Measurement of Higgs boson production in association with top quarks by ATLAS and CMS

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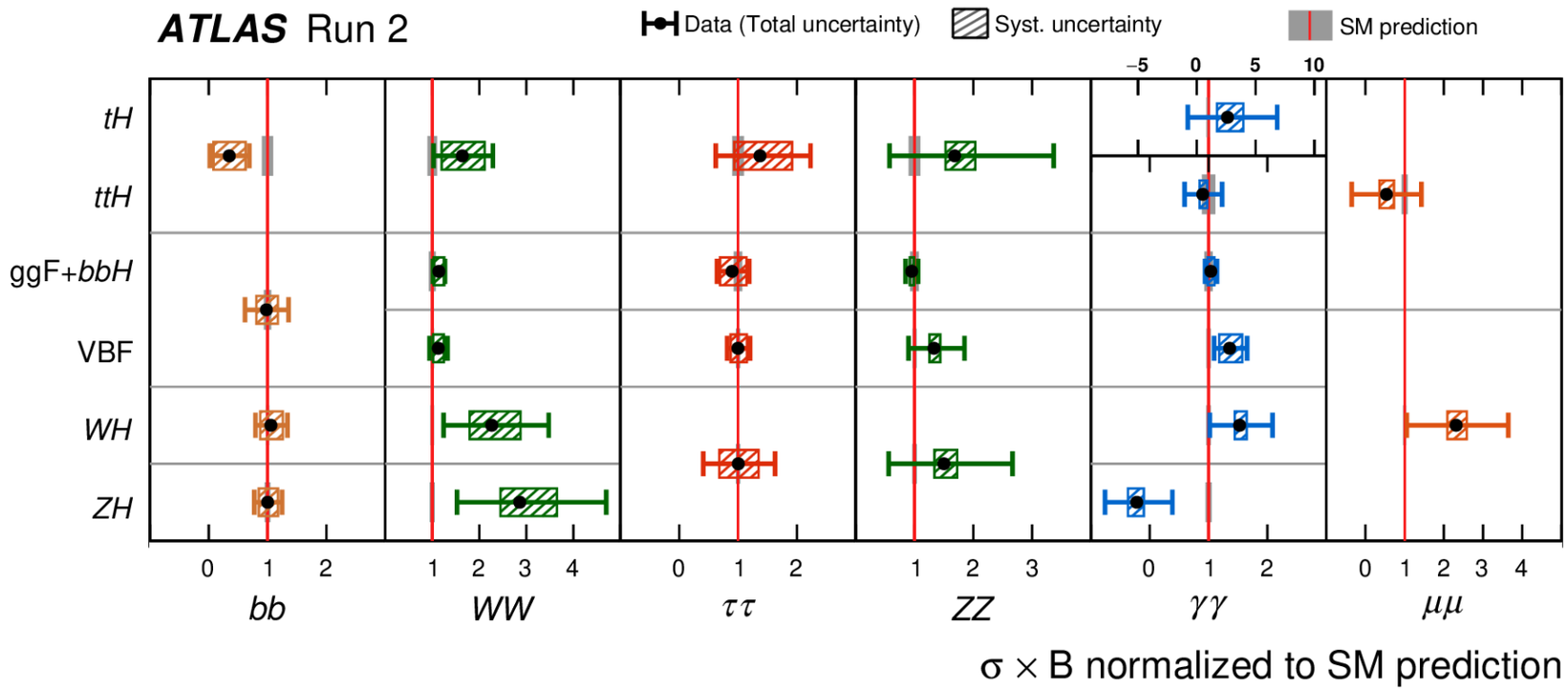
The Higgs boson

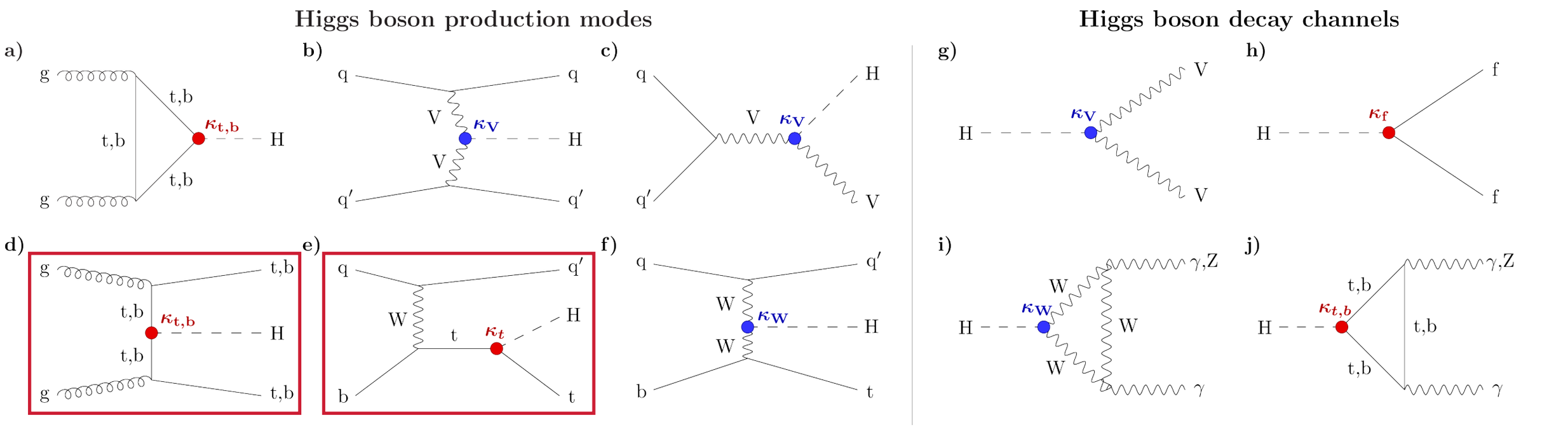
- Discovery 2012 by ATLAS and CMS @LHC
  - Observation from combination of 3 decay channels in 1 production process
- 10 years later
  - Single measurements in 7 decay channels and 6 production channels
  - Established spin-parity quantum numbers
  - Extremely precise mass measurement
  - Limits on pair production and self interaction

Nature 607, pages 52-59 (2022)



Top Yukawa coupling

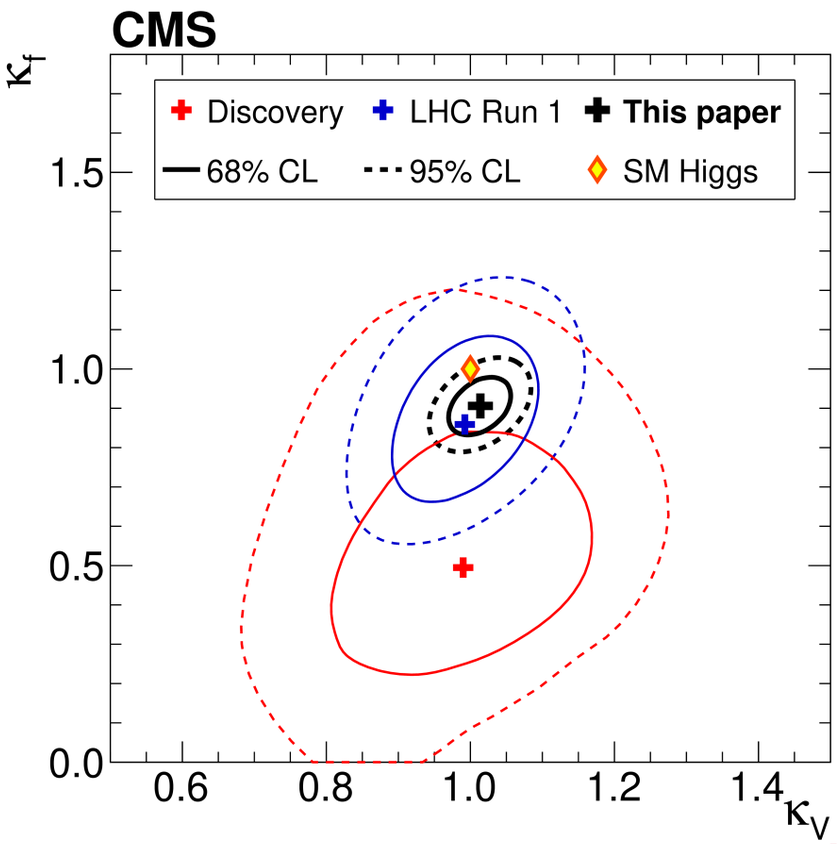
- Couplings to fermions (Yukawa couplings) proportional to mass
  - Top Yukawa coupling much larger than all others
  - Dominates fermion loop contributions → model-dependent extraction
- Model-independent measurement
  - via associated production with a top quark pair ($t\bar{t}H$) or a single top quark (tH)

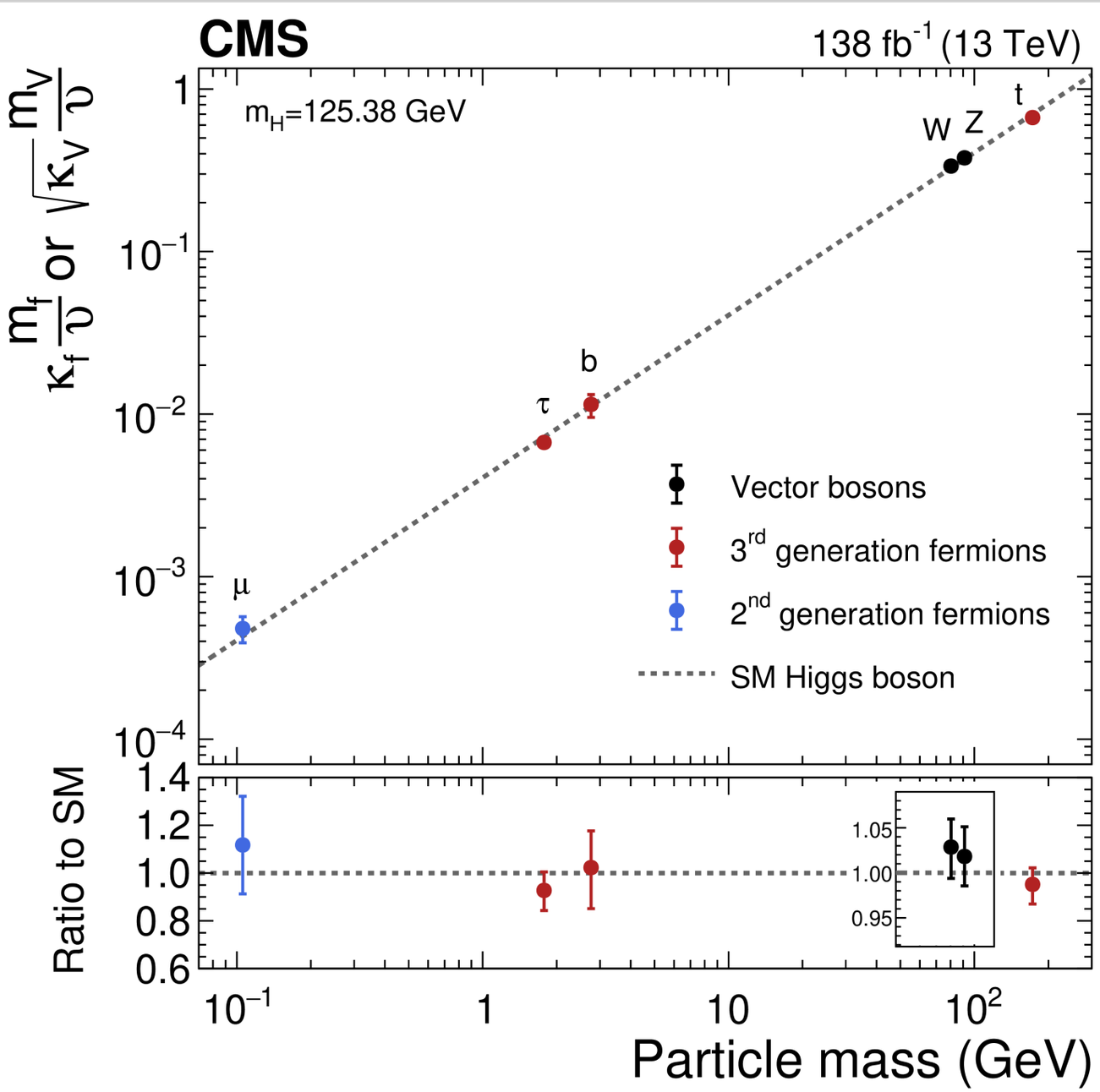


Nature 607, pages 60-68 (2022)

Deviations from SM?

- μ-framework for signal strengths
  - $\mu_{if} = \left(\sigma_i/\sigma_i^{\mathrm{SM}}\right) \times \left(B_f/B_f^{\mathrm{SM}}\right)$
- κ-framework for coupling modifiers
  - $\kappa_p^2 = \sigma_p/\sigma_p^{\mathrm{SM}} \quad \kappa_p^2 = \Gamma_p/\Gamma_p^{\mathrm{SM}}$





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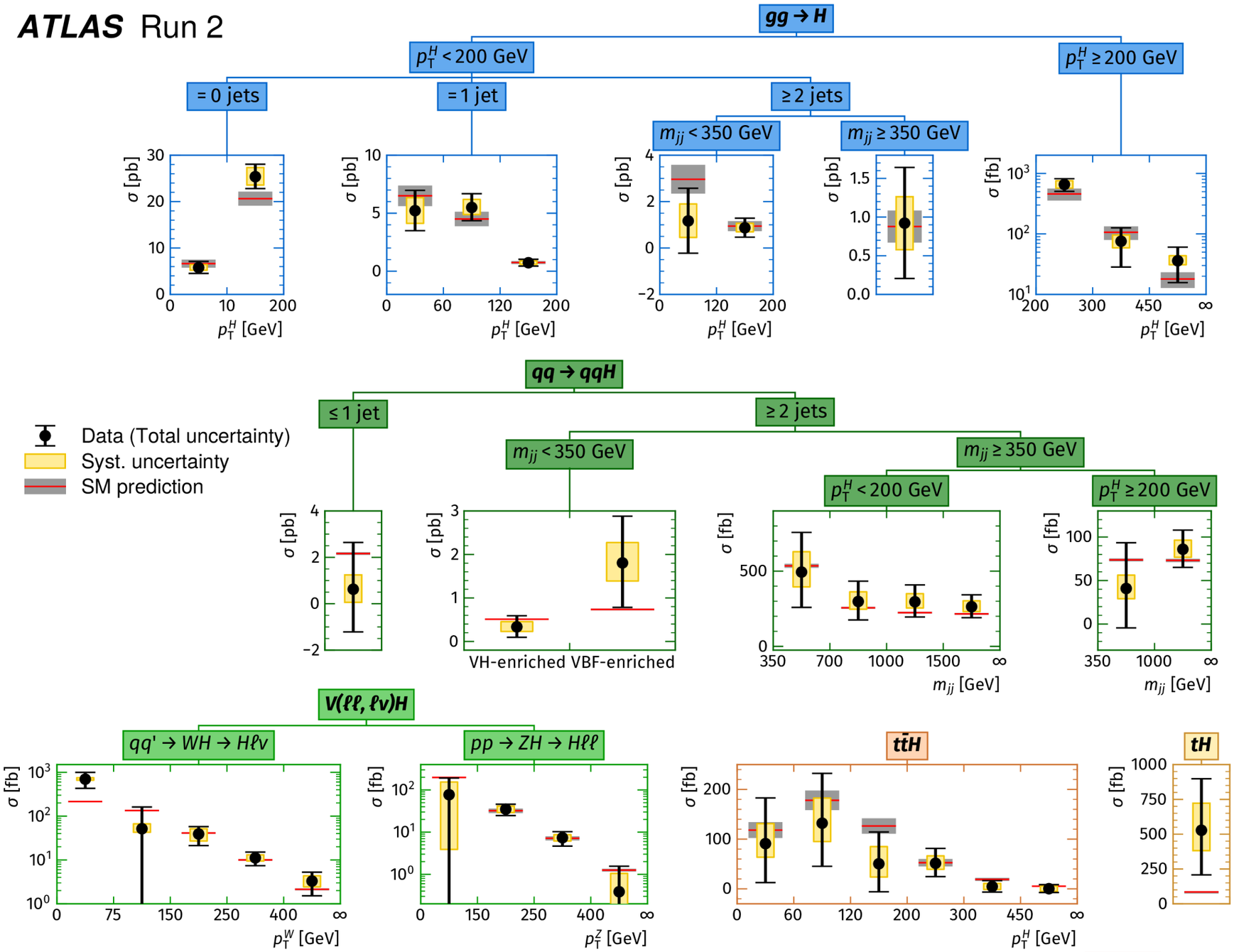
STXS approach

- [Simplified template cross sections]
  - defined in mutually exclusive regions of phase space
  - simplified fiducial volumes
  - inclusive in Higgs boson decay
  - SM production processes serving as kinematic templates
- Common choice of bins for ATLAS and CMS
  - allows for combination



Nature 607, pages 52-59 (2022)

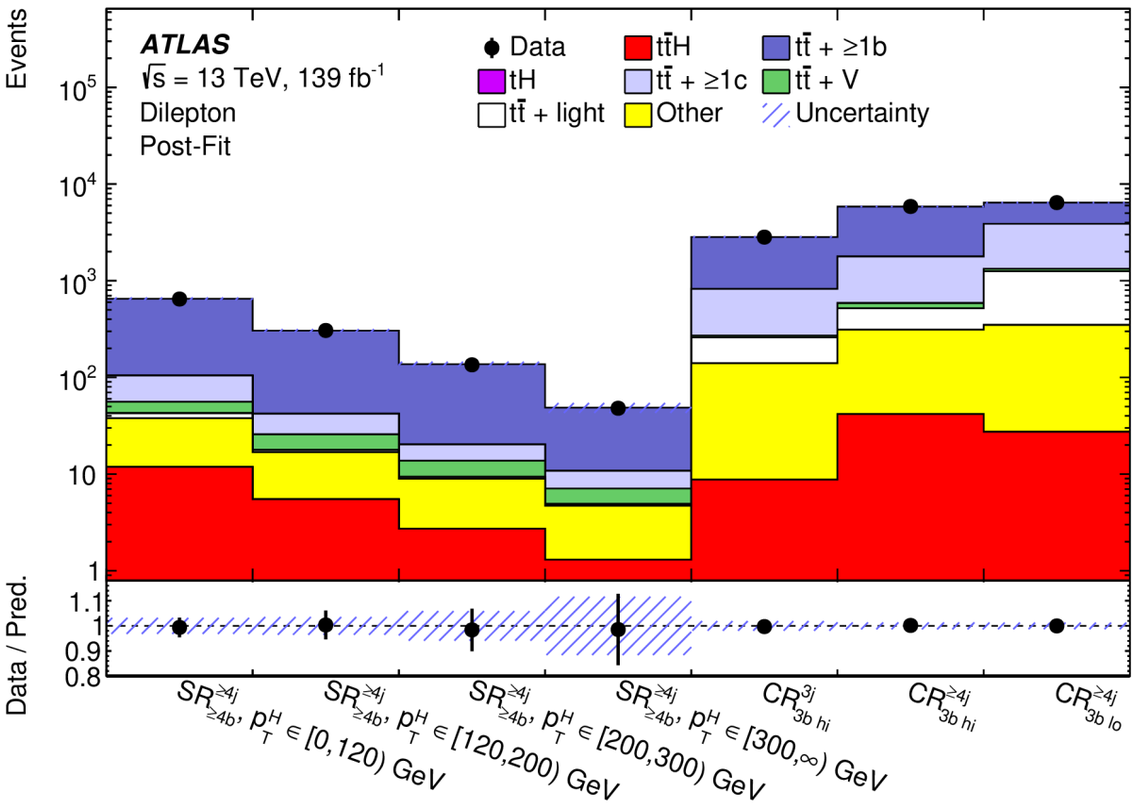
$t\bar{t}H$, $H \to b\bar{b}$

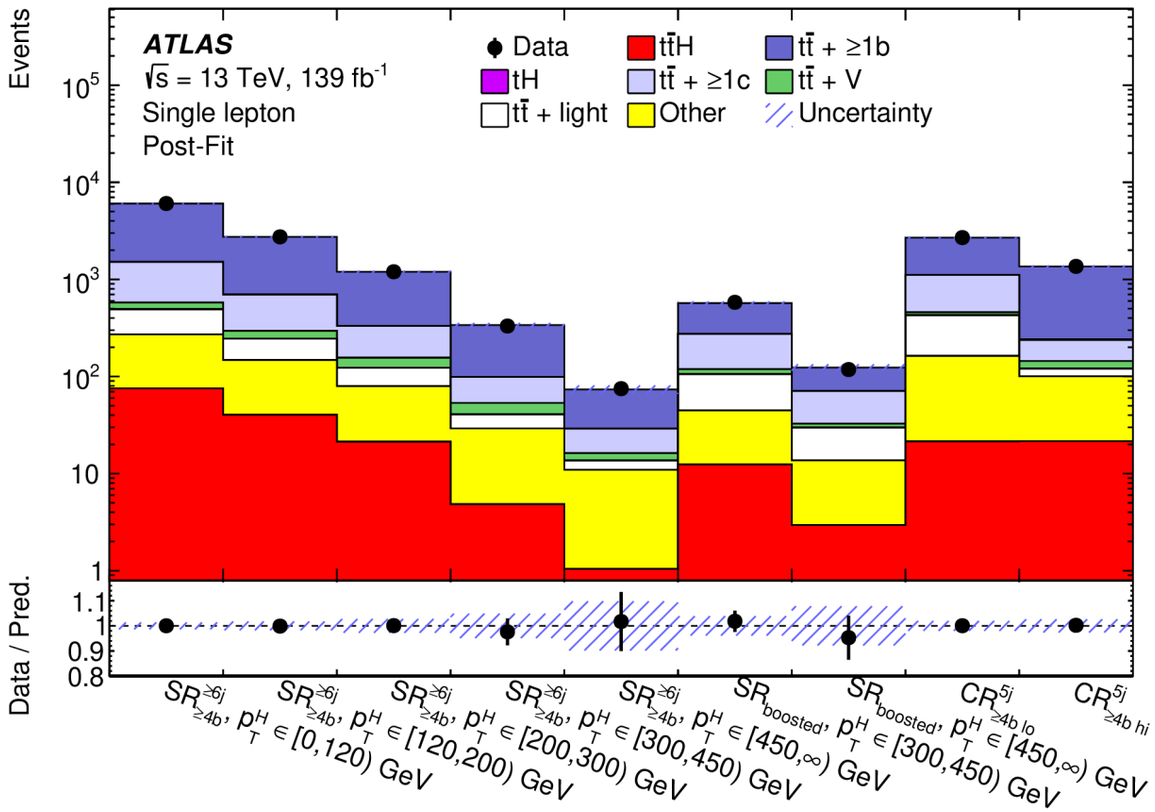
Single lepton and dilepton regions

Signal and control regions depending on number of jets and b-jets

Single lepton boosted for Higgs p_T > 300 GeV

Classification BDT for signal regions and yields for control regions in fit





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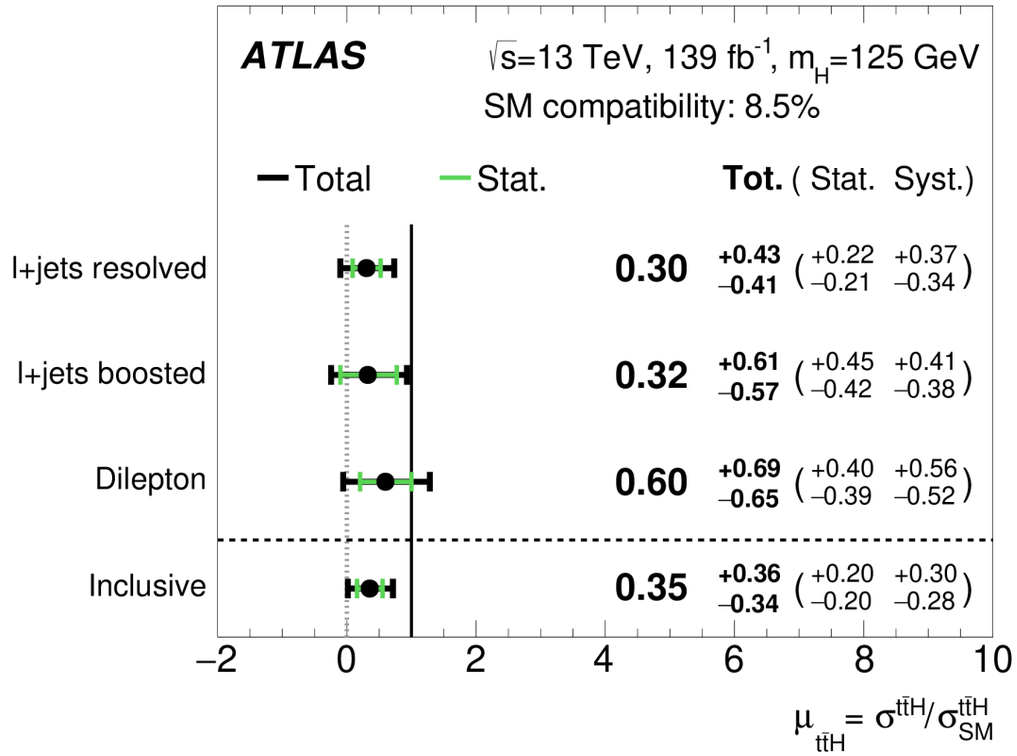
$t\bar{t}H$, $H \to b\bar{b}$

Inclusive measurement



Total uncertainty dominated by $t\bar{t}$+≥1b modelling systematics

No theoretical constraints applied to its cross section

$$k(t\bar{t} + \geq 1b) = 1.28 \pm 0.08$$

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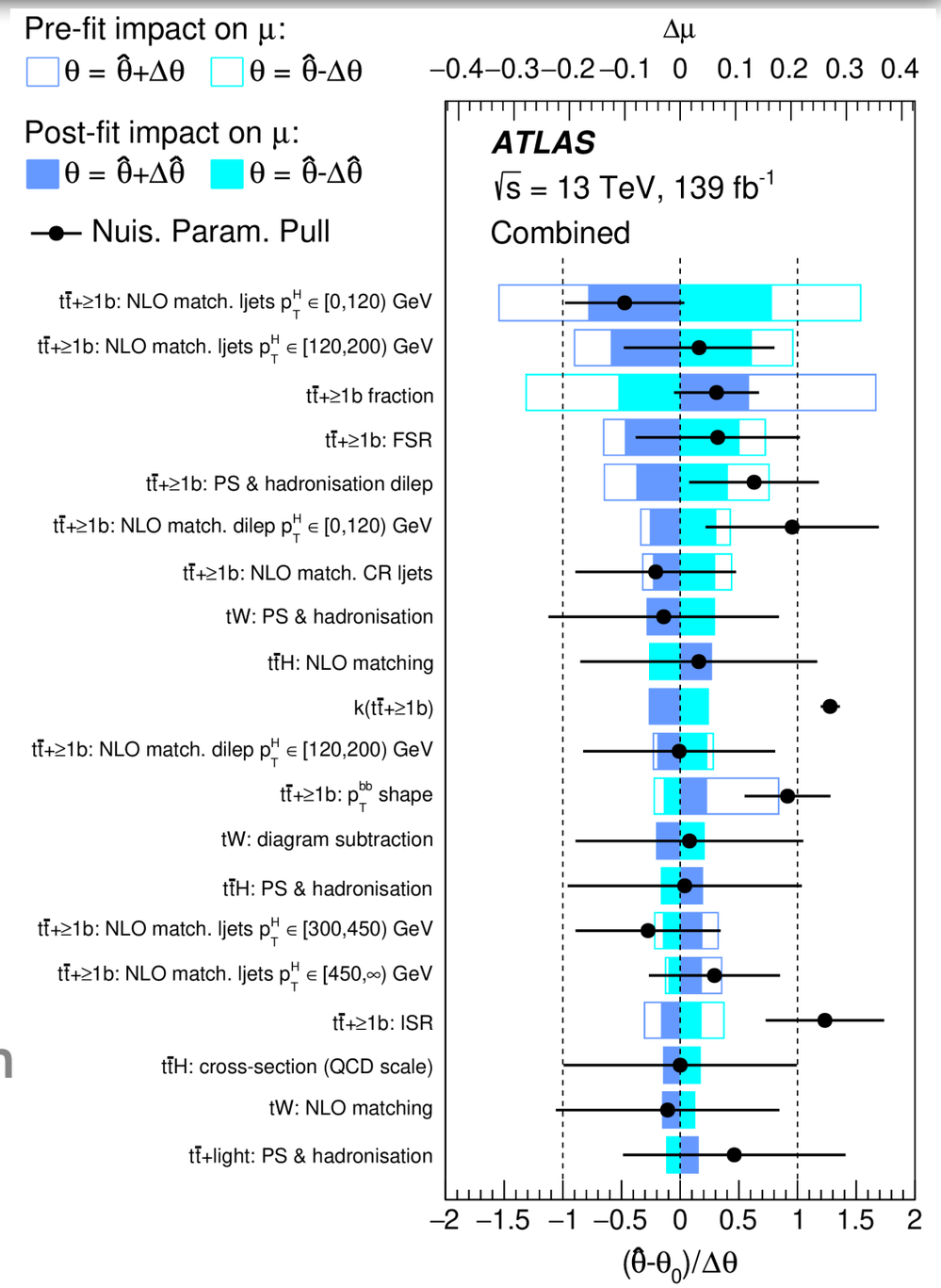
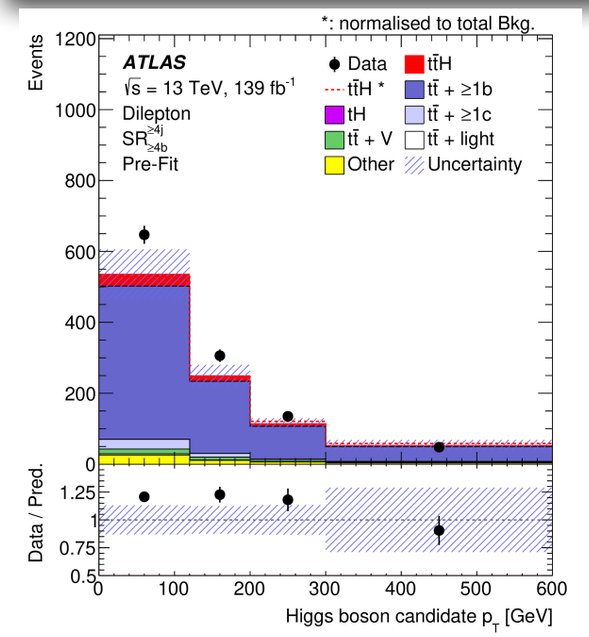
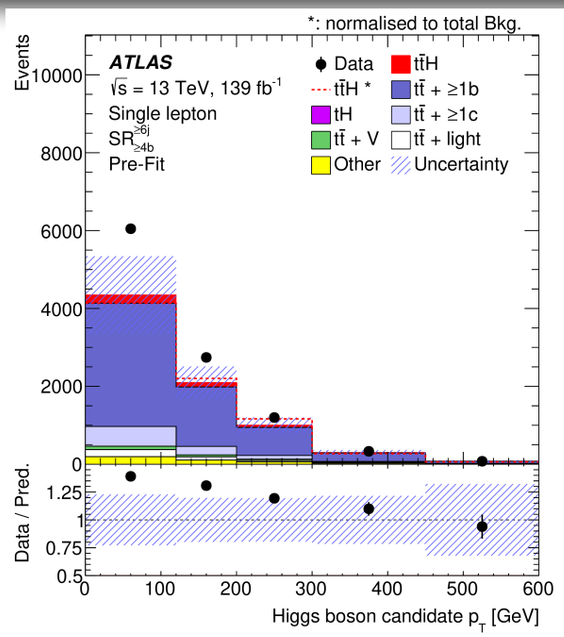
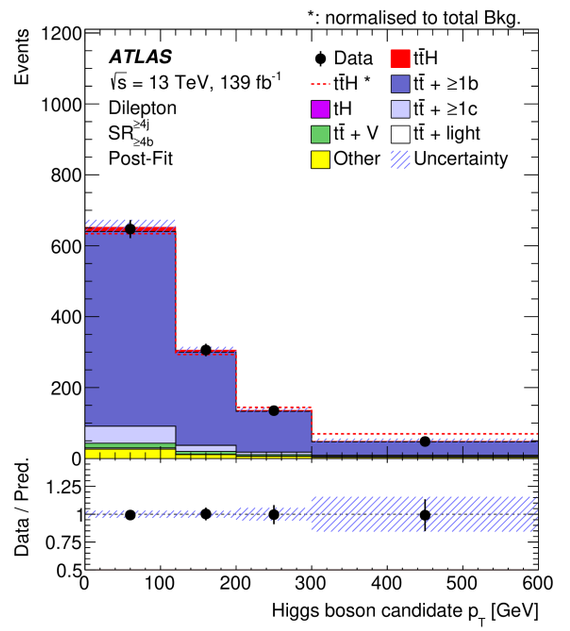


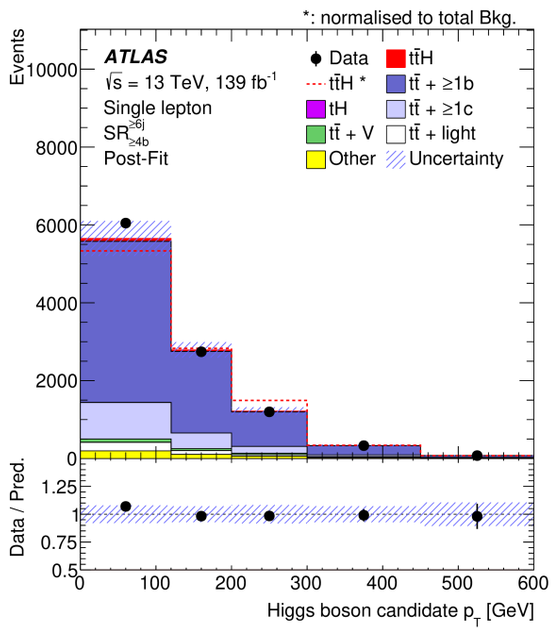
$t\bar{t}H$, $H \to b\bar{b}$





Dedicated systematics in $t\bar{t}b$





Differential measurement

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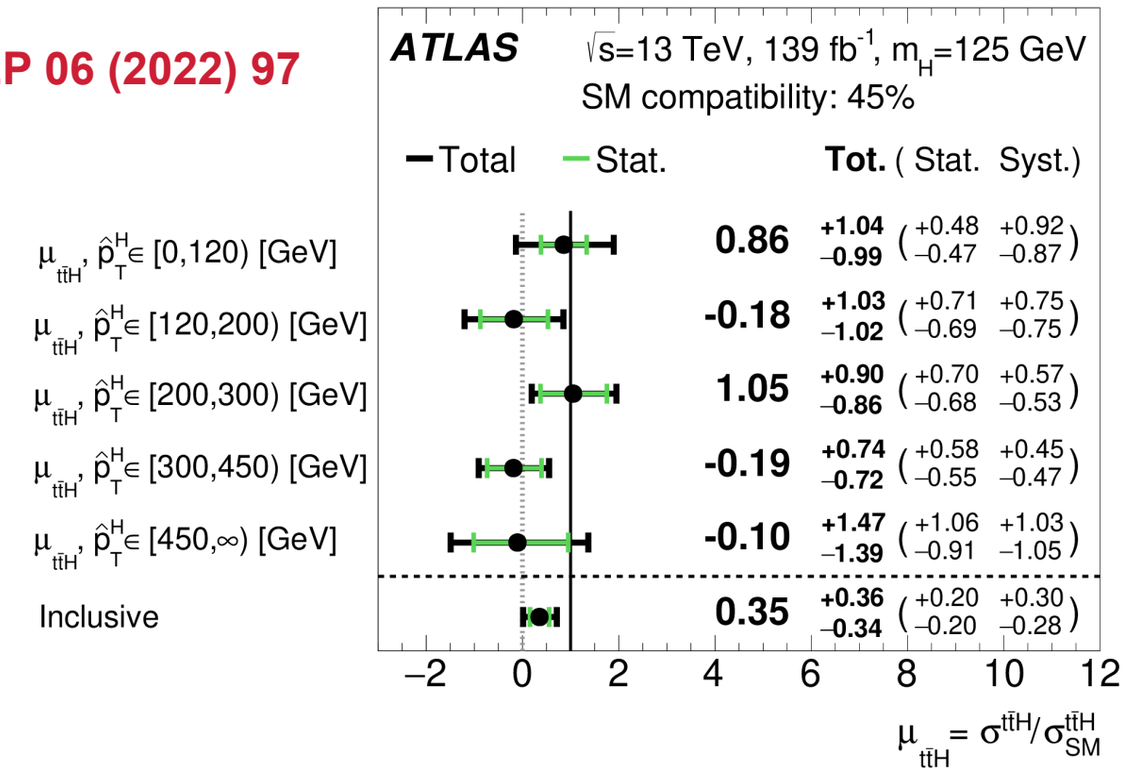


