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Simplified models for resonant neutral scalar production with missing transverse energy final states.

Work done in collaboration with Henning Bahl and Georg Weiglein

arXiv: 2112.12656

19 MULTIDARK CONSOLIDER WORKSHOP

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Introduction.

- After the 125 GeV SM-like Higgs discovery no hints for BSM physics have been found.

- There is room for extending the scalar sector of the SM with additional scalars. This could resolve open problems as the source of CP-violation for baryon asymmetry or it could be related with Dark Matter.

- Experimental searches rely on models such as the THDM or the THDMa to translate the data into actual models. This is quite restrictive since other BSM models are missrepresented.

- The solution to this problem is to find a model independent approach to read the data in such a way that different topologies of this approach can be identified with different BSM models.

Simplified Models for BSM Higgs searches.

- In order to study a general BSM Higgs sector we introduce these simplified models.
- Our simplified model approach is an extension of the SM with a heavy scalar, one mediator and one invisible particle.

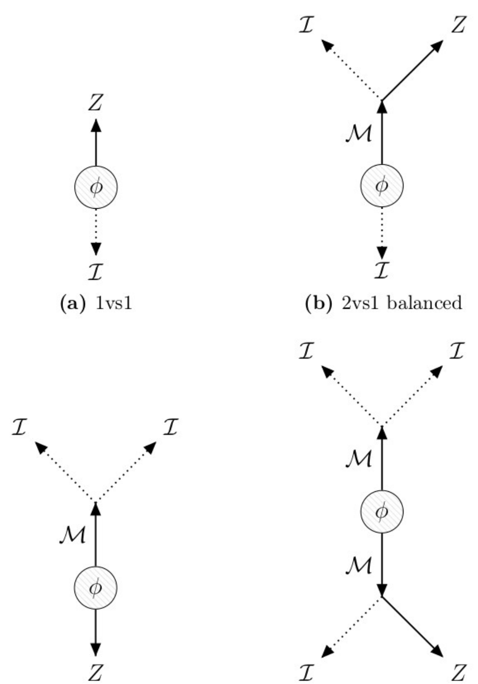
  - heavy scalar: ϕ,
  - neutral mediator: $\mathcal{M}_S$, $\mathcal{M}_F$, $\mathcal{M}_V$,
  - charged mediator: $\mathcal{M}_S^\pm$, $\mathcal{M}_F^\pm$, $\mathcal{M}_V^\pm$,
  - invisible particle: $\mathcal{I}_S$, $\mathcal{I}_F$, $\mathcal{I}_V$,

Where the subscripts represent the spin nature, S stands for scalar, F for fermion and V for vector.

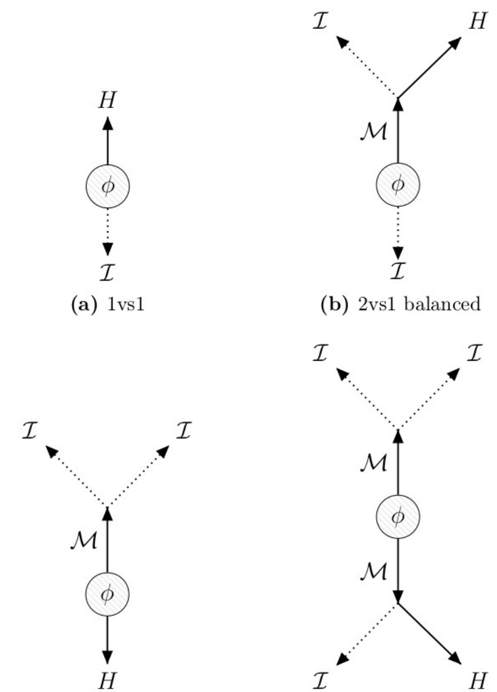
Simplified Models for BSM Higgs searches.

- Following this approach there are multiple signatures that one can study: Mono-Z/H, dilepton, diboson + missing transverse energy.

  - Mono-Z/H + missing transverse energy.



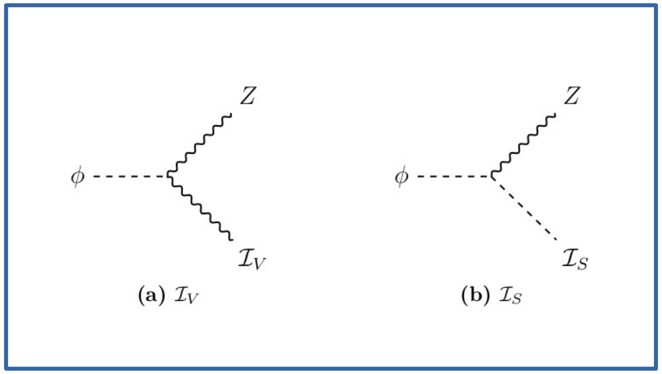
(a) 1vs1 (b) 2vs1 balanced (c) 2vs1 unbalanced (d) 2vs2 unbalanced

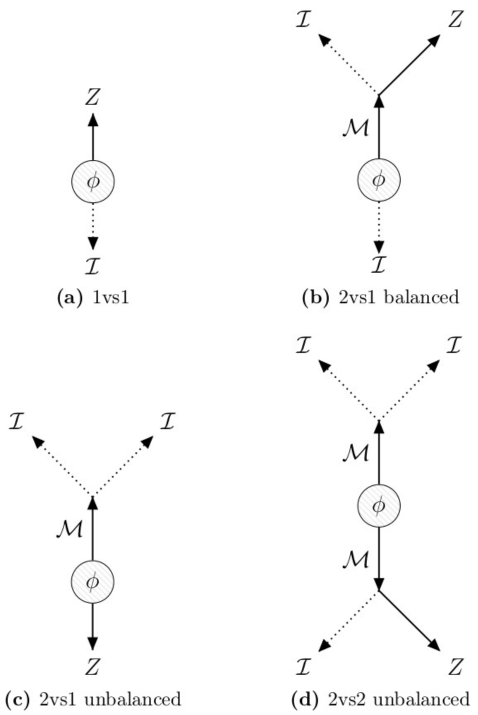


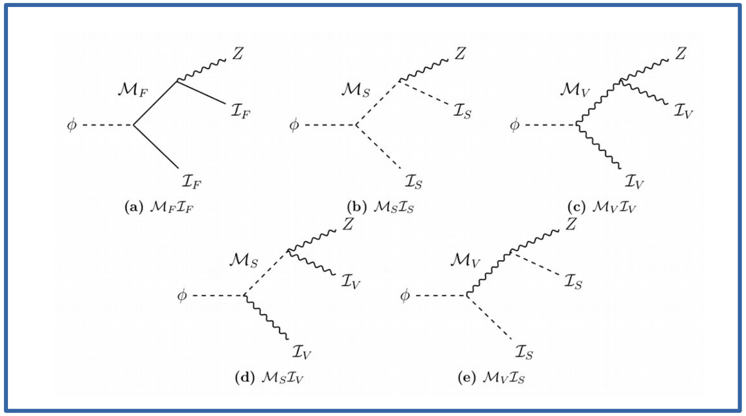
(a) 1vs1 (b) 2vs1 balanced (c) 2vs1 unbalanced (d) 2vs2

