Uncovering New Higgs Bosons in the ATLAS Analysis of Differential $t\bar{t}$ Cross-sections

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- Based on *arXiv.2308.07953*

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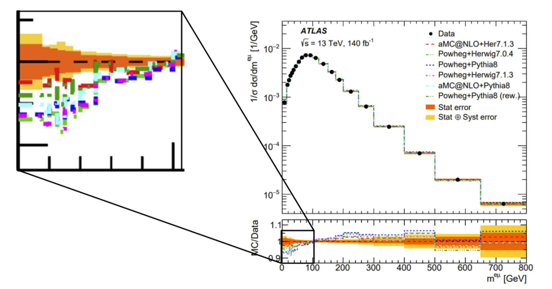
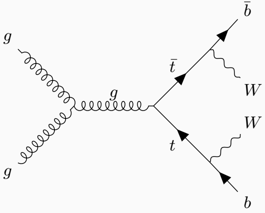
Outline

1. Motivation
2. Benchmark Model
3. Results
4. Conclusions

Deviations in differential $t\bar{t}$ cross-section

Normalised differential cross-sections as a function of the invariant mass of $e-\mu$ system from ATLAS [arXiv:2303.15340].

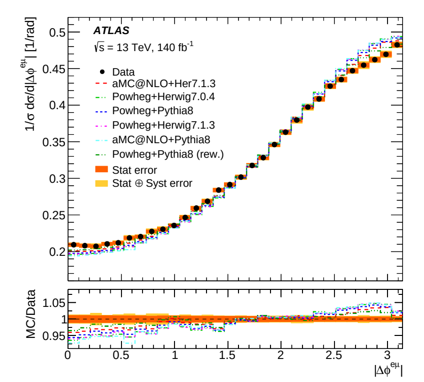




- SM predictions using six combinations of MC simulators.
- Significant deviations from the SM at low $m^{e\mu}$.

Deviations in differential $t\bar{t}$ cross-section

Normalised differential cross-sections as a function of the angle between the leptons ($\Delta\phi^{e\mu}$) from ATLAS [arXiv:2303.15340].



"No model can describe all measured distributions within their uncertainties." - ATLAS

Mismodelling of SM at the LHC or new physics effects?

Higgs boson at ≈ 95 GeV?

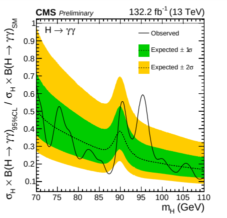


Figure 1: CMS: $H \to \gamma\gamma$ (2.9σ)

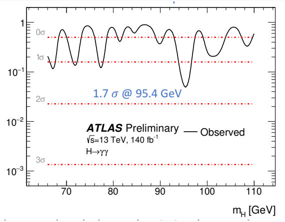


Figure 2: ATLAS: $H \to \gamma\gamma$ (1.7σ)

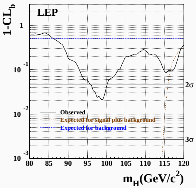


Figure 3: LEP: $H \to b\bar{b}$ (2σ)

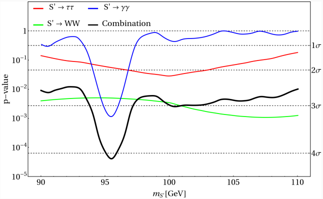
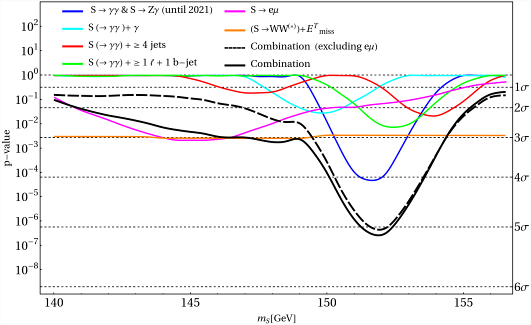


Figure 4: CMS+ATLAS (4.1σ)

Higgs boson at ≈ 150 GeV?

