Multi-Higgs Phenomenology at the LHC

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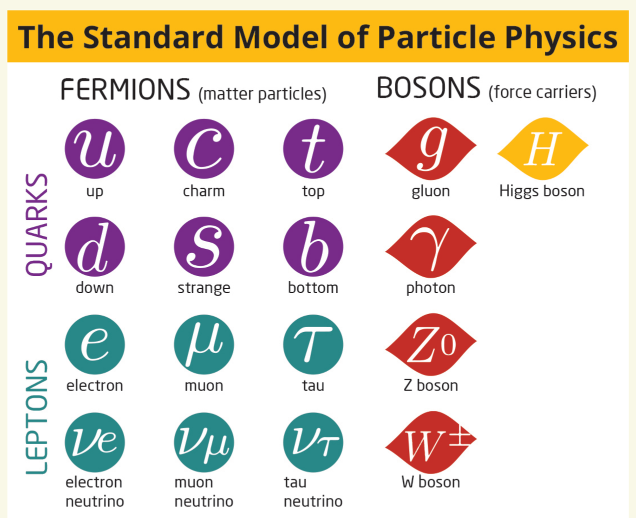
Background and motivation



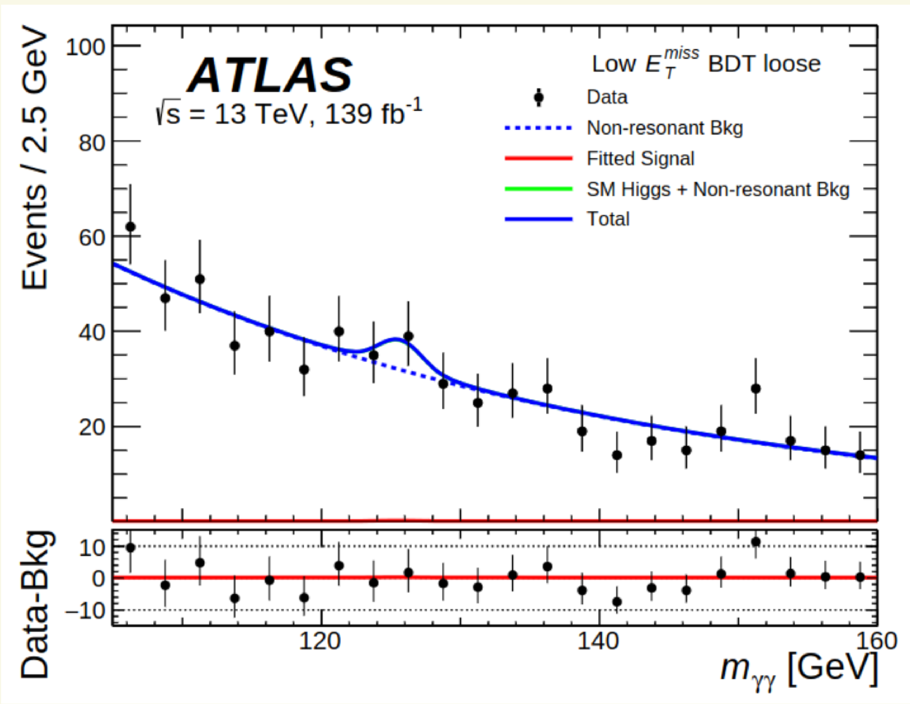
The Standard Model (SM) of particle physics stands as a remarkable triumph in our quest to comprehend the intricacies of the universe. It accurately explains the behaviour of natural phenomena over a broad range of energy scales.

