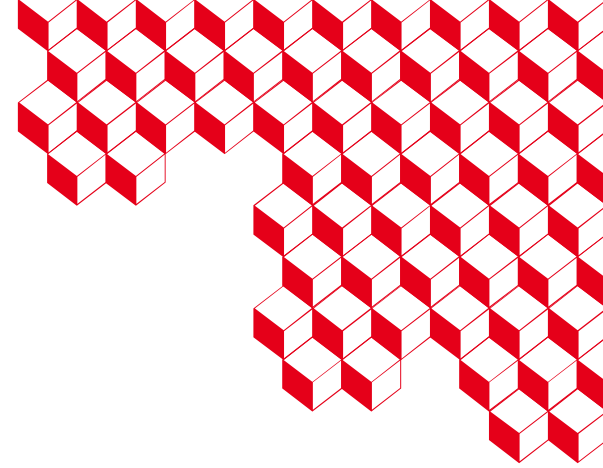




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# Measurement of the top Yukawa coupling in the $ttH+tH(bb)$ channel

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Top LHC France - 26/05/2026



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PARIS-SACLAY

# CPV in the Higgs sector

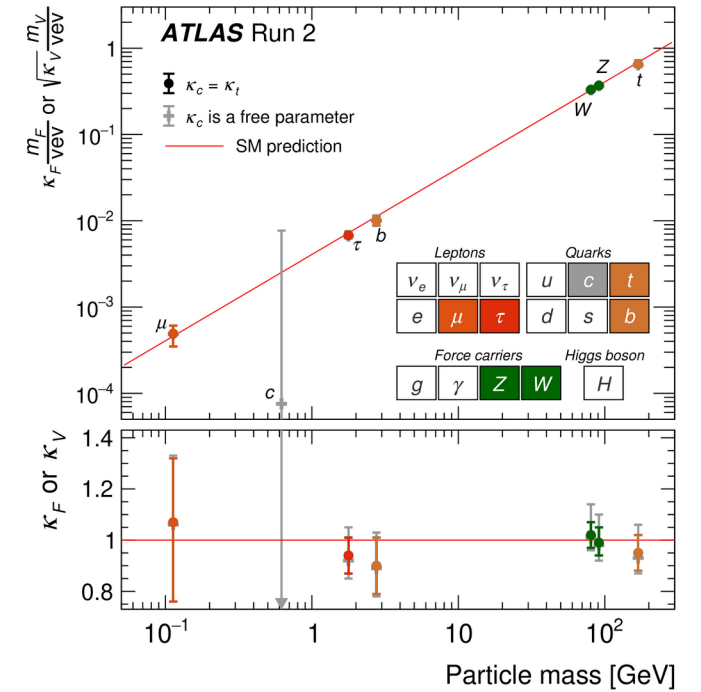
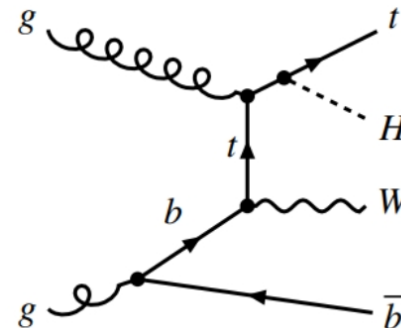
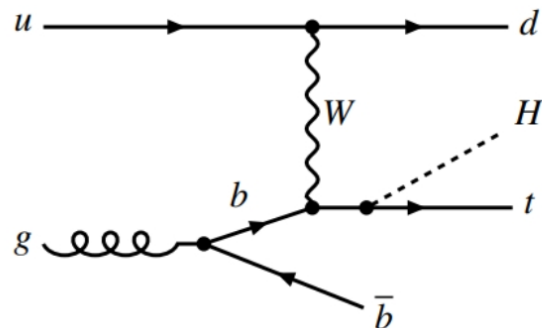
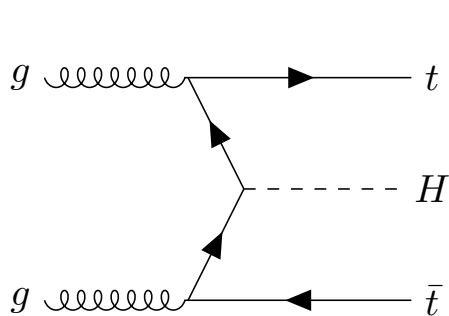
**CP violation (CPV)** is one of Sakharov's conditions to allow **Baryon Asymmetry of the Universe (BAU)**.

Standard Model does not (yet) provide enough CPV sources to describe BAU observed from cosmological sources.

Higgs sector is a good candidate for new CPV sources investigation :

- Linked to BAU via electroweak baryogenesis
- All Higgs couplings not yet tightly experimentally constrained

Top quark is the most strongly coupled SM particle to the Higgs boson, probed at Leading Order by ***ttH* and *tH* production**.



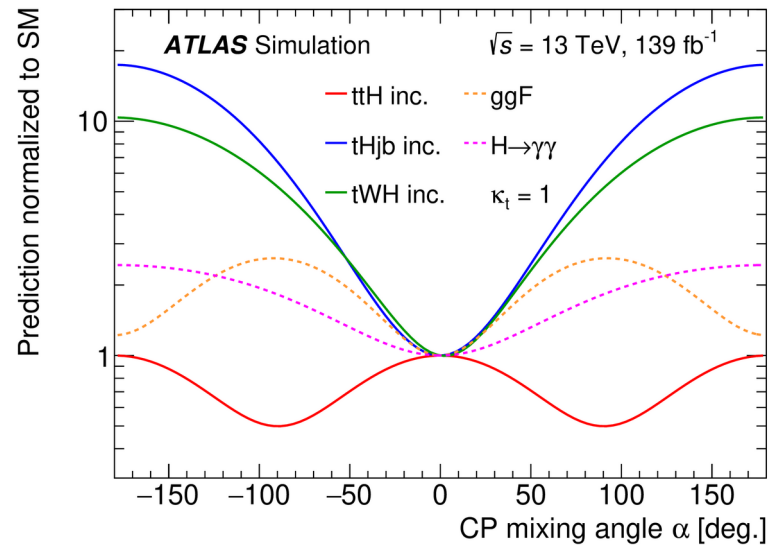
[Nature 607 52-59 \(2022\)](#)

# CPV in the Higgs sector

CPV modelled in the Higgs-top coupling by the  $(\kappa, \alpha)$  framework :

$$\mathcal{L}'_{t\bar{t}H} = -\kappa'_t \mathcal{Y}_t \phi \bar{\psi}_t \underbrace{(\cos \alpha)}_{\text{CP-even}} + \underbrace{i\gamma^5 \sin \alpha}_{\text{CP-odd}} \psi_t$$

At large  $\alpha$ ,  $tH$  cross section is enhanced, bringing a strong interest to consider it alongside  $ttH$ .



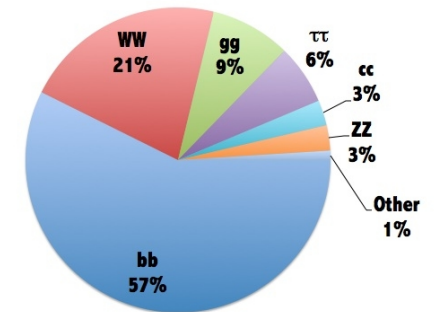
[PRL 125 \(2020\) 061802](#)

CPV probed either via  $\alpha$  likelihood profile fit or rederived from STXS  $\mu$  values.

Largest branching fraction for  $H \rightarrow bb$ :

- Single channel with highest available statistics
- Important  $tt$ +jets background contamination

Higgs decays at  $m_H = 125 \text{ GeV}$



# Overview

## “State of the art” Run 2 $ttH$ and $tH(bb)$ measurements

- CMS  $ttH+tH(bb)$  CP interpretation + STXS ([JHEP 02 \(2025\) 097](#))
- ATLAS  $ttH+tH(bb)$  CP interpretation ([PLB 829 \(2024\) 138469](#))
- ATLAS  $ttH(bb)$  STXS ([EPJC 85 \(2025\) 210](#))

## Phenomenology study [arXiv:2406.03950](#)

- Relevant (new) observables sensitive to CPV
- Expected sensitivities

## Perspectives and outlook



# CMS $ttH+tH(bb)$ : event selection

**Baseline selection** of events in 3 categories based on top decay channels, main cuts being:

Channel	Fully Hadronic (FH) $N_{lep} = 0$	Single Lepton (SL) $N_{lep} = 1$	Dilepton (DL) $N_{lep} = 2$
Lepton flavours	-	$e^\pm/\mu^\pm$	$e^+e^-/\mu^+\mu^-/e^\pm\mu^\mp$
# jets	$\geq 7$	$\geq 5$	$\geq 3$
# $b$ -tagged jets	$\geq 2$	$\geq 4$	$\geq 3$

$m_z$  excluded

Minimum number of jets required smaller than LO  $ttH$  prediction, designed to **balance  $ttH$  signal efficiency and  $tH$  signal acceptance**.

Three orthogonal  **$tt$ +jets background model** categories:

- $tt+B$ :  $\geq 1$  additional jets with  $\geq 1$   $b$ -hadron  
→ further split in  $ttH+b$  and  $ttH+2b$
- $tt+C$ :  $\geq 1$  additional jets with  $c$ -hadrons and no  $b$ -hadrons
- $tt+LF$ : remainder

# CMS $ttH+tH(bb)$ : Signal and background regions

In each channel, an **ANN** is trained to separate signal from  $tt$ +jets backgrounds **for each Run 2 data-taking year**.

## FH channel:

For each SR are defined 2 mutually exclusive **CR** with **looser  $b$ -tagging requirement**:

<b>Label:</b> 7 or 8 (9) jets		$30 < m_{qq} < 60(72)$ GeV
	$60(72) < m_{qq} < 100(90)$ GeV	or $100(90) < m_{qq} < 250$ GeV
2 b tags	<i>training region (TR)</i>	<i>validation region (VR-TR)</i>
$\geq 4$ loose b tags	QCD events for ANN training	input variable validation
3 b tags	<i>evaluation region (ER)</i>	<i>validation region (VR-ER)</i>
$\geq 4$ loose b tags	discriminant shape for QCD	discriminant shape for QCD
$\geq 4$ b tags	<i>signal region (SR)</i>	<i>validation region (VR-SR)</i>
	analysis region	comparison of QCD shape with data

Compute  $m_{qq}$  from pair non  $b$ -tagged jets with mass closest to  $m_w$

## SL and DL channels:

SL: ( $\geq 6$  jets,  $\geq 4$   $b$ -tags) and (5 jets,  $\geq 4$   $b$ -tags)

DL: ( $\geq 4$  jets,  $\geq 3$   $b$ -tags) and (3 jets, 3  $b$ -tags)

