in collaboration with L. Merlo (Madrid, IFT), Jean-Loup Tastet (Madrid, IFT)

HIDDeν — Hunting Invisibles: Dark sectors, Dark matter and Neutrinos

Instituto de Física Teórica UAM-CSIC

based on **2212.11290**

Down to the Seesaw Line via the JALZ ALP-HNL Portal

by **Arturo de Giorgi (Madrid, IFT)**

HNL

- **Neutrinos** need a **mass** ⇒ **right-handed** neutrinos, N_R ?

$$\mathscr{L}_{\rm HNL} = i\overline{N_R}\not{\partial}N_R - \left(\overline{L_L}\tilde{H}\boldsymbol{Y}_N N_R + \frac{1}{2}\overline{N_R^c}\boldsymbol{M}_N N_R + \text{h.c.}\right)$$

- **Smallness** of m_ν? **Majorana mass** is a free parameter ⇒ **Seesaw** mechanisms

$$m_\nu \sim v^2 Y^2 / M_N$$

- N_R interacts with **gauge bosons** via **mixing** with active neutrinos ν_α

$$\nu_\alpha \to \nu_\alpha + \Theta_\alpha N_R^c \qquad \text{"mixing-angle"}$$

"Seesaw Line" $\quad ||\Theta||^2 \sim \dfrac{||\boldsymbol{m}_\nu||}{||\boldsymbol{M}_N||} \lesssim 10^{-12}$ ⇒ **hardly testable!**

Another portal?

ALP

- **Pseudo-Goldstone boson**
- Generated by spontaneous **breaking** of a **global symmetry**, e.g. **U(1)**
- Part of many **BSM** scenarios, including **String Theory**
- Missing a UV? Mainly studied via **EFT**

$$\mathscr{L}_a = \frac{1}{2}\partial_\mu a\,\partial^\mu a - \frac{1}{2}m_a^2 a^2 - \frac{a}{f_a}\sum_X c_{aXX}\, X^{\mu\nu}\tilde{X}_{\mu\nu} - \frac{\partial_\mu a}{f_a}\sum_\psi \overline{\psi}\, \boldsymbol{c}_\psi \gamma^\mu \psi$$

anomalous — **shift-symmetric**

- **Coupling** proportional to **fermion mass**

$$\frac{\partial_\mu a}{f_a}\bar{\psi}\gamma^\mu\psi \sim \frac{a}{f_a}m_\psi \bar{\psi}\psi \quad \Rightarrow \quad \textbf{heavier = better!}$$

