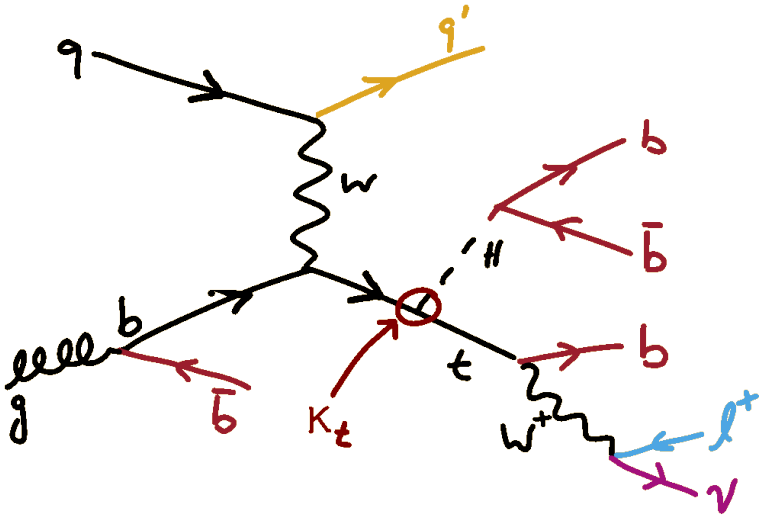
Search for tH (H→bb) production at 13 TeV

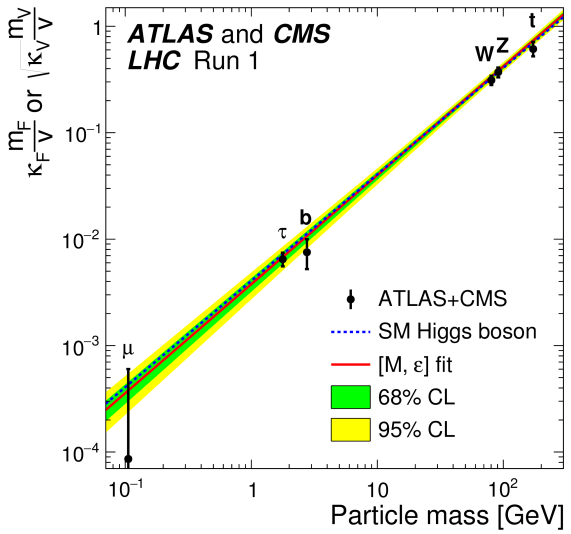
Thorsten Chwalek, Nils Faltermann, Simon Fink, Kevin Flöh, Benedikt Maier, Denise Müller, Thomas Müller, Johann Rauser, Frank Roscher, Matthias J. Schnepf

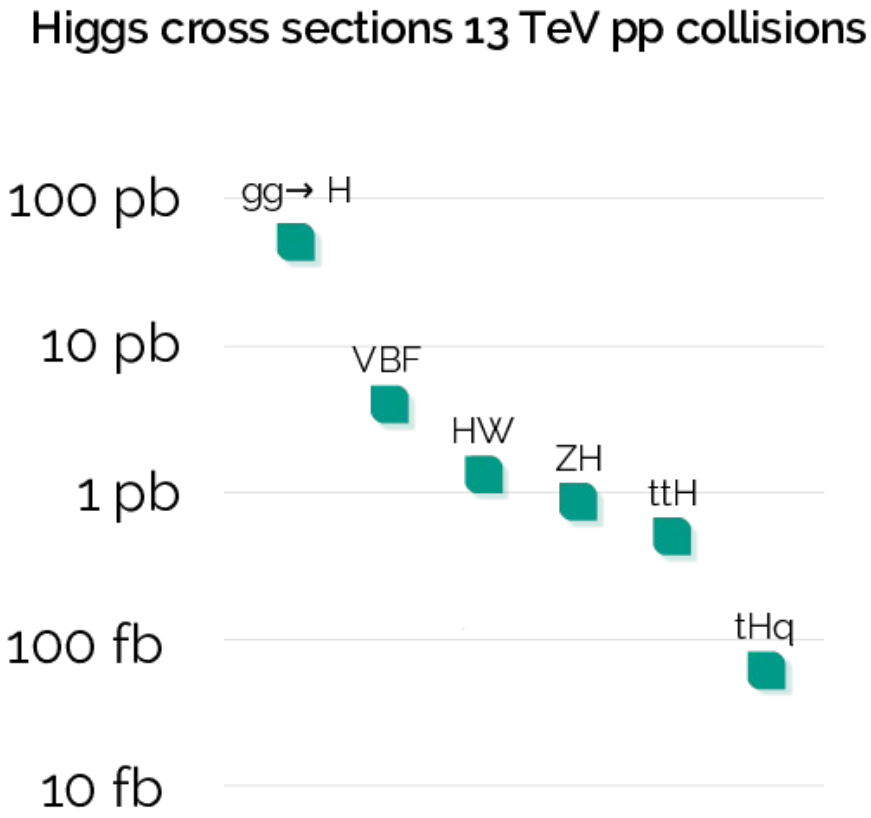
Institut für Experimentelle Kernphysik, KIT



Introduction

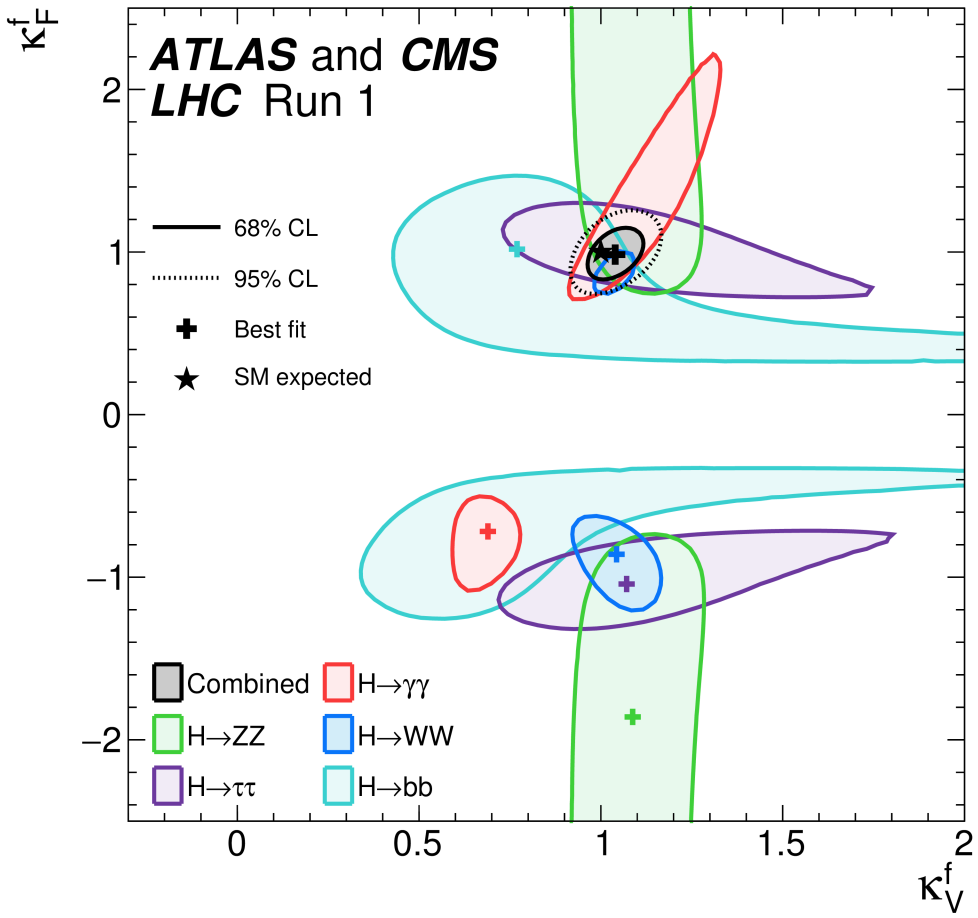
- Higgs couples to fermions via Yukawa coupling
- Cross section of $t\bar{t}H$ already very small
- tH processes are even more challenging





