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PSI & UZH

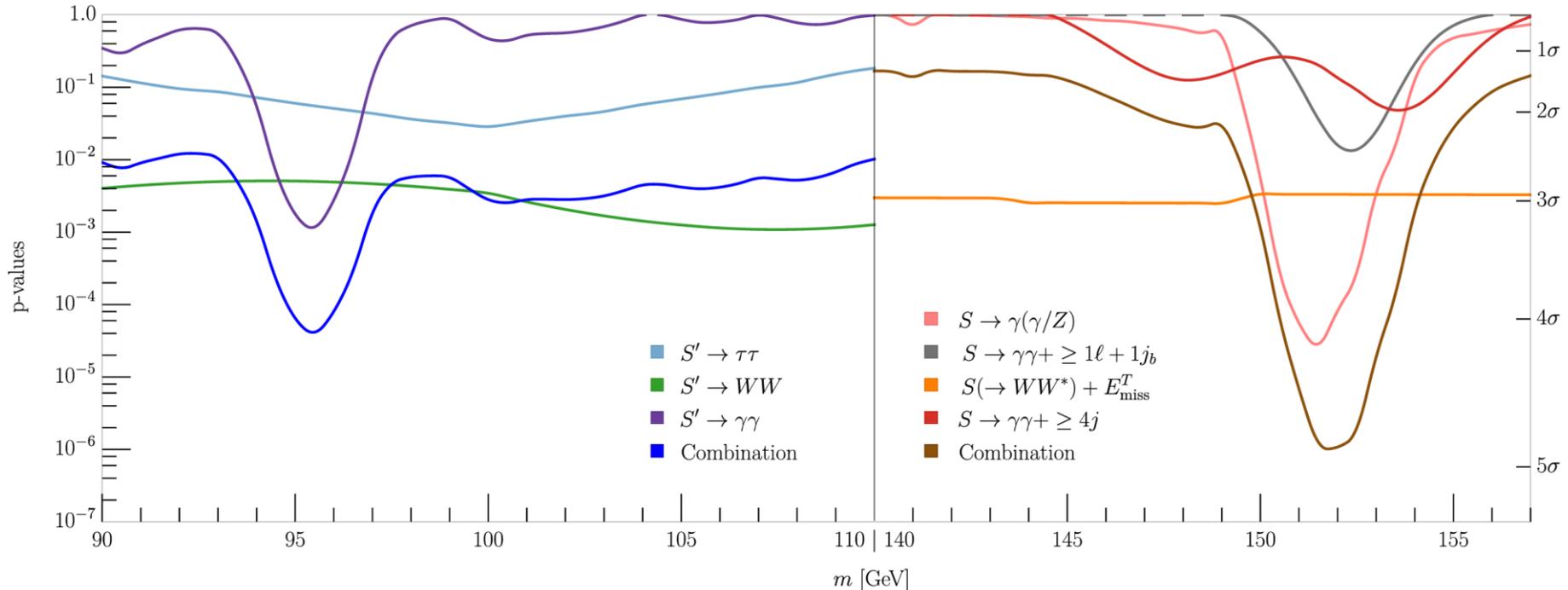
New Higgses at the Electroweak Scale and Differential Top-Quark Distributions

MPI Heidelberg, 23.04.2024

Hints for new Scalars at 95 GeV & 151.5 GeV

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

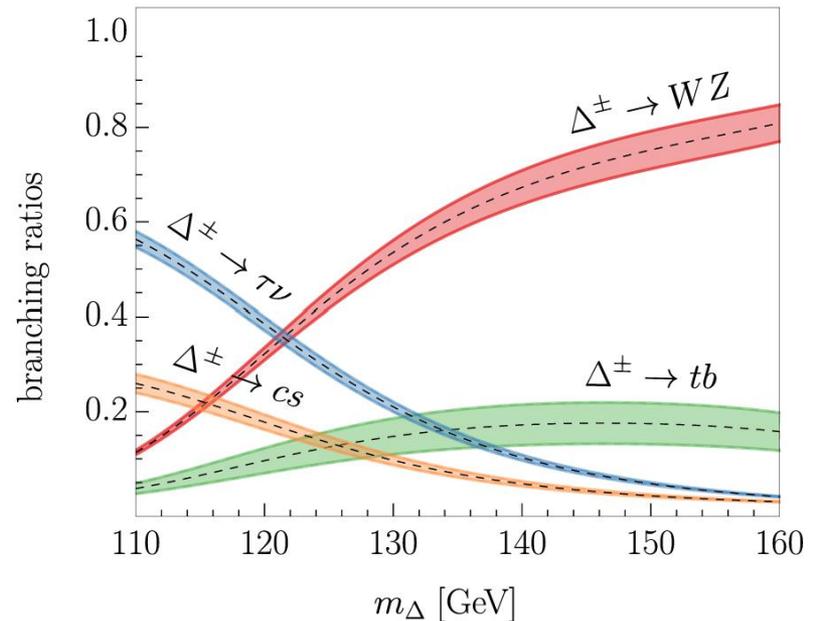
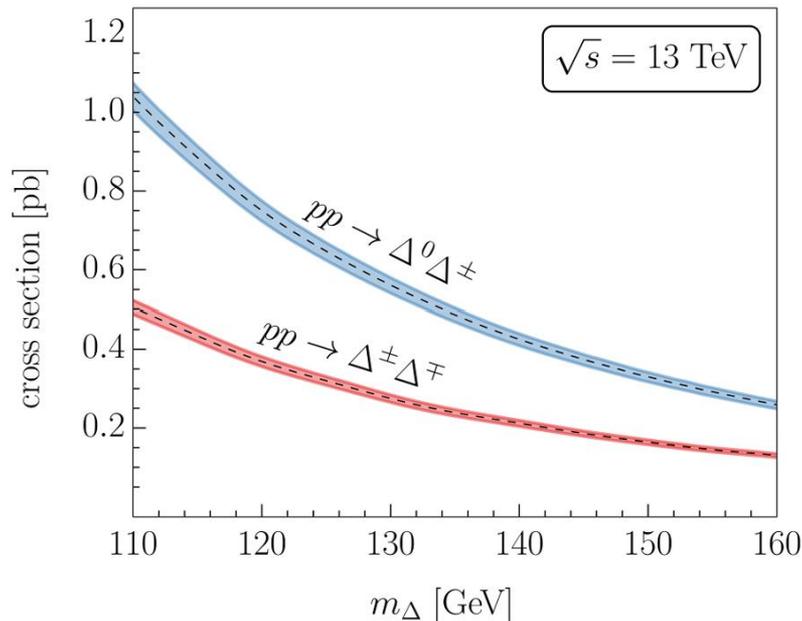
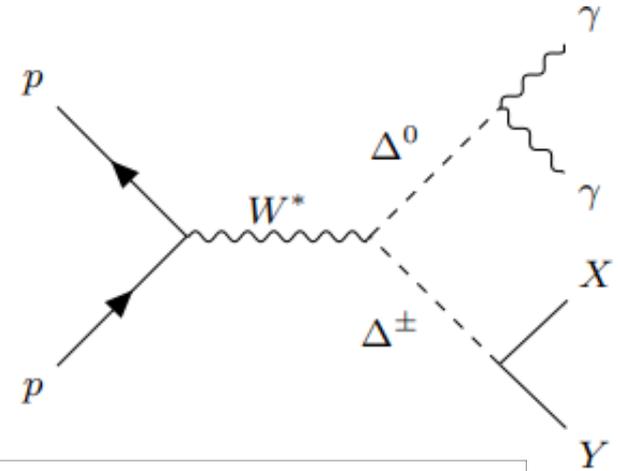
S. Bhattacharva, G. Coloretti, A. Crivellin, et al. arXiv:2306.17209



