

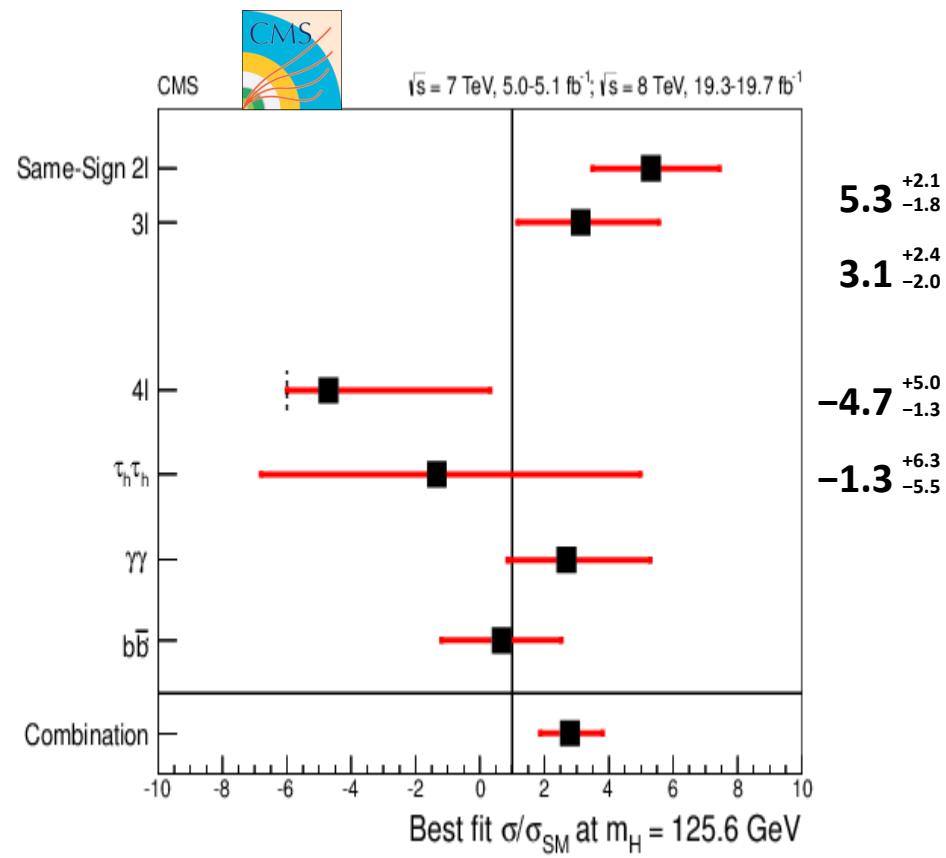
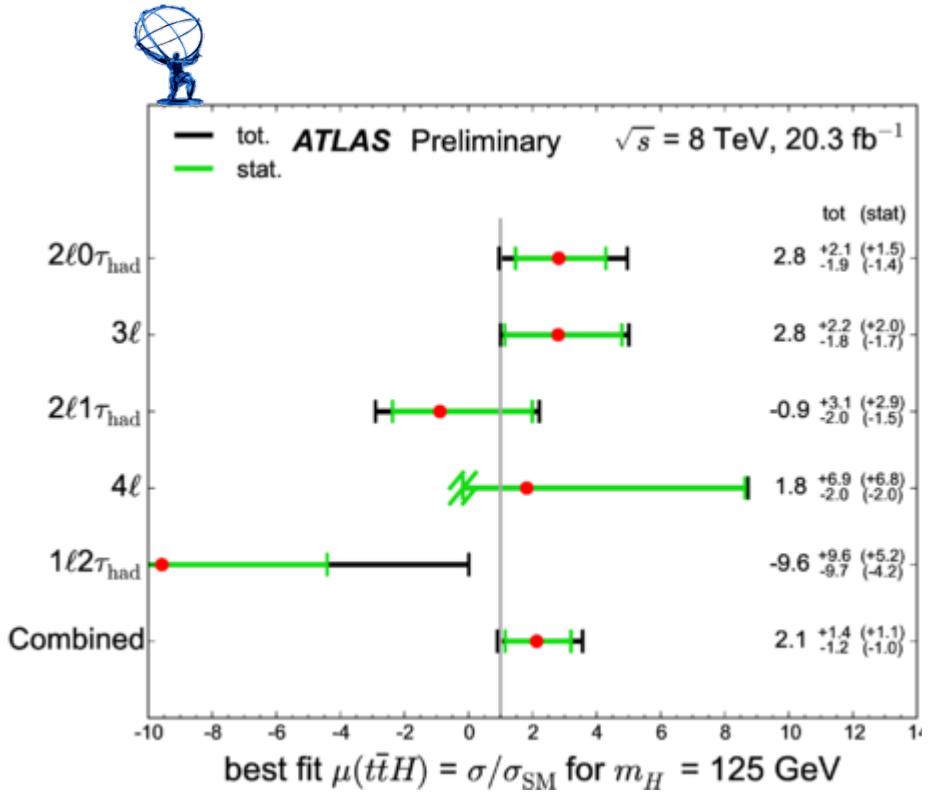


