The Third-Generation-Philic WIMP

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IMPRS PhD Recruitment Workshop

Master's Thesis work under the supervision of Prof. Gino Isidori

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Overview

The Standard Model as an EFT

The Standard Model is a remarkably simple and elegant description of fundamental physics

$$\Downarrow$$

$$SU(3)_{\mathrm{c}} \times SU(2)_{\mathrm{L}} \times U(1)_{\mathrm{Y}}$$

$$\Downarrow$$

The Standard Model is only the EFT of a more complete UV theory with more degrees of freedom

The Standard Model as an EFT

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with more degrees of freedom

- Hierarchy Problem

- Flavour Puzzle
- Neutrino Masses

- Dark Matter
- Dark Energy
- Inflation

The Standard Model as an EFT

The Standard Model is only the EFT of a more complete UV theory with more degrees of freedom

- Hierarchy Problem
- Flavour Puzzle
- Dark Matter

Hierarchy problem

In order to reproduce the SM spectrum $\mu \approx \mathcal{O}(100\ \text{GeV})$ if $\lambda \ll 1$

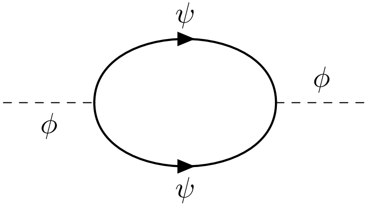
↑

$$V(\phi)_{Higgs} = \mu^2|\phi|^2 + \lambda|\phi|^4$$

↓

WHY $\mu \approx \mathcal{O}(100)$ GeV and not equal to any higher scale, like the GUT scale (10^{16} GeV) or the Planck Scale (10^{19} GeV)

Hierarchy problem



↓

$$\delta m_H^2 = \frac{\Lambda^2}{16\pi^2}\left[6\lambda + \frac{9}{4}g_2^2 + \frac{3}{4}g_Y^2 - 6\,y_t^2 + \cdots\right]$$

↓

If the scale of new physics is very high, an "unnatural" cancellation is required to produce the small finite Higgs mass.

Universal Interactions Solutions

For the past decades the archetypal paradigm in BSM theories was the stabilization of the Higgs mass via the inclusion of NP at low energies and deferring the solution of the flavor problem to higher scales.

Supersymmetry

Relate bosons to fermions and use Chiral Symmetry protection.

$\Downarrow$

Flavor physics origin forces sparticles to be very heavy $\Lambda \gg 100$ TeV [Dimopoulos Sutter '95]

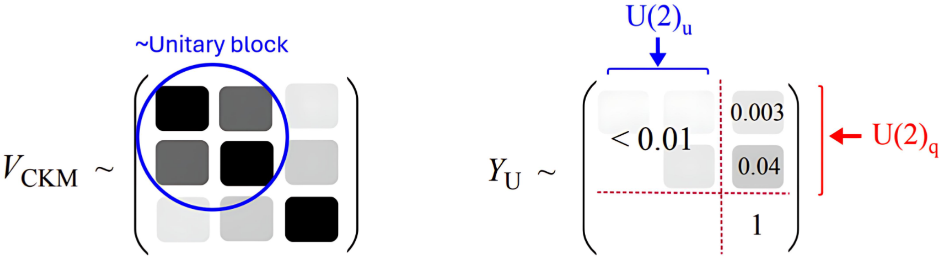
Higgs Compositeness

Lower the scale of NP by postulating a composite Higgs model.

$\Downarrow$

Gauge bosons couple both to fermions and technifermions $\Lambda_{\mathrm{EXT}} \ll \Lambda_{\mathrm{TC}}$ [Hill Simmons '03]

Flavor Puzzle



The structure of the SM flavour dynamics is suspiciously symmetrical
IS THERE A DEEPER EXPLANATION?

