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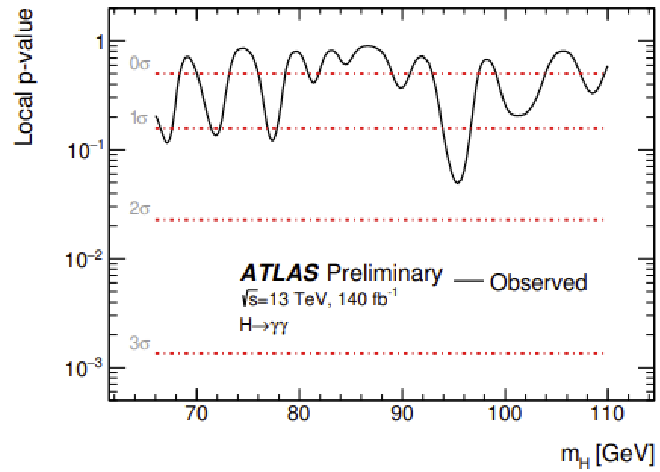
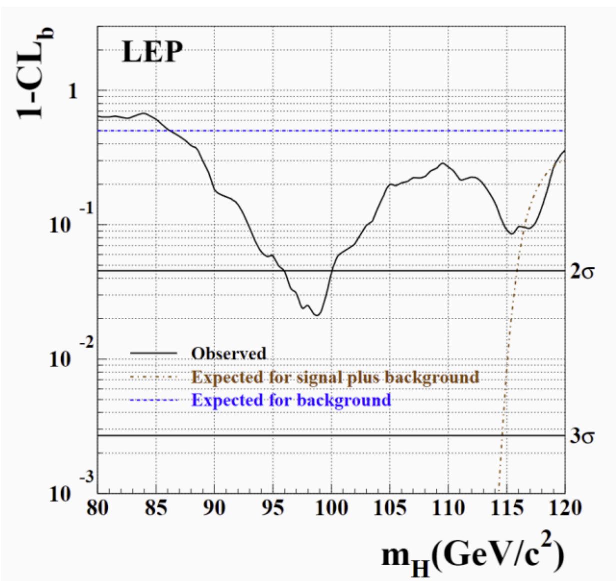
Anomalies pointing to new Higgses at the Electroweak Scale

