Searches for extra light and heavy Higgs bosons via cascade decays

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based on 1707.xxxx

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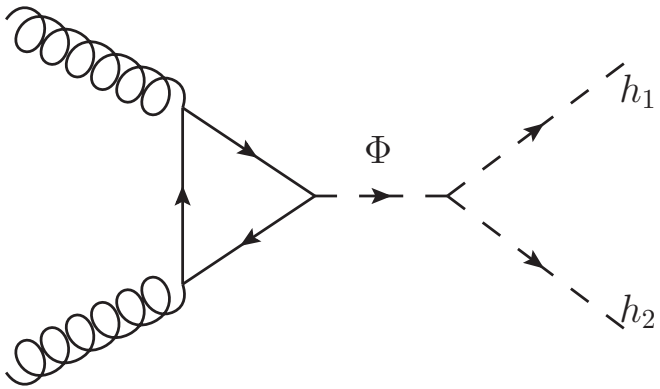
Motivation



Why Higgs-to-Higgs decays are interesting?

- Extended Higgs sectors are a common framework in BSM (SUSY, 2HDM, cxSM...).
- Measure the parameters of the scalar potential: allow us to test how EWSB is realised.
- So far, searches for resonant double SM Higgs production $\Phi \to hh$ (with $m_h = 125$ GeV) have been done. **However**, decays involving more scalars can be more promising...

Trilinear couplings

Terms in the lagrangian responsible for Higgs-to-Higgs decays.

What do we expect?

- Φhh with Φ a $SU(2)_L$ doublet. This trilinear coupling **is not gauge invariant** $\Rightarrow$ bounded by M_Z. Moreover, in the *alignment limit* (i.e. h has SM couplings), it is suppressed.
- However, Φ better be a doublet to have sizeable production through ggF or bbH (Excepting radions!).
- ΦhS with S a SM singlet. This term is gauge invariant, hence not bounded $\Rightarrow$ **Potentially large coupling!**
- If singlets exist at all, Higgs cascades may be their only sizeable production mode.

Realistic scenarios where this process takes place?

The NMSSM

This scenario can be realised in the NMSSM!

Higgs content of the NMSSM:

- Two SU(2) doublets H_u (couples to up-type fermions) and H_d (couples to down-type fermions) $\rightarrow$ like in the MSSM,
- A singlet S whose vev generates a Dirac mass term for higgsinos (replaces the μ term of the MSSM)

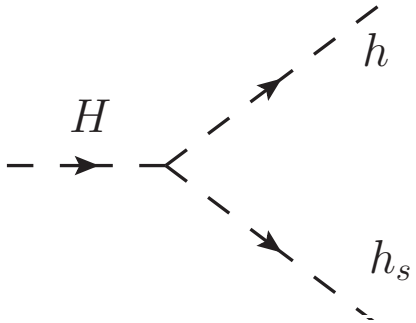
Mass eigenstates (– Goldstone boson):

- Three neutral scalars:
  - $h \rightarrow M_h \sim 125$ GeV
  - $h_s \rightarrow$ mostly singlet-like
  - $H \rightarrow$ mostly MSSM-like, heavy, see below
- Two neutral pseudoscalars
  - $a_s \rightarrow$ mostly singlet-like
  - $A \rightarrow$ mostly MSSM-like, heavy, see below
- One charged Higgs $H^{\pm} \rightarrow$ MSSM-like, heavy, see below

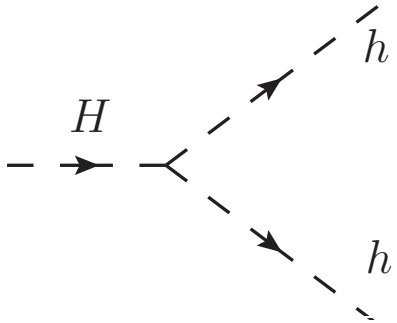
The NMSSM: $H \to hh_s/A \to ha_s$

Recall:

- $H, A, H^{\pm}$ are MSSM like, nearly degenerate in mass, with $M_A > 350$ GeV (to avoid $BR(b \to s + \gamma)$ too large).
- $M_{h_s} \sim 60 - 110$ GeV is natural, helps to explain $M_h \sim 125$ GeV (mixing effects) without inducing a too large $BR(h \to h_s h_s)$ which could reduce the SM-like branching fractions like $h \to Z^* Z$ below its measured values.
- The trilinear couplings Hhh_s/Aha_s are proportional to a soft-SUSY breaking term, A_λ. It can be large in natural regions of the parameter space [M.Carena et al.; U.Ellwanger, MRV], whereas $Hhh \to 0$ as $h \to h^{SM}$.



