The 152±1 GeV Scalar Candidate

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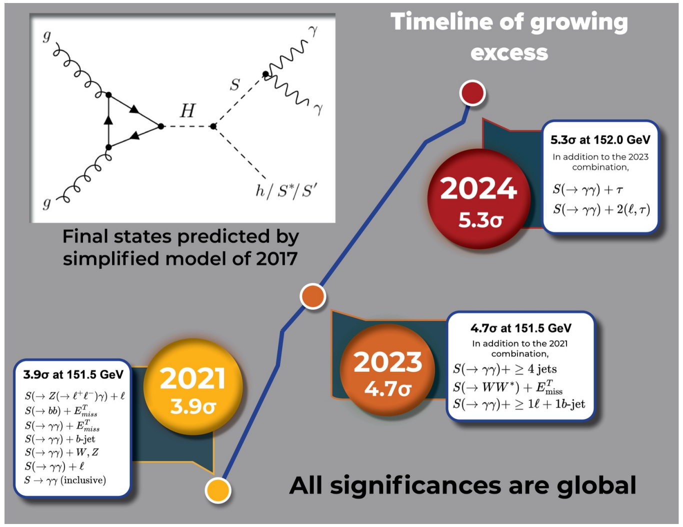
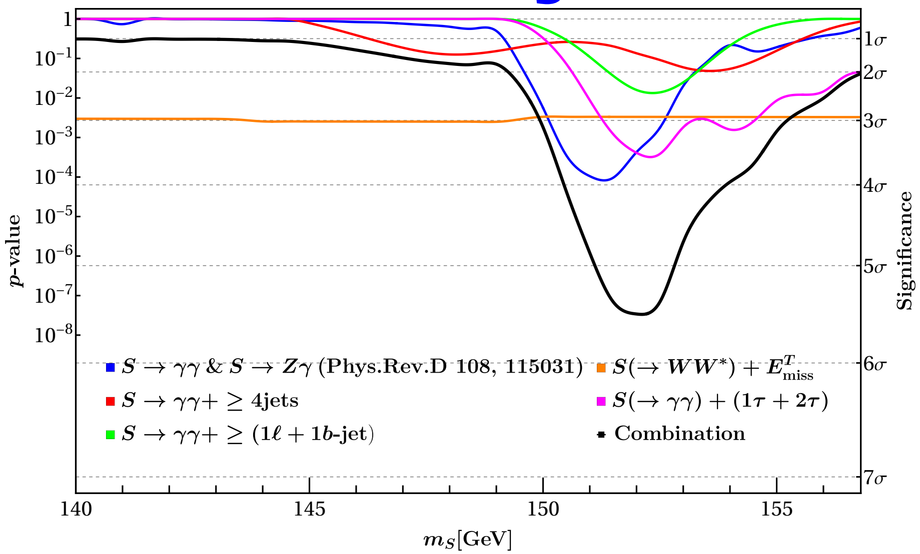
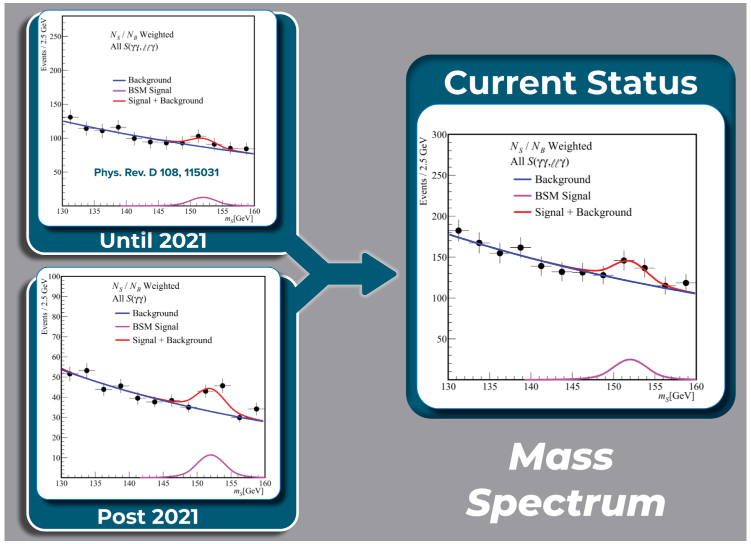
Outline

- ❑The Timeline
- ❑The multilepton anomalies
  - ❑**Prediction of m_S=150±5 GeV**
- ❑The S(152) candidate
  - ❑**The anatomy**







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 $m_S=150\pm5$ 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 ± 1
GeV with jets/leptons/MET
reaching $3.9\boldsymbol{\sigma}$
Phys.Rev.D 108 (2023) 11, 115031

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

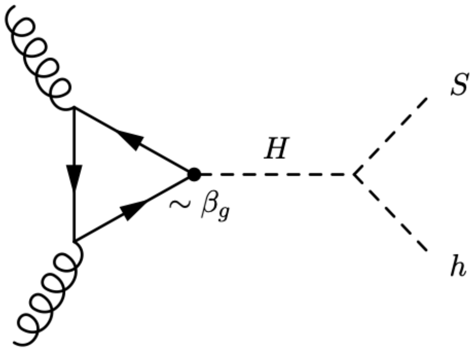
Currently, continue to accumulate excesses at 152 ± 1 GeV and exploring Triplet Y=0 leading to triboson excesses

The Simplified Model

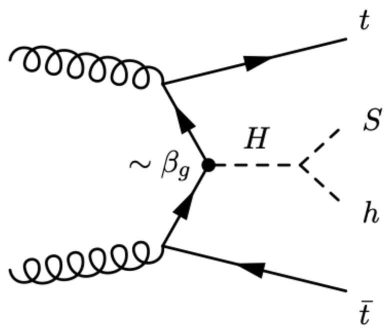
Eur. Phys. J. C (2016) 76:580

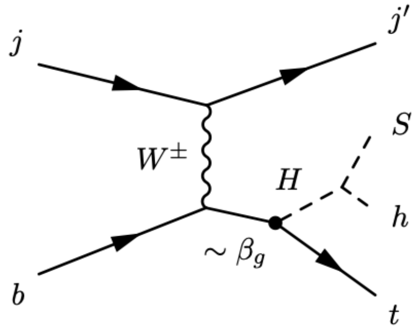
The simplified Model (from Run I)

1. The starting point of the hypothesis is the existence of a boson, H, that contains Higgs-like interactions, with a mass in the range 250-280 GeV
2. In order to avoid large quartic couplings, incorporate a mediator scalar, S, that interacts with the SM and Dark Matter.
3. Dominance of H→Sh,SS decay over other decays



(a) Gluon fusion (ggF).





$$\mathcal{L}_{\text{int}} \supset -\beta_g \frac{m_t}{v} t\bar{t}H + \beta_V \frac{m_V^2}{v} g_{\mu\nu} V^{\mu} V^{\nu} H$$

$$\mathcal{L}_{HhS} = -\frac{1}{2} v \Big[\lambda_{hhS} hhS + \lambda_{hSS} hSS + \lambda_{HHS} HHS + \lambda_{HSS} HSS + \lambda_{HhS} HhS \Big],$$