Introduction

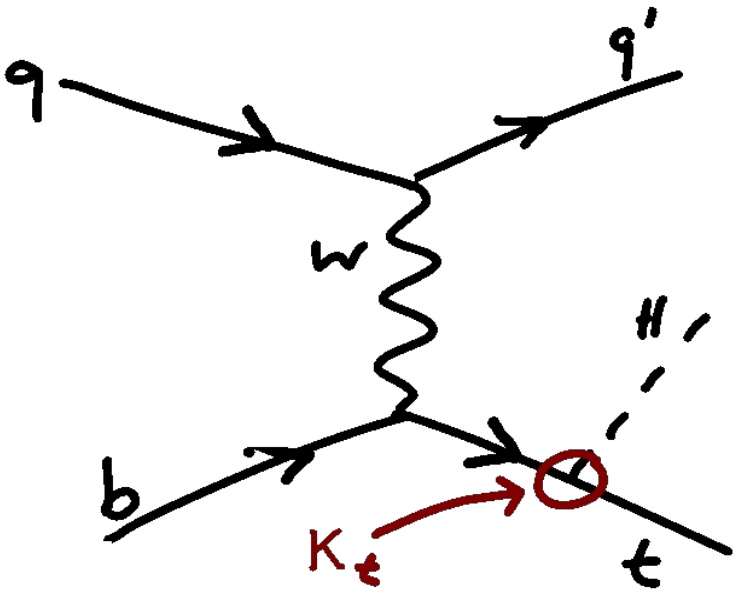
- Most analyses not sensitive to sign of κ_t

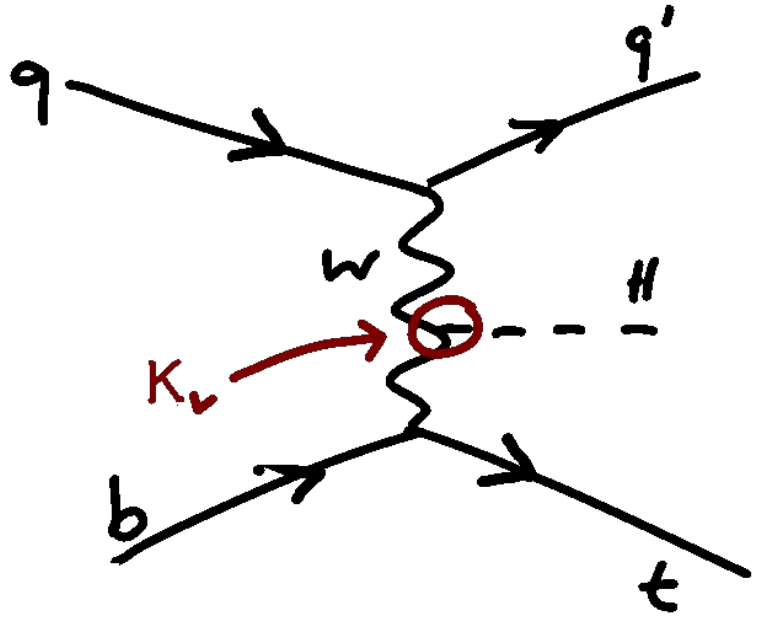


CMS-PAS-HIG-15-002
ATLAS-CONF-2015-044

Introduction

- Higgs can couple either to top quark (κ_t) or to vector boson (κ_v)
- $A \sim (\kappa_v - \kappa_t) \cdot \sqrt{s} + \text{const.} \rightarrow$ sensitive to sign of $\kappa_t \cdot \kappa_v$

