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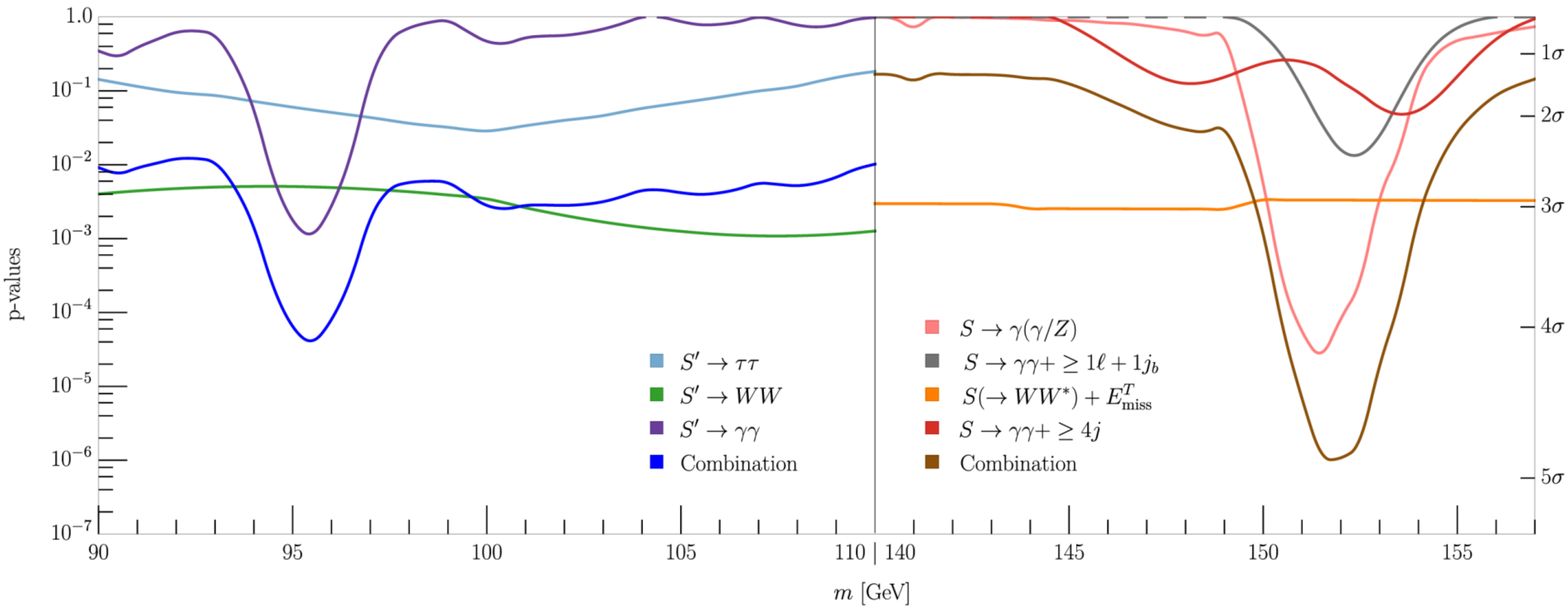
New Higgses at the Electroweak Scale and Differential Top-Quark Distributions

DIS, Grenoble, 09.04.2024

Hints for new Scalars at 95 GeV & 151.5 GeV

- 95 GeV: Only inclusive searches at LHC
- 151.5 GeV: SM Higgs γγ and Zγ side-bands in associated production channels (no sign in ZZ)

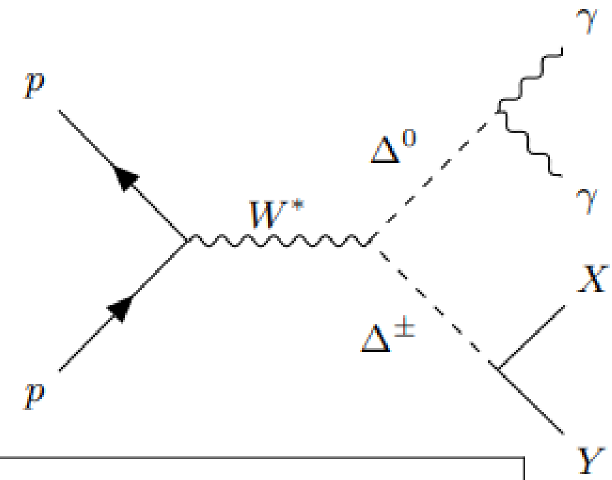
S. Bhattacharya, G. Coloretti, A. Crivellin, et al. arXiv:2306.17209

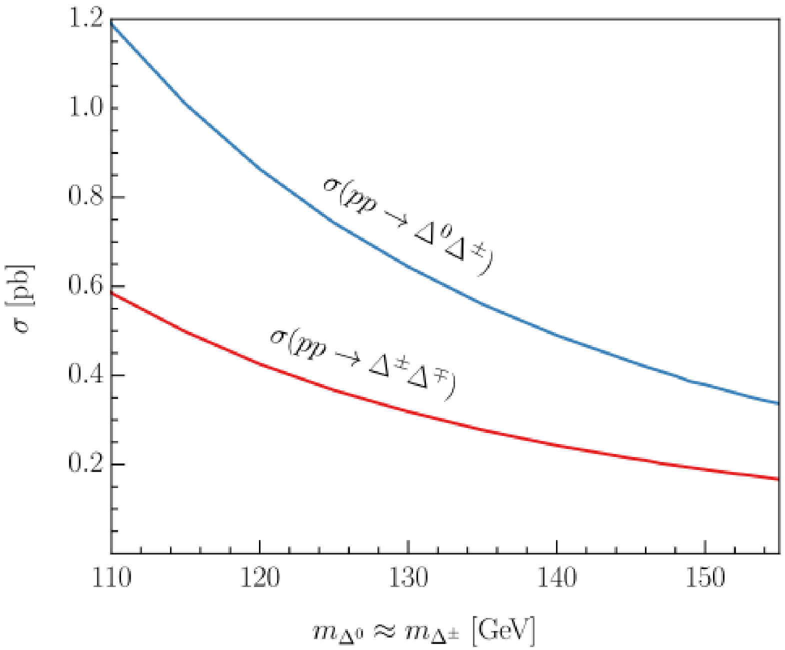


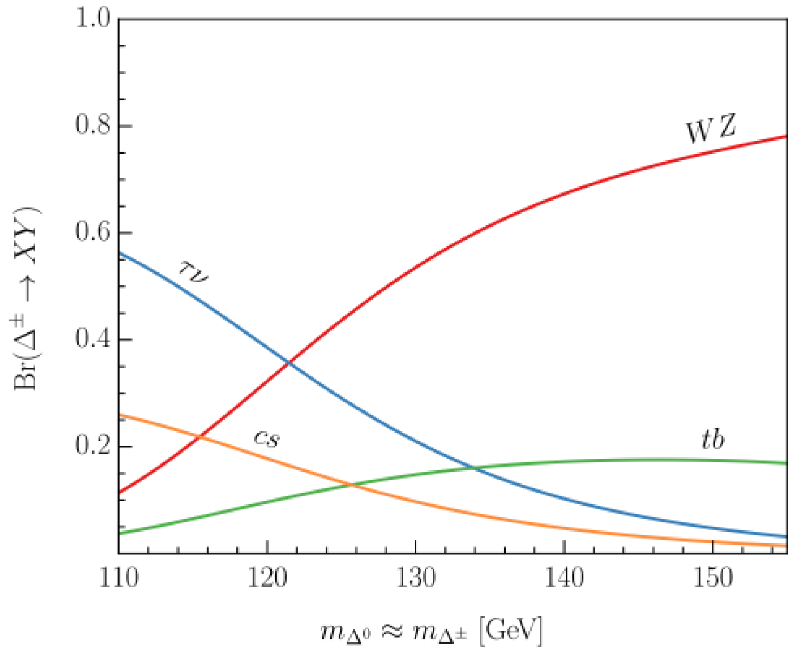
3.8σ & 4.7σ global significance

Is the 151.5 GeV Higgs a Triplet (Δ)

