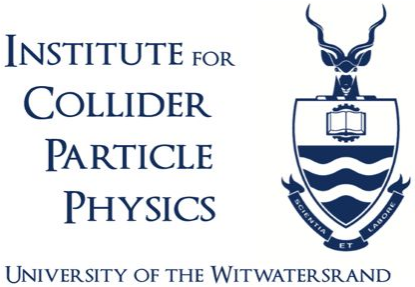
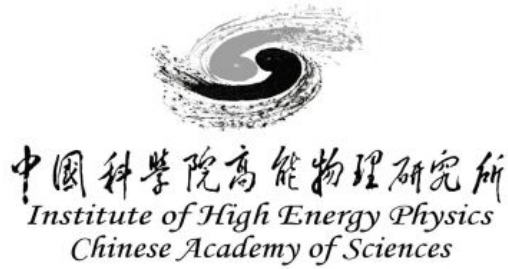
ICFP 2026

Investigation of a Diphoton Excess Near 152 GeV in Association with Dijets Using Run 3 Data at the LHC.

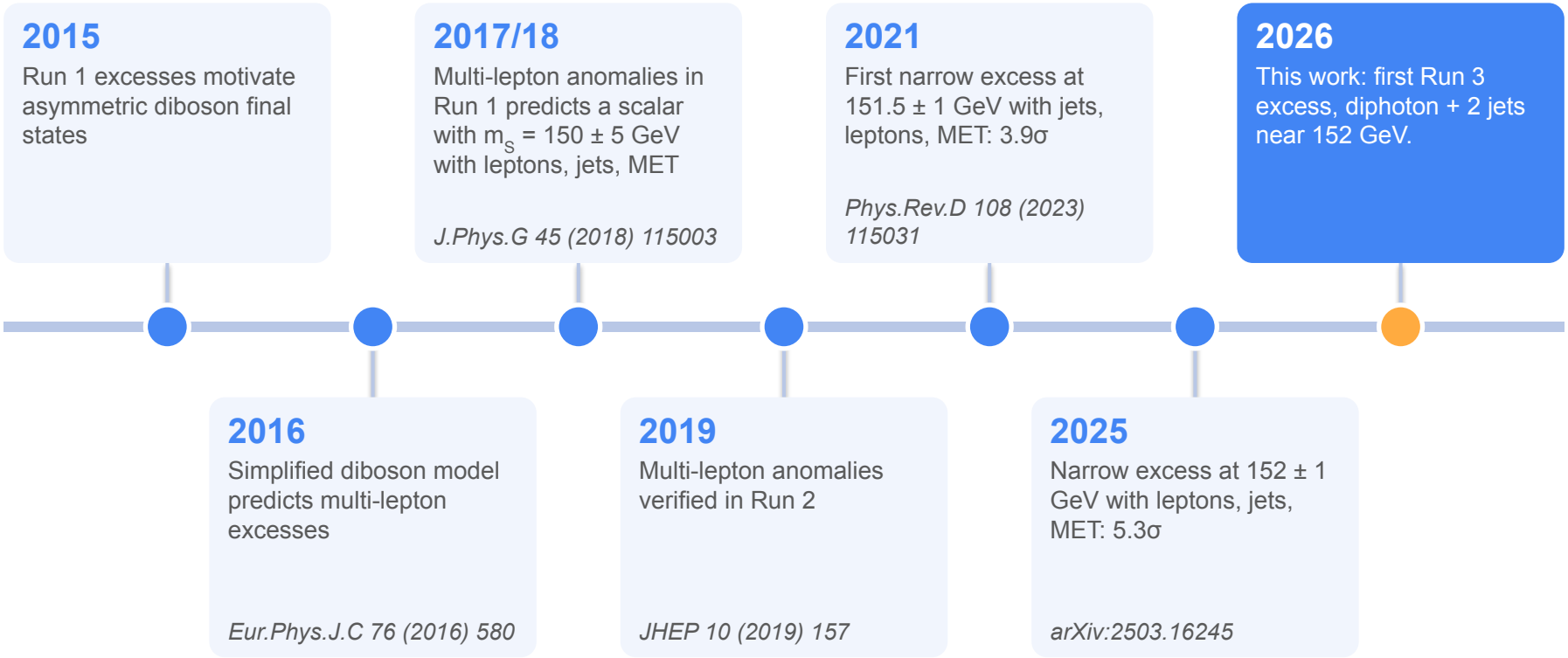






Pramod Sharma, **Arnav Chauhan**, Mukesh Kumar, Sukanta Dutta, Rachid Mazini, Bruce Mellado

The 152 GeV story



Excesses keep accumulating at 152 ± 1 GeV

Multi-lepton anomalies: The scalar comes with leptons

Final state	Characteristic	Dominant SM process	Significance
l^+l^- + jets, b-jets	m_{ll} < 100 GeV, mostly 0b and 1b	$t\bar{t}$ + 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
$l^\pm l^\pm$ & $l^\pm l^\pm l$, no b-jets	In association with h	Wh, WWW	4.2σ
$Z(\rightarrow l^+l^-)$ + l	p_T^Z < 100 GeV	ZW	> 3σ

Review: Nature Rev. Phys. 6 (2024) 294

Di-lepton invariant-mass spectra point to a scalar S with m_S = 150 ± 5 GeV, produced in association with leptons and jets.

