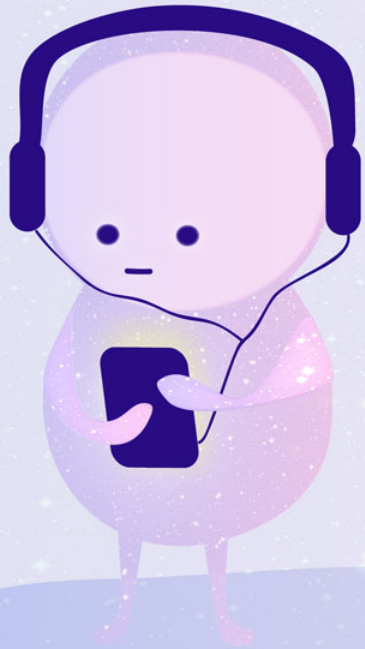
Probing Heavy Neutral Leptons with Direct Searches & Neutrinoless Double Beta Decay



Zhong Zhang

zhong.zhang.19@ucl.ac.uk

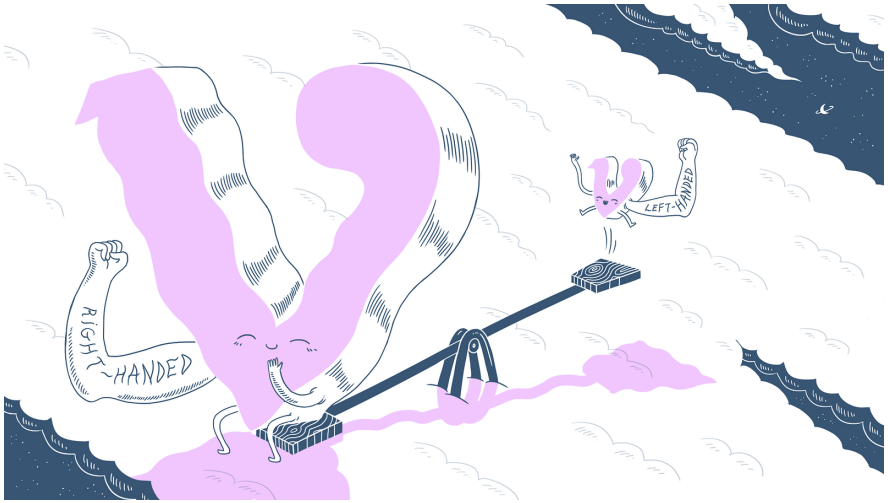
University College London

In Collaboration with:

P.D.Bolton, F.F.Deppisch, M.Rai

Seesaw Mechanism

Motivation:Massless SM neutrinos
HNLs give mass to light active neutrinos



Dirac mass by **Right-Handed Neutrinos**:

$$\mathscr{L}_{Dirac} = -Y_\nu \bar{L} \cdot H\nu_R + \text{h.c.}$$

Majorana mass:

$$\mathscr{L}_{Dirac+Majorana} = -Y_\nu \bar{N} L \cdot H - 1/2 \bar{N}^c M_R N + \text{h.c.}$$