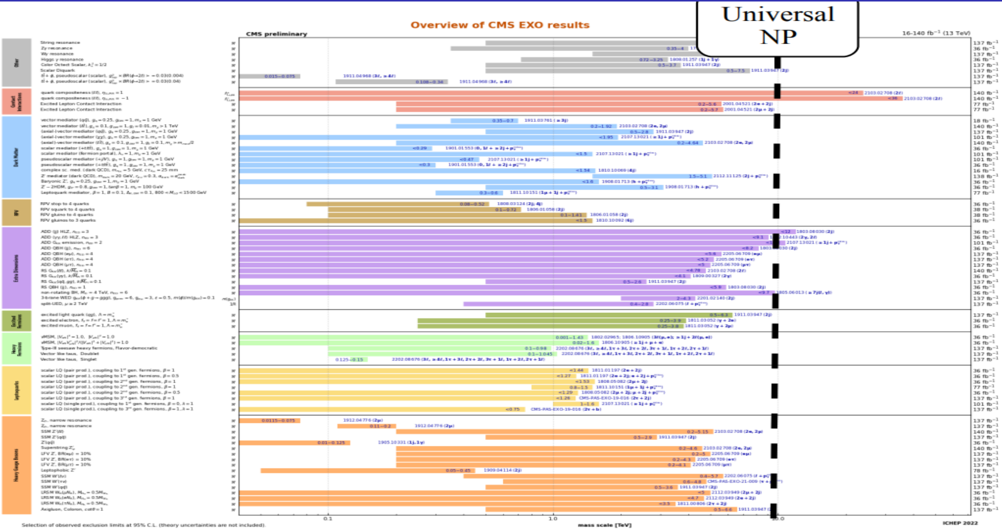
Universal Interactions Solutions

For the past decades the archetypal paradigm in BSM theories was the stabilization of the Higgs mass via the inclusion of NP at low energies and deferring the solution of the flavor problem to higher scales

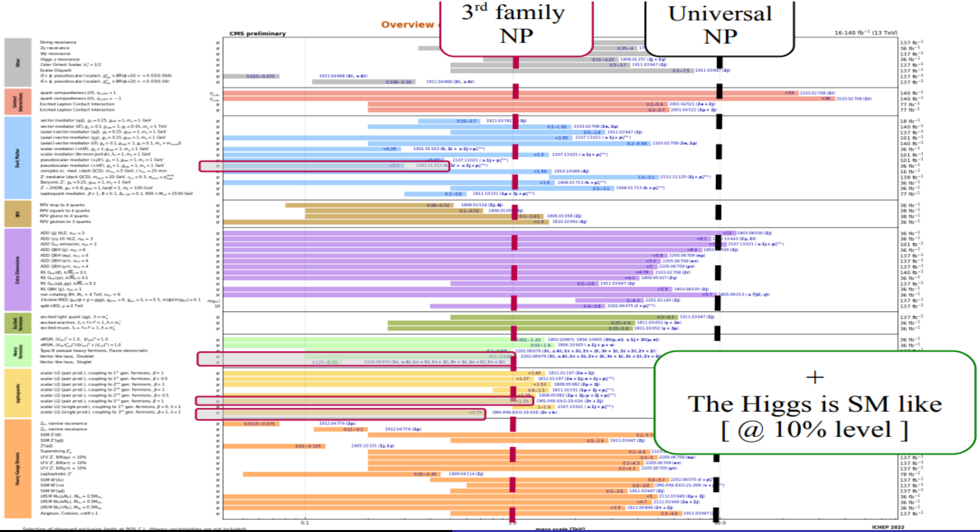
$\downarrow$

... LHC results made such models unattractive ...