Event yields

Category	q mis-id	Non-prompt	$t\bar{t}W$	$t\bar{t}Z$	Diboson	Expected Bkg.	$t\bar{t}H (\mu = 1)$	Observed
$ee + \geq 5j$	1.1 ± 0.5	2.3 ± 1.2	1.4 ± 0.4	0.98 ± 0.32	0.47 ± 0.42	6.5 ± 2.0	0.73 ± 0.11	10
$e\mu + \geq 5j$	0.85 ± 0.35	6.7 ± 2.4	4.8 ± 1.4	2.1 ± 0.7	0.38 ± 0.32	15 ± 4	2.13 ± 0.31	22
$\mu\mu + \geq 5j$	—	2.9 ± 1.4	3.8 ± 1.1	0.95 ± 0.31	0.69 ± 0.63	8.6 ± 2.5	1.41 ± 0.21	11
$ee + 4j$	1.8 ± 0.7	3.4 ± 1.7	2.0 ± 0.4	0.75 ± 0.25	0.74 ± 0.58	9.1 ± 2.3	0.44 ± 0.06	9
$e\mu + 4j$	1.4 ± 0.6	12 ± 4	6.2 ± 0.9	1.5 ± 0.2	1.9 ± 1.2	24.0 ± 4.5	1.16 ± 0.14	26
$\mu\mu + 4j$	—	6.3 ± 2.6	4.7 ± 0.9	0.80 ± 0.26	0.53 ± 0.30	12.7 ± 3.0	0.74 ± 0.10	20
3ℓ	—	3.2 ± 0.7	2.3 ± 0.9	3.9 ± 0.9	0.86 ± 0.59	11.4 ± 3.1	2.34 ± 0.32	18
$2\ell 1\tau_{\text{had}}$	—	$0.4^{+0.6}_{-0.4}$	0.38 ± 0.15	0.37 ± 0.09	0.12 ± 0.15	1.4 ± 0.6	0.47 ± 0.02	1
$1\ell 2\tau_{\text{had}}$	—	15 ± 5	0.17 ± 0.07	0.37 ± 0.10	0.41 ± 0.42	16 ± 6	0.68 ± 0.07	10
4ℓ Z-enr.	—	$\lesssim 10^{-3}$	$\lesssim 3 \times 10^{-3}$	0.43 ± 0.13	0.05 ± 0.02	0.55 ± 0.17	0.17 ± 0.01	1
4ℓ Z-dep.	—	$\lesssim 10^{-4}$	$\lesssim 10^{-3}$	0.002 ± 0.002	$\lesssim 2 \times 10^{-5}$	0.007 ± 0.005	0.03 ± 0.00	0

