
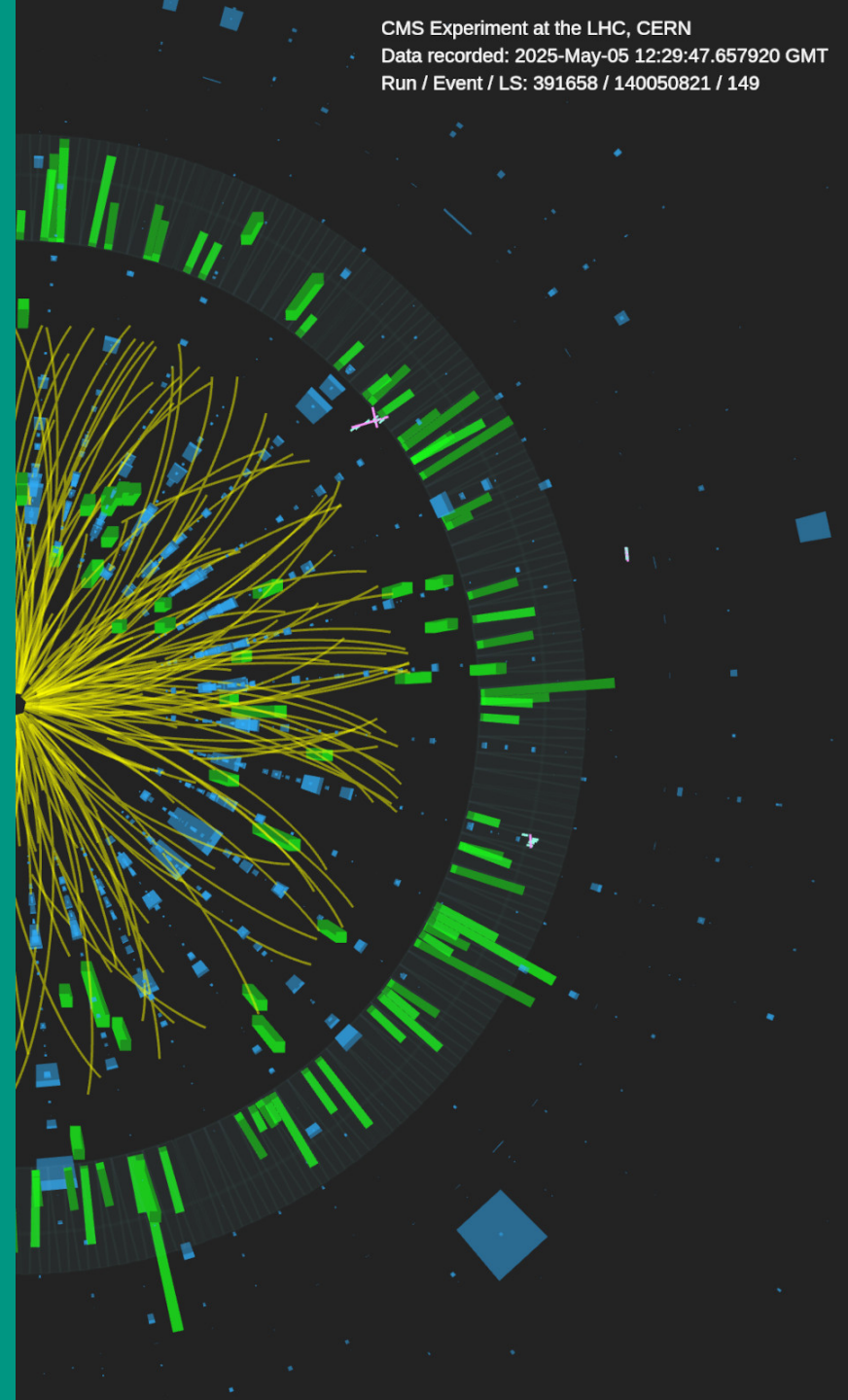
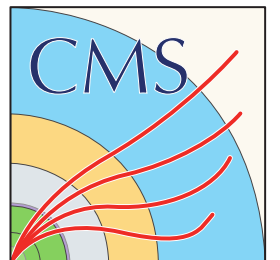
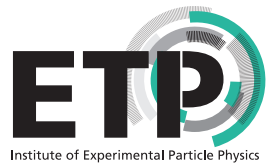


Measurements of $t\bar{t}t\bar{t}$ and $t\bar{t}t$ production: Recent results from the CMS experiment

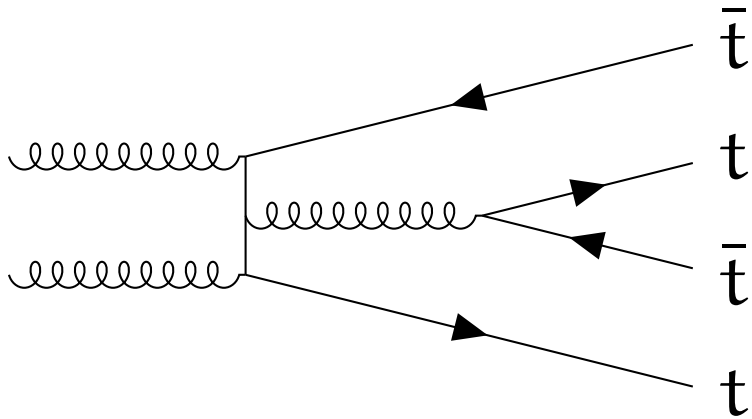
Joscha Ahäuser joscha.ahauser@cern.ch 
on behalf of the CMS Collaboration | 27 May 2026

CMS Experiment at the LHC, CERN
Data recorded: 2025-May-05 12:29:47.657920 GMT
Run / Event / LS: 391658 / 140050821 / 149

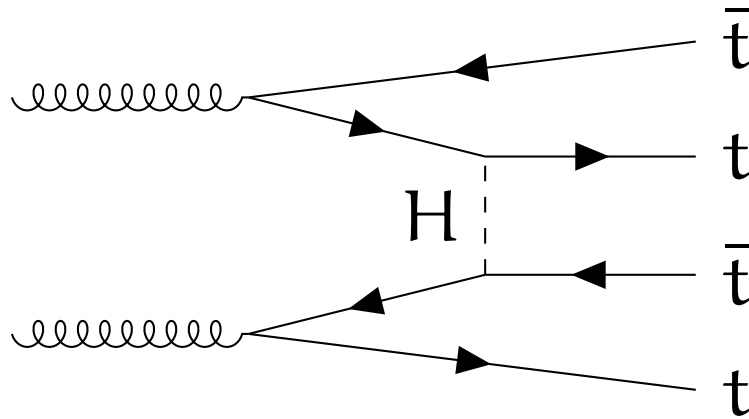


Why $t\bar{t}t\bar{t}$ and $tt\bar{t}$?

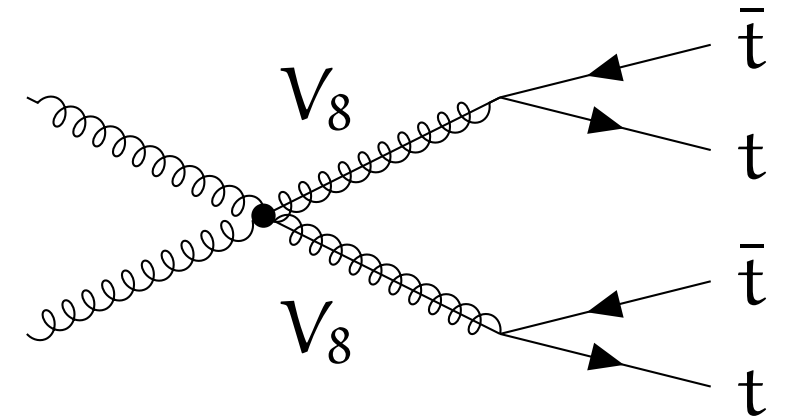
heaviest observed QCD process



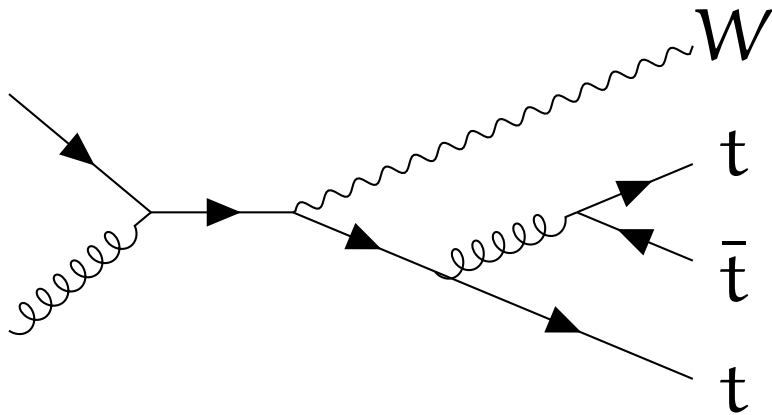
sensitive to y_t^2



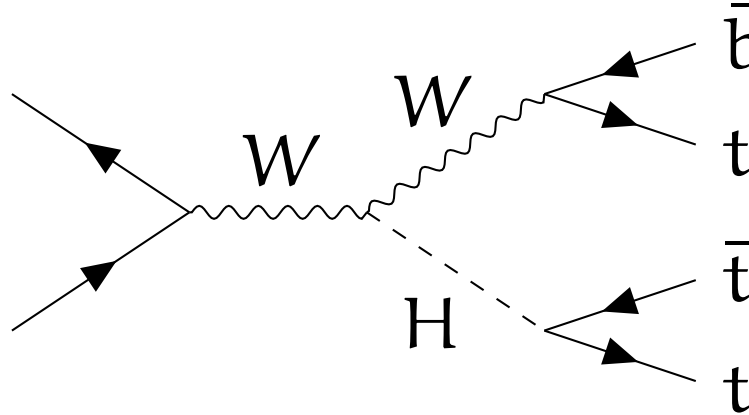
sensitive to heavy NP



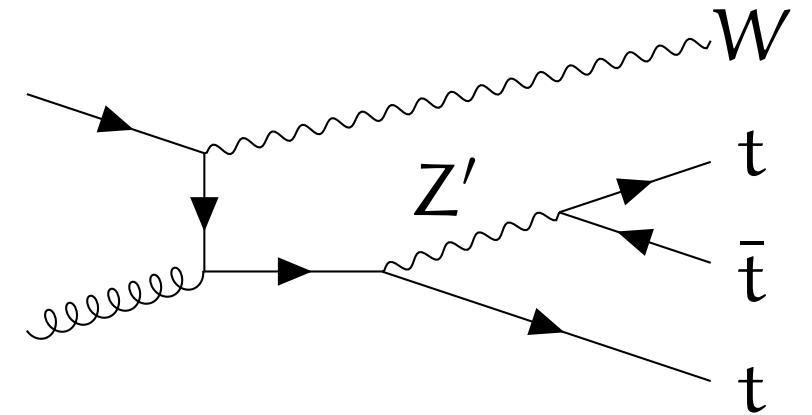
high-energy QCD-EW interplay



sensitive to sign of y_t

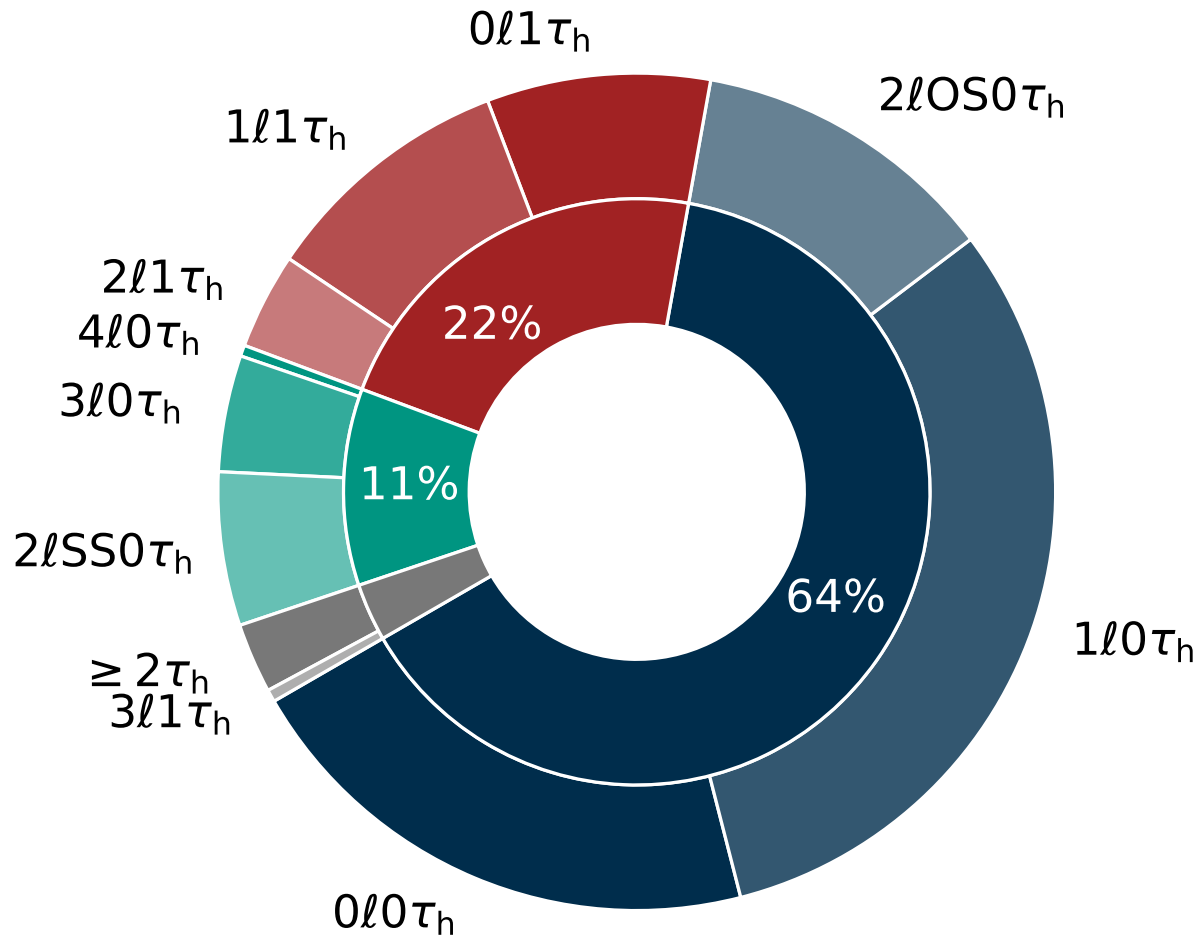


sensitive to heavy NP



Experimental signature of $t\bar{t}\bar{t}$ and $t\bar{t}t$

branching fractions of $t\bar{t}\bar{t}$ decay channels:



“multilepton” analysis: $2lSS, 3l, 4l$

- precise e, μ reconstruction, good fake suppression
- small branching ratio, but least backgrounds
- ⇒ $t\bar{t}\bar{t}$ with $>5\sigma$ achieved in this channel

$2lOS, 1l, 0l$ analysis

- largest branching ratio, but huge $t\bar{t}$ +jets background

new: τ_h analysis

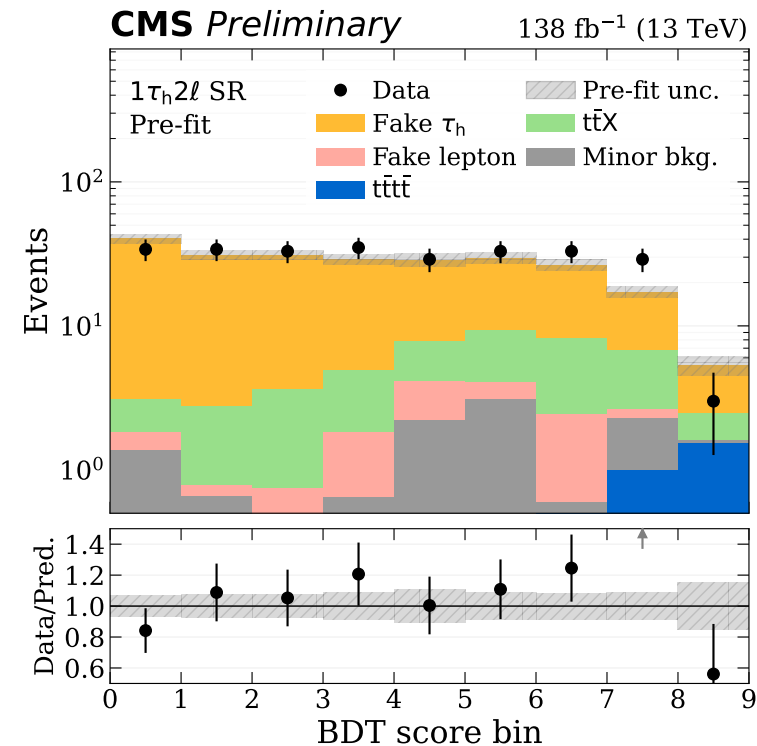
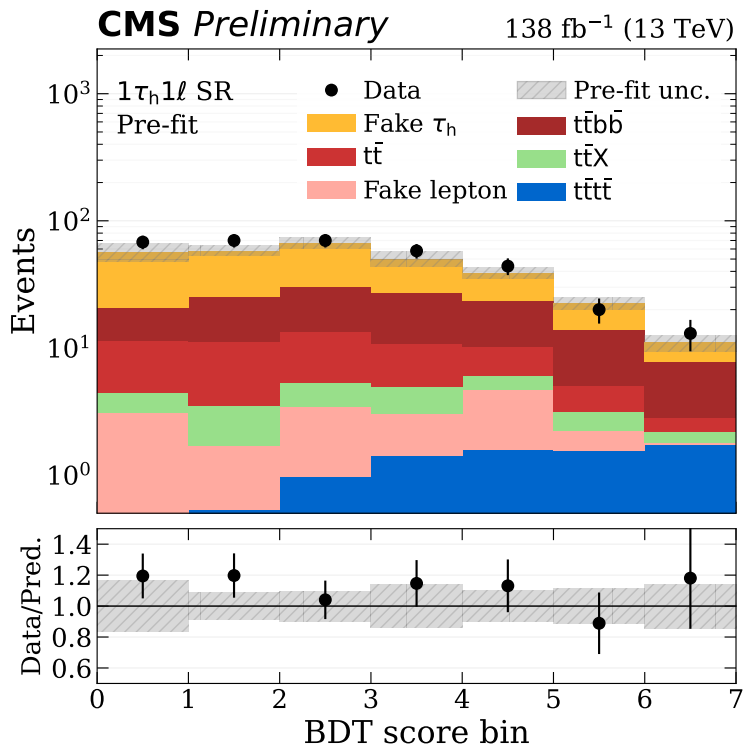
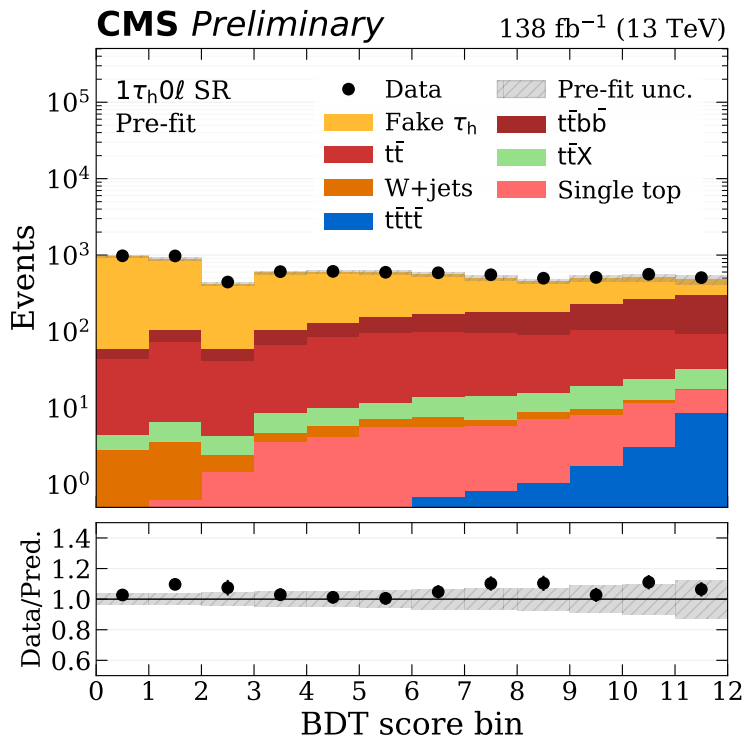
- hadronic τ reconstruction less efficient than e, μ
- unique sensitivity to 3rd-generation NP