J.Phys.G 45 (2018) 115003; Phys.Rev.D 108 (2023) 115031; arXiv:2306.17209

What the model predicted

gg → H
$m_H \approx 270$ GeV

↓

H → S S*
one S off shell

↓

S → W W
W → l ν, jj

↓

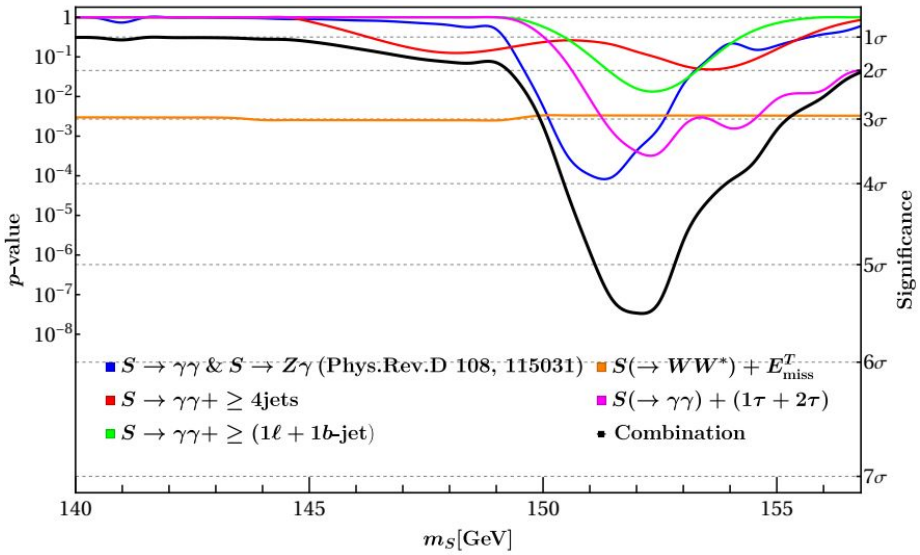
≥ 2 leptons
+ jets / b-jets + MET

Seen in data as anomalies: > 5σ combined

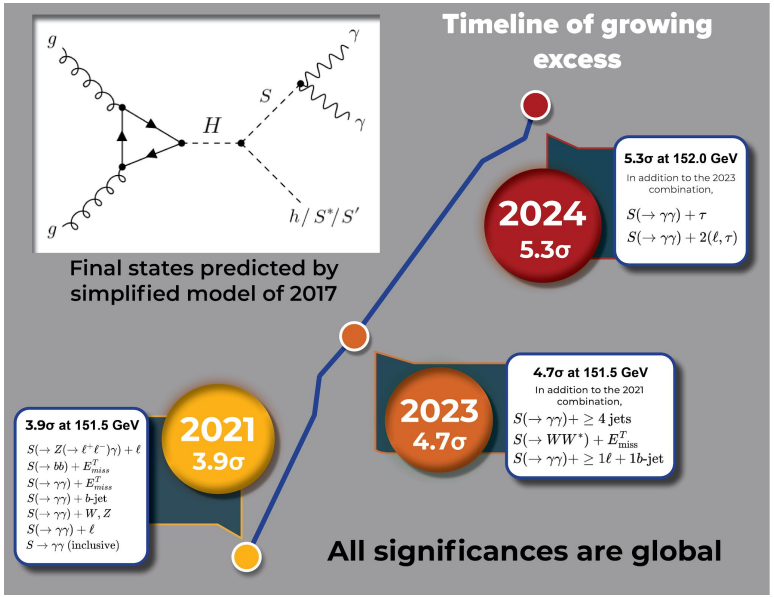
The Global excess in Run 2 at 152 GeV

150 ± 5 GeV mass was predicted by the model from the multi-lepton data, before it was seen in the diphoton spectrum

> 5σ global significance of the narrow excess at 152 ± 1 GeV after look-elsewhere (γγ, Zγ, WW with leptons, jets, MET)



S.Bhattacharya, et al. 2503.16245

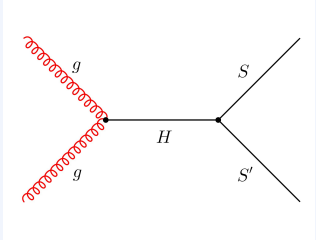


2021 (Group 1)	2023 (Group 2)	2025 (Group 3)
$\gamma\gamma + E^T_{\rm miss}$ [20, 43]	$\gamma\gamma + \geq (1\ell + 1b\text{-jet})$ [44]	$\gamma\gamma + \tau$ [45]
$\gamma\gamma + W, Z$ [46, 47]	$\gamma\gamma + \geq 4$ jets [44]	$\gamma\gamma + 2(\ell, \tau)$ [45]
$\gamma\gamma + b$-jet [48, 49]	$WW^*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

Signal models: 2HDM+S and HTM

2HDM+S

$gg \to H \to S(152)\, S'(95)$

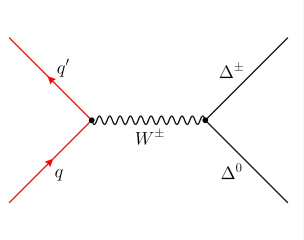


- Heavy scalar H, m_H = 270 GeV, produced via gluon fusion
- $H \to S\, S'$ with m_S = 152 GeV, $m_{S'}$ = 95 GeV
- $S \to \gamma\gamma$ gives the diphoton resonance; S' decays through all channels: $b\bar{b}$, ZZ, W^+W^-, $\gamma\gamma$, $\tau^+\tau^-$
- Motivated by the multi-lepton anomalies and the 152 GeV excess

MadGraph5 · 200k events

HTM

$pp \to W^{\pm *} \to \Delta^{\pm}\, \Delta^0$



- Drell–Yan production of the charged and neutral triplet scalars, $m_{\Delta^\pm} \simeq m_{\Delta^0}$ = 152 GeV
- $\Delta^0 \to \gamma\gamma$ (loop induced): clean diphoton signature
- $\Delta^\pm \to tb$, W*Z, WZ* with off-shell t*, W*, Z* decays
- Neutral member of a Y = 0 triplet: no $S \to ZZ$ expected

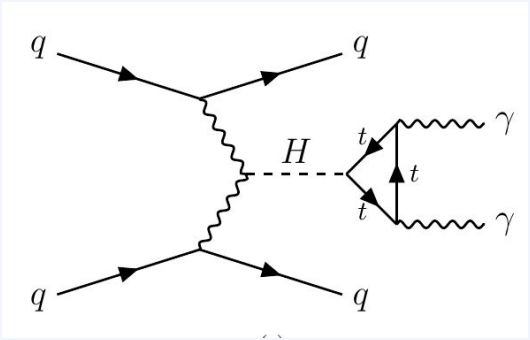
MadGraph5 · 400k events

MadGraph5 matrix elements → **Pythia 8.3** shower, hadronisation → **Delphes 3.5.0** fast detector sim → **ATLAS selection** ($\gamma\gamma$ + 2 jets) → **3-class DNN** VBF / ggF / $\gamma\gamma$+jj

