UK HEP Forum

21st November 2023

Heavy neutral leptons from kaon decays in effective field theory

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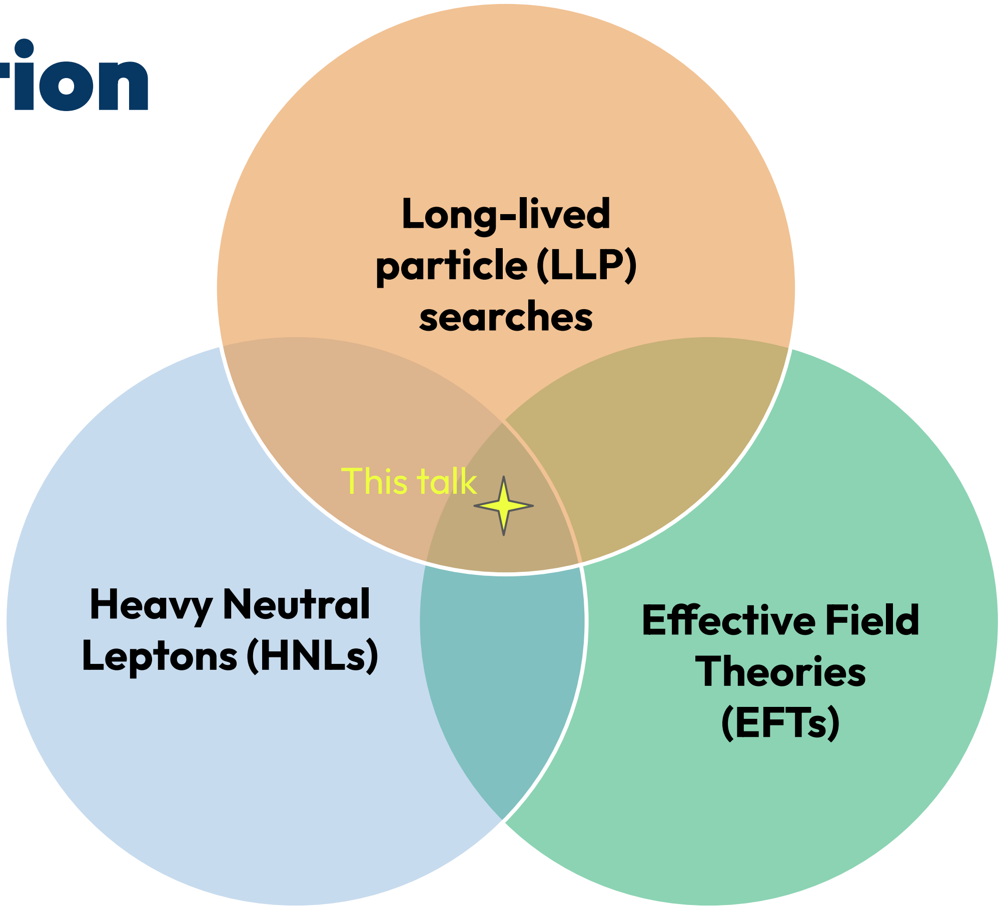
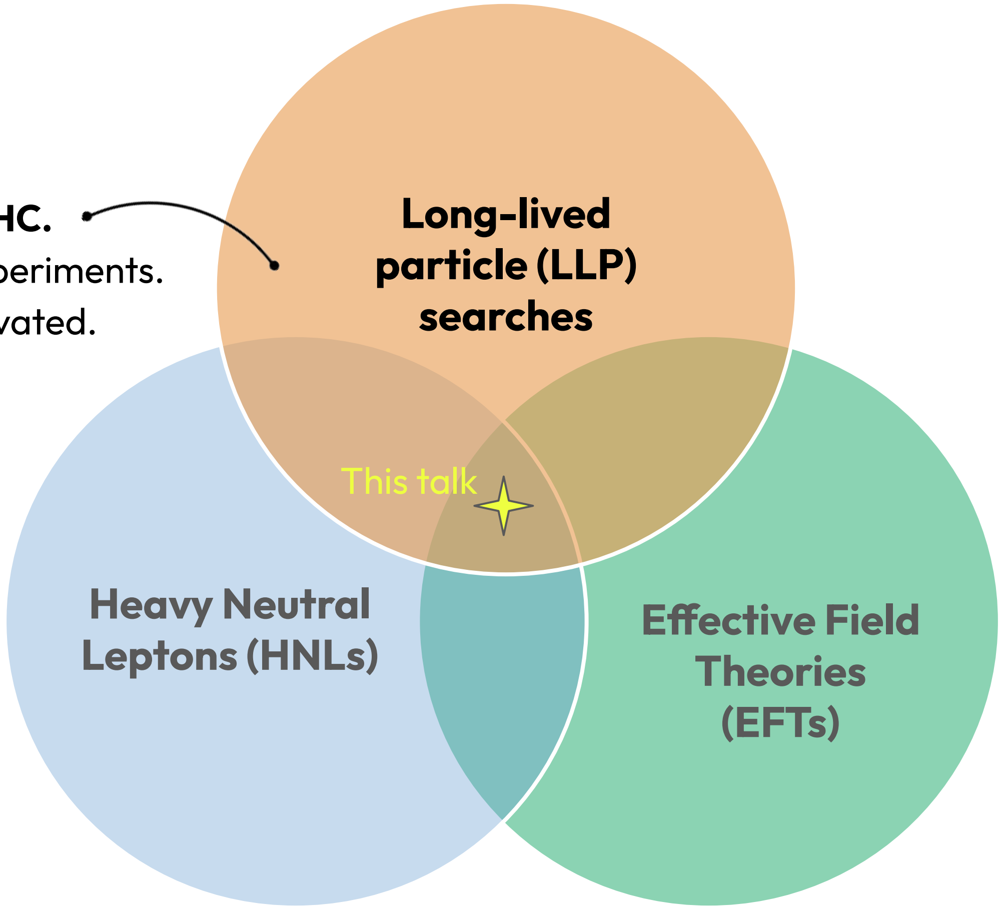
Motivation


