Dark Matter: Candidates, signals and LHC consequences

Yann Mambrini, LPT Orsay

EPNT13 workshop, April 3d 2013, University of Luminy, Marseille

Constraints in «portal like» models

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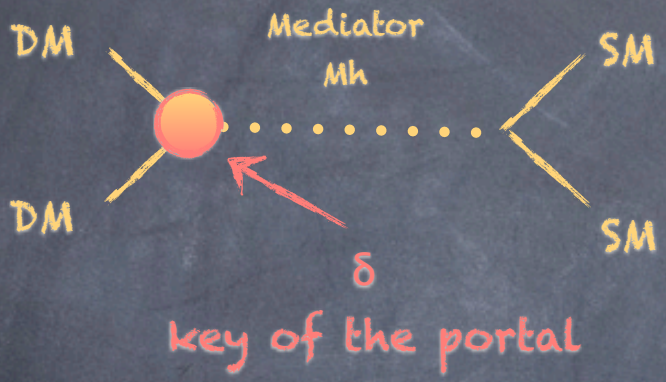
WMAP : $\sigma v \sim 10^{-26}$ cm3 s-1



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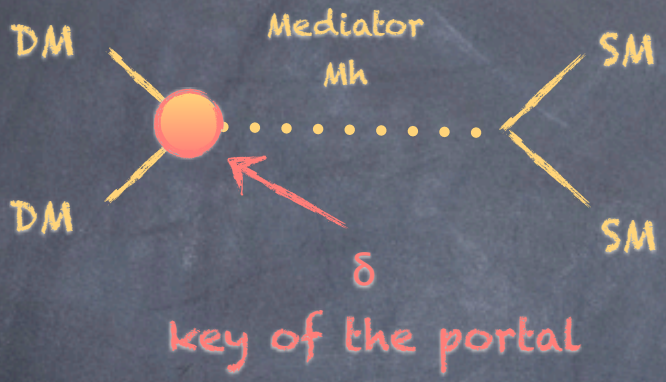

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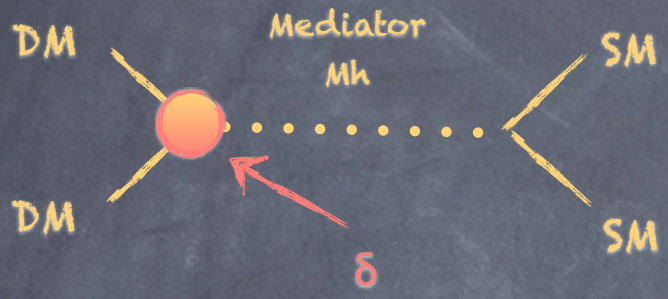

key of the portal

$\sigma_{DM\text{-}SM} \sim 10\text{-}36$ cm2

=> excess in DD exp.

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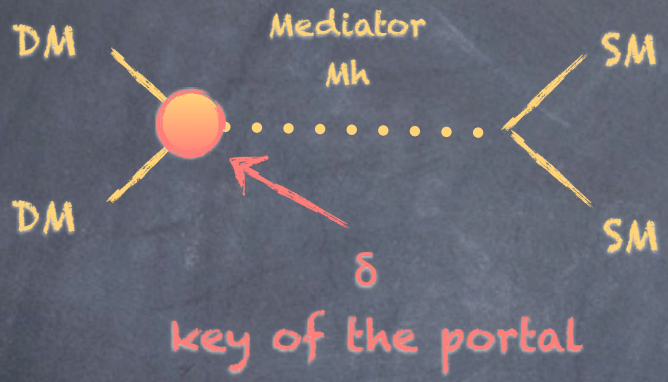

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Except around the pole : $2M_{DM} = Mh$: small δ to respect WMAP

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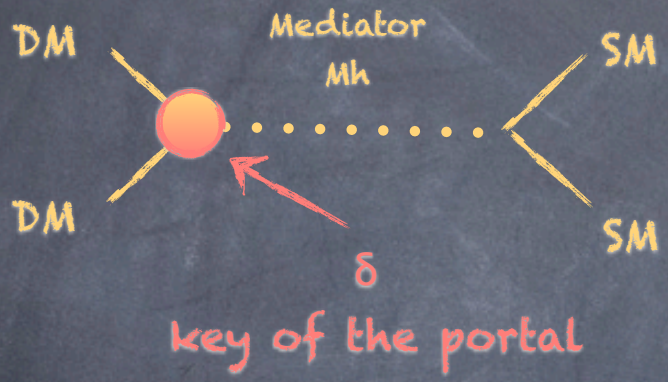

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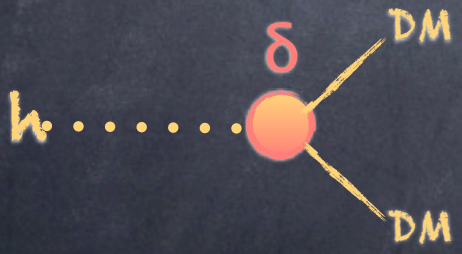

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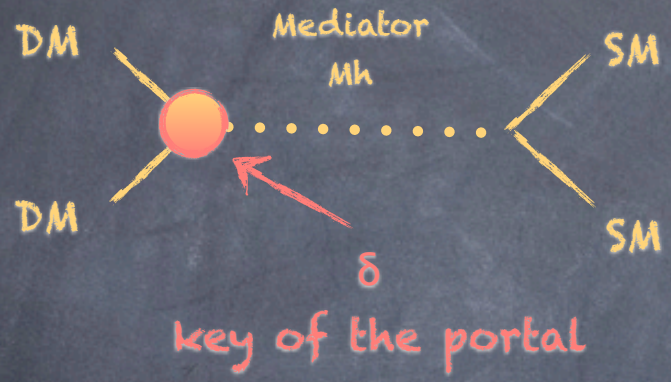

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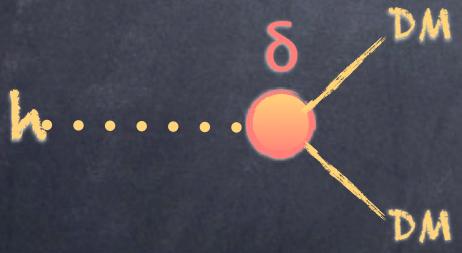

If direct detection experiments see nothing

=> $\delta < \delta max$

=> $\Gamma(h \to DM\ DM) < \Gamma max$

=> h is invisible at LHC

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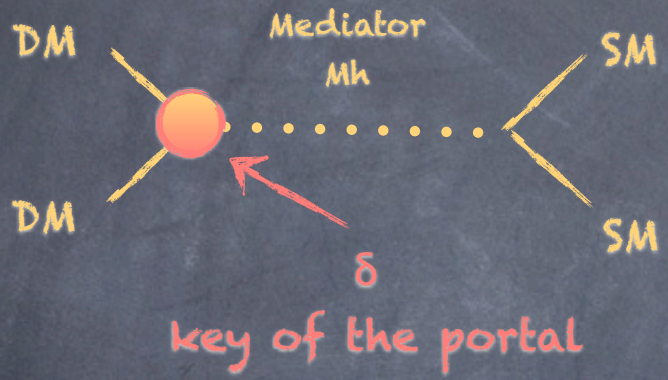

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XENON

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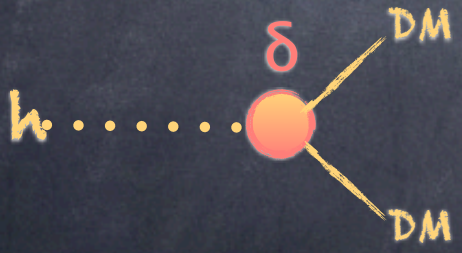

LHC/ILC

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YM 2010
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Gauge extension: Extra $U_D(1)$

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$SU(3)*SU(2)*U(1)*U_D(1)$

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$$SU(3) * SU(2) * U(1) * U_D(1)$$
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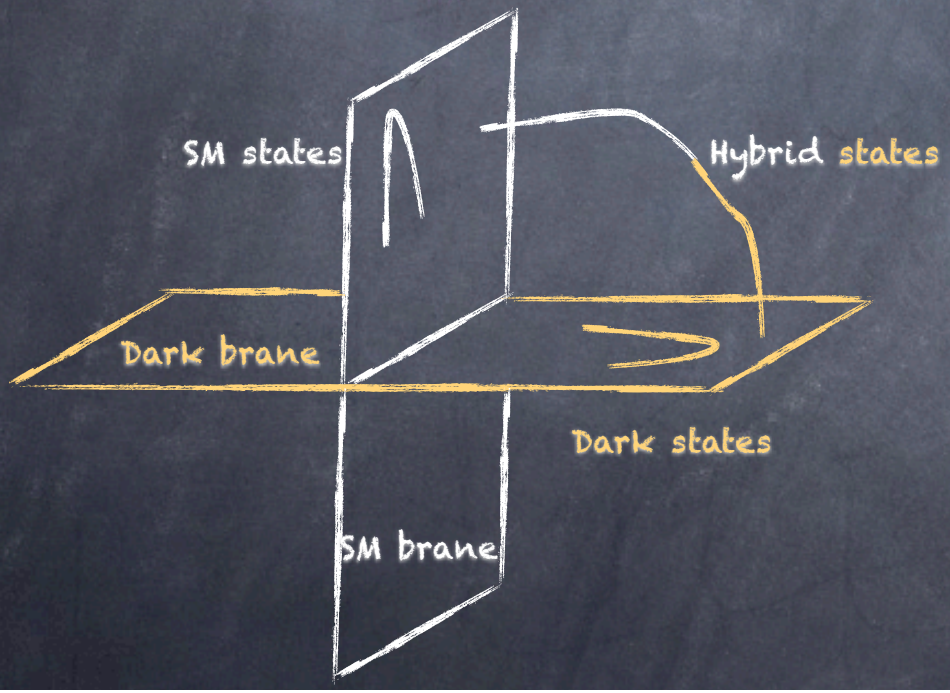

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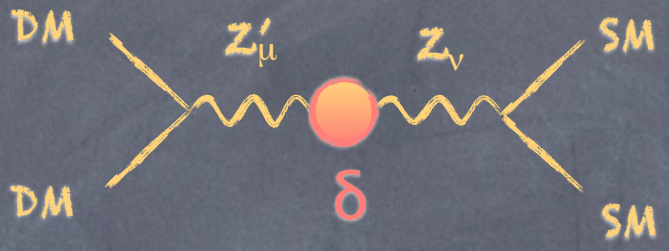

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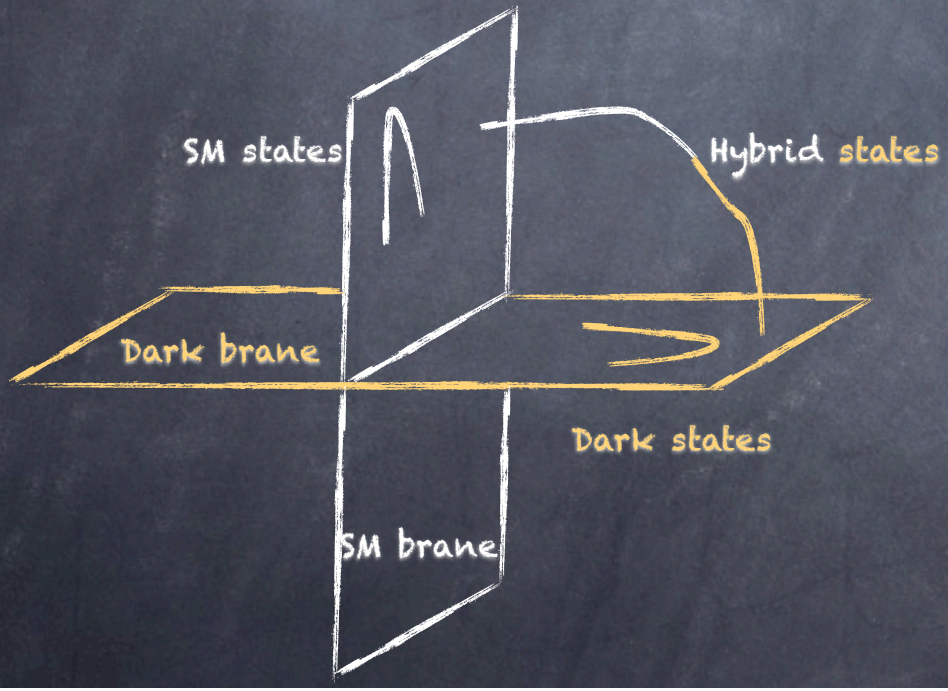

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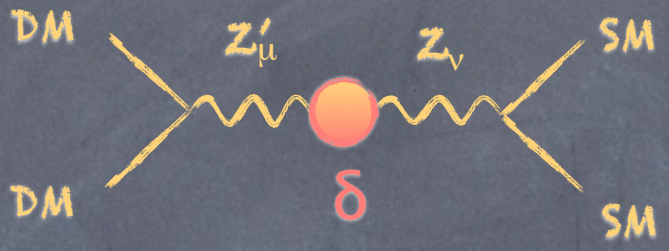

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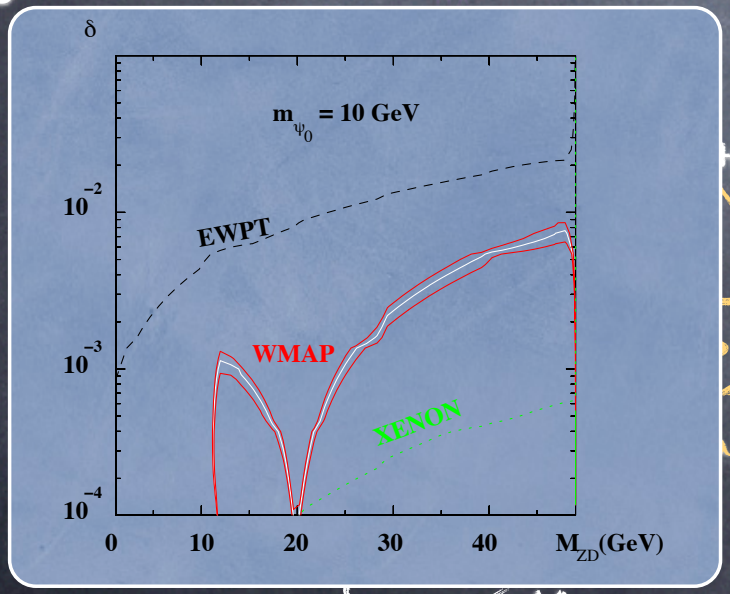
δ



Hybrid states

tes

M_{DM} = 10 GeV

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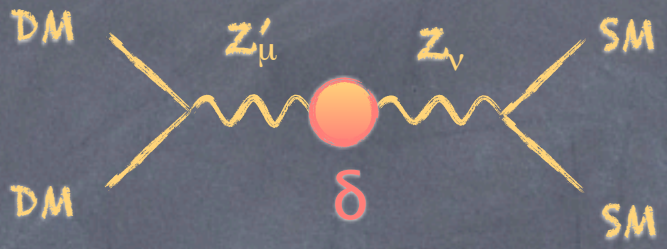

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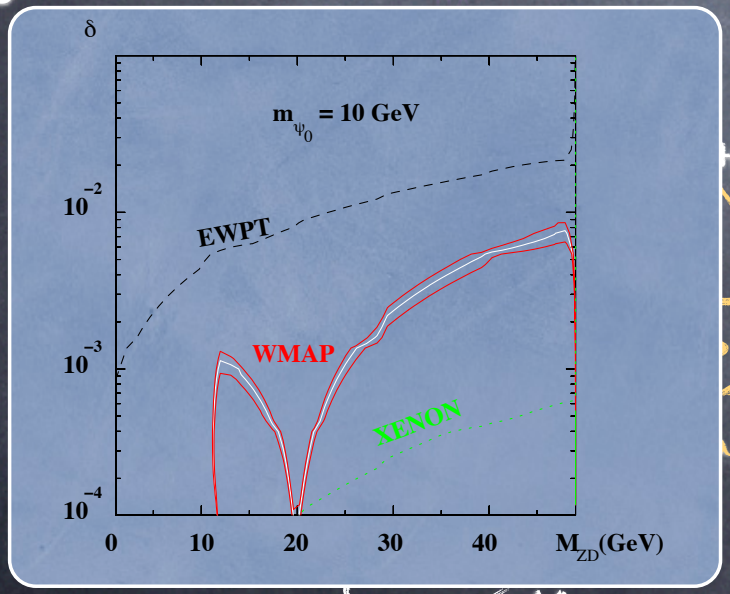

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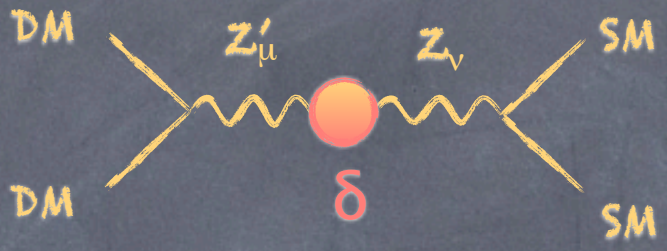

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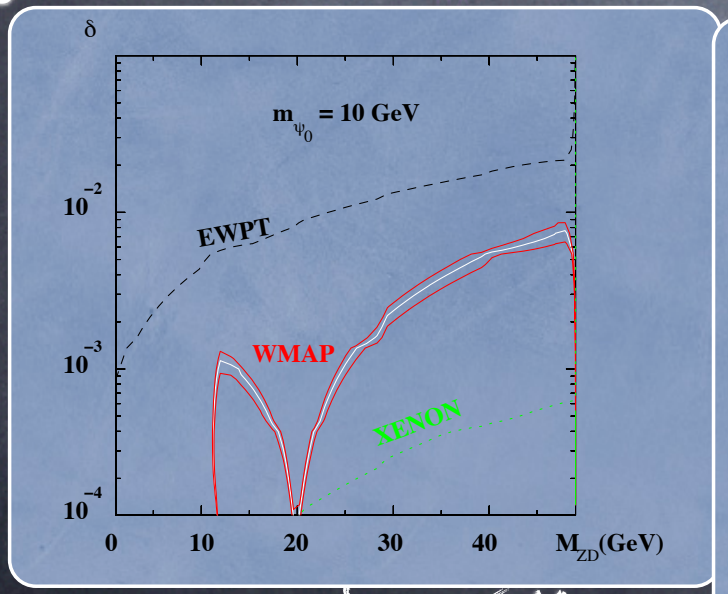

