Novel signatures of pseudo-Goldstone dark matter, in composite Higgs models.

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1. MOTIVATION

Dark matter (DM) can arise along with the Higgs boson as a pseudo-Nambu Goldstone boson (pNGB) of an extended global symmetry, that is spontaneously broken at a scale *f*. This scenario arises naturally in non-minimal **composite Higgs models** (CHMs), where:

- the DM scale is predicted to be the WIMP's;
- its mass is protected from large UV corrections;
- new derivative interactions among the NGBs can accomodate the relic density *per se*.

The coupling between the SM and vector-like fermions of the composite sector generates the DM mass at the loop-level. In anomaly-free models, **extra pNGBs arise which can be lighter than the DM**:

$$m_\eta^2 \sim \frac{y_t^2}{(4\pi)^2} f^2 \gg m_\kappa^2 \sim \frac{y_b^2}{(4\pi)^2} f^2 , \quad \text{with} \quad f \sim \text{TeV} .$$

They can therefore affect its phenomenology non-trivially. To study further this case, we focus on the **SO(7)/SO(6)** CHM, where a singlet pseudoscalar κ arises on top of the DM candidate η [1].

2. RELIC DENSITY

$$\sigma_{\text{ann}} v(\eta\eta \to \kappa\kappa) \simeq \frac{1}{64\pi m_\eta^2}\left[\lambda_{\eta\kappa} - \frac{4m_\eta^2}{f^2}\right]^2 \left[1 - \frac{m_\kappa^2}{m_\eta^2}\right]^{1/2}$$

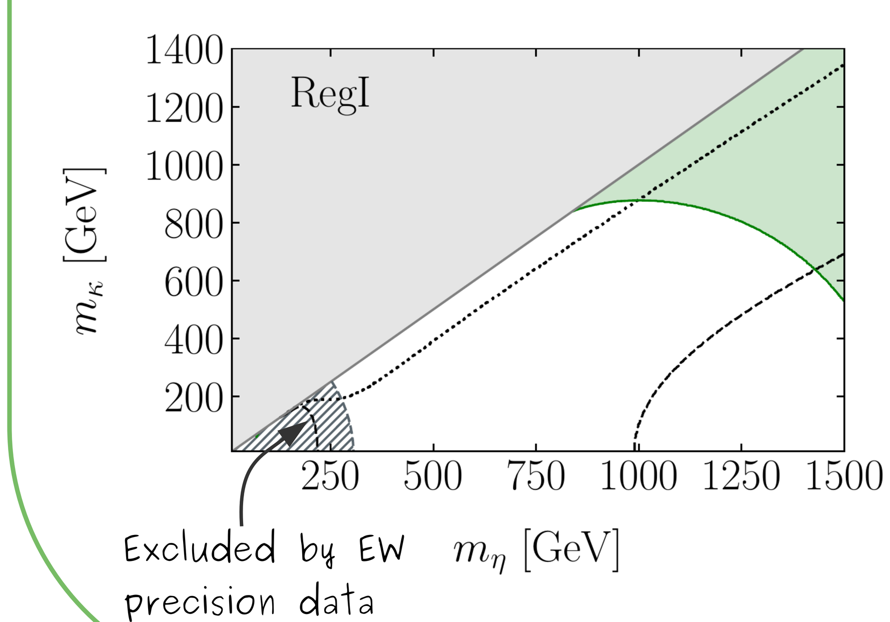
Two following regimes can arise depending on how the SM fermions are embedded in SO(7):

$$\text{RegI}: \ \lambda_{\eta H} \sim \lambda_H \gg \lambda_{\eta\kappa} ,$$

obtained when q_L and t_R transform in the **27** and **1** representations. We find that