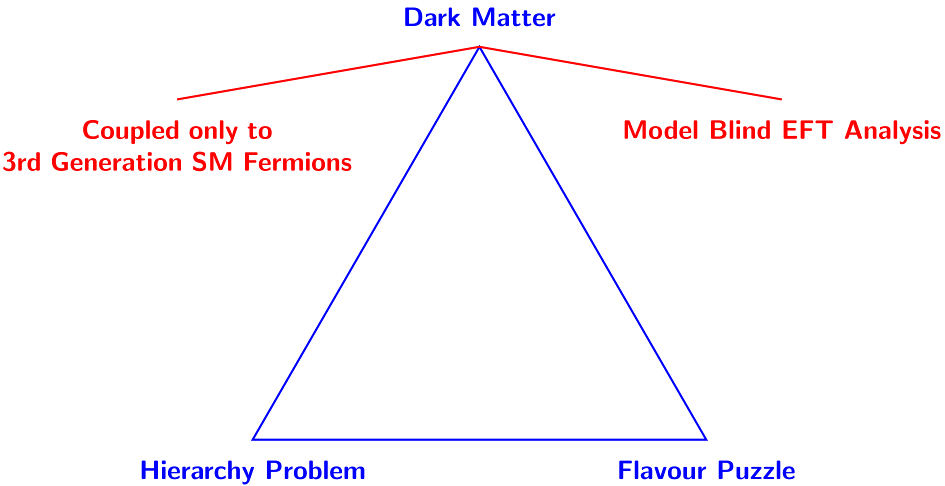
Universal Interaction



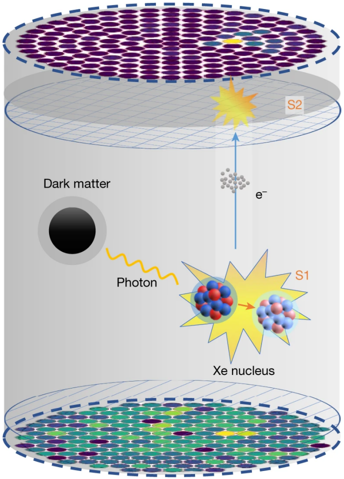
Non so flavor universal interaction



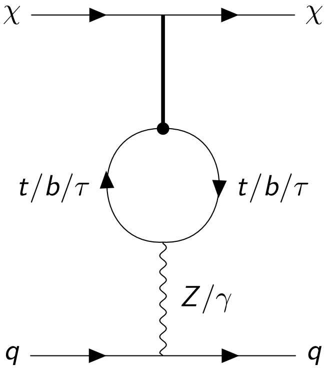
The flavour–symmetry triangle



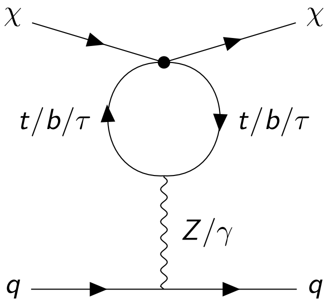
Direct Detection Nuclear Recoil Experiments



Direct Detection Diagram Reduction



$\Rightarrow$



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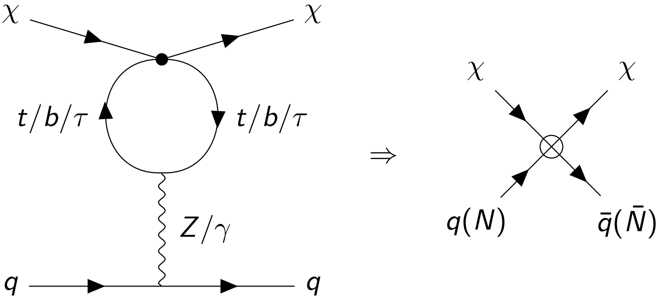
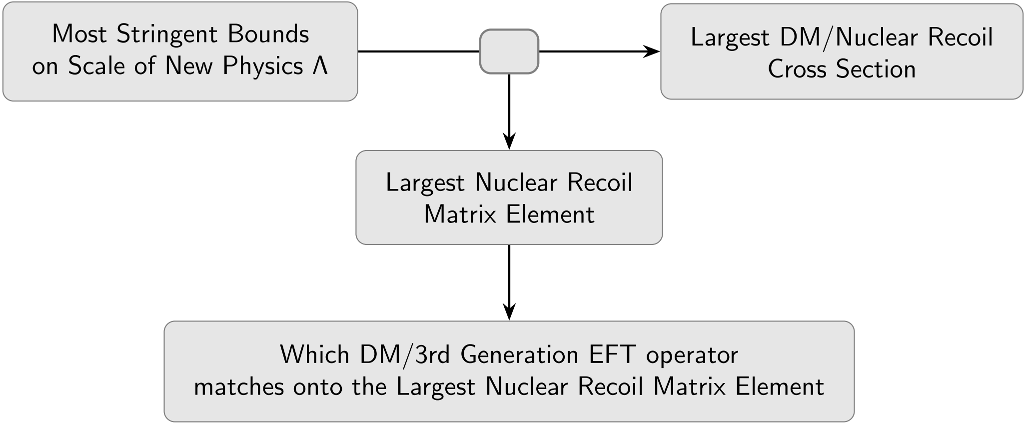


