Direct detection of Higgs-portal Dark Matter at the LHC

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Introduction

- Starting point : Higgs boson of 125 GeV.
- The Higgs particle may have other decay channels that are not predicted by the SM.
- Existing LHC data already constrains the invisible width.

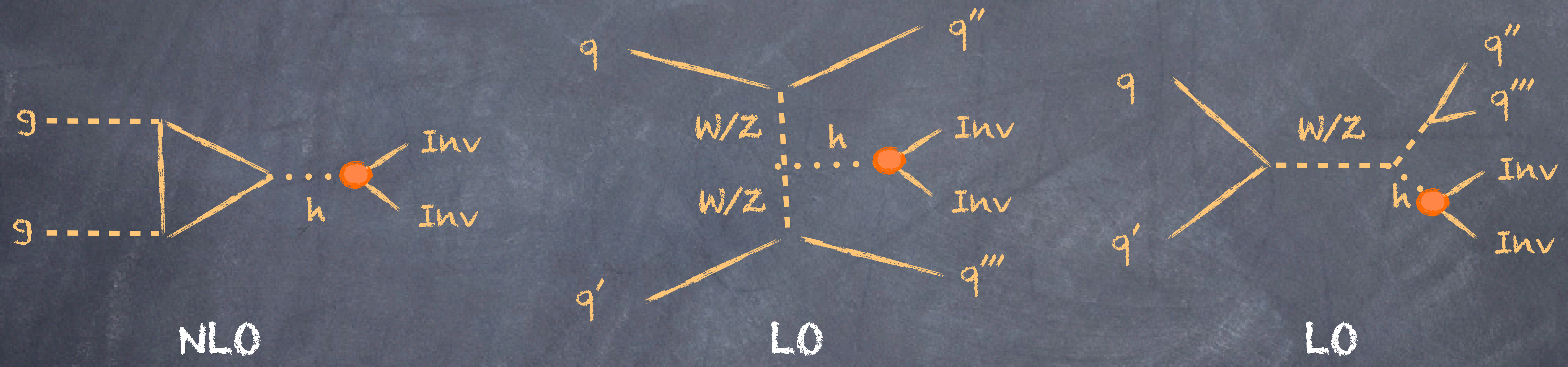
-> I. Monojet constraints on the invisible width

- Interesting interplay between LHC and direct dark matter detection in the context of Higgs portal models.

-> II. LHC and direct dark matter detection

Monojet constraints on the invisible width

Composition of the H(->Inv) + 1jet signal :



Principal backgrounds : Z -> νν+jets and W -> νl +jets
(with systematics ~ 10%)