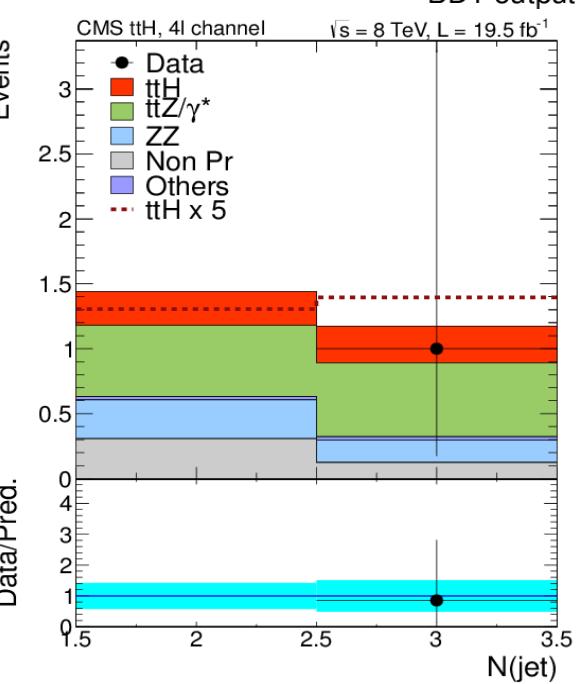
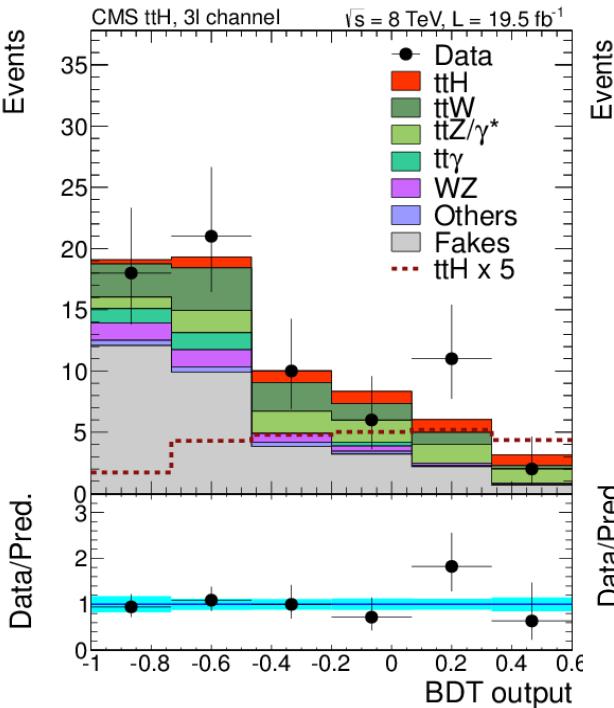
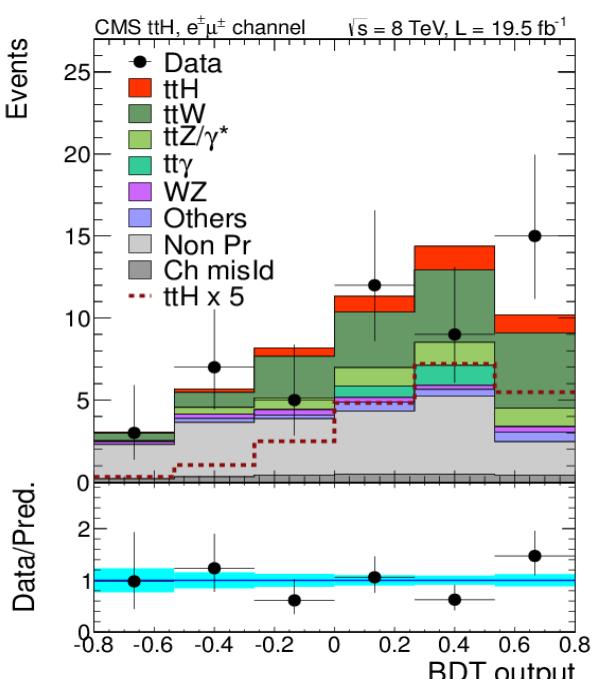
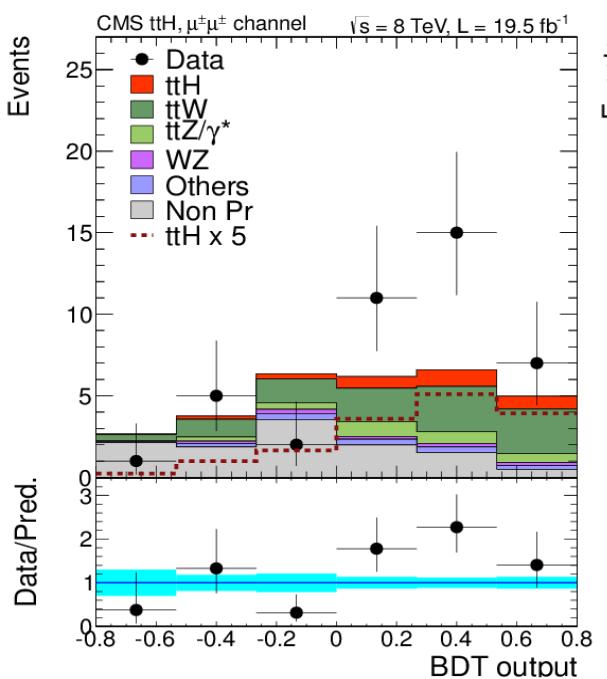
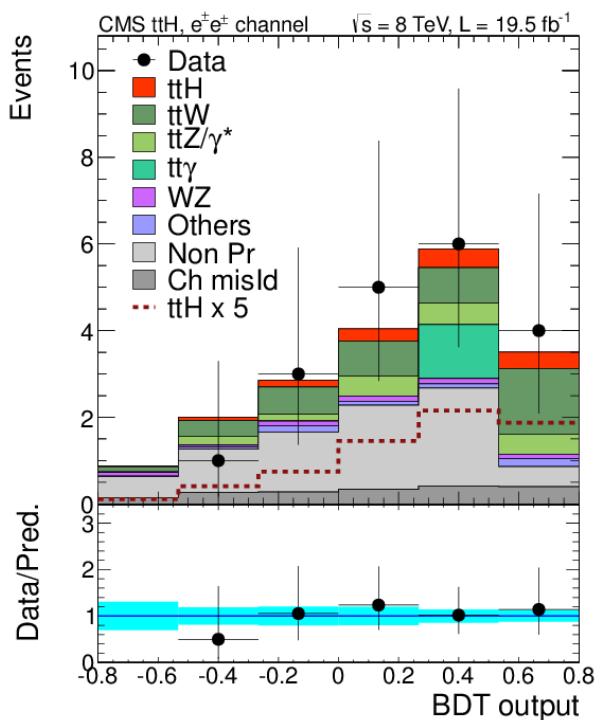
	ee	$e\mu$	$\mu\mu$	3ℓ	4ℓ	CMS
$t\bar{t}H$, $H \rightarrow WW$	1.0 ± 0.1	3.2 ± 0.4	2.4 ± 0.3	3.4 ± 0.5	0.29 ± 0.04	
$t\bar{t}H$, $H \rightarrow ZZ$	—	0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.09 ± 0.02	
$t\bar{t}H$, $H \rightarrow \tau\tau$	0.3 ± 0.0	1.0 ± 0.1	0.7 ± 0.1	1.1 ± 0.2	0.15 ± 0.02	
$t\bar{t}W$	4.3 ± 0.6	16.5 ± 2.3	10.4 ± 1.5	10.3 ± 1.9	—	
