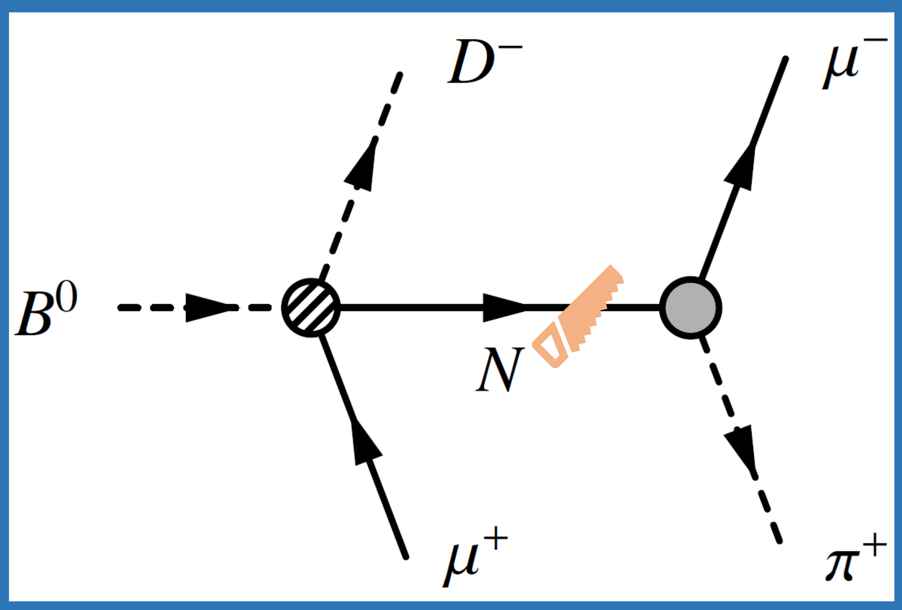

Probing sterile neutrino in meson decays with and without sequential neutrino decay

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[arXiv:1908.00376]

Properties of sterile neutrino

- **Electrically neutral** - It is assumed to interact with SM particles only through mixing $|U_{lN}|^2$. Therefore we choose the mode with a ν_l at the final state and replace it by N.
- **Spin ½** - In the decays such as $B \to D^*\mu N$ or $B \to KNN$, N can have the spin, S_N=1/2, 3/2, so we choose $B \to D\mu N$, where only S_N=1/2 is possible.
- **Massive** - N will have a certain mass m_N therefore its momentum squared is fixed, $\boldsymbol{p_N^2 = m_N^2}$. Thus we can use the decay mode $B \to D\mu N$ and see if it gives $(p_B - p_D - p_\mu)^2 = m_N^2$ to find N or constrain $|U_{lN}|^2$ whether N decays sequentially or not.
- **Long-living** - The mixing parameter $|U_{lN}|^2$ is very small that N will live long. It **may or may not** decay inside a detector depending on $|U_{lN}|^2, m_N, p_N$ and the detector size L_D.
- **Majorana or Dirac** - Sterile neutrino can either be Dirac or Majorana. We should look at the sequential decay of N to distinguish it's Majorana nature.

$B \to D\mu N (\to D\mu\mu\pi)$

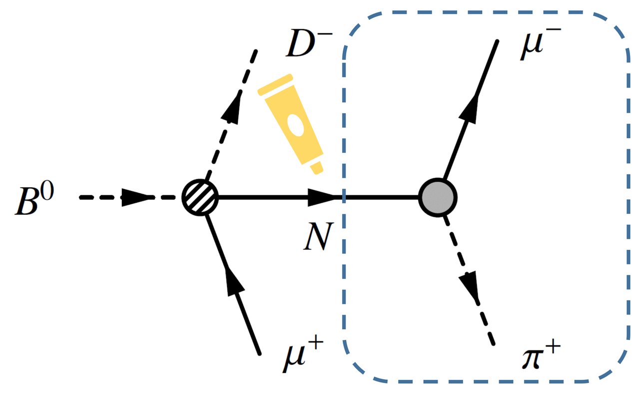
Goal

- Find N or constrain $|U_{lN}|^2$
- (And Distinguish Majorana nature of N by LNV)

Assumptions

- One sterile neutrino.
- N is on-shell
- m_N around GeV

$(m_\mu + m_\pi \leq)\ m_N \leq m_B - m_D - m_\mu$



[arXiv:1904.12858]

Feature

- We will see the fixed missing momentum squared $(p_B - p_D - p_\mu)^2 = {m_N}^2$ if N exists and has proper mixing.
- (Displaced vertex due to small Γ_N. This eliminates background. But N may or **may not** decay inside a detector, i.e. $\mathrm{BR_{eff}}(B \to D\mu\mu\pi)$ is suppressed, especially when N is relatively light.)

