Higgs triplets at the LHC

Guglielmo Coloretti
University of Zurich and Paul Scherrer Institut
31.10.2023

Is there NP at the EW scale?

2306.17209

SM scalar sector is minimal and leaves room for NP

- W mass (2.2σ/3.7σ tension exl/in-cluding CDF II)
- Narrow resonances ($\gamma\gamma, WW, \tau\bar{\tau}, Z + b\bar{b}$) at 95 (3.8$\sigma$)
- Multi-lepton anomalies:
  1. $t\bar{t}, t\bar{t}W, 4t, Wh, WWW$
  2. **Hints for low mass $\boldsymbol{WW}$ resonances ($\geq 2\sigma$)**

Custodial Symmetry

Direct hints and Associated production

Multi-lepton anomalies (MLA)

- Multi-lepton anomalies (MLA): deviations from SM in processes with W- like signature (e/μ + MET)

Final state	Characteristics	SM backgrounds	Significance
$\ell^+\ell^-$+(b-jets)[51,54,55]	$m_{\ell\ell} < 100$ GeV, $(1b, 2b)$	$t\bar{t}, Wt$	$> 5\sigma$
→ $\ell^+\ell^-$+(no jet)[50,56]	$m_{\ell\ell} < 100$ GeV	W^+W^-	$\approx 3\sigma$
$\ell^\pm\ell^\pm, 3\ell$ + b-jets[53,57,58]	Moderate H_T	$t\bar{t}W^\pm, t\bar{t}t\bar{t}$	$> 3\sigma$
$\ell^\pm\ell^\pm, 3\ell$, (no b-jet)[52,59,60]	In association with h	$W^\pm h(125), WWW$	$\gtrapprox 4\sigma$
$Z(\to \ell\ell)\ell$, (no b-jet)[51,61]	$p_T^Z < 100$ GeV	$ZW^\pm$	$> 3\sigma$

(2109.06065)

- The EW scale NP is not yet fully explored at the LHC (**associated production**)

- **LHC Run3 data, FCC and CEPC** will be able to scrutinize BSM scenarios at this scale

WW analysis

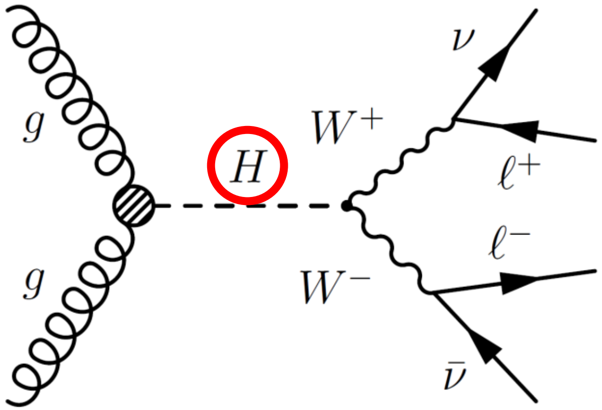
2302.07276

- **No dedicated BSM search for $gg \to H \to WW$** with full luminosity and including 90 GeV for the range of m_H

- CMS (2206.09466) and ATLAS (2207.00338) analyses available for **SM Higgs ($135\ \mathrm{fb}^{-1}$)**

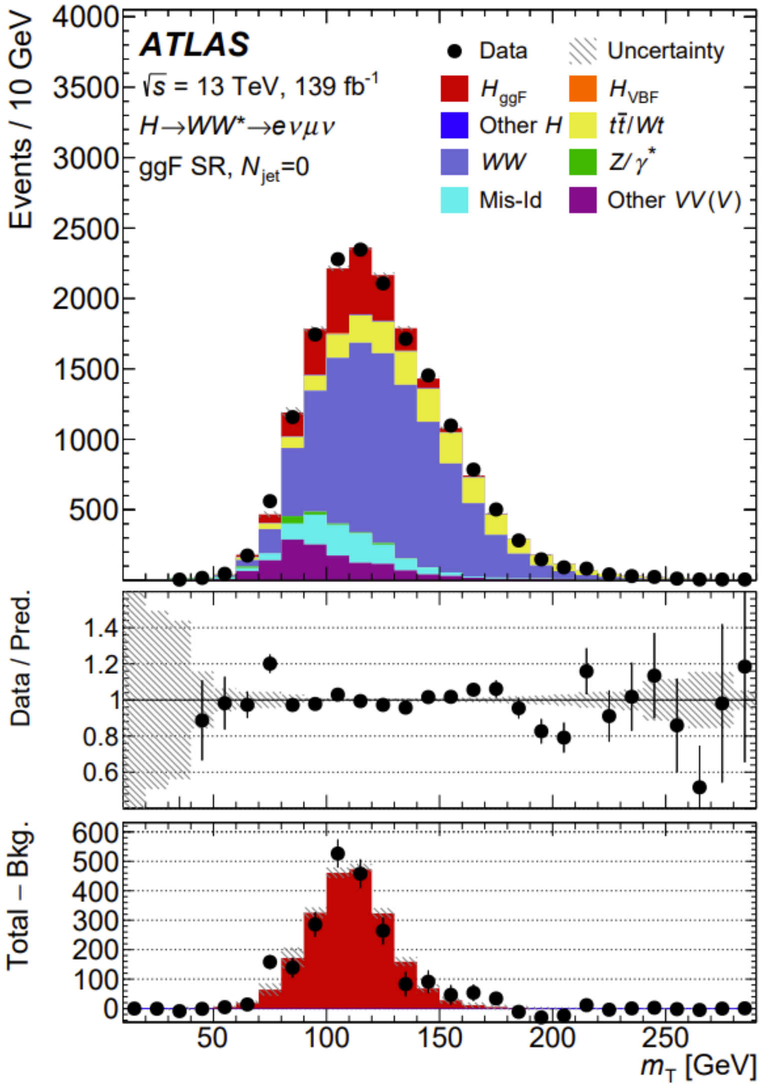
- Re-casting analyses to search **for new scalars**

