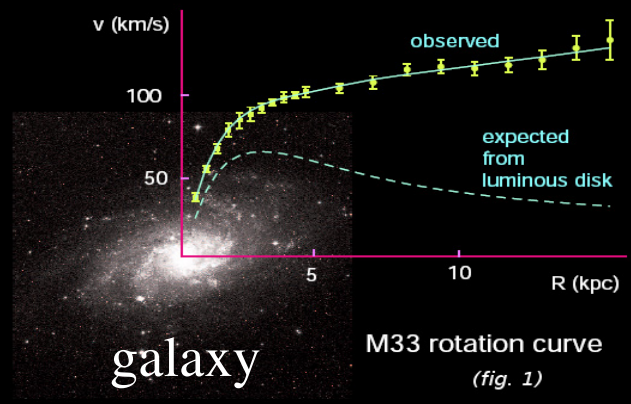
Fermionic dark matter via Higgs portal

Laura Lopez Honorez

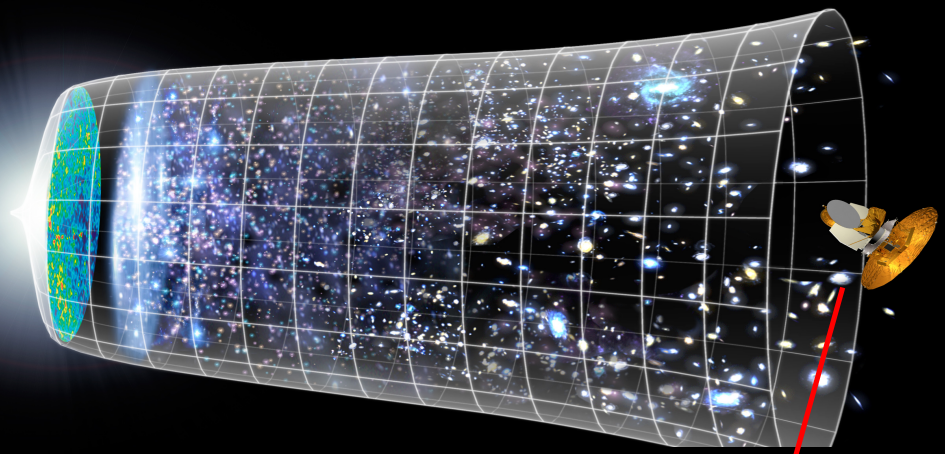
based on arXiv:1203.2064

in collaboration with Thomas Schwetz and Jure Zupan

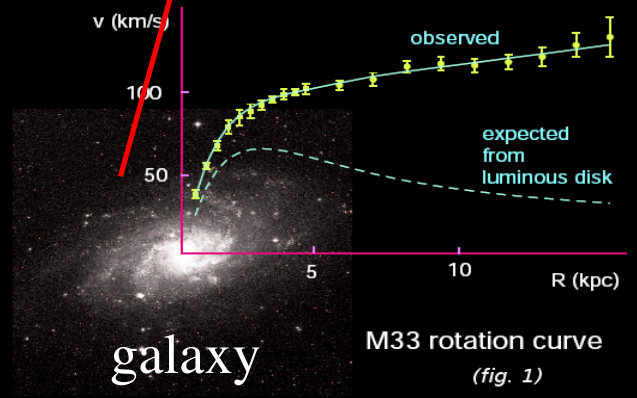
GGI workshop - Firenze



The Quest to determine the Composition of our Universe



Dark matter



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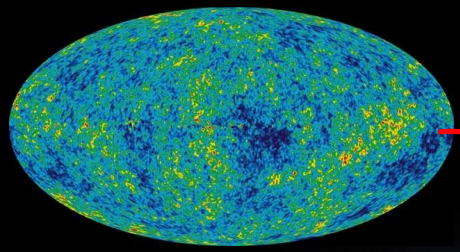
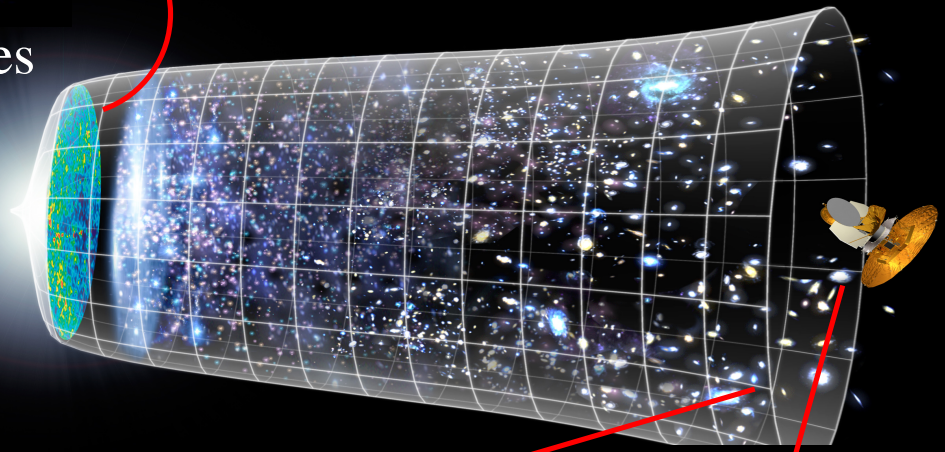


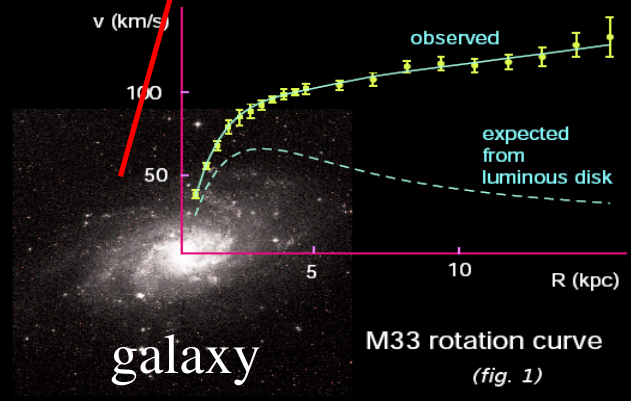
CMB anisotropies



Large Scale Structures (LSS)

SDSS galaxy map

Dark matter



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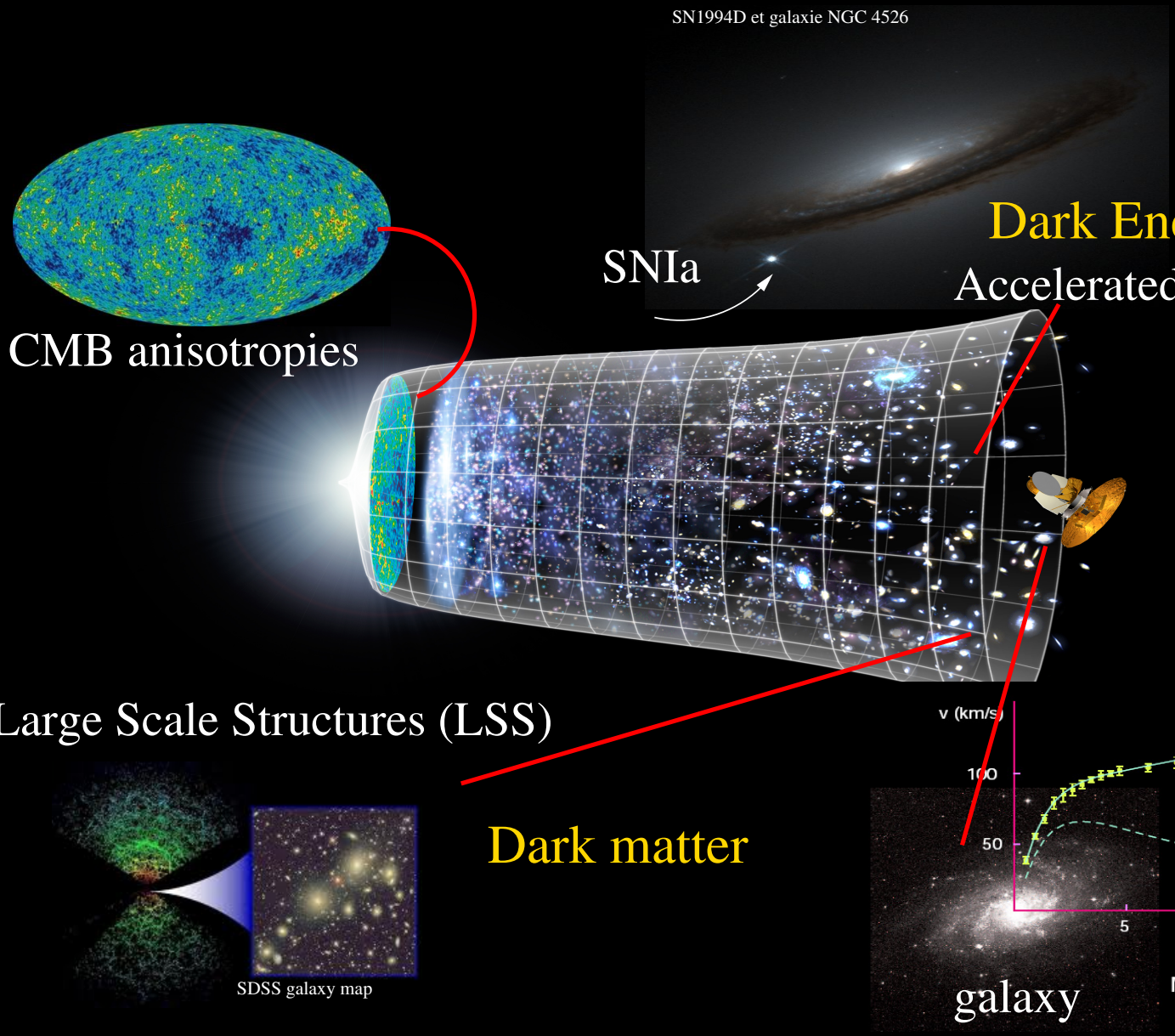

