Background simulation for ProtoDUNE

Salvador Urrea (Salvador.Urrea@ific.uv.es)

In collaboration with Justo Martín-Albo, Josu Hernández-García

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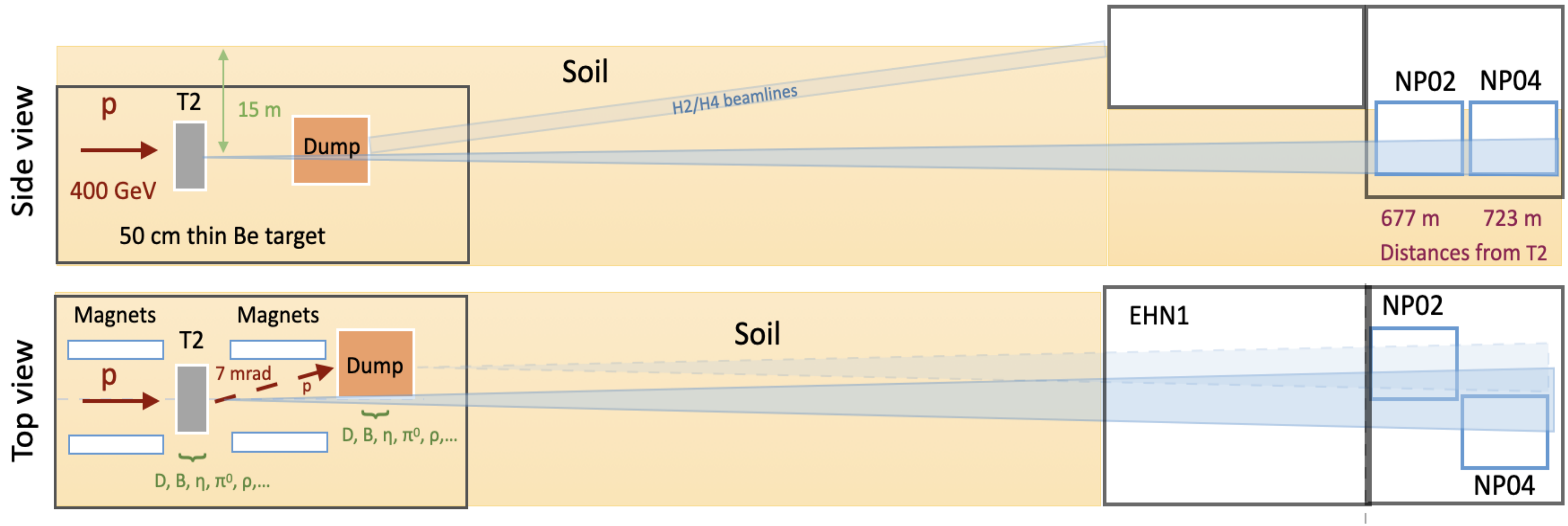
Experimental set-up: T2 target