Long-lived particle (LLP) searches
This talk
Heavy Neutral Leptons (HNLs)
Effective Field Theories (EFTs)

LLPs

Rich program @ LHC.
New dedicated experiments.
Theoretically motivated.



LLPs

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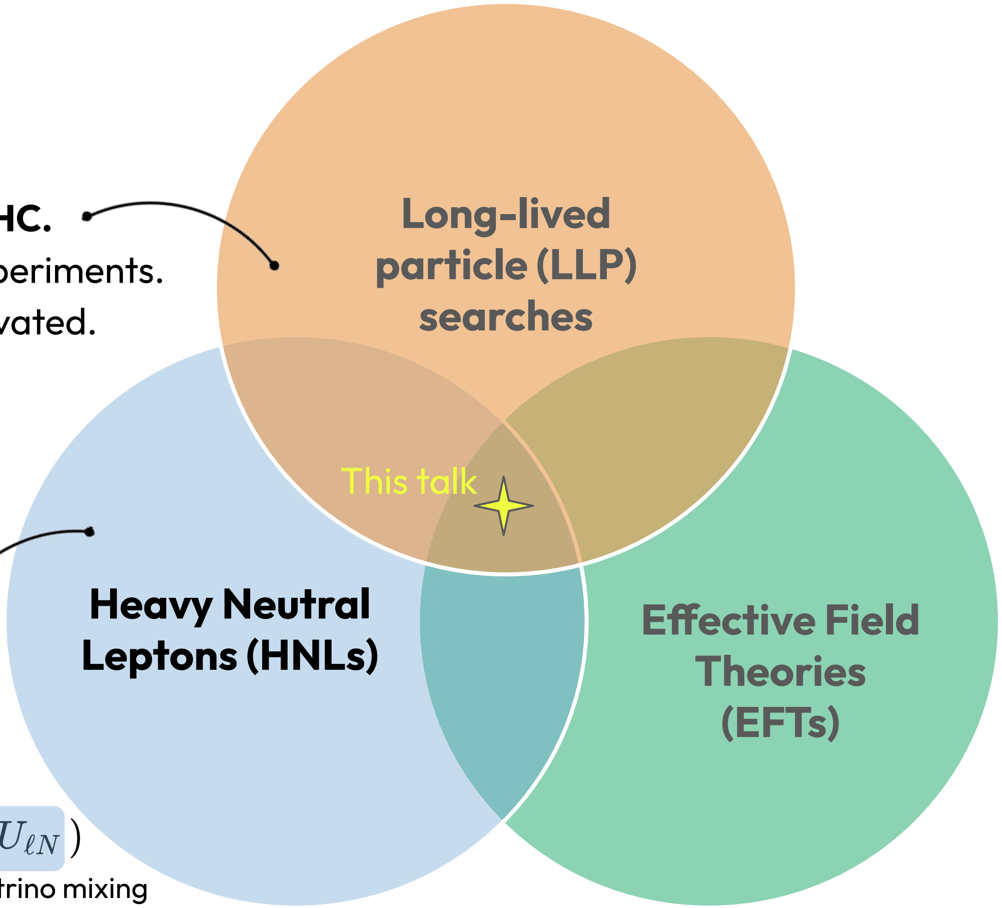


