Recent (SM-like) tHq results

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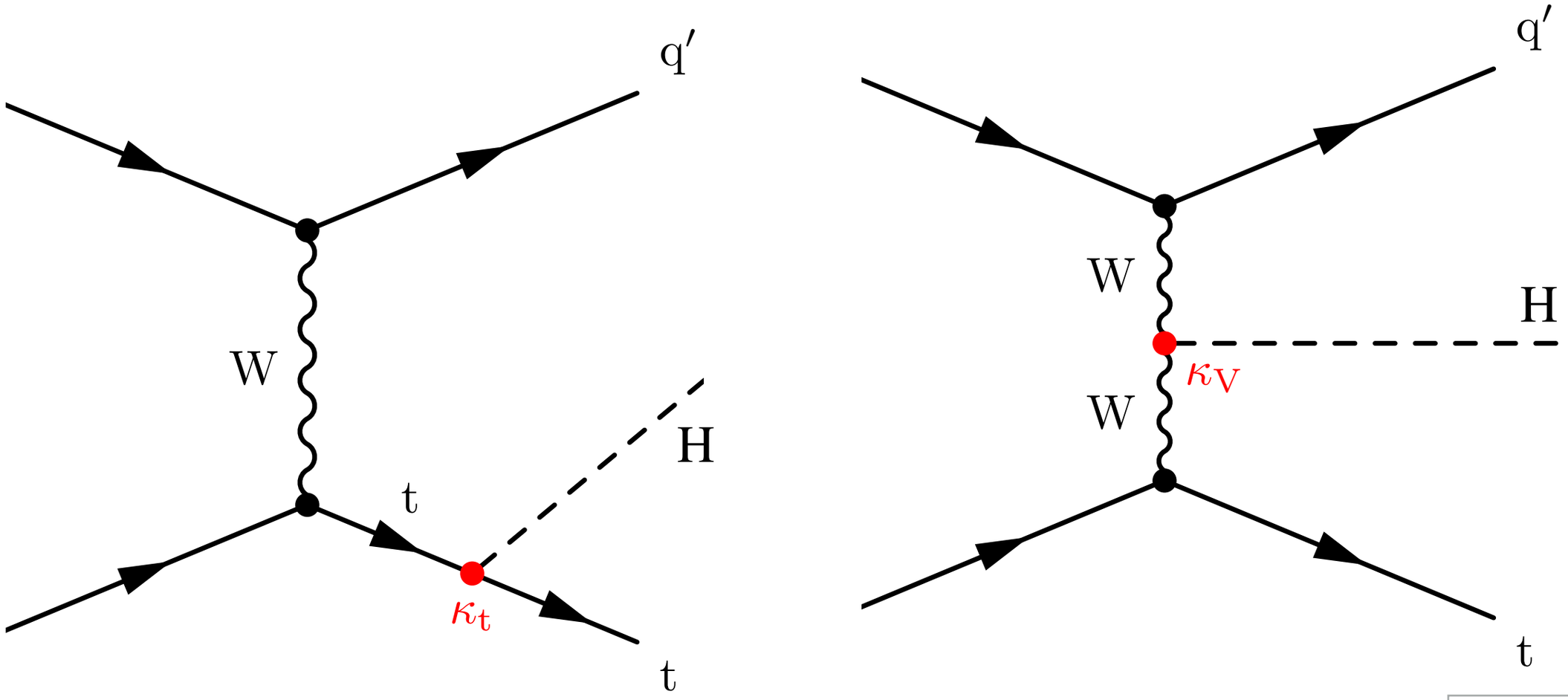
On behalf of CMS and ATLAS

Higgs Toppings Workshop (Benasque) May 31st 2018

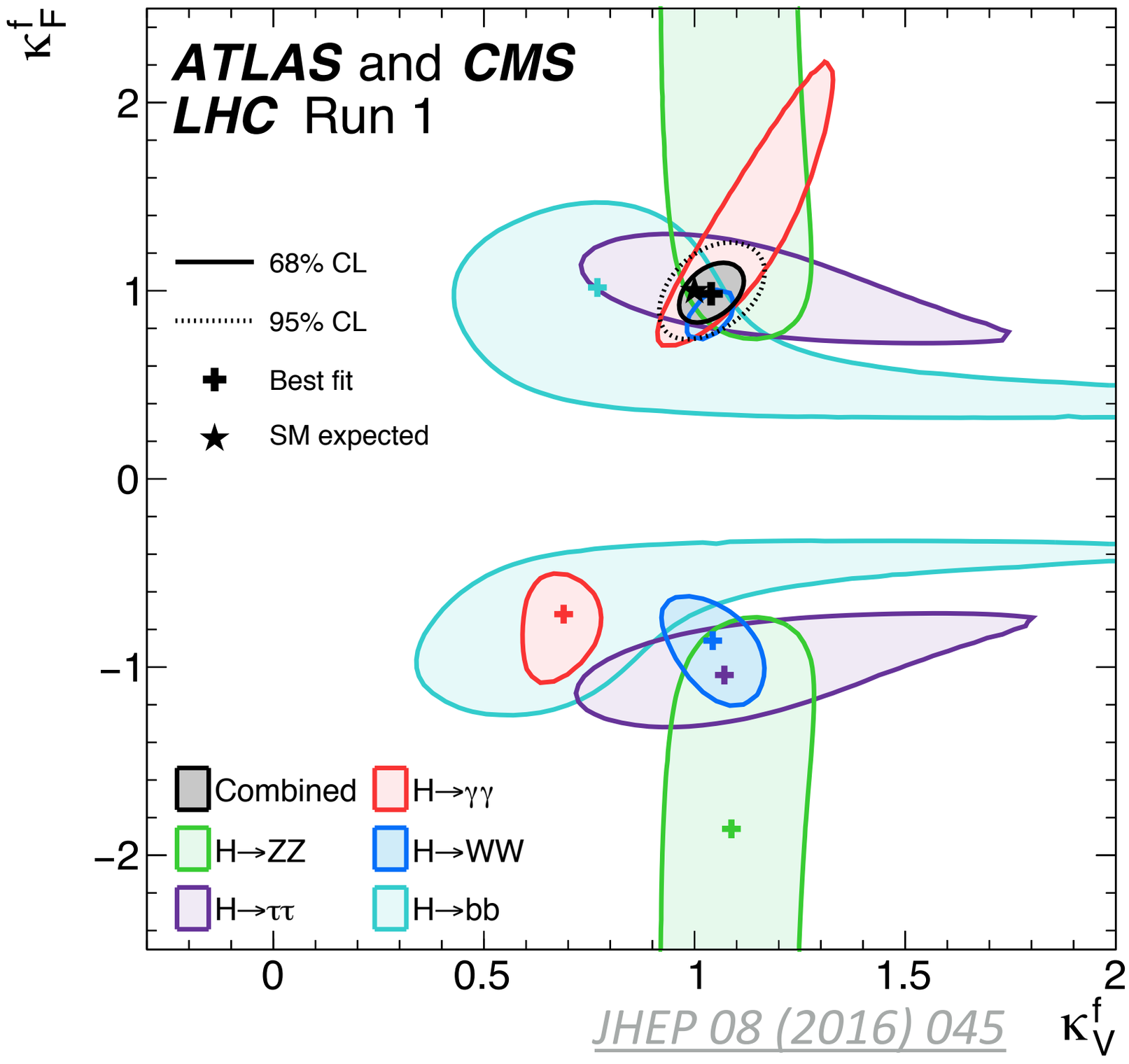
Motivation for single top + Higgs



$\kappa = C/C_{SM}$

- **Interference** between leading order diagrams
  - Sensitivity to **relative sign, amplitude, and phase**
  - Destructive in SM (σ ~70 fb @ 13 TeV)
  - Non-SM couplings can massively enhance tH cross section
- No need for **assumptions on particles in loops**
- Similar features for **tHW**, while s-channel almost negligible

Previous constraints on κ_f/κ_V coupling sign from $H\rightarrow\gamma\gamma$ via t-W loop interference.



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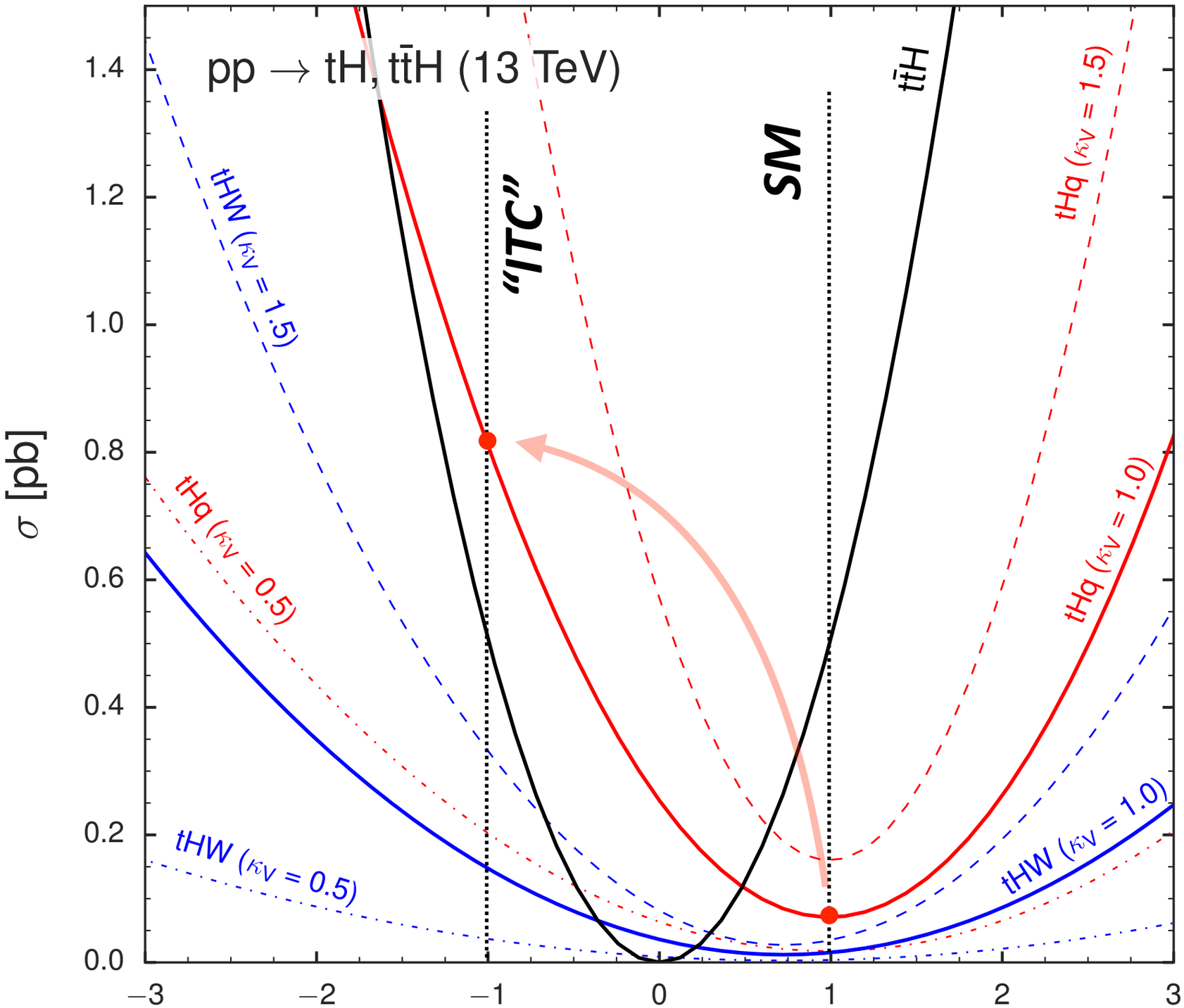
tH/ttH cross sections versus couplings