The ATLAS Run 3 analysis

What ATLAS measured

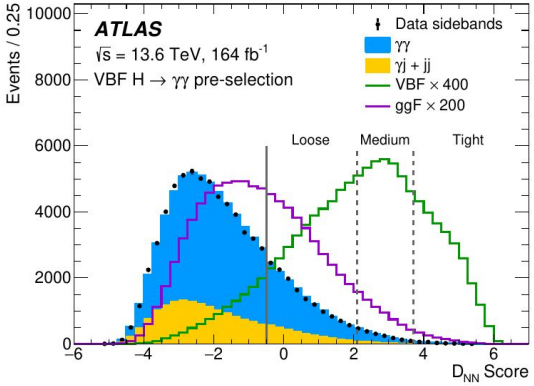
- Higgs bosons from vector-boson fusion (VBF), H → γγ, with two jets
- 164 fb^{-1} of pp collisions at 13.6 TeV
- Higgs coupling to W and Z: CP violation and polarisation. All results agree with the Standard Model
- Result: all measurements agree with the Standard Model



VBF H → γγ (ATLAS, arXiv:2603.20087)

Why a neural network, and why three categories

- VBF H → γγ is rare; ATLAS scales VBF by ×400 to show it
- Continuum γγ + jets and ggF Higgs, which also gives γγ + 2 jets. The selection alone leaves a large background
- Multi-class Neural Network: 16 inputs, three outputs (VBF, ggF, γγ + jets) combined into one score
- Trained to be uncorrelated with $m_{\gamma\gamma}$, so it does not sculpt the spectrum



$$D_{\mathrm{NN}} = \log\left(\frac{p_{\mathrm{VBF}}}{f_{\mathrm{ggF}}\, p_{\mathrm{ggF}} + (1 - f_{\mathrm{ggF}})\, p_{\mathrm{cont}}}\right)$$

Three categories by VBF purity

Tight: $D_{NN} \geq 3.7$
highest VBF purity

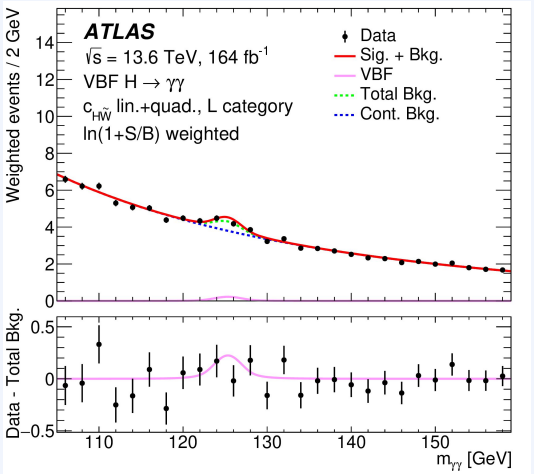
Medium: $2.1 \leq D_{NN} < 3.7$
lower purity, more events

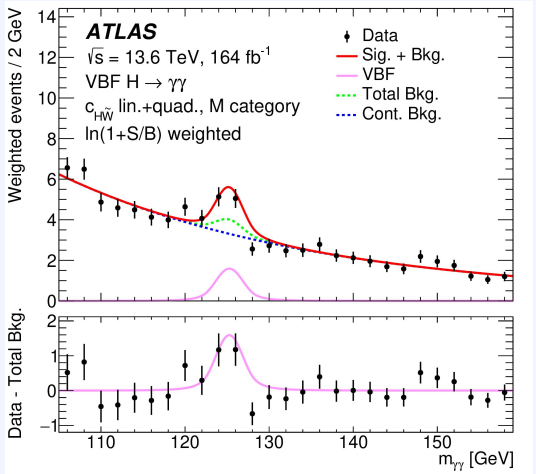
Loose: $-0.5 \leq D_{NN} < 2.1$
holds many ggF Higgs

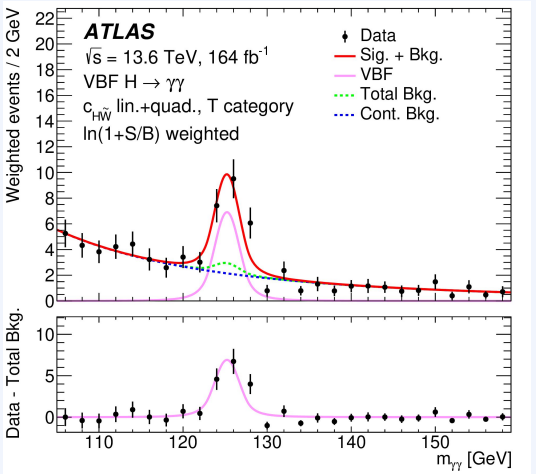
ATLAS results: The data we reuse

What we take from the ATLAS paper

- Sum the bins of the DNN-score figure to get the VBF and background yields (ggF, γγ, γj + jj) in each category
- From these, compute ln(1 + S/B) for each category
- Use it to unweight the ATLAS $m_{\gamma\gamma}$ spectra, which are ln(1 + S/B) weighted, and recover the event counts we fit
- Excess: a bump in $m_{\gamma\gamma}$ near 150 GeV, largest in the bins least compatible with VBF







Figures: ATLAS, arXiv:2603.20087 (HIGP-2024-23); data digitised from the published plots

Cutflow for fast-sim samples

Cut	SM VBF	SM ggF	SM γγ+jj	2HDM+S	HTM
Generated events	434,809	586,896	1,800,000	200,000	400,000
≥ 2γ (E_T > 25 GeV, $\|\eta\|$ < 2.37)	0.602	0.545	0.406	0.385	0.471
$E_T(\gamma_1)$ > 35 GeV, $E_T(\gamma_2)$ > 25 GeV	0.601	0.544	0.399	0.384	0.471
120 < $m_{\gamma\gamma}$ < 130 GeV	0.596	0.541	0.361	0.384	0.471
$E_T(\gamma_1)/m_{\gamma\gamma}$ > 0.35, $E_T(\gamma_2)/m_{\gamma\gamma}$ > 0.25	0.534	0.493	0.283	0.331	0.407
≥ 2 jets (p_T > 20 GeV, $\|\eta\|$ < 4.4)	0.479	0.441	0.227	0.269	0.318
$p_T(j_1)$ > 30 GeV, $p_T(j_2)$ > 30 GeV	0.421	0.384	0.180	0.218	0.278
$\|\Delta\eta_{jj}\|$ > 2	0.359	0.176	0.062	0.076	0.037
η^{Zepp} < 5	0.359	0.175	0.062	0.075	0.037

Cumulative efficiencies. The γγ+jj sample is generated with $p_T(\gamma)$ > 20 GeV; the $m_{\gamma\gamma}$ window is not applied to the 2HDM+S and HTM samples.