3.8 σ & 4.7 σ 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

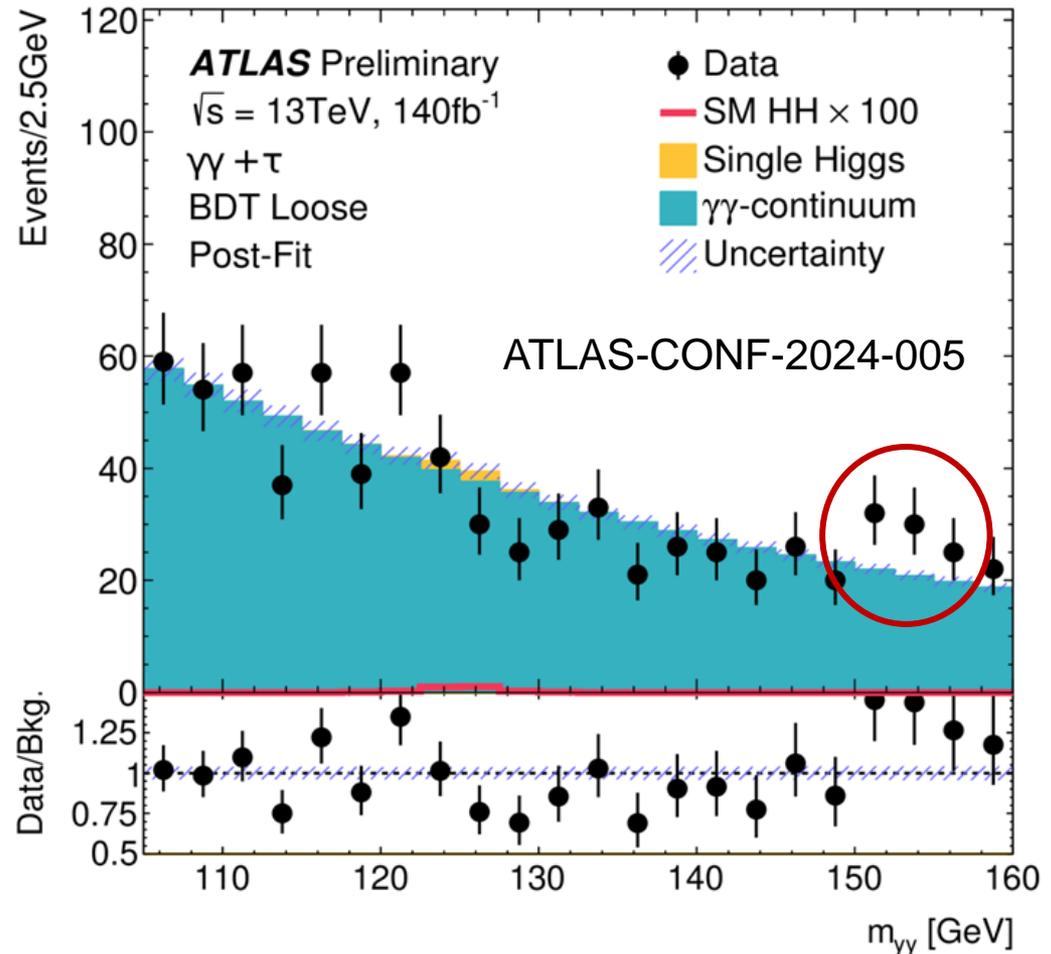


Drell-Yan production at the LHC

$h \rightarrow \gamma\gamma + X$ from ATLAS

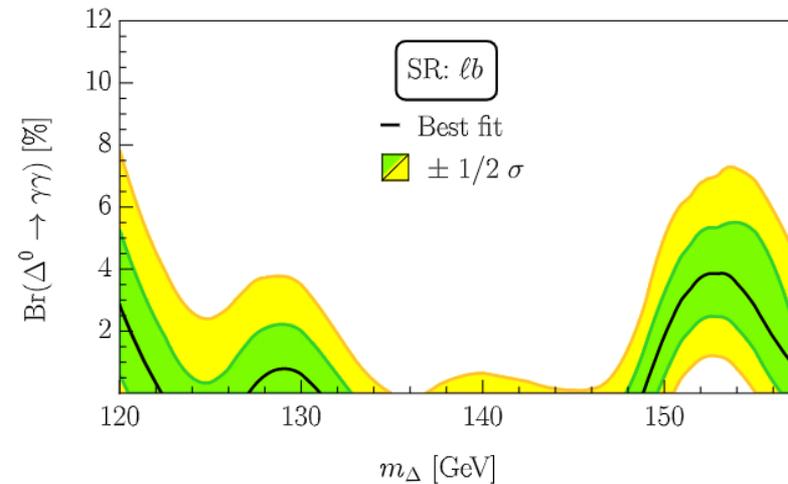
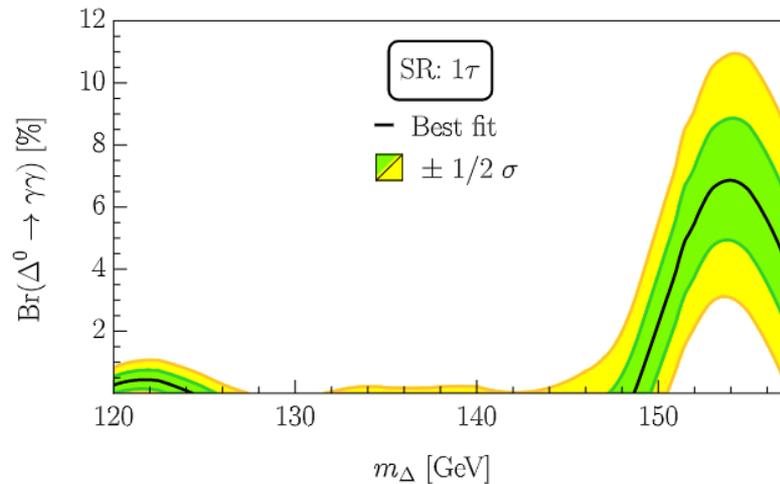
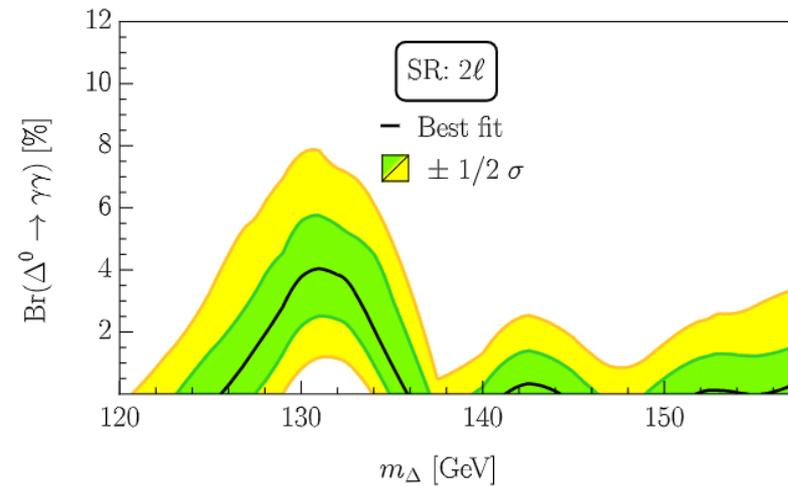
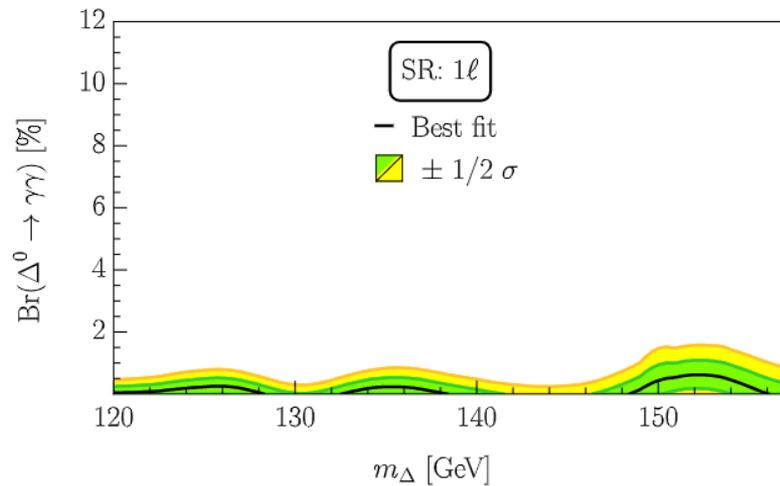
S. Ashanujjaman, S. Banik, G. Coloretti, A.C. S. P. Maharathy,
B. Mellado, 2402.00101