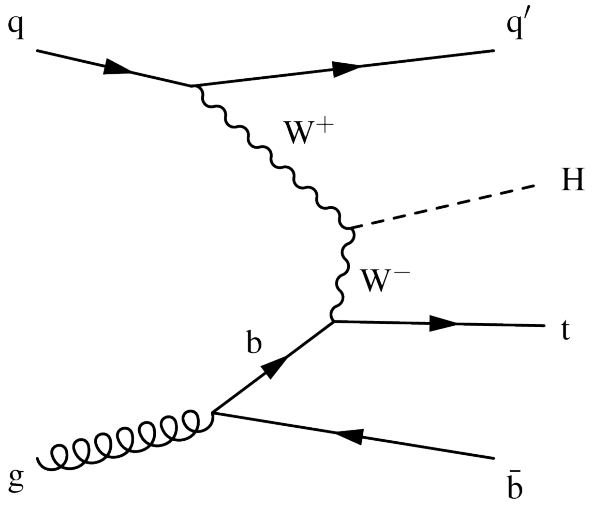


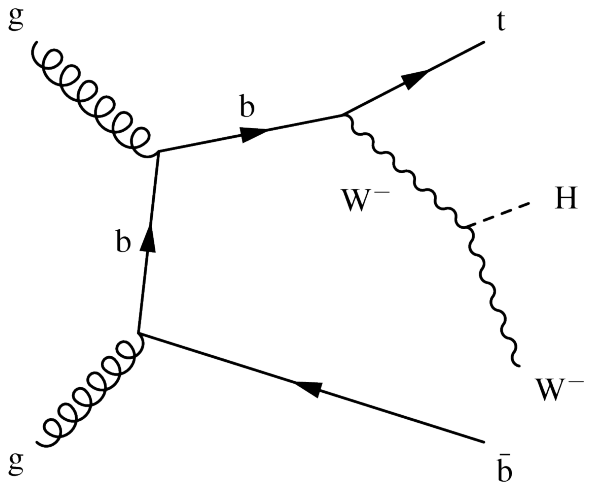


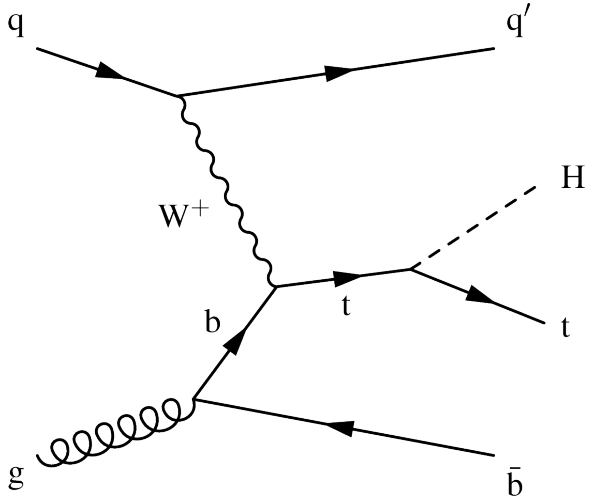
$\kappa_t = y_t / y_t^{(SM)}$

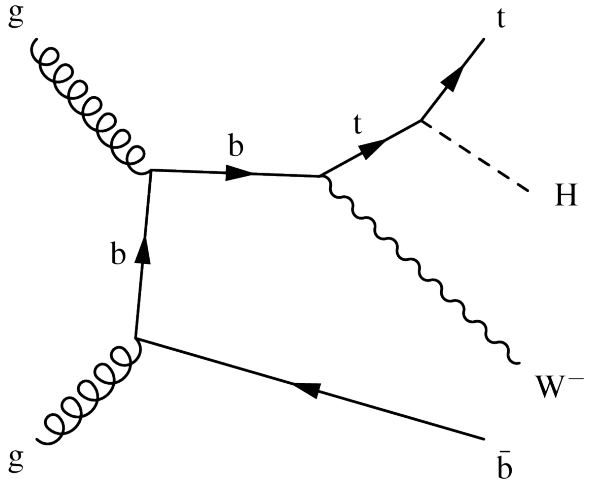
$\kappa_v = g_{HWW} / g_{HWW}^{(SM)}$

Two Channels: tHq & tHW



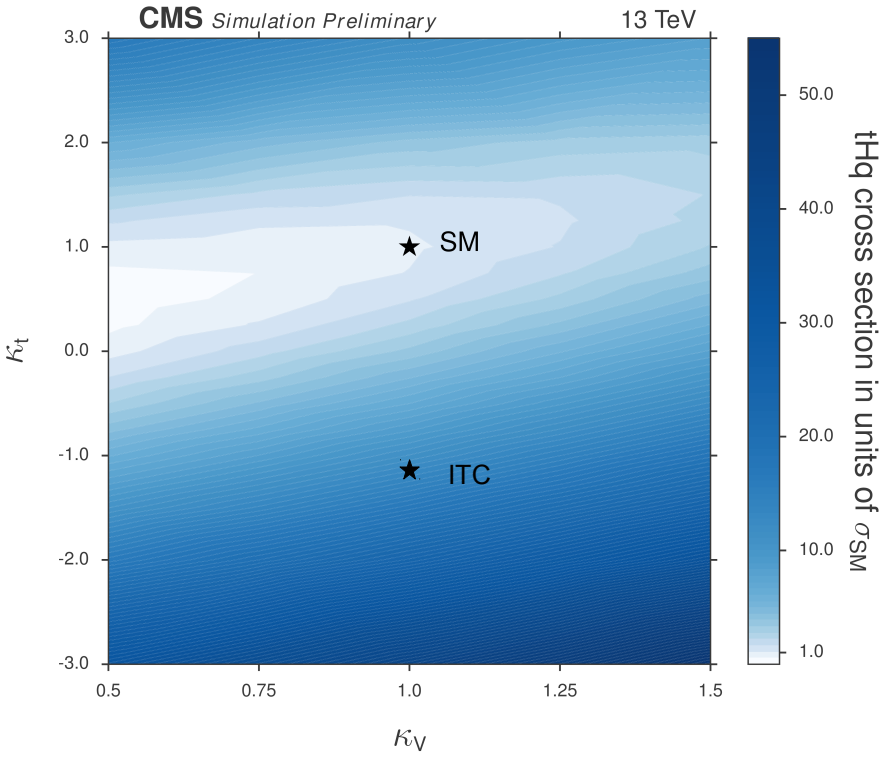


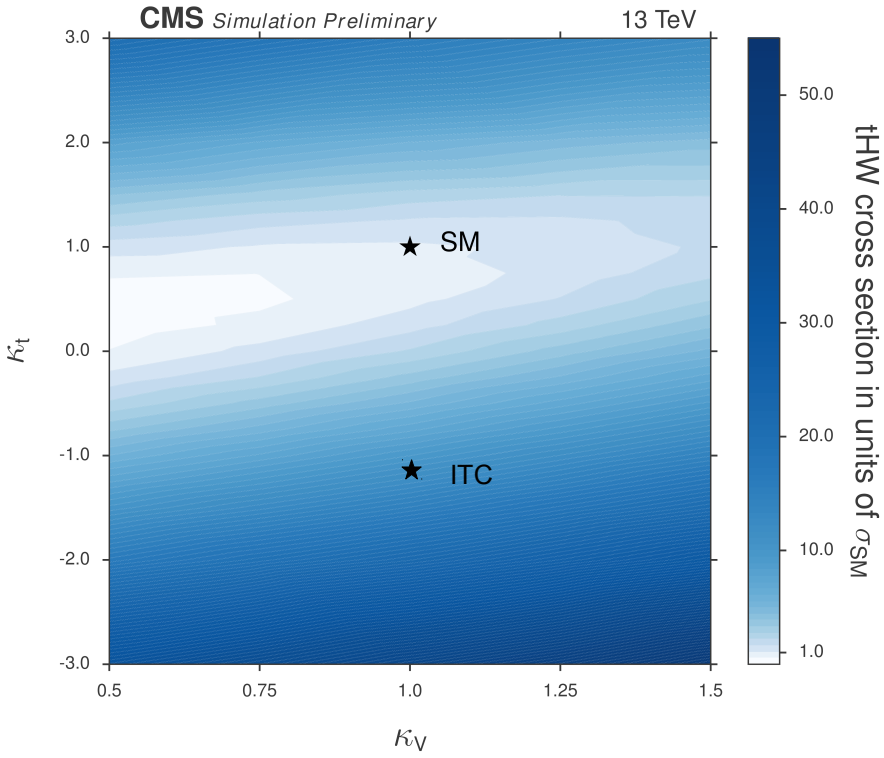




Cross Sections

- The cross sections and kinematics of the processes strongly depend on the values of κ_t and κ_V



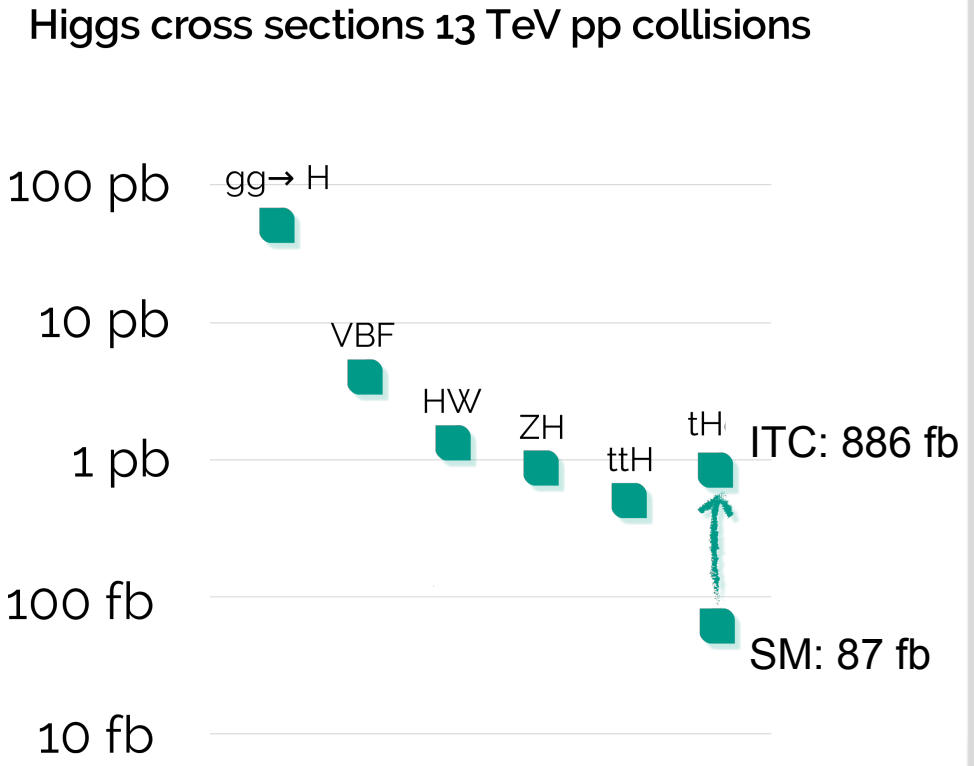


SM & ITC Case

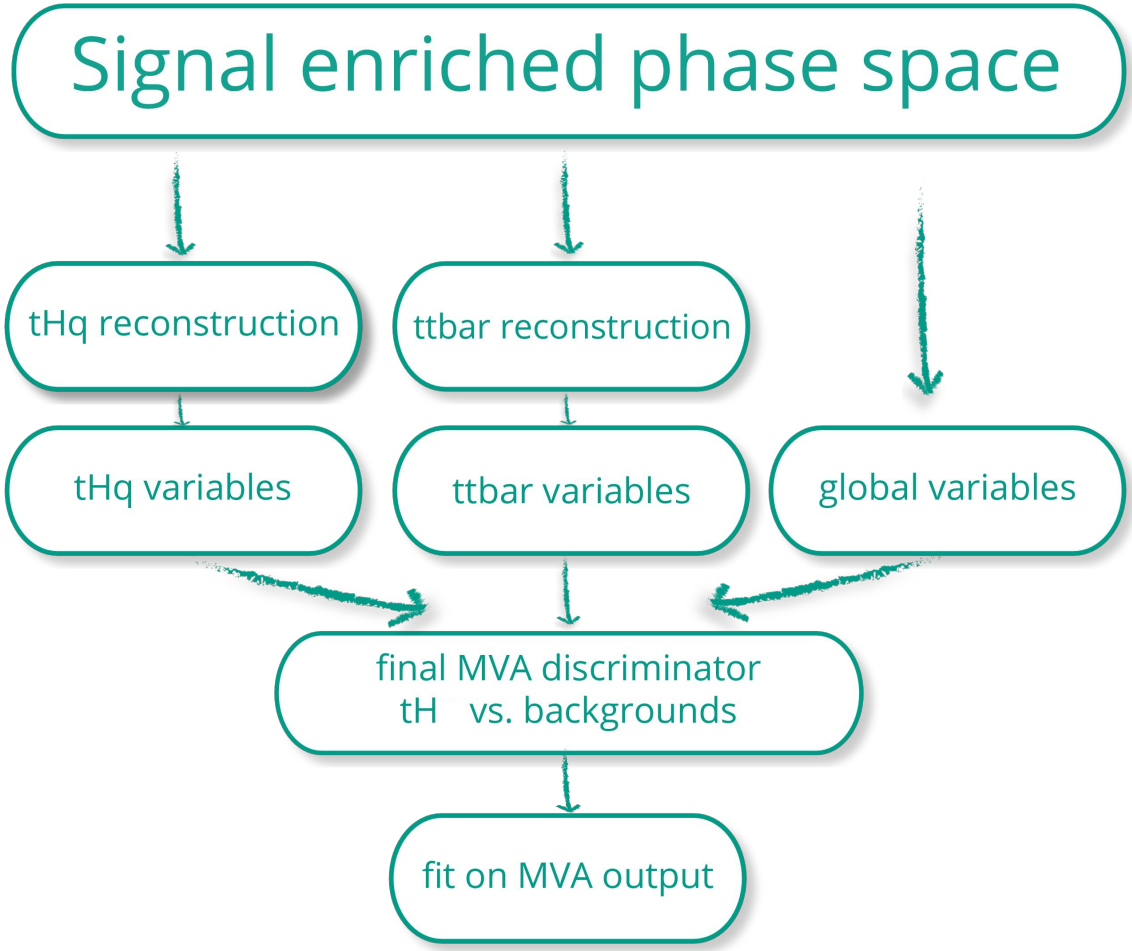
- SM: $\kappa_t = 1$; $\kappa_v = 1$

  → destructive interference
- ITC: Inverted top coupling
  $\kappa_t = -1$; $\kappa_v = 1$

