From an effective to a microscopic approach: The case of the Z'

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The effective approach

The effective approach

TENTATIVO DI UNA TEORIA DEI RAGGI β

Nota (1) di Enrico Fermi

Sunto. - *Si propone una teoria quantitativa dell'emissione dei raggi β in cui si ammette l'esistenza del «neutrino» e si tratta l'emissione degli elettroni e dei neutrini da un nucleo all'atto della disintegrazione β con un procedimento simile a quello seguito nella teoria dell'irradiazione per descrivere l'emissione di un quanto di luce da un atomo eccitato. Vengono dedotte delle formule per la vita media e per la forma dello spettro continuo dei raggi β, e le si confrontano coi dati sperimentali.*

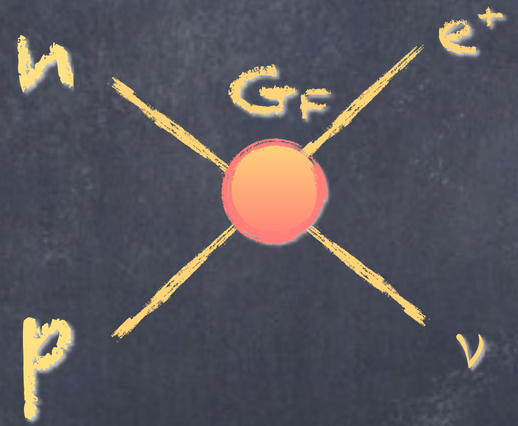
Ipotesi fondamentali della teoria.

§ 1. Nel tentativo di costruire una teoria degli elettroni nucleari e dell'emissione dei raggi β, si incontrano, come è noto, due difficoltà principali. La prima dipende dal fatto che i raggi β primari vengono emessi dai nuclei con una distribuzione continua di velocità. Se non si vuole abbandonare il principio della conservazione dell'energia, si deve ammettere perciò che una frazione dell'energia che si libera nel processo di disintegrazione β sfugga alle nostre attuali possibilità di osservazione. Secondo la proposta di Pauli si può p. es. ammettere l'esistenza di una nuova particella, il così detto «neutrino», avente carica elettrica nulla e massa dell'ordine di grandezza di quella dell'elettrone o minore. Si ammette poi che in ogni processo β vengano emessi simultaneamente un elettrone, che si osserva come raggio β, e un neutrino che sfugge all'osservazione portando seco una parte dell'energia. Nella presente teoria ci baseremo sopra l'ipotesi del neutrino.

Una seconda difficoltà per la teoria degli elettroni nucleari, dipende dal fatto che le attuali teorie relativistiche delle particelle leggere (elettroni o neutrini) non danno una soddisfacente spiegazione della possibilità che tali particelle vengano legate in orbite di dimensioni nucleari.

(1) Cfr. la nota preliminare in «La Ricerca Scientifica», 2, fasc. 12, 1933.

First approach used by Fermi[1] in 1933 to explain the β decay well before the discovery of neutral/charged currents in 1983. This was valid at the energies reachable at this time (much below the GeV scale)



$G_F = 10^{-5}\ GeV^{-2}$

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The effective approach

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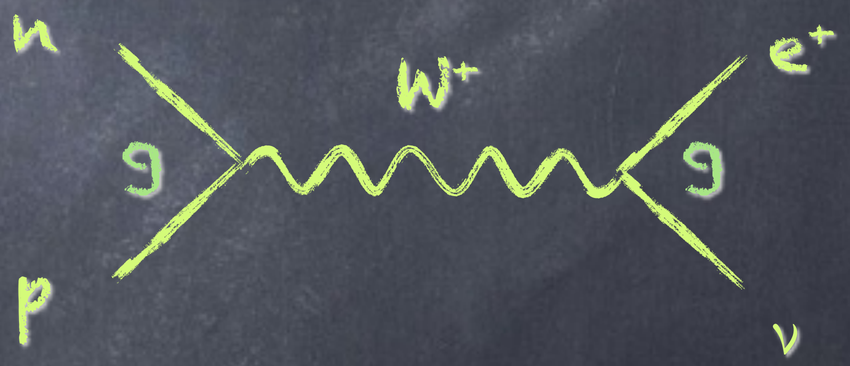
microscopic

→

approach



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$G_F \sim (g/M_W)^2$

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The effective approach applied to dark matter interaction

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operator	annihilation $\langle\sigma v\rangle$	direct detection [A,v_0]
$g\ \bar{\chi}\chi\bar{q}q$	$\propto g^2 v^2$ [$\bar{\chi}\chi$: S=1, L=1]	SI $\propto g^2 A^2 \times f^N(q)$
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$g = \frac{1}{\Lambda^2}$ (Effective approach)

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Scalar interaction (Higgs portal)

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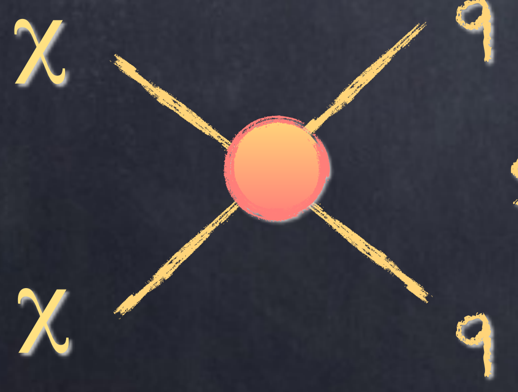

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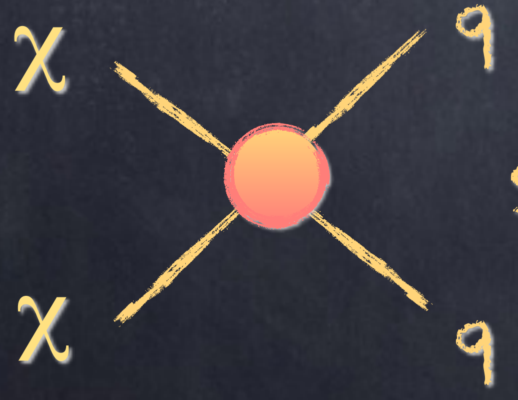

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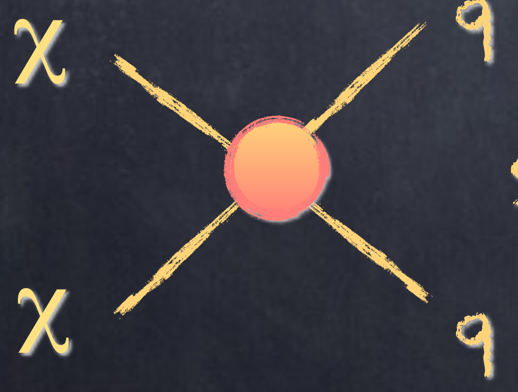

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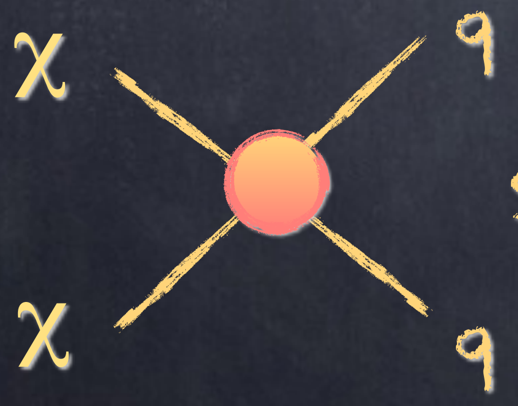

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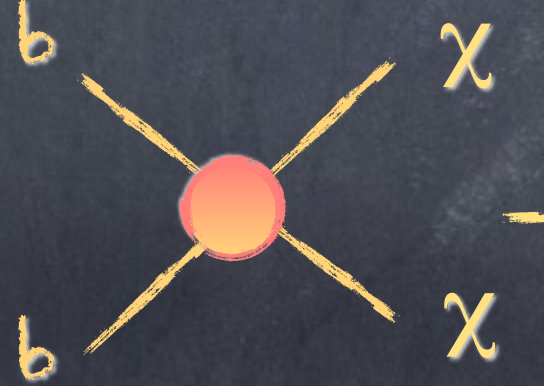

DM production at LHC (complementarity) (synergy) (multi-wavelength)

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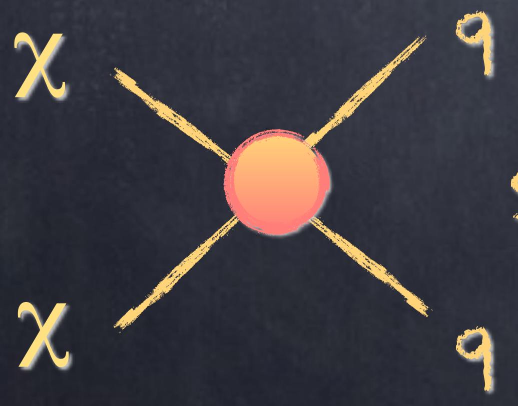

$g=\frac{1}{\Lambda^2}$ (Effective approach)

DM ... ction at LHC

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(multi-wavele... n)

Valid?

Limits of the effective theory approach

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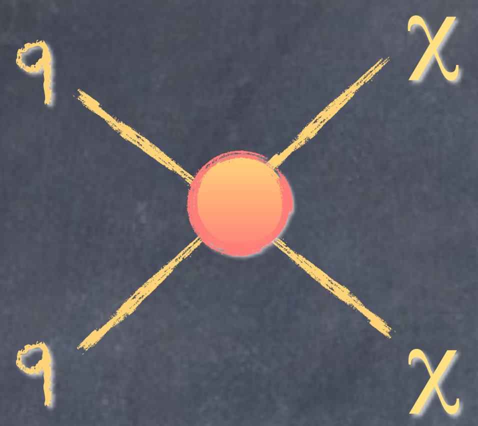
1)



$\frac{1}{\Lambda^2}$

Is it allowed to compute production rates at LHC with 14 TeV CoM energy ?

No if the effective BSM scale is below ~3 TeV (pole effects of a s-channel mediator increase largely the DM production [B. Zaldivar talk])

Limits of the effective theory approach

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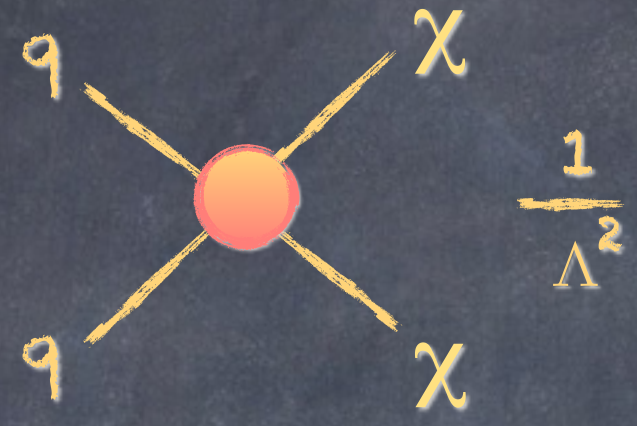

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2)

A typical example in the dark matter literature is the Lee-Weinberg bound that was over used some time ago (M_χ > 2-4 GeV).

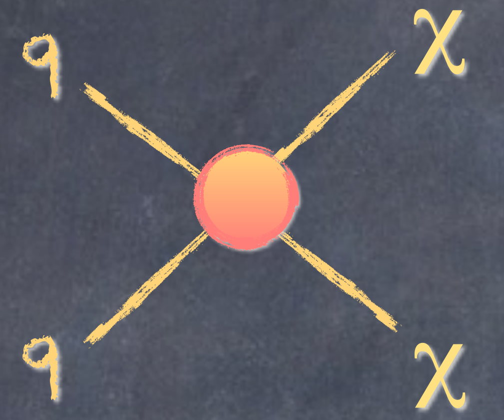
This bound is coming from the approximation

$\langle \sigma v \rangle \sim (G_F M_\chi)^2 > 10^{-9}\ \mathrm{GeV}^{-2}$ [WMAP]

This is not valid anymore in microscopic models, near the pole or if exchanging a light scalar/Z'... ($G_F \to G'_F$)

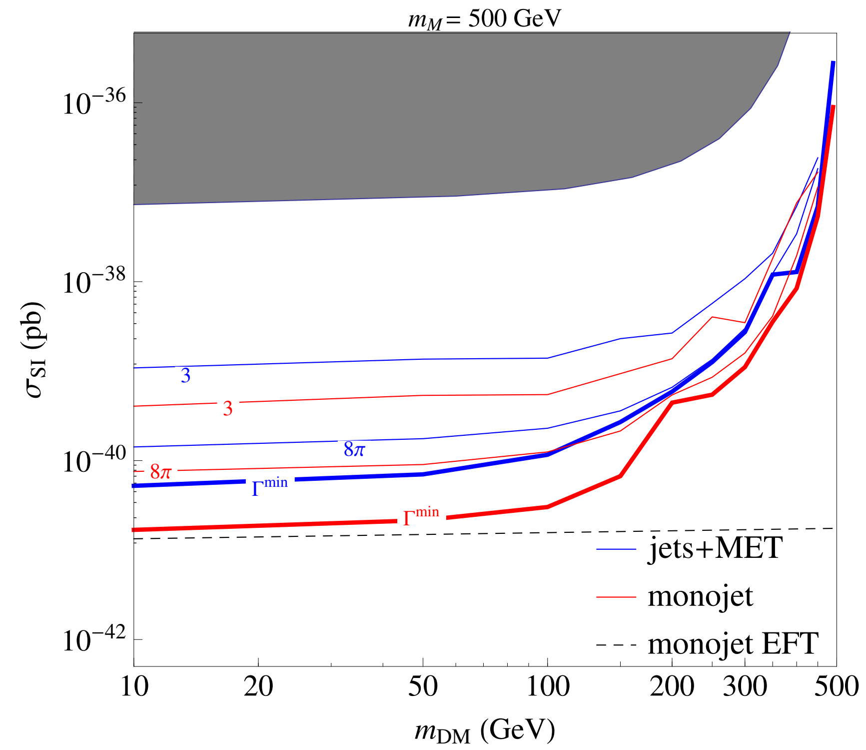
Limits of

1)



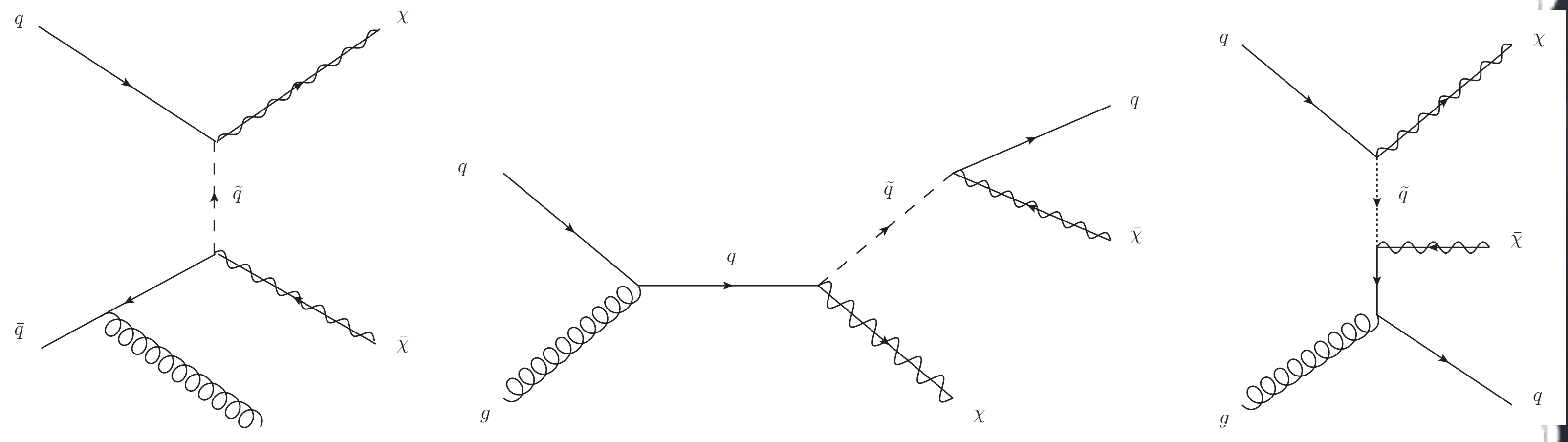
2)

3)

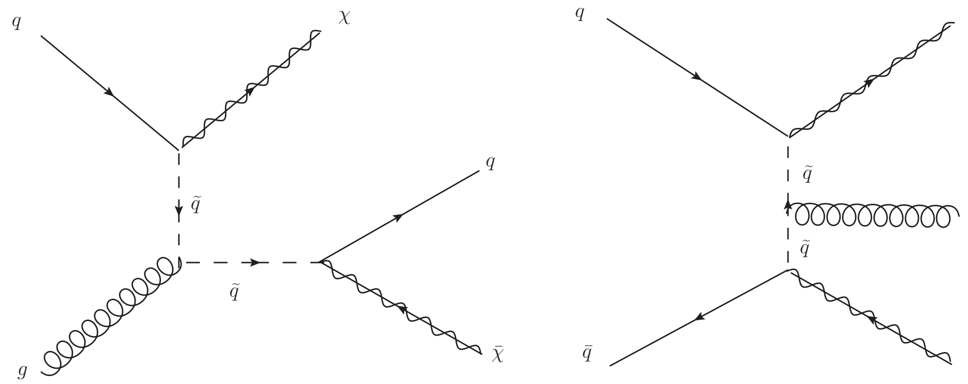


Limit of the approach

Papucci, Zurek [1402.2285]



(a) (b) (c)



