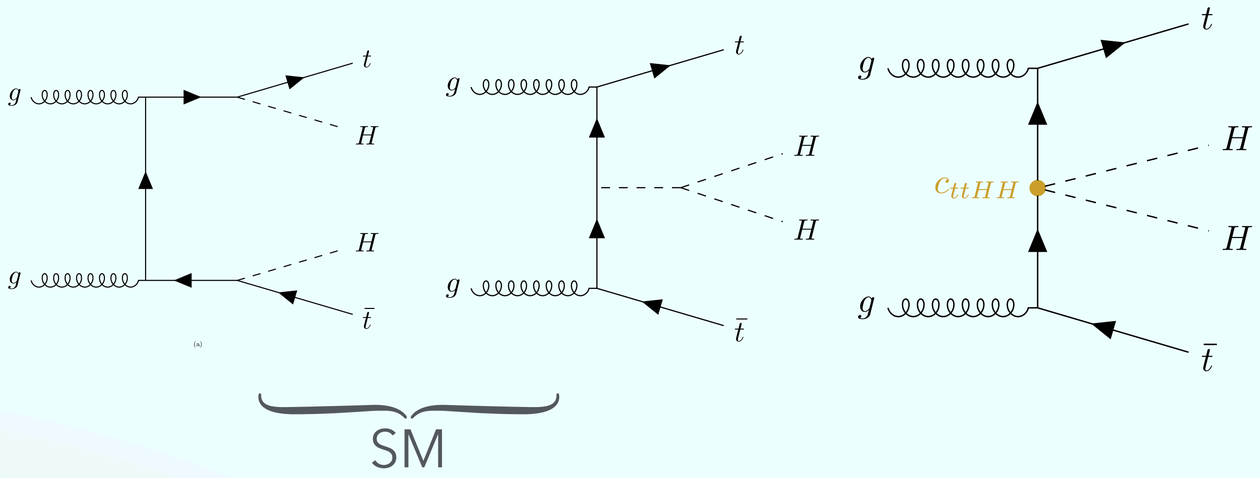
Probing the Top-Higgs Quartic interaction

through an EFT interpretation of ttHH production at ATLAS

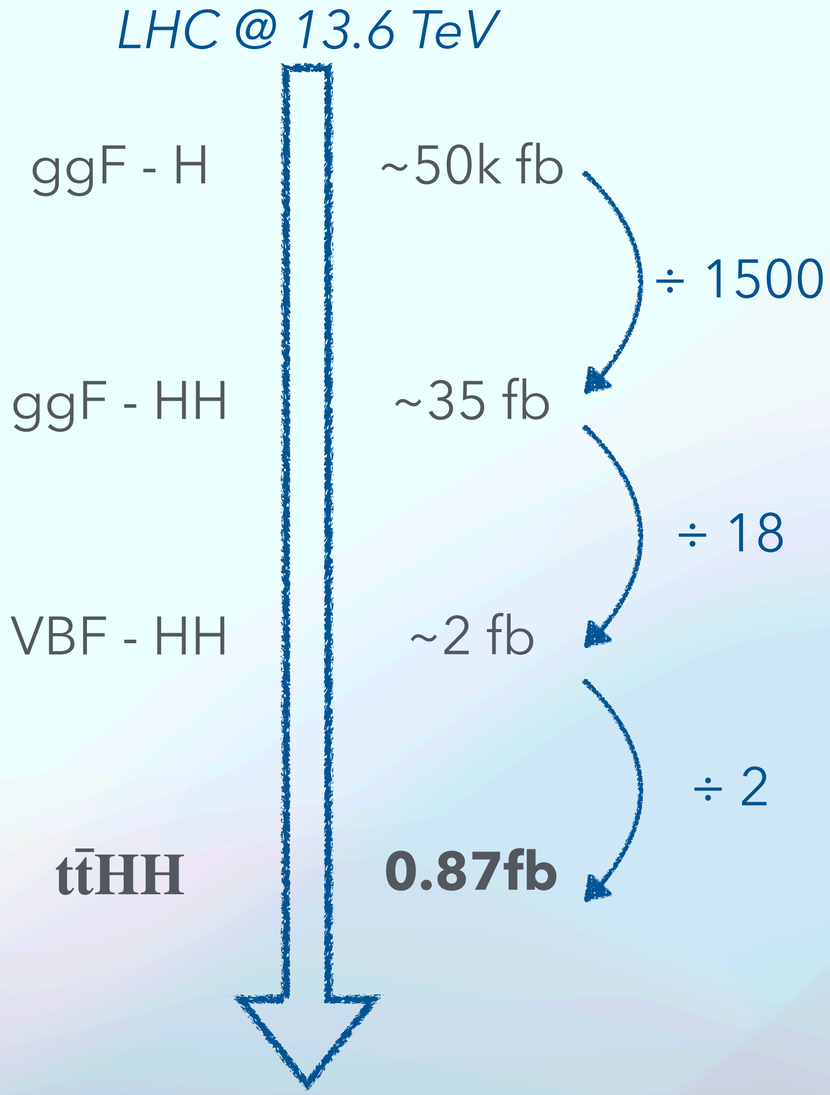
Adrien Auriol, `adrien.auriol@cern.ch`
o.b.o the ATLAS collaboration
21st March, 2026

Run: 438481
Event: 550081963

Motivations



- 3rd leading HH production mode @ LHC



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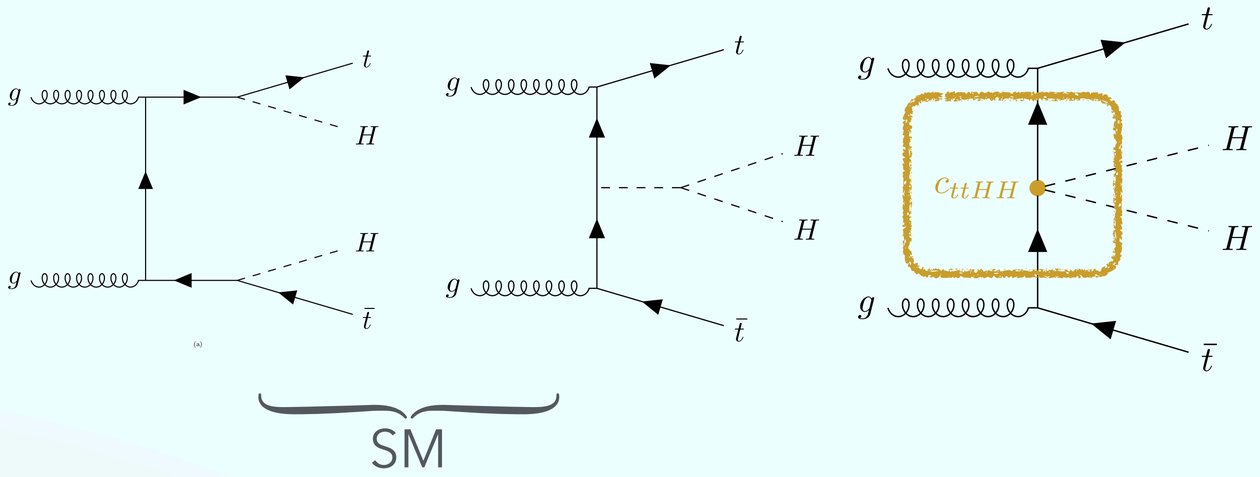
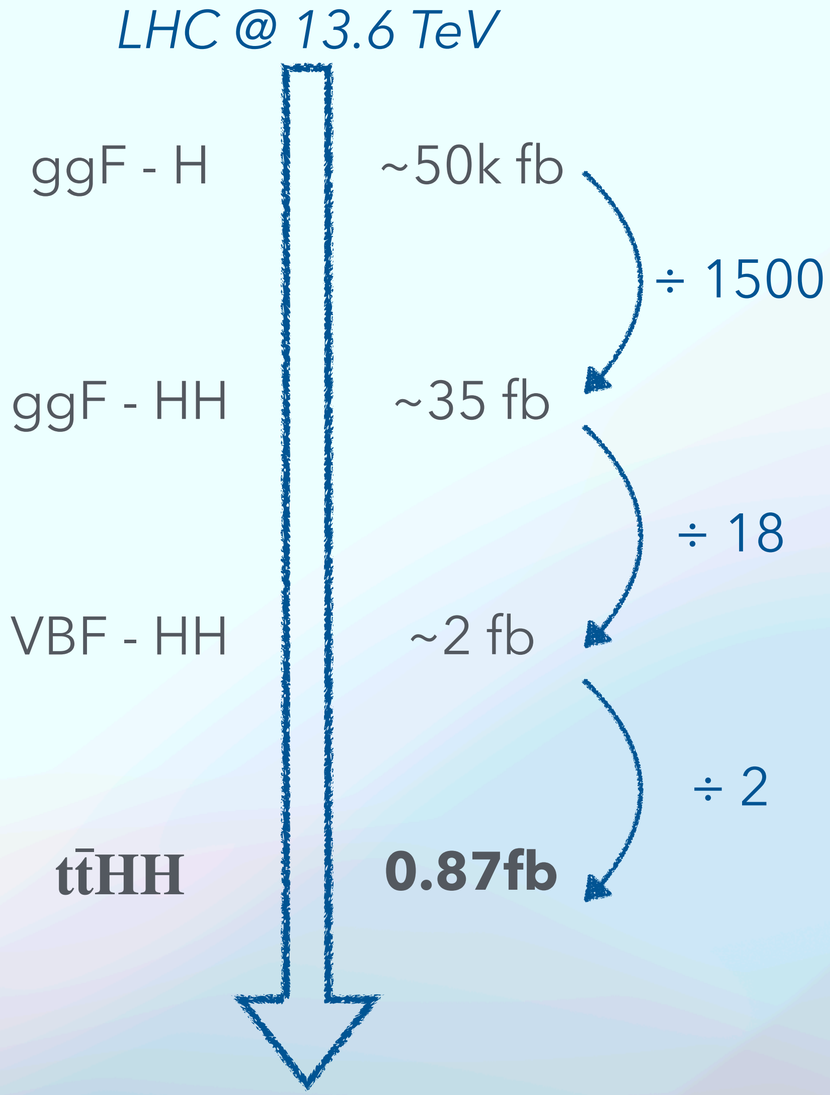
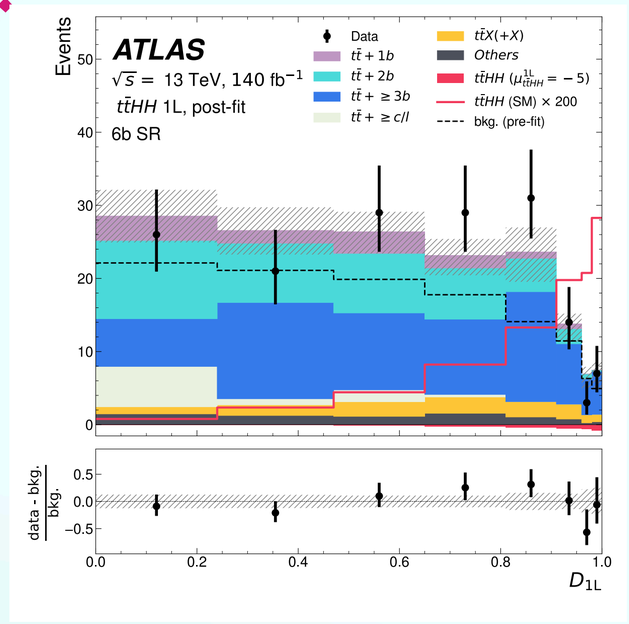


- <u>3rd leading</u> HH production mode @ LHC
- Gives **direct** access to $t\bar{t}HH$ quartic interaction



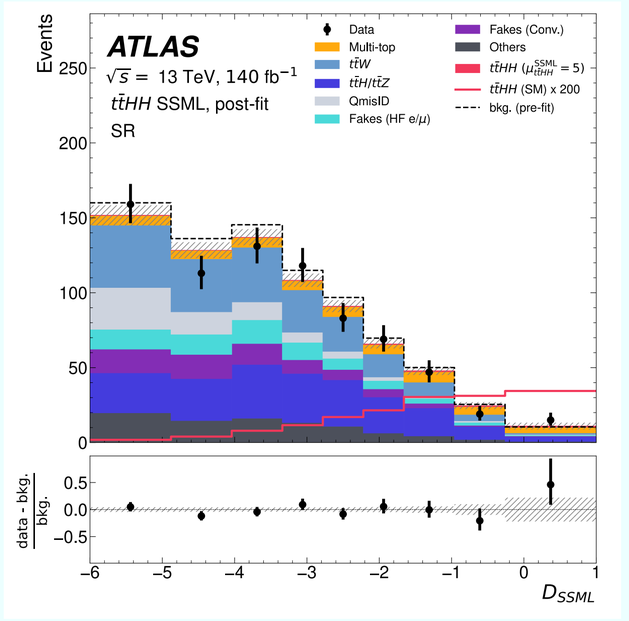
Strategy



Single lep. channel (1L)

$HH \to 4b$ and semileptonic $t\bar{t}$

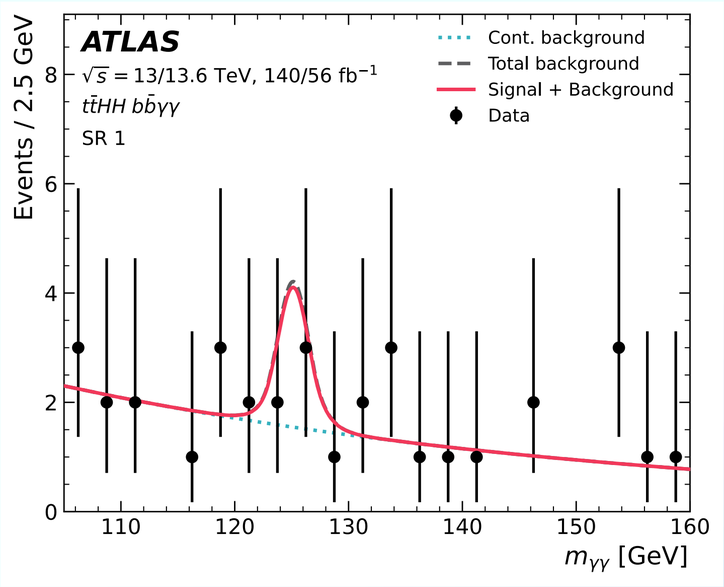
Obs. limit on μ : **26** x SM



Multi-lep. Channel (ML)