Statistical and systematic uncertainties of similar size in most bins

Results compatible with SM predictions within 1-2 σ,
but several negative fit values

$t(\bar{t})H,\ H\to b\bar{b}$

CMS-PAS-HIG-19-011

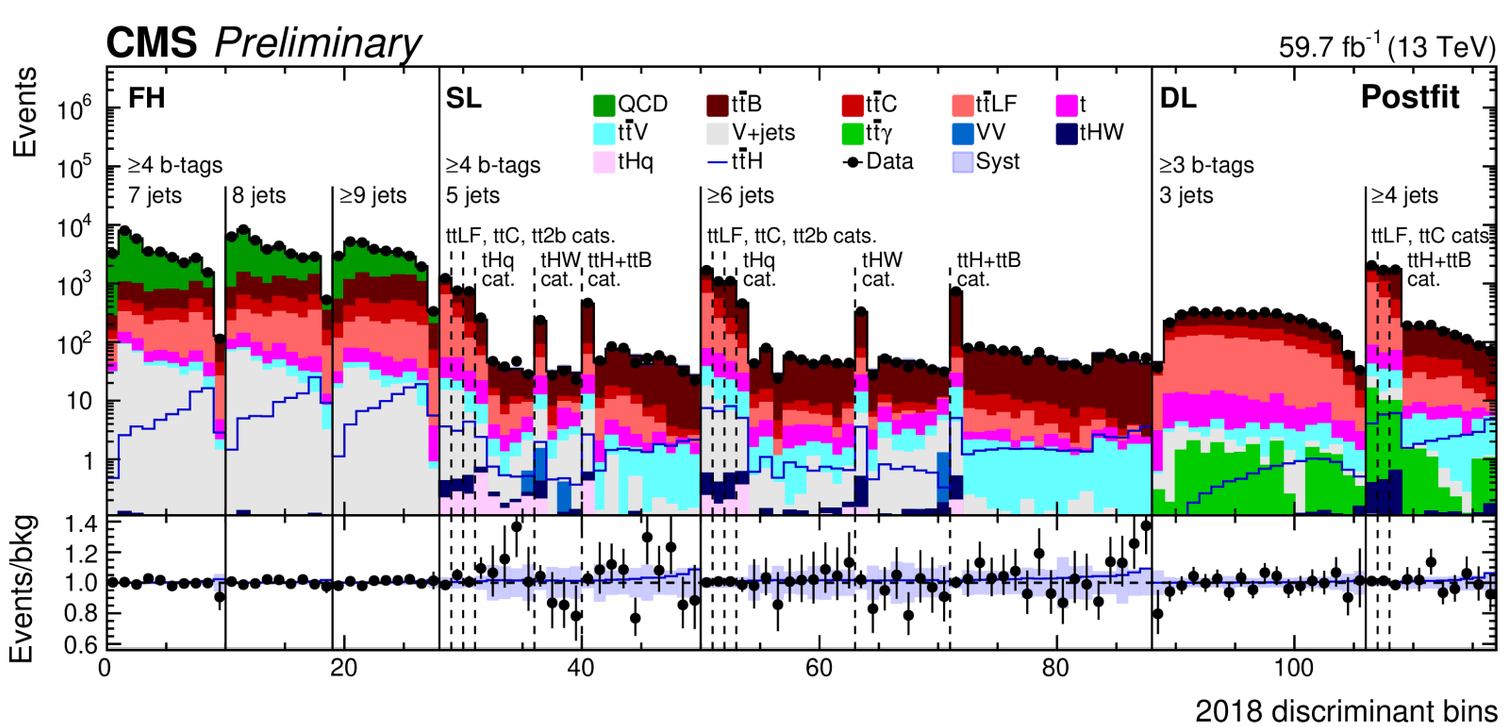
Full hadronic, single lepton and dilepton regions

Signal and control regions depending on number of jets and b-jets

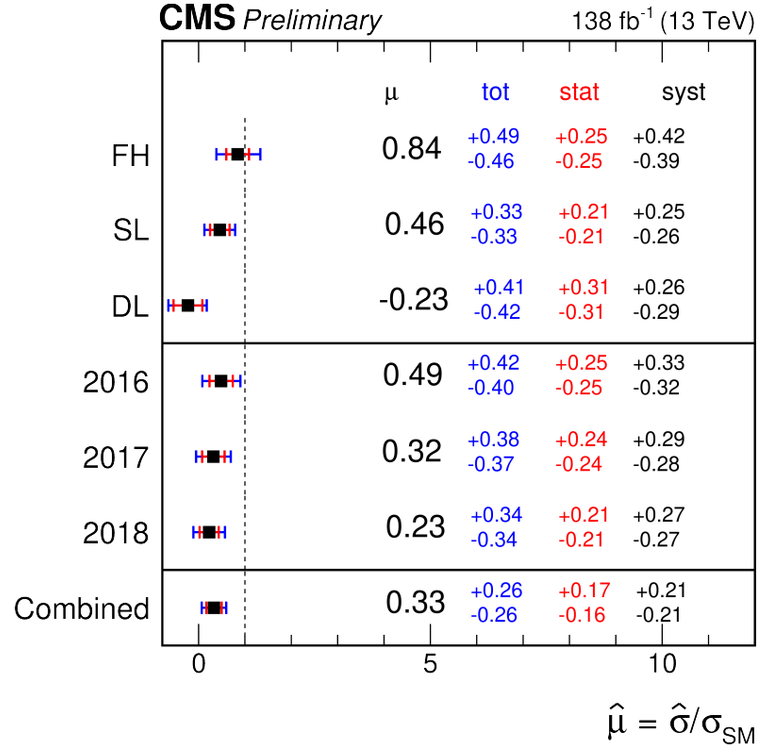
Multiclass ANNs separately for each year

ANN output and likelihood ratio of outputs used in fit

Different treatment of $t\bar{t}$+≥1b background wrt ATLAS

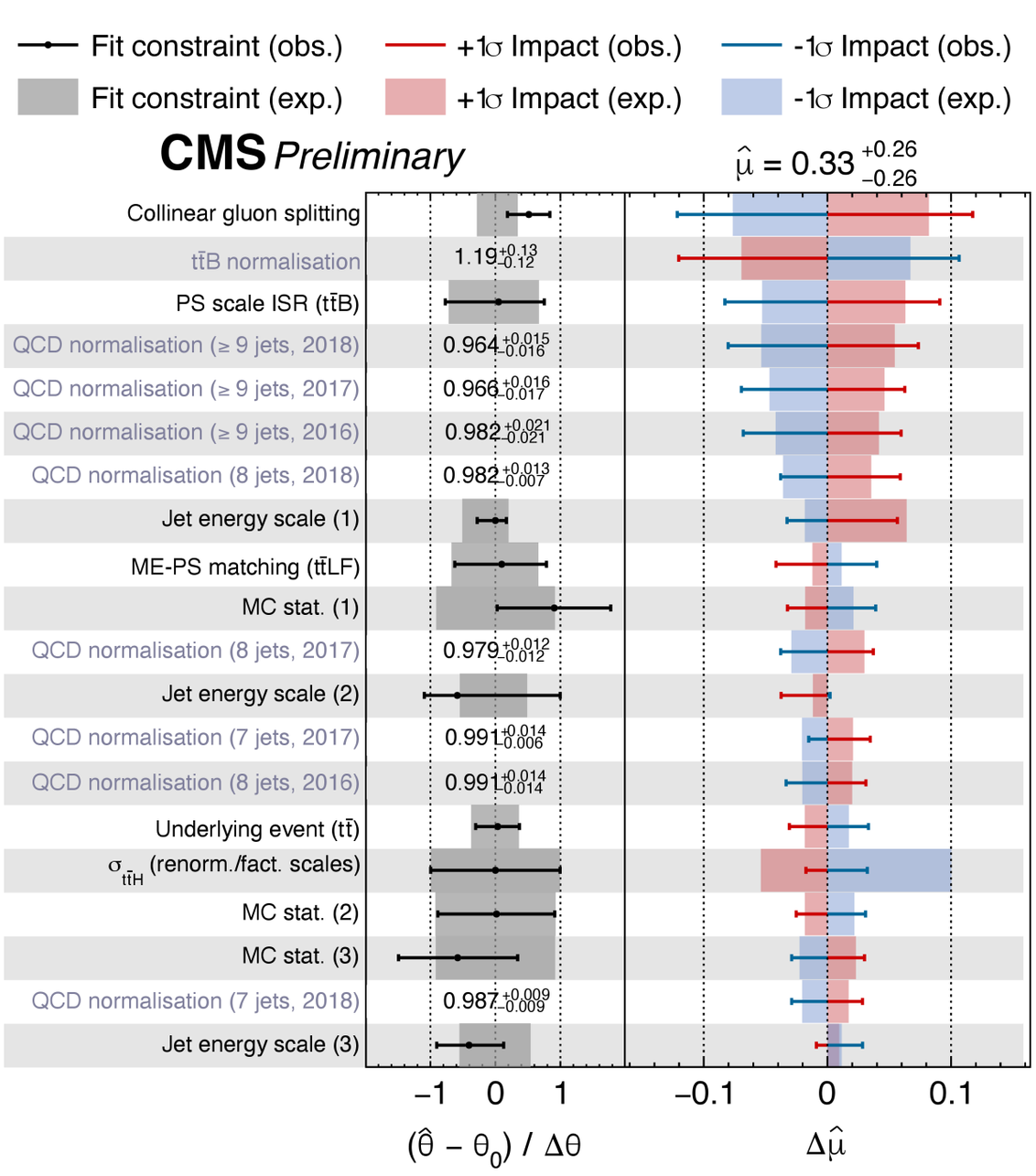


Fitted distributions

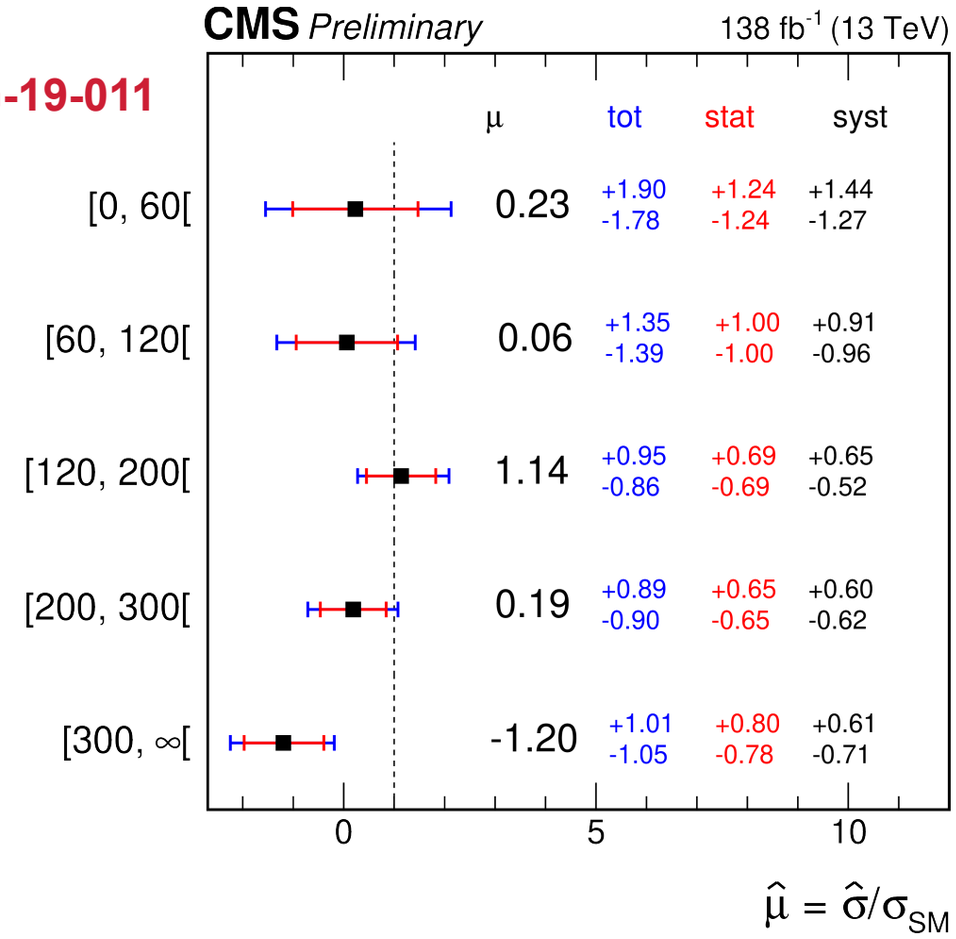


Inclusive measurement

$t\bar{t}H$, $H \to b\bar{b}$



CMS-PAS-HIG-19-011



Results compatible with SM (≤2.4σ) and similar to ATLAS

Uncertainty dominated by systematics for the inclusive measurement, mostly similar size for differential

tH, H→b$\bar{b}$

μ_{tH} < 14.6 @ 95%CL

With $\mu_{t\bar{t}H}$ fixed to 1 and treated as background

CMS-PAS-HIG-19-011

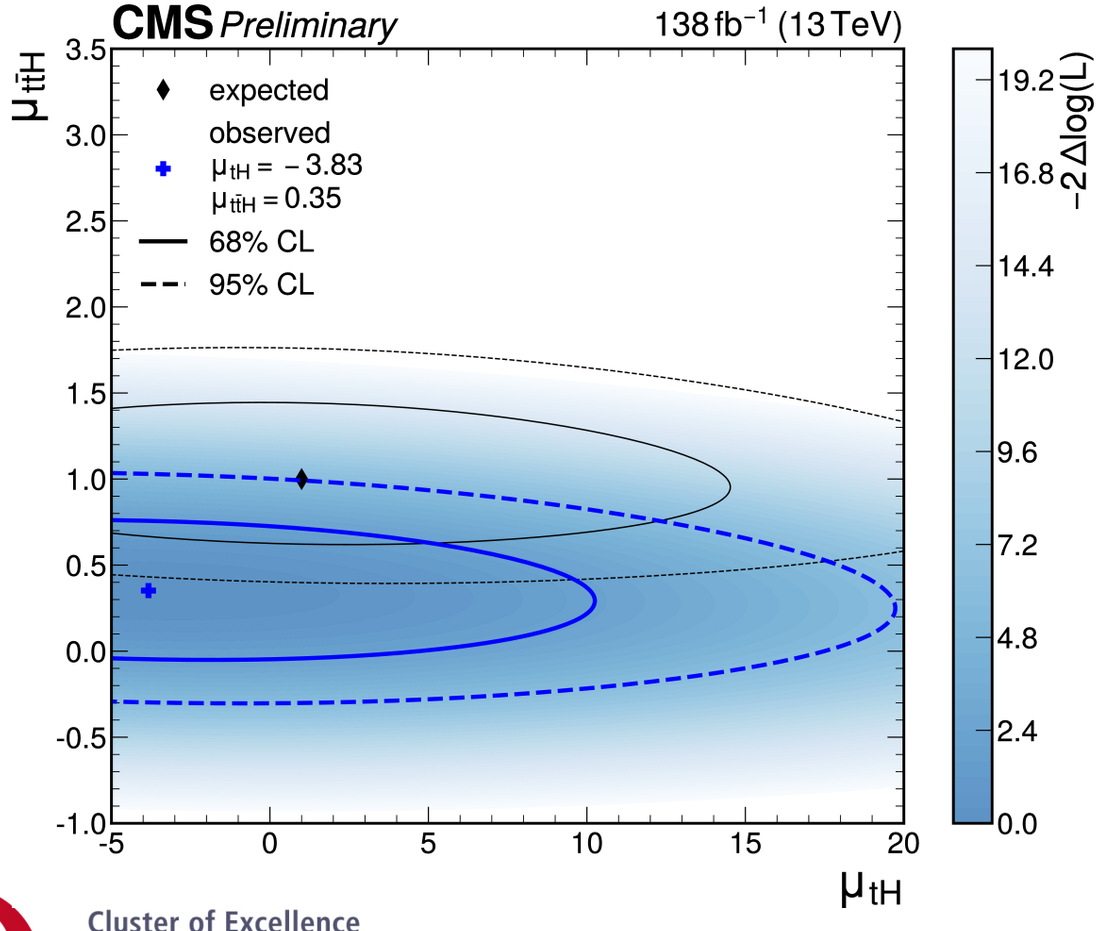
Coupling measurement

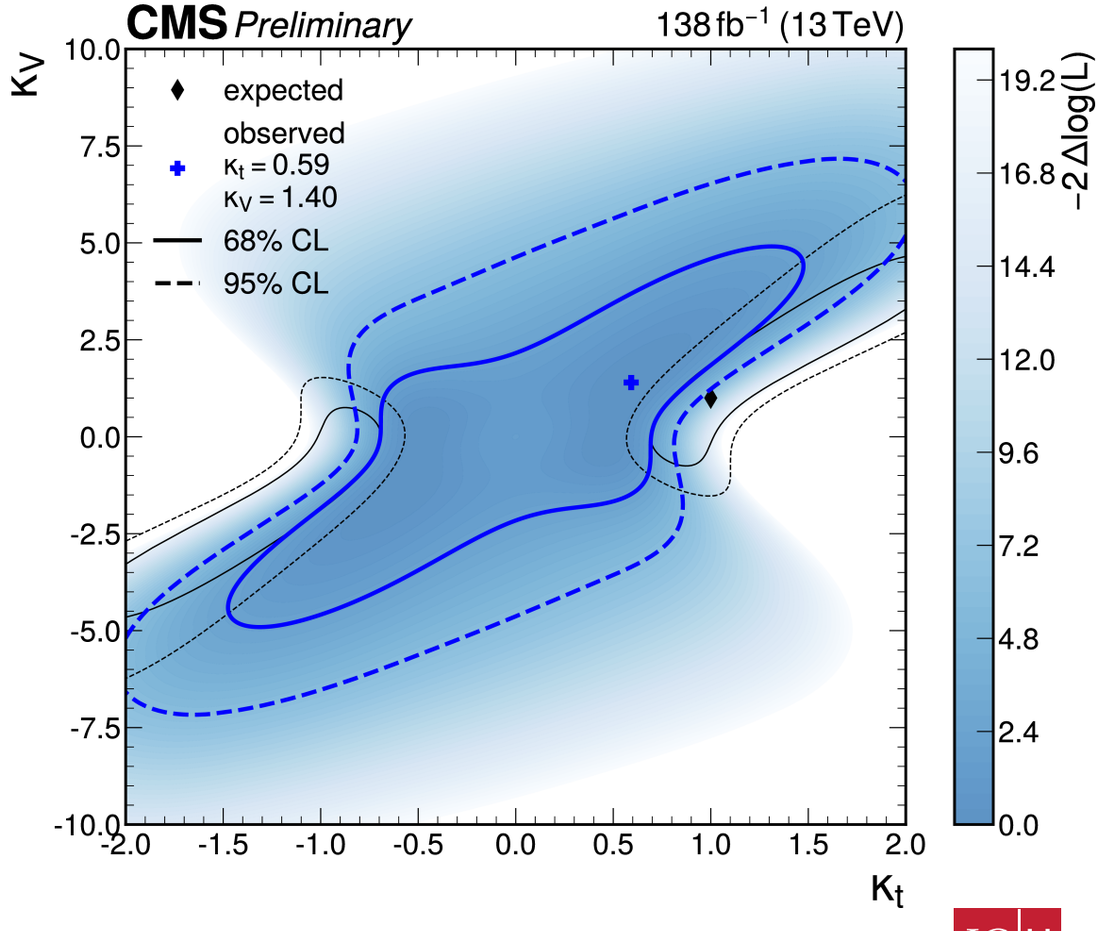
Assuming SM Higgs boson coupling structure

$$\sigma_{tHq} = \left(2.63 \cdot \kappa_t^2 + 3.58 \cdot \kappa_V^2 - 5.21 \cdot \kappa_t \kappa_V\right) \sigma_{tHq}^{SM},$$

$$\sigma_{tHW} = \left(2.91 \cdot \kappa_t^2 + 2.40 \cdot \kappa_V^2 - 4.22 \cdot \kappa_t \kappa_V\right) \sigma_{tHW}^{SM}.$$

Simultaneous fit





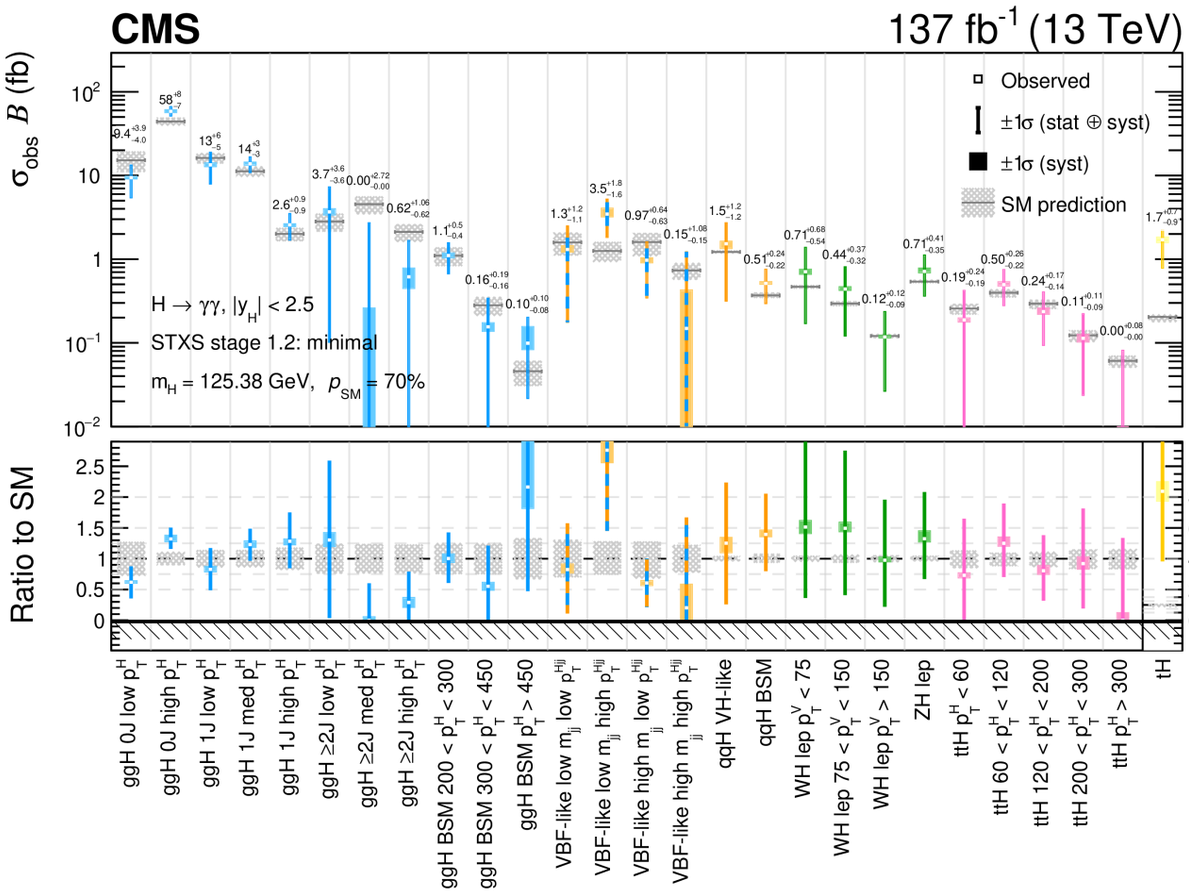
H→γγ

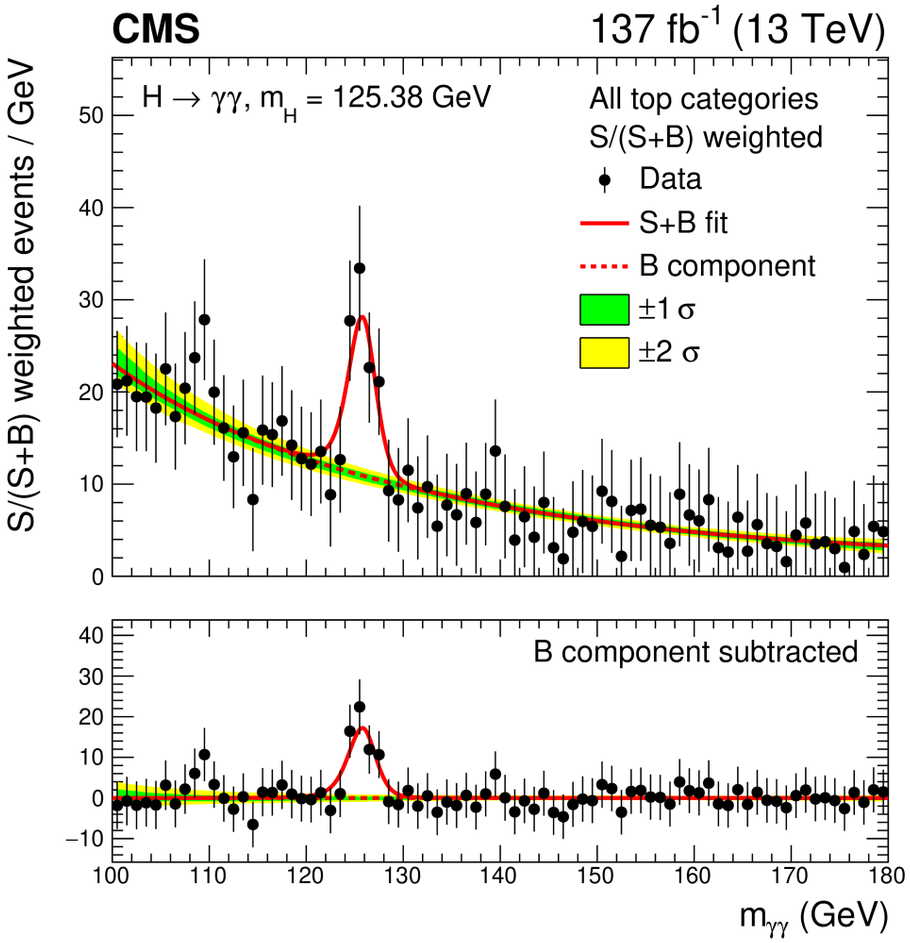
Same decay channel, several production processes

First differential measurement of tt̄H

BDT to distinguish top-associated production from other sources

DNN to separate tH from tt̄H





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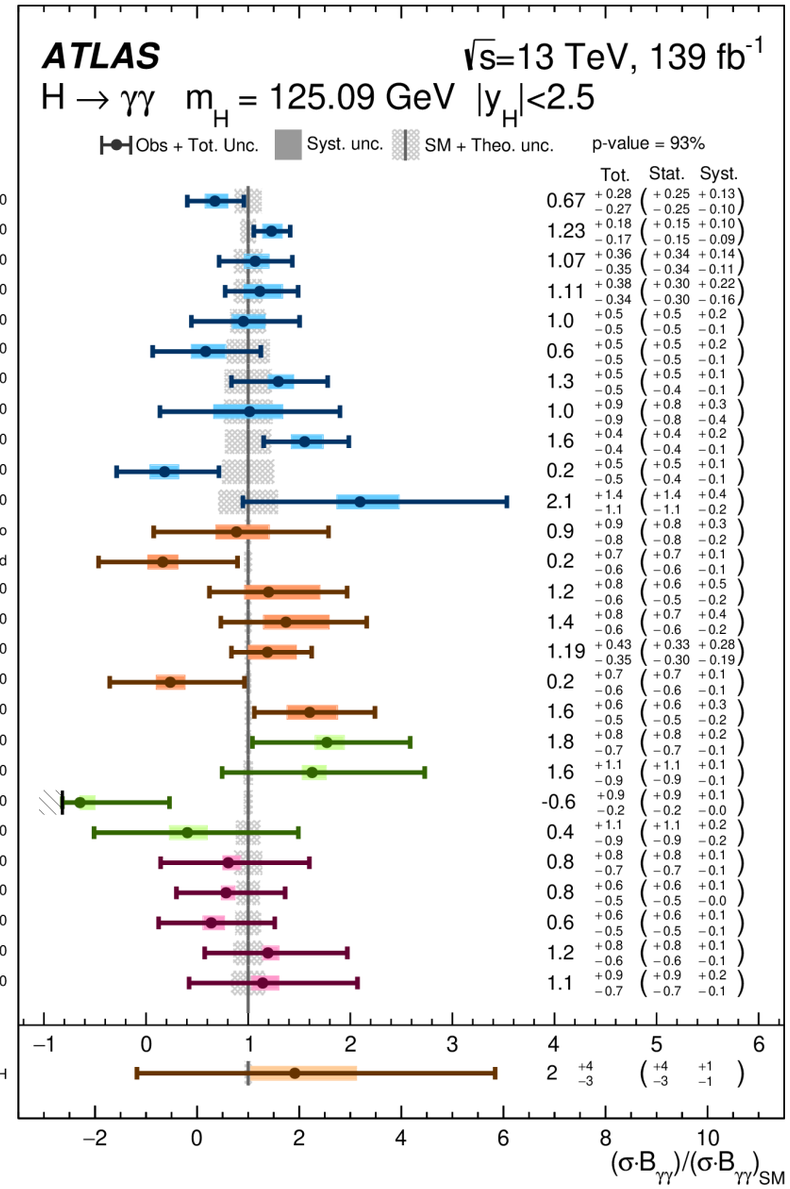
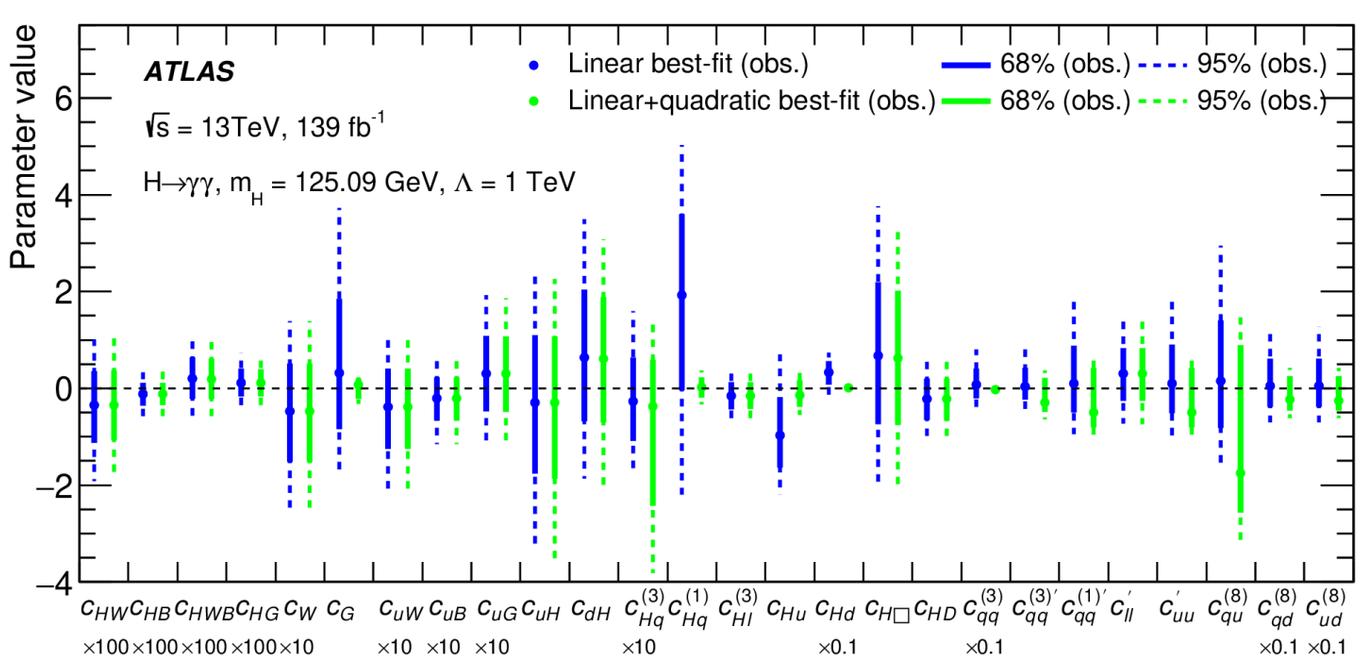
H→γγ

Multiclass BDT plus binary BDTs within top-associated production categories

SMEFT interpretation additionally to κ-framework

All results in agreement with SM expectations





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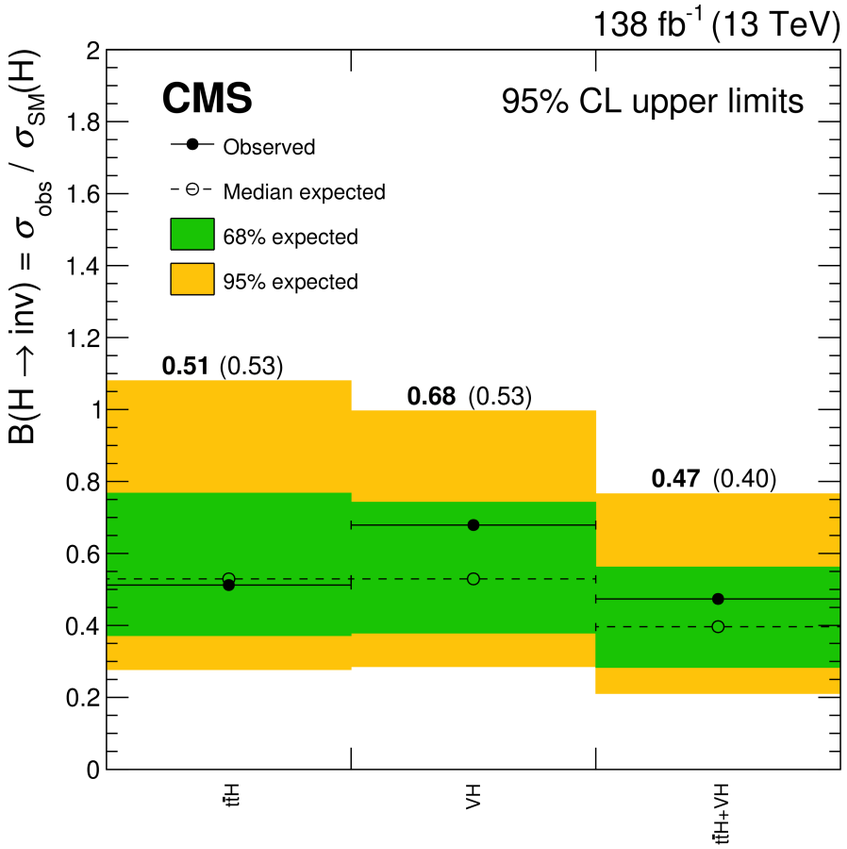
H→invisible