Limits of

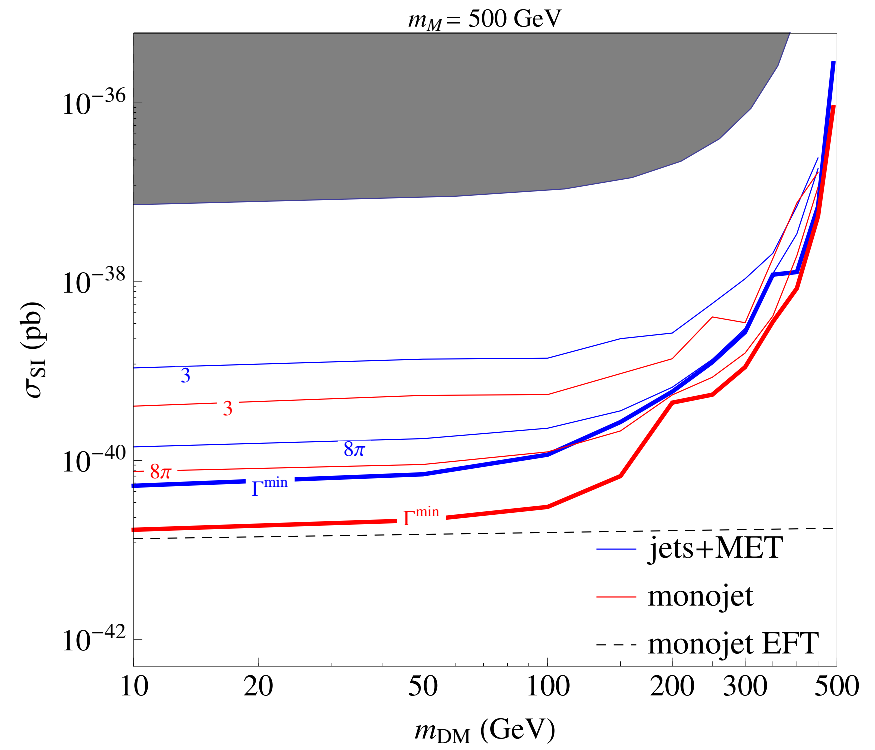
3)

Conclusion 1: the effective approach is not valid anymore in the energy range of interest at LHC !!!
One NEEDS to build microscopic extensions

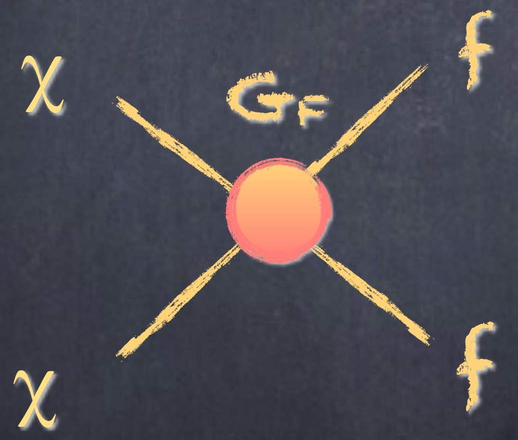
1)

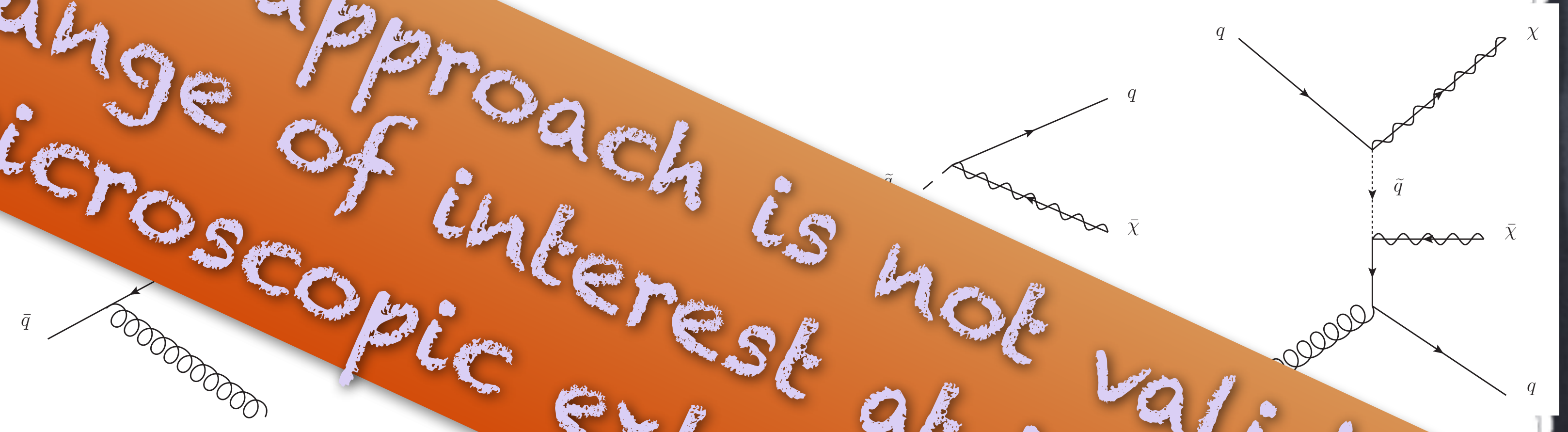
approach

2.2285]

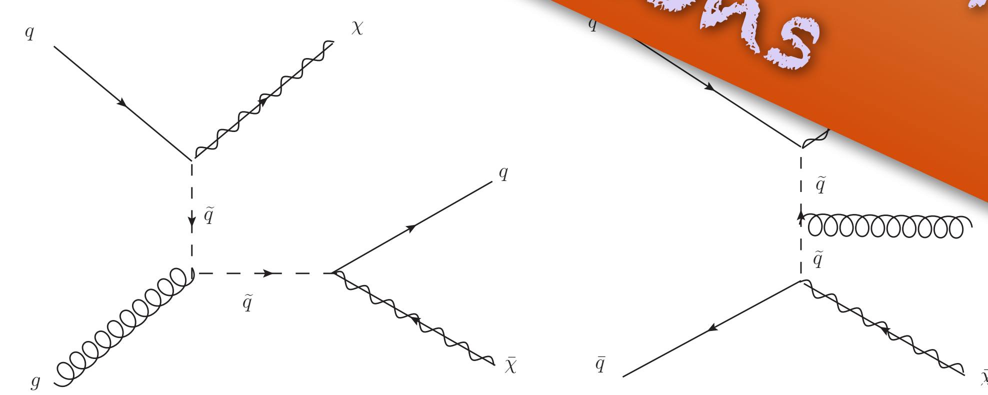


2)





(a)



« vices et vertues » of combined analysis

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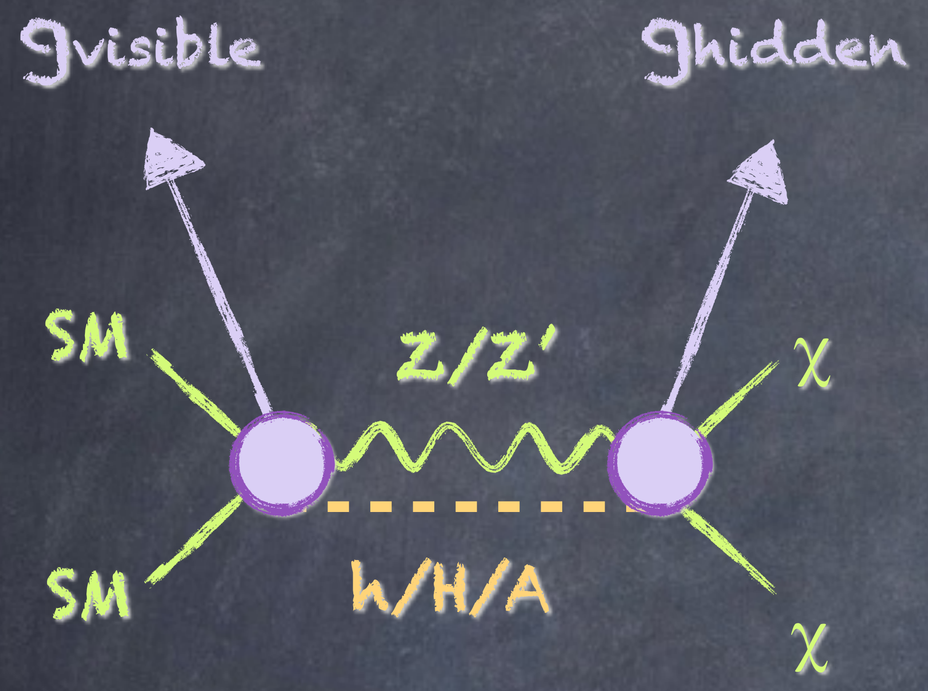
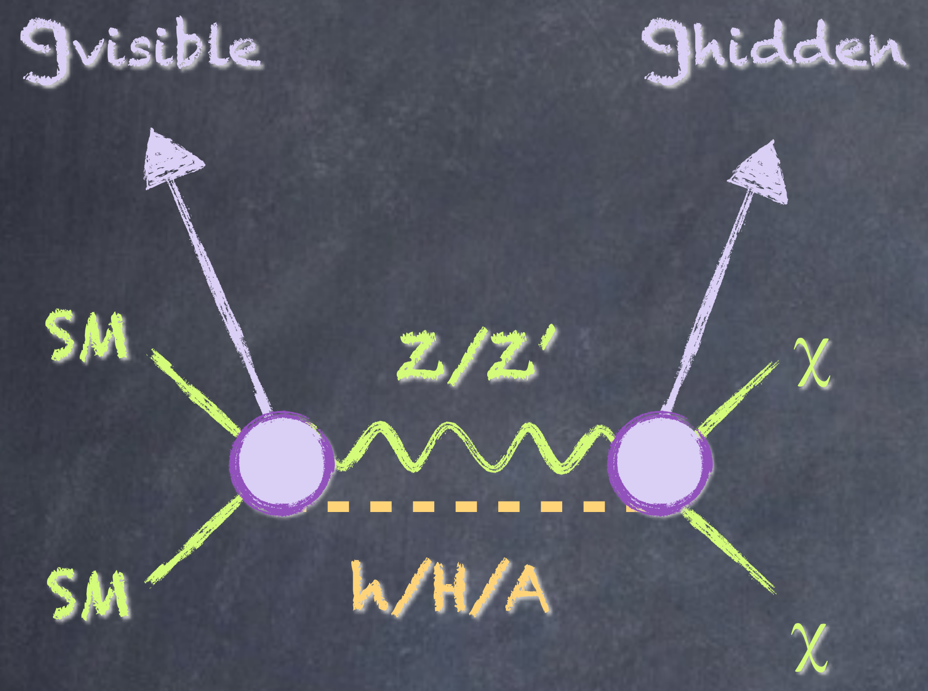


« vices et vertues » of combined analysis



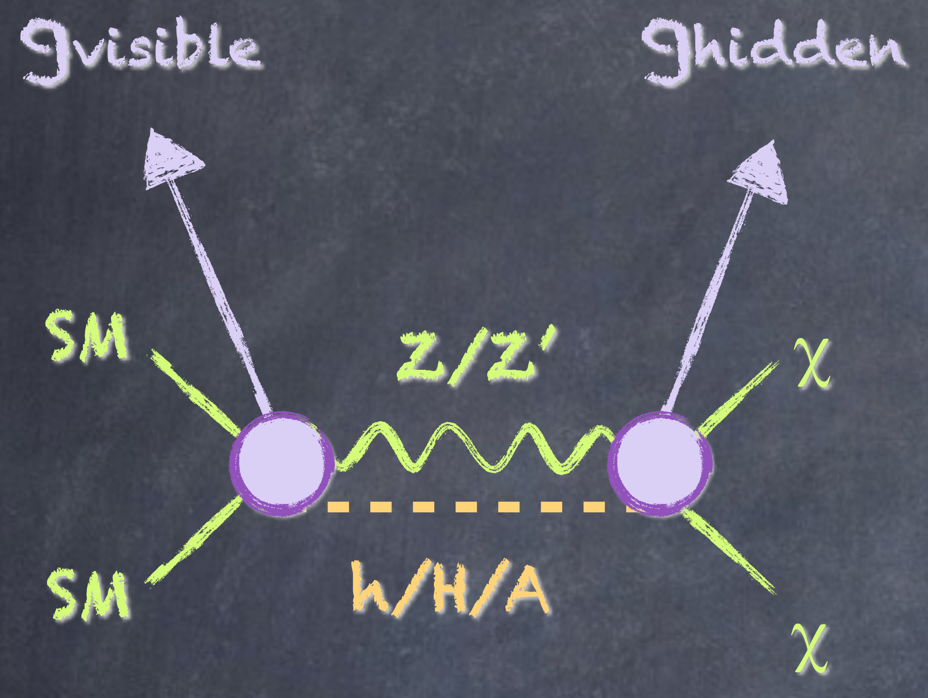
Tendencies:

Large $g_{visible}$ is strongly constrained by LHC

Large g_{hidden} is strongly constrained by DD experiments

Small $g_{visible}$ and g_{hidden} are strongly constrained by WMAP (overabundance)

« vices et vertues » of combined analysis



$\varepsilon \ll 1$

$g_{visible}$	g_{hidden}	DD	WMAP	LHC
1	1	✗	✓	✗
ε	1	✓	✓	✓
1	ε	✓	✓	✗
ε	ε	✓	✗	✓

Tendencies:

Large $g_{visible}$ is strongly constrained by LHC

Large g_{hidden} is strongly constrained by DD experiments

Small $g_{visible}$ and g_{hidden} are strongly constrained by WMAP (overabundance)

What are the possible mediators?

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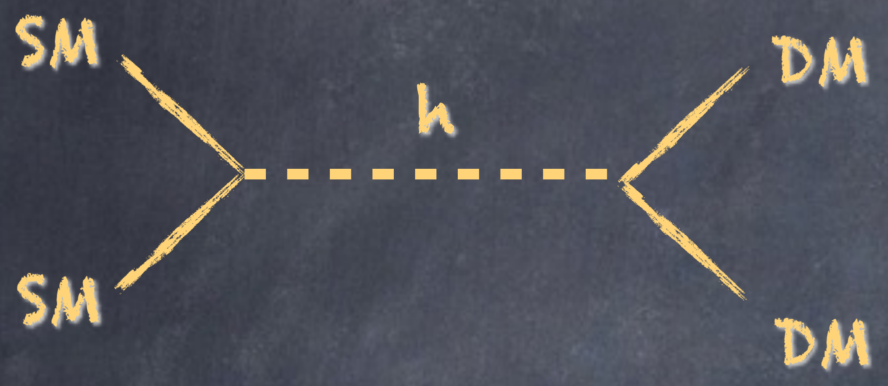

Higgs portal
darkons
phantom DM

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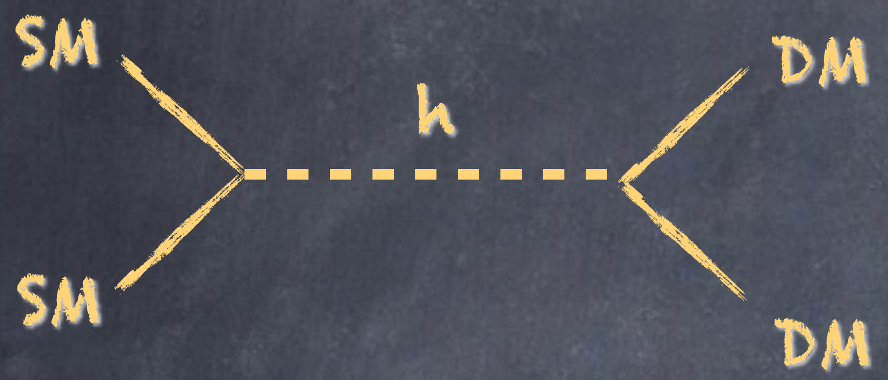

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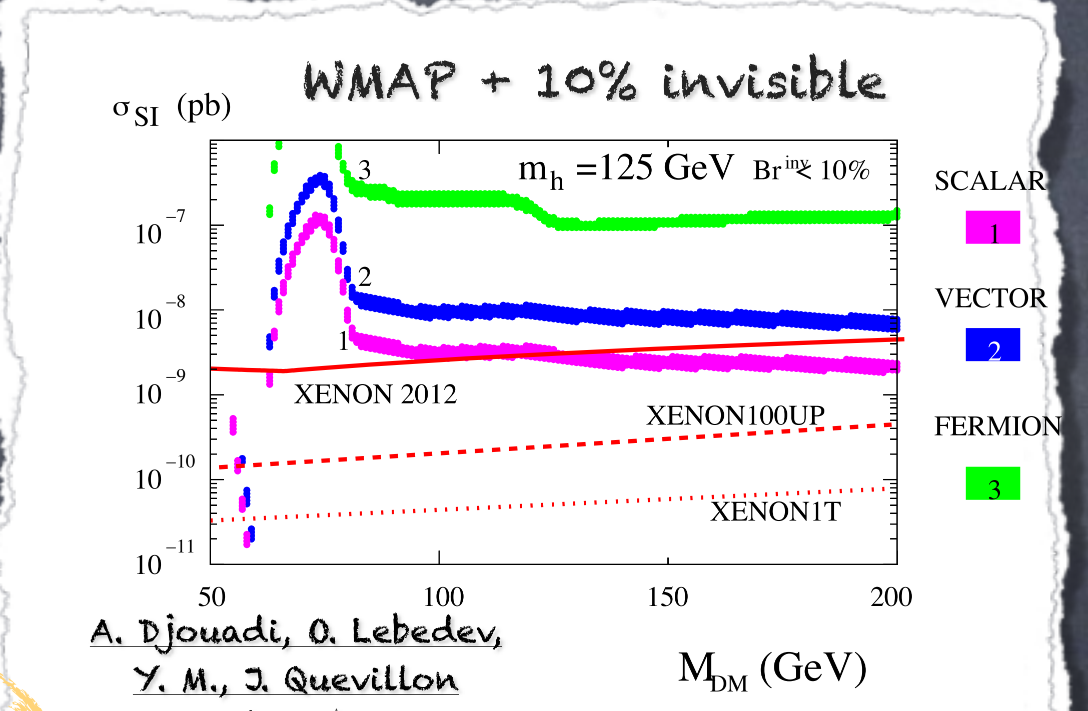
Excluded by direct detection of Dark Matter



A. Djouadi, O. Lebedev, Y. M., J. Quevillon (2012)

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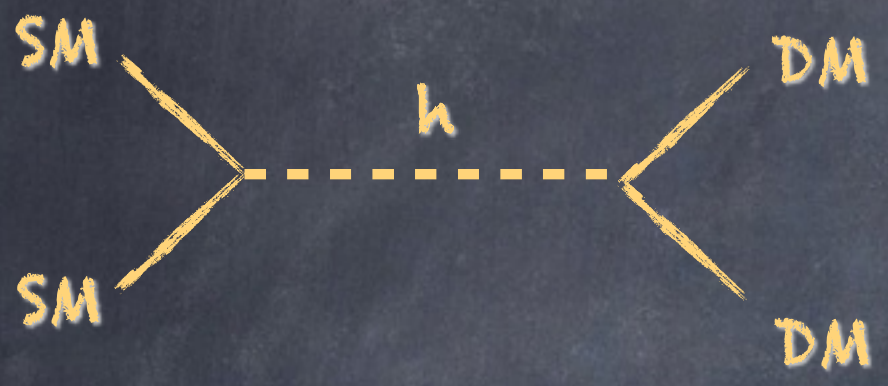

