

Impact of Dark Matter Direct and Indirect Detection on Simplified (GUT Inspired) DM Models

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Motivation and Outline

Z' scenarios are a popular benchmark for new physics searches at the LHC.
Typically arise in $U(1)$ extensions of the SM.

Case of study: Embedding of Z' setups with (fermionic) Dark Matter in GUT theories.

Analogy with simplified models recently adopted by ATLAS/CMS
(J. Abdallah et al. 2015, D. Abercrombie et al. 2015)

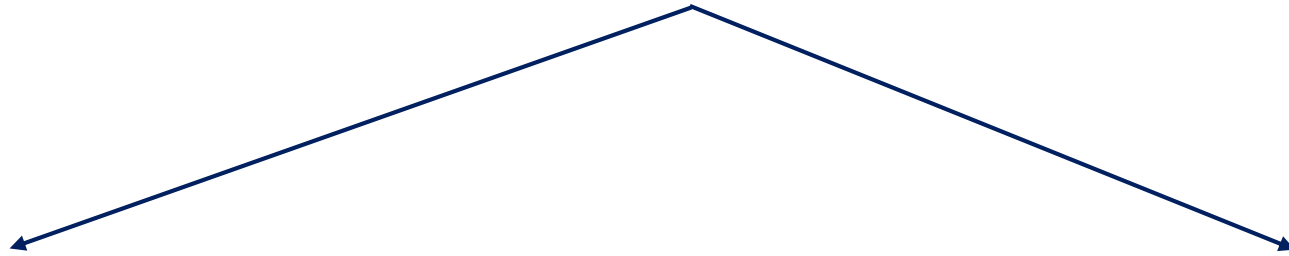
Possible explanation of recent Diboson excess
(ATLAS collaboration 1506.00962, Hisano et al 1506.03931, Brehemer et al. 1507.00013)

$E_6 \rightarrow SO(10) \times U(1)_\psi$ \longrightarrow Extra U(1) from Grand Unified theories

$SO(10) \rightarrow SU(5) \times U(1)_\chi$

$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \rightarrow SU(2) \times U(1)_Y \times U(1)_{LR}$

Definite theoretical frameworks provide predictions of the relevant couplings.



Comparison with current constraints.

Prediction of future signals

General implementation

General implementation:

$$\mathcal{L} = \sum_f g'_f \bar{f} \gamma^\mu \left(\epsilon_L^f P_L + \epsilon_R^f P_R \right) f Z'_\mu + g'_\chi \bar{\chi} \gamma^\mu \left(\epsilon_L^\chi P_L + \epsilon_R^\chi P_R \right) \chi Z'_\mu$$

$$\epsilon_{L,R}^f = \hat{\epsilon}_{L,R}^f / D$$

DM phenomenology relies on vectorial and axial combinations.

	χ	ψ	η	LR	B-L	SSM
D	$2\sqrt{10}$	$2\sqrt{6}$	$2\sqrt{15}$	$\sqrt{5/3}$	1	1
$\hat{\epsilon}_L^u$	-1	1	-2	-0.109	1/6	$\frac{1}{2} - \frac{2}{3} \sin^2 \theta_W$
$\hat{\epsilon}_L^d$	-1	1	-2	-0.109	1/6	$-\frac{1}{2} + \frac{1}{3} \sin^2 \theta_W$
$\hat{\epsilon}_R^u$	1	-1	2	0.656	1/6	$-\frac{2}{3} \sin^2 \theta_W$
$\hat{\epsilon}_R^d$	-3	-1	-1	-0.874	1/6	$\frac{1}{3} \sin^2 \theta_W$
$\hat{\epsilon}_L^\nu$	3	1	1	0.327	-1/2	$\frac{1}{2}$
$\hat{\epsilon}_L^l$	3	1	1	0.327	-1/2	$-\frac{1}{2} + \sin^2 \theta_W$
$\hat{\epsilon}_R^e$	1	-1	2	-0.438	-1/2	$\sin^2 \theta_W$

$$g' V_f = \frac{g'_f}{2} \left(\epsilon_L^f + \epsilon_R^f \right) \quad g' A_f = \frac{g'_f}{2} \left(\epsilon_L^f - \epsilon_R^f \right)$$

$$g' V_\chi = \frac{g'_\chi}{2} \left(\epsilon_L^\chi + \epsilon_R^\chi \right) \quad g' A_\chi = \frac{g'_\chi}{2} \left(\epsilon_L^\chi - \epsilon_R^\chi \right)$$

Han et al. 1308.2738

Correlation between relic density and DD

The pair annihilation cross-section can be expressed in terms of observable quantities, i.e. DM scattering cross-sections.

s-wave or p-wave dominated according the nature of the DM coupling

$$\langle\sigma v\rangle = f_1\sigma_{\chi N}^{\text{SI}} + f_2\sigma_{\chi N}^{\text{SD}}$$

Possible constraints from ID

DD constraints the relic abundance of DM.