  → constructive interference
- ITC results in ~10 times the SM cross section
- Our analysis:
  - $-3.0 \leq \kappa_t \leq 3.0$
  - $\kappa_v = \{0.5; 1.0; 1.5\}$
  - 51 different combinations
- Main background from different $t\bar{t}$ processes

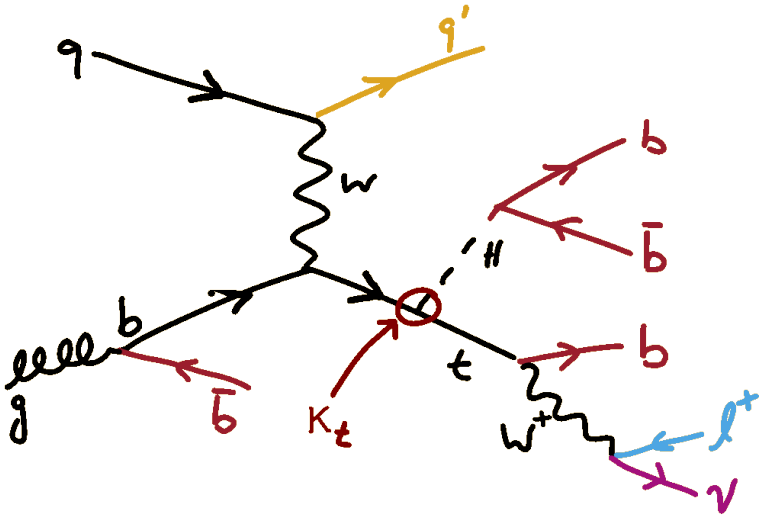


Analysis Workflow



Event Selection

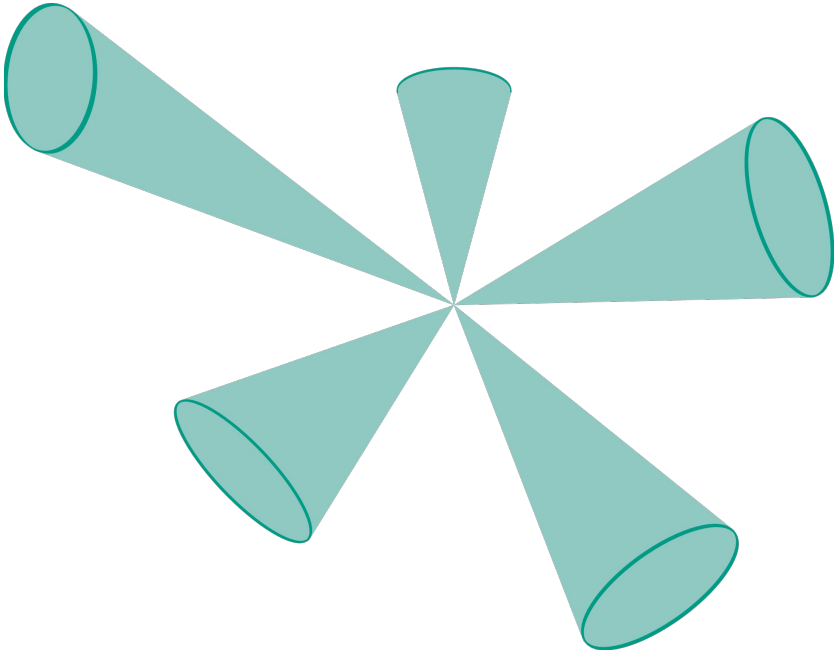
- event topology
  - 4 b jets
  - 1 isolated lepton
  - 1 light forward jet
  - missing transverse energy

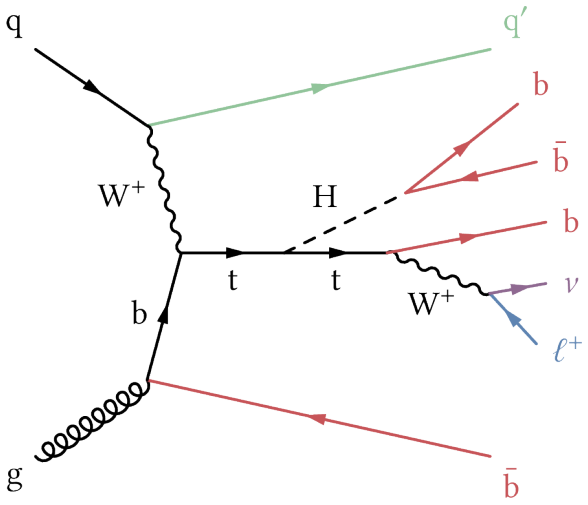


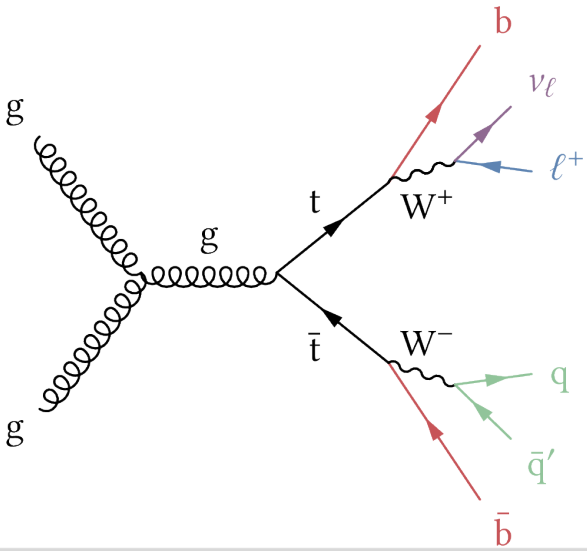
- 3 tag signal region
  - 3 b-tags
  - # jets >= 4
  - exactly one muon or electron
- 4 tag signal region
  - 4 b-tags
  - # jets >= 5
  - exactly one muon or electron
- ~ 4000 expected events in total
- Signal events: 20 for ITC