HNLs

Neutrino Portal
(renormalisable)

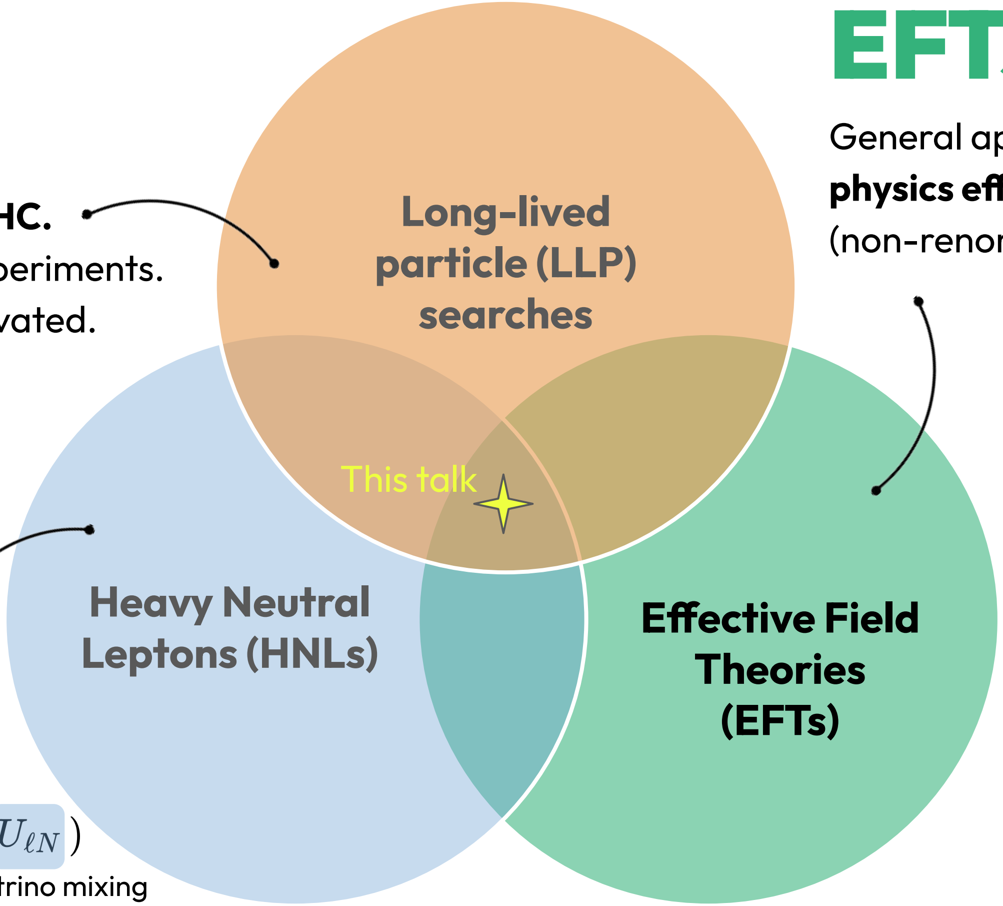
Minimal model: $(m_N \, , U_{\ell N})$
mass, neutrino mixing

