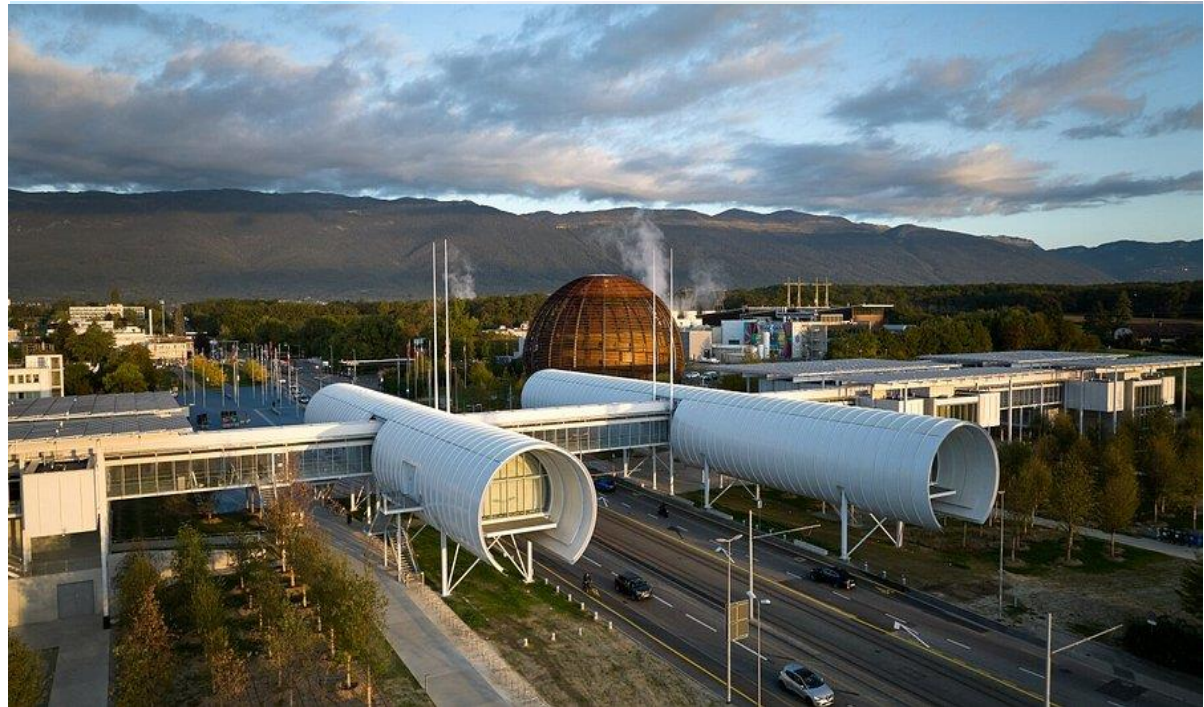




Universität  
Zürich <sup>UZH</sup>

FNSNF



**Andreas Crivellin**

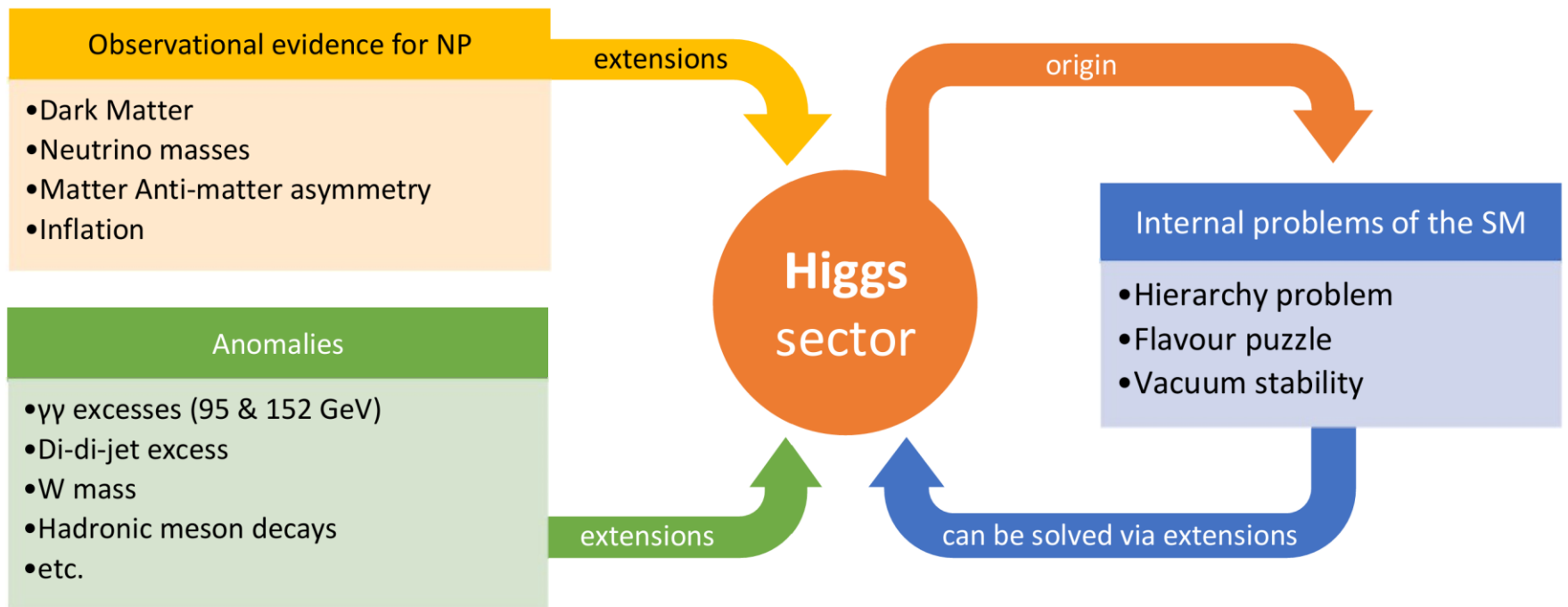
University of Zurich

# New Higgses at the Electroweak Scale and the Multi-Lepton Anomalies

CERN, reinterpretation forum, 28.02.2025

# Why new Higgses

- No theoretical principle forbids new Higgses
- Nearly all top-down approaches have new scalars

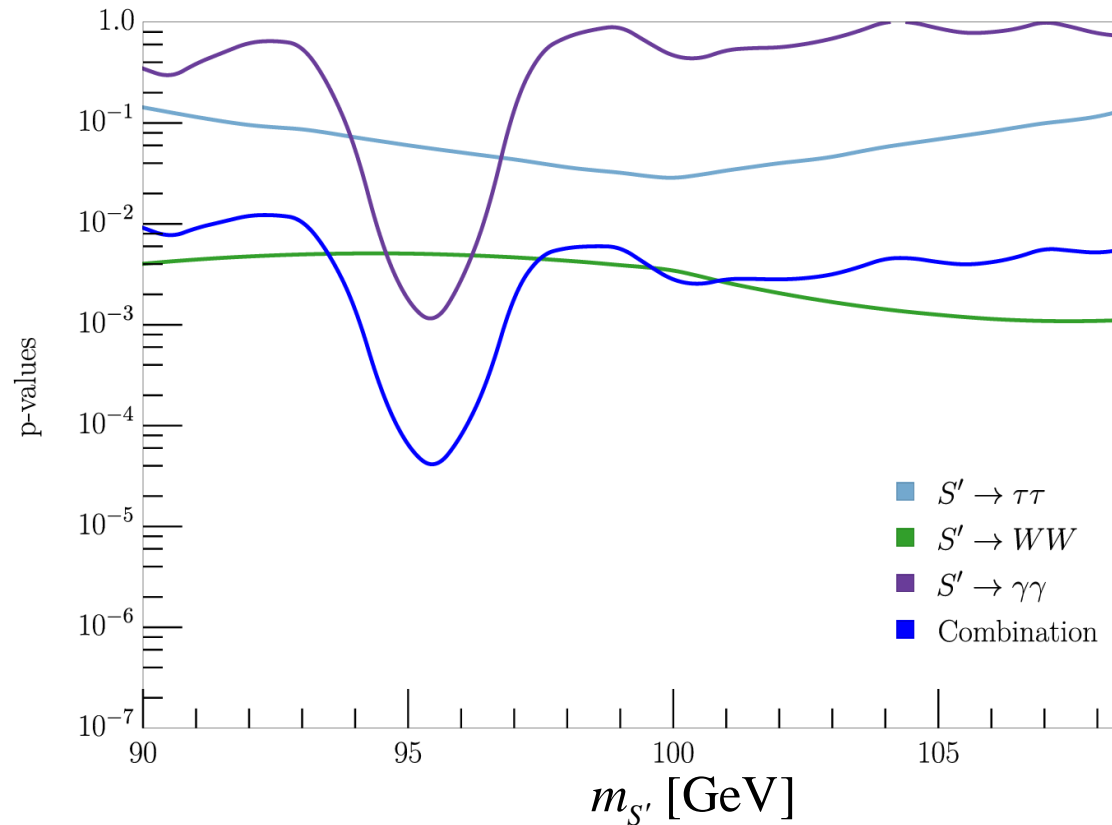


Higgs sector very promising place to expect NP

# 95 GeV Combination

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

- LEP used to reduce the LLE
- No ATLAS signal in  $\tau\tau$ ; reduced significance

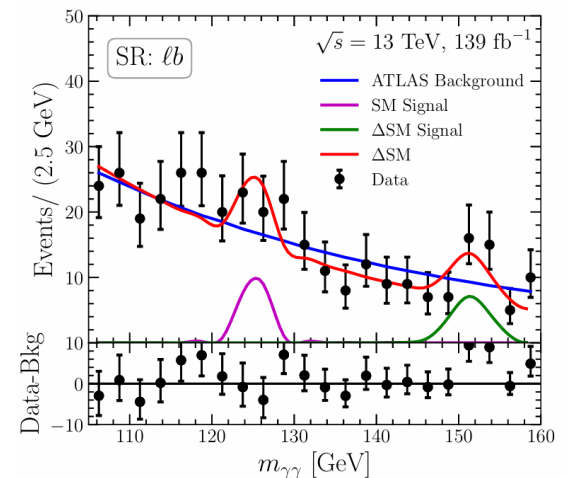
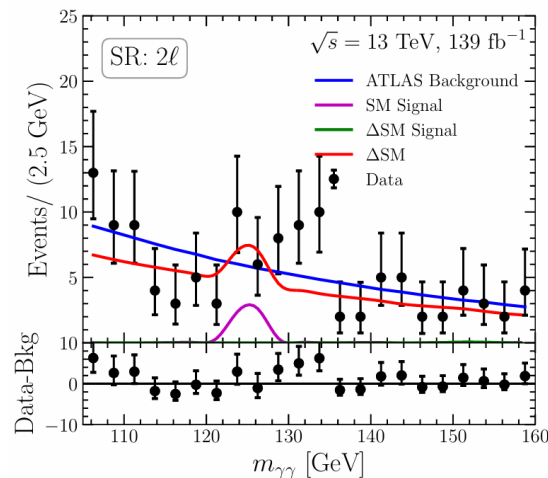
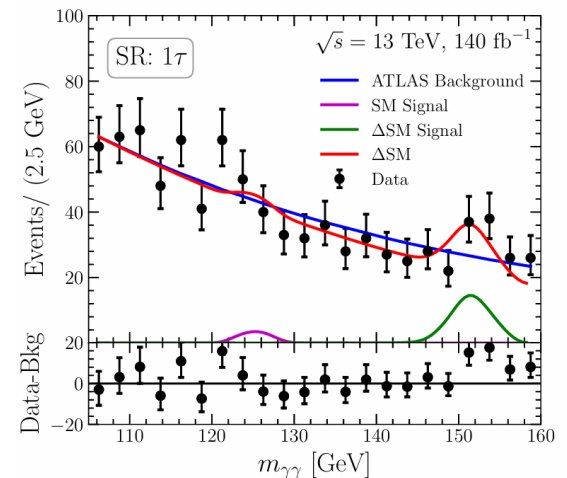
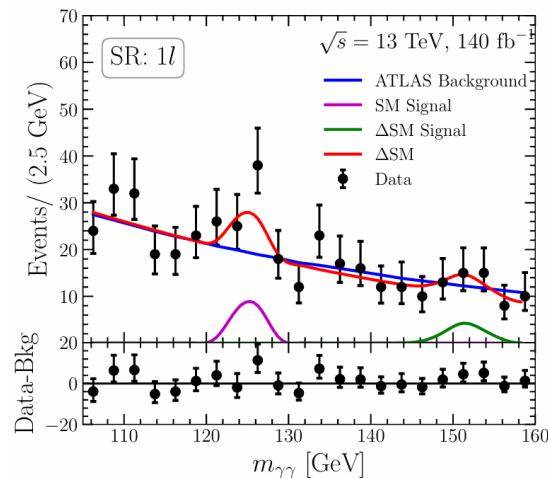