~5-7x10^{12} protons/spill with a spill duration of 4.8 s →3.5x10^{18}PoT/year

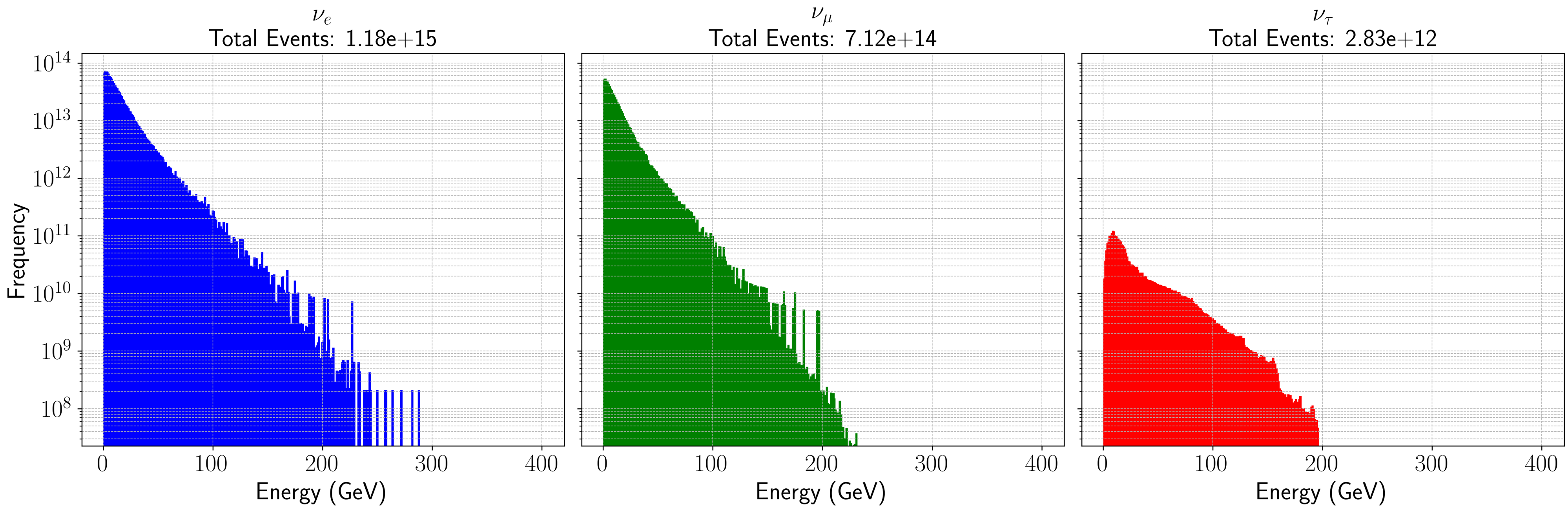


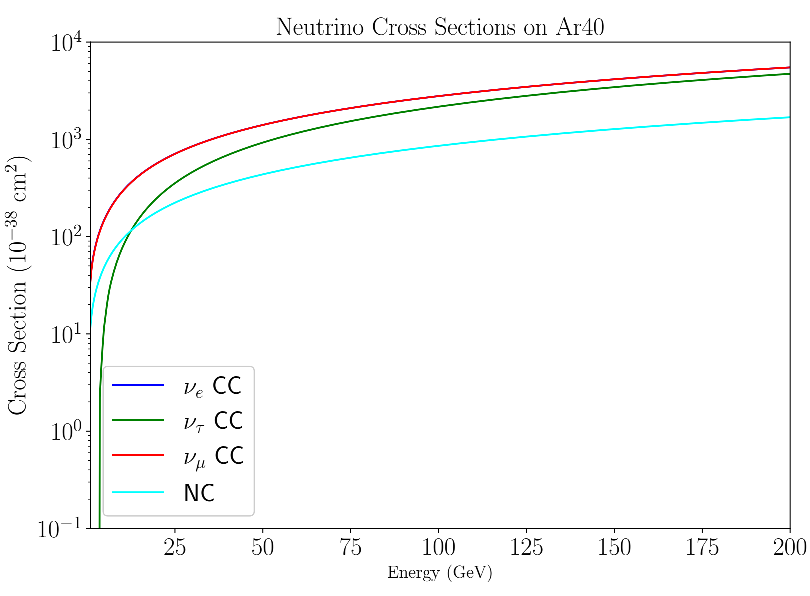
P	T2 production yield (1/PoT)	channel	BR($P \to$ channel)	ν_α crossing ND (1/PoT)
K_S^0	2.3×10^{-1}	$\pi^- e^+ \nu_e$	7.04×10^{-4}	3.90×10^{-6}
K_L^0		$\pi^- e^+ \nu_e$	40.55%	4.44×10^{-5}
		$\pi^- \mu^+ \nu_\mu$	27.04%	2.94×10^{-5}
D^+	3.4×10^{-4}	$e^+ \nu_e$	9.49×10^{-9}	4.78×10^{-14}
		$\overline{K^0} e^+ \nu_e$	8.72%	4.41×10^{-7}
		$\mu^+ \nu_\mu$	3.74×10^{-4}	1.92×10^{-9}
		$\overline{K^0} \mu^+ \nu_\mu$	8.76%	4.48×10^{-7}
		$\tau^+ \nu_\tau$	1.20×10^{-3}	6.09×10^{-9}
D_s^+	9.8×10^{-5}	$e^+ \nu_e$	1.25×10^{-7}	1.48×10^{-13}
		$\mu^+ \nu_\mu$	5.43×10^{-3}	6.54×10^{-9}
		$\tau^+ \nu_\tau$	5.32%	6.33×10^{-8}
τ^+	5.2×10^{-6}	$\overline{\nu_\tau} e^+ \nu_e$	17.82%	1.13×10^{-8}
		$\overline{\nu_\tau} \mu^+ \nu_\mu$	17.39%	1.11×10^{-8}
τ^-		$\overline{\nu_\alpha} \ell_\alpha^- \nu_\tau$	35.21%	2.22×10^{-8}
		$\pi^0 \pi^- \nu_\tau$	25.49%	1.60×10^{-8}
		$\pi^- \nu_\tau$	10.82%	6.80×10^{-9}

Table 1. PRELIMINARY. List of parents P produced in the primary target T2, and decaying into SM neutrinos of flavor α. The numbers are normalized per PoT.

Neutrinos entering the detector

These neutrino fluxes are based on the meson simulation done with Pythia 8.3





Neutrinos interacting in the detector

Interaction Type	Number of neutrino events
ν_e CC	55156
ν_e NC	17390
ν_μ CC	28389
ν_μ NC	9020
ν_τ CC	146
ν_τ NC	76

1.75×10^{19}PoT in 5 years

 Simulated with GENIE

HNL

HNL: Production

$$\mathrm{L} \supset -\frac{m_W}{v}\bar{N}U^*_{\alpha 4}\gamma^\mu l_{L\alpha}W^+_\mu - \frac{m_Z}{\sqrt{2}v}\bar{N}U^*_{\alpha 4}\gamma^\mu \nu_{L\alpha}Z_\mu$$

We consider the simplified phenomenological benchmarks of one HNL mixing with one SM neutrino of a given flavour

