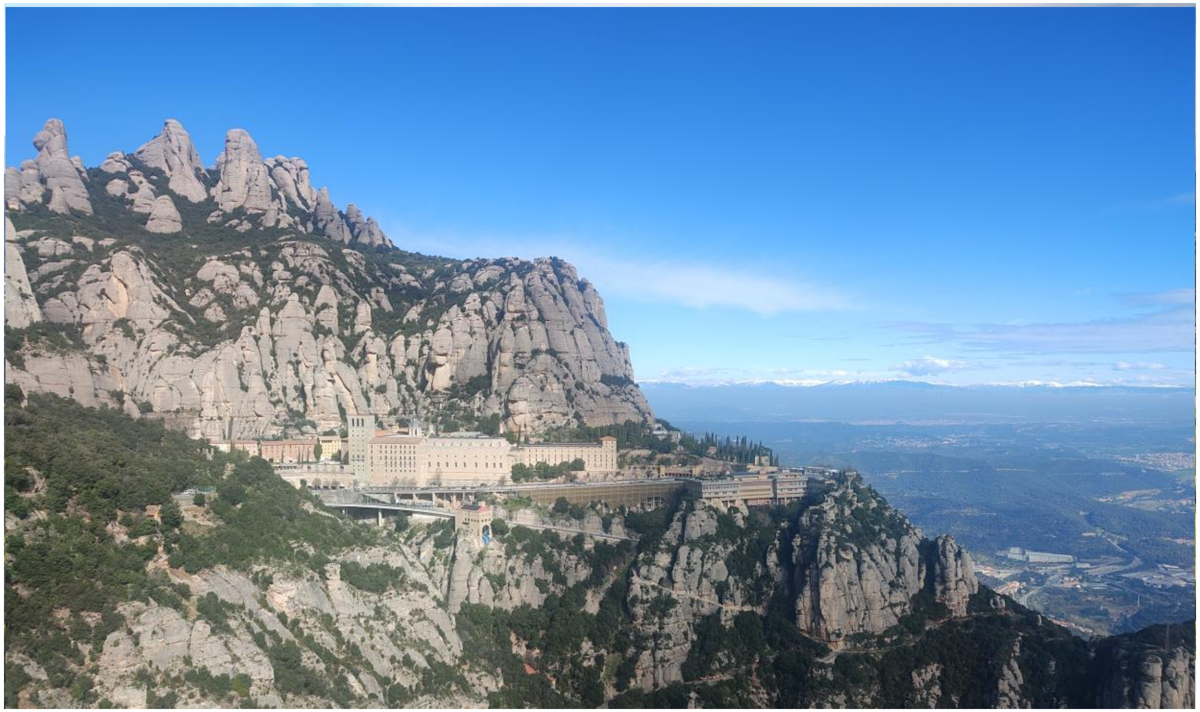


Andreas Crivellin

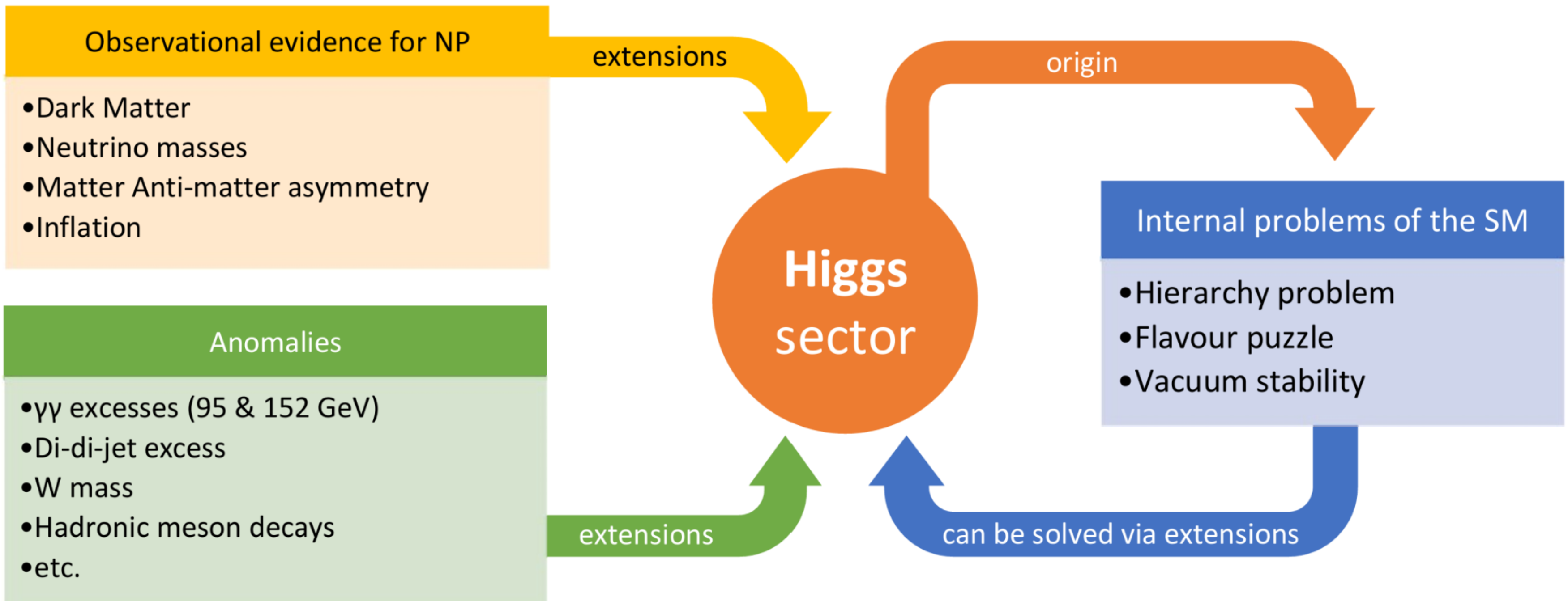
University of Zurich

Evidence for New Higgses at the EW scale and Implications for CEPC

CEPC workshop, Barcelona, 17.06.2025

Why new Higgses?

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



Higgs sector very promising place to expect NP

New Higgses at the Electroweak Scale

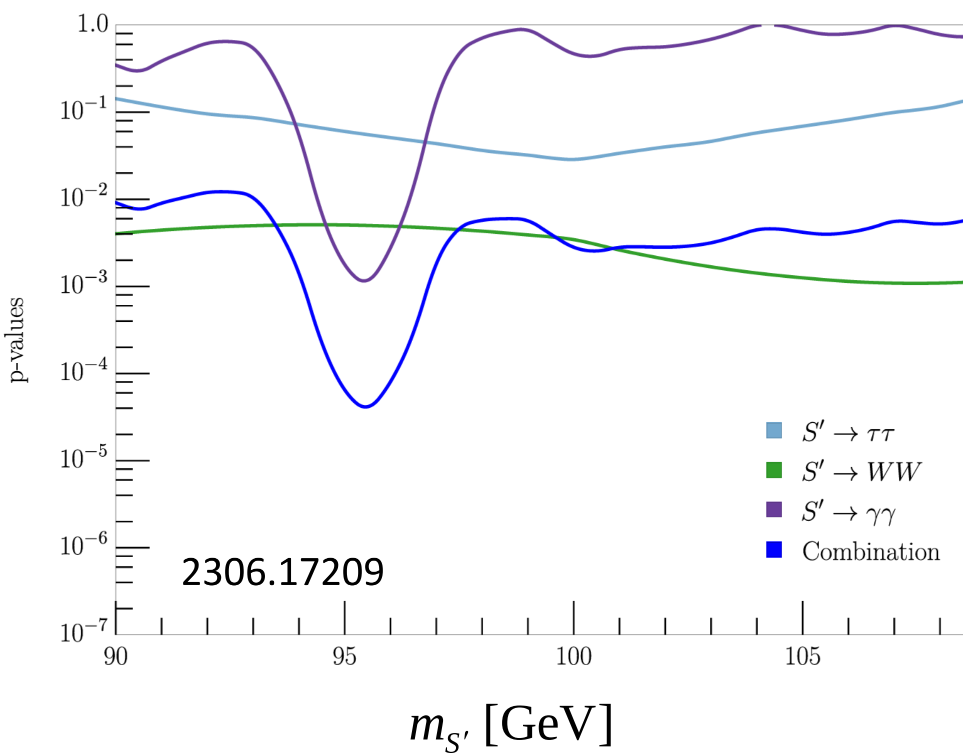
- Signatures of new Higgses expected to be sub-leading compared to the SM Higgs
  (SM-signal strength as EW precision)
- Large SM background
- Small p_T leads to low detector efficiencies
- Non-resonant signatures, like scalars decaying to W bosons (directly or via top quarks) are weakly constrained

EW scale Higgses could be hiding in the LHC data

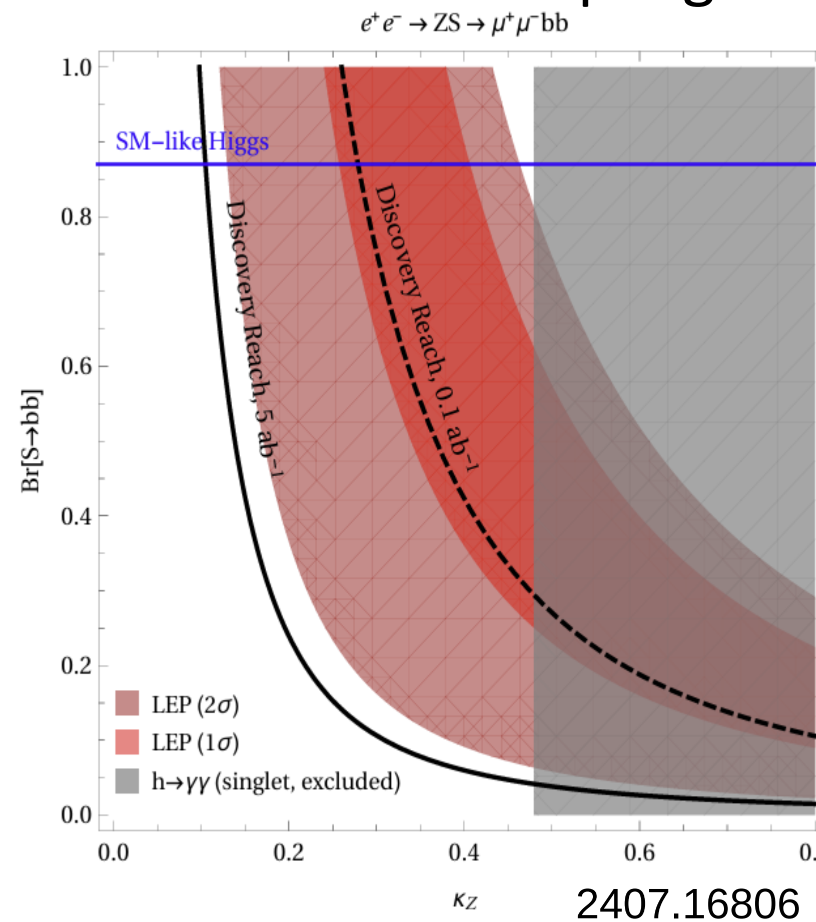
- Associated searches can significantly reduce the ratio of signal over background!