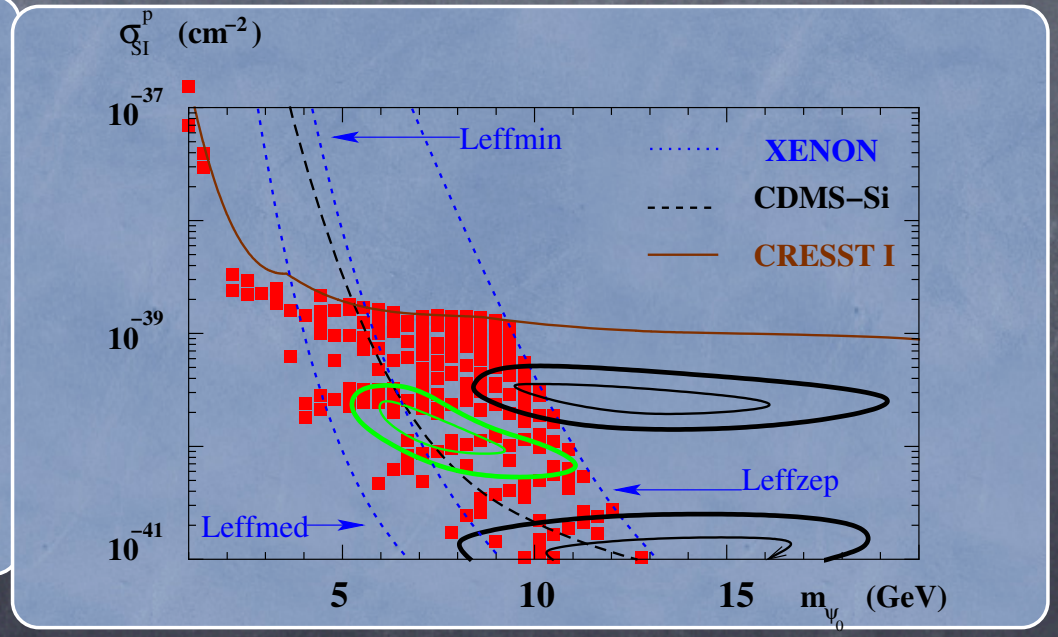

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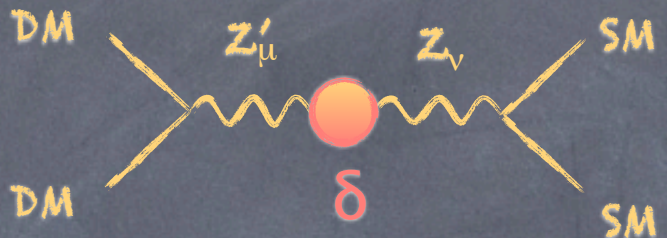

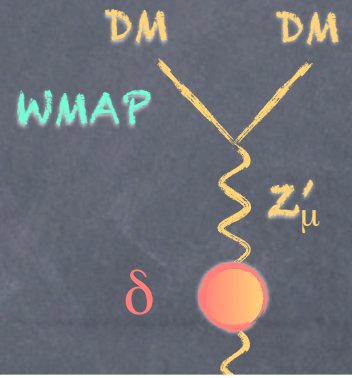

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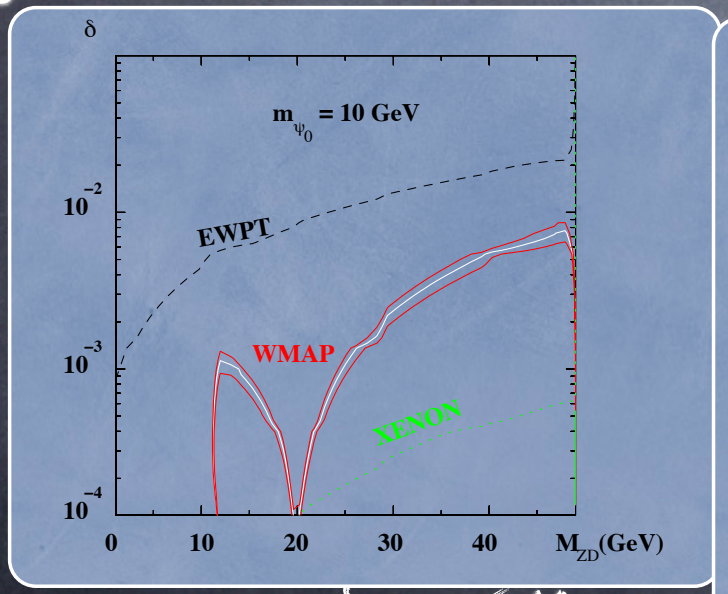

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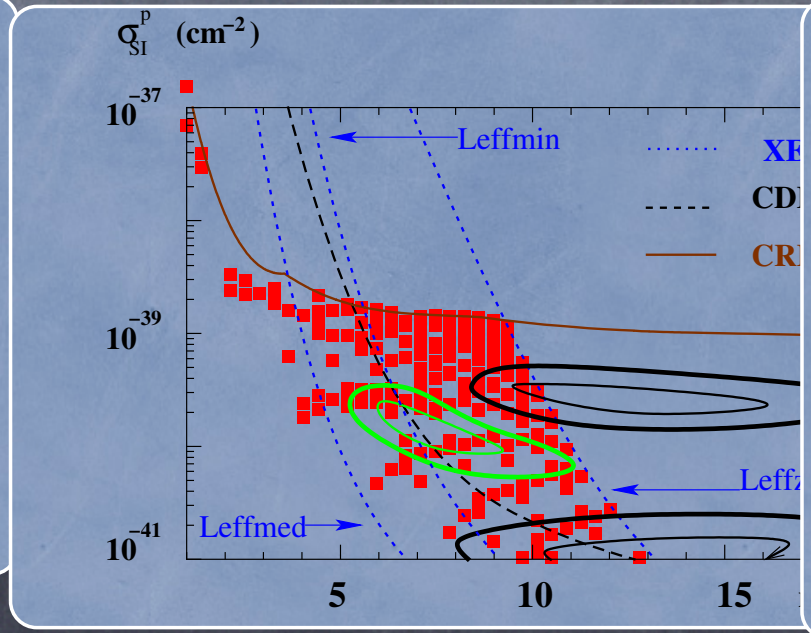

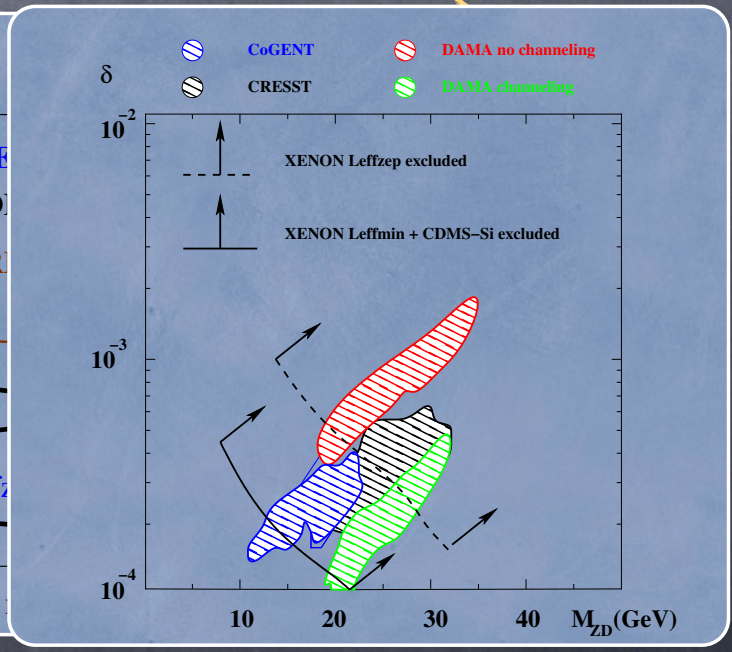

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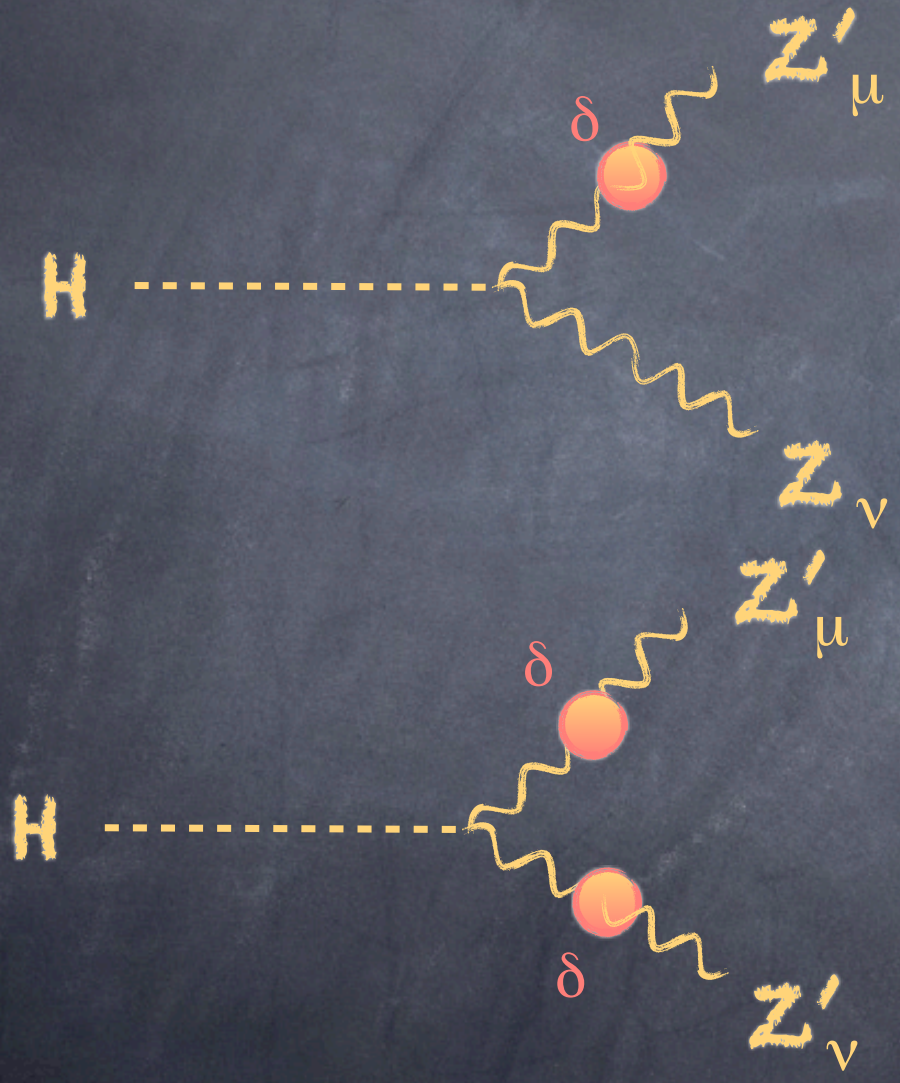

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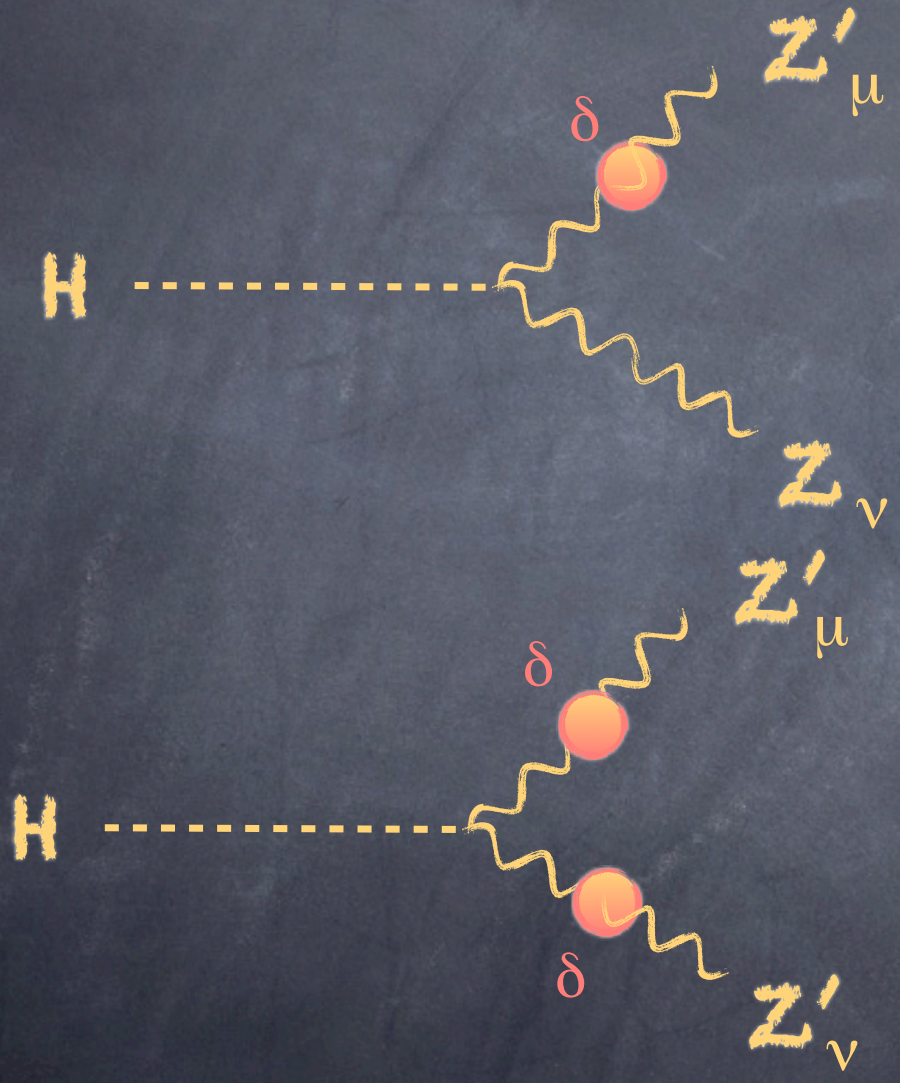

$\alpha \quad \delta^2$

$\alpha \quad \delta^4$

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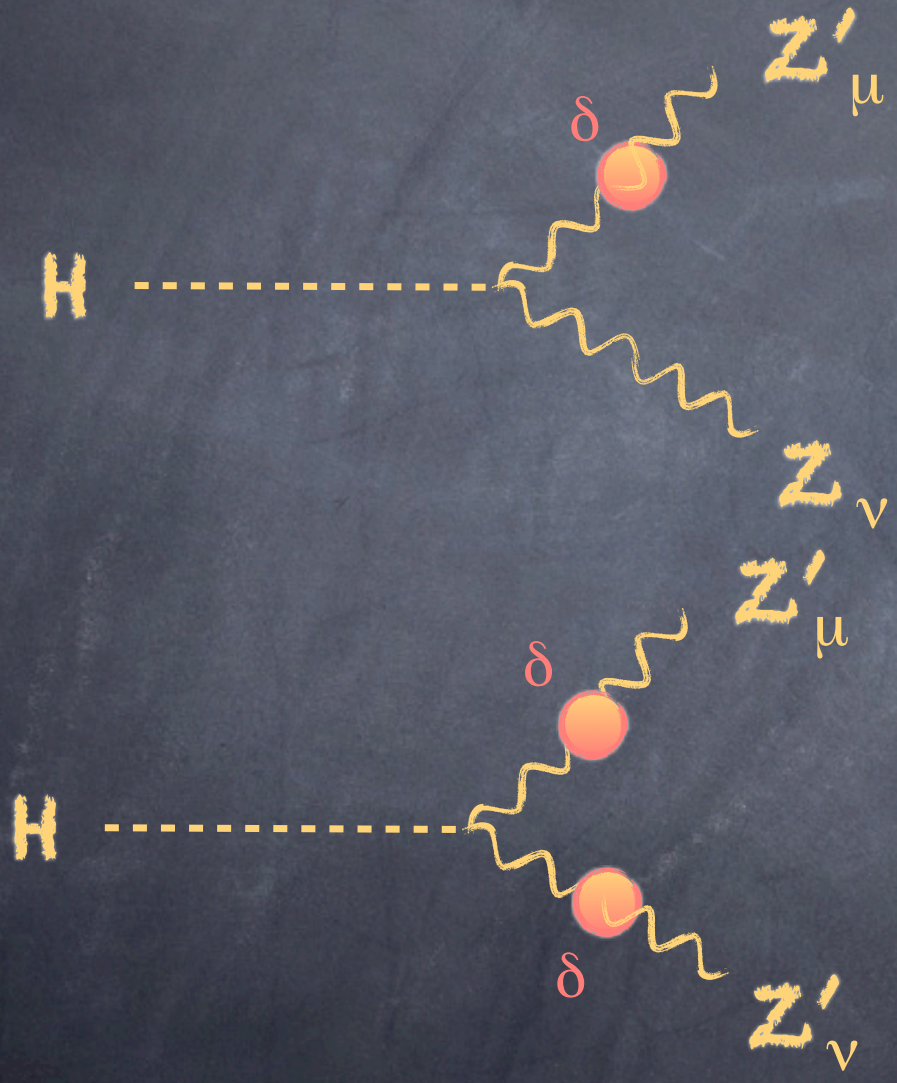

$\alpha \quad \delta^2$

$\alpha \quad \delta^4$

$M_{Z'} = 5$ GeV

$\delta = 5 \times 10^{-3}$

$m_h = 125$ GeV

$\Rightarrow \Gamma_{h \to ZZ'} \simeq 10^{-10}$ GeV

$(\Gamma_h^{SM} = 3.9 \times 10^{-3}$ GeV$)$

Hypercharge-portal

Kumar,Wells 08
Anastopoulos, Bianchi, Dudas, Kiritsis 06
Anastopolos, Fucito, Lionetto, Pradisi, Racioppi, Stanev 08
Dudas, YM, Pokorski, Romagnoni 09 + 12
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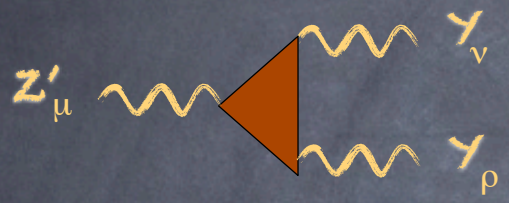

Heavy Fermions (Ψ_h)

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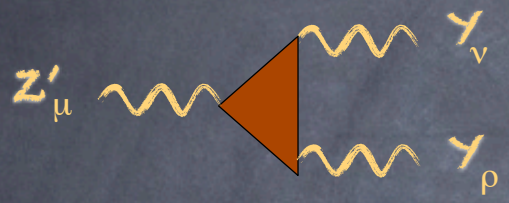