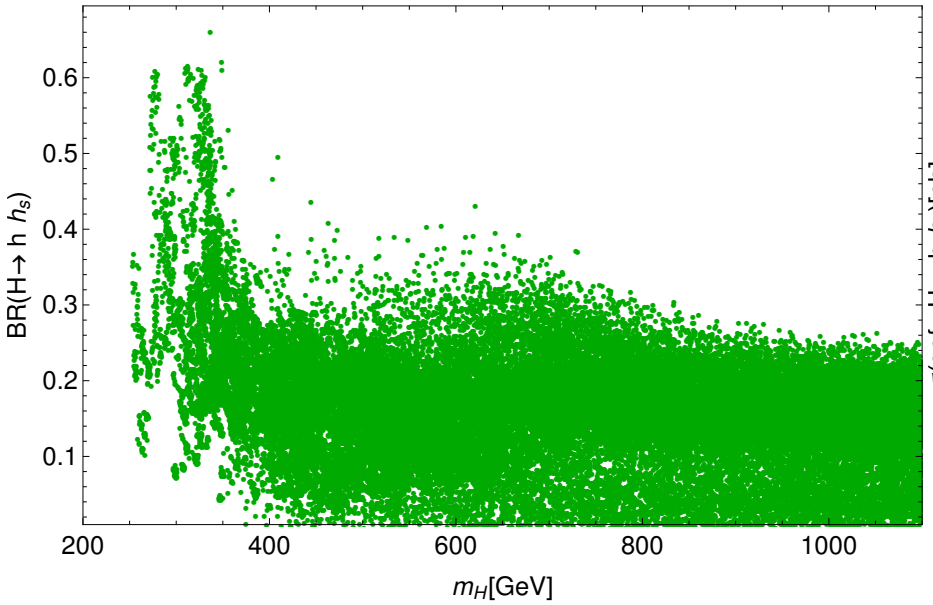
$\propto A_\lambda \sim 100GeV \ldots \mathcal{O}(TeV)$

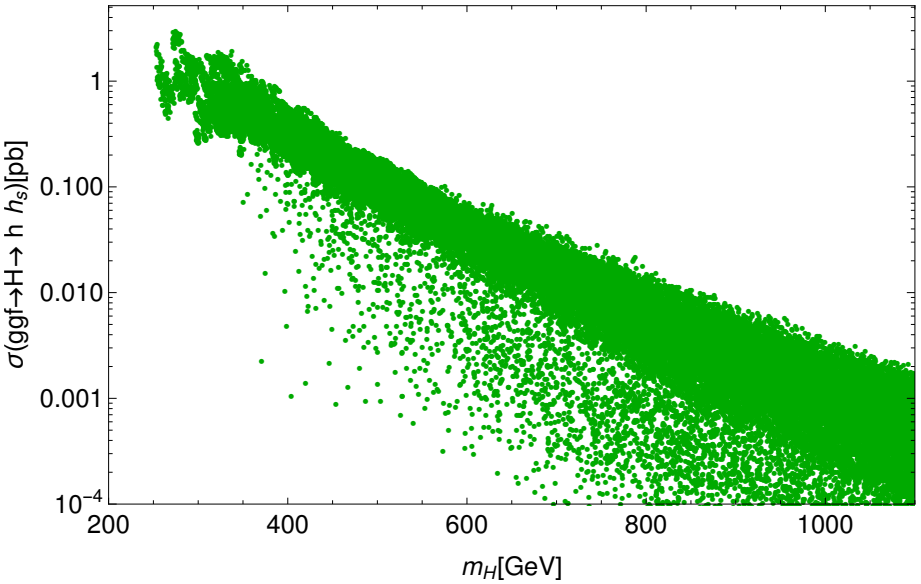


$\to 0$

$\sigma(ggF \to H \to hh_s)$ from a scan of the param. space

Using NMSSMTools, we perform a scan in a large region of parameter space, including latest constraints from the experimental collaborations. Large signals are possible in $ggF \to H \to hh_s$:





Are these cross sections visible at the LHC?
Which channels should we look for?

Monte Carlo study

We performed a thorough signal-to-background study in three different channels, with $M_H = 350 \ldots 1000$ GeV, $M_{h_s} = 25 \ldots 400$ GeV.