$HH \to b\bar{b}WW, b\bar{b}\tau\tau, \ldots$

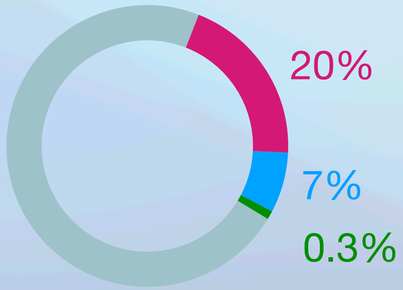
Obs. limit on μ : **40** x SM



$b\bar{b}\gamma\gamma$ **channel**

$HH \to b\bar{b}\gamma\gamma$

Obs. limit on μ : **75** x SM



- 1L and ML : Fit Transformer score
- $b\bar{b}\gamma\gamma$: Fit on $m_{\gamma\gamma}$ after BDT selection

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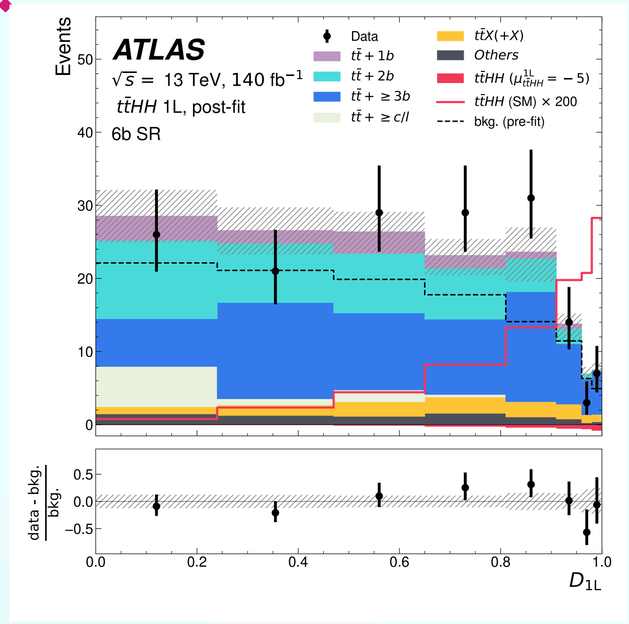

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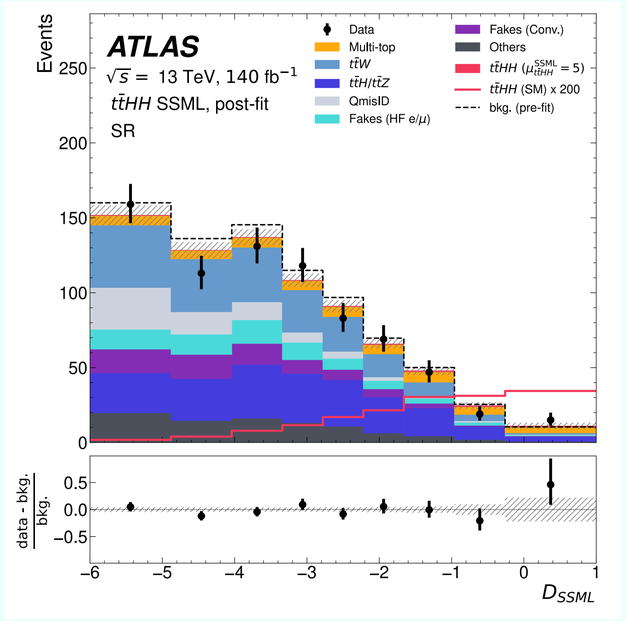

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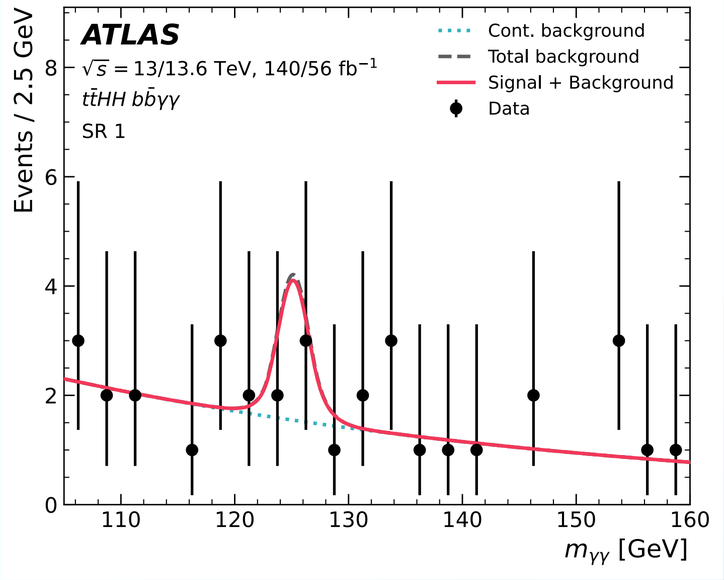

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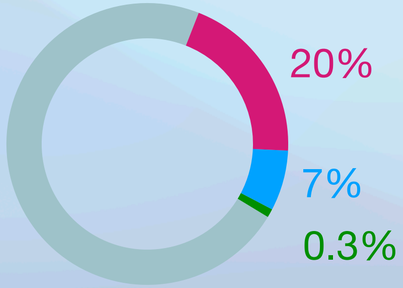

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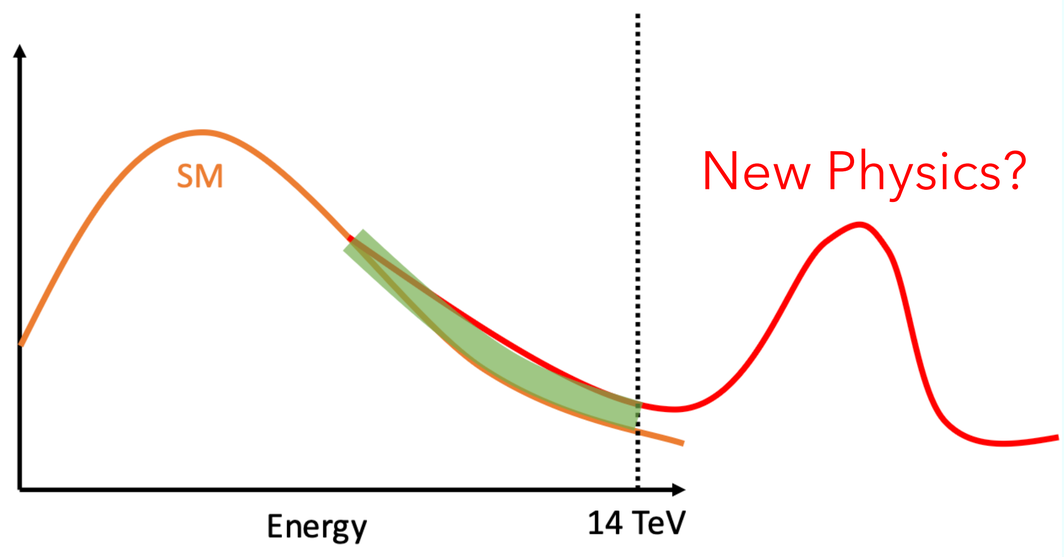
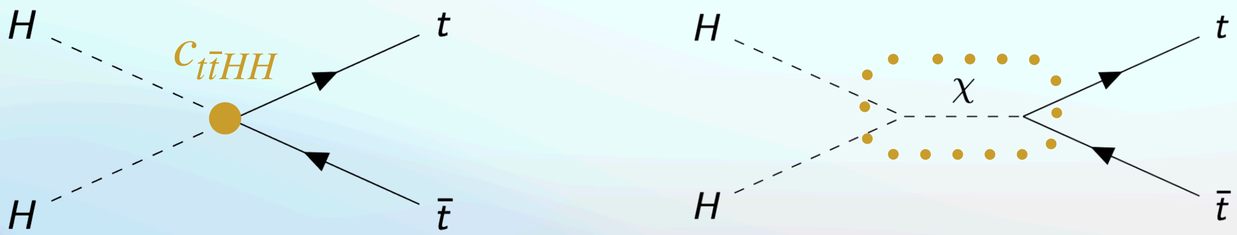
(Higgs) Effective Field Theory

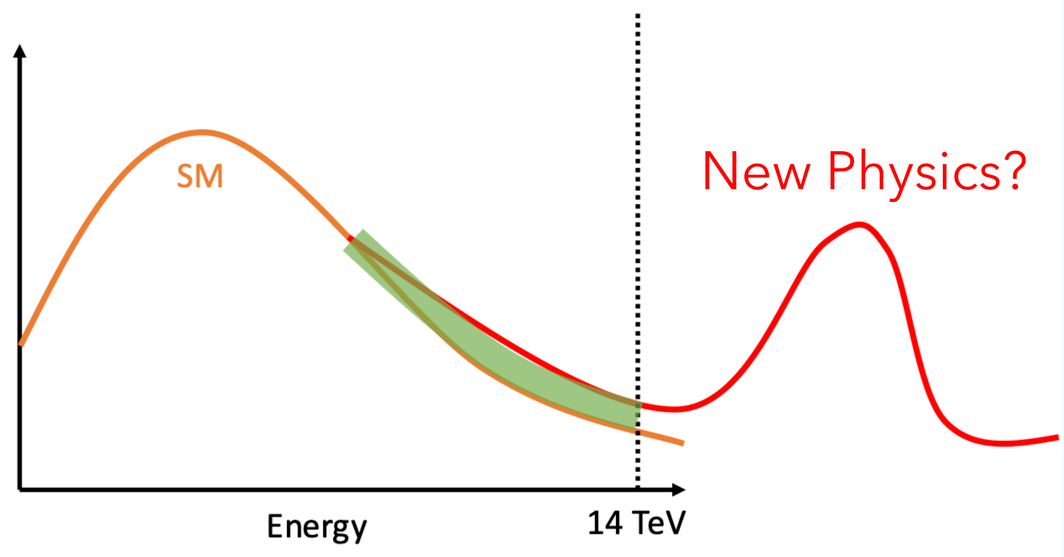


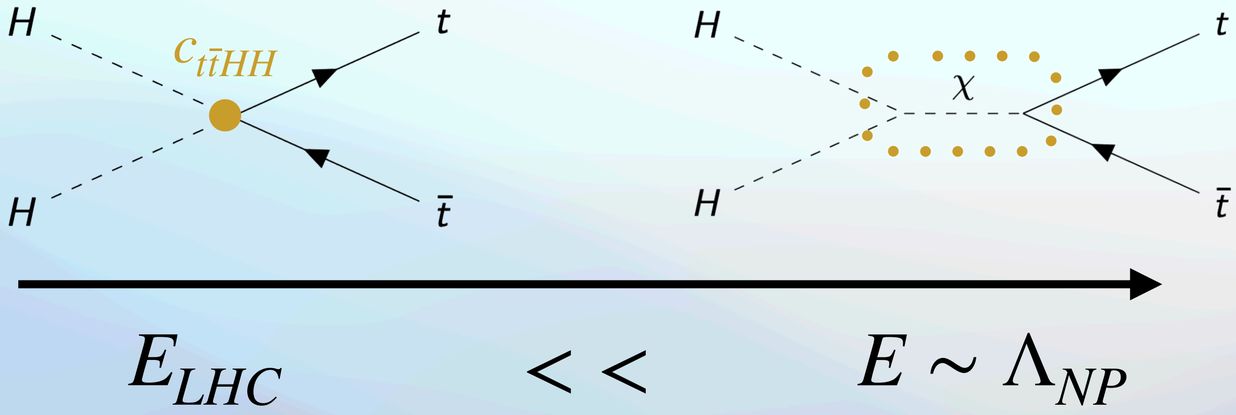


$$E_{LHC} << E \sim \Lambda_{NP}$$

(Higgs) Effective Field Theory

$$\mathscr{L}_{\text{HEFT}} \supset -m_t(c_{t\bar{t}H}\frac{h}{v} + c_{t\bar{t}HH}\frac{h^2}{v^2})t\bar{t} - \kappa_\lambda \frac{m_H^2}{2v}h^3$$





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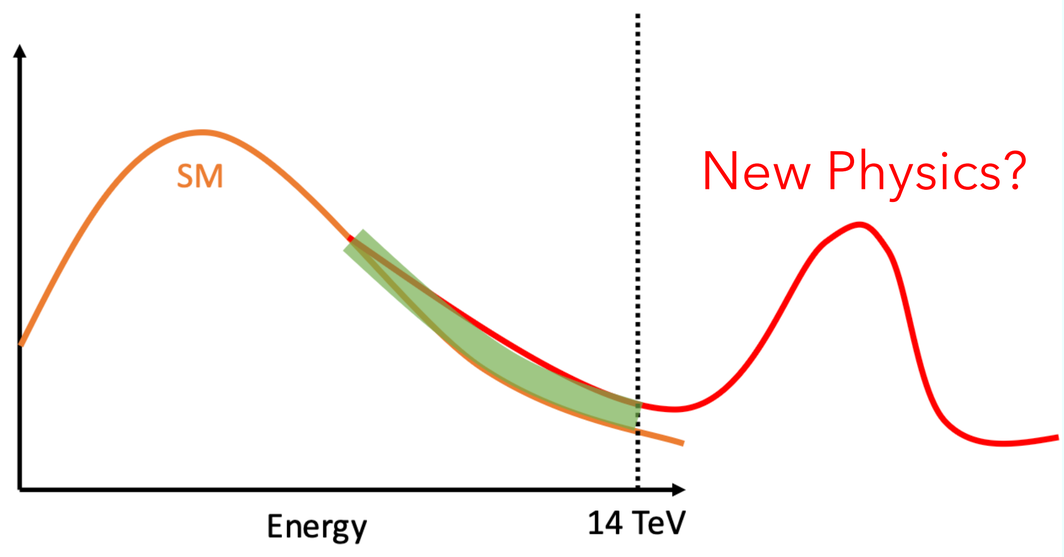
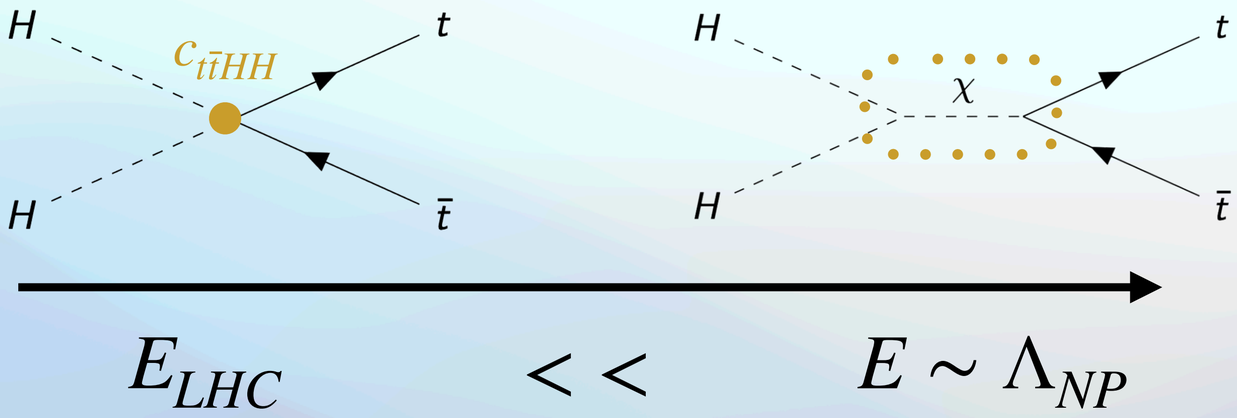