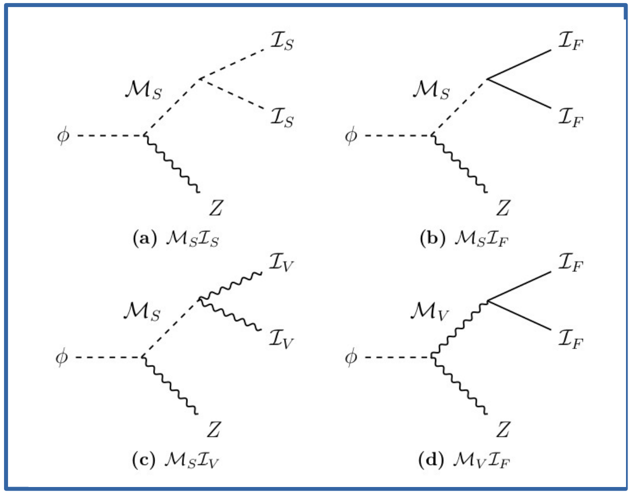
Simplified Models for BSM Higgs searches.

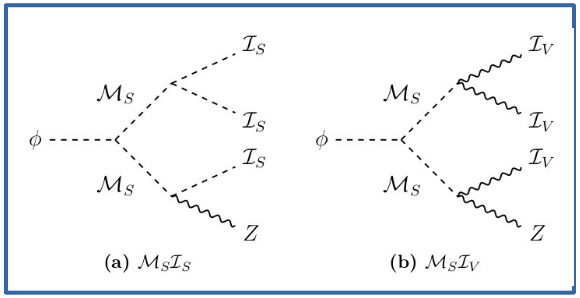
Mono-Z + missing transverse energy signature: we can explore the Feynman diagrams for each topology.







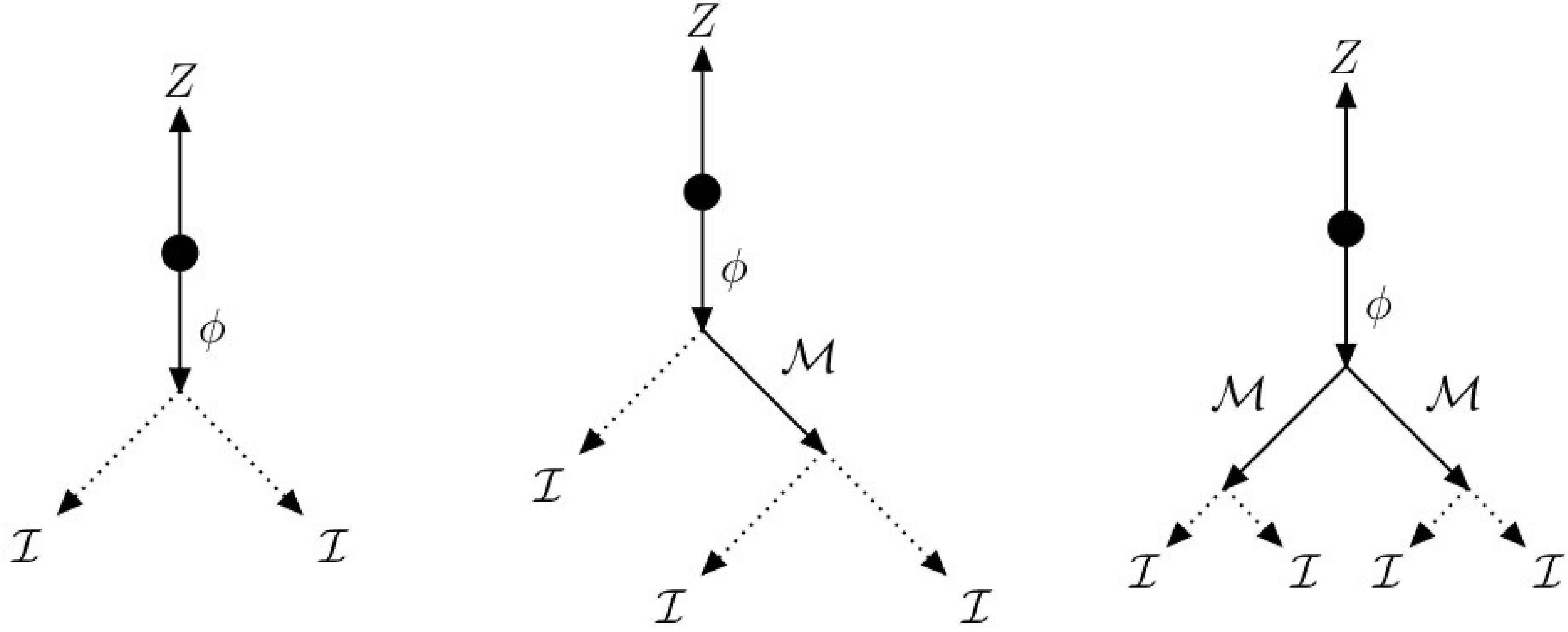




Simplified Models for BSM Higgs searches.

- Mono-Z + missing transverse energy signature: we can explore the Feynman diagrams for each topology.

