Dark Matter: Candidates, signals and LHC consequences

Yann Mambrini, LPT Orsay

LAL seminar, february 21th 2012, Paris

Outline

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- Dark matter evidences : scales and methodology

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- Complementarity with the LHC

Astroparticle

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- LHC provides his own background, whereas in the Universe, you have no idea of the background as you always measure Signal+Background.

Dark matter evidence : Galactic scale

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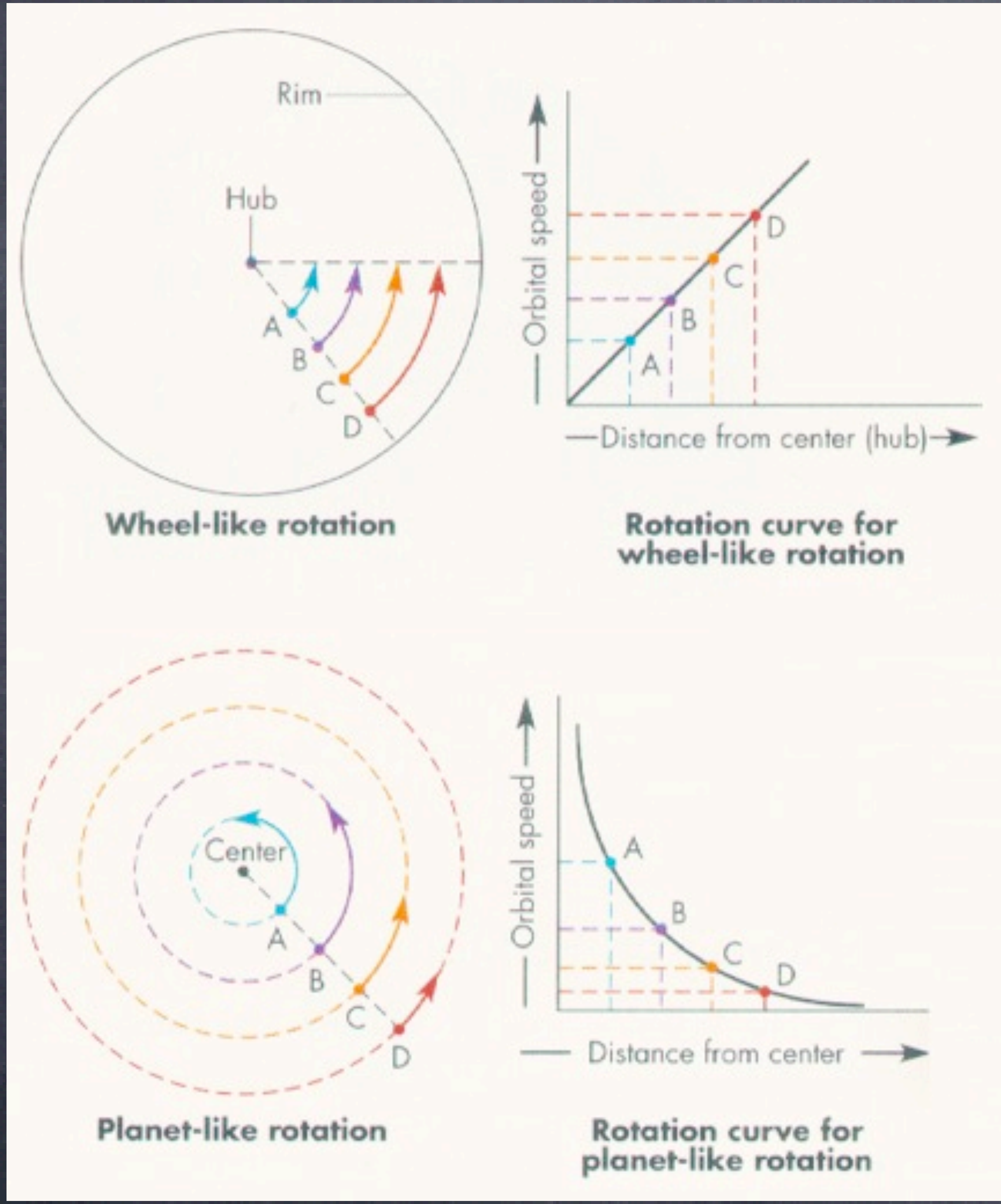

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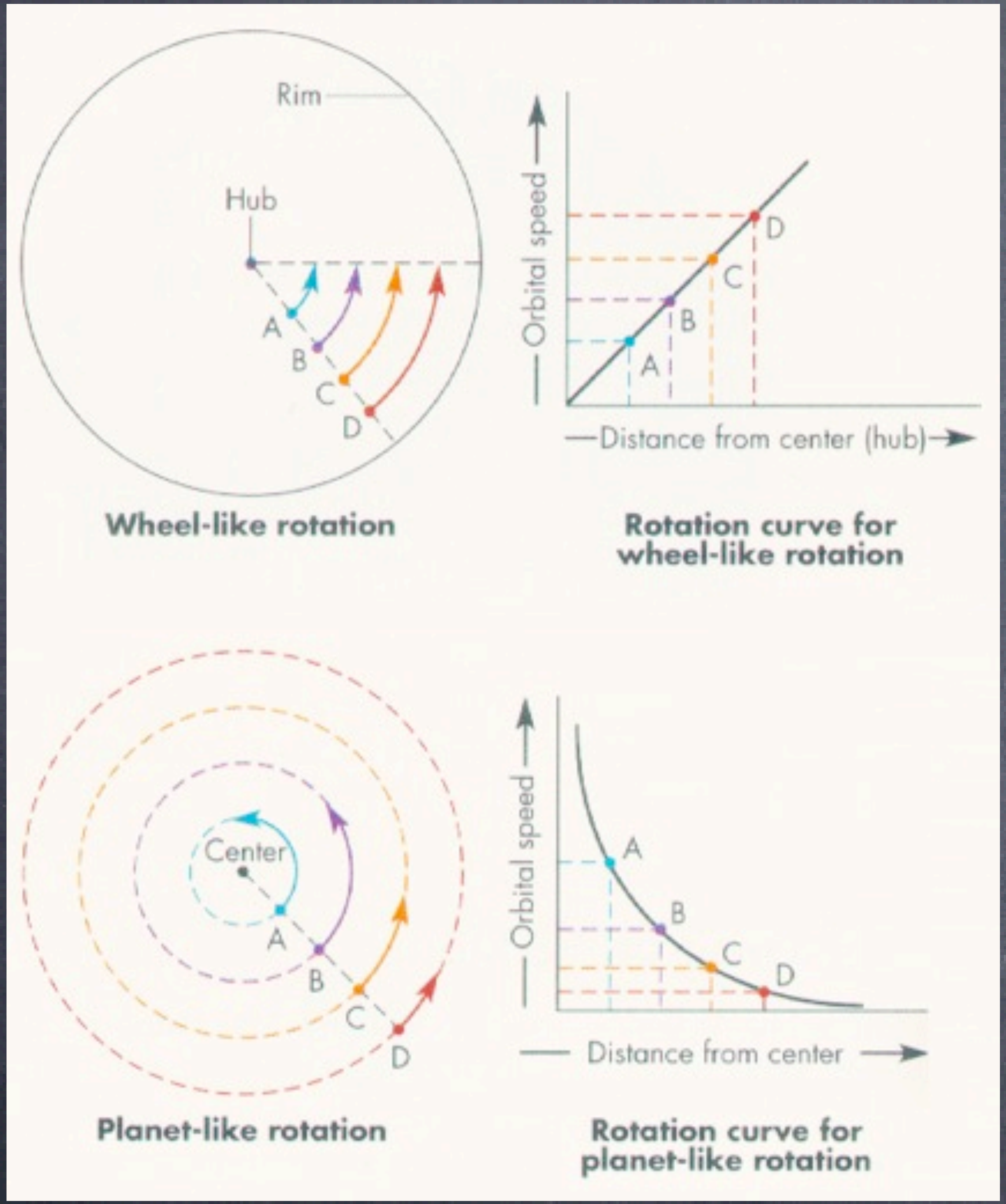

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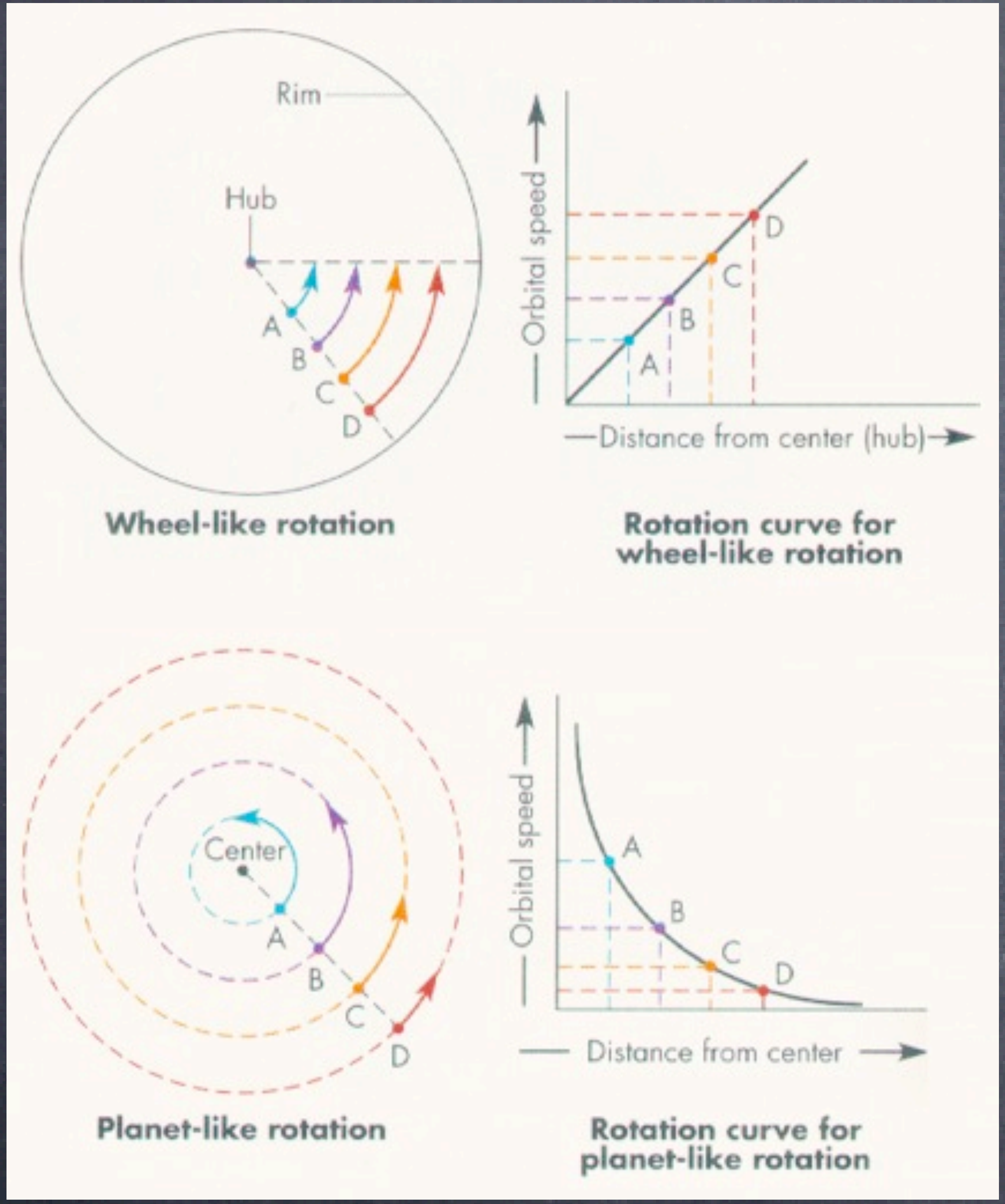

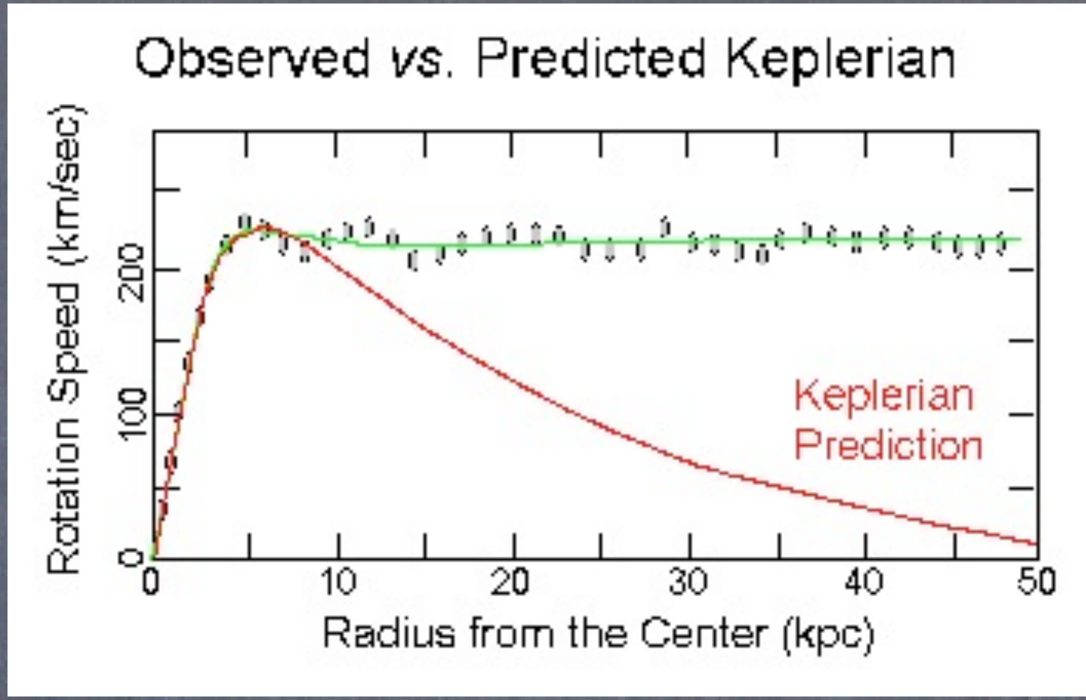

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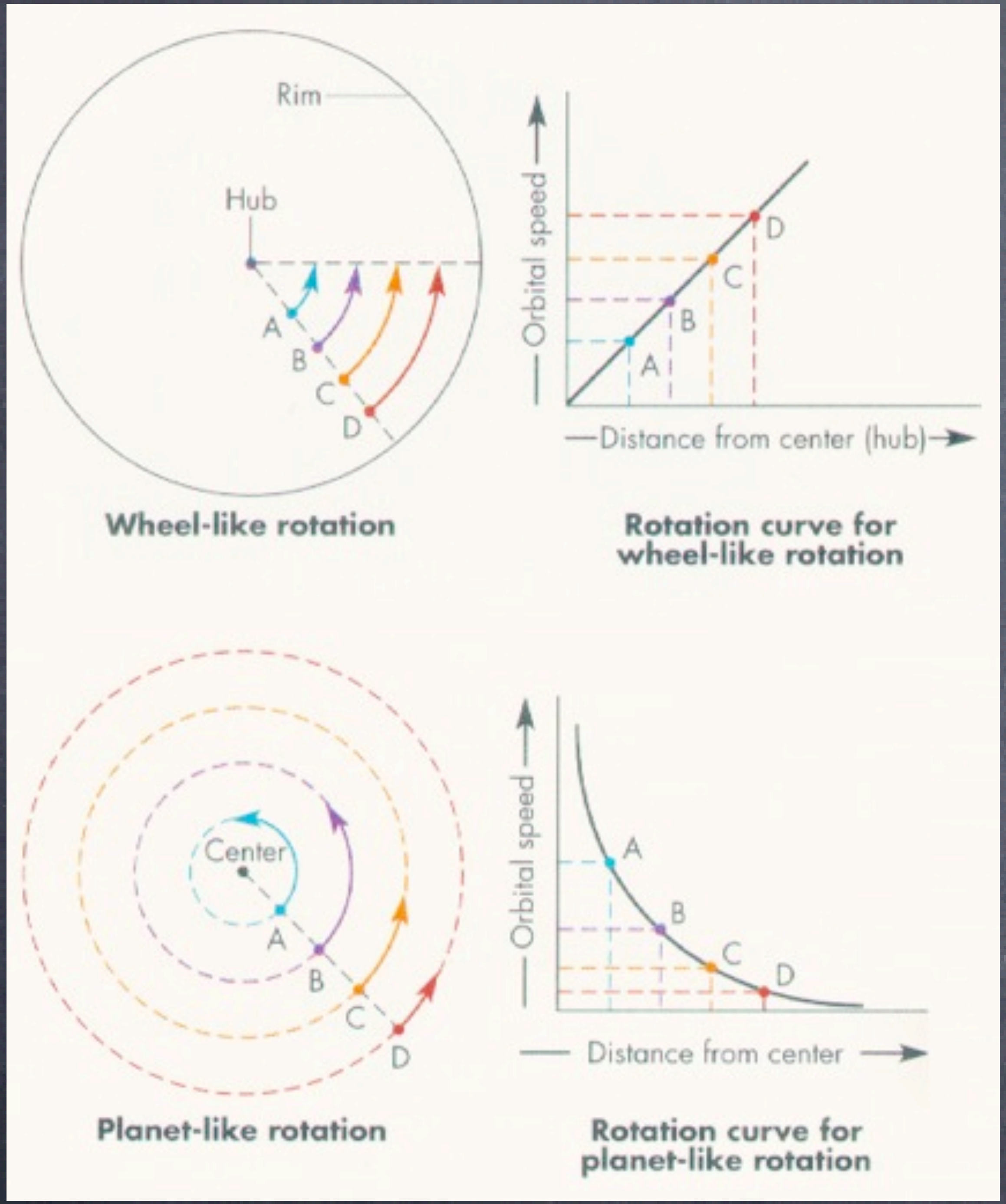

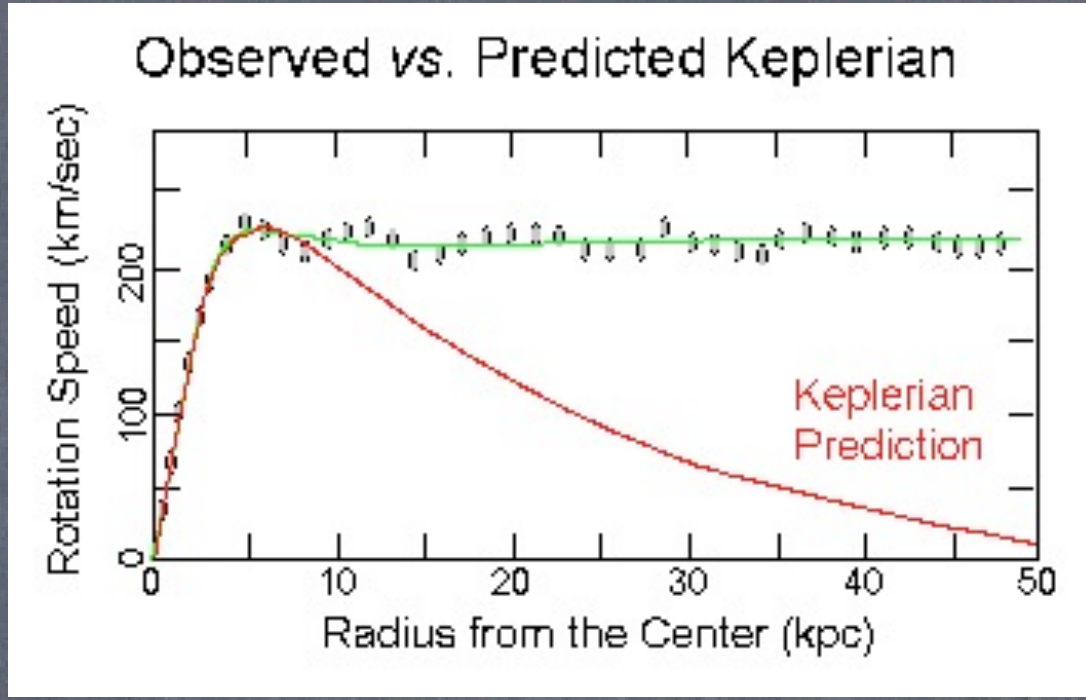

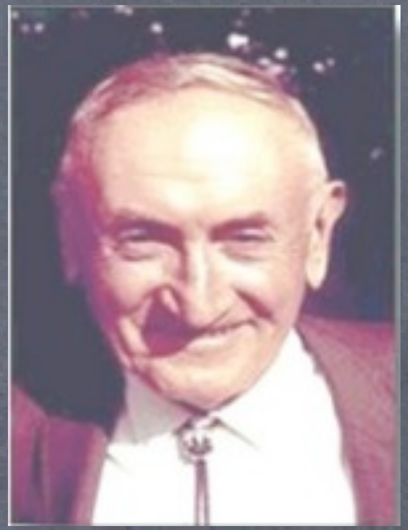

$$\rho_{DM} \propto \frac{1}{r^2} \rightarrow M_{gal} = Volume * \rho \propto r \rightarrow v \sim cte$$

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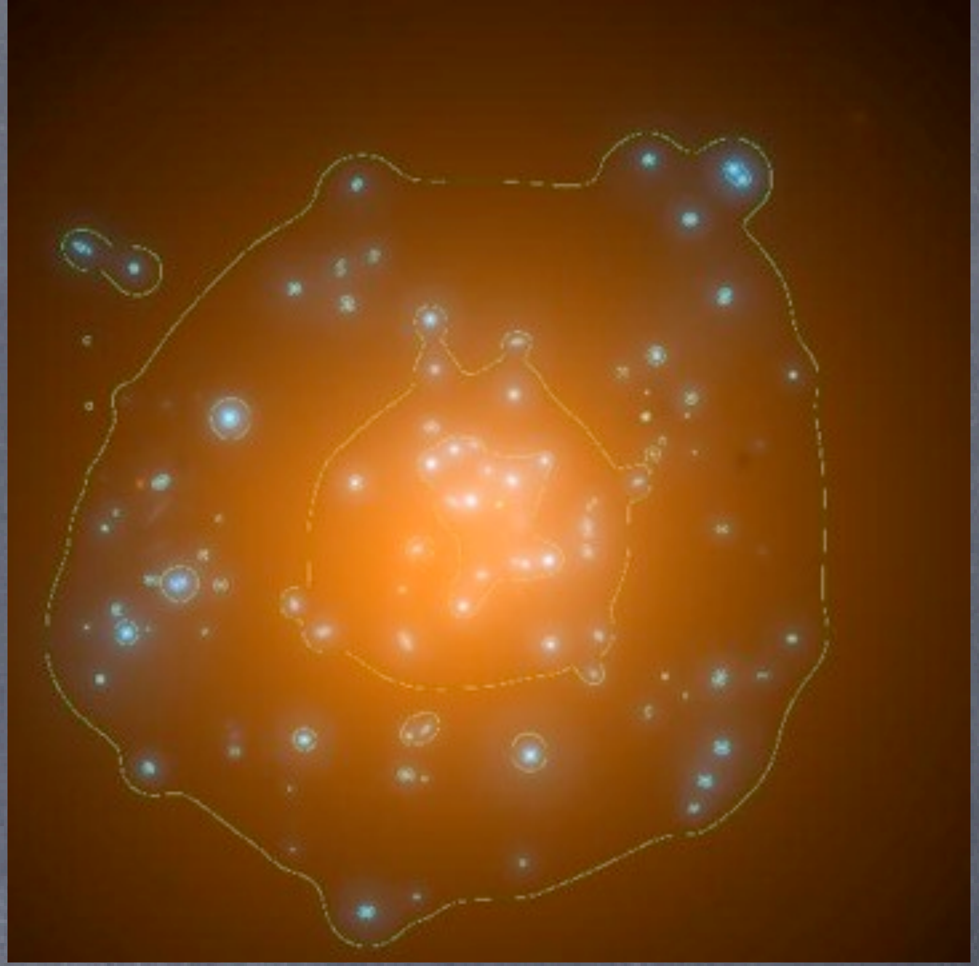
Cluster of Galaxy scale



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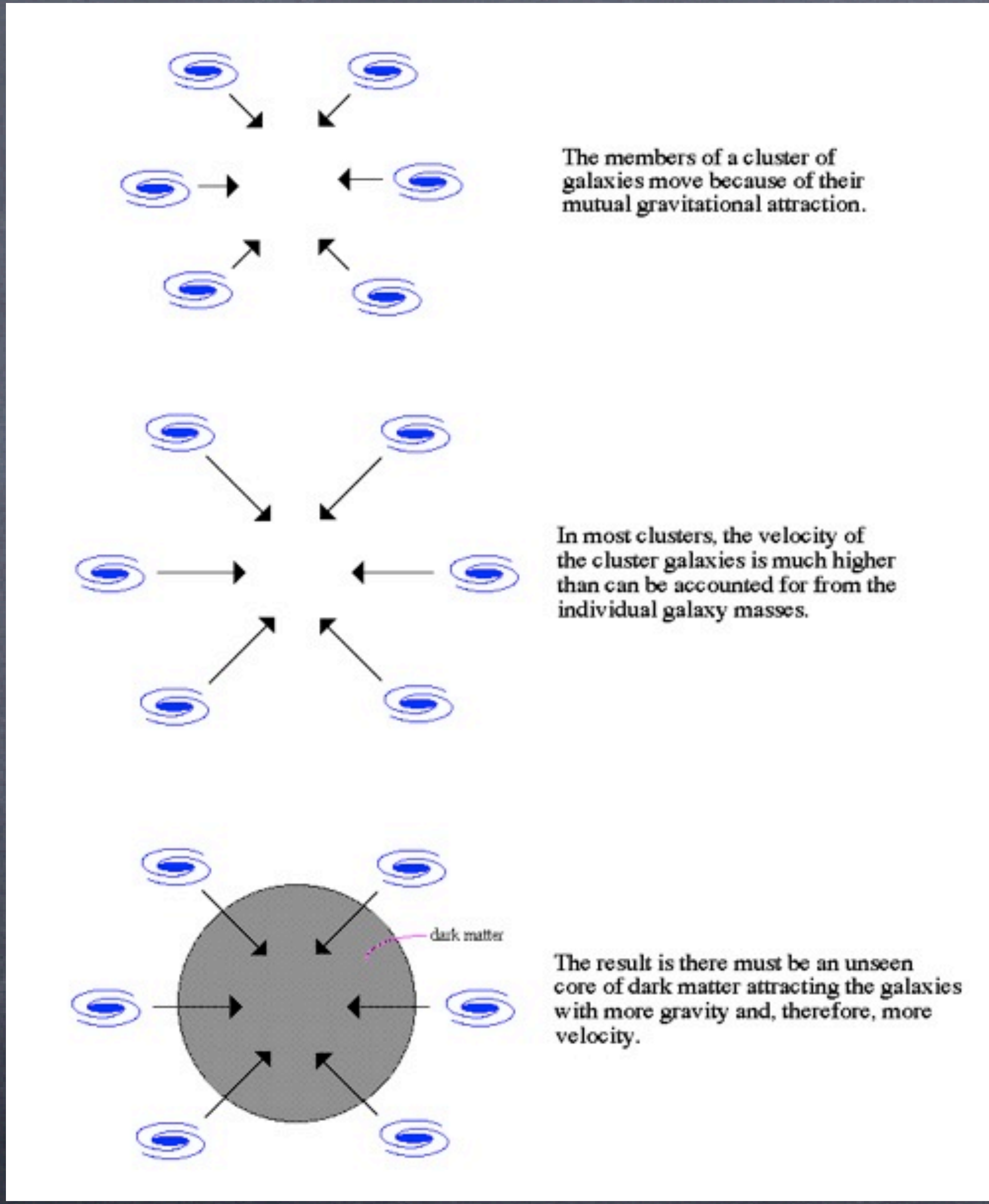

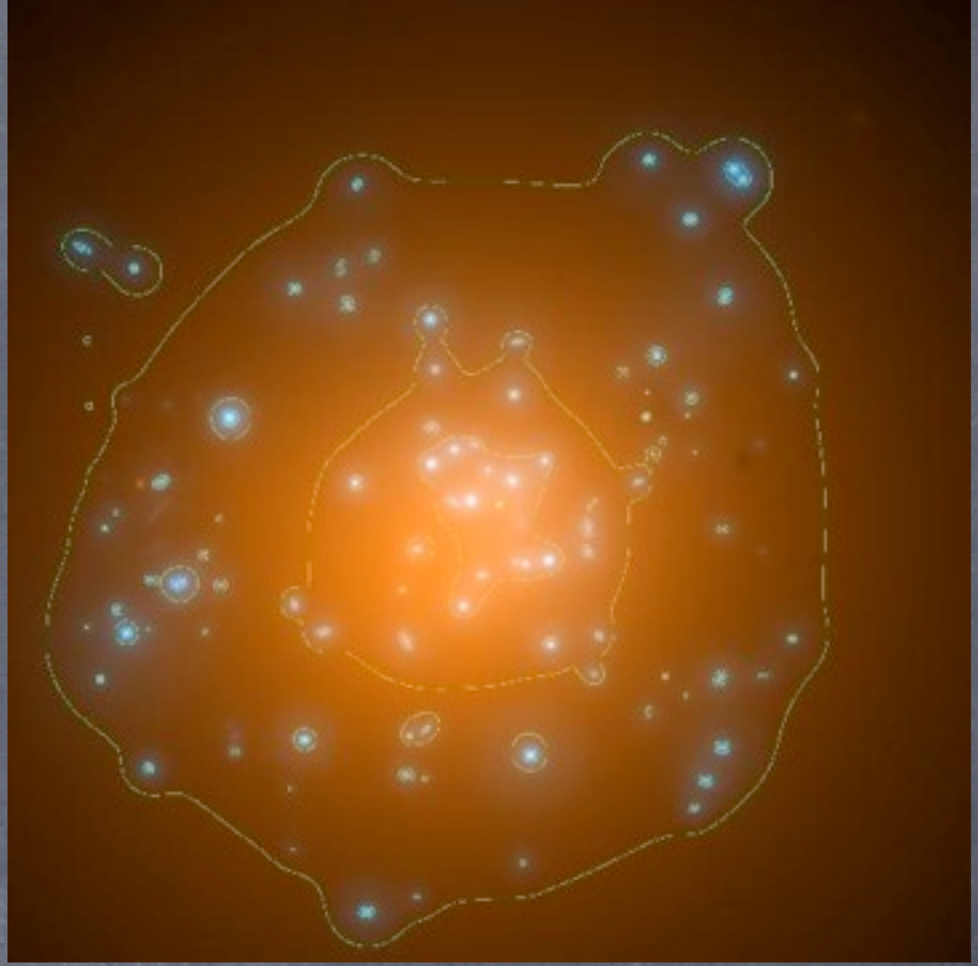

Cosmological scale

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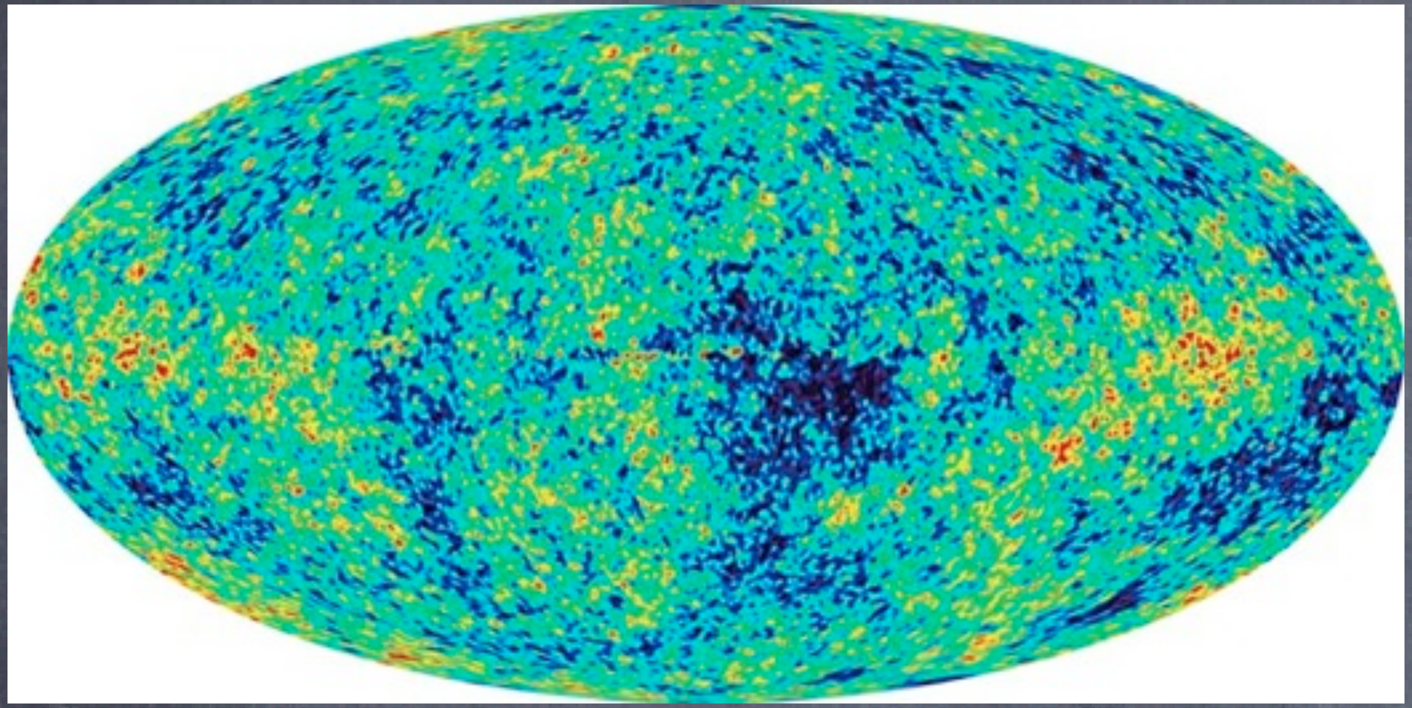
Cosmic Microwave Background (CMB)



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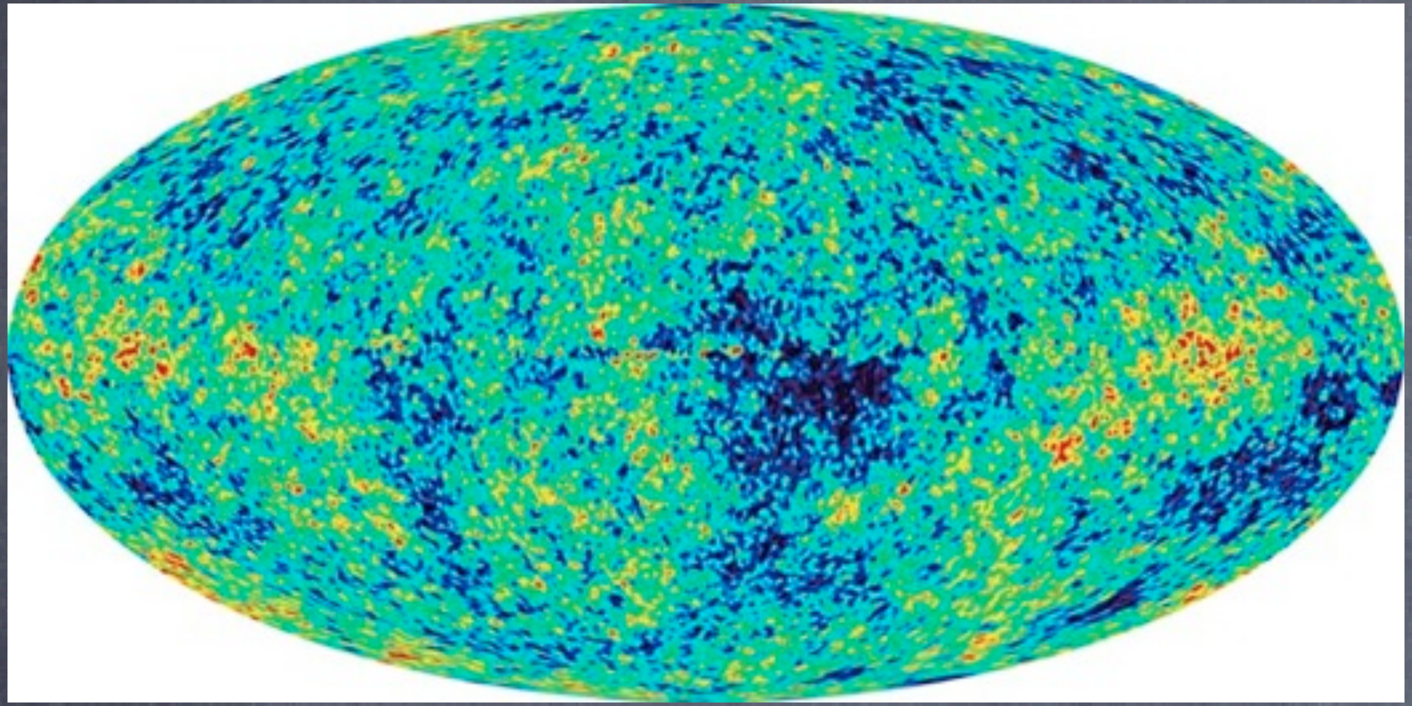