Heavy Fermions (Ψ_h)

Ψ	$U(1)$	$U'(1)$
Ψ_{SM}	X_{SM}	0
Ψ_i	X_i	X'_i
Ψ_h	0	X'_h

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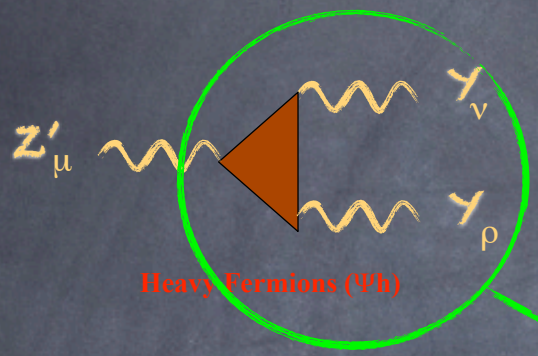

U'(1)

Ψ	U(1)	U'(1)
ΨSM	XSM	0
Ψi	Xi	X'i
Ψh	0	X'h

$$\mathcal{L} \xrightarrow{U'(1)} \mathcal{L} + \lambda\, \varepsilon^{\mu\nu\rho\sigma}\, F^{Y}_{\mu\nu}\, F^{Y}_{\rho\sigma}$$

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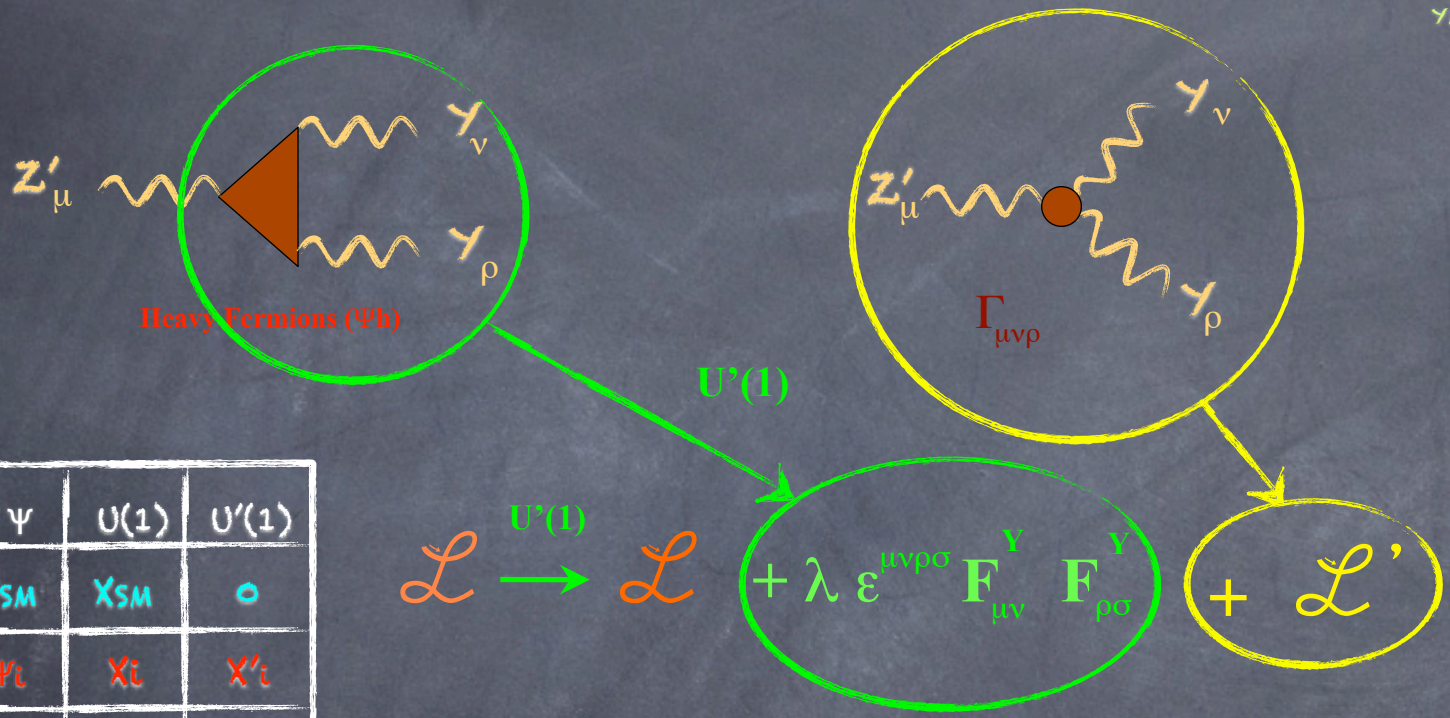

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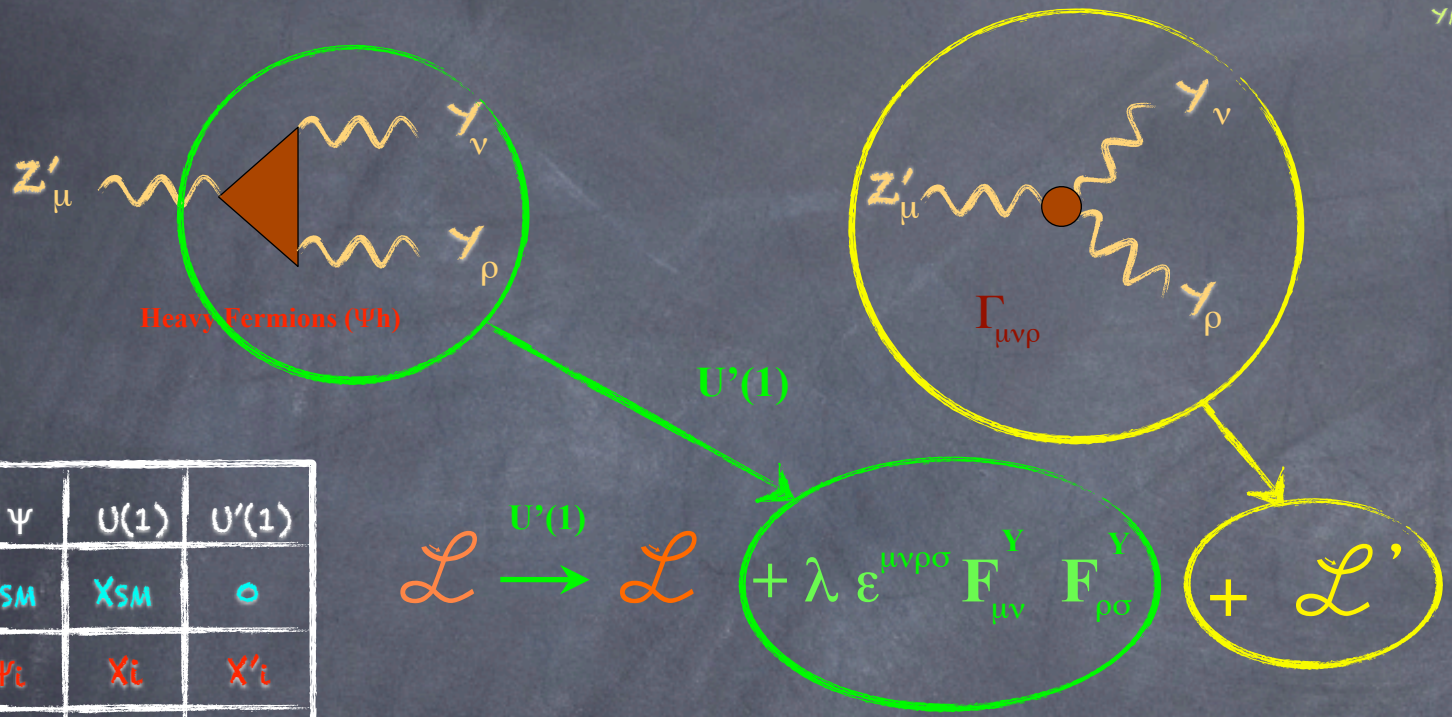

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$$\mathcal{L}' = B\, a\, \varepsilon^{\mu\nu\rho\sigma} F^Y_{\mu\nu} F^Y_{\rho\sigma} + C\, \varepsilon^{\mu\nu\rho\sigma} X_\mu Y_\nu F^Y_{\rho\sigma}$$

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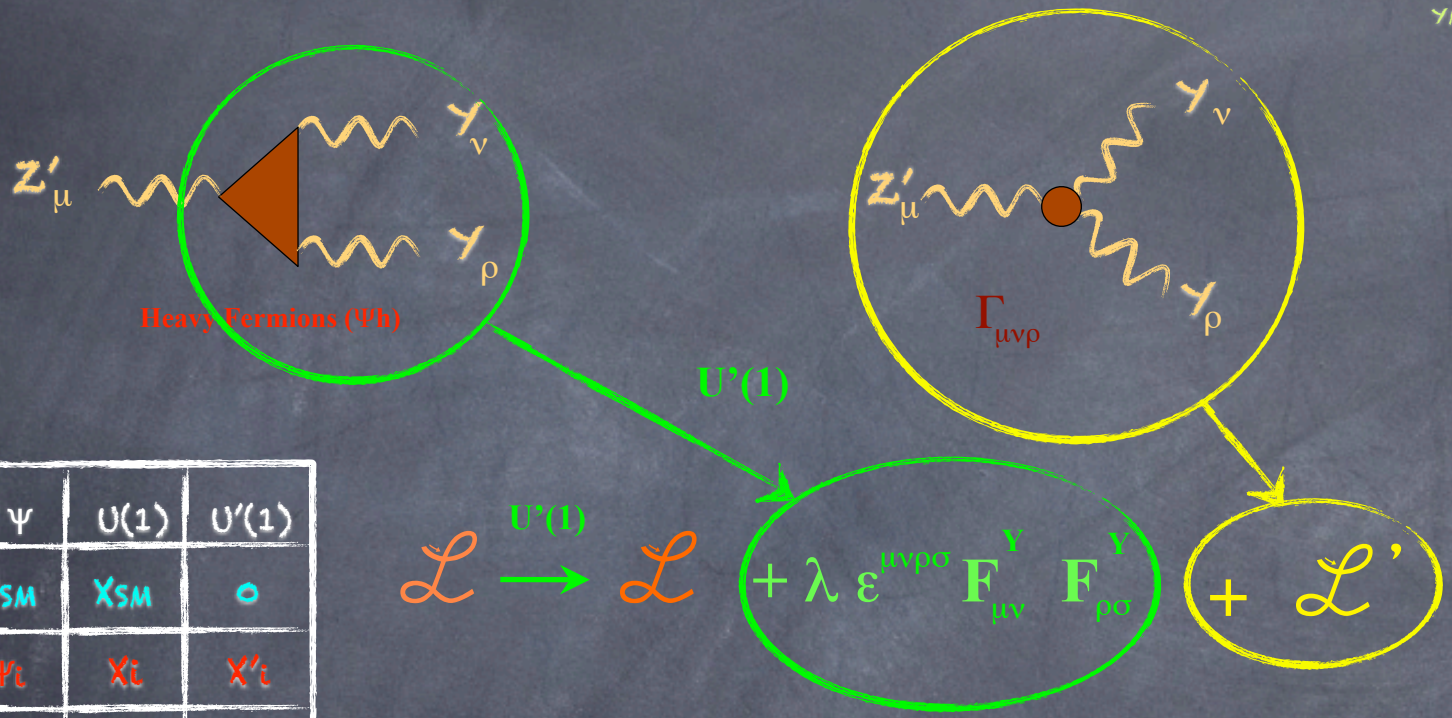

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$$\delta \mathcal{L}' = -\,\delta \Big(Z'_\mu \quad Y_\nu \quad Y_\rho \Big)$$

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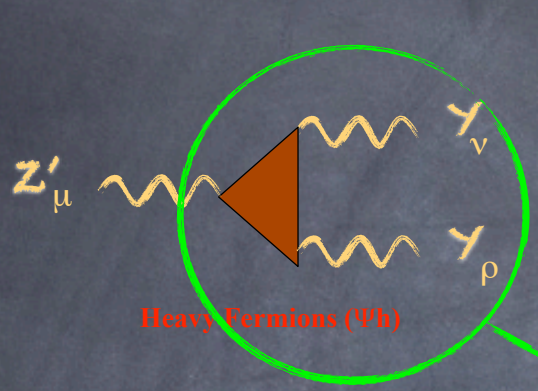
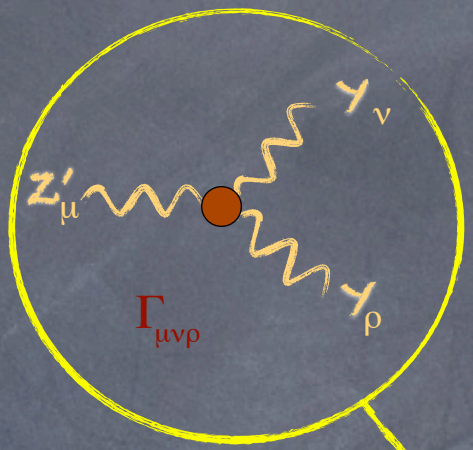
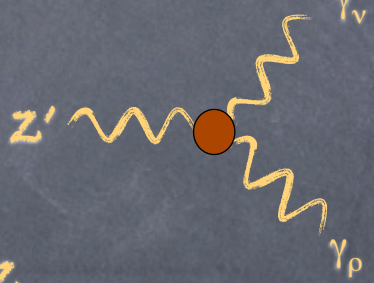
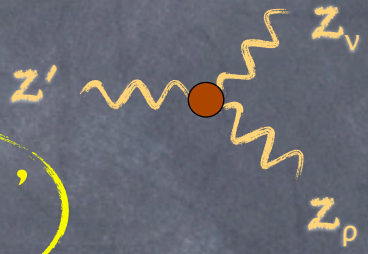








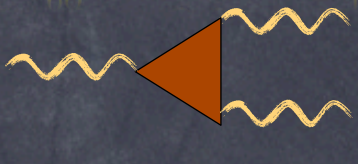
U'(1)

$\mathcal{L} \xrightarrow{U'(1)} \mathcal{L} + \lambda\, \varepsilon^{\mu\nu\rho\sigma} F^Y_{\mu\nu} F^Y_{\rho\sigma} + \mathcal{L}'$

Ψ	U(1)	U'(1)
Ψ_{SM}	X_{SM}	0
Ψ_i	X_i	X'_i
Ψ_h	0	X'_h

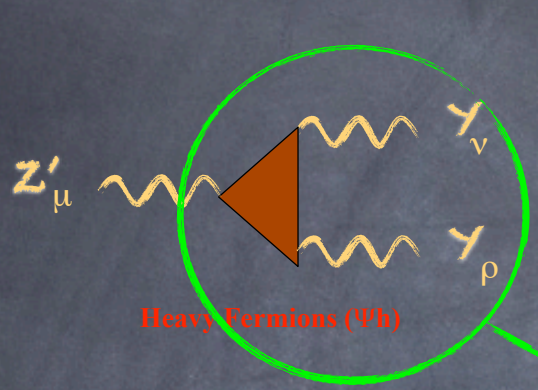
$$\mathcal{L} = F^{Y\mu\nu} F^Y_{\mu\nu} - (d_\mu a - M_X X_\mu)^2 - i\,\overline{\Psi}_h\, \gamma^\mu D_\mu \Psi_h$$

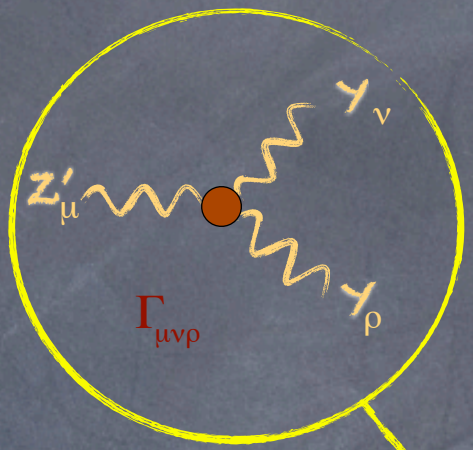
$$\mathcal{L}' = B\, a\, \varepsilon^{\mu\nu\rho\sigma} F^Y_{\mu\nu} F^Y_{\rho\sigma} + C\, \varepsilon^{\mu\nu\rho\sigma} X_\mu Y_\nu F^Y_{\rho\sigma}$$

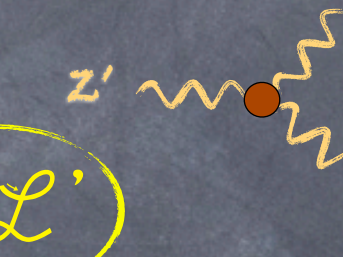
$\delta \mathcal{L}' = -\delta$ ()

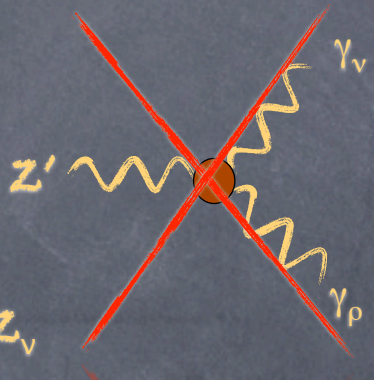
Hypercharge-portal

Kumar,Wells 08
Anastopoulos, Bianchi, Dudas, Kiritsis 06
Anastopolos, Fucito, Lionetto, Pradisi, Racioppi, Stanev 08
Dudas, YM, Pokorski, Romagnoni 09 + 12
YM 09