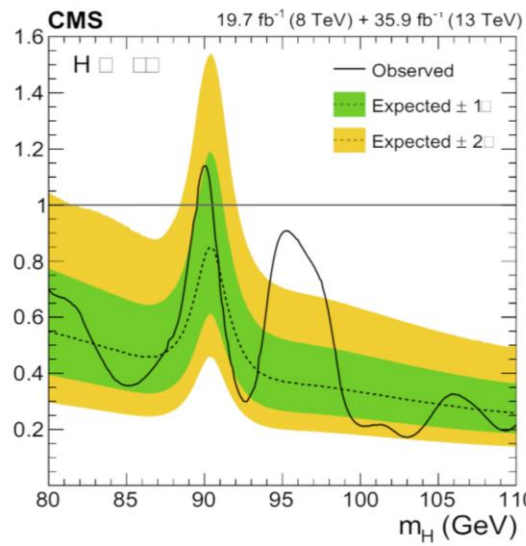
Taipei, 22.10.2024

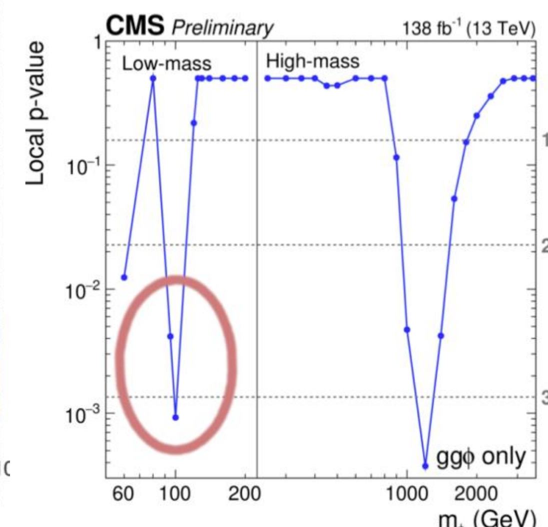
Hints for a 95 GeV Higgs

- LEP: Z+bb
- ATLAS & CMS: γγ
- CMS: ττ (no signal in ATLAS)
- 680⟶95+125







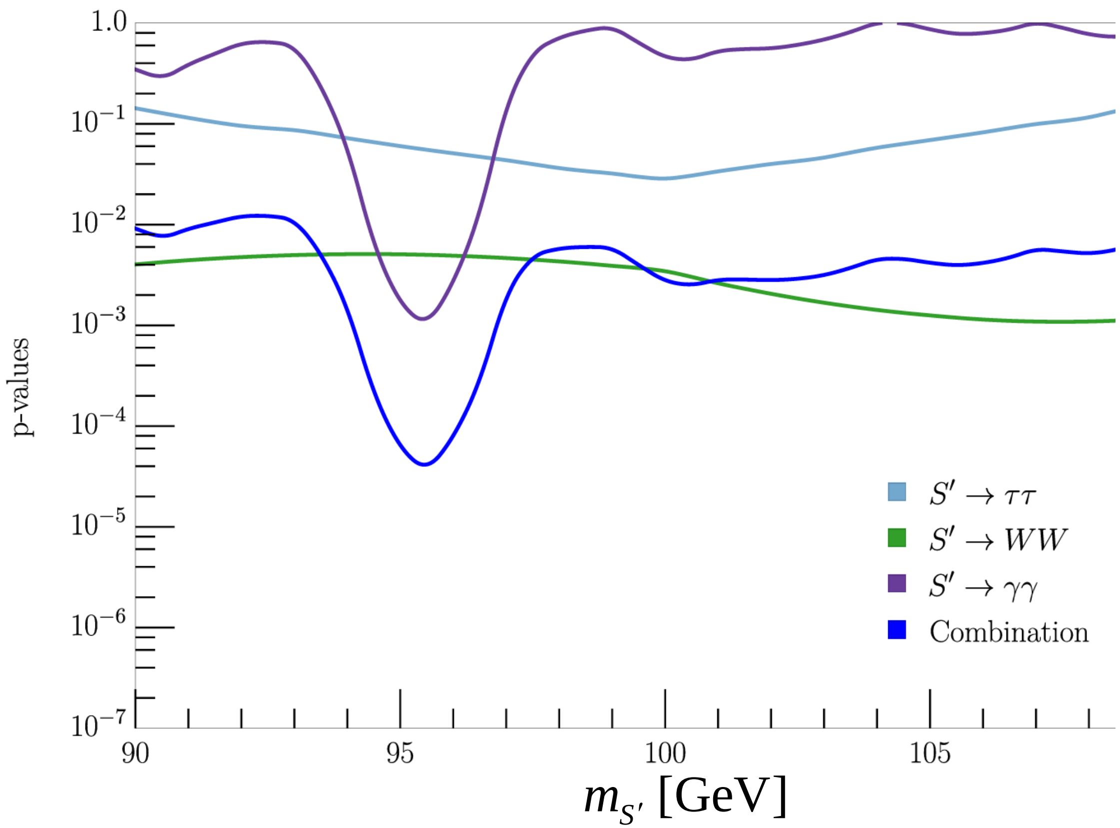


Multiple channels, no associated search

95 GeV Combination

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

- LEP used to reduce the LLE
- No ATLAS signal in ττ; reduced significance

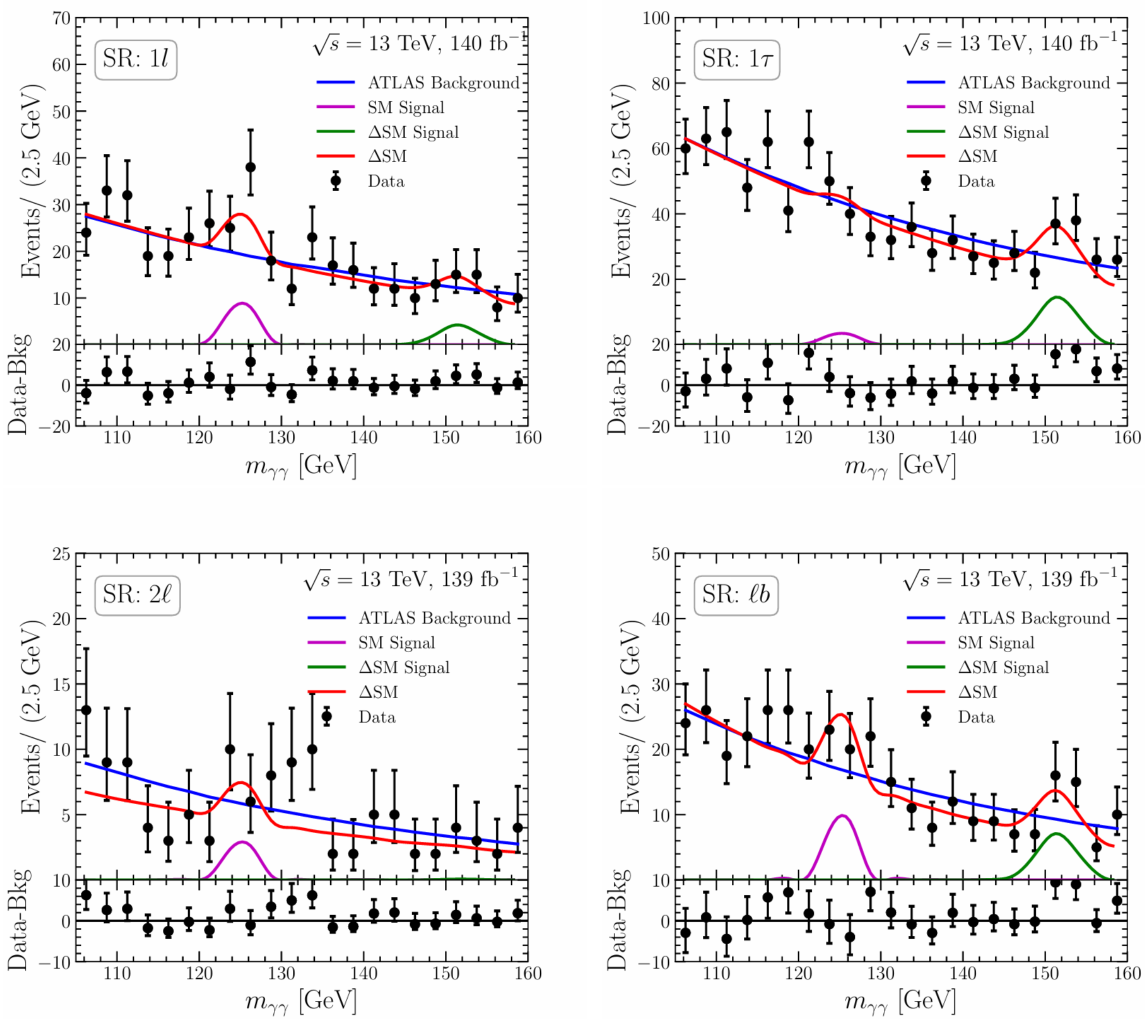


3.4σ global significance

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 γγ+X

Hints for a 152 GeV scalar

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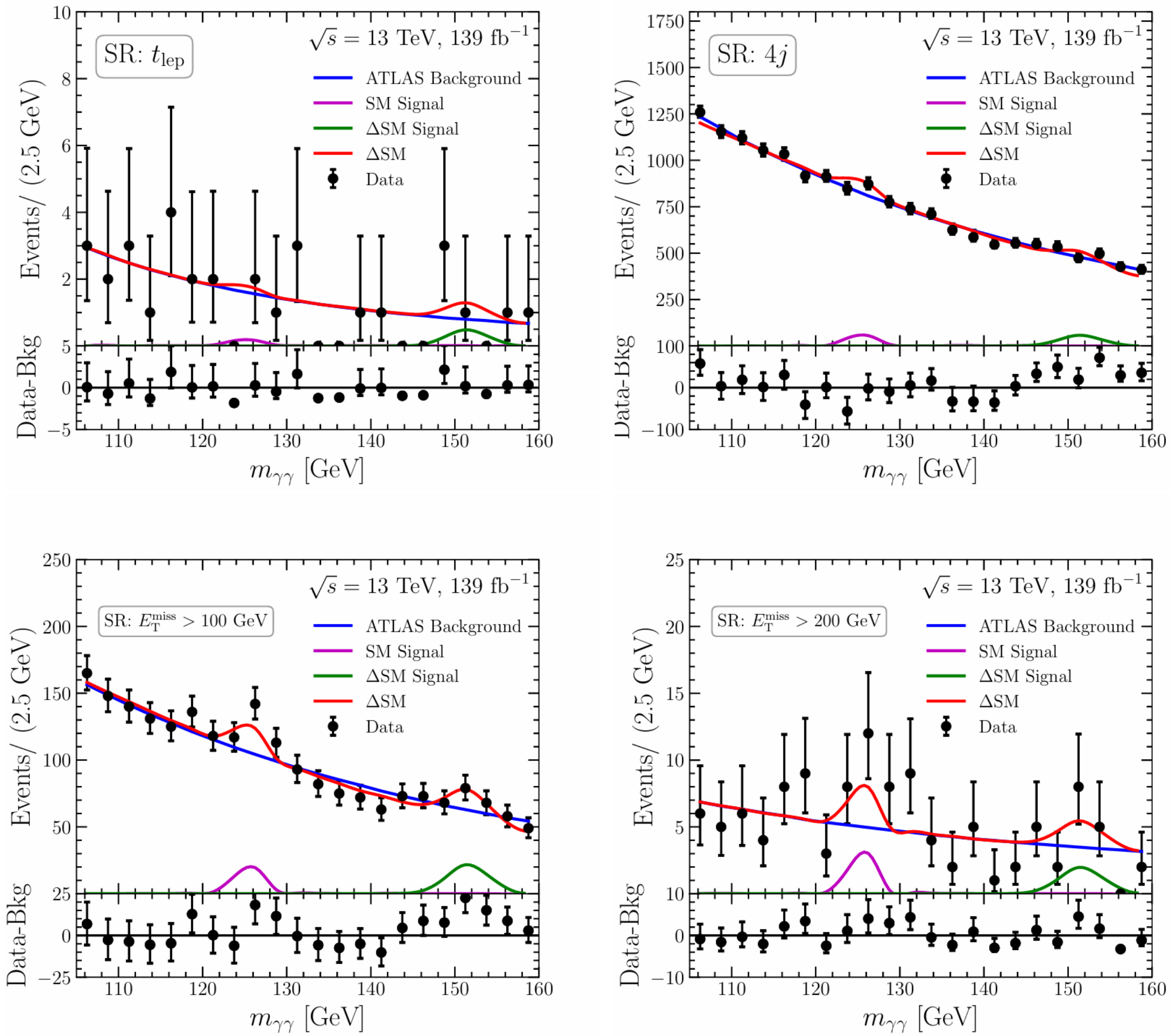
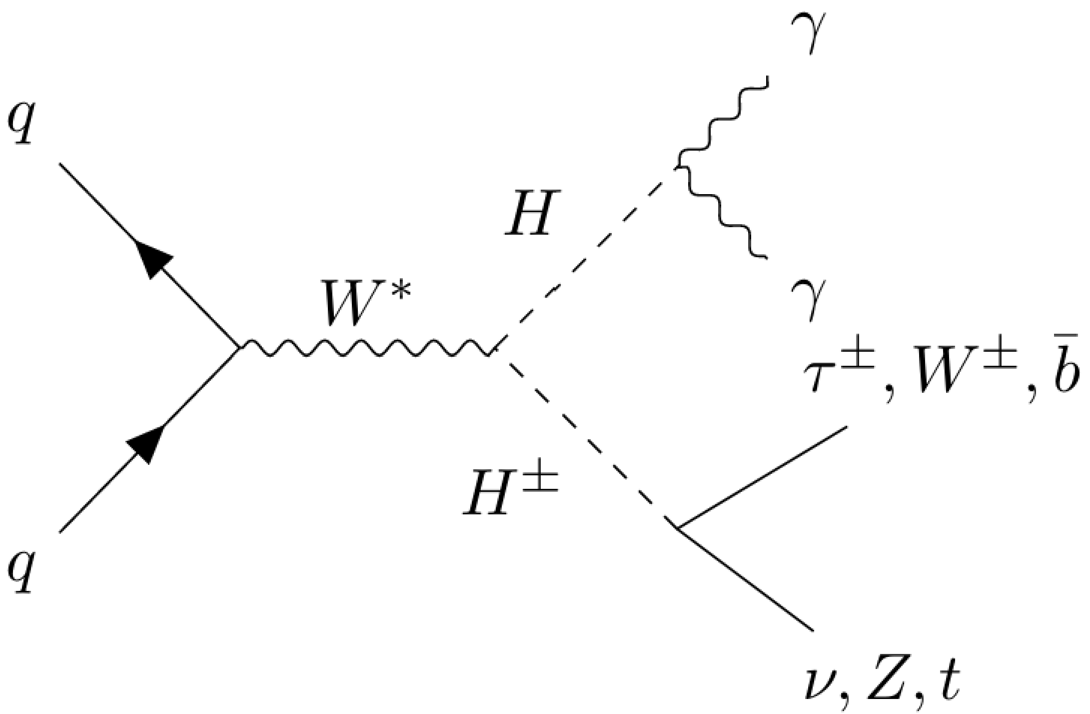


Dominant channels are γγ+X

Drell-Yan Production

Banik, AC, 2407.06267

- One leptons, but not two leptons
- One tau but not two taus
- lb but not t_{lep}
- Moderate MET