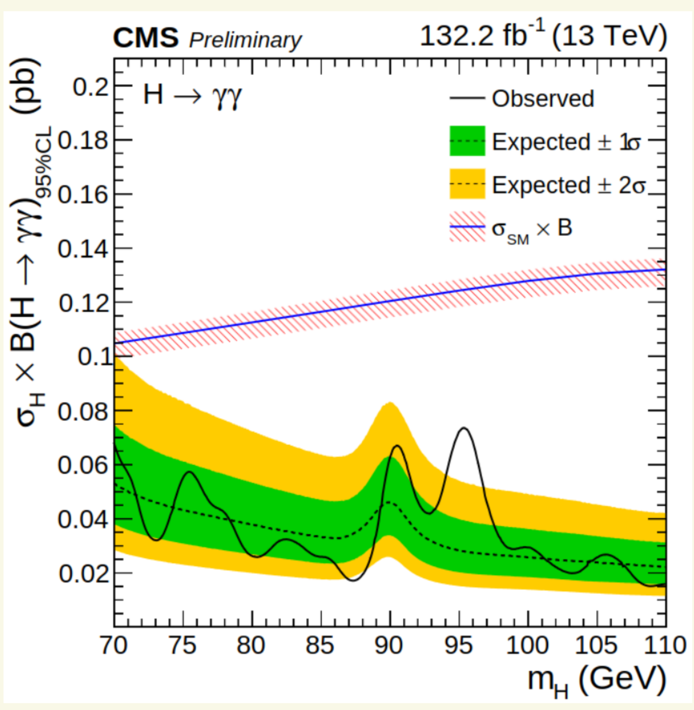
- Nevertheless, it is clearly **incomplete**, as it cannot account for all the phenomenology witnessed.
- The **minimality** of the SM Higgs sector is not guaranteed by any theoretical principle or symmetry.

The **Large Hadron Collider** (LHC) at CERN has the best potential to unveil new physics (NP) during its upcoming Run 3 and High-Luminosity phase.

Hints for New Higgs Bosons

- ATLAS and CMS analysis show excesses for neutral scalar particles with masses ≈ **152 GeV** and ≈ **95 GeV**.



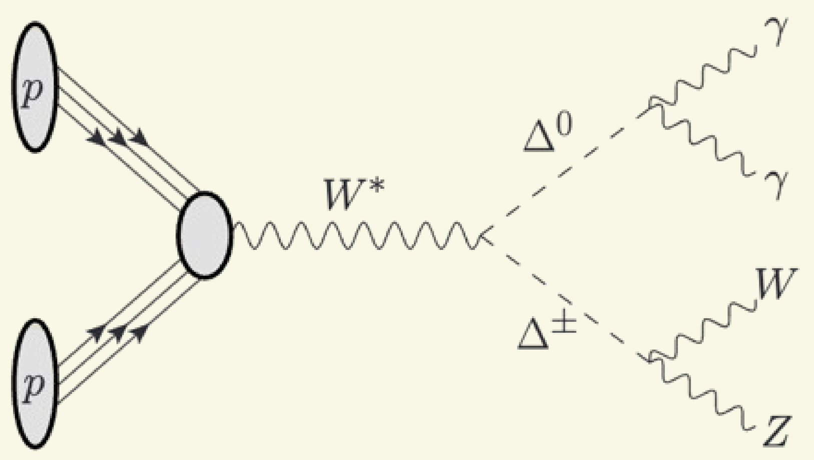


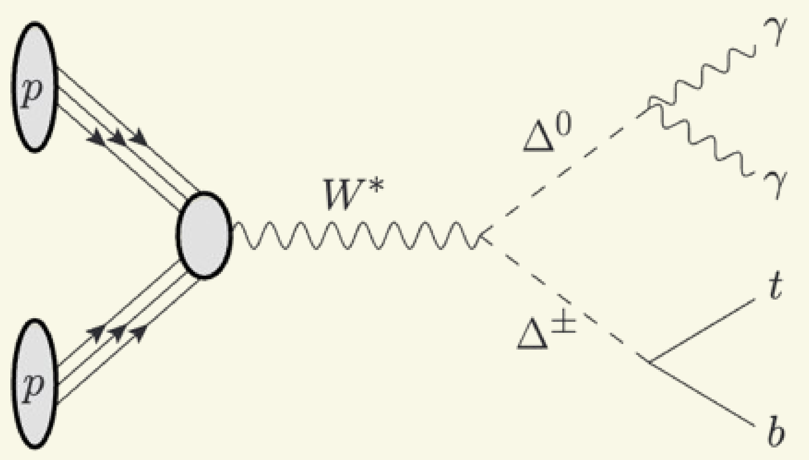
- Data suggests **associated production** for 152 GeV scalar. This signature is not yet fully explored at the LHC.
- The excesses at 152 GeV, are further supported by the **multi-lepton anomalies**, namely deviations observed in processes involving multiple leptons and missing energy in the final state.