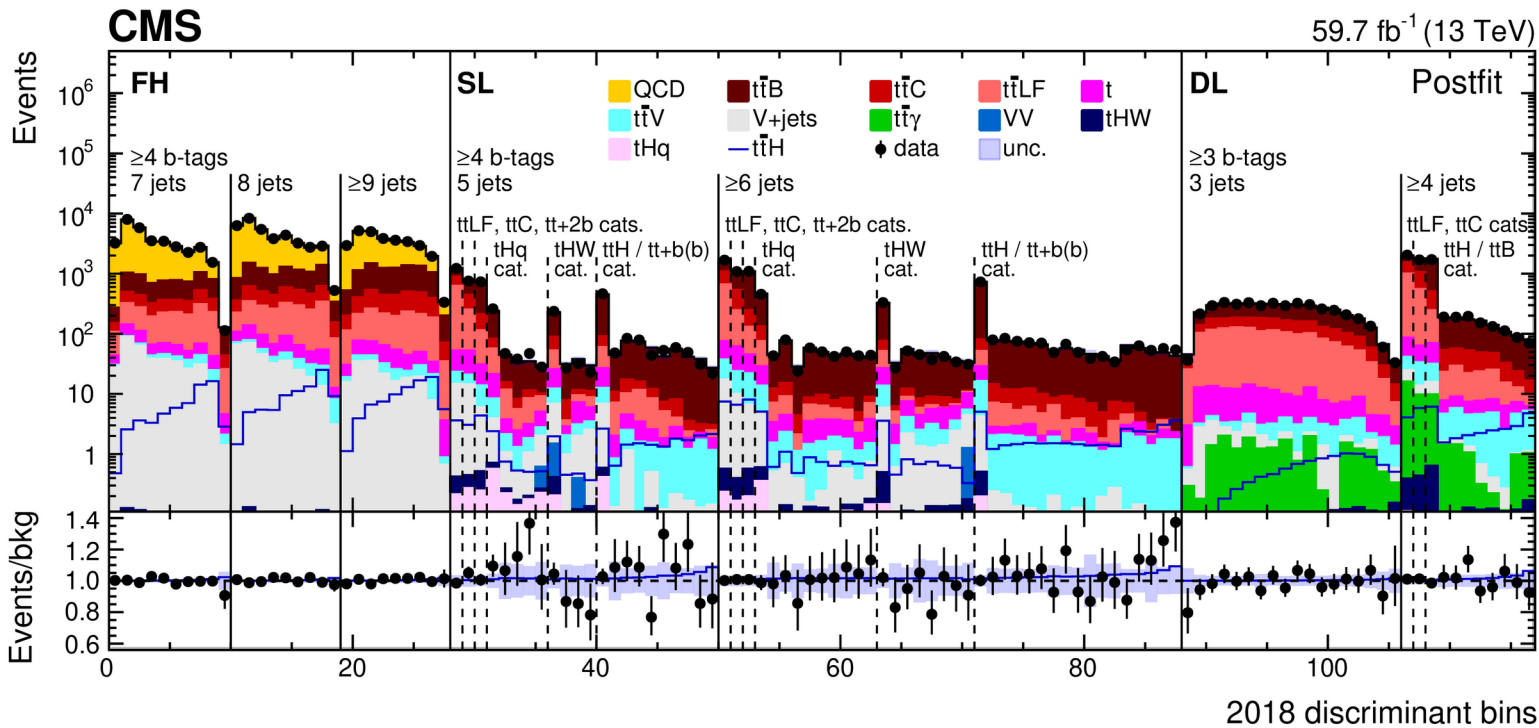
Multiclassifier ANN output based discrimination to define SR cuts.

$$R_{SL} = \frac{O(ttH)}{O(ttH) + O(t\bar{t} + b(\bar{b})) + O(t\bar{t} + 2b)}$$

$$R_{DL} = \frac{O(t\bar{t}H)}{O(t\bar{t}H) + O(t\bar{t}B)}$$

# CMS $ttH+tH(bb)$ : $\mu_{ttH}$ measurement

$tH$  assumed to follow SM prediction, treated as background.



Measured production rate smaller than SM prediction.

→  $ttB$  ( $ttC$ ) normalisation parameter fitted at  $1.19_{-0.12}^{+0.13}$  ( $1.07_{-0.19}^{+0.20}$ ) consistent with inclusive  $ttbb$  and  $ttcc$  cross section measurements.

→ Large impact of gluon-splitting uncertainty, a-priori knowledge does not reflect the data distributions.

CMS 138 fb<sup>-1</sup> (13 TeV)

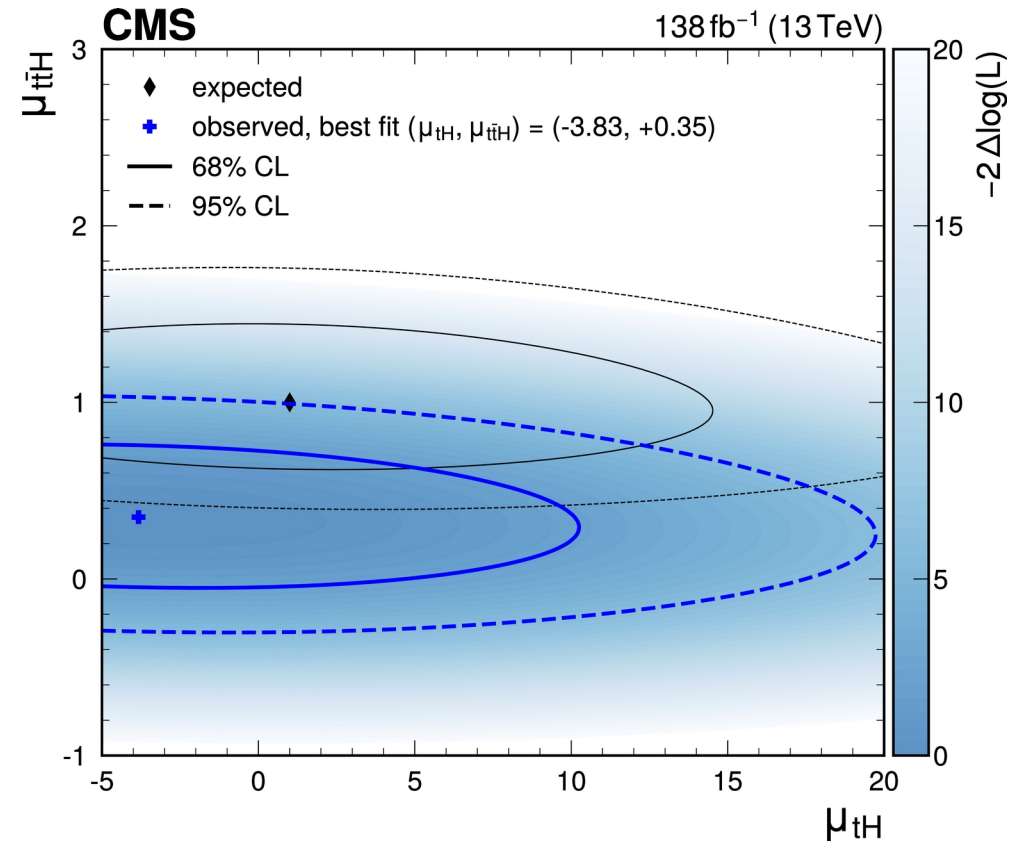
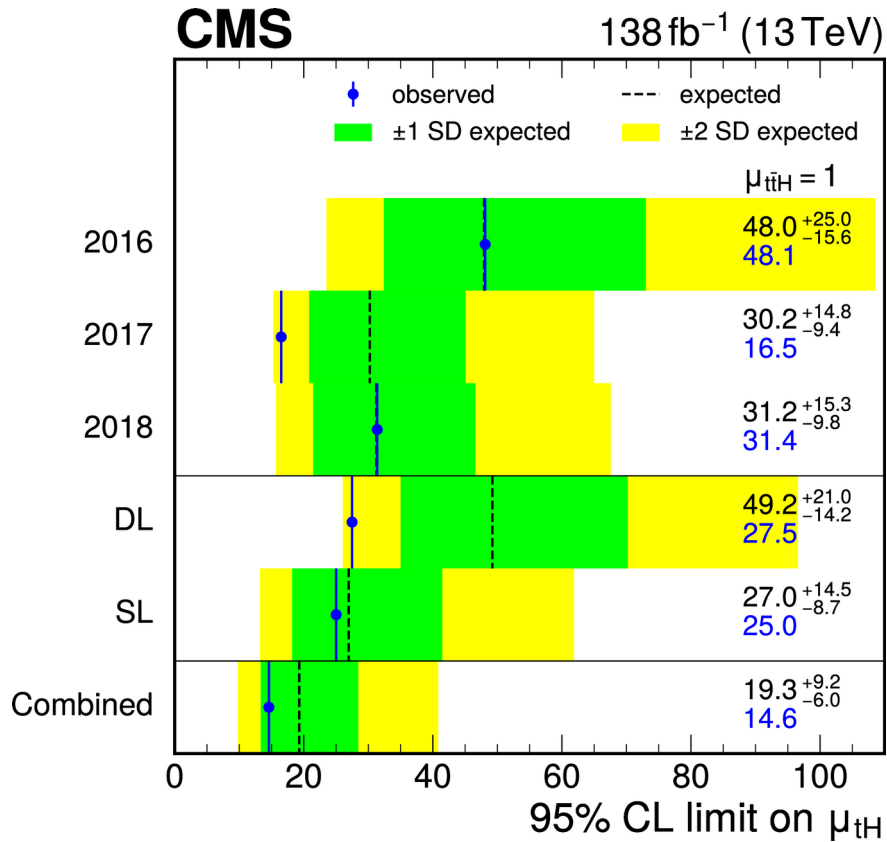
	tot exp.	$\hat{\mu}$	tot	stat	syst
FH		0.84	+0.49 -0.46	+0.24 -0.24	+0.42 -0.39
SL		0.46	+0.33 -0.33	+0.21 -0.21	+0.25 -0.26
DL		-0.23	+0.41 -0.42	+0.31 -0.31	+0.26 -0.29
2016		0.49	+0.42 -0.40	+0.25 -0.25	+0.33 -0.32
2017		0.32	+0.38 -0.37	+0.24 -0.24	+0.29 -0.28
2018		0.23	+0.34 -0.34	+0.21 -0.21	+0.27 -0.27
Combined		0.33	+0.26 -0.26	+0.17 -0.16	+0.20 -0.21

$$\hat{\mu} = \hat{\sigma} / \sigma_{SM}$$

# CMS $ttH+tH(bb)$ : $\mu_{tH}$ measurement

$ttH$  cross section assumed to follow SM prediction, treated as background.