- **Simulation with MadGraph5_aMC@NLO (Pythia8, Delphes)**



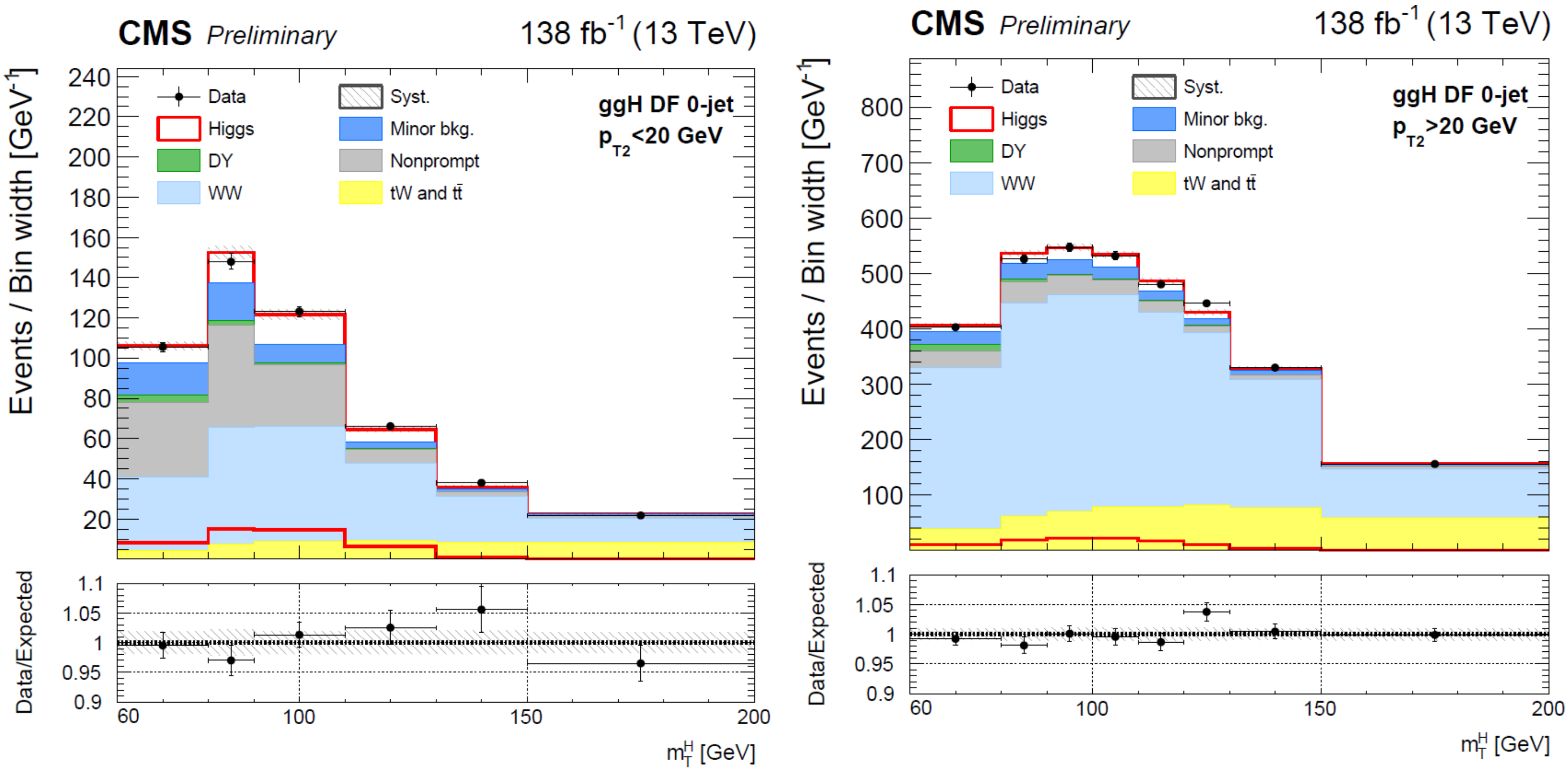
- 0-jet
- Different flavour opposite sign lepton pair

