Production of a 95 GeV scalar in association with a *Z*-boson at e^+e^- colliders

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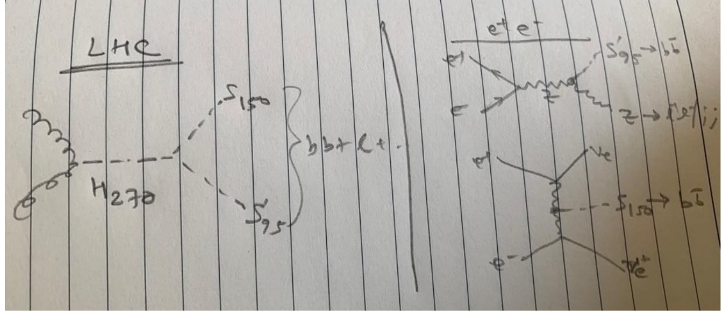
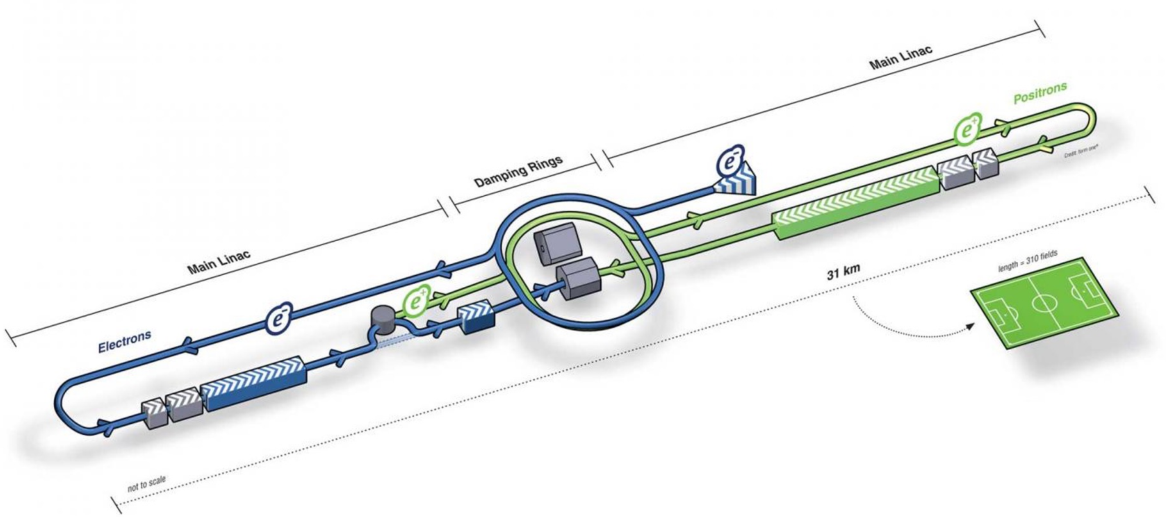
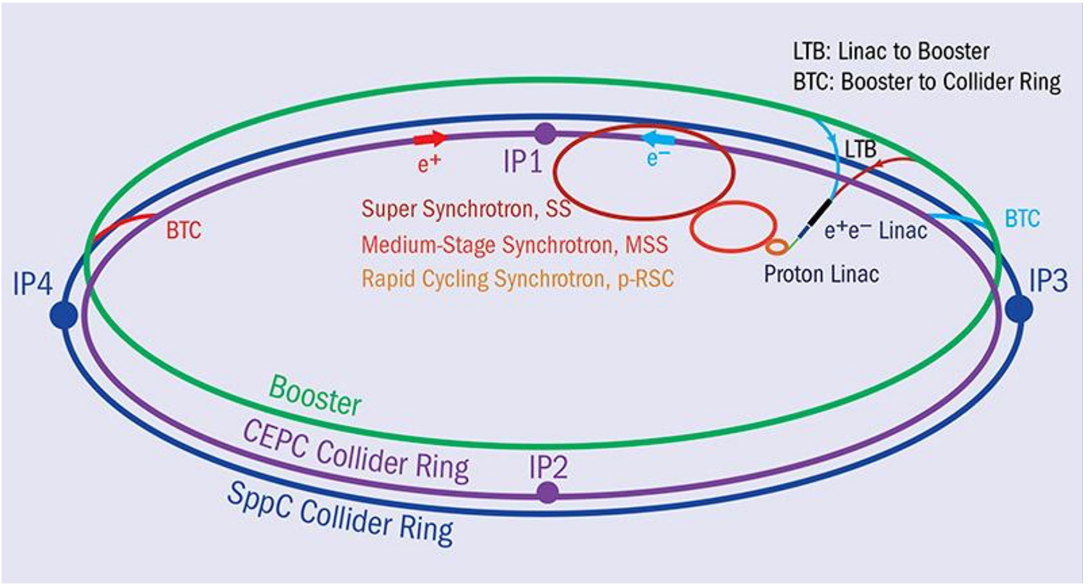


- Models: Extending 2HDM+S model with one more singlet scalar and/or Higgs-Triplet model(s)
- Phenomenology at LHC: search through g g $\rightarrow H(270\ \mathrm{GeV}) \rightarrow S(150\ \mathrm{GeV})S'(95\ \mathrm{GeV})$
- Physics at Proposed future e^+e^- collider: ILC/CEPC (contribution to BSM section in Whitepaper)
- **Machine Learning** approach in Particle Physics Projects
- Involved analysis through Open Data resources: Run 1 and 2 from ATLAS/CMS



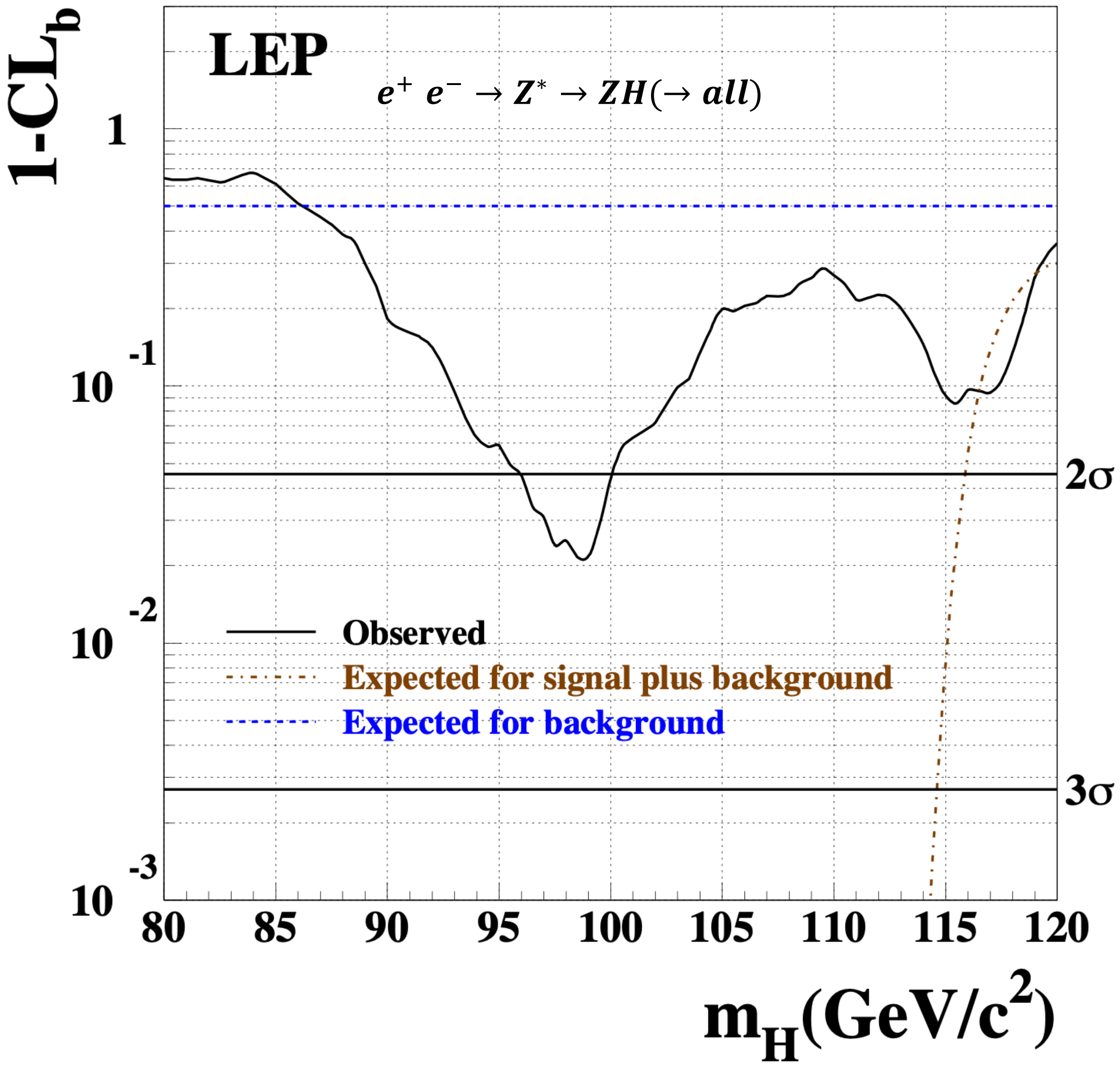
International Linear Collider (ILC)