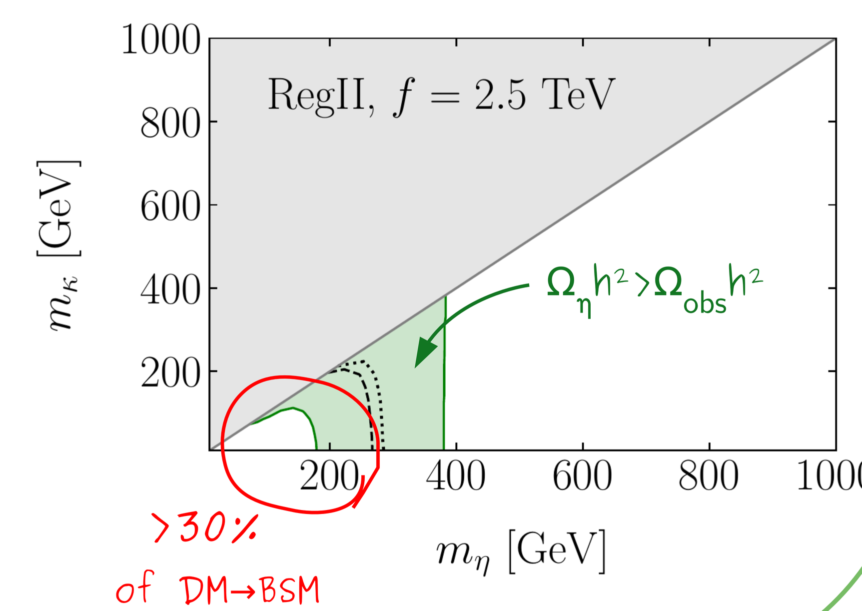
$$2.8 \lesssim f \lesssim 3.3 \text{ TeV} ,$$

if our candidate is all the DM.



$$\text{RegII}: \ \lambda_{\eta\kappa} \sim \lambda_H \gg \lambda_{\eta H} ,$$

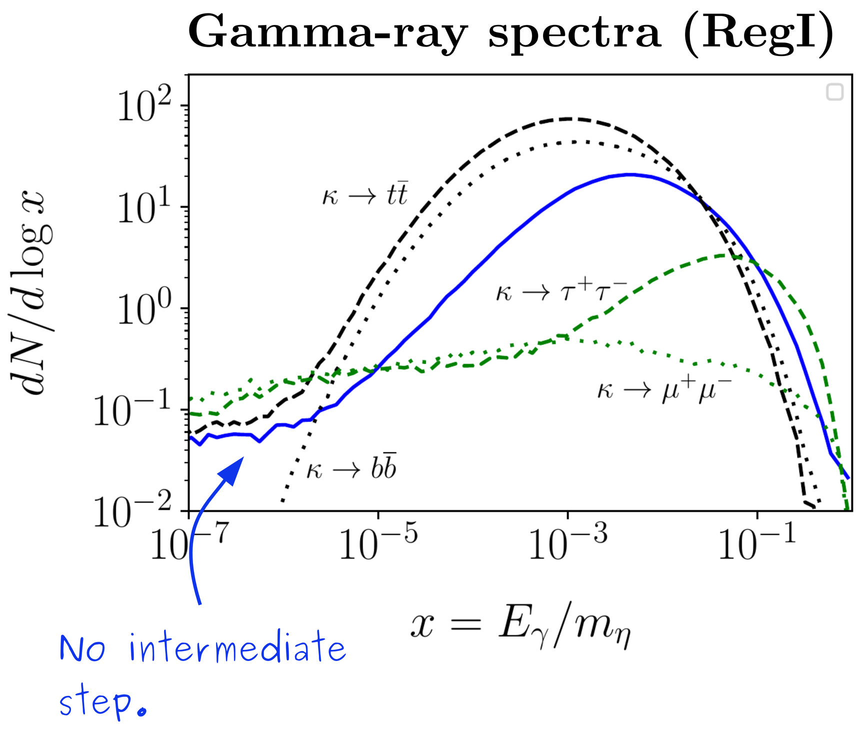
obtained when q_L and t_R both transform in the fundamental representation. The new physics scale remains however a free parameter.