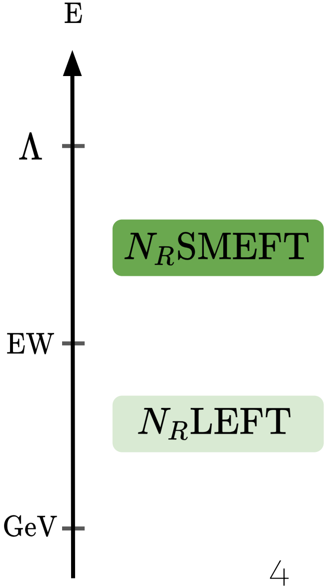
LLPs

Rich program @ LHC.
New dedicated experiments.
Theoretically motivated.

EFTs

General approach to describe **new physics effects** at **low energies** (non-renormalisable interactions)





HNLs

Neutrino Portal
(renormalisable)

Minimal model: $(m_N \, , U_{\ell N})$
mass, neutrino mixing

✦ **Could the far detectors @ LHC probe low-mass scale HNLs in non-minimal scenarios, i.e. N_RLEFT?**

[2309.11546] RB, J. Günther, M. Hirsch, A. Titov, Z.S. Wang

N_RLEFT : Low-energy EFT of the SM extended with HNLs.

$$\mathcal{L}^{\text{eff}} = \mathcal{L}^{d=4} + \sum_{d\geq 5} c_i^{(d)} \mathcal{O}_i^{(d)}$$

Wilson Coefficients $c^{(d)} \propto \frac{\alpha}{\Lambda^{d-4}}$

Invariant operators $SU(3)_{\rm C} \times U(1)_{\rm EM}$

***d* = 6 operators** triggering **kaon decays** into HNLs:

Pair-N_R

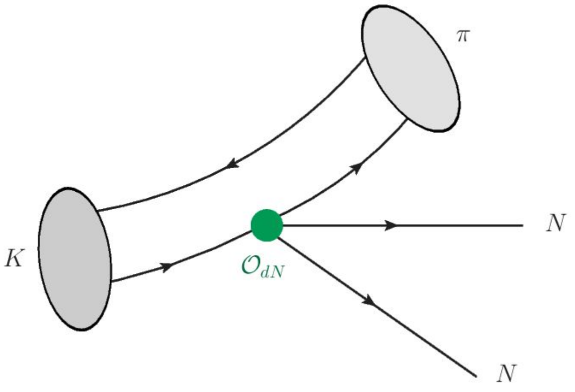
$\mathcal{O}_{dN}^{V,RR}$ $\left(\overline{d_R}\gamma_\mu d_R\right)\left(\overline{N_R}\gamma^\mu N_R\right)$

$\mathcal{O}_{dN}^{S,RR}$ $\left(\overline{d_L} d_R\right)\left(\overline{N_R^c} N_R\right)$