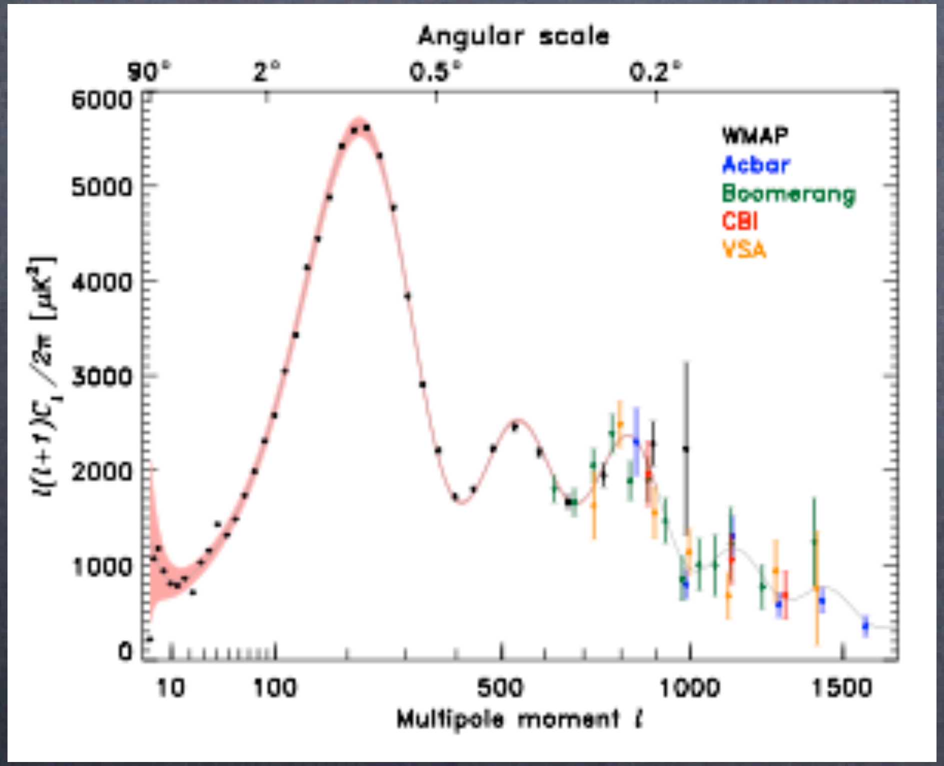

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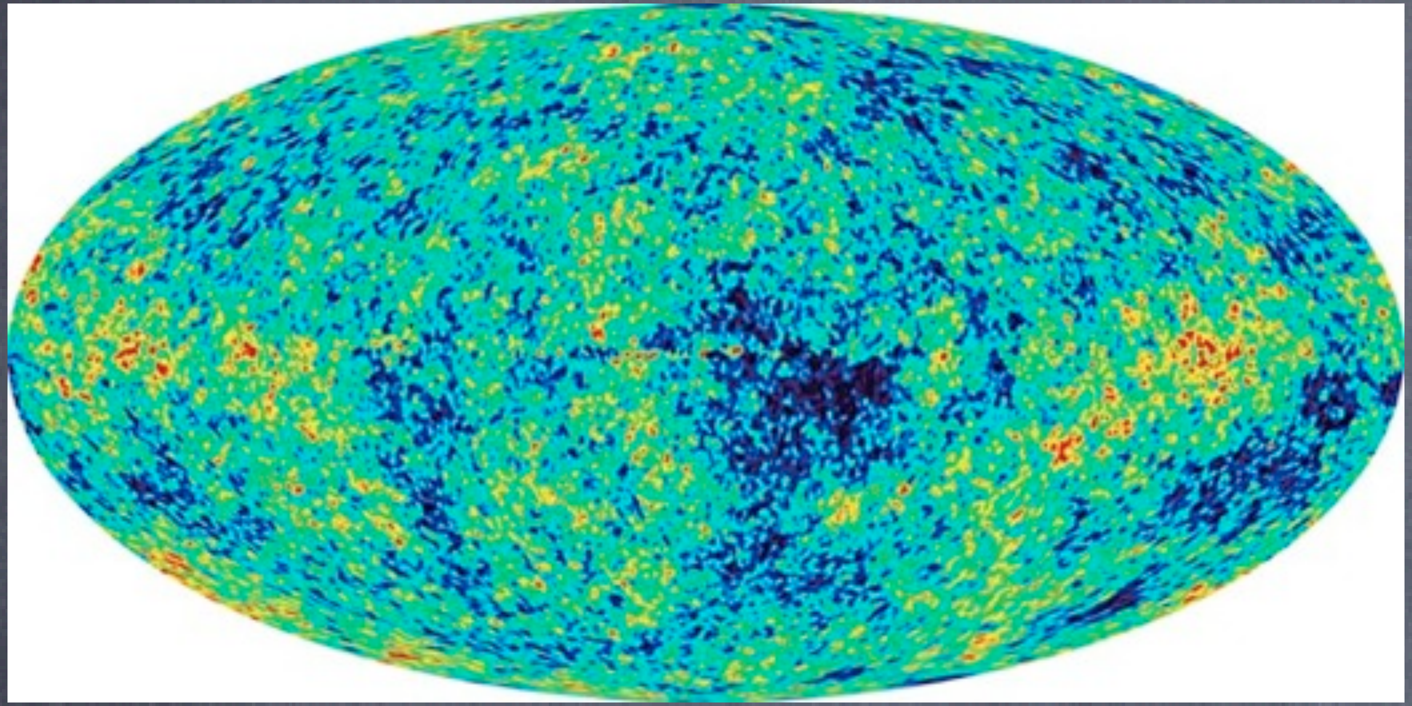

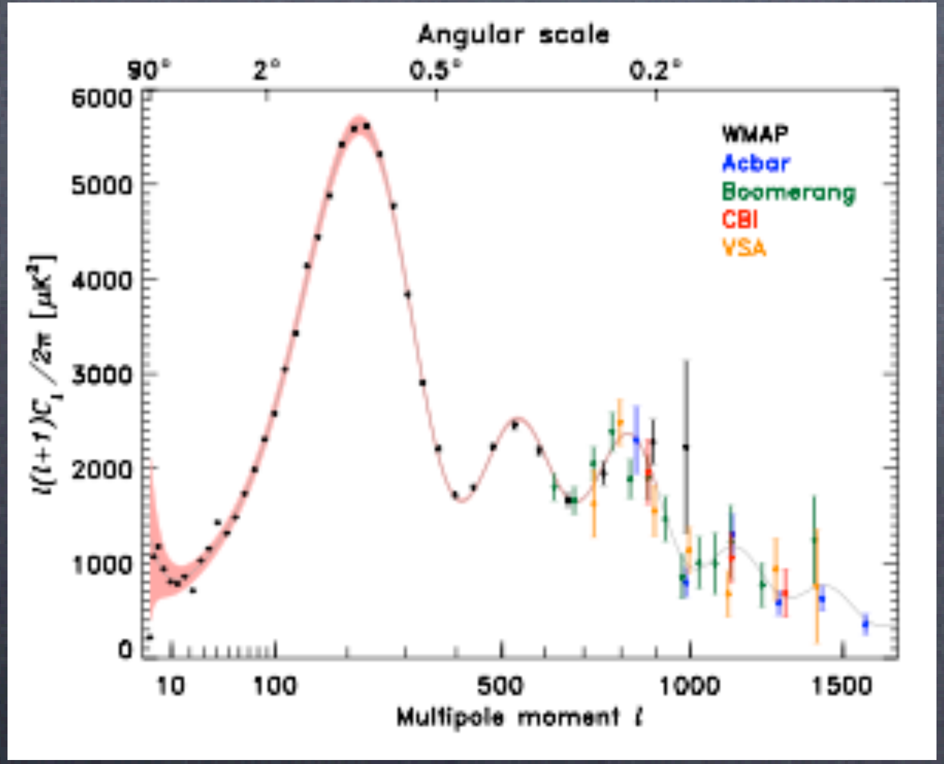

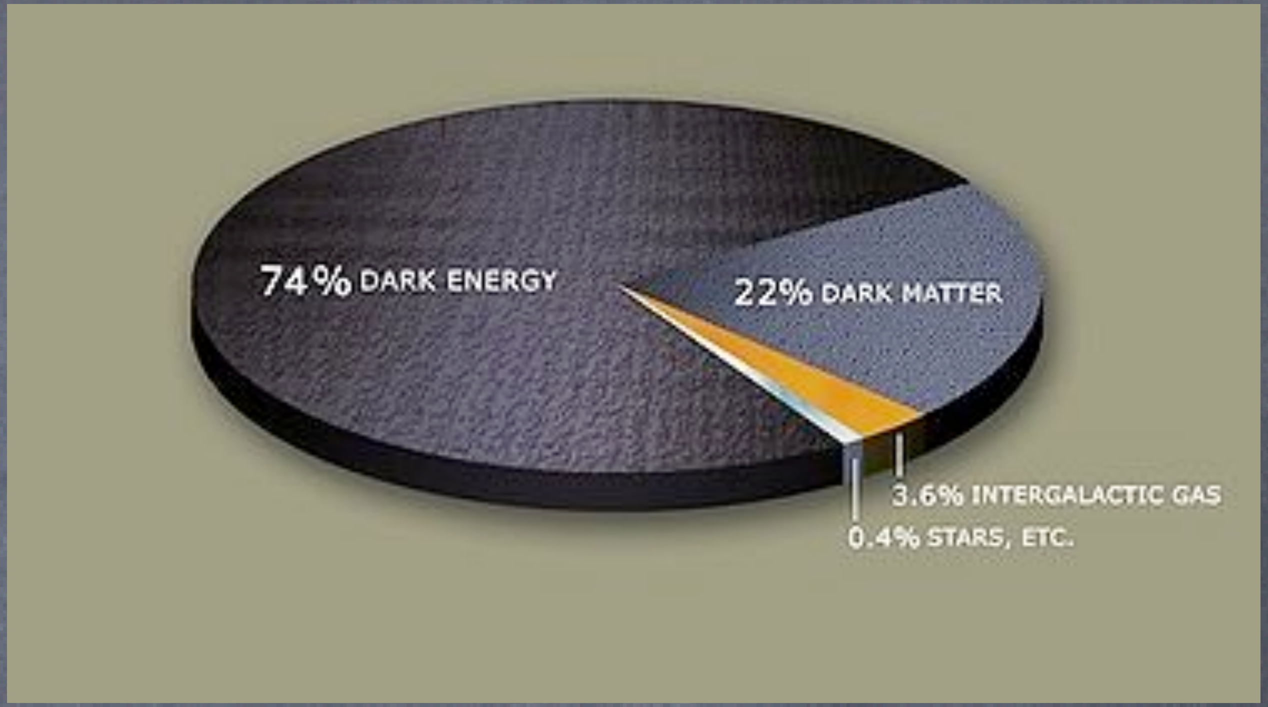

Budget of the Universe

A little thermal history of the Universe (I)

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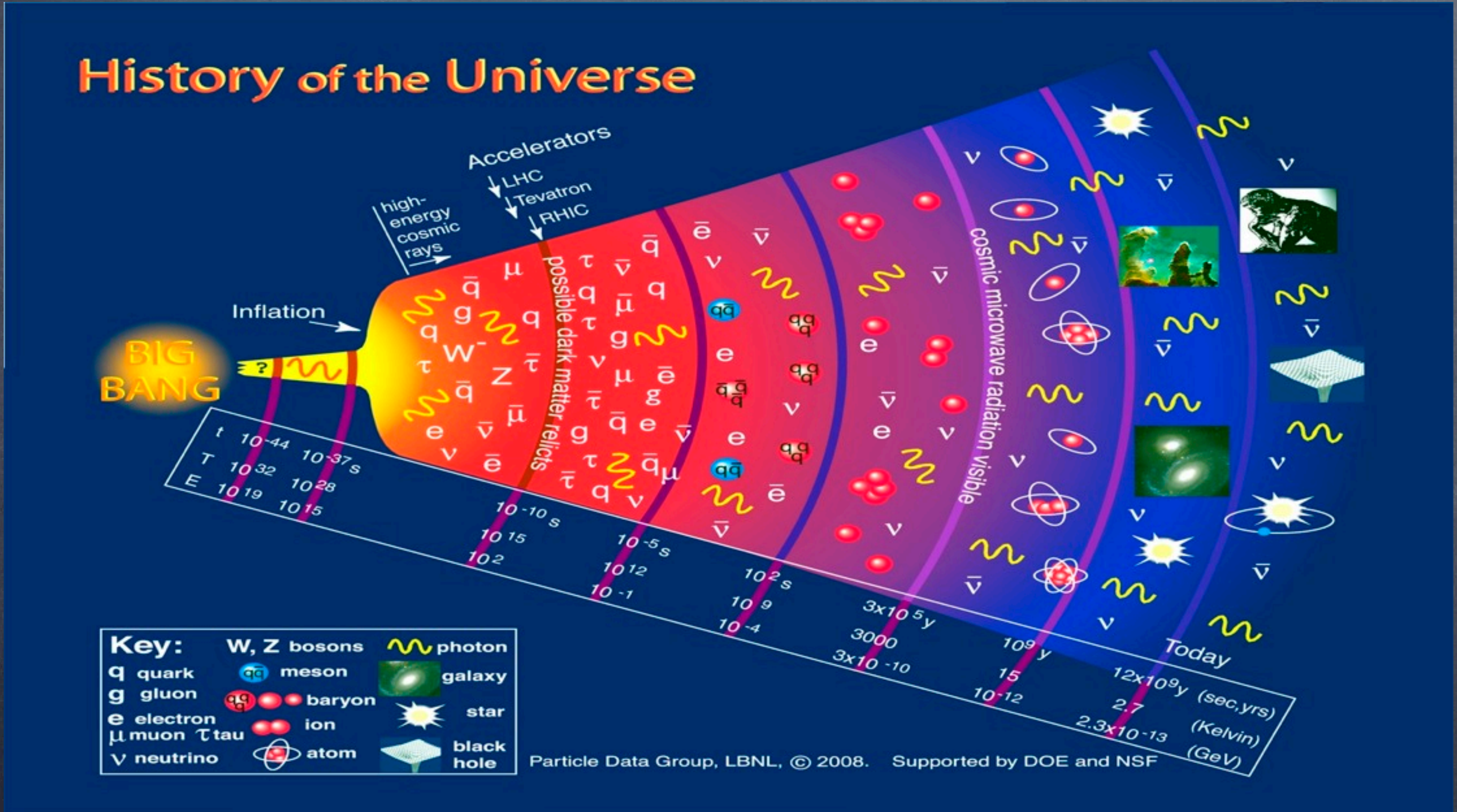

A little thermal history of the Universe (II)

T

time

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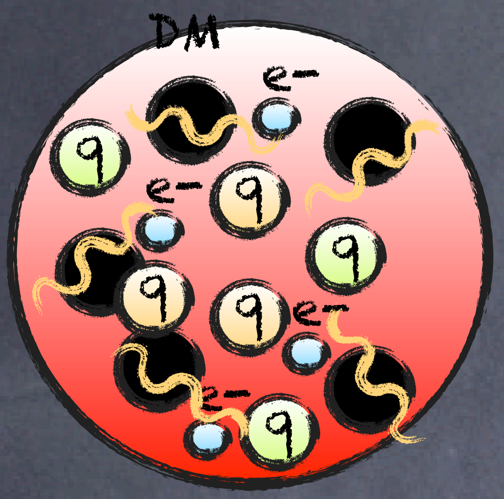

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Equilibrium:
Thermal bath

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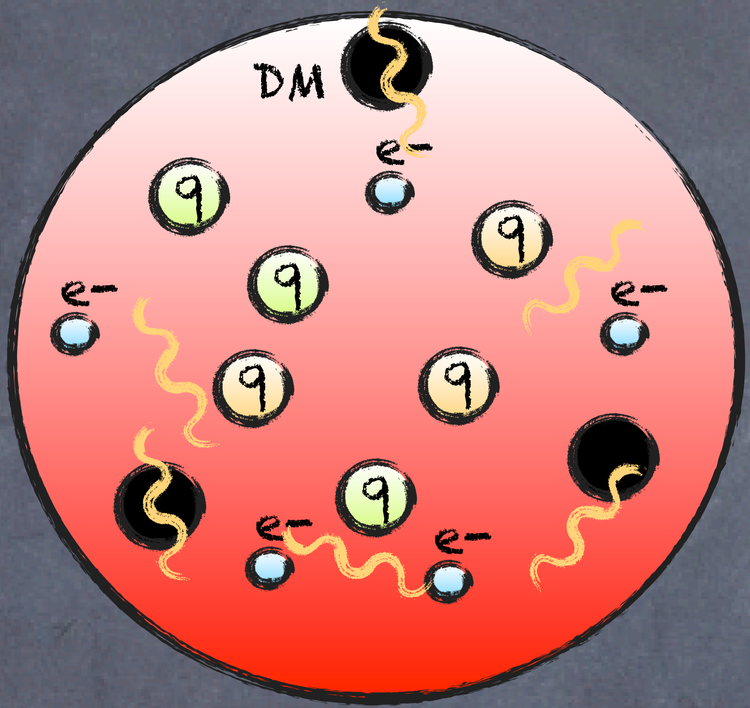

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Dark Matter
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10 GeV
10-5 sec

time

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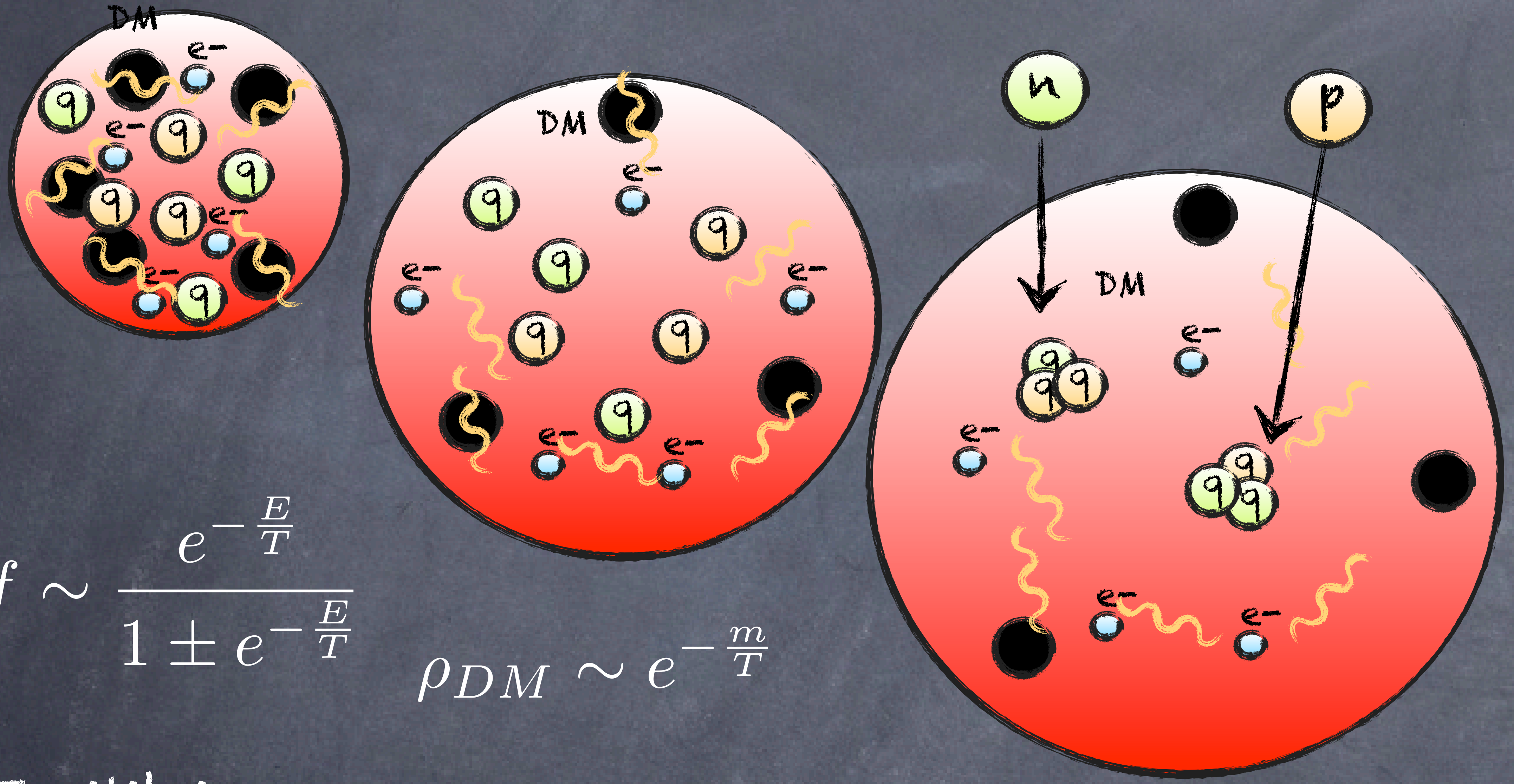

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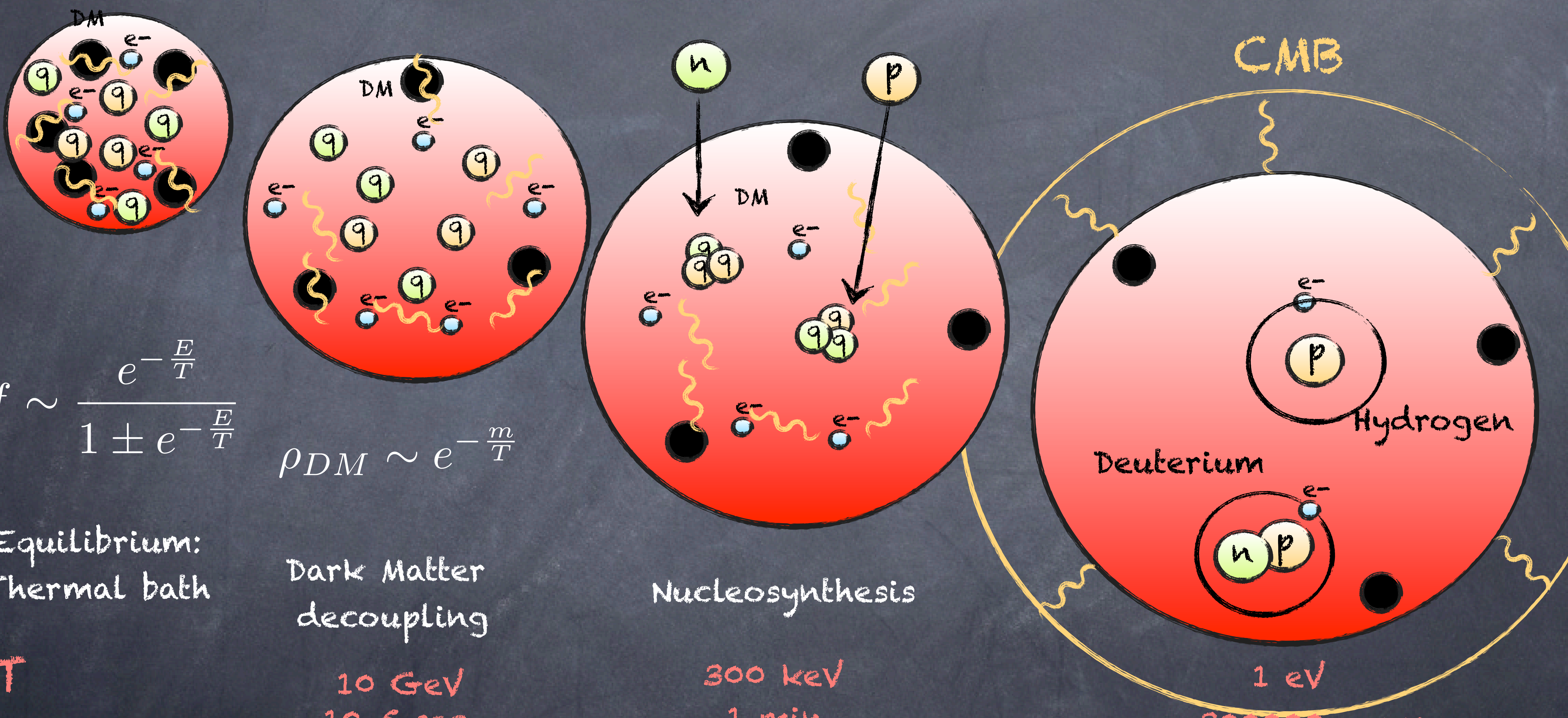

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The density of each species can be written

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with BH = mp + me - mH
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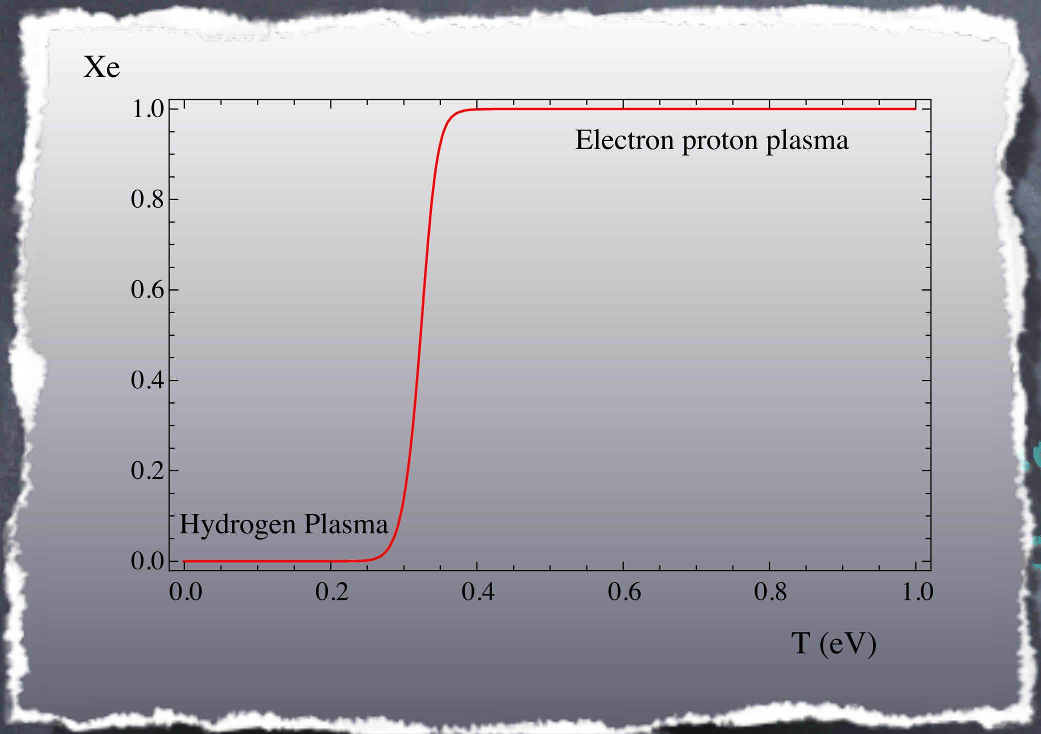

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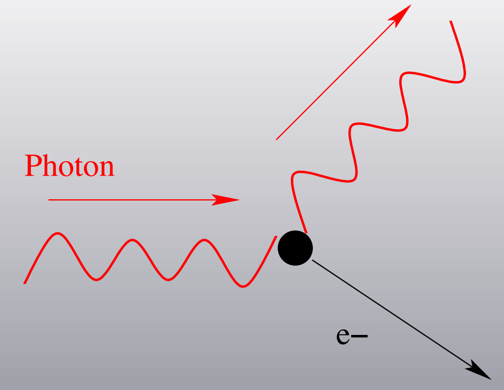

Thomson scattering

$$\Gamma_\gamma = \sigma_T c n_e \quad [\mathrm{s}^{-1}]$$

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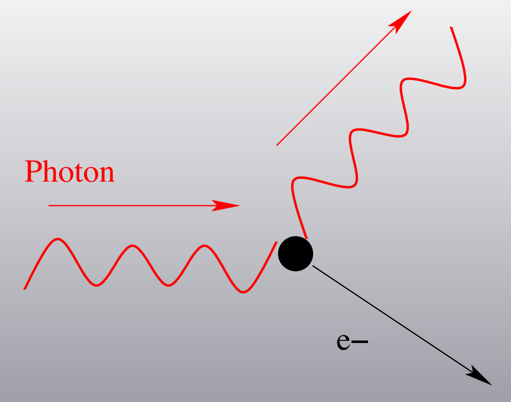

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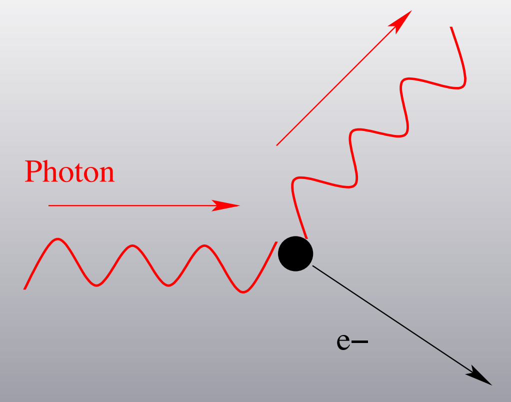

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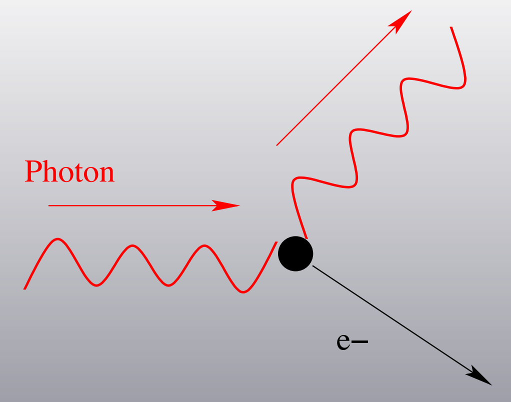

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Remark : Tdec is lower that BH (0.2 < 13.6 eV)
because even if T < BH, still sufficiently numerous photons with Eγ > 13.6 GeV to destroy the atom of Hydrogen.
(both σ and n contribute to annihilation rate)

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Boltzmann Equation

$$\frac{dn}{dt}$$

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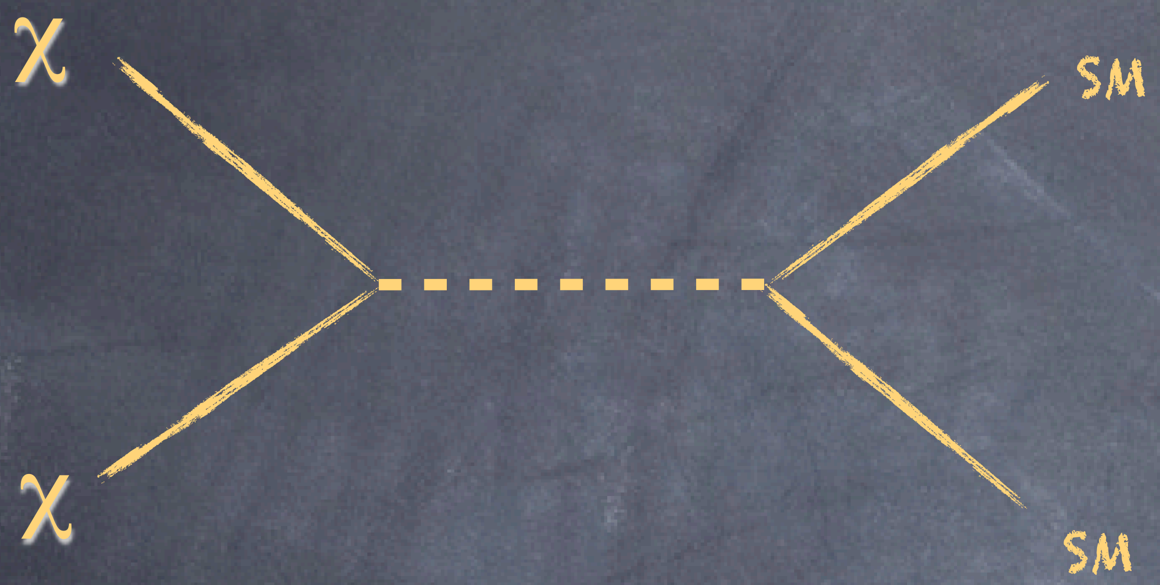

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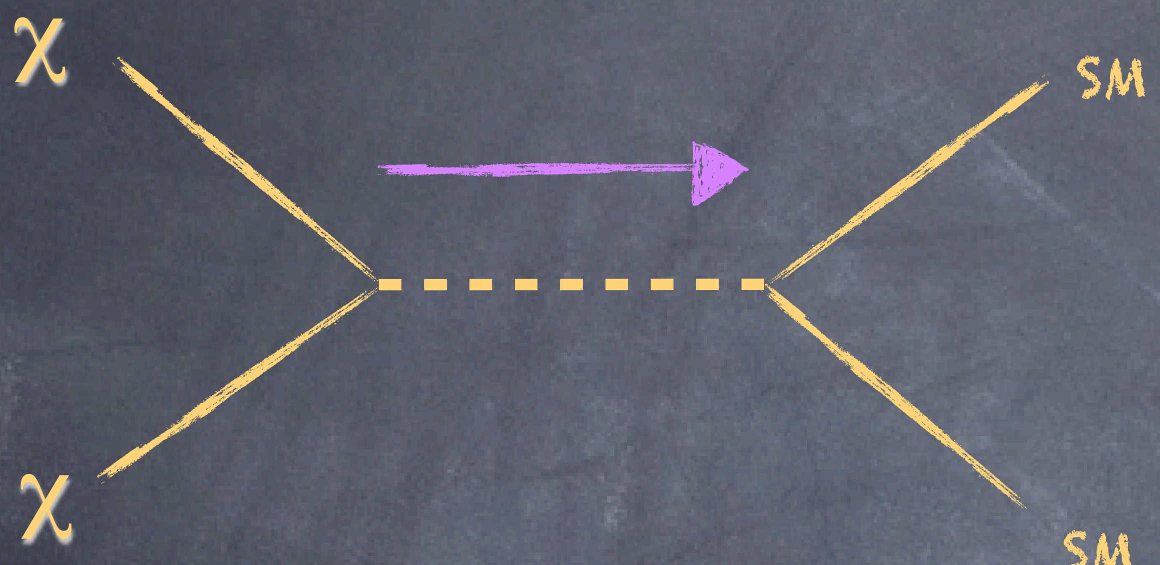

Boltzmann Equation

$$\frac{dn}{dt} = -3\,H\,n - \langle \sigma v \rangle\, n^2$$

$(H = \dot{R} / R)$

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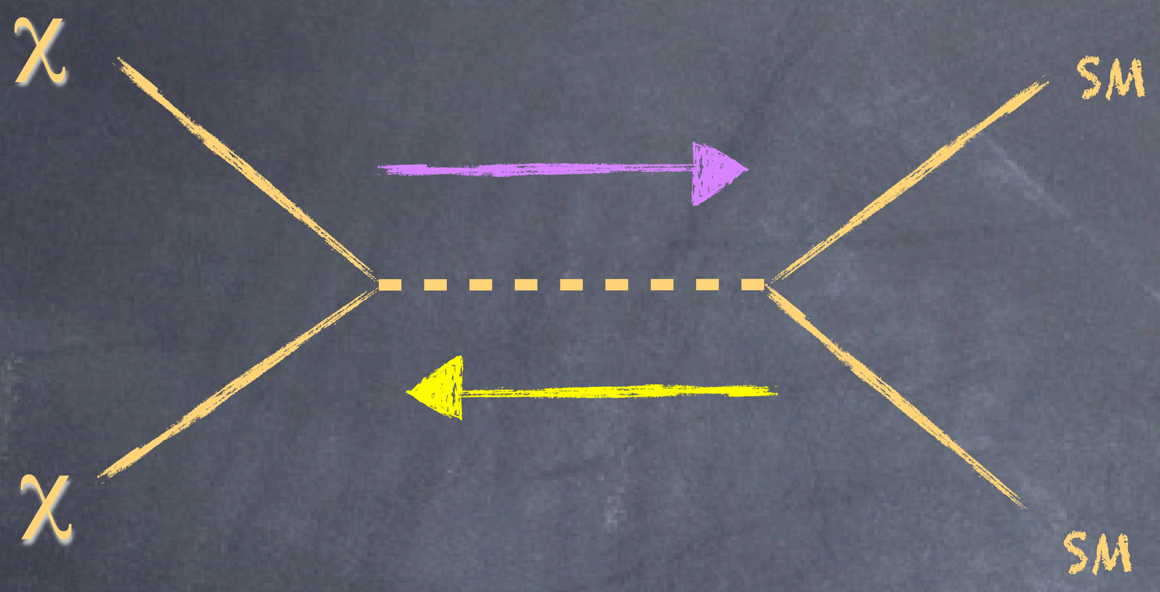

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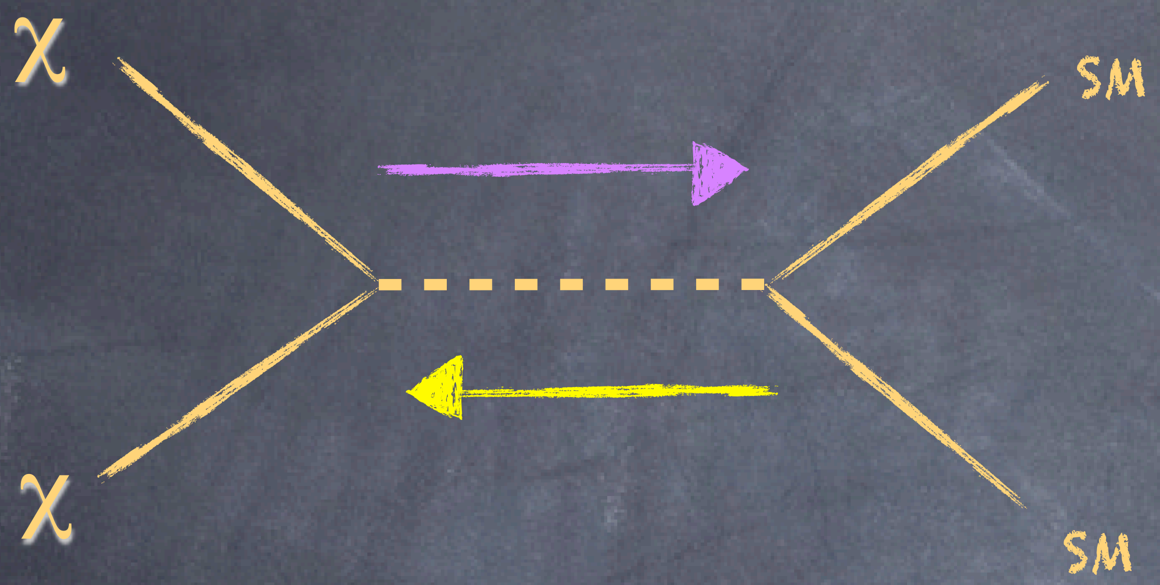