Constraints on $|U_{\mu N}|^2$ and $|U_{\tau N}|^2$

Define theoretically calculable quantities $\underline{Br}$, **canonical branching ratio** and $\underline{\Gamma}$, **canonical decay width** by factoring out unknown $|U_{\mu N}|^2$ from Br and Γ respectively.

$$\Gamma(B \to D\mu N) = |U_{\mu N}|^2 \underline{\Gamma}(B \to D\mu N)$$

$$\underline{Br}(B \to D\mu N) = \frac{\underline{\Gamma}(B \to D\mu N)}{\Gamma_B}$$

*Note that for $m_N = 0$, $\underline{\Gamma}(B \to D\mu N) = \Gamma(B \to D\mu\nu)$.

And then we get

$$\mathrm{BR}(B \to D\mu N) = |U_{\mu N}|^2 \underline{Br}(B \to D\mu N) \frac{N_{B\to D\mu N}}{N_B}$$

equivalently,

$$|U_{\mu N}|^2 = \frac{N_{B\to D\mu N}}{N_B\, \underline{Br}(B \to D\mu N)}$$

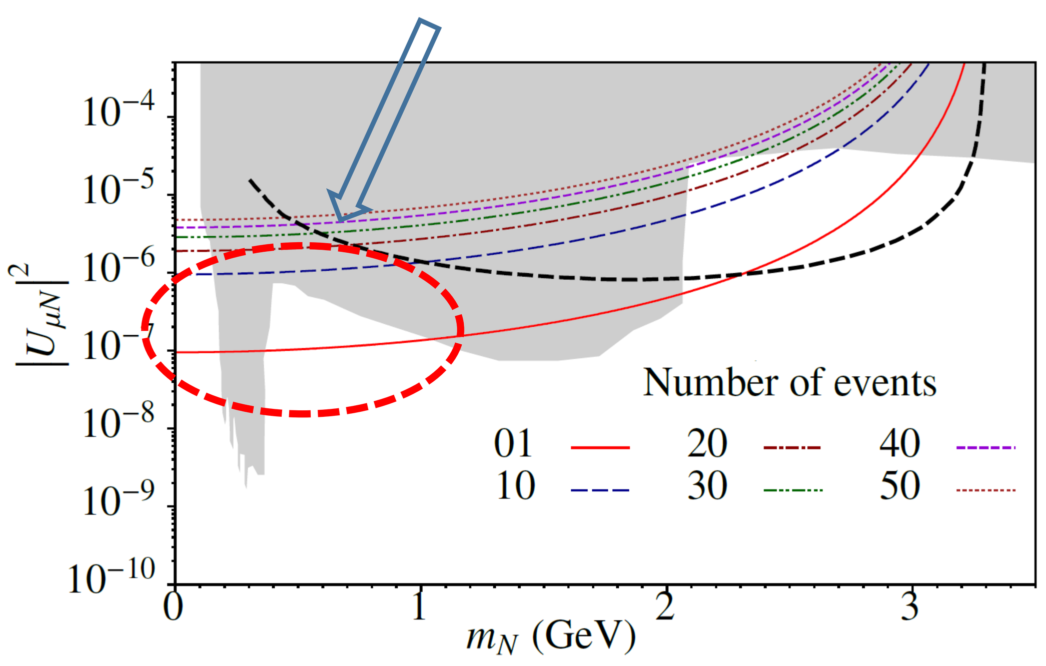
But for first stage of our study (without considering decay of N), only Belle-II type of experiment is available where all the momenta of Initial and final particle except N are measurable.

- $4.8 * 10^8$ fully reconstructed B mesons at Belle-II out of 10^{11}
- $4.8 * 10^{12}$ B mesons at LHCb

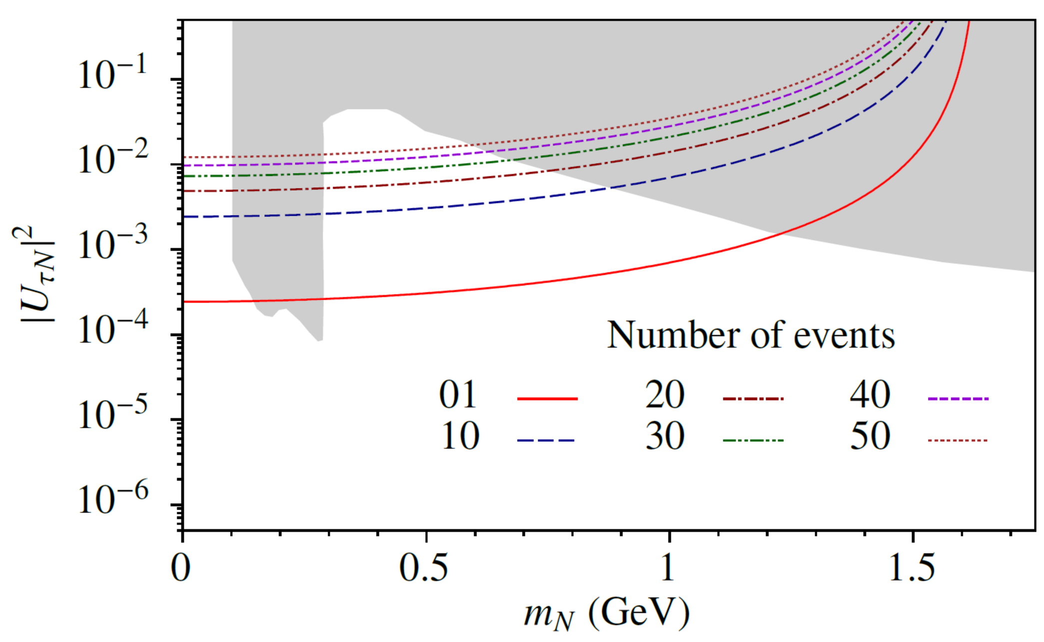
Despite 10^4 times Less N_B, $B \to D\mu N$ gives competitive results.