3.4 $\sigma$  global significance

# Hints for a 152 GeV scalar

JHEP 07 (2023) 176  
ATLAS-CONF-2024-005

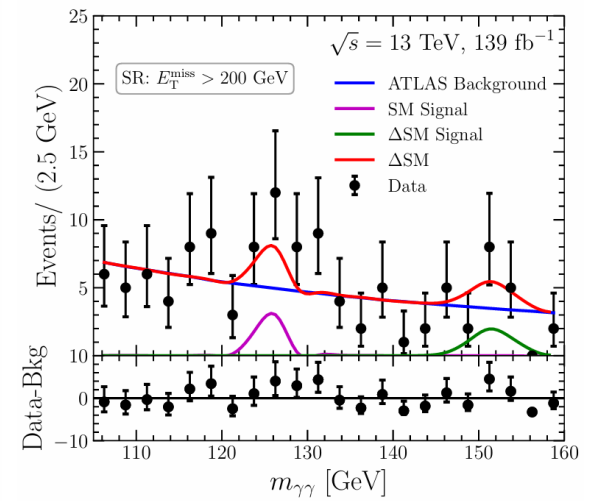
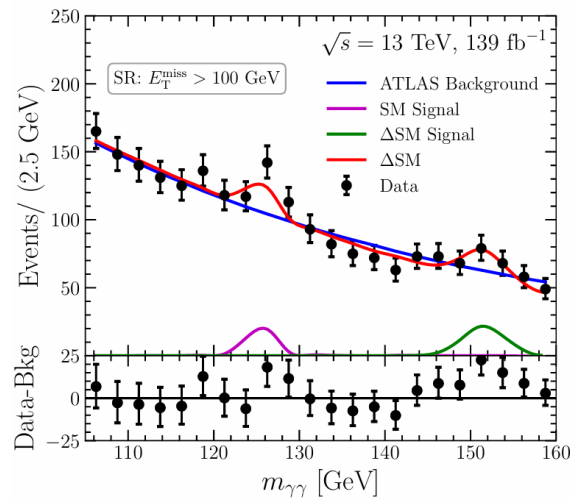
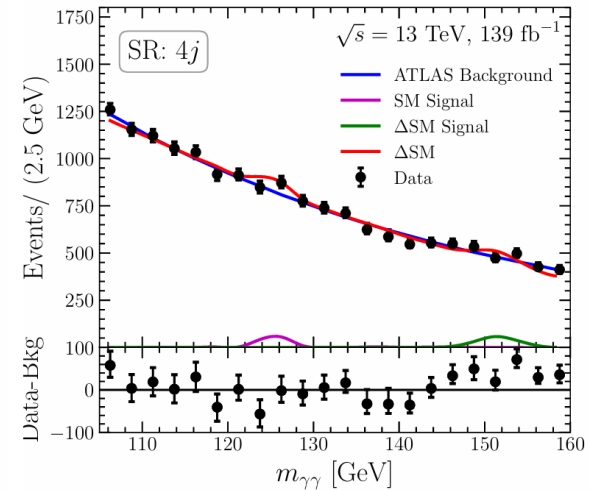
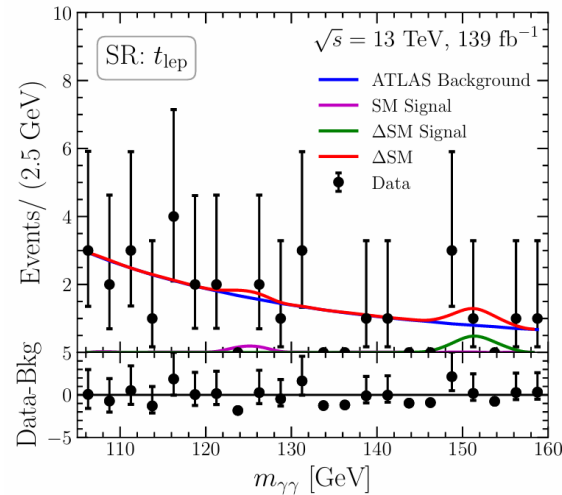
- Hints for a resonance decaying to photons in association with leptons missing energy and b-jets



Dominant channels are  $\gamma\gamma+X$

# Hints for a 152 GeV scalar

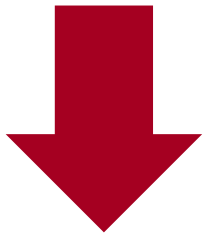
- Hints for a resonance decaying to photons in association with leptons missing energy and b-jets



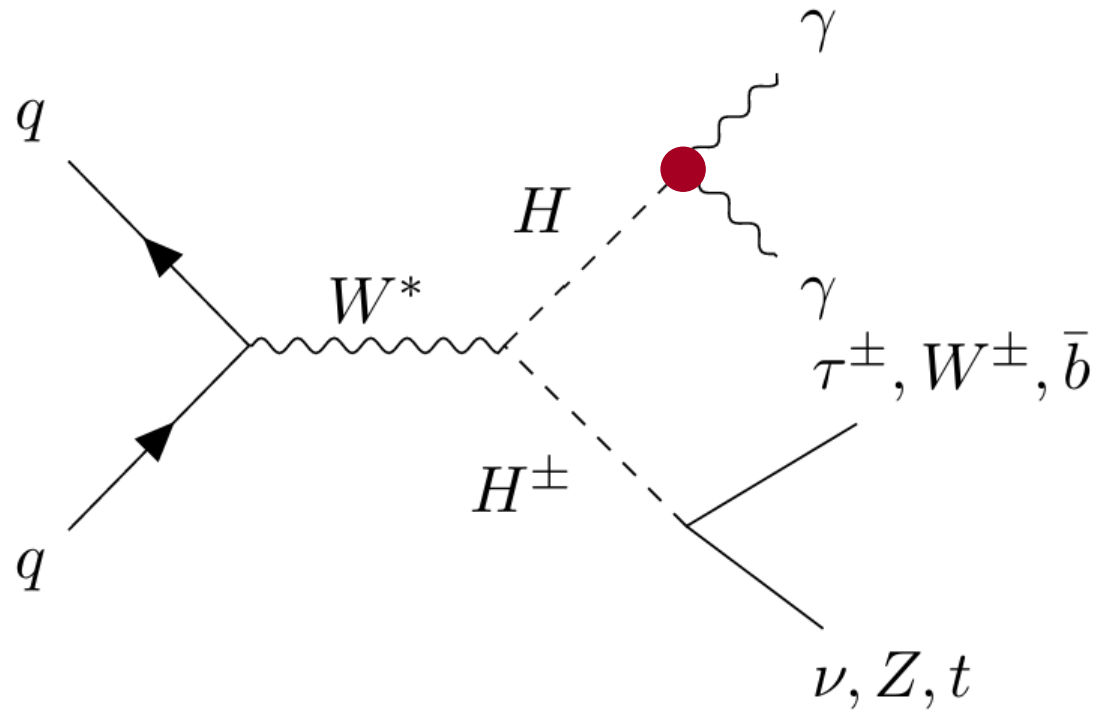
Dominant channels are  $\gamma\gamma+X$

# Drell-Yan Production

- One leptons, but not two leptons
- One tau but not two taus
- $l b$  but not  $t_{lep}$
- Moderate MET



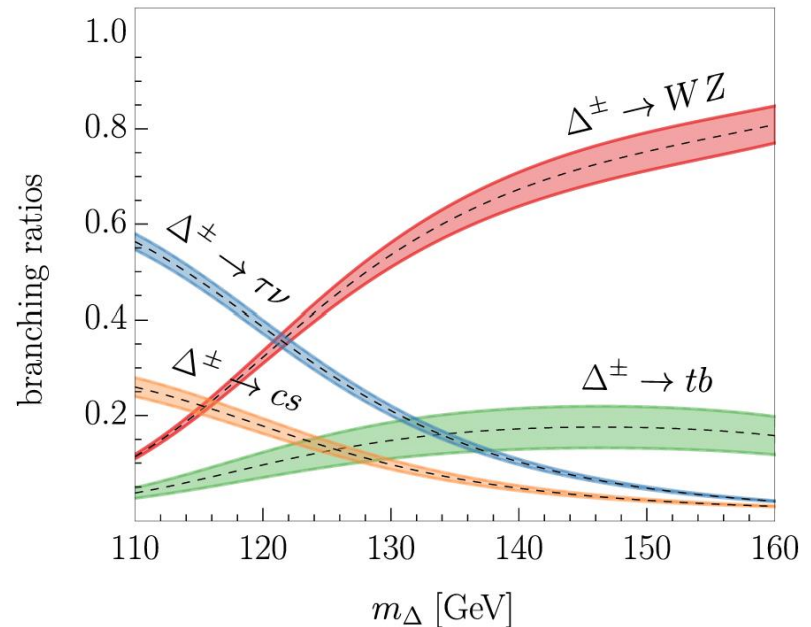
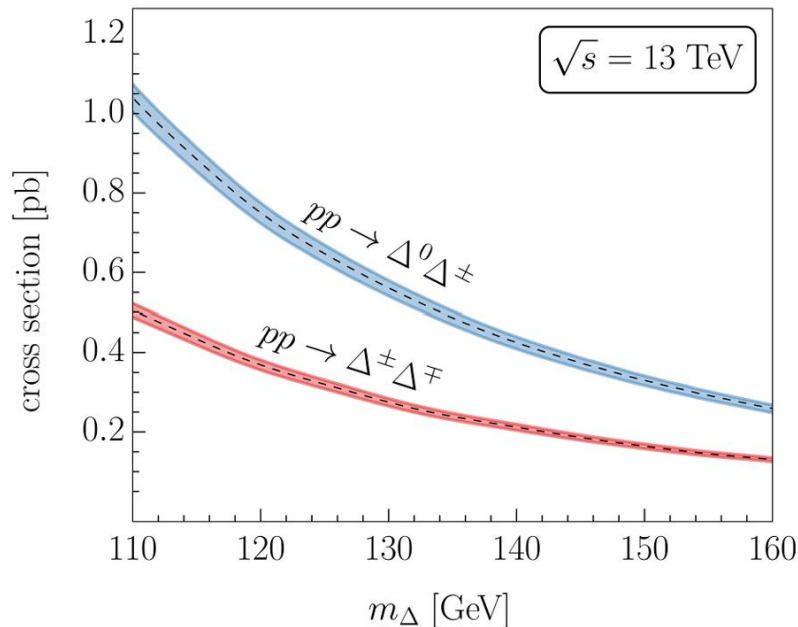
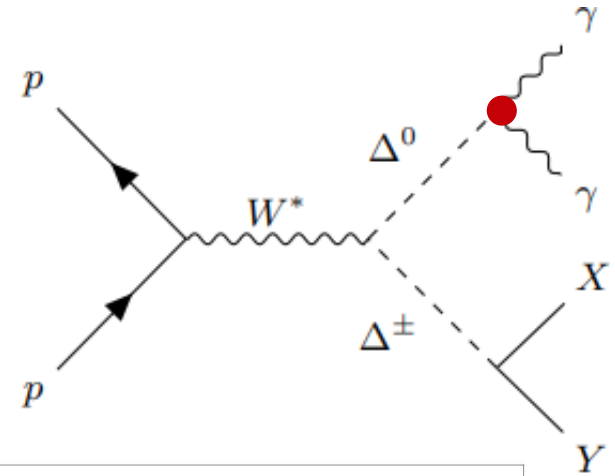
- DY production of charged and neutral Higgs