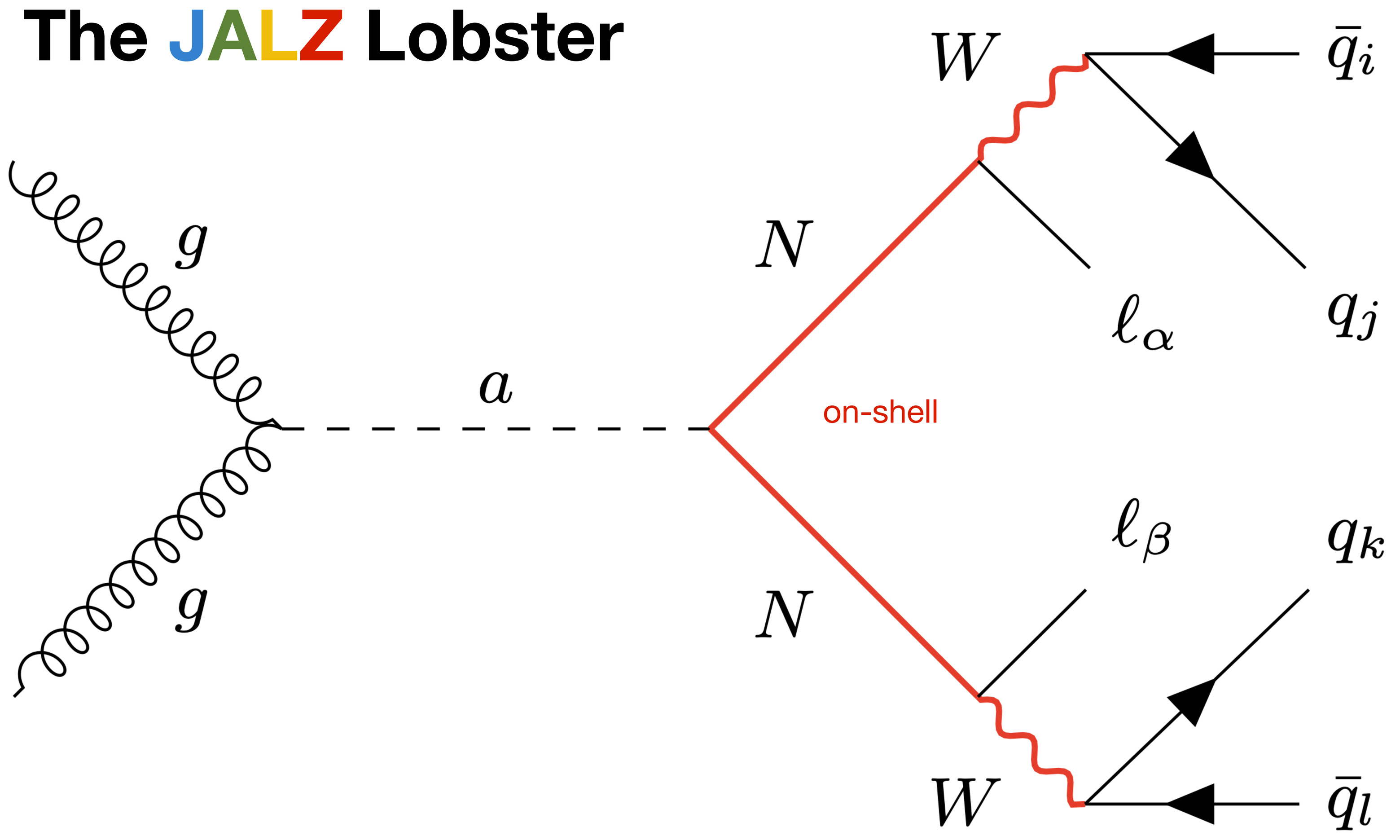
Can we take advantage of that?

$$\mathscr{L}^{\rm eff} = \mathscr{L}_{\rm SM} + \mathscr{L}_{\rm HNL} + \mathscr{L}_a \qquad \mathscr{L}_a \supset -\frac{\partial_\mu a}{f_a}\overline{N_R}\gamma^\mu \boldsymbol{c}_N N_R$$