SM WW searches: ATLAS 2207.00338



- ATLAS reports the postfit data
- Only SM contribution is rescaled by a factor of 1.21

SM WW searches: CMS 2206.09466



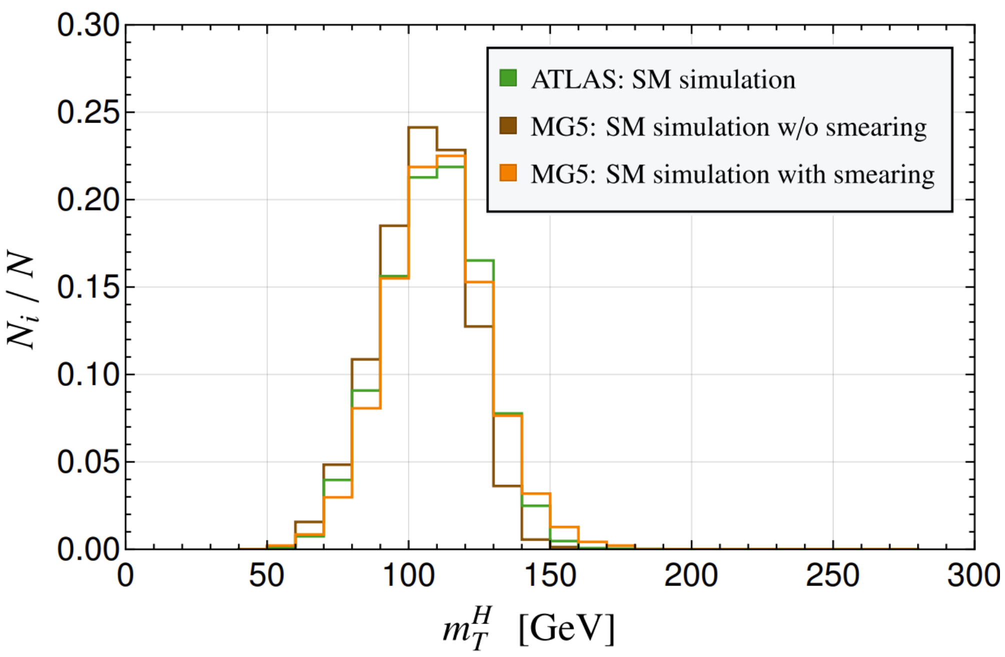
- CMS performs a simultaneous fit of SM+background

WW simulation

Limitations of fast simulation

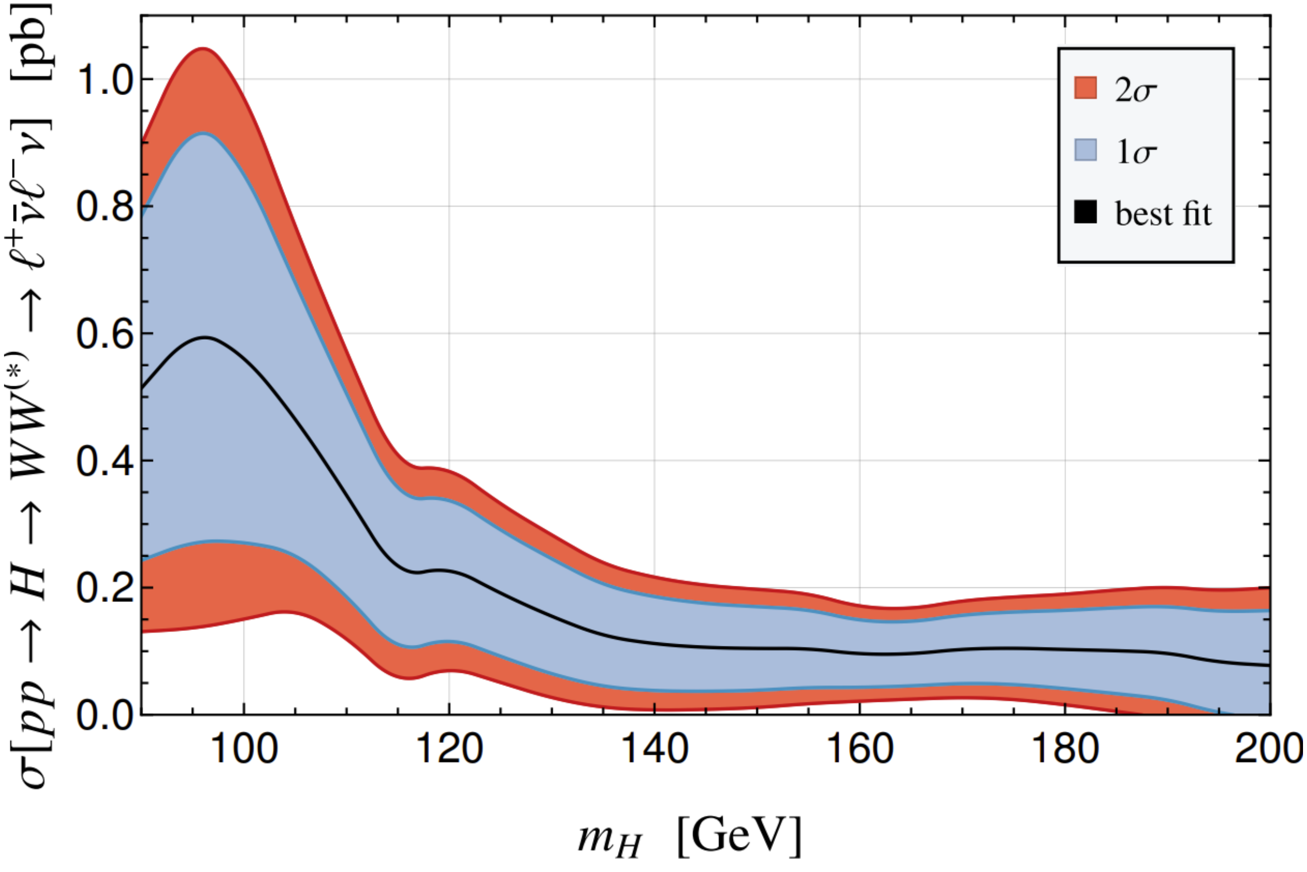
- **Smearing and shifts**
- Corrected **for efficiency (energy dependence)**
- Corrected for **QCD NNLO effects in production cross section**