- Analysis of $h \rightarrow \gamma\gamma + X$
- 23 channels ($X=l, MET, 4j, \dots$)
- 8 sensitive to the triplet
- Only mass and $\text{Br}(\Delta^0 \rightarrow \gamma\gamma)$ are relevant free parameters



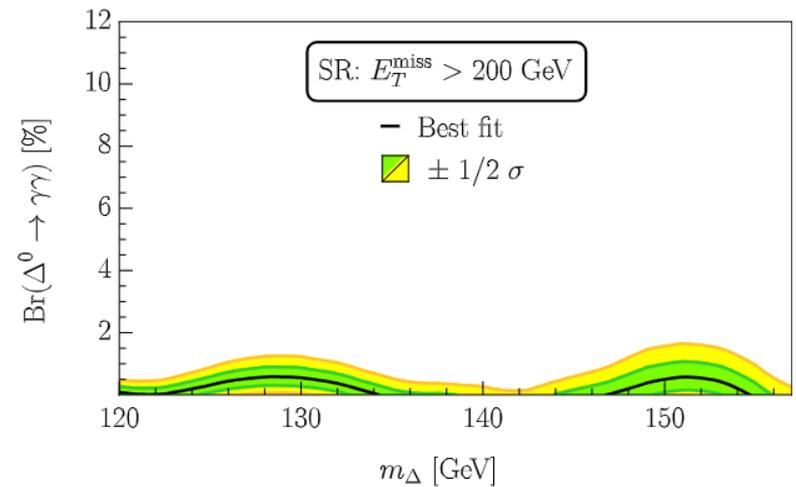
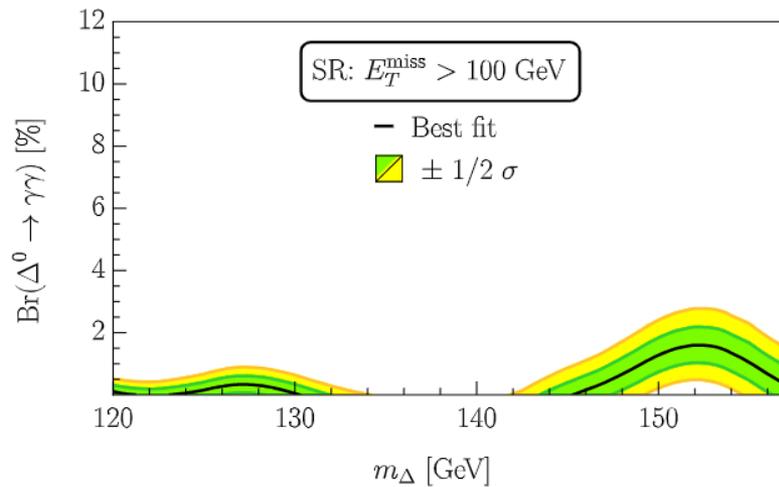
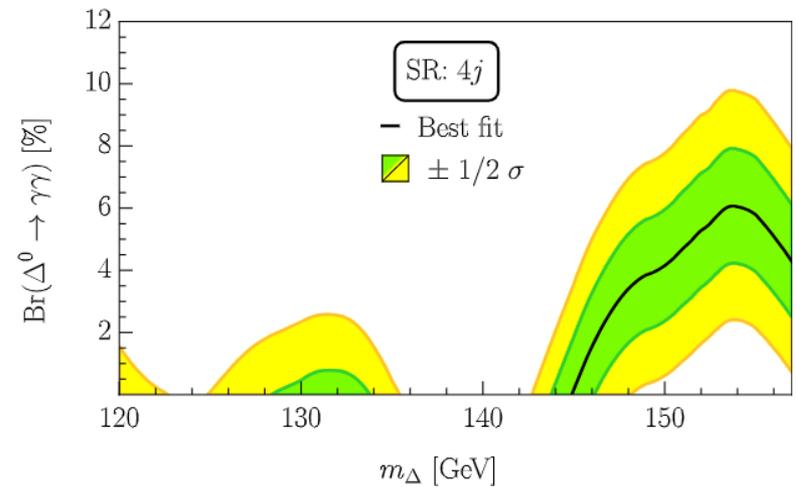
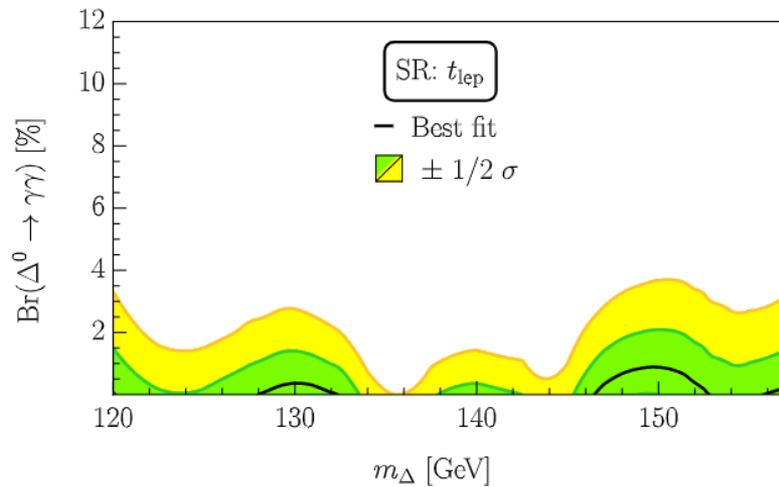
Triplet consistently explains $h \rightarrow \gamma\gamma + X$ excesses

$h \rightarrow \gamma\gamma + X$ from ATLAS



Triplet consistently explains $h \rightarrow \gamma\gamma + X$ excesses

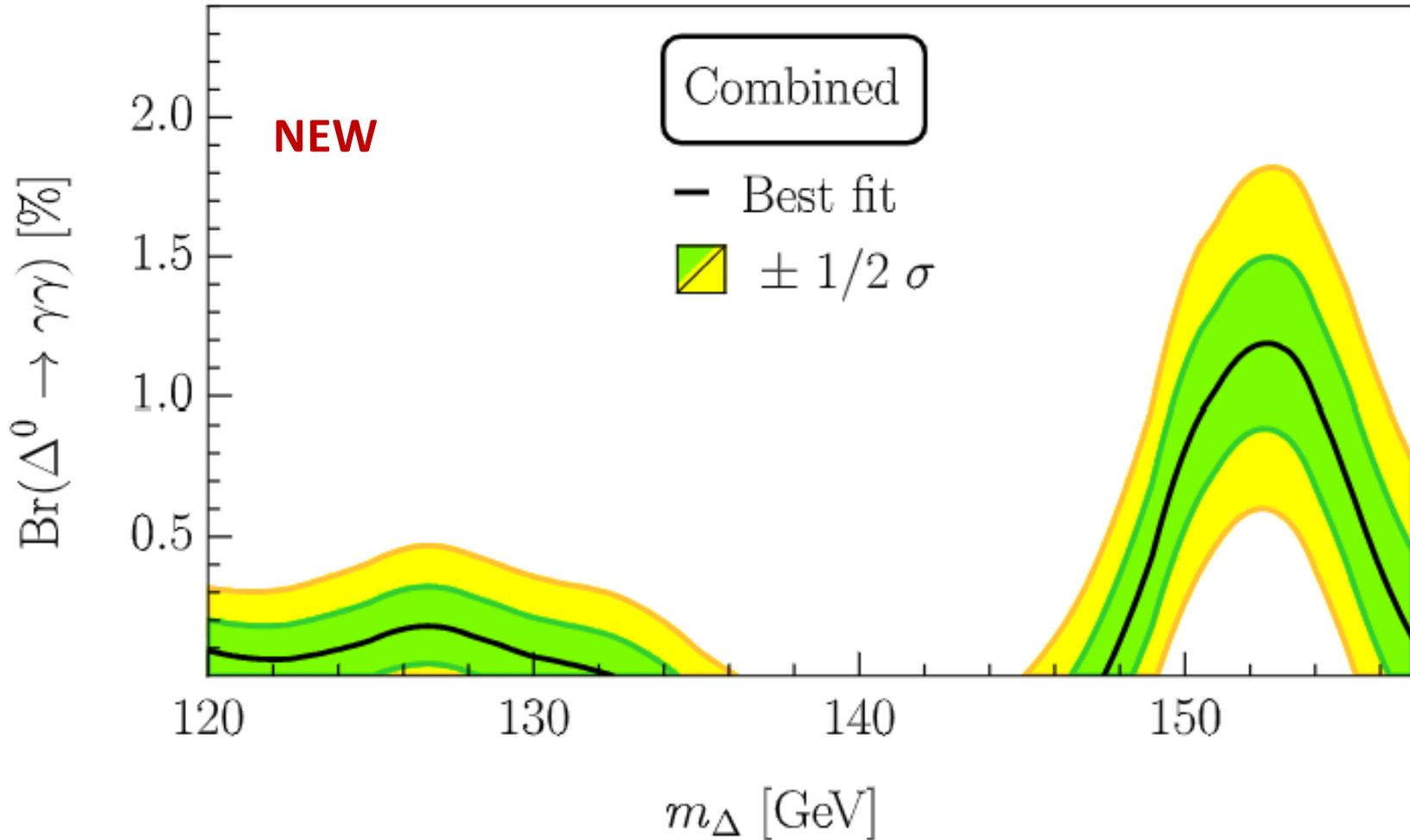
$h \rightarrow \gamma\gamma + X$ Channels