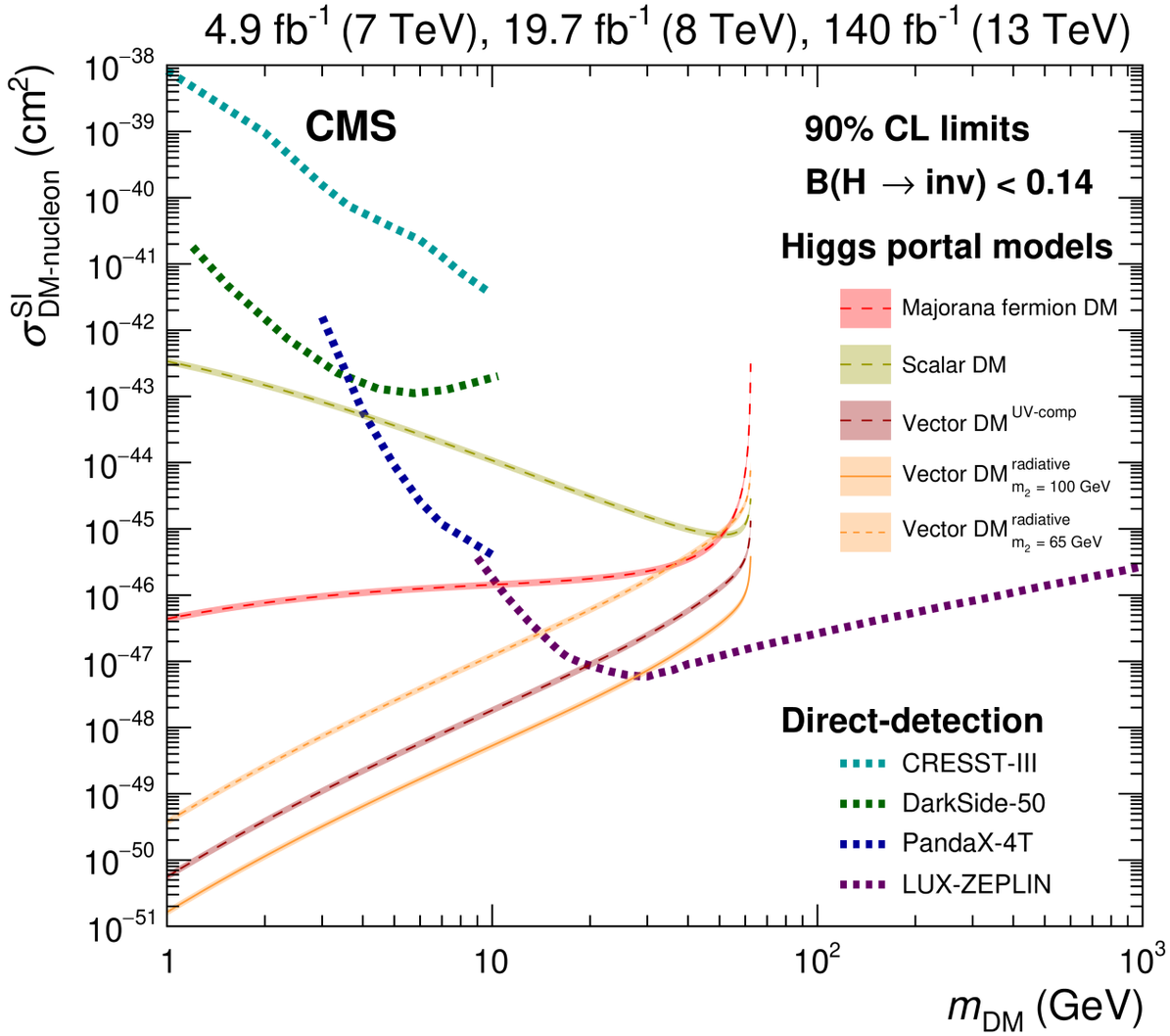
arXiv:2303.01214

Search in $t\bar{t}H$ and VH

with fully hadronic decay of the top-pair or associated vector boson

Control regions for background estimate include leptons or photons





Combination with Run 1 and other channels

CP structure

Search for an admixture of a CP-odd component in the top-Higgs coupling

Expressed as a coupling modifier $\tilde{\kappa}_t$ or κ'_t and a mixing angle α

Sensitive variables are e.g. relative directions of the top quarks

$$\mathcal{L}_{t\bar{t}H} = -\kappa'_t y_t \phi \bar{\psi}_t (\cos\alpha + i\gamma_5 \sin\alpha)\psi_t$$

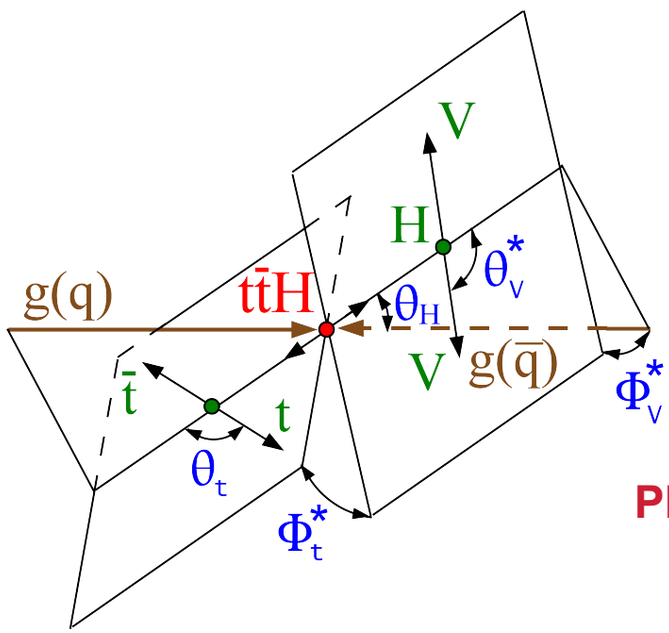
$$\mathcal{L}_{t\bar{t}H} = \frac{m_t}{v}\bar{\psi}_t (\kappa_t + i\gamma_5 \tilde{\kappa}_t)\psi_t H$$

$$b_2 = \frac{(\vec{p}_1 \times \hat{z}) \cdot (\vec{p}_2 \times \hat{z})}{|\vec{p}_1||\vec{p}_2|}, \quad \text{and} \quad b_4 = \frac{(\vec{p}_1 \cdot \hat{z})(\vec{p}_2 \cdot \hat{z})}{|\vec{p}_1||\vec{p}_2|}$$

$$\cos\alpha = \frac{\kappa_t}{\sqrt{\tilde{\kappa}_t^2 + \kappa_t^2}}$$

arXiv:2303.05974

CMS-PAS-HIG-19-011



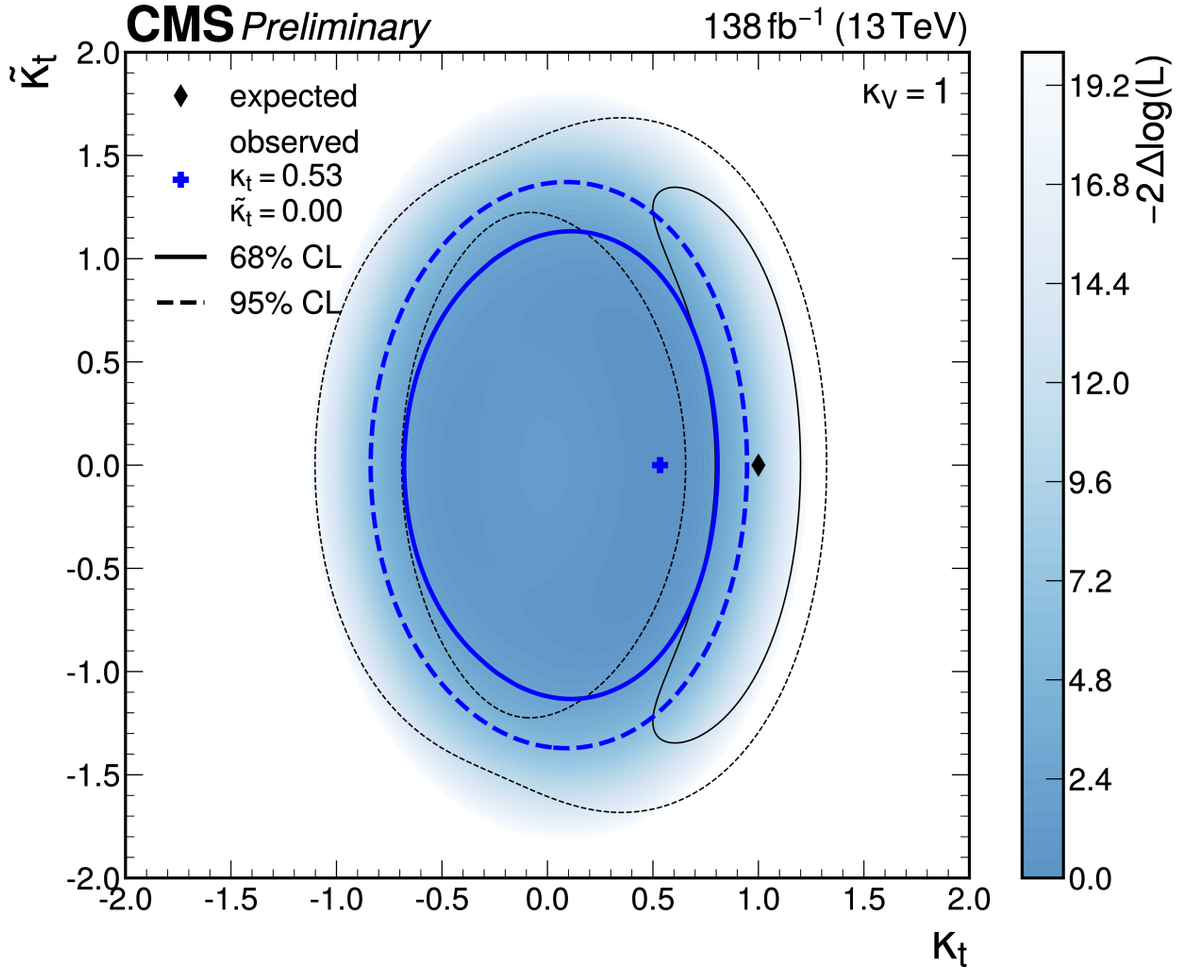
Phys. Rev. D 104 (2021) 052004

$H \to b\bar{b}$

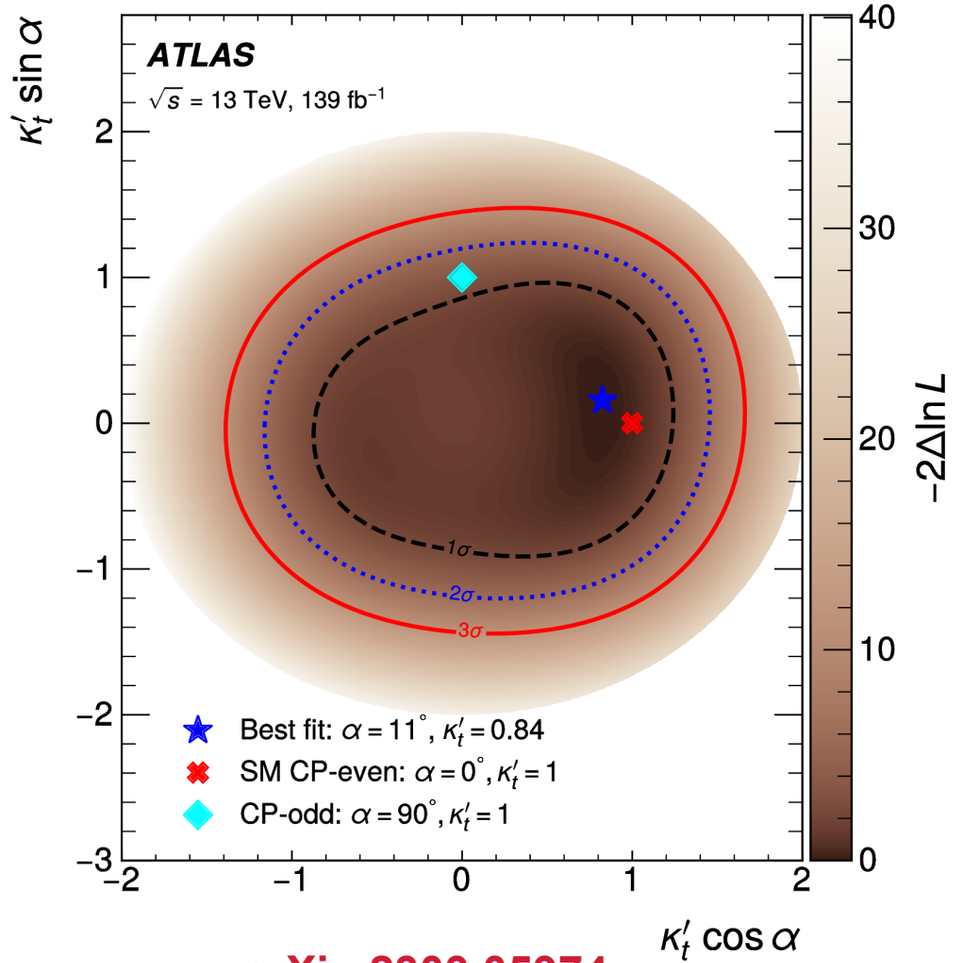
Dedicated ATLAS result with 1 or 2 leptons

CMS result with same selection as cross section measurement, only leptonic channels

Results compatible with pure CP-even coupling structure



CMS-PAS-HIG-19-011

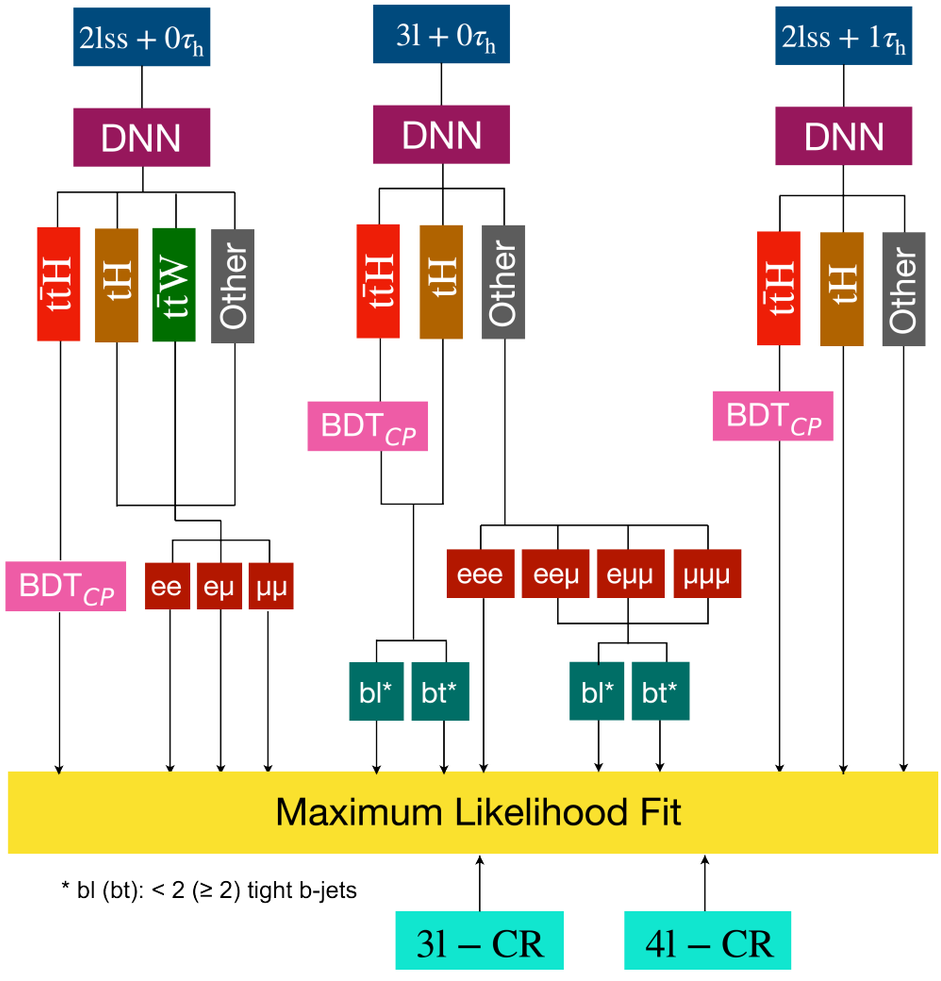


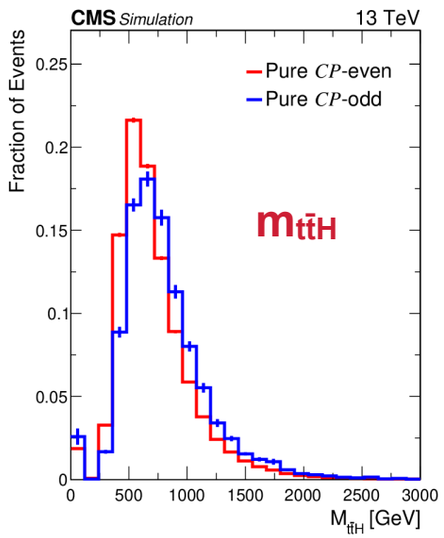
arXiv:2303.05974

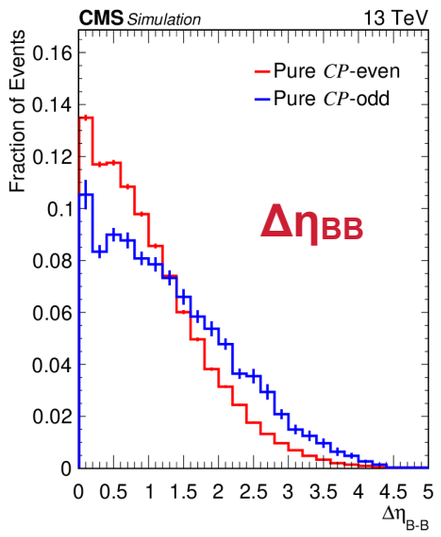
H→ττ or H→WW

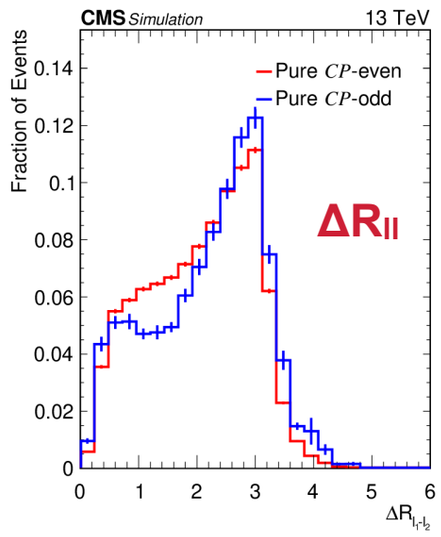
Dedicated multilepton analysis

Results compatible with pure CP-even coupling structure



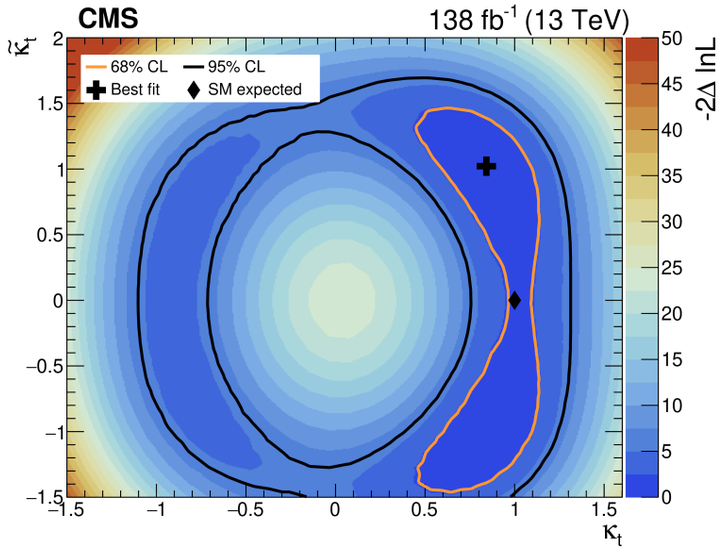




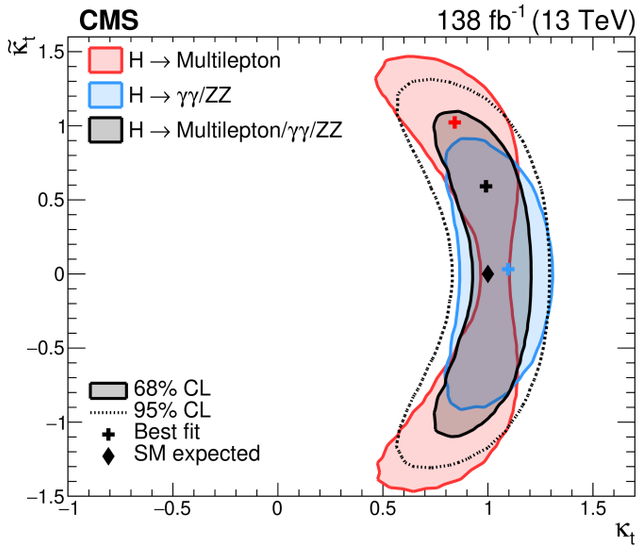


Input variables to CP BDT

Multilepton fit



Combined fit



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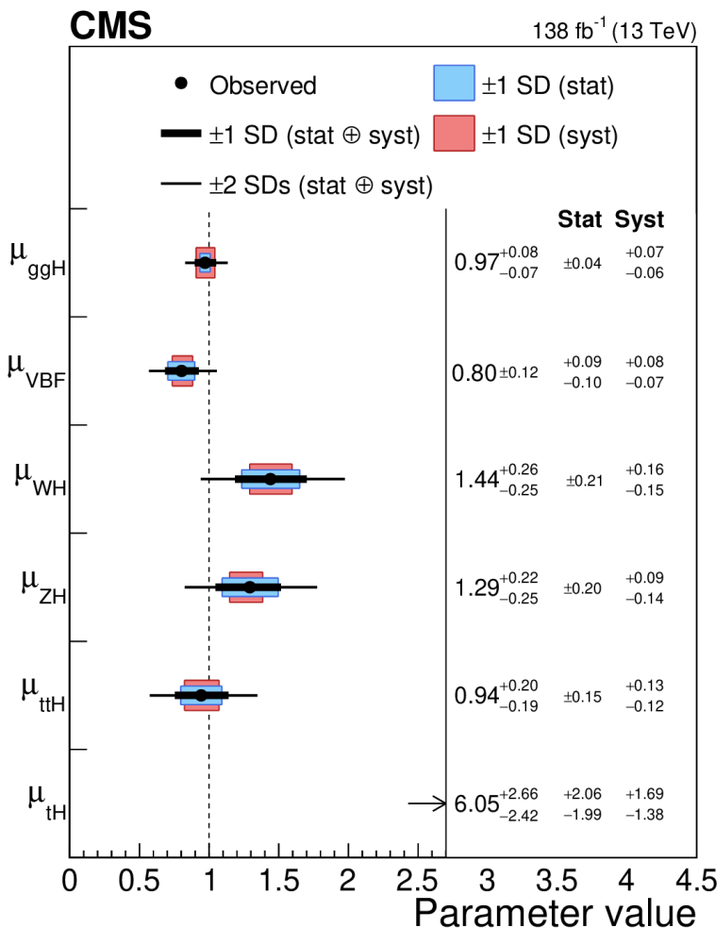
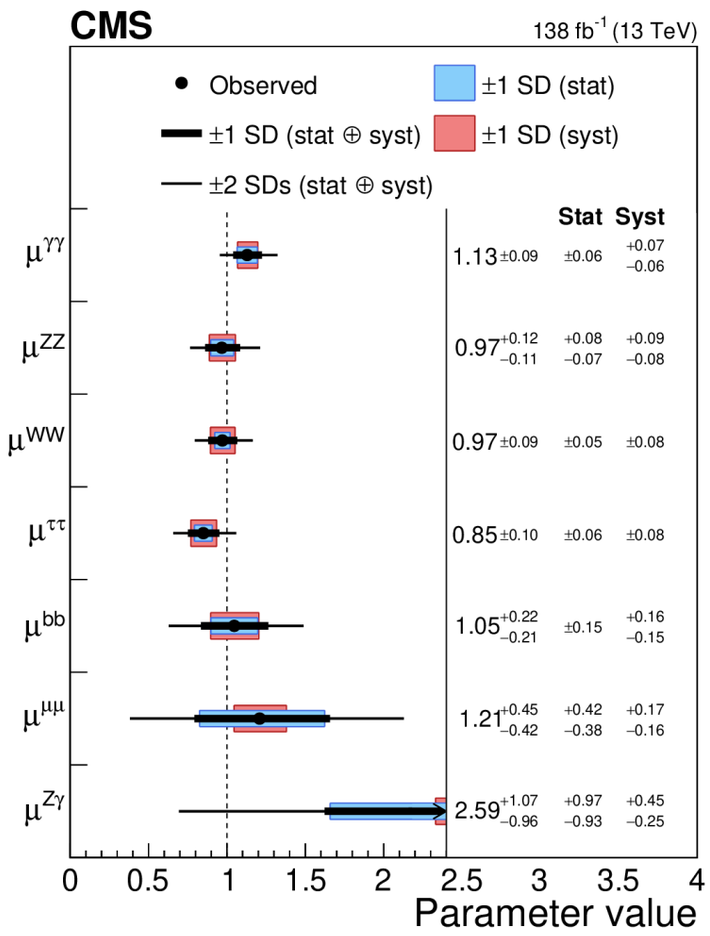
Summary

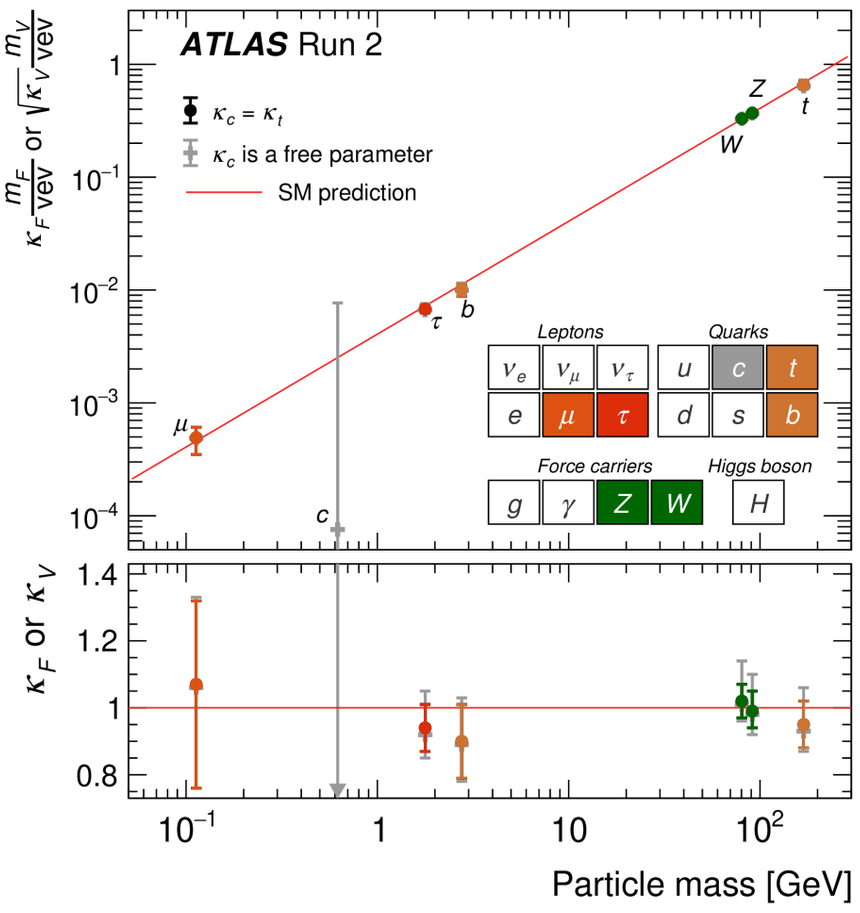
- $t\bar{t}H$ and tH
  - Allow for a precise study of the top-Higgs coupling
  - Inclusive and differential cross section measurements compatible with SM predictions
    - In $t\bar{t}H(b\bar{b})$ ATLAS and CMS measure similar $\mu_{t\bar{t}H}$, <2.4σ below SM expectation
  - Heavily using machine learning techniques
    - Better understanding of background necessary to exploit upcoming high statistics datasets
- CP structure of the top-Higgs coupling
  - Has impact on several kinematic distributions
  - Searches for admixture of CP-odd component, expressed as mixing angle or fraction
  - All results compatible with SM prediction

Additional material

10 years Higgs boson







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$t\bar{t}H$, $H \to b\bar{b}$

ATLAS EXPERIMENT

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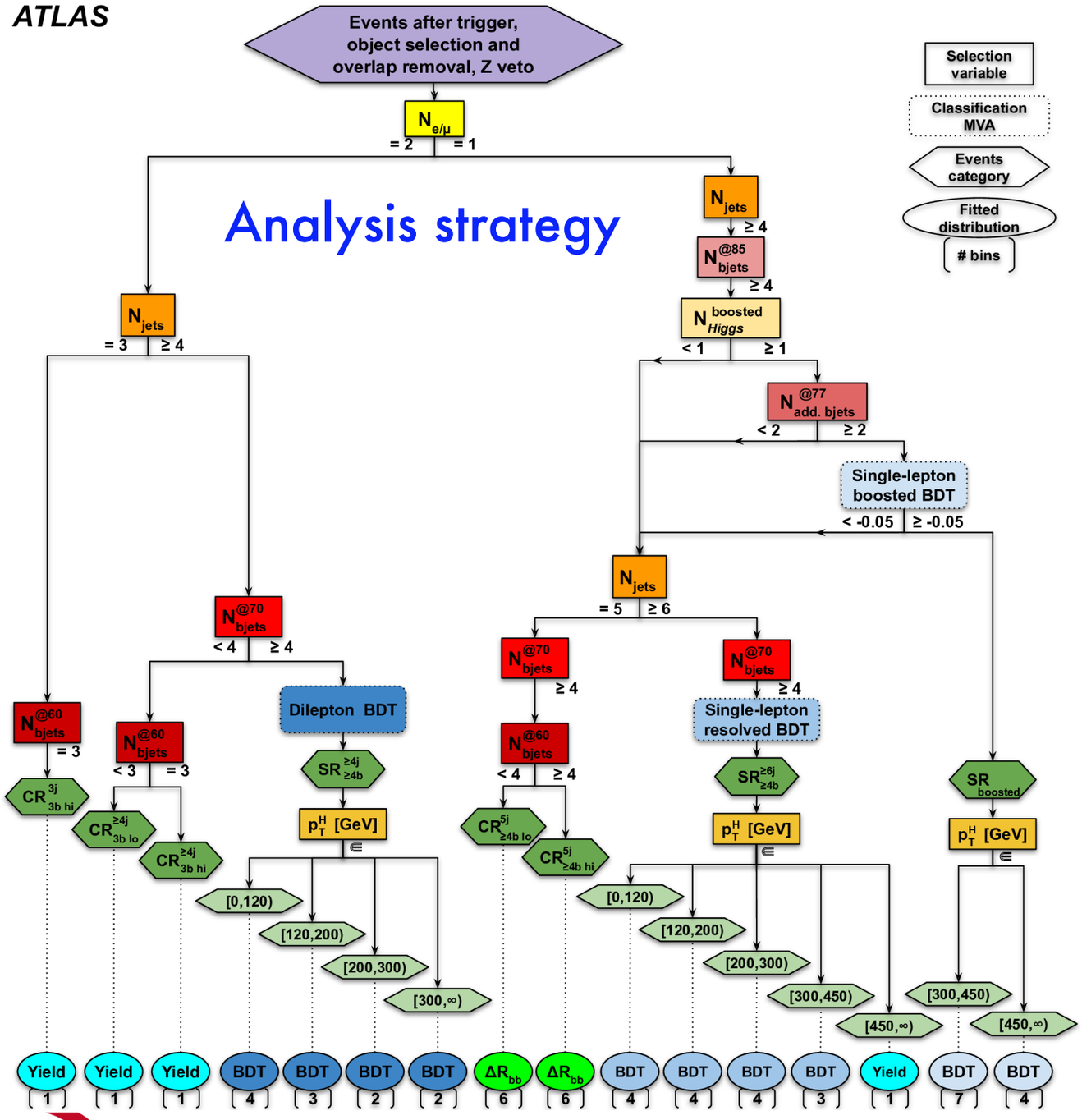
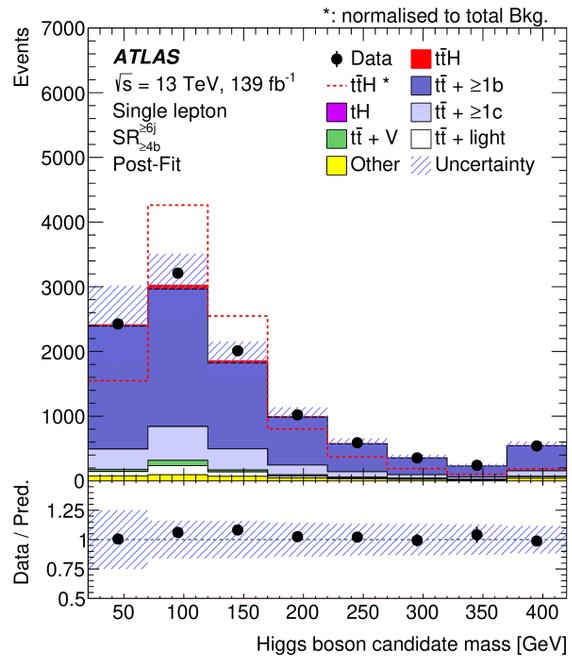
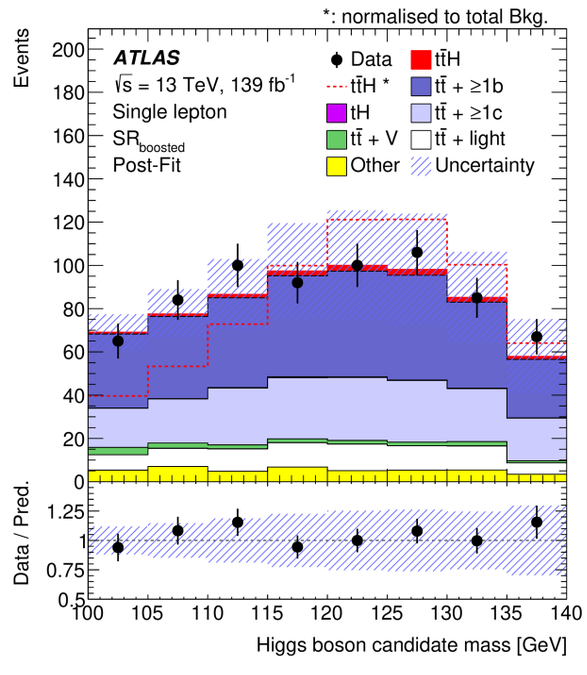
Analysis strategy

