



Extra $U(1)$, effective operators, anomalies and dark matter

Lucien Heurtier

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hep-ph 1307.0005 : E. Dudas ^a, L. Heurtier ^a, Y. Mambrini ^b, B. Zaldivar ^c

a : CPhT, Ecole Polytechnique, 91128 Palaiseau Cedex, France

b : Laboratoire de Physique Théorique, Université Paris-Sud, F-91405 Orsay, France

c : Instituto de Fisica Teorica, IFT-UAM/CSIC, 28049 Madrid, Spain

Introduction : Motivations

Simplest extension of SM \rightarrow add a $U(1)'$ symmetry

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- **Charged SM fermions**

- \rightarrow FCNC constraints

- $\rightarrow B - L, \alpha(B - L) + \beta Y$ models heavy Z'

- \rightarrow Stringy light Z' , anomaly cancellation a la Green-Schwarz

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- **Uncharged SM fermions**

- \rightarrow Motivations from string theory (D-brane models)

- \rightarrow Heavy mediators \rightsquigarrow effective higher-dimensional operators

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	ψ_{DM}	Ψ_M	ψ_{SM}
$U(1)'$	•	•	
$U(1) \times SU(2) \times SU(3)$		•	•

Introduction : The model

◇ Heavy mediators : heavy SM fermions

Heavy mass scale : breaking of the heavy $U(1)'$ higgs sector

Stueckelberg realization

$$\Phi = \frac{V + \phi}{\sqrt{2}} \exp(ia_X/V) \longrightarrow \Phi = \frac{V}{\sqrt{2}} \exp(ia_X/V)$$

$U(1)'$ transformations

$$\delta Z'_\mu = \partial_\mu \alpha \quad , \quad \delta \theta_X = \frac{g_X}{2} \alpha \quad \text{where} \quad \theta_X \equiv \frac{a_X}{V}$$

Introduction : The model

Initial lagrangian

$$\begin{aligned}
 \mathcal{L} = & \mathcal{L}_{SM} + \frac{1}{2}(\partial_\mu a_X - M_{Z'} Z'_\mu)^2 - \frac{1}{4} F_{\mu\nu}^X F^{X\mu\nu} \\
 & + \bar{\Psi}_L^i \left(i\gamma^\mu D_\mu + \frac{g_X}{2} X_L^i \gamma^\mu Z'_\mu \right) \Psi_L^i + \bar{\Psi}_R^i \left(i\gamma^\mu D_\mu + \frac{g_X}{2} X_R^i \gamma^\mu Z'_\mu \right) \Psi_R^i \\
 & - \left(\bar{\Psi}_L^i M_{ij} e^{\frac{ia_X(X_L^i - X_R^j)}{V}} \Psi_R^j + \text{h.c.} \right)
 \end{aligned} \tag{1.1}$$

$$\text{where} \quad M_{Z'} \equiv g_X \frac{V}{2}. \tag{1.2}$$

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Initial lagrangian

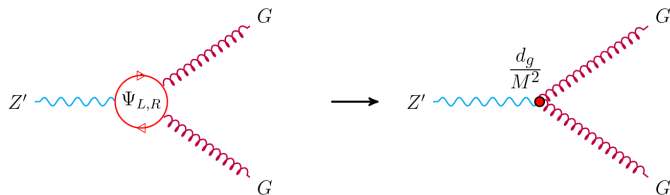
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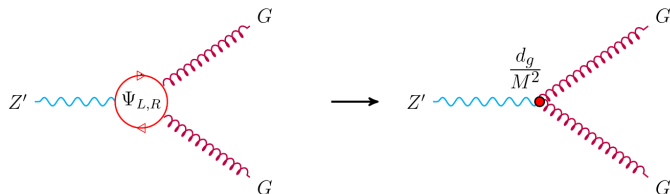
- Invariant under $U(1)'$ transformations
- \mathcal{L} anomaly-free & \mathcal{L}_{SM} neutral under $U(1)'$ $\Rightarrow \Psi_M$ set anomaly-free
- Kinetic mixing term $\frac{\delta}{2} F_X^{\mu\nu} F_{\mu\nu}^Y$ is neglected

Why?...

