Interplay between Direct and LHC detection in Z´ scenarios

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G.A., Y. Mambrini, M. Tytgat and B. Zaldivar
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PEOPLE

invisibles
neutrinos, dark matter & dark energy physics

Outline of the talk

Interplay between Direct Detection and LHC in generic (dark Z´) realizations.

-Impact of Z´ invisible branching fraction on resonance searches.

Case of Study: Z´+(dirac) fermion DM. Couplings with fermions as SSM.

-Extensions of the analysis

Impact of monojet searches
DM relic density

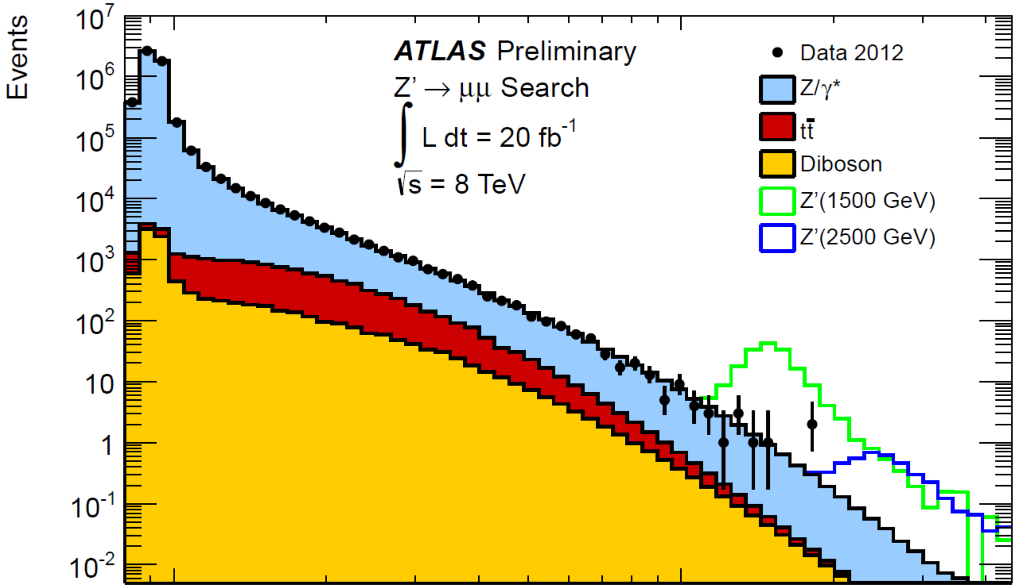
Z′ scenarios are a popular benchmark for new physics searches at the LHC.

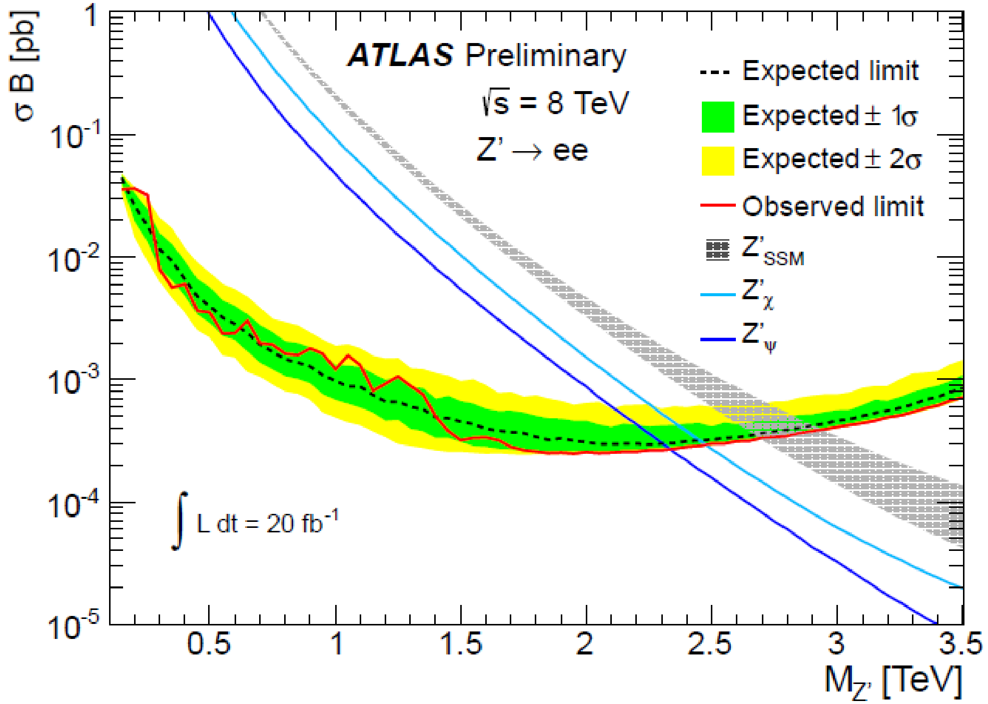
Can be embedded in theoretical motivated scenarios, e.g. gauged B-L, E6.

Current experimental strategies rely on searches of resonances in dileptons (dijet) distributions.

Already strong constraints obtained.

Current bounds can be relaxed including coupling with the DM.





Dark Z´ prime scenario

$$\Delta\mathcal{L} \supset \quad g_D \bar{\chi}\gamma^\mu \left(V_D^\chi - A_D^\chi \gamma^5\right) \chi \; Z'_\mu \; + g_D \sum_f \bar{f}\gamma^\mu \left(V_D^f - A_D^f \gamma^5\right) f \; Z'_\mu$$

Dirac fermion considered for definiteness.
Straightforward extension to other DM candidates.

For semplicity we neglect kinetic mixing.

Relevant parameters: $g_D, V_D^\chi, A_D^\chi, m_{Z'}, m_\chi$ $\qquad$ $\alpha = A_D^\chi / V_D^\chi$

