Searching for Low-Mass Resonances Decaying into W Bosons

Based on arxiv:2302.07276 (GC, A. Crivellin, S. Bhattacharya, B. Mellado)

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Structure of the talk

1. Overview and motivations
2. Experimental search
3. BSM simulation
4. Statistical analysis
5. Results

Overview and Motivations: Multi-lepton anomalies (MLA)

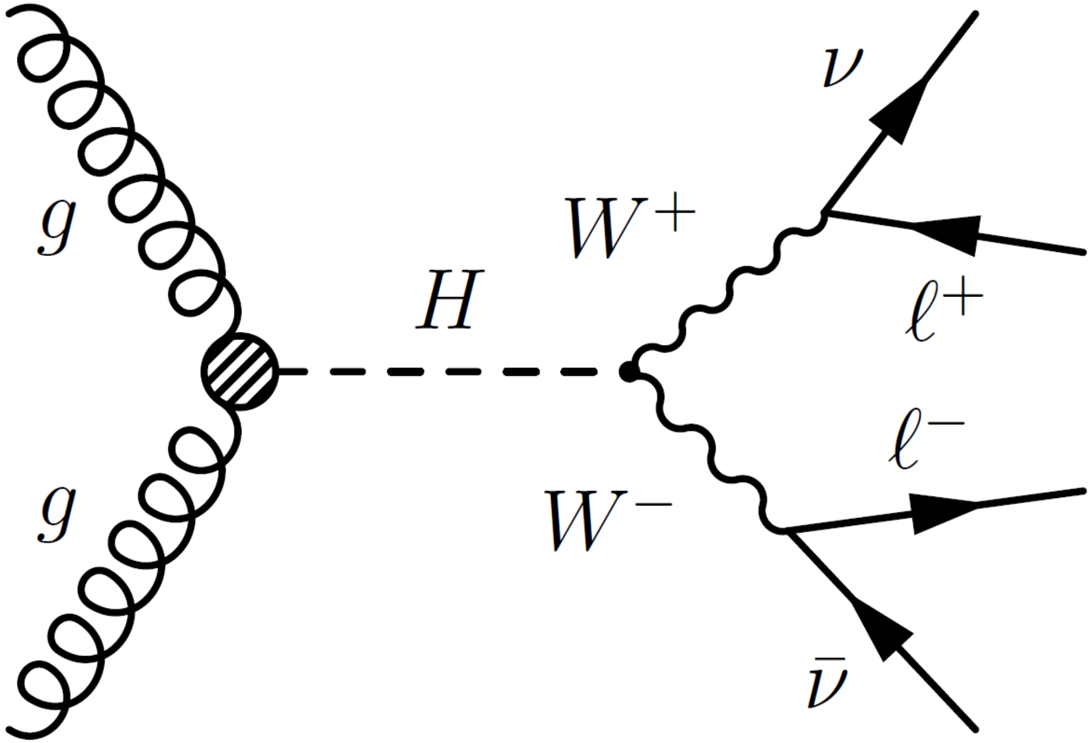
- MLA display very clean signatures
- MLA motivates existence of new states decaying to WW
- In addition: **resonant hints at 150 GeV and 95 GeV** in $\gamma\gamma$ and $\tau\tau$ channels
- **No dedicated resonant BSM searches for $gg \to H \to WW$** with full luminosity and scanning down to 95 GeV
- CMS and ATLAS analyses for **SM higgs in $gg \to h \to WW$ with full luminosity 135 fb^{-1} available**

