Modelli Teorici di Dark Matter

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invisibles
neutrinos, dark matter & dark energy physics

PEOPLE

PARTICLE DM

Dark Matter is one of the building blocks of the Standard Cosmological model.
Contributes to around 27% of the energy budget of the Universe.
Evidences from astrophysics and cosmology.

Stable on cosmological scales.
Weakly or SuperWeakly interacting with ordinary matter, photons.
Cold (up to warm) as opposed to hot.

No (confirmed) detection so far.

DM CANDIDATES

Neither the particle nature nor the DM generation mechanims have been identified.

Many candidates proposed:

- Weakly Interacting Massive Particles (WIMPs)
- SuperWIMPs
- Feebly Interacting Massive Particles (FIMPs)
- Sterile Neutrinos (WDM)
- Asymmetryc DM
- Non-thermal DM
- Axion/Axinos
- Self-Interacting Dark Matter (SIMPs)

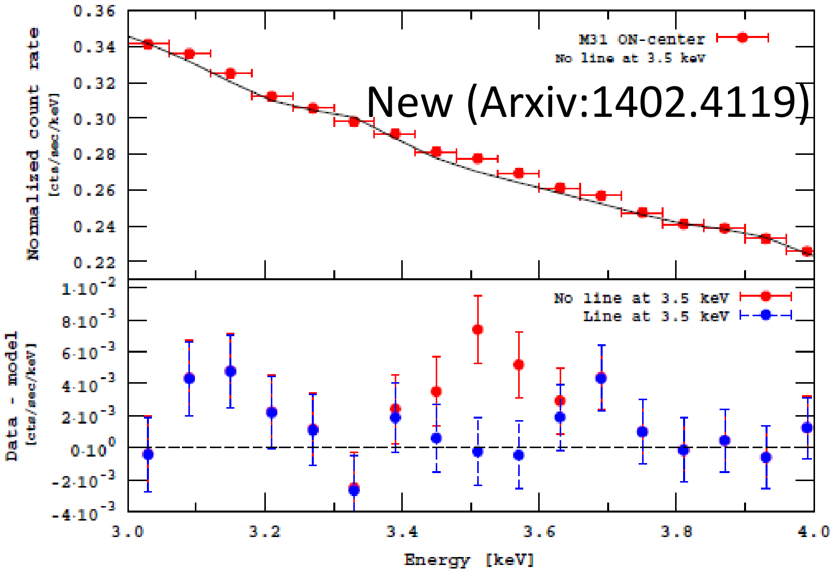
DM Searches

Three, possibly complementary, kinds of DM searches:

Indirect Detection (ID)

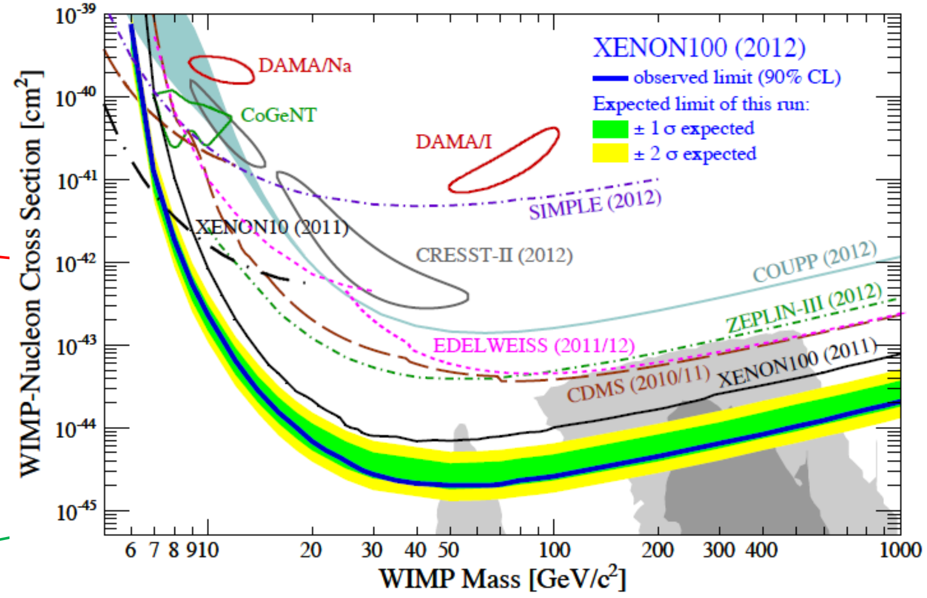
Fermi, Pamela, AMS-02, H.E.S.S.
Chandra, XMM

New (Arxiv:1402.4119)



Direct Detection (DD)

XENON, DAMA-LIBRA, COGENT, CRESST,
LUX, SuperCDMS



Collider

LHC

INTERPLAY BETWEEN DM SEARCHES AND LHC

Correlation between Dark Matter Direct/Indirect detection and searches of new physics at the LHC

Possible strategies:

Simple (Simplified) models

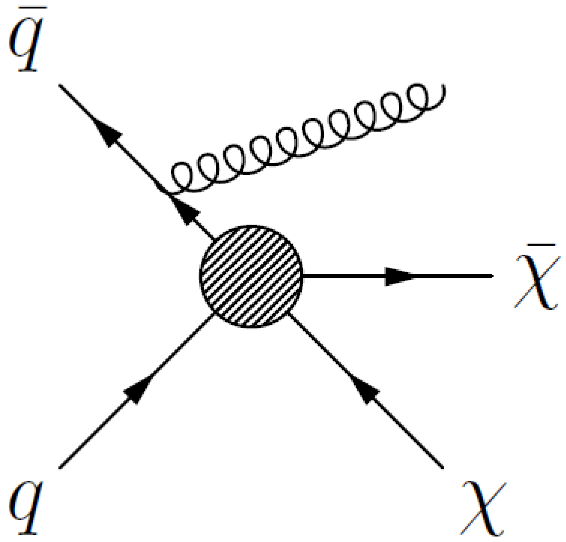
General but often non satisfactory.

Specific models

Better motivated but require dedicated studies.

DM at LHC

DM can be pair produced at collider and detected in events with missing energy + one jet.



Results normally interpreted in terms of effective operators.

$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2},$$

$$\mathcal{O}_A = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2},$$

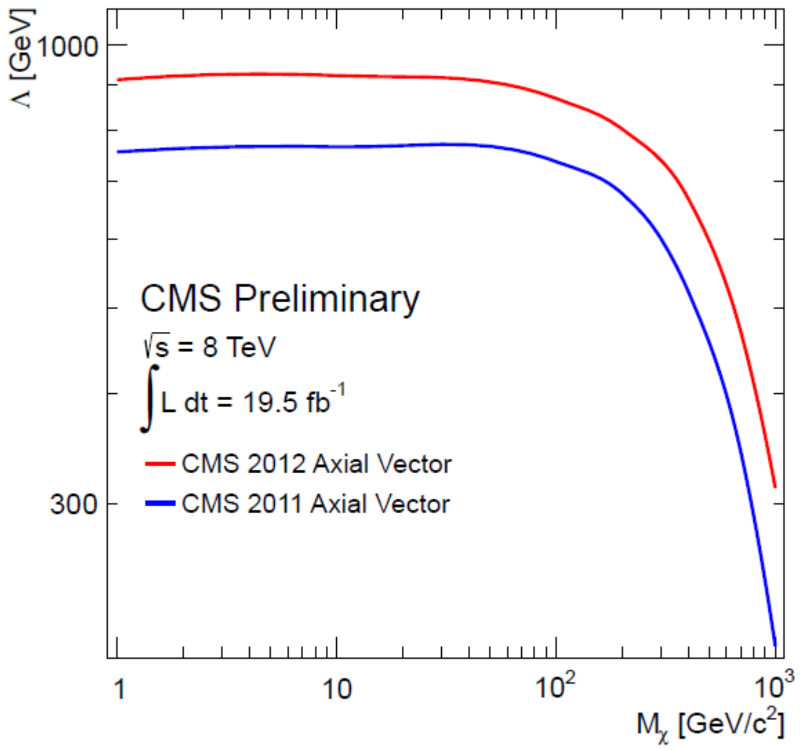
$$\mathcal{O}_t = \frac{(\bar{\chi}P_R q)(\bar{q}P_L\chi)}{\Lambda^2} + (L \leftrightarrow R),$$