Monojet constraints on the invisible width

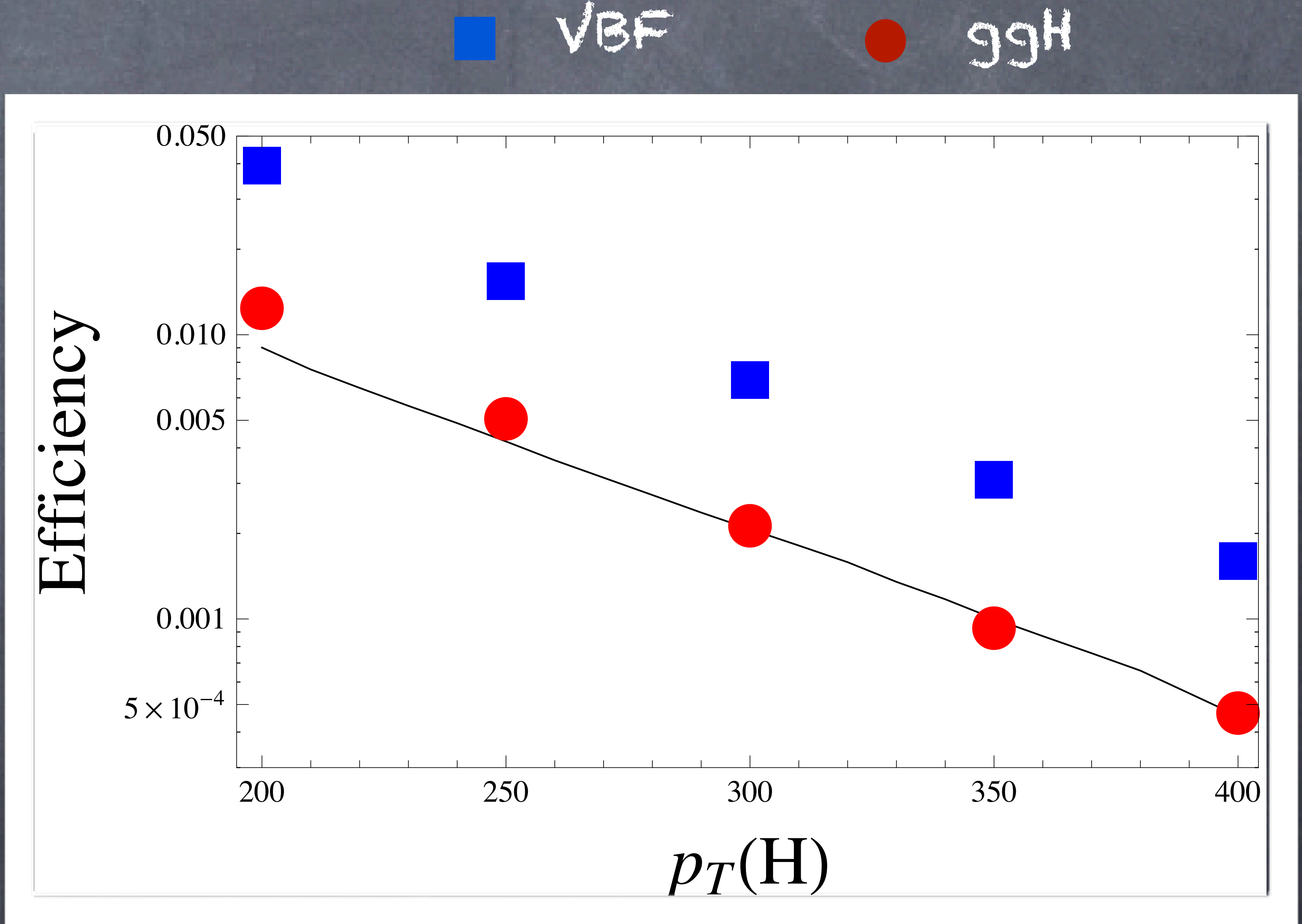
CMS monojet search [1206.5663] updated to 5 fb-1 :

- at least 1 jet with PT> 110 GeV and $|\eta| < 2.4$
- at most 2 jets with PT> 30 GeV
- no isolated lepton
- missing PT ≳ 200-400 GeV

A Higgs produced with a significant PT and decaying to invisible can lead to the topology targeted by monojet searches.

For example, for PTmiss ≳350 GeV CMS observes 1142 events vs predicted background 1225 ± 101

For Higgs with SM cross section fully invisible additional ~100 events, comparable to errors



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=> Monojet searches may already provide interesting constraints

What is the sensitivity of the CMS monojet-search to the invisible Higgs signal?

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With CMS data [1206.5663]

$p_T^{\rm miss}$ [GeV]	$N_{\rm inv}^{\rm ggF}$	$N_{\rm inv}^{\rm VBF}$	$\Delta N_{\rm Bkg}$	$R_{\rm inv}^{\rm exp}$	$R_{\rm inv}^{\rm obs}$
200	630	260	$\sim$ 1200	2.6	1.8
250	250	110	367	2.0	1.3
300	110	50	167	2.1	2.2
350	46	25	101	2.8	1.6
400	22	13	65	3.7	2.2

$R_{\rm inv}^{\rm ggF} = \frac{\sigma(gg \to H) \times {\rm BR}(H \to {\rm inv.})}{\sigma(gg \to H)_{SM}}$ ≲ 1.83 @95%CL

$R_{\rm inv}^{\rm VBF} = \frac{\sigma(qq \to Hqq) \times {\rm BR}(H \to {\rm inv.})}{\sigma(qq \to Hqq)_{SM}}$ ≲ 4.13 @95%CL