→ We re-cast CMS and ATLAS SM Higgs analyses to search **for new scalars**

$gg \to H \to WW$

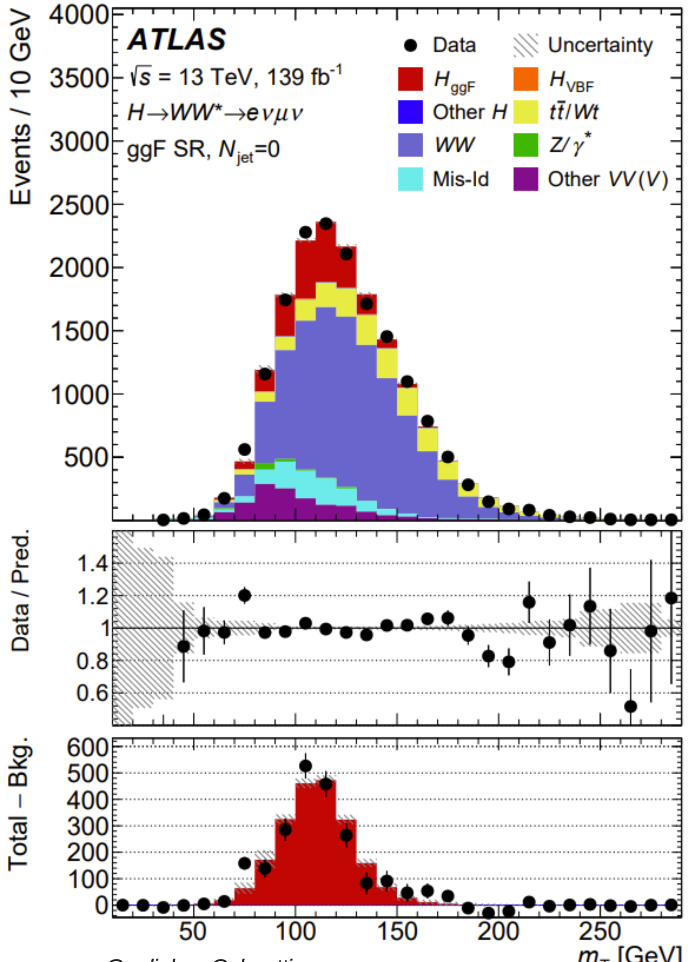
CATEGORY
1. 0-jet 2. Gluon fusion (ggH) 3. DFOS lepton pair

- A pair of different flavour opposite sign **(DFOS) leptons**
- Addition of **missing energy**
- **Jet veto** category
- Exclusion of Drell-Yan background
- Refining to **spin-0** candidates