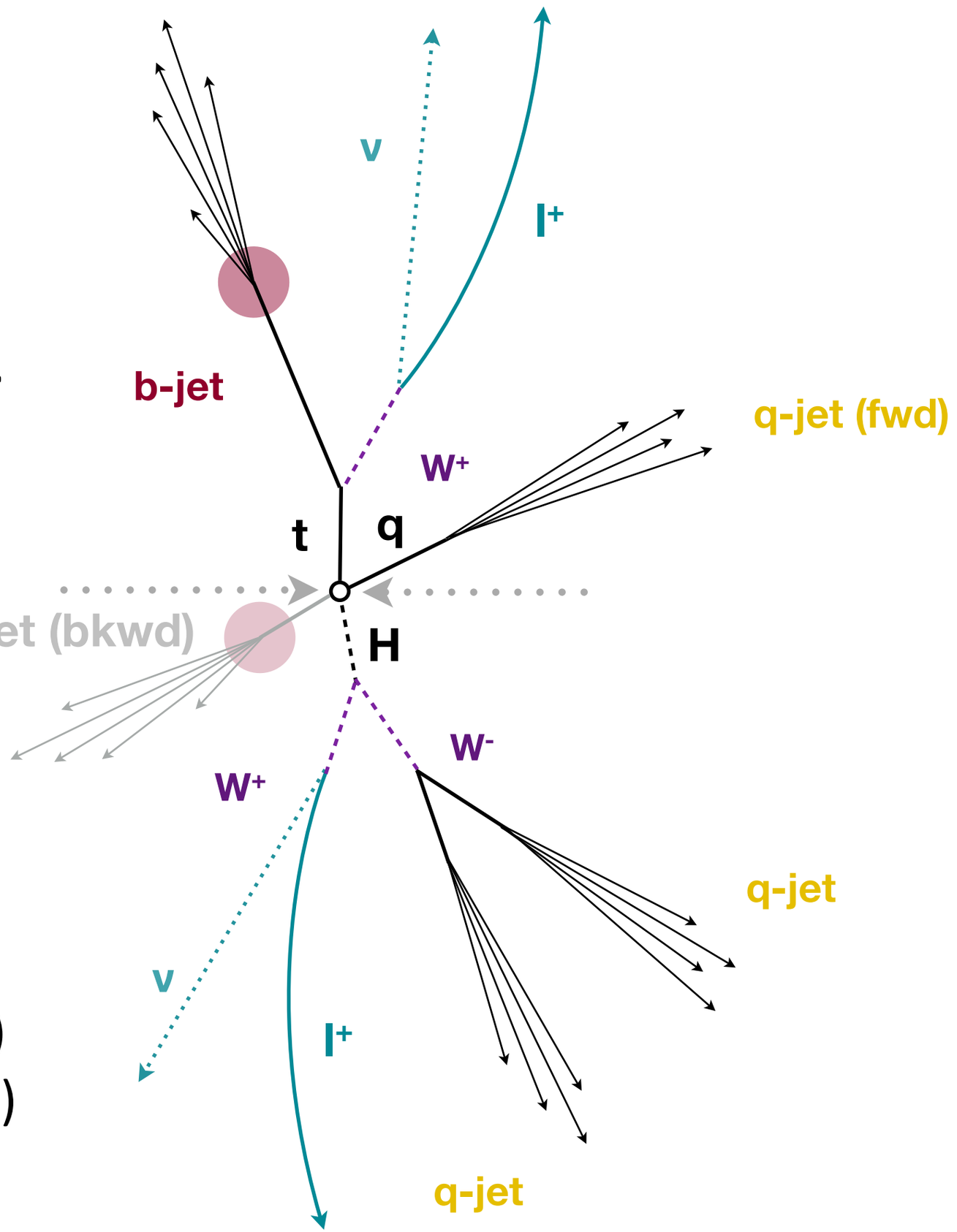
"ITC" = Inverted Top Couplings

YR4 Numbers

Experimental Signature

- t-channel single top with a Higgs radiation
- top and Higgs tend to be **back-to-back**
- Light **forward jet**

  (And a soft backward b)



- Most **accessible channels**
  - Multileptons (H→WW/ZZ/ττ)
  - Leptonic top + diphoton (H→γγ)
  - Hadronic top + diphoton (H→γγ)
  - Leptonic top + b-jets (H→bb)

Public Results

- **8 TeV** publication by CMS: *JHEP 06 (2016) 177*
  - Upper limit on tHq: $\sigma/\sigma_{\kappa t=-1.0} < 2.8$
  - γγ, $b\bar{b}$, multilepton, ττ channels

- **13 TeV** preliminary results by CMS:
  - **HIG-16-019**: **$b\bar{b}$** 2015 dataset (2.3 fb^{-1}), $\sigma/\sigma_{\kappa t=-1.0} < 6.0$
  - **HIG-17-005**: **multilepton** full 2016 dataset (35.9 fb^{-1}) ←

- ATLAS: dedicated tH categories in γγ analysis
  - Most recently in *arXiv:1802.04146* (HIGG-2016-21)
  - No dedicated limits on SM-like tHq production

Multilepton tHq Analysis

CMS-HIG-17-005

- Extension of **ttH multilepton** analysis
  - Recycled object selections and background estimations
  - Adjust **event selection** and develop **tHq classifier(s)**

- Three channels: **3 leptons**, same-sign $\mu^{\pm}\mu^{\pm}$, $e^{\pm}\mu^{\pm}$
  - Veto additional loose leptons, OSSF pairs within 15 GeV of m_Z (3l)
  - **At least one b-tagged jet**, $p_T > 25$ GeV
  - **At least one untagged jet**, $p_T > 25$ (40) GeV ($|\eta| < 2.4$ (>2.4))

- Reducible backgrounds estimated from data
  - Non-prompt leptons via fake-rate method
  - Electron charge mis-identification via charge flip probability

