Search for new physics at the LHC with multi-lepton final states

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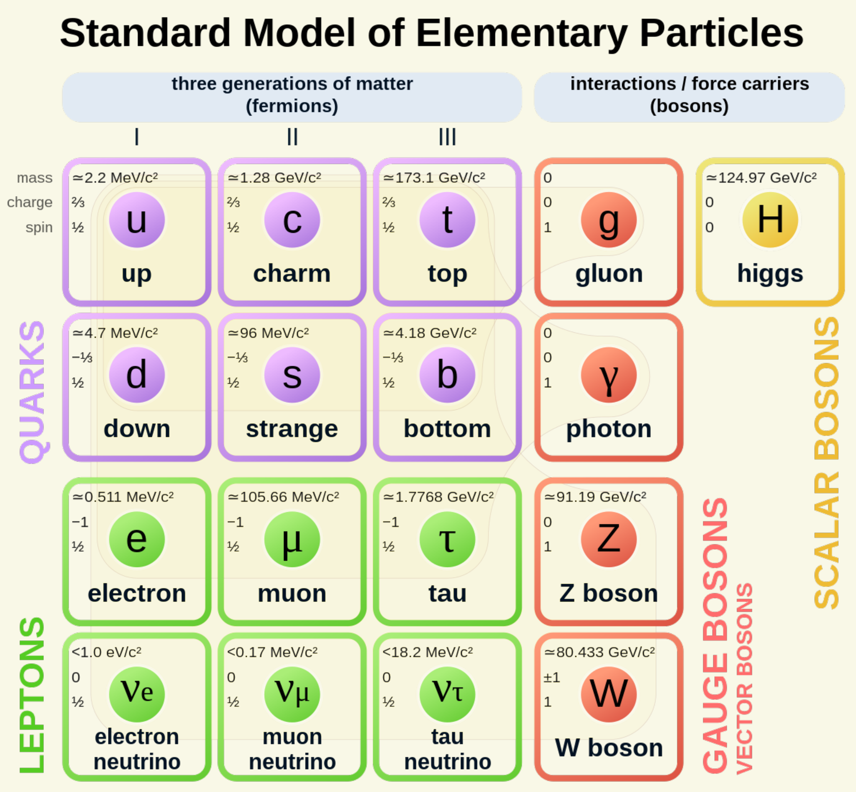
Background and motivation



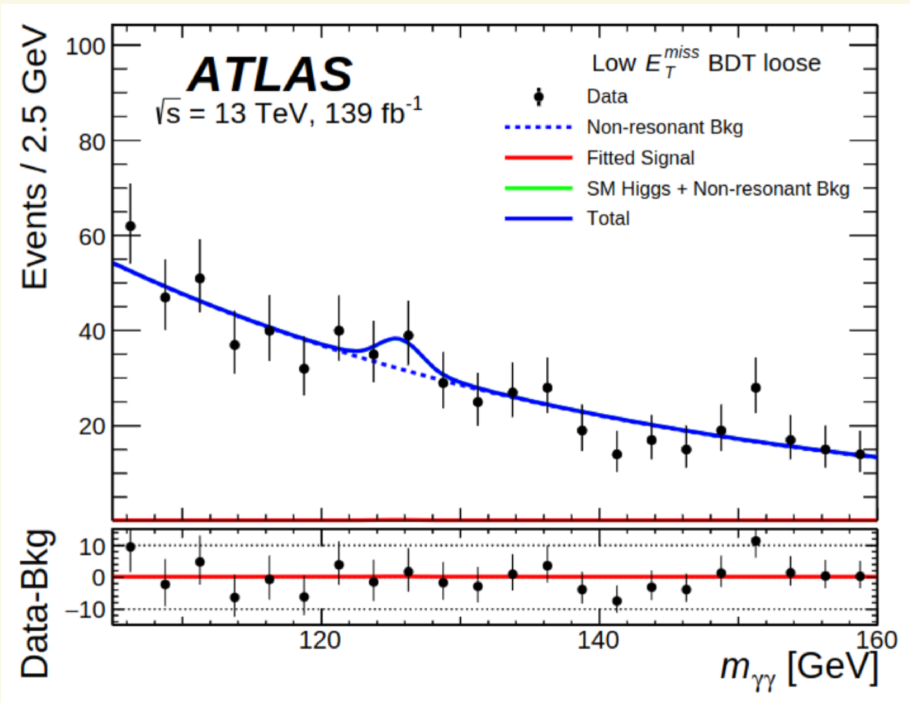
The Standard Model (SM) of particle physics stands as a remarkable triumph in our quest to comprehend the intricacies of the universe. It accurately explains the behaviour of natural phenomena over a broad range of energy scales.

