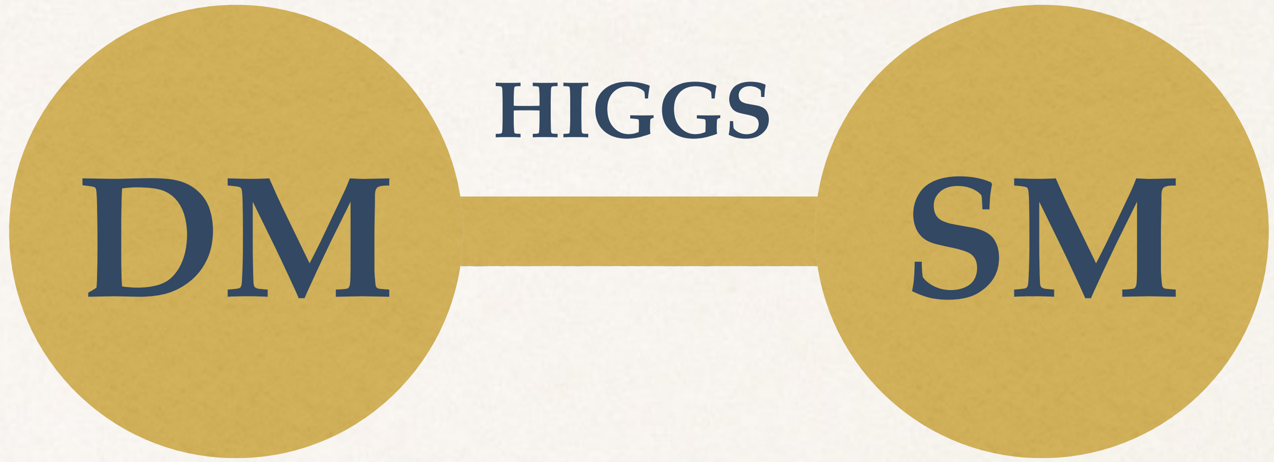
Non-linear Higgs portals

Veronica Sanz (Sussex)

based on work with

Ilaria Brivio (NBI), Belen Gavela, Luca Merlo, Rocio del Rey (Madrid)
and J.M. No and Ken Mimasu (King's, UCL)

Higgs portals

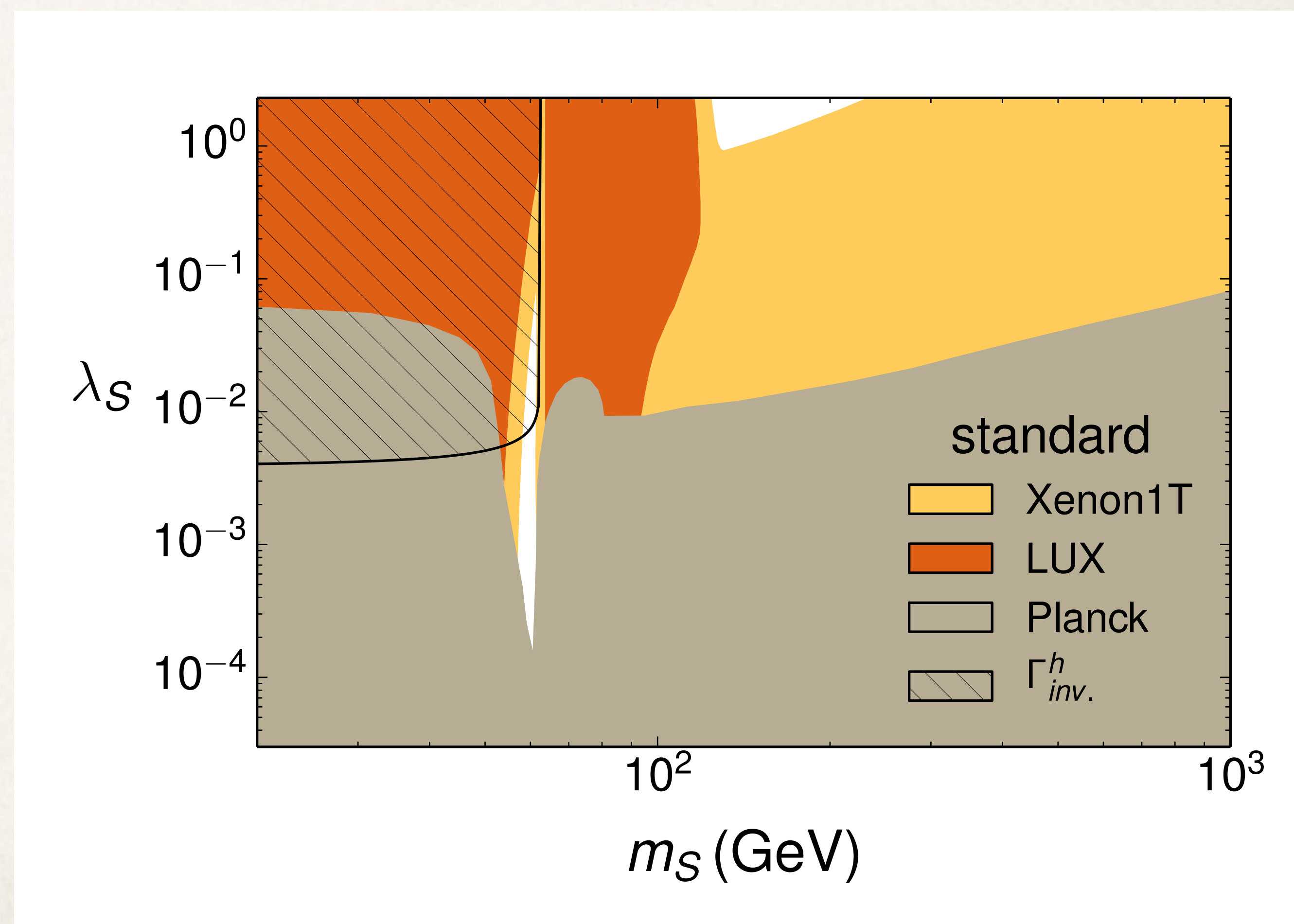


Predictive scenario

e.g. Scalar DM

$$\boxed{\mathcal{L} \supset -\frac{\lambda_S}{2} S^2 \Phi^\dagger \Phi}$$

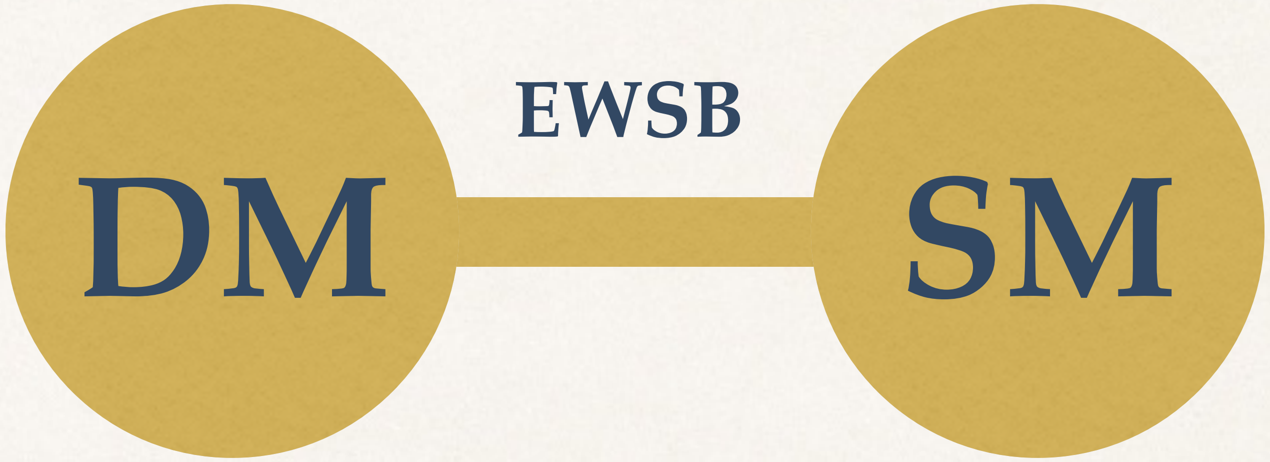
constrained by DD, relic abundance and Higgs invisible width