$t\bar{t}t\bar{t}$ in τ_h events: Analysis

$1\tau_h 0\ell$
 $N_j \geq 8, N_b \geq 3, H_T > 480 \text{ GeV}$

$1\tau_h 1\ell$
 $N_j \geq 7, N_b \geq 3, H_T > 480 \text{ GeV}$

$1\tau_h 2\ell$
 $N_j \geq 4, N_b \geq 2, H_T > 200 \text{ GeV}$

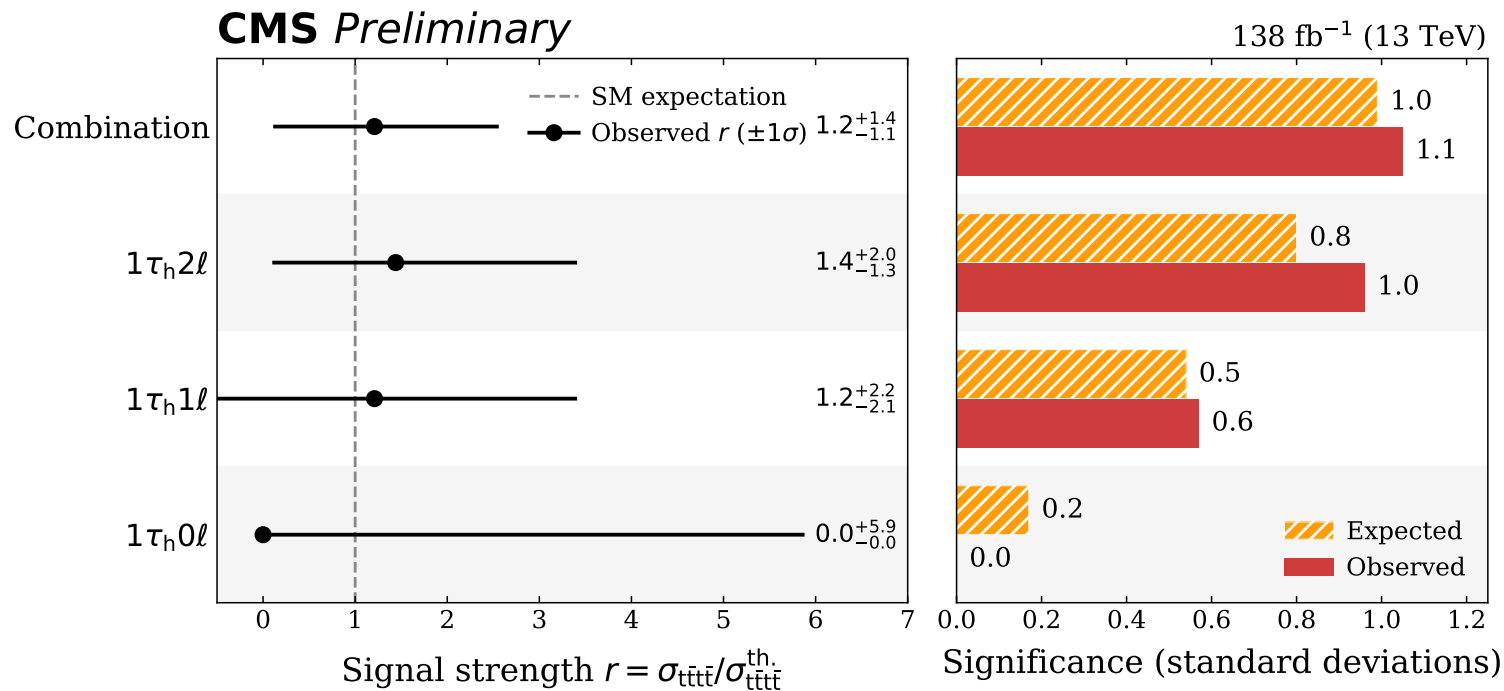


■ binary BDT $t\bar{t}t\bar{t}$ vs. background, for each SR, using kinematic properties and b-tagging information

■ fake τ_h and fake ℓ background estimated from data; dominant MC backgrounds: $t\bar{t}b\bar{b}$, $t\bar{t}$, $t\bar{t}W/t\bar{t}Z$

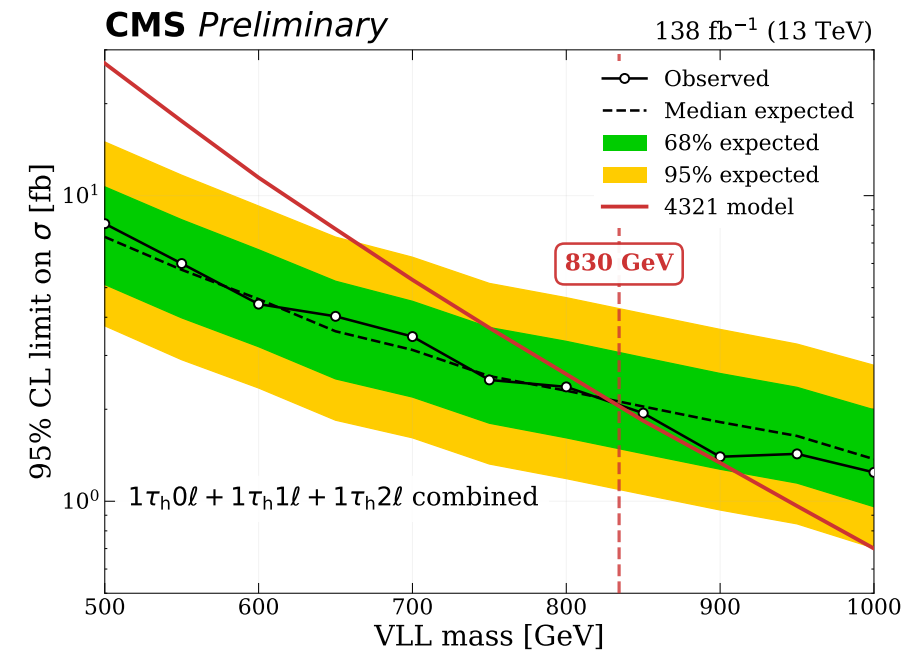
$t\bar{t}t\bar{t}$ in τ_h events: Results

$t\bar{t}t\bar{t}$ cross section



- best-fit cross section: 16^{+18}_{-15} fb, consistent with SM prediction
- sensitivity driven by $1\tau_h 2\ell$ channel
- limited by statistical uncertainty; leading systematics: $t\bar{t}b\bar{b}$ modeling

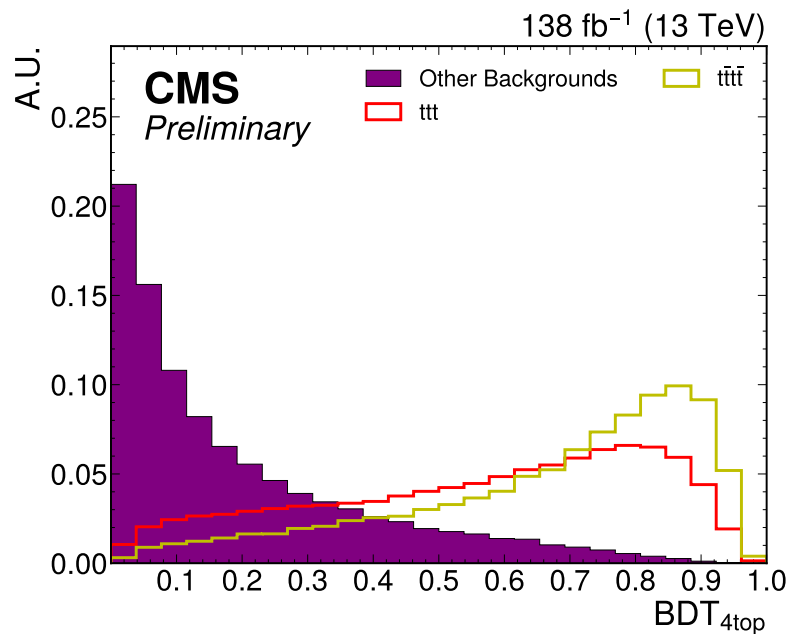
VLL exclusion limits



- 4321 model: VLLs coupled to 3rd-generation fermions, e.g.: $pp \rightarrow EN \rightarrow b(tv_\tau)t(b\tau)$
- dedicated BDTs trained for signal vs SM backgrounds (including $t\bar{t}t\bar{t}$)

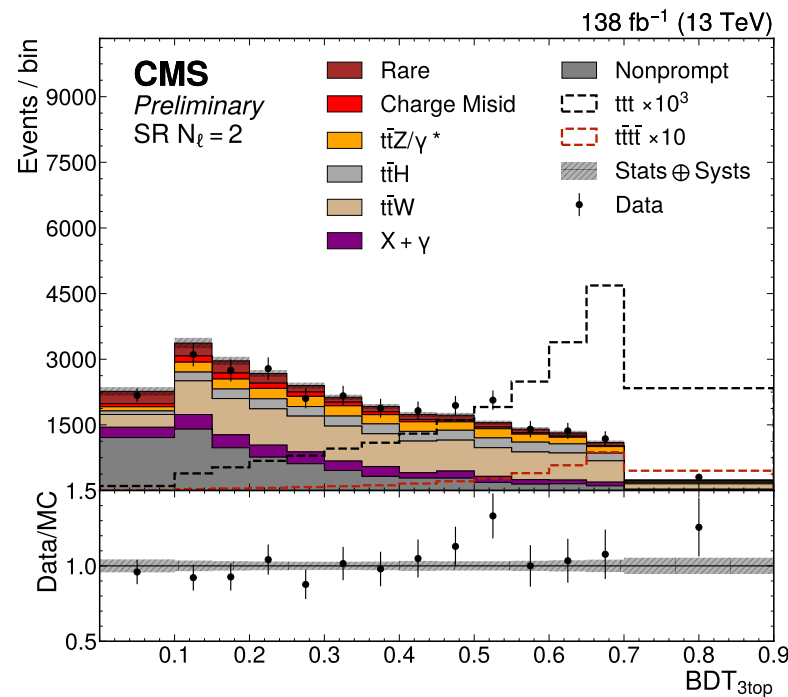
t \bar{t} t search: Multilepton analysis

BDT strategy



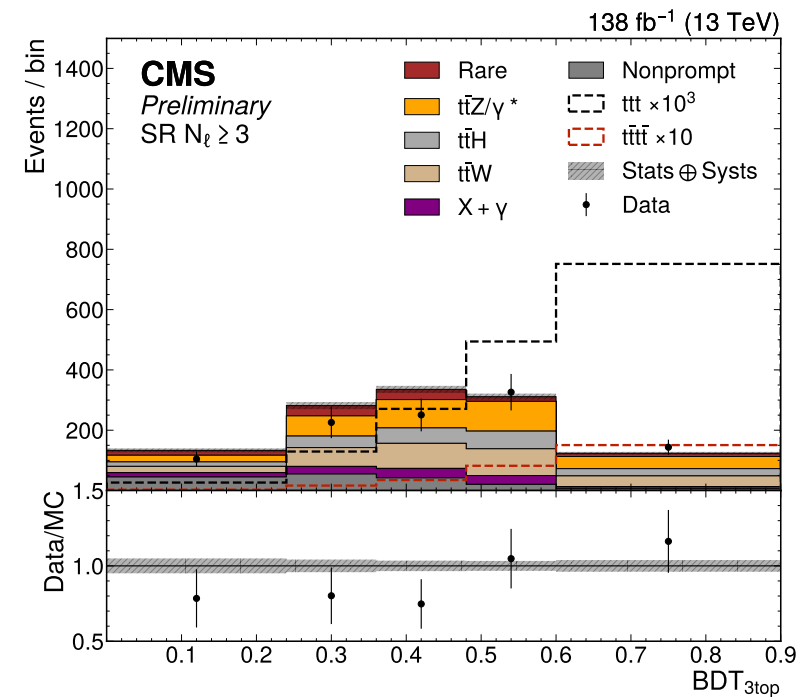
- 1st BDT: $t\bar{t}t$ vs. $t\bar{t}t + \text{bkg}$
→ define $t\bar{t}t$ CR
- 2nd BDT: $t\bar{t}t$ vs. bkg (no $t\bar{t}t$)
→ SR discriminant

2ℓSS



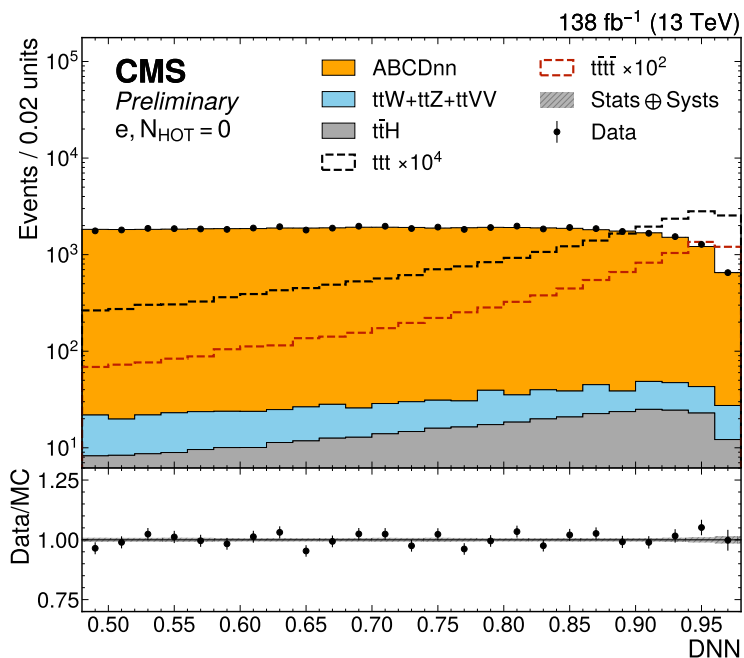
- common selection: $N_j \geq 3, N_b \geq 1, H_T > 250 \text{ GeV}$
- **charge-flip** & **fake ℓ** backgrounds estimated from data
- dominant MC backgrounds (besides $t\bar{t}t$): $t\bar{t}W$ and $t\bar{t}Z$

3ℓ+4ℓ

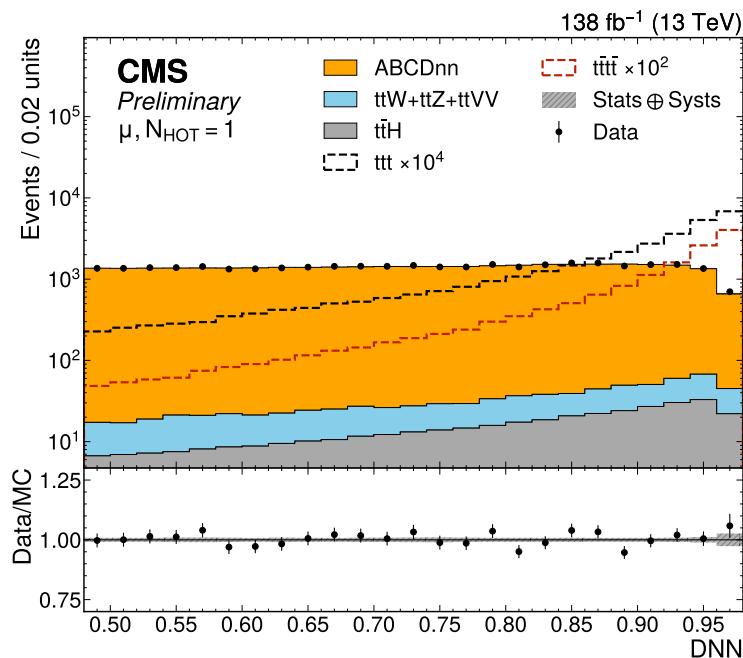


ttt search: Single-lepton analysis & results

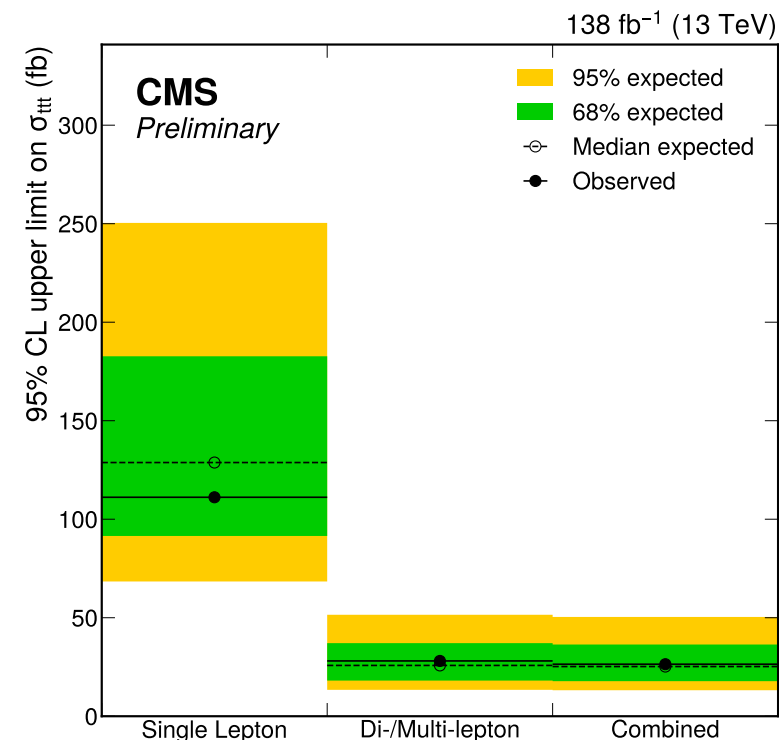
1e



1μ



ttt cross section limit



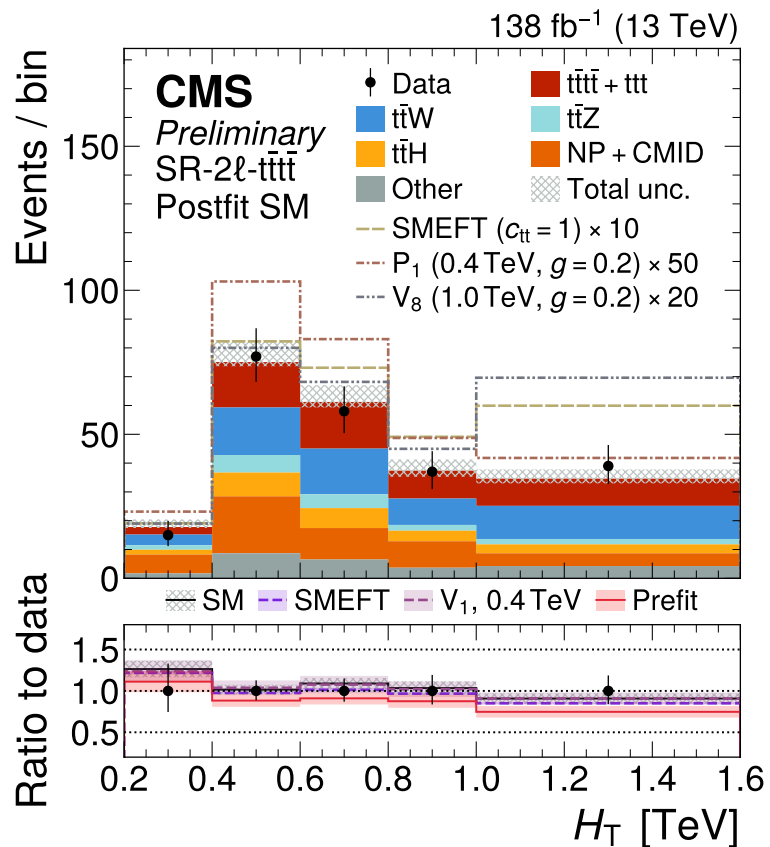
- common selection: $N_j \geq 6, N_b \geq 2, H_T > 450/500$ GeV
- 1st NN: hadronic top tagger → split into =0 and =1 regions
- 2nd NN: separate ttt signal from $t\bar{t}$ background
- 3rd NN: predict $t\bar{t}$ shape; normalization with ABCD method

■ upper limit: $12 \times \text{SM}$ (95% CL)