Prediction of the value of the scattering cross-section from the requirement the DM is thermal.

$$\sigma_{SI}^p = \frac{g'^4 \mu_\chi^2}{\pi m_{Z'}^4} |V_\chi|^2 \alpha_{SI}$$

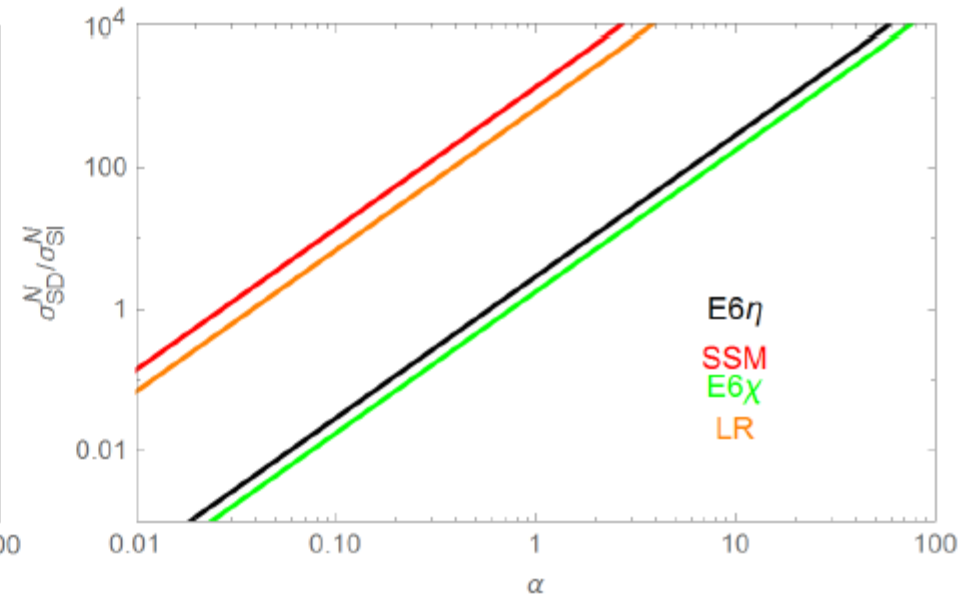
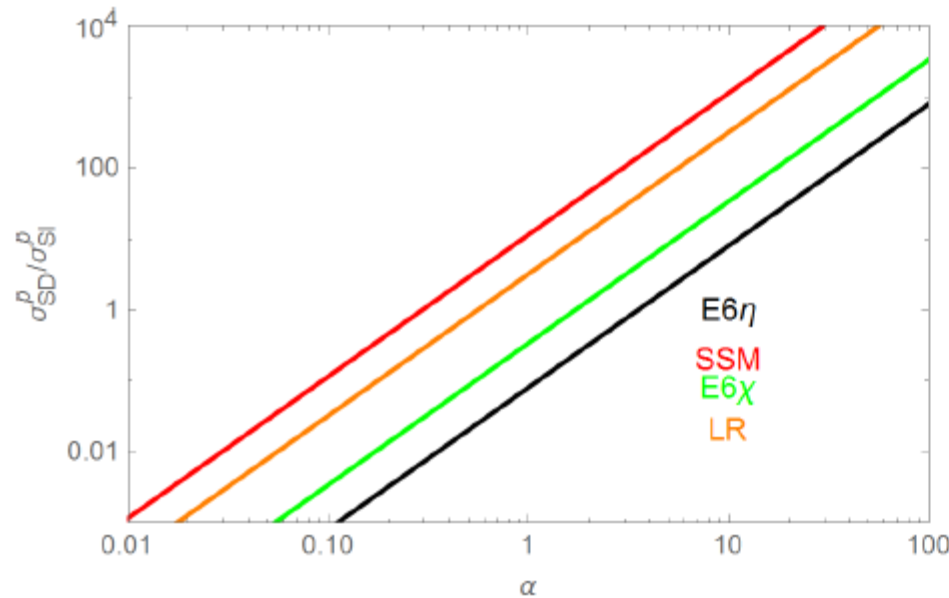
$$\sigma_{SD}^p = \frac{3g'^4 \mu_\chi^2}{\pi m_{Z'}^4} |A_\chi|^2 \alpha_{SD}$$