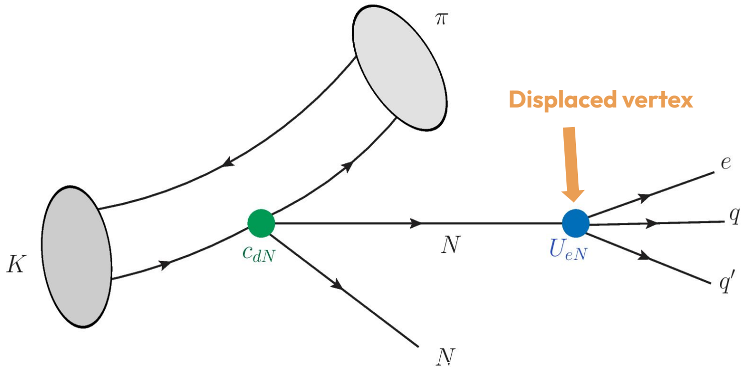
Single-N_R

$\mathcal{O}_{udeN}^{V,RR}$ $(\overline{u_R}\gamma_\mu d_R)(\overline{e_R}\gamma^\mu N_R)$

$\mathcal{O}_{udeN}^{S,RR}$ $(\overline{u_L} d_R)(\overline{e_L} N_R)$



Benchmark 1.1



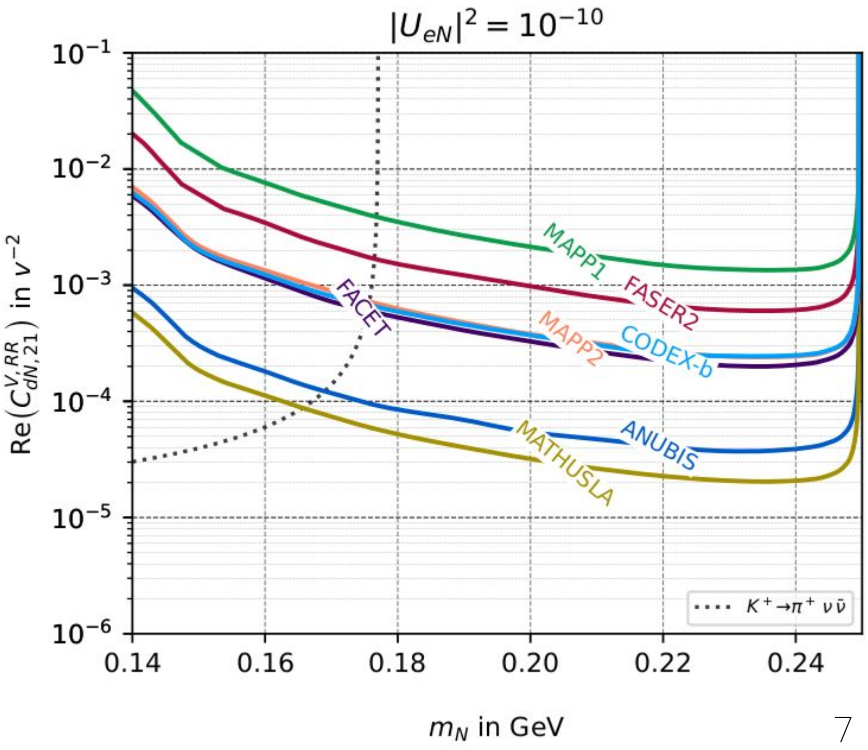
HNL production

$$\propto c^{V,RR}_{dN,21} (\overline{s_R}\gamma_\mu d_R)\left(\overline{N_R}\gamma^\mu N_R\right)$$

HNL decay

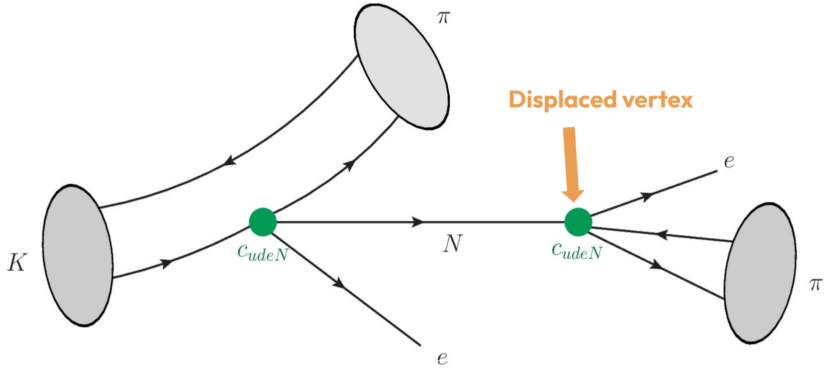
$$\propto G_F U_{eN} (\overline{u_L}\gamma_\mu d_L)(\overline{e_L}\gamma^\mu N_R^c)$$