  - We can also have the Z radiated from the initial state:

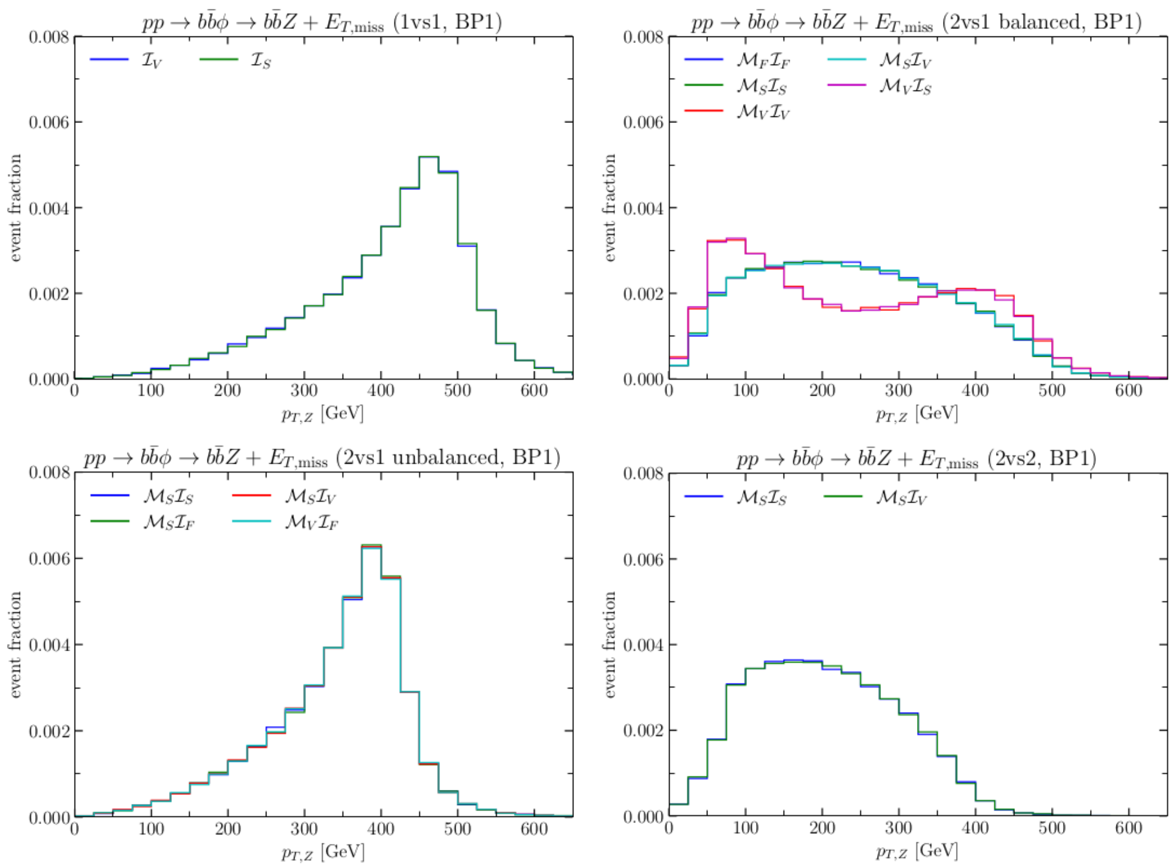


Simplified Models for BSM Higgs searches.

- We have implemented these simplified models in a UFO model file using FeynRules.
- In order to study the impact of the different diagrams we have simulated the mono-Z signature using MadGraph5_aMC@NLO, Pythia 8 and Delphes 3 and we have analysed the results using MadAnalysis 5.
- For the numerical analysis we have chosen 4 benchmark points:
  - BP1: $m_\phi = 1$ TeV, $m_{\mathcal{M}} = 400$ GeV, $m_{\mathcal{I}} = 10$ GeV,
  - BP2: $m_\phi = 1$ TeV, $m_{\mathcal{M}} = 400$ GeV, $m_{\mathcal{I}} = 100$ GeV,
  - BP3: $m_\phi = 1$ TeV, $m_{\mathcal{M}} = 260$ GeV, $m_{\mathcal{I}} = 10$ GeV,
  - BP4: $m_\phi = 1.5$ TeV, $m_{\mathcal{M}} = 400$ GeV, $m_{\mathcal{I}} = 10$ GeV.

Simplified Models for BSM Higgs searches.

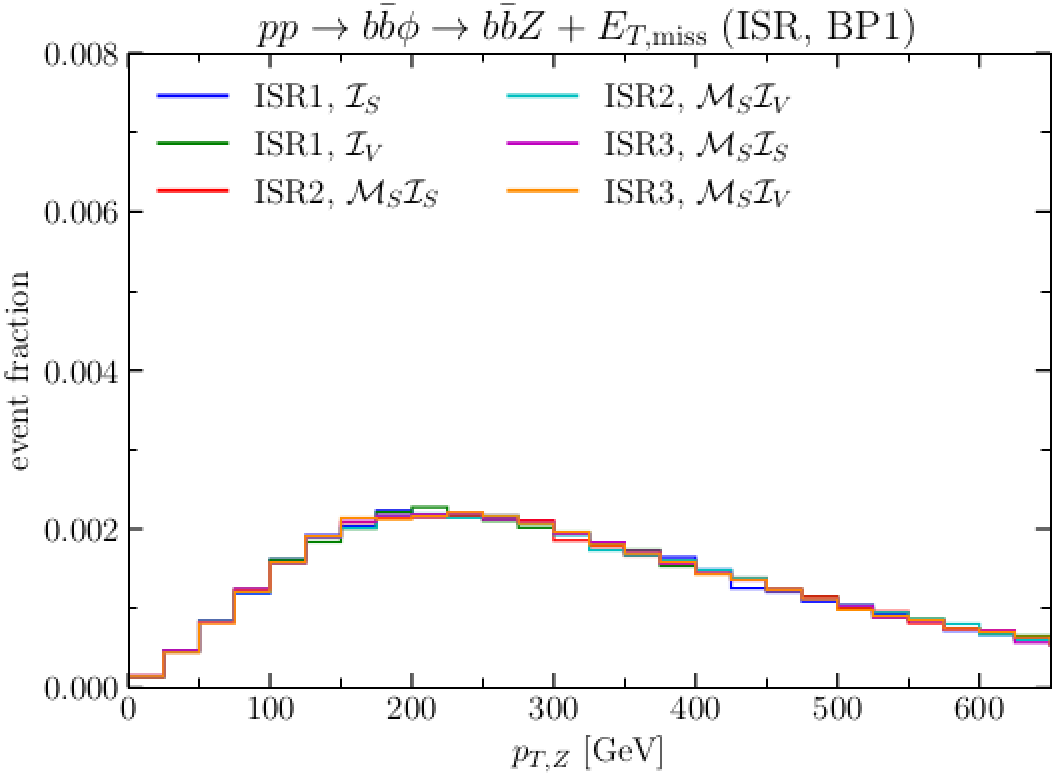
Mono-Z + missing transverse energy.



Spin of mediators has relatively small impact (except for vector mediators).