$g_D V_D^f, g_D A_D^f$ in principle free

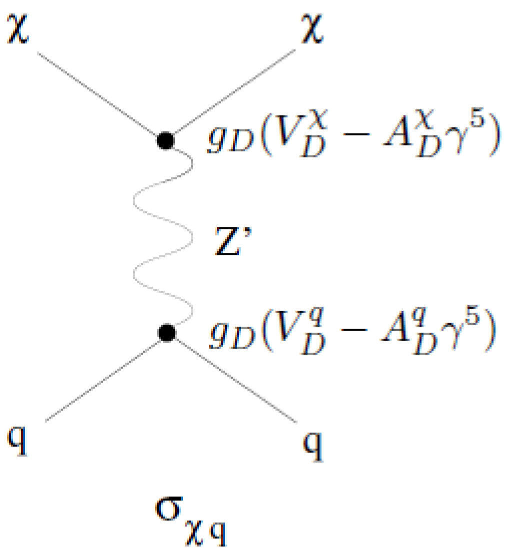
We can express them in term of definite realizations,
e.g. SSM, E6, B-L

channels	$g_D\ V_D^f$ [SSM]	$g_D\ A_D^f$ [SSM]
$e^+\ e^-$	$\frac{g}{4\cos\theta_W}(4\sin^2\theta_W - 1)$	$-\frac{g}{4\cos\theta_W}$
$\nu\ \nu$	$\frac{g}{4\cos\theta_W}$	$\frac{g}{4\cos\theta_W}$
$u\ u$	$\frac{g}{4\cos\theta_W}(-\frac{8}{3}\sin^2\theta_W + 1)$	$\frac{g}{4\cos\theta_W}$
$d\ d$	$\frac{g}{4\cos\theta_W}(\frac{4}{3}\sin^2\theta_W - 1)$	$-\frac{g}{4\cos\theta_W}$

	$g_D\ V_D^f$ [B-L]	$g_D\ A_D^f$ [B-L]
$e^+\ e^-$	$-\sqrt{5/6}\tan\theta\, g$	0
$\nu\ \nu$	$-\sqrt{5/6}\tan\theta\, g$	0
$u\ u$	$\sqrt{5/6}\tan\theta\, g/3$	0
$d\ d$	$\sqrt{5/6}\tan\theta\, g/3$	0

	$g_D\ V_D^f[E_6]$	$g_D\ A_D^f[E_6]$
$e^+\ e^-$	0	$\sqrt{5}\tan\theta\, g$
$\nu\ \nu$	0	$\sqrt{5}\tan\theta\, g$
$u\ u$	0	$\sqrt{5}\tan\theta\, g$
$d\ d$	0	$\sqrt{5}\tan\theta\, g$

DM Direct Detection



$$\sigma_{\chi N}^{\rm SI} = \frac{4 g_D^4 (V_D^\chi)^2 \mu_{\chi N}^2}{\pi M_{Z'}^4} \left[V_D^u \left(1 + \frac{Z}{A}\right) + V_D^d \left(2 - \frac{Z}{A}\right)\right]^2$$

$$\sigma_{\chi N}^{SD} = \frac{12 g_D^4 \mu_{\chi N}^2 |A_D^\chi|^2}{\pi M_{Z'}^4 (S_p^A + S_n^A)^2} \Big[A_D^u (\Delta_u^p S_p^A + \Delta_d^p S_n^A) + A_D^d \left((\Delta_d^p + \Delta_s^p) S_p^A + (\Delta_u^p + \Delta_s^p) S_n^A \right) \Big]^2$$

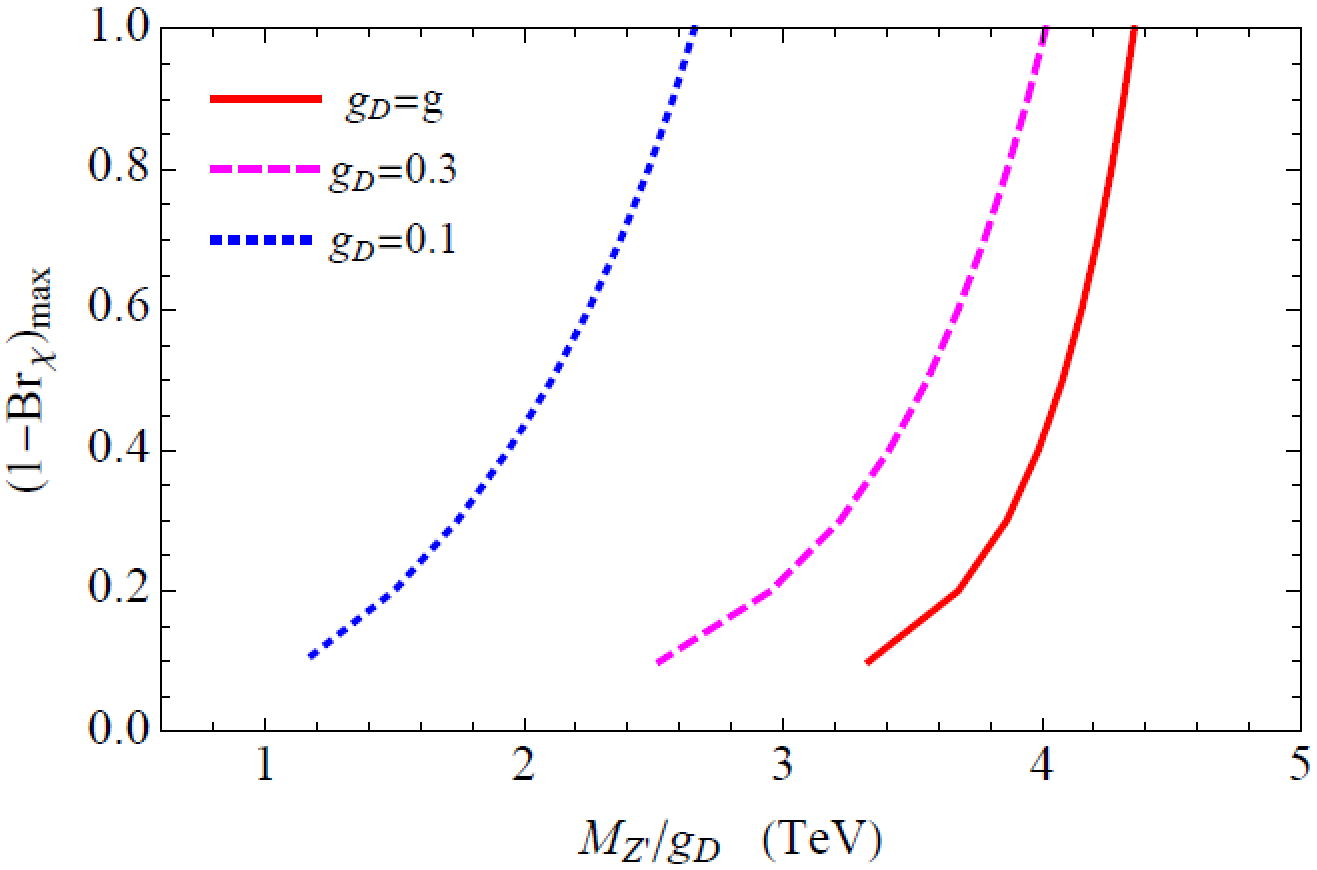
Direct detection limits dominated by LUX (SI component)