Triplet consistently explains $h \rightarrow \gamma\gamma + X$ excesses

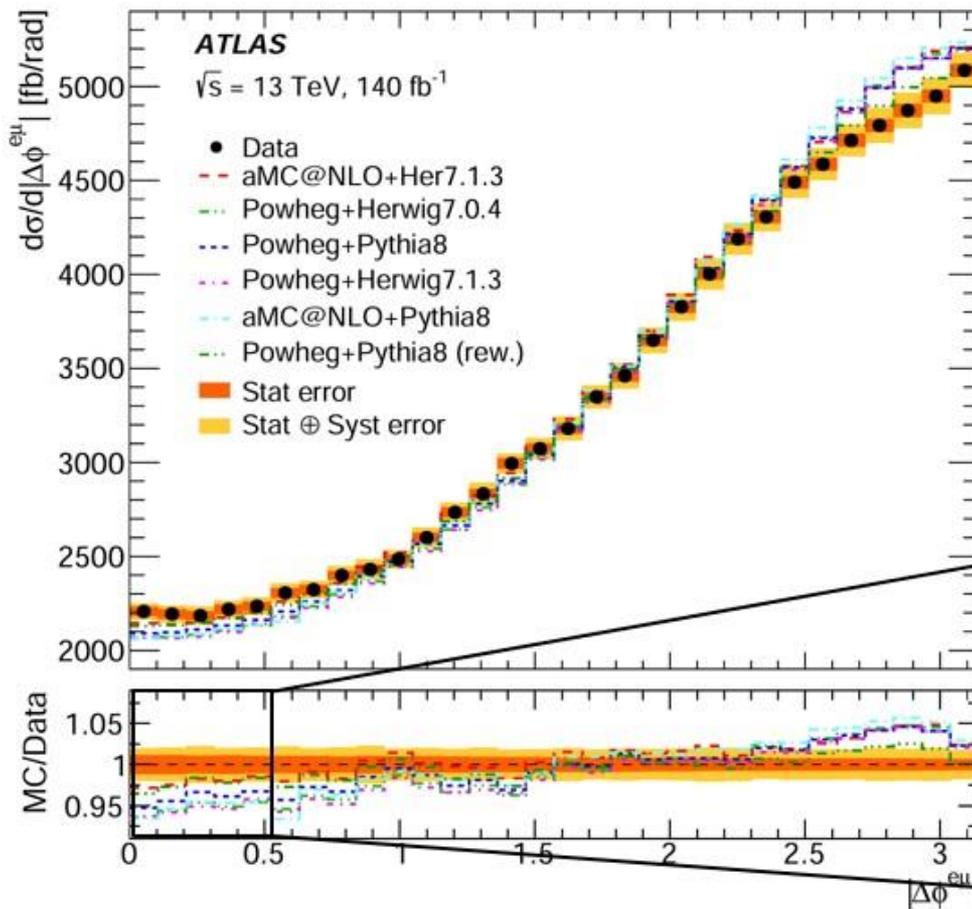
Combination

S. Ashanujjaman, S. Banik, G. Coloretti, A.C. S. P. Maharathy,
B. Mellado, 2404.xxxxx

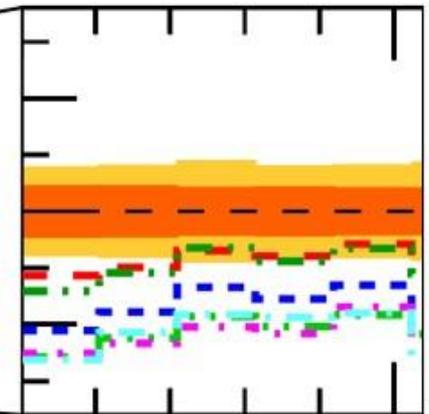


4.3 σ excess at 152GeV

Differential Top-Quark Distributions



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

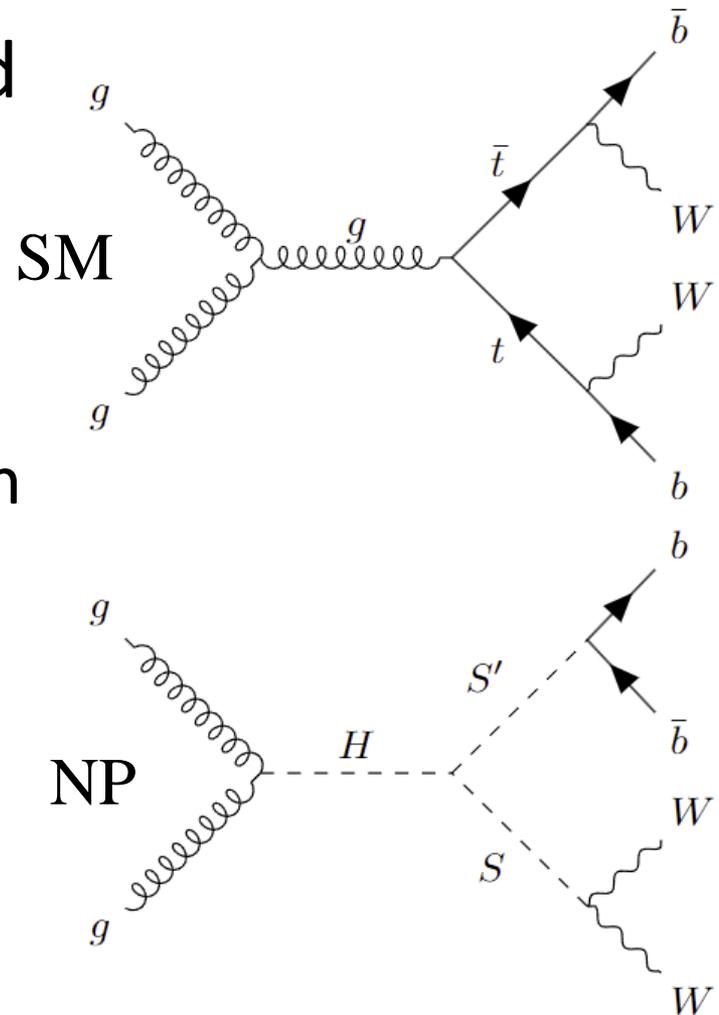


- $\Delta\phi^{e\mu}$ angle between the leptons from the W decays

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 angles can explain deficit at large angles
- Associated production of new scalars decaying to WW and bb has a top-like signature

