Electroweak pair-production of Higgs bosons in Type-I 2HDM

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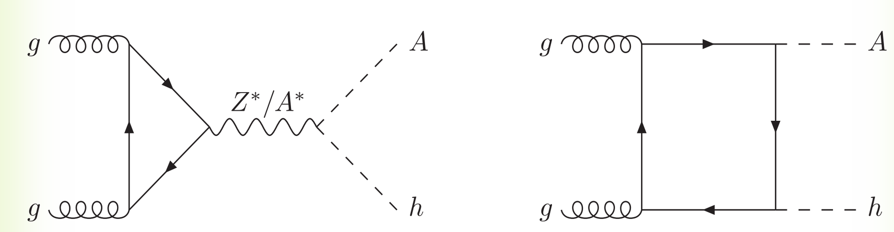
Multiple Higgs bosons

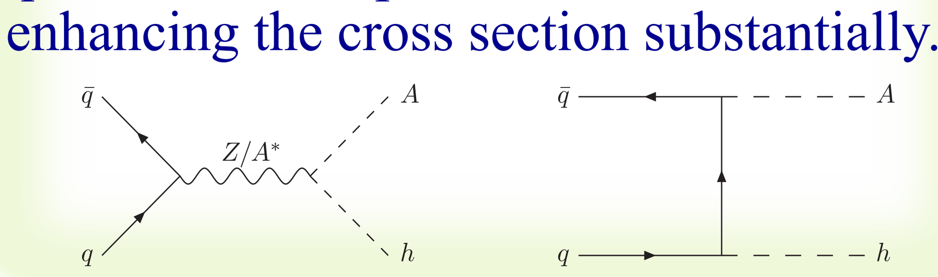
- Most models of new physics predict more than one Higgs boson.
- One (or more) of these should (collectively) have properties consistent with the Standard Model (SM)-like Higgs boson, H_{obs}, observed at the LHC.
- The rest of them remain undiscovered so far in the conventional search channels, due to their relatively weak couplings to the SM particles.
- A 2-Higgs Doublet Model (2HDM) is one of the simplest extensions of the SM and contains three neutral Higgs bosons - two scalars (h, H) and a pseudoscalar (A) - as well as a charged pair ($H^\pm$).
- At the LHC, these Higgs bosons of the 2HDM can be produced both singly and in identical or mixed pairs.

Higgs pair-production at the LHC

Owing to the very large PDF of a gluon at small x and large Q^2, QCD-induced production of a pair of Higgs bosons is generally assumed to be highly dominant over electroweak (EW) production. However, due to the Landau-Yang theorem, the scattering of two gluons into a pair of light Higgs bosons cannot proceed via an on-shell Z boson.



A resonant Z boson can contribute in the quark-initiated production instead, thus enhancing the cross section substantially.



The Type-I 2HDM

In order to avoid large FCNCs, a Z_2 symmetry is imposed on the Higgs potential of a 2HDM. The four basic ways of assigning the Z_2 charges to the Higgs doublets lead to 'Types I-IV' of the 2HDM.

In the Type-I 2HDM, unlike some the other Types, the b-physics experiments do not impose strong lower limits on the mass of $H^\pm$. As a result the Higgs bosons other than the one mimicking the H_{obs} can also be rather light, without violating the constraints from EW precision measurements.

When the combined mass of h and A (when H is identified with the H_{obs}) is less than that of the Z boson, the latter, produced on-shell electroweak-ly, can have a substantially large decay width into the hA pair.

