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Specific Dark Matter signatures from hidden U(1)

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Several constructions motivate the existence of a dark $U(1)_D$ gauge boson which interacts with the Standard Model only through its kinetic mixing or loop induced processes. We describe two typical examples with specific signatures in particular we show that a region with relatively light WIMPS, $M_{Z_D} \lesssim 40$ GeV and a kinetic mixing $10^{-4} \lesssim \delta \lesssim 10^{-3}$ is not yet excluded by the last experimental data and seems to give promising signals in a near future. We also show that conditions from anomaly cancelation generate tri-vector couplings $Z'Z\gamma$ leading to a specific gamma ray line observable by FERMI telescope.

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1. Introduction

Neutral gauge sectors with an additional dark $U(1)_D$ symmetry in addition to the Standard Model (SM) hypercharge $U(1)_Y$ and an associated Z_D are among the best motivated extensions of the SM, and give the possibility that a dark matter candidate lies within this new gauge sector of the theory [1]. The new vector boson Z_D can interact with the SM, even if no SM fermions are directly charged under the additional gauge symmetry. This interaction can occurs via mixed kinetic terms between the SM's hypercharge field strength and the new abelian field strength [2, 3, 4] or through couplings generated by counter-term to preserve the anomaly cancelation condition [5, 6]. Whereas the former couplings can give significant signals in direct detection experiment even fitting the last DAMA [7] or COGENT [8] excesses [9, 10, 11], the latter can give rise to a gamma-ray line observable in satellite telescopes [12, 13, 14, 15]

2. The dark kinetic mixing

The matter content of any *dark* $U(1)_D$ extension of the SM can be decomposed into three families of particles:

- The *Visible sector* is made of particles which are charged under the SM gauge group $SU(3) \times SU(2) \times U(1)_Y$ but not charged under $U(1)_D$ (hence the *dark* denomination for this gauge group)
- the *Dark sector* is composed by the particles charged under $U(1)_D$ but neutral with respect of the SM gauge symmetries. The dark matter (ψ_0) candidate is the lightest particle of the *dark sector*
- The *Hybrid sector* contains states with SM *and* $U(1)_D$ quantum numbers. These states are fundamental because they act as a portal between the two previous sector through the kinetic mixing they induce at loop order.

From these considerations, it is easy to build the effective lagrangian generated at one loop :

$$\begin{aligned}\mathscr{L} &= \mathscr{L}_{\rm SM} - \frac{1}{4}\tilde{B}_{\mu\nu}\tilde{B}^{\mu\nu} - \frac{1}{4}\tilde{X}_{\mu\nu}\tilde{X}^{\mu\nu} - \frac{\delta}{2}\tilde{B}_{\mu\nu}\tilde{X}^{\mu\nu} \\ &+ i\sum_i \psi_i\gamma^\mu D_\mu \psi_i + i\sum_j \Psi_j\gamma^\mu D_\mu \Psi_j \end{aligned} \tag{2.1}$$

B_μ being the gauge field for the hypercharge, X_μ the gauge field of $U(1)_D$ and ψ_i the particles from the hidden sector, Ψ_j the particles from the hybrid sector, $D_\mu = \partial_\mu - i(q_Y\tilde{g}_Y\tilde{B}_\mu + q_D\tilde{g}_D\tilde{X}_\mu + gT^aW^a_\mu)$, T^a being the $SU(2)$ generators, and

$$\delta = \frac{\tilde{g}_Y\tilde{g}_D}{16\pi^2}\sum_j q_Y^j q_D^j \log\left(\frac{m_j^2}{M_j^2}\right) \tag{2.2}$$

with m_j and M_j being hybrid mass states [3]. Notice that the sum is on all the hybrid states, as they are the only ones which can contribute to the $Y_\mu X_\mu$ propagator. After diagonalization of the current eigenstates, one makes the gauge kinetic terms of Eq.(2.1) diagonal and canonical.

