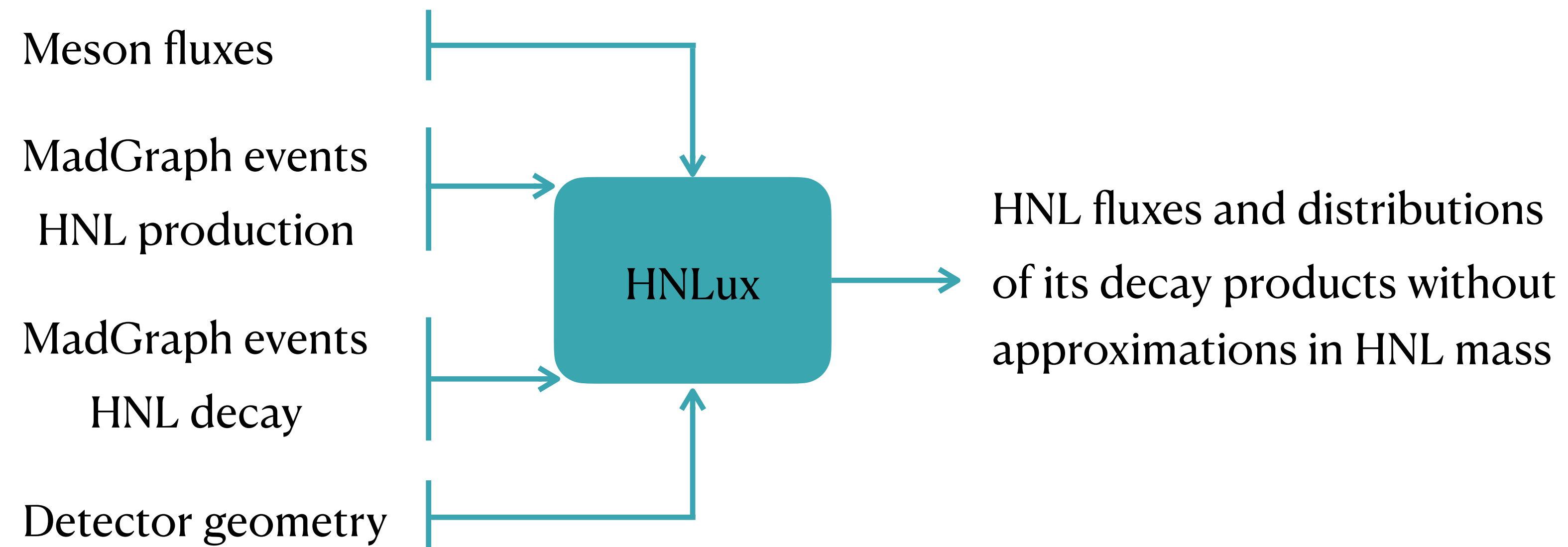


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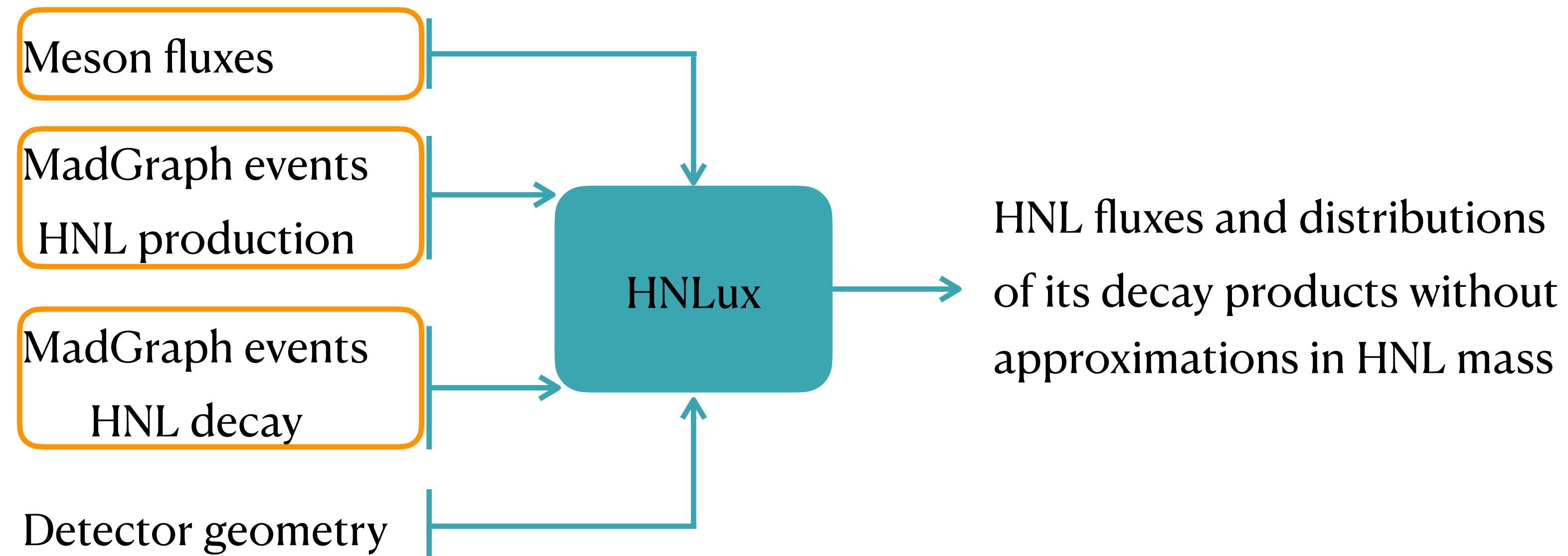
Heavy Neutral Leptons: signal simulation

The simulations were performed with HNLux, a tool to simulate HNL fluxes



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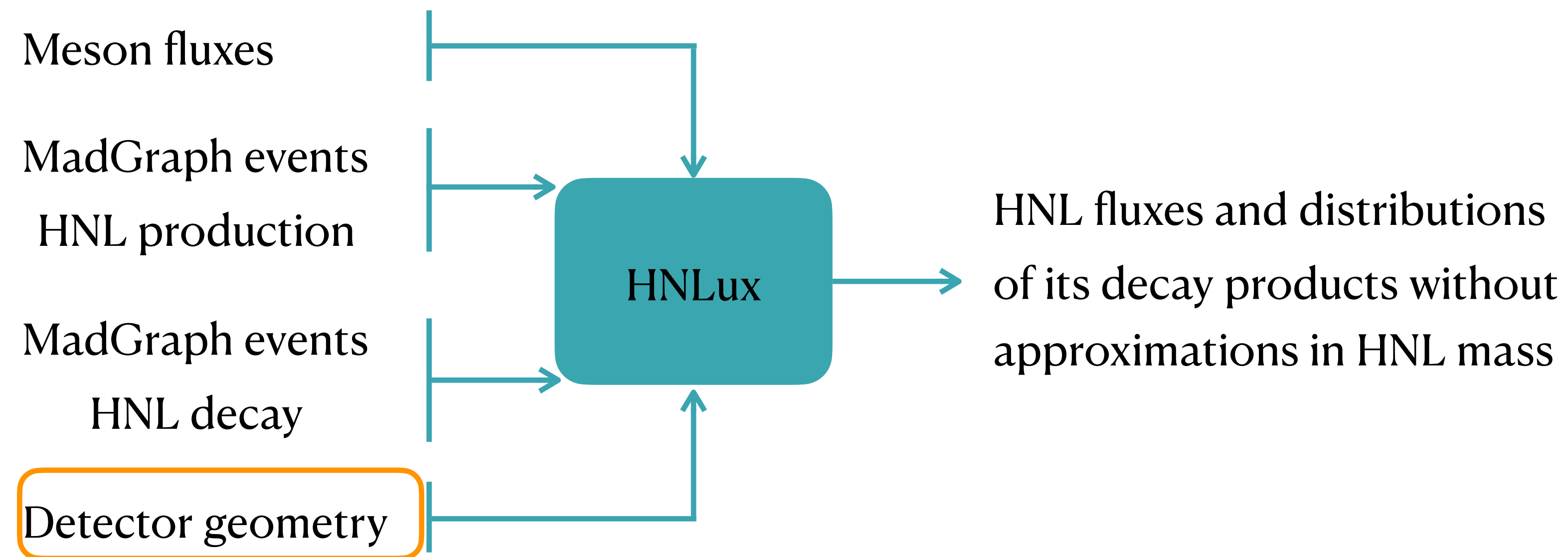


Versatility of HNLux. This tool can be adapted to:

- Other LLP benchmarks by changing the FeynRules model file within the MathGraph simulations, and the meson flux prediction.

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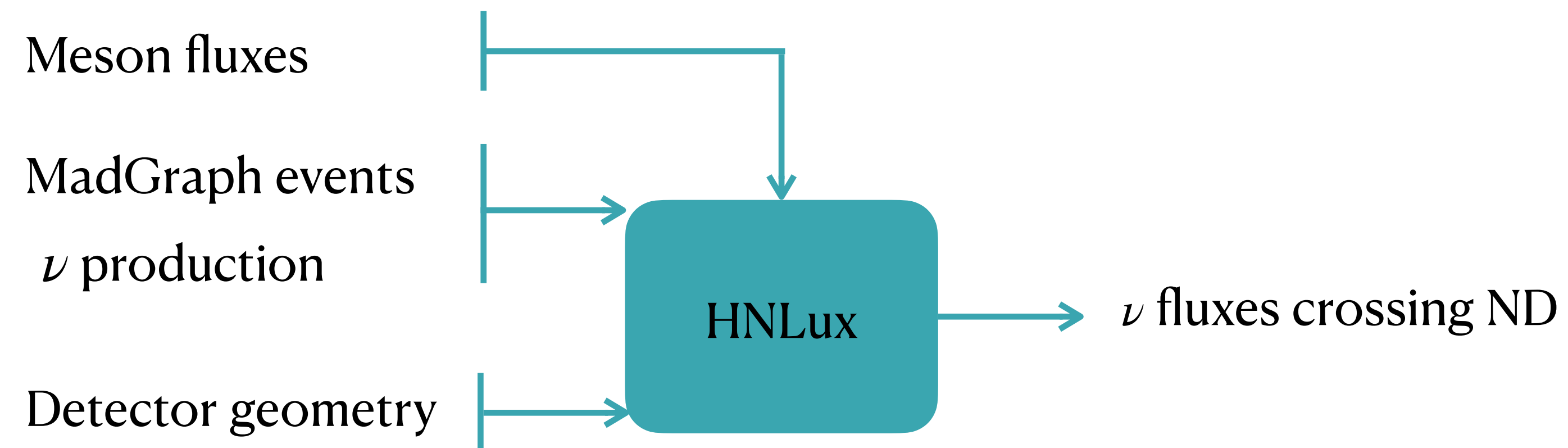


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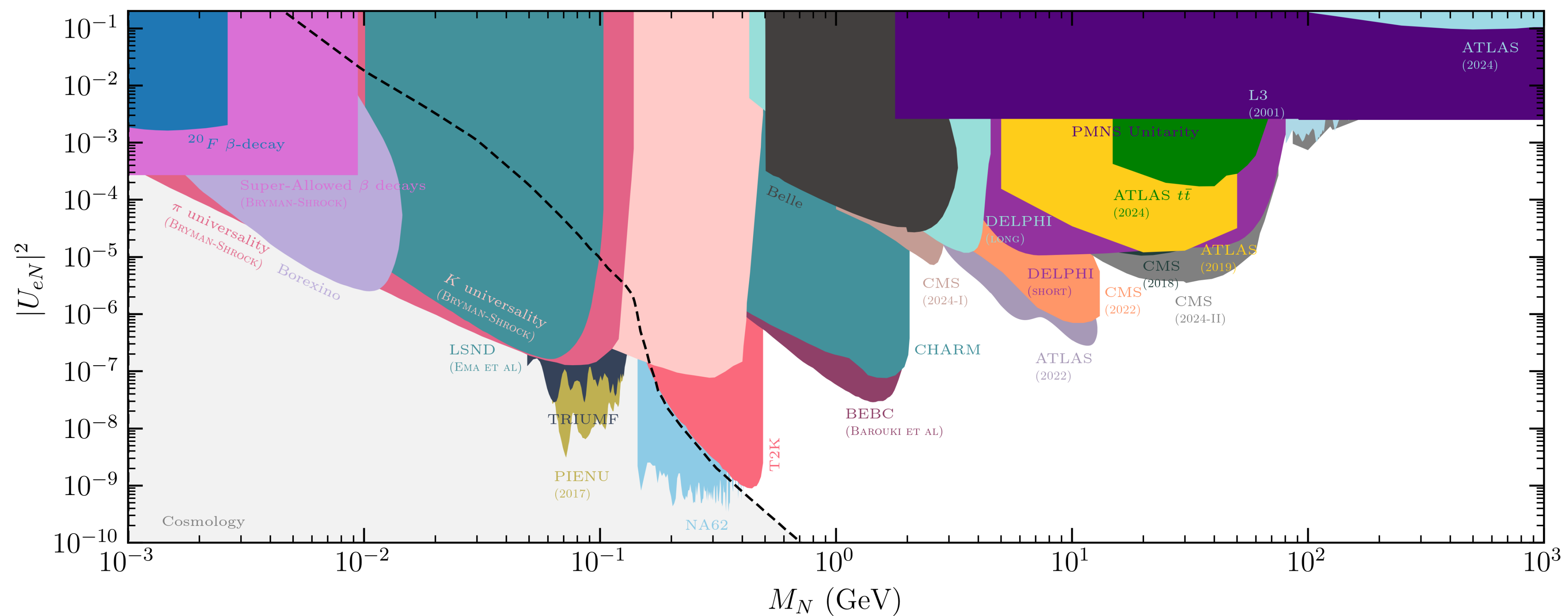
- Other LLP benchmarks by changing the FeynRules model file within the MathGraph simulations, and the meson flux prediction.
- NP04 or NP02 by changing the detector geometry

Light neutrino bkg: flux simulation

The same tool can be used to simulate the light neutrino fluxes



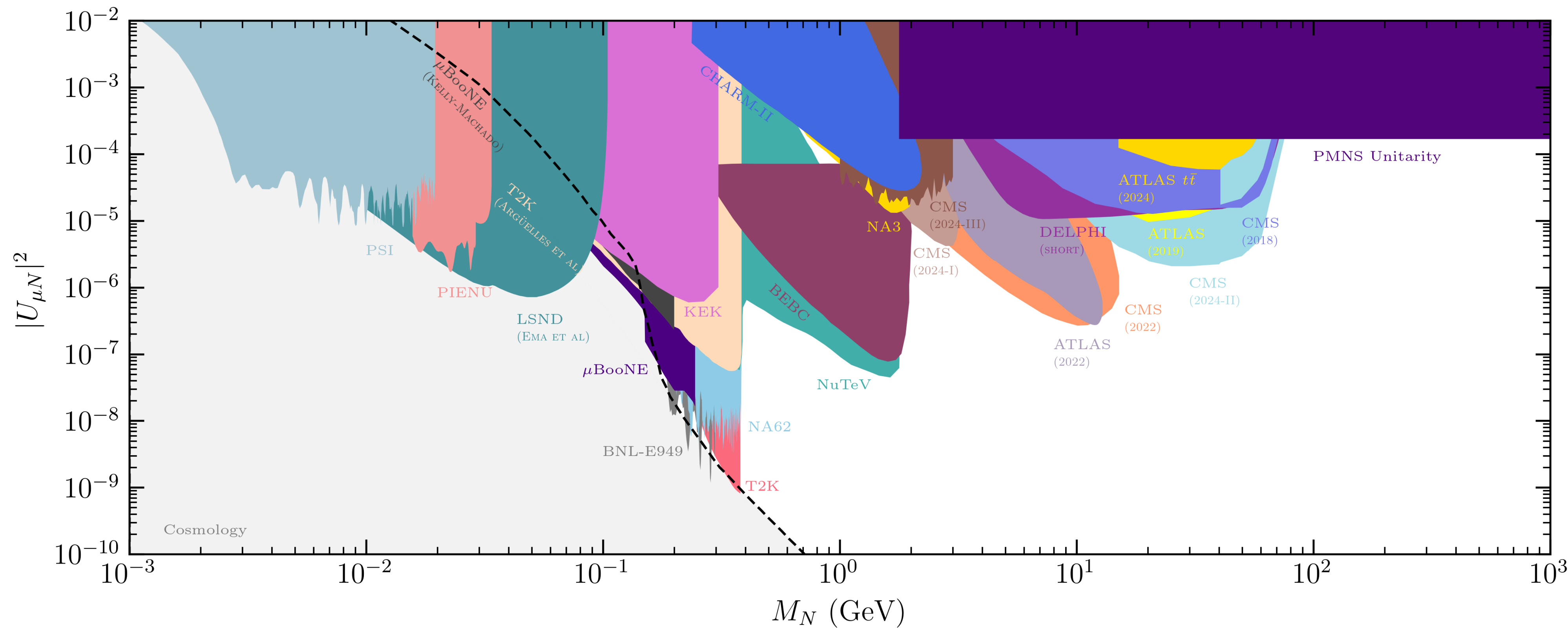
Heavy Neutral Leptons: present bounds



Present bounds in the HNL mixing from ν oscillations, kinks in beta-decay, peaks in meson decays, beam-dumps, colliders, and non-unitarity of the PMNS.