Proof of Concept Strategy



Reduction of Fermionic DM Scattering Operators [Fitzpatrick, Haxton 13 /Fan,Reece 10]

Operator	Dimensionality	Reduction
$\bar{\chi}\,\gamma_\mu\,\chi\;\bar{N}\,\gamma^\mu\,N$	6	$4m_\chi m_N\,1_\chi\,1_N$
$\bar{\chi}\,\gamma_\mu\gamma_5\,\chi\;\bar{N}\,\gamma^\mu\,N$	6	$8m_\chi m_N\,\vec{S}_\chi\cdot\vec{v}^\perp + 8m_\chi\,i\,\vec{S}_\chi\cdot(\vec{S}_N\times\vec{q})$
$\bar{\chi}\,\gamma_\mu\,\chi\;\bar{N}\,\gamma^\mu\gamma_5\,N$	6	$-8m_\chi m_N\,\vec{S}_\chi\cdot\vec{v}^\perp + 8m_\chi\,i\,\vec{S}_\chi\cdot(\vec{S}_N\times\vec{q})$
$\bar{\chi}\,\gamma_\mu\gamma_5\,\chi\;\bar{N}\,\gamma^\mu\gamma_5\,N$	6	$-16m_\chi m_N\,\vec{S}_\chi\cdot\vec{S}_N$
$\bar{\chi}\,\chi\;\bar{N}\,N$	7	$4m_\chi m_N\,1_\chi\,1_N$
$\bar{\chi}\,i\gamma_5\,\chi\;\bar{N}\,N$	7	$-4m_N\,i\,\vec{S}_\chi\cdot\vec{q}$
$\bar{\chi}\,\chi\;\bar{N}\,i\gamma_5\,N$	7	$4m_N\,i\,\vec{S}_N\cdot\vec{q}$
$\bar{\chi}\,i\gamma_5\,\chi\;\bar{N}\,i\gamma_5\,N$	7	$4\,(\vec{S}_\chi\cdot\vec{q})\,(\vec{S}_N\cdot\vec{q})$
$\bar{\chi}\,\sigma^{\mu\nu}\,\chi\;\bar{N}\,\sigma_{\mu\nu}\,N$	7	$32m_\chi m_N\,\vec{S}_\chi\cdot\vec{S}_N$
$\bar{\chi}\,i\sigma^{\mu\nu}\gamma_5\,\chi\;\bar{N}\,\sigma_{\mu\nu}\,N$	7	$8\left(m_\chi\,i\,\vec{S}_\chi\cdot\vec{q} - m_N\,i\,\vec{S}_N\cdot\vec{q}\right) - 4m_\chi m_N\,\vec{v}^\perp\cdot(\vec{S}_\chi\times\vec{S}_N)$

Reduction of Fermionic DM Scattering Operators

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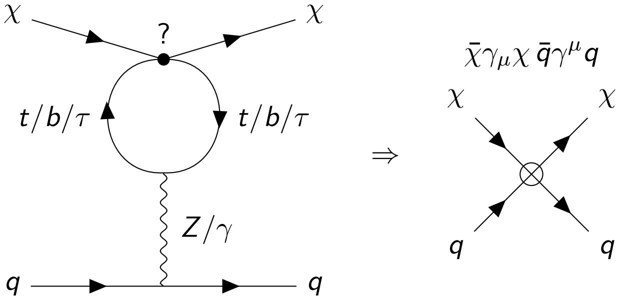
Which is the dominant DM/Third generation EFT operator?