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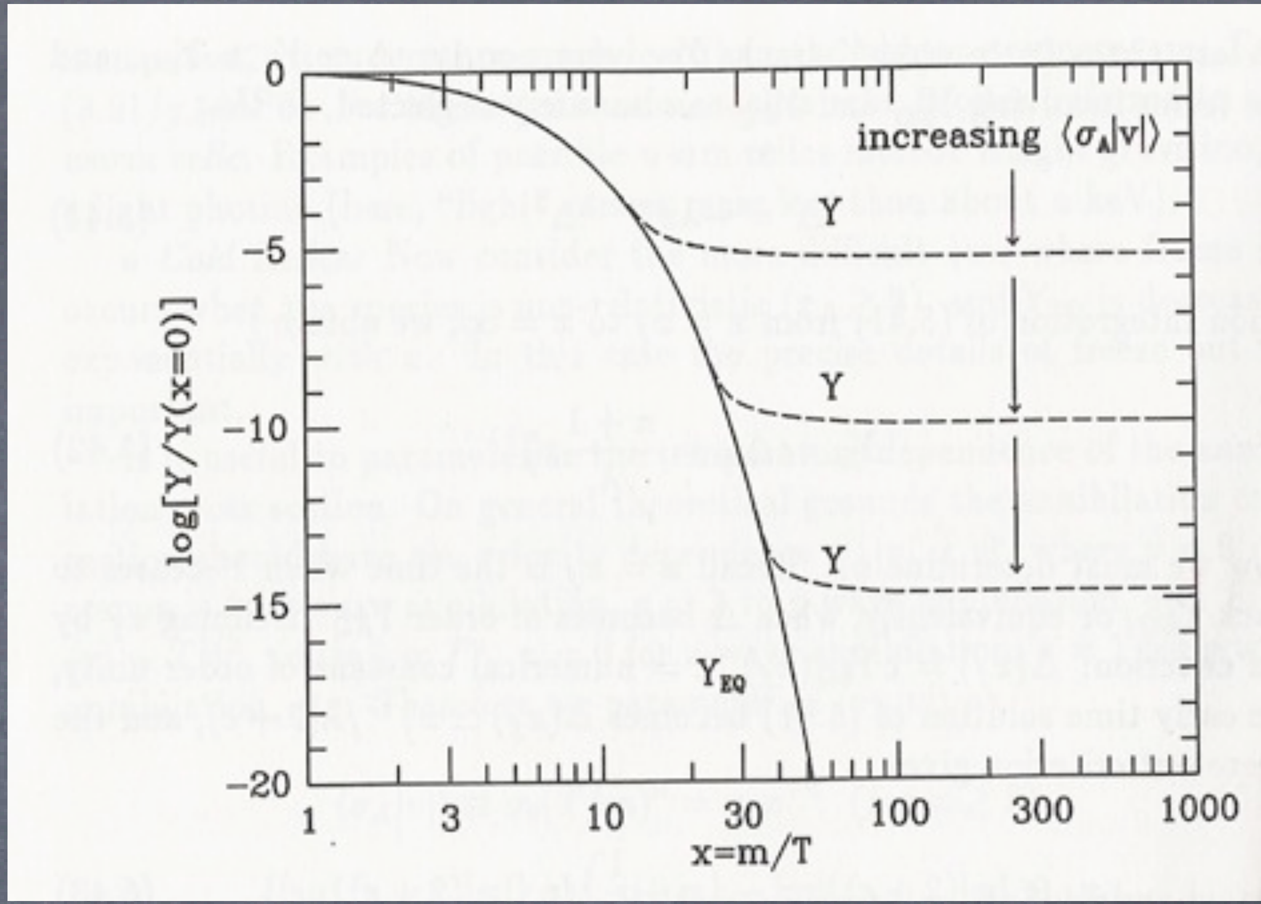

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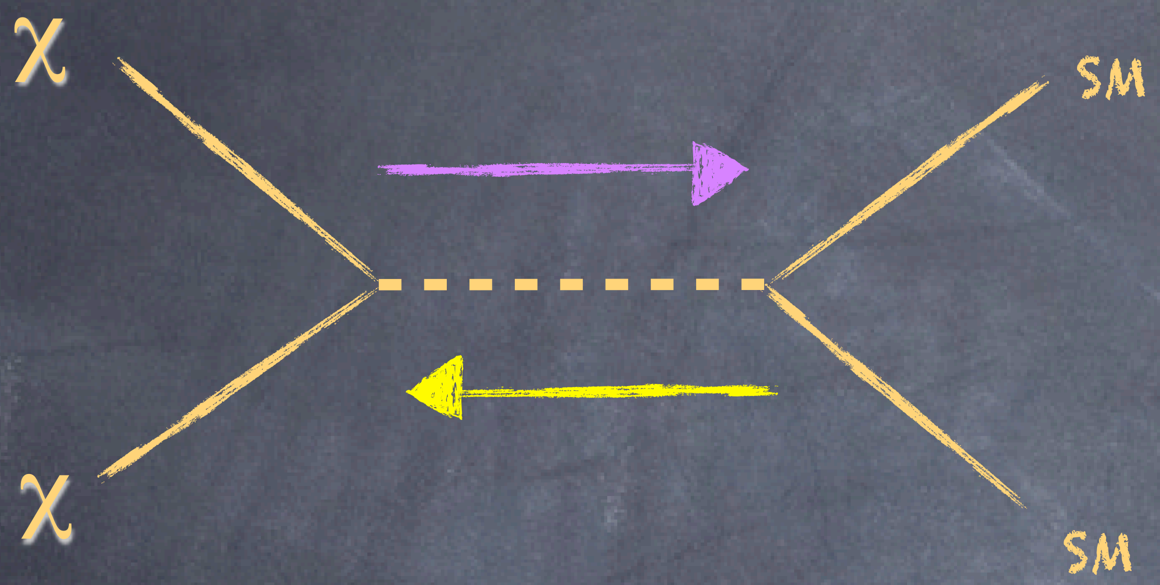

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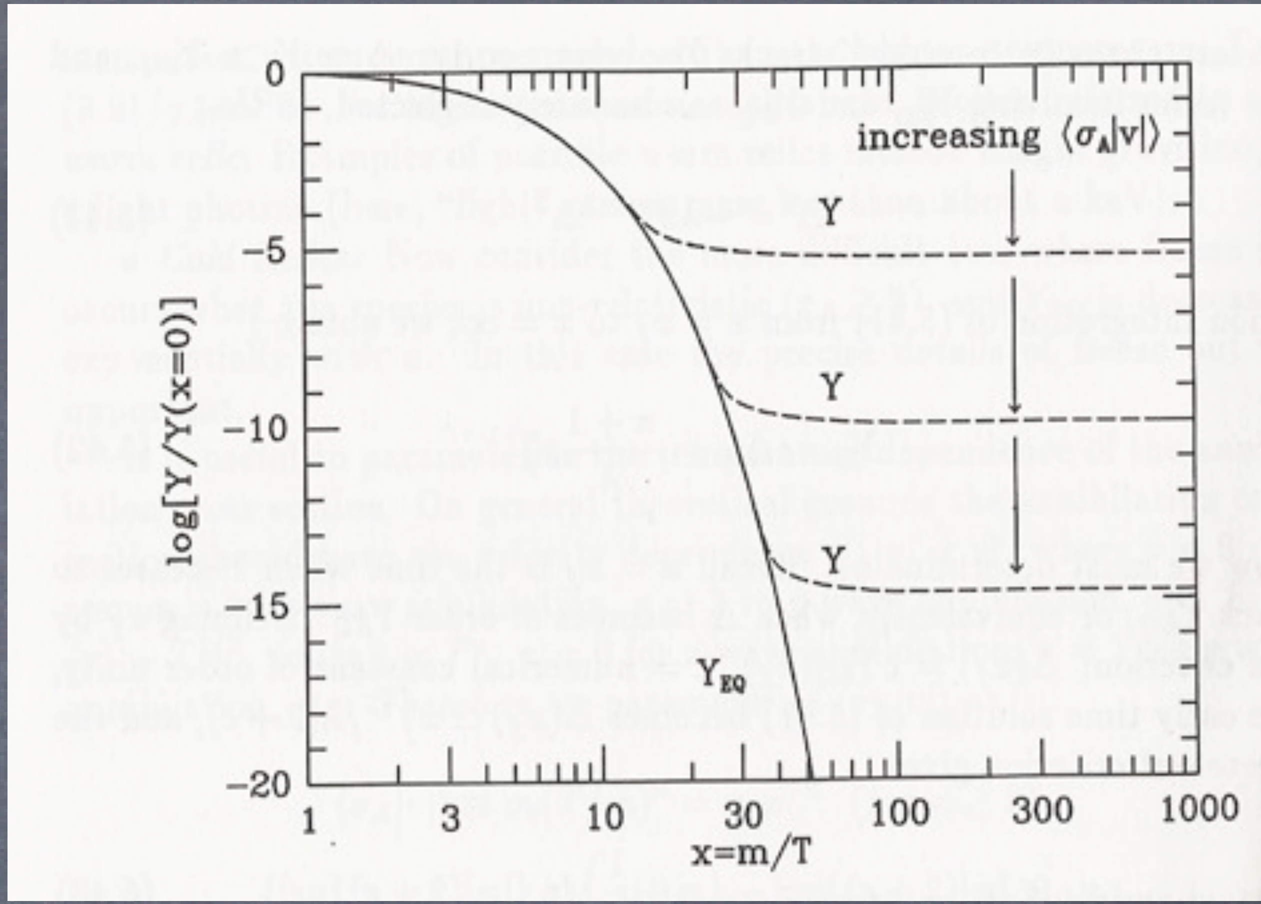

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$$\Omega h^2 \sim \frac{3.10^{-27}\,cm^3\,s^{-1}}{\langle \sigma v \rangle} \sim 0.1,$$

decoupling at $T \sim M_X/20$

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- DAMA + DAMA/LIBRA : DD ; 5-20 GeV WIMP
- EGRET : IDγ ; 40-100 GeV WIMP
- INTEGRAL : IDe+ ; 2-5 MeV DM
- HEAT : IDe+ ; 100 GeV DM
- HESS : IDγ ; > 15 TeV DM
- PAMELA + FERMI : IDe+ ; 100 GeV or > 5 TeV DM
- CDMS : DD ; 10-100 GeV WIMP
- CoGENT : DD ; 6-15 GeV WIMP
- CRESST : DD ; 10-20 GeV WIMP

Direct detection : principle

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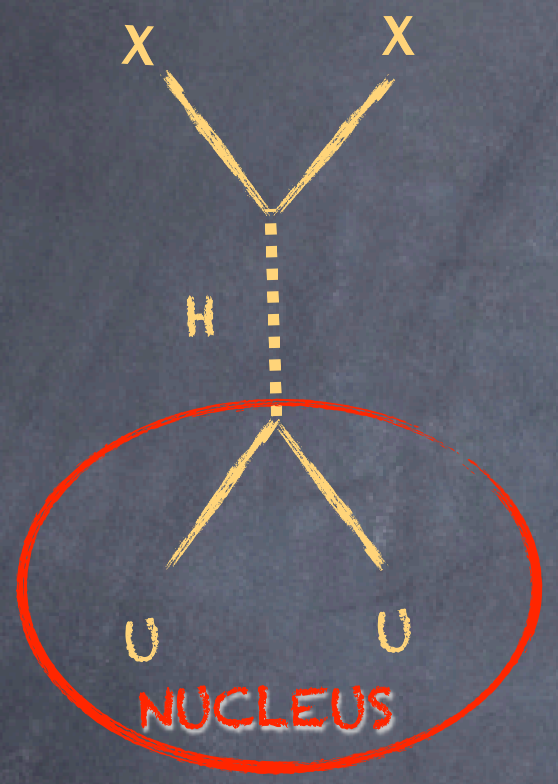

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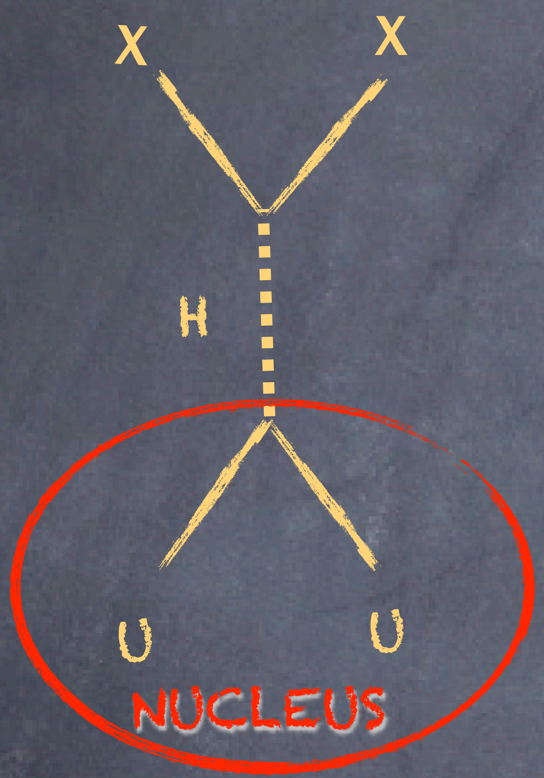

XENON (1 evt per kg per year) : 10 kg - 100kg - 1T

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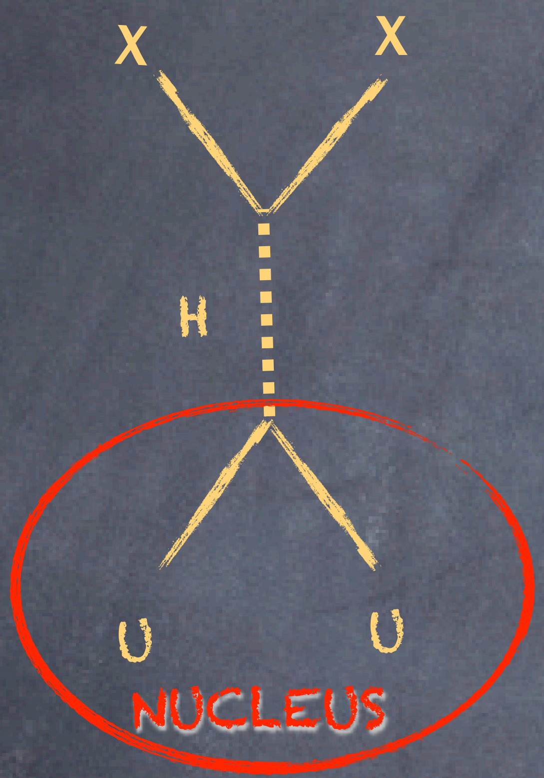

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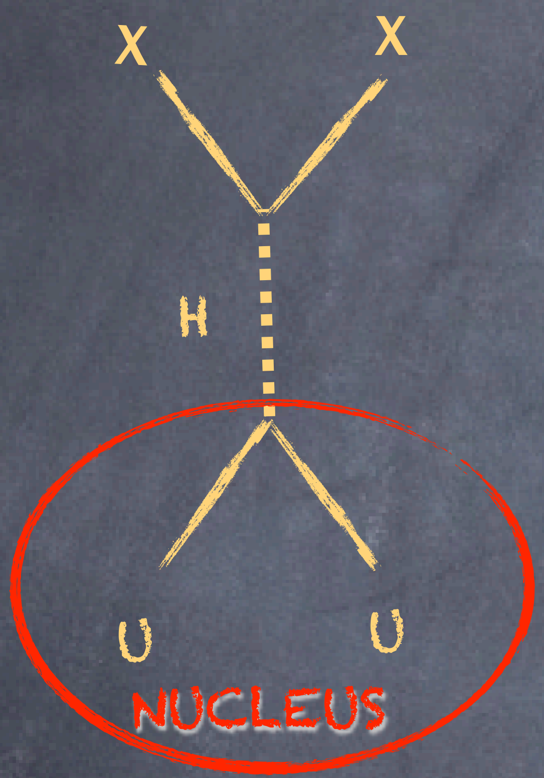

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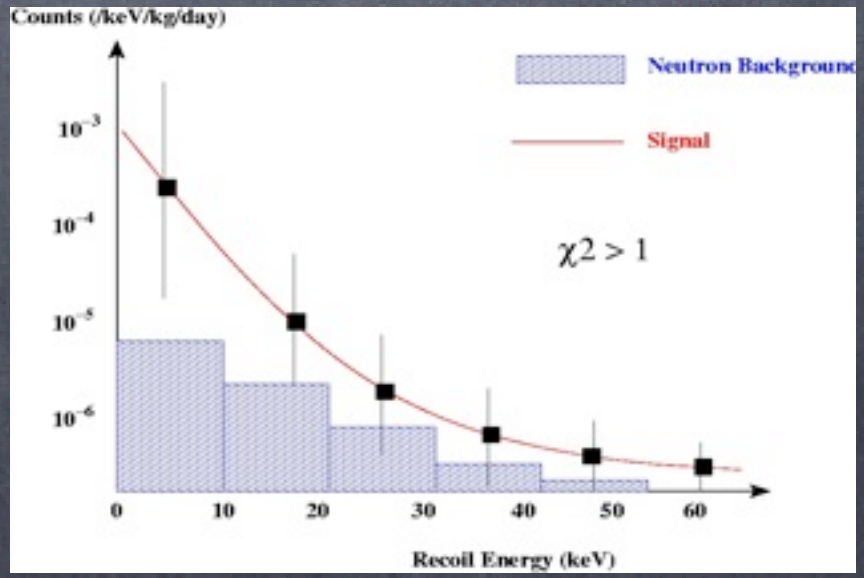

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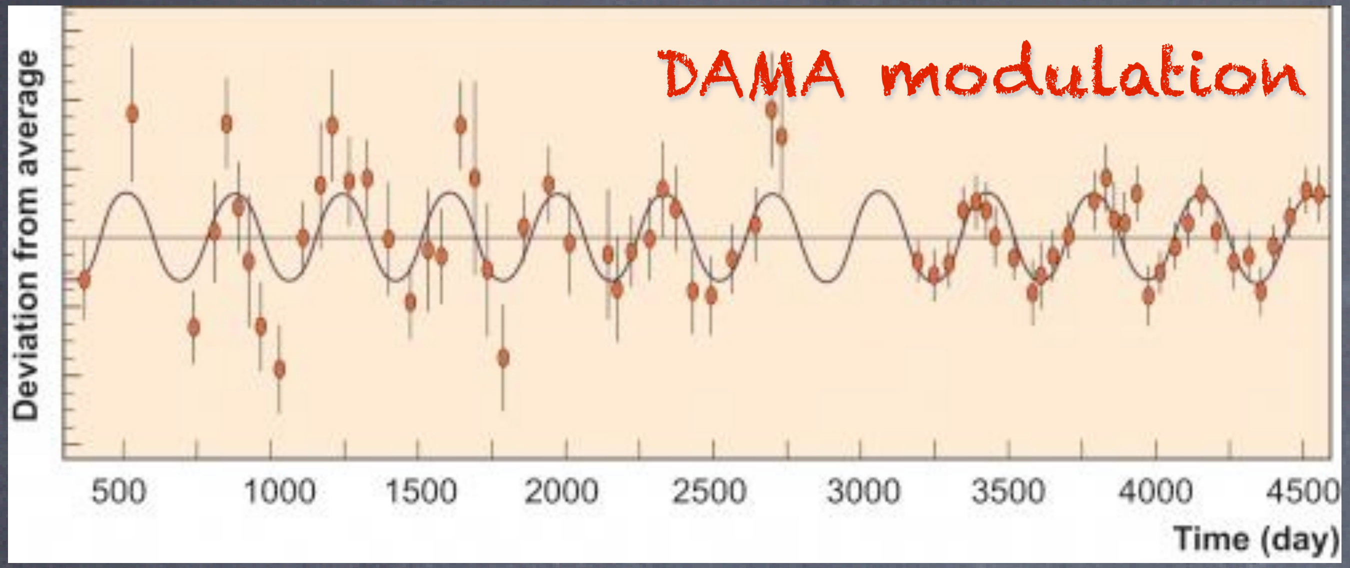

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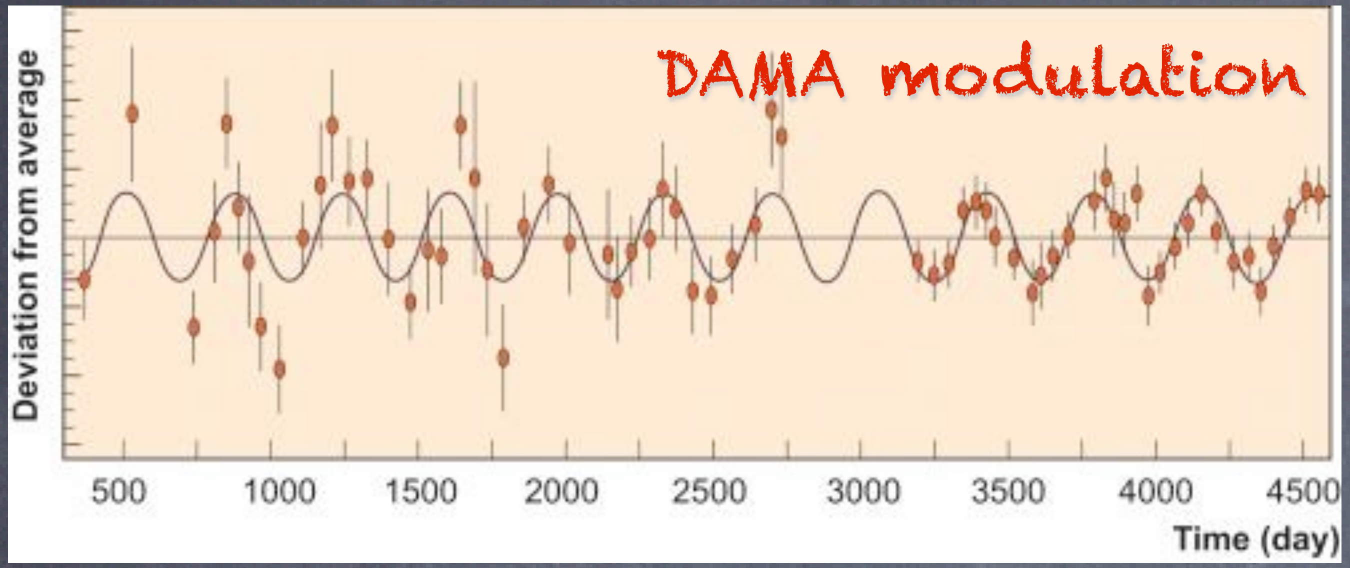

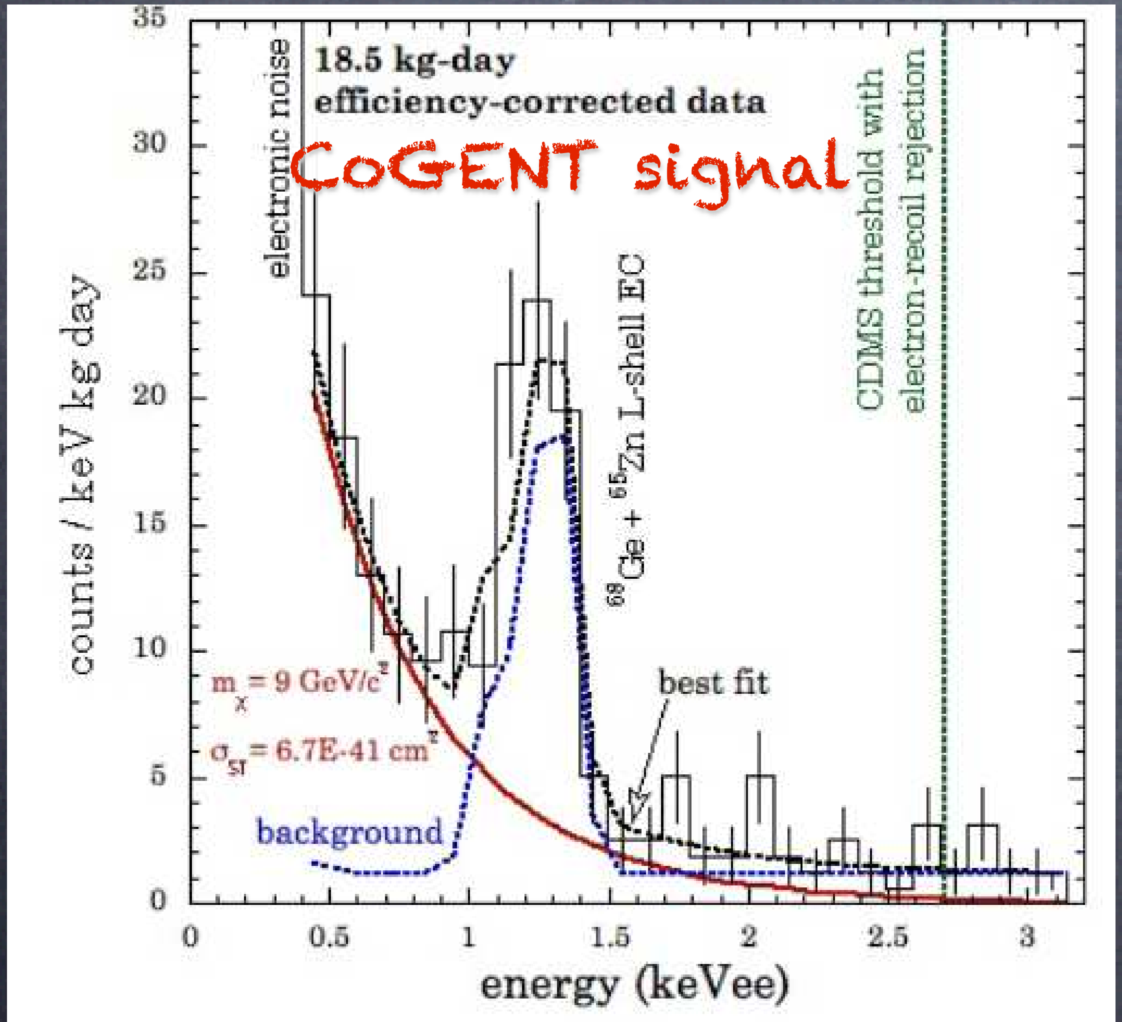

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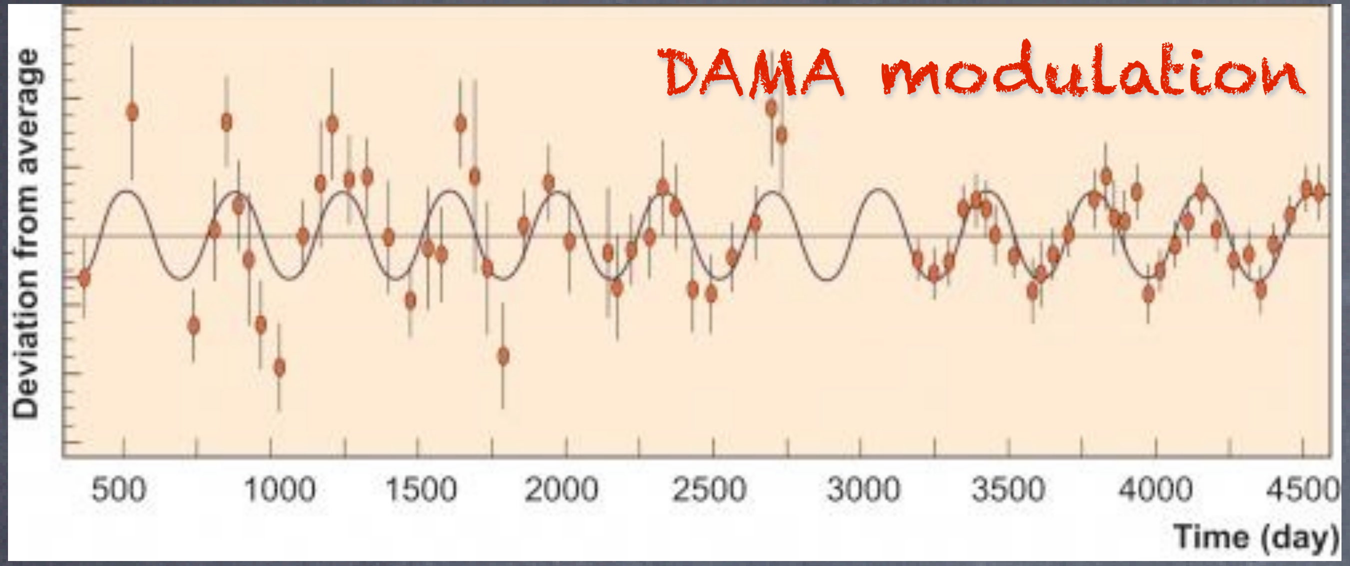

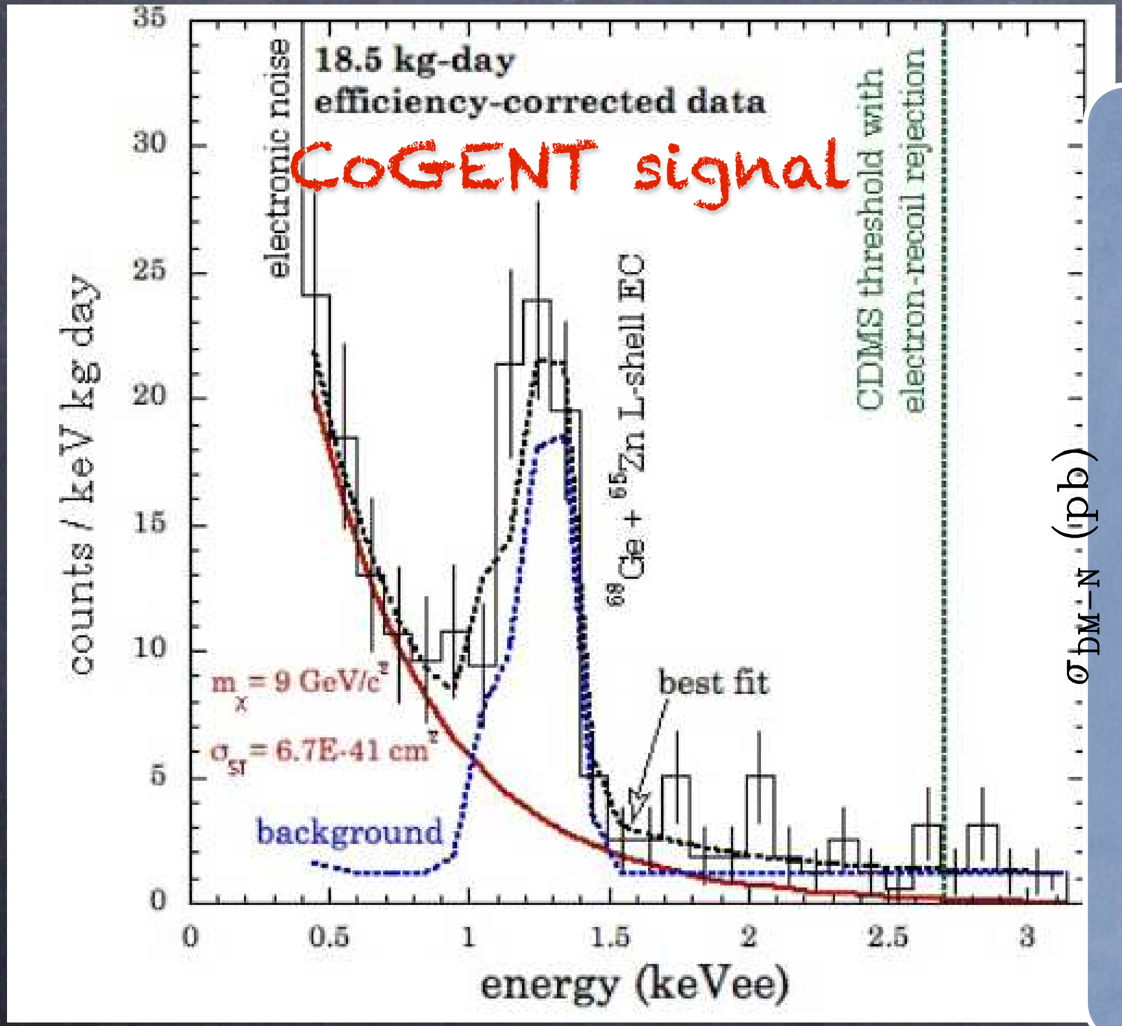

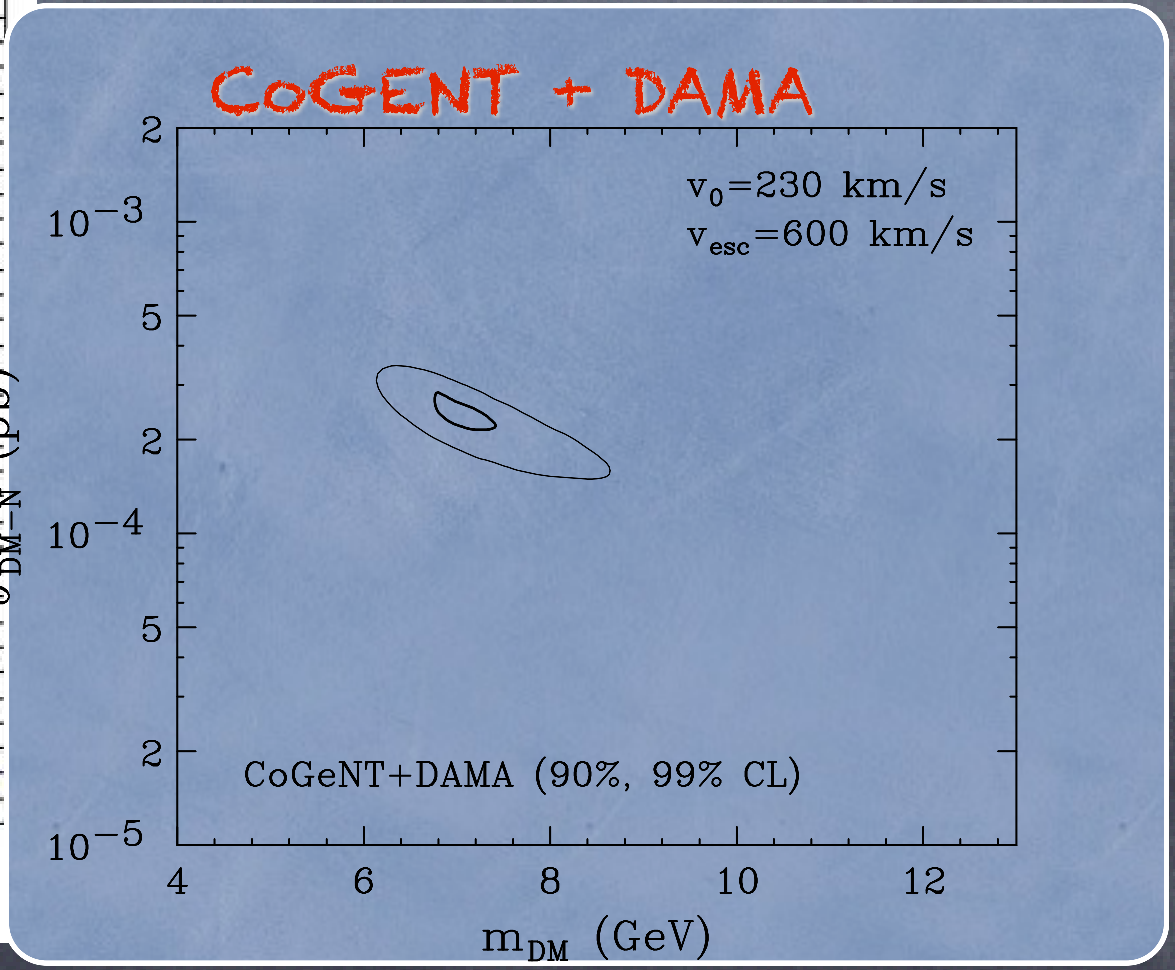

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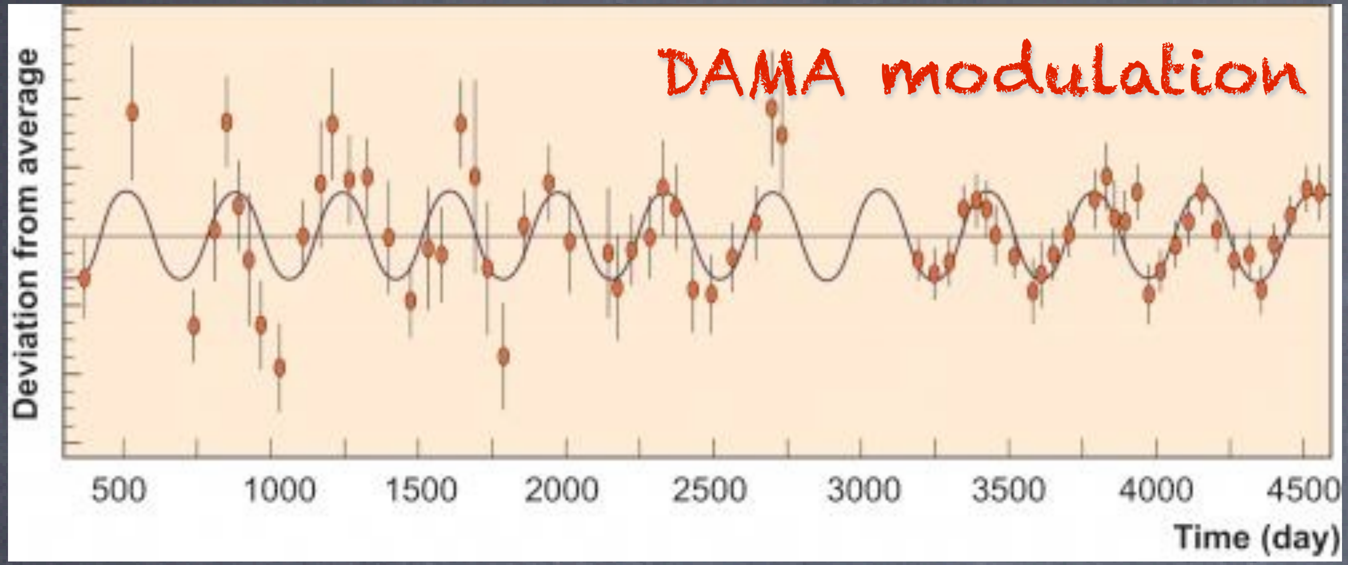

