Radiative Signature of New Scalar Boson Decays in the $m_{\ell\ell\gamma}$ Spectrum at the LHC

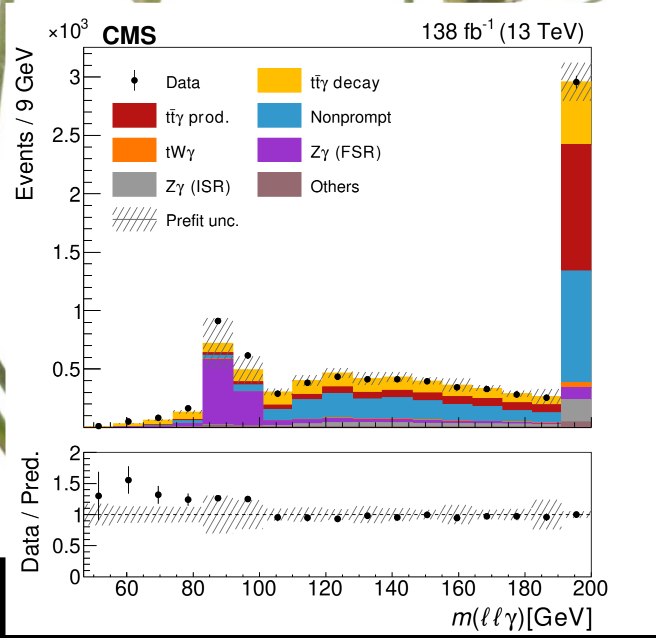
Institute for Collider Particle Physics
University of the Witwatersrand

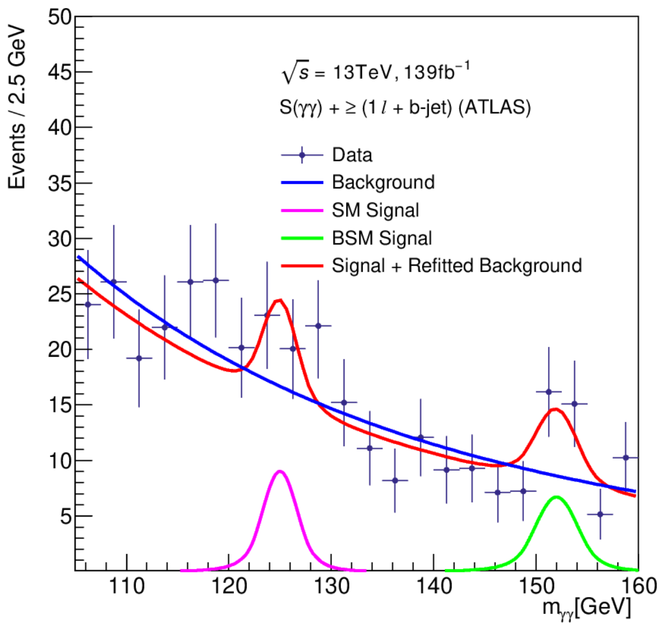
Pramod Sharma, Arnav Chauhan, Mukesh Kumar, Andreas Crivellin, Sukanta Dutta, Rachid Mazini and Bruce Mellado

arXiv: 2606.24801

THE 152 GEV CANDIDATE (2.7σ)

MUKESH KUMAR





Radiative Signature of New Scalar Boson Decays in the $m_{\ell\ell\gamma}$ Spectrum at the LHC

Pramod Sharma,[1,2,*] Arnav Chauhan,[1,2,†] Mukesh Kumar,[1,‡] Andreas Crivellin,[3,4,§] Sukanta Dutta,[2,5,¶] Rachid Mazini,[1,**] and Bruce Mellado[6,1,††]

[1] *School of Physics and Institute for Collider Particle Physics, University of the Witwatersrand, Johannesburg, Wits 2050, South Africa*

[2] *SGTB Khalsa College, University of Delhi, Delhi, India-110007.*

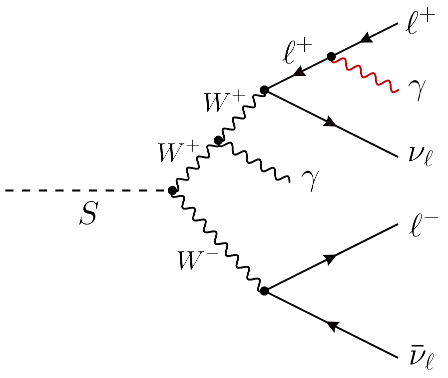
[3] *Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona*

[4] *ICREA, Institució Catalana de Recerca i Estudis Avançats, Passeig de Lluís Companys 23, 08010 Barcelona, Spain*