Checks over SM-samples:
ATLAS full-simulation VS **MG5 fast-simulation**

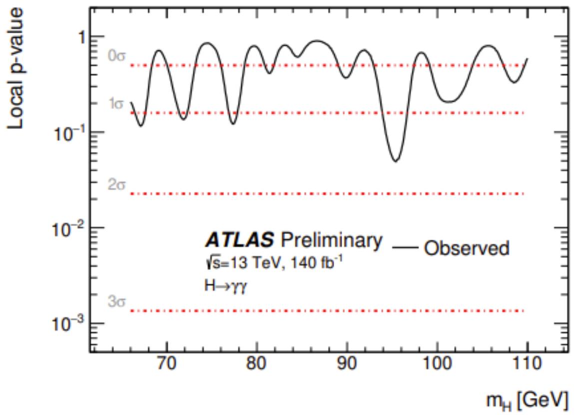


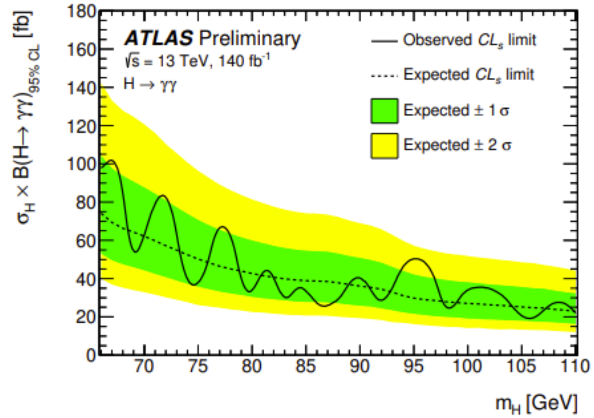
WW results

- Observed limit is weaker than expected over the whole mass range (**preference for BSM $\geq 2\sigma$**)