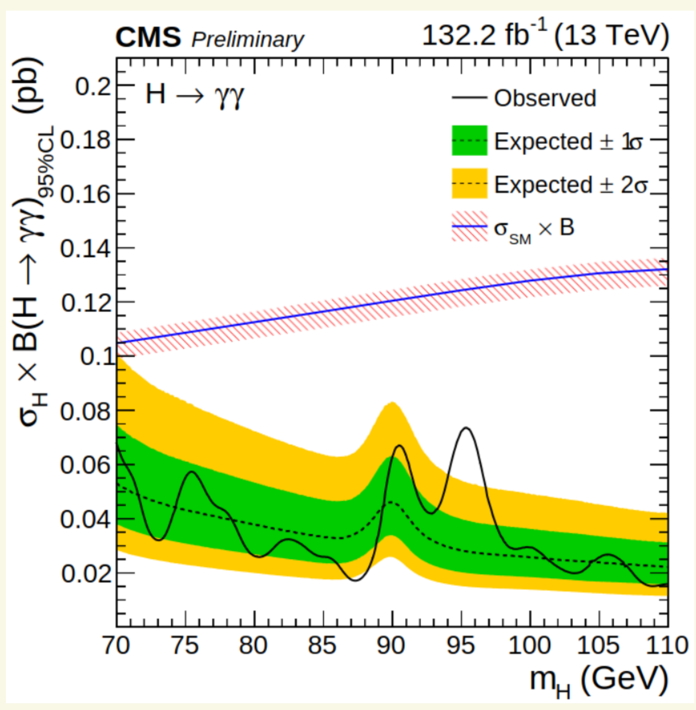
- Nevertheless, it is clearly incomplete, as it cannot account for all the phenomenology witnessed.
- The Large Hadron Collider (LHC) at CERN is the best current playground to seek for hints of new physics (NP).

The upcoming Run 3 data will collect the finest statistics ever reached and will scrutinize several NP scenarios

Hints for new physics

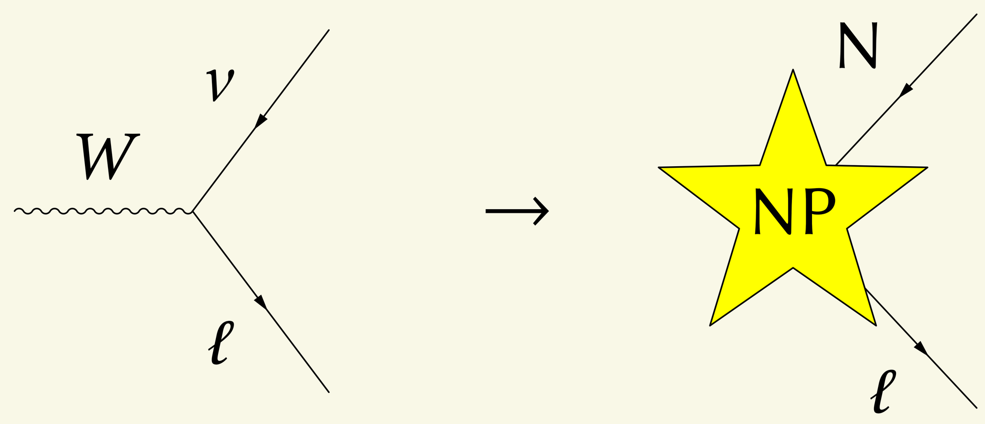
- The scalar sector serves as a vital arena for validating the predictions of the SM.
- CMS and ATLAS experiments measured several excesses for scalar particles with masses at the electro-weak scale.





The most compelling excesses are the multi-lepton anomalies, i.e. deviation from SM in processes with W-like signature (charged lepton ℓ and missing energy N)

Final state	Characteristics	SM backgrounds
$\ell^+\ell^-$+b-jets	$m_{\ell\ell} < 100$ GeV	$t\bar{t}$, Wt
$\ell^+\ell^-$+ jet veto	$m_{\ell\ell} < 100$ GeV	W^+W^-
$\ell^\pm\ell^\pm$, 3ℓ +b-jets	Moderate H_T	$t\bar{t}W^\pm$, $t\bar{t}t\bar{t}$
$\ell^\pm\ell^\pm$, 3ℓ, $n_b = 0$	In association with h	$W^\pm h$, WWW
$Z(\to \ell\ell)\ell$, $n_b = 0$	$p_Z^T < 100$ GeV	$ZW^\pm$