Combining (assuming SM proportions of ggF and VBF) :

$$R_{\rm inv} = \frac{\sigma(pp \to H) \times {\rm BR}(H \to {\rm inv.})}{\sigma(pp \to H)_{SM}}$$ ≲ 0.94 (1.27) @90 (95)%CL

Monojet constraints on the invisible width

$$R^{\rm ggF}_{\rm inv} = \frac{\sigma(gg \to H) \times {\rm BR}(H \to {\rm inv.})}{\sigma(gg \to H)_{SM}} \qquad R^{\rm VBF}_{\rm inv} = \frac{\sigma(qq \to Hqq) \times {\rm BR}(H \to {\rm inv.})}{\sigma(qq \to Hqq)_{SM}}$$

With CMS data [1206.5663]

$p_T^{\rm miss}$ [GeV]	$N^{\rm ggF}_{\rm inv}$	$N^{\rm VBF}_{\rm inv}$	$\Delta N_{\rm Bkg}$	$R^{\rm exp}_{\rm inv}$	$R^{\rm obs}_{\rm inv}$
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$\lesssim$ 1.83 @95%CL

$\lesssim$ 4.13 @95%CL

$\lesssim$ 0.94 (1.27) @90 (95)%CL

With ATLAS data [ATLAS-CONF-2012-084]

$p_T^{\rm miss}$ [GeV]	$N^{\rm ggF}_{\rm inv}$	$N^{\rm VBF}_{\rm inv}$	$\Delta N_{\rm Bkg}$	$R^{\rm exp}_{\rm inv}$	$R^{\rm obs}_{\rm inv}$
120	1870	700	4000	3.0	3.3
220	280	140	400	1.9	1.5
350	30	18	60	2.5	3.2
500	3.8	2.7	14	4.3	3.3

$\lesssim$ 2.22@95%CL

$\lesssim$ 4.49@95%CL

$\lesssim$ 1.18 (1.49) @90 (95)%CL

Monojet constraints on the invisible width

- Projection of the CMS study to the ongoing 8 TeV run:
  - We assume the error on the Z -> νν+jets background dominated by the statistics of the Z -> μμ+jets control sample (as in the current run).
  - We assume the systematic error on the W -> νl +jets background will be brought down to 5%

$$R_{\text{inv}} = \frac{\sigma(pp \to H) \times \text{BR}(H \to \text{inv.})}{\sigma(pp \to H)_{SM}}$$ ≤ 0.9 95%CL with 15 fb-1 @ LHC 8 TeV

  - Just a crude estimate, depends on experiments' ability to control systematic errors on the V+jets backgrounds.

Monojet constraints on the invisible width

- no direct constraints on the visible branching fraction if Higgs produced with the SM rate.