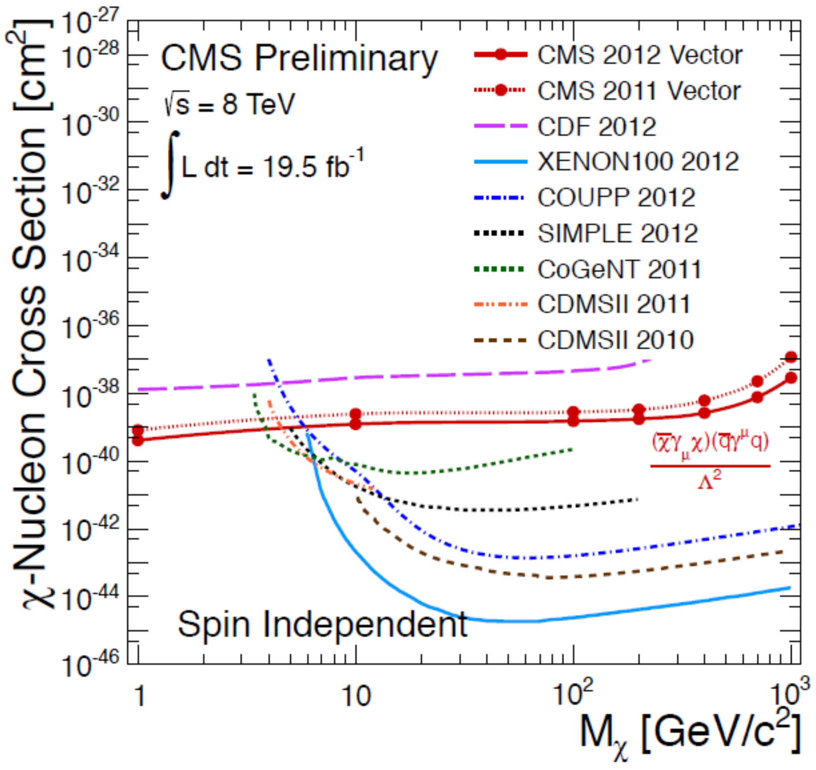
$$\mathcal{O}_g = \alpha_s \frac{(\bar{\chi}\chi)\,(G^a_{\mu\nu}G^{a\mu\nu})}{\Lambda^3}$$

Fox et al., arXiv:1109.4398

´Model Independent Analysis´.

Results can be straighforwardly correlated to limits from direct detection.





(CMS-EXO-18-48-PAS)

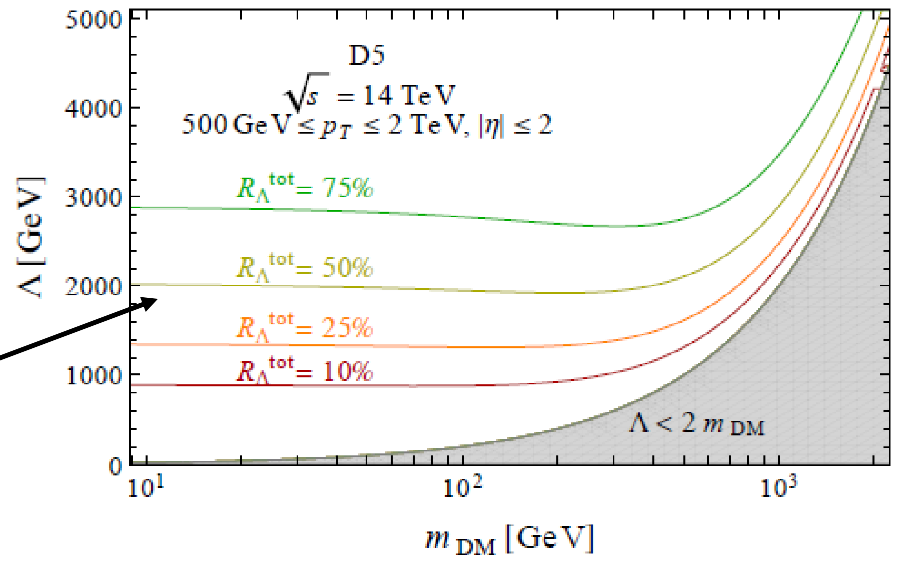
For many phenomenological setups effective operator description not satisfying (e.g. the mediator is accessible at the LHC). Refinement of theoretical framework needed.

$Q_{\rm tr} \lesssim \Lambda$

Momentum transfer

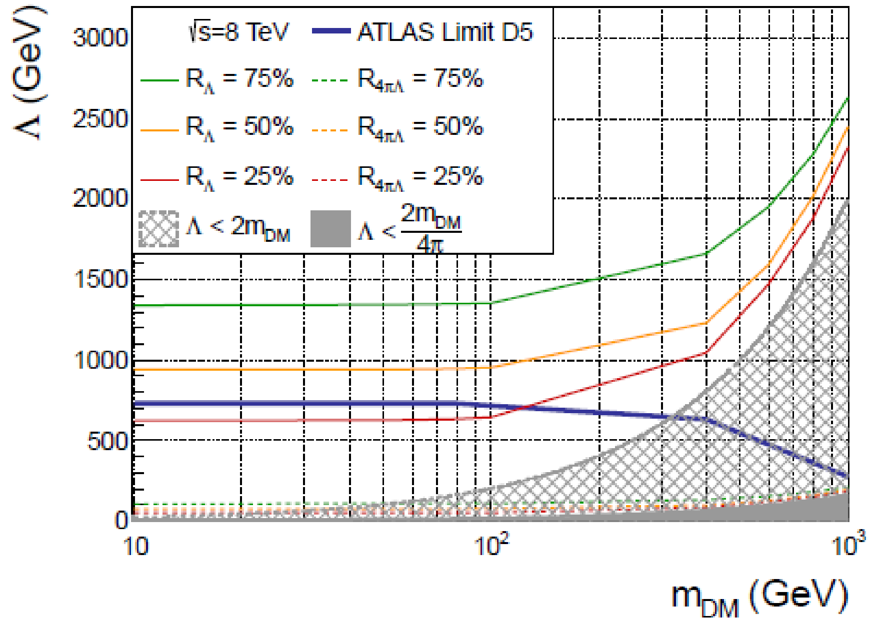
Name	Operator	Coefficient
D1	$\bar{\chi}\chi\ \bar{q}q$	m_q/Λ^3
D1’	$\bar{\chi}\chi\ \bar{q}q$	$1/\Lambda^2$
D2	$\bar{\chi}\gamma^5\chi\ \bar{q}q$	im_q/Λ^3
D2’	$\bar{\chi}\gamma^5\chi\ \bar{q}q$	i/Λ^2
D3	$\bar{\chi}\chi\ \bar{q}\gamma^5 q$	im_q/Λ^3
D3’	$\bar{\chi}\chi\ \bar{q}\gamma^5 q$	i/Λ^2
D4	$\bar{\chi}\gamma^5\chi\ \bar{q}\gamma^5 q$	m_q/Λ^3
D4’	$\bar{\chi}\gamma^5\chi\ \bar{q}\gamma^5 q$	$1/\Lambda^2$
D5	$\bar{\chi}\gamma_\mu\chi\ \bar{q}\gamma^\mu q$	$1/\Lambda^2$
D6	$\bar{\chi}\gamma_\mu\gamma^5\chi\ \bar{q}\gamma^\mu q$	$1/\Lambda^2$
D7	$\bar{\chi}\gamma_\mu\chi\ \bar{q}\gamma^\mu\gamma^5 q$	$1/\Lambda^2$
D8	$\bar{\chi}\gamma_\mu\gamma^5\chi\ \bar{q}\gamma^\mu\gamma^5 q$	$1/\Lambda^2$
D9	$\bar{\chi}\sigma_{\mu\nu}\chi\ \bar{q}\sigma^{\mu\nu} q$	$1/\Lambda^2$
D10	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\ \bar{q}\sigma^{\mu\nu} q$	i/Λ^2
D11	$\bar{\chi}\chi\ G^{\mu\nu}G_{\mu\nu}$	$\alpha_s/4\Lambda^3$
D12	$\bar{\chi}\gamma^5\chi\ G^{\mu\nu}G_{\mu\nu}$	$i\alpha_s/4\Lambda^3$
D13	$\bar{\chi}\chi\ G^{\mu\nu}\tilde{G}_{\mu\nu}$	$i\alpha_s/4\Lambda^3$
D14	$\bar{\chi}\gamma^5\chi\ G^{\mu\nu}\tilde{G}_{\mu\nu}$	$\alpha_s/4\Lambda^3$