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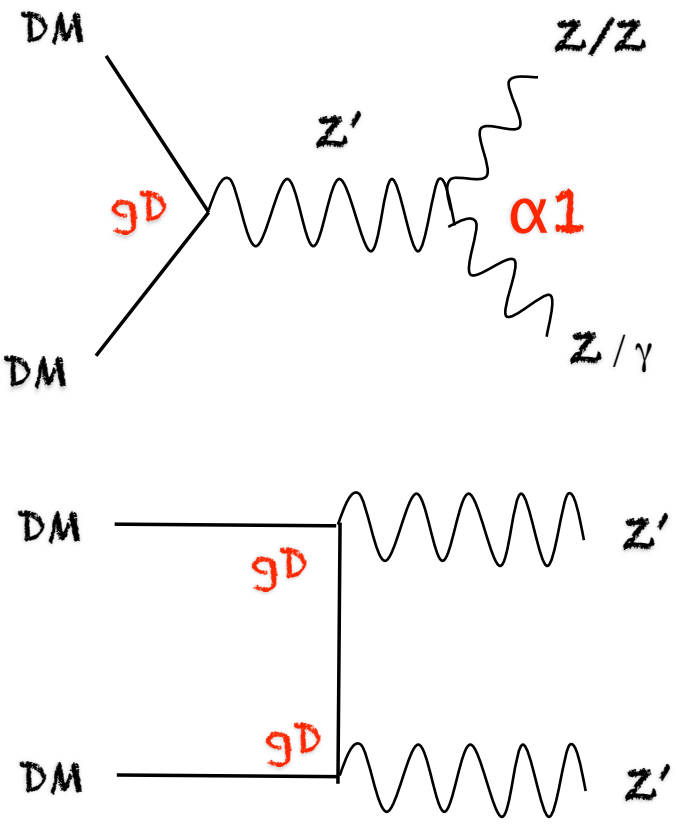
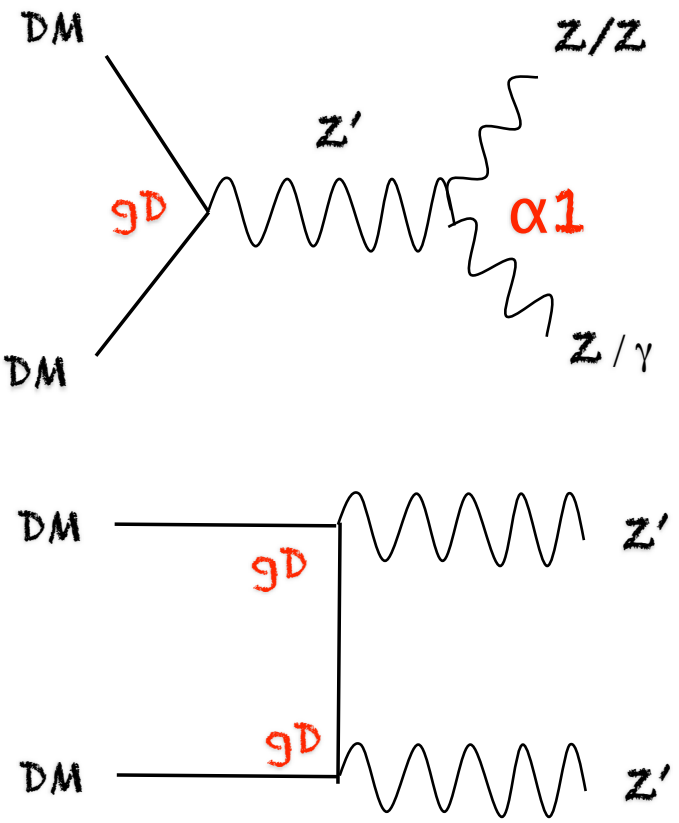
$$\delta\mathcal{L}' = -\,\delta\,\Big(\; Z'_\mu \;\; \gamma_\nu \;\; \gamma_\rho \;\Big)$$

Results

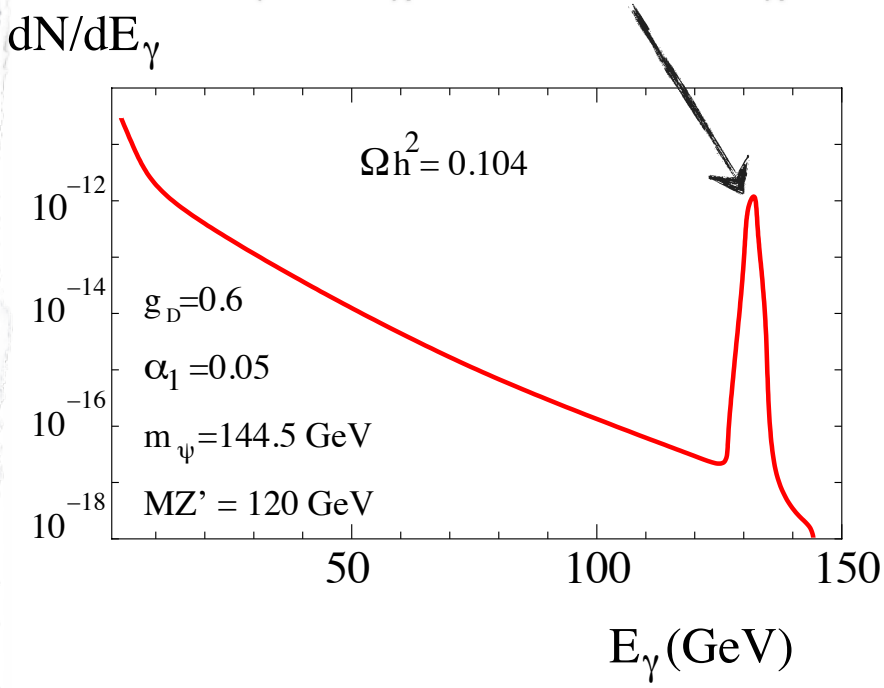
Results



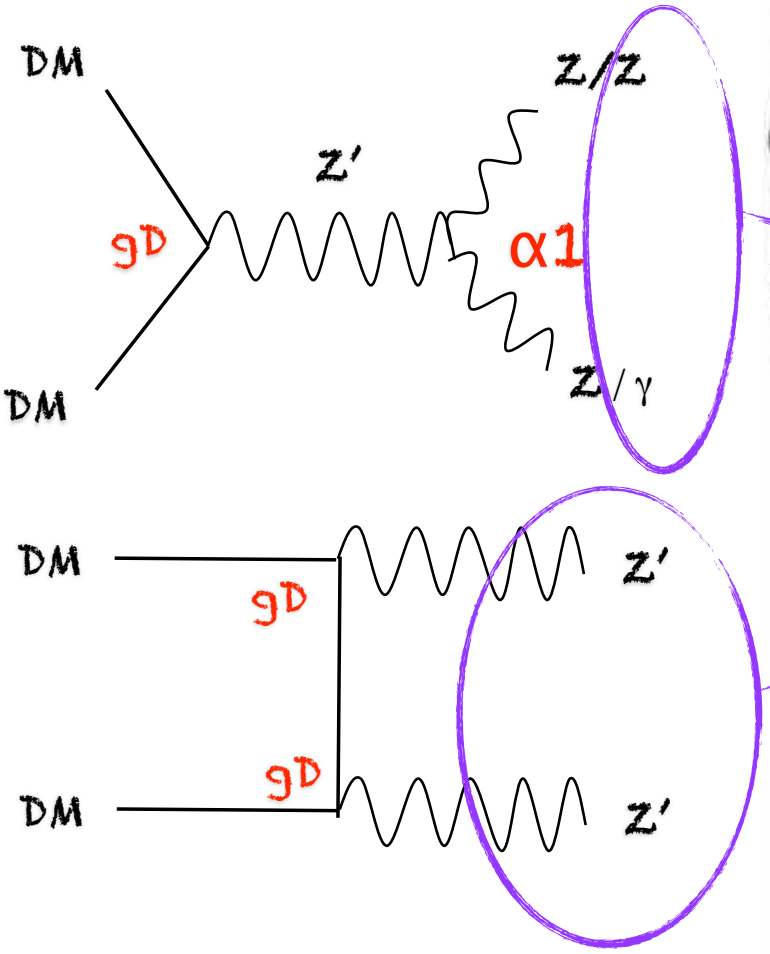
Results



$E_\gamma = M_X\,[1 - (M_Z/2M_X)^2]$



Results



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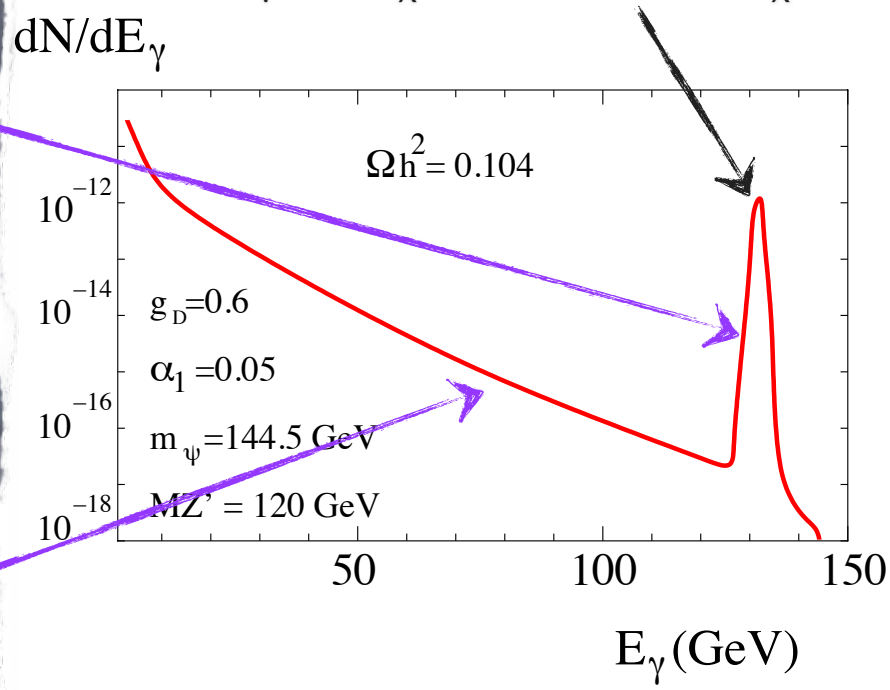
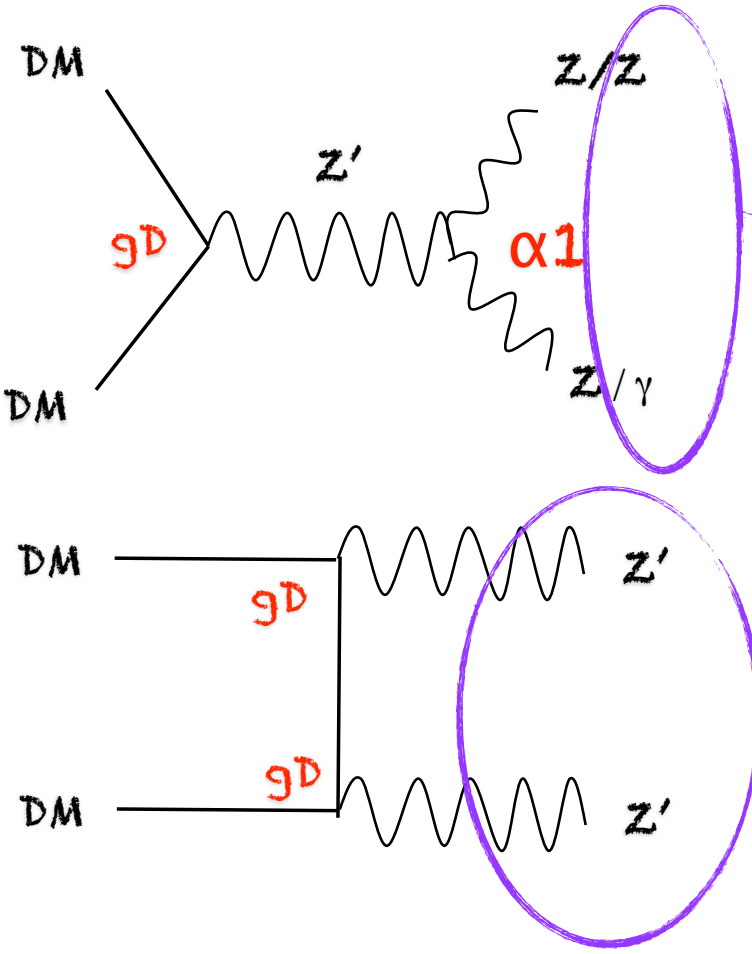


Results



$E_\gamma = M_X\,[1 - (M_Z/2M_X)^2]$

dN/dE_γ

$\Omega h^2 = 0.1$

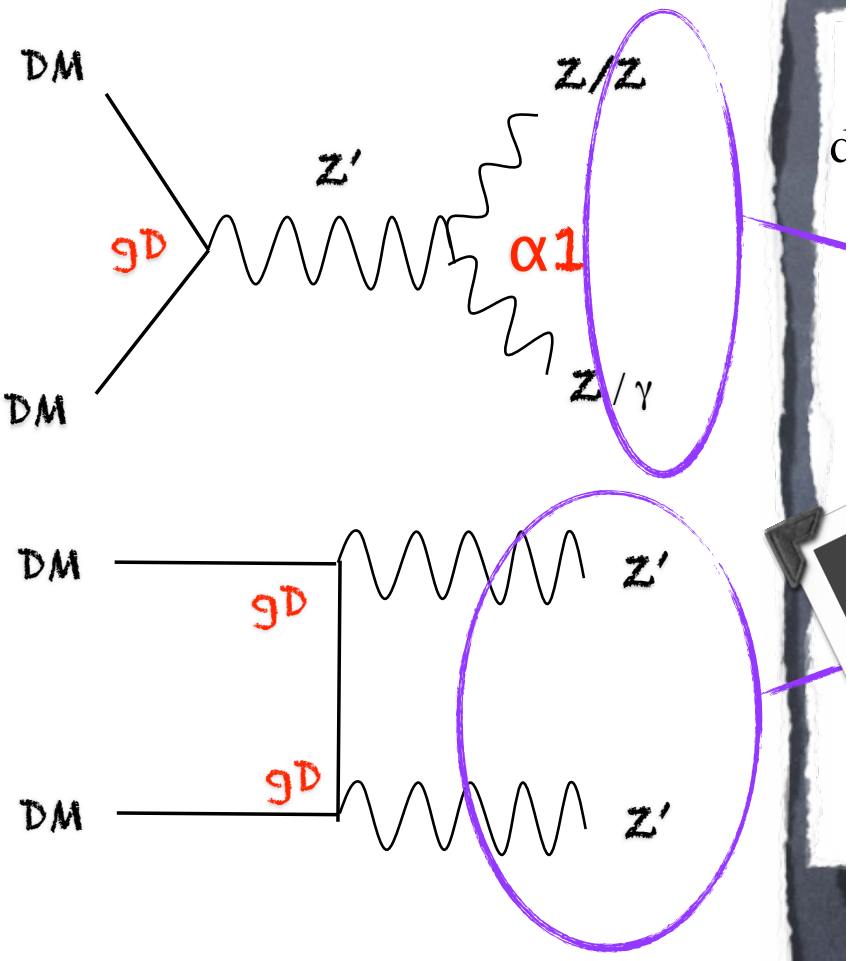
10^{-12}

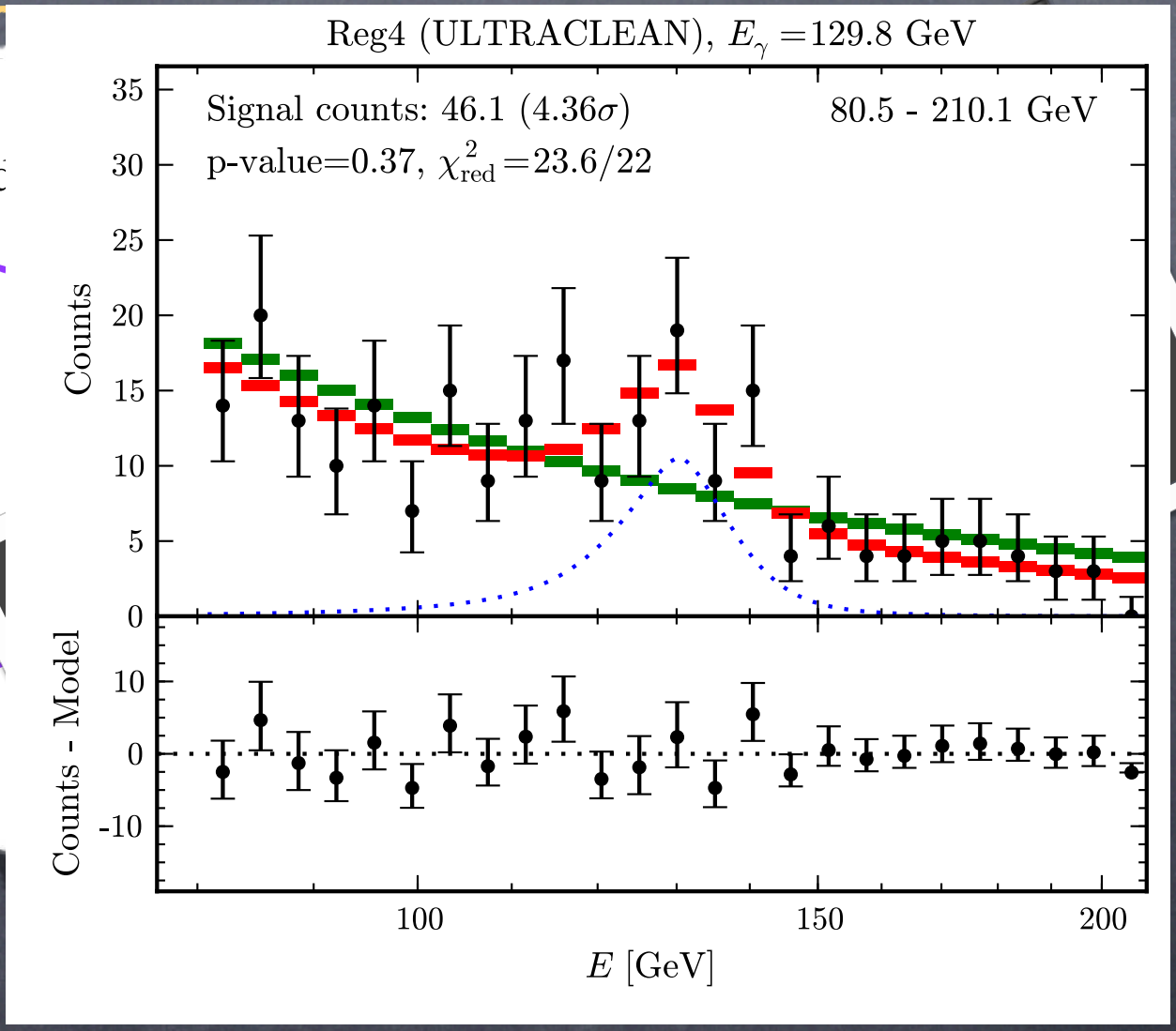
10^{-14}

$g_D = 0$

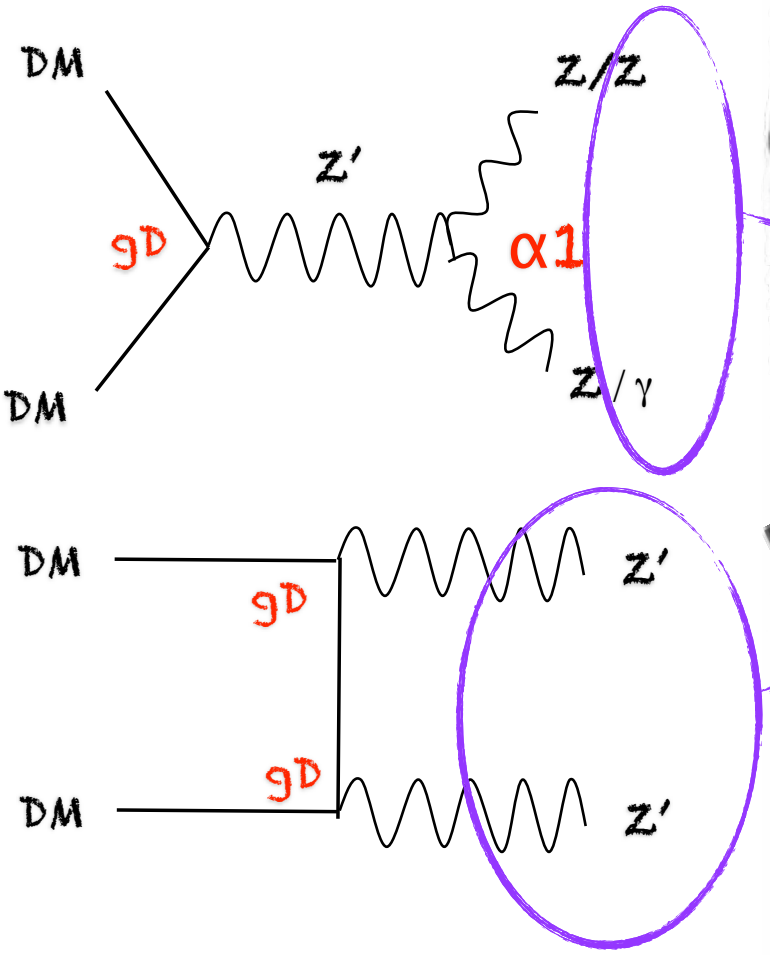
Observation of a Line
at 130 GeV 2.2-3.3 σ ??
Weniger 1204.2797
Tempel et al 1205.1045

