Searching for Low-Mass Resonances Decaying into W Bosons

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

Guglielmo Coloretti (University of Zurich and Paul Scherrer Institute)

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** motivates existence of new states decaying to WW [see Bruce Mellado's talk]
- In addition: **resonant hints at 150 GeV and 95 GeV** in $\gamma\gamma$ and $\tau\tau$ channels
- **No dedicated resonant BSM searches for $\boldsymbol{gg \to H \to WW}$** with full luminosity and scanning down to 95 GeV
- CMS and ATLAS analyses for **SM higgs in $\boldsymbol{gg \to h \to WW}$ with full luminosity 135 $\boldsymbol{fb^{-1}}$ available**

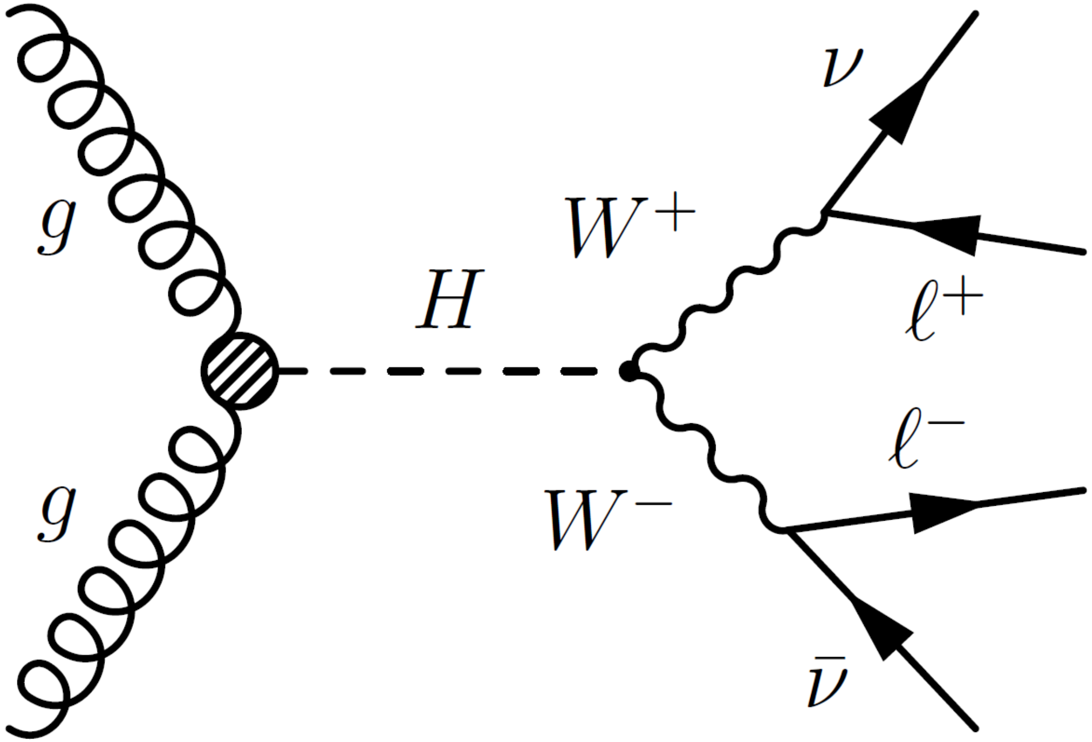
→ We re-cast CMS and ATLAS SM Higgs analyses to search **for new scalars**

$gg \to H \to WW$

CATEGORY:

0 jet – ggH – DFOS

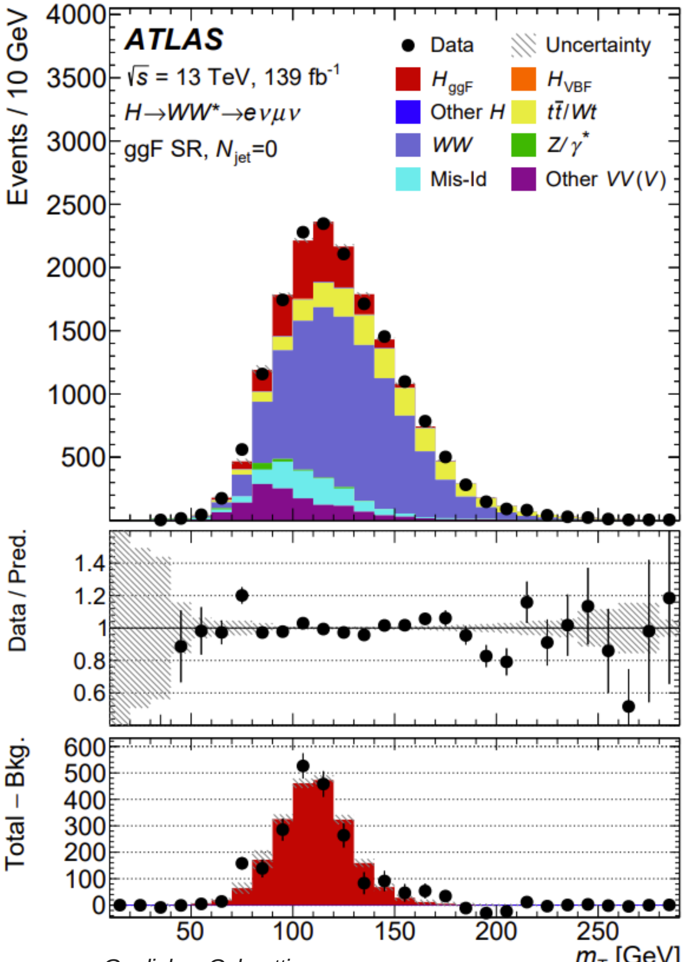
- A pair of different flavour opposite sign **(DFOS) leptons**
- Addition of **missing energy**
- **Jet veto** category
- Exclusion of Drell-Yan background
- Refining to **spin-0** candidates