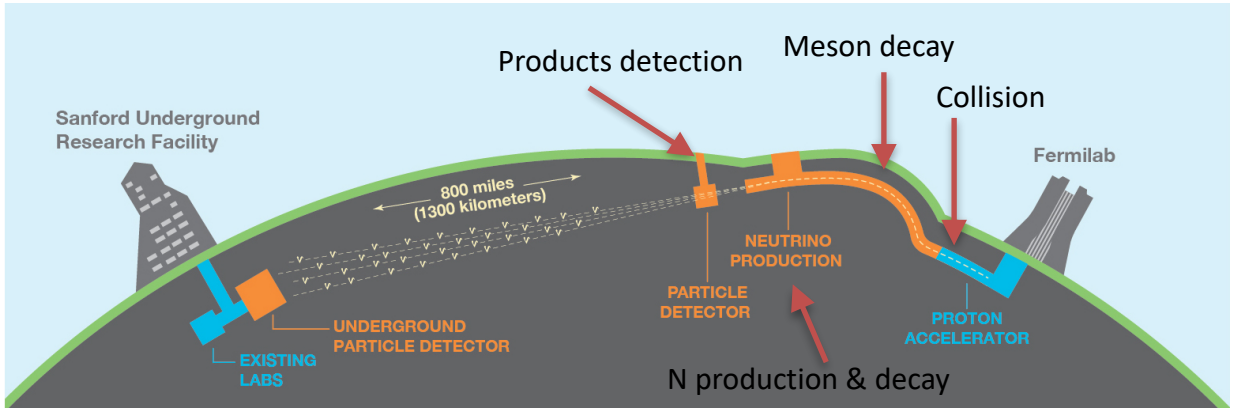
$$\mathscr{M}_\nu = \begin{pmatrix} 0 & m_D \\ m_D & M_R \end{pmatrix} = U \begin{pmatrix} m_\nu & 0 \\ 0 & m_N \end{pmatrix} U^T$$

Light Neutrino Mass:

$$m_\nu \simeq \frac{m_D^2}{M_R} \simeq \frac{(1)^2}{10^{10}}\text{GeV} = 0.1\text{eV}$$

$$|V_{eN}|^2 \simeq \frac{m_\nu}{M_R}$$ Active-Sterile mixing (Standard Seesaw Limit)

DUNE Experiment

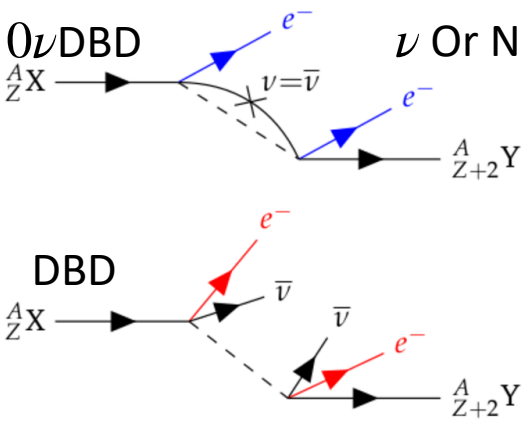


Proton-target interaction

$$K/\pi^+ \to l^\pm N \to l^\pm \nu$$

Detected at ND

Neutrinoless Double Beta Decay (0νDBD)



Atomic phase space

Decay half-life: $T^{-1}_{1/2} = \left|m_{\beta\beta}\right|^2 G^{0\nu} \left|M^{0\nu}\right|^2$