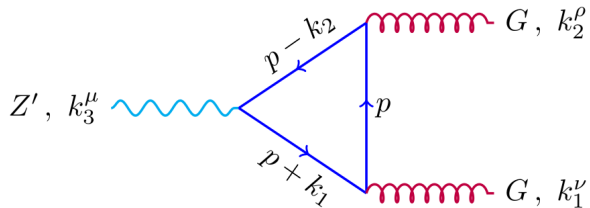
Effective couplings

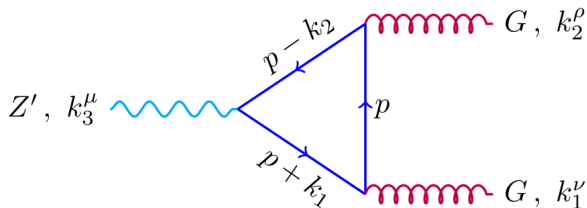


Effective couplings



$$\begin{aligned}
 \mathcal{L}_{\text{CP even}}^{(6)} = & \frac{1}{M^2} \left\{ d_g \partial^\mu D_\mu \theta_X \text{Tr}(G \tilde{G}) + d'_g \partial^\mu D^\nu \theta_X \text{Tr}(G_{\mu\rho} \tilde{G}_\nu^\rho) \right. \\
 & + e_g D^\mu \theta_X \text{Tr}(G_{\nu\rho} \mathcal{D}_\mu \tilde{G}^{\rho\nu}) + e'_g D_\mu \theta_X \text{Tr}(G_{\alpha\nu} \mathcal{D}^\nu \tilde{G}^{\mu\alpha}) \left. \right\} \\
 & + \frac{1}{M^2} \left\{ D^\mu \theta_X \left[i(D^\nu H)^\dagger (c_1 \tilde{F}_{\mu\nu}^Y + 2c_2 \tilde{F}_{\mu\nu}^W) H + h.c. \right] \right. \\
 & + \partial^m D_m \theta_X (d_1 \text{Tr}(F^Y \tilde{F}^Y) + 2d_2 \text{Tr}(F^W \tilde{F}^W)) \\
 & + d'_{ew} \partial^\mu D^\nu \theta_X \text{Tr}(F_{\mu\rho} \tilde{F}_\nu^\rho) \\
 & \left. + e_{ew} D^\mu \theta_X \text{Tr}(F_{\nu\rho} \mathcal{D}_\mu \tilde{F}^{\rho\nu}) + e'_{ew} D_\mu \theta_X \text{Tr}(F_{\alpha\nu} \mathcal{D}^\nu \tilde{F}^{\mu\alpha}) \right\}, \quad (1.3)
 \end{aligned}$$





$$\begin{aligned}
 \mathcal{O} &= \frac{g_3^2}{24\pi^2} \sum_i \text{Tr} \left(\frac{(X_L - X_R) T_a T_a}{M^2} \right)_i \\
 &\times \left[\partial^\mu D_\mu \theta_X \text{Tr}(G \tilde{G}) - 2D_\mu \theta_X \text{Tr}(G_{\alpha\nu} \mathcal{D}^\nu \tilde{G}^{\mu\alpha}) \right]. \quad (1.4)
 \end{aligned}$$