$t\bar{t}\bar{t} + ttt$ multilepton interpretation: Setup

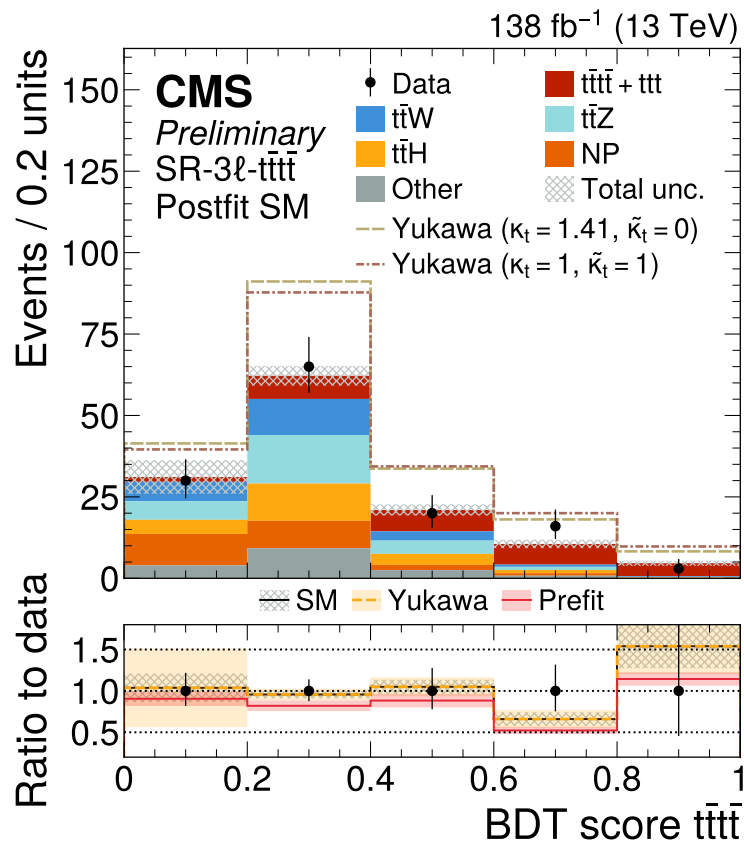
$2\ell SS$

$N_j \geq 4/6, N_b \geq 3/2, H_T > 280 \text{ GeV}$

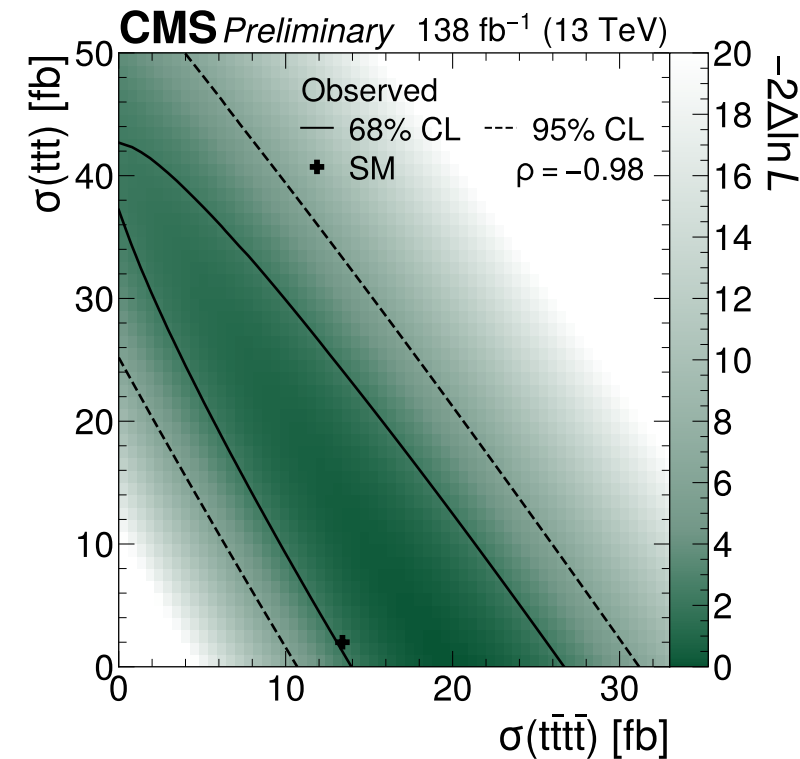


3ℓ

$N_j \geq 3, N_b \geq 2, H_T > 200 \text{ GeV}$



SM fit results

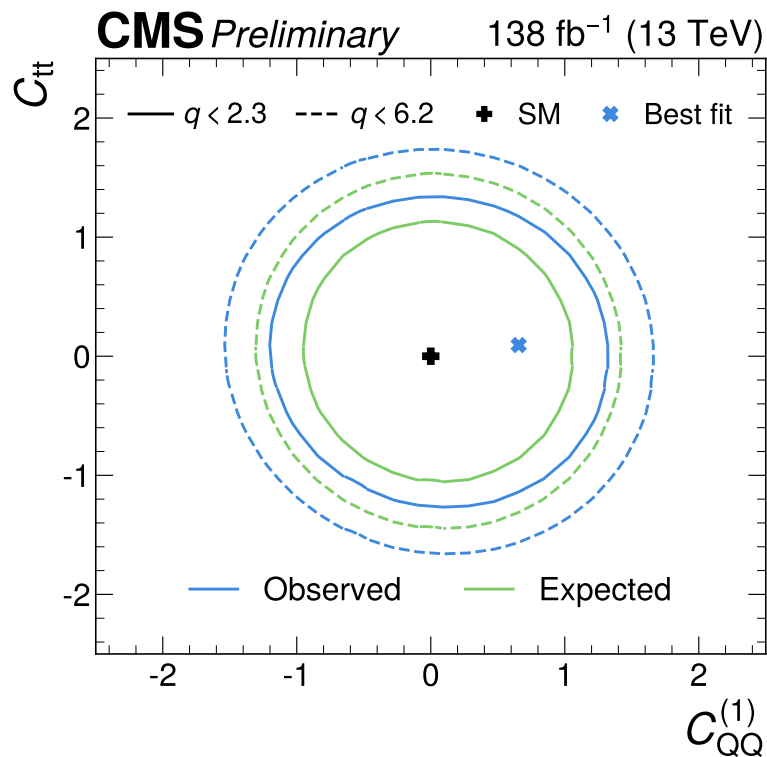


- ttt̄-only fit: $18.9^{+4.4}_{-4.0}$ fb
- 2D fit: ttt̄ and ttt not distinguishable

■ multiclass BDT ttt̄ vs. tt̄W/tt̄Z/tt̄H vs. tt̄ (no ttt) for SR definition

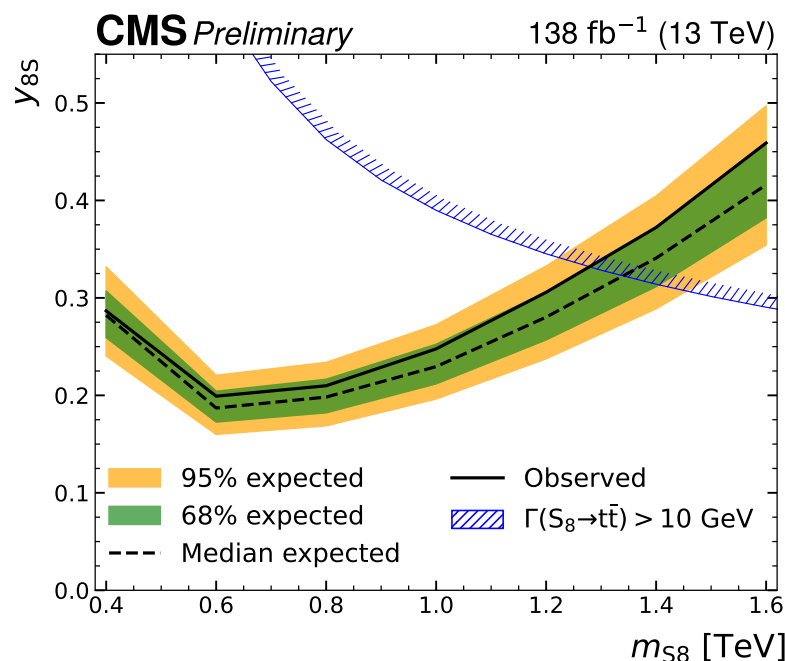
$t\bar{t}\bar{t} + ttt$ multilepton interpretation: Results

SMEFT operators



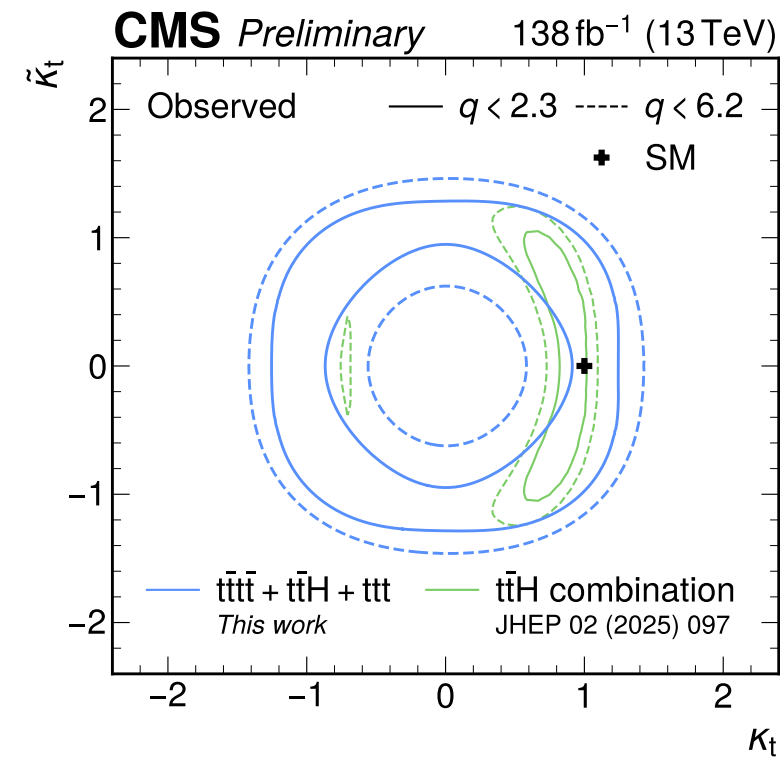
- four-heavy-quark operators: $C_{tt}, C_{QQ}^{(1)}, C_{Qt}^{(1)}, C_{Qt}^{(8)}$
- top-Higgs operators: C_{tH}^{Re}, C_{tH}^{Im}

topphilic heavy resonances



- six considered models: (scalar, pseudoscalar, vector) × (color singlet or octet)
- mass range: 400 GeV to 1.6 TeV
- narrow resonances: $\Gamma = 10$ GeV

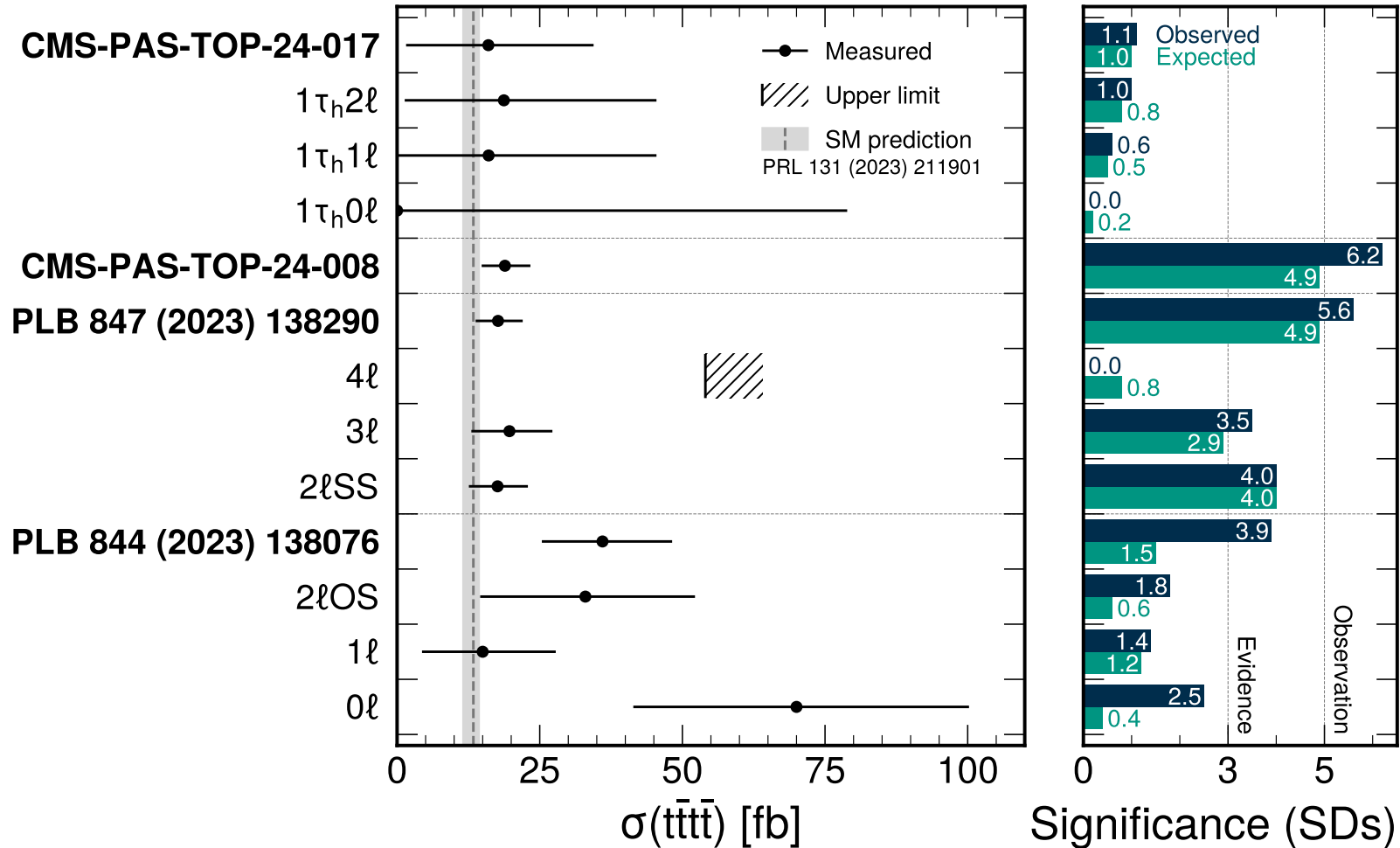
Yukawa coupling modifiers



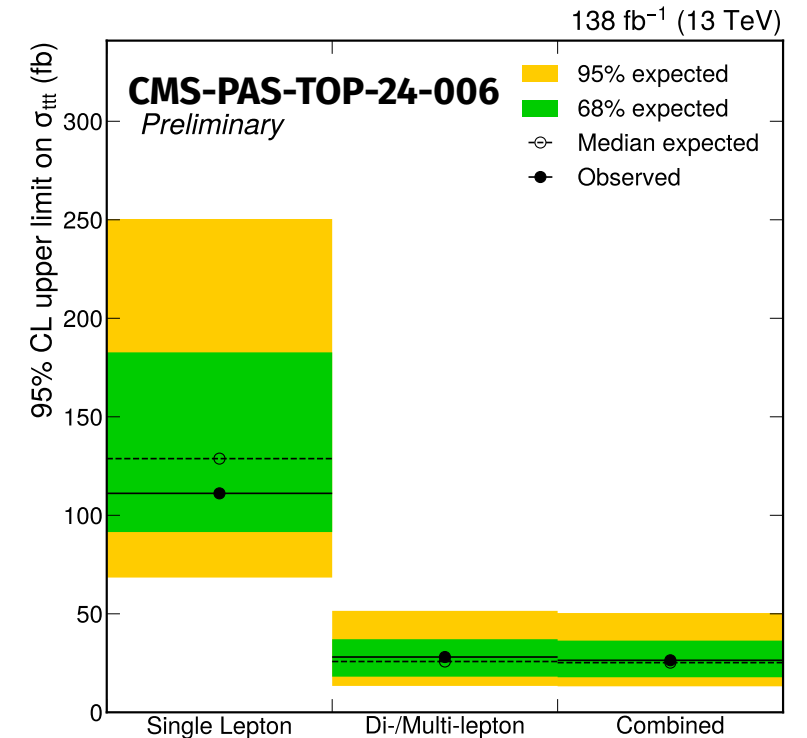
- 1D: $0.8 < |\kappa_t| < 1.3$ (95% CL)
- 2D: CP-even or CP-odd both possible

Summary

$t\bar{t}\bar{t}$ measured in (almost) all possible final states



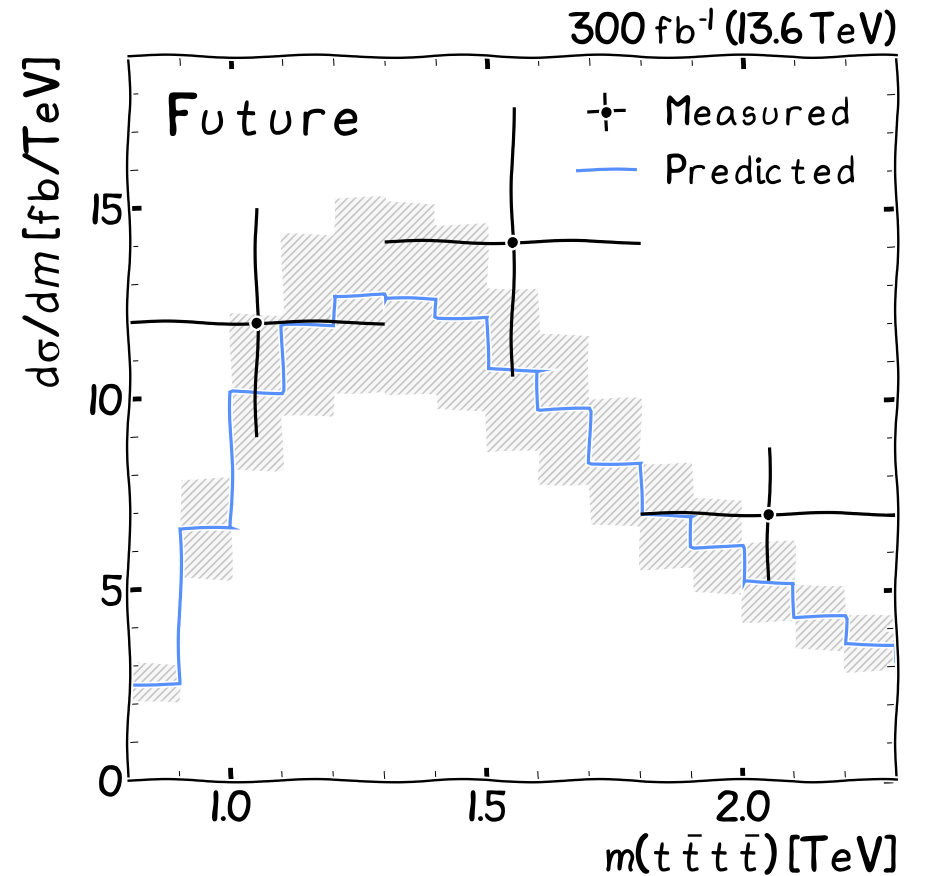
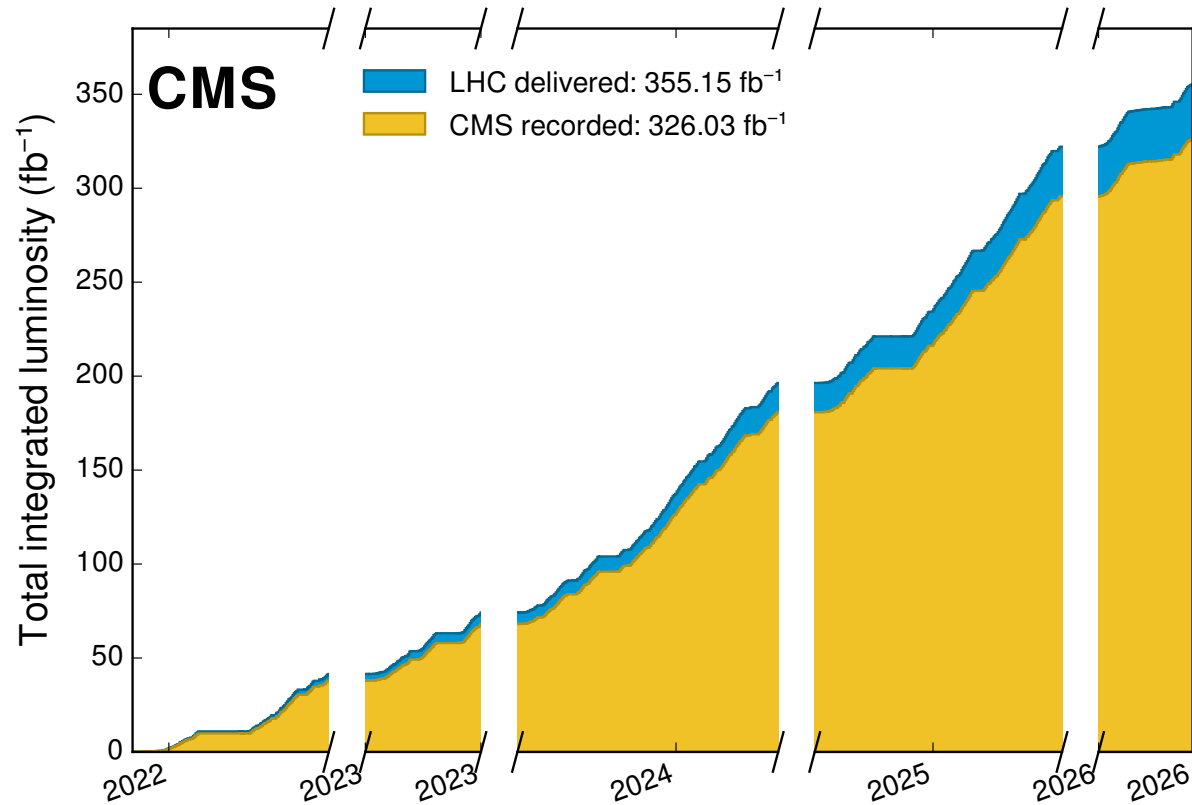
first dedicated $t\bar{t}t$ search



and many NP interpretations






- VLLs, SMEFT, heavy resonances, Yukawa modifiers, ...

Outlook: Run 3!