- HEFT relaxes the assumption that the physical Higgs boson h is part of a $SU(2)_L$ doublet

  → Higgs properties unconstrained by EWSB pattern

  → **single and multi-Higgs couplings are decoupled**



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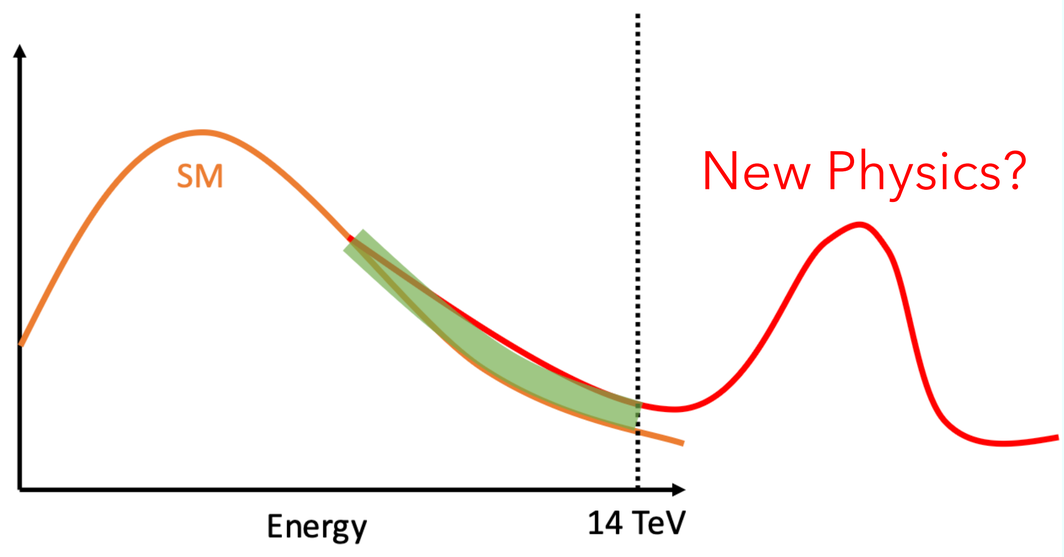

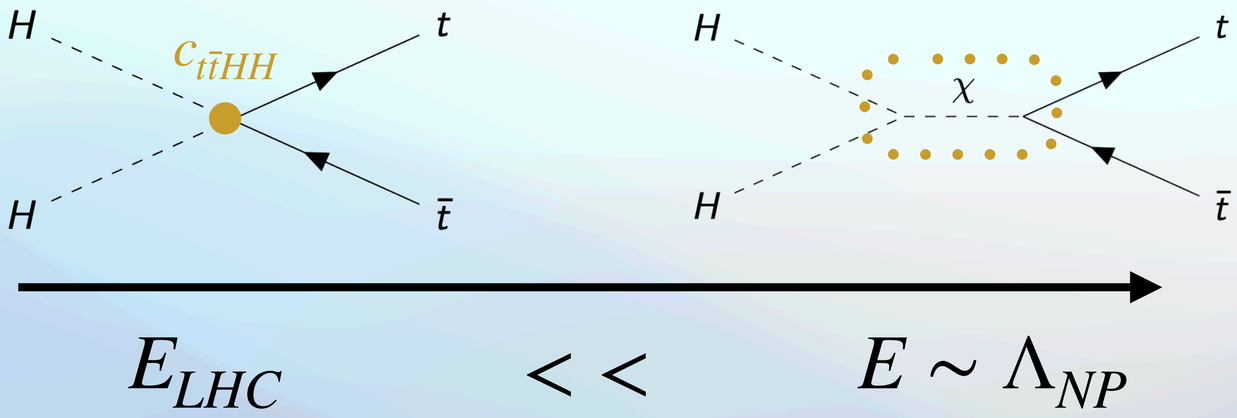

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- Other Wilson coefficients affecting the process such as $\kappa_\lambda, c_{t\bar{t}H}$ *left at SM values (= 1)*

Strategy and results

Exploit **cross-section dependance** in 1L and ML channels

Reinterpretation

$$\mathscr{L}(d\,|\,\mu) \longrightarrow \mathscr{L}(d\,|\,\sigma(\,c_{t\bar{t}HH}\,))$$

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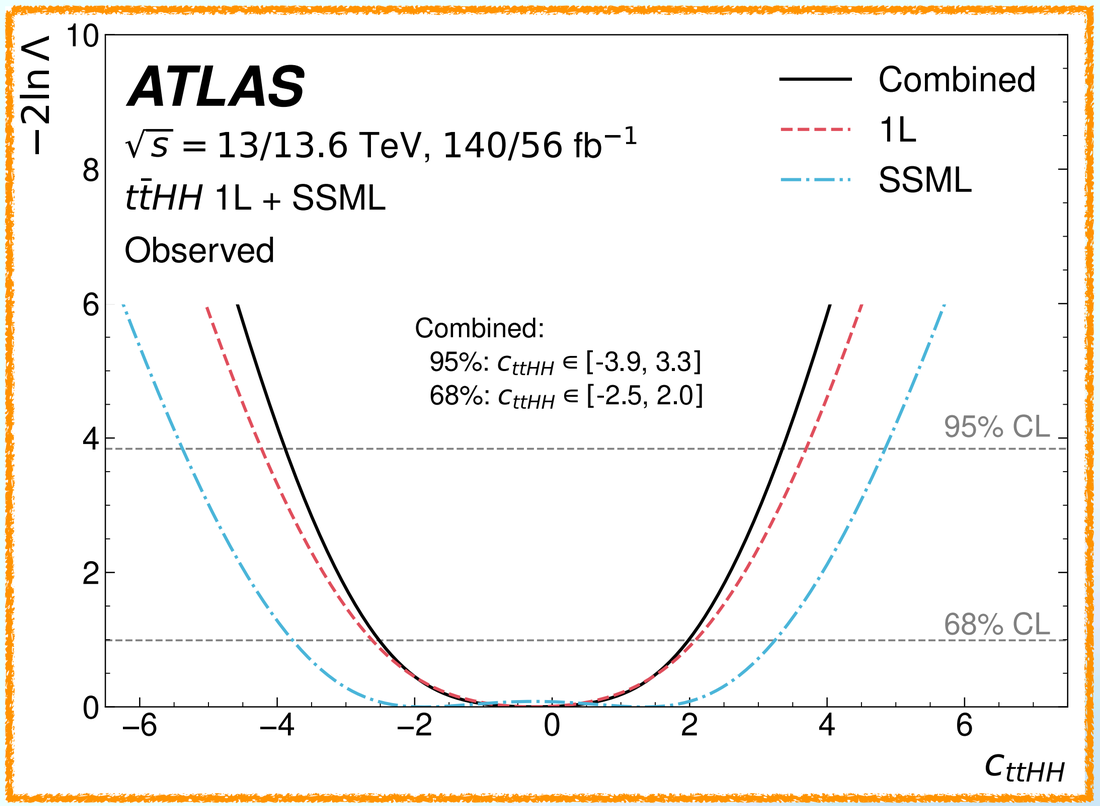

Almost flat likelihood (small degeneracy in ML channel)

Exp. : $c_{t\bar{t}HH} \in [-4.1, 3.5]$ @ 95 % CL

Obs. : $c_{t\bar{t}HH} \in [-3.9, 3.3]$ @ 95 % CL

Conclusion and outlook

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	CMS $t\bar{t}HH$ [CMS-PAS-HIG-23-004]	**ATLAS HH comb.** [arXiv:2406.09971]	**CMS HH comb.** [arXiv:2510.07527]
Obs. 95% CL limits on $c_{t\bar{t}HH}$	[-8.0, 7.5]	[-0.19, 0.7]	[-0.29, 0.59]

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- ggF more sensitive, but parametrised with two additional Higgs-gluon couplings : c_{ggH} and c_{ggHH}

  → In $t\bar{t}HH$, these enter at higher loop order

  → More challenging in ggF unless further assumptions imposed

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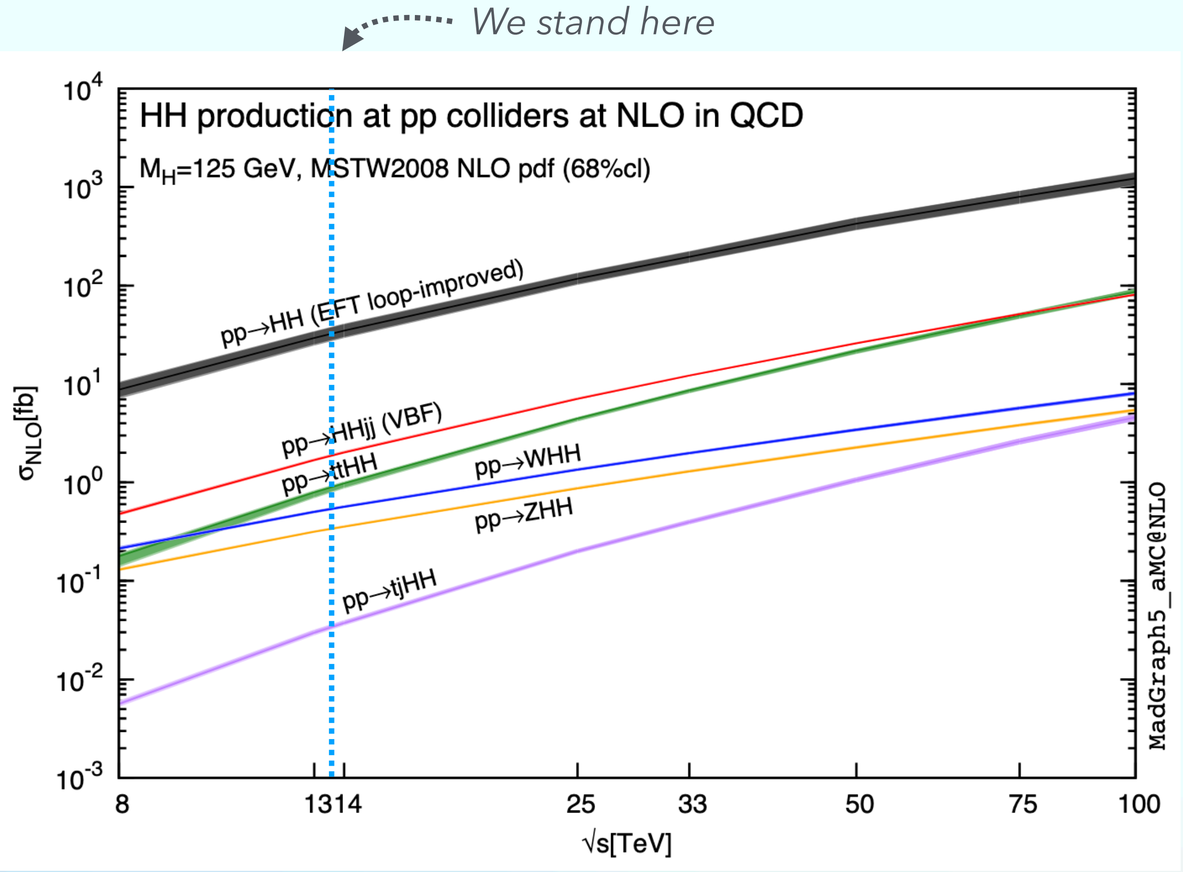
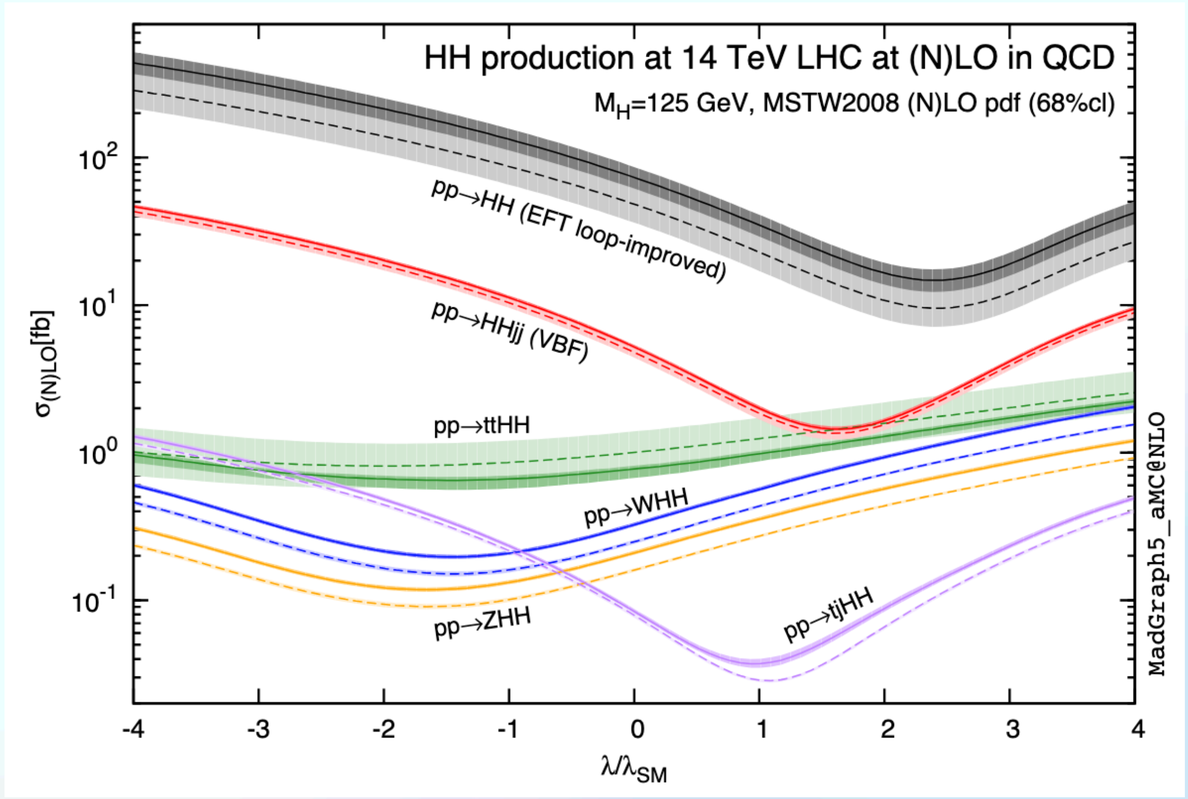
Backup