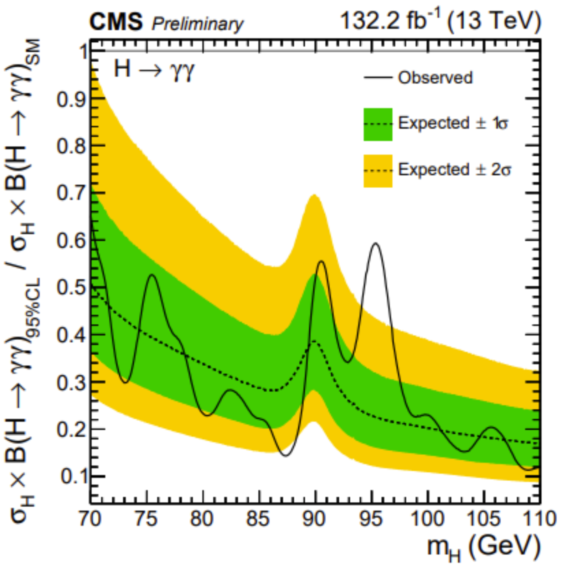


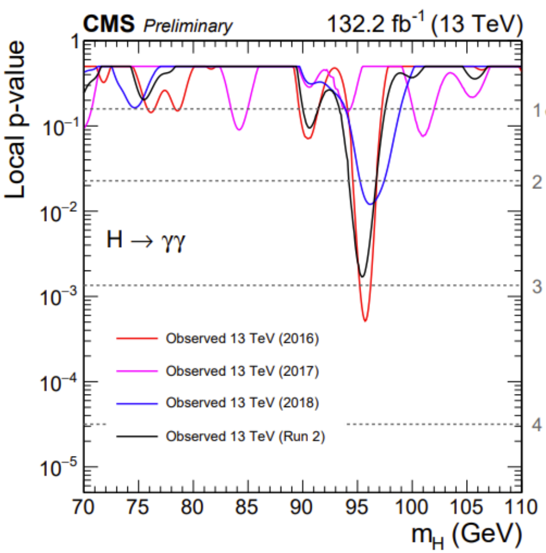
$\gamma\gamma$ excess at 95 GeV





ATLAS





CMS

Triplets at the LHC

Could the 95 GeV hints be explained by a real $SU(2)_L$ scalar triplet?

$$\Delta = \frac{1}{2}\begin{pmatrix} \delta^0 & \sqrt{2}\delta^+ \\ \sqrt{2}\delta^- & -\delta^0 \end{pmatrix}$$

- **Natural explanation of W mass anomaly** if the neutral component δ^0 acquires a small vacuum expectation value $v_\Delta \approx O(1\text{ GeV})$

Physical fields	*Parameters*
CP-even scalar H	α: mixing angle with SM-Higgs
Charged scalar $H^\pm$	v_Δ: vev of δ^0

$H(95) \to \gamma\gamma$: results

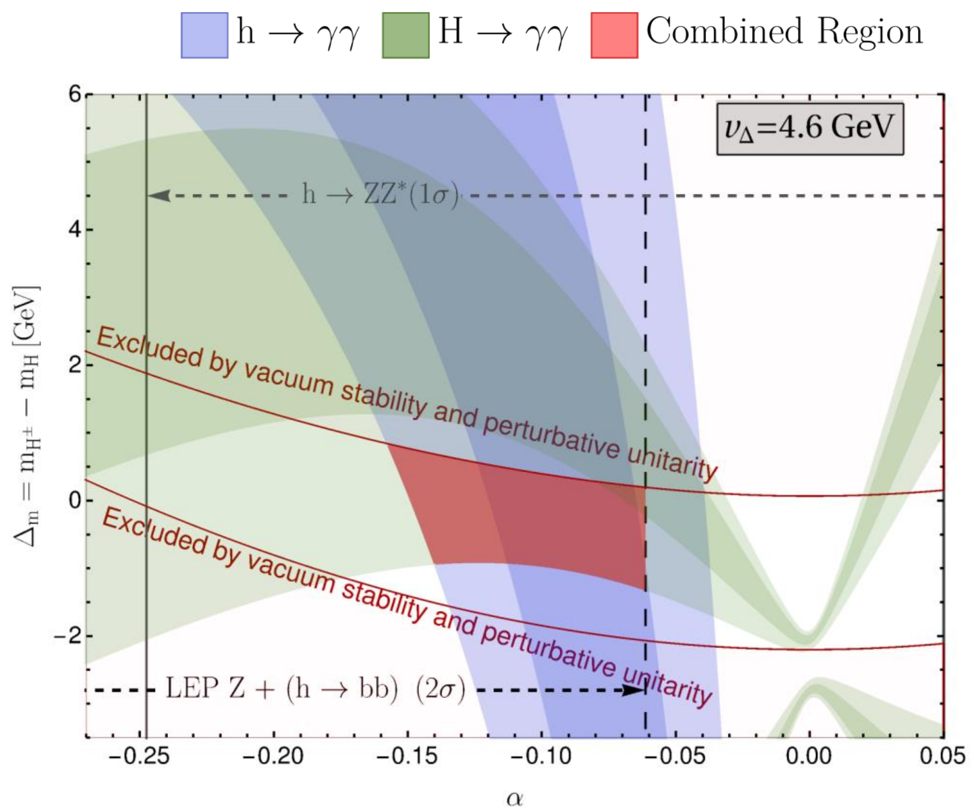
2306.15722

Constraints:

- Br$[h \to \gamma\gamma/ZZ]$
- Perturbative unitarity
- Vacuum stability

Hints for 95 GeV scalar:

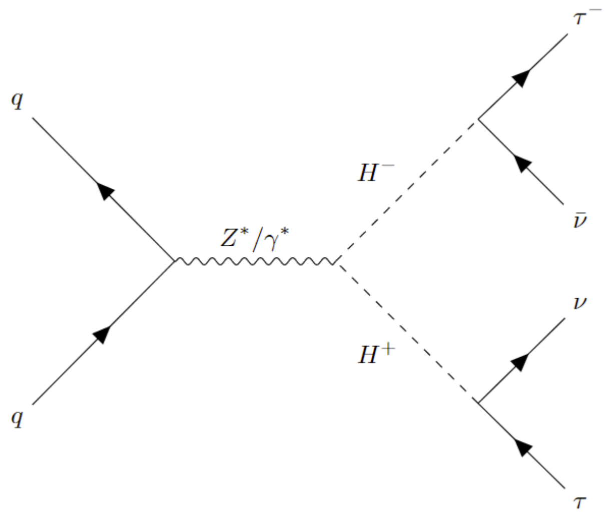
- $H \to \gamma\gamma$ (CMS and ATLAS)
- $Z + (H \to b\bar{b})$ (LEP)
- W mass



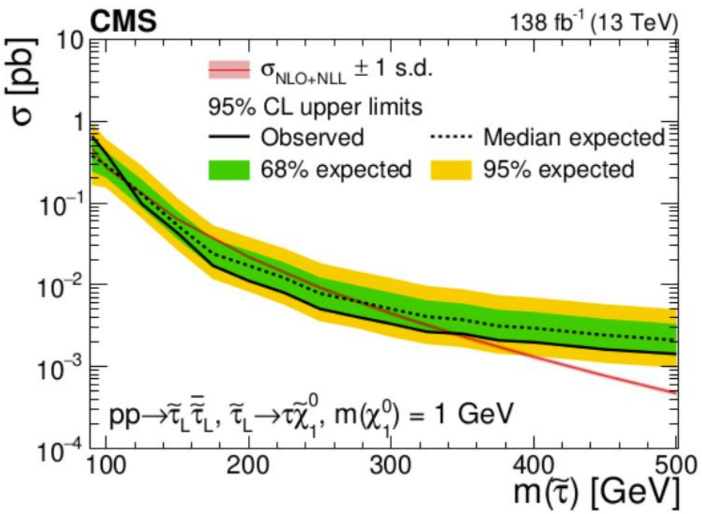
Since effects in W mass are small, $v_\Delta \approx O(1\text{GeV})$, thus a small mass splitting $m_{H^\pm} \approx m_H \approx 95$ GeV

$H^{\pm}(95) \to \tau\nu$: stau searches

- Drell-Yan production $pp \to H^{\pm} \to \tau\nu$ **has same signature as stau decays**



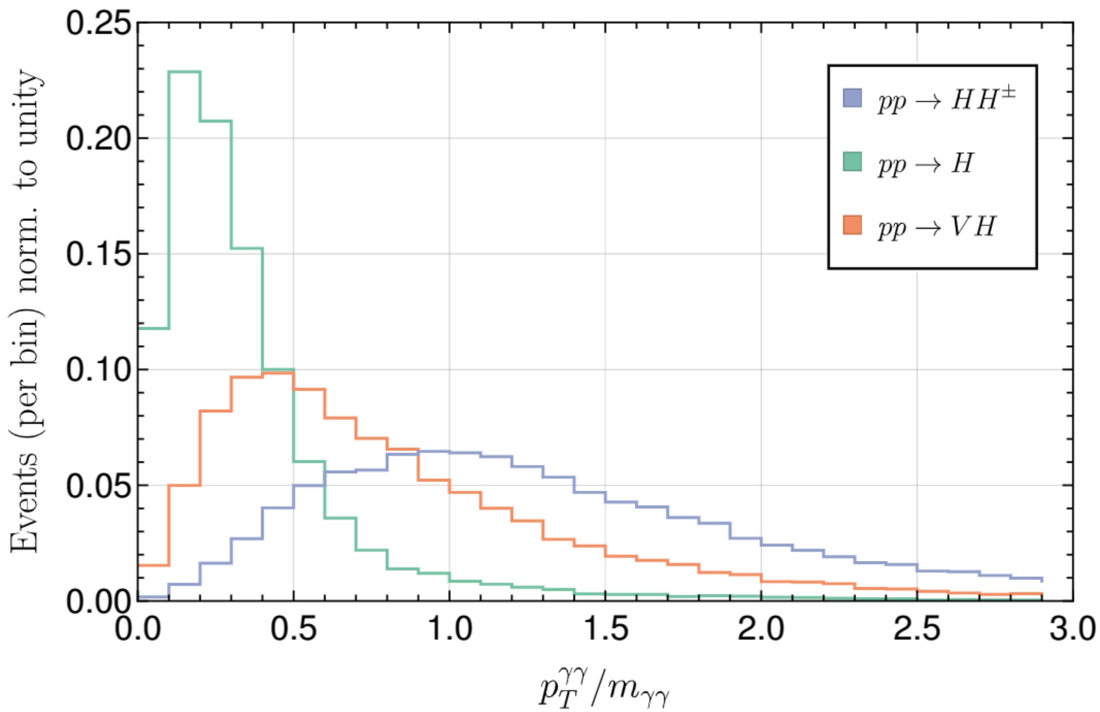
- $\sigma(pp \to H^{\pm} \to \tau\nu)$ borderline with existent CMS and ATLAS stau searches limits