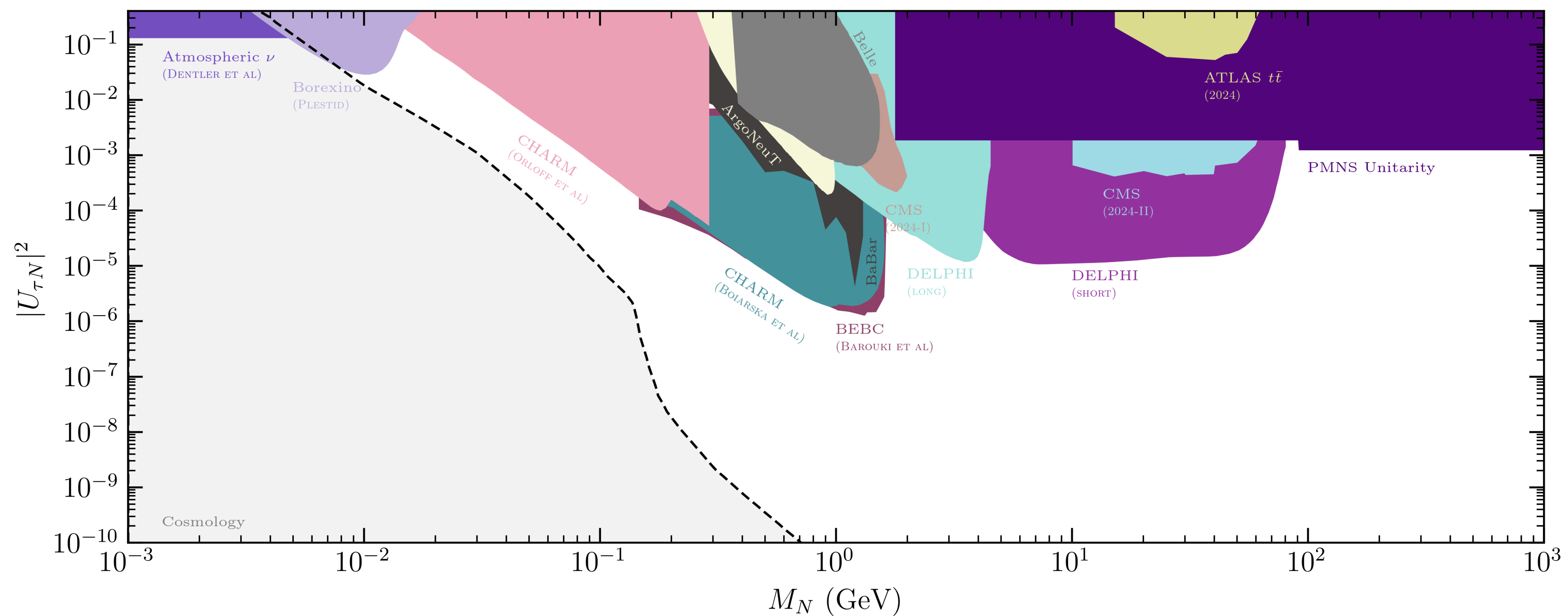
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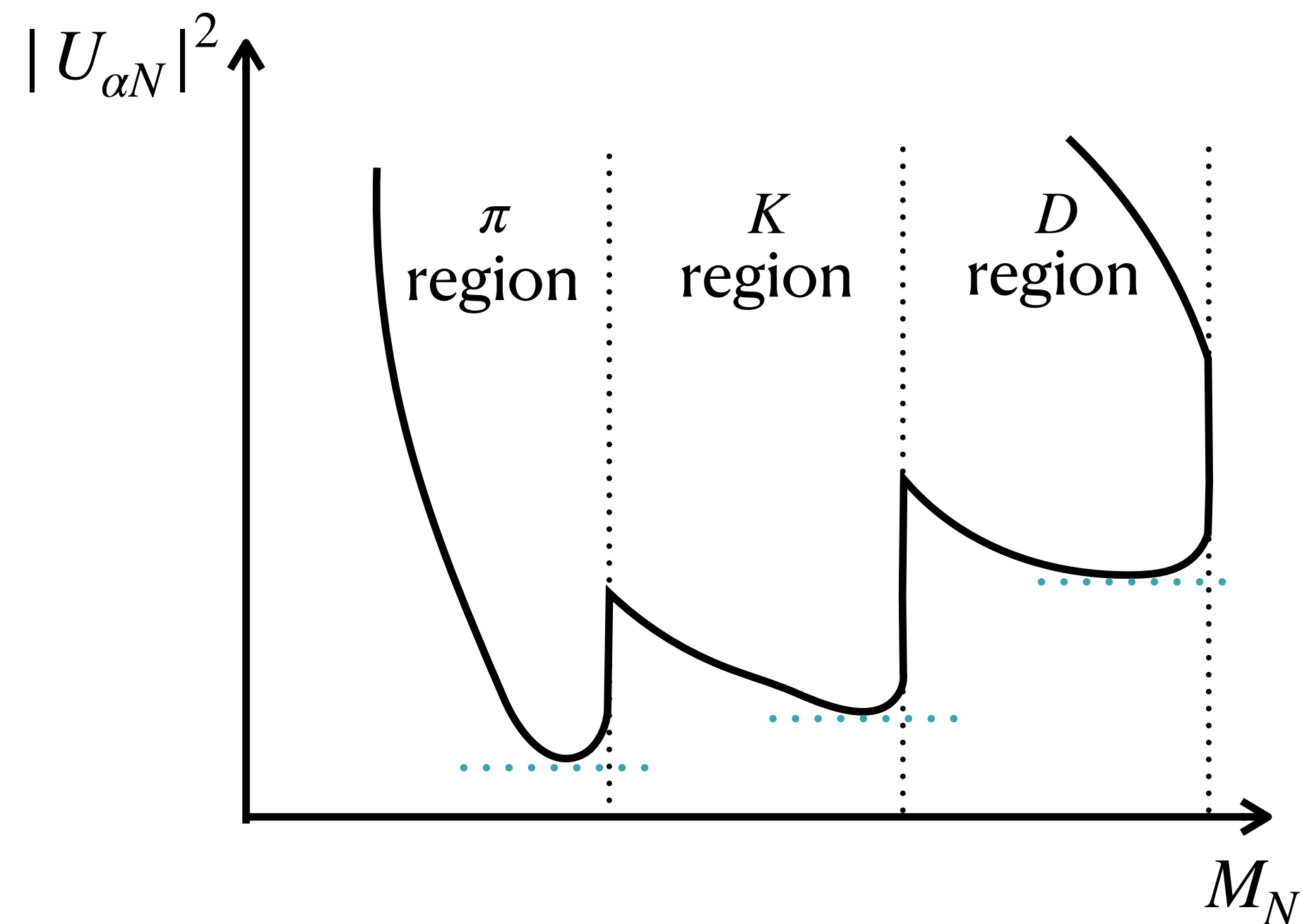


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The shape of the sensitivity line

The HNL sensitivity line shows a characteristic shape coming from:

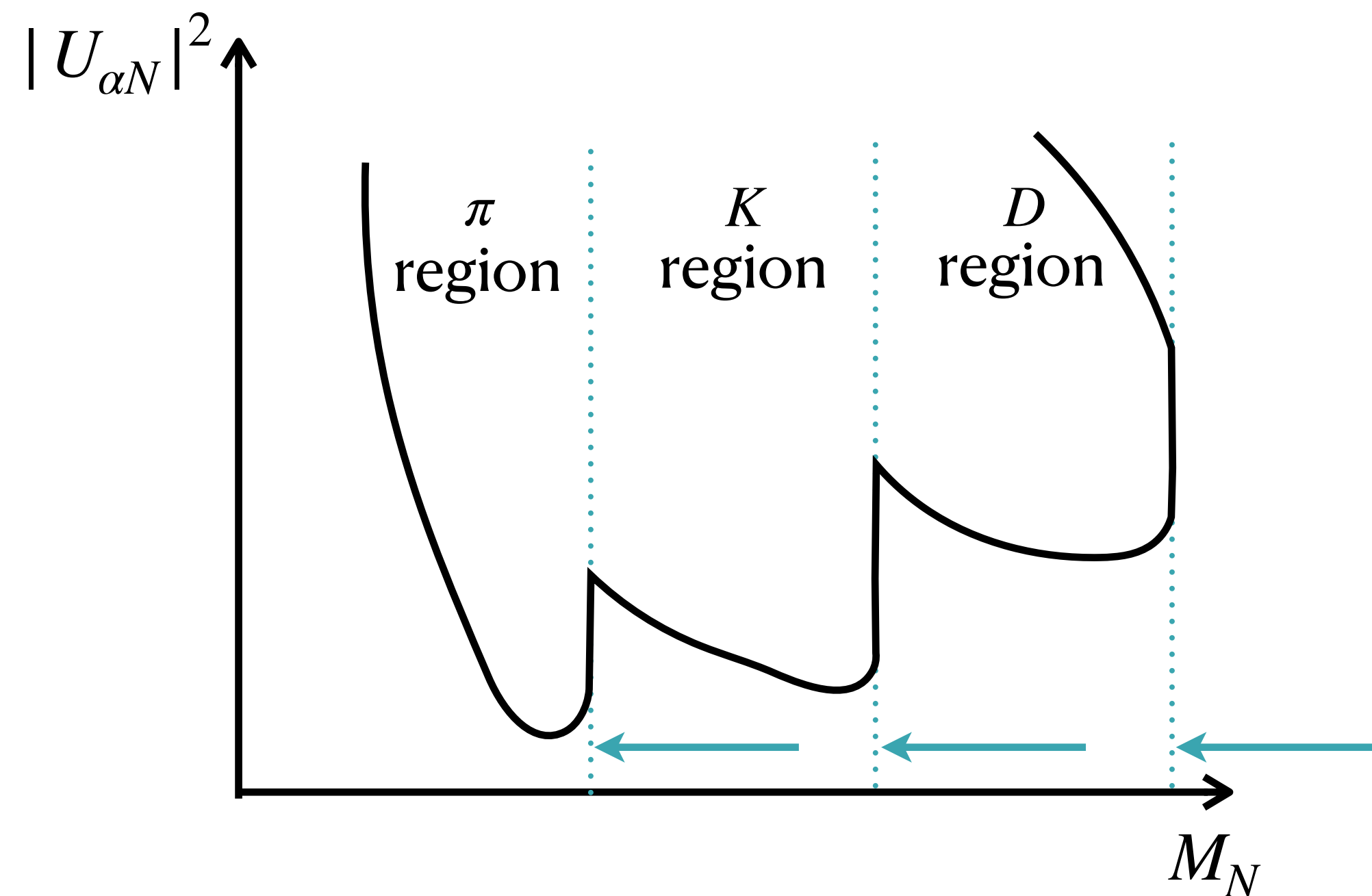


- Meson production yield N_M
 - proton E
 - luminosity (PoT)
 - target material/geometry