The search strategy mimics resonant double SM Higgs searches, varying the mass of one of the Higgs bosons.

Simulations: `MadGraph5@NLO` + `Pythia` + `Delphes`, including b-tagging efficiencies as reported by the experimental collaborations for Run 2.

$b\bar{b}b\bar{b}$

- Resolved topologies
- Large QCD multijet background ($b\bar{b}b\bar{b}$, $b\bar{b}c\bar{c}$,$b\bar{b}jj$), but large branching ratios.

$b\bar{b}\tau\tau$ ($\tau\tau b\bar{b}$)

- 3 subchannels: $\tau_h\tau_h$, τ_h, e, τ_h, μ.
- Dominant background: $t\bar{t}$ and, to a less extent, Z+jets

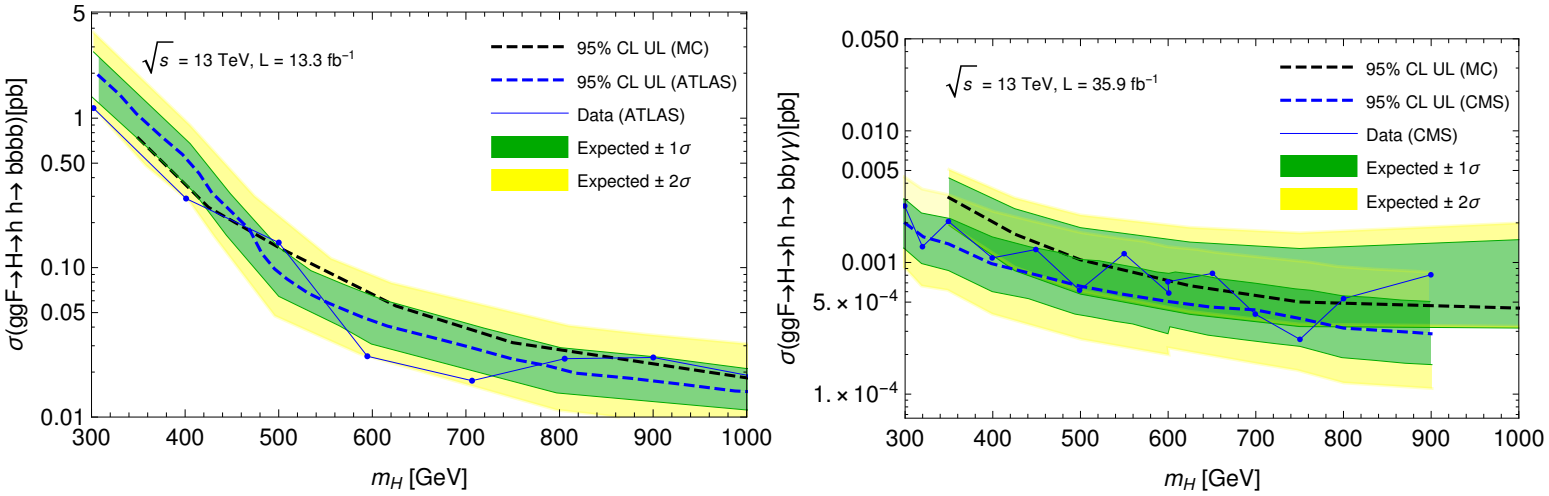
$b\bar{b}\gamma\gamma$ ($\gamma\gamma b\bar{b}$)

- Many different sources of background
- Cleaner than $b\bar{b}b\bar{b}$, but reduced cross sectios.
- Low statistics.

Goal: optimize search strategies, obtain realistic expected sensitivities for the process $ggF \to H/A \to h + h_s/a_s$.