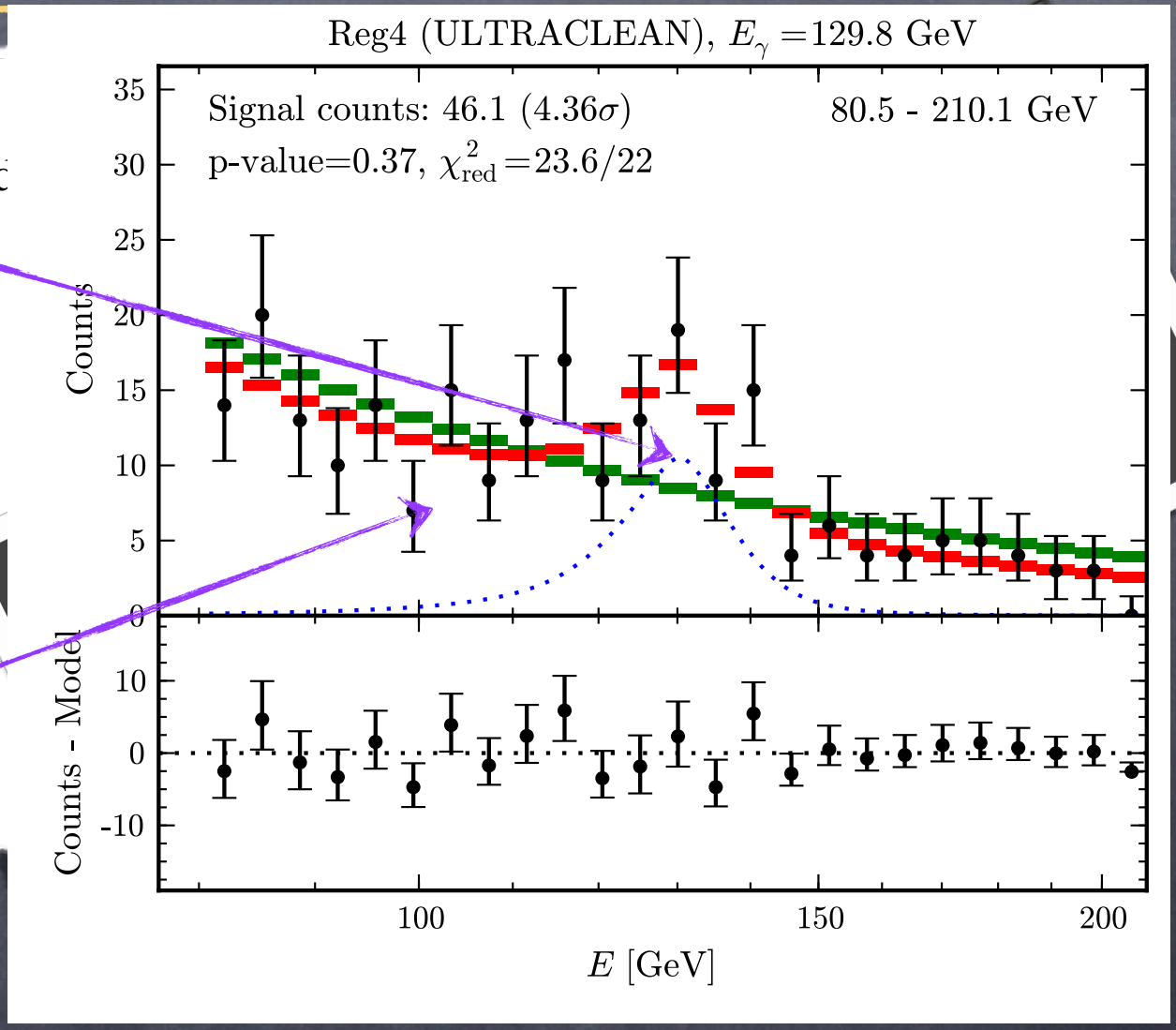
Results


DM
DM
Z'
gD
Z/Z
α1
Z/γ
DM
DM
gD
Z'
gD
Z'


Reg4 (ULTRACLEAN), E_γ =129.8 GeV
Signal counts: 46.1 (4.36σ)
80.5 - 210.1 GeV
p-value=0.37, $\chi^2_{\rm red}$=23.6/22
Counts
Counts - Model
E [GeV]

Results


DM
DM
Z'
gD
Z/Z
α1
Z/γ
DM
DM
gD
Z'
gD
Z'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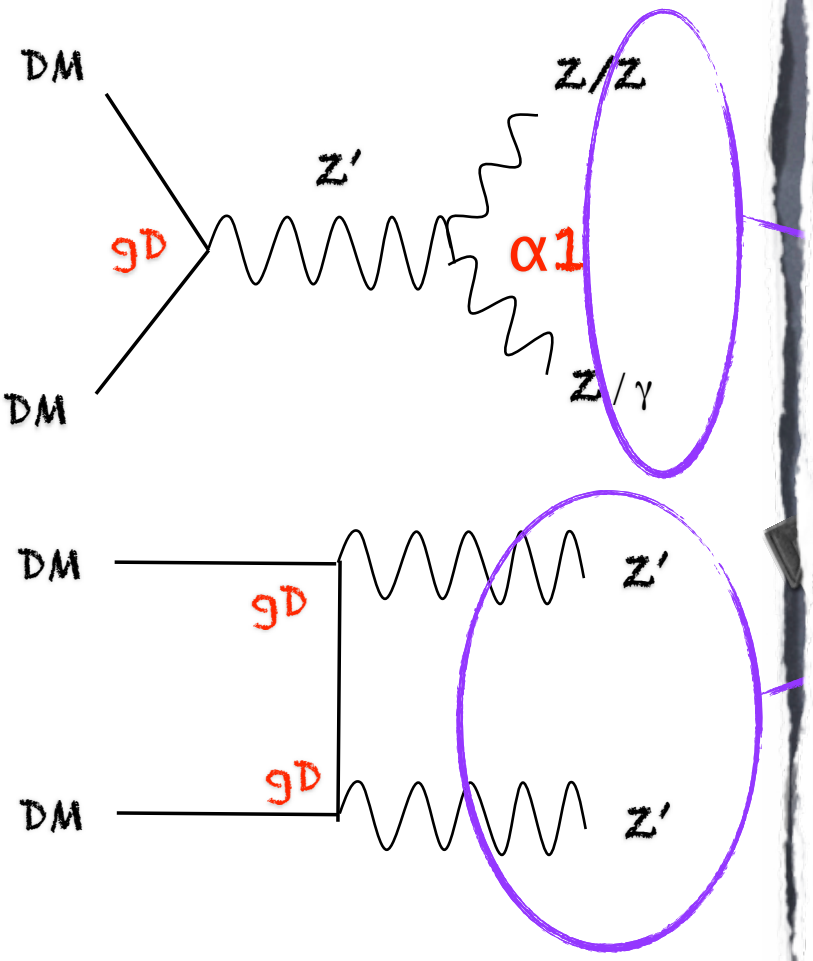
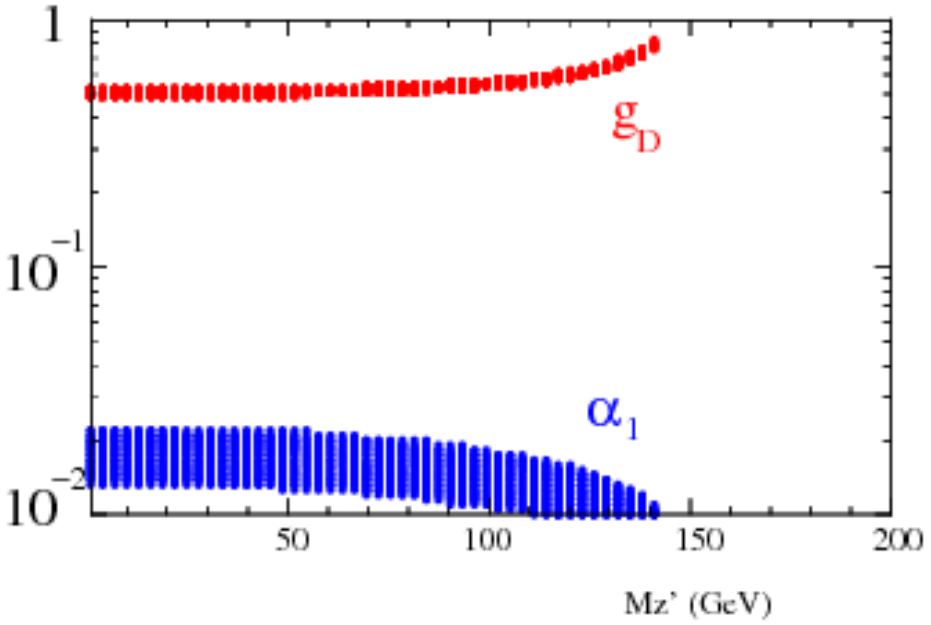
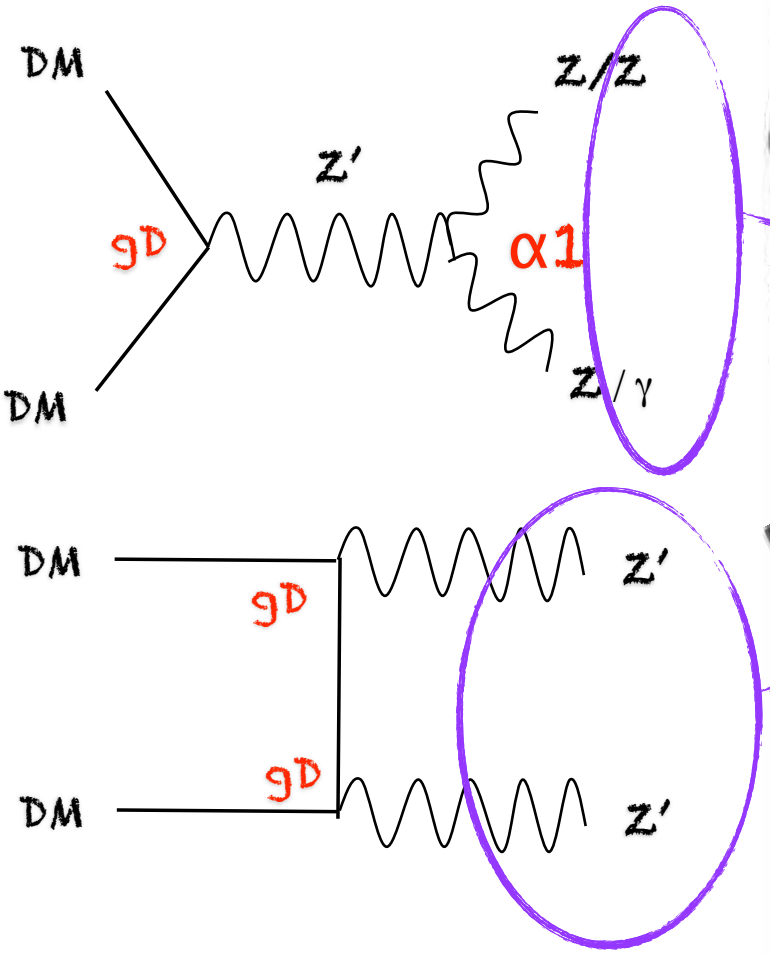


WMAP + fitting monochromatic line



Results



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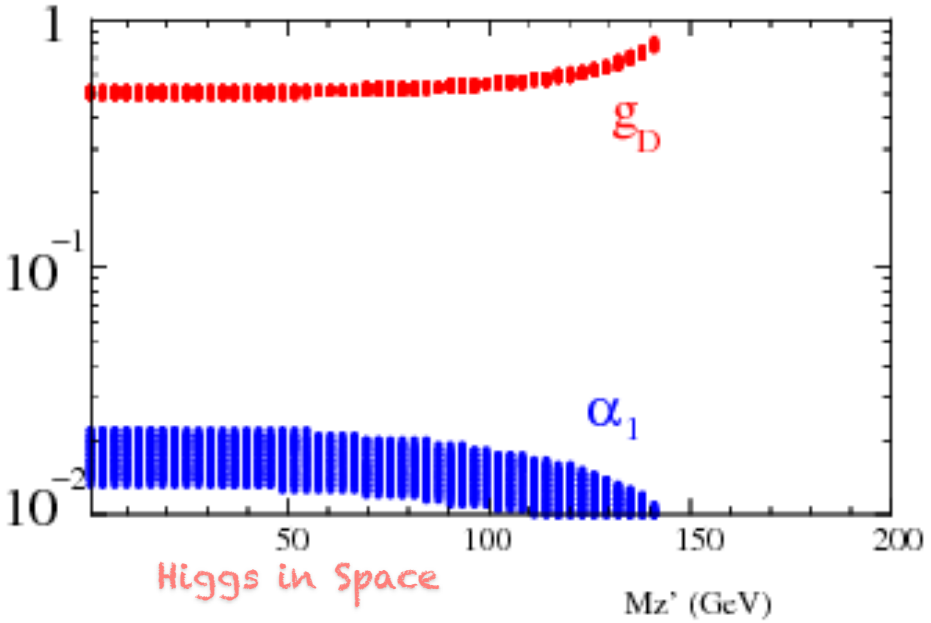
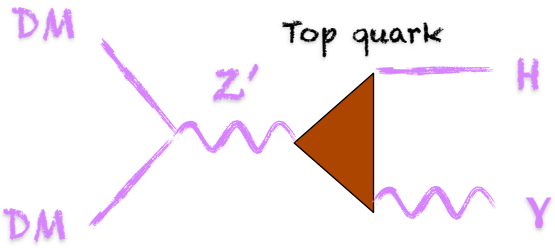


Higgs in Space



[Jackson, Servant, Shaughnessz, Tait, Taoso 09]

Djouadi et al 2012/2013
YM 2011
Strumia et al 2011
Tytgat et al 2009
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The Higgs portal

To build the simplest gauge invariant extension of the SM

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$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{\lambda_S}{4} S^4 - \frac{\mu_S^2}{2} S^2 - \frac{\lambda_{HS}}{4} S^2 H^\dagger H - \frac{\kappa_1}{2} H^\dagger H S - \frac{\kappa_3}{3} S^3$$

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Stability of S as DM candidate:
HHS -> <H> HS after SU(2)*U(1) breaking
-> Higgs mixes with S
-> S -> ff possible and is thus not a viable DM candidate.
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No phenomenology (<S>=0)

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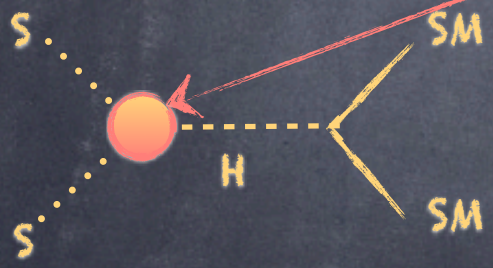

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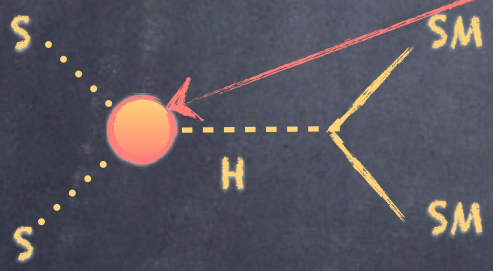

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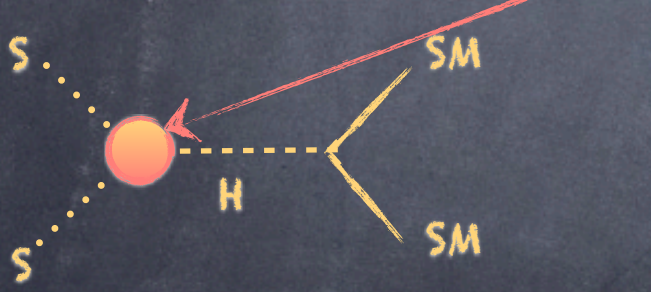

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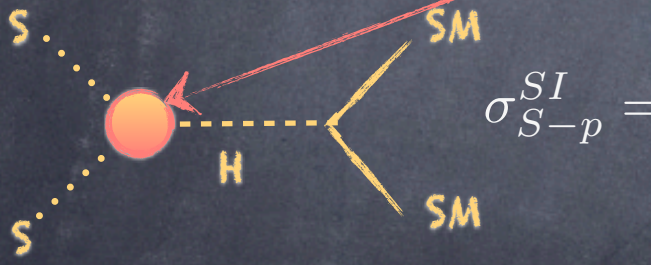