$$N_\pi > N_K > N_D \Rightarrow \text{different regions}$$

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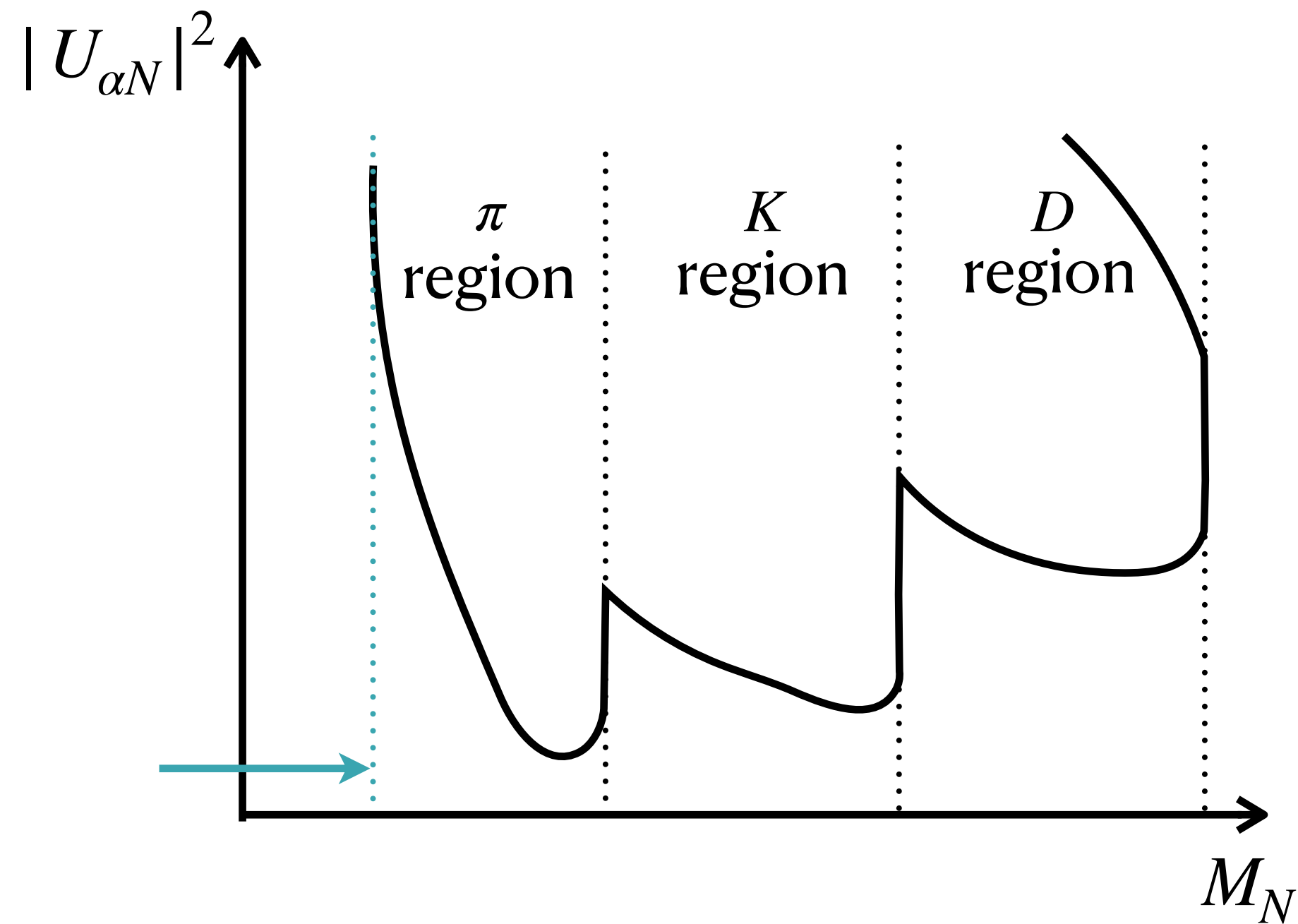
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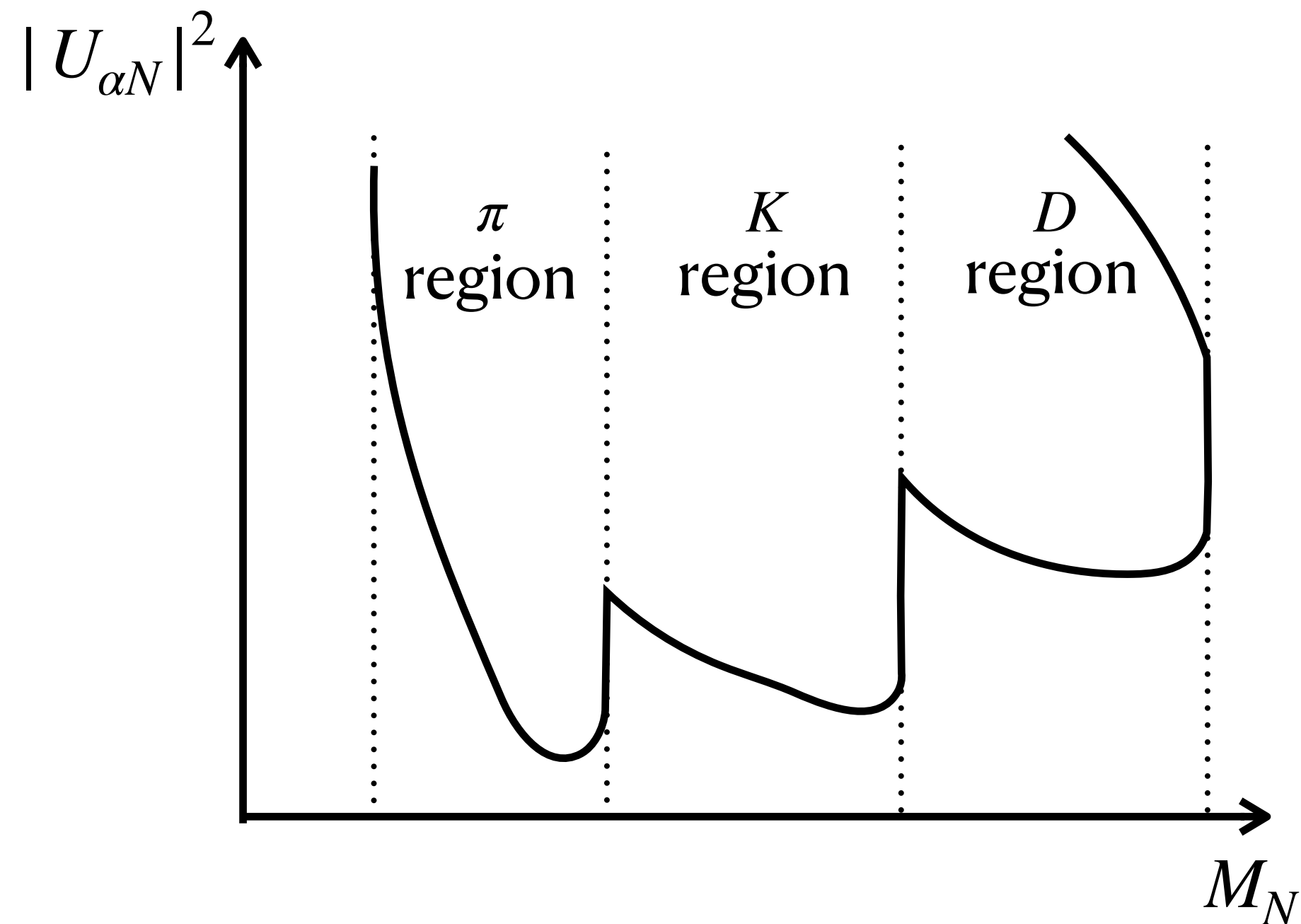
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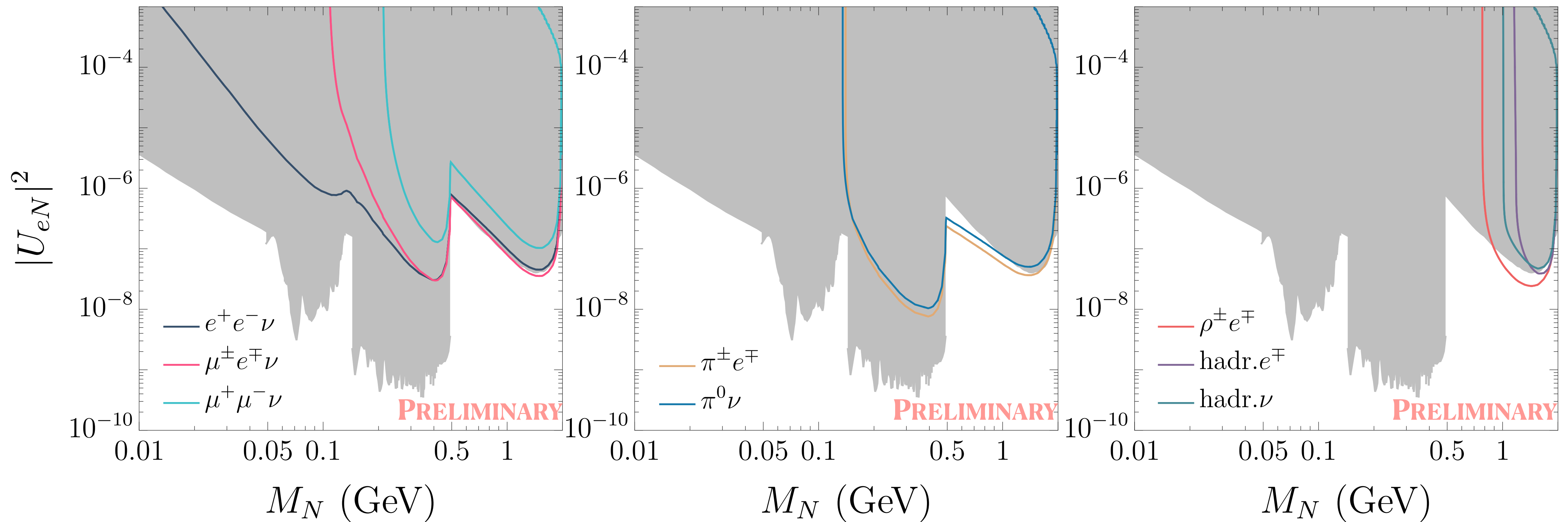
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$|U_{\tau N}|^2$ only via $D/D_s \rightarrow \tau$, and τ decays $\Rightarrow$ less sensitivity due to suppressed production yield

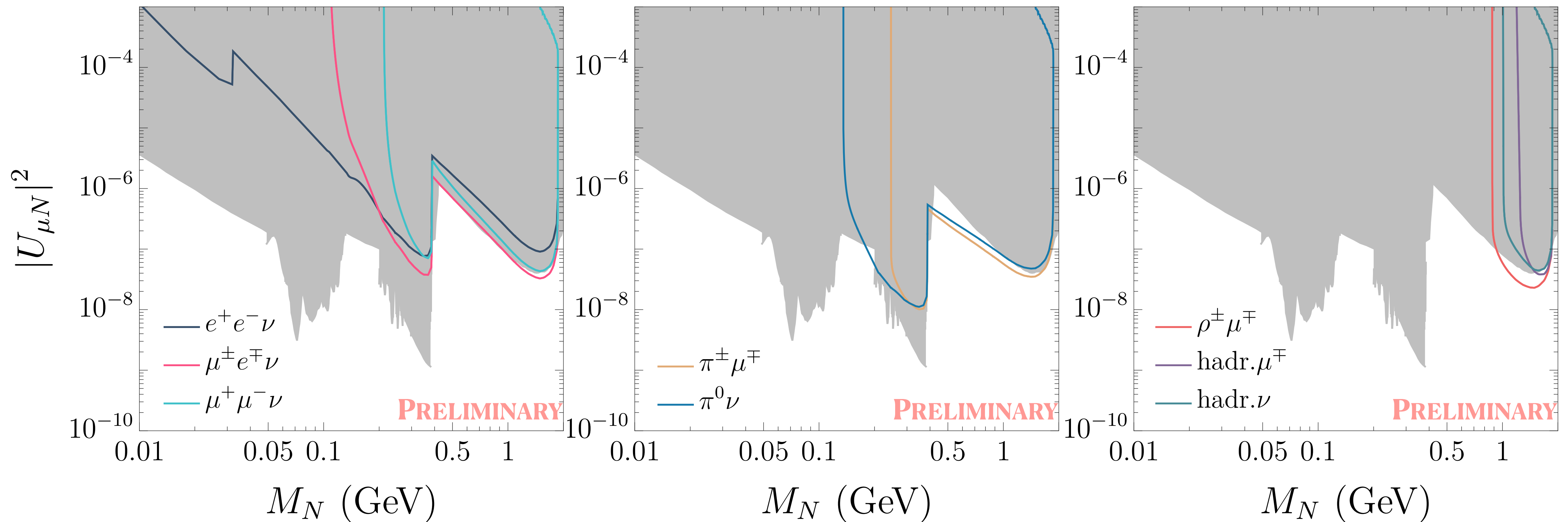
Heavy Neutral Leptons: signal sensitivity

Following the Feldman and Cousins prescription for a Poisson distribution with no background: $N_{ev}^{ex} < 2.3 \Rightarrow 90\% \text{ CL}$



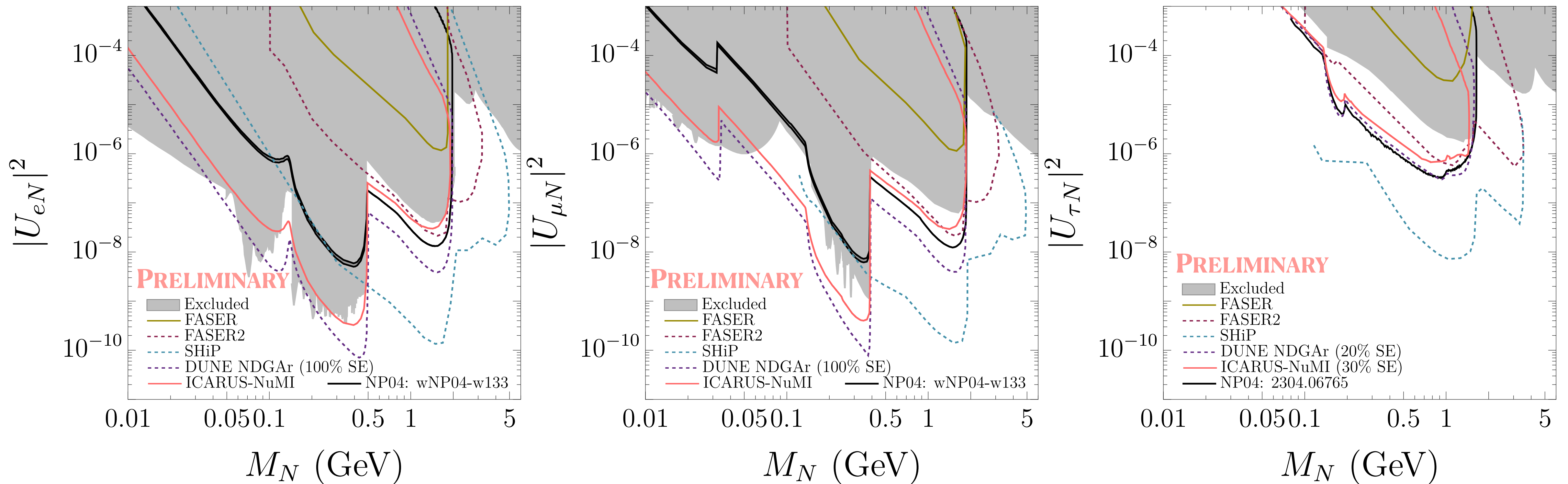
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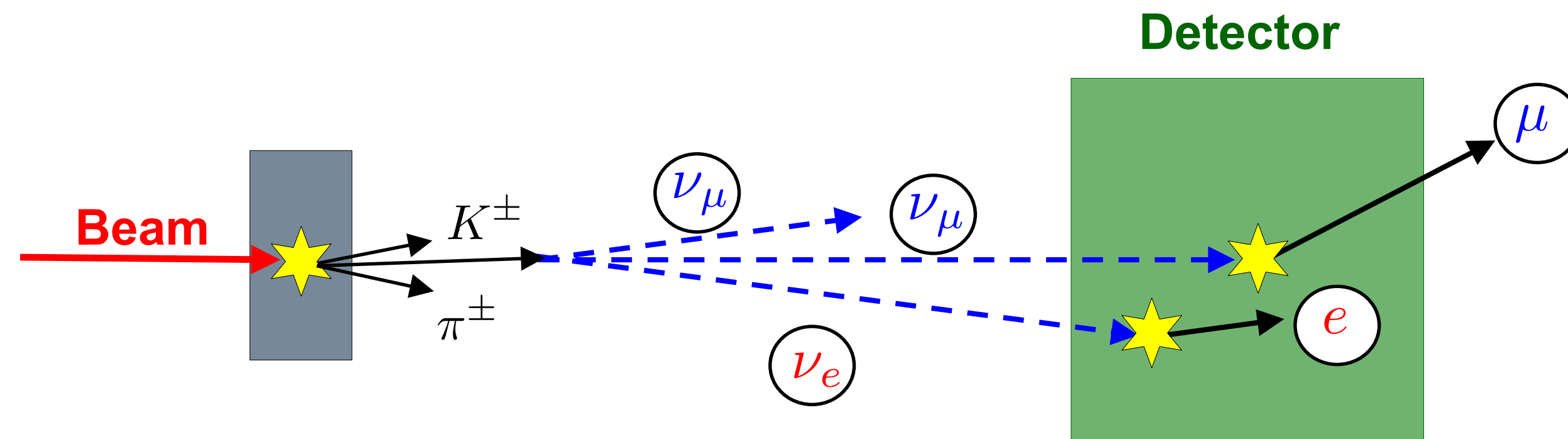
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Sterile neutrino oscillations

1) BSM physics with neutrinos?