3 signal events @ far detectors $N_{sig}\left(m_N\,,\,U_{\ell N}\,,\,c^{(6)}_{\mathcal{O}}\right)$



Benchmark 3

3 signal events @ far detectors $N_{sig}\left(m_N\,,\,c_{\mathcal{O}}^{(6)}\right)$

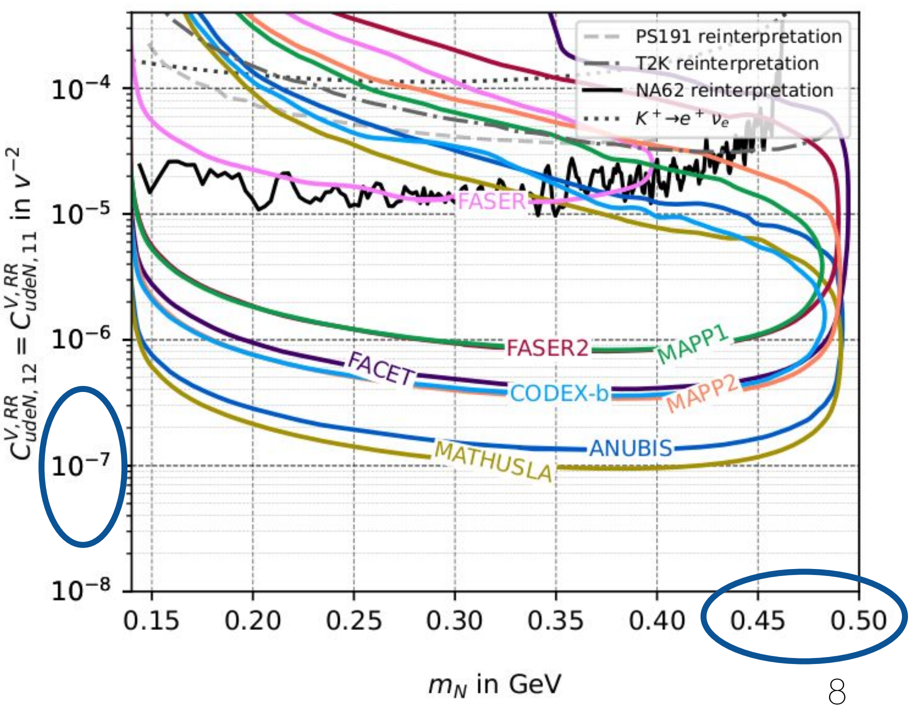


HNL production

$$\propto c_{udeN,12}^{V,RR}(\overline{u_R}\gamma_\mu s_R)(\overline{e_R}\gamma^\mu N_R)$$

HNL decay

$$\propto c_{udeN,11}^{V,RR}(\overline{u_R}\gamma_\mu d_R)(\overline{e_R}\gamma^\mu N_R)$$



Take-home message

- Huge discovery potential of the far detectors @ LHC.
- Promising sensitivity prospects for HNLs within N_RLEFT.