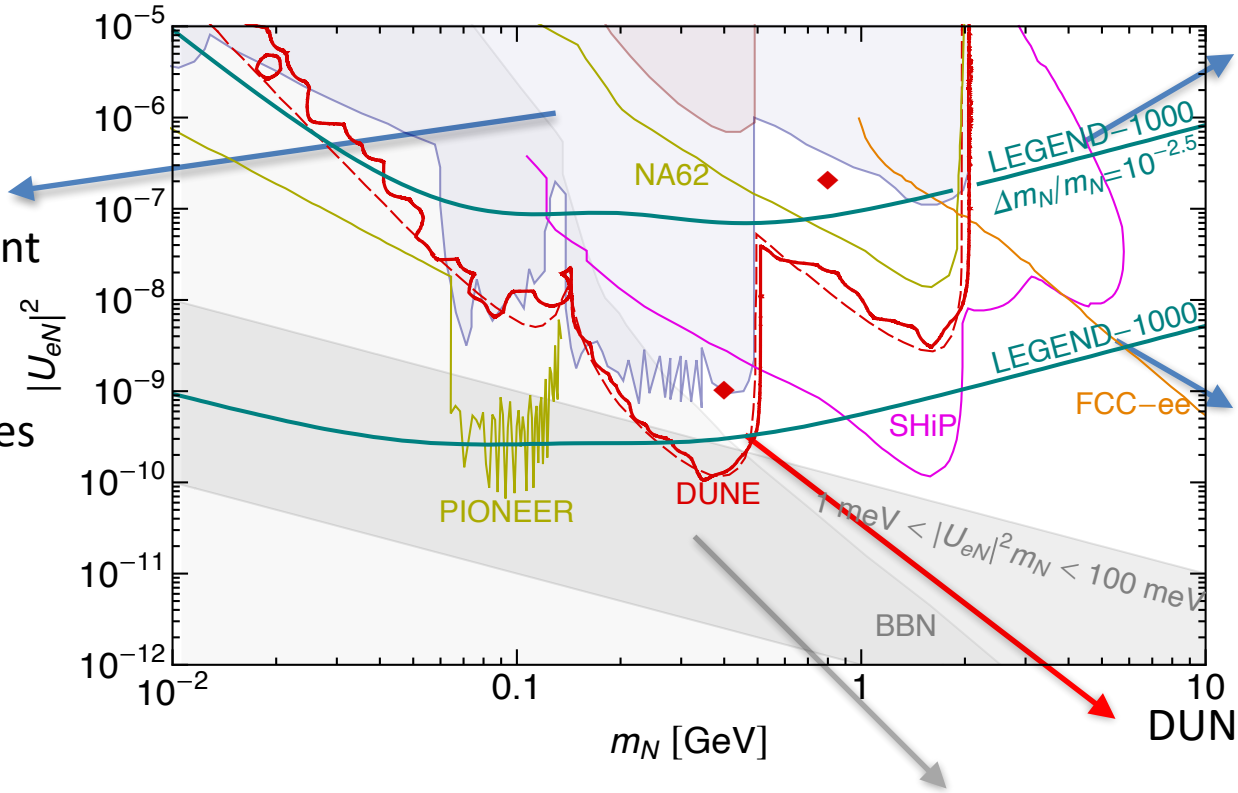
Particle Physics: $m_{\beta\beta} = \sum_{i=1}^{3} U_{ei}^2 m_{\nu_i}$

Nuclear Physics

Benchmarks

$$|V_{eN}|^2 = |U_{e1}|^2 + |U_{e2}|^2 \simeq |U_{e1}|^2 \simeq s_{e1}^2 = |\Theta_{e1}|^2$$

Shaded current excluded region by direct searches



DBD current limit: 10^{26} years

DBD future sensitivity: 10^{28} years (Legend-1000)