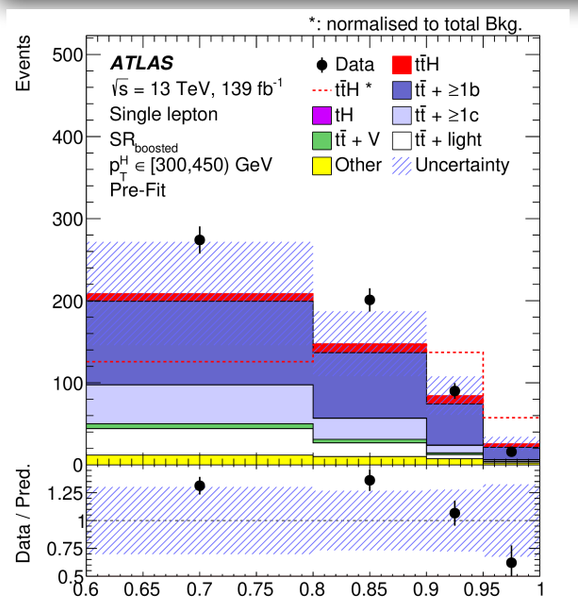


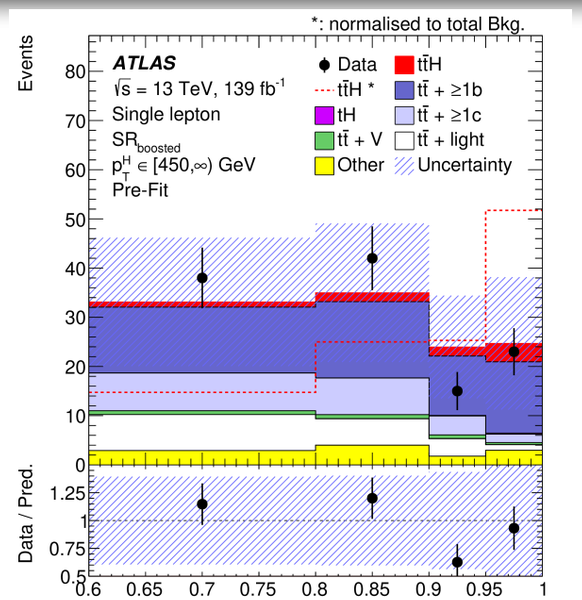


Mass distributions



$t\bar{t}H$, $H \to b\bar{b}$

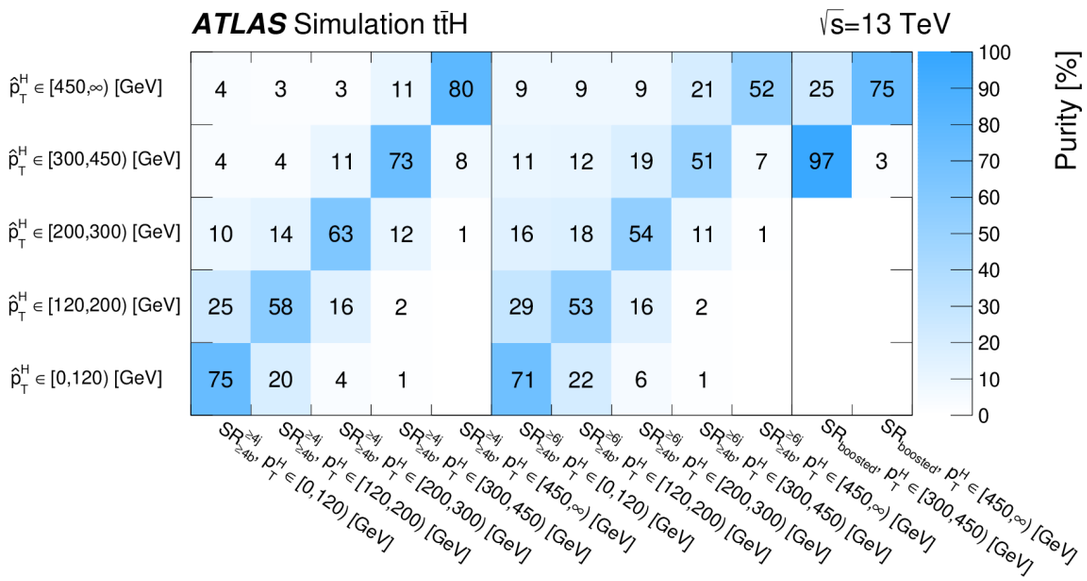




Higgs candidate DNN-tagger P(H)

Higgs candidate DNN-tagger P(H)

Boosted Higgs DNN tagger output



Migration matrix

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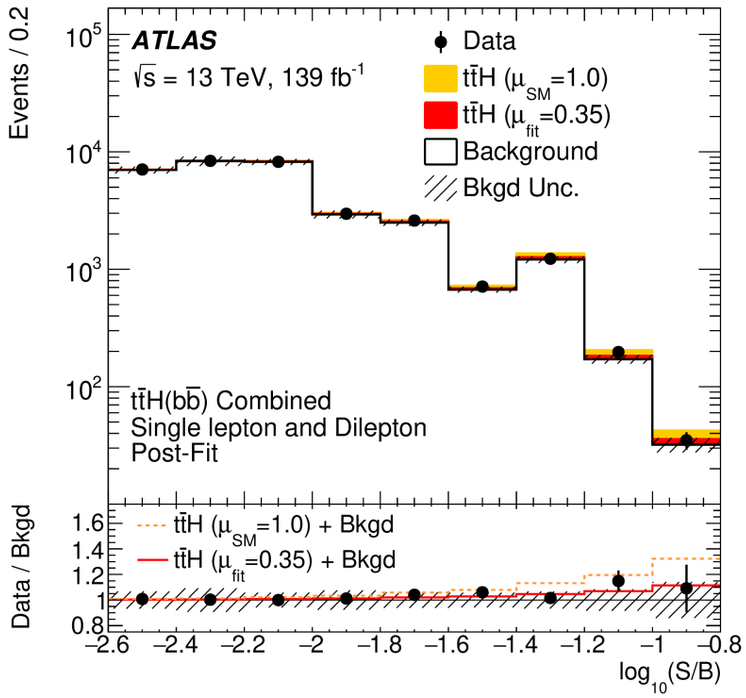
Uncertainty source	Description		Components
$t\bar{t}$ cross-section	±6%		$t\bar{t}+$light
$t\bar{t}+\geq1b$ normalisation	Free-floating		$t\bar{t}+\geq1b$
$t\bar{t}+\geq1c$ normalisation	±100%		$t\bar{t}+\geq1c$
NLO matching	MadGraph5_aMC@NLO + Pythia 8 vs Powheg Box + Pythia 8		All
PS & hadronisation	Powheg Box + Herwig 7 vs Powheg Box + Pythia 8		All
ISR	Varying α_s^{ISR} (PS), μ_r & μ_f (ME)	in Powheg Box Res + Pythia 8	$t\bar{t}+\geq1b$
		in Powheg Box + Pythia 8	$t\bar{t}+\geq1c$, $t\bar{t}+$light
FSR	Varying α_s^{FSR} (PS)	in Powheg Box Res + Pythia 8	$t\bar{t}+\geq1b$
		in Powheg Box + Pythia 8	$t\bar{t}+\geq1c$, $t\bar{t}+$light
$t\bar{t}+\geq1b$ fractions	Powheg Box + Herwig 7 vs Powheg Box + Pythia 8		$t\bar{t}+1b$, $t\bar{t}+\geq2b$
p_T^{bb} shape	Shape mismodelling measured from data		$t\bar{t}+\geq1b$

$t\bar{t}$+jets uncertainties



log(S/B) distribution

$t\bar{t}H$, $H \to b\bar{b}$

ATLAS EXPERIMENT

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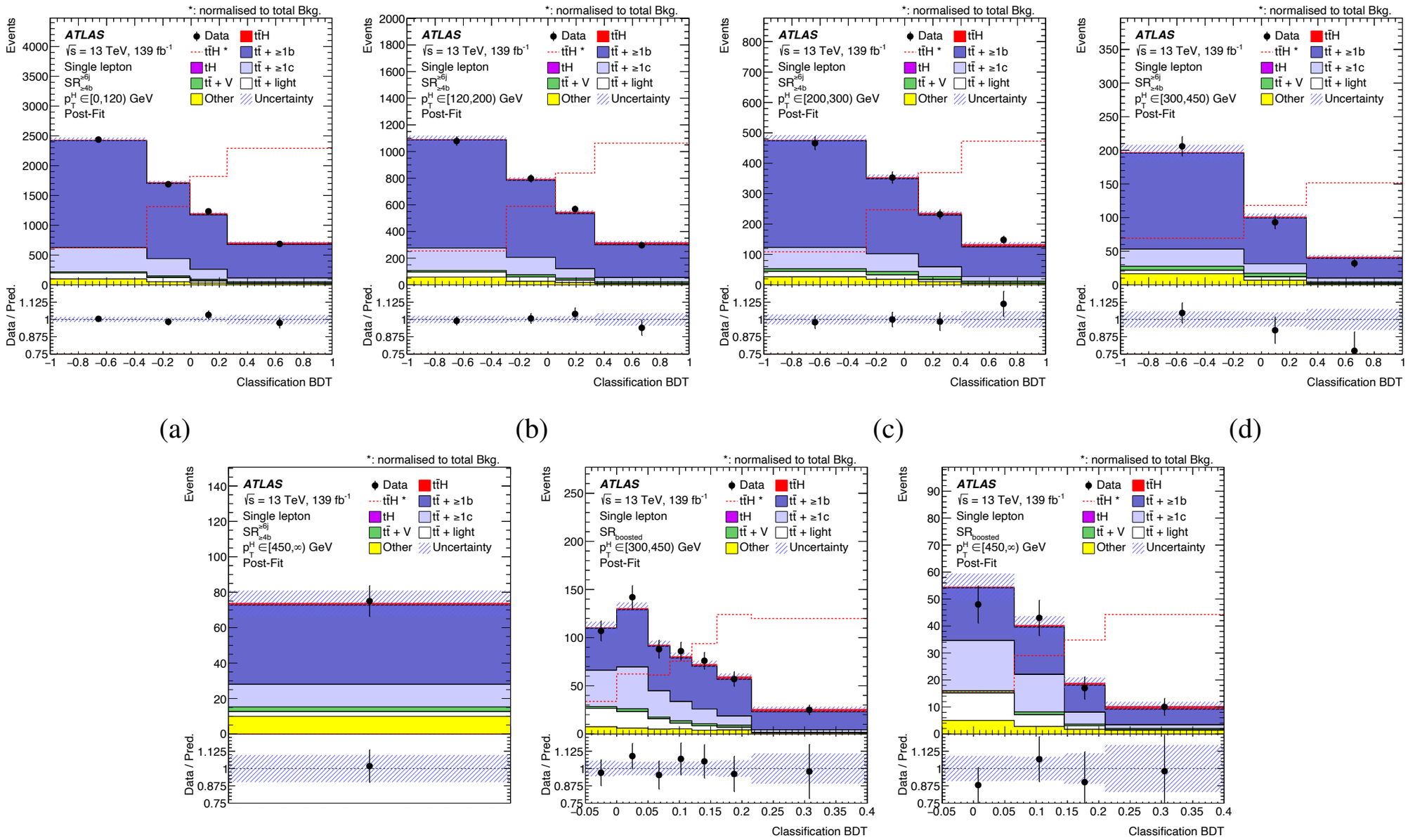
Fitted distributions single lepton SRs



$t\bar{t}H$, $H \to b\bar{b}$

ATLAS EXPERIMENT

Fitted distributions dilepton SRs and single lepton CRs

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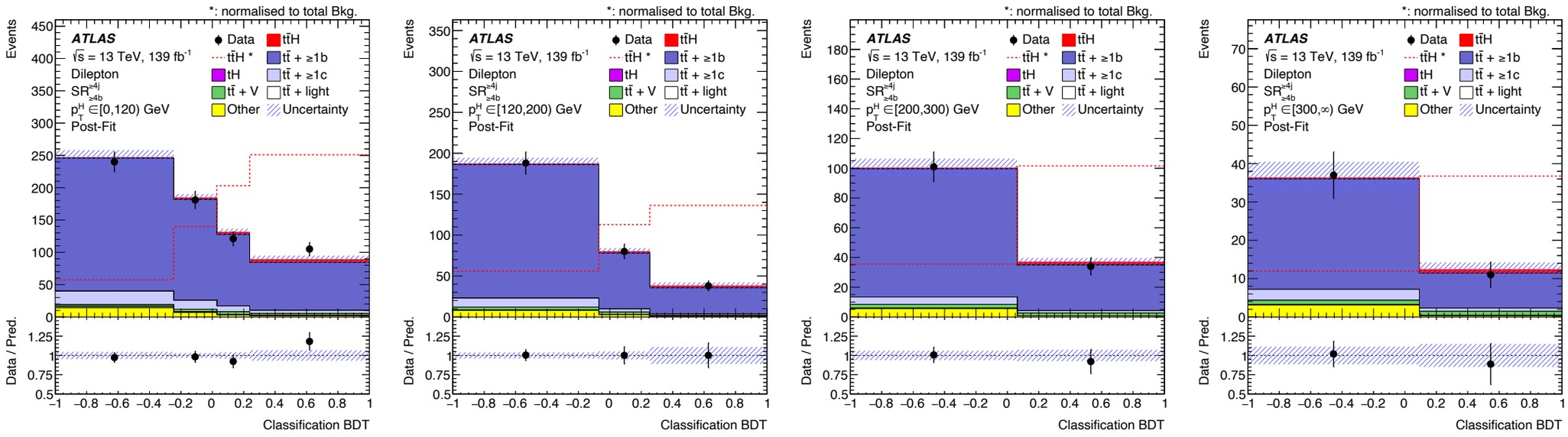
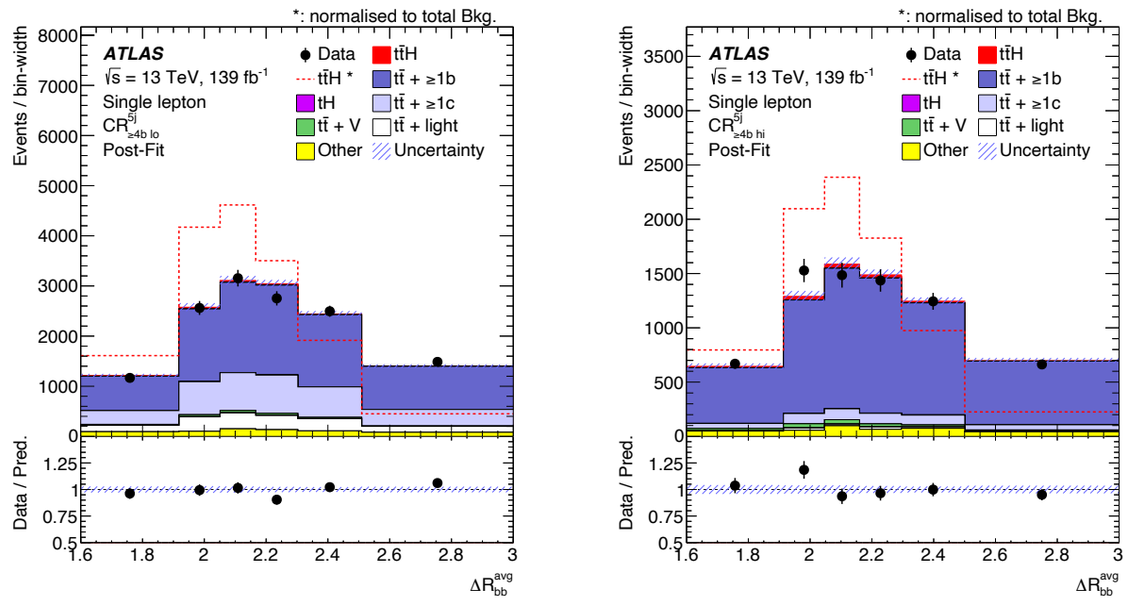


(a) (b) (c) (d)



(a) (b)

$t\bar{t}H$, $H \to b\bar{b}$

ATLAS EXPERIMENT

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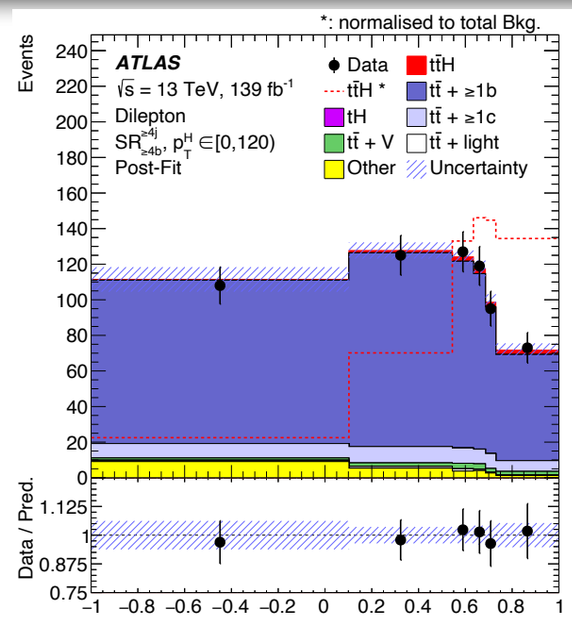
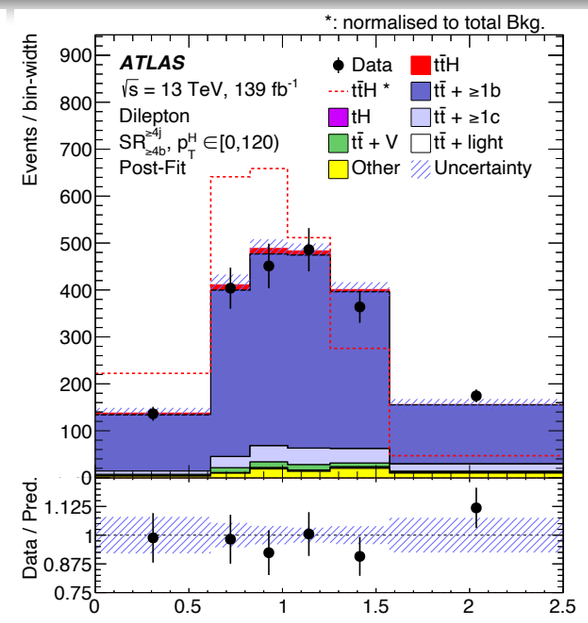
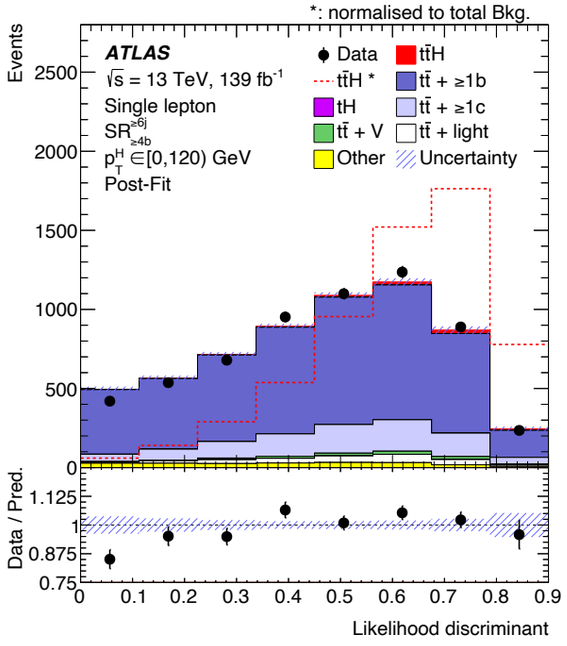
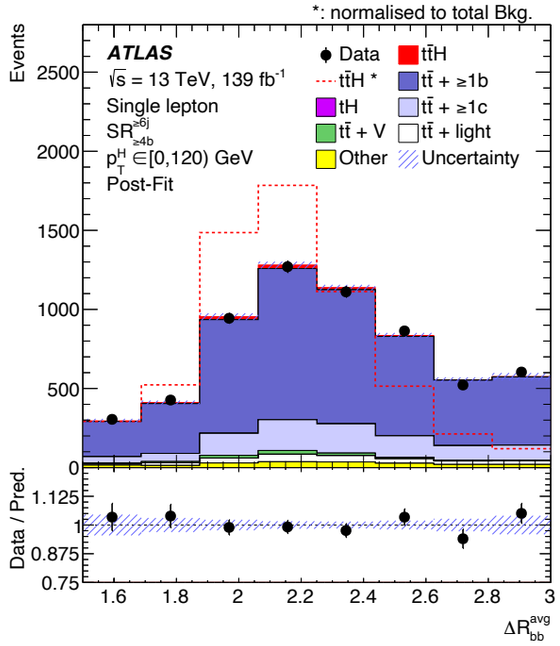
Data/MC comparisons

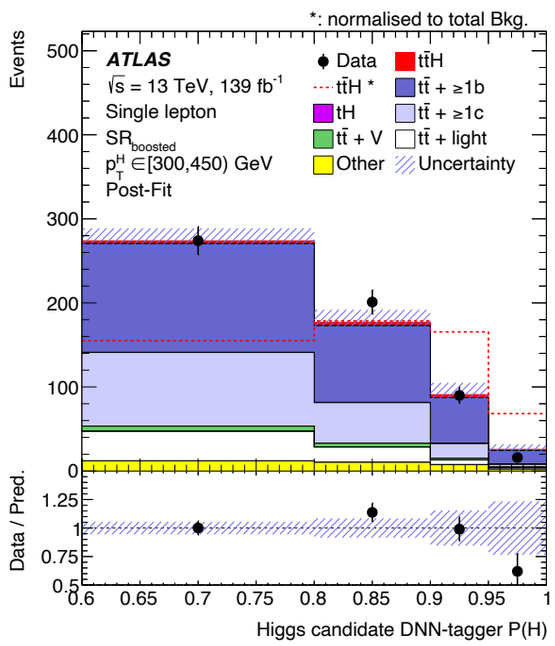


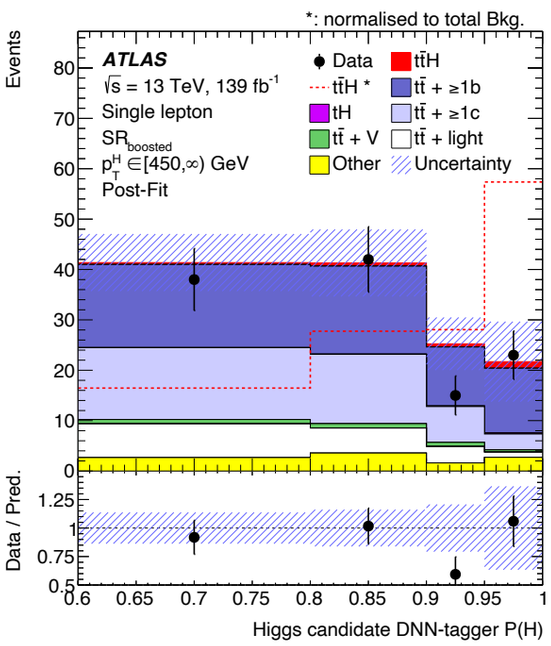


Reconstruction BDT









$t\bar{t}H$, $H \to b\bar{b}$

Jet multiplicities

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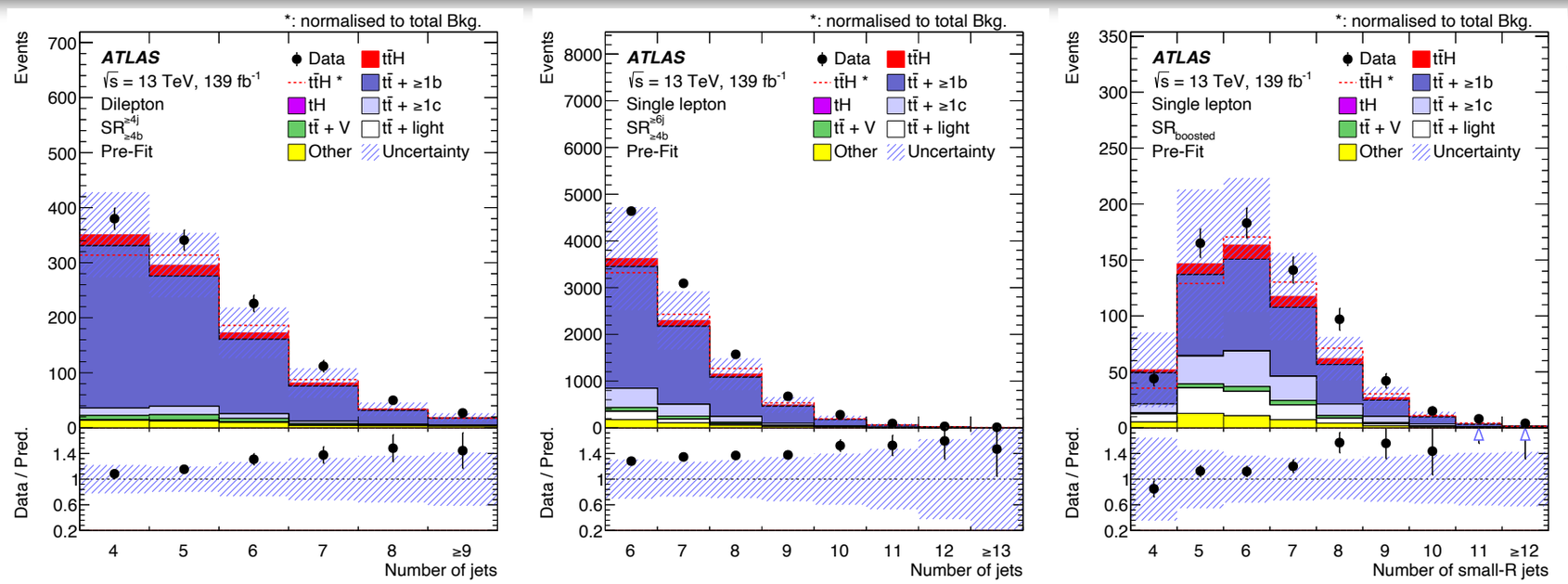
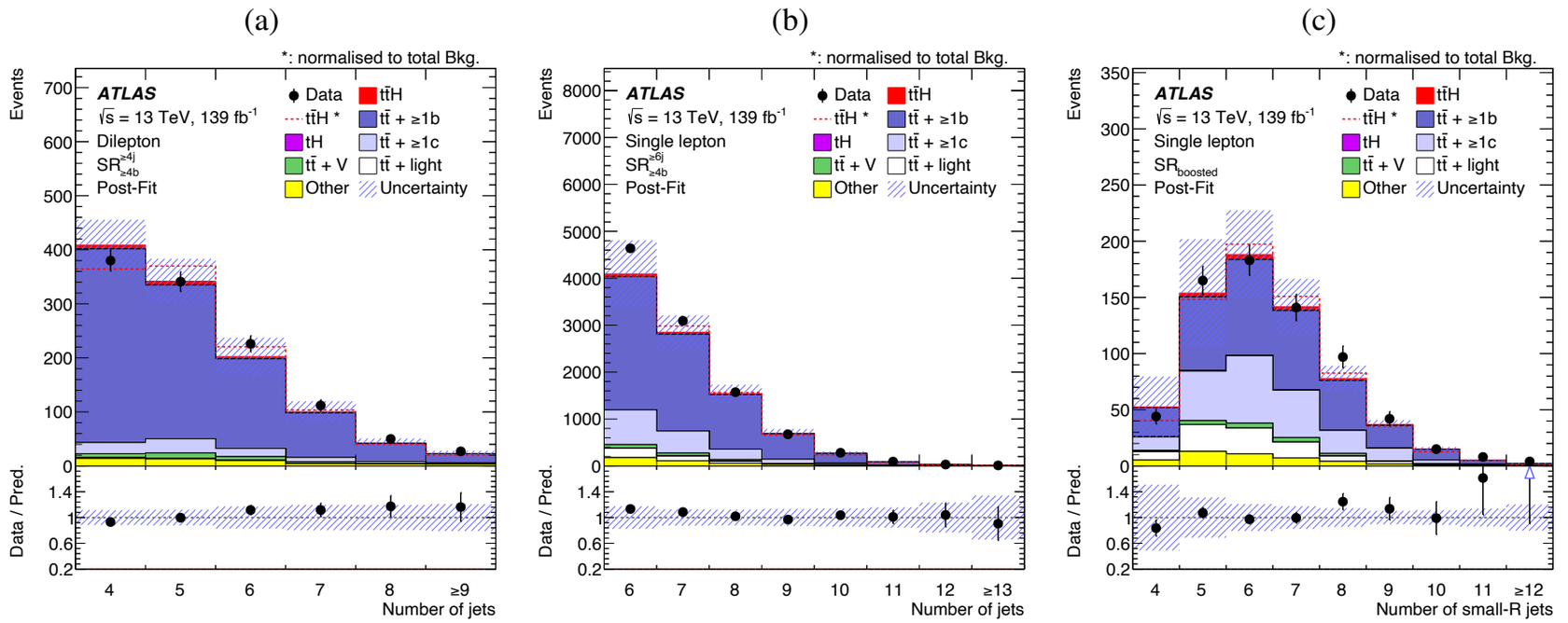
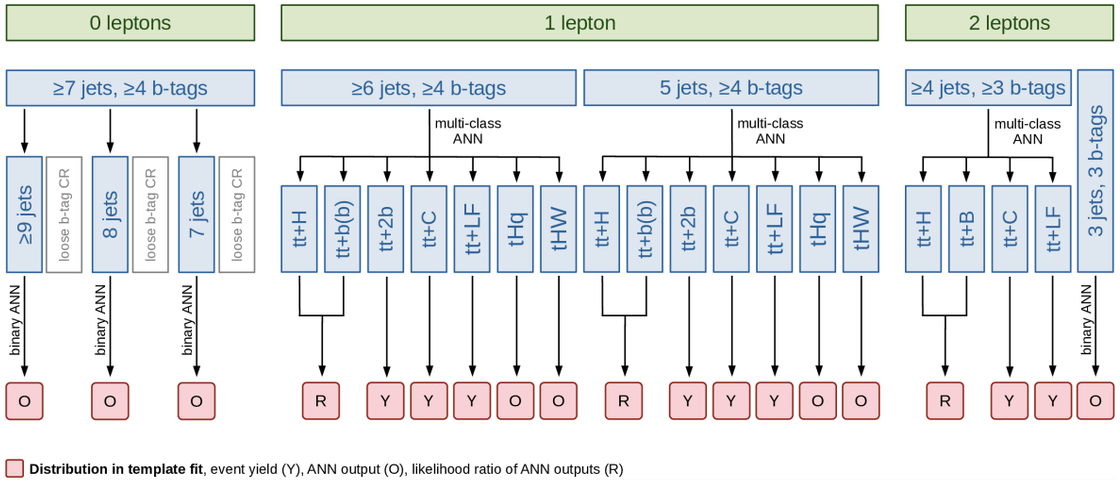




t(t̄)H, H→bb̄



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

Analysis strategy

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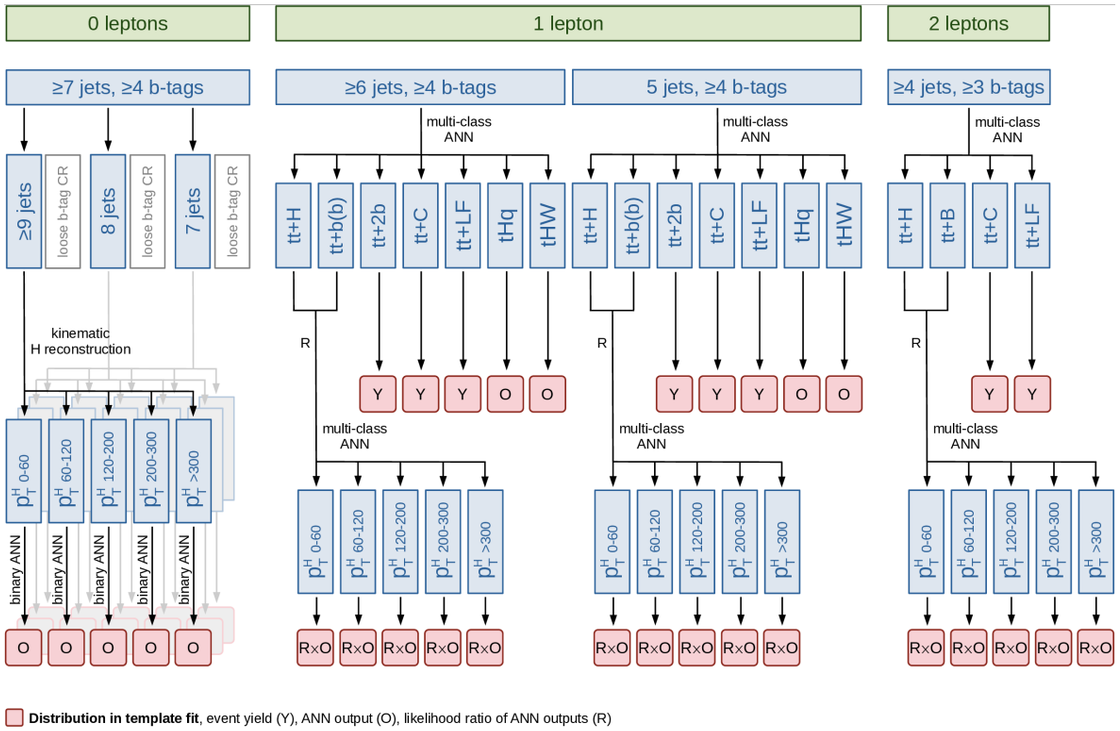
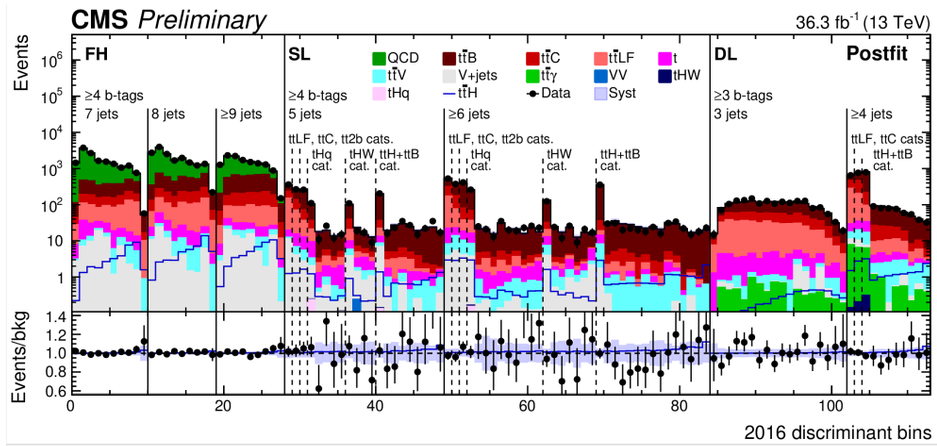
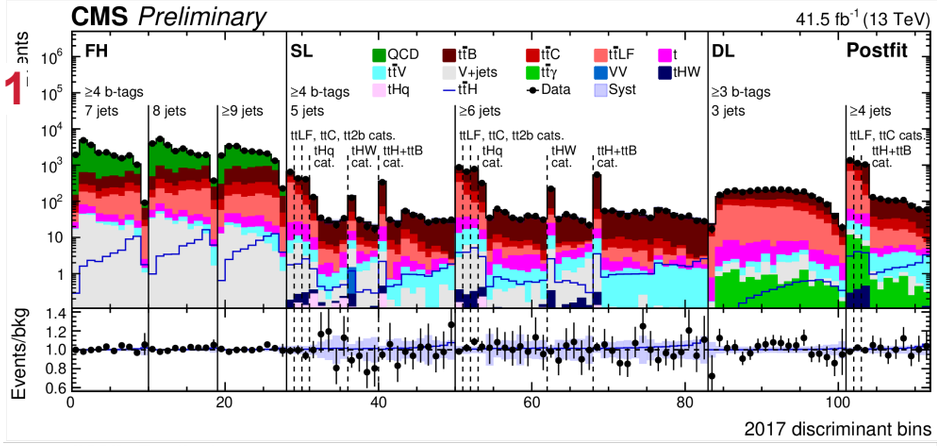
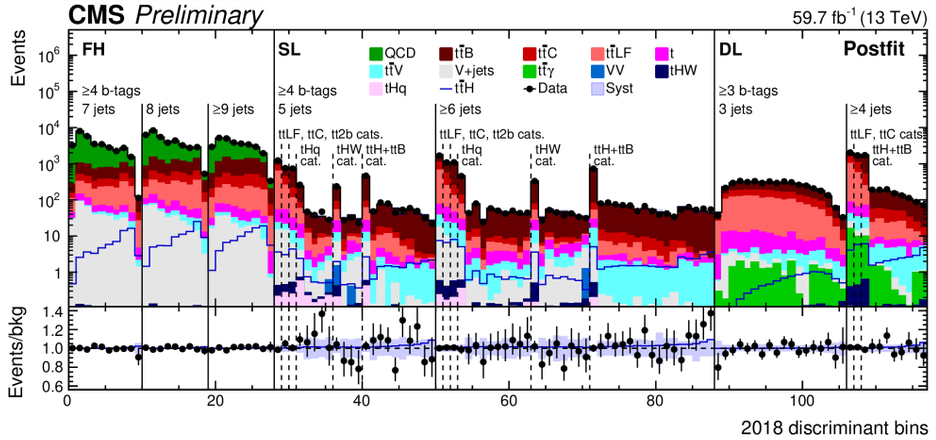