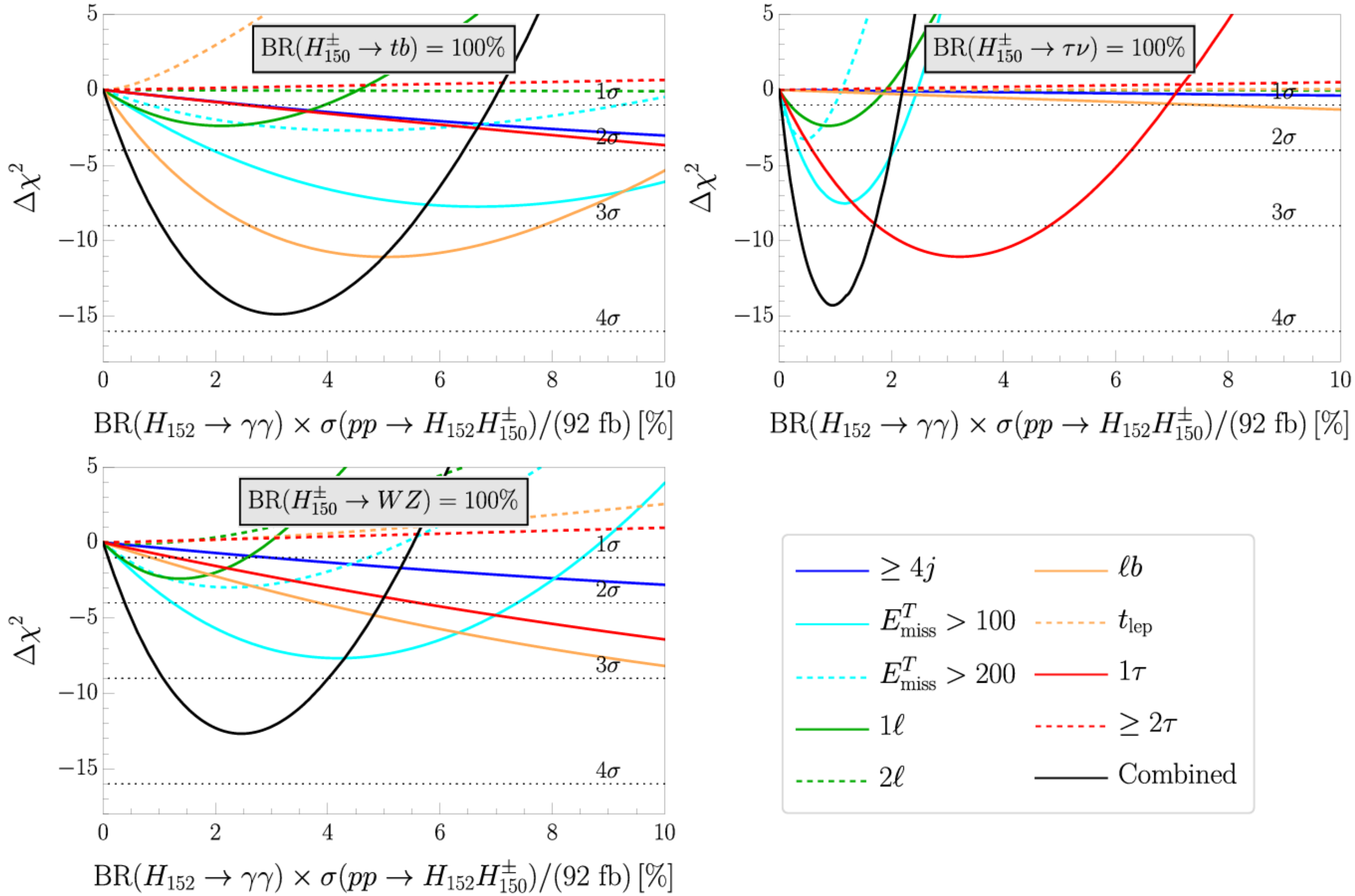


- DY production of charged and neutral Higgs

New Scalar with non-trivial SU(2) representation

Simplifed Model Analysis

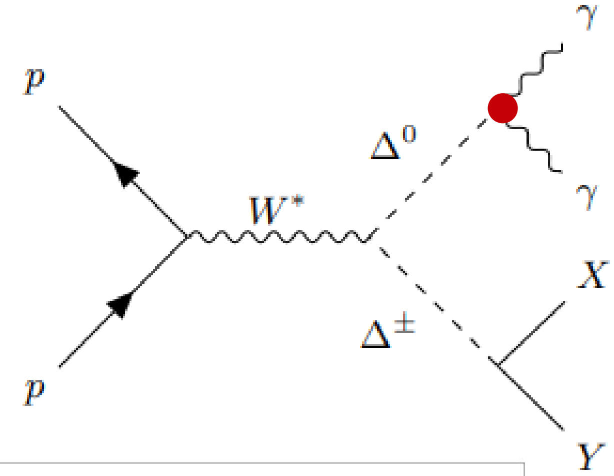
S. Banik, AC, 2407.06267

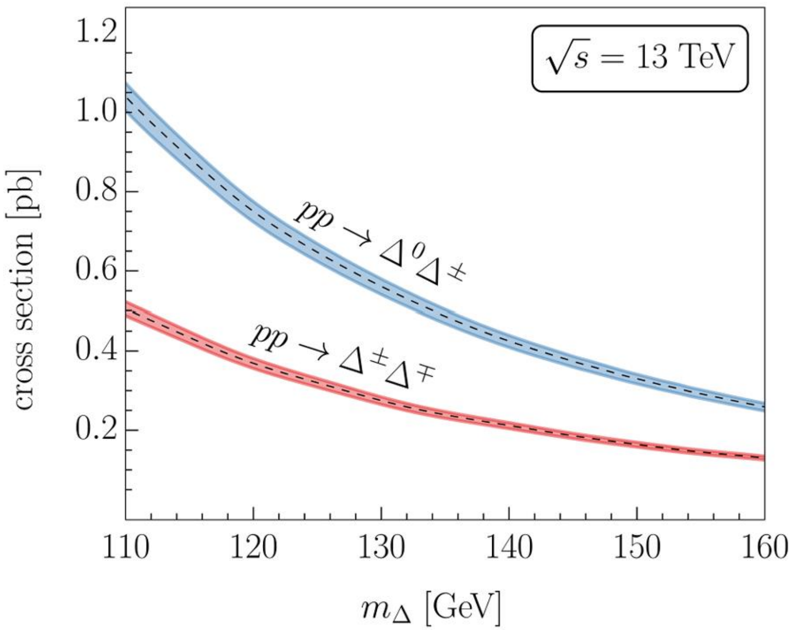


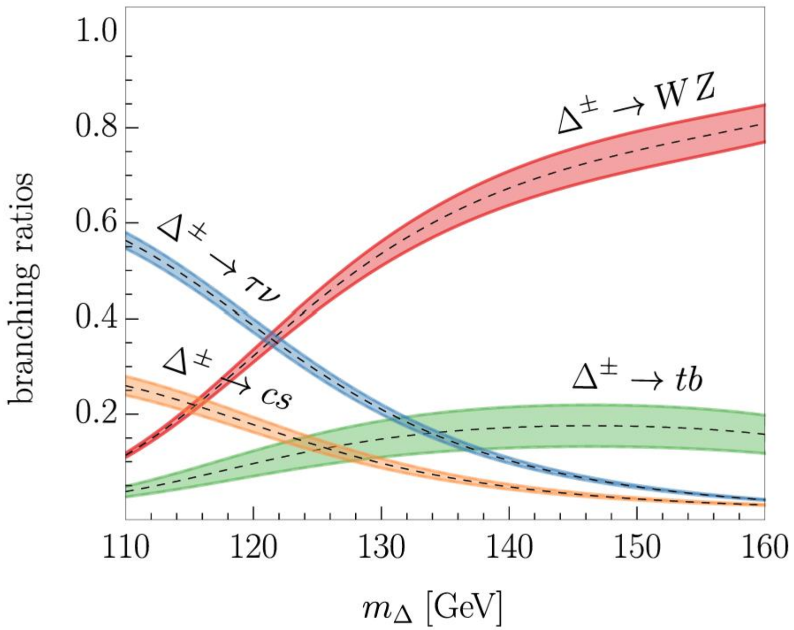
Triplet or Doublet?

Is the 152 GeV Higgs a Triplet (Δ)?

