Higgs Hunting 2024 (Orsay and Paris)
25 Sep 2024

Theory prospects for HL-LHC

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Anomalies in Higgs-related final states

Model-independent search for the presence of new physics in events including $H \to \gamma\gamma$ with $\sqrt{s} = 13$ TeV pp data recorded by the ATLAS detector at the LHC

JHEP 07 (2023) 176 [arXiv:2301.10486]

The ATLAS collaboration

E-mail: atlas.publications@cern.ch

Abstract: A model-independent search for new physics leading to final states containing a Higgs boson, with a mass of 125.09 GeV, decaying to a pair of photons is performed with 139 fb^{-1} of $\sqrt{s} = 13$ TeV pp collision data recorded by the ATLAS detector at the Large Hadron Collider at CERN. This search examines 22 final states categorized by the objects that are produced in association with the Higgs boson. These objects include isolated electrons or muons, hadronically decaying τ-leptons, additional photons, missing transverse momentum, and hadronic jets, as well as jets that are tagged as containing a b-hadron. No significant excesses above Standard Model expectations are observed and limits on the production cross section at 95% confidence level are set. Detector efficiencies are reported for all 22 signal regions, which can be used to convert detector-level cross-section limits reported in this paper to particle-level cross-section constraints.

Anomalies in Higgs-related final states

Target	Region	Detector level	Particle level
Heavy flavour	$\geq 3b$	$n_{b\text{-jet}} \geq 3$, 85% WP	$n_{b\text{-jet}} \geq 3$
	$\geq 4b$	$n_{b\text{-jet}} \geq 4$, 85% WP	$n_{b\text{-jet}} \geq 4$
High jet activity	$\geq$4j	$n_{\text{jet}} \geq 4$, $\lvert\eta_{\text{jet}}\rvert < 2.5$	$n_{\text{jet}} \geq 4$, $\lvert\eta_{\text{jet}}\rvert < 2.5$
	$\geq$6j	$n_{\text{jet}} \geq 6$, $\lvert\eta_{\text{jet}}\rvert < 2.5$	$n_{\text{jet}} \geq 6$, $\lvert\eta_{\text{jet}}\rvert < 2.5$
	$\geq$8j	$n_{\text{jet}} \geq 8$, $\lvert\eta_{\text{jet}}\rvert < 2.5$	$n_{\text{jet}} \geq 8$, $\lvert\eta_{\text{jet}}\rvert < 2.5$
	$H_{\text{T}} > 500$ GeV	$H_{\text{T}} > 500$ GeV	$H_{\text{T}} > 500$ GeV
	$H_{\text{T}} > 1000$ GeV	$H_{\text{T}} > 1000$ GeV	$H_{\text{T}} > 1000$ GeV
	$H_{\text{T}} > 1500$ GeV	$H_{\text{T}} > 1500$ GeV	$H_{\text{T}} > 1500$ GeV
$E_{\text{T}}^{\text{miss}}$	$E_{\text{T}}^{\text{miss}} > 100$ GeV	$E_{\text{T}}^{\text{miss}} > 100$ GeV	$E_{\text{T}}^{\text{miss,tru}} > 100$ GeV
	$E_{\text{T}}^{\text{miss}} > 200$ GeV	$E_{\text{T}}^{\text{miss}} > 200$ GeV	$E_{\text{T}}^{\text{miss,tru}} > 200$ GeV
	$E_{\text{T}}^{\text{miss}} > 300$ GeV	$E_{\text{T}}^{\text{miss}} > 300$ GeV	$E_{\text{T}}^{\text{miss,tru}} > 300$ GeV
Top	ℓb	$n_{\ell=e,\mu} \geq 1$, $n_{b\text{-jet}} \geq 1$, 70% WP	$n_{\ell=e,\mu} \geq 1$, $n_{b\text{-jet}} \geq 1$
	t_{lep}	$n_{\ell=e,\mu} = 1$, $n_{\text{jet}} = n_{b\text{-jet}} = 1$, 70% WP	$n_{\ell=e,\mu} = 1$, $n_{\text{jet}} = n_{b\text{-jet}} = 1$
	t_{had}	$n_{\ell=e,\mu} = 0$, $n_{\text{jet}} = 3$, $n_{b\text{-jet}} = 1$, 70% WP, $\text{BDT}_{\text{top}} > 0.9$	$n_{\ell=e,\mu} = 0$, $n_{\text{jet}} = 3$, $n_{b\text{-jet}} = 1$
Lepton	$\geq 1\ell$	$n_{\ell=e,\mu} \geq 1$	$n_{\ell=e,\mu} \geq 1$
	2ℓ	ee, $\mu\mu$, or $e\mu$	ee, $\mu\mu$, or $e\mu$
	2ℓ–$\not{Z}$	$ee, \mu\mu, e\mu$; $\lvert m_{\ell\ell} - m_Z\rvert > 10$ GeV for same-flavour leptons	$ee, \mu\mu, e\mu$; $\lvert m_{\ell\ell} - m_Z\rvert > 10$ GeV for same-flavour leptons
	SS-2ℓ	ee, $\mu\mu$, or $e\mu$ with same charge	ee, $\mu\mu$, or $e\mu$ with same charge
	$\geq 3\ell$	$n_{\ell=e,\mu} \geq 3$	$n_{\ell=e,\mu} \geq 3$
	$\geq 2\tau$	$n_{\tau,\text{had}} \geq 2$	$n_{\tau} \geq 2$
Photon	1γ–$m_{\gamma\gamma}^{12}$	$n_{\gamma} \geq 3$, $m_{\gamma\gamma}$ defined with γ_1,γ_2	$n_{\gamma} \geq 3$, $m_{\gamma\gamma}$ defined with γ_1,γ_2
	1γ–$m_{\gamma\gamma}^{23}$	$n_{\gamma} \geq 3$, $m_{\gamma\gamma}$ defined with γ_2,γ_3	$n_{\gamma} \geq 3$, $m_{\gamma\gamma}$ defined with γ_2,γ_3

Anomalies in Higgs-related final states

Model-independent search for the presence of new physics in events including $X \to \gamma\gamma$ with $\sqrt{s} = 13$ TeV pp data recorded by the ATLAS detector at the LHC

ATLAS EXPERIMENT

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ABSTRACT: A model-independent search for new physics leading to final states containing a Higgs boson, with a mass of 125.09 GeV, decaying to a pair of photons is performed with 139 fb^{-1} of $\sqrt{s} = 13$ TeV pp collision data recorded by the ATLAS detector at the Large Hadron Collider at CERN. This search examines 22 final states categorized by the objects that are produced in association with the Higgs boson. These objects include isolated electrons or muons, hadronically decaying τ-leptons, additional photons, missing transverse momentum, and hadronic jets, as well as jets that are tagged as containing a b-hadron. ? No significant excesses above Standard Model expectations are observed and limits on the production cross section at 95% confidence level are set. Detector efficiencies are reported for all 22 signal regions, which can be used to convert detector-level cross-section limits reported in this paper to particle-level cross-section constraints.