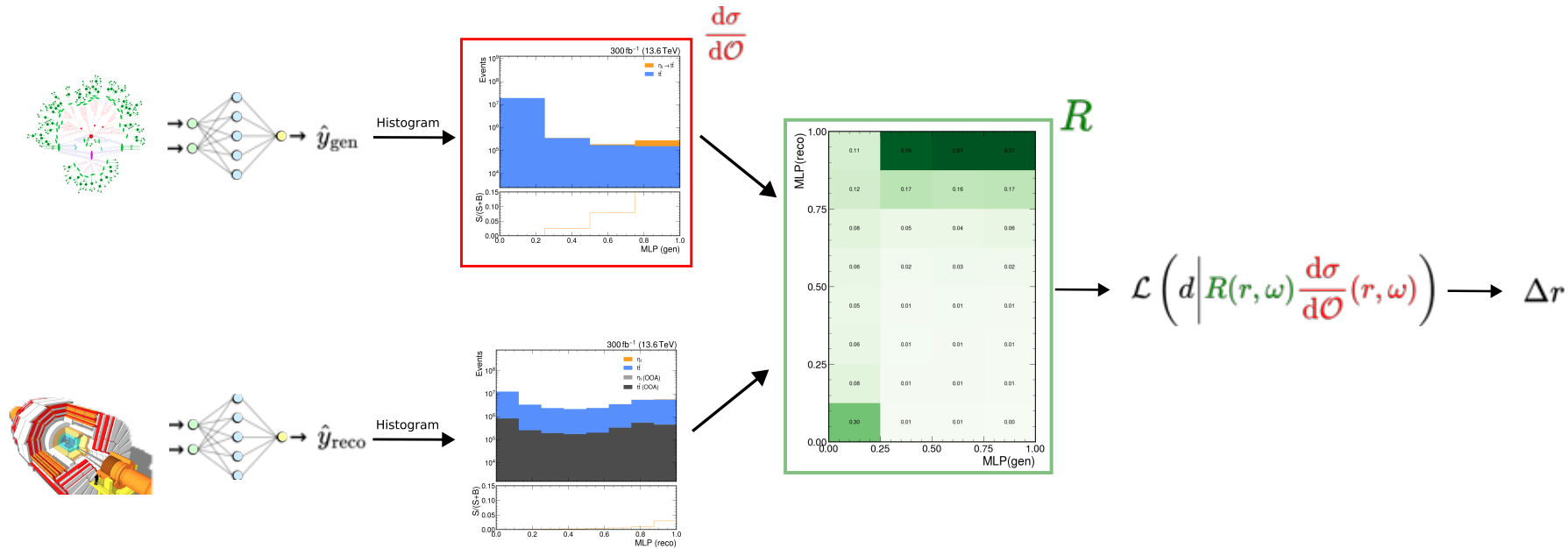
?

References

-  CMS Collaboration, “Evidence for four-top quark production in proton-proton collisions at $\sqrt{s} = 13$ TeV”, Phys. Lett. B 844 (2023) 138076 [↗](#)
-  CMS Collaboration, “Observation of four top quark production in proton-proton collisions at $\sqrt{s} = 13$ TeV”, Phys. Lett. B 847 (2023) 138290 [↗](#)
-  CMS Collaboration, “Search for physics beyond the standard model in four and three top quark production events using proton-proton collisions at $\sqrt{s} = 13$ TeV”, CMS-PAS-TOP-24-008, 2025 [↗](#)
-  CMS Collaboration, “Four-top-quark production in final states with hadronically decaying tau leptons and search for vector-like leptons at $\sqrt{s} = 13$ TeV”, CMS-PAS-TOP-24-017, 2026 [↗](#)
-  CMS Collaboration, “Search for three-top-quark production in the single lepton, same-sign dilepton, and multilepton final states in proton-proton collisions at $\sqrt{s} = 13$ TeV”, CMS-PAS-TOP-24-006, 2026 [↗](#)

Backup: Differential observables optimized with ML

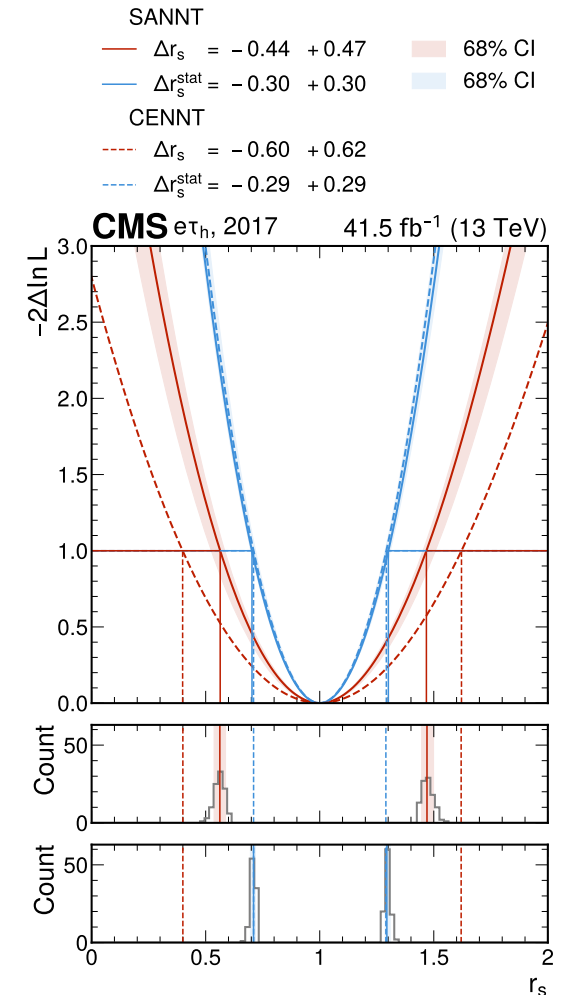
Optimal Observable Machine (Mohr, JA, et al., 2601.08813) [↗](#)



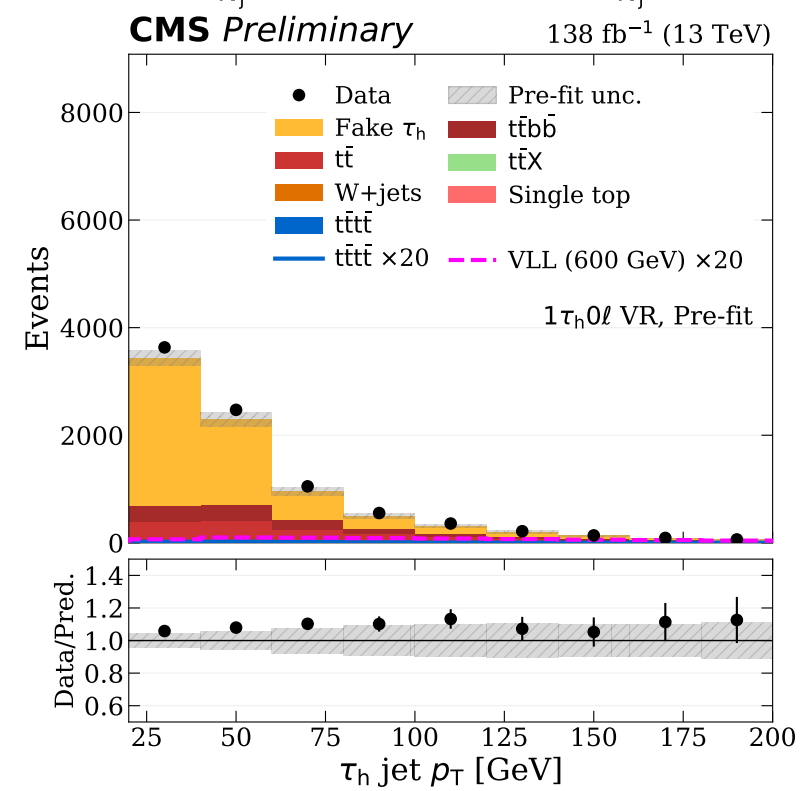
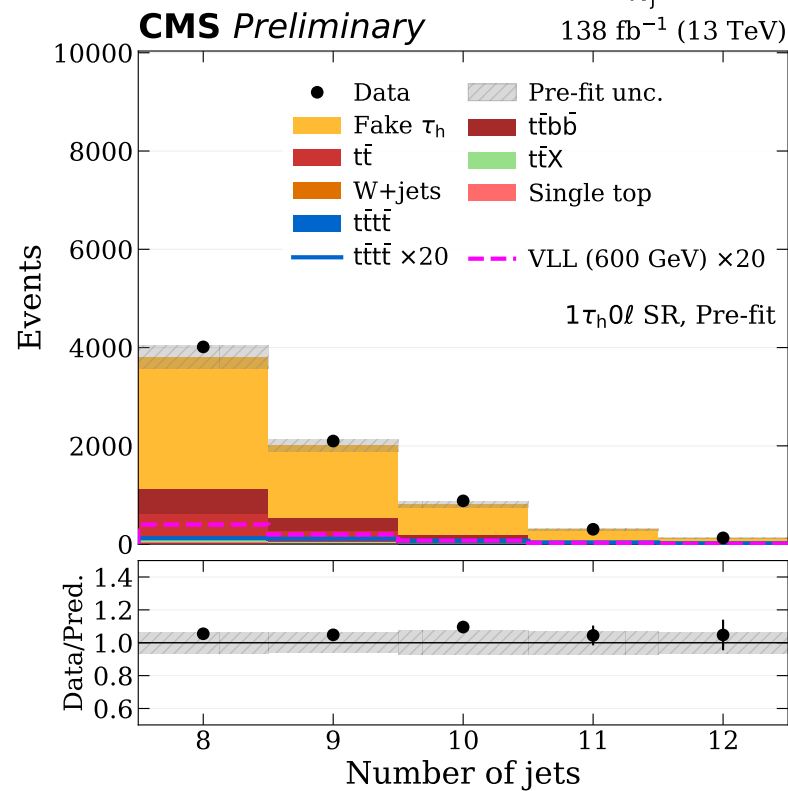
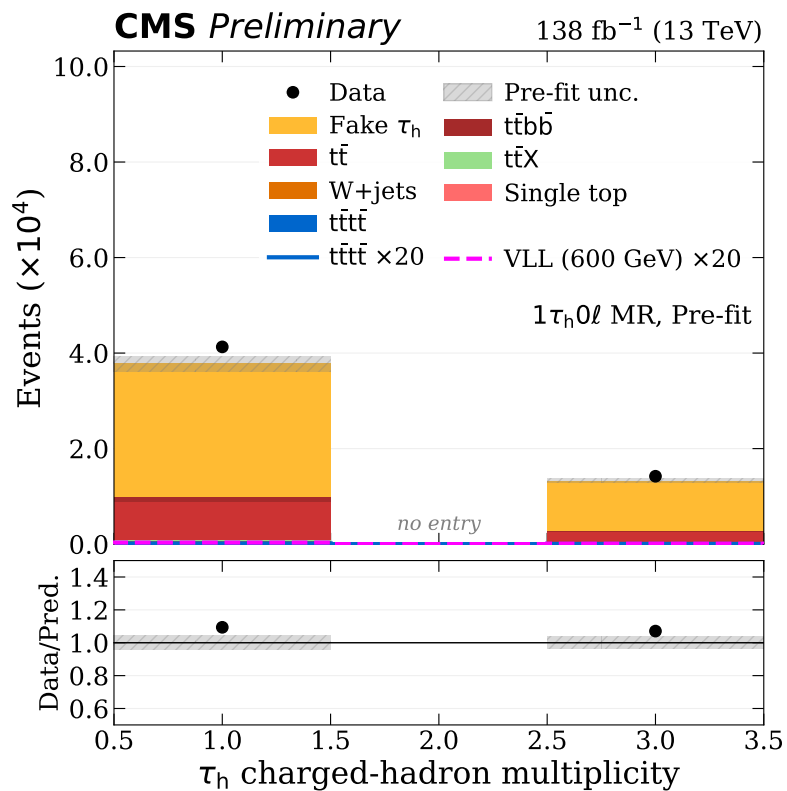
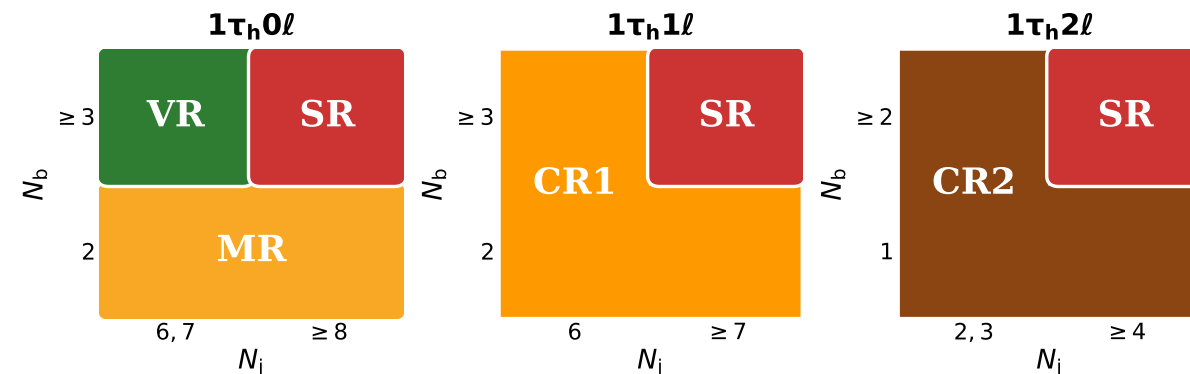
simultaneously optimize generator-level and detector-level observable for best sensitivity to POI, including systematic uncertainties; e.g. could be applied to:

- separate $t\bar{t}t$ from $t\bar{t}\bar{t}$, but can unfold both processes together
- optimal sensitivity to EFT operator, and easy to use in reinterpretation

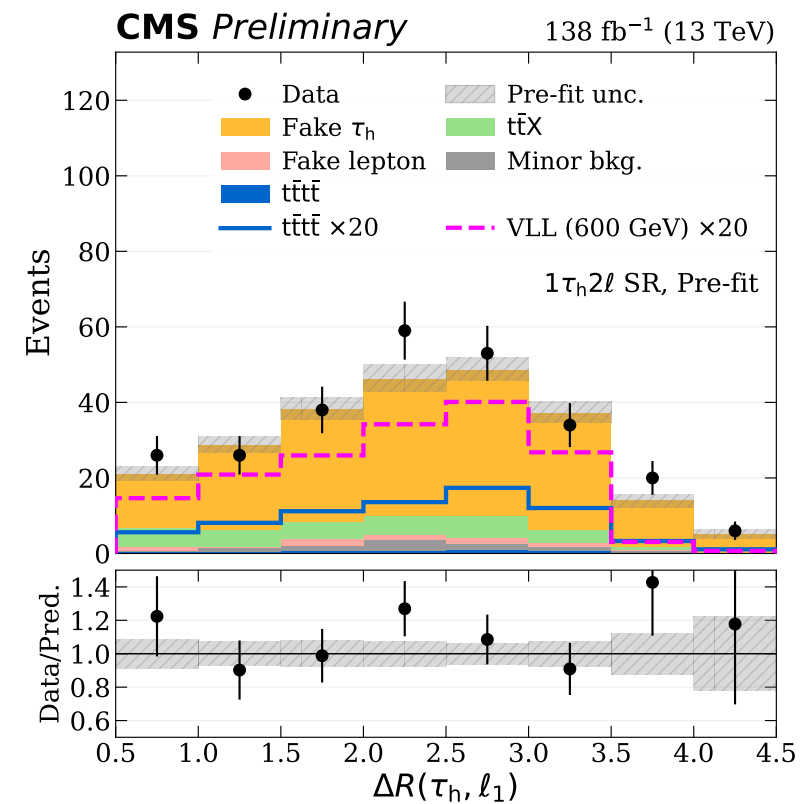
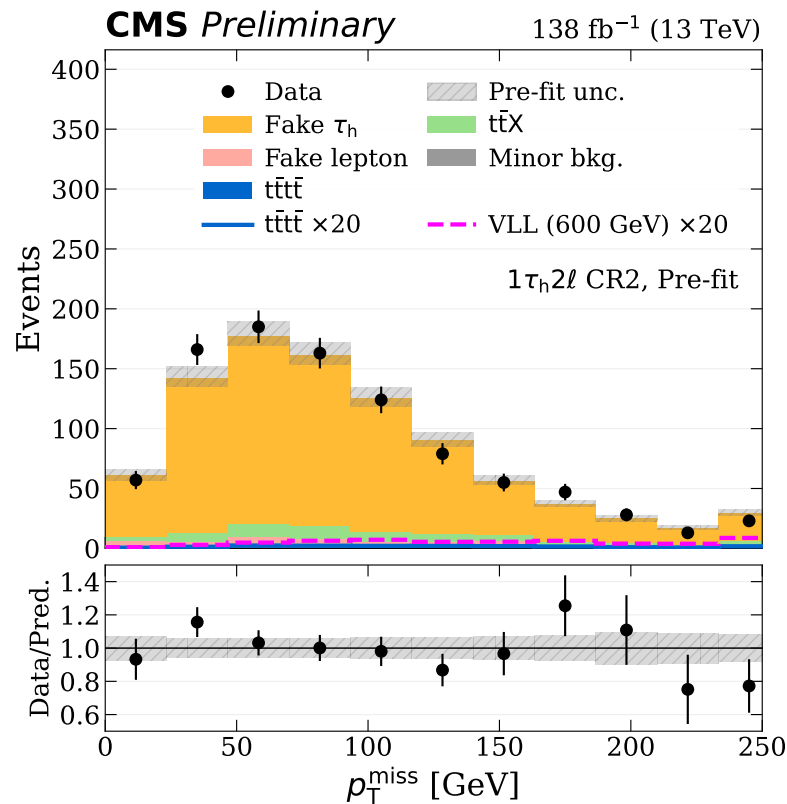
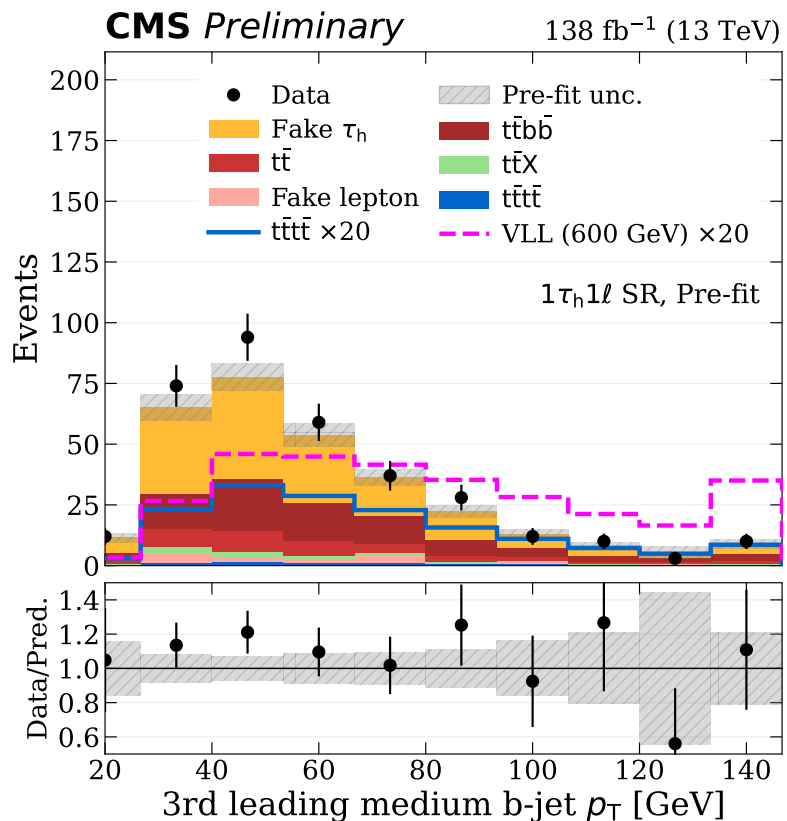
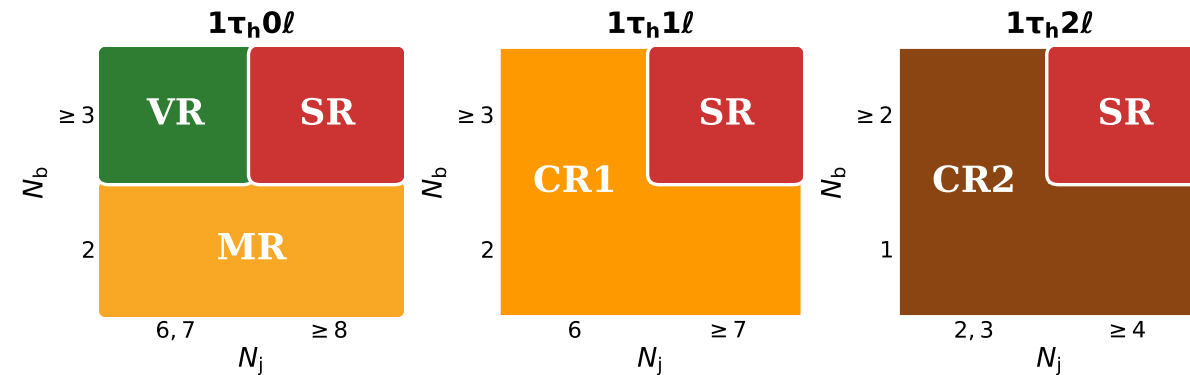
CMS-MLG-23-005 [↗](#)