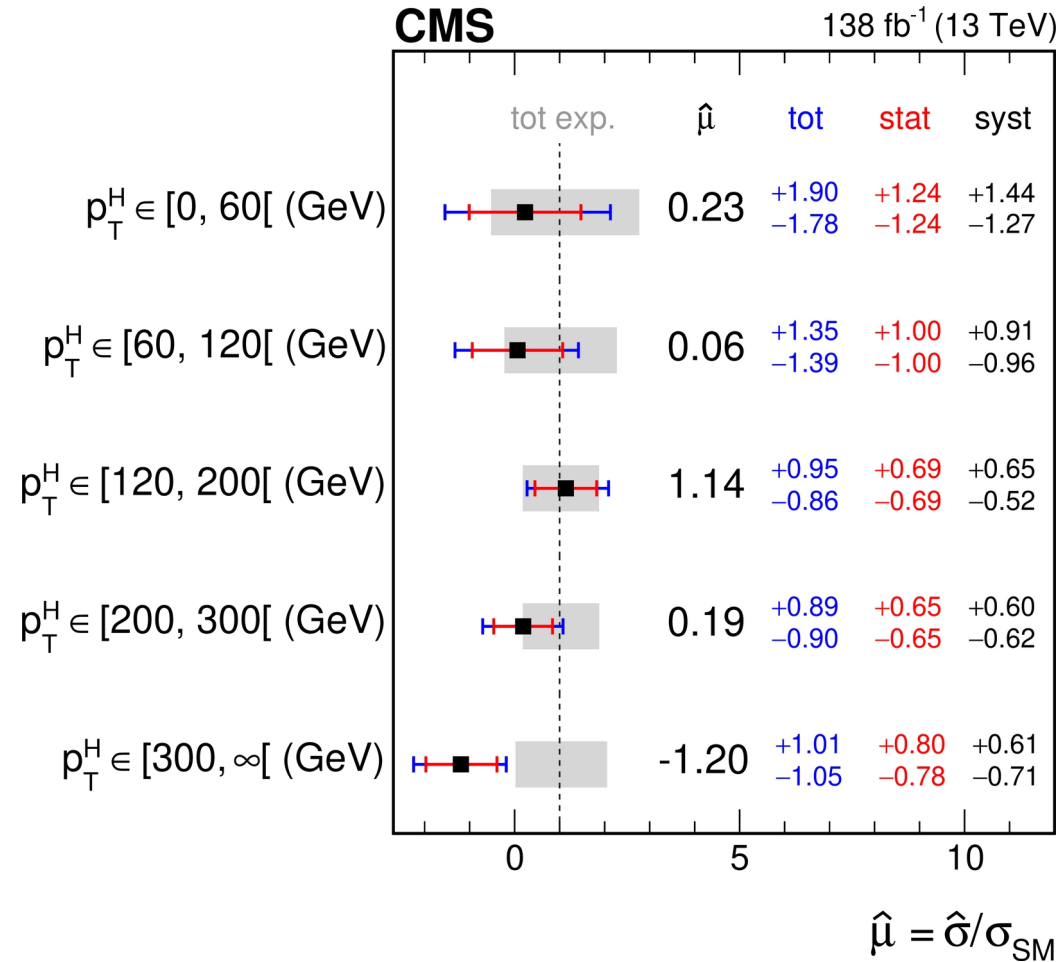
Simultaneous fit of  $ttH$  and  $tH$  signal strengths.



Weak correlation  
 → discrimination well achieved by the analysis.

# CMS $ttH+tH(bb)$ : STXS measurement

STXS measurement performed in bins of  $p_T^H$  in SL and DL regions only confirms signal strengths smaller than 1, post-fit value of  $ttB$  background normalisation compatible with inclusive measurement.



# CMS $ttH+tH(bb)$ : Yukawa coupling measurement

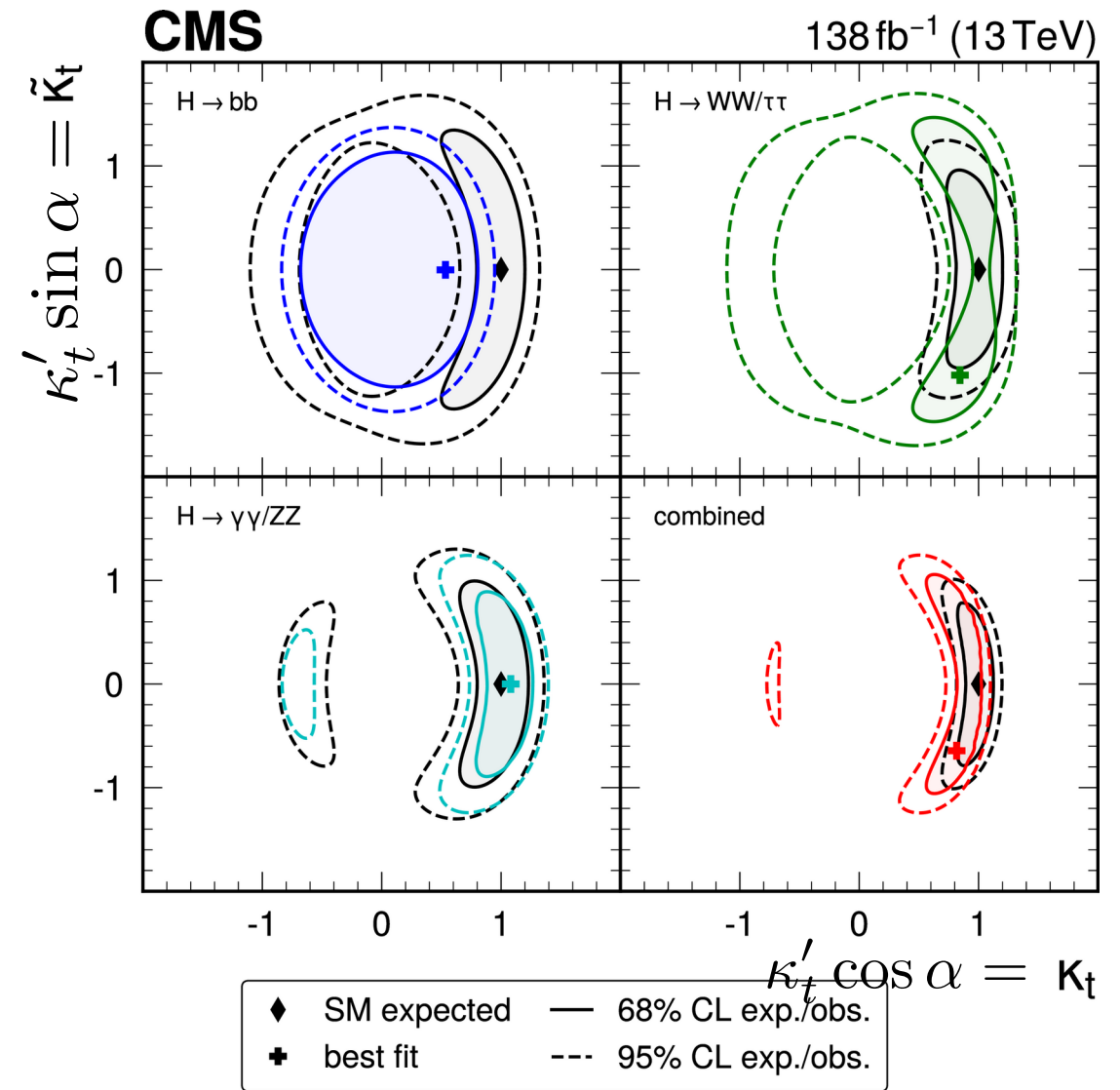
Both  $ttH$  and  $tH$  as signal in the fit,  $\kappa_V$  fixed at 1 for CP mixing angle  $\alpha$  measurement.

No 95 % CL exclusion on  $\alpha$  from this analysis alone but performs a **combination** with :

- [ttH\( \$\gamma\gamma\$ \)](#)
- [ttH\(ZZ\)](#)
- [ttH/tH\(WW/ \$\tau\tau\$ \)](#)

Combined limits:  $\cos \alpha > 0.39$  at 95% CL.

$$\Leftrightarrow |\alpha| < 67^\circ$$



# ATLAS $ttH+tH(bb)$ : STXS and CP interpretation

**Single and dilepton top decay channels only.** Same strategy used for background modelling in both STXS and CP analyses:

Use of a **transformer MVA** to classify background events into SR and CRs:

-  $tt+\geq 1b$

→  $tt+1B$  sub-CR for large radius jet compatible with boosted  $bb$  added for STXS measurement

→  $tt+\geq 2b$  sub-CR added for STXS measurement

-  $tt+\geq 1c$

-  $tt+\text{light}$

**CP interpretation** ([PLB 829 \(2024\) 138469](#))

**STXS measurement** ([EPJC 85 \(2025\) 210](#))

CP-sensitive observables used for to constrain  $\alpha$  in SR:

$$1 \text{ lepton : } b_2 = \frac{(\vec{p}_t \times \vec{u}_z) \cdot (\vec{p}_{\bar{t}} \times \vec{u}_z)}{|\vec{p}_t| |\vec{p}_{\bar{t}}|}$$

Boosted SR: dedicated BDT

$$2 \text{ leptons : } b_4 = \frac{(\vec{p}_t \cdot \vec{u}_z)(\vec{p}_{\bar{t}} \cdot \vec{u}_z)}{|\vec{p}_t| |\vec{p}_{\bar{t}}|}$$

STXS fit with bins of  $p_{T^H}$ :