$t\bar{t}Z/\gamma^*$	1.8 ± 0.4	4.9 ± 0.9	2.9 ± 0.5	8.4 ± 1.7	1.12 ± 0.62	
$t\bar{t}WW$	0.1 ± 0.0	0.4 ± 0.1	0.3 ± 0.0	0.4 ± 0.1	0.04 ± 0.02	
$t\bar{t}\gamma$	1.3 ± 0.3	1.9 ± 0.5	—	2.6 ± 0.6	—	
WZ	0.6 ± 0.6	1.5 ± 1.7	1.0 ± 1.1	3.9 ± 0.7	—	
ZZ	—	0.1 ± 0.1	0.1 ± 0.0	0.3 ± 0.1	0.47 ± 0.10	
Rare SM bkg.	0.4 ± 0.1	1.6 ± 0.4	1.1 ± 0.3	0.8 ± 0.3	0.01 ± 0.00	
Non-prompt	7.6 ± 2.5	20.0 ± 4.4	11.9 ± 4.2	33.3 ± 7.5	0.43 ± 0.22	
Charge misidentified	1.8 ± 0.5	2.3 ± 0.7	—	—	—	
All signals	1.4 ± 0.2	4.3 ± 0.6	3.1 ± 0.4	4.7 ± 0.7	0.54 ± 0.08	
All backgrounds	18.0 ± 2.7	49.3 ± 5.4	27.7 ± 4.7	59.8 ± 8.0	2.07 ± 0.67	
Data	19	51	41	68	1	

