$H_{125\,\mathrm{GeV}}$ self-coupling and pair production

Shota Izumiyama (KMI, Nagoya Univ.)
on behalf of the ATLAS Collaboration

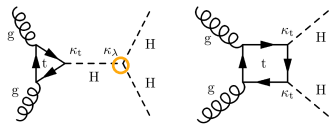
Higgs Hunting 2026,
Orsay/Paris (France), 16 September 2026

Self-coupling & pair production

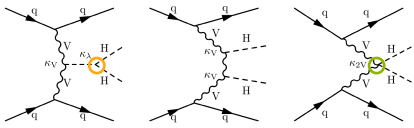
- Self-coupling induced by Higgs potential

$$\text{SM after EWSB: } \mathcal{L}^{H}_{\text{Higgs}} = -\frac{1}{2}m_H^2 H^2 - \boxed{\lambda v H^3} - \frac{1}{4}\lambda H^4$$

ggF



VBF



Xsec, σ_{HH}, at 13.6 TeV and $m_H = 125$ GeV

$\sigma_{\text{ggF}} = 34.13\,\text{fb}\ ^{+6\,\%}_{-23\,\%}$

Non-resonant HH production

$\sigma_{\text{VBF}} = 1.874\,\text{fb}\ \pm 2.7\,\%$

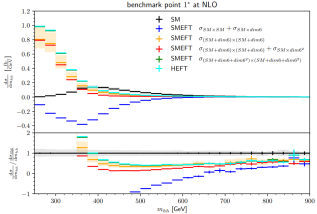
Unique sensitivity to $VVHH$ coupling

$\Rightarrow \mathcal{O}(10000)$ events in ATLAS Run 1–3

Not yet observed

New physics searches

- Effective Field Theory approach
  - No dedicated physics model
  - ⇒ Interpretation from non-resonant analysis

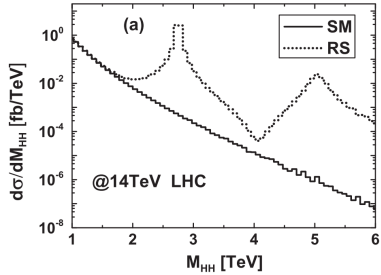


JHEP 10 (2023) 086

Kinematics variation
by different coefficients

- Resonance search
  - MSSM, extra dimension, etc.
  - ⇒ Direct search for additional scalars X, Y:
    $X \to YY$, $X \to Yh$

RS graviton, $G \to HH$



PRD 92 (2015) 116005

Analysis channels × kinematic regions

Channels

- Three golden channels

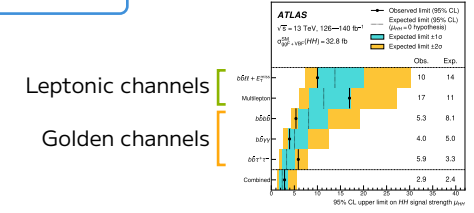
	Pros.	Cons.
$b\bar{b}b\bar{b}$	Largest branch	QCD background
$b\bar{b}\tau^-\tau^+$	Sizeable branch &	Characteristic signature
$b\bar{b}\gamma\gamma$	Clear signature	Tiny branch

