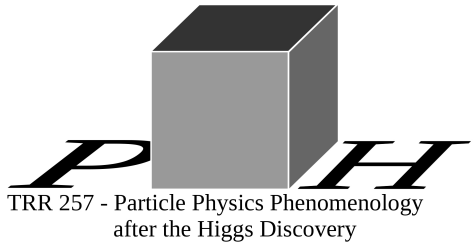
Tasting Flavoured Majorana Dark Matter

Harun Reşid Acaroğlu

This talk is based on
H.R.A. and M. Blanke, arXiv:2109.10357.



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Motivation

You know the story ...

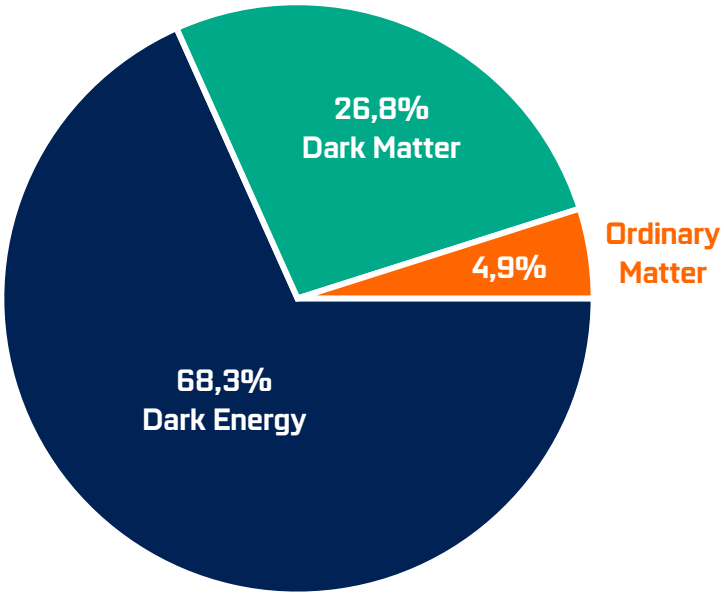


Fig. 1: Estimated energy-matter content of the universe. [1807.06209]

DM properties:

- what is its particle nature?
- single particle vs sector?
- analogy to SM matter?

Assumption

DM is a flavoured Majorana fermion that comes in three generations

Flavoured Majorana DM

We consider flavoured Majorana fermionic DM $\chi = (\chi_L, i\,\sigma_2\ \chi_L^*)^T$ coupling to right-handed up-type quarks via a scalar $(\mathbf{3},\mathbf{1})_{2/3}$ mediator ϕ:

$$\begin{aligned}\mathcal{L}_{\text{NP}} \supset & \frac{1}{2}\left(i\bar{\chi}\partial\!\!\!/\chi - M_\chi\bar{\chi}\chi\right) \\ & + (D_\mu\phi)^\dagger(D^\mu\phi) - m_\phi^2\,\phi^\dagger\phi \\ & - \left(\tilde{\lambda}_{ij}\,\bar{u}_{Ri}\chi_j\,\phi + h.c.\right)\,,\end{aligned}$$

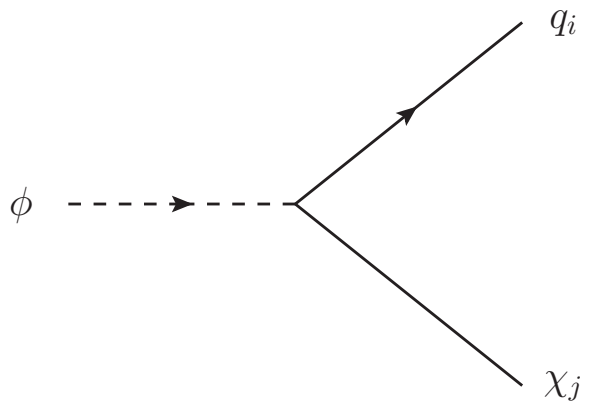


Fig. 2: NP interaction vertex.

with $M_\chi = \text{diag}(m_{\chi_1}, m_{\chi_2}, m_{\chi_3})$ and the hierarchy $m_{\chi_1} > m_{\chi_2} > m_{\chi_3}$.