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



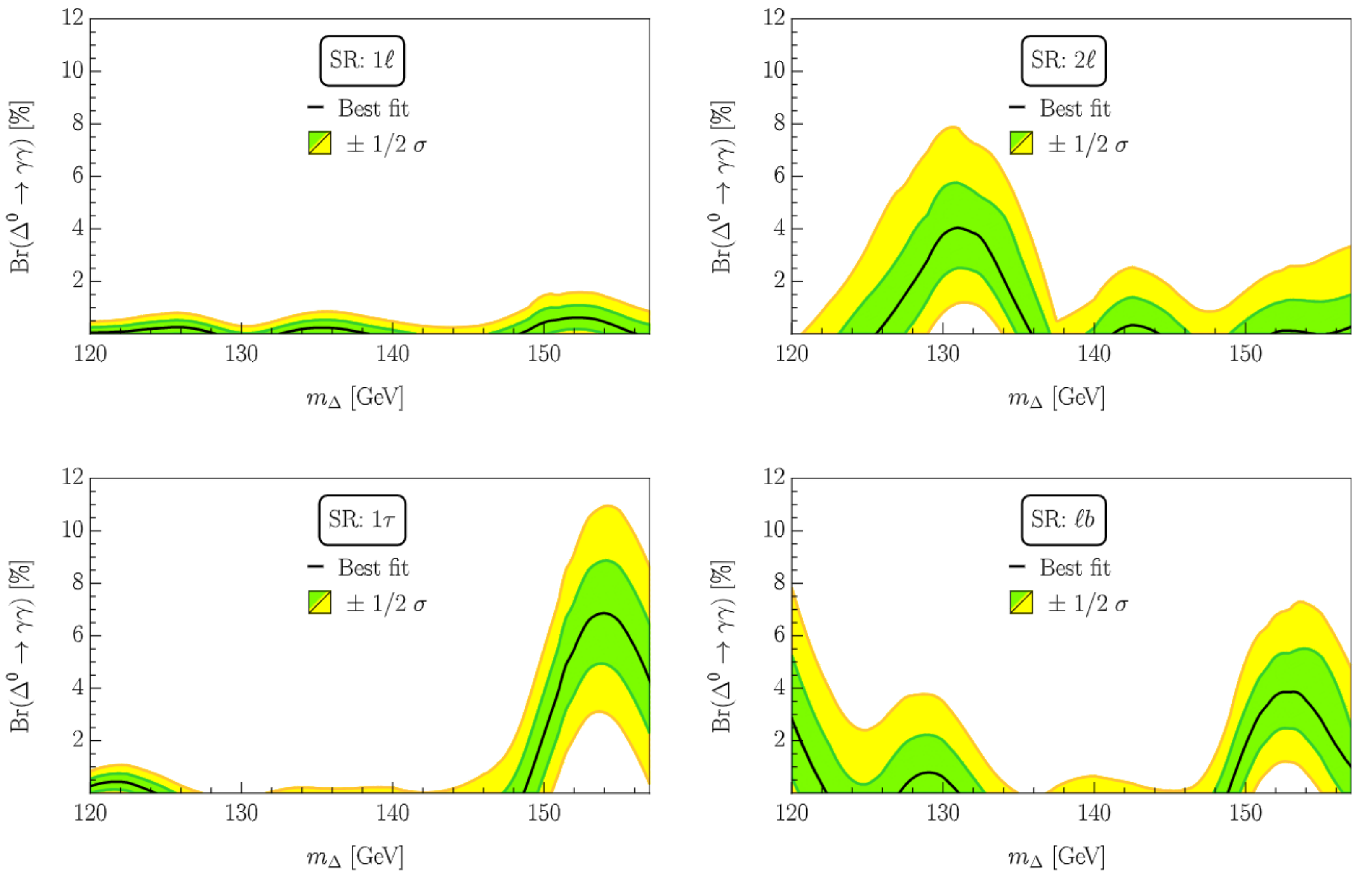




Drell-Yan production at the LHC

h→γγ+X from ATLAS

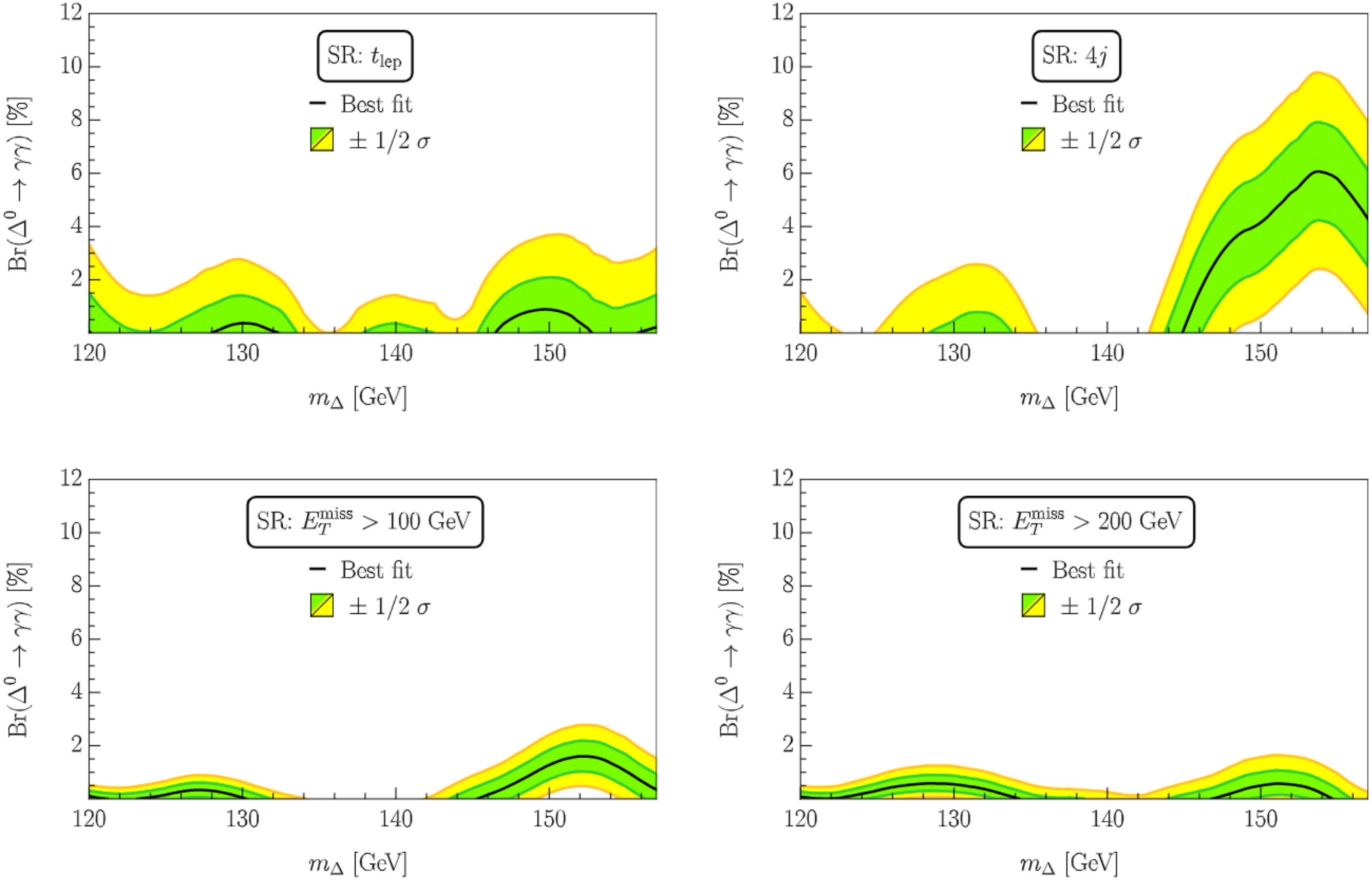
S. Ashanujjaman, S. Banik, G. Coloretti, A.C. S. P. Maharathy, B. Mellado, 2404.14492



Triplet consistently explains h→γγ+X excesses

h→γγ+X Channels

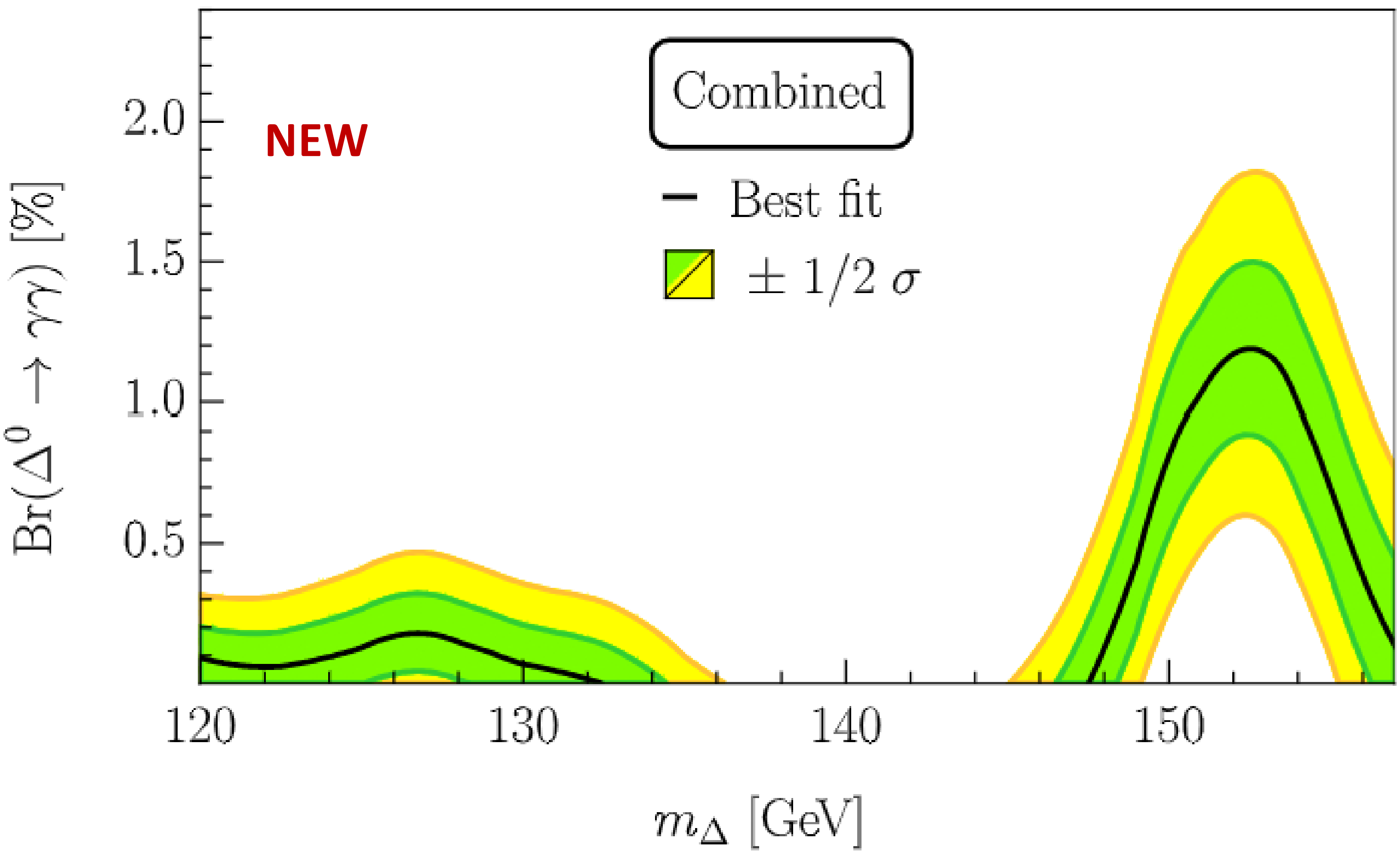
S. Ashanujjaman, S. Banik, G. Coloretti, A.C. S. P. Maharathy,
B. Mellado, 2404.14492



Triplet consistently explains h→γγ+X excesses

Combination

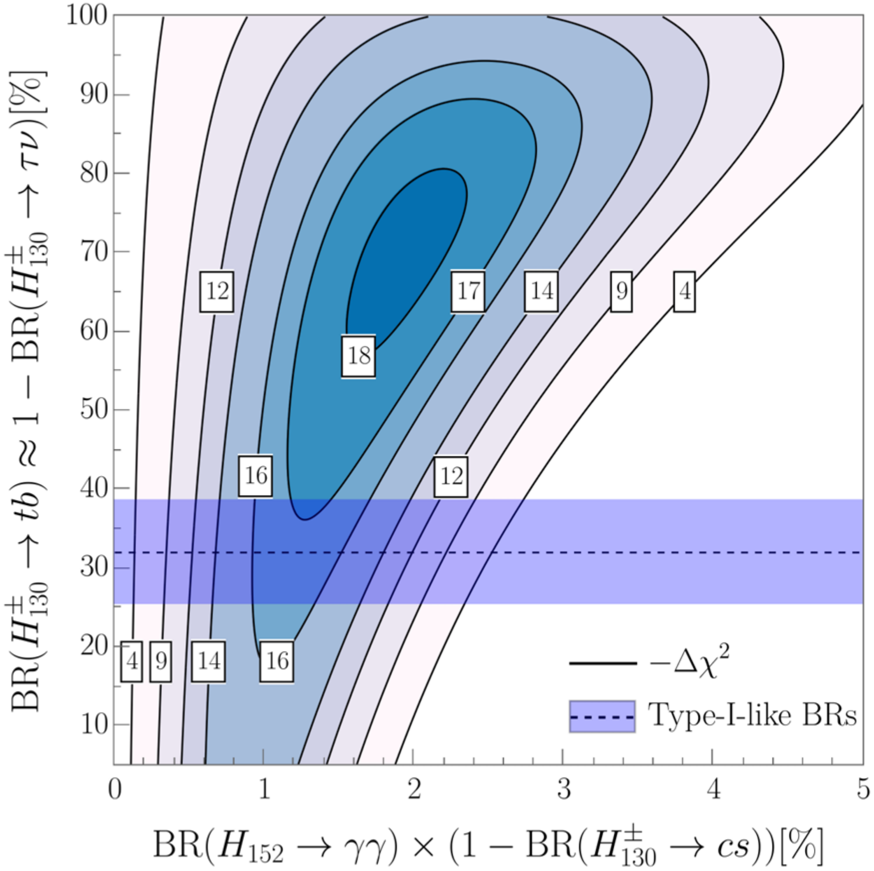
S. Ashanujjaman, S. Banik, G. Coloretti, A.C. S. P. Maharathy, B. Mellado, 2404.14492

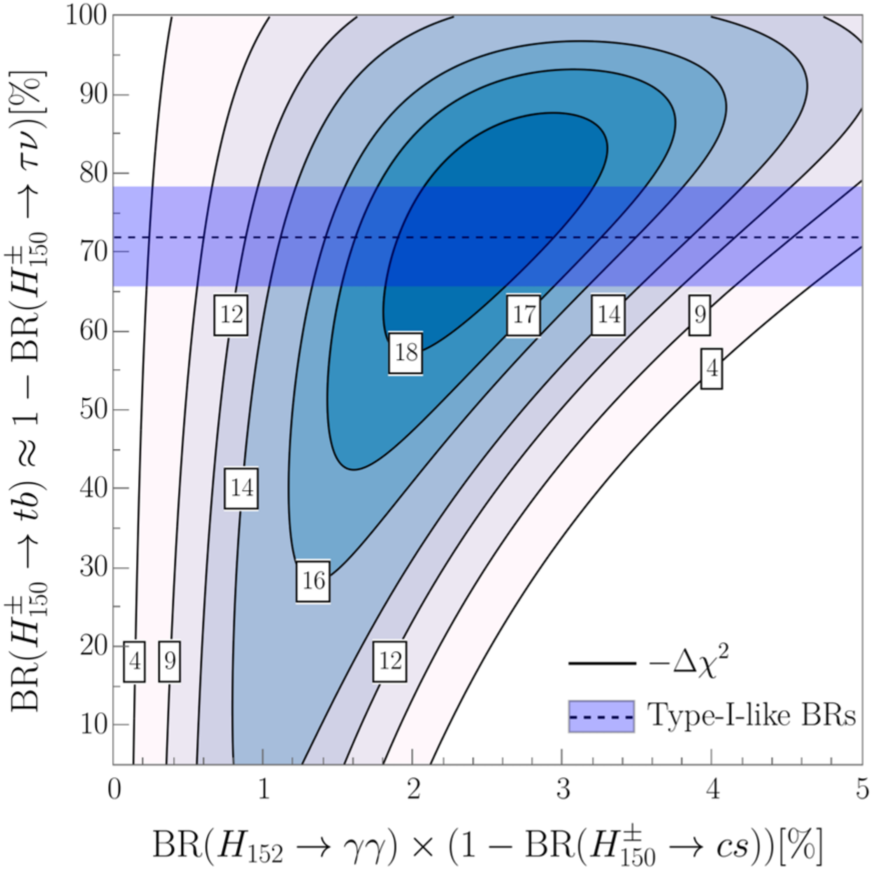


≈4σ excess at 152GeV

Two-Higgs Doublet Model type-I

- $\mathrm{Br}\left(H^{\pm} \to WZ\right) = 0$ (at tree-level)