LHC limits

$$\sigma(q\bar{q} \to Z' \to \ell\ell) \approx \frac{g_D^4}{12\pi}(|V^q|^2 + |A^q|^2)(|V^\ell|^2 + |A^\ell|^2) \times \frac{s}{(s - M_{Z'}^2)^2 + \Gamma_{Z'}^2 M_{Z'}^2}$$

$$\approx \frac{g_D^4}{12\pi}(|V^q|^2 + |A^q|^2)(|V^\ell|^2 + |A^\ell|^2)$$

$$\times \frac{M_{Z'}}{\Gamma_{Z'}}\pi\delta(s - M_{Z'}^2) \longrightarrow \frac{M_{Z'}}{\Gamma_{Z'}^{SM}}(1 - Br_\chi)$$



LHC limit rescaled in presence of invisible branching fraction

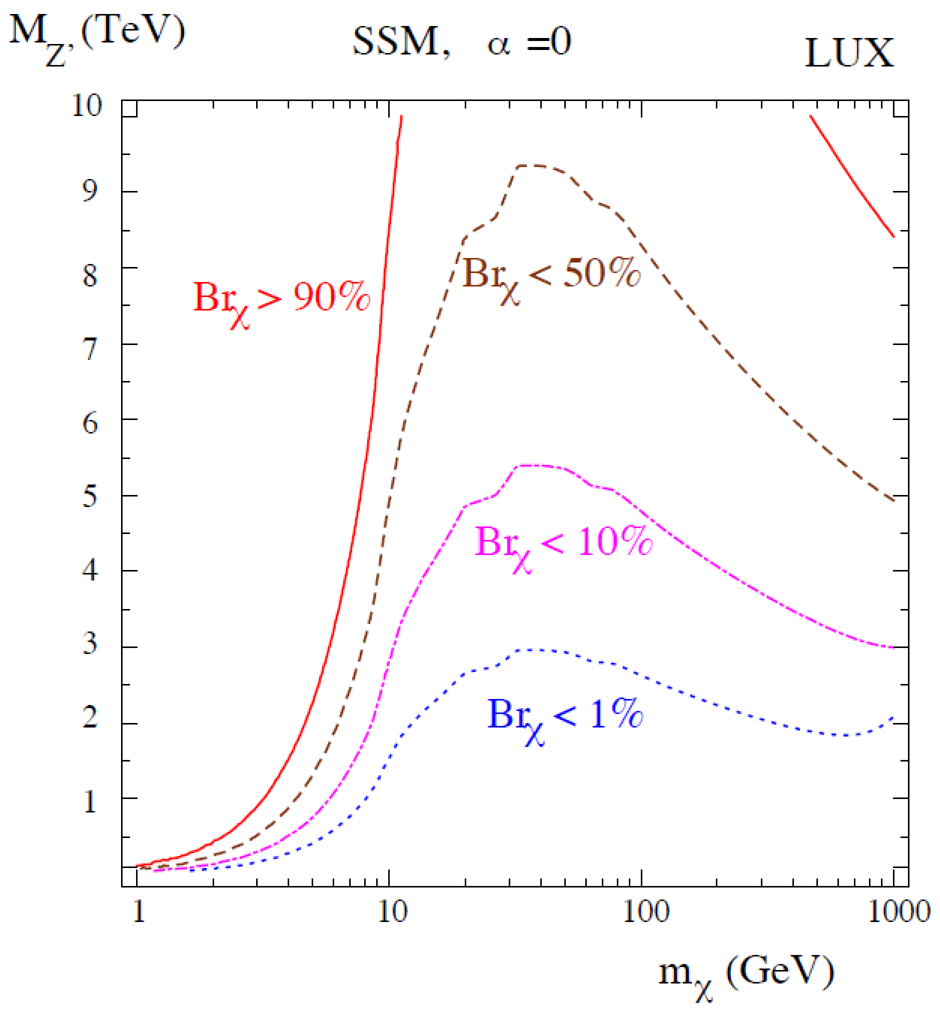
$$\sigma_{Z'll} \to \left(\frac{g_D}{g}\right)^2 \times (1 - Br_\chi) \times \sigma_{Z'll}$$

The invisible branching fraction can be related to the DM scattering cross section.

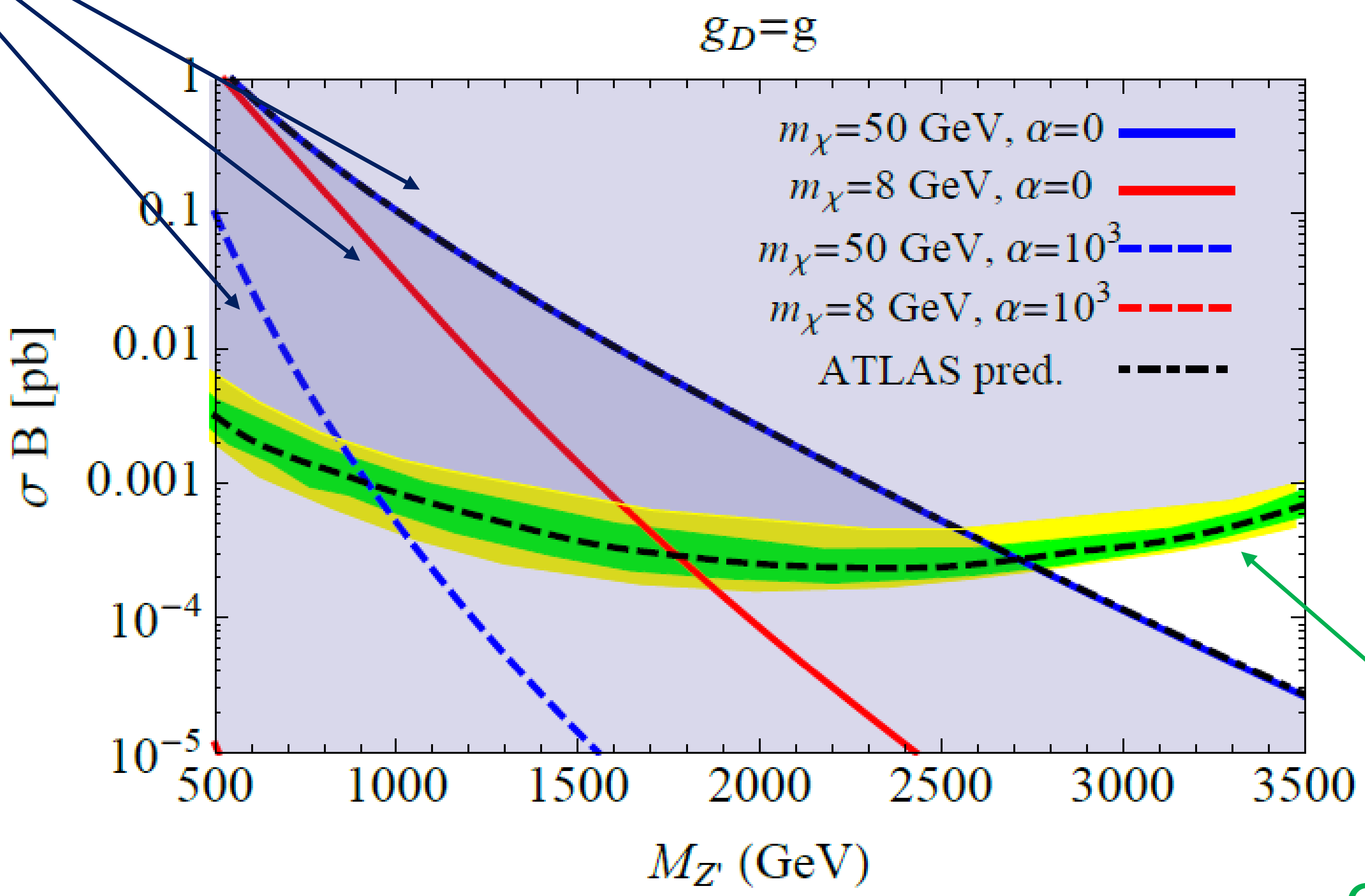
$$\Gamma^i_{Z'} = \frac{g_D^2 c_i}{12\pi} M_{Z'} \sqrt{1 - \frac{4m_i^2}{M_{Z'}^2}} \times \left[(V_D^i)^2 \left(1 + 2\frac{m_i^2}{M_{Z'}^2}\right) + (A_D^i)^2 \left(1 - 4\frac{m_i^2}{M_{Z'}^2}\right) \right]$$