ttHH production

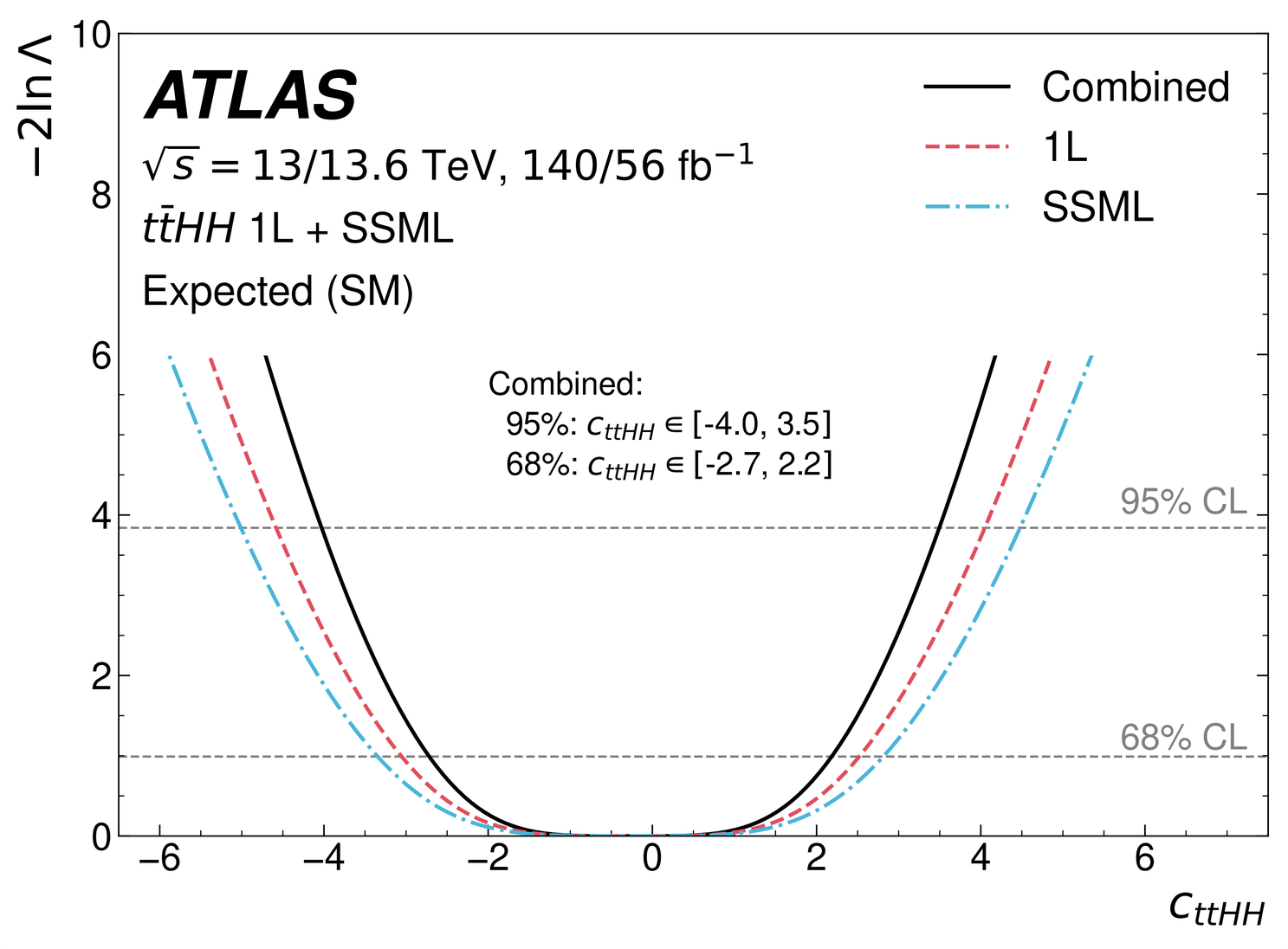
[arXiv:1401.7340]





- Cross-section scales faster with $\sqrt{s}$
- Unique interference pattern dependance on κ_λ

Expected likelihood for EFT fit



EFT modelling

- Modification of the SM Lagrangian with additional vertices $c_{t\bar{t}HH}$, $c_{t\bar{t}H}$, κ_λ
- Implemented by M. Ryczkowski & R. Groeber using FeynRules UFO model format. Can be found on github.com/Ryczek/CttHH
- Model validated against SMEFT using SMEFTsim with internal studies

$$c_{t\bar{t}HH} = -\frac{3v^3}{2\sqrt{2}\Lambda^2 m_t} c_{uH} + \frac{v^2}{\Lambda^2} c_{H\Box} - \frac{v^2}{4\Lambda^2} c_{HD}$$

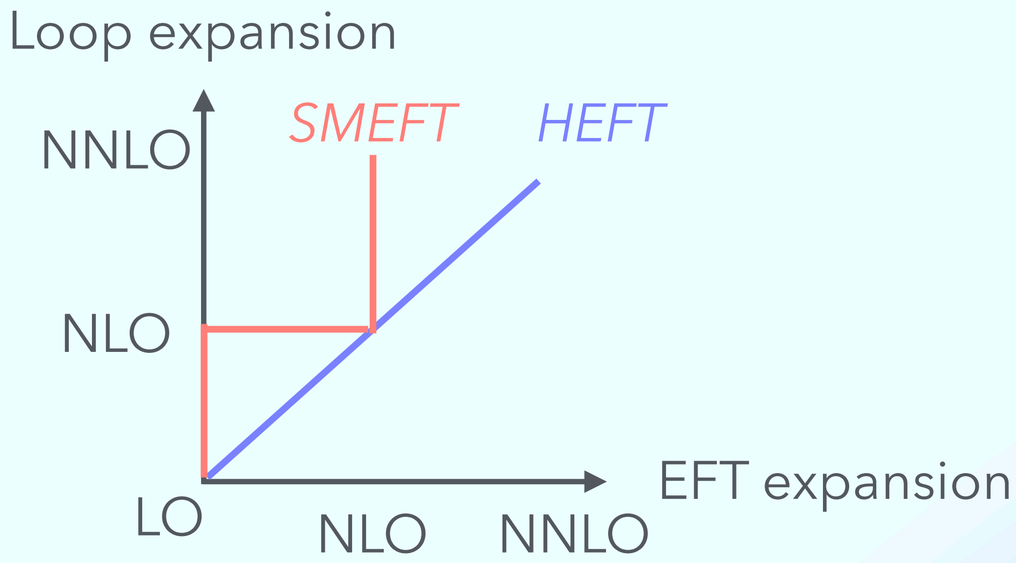
$$c_{HHH} = 1 - \frac{v^2}{\Lambda^2}\left(2\frac{v^2}{m_H^2} c_H - 3c_{H\Box} + \frac{3}{4} c_{HD}\right)$$

$$c_{t\bar{t}H} = 1 - \frac{v^2}{\Lambda^2}\left(c_{H\Box} - \frac{1}{4} c_{HD}\right) - \frac{v^3}{\sqrt{2}\Lambda^2 m_t} c_{uH}$$

[arXiv:2304.01968]

HEFT vs. SMEFT power counting

[arXiv:2511.23410]



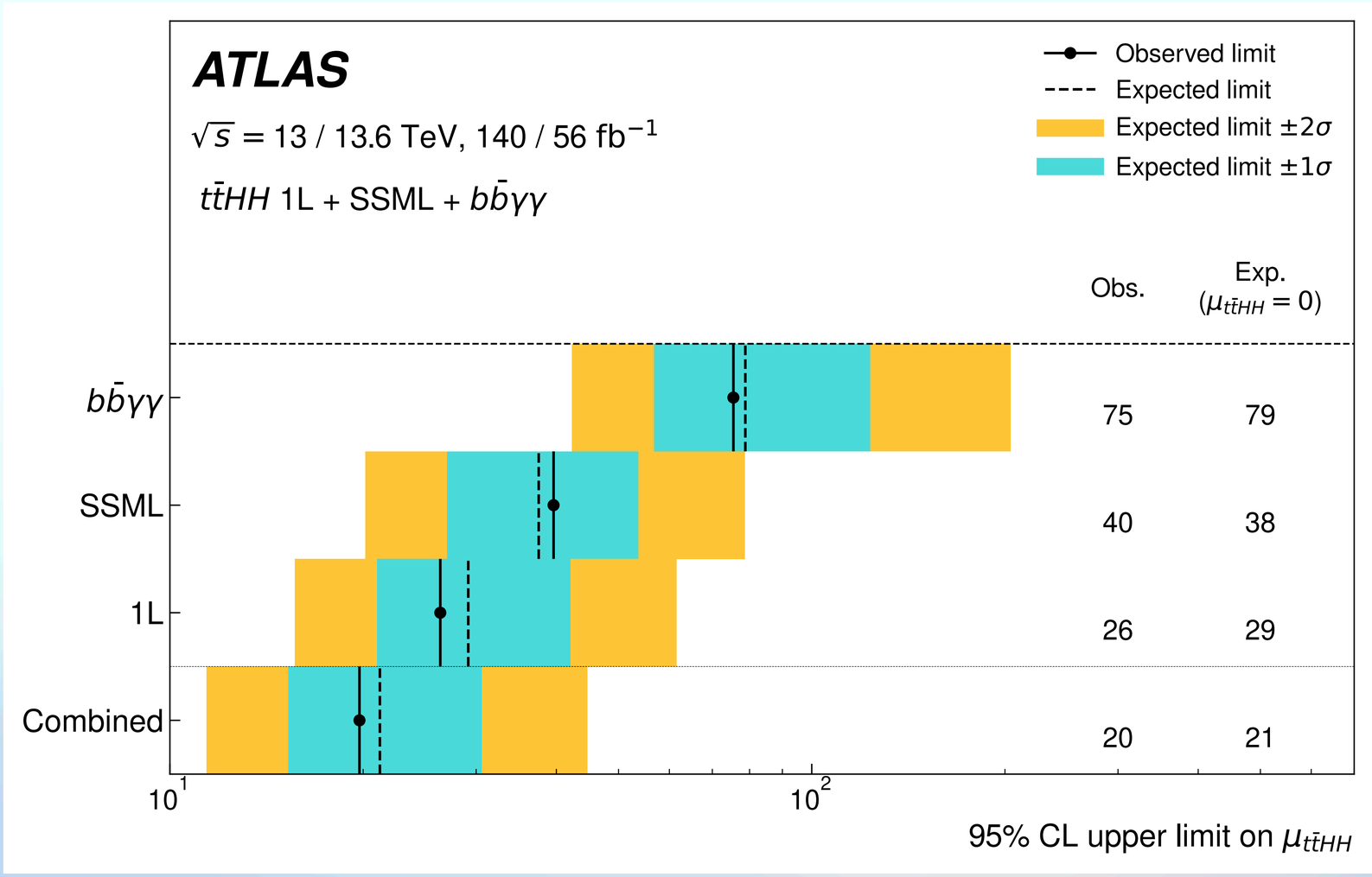
SMEFT power counting keeps EFT independent of loop expansion

HEFT power counting counts loops, so one is constrained on the diagonal

EFT uncertainties

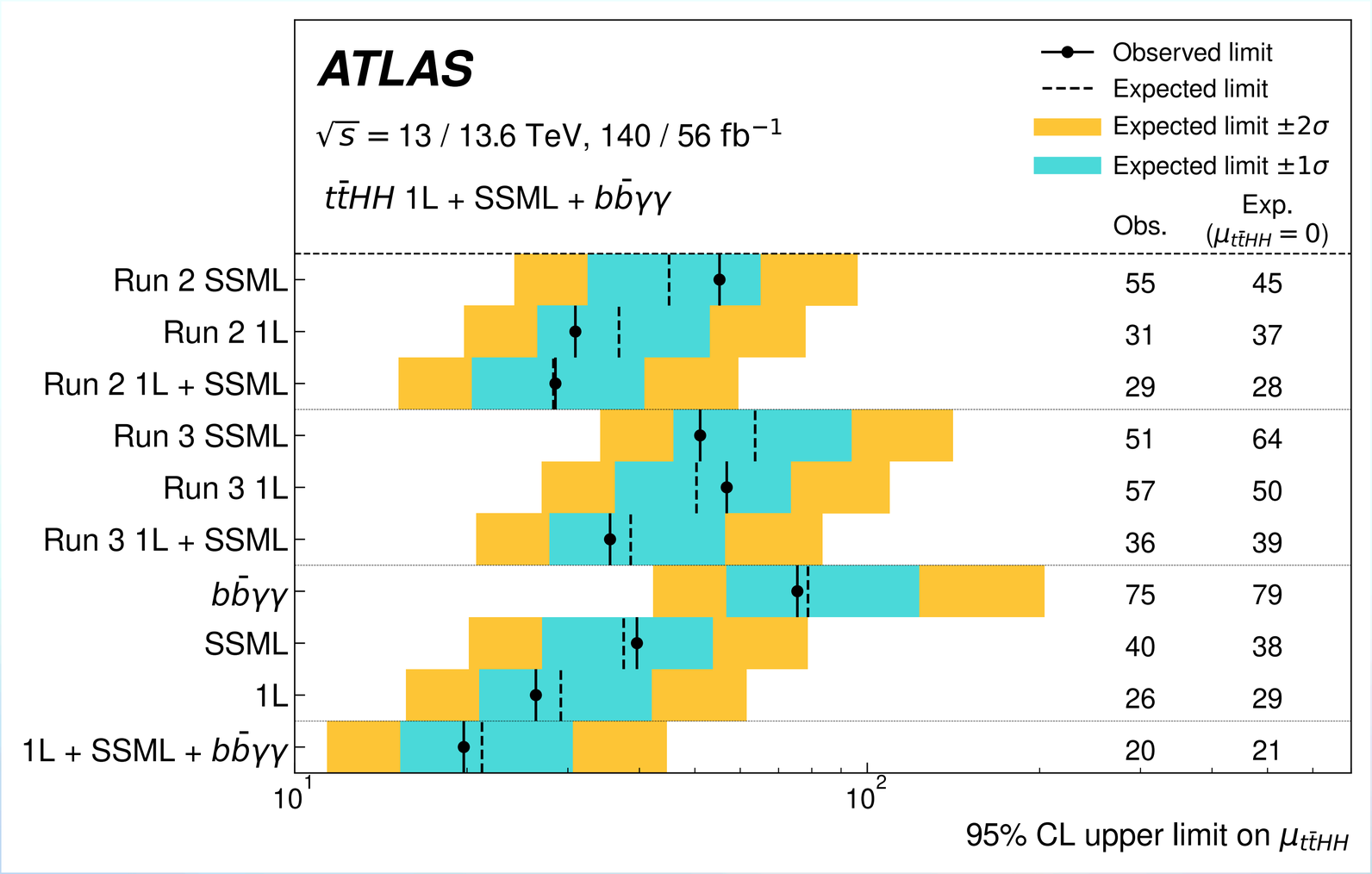
Acceptance effects are evaluated for values of $c_{t\bar{t}HH}$ close to the exclusion limits and are covered by an additional 30% uncertainty in the signal yield included in the measurement. An estimate of the kinematic-shape effects is found to impact the 95% CL interval on $c_{t\bar{t}HH}$ by at most 10%, which is not included in the quoted limits.