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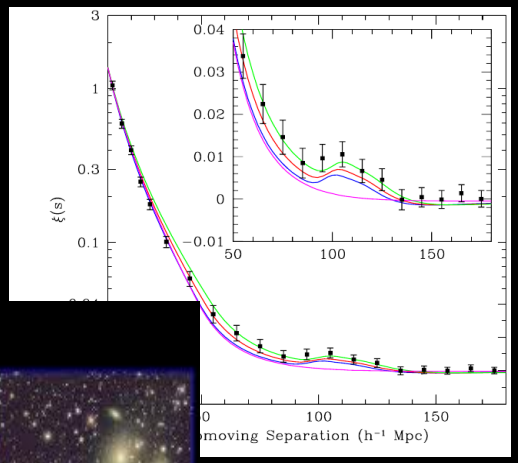
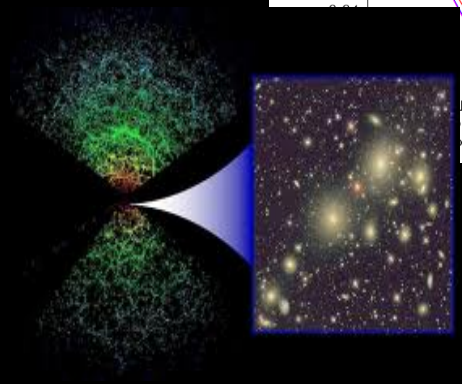
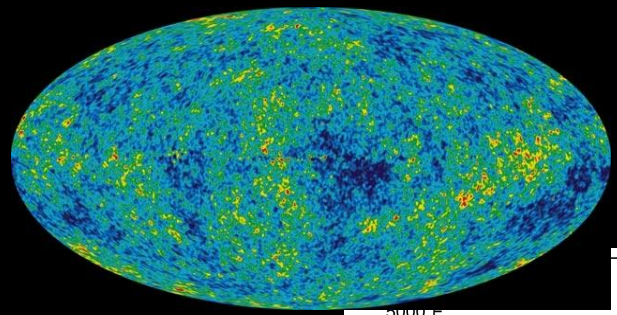
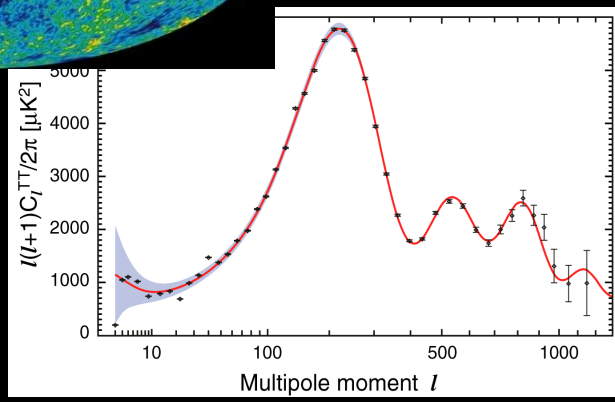
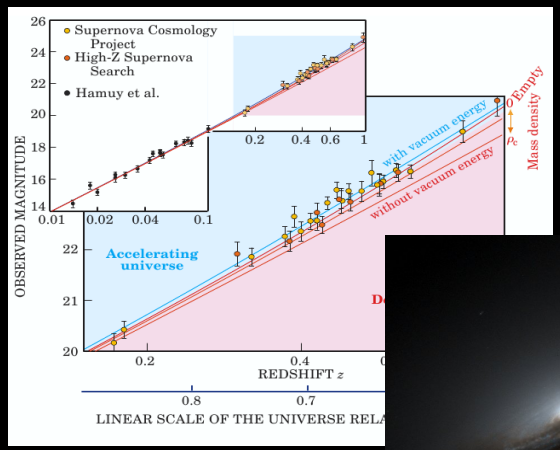
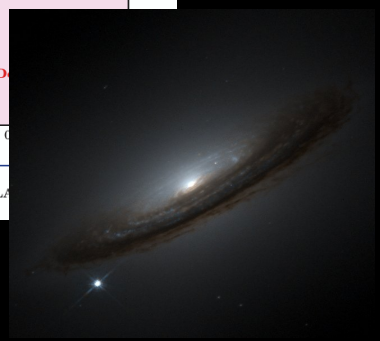

ξ(s)
moving Separation (h⁻¹ Mpc)





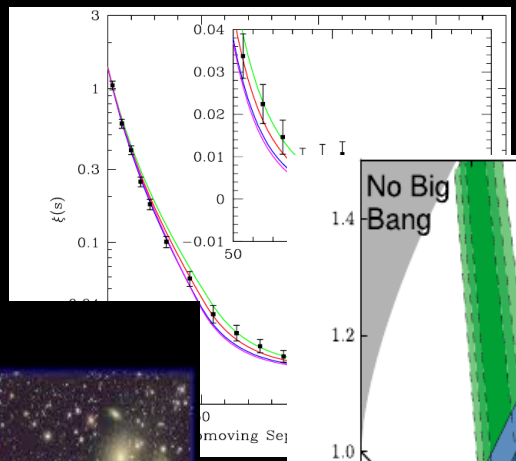

$l(l+1)C_l^{TT}/2\pi$ [μK²]
Multipole moment l

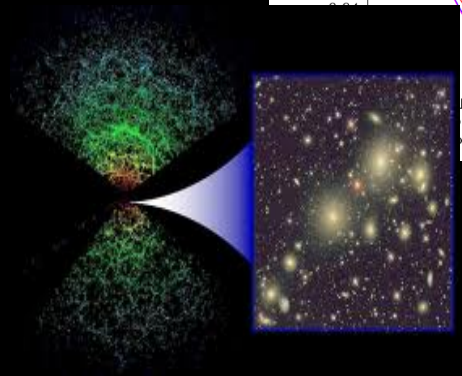

Supernova Cosmology Project
High-Z Supernova Search
Hamuy et al.
OBSERVED MAGNITUDE
REDSHIFT z
Accelerating universe
with vacuum energy
without vacuum energy
Mass density