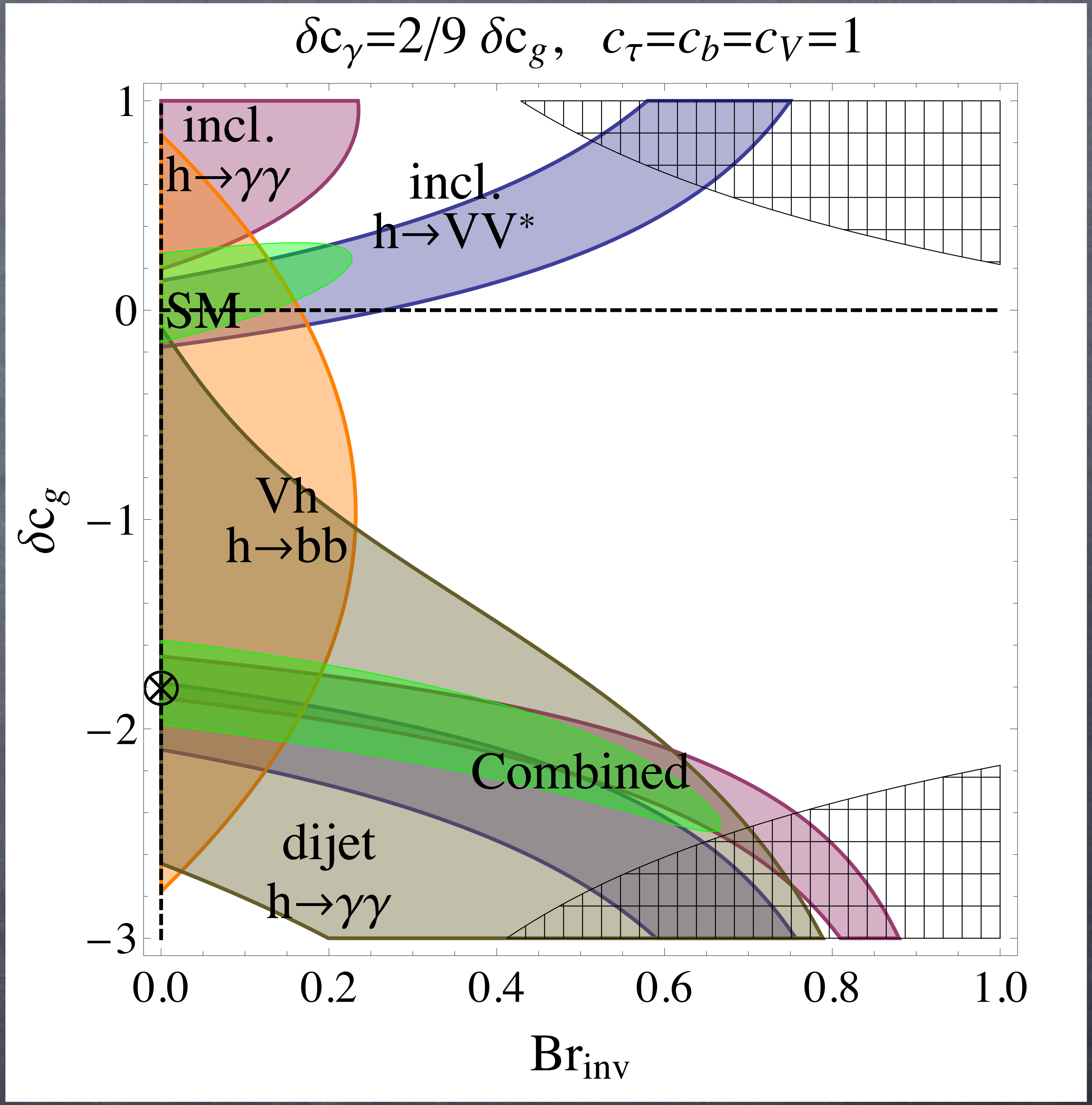
- Indirectly a better bound from observation of visible Higgs decays :
  BR(h->inv) < 0.4 Giardino,Kannike,Raidal,Strumia [1203.4254]
  BR(h->inv) < 0.20 (with 2012 data), Carmi,Falkowski,Kuflik,Volansky,Zupan [1207.1718]

Giardino,Kannike,Raidal,Strumia[1203.4254]

Monojet constraints on the invisible width

Carmi,Falkowski,Kuflik,Volansky,Zupan [1207.1718]

- However, if Higgs rate enhanced (4th chiral generation or in many BSM models) then our analysis provides non-trivial constraints.
- Monojet searches are sensitive mostly to the ggF mode, thus they can probe invisible Higgs in models where the Higgs couplings to the W,Z bosons are reduced (complementarity to invisible Higgs searches in VBF mode).
- Sensitivity of monojet searches to invisible Higgs turns out to be much better than expected => LHC is already sensitive to Rinv ~ 1.