The Decays of H

- In the general case, H can have couplings as those displayed by a Higgs boson in addition to decays involving the intermediate scalar and Dark Matter

$$H \to WW, ZZ, q\bar{q}, gg, Z\gamma, \gamma\gamma, \chi\chi$$

$$+ \quad H \to SS, Sh, hh$$

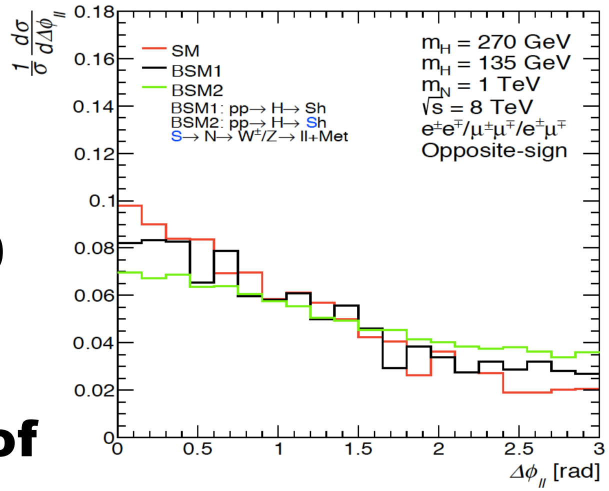
Dominant decays

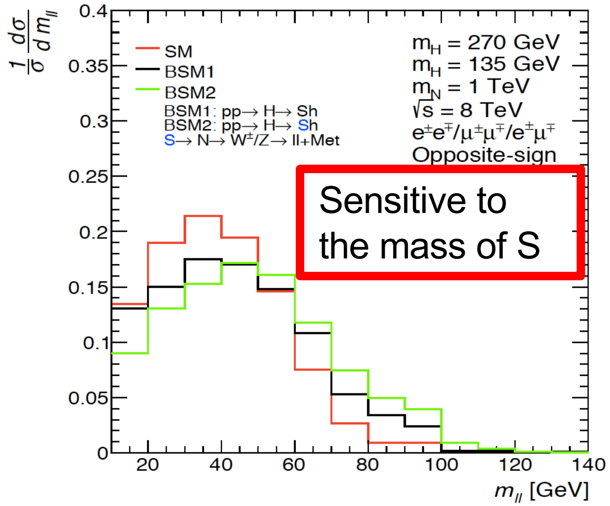
Diboson decay

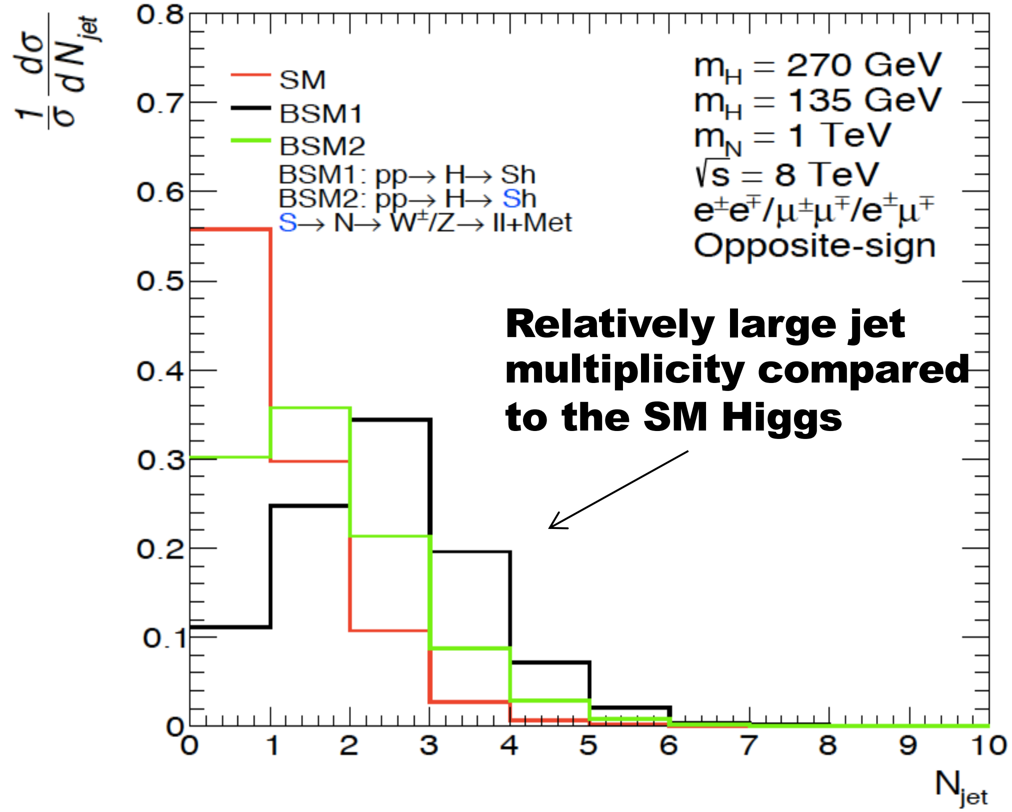
$$\boxed{H \to h(+X), S(+X)}$$

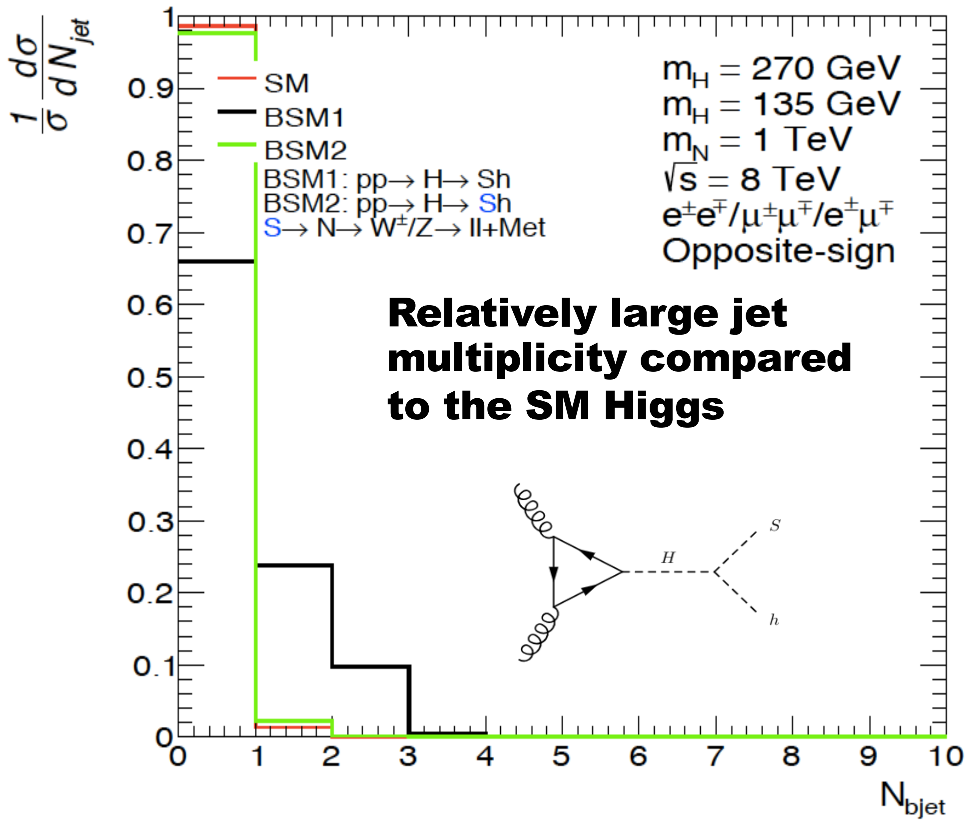
$pp \to H \to Sh, SS \to \ell^+ \ell^- + X$

Expect di-leptons (m_{ll}<100 GeV, due to S→WW→ lνlν) with jets and b-jets with rates comparable to that of the SM Higgs boson









Nature Rev.Phys. **6** 294 (2024), https://www.nature.com/articles/s42254-024-00703-6

Anatomy of the multi-lepton anomalies (2024)