- Additional channels
  - Wider coverage: leptonic channels

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

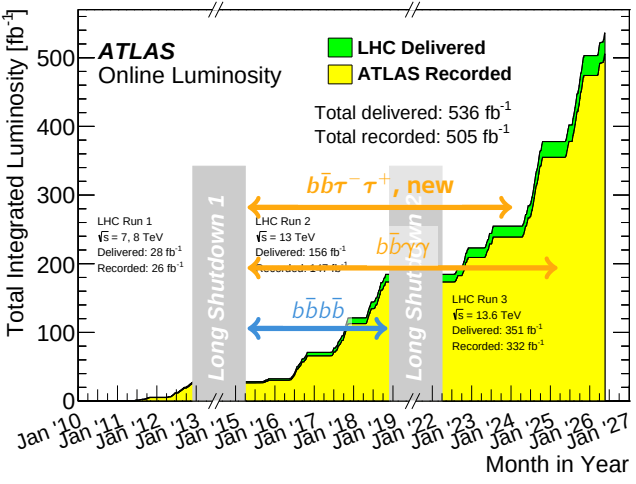
Resolved/boosted $b/X_{b\bar{b}}$-jet

	ΔR	Flavor tagger
Small-R	0.4	GN2
Large-R	1.0	$X_{b\bar{b}}$, GN2X/GN3X



PRL 133 (2024) 101801

Strategy in ATLAS: datasets



Run 2: $140\,\mathrm{fb}^{-1}$
exotic channels, combination of all channels

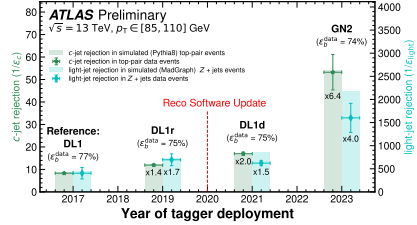
Run 3: $\sim 330\,\mathrm{fb}^{-1}$
expanding dataset coverage
Partial Run 3 $\rightarrow$ full Run 3.

$b\bar{b}\gamma\gamma$	PLB 876 (2026) 140280
$b\bar{b}\tau^-\tau^+$	arXiv:2607.26879

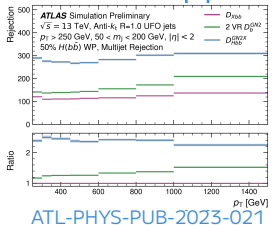
Strategy in ATLAS: new tools

Flavor (b-jet, $X_{b\bar{b}}$) tagger

- Deep Learning
  $\rightarrow$ Transformer (GN2)
  - Light-jet rejection $\times 2$
  - Further improvement is expected for full Run 3 analysis



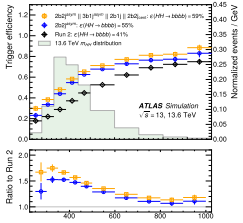
FTAG-2023-07

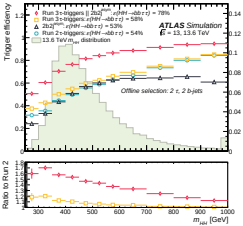


ATL-PHYS-PUB-2023-021

Run 3 triggers

- Factor 1.5–2 better efficiencies
  - Asymmetric p_T thresholds
  - New b-jet/τ taggers





JINST 20 (2025) P03002

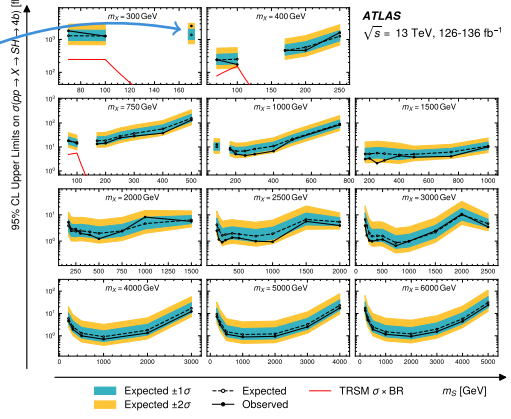
See details in Thomas's talk later

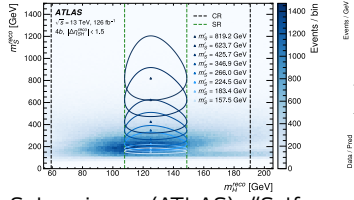
Updates with Run 2 data

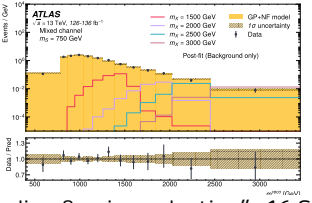
New analysis: $X \to SH \to b\bar{b}b\bar{b}$

arXiv:2607.18484

- Mixture of small & large-R jets
- Spectrum fit on m_X
  - Data-driven QCD BG modeling
    by **Gaussian Process + Normalizing Flow**
- No deviation from SM
  - Largest excess: $1.8\ \sigma_{\text{local}}$
  - Reaching sensitivity to
    TwoRealSingletModel @ $m_X \sim 400\,\text{GeV}$







No excess at mass points reported by CMS,
$(m_X[\text{GeV}], m_S[\text{GeV}]) = (650, 350), (700, 400), (1200, 900)$