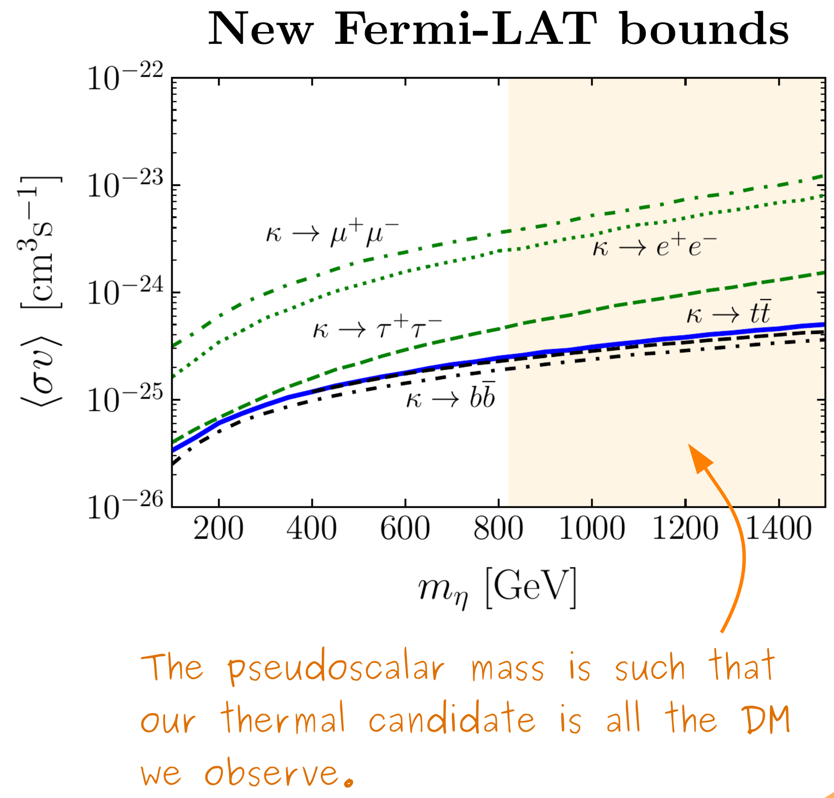
3. INDIRECT DETECTION

Since the DM can annihilate into the exotic particle, the spectra of stable particles and their flux at telescopes is modified. Therefore, the bounds from experimental collaborations cannot be directly applied. We therefore make dedicated simulations of the spectra in different annihilation channels to obtain the new indirect detection bounds. We focus on prompt gamma rays and use the likelihoods of the Fermi-LAT experiment (Pass 8 data) to constrain our scenario.

Gamma-ray spectra (RegI)