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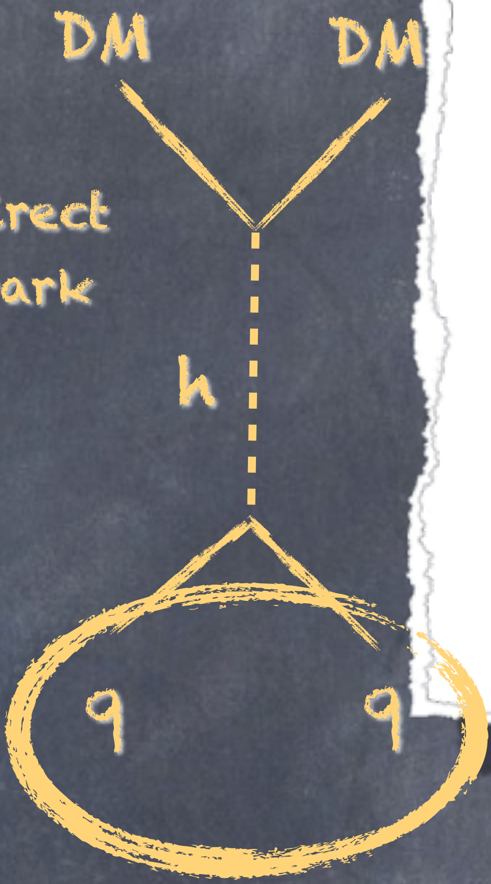

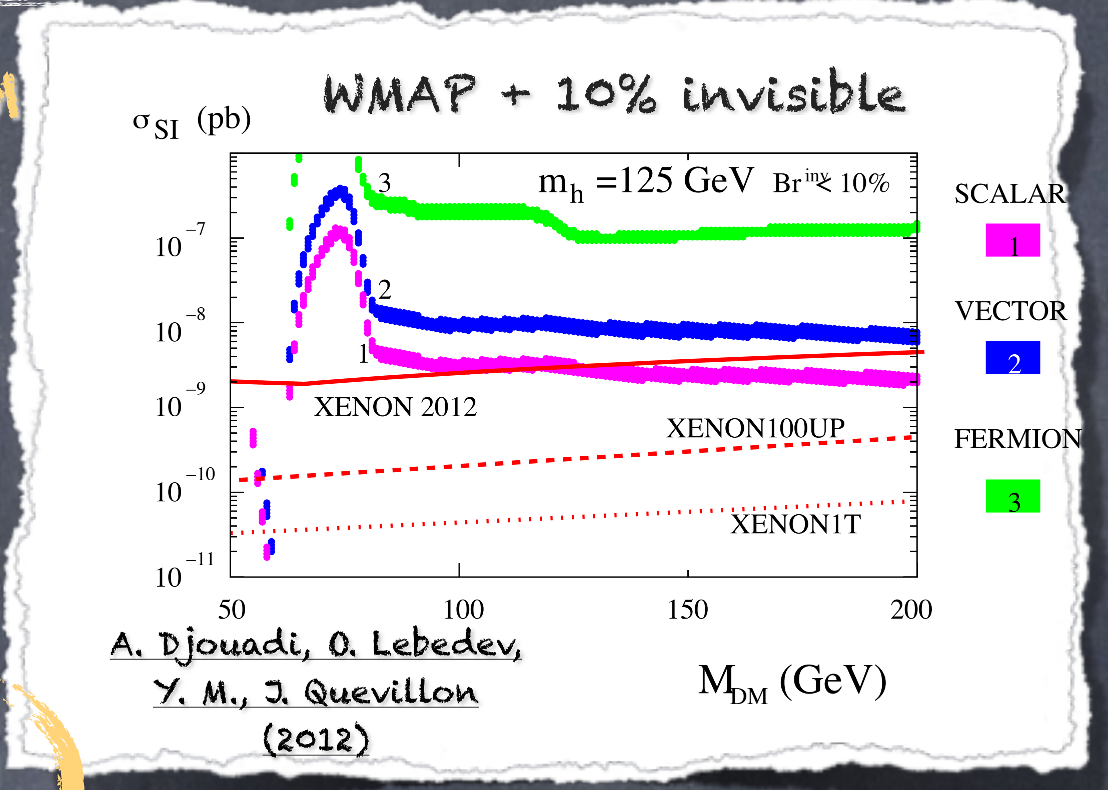

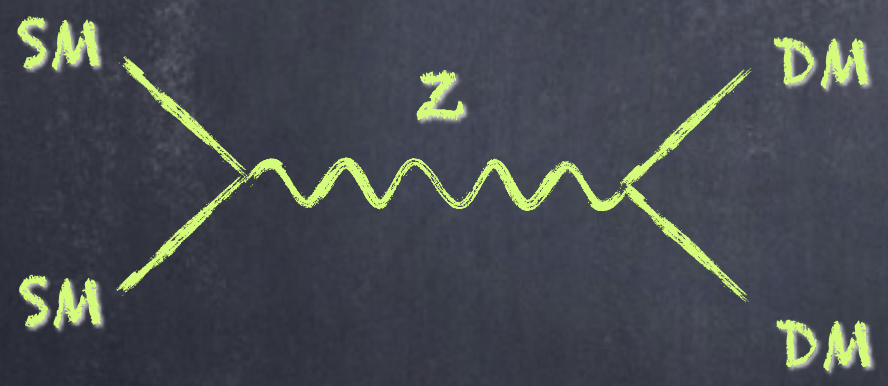

Z portal
(sneutrino dark
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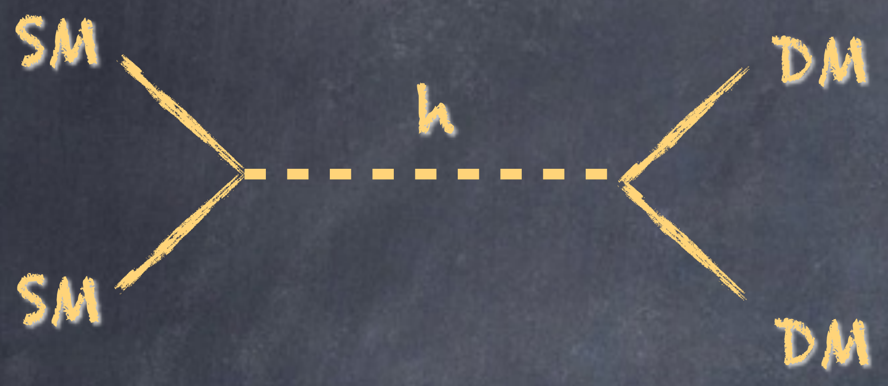

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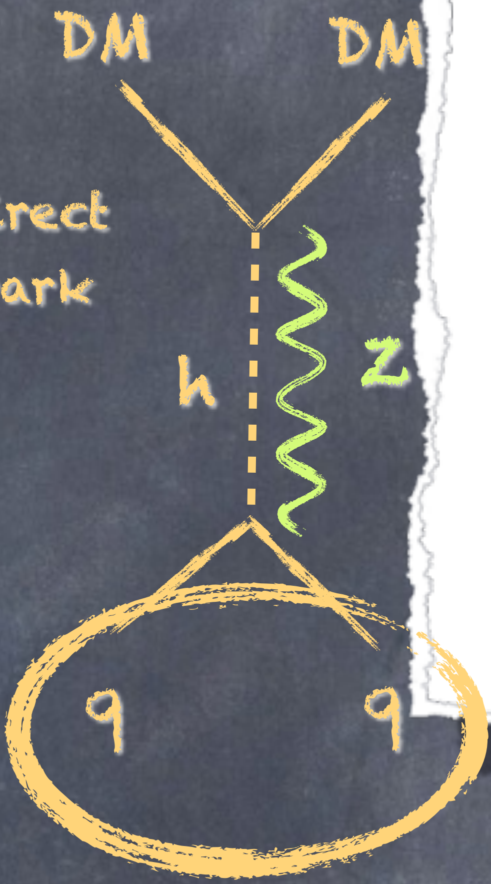

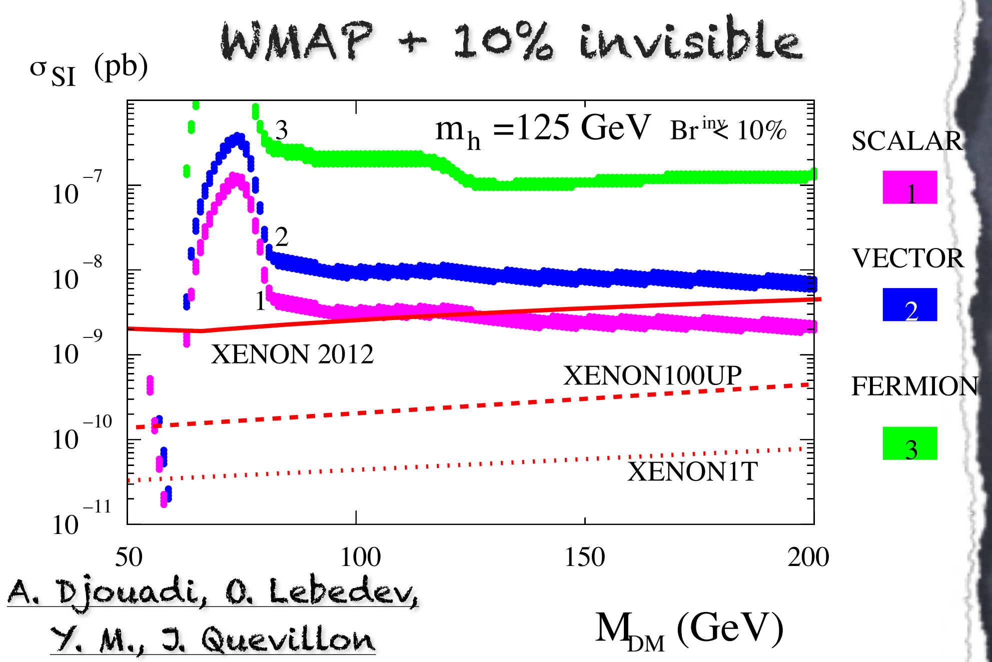

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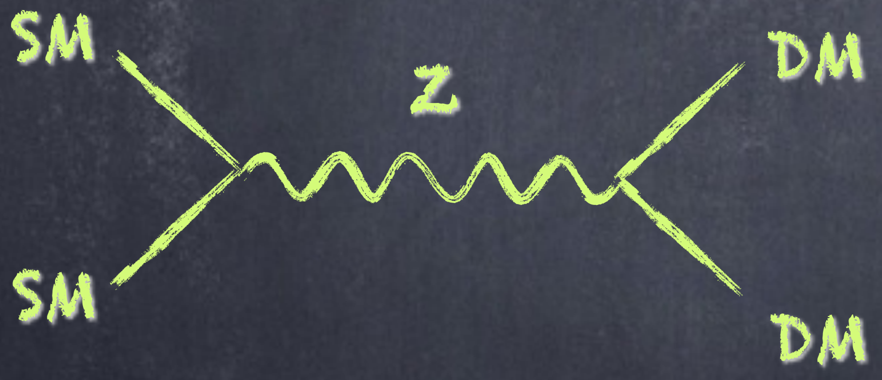

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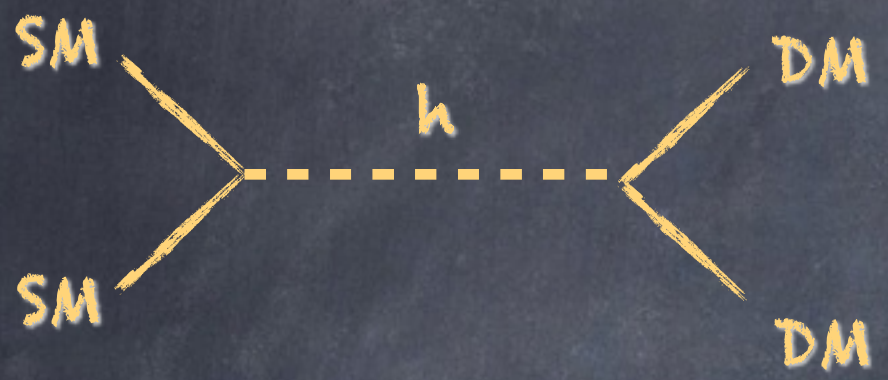

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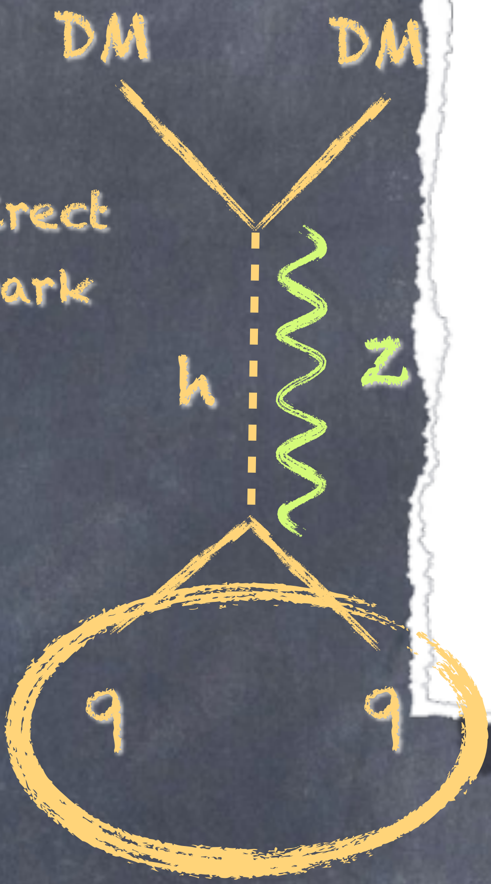
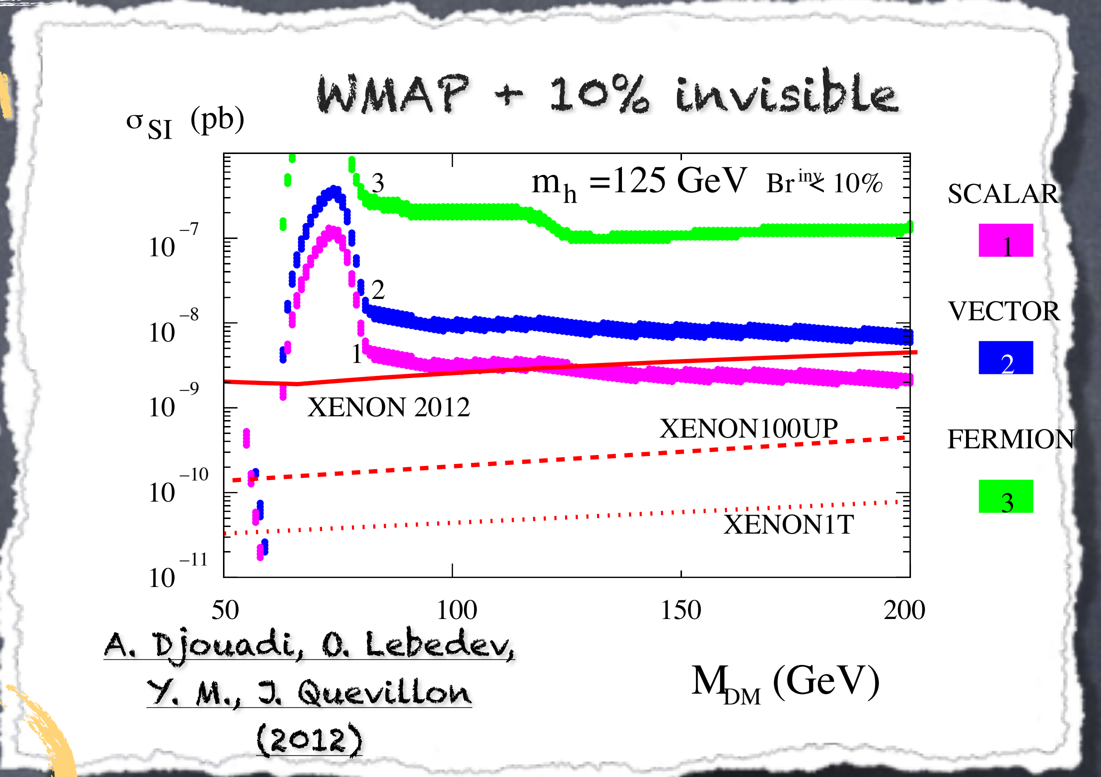
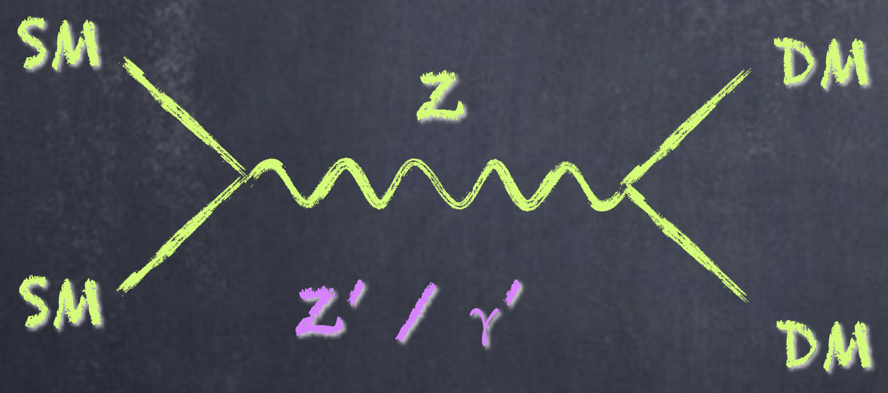