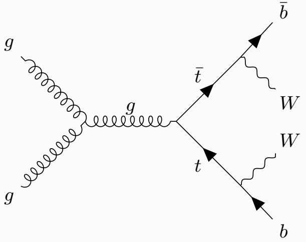
[arXiv:2306.17209] by S. Bhattacharya, G. Coloretti, A. Crivellin, S. Dahbi, Y. Fang, M. Kumar, B. Mellado



Global significance of 4.9σ obtained for a simplified model.

Benchmark Model

- NP model should have opposite-sign different-flavour di-leptons with one or more b-jets.
- We consider a simplified model with three Higgs bosons [arXiv:2308.07953].



- Fixed the masses of S and S' by hints for 95 GeV and 150 GeV resonances. Fixed mass of H to 270 GeV, no effects by varying.
- Assumption: $\text{Br}[S \to WW] = 100\%$ and $\text{Br}[S' \to b\bar{b}] = 100\%$.

Benchmark Model

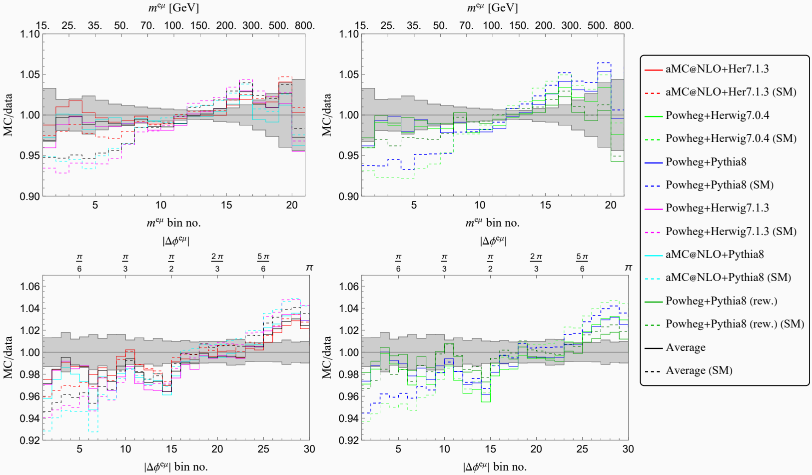
- Focus on the $m^{e\mu}$ and $|\Delta\phi^{e\mu}|$ distributions due to significant deviations. (Other observables consistent)
- Extract experimental data by digitizing the ATLAS plots: $x_i = \frac{\mathrm{MC}_i}{\mathrm{data}_i}$.
- Correlation matrix (ρ_{ij}) between $m^{e\mu}$-$|\Delta\phi^{e\mu}|$ and within single distribution by simulating 1600k events of $pp \to t\bar{t}$ in SM.
- Add normalized NP physics contribution r_i obtained from MadGraph5aMC@NLO+Pythia.
- Treating NP linearly as a small perturbation

$$\boxed{\chi^2_{\mathrm{NP}} = \sum_{i,j=1} (a x_i + \varepsilon_{\mathrm{NP}} r_i - 1)\, \rho^{-1}_{ij} \left(a x_j + \varepsilon_{\mathrm{NP}} r_j - 1\right)}.$$

- For best-fit, minimize χ^2_{NP} with respect to $\varepsilon_{\mathrm{NP}}$ and a.

Results

The solid lines are the predictions of our NP model for the best fit to data, and the dashed lines depict the SM.