BRIVIO ET AL. 1511.01099

Higgs portals

In fact, what we mean is



Sensitive to the realization of EWSB

It is unclear whether the breaking is linearly or non-linearly realized

Impact of non-linearity on Higgs portals?

Non-linear Higgs

EWSB: spontaneous breaking
delivers *longitudinal* W,Z polarizations and a another scalar particle (Higgs)

Generic parametrization of the would-be GBs

$$\mathbf{U}(x) \equiv e^{i\sigma_a \pi^a(x)/v}$$

with covariant derivative

$$\mathbf{D}_\mu \mathbf{U}(x) \equiv \partial_\mu \mathbf{U}(x) + \frac{ig}{2} W_\mu^a(x) \sigma_a \mathbf{U}(x) - \frac{ig'}{2} B_\mu(x) \mathbf{U}(x) \sigma_3$$

and the Higgs particle
singlet under SU(2), can couple to other singlet combinations of SM fields

Non-linear Higgs

A limiting case of this parametrization is the SM (linear realization)

$$\Phi \equiv \frac{v+h}{\sqrt{2}}\,\mathbf{U}\begin{pmatrix}0\\1\end{pmatrix}$$

Why do we prefer a linear realization? It is **simpler**

Non-linear Lagrangian

ALONSO ET AL. 1212.3305

$$\begin{aligned}\mathscr{L}_h = \;& \frac{1}{2}(\partial_\mu h)(\partial^\mu h)\,\left(1 + c_H\,\xi\,\mathcal{F}_H(h)\right) - V(h) + \\ & - \frac{v^2}{4}\mathrm{Tr}\left[\mathbf{V}^\mu\mathbf{V}_\mu\right]\mathcal{F}_C(h) + c_T\,\xi\,\frac{v^2}{4}\mathrm{Tr}\left[\mathbf{T}\mathbf{V}^\mu\right]\mathrm{Tr}\left[\mathbf{T}\mathbf{V}_\mu\right]\mathcal{F}_T(h) + \\ & - \left(\frac{v}{\sqrt{2}}\bar{Q}_L\mathbf{U}(x)\,\mathbf{Y}\,\mathbf{diag}\left(\mathcal{F}^U_Y(h), \mathcal{F}^D_Y(h)\right)Q_R + \mathrm{h.c.}\right) + \ldots ,\end{aligned}$$

Higgs-gauge

Higgs-fermion

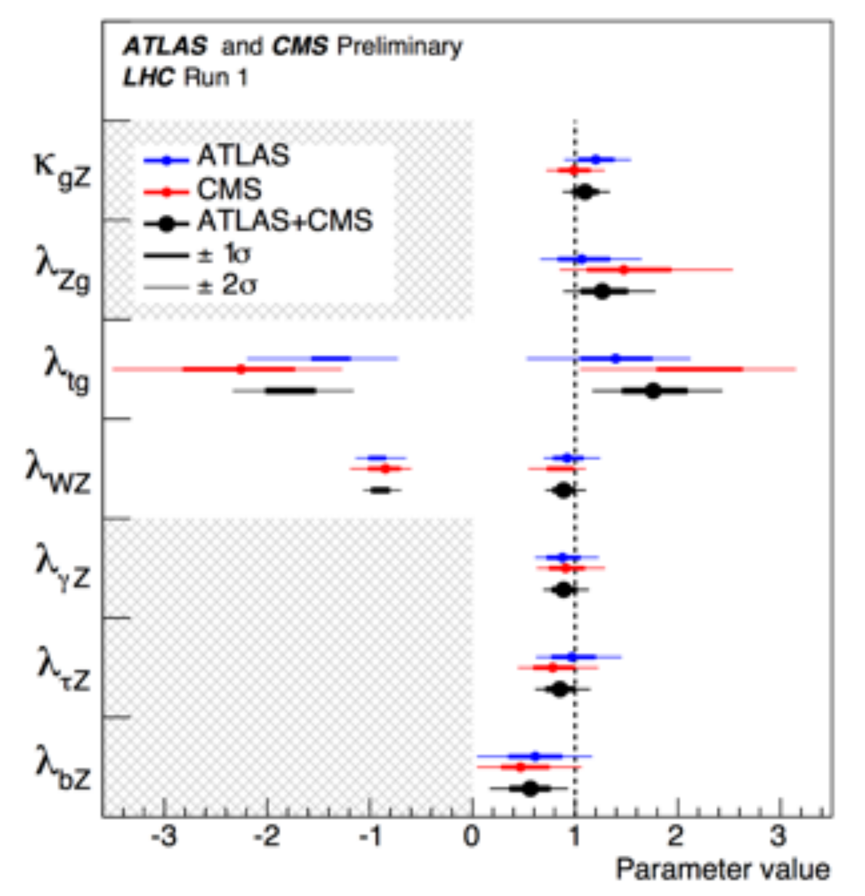
Non-linear Higgs

A limiting case of this parametrization is the SM (linear realization)

$$\Phi \equiv \frac{v+h}{\sqrt{2}}\mathbf{U}\begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