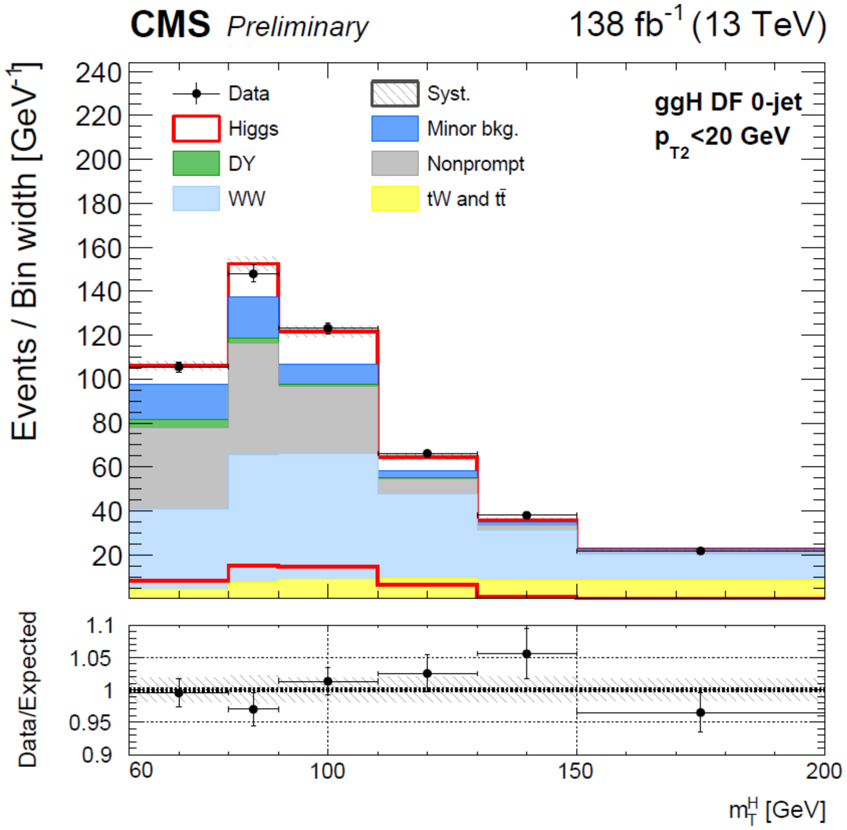


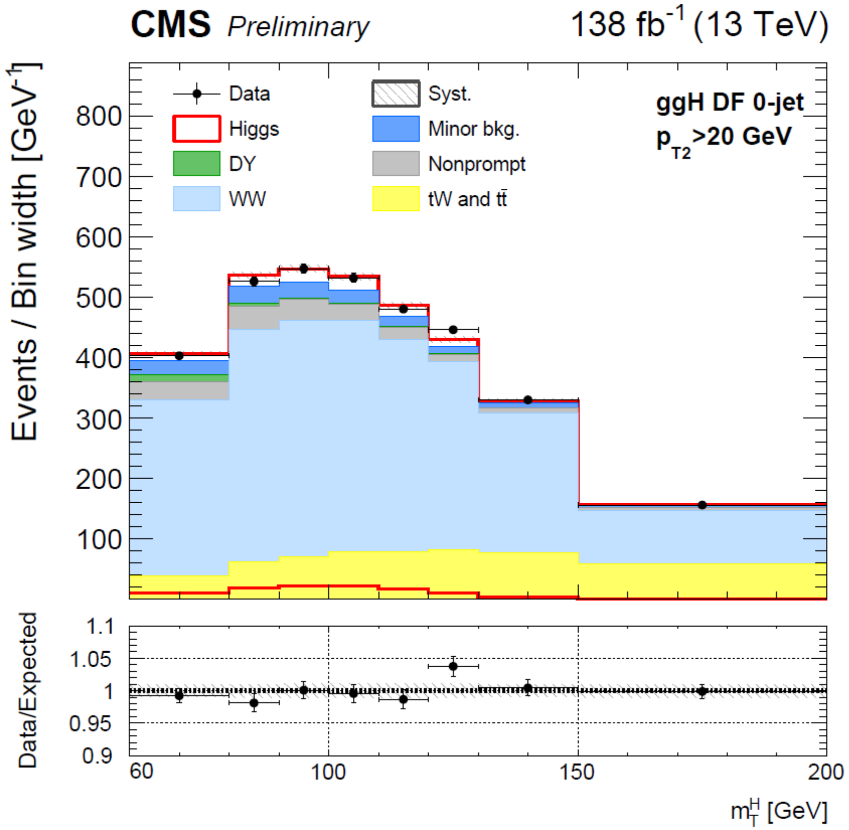
Experimental analysis

ATLAS [ARXIV:2207.00338]



CMS [ARXIV:2206.09466]