- Irreducible backgrounds from MC with scale factors

Yields at 35.9 fb^{-1}, 13 TeV

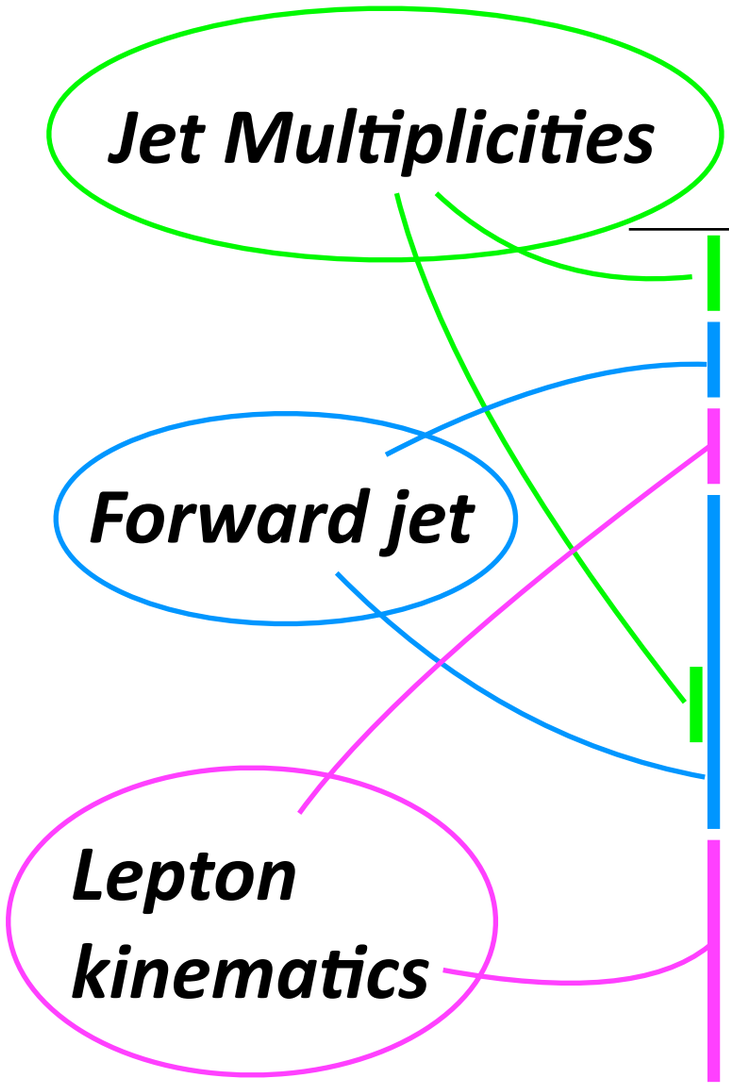
CMS-HIG-17-005

Process	$\ell\ell\ell$	$\mu\mu$	eμ
$t\bar{t}W^{\pm}$	22.50 ± 0.35	68.03 ± 0.61	97.00 ± 0.71
$t\bar{t}Z/t\bar{t}\gamma$	32.80 ± 1.79	25.89 ± 1.12	64.82 ± 2.42
WZ	8.22 ± 0.86	15.07 ± 1.19	26.25 ± 1.57
ZZ	1.62 ± 0.33	1.16 ± 0.29	2.86 ± 0.45
$W^{\pm}W^{\pm}qq$	–	3.96 ± 0.52	6.99 ± 0.69
$W^{\pm}W^{\pm}$(DPS)	–	2.48 ± 0.42	4.17 ± 0.54
VVV	0.42 ± 0.16	2.99 ± 0.34	4.85 ± 0.43
tttt	1.84 ± 0.44	2.32 ± 0.45	4.06 ± 0.57
tZq	3.92 ± 1.48	5.77 ± 2.24	10.73 ± 3.03
tZW	1.70 ± 0.12	2.13 ± 0.13	3.91 ± 0.18
γ conversions	7.43 ± 1.94	–	23.81 ± 6.04
Non-prompt	25.61 ± 1.26	80.94 ± 2.02	135.34 ± 2.83
Charge flips	–	–	58.20 ± 0.30
Total Background	106.05 ± 3.45	210.74 ± 3.61	443.30 ± 8.01
$t\bar{t}H$	18.29 ± 0.41	24.18 ± 0.48	35.21 ± 0.58
tHq (SM)	0.52 ± 0.02	1.43 ± 0.04	1.92 ± 0.04
tHW (SM)	0.62 ± 0.03	0.71 ± 0.03	1.11 ± 0.04
Total SM	125.48 ± 3.47	237.06 ± 3.64	481.54 ± 8.03
tHq ($\kappa_V = 1 = -\kappa_t$)	7.48 ± 0.14	18.48 ± 0.22	27.41 ± 0.27
tHW ($\kappa_V = 1 = -\kappa_t$)	7.38 ± 0.16	7.72 ± 0.17	11.23 ± 0.20
Data	~~**149**~~	**280**	**525**

tHq Signal Extraction

CMS-HIG-17-005

- **Two main backgrounds**: ttW/Z and non-prompt leptons ($t\bar{t}$)
- Train two BDT classifiers to separate tHq (κ_t = -1.0) from either



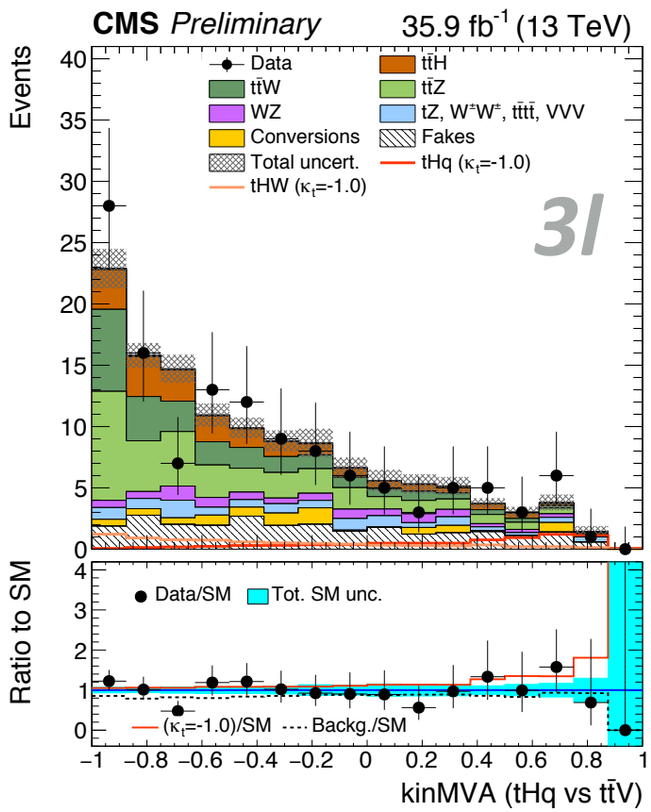
Number of jets with $p_{\mathrm{T}} > 25\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.4$
Maximum $\lvert\eta\rvert$ of any (non-b-tagged) jet ("forward jet")
Sum of lepton charges
Number of non-b-tagged jets with $\lvert\eta\rvert > 1.0$
$\Delta\eta$ between forward light jet and leading b-tagged jet
$\Delta\eta$ between forward light jet and sub-leading b-tagged jet
$\Delta\eta$ between forward light jet and closest lepton
$\Delta\phi$ of same-sign lepton pair
Minimum ΔR between any two leptons
p_{T} of sub-leading (or 3^{rd}) lepton

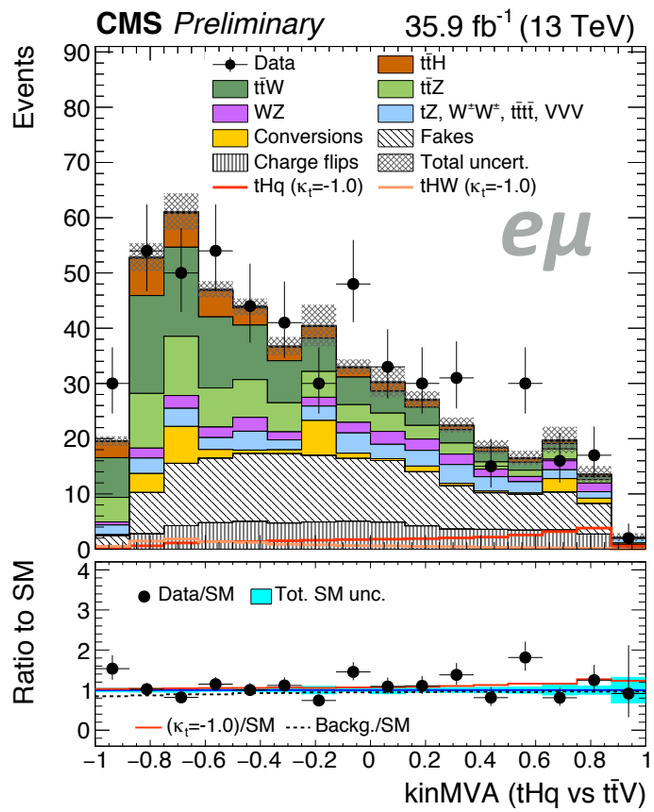
- Combine 2D output into 1D distribution to use in the fit