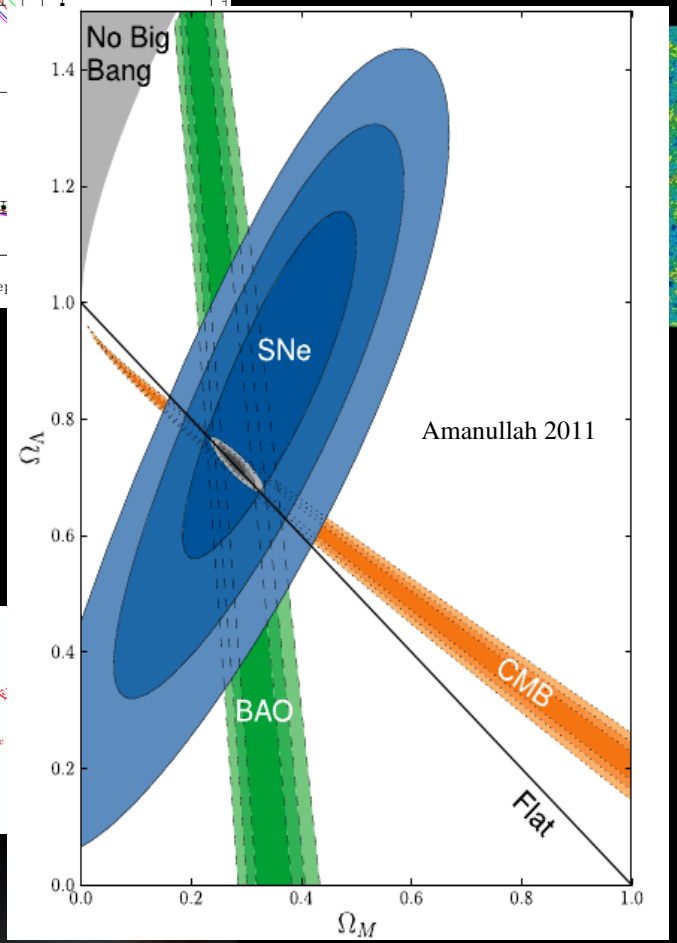


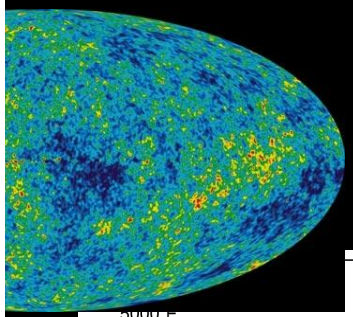
SDSS

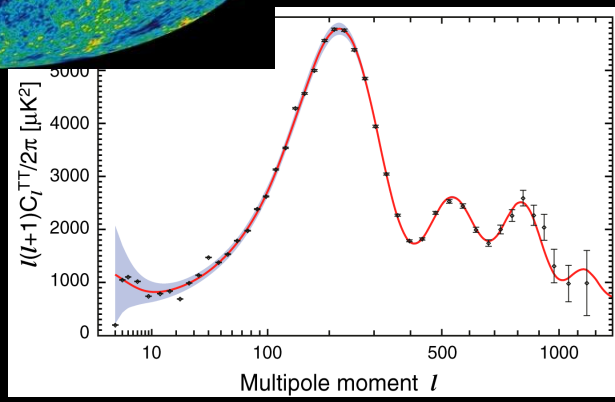
Eisenstein et al 2005



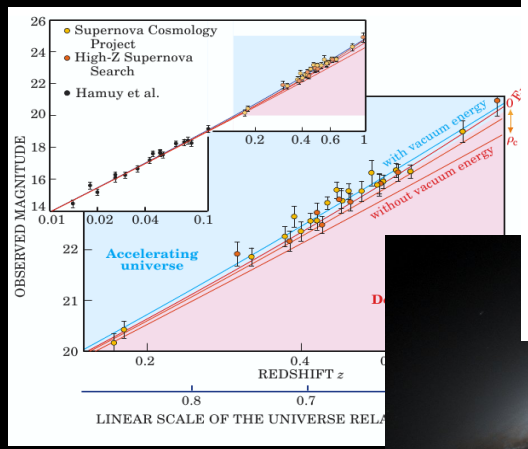




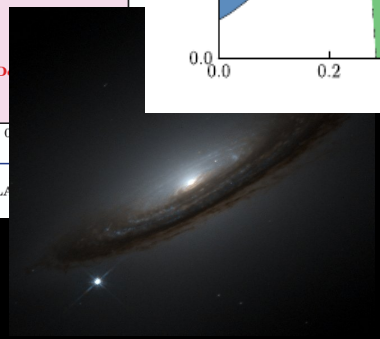




WMAP7, Larson et al 2010



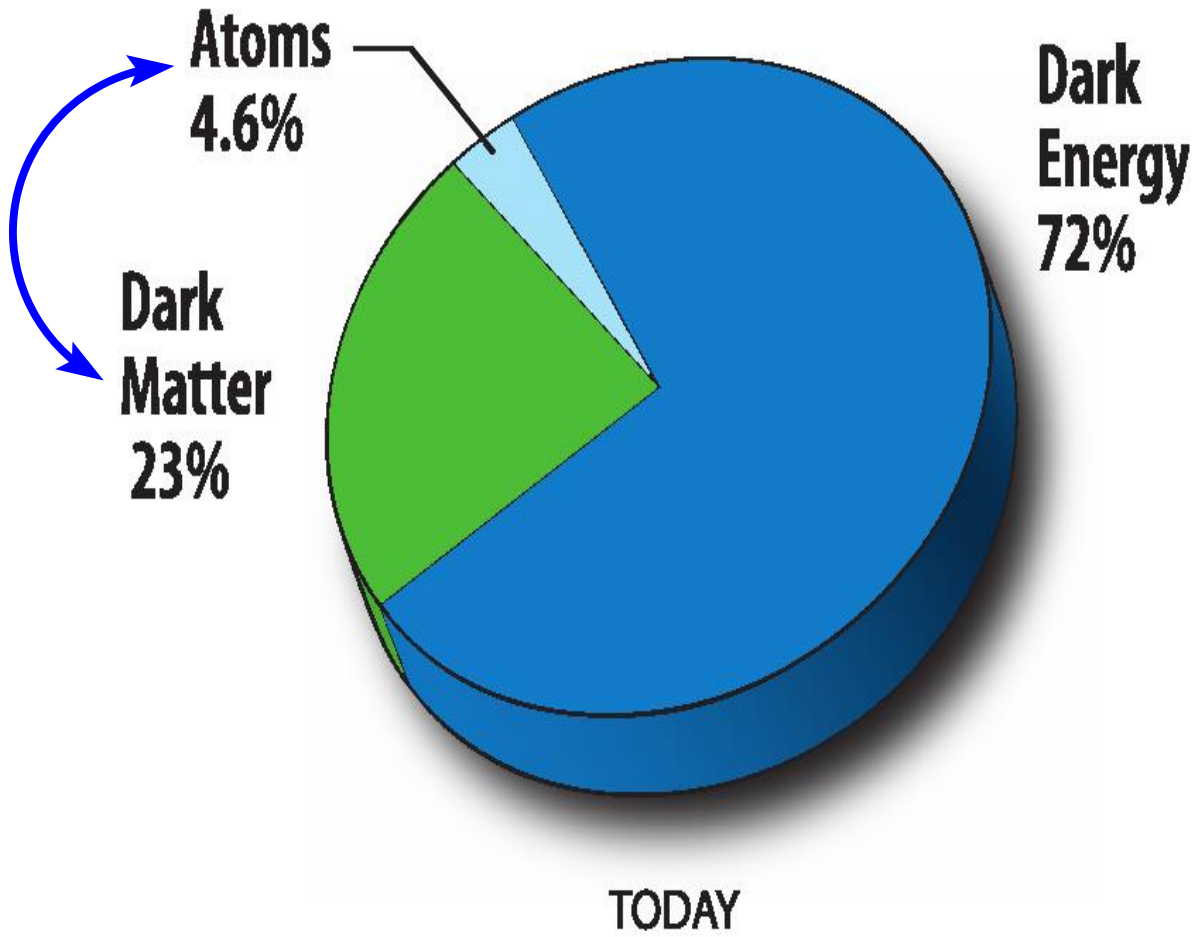
Pelmutter 2003



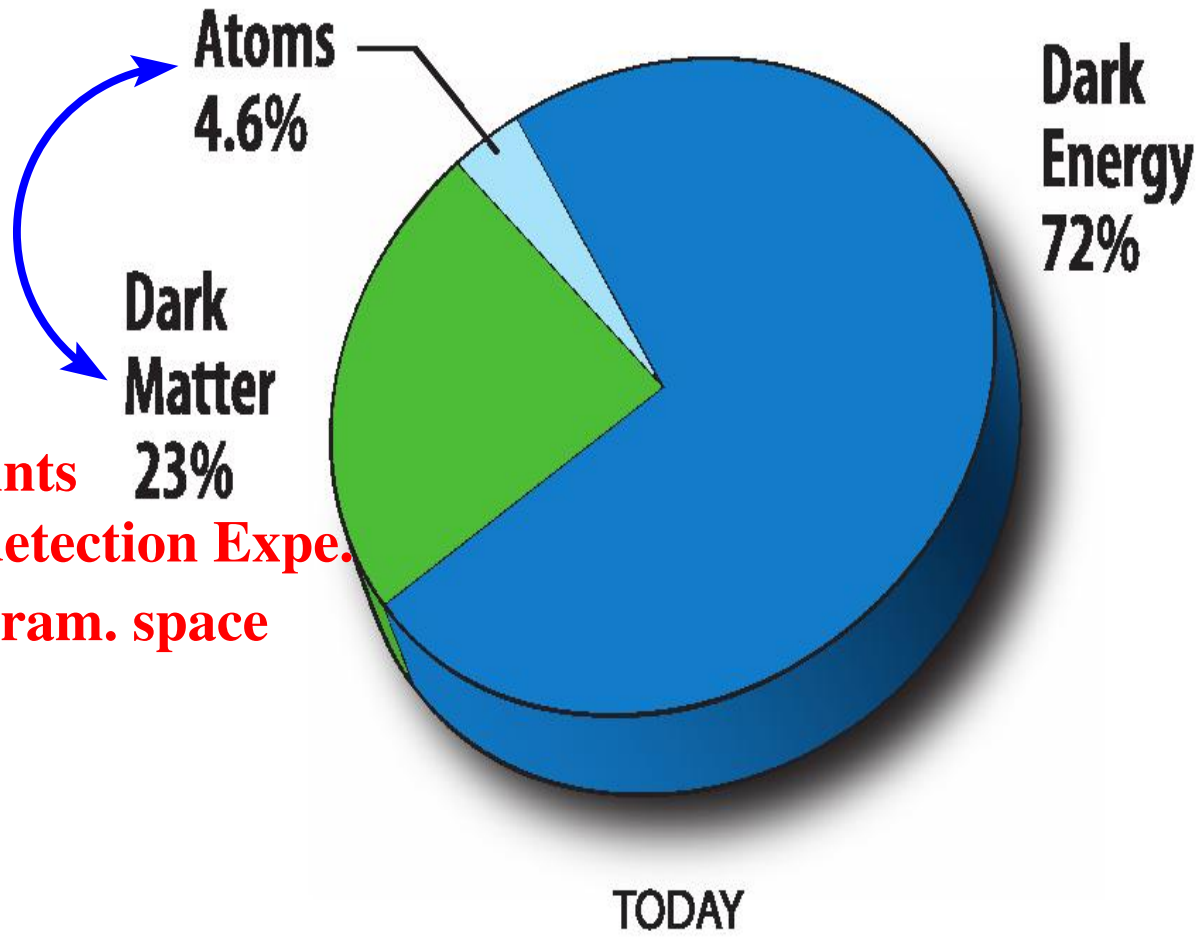
Concordance for a flat Universe today made of

~ 70% of dark energy as a Cosmo. Cst.

~ 30% of matter


Atoms
4.6%
Dark
Matter
23%
Dark
Energy
72%
TODAY

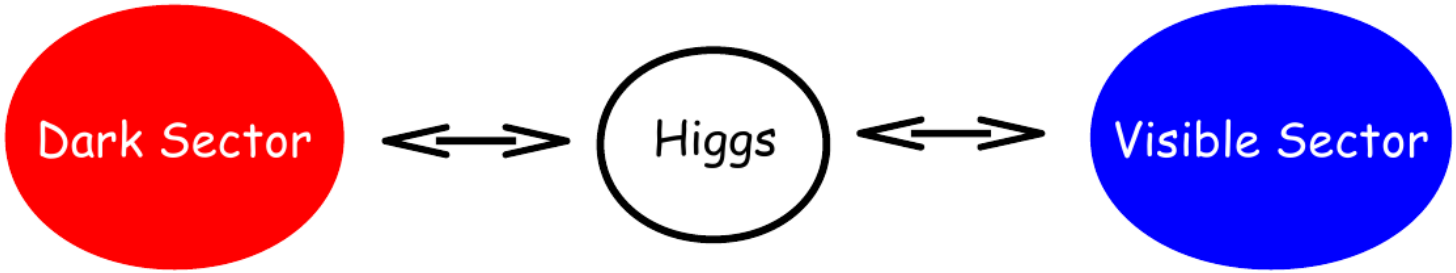
In this TALK! **Higgs portal – fermionic DM Model**



+ Constraints from DM detection Expe.

Viable param. space

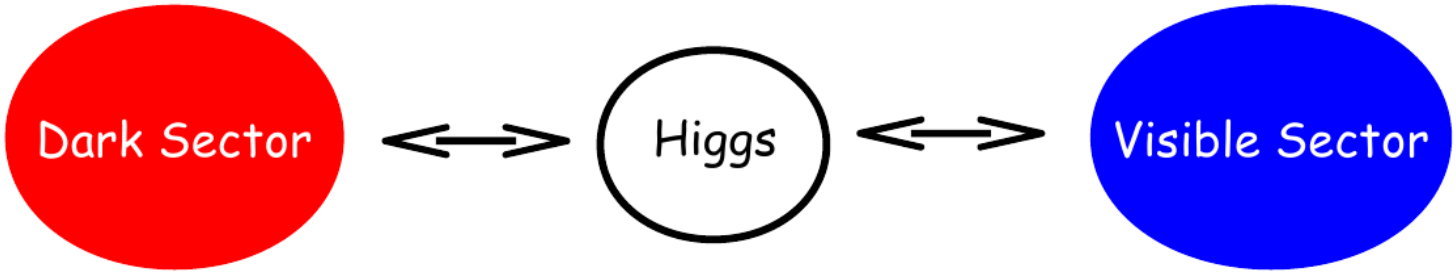
Higgs portal



- Typically $(H^\dagger H)$- dark sector operators drive the SM-DM interactions

  [Patt-Wilczeck '06]