$$Br_\chi = \frac{\Gamma^\chi_{Z'}}{\Gamma^\chi_{Z'} + \sum_f \Gamma^f_{Z'}} \qquad \alpha^{\rm SI}_{Z,A} \equiv \left[V_D^u (1 + \frac{Z}{A}) + V_D^d (2 - \frac{Z}{A}) \right]^2$$

$$Br_\chi = \left[1 + \left(\frac{2 g_D^2 \mu_{\chi N}}{M_{Z'}^2} \right)^2 \frac{\tilde{c}_F \alpha^{\rm SI}_{Z,A}}{\pi (1 + \alpha^2) \sigma^{\rm SI}_{\chi N}} \right]^{-1}$$



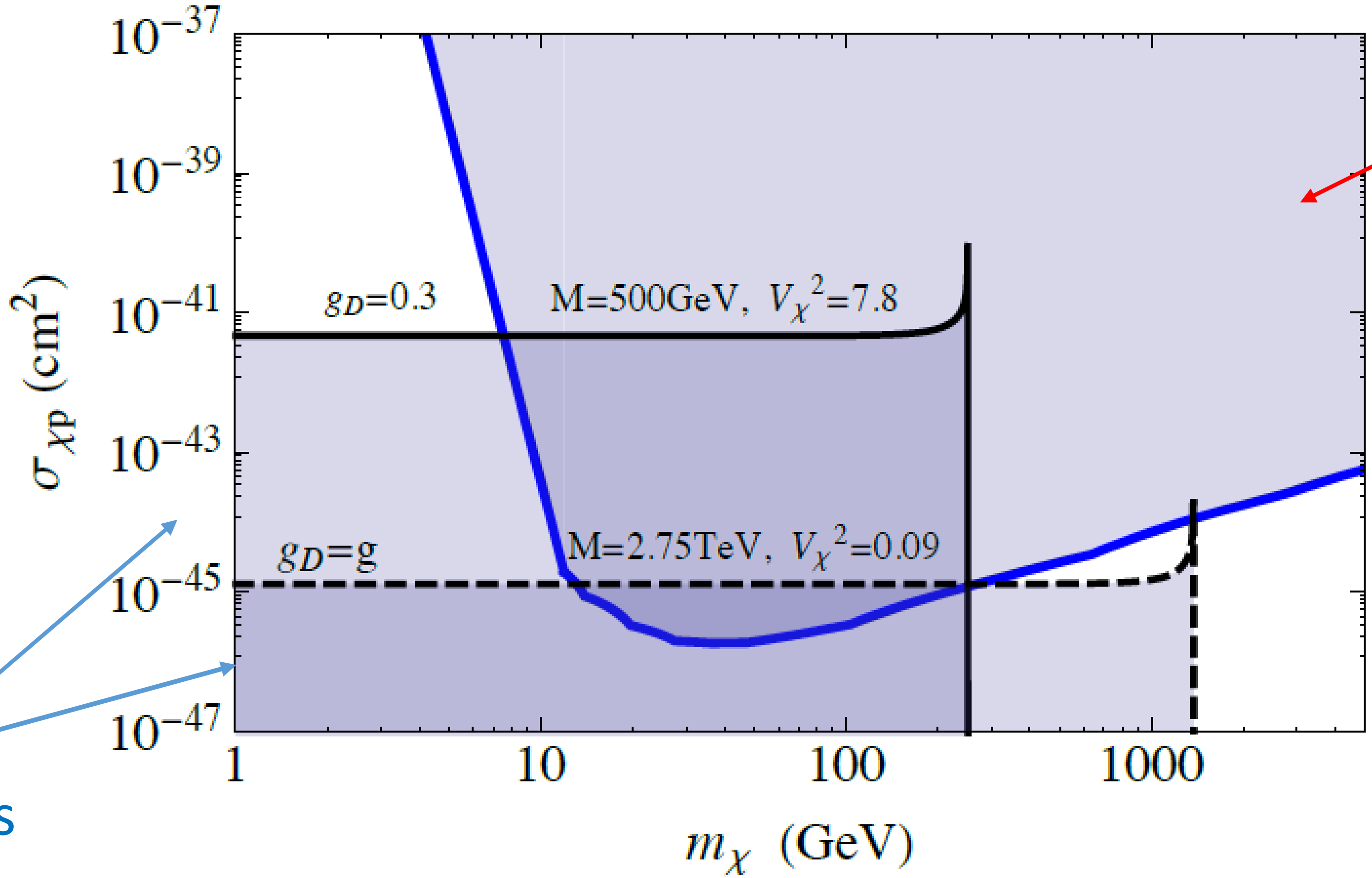
LUX exclusion



Observational LHC exclusion

We can reformulate the results in terms of the SI cross-section

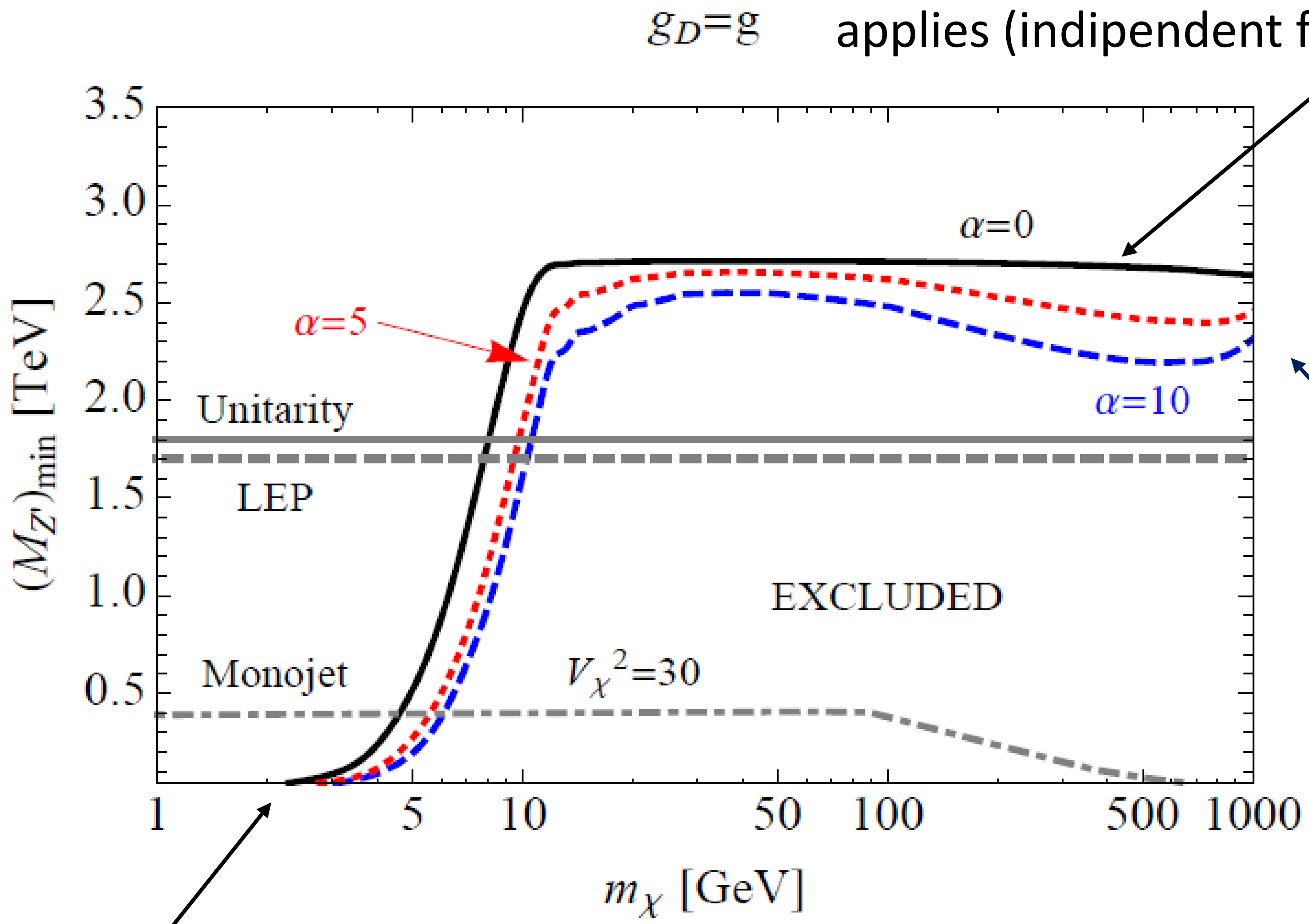
Exclusion by LUX



Excluded by Dilepton searches