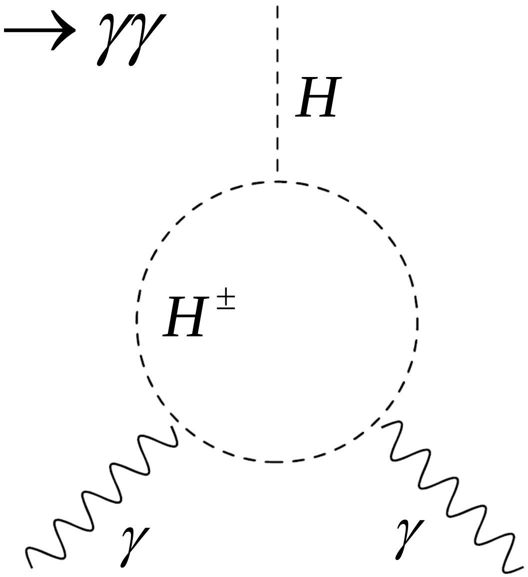


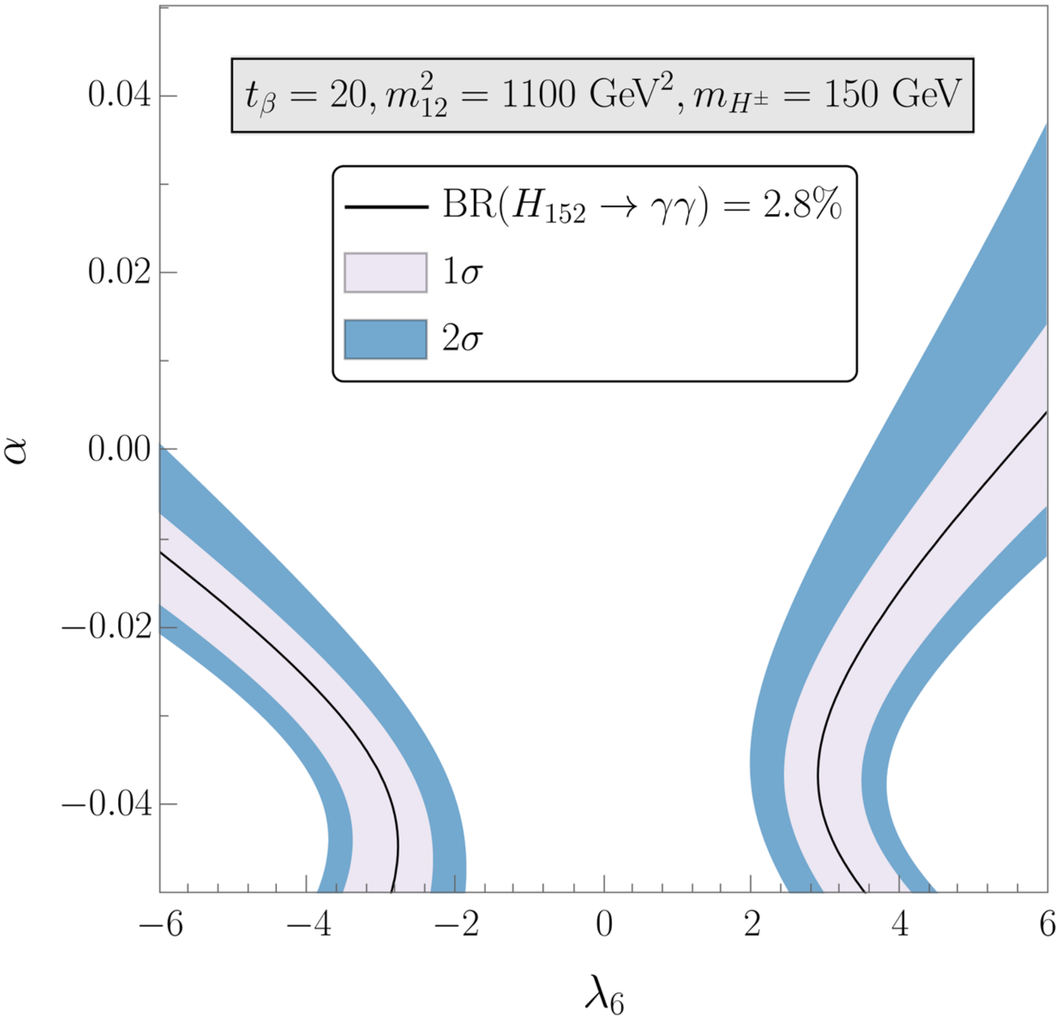
Above 4σ, large Br needed

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

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

- Dominant effect in $H \to \gamma\gamma$ but suppressed in $h \to \gamma\gamma$





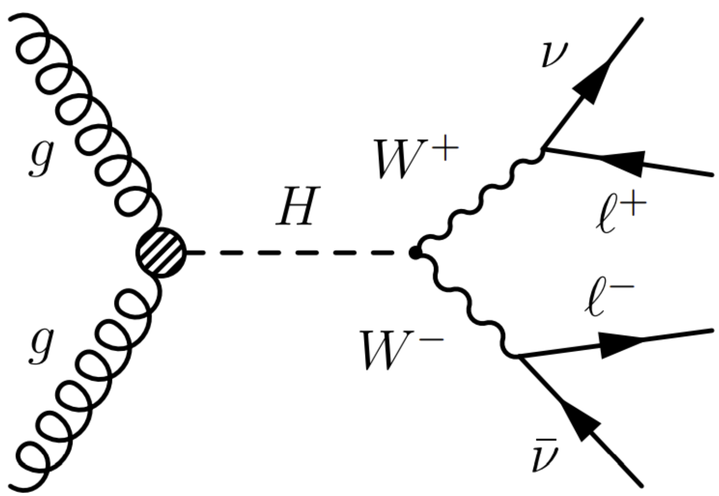
Consistent with vacuum stability, perturbativity

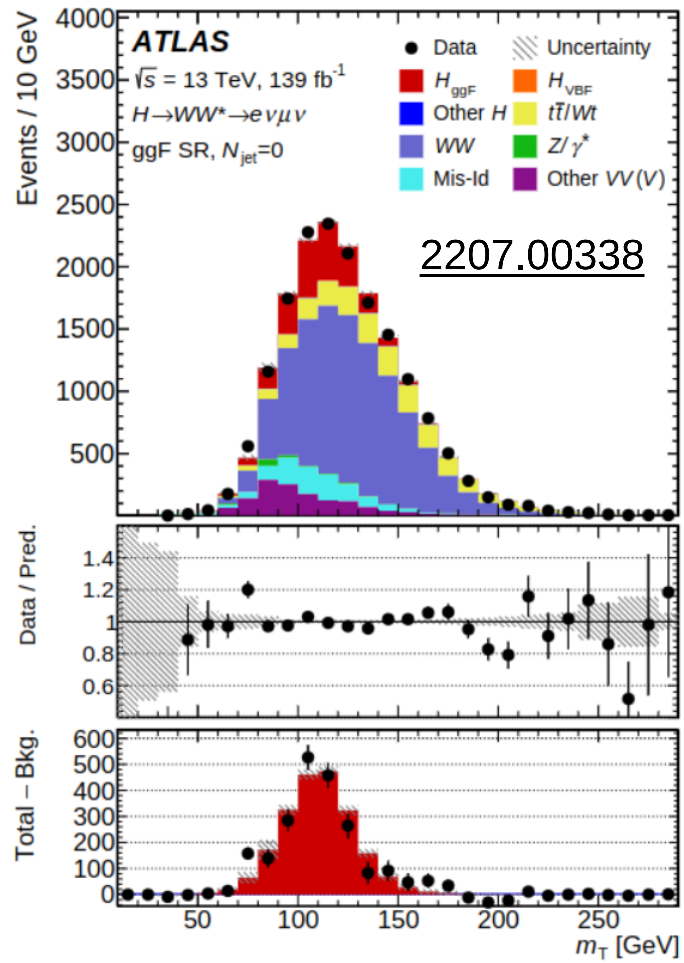
Multi-lepton anomalies

Dominant SM process(es)	Experimental signature	New Physics contamination
$WW, h\to WW$	$e^\pm\mu^\mp + \not{E}_T$	$H\to WW, H\to SS'\to WW+\text{MET}$ $H\to(N\to W\ell)\nu$
tt, tW	$e^\pm\mu^\mp + \geq 1b$	$H\to SS'\to WWbb, A\to W(H\to tb)$ $T\bar{T}\to bb(H^+\to t\bar{b})(H^-\to \bar{t}b)$
$ttW, tttt$	$\ell^\pm\ell^\pm, 3\ell+\geq 1b$	$A\to W(H^\pm\to tb), tt(H\to tt)$ $A\to Z^*(H\to tt), tt(H\to WW)$
$3W, W(h\to WW)$	$\ell^\pm\ell^\pm, 3\ell+\not{E}_T$	$A\to Z^*(H\to WW)$ $NN\to WW\ell\ell,\ W(H\to WW)$
ZW	$(Z\to\ell\ell)+\ell+\not{E}_T$	$A\to Z(H\to WW)$ $NN\to Z\nu W\ell$