Event Reconstruction

- Reconstruct each event under tHq and $t\bar{t}$ hypotheses

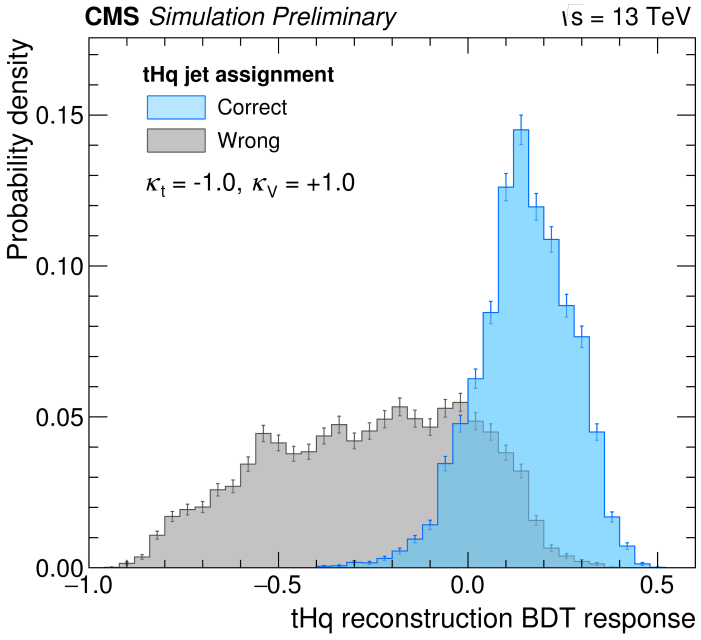


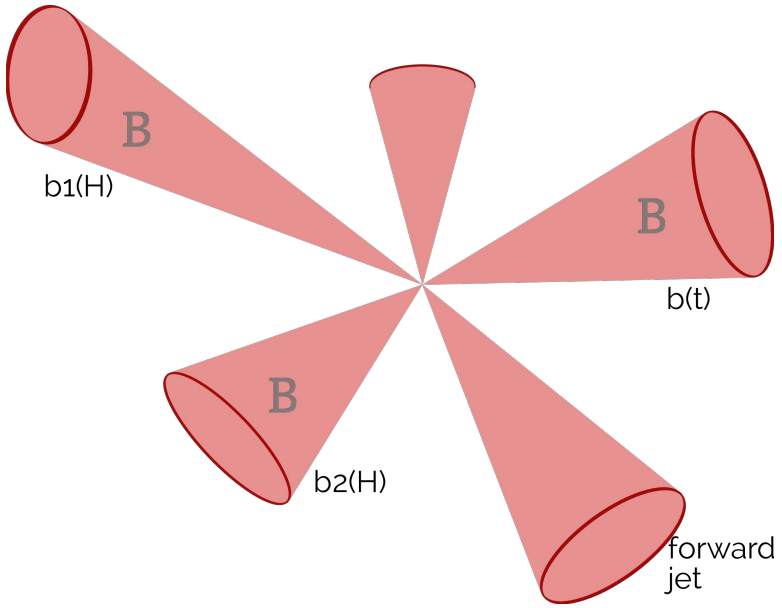




tHq Reconstruction

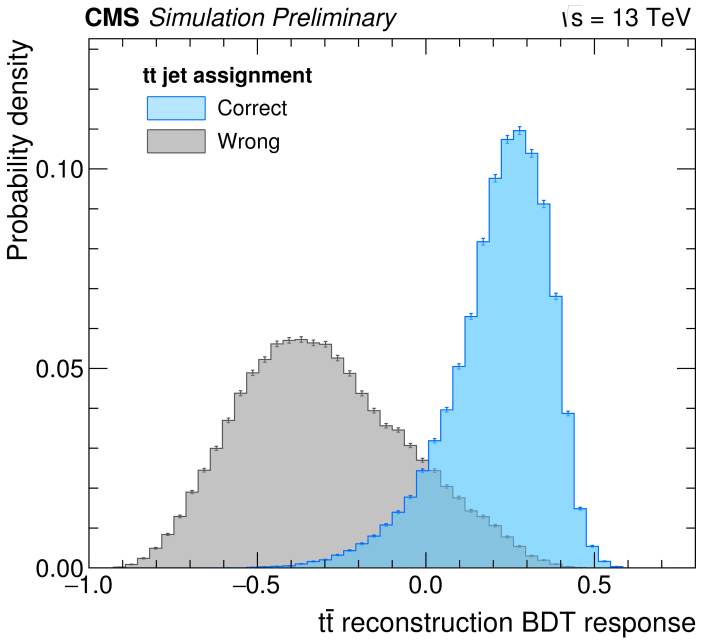
- Train BDT to separate between wrong and correct jet assignments
- Input variables are kinematics of reconstructed objects
- Train one BDT for each of the 51 different κ_t - κ_V combinations
- Choose reconstruction with highest BDT output for each event and each κ_t - κ_V combination

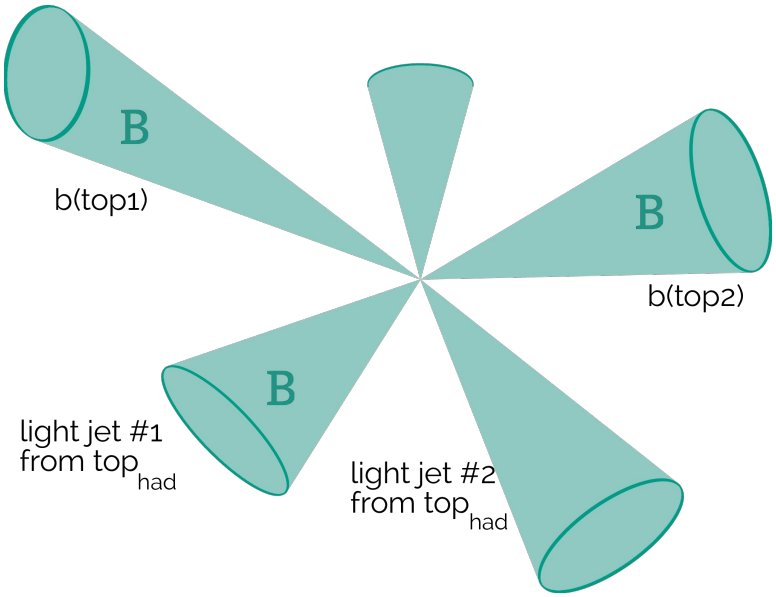




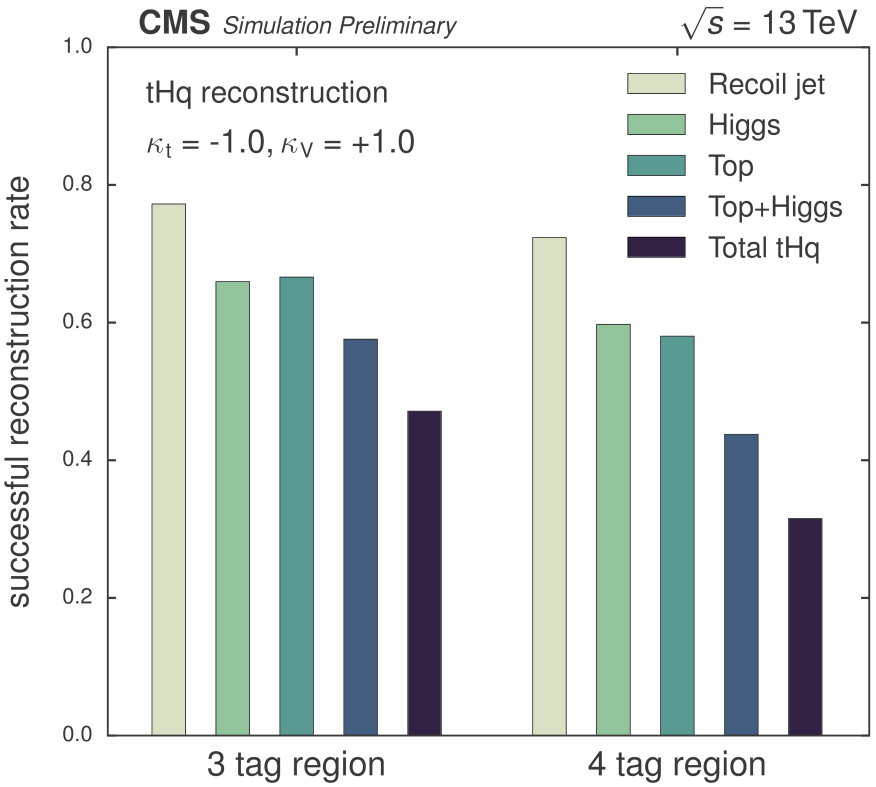
$t\bar{t}$ Reconstruction

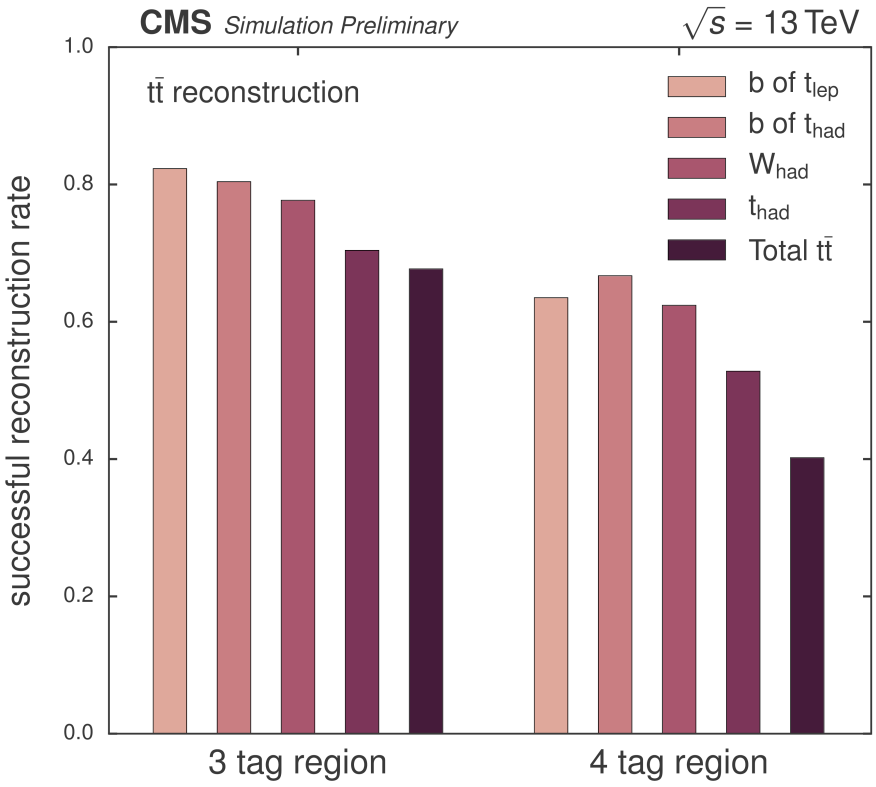
- Train BDT to separate between wrong and correct jet assignments
- Input variables are kinematics of reconstructed objects
- Choose reconstruction with highest BDT output for each event