95 GeV Combination

- LEP used to reduce the look-elsewhere effect



- CEPC prospects depend on electron coupling

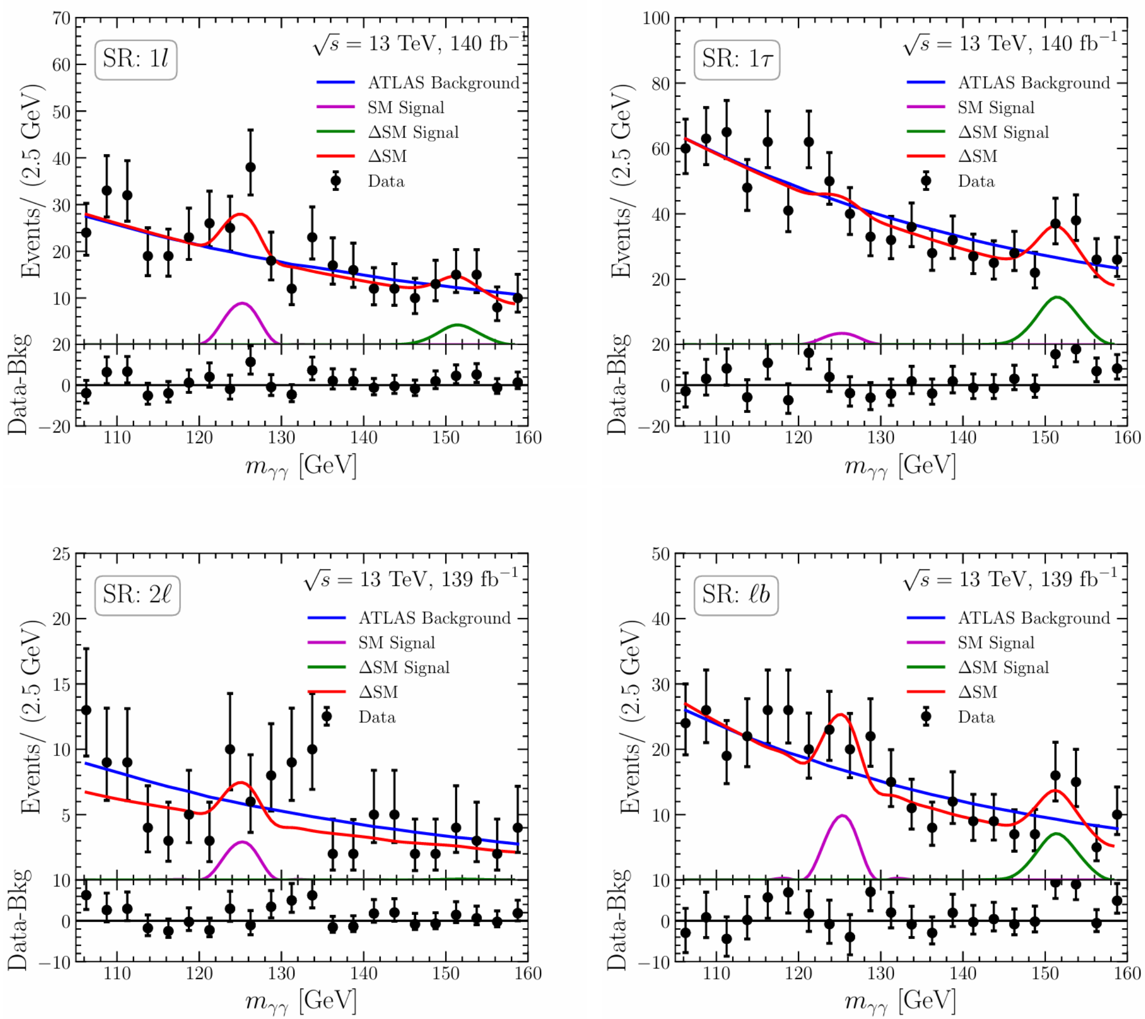


3.4σ global significance

Hints for a 152 GeV scalar

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

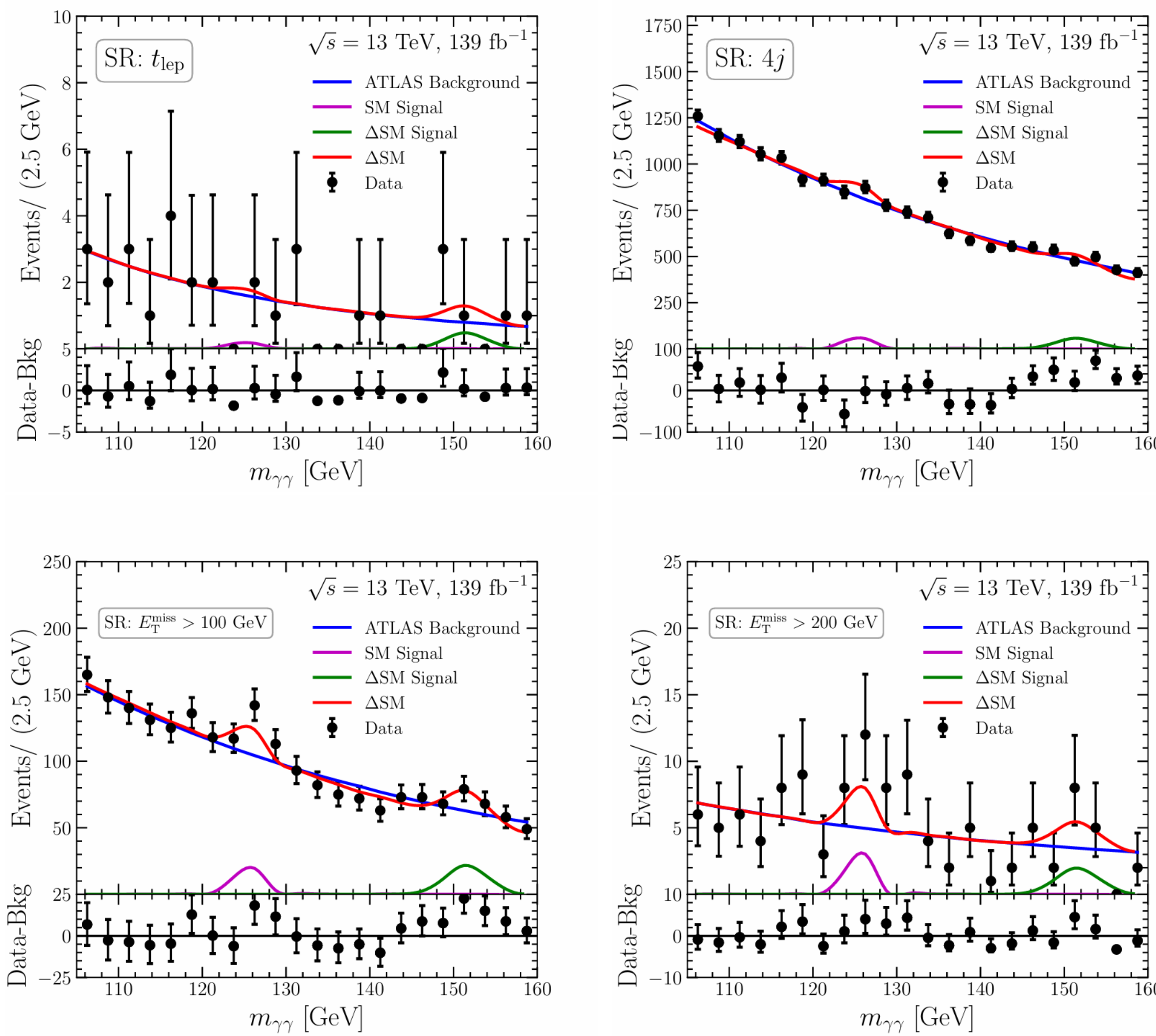
- Hints for a resonance decaying to photons in association with leptons missing energy and b-jets



Dominant channels are γγ+X

Hints for a 152 GeV scalar

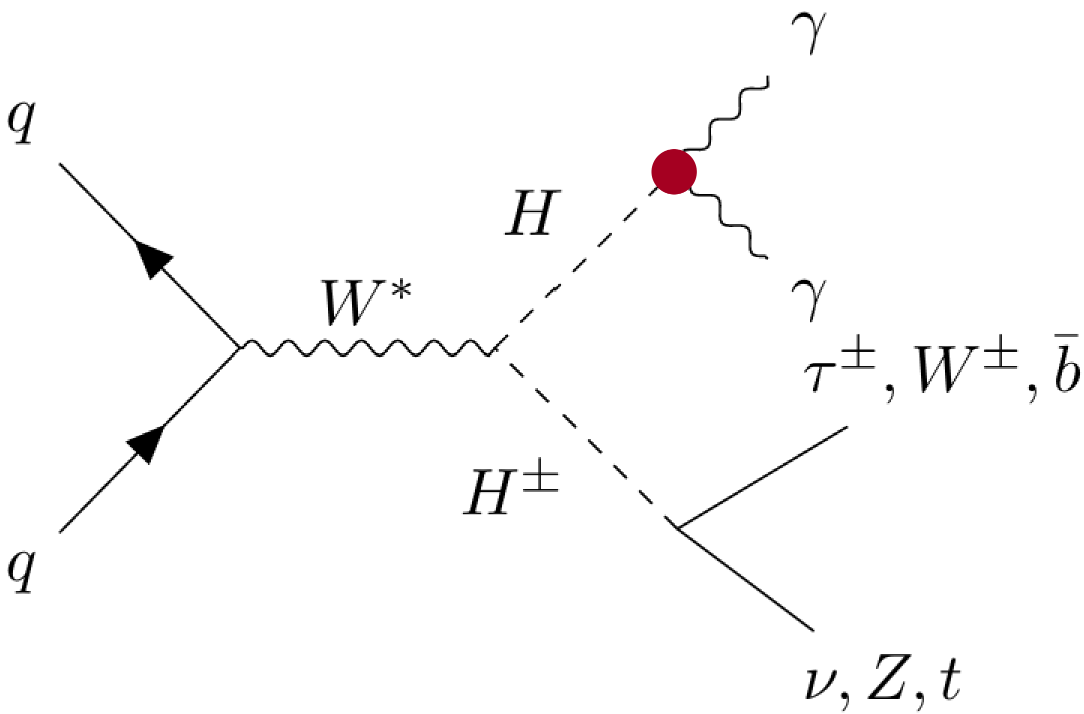
- Hints for a resonance decaying to photons in association with leptons missing energy and b-jets



Dominant channels are γγ+X

Drell-Yan Production

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

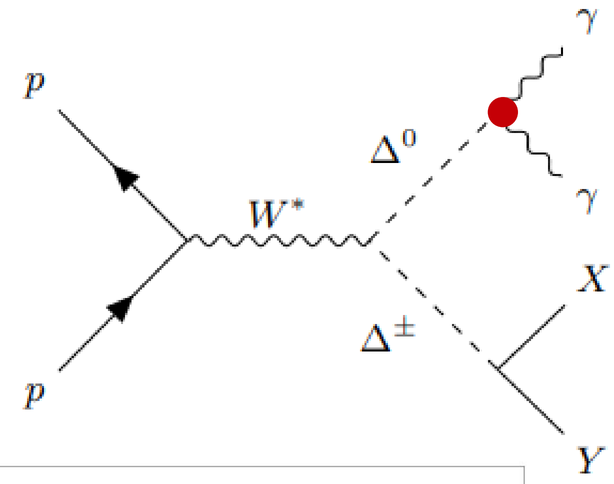


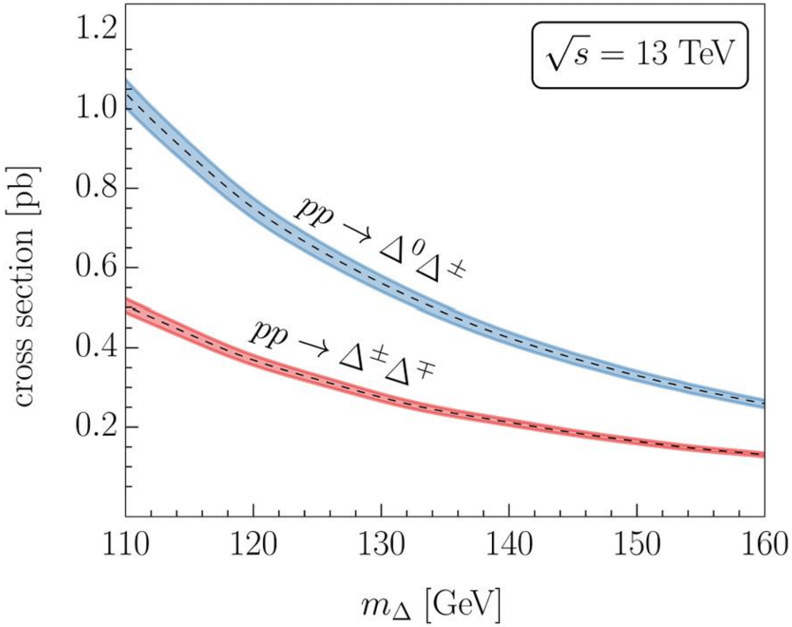
- DY production of charged and neutral Higgs

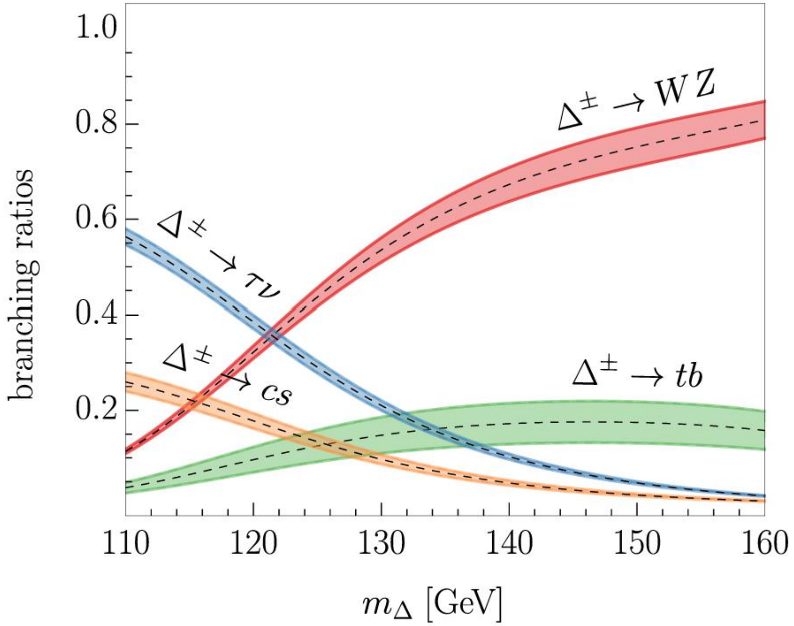
New Scalar with non-trivial SU(2) representation