DNN classifier: Architecture and training



Input features (16)

- Jets: p_T, η of j1, j2; $N_{\text{central jets}}$; $\Delta R(\gamma j)_{\text{min}}$
- Dijet: m_{jj}, $\Delta\eta_{jj}$, $p_{T,jj}$
- Diphoton: $\Delta R(\gamma\gamma)$, $p_T/m_{\gamma\gamma}$, $p_{Tt}/m_{\gamma\gamma}$
- γγjj: $\Delta\varphi$, η^{Zepp}, $\cos\Theta^*$, $p_{T,\gamma\gamma jj}$
- $|\cdot|$ for sign-blind variables, log for momenta and masses

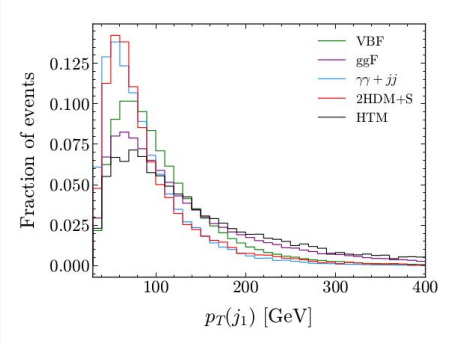
Training setup

- PyTorch, fully connected network
- Multi-class cross-entropy on the logits, softmax for probabilities
- Adam optimiser, learning rate 10^{-5}
- Dropout 0.1 after the 2nd and 3rd layers
- About 1000 epochs

Data set

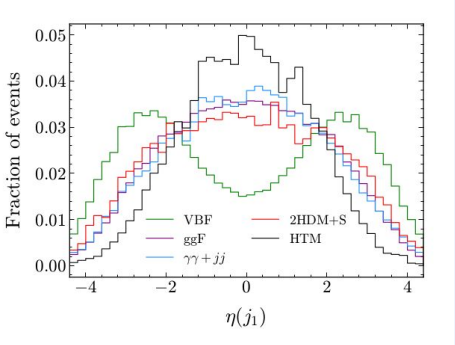
- 102,947 events per class: VBF, ggF, γγ+jj
- 308,841 events × 16 features
- Train : test = 0.8 : 0.2
- Same feature scaler applied to 2HDM+S and HTM, no retraining

Features: Jet kinematics



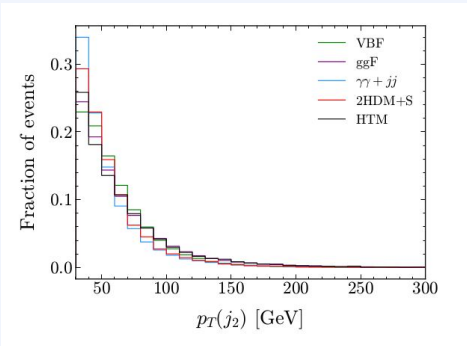
$p_T(j_1)$

All samples peak at 50–80 GeV; HTM has the hardest tail. Weak discriminant.



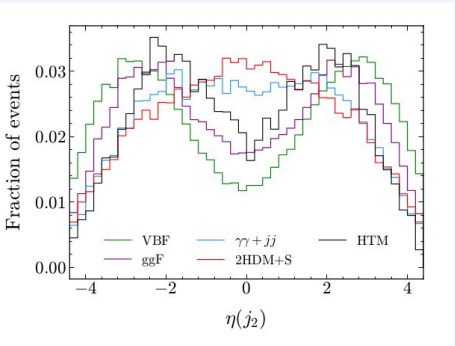
$\eta(j_1)$

VBF jets are forward (humps at $|\eta| \approx 2$–3, dip at 0); the HTM leading jet is central.



$p_T(j_2)$

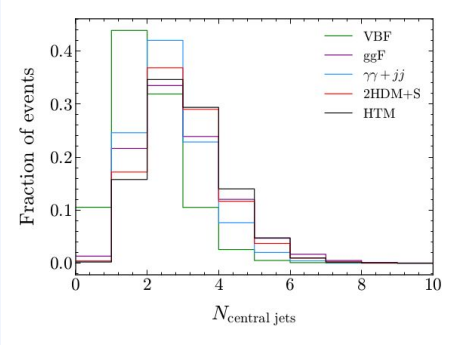
Steeply falling for every sample and set by the 30 GeV cut: little separation.



$\eta(j_2)$

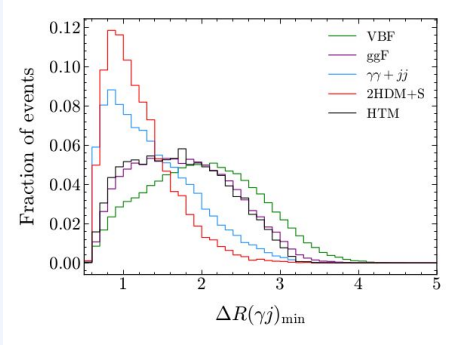
Same VBF double hump with a central dip; 2HDM+S and γγ+jj are flatter.