Distribution in template fit, event yield (Y), ANN output (O), likelihood ratio of ANN outputs (R)







$t\bar{t}H$, $H \to b\bar{b}$

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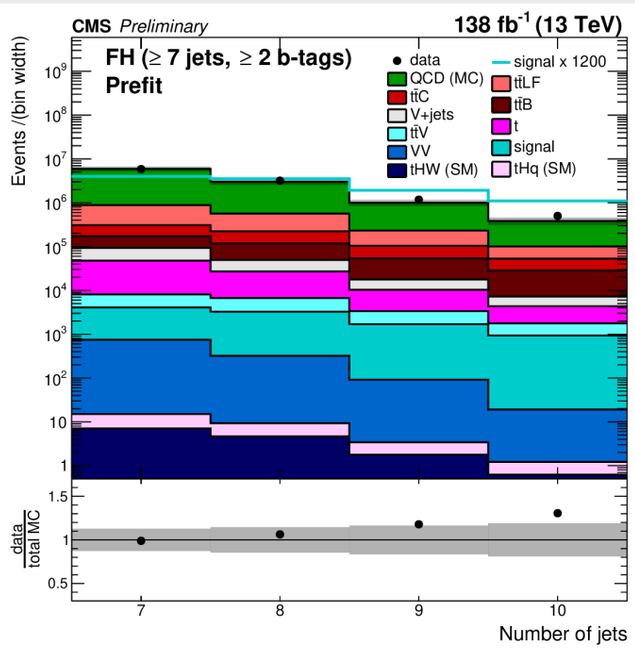
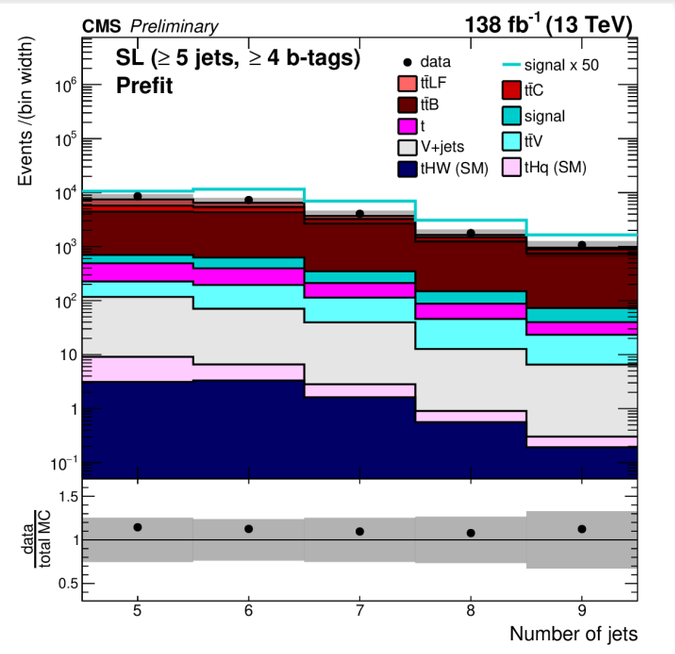
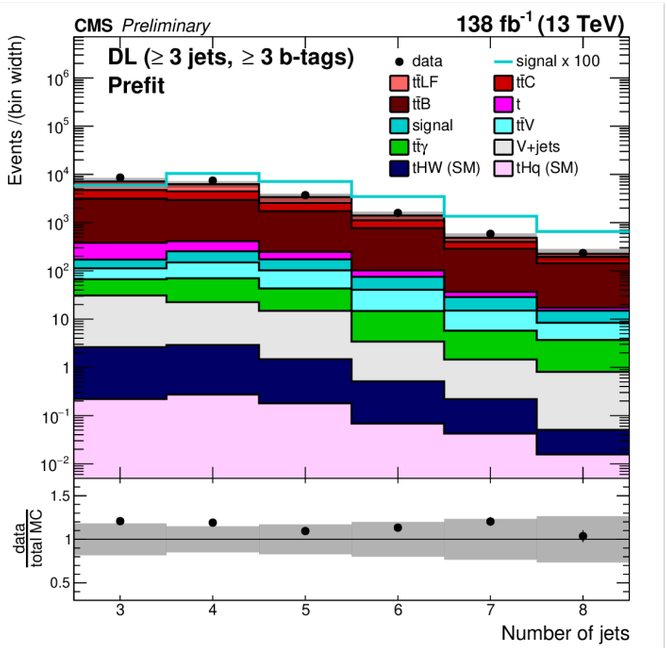




Jet multiplicities



$t\bar{t}H$, $H \to b\bar{b}$

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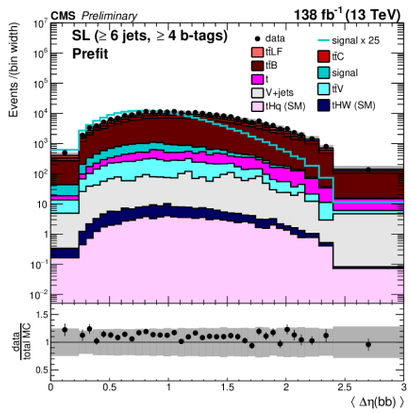
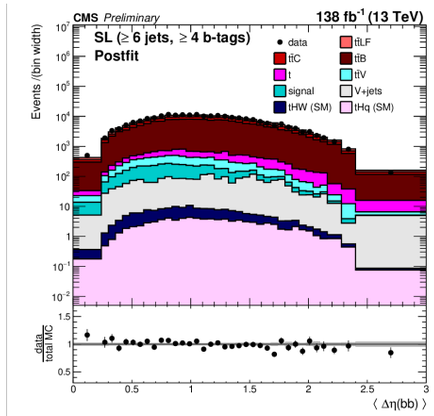
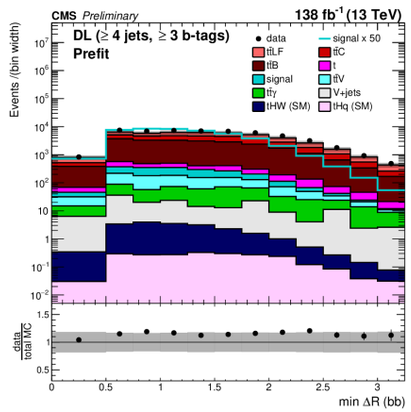
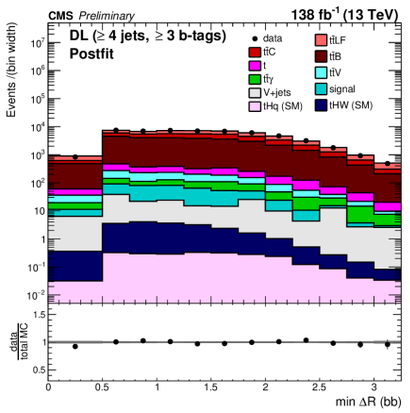
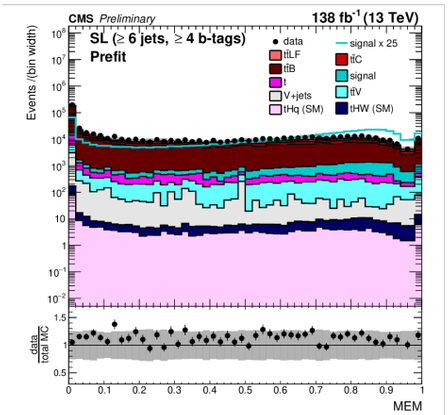
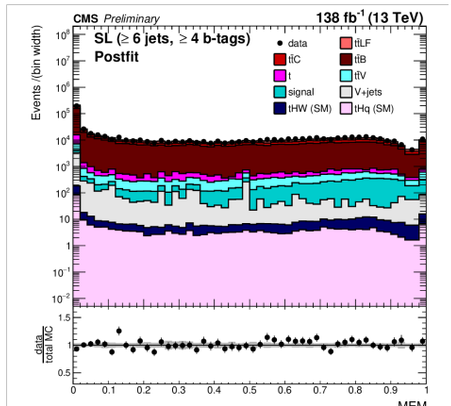


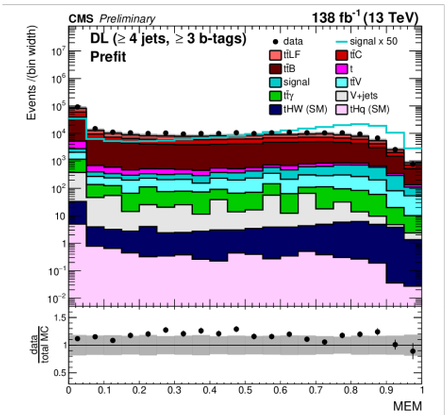


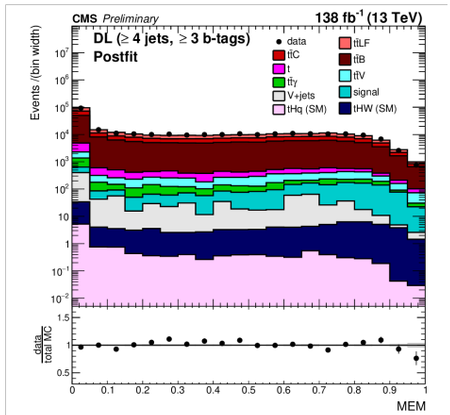


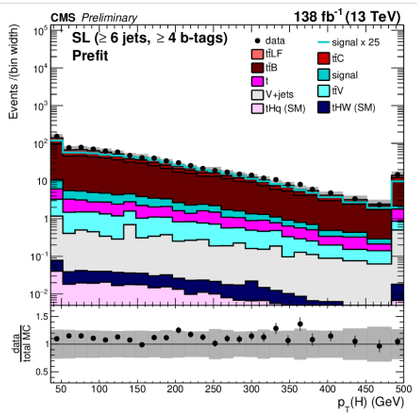


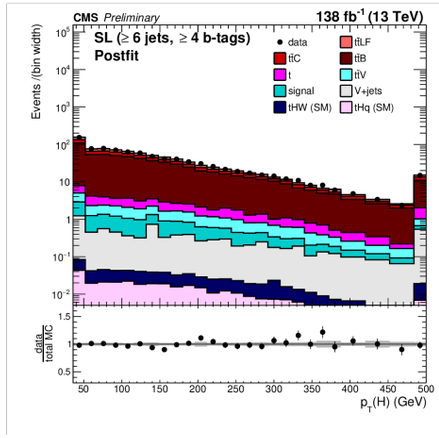


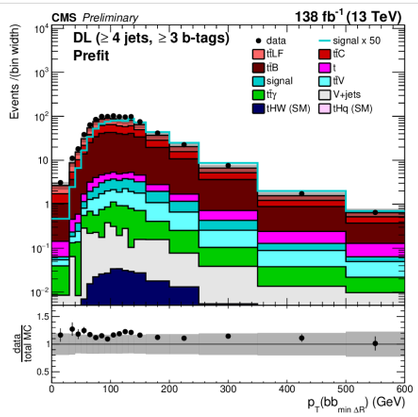


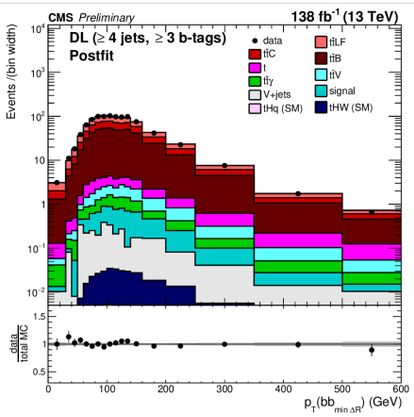








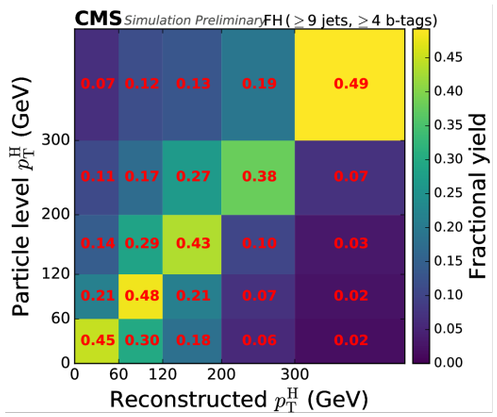


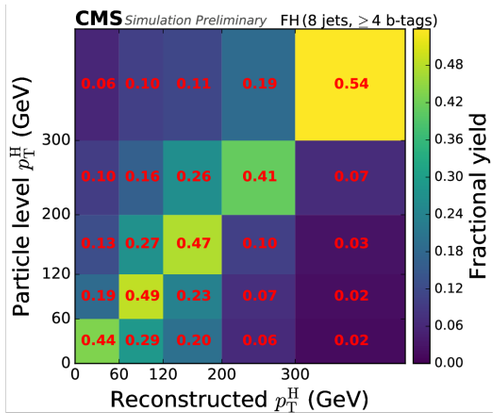


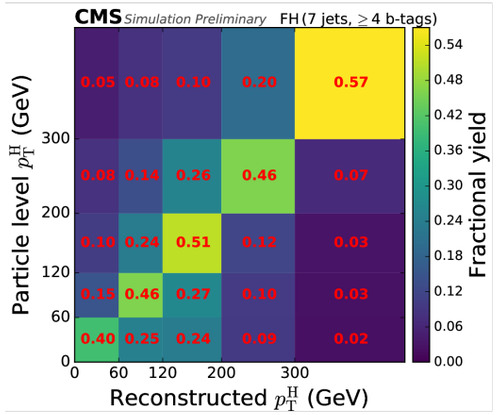
Data/MC comparisons

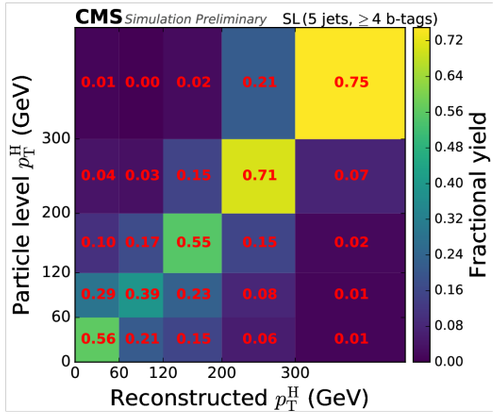
$t\bar{t}H$, $H \to b\bar{b}$

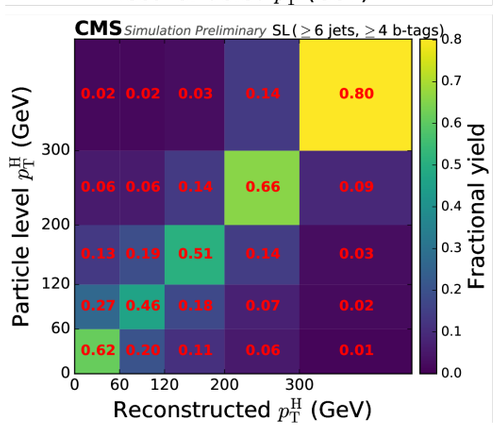
Categorisation efficiency

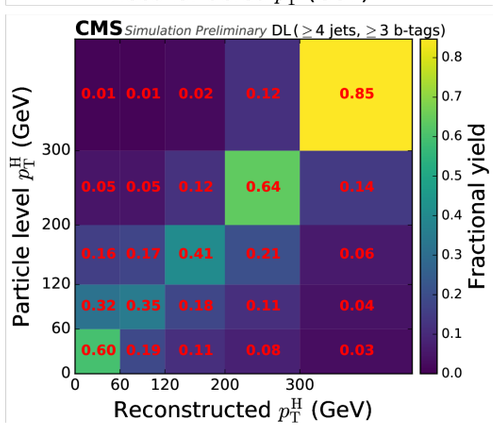




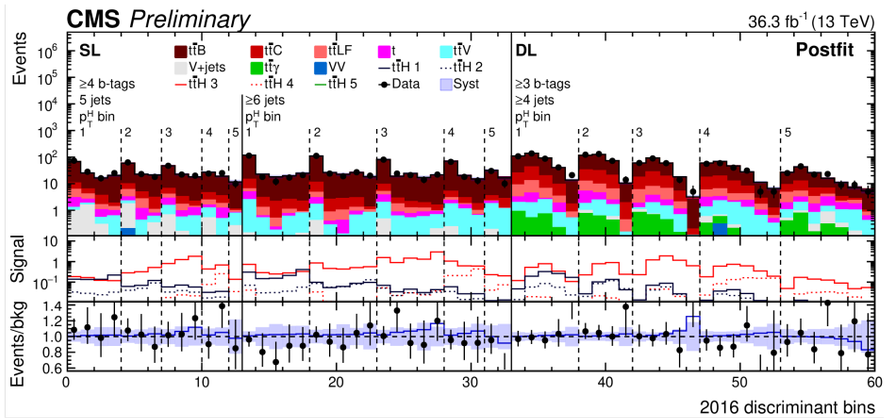


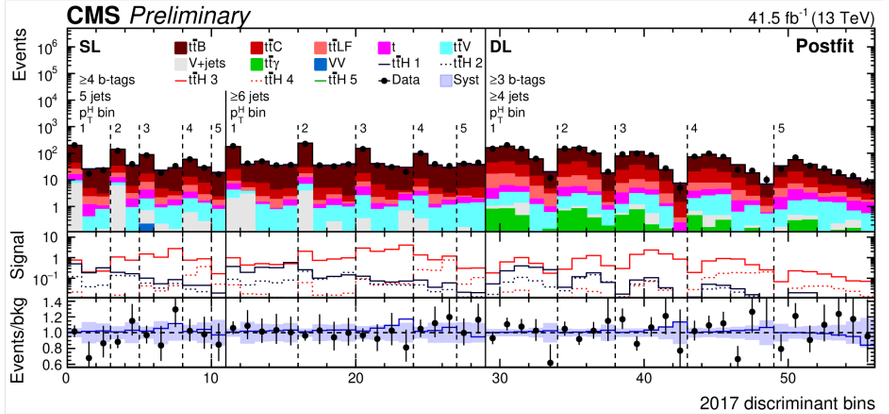


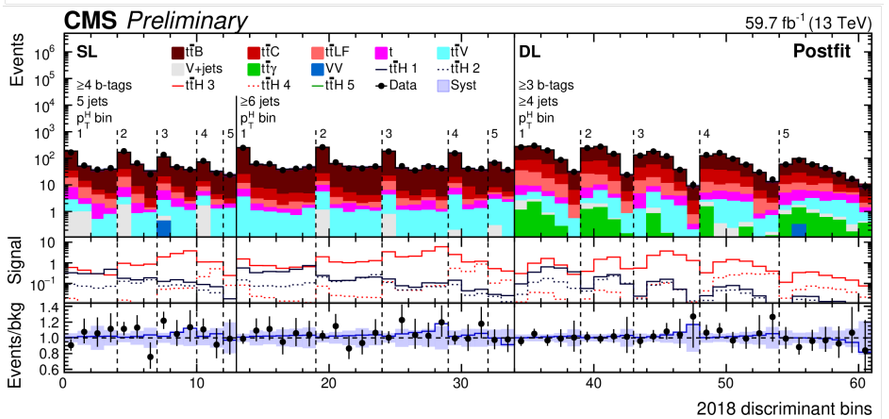




STXS fit







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$t\bar{t}H$, $H \to b\bar{b}$

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Analysis regions

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	FH channel	SL channel	DL channel
Number of leptons	0	1	2
Sign and flavour of leptons	—	$e^{\pm}$, $\mu^{\pm}$	$e^{+}e^{-}$, $\mu^{\pm}e^{\mp}$, $\mu^{+}\mu^{-}$
Min. p_T of leading electron (GeV)	—	29/30/30	25
Min. p_T of leading muon (GeV)	—	26/29/26	25
Min. p_T of additional leptons (GeV)	—	—	15
Max. p_T of additional leptons (GeV)	15	15	—
Max. $\lvert\eta\rvert$ of leptons	2.4	2.4	2.4
Min. $m_{\ell\ell}$ (GeV)	—	—	20
$m_{ee/\mu\mu}$ (GeV)	—	—	< 76 or > 106
Min. number of jets	7	5	3
Min. p_T of jets (GeV)	30	30	30
Min. p_T of 6th jet (GeV)	40	—	—
Max. $\lvert\eta\rvert$ of jets	2.4	2.4	2.4
Min. number of b-tagged jets	2	4	3
m_{qq} (GeV)	> 30 and < 250	—	—
Min. H_T (GeV)	500	—	—
Min. p_T^{miss} (GeV)	—	20	40

CMS

Region	Dilepton				Single-lepton			
	$SR^{\geq 4j}_{\geq 4b}$	$CR^{\geq 4j}_{3b\ hi}$	$CR^{\geq 4j}_{3b\ lo}$	$CR^{3j}_{3b\ hi}$	$SR^{\geq 6j}_{\geq 4b}$	$CR^{5j}_{\geq 4b\ hi}$	$CR^{5j}_{\geq 4b\ lo}$	$SR_{boosted}$
#leptons	$= 2$				$= 1$			
#jets	≥ 4			$= 3$	≥ 6	$= 5$		≥ 4
#b-tag @85%	–				≥ 4			
#b-tag @77%	–				–			$\geq 2^{\dagger}$
#b-tag @70%	≥ 4	$= 3$			≥ 4			–
#b-tag @60%	–	$= 3$	< 3	$= 3$	–	> 4	< 4	–
#boosted cand.	–				0			≥ 1
Fit input	BDT	Yield			BDT/Yield	ΔR_{bb}^{avg}		BDT

ATLAS

Leading lepton $p_T > 27$ GeV
Additional lepton $p_T > 10$ GeV
Lepton $|\eta| < 2.47$ (e), 2.5 (μ)
$m_{ll} > 15$ GeV, $m_{ee/\mu\mu} < 83$ GeV or > 99 GeV
Jet $p_T > 25$ GeV
Jet $|\eta| < 2.5$

$t\bar{t}H$, $H \to b\bar{b}$

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Background simulation

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Process	ME generator	ME PDF	PS	Normalisation
$t\bar{t}$	POWHEG BOX v2	NNPDF3.0NLO	PYTHIA 8.230	NNLO+NNLL [45,46,47,48,49,50,51]
	POWHEG BOX v2	NNPDF3.0NLO	HERWIG 7.04	NNLO+NNLL [45,46,47,48,49,50,51]
	MADGRAPH5_aMC@NLO 2.6.0	NNPDF3.0NLO	PYTHIA 8.230	NNLO+NNLL [45,46,47,48,49,50,51]
$t\bar{t}+b\bar{b}$	POWHEG BOX RES	NNPDF3.0NLO nf4	PYTHIA 8.230	–
	SHERPA 2.2.1	NNPDF3.0NNLO nf4	SHERPA	–

ATLAS

	$t\bar{t}$ sample		$t\bar{t}b\bar{b}$ sample
POWHEG version	`Powheg v2`		`Powheg-Box-Res`
PYTHIA version	8.230		8.230
Flavour scheme	5	**CMS**	4
PDF set	NNPDF3.1		NNPDF3.1
m_t	172.5 GeV		172.5 GeV
m_b	0		4.75 GeV
μ_R	$\sqrt{\frac{1}{2}\left(m_{T,t}^2 + m_{T,\bar{t}}^2\right)}$		$\frac{1}{2}\sqrt[4]{m_{T,t} \cdot m_{T,\bar{t}} \cdot m_{T,b} \cdot m_{T,\bar{b}}}$
μ_F	μ_R		$\frac{1}{4}\left[m_{T,t} + m_{T,\bar{t}} + m_{T,b} + m_{T,\bar{b}} + m_{T,g}\right]$
h_{damp}	$1.379 \cdot m_t$		$1.379 \cdot m_t$
Tune	CP5		CP5

$$\frac{0.5 \times \Sigma_{i=t,\bar{t},b,\bar{b},j} m_T(i)}{\sqrt[4]{m_T(t) \cdot m_T(\bar{t}) \cdot m_T(b) \cdot m_T(\bar{b})}}$$

$$0.5 \times \Sigma_{i=t,\bar{t},b,\bar{b}} m_T(i)$$

A14

$t\bar{t}H$, $H \to b\bar{b}$

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Systematic uncertainties on $t\bar{t}$+≥1b

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Source	Type	Correlation	Remarks
Renorm./fact. scales	R	correlated	Scale uncertainty of (N)NLO prediction, independent for $t\bar{t}H$, tHq, tHW, $t\bar{t}$, t, V+jets, VV
Collinear gluon splitting†	S	correlated	Additional 100% rate uncertainty on $t\bar{t}+2b$ component of $t\bar{t}B$ background
μ_R scale	S	correlated	Renormalisation scale uncertainty of the ME generator, independent for $t\bar{t}H$, tHq, tHW, $t\bar{t}B$ ($t\bar{t}b\bar{b}$ sample), other $t\bar{t}$ ($t\bar{t}$ sample)
μ_F scale	S	correlated	Factorisation scale uncertainty of the ME generator, independent for $t\bar{t}H$, tHq, tHW, $t\bar{t}B$ ($t\bar{t}b\bar{b}$ sample), other $t\bar{t}$ ($t\bar{t}$ sample)
PDF shape	S	correlated	From NNPDF variations, independent for tHq, tHW, $t\bar{t}B$ ($t\bar{t}b\bar{b}$ sample), other $t\bar{t}$ ($t\bar{t}$ sample) and $t\bar{t}H$
PS scale ISR†	S	correlated	Initial state radiation uncertainty of the PS (PYTHIA), independent for $t\bar{t}H$, $t\bar{t}B$ ($t\bar{t}b\bar{b}$ sample), other $t\bar{t}$ ($t\bar{t}$ sample)
PS scale FSR†	S	correlated	Final state radiation uncertainty of the PS (PYTHIA), independent for $t\bar{t}H$, $t\bar{t}B$ ($t\bar{t}b\bar{b}$ sample), other $t\bar{t}$ ($t\bar{t}$ sample)
ME-PS matching ($t\bar{t}$)†	R	correlated	NLO ME-PS matching (for $t\bar{t}$ + jets events), independent for $t\bar{t}B$, $t\bar{t}C$, $t\bar{t}LF$
Underlying event ($t\bar{t}$)	R	correlated	Underlying event (for all $t\bar{t}$ + jets events)

CMS

Uncertainty source	Description		Components
$t\bar{t}$ cross-section	±6%		$t\bar{t}$ + light
$t\bar{t}+\geq 1b$ normalisation	Free-floating		$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1c$ normalisation	±100%		$t\bar{t}+\geq 1c$
NLO matching	MadGraph5_aMC@NLO + Pythia 8 vs Powheg Box + Pythia 8		All
PS & hadronisation	Powheg Box + Herwig 7 vs Powheg Box + Pythia 8		All
ISR	Varying α_s^{ISR} (PS), μ_r & μ_f (ME)	in Powheg Box Res + Pythia 8	$t\bar{t}+\geq 1b$
		in Powheg Box + Pythia 8	$t\bar{t}+\geq 1c$, $t\bar{t}$ + light
FSR	Varying α_s^{FSR} (PS)	in Powheg Box Res + Pythia 8	$t\bar{t}+\geq 1b$
		in Powheg Box + Pythia 8	$t\bar{t}+\geq 1c$, $t\bar{t}$ + light
$t\bar{t}+\geq 1b$ fractions	Powheg Box + Herwig 7 vs Powheg Box + Pythia 8		$t\bar{t}+1b$, $t\bar{t}+\geq 2b$
p_T^{bb} shape	Shape mismodelling measured from data		$t\bar{t}+\geq 1b$

ATLAS

$t\bar{t}H$, $H \to b\bar{b}$

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Impact of systematic uncertainties

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CMS

Uncertainty source	$\Delta\mu_{t\bar{t}H}$ (observed)	$\Delta\mu_{t\bar{t}H}$ (expected)
Total experimental	$+0.10/-0.10$	$+0.11/-0.10$
jet energy scale and resolution	$+0.08/-0.07$	$+0.09/-0.09$
b tagging	$+0.07/-0.06$	$+0.06/-0.02$
luminosity	$+0.02/-0.02$	$+0.01/-0.01$
Total theory	$+0.16/-0.16$	$+0.18/-0.14$
$t\bar{t}$ + jets background	$+0.15/-0.16$	$+0.12/-0.11$
signal modelling	$+0.06/-0.01$	$+0.13/-0.06$
Size of the simulated event samples	$+0.13/-0.12$	$+0.10/-0.10$
Total systematic	$+0.20/-0.21$	$+0.23/-0.19$
Statistical	$+0.17/-0.16$	$+0.17/-0.17$
background normalisation	$+0.13/-0.13$	$+0.13/-0.13$
$t\bar{t}B$ and $t\bar{t}C$ normalisation	$+0.12/-0.12$	$+0.12/-0.12$
QCD normalisation	$+0.01/-0.01$	$+0.01/-0.01$
Total	$+0.26/-0.26$	$+0.28/-0.25$

ATLAS

Uncertainty source	$\Delta\mu$	
Process modelling		
$t\bar{t}H$ modelling	$+0.13$	-0.05
$t\bar{t}+\geq 1b$ modelling		
$t\bar{t}+\geq 1b$ NLO matching	$+0.21$	-0.20
$t\bar{t}+\geq 1b$ fractions	$+0.12$	-0.12
$t\bar{t}+\geq 1b$ FSR	$+0.10$	-0.11
$t\bar{t}+\geq 1b$ PS & hadronisation	$+0.09$	-0.08
$t\bar{t}+\geq 1b$ p_{T}^{bb} shape	$+0.04$	-0.04
$t\bar{t}+\geq 1b$ ISR	$+0.04$	-0.04
$t\bar{t}+\geq 1c$ modelling	$+0.03$	-0.04
$t\bar{t}+$ light modelling	$+0.03$	-0.03
tW modelling	$+0.08$	-0.07
Background-model statistical uncertainty	$+0.04$	-0.05
b-tagging efficiency and mis-tag rates		
b-tagging efficiency	$+0.03$	-0.02
c-mis-tag rates	$+0.03$	-0.03
l-mis-tag rates	$+0.02$	-0.02
Jet energy scale and resolution		
b-jet energy scale	$+0.00$	-0.01
Jet energy scale (flavour)	$+0.01$	-0.01
Jet energy scale (pile-up)	$+0.00$	-0.01
Jet energy scale (remaining)	$+0.01$	-0.01
Jet energy resolution	$+0.02$	-0.02
Luminosity	$+0.01$	-0.00
Other sources	$+0.03$	-0.03
Total systematic uncertainty	$+0.30$	-0.28
$t\bar{t}+\geq 1b$ normalisation	$+0.04$	-0.07
Total statistical uncertainty	$+0.20$	-0.20
Total uncertainty	$+0.36$	-0.34