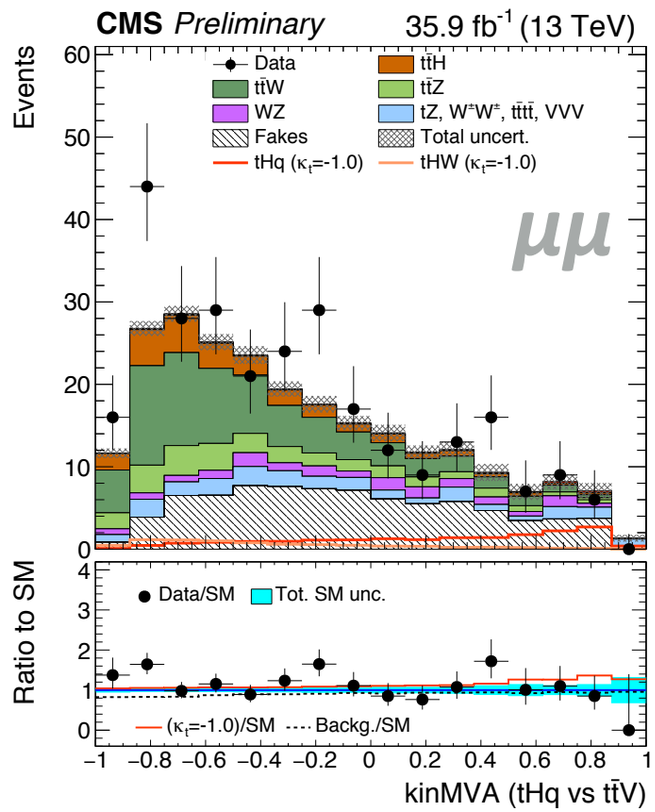
Prefit Classifier Outputs

CMS-HIG-17-005

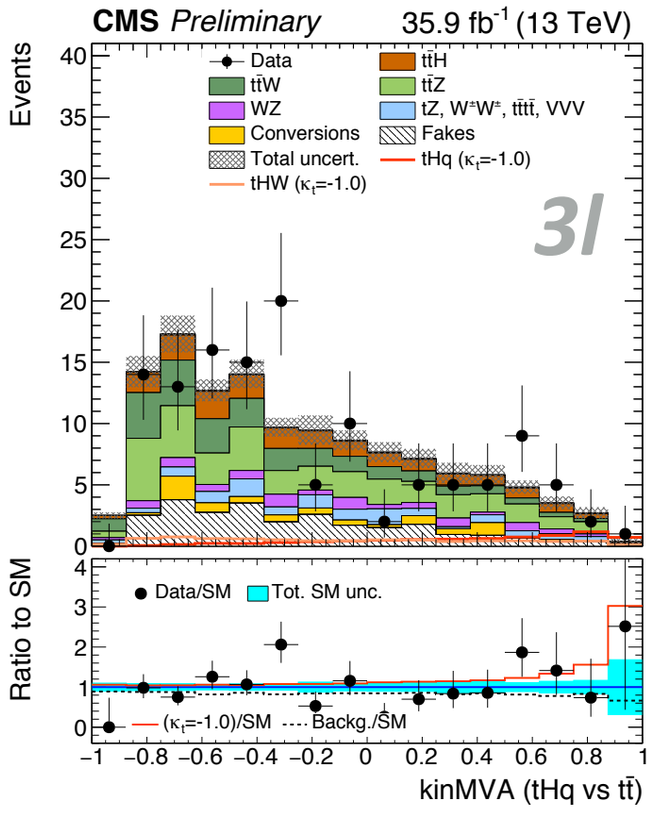
vs ttV

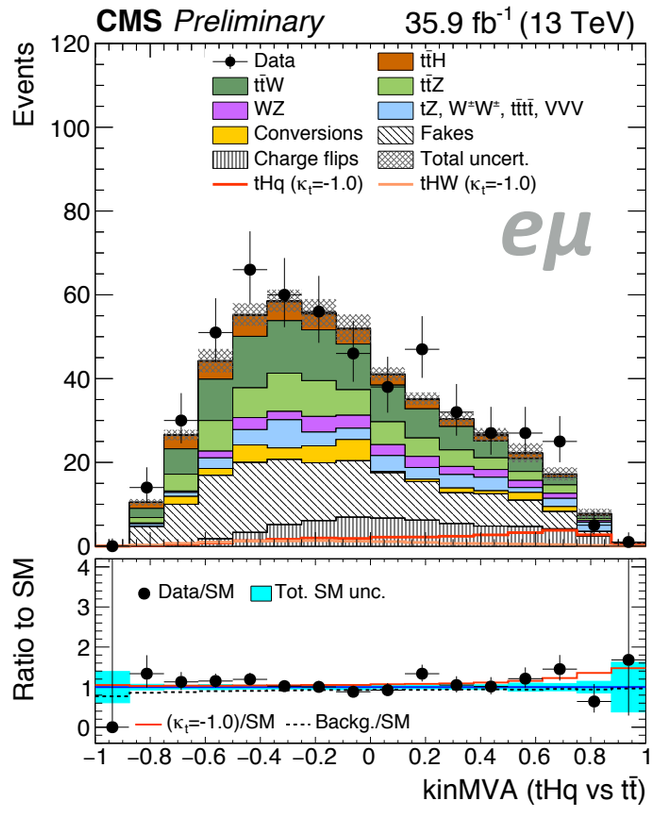


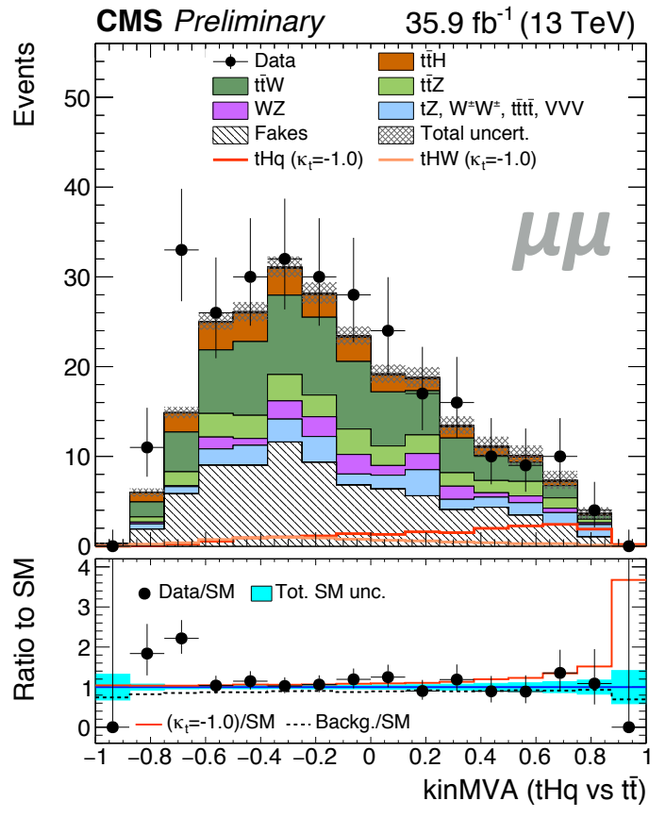




vs ttbar







Constrain κ_t/κ_V to be within **[-1.25, 1.60]** (κ_V = 1.0)

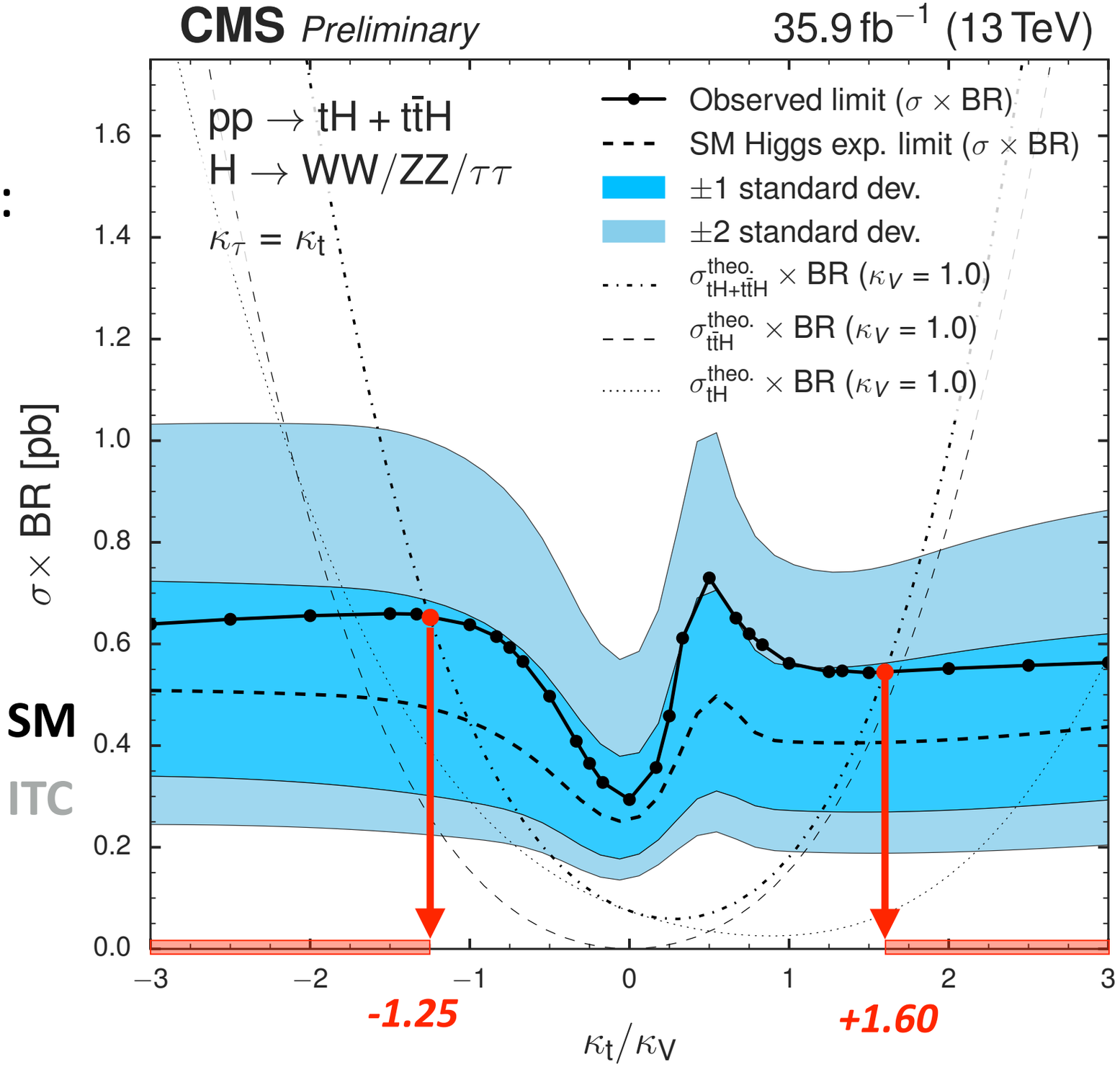
CMS-HIG-17-005

- Float a **common tH+ttH signal strength**

- Best-fit signal strengths:
  - SM: **1.8 ± 0.7**
  - ITC: **0.7 ± 0.4**

- Observed excess consistent with SM-like ttH production
  - 2.7σ obs. (1.5σ exp.) **SM**
  - 1.7σ obs. (2.5σ exp.) **ITC**

- Fit prefers positive signs by about 2σ



- tH cross sections strongly sensitive to relative sign of κ_t and κ_V
- No assumptions on unknown particles in loops

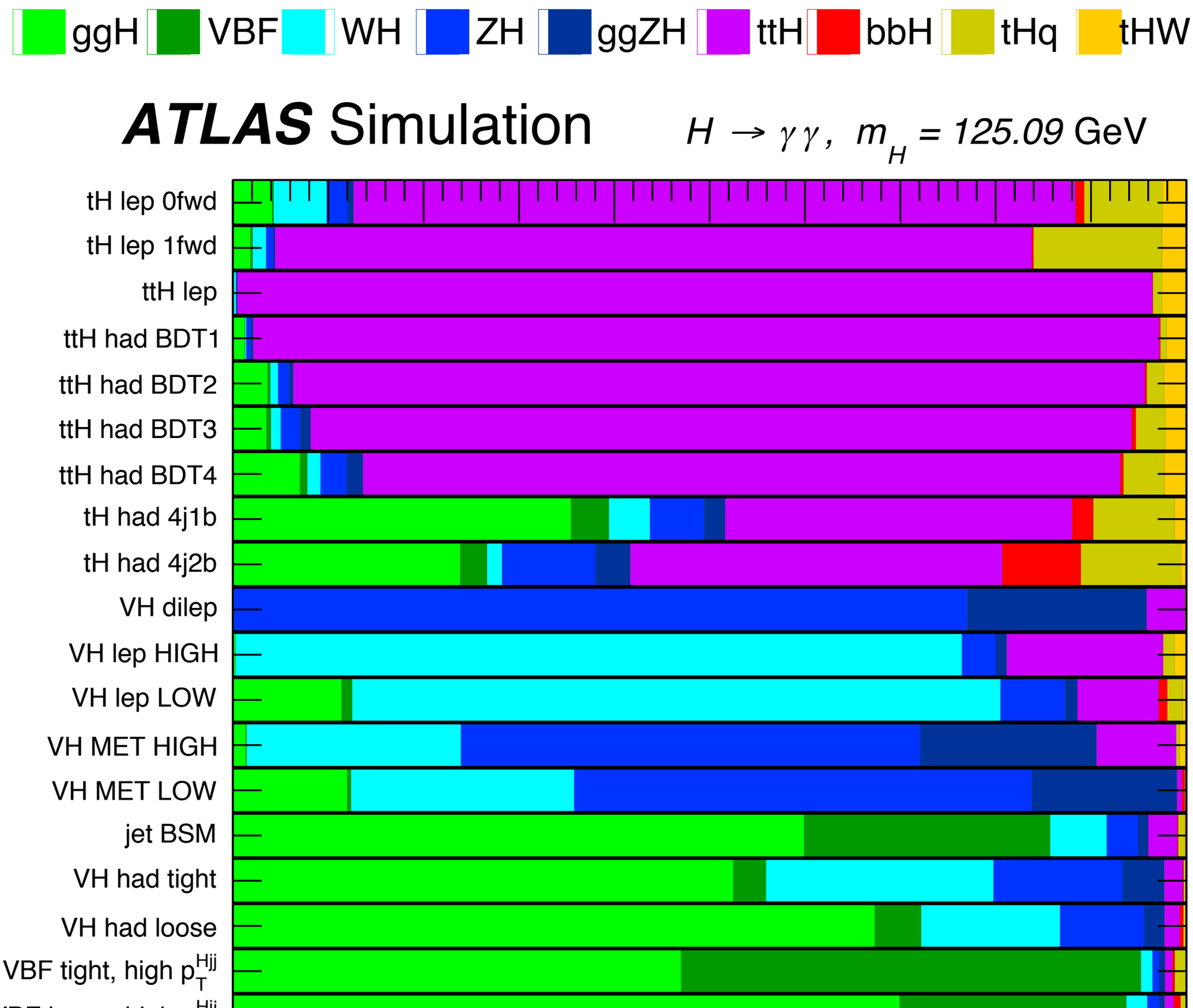
- Dedicated analyses can set independent limits on κ_t/κ_V
  - Not yet included in overall combination