→ **Where** to look? Promising signal with **4-jets** and **2-leptons** →

J4L2
JALZ

The JALZ Lobster



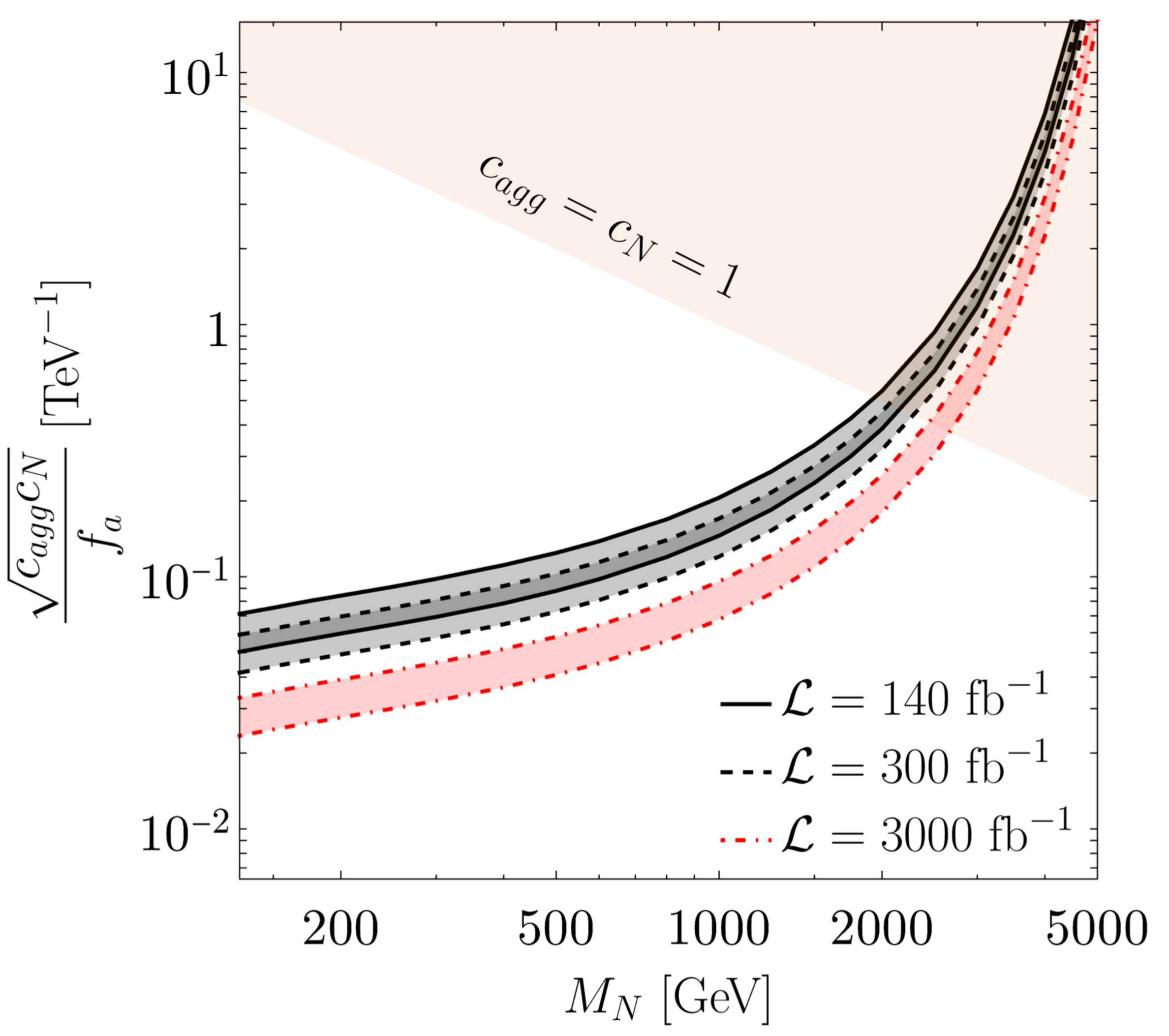
Why JALZ?

Advantages:

1. $\mathscr{M} \propto M_N/f_a$ → **enhancement!**
2. ~~$\mathscr{M} \propto \Theta_\alpha$~~
3. ~~$\mathscr{M}(m_a)$~~
4. **2 HNLs** → **2 peaks**
5. $\ell_\alpha^\pm \ell_\beta^\pm$ → SM **background suppressed!**