H→γγ

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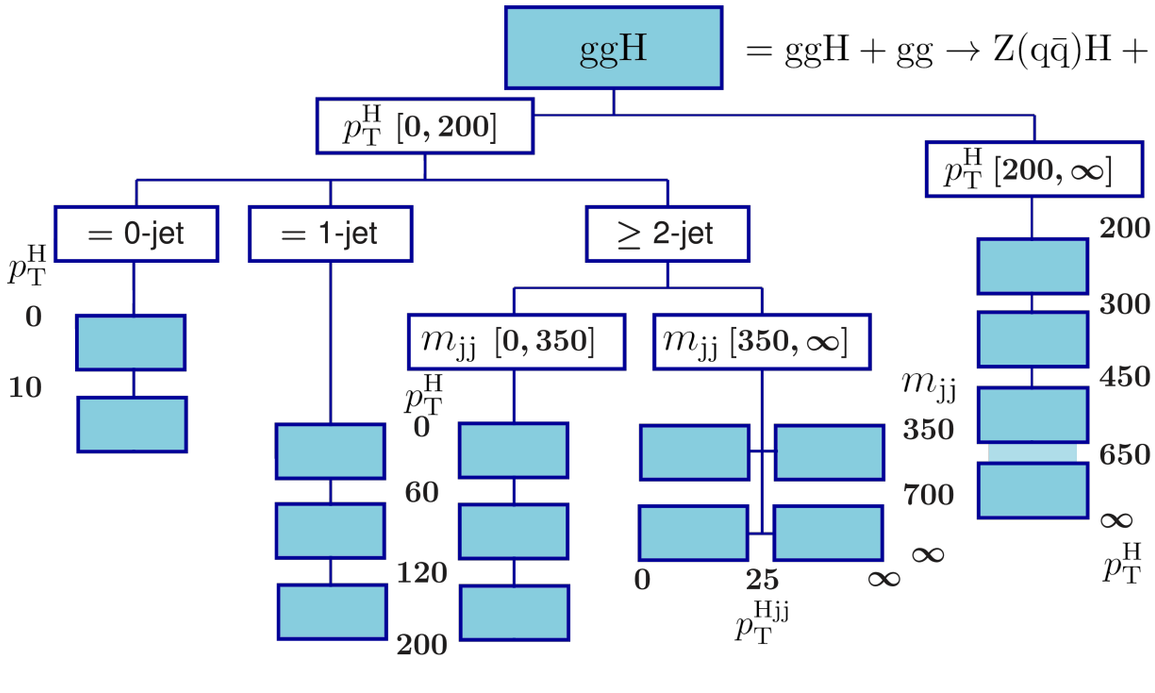
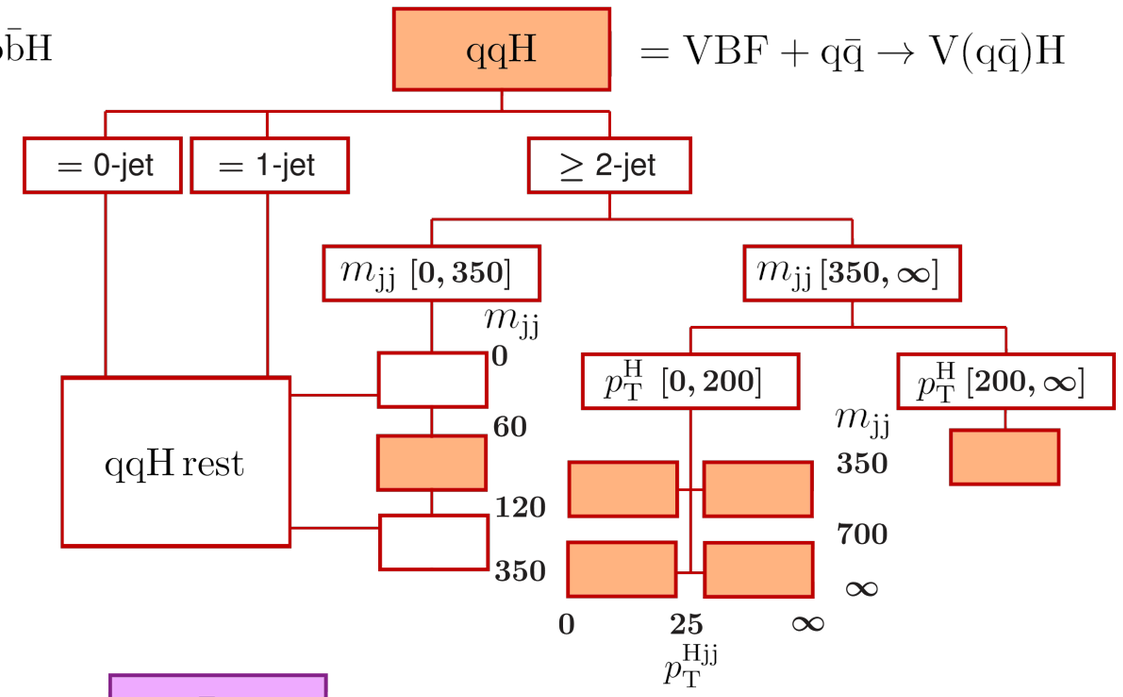
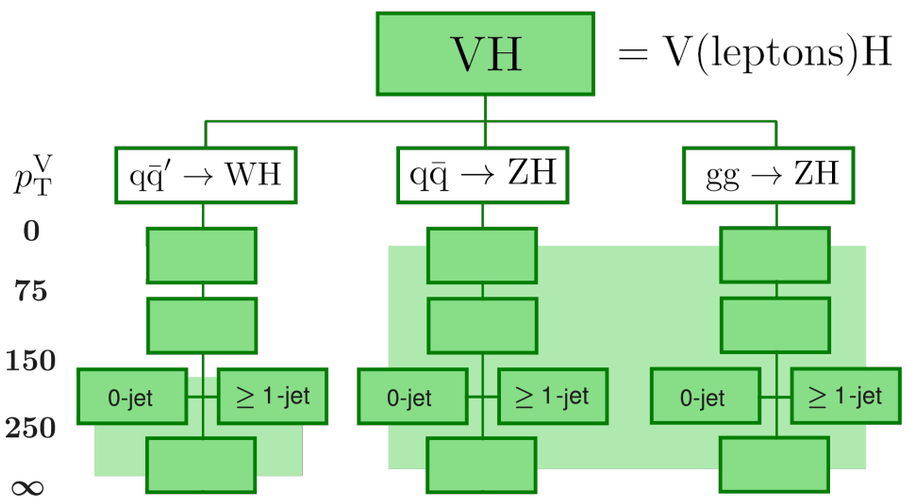
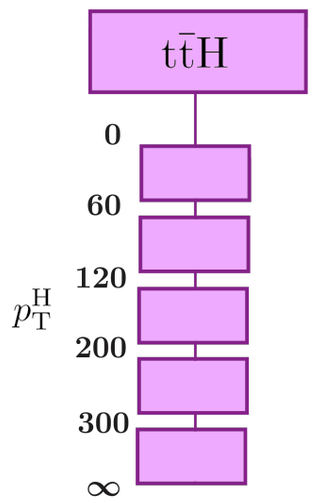
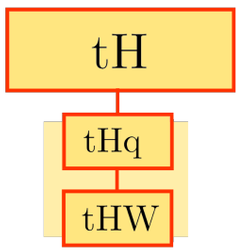
STXS bins











H→γγ

Photons, vertices and mass

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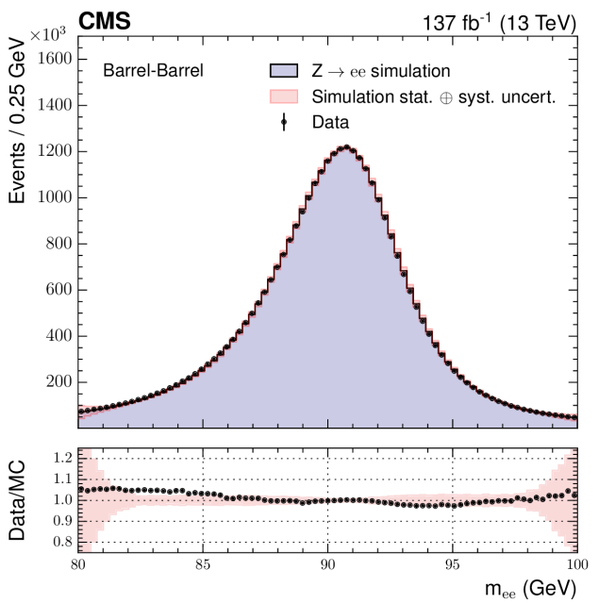

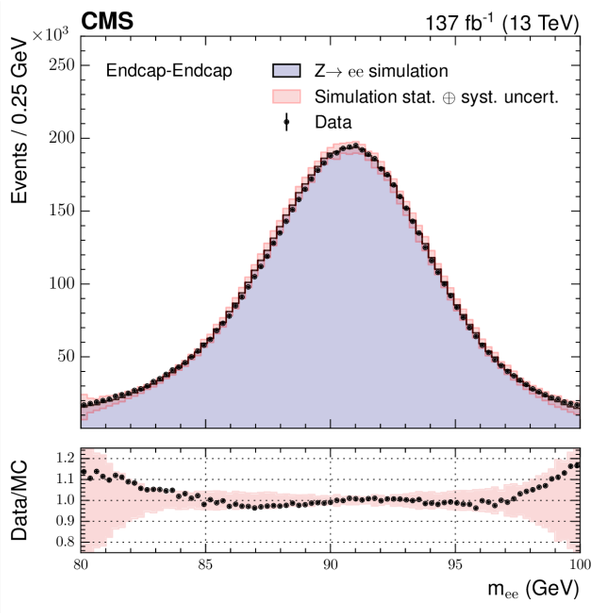

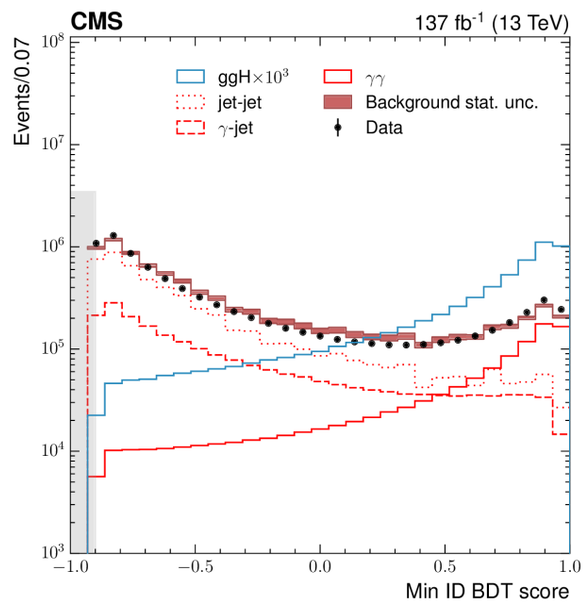

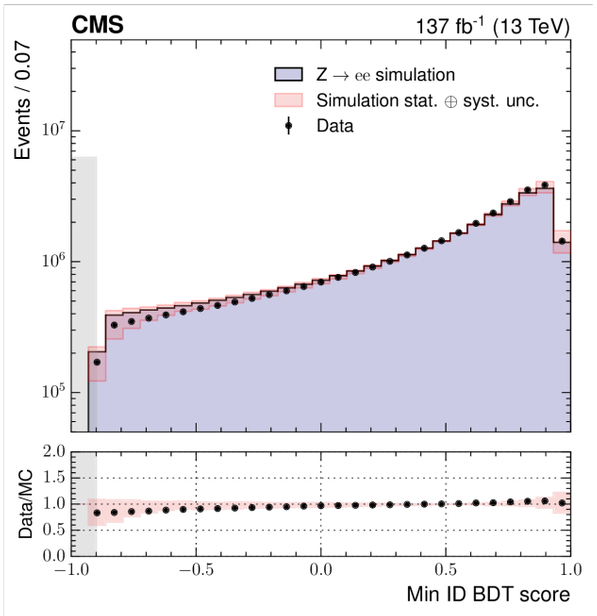

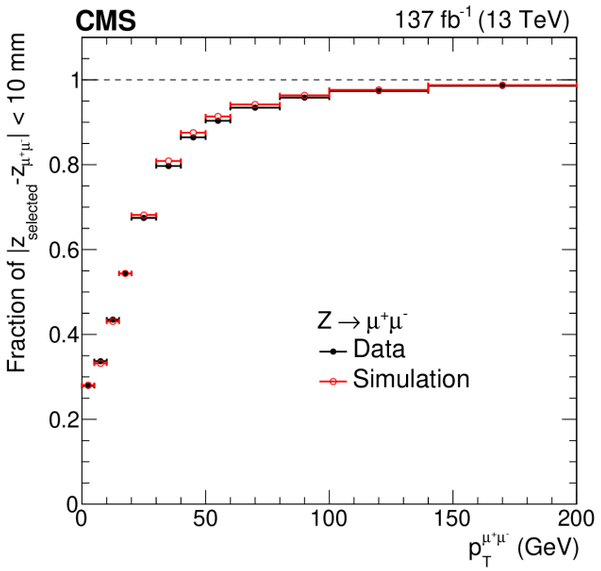

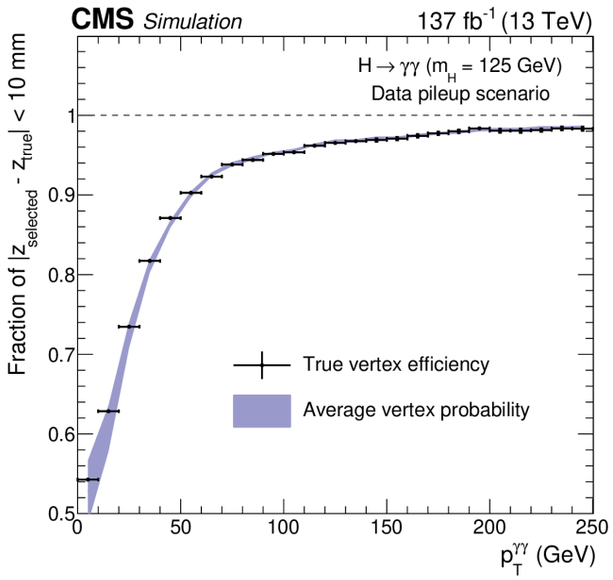

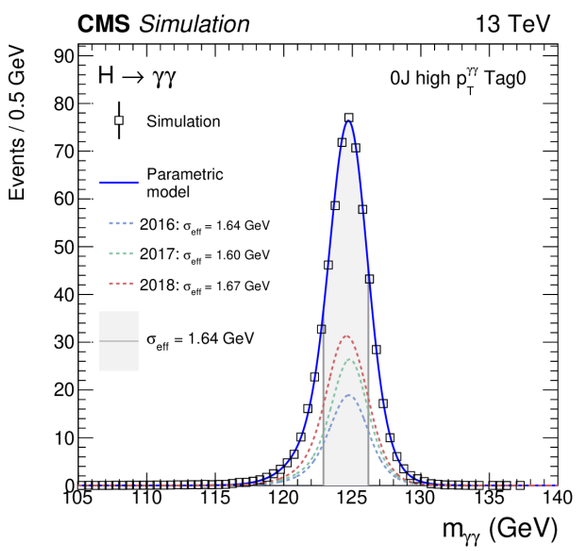

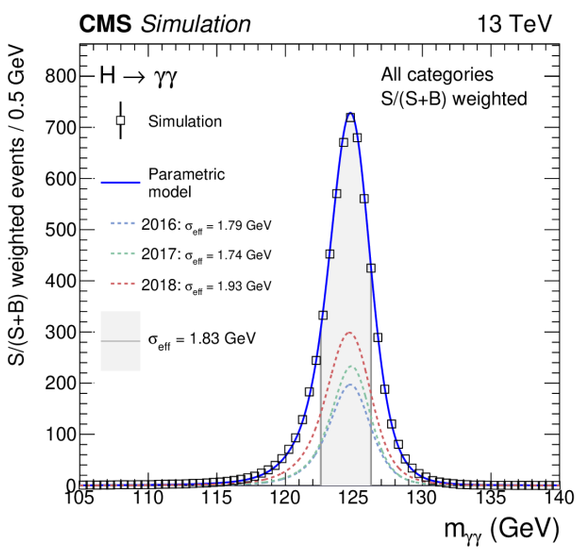

H→γγ

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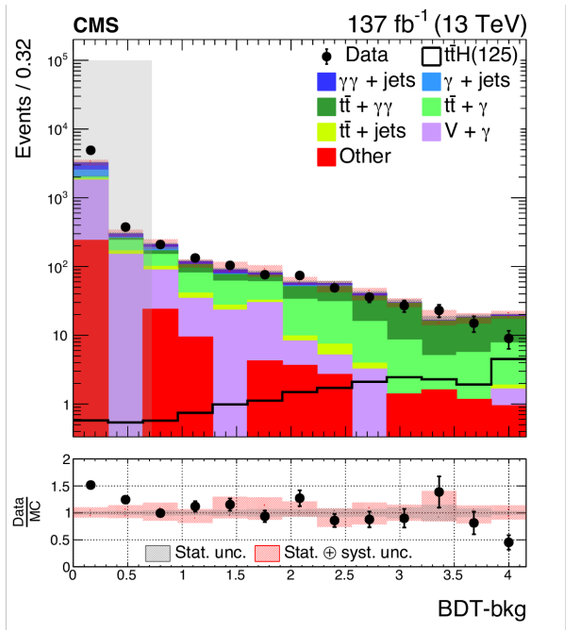
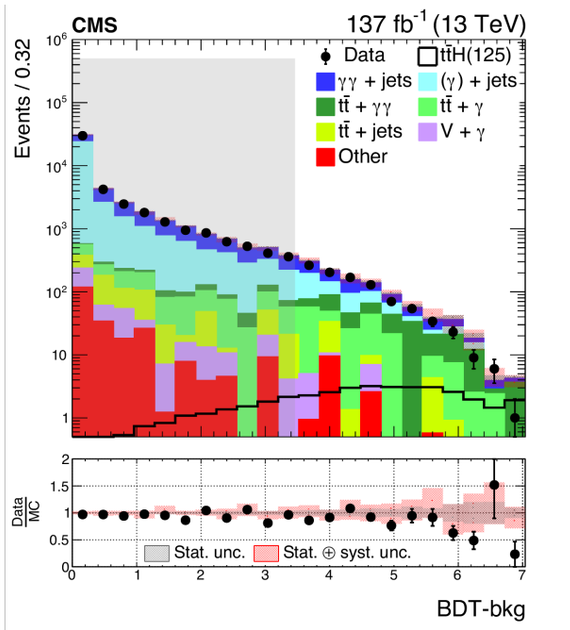
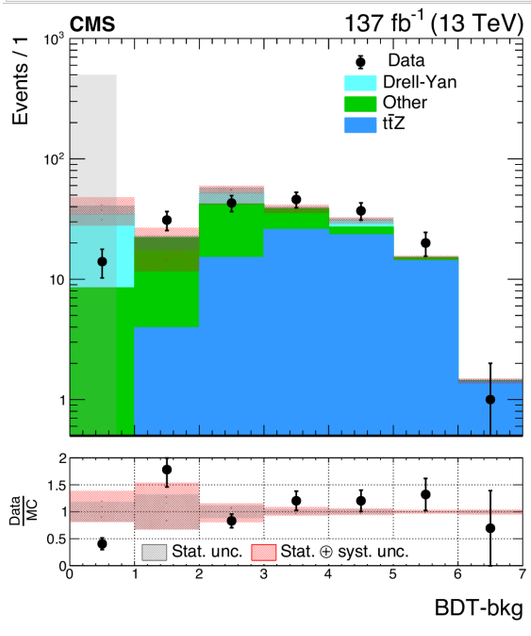
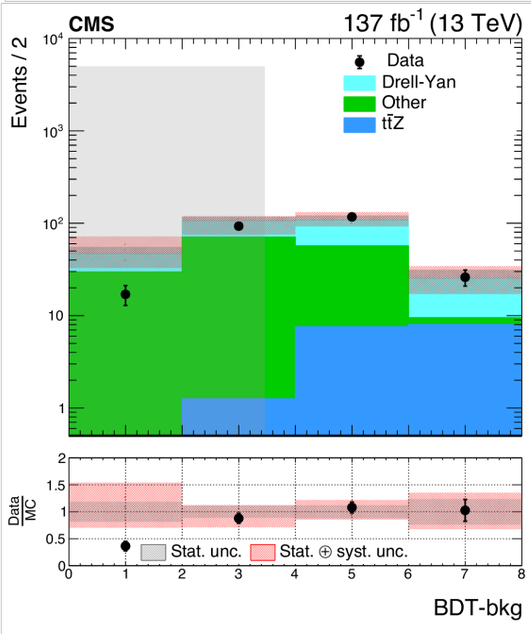
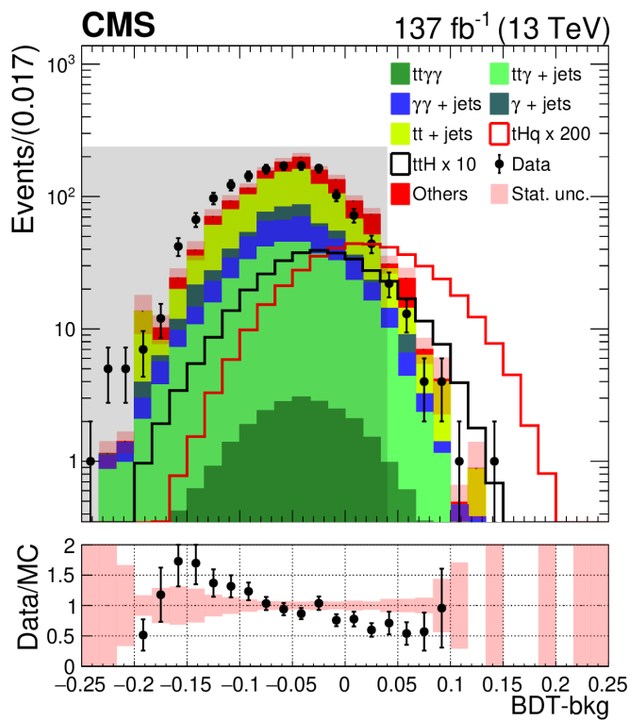
BDT-bkg output

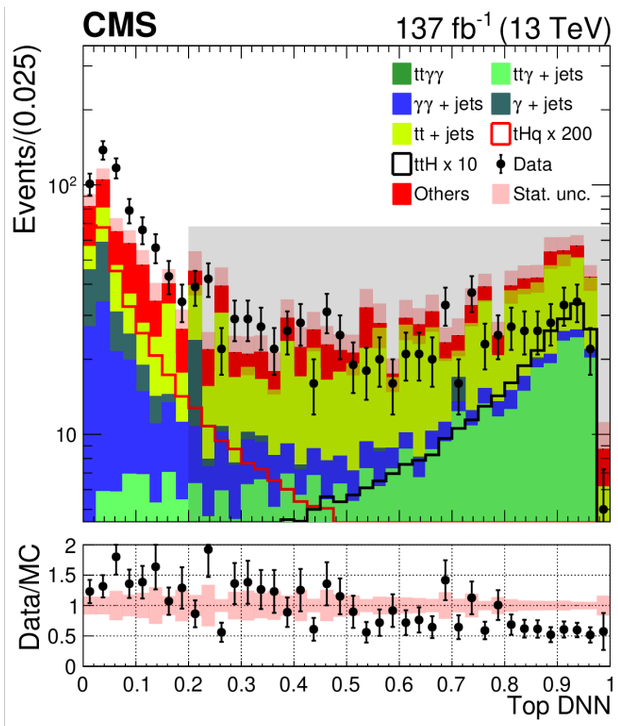












H→γγ

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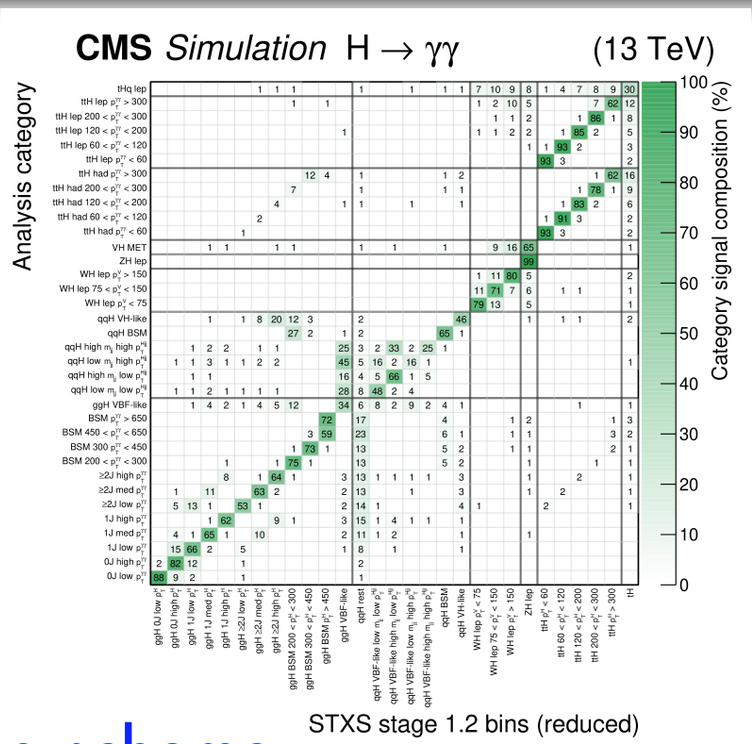
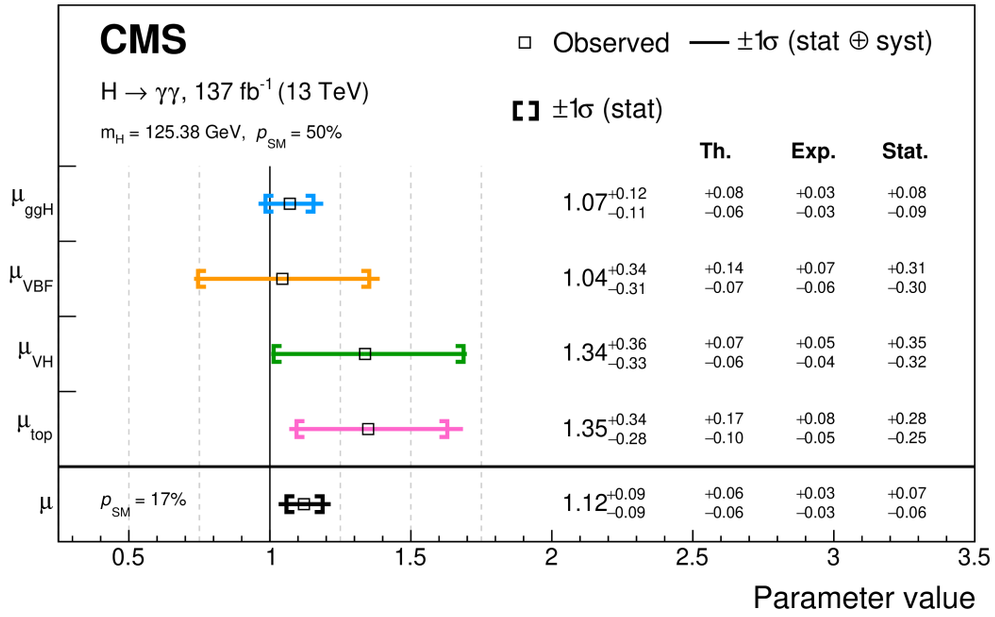
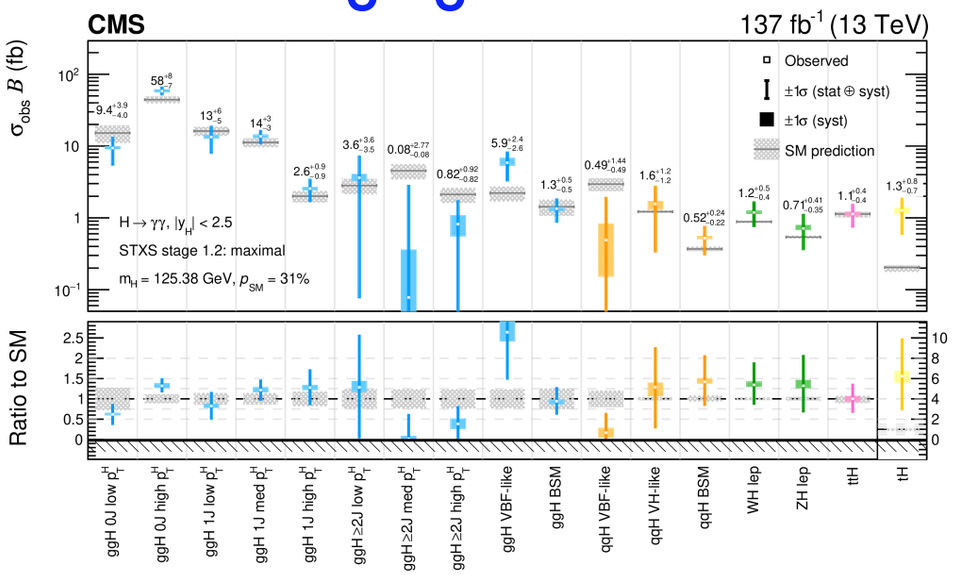
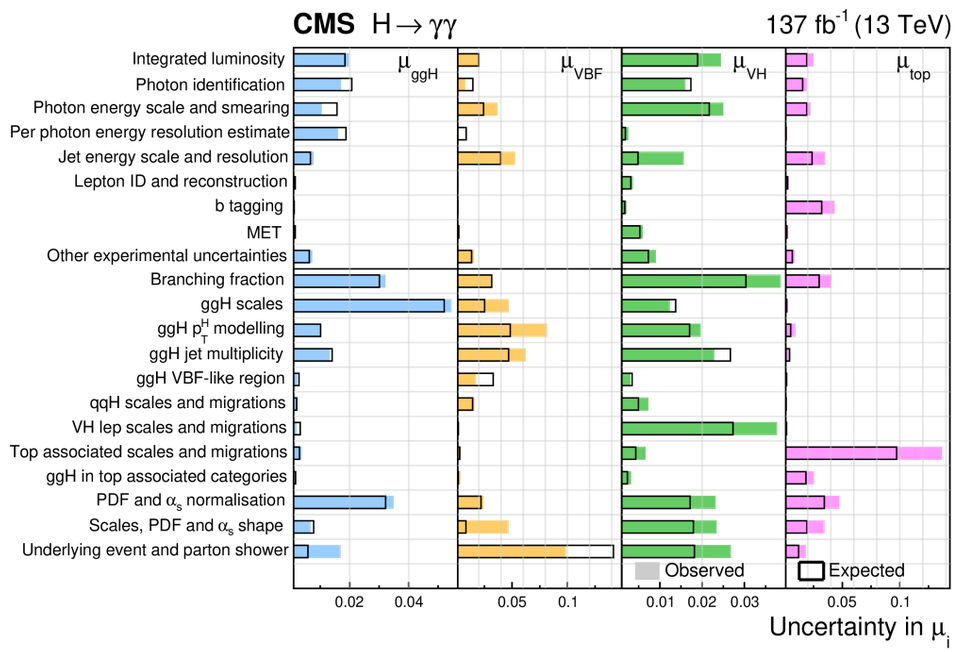
Category composition





Maximal merging scheme





Principal production modes and systematics

H→γγ

STXS bins

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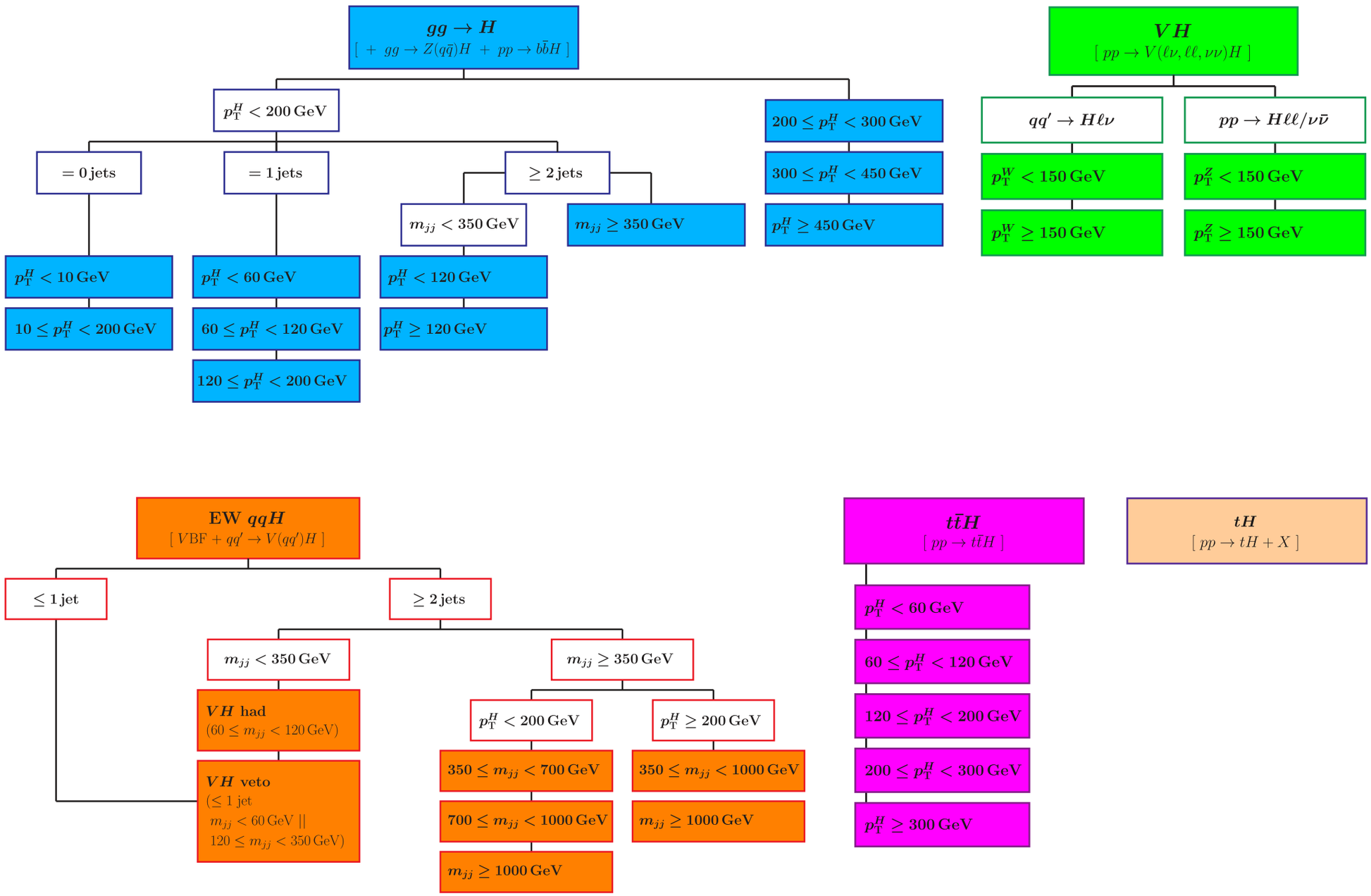

H→γγ

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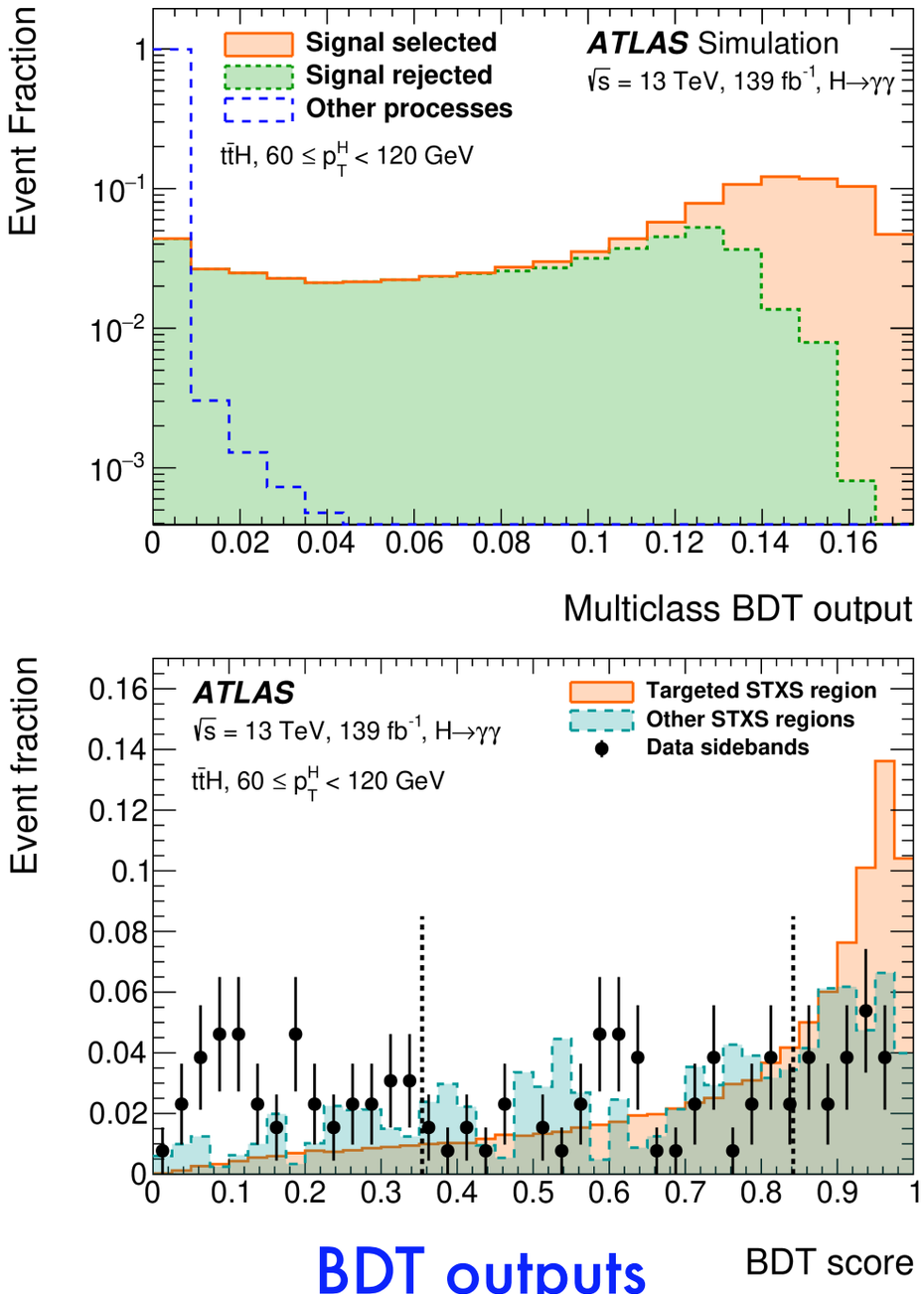
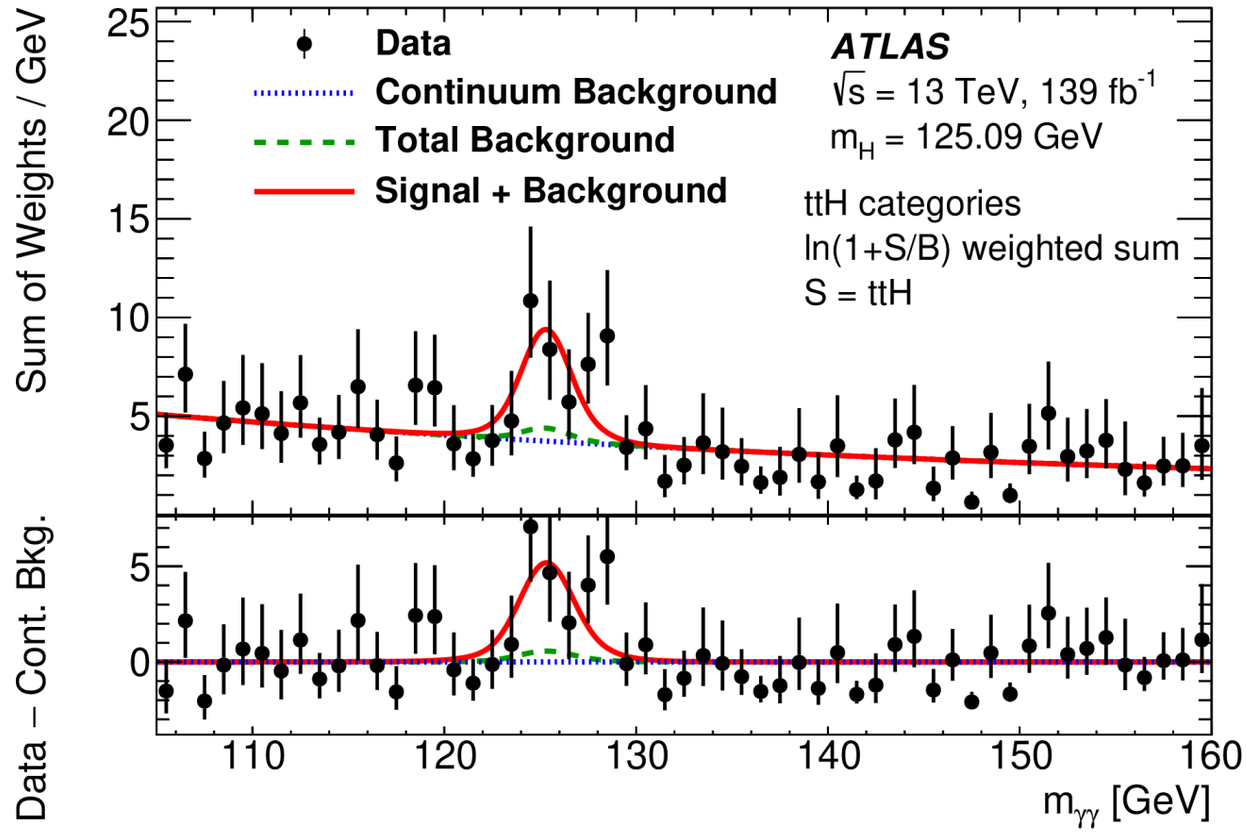