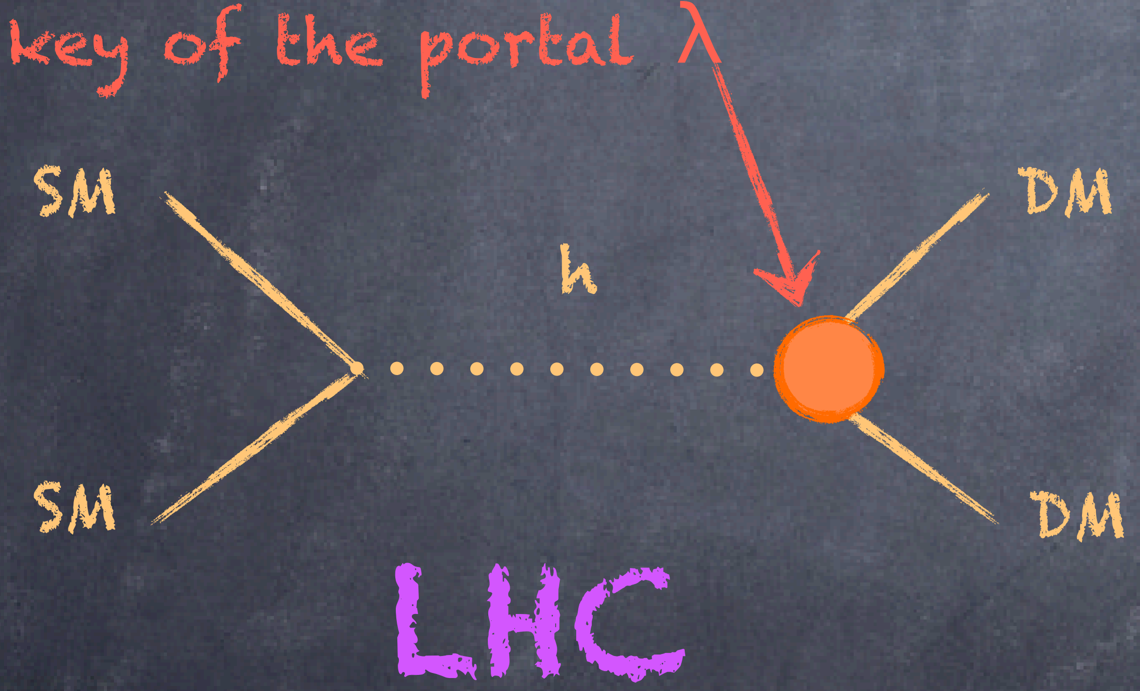


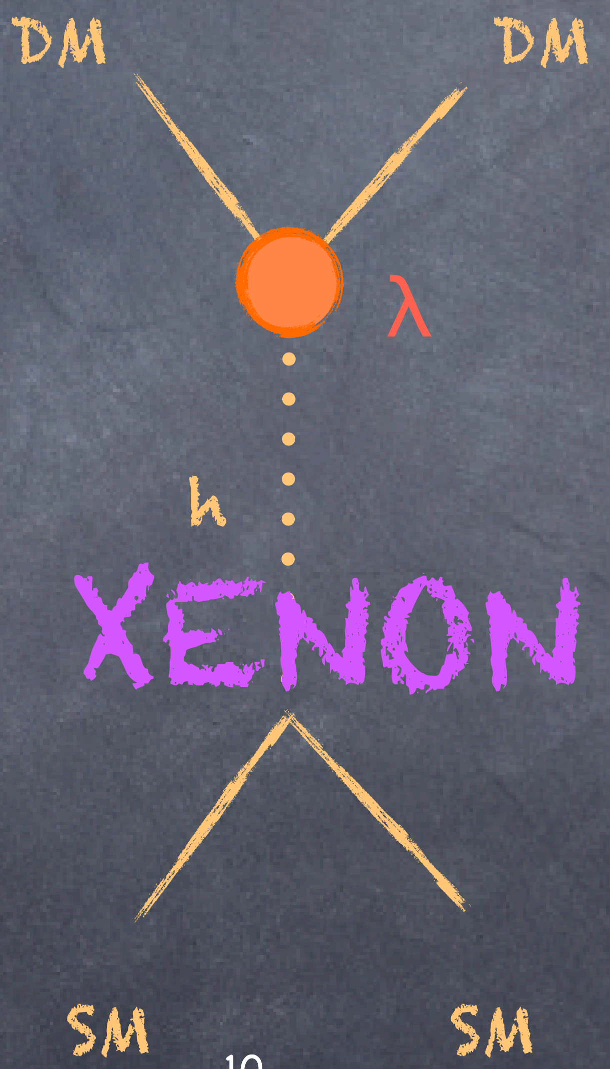
Higgs-portal models

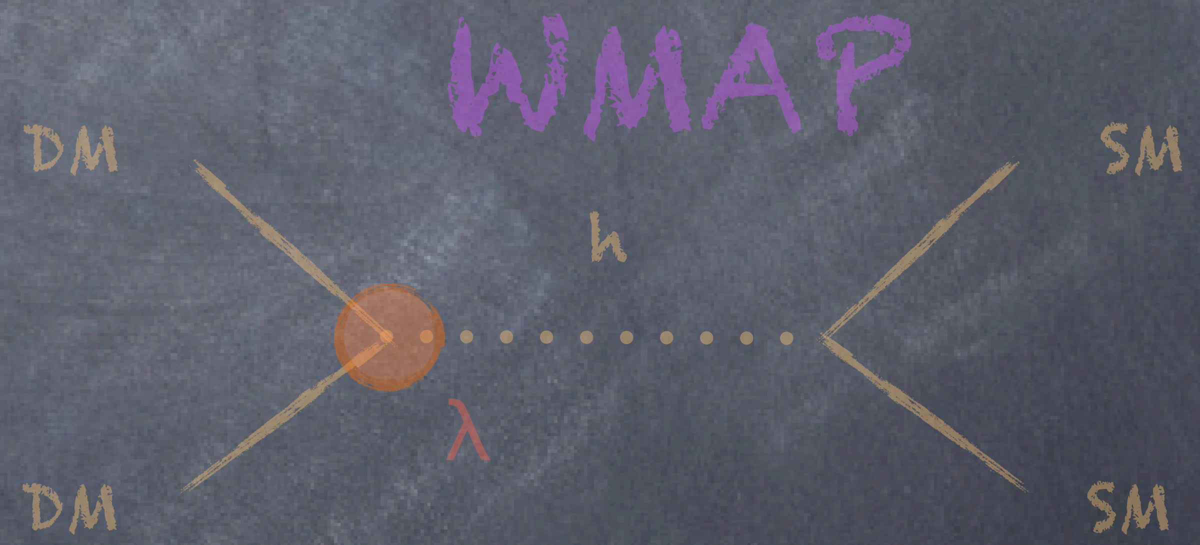
$$\mathcal{L}_S = \mathcal{L}_{SM} - \frac{1}{2}m_S^2 S^2 - \frac{1}{4}\lambda_S S^4 - \frac{1}{4}\lambda_{hSS} H^\dagger H S^2$$ Scalar DM

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

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







Higgs-portal models

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

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

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

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

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

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