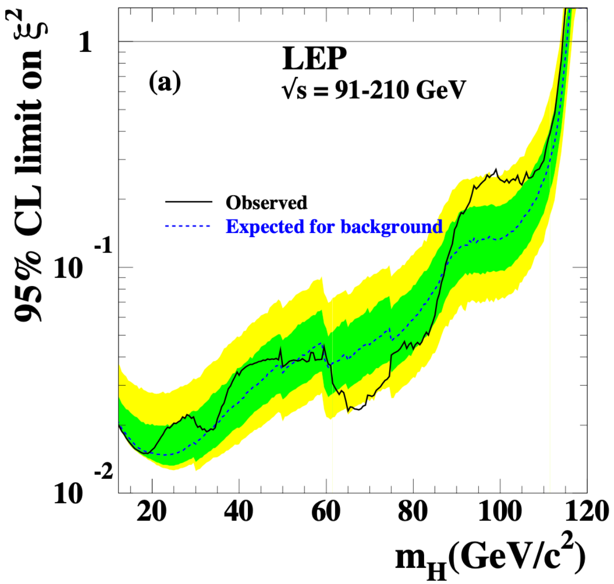


Circular electron-proton collider (CEPC)

ALEPH, DELPHI, L3 and OPAL Collaborations
The LEP Working Group for Higgs Boson Searches

CERN-EP/2003-011
LEP, Phys. Lett. B 565 (2003) 61–75





$$\xi^2 = (g_{\mathrm{HZZ}}/g_{\mathrm{HZZ}}^{\mathrm{SM}})^2$$

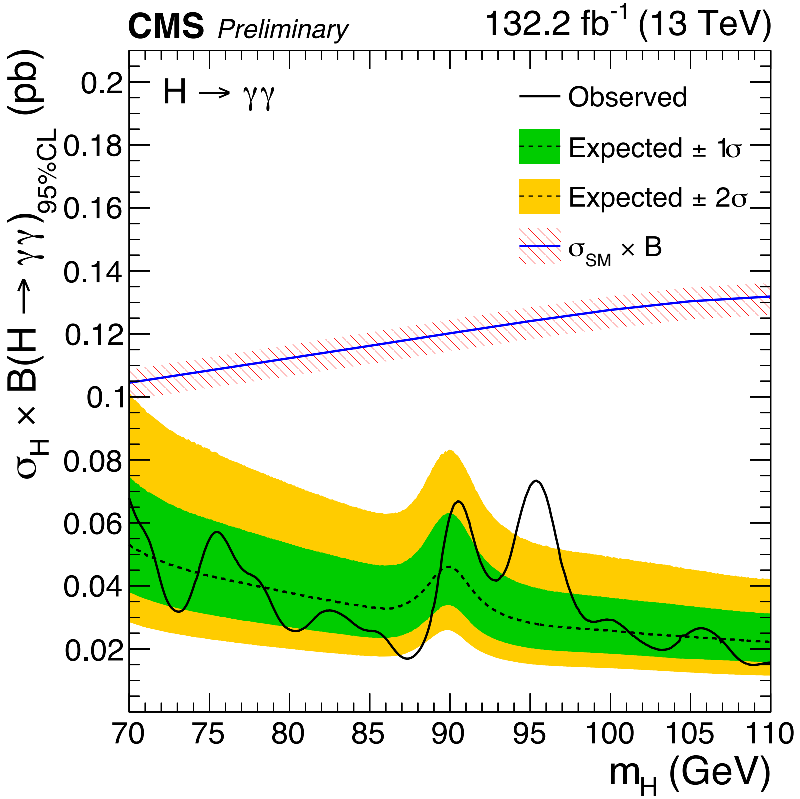
Combination of all SM Higgs-like decay modes

Search for SM Higgs-like boson with categorization assuming SM-like production mechanisms (ggF, VBF, VH, ttH).

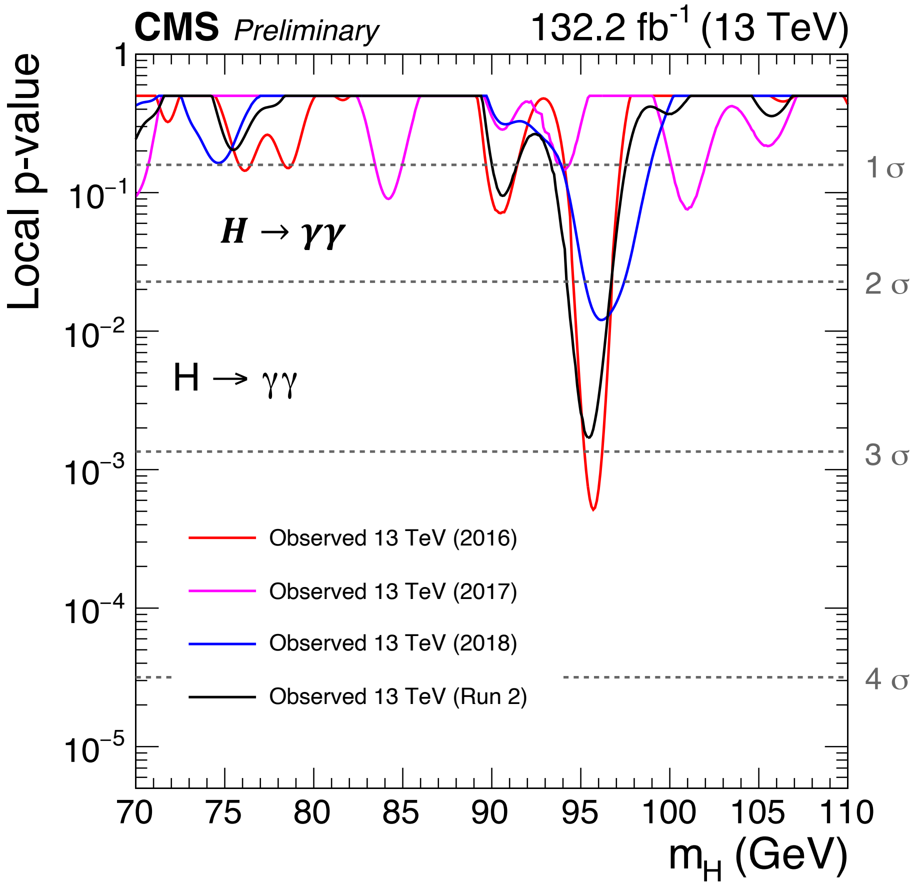
CMS, PLB 793 (2019) 320
CMS-PAS-HIG-20-002

$$\mu_{\text{LEP}} = \frac{\sigma\left(e^+e^- \to Z\phi \to Zb\bar{b}\right)}{\sigma^{SM}\left(e^+e^- \to ZH_{\text{SM}} \to Zb\bar{b}\right)} = 0.117 \pm 0.057$$

$$\mu_{\gamma\gamma}^{\text{exp}} = \frac{\sigma^{\text{exp}}\left(gg \to \phi \to \gamma\gamma\right)}{\sigma^{\text{SM}}\left(gg \to H \to \gamma\gamma\right)} = 0.35 \pm 0.12$$



Local (global) 2.9 (1.3)σ @95.4 GeV

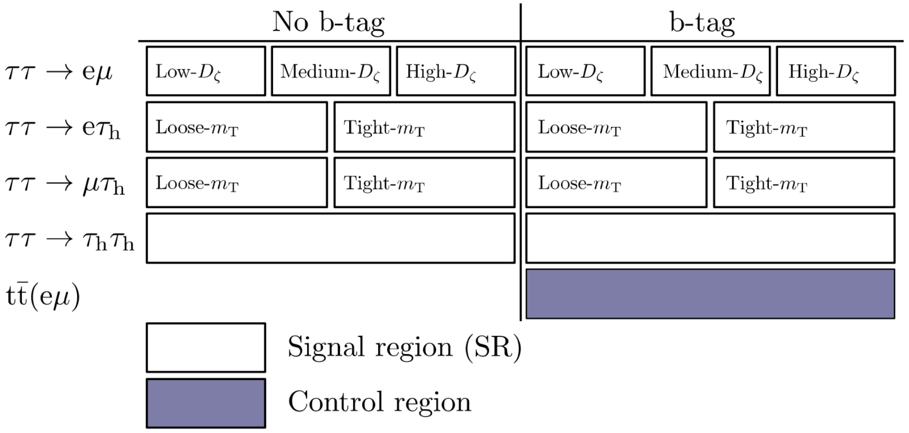


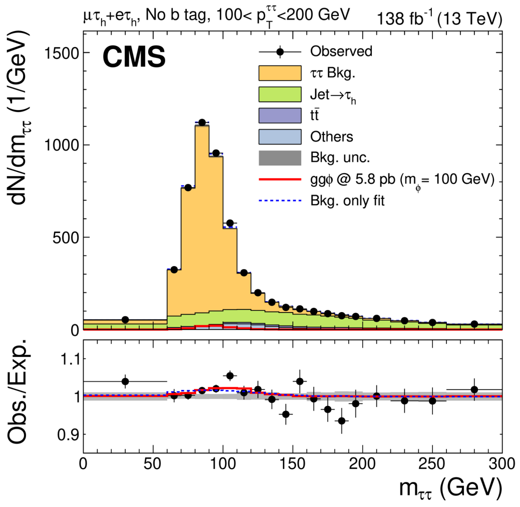
CMS, arXiv:2208.02717

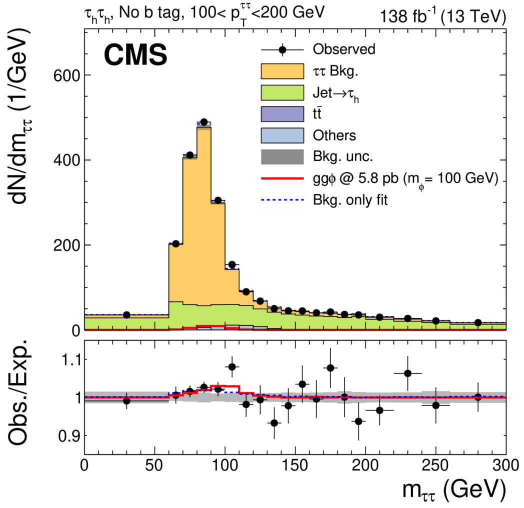
Dedicated search for scalar decaying into tau pairs. CMS observes a local (global) excess of 3.1 (2.7)σ at ~100 GeV.