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



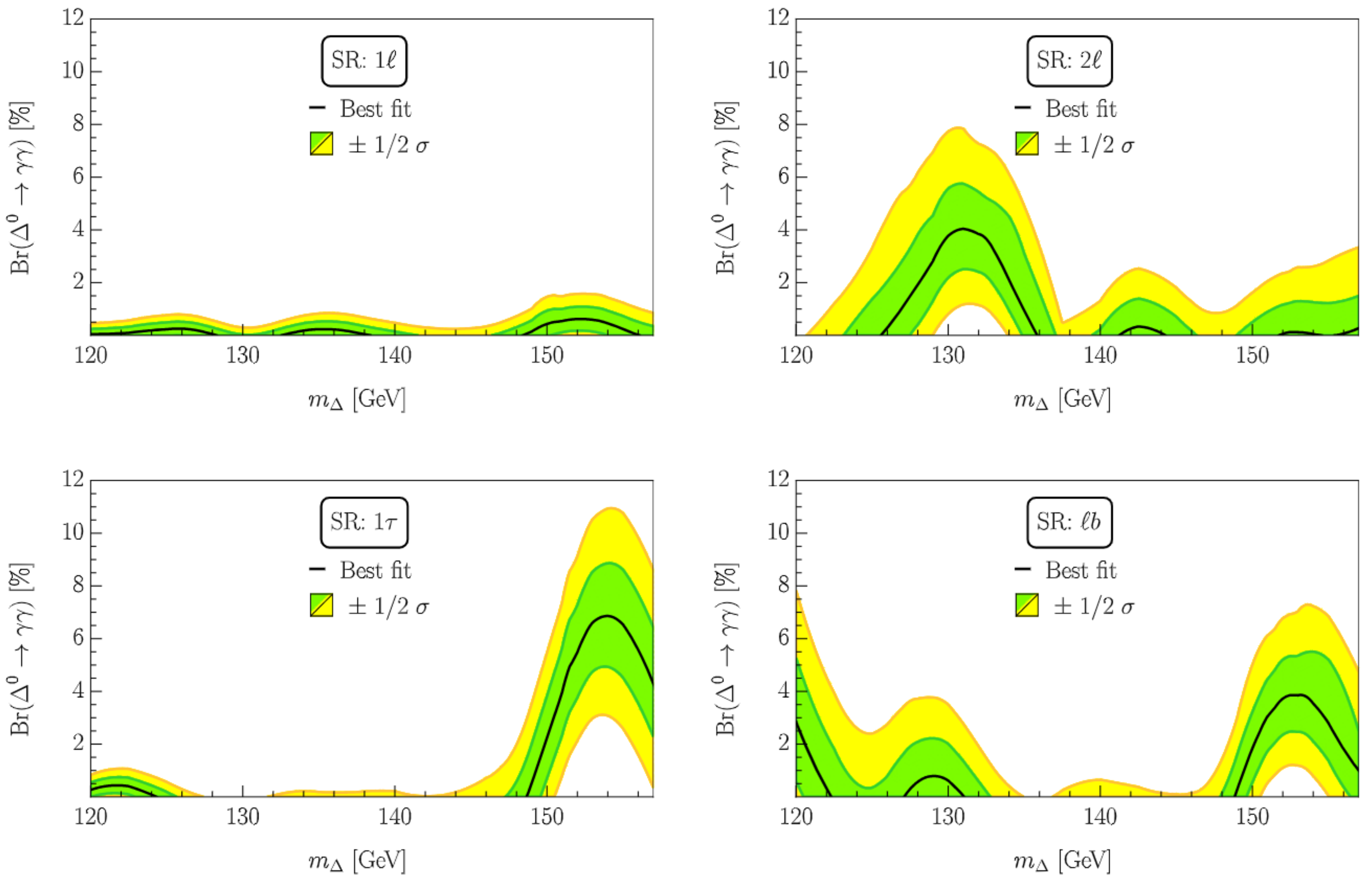




Drell-Yan production at the LHC

h→γγ+X from ATLAS

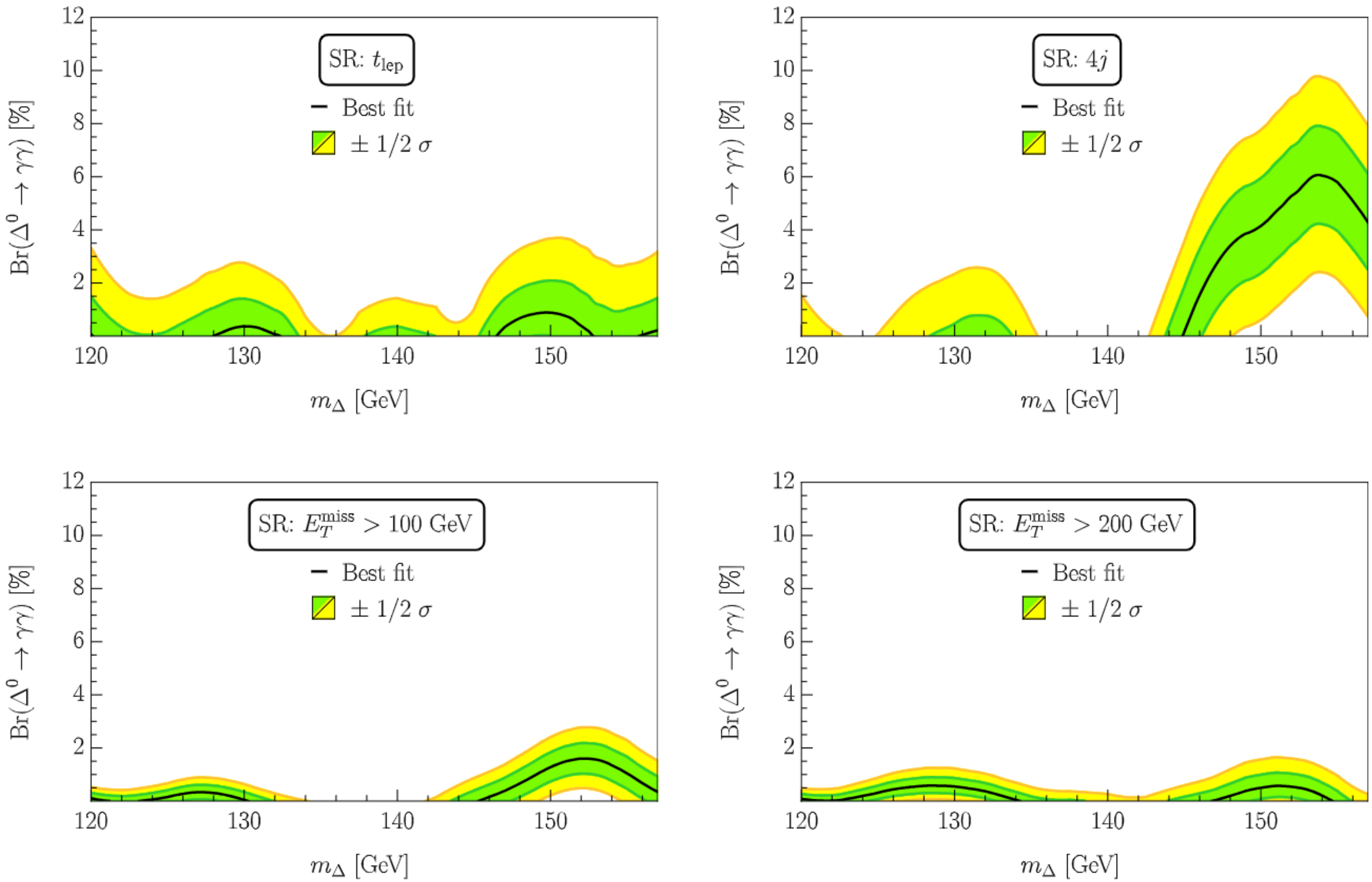
S. Ashanujjaman, S. Banik, G. Coloretti, A.C. S. P. Maharathy, B. Mellado, 2404.14492



Triplet consistently explains h→γγ+X excesses

h→γγ+X Channels

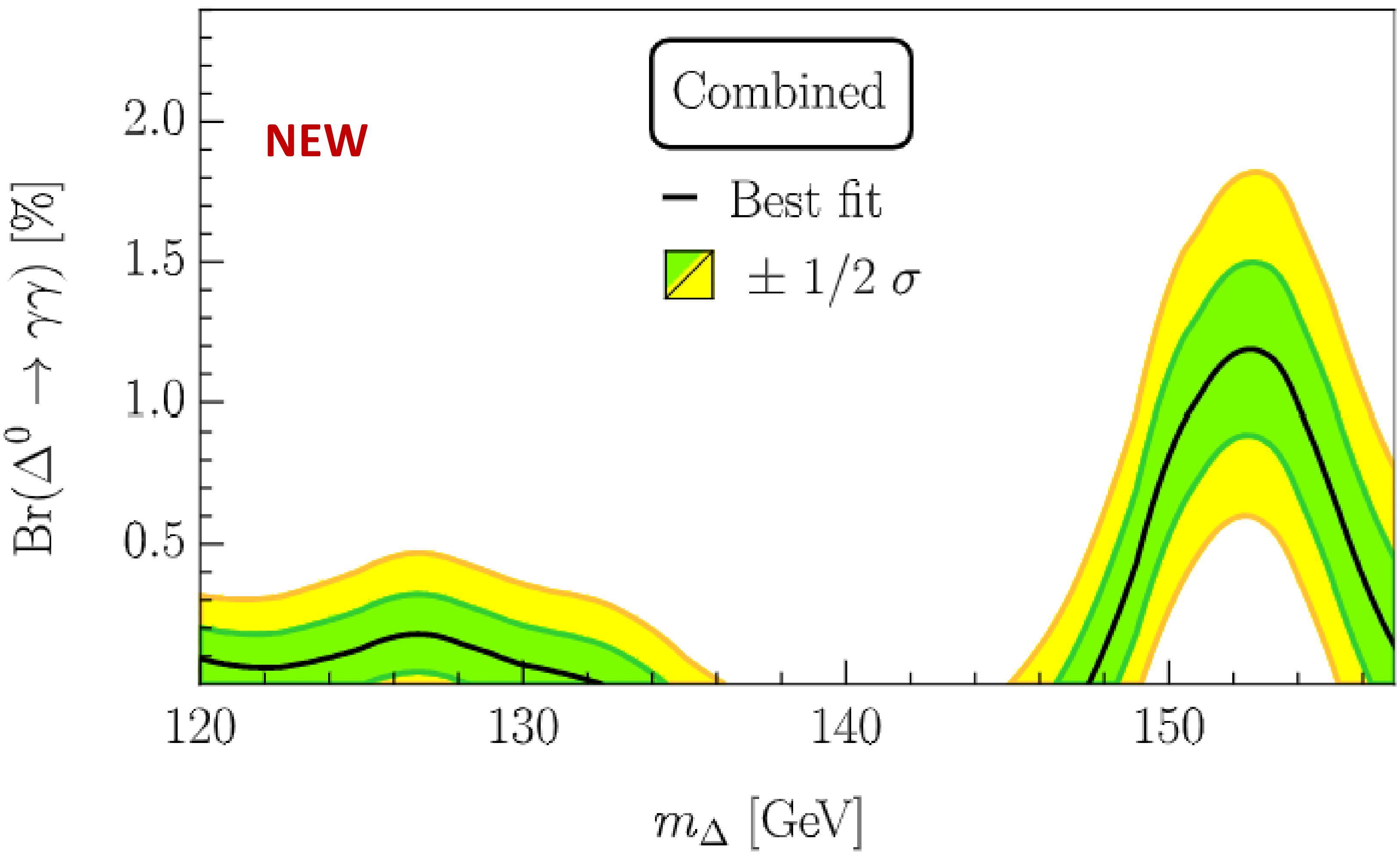
S. Ashanujjaman, S. Banik, G. Coloretti, A.C. S. P. Maharathy, B. Mellado, 2404.14492