- tH-enriched categories used in global combinations

BACKUP

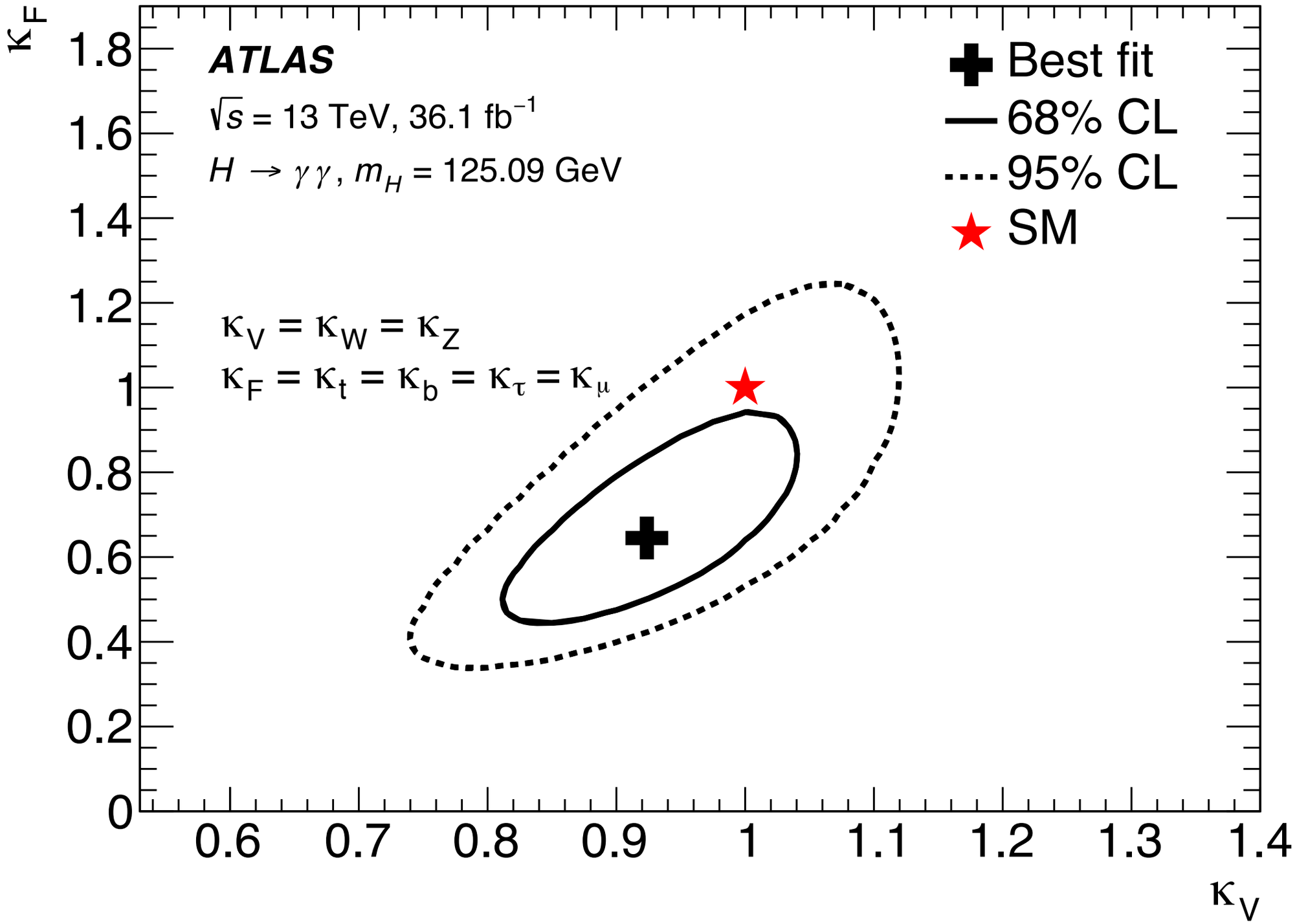
ATLAS tH categories (γγ analysis)

arXiv:1802.04146

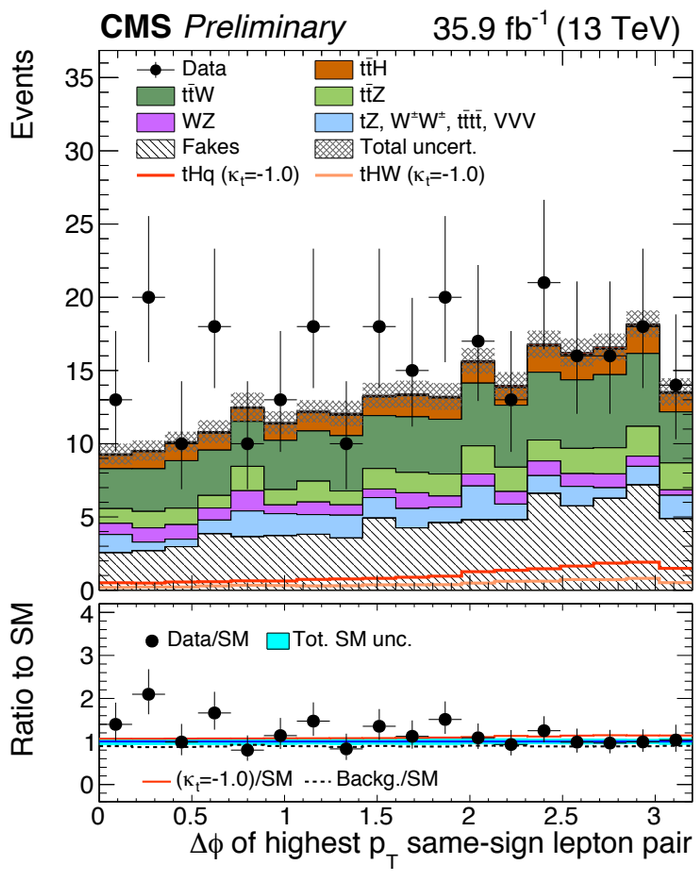


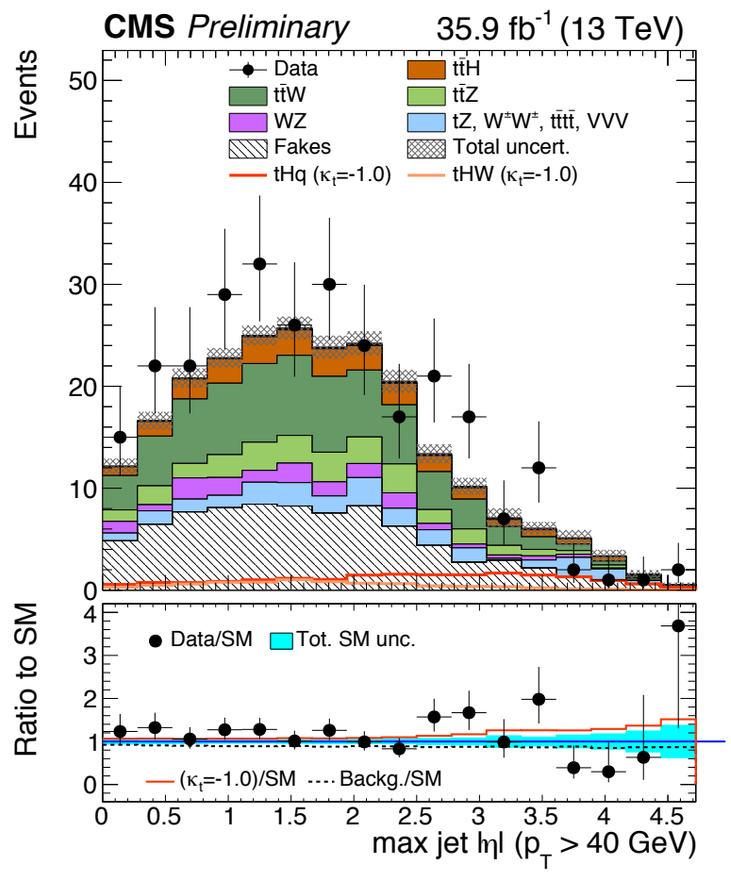
ATLAS κ_F/κ_V constraints ($\gamma\gamma$)