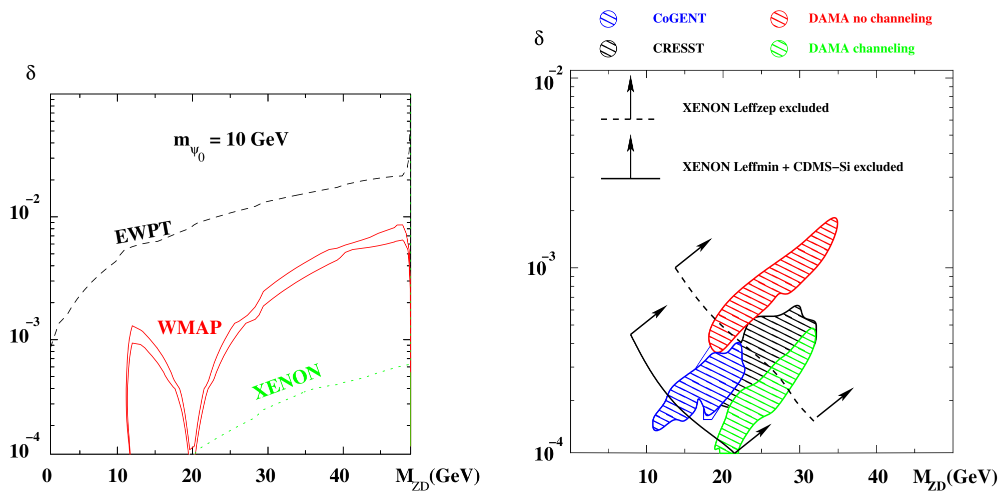

Figure 1: Left : example of allowed parameter space for $m_{\psi_0} = 10$ GeV in the (M_{Z_D}, δ) plane (left). The points between the full-red region respect the 5σ WMAP constraint, the points below the dashed-black line do not exceed accelerator data on precision tests, and the points above the dotted-green line are excluded by XENON100 data. Right: parameter space allowed within 90 % of C.L. for the CoGeNT signal (blue), DAMA without channeling (red), with channeling (green), CRESST (black), and the exclusion region depending on the hypothesis concerning L_{eff}.

We show in Fig.1 (left) the points that fulfill the WMAP 5σ bound [16] on $\Omega_{\rm DM}$ for $m_{\psi_0} =$ 10 GeV in the (M_{Z_D}, δ) plane. One can clearly see the Z_D-pole region when $M_{Z_D} \sim m_{\psi_0}$. One important point is that for a given M_{Z_D} and m_{ψ_0}, there exists a unique solution δ (up to the very small uncertainties at 5σ) fulfilling WMAP constraints : from 3 parameters $(m_{\psi_0}, M_{Z_D}, \delta)$, the WMAP constraints reduce it to two (M_{Z_D}, δ).
We show in Fig.1 the points respecting WMAP, and the DAMA/LIBRA (with and without channeling) CoGeNT and CRESST[1] results at 90 % of CL. All the constraints have been calculated for a standard Maxwellian velocity distribution (with mean velocity $v_0 = 230$ km/s and an escape velocity $v_{esc} = 600$ km/s). One can observe in Fig.1 that for all experiments, the regions are quite surprisingly near and correspond to 10 GeV $\lesssim M_{Z_D} \lesssim$ 30 GeV and $10^{-4} \lesssim \delta \lesssim 10^{-3}$, which is in complete agreement with the measurement of electroweak precision tests. Moreover, such values of δ are typical of one loop-order corrections and can easily be generated by heavy-fermions loops in the $Z - Z_D$ propagator.

3. Anomalies and gamma-ray line

It is well known that any extension of the SM which introduces chiral fermions with respect to gauge fields suffers from anomalies, a phenomenon of breaking of gauge symmetries of the classical theory at one-loop level. Anomalies are responsible for instance for a violation of unitarity and make a theory inconsistent [18, 19]. For this reason if any construction introduces a new fermionic sector to address the DM issue of the SM, it is vital to check the cancelation of anomalies and its

[1]For the CRESST estimation, we used an extrapolation given in the talk of T. Schwetz and the CRESST collaboration [17].

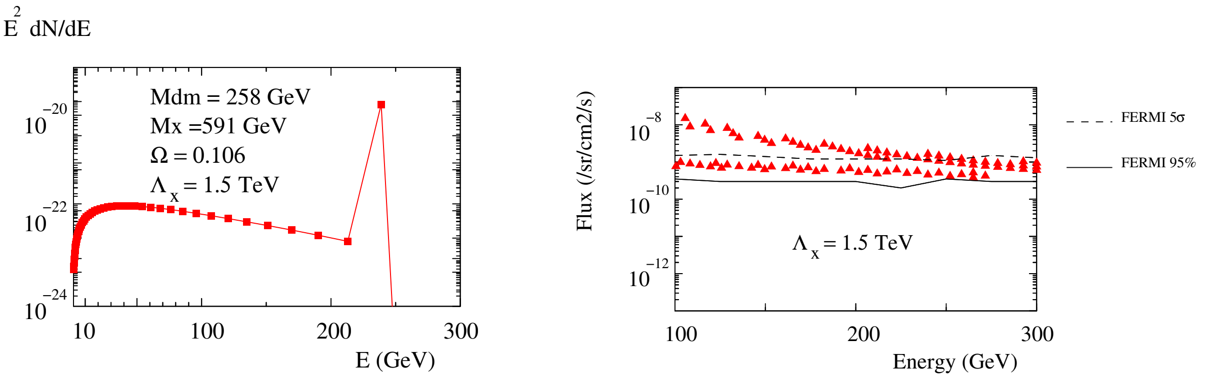

Figure 2: Left: example of gamma–ray flux respecting WMAP constraint for a DM mass of 258 GeV. Right: monochromatic γ–ray fluxes generated by anomaly-cancelation mechanism in comparison with expected 5σ and 95% CL sensitivity contours (5 years of FERMI operation) for the conventional background and unknown WIMP energy, for an effective scale $\Lambda_X = 1.5$ TeV

