From an effective to a microscopic approach. The pros and cons

Yann Mambrini, LPT Orsay, University Paris XI

http://www.ymambrini.com/My_World/Physics.html

Dark Matter thematic day, 19th of June 2014

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)

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

1 : "Tentativo di una teoria dei raggi β", Ricerca Scientifica, 1933

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.*

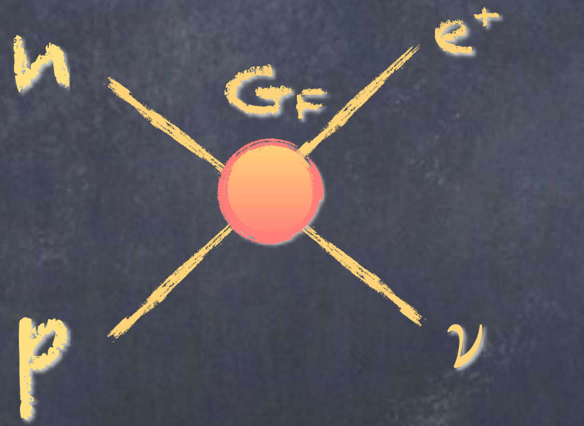
Ipotesi fondamentali della teoria.

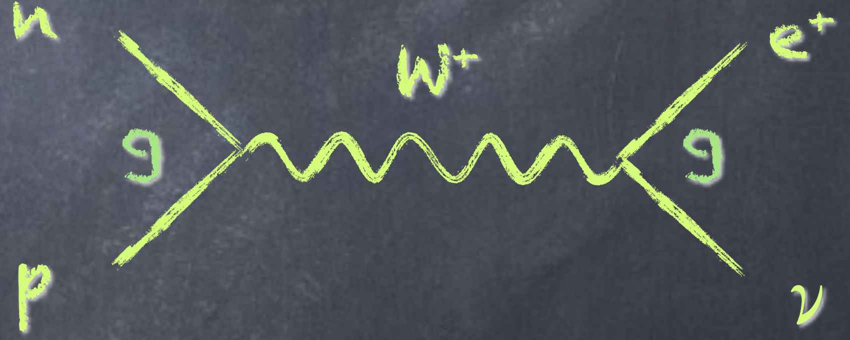
§ 1. Nel tentativo di costruire una teoria degli elettroni nucleari e dell'emissione dei raggi β, si incontrano, come è noto, due difficoltà principali. La prima dipende dal fatto che i raggi β primari vengono emessi dai nuclei con una distribuzione continua di velocità. Se non si vuole abbandonare il 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)





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

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

1 : "Tentativo di una teoria dei raggi β", Ricerca Scientifica, 1933

The effective approach applied to dark matter interaction

The effective approach applied to dark matter interaction

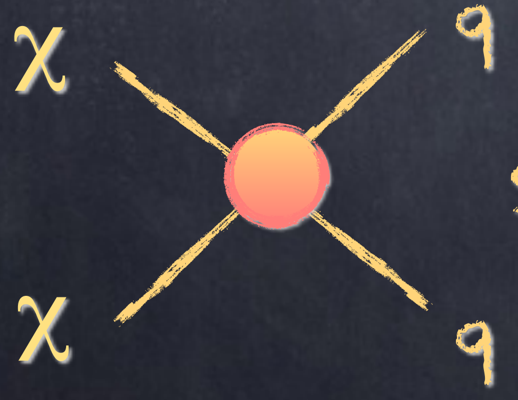
operator	annihilation $\langle \sigma v \rangle$	direct detection [A,v_0]
$g\ \bar{\chi}\chi\bar{q}q$	$\propto g^2 v^2$ [$\bar{\chi}\chi$: S=1, L=1]	SI $\propto g^2 A^2 \times f^N(q)$
$g\ \bar{\chi}\gamma^5\chi\bar{q}q$	$\propto g^2 m_q^2$ [$\bar{\chi}\gamma^5\chi$: S=0, L=0 $\Rightarrow J = 0$:h.f.]	0 [$\propto (v_0^\chi)^2$]
$g\ \bar{\chi}\chi\bar{q}\gamma^5 q$	$\propto g^2 v^2$ [$\bar{\chi}\chi$: S=1, L=1]	0 [$\propto (v_0^q)^2$]
$g\ \bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	$\propto g^2 m_q^2$ [$\bar{\chi}\gamma^5\chi$: S=0, L=0 $\Rightarrow J = 0$:h.f.]	0 [$\propto (v_0^q)^2 (v_0^\chi)^2$]
$g\ \bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$\propto g^2$	SI $\propto g^2 \times (2u+d) \times p_\chi . p_q$
$g\ \bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$\propto g^2$	0 [$\propto (v_0^q)^2$]
$g\ \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	0 [$\propto (v_0^\chi)^2$]
$g\ \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	SD $\propto g^2 \times (A-2Z)^2$

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

The effective approach applied to dark matter interaction

Scalar interaction
(Higgs portal)

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 $\propto g^2 A^2 \times f^N(q)$
$g\ \bar{\chi}\gamma^5\chi\bar{q}q$	$\propto g^2 m_q^2$ [$\bar{\chi}\gamma^5\chi$: S=0, L=0 $\Rightarrow J=0$:h.f.]	0 [$\propto (v_0^{\chi})^2$]
$g\ \bar{\chi}\chi\bar{q}\gamma^5 q$	$\propto g^2 v^2$ [$\bar{\chi}\chi$: S=1, L=1]	0 [$\propto (v_0^{q})^2$]
$g\ \bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	$\propto g^2 m_q^2$ [$\bar{\chi}\gamma^5\chi$: S=0, L=0 $\Rightarrow J=0$:h.f.]	0 [$\propto (v_0^{q})^2 (v_0^{\chi})^2$]
$g\ \bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$\propto g^2$	SI $\propto g^2 \times (2u+d) \times p_\chi . p_q$
$g\ \bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$\propto g^2$	0 [$\propto (v_0^{q})^2$]
$g\ \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	0 [$\propto (v_0^{\chi})^2$]
$g\ \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	SD $\propto g^2 \times (A-2Z)^2$



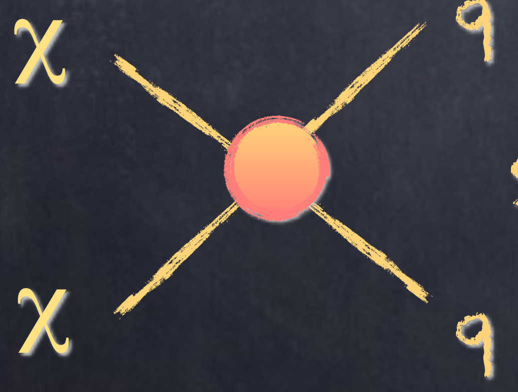
$g = \frac{1}{\Lambda^2}$ (Effective approach)

The effective approach applied to dark matter interaction

Scalar interaction
(Higgs portal)

Pseudoscalar interaction
(A exchange SUSY)

operator	annihilation $\langle\sigma v\rangle$	direct detection [A,v_0]
$g\ \bar{\chi}\chi\bar{q}q$	$\propto g^2v^2$ [$\bar{\chi}\chi$: S=1, L=1]	SI $\propto g^2A^2 \times f^N(q)$
$g\ \bar{\chi}\gamma^5\chi\bar{q}q$	$\propto g^2m_q^2$ [$\bar{\chi}\gamma^5\chi$: S=0, L=0 $\Rightarrow J=0$:h.f.]	0 [$\propto (v_0^\chi)^2$]
$g\ \bar{\chi}\chi\bar{q}\gamma^5q$	$\propto g^2v^2$ [$\bar{\chi}\chi$: S=1, L=1]	0 [$\propto (v_0^q)^2$]
$g\ \bar{\chi}\gamma^5\chi\bar{q}\gamma^5q$	$\propto g^2m_q^2$ [$\bar{\chi}\gamma^5\chi$: S=0, L=0 $\Rightarrow J=0$:h.f.]	0 [$\propto (v_0^q)^2(v_0^\chi)^2$]
$g\ \bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$\propto g^2$	SI $\propto g^2 \times (2u+d) \times p_\chi.p_q$
$g\ \bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5q$	$\propto g^2$	0 [$\propto (v_0^q)^2$]
$g\ \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	0 [$\propto (v_0^\chi)^2$]
$g\ \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	SD $\propto g^2 \times (A-2Z)^2$



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

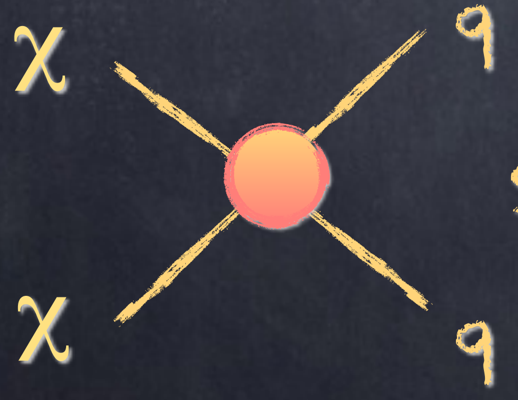
The effective approach applied to dark matter interaction

Scalar interaction (Higgs portal)

Pseudoscalar interaction (A exchange SUSY)

Vectorial interaction (γ / γ' exchange)

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 $\propto g^2 A^2 \times f^N(q)$
$g\ \bar\chi\gamma^5\chi\bar q q$	$\propto g^2 m_q^2$ [$\bar\chi\gamma^5\chi$: S=0, L=0 $\Rightarrow J=0$:h.f.]	0 [$\propto (v_0^\chi)^2$]
$g\ \bar\chi\chi\bar q\gamma^5 q$	$\propto g^2 v^2$ [$\bar\chi\chi$: S=1, L=1]	0 [$\propto (v_0^q)^2$]
$g\ \bar\chi\gamma^5\chi\bar q\gamma^5 q$	$\propto g^2 m_q^2$ [$\bar\chi\gamma^5\chi$: S=0, L=0 $\Rightarrow J=0$:h.f.]	0 [$\propto (v_0^q)^2 (v_0^\chi)^2$]
$g\ \bar\chi\gamma^\mu\chi\bar q\gamma_\mu q$	$\propto g^2$	SI $\propto g^2 \times (2u+d) \times p_\chi . p_q$
$g\ \bar\chi\gamma^\mu\chi\bar q\gamma_\mu\gamma^5 q$	$\propto g^2$	0 [$\propto (v_0^q)^2$]
$g\ \bar\chi\gamma^\mu\gamma^5\chi\bar q\gamma_\mu q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	0 [$\propto (v_0^\chi)^2$]
$g\ \bar\chi\gamma^\mu\gamma^5\chi\bar q\gamma_\mu\gamma^5 q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	SD $\propto g^2 \times (A-2Z)^2$



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

The effective approach applied to dark matter interaction

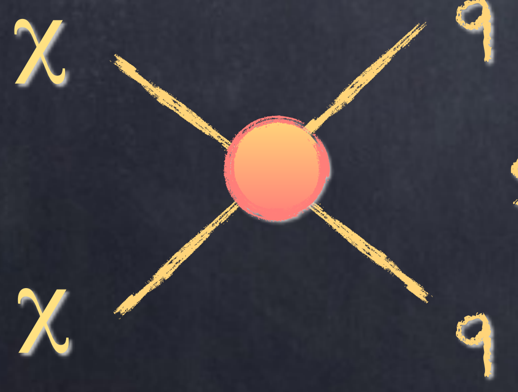
Scalar interaction
(Higgs portal)

Pseudoscalar interaction
(A exchange SUSY)

Vectorial interaction
(γ / γ' exchange)

Axial interaction
(Z/Z' exchange)

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 $\propto g^2 A^2 \times f^N(q)$
$g\ \bar\chi\gamma^5\chi\bar q q$	$\propto g^2 m_q^2$ [$\bar\chi\gamma^5\chi$: S=0, L=0 $\Rightarrow J = 0$:h.f.]	0 [$\propto (v_0^\chi)^2$]
$g\ \bar\chi\chi\bar q\gamma^5 q$	$\propto g^2 v^2$ [$\bar\chi\chi$: S=1, L=1]	0 [$\propto (v_0^q)^2$]
$g\ \bar\chi\gamma^5\chi\bar q\gamma^5 q$	$\propto g^2 m_q^2$ [$\bar\chi\gamma^5\chi$: S=0, L=0 $\Rightarrow J = 0$:h.f.]	0 [$\propto (v_0^q)^2(v_0^\chi)^2$]
$g\ \bar\chi\gamma^\mu\chi\bar q\gamma_\mu q$	$\propto g^2$	SI $\propto g^2 \times (2u+d) \times p_\chi.p_q$
$g\ \bar\chi\gamma^\mu\chi\bar q\gamma_\mu\gamma^5 q$	$\propto g^2$	0 [$\propto (v_0^q)^2$]
$g\ \bar\chi\gamma^\mu\gamma^5\chi\bar q\gamma_\mu q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	0 [$\propto (v_0^\chi)^2$]
$g\ \bar\chi\gamma^\mu\gamma^5\chi\bar q\gamma_\mu\gamma^5 q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	SD $\propto g^2 \times (A-2Z)^2$



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

The effective approach applied to dark matter interaction

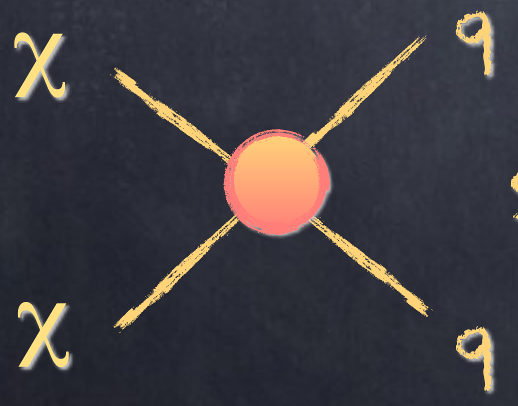
Scalar interaction (Higgs portal)

Pseudoscalar interaction (A exchange SUSY)

Vectorial interaction (γ / γ' exchange)

Axial interaction (Z/Z' exchange)

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 $\propto g^2 A^2 \times f^N(q)$
$g\ \bar{\chi}\gamma^5\chi\bar{q}q$	$\propto g^2 m_q^2$ [$\bar{\chi}\gamma^5\chi$: S=0, L=0 $\Rightarrow J=0$:h.f.]	0 [$\propto (v_0^\chi)^2$]
$g\ \bar{\chi}\chi\bar{q}\gamma^5 q$	$\propto g^2 v^2$ [$\bar{\chi}\chi$: S=1, L=1]	0 [$\propto (v_0^q)^2$]
$g\ \bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	$\propto g^2 m_q^2$ [$\bar{\chi}\gamma^5\chi$: S=0, L=0 $\Rightarrow J=0$:h.f.]	0 [$\propto (v_0^q)^2 (v_0^\chi)^2$]
$g\ \bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$\propto g^2$	SI $\propto g^2 \times (2u+d) \times p_\chi.p_q$
$g\ \bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$\propto g^2$	0 [$\propto (v_0^q)^2$]
$g\ \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	0 [$\propto (v_0^\chi)^2$]
$g\ \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	SD $\propto g^2 \times (A-2Z)^2$



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

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

The effective approach applied to dark matter interaction

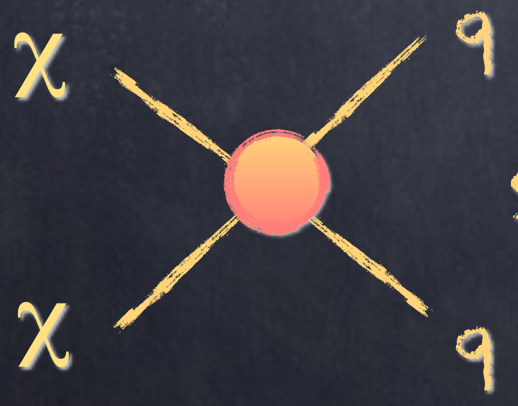
Scalar interaction
(Higgs portal)

Pseudoscalar interaction
(A exchange SUSY)

Vectorial interaction
(γ / γ' exchange)

Axial interaction
(Z/Z' exchange)

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 $\propto g^2 A^2 \times f^N(q)$
$g\ \bar{\chi}\gamma^5\chi\bar{q}q$	$\propto g^2 m_q^2$ [$\bar{\chi}\gamma^5\chi$: S=0, L=0 $\Rightarrow J = 0$:h.f.]	0 [$\propto (v_0^{\chi})^2$]
$g\ \bar{\chi}\chi\bar{q}\gamma^5 q$	$\propto g^2 v^2$ [$\bar{\chi}\chi$: S=1, L=1]	0 [$\propto (v_0^{q})^2$]
$g\ \bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	$\propto g^2 m_q^2$ [$\bar{\chi}\gamma^5\chi$: S=0, L=0 $\Rightarrow J = 0$:h.f.]	0 [$\propto (v_0^{q})^2(v_0^{\chi})^2$]
$g\ \bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$\propto g^2$	SI $\propto g^2 \times (2u+d) \times p_\chi . p_q$
$g\ \bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$\propto g^2$	0 [$\propto (v_0^{q})^2$]
$g\ \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	0 [$\propto (v_0^{\chi})^2$]
$g\ \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$\propto m_q^2$ [L=0,S=0(C=1) $\Rightarrow$ J=0:h.f.]	SD $\propto g^2 \times (A-2Z)^2$



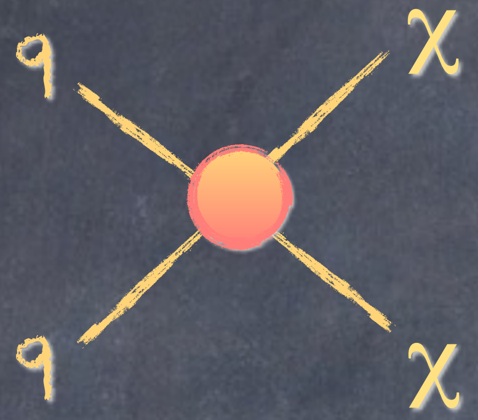
$g = \frac{1}{\Lambda^2}$ (Effective approach)

DM ... tion at LHC
(... rity)
(sy...
(multi-wavele... ...n)

Valid?

Limits of the effective theory approach

Limits of the effective theory approach

1) 

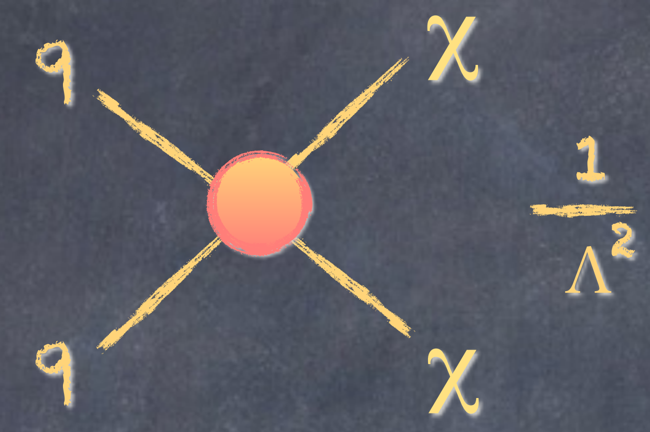
$\frac{1}{\Lambda^2}$

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

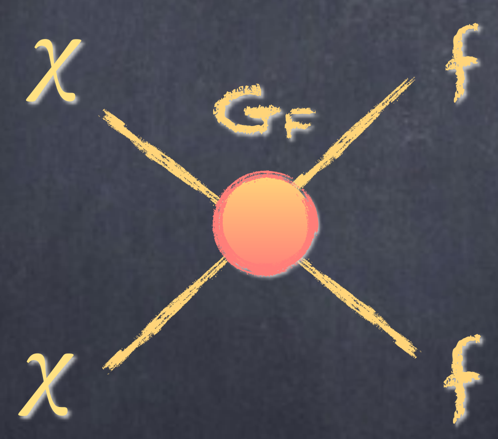
1)



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])

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).