Effective cross-section/real cross section

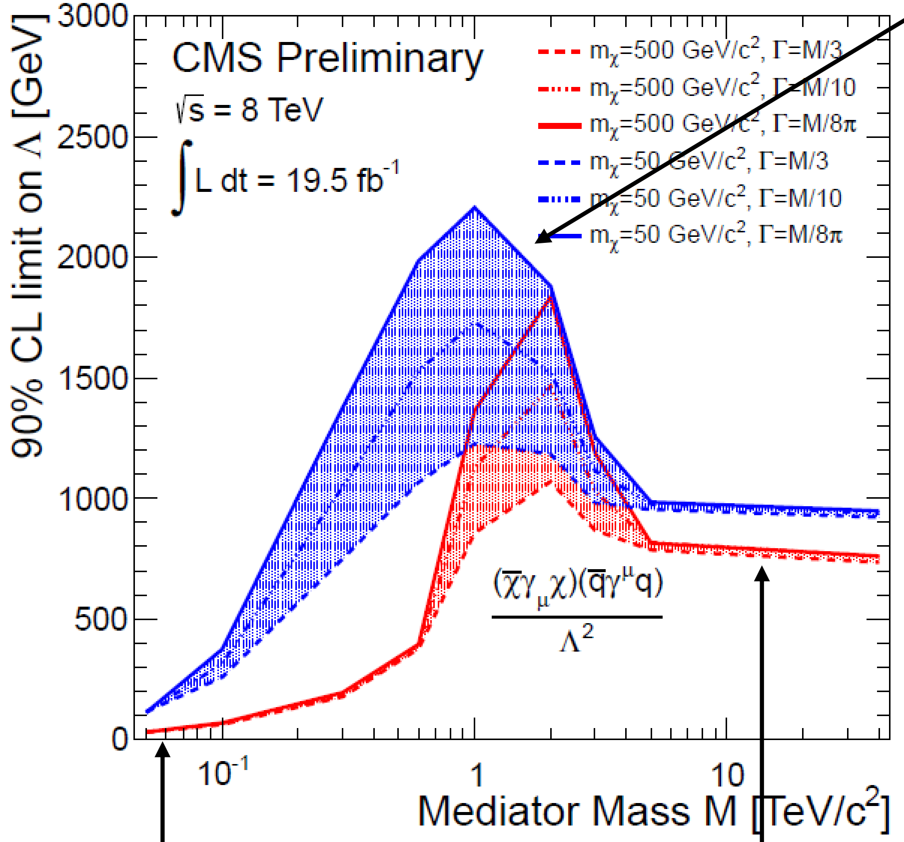


G. Busoni et al, arXiv:1402.1275

Experimental limits should be reformulated when accounting limitations of effective theory



Light mediator



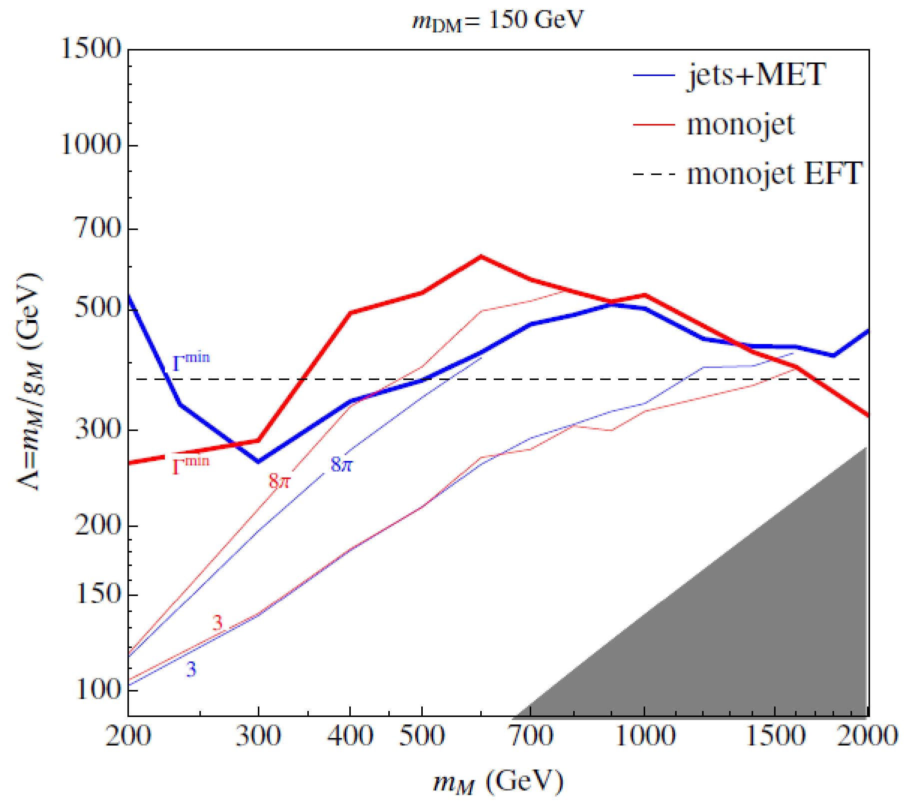
(CMS-EXO-18-48-PAS)

On-shell mediator production (stronger limit respect to EFT)

Cross-section reduced by analysis cut.