arXiv:1802.04146



$\mu^{\pm}\mu^{\pm}$


CMS Preliminary
35.9 fb-1 (13 TeV)
Data
tt̄W
WZ
Fakes
tHq (κt=-1.0)
tt̄H
tt̄Z
tZ, W±W±, tt̄tt̄, VVV
Total uncert.
tHW (κt=-1.0)
Events
Ratio to SM
Data/SM
Tot. SM unc.
(κt=-1.0)/SM
Backg./SM
Δϕ of highest pT same-sign lepton pair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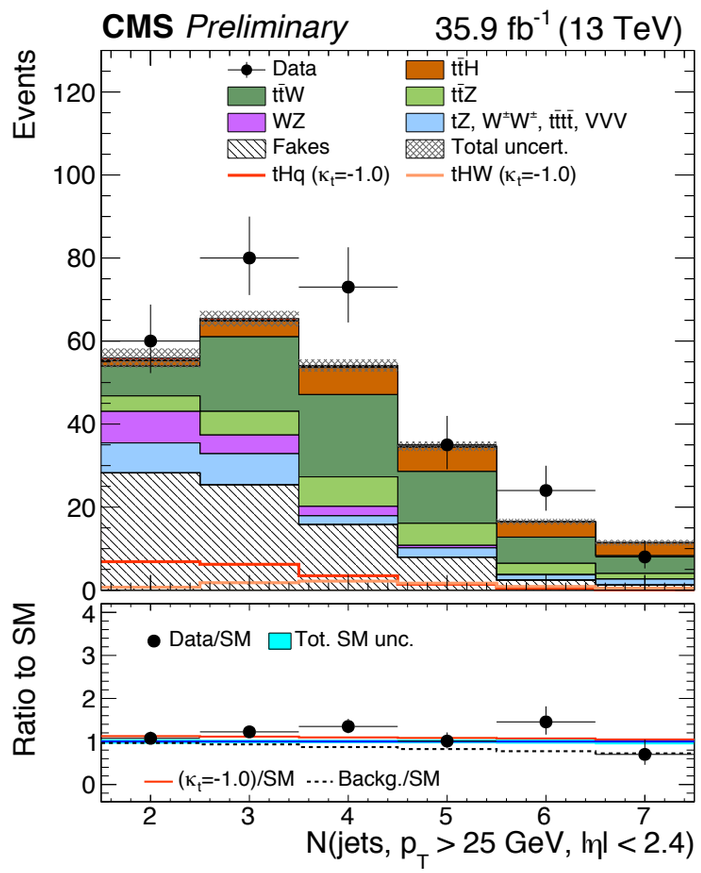
Events
Ratio to SM
Data/SM
Tot. SM unc.
(κt=-1.0)/SM
Backg./SM
max jet |η| (pT > 40 GeV)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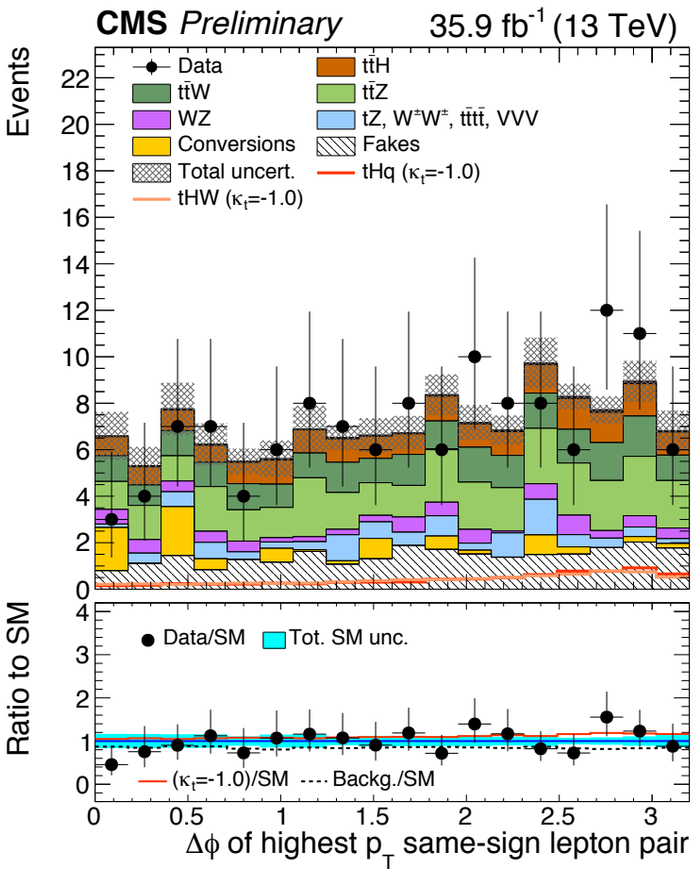
Tot. SM unc.
(κt=-1.0)/SM
Backg./SM
N(jets, pT > 25 GeV, |η| < 2.4)

3l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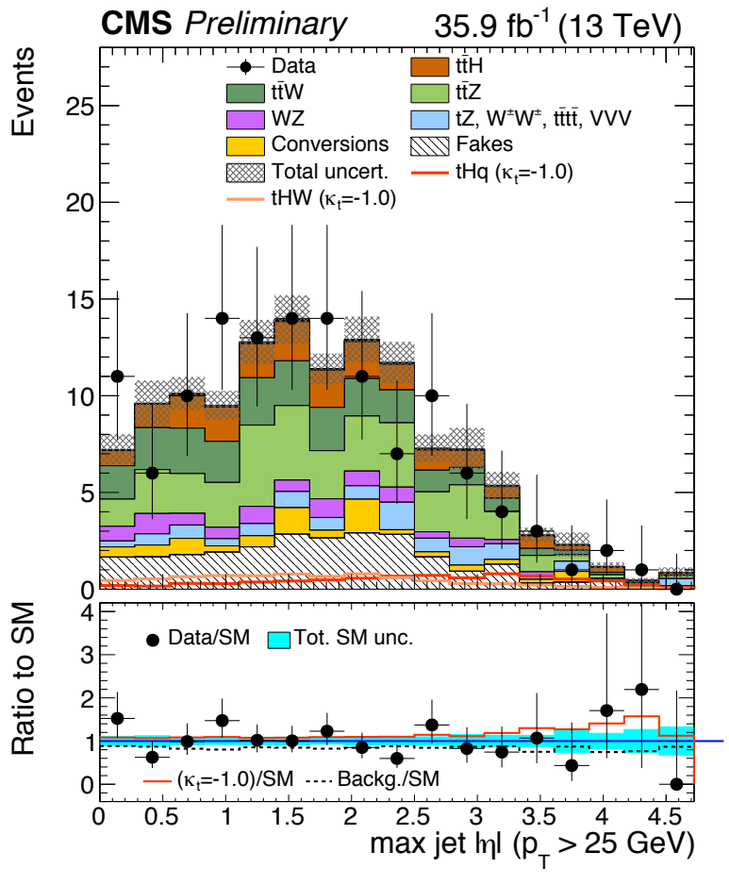
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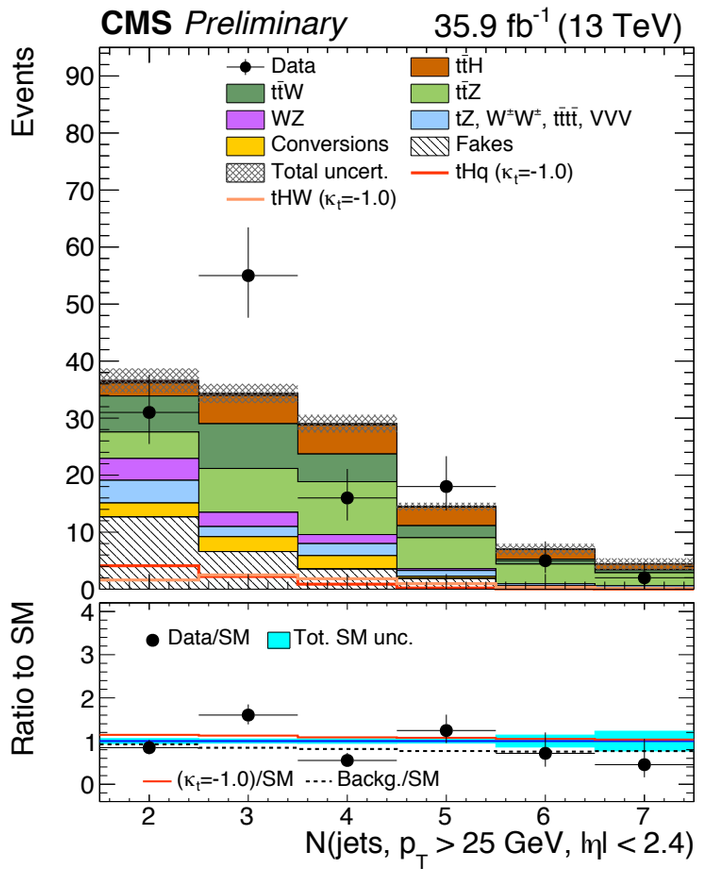
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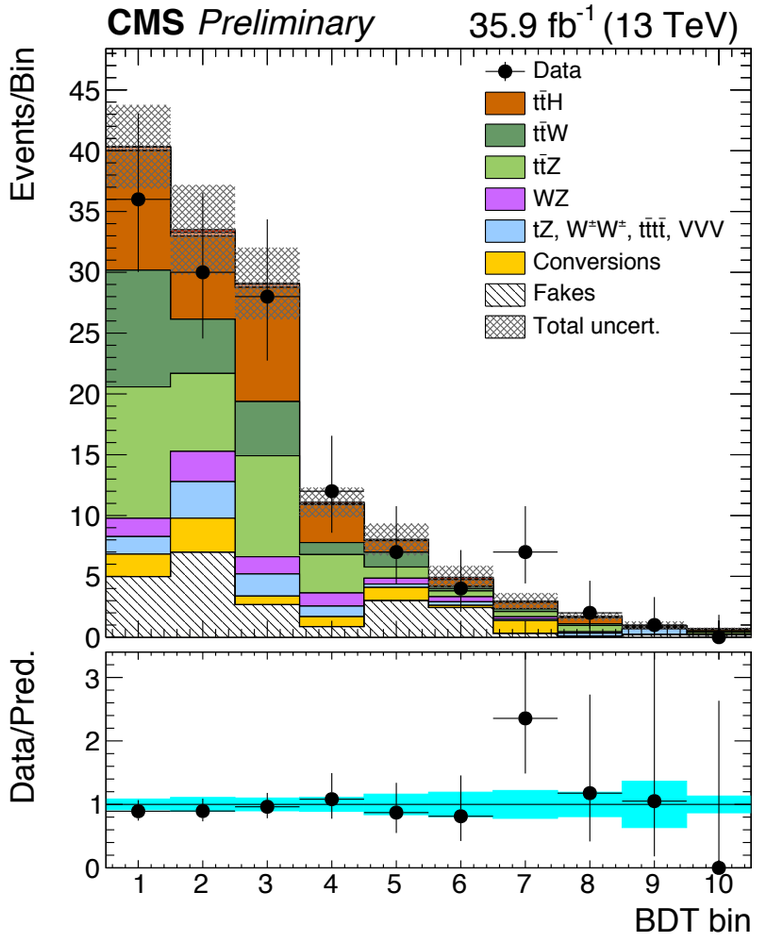
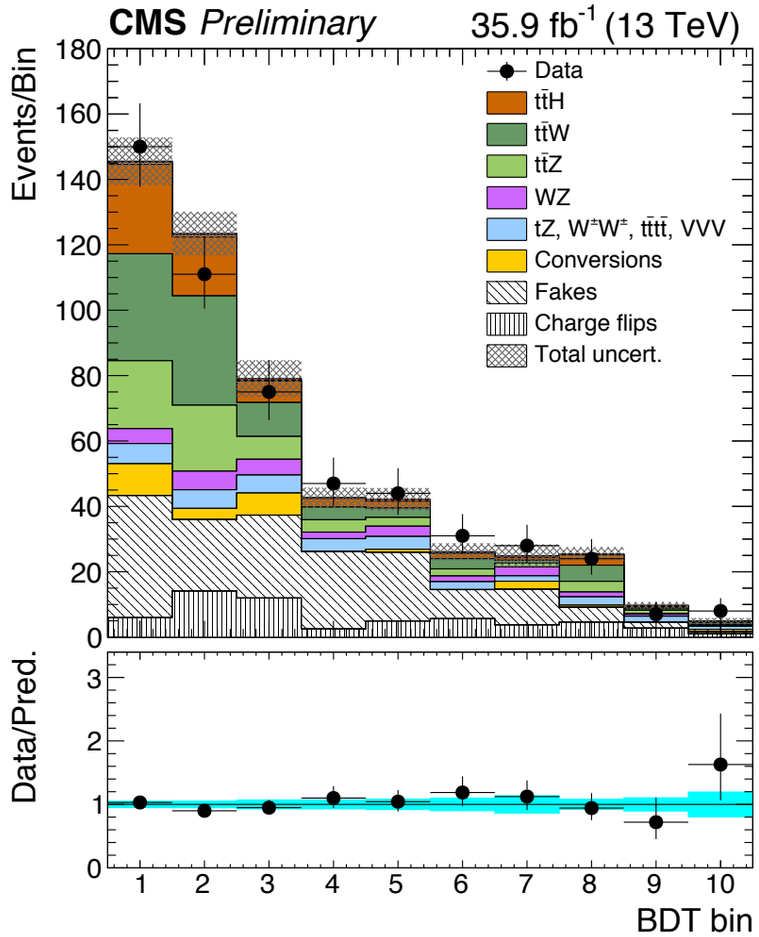
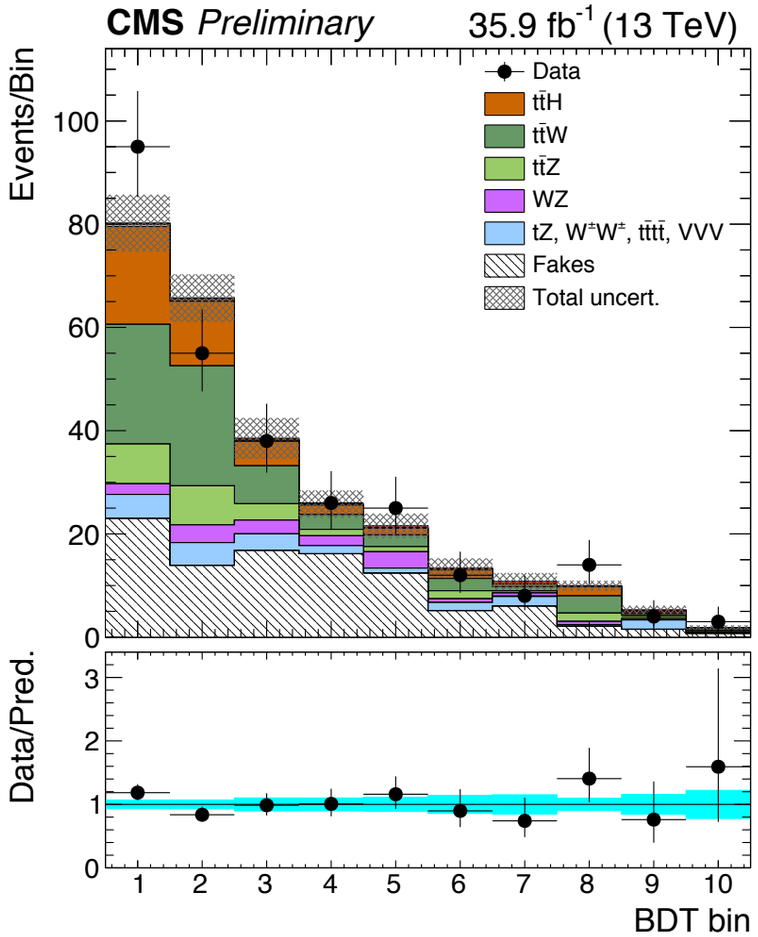
Post-fit Final Distributions