U_{e4} $U_{\mu 4}$ $U_{\tau 4}$

We don't have pions and kaons

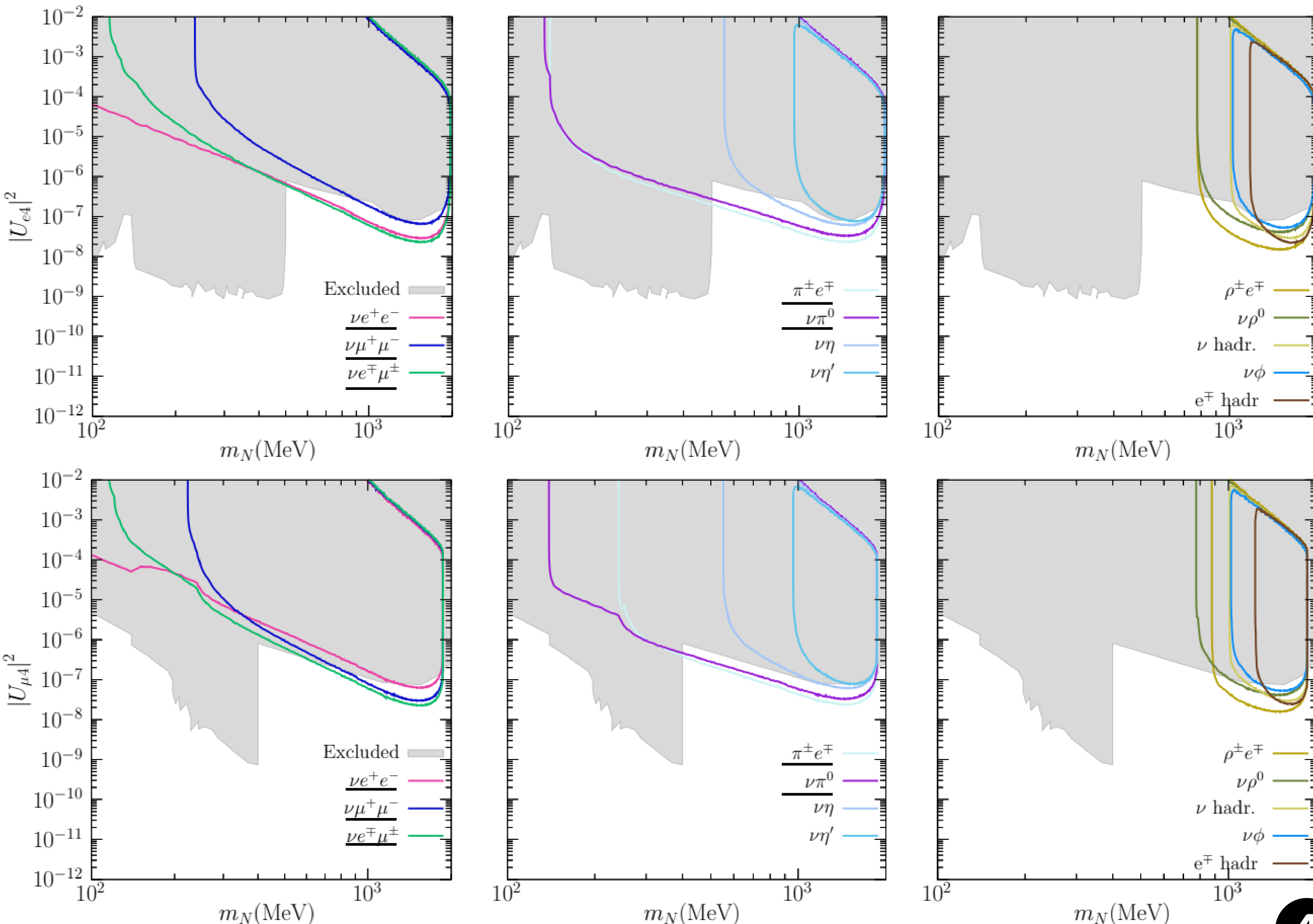
Parent	2-body decay	3-body decay
$\pi^+ \to$	e^+N_4	—
	μ^+N_4	
$K^+ \to$	e^+N_4	$\pi^0 e^+ N_4$
	μ^+N_4	$\pi^0 \mu^+ N_4$
$\tau^- \to$	$\pi^- N_4$	$e^-\overline{\nu}N_4$
	$\rho^- N_4$	$\mu^-\overline{\nu}N_4$

Parent	2-body decay	3-body decay
$D^+ \to$	e^+N_4	$e^+\overline{K^0}N_4$
	μ^+N_4	$\mu^+\overline{K^0}N_4$
	τ^+N_4	
$D_s^+ \to$	e^+N_4	—
	μ^+N_4	
	τ^+N_4	

(normalised per PoT)

D	D_s	τ
$4.8 \cdot 10^{-4}$	$1.4 \cdot 10^{-4}$	$7.4 \cdot 10^{-6}$

$Br(D_s^- \to \tau^- \overline{\nu}_\tau) = 5.43\%$



$|U_{e4}|^2$
$|U_{\mu4}|^2$
m_N(MeV)
Excluded
$\nu e^+ e^-$
$\nu \mu^+ \mu^-$
$\nu e^\mp \mu^\pm$
$\pi^\pm e^\mp$
$\nu \pi^0$
$\nu \eta$
$\nu \eta'$
$\rho^\pm e^\mp$
$\nu \rho^0$
ν hadr.
$\nu \phi$
$e^\mp$ hadr