Anomalies in Higgs-related final states

Search for non-resonant Higgs boson pair production in final states with leptons, taus, and photons in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

JHEP 08 (2024) 164 [arXiv:2405.20040]

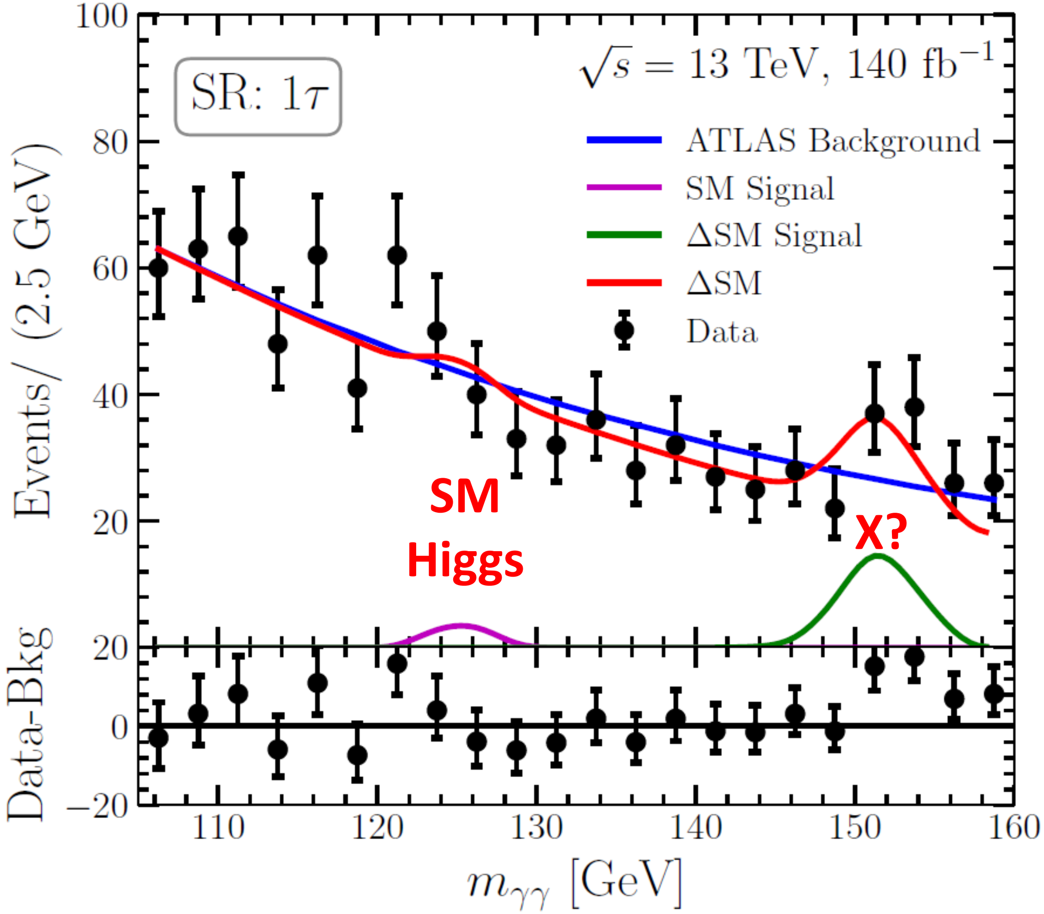
The ATLAS collaboration

E-mail: atlas.publications@cern.ch

Abstract: A search is presented for non-resonant Higgs boson pair production, targeting the $bbZZ$, $4V$ ($V = W$ or Z), $VV\tau\tau$, 4τ, $\gamma\gamma VV$ and $\gamma\gamma\tau\tau$ decay channels. Events are categorised based on the multiplicity of light charged leptons (electrons or muons), hadronically decaying tau leptons, and photons. The search is based on a data sample of proton-proton collisions at $\sqrt{s} = 13$ TeV recorded with the ATLAS detector during Run 2 of the Large Hadron Collider, corresponding to an integrated luminosity of 140 fb^{-1}. No evidence of the signal is found and the observed (expected) upper limit on the cross-section for non-resonant Higgs boson pair production is determined to be 17 (11) times the Standard Model predicted cross-section at 95% confidence level under the background-only hypothesis. The observed (expected) constraints on the HHH coupling modifier, κ_λ, are determined to be $-6.2 < \kappa_\lambda < 11.6$ ($-4.5 < \kappa_\lambda < 9.6$) at 95% confidence level, assuming the Standard Model for the expected limits and that new physics would only affect κ_λ.

Anomalies in Higgs-related final states

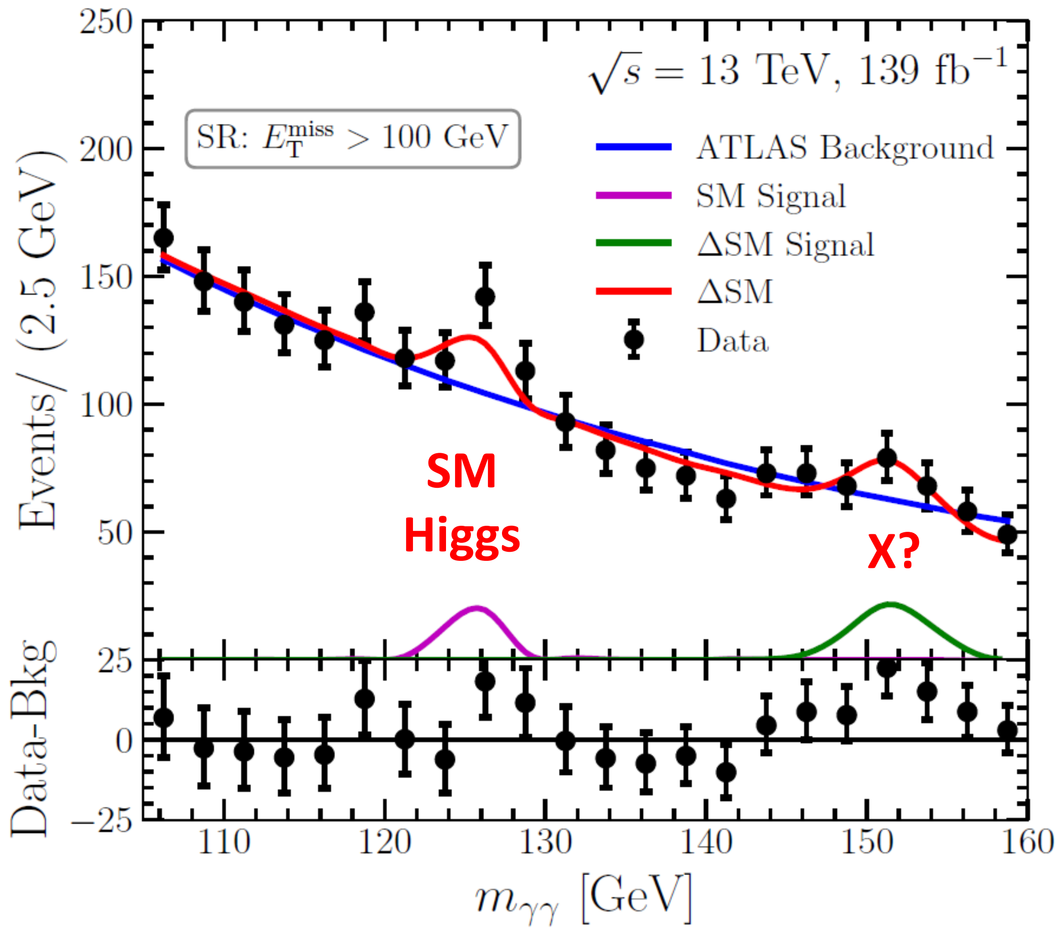
Diphotons in association with an hadronic tau