EFT limit

For light mediators there are complementary searches

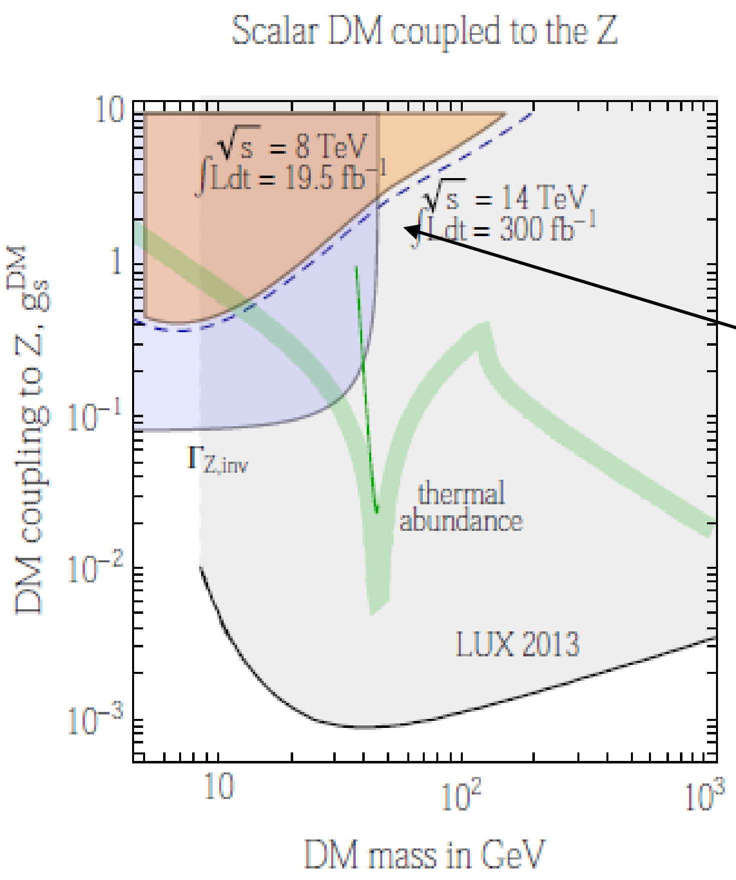


M. Papucci, A. Vichi and K. Zurek, arXiv:1402.2285

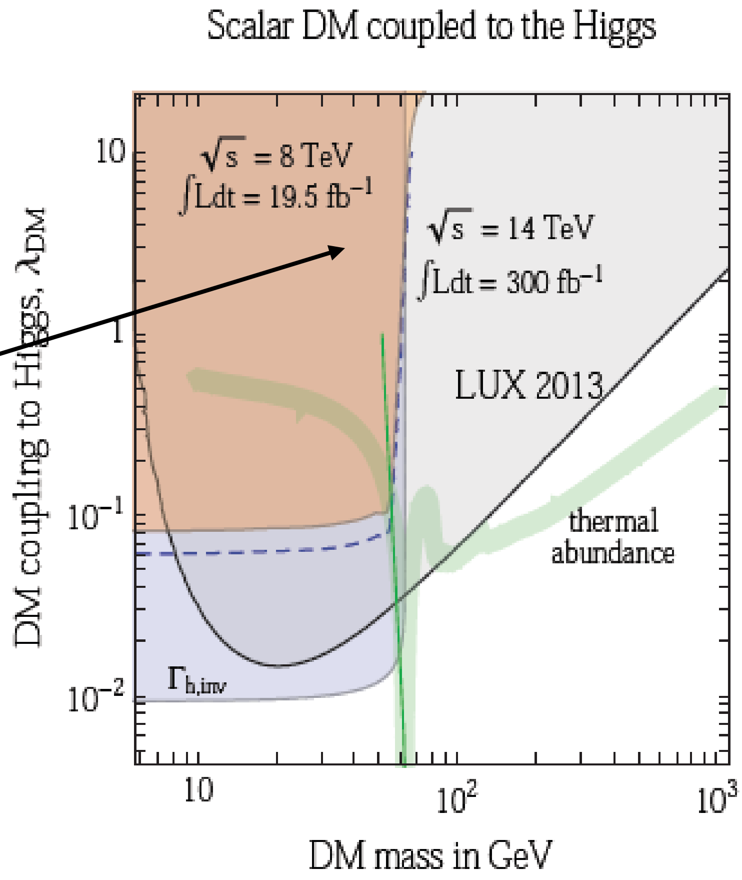
CONCRETE EXAMPLES:PORTAL MODELS

Minimal SM extension with DM coupled to the Z or Higgs boson

(A. De Simone, G. Giudice, A. Strumia arXiv:1402.6287)



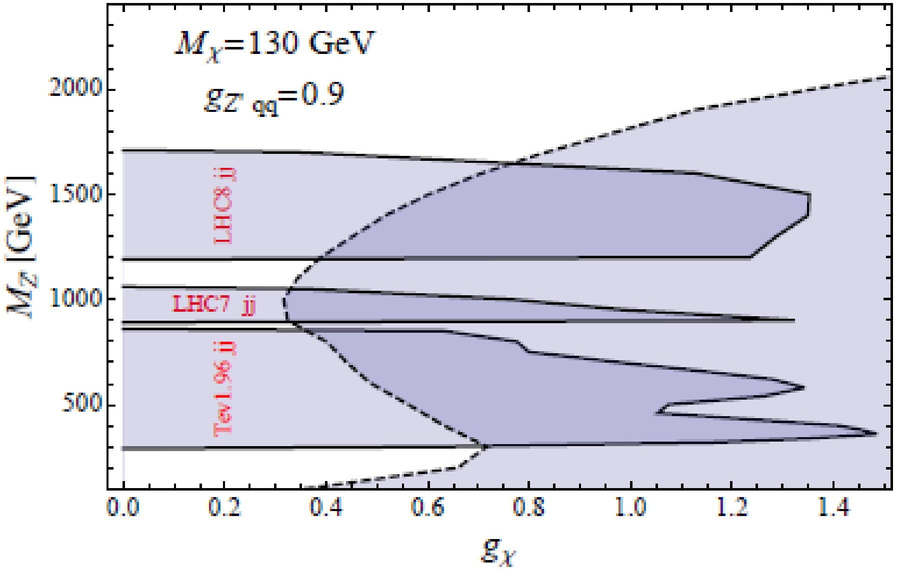
Monojet exclusion

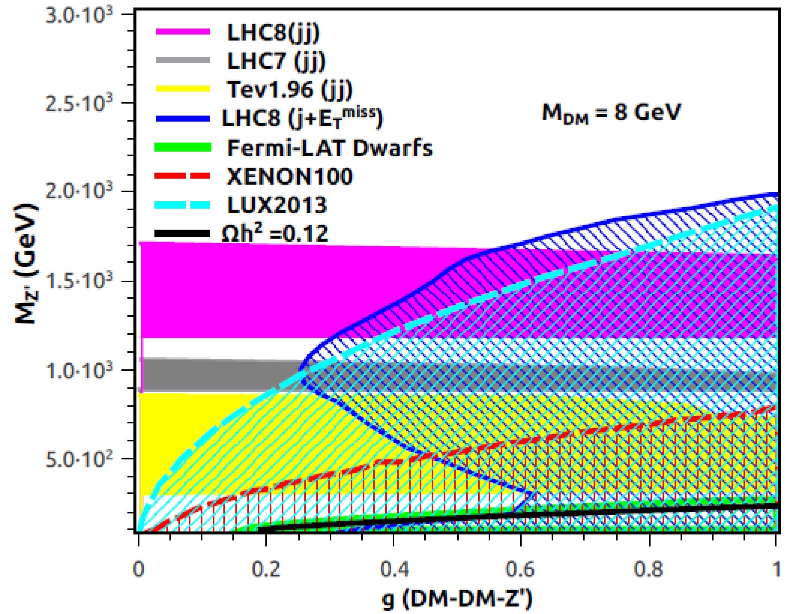


DARK Z´: LHC vs DM DETECTION

Leptophobic Z´

Alves, Profumo, Queiros (arXiv:1312.5281)