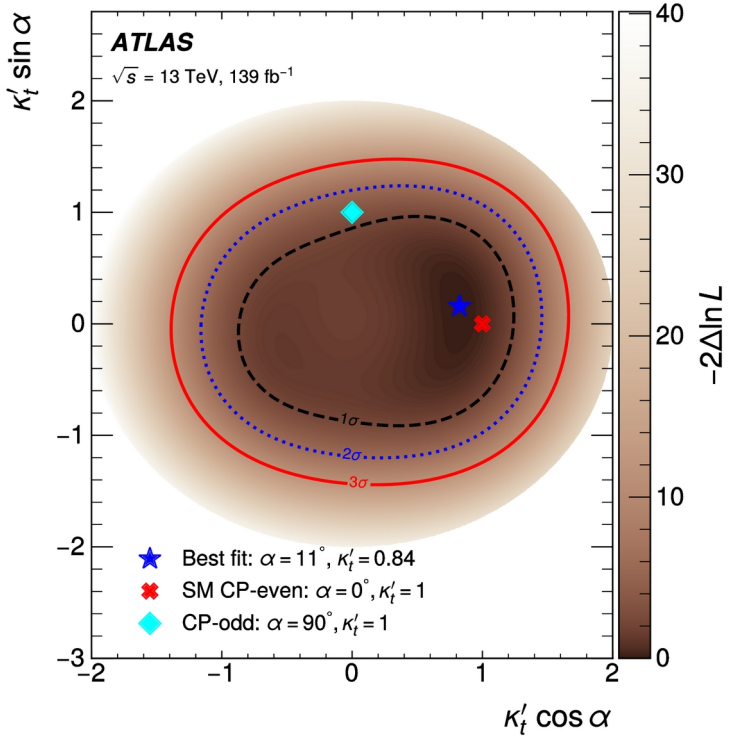
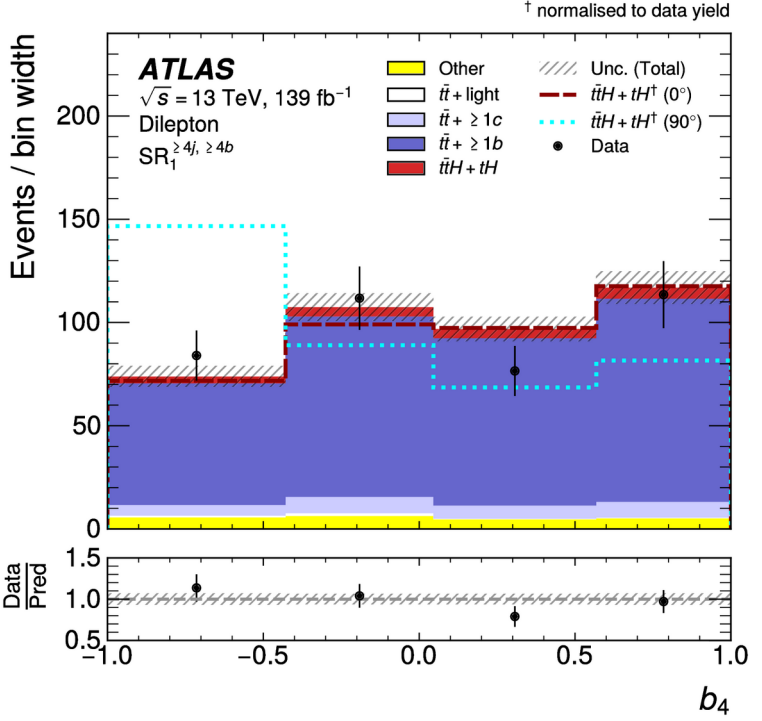
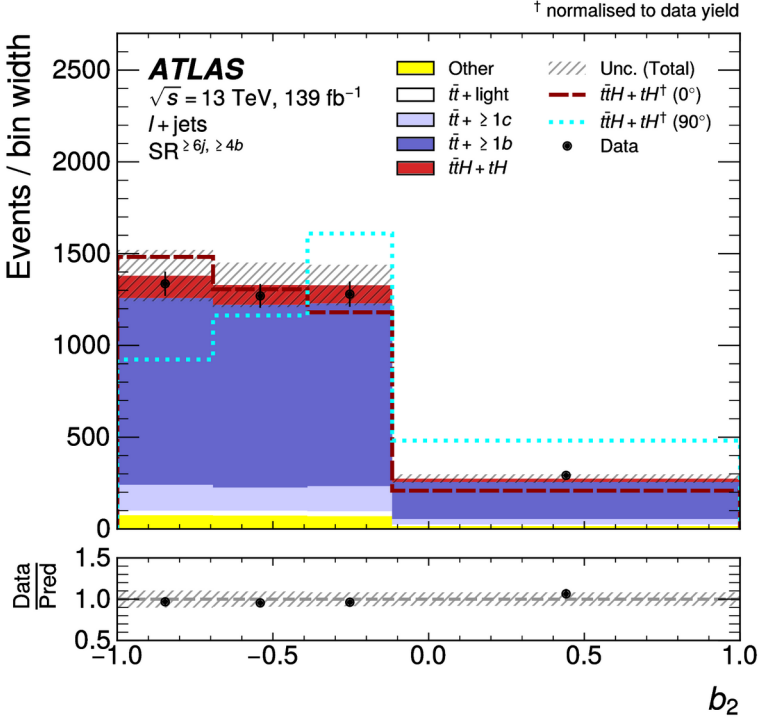
[0, 60, 120, 200, 300, 450,  $+\infty$ ] GeV

# ATLAS $t\bar{t}H+tH(bb)$ : CP interpretation

No 95 % CL exclusion of  $\alpha$  obtained from the fit.

Uncertainties dominated by modelling of  $t\bar{t}+b$  background:

→ 4 vs 5 FS generation, NLO matching, PS and hadronisation.



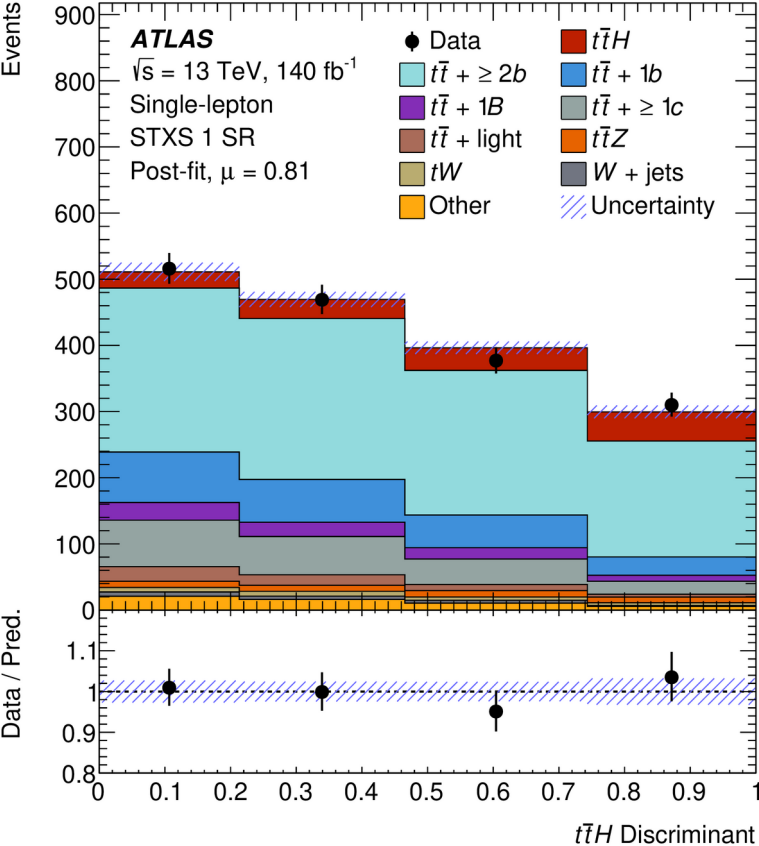
# ATLAS $t\bar{t}H(bb)$ : STXS measurement

No signal strength measured for  $tH$ .

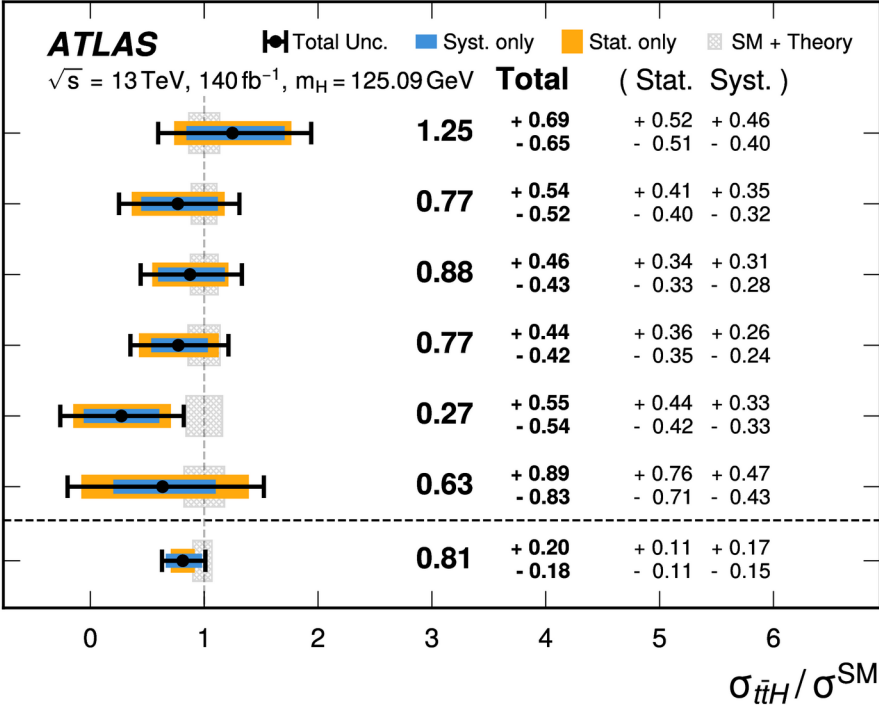
Outputs of the transformer MVA combined into a discriminant  $d_{t\bar{t}H}$  to bin every STXS region.

$$d_i = \frac{p_i}{\sum_{i \neq j} p_j \cdot \hat{N}_{ij}}$$

$$\hat{N}_{ij} = N_j / \sum_{k \neq i} N_k$$



$p_T^H \in [0, 60) \text{ GeV}$   
 $p_T^H \in [60, 120) \text{ GeV}$   
 $p_T^H \in [120, 200) \text{ GeV}$   
 $p_T^H \in [200, 300) \text{ GeV}$   
 $p_T^H \in [300, 450) \text{ GeV}$   
 $p_T^H \in [450, \infty) \text{ GeV}$   
 Inclusive



# Alternative ways to constrain top Yukawa coupling

Comparable CMS and ATLAS results:

- $H \rightarrow bb$  channel alone weakly constrains the  $\alpha$  angle
- ATLAS analysis gives slightly more precise signal strength for the STXS

Limits obtained via **MVA** :

- + optimally stringent limits
- training relies on assumed theory model

**STXS** results:

- + minimizes dependence on theory uncertainties
- + easier combination with other analyses
- limits not as constraining as from MVA

[Phenomenology ttH study](#) presents a possible extension that enhances the CP sensitivity of STXS.

**Idea:** adding a second dimension to the  $p_{T^H}$  in the STXS regions definition.

# Observables sensitive to CPV

observable	definition	frame
$p_{T,H}$	-	lab, $t\bar{t}$ , $t\bar{t}H$
$\Delta\eta_{t\bar{t}}$	$ \eta_t - \eta_{\bar{t}} $	lab, $H$ , $t\bar{t}H$
$\Delta\phi_{t\bar{t}}$	$ \phi_t - \phi_{\bar{t}} $	lab, $H$ , $t\bar{t}H$
$m_{t\bar{t}}$	$(p_t + p_{\bar{t}})^2$	frame-invariant
$m_{t\bar{t}H}$	$(p_t + p_{\bar{t}} + p_H)^2$	frame-invariant
$ \cos\theta^* $	$\frac{ \mathbf{p}_t \cdot \mathbf{n} }{ \mathbf{p}_t  \cdot  \mathbf{n} }$	$t\bar{t}$
$b_1$	$\frac{(\mathbf{p}_t \times \mathbf{n}) \cdot (\mathbf{p}_{\bar{t}} \times \mathbf{n})}{p_{T,t} p_{T,\bar{t}}}$	all
$b_2$	$\frac{(\mathbf{p}_t \times \mathbf{n}) \cdot (\mathbf{p}_{\bar{t}} \times \mathbf{n})}{ \mathbf{p}_t   \mathbf{p}_{\bar{t}} }$	all
$b_3$	$\frac{p_t^x p_{\bar{t}}^x}{p_{T,t} p_{T,\bar{t}}}$	all
$b_4$	$\frac{p_t^z p_{\bar{t}}^z}{ \mathbf{p}_t   \mathbf{p}_{\bar{t}} }$	all
$\phi_C$	$\arccos\left(\frac{ (\mathbf{p}_{p_1} \times \mathbf{p}_{p_2}) \cdot (\mathbf{p}_t \times \mathbf{p}_{\bar{t}}) }{ \mathbf{p}_{p_1} \times \mathbf{p}_{p_2}   \mathbf{p}_t \times \mathbf{p}_{\bar{t}} }\right)$	$H$

$\mathbf{n}$  = unit vector on the z axis.

Angular variables taken from dedicated Higgs CP theory publications ([1](#), [2](#), [3](#), [4](#)).

Observables accessible at reconstructed level without top-antitop distinction.