Limits on the mass of Z´ can be sensitively lowered in case strong couplings with DM

High DM masses. LUX limit implies low invisible branching fraction. LHC Dilepton limit applies (indipendent from DM mass)



Weaker limits in presence of axial couplings

Low DM masses. Sensitive invisible branching fraction allowed. LHC limits should be modified.

Future prospects

High invisible branching fraction:

monojet searches → Dedicated study is required beyond effective theory approach

↕ Correlation

Low Invisible branching fraction

Resonance searches

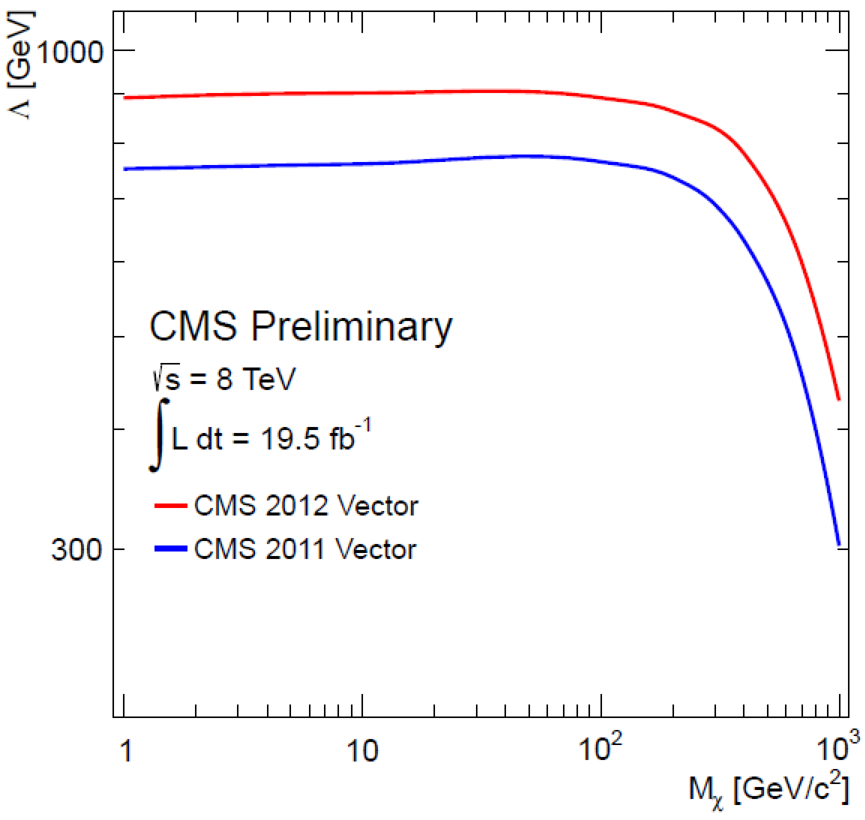
$$\sigma(q\bar{q} \to \chi\chi j) \propto \frac{s}{\Lambda^4}$$