Crivellin, Ashanujjaman, Banik, Coloretti, Maharathy, Mellado, arXiv:2404.14492

Anomalies in Higgs-related final states

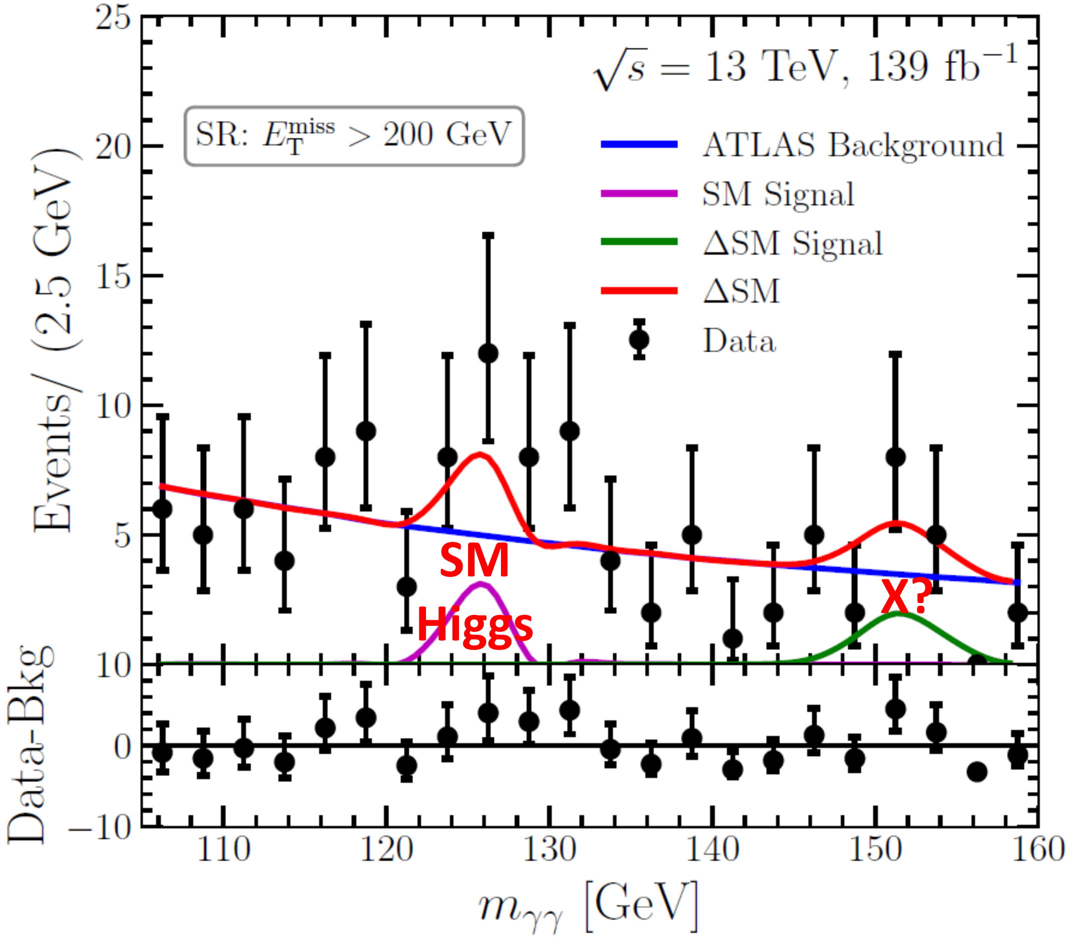
Diphotons in association with MET



Crivellin, Ashanujjaman, Banik, Coloretti, Maharathy, Mellado, arXiv:2404.14492

Anomalies in Higgs-related final states

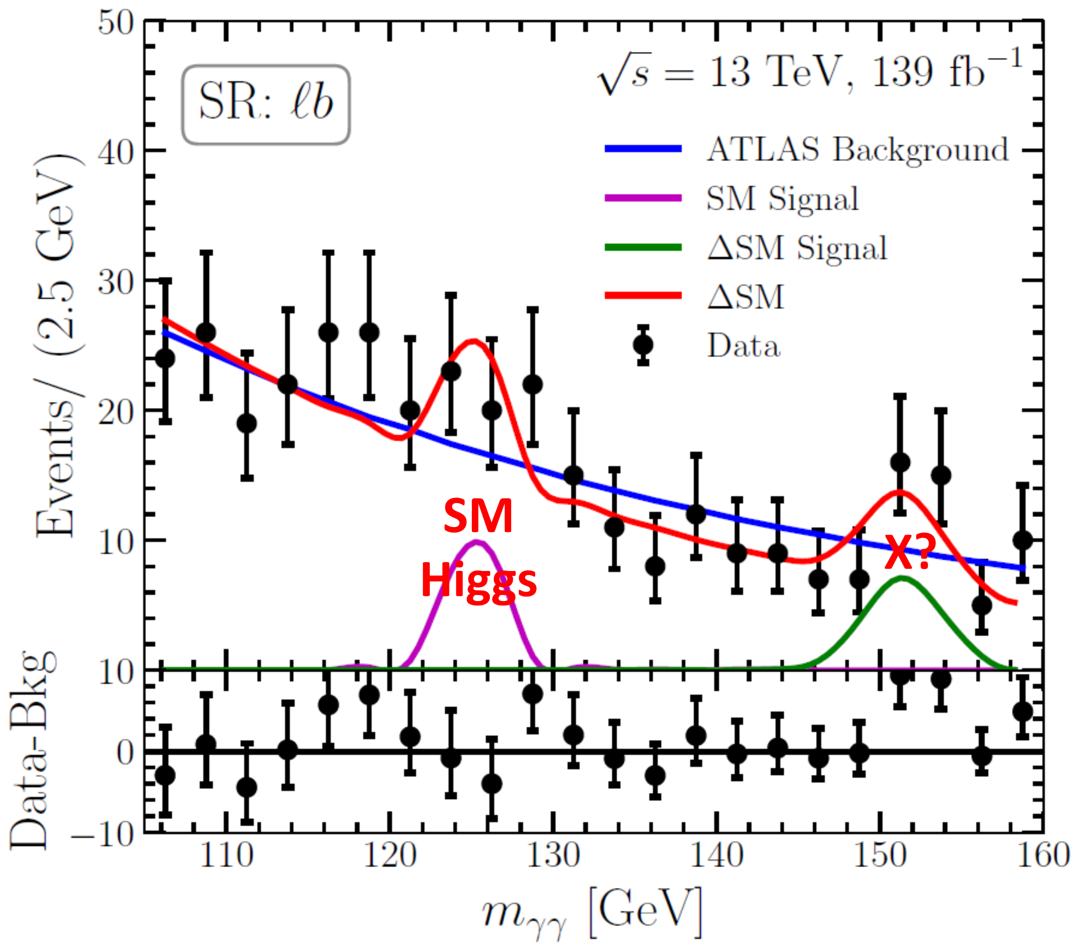
Diphotons in association with more MET