Why do we prefer a linear realization? It is is good agreement with data

rho-parameter and LHC measurements
coupling Higgs to vector bosons



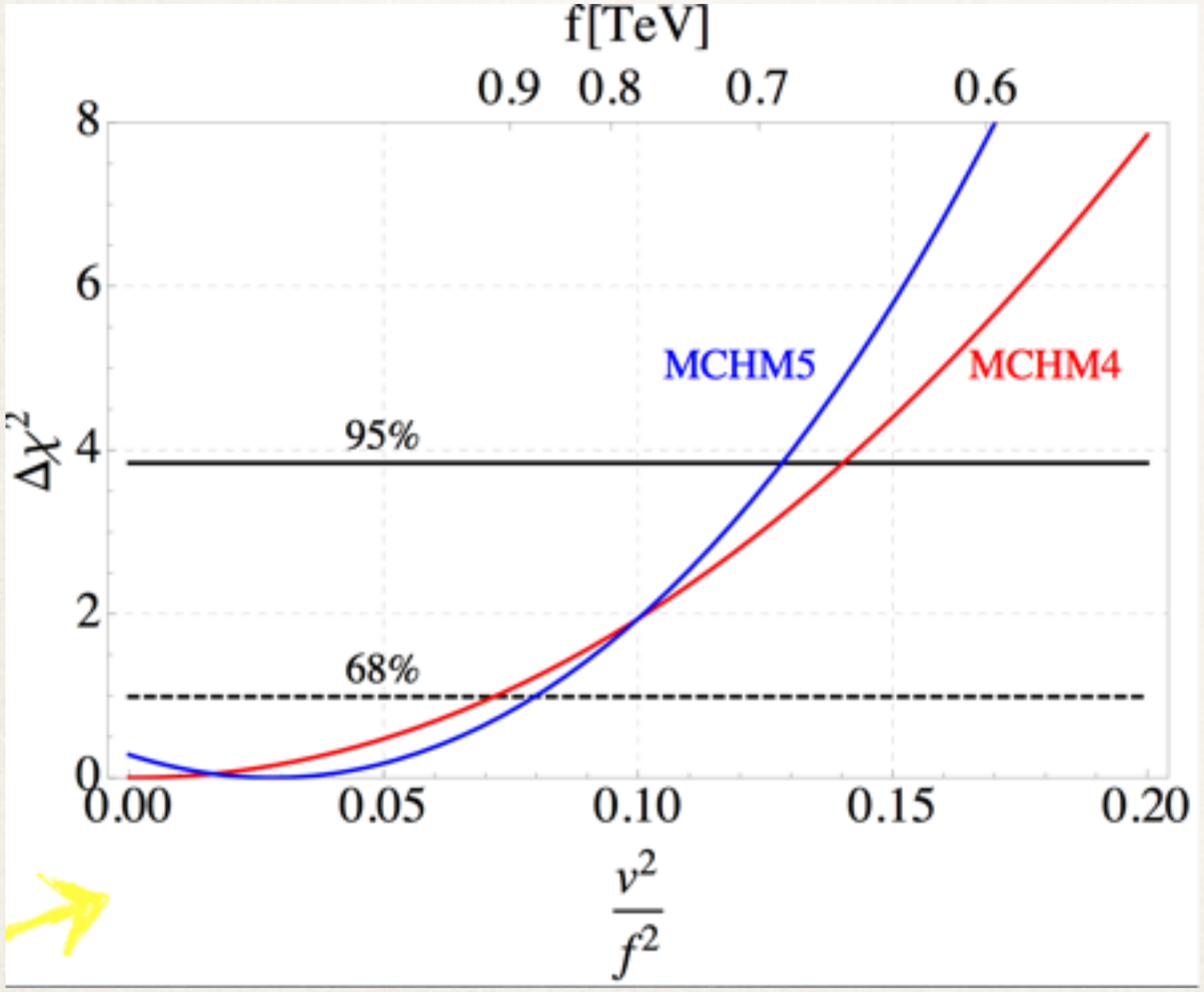
ATLAS+CMS
8 TeV
combination

Non-linear Higgs

Why do we consider non-linear realizations?

Needs to be tested, and it is a generic feature in

Composite Higgs models



FALKOWSKI'S TALK AT HC

Current constraints are still

weak

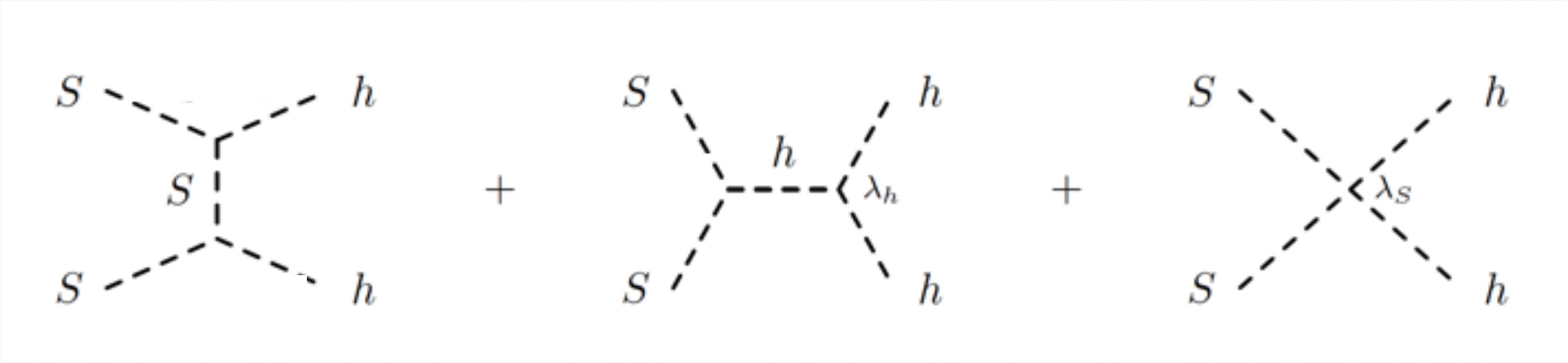
scale of non-linearity

f ~ 600 GeV

Linear vs non-linear portals

Linear: DM coupling to one and two Higgses are related

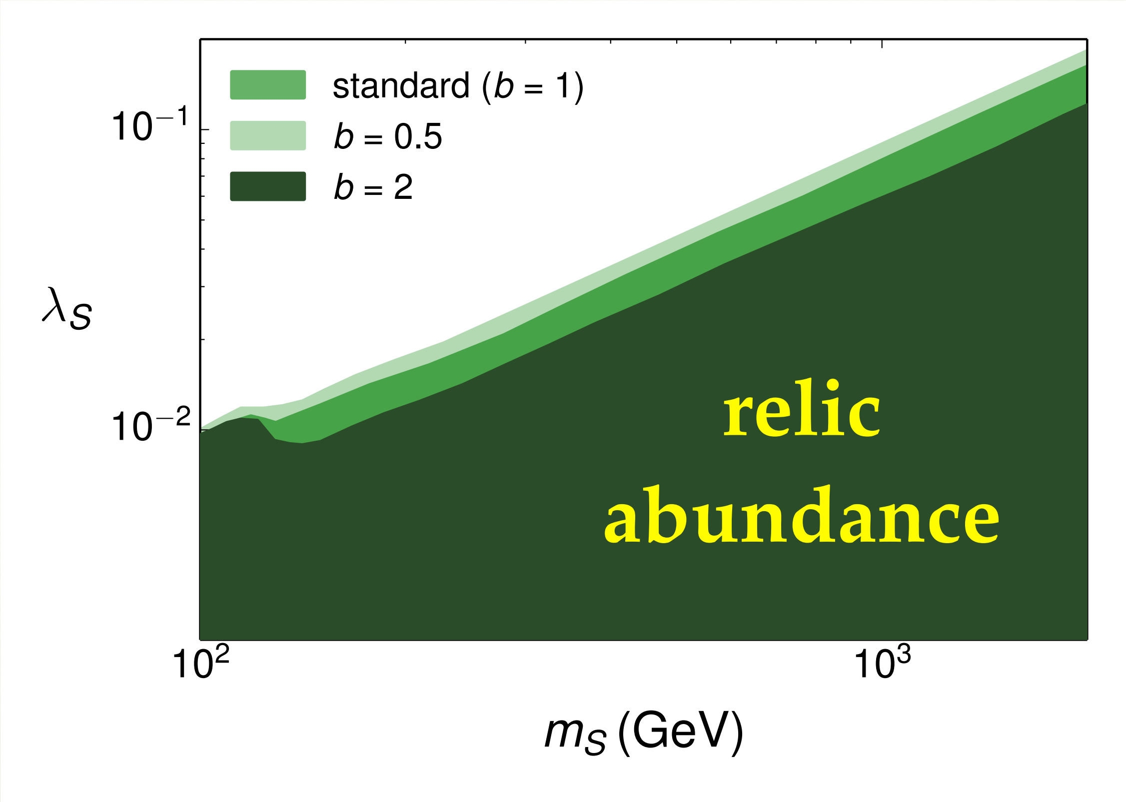
$$\lambda_S S^2 \Phi^\dagger \Phi \longrightarrow \lambda_S S^2 (v+h)^2 \longrightarrow \lambda_S S^2(2vh + h^2)$$