Triplet consistently explains h→γγ+X excesses

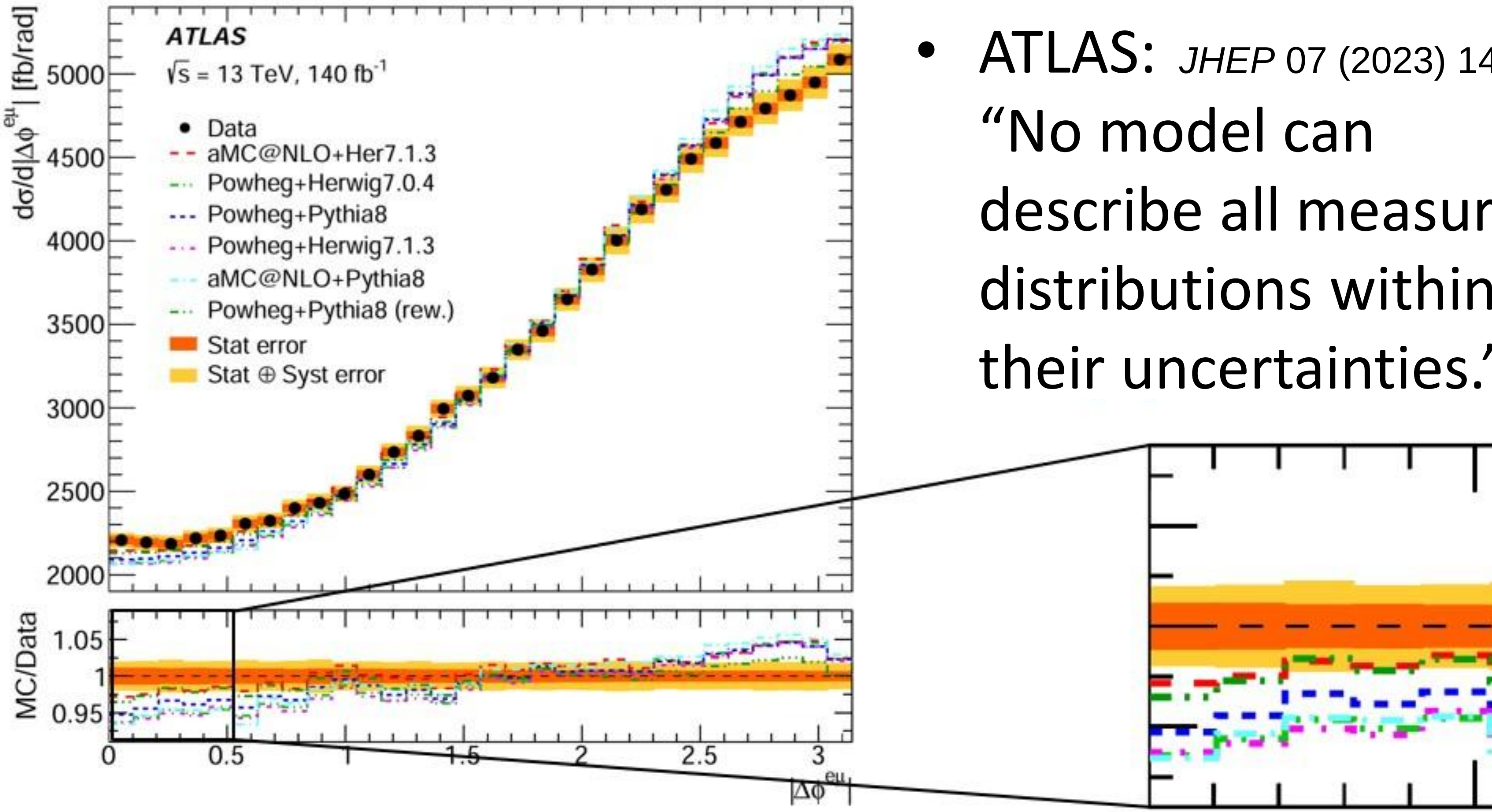
Triplet Combination

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



≈4σ excess at 152GeV

Differential Top-Quark Distributions

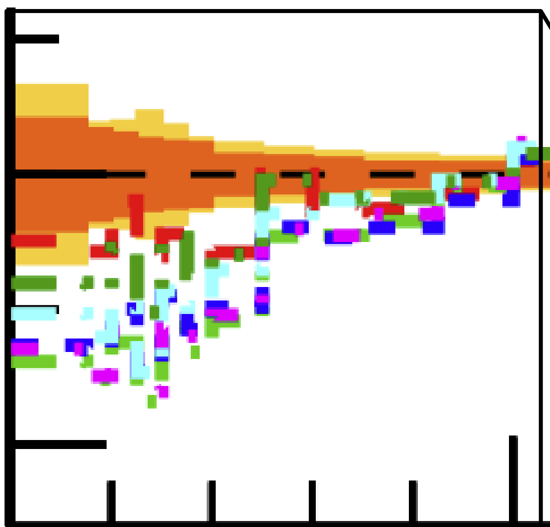


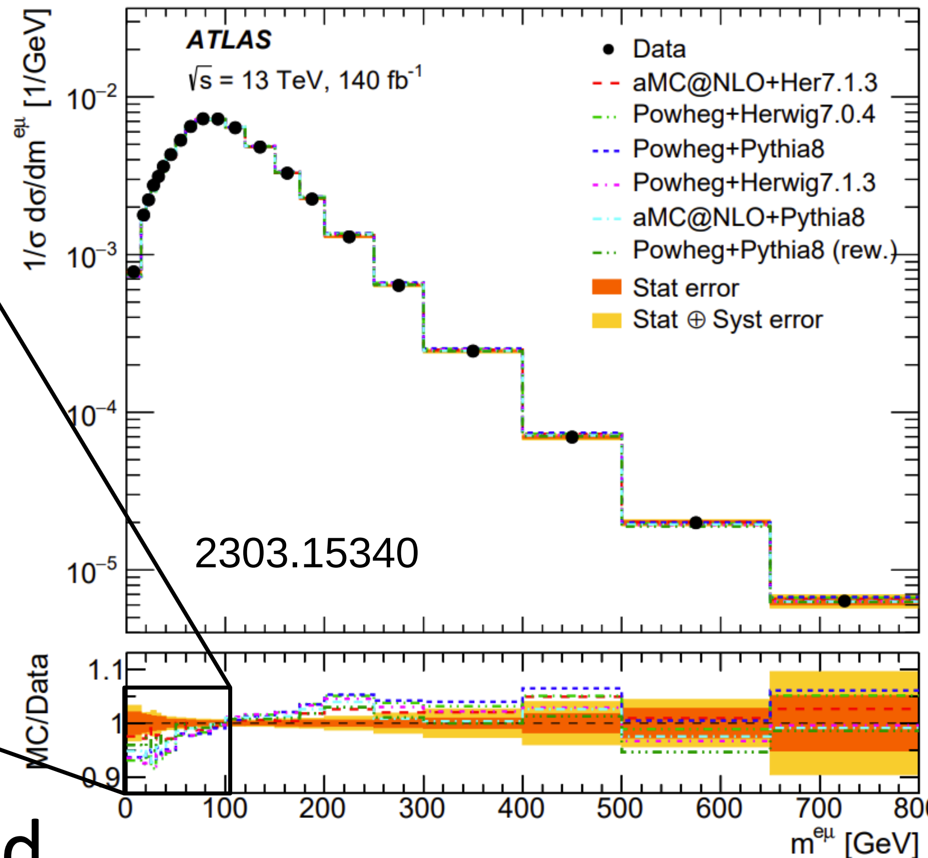
- ATLAS: *JHEP* 07 (2023) 141
  "No model can describe all measured distributions within their uncertainties."

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

New Physics pollution of this SM measurement?

Differential Top-Quark Distributions



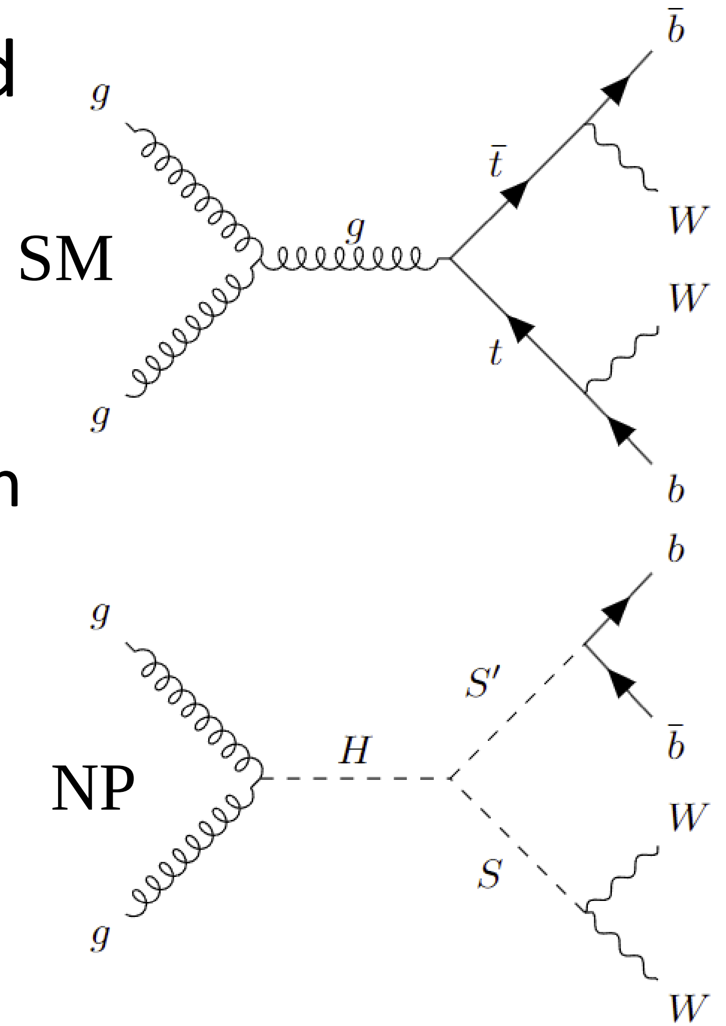


- ATLAS:
  "No model can describe all measured distributions within their uncertainties."

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

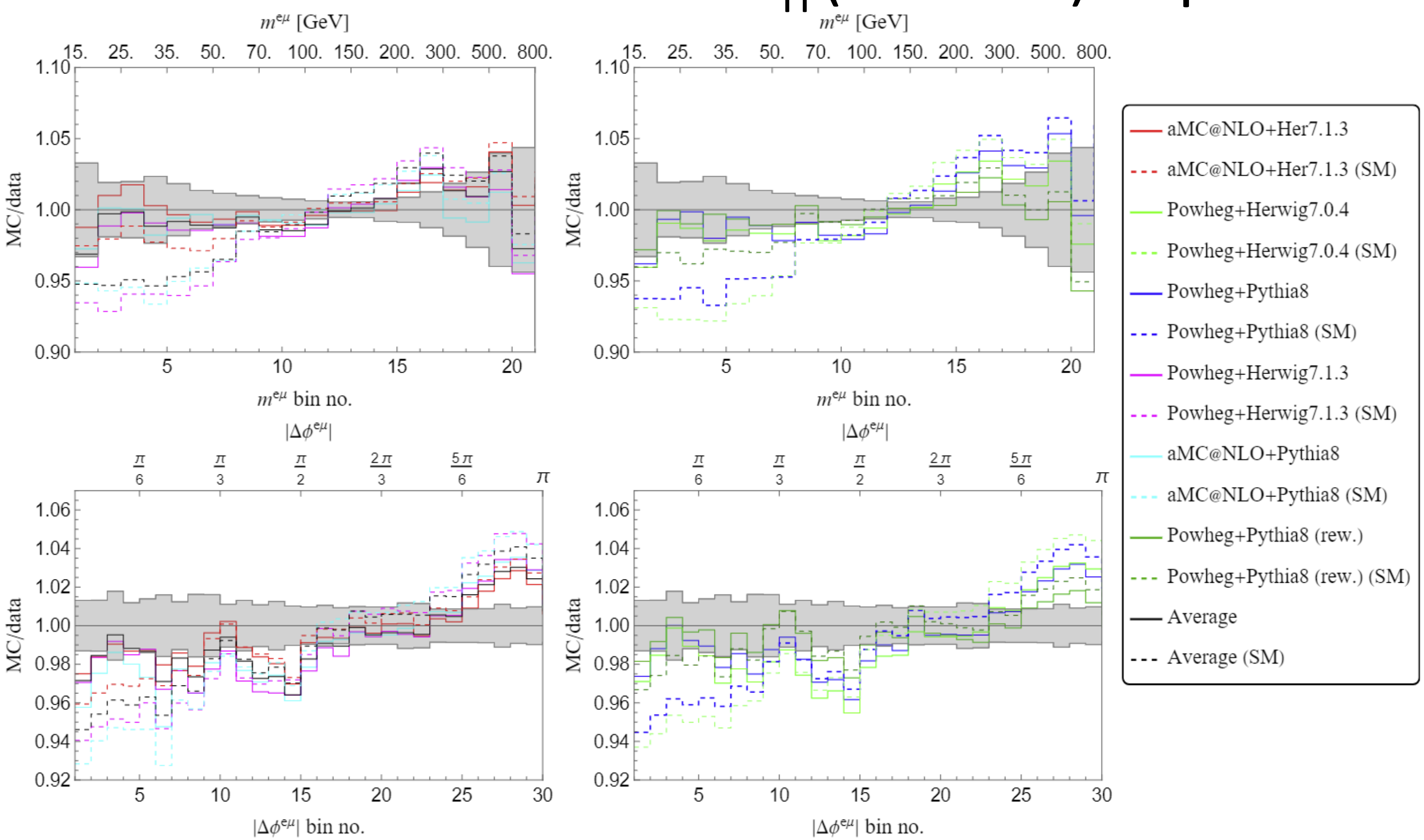


Related to the 95 GeV and 151.5 GeV hints?