Signal modeling

- Want to **float tHq, tHW, and ttH coherently in our fit**
  - Have 3 processes (tHq, tHW, ttH) and 3 decay modes (WW, ZZ, ττ)
    → 9 signal components each with a different shape

- What depends on κ_t and κ_V?
  - tH kinematics
  - Production cross sections
  - Higgs decay branching ratios

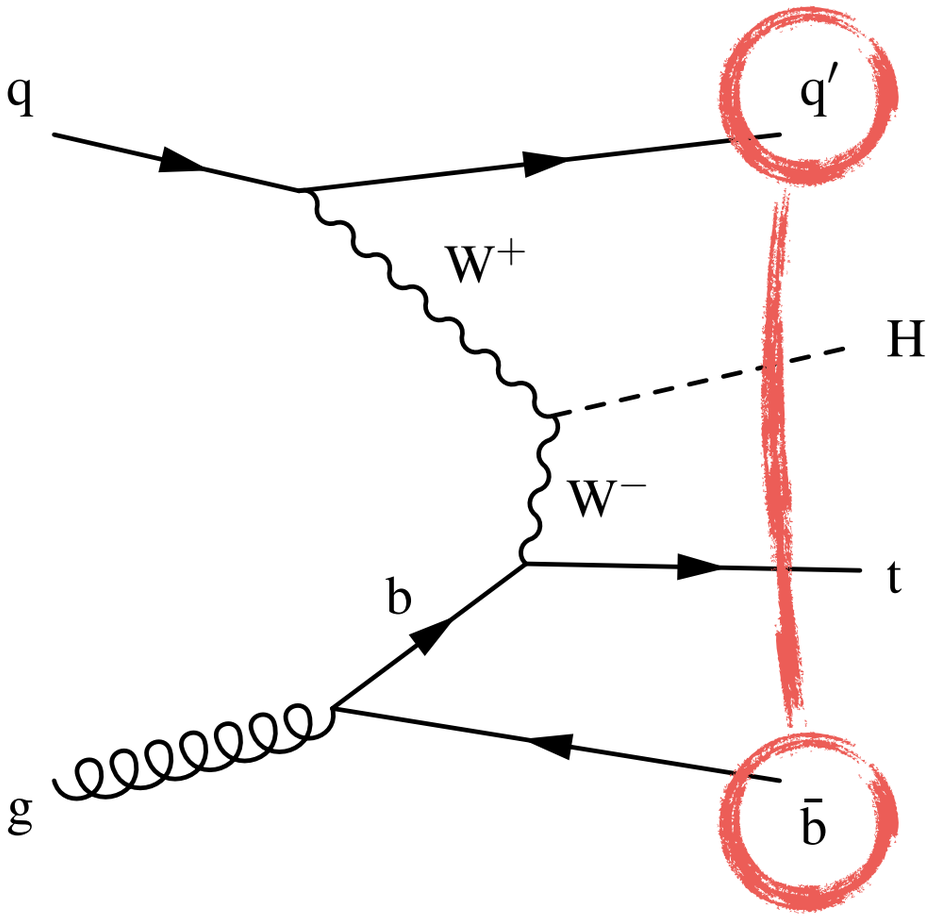
- Kinematics only depend **on the ratio κ_t/κ_V**
  - Also relative fractions of tHq/tHW/ttH are fixed when fixing κ_t/κ_V
  - And, assuming $\kappa_{tau} = \kappa_{top}$, also WW/ZZ/ττ fractions fixed with κ_t/κ_V