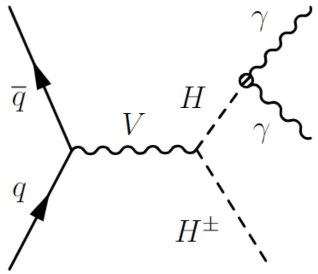


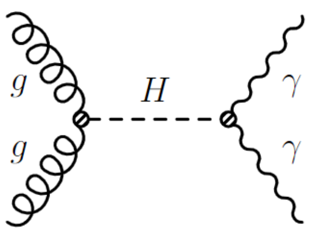
- Although $m_{H^{\pm}} \approx m_H$, the maximum mass splitting is $\approx 4(v_\Delta/v_{SM})^2$
- This **opens the channel $H^{\pm} \to HW^*$ and reduces the branching ratios of $H^{\pm} \to \tau\nu$**
- Alternative solution: Vector Like Quarks to enhance $H^{\pm} \to cs$

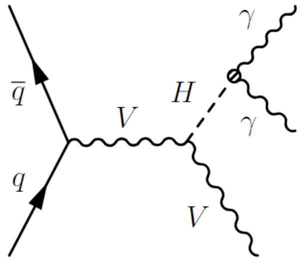
Predictions for p_T of $H \to \gamma\gamma$

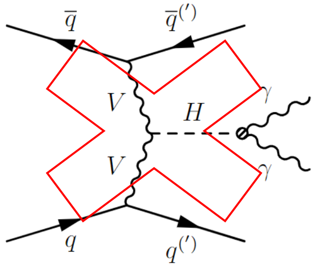
- H produced in DY with $H^{\pm}$:
  $pp \to H^{\pm}\,(H \to \gamma\gamma)$
- p_T not GF – like:
  $pp \to H \to \gamma\gamma$
- p_T not VH – like:
  $pp \to V(H \to \gamma\gamma)$







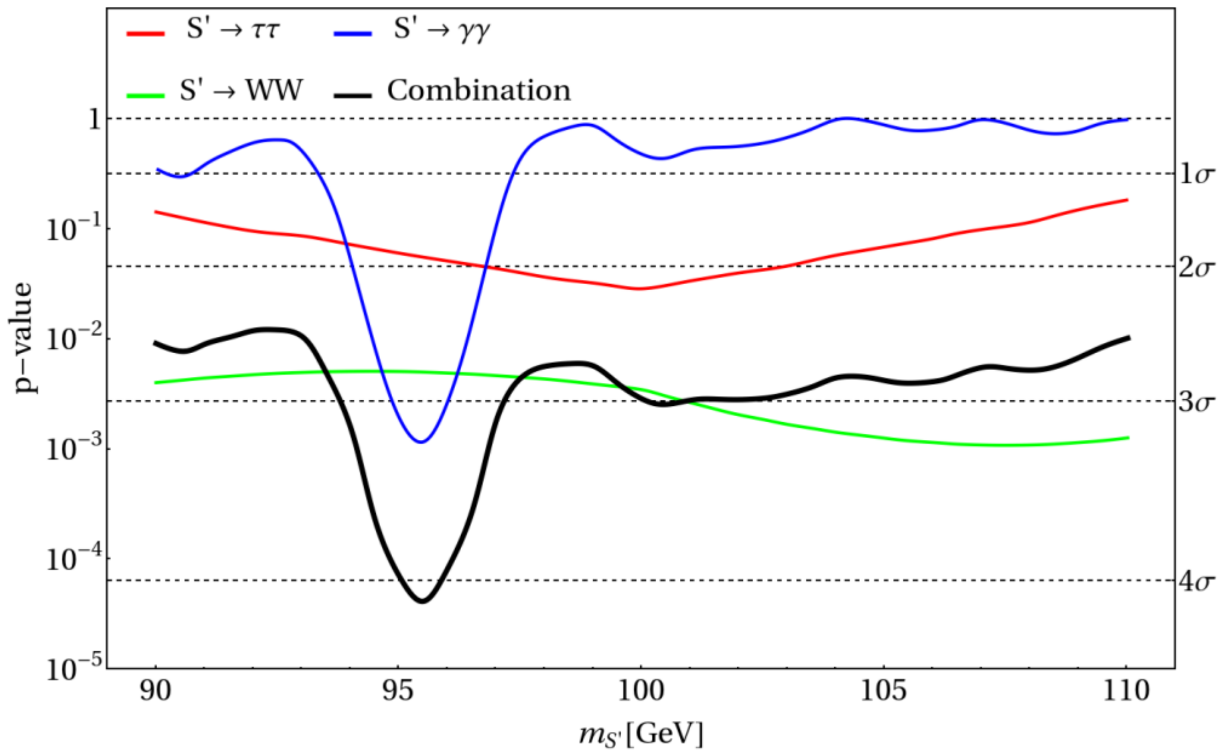




Thanks for your attention!