Non-linear: DM coupling to Higgs is a generic function

$$\lambda_S S^2(2vh + b\, h^2)$$

yet the effect is not dramatic, dominated by SS->WW



Linear vs non-linear portals

Linear: Power-counting of interactions is the usual one

$$\mathcal{L} \supset -\frac{\lambda_S}{2} S^2 \, \Phi^\dagger \Phi$$

Higgs portal: dim-4 interaction

Non-linear: Power-counting as in the pion Chiral Lagrangian

$$\mathscr{L}_S = \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{m_S^2}{2} S^2 \mathcal{F}_{S_1}(h) - \lambda S^4 \mathcal{F}_{S_2}(h) + \sum_{i=1}^{5} c_i \mathcal{A}_i(h)$$

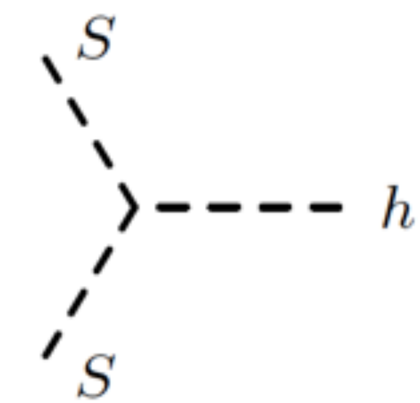
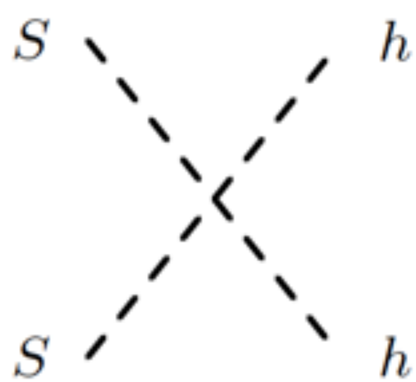
$$\left.\begin{aligned} \mathcal{A}_1 &= \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) S^2 \mathcal{F}_1(h) \\ \mathcal{A}_2 &= S^2 \Box \mathcal{F}_2(h) \end{aligned}\right\} \quad \text{Custodial Preserving}$$

$$\left.\begin{aligned} \mathcal{A}_3 &= \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\,\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) S^2 \mathcal{F}_3(h) \\ \mathcal{A}_4 &= i\,\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)(\partial^\mu S^2)\mathcal{F}_4(h) \\ \mathcal{A}_5 &= i\,\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) S^2 \partial^\mu \mathcal{F}_5(h) \end{aligned}\right\} \quad \text{Custodial Violating}$$

$$\mathcal{F}_i(h) \equiv 1 + 2\,a_i\,h/v + b_i\,h^2/v^2 + \mathcal{O}(h^3/v^3)$$

Non-linear portals

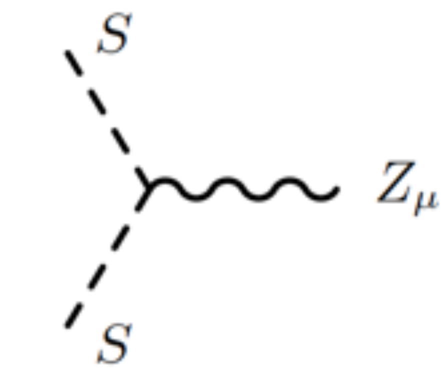
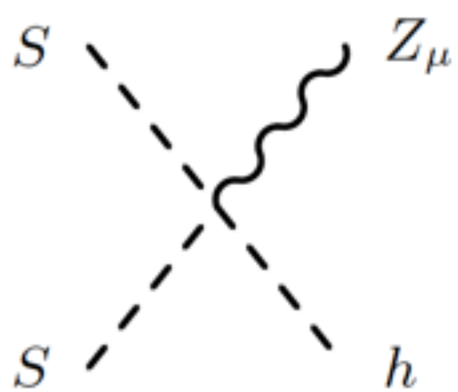
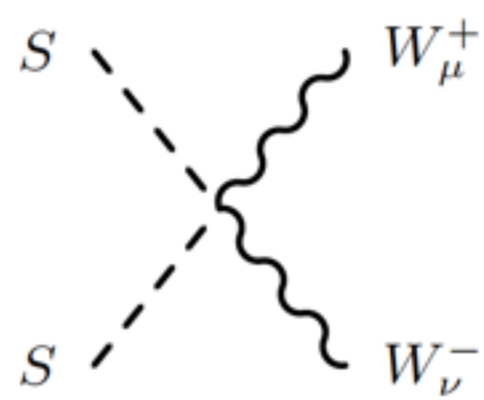
New structures in the Higgs-DM interactions appear at leading-order in the chiral Lagrangian

	Linear	**Non-linear**
	$-4i\lambda_S v$	$-4i\left(\lambda_S v + \frac{c_2 a_2 p_h^2}{v}\right)$
	$-4i\lambda_S$	$-4i\left(\lambda_S b + \frac{c_2 b_2 (p_{h1} + p_{h2})^2}{v^2}\right)$

new momentum dependence

Non-linear portals

New interactions with gauge bosons

	Linear	**Non-linear**
	–	$\frac{2gc_4}{c_\theta} p_Z^\mu$
	–	$\frac{4g}{vc_\theta} \left(c_4 a_4 (p_Z + p_h)^\mu - c_5 a_5 p_h^\mu\right)$
	–	$-2ig^2 c_1 g_{\mu\nu}$