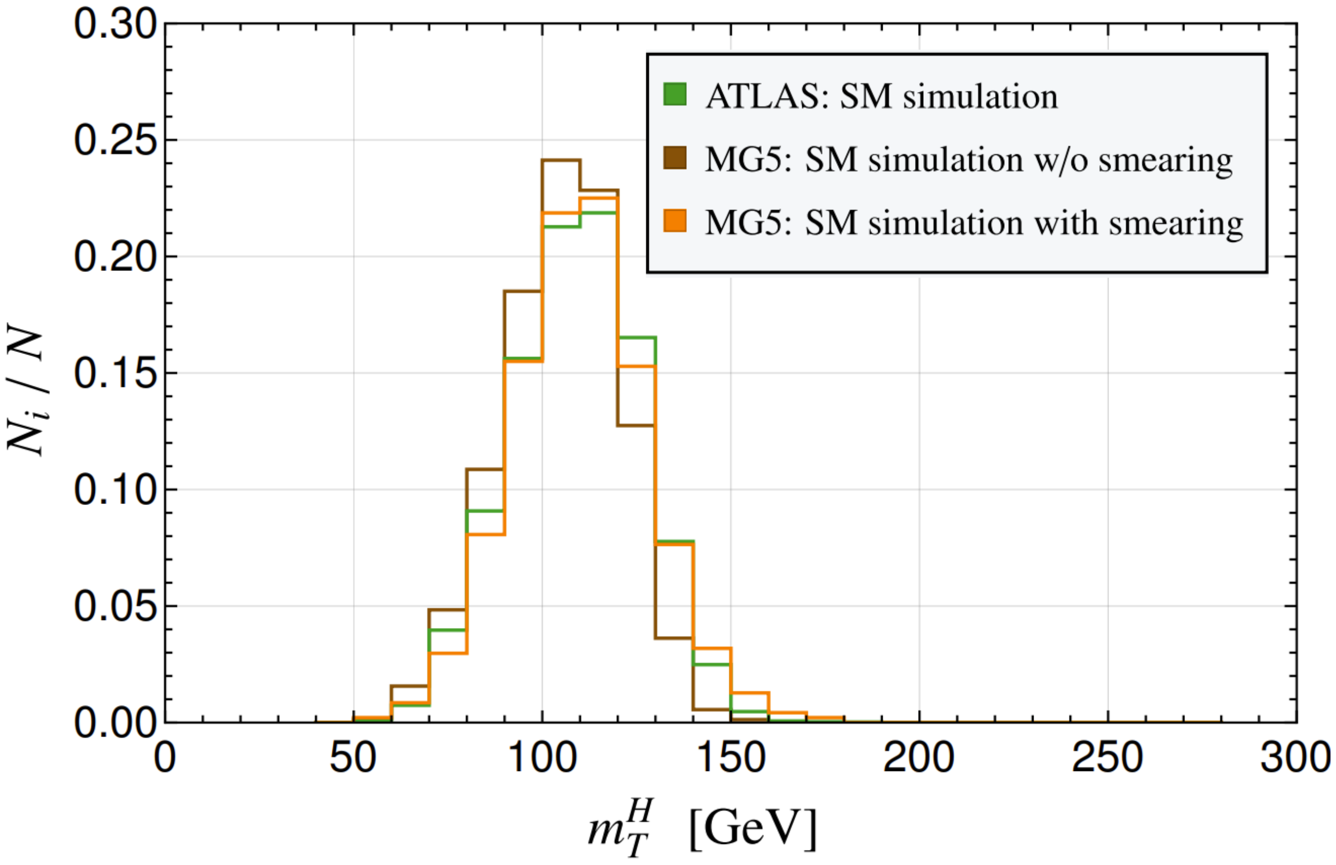
Observable: transverse Higgs mass*

Simulation

- HEP tools:
  - → **MadGraph5_aMC@NLO**
  - → Pythia8 (showering)
  - → Delphes3 (detector)

- **Limitations of fast simulation**
  - → SM-simulation VS ATLAS one
  - → **Smearing and shifts**
  - → Corrected **for efficiency (energy dependence)**
  - → Corrected for **NNLO effect in production cross section**

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



Uncertainties

ATLAS

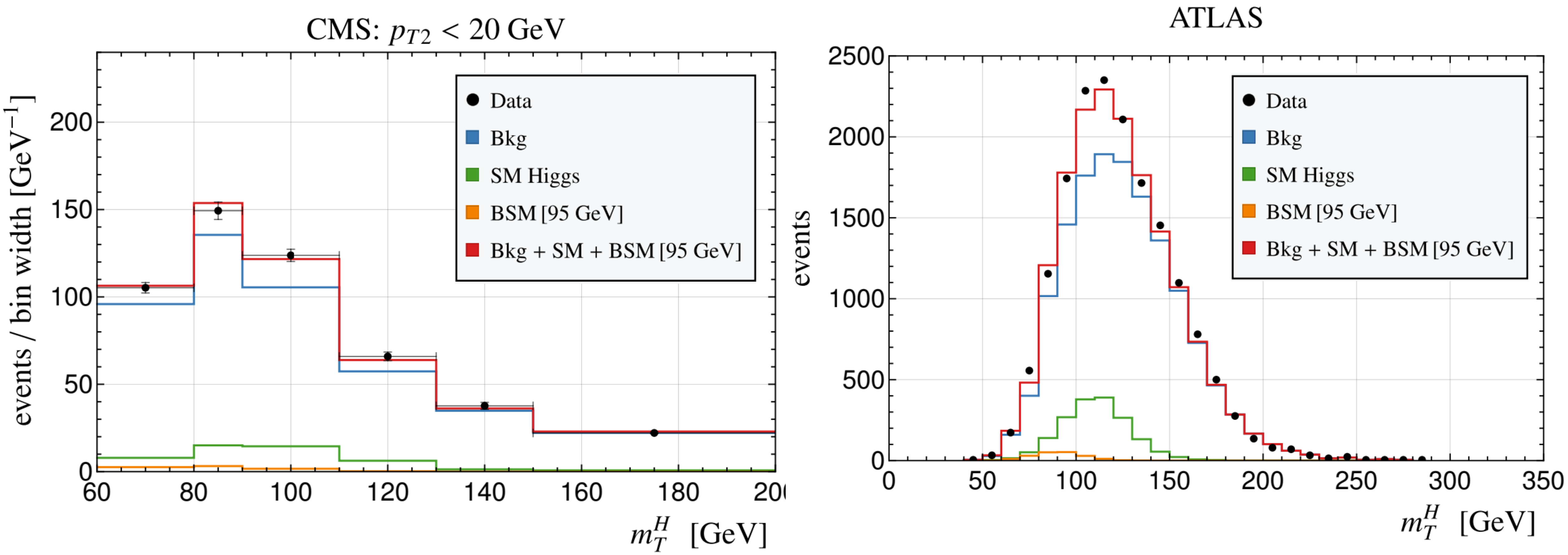
- **ATLAS scaled SM theory prediction by 1.21**
- Strong anti-correlations among the different background signals (including the SM Higgs)
- Mis-Id background is least correlated and the total uncertainty matches total one
  → Mis-Id uncertainty chosen as the total experimental systematic uncertainty
- **Theory uncertainty (systematic):**
  7% uncertainty on the SM Higgs signal