Back-up slides

95 and 152 excesses: summary



2109.06065

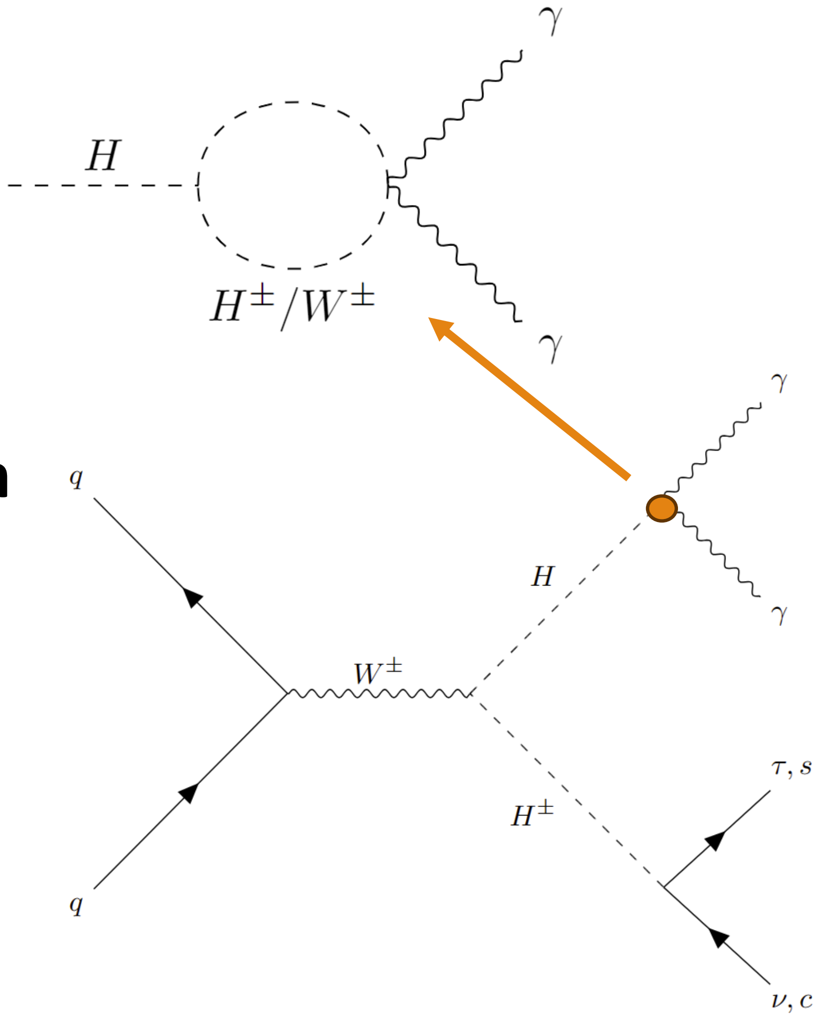
- The p-values of the individual high mass channels as well as their combination, both including and excluding the μe signal

Triplet Drell-Yan production

- $\gamma\gamma$ production:
  1. **Drell-Yan**
  2. **GF (SM mixing)**

- **Br[$H \to \gamma\gamma$] sizable as a function of mixing CP-even angle α and mass splitting $m_{H^\pm} - m_H$**

- Although $H^\pm \to$ jets, **no VBF signal** (jets angular distribution)



FCCC mediated by $\boldsymbol{H^{\pm}}$

- Coupling of Δ to fermions happens **only via mixing** with the SM Higgs doublet

- Couplings of $H^{\pm}$ to fermions are fixed by gauge invariance and proportional to $\boldsymbol{Sin}(\boldsymbol{\epsilon}) \approx \boldsymbol{v}_{\Delta}/\sqrt{\boldsymbol{v}_{\Delta}^{2} + \boldsymbol{v}_{SM}^{2}}$, with ϵ being the mixing angle among the charged component of the triplet and the SM charged Goldstone boson

- **Since v_{Δ} is small (m_W only slightly enhanced), effects related to FCCC mediated by $H^{\pm}$ are negligible**

Reduction of Br[$H^{\pm} \rightarrow \tau\nu$]

- Although $m_{H^{\pm}} \approx m_H$, opening of the channel $H^{\pm} \rightarrow HW^*$
- Reducing the decay rate $H^{\pm} \rightarrow \tau\nu$
- **Alternative solution: Vector Like Quarks to enhance $H^{\pm} \rightarrow cs$**