DM annihilation into Gluons

couplings

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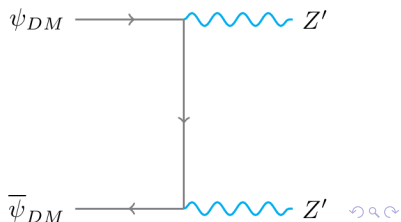
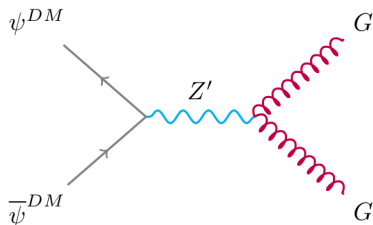
$$\mathcal{L}_{DM} = \bar{\psi}_L^{DM} \frac{1}{2} g_X X_L^{DM} \gamma^\mu Z'_\mu \psi_L^{DM} + \bar{\psi}_R^{DM} \frac{1}{2} g_X X_R^{DM} \gamma^\mu Z'_\mu \psi_R^{DM} \quad (2.2)$$

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DM annihilation into Gluons

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DM annihilation into Gluons

→ Non-chiral dark matter : no contribution

→ Chiral dark matter :

$$\langle \sigma v \rangle_{s\text{-channel}} \simeq \frac{d_g^2}{M^4} \frac{g_X^4 m_\psi^6 (X_L - X_R)^2}{\pi M_{Z'}^4} \left\{ \frac{2 (M_{Z'}^2 - 4m_\psi^2)^2}{\left(M_{Z'}^2 \Gamma^2(Z') + (M_{Z'}^2 - 4m_\psi^2)^2 \right)} \right\}$$

$$\langle \sigma v \rangle_{t\text{-channel}} \simeq \frac{g_X^4 \sqrt{m_\psi^2 - M_{Z'}^2}}{128 \pi^2 m_\psi M_{Z'}^2 (2m_\psi^2 - M_{Z'}^2)^2} P_4(m_\psi^2, M_{Z'}^2, X_R^2, X_L^2)$$

Experimental constraints

A few parameters in this model : $M_{Z'}$, m_ψ , g_X , $\frac{d_g}{M^2}$, X_L , X_R .

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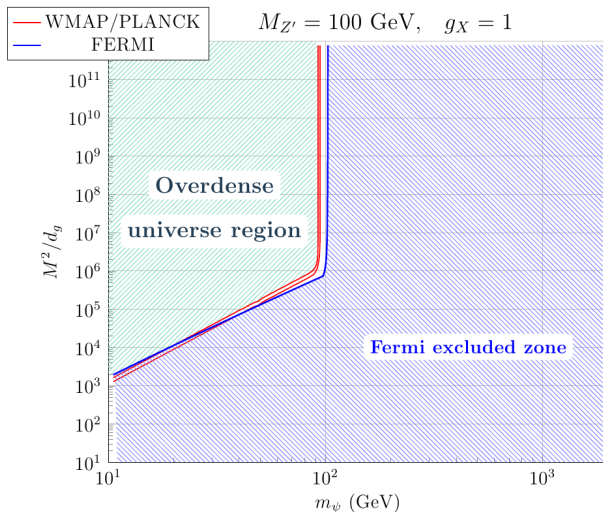
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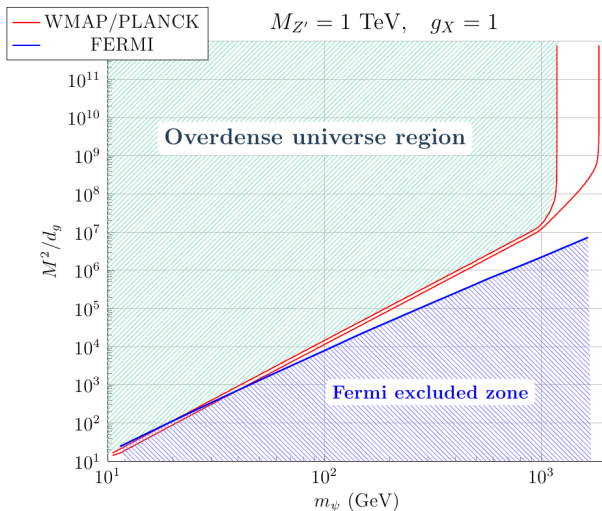
- Relic abundance
- Indirect detection
- LHC mono-jets events