DUNE sensitivity

Benchmarks: 400MeV at $|V_{eN}|^2 = 10^{-9}$

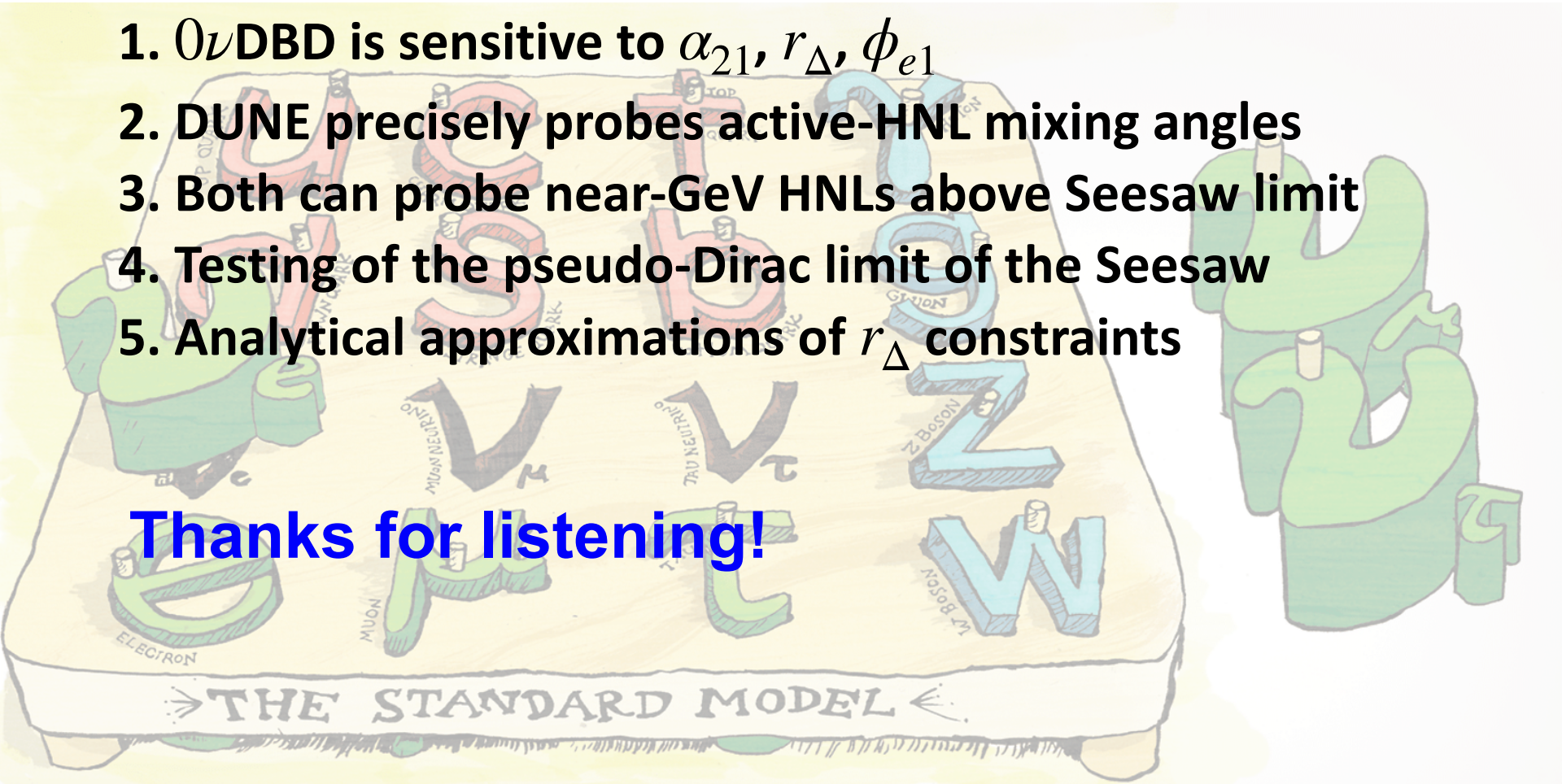
800MeV at $|V_{eN}|^2 = 2 \times 10^{-7}$

Standard Seesaw relation limit by $|V_{eN}|^2 = m_\nu / m_N$

Conclusion

1. 0νDBD is sensitive to α_{21}, r_Δ, ϕ_{e1}
2. DUNE precisely probes active-HNL mixing angles
3. Both can probe near-GeV HNLs above Seesaw limit
4. Testing of the pseudo-Dirac limit of the Seesaw
5. Analytical approximations of r_Δ constraints

Thanks for listening!



Results

μ channel is added in DUNE analysis

5 Free Parameters: α_{21},m_N, $|\Theta_{e1}|^2$, ϕ_{e1}, r_Δ

Ordering	α_{21}	m_N [MeV]	$\lvert\Theta_{e1}\rvert^2$	$\lvert\Theta_{\mu1}\rvert^2$	r_Δ	ϕ_{e1}
IO	0	800	$10^{-6.70}$	$10^{-7.05}$	$10^{-2.50}$	$\pi/2$
NO	0	800	$10^{-7.50}$	$10^{-6.58}$	$10^{-1.50}$	$\pi/2$

Ordering	$T^{0\nu}_{1/2}$ [yr]	$\lambda_{0\nu}$	$\lambda_{\rm DUNE}$	$\lambda_{\rm DUNE\ (e)}$	$\lambda_{\rm DUNE\ (\mu)}$
IO	$10^{26.7}$	65.2	192	71.5	28.1
NO	$10^{27.1}$	28.2	193	12.3	95.4

Light effective masses (m_ν in 1+2):

IO: $10^{-1.3}$ eV

NO: $10^{-2.4}$ eV