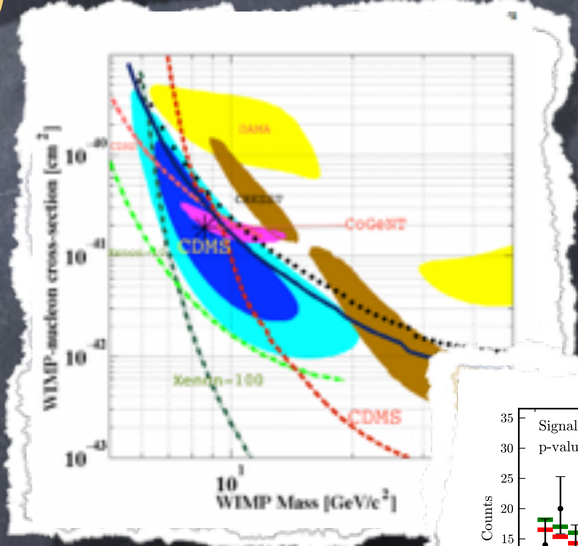
Z portal
(sneutrino dark matter)

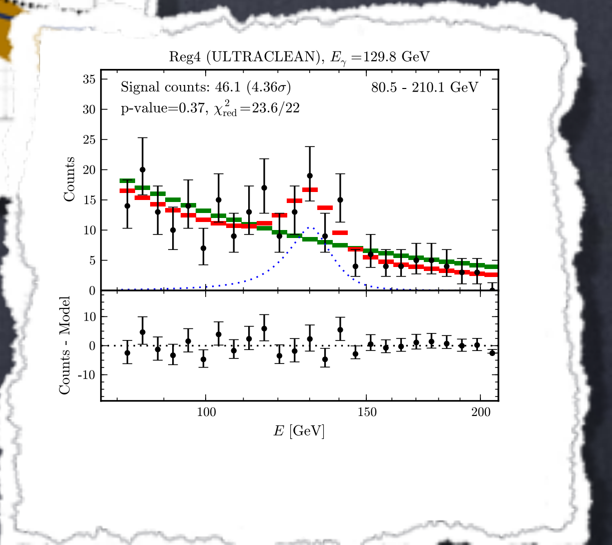
Excluded by direct detection of Dark Matter

Falk, Olive, Srednicki (1994)

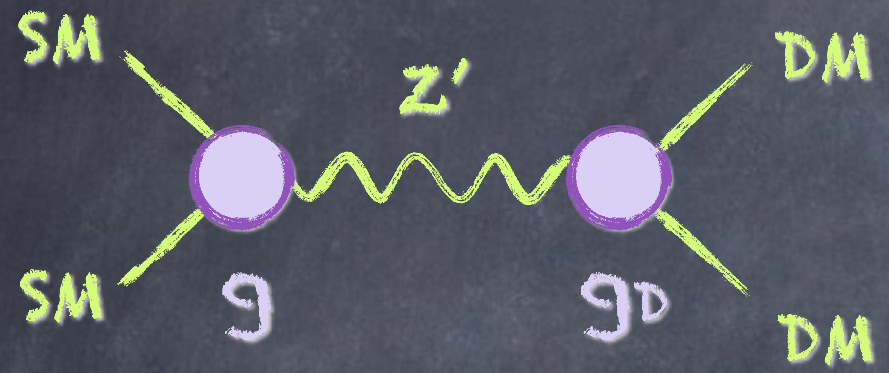
Z' portal
Hidden photon
(mirror dark matter)

Not excluded
Can explain excess observed by CRESST/CoGENT/DAMA
or FERMI monochromatic line





The Z′ case



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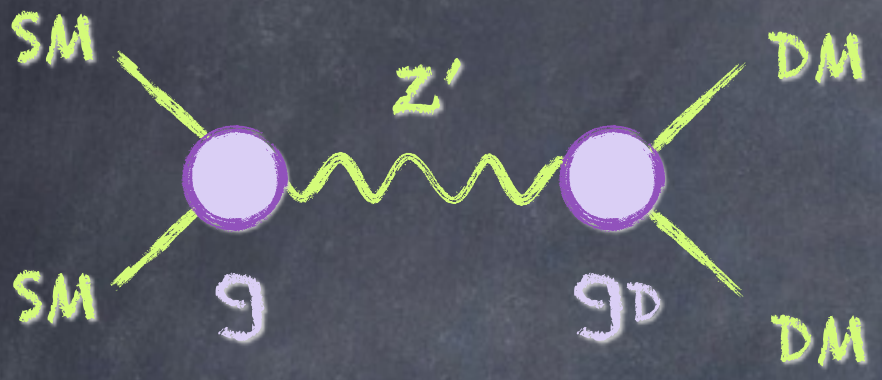

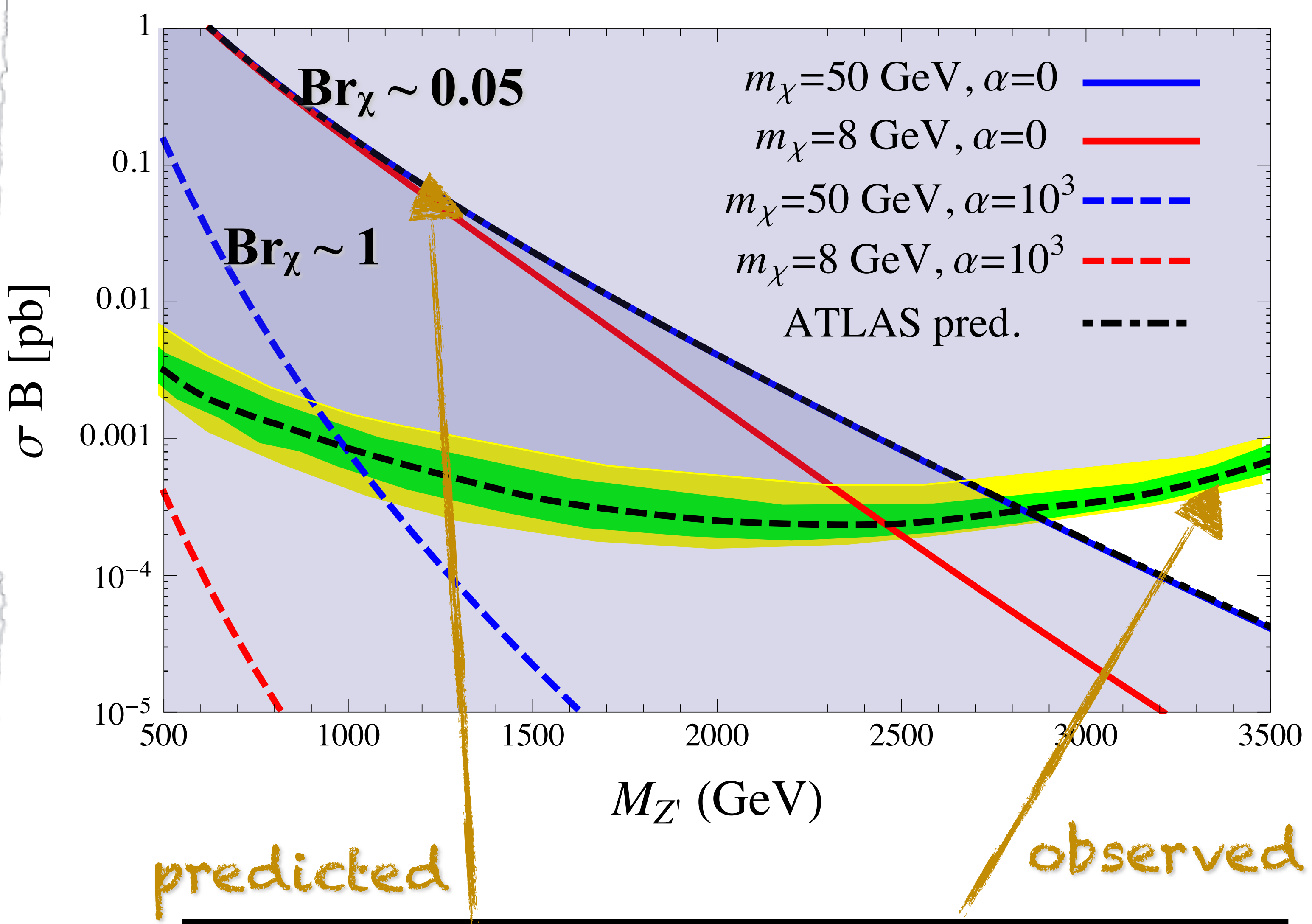

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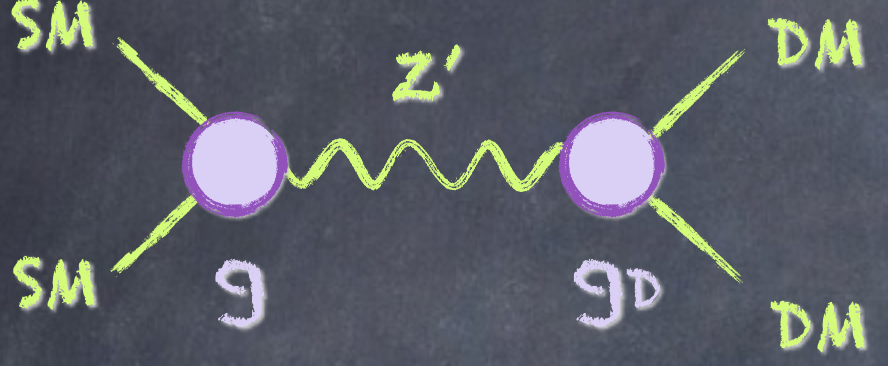

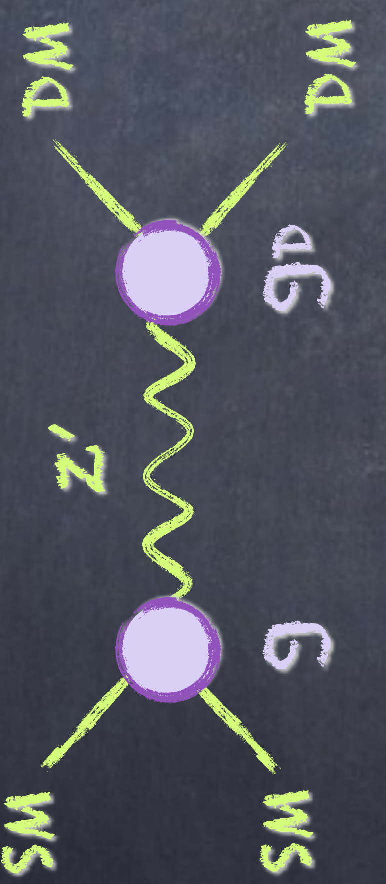

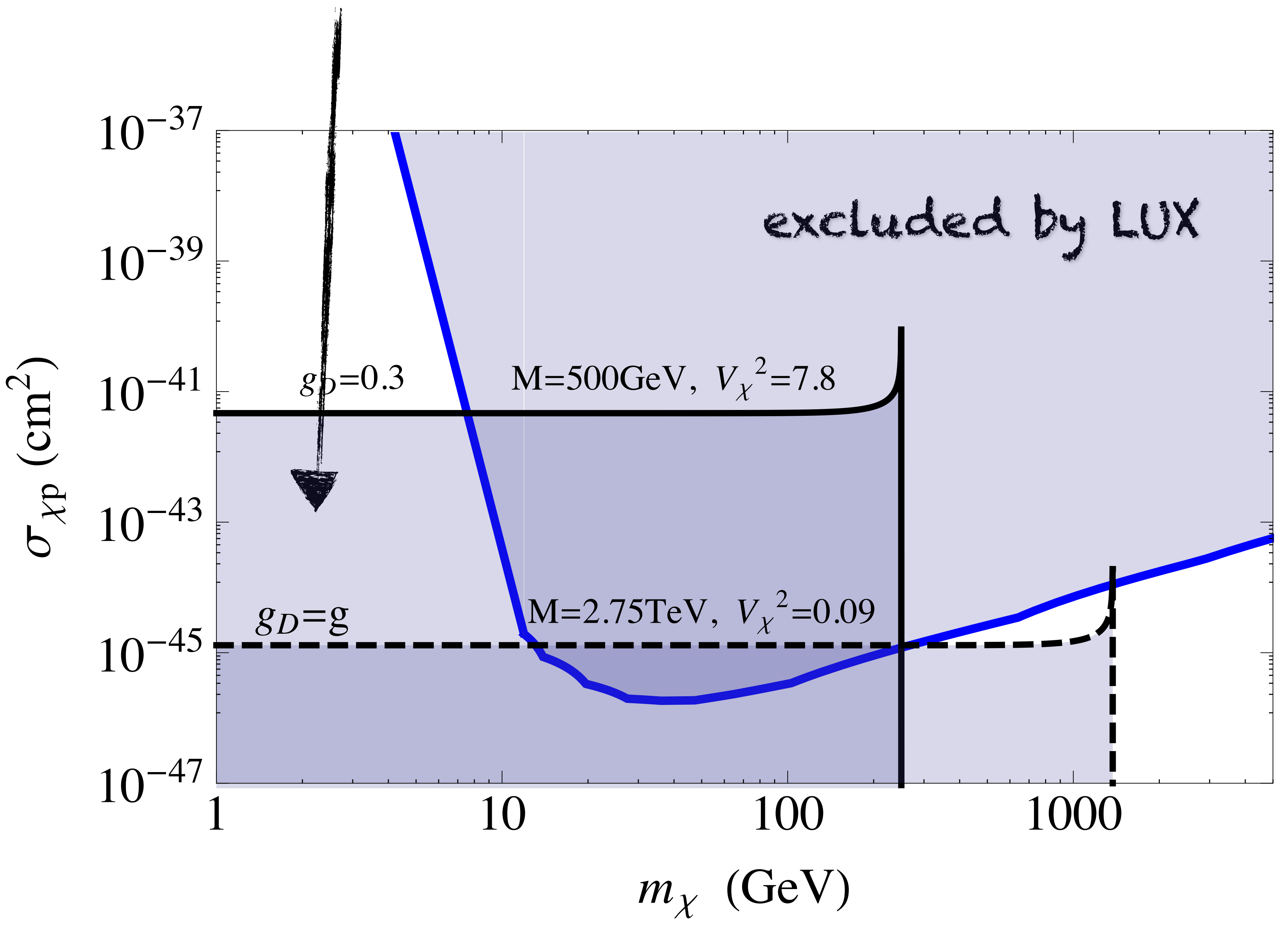

LHC + LUX limits

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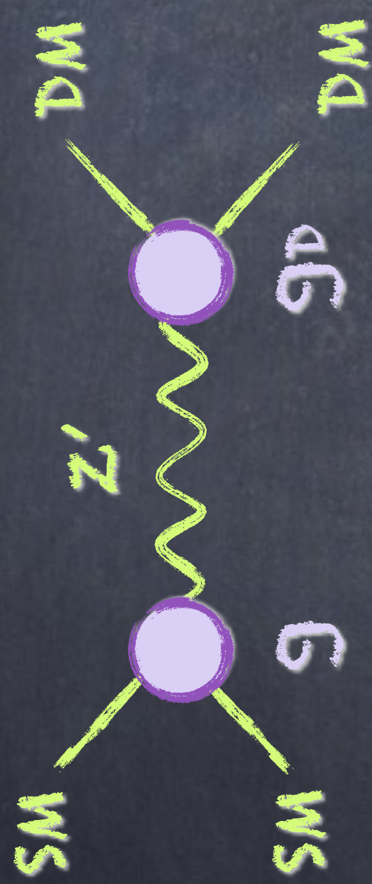
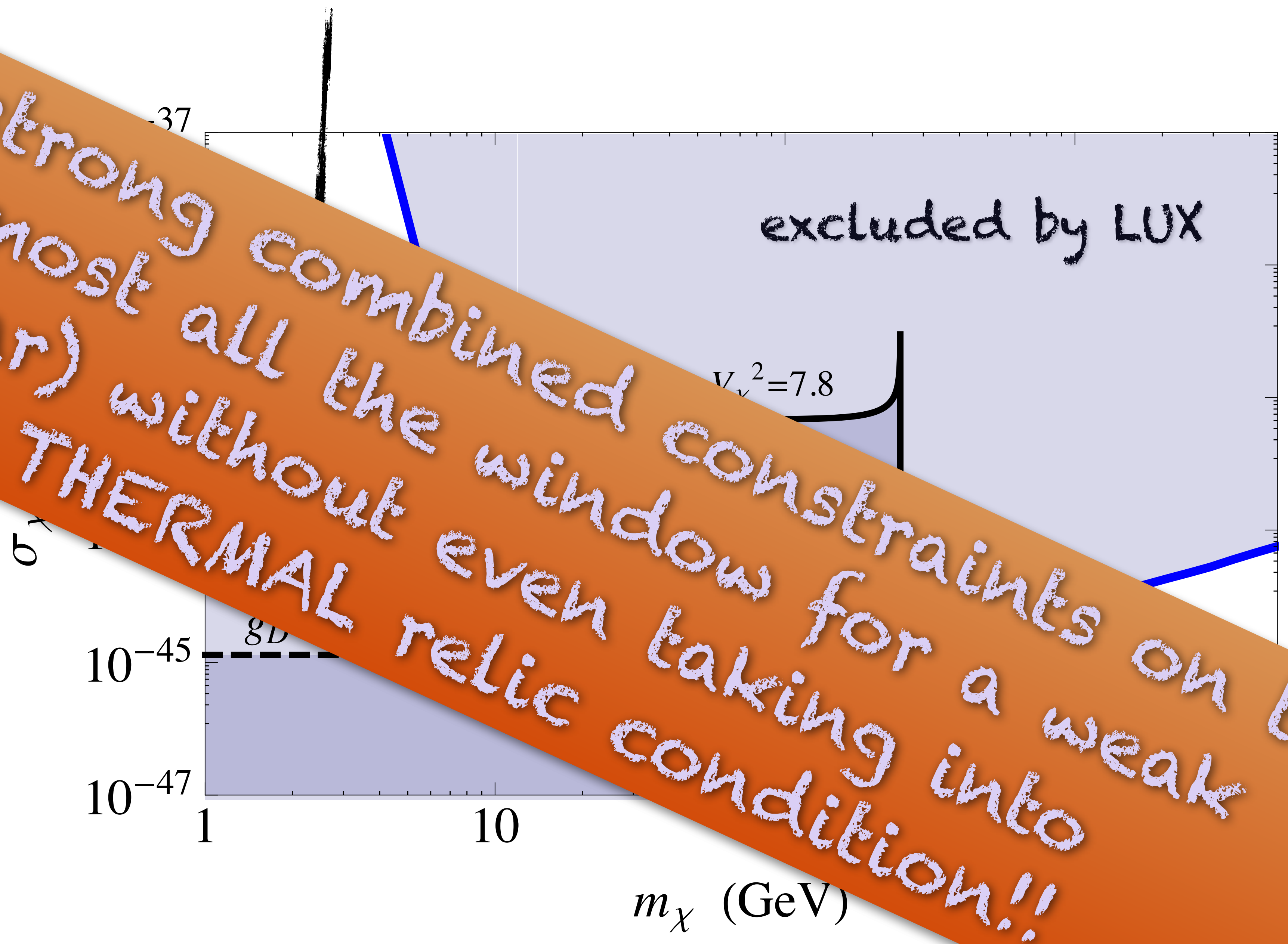
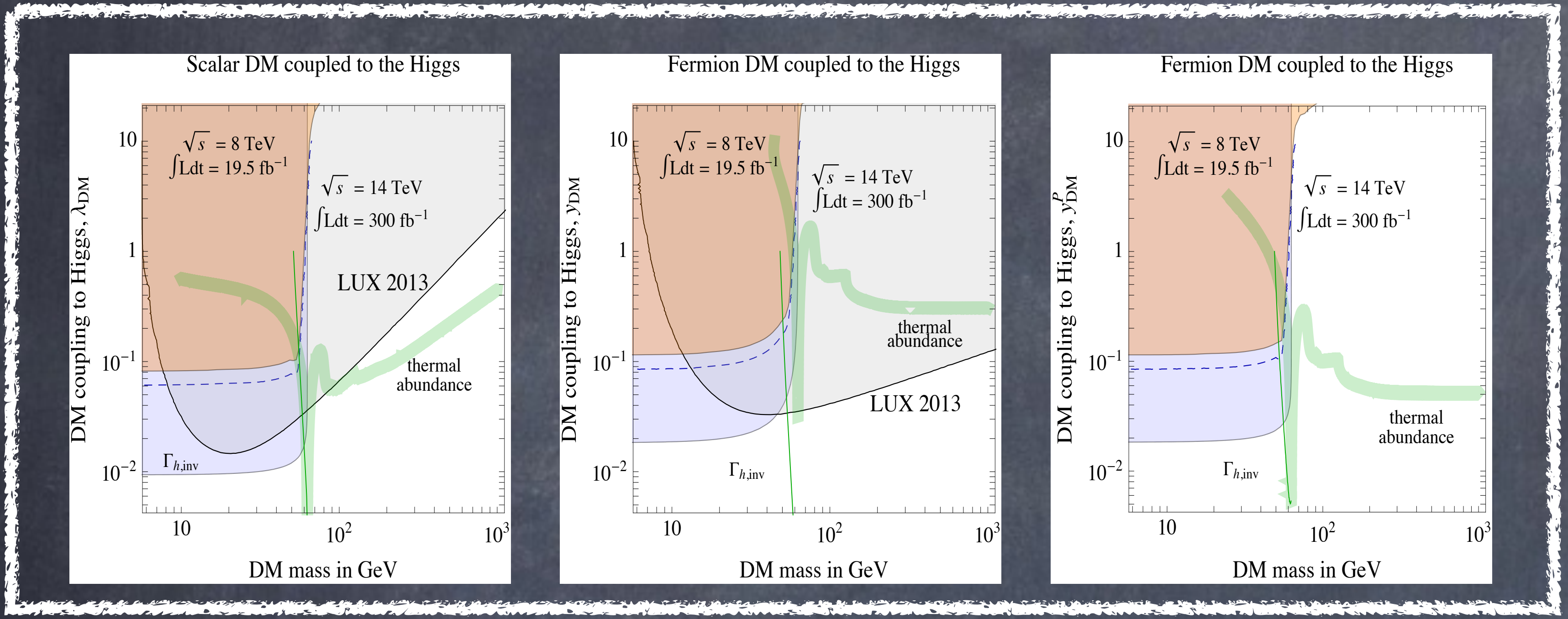