Relic abundance and indirect detection



Other curves

Relic abundance and indirect detection



Other curves

LHC constraints

Possible mono-jets final states

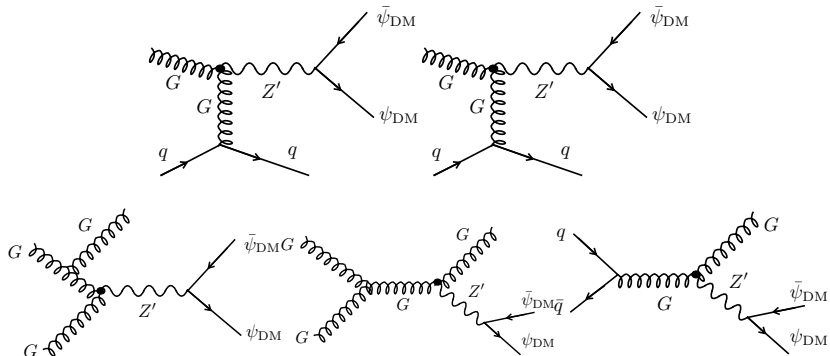


Figure : Dark matter production processes at the LHC (at partonic level), in association with 1 jet : $p p \rightarrow j \bar{\psi}_{DM} \psi_{DM}$.

LHC constraints

Using CMS data [CMS Collaboration], CMS-PAS-EXO-12-048], $E_{CM} = 8$ TeV :

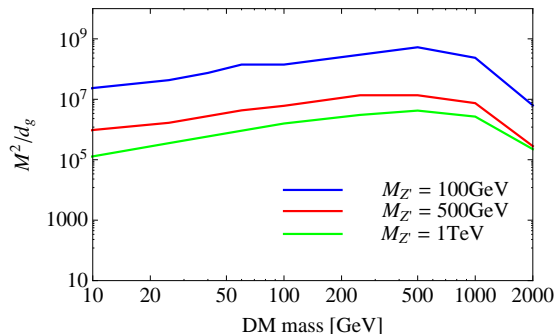
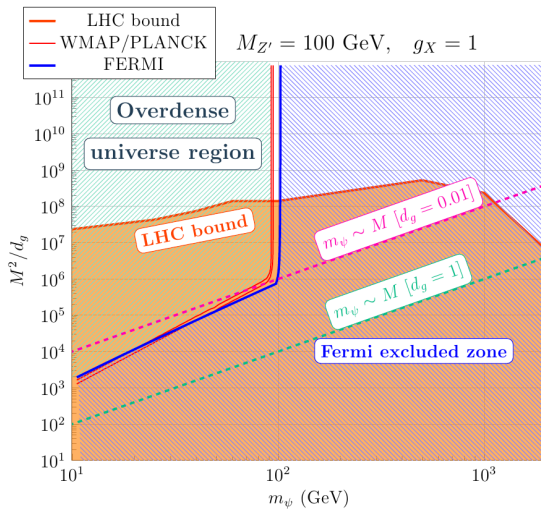


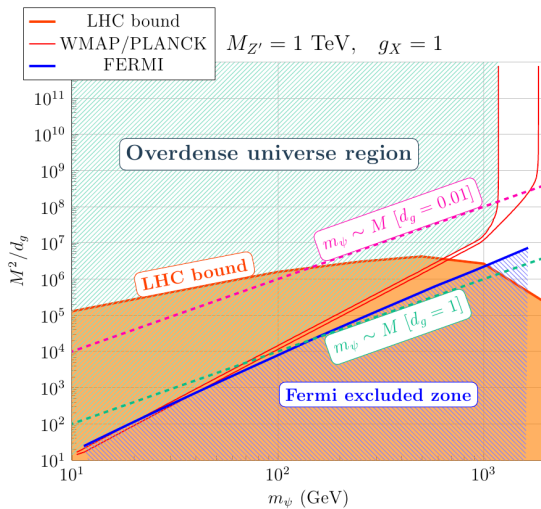
Figure : 90% CL lower bounds on the quantity M^2/d_g as a function of the dark matter mass, for $M_{Z'}$ = 100 GeV (blue), 500 GeV (red) and 1 TeV (green). Based on the CMS analysis with collected data using a center-of-mass energy of 8 TeV and a luminosity of 19.5/fb.