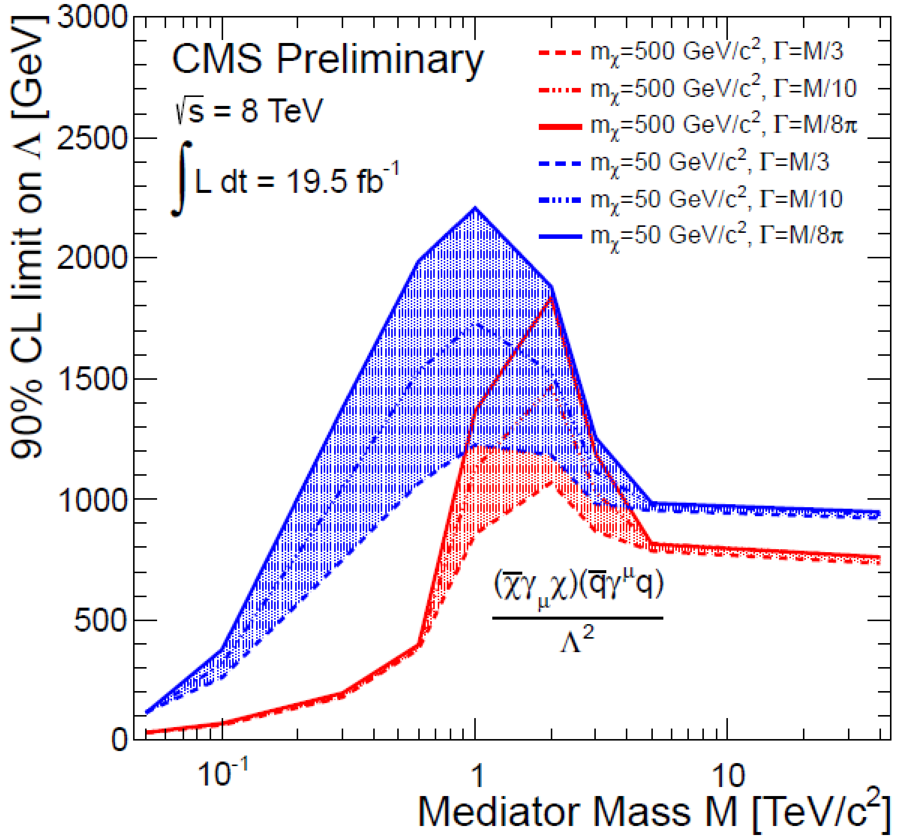
$$\Lambda = M_{Z'}/\sqrt{g_f g_\chi}$$

$$g_f = g_D V_D^f$$

$$g_\chi = g_D V_D^\chi$$

$$\sigma(q\bar{q} \to \chi\chi j) \propto g_\chi^2 g_f^2 \frac{s}{\left(s - M_{Z'}^2\right)^2 + M_{Z'}^2 \Gamma_{Z'}^2}$$





DM Relic Density

DM relic density follows standard WIMP paradigm

$$\langle \sigma v \rangle = \frac{1}{8 m_\chi^4 T K_2 \left(\frac{m_\chi}{T}\right)^2} \int_{4m_\chi^2}^{\infty} ds \sigma(s) \sqrt{s} \left(s - 4m_\chi^2\right) K_1 \left(\frac{\sqrt{s}}{T}\right)$$

Correct relic density for:

$$\langle \sigma v \rangle \sim 3 \times 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1}$$

$$\langle \sigma v \rangle = \sum_{m_f < m_\chi} n_c^f \sqrt{m_\chi^2 - m_f^2}$$

$$\frac{2\left(|A_D^f|^2|A_D^\chi|^2 m_f^2 \left(M_{Z'}^2 - 4m_\chi^2\right)^2 + M_{Z'}^4 |V_D^\chi|^2 \left(2|A_D^f|^2 \left(m_\chi^2 - m_f^2\right) + |V_D^f|^2 \left(m_f^2 + 2m_\chi^2\right)\right)\right)}{4\pi m_\chi M_{Z'}^4 \left(M_{Z'}^2 - 4m_\chi^2\right)^2}$$

$$- \frac{1}{24\pi m_\chi M_{Z'}^4 \sqrt{m_\chi^2 - m_f^2} \left(M_{Z'}^2 - 4m_\chi^2\right)^3} v^2 \left(|A_D^f|^2 \left(2M_{Z'}^4 |V_D^\chi|^2 (m_f - m_\chi)(m_f + m_\chi)\right.\right.$$

$$\left(-2m_\chi^2 \left(46m_f^2 + M_{Z'}^2\right) + 11m_f^2 M_{Z'}^2 + 56m_\chi^4\right) - |A_D^\chi|^2 \left(M_{Z'}^2 - 4m_\chi^2\right)$$