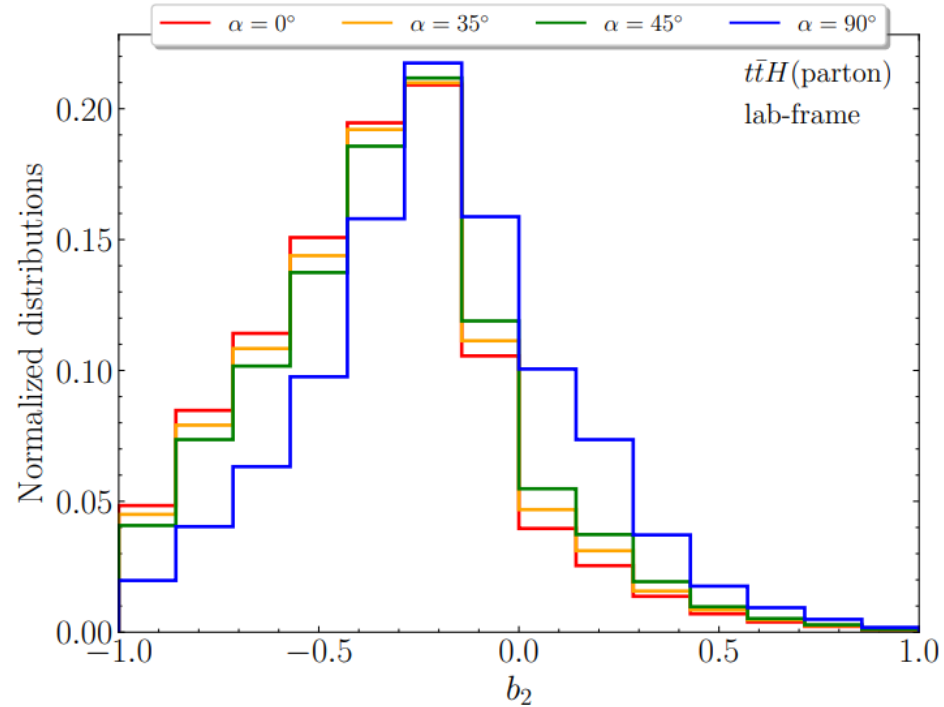
Considering multilepton,  $bb$  and  $\gamma\gamma$  decays.  
→ Focus on  $bb$  channel.

→ **Quantify which observable** is best paired up with  $p_T^H$  for sensitivity to non-zero  $\alpha$ .

# Observables sensitive to CPV: examples

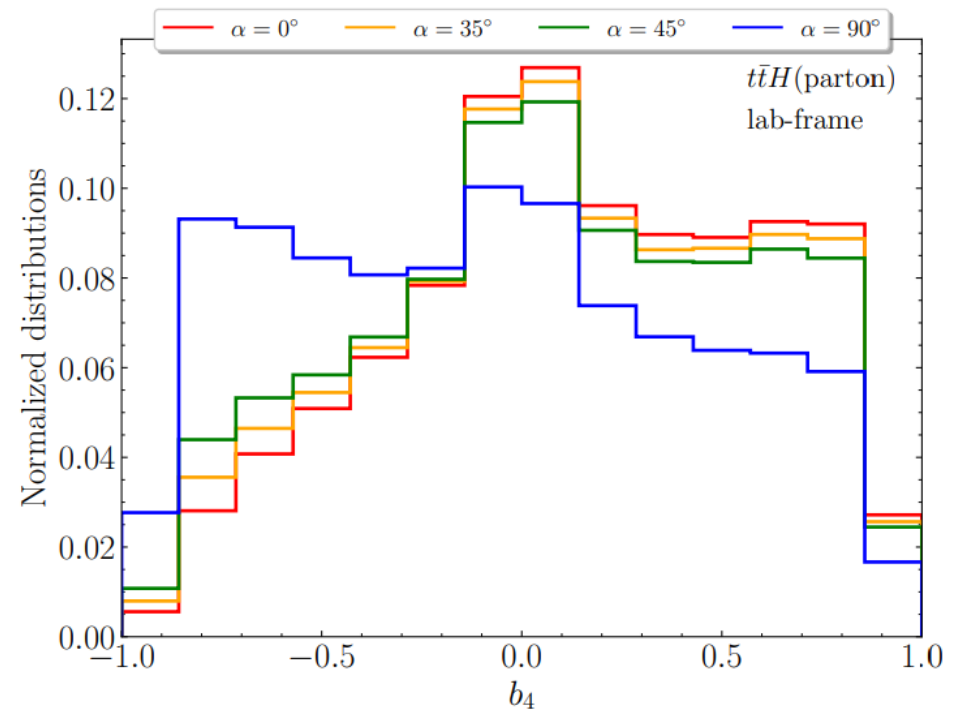
Parton level

$$b_2 = \frac{(\mathbf{p}_t \times \mathbf{n}) \cdot (\mathbf{p}_{\bar{t}} \times \mathbf{n})}{|\mathbf{p}_t| |\mathbf{p}_{\bar{t}}|}$$



Parton level

$$b_4 = \frac{p_t^z p_{\bar{t}}^z}{|\mathbf{p}_t| |\mathbf{p}_{\bar{t}}|}$$



(Lab frame in these examples)

$$S = \sqrt{N_{\text{bins}}} \sum_{i=1}^{N_{\text{bins}}} S_i^2 = \sqrt{-2 N_{\text{bins}} \sum_{i=1}^{N_{\text{bins}}} \left( n_i \ln \frac{m_i}{n_i} + \underbrace{n_i}_{\text{SM expected signal yield}} - \underbrace{m_i}_{\text{BSM expected signal yield}} \right)}$$

# Mimicking detector effects

Analysis accounts for:

- BR per channel
  - ATLAS detector acceptance
  - Efficiency factors
  - Smeared the Higgs and top/antitop for resolution
- Performed for three channels separately, validated from ATLAS and CMS public results.



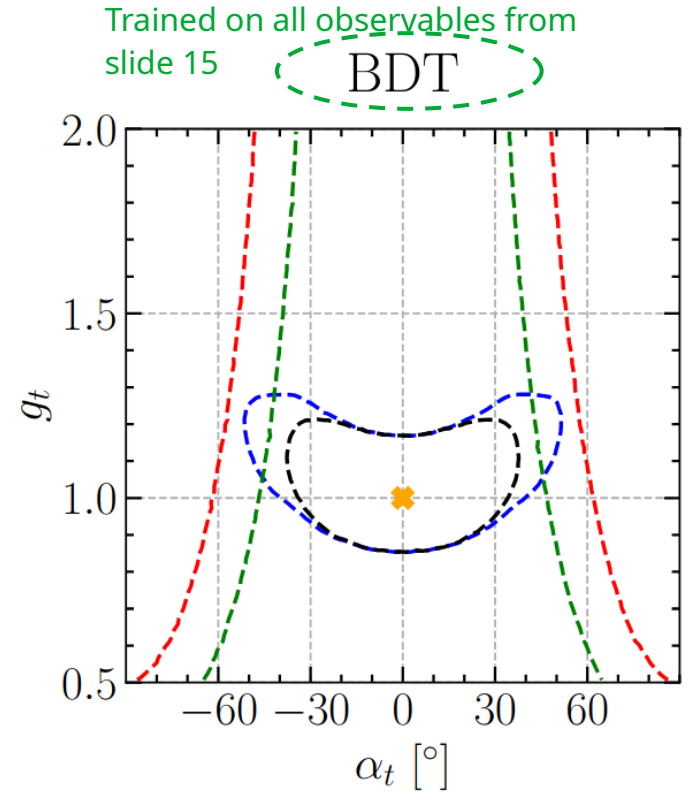
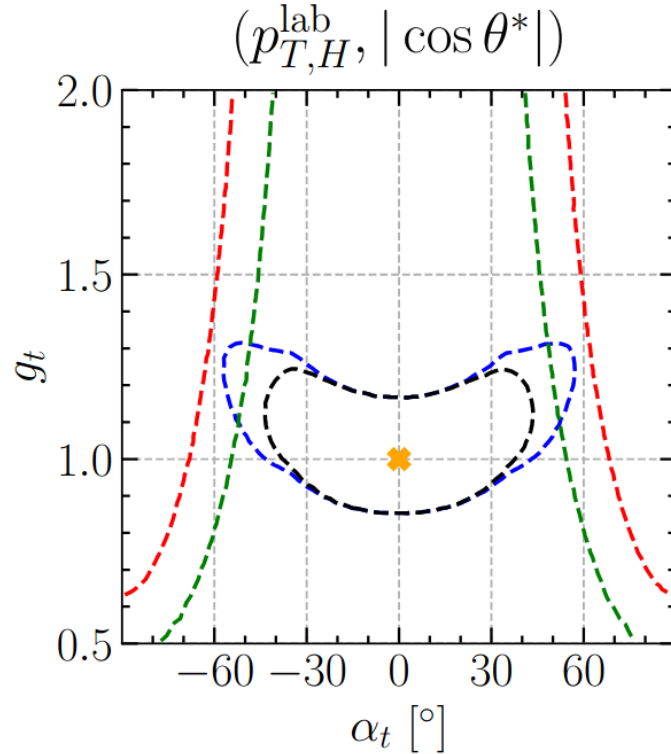
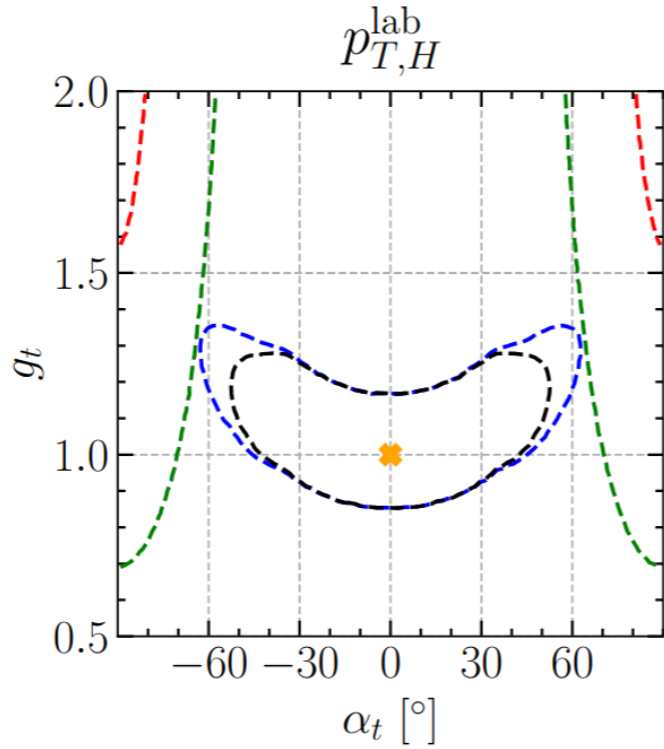
# Observables sensitive to CPV

- 1 – Comparison of significances of different  $p_T^H$  x observable/frame possibilities with standard binning.
- 2 – Optimize binning for most promising:  $p_T^H$  with  $\Delta\phi_{t\bar{t}}$  (lab.),  $b_1$  (lab.),  $\Delta\eta_{t\bar{t}}$  (tt),  $\theta^{*,tt}$ ,  $b_2$  (tt).
- 3 – Final significance estimation:

	$\alpha_t = 35^\circ$	$t\bar{t}H @ \mathcal{L} = 300 \text{ fb}^{-1}$			comb. w/ $p_{T,H}^{\text{lab}}$	
$H \rightarrow \gamma\gamma$	1.51	1.57	1.56	1.57	1.58	1.59
Multilep.	0.49	0.94	0.93	0.92	0.81	0.83
$H \rightarrow b\bar{b}$	0.31	0.55	0.55	0.55	0.51	0.52
Combined	1.61	1.91	1.9	1.9	1.85	1.87
		$p_{T,H}$	$\Delta\phi_{t\bar{t}}$	$b_1$	$b_2$	$\Delta\eta_{t\bar{t}}$   $ \cos \theta^* $
		lab frame			$t\bar{t}$ frame	

# Expected constraints on $\alpha$ angle

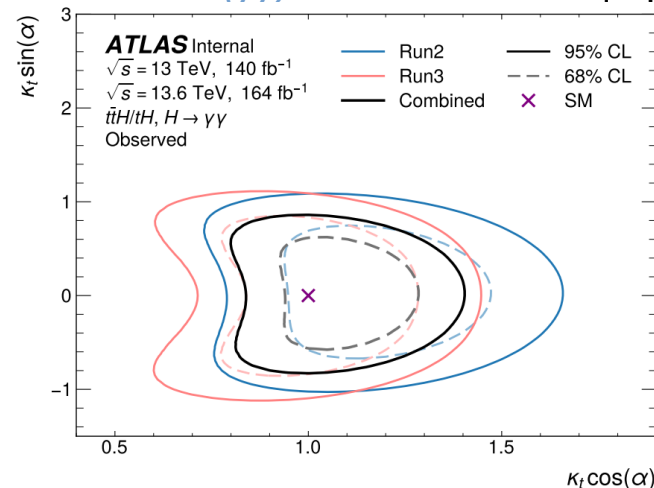
Comparison of expected exclusion limits on  $\alpha$  depending on  $\mu_{ttH}$  for  $p_T^H$  alone vs 2D analysis using the **best observable**  $\theta^{*,tt}$  to pair with  $p_T^H$  (95 % CL).



Channel	$\alpha$ 95% CL ( $g_t=1$ ) $p_T^H$	$\alpha$ 95% CL ( $g_t=1$ ) $p_T^H \times \cos \theta^{*,tt}$	$\alpha$ 95% CL ( $g_t=1$ ) BDT
<i>bb</i>	$-90^\circ, 90^\circ$	$-68^\circ, 68^\circ$	$-62^\circ, 62^\circ$
Combined	$-42^\circ, 42^\circ$	$-38^\circ, 38^\circ$	$-33^\circ, 33^\circ$

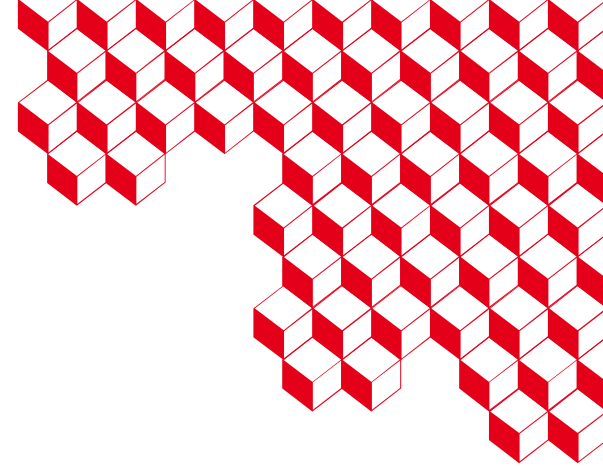
# Conclusion and outlook

- Phenomenology study included detection effects, selection efficiencies → mimic data efficiency and resolution
- Shows reasonable competitiveness of 2D binning with MVA strategies
- Easier reinterpretation of results for combinations and theoreticians
- Five main candidates retained to extend  $p_{T^H}$  based STXS measurement :  
→  $\Delta\phi_{tt}$  (lab.),  $b_1$  (lab.) ,  $\Delta\eta_{tt}$  (tt),  $\theta^{*,tt}$  ,  $b_2$  (tt)
- Yet to be implemented with LHC data → **Ongoing  $ttH+tH(bb)$  ATLAS analysis for CPV reinterpretation + STXS**
- Will be compared with latest ATLAS  $ttH+tH(\gamma\gamma)$  constraints on  $|\alpha| > 38^\circ$  at 95% CL



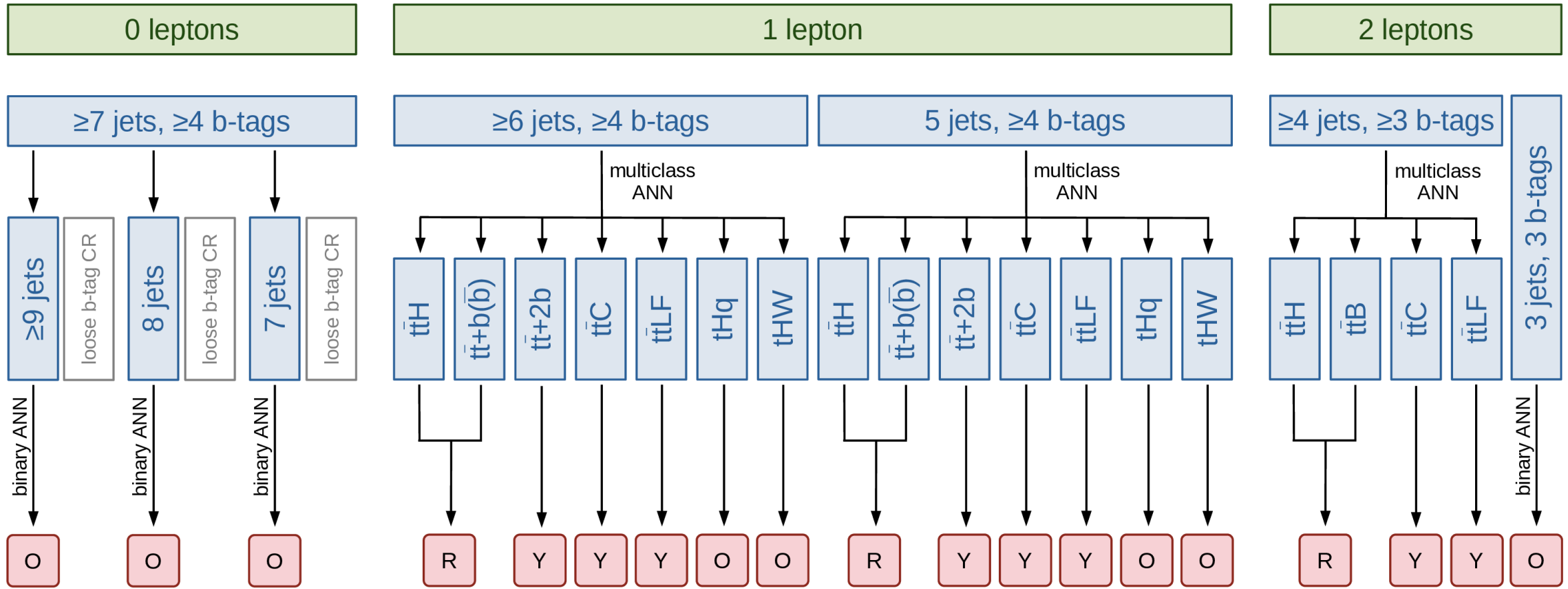


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Back-up

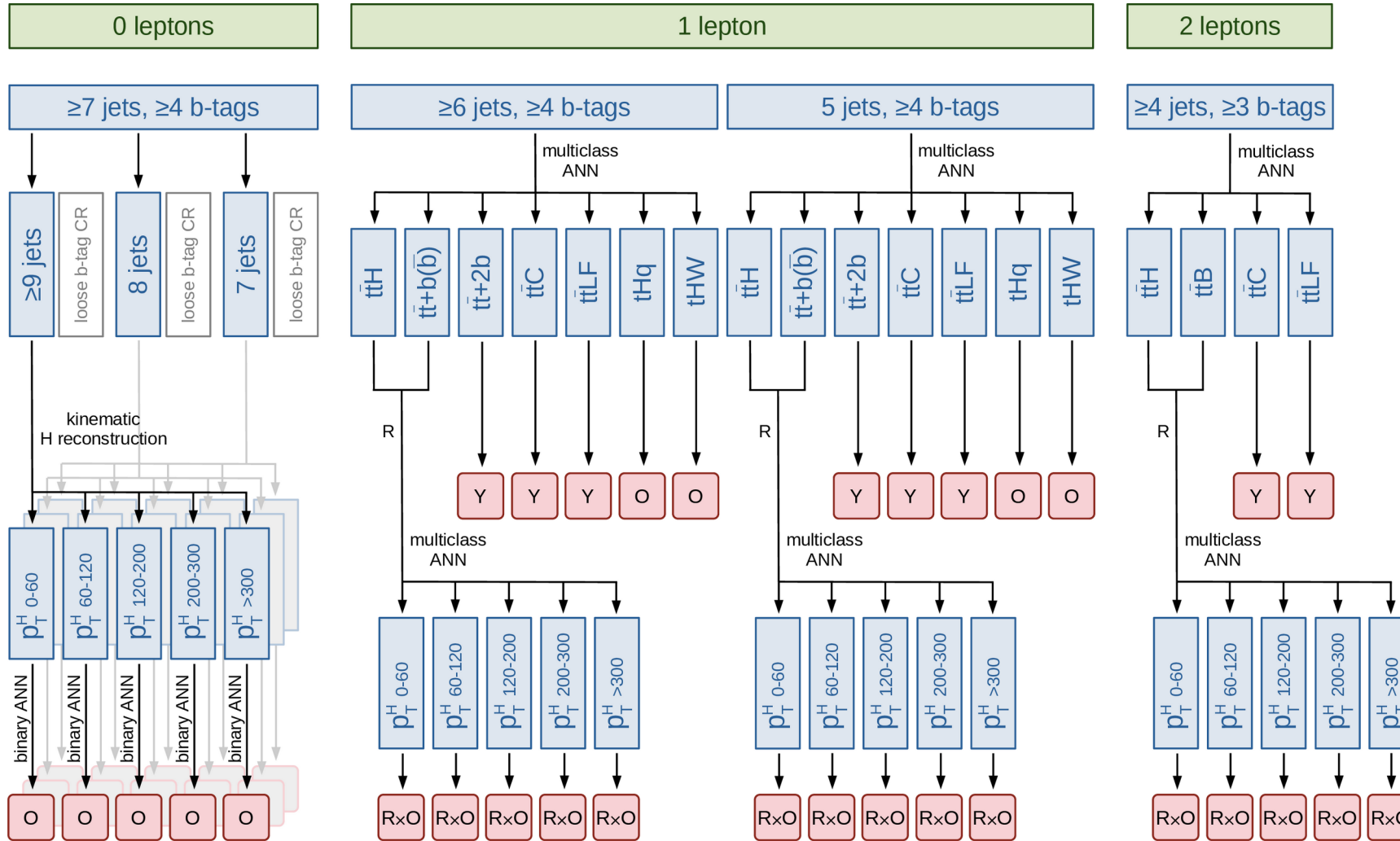
# CMS $ttH+tH(bb)$ : Analysis strategy (CP)



Legend:   Distribution in template fit, event yield (Y), ANN output (O), likelihood ratio of ANN outputs (R)

What is the fit performed on to extract  $\mu$ ?