HH combination of ATLAS and CMS

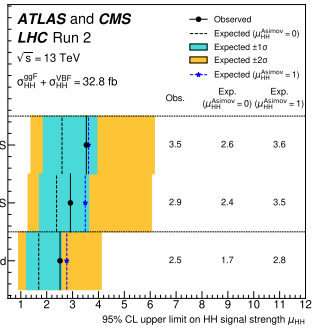
arXiv:2602.23991

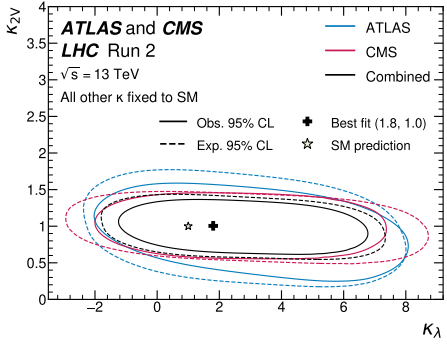
- Run 2 full combination: $126\text{–}140\,\text{fb}^{-1} \times 2$ experiments
- Signal strength $\hat{\mu} = 0.8^{+0.9}_{-0.7} = 0.8^{+0.7}_{-0.6}(\text{stat.})^{+0.4}_{-0.2}(\text{theory})^{+0.3}_{-0.3}(\text{exp.})$
  - Correlated theory uncertainties
  - Common κ_t treatment

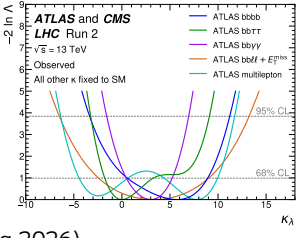
Principal contributors to sensitivity

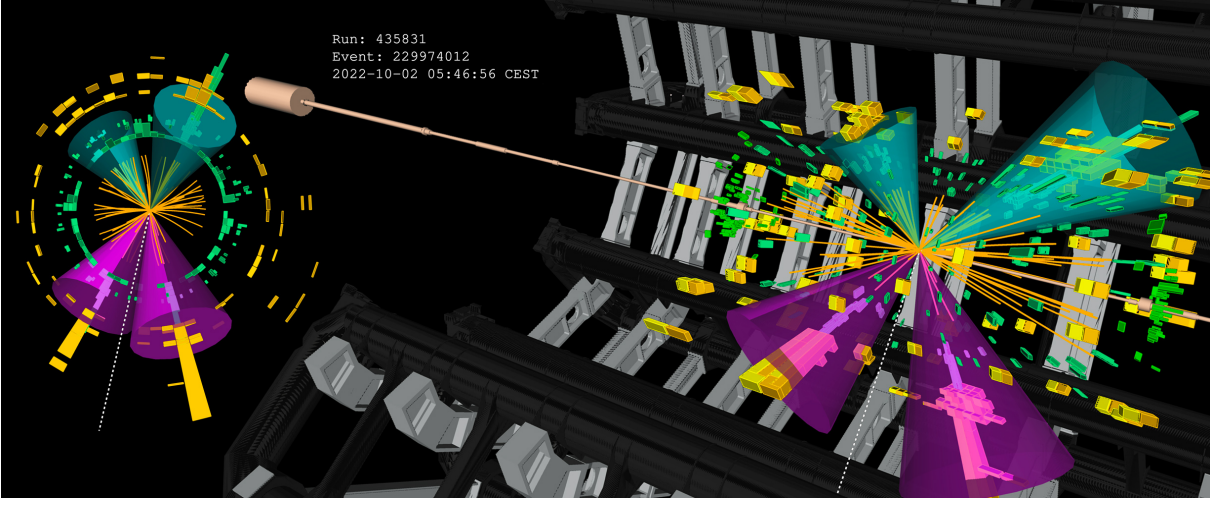
κ_λ $b\bar{b}\gamma\gamma$, $b\bar{b}\tau^-\tau^+$

κ_{2V} boosted $b\bar{b}b\bar{b}$







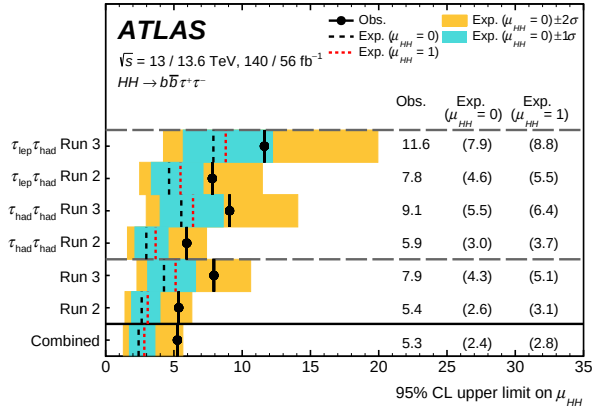


Updates with partial Run 3 data

New result: $HH \to b\bar{b}\tau^-\tau^+$

arXiv:2607.26879

- Run 2 ($140\,\text{fb}^{-1}$)
  + partial Run 3 ($56\,\text{fb}^{-1}$)
  - $b\bar{b}\tau_{\text{had}}\tau_{\text{had}}$ and $b\bar{b}\tau_{\text{lep}}\tau_{\text{had}}$ channels
  - Full re-analysis of Run 2
- Modernized method
  - Object tagger: $\tau \sim$ RNN, b-jet $\sim$ GN2
  - MVA (transformer) categorization: template fit on score distributions