Crivellin, Ashanujjaman, Banik, Coloretti, Maharathy, Mellado, arXiv:2404.14492

Anomalies in Higgs-related final states

Diphotons in association with a lepton+*b*



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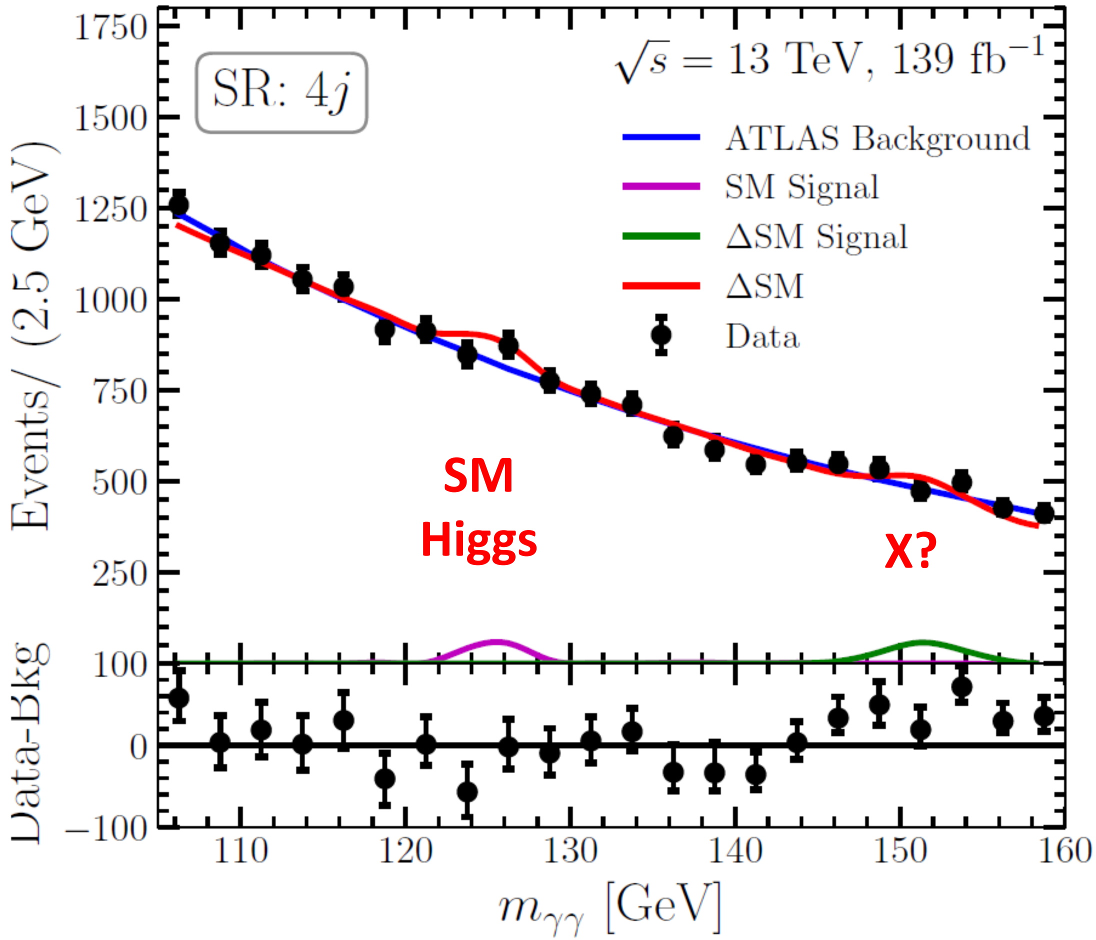
Anomalies in Higgs-related final states

Diphotons in association with 4 jets



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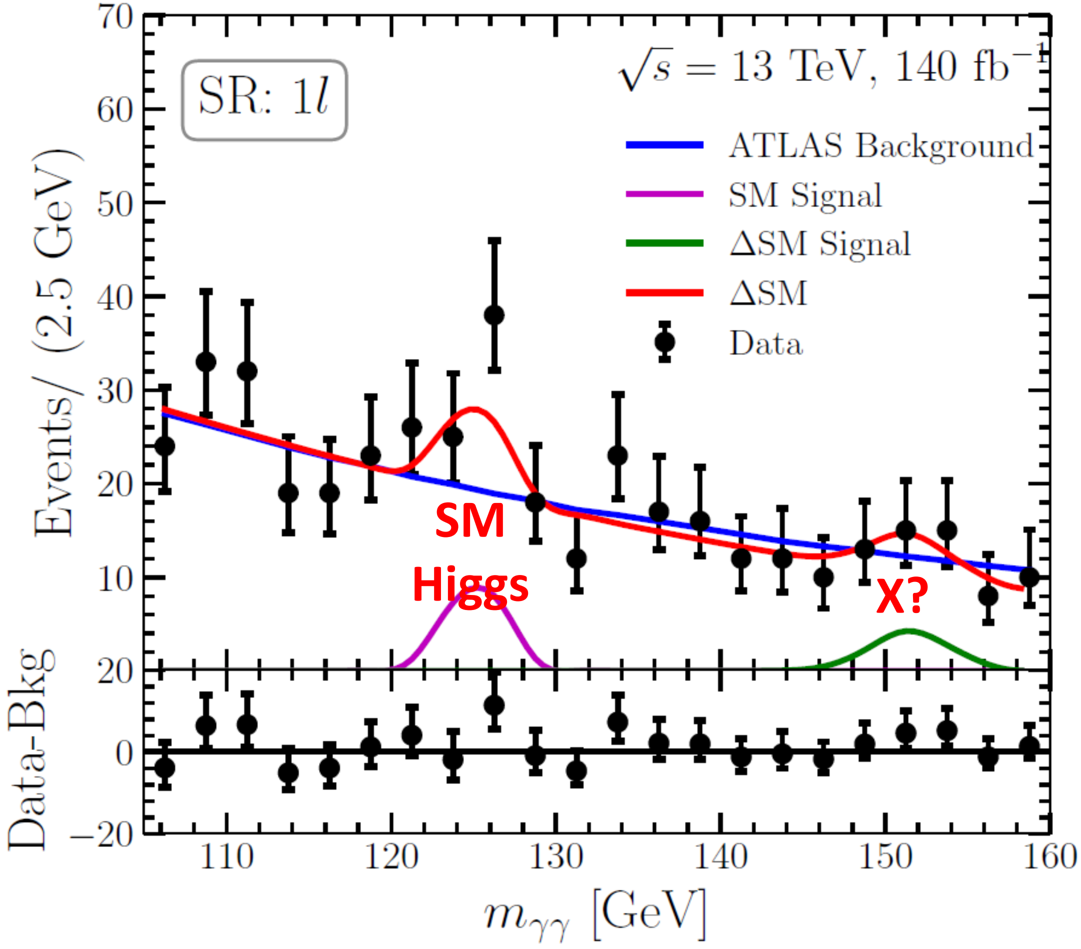
Anomalies in Higgs-related final states