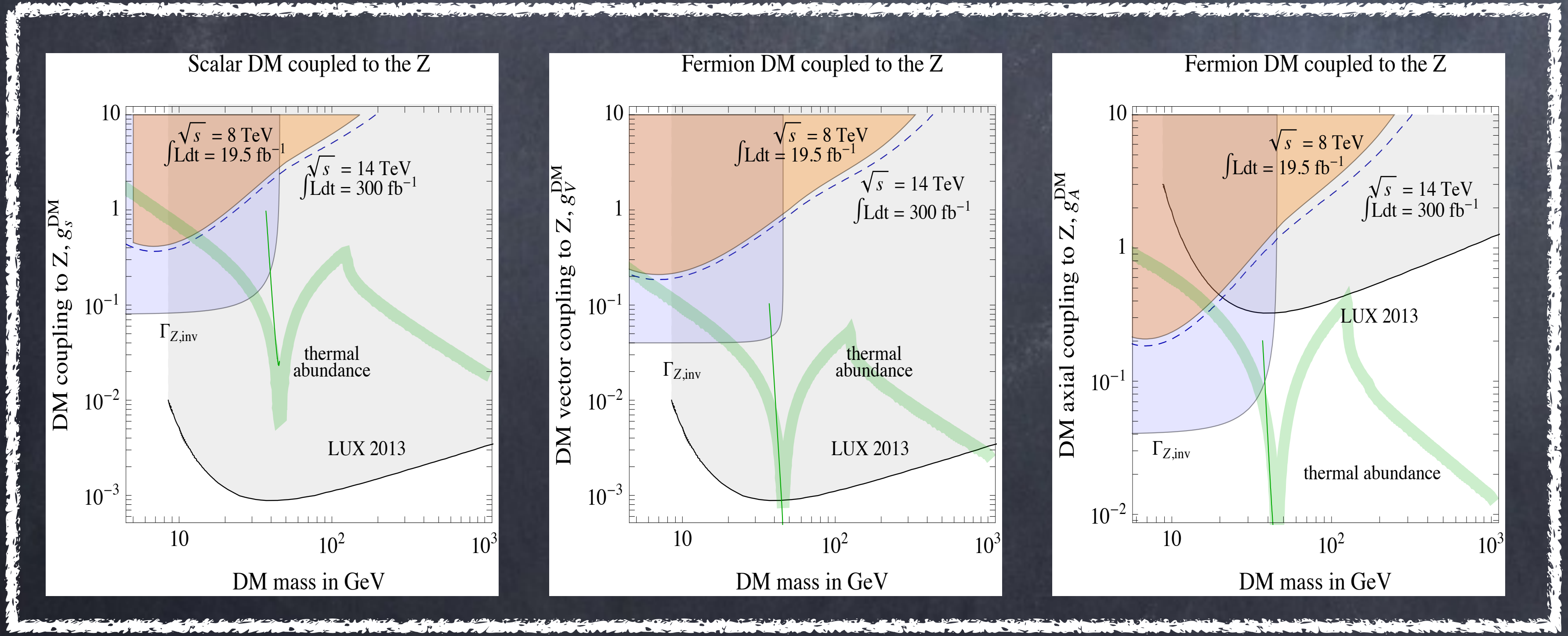
Conclusion 2: very strong combined constraints on the mediator close almost all the window for a weak scale Z' (or scalar) without even taking into consideration the THERMAL relic condition!!

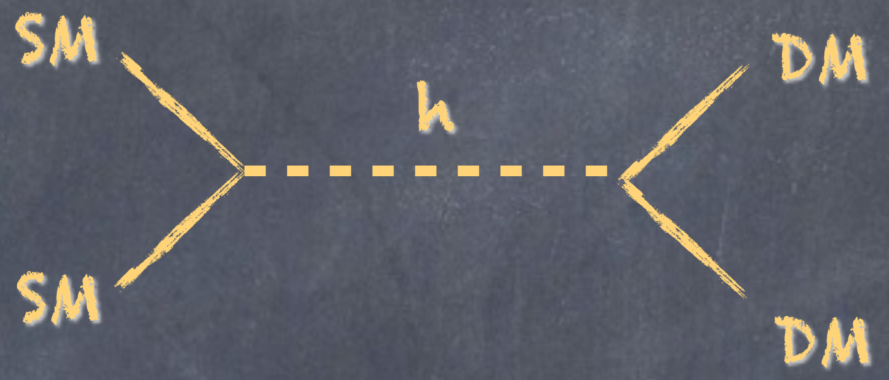
LHC + LUX limits

Beyond the basics couplings

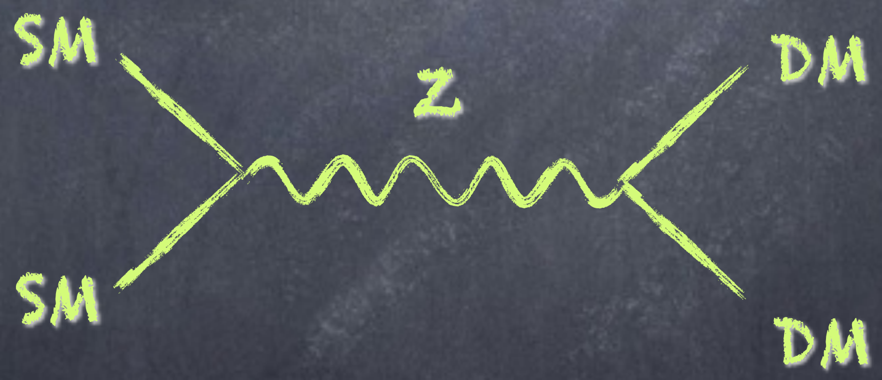


A. De Simonea, G. F. Giudice, A. Strumia, 1402.628



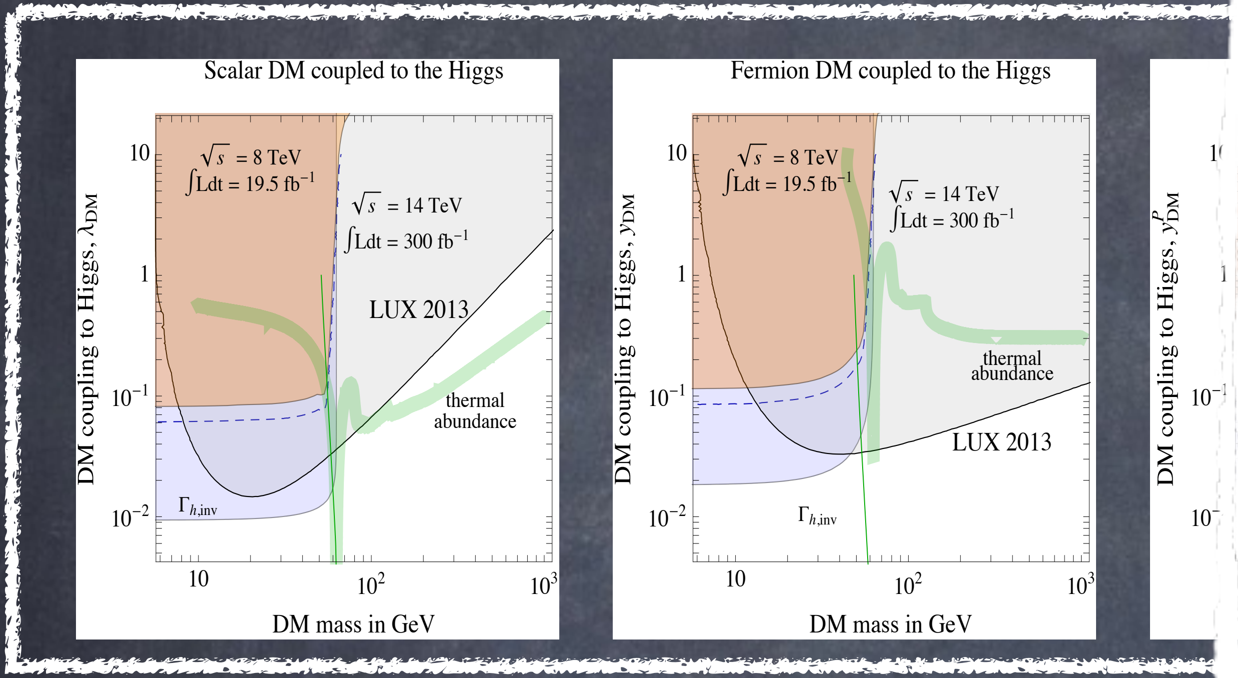


$$\mathcal{L} = -H^\dagger H\left[\bar\psi_{\rm DM}\frac{(y_{\rm DM}+iy^P_{\rm DM}\gamma_5)}{2v}\psi_{\rm DM}+\frac{\lambda_{\rm DM}}{4}s^2_{\rm DM}\right].$$



$$\mathcal{L} = \frac{4i}{v^2}(H^\dagger D^\mu H)\Big[\bar\psi_{\rm DM}\gamma_\mu(g_V^{\rm DM}+\gamma_5 g_A^{\rm DM})\psi_{\rm DM}+g_s^{\rm DM}(s^*_{\rm DM}(i\partial_\mu s_{\rm DM}$$

Beyond



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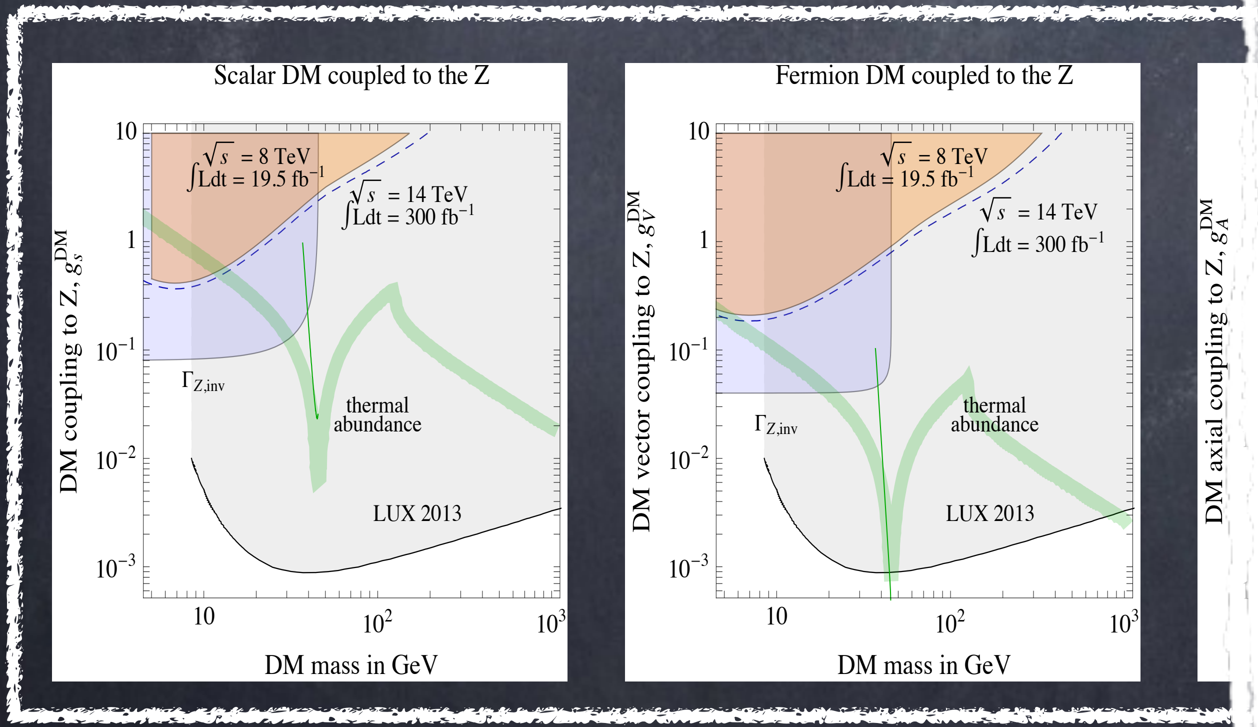

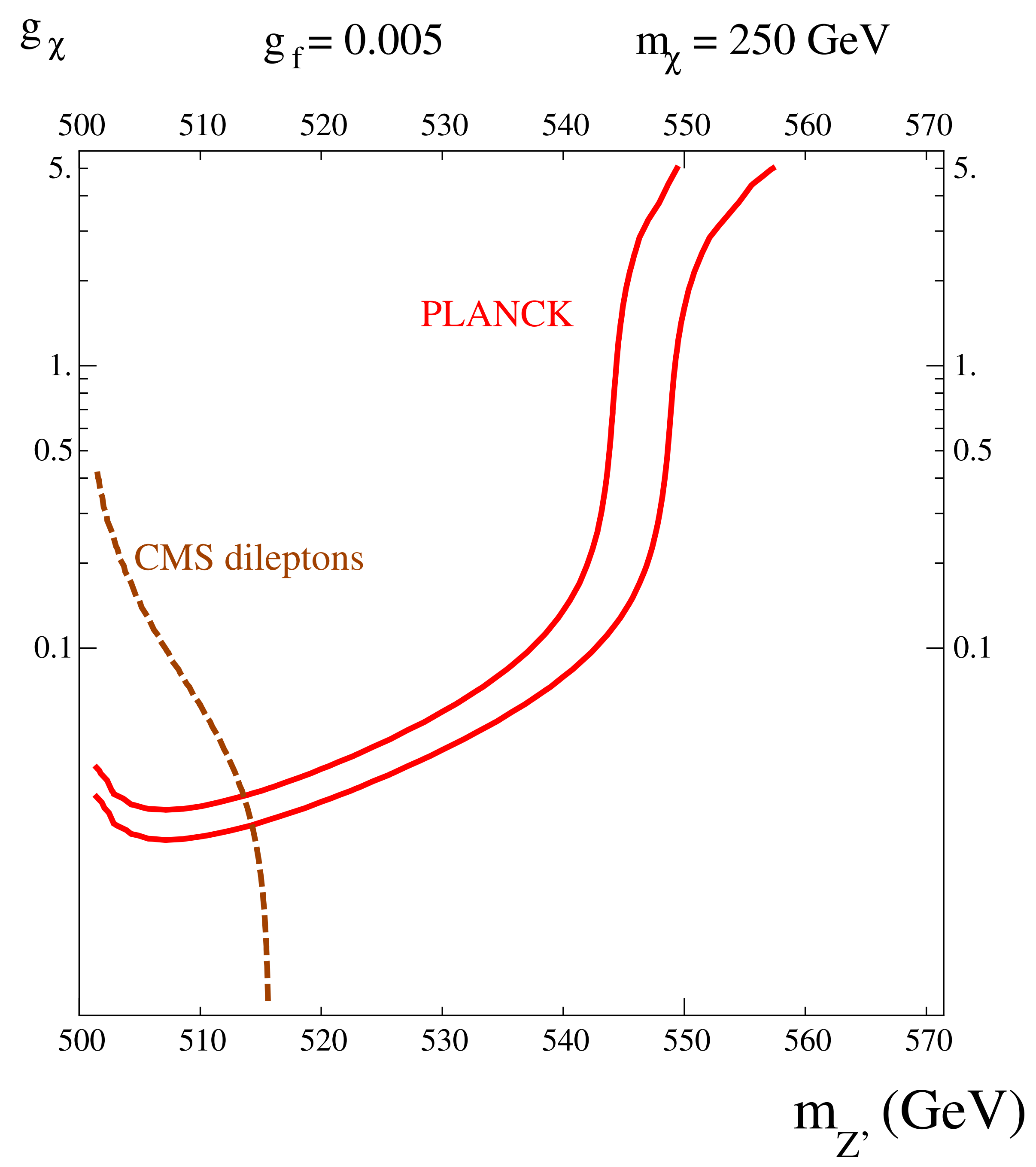

A possible solution : axial Z′ (AxDM)
1403.4837 (PLB)

$$\mathcal{L}^{\rm eff}_{\rm int} = \sum_f g_f \; Z'_\mu \; \bar f \gamma^\mu \gamma^5 f + g_\chi \; Z'_\mu \; \bar\chi \gamma^\mu \gamma^5 \chi \; .$$