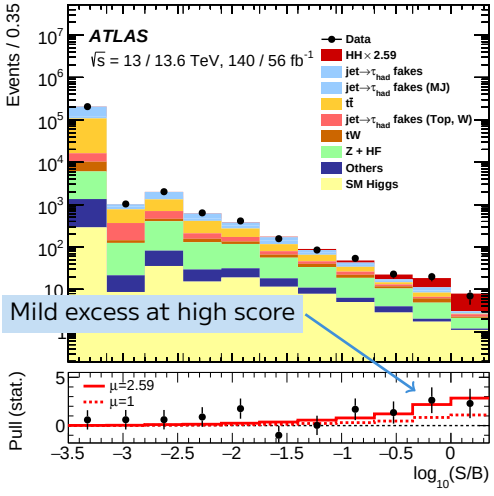


Measured signal strength: $\mu_{HH} = 2.6^{+1.4}_{-1.0} = 2.6^{+1.0}_{-0.9}(\text{stat.})^{+1.0}_{-0.5}(\text{syst.})$

Significance (obs./exp.): 2.6/1.2

New result: $HH \to b\bar{b}\tau^-\tau^+$ (cont.)

arXiv:2607.26879



Source of uncertainty	$\sigma_{\mu_{HH}}$
Total	1.20
Statistical	0.91
Systematic	0.76
Experimental uncertainties	0.20
Electron and muon	0.01
τ_{had}	0.13
E_T^{miss}	0.03
Jet	0.14
Flavour tagging	0.04
Pile-up	0.01
Luminosity	0.03
Modelling uncertainties	0.71
Background template statistical	0.21
HH	0.54
ZH	0.02
ZZ	<0.01
Other SM Higgs	0.25
Z+jets	0.07
tW	0.21
Top	0.12
jet → τ_{had} fakes	0.07
Others	0.01

Stat. limited

ID, trigger, energy scale

Energy scale/resolution, jet-vertex tagger

HH_{ggF} production unc. by QCD scales + top-mass scheme

New result: $ZH/ZZ \to b\bar{b}\tau^-\tau^+$

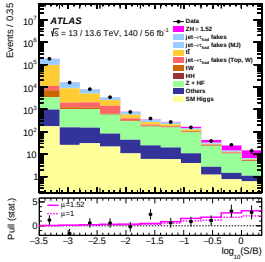
arXiv:2607.26879

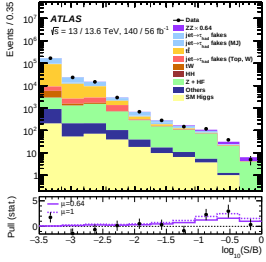
- Validation of analysis method
  - Retrained MVA classifier with same strategy

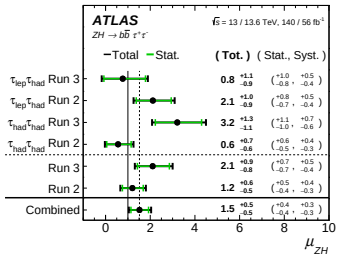
$\Rightarrow$ Good consistency with $\mu = 1$

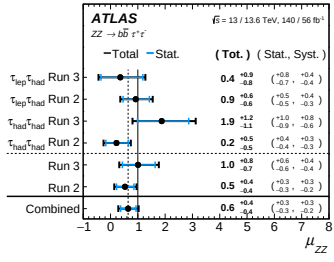
$$\mu_{ZZ} = 0.64^{+0.39}_{-0.36}$$
$$= 0.64 \pm 0.28(\text{stat.})^{+0.25}_{-0.28}(\text{syst.})$$
$$\mu_{ZH} = 1.52^{+0.52}_{-0.48}$$
$$= 1.52 \pm 0.40(\text{stat.})^{+0.33}_{-0.28}(\text{syst.})$$