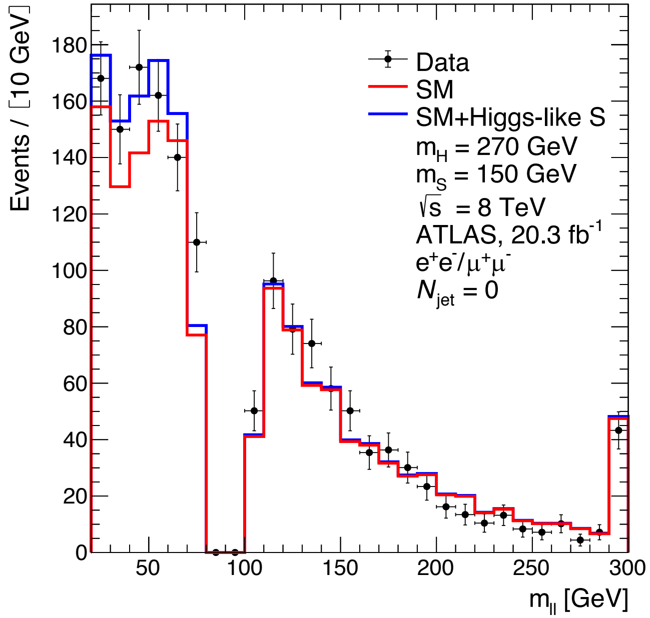
Final state	Characteristic	Dominant SM process	Significance
l^+l^- + jets, b-jets	m_{ll}<100 GeV, dominated by 0b-jet and 1b-jet	tt+Wt	>5σ
l^+l^- + full-jet veto	m_{ll}<100 GeV	WW	~3σ
$l^\pm l^\pm$ & $l^\pm l^\pm l$ + b-jets	Moderate H_T	ttW, 4t, ttZ/tWZ	>3σ
$l^\pm l^\pm$ & $l^\pm l^\pm l$ et al., no b-jets	In association with h	Wh, WWW	4.2σ
$Z(\rightarrow l^+l^-)+l$	p_{TZ}<100 GeV	ZW	>3σ

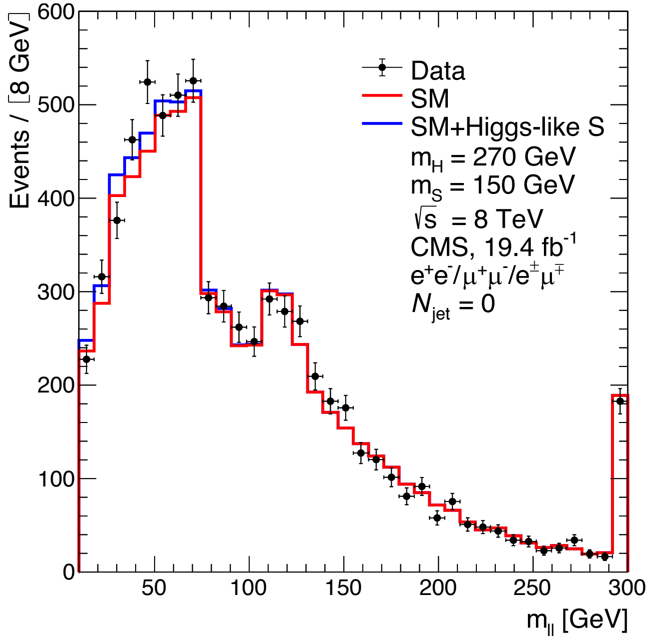
Di-lepton invariant mass in MLA predict a scalar with a mass 150±5 GeV (J.Phys. G45 (2018) no.11, 115003, see also Phys.Rev.D 108 (2023) 11, 115031 and 2503.16245) in association with leptons, jets, MET.

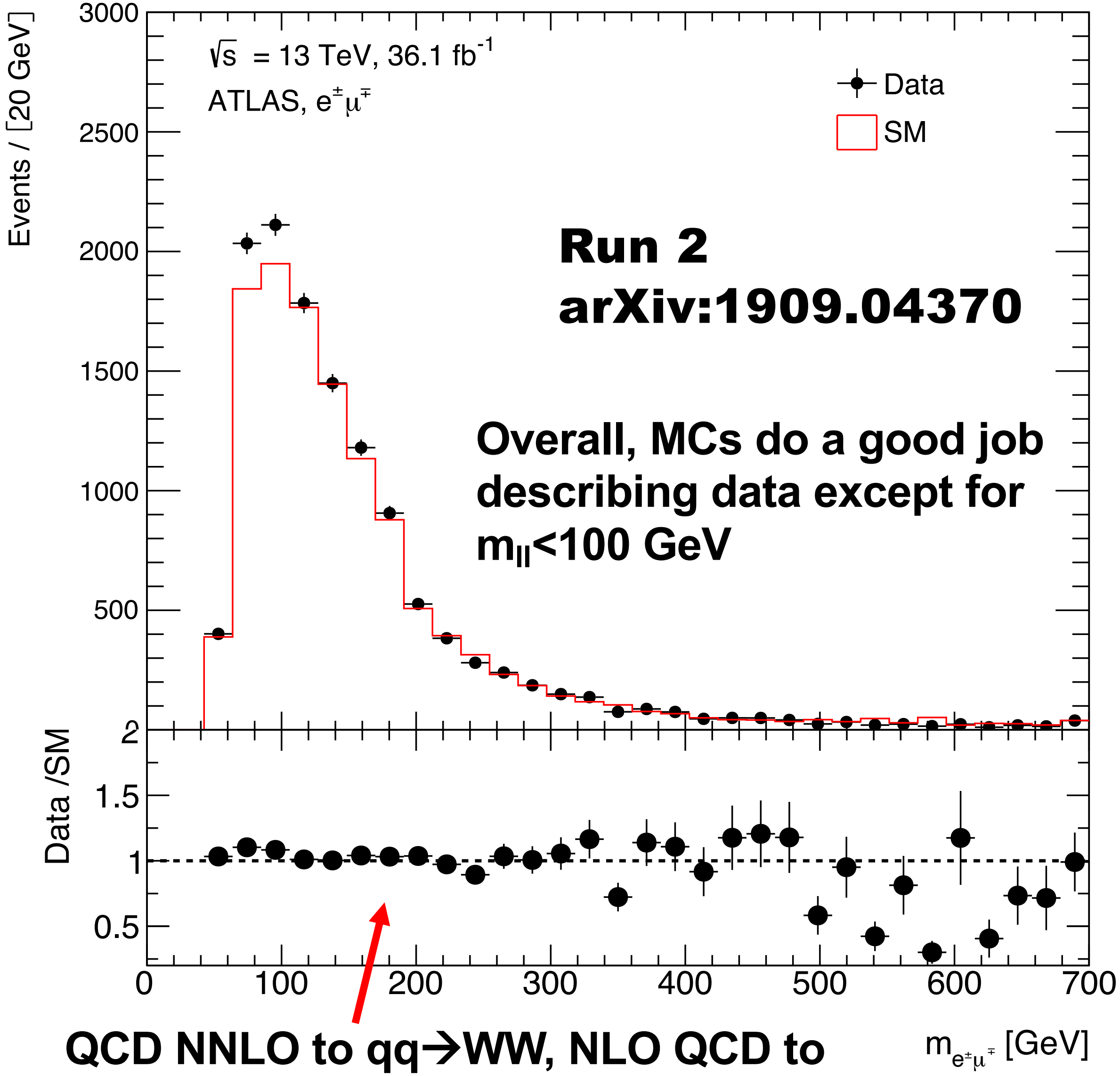
Excesses in di-leptons with full-jet veto. Excludes tt as source.

From Run 1 multi-lepton excesses model-dependent prediction of $m_s = 150 \pm 5$ GeV

Run 1, J.Phys. G45 (2018) no.11, 115003







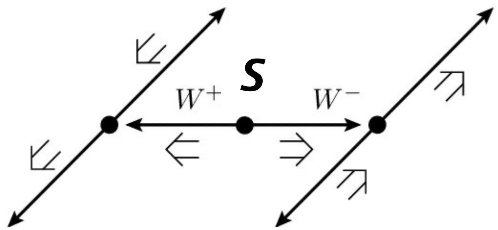
Run 2
arXiv:1909.04370

Overall, MCs do a good job describing data except for m_{ll}<100 GeV

QCD NNLO to qq→WW, NLO QCD to gg→WW and NLO EW corrections applied

Prediction from the multi-lepton anomalies.
The di-lepton invariant mass is sensitive to the mass of S.
Assuming S→WW→llνν:

$$m_S = 150 \pm 5\ GeV$$



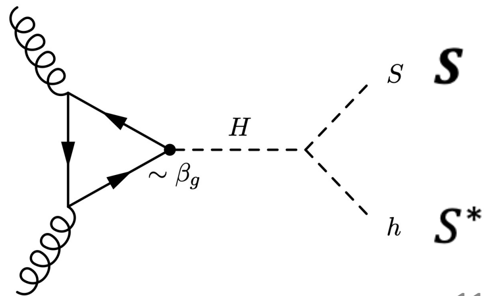
J.Phys. G45 (2018) no.11, 115003

The 152 GeV Candidate

Procedure

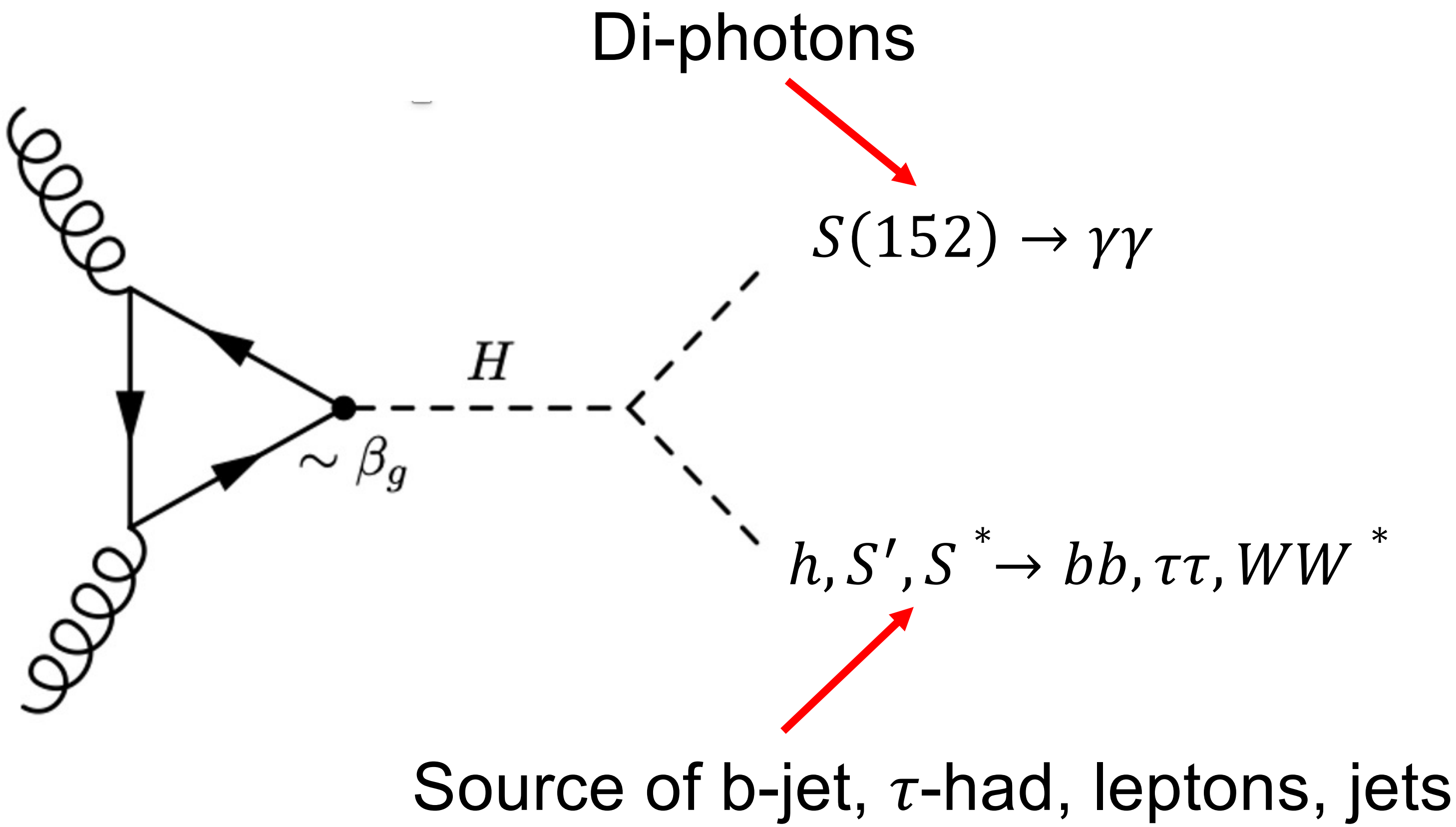
(avoiding "cherry picking")

- Setting a well-defined procedure is essential to the integrity of a search. Scanning nullifies significance
- From the di-lepton anomalies: $m_h < m_s < 170$ GeV
  - It is critical that search be localized and motivated
- Focus on $\gamma\gamma$ and $Z\gamma$ decays
- As per the model that described the multi-lepton anomalies, we select final state according to di-boson signatures. S is produced via the decay of something heavier and not directly
  - Re-use Higgs boson data
  - Remove VBF and boosted topologies
    - Related to direct production



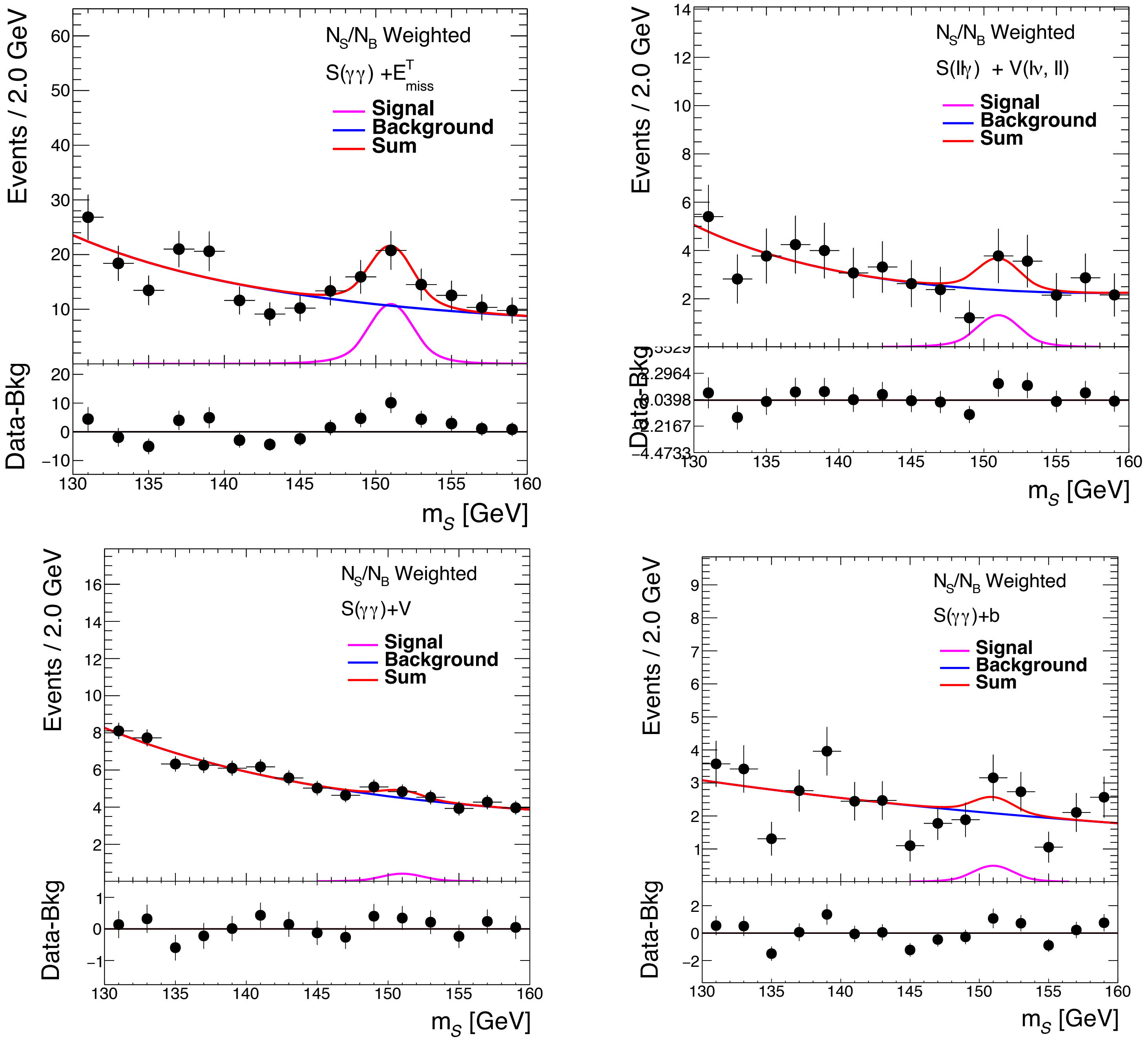
From Run 1 multi-lepton excesses model-dependent prediction of $m_s = 150 \pm 5$ GeV