Two benchmark scenarios

- Quasi-Degenerate Freeze-Out (QDF): mass splitting is below 1%
- Single-Flavour Freeze-Out (SFF): mass splitting is above 10%

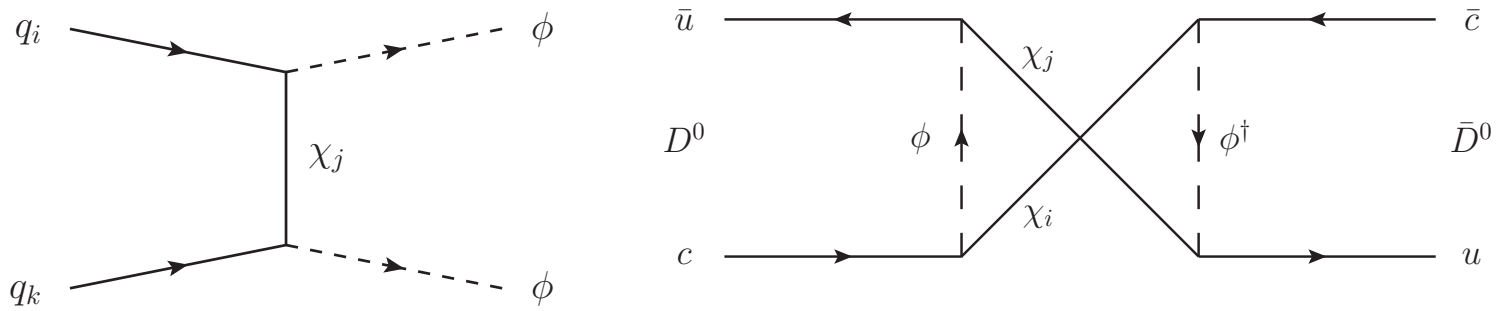
Phenomenology

Collider Searches:

- relevant signatures are tops $+ \not{E}$ and jets $+ \not{E}$
- Majorana-specific same-sign signature $tt + \not{E}$

Flavour Physics:

- strong limits from $D^0 - \bar{D}^0$ mixing
- additional crossed diagram extends the allowed parameter space



(a) same-sign $\phi\phi$ production

(b) crossed box diagram

Fig. 3: Majorana-specific Feynman diagrams for collider searches and $D^0 - \bar{D}^0$ mixing.

Relic Density:

- additional u-channel annihilation diagram for $\chi\chi \to q\bar{q}$
- p-wave suppression of $\langle \sigma v \rangle$ when annihilating into massless final states in the SFF scenario

Direct Detection:

- $\bar{\chi}\gamma^{\mu}\chi = \bar{\chi}\sigma^{\mu\nu}\chi = 0 \to$ spin-dependent scattering limits relevant
- weak constraints from direct detection

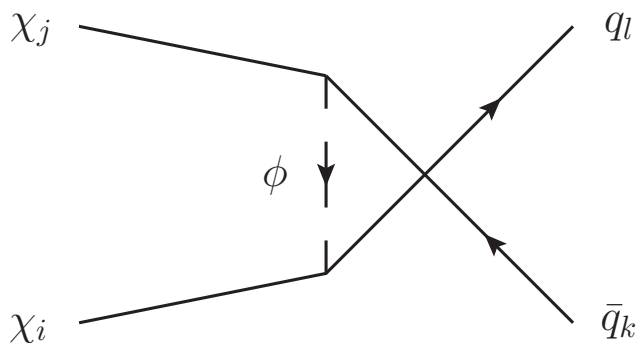


Fig. 4: Majorana-specific u-channel annihilation diagram.

Combined Analysis

- $D^0 - \bar{D}^0$ mixing and relic density constraints are dominant
- strong m_ϕ dependence due to p-wave suppression