Results on signal stength



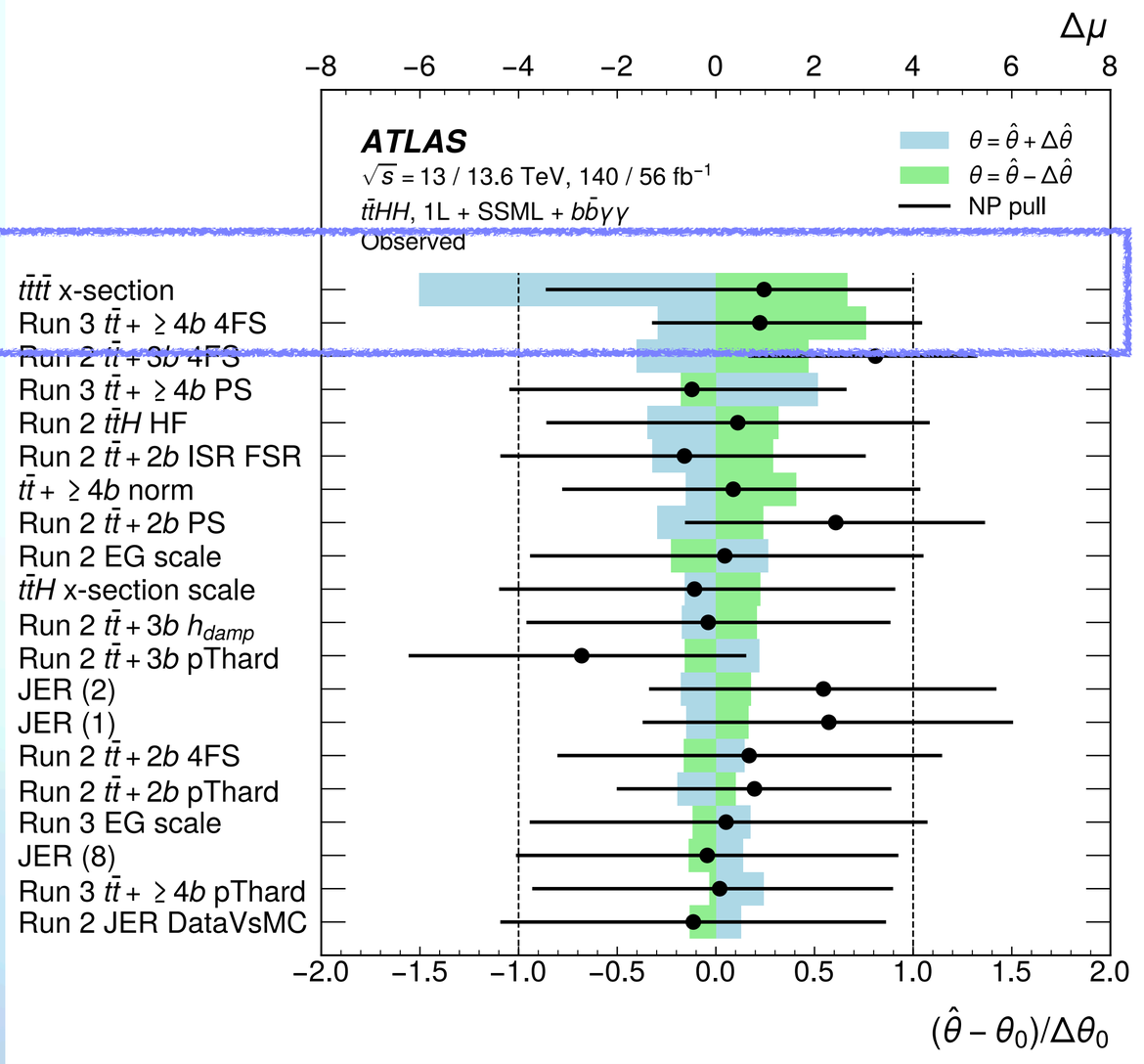
- No excess observed
- 95% CL Upper Limits : **20 (21) x SM**
- Most stringent limits to date

Signal strength results split by channels



- 1L and ML are the most sensitive channels

Syst. uncertainty splitting



- Dominated by 4 tops and $t\bar{t} + jets$

Input variables to the GNN

Variable	Description
(p_T, η, ϕ, E)	Kinematic variables of the object, i.e. transverse momentum, pseudorapidity, azimuthal angle, and energy.
w_{GN2}	GN201 b-tagging pseudo-continuous score for identifying jets. Non-jet objects are assigned a value of zero.
$q_{\text{Lep.}}$	Charge of the object. Non-lepton objects are assigned a value of zero.
(isJet, isLep, isMET)	Boolean flags indicating the object type: jet, lepton, or missing transverse energy.

Single-lepton channel

Variable	Description
Event-level	
N_{jets}	Number of jets
$N_{\text{b-jets}}$	Number of b-tagged jets
N_{lepton}	Number of leptons
H_{T}	The scalar sum of the transverse momenta of the leptons and jets in an event.
MET	Transverse energy of the missing momentum vector.
MET_PHI	Azimuthal angle of the missing momentum vector.
Object-level	
(p_T, η, ϕ)	Kinematic variables of the object, i.e. transverse momentum, pseudorapidity, and azimuthal angle.
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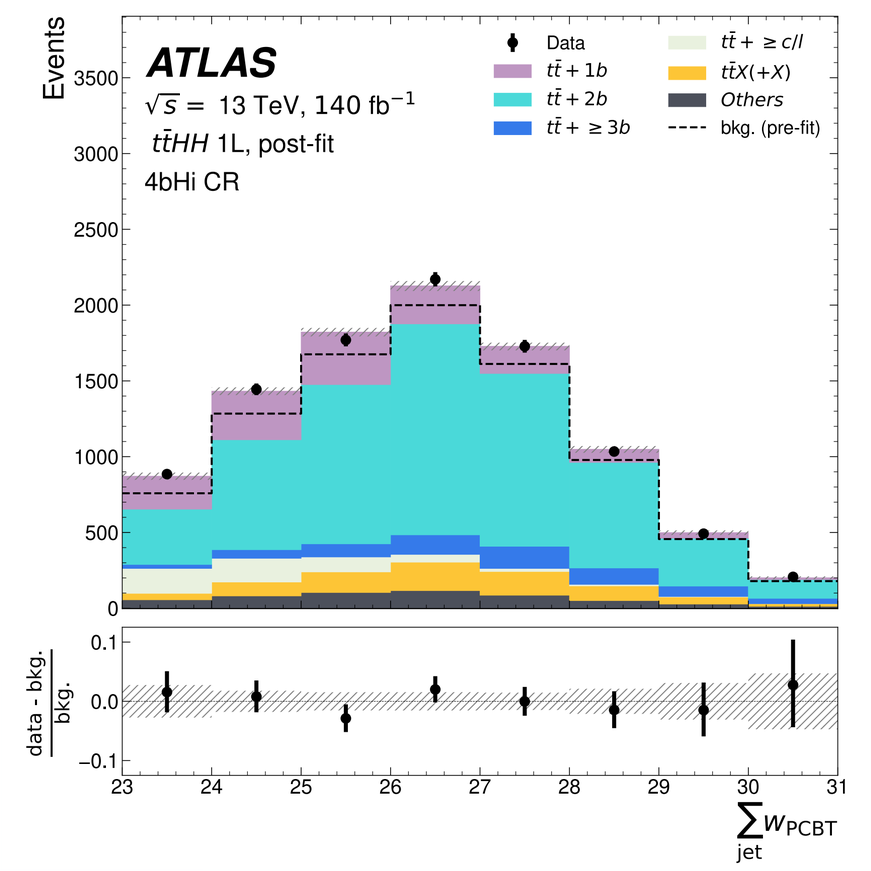
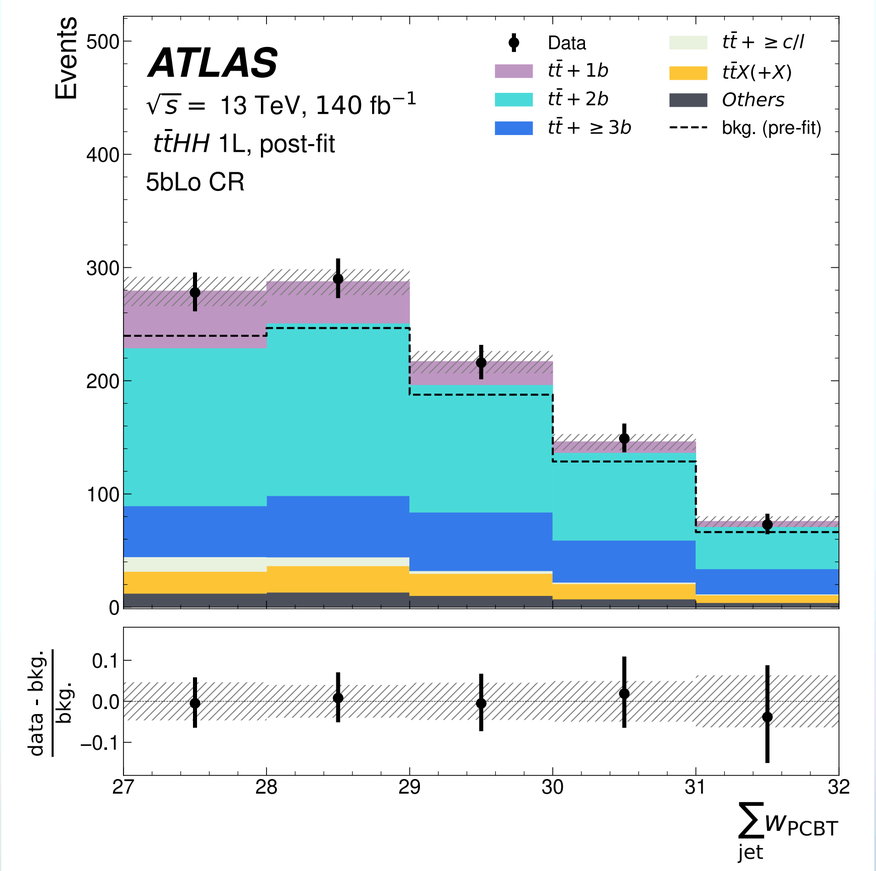
(isJet, isElectron, isMuon)	Boolean flags indicating the object type: jet, electron, or muon.