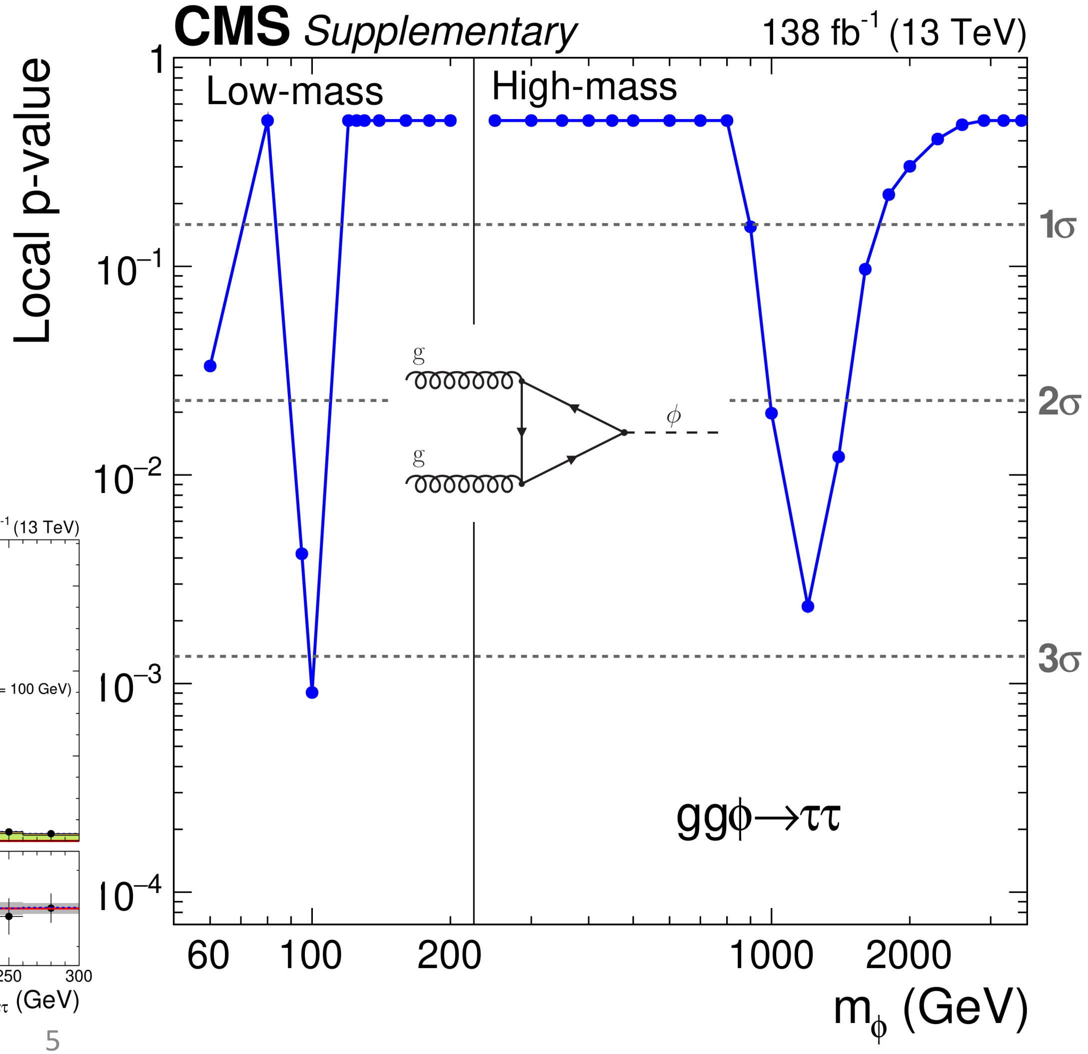
$H \to \tau\tau$

Event classification scheme



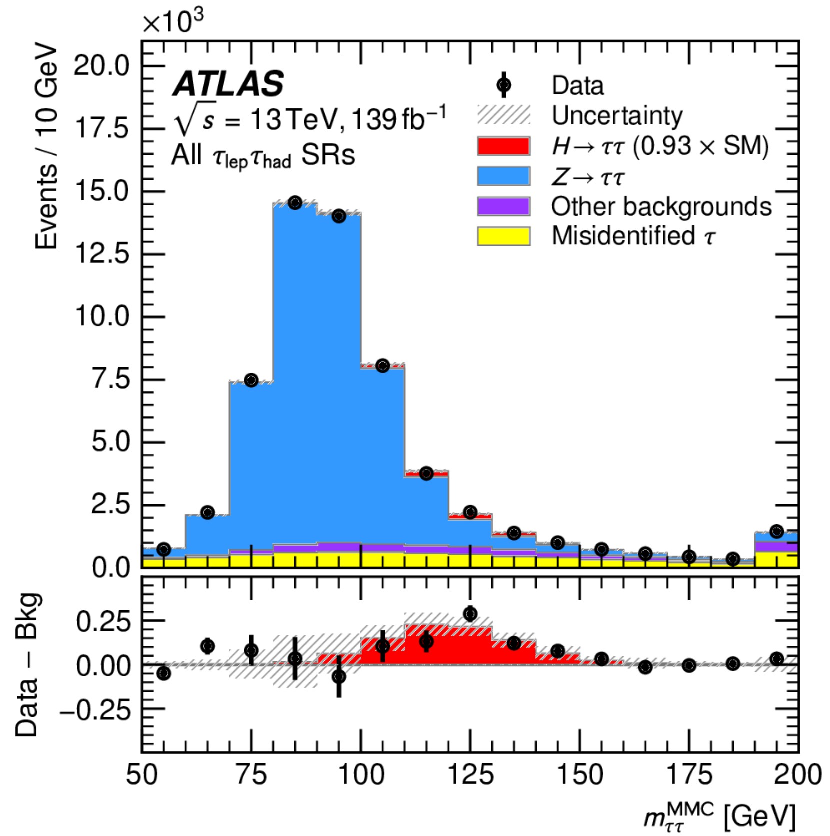


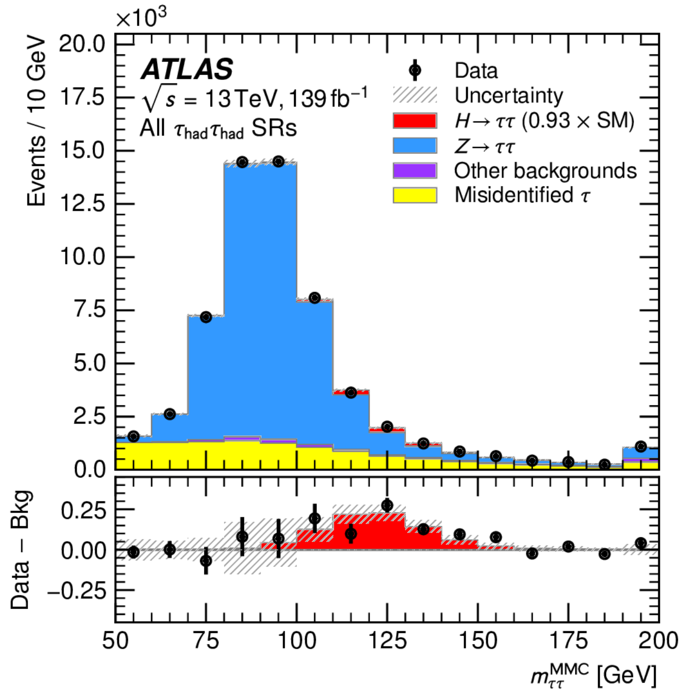


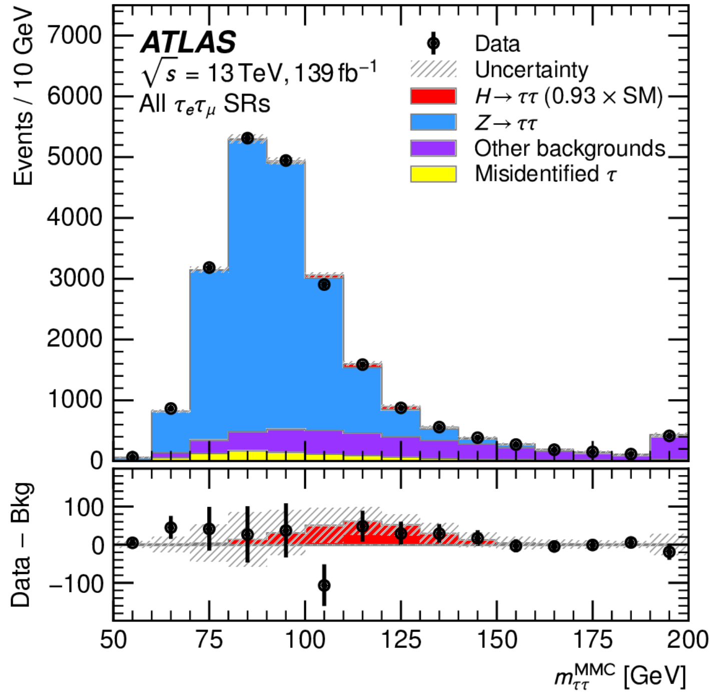


ATLAS, arXiv:2201.08269

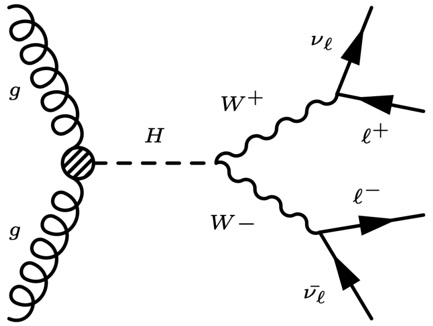
$H \to \tau\tau$