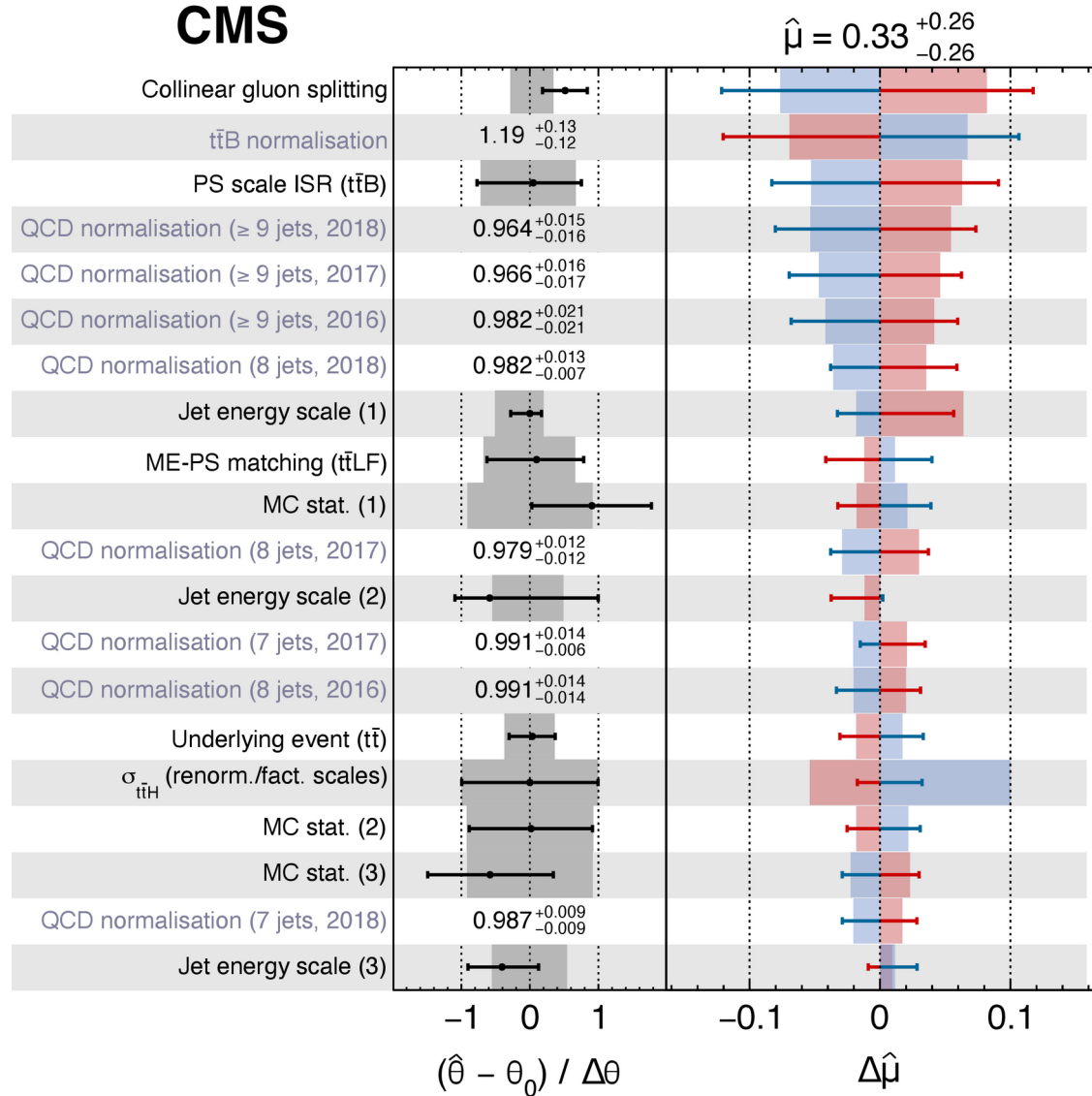
# CMS $ttH+tH(bb)$ : Analysis strategy (STXS)



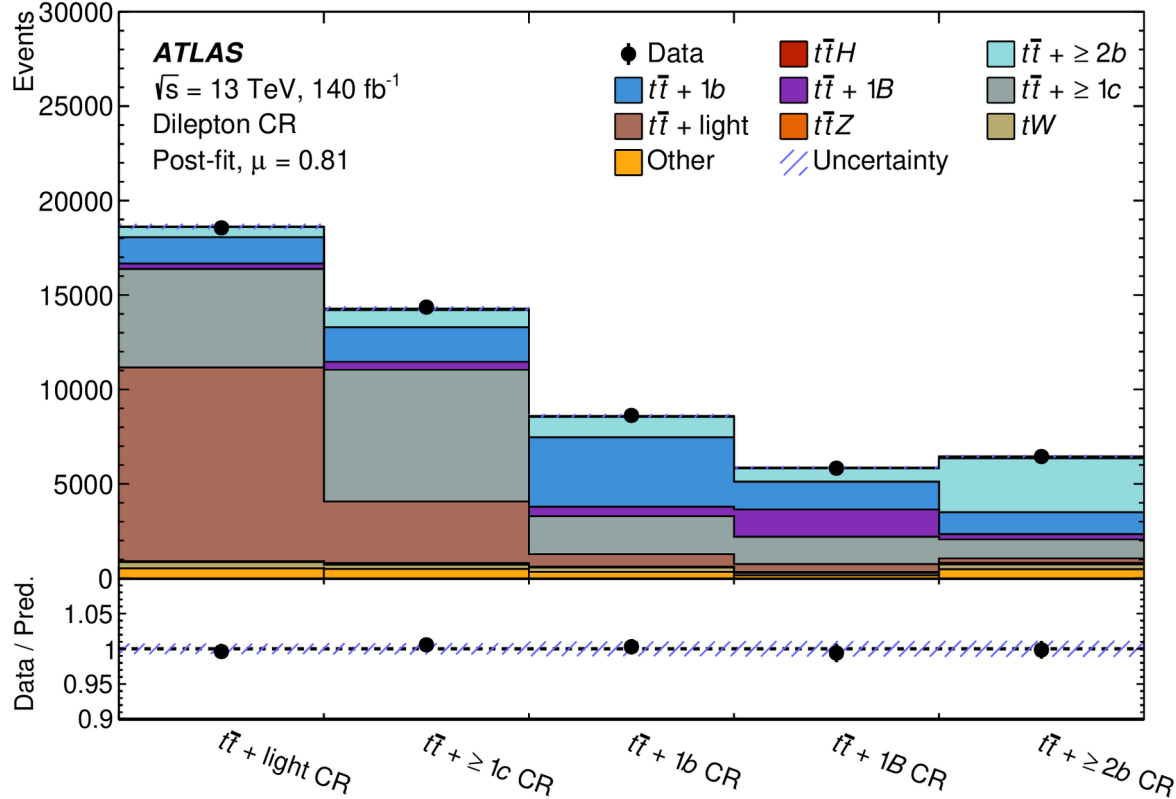
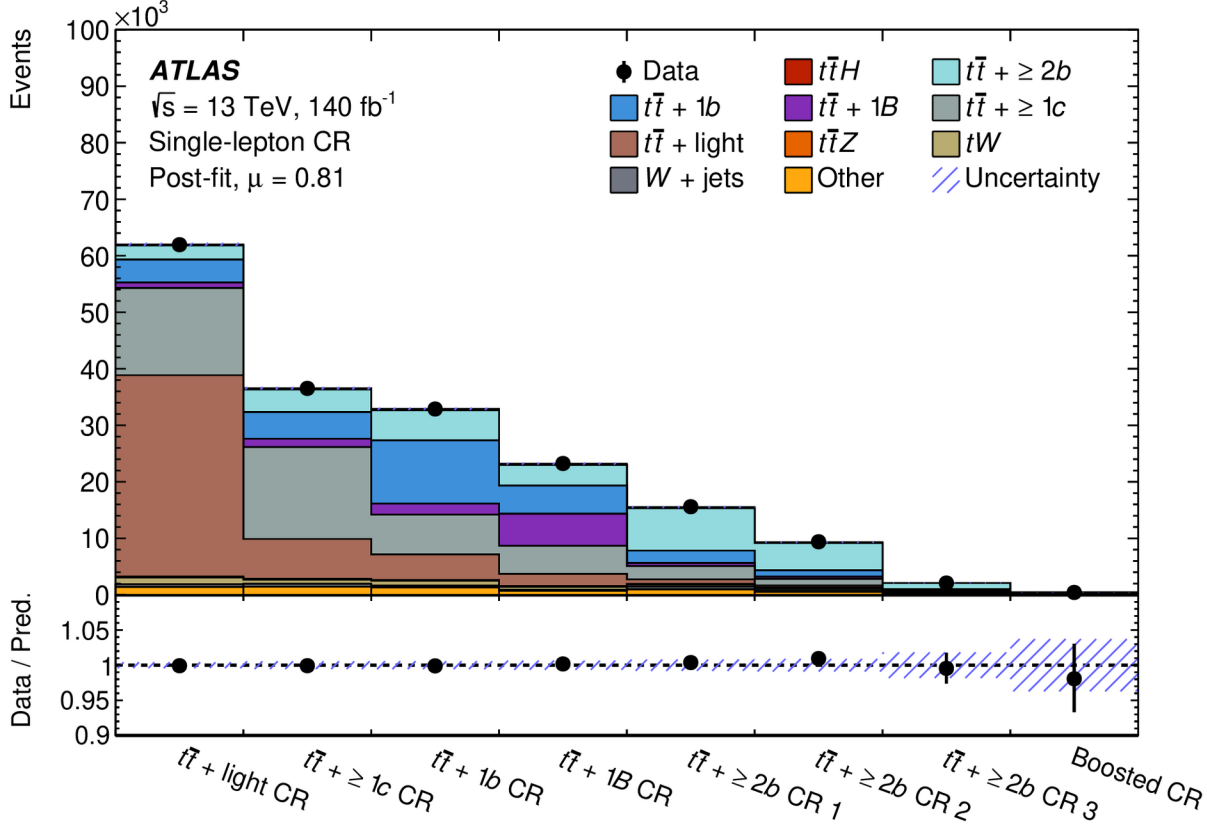
  Distribution in template fit, event yield (Y), ANN output (O), likelihood ratio of ANN outputs (R), product of likelihood ratio of ANN outputs and STXS ANN output ( $R \times O$ )

# CMS $ttH+tH(bb)$ : Uncertainties

- Fit constraint (obs.)    — +1 $\sigma$  Impact (obs.)    — -1 $\sigma$  Impact (obs.)
- Fit constraint (exp.)    ■ +1 $\sigma$  Impact (exp.)    ■ -1 $\sigma$  Impact (exp.)