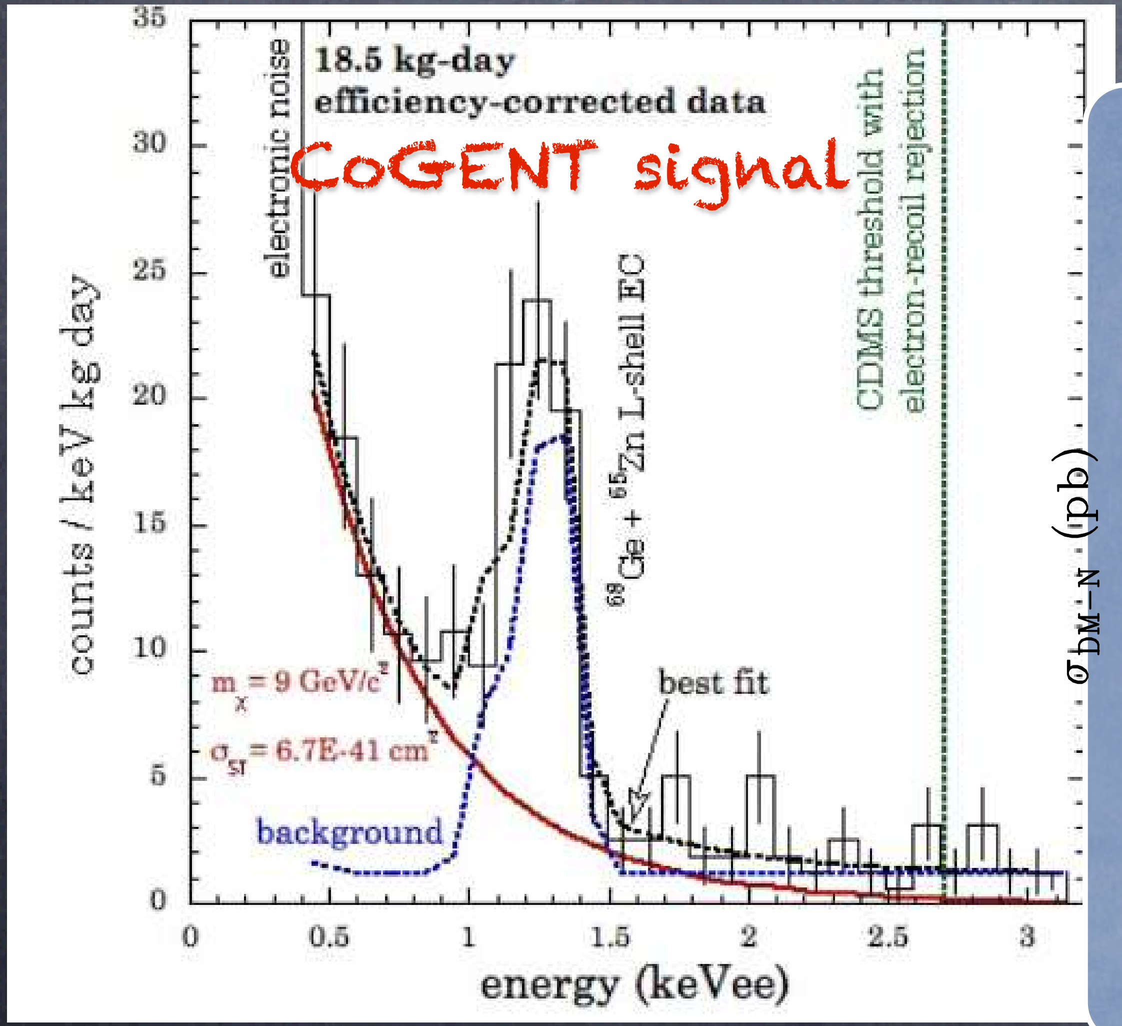

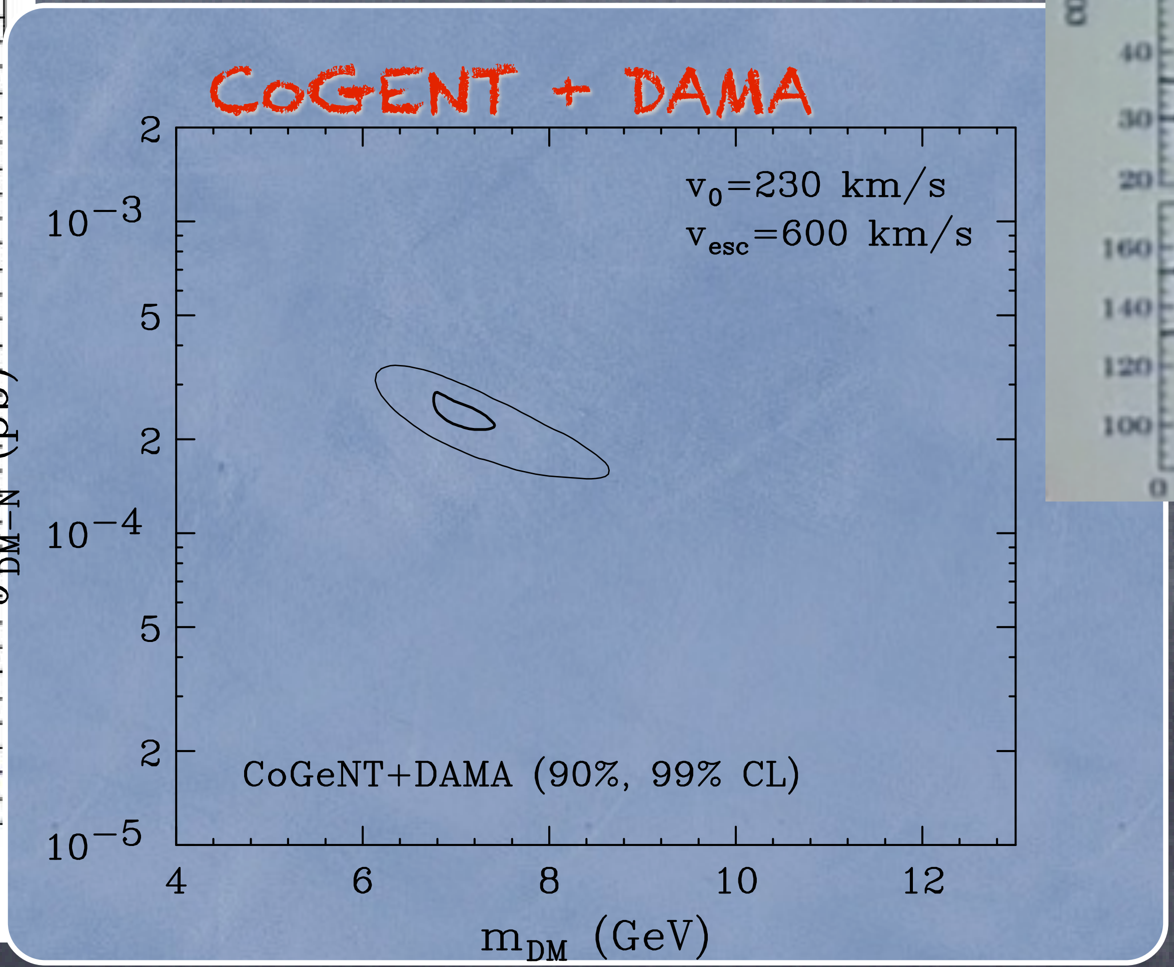

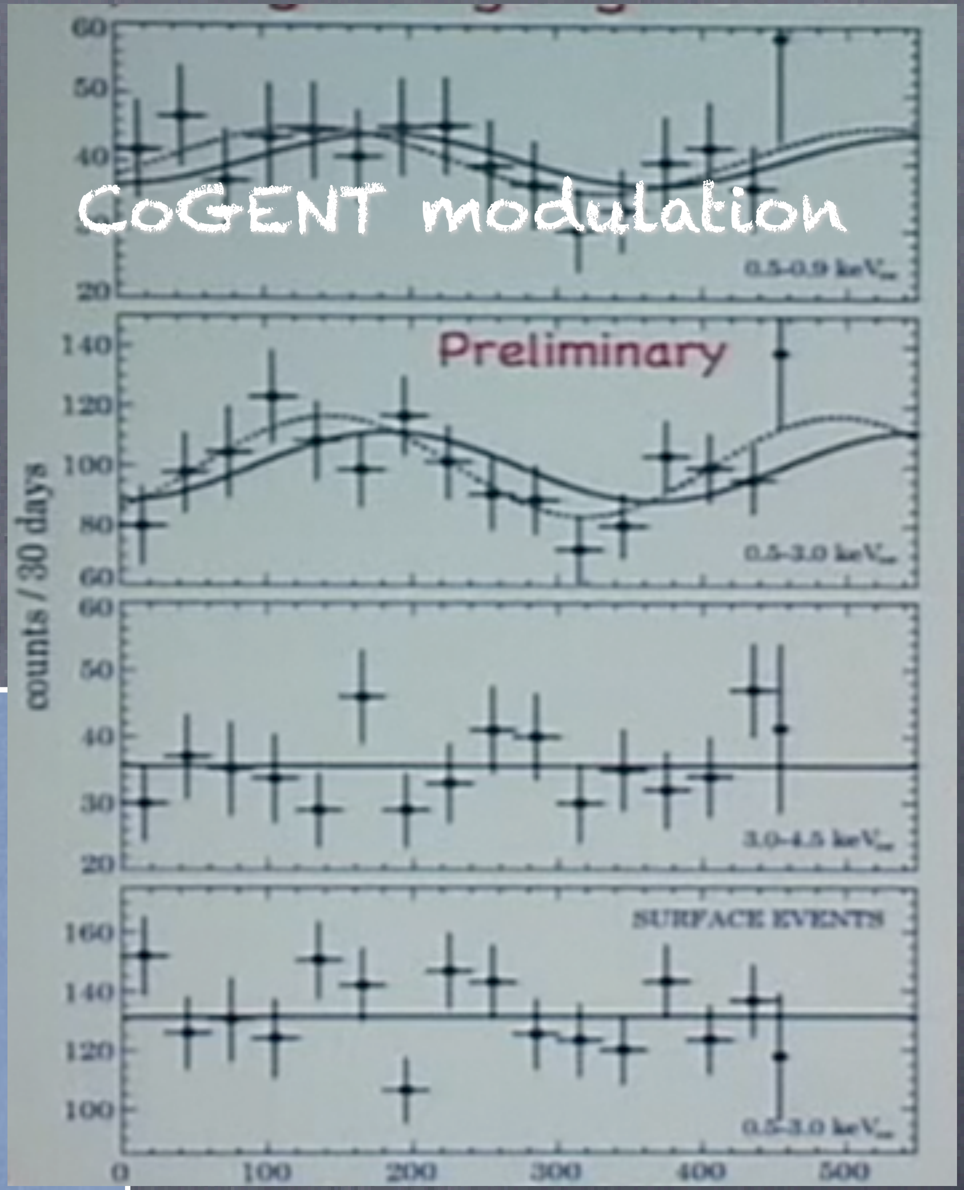

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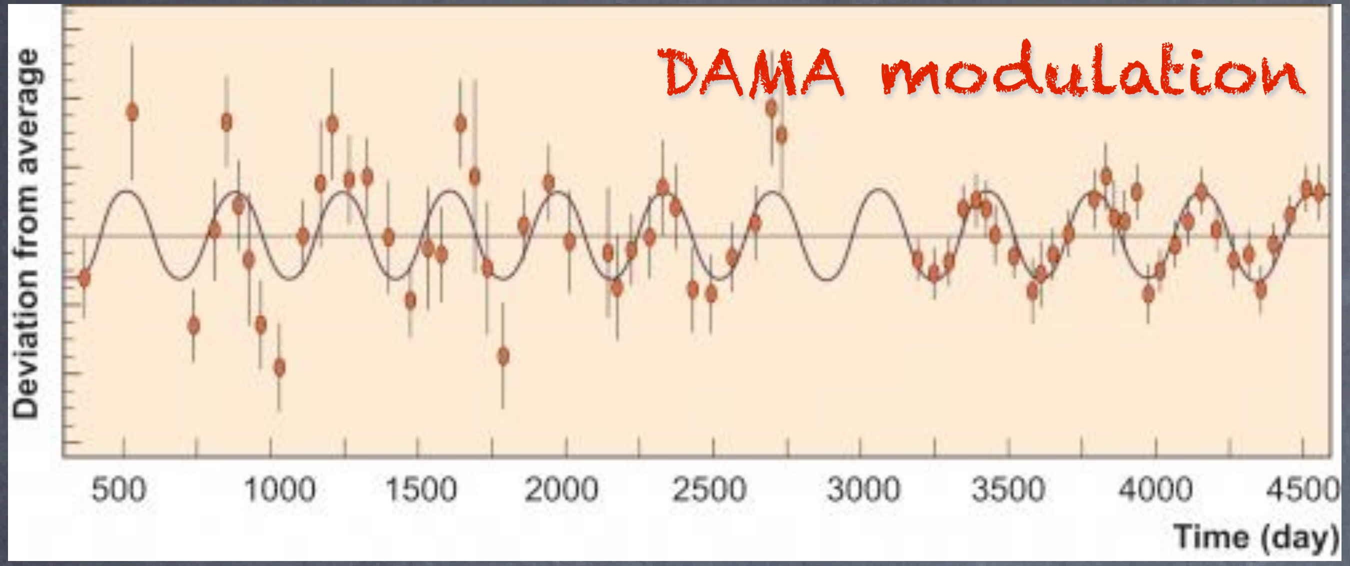

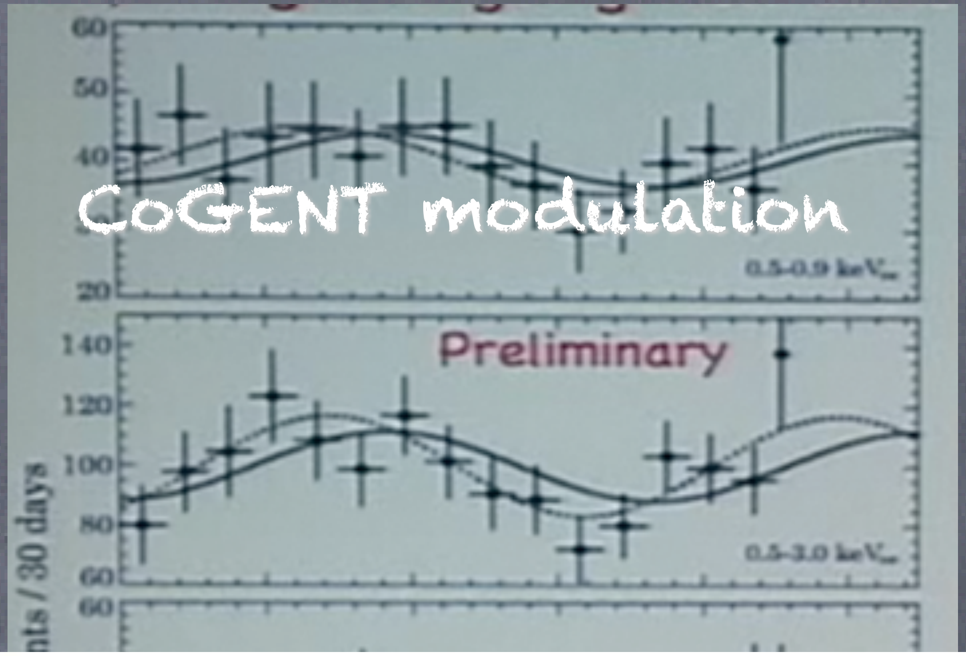

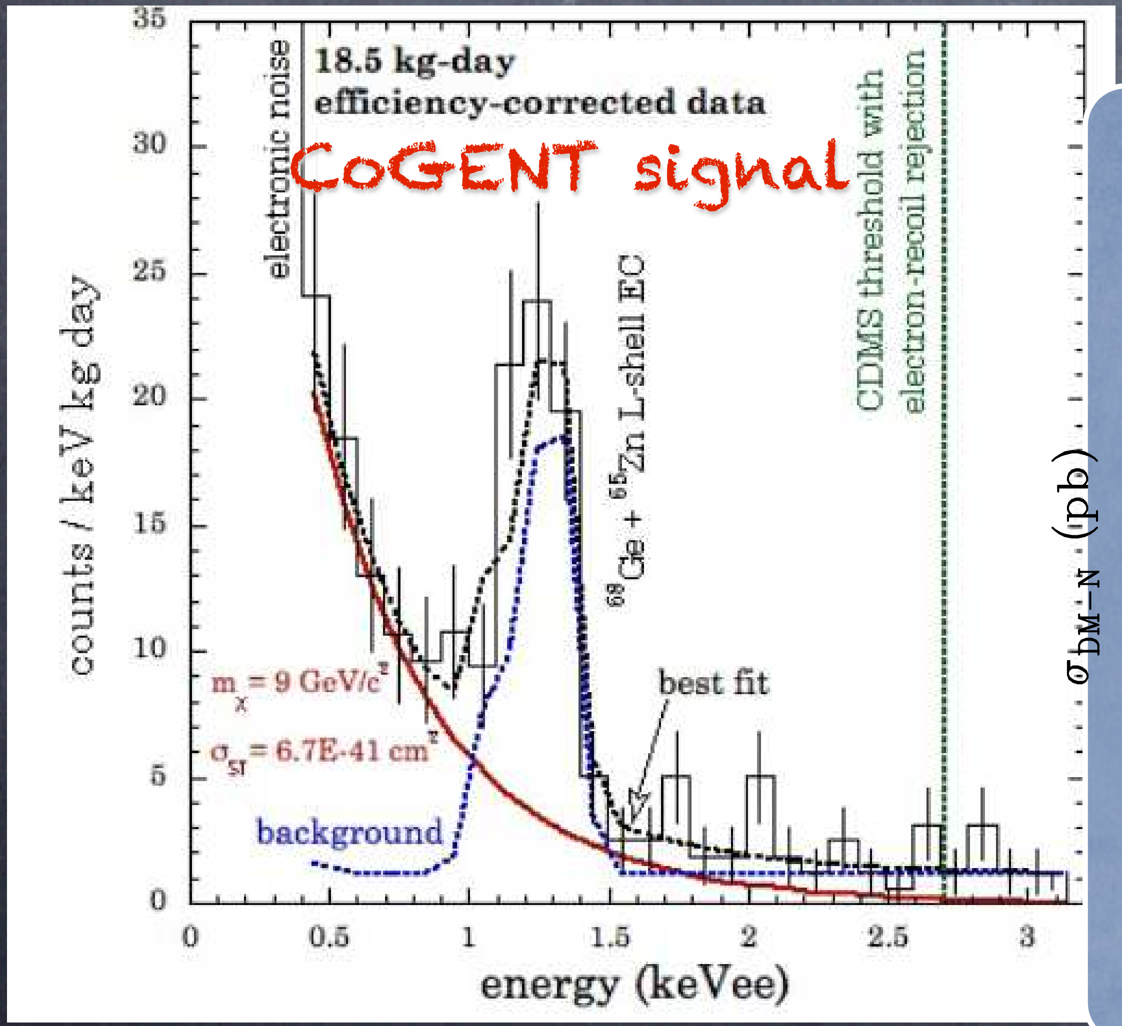

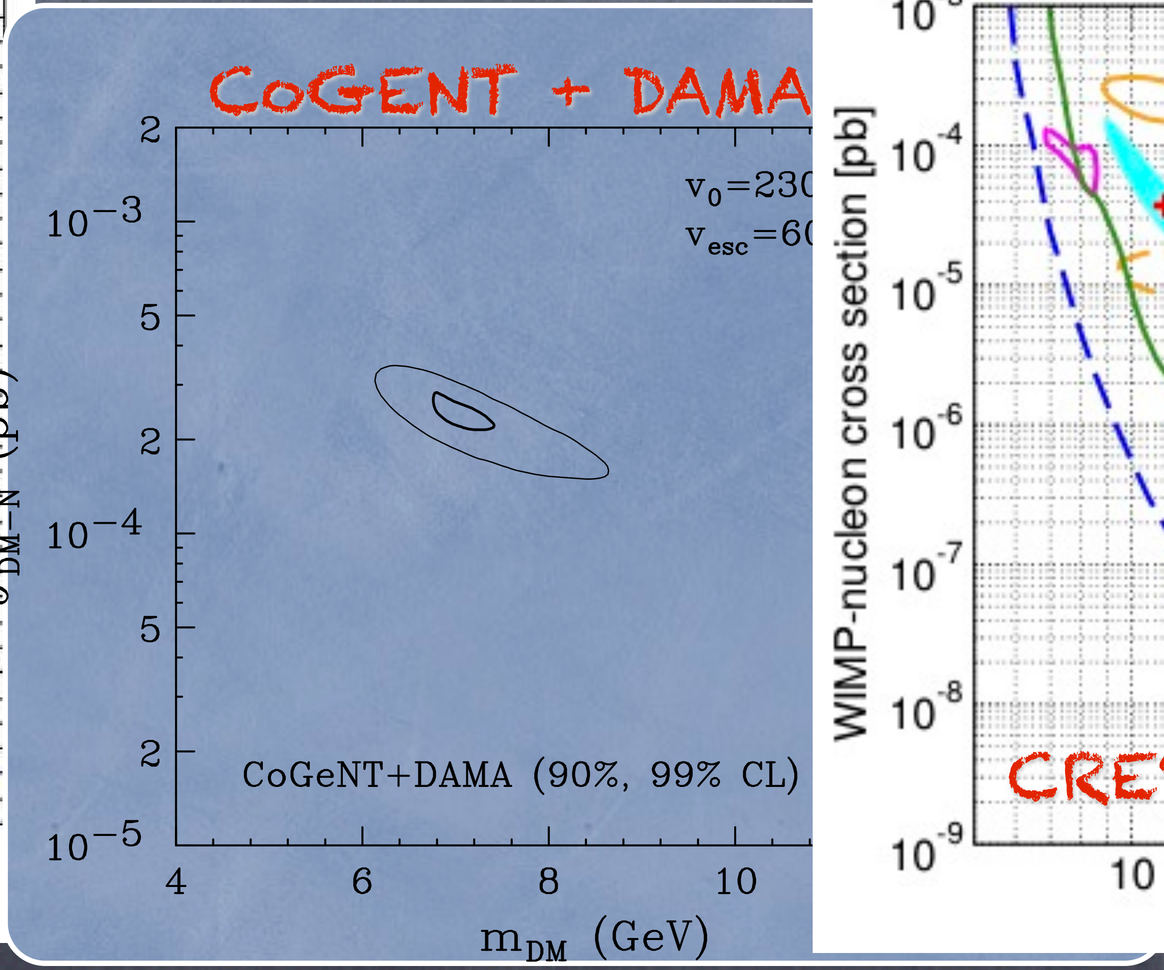

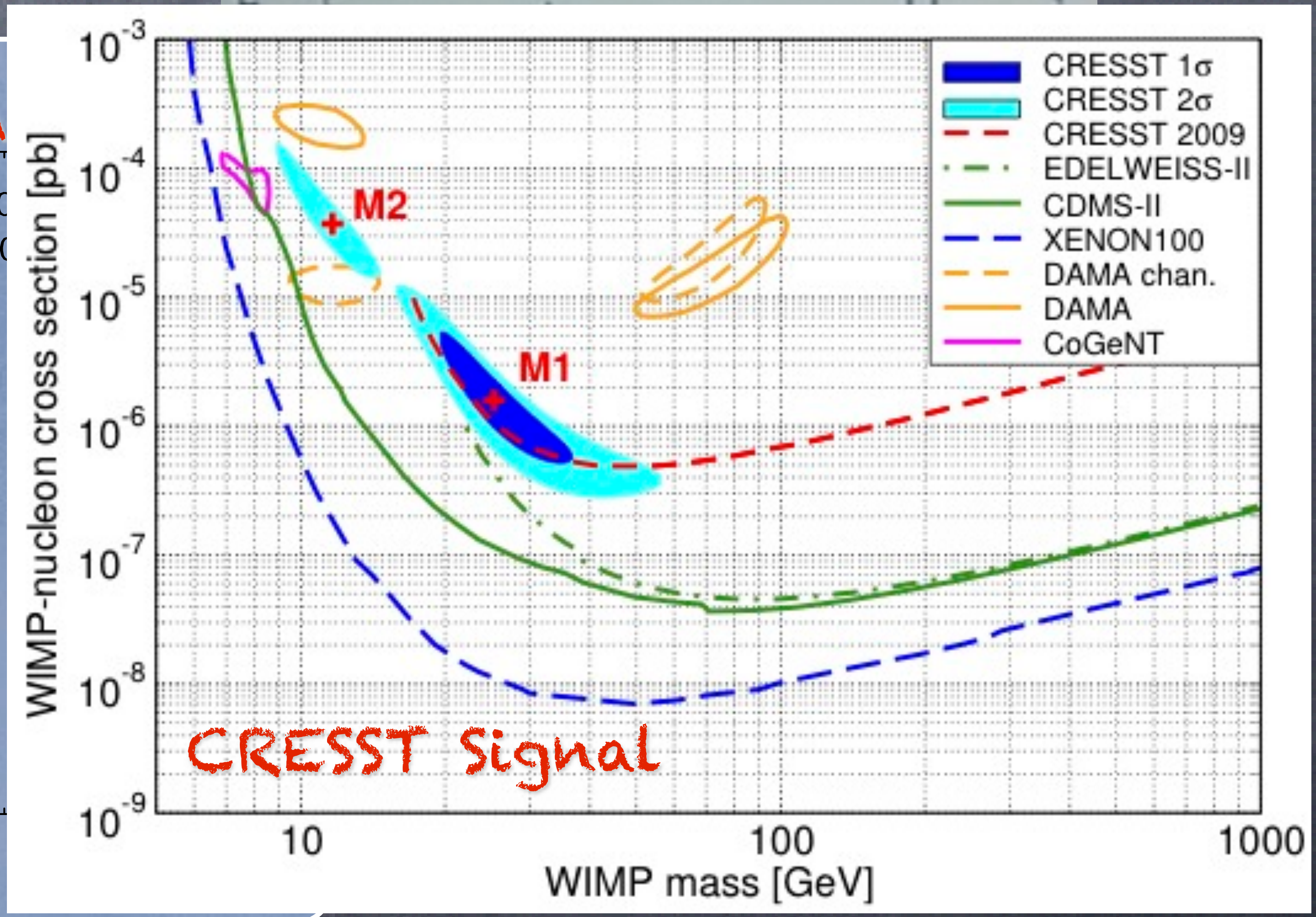

Constraints in «portal like» models

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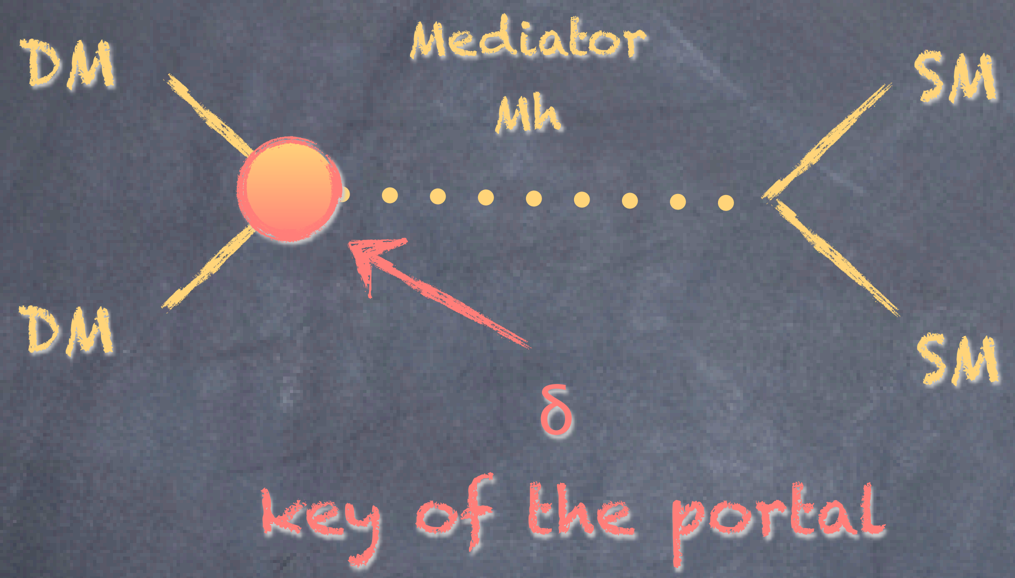
WMAP : σv ~ 10-26 cm3 s-1



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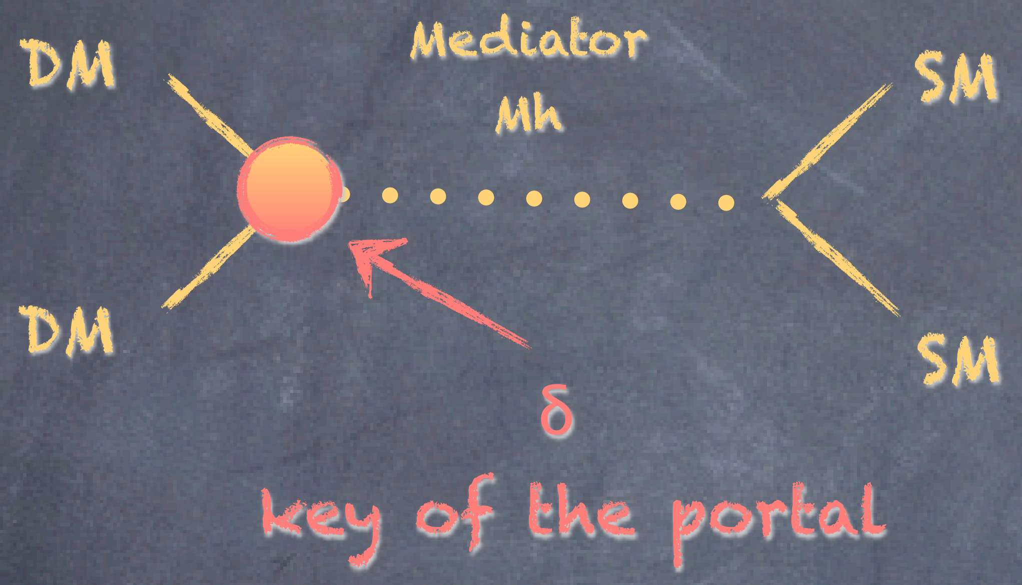

Mediator can be mater fields (Higgs, squarks..) or generated by symmetries (Z'..)

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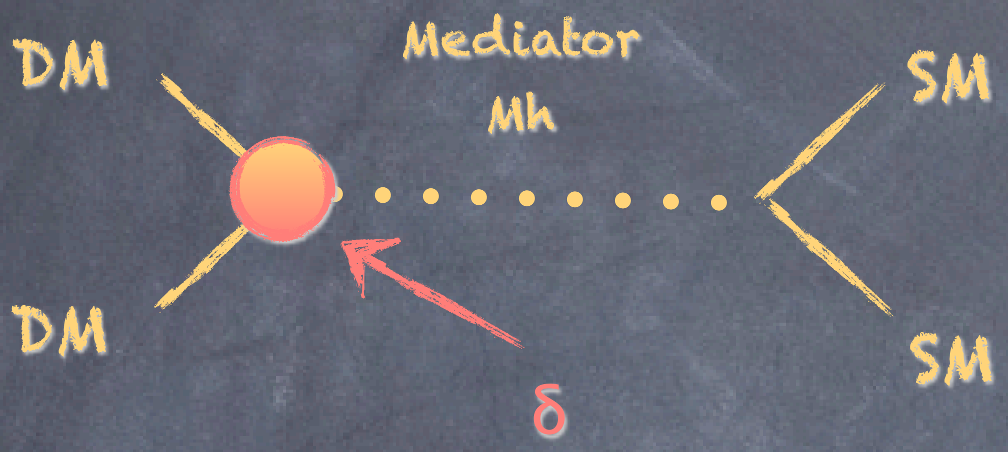

key of the portal

σDM-SM ~ 10-36 cm2
=> excess in DD exp.

Mediator can be mater fields (Higgs, squarks..) or generated by symmetries (Z'..)

Constraints in «portal like» models

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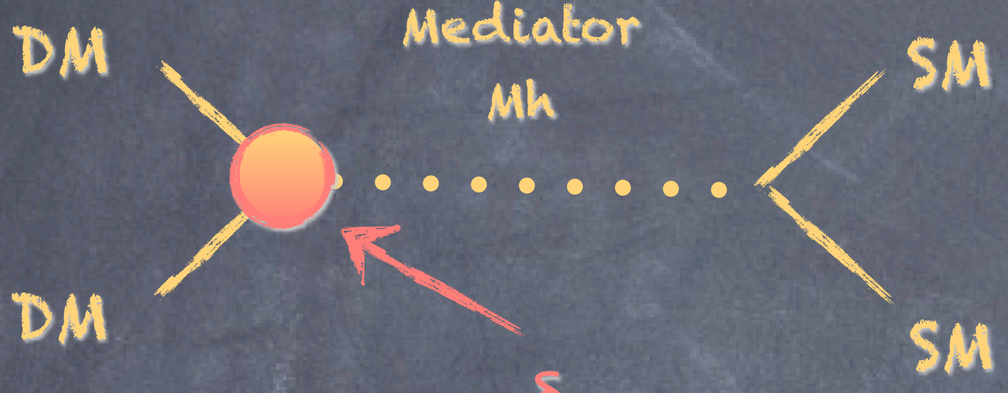

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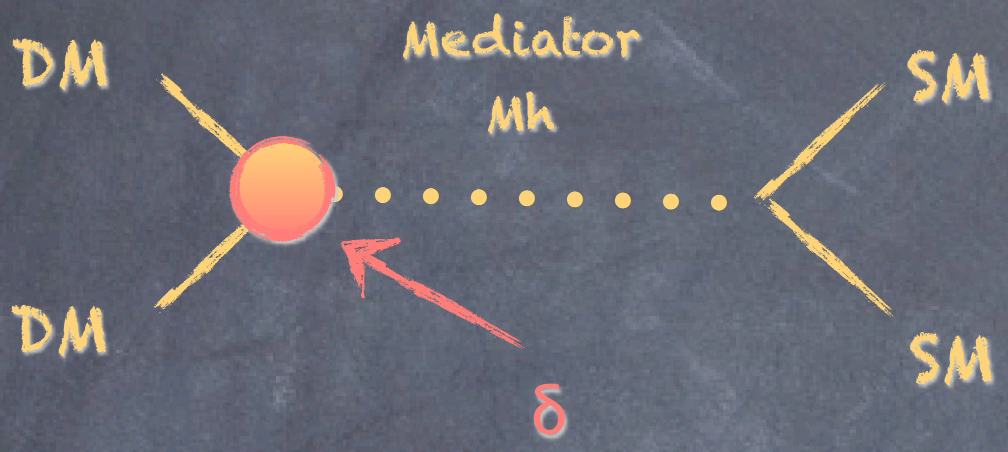
Except around the pole : $2M_{DM}$ = Mh : small δ to respect WMAP

=> small σ_{DM-SM}

Constraints in «portal like» models

WMAP : $\sigma v \sim 10^{-26}$ cm^3 s^{-1}



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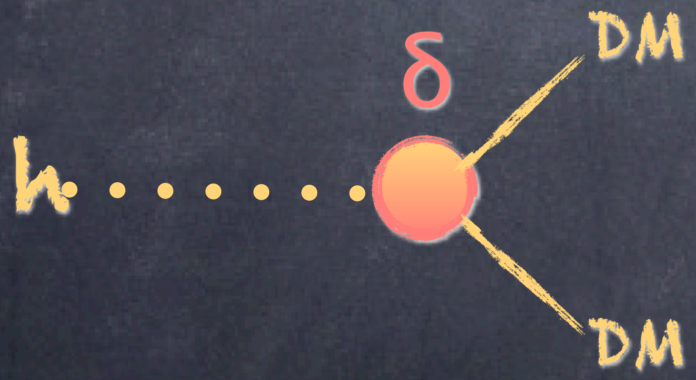

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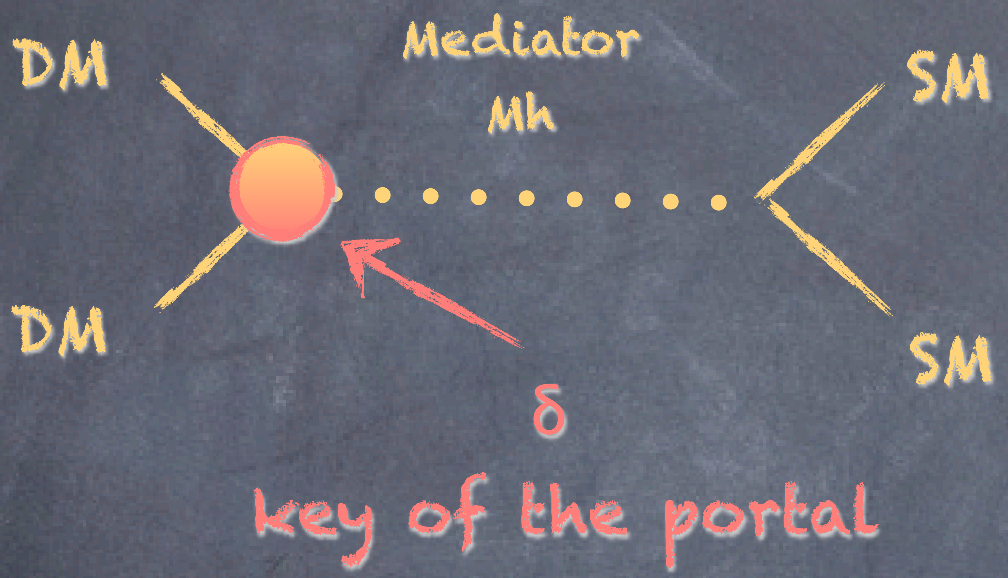

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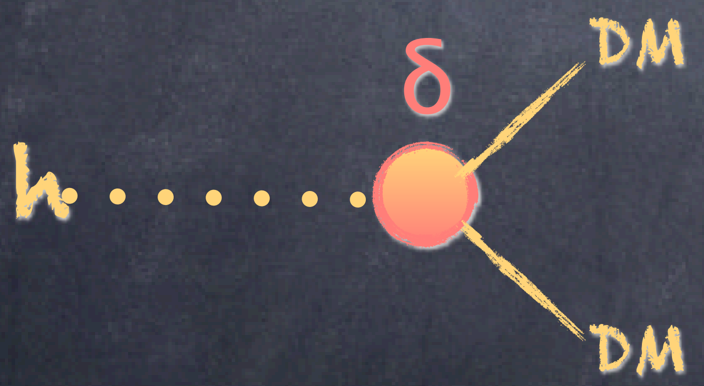
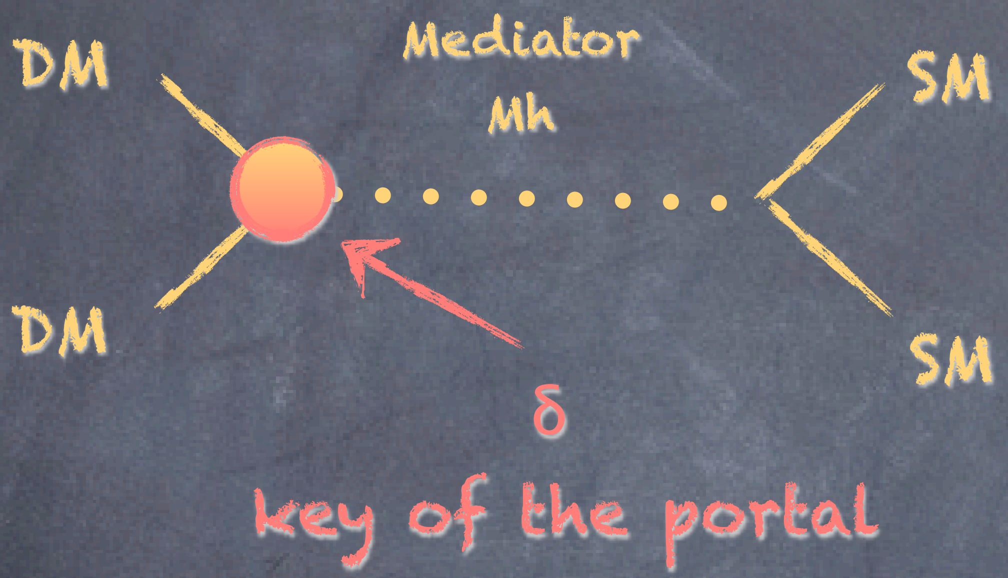