- First evidence of ZH in $b\bar{b}\tau^-\tau^+$ channel





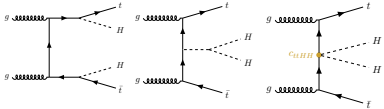




New channel: $t\bar{t}HH$

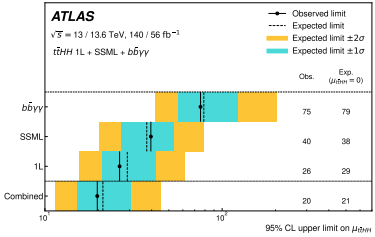
JHEP 08 (2026) 020

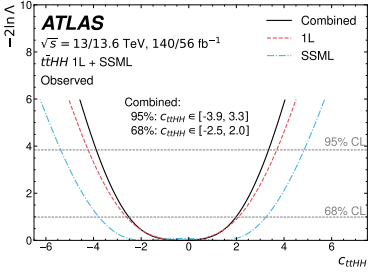
- Three LO diagrams



$\sigma_{\mathrm{SM}} = 0.76/0.86\,\mathrm{fb}$ (13/13.6 TeV)

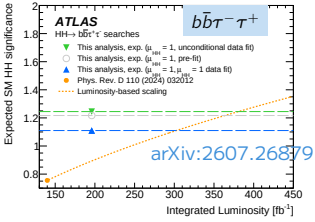
  - Sensitive to BSM $c_{t\bar{t}HH}$
- Three channels
  - 1L: 1 lepton + 5 b-jet ($HH \to b\bar{b}b\bar{b}$)
  - SSML: same-sign dilepton pair(+more) + 2(+more) b-jet
  - $b\bar{b}\gamma\gamma$: 2γ + 2(+more) b-jet ($H \to \gamma\gamma$)
- No excess: setting limits
  - $-3.9 < c_{ttHH} < 3.3$ (95% CL)
    (expected, $-4.0 < c_{ttHH} < 3.5$)



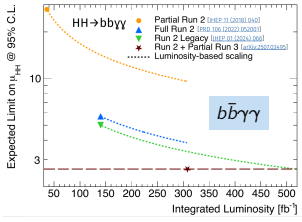


Run 3: analysis improvements are as important as luminosity

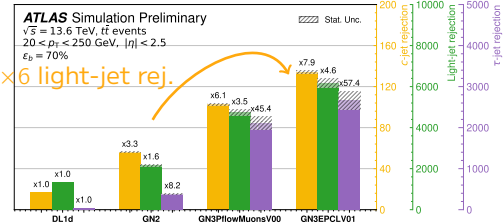
Overcoming luminosity scaling by method improvements



arXiv:2607.26879



- Reaching 1σ range in each channel
  - Increase of statistics, modern tools (Flavor tag, MVA)
- Toward fully exploiting Run 3 dataset
  - Additional channels, $b\bar{b}b\bar{b}$ etc, and **statistics ($\times 2$)**
  - Further flavor tagging improvement: GN3 series
  - Harmonization



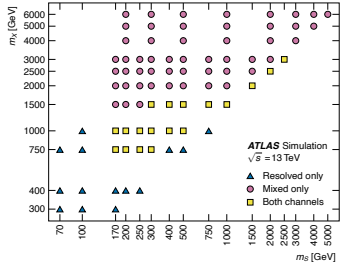
FTAG-2026-07

Summary

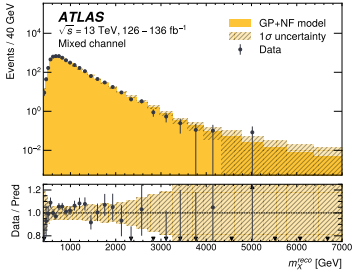
- HH production as a probe of Higgs potential structure
  - $\mathcal{O}(10^4)$ HH events in ATLAS so far
- Flavor tagging
  - Significant contribution to breaking scaling law of sensitivities
  - DL1r (Run 2) $\rightarrow$ GN2 (partial Run 3) $\rightarrow$? (Run 3)
- ATLAS+CMS Run 2 full combination $\Rightarrow \mu_{HH} = 0.8^{+0.9}_{-0.7}$
  - 1σ range only with Run 2 full statistics
- Partial Run 3 analyses are published gradually
  - (New) $b\bar{b}\tau^-\tau^+$ partial Run 3 (2022–23): $\mu_{HH} = 2.6^{+1.4}_{-1.0}$
  - 1σ range in each channel