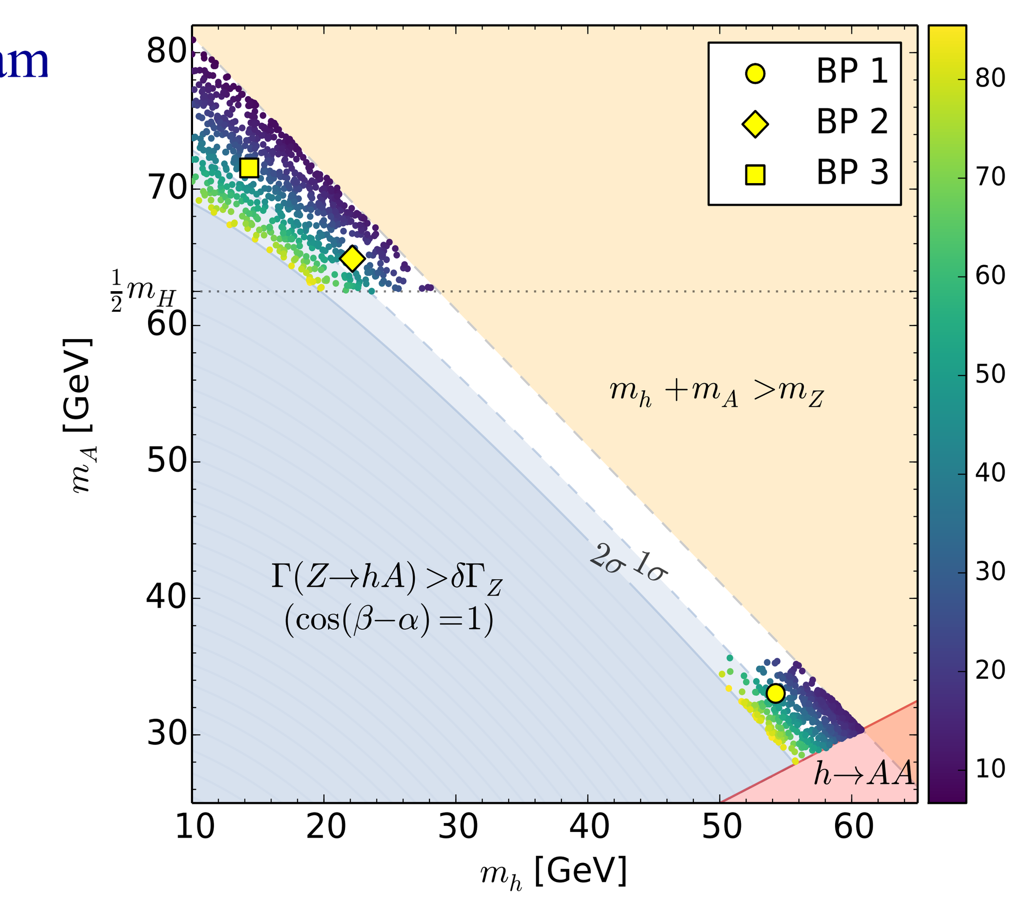
Numerical anaylsis

The 5-dimensional parameter space of Type-I 2HDM scanned with the 2HDMC program requiring unitarity, perturbativity and vacuum stability conditions to be satisfied.

Consistency, at the 95% confidence level, also ensured with

✓ the measurements of the S, T and U parameters,
✓ the measurements of b-physics observables, using SuperIso,
✓ the LHC measurements of H_{obs} signal rates, using HiggsSignals,
✓ limits from Higgs boson searches at LEP, Tevatron and LHC, using HiggsBounds.

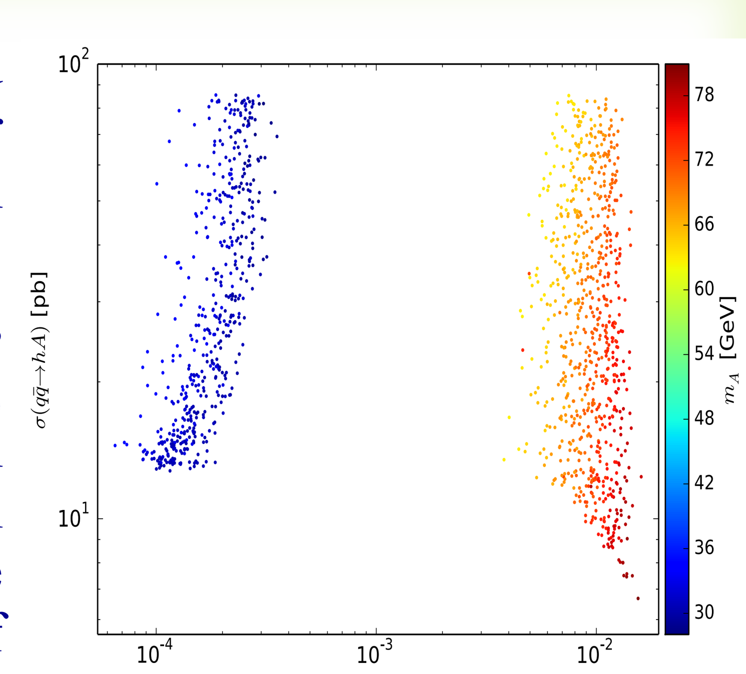
Parameter	Initial range	Refined range
m_h (GeV)	$(10,\ 80)$	$(10,\ 2M_Z/3)$
m_A (GeV)	$(10,\ M_Z - m_h)$	$(m_h/2,\ M_Z - m_h)$
$m_{H^\pm}$ (GeV)	$(90,\ 500)$	$(90,\ 150)$
$s_{\beta-\alpha}$	$(-1,\ 1)$	$(-0.25,\ 0)$
m_{12}^2 (GeV^2)	$(0,\ m_A^2 \sin\beta\cos\beta)$	$(0,\ m_A^2 \sin\beta\cos\beta)$
$\tan\beta$	$(2,\ 25)$	$(-0.95,\ -1.1)/s_{\beta-\alpha}$



EW vs. QCD production

MadGraph5_aMC@NLO used to calculate the cross sections for each of the two hA production modes.