$$\sigma^{SI}_{S-N} = \frac{\lambda^2_{hSS}}{16\pi m_h^4}\frac{m_N^4 f_N^2}{(M_S+m_N)^2}$$

$$\sigma^{SI}_{V-N} = \frac{\lambda^2_{hVV}}{16\pi m_h^4}\frac{m_N^4 f_N^2}{(M_V+m_N)^2}$$

$$\sigma^{SI}_{f-N} = \frac{\lambda^2_{hff}}{4\pi \Lambda^2 m_h^4}\frac{m_N^4 M_f^2 f_N^2}{(M_f+m_N)^2}$$

LHC

XENON

$$\frac{\Gamma(H\to\chi\chi)}{\sigma^{\rm SI}_{\chi p}} = r_\chi(M_\chi)$$

DM DM λ h SM SM

SM DM λ h SM DM

LHC and direct dark matter detection

- For a given M_χ, the invisible branching fraction probed at the LHC is connected to the dark matter-nucleon cross section probed by XENON100 :

$$\mathrm{BR}_\chi^{\mathrm{inv}} = \frac{\sigma_{\chi p}^{\mathrm{SI}}}{\Gamma_H^{\mathrm{SM}}/r_\chi + \sigma_{\chi p}^{\mathrm{SI}}}$$