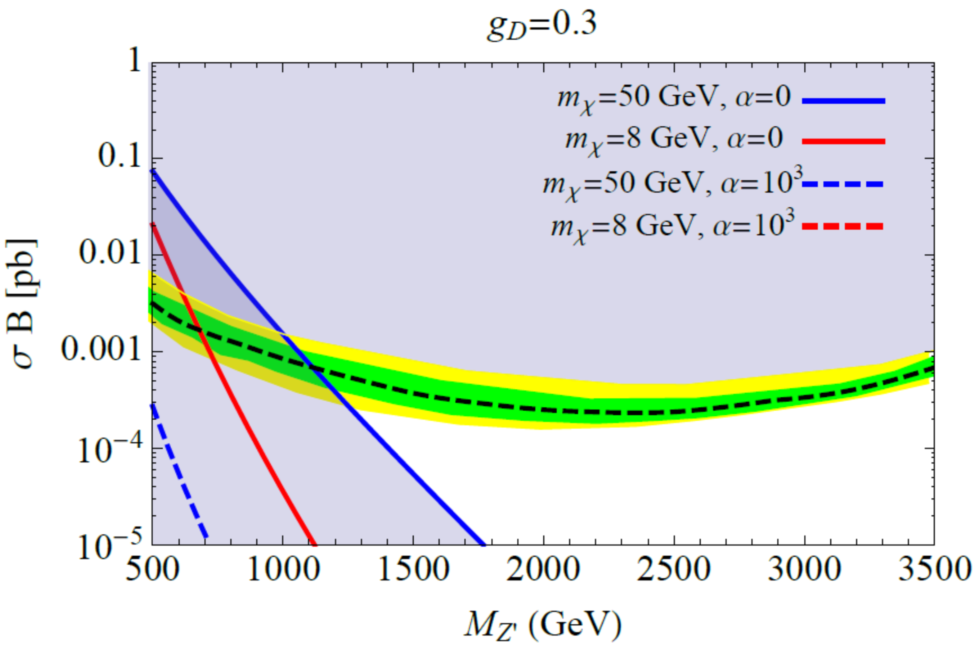
Correlation between diijet/monojet searches (according Z´ mass) and limits on spin-independent cross section.

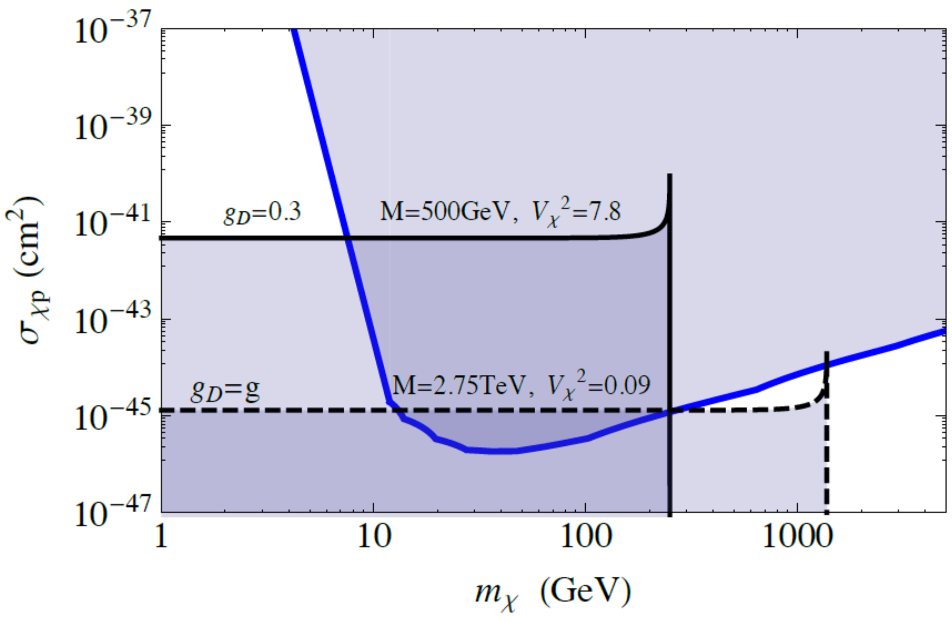
Generic Z´ portal

(G.A., Y. Mambrini, M. Tytgat, B. Zaldivar, arXiv:1401.0221)

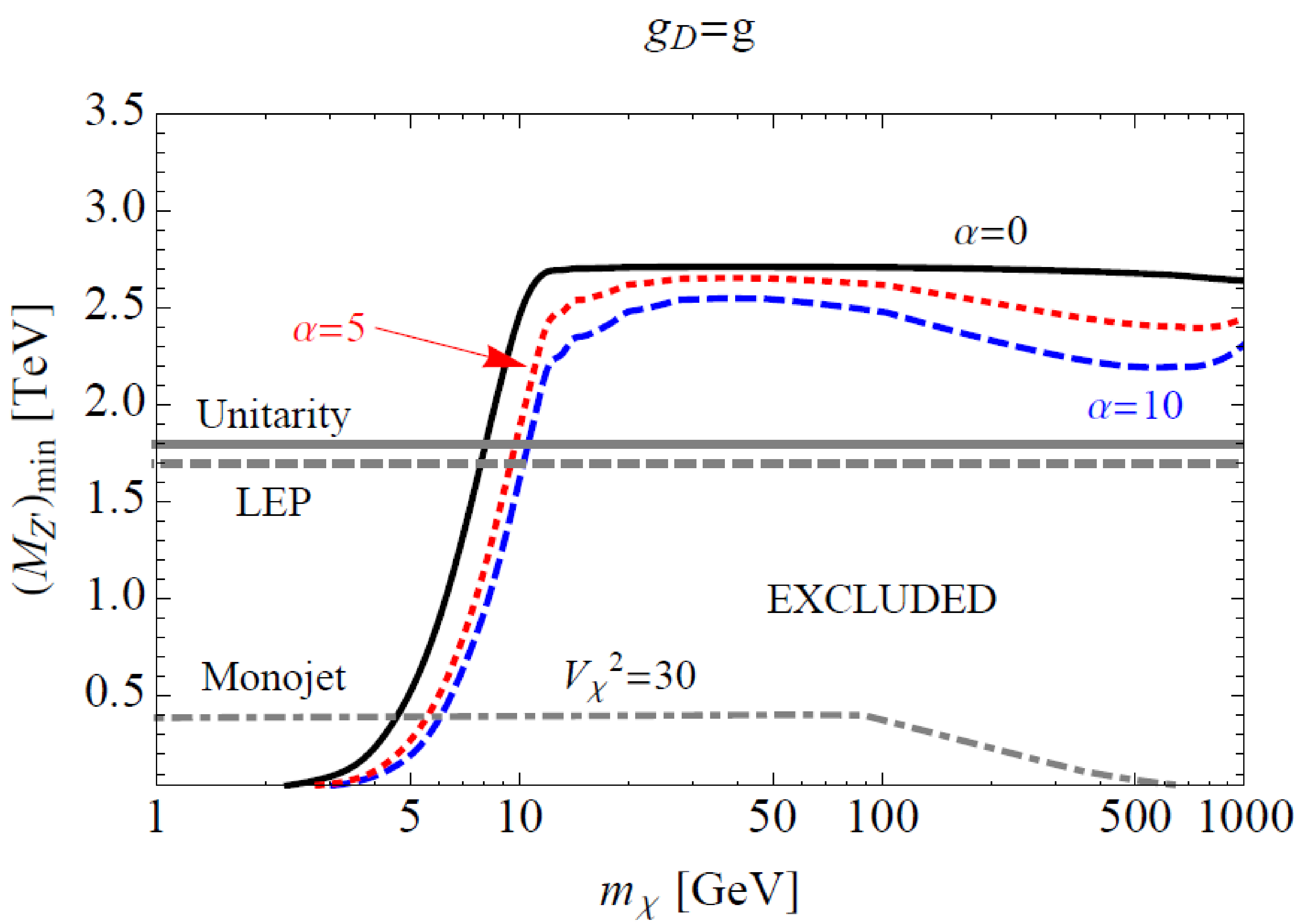
$$\Delta\mathcal{L} \supset \quad g_D \bar{\chi}\gamma^\mu \left(V_D^\chi - A_D^\chi \gamma^5\right) \chi \; Z'_\mu + g_D \sum_f \bar{f}\gamma^\mu \left(V_D^f - A_D^f \gamma^5\right) f \; Z'_\mu$$

$$\alpha = A_D^\chi / V_D^\chi$$





Correlation between dilepton/monojet searches and DD


g_D=g
3.5
3.0
2.5
2.0
1.5
1.0
0.5
$(M_{Z'})_{min}$ [TeV]
α=0
α=5
α=10
Unitarity
LEP
EXCLUDED
Monojet
V_χ^2=30
1
5
10
50
100
500
1000
m_χ [GeV]