Features: VBF dijet topology



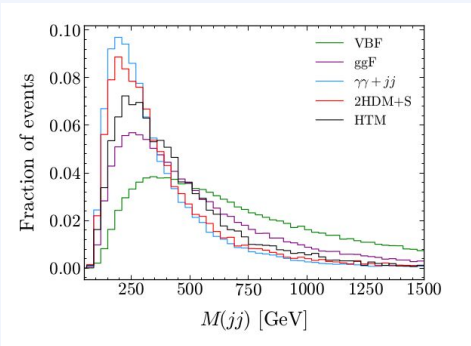
$N_{\text{central jets}}$

VBF peaks at 1 central jet (rapidity gap); the other samples peak at 2–3.



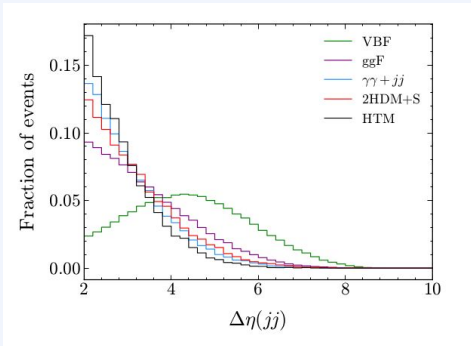
$\Delta R(\gamma j)_{\text{min}}$

2HDM+S and γγ+jj peak near 0.9 (photon close to a jet); VBF, ggF and HTM are broad at 1.5–2.5.



m_{jj}

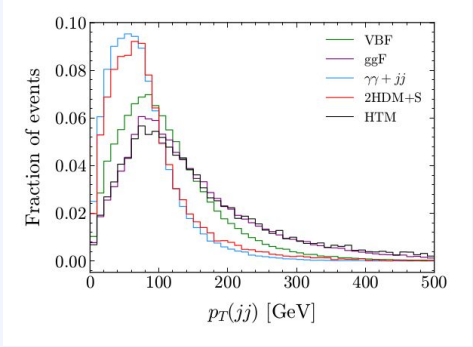
VBF has a long tail beyond 1 TeV; every other sample peaks at 200–300 GeV.



$\Delta\eta_{jj}$

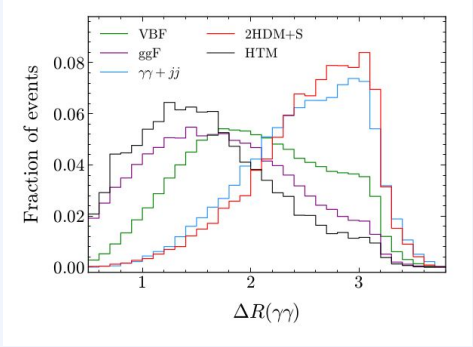
VBF peaks at 4–5; all other samples fall steeply from the cut at 2. The clearest VBF signature.

Features: Diphoton and dijet momentum



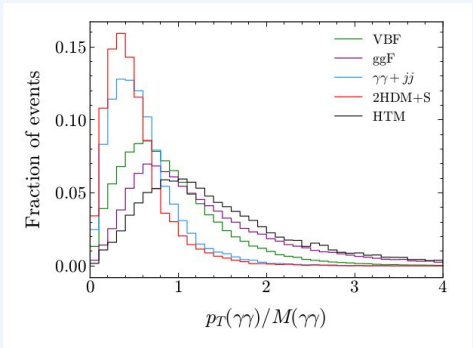
$p_T(jj)$

VBF, ggF and HTM peak near 90 GeV with long tails; 2HDM+S and γγ+jj are softer.



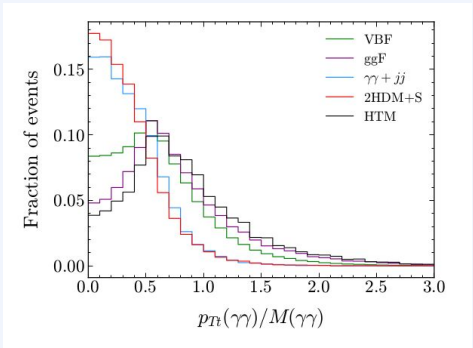
ΔR(γγ)

HTM peaks near 1.3; 2HDM+S and γγ+jj are back-to-back (≈ 3); VBF and ggF sit in between.



$p_T(\gamma\gamma)/m_{\gamma\gamma}$

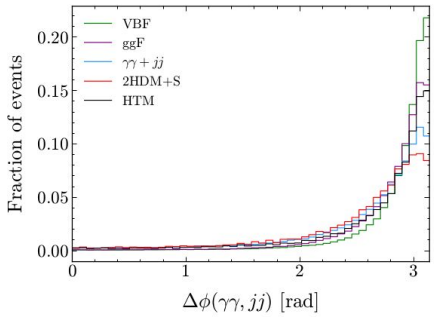
2HDM+S and γγ+jj peak near 0.4; HTM, ggF and VBF are harder, with tails to 3.



$p_{Tt}(\gamma\gamma)/m_{\gamma\gamma}$

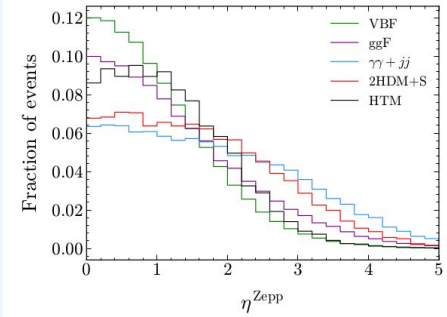
Same pattern: 2HDM+S and γγ+jj sit at small values, HTM and ggF are broader.

Features: The γγ + jj system



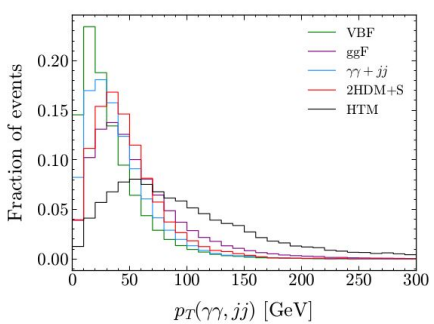
Δφ(γγ,jj)

Peaks at π for all samples (balanced system); sharpest for VBF, lowest for 2HDM+S.