BDT outputs



Fit to data including background estimate

H→γγ

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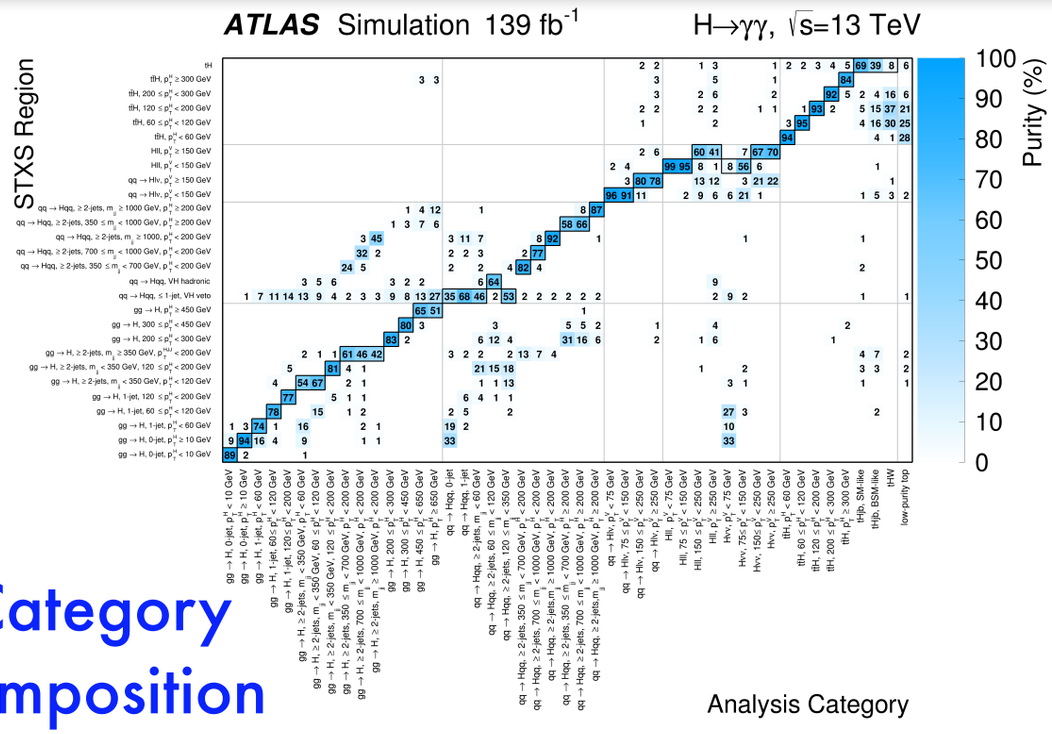
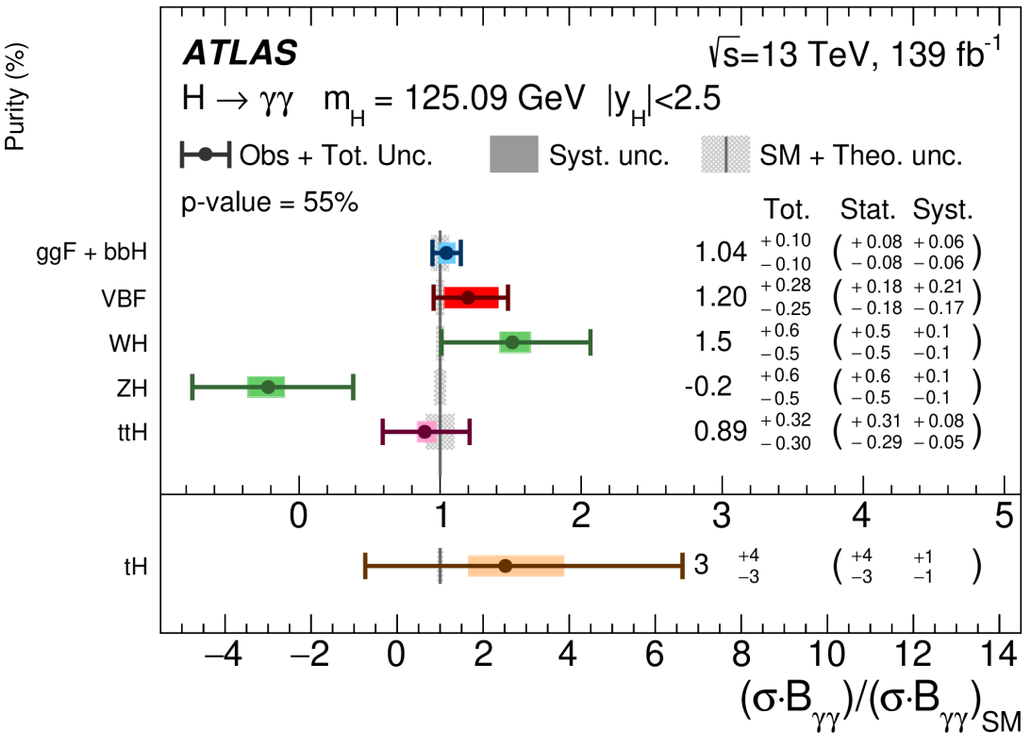
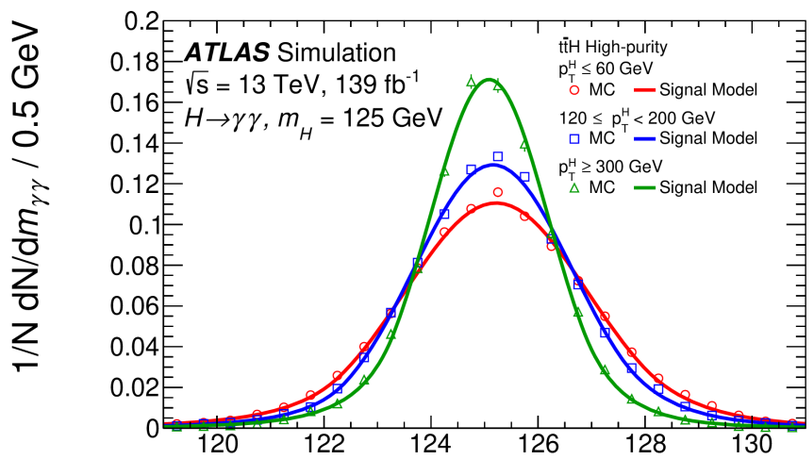


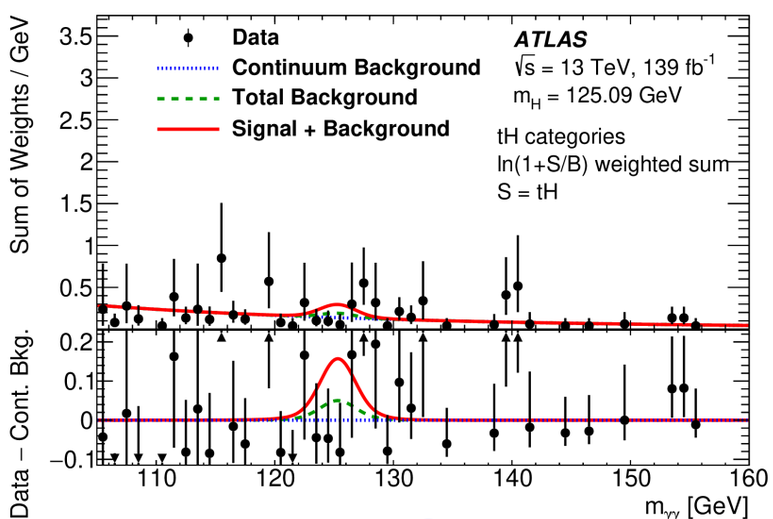
Category composition



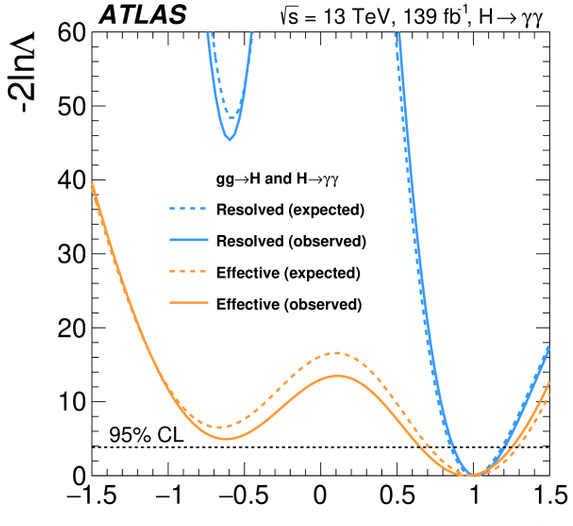
Principal production modes



Mass parametrisation



tH fit



κ-framework

H→γγ

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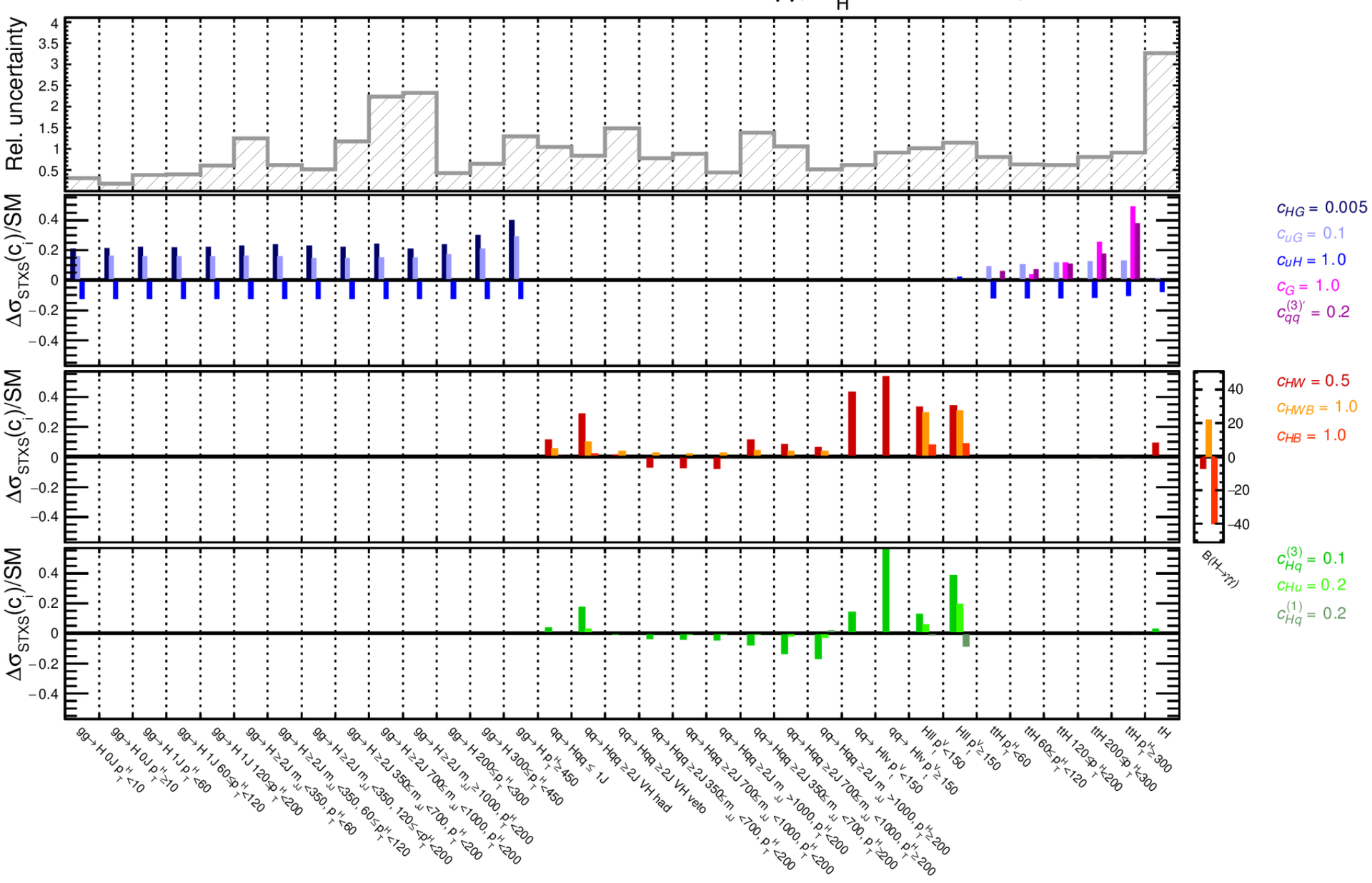
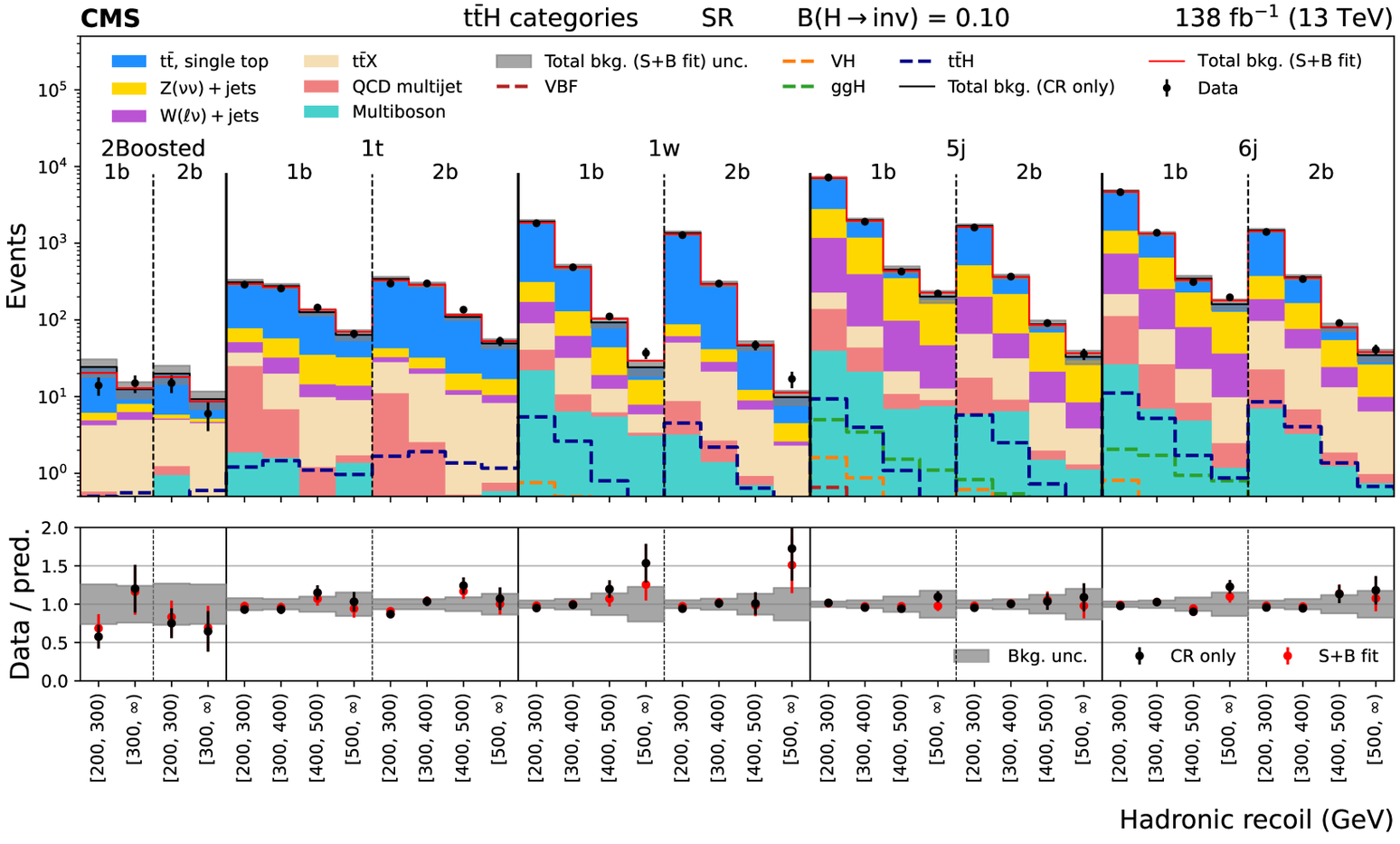


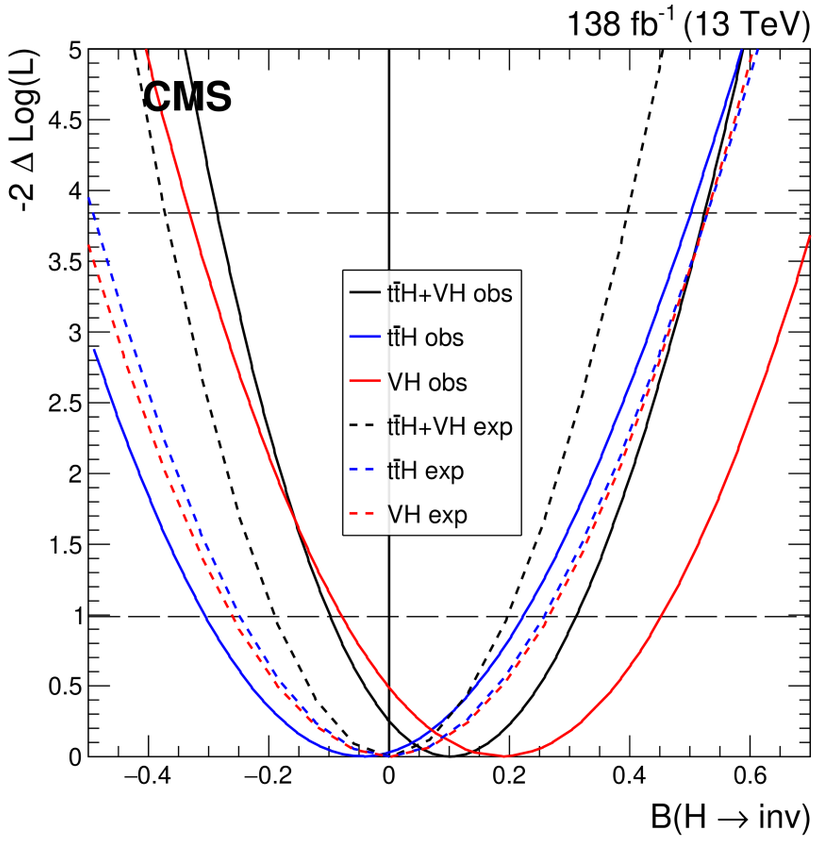
SMEFT interpretaion: sensitivity to Wilson coefficients

H→invisible

arXiv:2303.01214



SR distributions

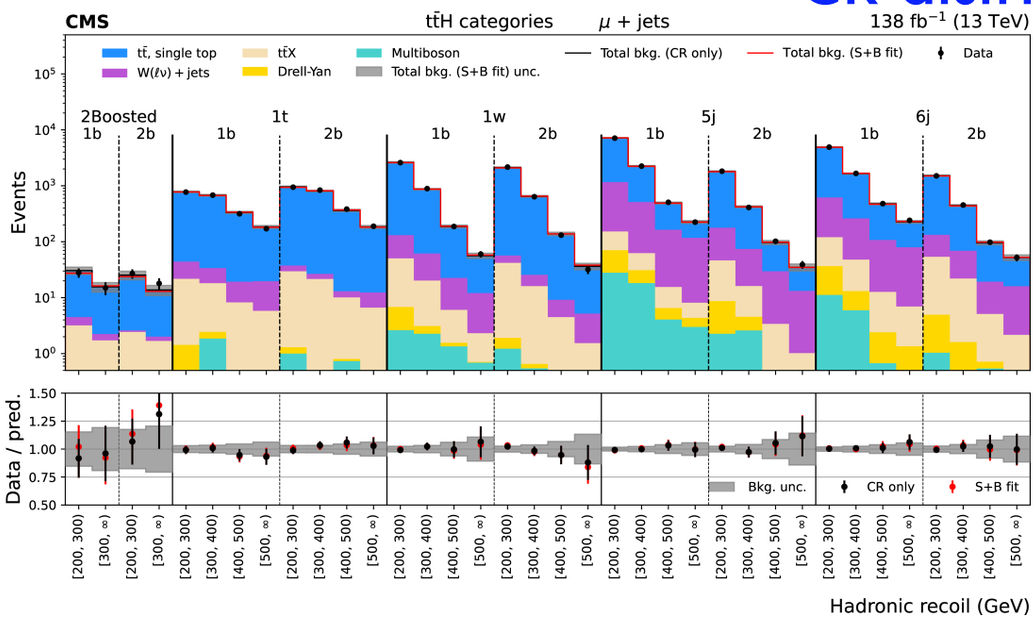


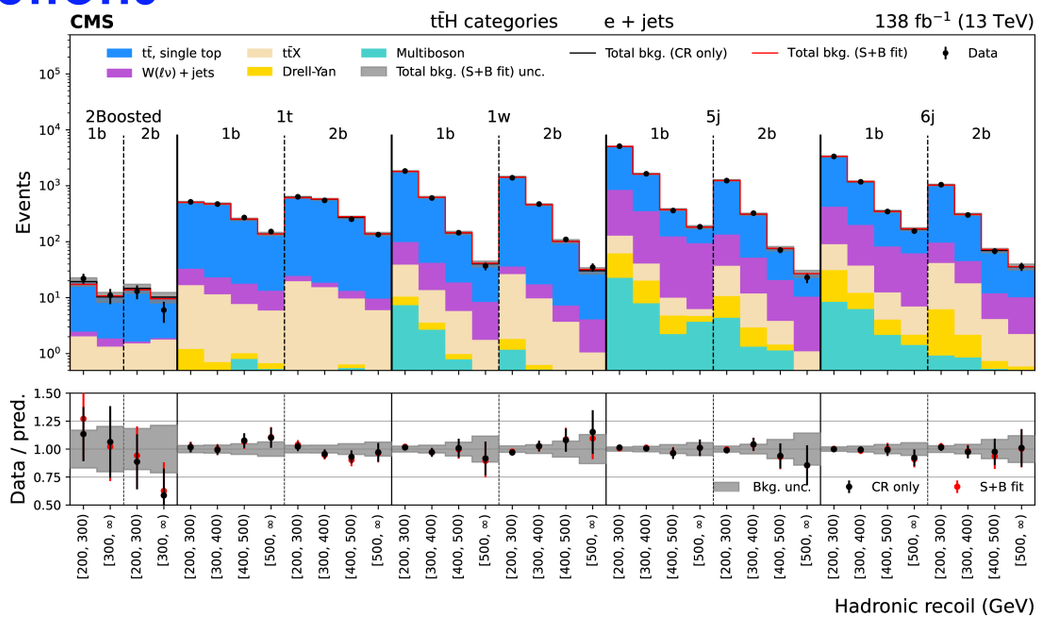
Likelihood curves

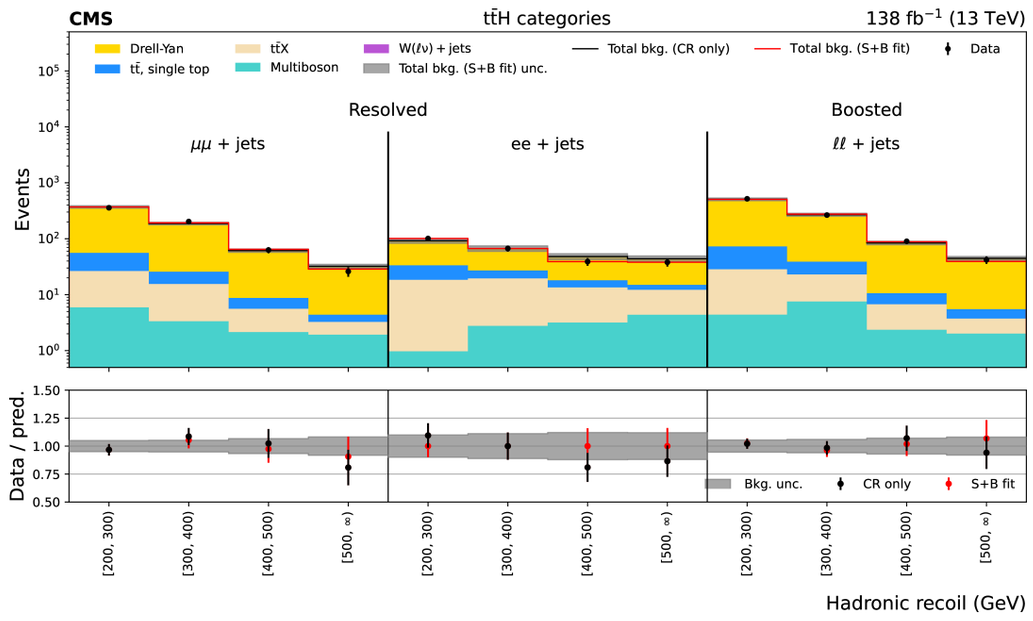
H→invisible

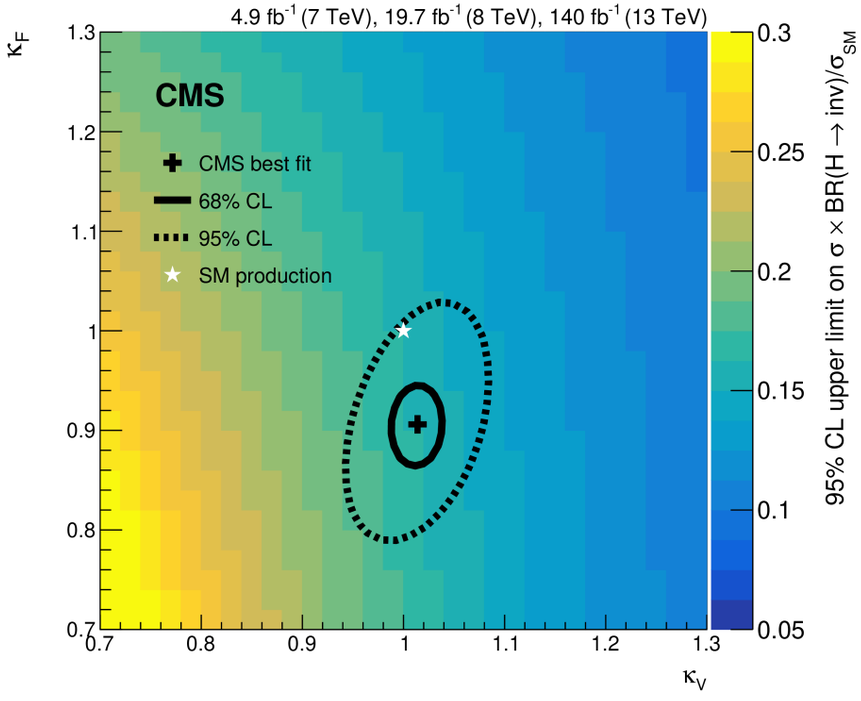
CR distributions

arXiv:2303.01214





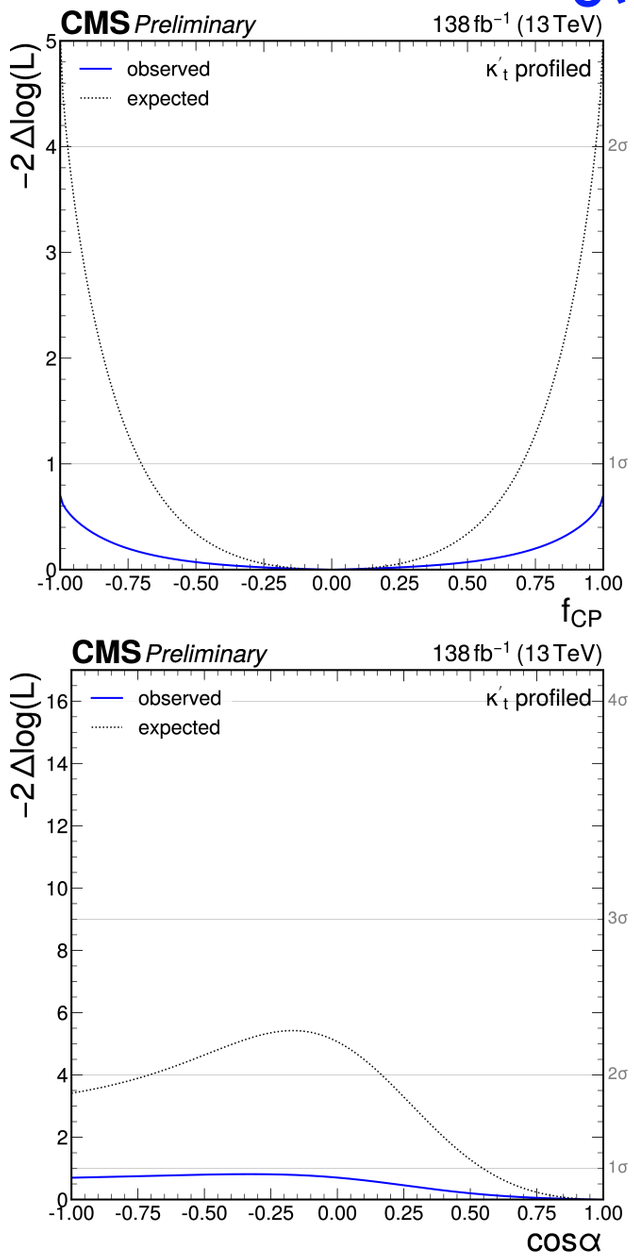




κ-framework

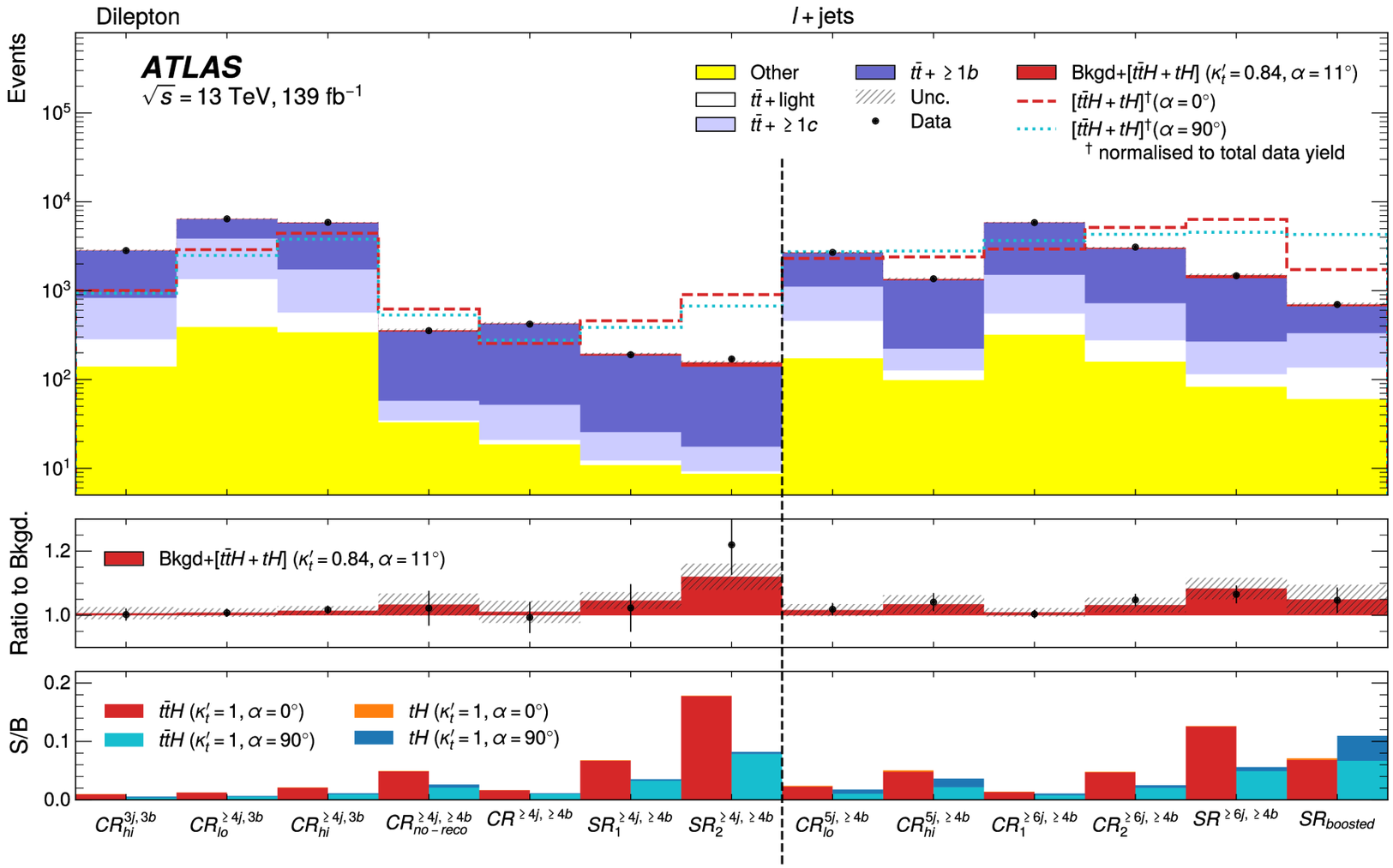
CP: H→bb̄

CMS-PAS-HIG-19-011 1D log(L)



arXiv:2303.05974

SR and CR yields



CP: H→ττ/WW

Data/MC comparisons in validation regions

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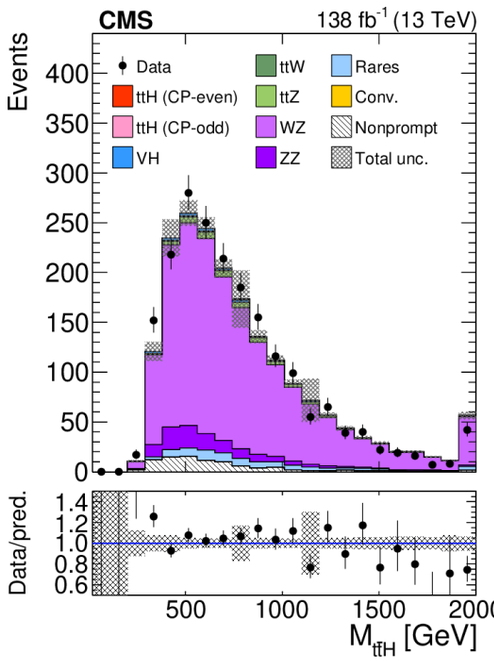