Higgs portal



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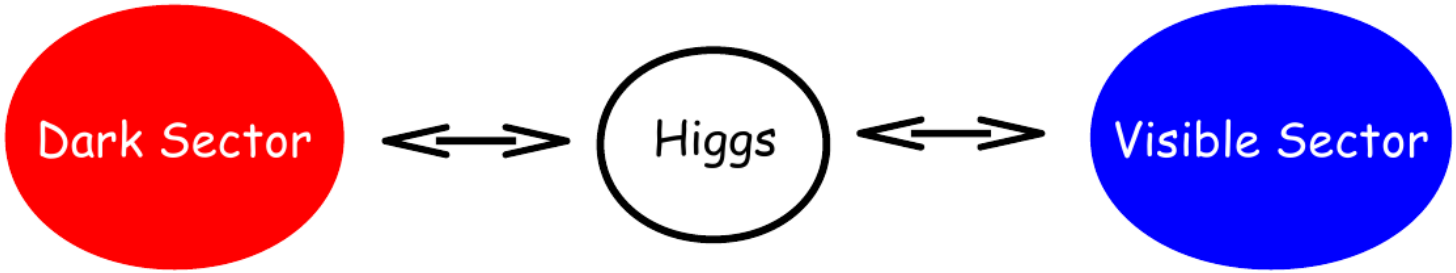
  [Patt-Wilczeck '06]
- Several extensions of the Standard model have been recently revisited with DM=singlet scalar S, vector V, fermion χ [Djouadi et al '11, '12]

Higgs portal



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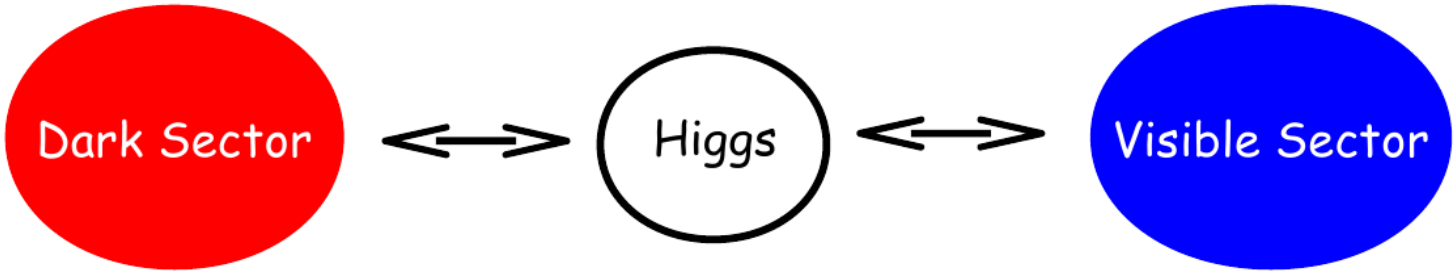
Higgs portal



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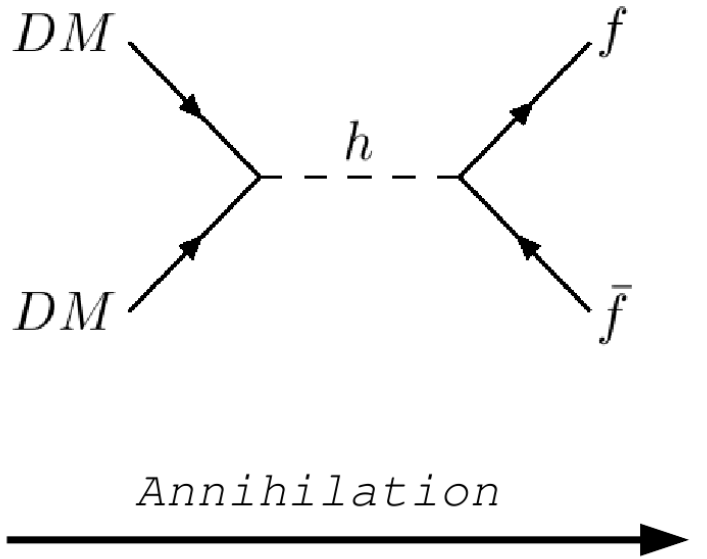
  - DM stability : Z_2 symmetry
  - Higgs-DM interactions :

$$\begin{aligned}\mathcal{L} \supset\ & \lambda_S S^2 (H^\dagger H) \\ & \lambda_V V_\mu V^\mu (H^\dagger H) \\ & \frac{\lambda_\chi}{\Lambda} \bar{\chi}\chi (H^\dagger H)\end{aligned}$$



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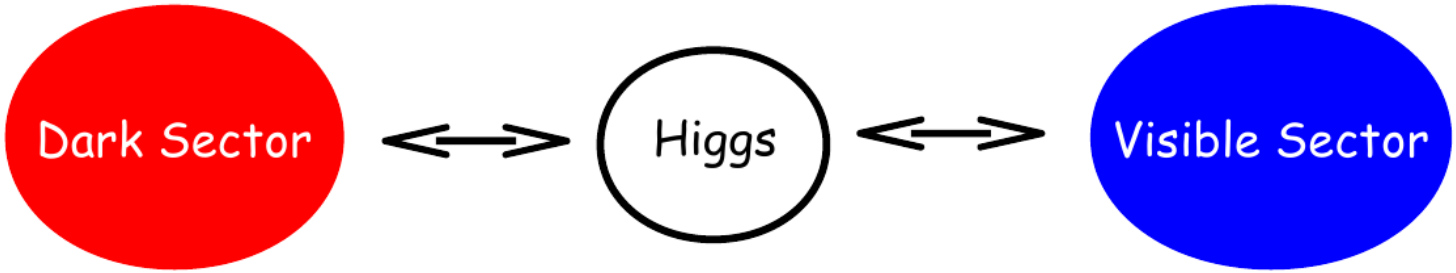

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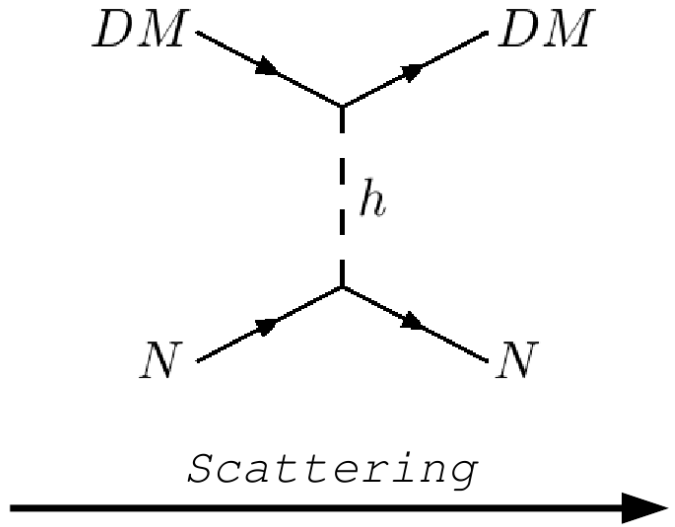
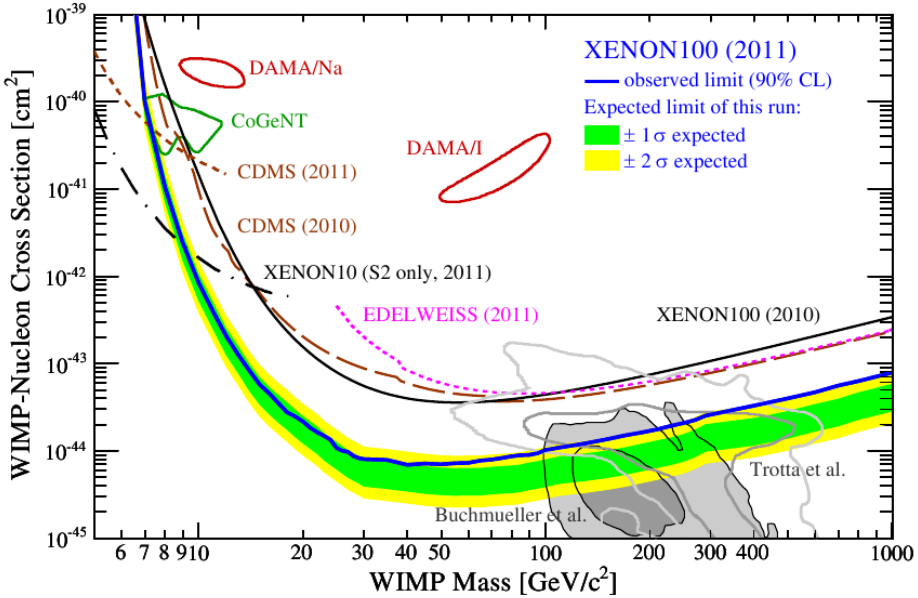


Direct detection : a serious threat for Higgs portal DM



Results from 100 Live Days of XENON100 Data

E. Aprile et al PRD '11

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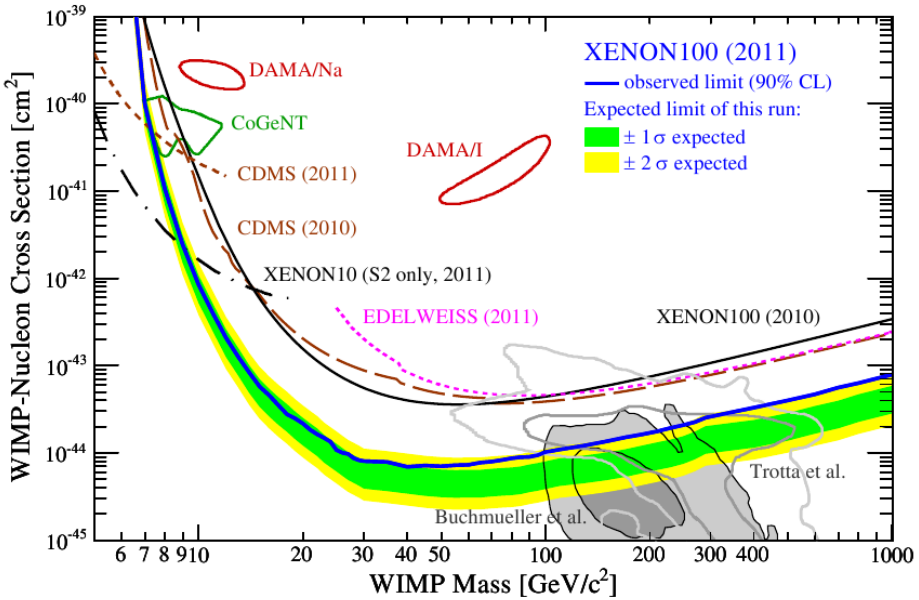

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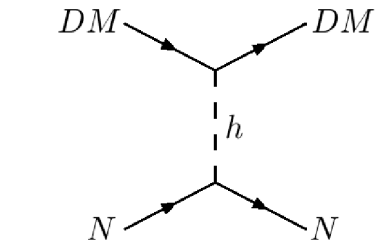
Relevant process for elastic scattering :



$$\sigma_{el} \propto \left(\frac{\lambda_{\mathrm{DM}} m_{\mathrm{red}}^2}{M_h^2} \right)^2$$