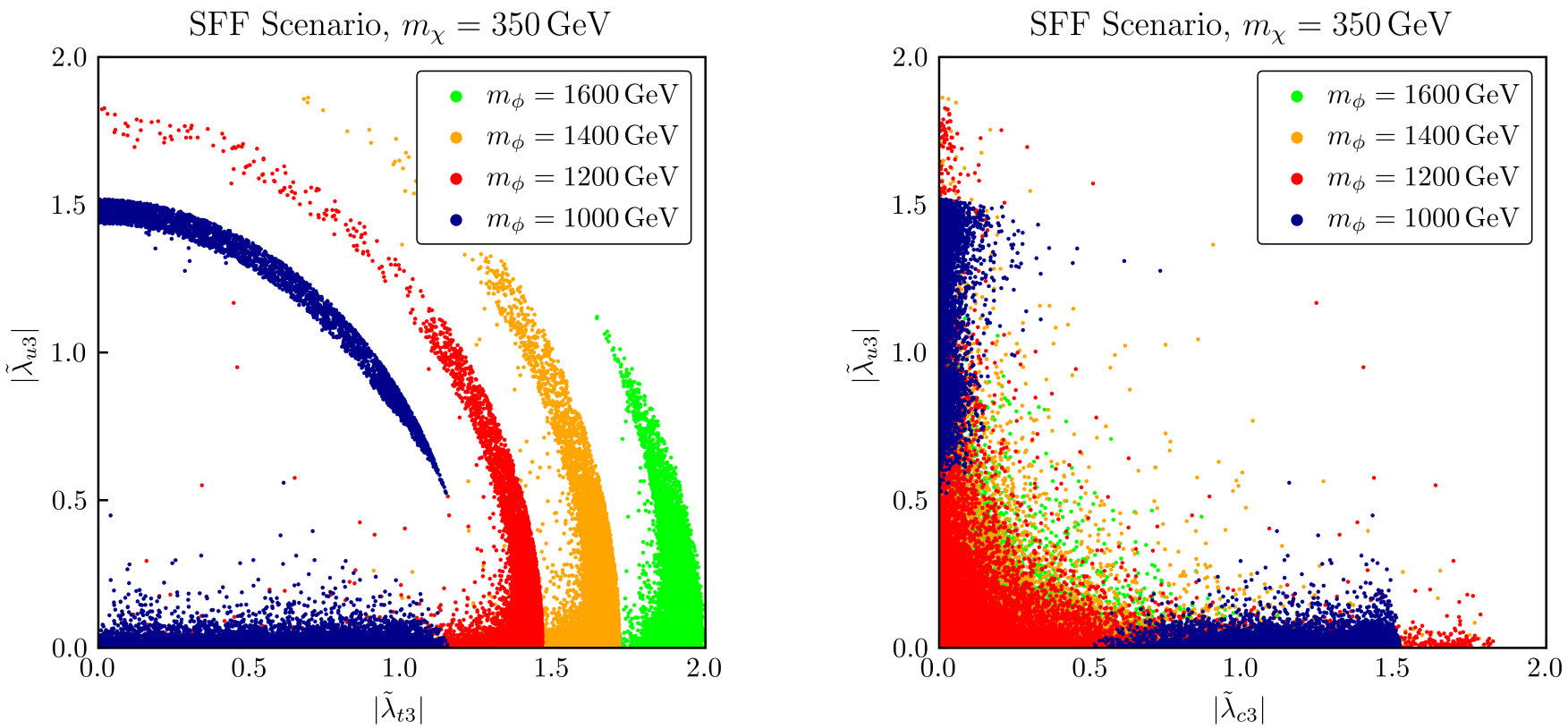


Fig. 5: Allowed couplings in the context of all constraints for the SFF scenario.

Direct CPV in Charm Decays

- LHCb measurement

LHCb Collab. in [1905.05428]

$$\Delta A_{\text{CP, LHCb}}^{\text{dir}} = A_{\text{CP}}(D \to K^+K^-) - A_{\text{CP}}(D \to \pi^+\pi^-)$$
$$= (-0.157 \pm 0.029)\%$$

- QCD light-cone sum-rule estimation

Khodjamirian, Petrov in [1706.07780]

$$\Delta A_{\text{CP, LCSR}}^{\text{dir}} = (0.02 \pm 0.003)\%$$

- hint at NP in $\Delta A_{\text{CP}}^{\text{dir}}$?

- large effects were found in non-flavoured model

Altmannshofer et al. in [1202.2866]

- we use the same approach to estimate size of $\Delta A_{\text{CP}}^{\text{dir}}$

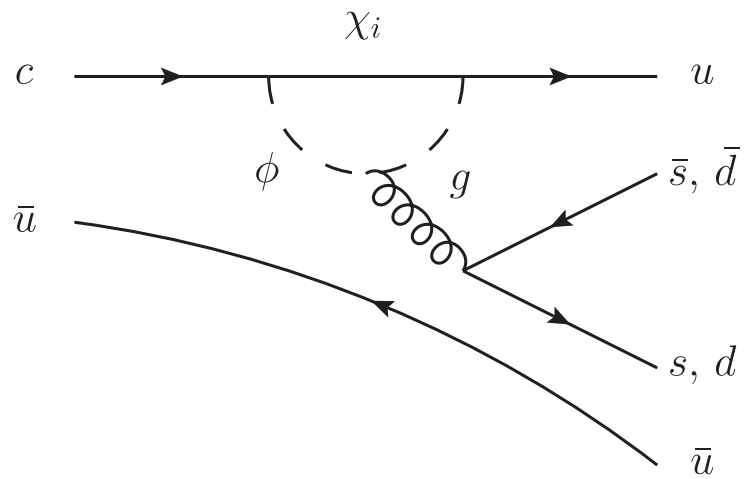


Fig. 6: Penguin diagram of NP D^0 decay.