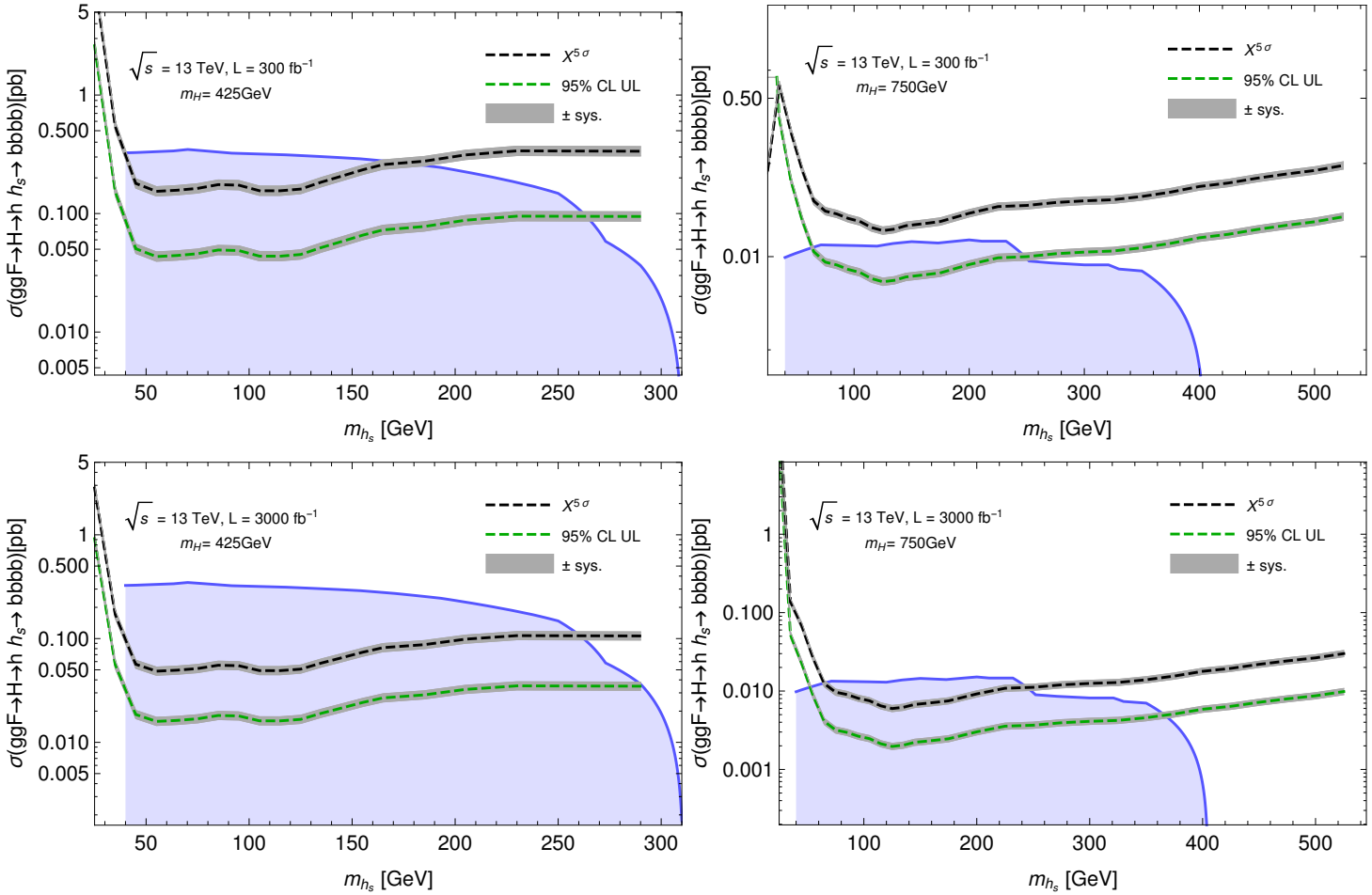
Validation of the MC

→ Background shapes from MC are in **good agreement with data.**
→ We **rescaled** the samples using data at $m_{h_s} = 125$ GeV, i.e. from double SM Higgs production [ATLAS-CONF-16-049, CMS-PAS-HIG-17-008, CMS-PAS-HIG-16-029].
→ The expected sensitivities from simulations reproduce well the ones from the experimental collaborations (data-driven).



Results: Expected sensitivities $b\bar{b}b\bar{b}$

Upper left: $M_H = 425$ GeV, 95% limits and $5\,\sigma$ discovery for $L = 300 fb^{-1}$
Upper right: $M_H = 750$ GeV, 95% limits and $5\,\sigma$ discovery for $L = 300 fb^{-1}$
Lower left: $M_H = 425$ GeV, 95% limits and $5\,\sigma$ discovery for $L = 3000 fb^{-1}$
Lower right: $M_H = 750$ GeV, 95% limits and $5\,\sigma$ discovery for $L = 3000 fb^{-1}$
Blue: NMSSM allowed region.