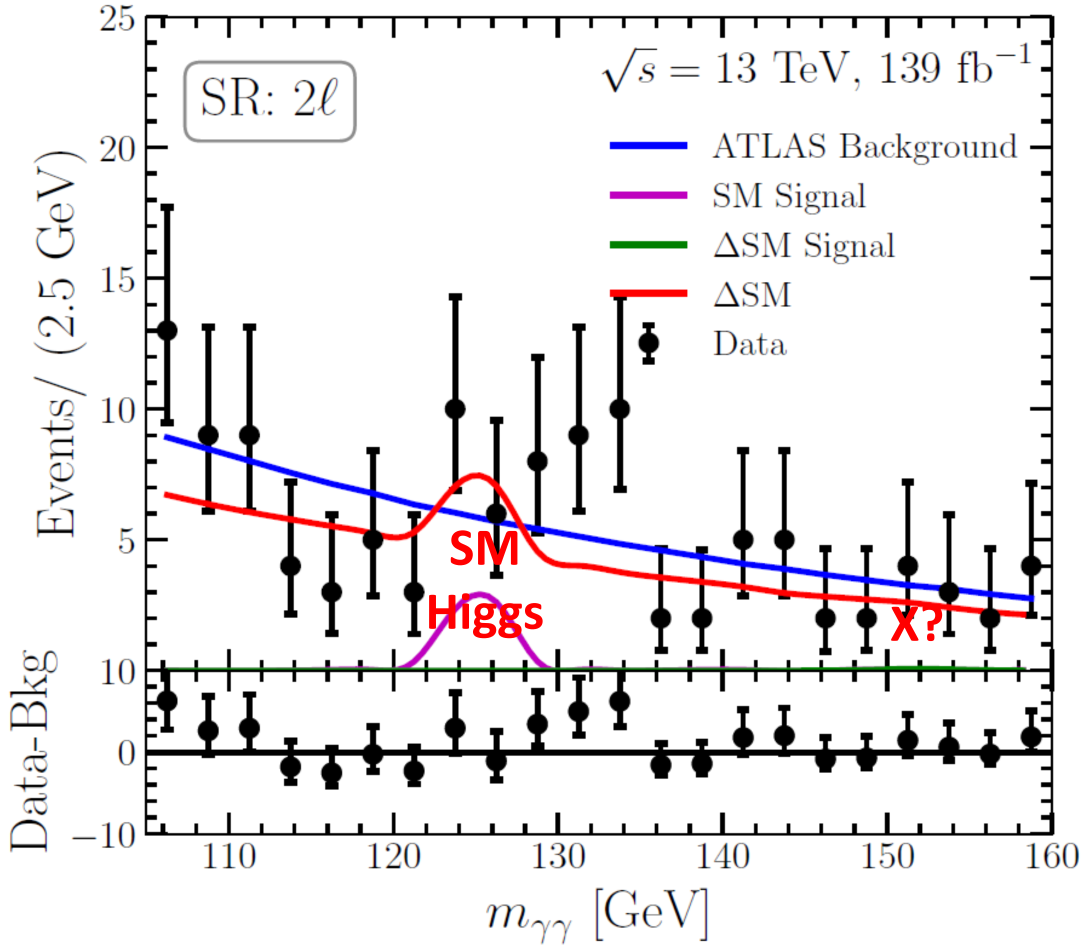
Diphotons in association with a light lepton



Crivellin, Ashanujjaman, Banik, Coloretti, Maharathy, Mellado, arXiv:2404.14492

Anomalies in Higgs-related final states

Diphotons in association with two light leptons



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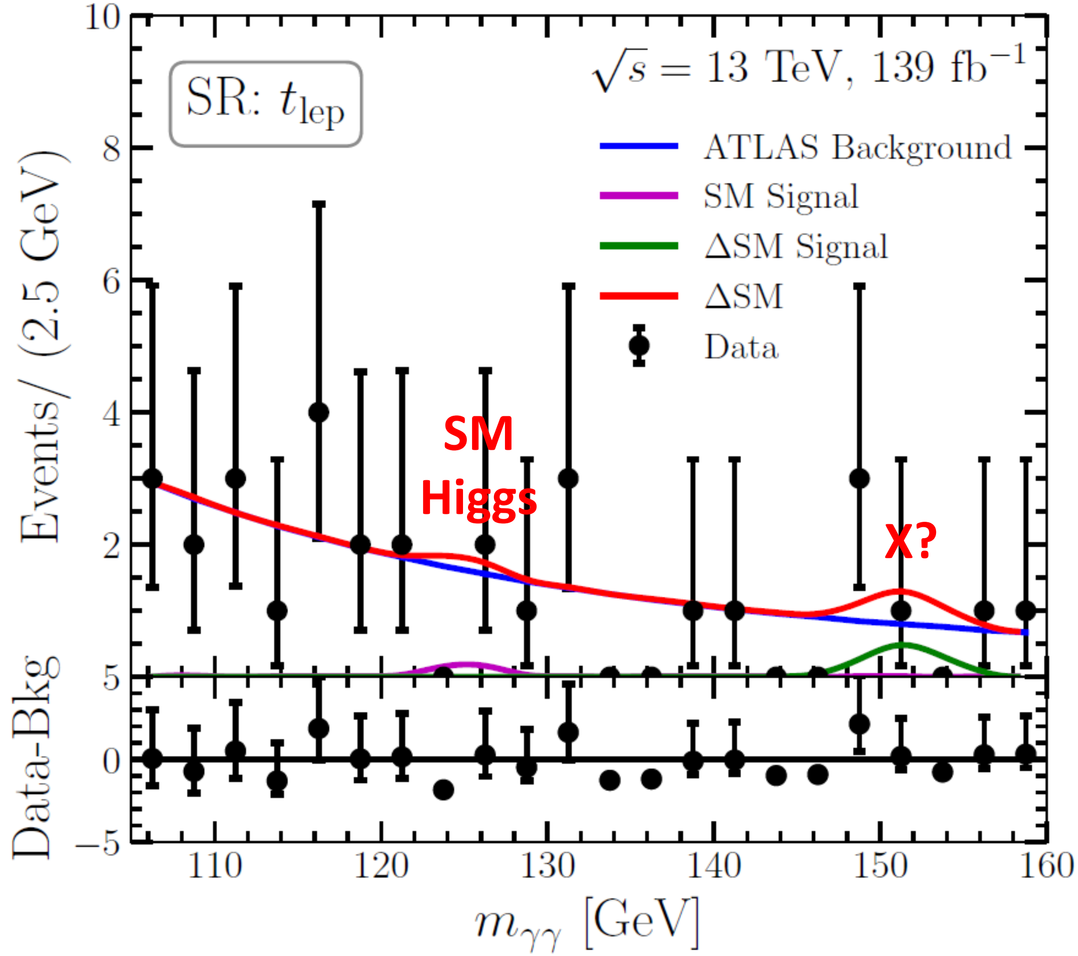
Anomalies in Higgs-related final states

Diphotons in association with a leptonic top



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Anomalies in Higgs-related final states

Intriguing excesses near 152 GeV
in several channels in ATLAS EXPERIMENT !

CMS Compact Muon Solenoid, what do you see?

No answer at the moment…

Hints of Higgs-like BSM physics?

One possible explanation:

Zero-hypercharge $SU(2)_L$ triplet scalar

Ashanujjaman, Banik, Coloretti, Crivellin, Maharathy, Mellado

arXiv:2402.00101, arXiv:2404.14492

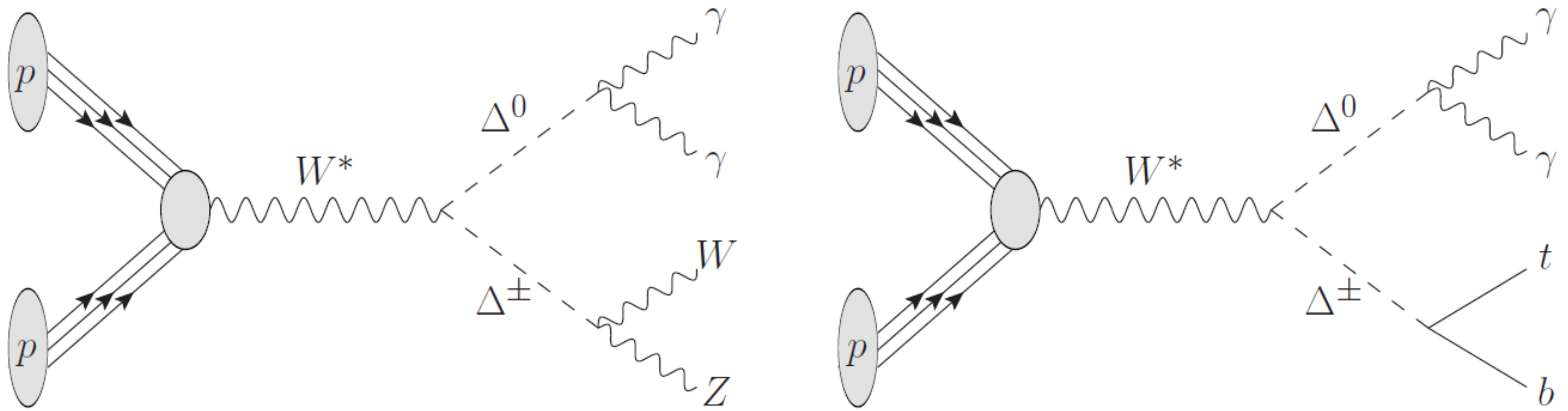

Fig. 1: Feynman diagrams showing the Drell-Yan production and decays of the triplet Higgses: $pp \to W^* \to (\Delta^\pm \to tb, WZ)(\Delta^0 \to \gamma\gamma)$, which we search for using the side-bands of the SM Higgs analyses of ATLAS.