Backgrounds

$\pi^{\pm}\mu^{\mp}$ or $\mu^{\pm}\mu^{\mp}$

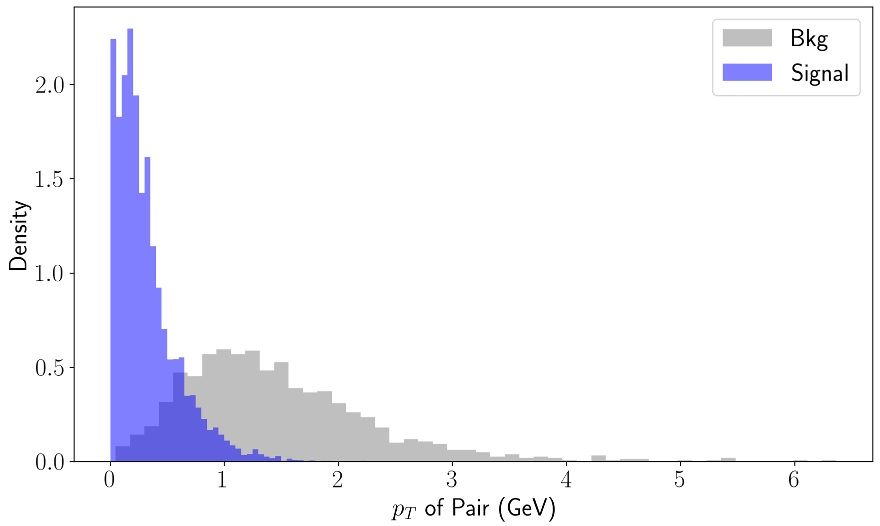
We have 1278 background events with the following cuts:

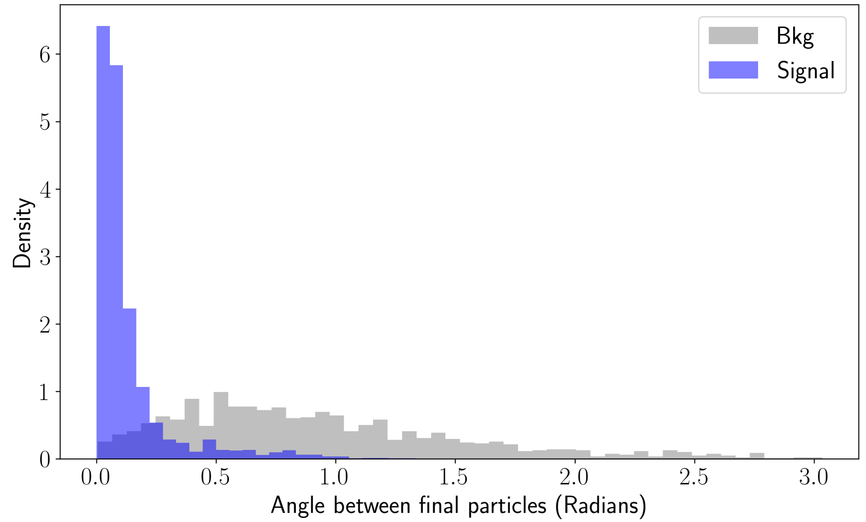
- We keep events with only two μ-like ($\pi^{\pm}$, $\mu^{\pm}$) particles, above an energy threshold of 30 MeV.
- We reject events with other detectable particles in the final state.

We can reduce the events to **15** events with the following kinematical cuts:

- $p_T < 0.35$ GeV.
- $\theta_{\mu\pi} < 0.18$ rad.

These 15 events of background are $\mu^{\pm}\pi^{\mp}$, for the channel $\mu^{+}\mu^{-}$, we could reduce this background further by noting that pions are more likely to interact in the TPC, producing noticeable differences in their tracks with respect to the muons.





Simulated with GENIE

$e^{\pm}\mu^{\mp}$ or $e^{\pm}\pi^{\mp}$

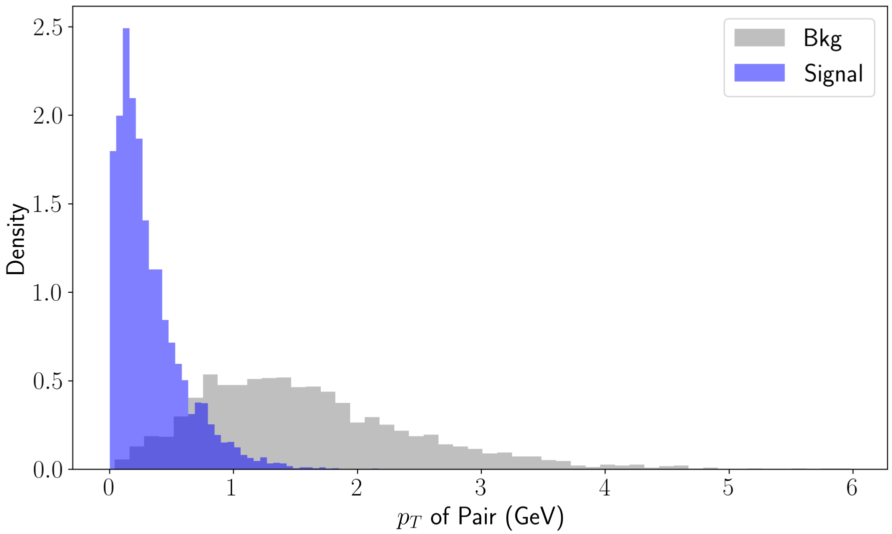
We have 1982 background events with the following cuts:

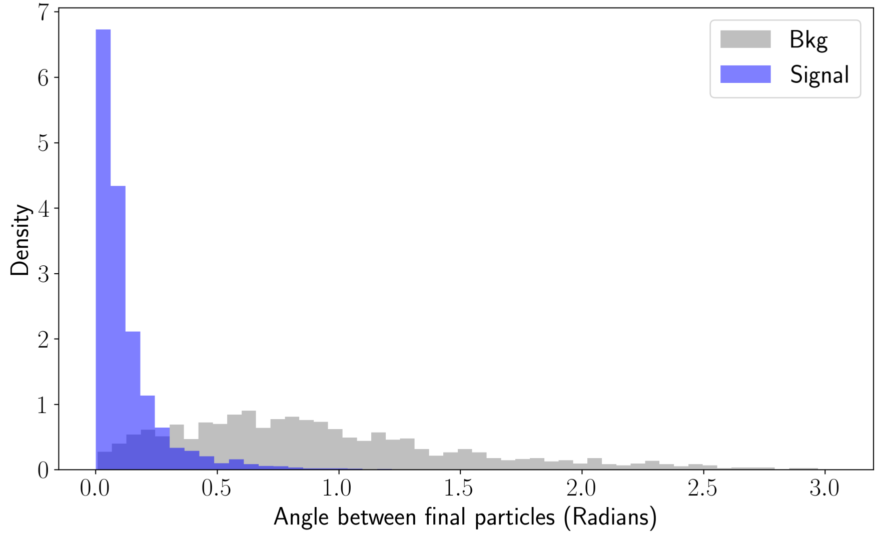
- We keep events with only one μ-like ($\pi^{\pm}$, $\mu^{\pm}$) particle and one ($e^{\pm}$), above an energy threshold of 30 MeV.
- We reject events with other detectable particles in the final state.

We can reduce the events to **24** events with the following kinematical cuts:

- $p_T < 0.35$ GeV.
- $\theta_{e\mu} < 0.180$ rad.

These 24 events of background are $e^{\pm}\pi^{\mp}$, for the channel $e^{-}\mu^{+}$, we could reduce this background further by noting that pions are more likely to interact in the TPC, producing noticeable differences in their tracks with respect to the muons.





Simulated with GENIE

π^0 or e^+e^-

We have **721** background events with one single π^0 in the final state. These π^0 will promptly decay into 2 photons and it will be a background for e^+e^- channels when only one of the γ convert into the TPC. This occurs for around 1% of the events leaving a background of $\sim$**7** background events for e^+e^-. Further kinematical cuts need to be explored.

Simulated with GENIE

Take home message

- Our preliminary studies tell us that some of the golden channels for the HNL will be close to background free.

What is next?