- Δ^0 decays dominantly to WW and only suppressed to ZZ
- Positive shift in the W mass as preferred by the EW fit



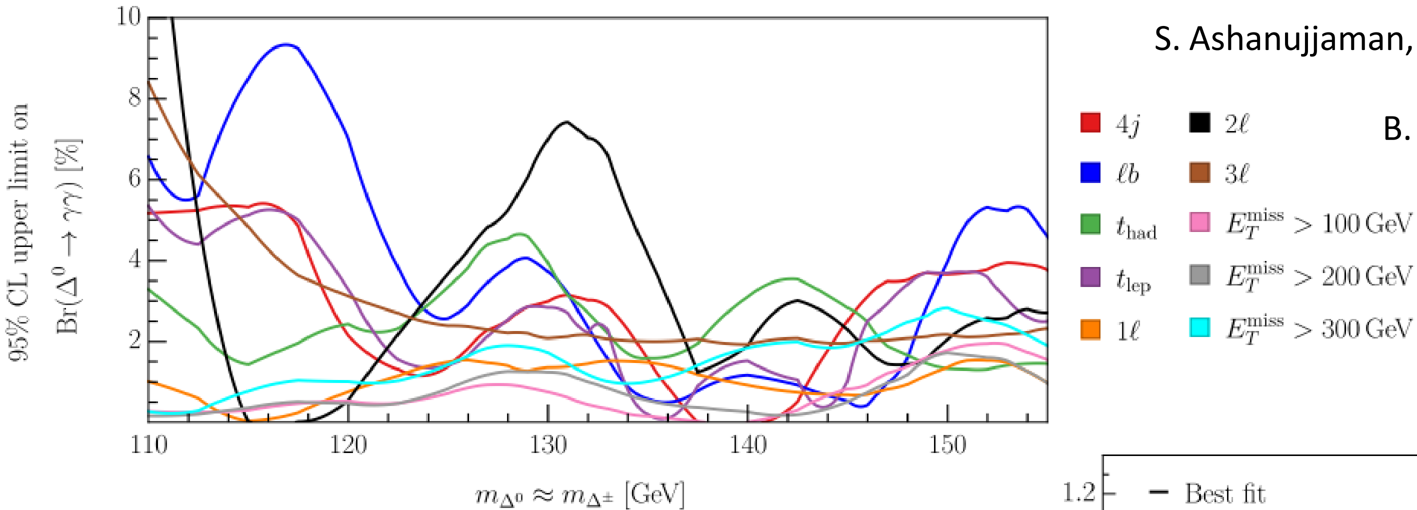




Drell-Yan production at the LHC

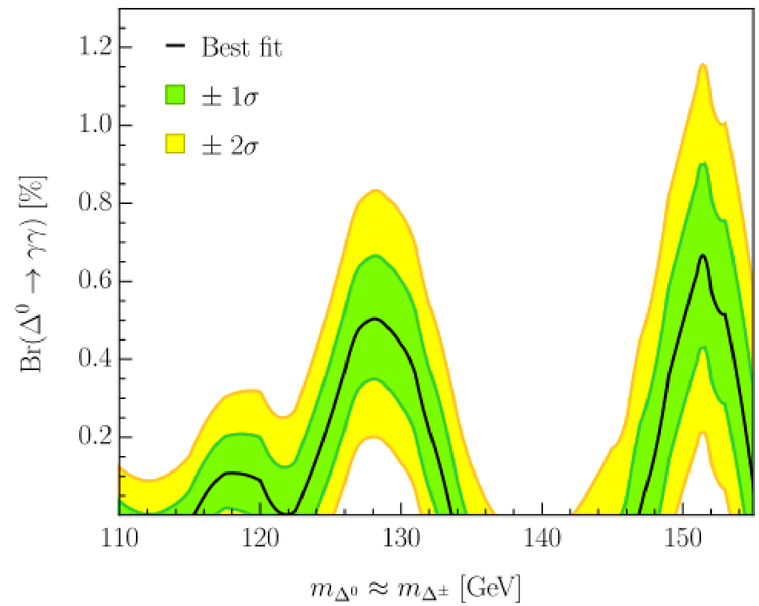
h→γγ+X from ATLAS

JHEP 07 (2023) 176



S. Ashanujjaman, S. Banik, G. Coloretti, A.C. S. P. Maharathy, B. Mellado, 2402.00101

- Analysis of h→γγ+X
- 22 channels (X=l,MET,4j,…)
- 10 relevant for the triplet
- 8 of them show excesses
- Only mass and Br(Δ^0→γγ) are relevant free parameters