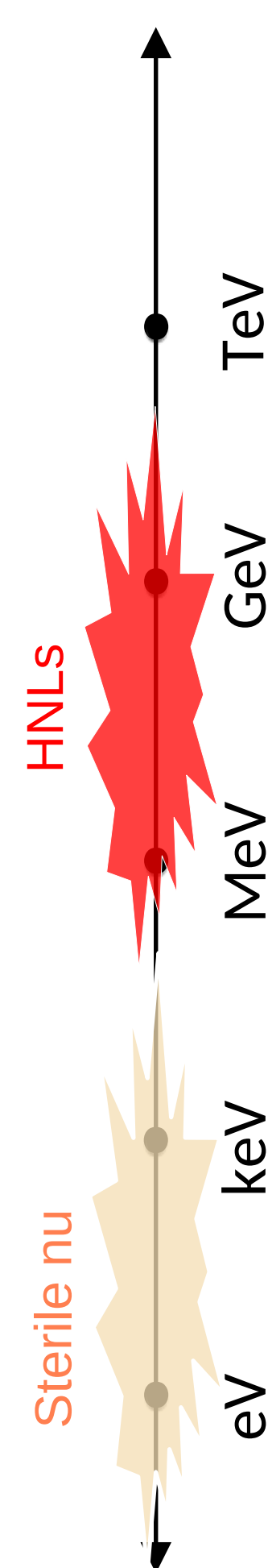


$$P_{\alpha\beta} = \sin^2 2\theta \sin^2 \frac{\Delta m^2 L}{4E}, \quad L \sim 700 \text{ m}$$

- Very small L/E : standard neutrino oscillations very suppressed.
- **Neutrino oscillation signal = New Physics Signal!**

See talk by J. Lopez-Pavon

Sterile neutrino oscillations



1) Sterile Neutrinos ("light HNLS")

- For very light scales M , HNLS (in this regime usually called sterile neutrinos) participate in neutrino oscillations. In simplified 3+1 scenario:

$$\mathcal{P}_{\alpha\beta} = 4|U_{\alpha 4}||U_{\beta 4}| \sin^2 \frac{\Delta m_{41}^2 L}{4E}$$

$$\mathcal{P}_{\alpha\alpha} = 1 - 4|U_{\alpha 4}|^2 \sin^2 \frac{\Delta m_{41}^2 L}{4E}$$

- Neutrino energy needs to be determined. Oscillation in muon neutrinos not accessible since muons not contained. More feasible channels:

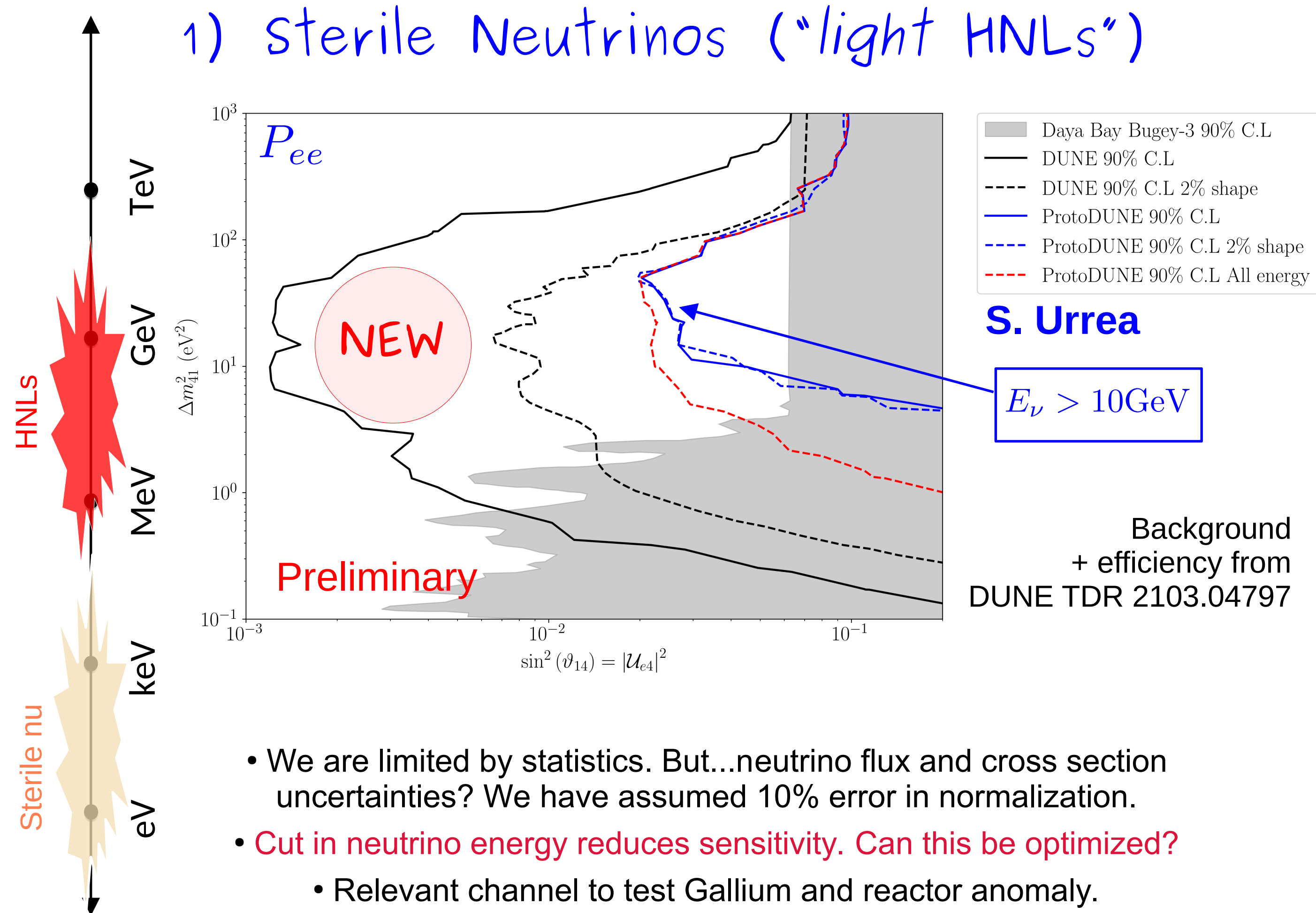
$$\mathcal{P}_{\mu e} \mathcal{P}_{ee}$$

- Can we detect tau neutrinos indirectly through hadronic tau decays?

$$\mathcal{P}_{\mu\tau}?$$

See talk by J. Lopez-Pavon

Sterile neutrino oscillations

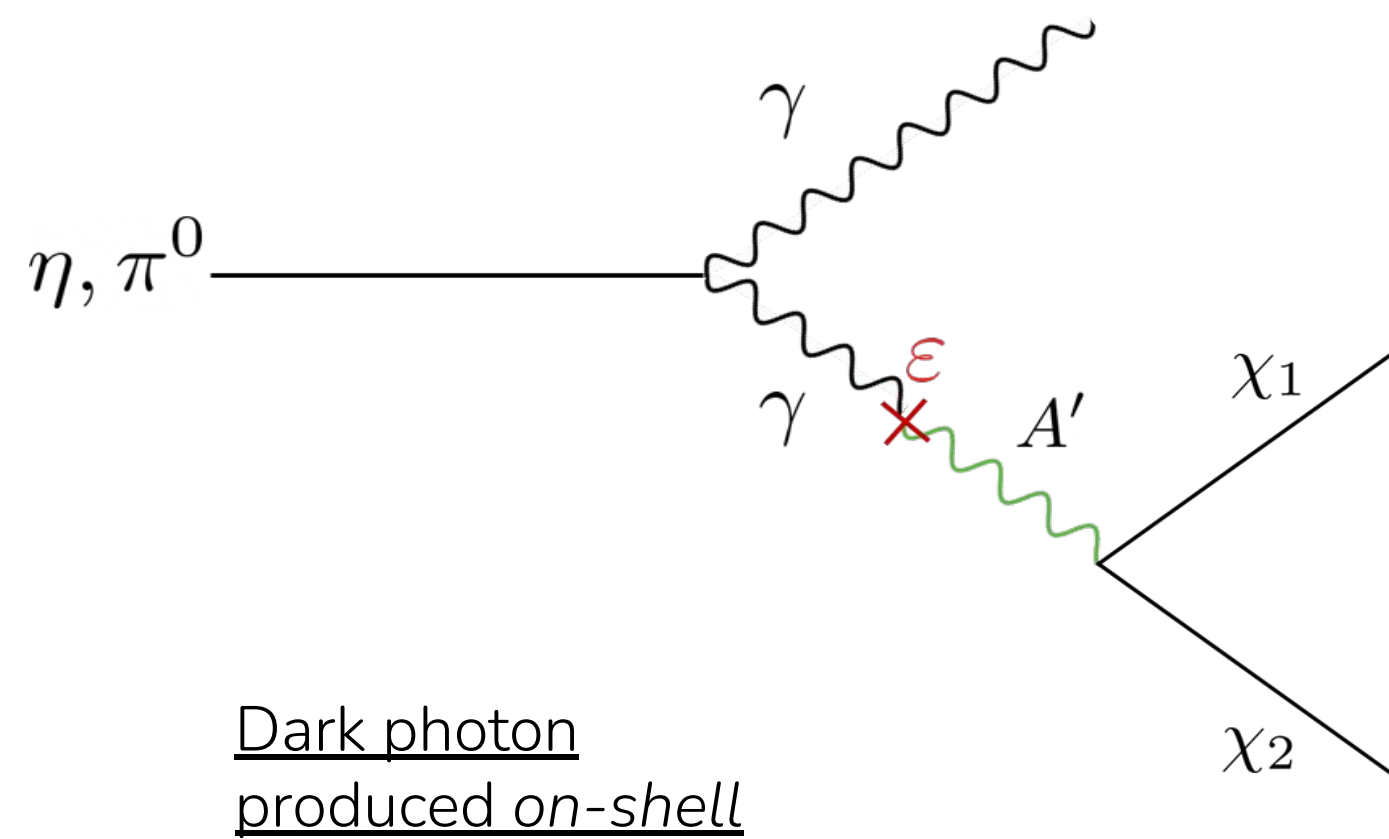


See talk by J. Lopez-Pavon

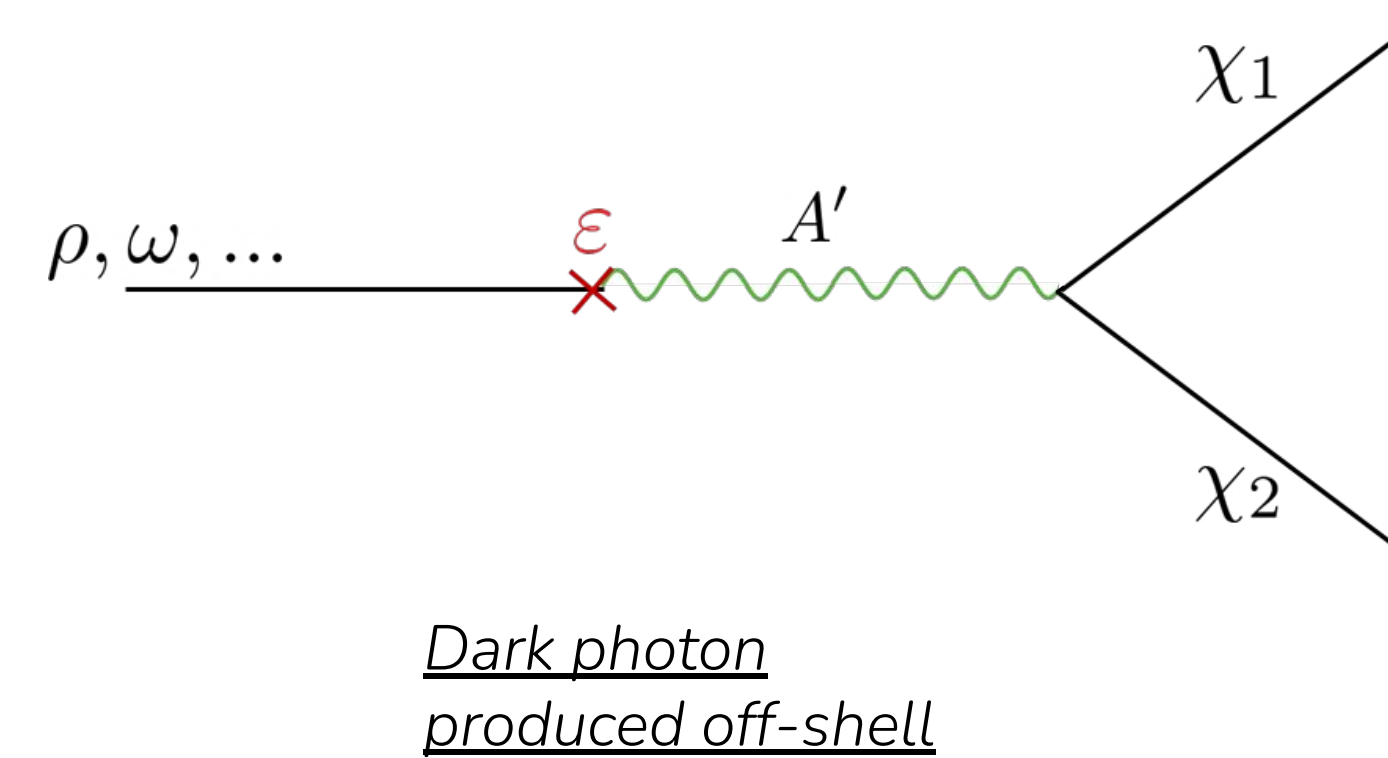
Inelastic Dark Matter

Production from meson decay

Pseudoscalar mesons:



Vector mesons:



⁷
See talk by S. Bianco

Inelastic Dark Matter

Sensitivity from ProtoDUNE: Scattering

Two limits:

→ Low mass region: $m_{A'}^2 \lesssim 2m_e E_e$

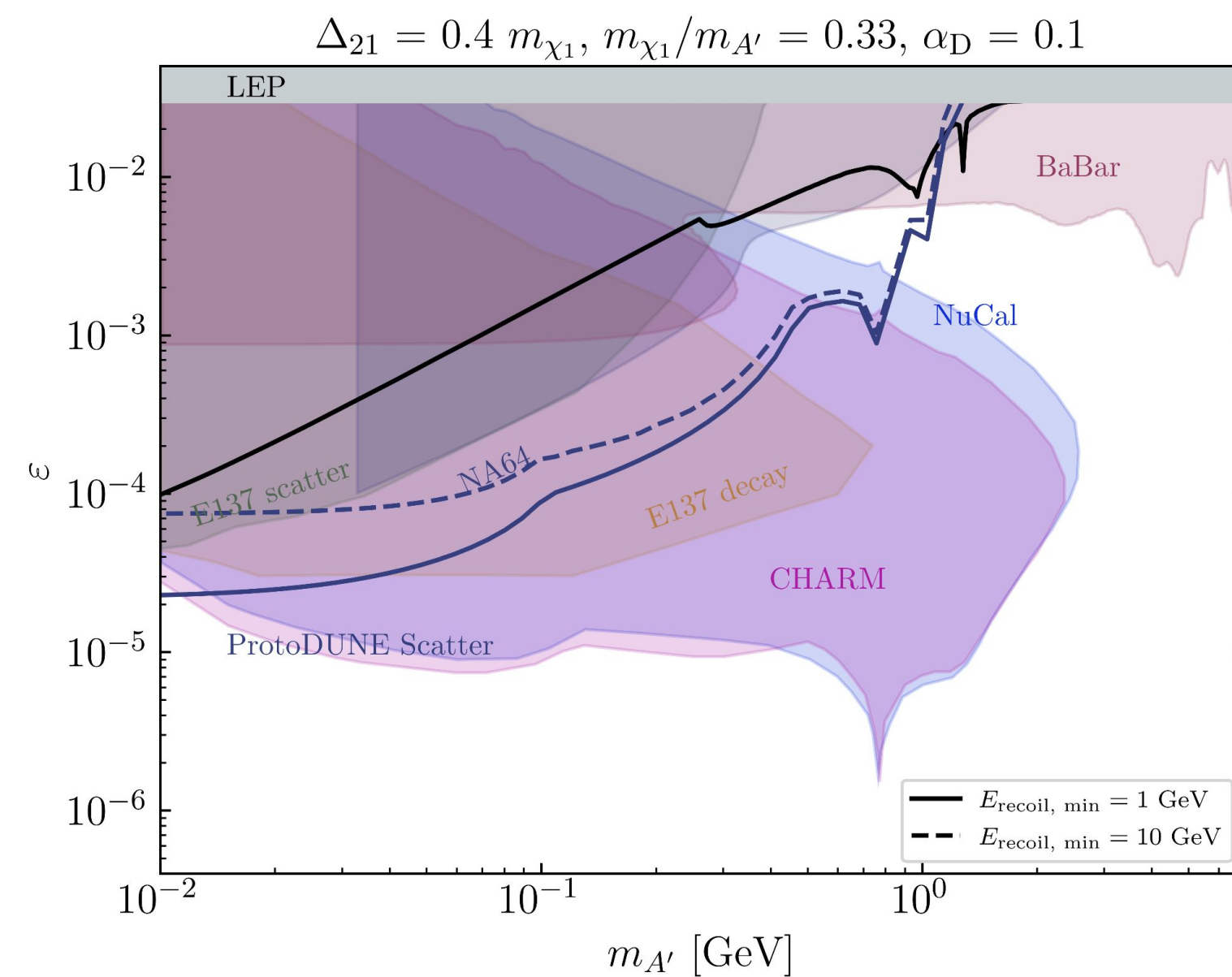
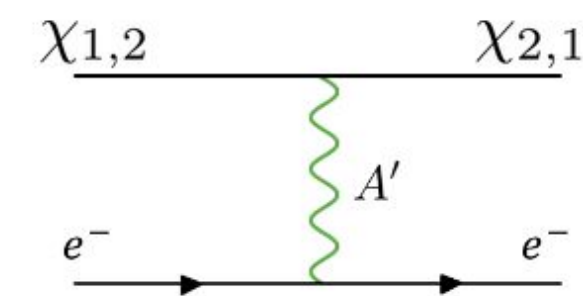
$$\frac{d\sigma}{dE_e} \approx 4\pi\epsilon^2\alpha_{EM}\alpha_D \frac{2E_{\chi_1}^2 m_e}{(E_{\chi_1}^2 - m_1^2)(m_{A'}^2 + 2m_e E_e)^2}$$

$$\gg \gg \sigma \propto \frac{1}{E_{\text{recoil, min}}}$$

→ High mass region: $m_{A'}^2 \gg 2m_e E_e$

$$\frac{d\sigma}{dE_e} \approx 8\pi\epsilon^2\alpha_{QED}\alpha_D \frac{2E_{\chi_1}^2 m_e - E_{\chi_1}(m_2^2 - m_1^2)}{E_{\chi_1}^2 m_{A'}^4}$$

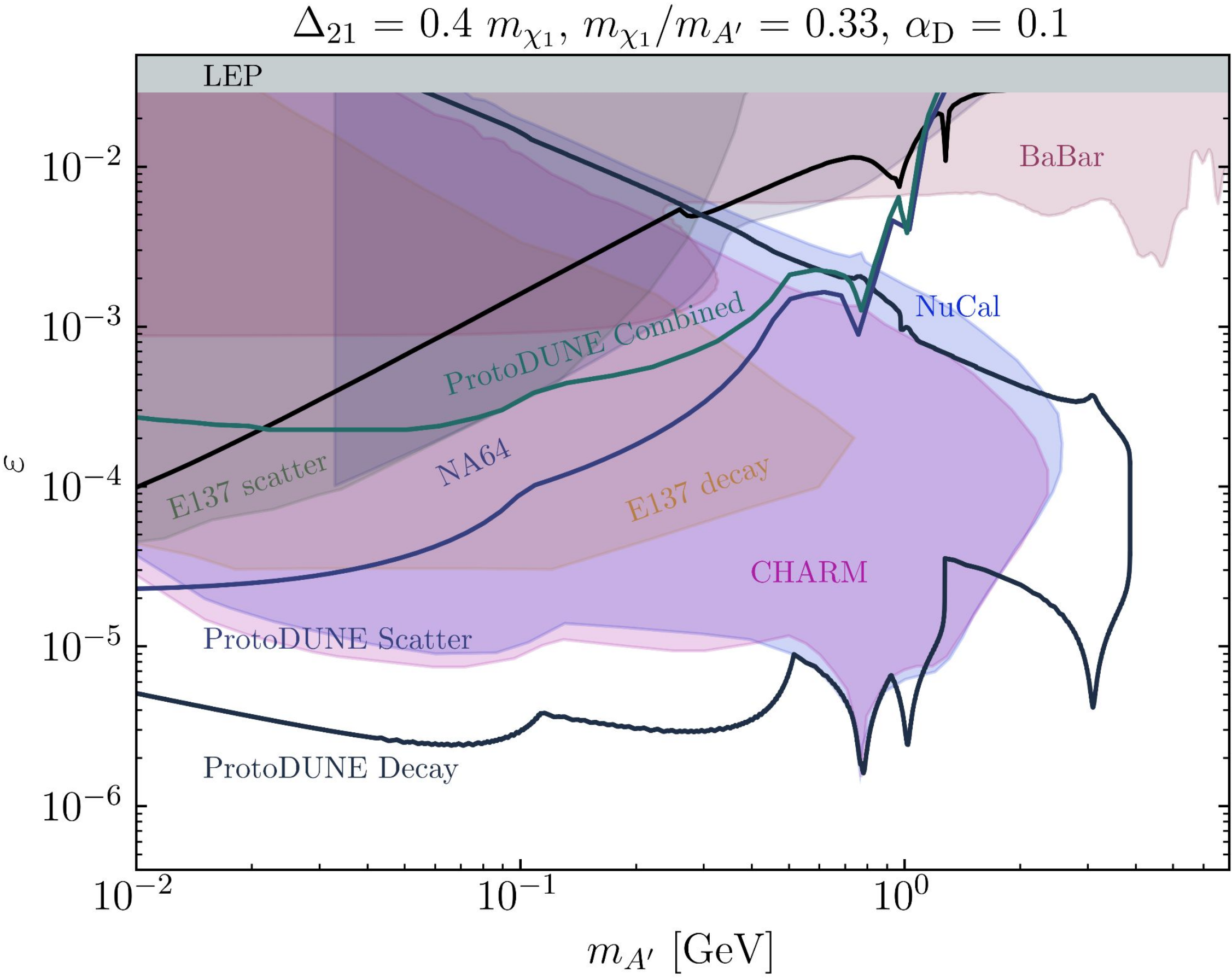
$$\gg \gg \sigma \propto E_{\text{recoil, max}} - E_{\text{recoil, min}} \approx E_{\text{recoil, max}}$$



12
See talk by S. Bianco

Inelastic Dark Matter

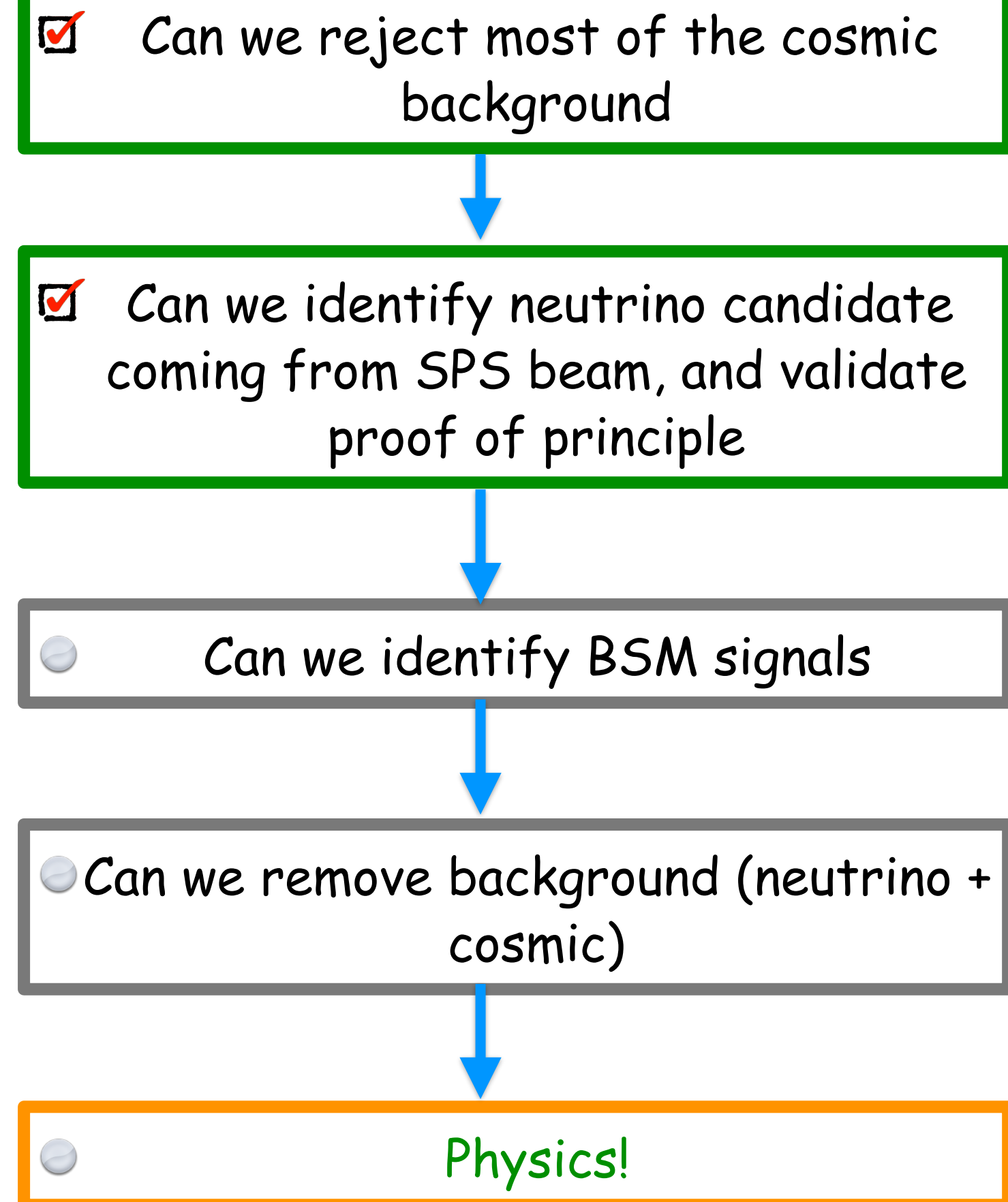
Thank you for
your attention!



See talk by S. Bianco

Plans for the analysis

- * Trigger rate of 1-2 Hz shows we **reject most cosmics at the trigger level** (but most of our triggered events are still cosmics)
- * Measured cosmic background rate from Spill Off data.
- * Analysis ongoing to show neutrino events from reconstructed data, results will be available soon!
- * MC simulation and event selection of BSM/HNL ongoing



See talk by A. Chatterjee

Axion-Like Particles: motivation

Arise in SM extensions as pseudo-Nambu-Goldstone bosons of a spontaneous global symmetry breaking

The best motivated example is the QCD axion introduced to address the strong CP problem in QCD

The ALPs could be coupled to the SM with different sets of effective operators

In the following I focus on the **gluon dominance** scenario

$$\delta\mathcal{L}_{a,int} = \frac{\alpha_S}{8\pi f_a} a G_{\mu\nu}^b \tilde{G}^{b\mu\nu}$$

Phenomenology encoded in **2 free parameters**: the ALP mass m_a and its decay constant f_a

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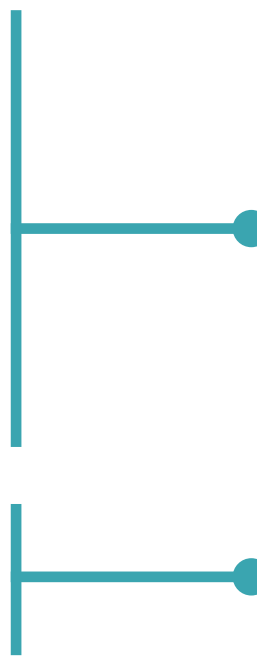
Concerning the ALP decay constant f_a :

- It characterizes the energy scale at which the global symmetry is spontaneously broken
- It controls how weakly the ALP interacts with SM particles: $1/f_a$ related to ALP interaction strength

Axion-Like Particles: present bounds

- Present leading **visible** bounds on ALPs coupled to gluons:

- $K^\pm \rightarrow \pi^\pm \gamma\gamma$: NA62 [arXiv: 1402.4334] and E949 [arXiv: hep-ex/0505069]
- $K_L \rightarrow \pi^0 \gamma\gamma$: NA48/2 [arXiv: hep-ex/0205010]] and kTEV [arXiv: 0805.0031]
- $B \rightarrow Ka, a \rightarrow \gamma\gamma$: BaBar [arXiv: 2111.01800]
- LLP decays into $\gamma\gamma$: CHARM [Phys. Lett. B 157 (1985) 458]



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bounds derived in
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- Present leading **invisible** bounds on ALPs coupled to gluons:

Bounds assuming that the ALP **scapes** the detector without decaying

- $K \rightarrow \pi a$ from $K \rightarrow \pi \nu \bar{\nu}$: NA62 [arXiv: 2011.11329, 2010.07644], E787 and E949 [arXiv: 0903.0030]
- $B \rightarrow Ka$ from $B \rightarrow K \nu \bar{\nu}$: Belle [arXiv: 1702.03224]

Bounds derived in arXiv: 2201.07805

Axion-Like Particles: production and decay

- ALP production

- $m_a < 1\text{GeV}$:

- via mixing with neutral pseudoscalar mesons

$$\pi^0, \eta, \eta' \cdots \times \cdots a$$

- $m_a > 1\text{GeV}$:

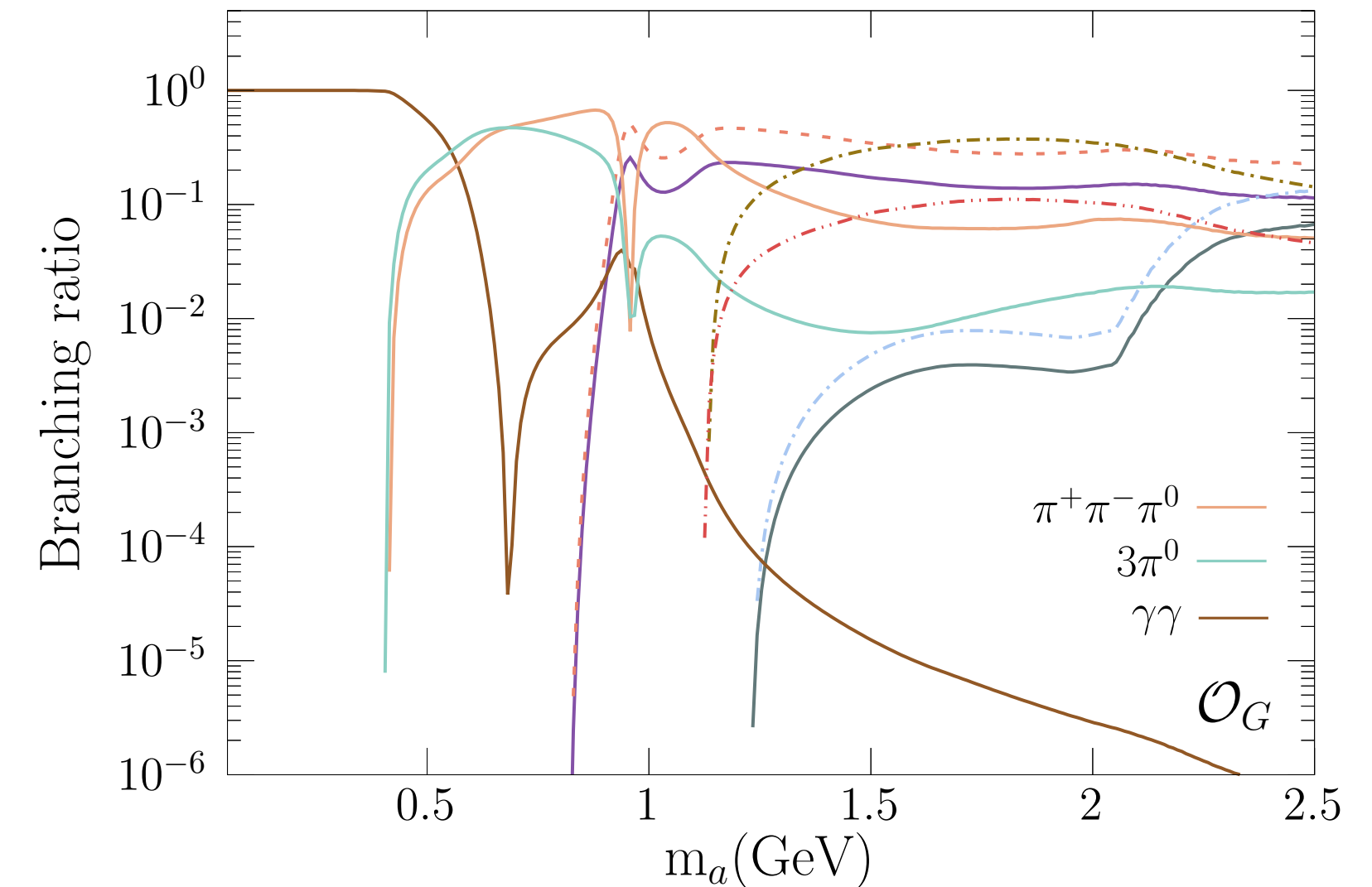
- via gluon fusion

- ALP decay

Relevant ALP decay channels in DUNE mass window

- $m_a < 3m_\pi : a \rightarrow \gamma\gamma$

- $m_a > 3m_\pi : a \rightarrow 3\pi^0$ and $a \rightarrow \pi^+\pi^-\pi^0$



Dark scalar: motivation

Additional scalars appear in BSM models to stabilize the EW vacuum

In minimal models the additional scalar mixes with the Higgs boson after EWSB

$$\mathcal{L} \supset c_2 |H|^2 S$$

Phenomenology encoded in **2 free parameters**: the dark scalar mass m_S and its mixing $\theta \sim c_2 v_H / m_H$

Dark scalar: production and decay

- Dark scalar production

One-loop FCNC processes

- $K^+ \rightarrow \pi^+ S$

- $K_L \rightarrow \pi^0 S$

D decays CKM suppressed

B decays not suppressed, but small production yield

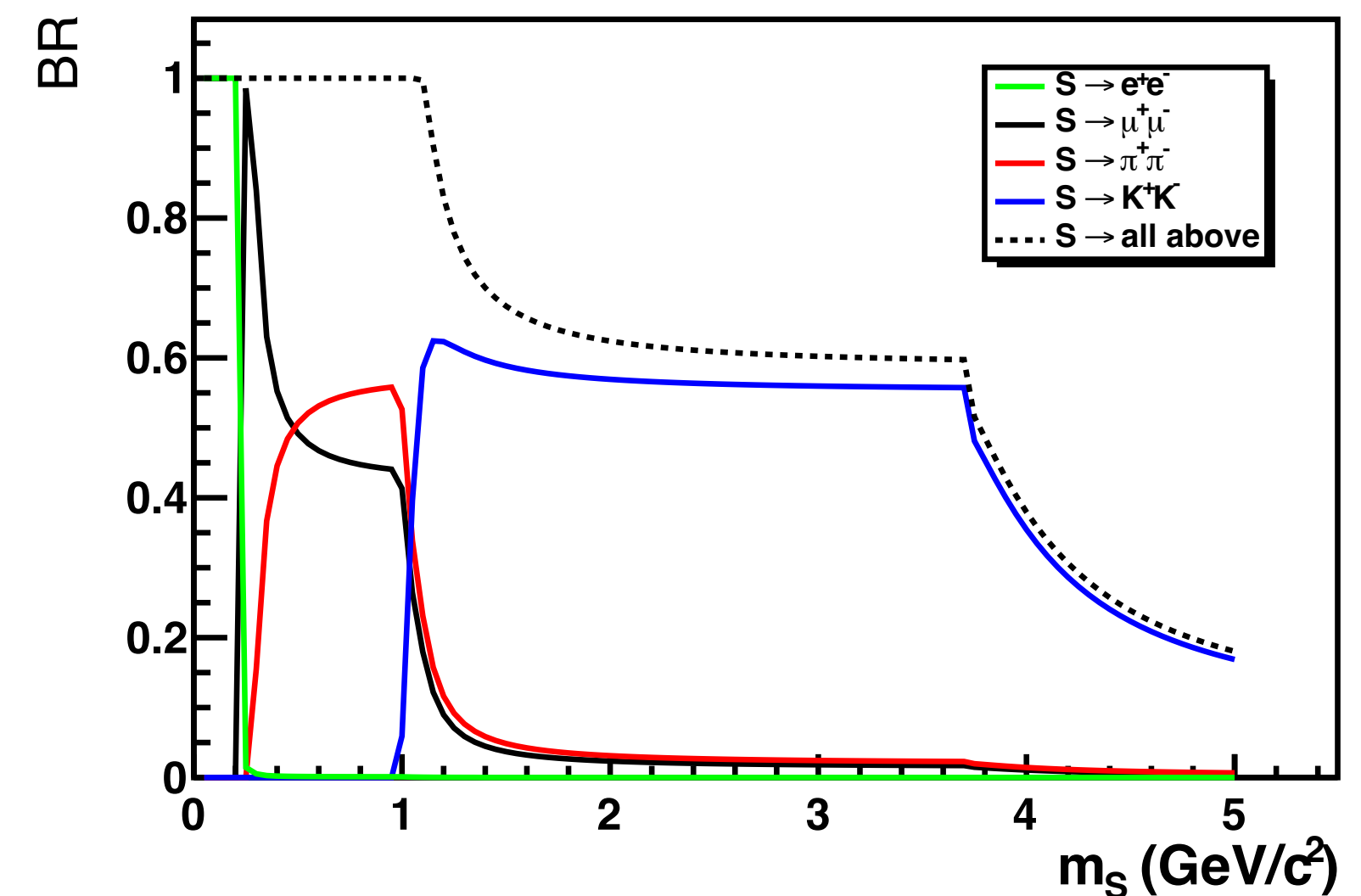
- Dark scalar decay

Relevant S decay channels in DUNE mass window

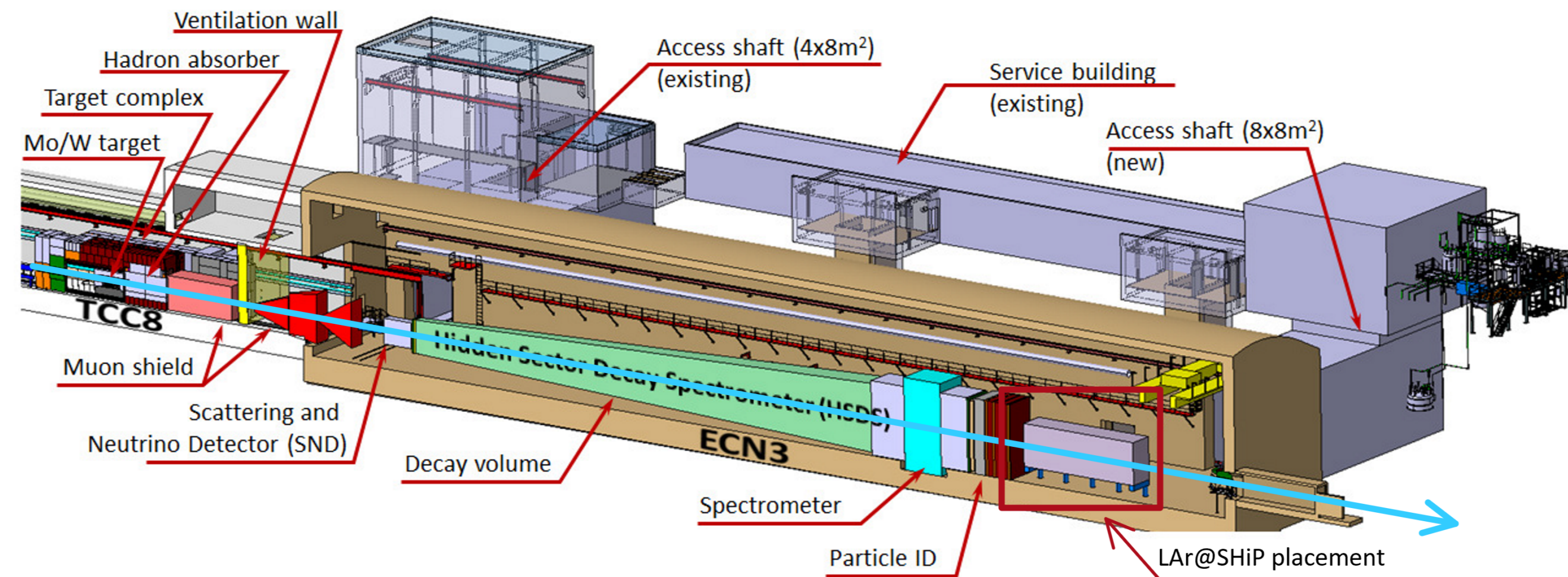
- $S \rightarrow e^+ e^-$

- $S \rightarrow \mu^+ \mu^-$

- $S \rightarrow \pi^+ \pi^-$ and $S \rightarrow \pi^0 \pi^0$



The SHiP experiment

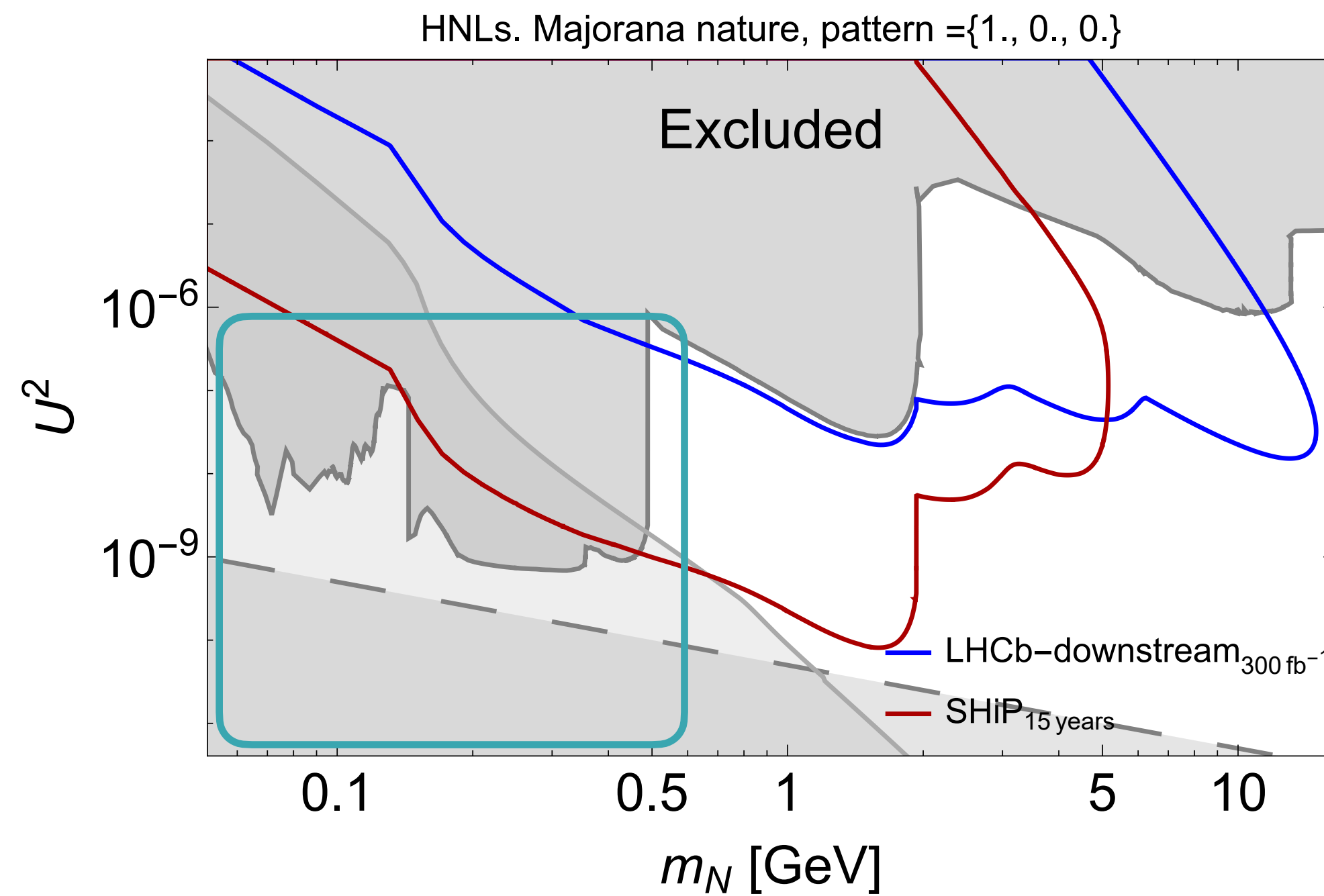
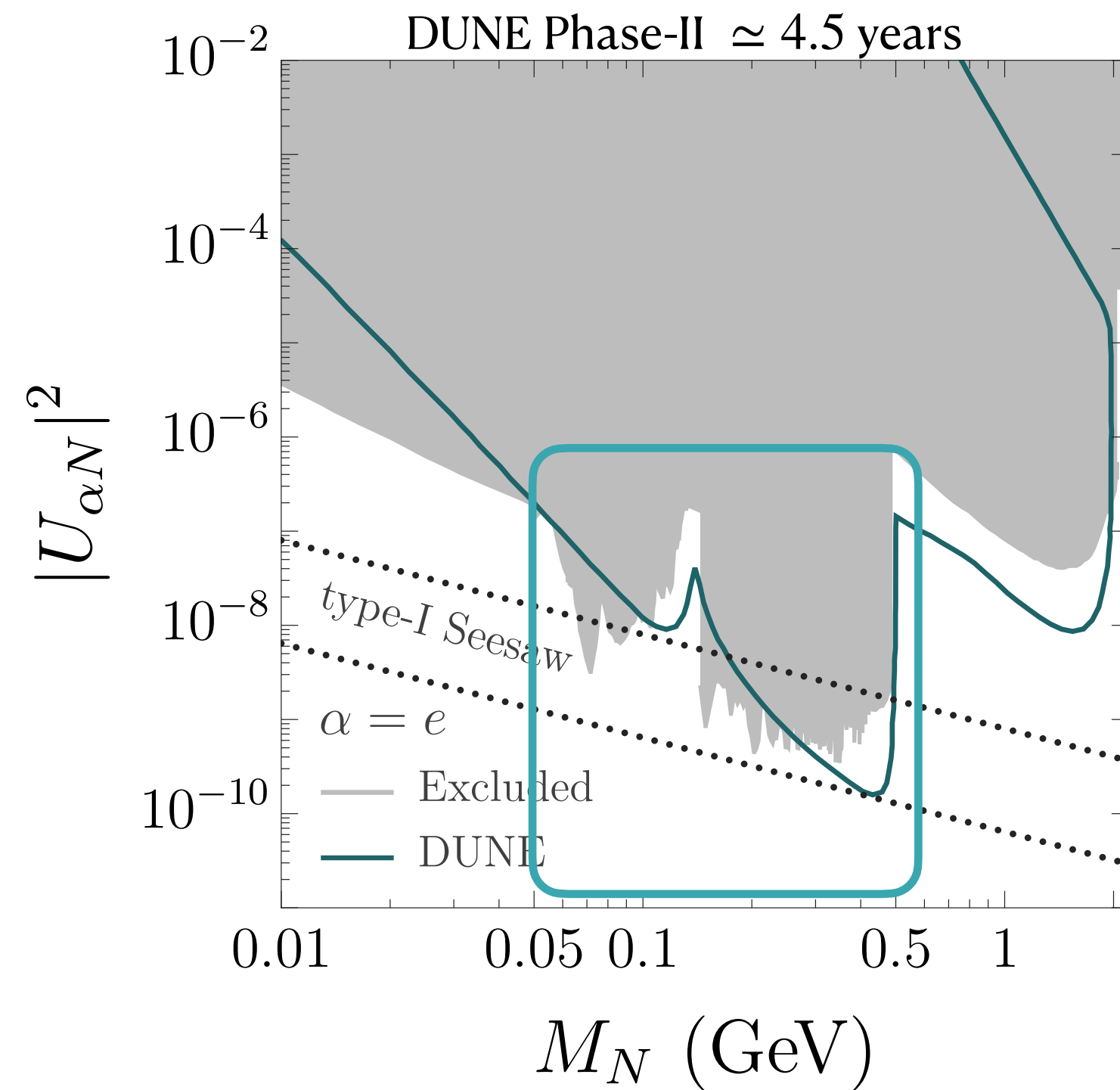