$$\bar{\chi}\gamma_\mu\chi\,\bar{q}\gamma^\mu q$$

Fermionic Dominant Operator

Dominant DM/Third-Generation Operator

$$\mathcal{O}_{VL}^{\chi f} = \bar{\chi}\gamma_\mu \chi \bar{f}\gamma^\mu f \qquad f = Q_L, t_R, b_R, \tau_R, L_L$$

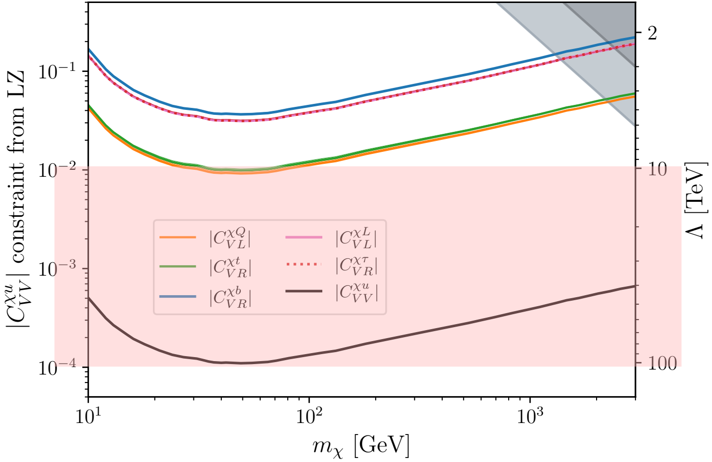
Fermionic Dominant Operator Wilson Coefficient

Wilson Coefficient of DM/Nucleus contact operator

$$C_{VV}^{\chi q} f(\Lambda) = -\frac{N_c^f}{\Lambda^2}\left[\frac{g^2 m_f^2}{4\pi^2 \cos^2(\theta_W) M_Z^2}\left(C_{VL}^{\chi f} - C_{VR}^{\chi f}\right) g_A^f g_V^q + \frac{e^2}{24\pi^2}\left(C_{VL}^{\chi f} + C_{VR}^{\chi f}\right) Q_f Q_q\right] \log\left(\frac{\Lambda^2}{m_f^2}\right)$$

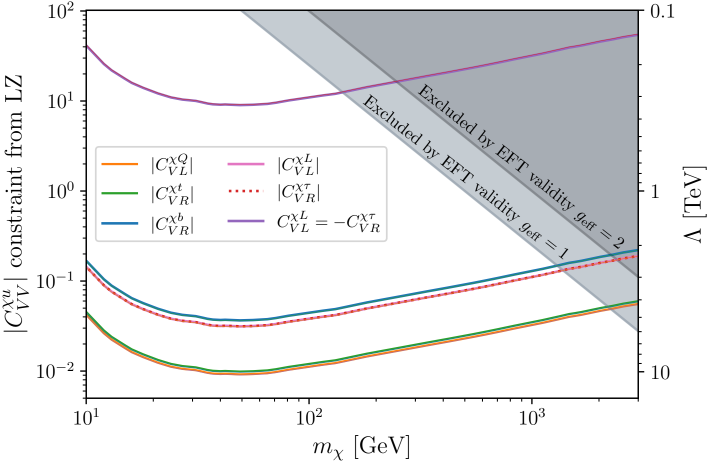
Bounds on Third Generation vs Bounds on Light Quarks