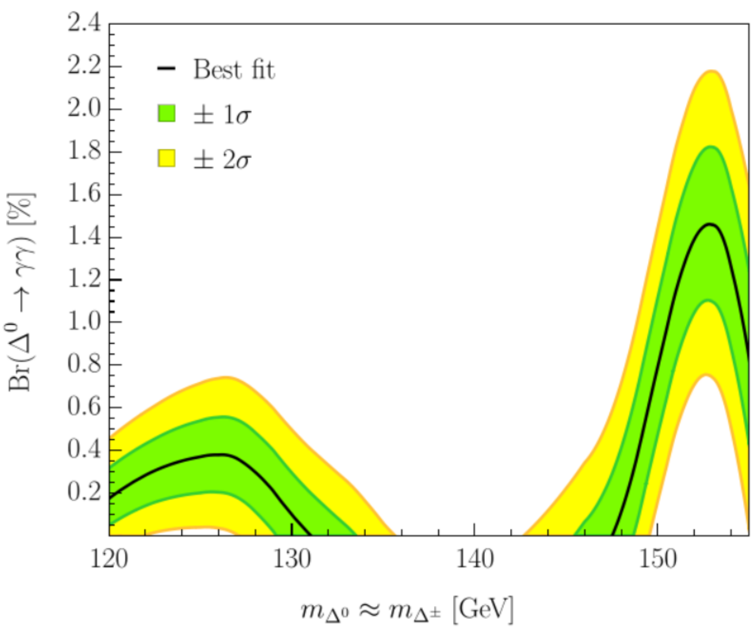


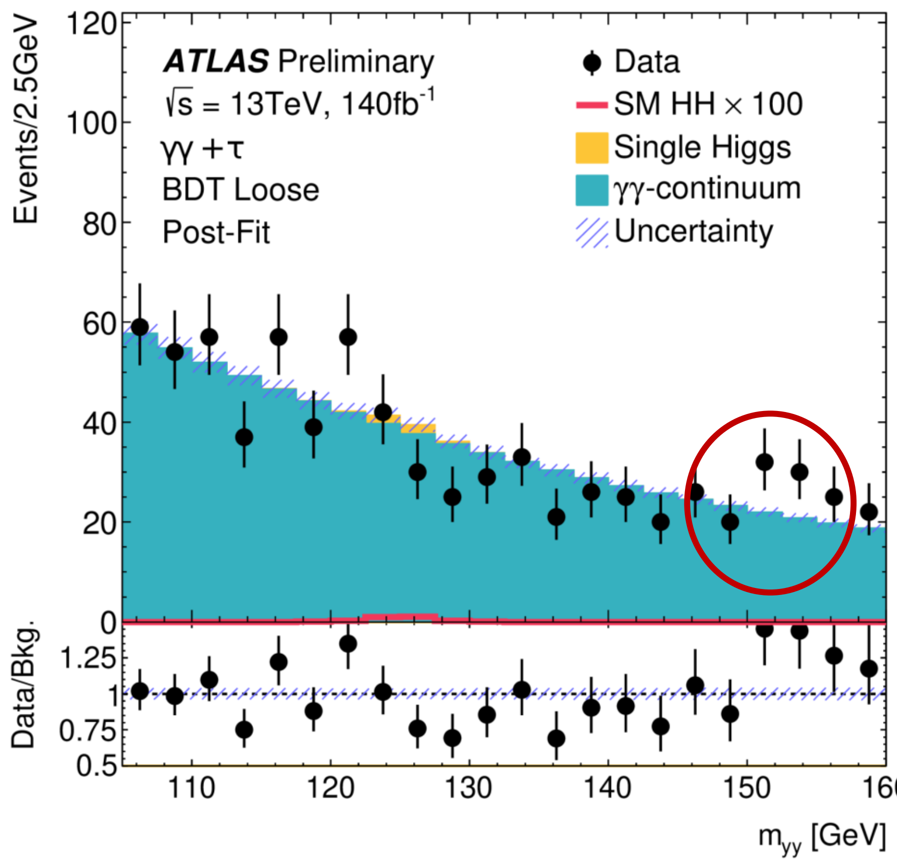
Triplet consistently explains h→γγ+X excesses

Moriond EW Update (ATLAS)

ATLAS-CONF-2024-005

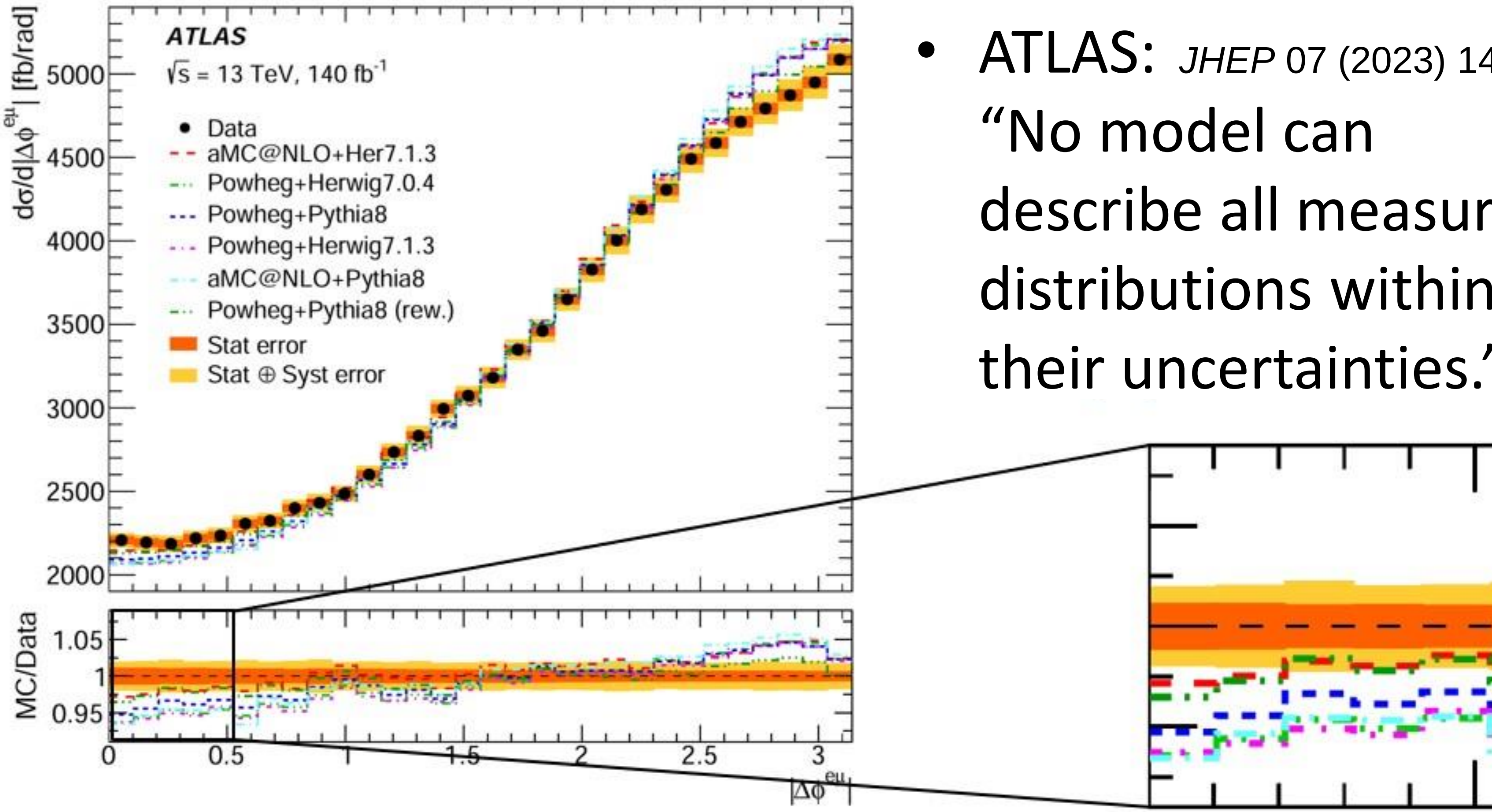
- New excess in γγ+τ
- Background refitting further increases significance





Compatible with the triplet

Differential Top-Quark Distributions



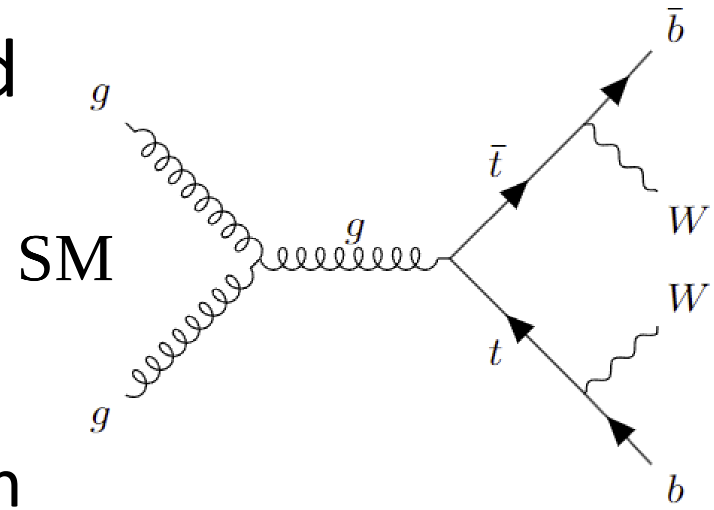
- ATLAS: *JHEP* 07 (2023) 141
  "No model can describe all measured distributions within their uncertainties."