We construct and perform detailed phenomenological analysis of **NP models** to explain such excesses.

Real Higgs Triplet Model

- Extension of the SM with an additional $SU(2)_L$ triplet scalar with hypercharge $Y = 0$, referred to as ΔSM.
- The field Δ contains two new **Higgs bosons**: Δ^0, $\Delta^\pm$.
- Breaking (slightly) custodial symmetry $\Longrightarrow$ enhancement of m_W induced via $\langle\Delta\rangle = v_\Delta \approx O(\mathrm{GeV})$.





Flavor aligned 2HDM

- 2HDMs are among the **best theoretically motivated** extensions of the scalar sector (Supersymmetry, Unification, etc. etc.)

$$\begin{aligned}\mathcal{V} = {} & Y_1\mathcal{H}_1^\dagger\mathcal{H}_1 + Y_2\mathcal{H}_2^\dagger\mathcal{H}_2 + [Y_3\mathcal{H}_1^\dagger\mathcal{H}_2 + \mathrm{h.c.}] \\ & + Z_1(\mathcal{H}_1^\dagger\mathcal{H}_1)^2 + Z_2(\mathcal{H}_2^\dagger\mathcal{H}_2)^2 + Z_3(\mathcal{H}_1^\dagger\mathcal{H}_1)(\mathcal{H}_2^\dagger\mathcal{H}_2) \\ & + Z_4(\mathcal{H}_1^\dagger\mathcal{H}_2)(\mathcal{H}_2^\dagger\mathcal{H}_1) + \{Z_5(\mathcal{H}_1^\dagger\mathcal{H}_2)^2 \\ & + \left[Z_6\mathcal{H}_1^\dagger\mathcal{H}_1 + Z_7\mathcal{H}_2^\dagger\mathcal{H}_2\right]\mathcal{H}_1^\dagger\mathcal{H}_2 + \mathrm{h.c.}\}\end{aligned}$$