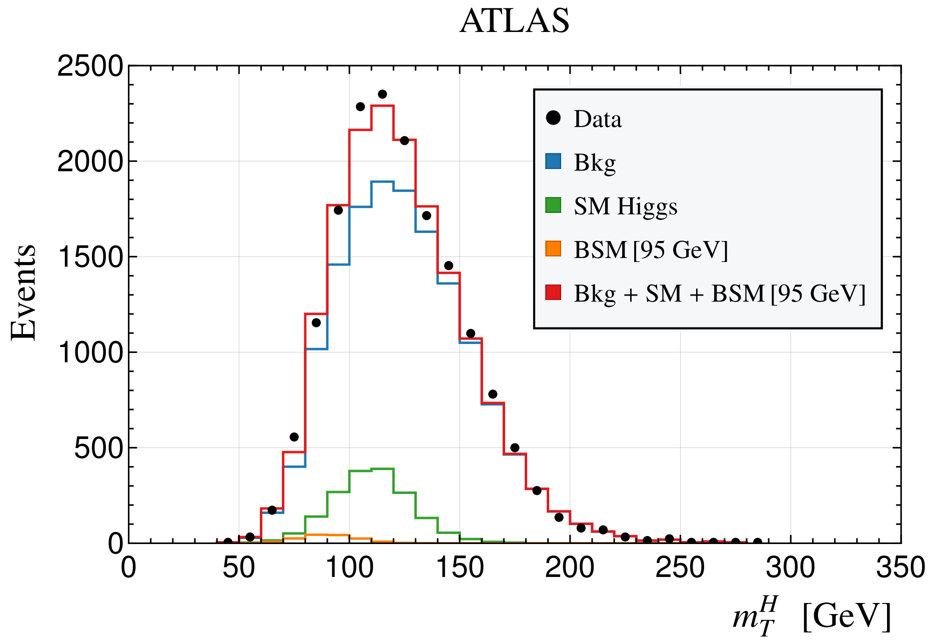


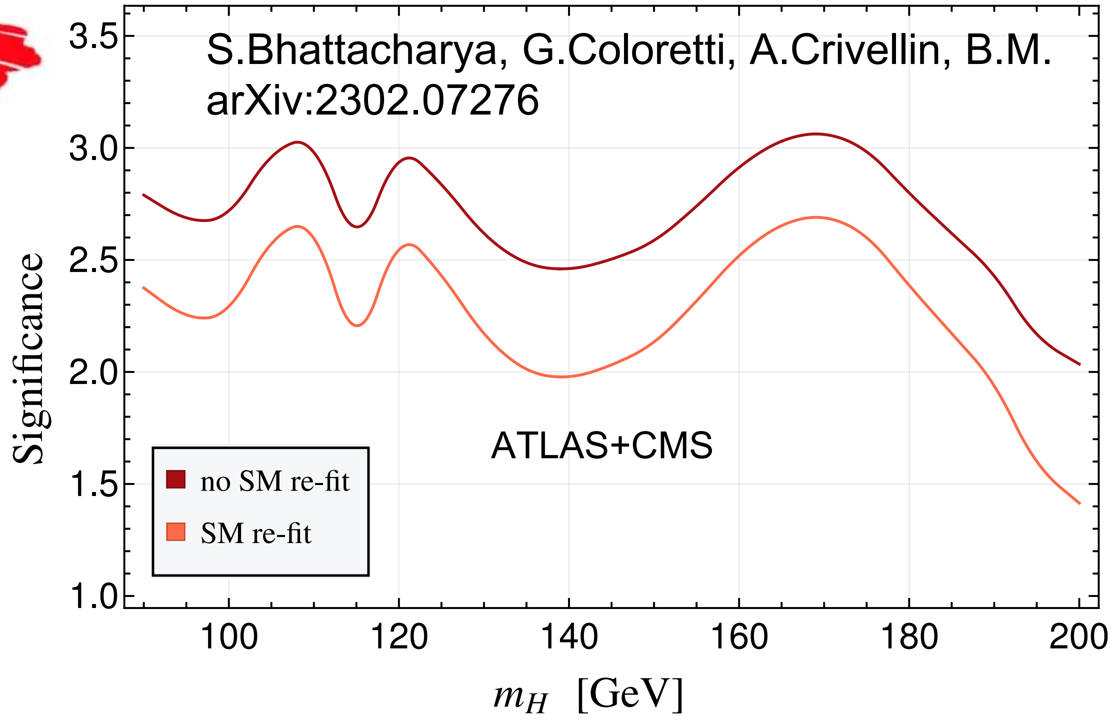


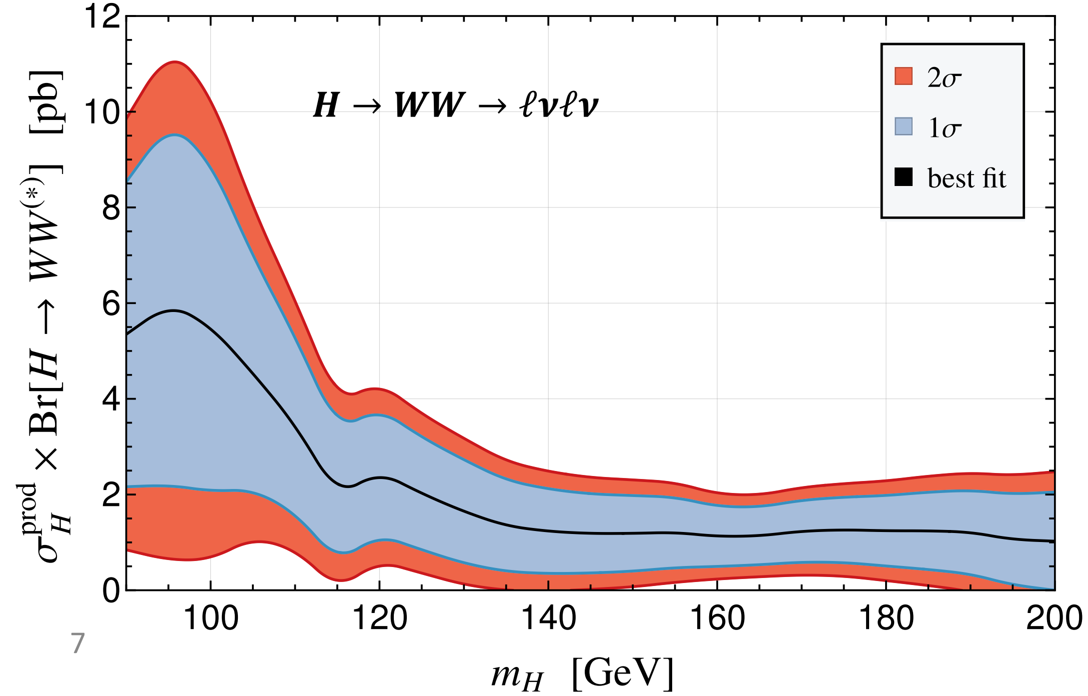


ATLAS has not performed a dedicated search for low mass scalar. That said we do not seem to see a clear excess around 95 GeV in the sideband. Is the CMS excess an upward fluctuation?