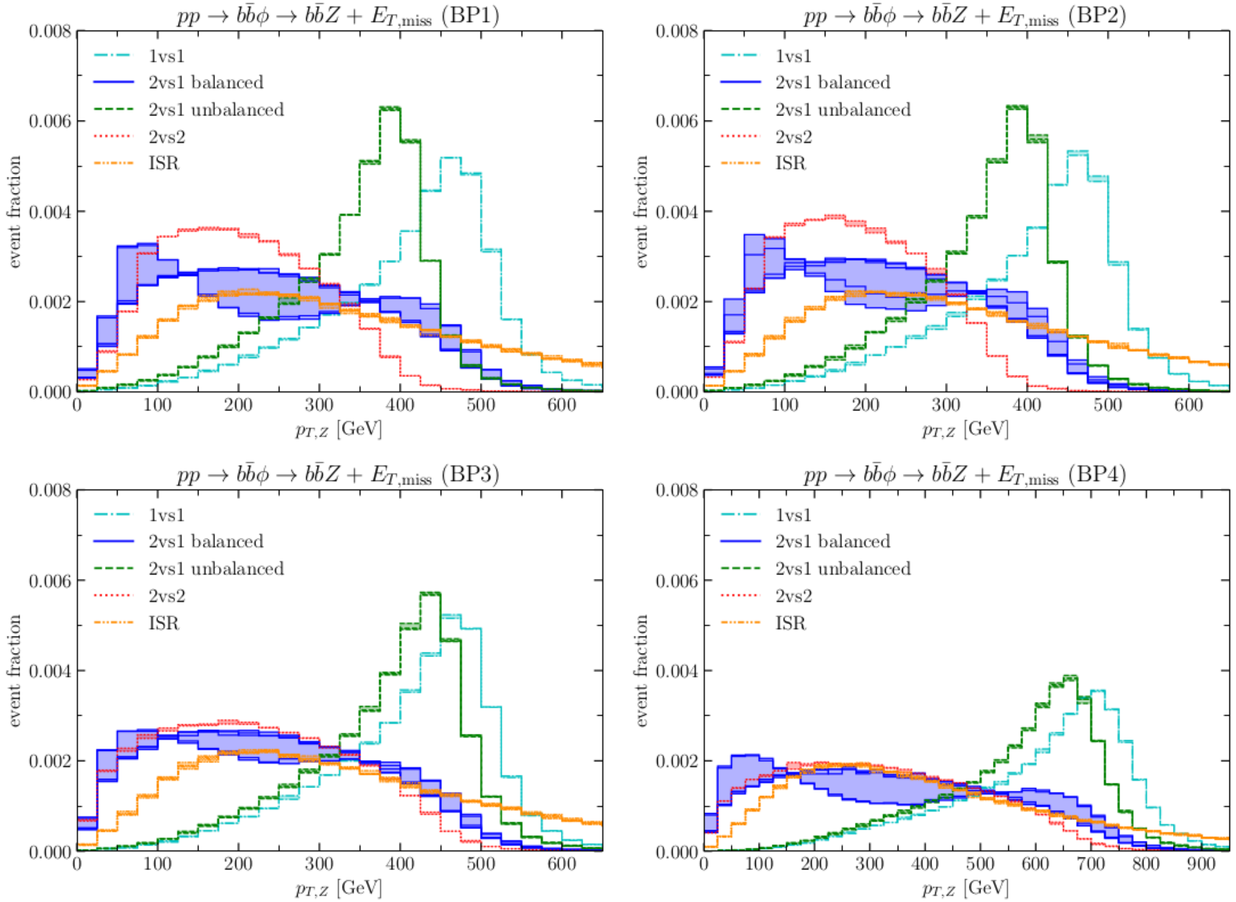
Simplified Models for BSM Higgs searches.

Mono-Z + missing transverse energy.



Simplified Models for BSM Higgs searches.

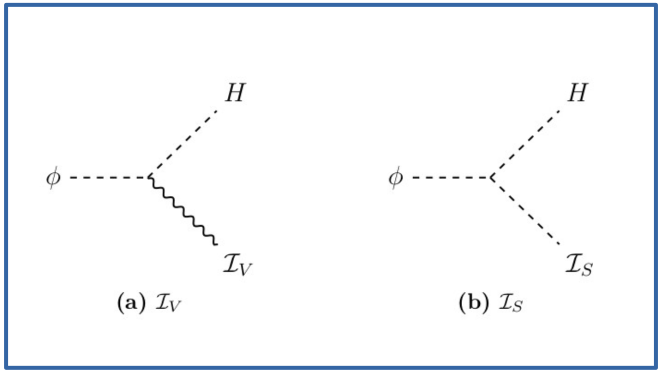
Mono-Z + missing transverse energy.

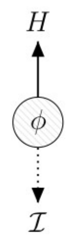


High sensitivity to different model topologies, invisible particle mass has almost no impact.

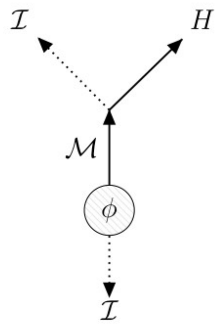
Simplified Models for BSM Higgs searches.

Mono-H + missing transverse energy.