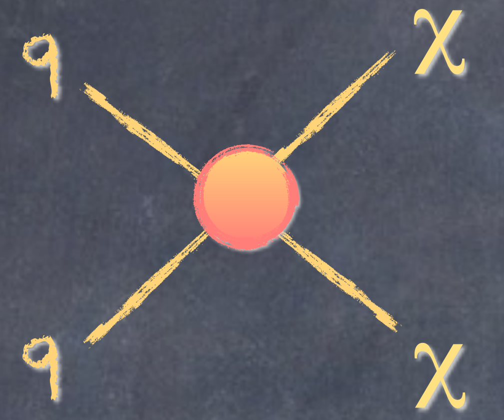
This bound is coming from the approximation $< \sigma v > \sim (G_F M_\chi)^2 > 10^{-9}$ GeV^{-2} [WMAP]

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

Limits of

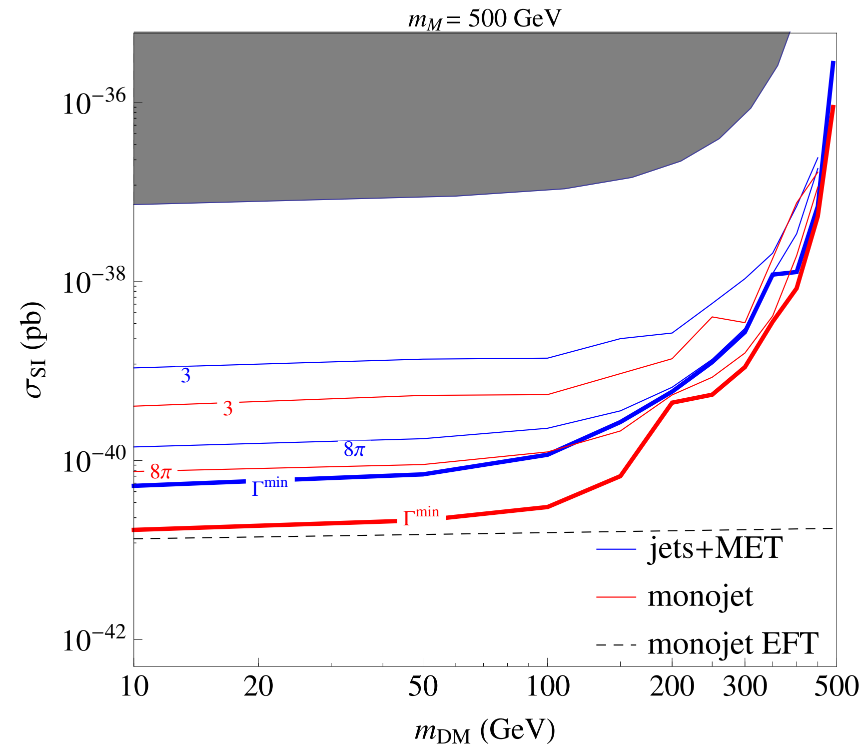
3)

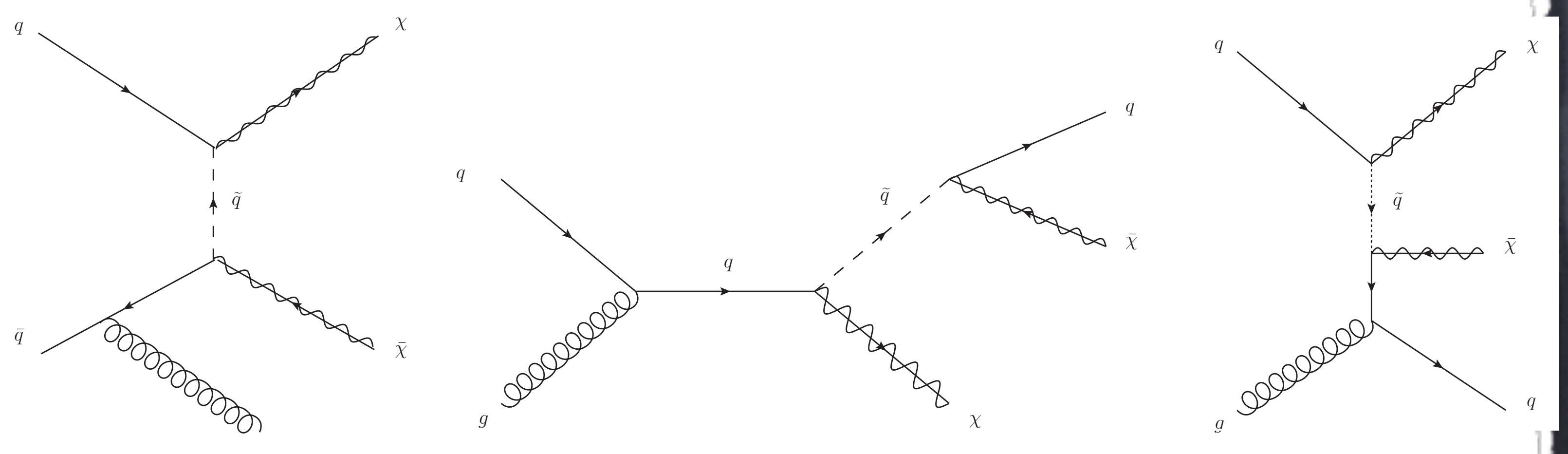
1)



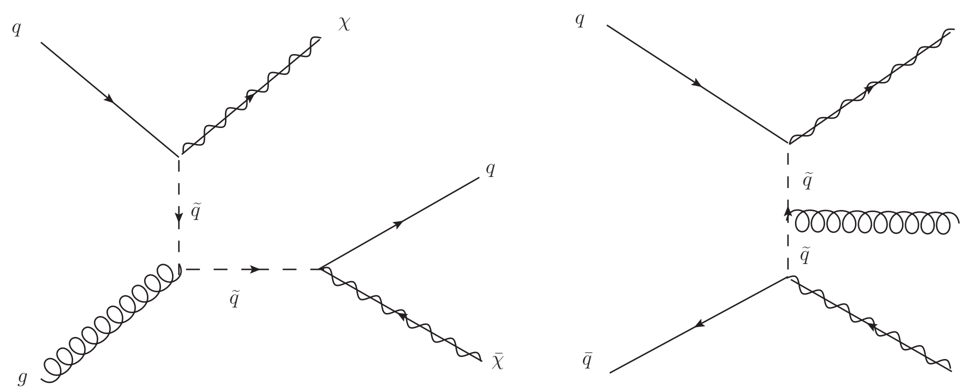
2)

Limit of the approach
Papucci, Zurek [1402.2285]





(a) (b) (c)



Limits of

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

1)

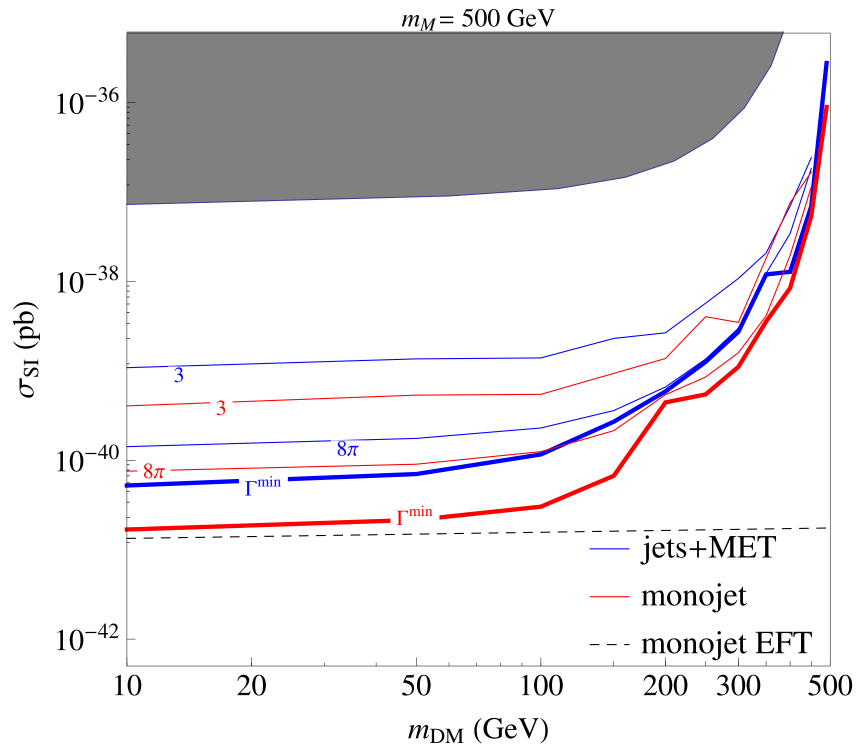
q

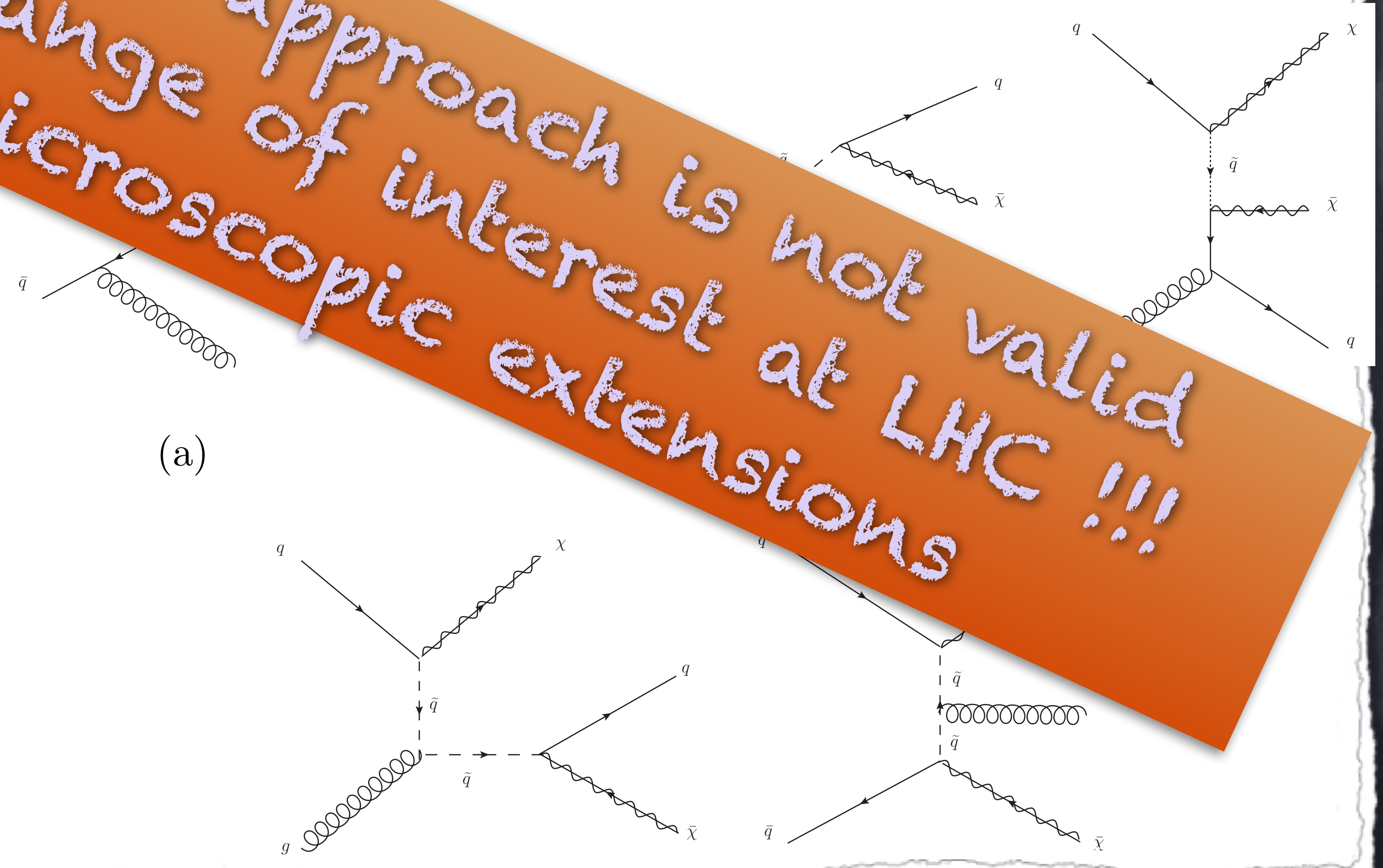
2)

3)

approach

2.2285]

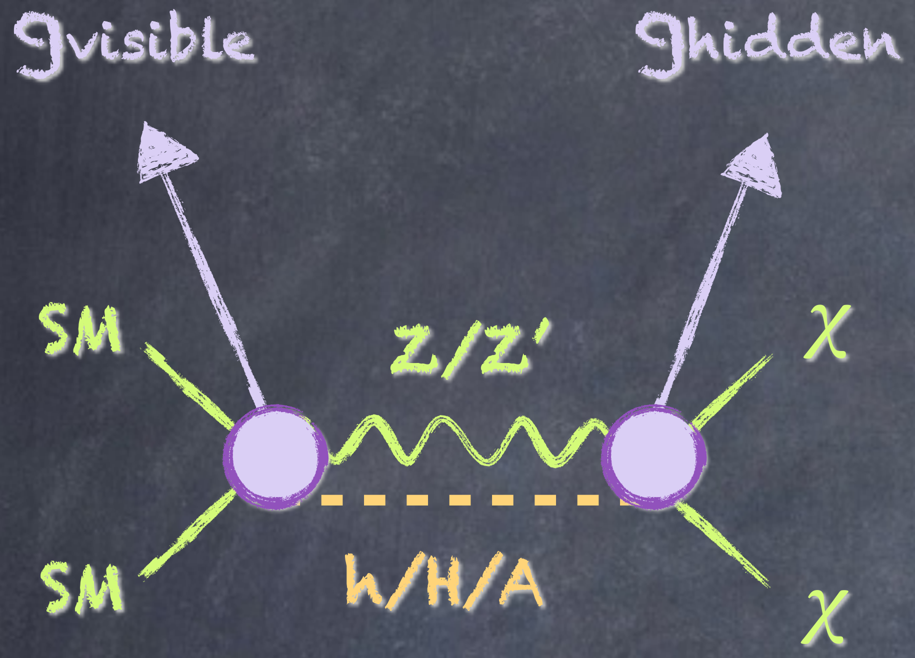




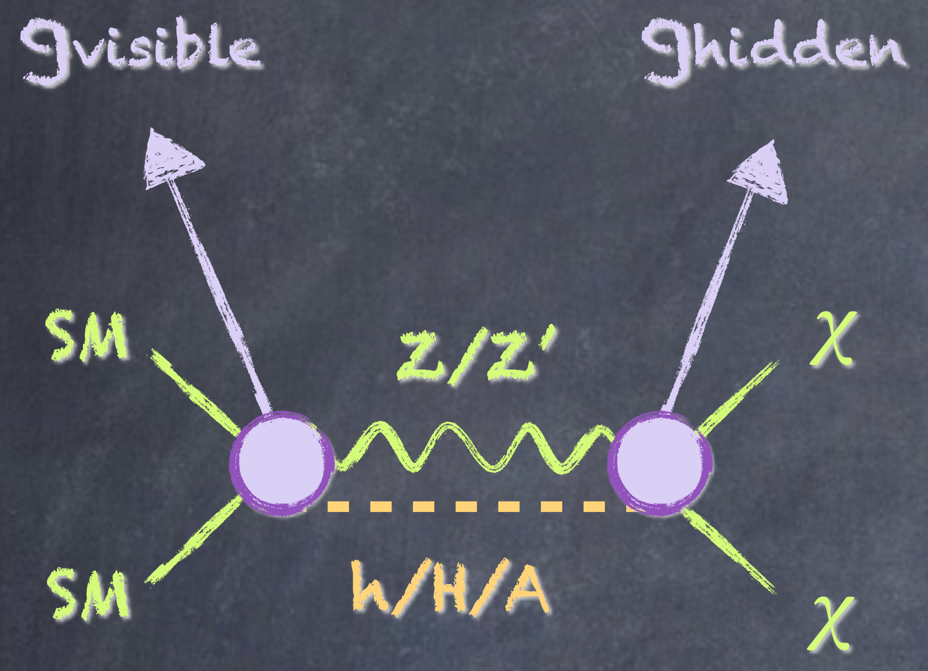
(a)

« vices et vertues » of combined analysis

« vices et vertues » of combined analysis



« vices et vertues » of combined analysis



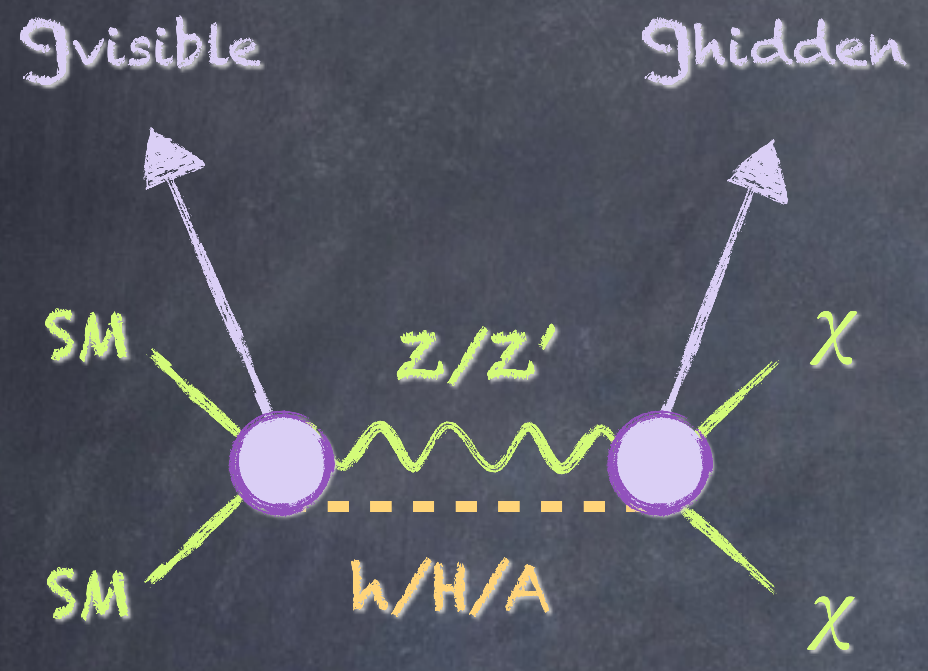
Tendencies:

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:

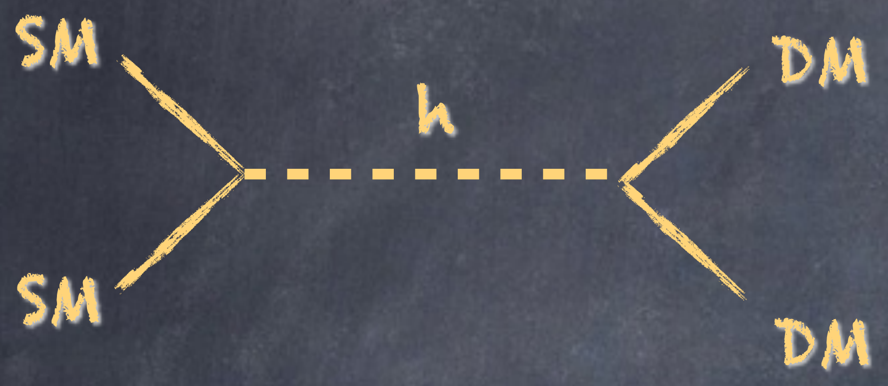
Large $g_{visible}$ is strongly constrained by LHC

Large g_{hidden} is strongly constrained by DD experiments

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

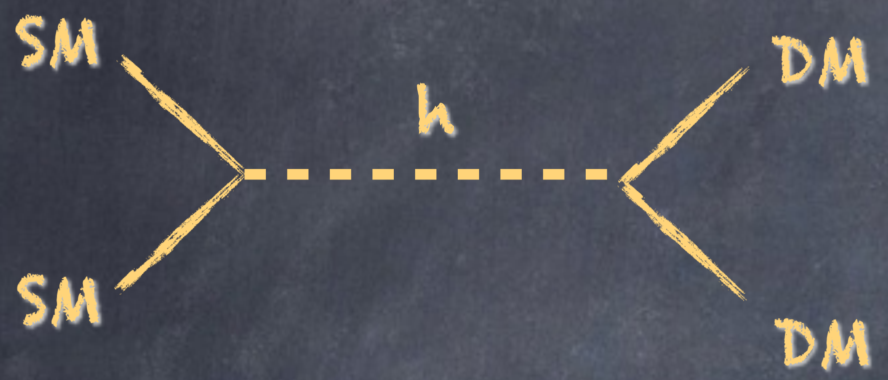
What are the possible mediators?

What are the possible mediators?



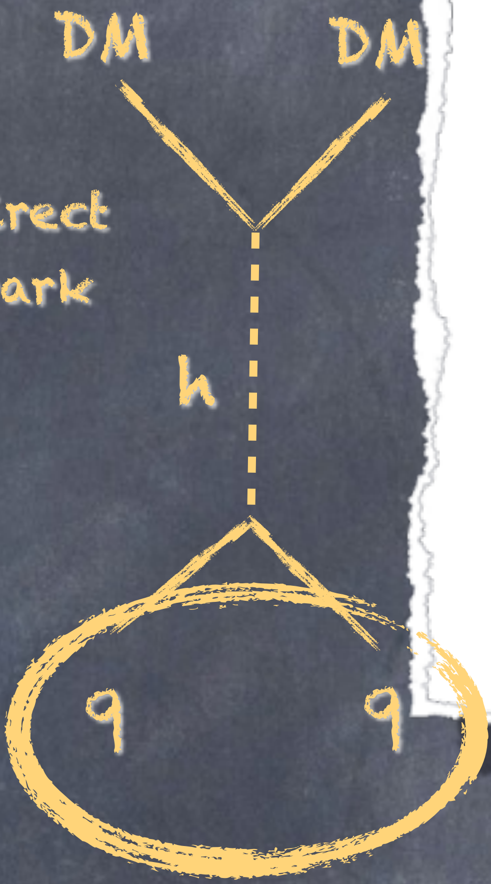
Higgs portal
darkons
phantom DM

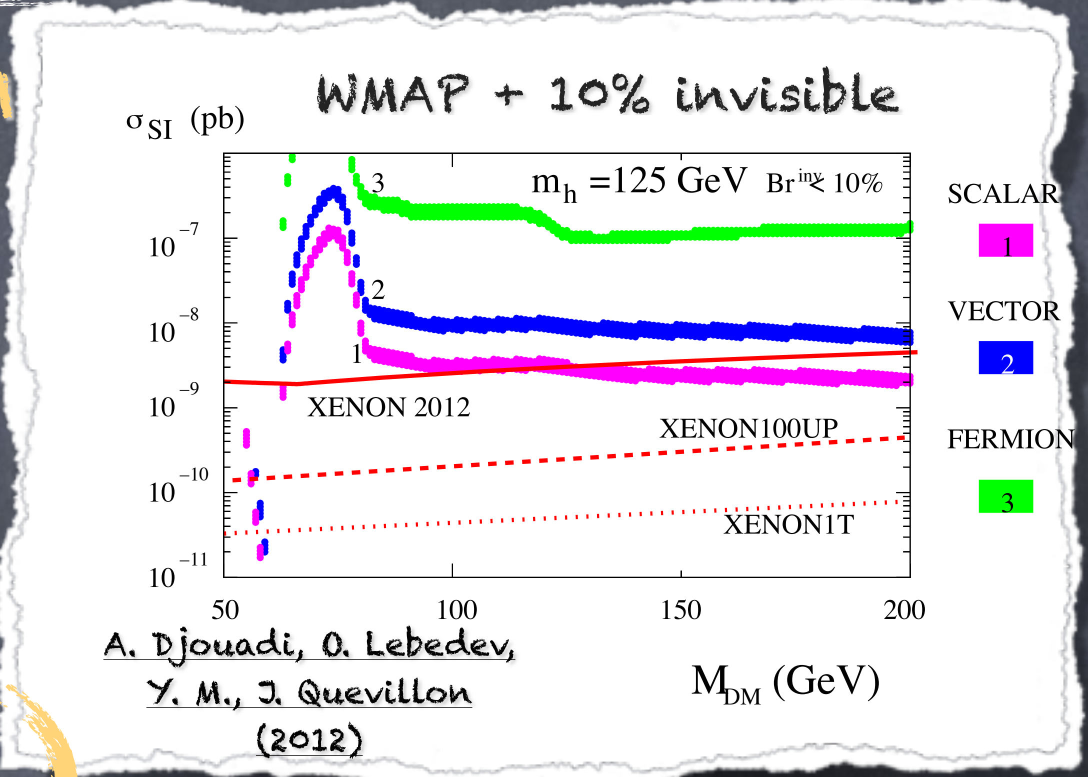
What are the possible mediators?