Procedure to choose final state: di-photon in association with b-jets, τ-had, leptons (e/μ) and jets



In *Eur.Phys.J.C* 76 (2016) 10, 580 also considered S→MET

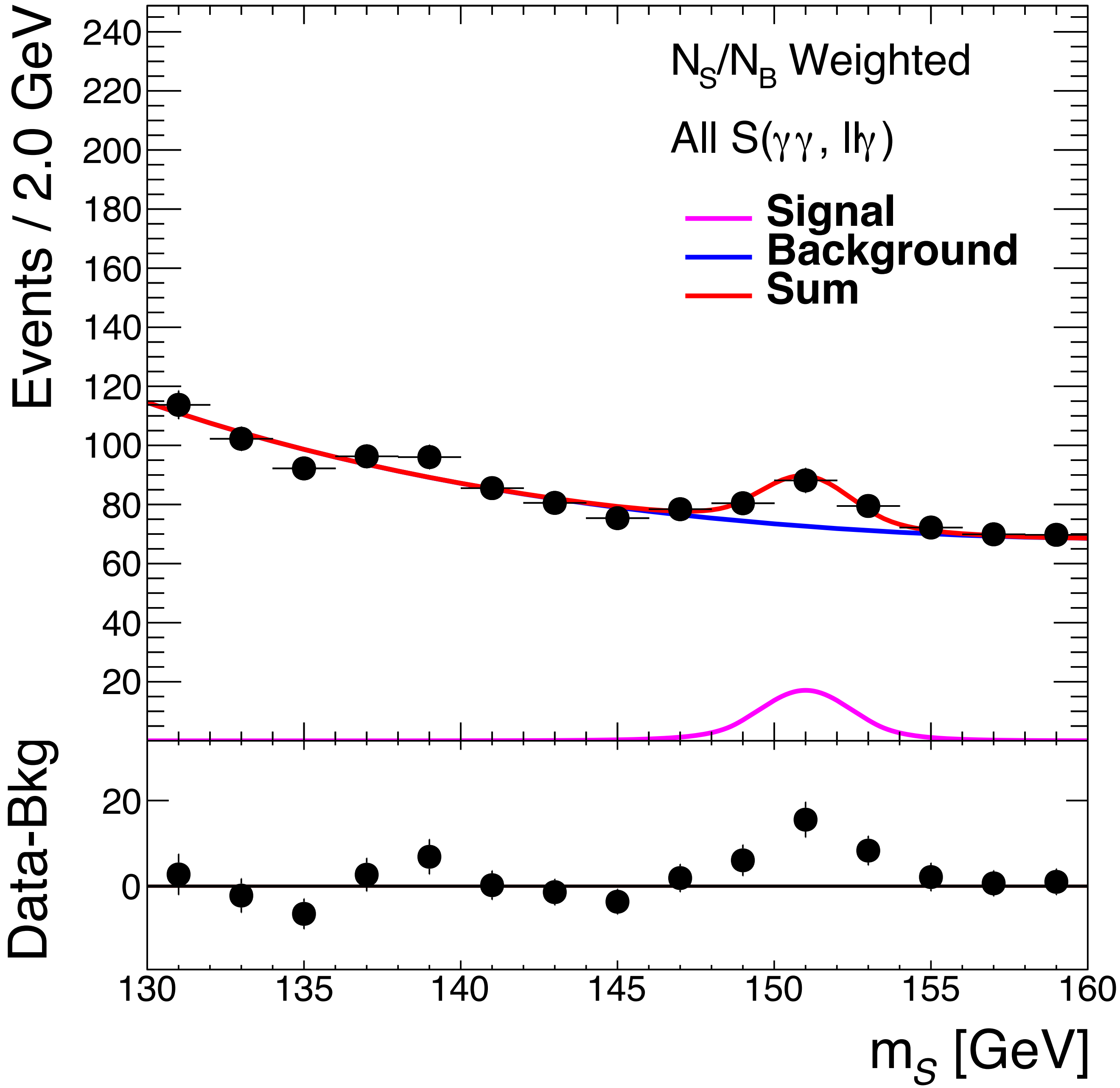
A.Crivellin et al. https://arxiv.org/abs/2109.02650



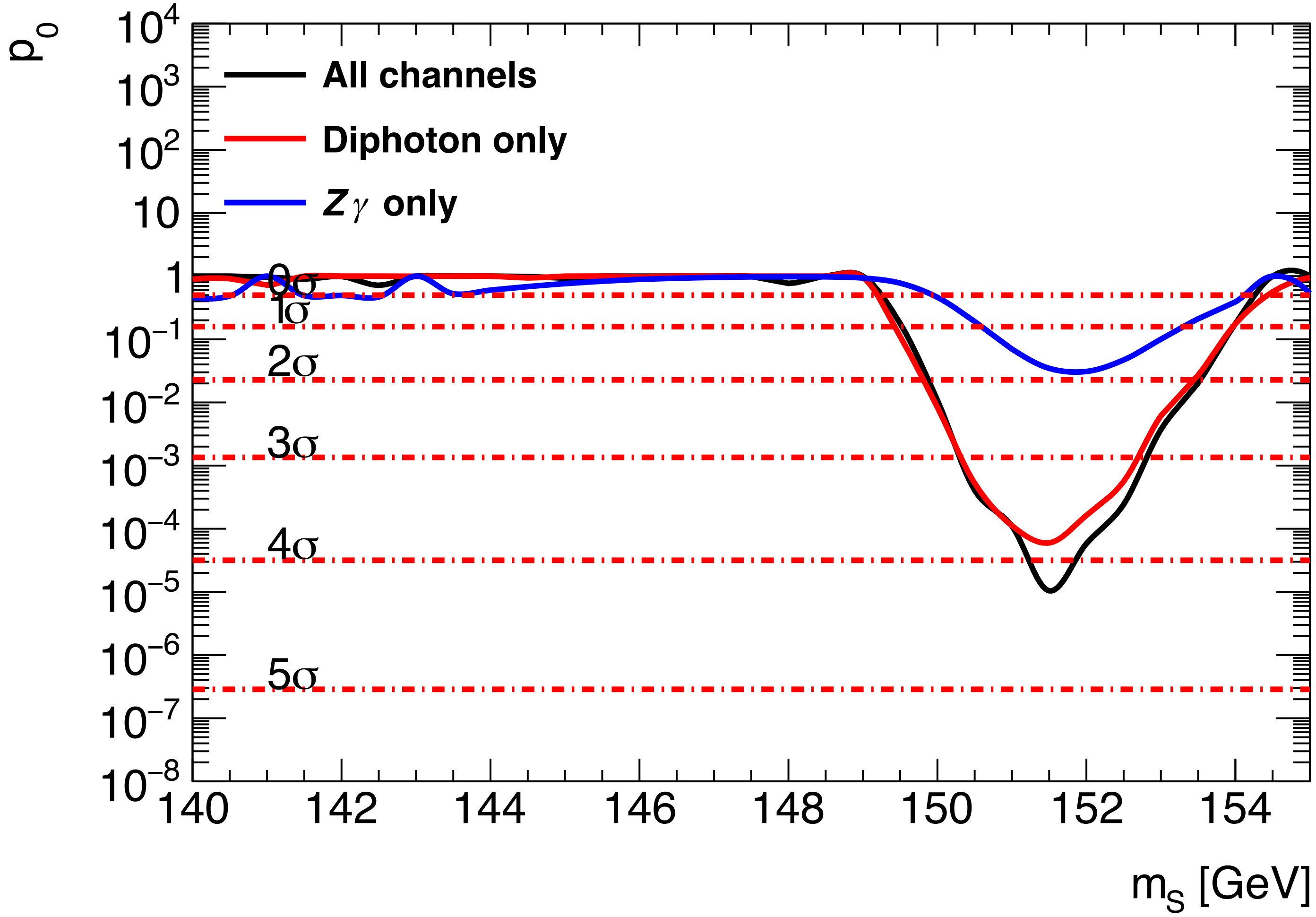
Analysis of publicly available $\gamma\gamma$, $Z\gamma$ spectra in associated production gives an excess at m_S=151.5 GeV.