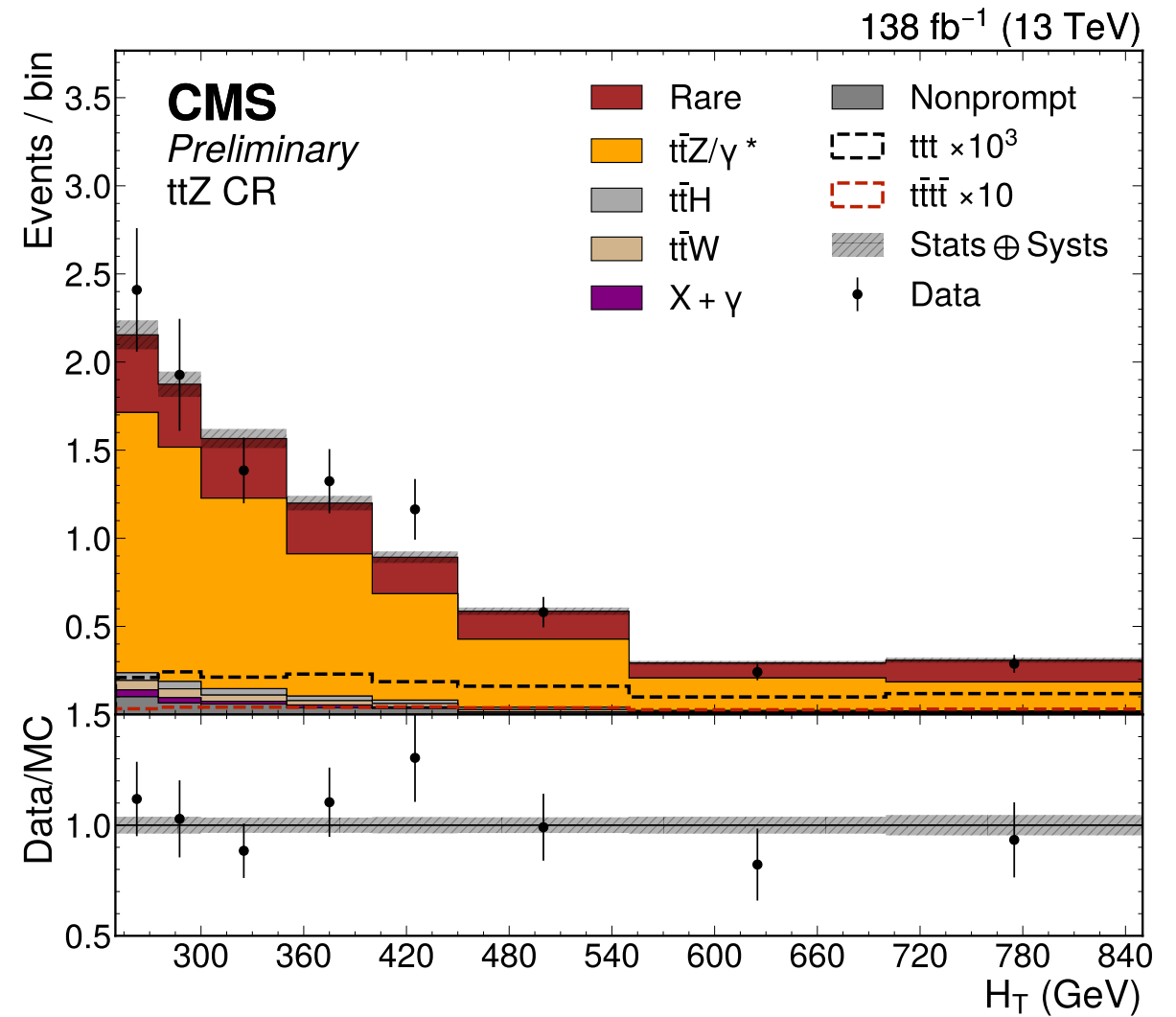
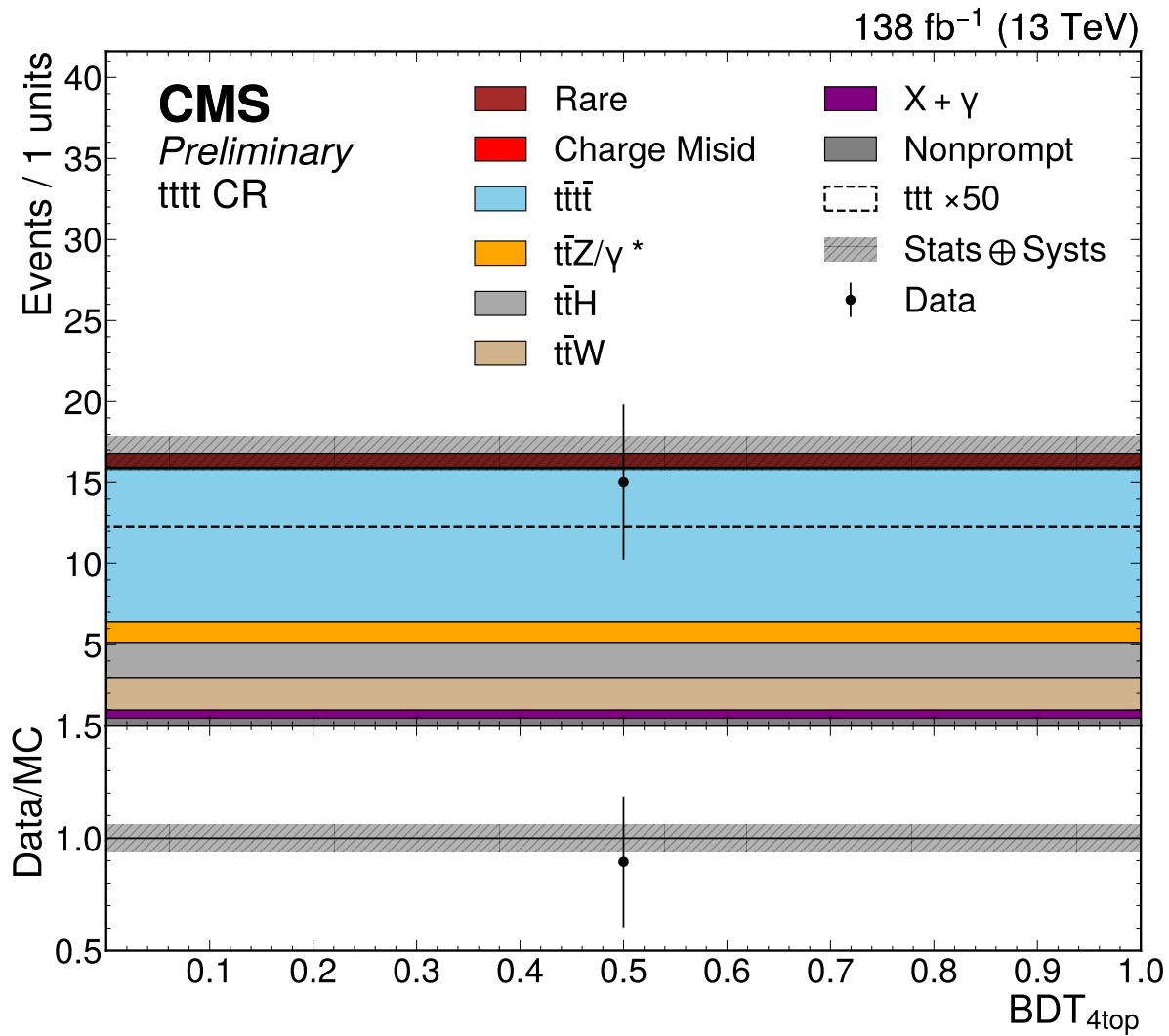
Backup: $t\bar{t}\bar{t}$ in τ_h events



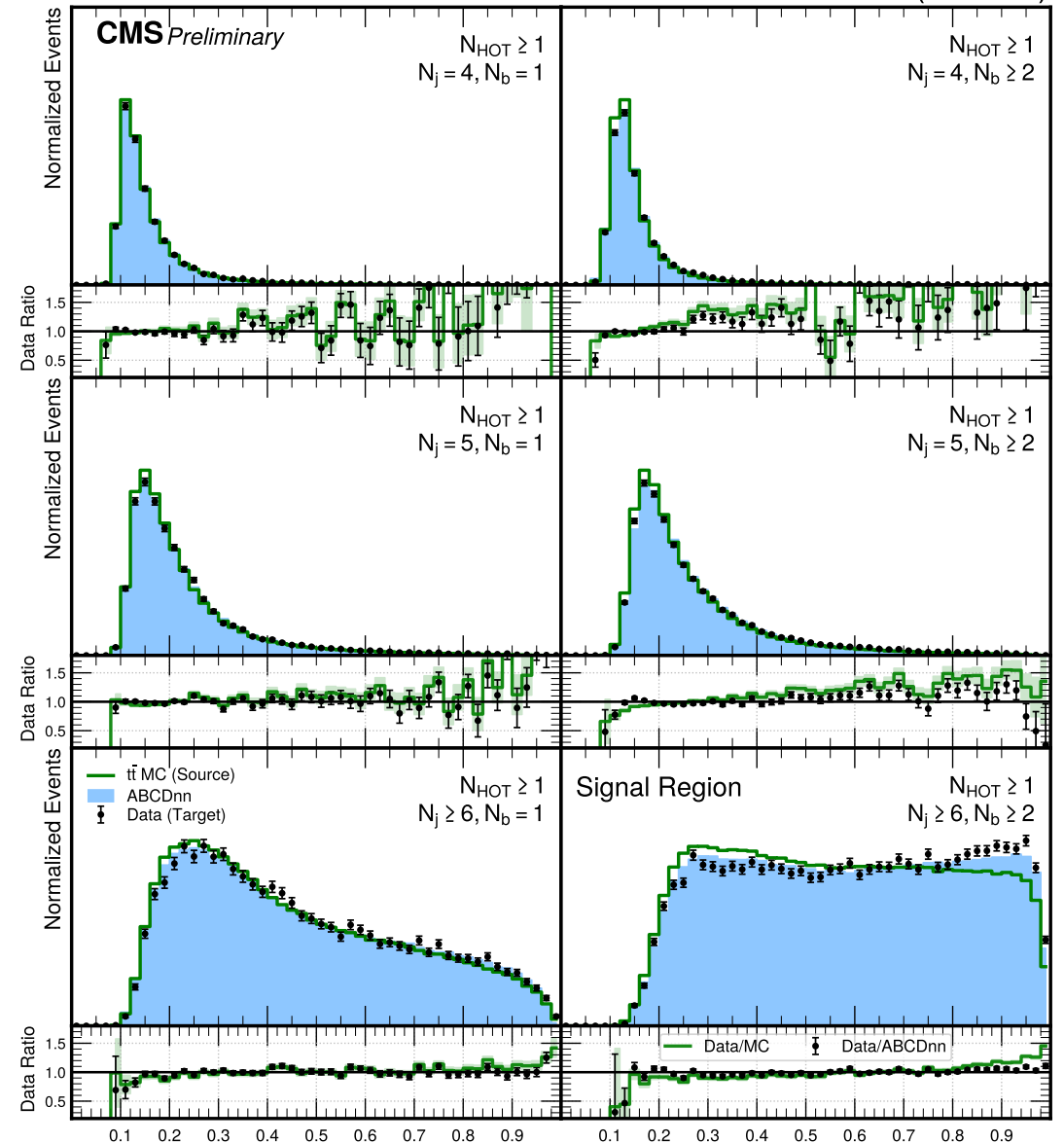
Backup: $t\bar{t}\bar{t}$ in τ_h events



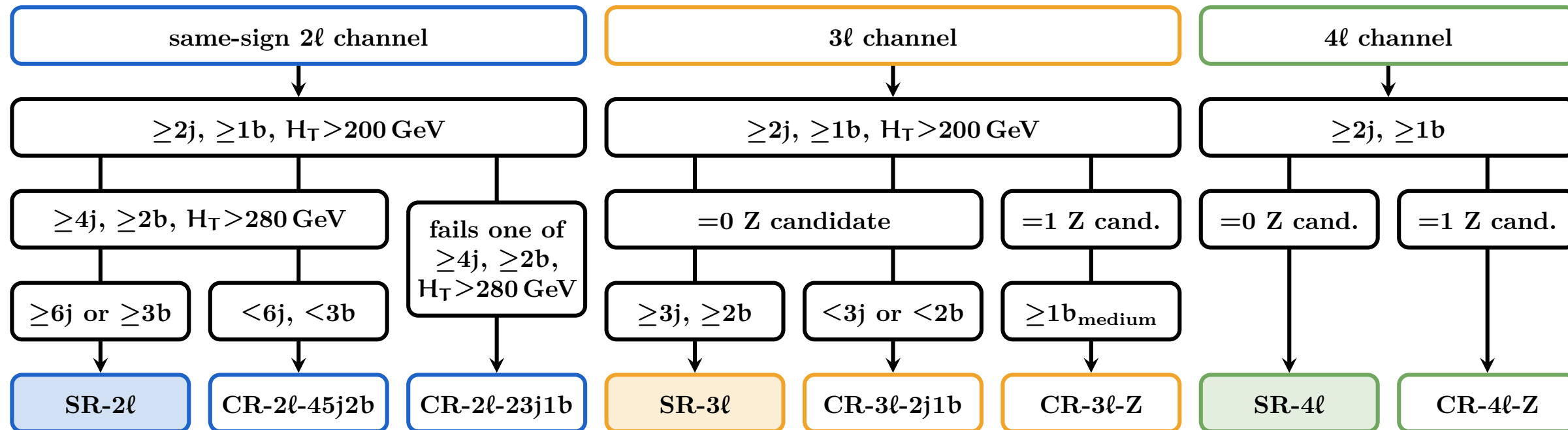
Backup: ttt search



Backup: ttt search

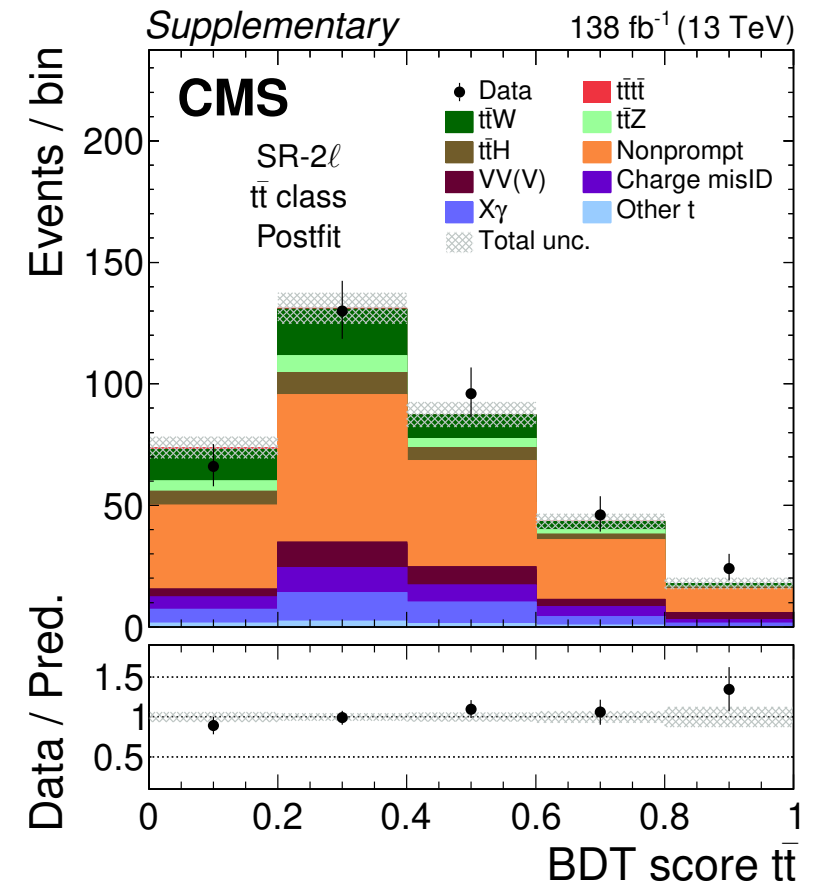
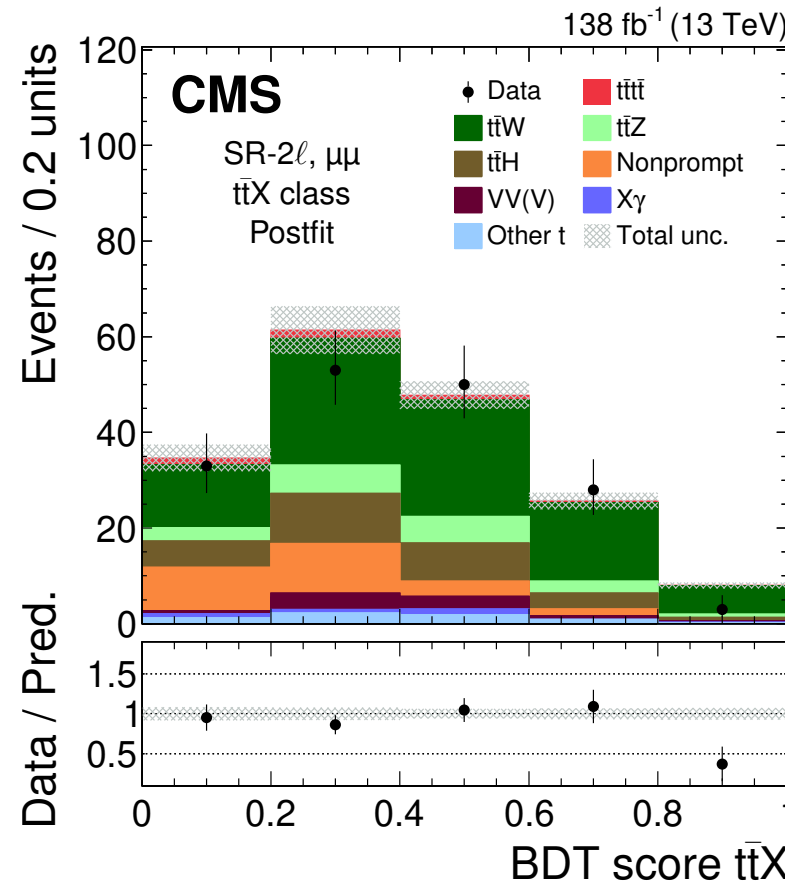
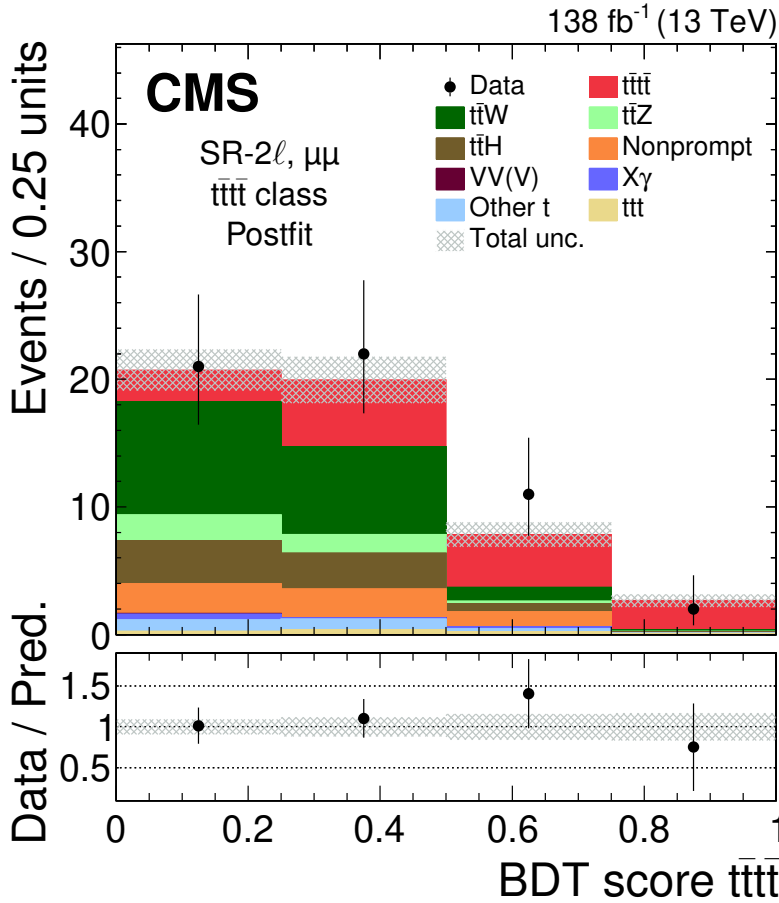
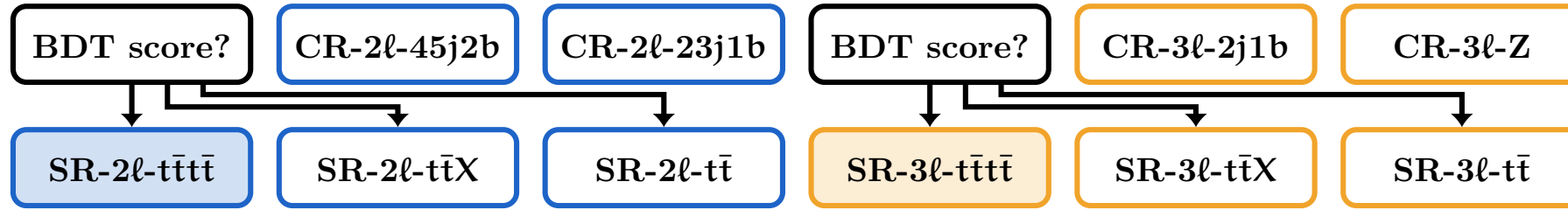