CMS

- CMS uses a combined fit to signal and background to account for systematic uncertainties
  → **re-fit background (including SM signal) when including new physics**
- **Theory uncertainty (systematic):**
  7% uncertainty on the SM Higgs signal

Systematics uncertainties correlations included

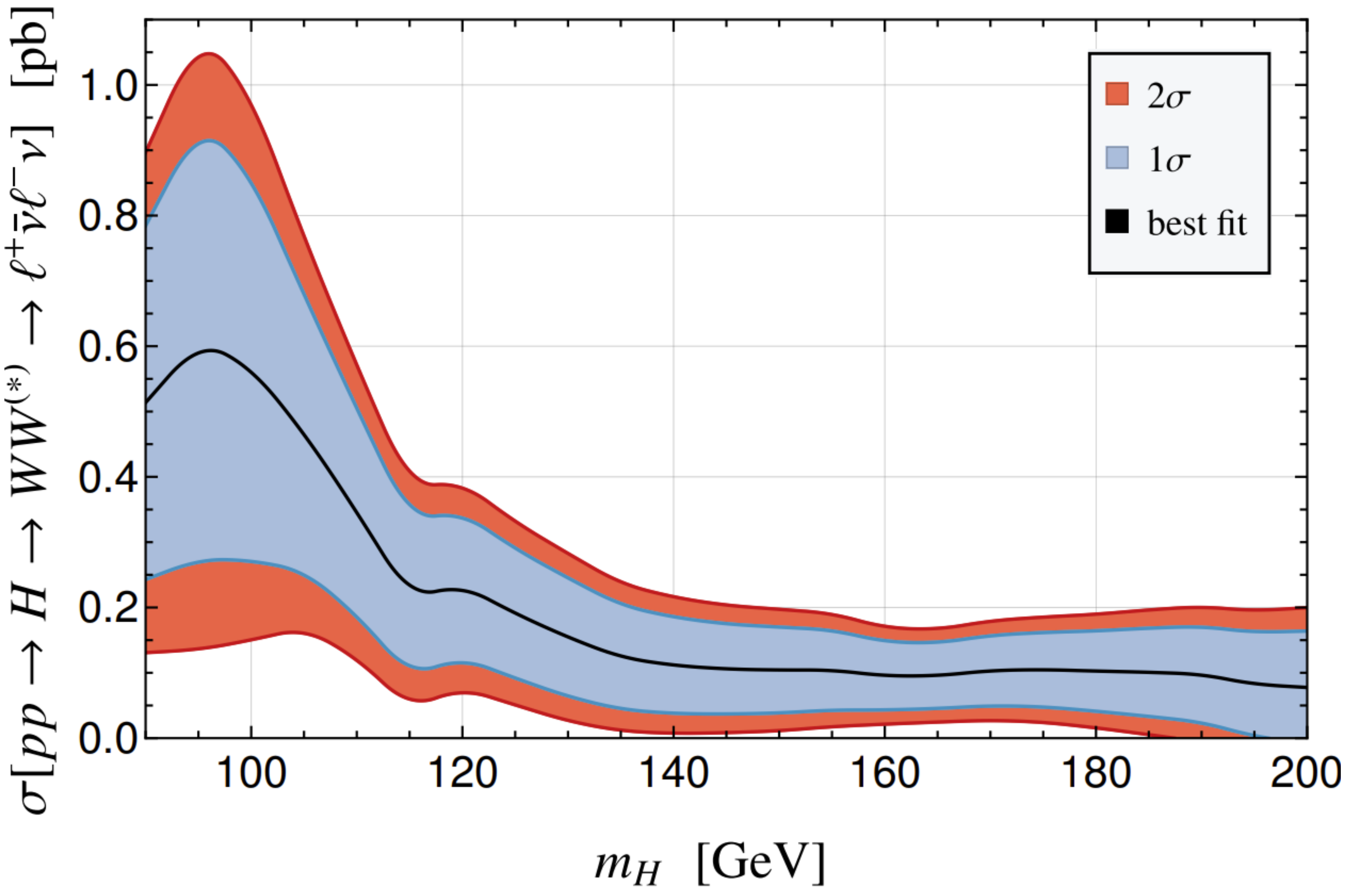
BSM signal fit with a mass of 95 GeV



CMS $p_{T2} > 20\ GeV$ plot not shown due to very small efficiency