+ SSZZ

note momentum dependence

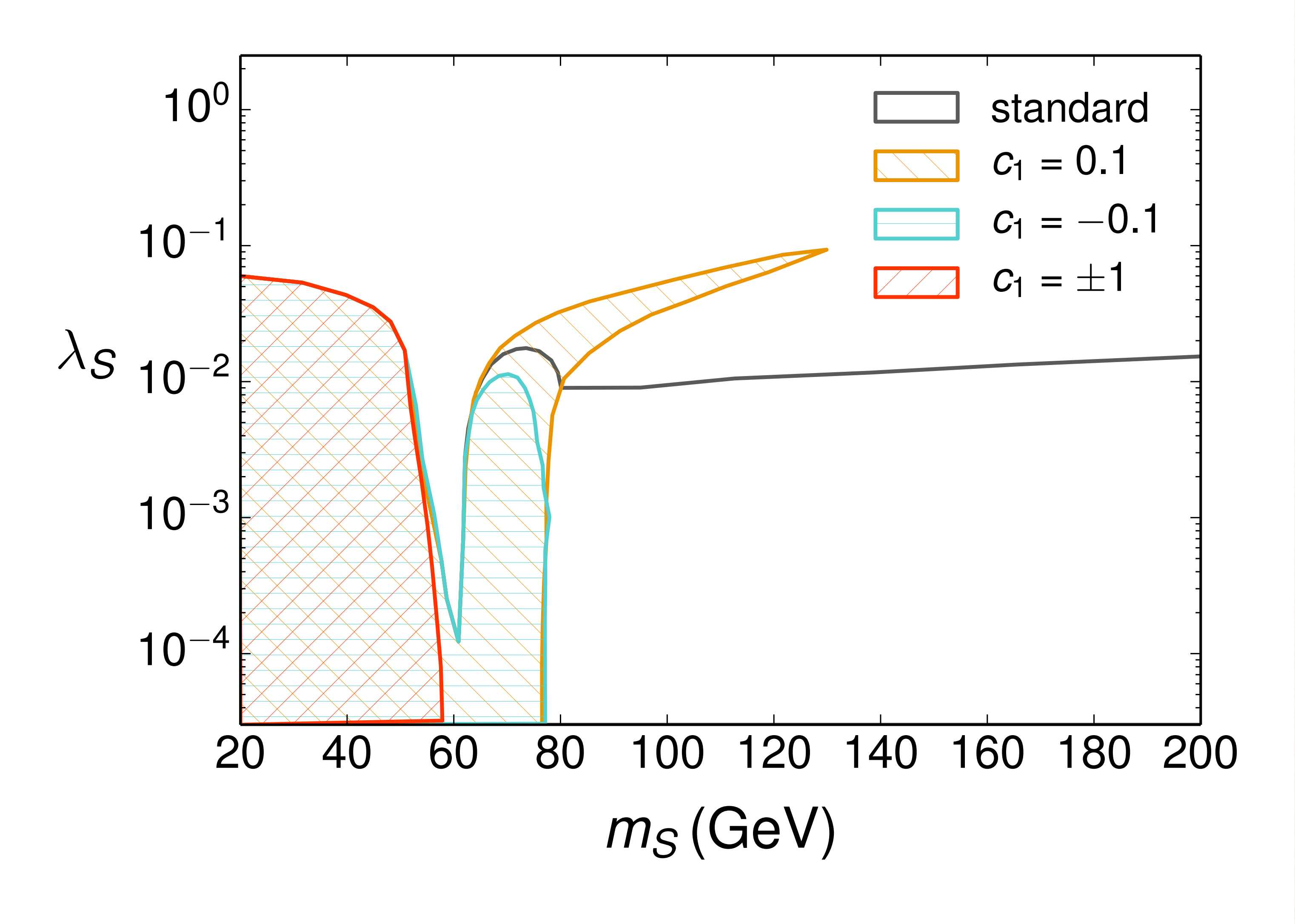
Non-linear portals: Relic abundance

The new interactions open up the parameter space, especially at high-mass where WW dominates
Excluded region is modified

e.g. coupling to WW via c1

negative c1: positive interference with linear coupling opens up parameter space

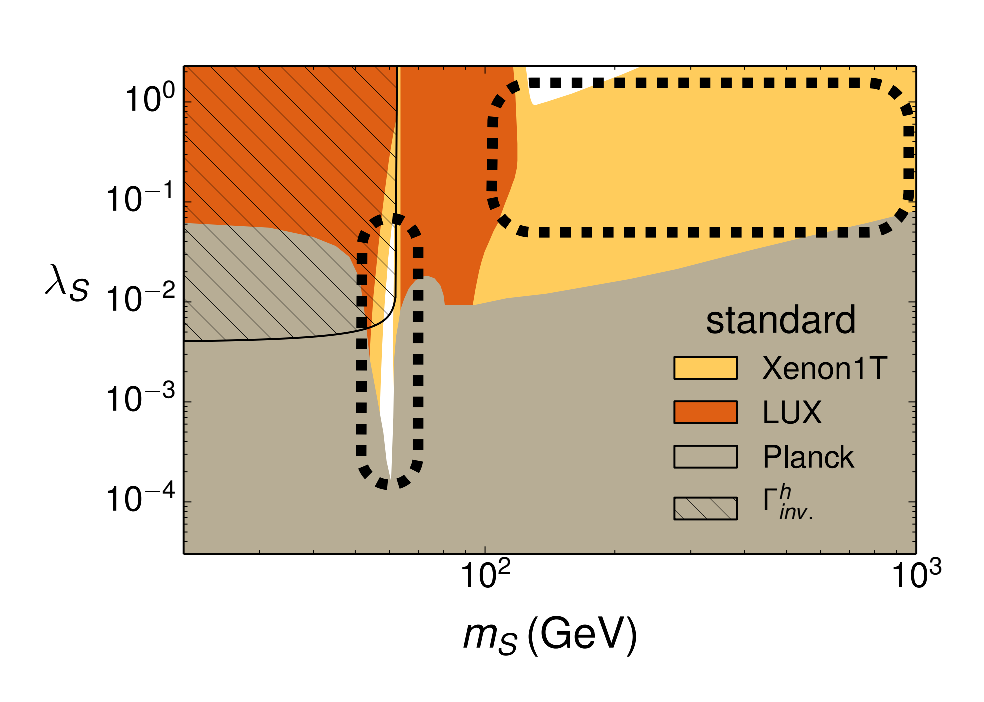
positive c1: cancellations are possible, rule out new regions



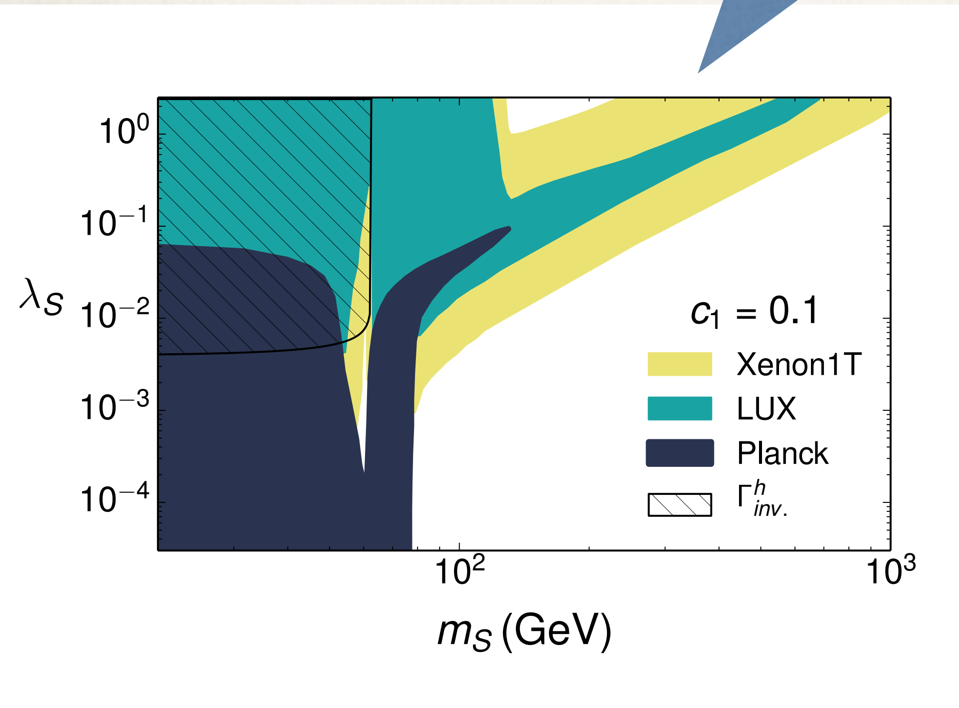
Non-linear portals: including direct detection