Factors depending on the couplings with the fermions and the detector material

$$\frac{\sigma_{SD}^p}{\sigma_{SI}^p} = 3\alpha^2 \frac{\alpha_{SD}}{\alpha_{SI}}$$

$$\alpha = \frac{A_\chi}{V_\chi}$$

Different Z' realizations might be distinguished by measuring both components of the DM scattering cross-section.



$$\langle \sigma v \rangle = \frac{m_\chi^2}{\pi m_{Z'}^4} |V_\chi|^2 [(a_V + b_V v^2) + \alpha^2 (a_A + b_A v^2)]$$

$$\frac{\langle \sigma v \rangle}{\sigma_\chi^{\text{SI}}} = \frac{m_\chi^2}{\mu_{\chi N}^2 \alpha_{\text{SI}}} [(a_V + b_V v^2) + \alpha^2 (a_A + b_A v^2)]$$

For light DM

$$\begin{aligned} \frac{\langle \sigma v \rangle}{\sigma_{N\chi}^{\text{SI}}} &\simeq \frac{m_\chi^2}{\mu_{\chi N}^2 \alpha_{\text{SI}}} \left[1 + \frac{\alpha^2}{2} \left[\frac{m_b^2}{m_\chi^2} \frac{|A_b|^2}{\sum_f |V_f|^2 + |A_f|^2} + \frac{v^2}{6} \right] \right] n_c^f \sum_f |V_f|^2 + |A_f|^2 \\ &\simeq \frac{m_\chi^2}{\mu_{\chi N}^2 \alpha_{\text{SI}}} \left[1 + \frac{\alpha^2}{12} \right] n_c^f \sum_f |V_f|^2 + |A_f|^2 \end{aligned}$$

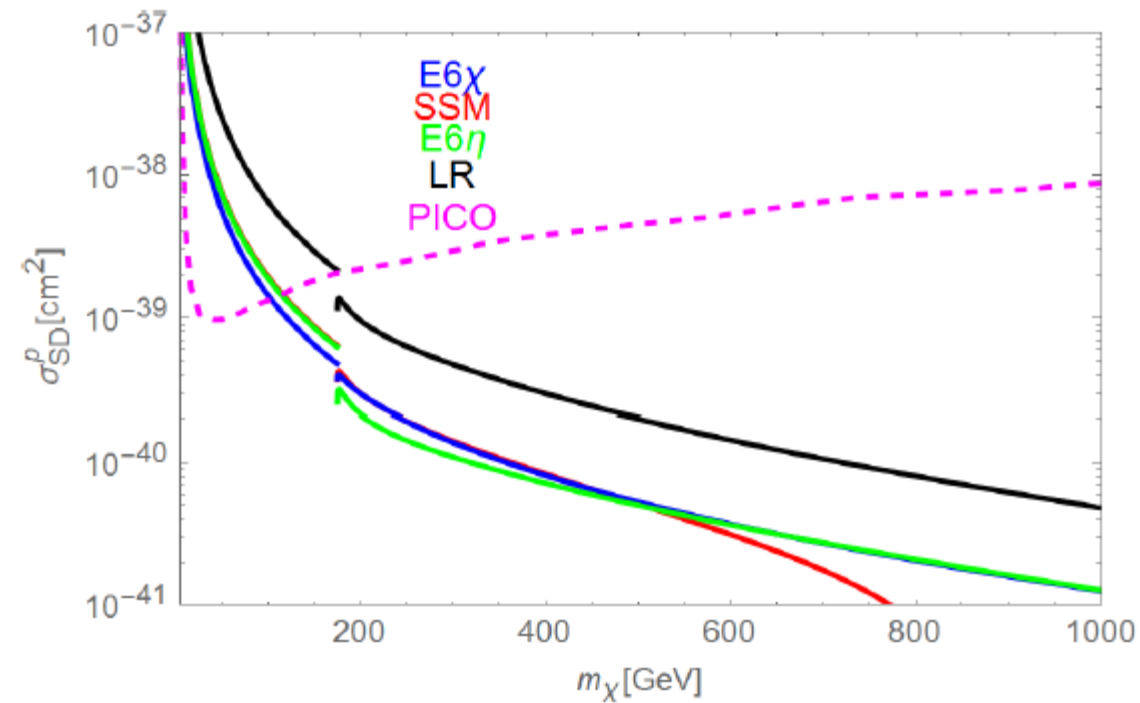
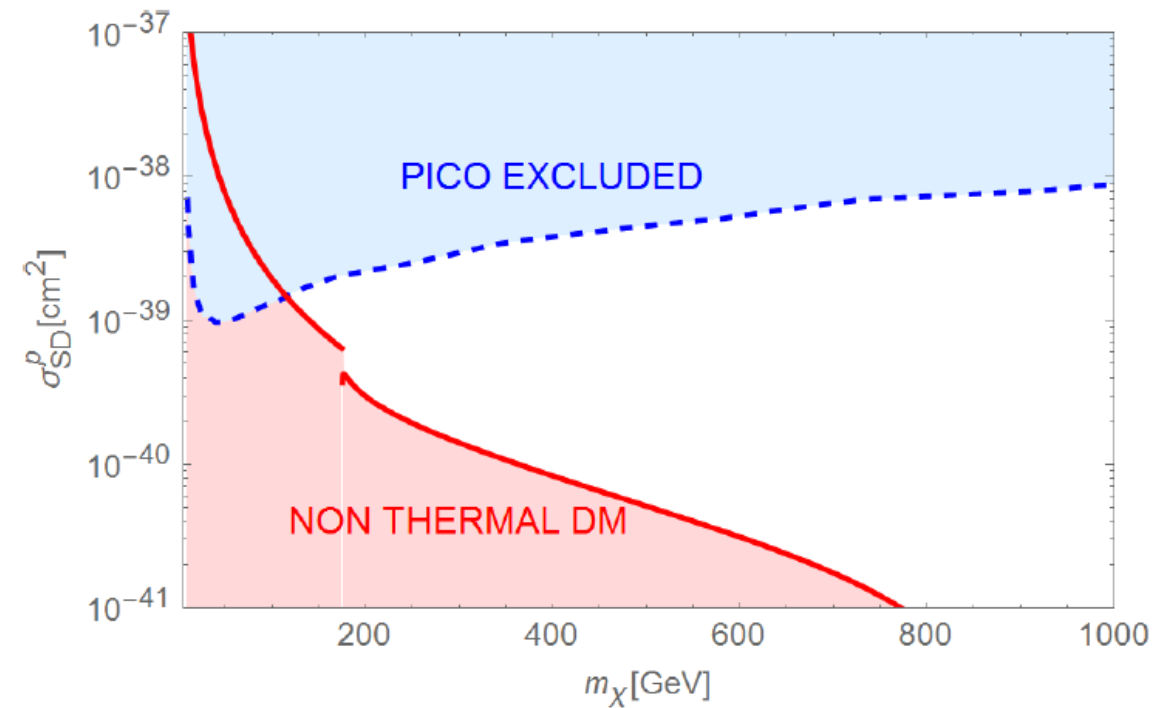
Very severe limits from direct detection (LUX) imply: $|V_\chi| \ll 1$