Scattering

with $m_{\mathrm{red}} = m_p m_{\mathrm{DM}} / (m_p + m_{\mathrm{DM}})$

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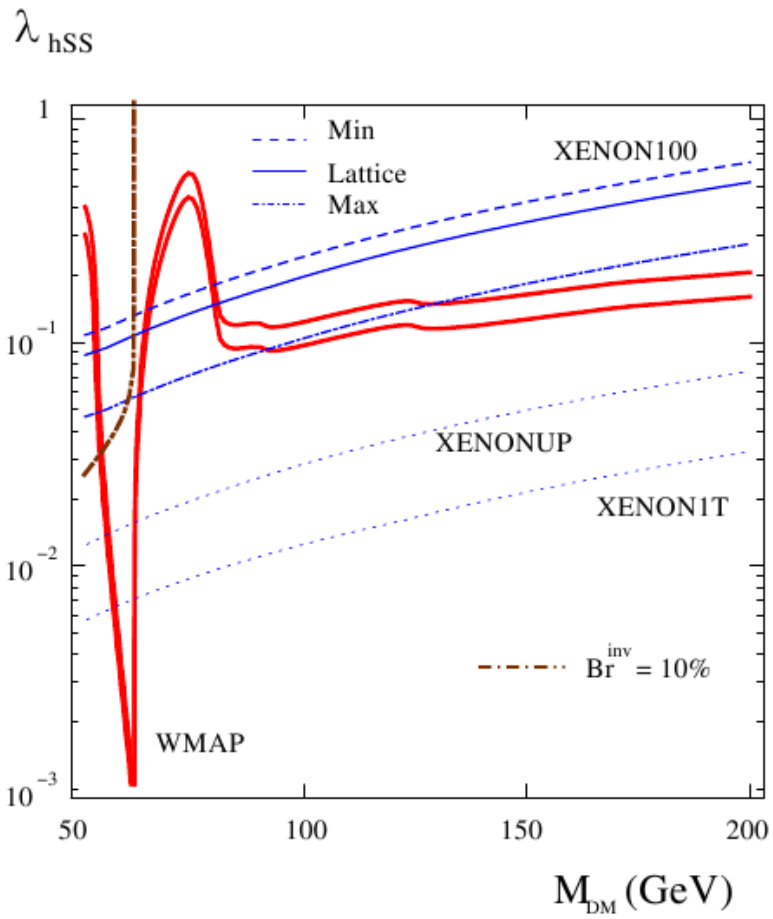

for $M_h = 125$ GeV

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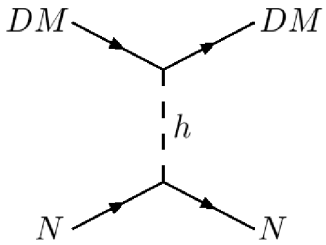

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For e.g. $M_h \sim 125$ GeV [Djouadi et al '11]

- Scalar, Vector DM ruled out for $m_{\rm DM} \lesssim 80$GeV

except for small resonant region $m_{\rm DM} \sim 62$ GeV and $\lambda_{\rm DM} \ll 1$

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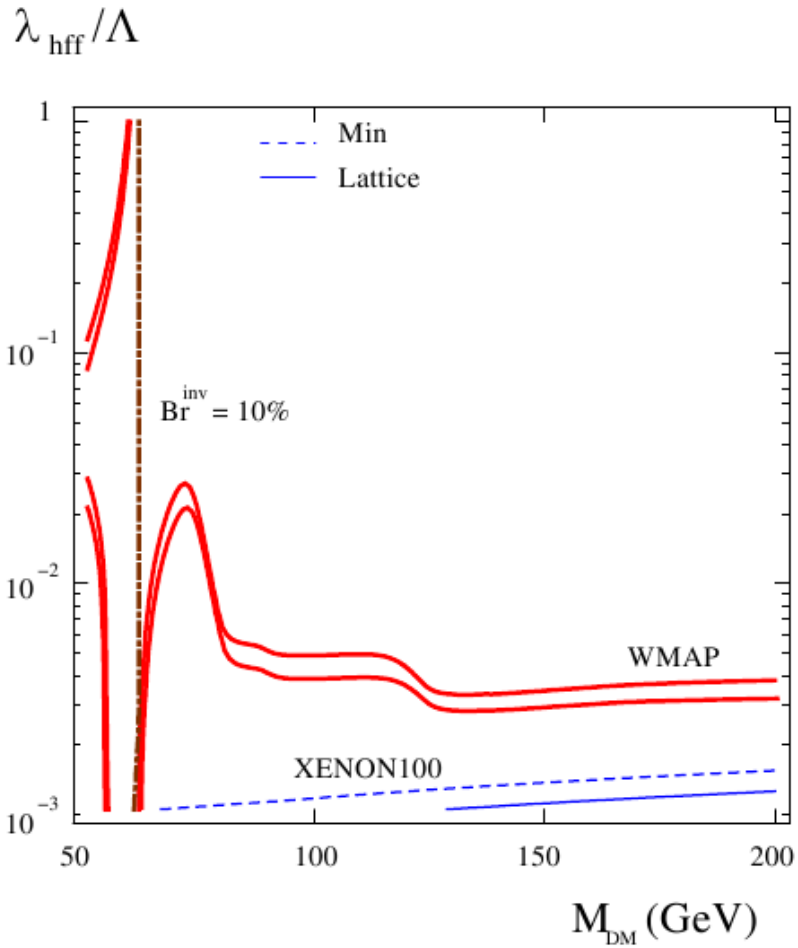

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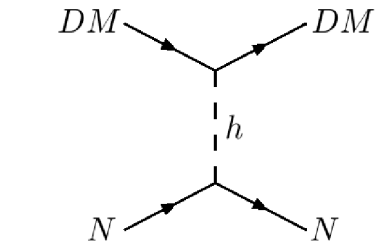

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- Scalar, Vector DM ruled out for $m_{\rm DM} \lesssim 80$GeV
- Fermionic DM ruled out for $m_{\rm DM}$ up to TeV scale

except for small resonant region $m_{\rm DM} \sim 62$ GeV and $\lambda_{\rm DM} \ll 1$

Higgs Portal Fermionic DM

We will see that Higgs Portal fermionic DM below the TeV range can be obtained :

[LLH, Schwetz & Zupan '12]

- In an Effective Field Theory (EFT) : "The pseudo Higgs portal"
  see also [Pospelov& Ritz '11]

Two types of dim-5 operators considered : $H_{\text{eff}} = \frac{1}{\Lambda_1} Q_1 + \frac{1}{\Lambda_5} Q_5$

$$Q_1 = (H^\dagger H)(\bar{\chi}\chi)\,, \qquad Q_5 = i(H^\dagger H)(\bar{\chi}\gamma_5\chi)\,,$$

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- When EFT breaks down : two other options in the scalar interaction case.
  - "Resonnant Higgs portal" :
    driven by resonnant annihilation into H or another mediator
  - "Indirect Higgs portal" :
    driven by annihilation into a low mass mediator
    $\equiv$ secluded DM [Pospelov '07]

EFT Higgs-Portal

EFT Higgs-Portal

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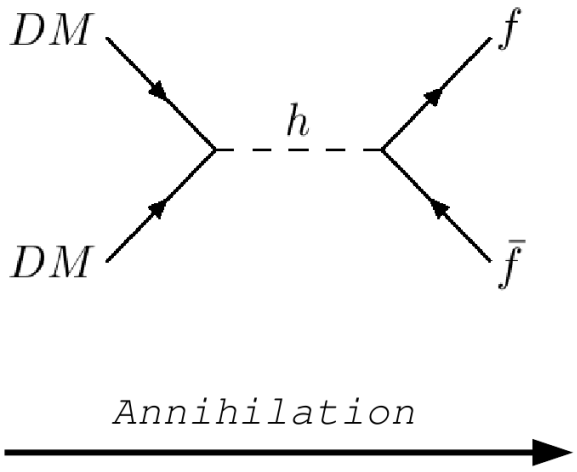

- Annihilation : $\chi\chi \to$ SM SM

$$\sigma_{\text{ann}} \mathrm{v} = \frac{f(m_\chi)}{4\pi} \times \qquad \frac{\mathrm{v}^2}{\Lambda_1^2} \quad \text{or} \quad \frac{1}{\Lambda_5^2}$$

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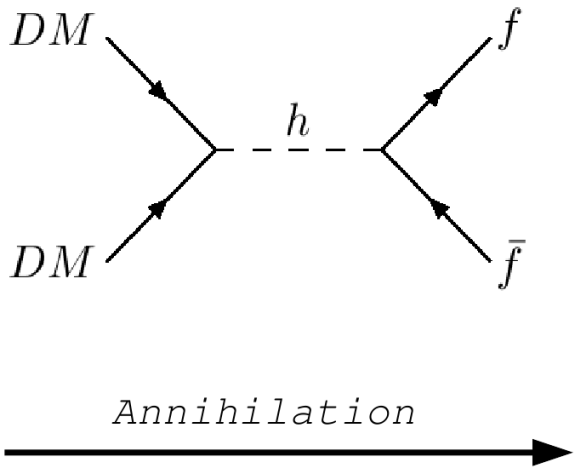

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EFT Higgs-Portal

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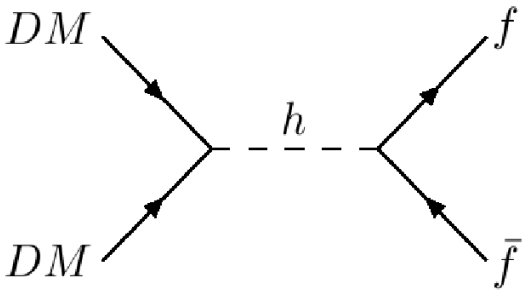