If direct detection experiments see nothing
=> δ < δmax
=> Γ (h -> DM DM) < Γmax
=> h not invisible at LHC

Constraints in «portal like» models

WMAP : σv ~ 10-26 cm3 s-1



WMAP

σDM-SM ~ 10-36 cm2
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XENON

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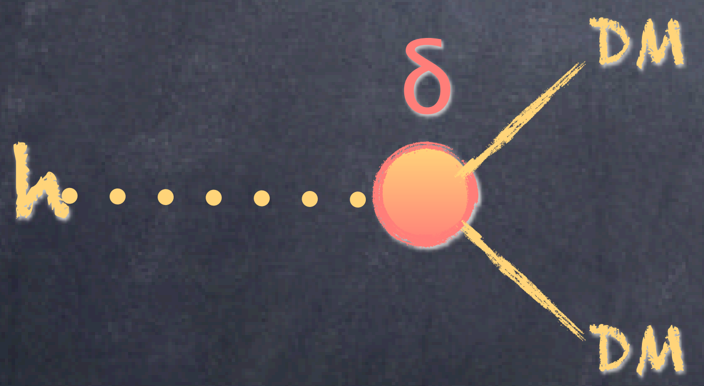

LHC/ILC

If direct detection experiments see nothing
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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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$SU(3) * SU(2) * U(1) * U_D(1)$

g_μ W_μ Y_μ X_μ

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$g_\mu \quad W_\mu \quad Y_\mu \quad X_\mu$

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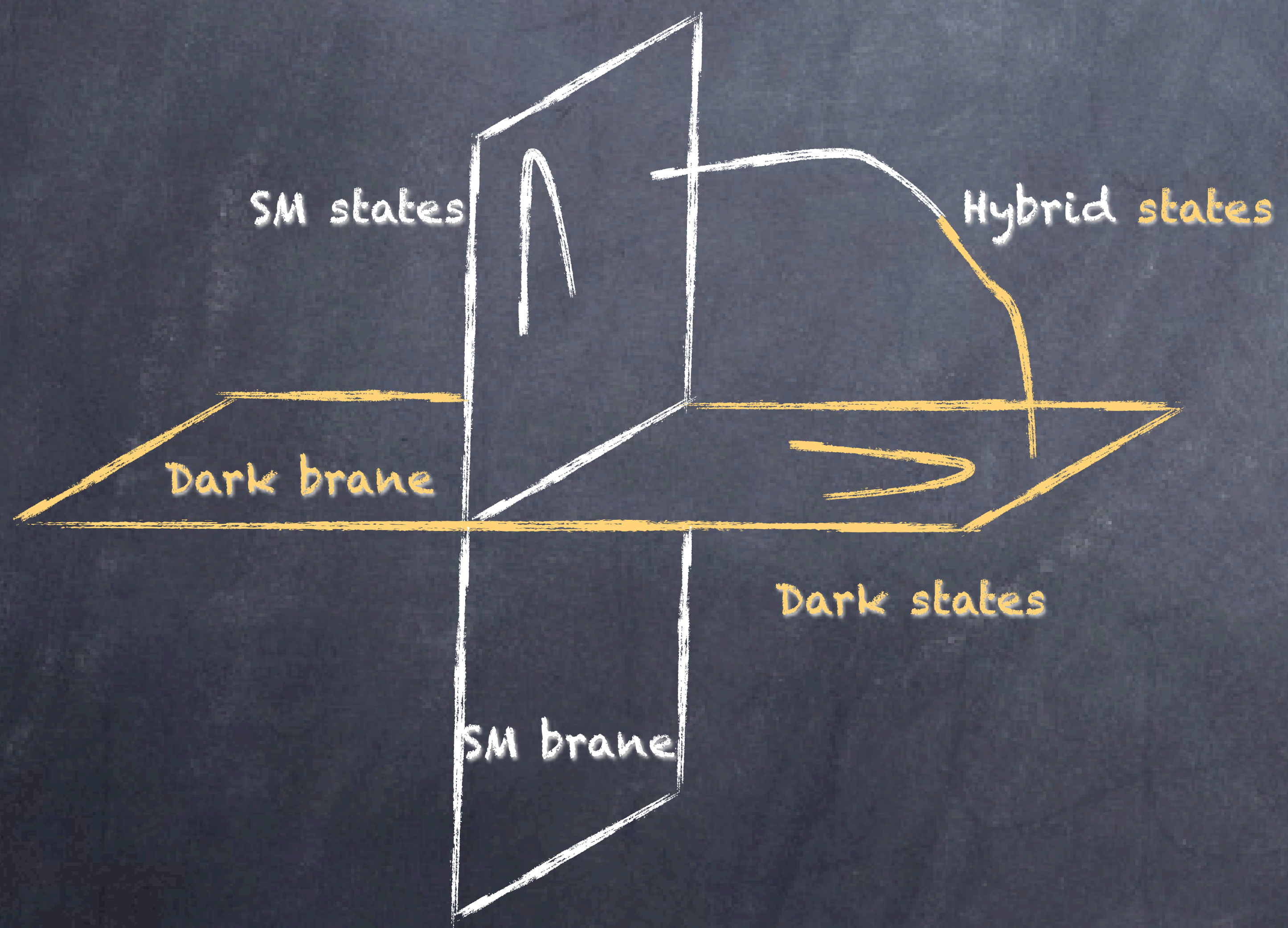

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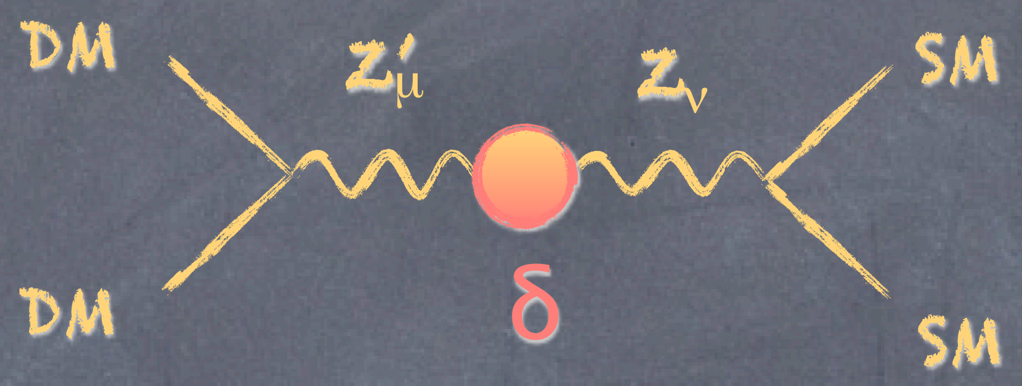

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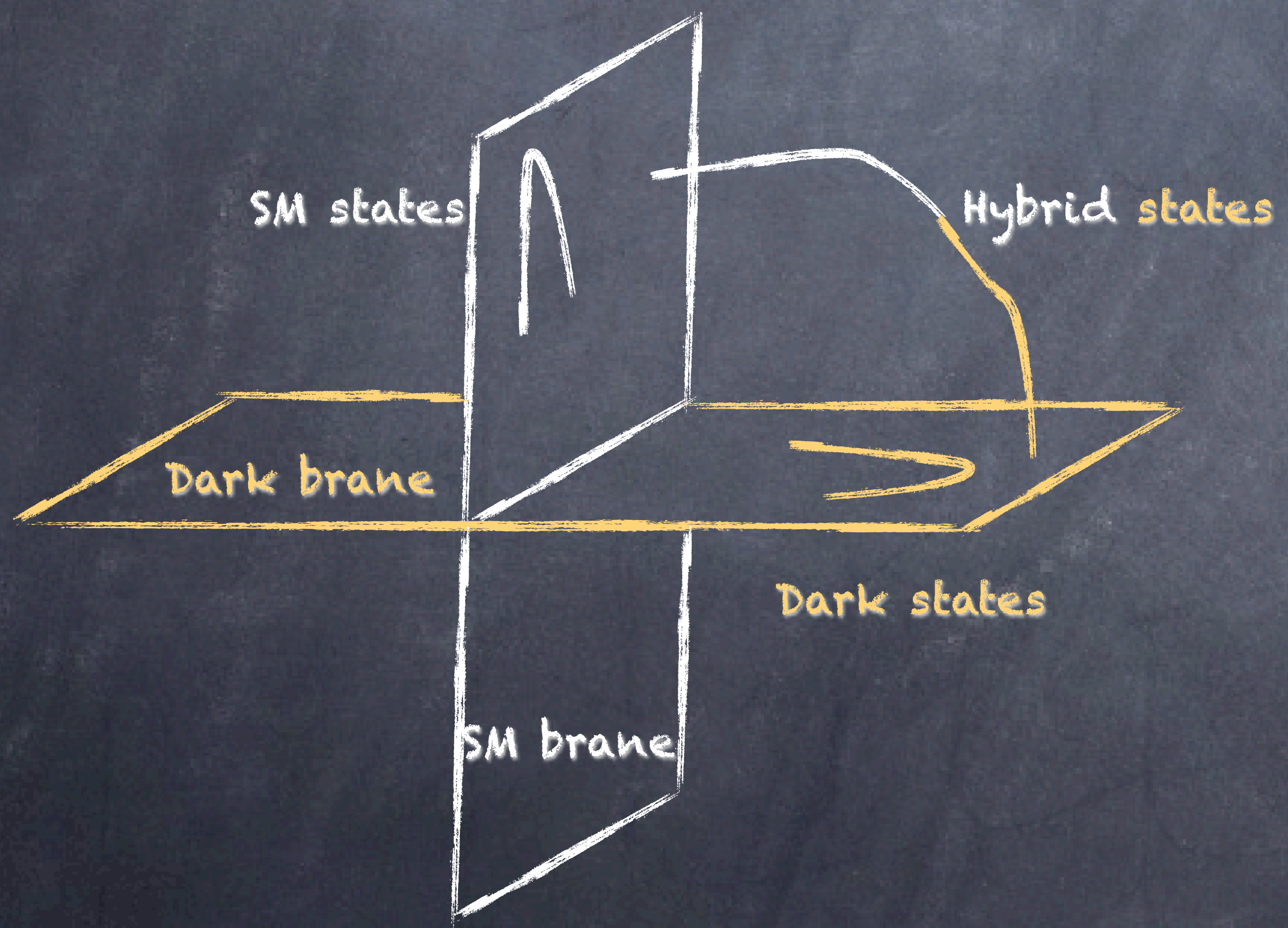

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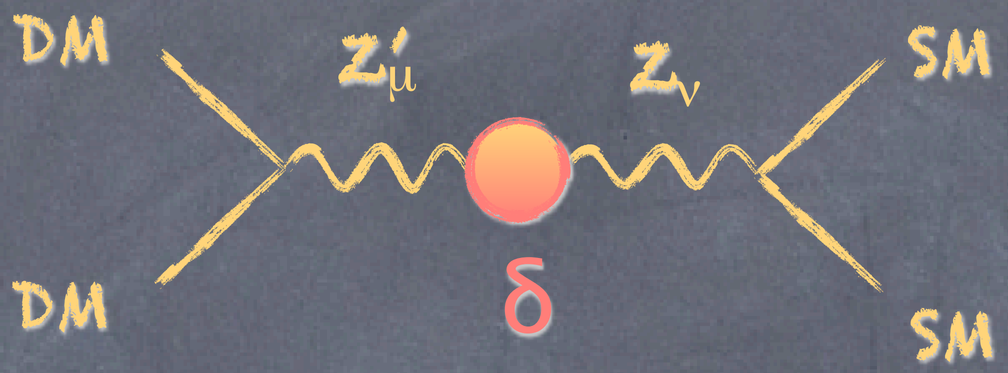

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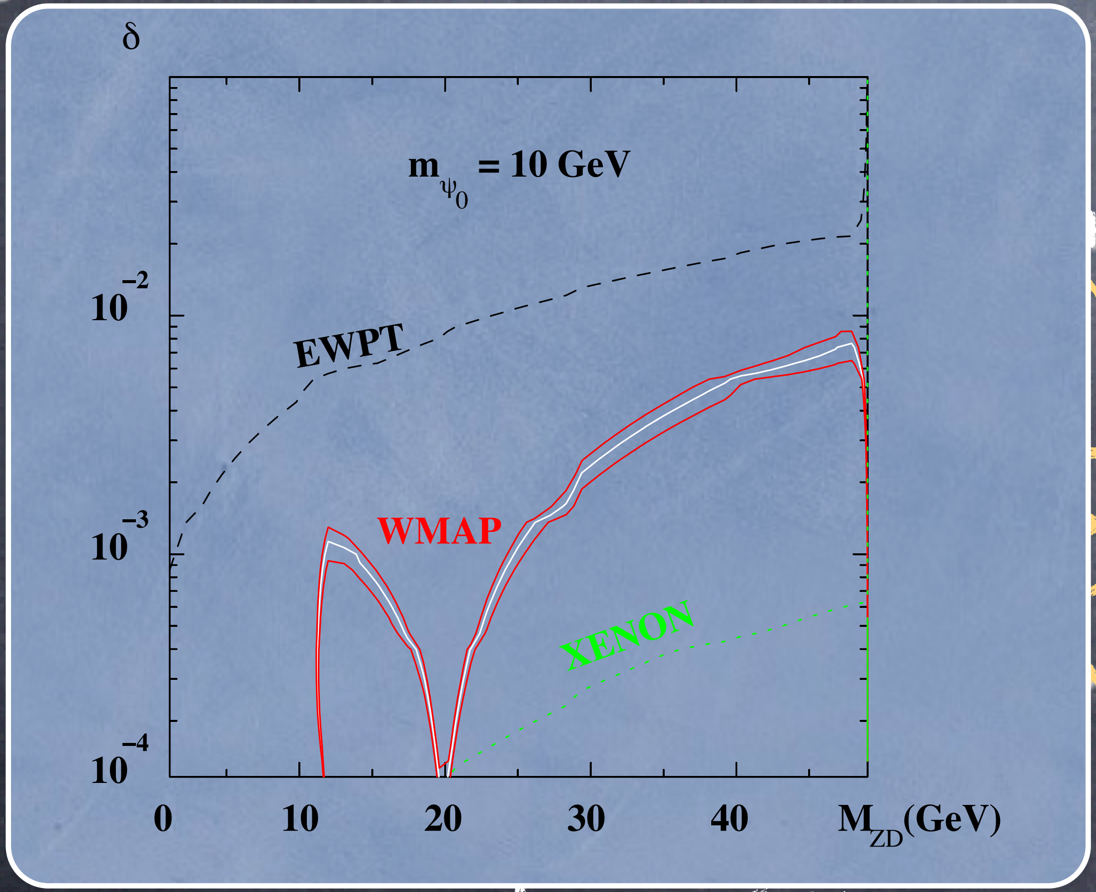
δ



Hybrid states

...ates

M_{DM} = 10 GeV

Mx

Gauge extension: Extra $U_D(1)$

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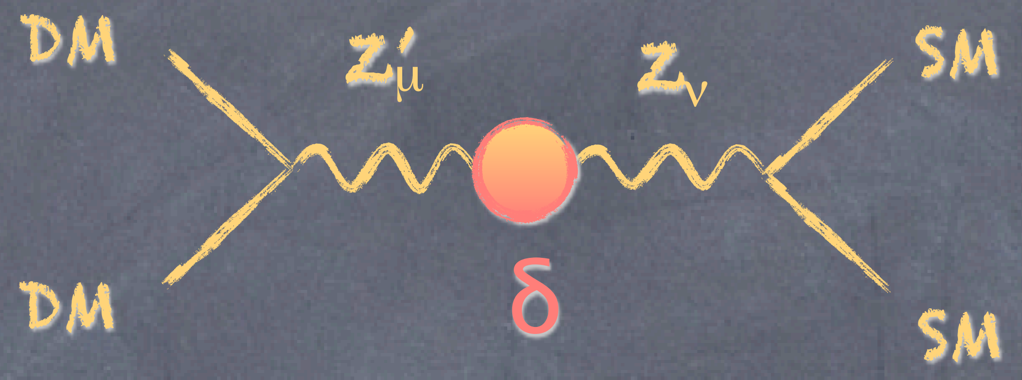

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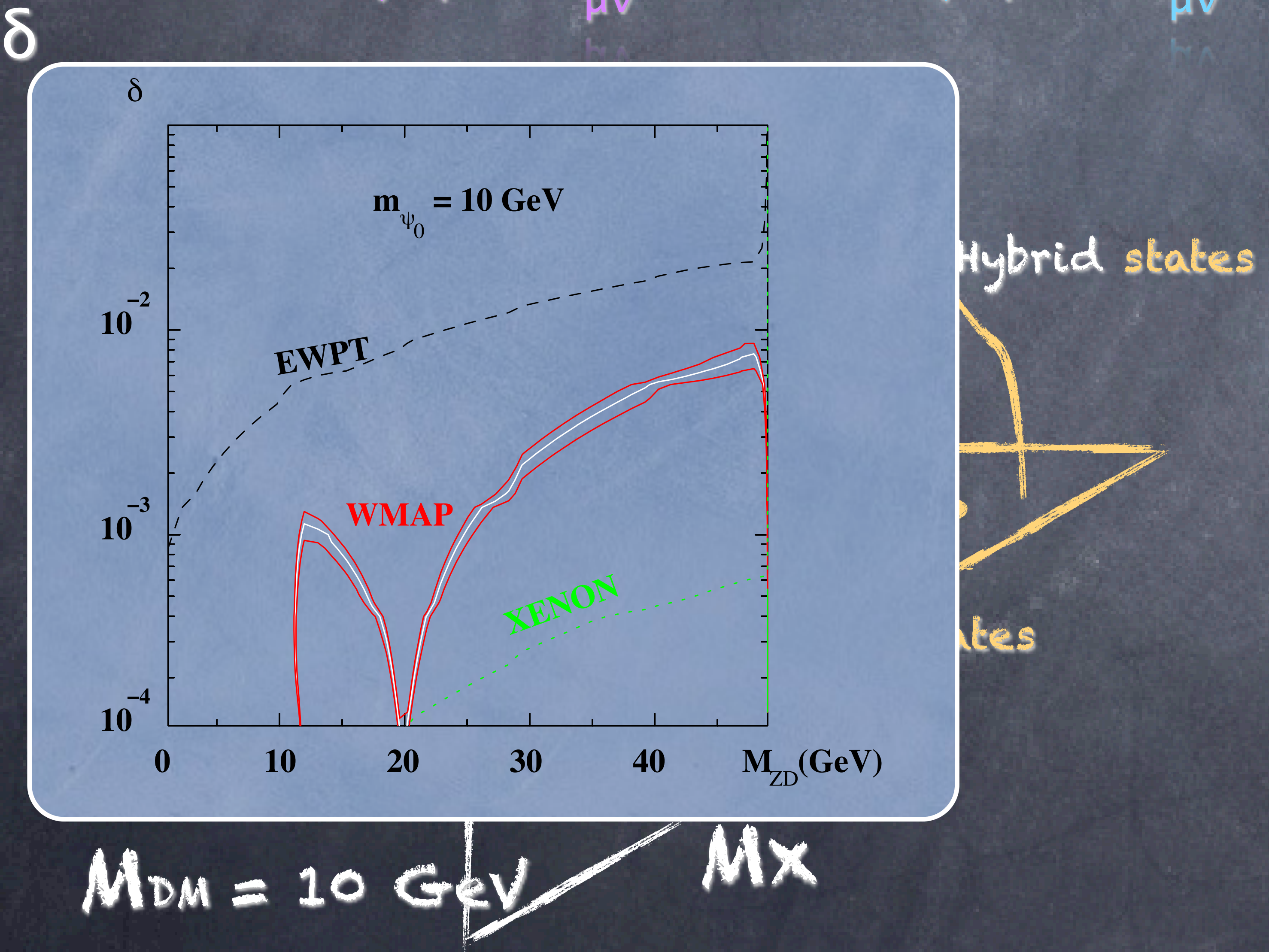

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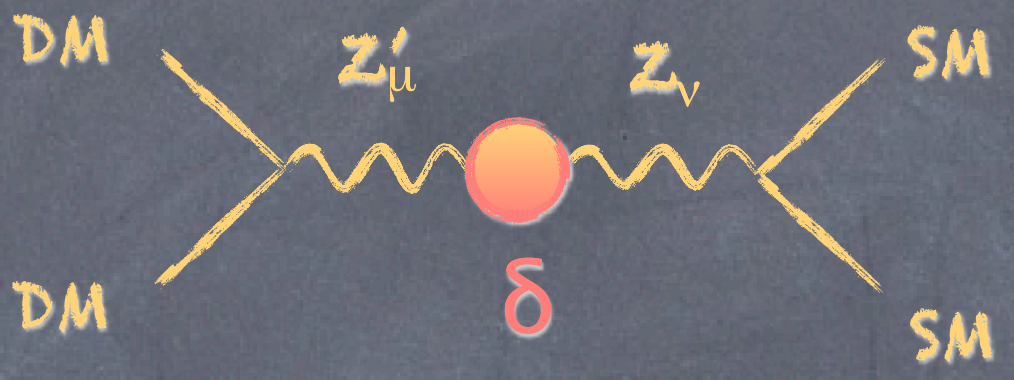

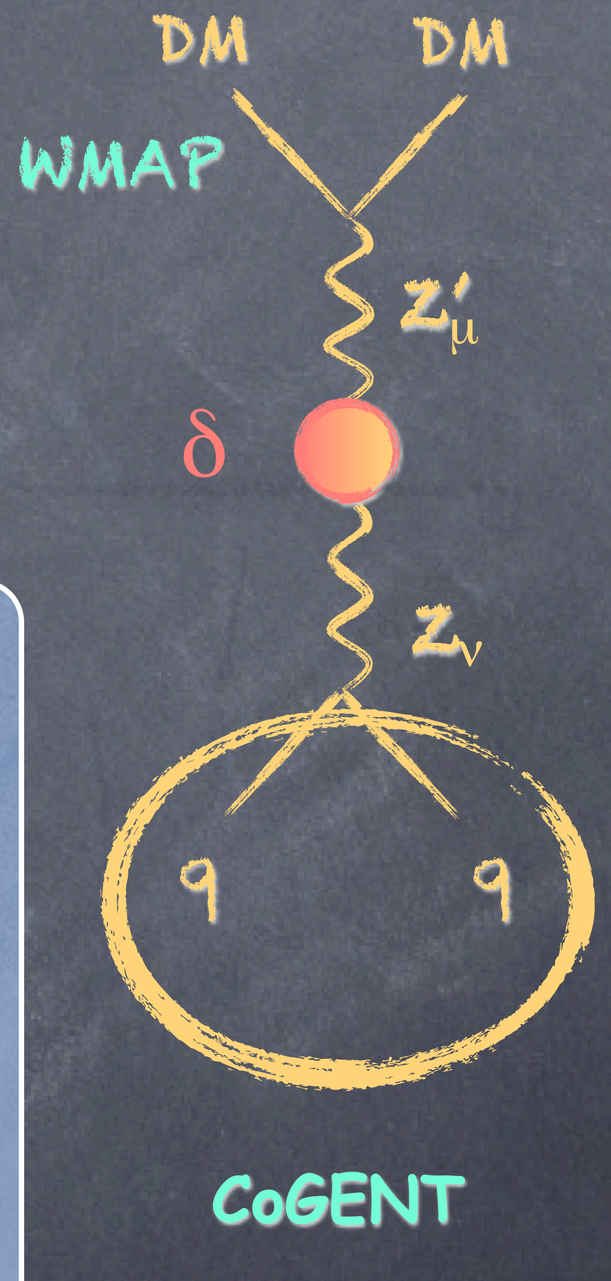

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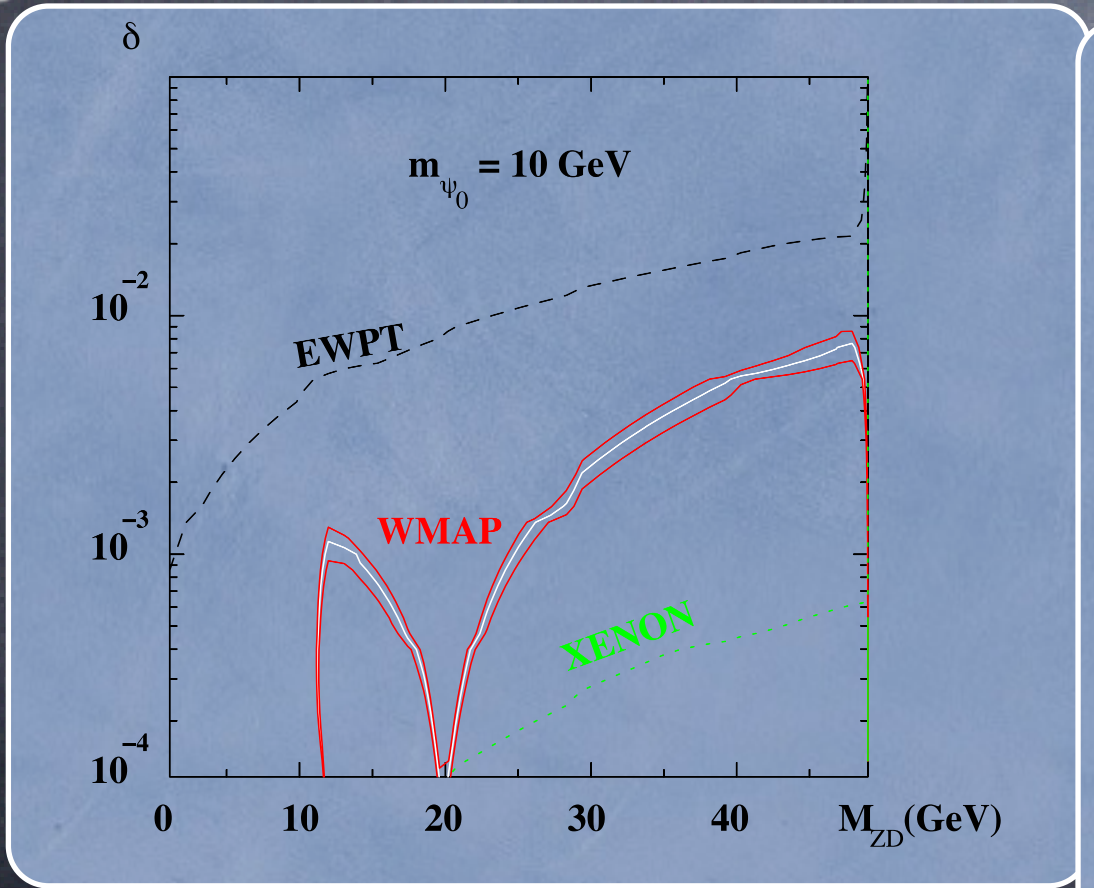

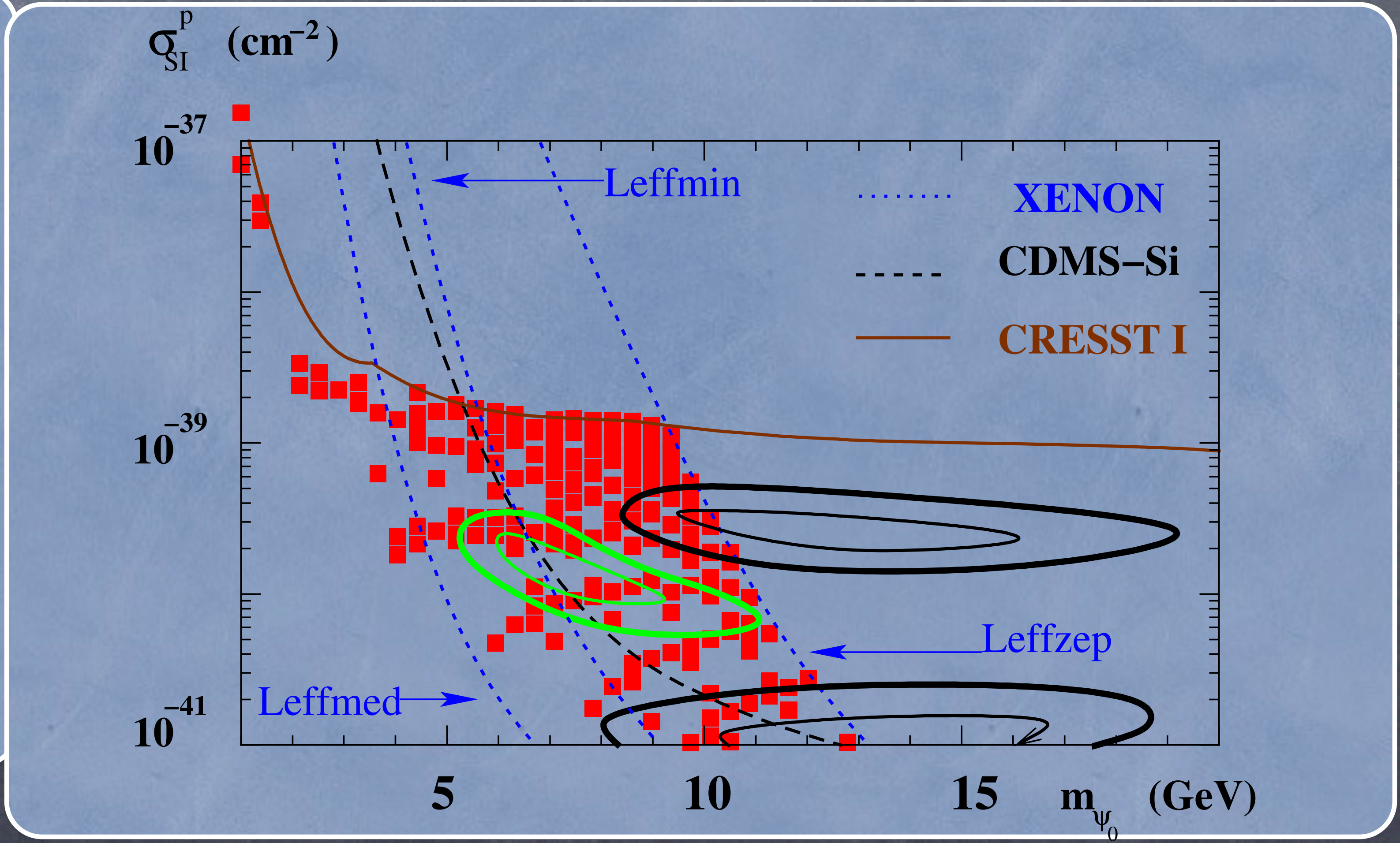

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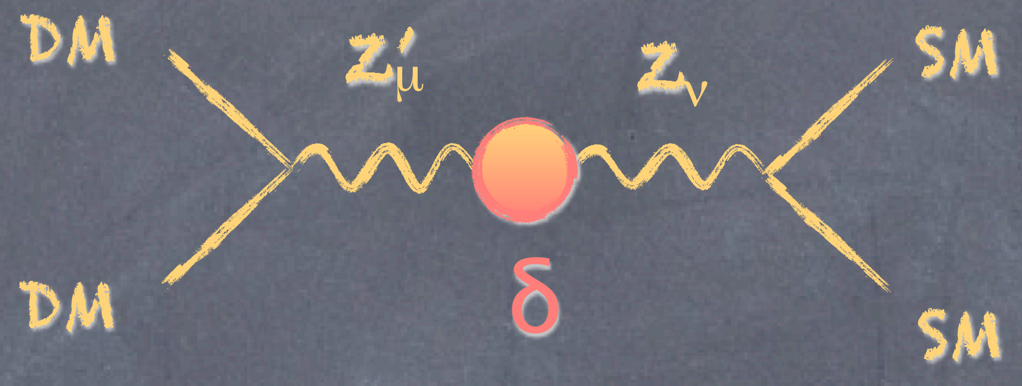

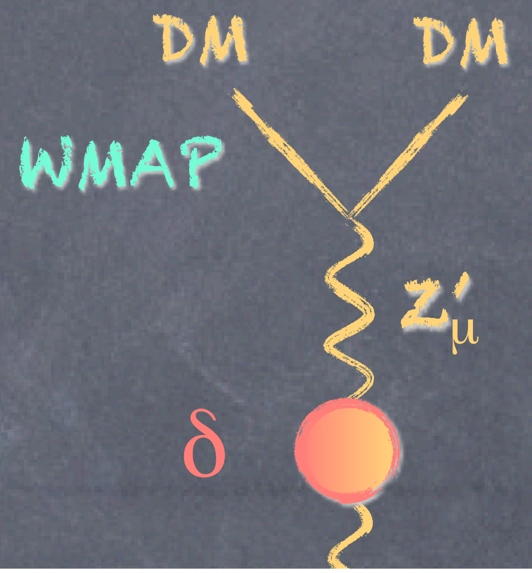

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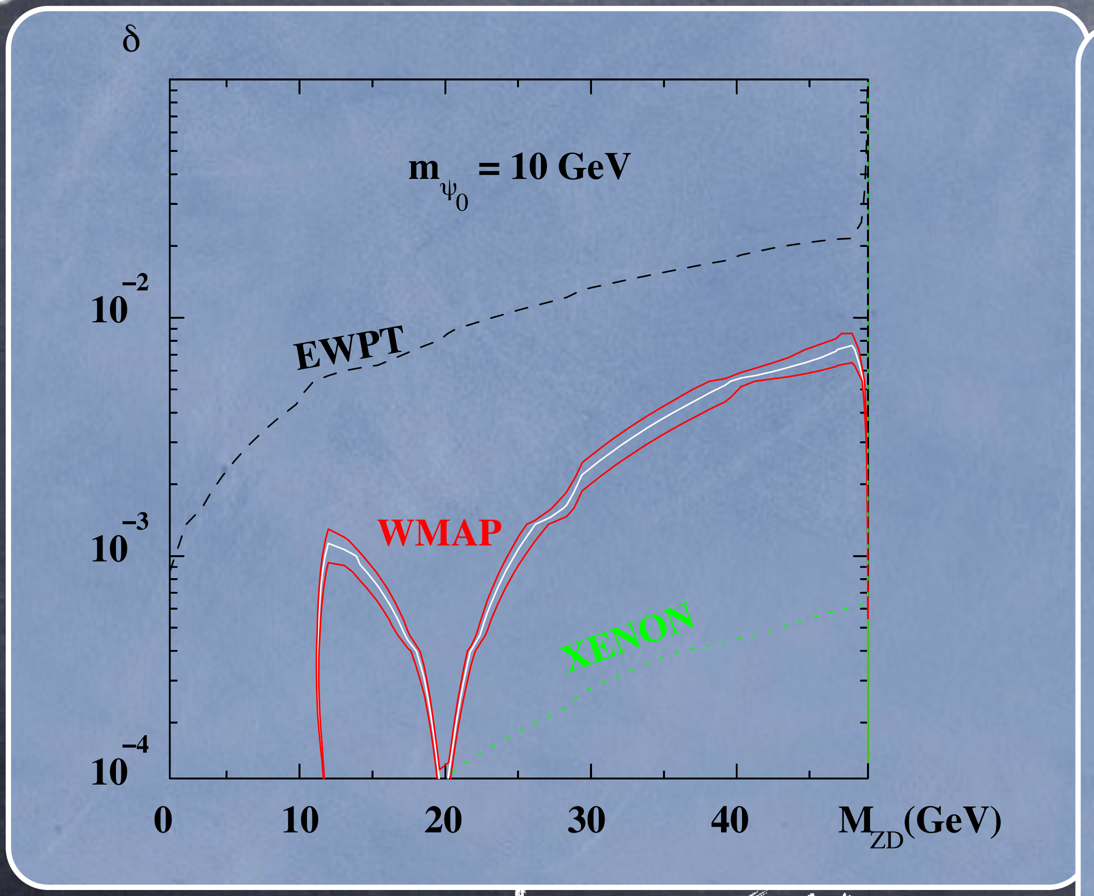

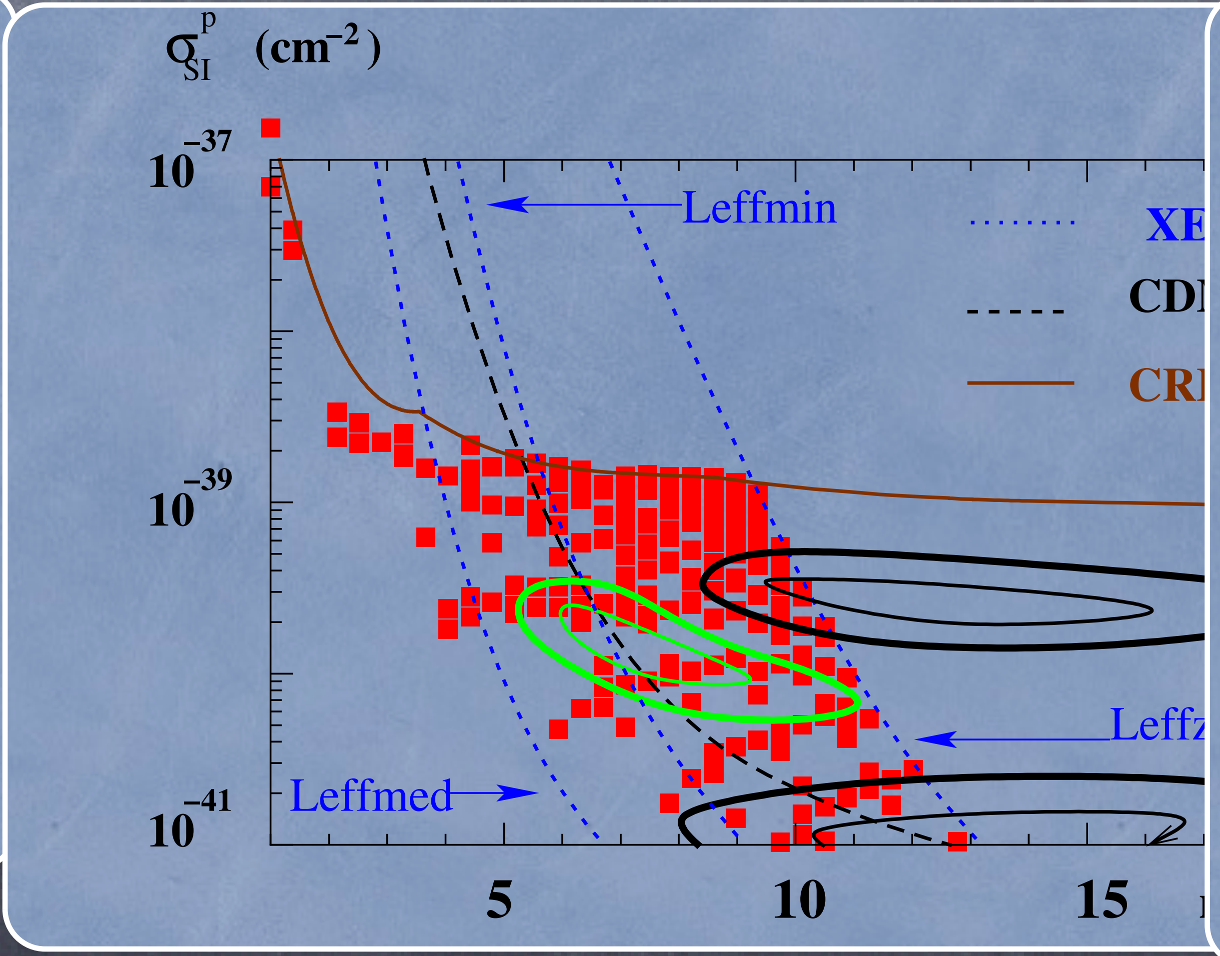

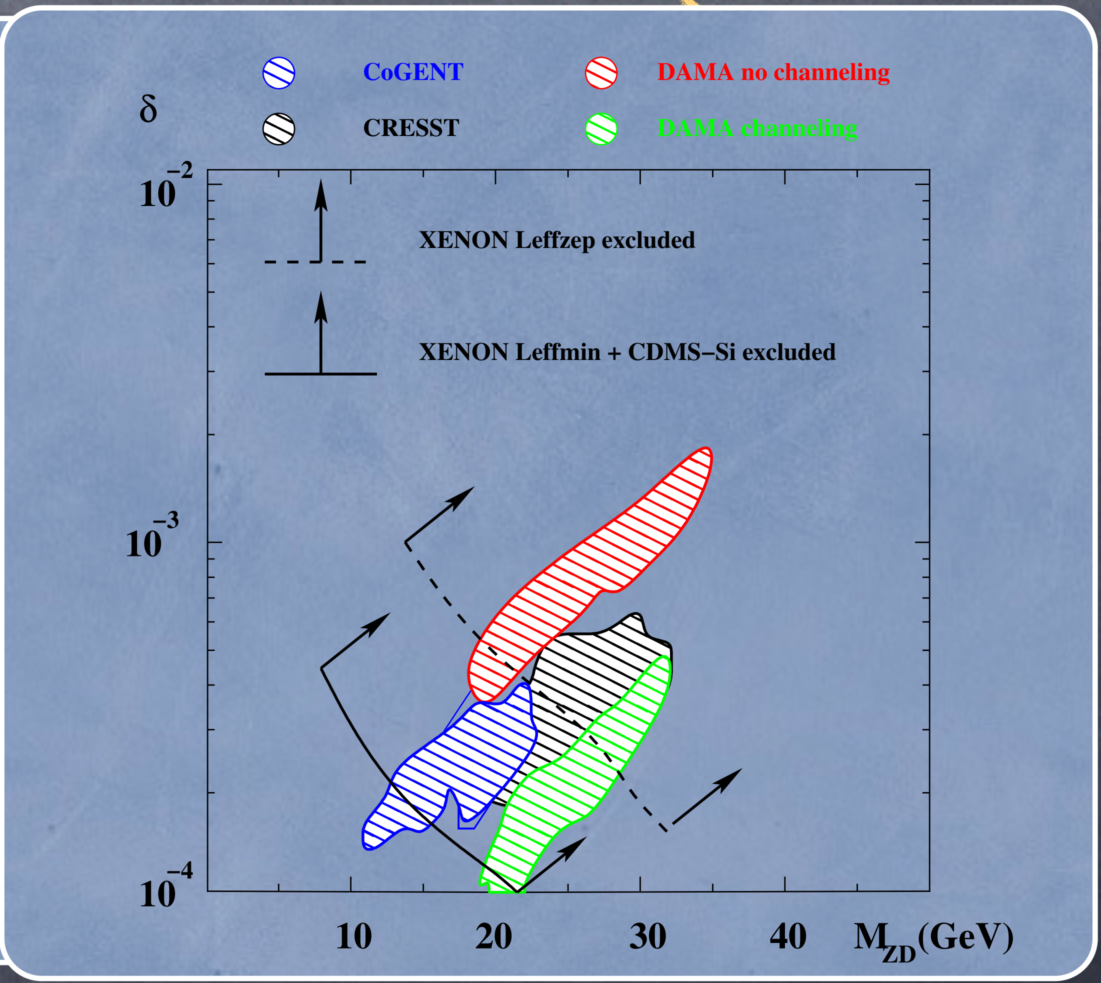

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Constraint from Higgs physics?