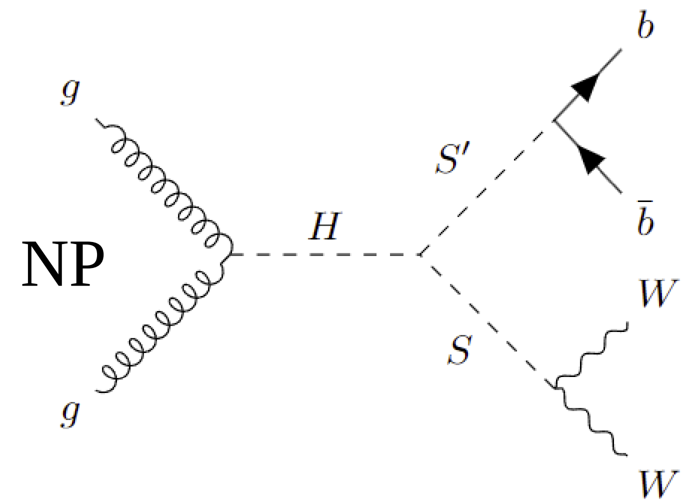
- $\Delta\phi^{e\mu}$ angle between the leptons from the W decays

New Physics pollution of this SM measurement?

New Physics in Top-Quark Distributions

- ATLAS analysis normalized to the total cross section
  - only sensitive to the shape of NP
  - NP at small angels can explain deficit at large angles
- Associated production of new scalars decaying to WW and bb has a top-like signature

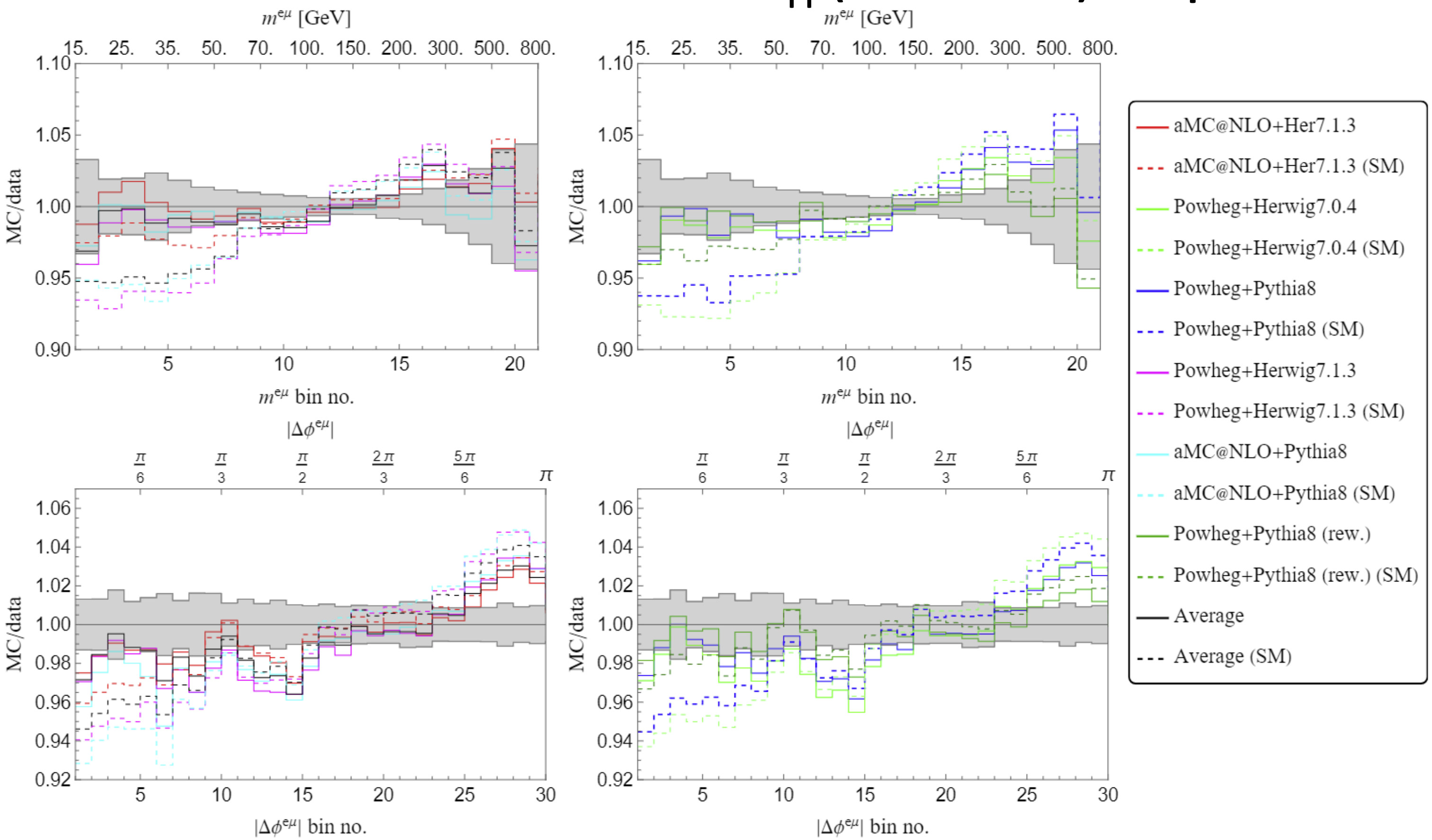




Related to the 95 GeV and 151.5 GeV hints?

Simplified Model: H→SS’→WWbb 2308.07953

- Fix m_S=151.5GeV and $m_{S'}$=95GeV by the hints for narrow resonances. Weak m_H (270GeV) dependence.