- general m_ϕ^2 suppression in both scenarios
- enhancement in SFF scenario for $m_\phi \in [1.0, 1.3]\,\mathrm{TeV}$

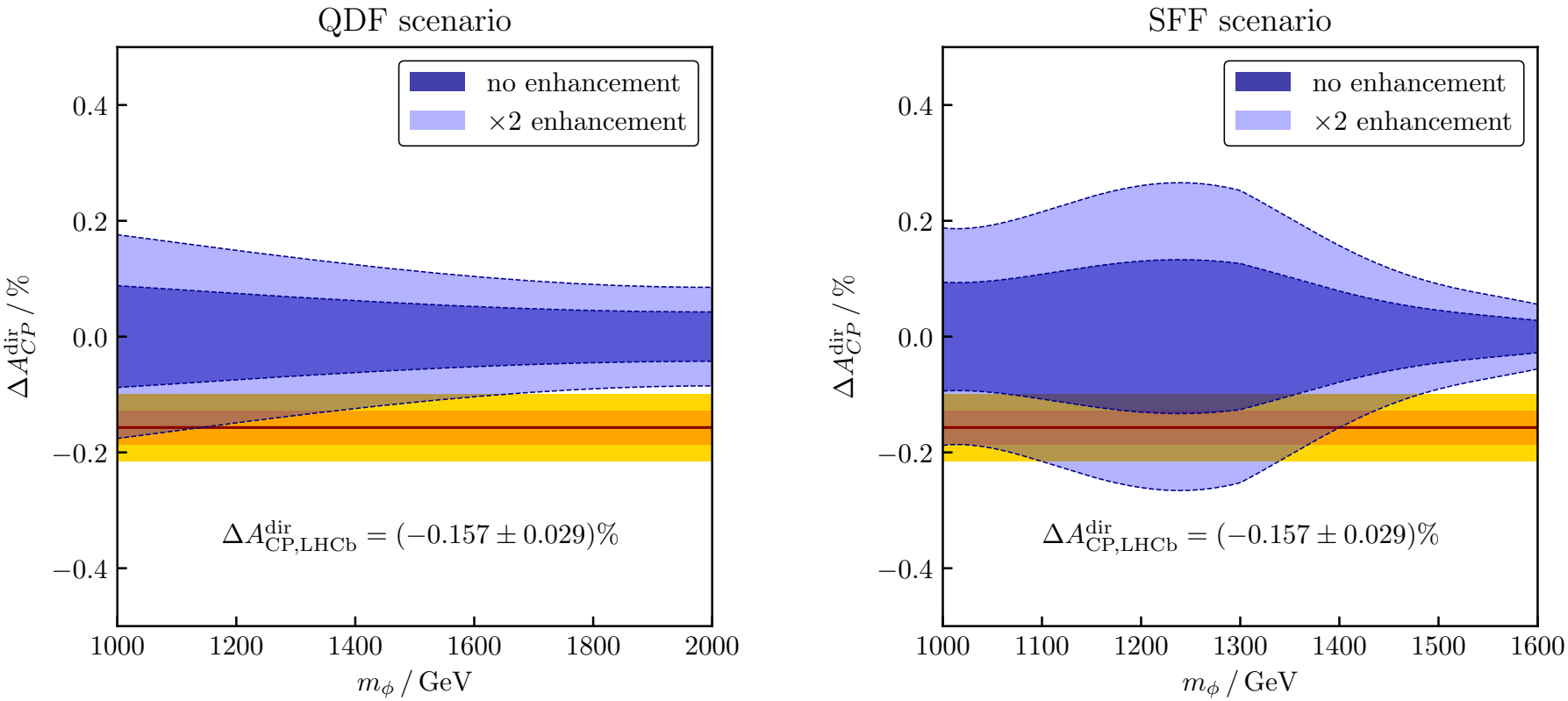


Fig. 7: $\Delta A_{\mathrm{CP}}^{\mathrm{dir}}$ in dependence of m_ϕ for the QDF scenario (left) and the SFF scenario (right). In both scenarios the DM mass is fixed to $m_\chi = 350\,\mathrm{GeV}$.

Summary

- flavoured DM models generally have a very rich phenomenology
- Majorana nature: new LHC signatures, additional mixing diagram, u-channel annihilation and weak direct detection constraints
- up-type flavoured Majorana particles are a viable DM candidate
- both freeze-out scenarios are capable of enhancing $\Delta A_{\mathrm{CP}}^{\mathrm{dir}}$ significantly

Thank you.