The new interactions open up the parameter space

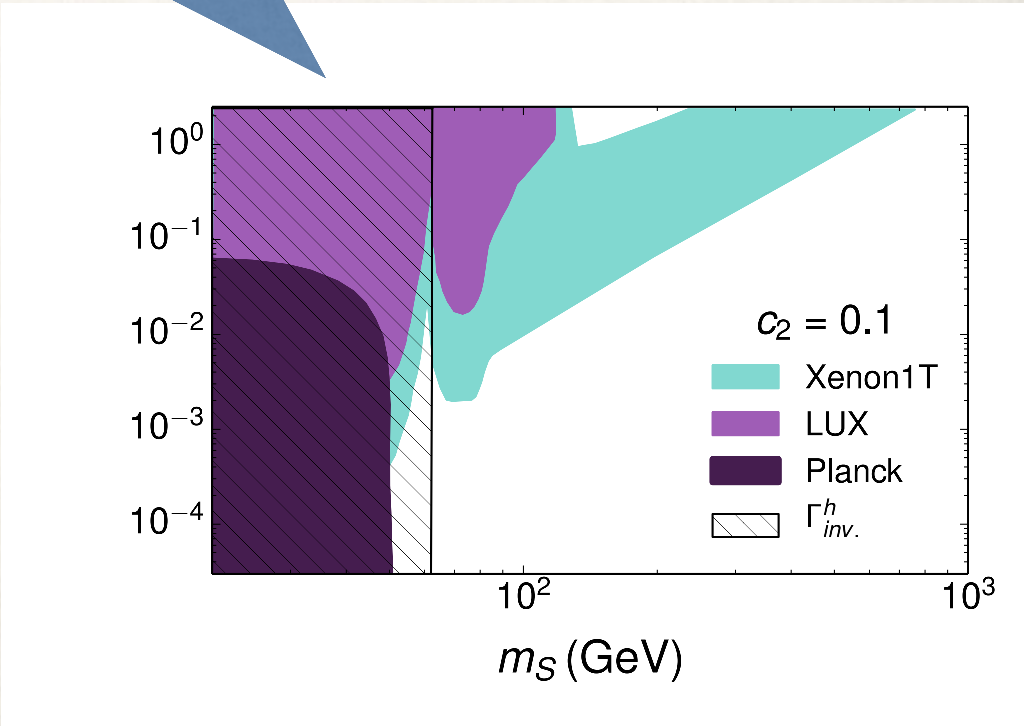
DD sensitivity depends on the values of non-linear interactions