Correct relic density requires: $\alpha \gg 1$

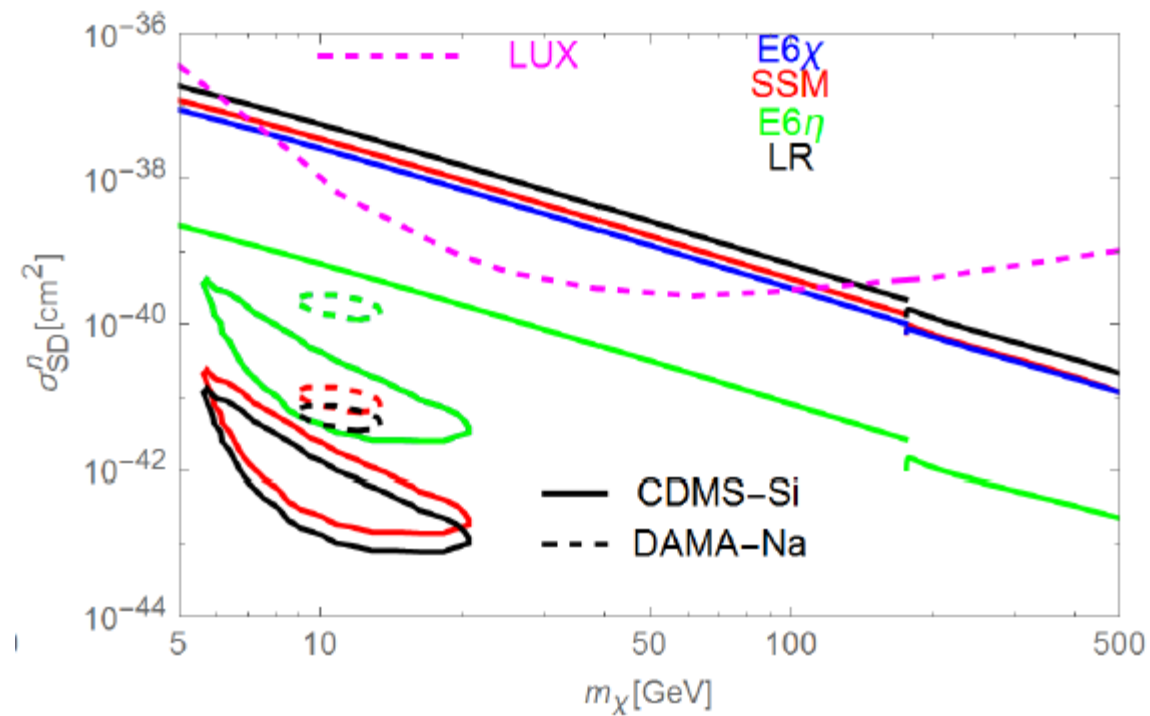
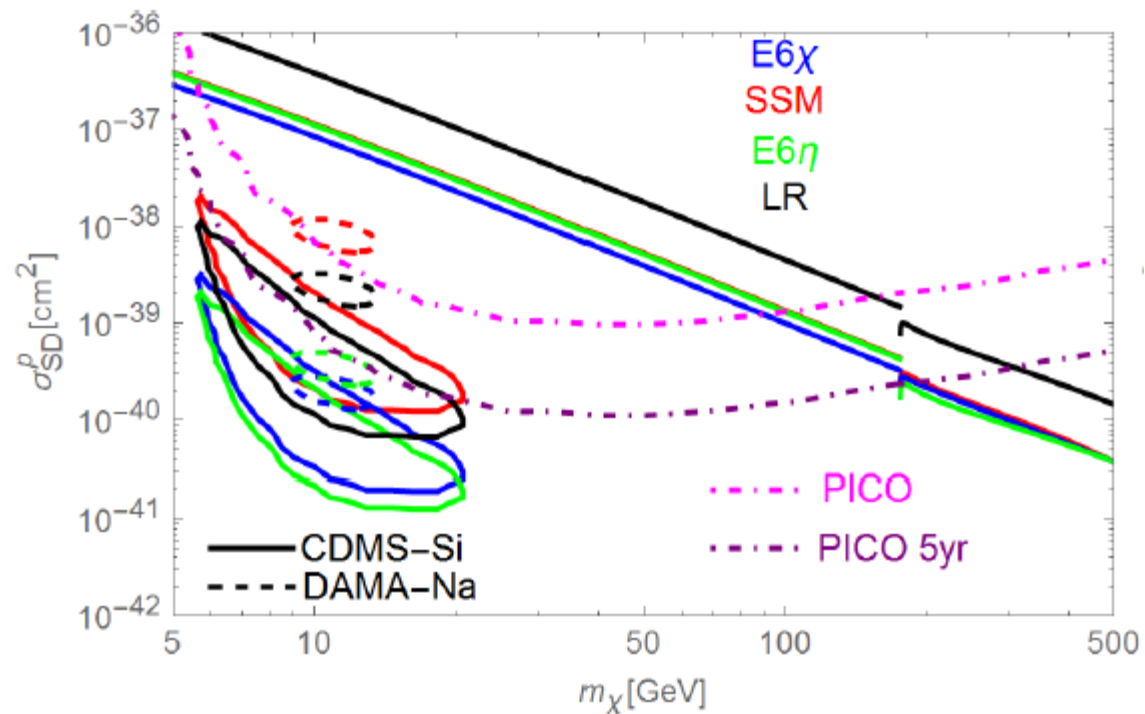
$$\alpha \approx 1.1 \times 10^3 \sqrt{\frac{\alpha_{\text{SI}}}{\sum_f n_c^f |V_f|^2 + |A_f|^2}} \left(\frac{\langle \sigma v \rangle}{3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}} \right)^{1/2} \left(\frac{\sigma_{N\chi}^{\text{SI}}}{10^{-44} \text{ cm}^2} \right)^{-1/2} \left(\frac{m_\chi}{100 \text{ GeV}} \right)^{-1}$$

Prediction for the SD cross-section:

$$\sigma_{N\chi}^{\text{SD}} \approx 1.6 \times 10^{-37} \text{ cm}^2 \frac{\alpha_{\text{SD}}}{n_c^f \sum_f |V_f|^2 + |A_f|^2} \left(\frac{\langle \sigma v \rangle}{3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}} \right) \left(\frac{m_\chi}{100 \text{ GeV}} \right)^{-2}$$



Limit on SD cross-section can probe thermal Dark matter up to O(150-200) GeV.