Synthesis



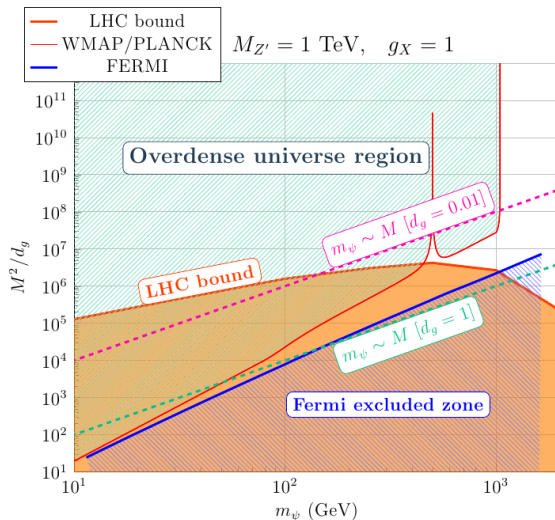
Other curves

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Comparison with EW sector



Conclusions and outlooks

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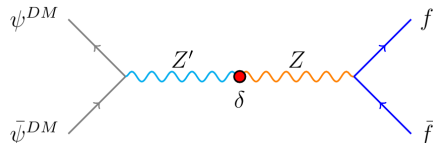
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- Microscopic computations of effective coupling to be extended to other interactions

The End

Thank you !

Constraints on kinetic mixing

If not neglected \rightarrow new diagrams



$$\langle \sigma v \rangle_{GG} \simeq \frac{d_g^2}{M^4} \frac{2g_X^4}{\pi} \frac{m_\psi^6}{M_{Z'}^4}. \quad (4.1)$$

\rightarrow [X. Chu, Y. Mambrini, J. Quevillon and B. Zaldivar, arXiv :1306.4677 [hep-ph]]

$$\langle \sigma v \rangle_\delta \simeq \frac{16}{\pi} g_X^2 g^2 \delta^2 \frac{m_\psi^2}{M_{Z'}^4}, \quad m_\psi < M_Z$$

$$\langle \sigma v \rangle_\delta \simeq \frac{g_X^2 g^2 \delta^2 M_Z^4}{\pi m_\psi^2 M_{Z'}^4}, \quad m_\psi > M_Z. \quad (4.2)$$

Constraints on kinetic mixing

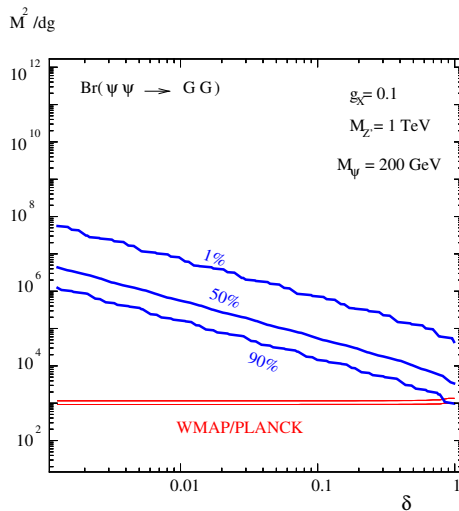
Kinetic mixing competes with other effective operators if

$$\delta \gtrsim \frac{d_g}{M^2} \frac{g_X}{2\sqrt{2}g} m_\psi^2, \quad m_\psi < M_Z$$

$$\delta \gtrsim \frac{d_g}{M^2} \frac{\sqrt{2}g_X}{g} \frac{m_\psi^4}{M_Z^2}, \quad m_\psi > M_Z \quad (4.3)$$