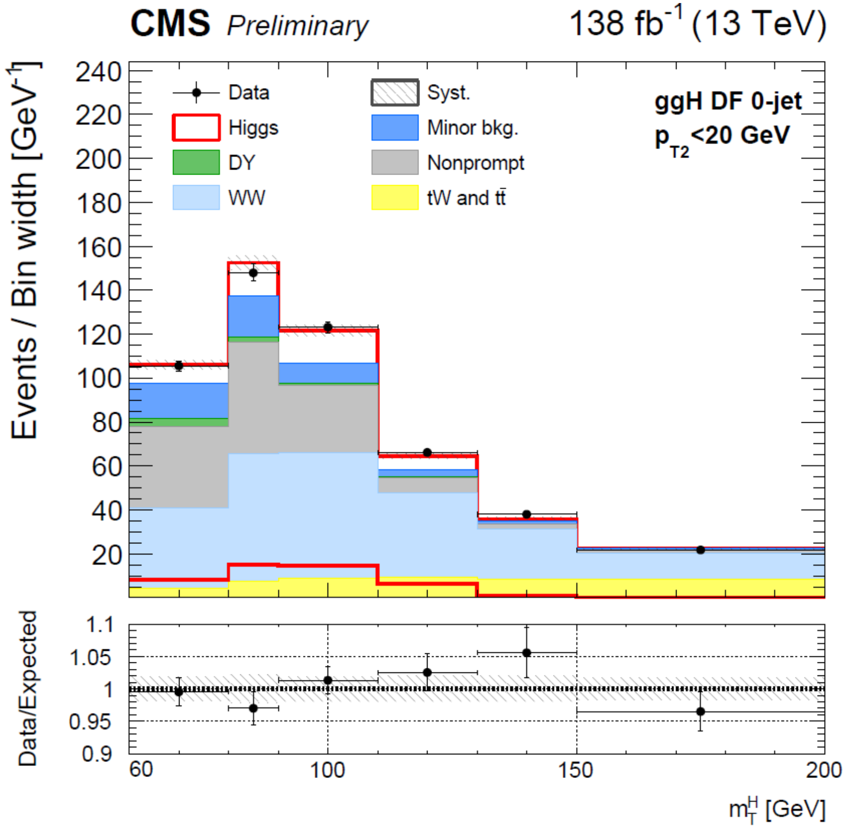


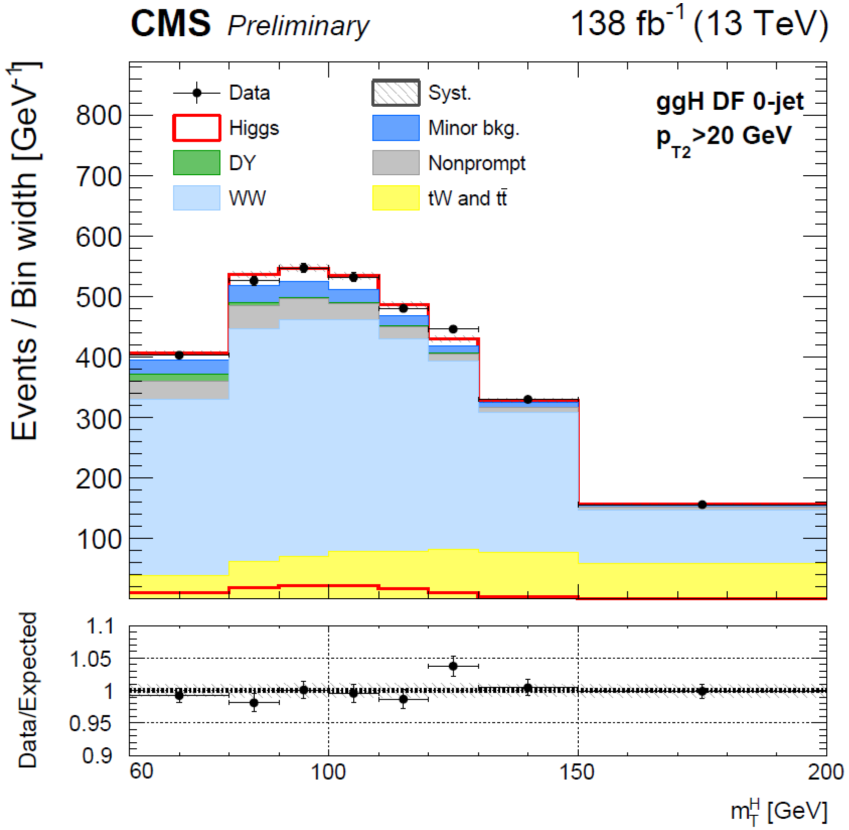
Experimental analysis

ATLAS [ARXIV:2207.00338]

CMS [ARXIV:2206.09466]