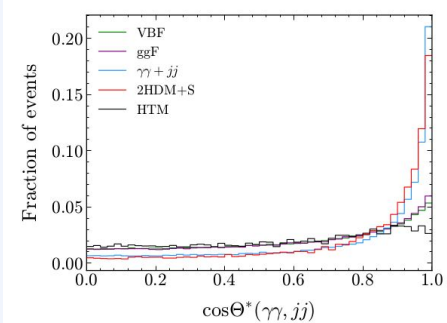
η^{Zepp}

VBF is the most central; γγ+jj and 2HDM+S have the widest tails.



$p_T(\gamma\gamma,jj)$

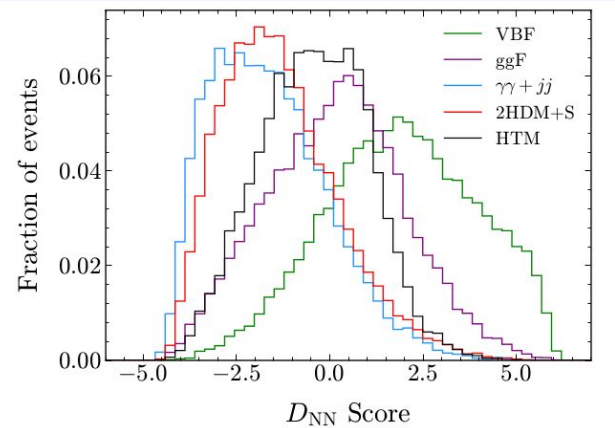
VBF is softest (peak near 20 GeV); HTM has the hardest spectrum.



$\cos\Theta^*(\gamma\gamma,jj)$

γγ+jj and 2HDM+S pile up near 1; HTM is almost flat.

DNN score distribution for Fast Sim



D_{NN} score of the five samples; the Tight, Medium and Loose regions are defined on this score.

- 2HDM+S follows γγ+jj at low scores
- HTM is shifted towards the ggF-like, intermediate region
- VBF extends to the highest scores (up to ≈ 6)

Region	DNN Efficiency				
	VBF	ggF	γγjj	2HDM+S	HTM
Tight: > 3.5	0.226	0.035	0.002	0.004	0.003
Medium: 1.6–3.5	0.336	0.180	0.030	0.046	0.078
Loose: −0.7–1.6	0.334	0.459	0.216	0.259	0.498

Points to note

- Regions are defined so that ε_{VBF} matches ATLAS in each one (0.226 / 0.336 / 0.334)
- BSM events are not VBF-like: below 0.5% fall in Tight (0.4% 2HDM+S, 0.3% HTM)
- HTM populates Medium and Loose more than 2HDM+S: 7.8% vs 4.6% and 49.8% vs 25.9%
- These ε_{DNN} fix the ratios of the signal sizes in the simultaneous fit

Fit model for the $m_{\gamma\gamma}$ spectrum

$$f_r(m_{\gamma\gamma}) = \underbrace{B(m_{\gamma\gamma})}_{\text{background}} + \underbrace{\mathrm{DSCB}_H(m_{\gamma\gamma}; N_H)}_{\text{SM Higgs, 125 GeV}} + \underbrace{\mathrm{DSCB}_S(m_{\gamma\gamma}; N_S)}_{\text{BSM scalar, 152 GeV}}$$

Fitted independently in each DNN category by χ^2 minimisation; yields taken in the 148–156 GeV window

Signal shape: double-sided Crystal Ball

$$\mathrm{DSCB}(m_{\gamma\gamma}) = N \times \begin{cases} A_L\,(B_L - t)^{-n_L}, & t < -\alpha_L, \\ e^{-t^2/2}, & -\alpha_L \le t \le \alpha_R, \\ A_R\,(B_R + t)^{-n_R}, & t > \alpha_R, \end{cases}$$

$$t = \frac{m_{\gamma\gamma} - \mu}{\sigma},$$

$$A_{L,R} = \left(\frac{n_{L,R}}{|\alpha_{L,R}|}\right)^{n_{L,R}} e^{-\alpha_{L,R}^2/2}, \quad B_{L,R} = \frac{n_{L,R}}{|\alpha_{L,R}|} - |\alpha_{L,R}|$$

- Gaussian core, power-law tails, N is the peak height
- Higgs: shape fixed, only N_H floats
- BSM: μ = 152 GeV, Higgs tails, σ scaled by 152/125, only N_S floats

Non-resonant background

$$B(m_{\gamma\gamma}) = N_B\,\exp\!\left(a\,m_{\gamma\gamma} + b\,m_{\gamma\gamma}^2\right)$$

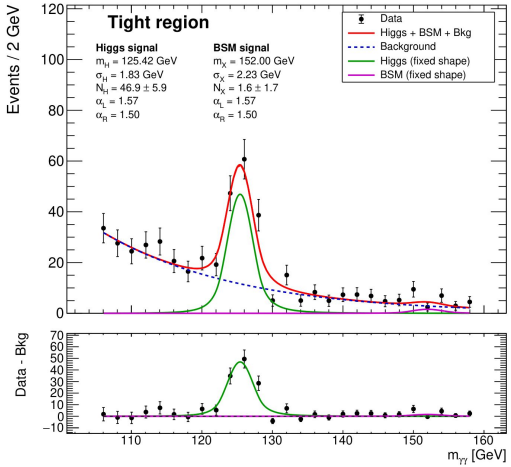
Exponential of a second-order polynomial.
All parameters float