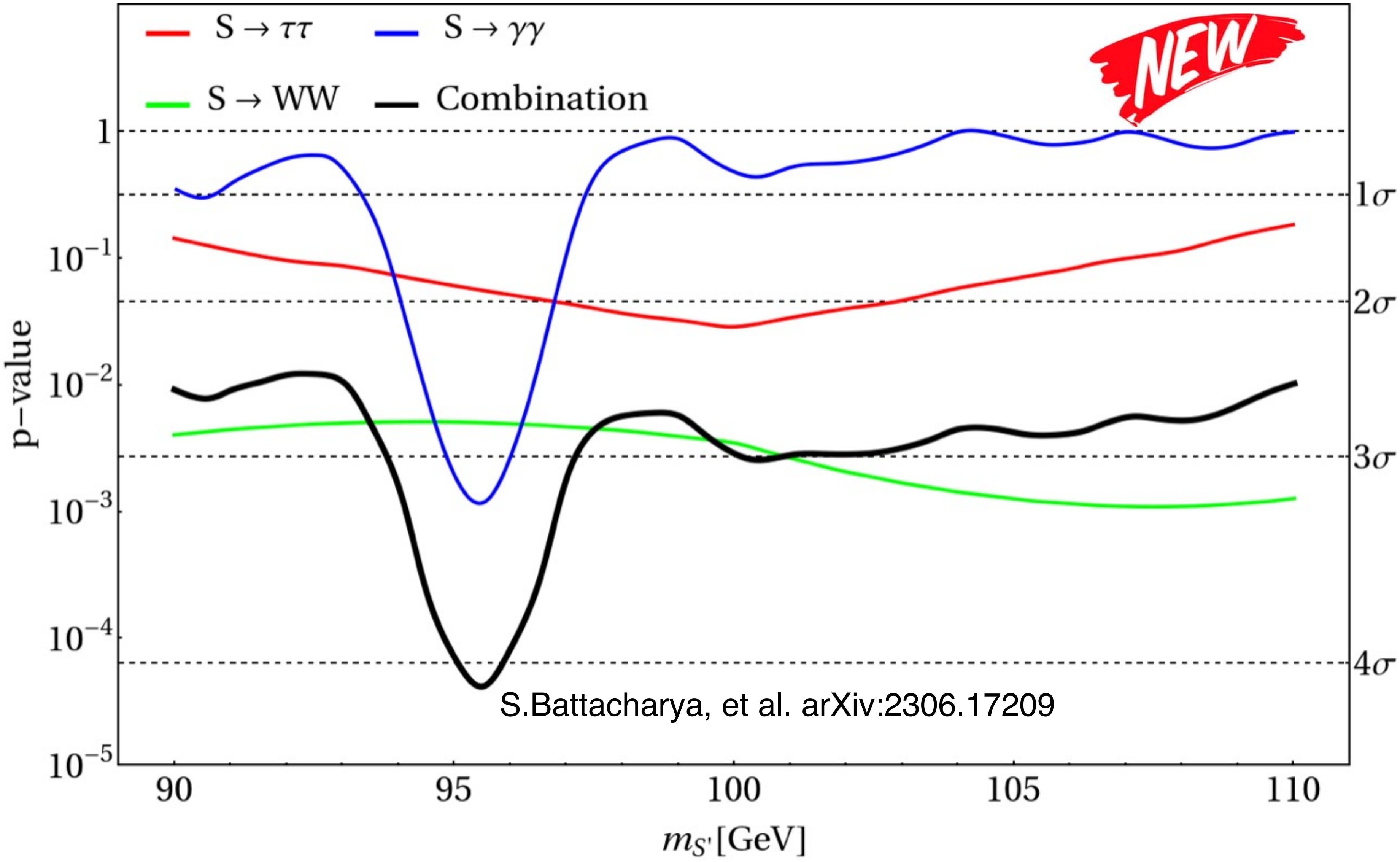




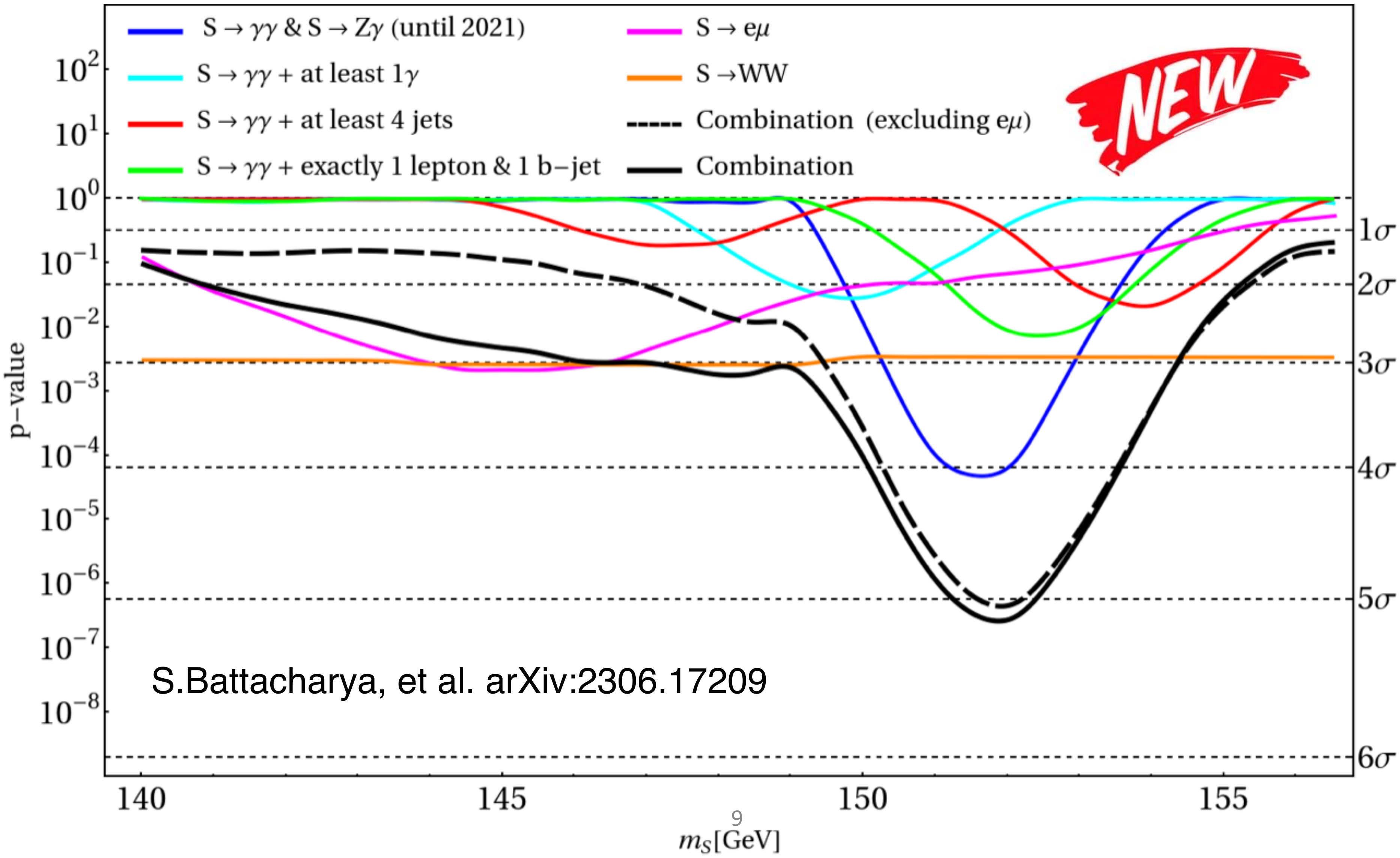


SM Higgs hypothesis alone. alone is having difficulty describing the ll+MET transverse mass spectra, giving room to other Higgs-like signals

With recent results reported by the ATLAS experiment the significance of a narrow resonance at 95 GeV has reached 3.8σ global significance.

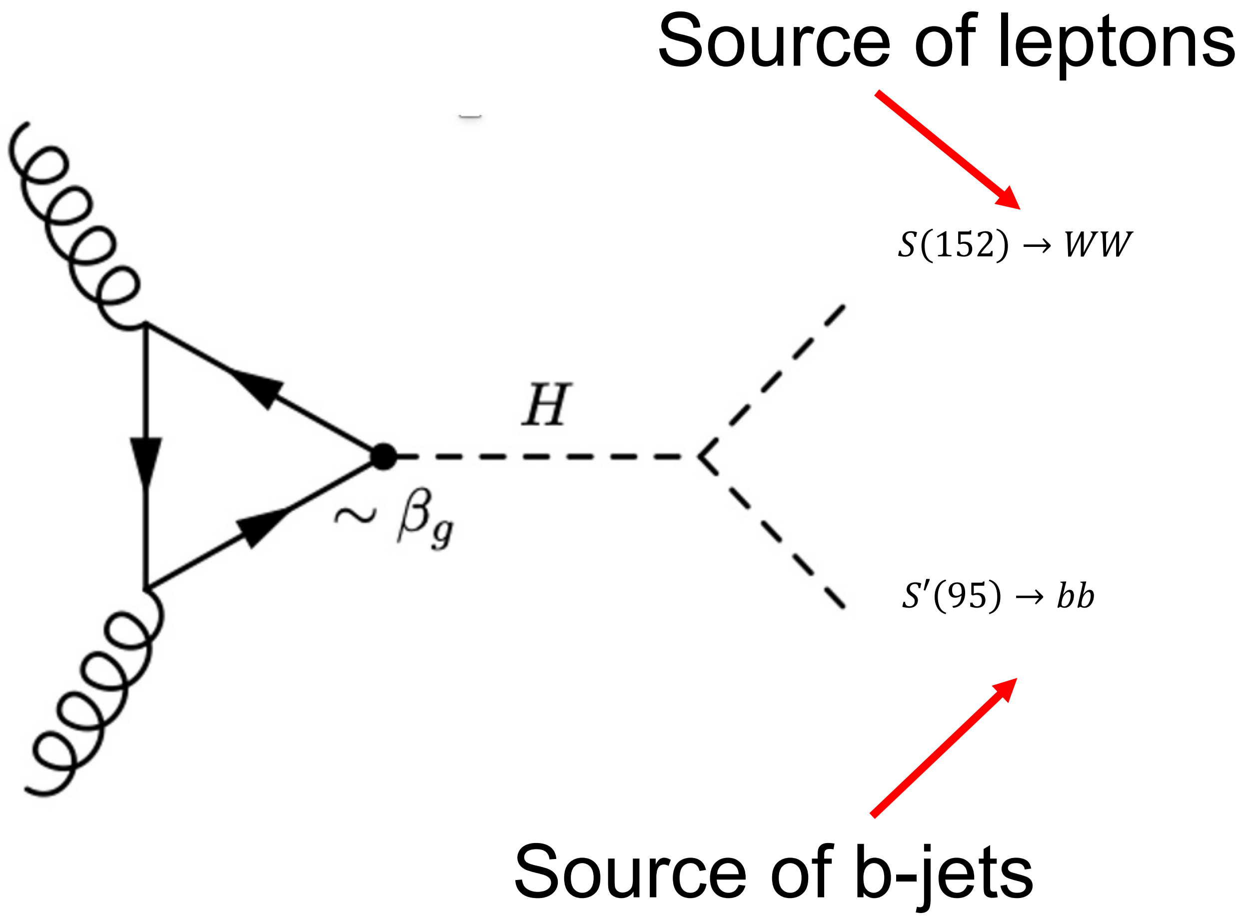


Current status of the combination, where global significance has reached 5σ. Largest global significance of a narrow structure beyond theSM at the LHC.