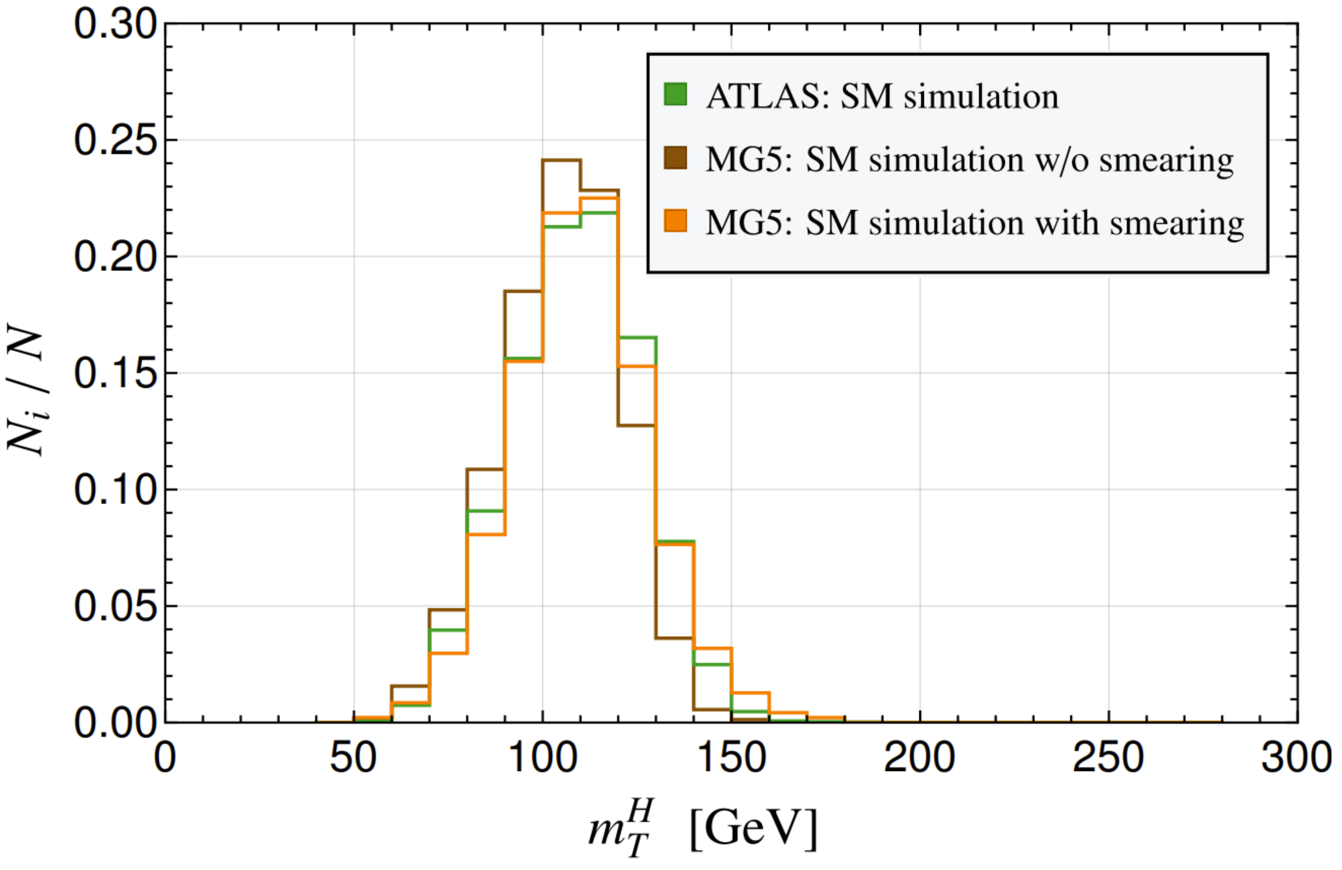


Observable: transverse Higgs mass*

Simulation

- HEP tools:
  - → **MadGraph5_aMC@NLO**
  - → Pythia8 (showering)
  - → Delphes3 (detector)
- **Limitations of fast simulation**
- Compared our SM-simulation to the ATLAS one
- To correct for differences: **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

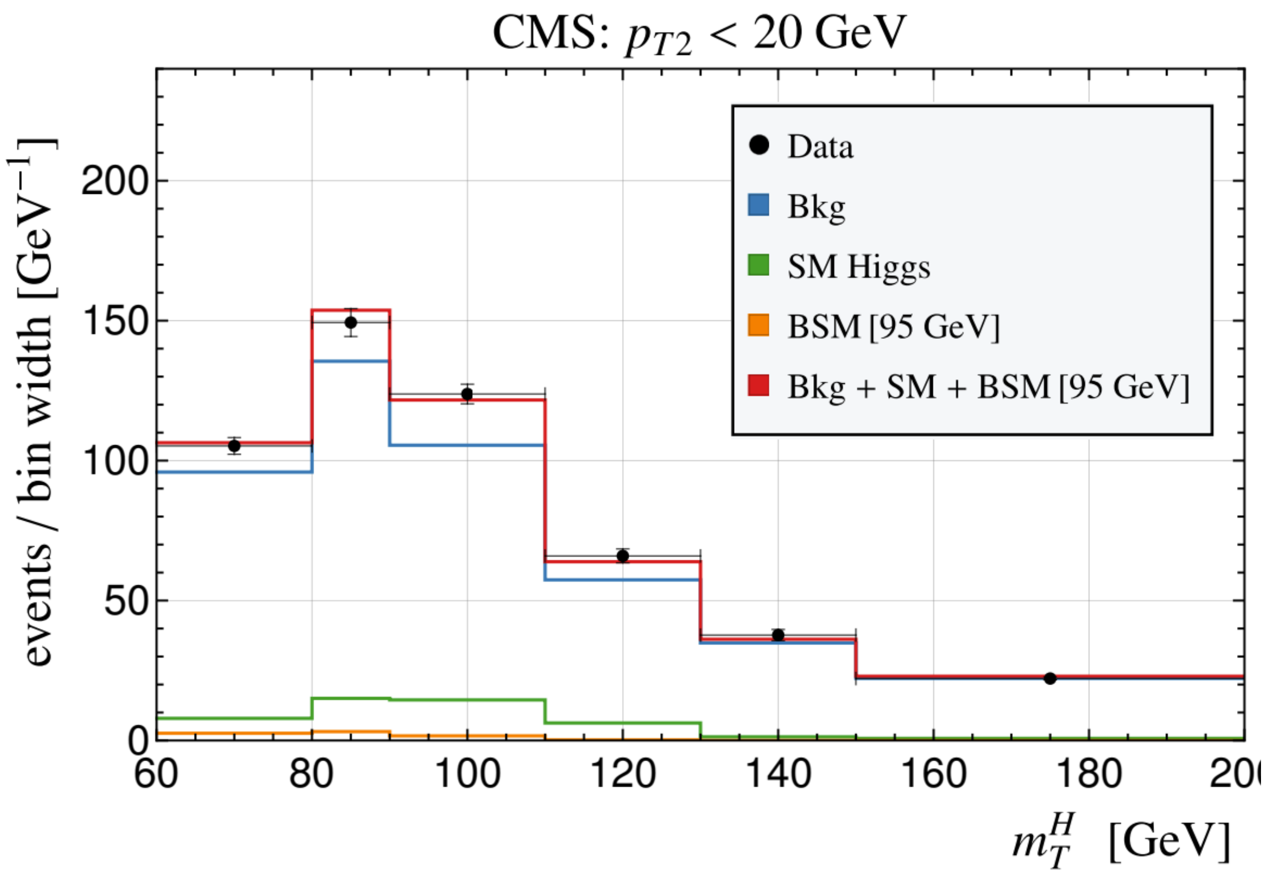
- **ATLAS scaled SM theory prediction by 1.21**
- Strong anti-correlations among the different background signals (including the SM Higgs)
- Mis-Id background is least correlated and the total uncertainty matches total one
  → Mis-Id uncertainty chosen as the total experimental systematic uncertainty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