New Scalar with non-trivial SU(2) representation

# Is the 152 GeV Higgs a Triplet ( $\Delta$ )?

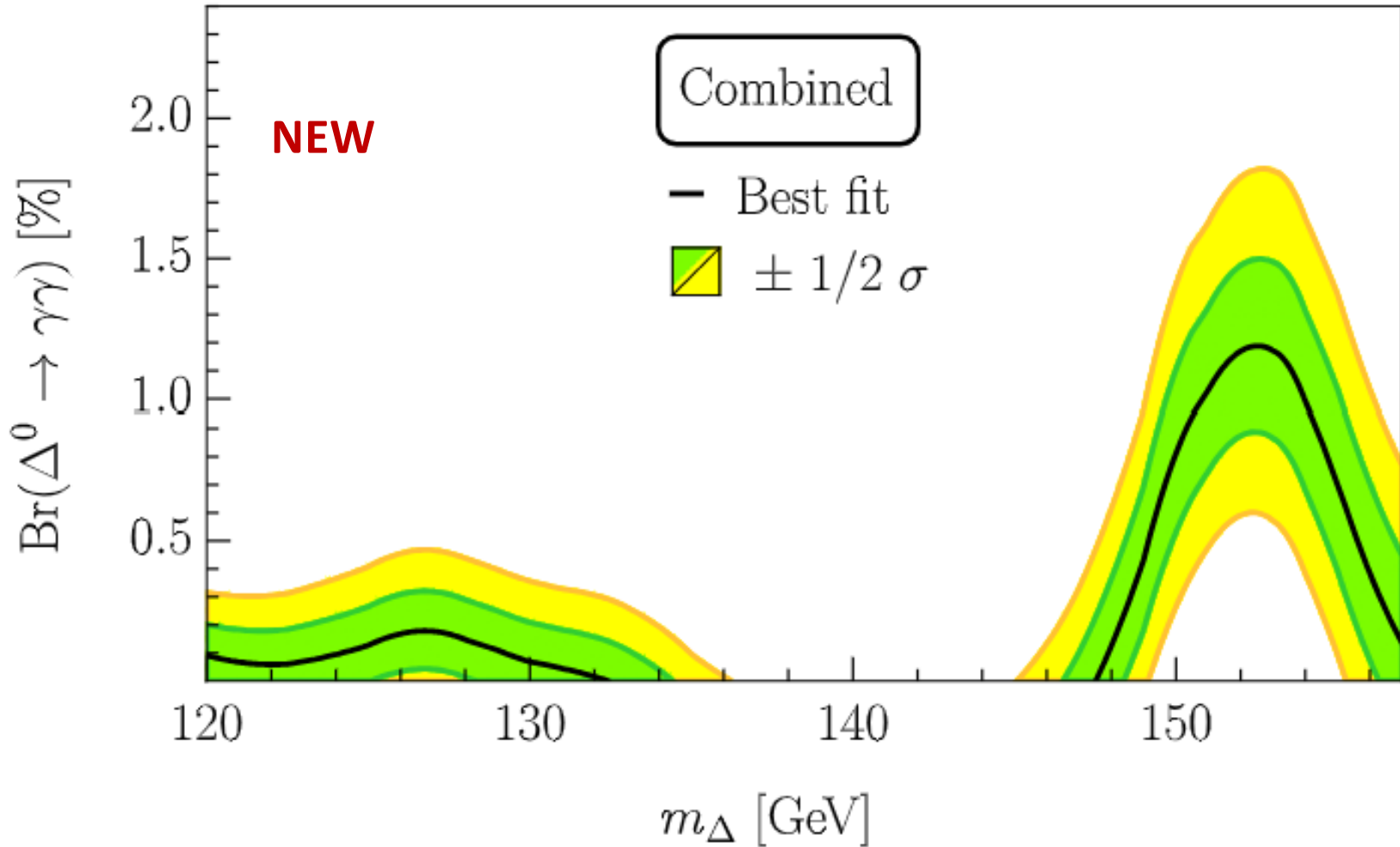
- $\Delta^0$  decays dominantly to  $WW$
- Positive shift in the  $W$  mass as preferred by the EW fit
- Quasi degenerate in mass



Drell-Yan production at the LHC

# Combination

S. Ashanujjaman, S. Banik, G. Coloretti, A.C. S. P. Maharathy,  
B. Mellado, 2404.14492

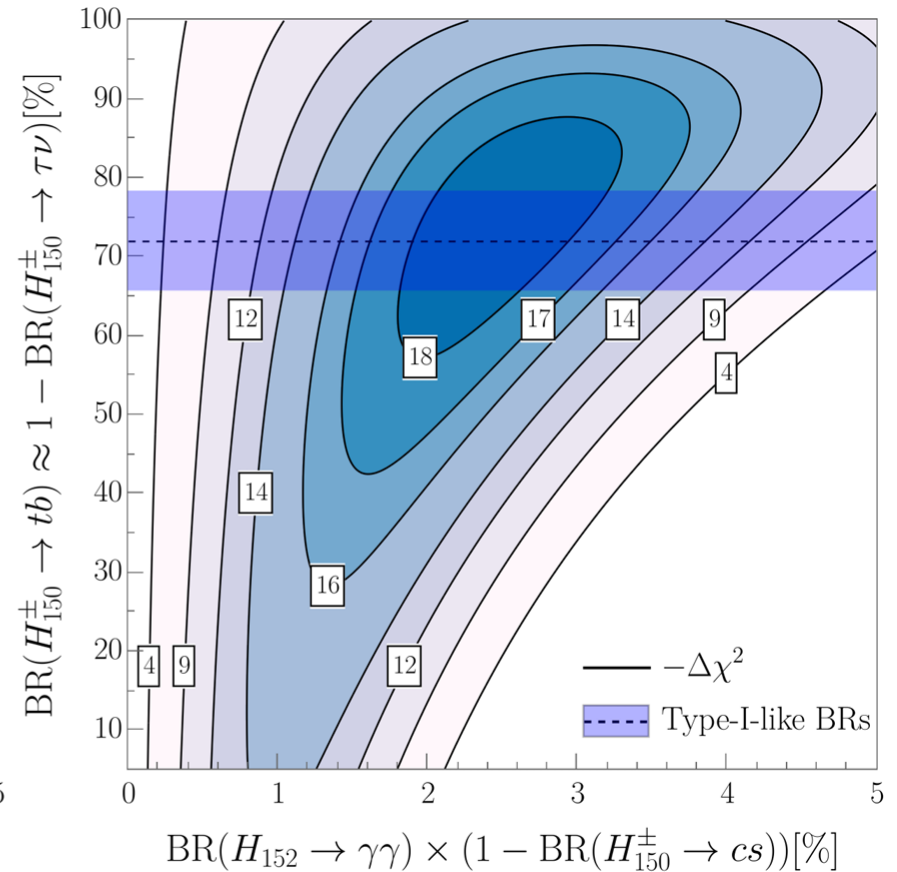
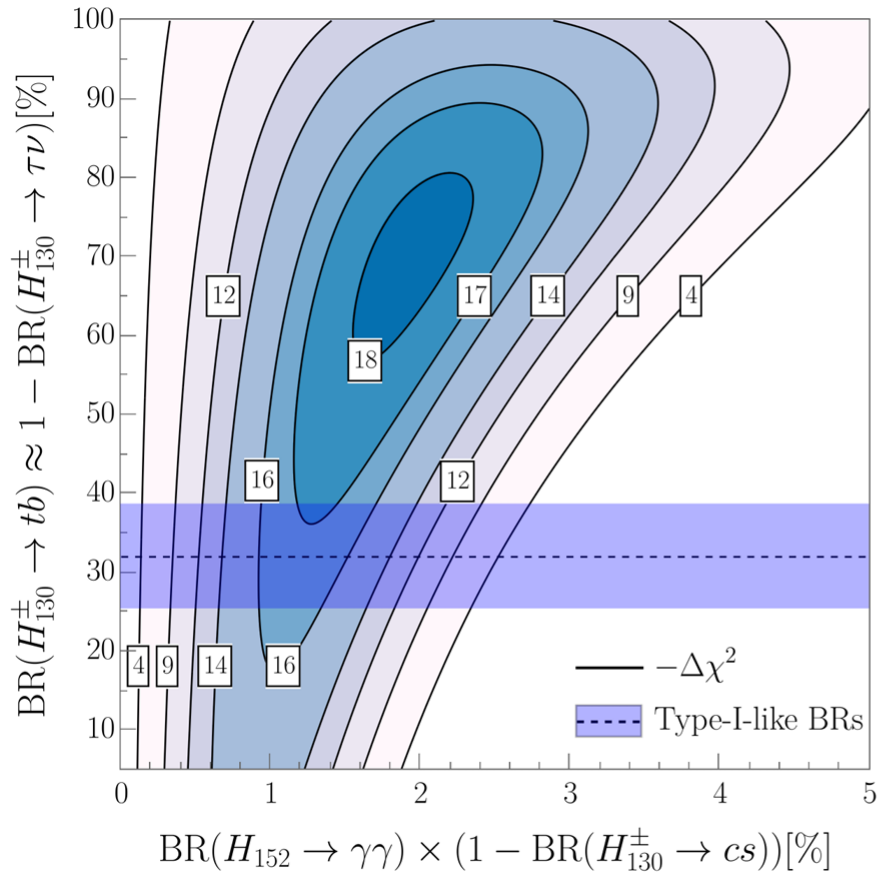


$\approx 4\sigma$  excess at 152 GeV



# Two-Higgs Doublet Model type-I

- $\text{Br}(H^\pm \rightarrow WZ) = 0$  (at tree-level)