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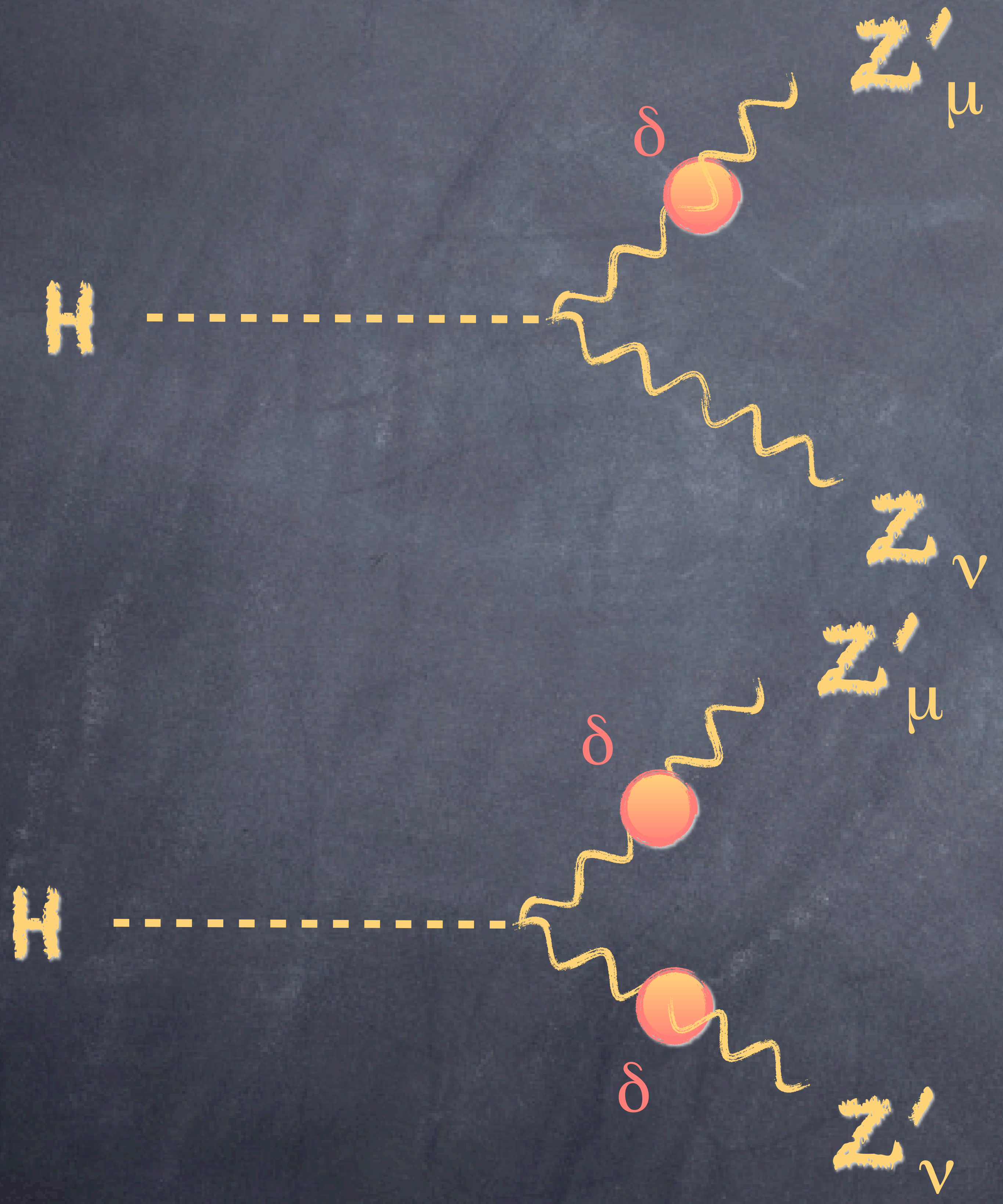

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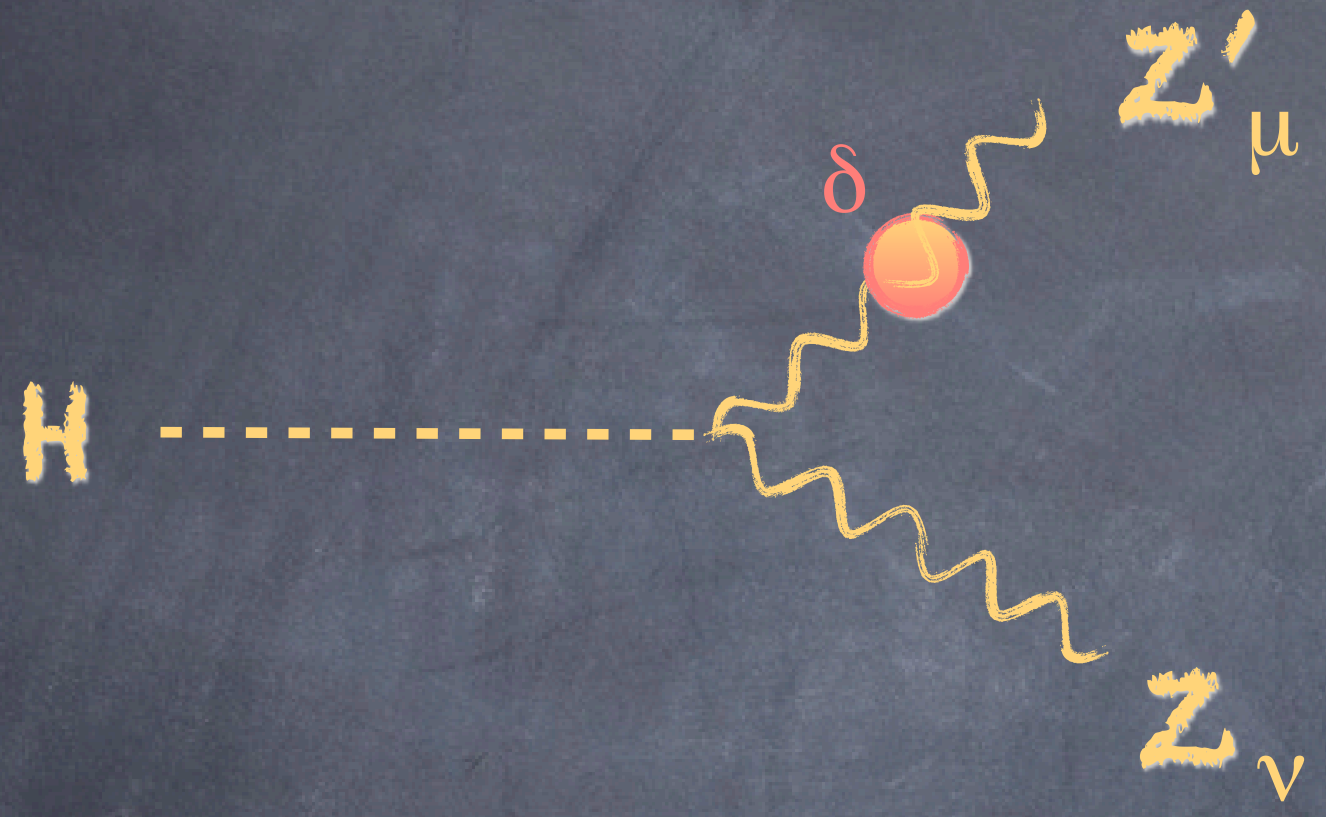
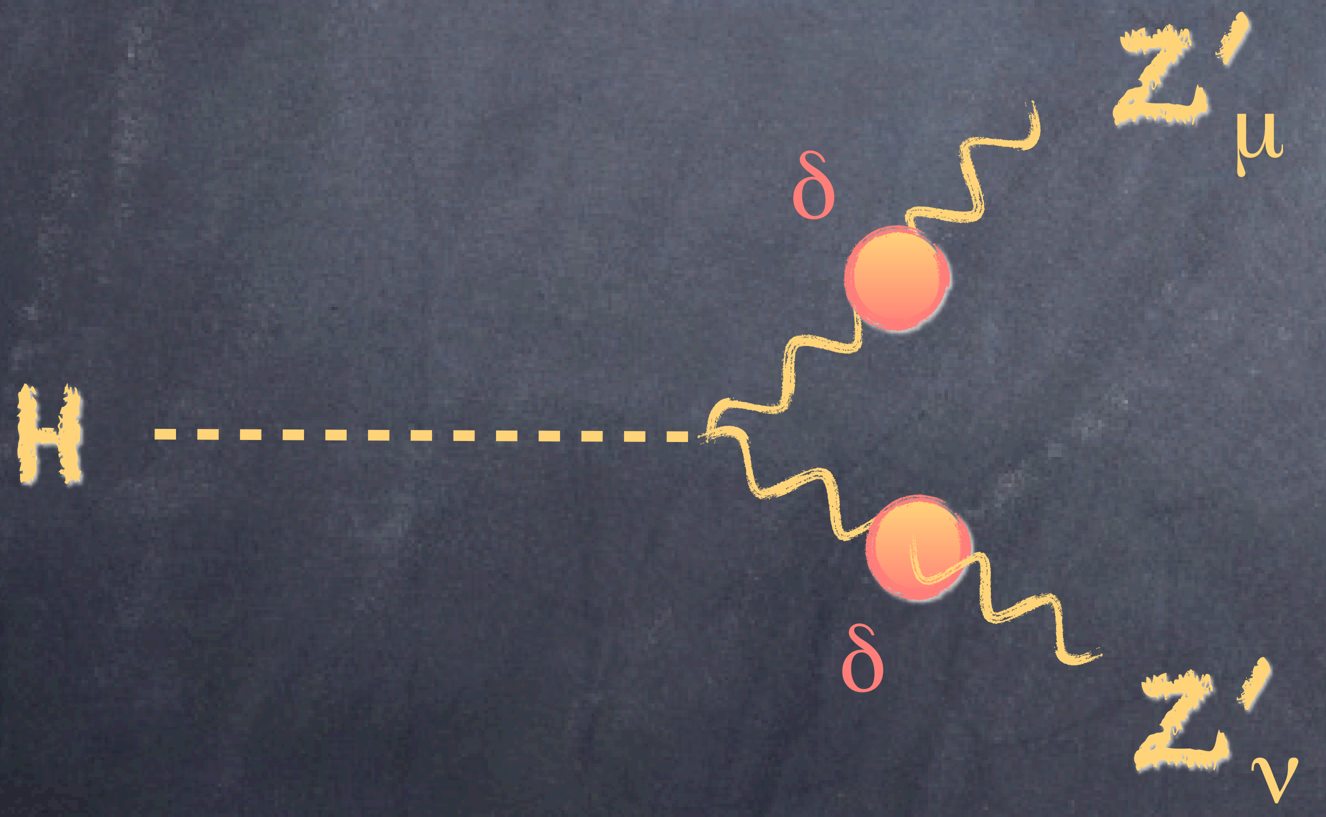


$\propto \delta^2$



$\propto \delta^4$

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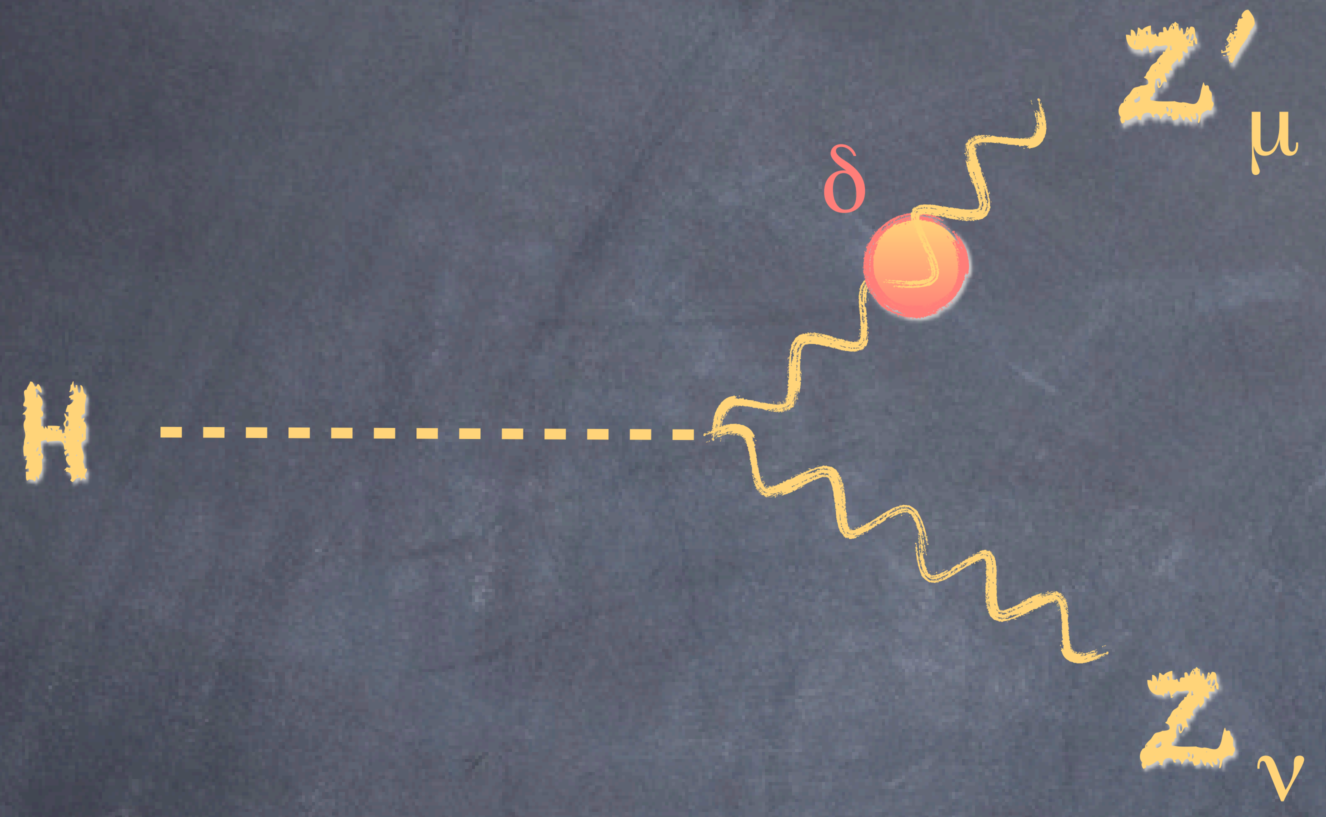

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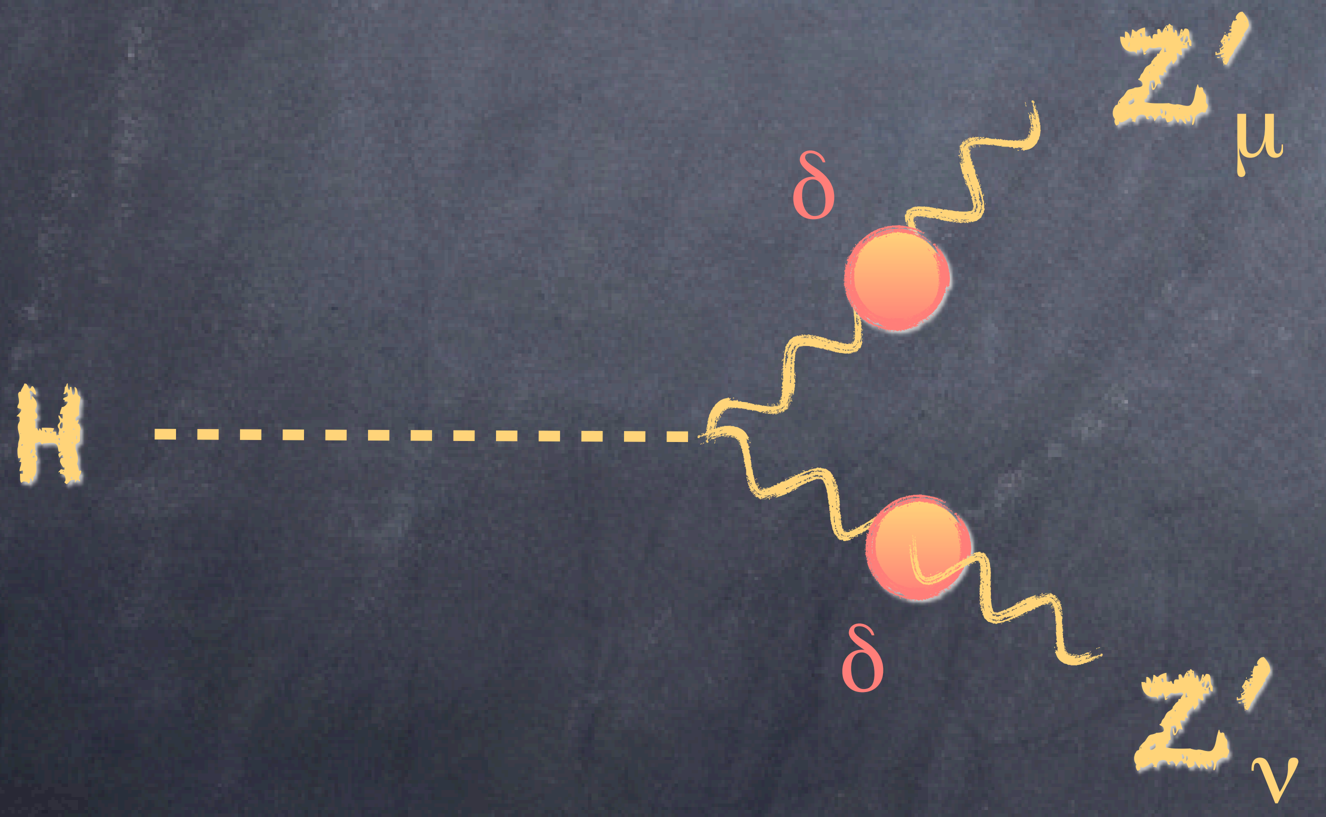

$\propto \delta^4$

$$M_{Z'} = 5 \text{ GeV}$$

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

$$m_h = 125 \text{ GeV}$$

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

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

Singlet Extension of the SM: Higgs portal

Y. Mambrini
2011

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2011

To build the simplest gauge invariant extension of the SM

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2011

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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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HHS -> <H> HS after SU(2)*U(1) breaking
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Solved by imposing a Z2 symmetry S-> -S

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No phenomenology (<S>=0)

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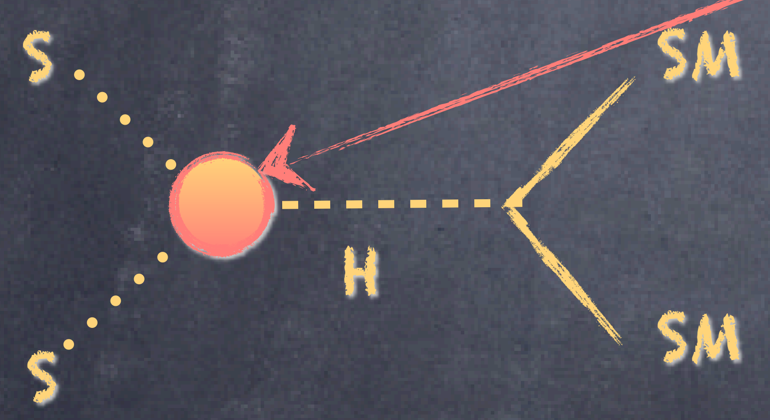

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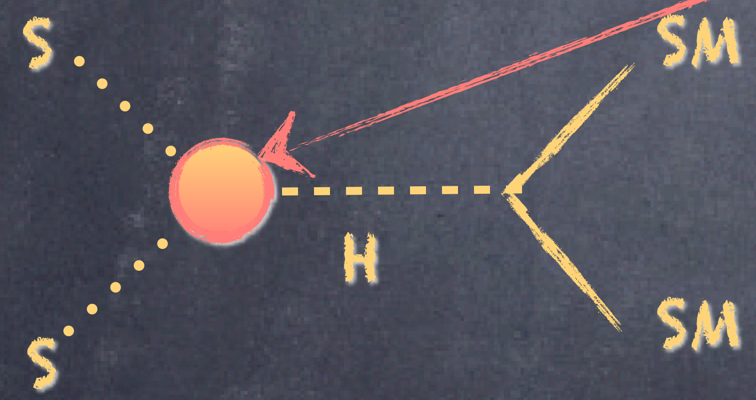

$$\langle \sigma_{f\bar{f}} v \rangle = \frac{\lambda_{HS}^2 (m_S^2 - m_f^2)^{3/2} m_f^2}{16\pi m_S^3 [(4m_s^2 - M_H^2)^2 + M_H^2 \Gamma_H^2]}$$

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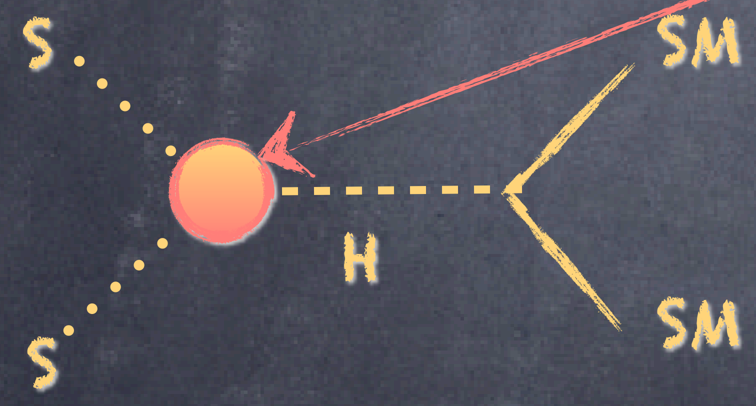

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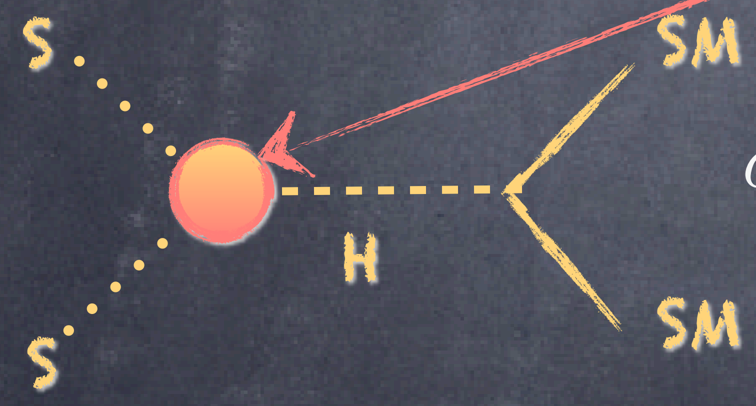
Singlet Extension of the SM: Higgs portal

Y. Mambrini
2011

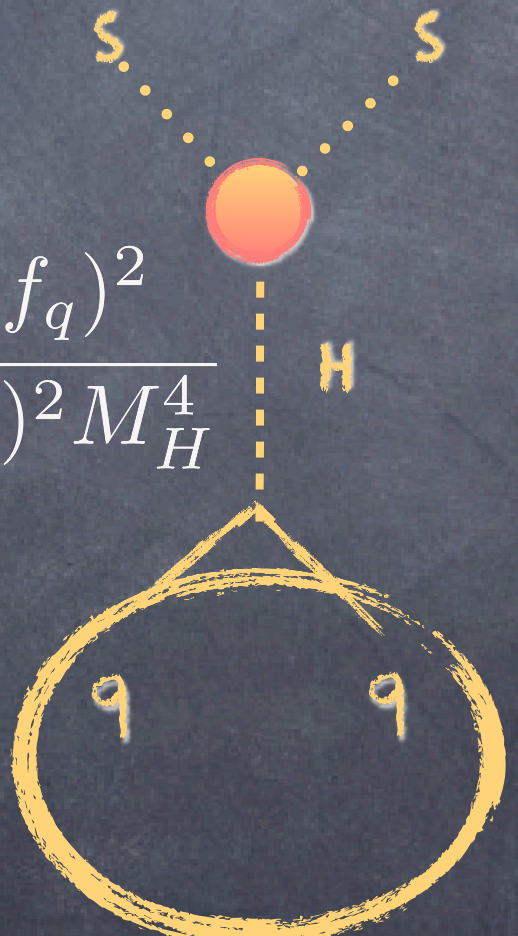
To build the simplest gauge invariant extension of the SM

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

No phenomenology (<S>=0)



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



$$\langle \sigma_{f\bar{f}} v \rangle = \frac{\lambda_{HS}^2 (m_S^2 - m_f^2)^{3/2} m_f^2}{16\pi m_S^3 [(4m_s^2 - M_H^2)^2 + M_H^2 \Gamma_H^2]}$$

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.

Solved by imposing a Z2 symmetry S-> -S

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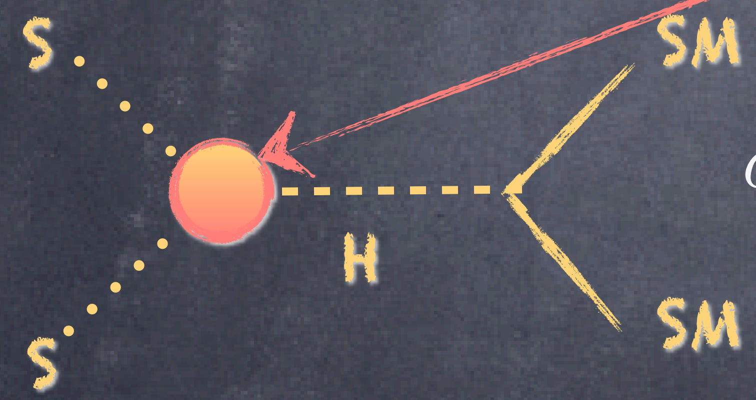

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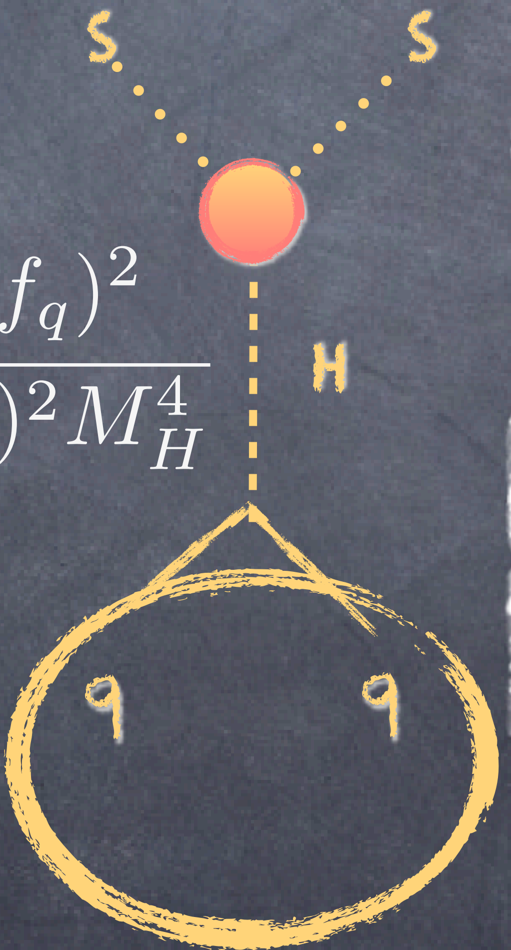

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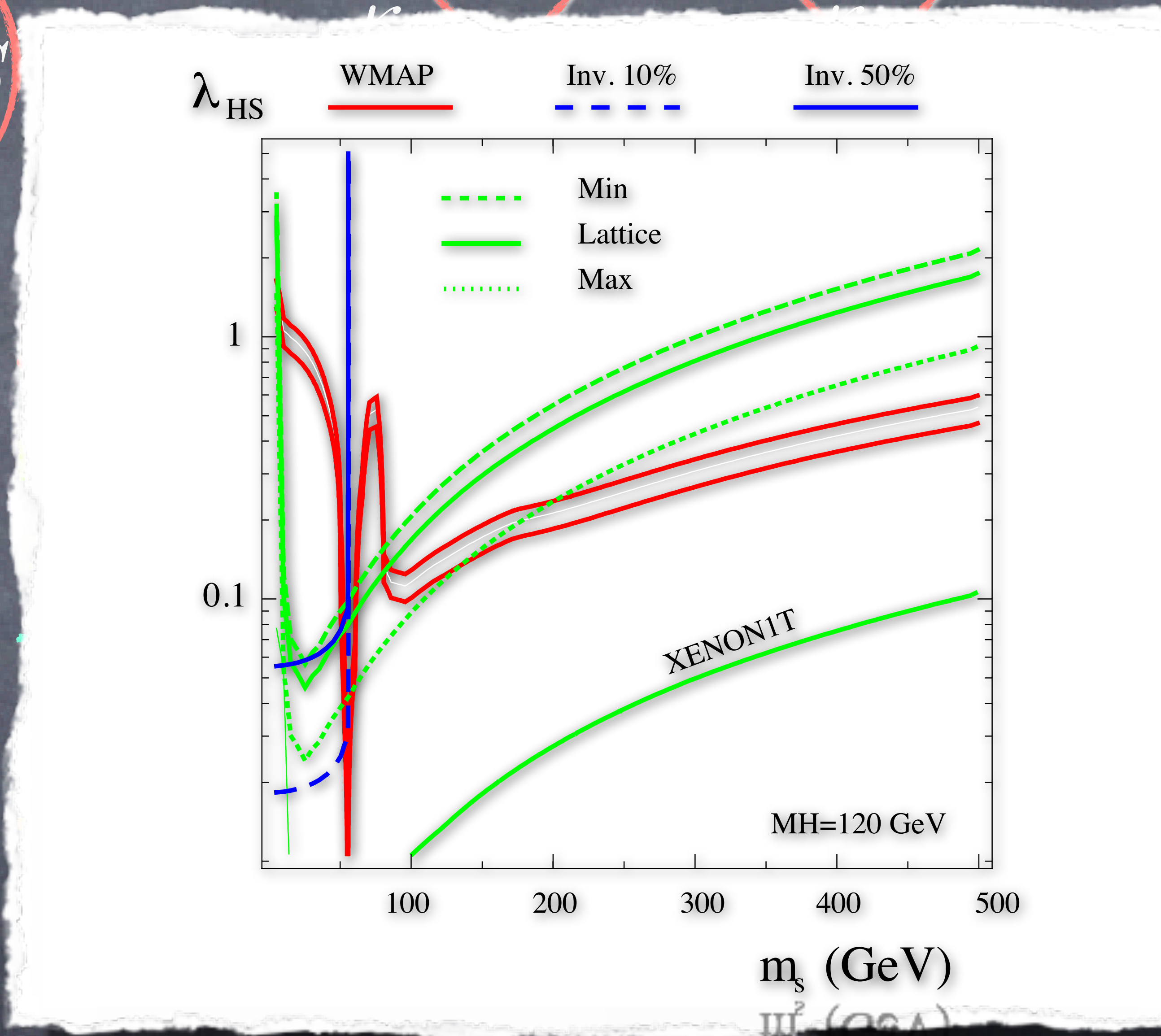

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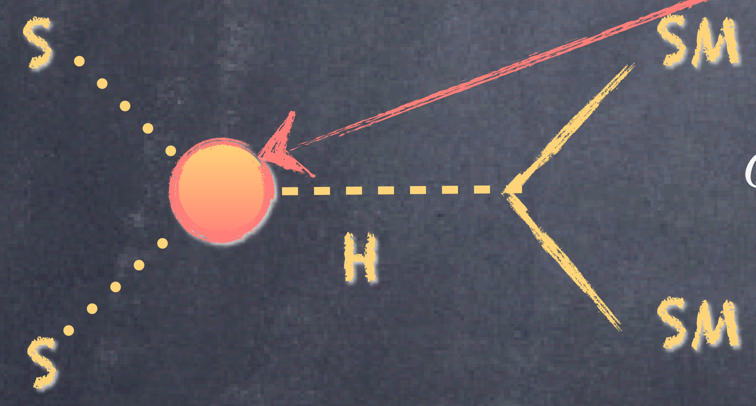

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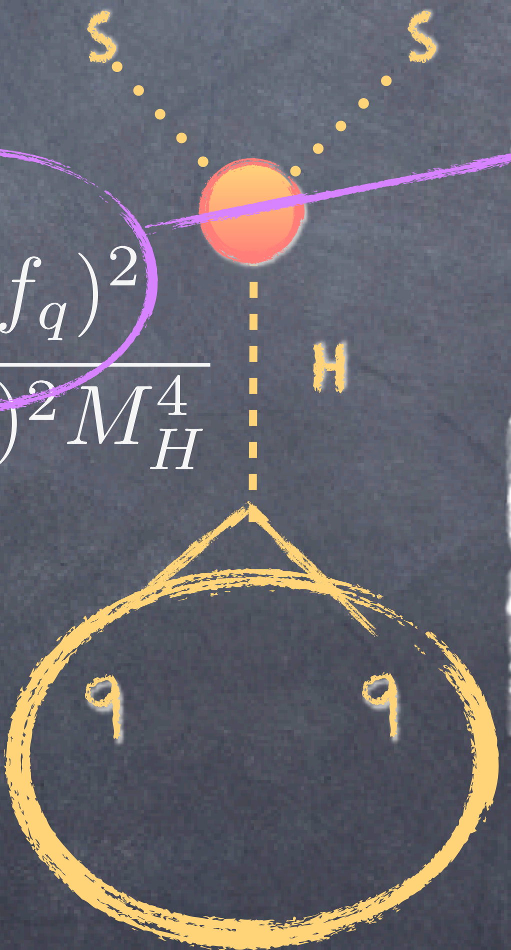