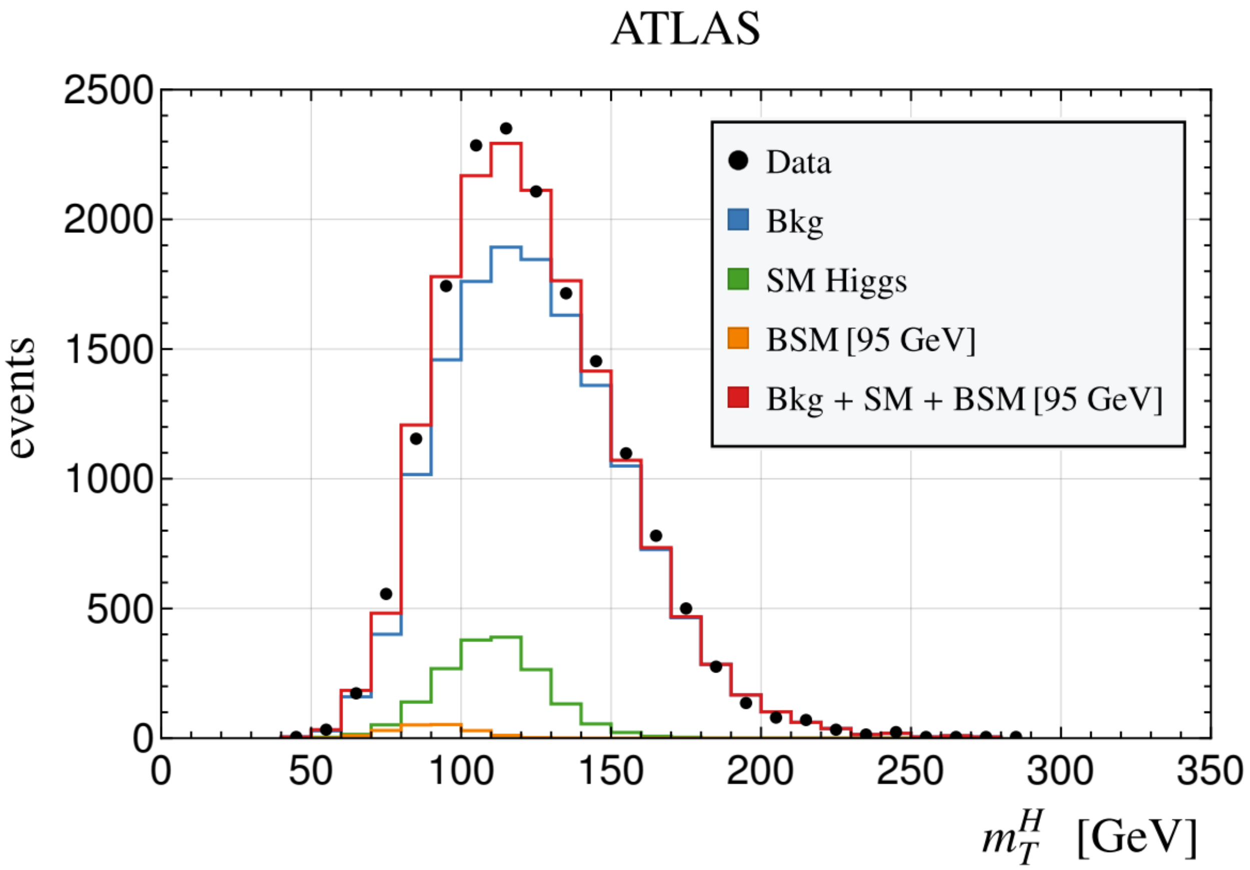
CMS

- 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

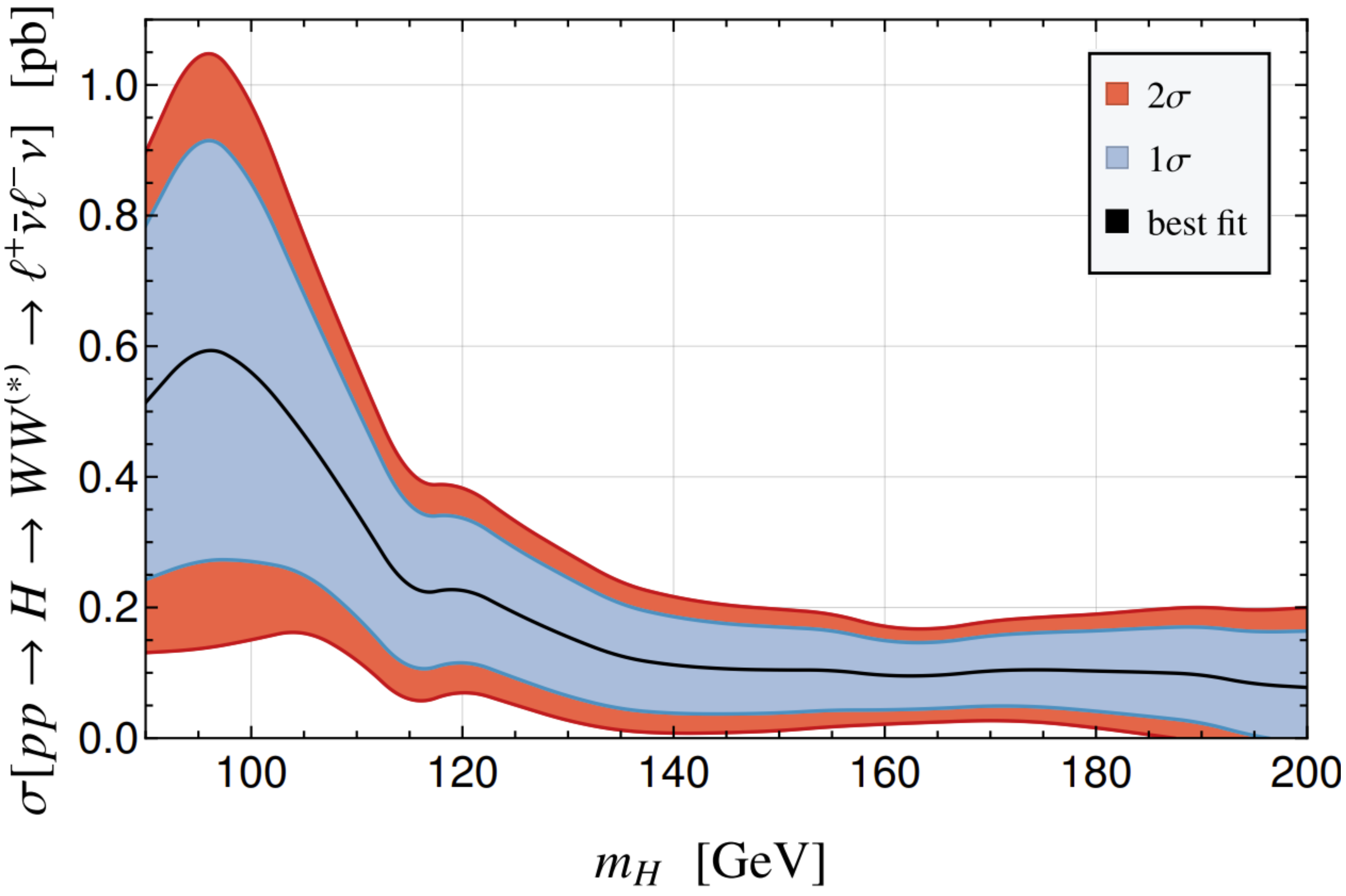




CMS $p_{T2} > 20\ GeV$ plot not shown due to very small efficiency

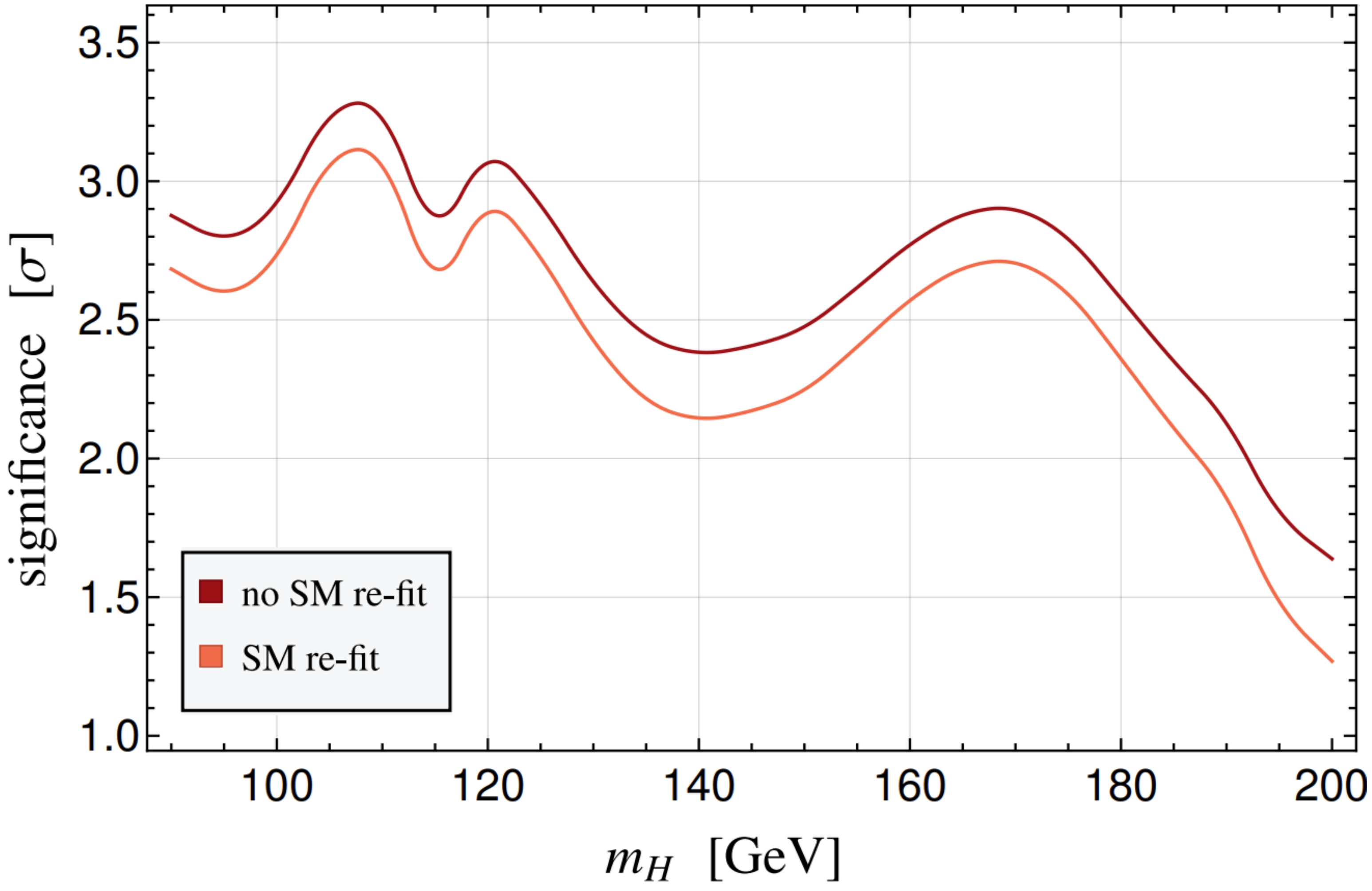
Cross section

- 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**
- **Real scalar triplet with $Y = 0$**
- Neutral component H^0 does **not couple to ZZ** at tree level (only mixing with SM Higgs boson)
- **Enhancement of the W boson mass** (CDF II)

$$\begin{pmatrix} \frac{T^0}{\sqrt{2}} & T^+ \\ T^- & -\frac{T^0}{\sqrt{2}} \end{pmatrix}$$