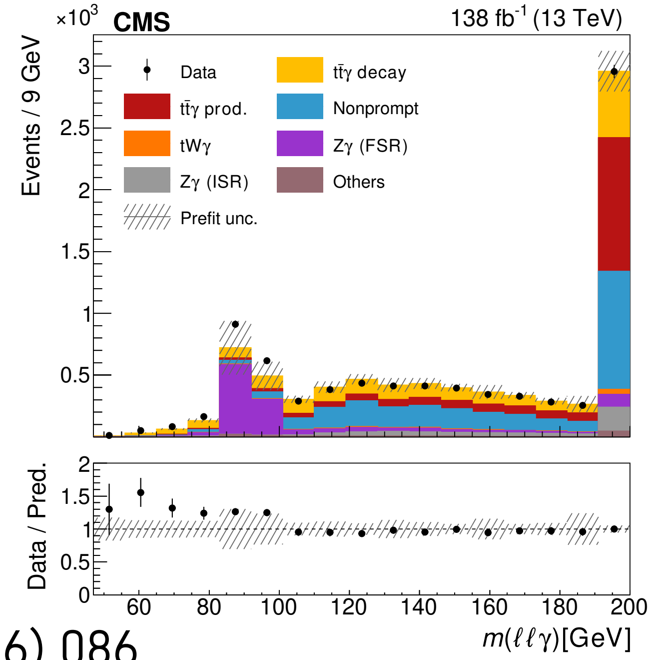
[5] *Delhi School of Analytics, Institution of Eminence, University of Delhi, Delhi, India-110007.*

[6] *Institute of High Energy Physics, 19B, Yuquan Road, Shijing District, 100049, Beijing, China*

(Dated: June 24, 2026)



We investigate the radiative decay $S \to W^+W^-\gamma$ in the context of the multi-lepton anomalies and recent indications of a narrow scalar resonance near $m_S = 152 \pm 1$ GeV in the $\gamma\gamma$, $Z\gamma$, and W^+W^- channels at the Large Hadron Collider. These excesses arise in final states containing leptons, missing transverse momentum, and associated b-jets, and motivate a search for a corresponding localized excess in the invariant-mass spectrum of the dilepton–photon system, $m_{\ell\ell\gamma}$, in events with associated b-jets. We use recent CMS measurements of the $t\bar{t}\gamma$ differential cross sections [1] to study the $m_{\ell\ell\gamma}$ spectrum and perform a search for a scalar-resonance contribution. A localized excess is observed, compatible with the scalar-resonance hypothesis, with a global significance of 2.7σ at $m_S = 152$ GeV. This result provides additional support for the hypothesis of a narrow resonance. The ratio $\sigma(S \to W^+W^-\gamma)/\sigma(S \to W^+W^-) = (2.14\pm0.77)\%$ is extracted. This value is compatible with an enhanced radiative contribution that could arise in scenarios beyond the Standard Model.



[1] JHEP 04 (2026) 086

LHC Multi-Lepton Anomalies ($\boldsymbol{e\mu}(+\boldsymbol{b})$)

- The “multi-lepton anomalies”, are LHC processes with two or more leptons in the final state, with and without b-jets, where statistically significant disagreements with the SM predictions have been observed.

- Some of the excesses already emerged with Run-1 data (2011-2012) of ATLAS and CMS.

- They were confirmed by independent and larger data sets taken during Run-2 leading to disagreements with the SM, exceeding the 5σ threshold:

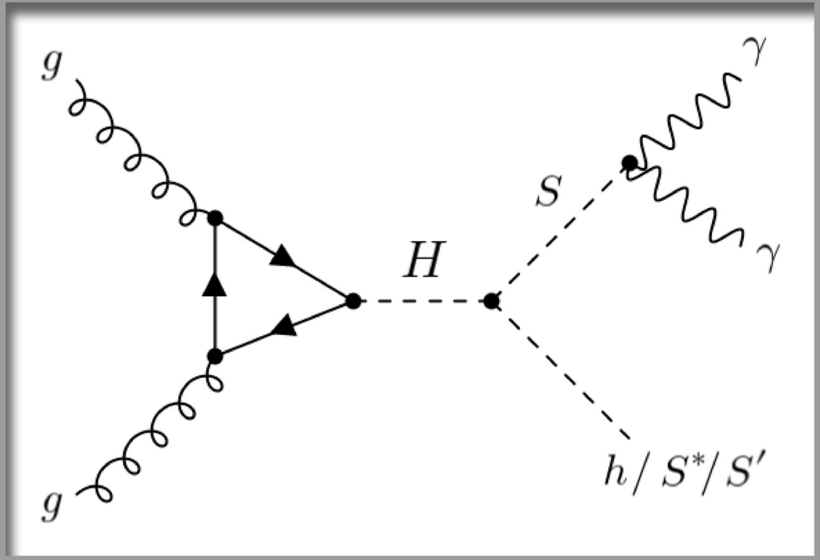
Final State	Characteristics	SM background	Significance
$\ell^+\ell^-$+(jets, b-jets)	$m_{\ell\ell} < 100\,\mathrm{GeV}$	$t\bar{t}, W^{\pm}t$	$> 5\sigma$
$\ell^+\ell^-$+(no jets)	$m_{\ell\ell} < 100\,\mathrm{GeV}$	W^+W^-	$\approx 3\sigma$
$\ell^{\pm}\ell^{\pm}, 3\ell$ + (b-jets)	Moderate H_T	$t\bar{t}W^{\pm}, t\bar{t}t\bar{t}, t\bar{t}Z/tW^{\pm}Z$	$> 3\sigma$
$\ell^{\pm}\ell^{\pm}, 3\ell$, (no b-jets)	In association with h	$W^{\pm}h, W^{\pm}W^{\mp}W^{\pm}$	$\approx 4\sigma$
$Z(\to \ell^+\ell^-)\ell^{\pm}$, (no b-jets)	$p_{\mathrm{T}Z} < 100\,\mathrm{GeV}$	$ZW^{\pm}$	$> 3\sigma$