Appendix

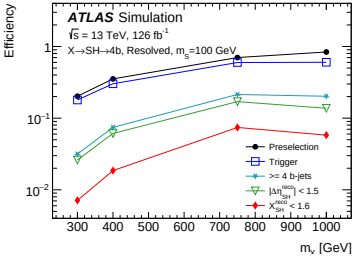
$X \to SH \to b\bar{b}b\bar{b}$ (arXiv:2607.18484)

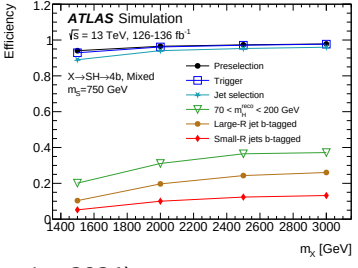


Mass points and analysis channels



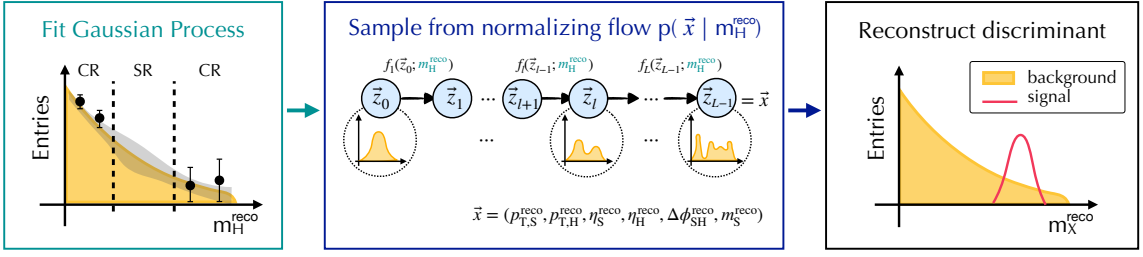
$m_X^{\text{reco.}}$ distribution predicted by Gaussian Process + flow





Selection efficiencies for resolved/mixed analysis

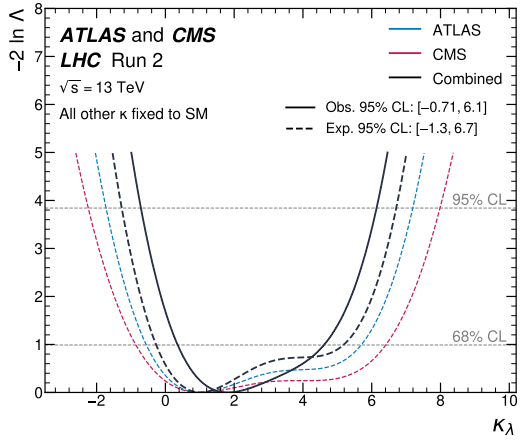
$X \to SH \to b\bar{b}b\bar{b}$ (arXiv:2607.18484)

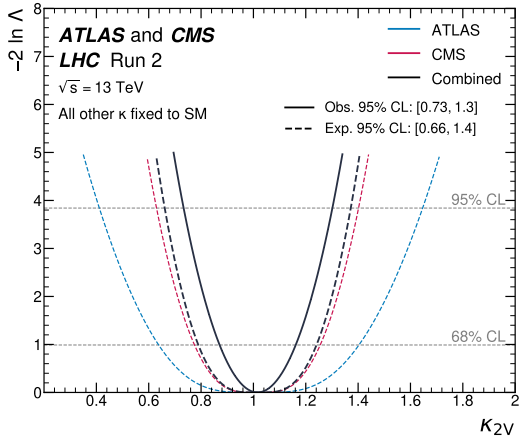


$X \to SH \to b\bar{b}b\bar{b}$ (arXiv:2607.18484)

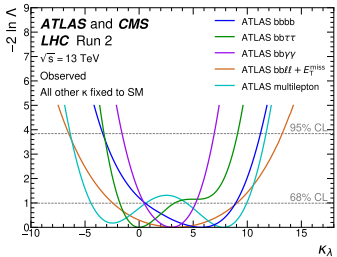
Uncertainty source	Relative impact of uncertainties [%]	
	Resolved Channel	Mixed Channel
Data statistical uncertainty	24–51	55–74
All systematic uncertainties	49–76	26–45
Experimental	48–76	26–45
Detector response	9–15	24–33
Luminosity and pileup	<1	<1
Flavor tagging	0–5.4	22–32
Jet reconstruction	0.1–2.7	0.4–2.5
Trigger efficiency	8–9	<1
Background modeling	44–73	1–26
Network retraining and CR stats	36–63	0.1–23
Non-closure and normalization	0–25	0.4–7.2
Theoretical	<1	<1
MC statistical	<1	<1