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

Statistical analyses

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

covariance matrix (statistic and systematic)

BSM signal

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

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

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

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

→ **both cases included in the fit**

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

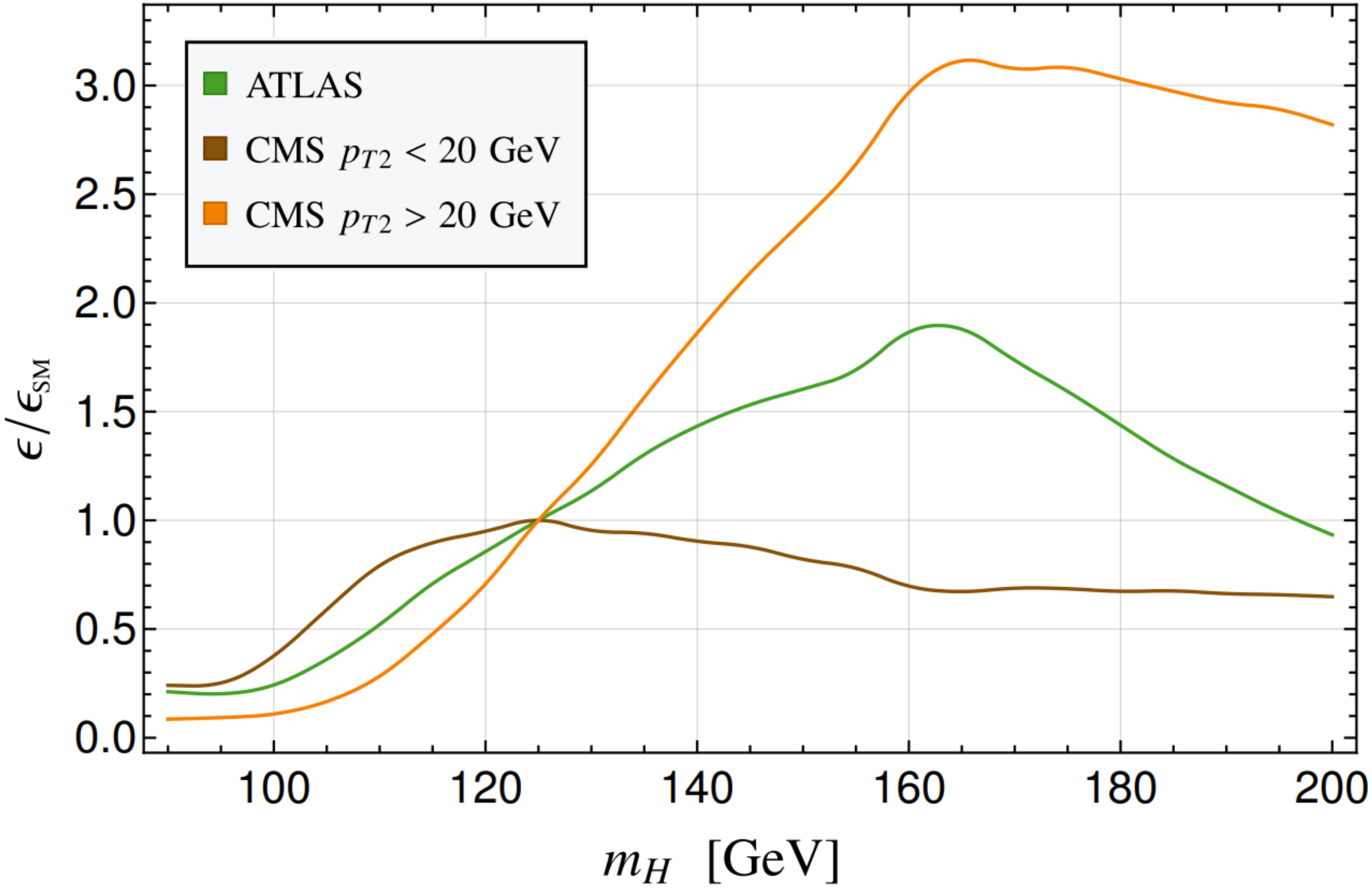
BSM signal strength @ 95 and 150

$m_H = 95\,\text{GeV}$	$\mu_{\text{BKG}}^{p_{T2}<20}$	$\mu_{\text{BKG}}^{p_{T2}>20}$	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