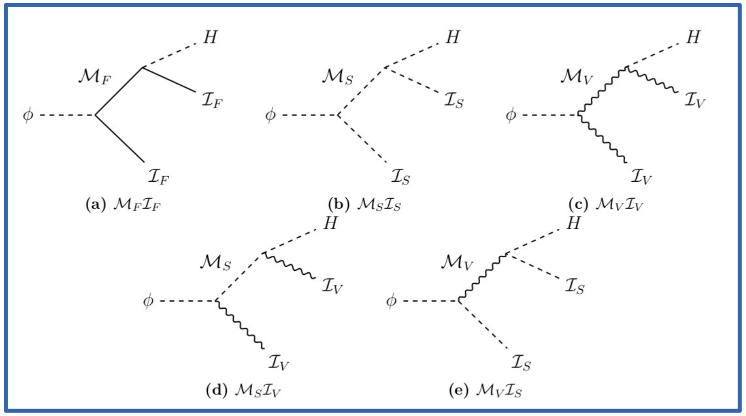


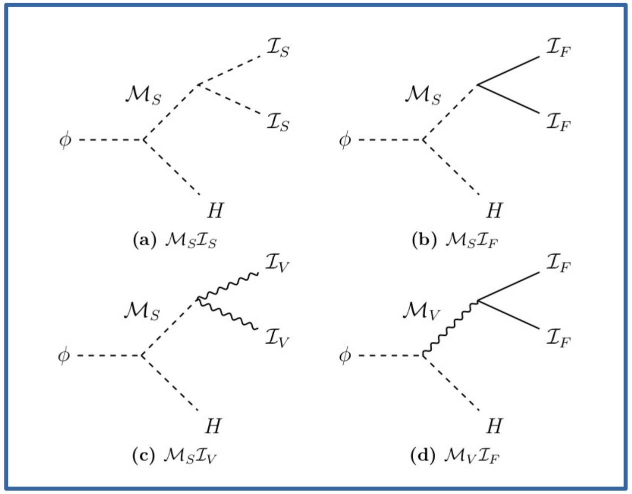


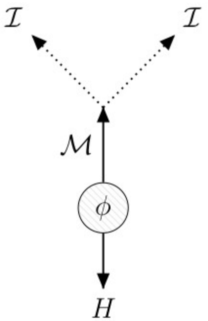
(a) 1vs1



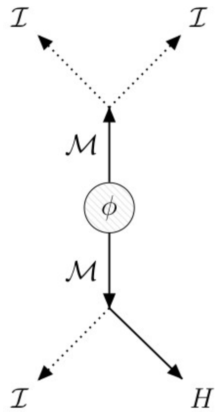
(b) 2vs1 balanced



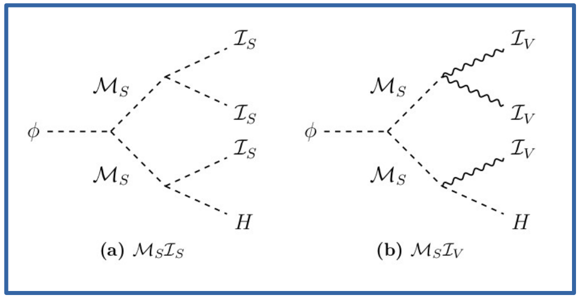




(c) 2vs1 unbalanced

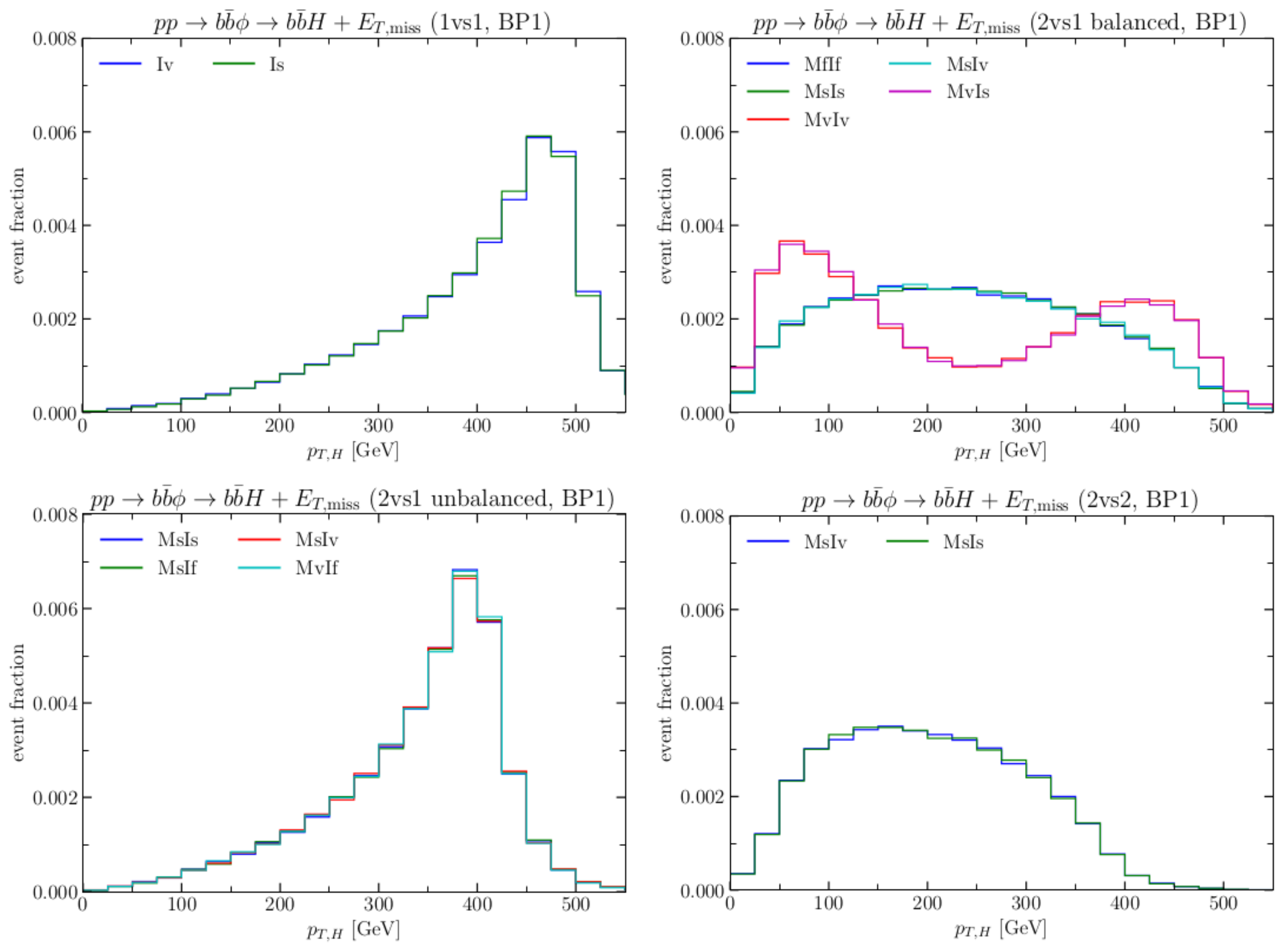


(d) 2vs2



Simplified Models for BSM Higgs searches.

Mono-H + missing transverse energy.