LHC SIGNALS FOR FEEBLE/SUPERWEAK DM

Correct DM abundance can be achieved even for extremely weak interactions with SM/mediators:

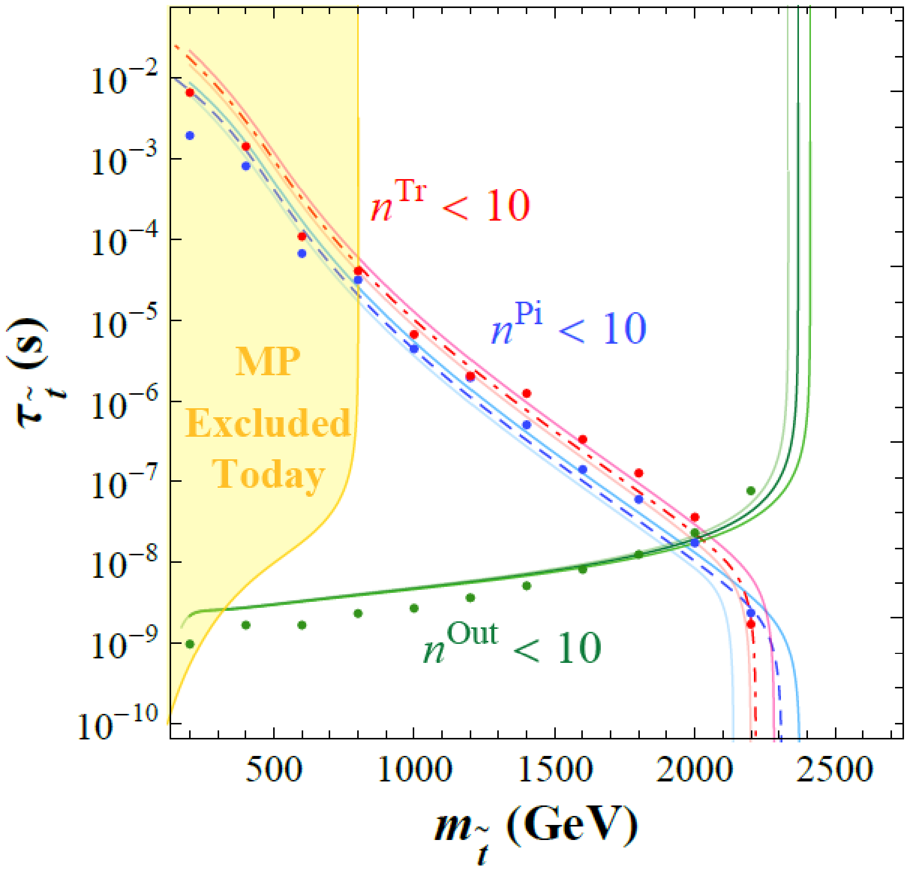
e.g.

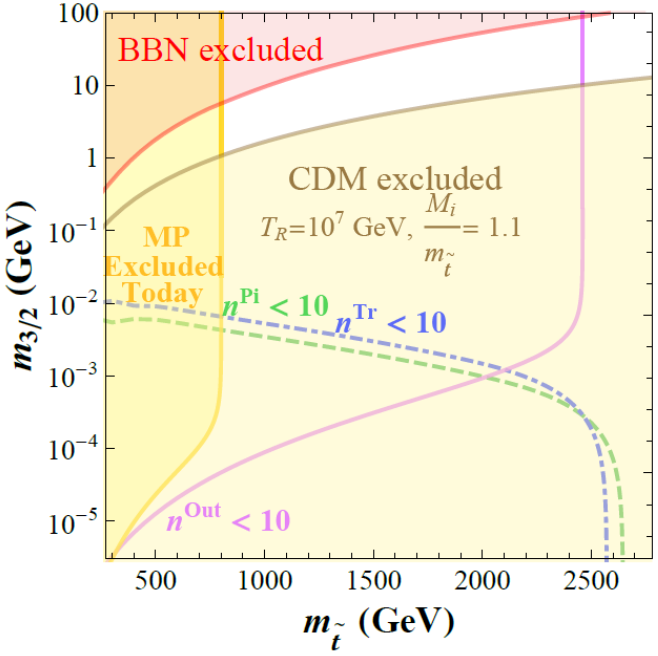
- Freeze-in production
- Production through thermal scatterings (Gravitino)
- Out-of-equilibrium production

LHC phenomenology altered with respect to conventional scenarios.
Appearence of displaced vertices and detector stable particles.

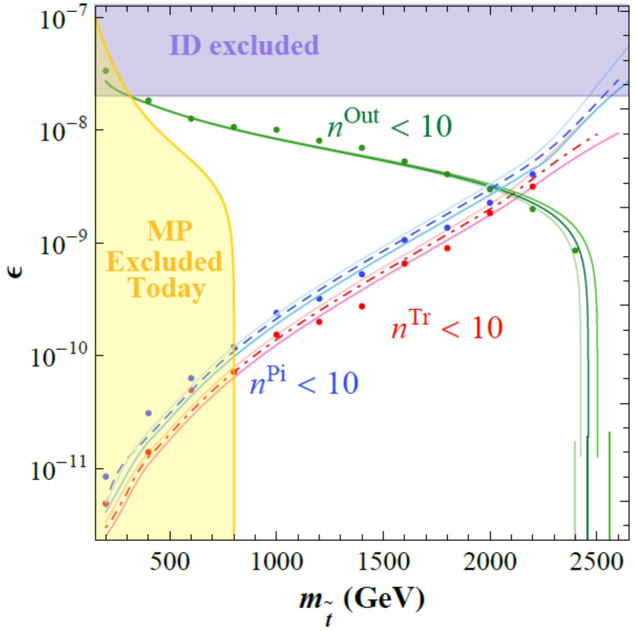
Long-lived stop at the LHC

(L. Covi and F. Dradi, arXiv:1403.4293)





RPC Scenario



RPV Scenario

INTERPLAY BETWEEN LHC AND DECAYING DM

G.A. and L. Covi, arXiv:1305.6587

$$L_{\rm eff} = \lambda_{\psi f L}\bar{\psi} f_L \Sigma_f^\dagger + \lambda_{\psi f R}\bar{\psi} f_R \Sigma_f^\dagger + h.c.$$

$$L_{\rm eff} = \lambda_d^{\prime} \bar{l}_R^c q_L \Sigma_d^\dagger + \lambda_d^{\prime\prime} \bar{u}_R d_L^c \Sigma_d^\dagger + h.c.$$