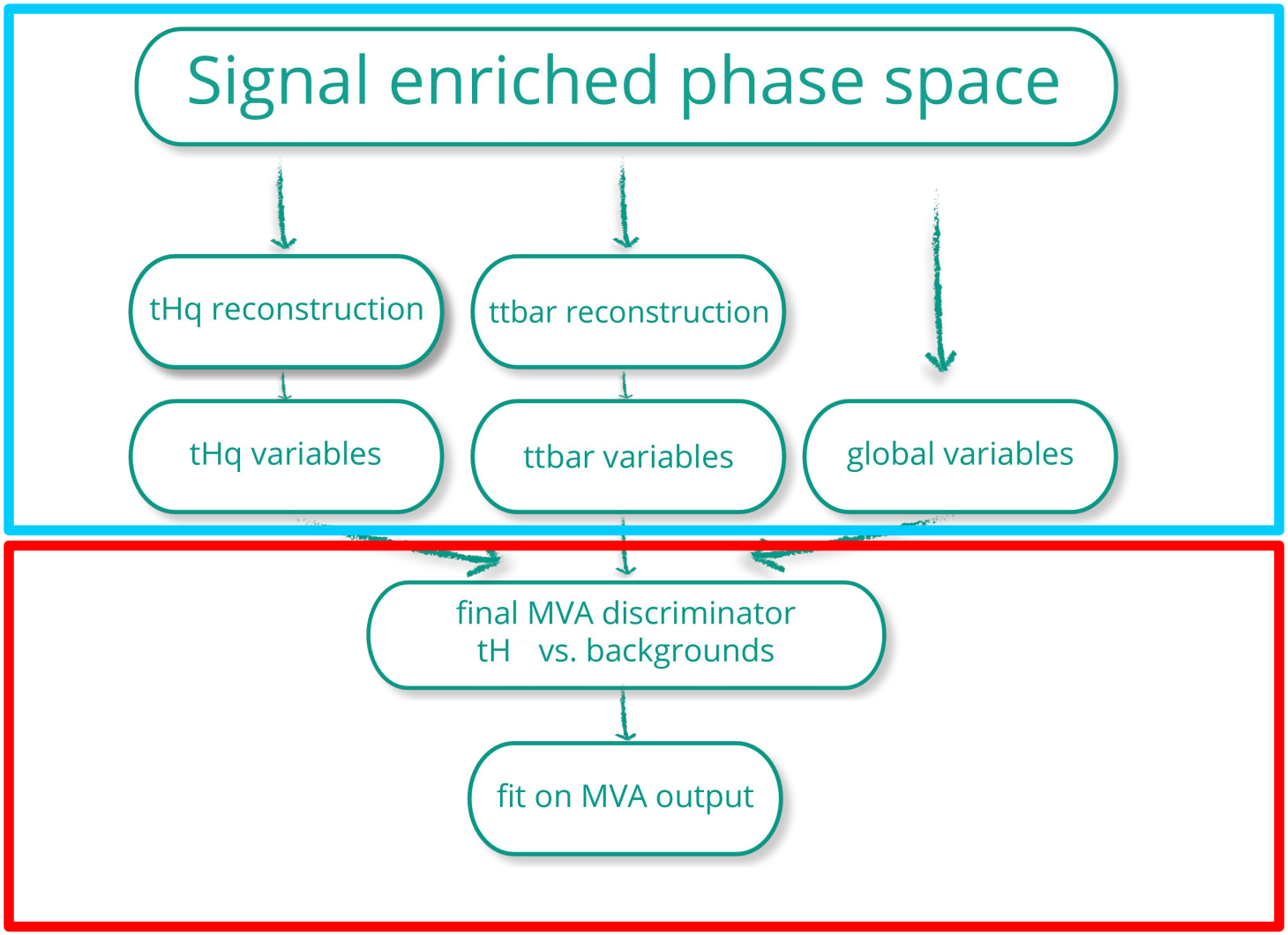


Reconstruction Efficiencies





Analysis Workflow



Classification Input Variables

Variables independent of any reconstruction

aplanarity	Aplanarity of the event
log m3	Invariant mass of three hardest jets in the event
Fox-Wolfram #1	First Fox-Wolfram moment of the event
q(ℓ)	Electric charge of the lepton

Variables based on objects reconstructed under the $t\bar{t}$ hypothesis

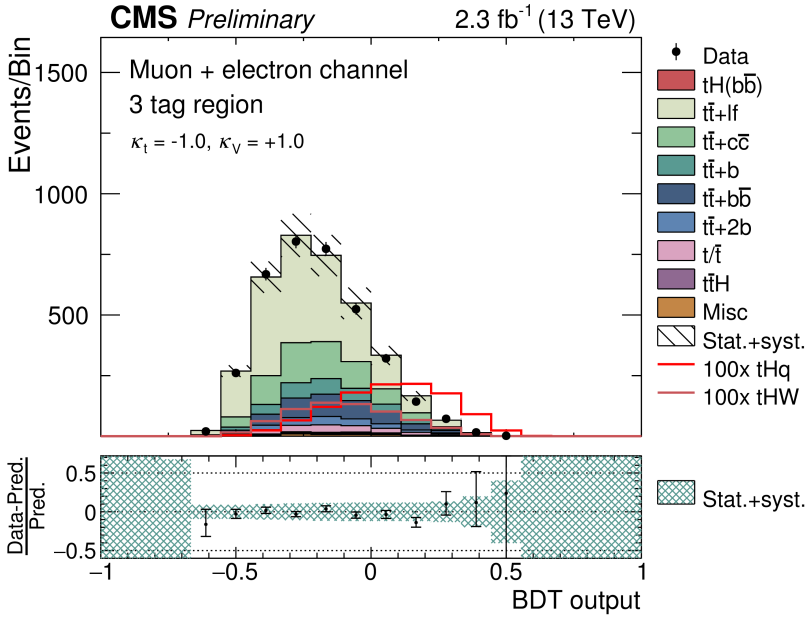
log m(t_{had})	Invariant mass of t_{had}
CSV(W_{had} jet 1)	CSVv2 output of the hardest jet assigned to W_{had}
ΔR(W_{had} jets)	ΔR between the two jets from the decay of W_{had}
CSV(W_{had} jet 2)	CSVv2 output of the second hardest jet assigned to W_{had}

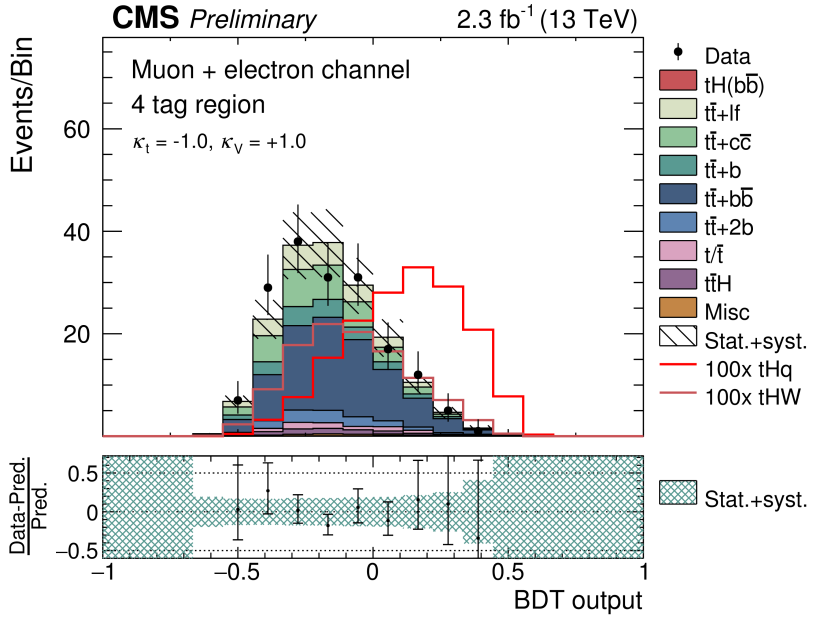
Variables based on objects reconstructed under the tHq hypothesis

