(In)visible Z' and Dark matter

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E. Dudas, Y. Mambrini, S. Pokorski, A.R.

in progress

Simplest extensions of Standard Model

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$\hookrightarrow$ Combine the two

Dangers with Gauge Theories

Theories in which fermions have chiral couplings with gauge fields suffer from anomalies

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Particles involved in anomaly cancellation may have very different masses (ex: the mass of the top quark in the SM is much higher than the masses of all other fermions).

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E. D'Hoker, E. Farhi, Nucl. Phys. B248 (1984)

The case of anomaly cancellation presents a notable counterexample to the decoupling theorem:

- anomalous (i.e. gauge-variant) terms in the effective action have topological nature and are therefore scale independent.
- they are not suppressed even at energies much smaller than the masses of the particles producing these terms via loop effects.

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Anomalous Z' theories

There are some un-canceled reducible anomalies. They cancel in the underlying theory due to :

- axions with Green-Schwarz type couplings in string theories.
- heavy chiral (wrt Z′) fermions in field theory models, which generate non-decoupling effects at low-energy.

Anomalous Z' theories

Anastasopoulos, Bianchi, Dudas, Kiritsis, JHEP 0611 (2006) 057, …

Effective action

$$\mathcal{S} = -\sum_i \int d^4x \frac{1}{4} F_{i,\mu\nu} F_i^{\mu\nu} + \frac{1}{2} \int d^4x \sum_i (\partial_\mu a^i - g_i V_i A_\mu^i)^2$$

$$+ \frac{1}{96\pi^2} C_{ij}^I \, \epsilon^{\mu\nu\rho\sigma} \int a^I F_{\mu\nu}^i F_{\rho\sigma}^j + \frac{1}{48\pi^2} E_{ij,k} \, \epsilon^{\mu\nu\rho\sigma} \int A_\mu^i A_\nu^j F_{\rho\sigma}^k \, .$$

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Stueckelberg mixing with axions which render the corresponding, "anomalous" gauge fields massive.

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Anastasopoulos, Bianchi, Dudas, Kiritsis, JHEP 0611 (2006) 057, ...

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Axionic exchanges: nonlocal contributions

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Generalized Chern-Simons terms: anomalous three gauge boson coupling

Anomalous three gauge boson couplings

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Anomaly cancelation requirement

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Q_i is the generator for A_i, and Trace over the spectrum

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Our starting point

Notice it is possible to have standard (anomaly-free) Z', $t_{ijk} = 0$, and non-vanishing anomalous three gauge boson couplings at low energy. They have the form

$$E_{ij,k} \, \epsilon^{\mu\nu\rho\sigma} \, (\partial a^i - M_i A^i)_\mu \, (\partial a^j - M_j A^j)_\nu \, F_{\rho\sigma}^k$$

Experimental signatures

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If SM fermions are charged with respect to the $\mathrm{U}(1)_X$ group, and the mass of the new Z' bosons is around the TeV scale, we should be able to see the corresponding resonance in the forthcoming runs of LHC; ex) $q\bar{q} \to Z' \to f\bar{f}$.
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What happens if the SM fermions are not charged with respect to the $\mathrm{U}(1)_X$ group?

(Antoniadis, Boyarsky, Espahbodi, Ruchayskiy, Wells, arXiv:0901.0639 [hep-ph]
$\to$ study of LHC detection)

(In)visible Z' and decoupling of heavy fermions

Definition

Let me define an (in)visible Z', an extra $\mathrm{U}(1)$ massive gauge boson, and:

- All SM fields are neutral under Z'
- There is a sector of heavy fermions charged both under the SM and Z', chiral but anomaly-free
- The effects of the heavy fermions are encoded at low-energy in effective couplings, containing anomalous three gauge boson couplings, and in particular $Z\,Z'\,\gamma$