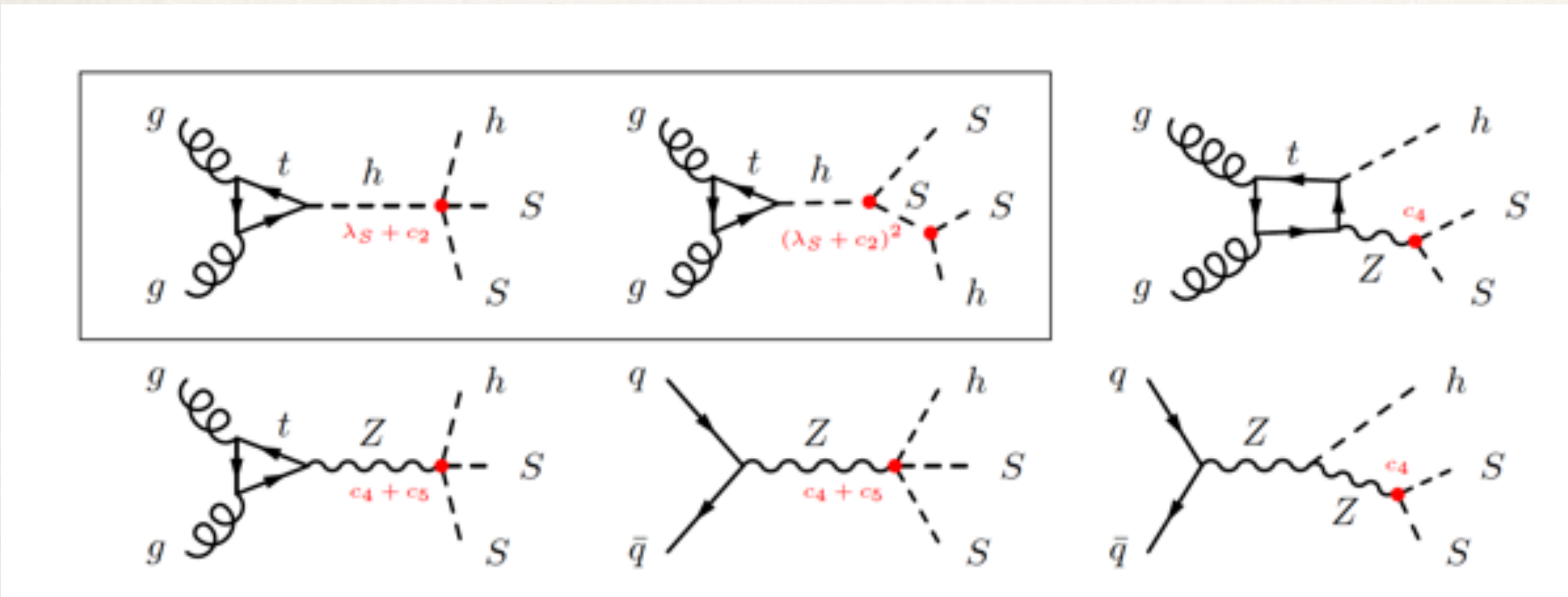
excluded regions



excluded regions

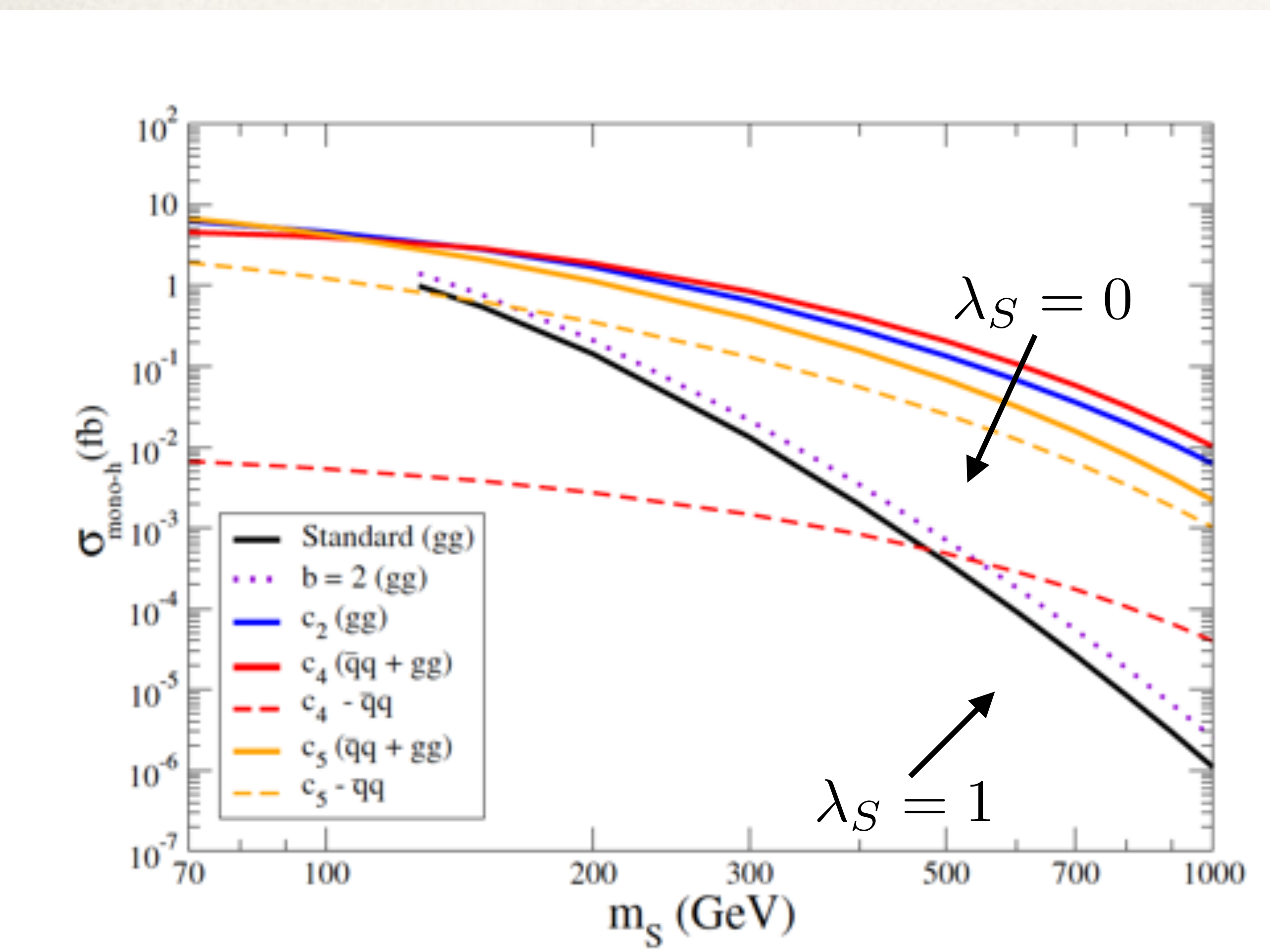


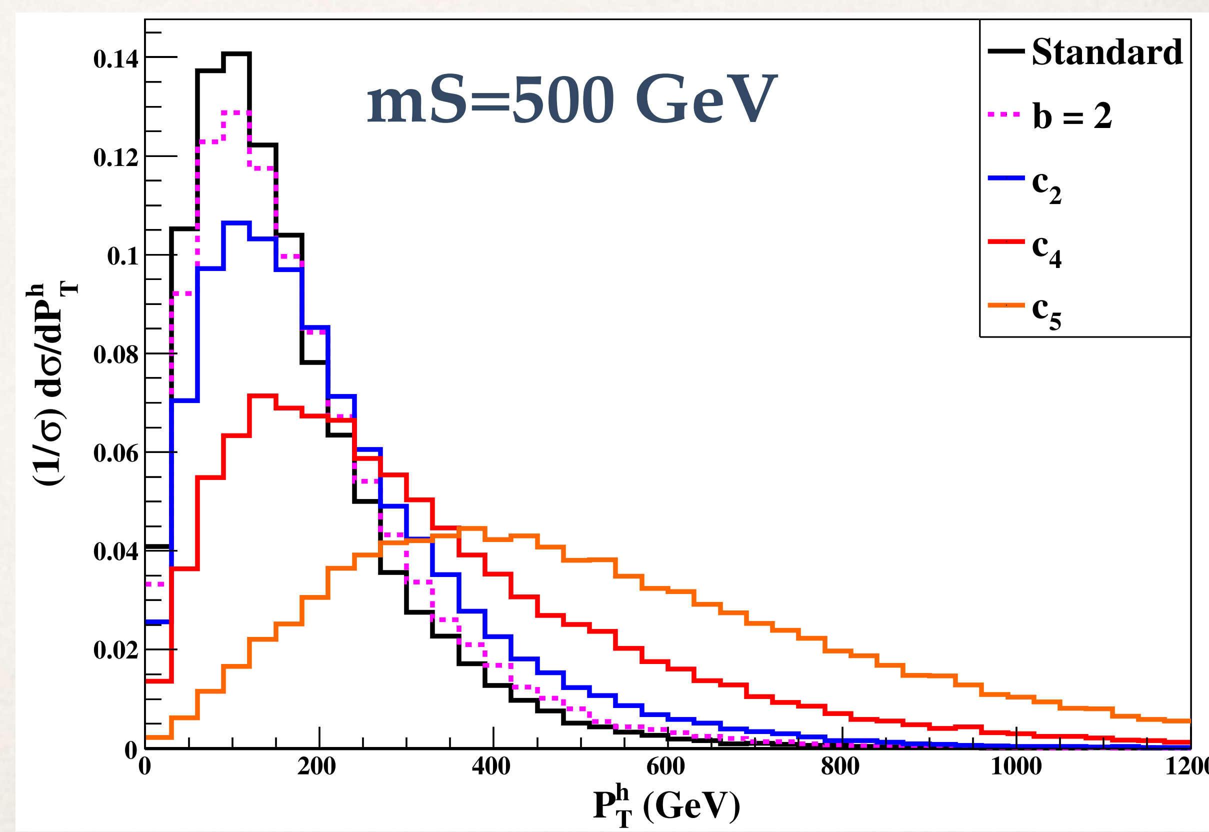
Non-linear portals: new collider signatures



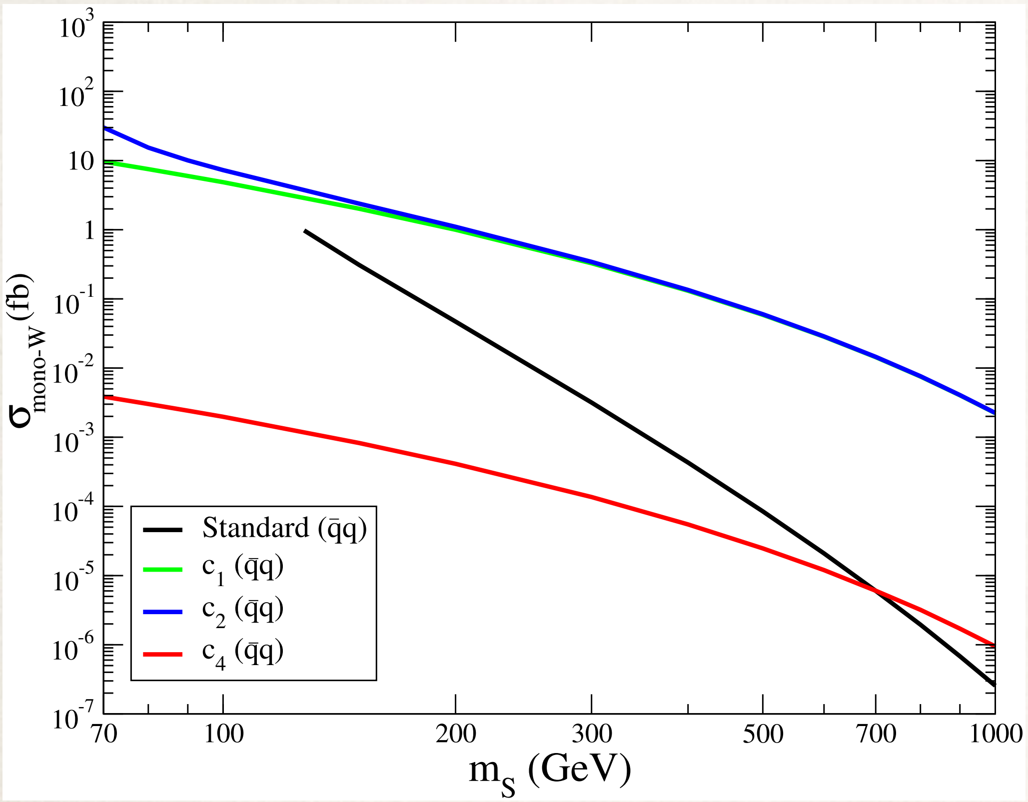
Mono-Higgs channel can be produced via EW bosons