Complementarity with collider searches

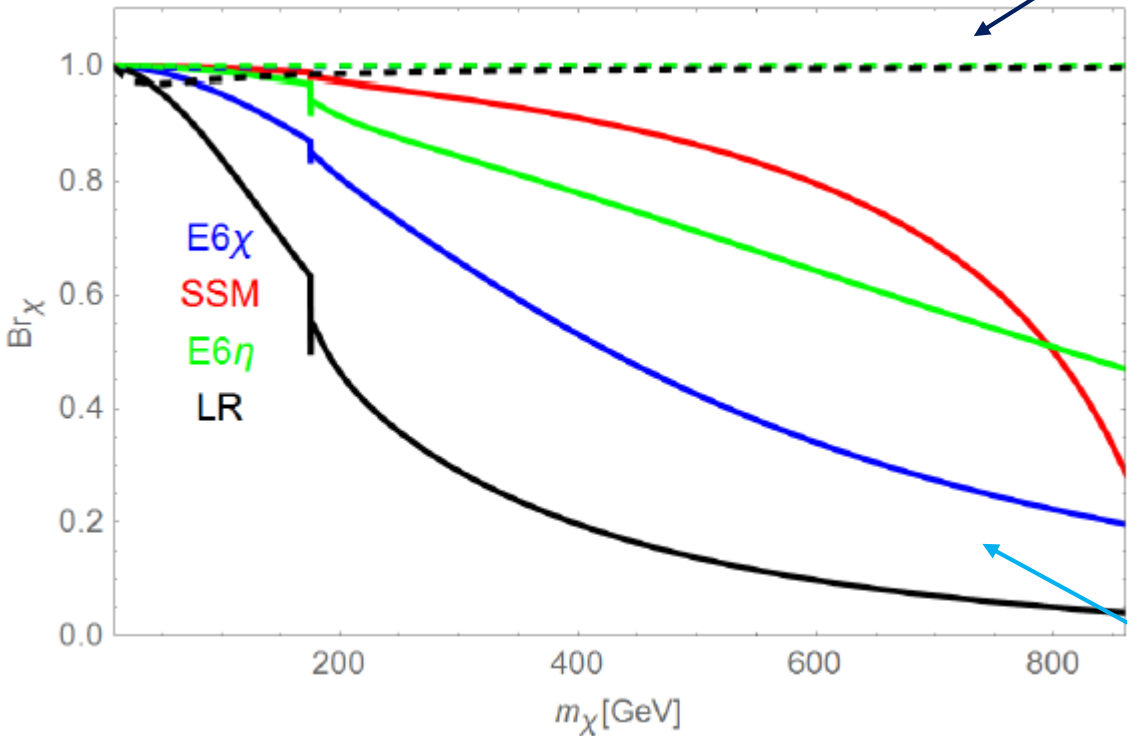
$$\sigma_{Z'u} \rightarrow \left(\frac{g'}{g}\right)^2 \times (1 - Br_\chi) \times \sigma_{Z'u}$$

Dilepton-Dijet production cross-section influenced by invisible branching fraction.