Also deficit at large $\Delta\phi^{e\mu}$ & $m^{e\mu}$ explained

Simplified Model: H→SS'→WWbb

2308.07953

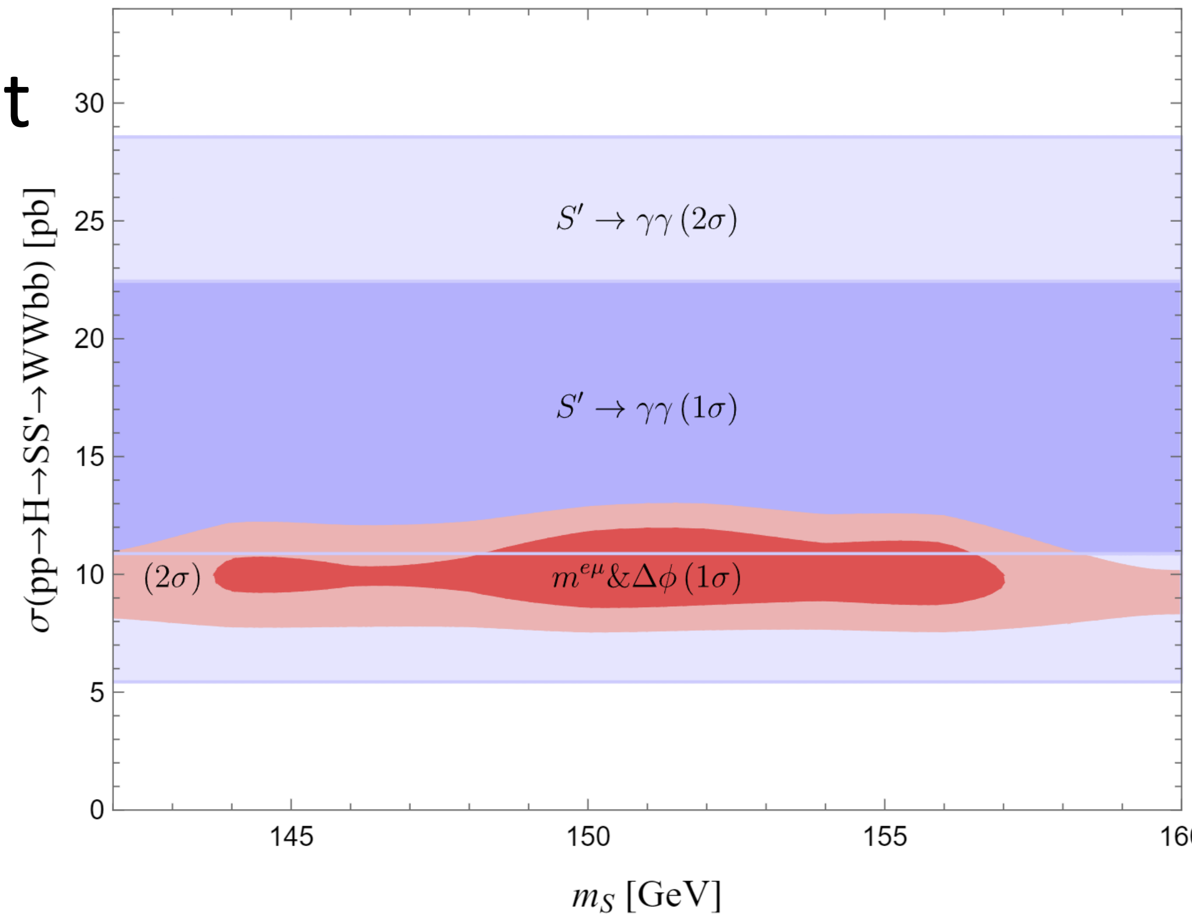
Monte Carlo	χ^2_{SM}	χ^2_{NP}	σ_{NP}	Sig.	m_S[GeV]
Powheg+Pyhtia8	213	102	9pb	10.5σ	$143-156$
aMC@NLO+Herwig7.1.3	102	68	5pb	5.8σ	$--$
aMC@NLO+Pythia8	291	163	10pb	11.3σ	148-157
Powheg+Herwig7.1.3	261	126	10pb	11.6σ	149-156
Powheg+Pythia8 (rew)	69	35	5pb	5.8σ	$--$
Powheg+Herwig7.0.4	294	126	12pb	13.0σ	149-156
Average	182	88	9pb	9.6σ	143-157

- Improvement of SM prediction imperative!

Agreement with data significantly improved (>5σ)

Is 95 GeV a singlet? Relation to 151.5 GeV?

- S’(95): Singlet decays dominantly to bb
- S(151.5): decays dominantly to WW

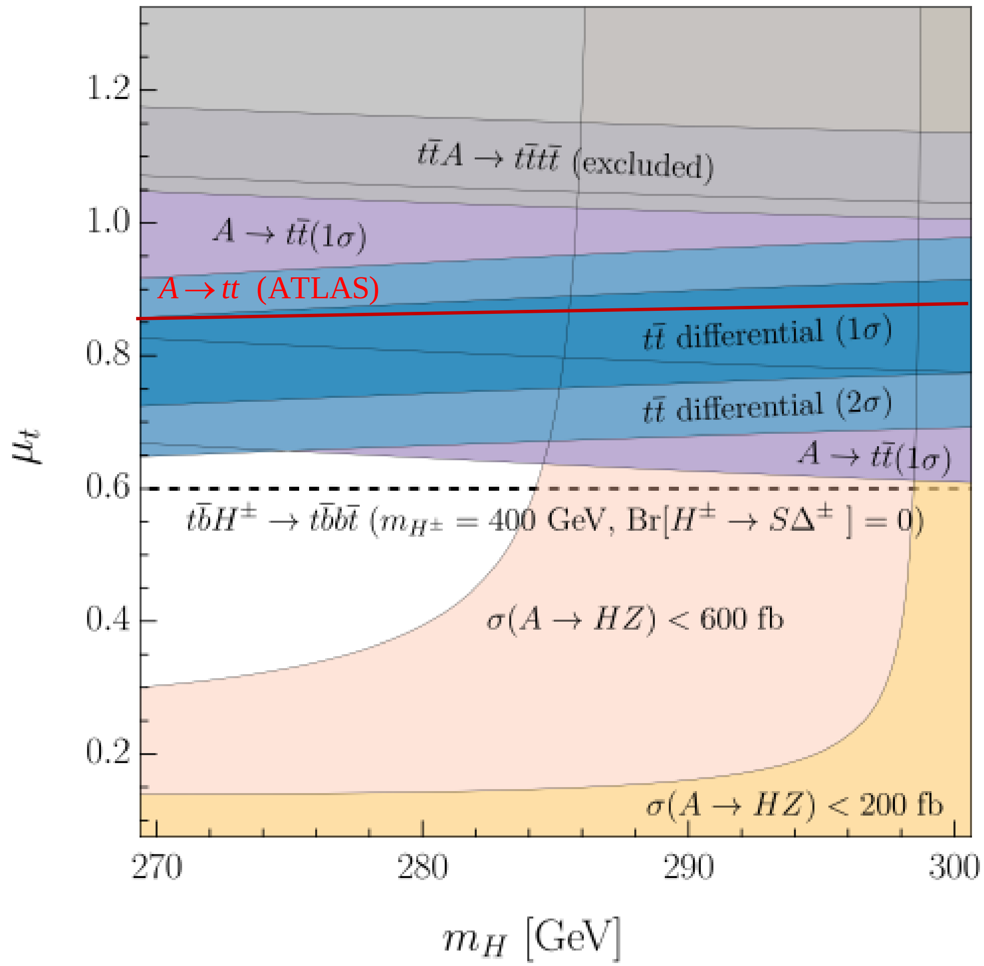


Consistent with 95 GeV γγ signal strength & a mass of S with 151.5 GeV

Δ2HDMS and top-quark production

Field	$SU(2)_L$	$U(1)_Y$
ϕ_s	2	0
ϕ_2	2	1/2
ϕ_1	2	1/2
Δ	3	0

G. Coloretti, A.C. and B. Mellado, 2312.17314



Explains:

- Top-quark differential distributions
- Di-photon excesses
- Resonant top-quark production Elevated 4-top cross section