Results by final state

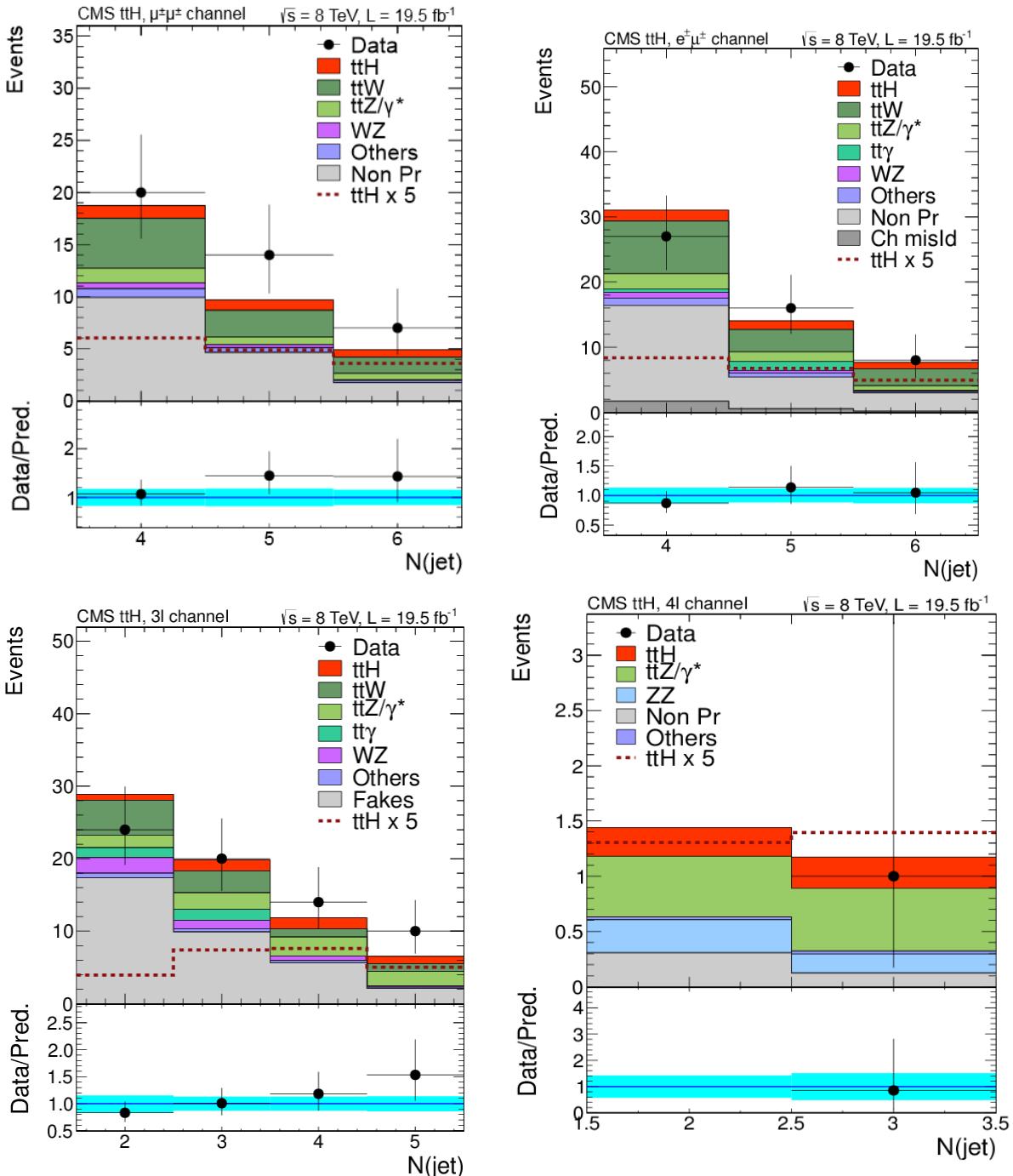


$$\mu(2\ell+3\ell+4\ell) = 3.9^{+1.7}_{-1.4}$$

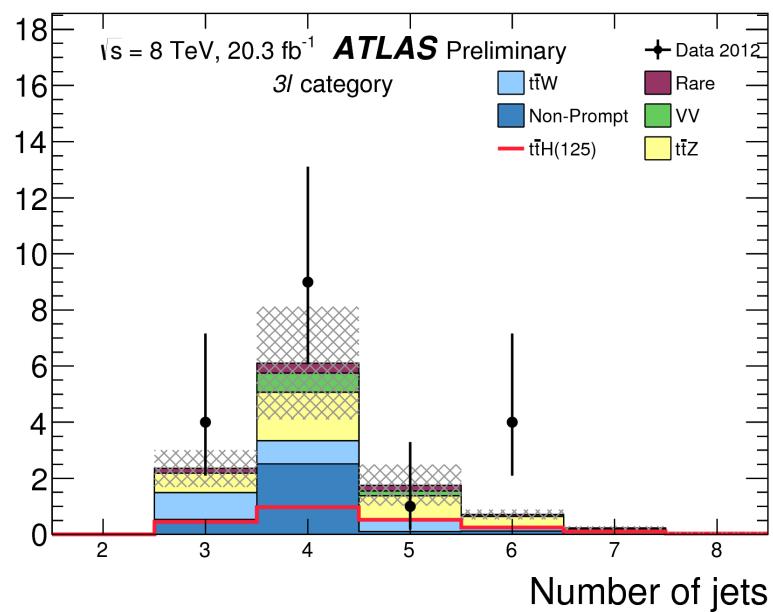