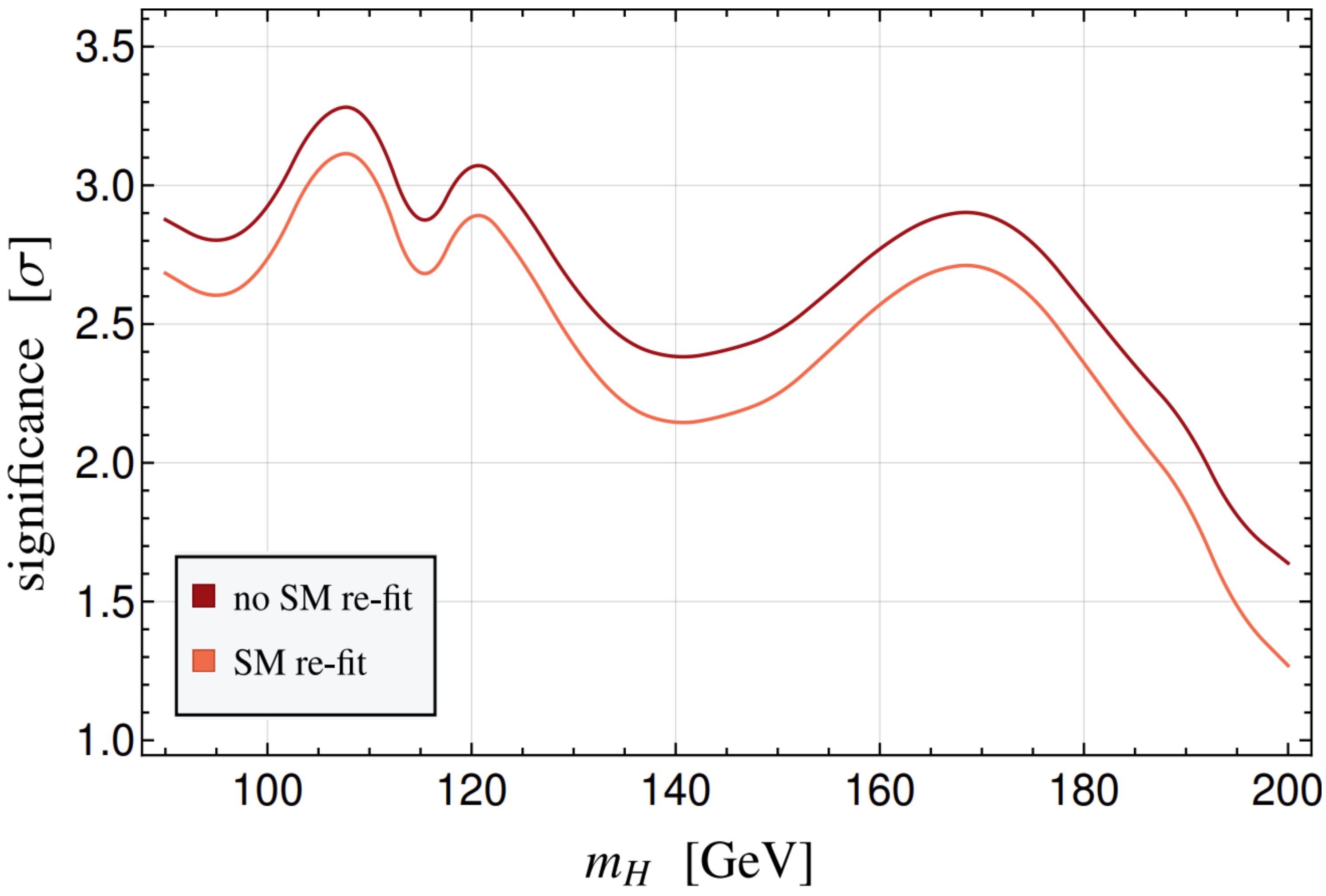
Cross section

- Observed limit is weaker than the expected one over the whole range **(preference for BSM contribution)**
- Allowed cross section is **largest around 95 GeV**



Significance

- **Global significance is only below ≈ 2 σ**
- Considering the existing hints for a scalar at 95 GeV **i.e. removing the look-elsewhere effect → significance of >~ 2.5 σ**.