$10^{-4} \longrightarrow 10^{-2}$

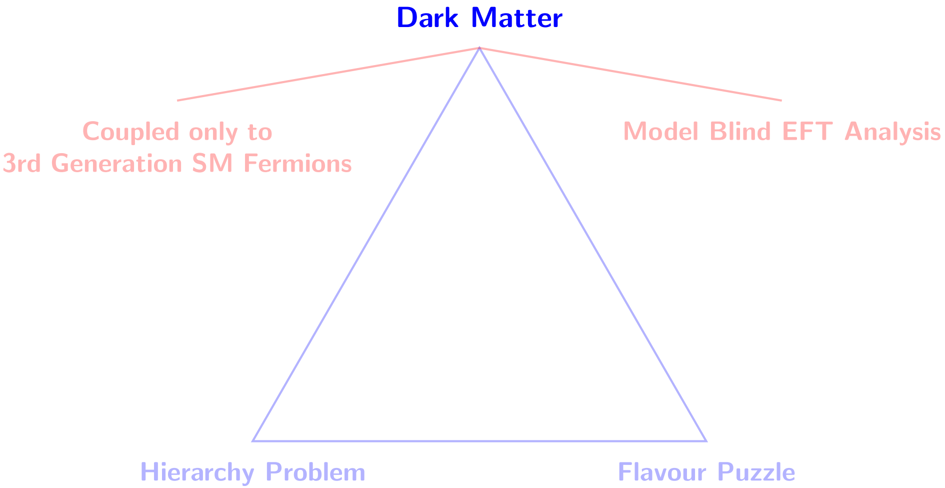


100 TeV $\longrightarrow$ 10 TeV

Bounds on Third Generation Fermions



Relic Abundance DM



Fermionic DM Relic Abundance in EFT

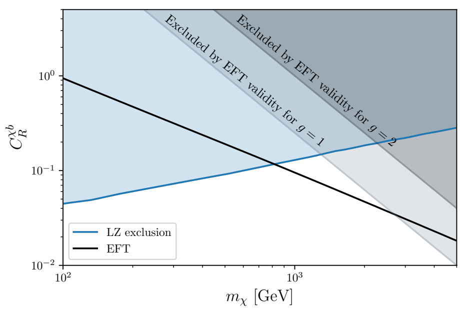


Figure: $\mathcal{O}_{V_R}^{\chi b_R}$ parameter space

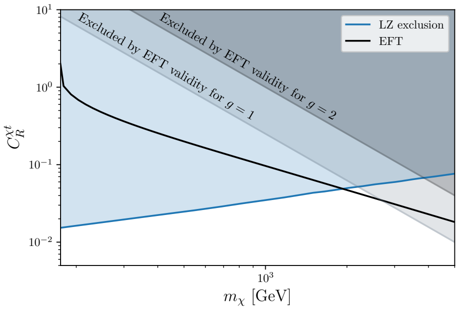


Figure: $\mathcal{O}_{V_R}^{\chi t_R}$ parameter space

$U(1)_X$ Simplified Paradigm Dirac

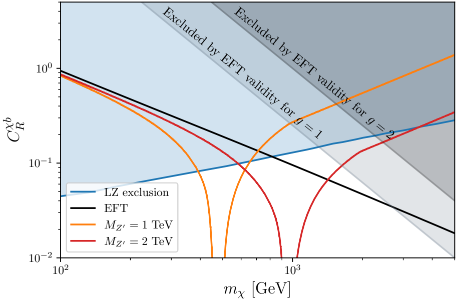


Figure: $\mathcal{O}_{VR}^{\chi b_R}$ parameter space

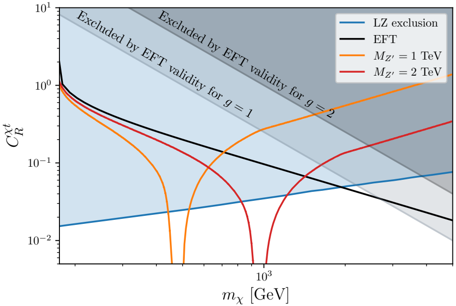


Figure: $\mathcal{O}_{VR}^{\chi t_R}$ parameter space

Conclusion

Under the assumption of a possible DM/3rd generation EFT it is possible to lower the scale of new physics below the 10 TeV scale while leaving a sizable coupling space available for Model Building [Demetriou, Isidori, Piazza, Pinsard 25]

Future Work

MODEL BUILDING BASED ON THE MINIMAL FLAVOR DECONSTRUCTION

Thank you for your attention