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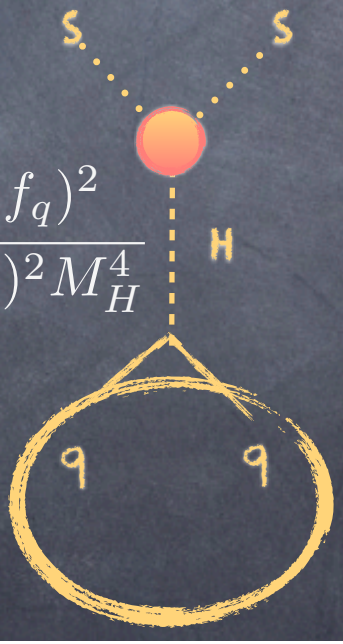

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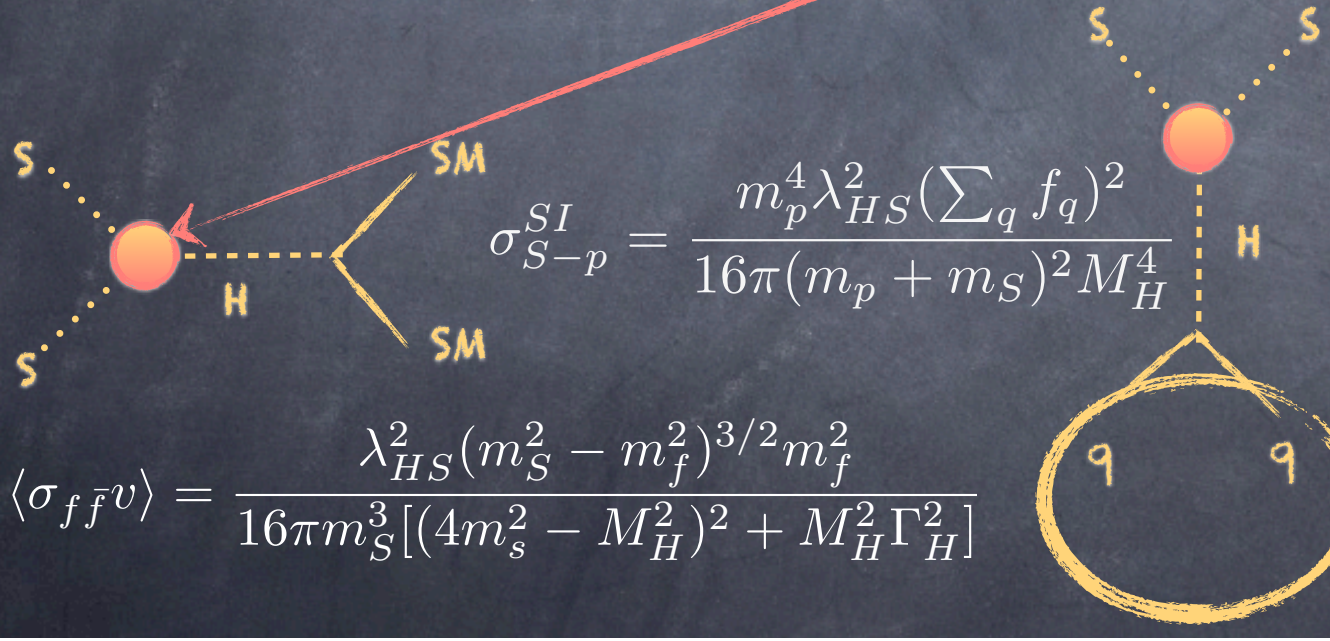

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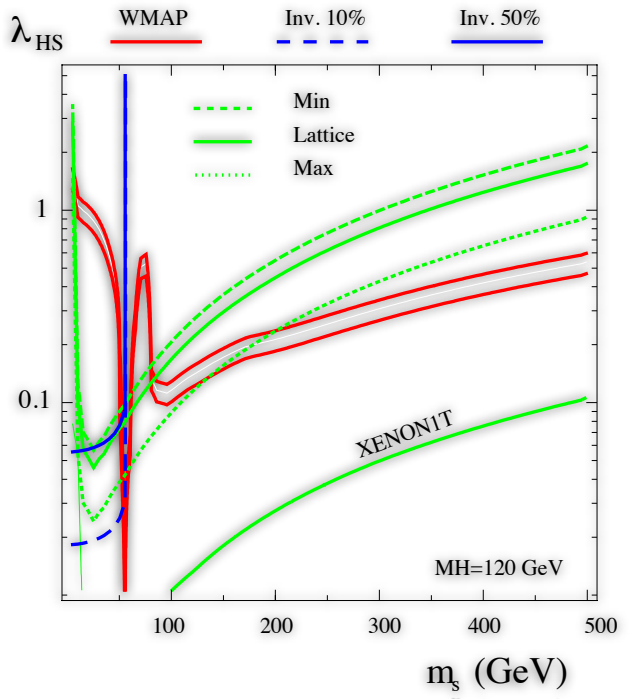

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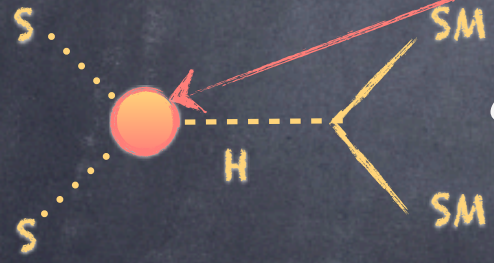

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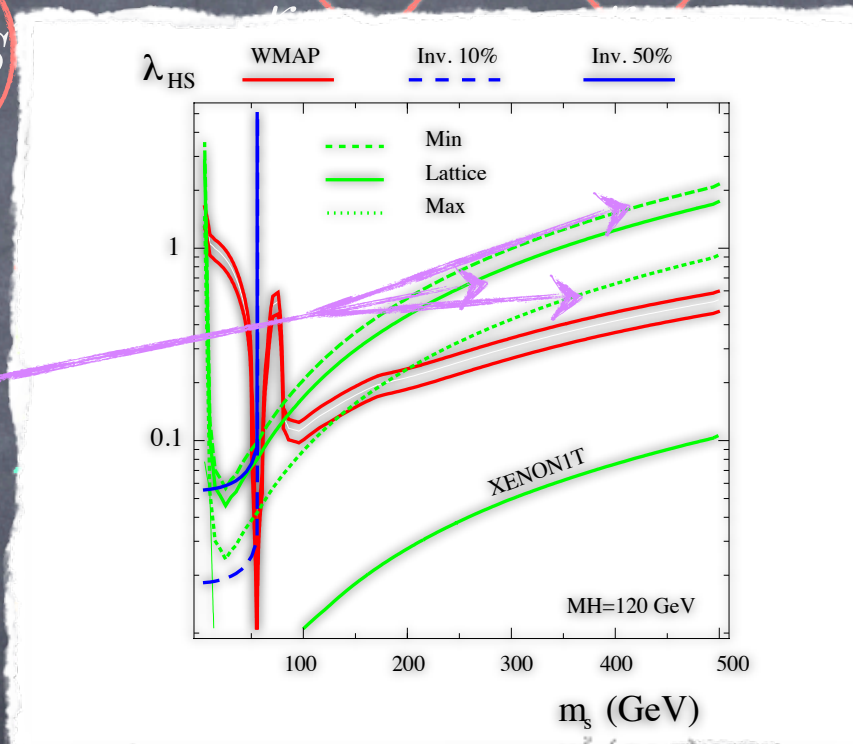

Combining direct detection constraint, WMAP and a 125 GeV Higgs

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→ WMAP

Combining direct detection constraint, WMAP and a 125 GeV Higgs

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$$\sigma_{S-p}^{SI} = \frac{m_p^4 \lambda_{HS}^2 (\sum_q f_q)^2}{16\pi (m_p + m_S)^2 M_H^4} \longrightarrow \text{direct detection (XENON100)}$$

Combining direct detection constraint, WMAP and a 125 GeV Higgs

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Invisible decay

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$$\Gamma_H(H \to SS) = \frac{\lambda_{HS}^2 M_W^2}{32\pi g^2 M_H^2} \sqrt{M_H^2 - 4m_S^2}$$

→ LHC

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O. Lebedev,
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1112.3299

Vectorial and fermionic dark matter

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Vectorial and fermionic dark matter

$$\mathcal{L}_S = \mathcal{L}_{SM} - \frac{1}{2}m_S^2 S^2 - \frac{1}{4}\lambda_S S^4 - \frac{1}{4}\lambda_{hSS} H^\dagger H S^2$$

$$\mathcal{L}_V = \mathcal{L}_{SM} + \frac{1}{2}m_V^2 V_\mu V^\mu + \frac{1}{4}\lambda_V (V_\mu V^\mu)^2 + \frac{1}{4}\lambda_{hVV} H^\dagger H V_\mu V^\mu$$

$$\mathcal{L}_f = \mathcal{L}_{SM} - \frac{1}{2}m_f \bar{\chi}\chi - \frac{1}{4}\frac{\lambda_{hff}}{\Lambda} H^\dagger H \bar{\chi}\chi$$

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$$\Gamma^{\rm inv}_{h\to SS} = \frac{\lambda_{hSS}^2 v^2 \beta_S}{64\pi m_h}$$

$$\Gamma^{\rm inv}_{h\to VV} = \frac{\lambda_{hVV}^2 v^2 m_h^3 \beta_V}{256\pi M_V^4}\left(1 - 4\frac{M_V^2}{m_h^2} + 12\frac{M_V^4}{m_h^4}\right)$$

$$\Gamma^{\rm inv}_{h\to\chi\chi} = \frac{\lambda_{hff}^2 v^2 m_h \beta_f^3}{32\pi\Lambda^2}$$

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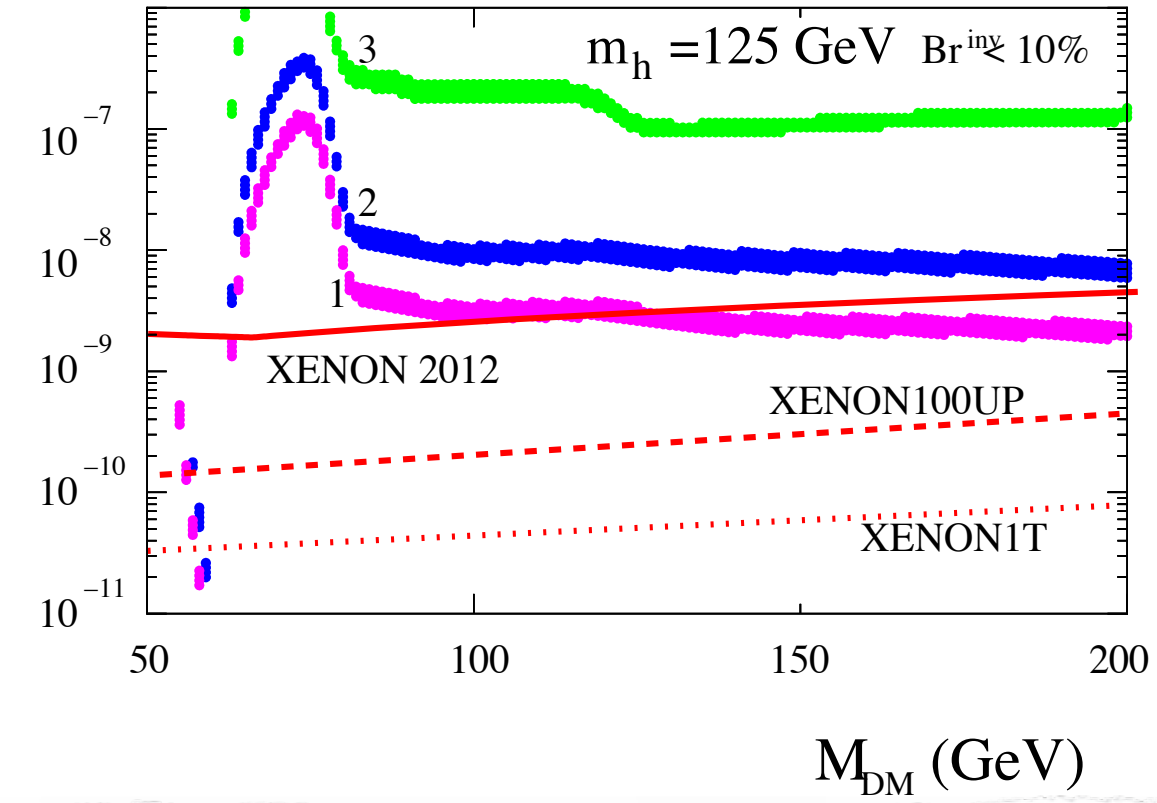
Vectorial and fermionic dark matter

WMAP + 10% invisible



$$n_S^2 S^2 - \frac{1}{4}\lambda_S S^4 - \frac{1}{4}\lambda_{hSS} H^\dagger H S^2$$

$$\lambda_V (V_\mu V^\mu)^2 + \frac{1}{4}\lambda_{hVV} H^\dagger H V_\mu V^\mu$$

$$_{SM} - \frac{1}{2} m_f \bar{\chi}\chi - \frac{1}{4}\frac{\lambda_{hff}}{\Lambda} H^\dagger H \bar{\chi}\chi$$

$$\Gamma^{\rm inv}_{h\to SS} = \frac{\lambda^2_{hSS} v^2 \beta_S}{64\pi m_h}$$

$$\frac{v^2 m_h^3 \beta_V}{6\pi M_V^4}\left(1 - 4\frac{M_V^2}{m_h^2} + 12\frac{M_V^4}{m_h^4}\right)$$

$$\Gamma^{\rm inv}_{h\to\chi\chi} = \frac{\lambda^2_{hff} v^2 m_h \beta_f^3}{32\pi\Lambda^2}$$

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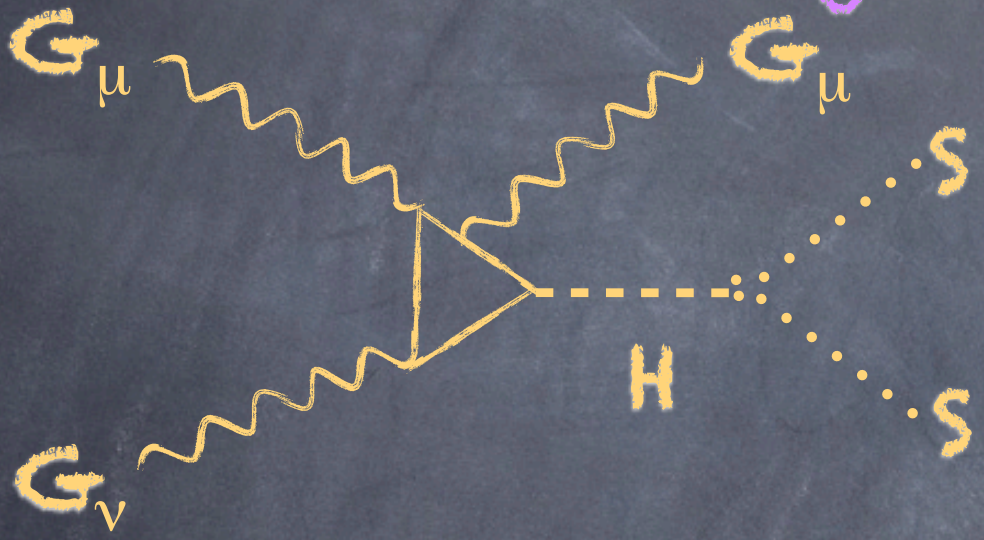
Monojet



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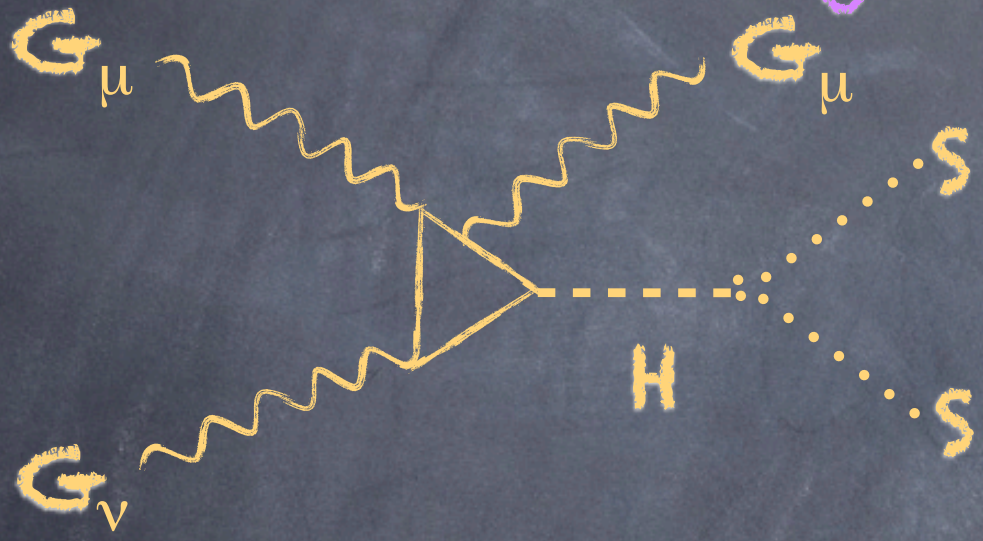

$$\sigma^{SI}_{S-p} = \frac{m_p^4 \lambda^2_{HS} (\sum_q f_q)^2}{16\pi (m_p + m_S)^2 M_H^4}$$

$$\Gamma_H(H \to SS) = \frac{\lambda^2_{HS} M_W^2}{32\pi g^2 M_H^2} \sqrt{M_H^2 - 4m_S^2}$$

$$\frac{\Gamma^{Inv}_H}{\sigma^{SI}_{S-p}} = \frac{(m_S + m_p)^2 M_H^2 M_W^2 \sqrt{M_H^2 - 4m_S^2}}{2g^2 f^2 m_p^4}$$