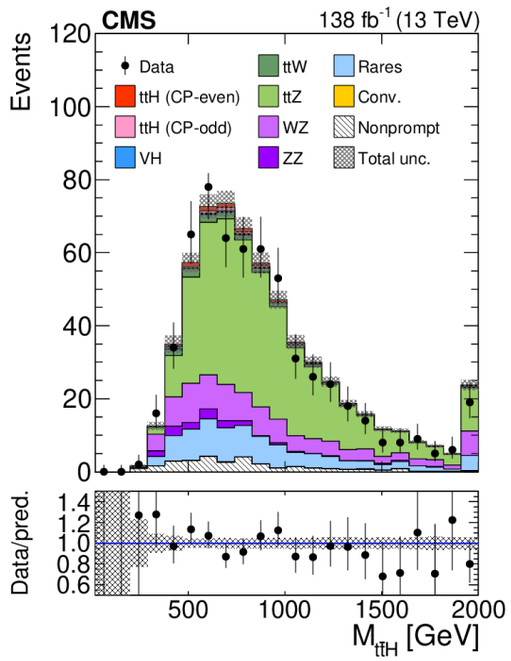

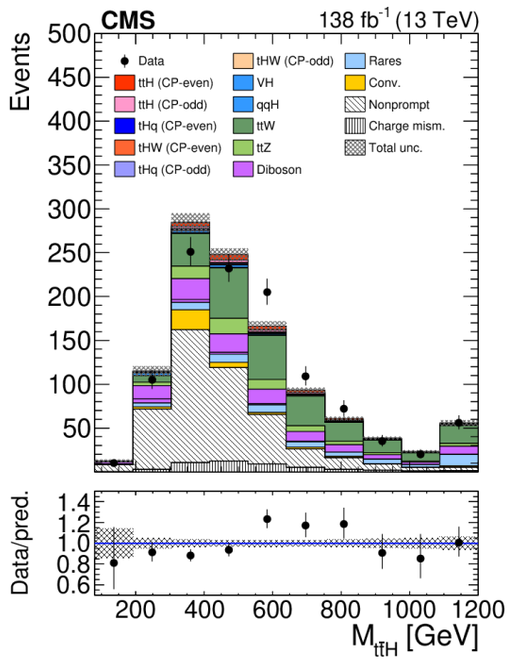

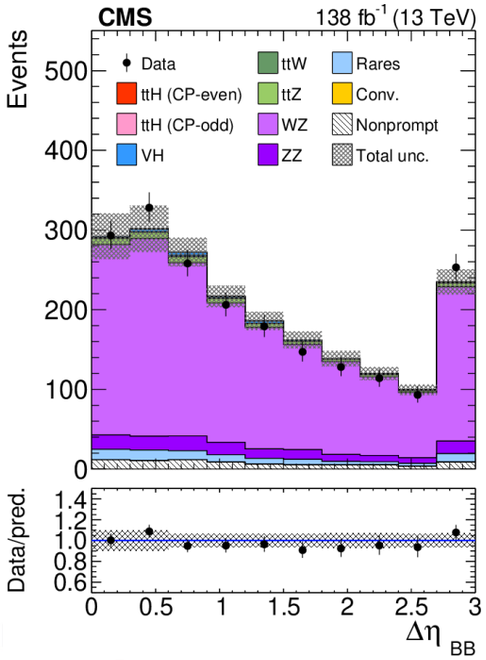

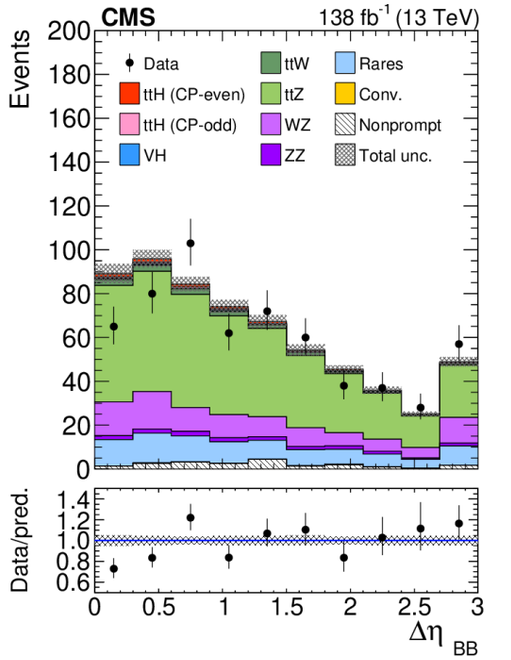

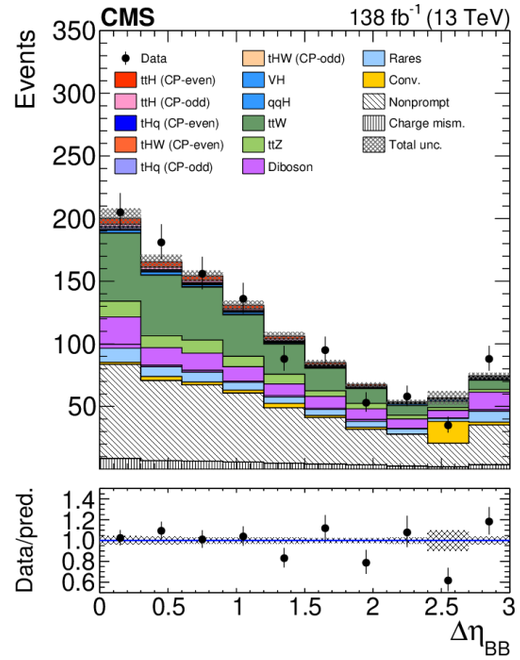

CP: H→ττ/WW

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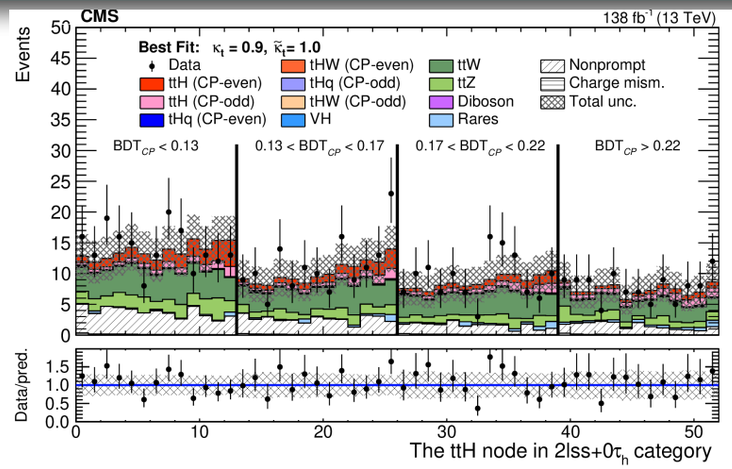
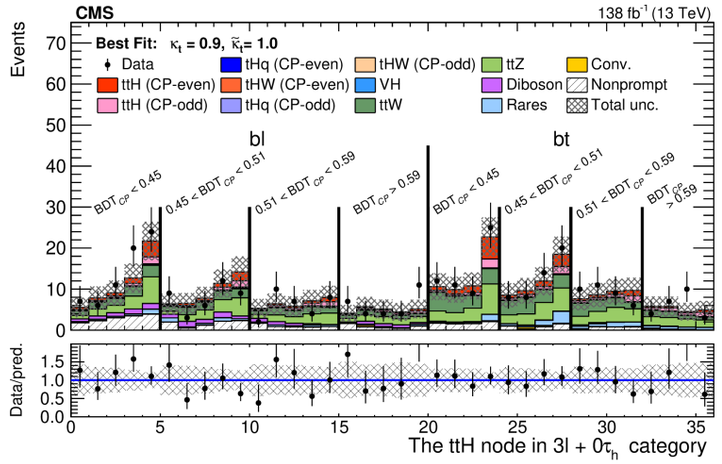
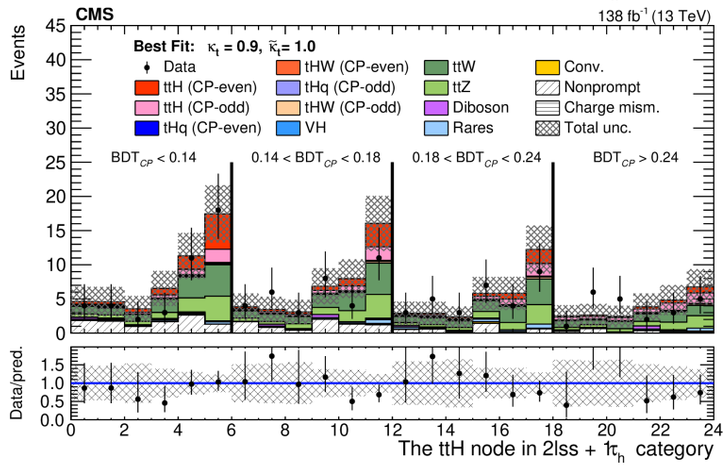
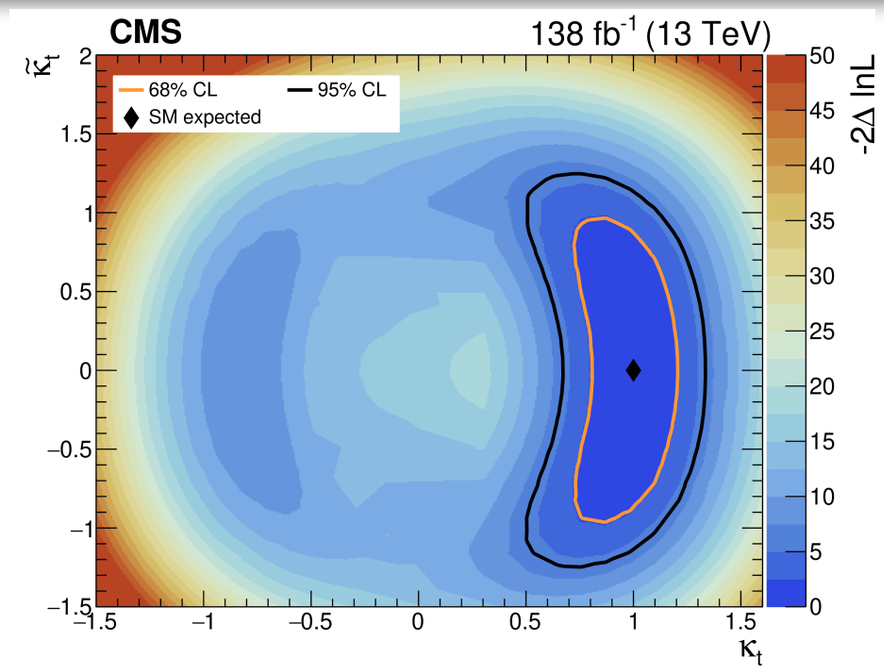
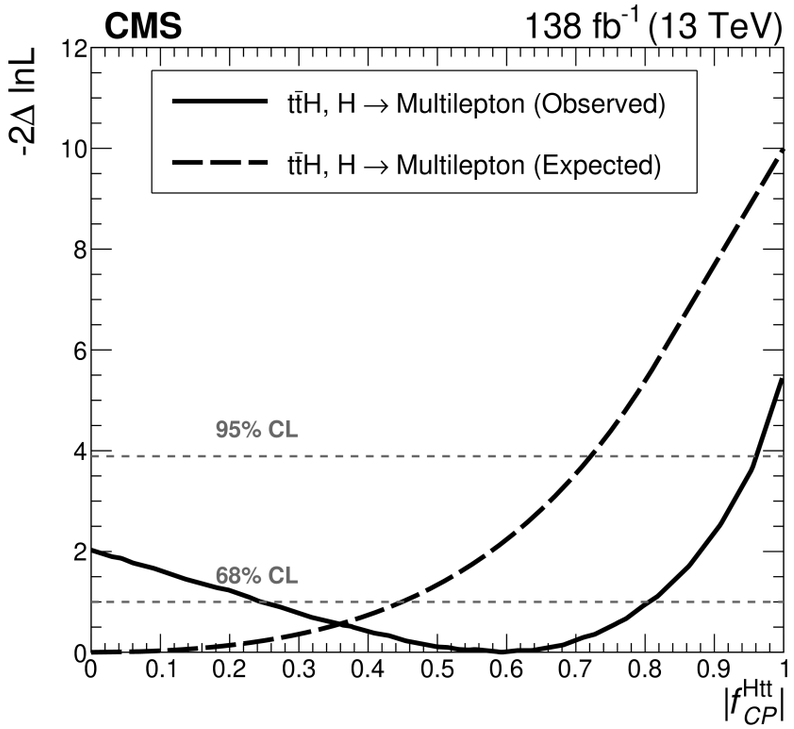
Fitted distributions











Expected limits

1D limits

H→4l

Dedicated analysis in several production channels

Combination with H→γγ and ggH

Results compatible with pure CP-even coupling structure

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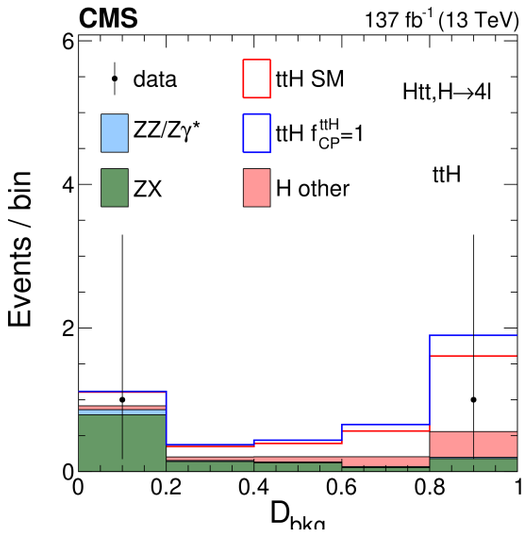

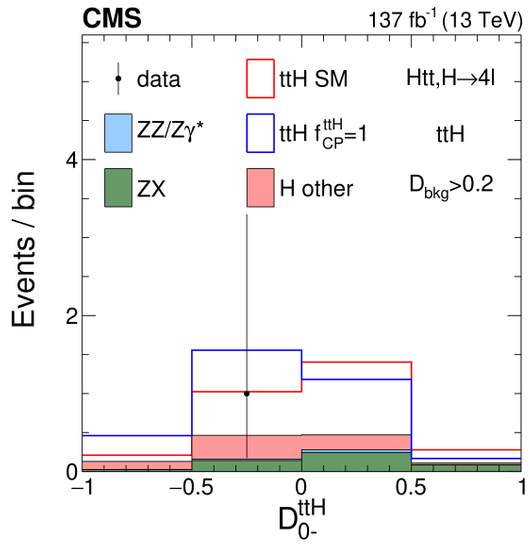

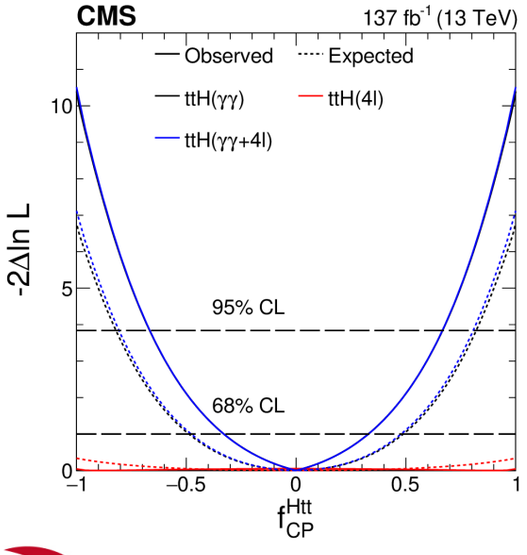

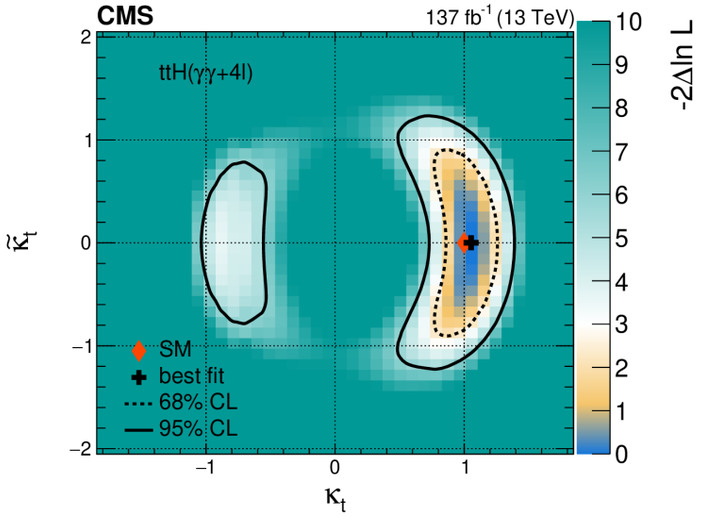

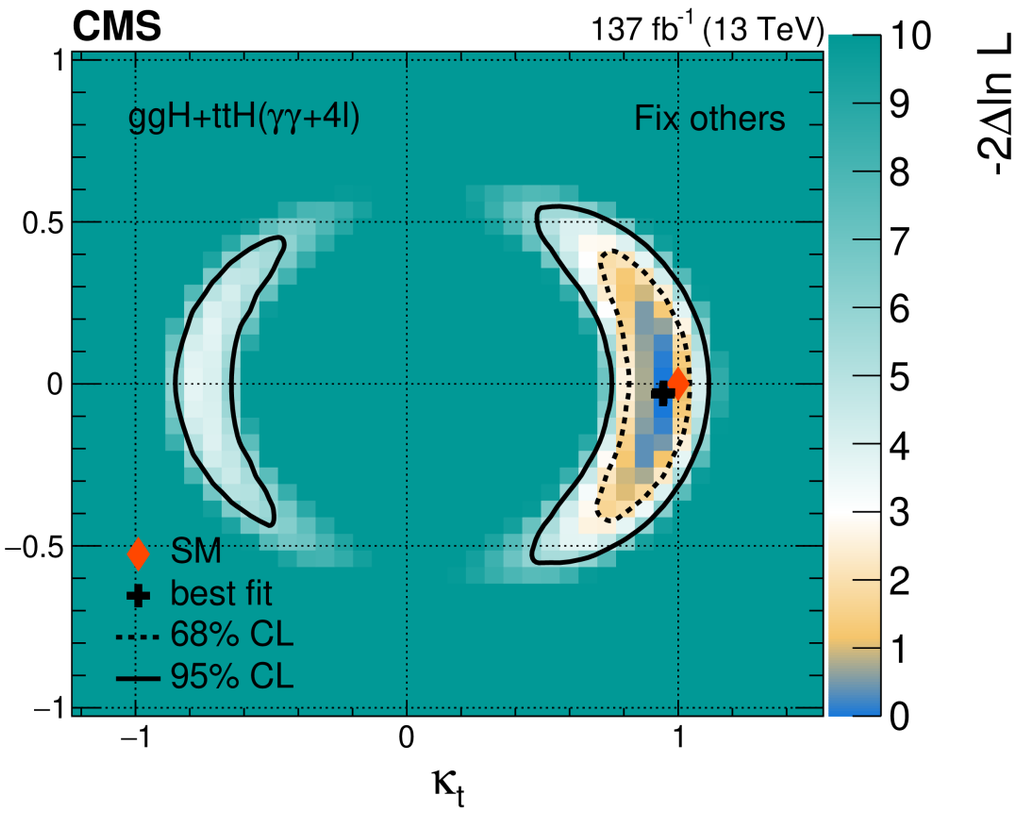

CP: H→4l

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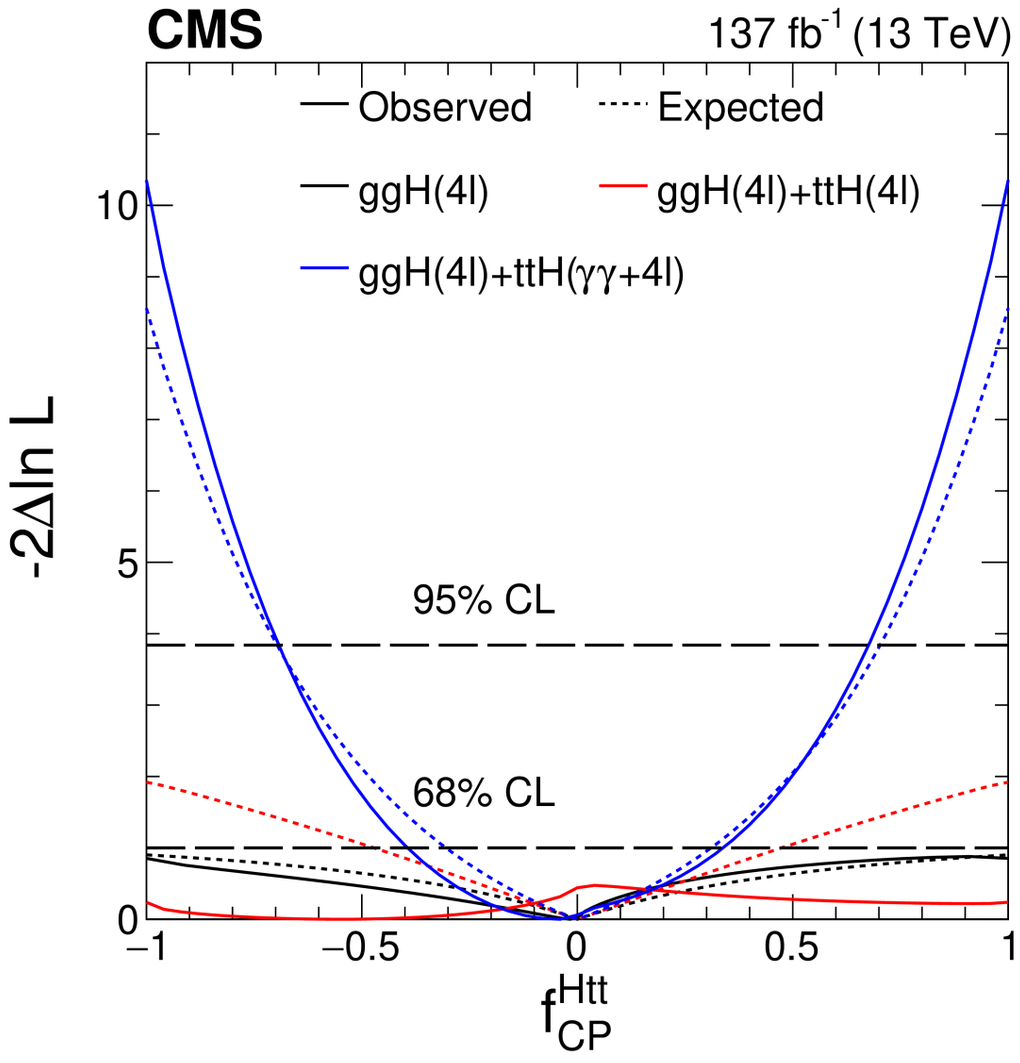
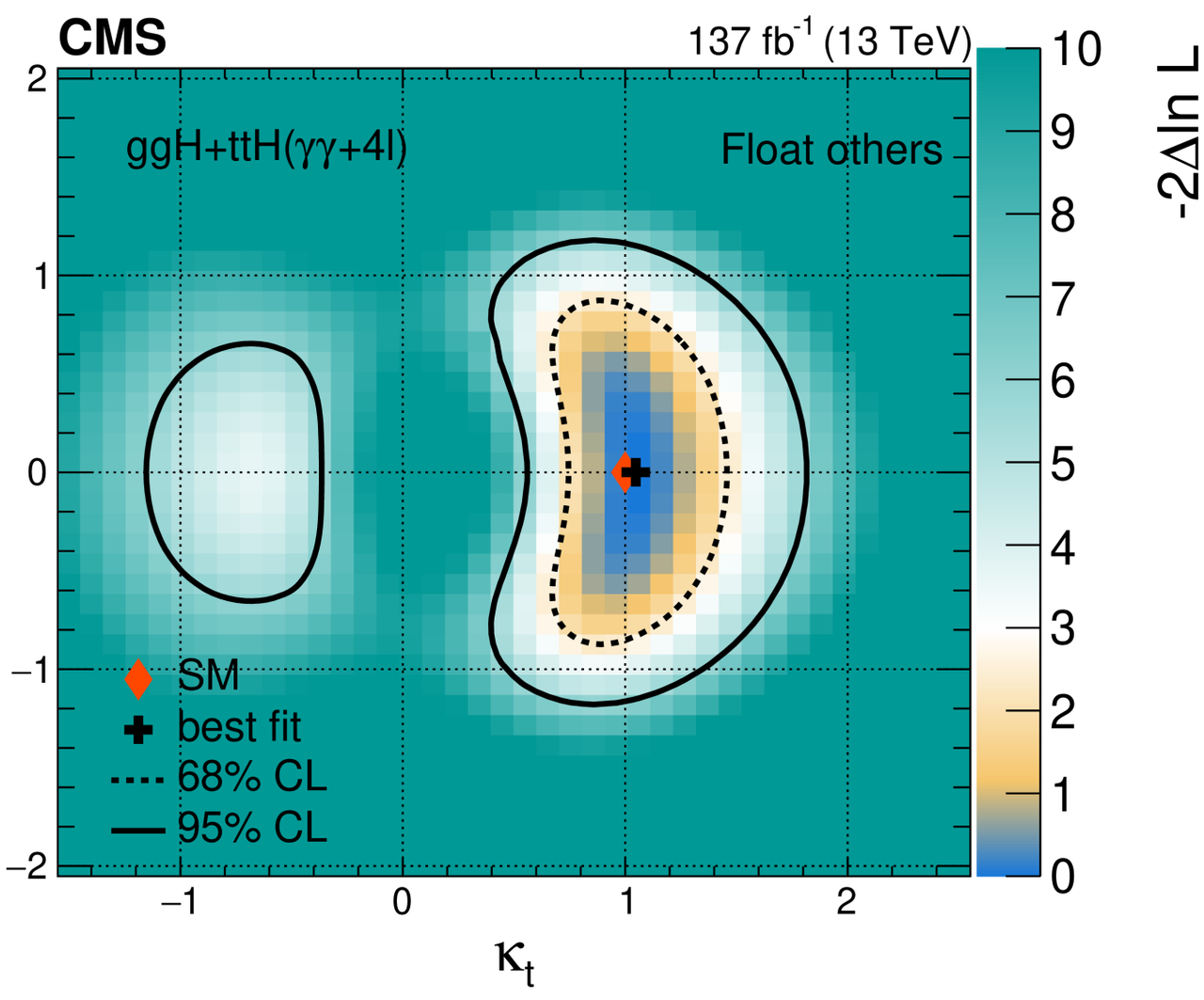
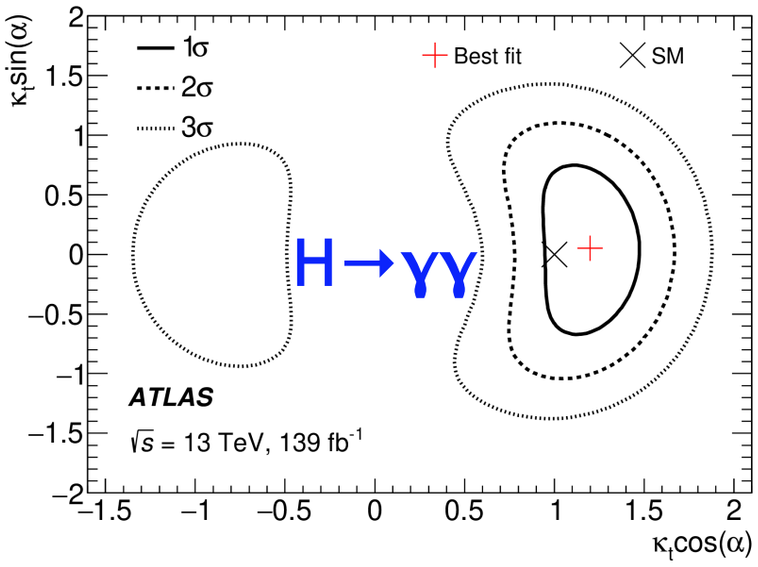
1D limits



2D limits



CP summary



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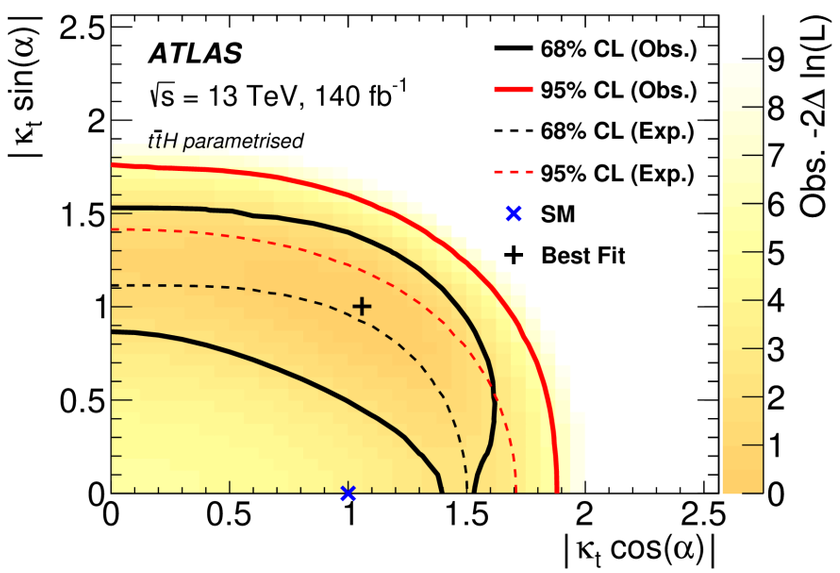

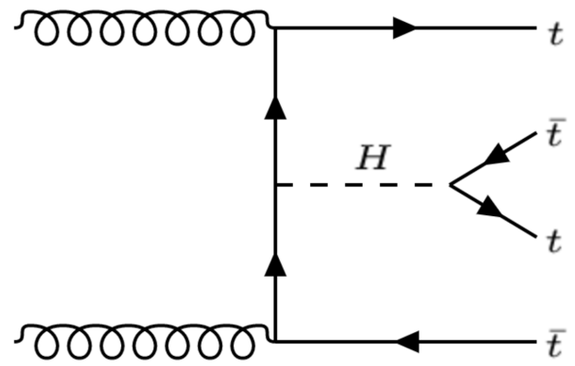

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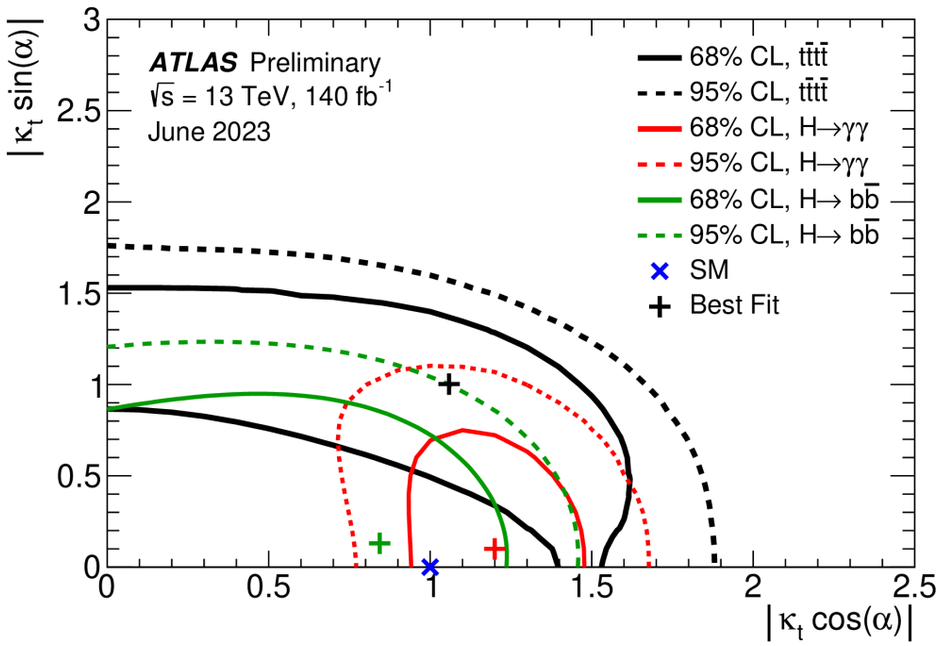

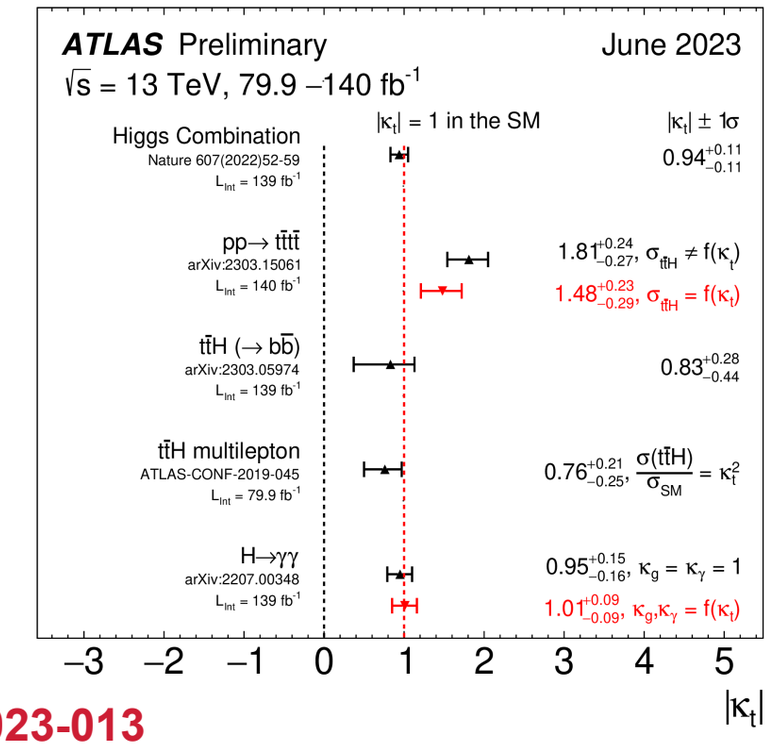

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