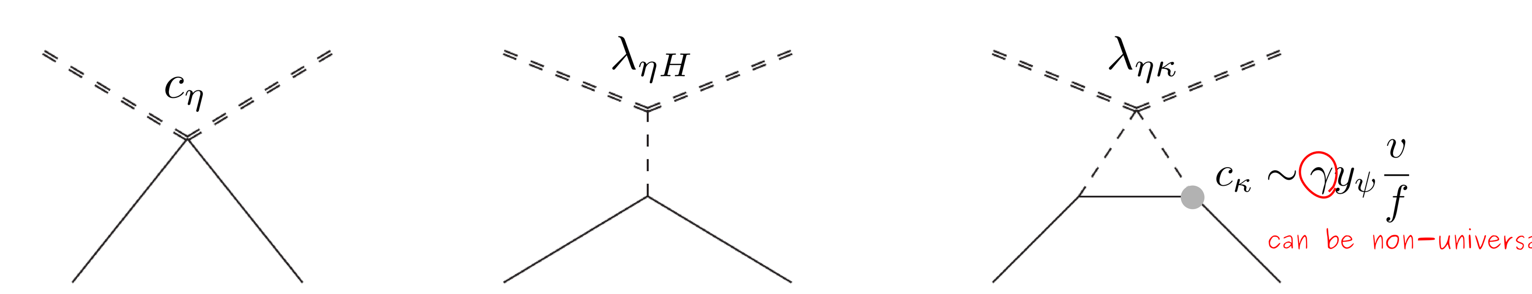


New Fermi-LAT bounds

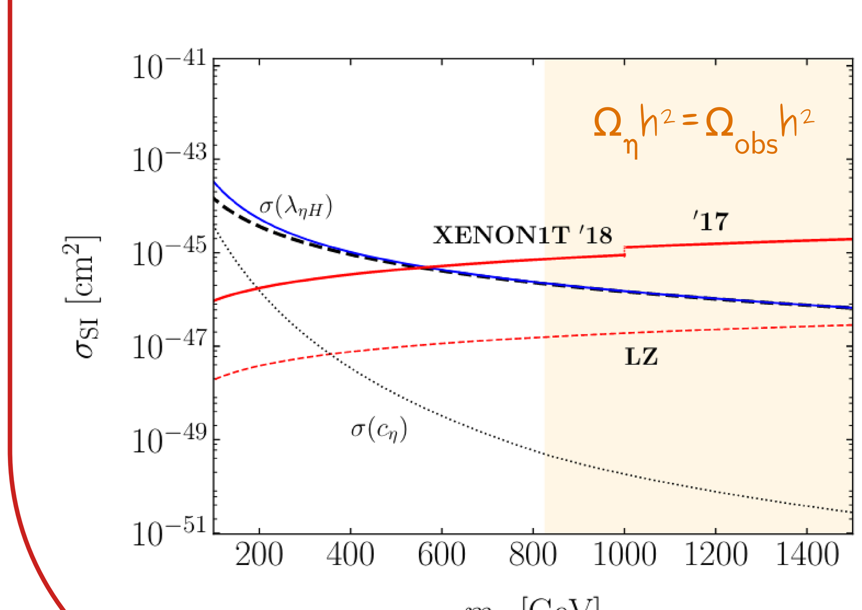


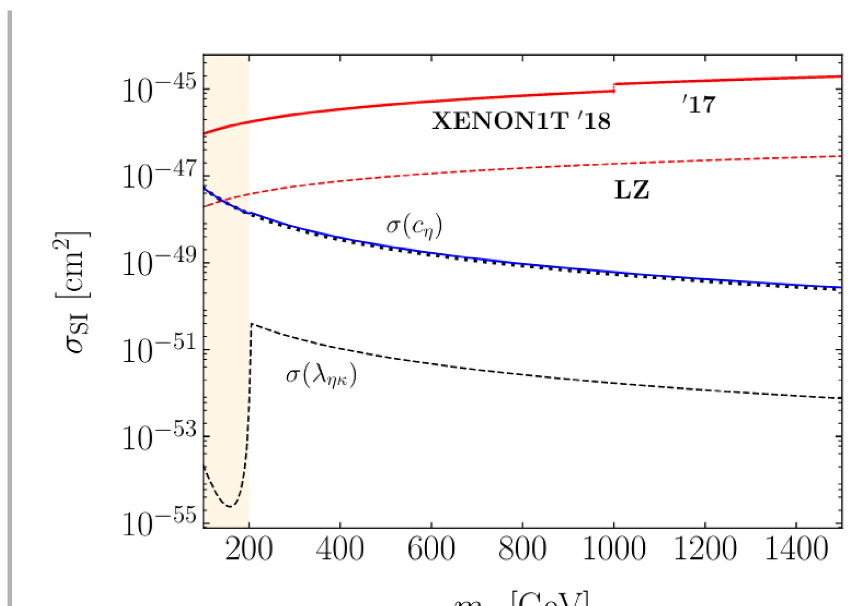
4. DIRECT DETECTION

The leading contributions to the spin-independent elastic cross section of the DM scattering off a nucleus are:



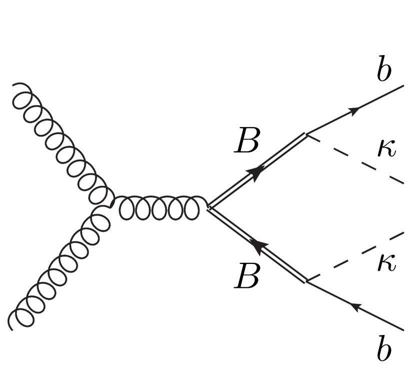
The first corresponds to a dimension-six operator that is typically subdominant; the corresponding Wilson coefficient is fixed in both regimes. The middle diagram gives the dominant contribution in RegI; it is however negligible in RegII, where the dominant scalar contribution is provided by a loop of the exotic pseudoscalar.

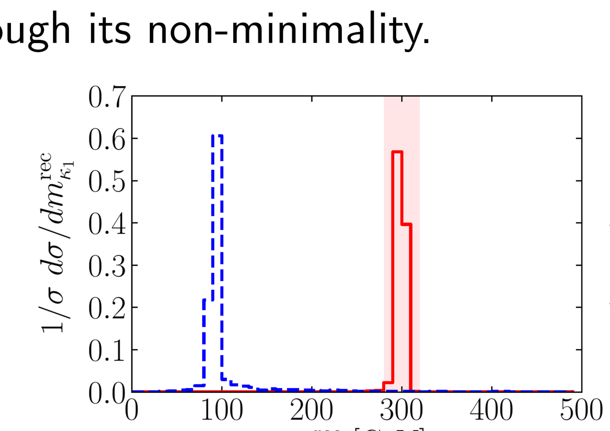


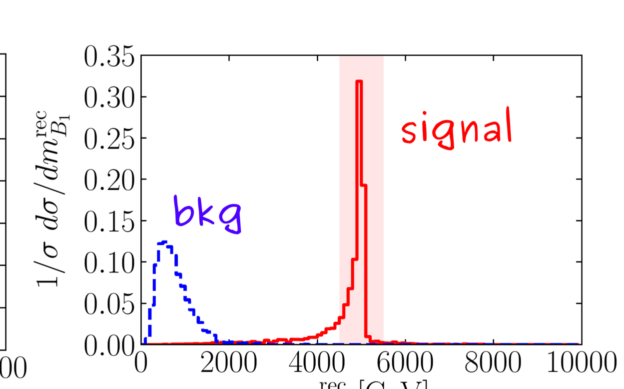


5. COLLIDER SEARCHES

The DM and the extra pNGB can be produced at colliders in decays of the heavy vector-like quarks. Let us focus on the case where they transform in the **27 = 1⊕6⊕20**, under SO(6). We therefore expect to find singlets in the low-energy spectrum. If the full singlet is the lightest resonance, no decay channel into the DM opens. In this case, the only way to probe the model is through its non-minimality.