Backup: $t\bar{t}t\bar{t}$ + ttt multilepton analysis

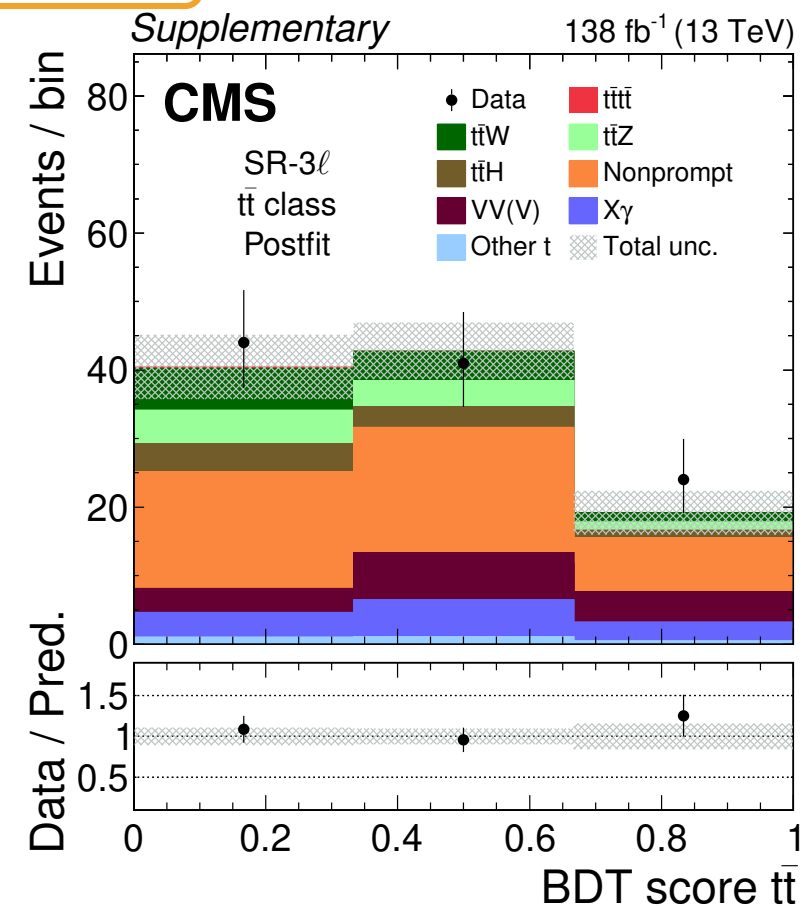
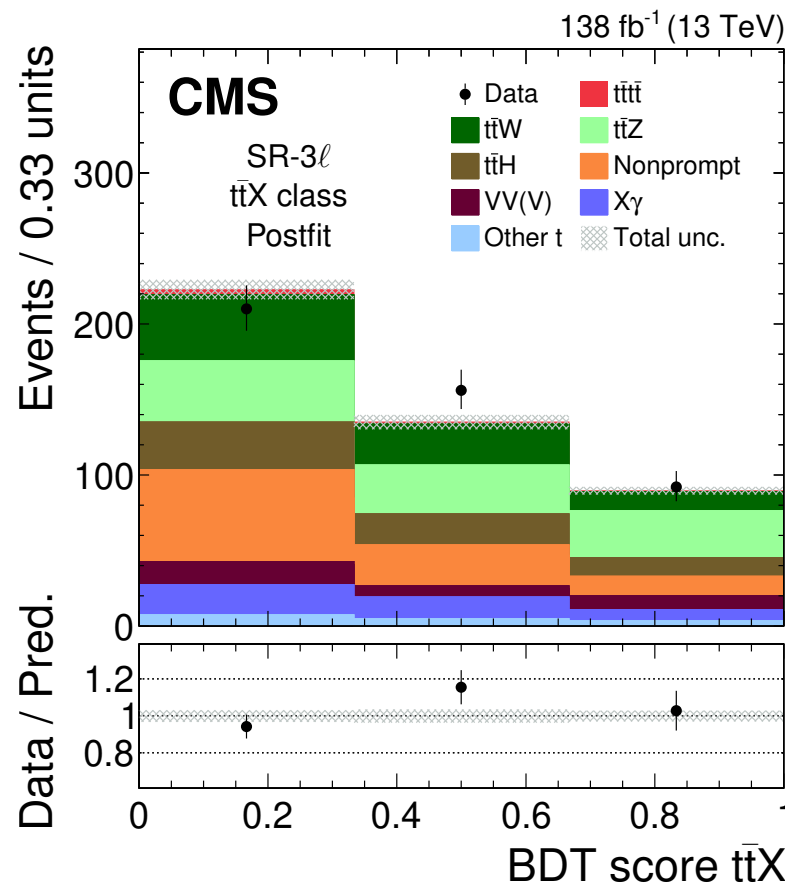
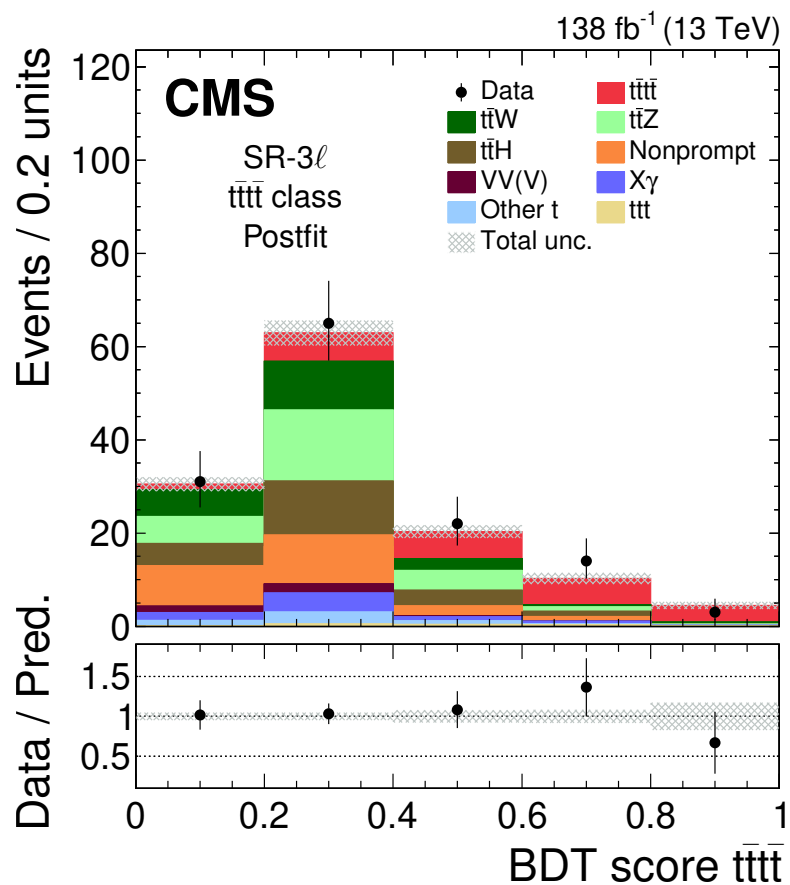
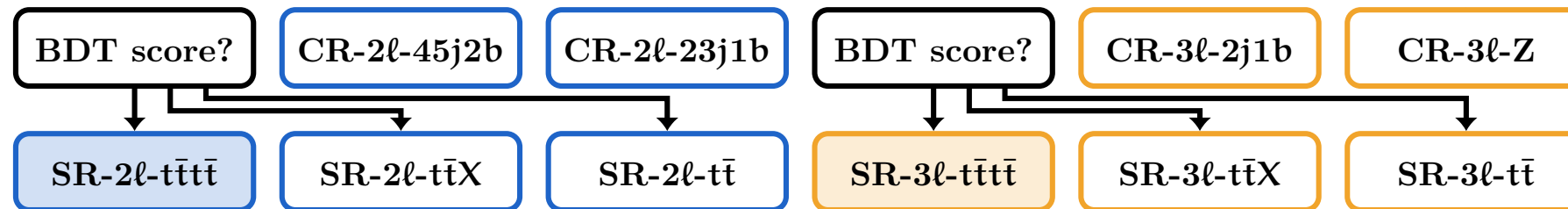


- 2016–2018 data at $\sqrt{s} = 13$ TeV, corresponding to 138 fb^{-1}
- multilepton channels: only 1/8 of total branching fraction, but small background contributions
- categorization optimized for each channel ($\ell^{\pm}\ell^{\pm}$, 3ℓ , 4ℓ) separately
- machine-learning discriminants for b tagging & lepton identification
 ⇒ huge improvement over previous Run-2 searches (higher signal efficiency, higher background rejection)

Backup: $t\bar{t}t\bar{t}$ + $t\bar{t}t$ multilepton analysis



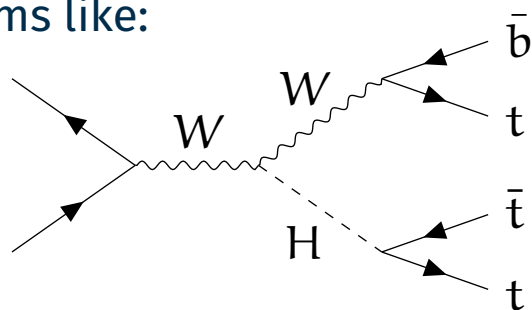
Backup: $t\bar{t}t\bar{t}$ + $t\bar{t}t$ multilepton analysis



Backup: Yukawa coupling

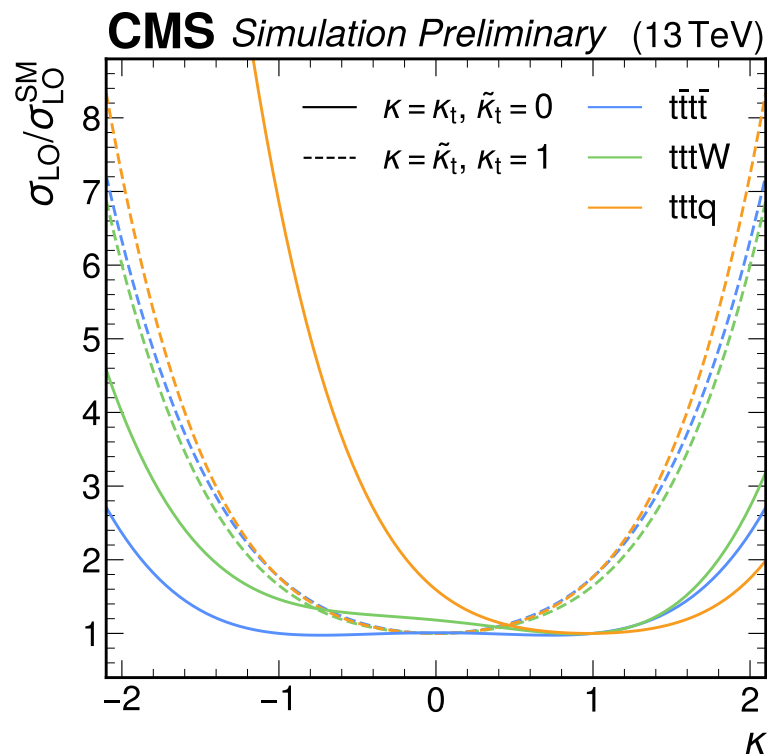
$$L_{Ht\bar{t}} = -\frac{m_t}{v} \bar{t} (\kappa_t + i\tilde{\kappa}_t \gamma_5) t H$$

- LO simulation for each process, fit with 4th-order polynomial
- $\sigma(t\bar{t}\bar{t})$ symmetric for positive/negative κ
- $\sigma(ttt)$ sensitive to sign via diagrams like:

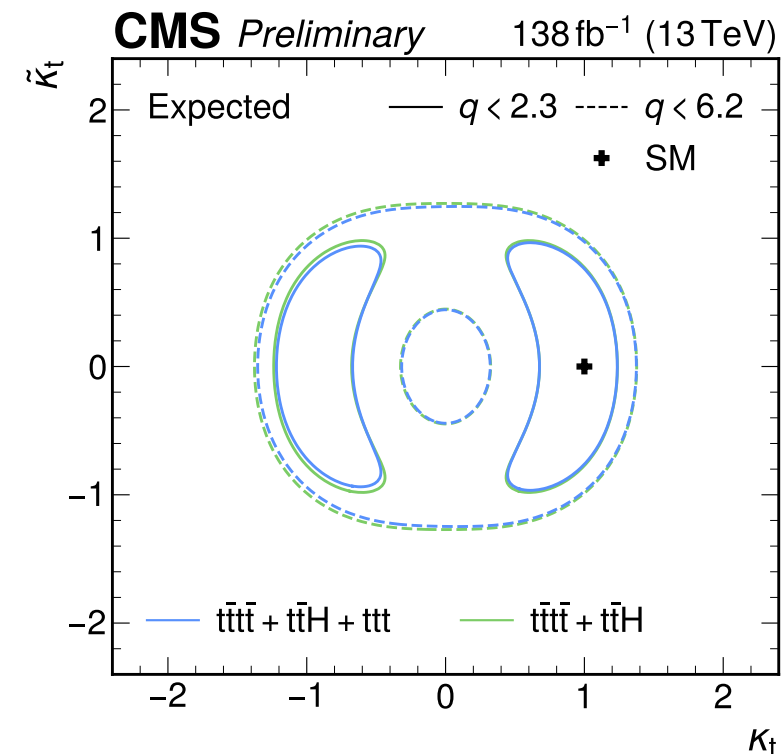


- scale ($t\bar{t}\bar{t}$) or shift (ttt) to match SM prediction ($\kappa = 1, \tilde{\kappa} = 0$)

parameterization



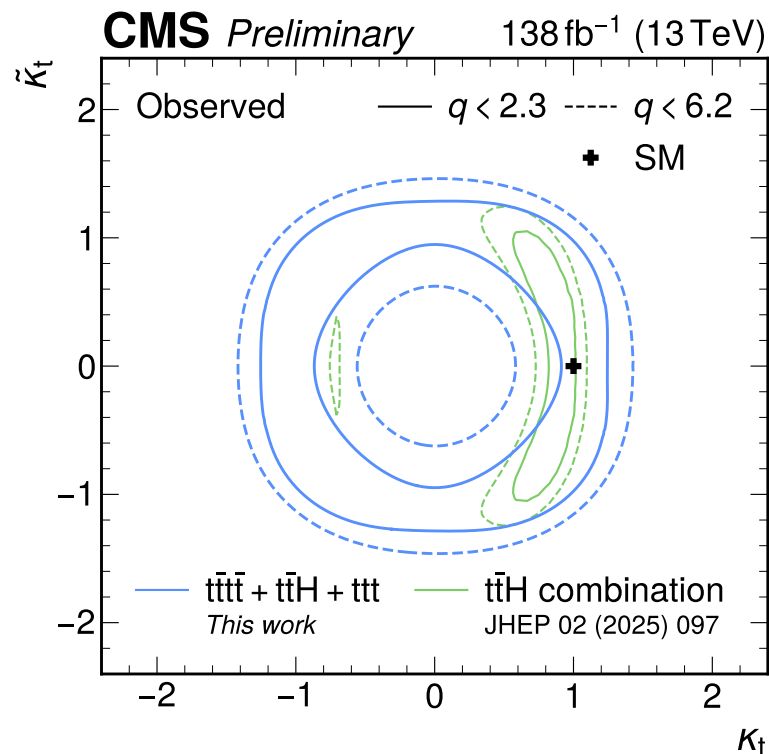
expected sensitivity



ttt sign dependence \Rightarrow stronger $\tilde{\kappa}_t$ limits at $\kappa_t < 0$ compared to > 0

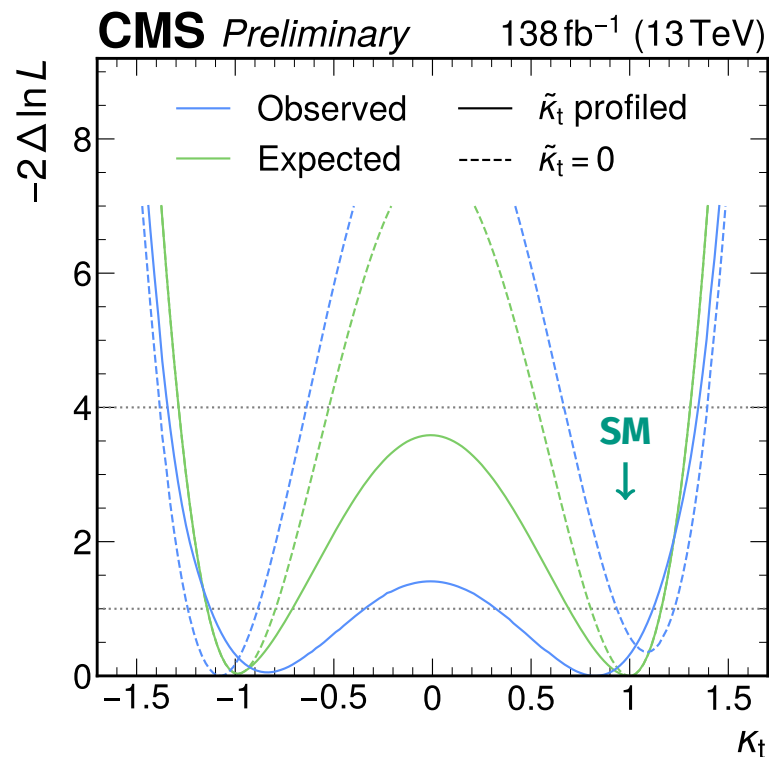
Backup: Yukawa coupling

2D scan



complementary to extraction from $t\bar{t}H$ measurements

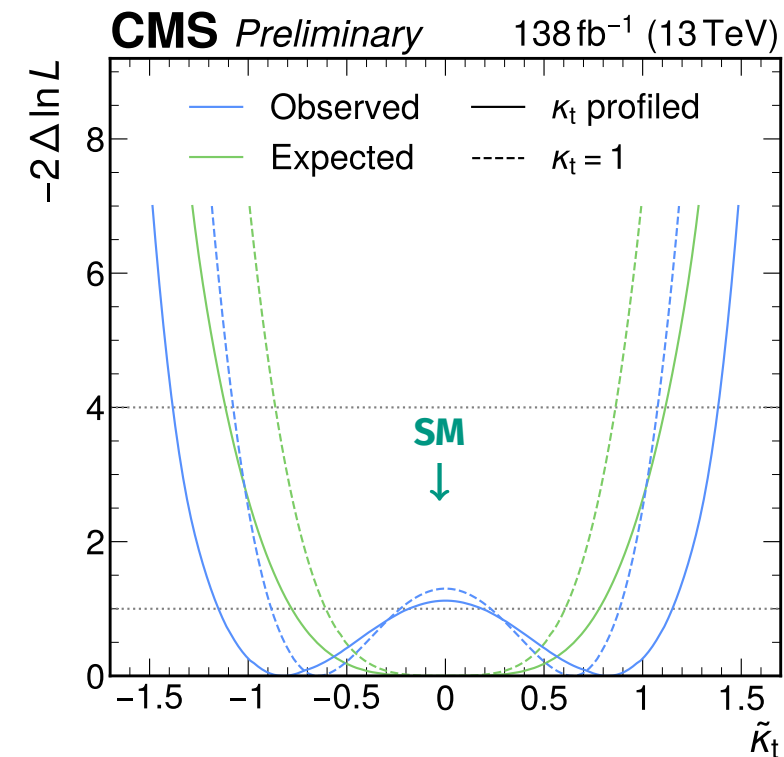
CP-even modifier



95% CL: $0.8 < |\kappa_t| < 1.3$

vs. $|\kappa_t| < 1.7$ in EPJC 80 (2020) 75 

CP-odd modifier



first time in $t\bar{t}\bar{t}$ @ CMS

Backup: Heavy resonances

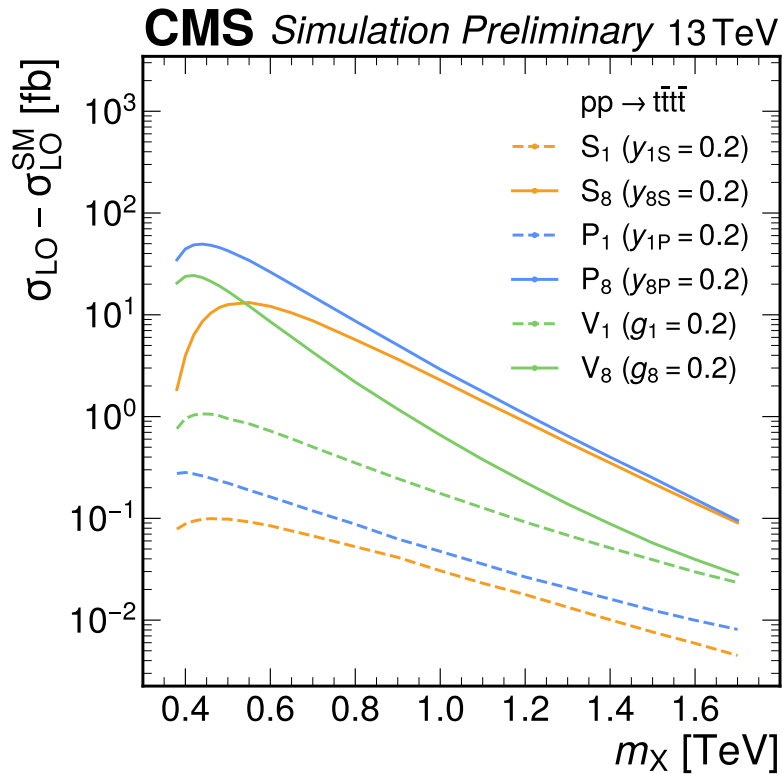
6 top-philic heavy resonance models:

JHEP 09 (2021) 143 / TopHeavyRes

[Scalar or Pseudoscalar or Vector]
 × [color singlet (1) or octet (8)]

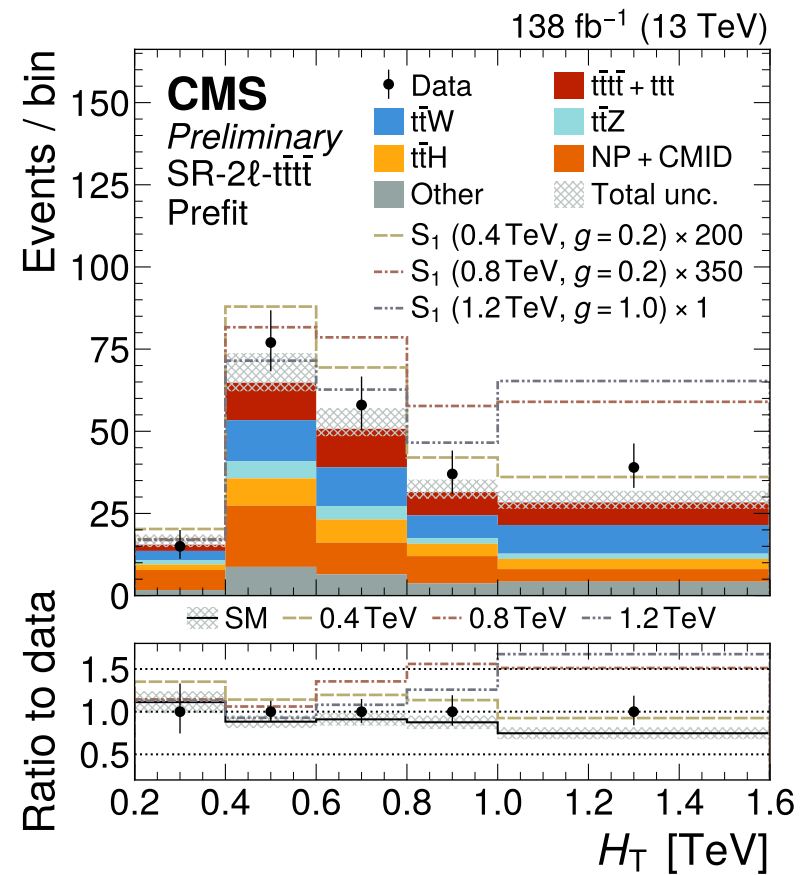
- mass: 400 GeV–1.6 TeV in 200 GeV steps
- coupling (y or g) to top quarks
- decay width fixed to 10 GeV
 ⇒ narrow resonances
- LO samples (interference + pure resonant), added to SM NLO
- single-resonant production:
 $pp \rightarrow t\bar{t}X \rightarrow t\bar{t}t\bar{t}$, $pp \rightarrow tX \rightarrow t\bar{t}t$
- double-resonant production:
 $pp \rightarrow X_8X_8 \rightarrow t\bar{t}t\bar{t}$

cross section prediction

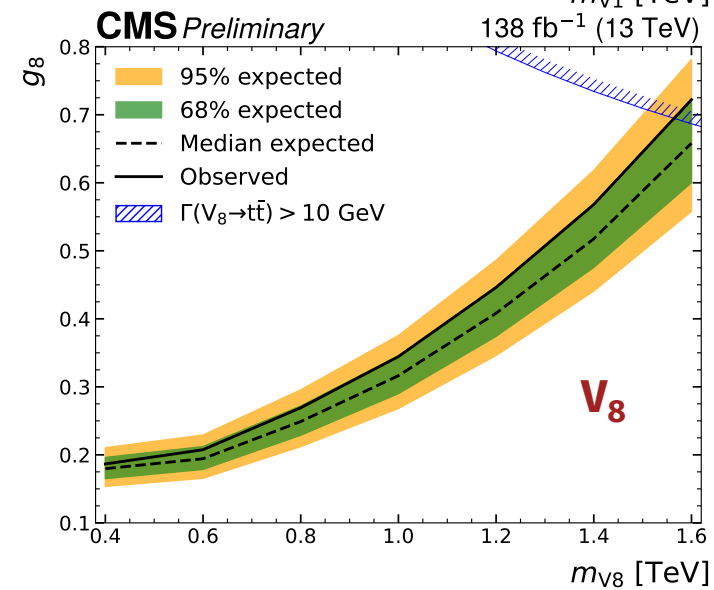
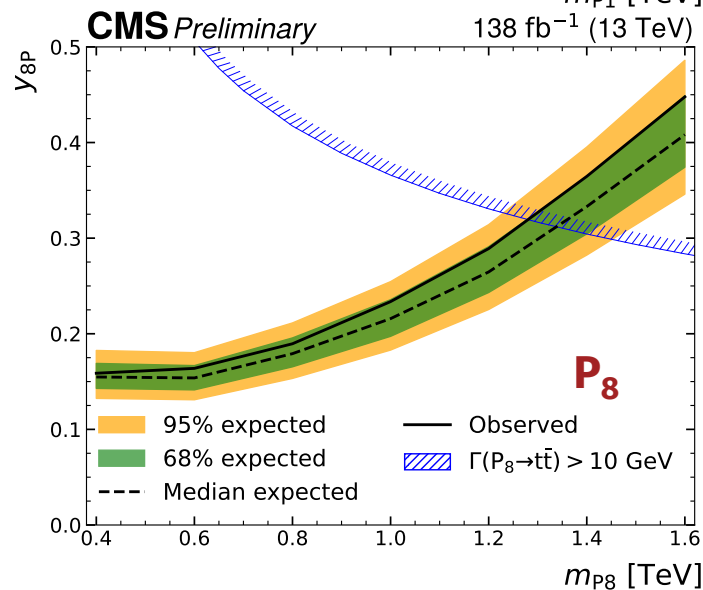
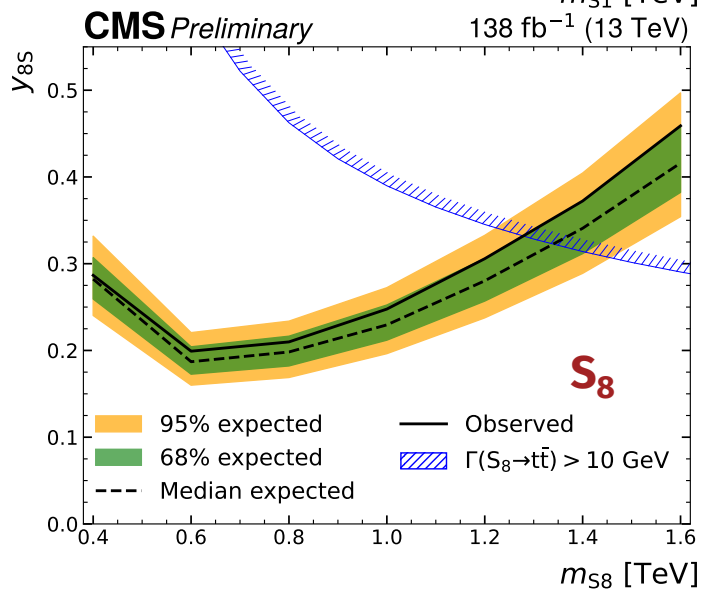
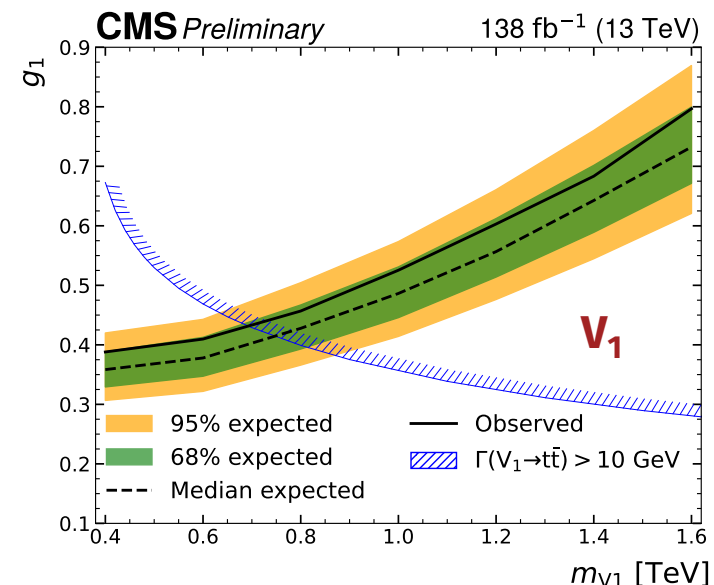
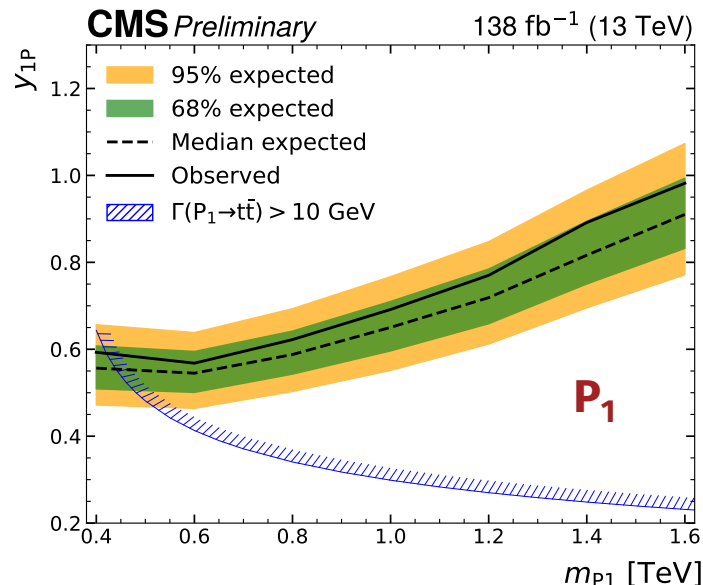
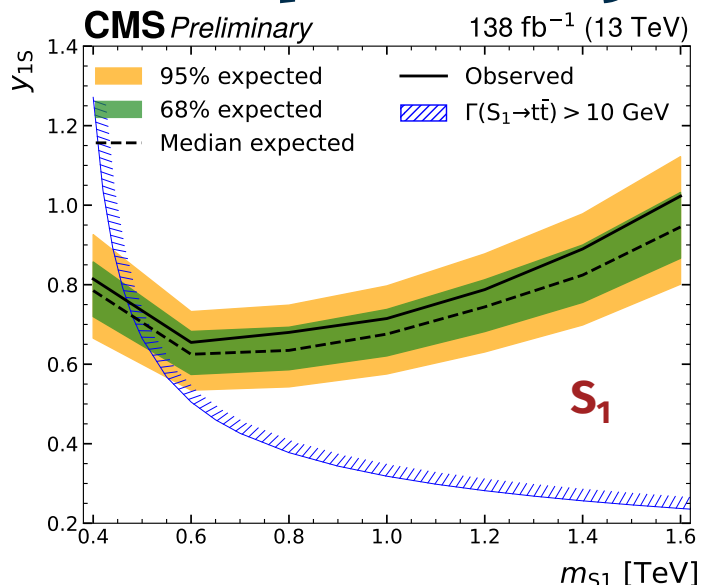


(peaks not clearly visible in limits with 200 GeV granularity)

fit distributions



Backup: Heavy resonances



Backup: SMEFT

$$L_{\text{SMEFT}} = L_{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2} Q_i$$

four-heavy-quark operators

c_{tt}	$(\bar{t}\gamma_\mu t)(\bar{t}\gamma^\mu t)$
$c_{QQ}^{(1)}$	$(\bar{Q}\gamma_\mu Q)(\bar{Q}\gamma^\mu Q)$
$c_{Qt}^{(1)}$	$(\bar{Q}\gamma_\mu Q)(\bar{t}\gamma^\mu t)$
$c_{Qt}^{(8)}$	$(\bar{Q}T^a\gamma_\mu Q)(\bar{t}T^a\gamma^\mu t)$

⇒ affect $t\bar{t}\bar{t}$ & $t\bar{t}t$, unique sensitivity

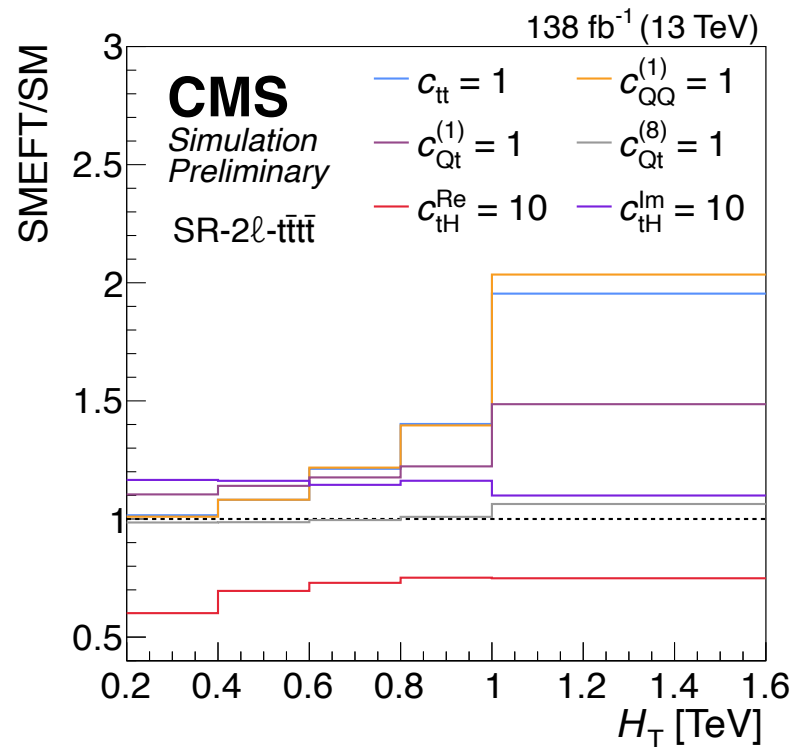
top-Higgs operators

$c_{tH}^{\text{Re}}, c_{tH}^{\text{Im}}$	$(H^\dagger H)(\bar{Q}\tilde{H}t)$
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⇒ affect $t\bar{t}\bar{t}$ & $t\bar{t}t$, but also $t\bar{t}H$

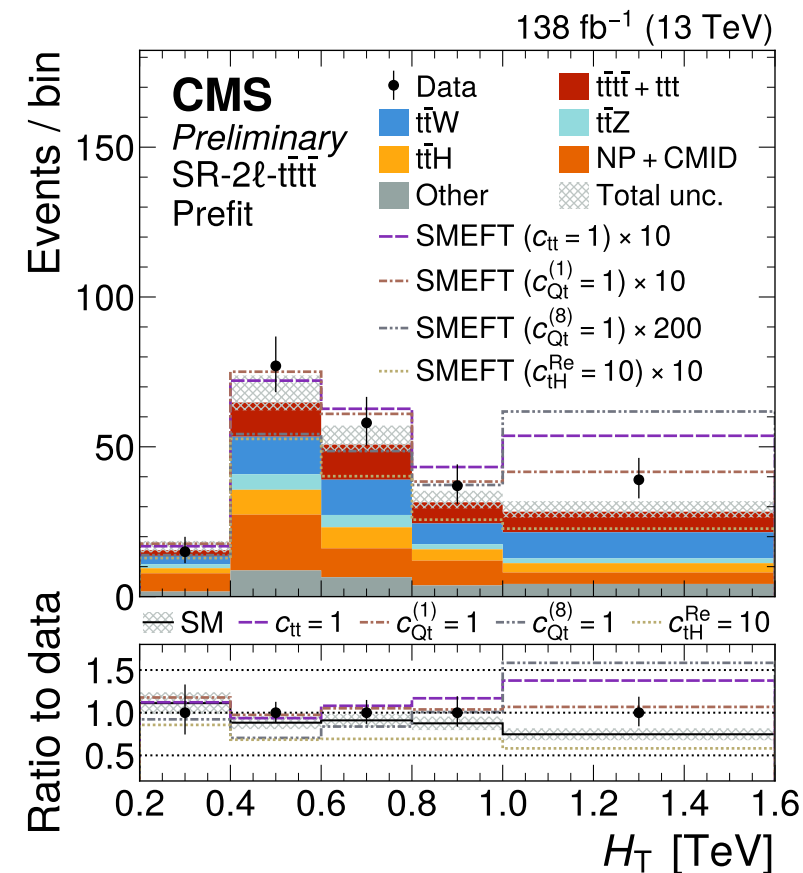
parameterization

evaluate linear+quadratic dependency from LO samples



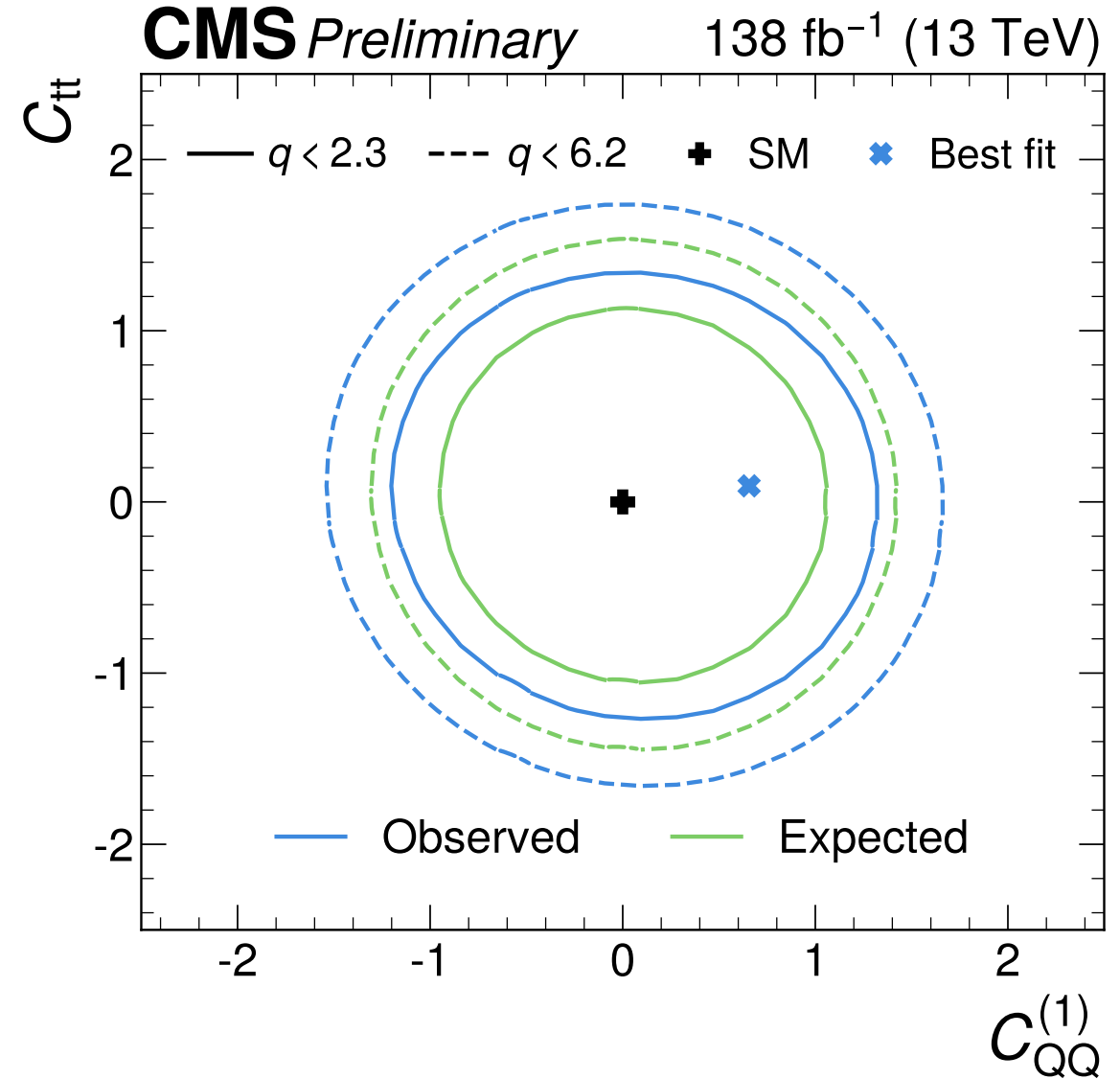
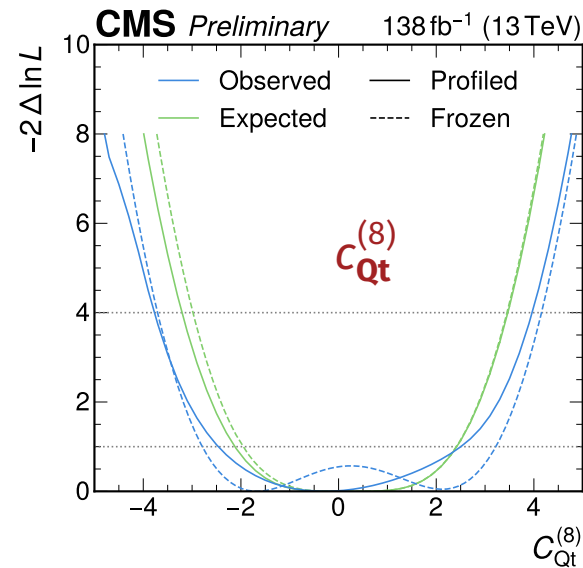
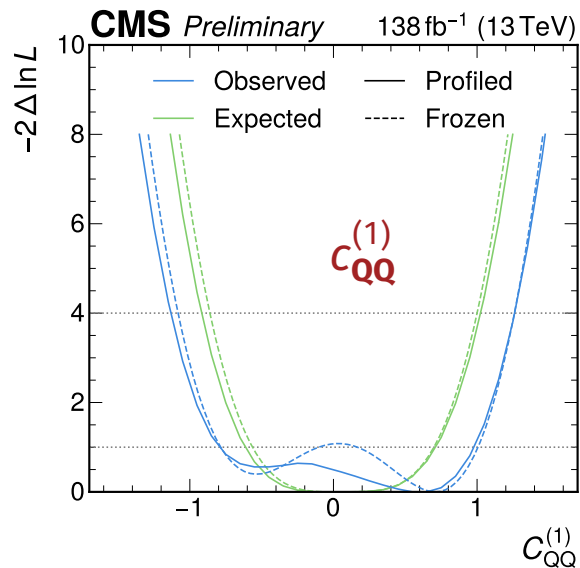
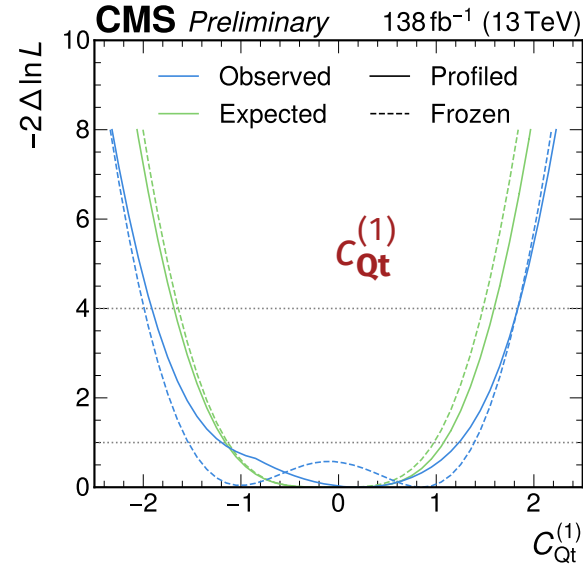
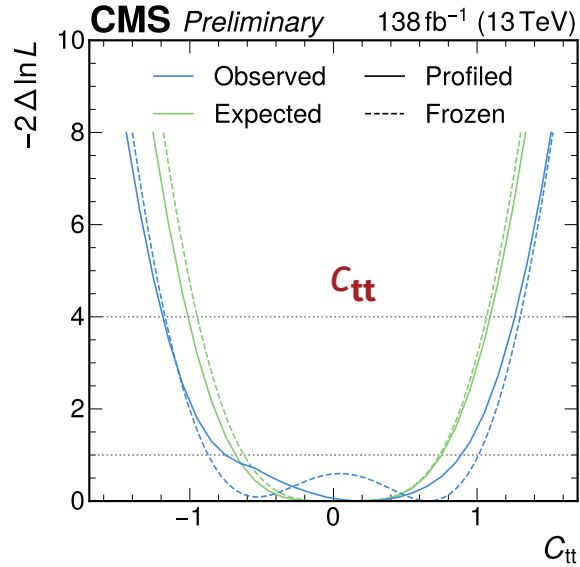
including flat effect from c_{tH} on $t\bar{t}H$