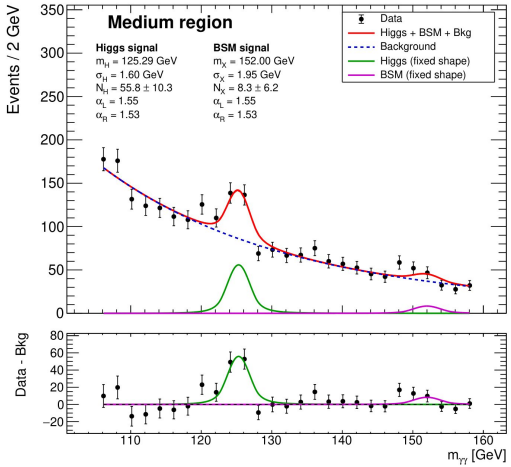
Fixed SM Higgs shape parameters

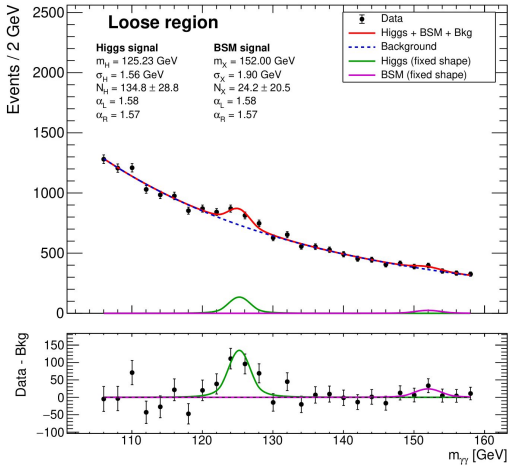
Category	μ_H	σ_H	α_L	n_L	α_R	n_R
Tight	125.42	1.83	1.57	4.03	1.50	3.01
Medium	125.29	1.60	1.55	3.67	1.53	2.87
Loose	125.23	1.56	1.58	3.45	1.57	2.90

μ_H, σ_H in GeV; from the ATLAS Higgs fit (arXiv:2603.20087)

An excess in all three categories for the independent fits







Yields in the 148–156 GeV window

Category	N_B	N_S	δN_S	$N_S/\sqrt{N_B}$
Tight	11.6	4.08	3.95	1.20
Medium	148.8	19.6	13.0	1.61
Loose	1457.7	55.8	38.9	1.46

Note on the fit

- An excess near 152 GeV in every category
- No signal model, and no relation between categories is assumed

Fiducial cross sections and the simultaneous fit

1 How σ_{fid} is calculated

The model-independent yield N_S of each independent fit is converted into the cross section each model would need:

$$\sigma^r_{\text{fid}} = \frac{N^r_S}{\mathcal{L}\,\varepsilon_{\text{reco}}\,\varepsilon^r_{\text{DNN}}} = \frac{N^r_S}{\mathcal{L}\,\varepsilon^r_{\text{tot}}}$$

$$\varepsilon_{\text{reco}} = \frac{\varepsilon_{\text{presel.}}}{\varepsilon_{\text{fid}}}, \qquad \varepsilon^r_{\text{tot}} = \varepsilon_{\text{reco}}\,\varepsilon^r_{\text{DNN}}$$

- L = 164 fb^{-1} (ATLAS Run 3, 13.6 TeV); $\delta\sigma_{fid}$ from $\delta N_S = \sqrt{(N_S + N_B)}$
- $\varepsilon_{reco} = \varepsilon_{presel.}/\varepsilon_{fid}$: full selection over diphoton selection (0.0909 HTM, 0.2266 2HDM+S)
- ε_{DNN}^{r}: category efficiency of the BSM sample

Per-category σ_{fid} from the independent fits

Category	N_S	σ_{fid} HTM [fb]	σ_{fid} 2HDM+S [fb]
Tight	4.08 ± 3.95	91 ± 88	27.4 ± 26.6
Medium	19.6 ± 13.0	16.9 ± 11.2	11.5 ± 7.6
Loose	55.8 ± 38.9	7.5 ± 5.2	5.8 ± 4.0

2 Simultaneous fit: how it works

- All three $m_{\gamma\gamma}$ spectra are fitted at once by χ^2 minimisation, each with background + Higgs + BSM peak at 152 GeV
- BSM signal in category r = $\sigma_{fid} \times L \times \varepsilon_{tot}^{r}$.
- One common σ_{fid} scales the peak in all categories
- The BSM shape follows the Higgs shape with σ rescaled by 152/125. No other BSM parameter floats
- **Starting point:** the per-category σ_{fid} from the independent fits. The background and Higgs parameters stay free in each category

DNN efficiencies tie the categories

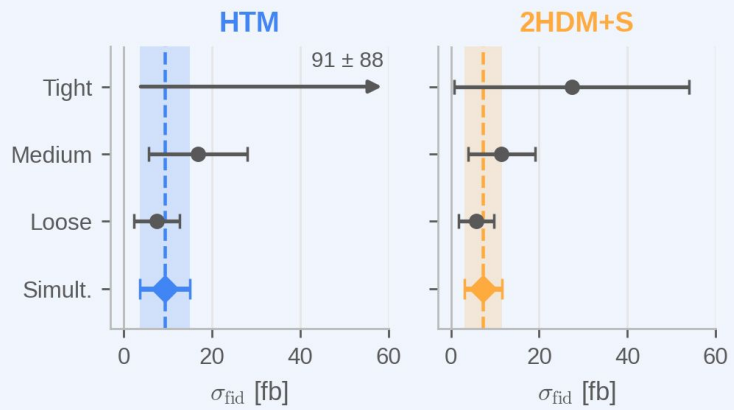
Category	ε_{DNN} HTM	ε_{DNN} 2HDM+S	ε_{tot} HTM	ε_{tot} 2HDM+S
Tight	0.003	0.004	0.000273	0.000906
Medium	0.078	0.046	0.00709	0.01042
Loose	0.498	0.259	0.04527	0.05869

Loose holds ≈ 86 % (HTM), ≈ 84 % (2HDM+S) of the signal

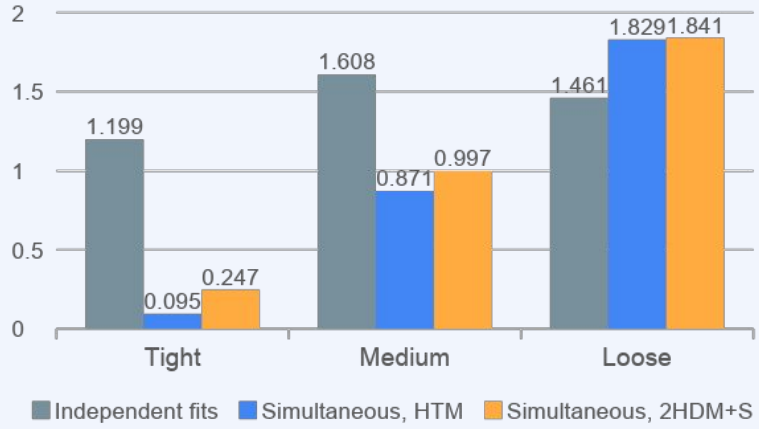
Simultaneous Fit Results

Model	Common σ_{fid} [fb]	Z Tight	Z Medium	Z Loose	Combined Z
HTM	9.38 ± 5.65	0.095	0.871	1.829	2.03σ
2HDM+S	7.29 ± 4.24	0.247	0.997	1.841	2.11σ