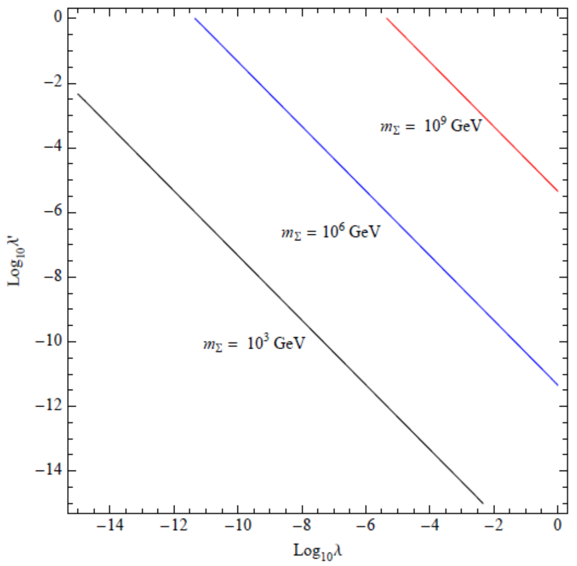
$$L_{\rm eff} = \lambda_u^{\prime\prime} \bar{d}_R d_L^c \Sigma_u^\dagger + h.c.$$

$$L_{\rm eff} = \lambda_q^{\prime} \bar{d}_R l_L \Sigma_q + h.c.$$

$$L_{\rm eff} = \lambda_e \bar{\nu}_L^c l_L \Sigma_e^\dagger + h.c.$$

$$L_{\rm eff} = \lambda_l \bar{e}_R l_L \Sigma_l + \lambda_l^{\prime} \bar{d}_R q_L \Sigma_l + h.c.$$

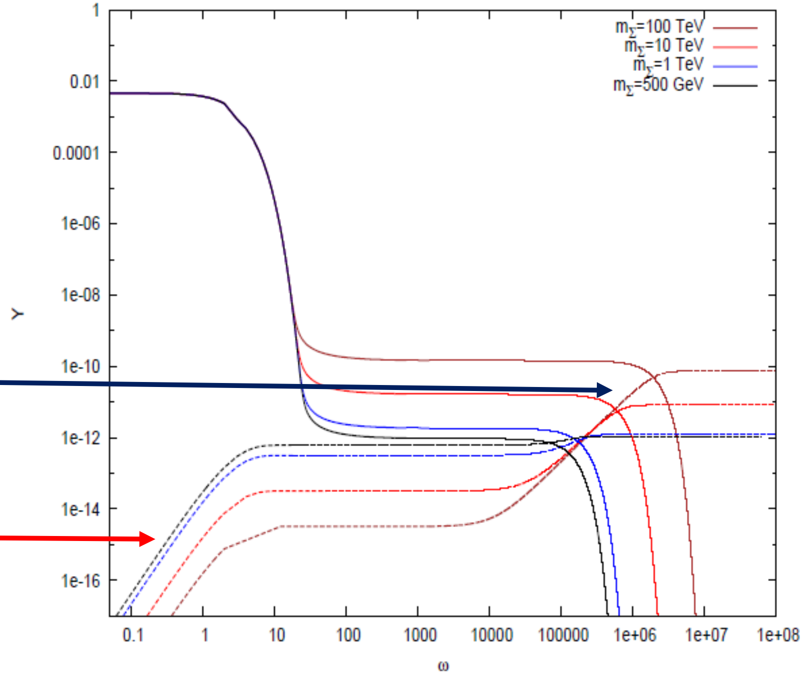
Couplings very suppressed by limits on DM ID.



DM relic density from:

Freeze-in: DM produced by interaction with particle species still in thermal equilibrium.
Example: DM produced by the decay of scalar field while still in thermal equilibrium. Relic density depends on the decay rate of the field into DM.

SuperWimp: DM produced out-of-equilibrium by a state after it has undergone conventional freeze-out. Relic density depends on the freeze-out abundance and the branching ratio of decay into DM.



SuperWimp

Freeze-in

The two mechanism act on different time scales. Relic density given by the sum of two contributions

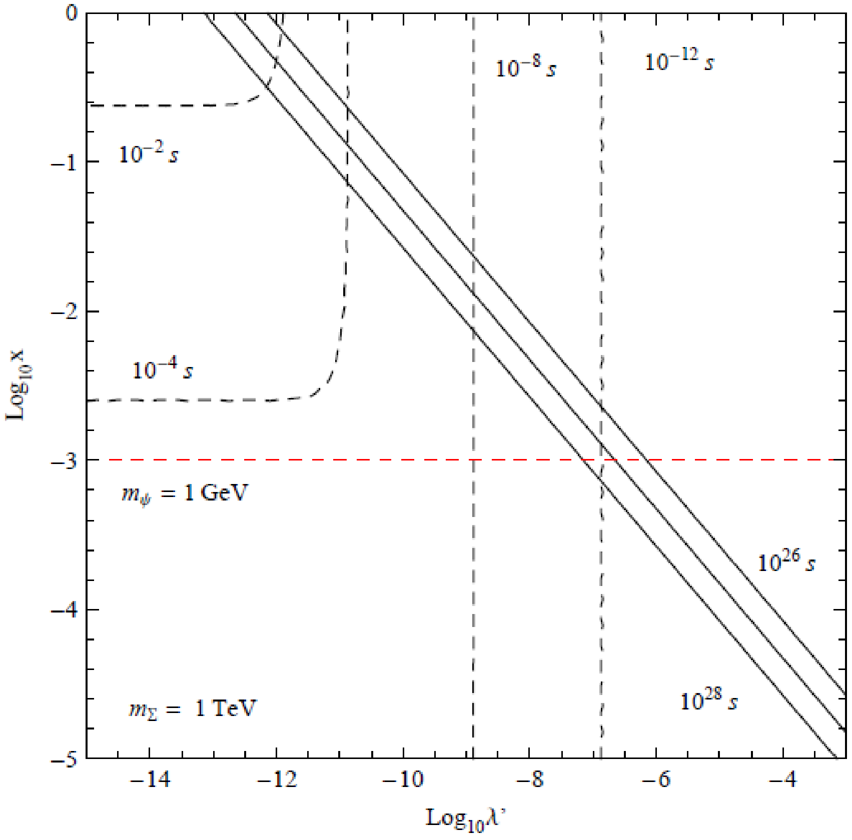
$$\Omega^{FI}h^2 = \frac{1.09 \times 10^{27} g_\Sigma}{g_*^{3/2}} \frac{m_\psi \Gamma(\Sigma_f \to \psi f)}{m_{\Sigma_f}^2}$$