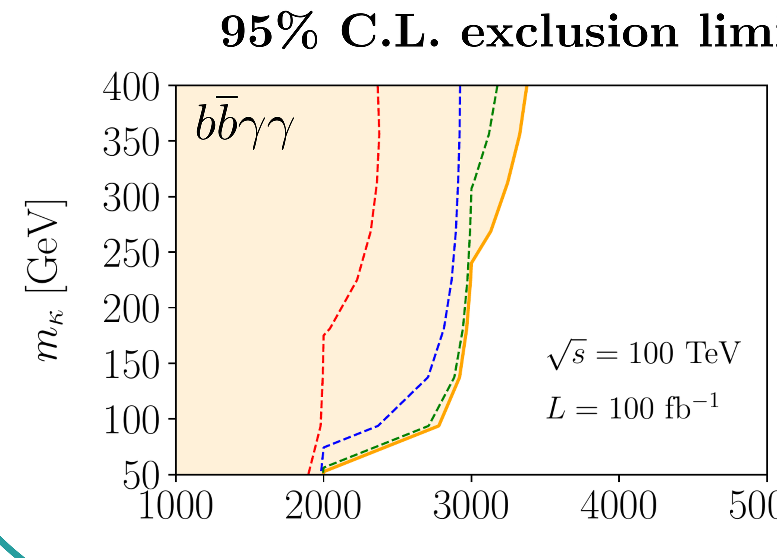


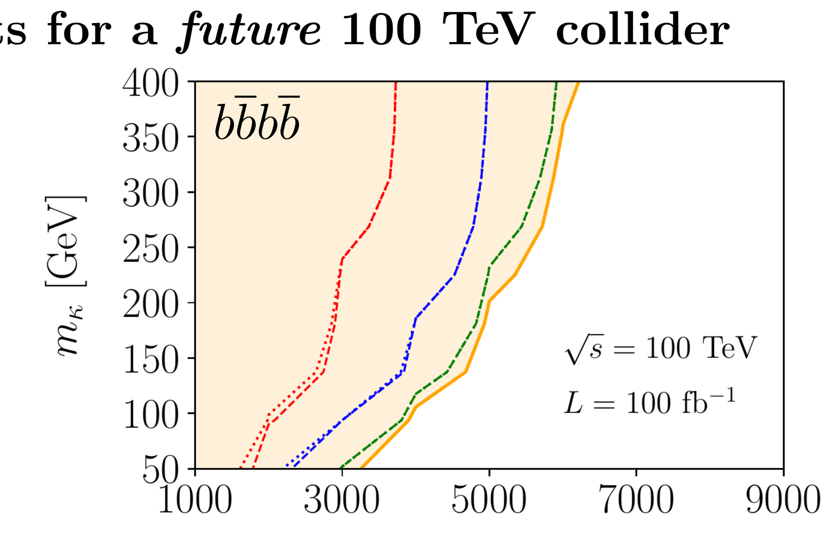




We focus on three possible decays of the exotic pNGB pair: $\mu^+\mu^-\mu^+\mu^-$; $b\bar{b}b\bar{b}$; and $\gamma\gamma b\bar{b}$. Among the most important cuts, we apply a *b*-tagging algorithm, setting the tagging efficiency to 70%; minimize the difference between the invariant masses of the oppositely charged pairs to reconstruct the scalars; and make optimized mass window cuts.

95% C.L. exclusion limits for a *future* 100 TeV collider





CONCLUSIONS

- The DM can freeze-out even in the absence of couplings to the SM
- In this case, new dedicated simulations are required to study the signal at indirect detection searches, namely we find that the exotic decay channels into light leptons are very weakly constrained
- Motivated regimes in the composite framework can escape all current (and future) constraints from DM searches
- Non-minimal complementary searches at colliders are therefore mandatory. In particular, the muonphilic scenario can be entirely probed at a future 100 TeV collider with L = 1 ab^{-1}

Dark matter in anomaly-free CHMs is far from being ruled out.

[1] M. Ramos, JHEP **07** (2020) 128, arXiv:1912.11061.

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