Conclusion

Hints for new scalars decaying to WW bosons

- We re-casted CMS and ATLAS searches of a SM-scalar decaying to WW to search for new resonances
- **Hints for new physic resonance in WW decays (compatible with existing one around 95 GeV and 150 GeV)**

Possible Solution?
(among other models currently under development)

- **No signal of a resonance decaying to ZZ**
- Coupling a scalar to **a subgroup of a gauge group**

→ **Real scalar SU(2) triplet with $Y = 0$**

$$\Delta = \frac{\sigma_k}{2} T_k = \tau_k T_k = \frac{1}{2} \begin{pmatrix} h_2 + v_t & \sqrt{2} T^+ \\ \sqrt{2} T^- & -h_2 - v_t \end{pmatrix}$$

$SU_c(3)$	$SU_L(2)$	$U_Y(1)$
1	2	0

Possible Solution?
(among other models currently under development)

- No direct coupling to ZZ bosons at tree level (only via mixing with SM-higgs)
- Enhancement of the W mass (CDF II)

$$\Delta = \frac{\sigma_k}{2} T_k = \tau_k T_k = \frac{1}{2} \begin{pmatrix} h_2 + v_t & \sqrt{2} T^+ \\ \sqrt{2} T^- & -h_2 - v_t \end{pmatrix}$$

$$D_\mu \Delta = \partial_\mu \Delta + i g_2 [W_\mu^k \tau^k, \Delta]$$

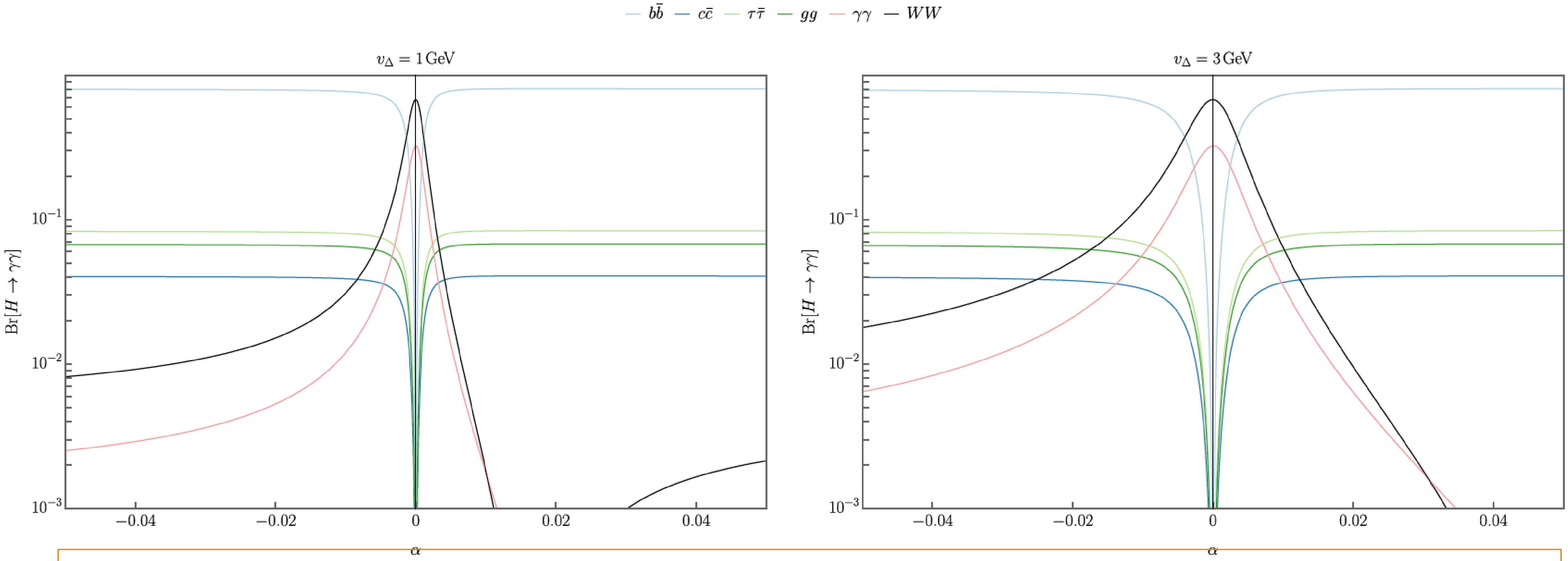
$$M_Z^2 = \frac{g_2^2 + g_1^2}{4} v_{SM}^2 = M_{Z(SM)}^2$$