Above  $4\sigma$ , large Br needed

# Large $\text{Br}(H_{152} \rightarrow \gamma\gamma)$ via $Z_2$ breaking in 2HDMs

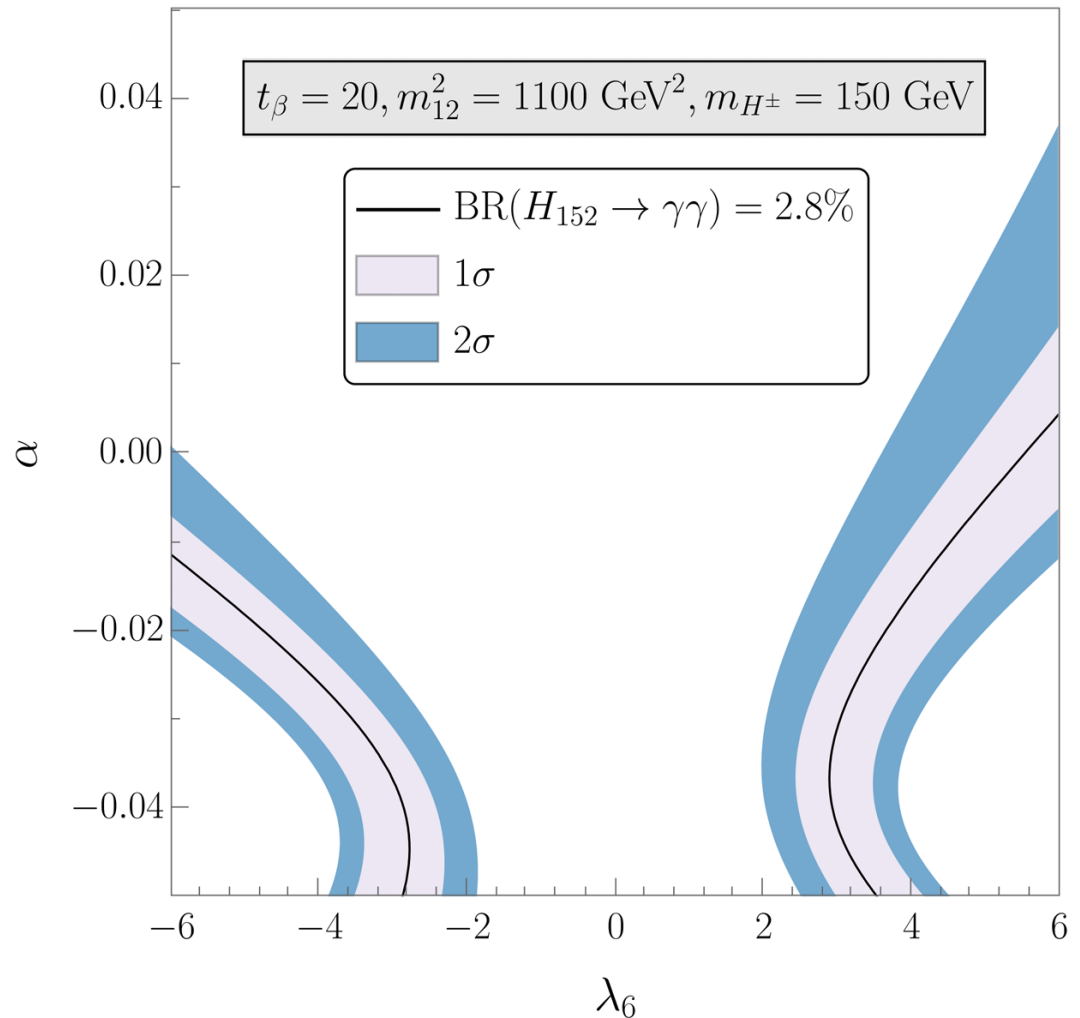
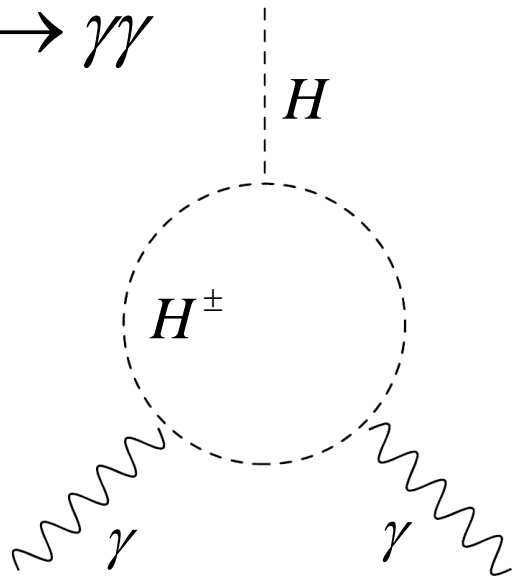
$$\lambda_6 H_1^\dagger H_1 H_2^\dagger H_1$$

- Dominant effect in

$$H \rightarrow \gamma\gamma$$

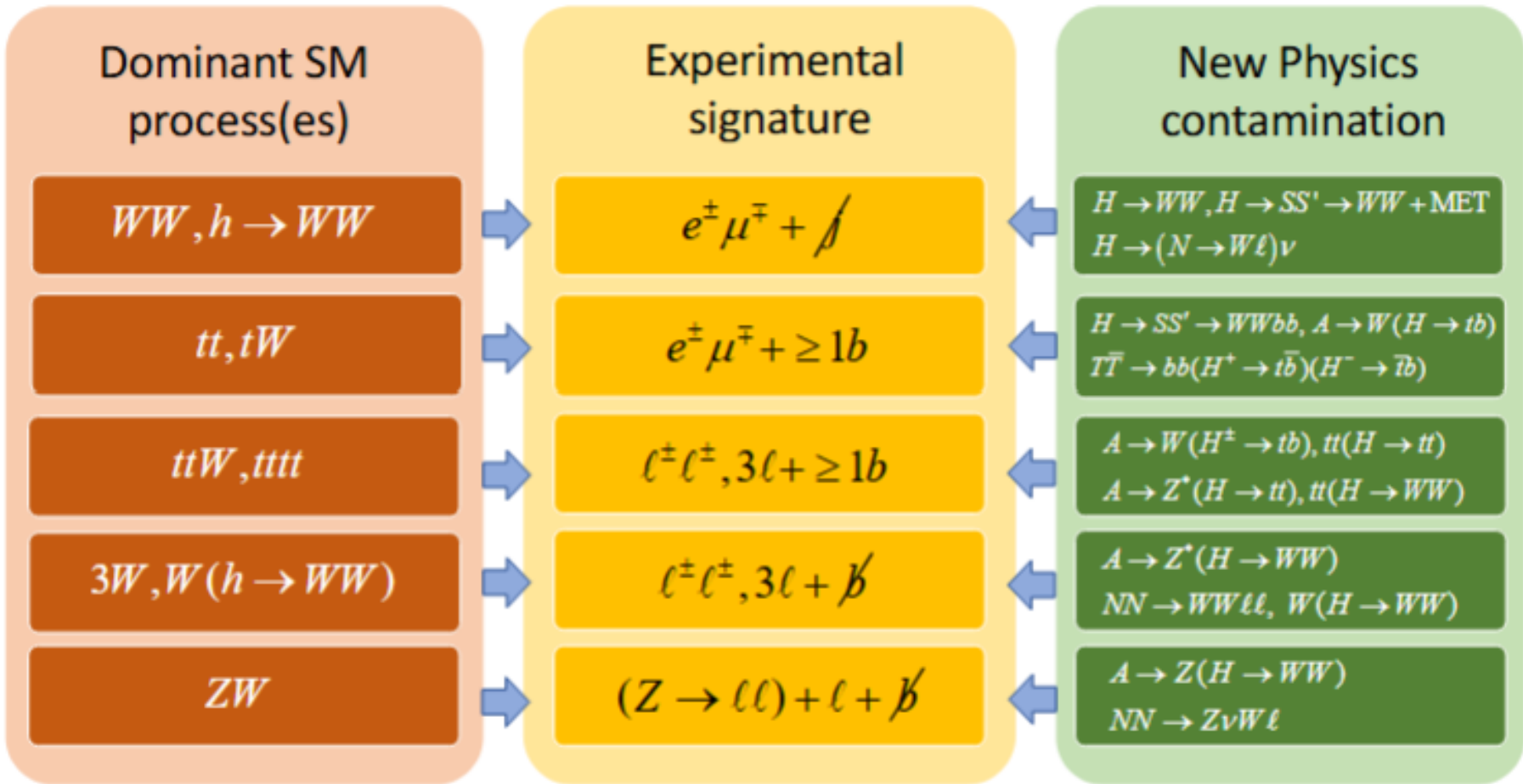
but suppressed in

$$h \rightarrow \gamma\gamma$$

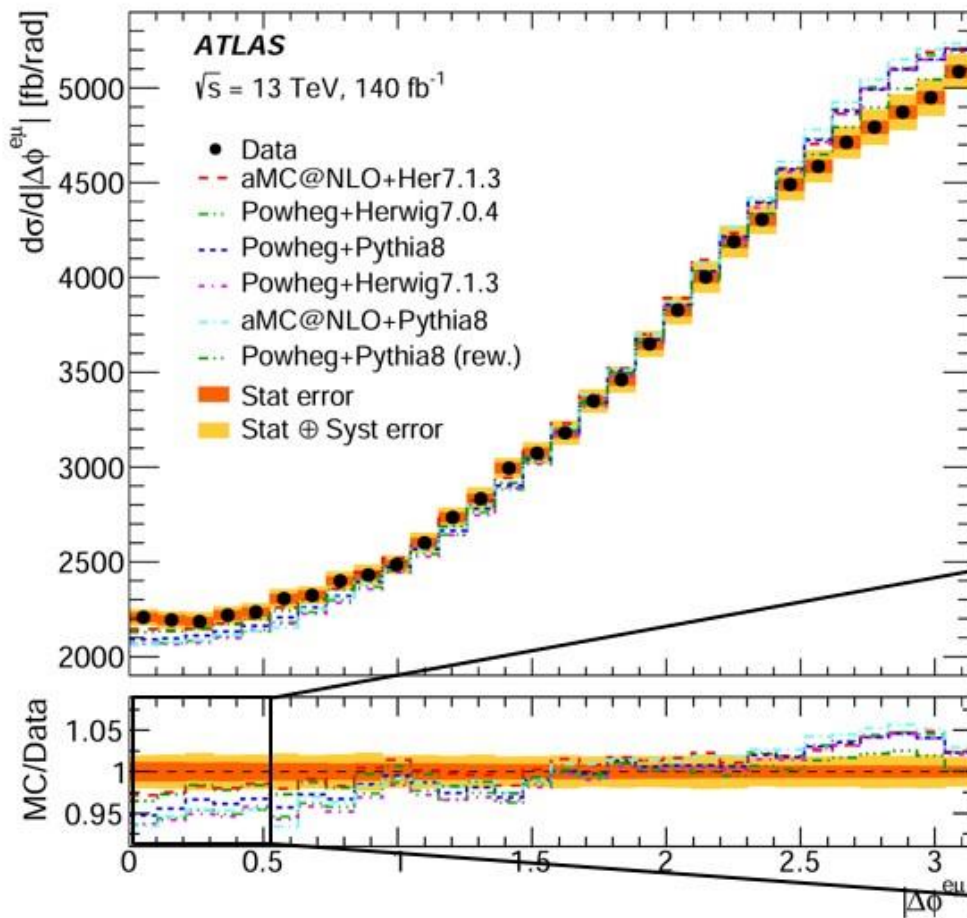


Consistent with vacuum stability, perturbativity

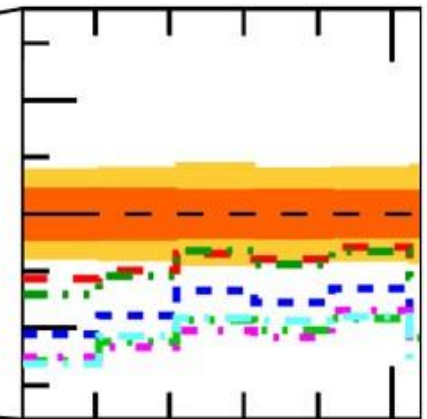
# Multi-lepton anomalies



# Differential Top-Quark Distributions



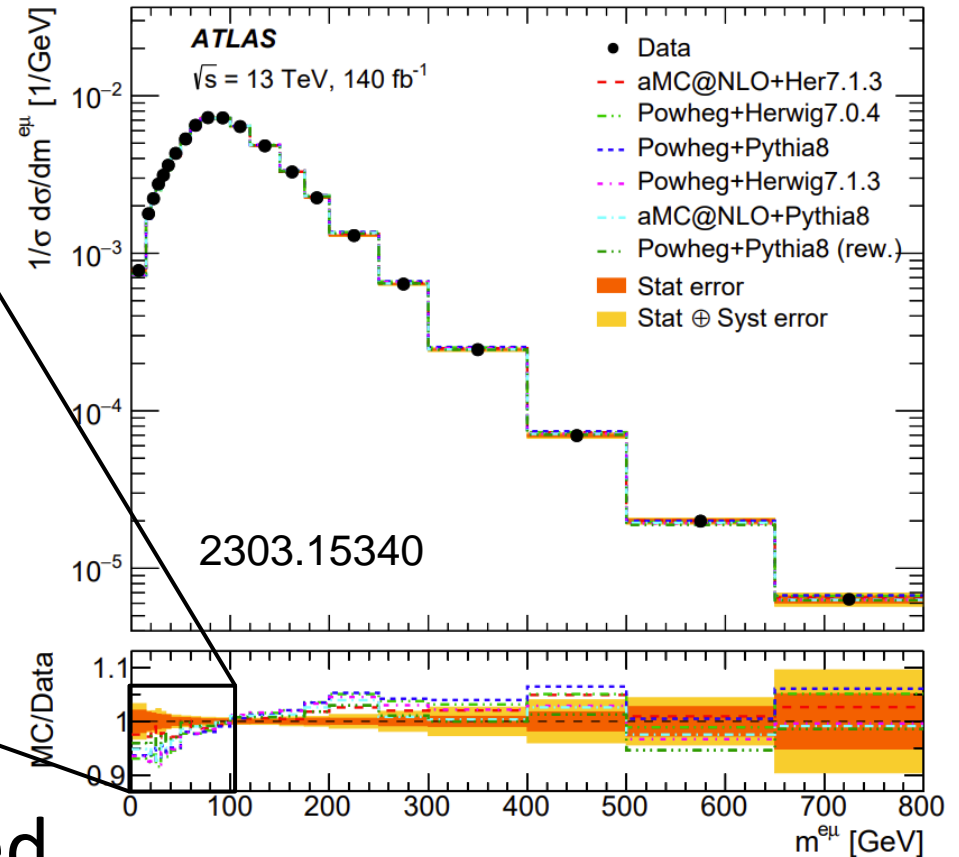
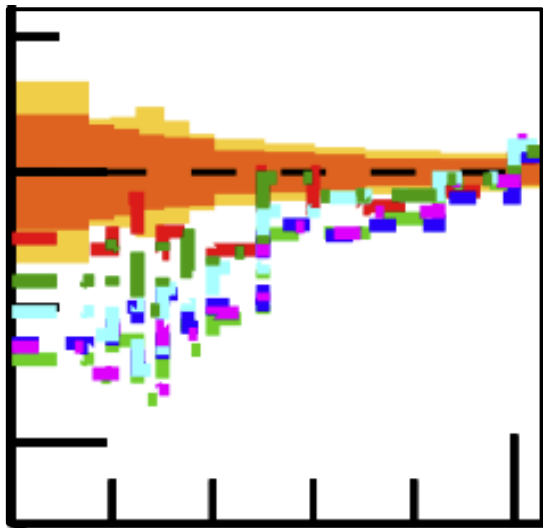
- ATLAS: *JHEP* 07 (2023) 141  
“No model can describe all measured distributions within their uncertainties.”