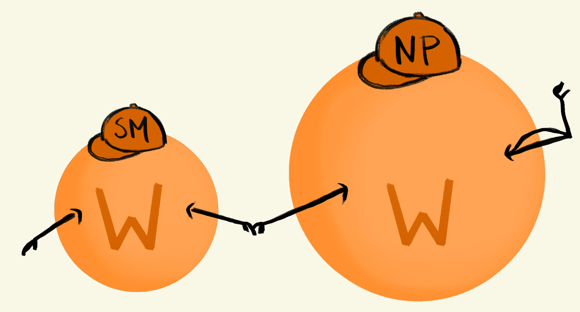


Hunting Higgses

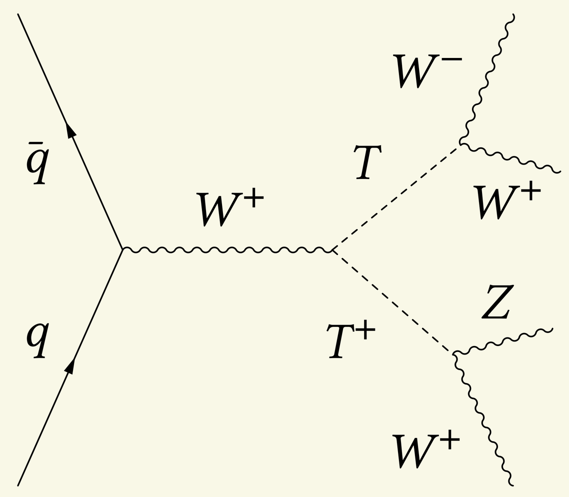
The Standard Model is based on two main ingredients, namely spontaneous symmetry breaking and gauge invariance of the group $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$.

How to extend it such to match experimental signatures?

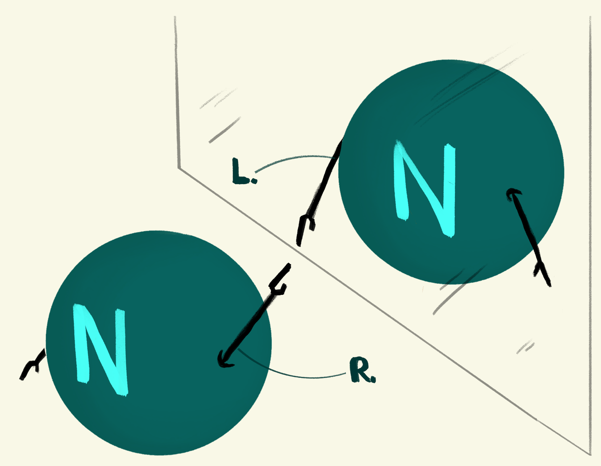
- $SU(2)_L$ scalar triplet: (i) another Higgs-like T, (ii) two oppositely charged Higgses $T^\pm$



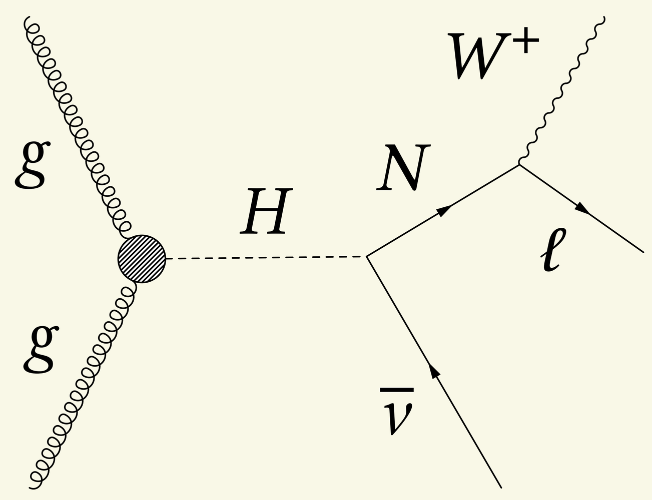
Prediction: heavier W boson, namely with a larger mass, as measured at the Tevatron (Fermilab, Chicago)



- $2HDM + U(1)' + N$: (i) another Higgs doublet (H,A,$H^\pm$), (ii) heavy vector-like neutrinos N



Differently from SM fermions, vector-like particles have both chiralities equally charged under symmetries



Phenomenology

- Extensions of the scalar sector are also very well motivated theoretically (SUSY, GUT ...) and related to cosmological observables such as gravitational waves.
- Once the model is built, it is necessary to provide accurate predictions (loops, etc. etc.) to be matched with data through a careful statistical analysis.
- This is carried out via simulations with sophisticated softwares for Monte Carlo generations (Madgraph, Pythia, Delphes, ROOT, etc. etc.).
- And if the answer is positive...

Time for New Physics?

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