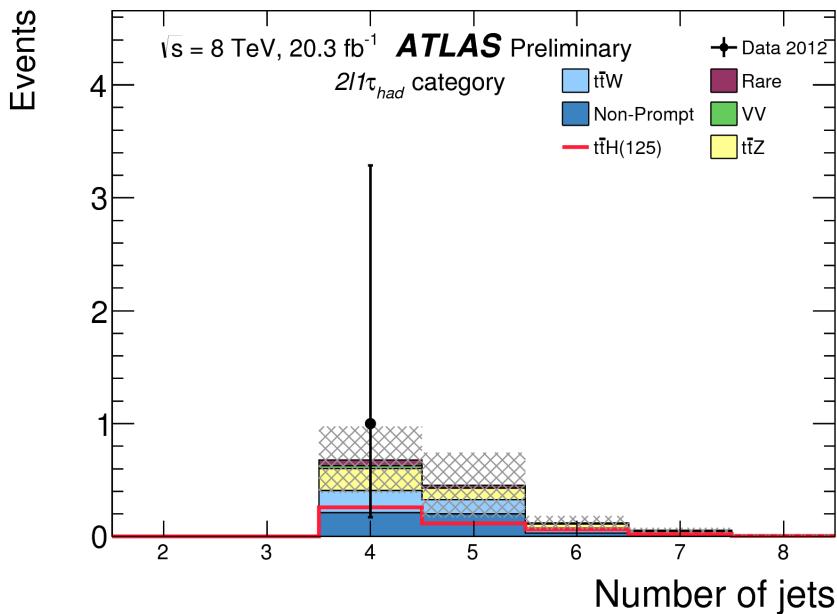
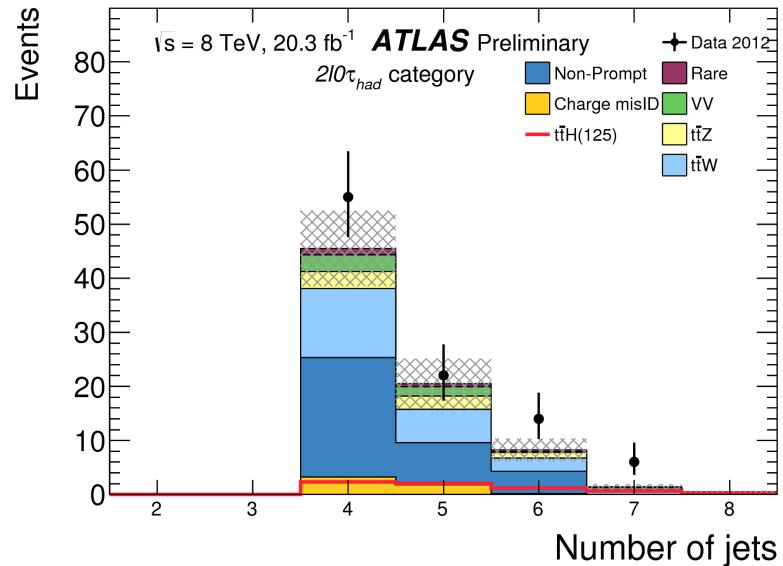
CMS: BDT distributions (N(jet) for 4ℓ)