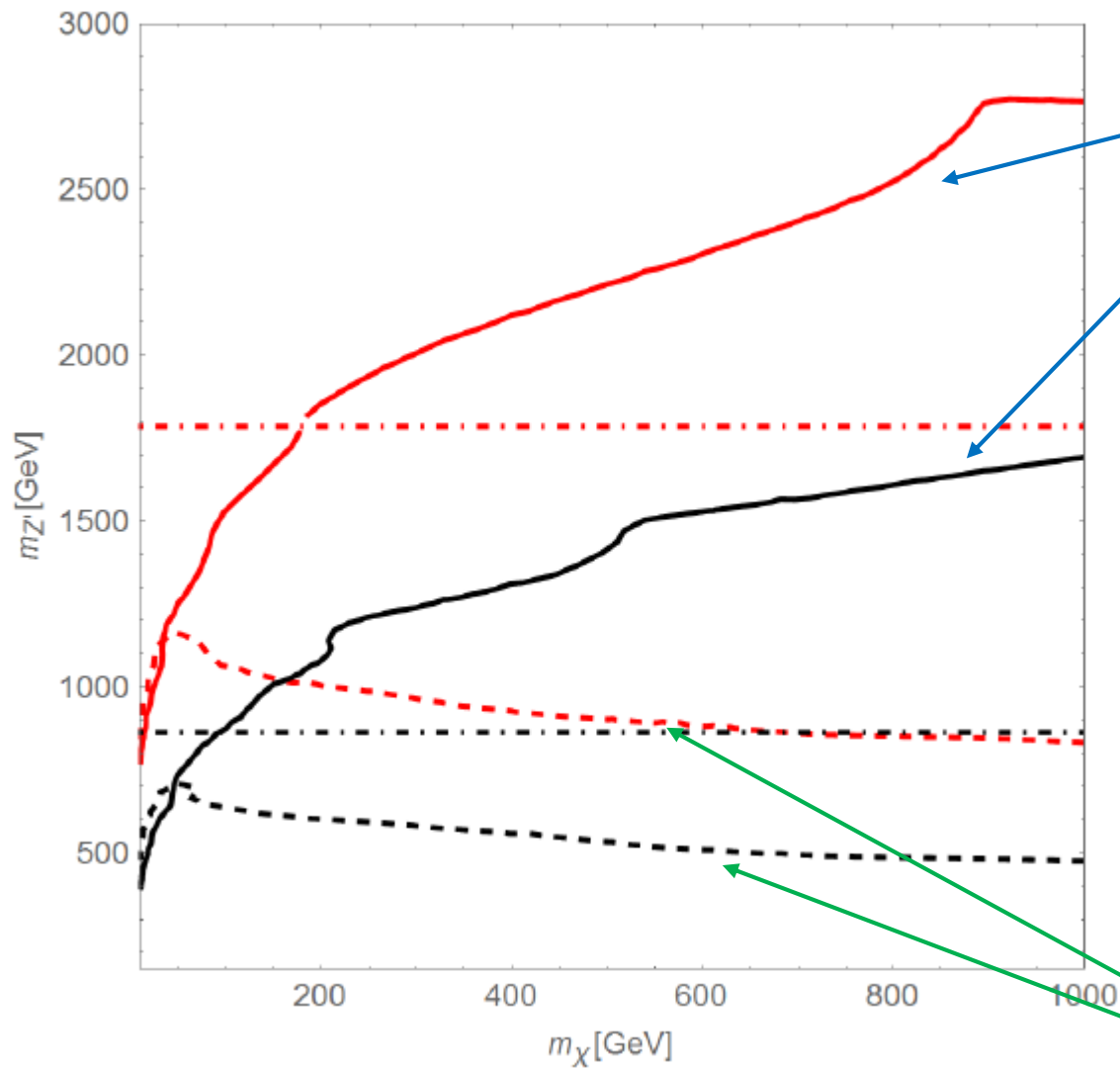
$$Br_\chi = \frac{\Gamma_{Z'}^\chi}{\Gamma_{Z'}^\chi + \sum_f \Gamma_{Z'}^f} = \left[1 + \left(\frac{2g_D^2 \mu_{\chi N}}{M_{Z'}^2 \sqrt{\pi}} \right)^2 \frac{\sum_f c_f [|V_D^f|^2 + |A_D^f|^2]}{\sigma_{\chi N}^{\text{SI}}/\alpha_{Z,A}^{\text{SI}} + 1/3 \sigma_{\chi N}^{\text{SD}}/\alpha_{Z,A}^{\text{SD}}} \right]^{-1}$$

Determined by DM relic density

Current SD limits still allow for invisible Z'



Invisible branching fraction allowed by relic density



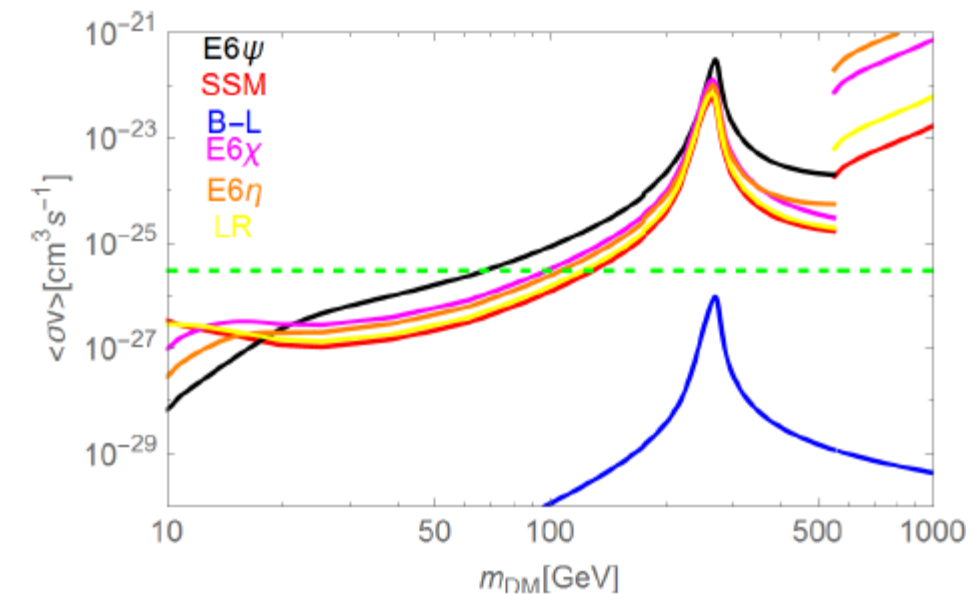
Exclusion constraints considering relic density

Non null invisible branching fraction (allowed by DM relic density) alter the limits on the mass of the Z' from searches of resonances.