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

Multilepton Anomalies predict Scalar S of mass 152±5 GeV candidate

2021 (Group 1)	2023 (Group 2)	2025 (Group 3)
$\gamma\gamma + E^T_{\text{miss}}$ [20, 43]	$\gamma\gamma + \geq (1\ell + 1b\text{-jet})$ [44]	$\gamma\gamma + \tau$ [45]
$\gamma\gamma + W, Z$ [46, 47]	$\gamma\gamma + \geq 4$ jets [44]	$\gamma\gamma + 2(\ell, \tau)$ [45]
$\gamma\gamma + b$-jet [48, 49]	$WW^* + E^T_{\text{miss}}$ [50, 51]	
$\gamma\gamma + 2b$-jets [52]		
$Z(\to \ell^+\ell^-)\gamma + 1\ell, jj$ [53]		

S.Battacharya, et al. 2503.16245



Final states predicted by simplified model of 2017

Timeline of growing excess

2021 3.9σ

3.9σ at 151.5 GeV

$S(\to Z(\to \ell^+\ell^-)\gamma) + \ell$
$S(\to bb) + E^T_{miss}$
$S(\to \gamma\gamma) + E^T_{miss}$
$S(\to \gamma\gamma) + b$-jet
$S(\to \gamma\gamma) + W, Z$
$S(\to \gamma\gamma) + \ell$
$S \to \gamma\gamma$ (inclusive)

2023 4.7σ

4.7σ at 151.5 GeV

In addition to the 2021 combination,

$S(\to \gamma\gamma) + \geq 4$ jets
$S(\to WW^*) + E^T_{\text{miss}}$
$S(\to \gamma\gamma) + \geq 1\ell + 1b$-jet