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

New Physics pollution of this SM measurement?

# Differential Top-Quark Distributions

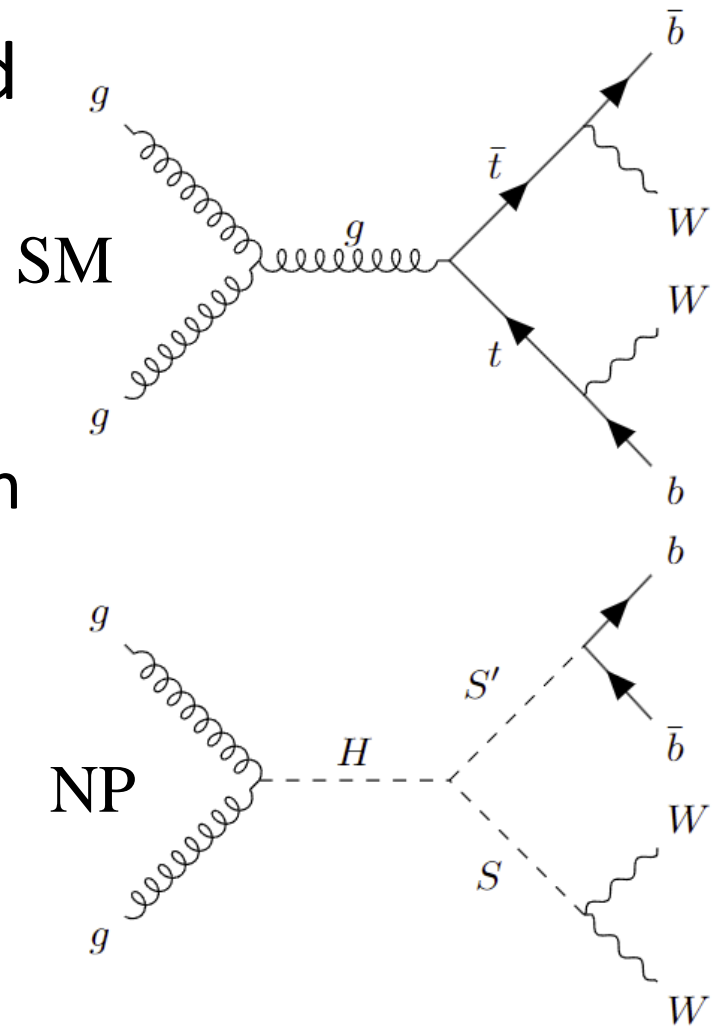


- ATLAS:  
“No model can describe all measured distributions within their uncertainties.”

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

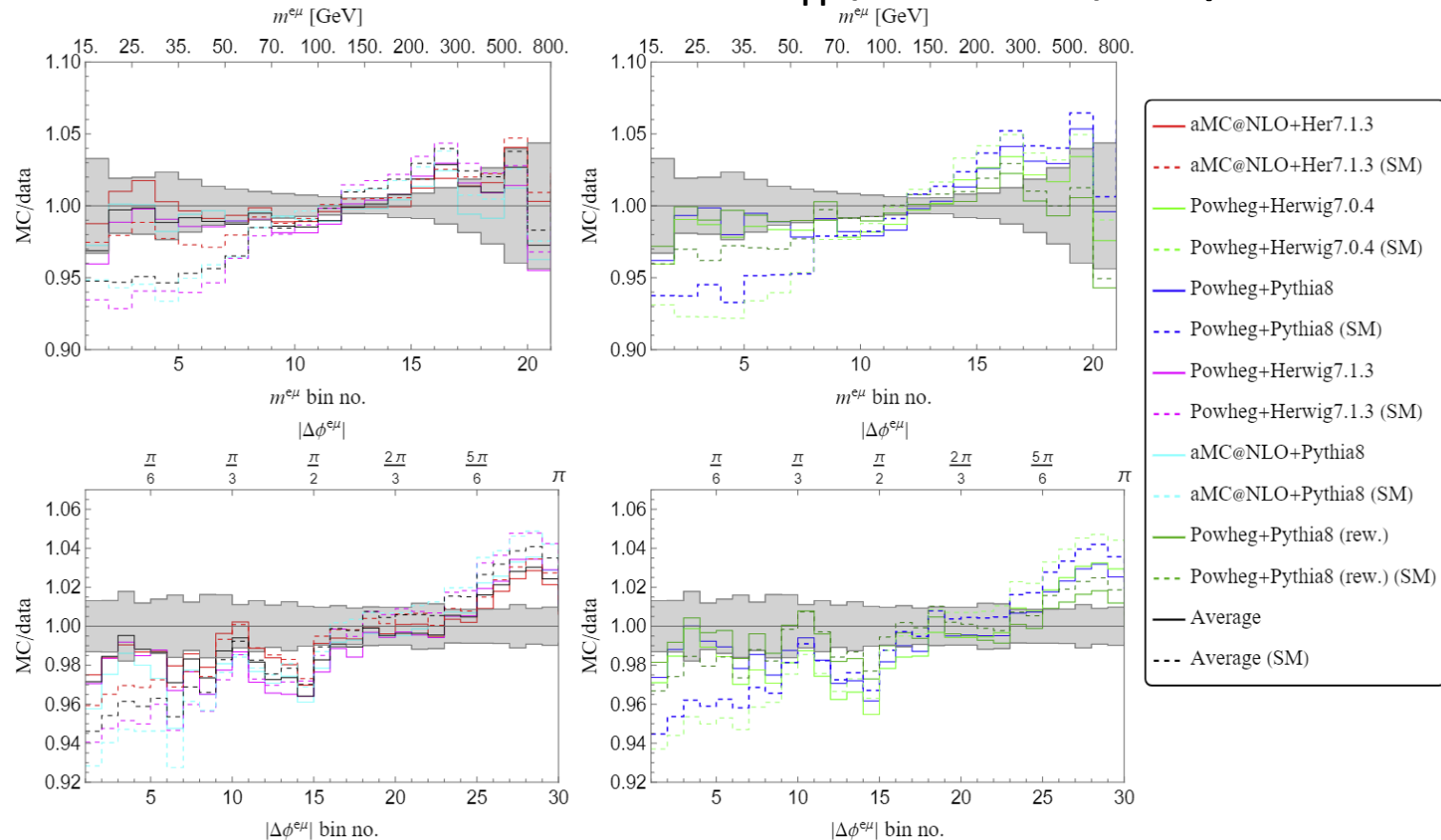


Related to the 95 GeV and 151.5 GeV hints?

# 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.



Deficit at large  $\Delta\phi^{e\mu}$  &  $m^{e\mu}$  explained as well

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

2308.07953

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

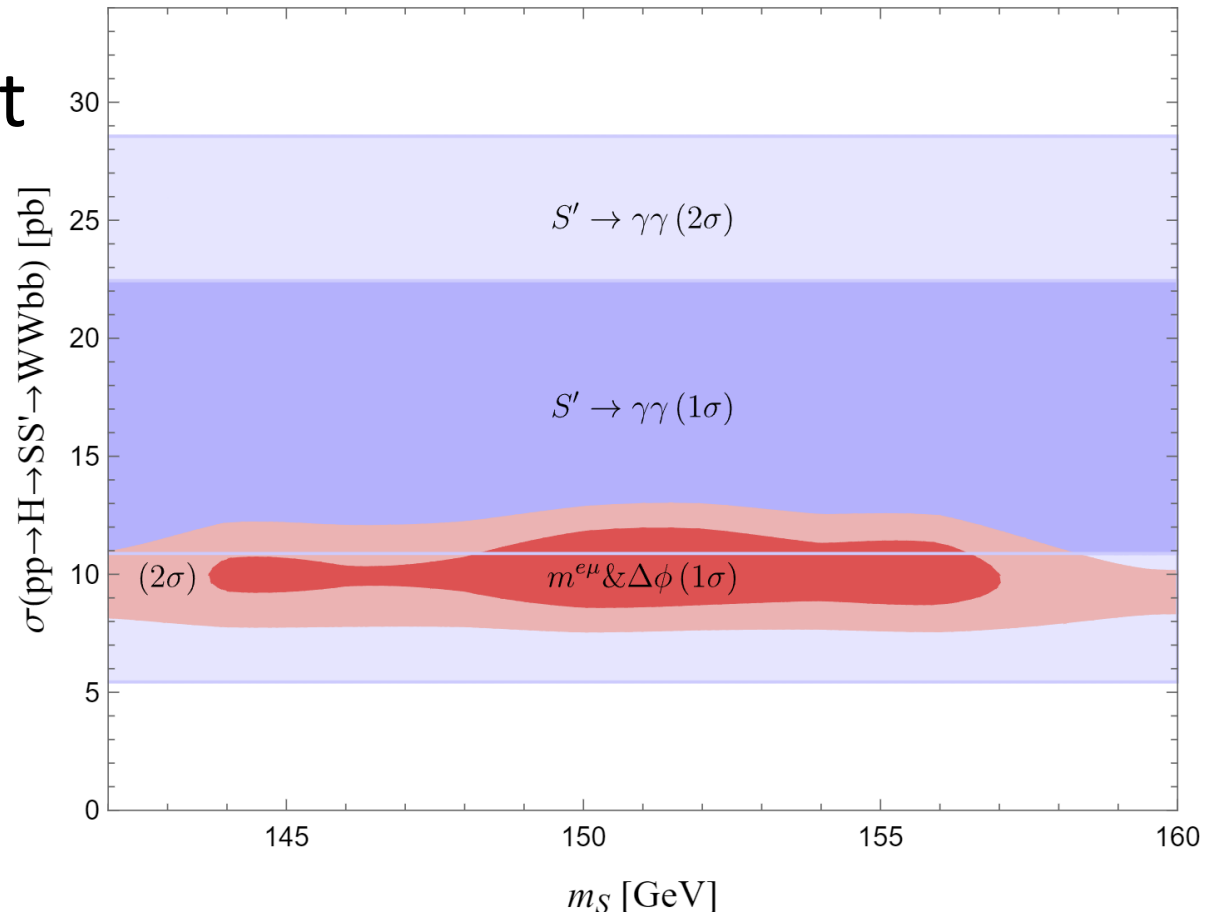
- Improvement of SM prediction imperative!