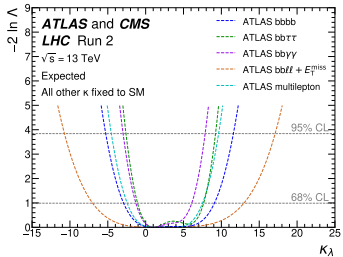
HH combination, ATLAS+CMS (arXiv:2602.23991)

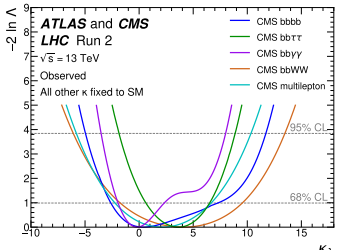


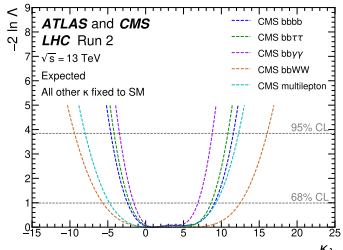


HH combination, ATLAS+CMS (arXiv:2602.23991) 22/16

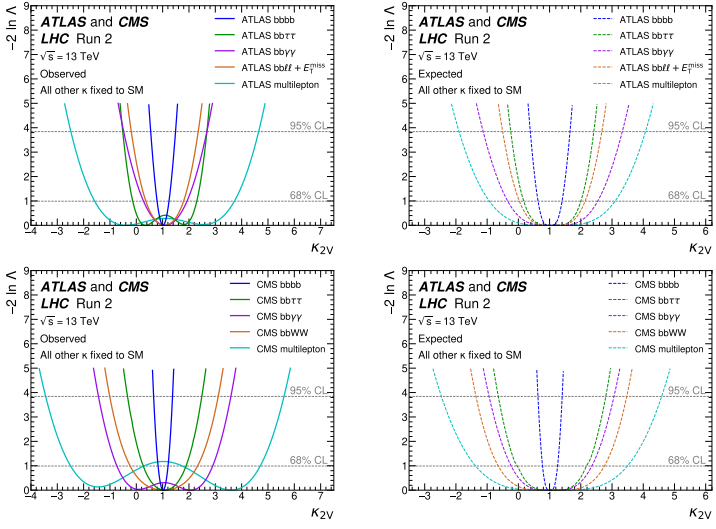




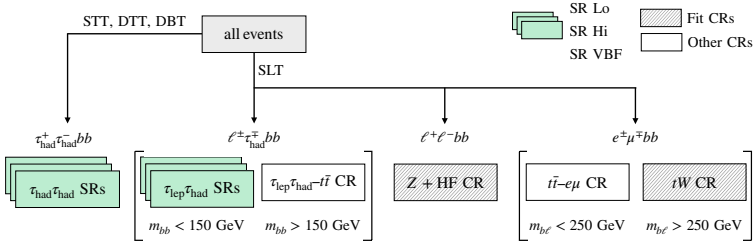




HH combination, ATLAS+CMS (arXiv:2602.23991)

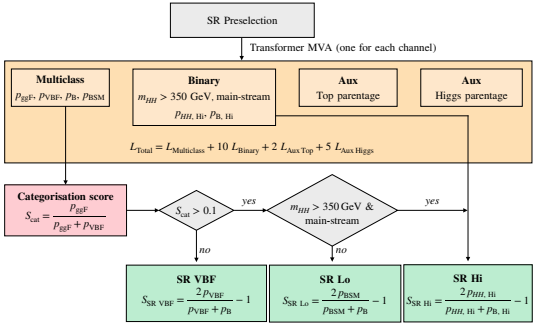


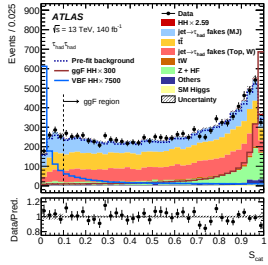
$b\bar{b}\tau^-\tau^+$ (arXiv:2607.26879)

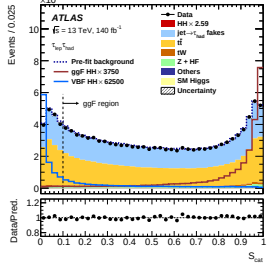


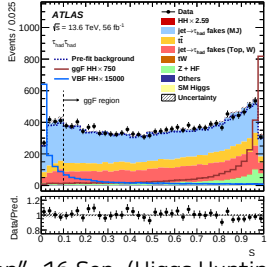
$b\bar{b}\tau^-\tau^+$ (arXiv:2607.26879)