Low mass WW searches

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



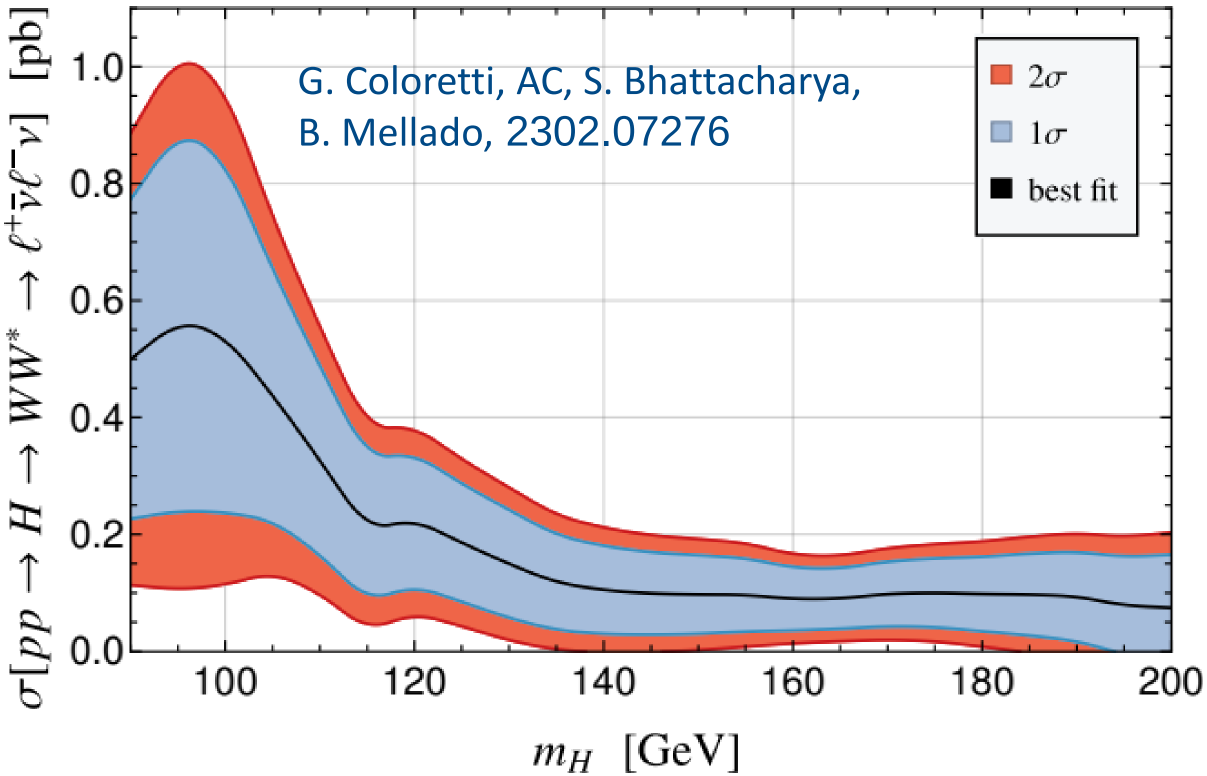


SM Higgs rescaled by 1.21

Room for NP

Low mass WW resonances searches

- ATLAS and CMS combination

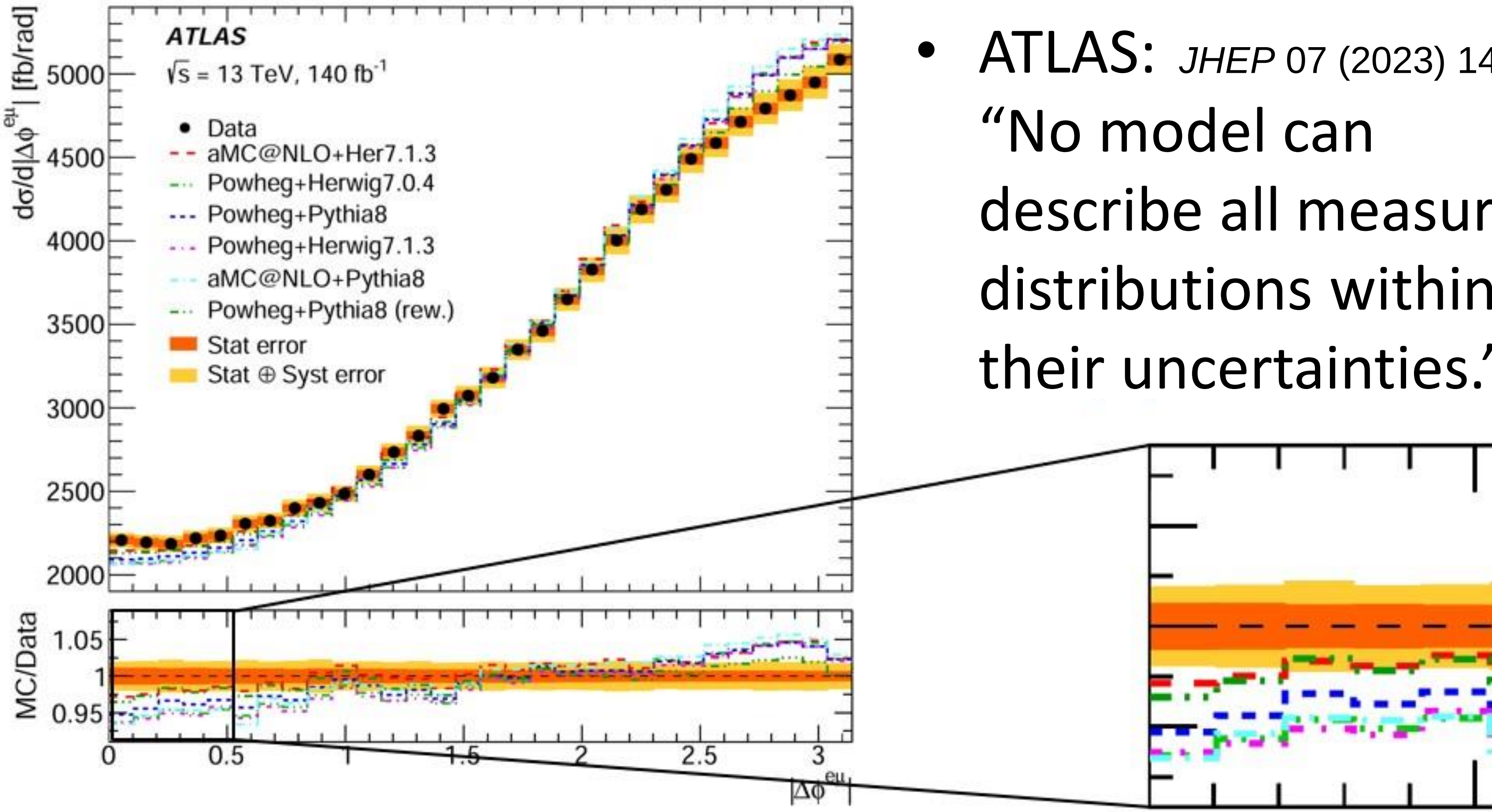


Transverse mass sensitive to additional missing energy from associated production

- New physics effect preferred over the whole range

Related to 95GeV and 151GeV?

Differential Top-Quark Distributions

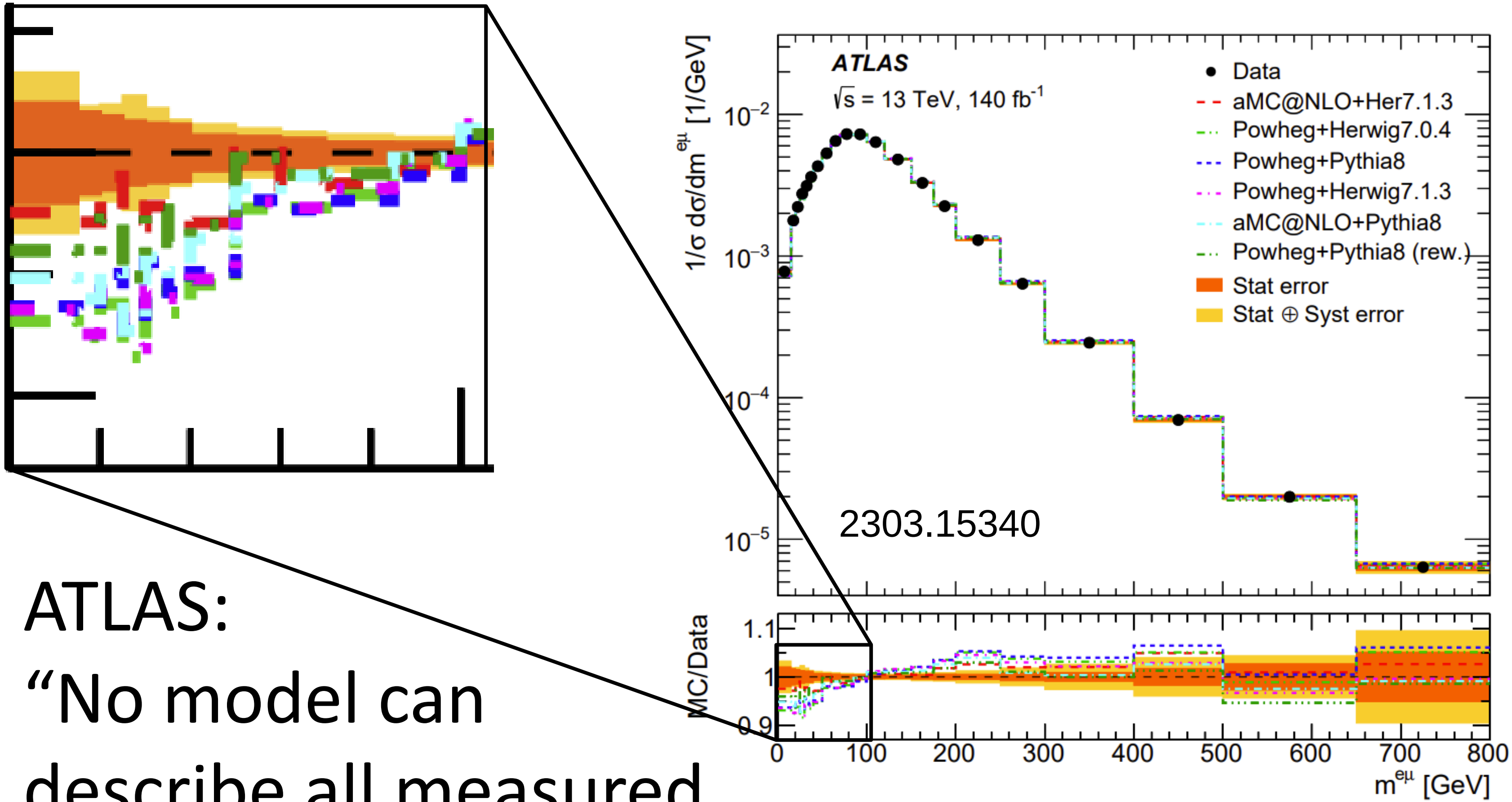


- ATLAS: *JHEP* 07 (2023) 141
  "No model can describe all measured distributions within their uncertainties."

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

New Physics pollution of this SM measurement?