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



# Is 95 GeV a singlet? Relation to 151.5 GeV?

- $S'(95)$ : Singlet decays dominantly to  $bb$
- $S(152)$ : decays dominantly to  $WW$



Consistent with 95 GeV  $\gamma\gamma$  signal strength & a mass of  $S$  with 151.5 GeV

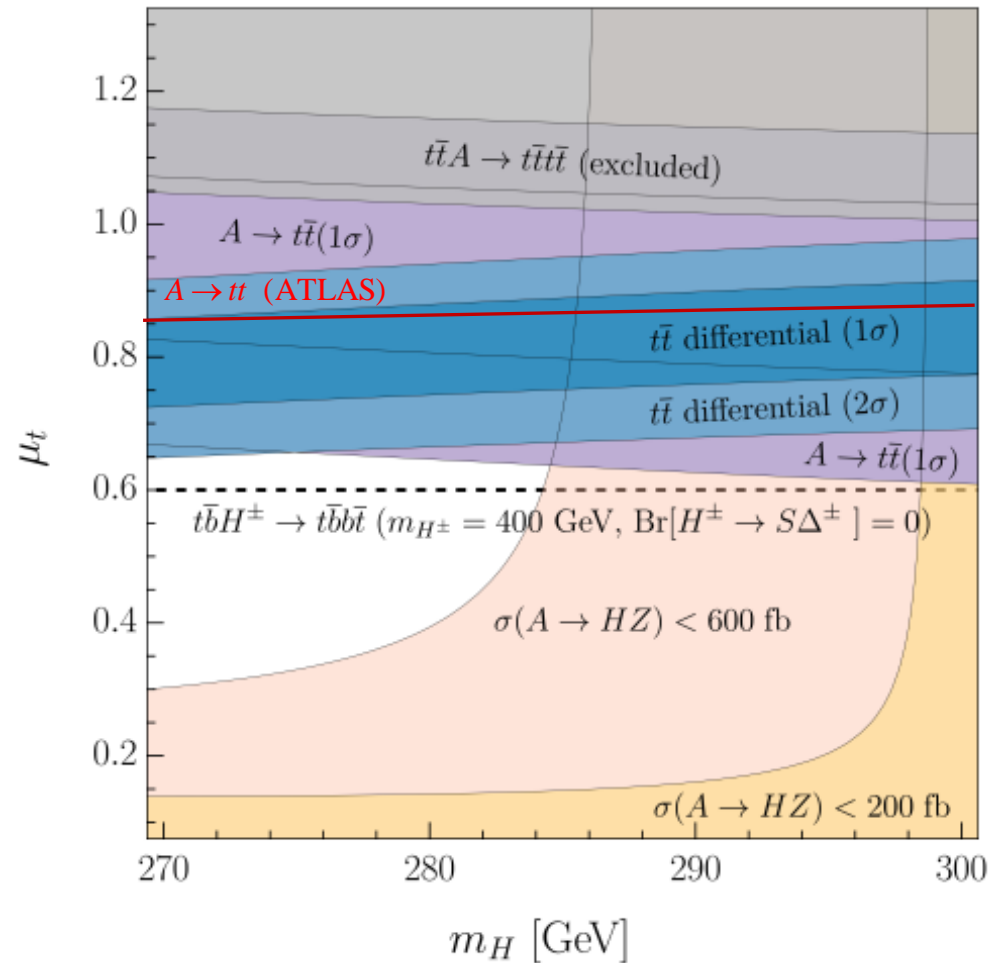
# $\Delta 2$ HDMS and top-quark production

Field	$SU(2)_L$	$U(1)_Y$
$\phi_s$	1	0
$\phi_2$	2	1/2
$\phi_1$	2	1/2
$\Delta$	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

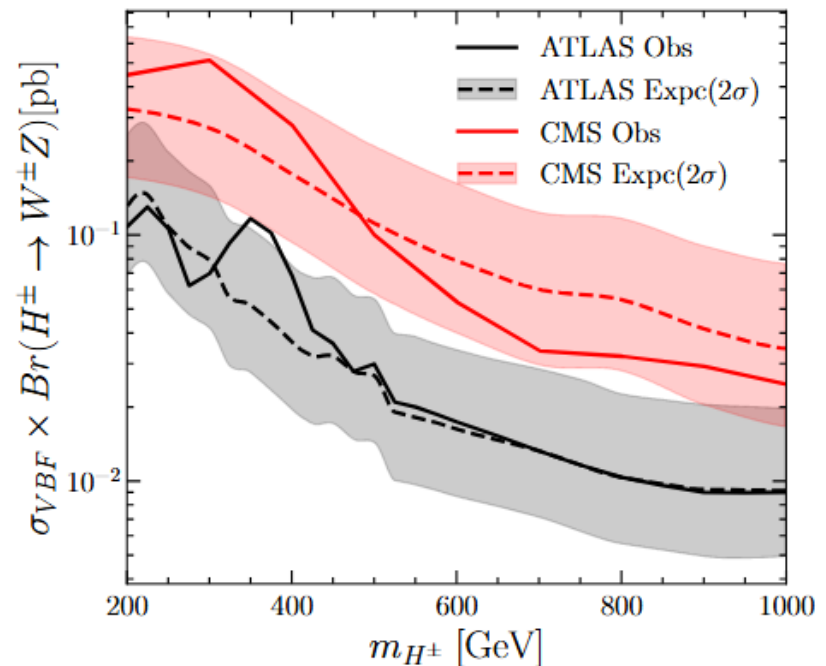
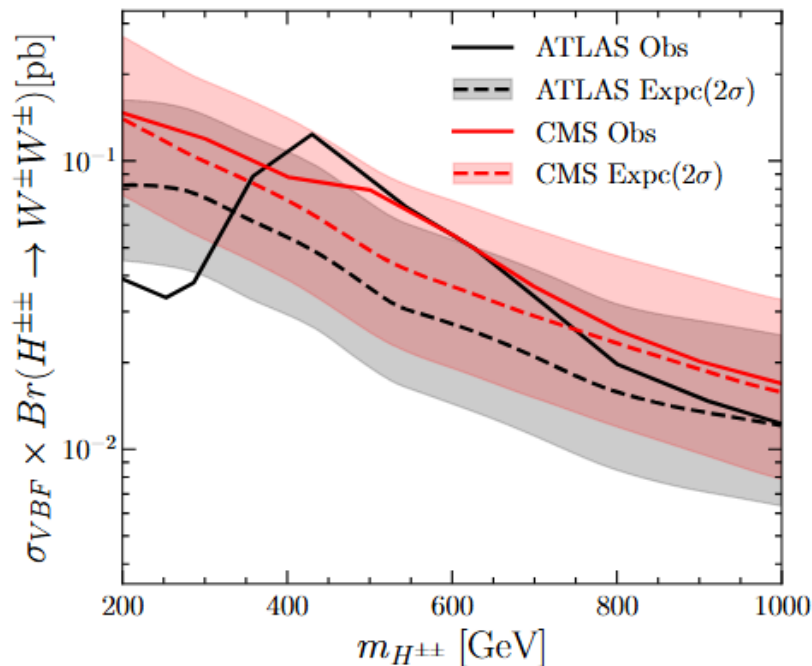


Combined explanation possible

# Generic Georgi-Machacek Model

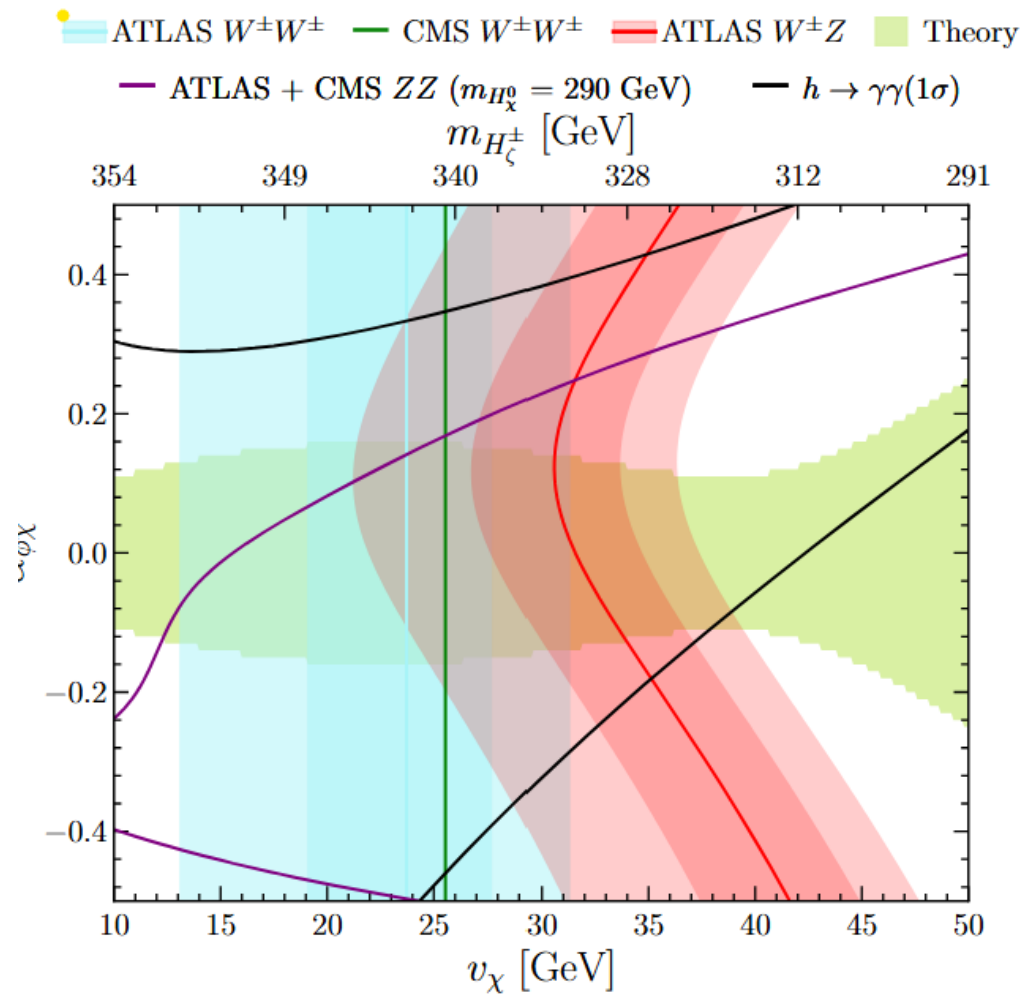
## SM extend

- SM extended by a  $Y=0$  and a  $Y=1$  triplet
- Vevs of the triplet can be sizable due to cancellation in the  $W$  mass  $\rightarrow$  sizable vector-boson fusion