Fiducial yields consistent with H→SS* hypothesis with m_H=270 GeV, which is used for the extraction of significance.

Excess not seen in S→ZZ→4l



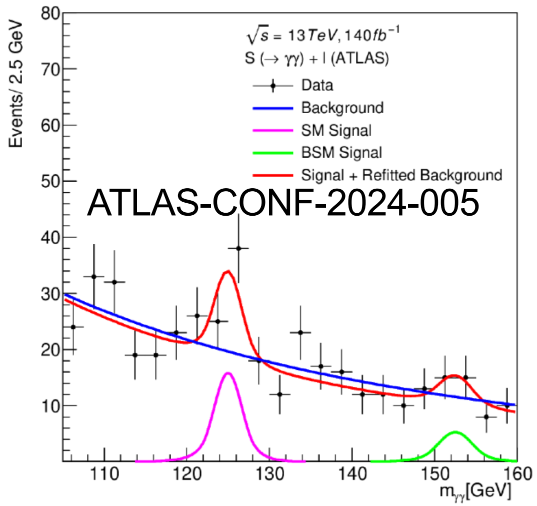
Result is obtained with public results from the LHC experiments. Using a simplified model and two degrees of freedom to include the decay of S→MET (as in Eur.Phys.J.C 76 (2016) 10, 580) and residual LEE, global significance goes to 3.9σ at 151.5 GeV.



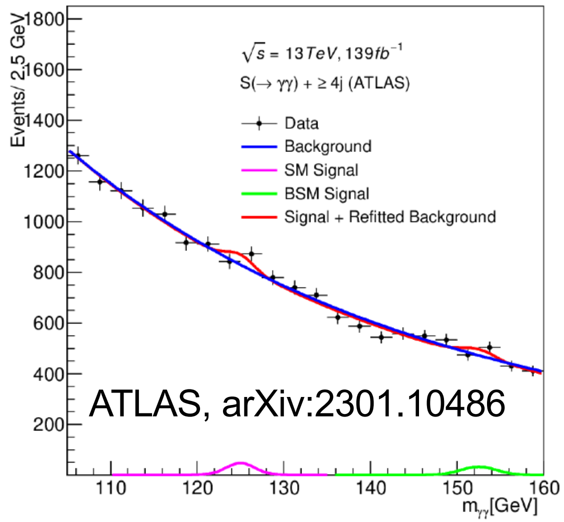
New excesses @151.5 GeV that appeared after the first combination (see above) in topologies consistent with associated production:

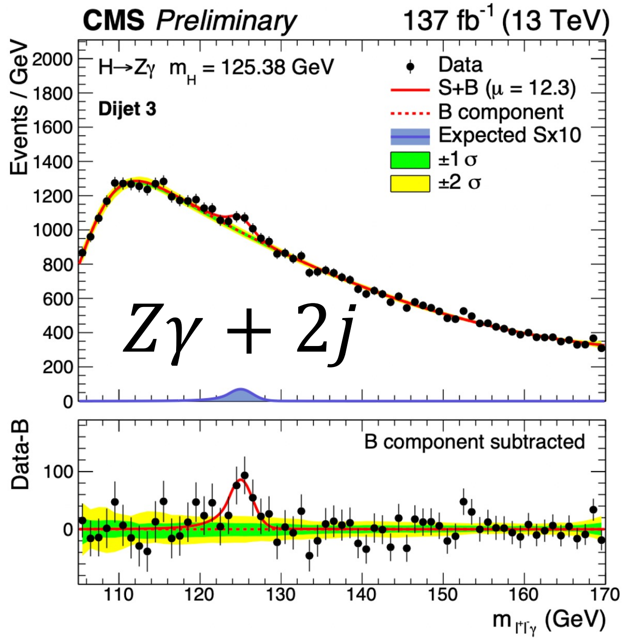
CMS-PAS-HIG-19-014

$\gamma\gamma + l\ (b - veto)$

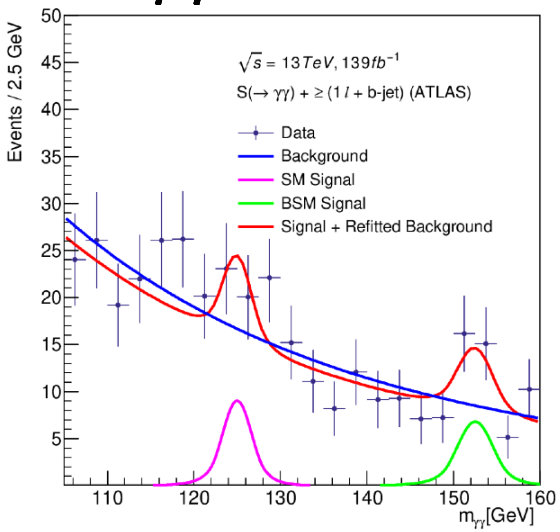


$\gamma\gamma + 4j$





$\gamma\gamma + l + b$



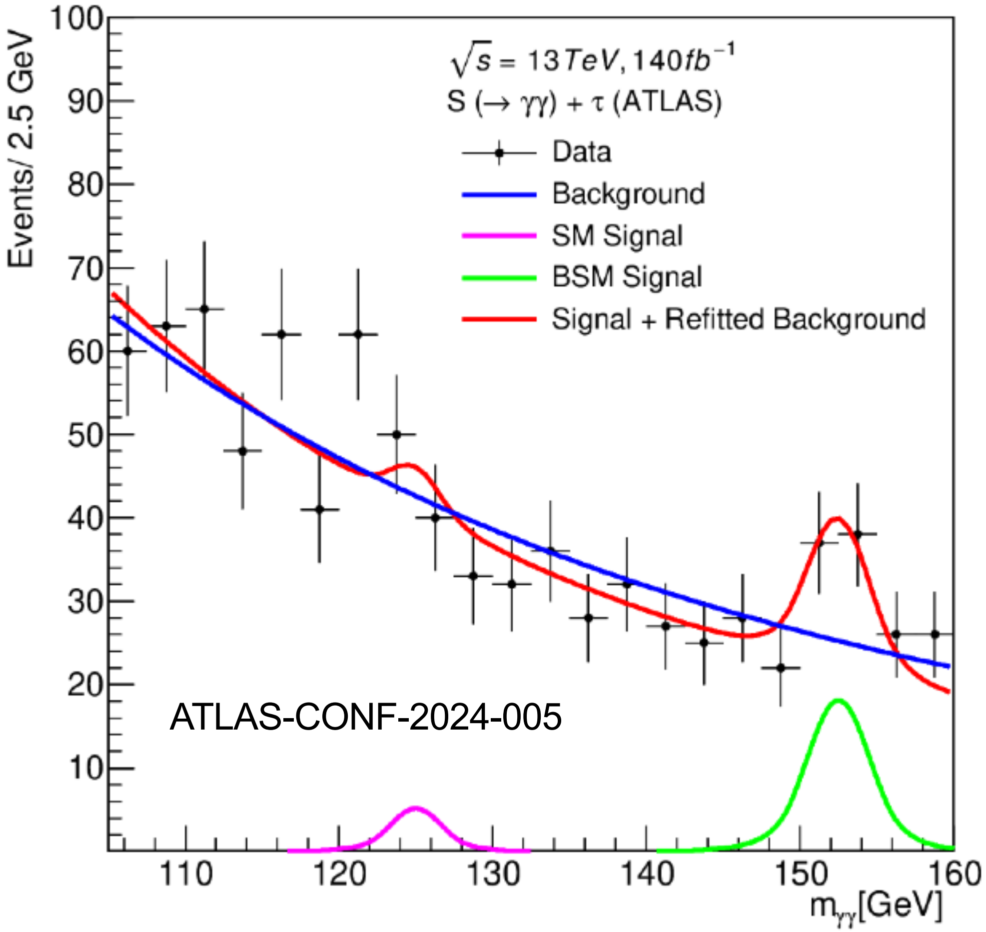
Excesses appear in corners of the phase-space predicted by the naive H→ SS* model with S being SM Higgs-like. In addition, seem to see S in association with MET and, possibly, with an extra photon

Bin for associated production VH, ttH, where excess is seen with di-photons.