Simplified Model: H→SS'→WWbb

2308.07953

- Fix m_S=152GeV and $m_{S'}$=95GeV 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→SS'→WWbb

2308.07953

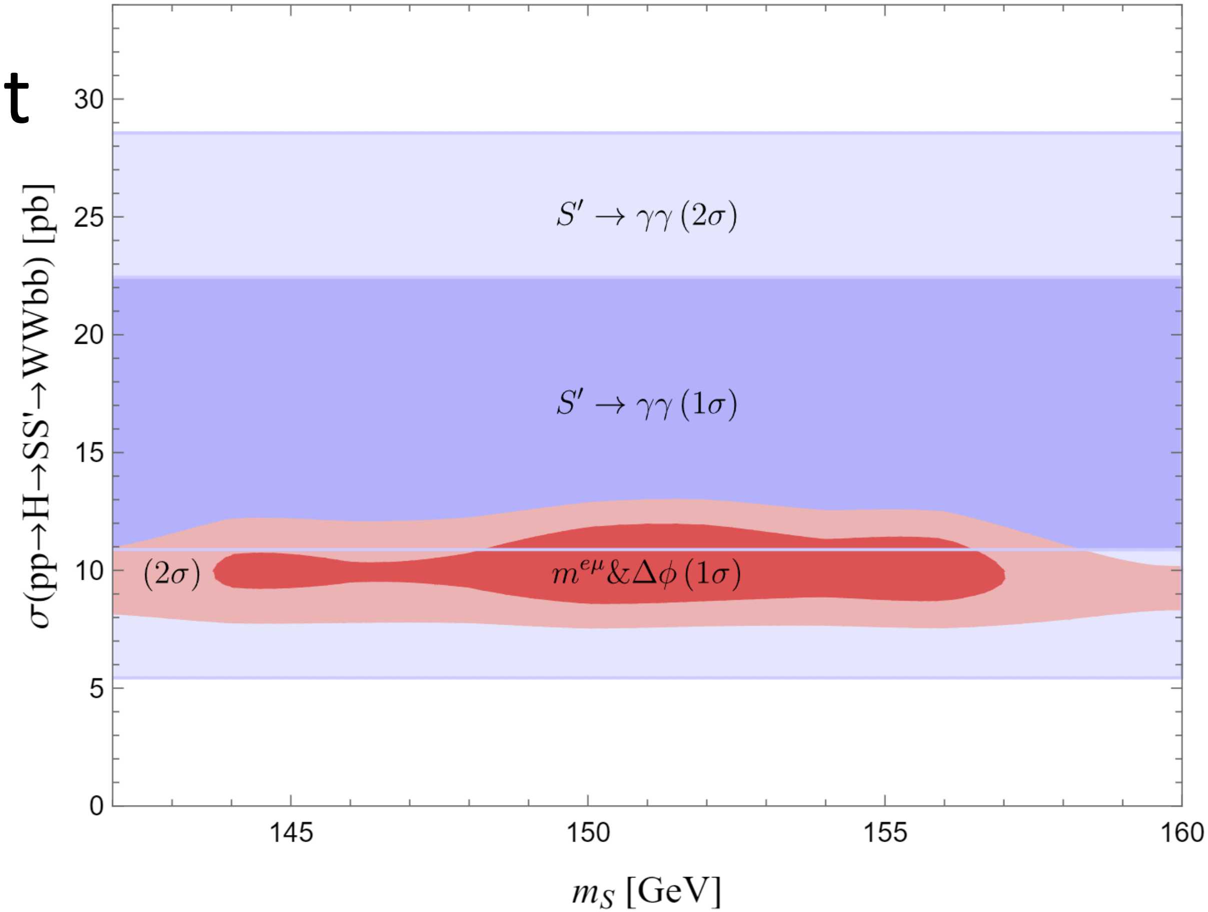
Monte Carlo	χ^2_{SM}	χ^2_{NP}	σ_{NP}	Sig.	m_S[GeV]
Powheg+Pyhtia8	213	102	9pb	10.5σ	$143-156$
aMC@NLO+Herwig7.1.3	102	68	5pb	5.8σ	$--$
aMC@NLO+Pythia8	291	163	10pb	11.3σ	148-157
Powheg+Herwig7.1.3	261	126	10pb	11.6σ	149-156
Powheg+Pythia8 (rew)	69	35	5pb	5.8σ	$--$
Powheg+Herwig7.0.4	294	126	12pb	13.0σ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

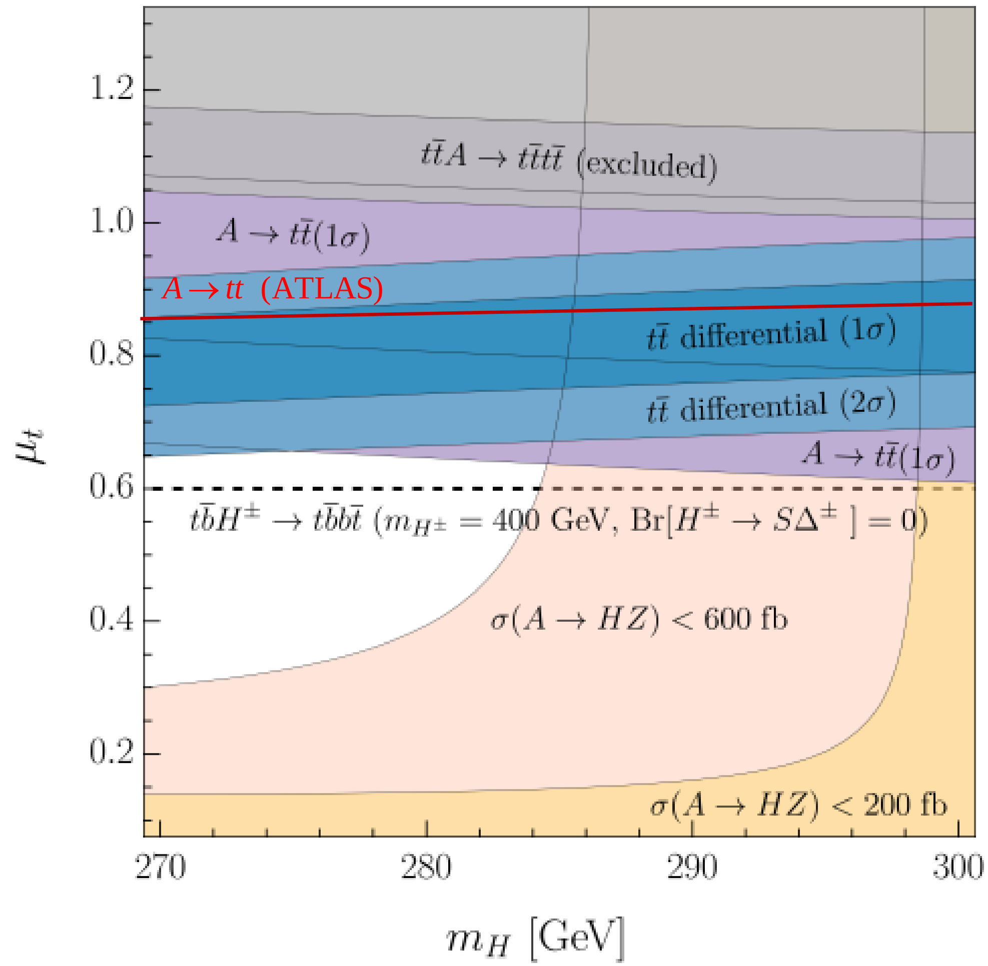


Consistent with 95 GeV γγ signal strength & a mass of S of 152 GeV

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



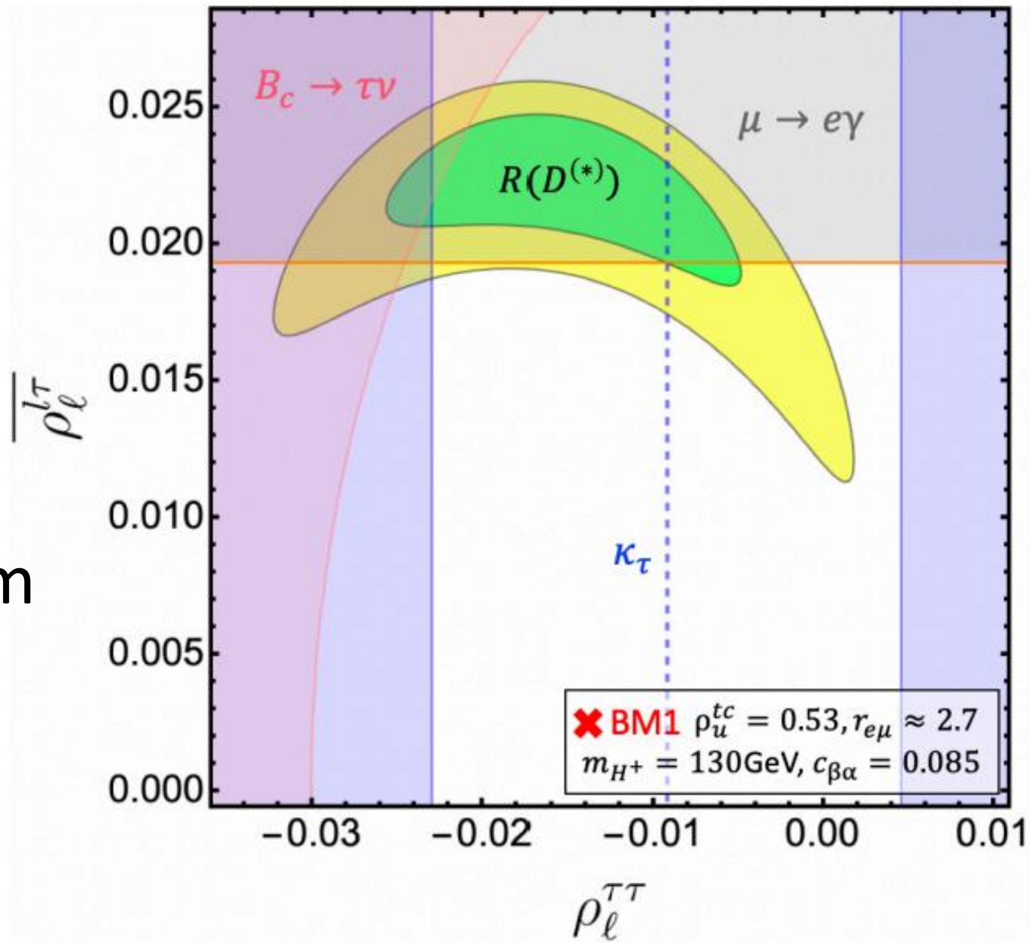
Explains:

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

Combined explanation possible

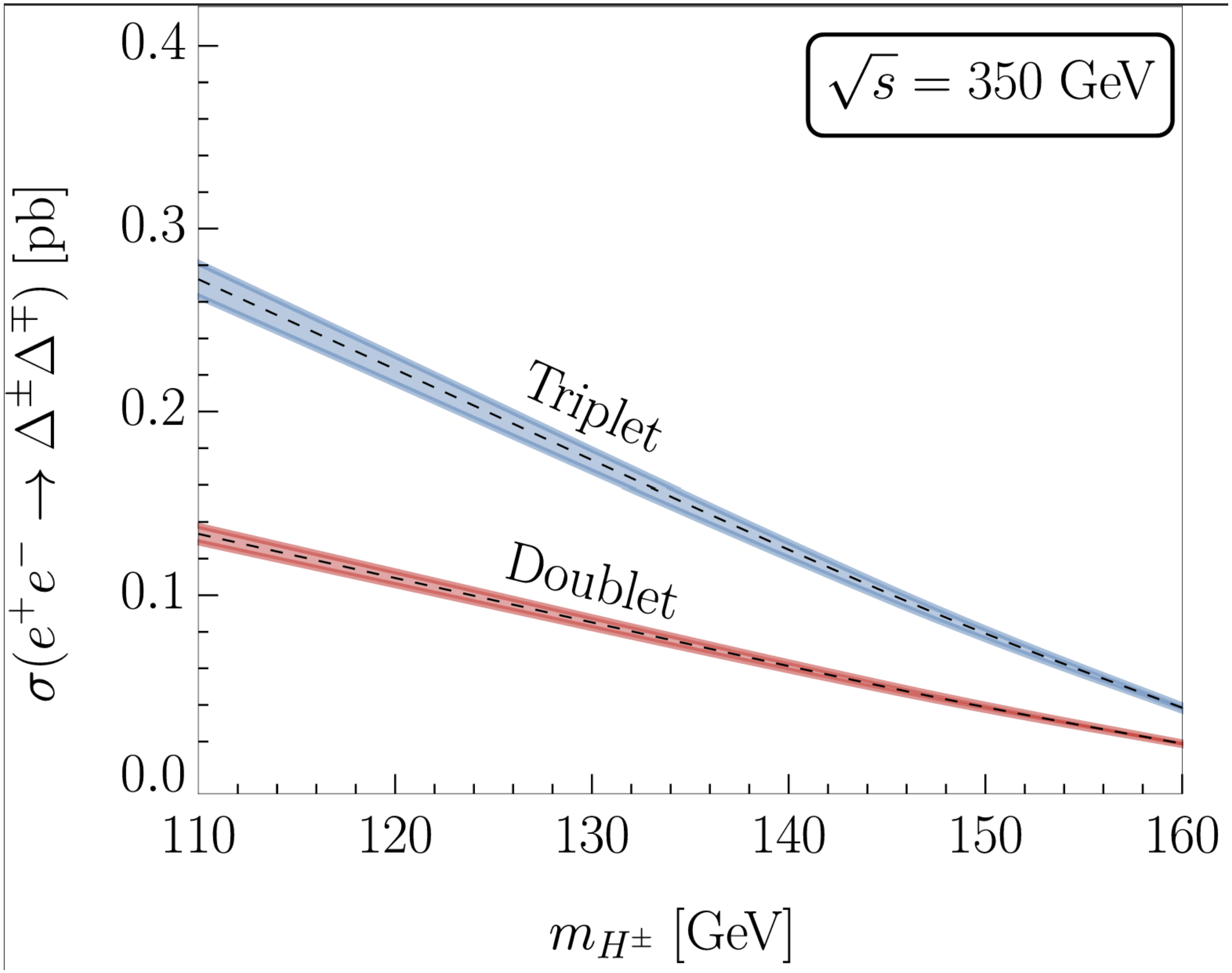
B anomalies and a light charged Higgs

- Charged Higgs can explain
  - R(D) and R(D*) at tree-level
  - $b \rightarrow s\mu^+\mu^-$ via an off-shell photon penguin
- Only light Higgs masses allowed from LHC searches
- ATLAS excess in $t \rightarrow (H^+ \rightarrow cb)b$