Differential Top-Quark Distributions

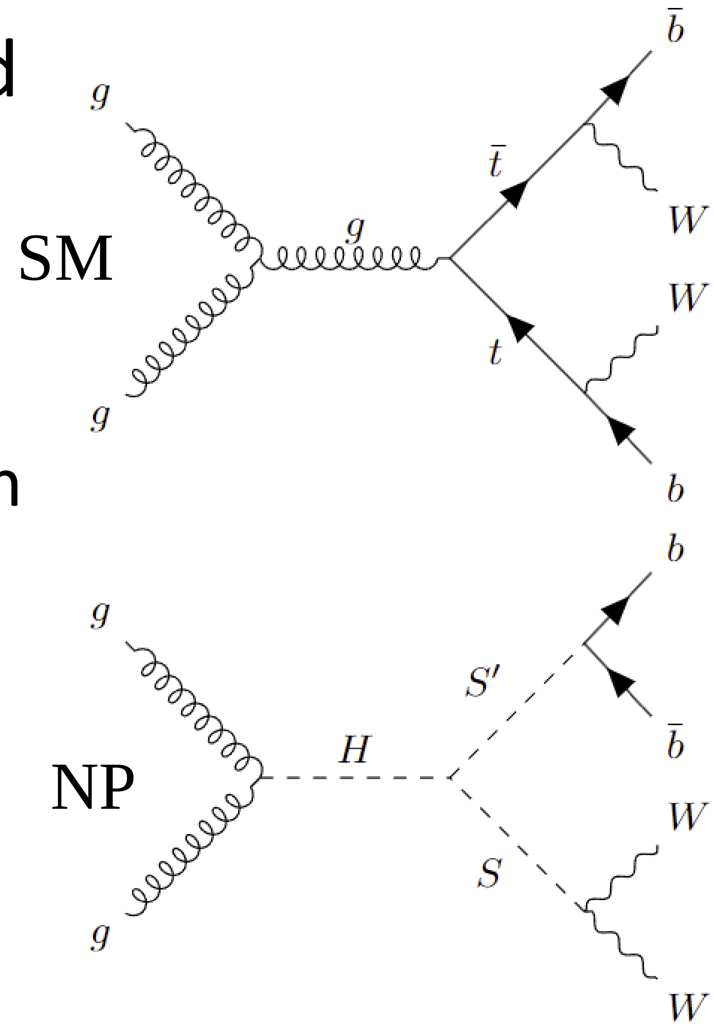


- ATLAS:
  "No model can describe all measured distributions within their uncertainties."

New Physics pollution of this SM measurement?

New Physics in Top-Quark Distributions

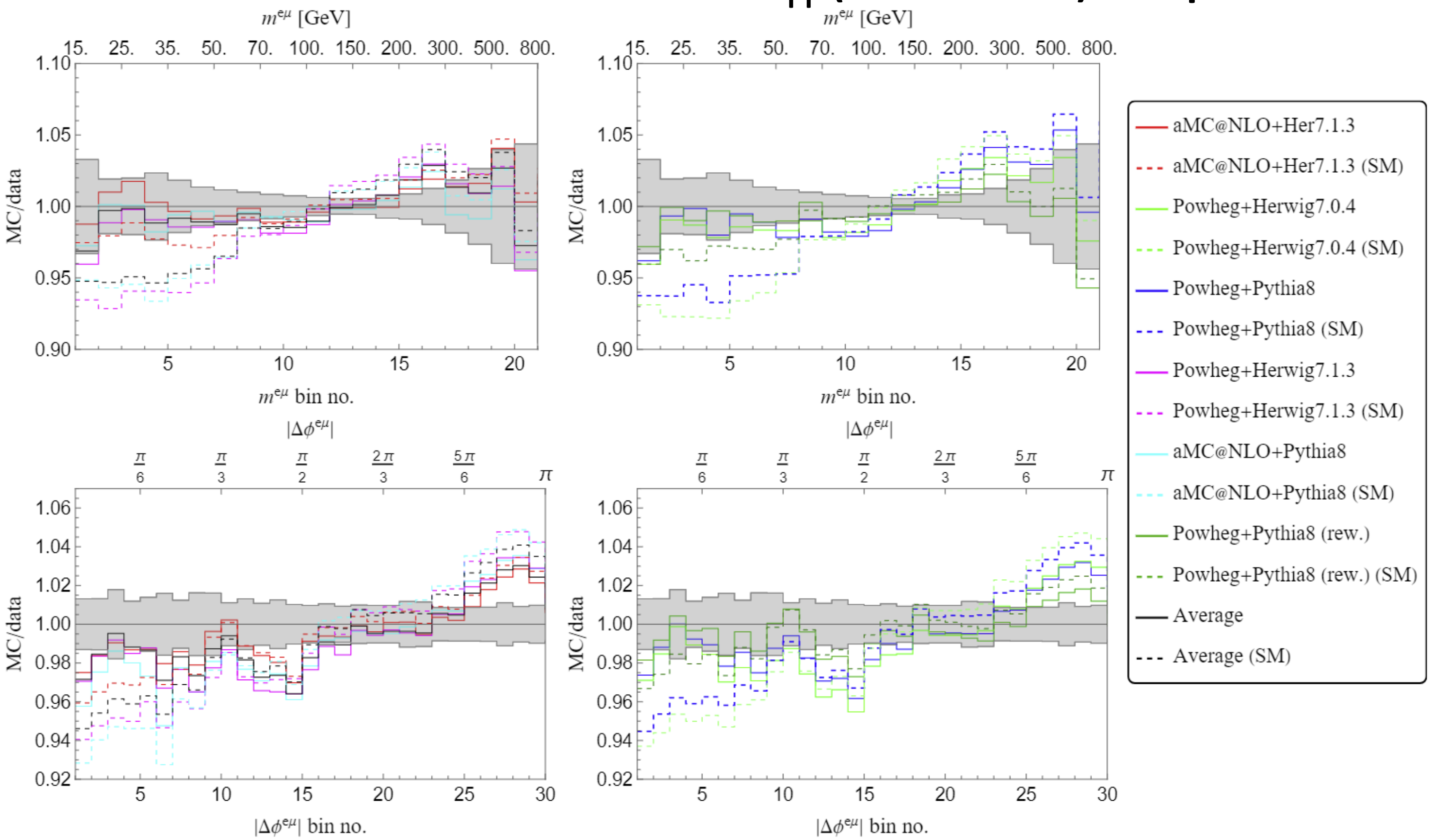
- ATLAS analysis normalized to the total cross section
  - only sensitive to the shape of NP
  - NP at small angels can explain deficit at large angles
- Associated production of new scalars decaying to WW and bb has a top-like signature



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

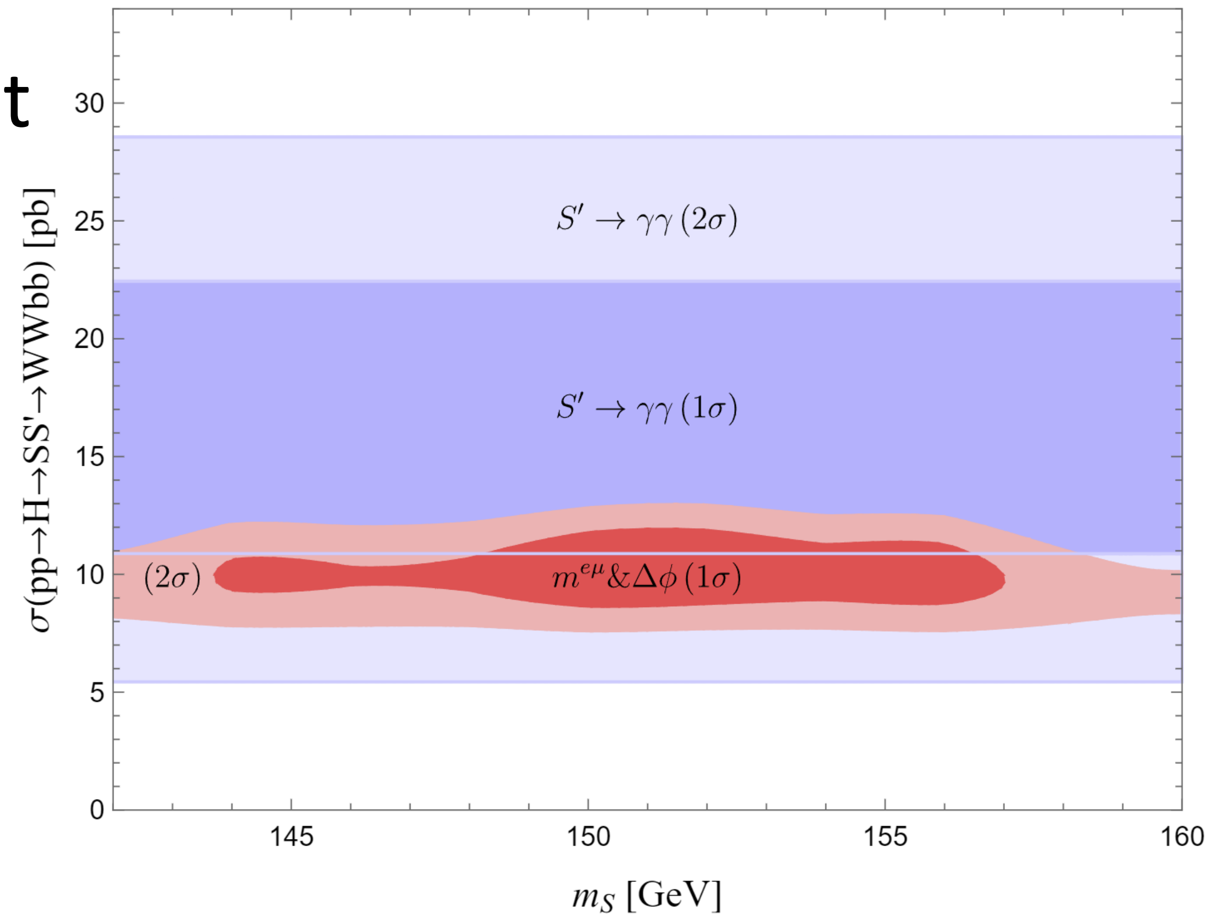
Monte Carlo	χ^2_{SM}	χ^2_{NP}	σ_{NP}	Sig.	m_S[GeV]
Powheg+Pyhtia8	213	102	9pb	10.5σ	$143-156$
aMC@NLO+Herwig7.1.3	102	68	5pb	5.8σ	$--$
aMC@NLO+Pythia8	291	163	10pb	11.3σ	148-157
Powheg+Herwig7.1.3	261	126	10pb	11.6σ	149-156
Powheg+Pythia8 (rew)	69	35	5pb	5.8σ	$--$
Powheg+Herwig7.0.4	294	126	12pb	13.0σ	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 152 GeV?