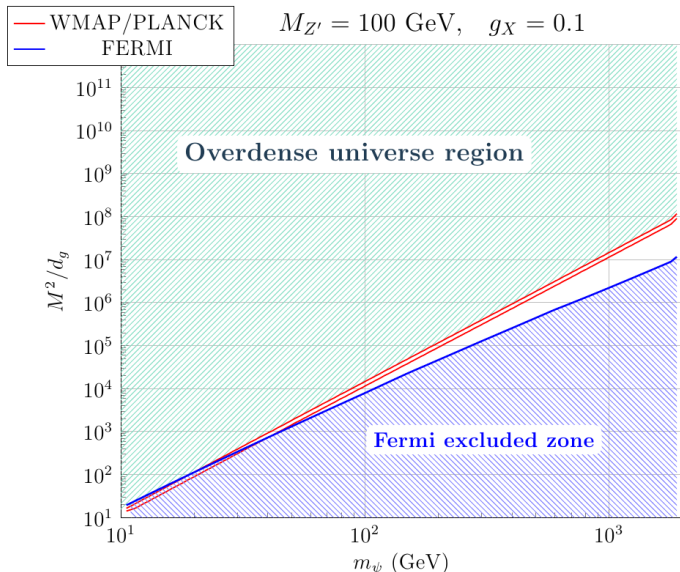
→ For $m_\psi = 200 \text{ GeV}$: $\frac{d_g}{M^2} \lesssim 10^{-4} \times \delta \text{ GeV}^{-2}$

Constraints on kinetic mixing

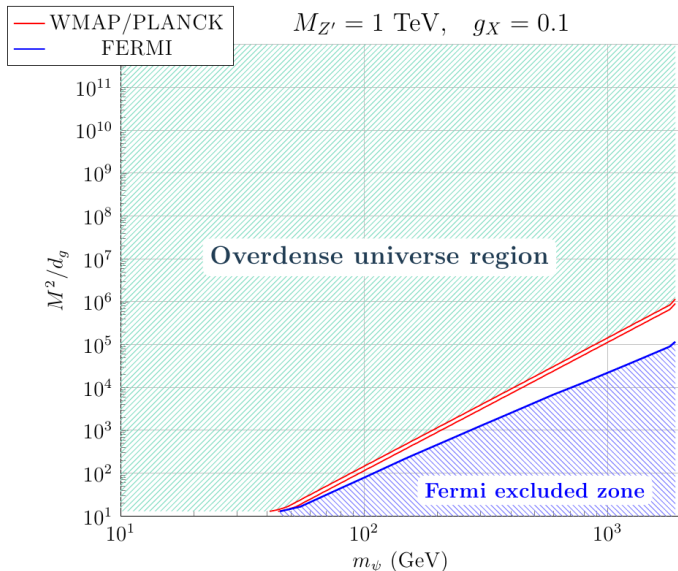


$\rightarrow \delta \gtrsim 0.8$ excluded by LEP experiments...

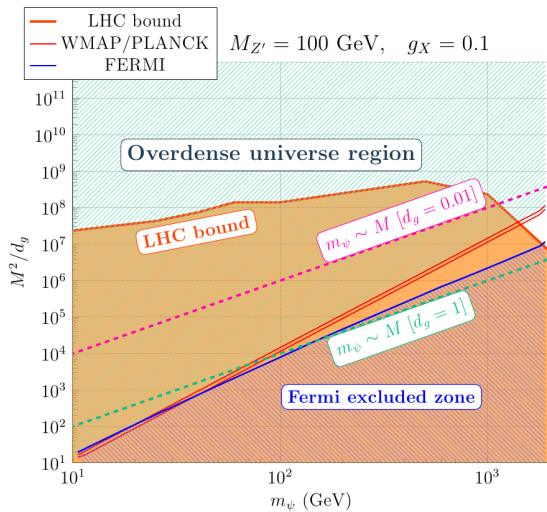
Relic abundance and indirect detection



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Synthesis



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