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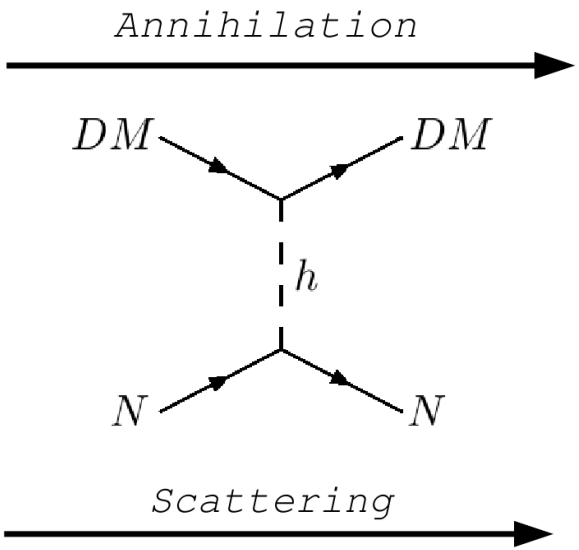
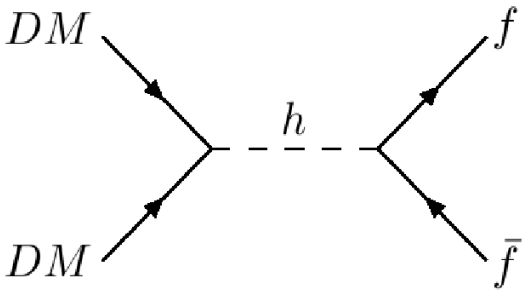


- Elastic scattering : $\chi p \to \chi p$

$$\sigma_{\text{p}} = \frac{4}{\pi} (m_p f_p)^2 \left(\frac{m_{\text{red}}}{m_h^2} \right)^2 \times \qquad \frac{1}{\Lambda_1^2} \quad \text{or} \quad \frac{2\,\text{v}^2}{\Lambda_5^2}$$

EFT Higgs-Portal

$$H_{\text{eff}} = \frac{1}{\Lambda_1} Q_1 + \frac{1}{\Lambda_5} Q_5 \quad \text{with} \quad Q_1 = (H^\dagger H)(\bar{\chi}\chi) \quad \text{and} \quad Q_5 = i(H^\dagger H)(\bar{\chi}\gamma_5\chi)\,,$$



- Annihilation : $\chi\chi \to$ SM SM

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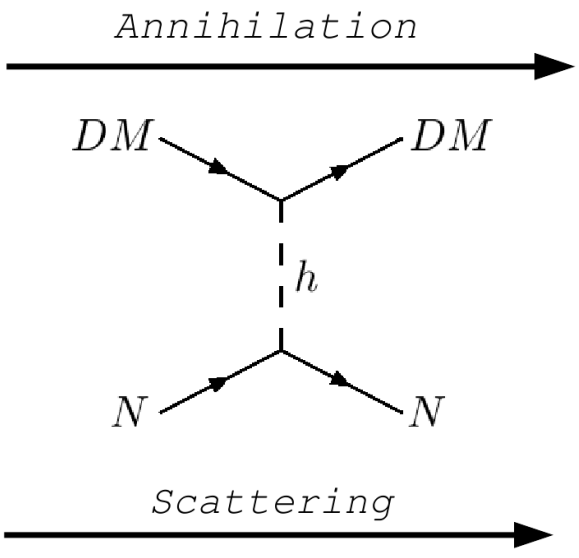
$\rightsquigarrow$ annihilation through parity conserving interactions is velocity suppressed.



- Elastic scattering : $\chi p \to \chi p$

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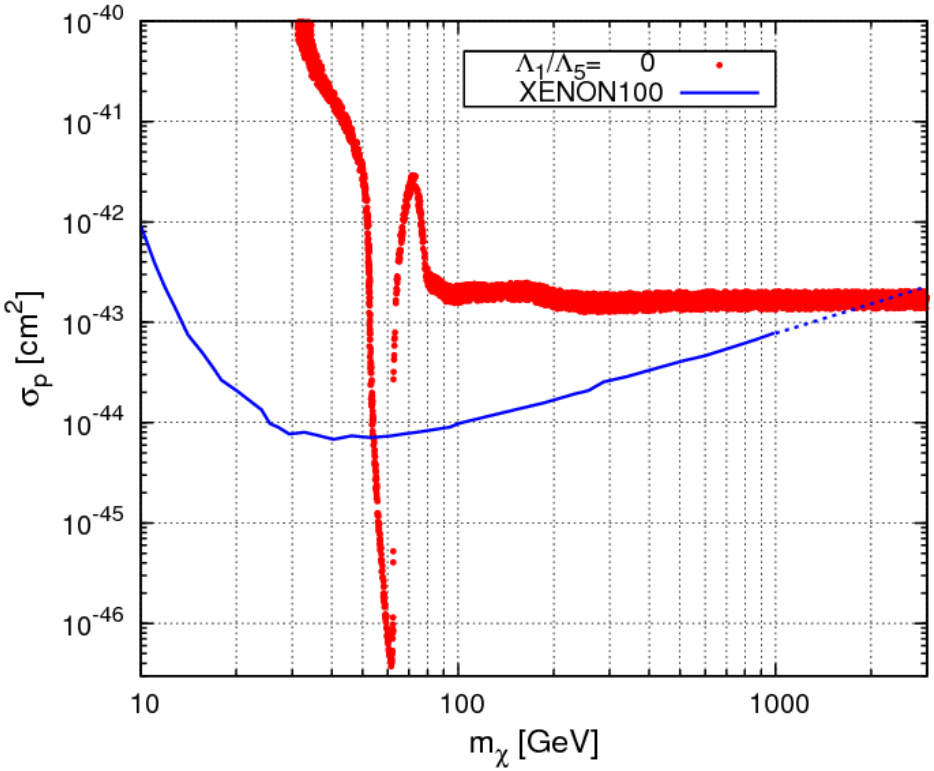
$\rightsquigarrow$ scattering through parity violating interactions is velocity suppressed.

"Pseudo" Higgs-Portal

For $M_h = 125$ GeV and $\Omega_\chi = \Omega_{WMAP}$



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- In the parity conserving case :
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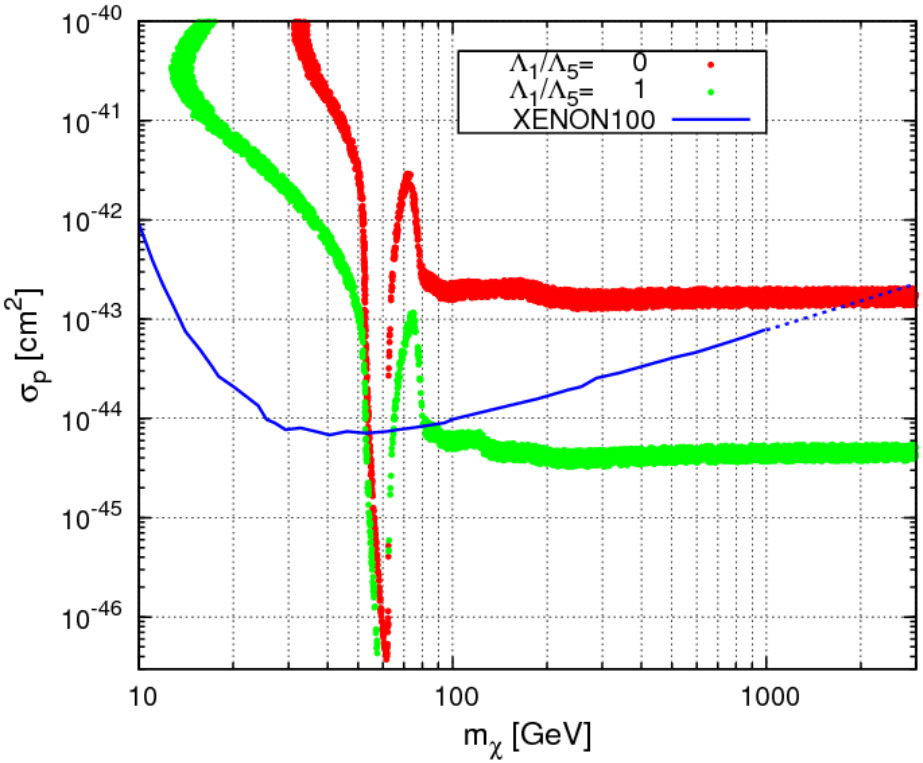

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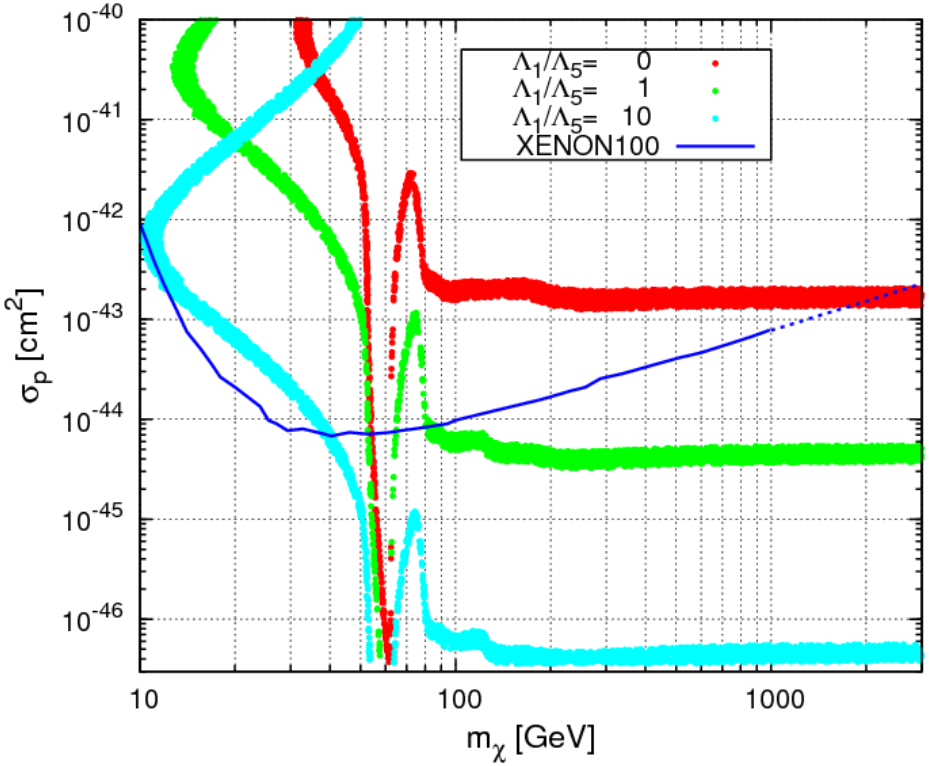