CMS: N(jet) distributions

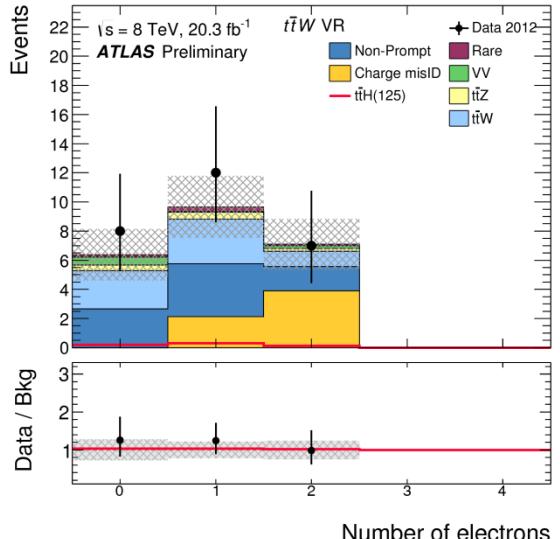


ATLAS: N(jet) distributions

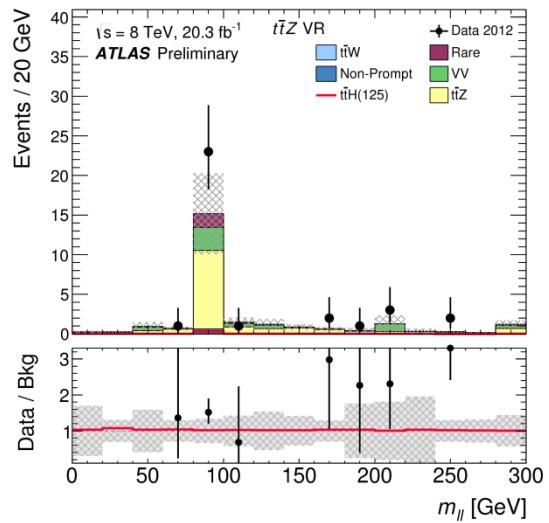


Validation regions

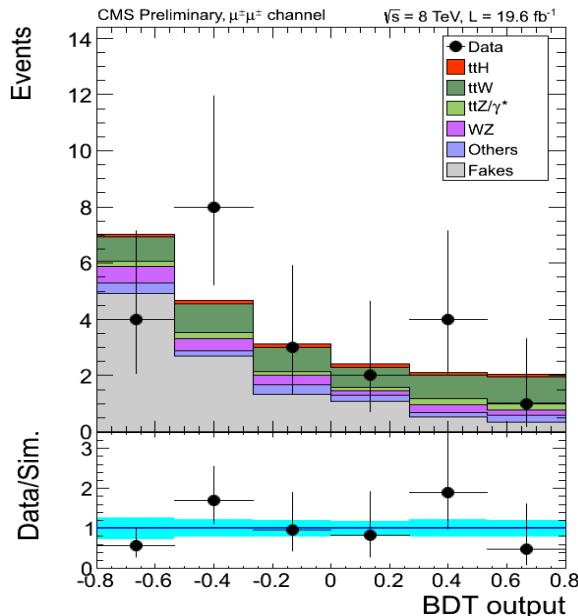
ATLAS $2\ell 0\tau^h$, $N(\text{jet}) \leq 3$, $N(\text{b}) = 2$



