**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 undetected 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 of 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 analysis**
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.

**EW vs. QCD production**
MadGraph5_aMC@NLO used to calculate the cross sections for each of the two \( hh \) production modes.

QCD production cross section is generally lower when \( m_h > m_A \), compared to when \( m_h < m_A \). 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.

**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 \( A \) in the decays of the \( t \)-quark.

**References**