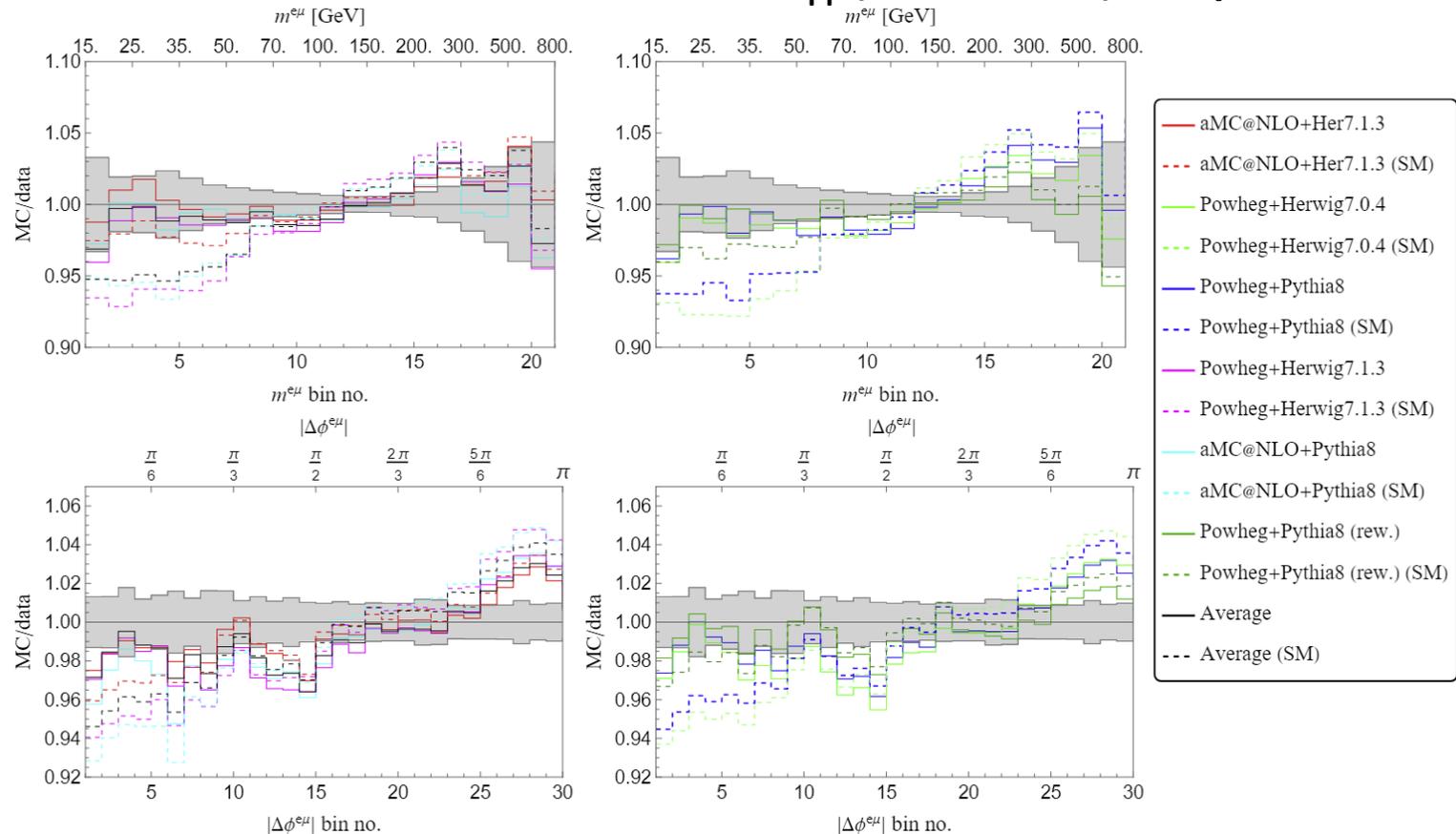


Related to the 95 GeV and 151.5 GeV hints?

Simplified Model: $H \rightarrow SS' \rightarrow WWbb$

2308.07953

- Fix $m_S=151.5\text{GeV}$ and $m_{S'}=95\text{GeV}$ 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: $H \rightarrow SS' \rightarrow WWbb$

2308.07953

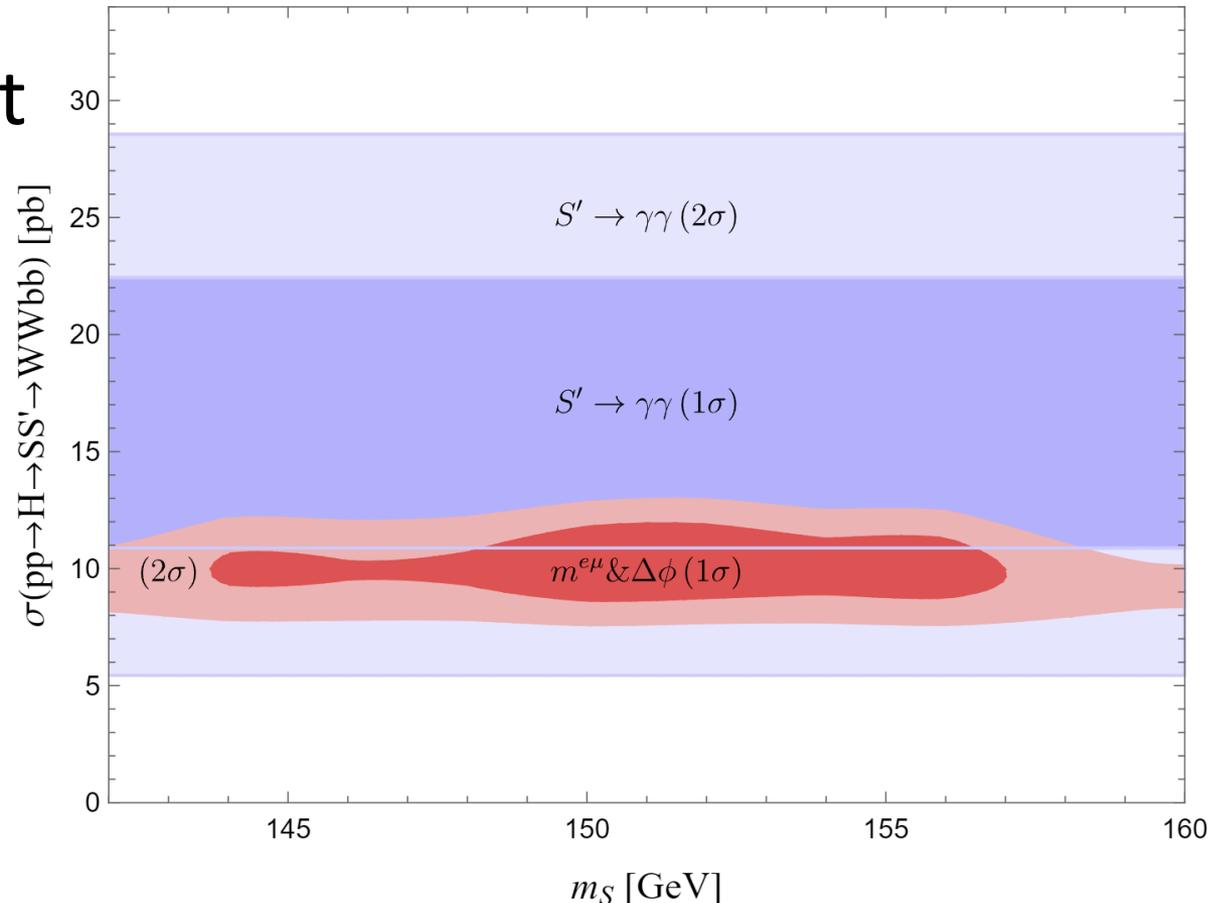
Monte Carlo	χ_{SM}^2	χ_{NP}^2	σ_{NP}	Sig.	m_S [GeV]
Powheg+Pythia8	213	102	9pb	10.5σ	143 – 156
aMC@NLO+Herwig7.1.3	102	68	5pb	5.8σ	—
aMC@NLO+Pythia8	291	163	10pb	11.3σ	148-157
Powheg+Herwig7.1.3	261	126	10pb	11.6σ	149-156
Powheg+Pythia8 (rew)	69	35	5pb	5.8σ	—
Powheg+Herwig7.0.4	294	126	12pb	13.0σ	149-156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

- Improvement of SM prediction imperative!