S.Battacharya, et al. arXiv:2306.17209

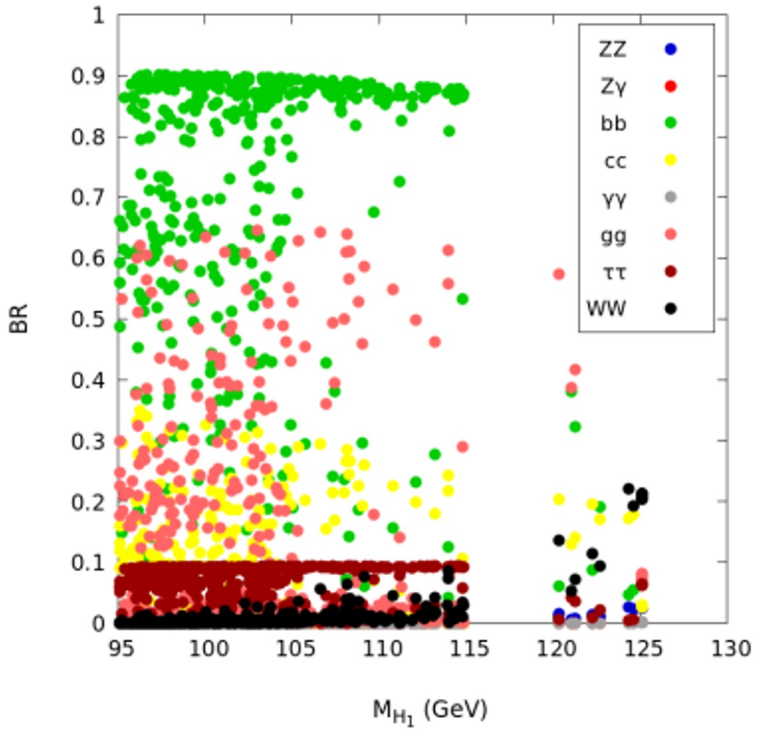
Potential contributor to multi-lepton anomalies at the LHC



2HDM+S Scanned Parameter space

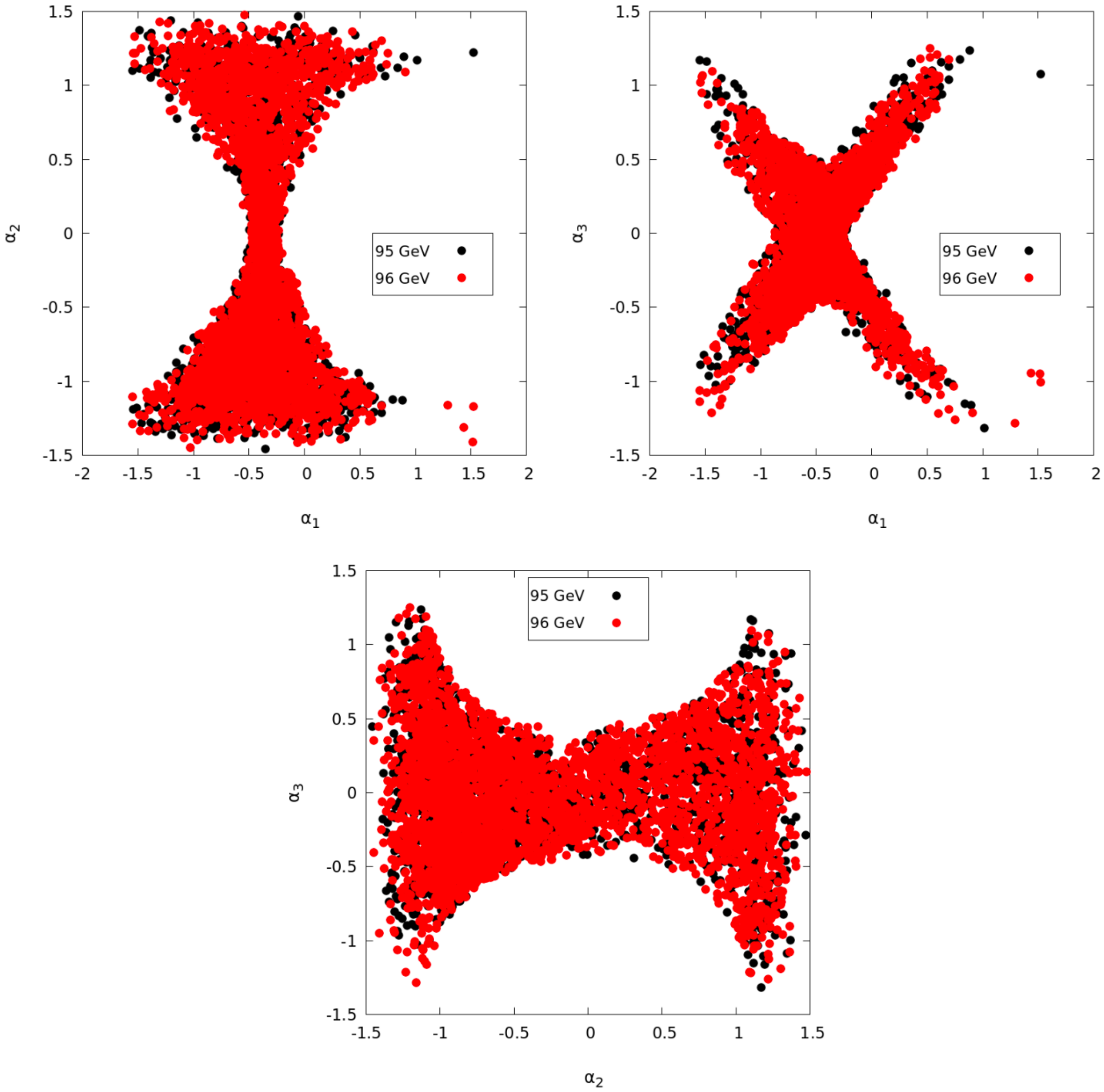
$$\alpha_1,\ \ \alpha_2,\ \ \alpha_3,\ \ t_\beta,\ \ ,v,\ \ v_S,\ \ m_{H_{1,2,3}},\ \ m_A,\ \ m_{H^\pm},\ \ m_{12}^2$$

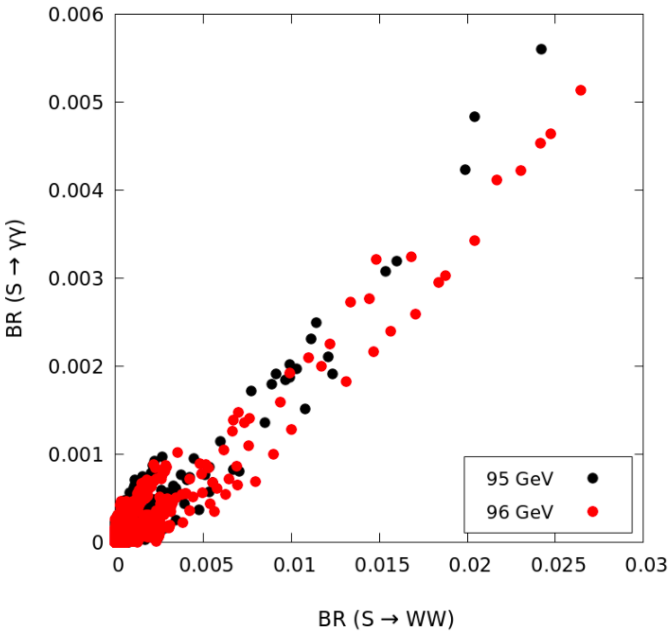
$$m_{H_1} = 95, 96 \text{ GeV}, \quad m_{H_2} = 125.09 \text{ GeV}, \quad 170 \text{ GeV} < m_{H_3} < 270 \text{ GeV},$$
$$300 \text{ GeV} < m_A < 900 \text{ GeV}, \quad 300 \text{ GeV} < m_{H_\pm} < 900 \text{ GeV}, \quad 0.5 < tan\beta < 4,$$
$$-\pi/2 < \alpha_i < \pi/2, \quad 100 \text{ GeV} < v_S < 1500 \text{ GeV}, \quad 0 < m_{12}^2 < 5 \times 10^5 \text{ GeV}^2$$



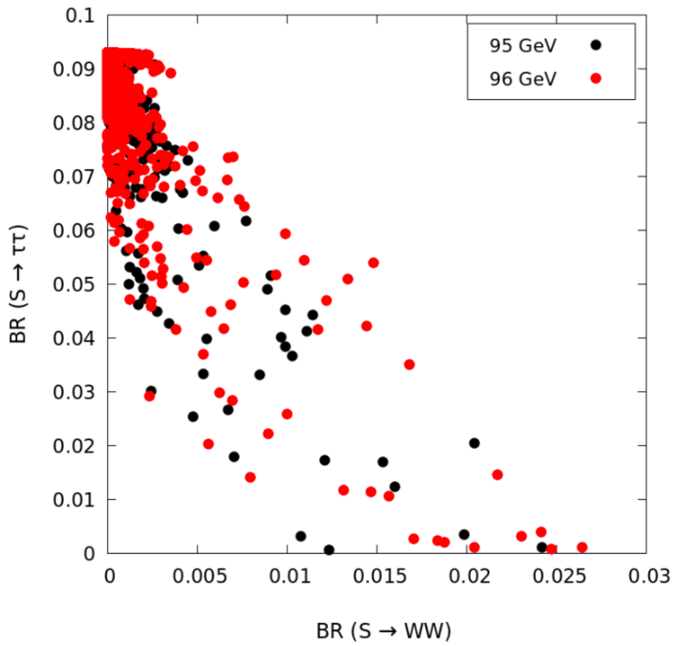
Assume the presence of one additional scalar only

- Scalar Higgs S at ee collider is produced through $e^+e^- \to e^+e^-S$, $e^+e^- \to \nu_e\tilde{\nu}_eS$, and $e^+e^- \to ZS$, there cross-sections for