Combined explanation possible

Conclusions and Outlook

- Hints for narrow resonances at 95 GeV & 151.5 GeV
- Significant tensions in top quark differential distributions (>5σ)
- Can be explained via pp→H→SS' with masses consistent with the narrow resonances
- 95 GeV decays to dominantly to bb ➡ singlet?
- 151.5 GeV decays dominantly to WW ➡ triplet?
- γγ+X excesses consistent with DY production of triplet
- New CMS excess in ttZ explained

Most significant hints for new particles at the LHC

Backup

Multi-leptons history

Based Higgs p_T, hh, tth, VV in Run 1
Eur. Phys. J. C (2016) 76:580

Model defined and predictions made for multilepton excesses

Multi-lepton excesses in Run 1 and few Run 2 results available in 2017

J.Phys.G 45 (2018) 11, 115003

Model <u>parameters fixed in 2017</u> with
m_H=270 GeV, m_S=150 GeV,
S treated as SM Higgs-like,
dominance of H→Sh,SS

Fixed final states and phase-space defined by fixed model parameters.
<u>NO tuning, NO scanning</u>

Update same final states with more data in Run 2

Study new final states where excesses predicted and data available in Run 1 and Run 2 (e.g., SS0b, 3l0b, ZW0b)

J.Phys. G46 (2019) no.11, 115001
JHEP 1910 (2019) 157
Chin.Phys.C 44 (2020) 6, 063103
Physics Letters B 811 (2020) 135964
Eur.Phys.J.C 81 (2021) 365

Talk of Bruce Mellado at ZPW 2023

Higgs Sector of the SM

$$L_{\Phi}^{SM} = \mu^2 \Phi^\dagger \Phi + \frac{\lambda}{4}\left(\Phi^\dagger \Phi\right)^2$$

$$L_{Y}^{SM} = -Y^d \bar{Q} \Phi d - Y^u \bar{Q} \tilde{\Phi} u - Y^\ell \bar{Q} \Phi \ell$$

- Custodial symmetry
- Single Higgs gives rise to all fermion masses
- Is the Higgs sector really minimal?
- Extensions possible if the effect on the ρ parameter SM-Higgs signal strength is small
- Scalars decaying to W bosons and/or produced in associate production weakly constrained

EW scale extension of the SM Higgs sector possible

Multi-lepton Anomalies

- Deviations from the SM predictions in LHC processes involving two or more leptons, with and without (b-)jets

Final state	Characteristics	SM backgrounds	Significance
$\ell^+\ell^-$+(b-jets)[62,65,66]	$m_{\ell\ell} < 100$ GeV, $(1b, 2b)$	$t\bar{t}, Wt$	$> 5\sigma$
$\ell^+\ell^-$+(no jet)[61,67]	$m_{\ell\ell} < 100$ GeV	W^+W^-	$\approx 3\sigma$
$\ell^\pm\ell^\pm, 3\ell$ + (b-jets)[64,68,69]	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)[63,70,71]	In association with h	$W^\pm h(125), WWW$	$\gtrsim 4\sigma$
$Z(\to \ell\ell)\ell$, (no b-jet)[62,72]	$p_T^Z < 100$ GeV	$ZW^\pm$	$> 3\sigma$

A.C., B. Mellado, arXiv:2309.03870

- 1711.07874 found m_S=150±5GeV

Buddenbrock et al. arXiv:1901.05300

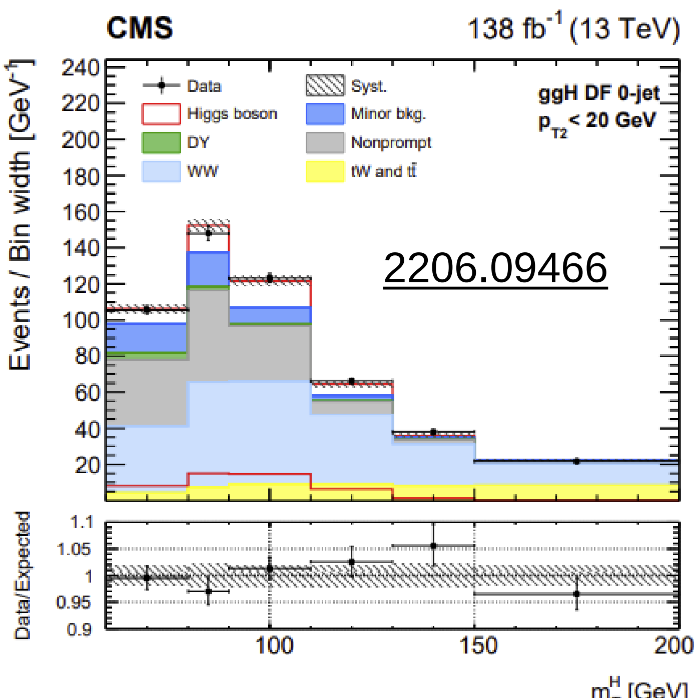
O. Fischer et al. arXiv: 2109.06065

- Here focus on:
  - WW
  - Top-quark differential distributions

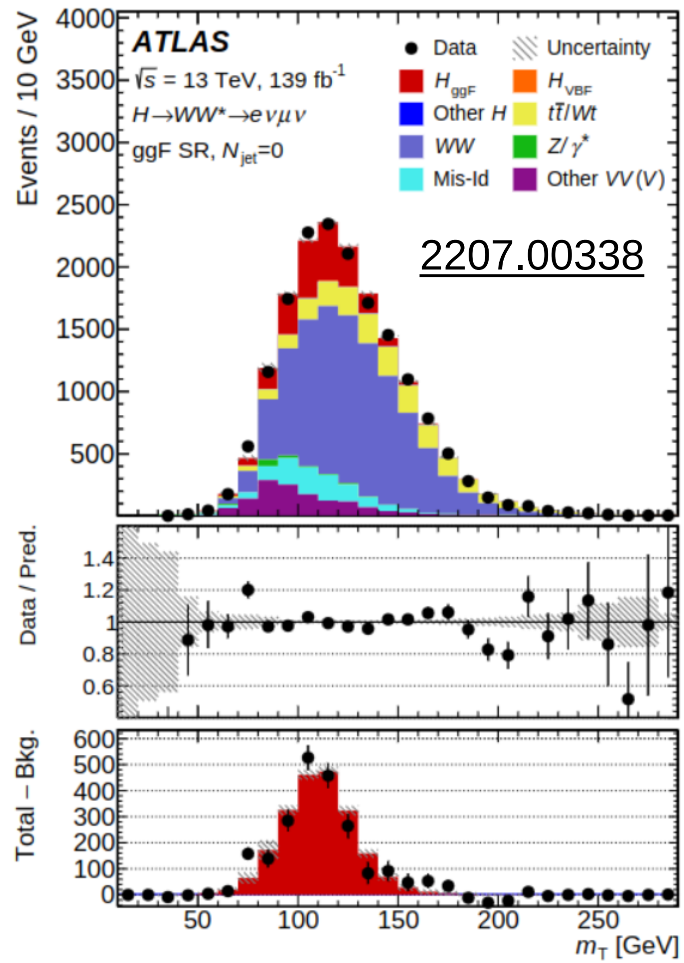
Statistically significant, motivate new EW scale scalars