Excesses in same-sign WW and ZW

# Generic Georgi-Machacek Model



Can explain WW, ZW and  $\gamma\gamma$

# Conclusions

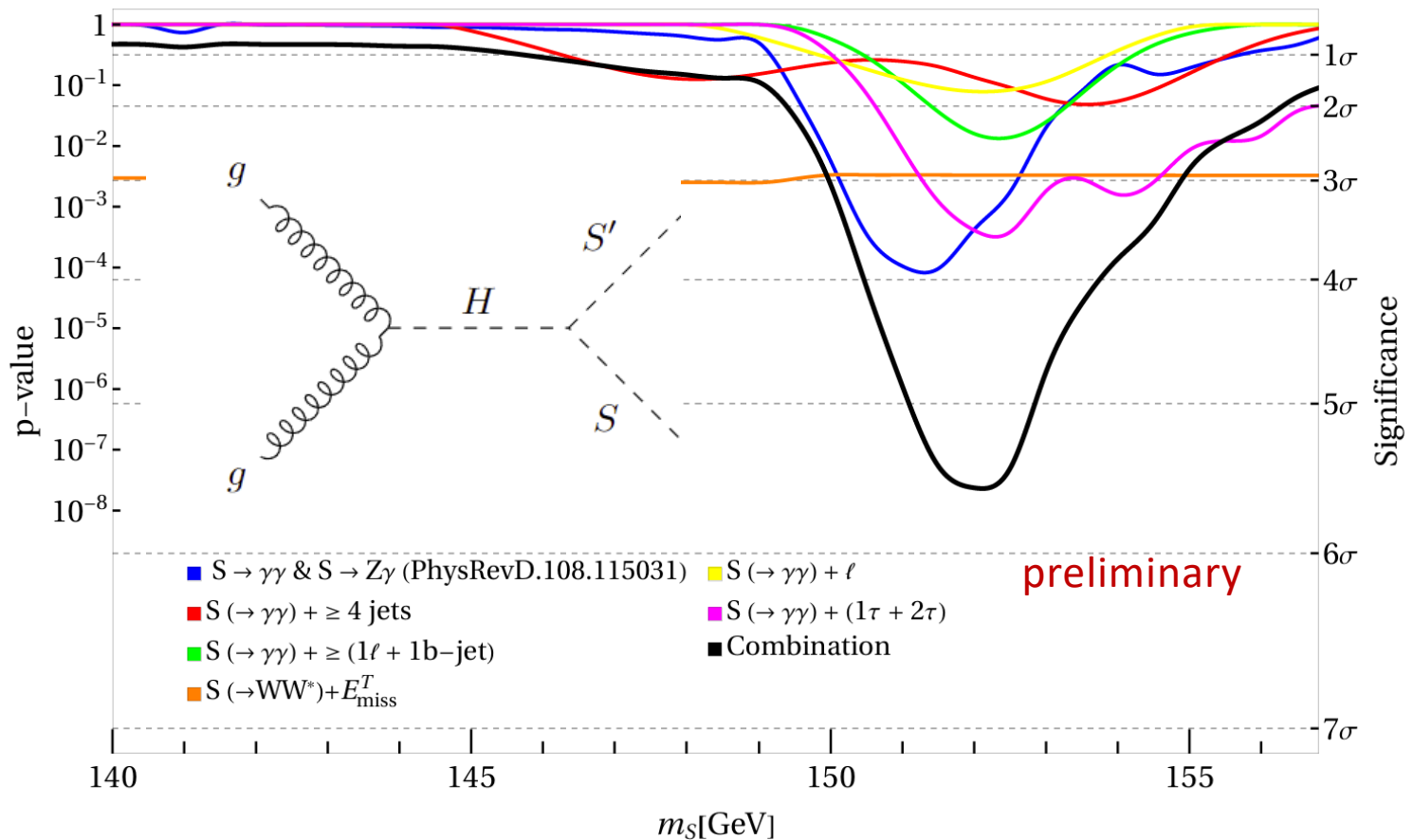
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- Hints for narrow resonances at 95 GeV & 152 GeV
- Significant tensions in top quark differential distributions ( $>5\sigma$ )
- Can be explained by EW scale Higgses
- Model independent searches are useful
- Provide as large sidebands as possible
- Minimum: Give cut-based results
- Best case: Provide PDT

Most significant hints for new particles at the LHC

# Hints for new Scalars at 152 GeV

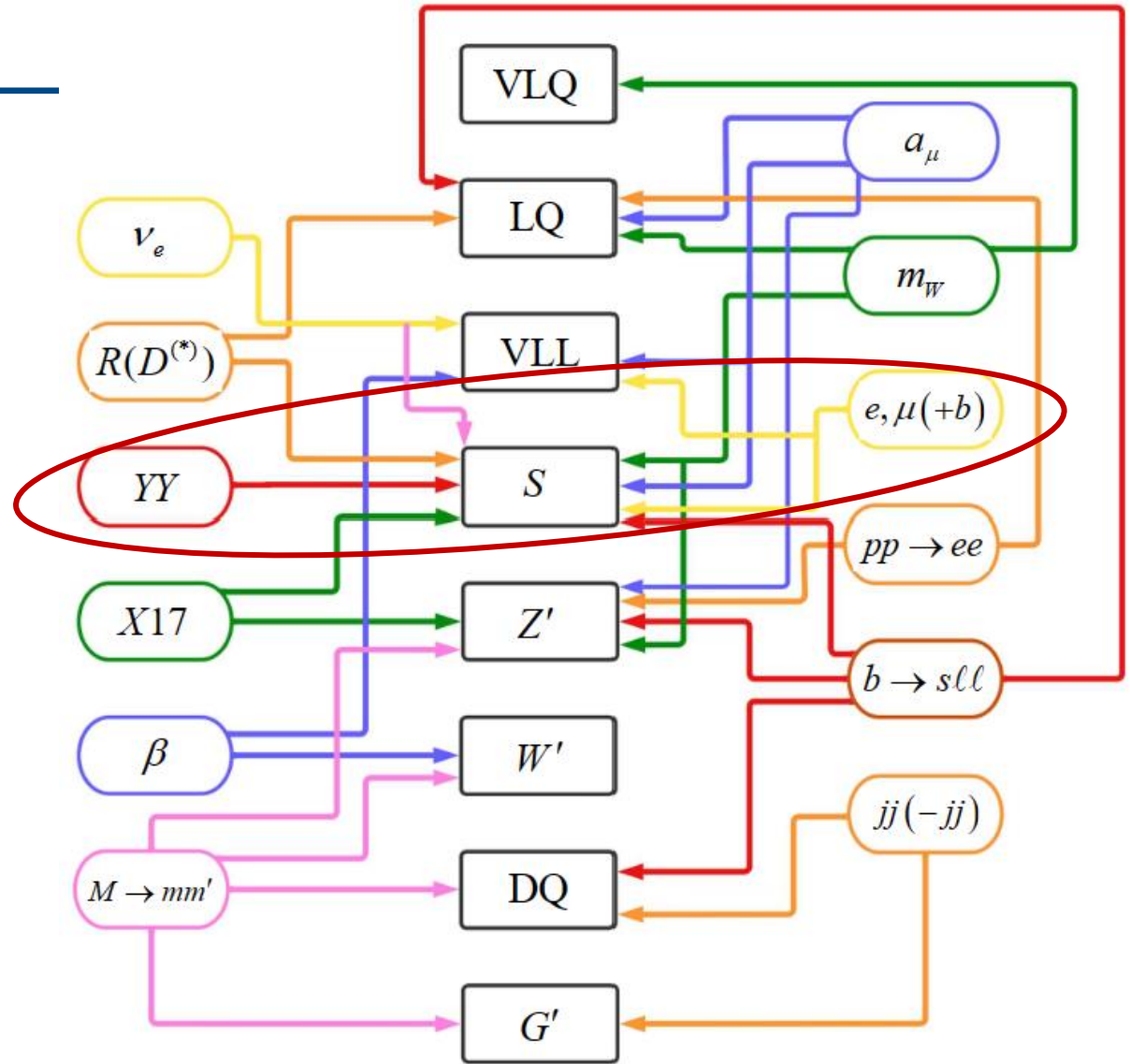
- Combination within the simplified model  
 $H \rightarrow SS^*$  with  $S \rightarrow WW, \text{MET}, \gamma\gamma$



>5 $\sigma$  global significance for simplified model

# Outlook

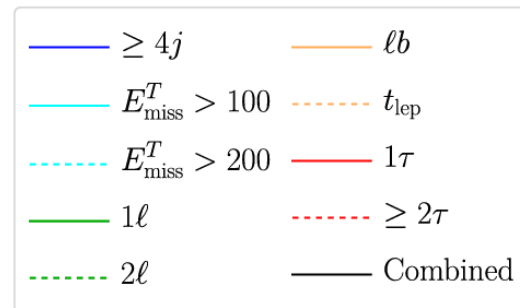
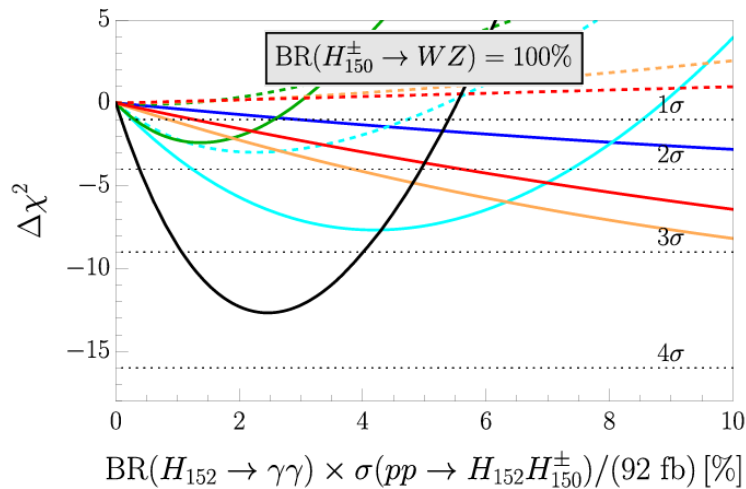
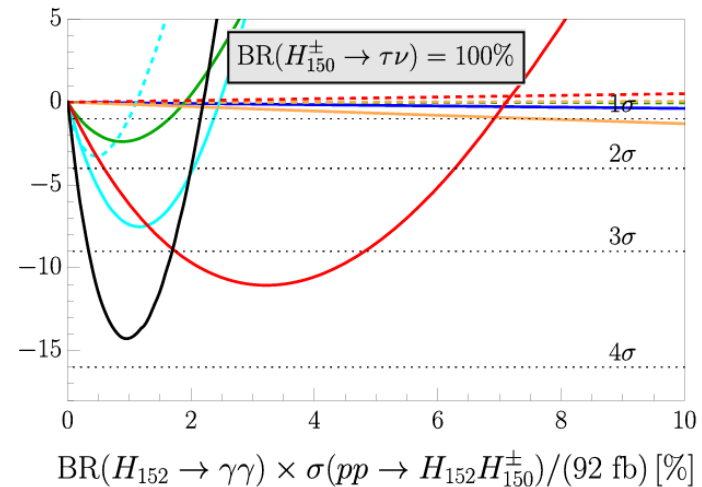
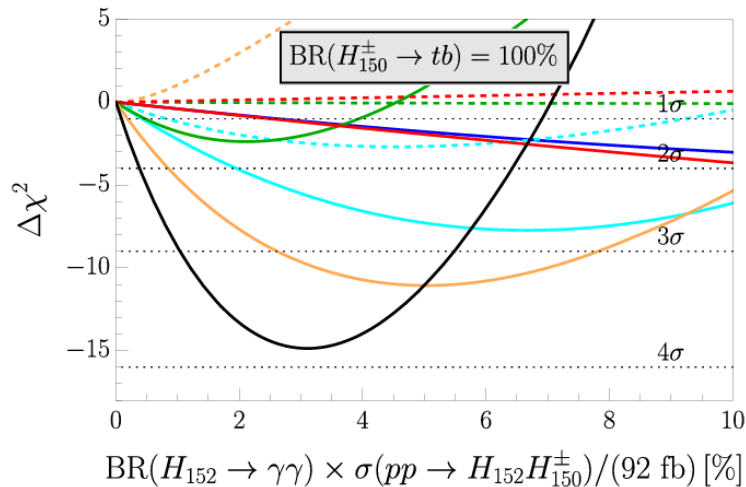
- Intriguing anomalies emerged in the last years which point towards new particles