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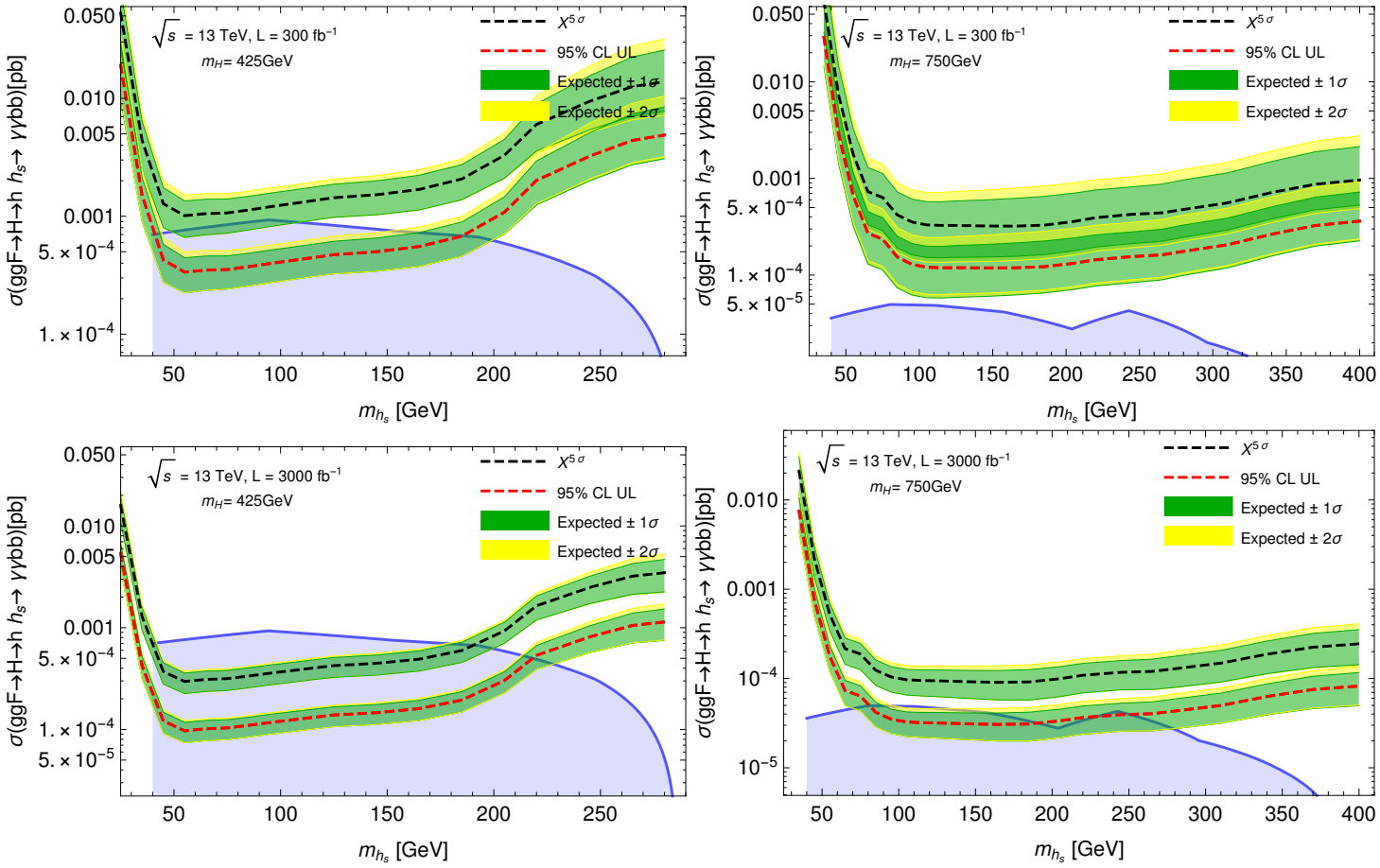

Conclusions

- Searches for $H/A \to h + h_s/a_s$ can be sensitive to very singlet-like h_s/a_s!
  Excesses would discover simultaneously H/A and h_s/a_s!
- 'Pure' singlets detectable although direct production cross section vanish.
- Regions featuring $m_{h_s} \lesssim m_h \Rightarrow BR(H \to hh_s) > 0$ will be largely covered for $m_H < 750$ GeV!
- Complementarity between $b\bar{b}\gamma\gamma$ and $b\bar{b}b\bar{b}$.
- These results could be easily reinterpreted in other models as $\Phi \to h^{125}h'$ (2HDM+S, C2HDM ...).
- We encourage the experimental collaborations to carry out the $H/A \to h + h_s/a_s$ search!

Thanks for your attention!

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Backup

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