Indications for a light charged Higgs from B physics

Light Charged Higgses at CEPC



Great discovery prospects

Conclusions

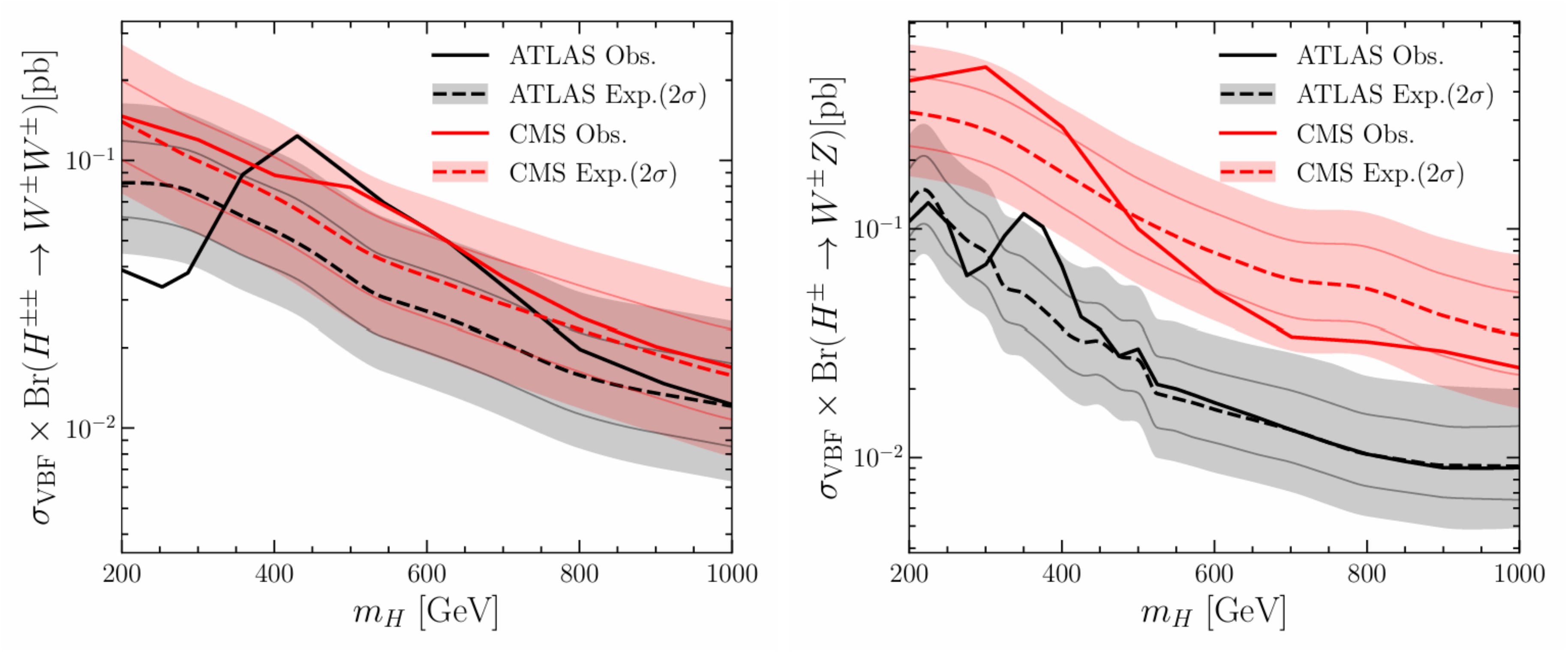
- Hints for narrow resonances at 95 GeV & 152 GeV
- Significant tensions in top quark differential distributions (>5σ)
- Can be explained via pp→H→SS' with masses consistent with the narrow resonances
- 95 GeV decays to dominantly to bb ➡ singlet?
- 152 GeV decays dominantly to WW ➡ triplet?
- γγ+X excesses consistent with DY production of triplet
- Doublet and GM model alternative options

Most significant hints for new particles at the LHC

VBF Di-Boson Excesses

2503.01974

- ATLAS excesses in same sign WW (450 GeV, 3.2σ) and ZW (375 GeV, 2.8σ) in vector-boson fusion
- CMS observes weaker-than expected limits

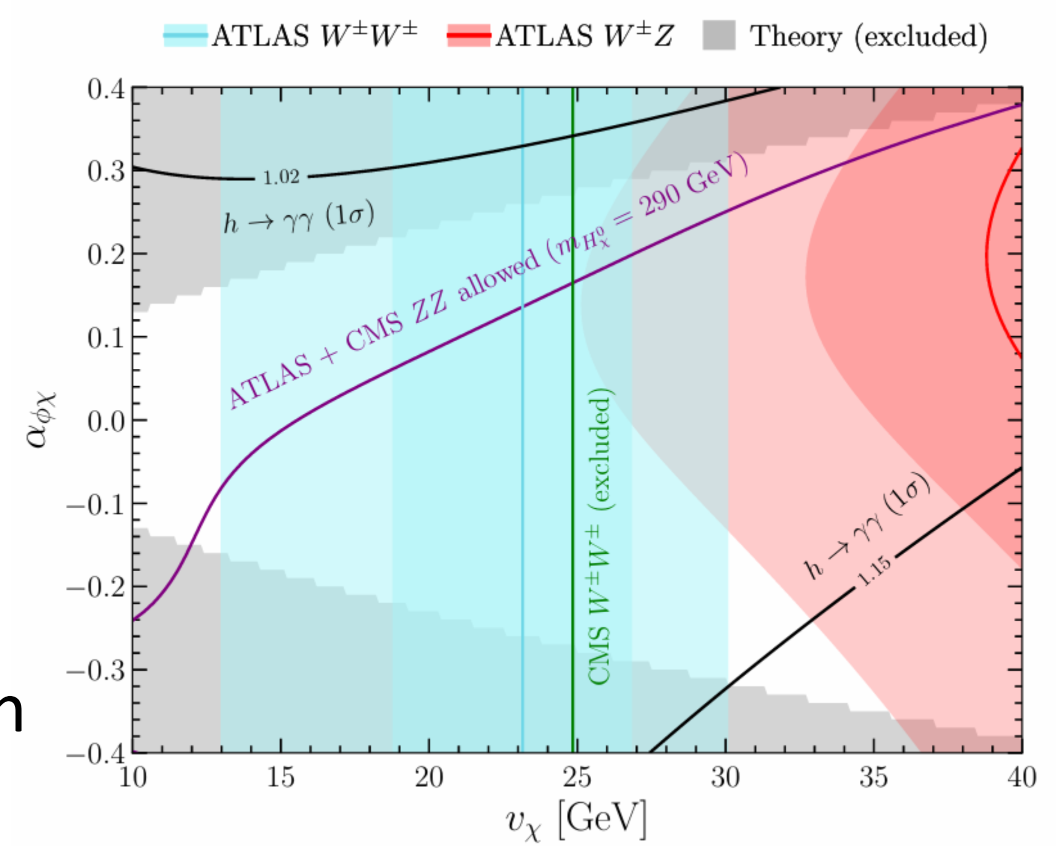


Tripelts with sizable vevs

Generic Georgi-Machacek Model

SM extend

- Y=0 triplet (ζ)
- Y=1 triplet (χ)
- Vevs of the triplet can be sizable due to cancellation in the W mass



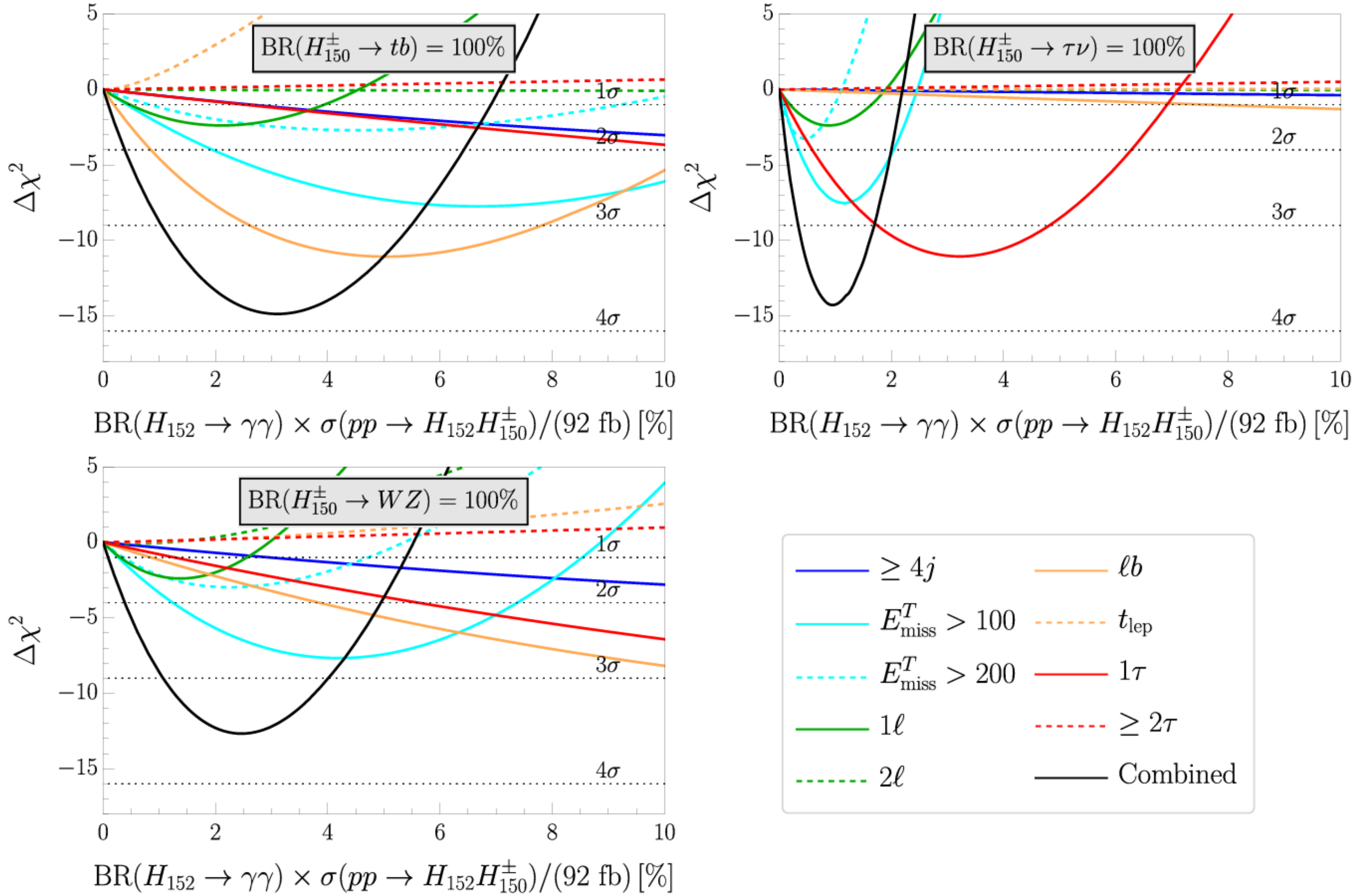
sizable vector-boson fusion cross section