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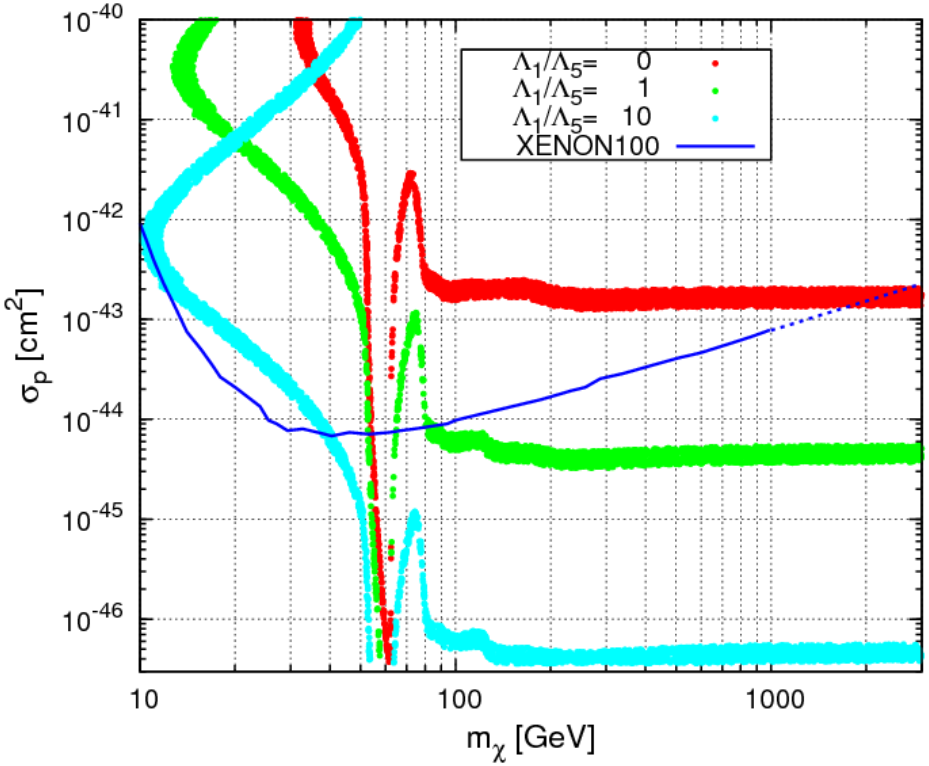

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$\rightsquigarrow$ In the framework of EFT, Higgs portal fermionic DM is viable below the TeV range including parity violating interaction

Beyond EFT

Toy Model embedding the EFT

Toy model ingredients

- SM with a Higgs doublet $H \rightsquigarrow 1/\sqrt{2}(h + v_1)$ + fermionic DM χ
- + extra real singlet scalar mediator $\varphi = \phi + v_2$ with :

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- Beyond EFT, we consider now $g_P = 0$
- λ_4 and $\mu \rightsquigarrow h - \phi$ mixing : physical states $H_1 \& H_2$ with α mixing.
  - we consider the case $\alpha \to 0 \equiv H_1 \simeq h$
  - all $\bar{\chi}\chi \to$ SM SM processes have $\sigma \propto \sin^2(2\alpha)$

Toy Model : DM signatures for scalar interactions

- Direct detection of DM :

$$\sigma_p \propto g_S^2 \sin^2 2\alpha \, m_{\text{red}}^2 \left(\frac{1}{m_{H_1}^2} - \frac{1}{m_{H_2}^2} \right)^2$$

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  - Bounds on the production Higgs cross-section constrain :

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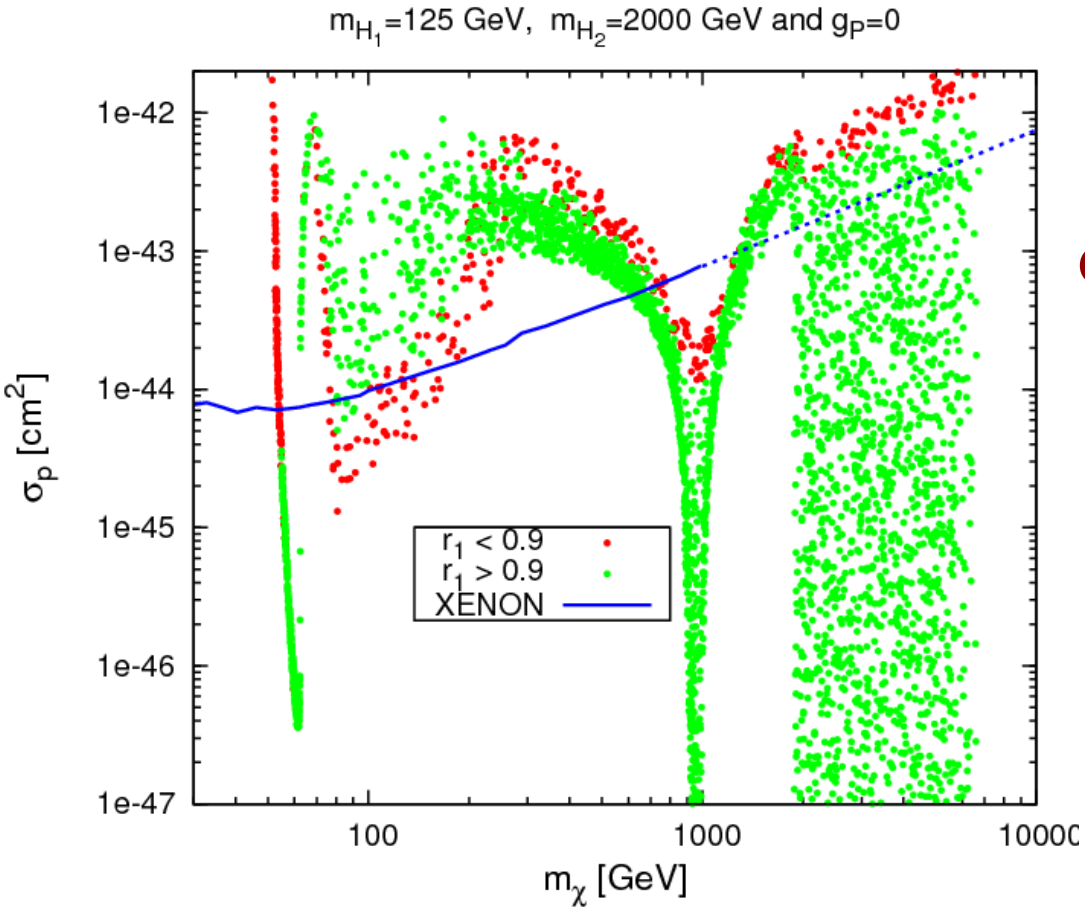
  - mixing and invisible branchings can reduce the signal strength [Beak '11, Englert '12] :

$$r_1 = \cos^4 \alpha \, \frac{\Gamma_{H_1}^{\rm SM}}{\Gamma_{H_1}} \quad \text{and} \quad r_2 = \sin^4 \alpha \, \frac{\Gamma_{H_2}^{\rm SM}}{\Gamma_{H_2}}$$

  - We spot "SM Higgs-like" H_1 as $r_1 > 0.9$

Example $m_{H_1} = 125$ GeV and $m_{H_2} = 2$ TeV



Constraints

- $0.09 < \Omega_\chi h^2 < 0.13$
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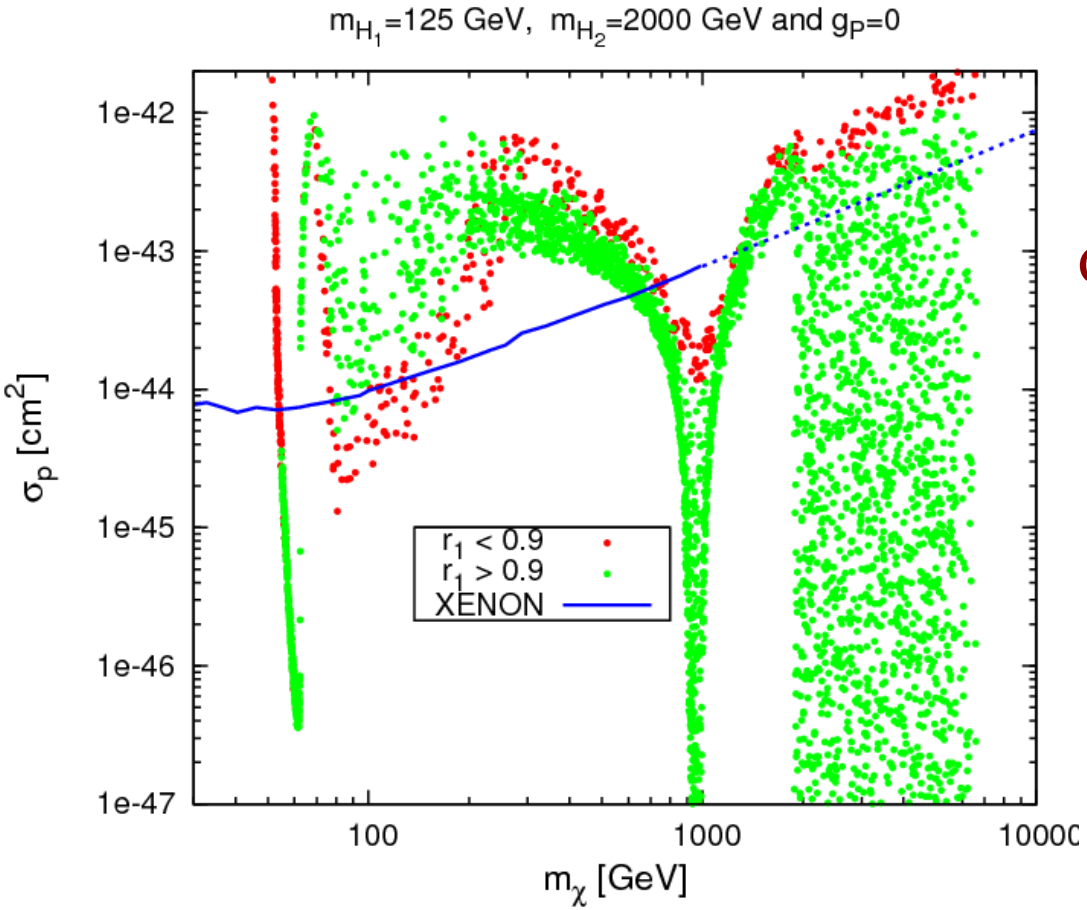

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Viable fermionic DM for "scalar" Higgs portal