$\lvert\eta$(recoil jet)$\rvert$	Absolute pseudorapidity of the recoil jet
CSV(Higgs jet 2)	CSVv2 output of the second hardest jet assigned to the Higgs boson
CSV(Higgs jet 1)	CSVv2 output of the hardest jet assigned to the Higgs boson
log p_T(recoil jet)	Transverse momentum of the recoil jet
log p_T(Higgs)	Transverse momentum of the Higgs boson
$\lvert\eta$(Higgs)$\rvert$	Absolute pseudorapidity of the Higgs boson
cos θ(t,ℓ)	Cosine of the angle between the top quark momentum and the sum of top quark and charged lepton, in their common rest frame

Classification Results

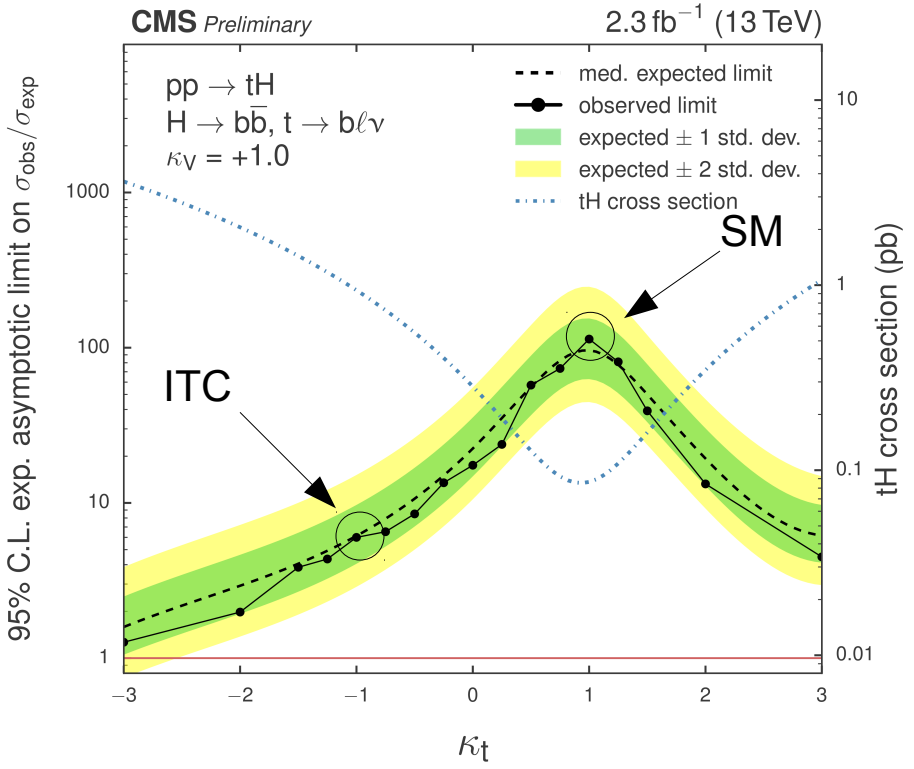
- Train 51 classification tHq vs. backgrounds BDTs
- 3774 observed events
- Most important systematic uncertainties:
  JES, Q^2 systematics, b-tagging, rate unc. on $t\bar{t}$ + $b\bar{b}$



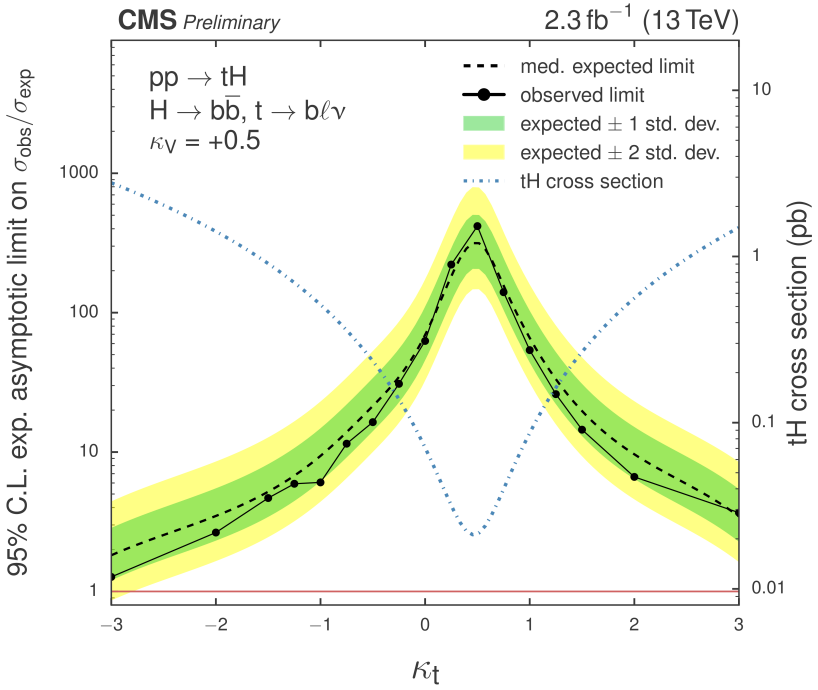


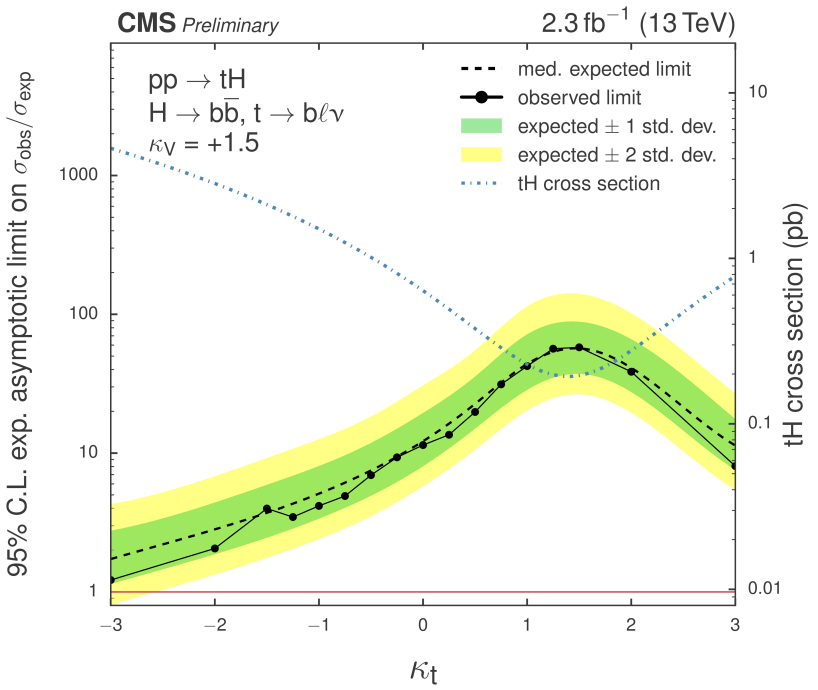
Results: Asymptotic Limits

- Asymptotic limits calculated with Combine
- Exclude at 95% CL a cross section that is 98.6 (6.4) times the expectation for the SM (ITC) case



Results: Asymptotic Limits





Published in CMS-PAS-HIG-16-019

Conclusion

- Searching for tH with H → bb at different points of (κ_t, κ_v) plane
- Same sensitivity with less data than analysis @ 8TeV
- Set upper limits at 95% CL for
  - SM: 98.6 times the expected cross section
  - ITC: 6.4 times the expected cross section

Outlook

- Run the analysis with 2016 data
- Combination with other tH channels as in Run I (arXiv: 1509.08159)
- Expected upper exclusion limits with full 100 fb^{-1} dataset:
  - ~ 7 times the SM cross section
  - ~ 0.5 times the ITC cross section (complete exclusion)

Thank you very much for your attention.