Fiducial cross sections σ_{fid}



Significance $N_S/\sqrt{N_B}$ per category



σ_{fid} = 9.4 ± 5.7 fb (HTM) and 7.3 ± 4.2 fb (2HDM+S); every category agrees with the common value

2.03σ (HTM) and 2.11σ (2HDM+S) from independent Run 3 data, in addition to the > 5σ global significance from Run 2

Summary

What we did

Recast the ATLAS Run 3 VBF H→γγ analysis (164 fb^{-1}, 13.6 TeV) with a 3-class DNN (VBF / ggF / γγ+jj) and Tight / Medium / Loose categories.

Tested two 152 GeV scenarios, 2HDM+S and HTM

A Run 3 excess at 152 GeV

Diphoton + 2 jets shows an excess in all three categories.

$N_S/\sqrt{N_B}$ = 1.20, 1.61, 1.46 (for TIght, Medium, Loose) from independent fits that assume no signal model.

Compatible cross sections

Per-category σ_{fid} seed one simultaneous fit: 9.4 ± 5.7 fb (HTM), 7.3 ± 4.2 fb (2HDM+S).

All categories are within 1σ.

2.03σ (HTM) and 2.11σ (2HDM+S), on top of the > 5σ Run 2 global significance.

Outlook: HL-LHC

If the 152 GeV scalar is confirmed in Run 3, the HL-LHC will offer a very rich physics programme. Precision measurements of the scalar and of its production and decay patterns, and a test of which scenario (2HDM+S, HTM) describes it.

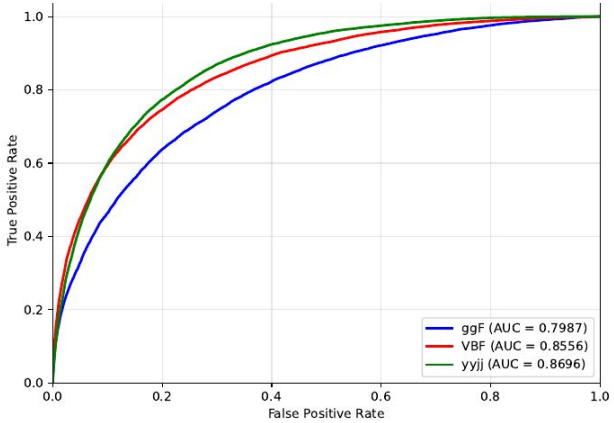
Extra Slides

DNN performance on the three classes

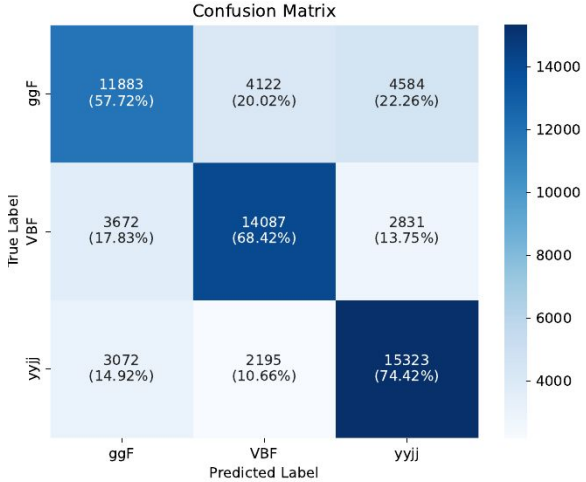
0.870
γγ+jj AUC

0.856
VBF AUC

0.799
ggF AUC



ROC curves, one per class



Confusion matrix, row-normalised

- Loss settles near 0.75 and accuracy near 67%; training and test curves overlap, so no sign of overtraining
- Confusion matrix (row-normalised): γγ+jj 74%, VBF 68%, ggF 58% correct; ggF is the hardest class, mixing with both VBF and γγ+jj
- The DNN is used as a VBF-likeness ranking for the Tight / Medium / Loose regions, not as a hard classifier

From class probabilities to the D_{NN} score

$$D_{NN} = \log\left[p_{VBF} / \left(f_{ggF} \cdot p_{ggF} + (1 - f_{ggF}) \cdot p_{cont} \right) \right]$$

p_{VBF}, p_{ggF}, p_{cont}: softmax outputs for VBF, ggF, continuum. $f_{ggF} = 0.022$, as in the ATLAS analysis.

Tight / Medium / Loose regions: ATLAS versus this work (ε_{VBF} matched)

Region	DNN cut (ATLAS → this work)	εVBF	εggF (ATLAS → this work)	εγγjj (ATLAS → this work)	ε2HDM+S	εHTM
Tight	> 3.7 → > 3.5	0.226 → 0.226	0.014 → 0.035	0.006 → 0.002	0.004	0.003
Medium	2.1–3.7 → 1.6–3.5	0.335 → 0.336	0.074 → 0.180	0.028 → 0.030	0.046	0.078
Loose	−0.5–2.1 → −0.7–1.6	0.334 → 0.334	0.385 → 0.459	0.173 → 0.216	0.259	0.498

- Region boundaries are chosen so that ε_{VBF} reproduces the ATLAS values in each region
- ε_{ggF} is higher than ATLAS in all three regions, so the background composition is not reproduced exactly by the fast-sim recast
- BSM events are mostly Loose: 25.9% (2HDM+S) and 49.8% (HTM), but only 0.4% and 0.3% in Tight