- Generic version needed for different masses

Y=1 Triplet in the GM model explain WW and ZW

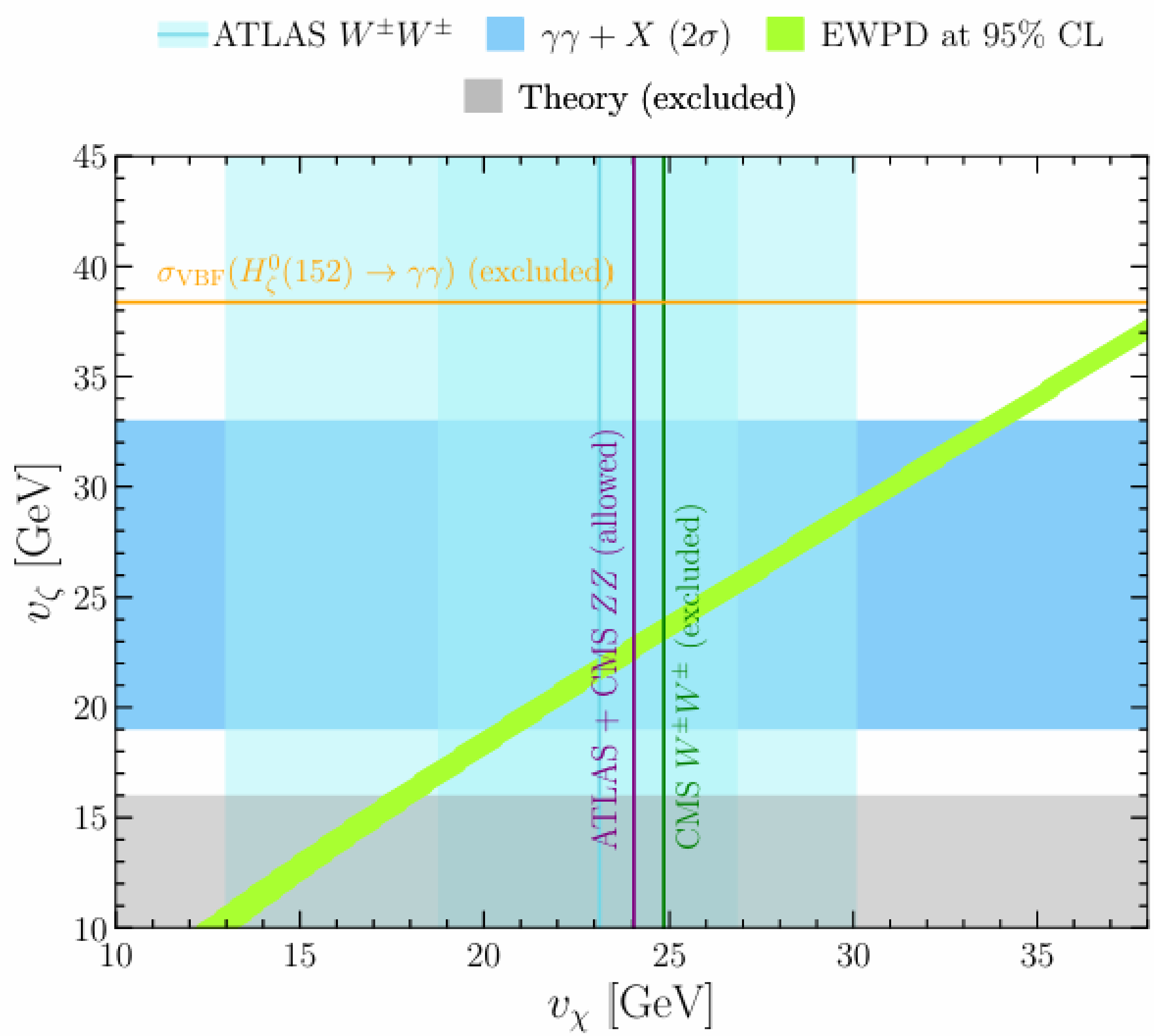
Simplifed Model Analysis

S. Banik, AC, 2407.06267



Triplet or Doublet?

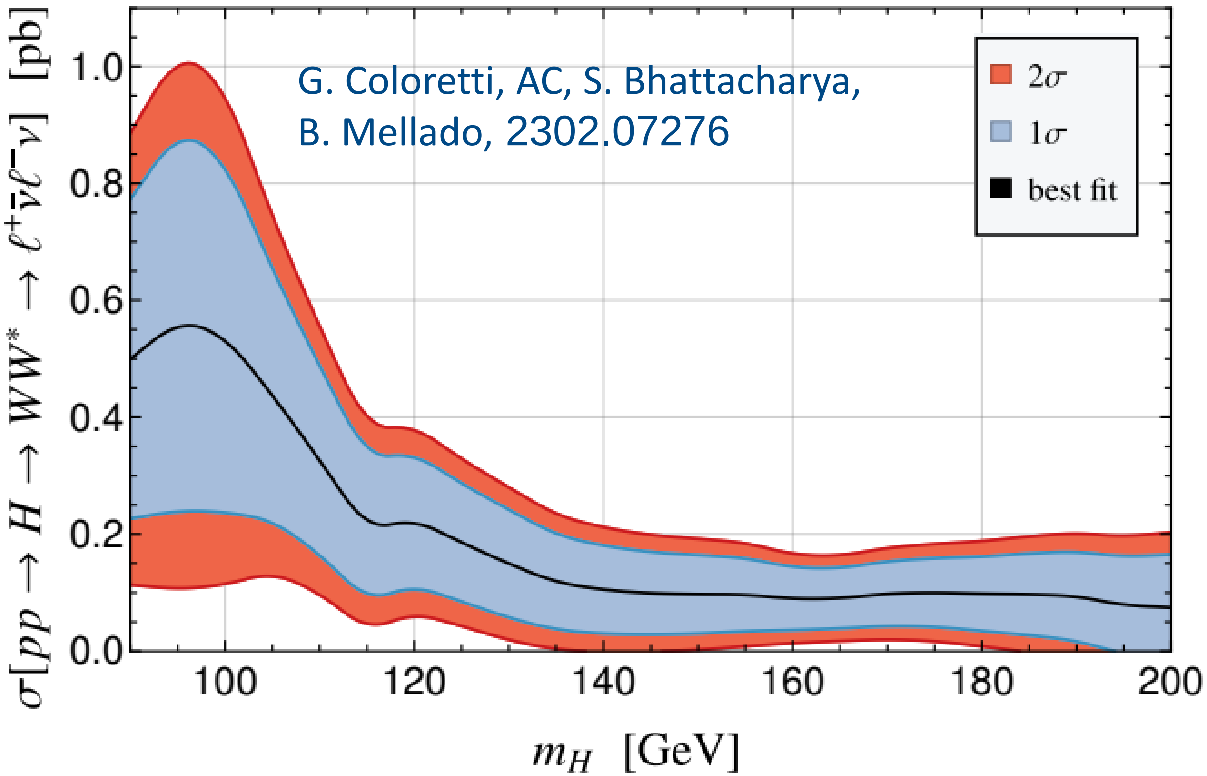
Generic Georgi-Machacek Model



Y=1 can explain WW, ZW; Y=0 γγ (152)

Low mass WW resonances searches

- ATLAS and CMS combination



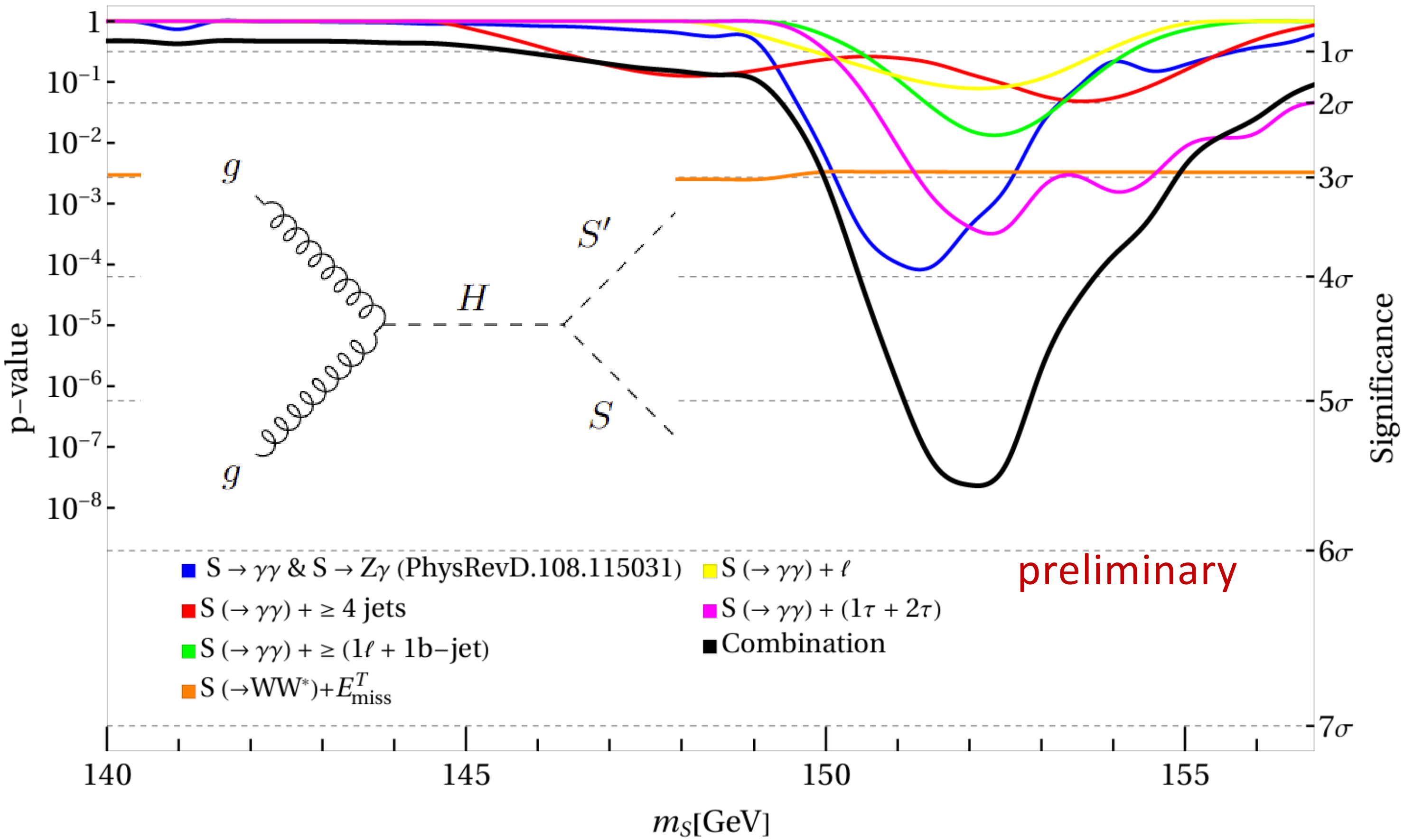
Transverse mass sensitive to additional missing energy from associated production

- New physics effect preferred over the whole range

Related to 95GeV and 151GeV?

Hints for new Scalars at 152 GeV

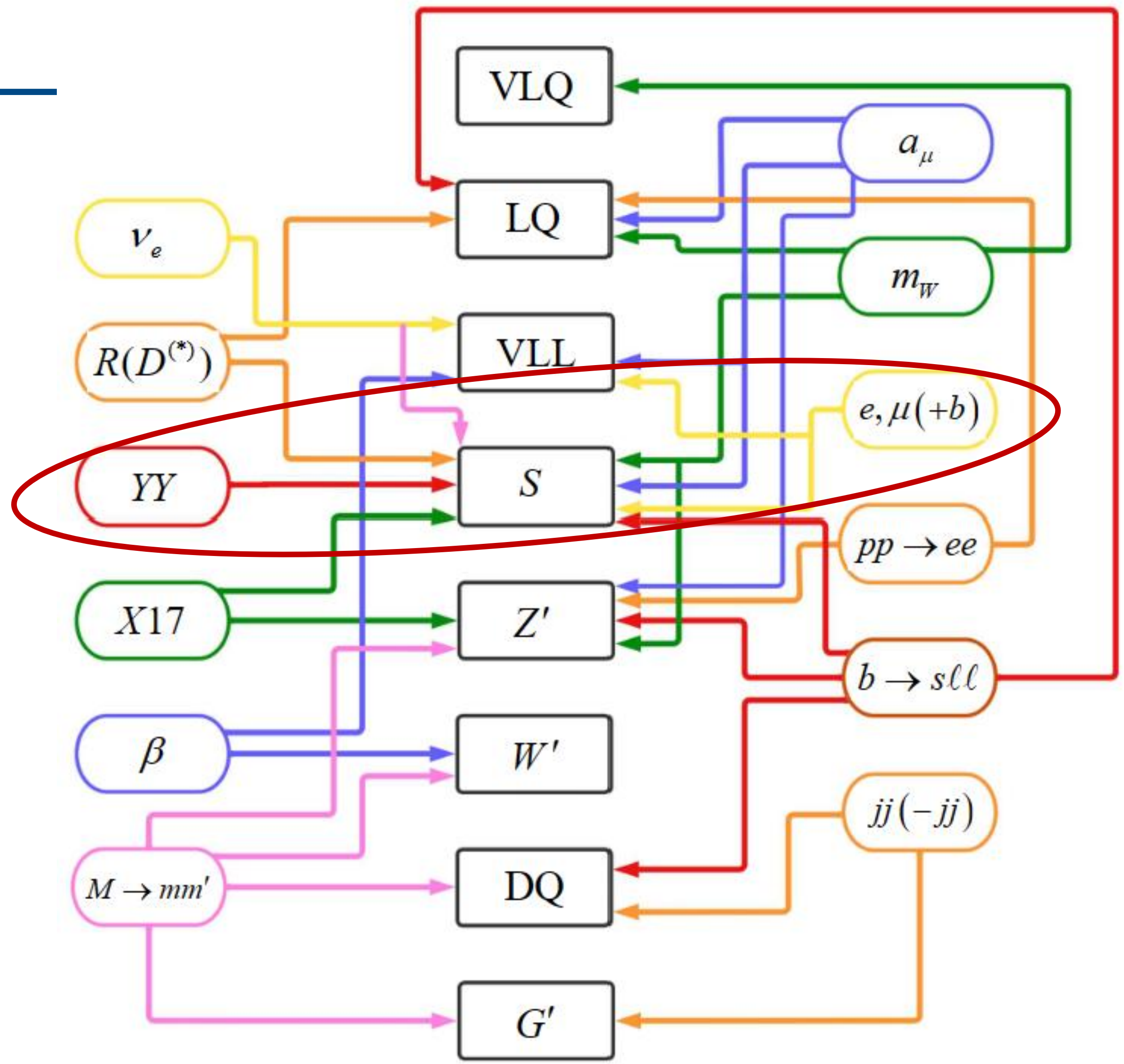
- Combination within the simplified model
  H→SS* with S→WW, MET, γγ