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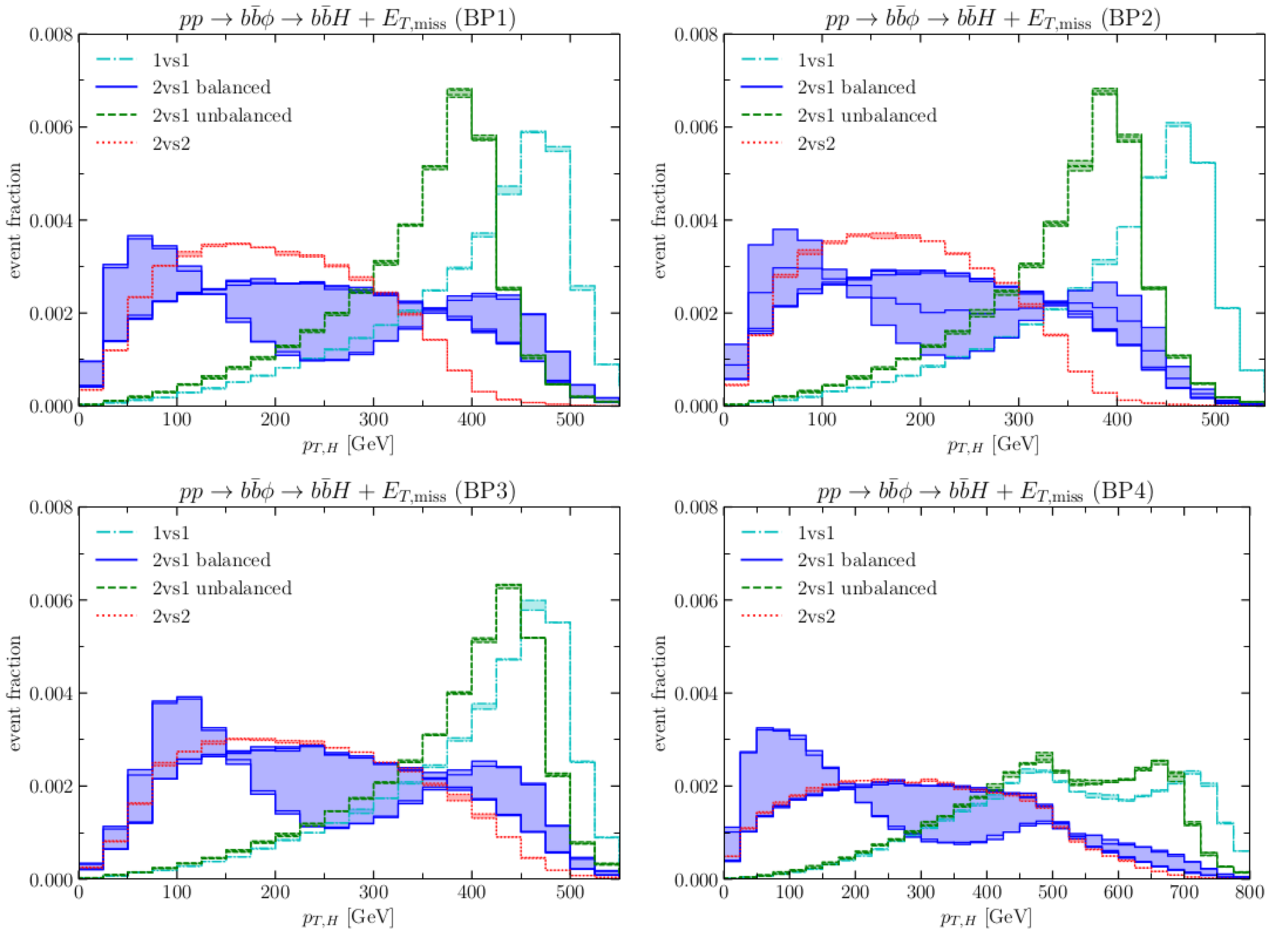
Simplified Models for BSM Higgs searches.

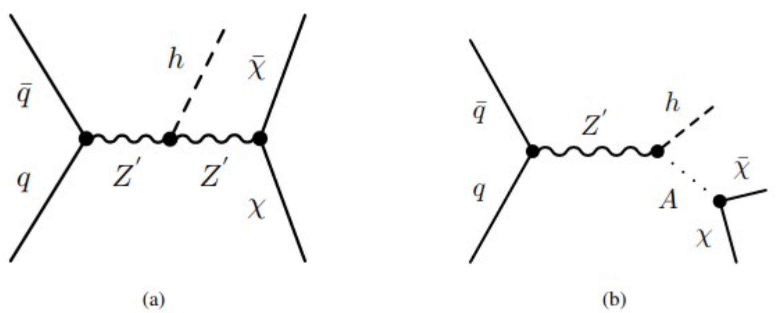
Mono-H + missing transverse energy.



High sensitivity to different model topologies, invisible particle mass has almost no impact.

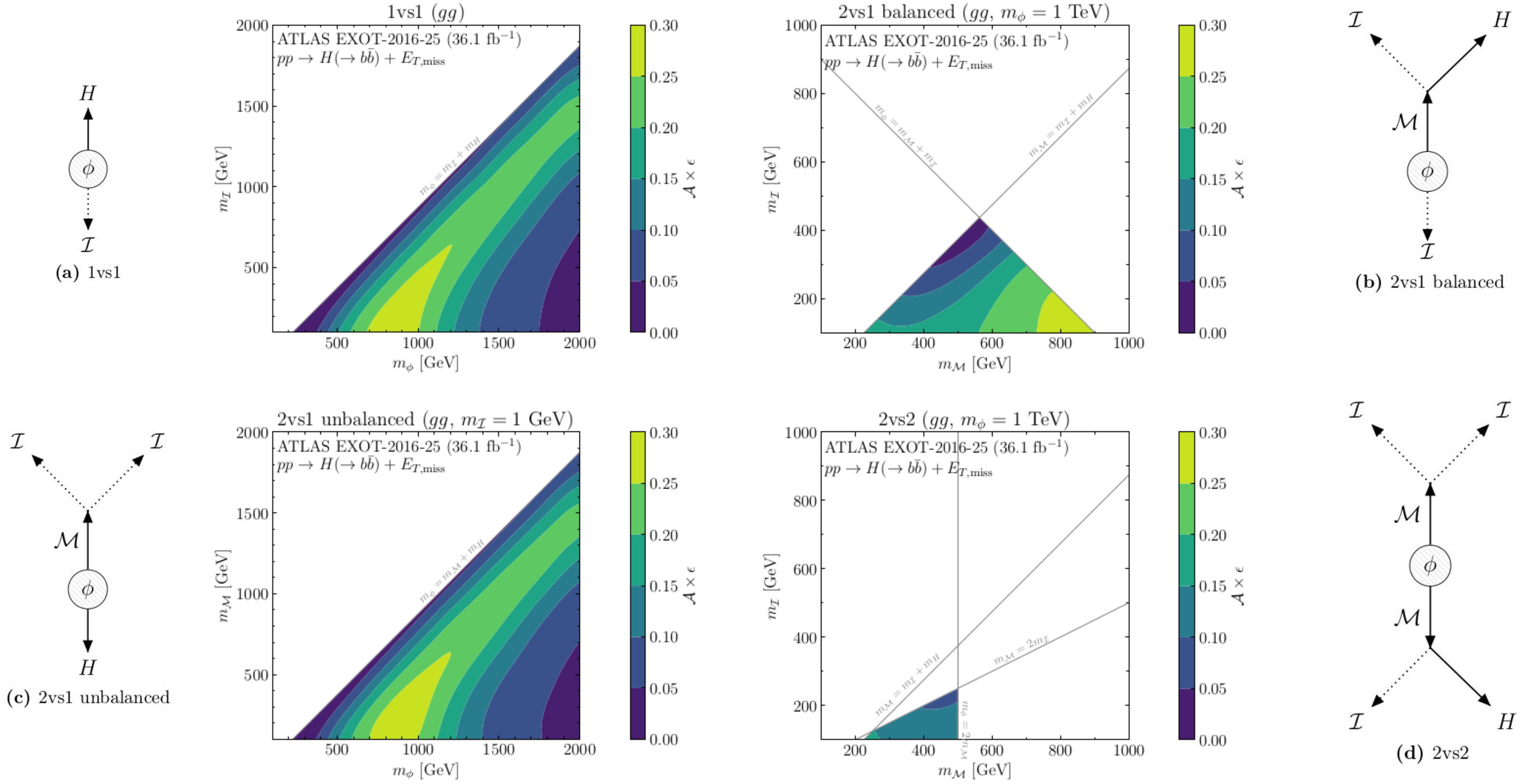
Example.