2024 5.3σ

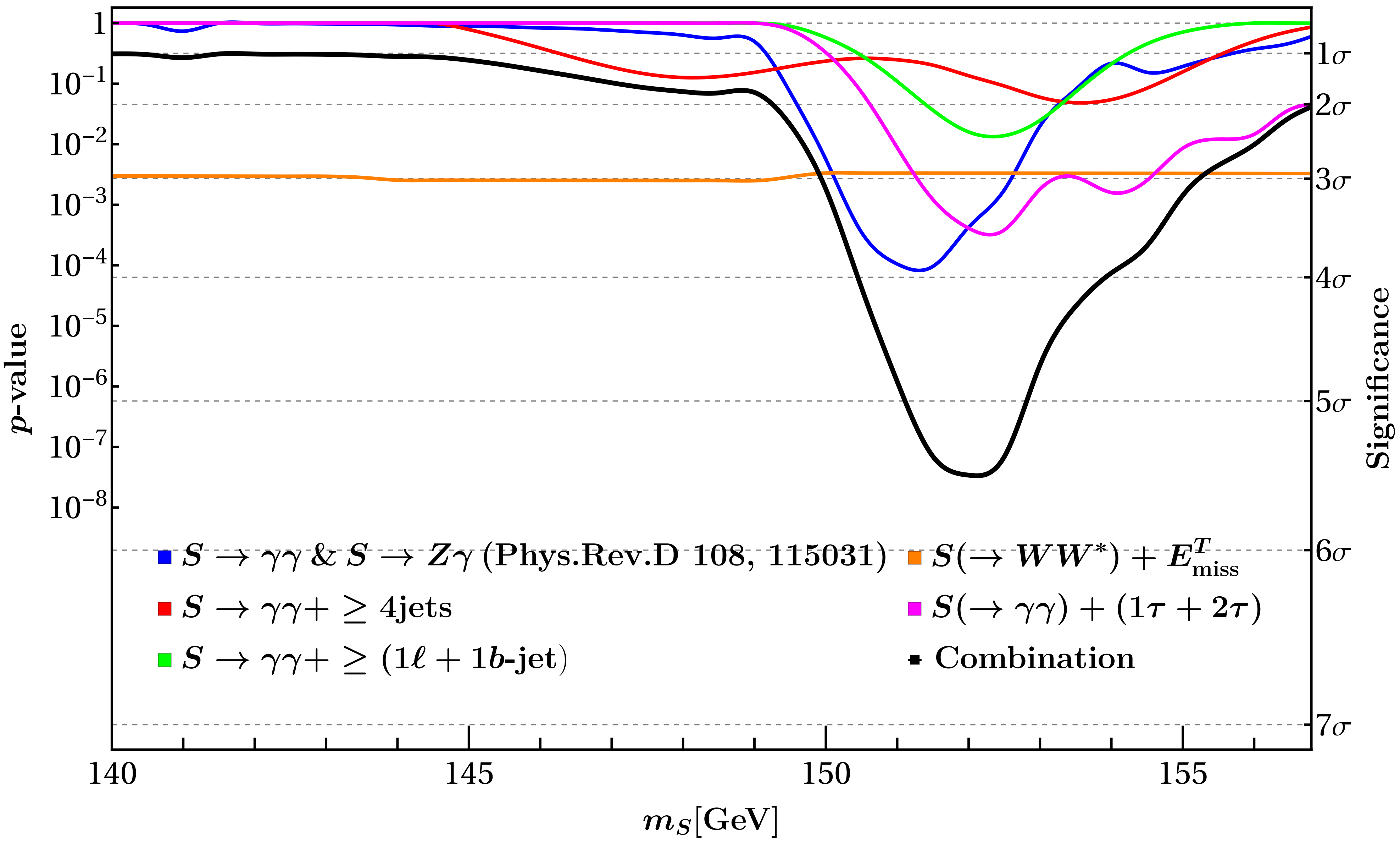
5.3σ at 152.0 GeV

In addition to the 2023 combination,

$S(\to \gamma\gamma) + \tau$
$S(\to \gamma\gamma) + 2(\ell, \tau)$

All significances are global

1603.01208
1606.01674
1608.03466
J.Phys.Conf.Ser. 802 (2017)
1706.06659
1707.05997
1709.09419
1711.07874
1809.06344
1901.05300
1909.03969
1912.00699
2102.10596
2109.02650
2208.14767
2306.17209
2404.07822
2503.16245
2509.14378



The Timeline

2015
Run 1 excesses
Motivating asymm.
Diboson final states

2016
Simplified di-boson model
predicting multi-lepton excesses
Eur.Phys.J.C 76 (2016) 10, 580

2017/2018
Multi-lepton anomalies in Run 1
Prediction of m_S=150$\pm$5 GeV
in association with leptons/jets/MET
J.Phys.G 45 (2018) 11, 115003

2019
Multi-lepton anomalies
verified in Run 2
JHEP 10 (2019) 157

2021
First narrow excess at 151.5$\pm$1
GeV with jets/leptons/MET
reaching 3.9$\boldsymbol{\sigma}$
Phys.Rev.D 108 (2023) 11, 115031

2025
Narrow excess at
152$\pm$1 GeV with 5.3$\boldsymbol{\sigma}$
with leptons/jets/MET
2503.16245

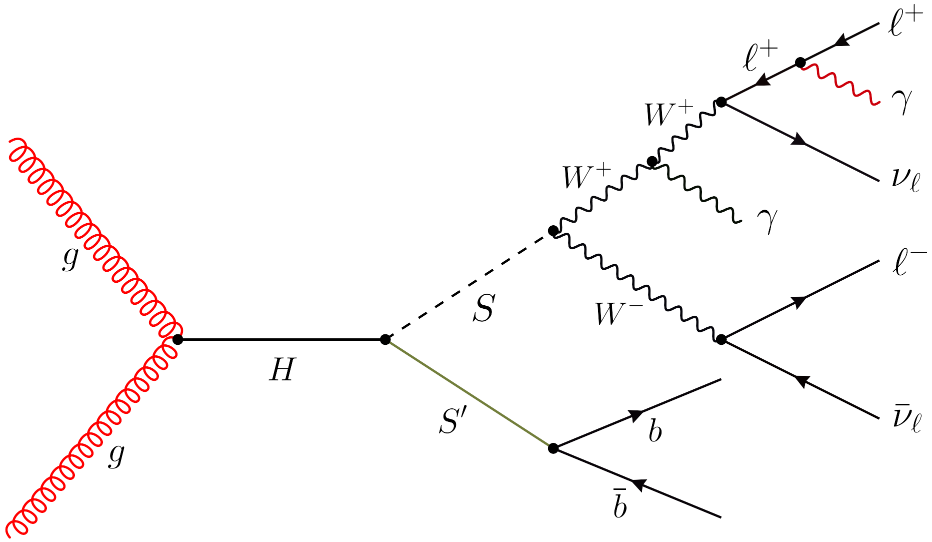
- Currently, continue to accumulate excesses at 152±1 GeV and exploring Triplet Y=0 leading to triboson excesses

Emergence of New Type of multilepton excess

- We examine a new type of multi-lepton excess that has emerged with the Run-2 data at the LHC, which involves the production of **two opposite-sign** leptons ($\ell = e, \mu$), a photon, and at least a b-jet.
- This excess could be interpreted as a radiative correction to $S \rightarrow W^+W^-$, i.e., $S \rightarrow W^+W^-\gamma$ produced in association with b-jets, as suggested by the multi-lepton anomalies.

The dominant process is $pp \rightarrow H \rightarrow SS'$ via gluon-fusion.