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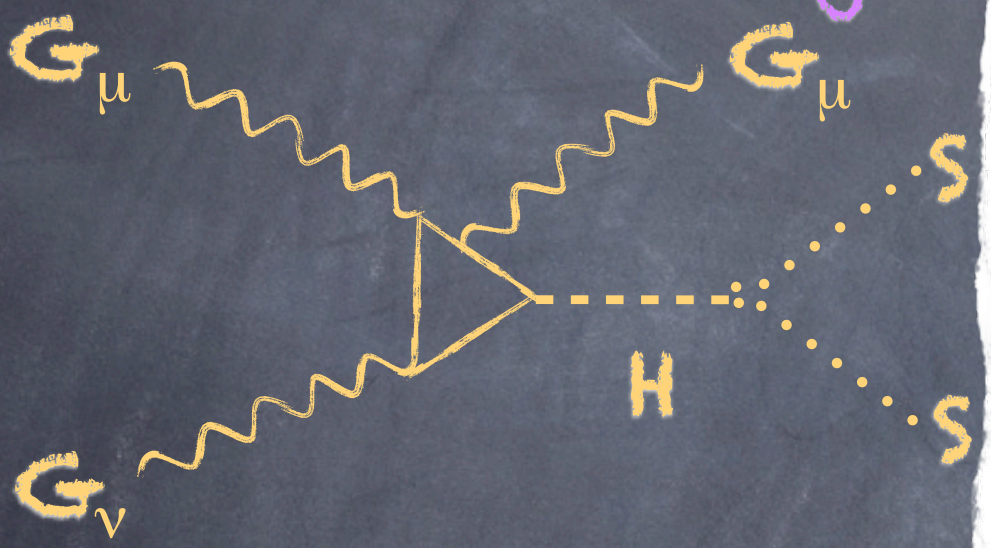

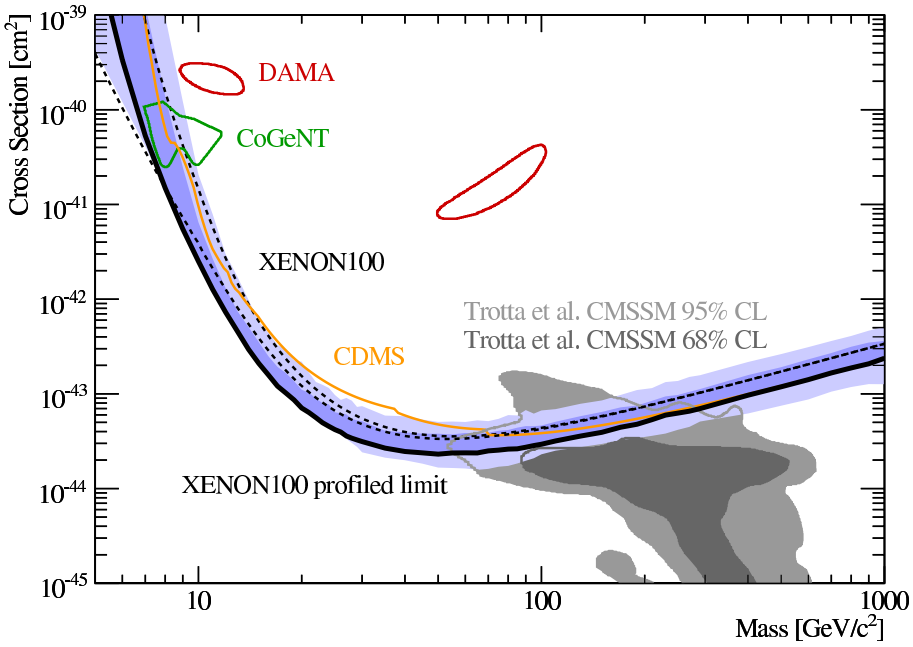

$$\frac{\Gamma_H^{Inv}}{\sigma_{S-p}^{SI}} = \frac{(m_S + m_p)^2 M_H^2 M_W^2 \sqrt{M_H^2 - 4m_S^2}}{2g^2 f^2 m_p^4}$$

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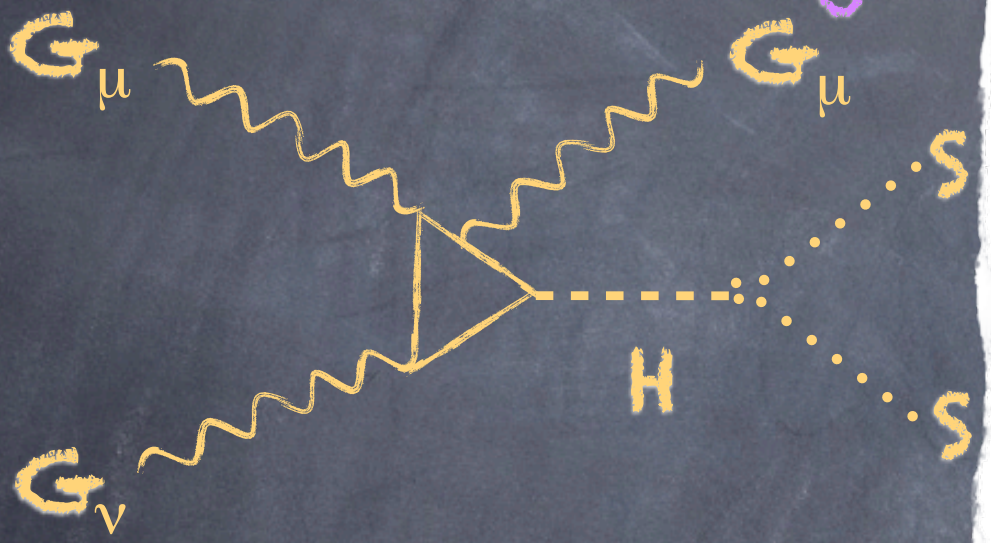

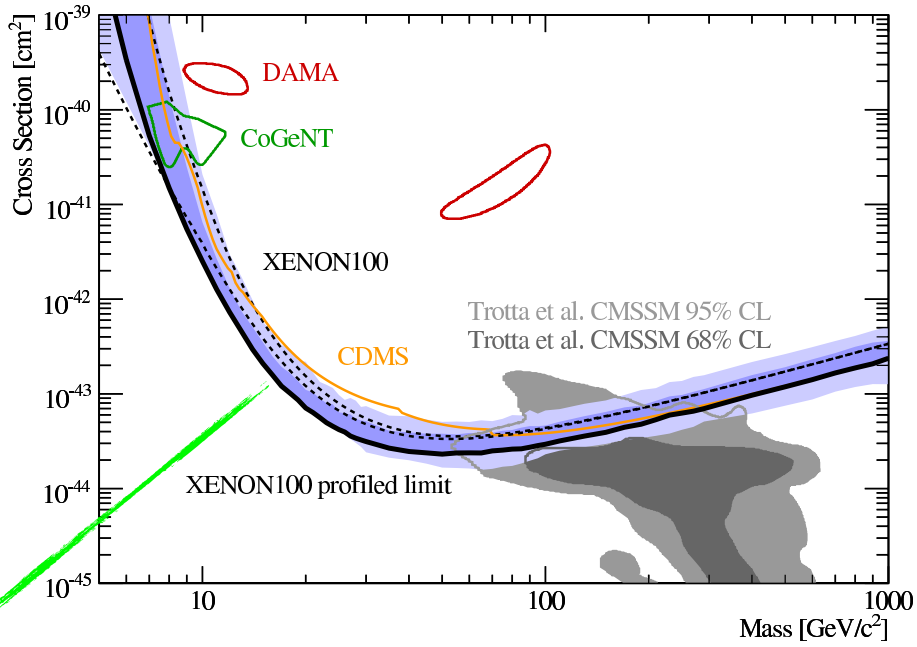

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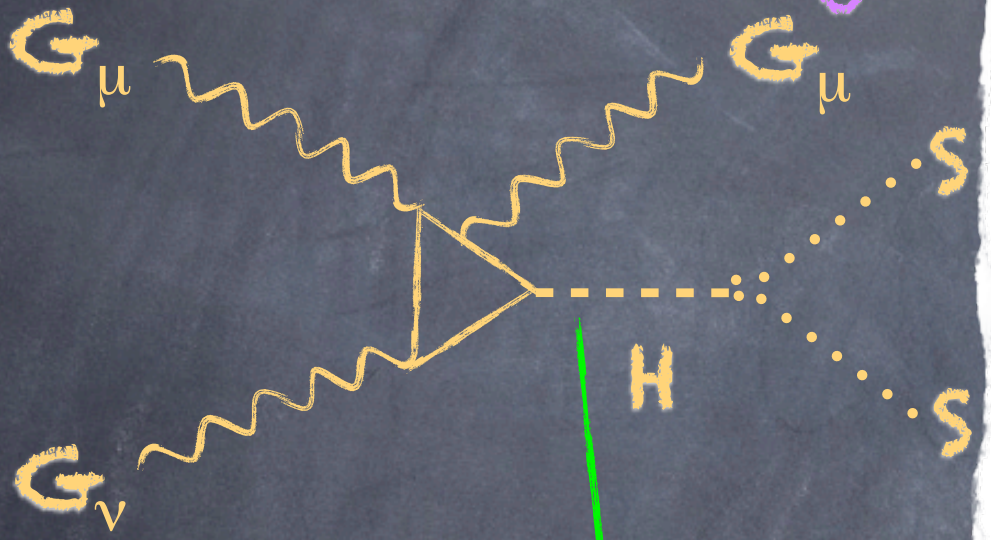

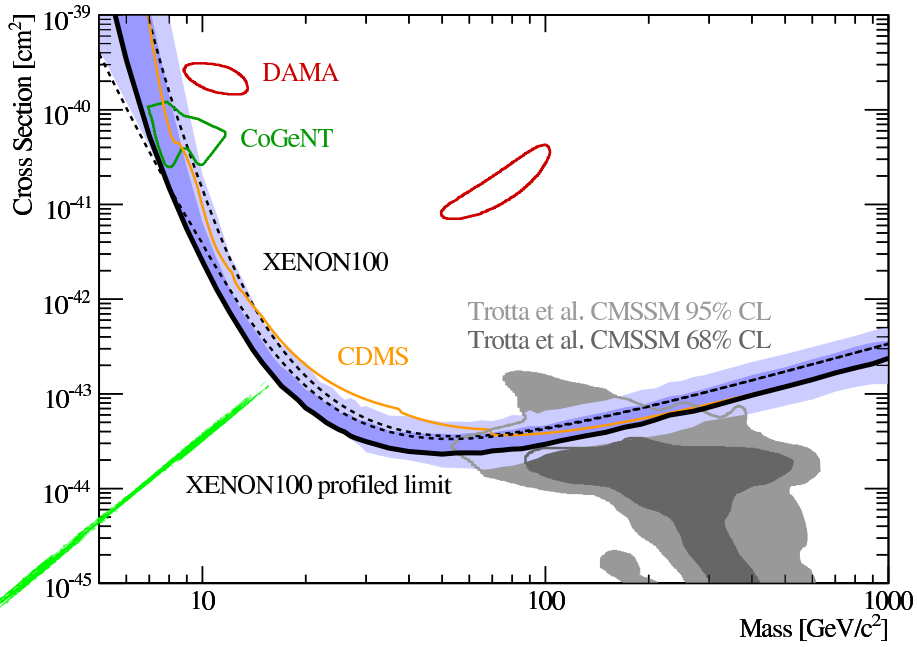

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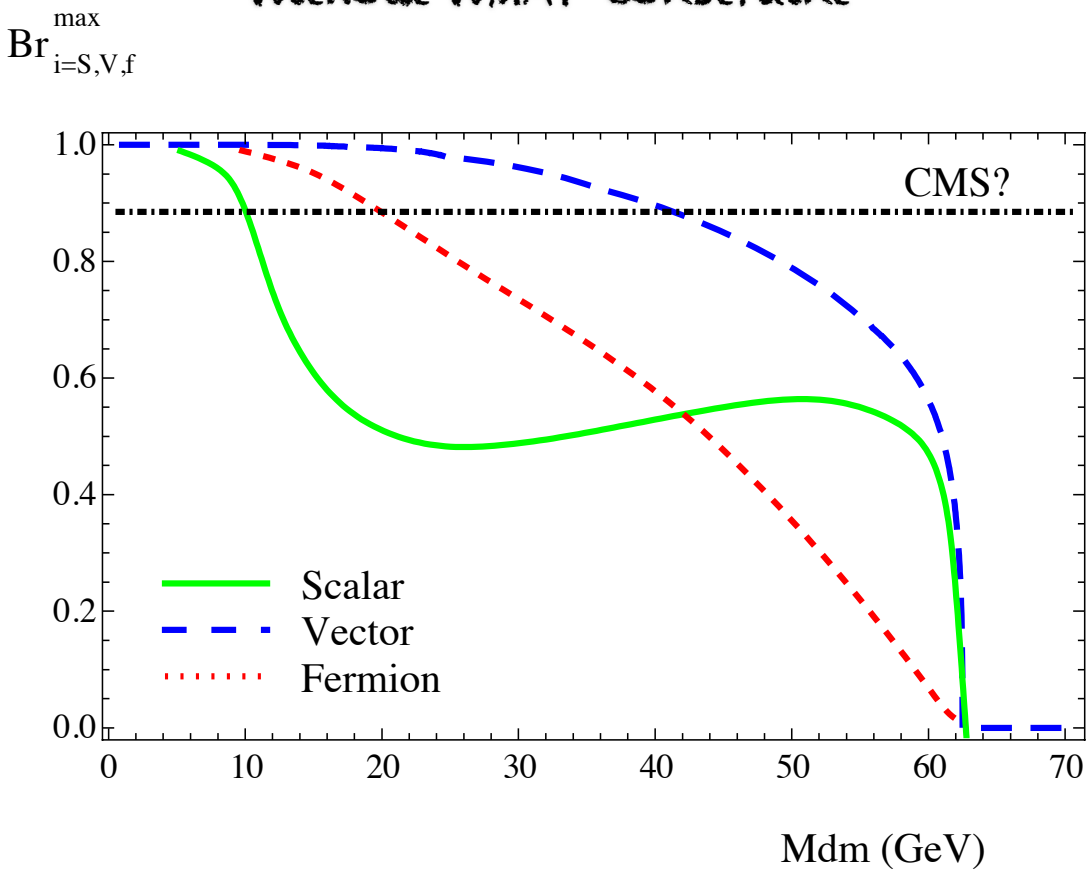
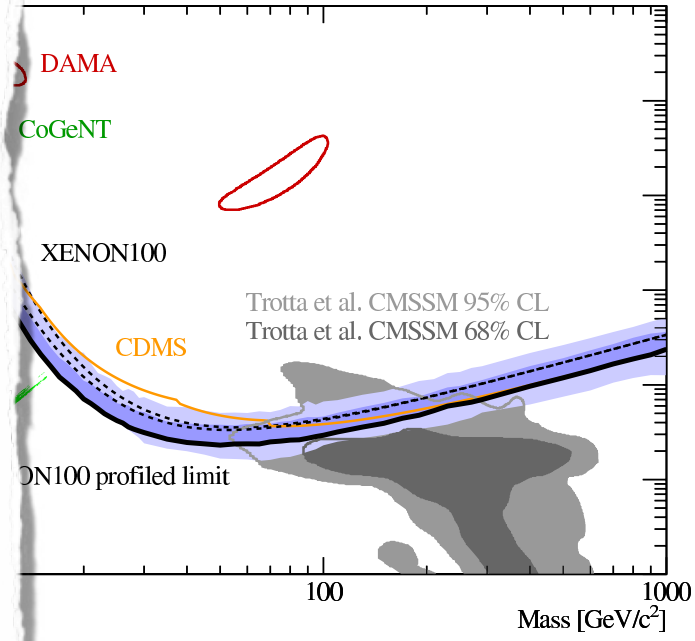
Without WMAP constraint





$$\sqrt{M_H^2 - 4m_S^2}$$

How to see an invis

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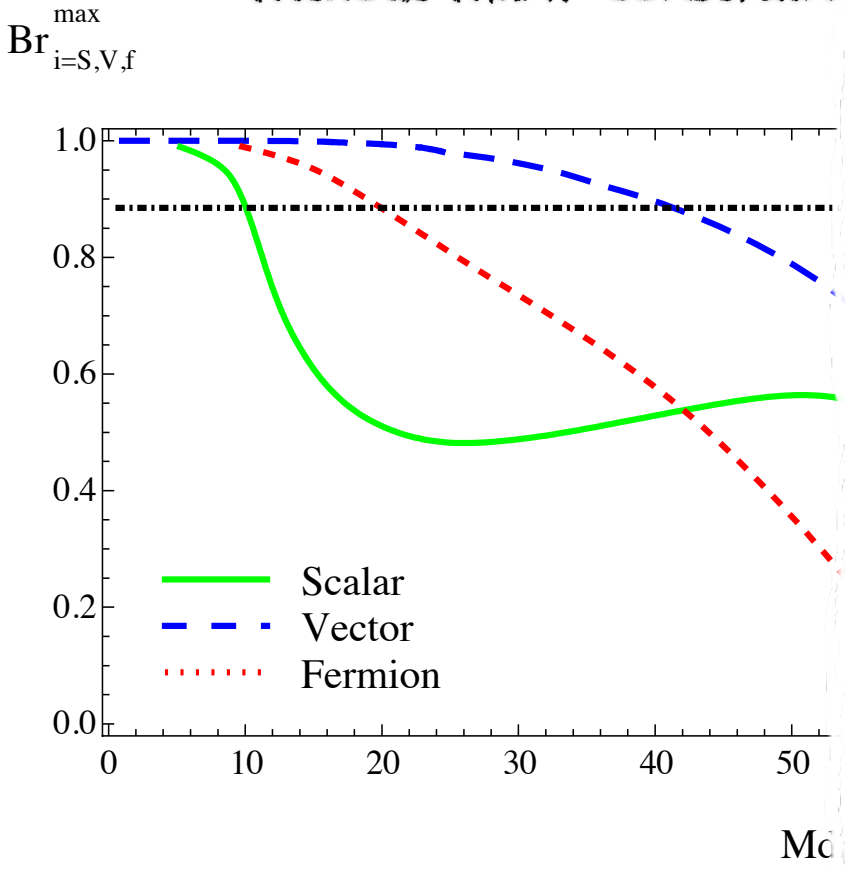
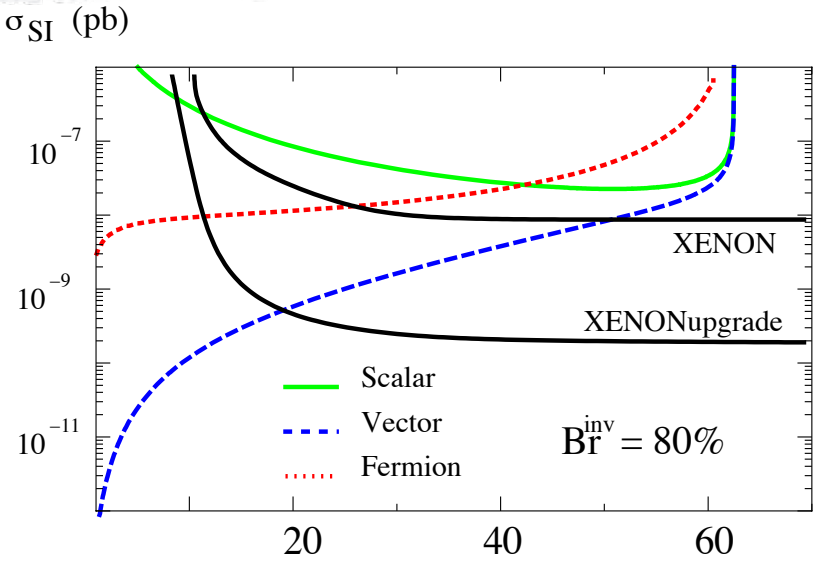
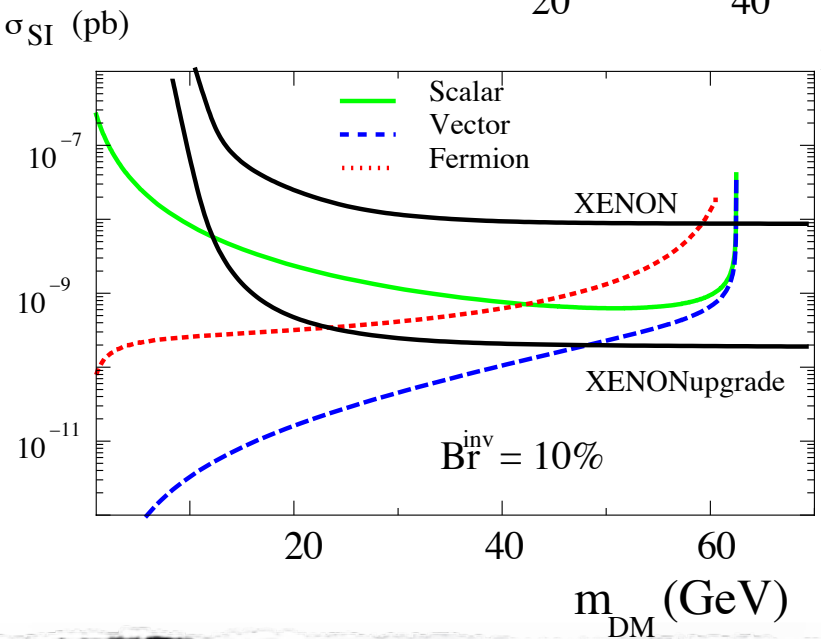
Without WMAP constrain