consequences on the Lagrangian and couplings. The idea is to add to the Lagrangian local gauge non-invariant terms in the effective action whose gauge variations cancel the anomalous triangle diagrams. There exist two kinds of term which can cancel the mixed $U(1)_D \times G_A^{\rm SM}$ anomalies, with $G_A^{\rm SM}$ being one of the SM gauge group $SU(3) \times SU(2) \times U_Y(1)$: the Chern Simons (CS) term which couples the $G_A^{\rm SM}$ to the $U(1)_D$ gauge boson, and the Peccei-Quinn (PQ, or Wess-Zumino (WZ)) term which couples the $G_A^{\rm SM}$ gauge boson to an axion. In the effective action, these terms are sometimes called Generalized Chern–Simons (GCS) terms [5]:

$$
\begin{aligned}
\mathscr{L}_{inv} &= -\frac{1}{4g'^2}F^{Y\mu\nu}F^{Y}_{\mu\nu} - \frac{1}{4g_X^2}F^{X\mu\nu}F^{X}_{\mu\nu} - \frac{1}{2}(\partial_\mu a_X - M_X X_\mu)^2 - i\overline{\psi}\gamma^\mu D_\mu \psi \\
\mathscr{L}_{var} &= \frac{C}{24\pi^2} a_X \varepsilon^{\mu\nu\rho\sigma} F^Y_{\mu\nu} F^Y_{\rho\sigma} + \frac{E}{24\pi^2}\varepsilon^{\mu\nu\rho\sigma} X_\mu Y_\nu F^Y_{\rho\sigma}.
\end{aligned}
\tag{3.1}
$$

The Stueckelberg axion a_X ensures the gauge invariance of the effective Lagrangian and g_X and $F^X_{\mu\nu} = \partial_\mu X_\nu - \partial_\nu X_\mu$ are the gauge coupling and field strength of $U(1)_D$. The axion has a shift transformation under $U(1)_D$

$$
\delta X_\mu \;=\; \partial_\mu \alpha \quad , \quad \delta a_X \;=\; \alpha\, M_X . \tag{3.2}
$$

The $\mathscr{L}_{var}$ will generate after the $SU(2) \times U(1)_Y$ tri-vectorial couplings $Z_D ZZ$ and $Z_D \gamma Z$ ($Z\gamma\gamma$ coupling being forbidden by spin- momentum conservation). This generates new annihilation processes $\psi_0\psi_0 \rightarrow Z_D \rightarrow ZZ/Z\gamma$ which can be observable through the *only* monochromatic gamma–ray line with energy $E_\gamma = m_{\psi_0}\left(1 - \frac{M_Z^2}{4m_{\psi_0}^2}\right)$ [12, 13]. Other models predicts several lines [20, 14], but none of them just one line.

As an illustrative point, we show in the left panel of Fig.2 an example of spectrum from the centre annulus that could be observable by the FERMI telescope, generated by DM annihilation within the pole region respecting WMAP constraint($m_{\psi_0} = 258$ GeV and $M_{Z_D} = 591$ GeV). We can clearly distinguish a γ–ray line centered around $E_\gamma = m_{\psi_0}\left(1 - \frac{M_Z^2}{4m_{\psi_0}^2}\right)$ above the continuous flux produced by the annihilation process $\psi_0\psi_0 \to ZZ/Z\gamma$. The expected sensitivity of FERMI telescope after 5 years of data taking is presented in the right panel of Fig.2.

We clearly see in the right panel of Fig.2 that for an effective scale $\Lambda_X = 1.5$ TeV (scale of the "new physics" corresponding to the fermions generating the anomalies), all the parameter space would be observable by FERMI at 95% CL. Indeed, the points that respect the WMAP constraints lie around the pôle $M_{Z_D} \sim 2m_{\psi_0}$ where $\sim 60\%$ of the annihilation rate is dominated by the $Z\gamma$ final state. This proportion still holds for annihilating DM in the Galactic halo and gives a monochromatic line observable by FERMI.

4. Conclusion

We showed that the existence of a *dark* $U(1)_D$ gauge sector which interacts with the Standard Model only through its kinetic mixing or anomaly-generated couplings possesses a valid dark matter candidate respecting accelerator, cosmological and the more recent direct detection constraints. Moreover, considering the latest results of DAMA/LIBRA, CoGENT and CRESST, we demonstrated that a specific range of the kinetic mixing ($\delta \sim 10^{-4} - 10^{-3}$) can explain all these excesses for a dark boson mass $M_{Z_D} \sim 10 - 20$ GeV, whereas anomaly cancelationconditions generate a monochromatic $\gamma-$ray line from DM annihilation into $Z\gamma$. Such a signature would be a smoking gun signal for these types of constructions It is interesting to notice that other constraints, coming from synchrotron radiation [21] or difuse gamma-ray emission [22] can give more restriction to the analysis.

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