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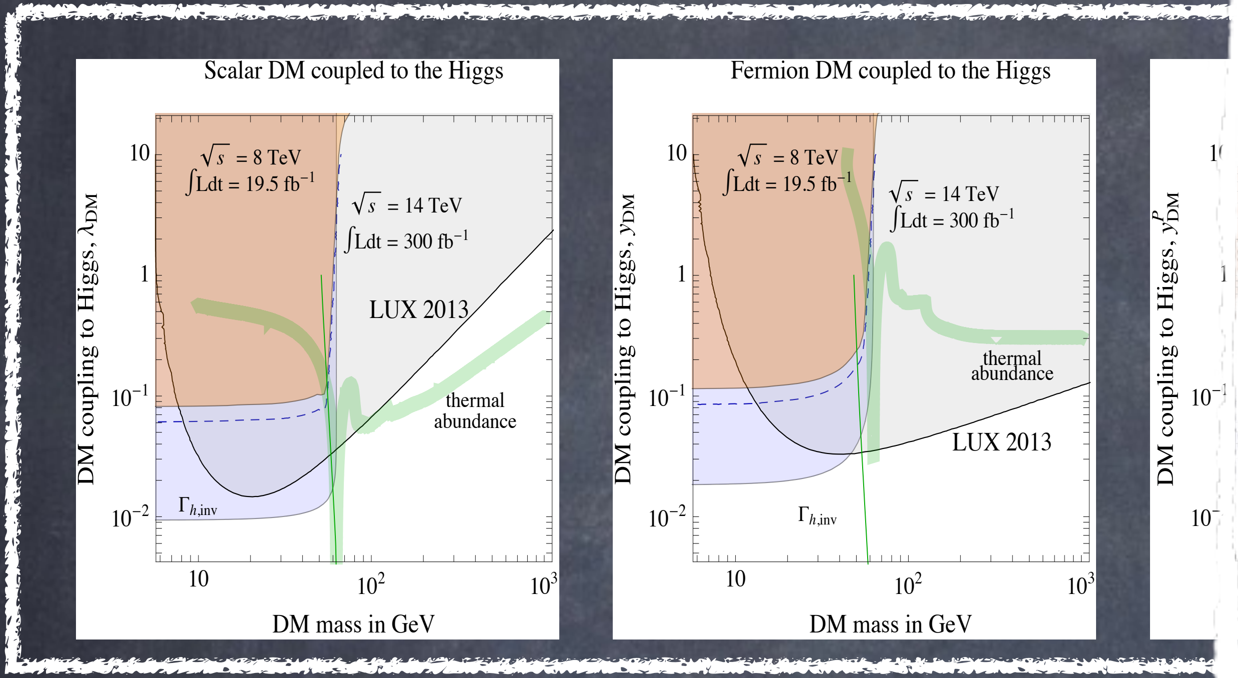

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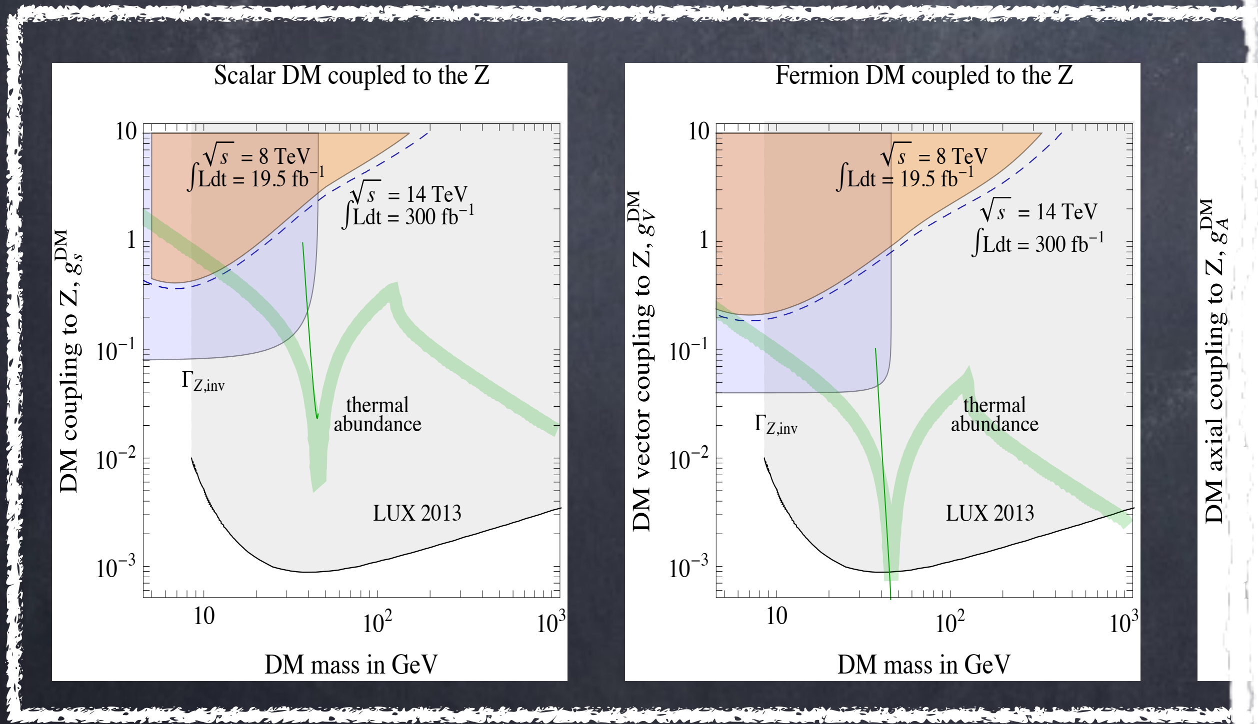
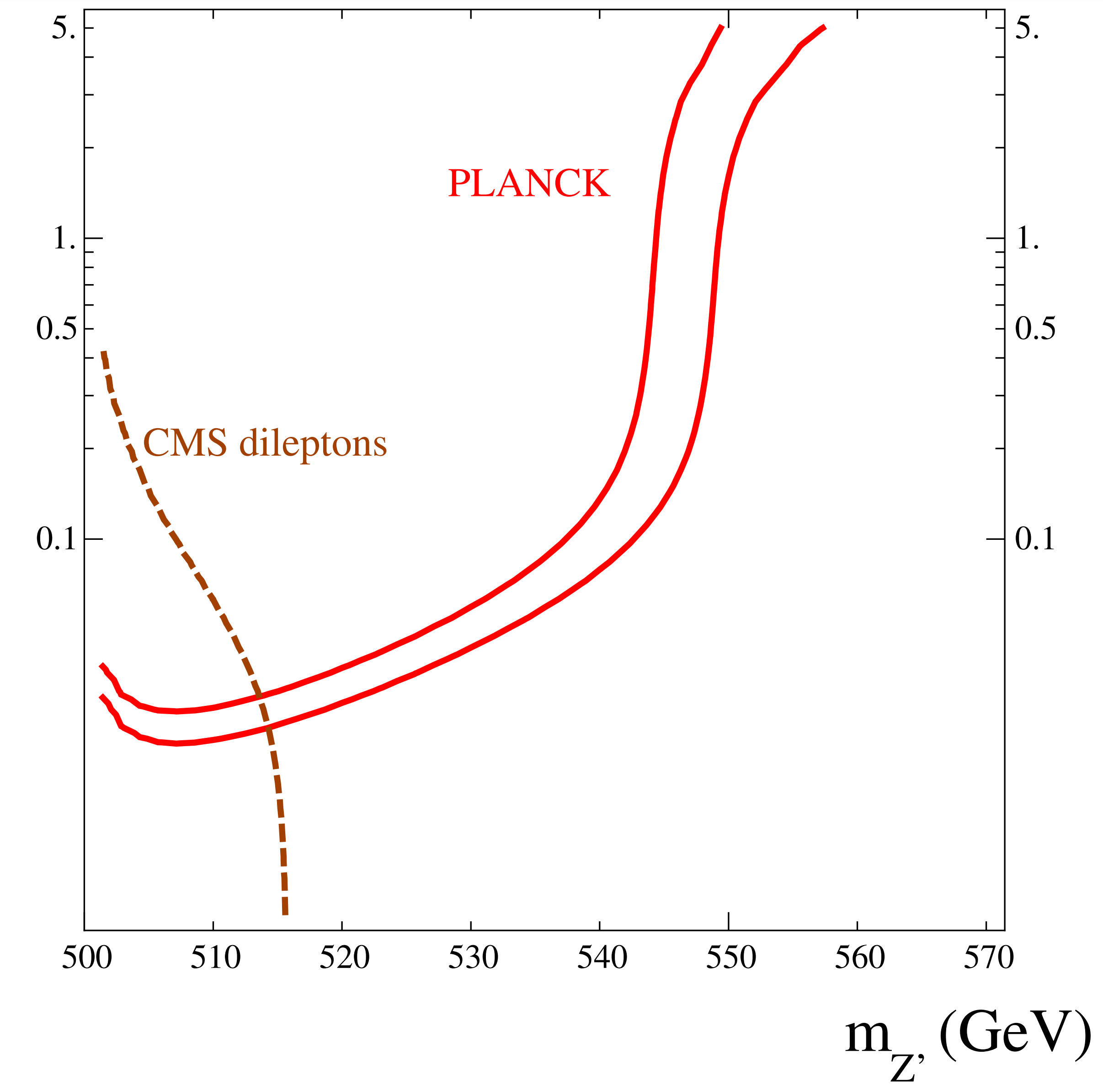


Another solution : « Coy Dark Matter (Boehm et al. '14)



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Neutralino
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No exclusions (yet)
Possible detection
+ possibility of non-SUSY scalar
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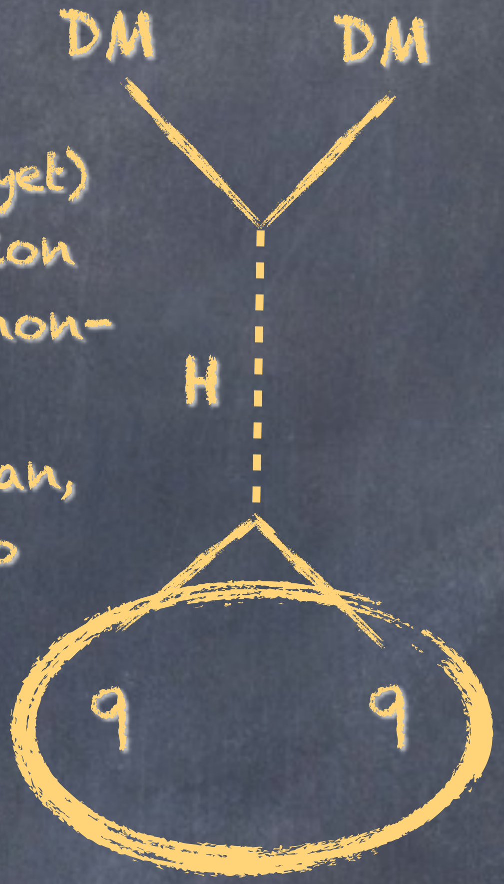
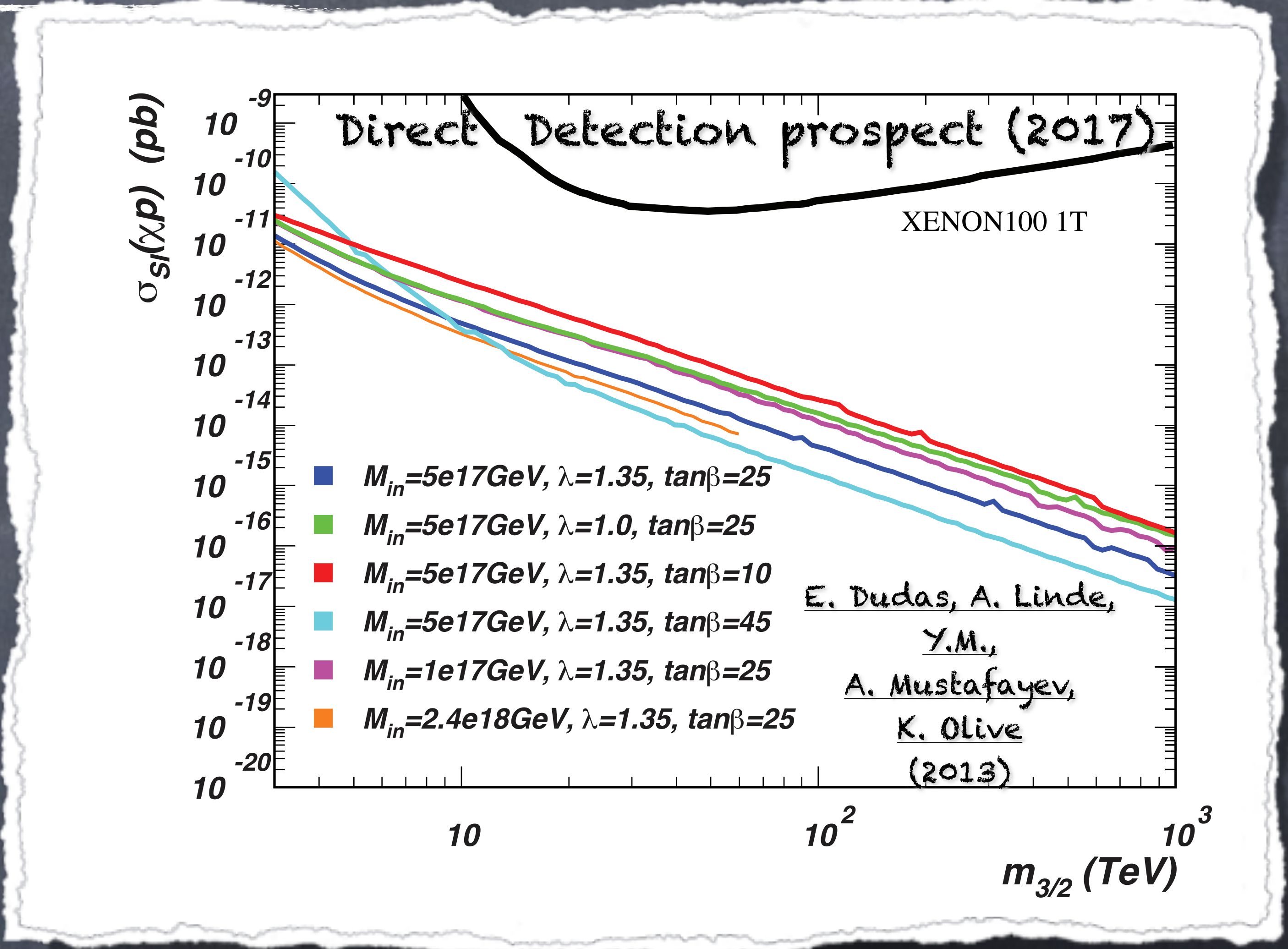


BUT in coherent Supergravity scenario, difficult to observe due to Higgs mass :

mh = Mz + Log(Mst/Mt) => heavy scalar sector => Heavy Higgses



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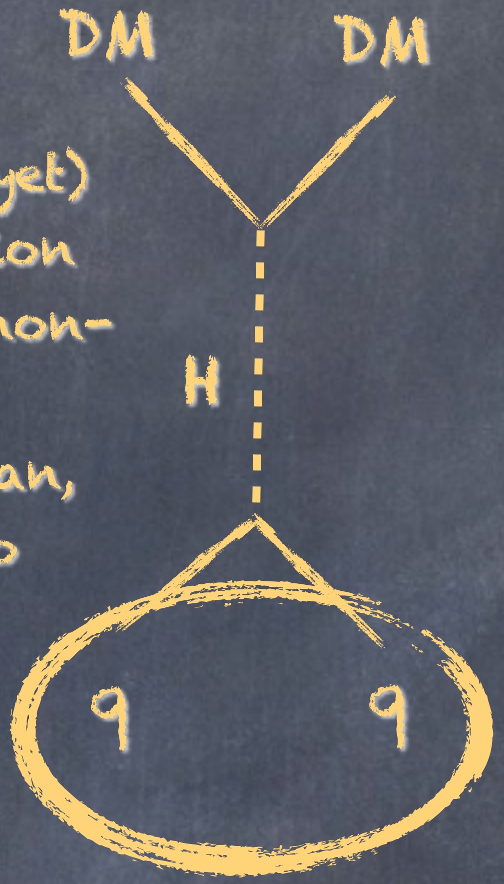