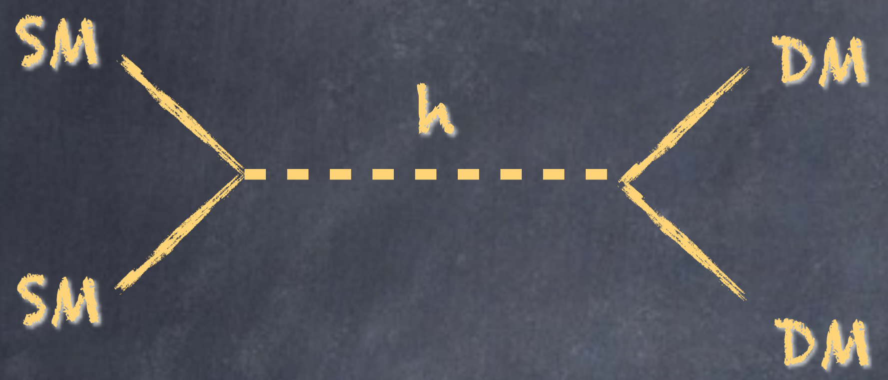
Higgs portal
darkons
phantom DM

Excluded by direct
detection of Dark
Matter



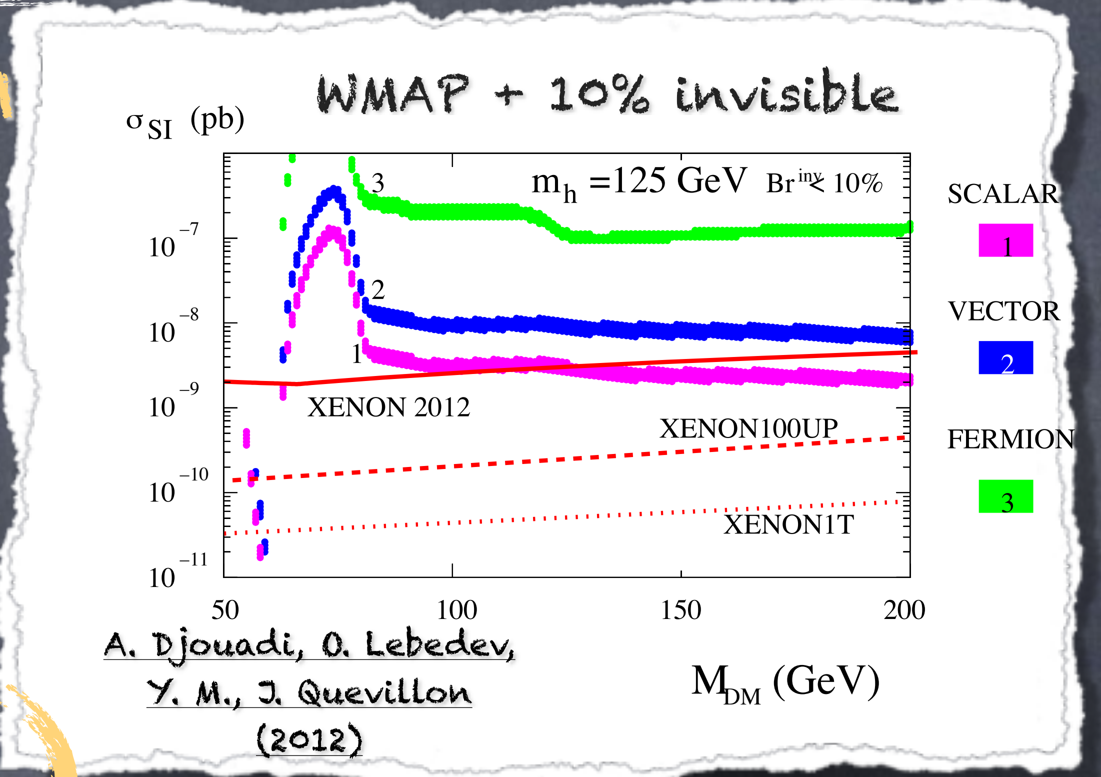


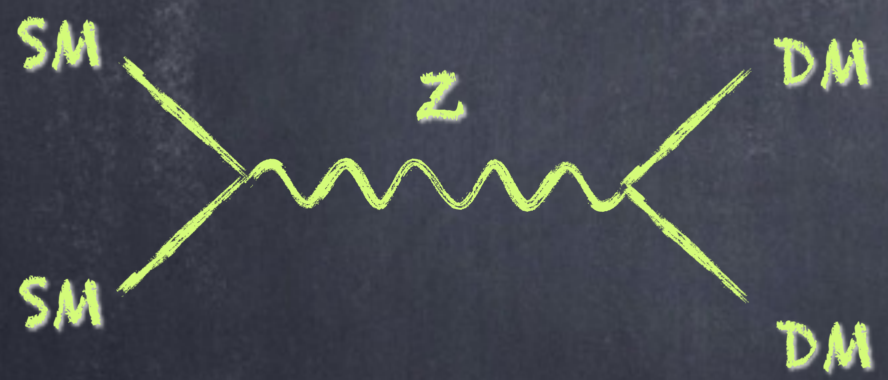
What are the possible mediators?



Higgs portal
darkons
phantom DM

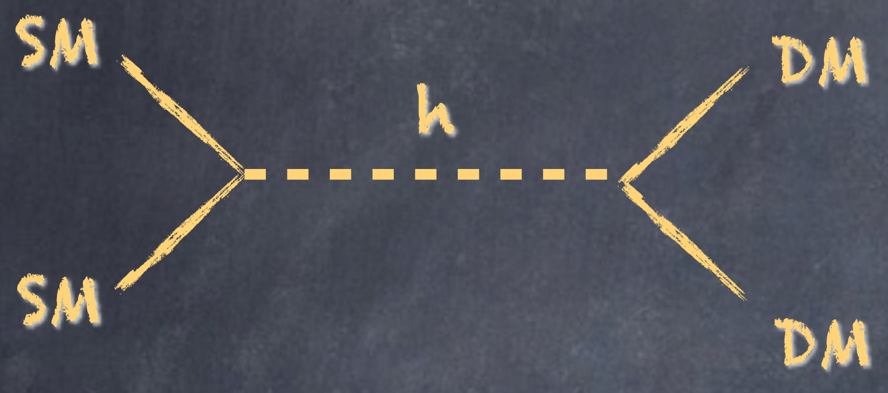
Excluded by direct
detection of Dark
Matter





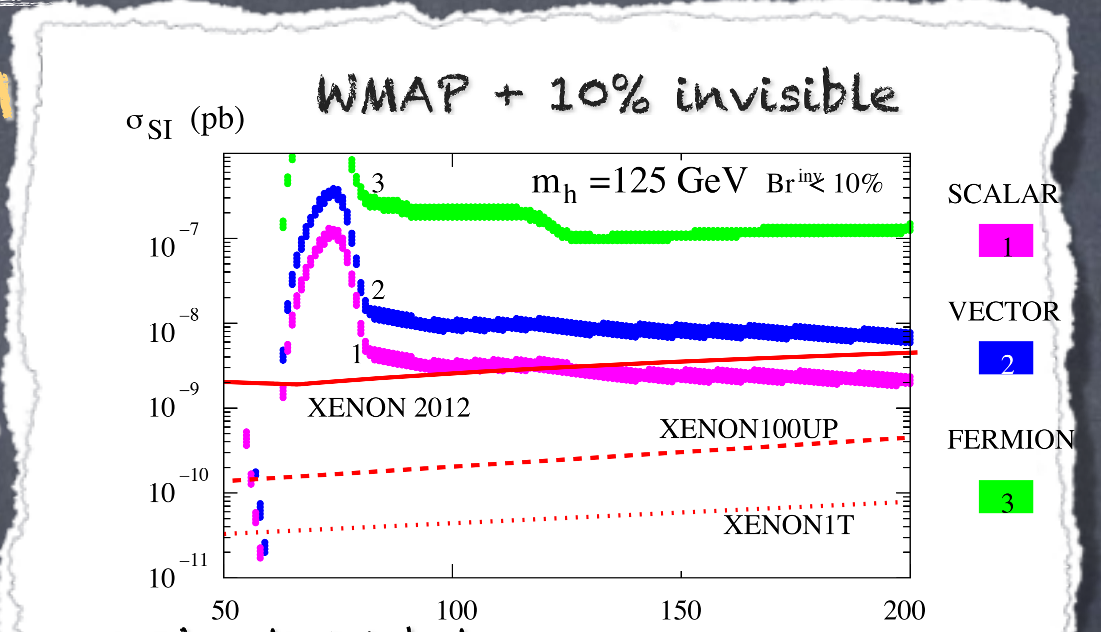
Z portal
(sneutrino dark
matter)

What are the possible mediators?

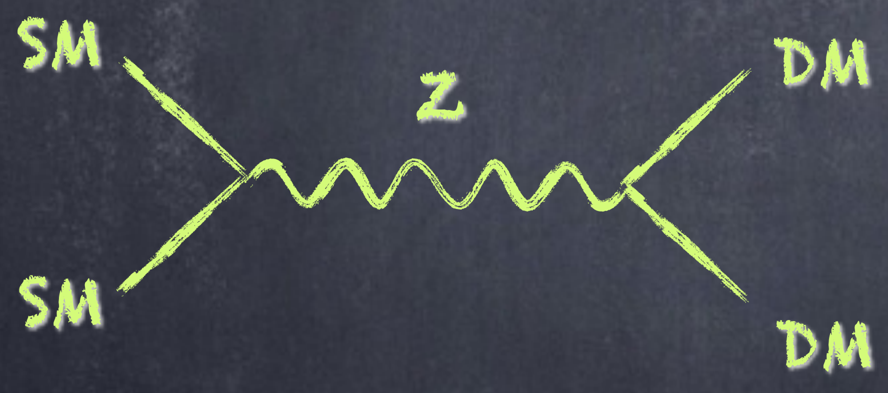


Higgs portal
darkons
phantom DM

Excluded by direct
detection of Dark
Matter



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

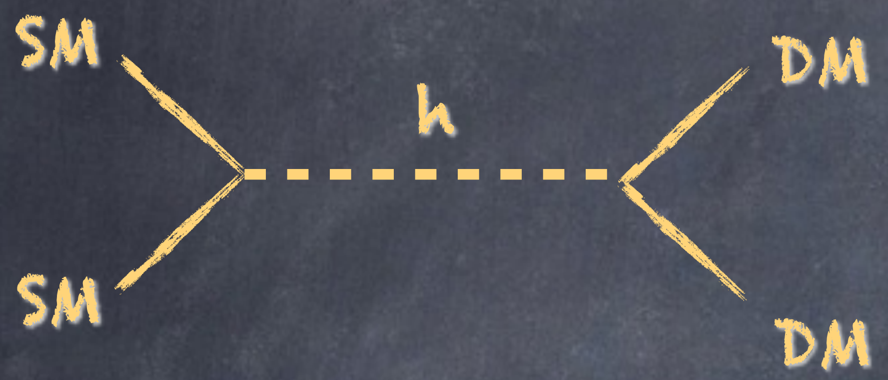


Z portal
(sneutrino dark
matter)

Excluded by direct
detection of Dark
Matter

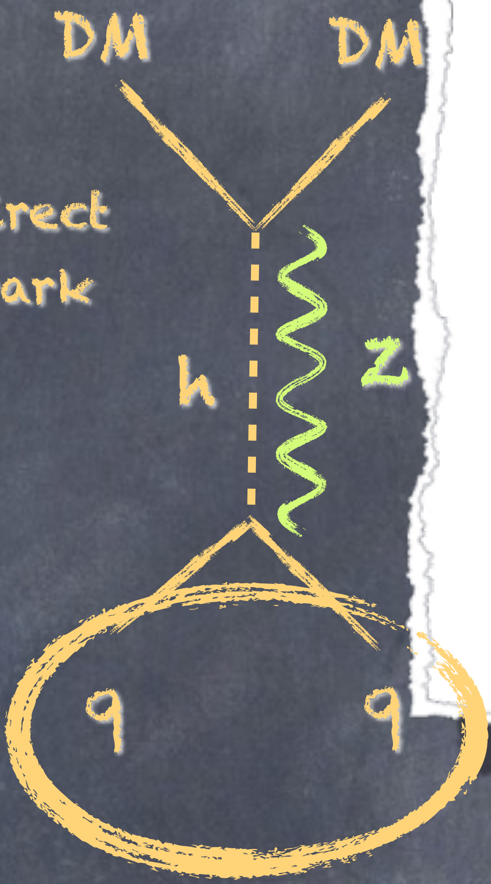
Falk, Olive, Srednicki
(1994)

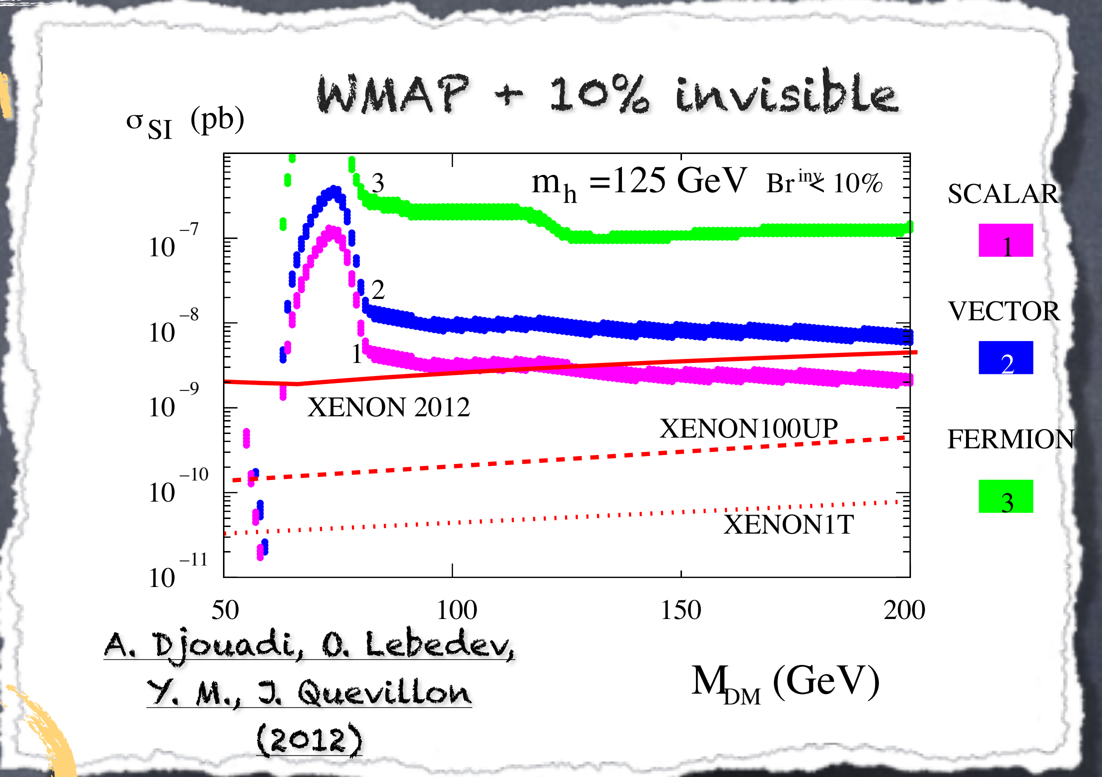
What are the possible mediators?

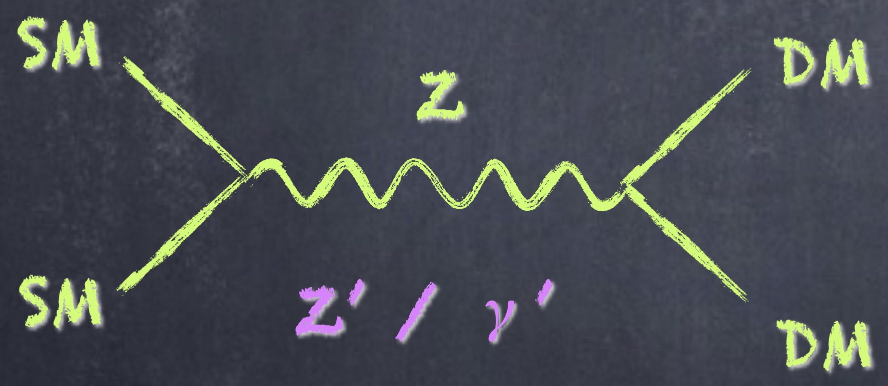


Higgs portal
darkons
phantom DM

Excluded by direct detection of Dark Matter







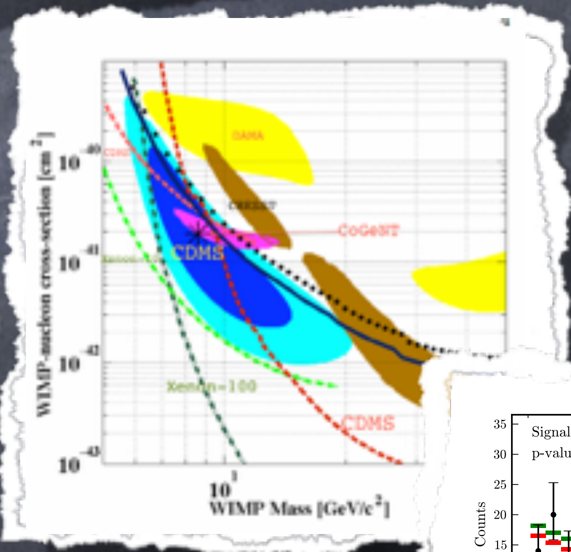
Z portal
(sneutrino dark matter)

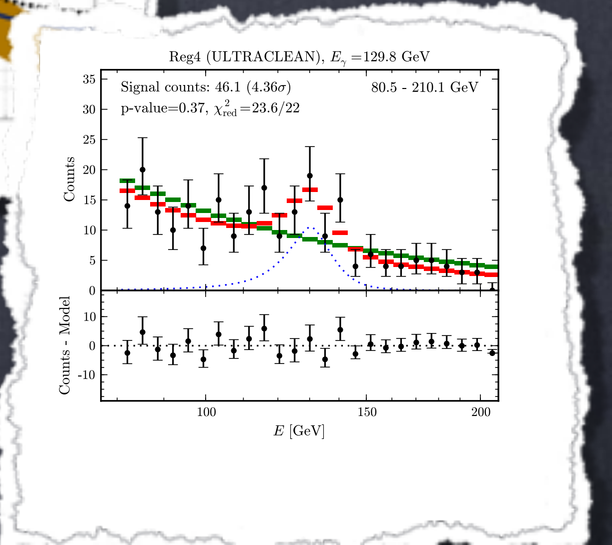
Excluded by direct detection of Dark Matter

Falk, Olive, Srednicki
(1994)

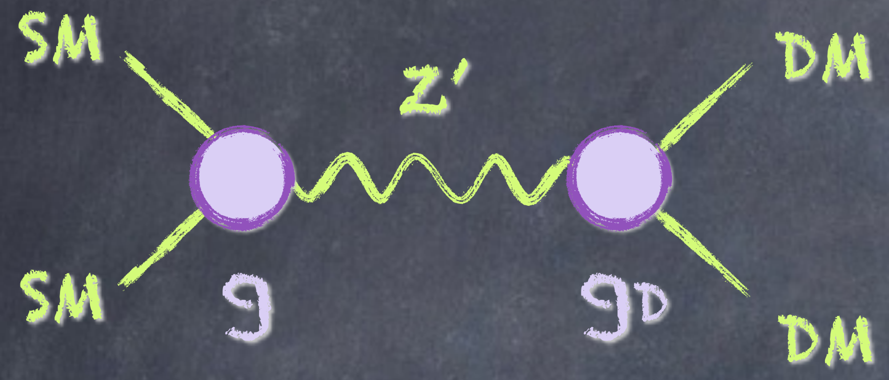
Z′ portal
Hidden photon
(mirror dark matter)