Agreement with data significantly improved ($>5\sigma$)

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 $\gamma\gamma$ signal strength & a mass of S with 151.5 GeV

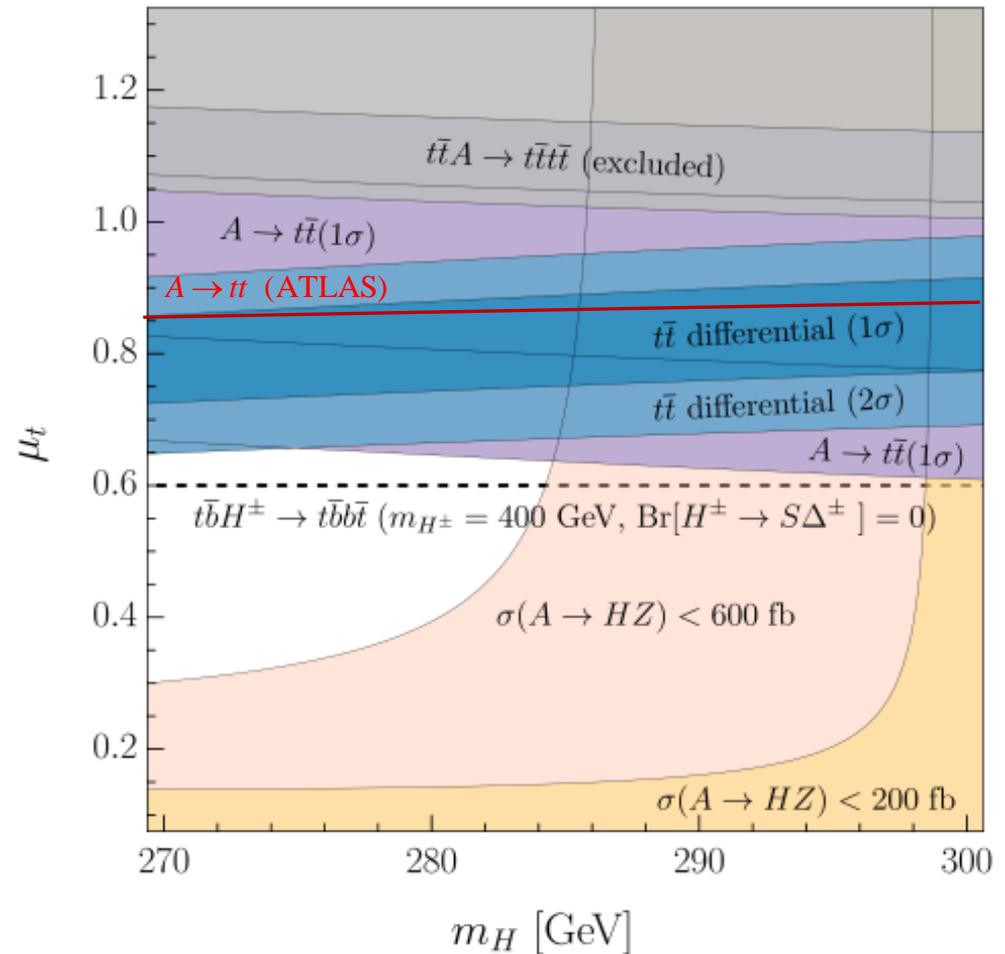
$\Delta 2\text{HDMS}$ and top-quark production

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

Explains:

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

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



Combined explanation possible

Conclusions and Outlook

- Hints for narrow resonances at 95 GeV & 151.5 GeV
- Significant tensions in top quark differential distributions ($>5\sigma$)
- Can be explained via $pp \rightarrow H \rightarrow SS'$ with masses consistent with the narrow resonances
- 95 GeV decays to dominantly to bb  singlet?
- 151.5 GeV decays dominantly to WW  triplet?
- $\gamma\gamma+X$ 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 parameters fixed in 2017 with
 $m_H=270$ GeV, $m_S=150$ GeV,
S treated as SM Higgs-like,
dominance of $H \rightarrow Sh, SS$

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

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

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

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

- 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
$l^+ l^- + (b\text{-jets})^{62, 65, 66}$	$m_{\ell\ell} < 100 \text{ GeV}, (1b, 2b)$	$t\bar{t}, Wt$	$> 5\sigma$
$l^+ l^- + (\text{no jet})^{61, 67}$	$m_{\ell\ell} < 100 \text{ GeV}$	$W^+ W^-$	$\approx 3\sigma$
$l^\pm l^\pm, 3l + (b\text{-jets})^{64, 68, 69}$	Moderate H_T	$t\bar{t}W^\pm, t\bar{t}\bar{t}$	$> 3\sigma$
$l^\pm l^\pm, 3l, (\text{no } b\text{-jet})^{63, 70, 71}$	In association with h	$W^\pm h(125), WWW$	$\approx 4\sigma$
$Z(\rightarrow \ell\ell)l, (\text{no } b\text{-jet})^{62, 72}$	$p_T^Z < 100 \text{ GeV}$	ZW^\pm	$> 3\sigma$

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

Buddenbrock et al. arXiv:1901.05300

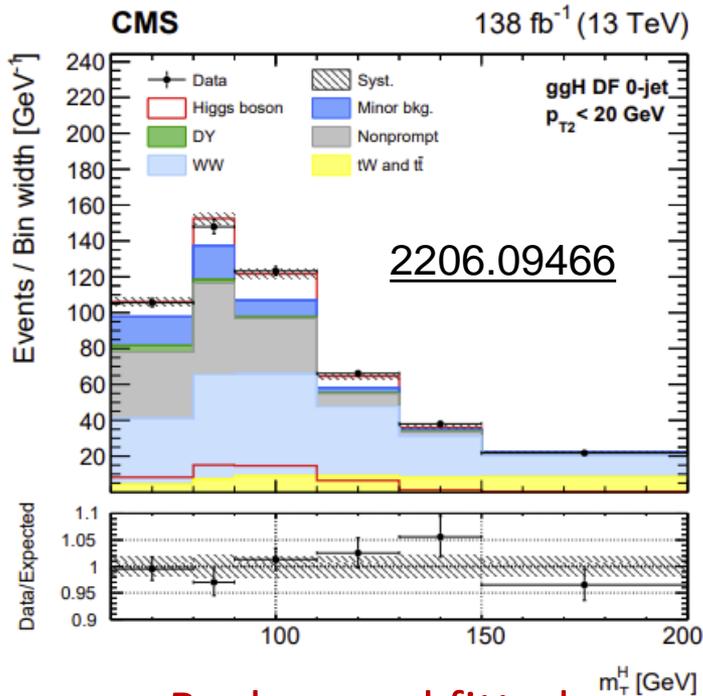
O. Fischer et al. arXiv: 2109.06065

- 1711.07874 found $m_S = 150 \pm 5 \text{ GeV}$
- Here focus on:
 - WW
 - Top-quark differential distributions