- We take an ATLAS search of mono-Higgs plus missing energy.
- "Search for Dark Matter Produced in association with a Higgs boson Decayin to bb using 36 fb^{-1} of pp collisions at $\sqrt{s}=13$ TeV with the ATLAS detectorin association". Phys. Rev. Lett 119 (2017) 181804 (arXiv: 1707.01302)



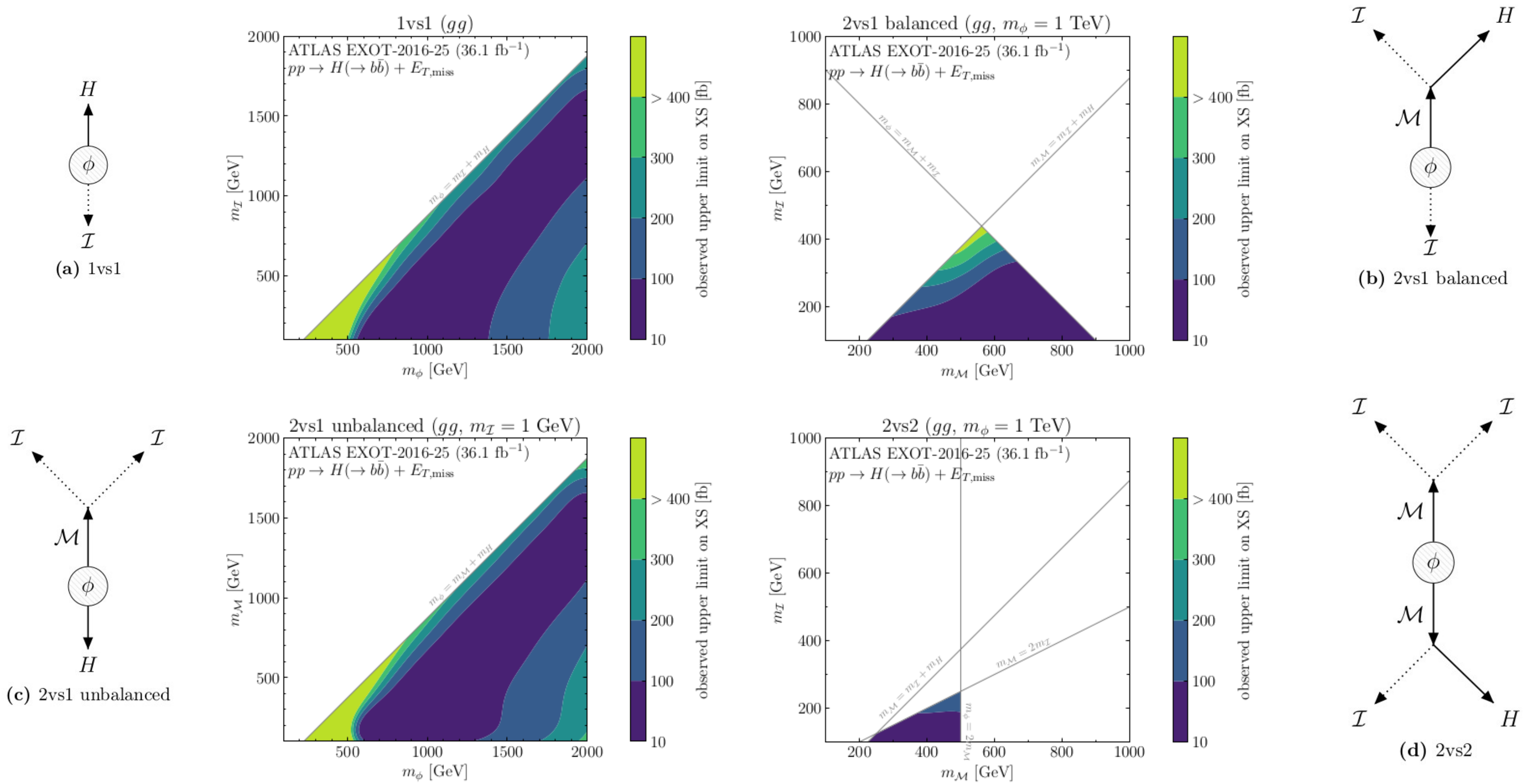
- The search requires $E_T^{\text{miss}} \geq 150$ GeV and two b-jets.
- The search is partially implemented in MadAnalysis, only the resolved signal region is available ($E_T^{\text{miss}} \leq 500$ GeV) $\rightarrow$ Lower acceptance to the high mass region.
- We test every topology against the experimental data.

Example.



Acceptance x efficiency maps can be used in order to set up exclusion limits for a wide range of BSM models.

Example.



(a) 1vs1

(b) 2vs1 balanced

(c) 2vs1 unbalanced

(d) 2vs2

Exclusion limits can be derived in terms of physical quantities (mass of the particles and cross sections).