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

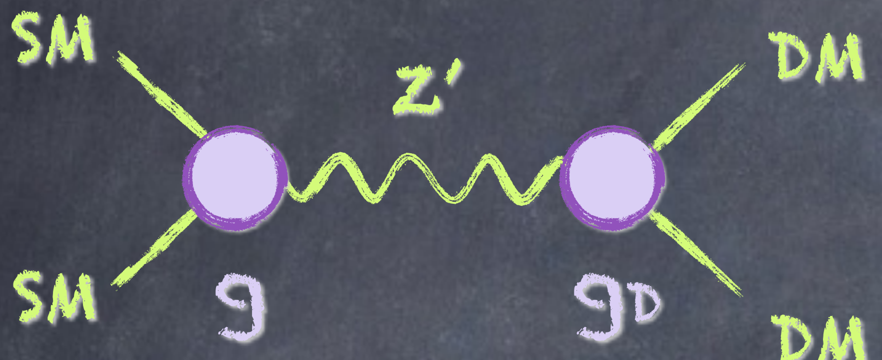


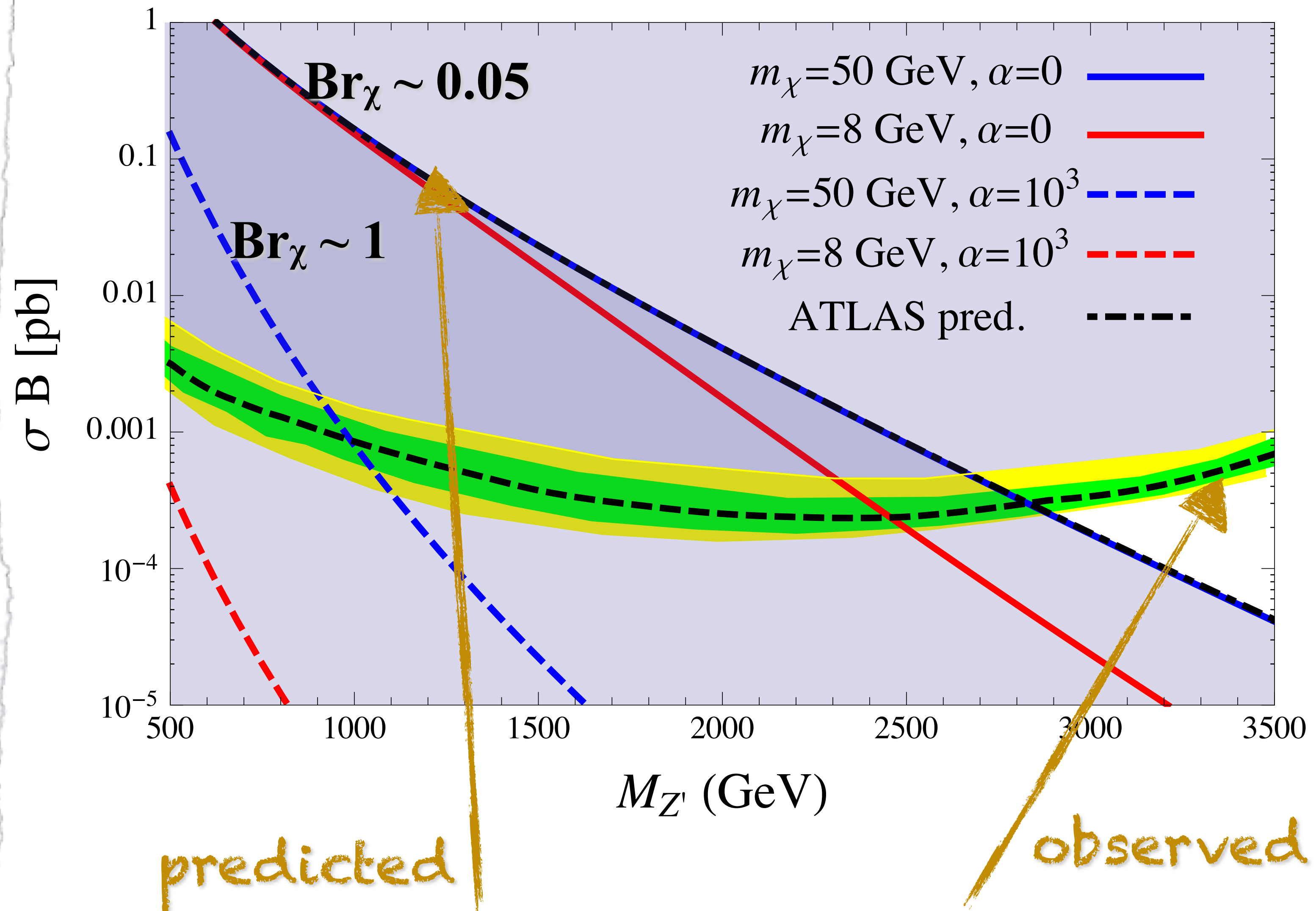


The Z′ case



The Z′ case

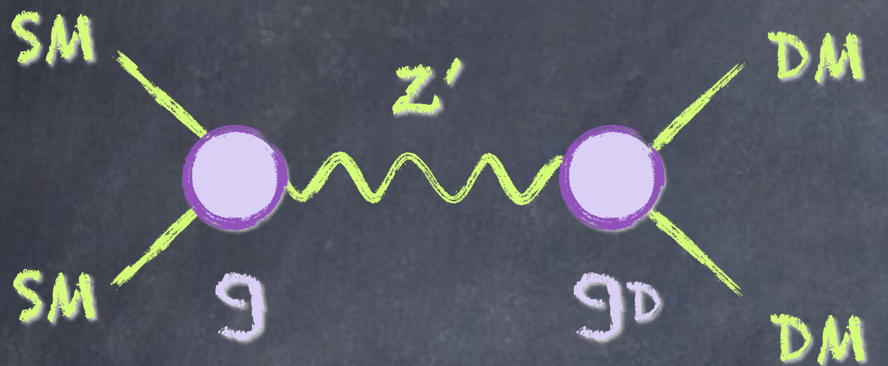


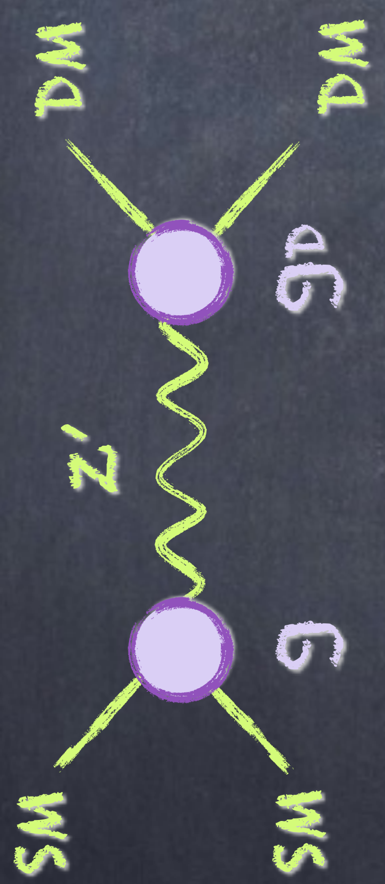


LHC production rate of a Z′ (B-L)

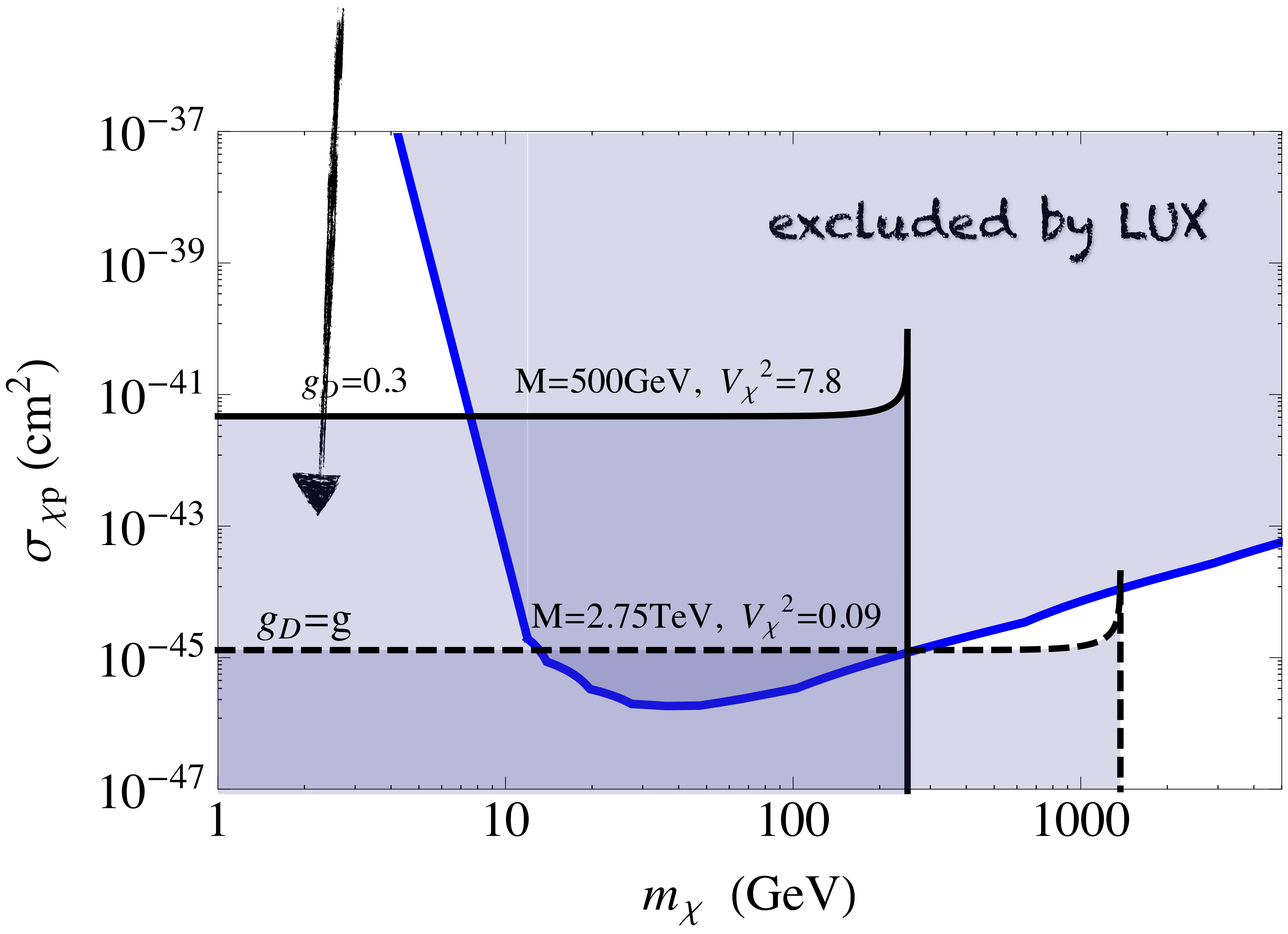
$g_D = 0$, $M_{Z'} > 2.85$ TeV

$g_D = 10^3\, g$, $M_{Z'} > 250$ GeV



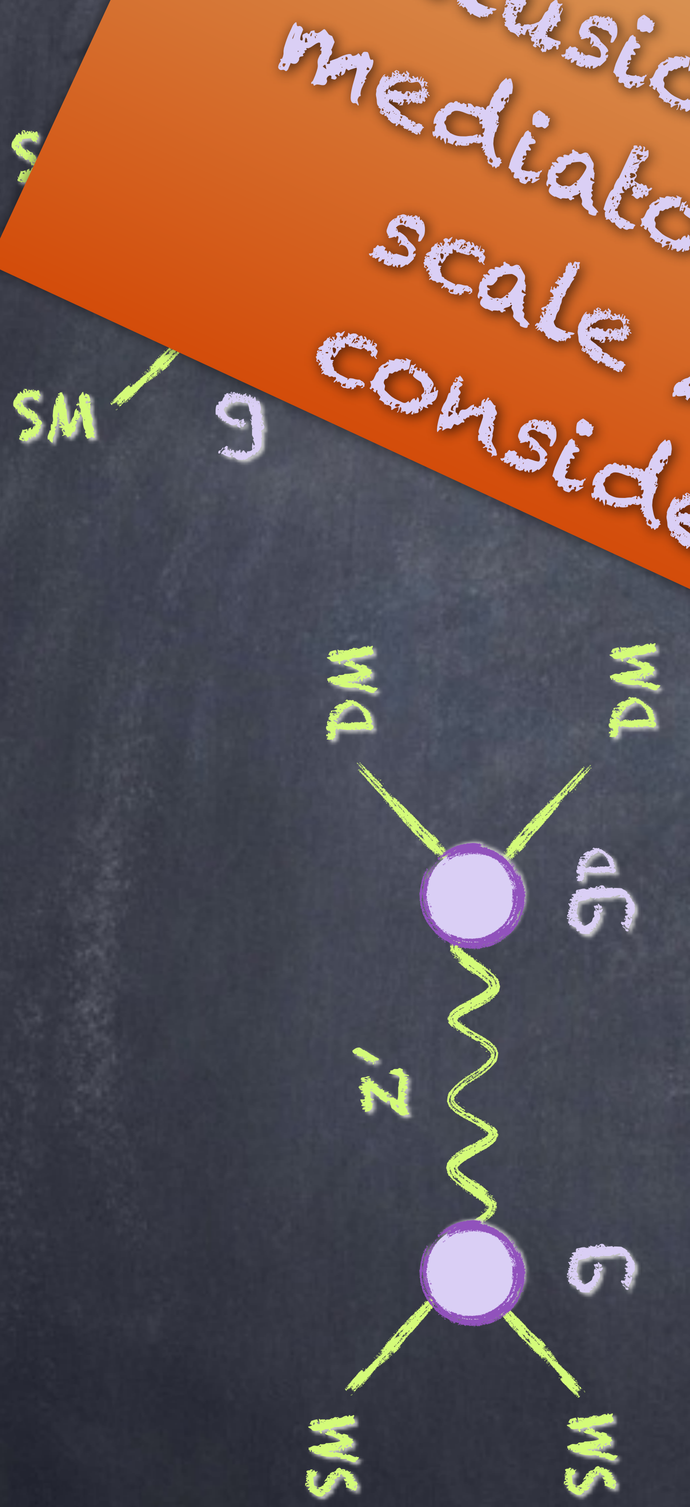


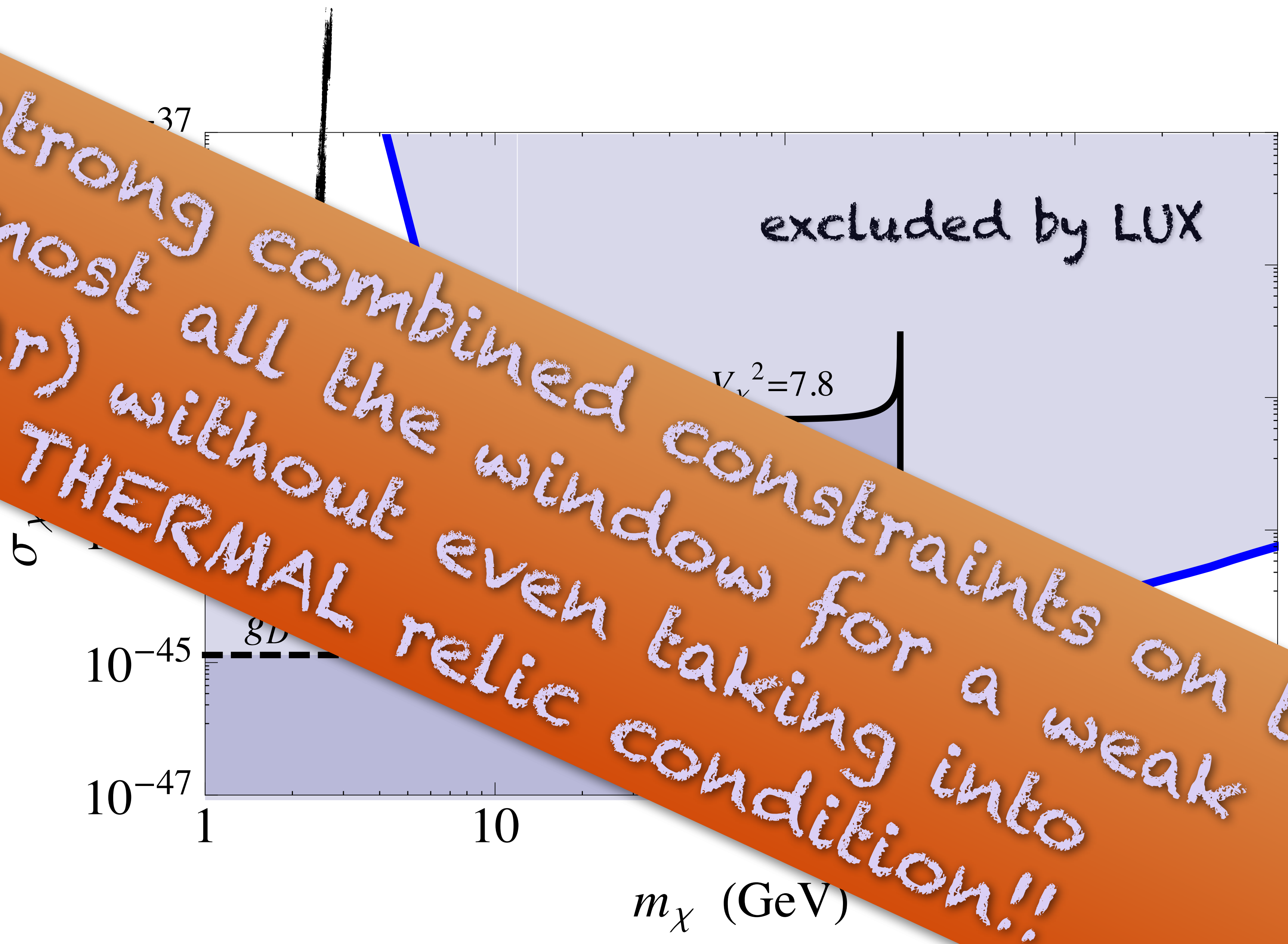
Excluded because small dark coupling gD
=> Z' produced abundantly at LHC:
this gives a LOWER bound on DD cross section



LHC + LUX limits

Excluded because small dark coupling g_D
=> Z' produced abundantly at LHC:
this gives a LOWER bound on DD cross section

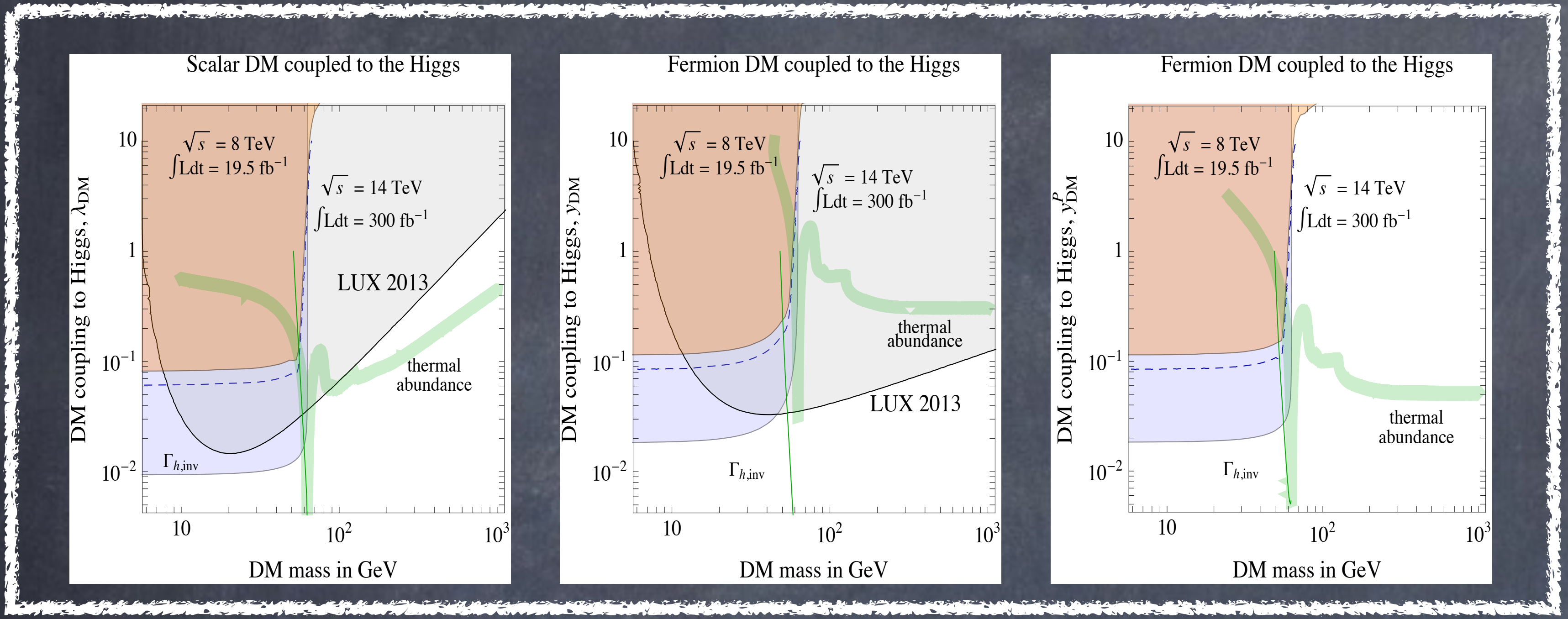




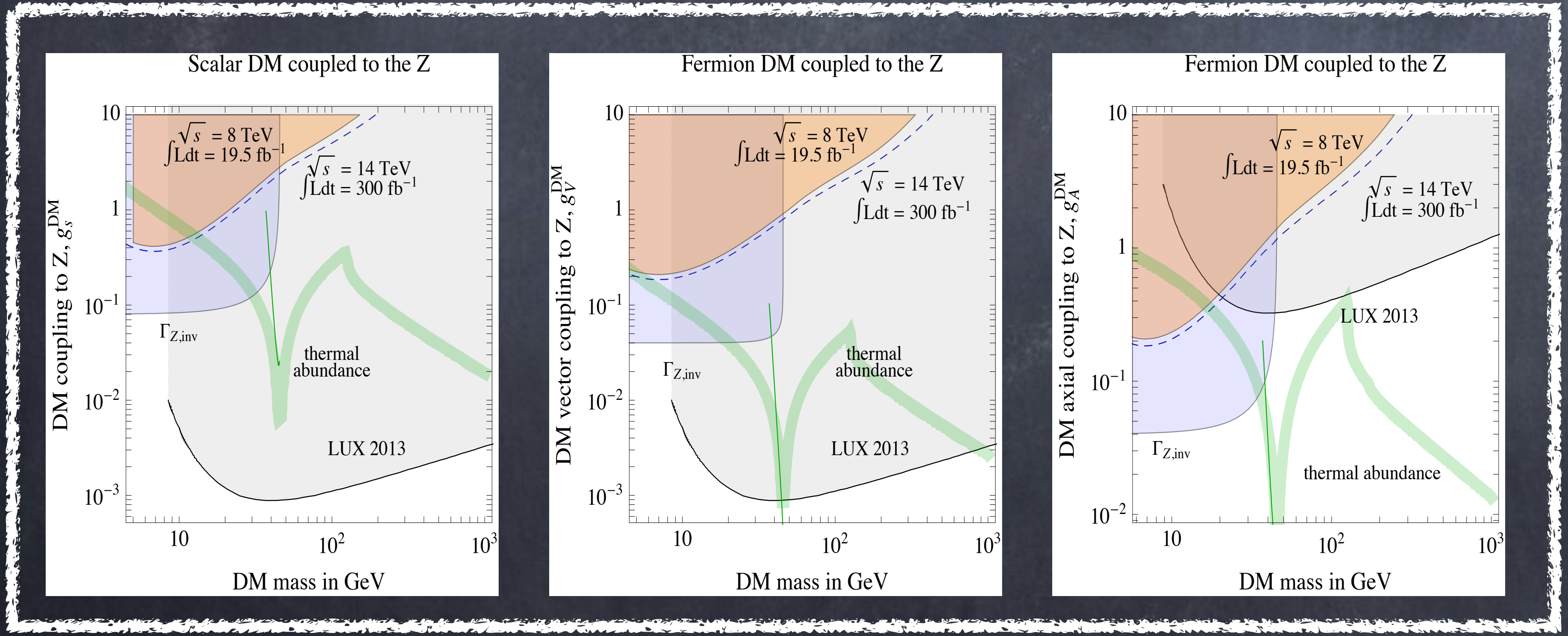
LHC + LUX limits

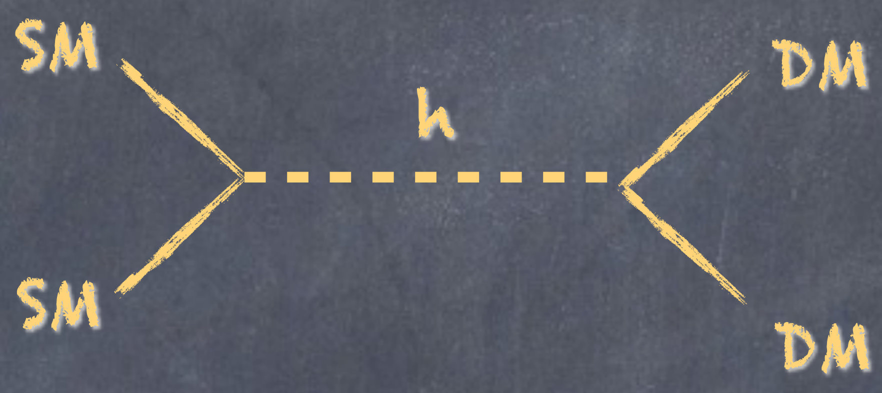
Conclusion 2: very strong combined constraints on the mediator close almost all the window for a weak scale Z' (or scalar) without even taking into consideration the THERMAL relic condition!!