fit distribution

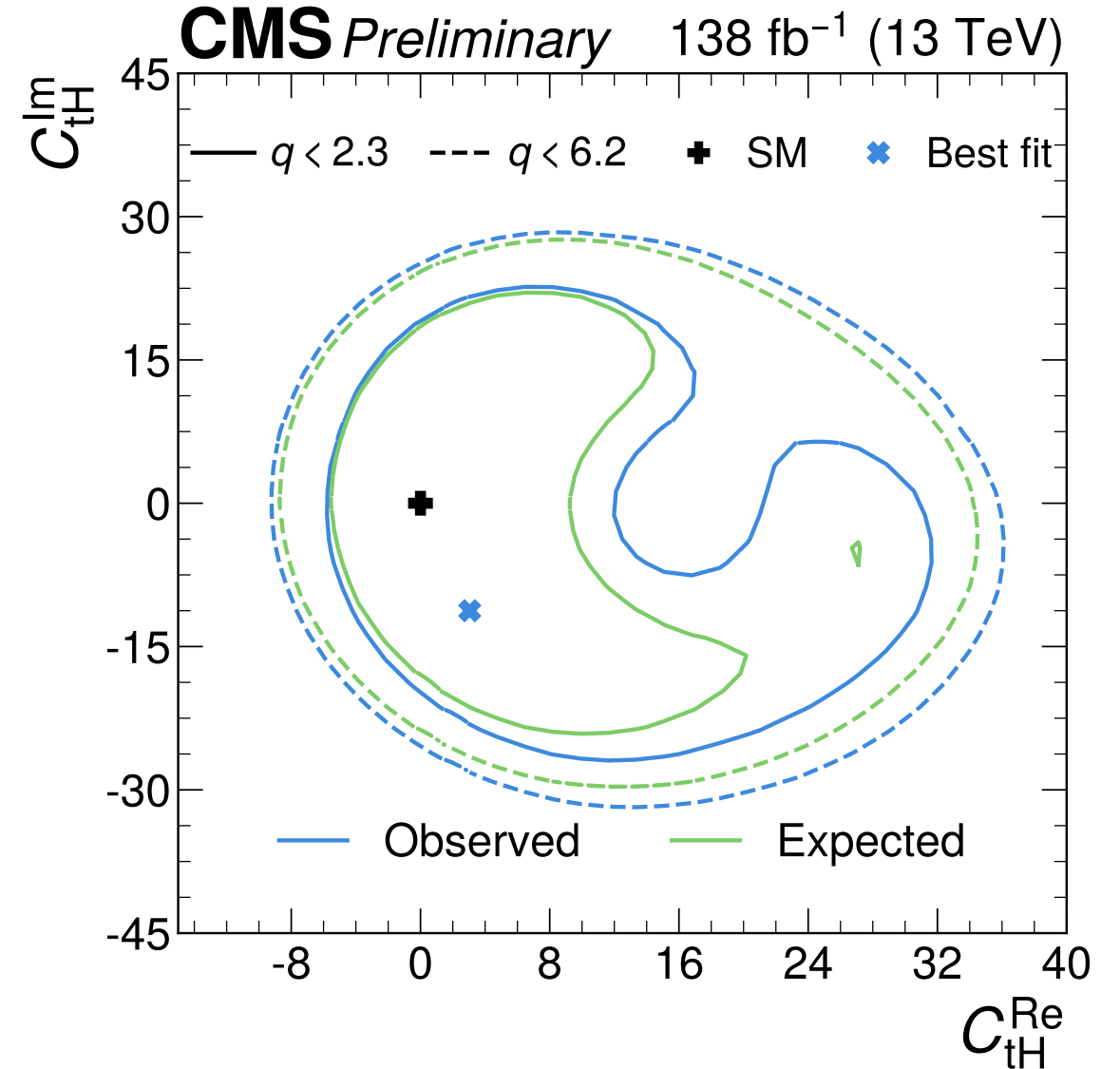
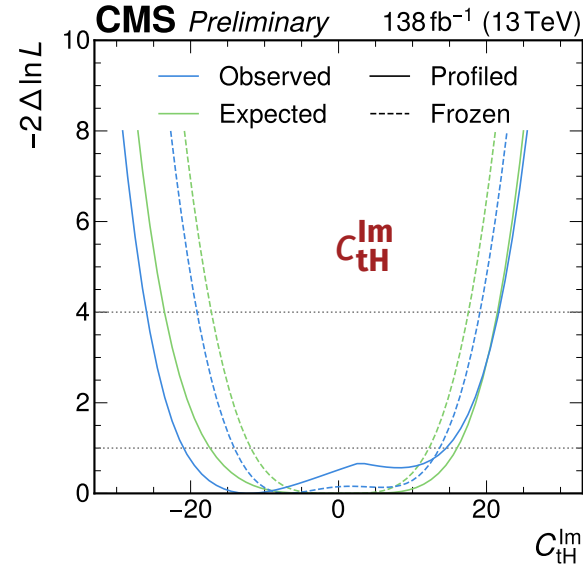
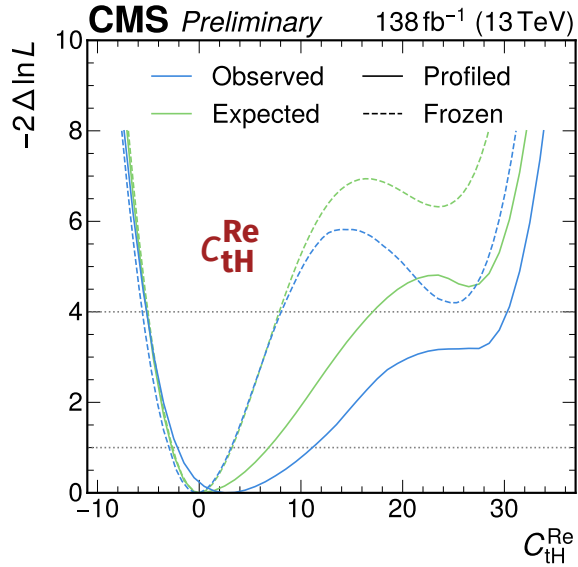


⇒ simultaneous 6D fit

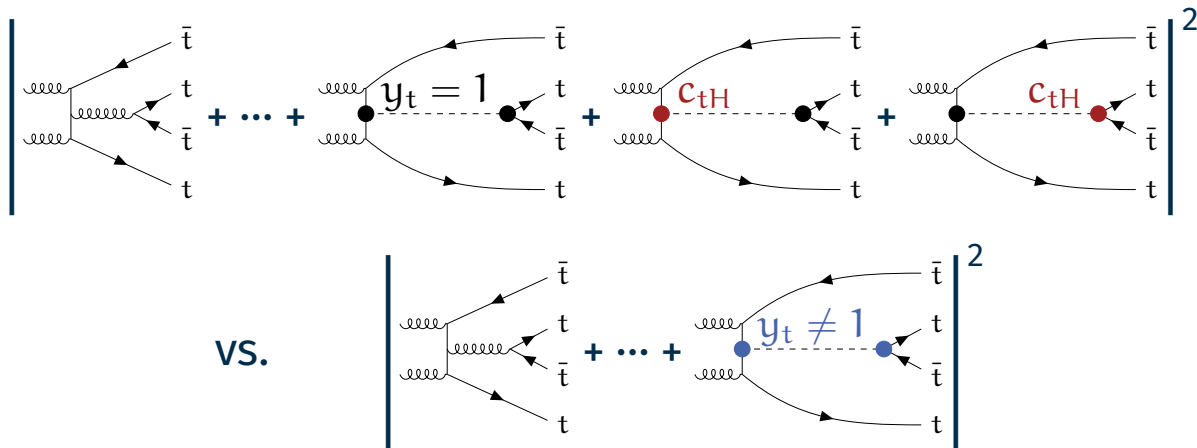
Backup: SMEFT



Backup: SMEFT



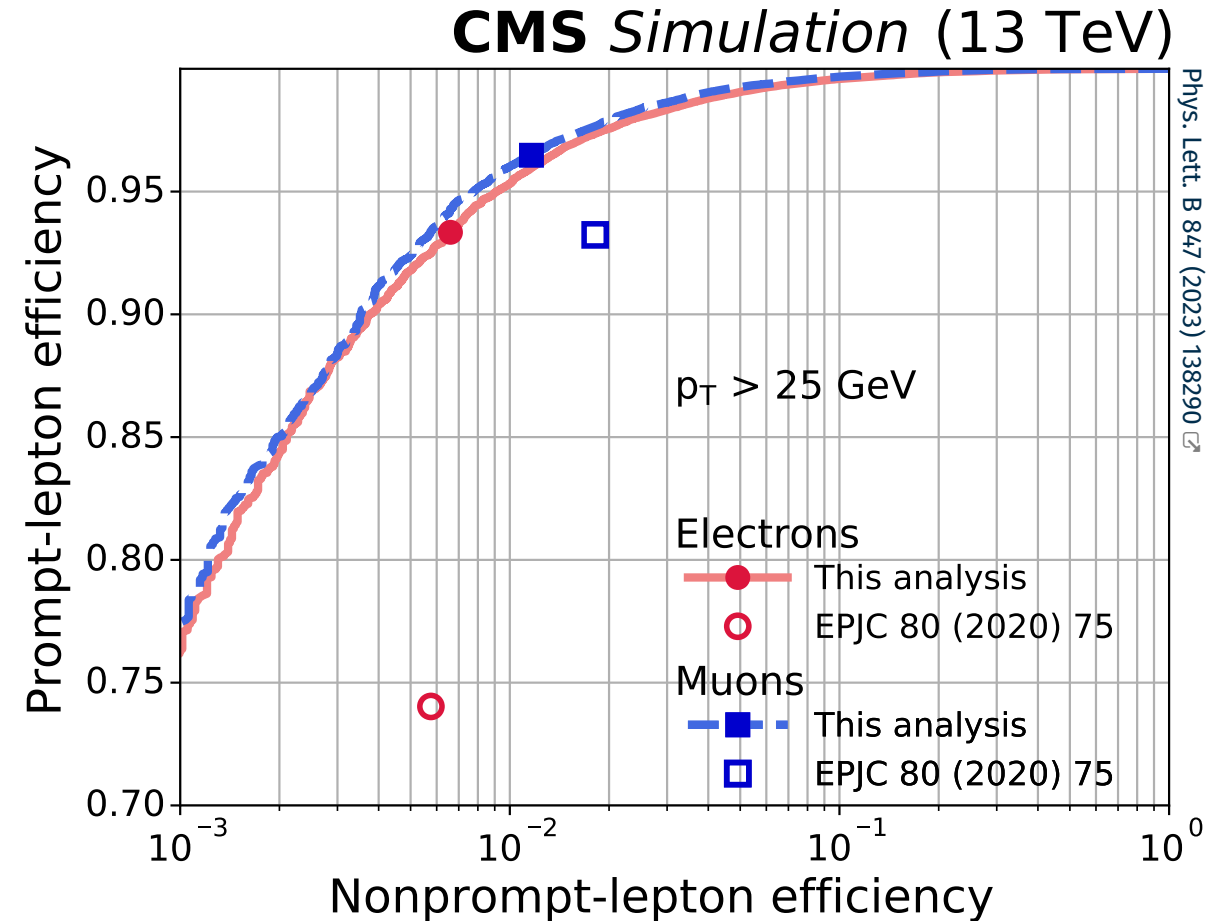
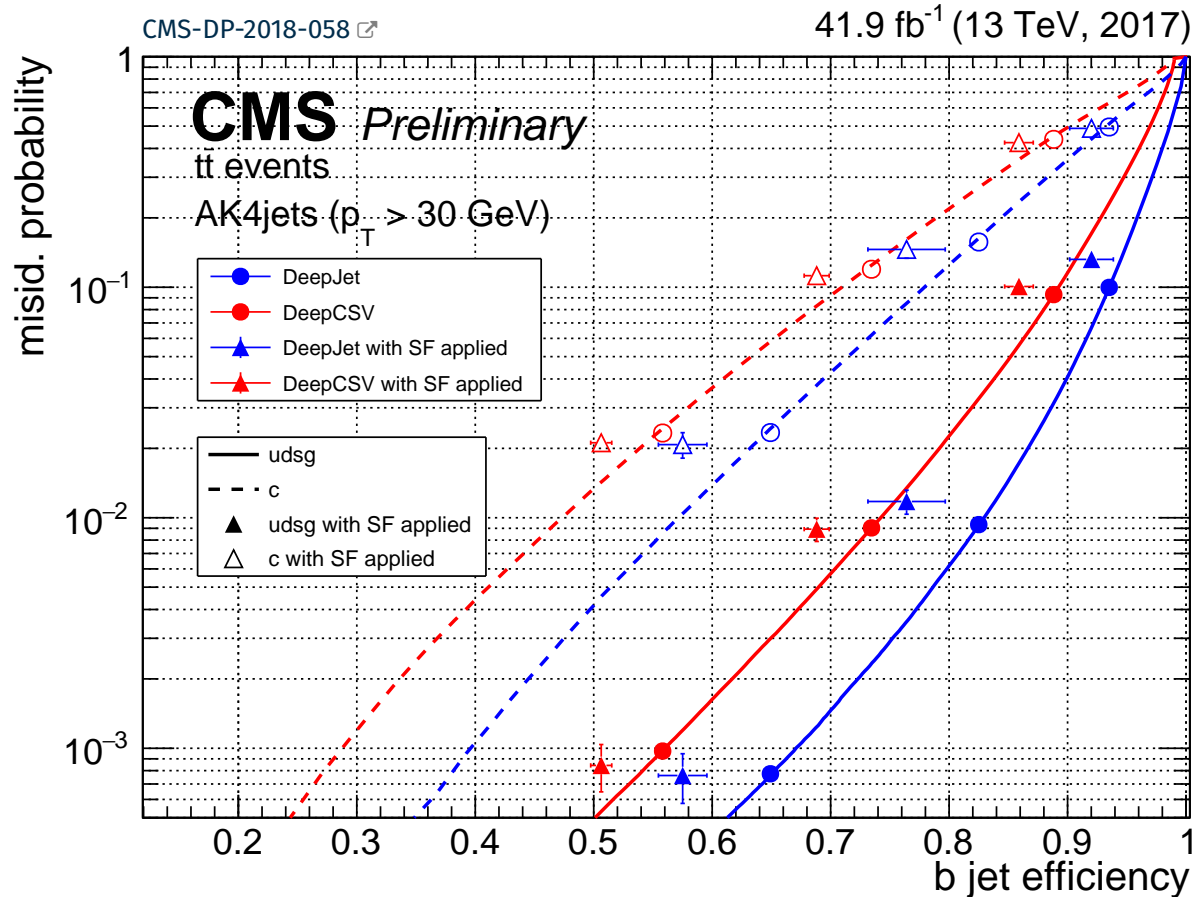
difference w.r.t. Yukawa interpretation:



Backup: b tagging & lepton ID improvements

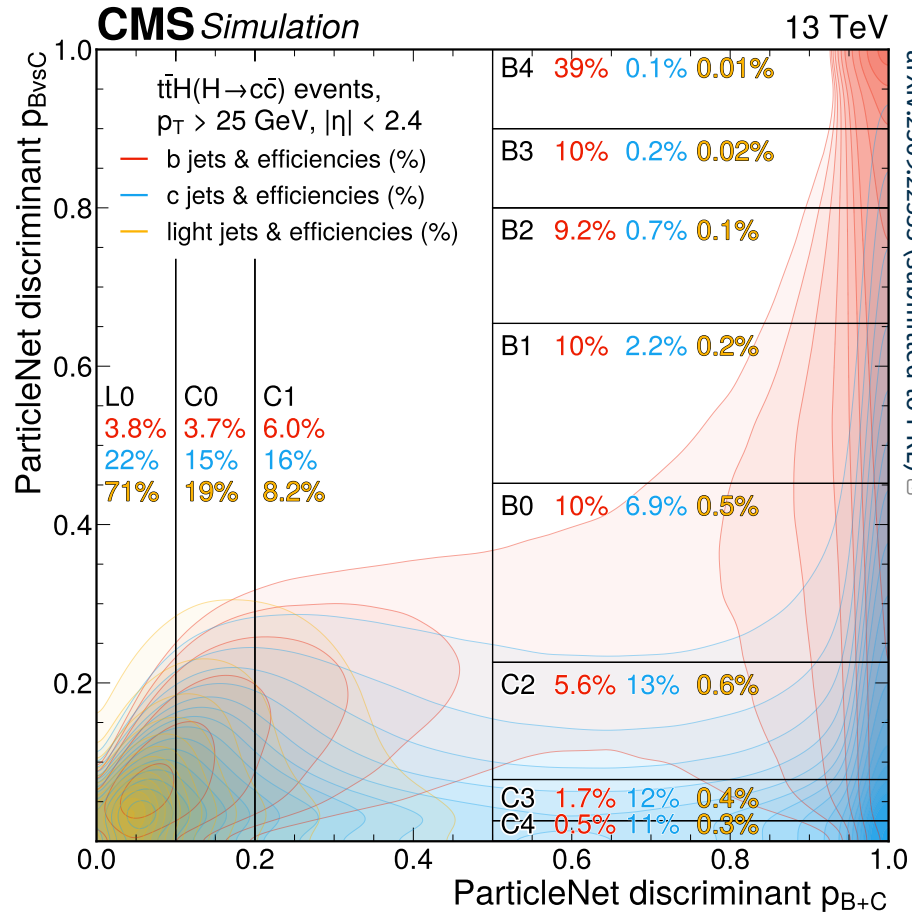
b tagging: DeepCSV \rightarrow DeepJet

electrons & muons: POG IDs \rightarrow custom MVA ID



Backup: more b tagging improvements

b tagging: ParticleNet Run-2



b tagging: CSVv1 → UParT