- Strongest (weakest) bound is derived in the vectorial (scalar) case

=> the LHC is currently the most sensitive dark matter detector *

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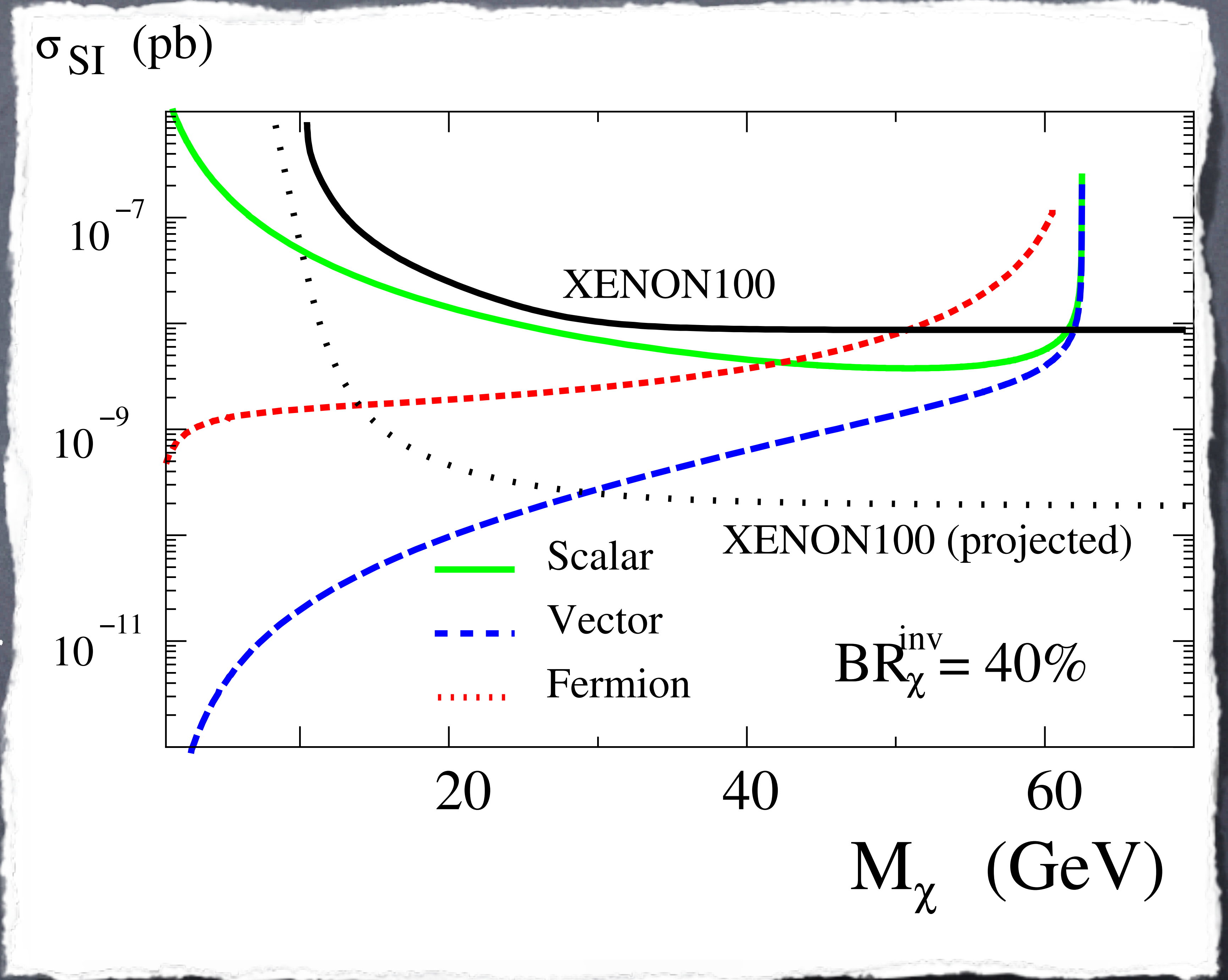

* in the context of simple Higgs-portal models

Conclusion

- Monojet searches at the LHC already provide interesting limits on invisible Higgs decays, constraining the invisible rate to be less than the total SM Higgs production rate at the 90%CL.
- This constrains the invisible branching fraction in models where the Higgs production cross section is enhanced.
- We expect that the monojet data which will be collected in the ongoing 8 TeV LHC run will place non-trivial constraints on the Higgs invisible branching fraction even if the Higgs production rate is SM-like.
- We also analyzed in a model-independent way the interplay between the invisible Higgs branching fraction and the dark matter scattering cross section on nucleons.
- The limits BRinv < 0.4 suggested by the combination of Higgs data in the visible channels, implies a limit on the direct detection cross section that is stronger than the current bounds from XENON100 for scalar, fermionic, vectorial DM.
- Hence in the context of Higgs-portal models the LHC is currently the most sensitive DM detection apparatus.

Merci de votre attention!