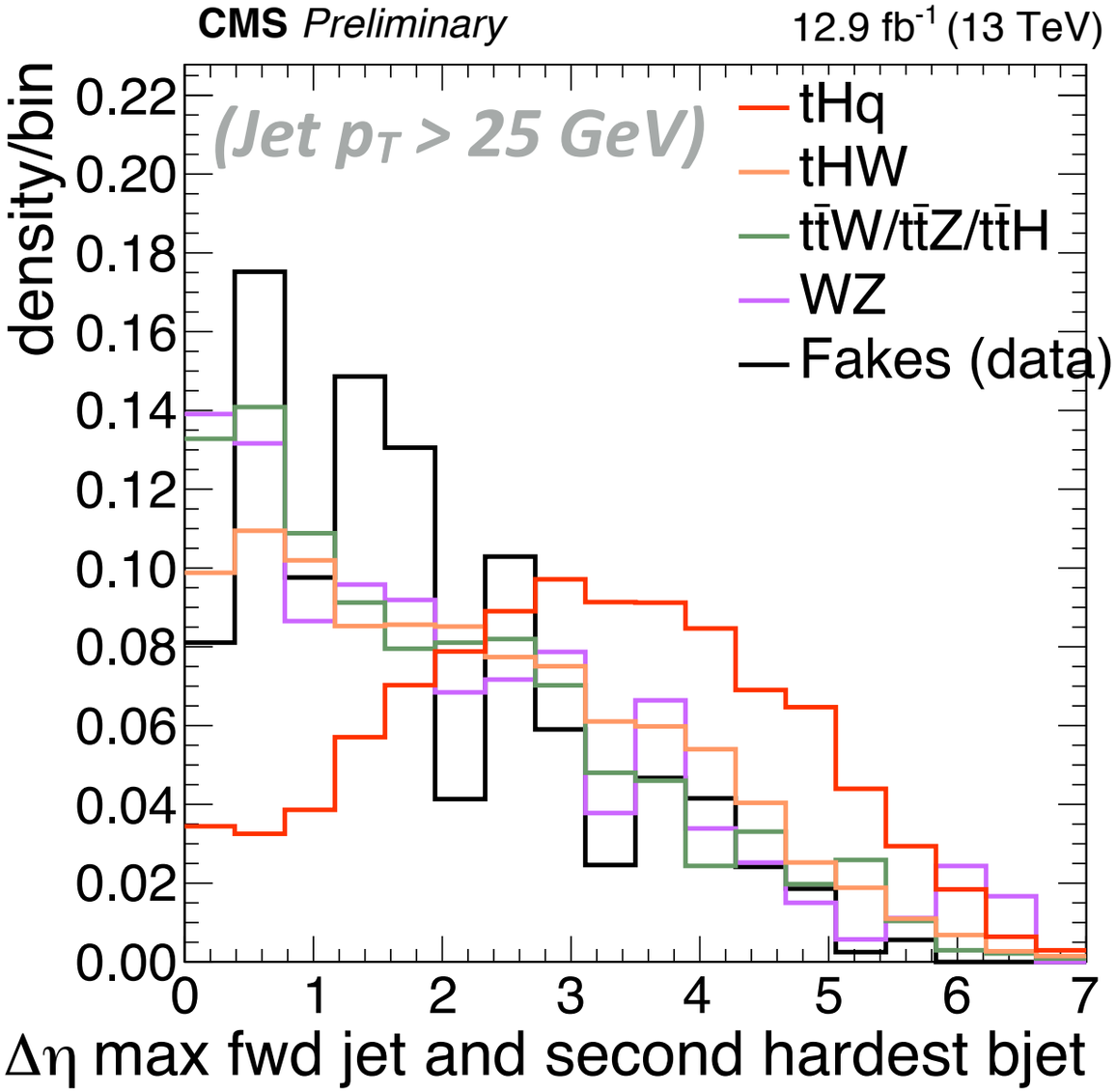
- In each point of κ_t/κ_V we can coherenly float tHq, tHW, and ttH with **one common signal strength**

Forward light jet vs. backward b-jet

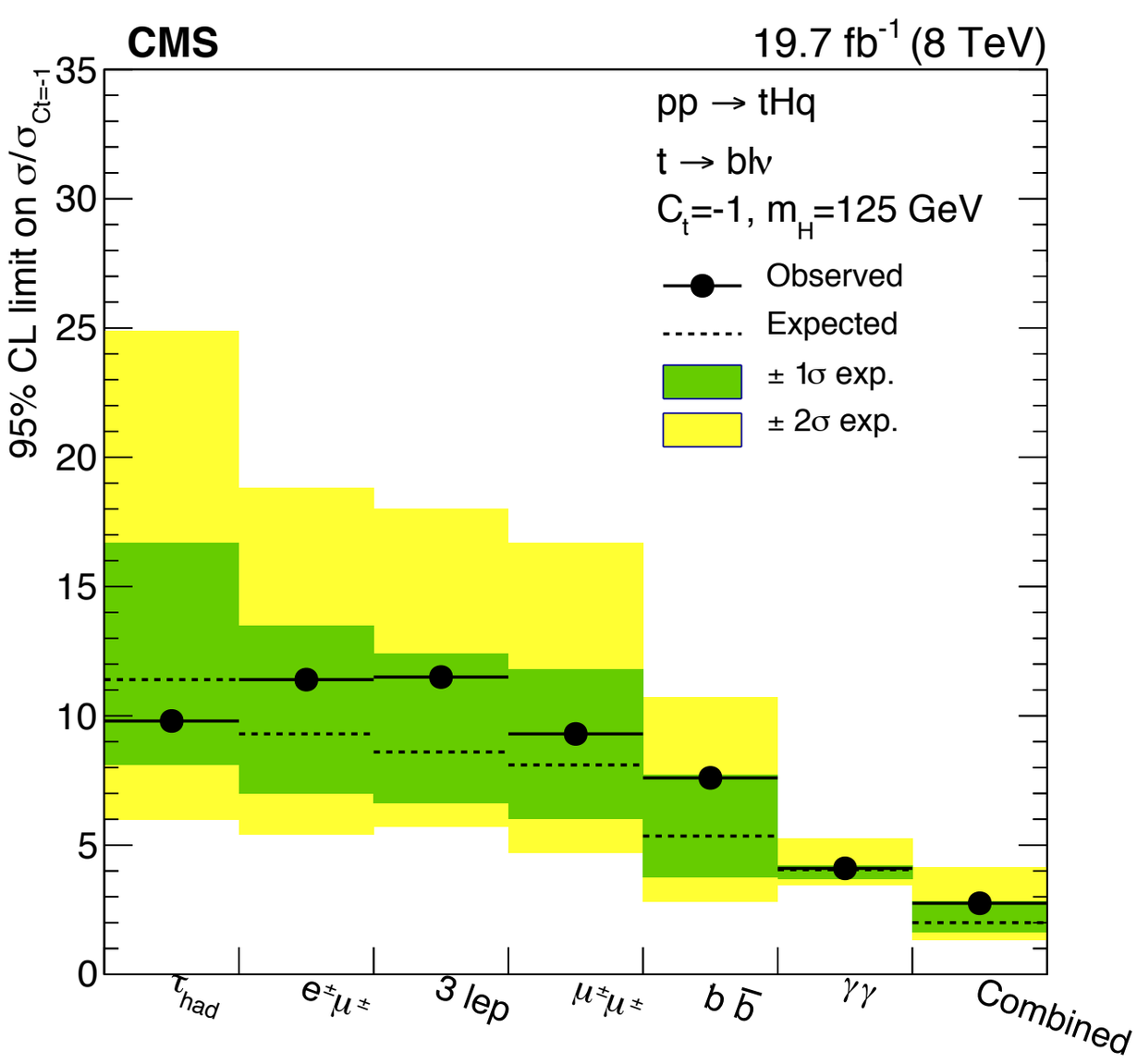
- Have **two** b-jets in about 30% of events in tHq signal
  - 70% of these are true b's from gluon splitting

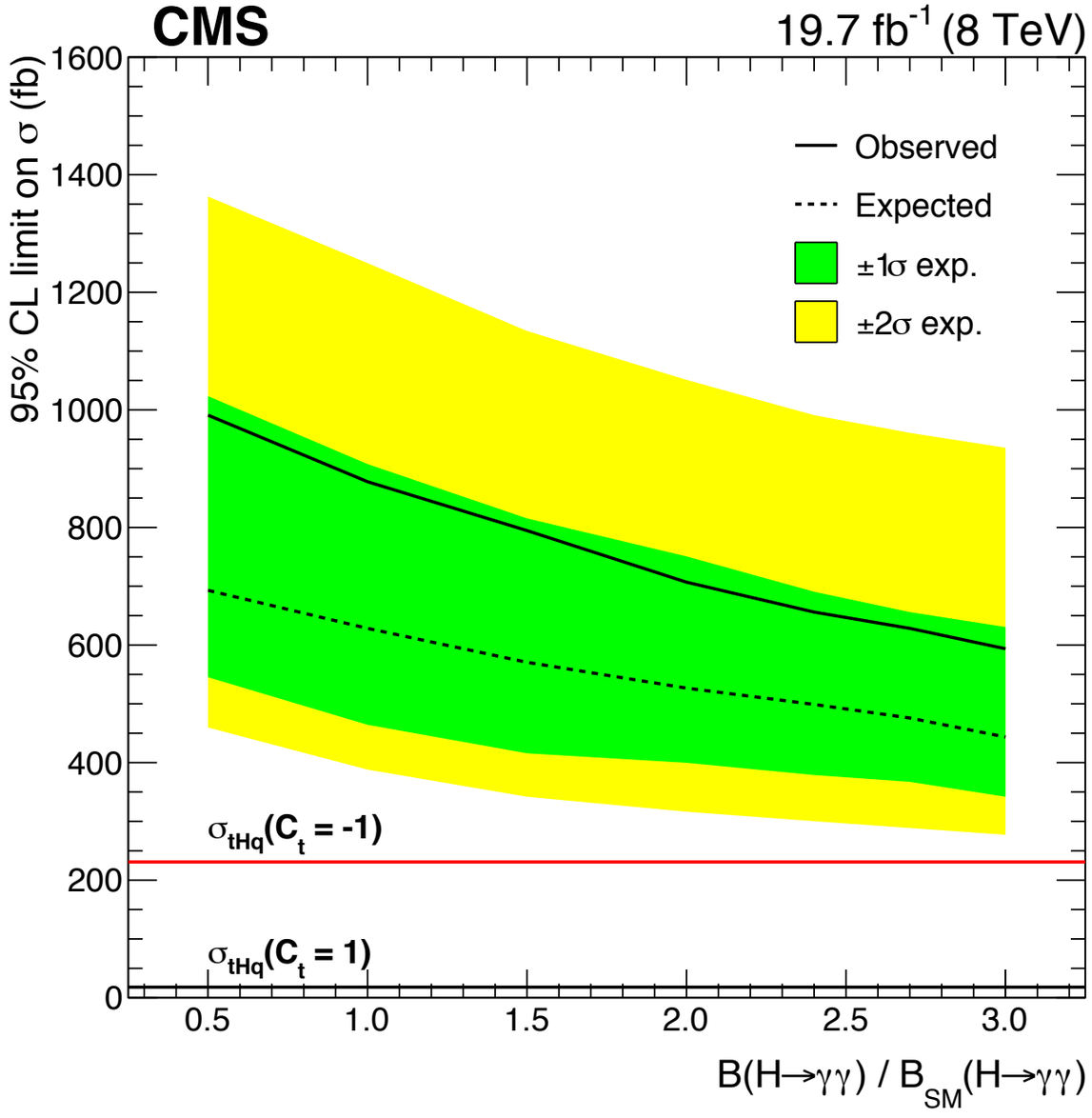
- Exploit the Δη between those and the most fwd. light jet:





8 TeV Results





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