QCD production cross section is generally lower when $m_h > m_A$, compared to when $m_A > m_h$. In both cases, the EW production cross section can exceed the QCD one by few orders of magnitude, reaching up to 90 pb at the 13 TeV LHC.



Benchmark points

The three benchmark points, one corresponding to the $m_h > m_A$ case and two to the $m_A > m_h$ case, show maximal consistency with the Z-width constraint as well as large EW production cross section.

These points can have some unique signatures at the LHC, owing to the very large branching ratios of h and A in the unconventional channels, Z^*A and Z^*h, respectively.

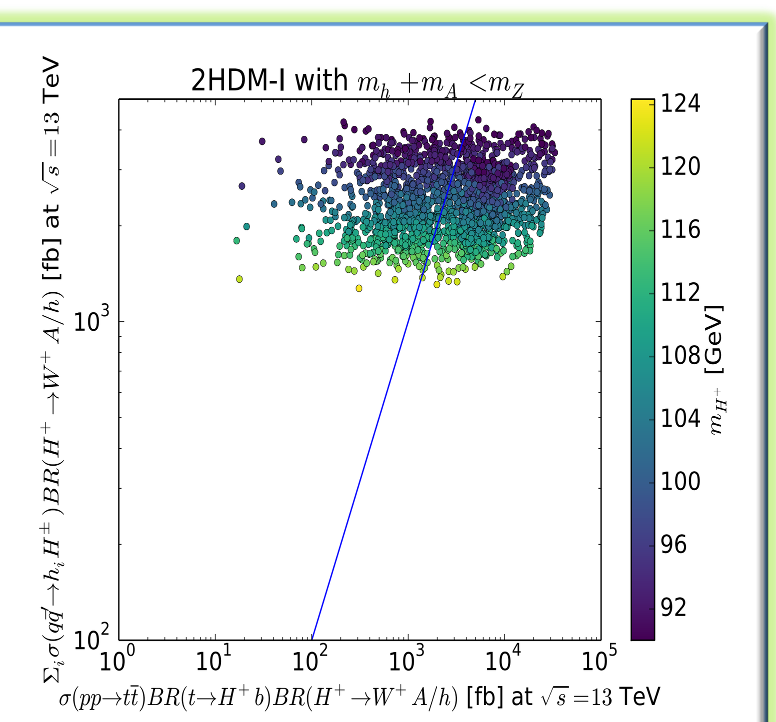
BP	m_h	m_A	$m_{H^\pm}$	$s_{\beta-\alpha}$	m_{12}^2	$\tan\beta$	$\sigma(q\bar{q})$	$\sigma(gg)$
1	54.2	33.0	95.9	−0.12	118.3	9.1	41.2	1.5×10^{-4}
2	22.2	64.9	101.5	−0.05	10.6	22.1	34.4	7.2×10^{-3}
3	14.3	71.6	107.2	−0.06	2.9	16.3	31.6	1.1×10^{-2}

	BR($h \to$ ...) [%]				BR($A \to$ ...) [%]		
BP	Z^*A	$b\bar{b}$	$\gamma\gamma$	$\tau\tau$	Z^*h	$b\bar{b}$	$\tau\tau$
1	**94**	5	< 1	< 1	0	**86**	7
2	0	**83**	3	7	**86**	12	1
3	0	**60**	**24**	7	**90**	8	1

Possible accompanying signatures

The light $H^\pm$ obtained in this scenario can have almost 100% branching ratio into either of the $hW^\pm$ and $AW^\pm$ states.

Such a $H^\pm$ can be produced electroweak-ly in association with h or A or in the decays of the t-quark.



References

1. R. Enberg, W. Klemm, S. Moretti and S. Munir, ArXiv: 1605.02498 [hep-ph].
2. A. Arhrib, R. Benbrik, R. Enberg, W. Klemm, S. Moretti and S. Munir, in preparation.