Can lead to strong 1st-order phase transition for weak-scale baryogenesis.

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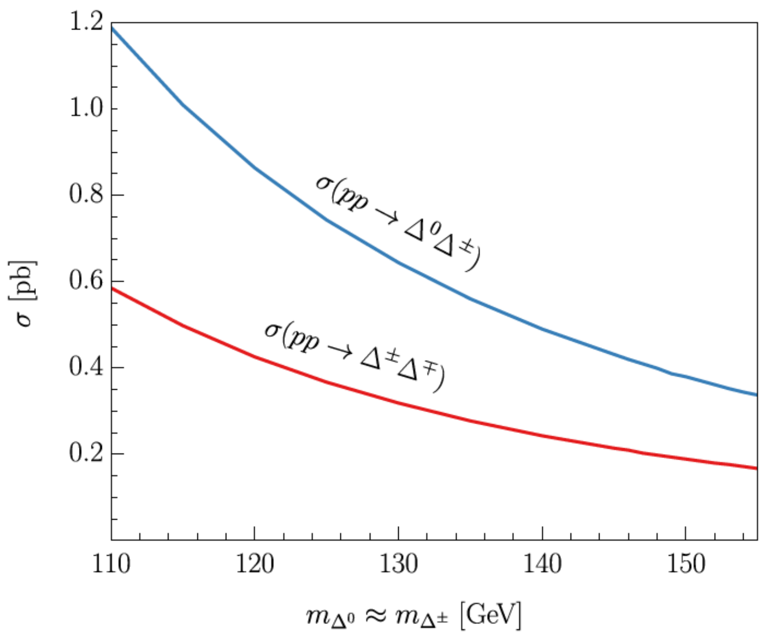

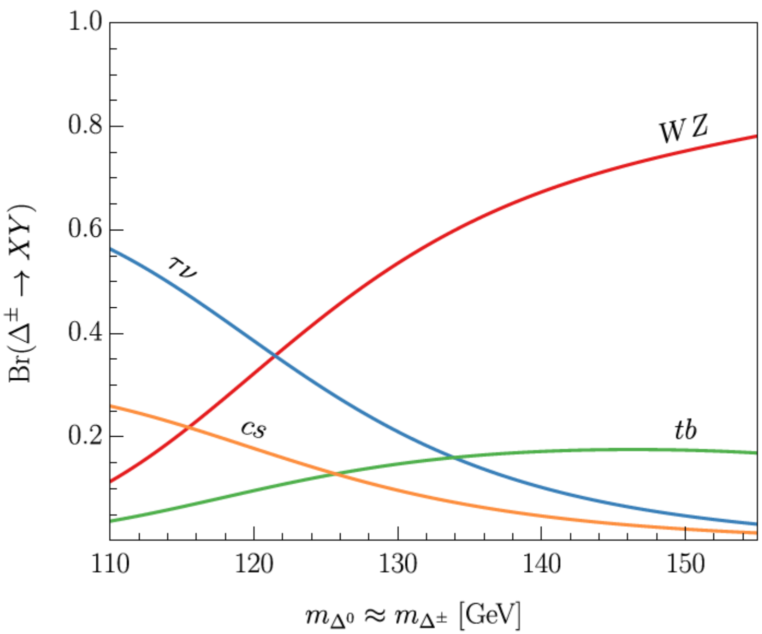

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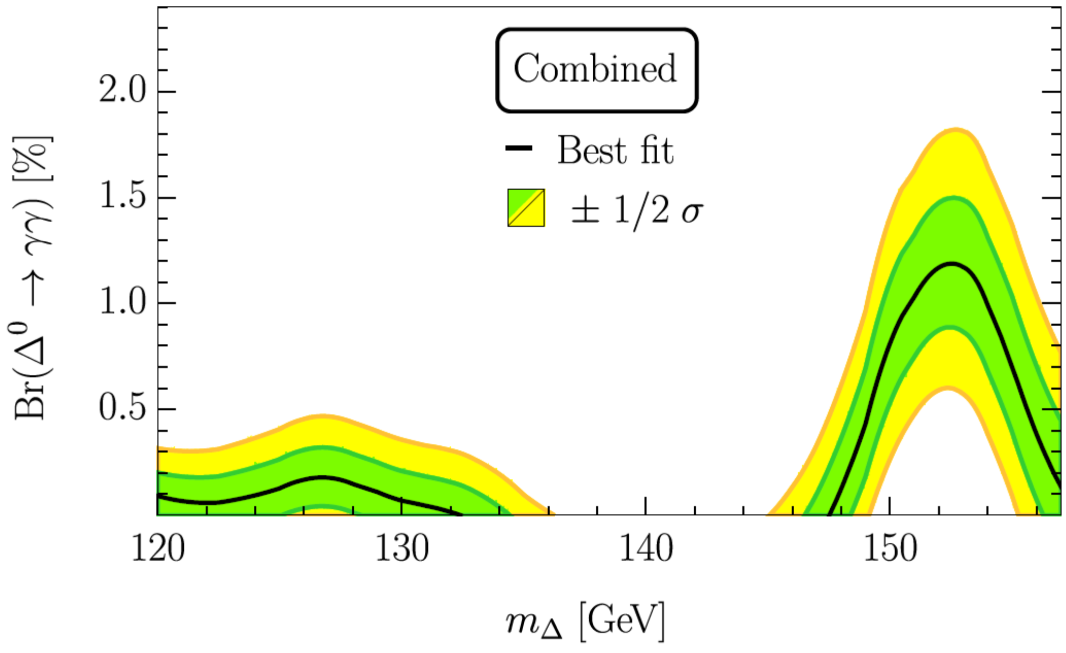