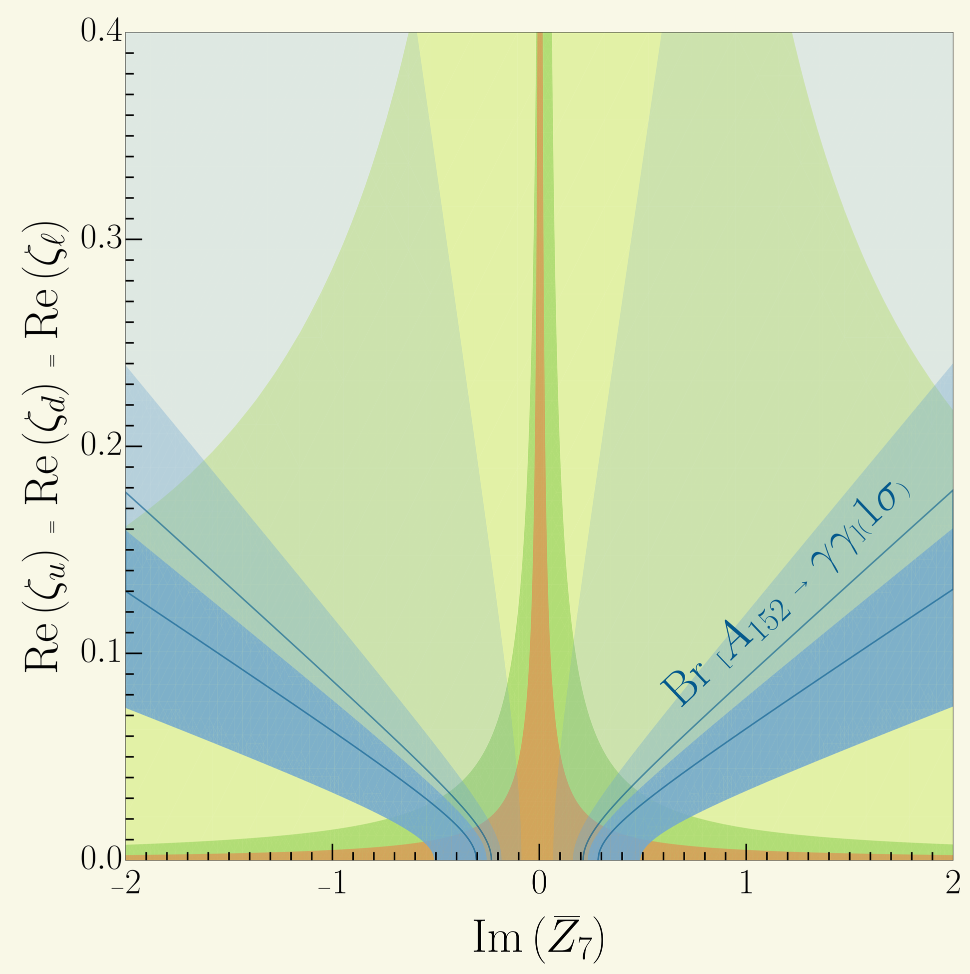
- The model contains four additional scalars: **CP-even** (H), **CP-odd** (A), **charged** ($H^\pm$).
- The Z_7 coupling enhances the Br($H/A \to \gamma\gamma$), which is the most sensitive signature for neutral scalars

$$\begin{aligned}\mathcal{L}_Y = & -\overline{Q}_L Y_d(\mathcal{H}_1 + \zeta_d\mathcal{H}_2)d_R - \overline{Q}_L Y_u(\tilde{\mathcal{H}}_1 + \zeta_u^*\tilde{\mathcal{H}}_2)u_R \\ & - \overline{L}_L Y_\ell(\mathcal{H}_1 + \zeta_\ell\mathcal{H}_2)\ell_R + \mathrm{h.c.}\,,\end{aligned}$$

- The Yukawa sector avoids **Flavor Changing Neutral Currents** since Yukawa matrices are proportional to each other by the $\zeta_u, \zeta_d, \zeta_\ell$ rescaling parameters.
- The model leads to **CP-violation** through the complex couplings Z_5, Z_6, Z_7 in the scalar potential and $\zeta_u, \zeta_d, \zeta_\ell$ in the Yukawa sector.

$|d_e| < 4.1 \times 10^{-30}$ e cm
$|d_p| < 10^{-29}$ e cm (prospect)
$|d_n| < 10^{-28}$ e cm (prospect)
$0.1\% < \mathrm{Br}[A \to \gamma\gamma] < 0.5\%$
$0.5\% < \mathrm{Br}[A \to \gamma\gamma] < 1\%$
$1\% < \mathrm{Br}[A \to \gamma\gamma] < 4\%$

Im(Z_7) drives Br($A \to \gamma\gamma$) and can be correlated with low energy CP-violating observables such as **Electric Dipole Moments (EDMs)**.



Phenomenology

- Theoretical predictions face experimental data through **simulations** using software: Model Building (`FeynRules`), Event Generator (`MadGraph5aMC@NLO`, `Pythia8`) and Detector Simulations (`Delphes`, `ROOT`).
- Testing an NP model requires an understanding of the **experimental searches**: coding (`C++`) and statistical analysis are fundamental to interpreting the data.

Curious in a project? JOIN US!



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