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

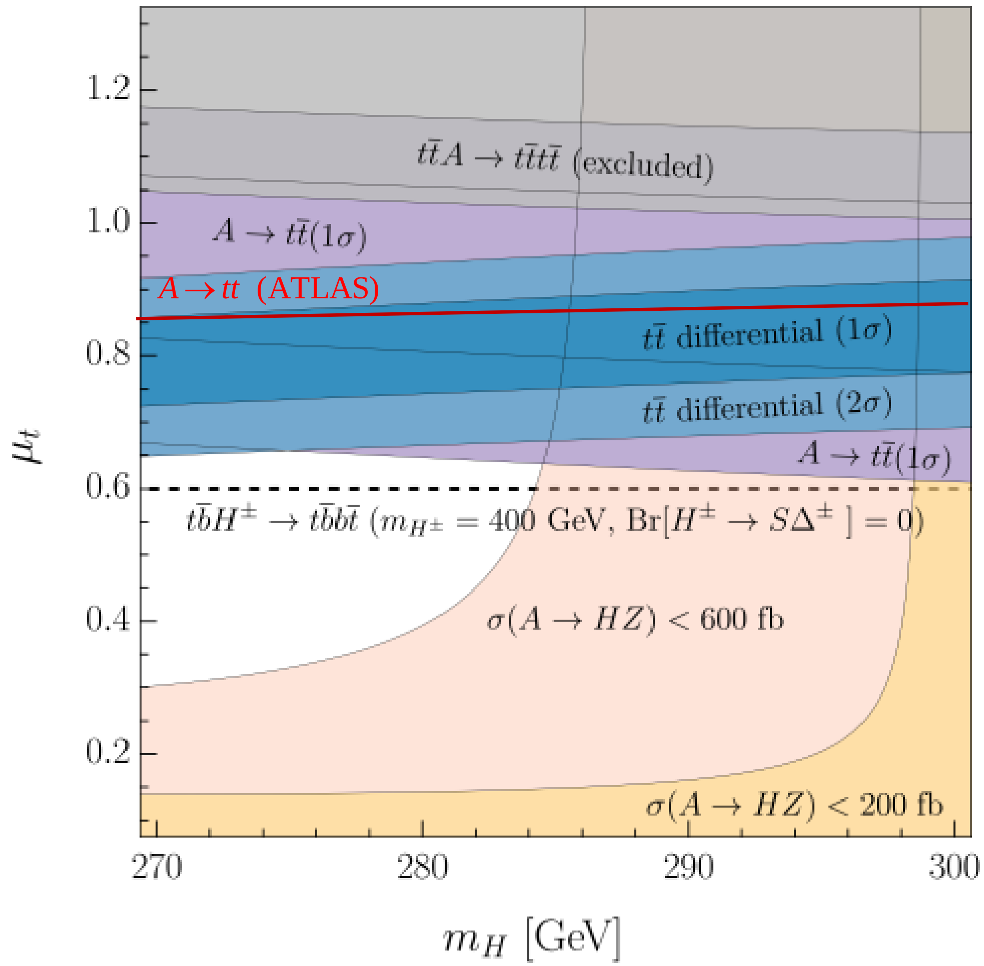


Consistent with 95 GeV γγ signal strength & a mass of S with 151.5 GeV

Δ2HDMS and top-quark production

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

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



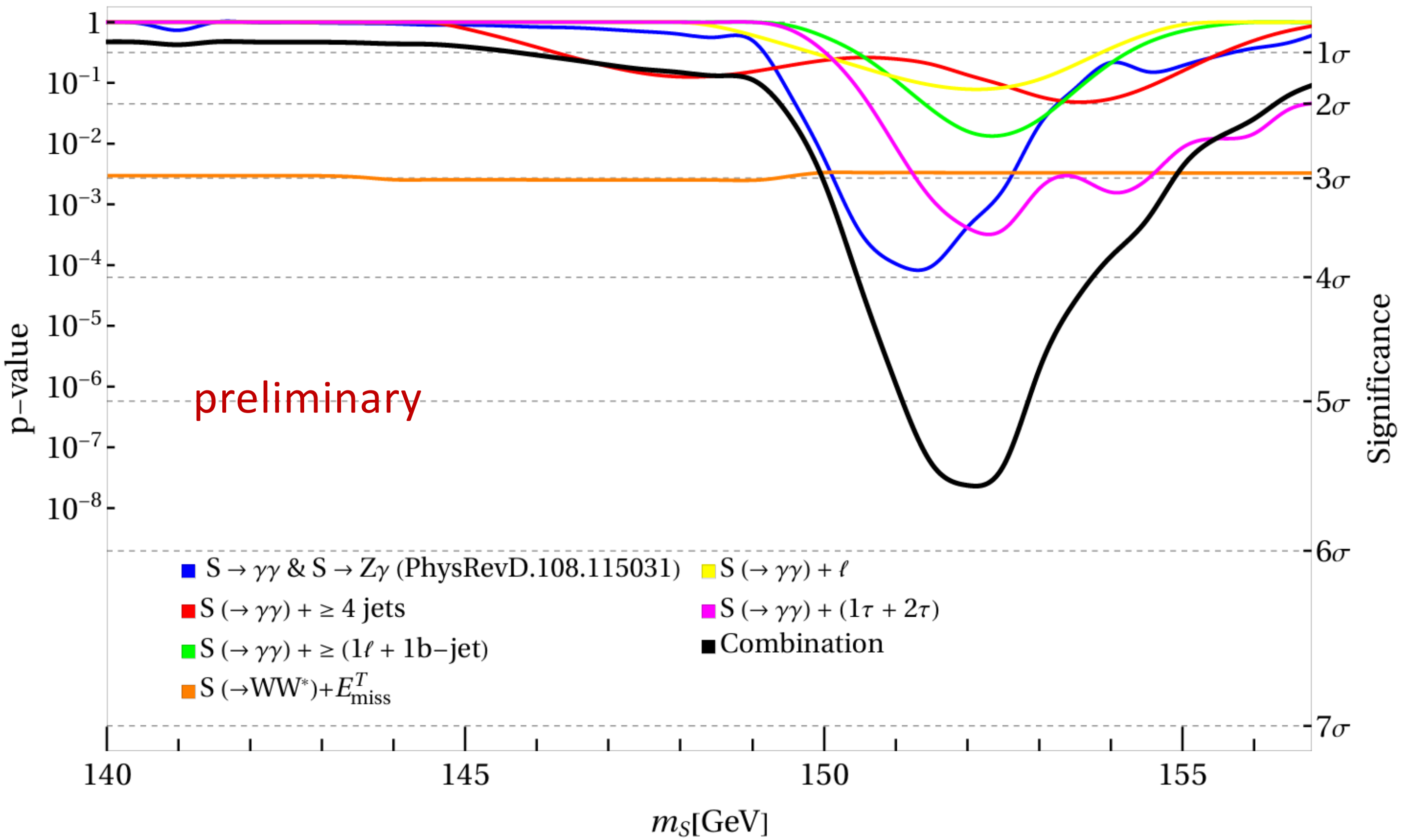
Explains:

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

Combined explanation possible

Hints for new Scalars at 152 GeV

- Combination within the simplified model $H \to SS^*$ with $S \to WW$, MET, $\gamma\gamma$



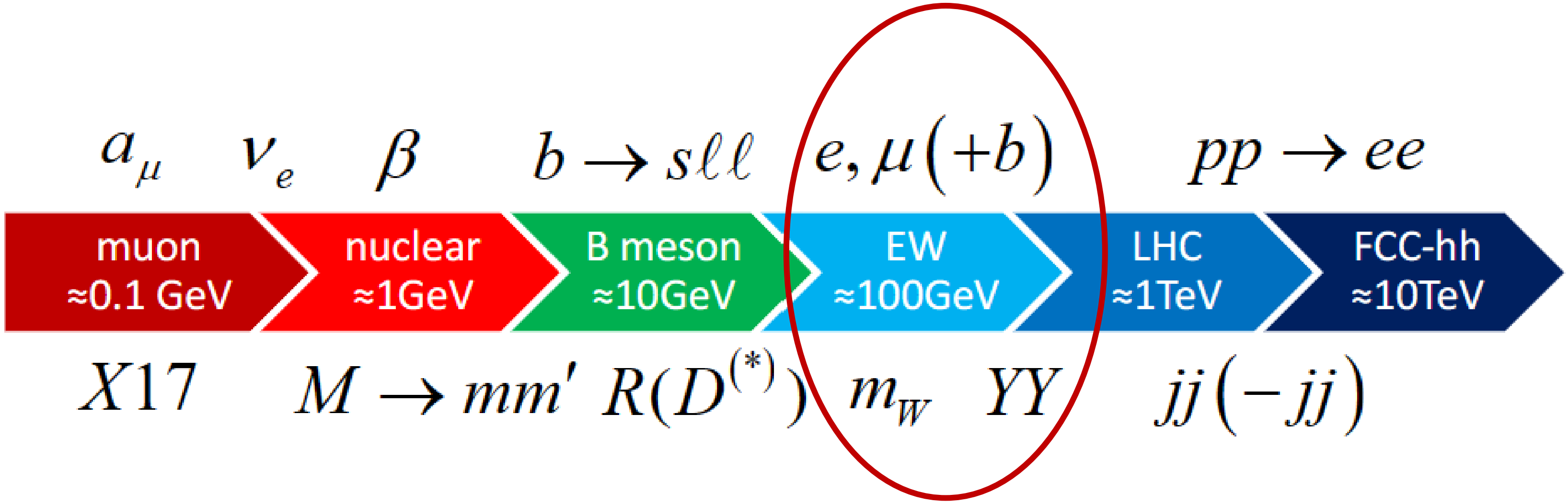
>5σ global significance

Conclusions

- Hints for narrow resonances at 95 GeV & 152 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

Most significant hints for new particles at the LHC

Outlook



Nature Rev.Phys. 6 (2024) 5, 294-309

Multi-leptons history

PAUL SCHERRER INSTITUT

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

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]	$m_{\ell\ell} < 100\,\text{GeV}$, $(1b, 2b)$	$t\bar{t}, Wt$	$> 5\sigma$
$\ell^+\ell^-$+(no jet)[61,67]	$m_{\ell\ell} < 100\,\text{GeV}$	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]	$p_T^Z < 100\,\text{GeV}$	$ZW^\pm$	$> 3\sigma$

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±5GeV
- Here focus on:
  - WW
  - Top-quark differential distributions

Statistically significant, motivate new EW scale scalars