Backup

Event Yields

13 TeV]Event yields for tHq and tHW signal (for the SM and ITC scenarios) as well as the various background processes in the two signal regions. The uncertainties include both systematic and statistical uncertainties. Additionally, the numbers of observed events in data are shown.

	3 tag	4 tag
$t\bar{t}$+LF	2119 ± 651	21.3 ± 21.6
$t\bar{t}$+c$\bar{c}$	852 ± 624	39 ± 46
$t\bar{t}$+b	324 ± 203	18.7 ± 15.3
$t\bar{t}$+b$\bar{b}$	333 ± 298	71 ± 67
$t\bar{t}$+2b	177 ± 102	13.0 ± 9.6
Single top	156 ± 44	6.0 ± 2.4
$t\bar{t}$H	20.3 ± 9.7	5.3 ± 2.9
$t\bar{t}$Z	9.4 ± 2.3	1.8 ± 1.7
$t\bar{t}$W	8.0 ± 2.5	0.4 ± 0.4
W+jets	42 ± 35	0.0 ± 0.0
Z+jets	10.2 ± 5.0	0.0 ± 0.0
Sum of Backgrounds	4051 ± 978	177 ± 86
tHq (SM)	0.77 ± 0.21	0.12 ± 0.04
tHW (SM)	0.61 ± 0.09	0.09 ± 0.02
tHq (ITC)	11.2 ± 3.1	1.7 ± 0.6
tHW (ITC)	6.7 ± 1.0	1.1 ± 0.3
Observed	**3603**	**171**

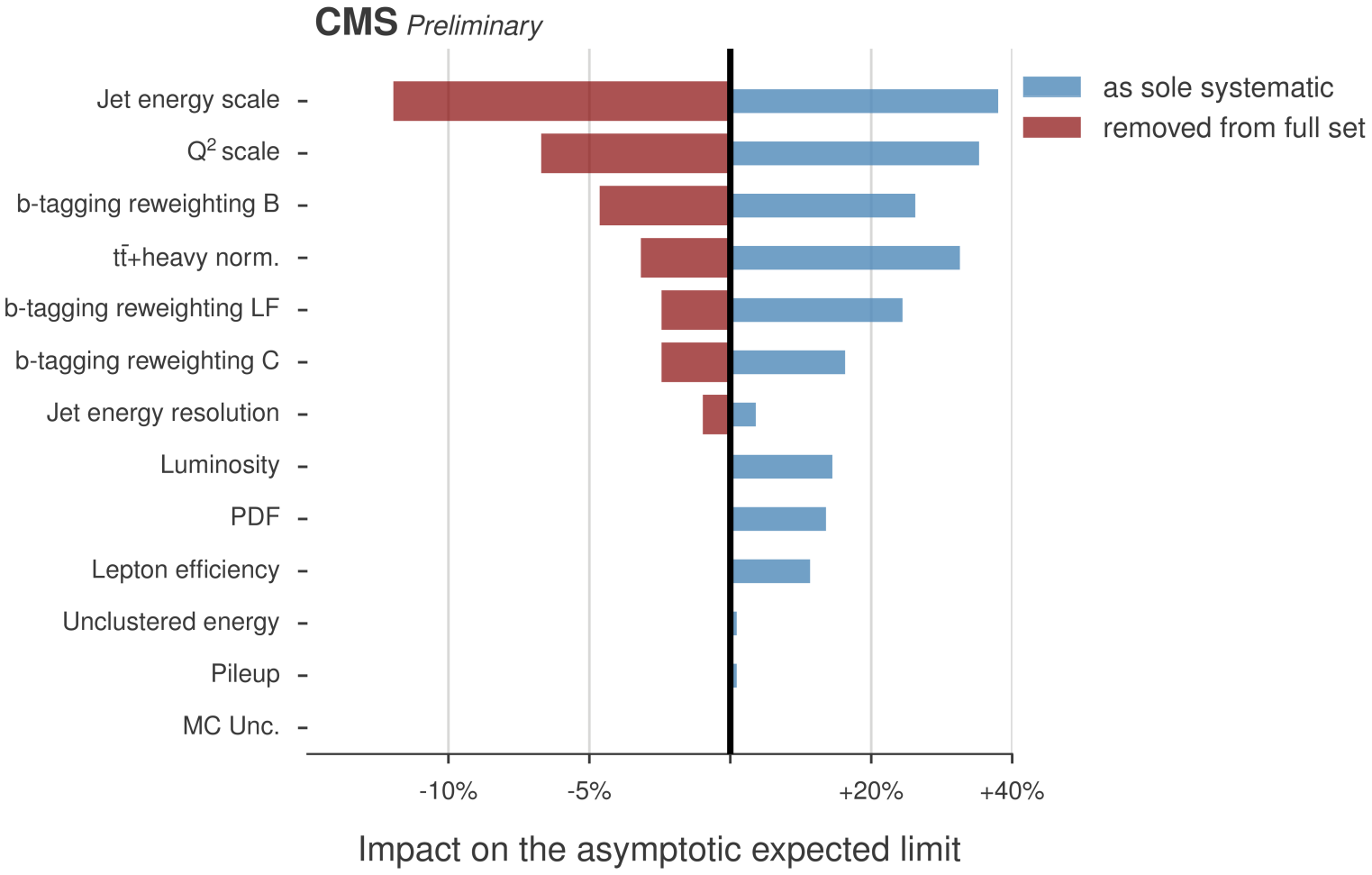
tHq Reconstruction Input Variables

Variable	Description
log m(H)	Invariant mass of the reconstructed Higgs boson
log m(t)	Invariant mass of the reconstructed top quark
ΔR(Higgs jets)	ΔR between the two jets from the Higgs boson decay
ΔR(b_t, W)	ΔR between the jet assigned to the b quark from the top quark decay and the W boson
relative H_T	Ratio of p_T(H) + p_T(t) + p_T(recoil jet) to the scalar sum of p_T of all jets, charged lepton, and E_T^{miss}
cos θ(t, ℓ)	Cosine of the angle between the top quark momentum and the sum of momenta of top quark and charged lepton, in their common rest frame
CSV(Higgs jet 2)	Output of the CSVv2 b-tagging algorithm for the second hardest jet assigned to the Higgs boson
CSV(b_t)	Output of the CSVv2 b-tagging algorithm for the jet assigned to the b quark from the top quark decay
$\lvert\eta(\text{recoil jet}) - \eta(b_t)\rvert$	Absolute difference of pseudorapidities of the recoil jet and of the b jet from the top quark decay
CSV(Higgs jet 1)	Output of the CSVv2 b-tagging algorithm for the hardest jet assigned to the Higgs boson
$\lvert\eta(b_t)\rvert$	Absolute pseudorapidity of the jet assigned to the b quark of the top quark decay
$\lvert\eta(t) - \eta(H)\rvert$	Absolute difference of pseudorapidities of reconstructed top quark and the reconstructed Higgs boson
log min(p_T(H jets))	Lower transverse momentum of the two jets assigned to the Higgs boson decay products
$\lvert\eta(\text{recoil jet})\rvert$	Absolute pseudorapidity of the recoil jet
ΔE(recoil jet, b_t)	Energy difference between the recoil jet and the jet assigned to the b quark from the top quark decay

$t\bar{t}$ Reconstruction Input Variables

Variable	Description
log m(W_{had})	Invariant mass of the two jets assigned to the W boson of t_{had}
log (m(t_{had}) - m(W_{had}))	Difference between the invariant masses of reconstructed t_{had} and W_{had}
log m(t_{lep})	Invariant mass of the reconstructed t_{lep}
CSV(W_{had} jet 1)	CSVv2 output of the hardest jet assigned to W_{had}
$\Delta R(b_{t_{lep}}, W_{lep})$	ΔR between the b quark of the reconstructed t_{lep} and W_{lep}
CSV(W_{had} jet 2)	CSVv2 output of the second hardest jet assigned to W_{had}
$\Delta R(W_{had}$ jets)	ΔR between the two jets assigned to the W boson of t_{had}
relative H_T	Ratio of $p_T(t_{had}) + p_T(t_{lep})$ to the scalar sum of p_T of all jets, charged lepton, and E_T^{miss}
$\Delta R(b_{t_{had}}, W_{had})$	ΔR between the b quark of the reconstructed t_{had} and W_{had}
log $p_T(t_{had})$	Transverse momentum of the reconstructed t_{had}
log $p_T(t_{lep})$	Transverse momentum of the reconstructed t_{lep}

Systematic Uncertainties



tHq vs. tHW – Kinematics