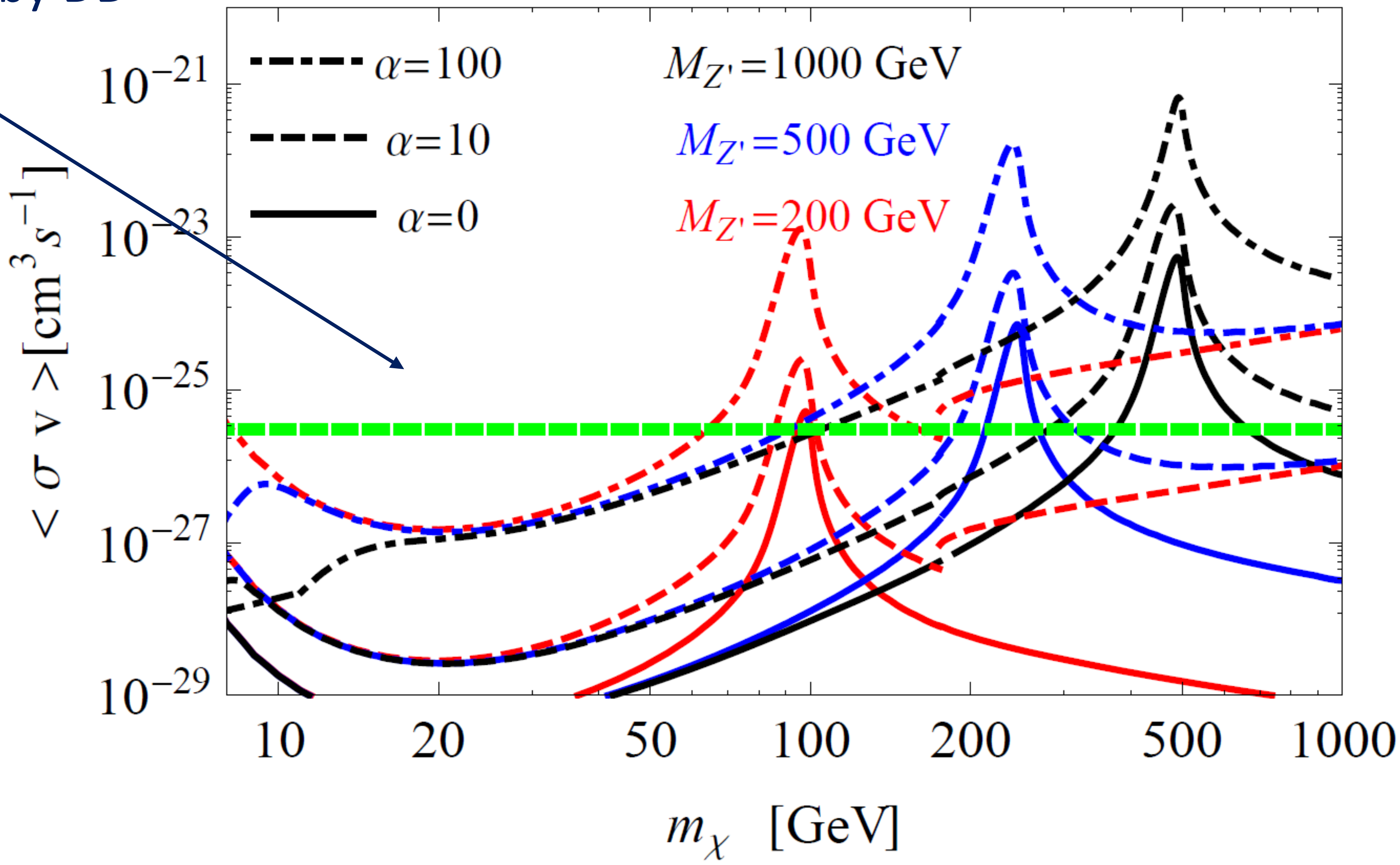
$$\left.\left(23m_f^4 M_{Z'}^4 - 192m_f^2 m_\chi^6 - 4m_f^2 m_\chi^2 M_{Z'}^2 \left(30m_f^2 + 7M_{Z'}^2\right) + 8m_\chi^4 \left(30m_f^4 + 12m_f^2 M_{Z'}^2 + M_{Z'}^4\right)\right)\right)$$

$$+M_{Z'}^4 |V_D^f|^2 \left(4|A_D^\chi|^2 \left(m_f^4 + m_f^2 m_\chi^2 - 2m_\chi^4\right) \left(M_{Z'}^2 - 4m_\chi^2\right)\right.$$

$$\left.\left. +|V_D^\chi|^2 \left(-11m_f^4 M_{Z'}^2 + 4m_\chi^4 \left(14m_f^2 + M_{Z'}^2\right) - 2m_f^2 m_\chi^2 \left(M_{Z'}^2 - 46m_f^2\right) - 112m_\chi^6\right)\right)\right)$$