Multi-lepton channel

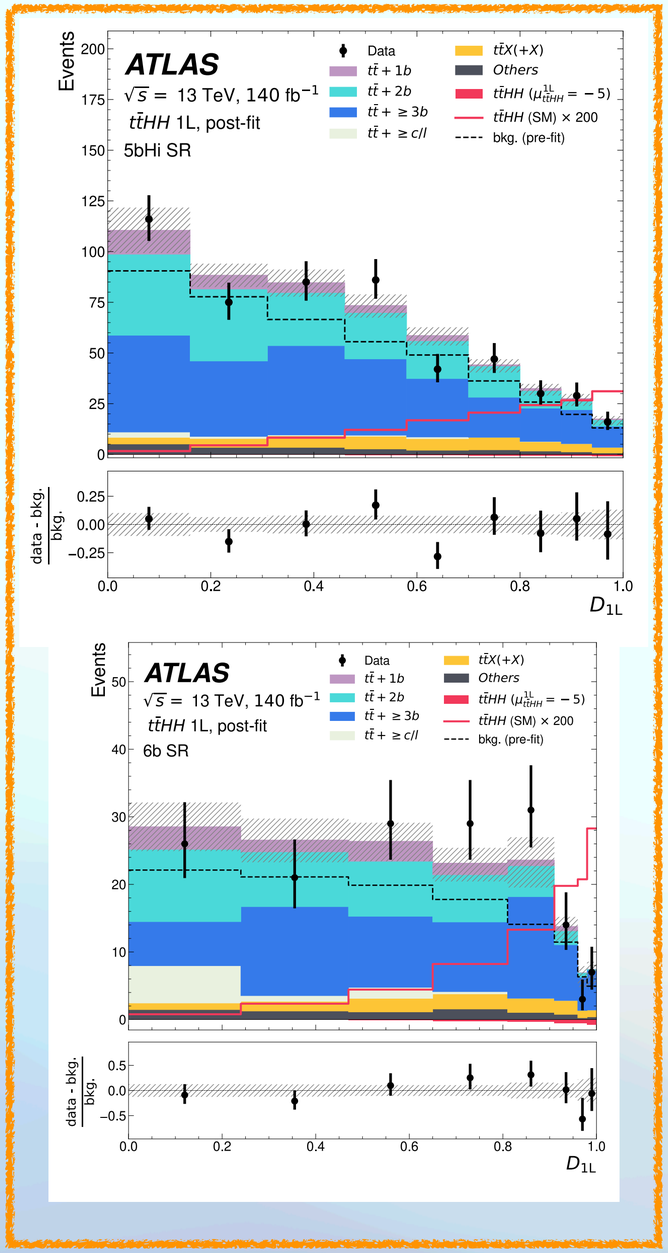
1L Run 2 CR distributions

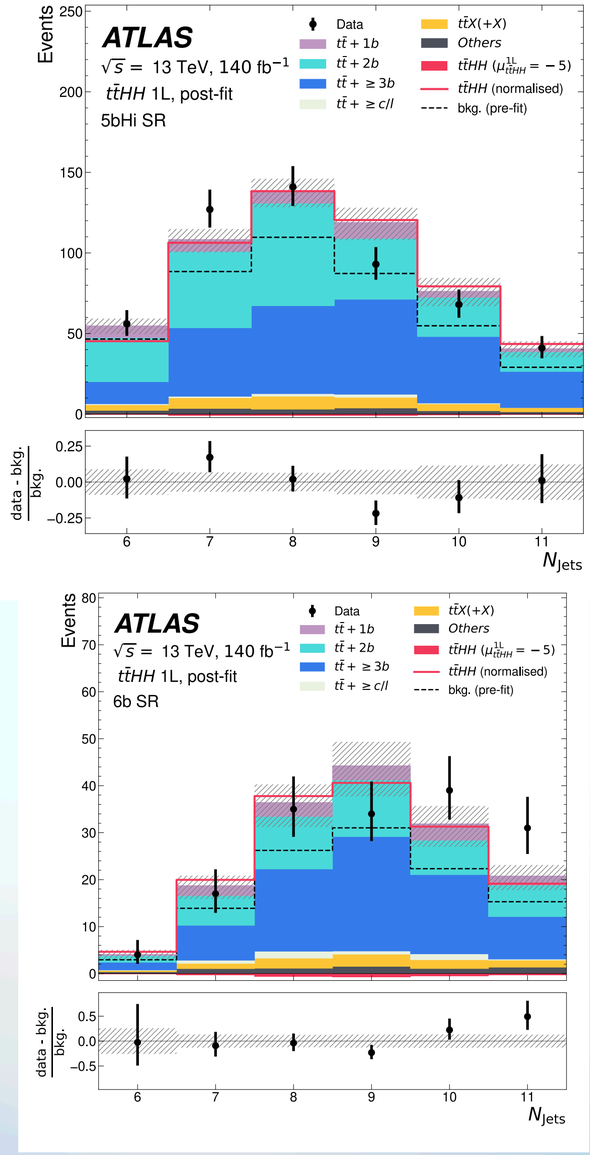


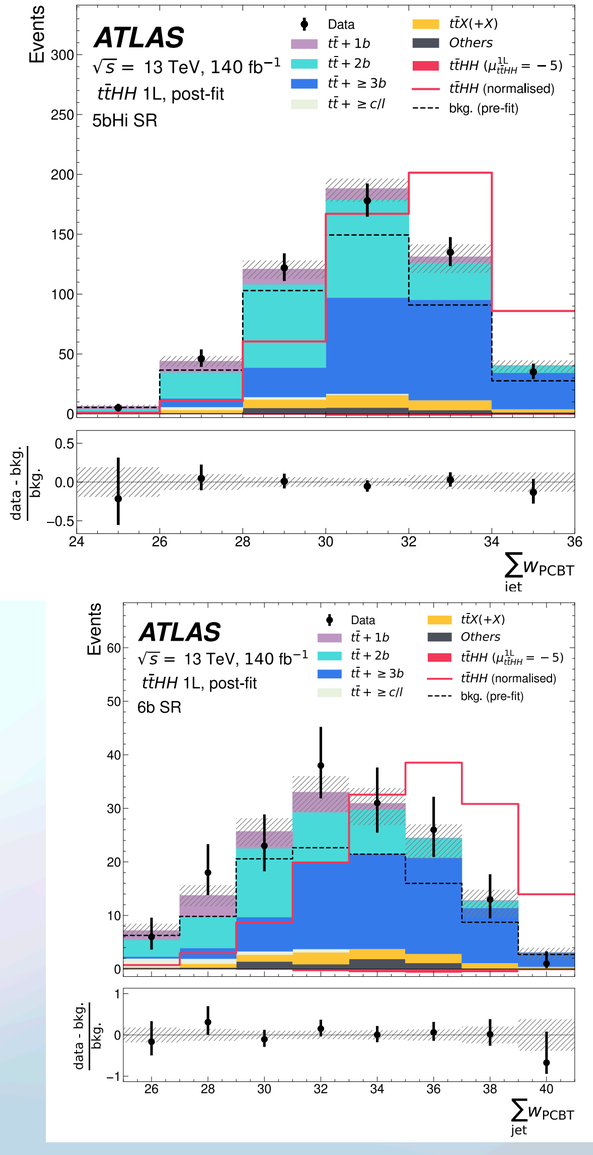


- Signal defined by jet multiplicity
- Well understood background

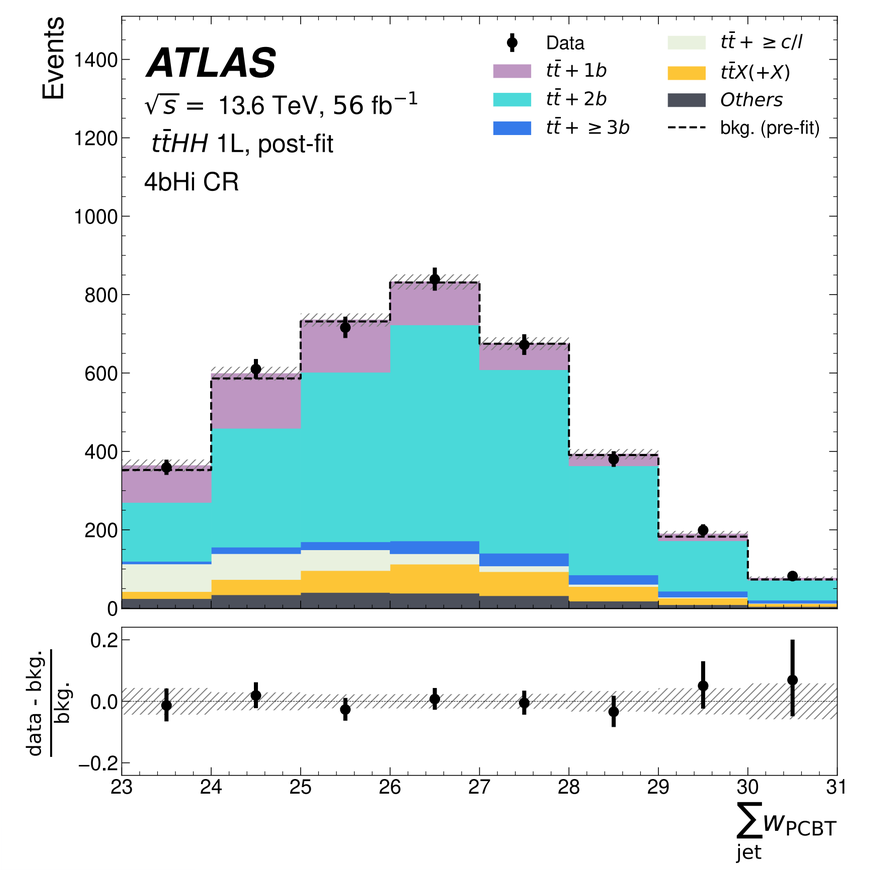
1L Run 2 SR distributions

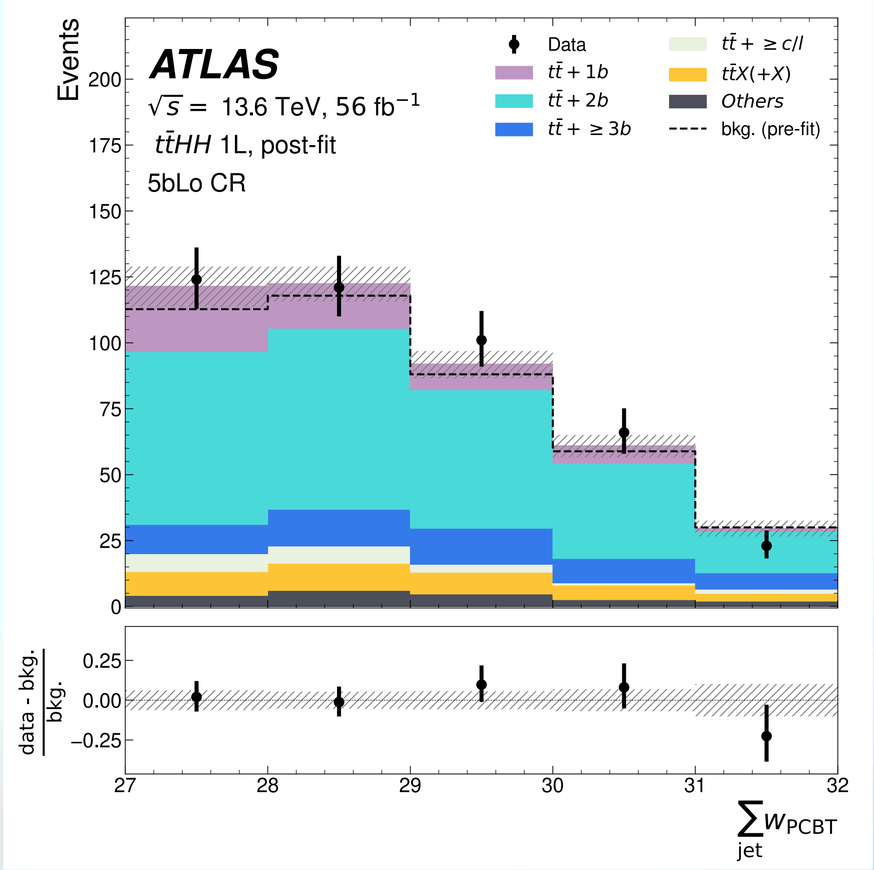






1L Run 3 CR distributions





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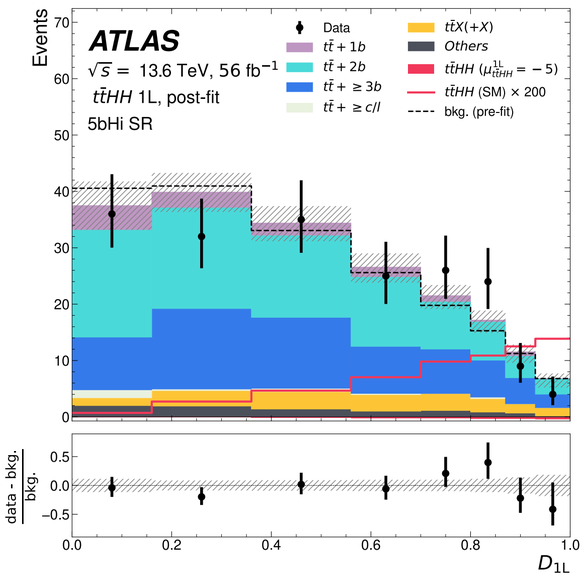
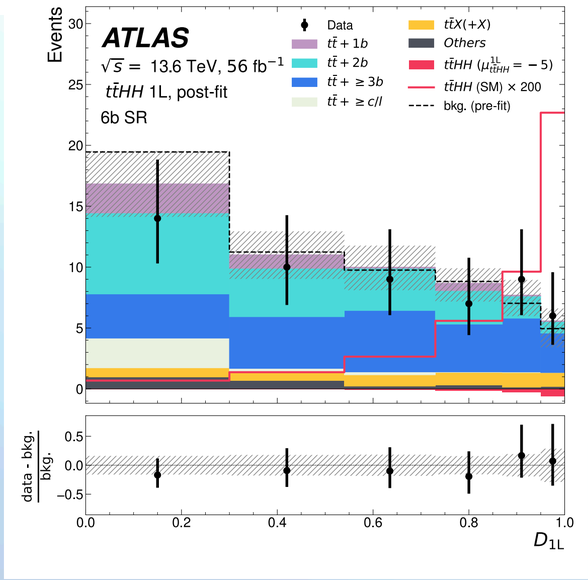
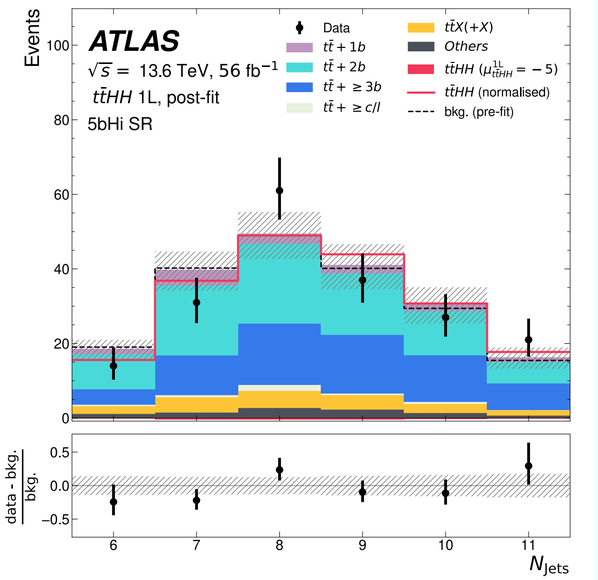
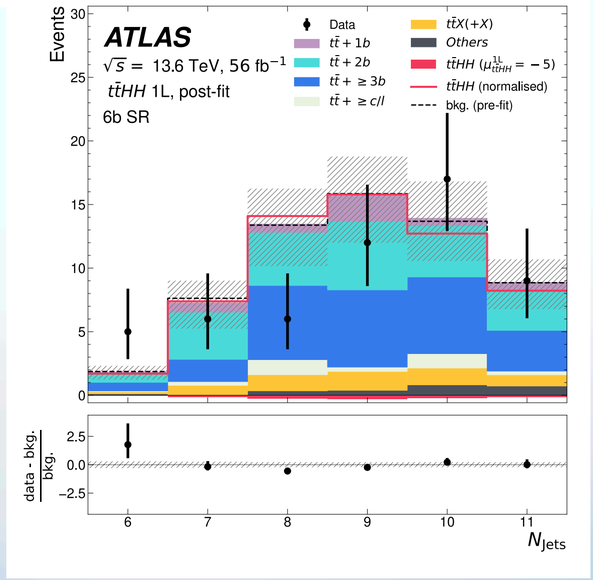
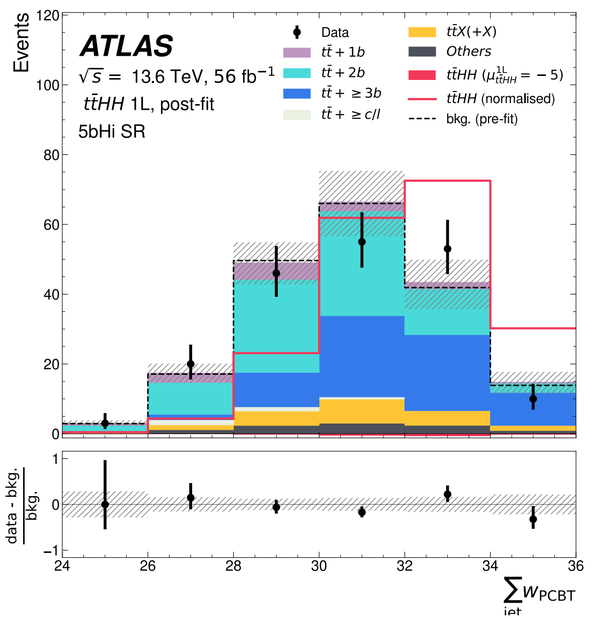
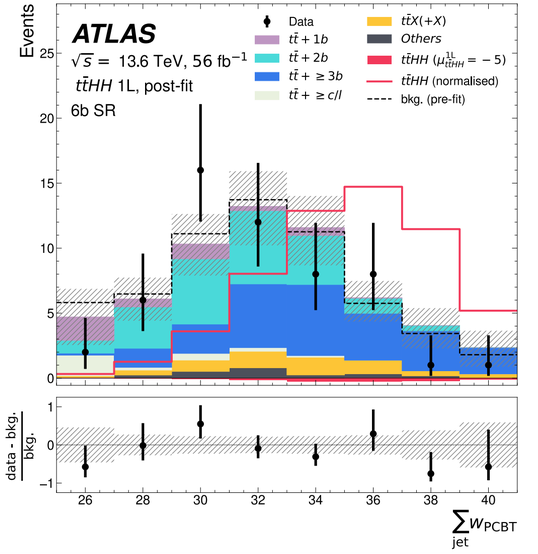