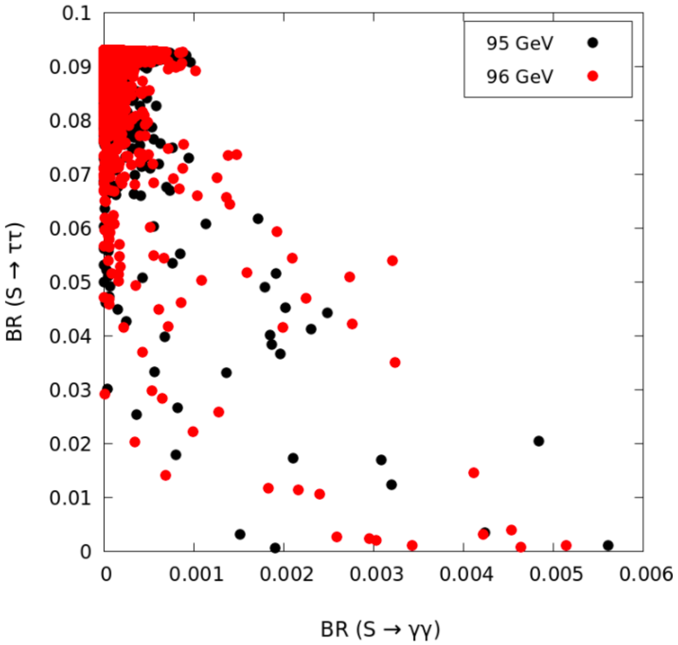

1.5
1
0.5
0
-0.5
-1
-1.5
-2
2
α2
α1
95 GeV
96 GeV
α3
α1
95 GeV
96 GeV
α3
α2
95 GeV
96 GeV

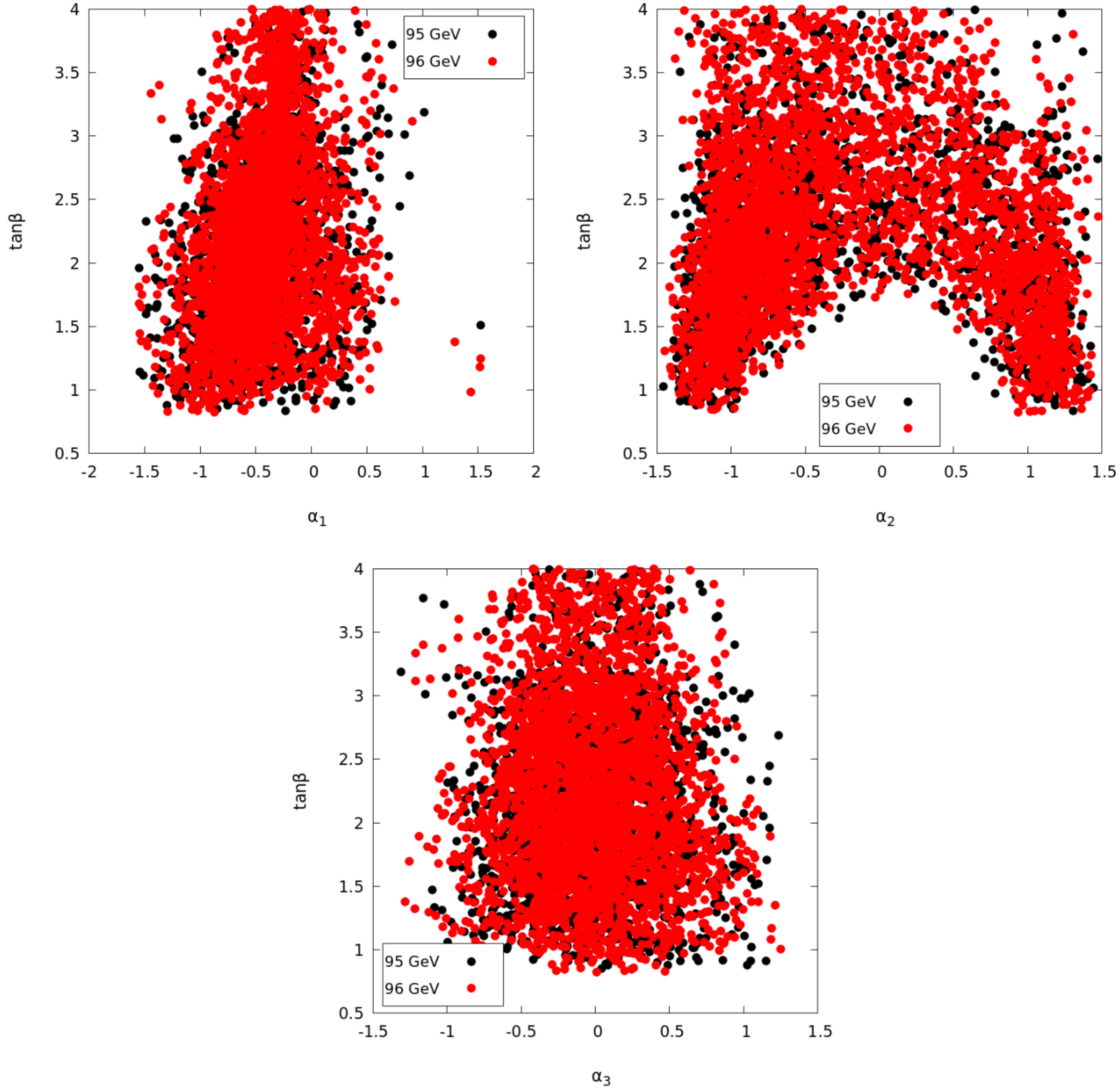

BR (S → γγ)
BR (S → WW)
95 GeV
96 GeV

(a)


BR (S → ττ)
BR (S → WW)
95 GeV
96 GeV

(b)


BR (S → ττ)
BR (S → γγ)
95 GeV
96 GeV


95 GeV
96 GeV
tanβ
α1
95 GeV
96 GeV
tanβ
α2
95 GeV
96 GeV
tanβ
α3

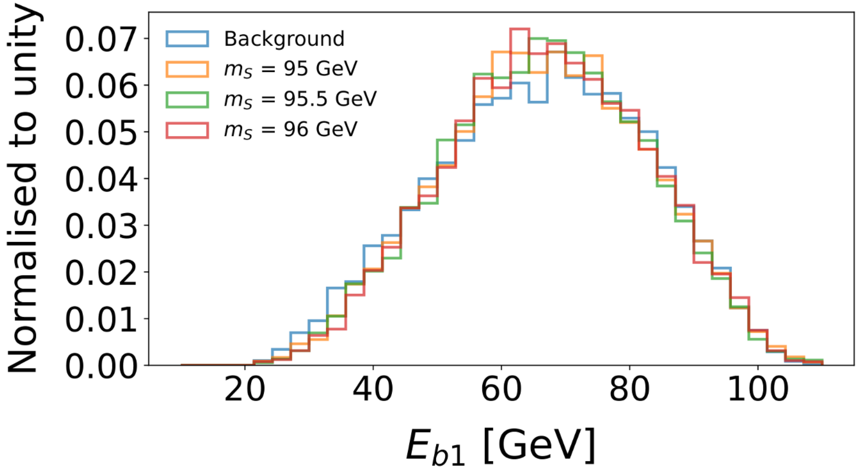
Machine learning approach: DNN

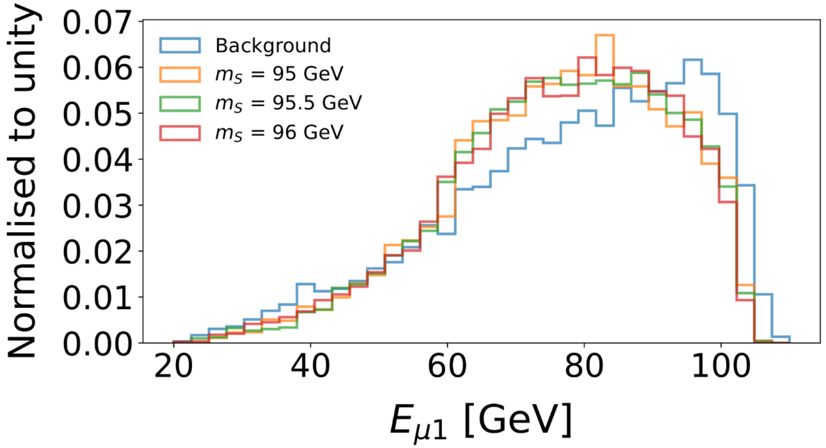
We have a 14 dimensional problem, where we are classify the signal from the background.

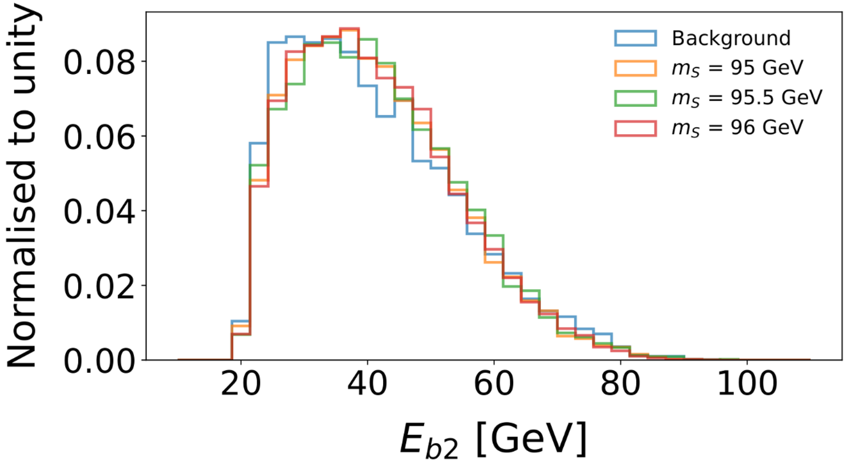
The 14 input variables include: the energy, polar angle and azimuthal angle for the muons and the b-tagged jets, as well as invariant mass of the b-tagged jets and recoil mass of the two muons.