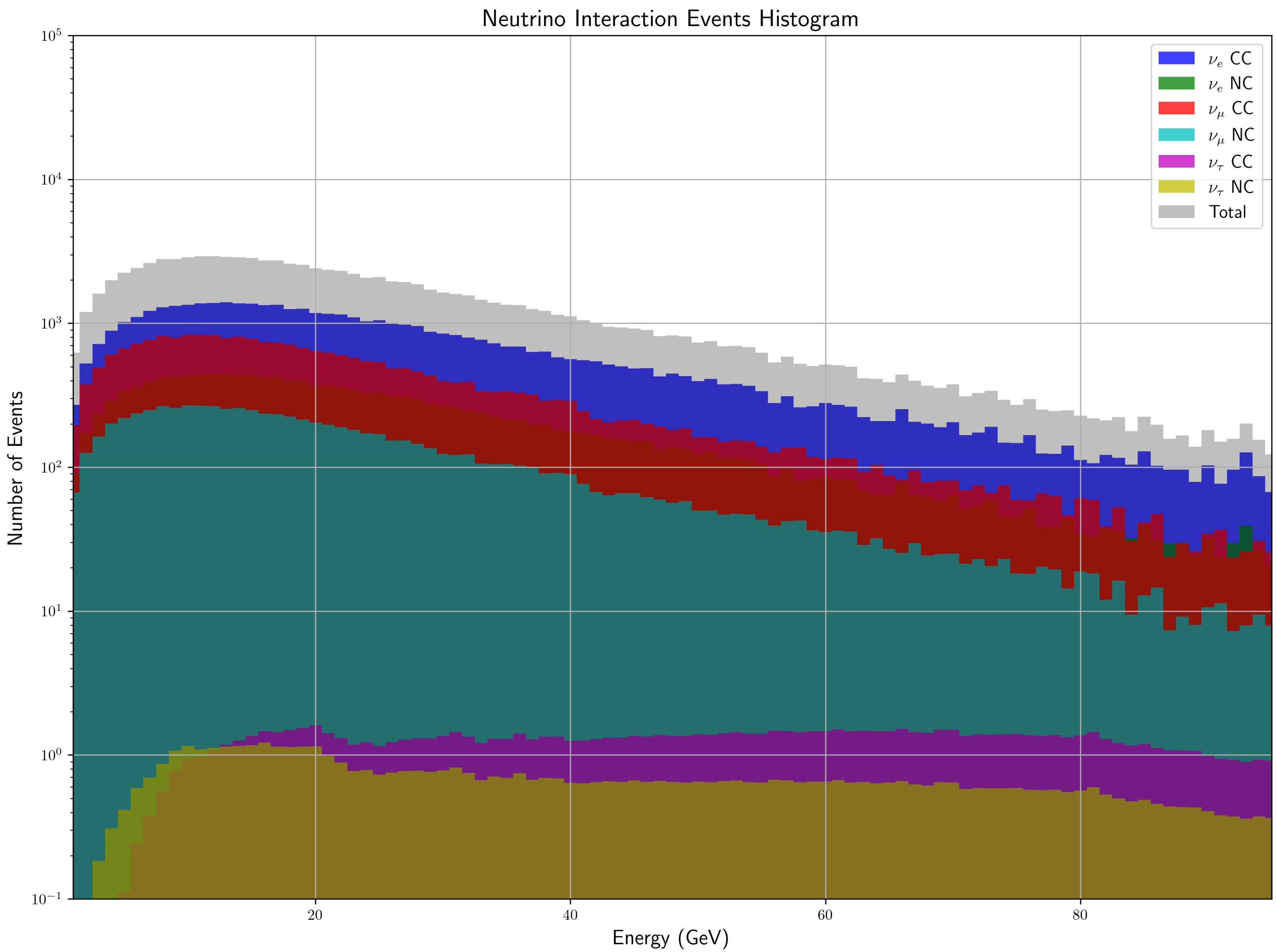
- We need to compute the background using the Geant4 simulation for the neutrino flux.

- Explore other sources of background like cosmics

- Compute the background for other types of searches, like Milicharged particles where the signal comes from scattering.