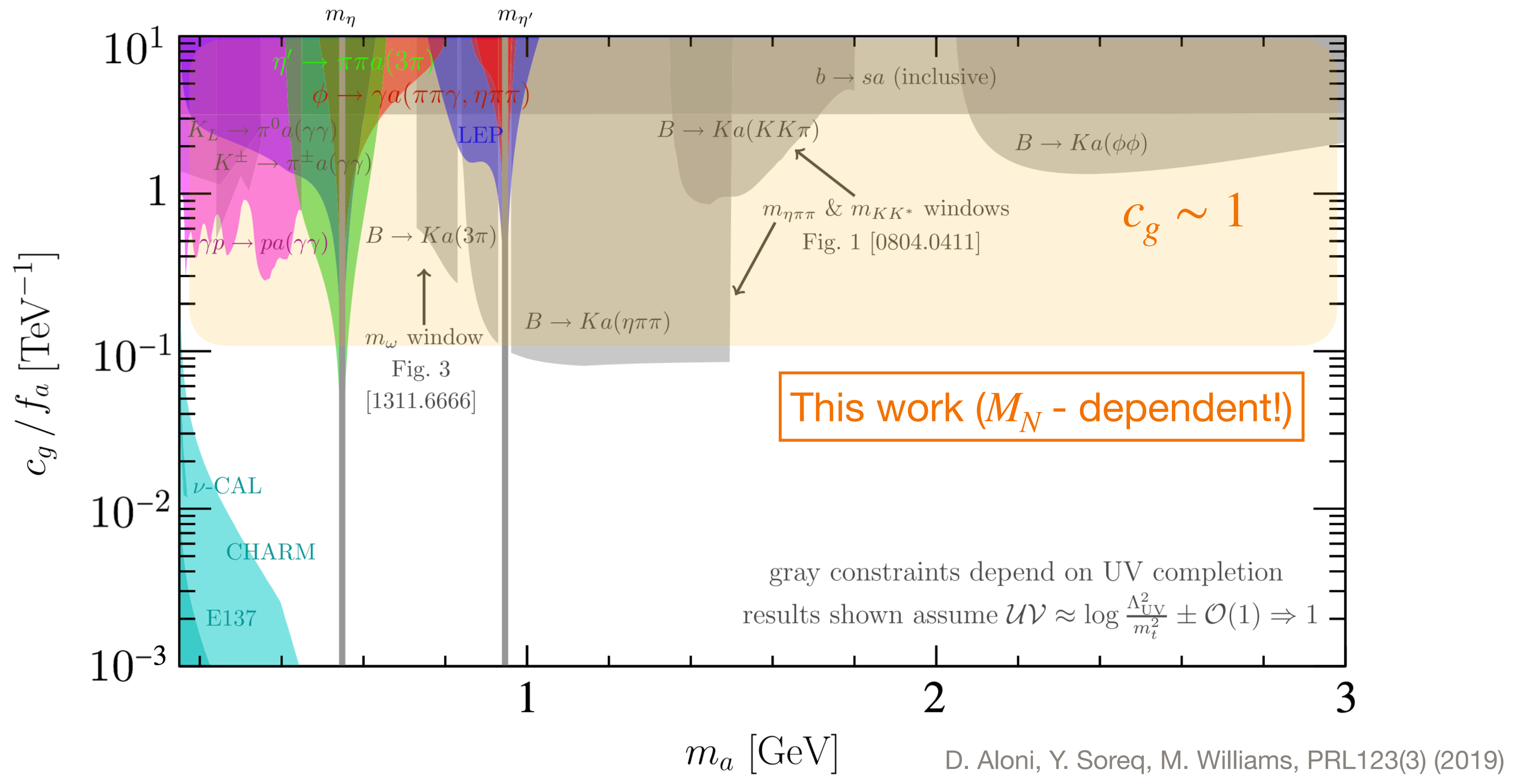
$$\sigma_{\alpha\beta} \propto \frac{c_{agg}^2 c_N^2}{f_a^4}\frac{|\Theta_\alpha|^2|\Theta_\beta|^2}{\Gamma_N^2} \propto \frac{c_{agg}^2 c_N^2}{f_a^4}\frac{|\Theta_\alpha|^2}{|\Theta|^2}\frac{|\Theta_\beta|^2}{|\Theta|^2}$$

Projected Limits



Astonishing bounds

- Dynamical origin of M_N ⇒ $\bar{N}_R^c M_N N_R \to \phi \bar{N}_R^c Y_N N_R$ ⇒ $c_N = 1$



D. Aloni, Y. Soreq, M. Williams, PRL123(3) (2019)

Take Home Messages

- **ALP?** Still, **neutrinos need masses**!
- **HNLs** ~ **simplest** and most **motivated** candidates to explain ν-masses
- **ALP-Portal** allows for **new channels** (e.g. **JALZ**) and **stronger bounds**!

Interesting phenomenology ahead of us!