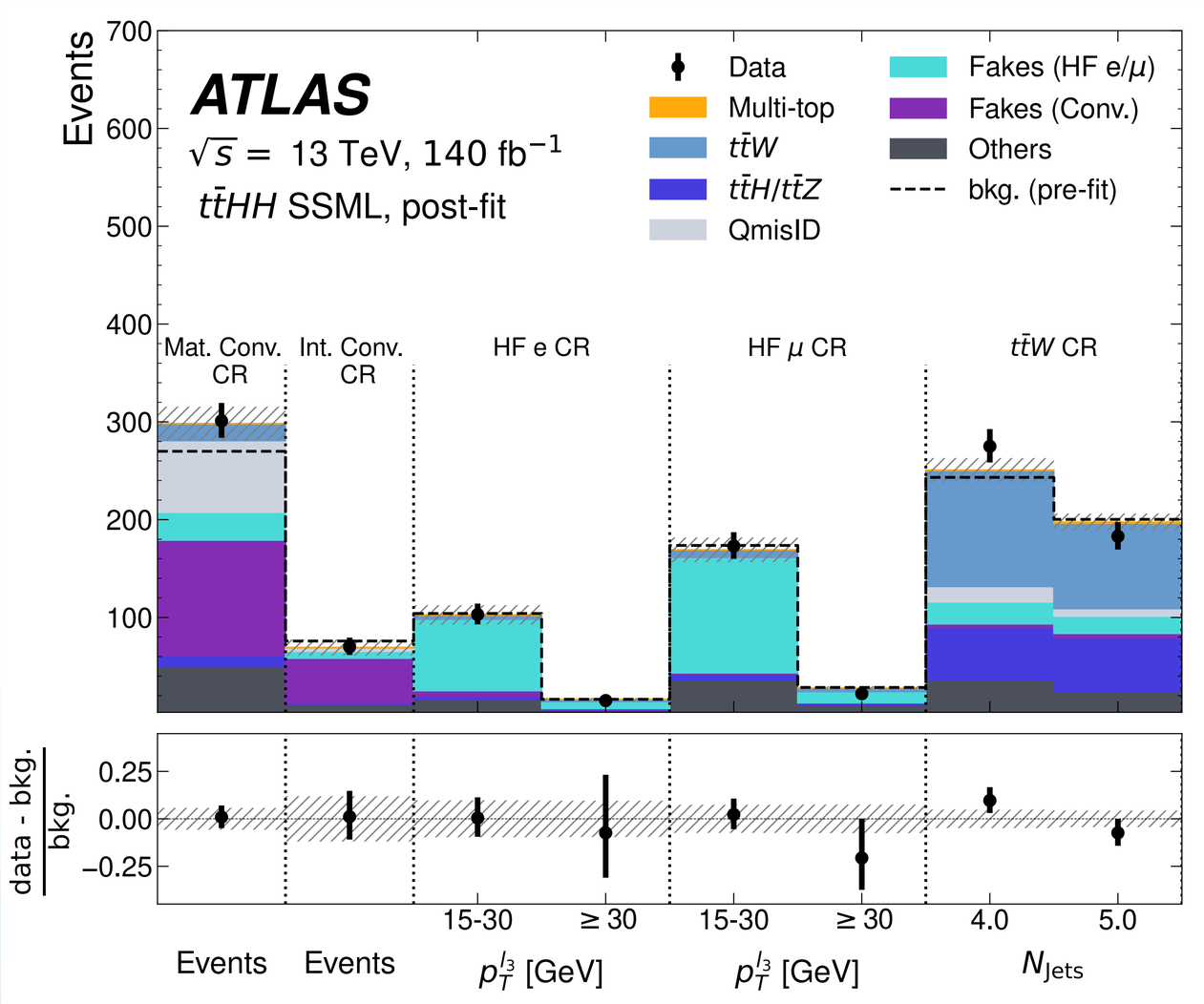




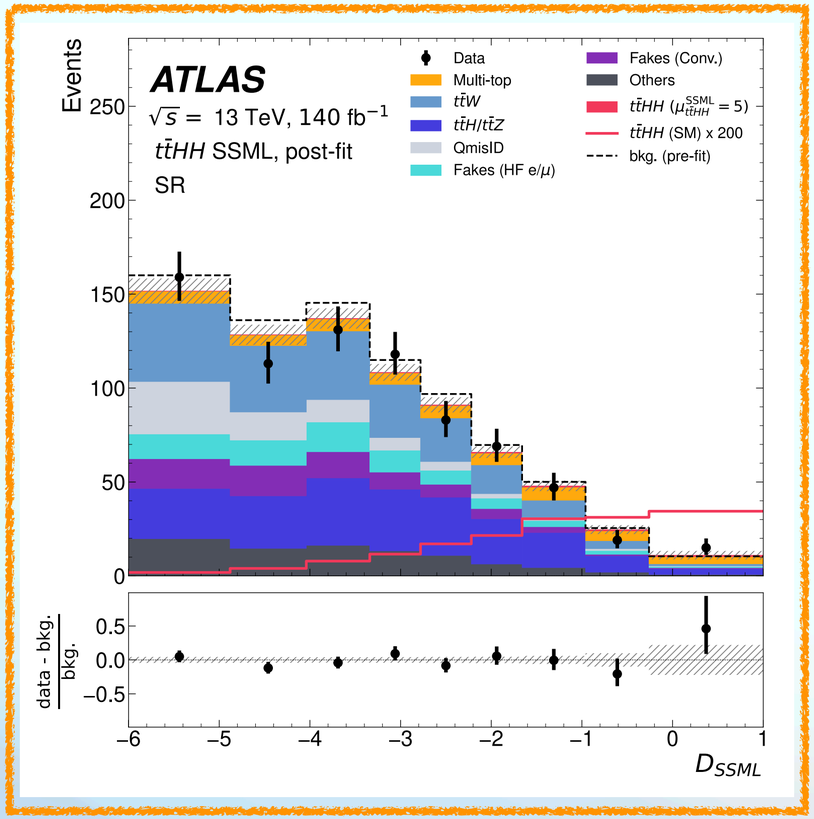


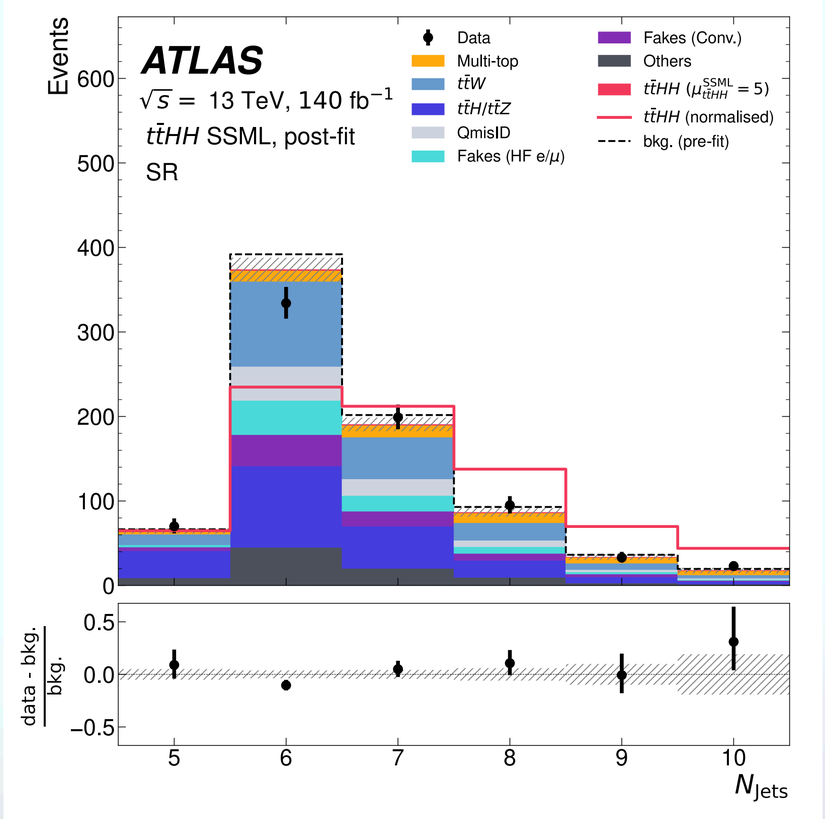


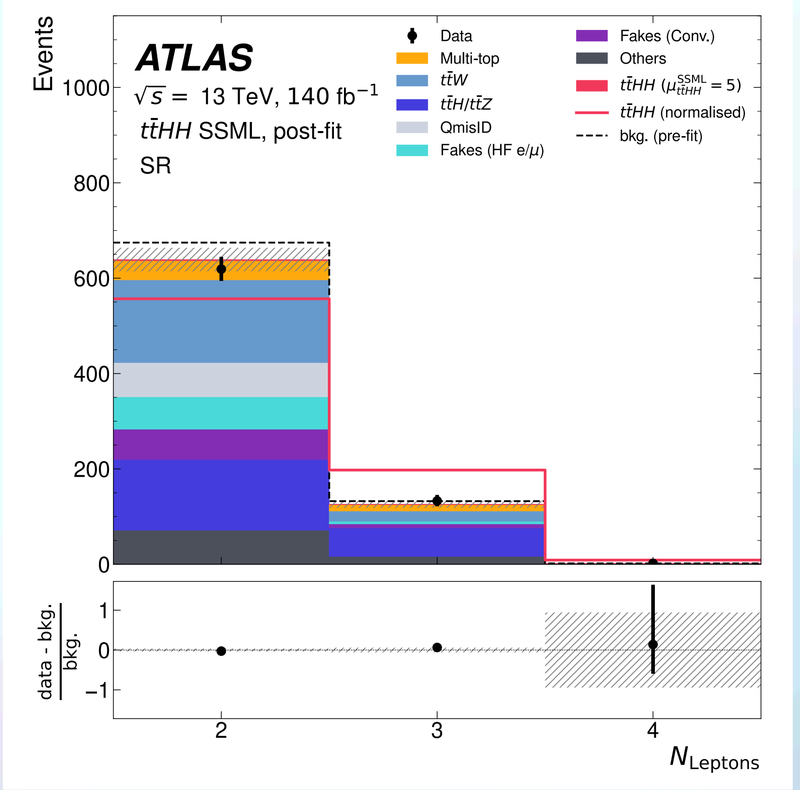
ML Run 2 CR distributions



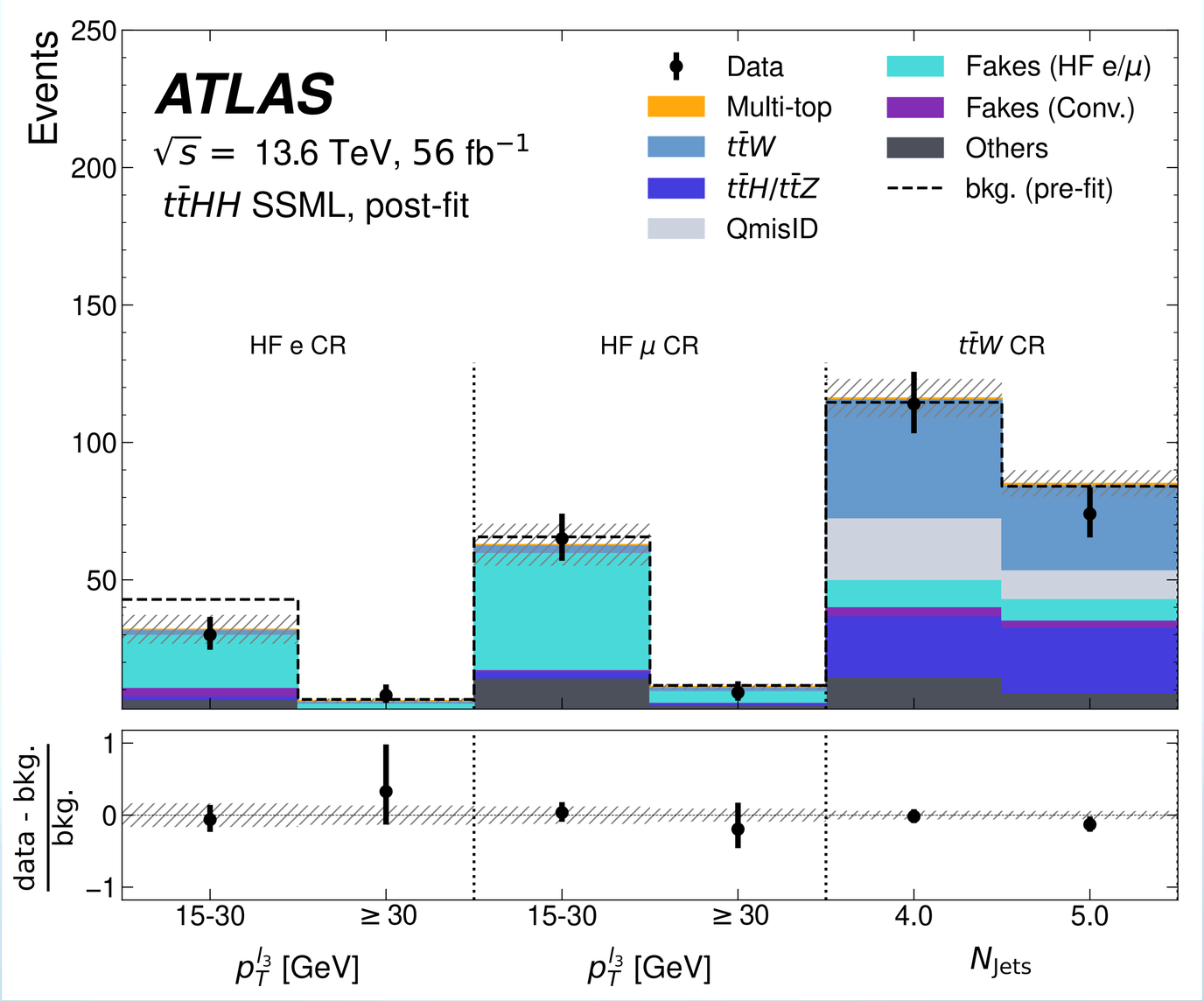
ML Run 2 SR distributions



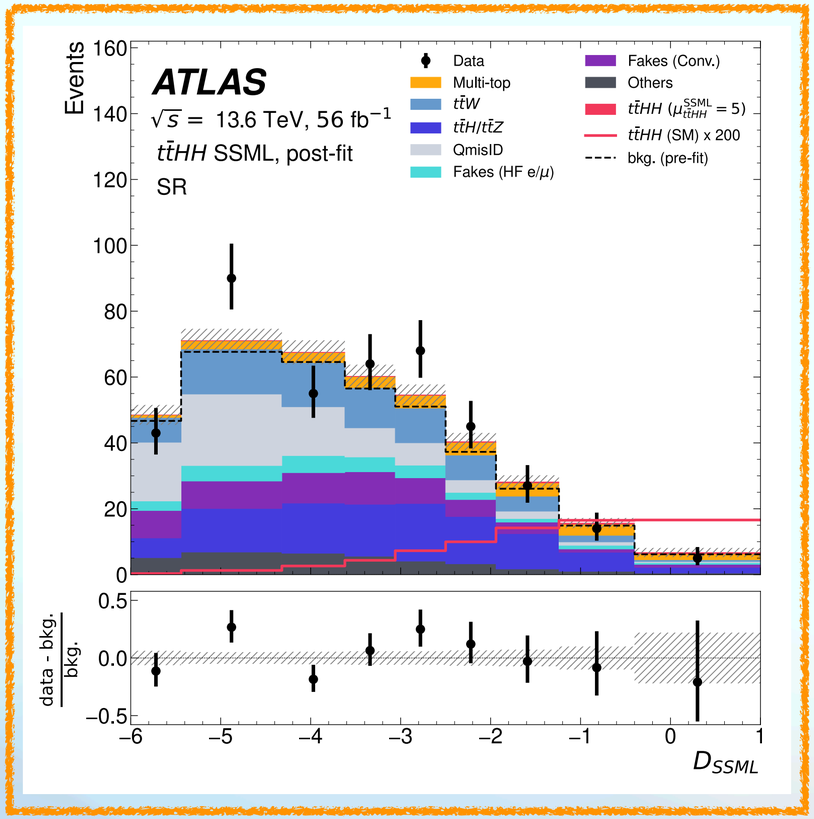


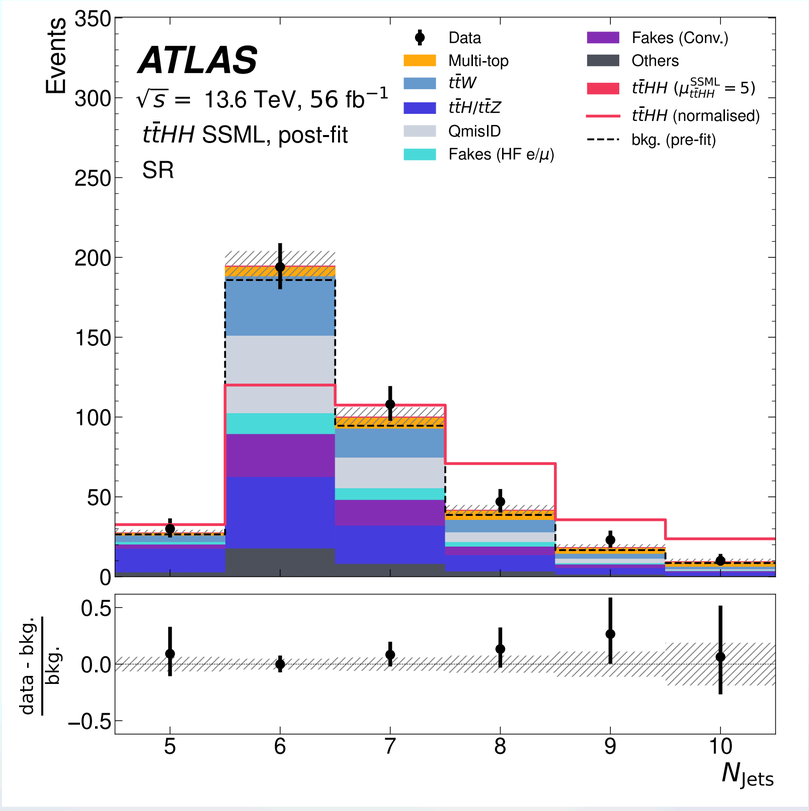


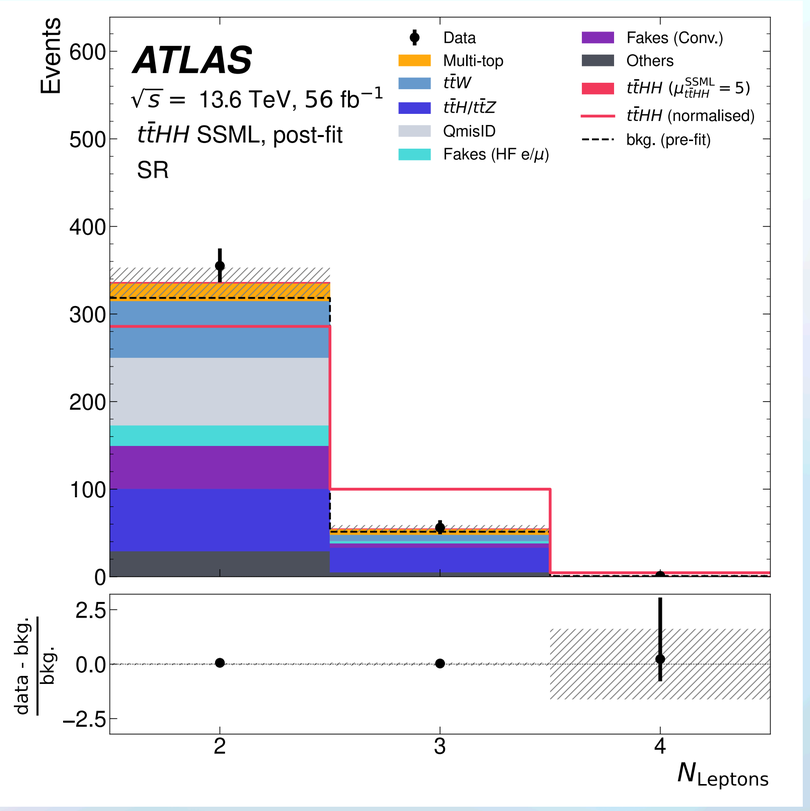
ML Run 3 CR distributions



ML Run 3 SR distributions







Backgrounds

Single-lepton channel

$t\bar{t}$ + HF (1b, 2b, ≥3b,≥1c/l) - $t\bar{t}V$ - $t\bar{t}H$ - Multitop ($t\bar{t}t\bar{t}$, $t\bar{t}t$) - V+jets

Multi-lepton channel

$t\bar{t}W$ Multitop ($t\bar{t}t\bar{t}$) - $t\bar{t}Z$ - $t\bar{t}H$ - Diboson/Triboson (VV/VVV)

Intrumental : QmisID & Fakes (non-prompt leptons)