Effective operators: Two Z' 's case

In this case there is a genuine non-decoupling effect.
The corresponding operator is

$$E_{Z'_1 Z'_2, Y}\, \epsilon^{\mu\nu\rho\sigma}\, (\partial a_1 - g_1 V_1 Z'_1)_\mu (\partial a_2 - g_2 V_2 Z'_2)_\nu\, F^Y_{\rho\sigma}$$

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It is easy to find examples of heavy fermionic sectors generating it (l_a fermions Ψ and l_m fermions χ)

	Y	Z'_1	Z'_2
Ψ^a_L	y_a	x_a	z_a
Ψ^a_R	y_a	$x_a - \epsilon_a$	z_a
χ^m_L	y_m	x_m	z_m
χ^m_R	y_m	x_m	$z_m - \epsilon_m$

gives $\quad E_{Z'_1 Z'_2, Y} \sim \sum_a l_a \epsilon_a y_a z_a - \sum_m l_m \epsilon_m x_m y_m$

whereas $\quad Tr(Z'_1 Z'_2 Y) \sim \sum_a l_a \epsilon_a y_a z_a + \sum_m l_m \epsilon_m x_m y_m$

Effective operators: One Z' case

We can list local polynomial effective operators constraining them by gauge invariance and CP symmetry

- $\frac{1}{\Lambda^2}\,\epsilon^{\mu\nu\rho\sigma}\,D_\mu\theta_{Z'}\,(H^\dagger D_\nu H - D_\nu H^\dagger H)\,F^Y_{\rho\sigma}$
  $\hookrightarrow \quad \frac{v^2}{\Lambda^2}\,\epsilon^{\mu\nu\rho\sigma}\,(Z'_\mu - \frac{\partial_\mu a_{Z'}}{V})\,(B_\nu - \frac{\partial_\mu a_Y}{v})\,F^Y_{\rho\sigma}$
- $\frac{1}{\Lambda^2}\,\partial^\lambda(Z'_\lambda - \frac{\partial_\lambda a_{Z'}}{V})\,\epsilon^{\mu\nu\rho\sigma}\,F^Y_{\mu\nu}F^Y_{\rho\sigma}$
- $\frac{1}{\Lambda^2}\,\epsilon^{\mu\nu\rho\sigma}\,F^Y_{\mu\lambda}\,F^{\lambda,Z'}_\nu\,F^Y_{\rho\sigma}$

where $\Lambda \sim$ mass of the heavy fermions.
Similar terms can be written for F^W.
We consider $0.01 \leq \frac{M_{DM}}{\Lambda} \leq 0.1$

Note

The operators mixing one Z' with SM do decouple

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Main Idea

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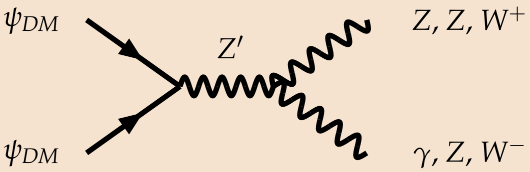

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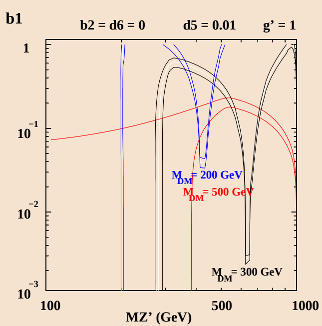

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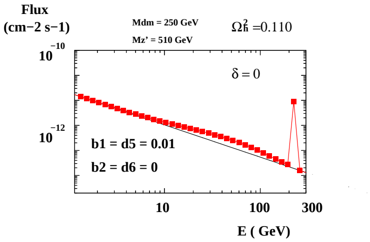
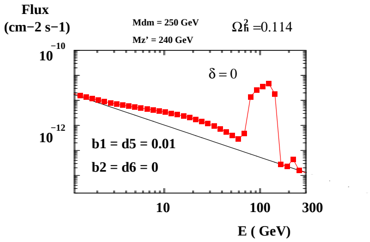
- It gives the correct relic density [new released version of micromegas]
- The same diagram produces a mono-chromatic gamma ray

  $$E_\gamma = M_{DM}\left[1 - \left(\frac{M_Z}{2M_{DM}}\right)^2\right] \;,$$

  which could be visible in future experiments.