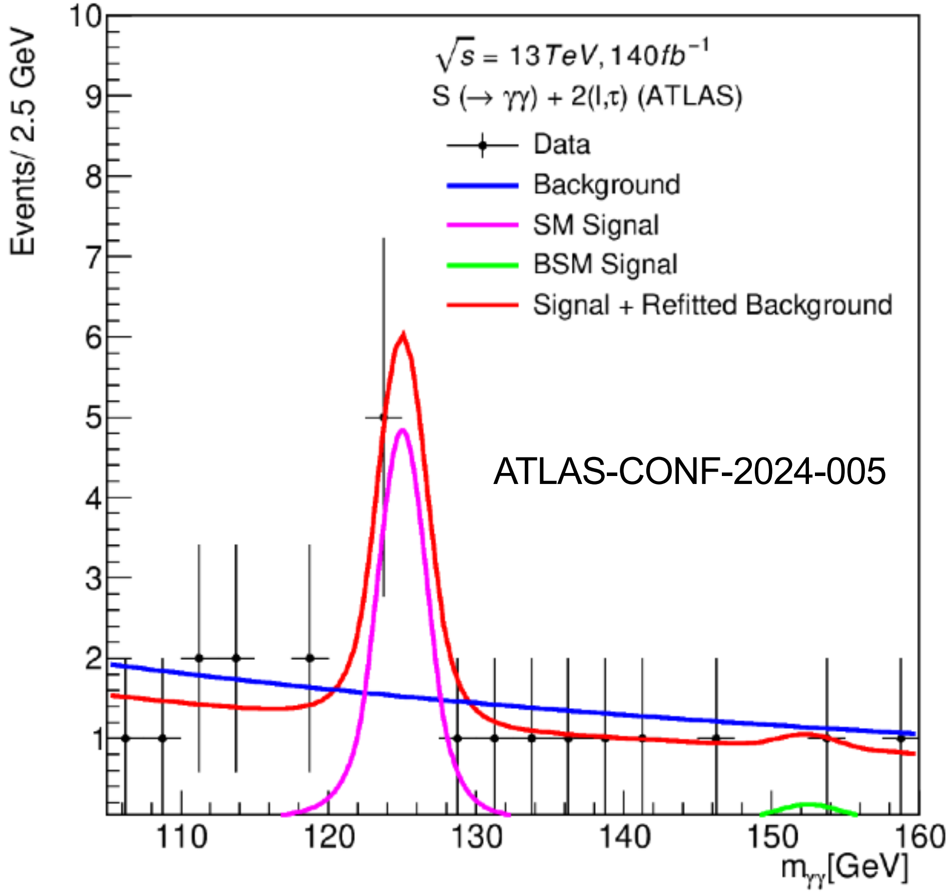
ATLAS, arXiv:2301.10486

https://cds.cern.ch/record/2894145/files/ATLAS-CONF-2024-005.pdf

$\gamma\gamma + \tau$

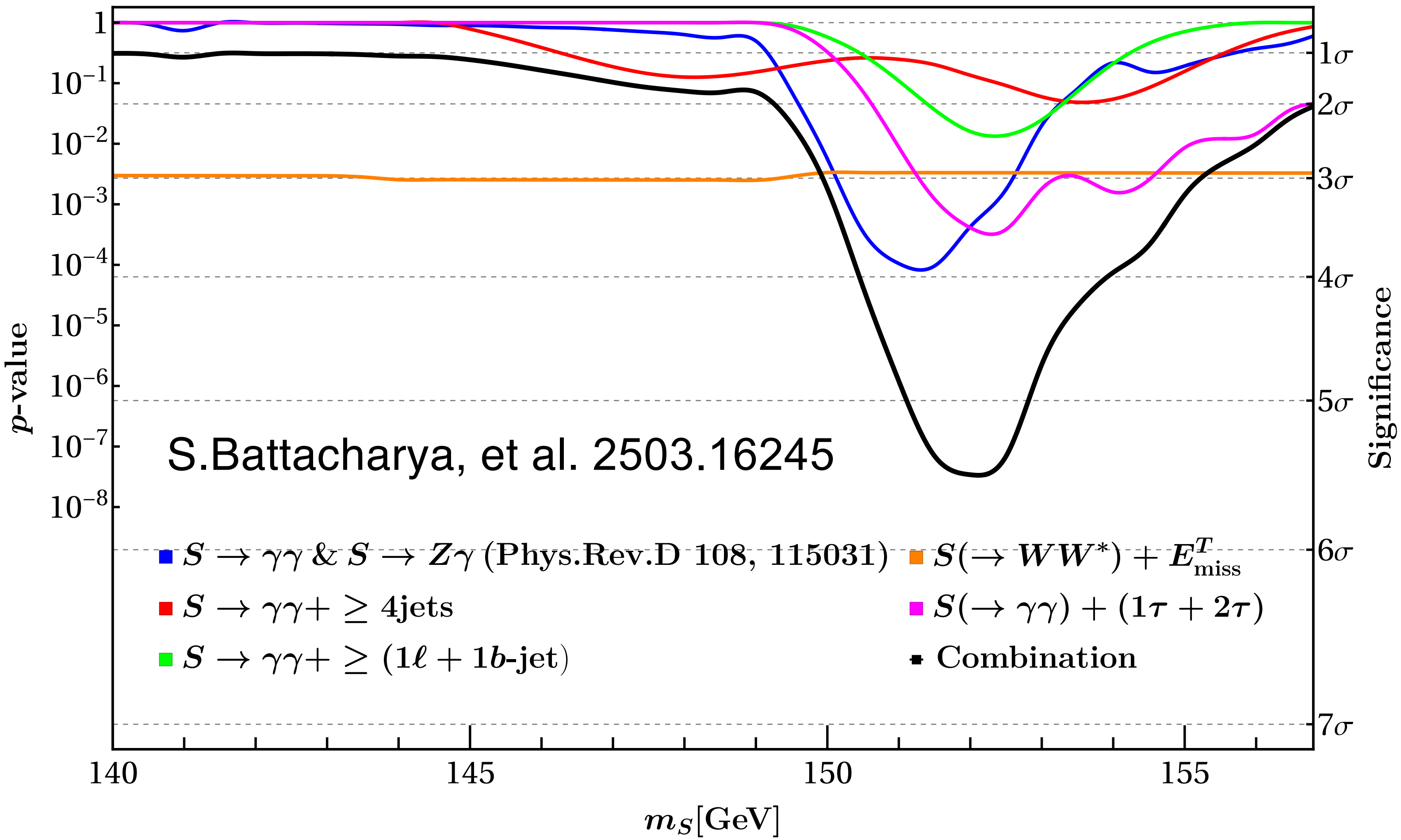


$\gamma\gamma + 2(\tau, \ell)$



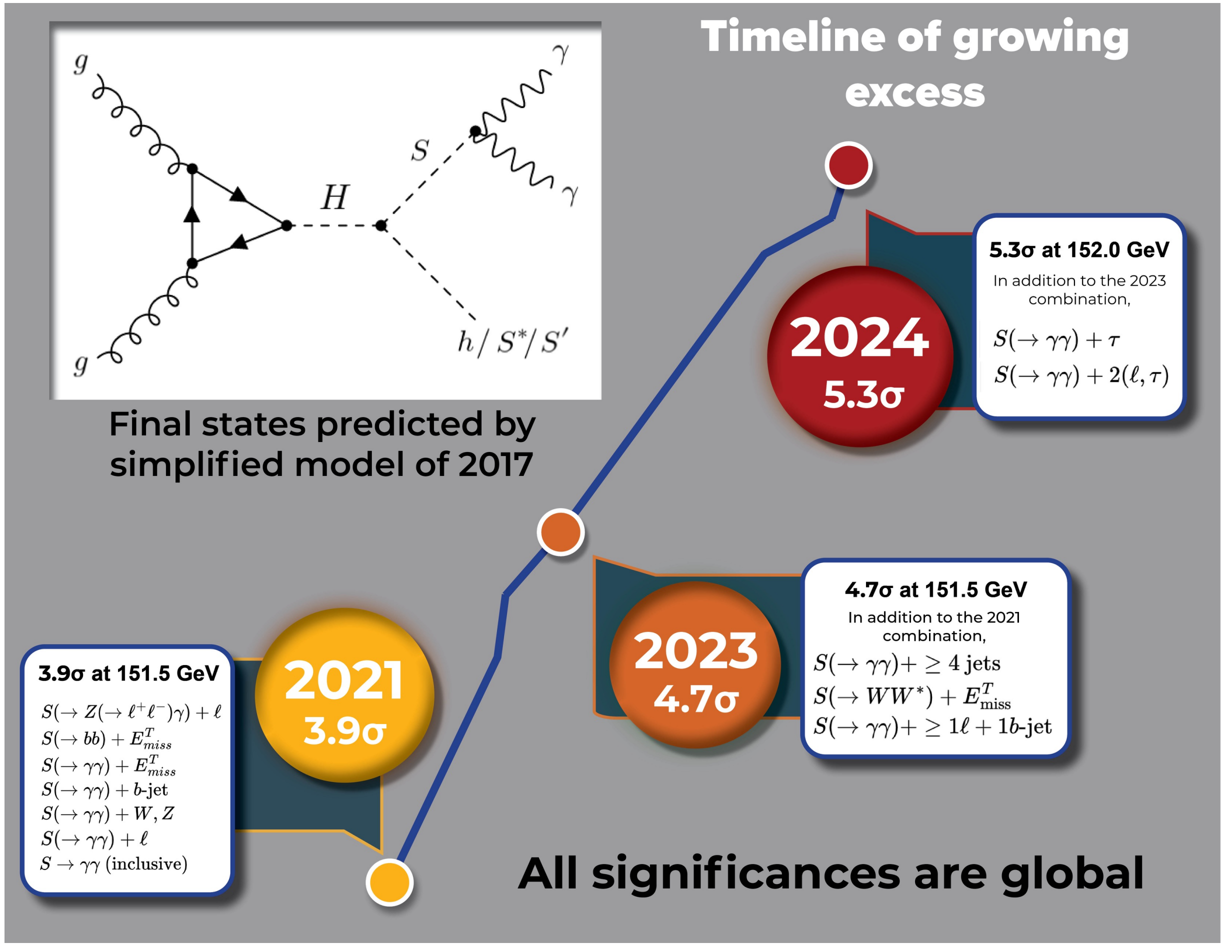
Single and double tau are combined assuming H→SS*

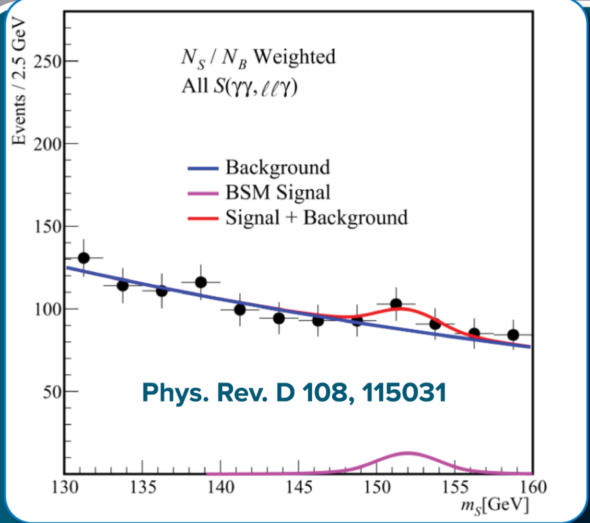
Current status of the combination, based on the Fischer method with 5 n.d.o.f yields largest global significance of a narrow structure beyond the SM at the LHC



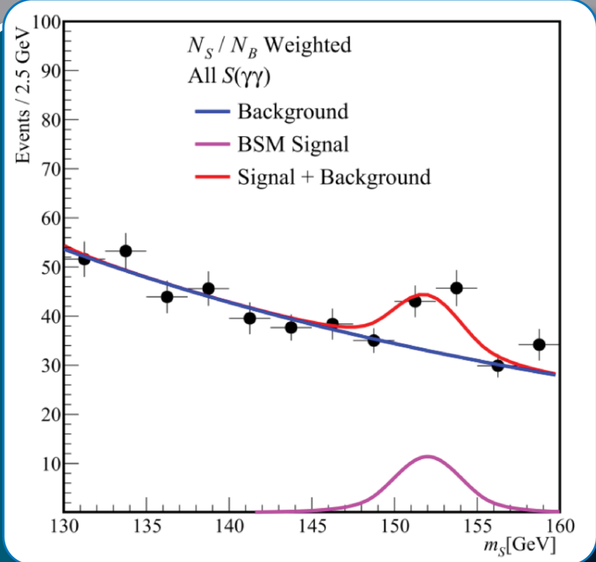
2021 (Group 1)	2023 (Group 2)	2025 (Group 3)
$\gamma\gamma + E^T_{\text{miss}}$ [20, 43]	$\gamma\gamma+ \geq (1\ell + 1b\text{-jet})$ [44]	$\gamma\gamma + \tau$ [45]
$\gamma\gamma + W, Z$ [46, 47]	$\gamma\gamma+ \geq 4$ jets [44]	$\gamma\gamma + 2(\ell, \tau)$ [45]