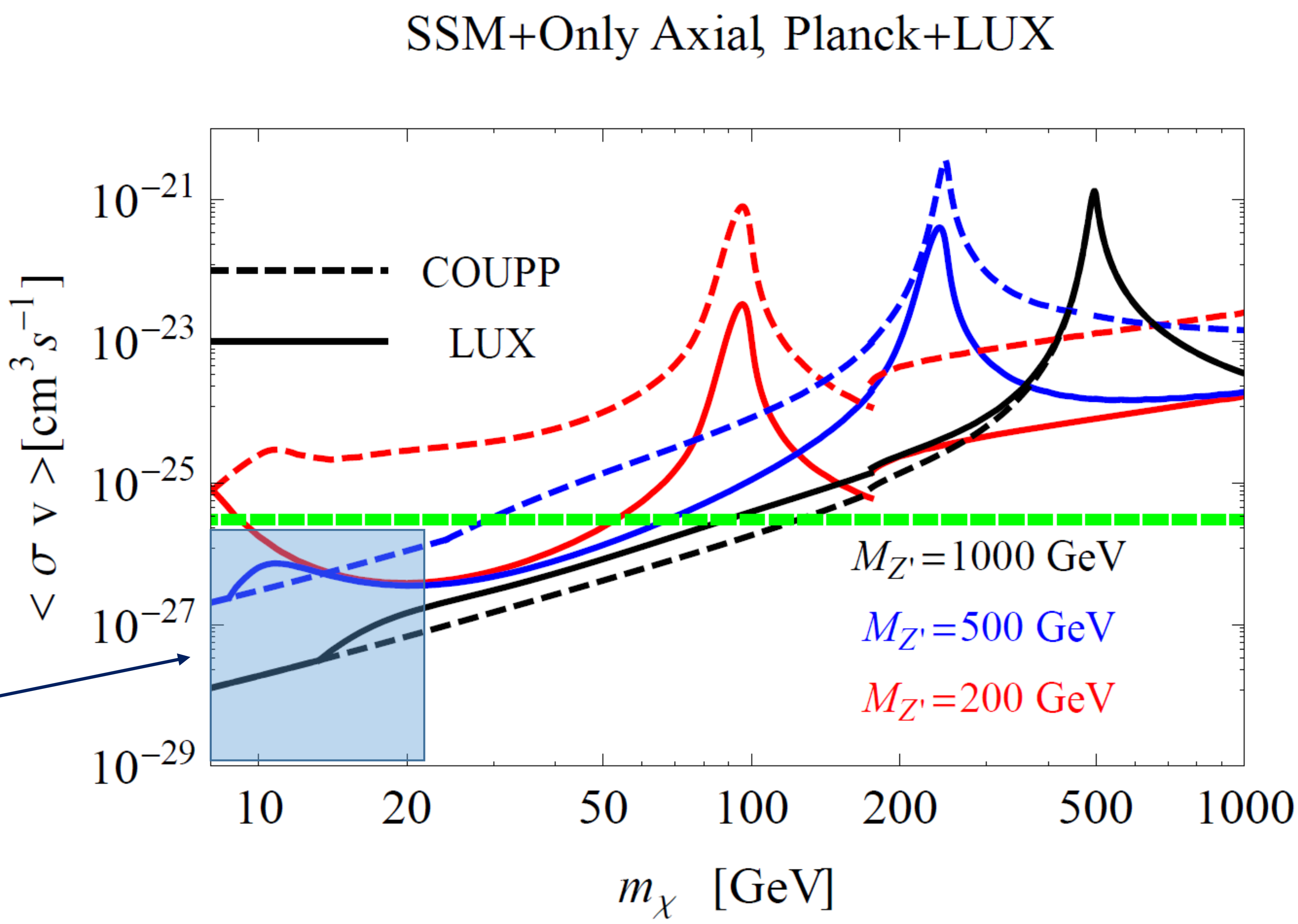
SSM, Planck+LUX

Excluded by DD

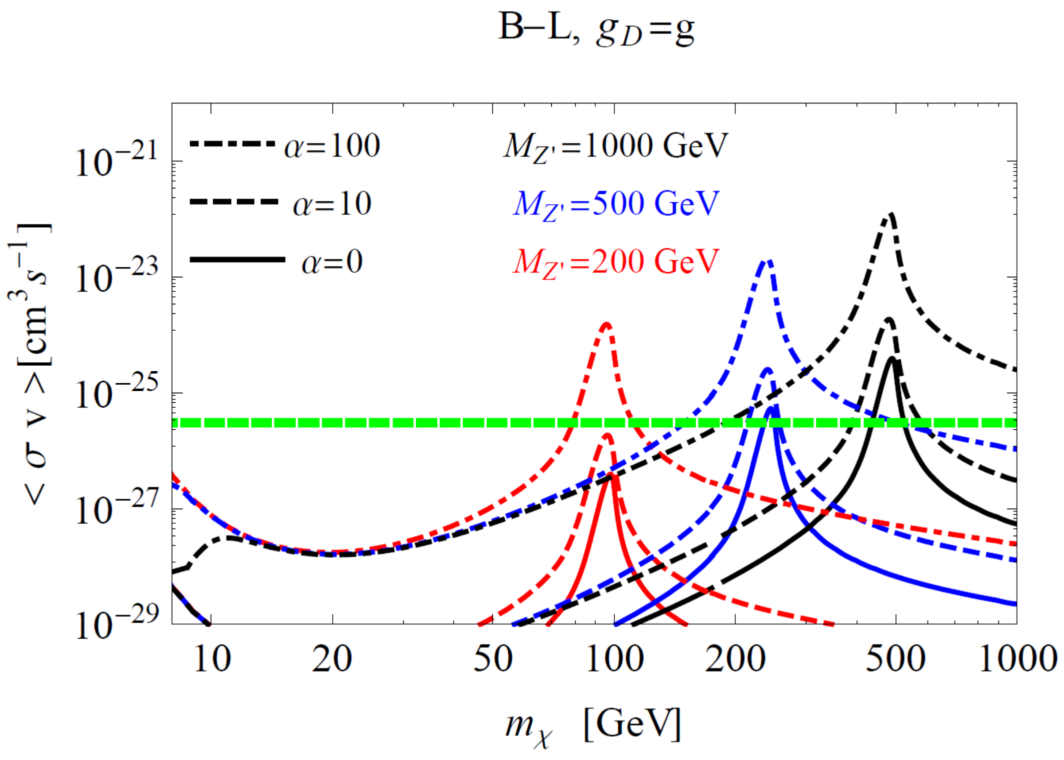


Thermal value

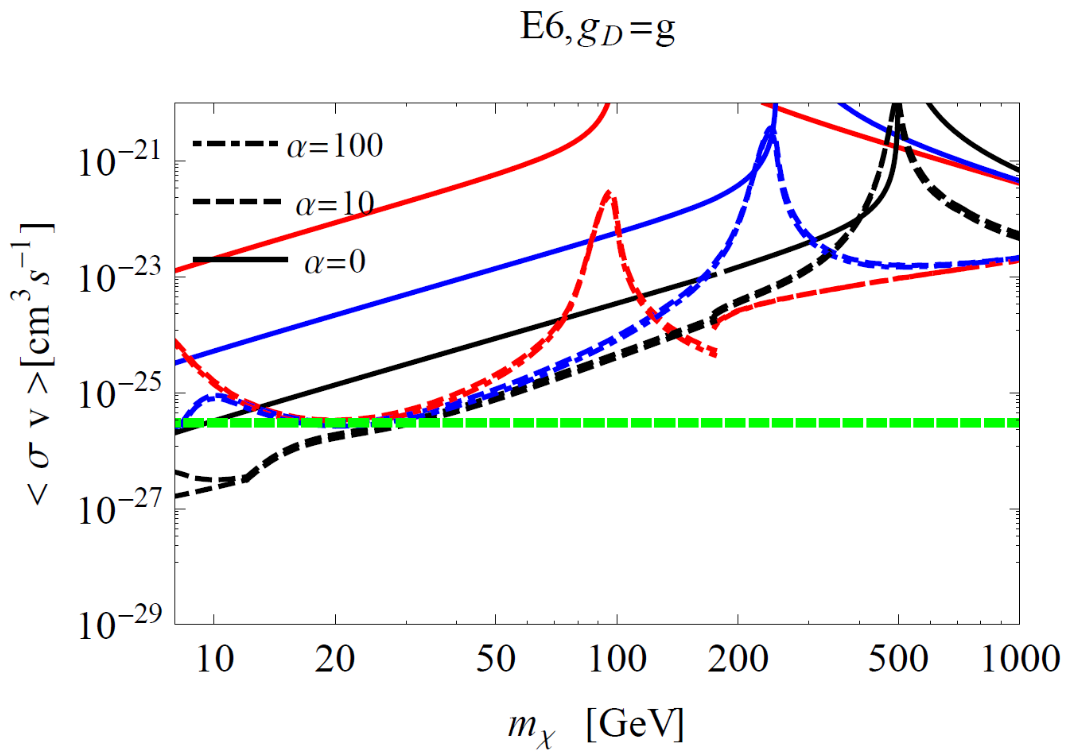
Only axial couplings



Couplings close of above perturbativity limit



B–L, g_D=g
α=100
α=10
α=0
$M_{Z'}$=1000 GeV
$M_{Z'}$=500 GeV
$M_{Z'}$=200 GeV
10^{-21}
10^{-23}
10^{-25}
10^{-27}
10^{-29}
10
20
50
100
200
500
1000
m_χ [GeV]
$<\sigma v>[cm^3 s^{-1}]$



E6, g_D=g
α=100
α=10
α=0
10^{-21}
10^{-23}
10^{-25}
10^{-27}
10^{-29}
10
20
50
100
200
500
1000
m_χ [GeV]
$<\sigma v>[cm^3 s^{-1}]$

Conclusions

We have considered the correlation between Dark Matter Direct Detection and LHC signals in a generic scenario featuring a Z´ boson coupled with SM fermion and a DM dirac fermion.

In the case of a (dark) sequential standard model an electroweak scale DM is excluded for masses of the Z´below 2 TeV (weaker bounds might be obtained for other assignments of the couplings).

Future extensions:

Correlation with monojet searches

Add information from DM relic density

Indirect Detection