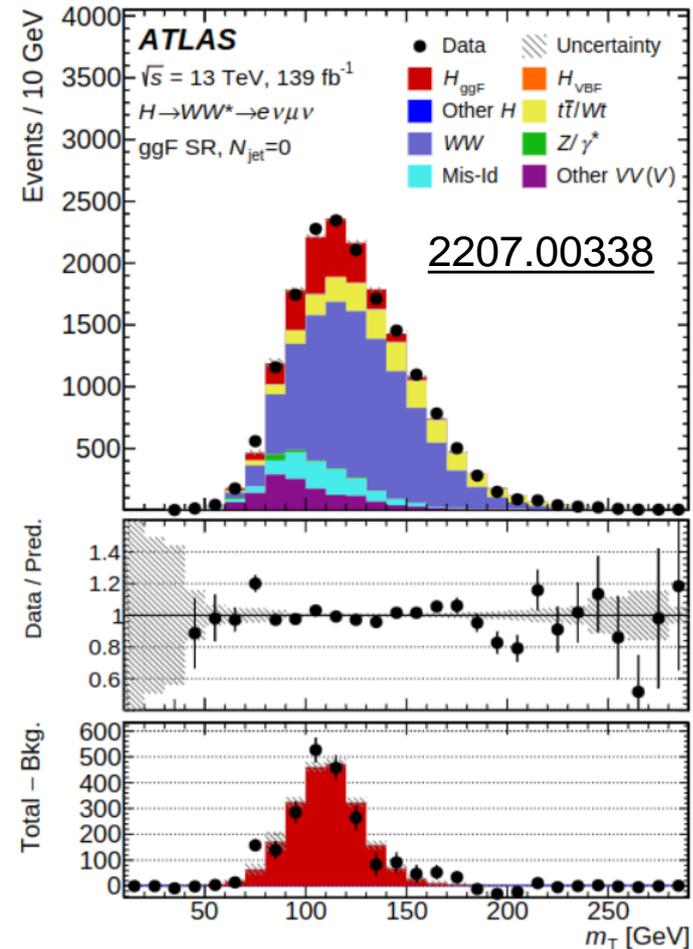
Statistically significant, motivate new EW scale scalars

Low mass WW searches

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



Background fitted

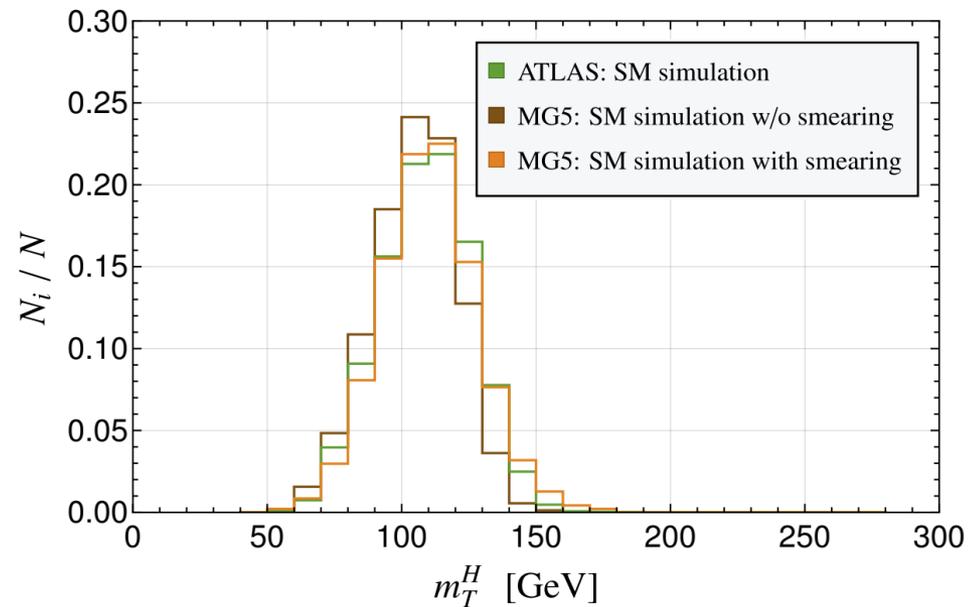
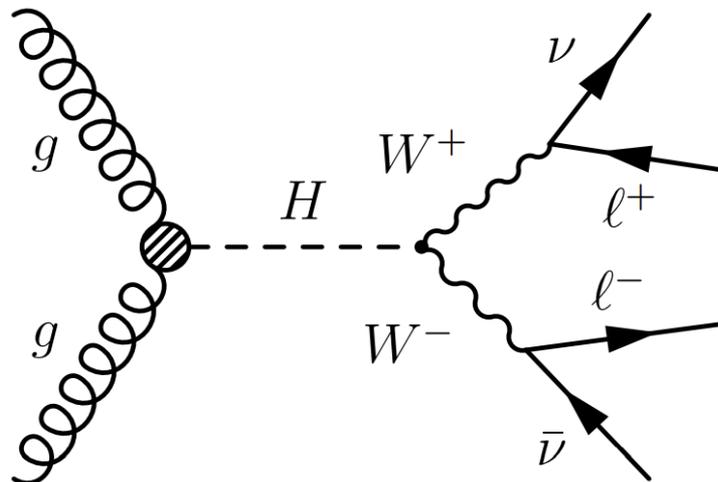


SM Higgs rescaled by 1.16

Room for NP

Simulation and Setup

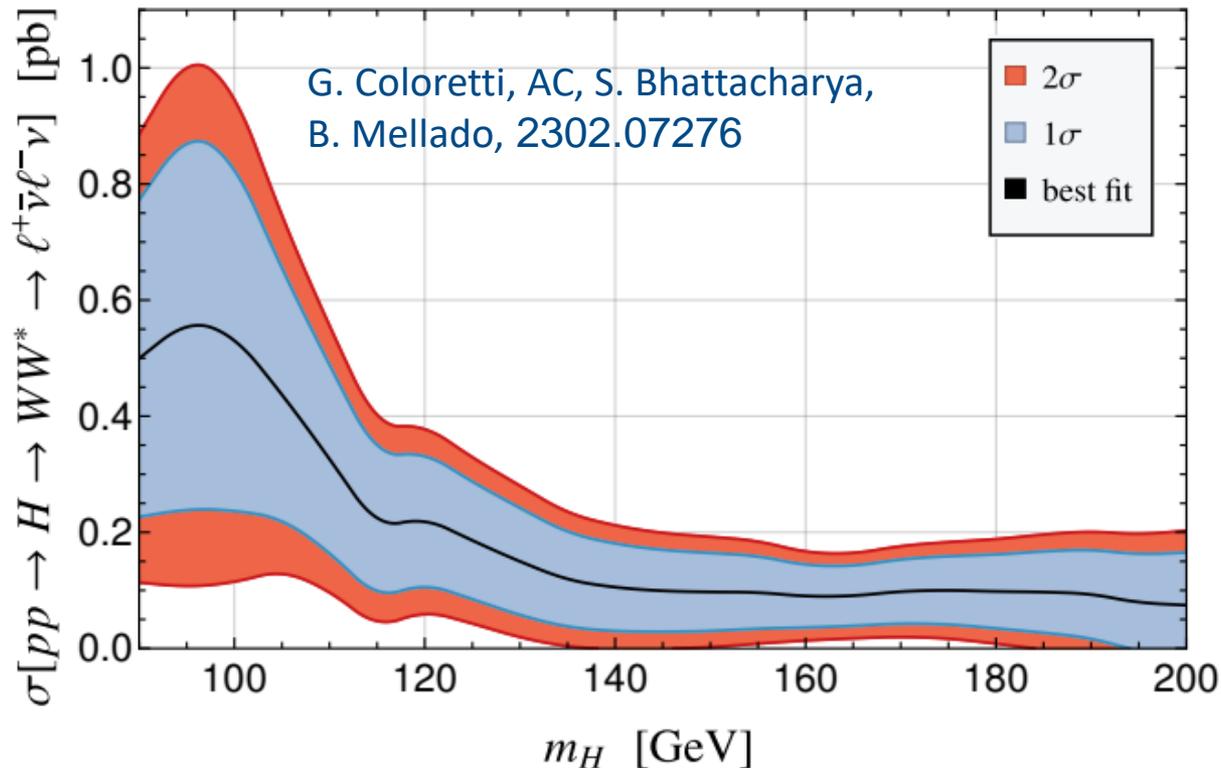
- Opposite sign, different flavour leptons with full jet veto
- New scalar H produced via gluon fusion
- Correcting for fast simulation by tuning signal vial smearing to the SM Higgs signal