Beyond the basics couplings

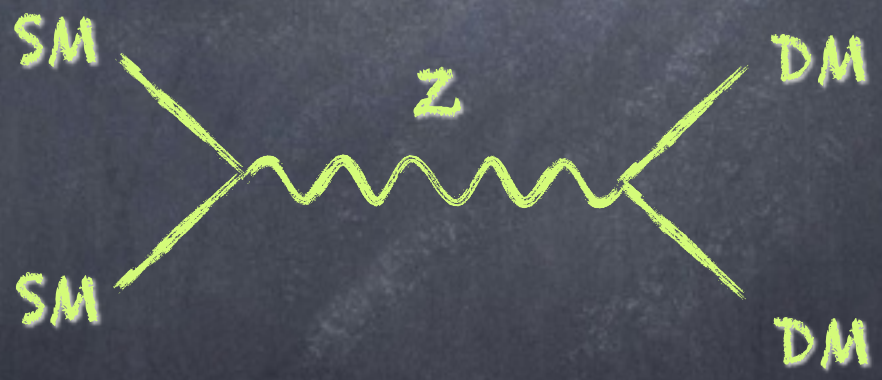


A. De Simonea, G. F. Giudice, A. Strumia, 1402.628



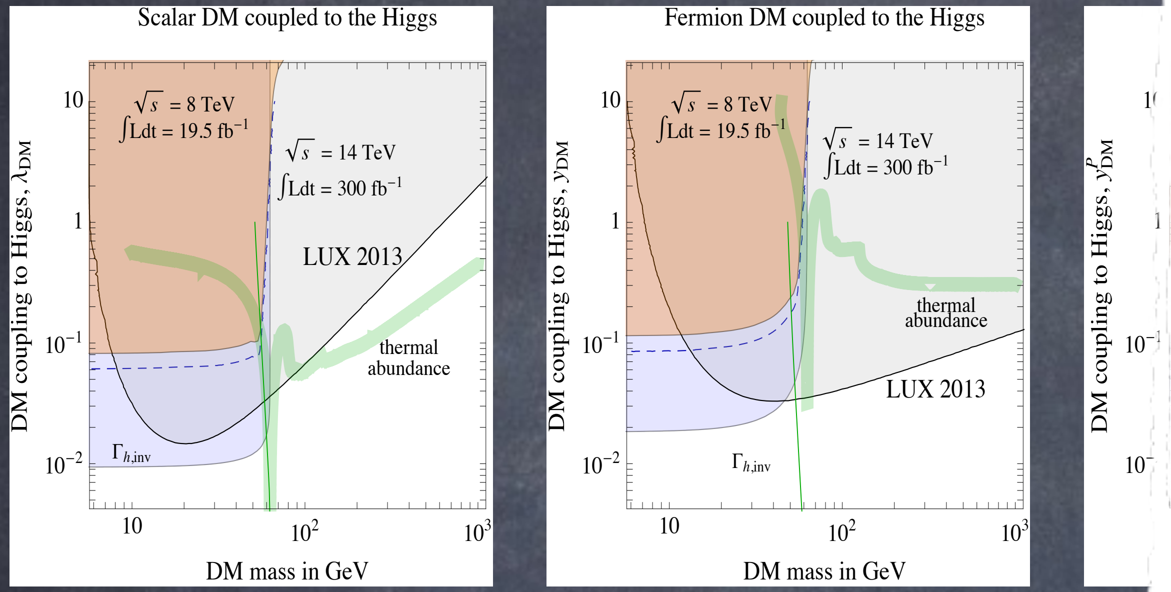


$$\mathcal{L} = -H^\dagger H\left[\bar\psi_{\rm DM}\frac{(y_{\rm DM} + i y^P_{\rm DM}\gamma_5)}{2v}\psi_{\rm DM} + \frac{\lambda_{\rm DM}}{4}s^2_{\rm DM}\right].$$

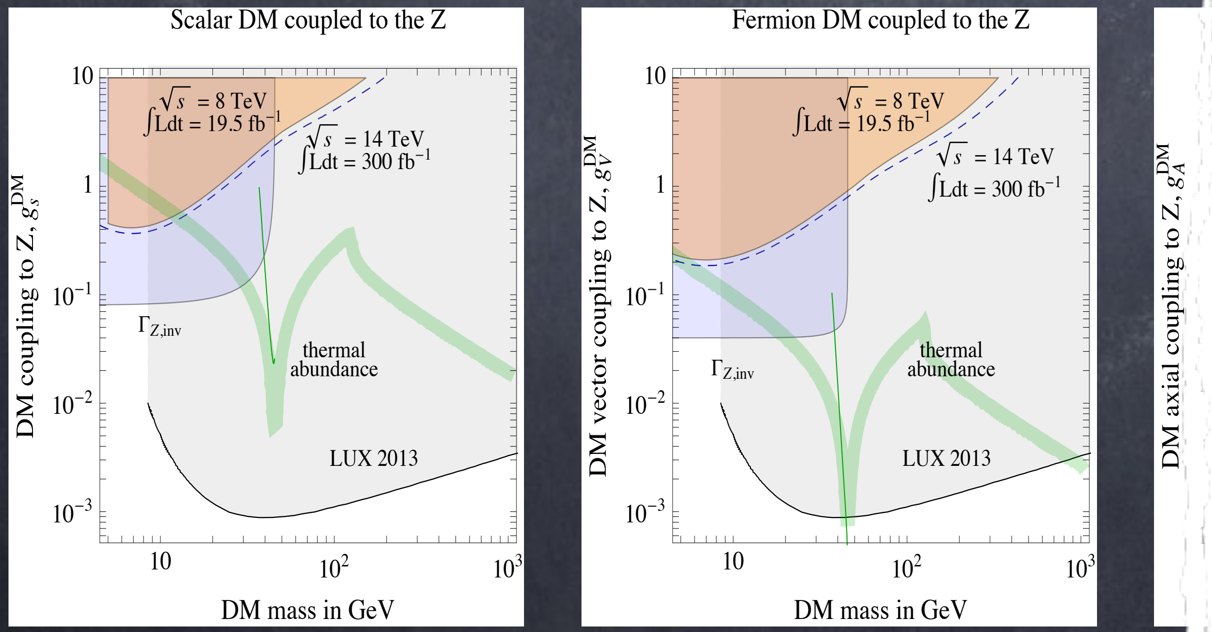


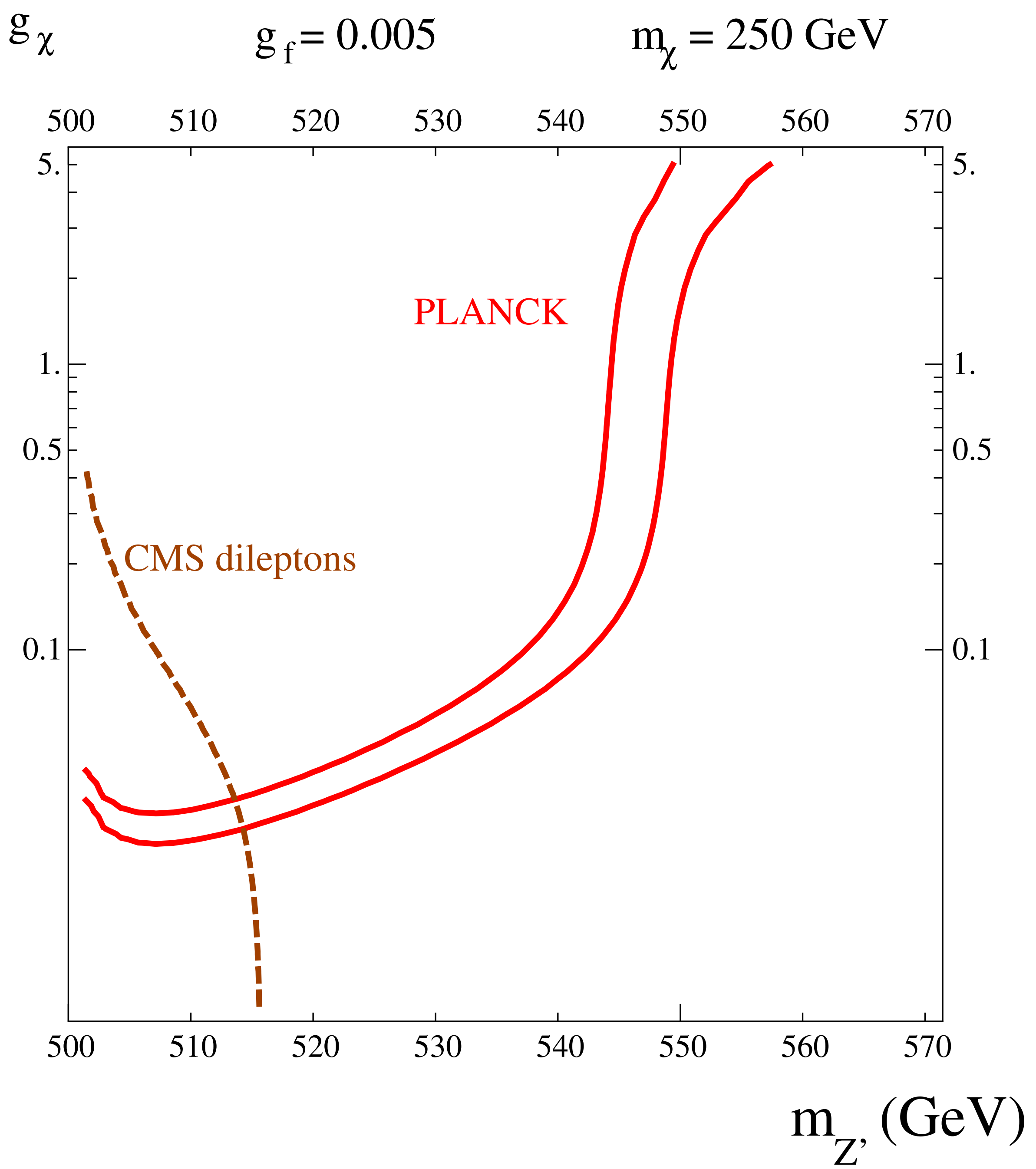
$$\mathcal{L} = \frac{4i}{v^2}(H^\dagger D^\mu H)\Big[\bar\psi_{\rm DM}\gamma_\mu(g_V^{\rm DM} + \gamma_5 g_A^{\rm DM})\psi_{\rm DM} + g_s^{\rm DM}(s^*_{\rm DM}(i\partial_\mu s_{\rm DM}$$

Beyond



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

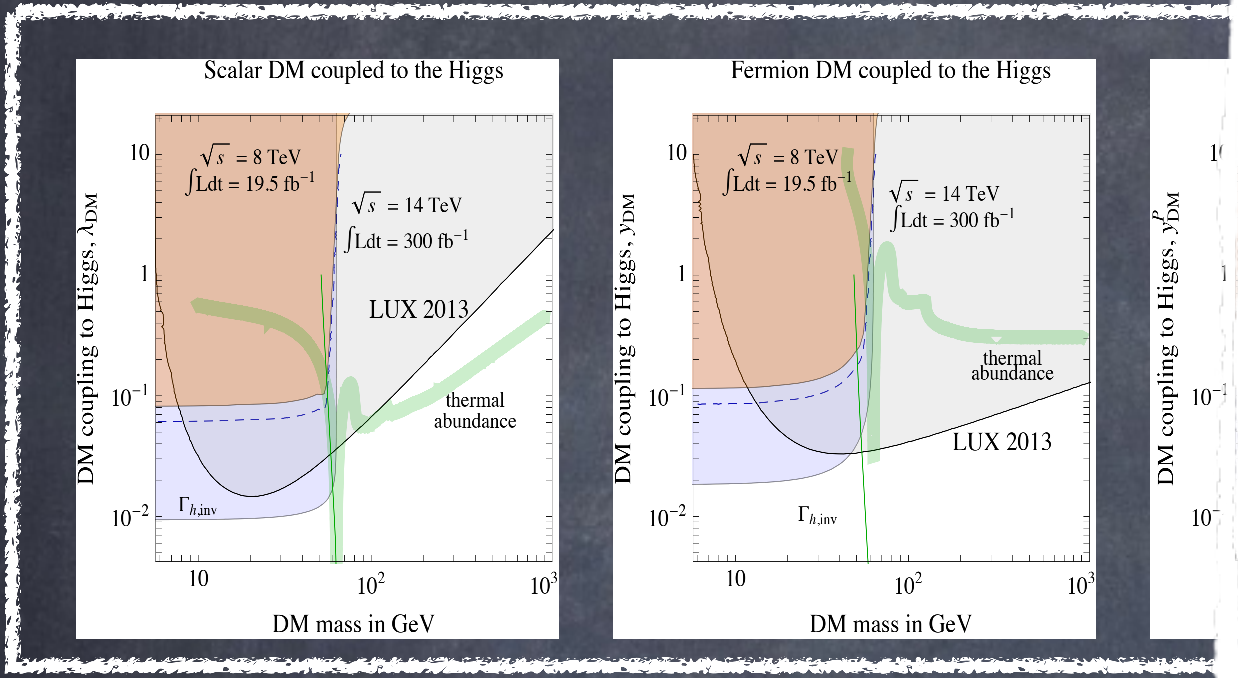




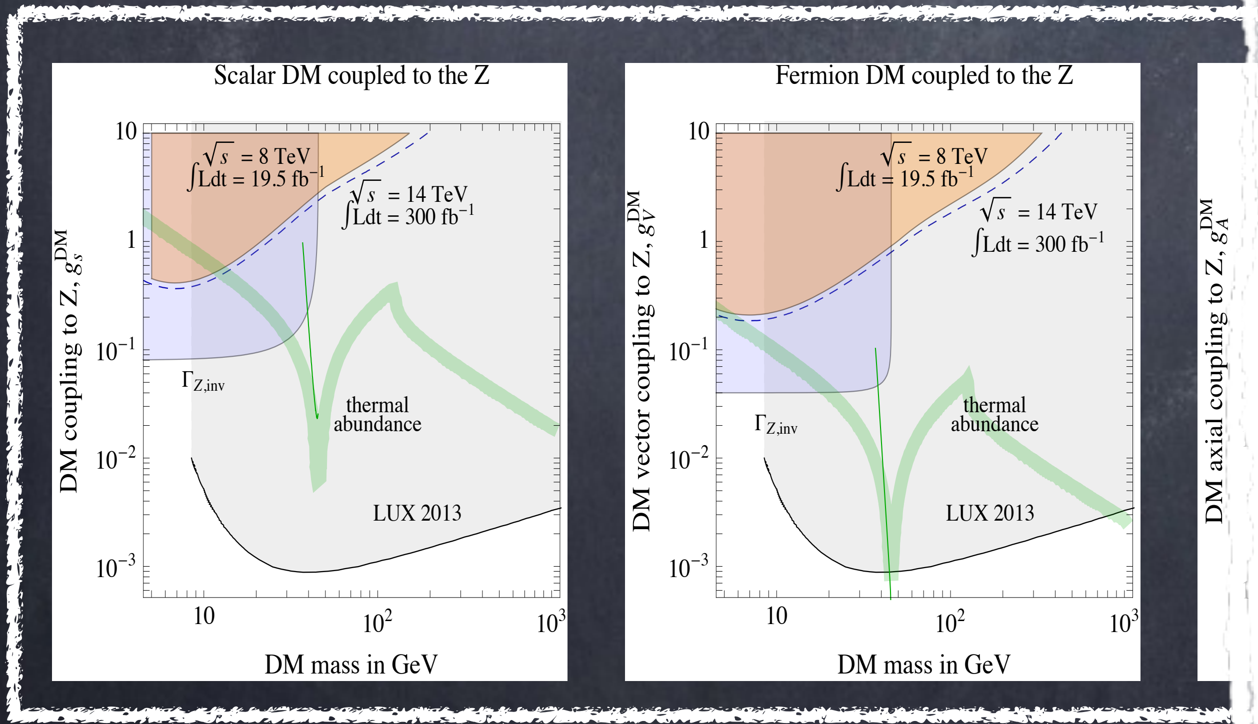
A possible solution : axial Z' (AxDM)
1403.4837 (PLB)

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

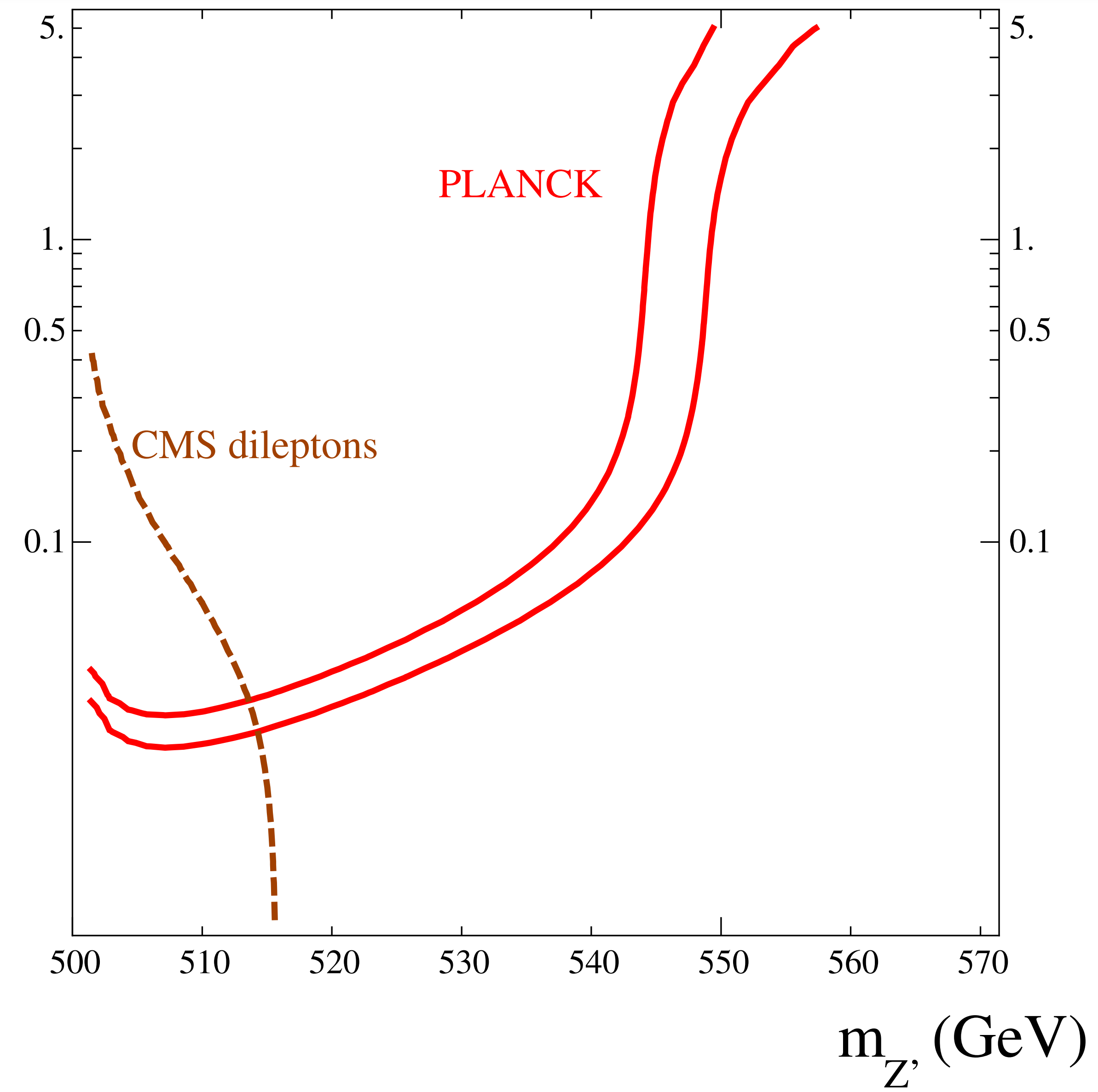
Beyond



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



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



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

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

What is the (s)mediator ?

What is the (s)mediator ?