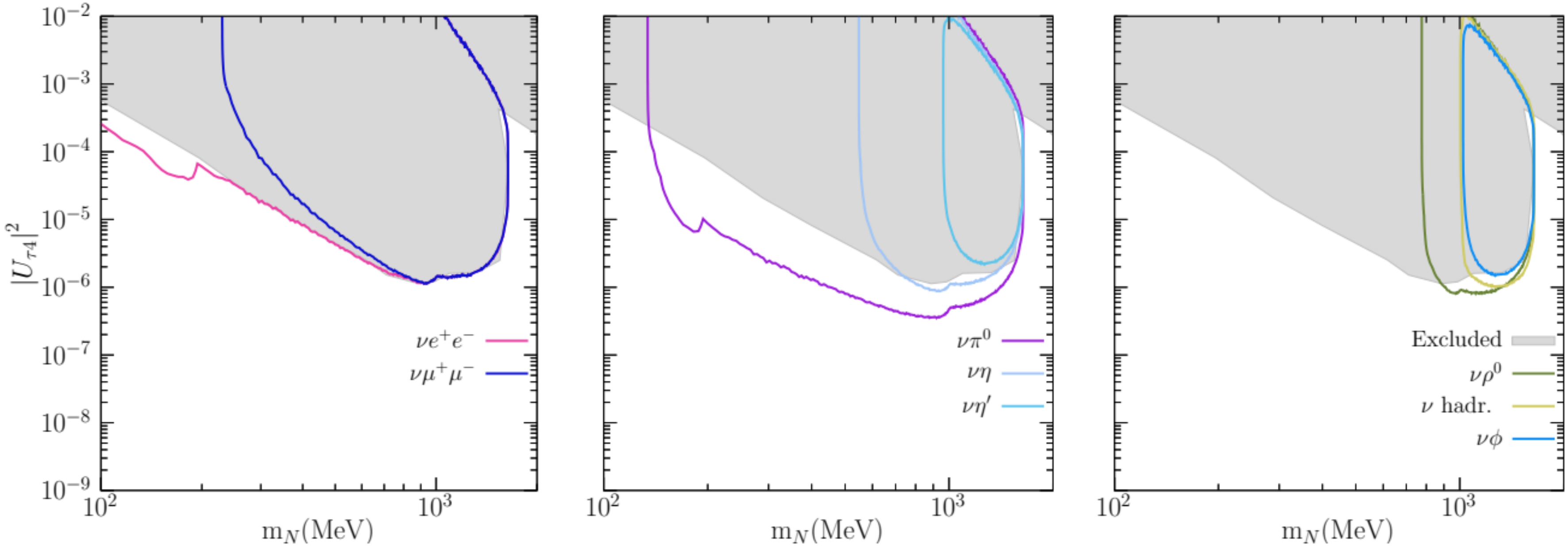
Thank you

Back-up



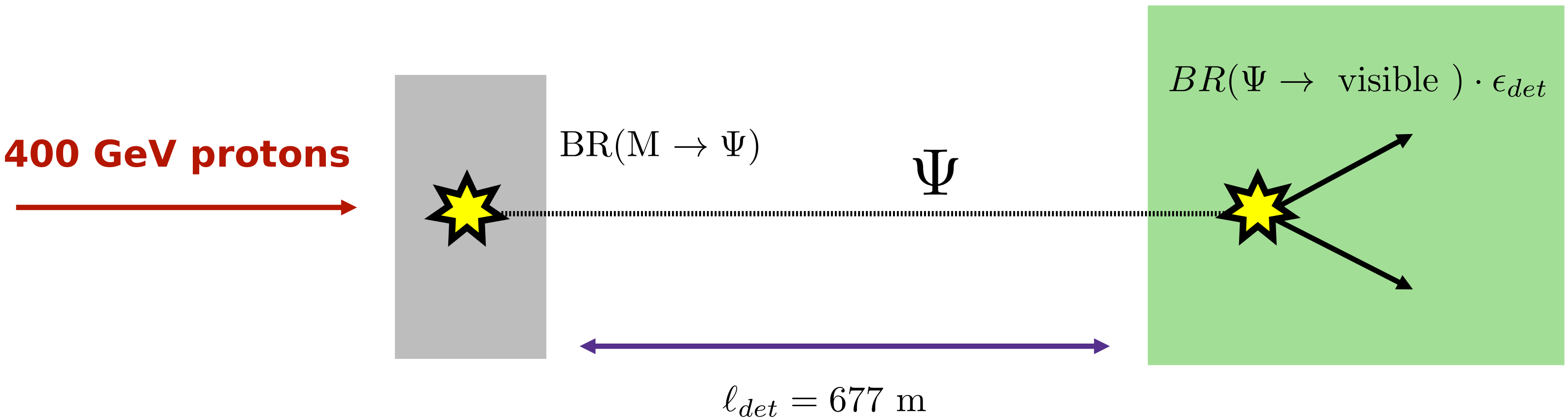
Neutrino Interaction Events Histogram
ν_e CC
ν_e NC
ν_μ CC
ν_μ NC
ν_τ CC
ν_τ NC
Total
Number of Events
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
20
40
60
80
Energy (GeV)

HNL: Decays into visible channels



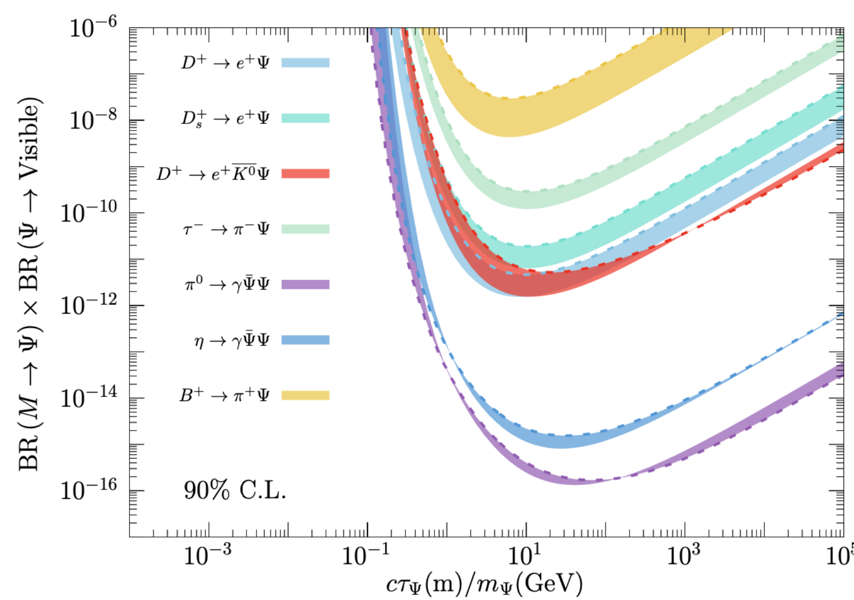
New Physics: Decay in flight inside the detector

Detector(NP02)
Liquid Argon TPC



$$\mathrm{N}^{M}_{dec} = N_{\mathrm{PoT}} Y_M \mathrm{BR}(M \to \Psi) \int dS \int dE_\Psi \mathcal{P}\left(c\tau_\Psi/m_\Psi, E_\Psi, \Omega_\Psi\right) \frac{dn^{M\to\Psi}}{dE_\Psi dS}$$

$$\mathrm{N}_{det} = N^{M}_{dec} \cdot BR(\Psi \to \text{ visible }) \cdot \epsilon_{det}$$