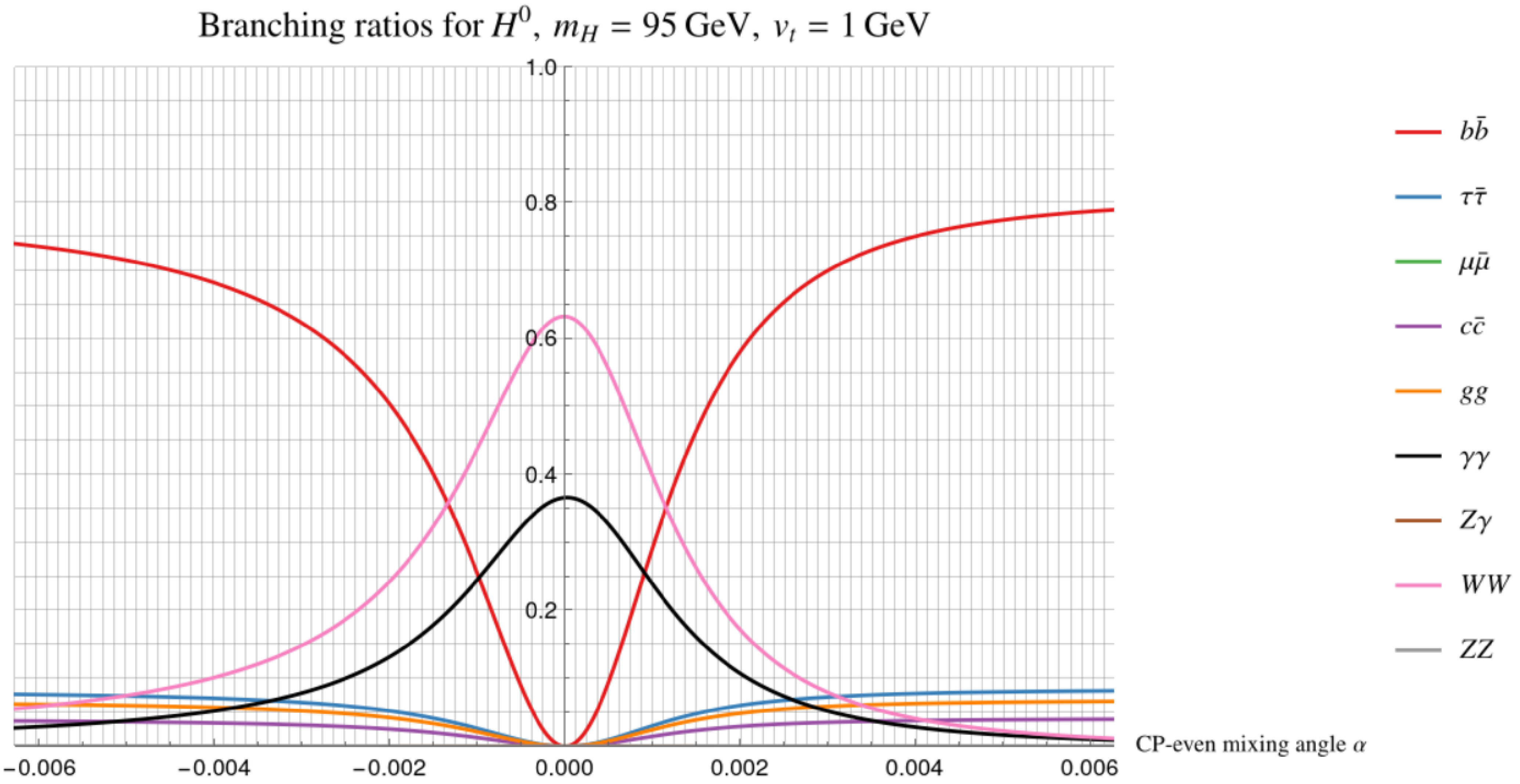
$m_H = 150\,\text{GeV}$	$\mu_{\text{BKG}}^{p_{T2}<20}$	$\mu_{\text{BKG}}^{p_{T2}>20}$	μ_{BSM}	χ^2_{BSM}	$\chi^{2,\text{re-fit}}_{\text{SM}}$	$\sigma^{\text{re-fit}}$	χ^2_{SM}	σ
ATLAS			0.1	54.5	57.7	1.8	57.7	1.8
CMS $p_{T2} < 20\,\text{GeV}$	0.97		0.6	1.5	5.5	2.0	6.8	2.3
CMS $p_{T2} > 20\,\text{GeV}$		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.