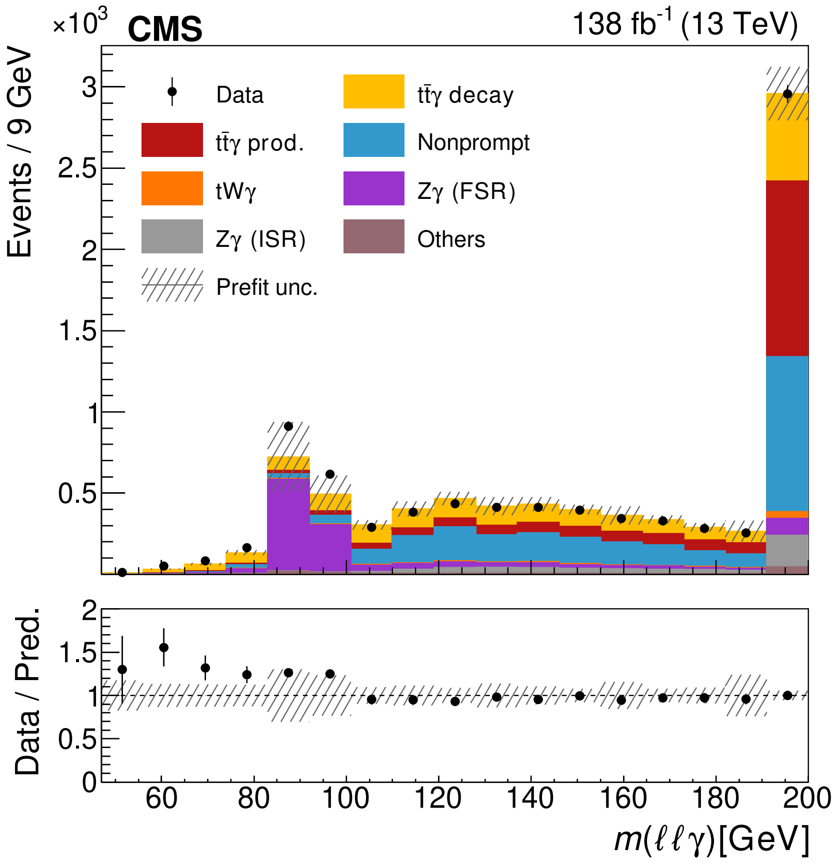
$$m_H = 270 \text{ GeV}, m_S' = 95 \text{ GeV}, m_S \in [100, 200] \text{ GeV}$$



**From this point onward, we use a shorthand notation in which only the decay of S is explicitly stated, with the production mechanism implicitly understood to be gluon fusion followed by the decay of the heavy scalar H. For example, $\sigma(S \rightarrow W^+W^-)$ denotes the cross section for the process $gg \rightarrow H \rightarrow SS'$, with $S \rightarrow W^+W^-$ and, for instance, $S' \rightarrow b\bar{b}$.

Dataset: [CMS Collaboration] Inclusive and differential measurements of the $t\bar{t}\gamma$ cross section and the $t\bar{t}\gamma/t\bar{t}$ cross section ratio in proton-proton collisions at $\sqrt{s}$= 13 TeV

Ref.[1] JHEP 04 (2026) 086



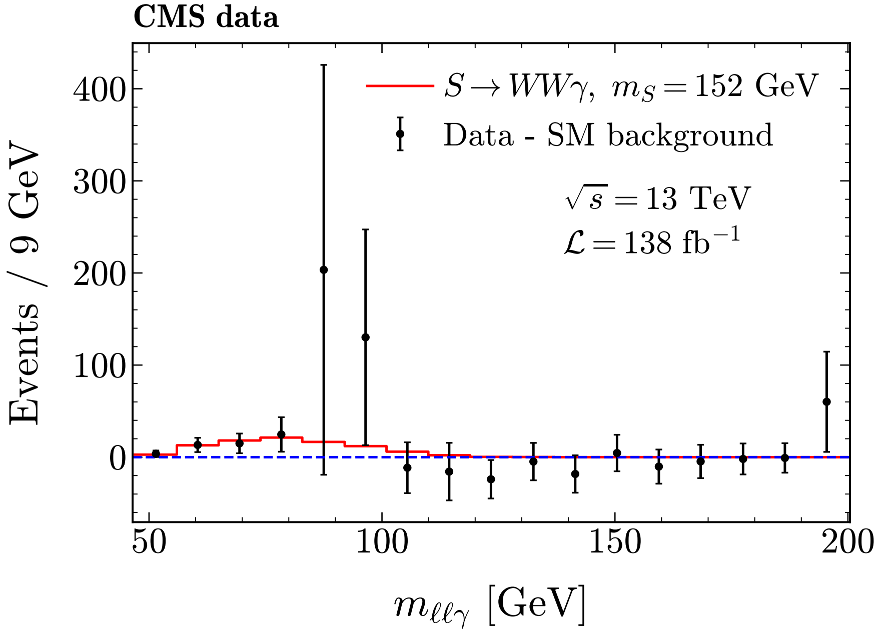
- The $m\ell\ell\gamma$ distribution reported by CMS exhibits good agreement between the observed and predicted event yields for $m\ell\ell\gamma$ > 120 GeV, as indicated by the data-to-prediction ratio shown in the lower panel.
- We therefore use this region to determine an overall normalization of the SM background prediction.
- Specifically, the background is normalized to the data using a factor defined as the ratio of the total number of observed events over the total predicted SM background yield above 120 GeV. The resulting normalization factor is 0.98, consistent with unity within the quoted systematic uncertainties.