Low mass WW seraches

- No dedicated low-mass WW search
- Recast SM Higgs analyses



Background fitted

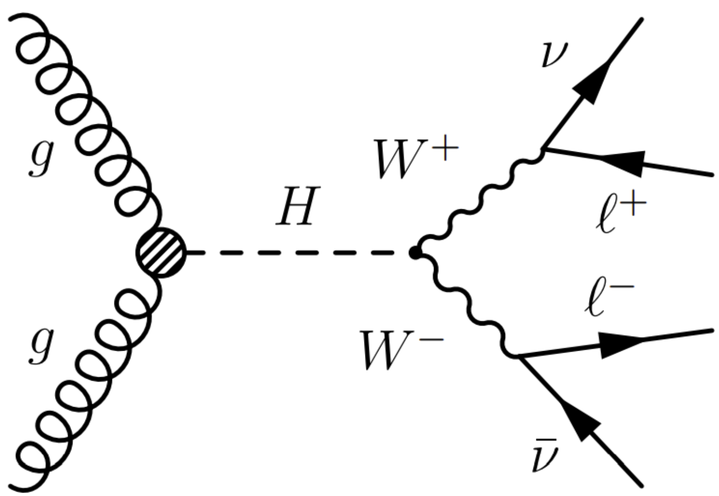


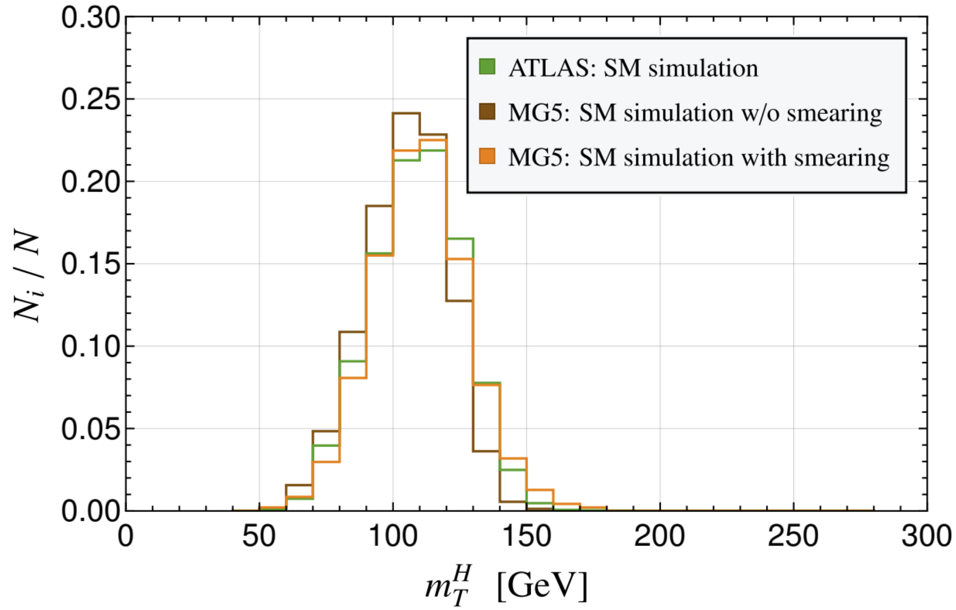
SM Higgs rescaled by 1.16

Room for NP

Simulation and Setup

- Opposite sign, different flavour leptons with full jet veto
- New scalar H produced via gluon fusion
- Correcting for fast simulation by tuning signal vial smearing to the SM Higgs signal

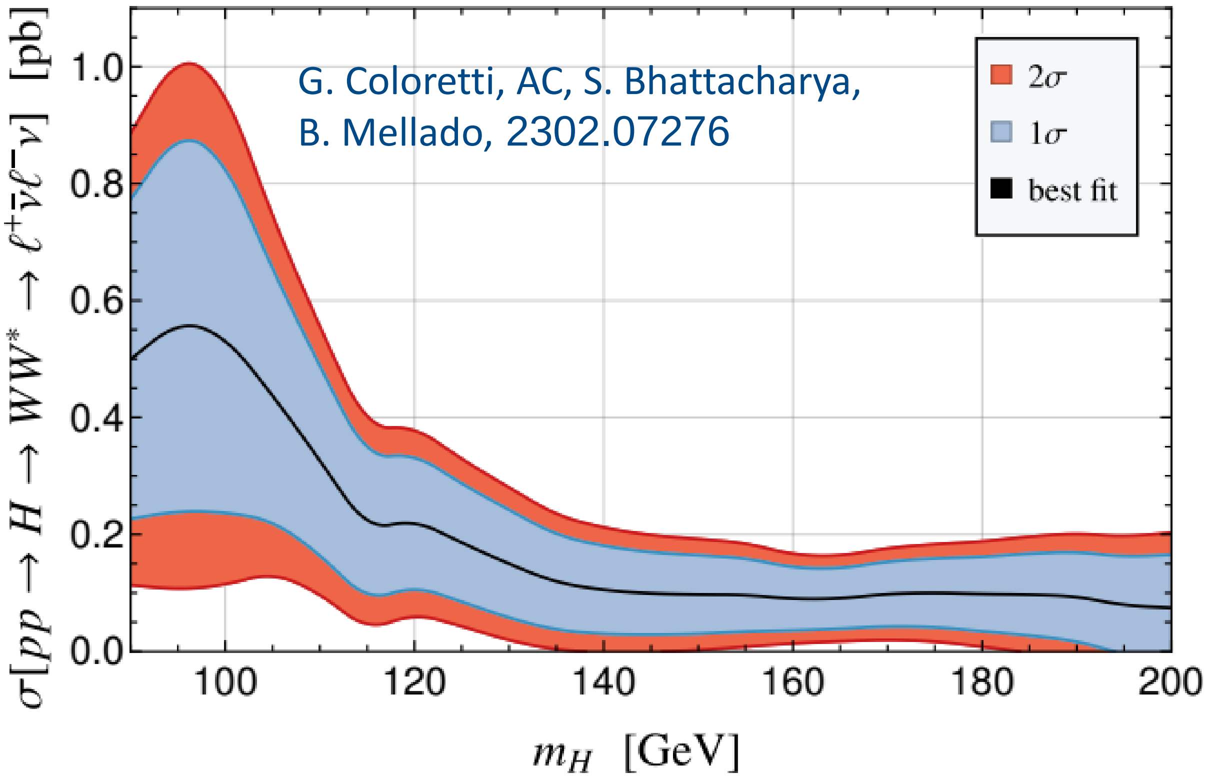




Simulation validated

Low mass WW resonances searches

- ATLAS and CMS combination



Transverse mass sensitive to additional missing energy from associated production