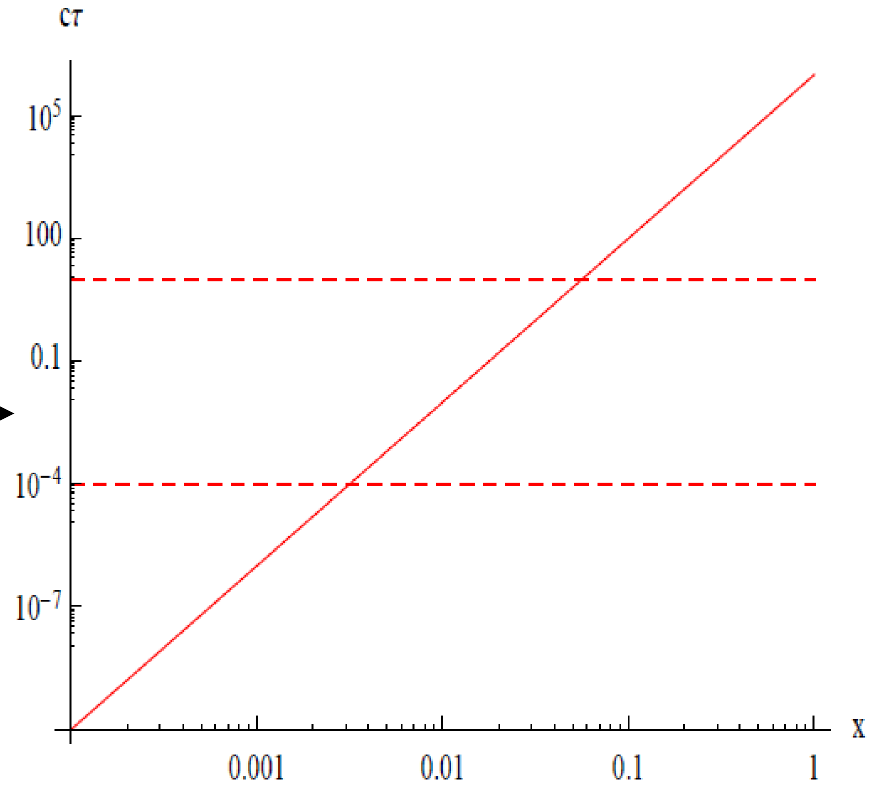
Hall et al, arXiv:0911.1120

$$\Omega_\psi^{SW} h^2 = x \, Br(\Sigma_f \to \psi + SM)\Omega_\Sigma h^2$$

$$x = m_\psi / m_{\Sigma_f}$$

Colored State (FIMP dominated)





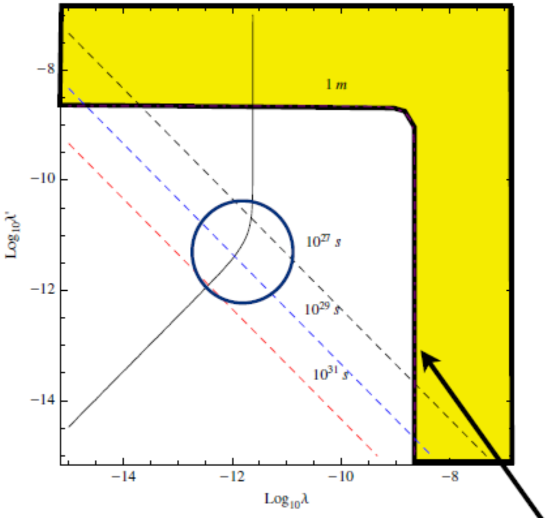
Detector Stable

Displaced vertices

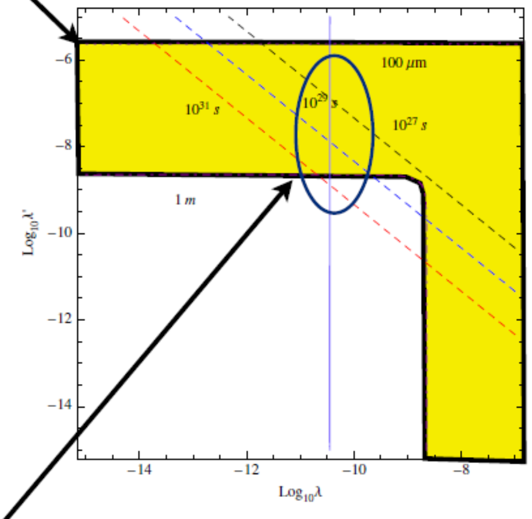
Prompt decays

Only EW charged field

Displaced vertex

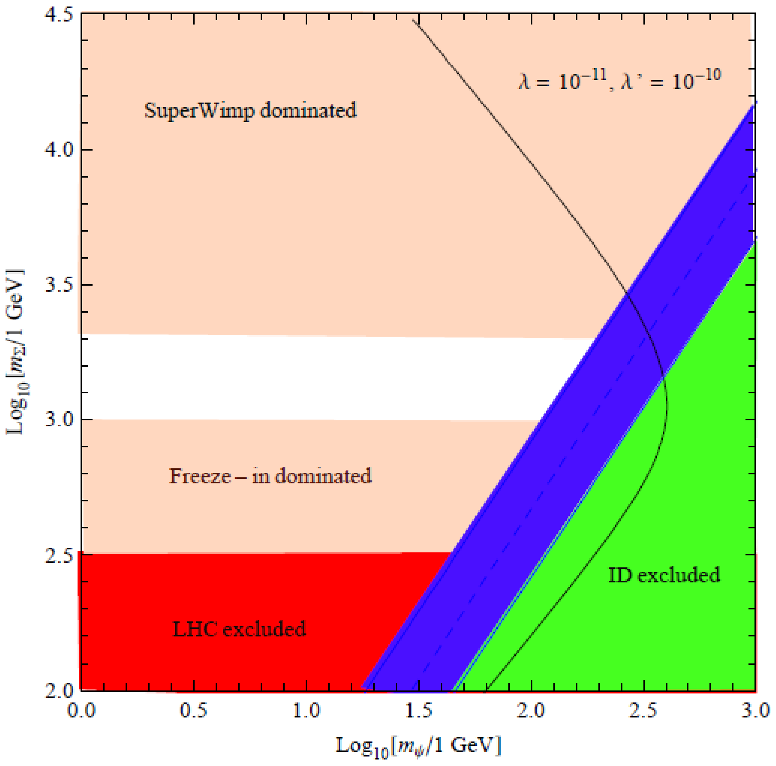


$x = 0.1$



$x = 0.001$

Scalar field decay length



CONCLUSIONS

The solution of the DM puzzle can be a guideline for the searches of New Physics.

Complementarity between different search strategies is a very powerful tool.

This is a crucial/exciting time for DM searches.

New theoretical efforts are required to face incoming experimental results.

GRAZIE

Back up

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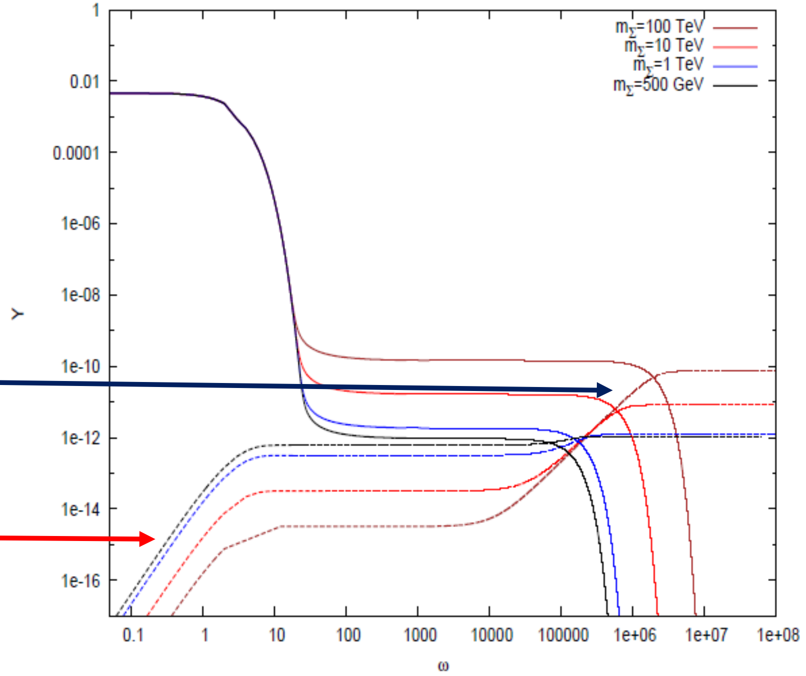
SuperWimp

Freeze-in



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