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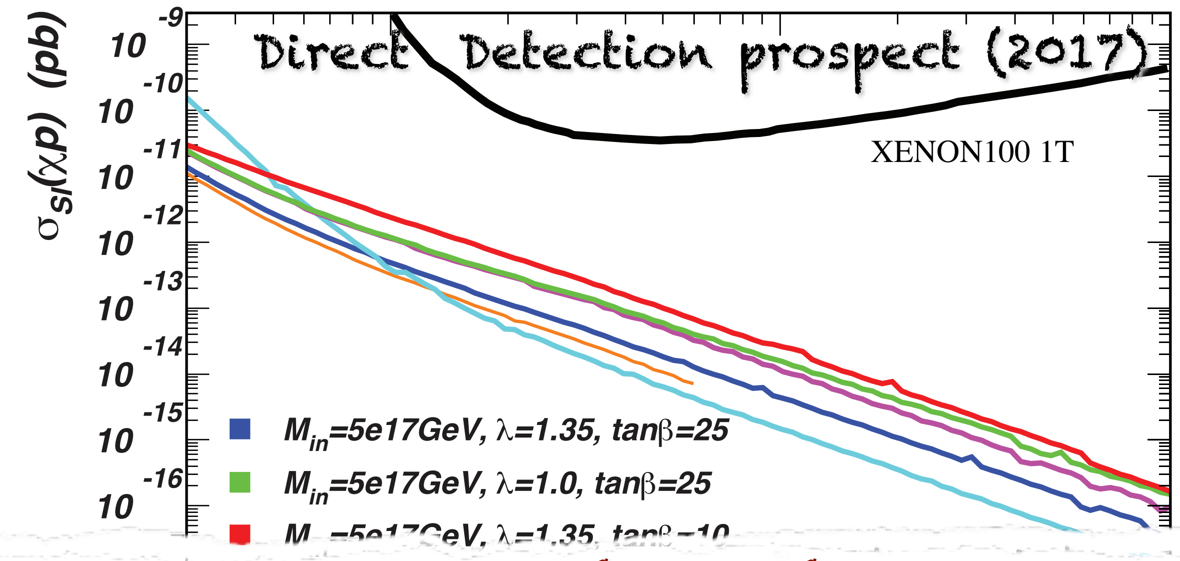

Feng, Kant, Profumo, Sanford
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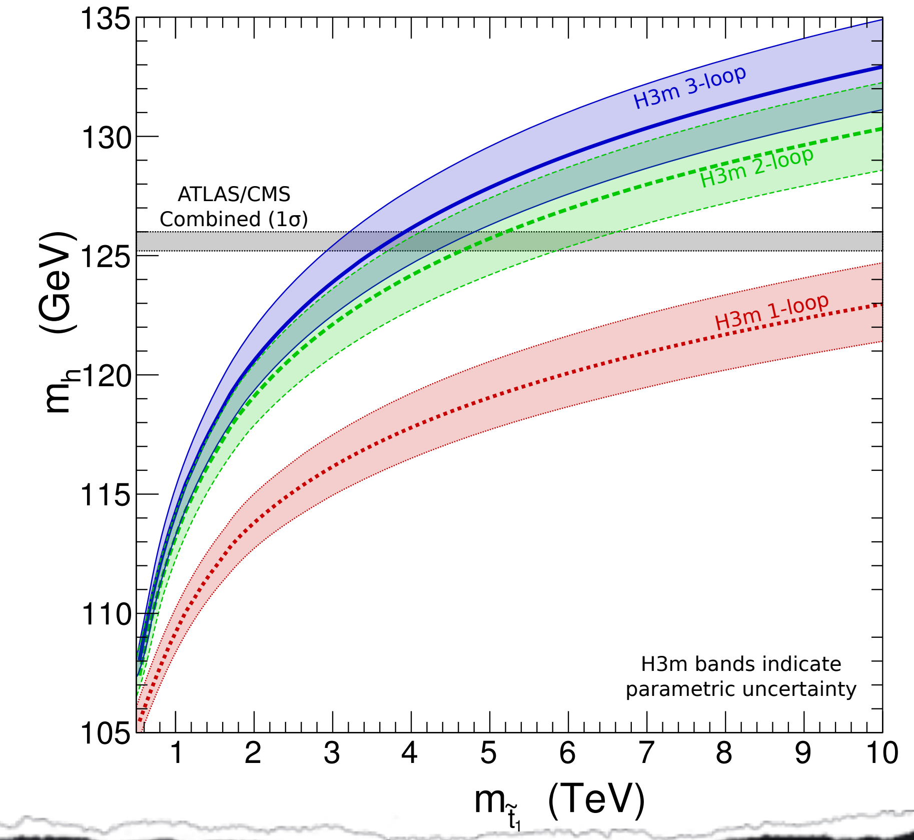

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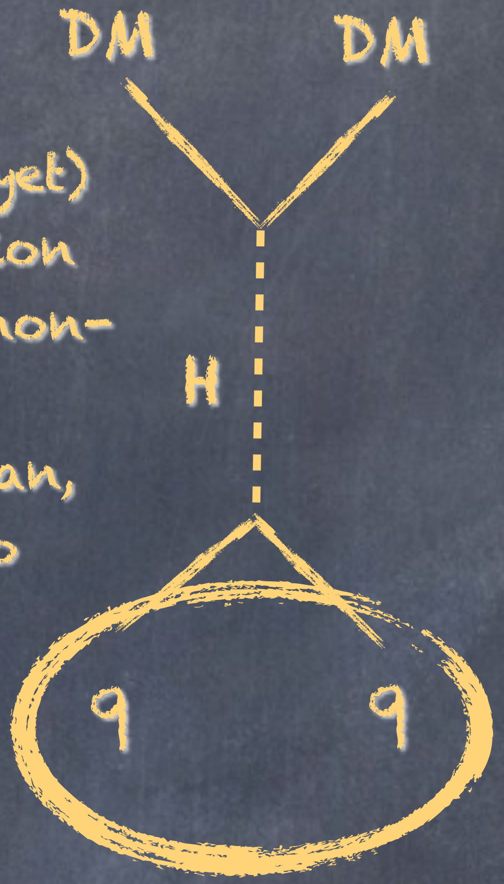

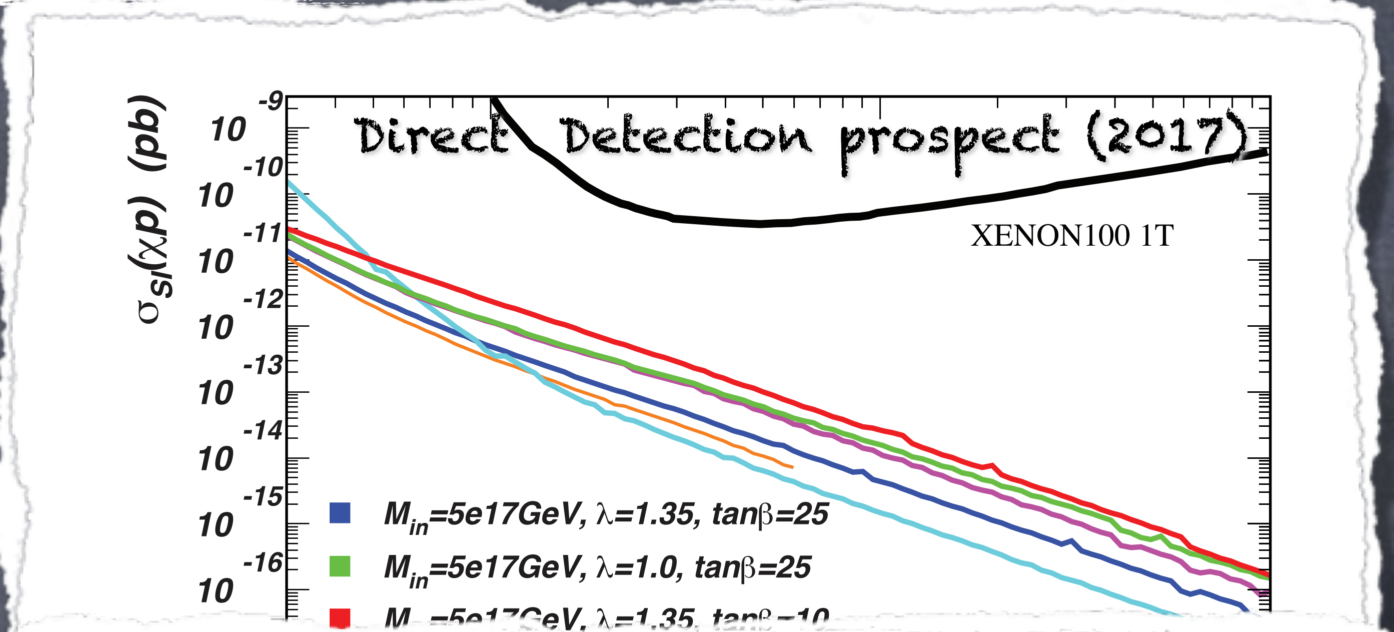

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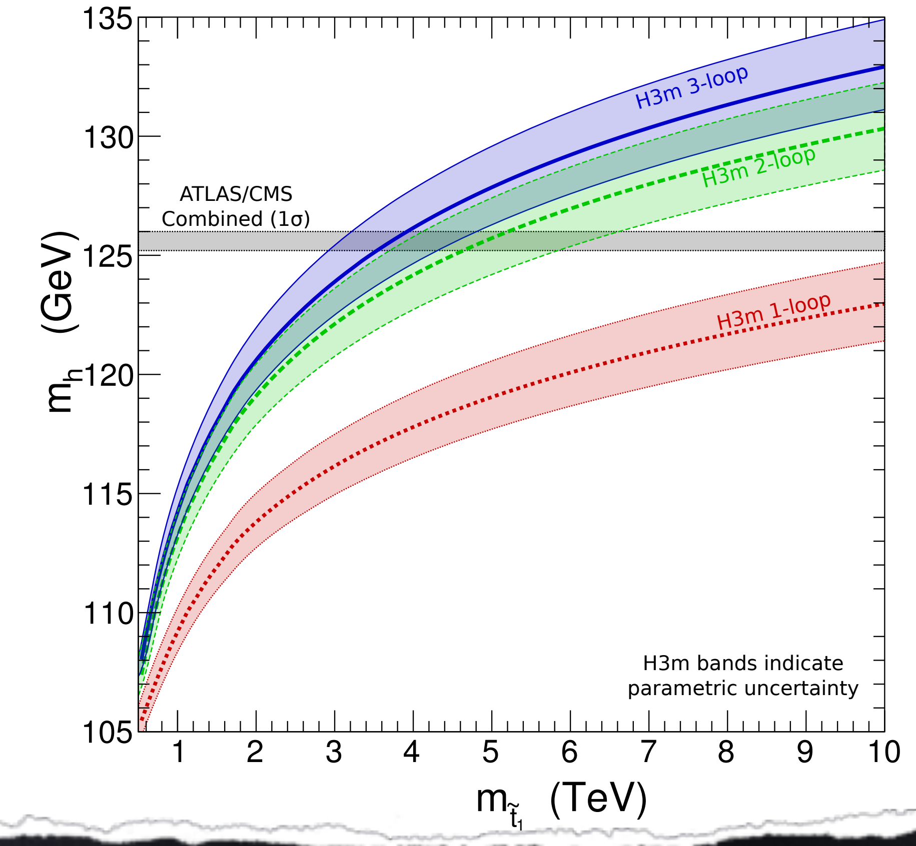

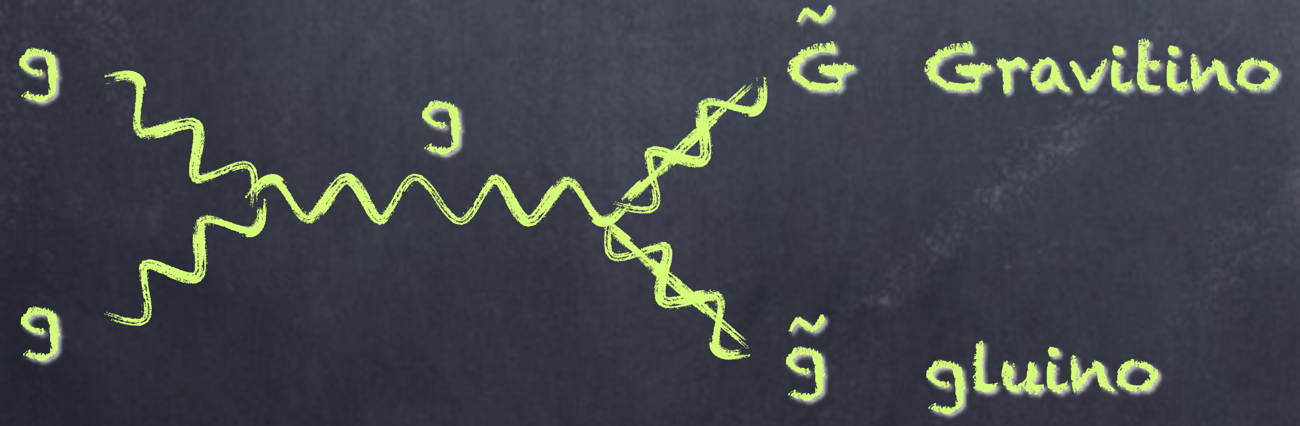

Gravitino dark matter
No detection hopes

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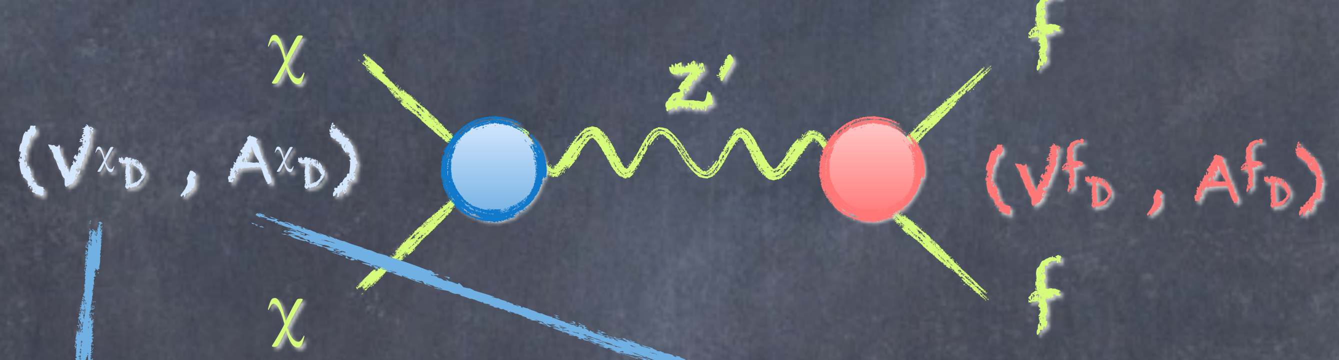

$$\langle\sigma v\rangle = \frac{s\sqrt{1-4\mu_f^2}}{64\mu_{\chi p}^2}\left[\frac{\sigma_{\chi p}^{SI}}{\alpha_{Z,A}^{SI}}\left([1+\mu_\chi^2](|V_D^f|^2+|A_D^f|^2)-16\mu_f^2\mu_\chi^2|A_D^f|^2\right)+\frac{4\sigma_{\chi p}^{SD}}{3\alpha_{Z,A}^{SD}}|A_D^f|^2\right]+O(\beta)$$

Is the dark matter thermal?

Conclusion 3: Very difficult to reconciliate electroweak scale mediator with thermal relic combined with direct detection experiments.

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<σ v > [illegible] if present DD constraints apply

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One NEEDS to build microscopic extensions

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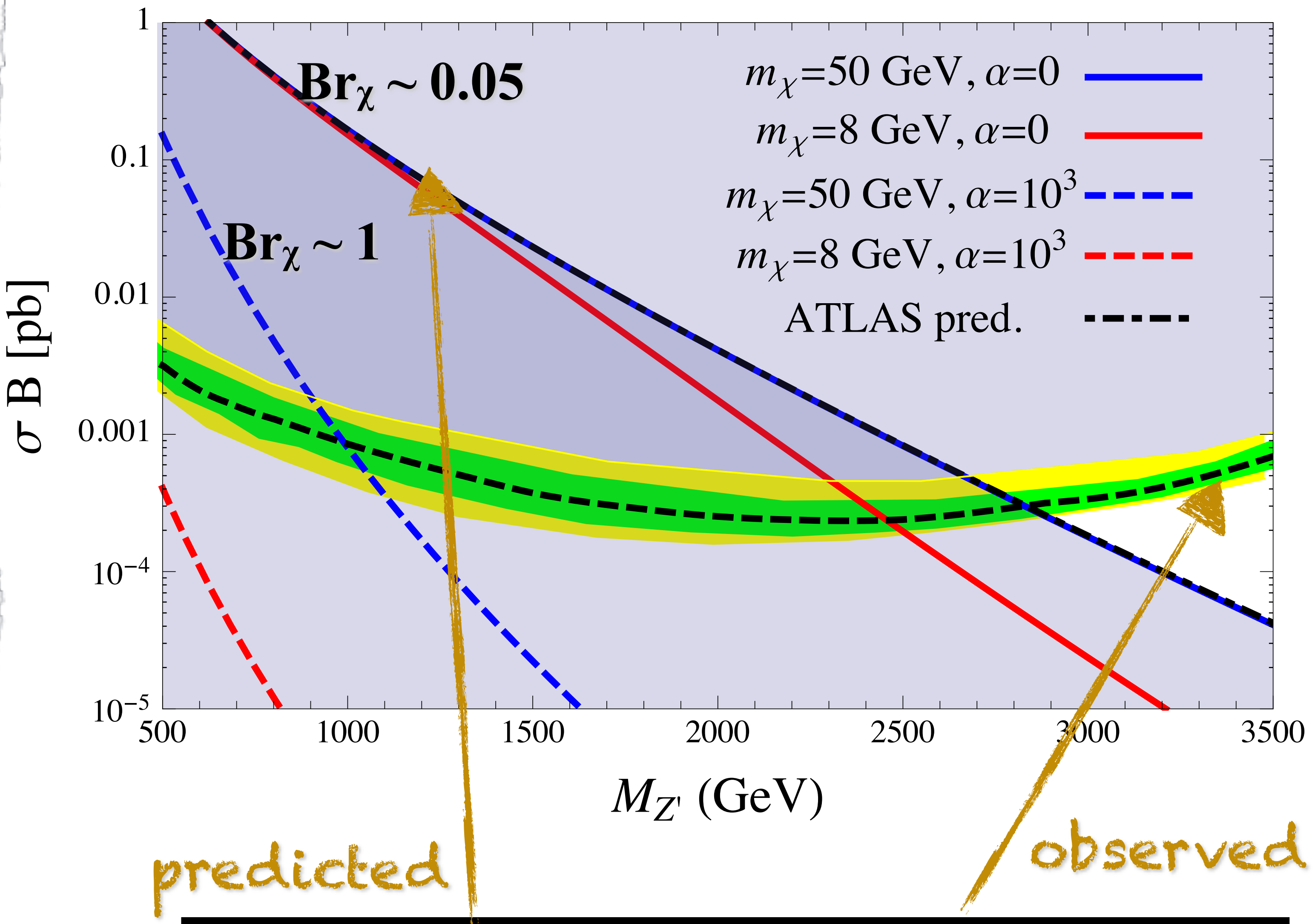
Co... probable that the MEDIATOR ... covered BEFORE the dark matter

Conclusion 3: Thermal scenario with electroweak mediator begins to be explored. Necessity to look at alternative scenario (Thomas' talk)

Conclusions



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Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Non-thermal scenarios?