Figure 4-b:
Distributions of the invariant mass of the two leptons + photon system, for events with two same-flavour leptons, as estimated by the simulation before the fit.

Dataset: Beyond the Standard Model (BSM) interpretation/fit

- SM process [CMS]: $pp \rightarrow t\bar{t} \rightarrow \ell^+\nu_\ell\ell^-\bar{\nu_\ell}\,\gamma b\bar{b}$
- BSM process: $pp \rightarrow H \rightarrow S\,S' \rightarrow \ell^+\nu_\ell\ell^-\bar{\nu_\ell}\,\gamma b\bar{b}$

The event selection, taken from Ref. [1], is defined as follows: Each event must contain at least two charged leptons ($\ell = e, \mu$). Electron candidates are selected if $p_T > 25\,\mathrm{GeV}$ for the leading lepton and $p_T > 20\,\mathrm{GeV}$ for the sub-leading leptons within the $|\eta| < 2.5$ region. Muons are required to satisfy $p_T > 25\,\mathrm{GeV}$ for the leading lepton and $p_T > 15\,\mathrm{GeV}$ for the sub-leading lepton, and $|\eta| < 2.4$. The two highest p_T leptons are selected as the leading pair and are required to have opposite electric charges. The allowed dilepton final states are $e^\pm\mu^\mp$, $e^\pm e^\mp$, and $\mu^\pm\mu^\mp$. The pair of leptons must have an invariant mass $m_{\ell\ell} > 40\,\mathrm{GeV}$. In addition, exactly one photon is required in the event with $p_T > 20\,\mathrm{GeV}$ and must lie within $|\eta| < 2.5$. Jets are required to have $p_T > 30\,\mathrm{GeV}$ and $|\eta| < 2.4$. A minimum of two jets is required, with at least one of them identified as a b-tagged jet.



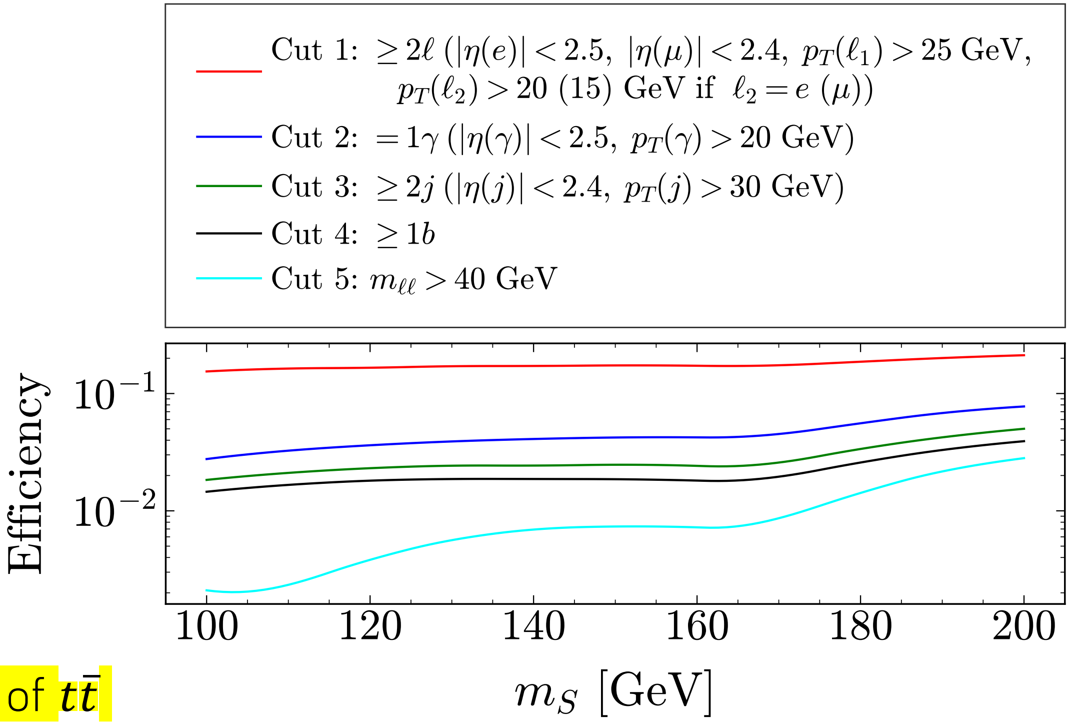
Event yields per 9 GeV after subtraction of the normalized SM backgrounds as a function of $m\ell\ell\gamma$ in GeV. Here, Data − SM background is defined as "excess." The background is normalized by a scale factor derived from the ratio of total event yields in data and background in the region $m\ell\ell\gamma$ > 120 GeV. The BSM signal for mS = 152 GeV is represented by a red line.