SHiP experiment highlights:

- Proton energy of 400 GeV
- Expected running time $\simeq 2030 - 2045$
- Large beam intensity $4 \cdot 10^{19}$ PoT/year $\Rightarrow$ an expected total of $\simeq 2 \cdot 10^{20}$ PoT
- “Background-free” experiment for many scenarios
- Fully instrumented

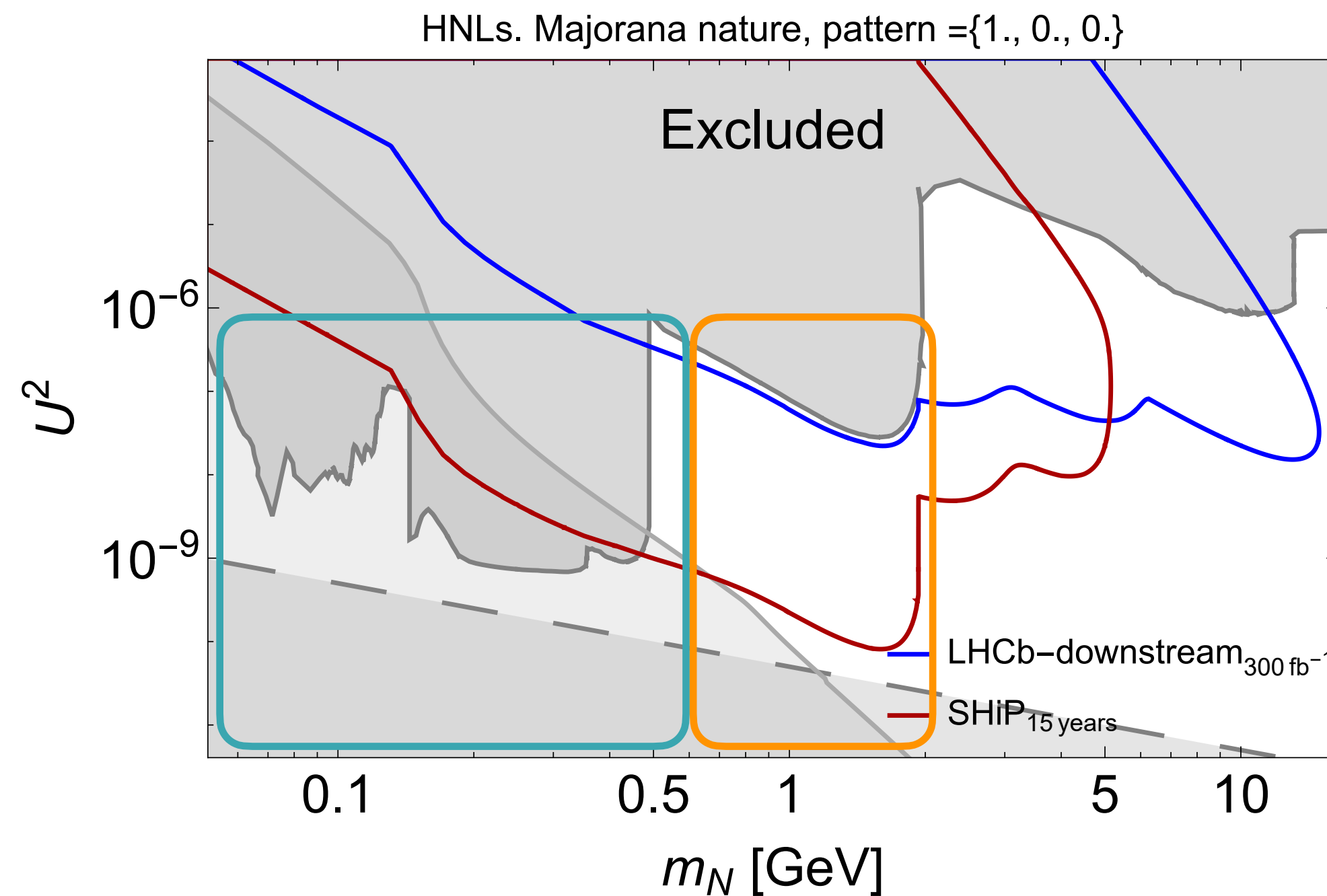
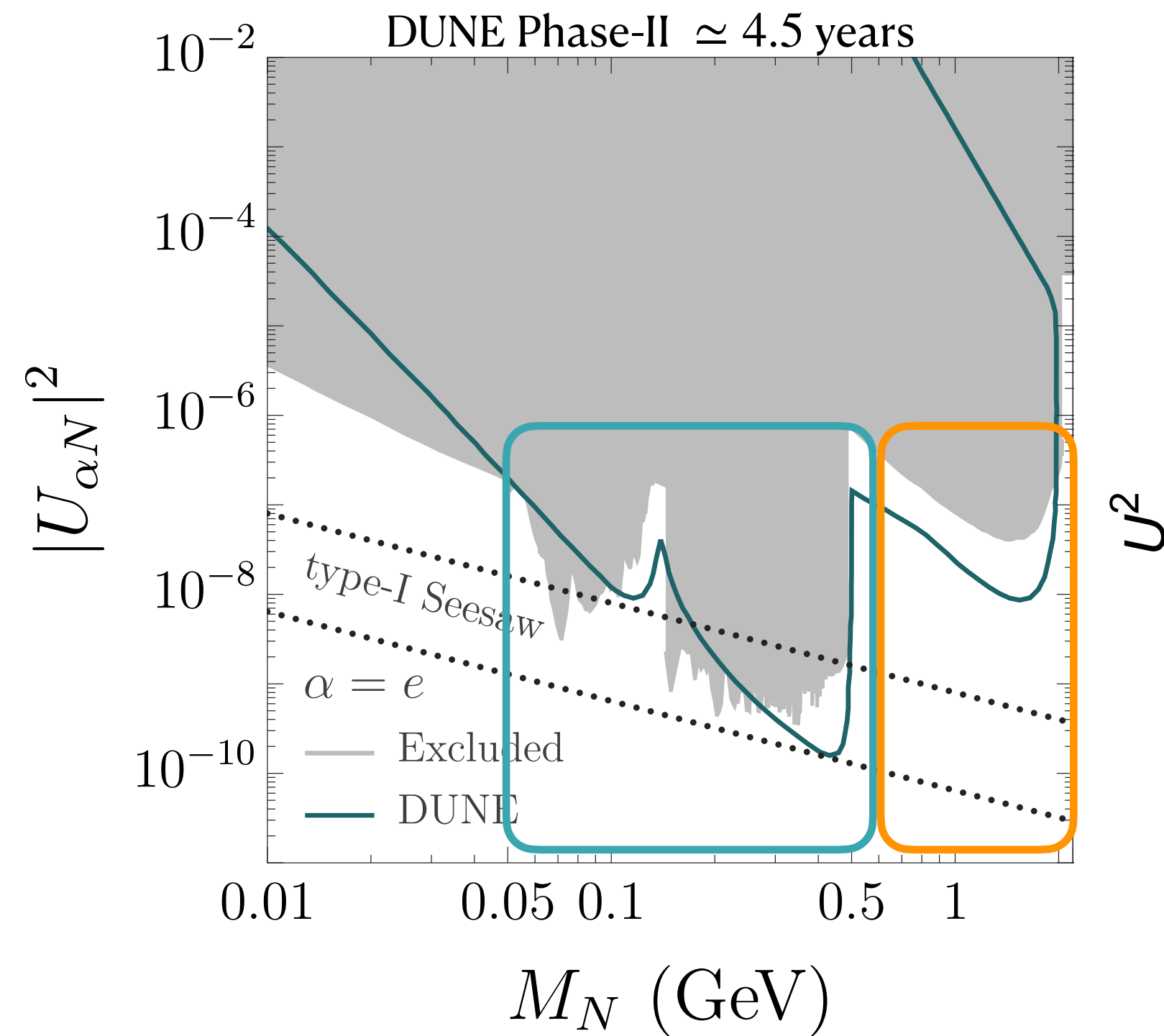
designed for
LLP searches

HNLs searches: DUNE ND-GAr vs SHiP



Better sensitivity of DUNE ND-GAr in the π and K regions

HNLs searches: DUNE ND-GAr vs SHiP

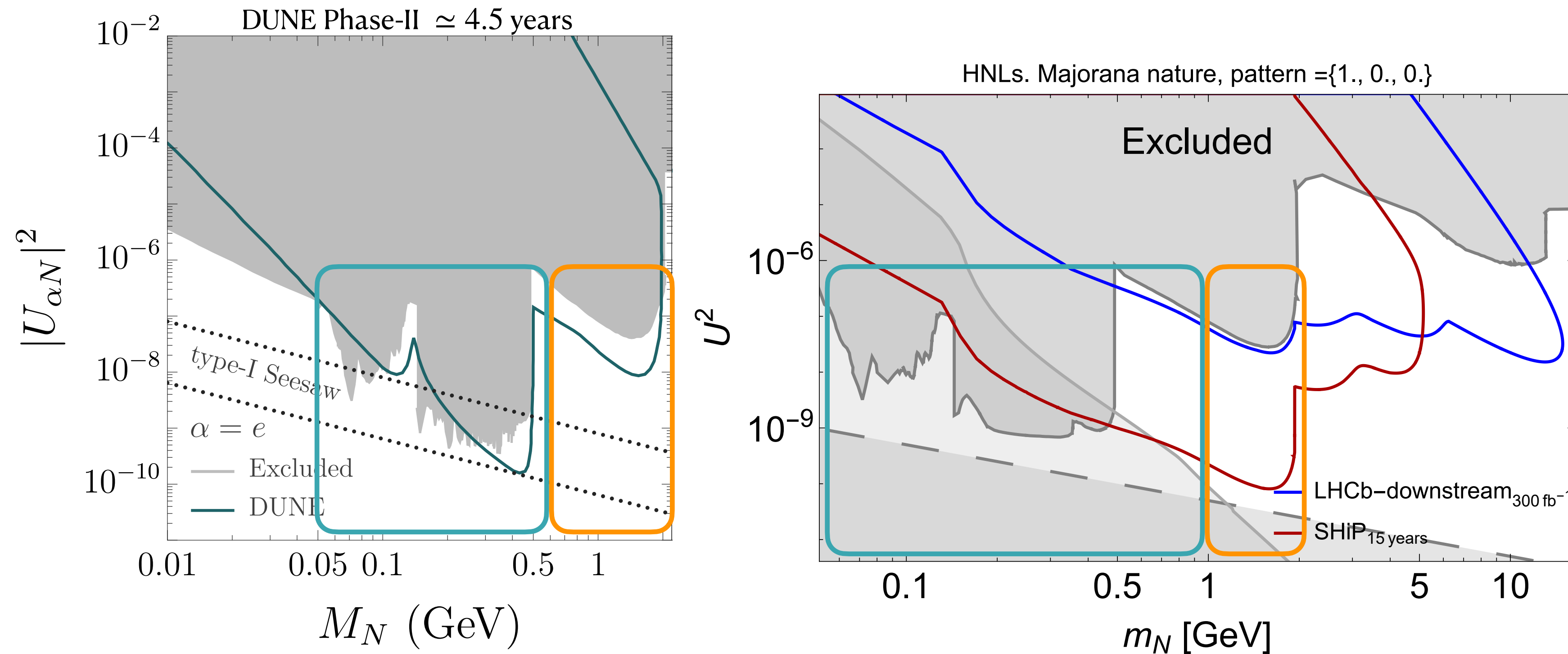


Better sensitivity of DUNE ND-GAr in the π and K regions

Better sensitivity of SHiP in the D and B regions

Maksym Ovchynnikov - Search for new physics at SHiP (IFIC seminar)