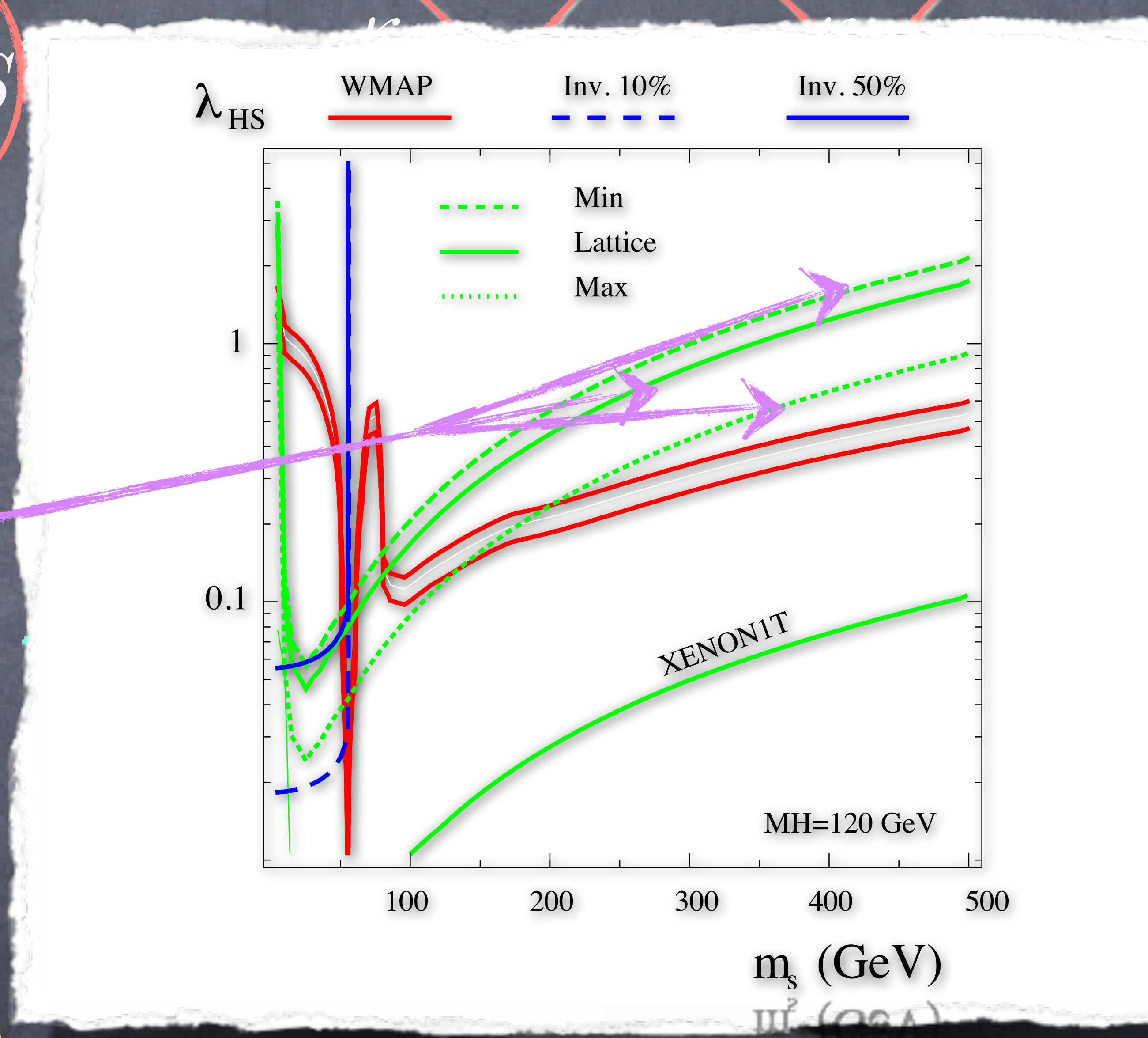

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Invisible width of the Higgs

Y. Mambrini
1108.0671

Invisible width of the Higgs

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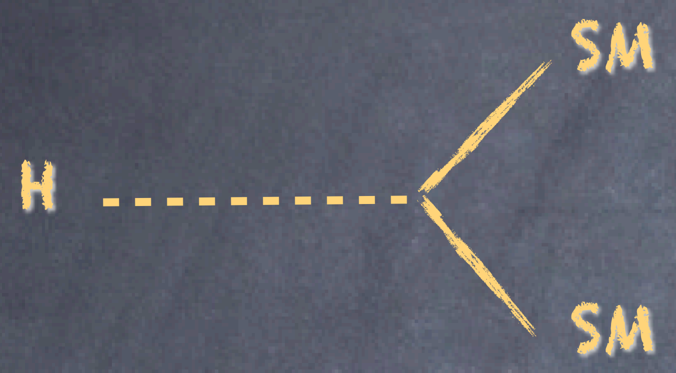
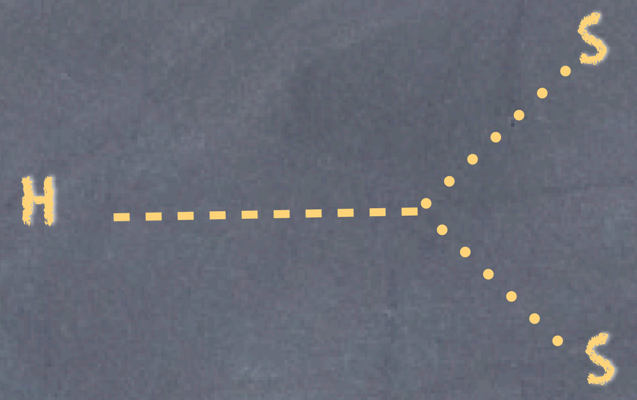


Visible decay



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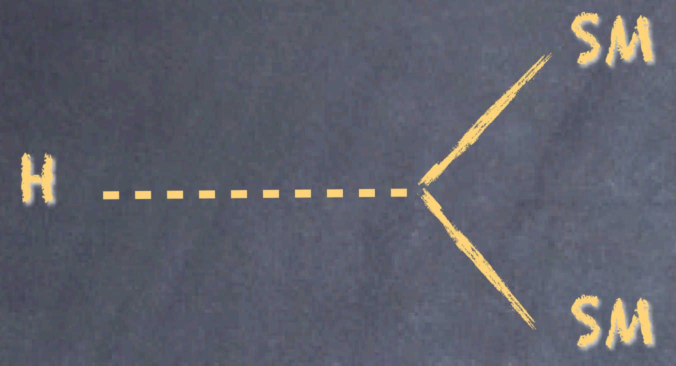

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Invisible decay

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

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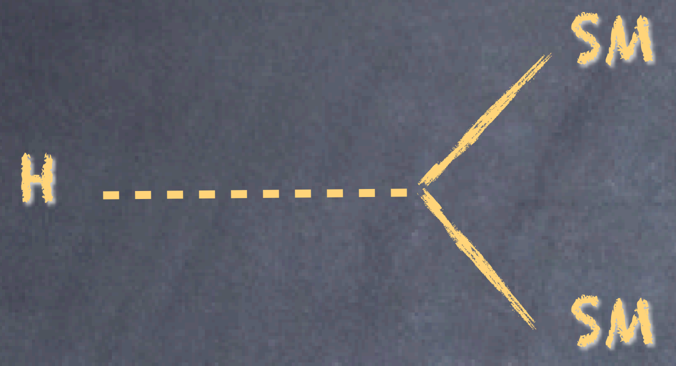

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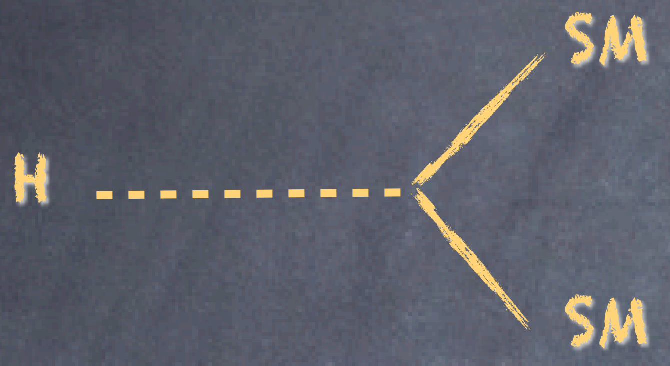

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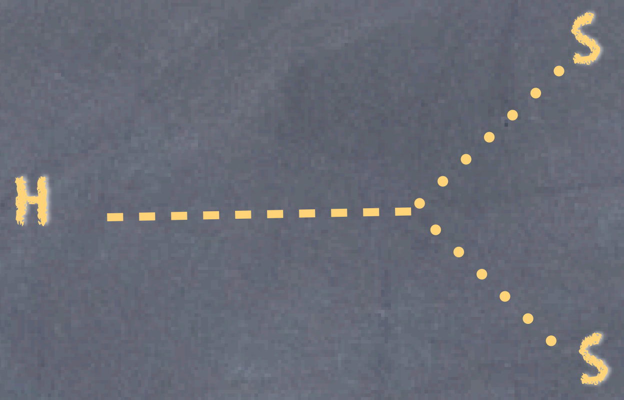

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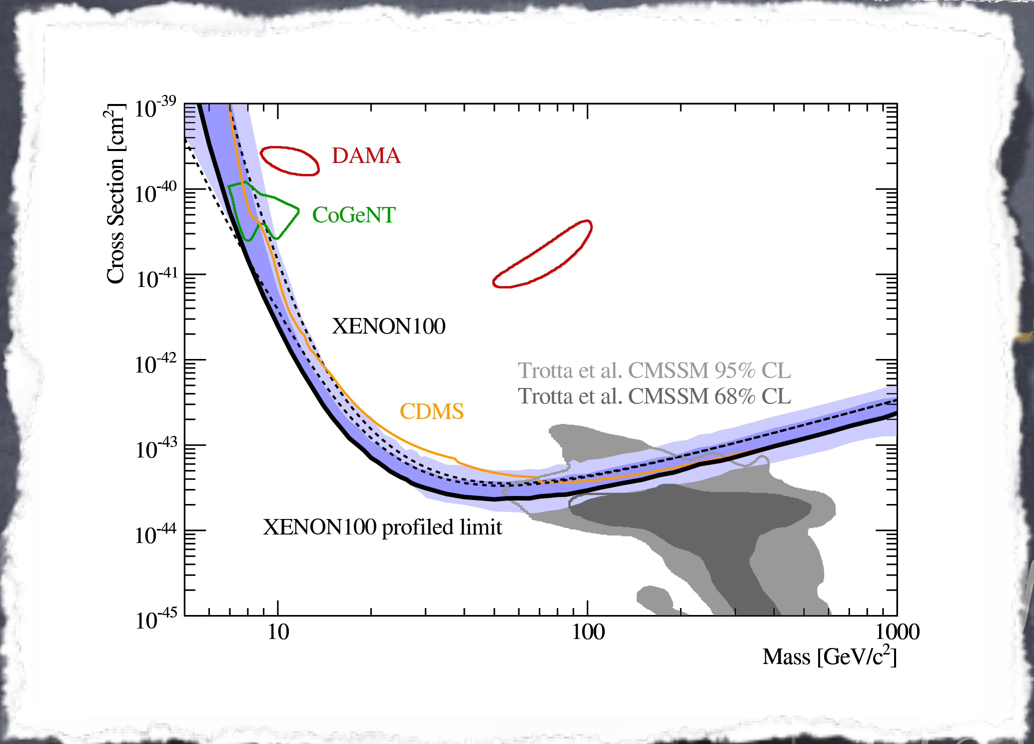

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$$\ldots f_q)^2 \ldots {}^2 M_H^4$$

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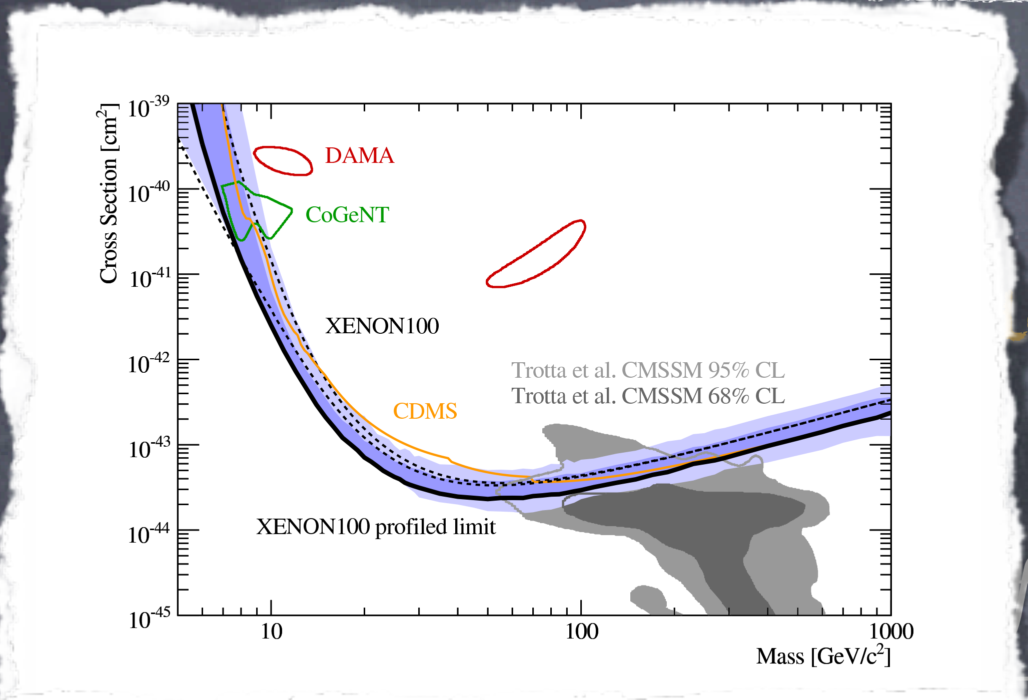

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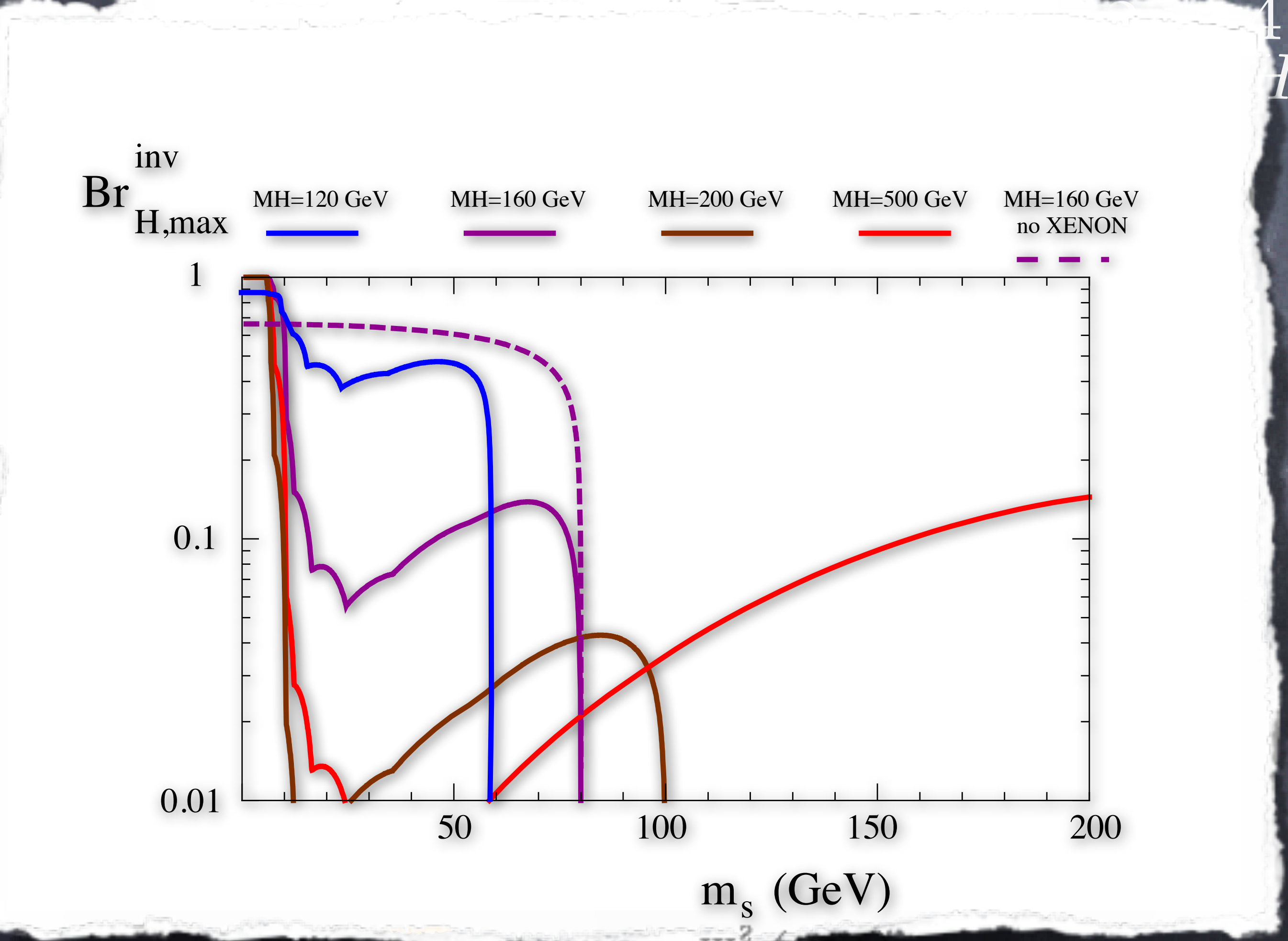

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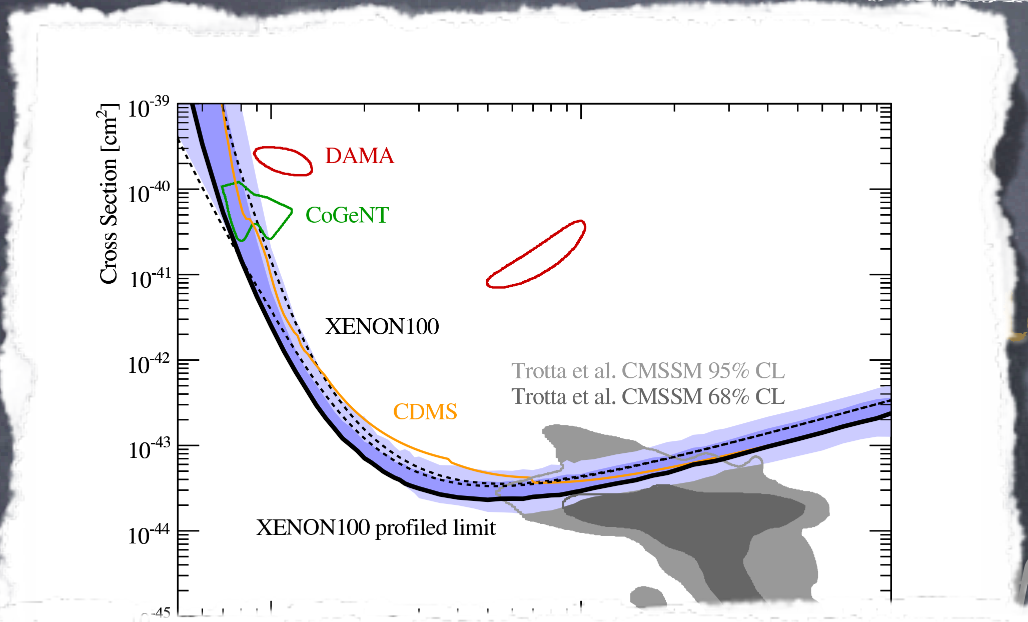

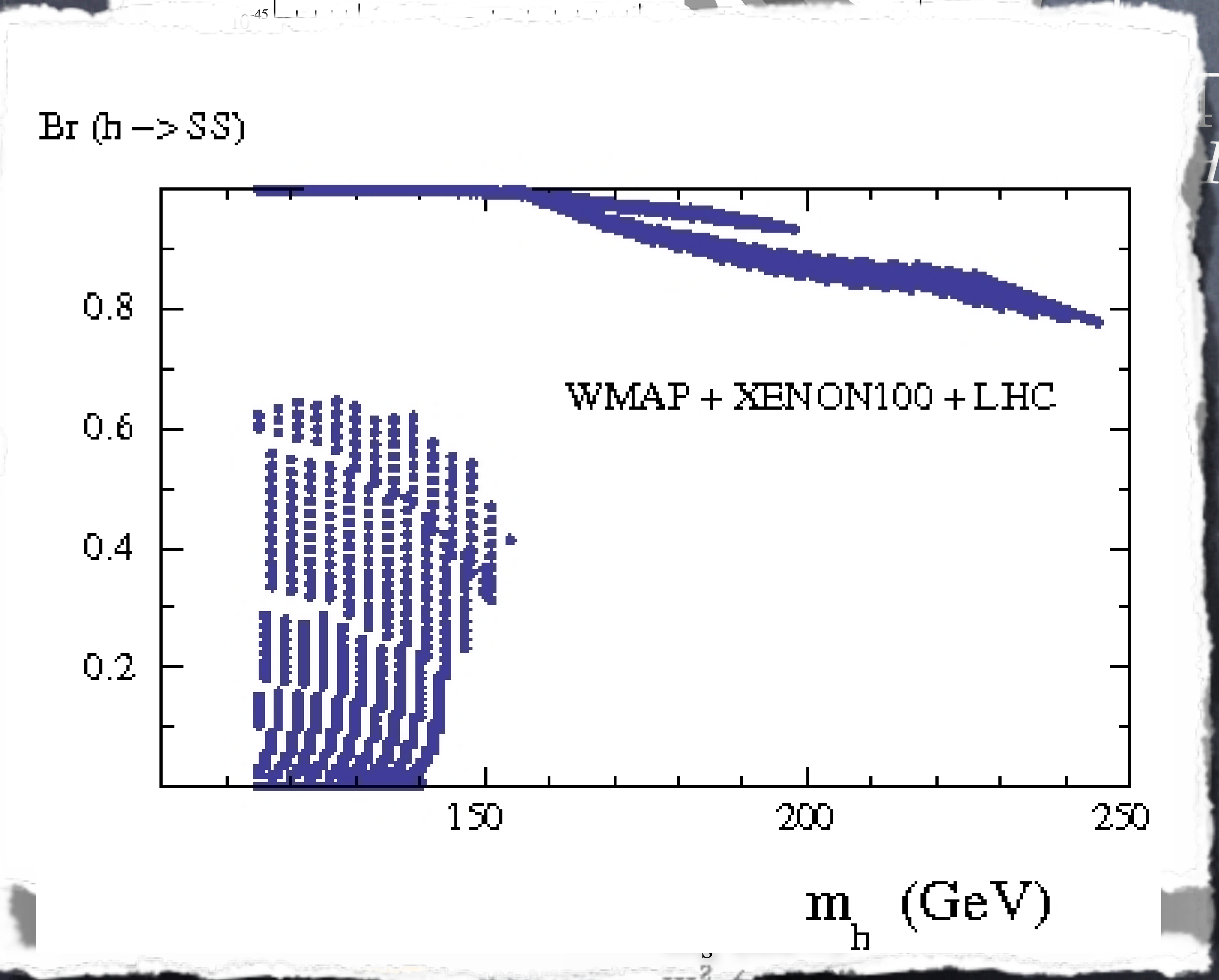

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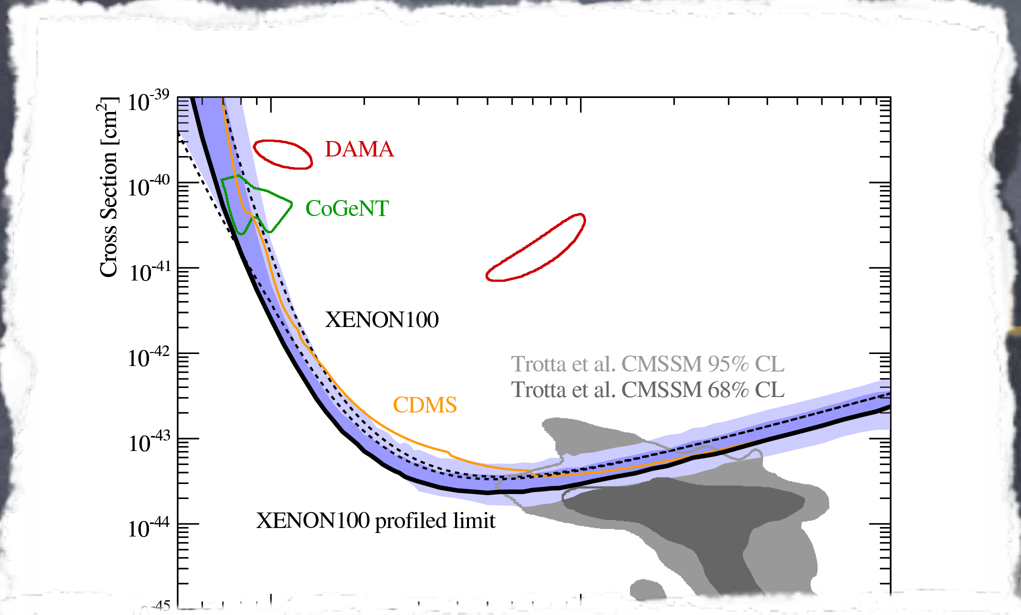
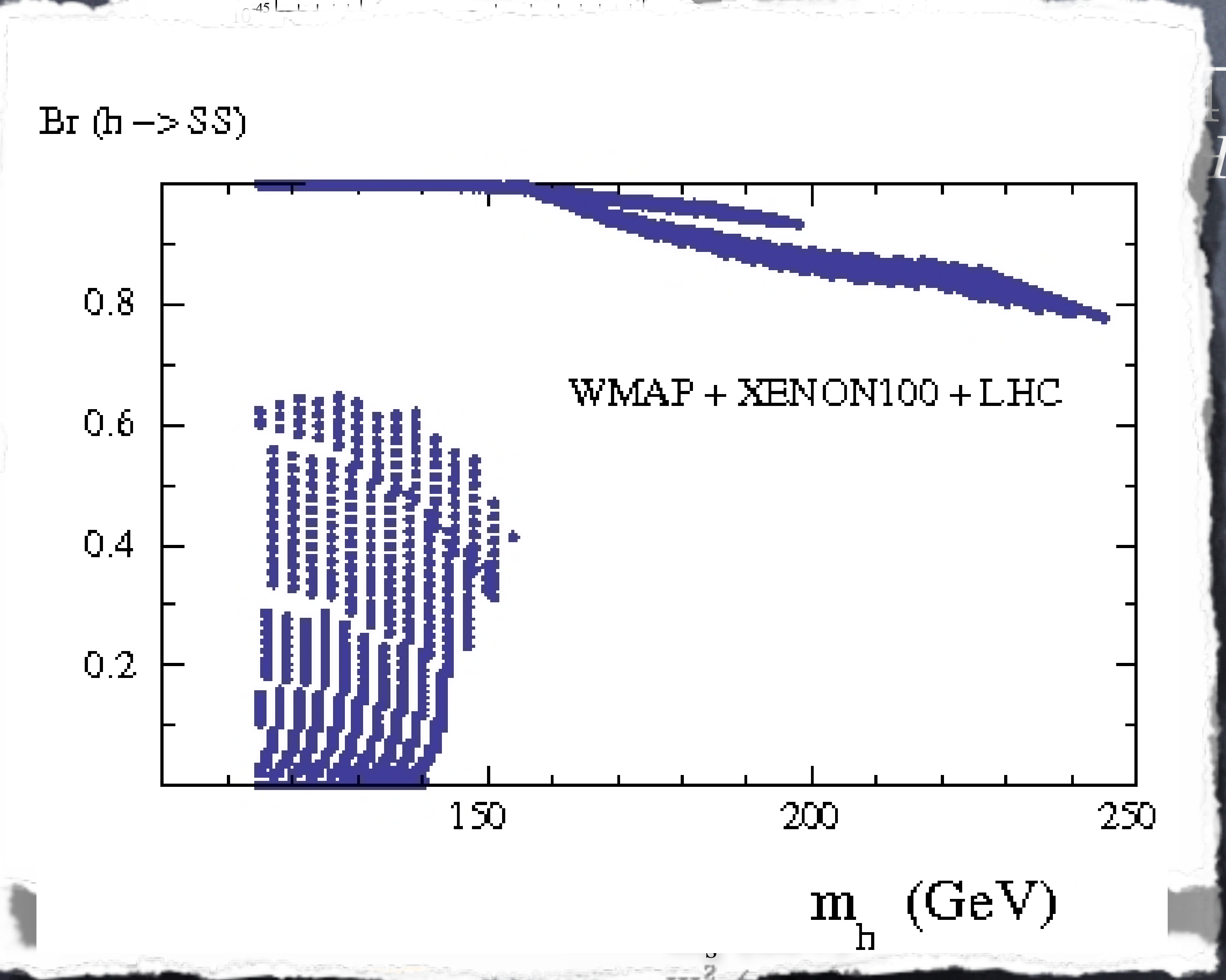


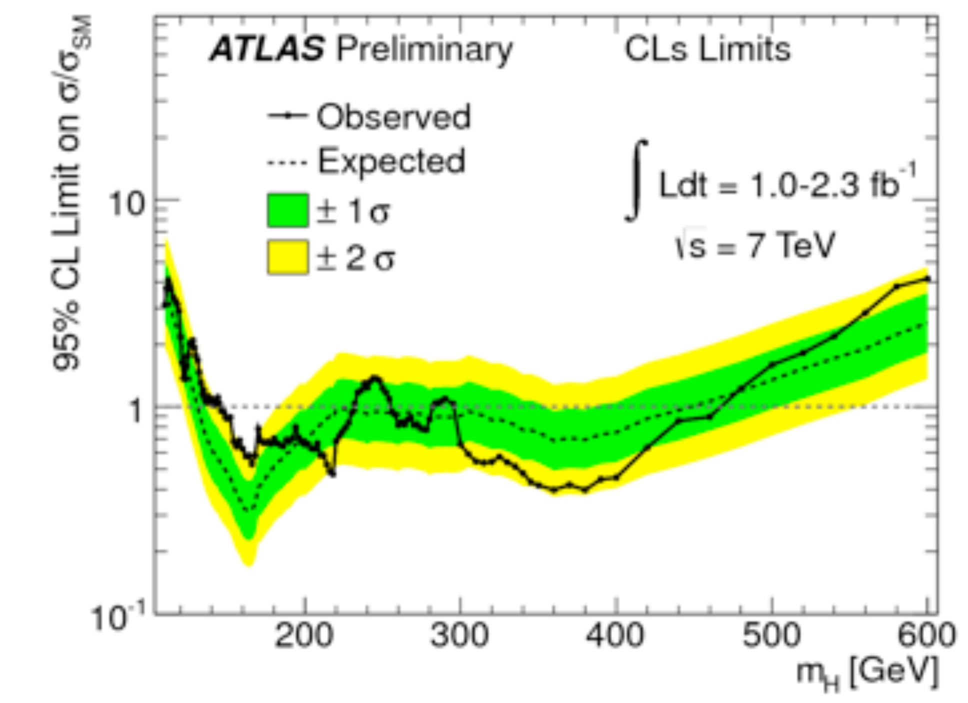
...e decay

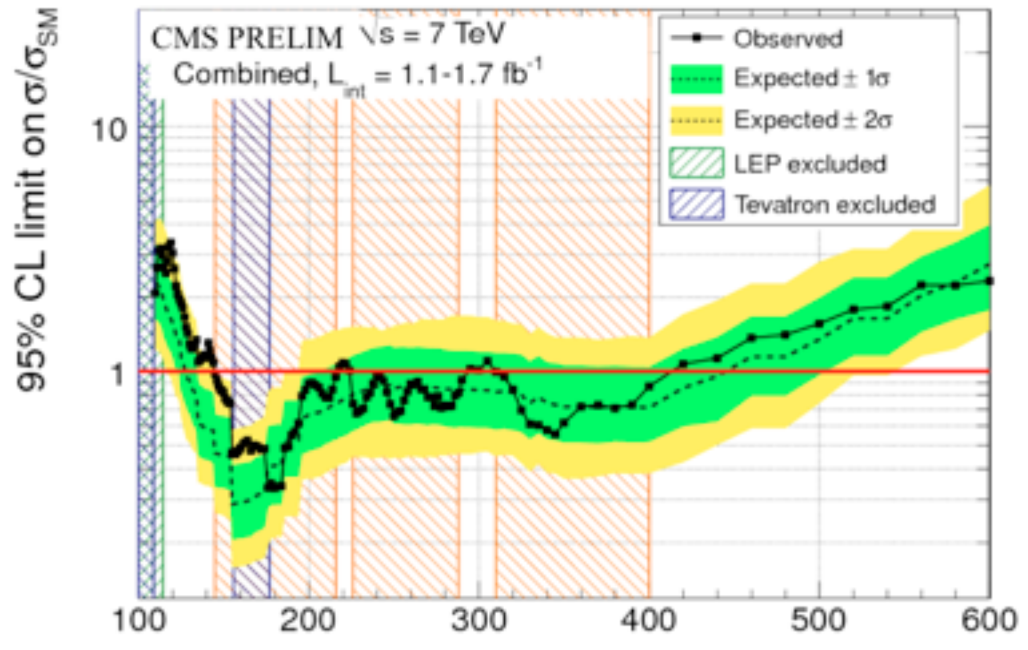
H ---

$\Gamma_H(H$

$\frac{\Gamma_H^{Inv}}{\sigma^{SI}_{S-p}} =$







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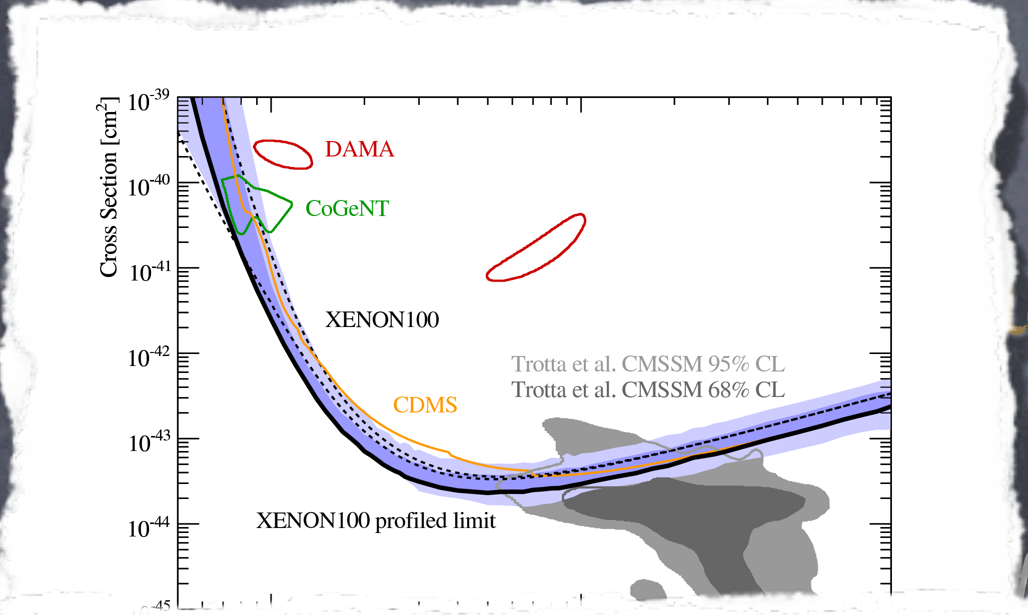

...e decay H ---

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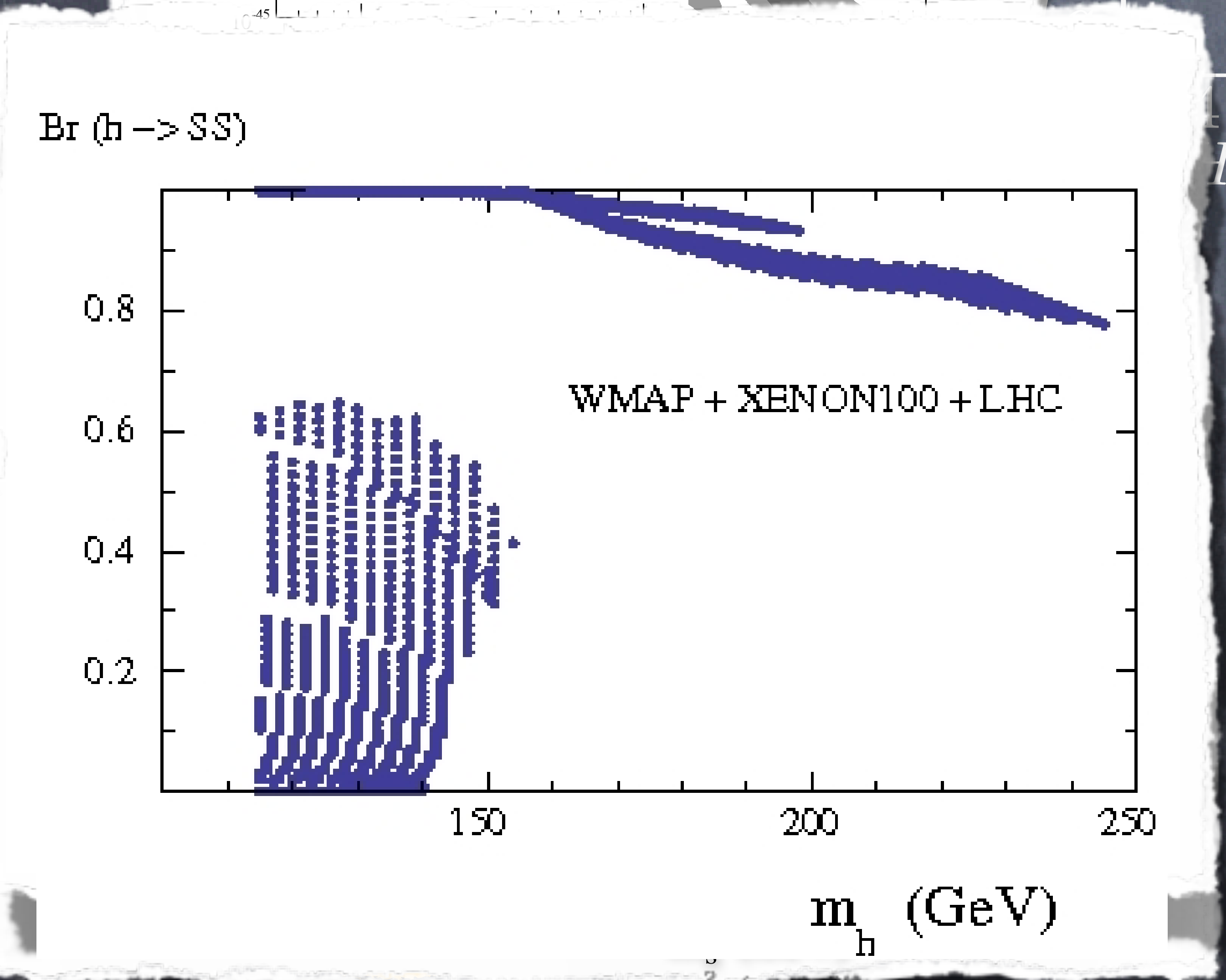