>5σ global significance for simplified model

Outlook

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

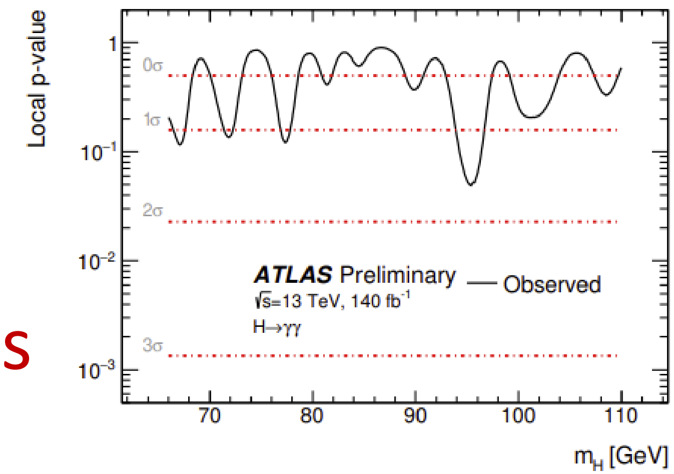


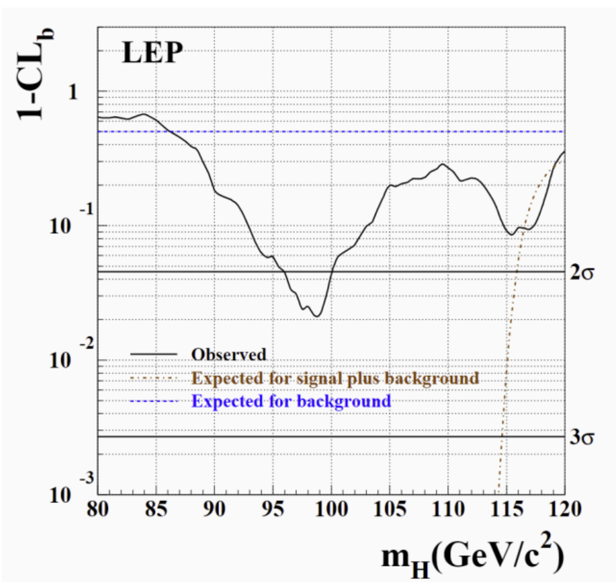
The Standard Model is crumbling

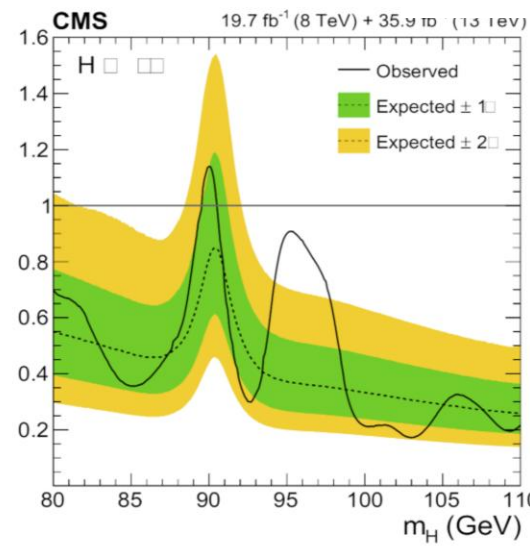
Backup

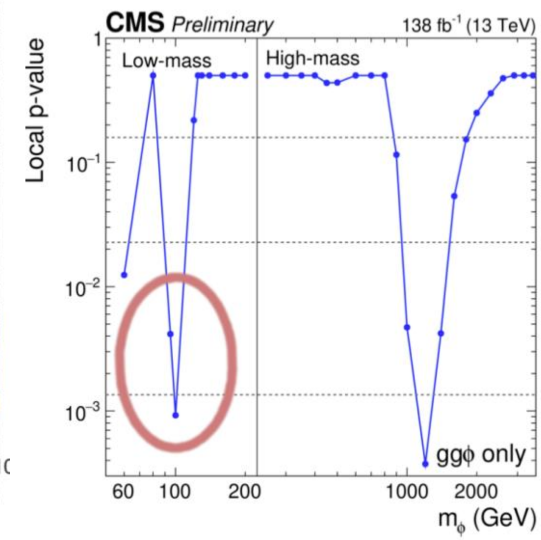
Hints for a 95 GeV Higgs

- LEP: Z+bb
- ATLAS & CMS: γγ
- CMS: ττ (no signal in ATLAS)
- Ask Sven and Thomas for details









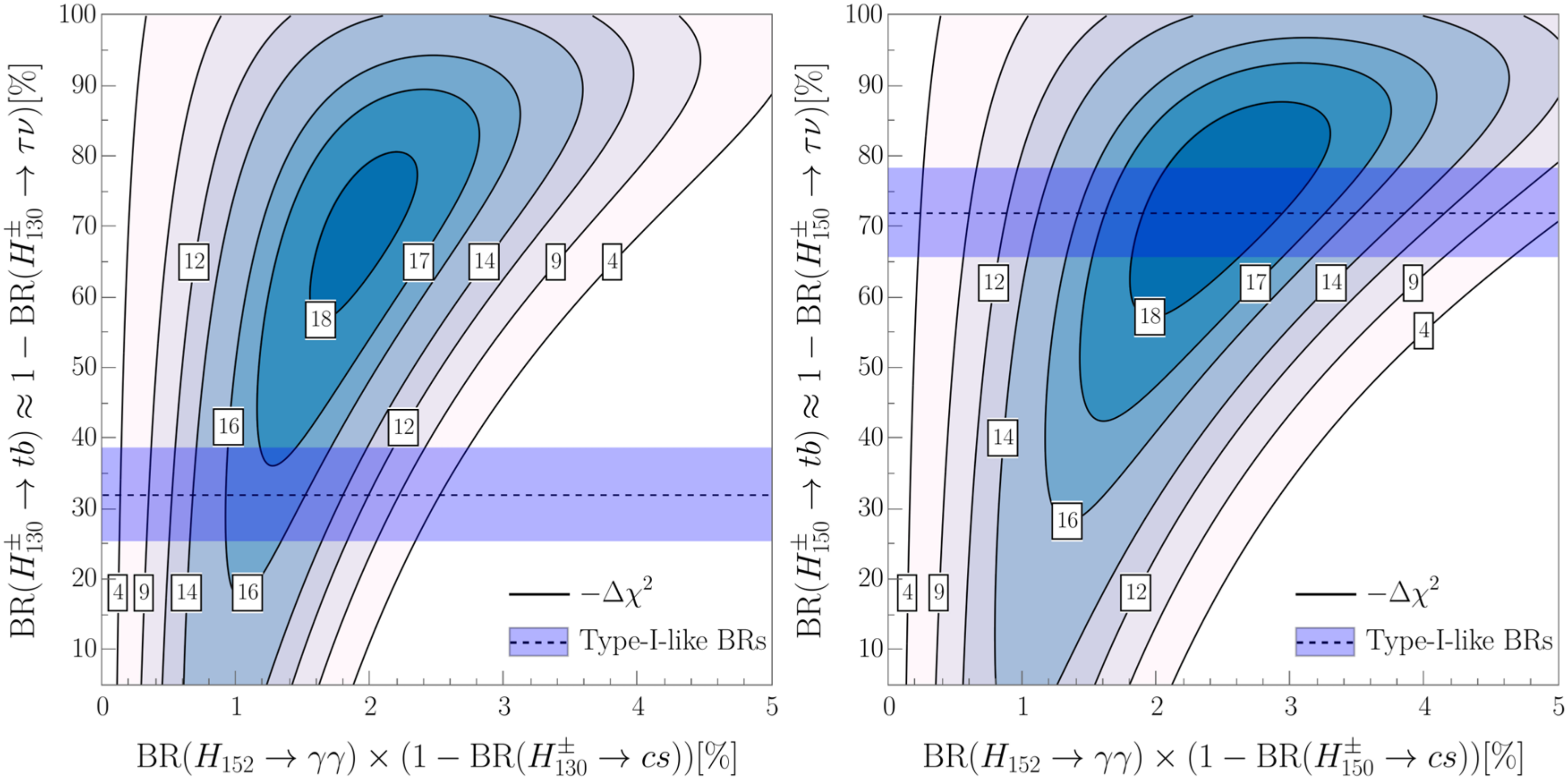
Multiple channels, no associated search

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	$(Z \to \ell\ell) + \ell + \not{E}_T$	$A \to Z(H \to WW)$ $NN \to Z\nu W\ell$

Two-Higgs Doublet Model type-I

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

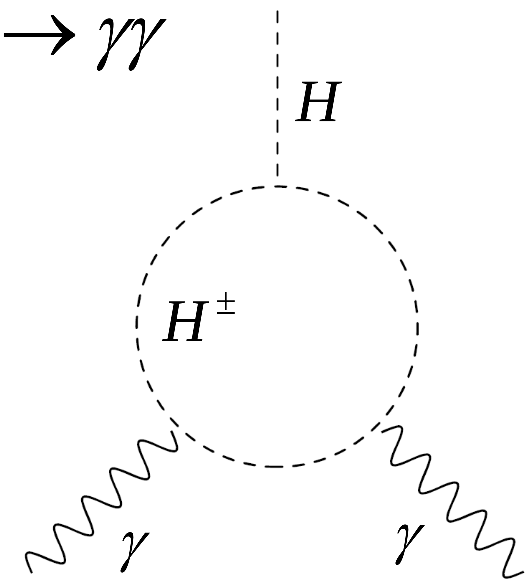


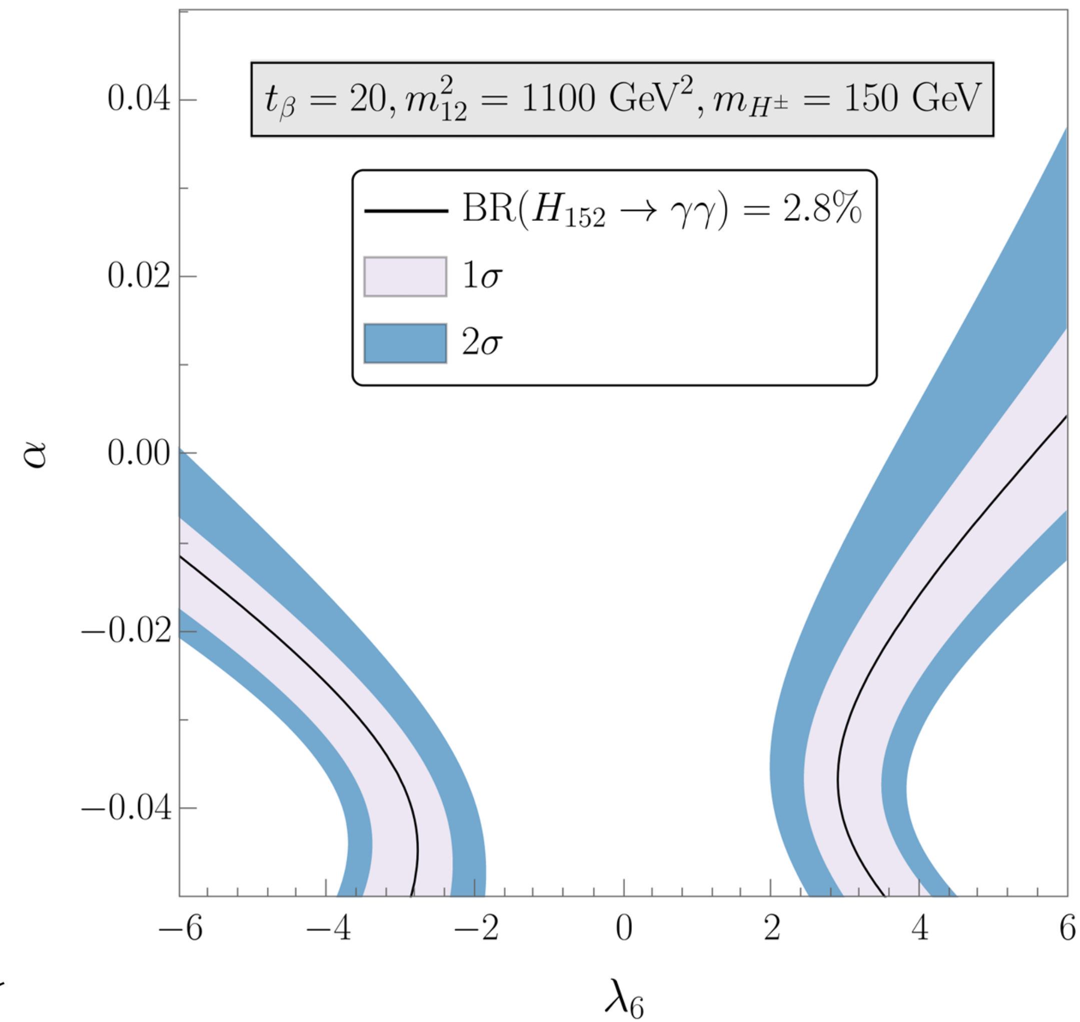
Above 4σ, large Br needed

Large Br(H_{152}→γγ) 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-leptons history

PAUL SCHERRER INSTITUT PSI

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→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

Talk of Bruce Mellado at ZPW 2023

Multi-lepton Anomalies

PAUL SCHERRER INSTITUT PSI

- 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	$W^\pm h(125), WWW$	$\gtrsim 4\sigma$
$Z(\rightarrow \ell\ell)\ell$, (no b-jet)[62,72]	$p_T^Z < 100$ 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