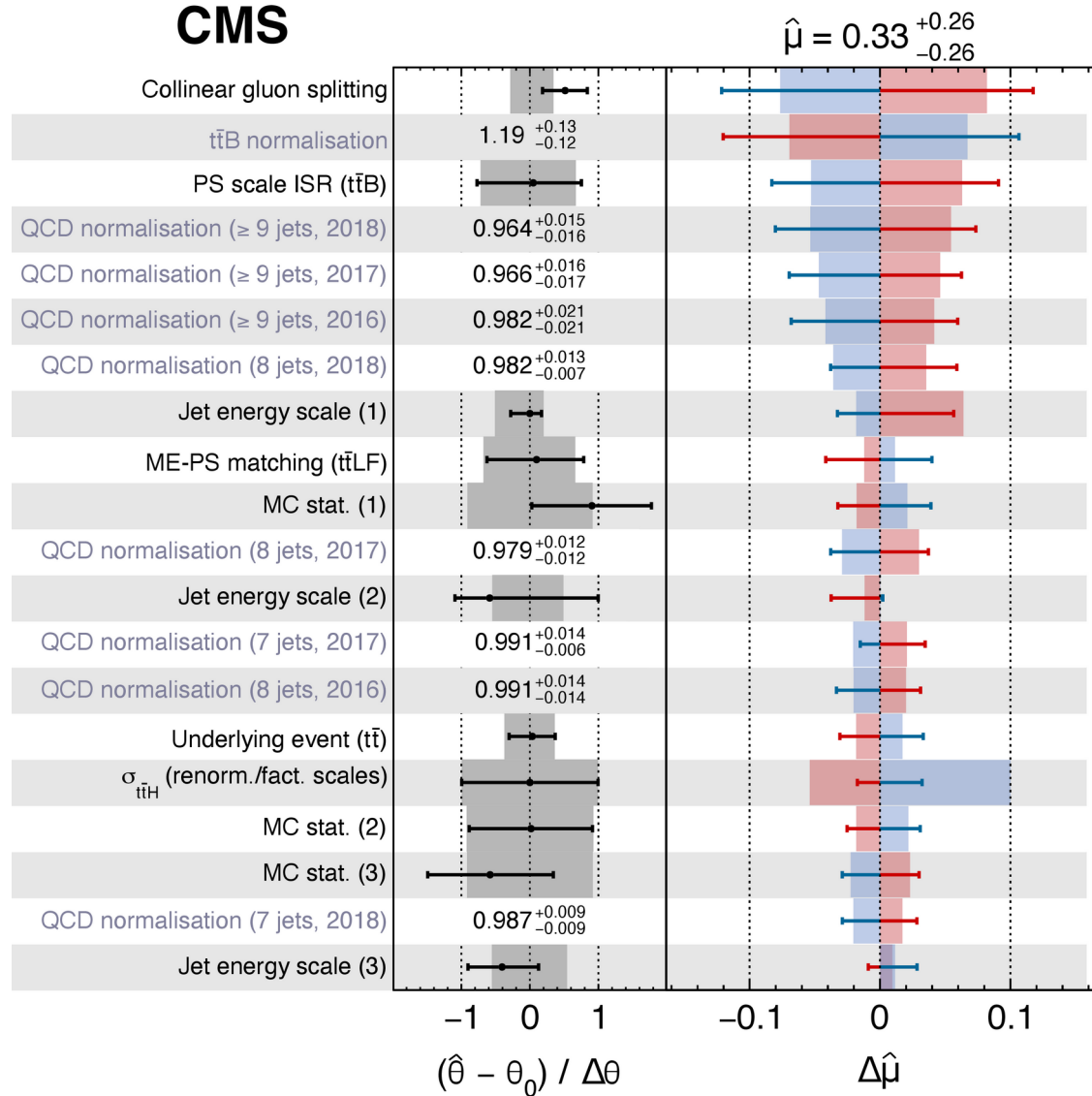


# ATLAS $t\bar{t}H(bb)$ : background



# CMS $ttH+tH(bb)$ : Uncertainties

- Fit constraint (obs.)    — +1 $\sigma$  Impact (obs.)    — -1 $\sigma$  Impact (obs.)
- Fit constraint (exp.)    ■ +1 $\sigma$  Impact (exp.)    ■ -1 $\sigma$  Impact (exp.)



# ATLAS $t\bar{t}H+tH(bb)$ : CP uncertainties

Uncertainty source	$\Delta\alpha$ [°]	
Process modelling		
Signal modelling	+8.8	-14
$t\bar{t} + \geq 1b$ modelling		
$t\bar{t} + \geq 1b$ 4V5 FS	+23	-37
$t\bar{t} + \geq 1b$ NLO matching	+22	-33
$t\bar{t} + \geq 1b$ fractions	+14	-21
$t\bar{t} + \geq 1b$ FSR	+5.2	-9.9
$t\bar{t} + \geq 1b$ PS & hadronisation	+16	-24
$t\bar{t} + \geq 1b$ $p_T^{b\bar{b}}$ shape	+5.4	-4.6
$t\bar{t} + \geq 1b$ ISR	+14	-24
$t\bar{t} + \geq 1c$ modelling	+6.6	-11
$t\bar{t} + \text{light}$ modelling	+2.5	-4.7
$b$ -tagging efficiency and mis-tag rates		
$b$ -tagging efficiency	+8.7	-15
$c$ -mis-tag rates	+6.7	-11
$l$ -mis-tag rates	+2.3	-2.7
Jet energy scale and resolution		
$b$ -jet energy scale	+1.6	-3.8
Jet energy scale (flavour)	+7.8	-11
Jet energy scale (pileup)	+5.2	-7.9
Jet energy scale (remaining)	+8.1	-13
Jet energy resolution	+5.7	-9.3
Luminosity	$\leq \pm 1$	
Other sources	+4.9	-8
Total systematic uncertainty		
	+41	-54
$t\bar{t} + \geq 1b$ normalisation		
	+8.2	-13
$\kappa'_i$	+17	-33
Total statistical uncertainty		
	+32	-49
Total uncertainty		
	+52	-73

Uncertainty source	$\Delta\kappa'_i$	
Process modelling		
Signal modelling	+0.10	-0.10
$t\bar{t} + \geq 1b$ modelling		
$t\bar{t} + \geq 1b$ 4V5 FS	+0.08	-0.23
$t\bar{t} + \geq 1b$ NLO matching	+0.15	-0.30
$t\bar{t} + \geq 1b$ fractions	+0.09	-0.21
$t\bar{t} + \geq 1b$ FSR	+0.01	-0.02
$t\bar{t} + \geq 1b$ PS & hadronisation	+0.09	-0.20
$t\bar{t} + \geq 1b$ $p_T^{b\bar{b}}$ shape	+0.07	-0.11
$t\bar{t} + \geq 1b$ ISR	+0.07	-0.17
$t\bar{t} + \geq 1c$ modelling	+0.04	-0.10
$t\bar{t} + \text{light}$ modelling	+0.00	-0.01
$b$ -tagging efficiency and mis-tag rates		
$b$ -tagging efficiency	+0.06	-0.12
$c$ -mis-tag rates	+0.03	-0.07
$l$ -mis-tag rates	+0.01	-0.03
Jet energy scale and resolution		
$b$ -jet energy scale	+0.02	-0.02
Jet energy scale (flavour)	+0.01	-0.05
Jet energy scale (pileup)	+0.02	-0.05
Jet energy scale (remaining)	+0.04	-0.08
Jet energy resolution	+0.03	-0.09
Luminosity	$\leq \pm 0.01$	
Other sources	+0.03	-0.07
Total systematic uncertainty		
	+0.29	-0.45
$t\bar{t} + \geq 1b$ normalisation		
	+0.05	-0.15
$\alpha$	+0.08	-0.07
Total statistical uncertainty		
	+0.09	-0.10
Total uncertainty		
	+0.30	-0.46

# ATLAS $t\bar{t}H(bb)$ : STXS uncertainties

Uncertainty source	$\Delta\alpha [^\circ]$	
Process modelling		
Signal modelling	+8.8	-14
$t\bar{t} + \geq 1b$ modelling		
$t\bar{t} + \geq 1b$ 4V5 FS	+23	-37
$t\bar{t} + \geq 1b$ NLO matching	+22	-33
$t\bar{t} + \geq 1b$ fractions	+14	-21
$t\bar{t} + \geq 1b$ FSR	+5.2	-9.9
$t\bar{t} + \geq 1b$ PS & hadronisation	+16	-24
$t\bar{t} + \geq 1b$ $p_T^{b\bar{b}}$ shape	+5.4	-4.6
$t\bar{t} + \geq 1b$ ISR	+14	-24
$t\bar{t} + \geq 1c$ modelling	+6.6	-11
$t\bar{t} + \text{light}$ modelling	+2.5	-4.7
$b$ -tagging efficiency and mis-tag rates		
$b$ -tagging efficiency	+8.7	-15
$c$ -mis-tag rates	+6.7	-11
$l$ -mis-tag rates	+2.3	-2.7
Jet energy scale and resolution		
$b$ -jet energy scale	+1.6	-3.8
Jet energy scale (flavour)	+7.8	-11
Jet energy scale (pileup)	+5.2	-7.9
Jet energy scale (remaining)	+8.1	-13
Jet energy resolution	+5.7	-9.3
Luminosity	$\leq \pm 1$	
Other sources	+4.9	-8
Total systematic uncertainty		
	+41	-54
$t\bar{t} + \geq 1b$ normalisation		
	+8.2	-13
$\kappa'_i$	+17	-33
Total statistical uncertainty		
	+32	-49
Total uncertainty		
	+52	-73

Uncertainty source	$\Delta\kappa'_i$	
Process modelling		
Signal modelling	+0.10	-0.10
$t\bar{t} + \geq 1b$ modelling		
$t\bar{t} + \geq 1b$ 4V5 FS	+0.08	-0.23
$t\bar{t} + \geq 1b$ NLO matching	+0.15	-0.30
$t\bar{t} + \geq 1b$ fractions	+0.09	-0.21
$t\bar{t} + \geq 1b$ FSR	+0.01	-0.02
$t\bar{t} + \geq 1b$ PS & hadronisation	+0.09	-0.20
$t\bar{t} + \geq 1b$ $p_T^{b\bar{b}}$ shape	+0.07	-0.11
$t\bar{t} + \geq 1b$ ISR	+0.07	-0.17
$t\bar{t} + \geq 1c$ modelling	+0.04	-0.10
$t\bar{t} + \text{light}$ modelling	+0.00	-0.01
$b$ -tagging efficiency and mis-tag rates		
$b$ -tagging efficiency	+0.06	-0.12
$c$ -mis-tag rates	+0.03	-0.07
$l$ -mis-tag rates	+0.01	-0.03
Jet energy scale and resolution		
$b$ -jet energy scale	+0.02	-0.02
Jet energy scale (flavour)	+0.01	-0.05
Jet energy scale (pileup)	+0.02	-0.05
Jet energy scale (remaining)	+0.04	-0.08
Jet energy resolution	+0.03	-0.09
Luminosity	$\leq \pm 0.01$	
Other sources	+0.03	-0.07
Total systematic uncertainty		
	+0.29	-0.45
$t\bar{t} + \geq 1b$ normalisation		
	+0.05	-0.15
$\alpha$	+0.08	-0.07
Total statistical uncertainty		
	+0.09	-0.10
Total uncertainty		
	+0.30	-0.46

# STXS resolution