$$M_W^2 = \frac{g_2^2}{4} (v_{SM}^2 + 4 v_t^2) = M_{W(SM)}^2 + g_2^2 v_t^2$$

Current and foreseen work:

- WZ, 3W, 4W
- Triplet (and other) models' study

$Y = 0$ triplet BR @95 GeV



Branching ratios of H @ 95 GeV. Dependences is on the CP-even mixing angle and the vacuum expectation value.

Statistical analyses

covariance matrix
(statistic and systematic)

- Significance computed via a χ^2 test $\chi^2 = [N_i^{\text{data}} - N_i^{\text{theory}}] \Sigma_{ij}^{-1} [N_j^{\text{data}} - N_j^{\text{theory}}]$

BSM signal

$$N_i^{\text{theory}} = p_{\text{BKG}}(N_i^{\text{SM}} + N_i^{\text{BKG}}) + p_{\text{BSM}} N_i^{\text{BSM}}$$

SM signal

CMS re-fit the background and SM-signal: we can therefore either float this contribution or take the nominal values of the paper

$$N_i^{\text{theory}} = p_{\text{BKG}}(N_i^{\text{SM}} + N_i^{\text{BKG}})$$

$$N_i^{\text{theory}} = N_i^{\text{SM}} + N_i^{\text{BKG}}$$

→ **both cases included in the fit**

- **BSM signal strength w.r.t. SM**: $\mu_{\text{BSM}} = \dfrac{\sigma[pp \to H \to WW^{(*)} \to \ell^+ \bar{\nu} \ell^- \nu]}{\sigma[pp \to h \to WW^* \to \ell^+ \bar{\nu} \ell^- \nu]}$

BSM signal strength @ 95 and 150

$m_H = 95\,\text{GeV}$	$\mu_{\text{BKG}}^{p_{T2}<20}$	$\mu_{\text{BKG}}^{p_{T2}>20}$	μ_{BSM}	χ^2_{BSM}	$\chi^{2,\text{re-fit}}_{\text{SM}}$	$\sigma^{\text{re-fit}}$	χ^2_{SM}	σ
ATLAS			0.7	49.0	57.7	3.0	57.7	3.0
CMS $p_{T2} < 20\,\text{GeV}$	1.01		0.0	5.5	5.5	0.0	6.8	1.2
CMS $p_{T2} > 20\,\text{GeV}$		1.01	-3.5	6.2	9.0	-	9.1	-
Combined Fit	1.00	1.00	0.5	65.4	72.2	2.6	73.3	2.8

$m_H = 150\,\text{GeV}$	$\mu_{\text{BKG}}^{p_{T2}<20}$	$\mu_{\text{BKG}}^{p_{T2}>20}$	μ_{BSM}	χ^2_{BSM}	$\chi^{2,\text{re-fit}}_{\text{SM}}$	$\sigma^{\text{re-fit}}$	χ^2_{SM}	σ
ATLAS			0.1	54.5	57.7	1.8	57.7	1.8
CMS $p_{T2} < 20\,\text{GeV}$	0.97		0.6	1.5	5.5	2.0	6.8	2.3
CMS $p_{T2} > 20\,\text{GeV}$		0.99	0.2	8.0	9.0	1.0	9.1	1.0
Combined Fit	1.01	0.99	0.1	67.2	72.2	2.2	73.3	2.5

TABLE I. Fit results for the two cases $m_H = 95\,\text{GeV}$ and $m_H = 150\,\text{GeV}$, motivated by the existing hints for new scalars at the LHC. Note that the sizable value of μ_{BSM} in the CMS $p_T > 20\,\text{GeV}$ category for the 95 GeV case is due to the very small efficiency.

Simulation efficiency