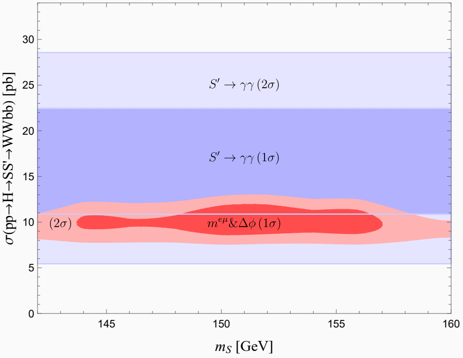
Results

	$m^{e\mu}$				$\Delta\phi^{e\mu}$				$m^{e\mu} + \Delta\phi^{e\mu}$				
	$\chi^2_{\rm SM}$	$\chi^2_{\rm NP}$	$\sigma_{\rm NP}$	Sig.	$\chi^2_{\rm SM}$	$\chi^2_{\rm NP}$	$\sigma_{\rm NP}$	Sig.	$\chi^2_{\rm SM}$	$\chi^2_{\rm NP}$	$\sigma_{\rm NP}$	Sig.	m_S[GeV]
Powheg+Pyhtia8	146	50	10pb	9.8σ	183	73	11pb	10.5σ	213	102	9pb	10.5σ	$143-156$
aMC@NLO+Herwig7.1.3	31	13	4pb	4.2σ	96	38	8pb	7.6σ	102	68	5pb	5.8σ	$--$
aMC@NLO+Pythia8	89	14	9pb	8.7σ	277	83	15pb	14.0σ	291	163	10pb	11.3σ	148-157
Powheg+Herwig7.1.3	138	32	10pb	10.3σ	245	93	13pb	12.3σ	261	126	10pb	11.6σ	149-156
Powheg+Pythia8 (rew)	40	12	5pb	5.3σ	54	26	6pb	5.3σ	69	35	5pb	5.8σ	$--$
Powheg+Herwig7.0.4	186	41	12pb	12.0σ	263	99	14pb	12.8σ	294	126	12pb	13.0σ	149-156
Average	93	23	8pb	8.4σ	172	63	11pb	10.4σ	182	88	9pb	9.6σ	143-157

- $\chi^2_{\rm NP}$ is for the benchmark point $m_S \approx 150$ GeV.
- m_S gives the preferred range from the fit.
- Averaging the six different SM predictions $\sigma(pp \to H \to SS' \to WWb\bar{b}) \approx 9$pb is preferred.
- NP preferred over the SM hypothesis by atleast 5.8σ.

Results

- Assuming $S'(95)$ is SM-like, i.e $\text{Br}[S' \to b\bar{b}] = 86\%$, and $\text{Br}[S \to WW] = 100\%$
- Red region preferred by $t\bar{t}$ distribution.
- Blue region preferred by $\gamma\gamma$ signal strength at 95 GeV.



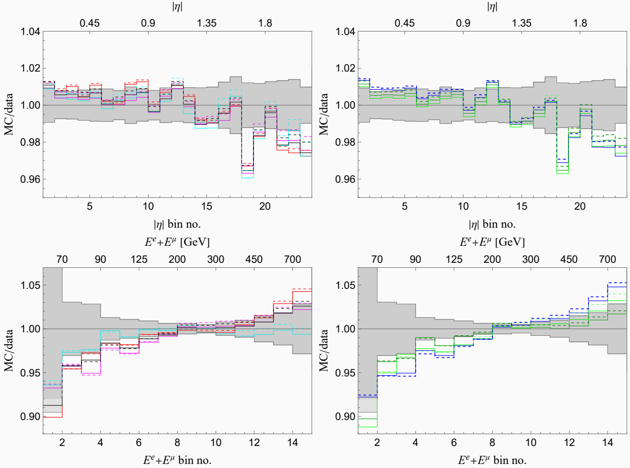
NP explanation of $t\bar{t}$ distributions compatible with $95 \to \gamma\gamma$ excess

Summary

- Significant deviations in differential lepton distribution $m^{e\mu}$ and $\Delta\phi^{e\mu}$ suggests mismodelling of the SM or new physics effects.
- Possibility of a new particle at the electroweak scale.
- Considered a simplified model with three Higgs that gives a NP background process $pp \to H \to SS' \to WWb\bar{b}$.
- Assuming $S(152)$ is from a triplet and $S'(95)$ is from a singlet, our simplified model is compatible with di-photon excess at 95 GeV.
- NP model can also explain the excess in W mass.
- Emergence of a new model with multiple scalars in a singlet(95)-doublet(125)-doublet(270)-triplet(150) pattern (future work).

Results

- For η and $E^e + E^\mu$



Results

- For $p^e + p^\mu$ and $p^{e\mu}$