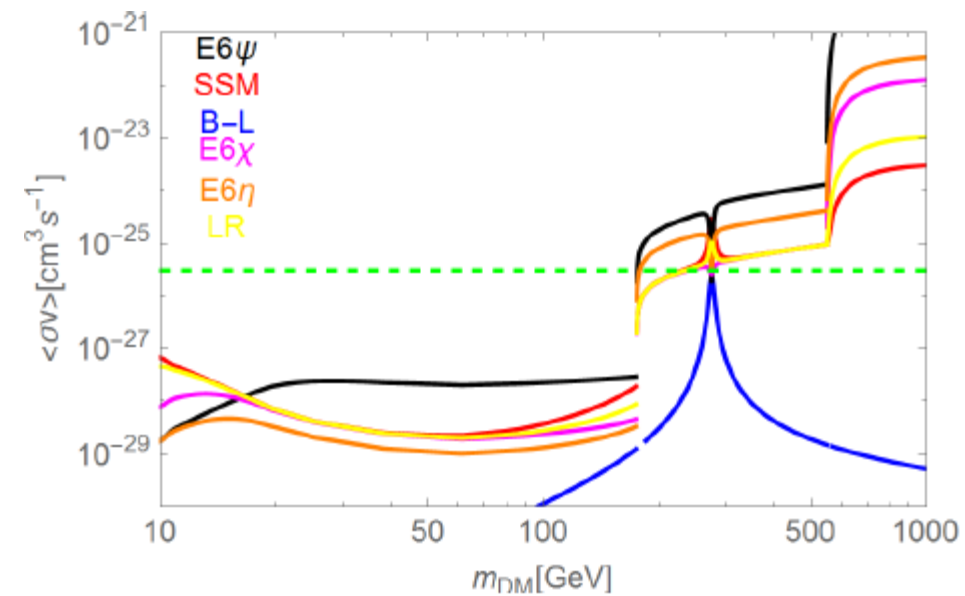
(See also G.A. et al, 1401.0221)

Exclusion constraints considering limits on SD

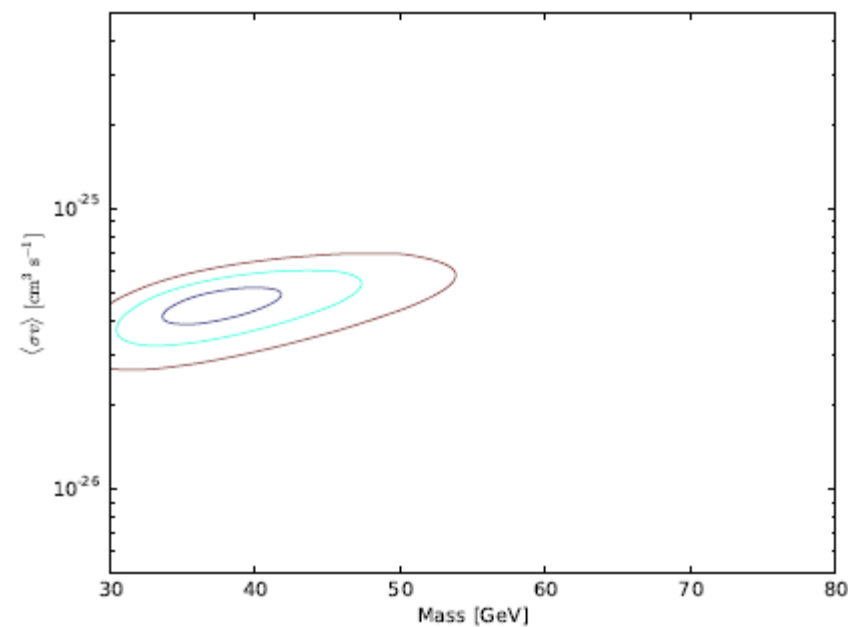
GC signal for Z'



Freeze-out



Now



Conclusions and outlook

Z' models represent a class of simple but theoretically motivated extension of the Standard Model.

Complementarity of DM constraints can allow to disentangle possible Z' realizations.

Prospects:

Extension of collider studies.

Quantitative analysis of future direct detection signals.