$b\bar{b}\gamma\gamma$ channel

Continuum : $\gamma\gamma$+jets - γ+jet/dijets fakes - $t\bar{t}\gamma\gamma$

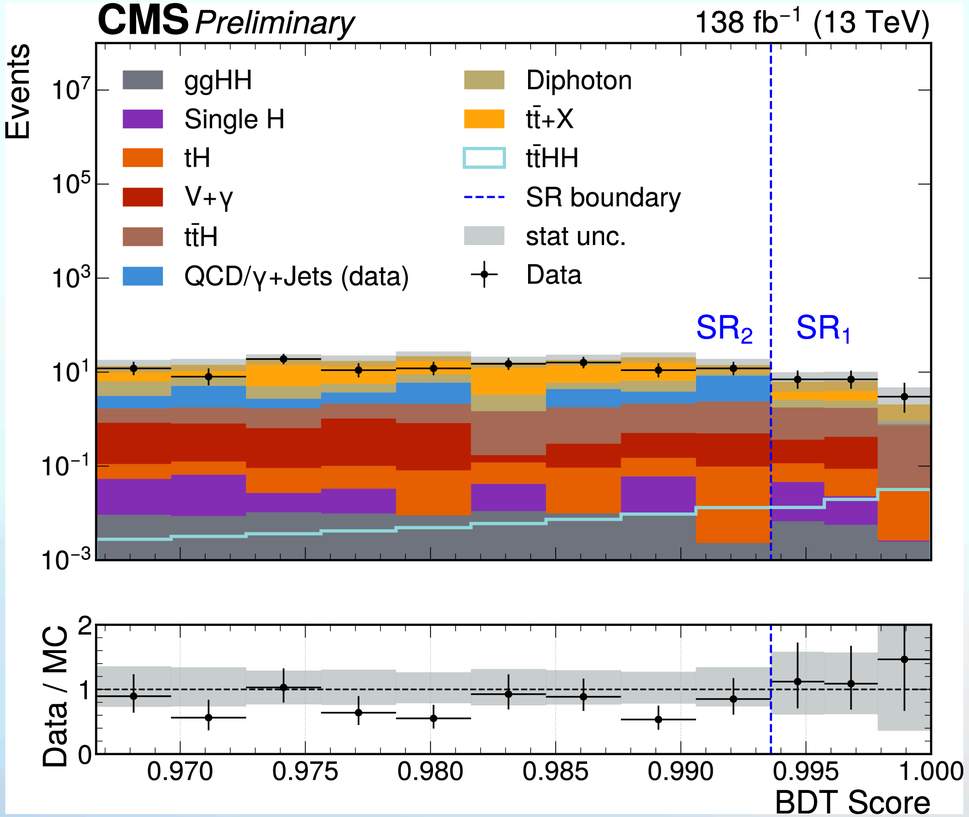
Resonant single Higgs : ggF/VBF/VH/$t\bar{t}H$

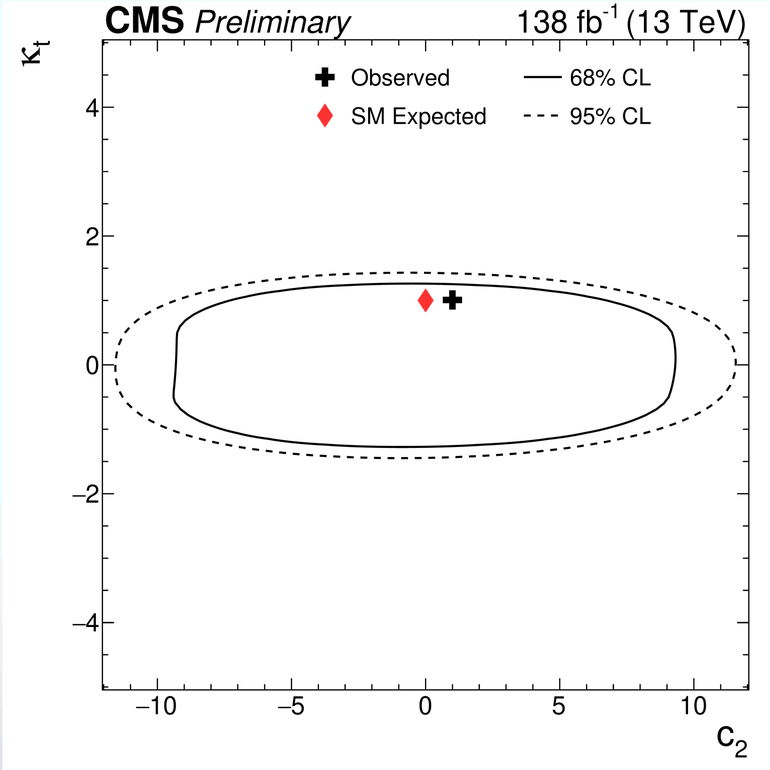
Resonant di-Higgs : ggF/VBF

CMS ttHH analysis (1)

[CMS-PAS-HIG-23-004]

- **Targets** $\gamma\gamma + X$ with $X \in [b, W^{\pm}, \tau^{\pm}]$ with **Run 2 data**
- Similar modelling strategy as ATLAS (MVA discriminant)
- **Both** $c_{t\bar{t}HH}$ and c_{tHH} probed (called resp. c_2 and κ_t)





CMS ttHH analysis (2)

[CMS-PAS-HIG-23-004]

Limits on **resonant production** of CP-even **heavy neutral scalar** (H_2) in the context of **type-II 2HDM** and **heavy VLQ** T' **pair production** in the $T' \to tH$ final state