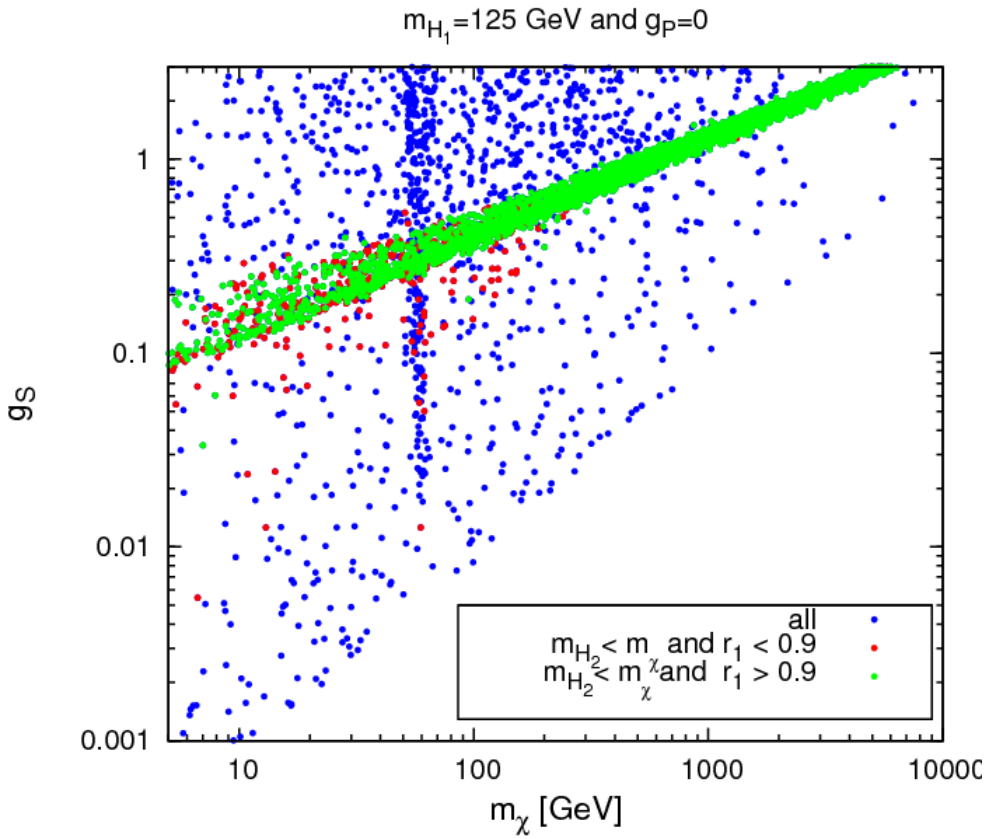
- at Higgs or mediator resonances : $m_\chi \approx m_{H_1}/2$ or $m_{H_2}/2$
- for $m_\chi < m_{H_2}$: Ω_χ mainly driven by α independent processes $\chi\chi \to \phi\phi$ while $\sigma_p \propto \sin^2(2\alpha)$

Indirect Higgs portal

We see that for $m_{H_2} < m_\chi$

- $g_S \phi \bar{\chi} \chi$
  $\rightsquigarrow$ u- and t-channel annihilation channels $\sigma_{\chi\chi \to \phi\phi} = \frac{3 {g_S}^4 v}{32\pi {m_\chi}^2}$
  $\rightsquigarrow$ g_S fixed for a given m_χ to comply with WMAP

Scann over m_{H_2}



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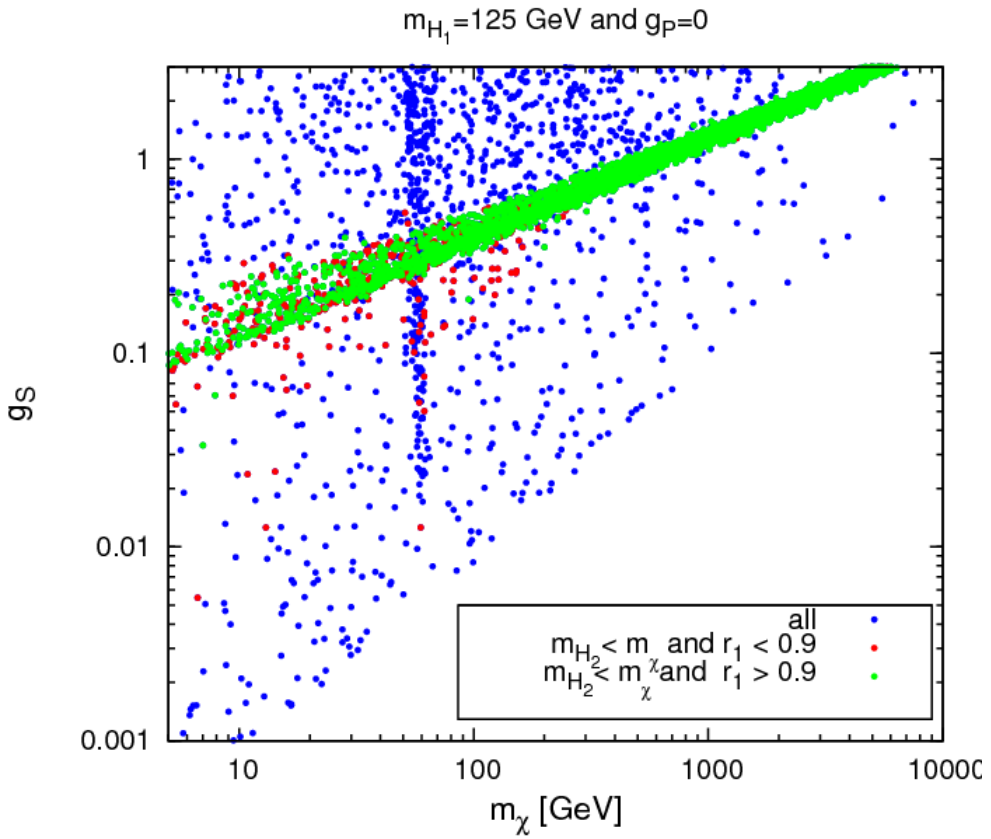

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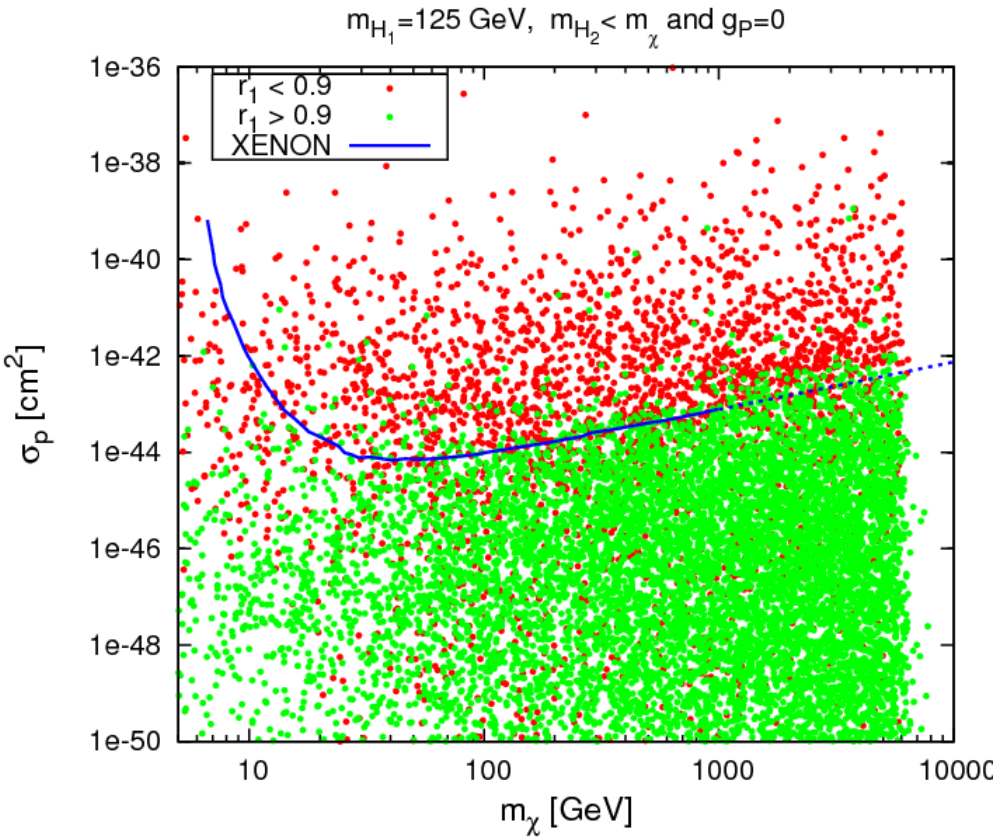

- The Higgs portal acts indirectly
- large range of viable fermionic DM masses allowed for scalar type of interactions

Conclusion

Viable Higgs Portal fermionic DM below the TeV range can be obtained :

[LLH, Schwetz & Zupan '12]

- In an Effective Field Theory (EFT) Two types of dim-5 operators have to be considered : $H_{\text{eff}} = \frac{1}{\Lambda_1} Q_1 + \frac{1}{\Lambda_5} Q_5$

$$Q_1 = (H^\dagger H)(\bar{\chi}\chi)\,, \qquad Q_5 = i(H^\dagger H)(\bar{\chi}\gamma_5\chi)\,,$$

  $\rightsquigarrow$ parity violating interactions have to be taken into account
  $\equiv$ "Pseudo-Higgs portal".

- When EFT breaks down : two other options for scalar interactions. Illustration in a toy model with H, χ and an extra scalar mediator ϕ
  - "Resonnant Higgs portal" :
    driven by resonnant annihilation into H or the mediator
  - "Indirect Higgs portal" :
    driven by annihilation into the extra mediator

Thank you for your attention ! ! !

Backup

Mixing

We define the mass eigenstates H_1 and H_2 in the following way :

$$H_1 = c_\alpha h + s_\alpha \phi \quad (1)$$

$$H_2 = -s_\alpha h + c_\alpha \phi \quad (2)$$

$$(3)$$

with $c_\alpha = \cos(\alpha), s_\alpha = \sin(\alpha)$, and α is the mixing angle which depends on the parameters present in the scalar potential in the following way :

$$\tan(2\alpha) = \frac{\sqrt{2}\mu v_1 + 2\lambda_4 v_1 v_2}{2\lambda_H v_1^2 - 2\lambda_\phi v_2^2 + \mu v_1^2/(2\sqrt{2}v2)} \quad (4)$$