$\gamma\gamma + b$-jet [48, 49]	$WW^*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

S.Battacharya, et al. 2503.16245



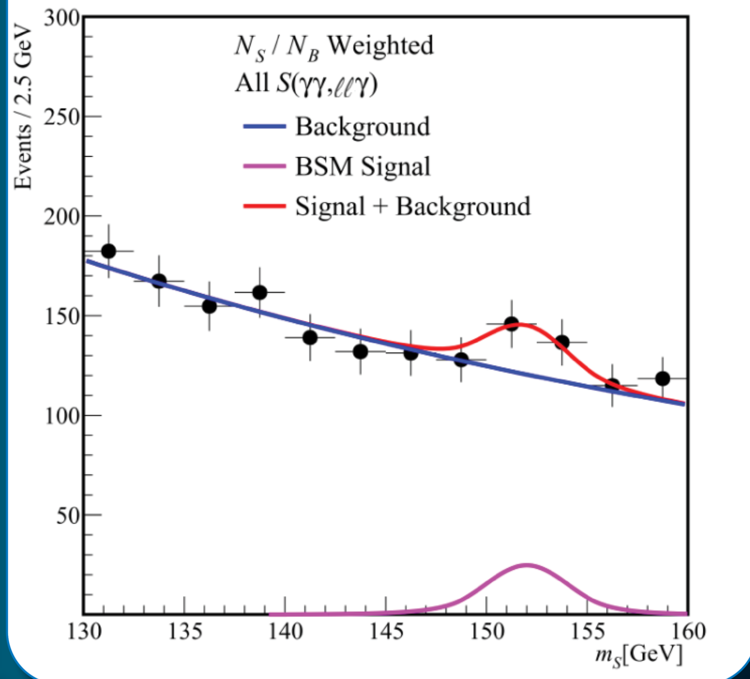


Until 2021



Post 2021

Current Status



Mass Spectrum

Outlook and Conclusions

- Discrepancies in multi-lepton final states at LHC w.r.t. current MCs are not statistical fluctuations
  - They appear in corners of the phase-space dominated by different processes (Wt/tt/4t, VV, ttV, Vh, WWW)
    - Excesses are Higgs-like with robust final states
- With these anomalies one predicts a scalar, S, with mass 150$\pm$5 GeV, in associated production
  - Prediction of a scalar in association with jets/leptons/MET
- Analysis of associated production gives large (>5σ) global significance of narrow excess with 152$\pm$1 GeV