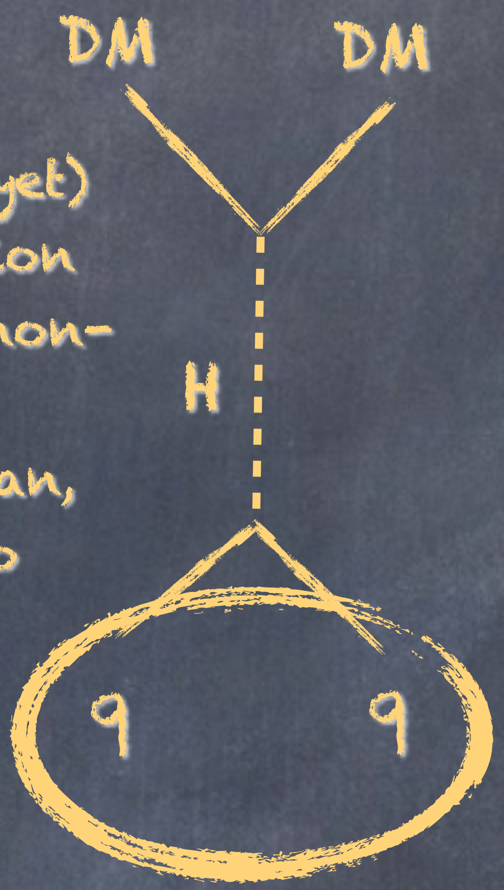
Neutralino
in (N)MSSM
No exclusions (yet)
Possible detection
+ possibility of non-SUSY scalar
Cotta, Rajaraman, Tait, Wijangco
1305.6609

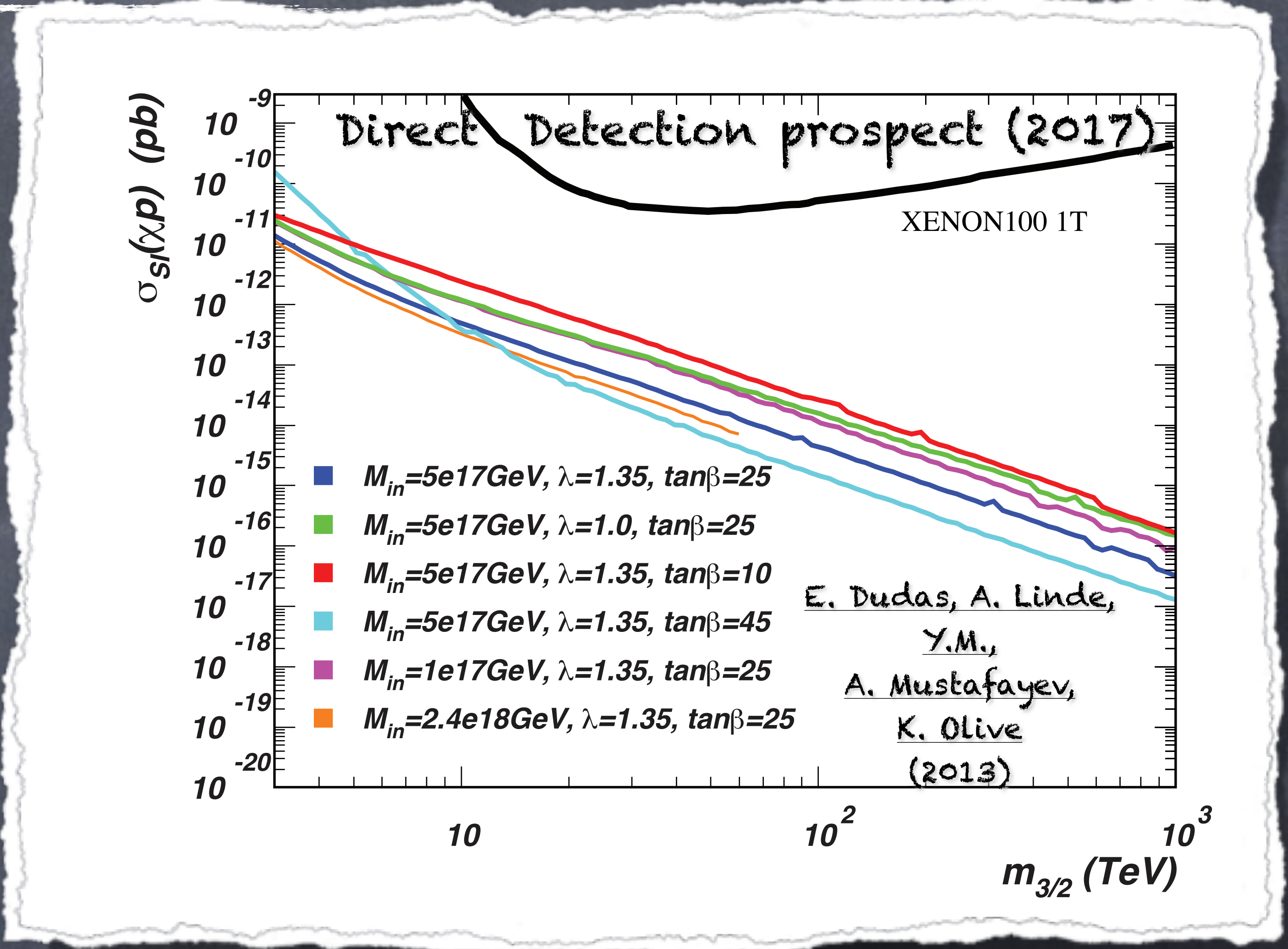
What is the (s)mediator ?

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

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

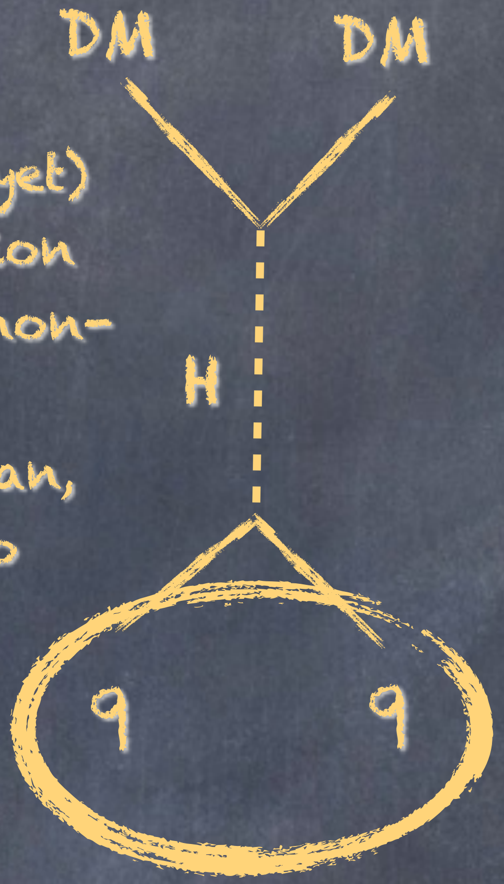
Neutralino in (N)MSSM
No exclusions (yet)
Possible detection
+ possibility of non-SUSY scalar
Cotta, Rajaraman, Tait, Wijangco
1305.6609



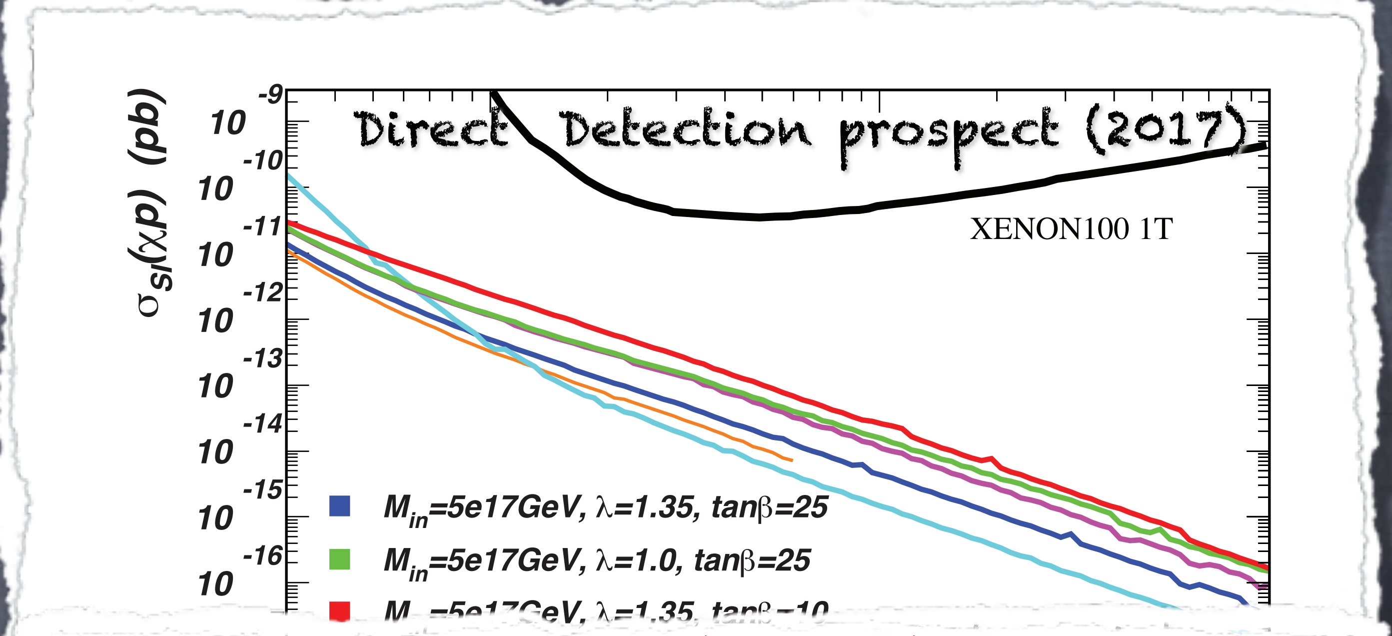


What is the (s)mediator ?

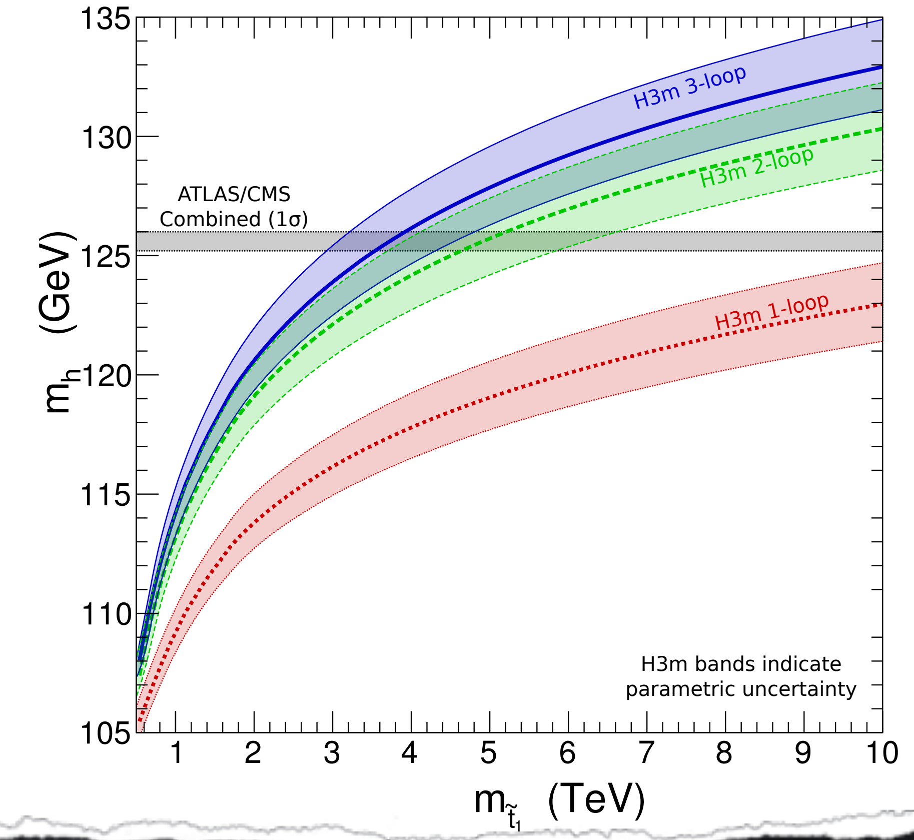
Neutralino
in (N)MSSM
No exclusions (yet)
Possible detection
+ possibility of non-SUSY scalar
Cotta, Rajaraman, Tait, Wijangco
1305.6609



BUT in coherent Supergravity scenario, difficult to observe due to Higgs mass :
mh = Mz + Log(Mst/Mt) => heavy scalar sector => Heavy Higgses

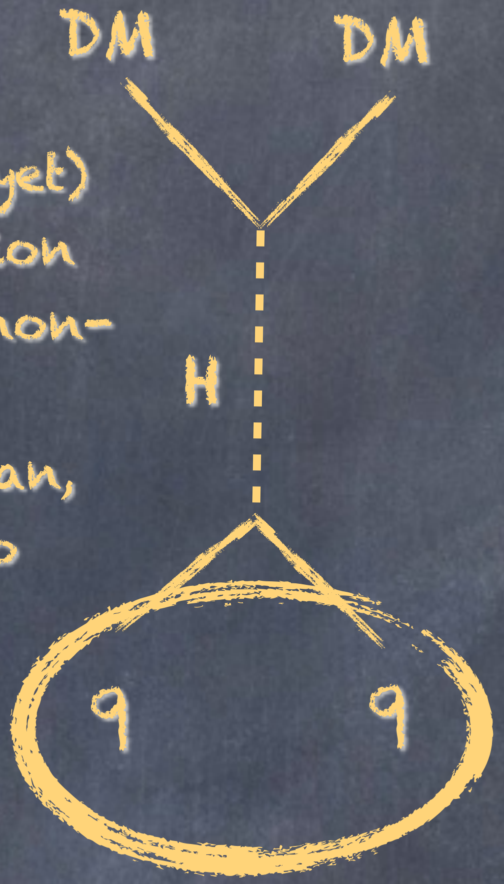


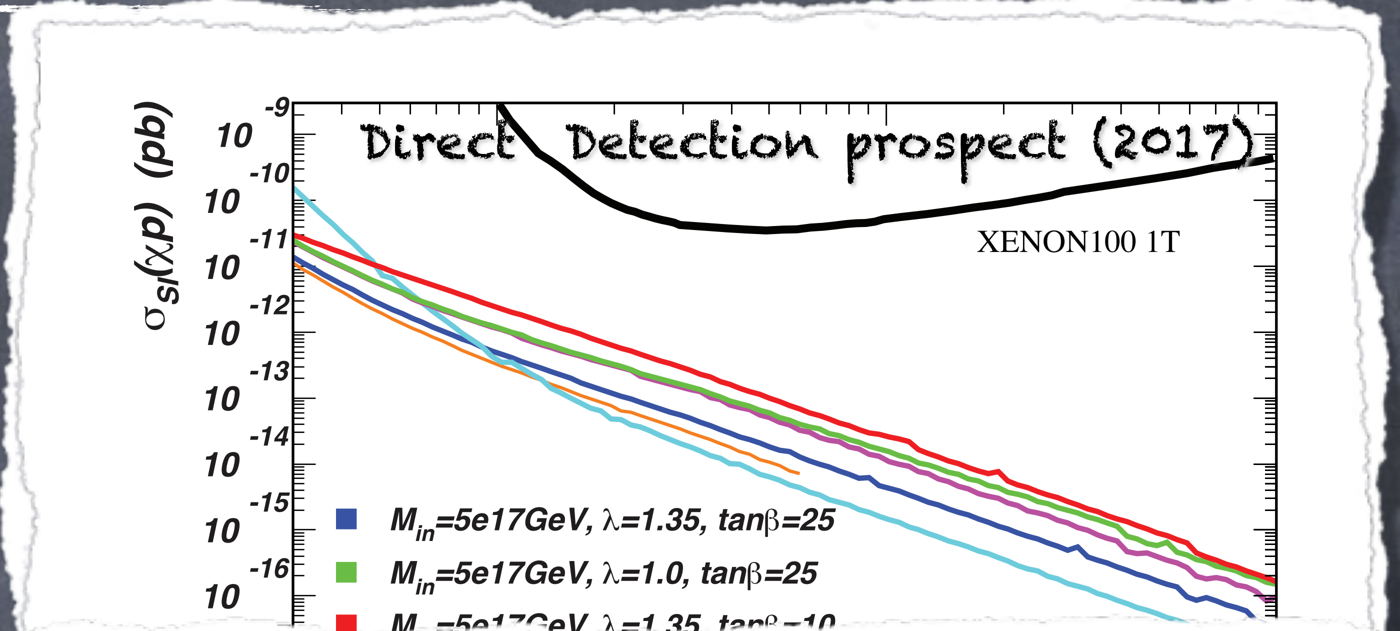
Feng, Kant, Profumo, Sanford
3 loops Higgs
1306.2318



What is the (s)mediator ?

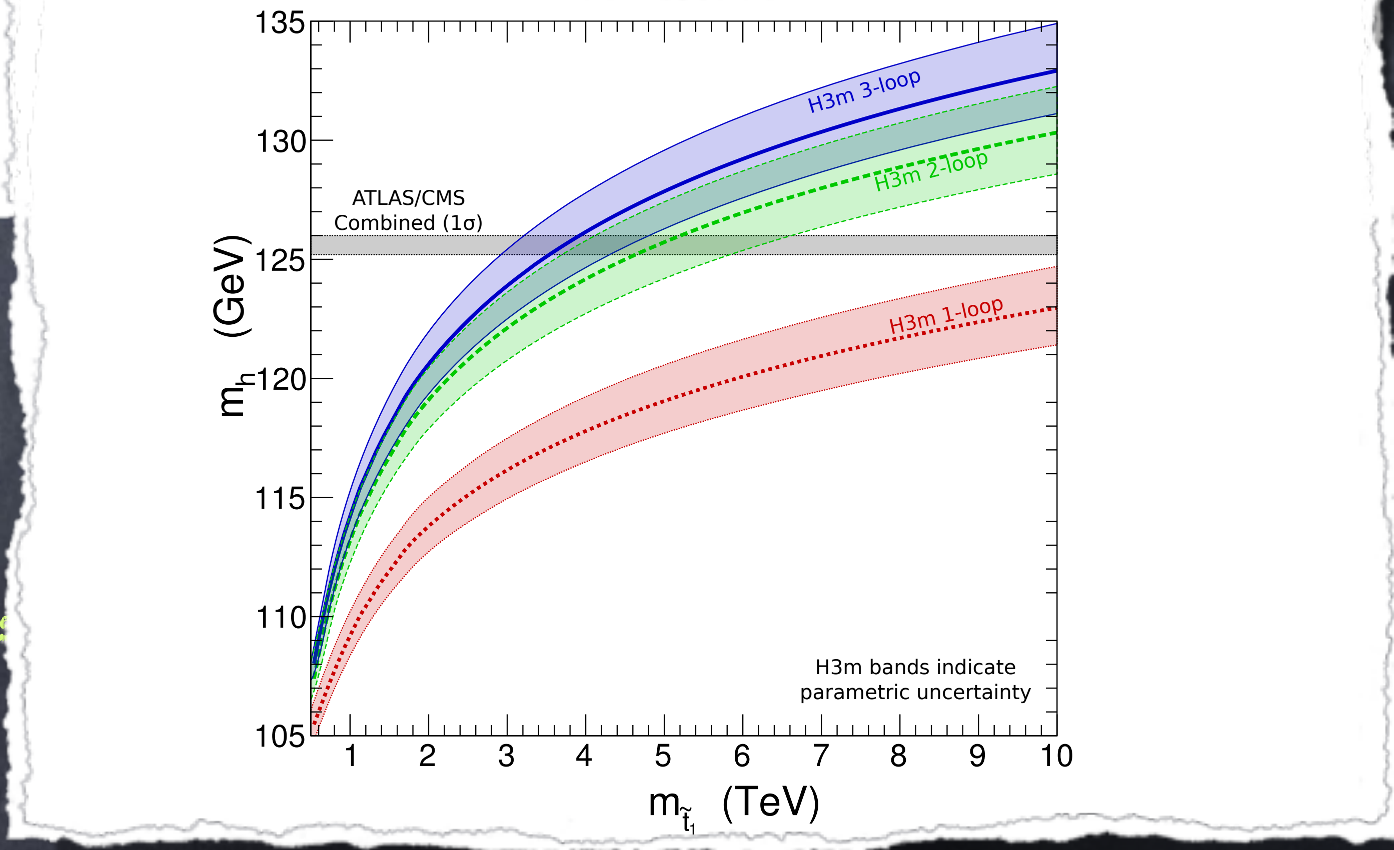
Neutralino
in (N)MSSM
No exclusions (yet)
Possible detection
+ possibility of non-SUSY scalar
Cotta, Rajaraman, Tait, Wijangco
1305.6609

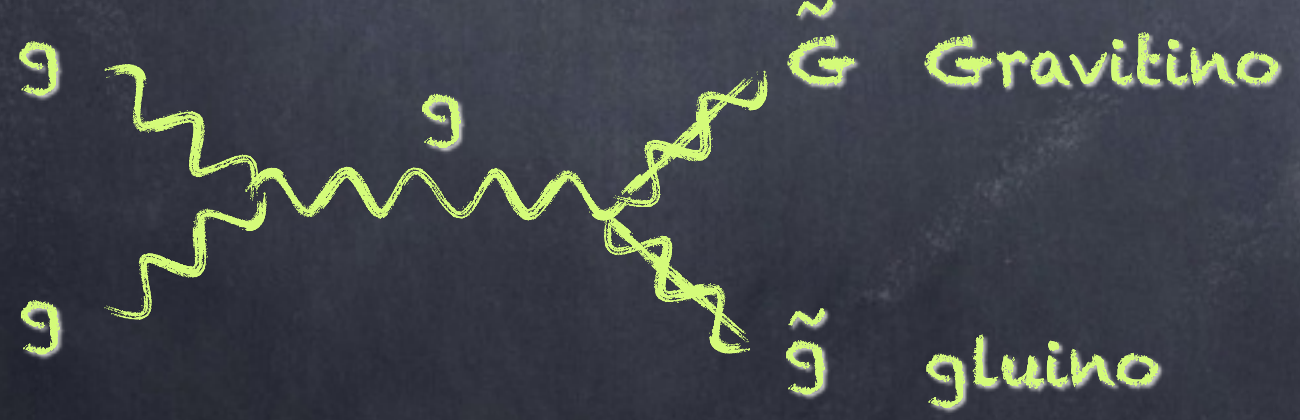




BUT in coherent Supergravity scenario, difficult to observe due to Higgs mass :
mh = Mz + Log(Mst/Mt) => heavy scalar sector => Heavy Higgses

Feng, Kant, Profumo, Sanford
3 loops Higgs
1306.2318





Gravitino dark matter
No detection hopes

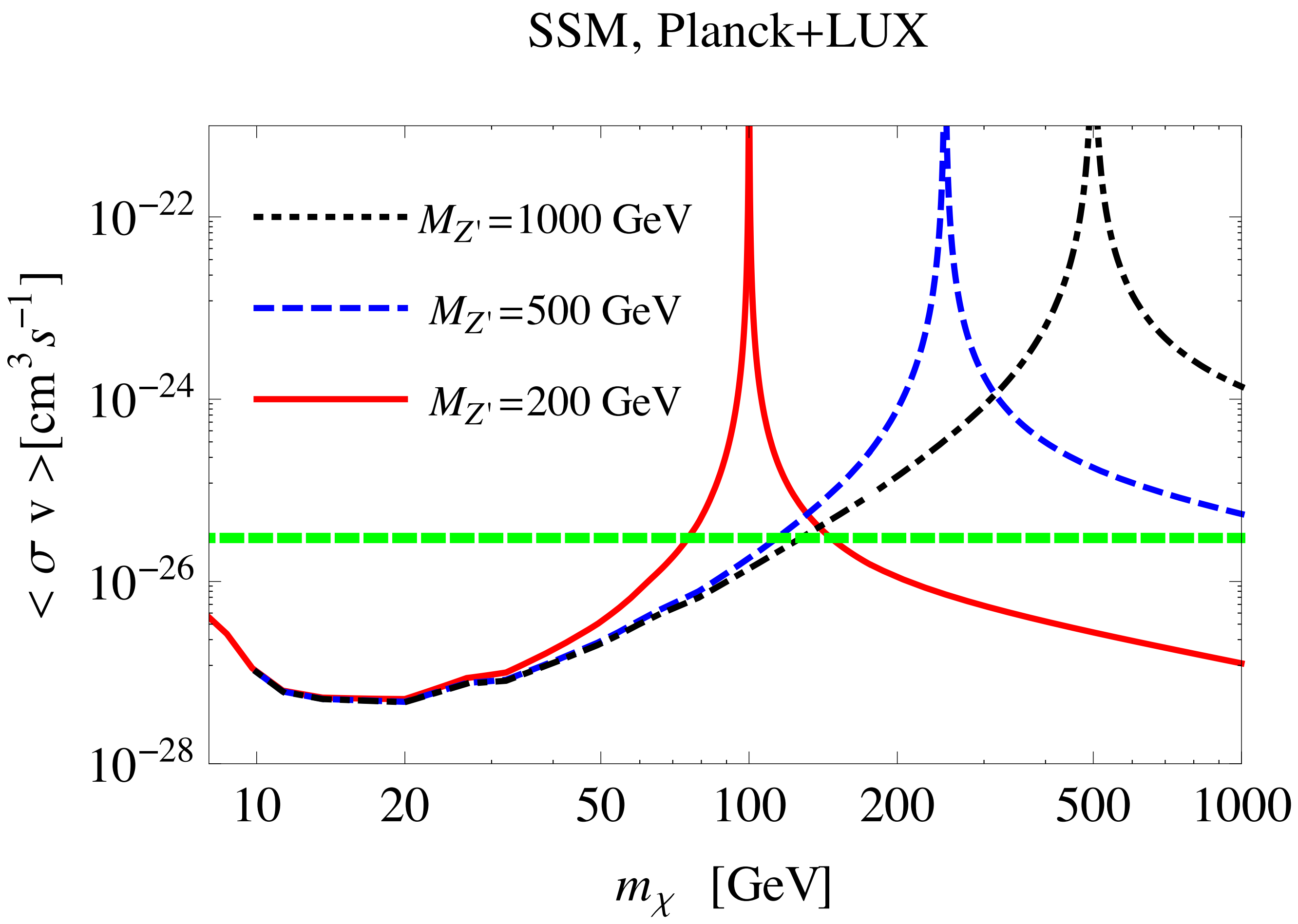
Is the dark matter thermal?