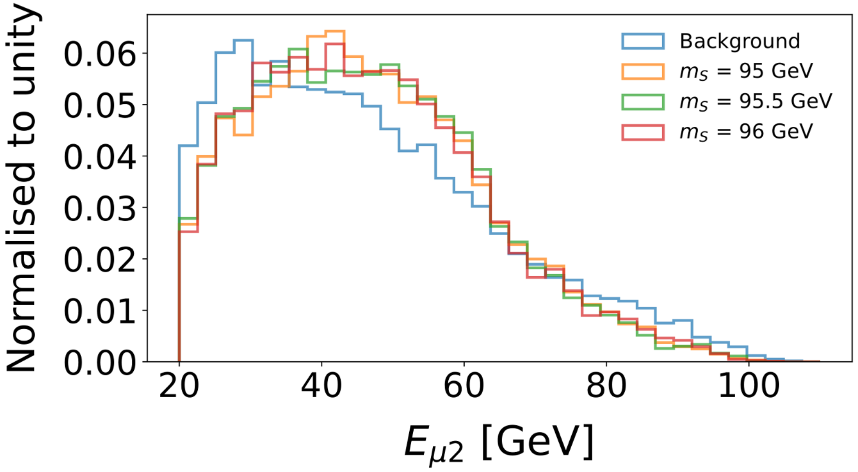
We deploy a binary classification algorithm to train the model on the 14 variables:

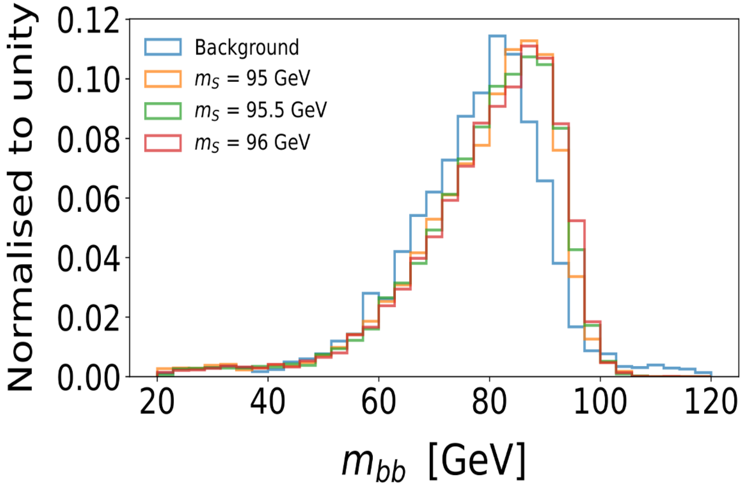
Machine Learning: Input variables



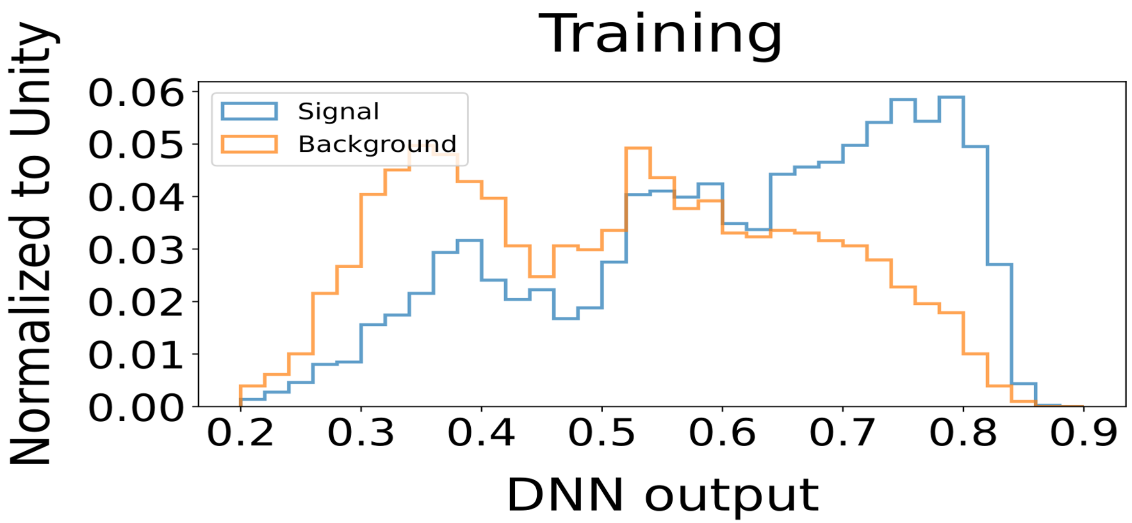


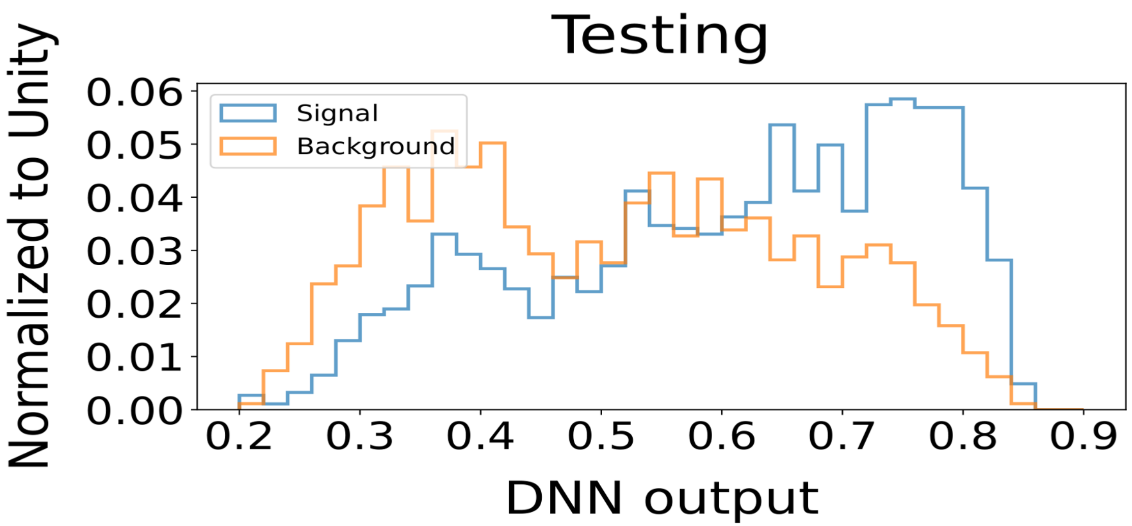




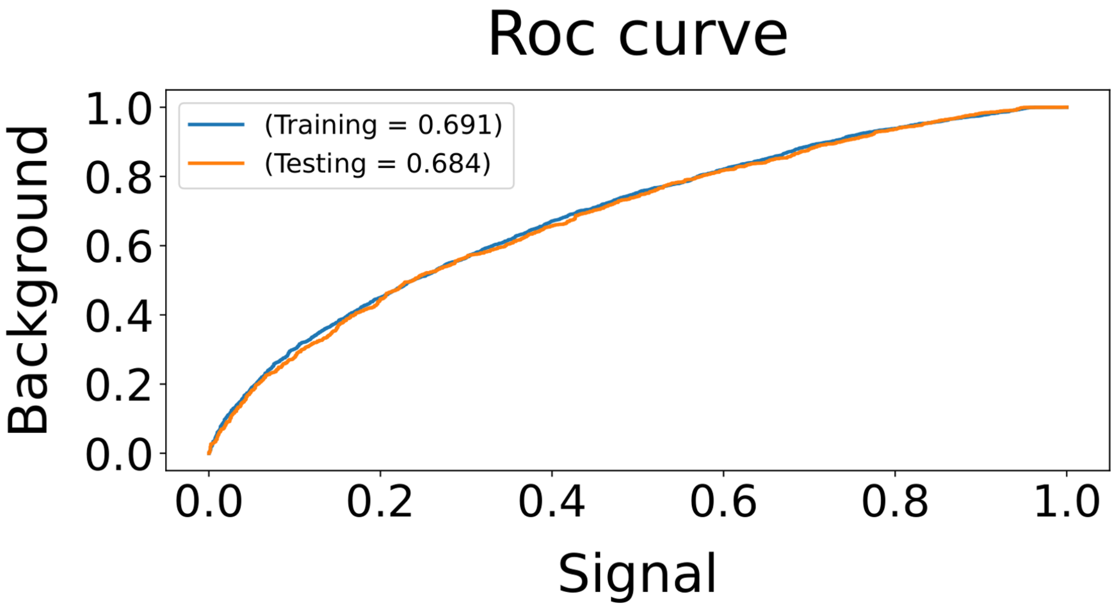


Machine Learning: classification results





This version of the training does not include the recoil mass. Discrimination is achieved with other kinematic features



Outlook

- Excess around 95 GeV seems to be growing at the LHC
- Excesses include di-photon, di-tautau and WW final states
  - Reached 3.8$\boldsymbol{\sigma}$ global significance just over 95 GeV
  - This excess fits well in a simplified model to explain the multi-lepton anomalies at the LHC
- Overall the 95 GeV excess can be explained within errors with a 2HDM+S model, where predictions for e^+e^- can be made
- Given the proximity of the Z peak, it is essential to use Machine Learning techniques to disentangle signal from background
  - Need to go in the direction of deep learning encompassing the entire final state