The Standard Model is crumbling

# Simplified Model Analysis

S. Banik, AC, 2407.06267

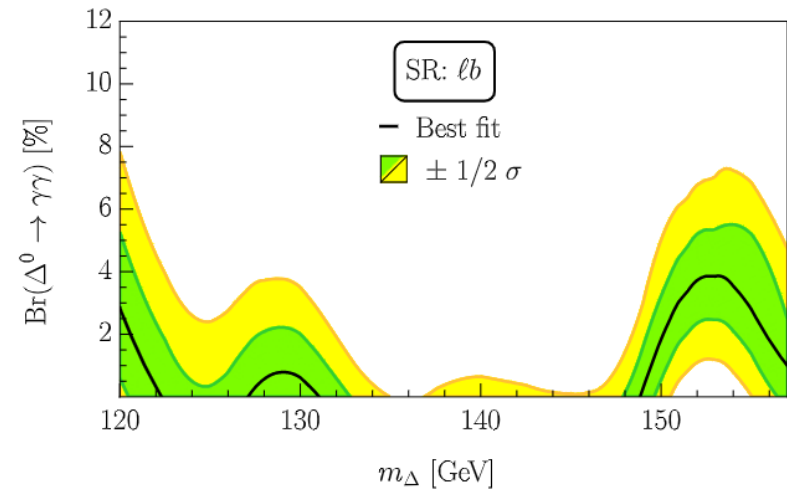
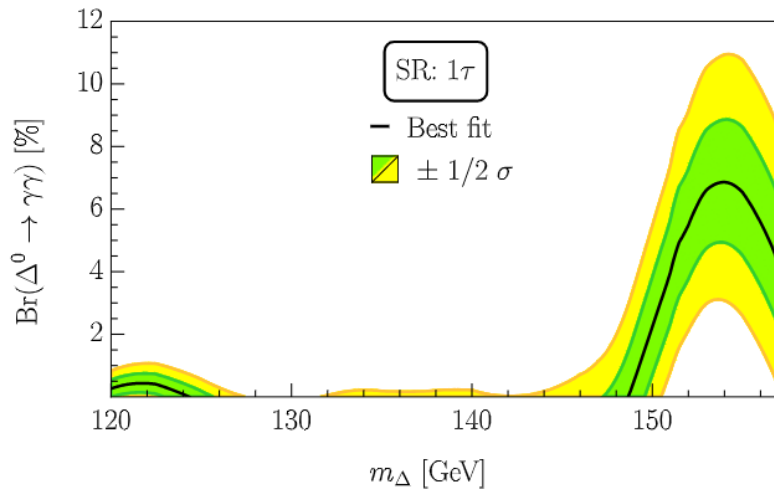
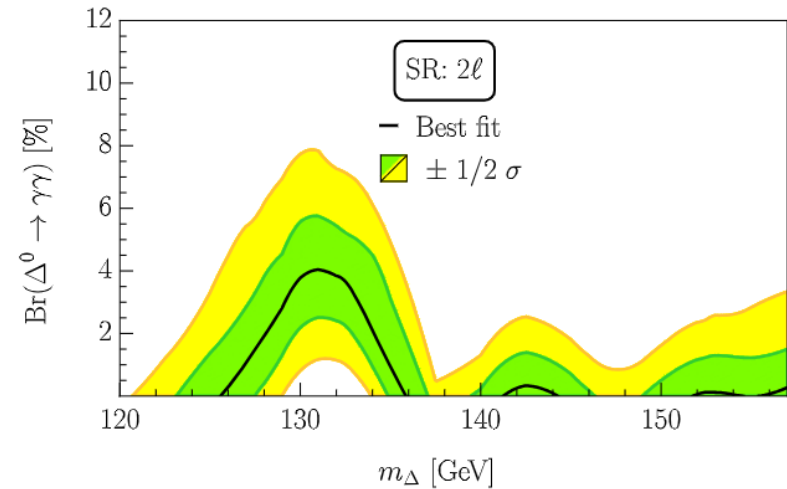
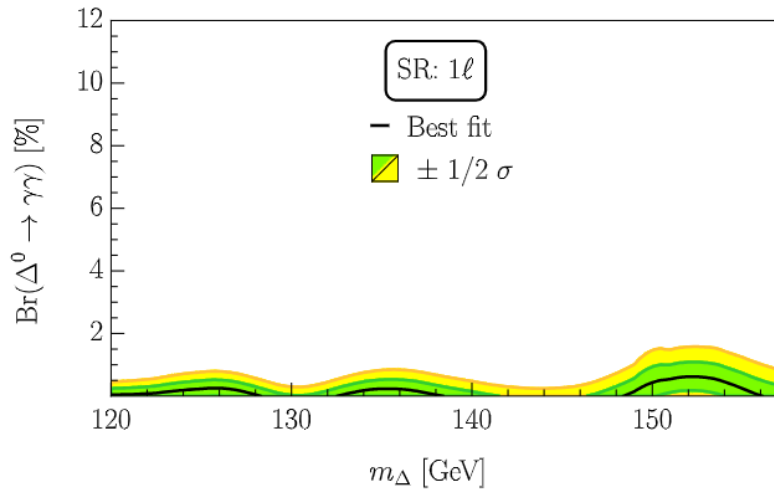


Triplet or Doublet?



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

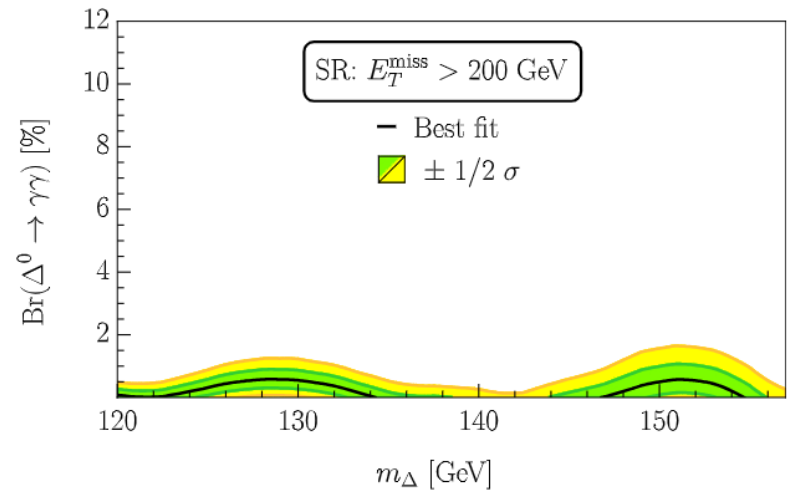
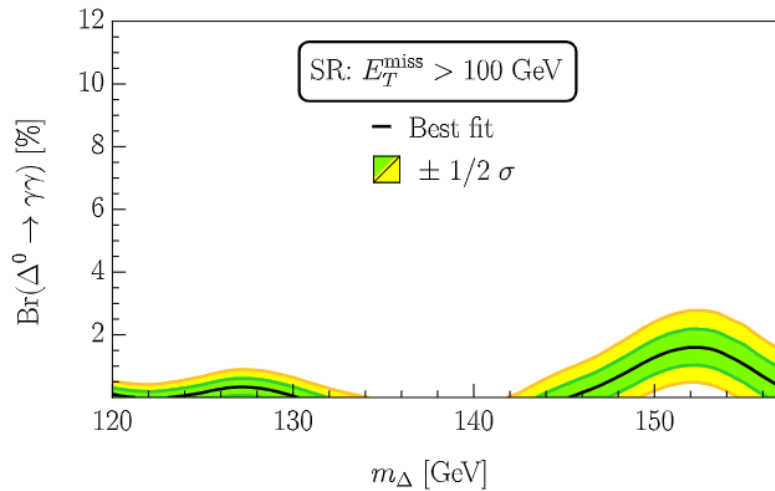
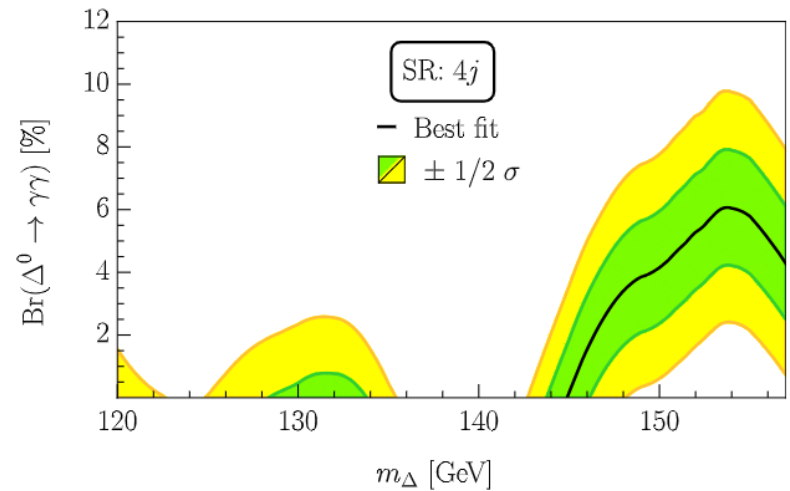
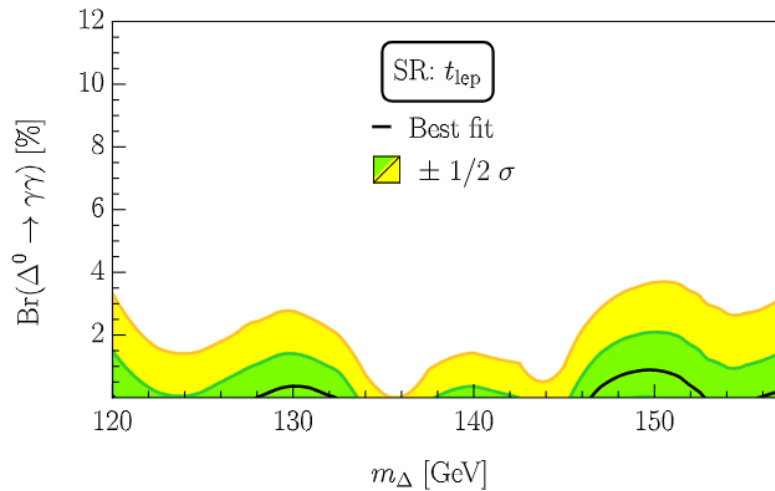
S. Ashanujjaman, S. Banik, G. Coloretti, A.C. S. P. Maharathy,  
B. Mellado, 2404.14492



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

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

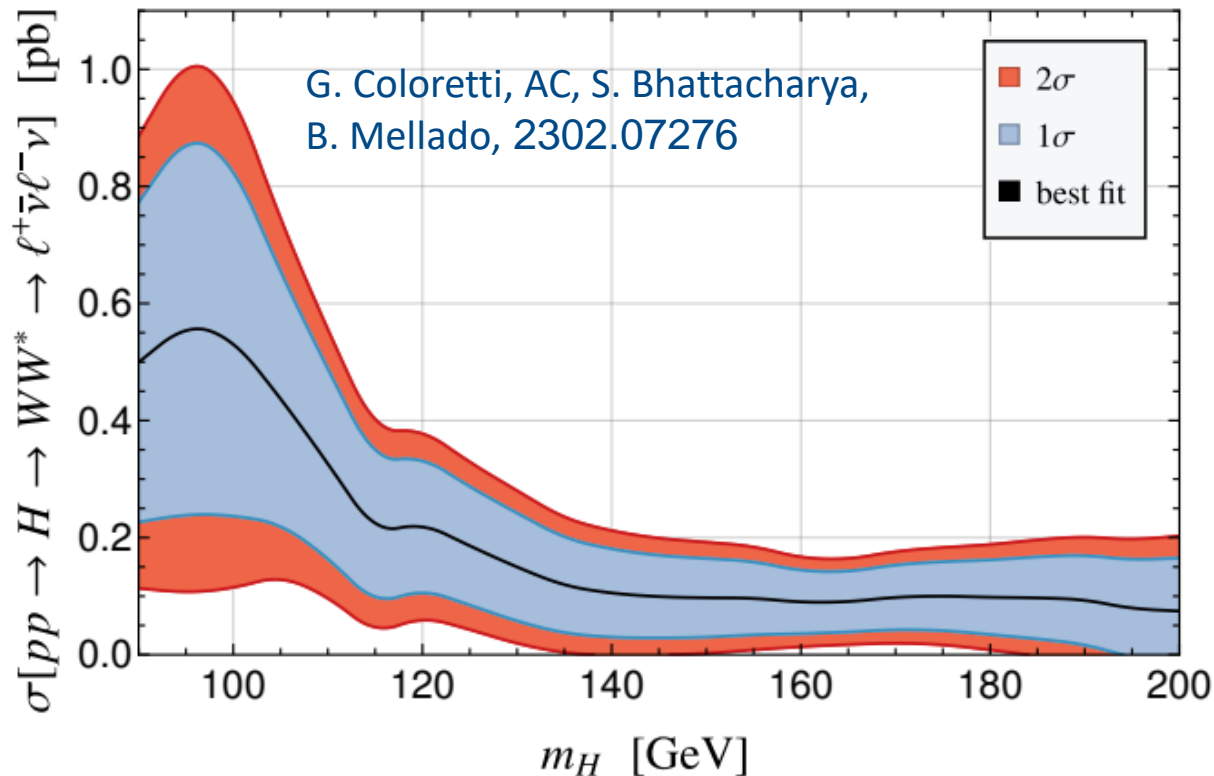
S. Ashanujjaman, S. Banik, G. Coloretti, A.C. S. P. Maharathy,  
B. Mellado, 2404.14492



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

# 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?