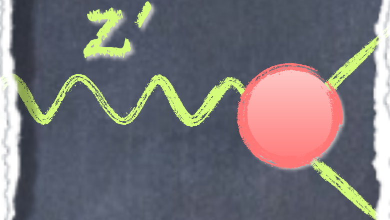
We can play the same game to constraint the thermal cross section $<\sigma\ v> = f(\sigma^{SI};\sigma^{SD})$ and see if present DD constraints apply

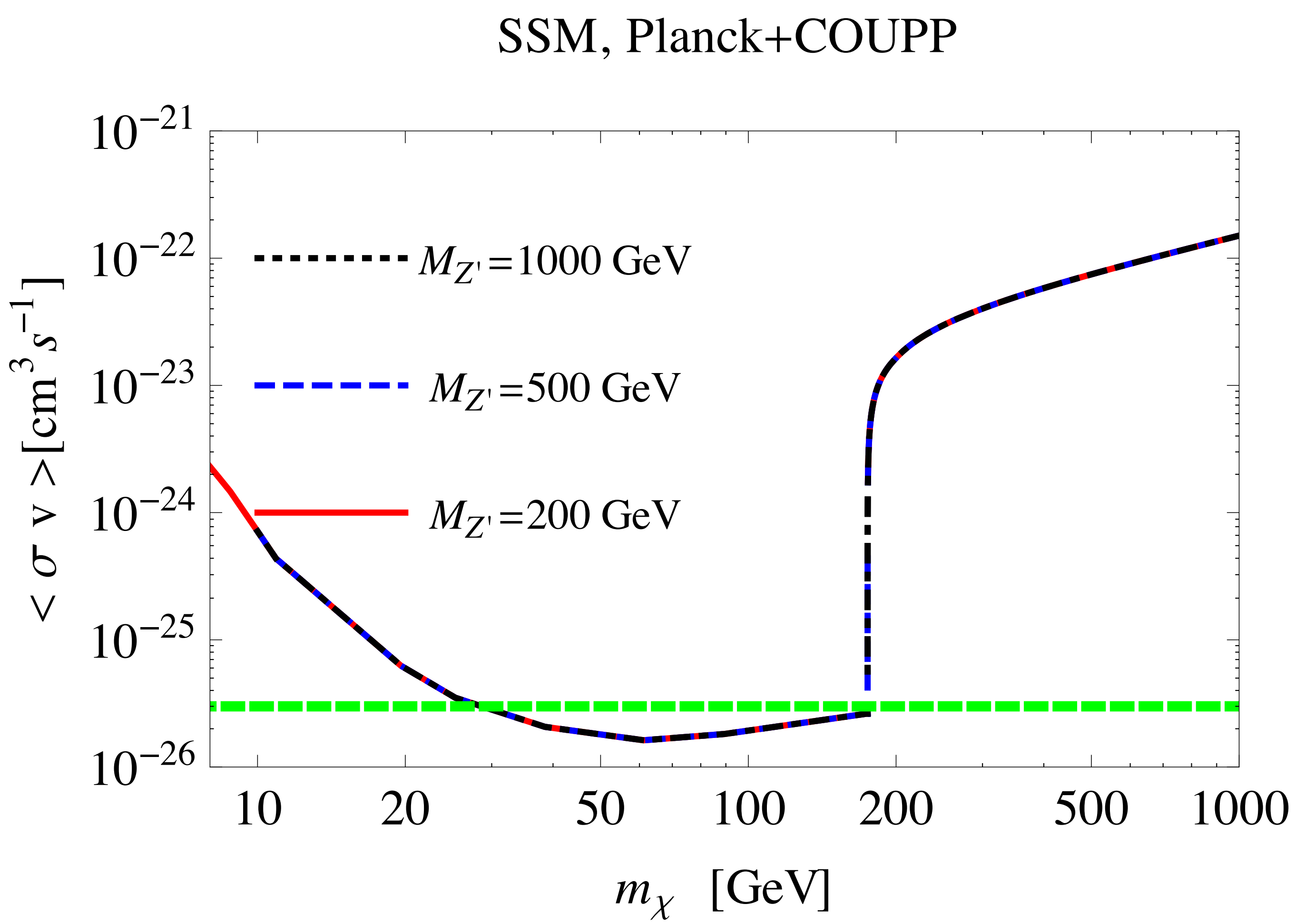
Is the dark matter thermal?

We can play the same game to constraint the thermal cross section $<\sigma\ v> = f(\sigma^{SI};\sigma^{SD})$ and see if present DD constraints apply

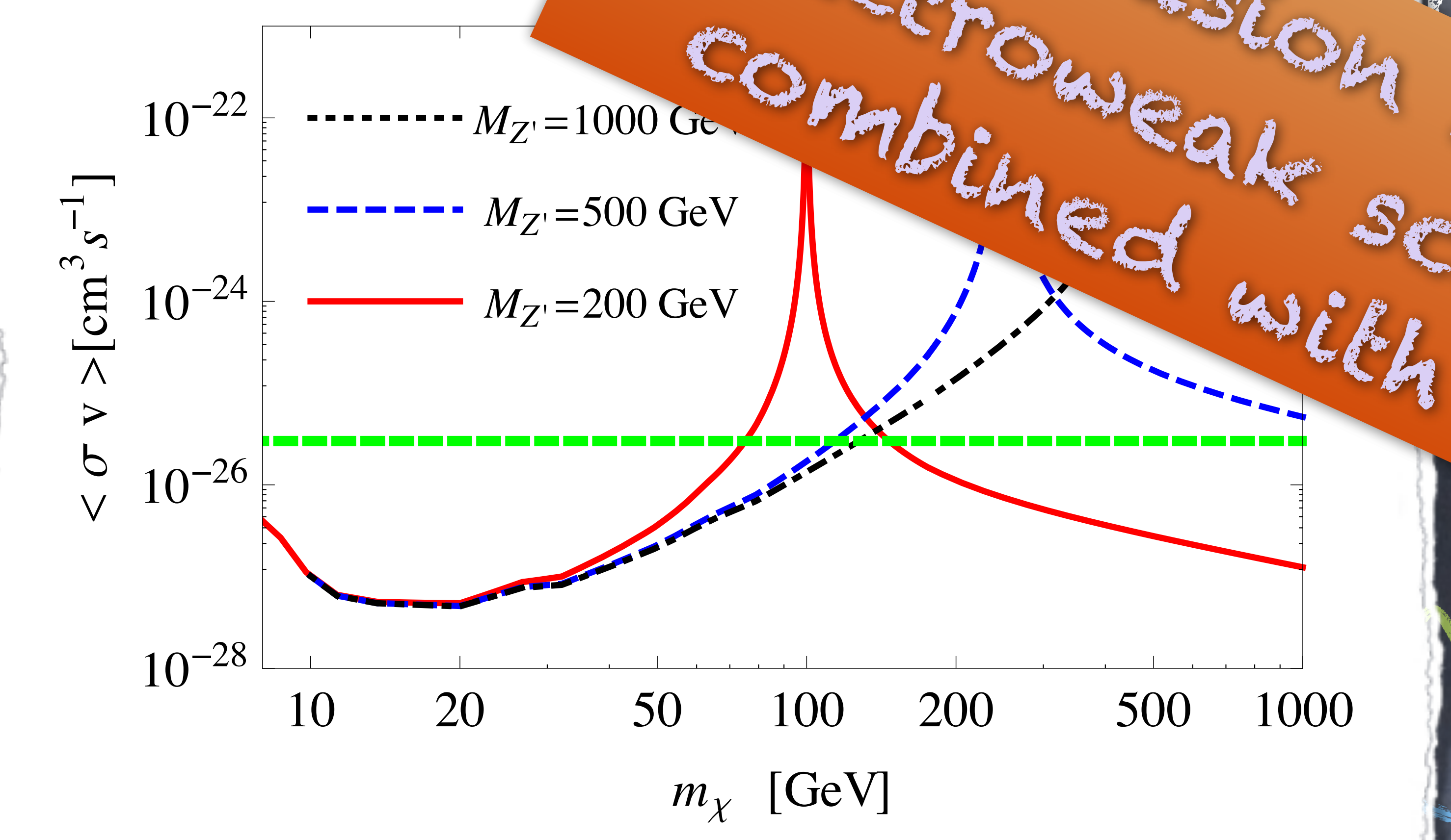
$$\langle\sigma v\rangle = \frac{s\sqrt{1-4\mu_f^2}}{64\mu_{\chi p}^2}\left[\frac{\sigma_{\chi p}^{SI}}{\alpha_{Z,A}^{SI}}\left([1+\mu_\chi^2](|V_D^f|^2+|A_D^f|^2)-16\mu_f^2\mu_\chi^2|A_D^f|^2\right)+\frac{4\sigma_{\chi p}^{SD}}{3\alpha_{Z,A}^{SD}}|A_D^f|^2\right]+O(\beta)$$

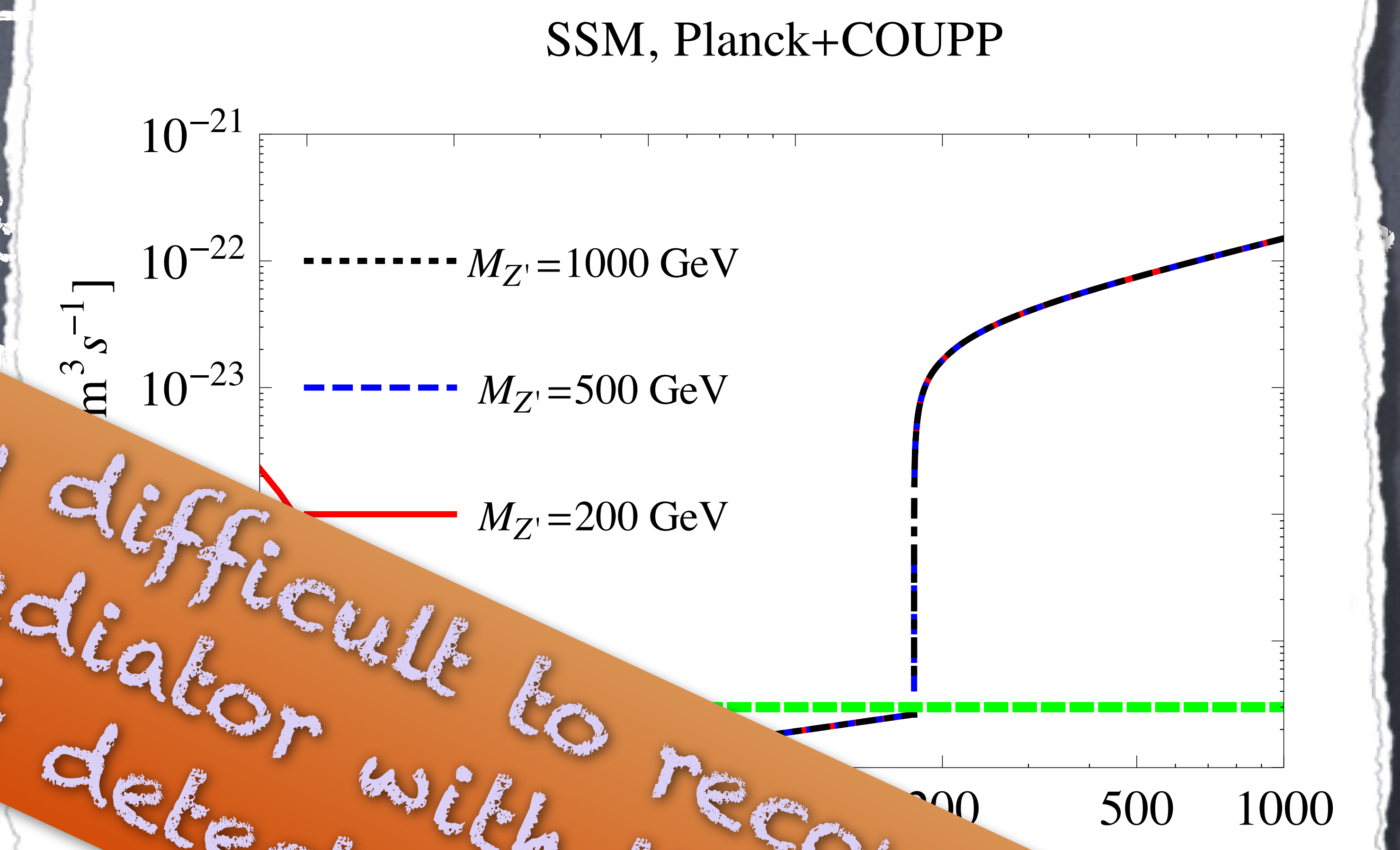






$$\langle\sigma v\rangle = \frac{s\sqrt{1-4\mu_f^2}}{64\mu_{\chi p}^2}\left[\frac{\sigma_{\chi p}^{SI}}{\alpha_{Z,A}^{SI}}\left([1+\mu_\chi^2](|V_D^f|^2+|A_D^f|^2)-16\mu_f^2\mu_\chi^2|A_D^f|^2\right)+\frac{4\sigma_{\chi p}^{SD}}{3\alpha_{Z,A}^{SD}}|A_D^f|^2\right]+O(\beta)$$





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

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

Conclusions

Conclusions

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

Conclusions

Conclusion 1: the effective approac[illegible] valid anymore in the energy range of [illegible] at LHC

One NEEDS to build micro[illegible] extensions

Conclusion 2: It is probable that the MEDIATOR will be discovered BEFORE the dark matter

Conclusions

Conclusion 1: the effecti
anymore in the energy
One NEEDS to buil

valid
at LHC
extensions

DIATOR will be
the dark matter

Conclusion 3: very strong combined constraints on the mediator close almost all the window for an electroweak scale Z' (or scalar) without even taking into consideration the THERMAL relic condition

Conclusions

Conclusion 1: the eff...
anymore in the...
One NEE...
... valid
... at LHC
... extensions

... onstraints on
... for an
... ing

Conclusion 4: Thermal scenario with electroweak mediator begins to be explored. Necessity to look at alternative scenario (Thomas' talk)

... DIATOR ...
... the dark matter

Conclusion 3: very s...
the mediator close almos...
electroweak scale Z' (or scalar) ...
into consideration the THERMAL rel...

Conclusions

Conclusion 5: Seems SM portals begins to be excluded, implying a more complex BSM sector that only DM + SM => rich accelerator phenomenology

Conclusion 1: the ...

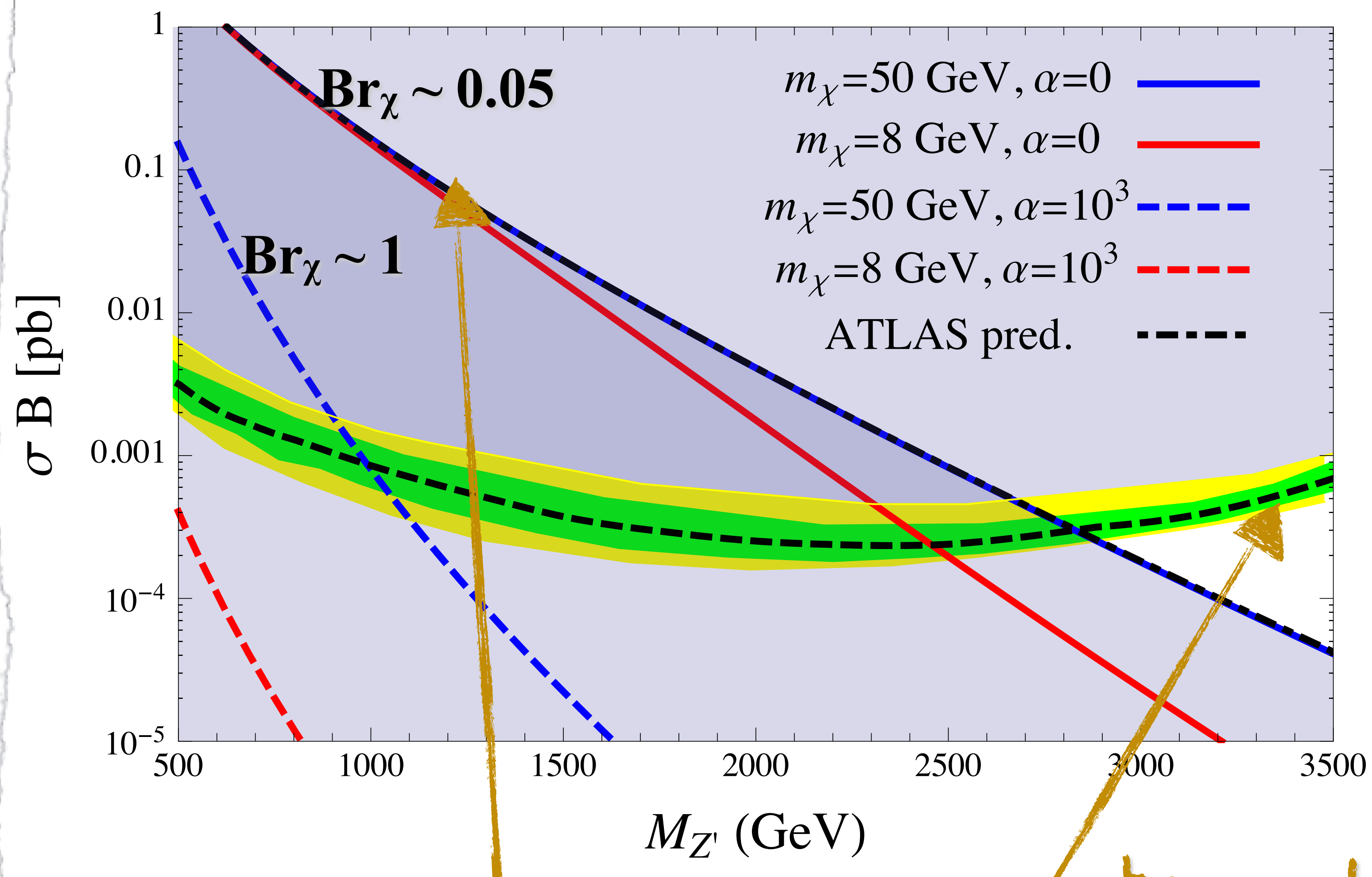
... onstraints on ... for an ...

Conc... ...ario with electroweak mediator begi... ...ssity to look at alternative sc...

Conclusion 3: very ... the mediator close alm... electroweak scale Z′ (or sca... into consideration the THERM...

... the dark ... extensions

Conclusions



predicted

observed

LHC production rate of a Z′ (B−L)

$g_D = 0$, $M_{Z'} > 2.85$ TeV

$g_D = 10^3\, g$, $M_{Z'} > 250$ GeV

Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Non-thermal scenarios?

Chu, Hambye
Tytgat
1112.0493

Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Non-thermal scenarios?

Chu, Hambye
Tytgat
1112.0493

$$\frac{dn}{dT} = 3\frac{n}{T} - \frac{\langle \sigma v \rangle}{HT}(n_{eq}^2 - n^2)$$

Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Non-thermal scenarios?

Chu, Hambye Tytgat 1112.0493

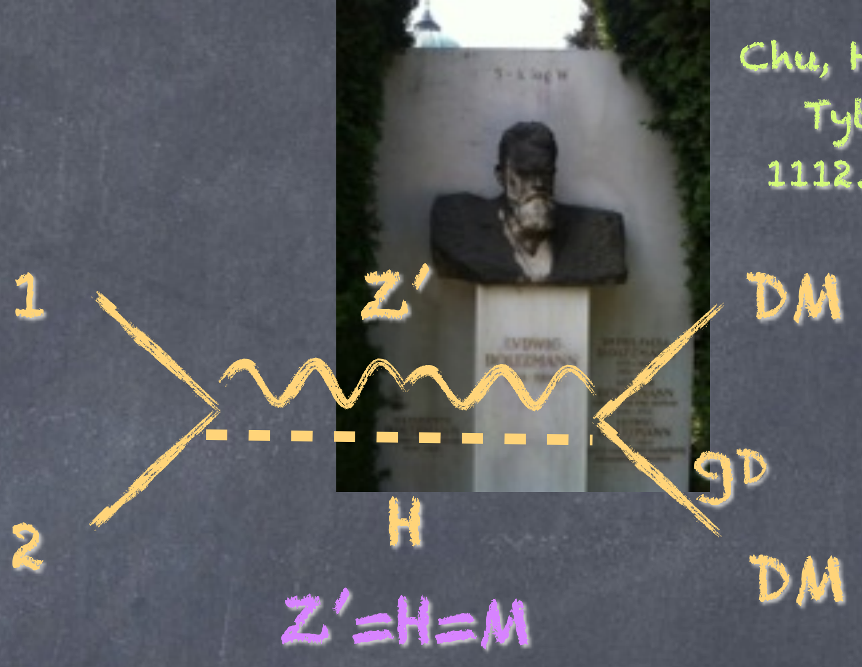
$$\frac{dn}{dT} = 3\frac{n}{T} - \frac{\langle\sigma v\rangle}{HT}(n_{eq}^2 - n^2)$$

$$\frac{dY}{dT} = T^2\frac{\langle\sigma v\rangle}{H(T)}(Y^2 - Y_{eq}^2); \quad Y = \frac{n}{s}; \quad H(T) \simeq \frac{T^2}{M_{Pl}}$$

Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Non-thermal scenarios?