MSSM interpretation.

- We take the MSSM and we focus on the 2vs1 balanced topology.
- We consider the production of a Heavy Higgs boson and its subsequent decay into two neutralinos.One of them is the lightest neutralino, $\tilde{\chi}_1$ that remains invisible while the other could be either $\tilde{\chi}_3$ or $\tilde{\chi}_2$. These will decay into the 125 GeV Higgs boson and the lightest neutralino.
- We have then eight different subchannels contributing to the mono Higgs plus $E_T^{\rm miss}$

  - $gg \to H \to \tilde{\chi}_2\tilde{\chi}_1 \to \tilde{\chi}_1\tilde{\chi}_1 h,$
  - $gg \to H \to \tilde{\chi}_3\tilde{\chi}_1 \to \tilde{\chi}_1\tilde{\chi}_1 h,$
  - $gg \to A \to \tilde{\chi}_2\tilde{\chi}_1 \to \tilde{\chi}_1\tilde{\chi}_1 h,$
  - $gg \to A \to \tilde{\chi}_3\tilde{\chi}_1 \to \tilde{\chi}_1\tilde{\chi}_1 h,$
  - $pp \to Hb\bar{b} \to \tilde{\chi}_2\tilde{\chi}_1 b\bar{b} \to \tilde{\chi}_1\tilde{\chi}_1 hb\bar{b},$
  - $pp \to Hb\bar{b} \to \tilde{\chi}_3\tilde{\chi}_1 b\bar{b} \to \tilde{\chi}_1\tilde{\chi}_1 hb\bar{b},$
  - $pp \to Ab\bar{b} \to \tilde{\chi}_2\tilde{\chi}_1 b\bar{b} \to \tilde{\chi}_1\tilde{\chi}_1 hb\bar{b},$
  - $pp \to Ab\bar{b} \to \tilde{\chi}_3\tilde{\chi}_1 b\bar{b} \to \tilde{\chi}_1\tilde{\chi}_1 hb\bar{b}.$

MSSM interpretation.

In order to show a phenomenological example we choose the following parameters: M_3 , M_2 and the gluino mass are set to $M_{\rm SUSY}$ that is 2 TeV.

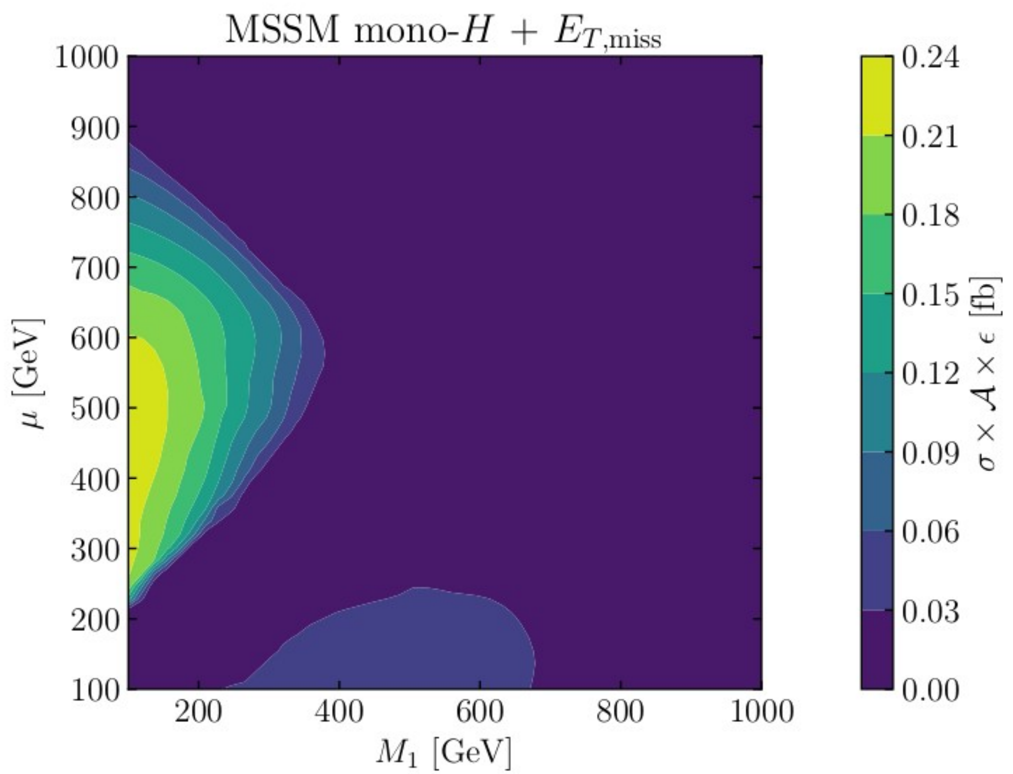
All the trilinear couplings are set to zero except fot the stop coupling which we set the stop mixing parameter, X_t , to 4 TeV.

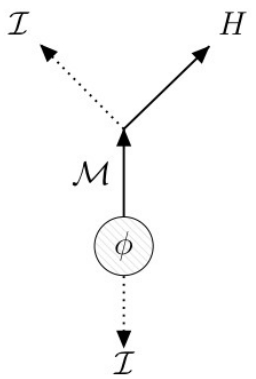
The scale of the non-SM Higgs boson is set to 1 TeV and the ration between the vacuum expectation values is set to $\tan\beta = 10$.

This lets us basically M_1 and μ as free parameters.

For our numerical analysis we use `FeynHiggs 2.18.0` to obtain the predictions for the Higgs spectrum and branching ratios. For the Higgs cross sections we use `SusHi 1.7.0` and `SUSY-HIT` to calculate the neutralinos branching ratios.

MSSM interpretation.





(b) 2vs1 balanced

The maximum values can be found in the regions $250 \text{ GeV} \lesssim \mu \lesssim 850 \text{ GeV}$ and $M_1 \lesssim 400 \text{ GeV}$ with a cross section $\sigma \times \mathcal{A} \times \epsilon \lesssim 0.25 \text{ fb}$.

Conclusions.

- We propose a simplified model framework in order to facilitate experimental analyses of dedicated searches for additional scalar resonances that decay into one or more BSM particles.
- The kinematical distributions show almost no differences for the different choices of spin nature of the particles involved.
- These simplified models have few parameters and can be used easily to translate experimental data to theory models.
- This simplfied model interpretation can be very helpful as a way to present the experimental results in a form that makes them easily applicable to a wide variety of possible models of BSM physics.

Thank you for your attention!