HNLs searches: DUNE ND-GAr vs SHiP

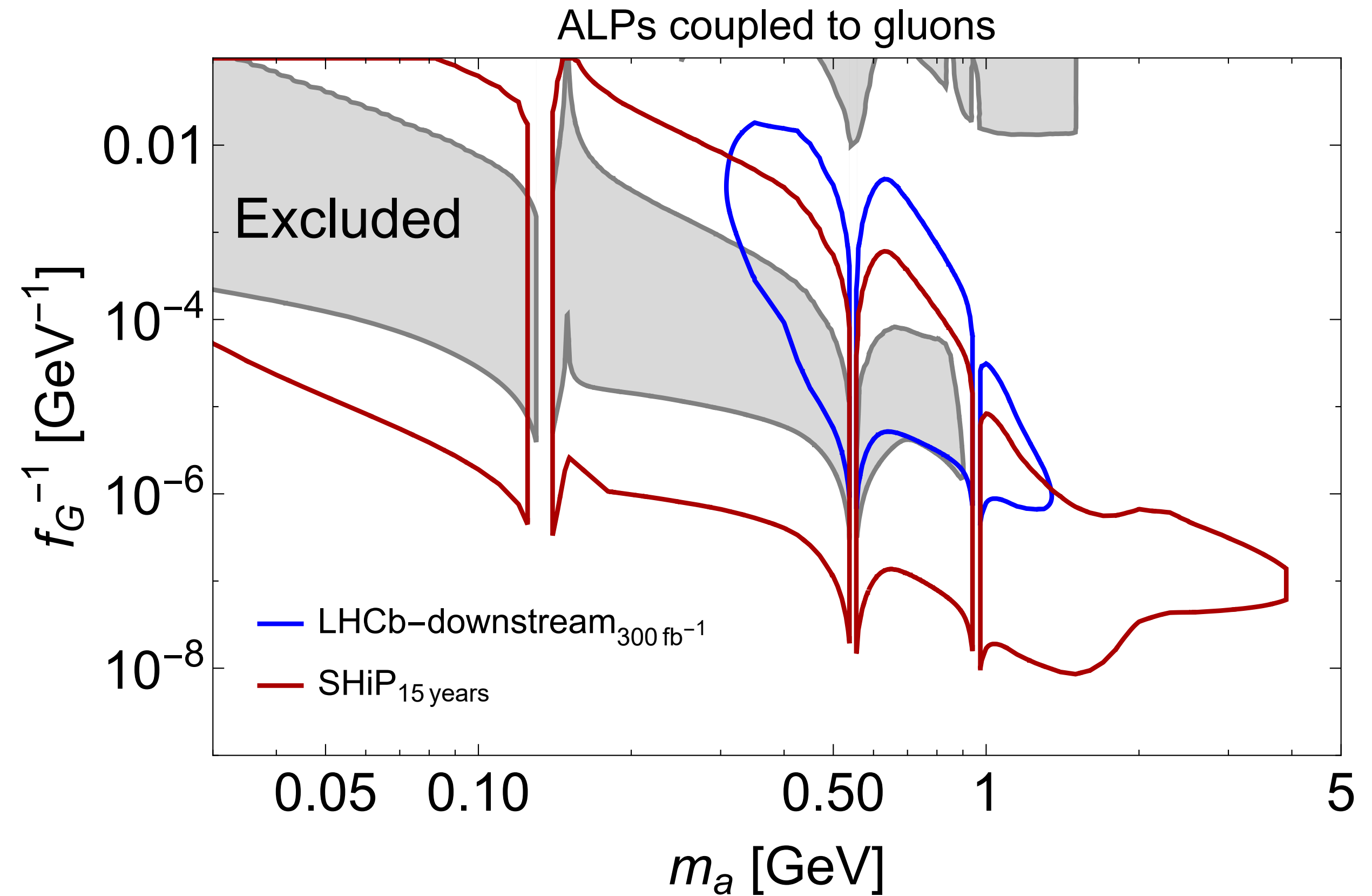
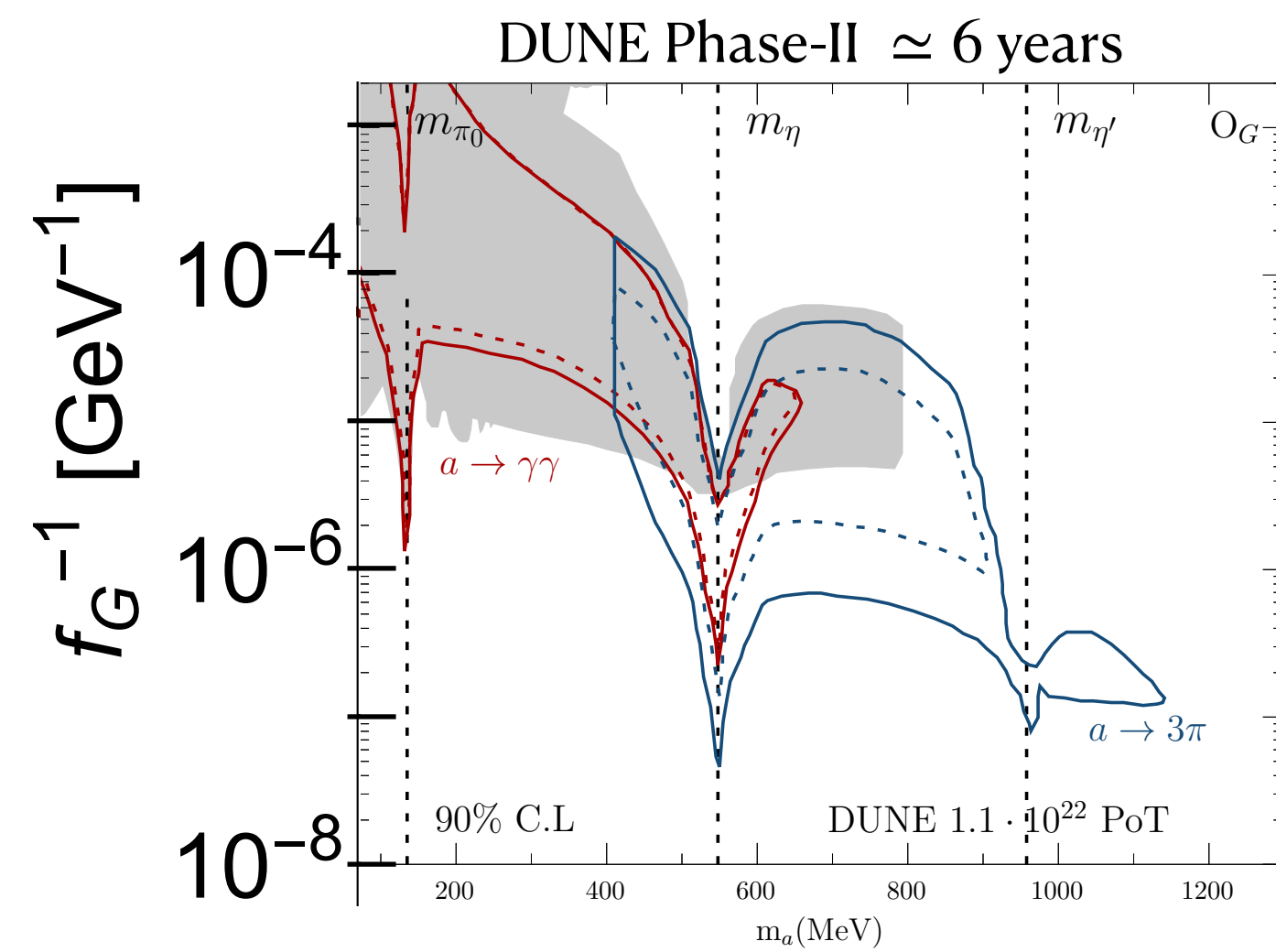


Better sensitivity of DUNE ND-GAr in the π and K regions

Better sensitivity of SHiP in the D and B regions

Similar results for the $|U_{\mu N}|^2$. Better sensitivity of SHiP in the $|U_{\tau N}|^2$ since it comes from D decays.

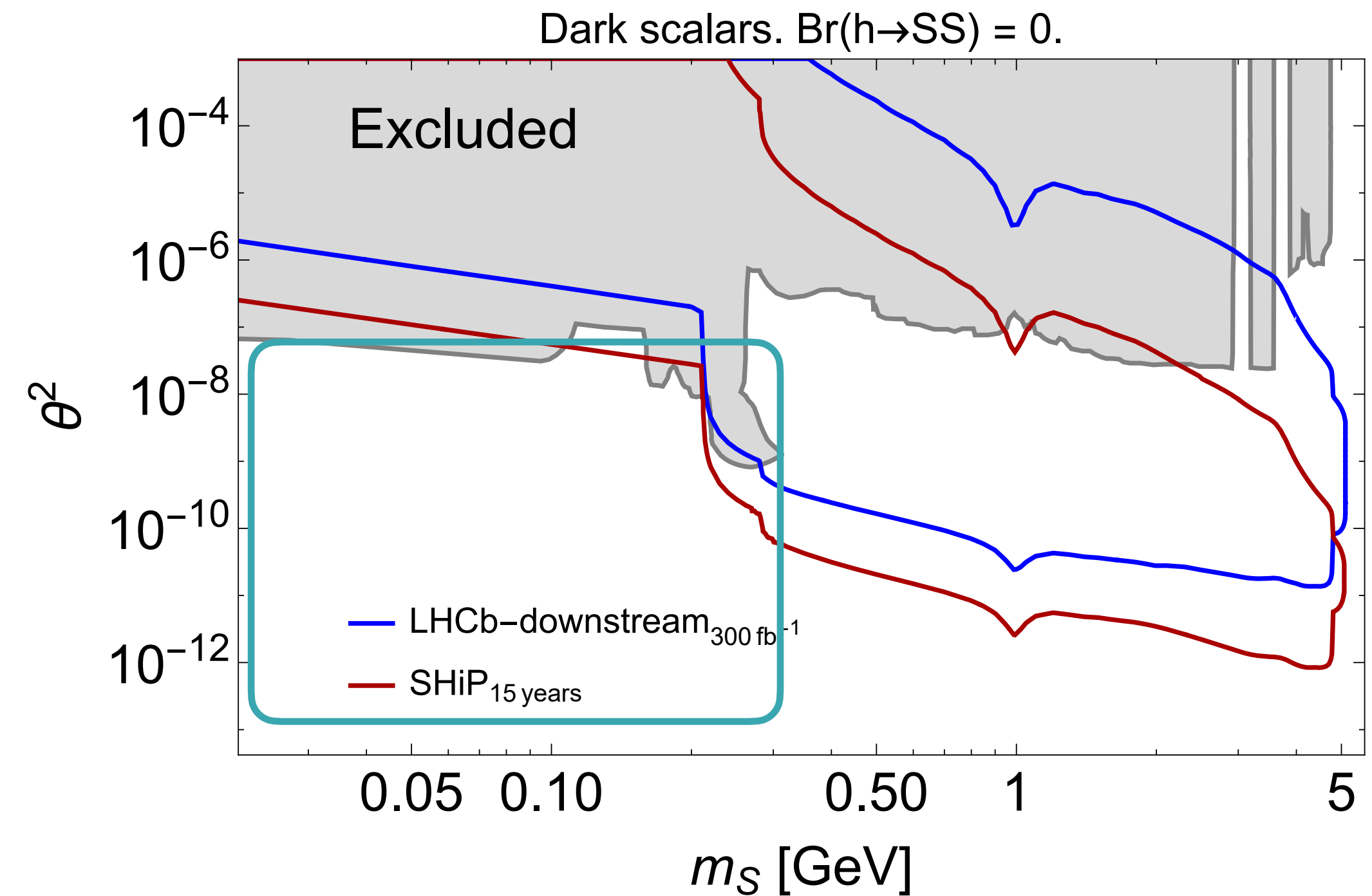
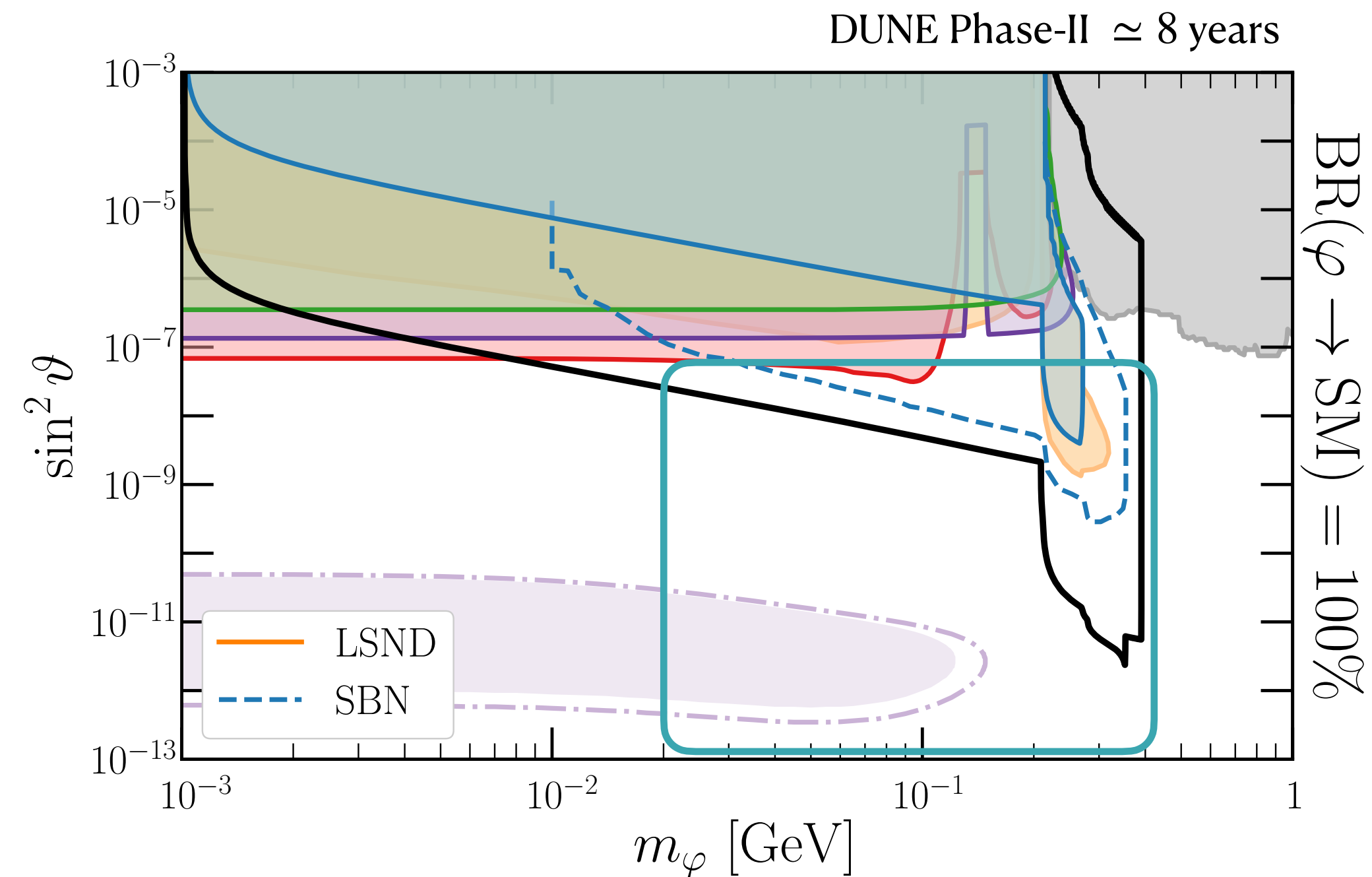
ALPs searches: DUNE ND-GAr vs SHiP



Better sensitivity of SHiP in the whole m_a range

Maksym Ovchinnikov - Search for new physics at SHiP (IFIC seminar)

Dark scalar searches: DUNE ND-GAr vs SHiP



Better sensitivity of DUNE ND-GAr in the K region

SHiP has potential to explore the region the $m_S \gtrsim 350$ MeV region

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