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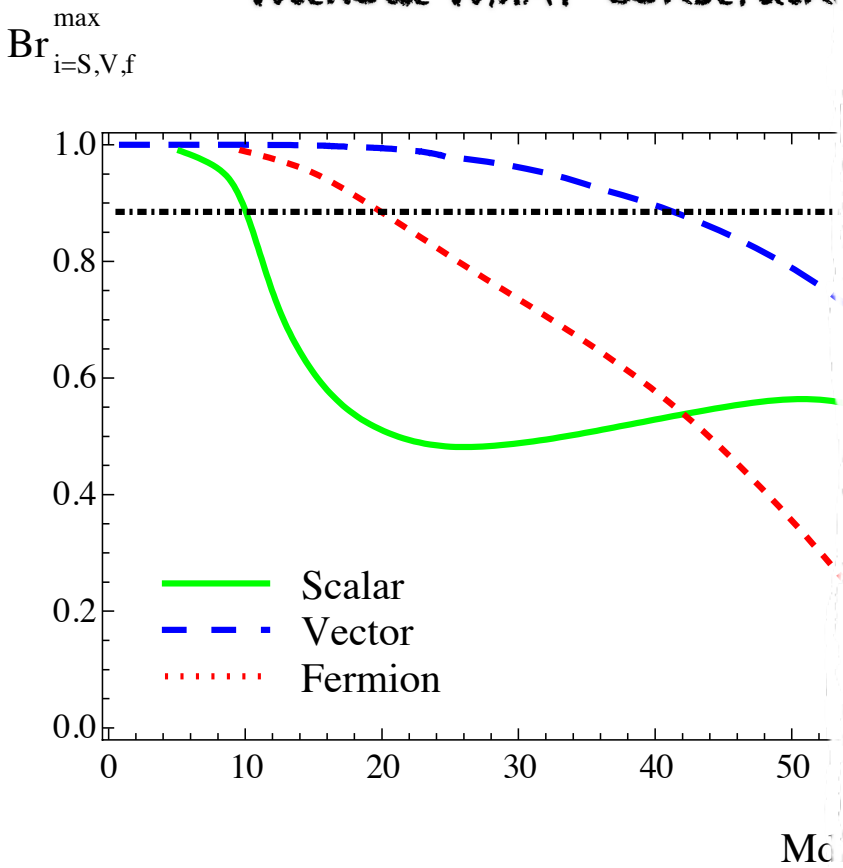

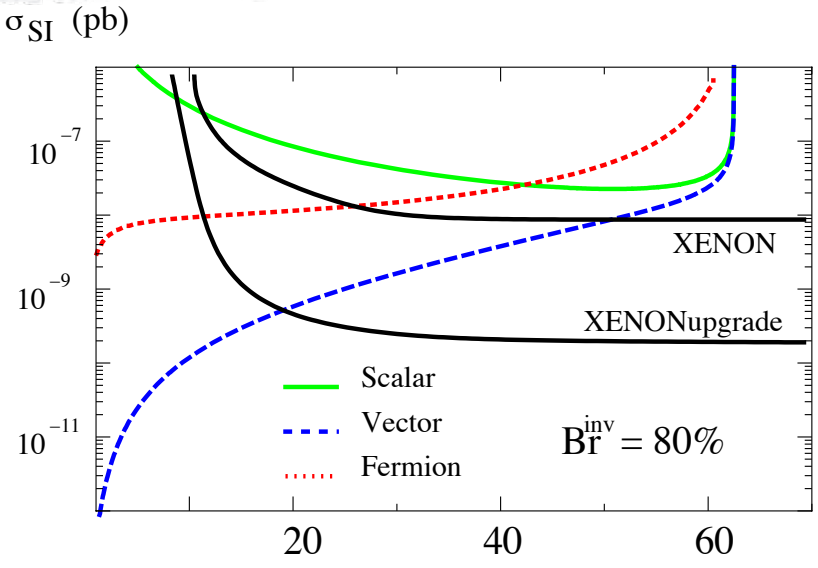

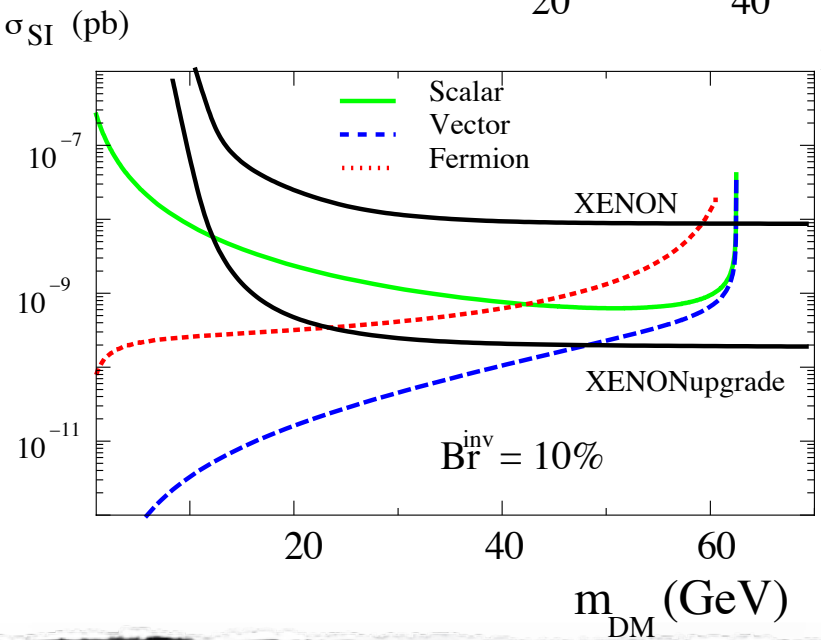

Conclusion: LHC can easily compete with direct detection experiments

Thermal scenarios too restrictive?

Example of very heavy mediator: Non-equilibrium thermal dark matter (NETDM)

Y. Mambrini, K. Olive,
J. Quevillon, B. Zaldivar
2013

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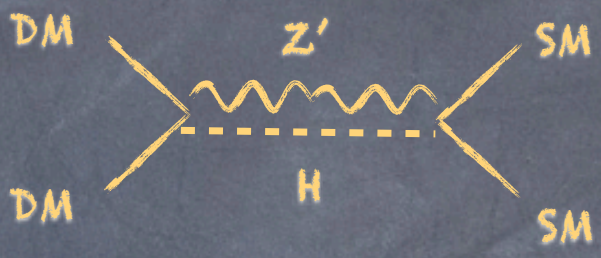

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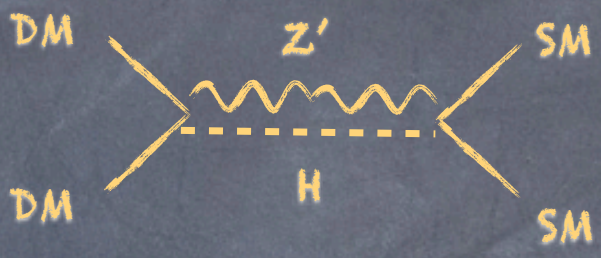
$M_{Z'/H} \ll T_{RH}$



$$\frac{dY}{dT} \propto \frac{M_P}{T^2} \Rightarrow Y \propto \frac{1}{T_0}$$

$$Y = \frac{n}{s}$$

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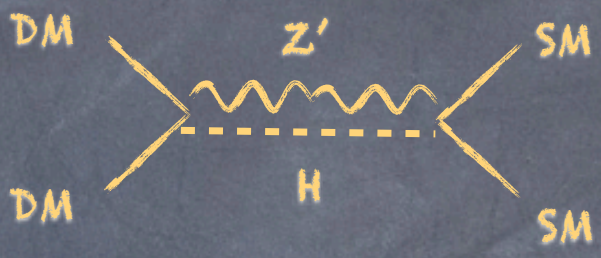

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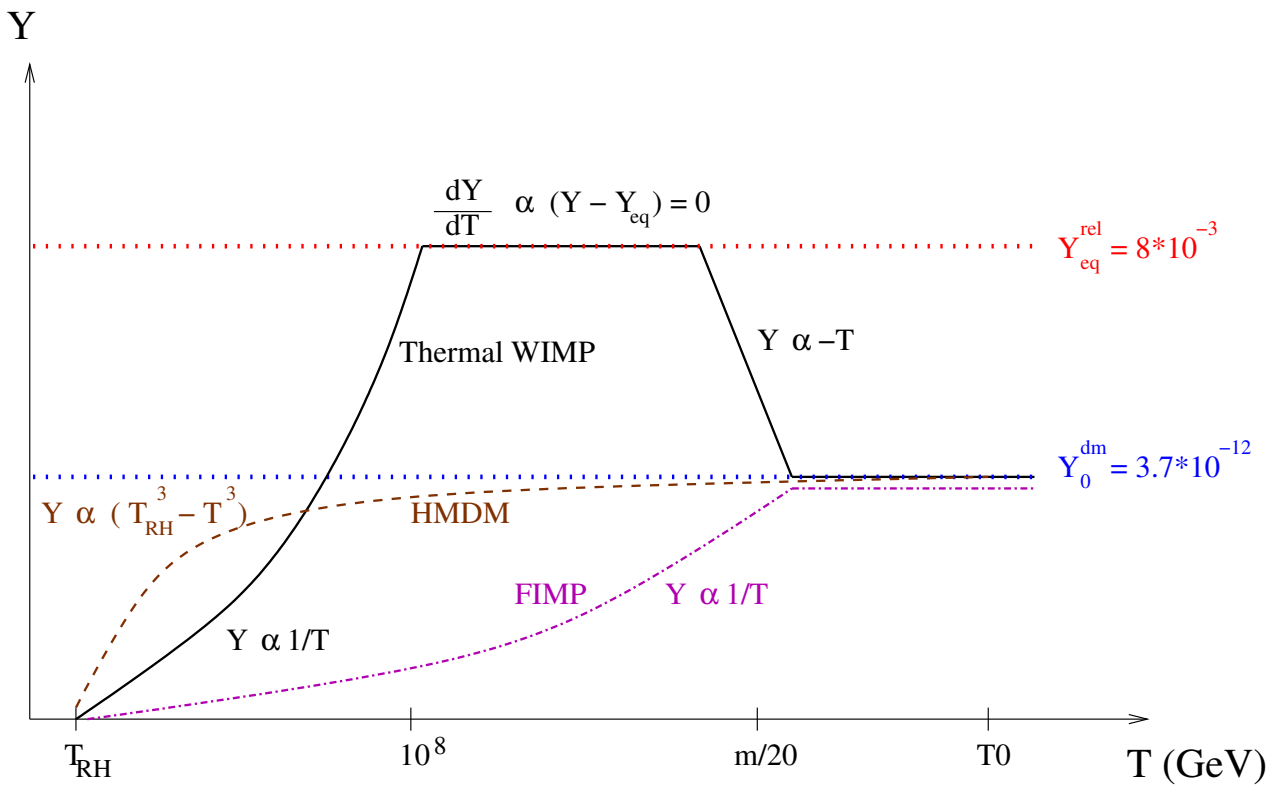

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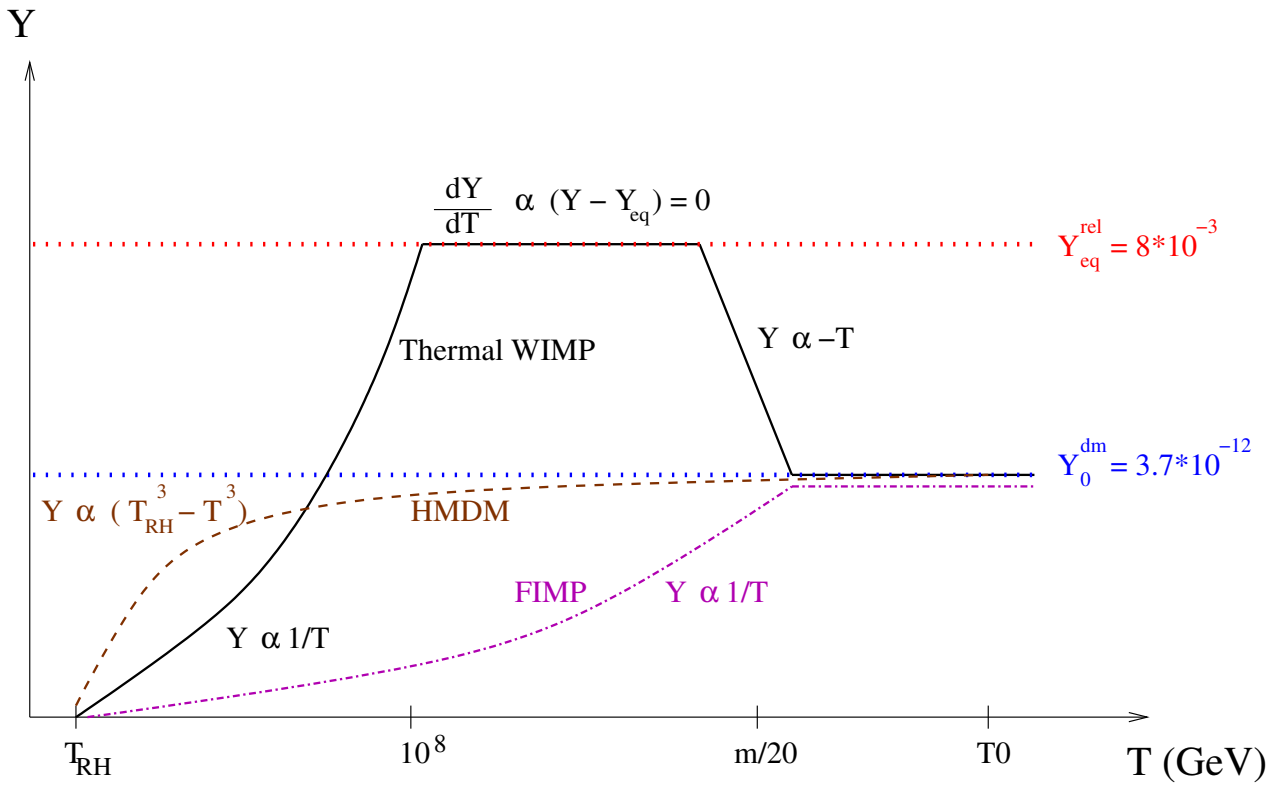
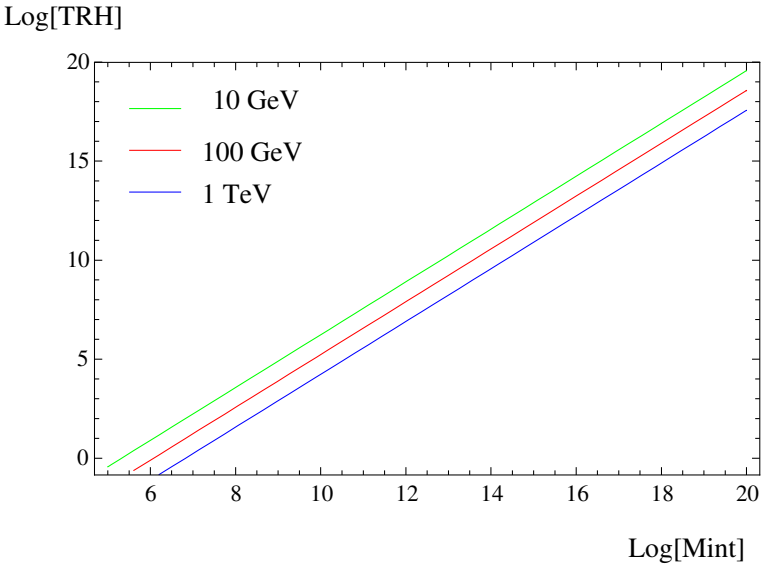


SM



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- Can be applied to any kind of SM extensions (SUSY, KK..)
- If no discoveries, need for new (non)thermal scenario ?