Dataset: Beyond the Standard Model (BSM) Selection efficiency

- SM process [Simulation]: $pp \to t\bar{t} \to \ell^+\nu_\ell\ell^-\bar{\nu_\ell}\,\gamma b\bar{b}$
- BSM process: $pp \to H \to S\,S' \to \ell^+\nu_\ell\ell^-\bar{\nu_\ell}\,\gamma b\bar{b}$

Efficiency of the BSM signal after applying the correction factor of 1.01.

The efficiencies are organized in terms of four consecutive steps: leptonic, photonic, jet, and b-jet requirements. And final requirement, $m_{\ell\ell} > 40$ GeV.



Note: ATLAS and CMS report excess of events in the vicinity of $t\bar{t}$ threshold. [adequacy of QCD prediction?]

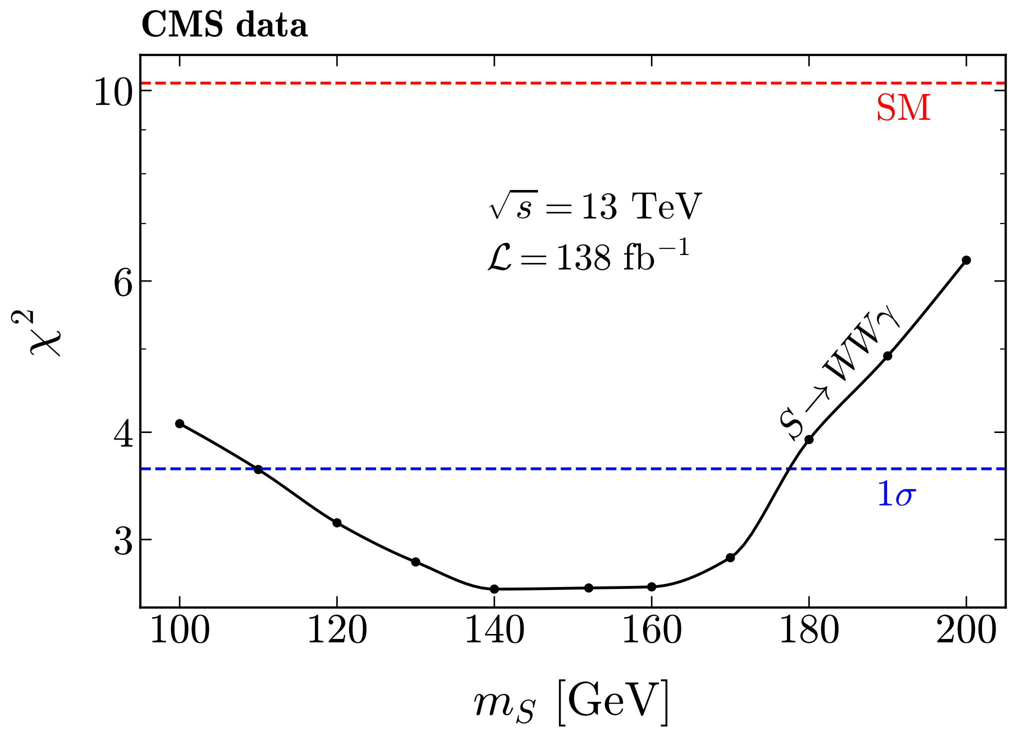
Interpreted as "toponium". $\sigma(pp \to \eta_t \to t\bar{t}\gamma) = 8.8^{+1.2}_{-1.4}$ pb.

clearly strong overestimate of missing threshold effects

⇨ Even with such a large cross-section impact on the $\ell\ell\gamma$ ($\to m_{\ell\ell\gamma}$) final state is very small

Results: Mass measurement

- The minimum occurs at m_S = 140 GeV, where χ^2 = 2.63.
- While the no-BSM hypothesis yields χ^2 = 10.21.
- At the 68% confidence level, the constraint on the scala mass is $m_S = 140^{+35}_{-30}$ GeV.
- The relatively wide confidence interval is primarily consequence of the restricted phase space imposed b the requirement $m_{\ell\ell}$ > 40 GeV, compounded by the larg systematic uncertainties near the Z-boson mass.
- The small value of the minimum χ^2 could be due to an overestimation of uncertainties.
- Evaluated at m_S = 152 GeV, the fit yields χ^2 = 2.63, corresponding to a significance of 2.7σ.



$$\chi^2(m_S) = \sum_{i=1}^{8} \frac{\left[E_i - N_i^{\mathrm{BSM}}(m_S)\right]^2}{\sigma_i^2},$$

$$E_i = N_i^{\mathrm{data}} - N_i^{\mathrm{SM\,bkg}}.$$

$$\sigma_i^2 = \left(\sigma_i^{\mathrm{stat}}\right)^2 + \left(\sigma_i^{\mathrm{syst}}\right)^2$$