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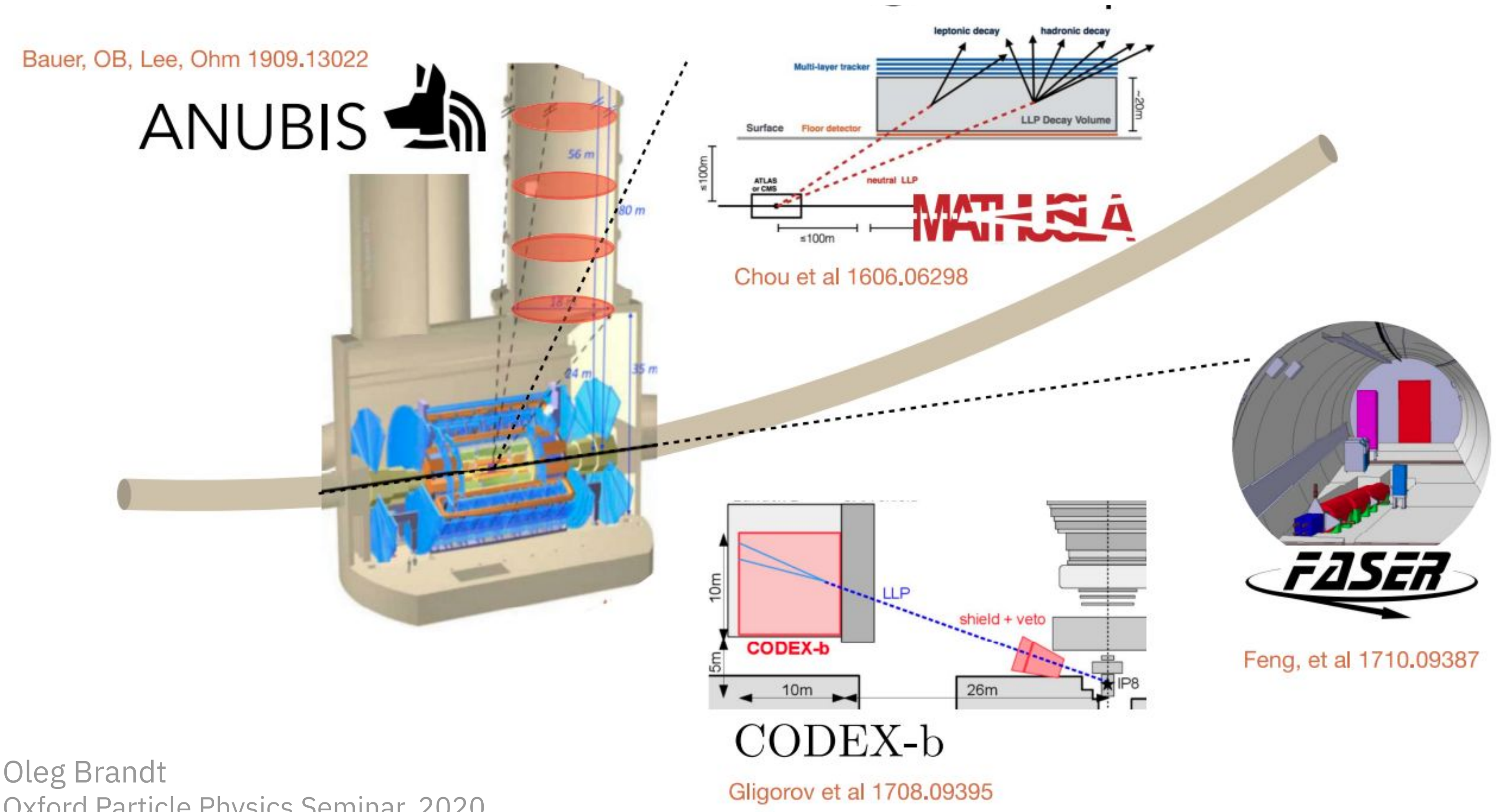
Backup slides: far detectors