(In)visible Z' as mediator of dark matter annihilation





Typical example of a gamma-ray differential spectrum (red boxes) for different values of Z' masses at a fixed DM mass, in comparison with the background (black line).

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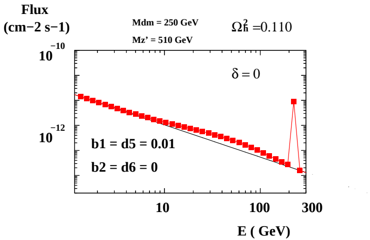

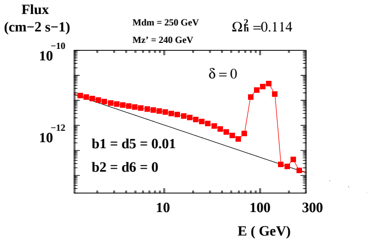

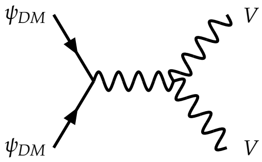

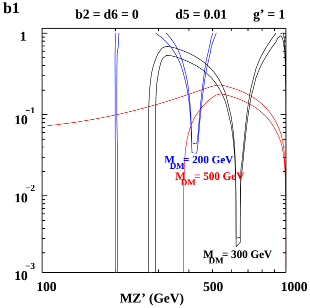

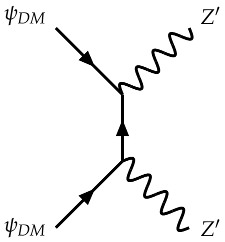

Kinetic Mixing

Actually the first non-trivial operator one can write is the kinetic mixing between Z' and Y

$$\delta\, F^{Z'}_{\mu\nu} F^{Y\,\mu\nu}$$

The possibilities given by this term have been already studied in many papers (see for example Arkani-Hamed et al. JHEP 0812:104,2008).

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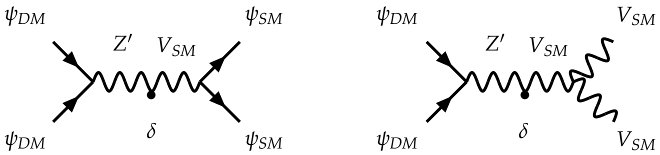
In our case, it can interplay in two ways:

- If δ is small, it just rotates mass states with respect to the gauge ones
- If it is dominant over $Z'\,Z\,\gamma$ coupling, it will tend to erase its effects (namely the gamma line)



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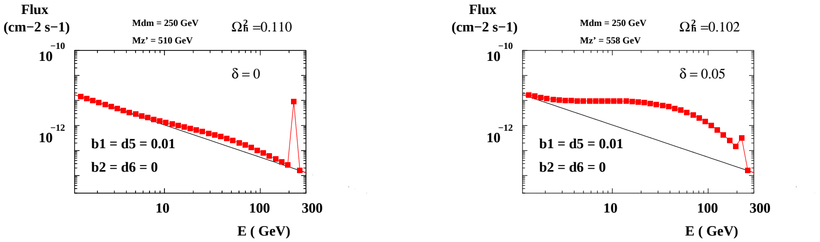

Flux spectrum profile changes when the kinetic mixing term δ is turned on, keeping the good value for relic density.

Conclusions & Outlook

- Three gauge boson "anomalous" vertices can connect an otherwise invisible Z' to SM.
- The diagram generating the correct relic density also generates a visible gamma-ray line.
- An (in)visible Z' can be light (GeV) $\rightarrow$ phenomenology to explore.
- It would be interesting to analyze more generally the non-decoupling effects of heavy chiral fermions : for two Z' is there a violation of the decoupling theorem ?