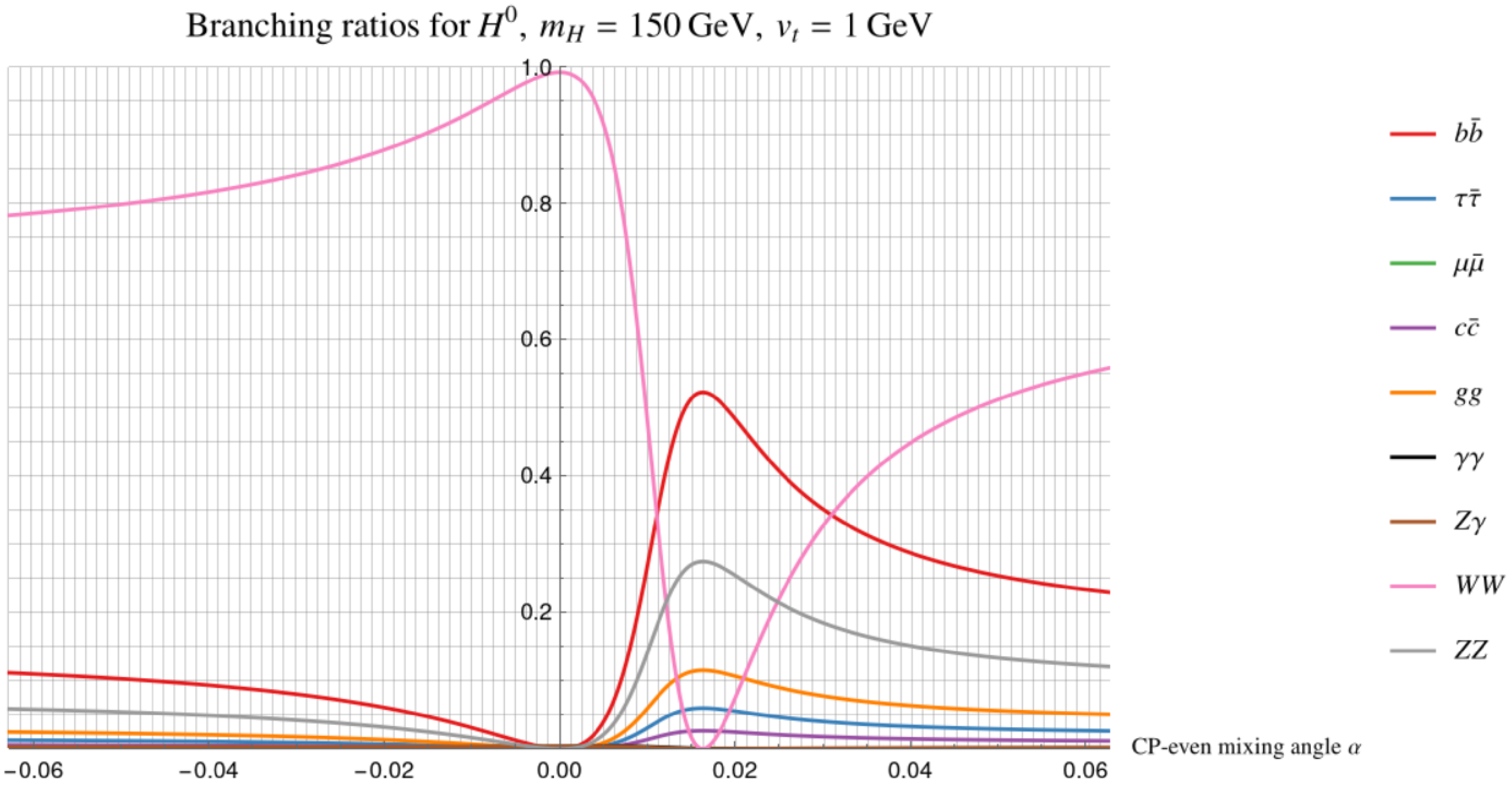
Simulation efficiency



$Y = 0$ triplet BR @95 GeV

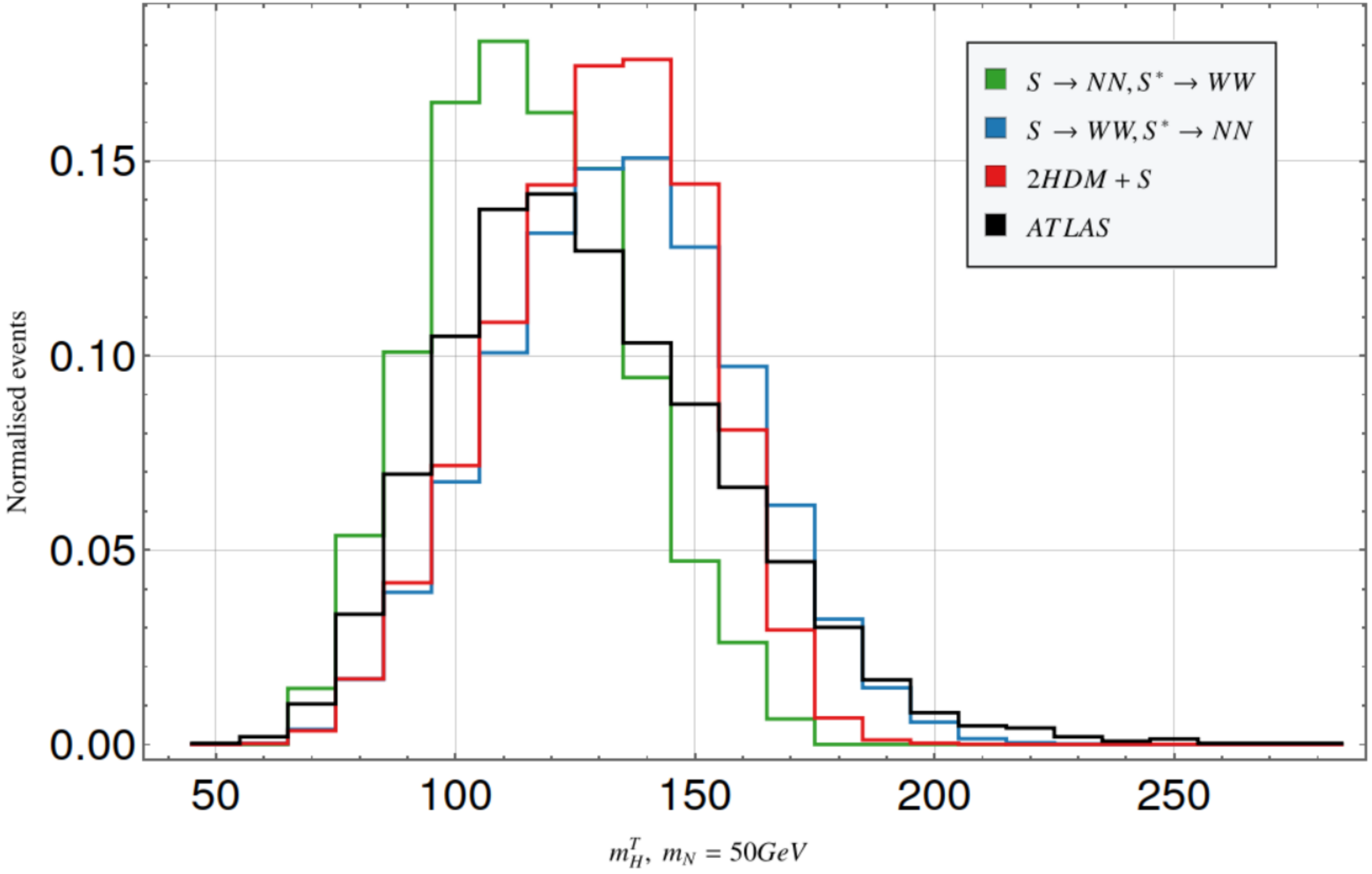


$Y = 0$ triplet BR @150 GeV



2HDM+S and right-handed neutrinos

- 150 GeV has a better fit compared to the case without missing energy



2HDM+S and right-handed neutrinos

150 GeV – miss	bkg CMS < 20	bkg CMS > 20	μ_{BSM}	χ^2_{BSM}	$\chi^{2\,refit}_{SM}$	σ^{refit}	χ^2_{SM}	σ
ATLAS			7.76344	49.2266	57.6562		57.6562	
CMS < 20	0.965477		2.11444	1.62004	5.48858		6.82523	
CMS > 20		0.986532	−14.4418	5.70301	9.03945		9.05016	
Comb. fit – 2 par	1.00473	0.978693	0.490567	63.8945	72.2081		73.2809	
Comb. fit – 1 par	1.00467	0.993217		65.4041	72.2081	2.60846	73.2809	2.80657