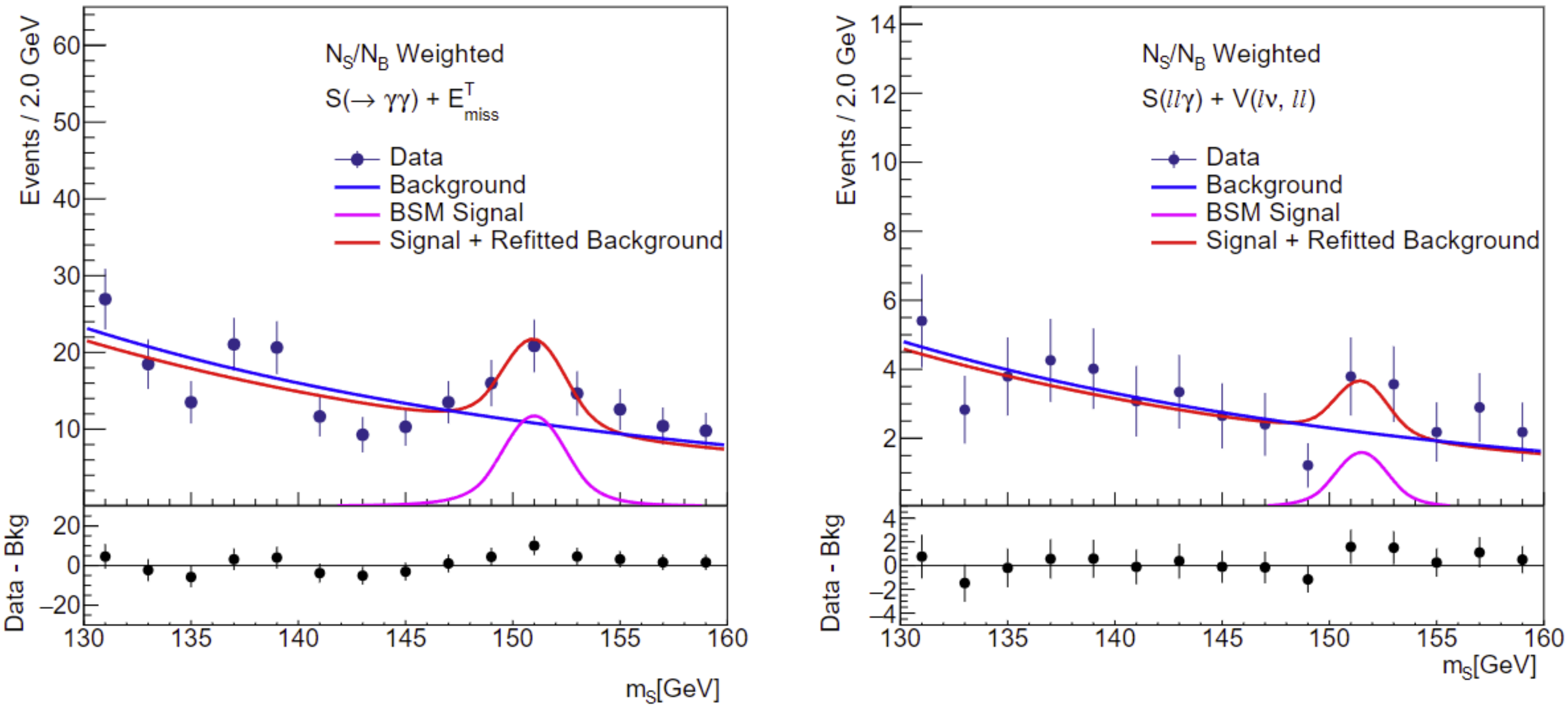
- New physics effect preferred over the whole range

Related to 95GeV and 151GeV?

Hints for a 152 GeV scalar

PAUL SCHERRER INSTITUT PSI

- Motivated by the mass range of 1711.07874 (not included)

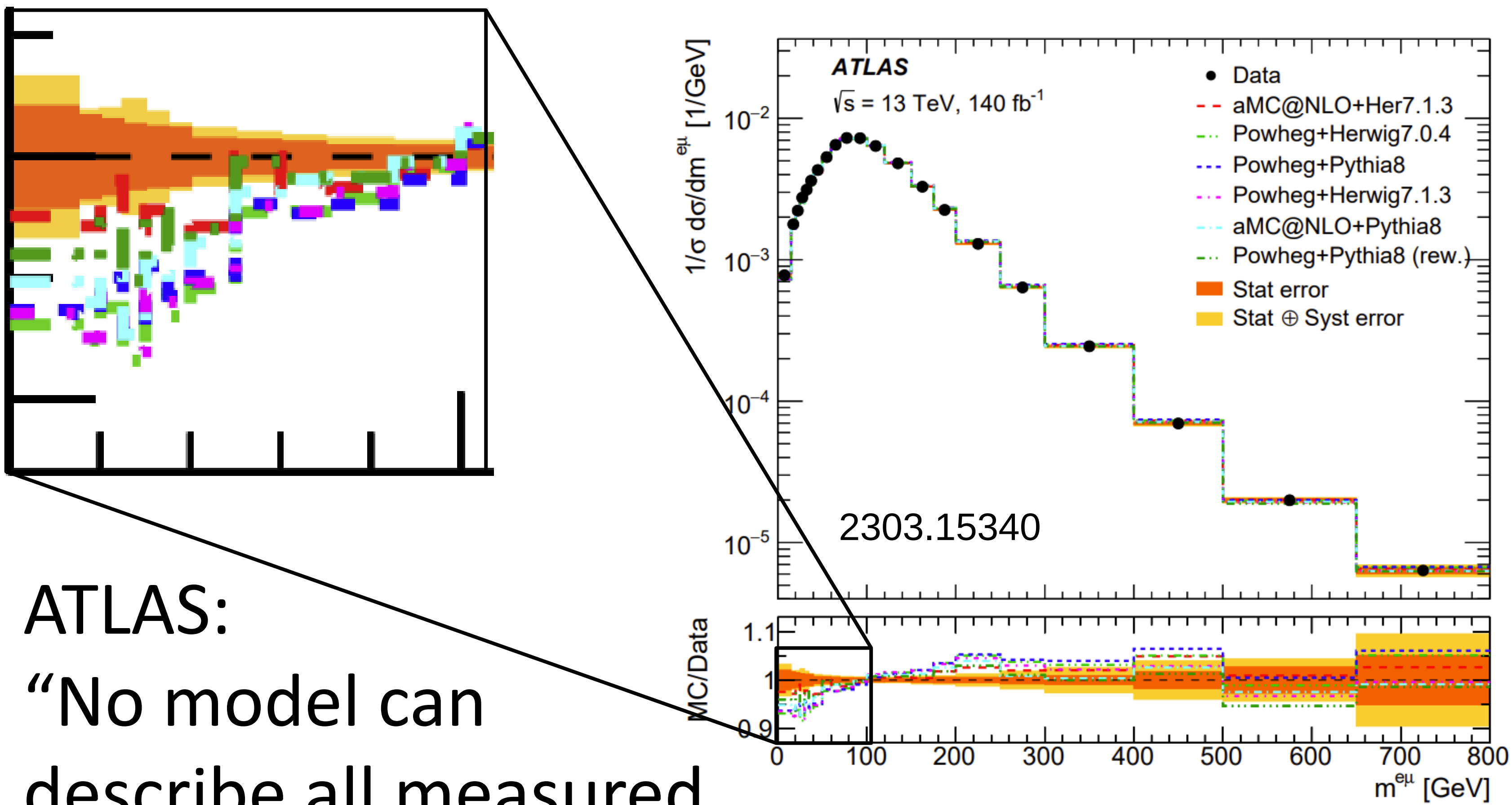


ATLAS: 2301.10486

- Hints for a resonance decaying to photons and Zγ

New Scalar (Higgs) boson? Relation to DM?

Differential Top-Quark Distributions



- ATLAS:
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