✓ Our proposed search($B \to D\mu N$) at Belle-II will give better constraint on $|U_{\mu N}|^2$ if $m_N < 2.3GeV$ than the future search using $B \to D\mu\mu\pi$ at LHCb.

✓ New constraint below 1GeV are found.



❖ 0.1% chance of full reconstruction of τ from its decays is assumed.



$B \to D\mu\mu\pi$

Including decay probability of $N \to \mu\pi$ inside a detector with a size L, we can rewrite a number of detectable signals

$$N_{B\to D\mu N} = N_B |U_{\mu N}|^2 \underline{\Gamma}(B \to D\mu N) \frac{1}{\Gamma_B} \qquad \frac{\underline{\Gamma}(N \to \mu\pi)}{\underline{\Gamma}_N}[1 - exp(-\lambda t)]$$

$$N^{det}_{B\to D\mu\mu\pi} = N_B |U_{\mu N}|^2 \int dE_N \frac{d\underline{\Gamma}(B\to D\mu N)}{dE_N} \frac{1}{\Gamma_B} \frac{\underline{\Gamma}(N\to\mu\pi)}{\underline{\Gamma}_N} \left[1 - exp\left(-\frac{L}{\beta_N}\frac{\Gamma_N}{\gamma_N}\right)\right]$$

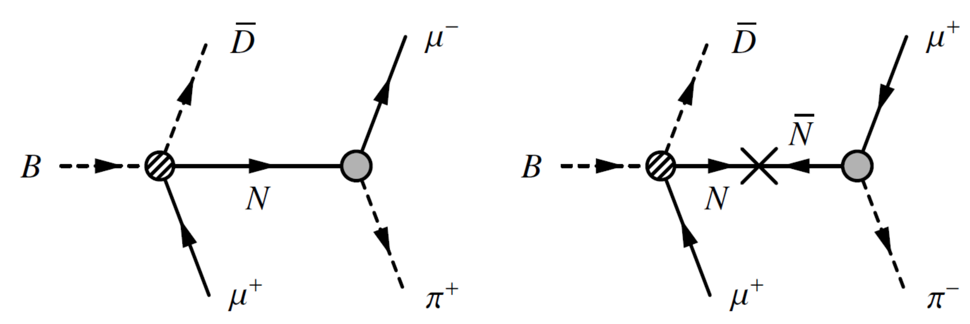
(In reality, B is not at rest and this effect is taken into account in real calculation.)

- Once the experiment is done, with an observed value of m_N, solving the above equation in terms of $|U_{\mu N}|^2$ will give the value of $|U_{\mu N}|^2$.
- Or if such a signal is not observed at all, we can give an upper bound on $|U_{\mu N}|^2$ by solving the following inequality

$$1 > N^{det}_{B\to D\mu\mu\pi} = N_B |U_{\mu N}|^2 \int dE_N \frac{d\underline{\Gamma}(B \to D\mu N)}{dE_N} \frac{1}{\Gamma_B} \frac{\underline{\Gamma}(N \to \mu\pi)}{\underline{\Gamma}_N} \left[1 - exp\left(-\frac{L}{\beta_N}\frac{\Gamma_N}{\gamma_N}\right)\right]$$

Majorana N

- If N is Majorana particle, it can be involved in both LNC and LNV modes.
- If the LNV decay, as in the figure (b) is detected, we can tell the sterile neutrino is Majorana
- The expected observable number of event, and the upper bound on $|U_{\mu N}|^2$ can be similarly calculated as before, considering **helicity flip** of N and additional LNV contributions on Γ_N, which suppress BR^{LNV}_{eff} further.



(a) Both Dirac and Majorana type of N (b) Only Majorana type of N