Significance: 4.3σ, although $\chi^2/\mathrm{dof} \sim 3$

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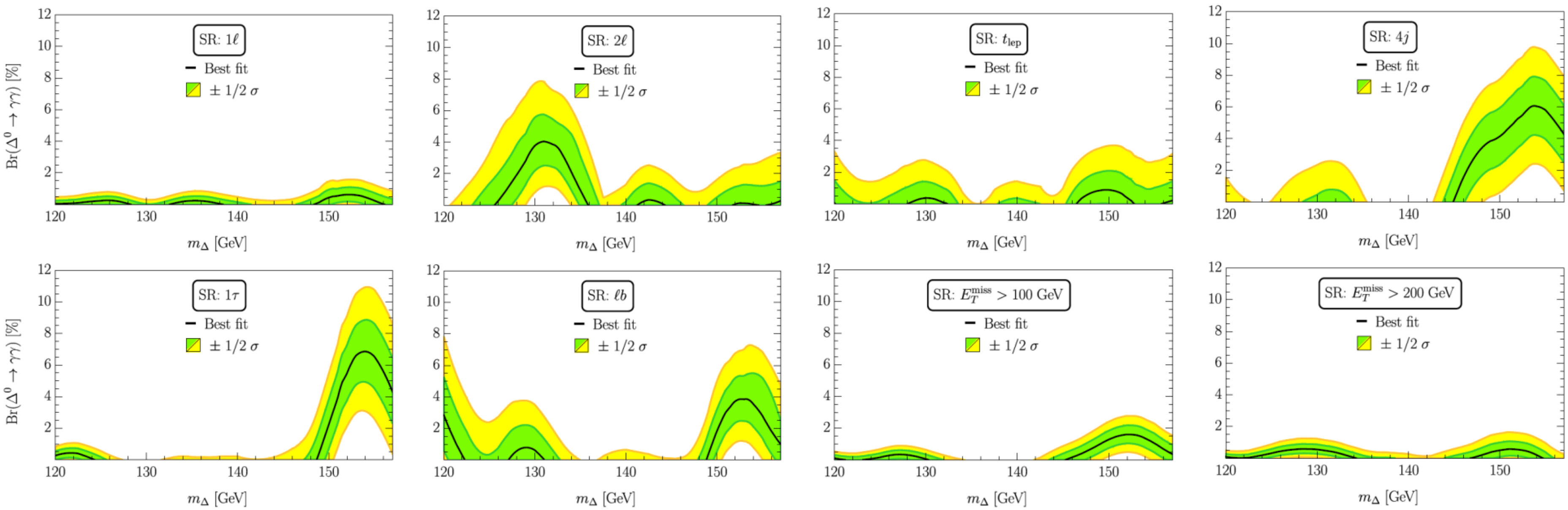

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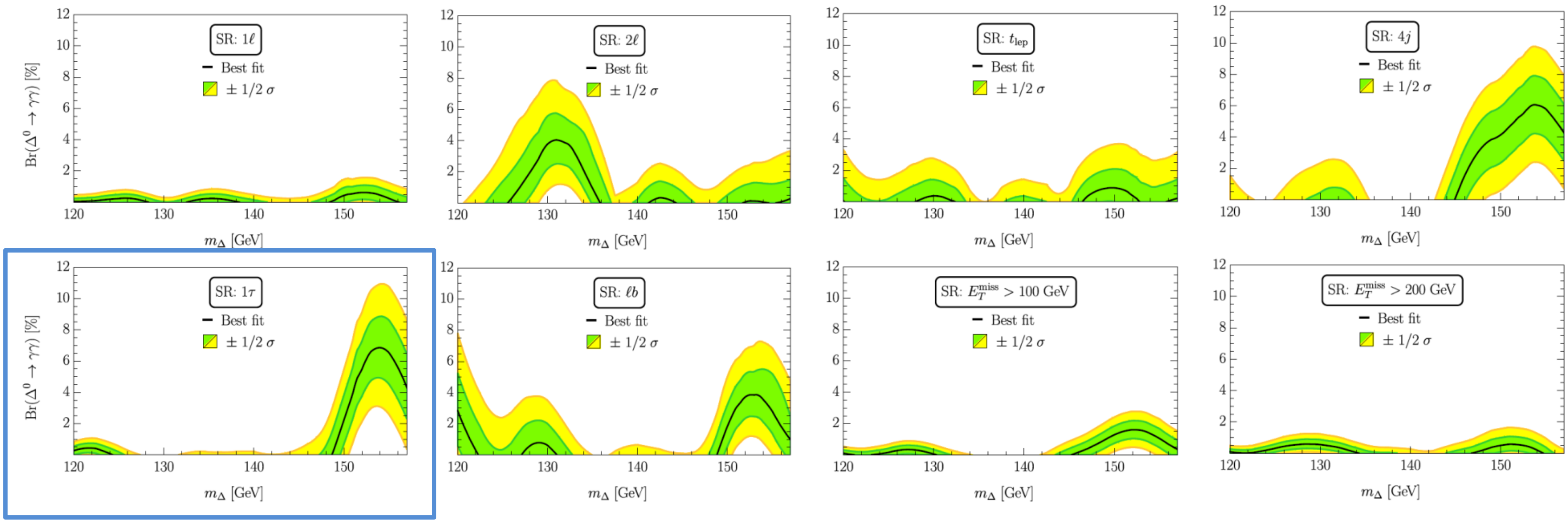

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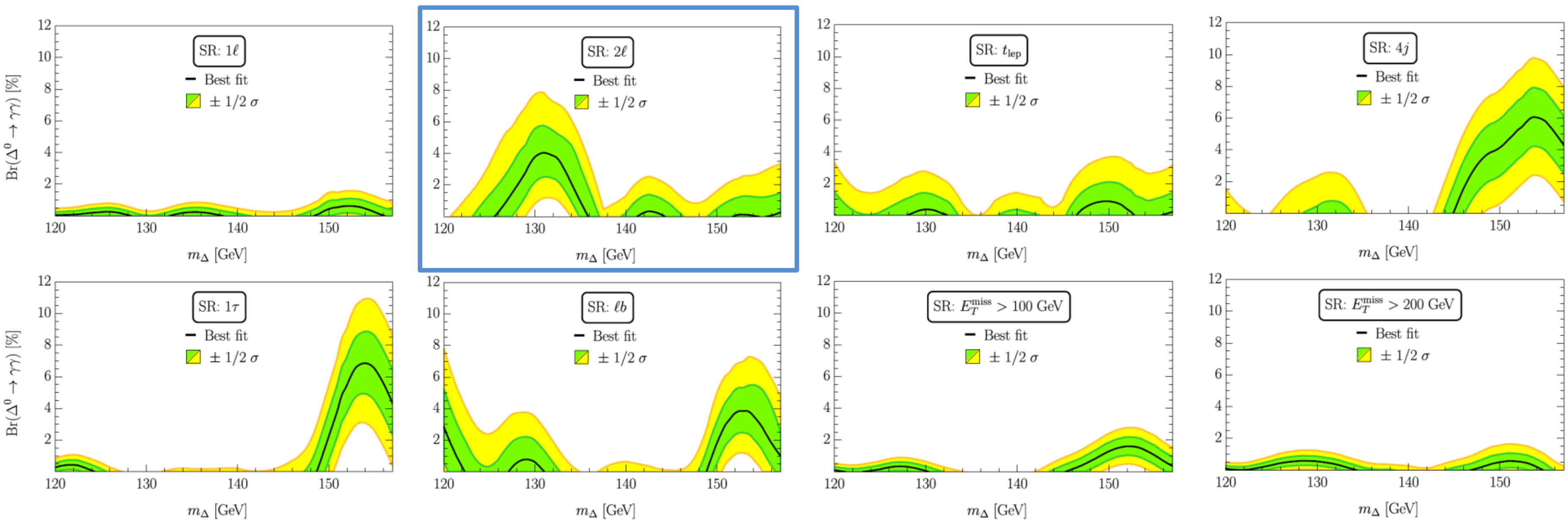

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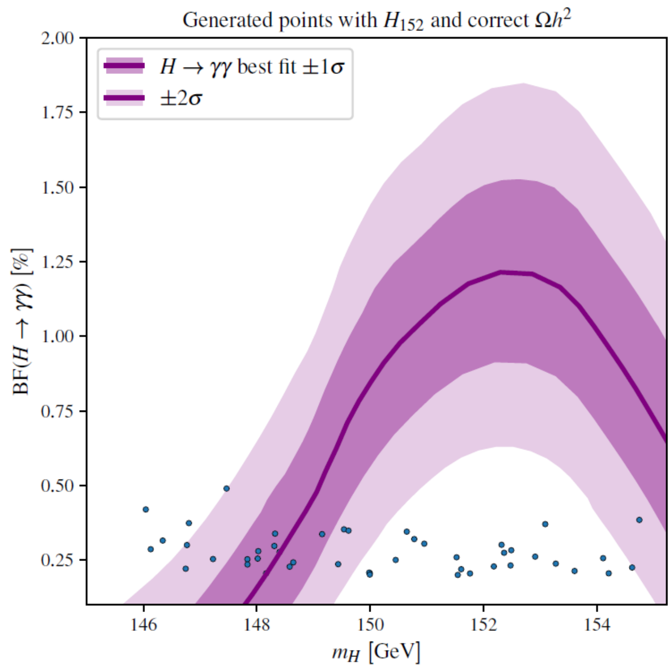
Zero-hypercharge $SU(2)_L$ triplet scalar

Can be part of a dark matter model, including also an $SU(2)_L$ triplet and singlet of Dirac fermions near 330 GeV. This may explain also CMS monojet excess.