Large couplings

$$e^{-\frac{\ell_{\mathrm{det}}}{L_\Psi}}$$

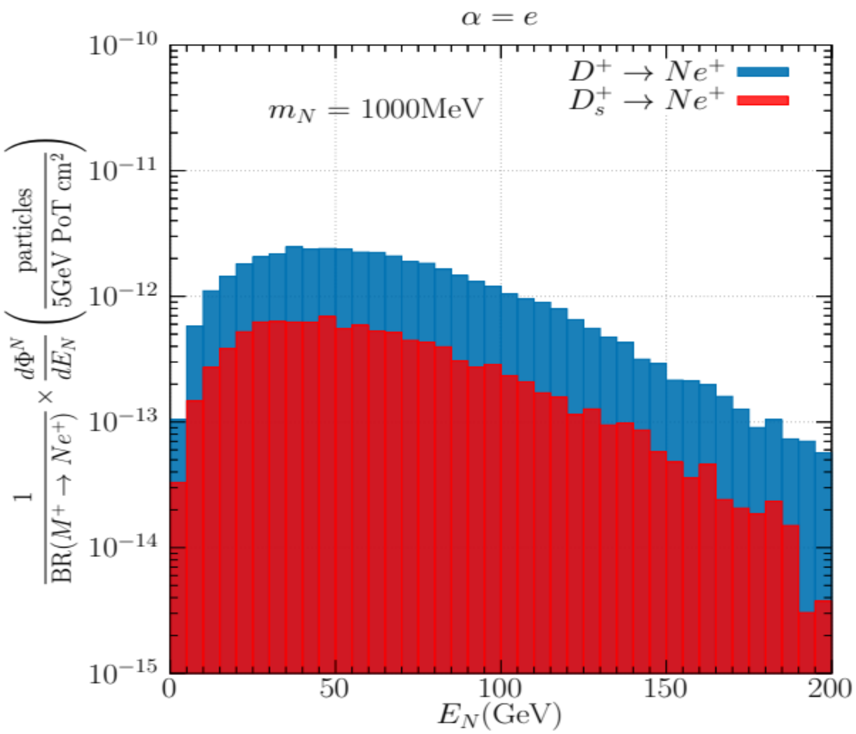
$$\mathrm{P} = \mathrm{e}^{\frac{-\ell_{\mathrm{det}}}{L_\Psi}}\left(1 - e^{\frac{-\Delta\ell_{\mathrm{det}}}{L_\Psi}}\right)$$

$$1 - e^{-\frac{\Delta\ell_{\mathrm{det}}}{L_\Psi}} \propto (coupling)^2$$

Small couplings

HNL: Fluxes

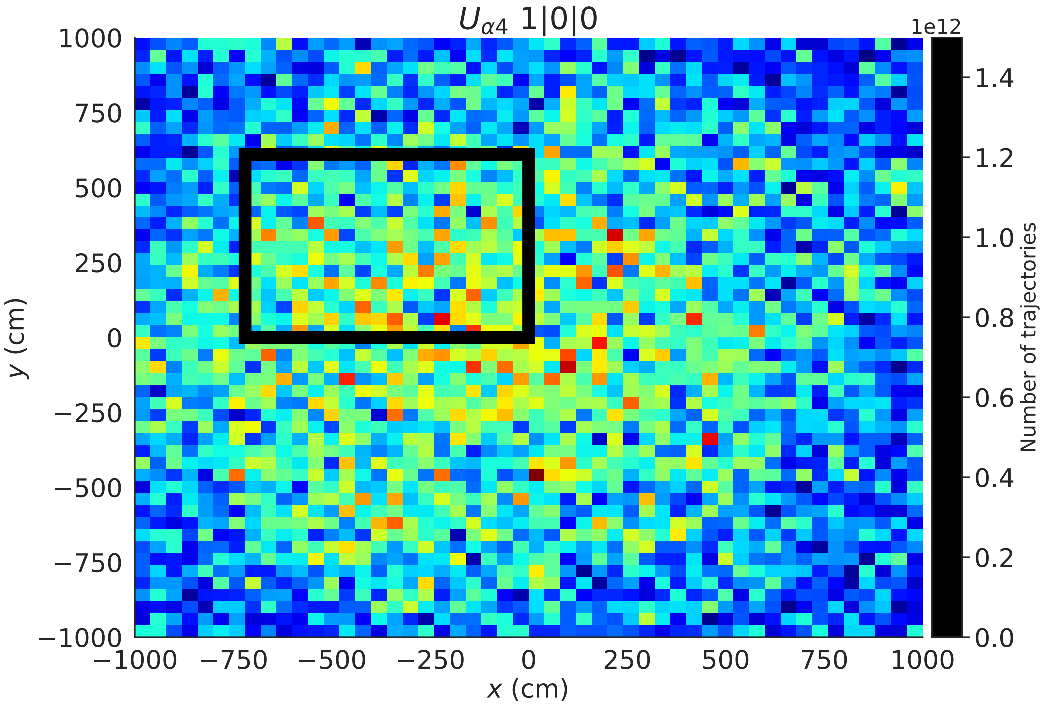
HNL intersecting the detector



- **Quite energetic HNL beam**

- **Wide HNL beam**
- **Small changes in the geometry will not significantly change the results**
- **Any of the two ProtoDUNE detectors can be used**

HNL at z = 677 m



HNL: Decays into visible channels (combination)

We consider the following channels $N \to \nu ee, \nu\mu\mu, \nu e\mu, e\pi, \mu\pi$ and $\nu\pi^0$