Chu, Hambye Tytgat 1112.0493



$$\frac{dn}{dT} = 3\frac{n}{T} - \frac{\langle \sigma v \rangle}{HT}(n_{eq}^2 - n^2)$$

$$\frac{dY}{dT} = T^2 \frac{\langle \sigma v \rangle}{H(T)}(Y^2 - Y_{eq}^2); \quad Y = \frac{n}{s}; \quad H(T) \simeq \frac{T^2}{M_{Pl}}$$

$$\langle \sigma v \rangle = \int_{T_{RH}}^{T} \Pi_i \ d^3\tilde{p}_i |\mathcal{M}|^2 e^{-\frac{E_1}{T}} e^{-\frac{E_2}{T}}$$

Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Non-thermal scenarios?

Chu, Hambye Tytgat 1112.0493

$Z'=H=M$

$$\frac{dn}{dT} = 3\frac{n}{T} - \frac{\langle \sigma v\rangle}{HT}(n_{eq}^2 - n^2) \qquad \frac{dY}{dT} = T^2\frac{\langle \sigma v\rangle}{H(T)}(Y^2 - Y_{eq}^2); \quad Y = \frac{n}{s}; \quad H(T) \simeq \frac{T^2}{M_{Pl}}$$

$$\langle \sigma v\rangle = \int_{T_{RH}}^{T} \Pi_i \; d^3\tilde{p}_i |\mathcal{M}|^2 e^{-\frac{E_1}{T}} e^{-\frac{E_2}{T}}$$

Two possibilities

Dark matter is <u>not</u> 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

Non-thermal scenarios?

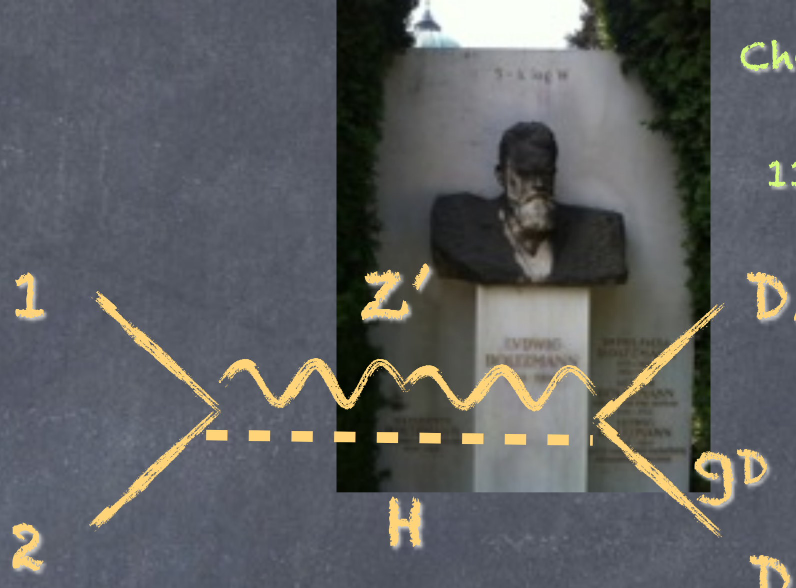
$$\frac{dn}{dT} = 3\frac{n}{T} - \frac{\langle \sigma v \rangle}{HT}(n_{eq}^2 - n^2) \qquad \frac{dY}{dT} = T^2 \frac{\langle \sigma v \rangle}{H(T)}(Y^2 - Y_{eq}^2); \quad Y = \frac{n}{s}; \quad H(T) \simeq \frac{T^2}{M_{Pl}}$$

$$\langle \sigma v \rangle = \int_{T_{RH}}^{T} \Pi_i \; d^3\tilde{p}_i |\mathcal{M}|^2 e^{-\frac{E_1}{T}} e^{-\frac{E_2}{T}}$$

Two possibilities

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

Chu, Hambye Tytgat 1112.0493



Z'=H=M

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

- gD ~ gEW

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

n(T) <σ v> << H(T)

WIMP

(neutralino, Higgs portal..)

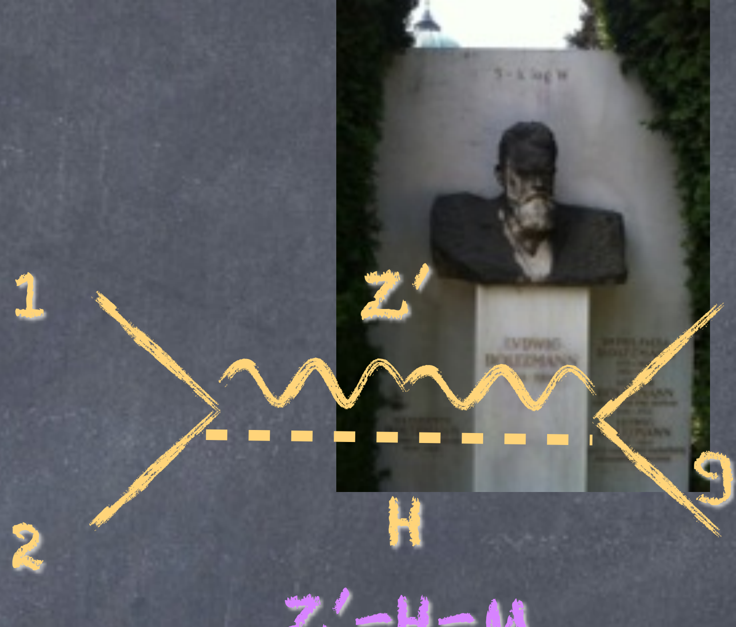
Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Non-thermal scenarios?

$$\frac{dn}{dT} = 3\frac{n}{T} - \frac{\langle\sigma v\rangle}{HT}(n_{eq}^2 - n^2) \qquad \frac{dY}{dT} = T^2\frac{\langle\sigma v\rangle}{H(T)}(Y^2 - Y_{eq}^2); \quad Y = \frac{n}{s}; \quad H(T) \simeq \frac{T^2}{M_{Pl}}$$

$$\langle\sigma v\rangle = \int_{T_{RH}}^{T} \Pi_i \, d^3\tilde{p}_i |\mathcal{M}|^2 e^{-\frac{E_1}{T}} e^{-\frac{E_2}{T}}$$

Chu, Hambye Tytgat 1112.0493



Z'=H=M

Two possibilities

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

- $M_M < T_{RH}$

$$|\mathcal{M}|^2 \propto g_D^2$$

$$\Rightarrow \frac{dY}{dT} \propto g_D^2 \frac{M_{Pl}}{T^2}$$

$$\Rightarrow Y(T) \propto g_D^2 \frac{M_{Pl}}{T}$$

$g_D \simeq g_{EW}$: WIMP

$g_D \simeq 10^{-10}$: FIMP

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

- $g_D \sim g_{EW}$

Standard freeze out (FO) scenario. $<\sigma v> \sim 10^{-9}$ The dark matter decouples when n is Boltzman suppressed :

$n(T) <\sigma v> \ll H(T)$

WIMP

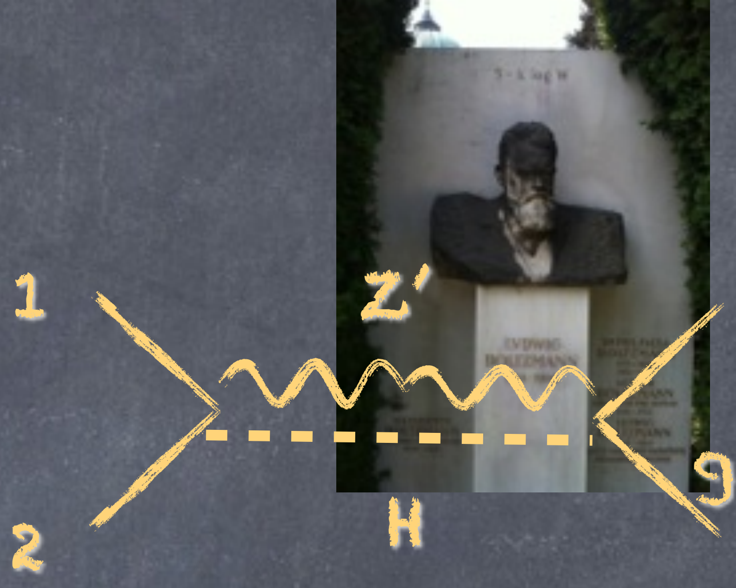
(neutralino, Higgs portal..)

Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Non-thermal scenarios?

Chu, Hambye
Tytgat
1112.0493

$$\frac{dn}{dT} = 3\frac{n}{T} - \frac{\langle\sigma v\rangle}{HT}(n_{eq}^2 - n^2) \qquad \frac{dY}{dT} = T^2\frac{\langle\sigma v\rangle}{H(T)}(Y^2 - Y_{eq}^2); \quad Y = \frac{n}{s}; \quad H(T) \simeq \frac{T^2}{M_{Pl}}$$



$$\langle\sigma v\rangle = \int_{T_{RH}}^{T} \Pi_i \; d^3\tilde{p}_i |\mathcal{M}|^2 e^{-\frac{E_1}{T}} e^{-\frac{E_2}{T}}$$

Z'=H=M

Two possibilities

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

- MM < TRH

$$|\mathcal{M}|^2 \propto g_D^2$$

$$\Rightarrow \frac{dY}{dT} \propto g_D^2 \frac{M_{Pl}}{T^2}$$

$$\Rightarrow Y(T) \propto g_D^2 \frac{M_{Pl}}{T}$$

$g_D \simeq g_{EW}$: WIMP

$g_D \simeq 10^{-10}$: FIMP

- MM > TRH

$$|\mathcal{M}|^2 \propto g_D^2 \left(\frac{T^2}{M_M^2}\right)^2$$

$$\Rightarrow \frac{dY}{dT} \propto g_D^2 \frac{M_{Pl} T^2}{M_M^4}$$

$$\Rightarrow Y(T) \propto g_D^2 \frac{M_{Pl}}{M_M^4} \; T_{RH}^3$$

Non Equilibrium Thermal (NETDM) :
SO(10), Intermediate scale

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..)

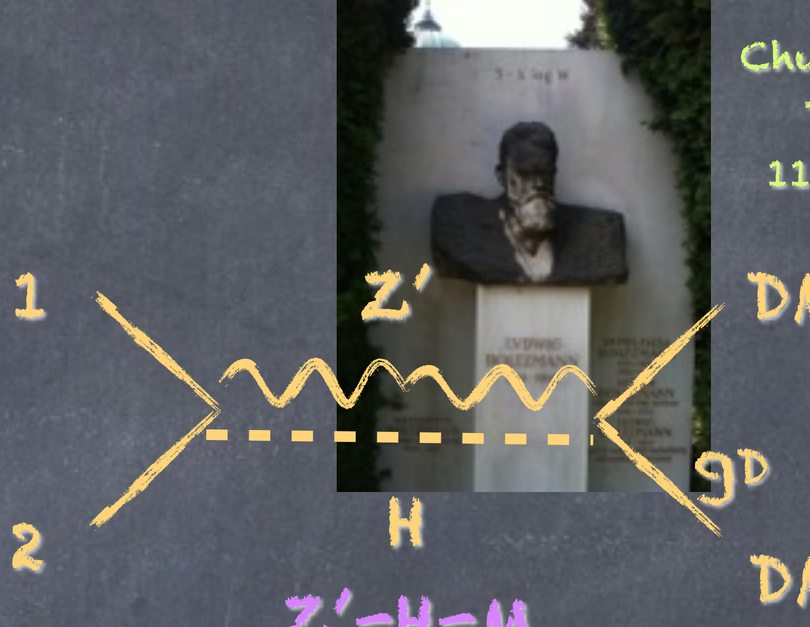
Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Non-thermal scenarios?

$$\frac{dn}{dT} = 3\frac{n}{T} - \frac{\langle\sigma v\rangle}{HT}(n_{eq}^2 - n^2) \qquad \frac{dY}{dT} = T^2\frac{\langle\sigma v\rangle}{H(T)}(Y^2 - Y_{eq}^2); \quad Y = \frac{n}{s}; \quad H(T) \simeq \frac{T^2}{M_{Pl}}$$

$$\langle\sigma v\rangle = \int_{T_{RH}}^{T} \Pi_i \; d^3\tilde{p}_i |\mathcal{M}|^2 e^{-\frac{E_1}{T}} e^{-\frac{E_2}{T}}$$

Chu, Hambye Tytgat 1112.0493



Z'=H=M

Two possibilities

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

- MM < TRH

$$|\mathcal{M}|^2 \propto g_D^2$$

$$\Rightarrow \frac{dY}{dT} \propto g_D^2 \frac{M_{Pl}}{T^2}$$

$$\Rightarrow Y(T) \propto g_D^2 \frac{M_{Pl}}{T}$$

$g_D \simeq g_{EW}$: WIMP

$g_D \simeq 10^{-10}$: FIMP

- MM > TRH

$$|\mathcal{M}|^2 \propto g_D^2 \left(\frac{T^2}{M_M^2}\right)^2$$

$$\Rightarrow \frac{dY}{dT} \propto g_D^2 \frac{M_{Pl} T^2}{M_M^4}$$

$$\Rightarrow Y(T) \propto g_D^2 \frac{M_{Pl}}{M_M^4} T_{RH}^3$$

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

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)

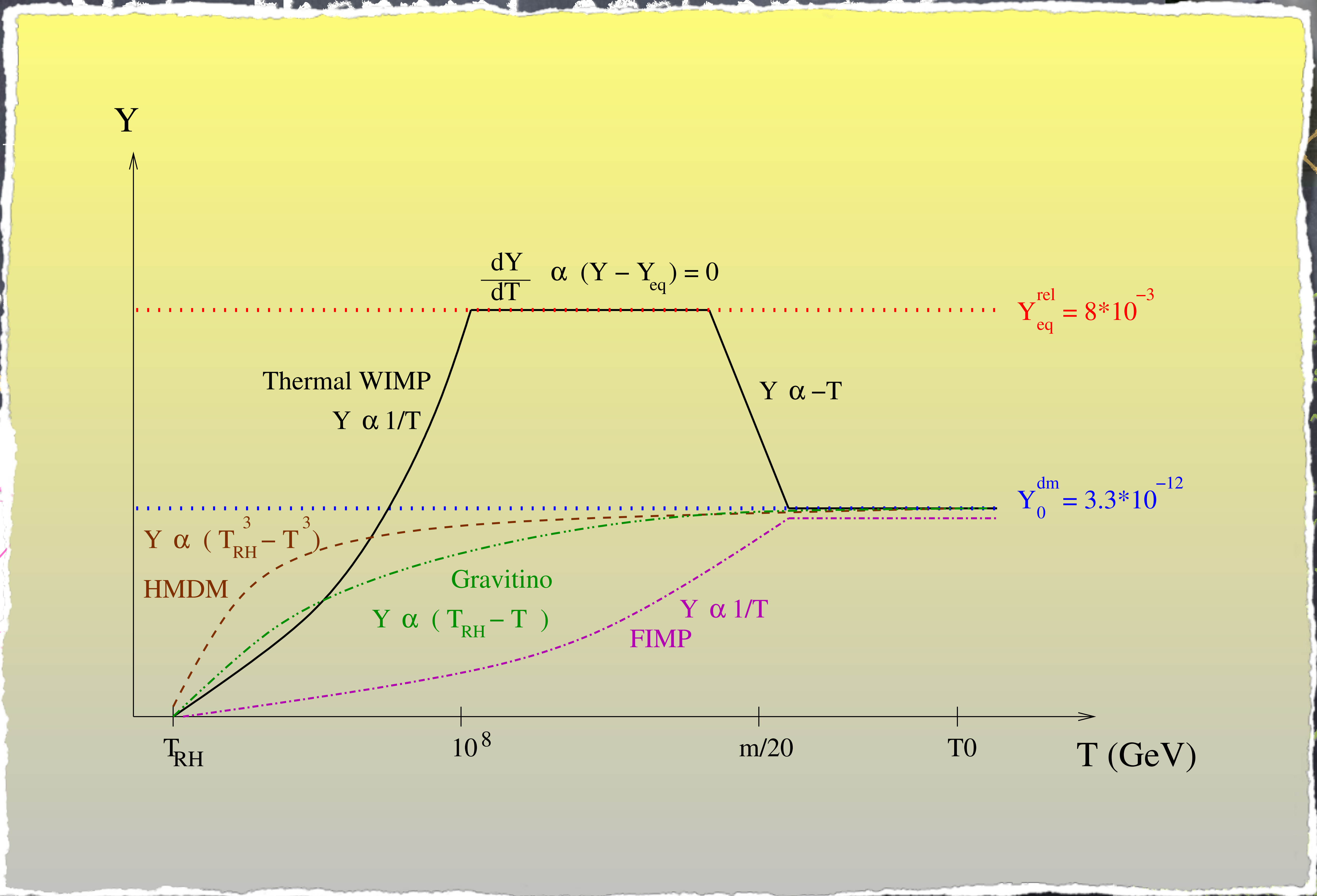
WIMP

(neutralino, Higgs portal..)

Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Chu, Hambye
Tytgat
1112.0493

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



DM

gD

DM

Two p…

… is produced
…m with the SM
…s at TRH

Dark matte…

~ gEW

…eze out (FO)
…> ~ 10^-9 The
…r decouples
Boltzman

Mм …

$|\mathcal{M}\ldots$

$\Rightarrow \frac{dY}{dT} \propto \ldots$

$\Rightarrow Y(T) \propto \ldots$

…> << H(T)

$g_D \simeq g_{EW}$

$g_D \simeq 10^{-10}\ldots$

…MP
…iggs portal..)

Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Chu, Hambye Tytgat 1112.0493

DM

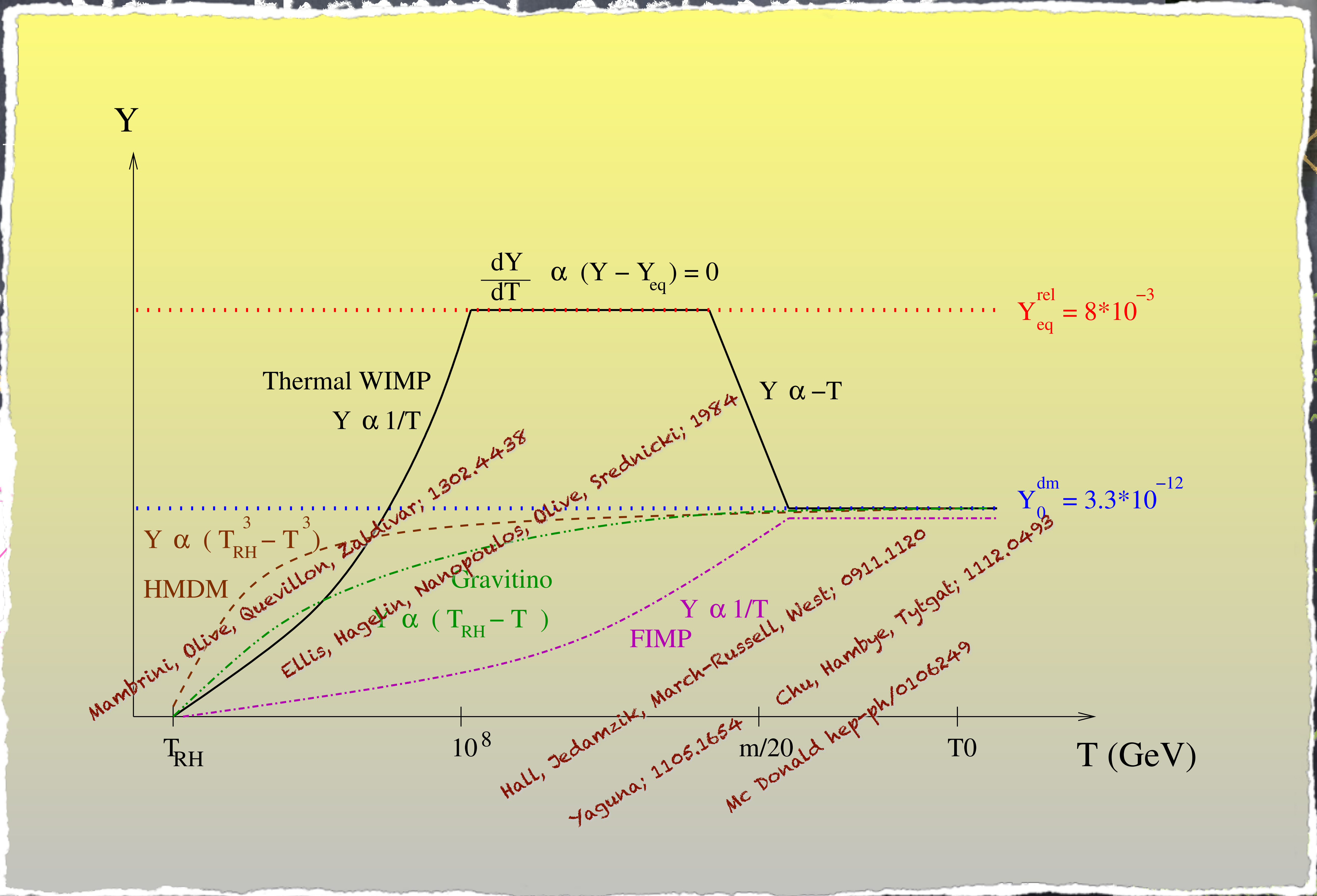
gD

DM

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

Two p

Dark matte



is produced

m with the SM

s at TRH

~ gEW

eze out (FO)

> ~ 10^-9 The

r decouples

Boltzman

> << H(T)

MP

iggs portal..)

MM

$|\mathcal{M}$

$$\Rightarrow \frac{dY}{dT} \propto$$

$$\Rightarrow Y(T) \propto$$

$g_D \simeq g_{EW}$

$g_D \simeq 10^{-10}$