Fuks, Goodsell, Murphy, arXiv:2409.03014

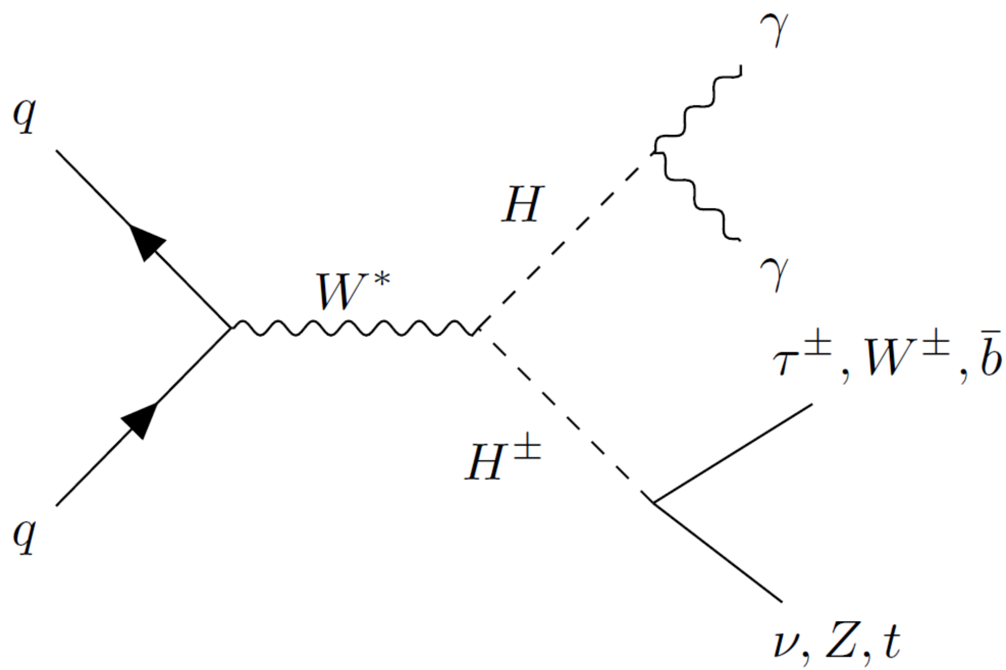


Hints of Higgs-like BSM physics?

Another possible explanation:

2HDM

Banik, Crivellin, arXiv:2407.06267



Absence of tree-level $H^\pm \to W^\pm Z$ decays is good for the fit.

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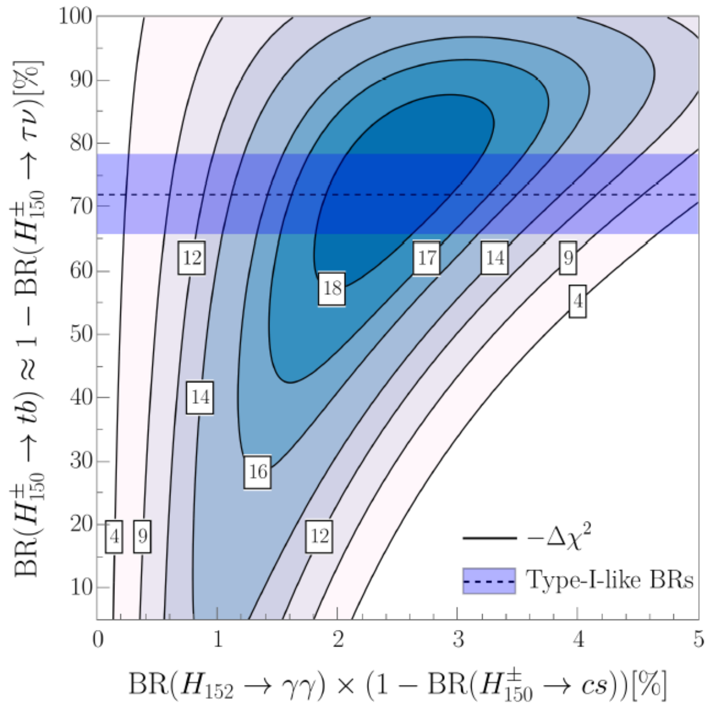

However, difficult to achieve diphoton BR of 2%. Can be done by adding higher-dimension operators (e.g., in composite Higgs) or the Z_2-violating term $-\lambda_6 H_1^\dagger H_1 H_2^\dagger H_1$ (for charged Higgs loop).

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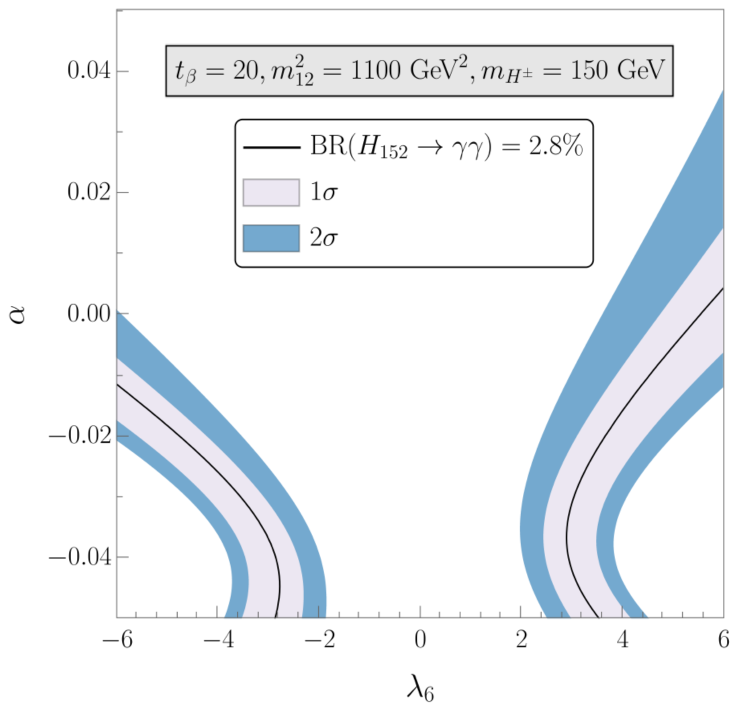
2HDM

Banik, Crivellin, arXiv:2407.06267

With $-\lambda_6 H_1^\dagger H_1 H_2^\dagger H_1$



Significance: 4.4σ

Outlook

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- The situation can be refined with CMS and Run 3 data. Worth looking there!
- Definitive conclusions likely with the HL-LHC.
- Worth pursuing dedicated searches for such final states, in the full diphoton mass range.

Thank you!