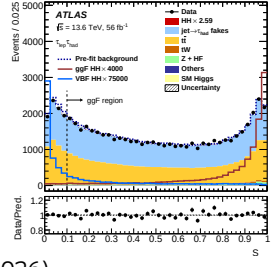
- Transformer MVA





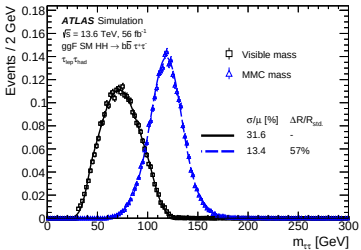


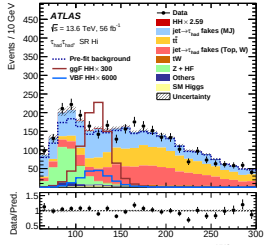


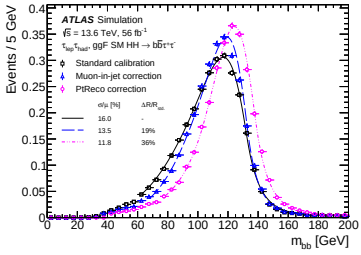


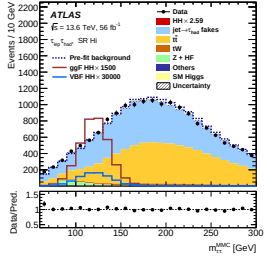
$b\bar{b}\tau^-\tau^+$ (arXiv:2607.26879)

- $H_{125\,\mathrm{GeV}}$ resonance by $\tau^-\tau^+$ and $b\bar{b}$
  - Missing Mass Calculator (MMC) for $\tau^-\tau^+$
  - μ+p_{T} reco for $b\bar{b}$



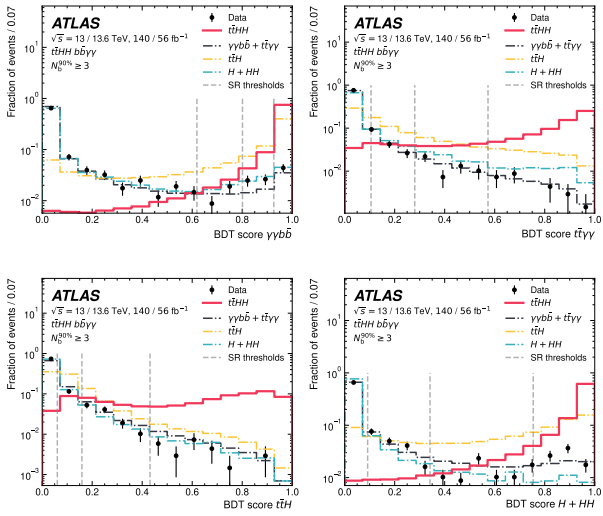




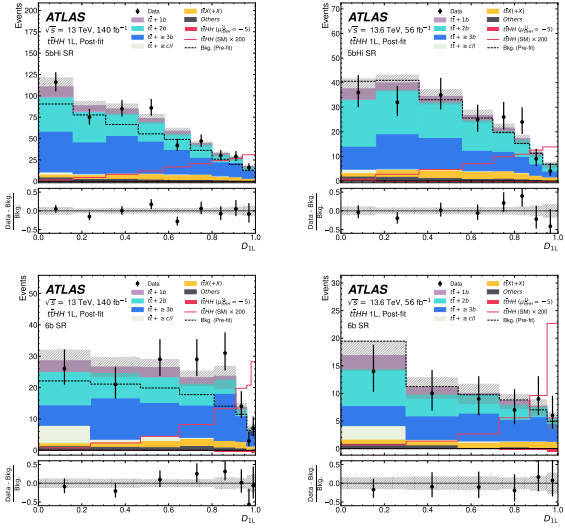


$t\bar{t}HH$ JHEP 08 (2026) 020

- BDTs for $t\bar{t}HH$ extraction



$t\bar{t}HH$ JHEP 08 (2026) 020



S. Izumiyama (ATLAS) “Self-coupling & pair production” 16 Sep. (Higgs Hunting 2026)

$t\bar{t}HH$ JHEP 08 (2026) 020