Chu, Hambye
Tytgat
1112.0493

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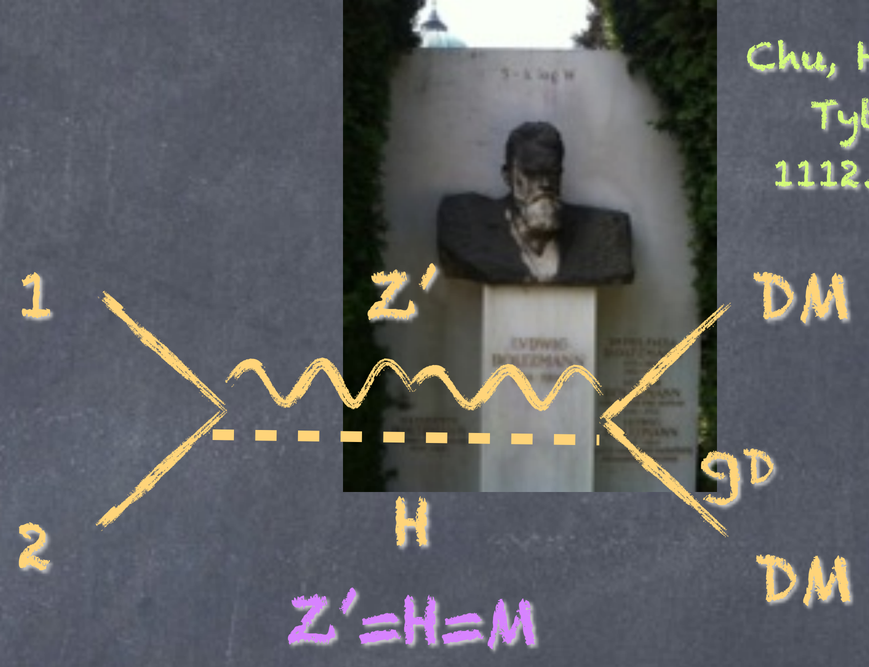

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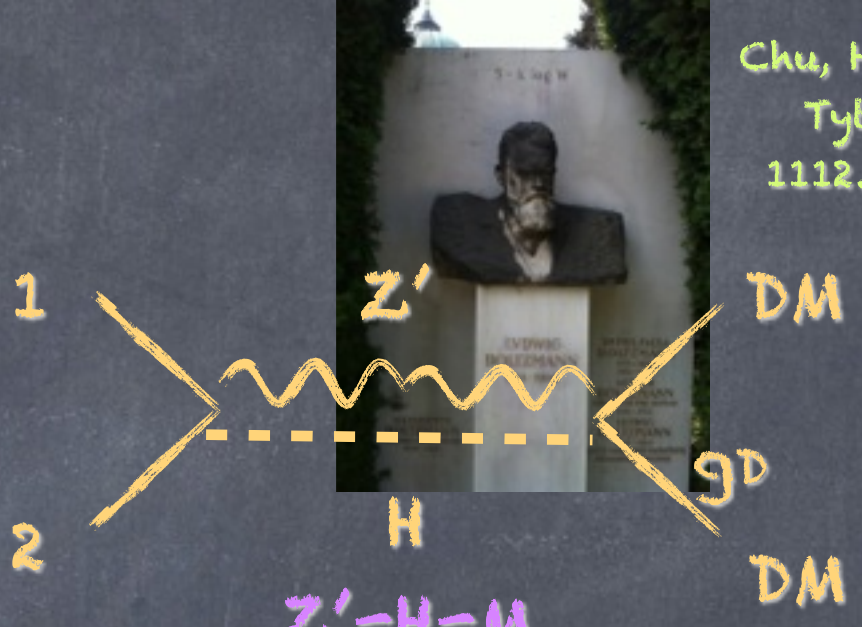

Z'=H=M

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Two possibilities

Dark matter is not produced by inflaton decay at reheating time TRH

Dark matter is produced in equilibrium with the SM species at TRH

Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

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Two possibilities

Dark matter is not produced by inflaton decay at reheating time TRH

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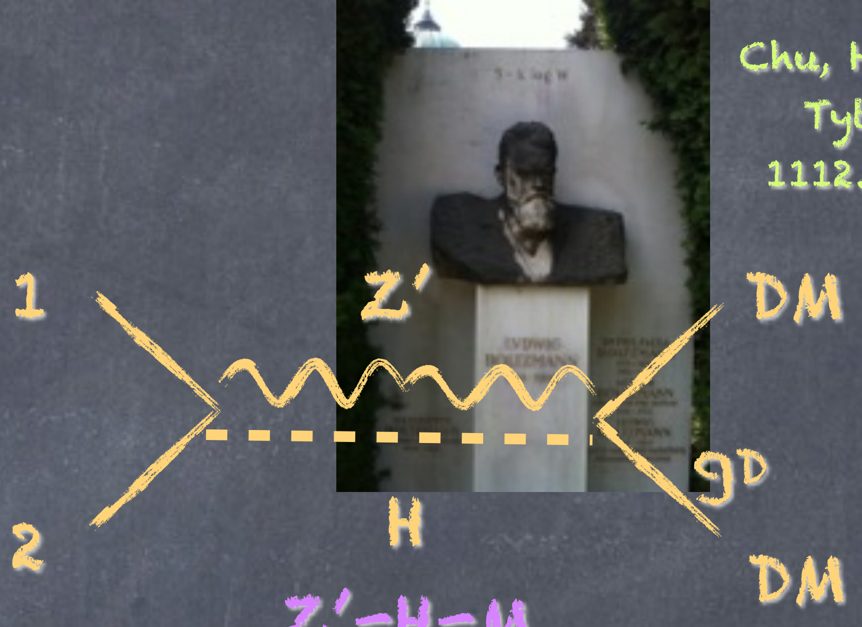

Z'=H=M

Dark matter is produced in equilibrium with the SM species at TRH

- gD ~ gEW

Standard freeze out (FO) scenario. <σv> ~ 10^-9 The dark matter decouples when n is Boltzman suppressed :

n(T) <σv> << H(T)

WIMP

(neutralino, Higgs portal..)

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Non Equilibrium Thermal (NETDM) :

SO(10), Intermediate scale

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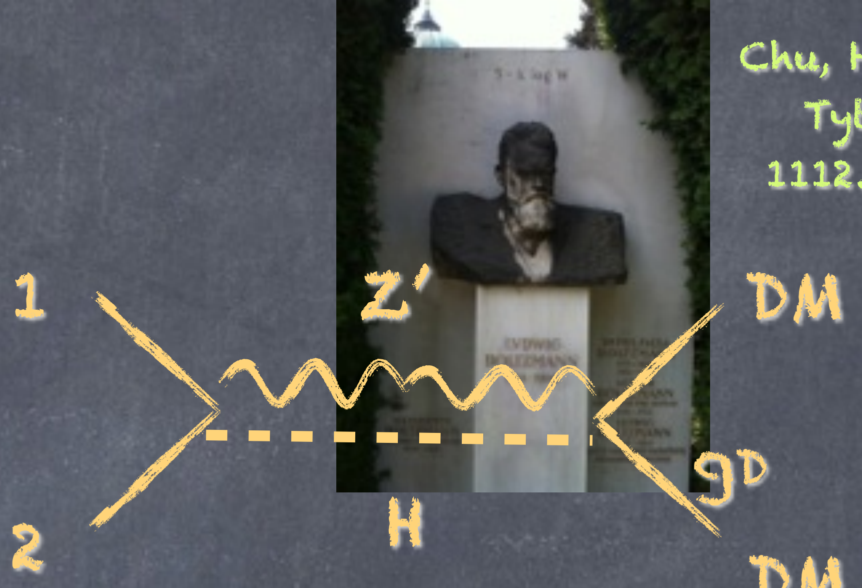

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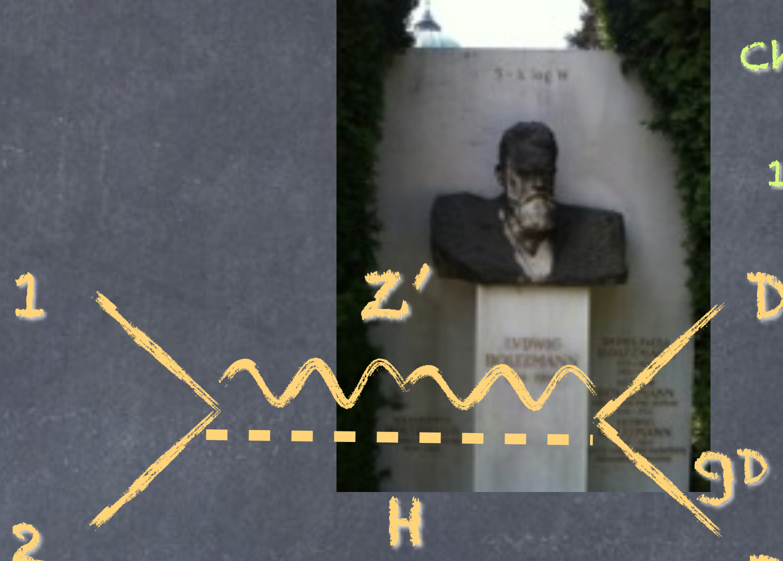

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Non Equilibrium Thermal (NETDM) :

SO(10), Intermediate scale

- gD ~ T/MPl

Planck/gravitational induced coupling

$$\langle \sigma v \rangle \propto \frac{1}{M_{Pl}^2}$$

$$\Rightarrow \frac{dY}{dT} \propto \frac{1}{M_{Pl}}$$

$$\Rightarrow Y(T) \propto \frac{T_{RH} - T}{M_{Pl}}$$

$$\simeq \frac{T_{RH}}{M_{Pl}}$$

Gravitino DM prob. :TRH~10^8 GeV

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DM

gD

DM

$$\frac{dn}{dT} = 3\frac{n}{T} - \ldots$$

Two p…

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$|\mathcal{M}\ldots$

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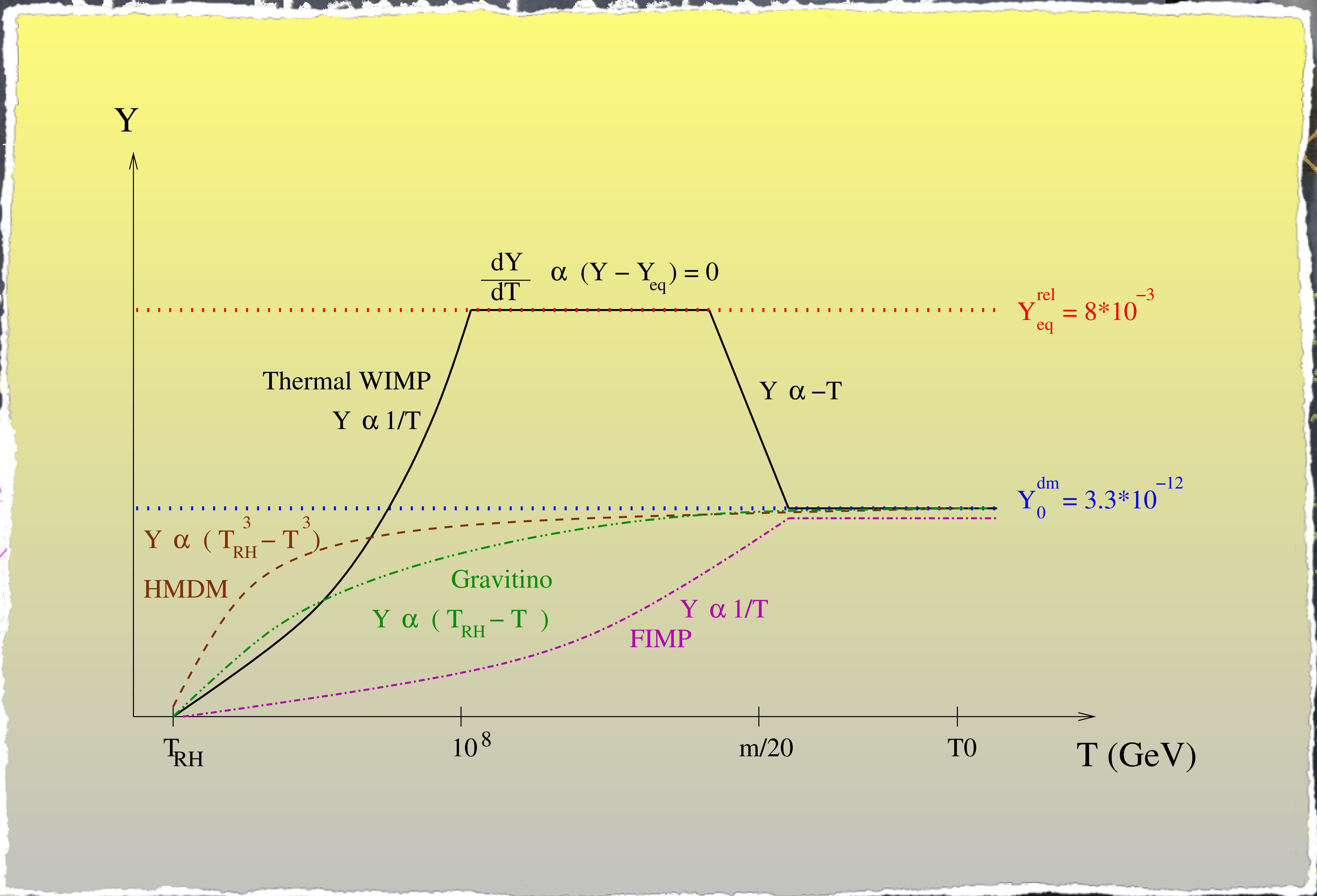

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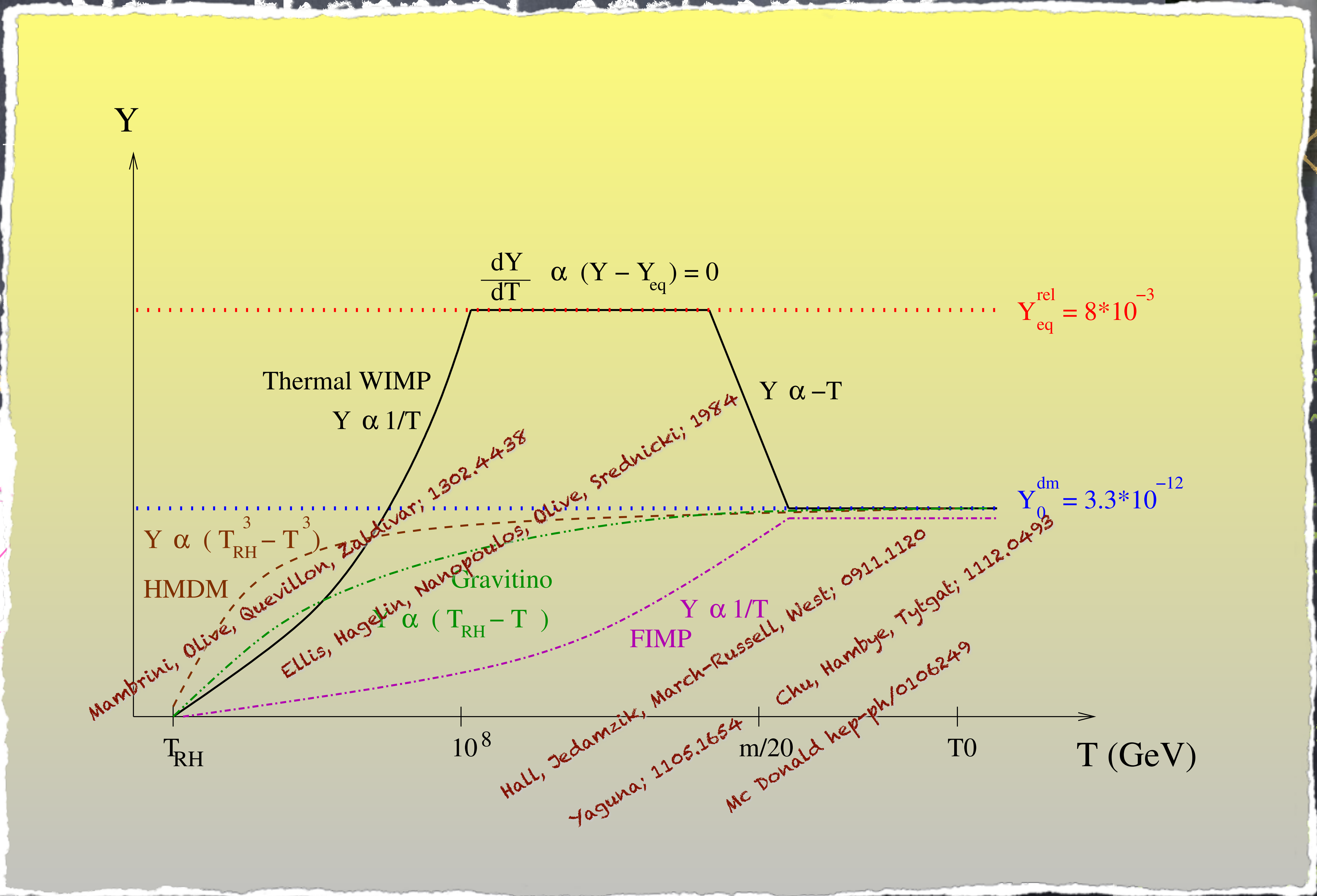

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