Simulation validated

Low mass WW resonances searches

- ATLAS and CMS combination



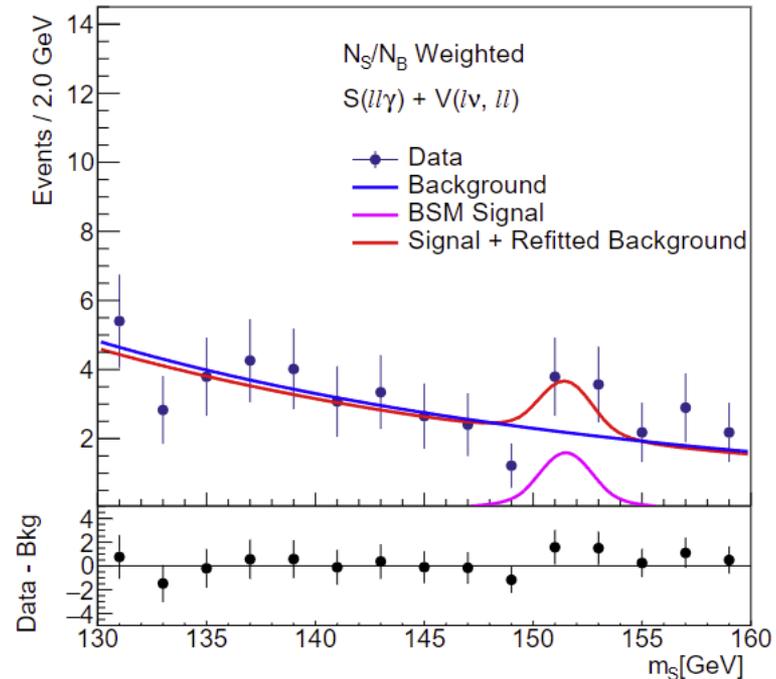
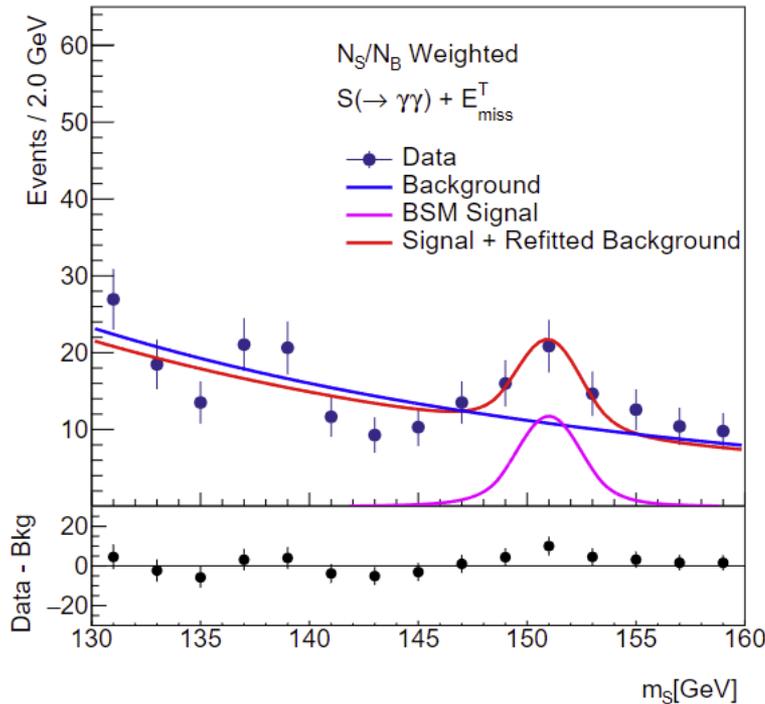
Transverse mass sensitive to additional missing energy from associated production

- New physics effect preferred over the whole range

Related to 95GeV and 151GeV?

Hints for a 152 GeV scalar

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

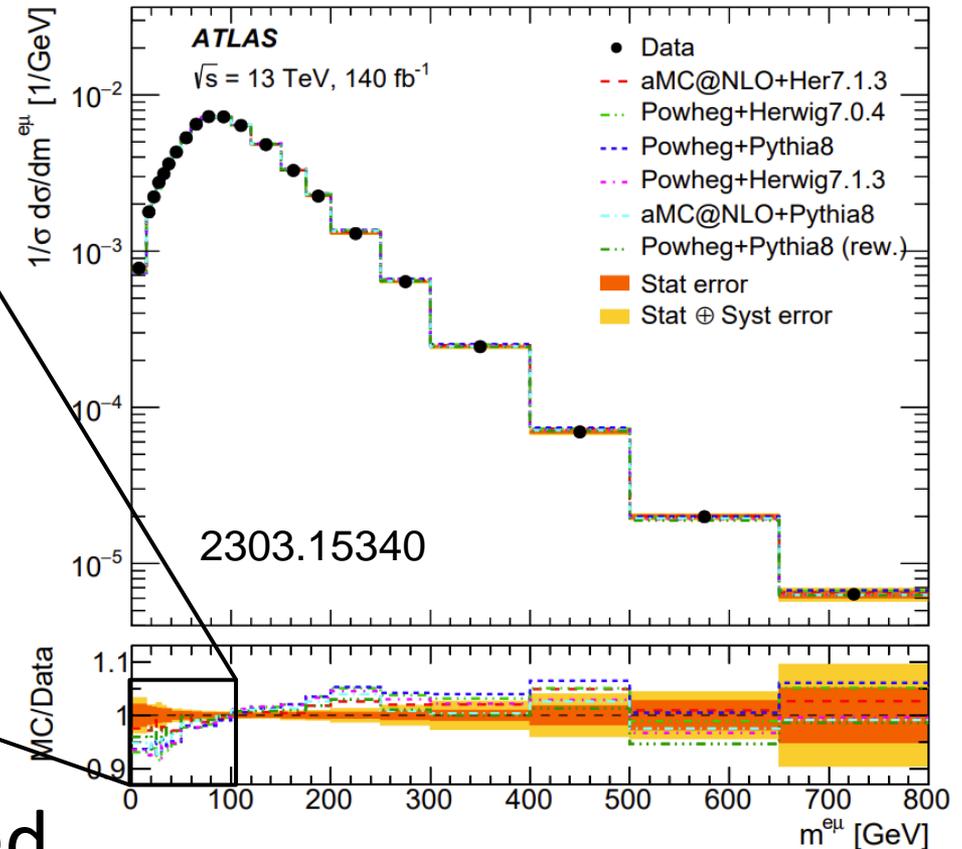
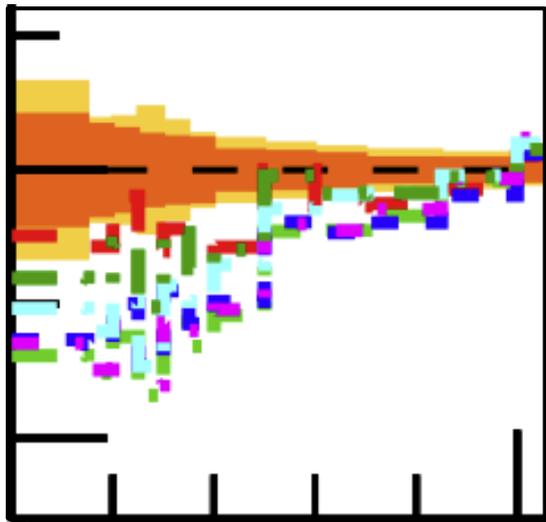


ATLAS: 2301.10486

- Hints for a resonance decaying to photons and $Z\gamma$

New Scalar (Higgs) boson? Relation to DM?

Differential Top-Quark Distributions



- ATLAS:
“No model can describe all measured distributions within their uncertainties.”

New Physics pollution of this SM measurement?