Conclusion(s): Mass measurements of Scalar Candidate around 150 GeV

Mass (GeV)	Channel	Reference
150^{+5}_{-5}	$S \to W^+W^- \to \ell^+\nu_\ell\ell^-\nu_\ell$ (b-jet veto applied)	[12]
150^{+7}_{-6}	$S \to W^+W^- \to \ell^+\nu_\ell\ell^-\nu_\ell$ (with associated b-jet)	[45]
152^{+1}_{-1}	$S \to \gamma\gamma, Z\gamma$	[19, 21]
140^{+35}_{-30}	$S \to W^+W^-\gamma \to \ell^+\nu_\ell\ell^-\nu_\ell\gamma$	This work

- The result provides additional support for the hypothesis of a narrow resonance near 152 GeV corresponding to an additional significance of 2.7σ.

[12] S. von Buddenbrock, A. S. Cornell, A. Fadol, M. Kumar, B. Mellado, and X. Ruan, Multi-lepton signatures of additional scalar bosons beyond the Standard Model at the LHC, J. Phys. G **45**, 115003 (2018), arXiv:1711.07874

[45] S. Banik, G. Coloretti, A. Crivellin, and B. Mellado, Uncovering new Higgses in the LHC analyses of differential $t\bar{t}$ cross sections, JHEP **01**, 155, arXiv:2308.07953 [hep-

[19] A. Crivellin, Y. Fang, O. Fischer, S. Bhattacharya, M. Kumar, E. Malwa, B. Mellado, N. Rapheeha, X. Ruan, and Q. Sha, Accumulating evidence for the associated production of a new Higgs boson at the LHC, Phys. Rev. D **108**, 115031 (2023), arXiv:2109.02650 [hep-

[21] S. Bhattacharya, B. Lieberman, M. Kumar, A. Crivellin, Y. Fang, R. Mazini, and B. Mellado, Emerging Excess Consistent with a Narrow Resonance at 152 GeV in High-Energy Proton-Proton Collisions, (2025), arXiv:2503.16245 [hep-ph].

Conclusion(s): Cross-section Ratio of Scalar Candidate = 150 GeV

We also determine the ratio $\sigma(S \rightarrow W^+W^-\gamma)/\sigma(S \rightarrow W^+W^-) = 2.14 \pm 0.77\%$, which is larger than expected from radiative corrections induced by SM processes alone.

- This value is somewhat larger than the expectation from purely SM radiative processes, which is of order 1%, and may therefore point to an enhancement driven by physics beyond the Standard Model. However, more data will be needed to shed light on this hint.

- On the experimental side, this work supports relaxing the $m_{\ell\ell}$ > 40 GeV requirement in future measurements of the $t\bar{t}\gamma$ cross section and of the differential $t\bar{t}\gamma/t\bar{t}$ cross-section ratio. Extending the accessible $m_{\ell\ell}$ range, together with the larger Run-3 data set, will be important for clarifying the nature and detailed shape of the excess.

Thank you.

Inclusive and differential measurements of the $\mathrm{t\bar{t}\gamma}$ cross section and the $\mathrm{t\bar{t}\gamma/t\bar{t}}$ cross section ratio in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS collaboration

ABSTRACT: Inclusive and differential cross section measurements of top quark pair ($\mathrm{t\bar{t}}$) production in association with a photon (γ) are performed as a function of lepton, photon, top quark, and $\mathrm{t\bar{t}}$ kinematic observables, using data from proton-proton collisions at $\sqrt{s} = 13\,\mathrm{TeV}$, corresponding to an integrated luminosity of $138\,\mathrm{fb}^{-1}$, collected at the CERN LHC with the CMS detector. Events containing two leptons (electrons or muons) and a photon in the final state are considered. The fiducial cross section of $\mathrm{t\bar{t}\gamma}$ is measured to be $137 \pm 8\,\mathrm{fb}$, in a phase space including events with a high momentum, isolated photon. The fiducial cross section of $\mathrm{t\bar{t}\gamma}$ is also measured to be $56 \pm 5\,\mathrm{fb}$ when considering only events where the photon is emitted in the production part of the process. Both measurements are in agreement with the theoretical predictions, of $126 \pm 19\,\mathrm{fb}$ and $57 \pm 5\,\mathrm{fb}$, respectively. Differential measurements are performed at the particle and parton levels. Additionally, inclusive and differential ratios between the cross sections of $\mathrm{t\bar{t}\gamma}$ and $\mathrm{t\bar{t}}$ production are measured. The inclusive ratio is found to be 0.0133 ± 0.0005, in agreement with the standard model prediction of 0.0127 ± 0.0008. The top quark charge asymmetry in $\mathrm{t\bar{t}\gamma}$ production is also measured to be -0.012 ± 0.042, compatible with both the standard model prediction and with no asymmetry.

ArXiv ePrint: 2511.01995

JHEP04(2026)086