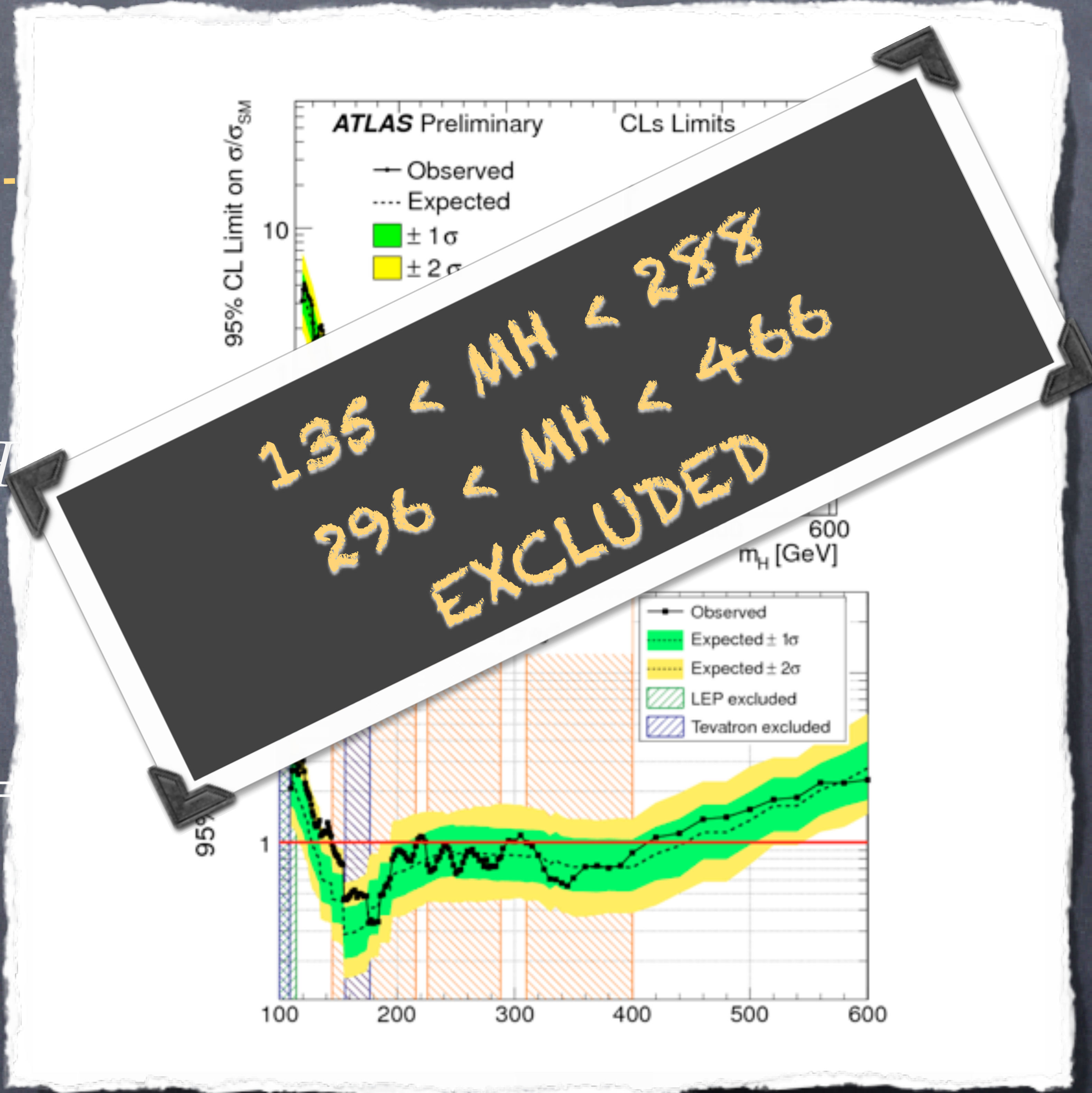

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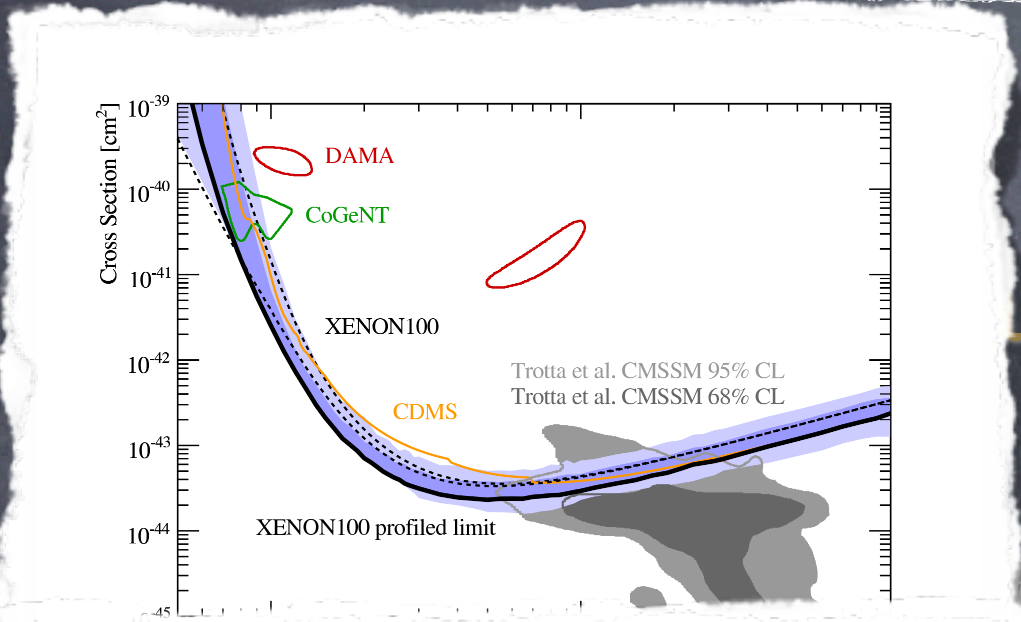

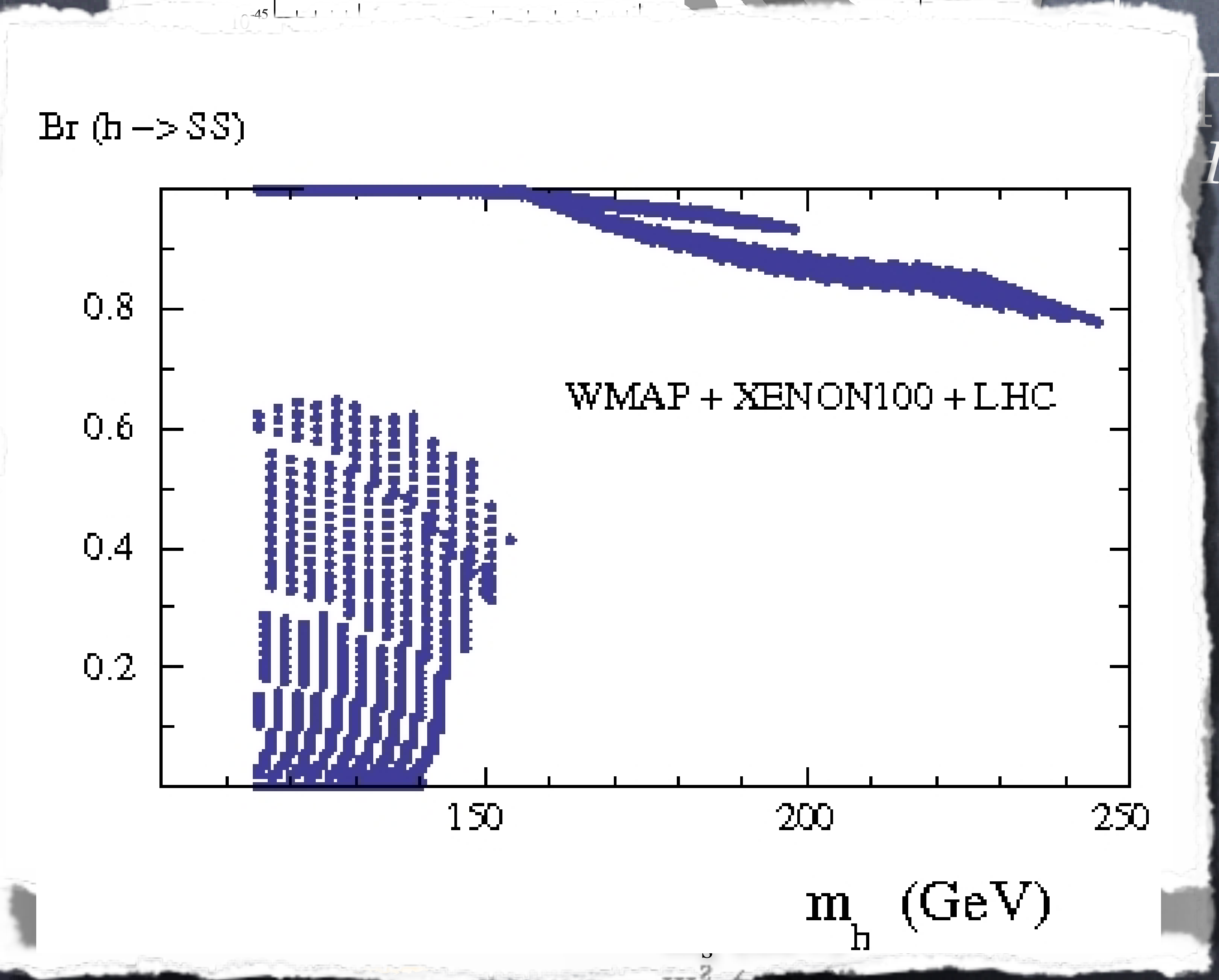

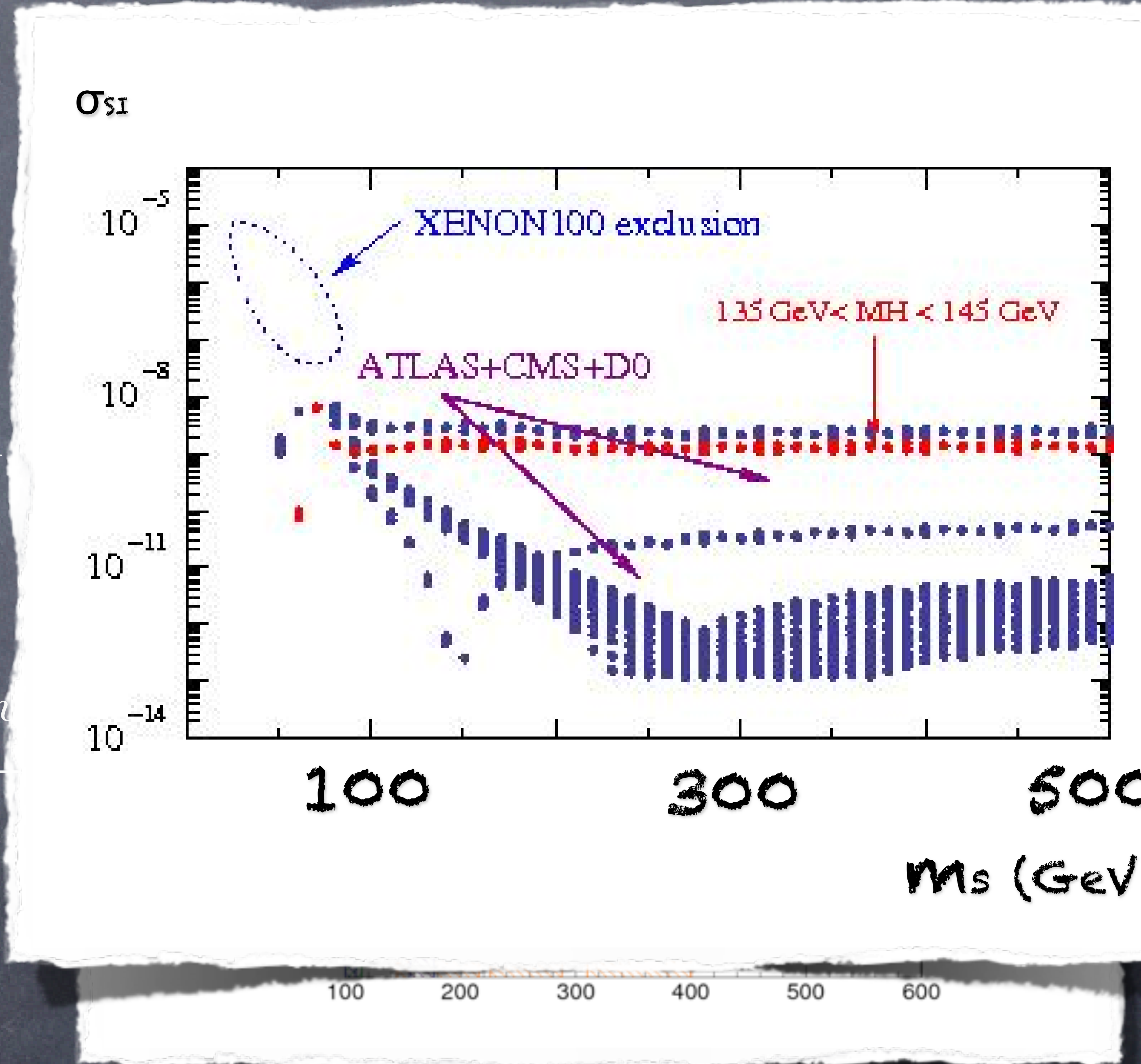

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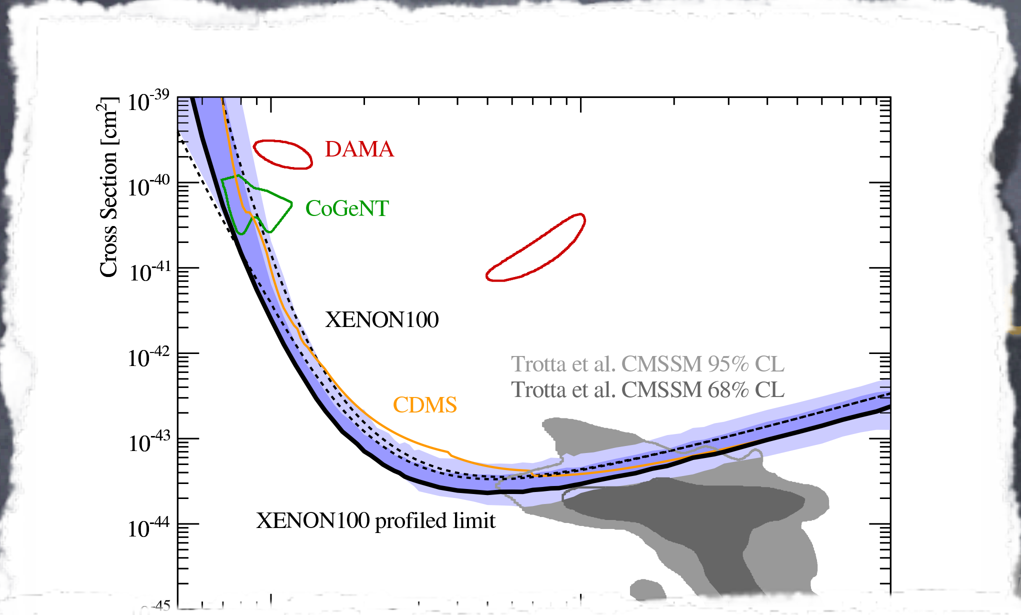

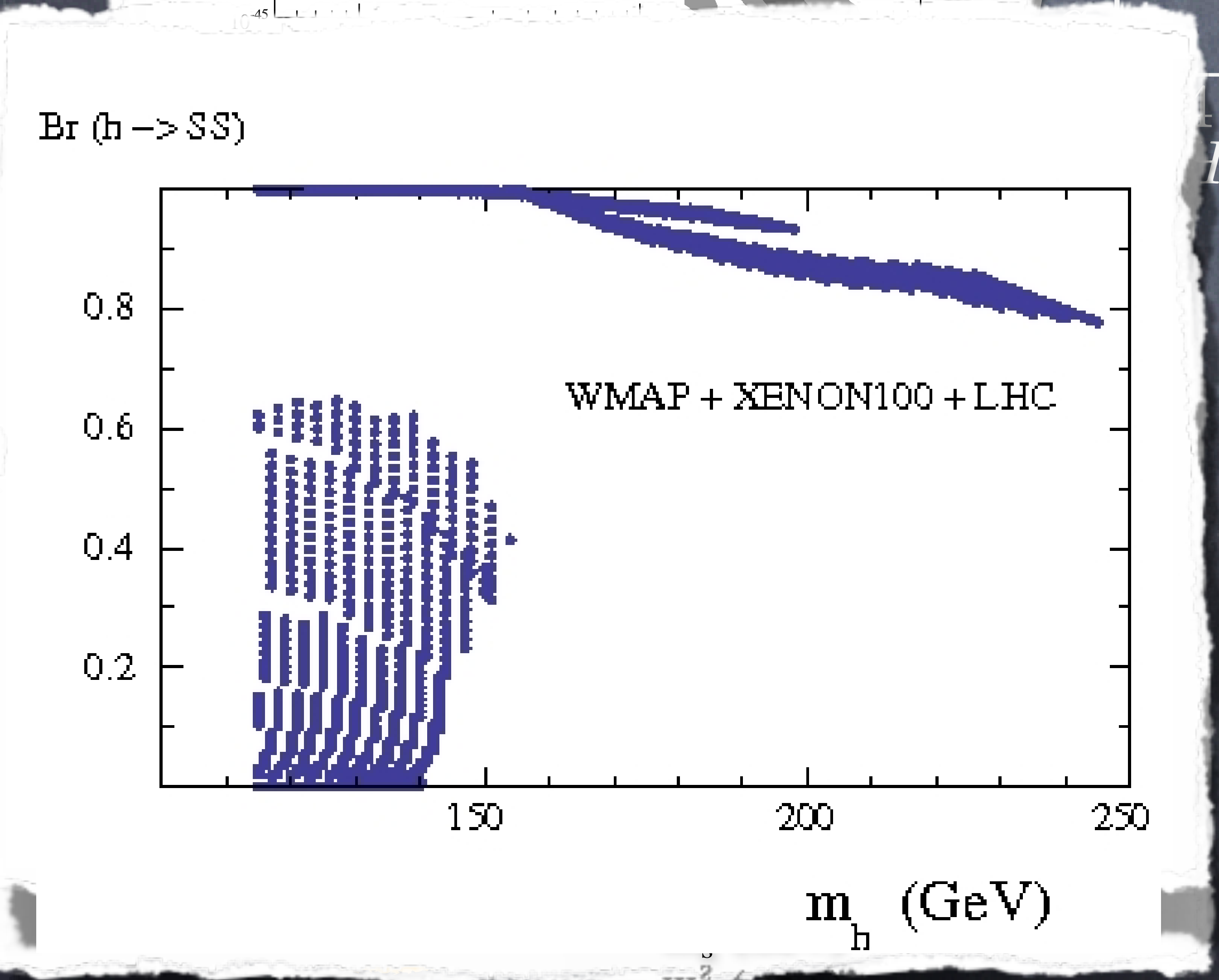

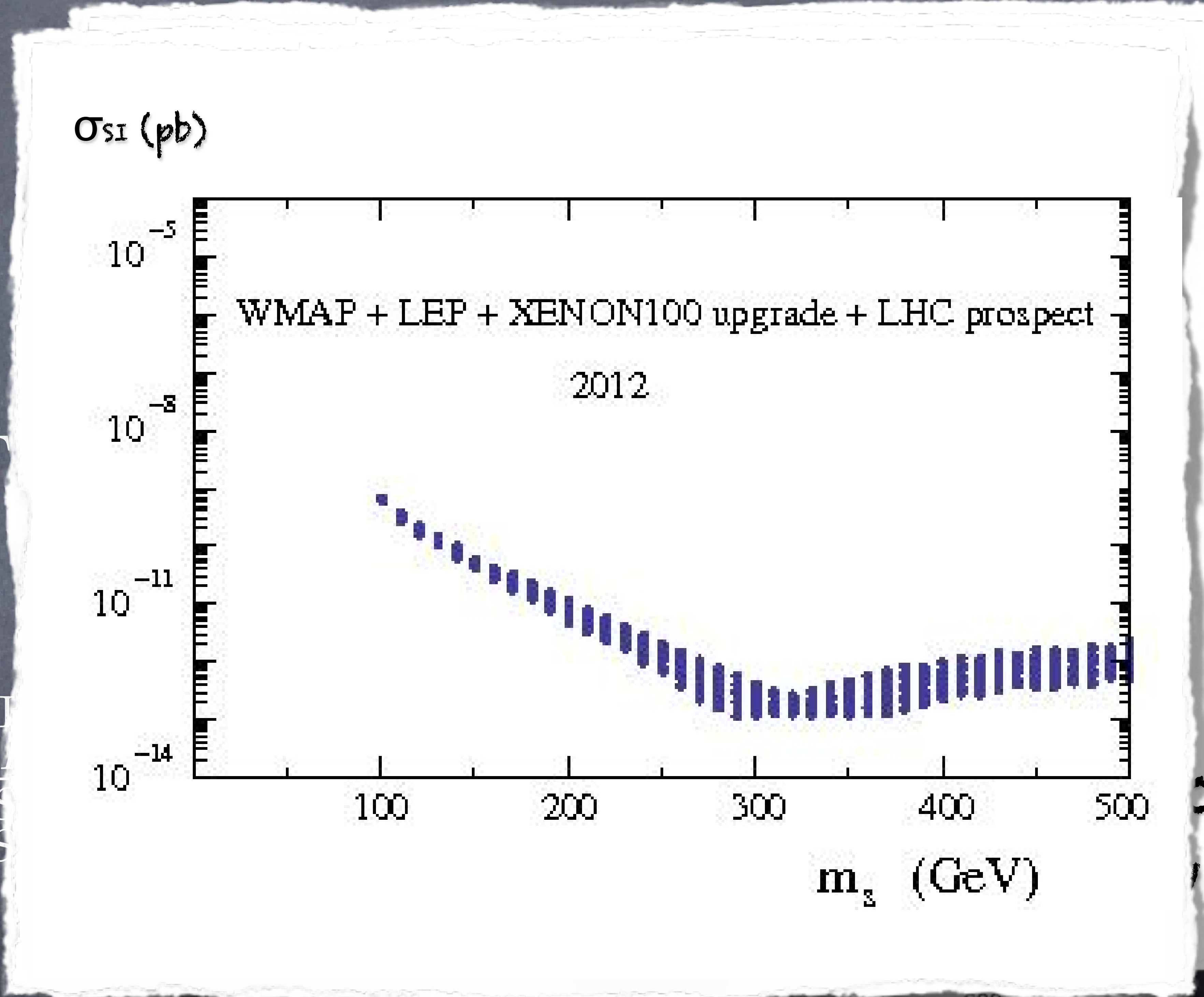

Vectorial Dark Matter?

O. Lebedev,
H.M. Lee,
Y. Mambrini
1111.4482

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Vectorial Dark Matter?

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{\lambda_{hV}}{4} H^\dagger H V^\mu V_\mu + \frac{\lambda}{4}(V^\mu V_\mu)^2 + \frac{1}{2} m^2 V^\mu V_\mu$$

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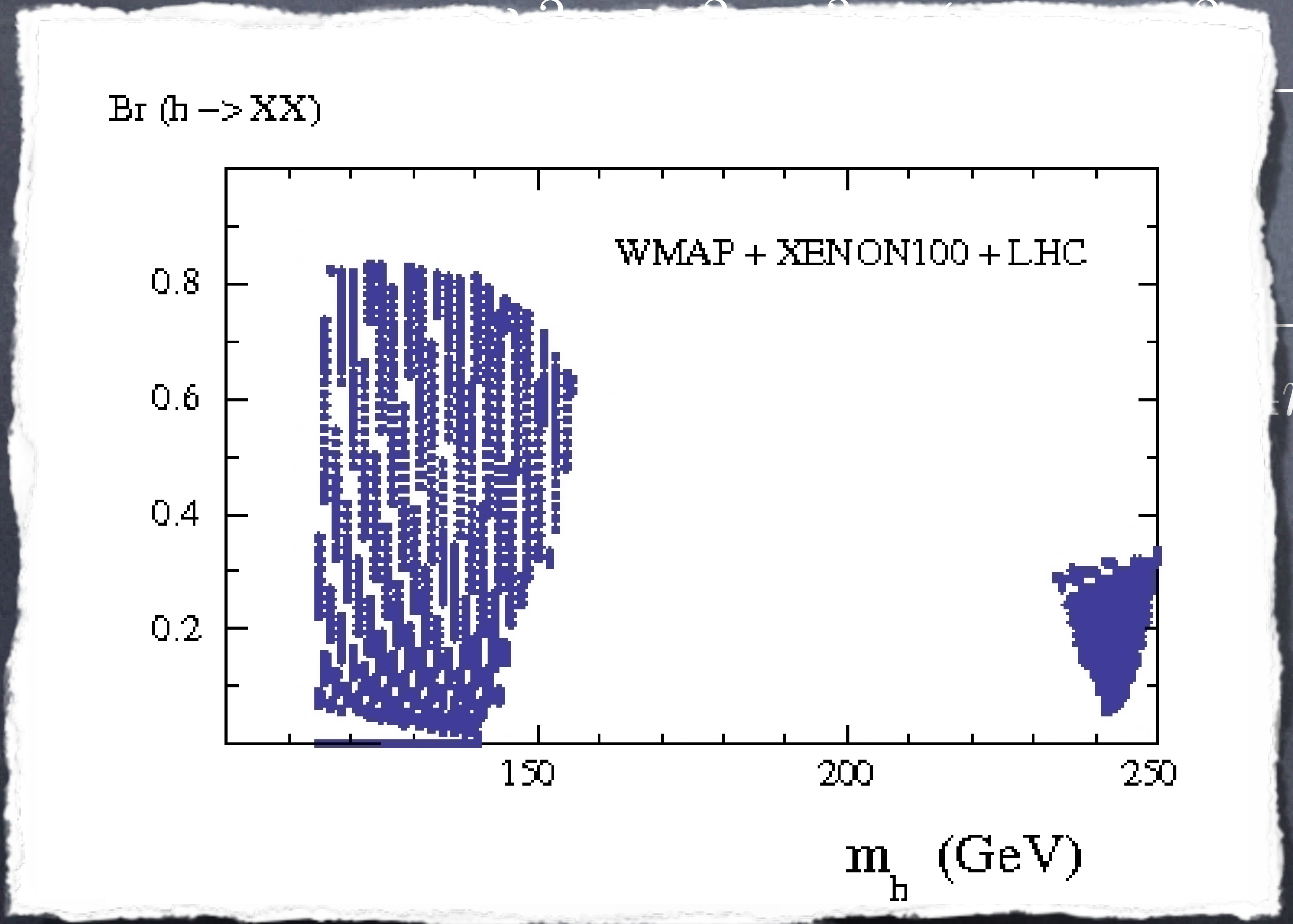
$$\ldots + 12\frac{m_V^4}{m_H^4}\Bigg)\sqrt{1-4\frac{m_V^2}{m_H^2}}$$

$$\ldots m_S^2$$



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J. Quevillon
1112.3299

A 125 GeV Higgs?

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Idea : to combine ATLAS/CMS Higgs analysis in a model independant approach

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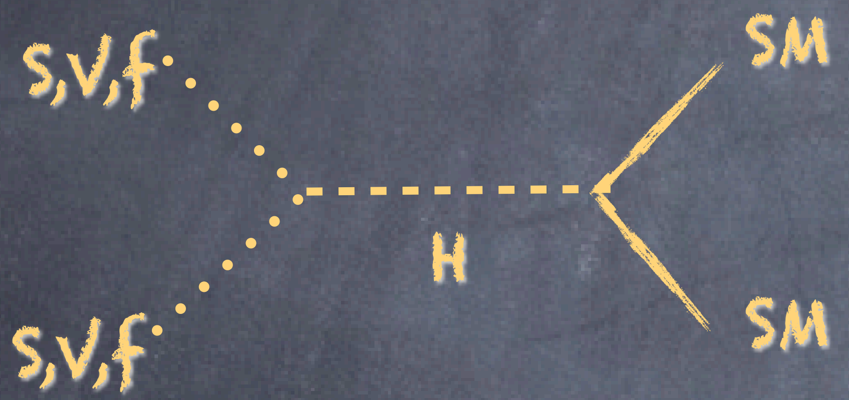

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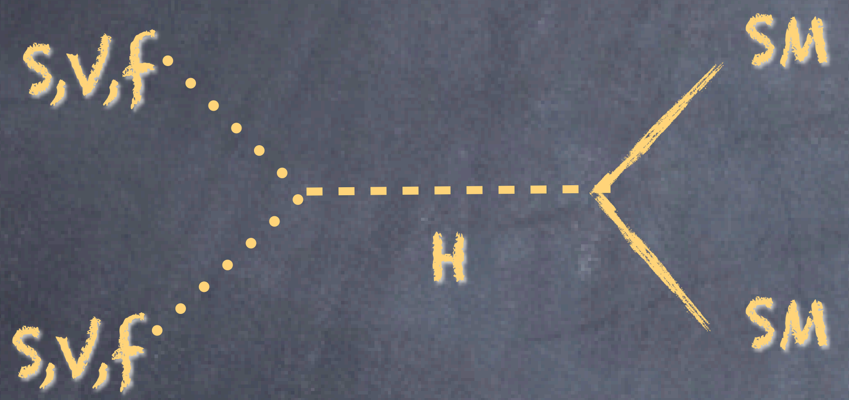

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$$\mathcal{L}_f = \mathcal{L}_{SM} - \frac{1}{2} m_f \bar{\chi}\chi - \frac{1}{4} \frac{\lambda_{hff}}{\Lambda} H^\dagger H \bar{\chi}\chi$$

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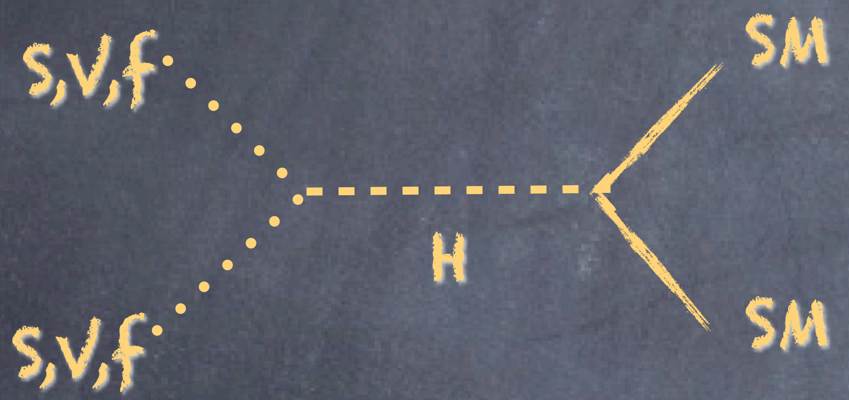

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$$\mathcal{L}_f = \mathcal{L}_{SM} - \frac{1}{2}m_f \bar{\chi}\chi - \frac{1}{4}\frac{\lambda_{hff}}{\Lambda} H^\dagger H \bar{\chi}\chi$$

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

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

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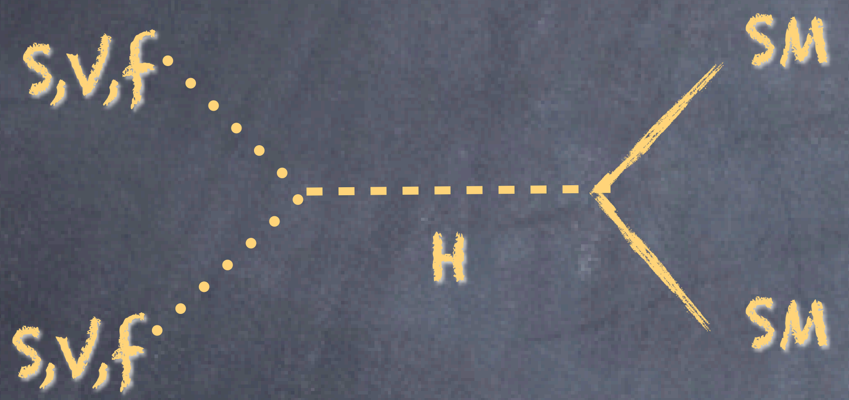

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$$\mathcal{L}_V = \mathcal{L}_{SM} + \frac{1}{2} m_V^2 V_\mu V^\mu + \frac{1}{4}\lambda_V (V_\mu V^\mu)^2 + \frac{1}{4}\lambda_{hVV} H^\dagger H V_\mu V^\mu$$

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

If mh is fixed (125 GeV) for a given DM mass, λhii is determined by WMAP.

QS: is it compatible with direct detection constraints

(λhii < λhiiMAX)

and a visible Higgs (Γinv < 10%),

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

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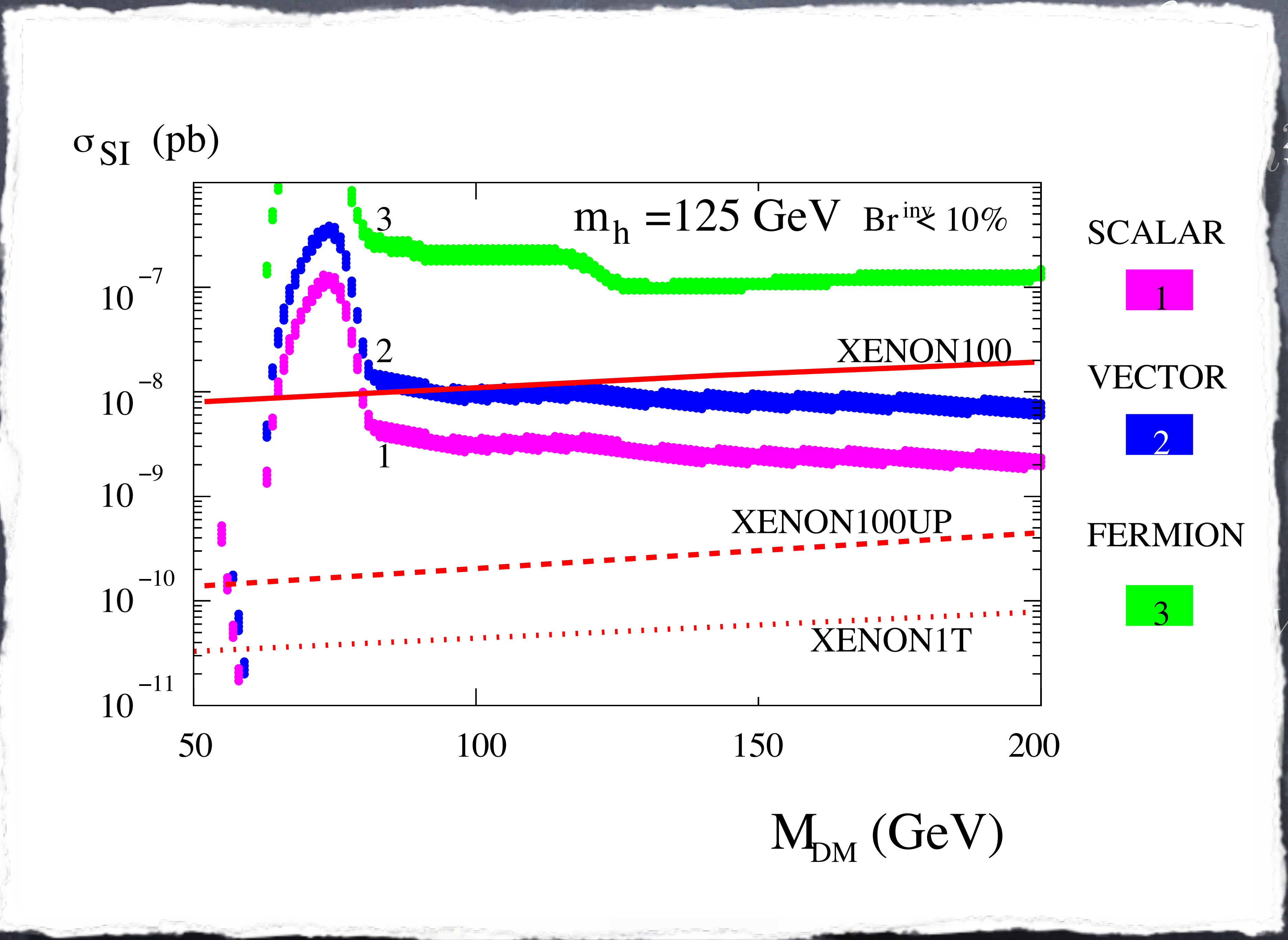
A 125 GeV Higgs?

Idea : to combine ATLAS/CMS Higgs analysis in a model independant approach



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

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

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

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

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

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

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- Several models could be excluded by the end of next year
- Complementarity with LHC is fundamental in any analysis
- Can be applied to any kind of SM extensions (SUSY, KK..)