N_RLEFT four-fermion operators

Pair-N_R

LNC	$\mathcal{O}_{uN}^{V,RR}$	$(\overline{u_R}\gamma^\mu u_R)\left(\overline{N_R}\gamma_\mu N_R\right)$
LNC	$\mathcal{O}_{dN}^{V,RR}$	$\left(\overline{d_R}\gamma^\mu d_R\right)\left(\overline{N_R}\gamma_\mu N_R\right)$
LNC	$\mathcal{O}_{uN}^{V,LR}$	$(\overline{u_L}\gamma^\mu u_L)\left(\overline{N_R}\gamma_\mu N_R\right)$
LNC	$\mathcal{O}_{dN}^{V,LR}$	$\left(\overline{d_L}\gamma^\mu d_L\right)\left(\overline{N_R}\gamma_\mu N_R\right)$
LNV	$\mathcal{O}_{uN}^{S,RR}$	$(\overline{u_L}u_R)\left(\overline{N_R^c}N_R\right)$
LNV	$\mathcal{O}_{dN}^{S,RR}$	$\left(\overline{d_L}d_R\right)\left(\overline{N_R^c}N_R\right)$
LNV	$\mathcal{O}_{uN}^{S,LR}$	$(\overline{u_R}u_L)\left(\overline{N_R^c}N_R\right)$
LNV	$\mathcal{O}_{dN}^{S,LR}$	$\left(\overline{d_R}d_L\right)\left(\overline{N_R^c}N_R\right)$

Single-N_R

LNC	$\mathcal{O}_{udeN}^{V,RR}$	$(\overline{u_R}\gamma^\mu d_R)(\overline{e_R}\gamma_\mu N_R)$
LNC	$\mathcal{O}_{udeN}^{V,LR}$	$(\overline{u_L}\gamma^\mu d_L)(\overline{e_R}\gamma_\mu N_R)$
LNC	$\mathcal{O}_{udeN}^{S,RR}$	$(\overline{u_L}d_R)(\overline{e_L}N_R)$
LNC	$\mathcal{O}_{udeN}^{T,RR}$	$(\overline{u_L}\sigma_{\mu\nu}d_R)(\overline{e_L}\,\sigma^{\mu\nu}N_R)$
LNC	$\mathcal{O}_{udeN}^{S,LR}$	$(\overline{u_R}d_L)(\overline{e_L}N_R)$
LNV	$\mathcal{O}_{udeN}^{V,LL}$	$(\overline{u_L}\gamma^\mu d_L)(\overline{e_L}\gamma_\mu N_R^c)$
LNV	$\mathcal{O}_{udeN}^{V,RL}$	$(\overline{u_R}\gamma^\mu d_R)(\overline{e_L}\gamma_\mu N_R^c)$
LNV	$\mathcal{O}_{udeN}^{S,LL}$	$(\overline{u_R}d_L)(\overline{e_R}N_R^c)$
LNV	$\mathcal{O}_{udeN}^{T,LL}$	$(\overline{u_R}\sigma_{\mu\nu}d_L)(\overline{e_R}\,\sigma^{\mu\nu}N_R^c)$
LNV	$\mathcal{O}_{udeN}^{S,RL}$	$(\overline{u_L}d_R)(\overline{e_R}N_R^c)$

Benchmarks

Benchmark	Production	Decay
B1.1	$c^{V,RR}_{dN,21} \in \mathbb{R}$	U_{eN}
B1.2	$c^{V,RR}_{dN,21} \in i\,\mathbb{R}$	U_{eN}
B2.1	$c^{S,RR}_{dN,21} \in \mathbb{R}$	U_{eN}
B2.2	$c^{S,RR}_{dN,21} \in i\,\mathbb{R}$	U_{eN}

Benchmark	Production	Decay
B3	$c^{V,RR}_{udeN,12}$	$c^{V,RR}_{udeN,11}$
B4	$c^{S,RR}_{udeN,12}$	$c^{S,RR}_{udeN,11}$
B5	$c^{V,RR}_{udeN,12}$ and U_{eN}	U_{eN}
B6	$c^{S,RR}_{udeN,12}$ and U_{eN}	U_{eN}
B7	$c^{V,RL}_{udeN,12}$ and U_{eN}	U_{eN}
B8	$c^{S,RL}_{udeN,12}$ and U_{eN}	U_{eN}

Table 4. Benchmarks for the scenarios with pair-N_R (left) and single-N_R (right) operators.

Sensitivity plot U_{eN} vs m_N

B1.1