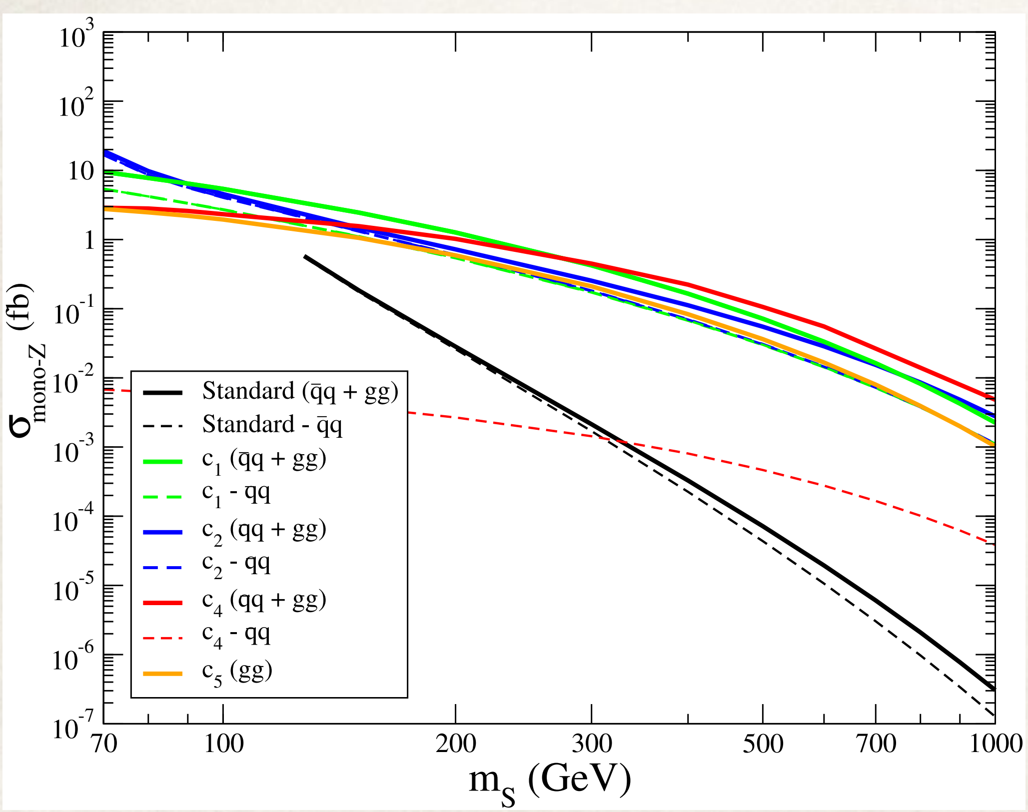
momentum-dependent coupling characteristic cross sections and differential distributions





Non-linear portals: new collider signatures

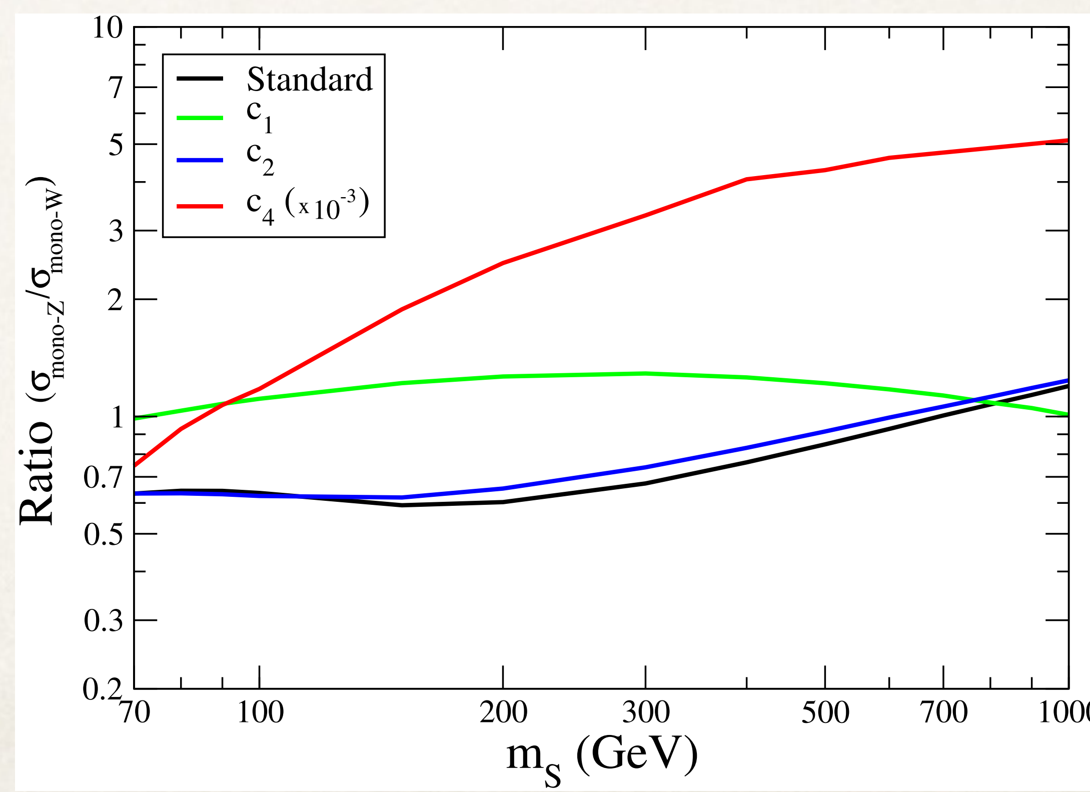




Mono-(W,Z) channels

again, very different cross sections and differential distributions (help on reducing BG)

ratio of measurements:
a possible *smoking gun* for non-linearity



Summary

- The *standard* Higgs portal: largely ruled out by relic abundance+DD, expect tiny signals at the LHC
- The Higgs portal is actually a portal via the sector breaking EW symmetry. EWSB could be non-linearly realized, then modifications to the portal are expected
- Non-linearity opens up a large region of the parameter space, it correlates with larger signals at LHC
- **Much more work to be done:** other non-scalar portals, could provide a benchmark to non-standard direct detection, new correlations with indirect detection