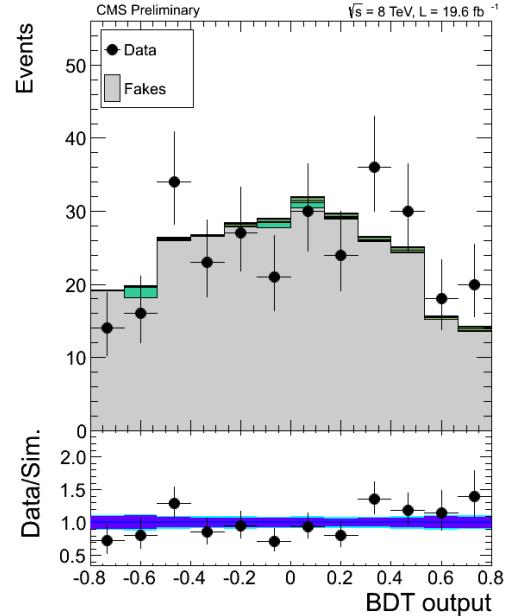
ATLAS 3ℓ , Z peak



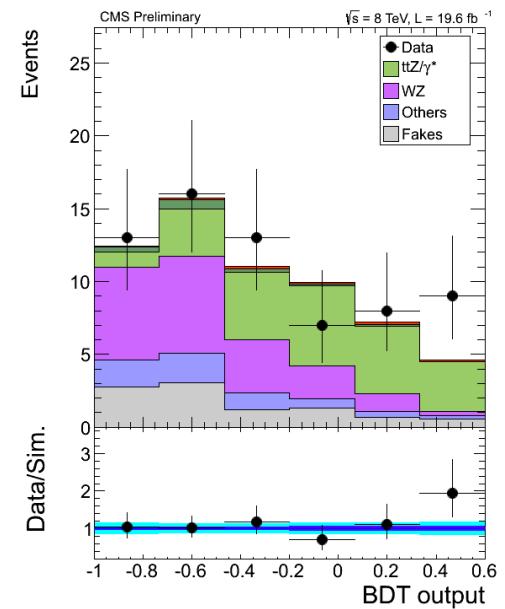
CMS μμ, N(Jet) == 3



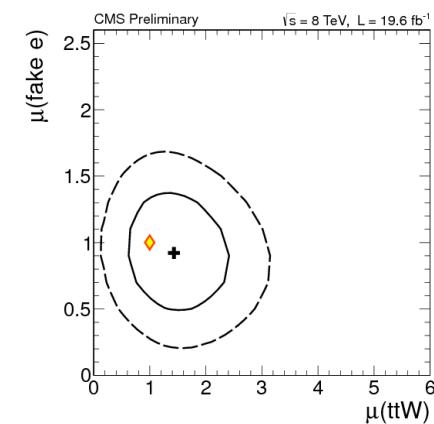
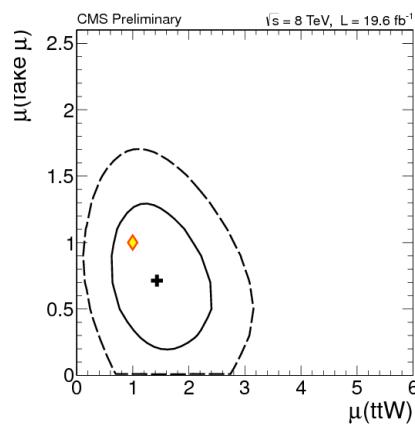
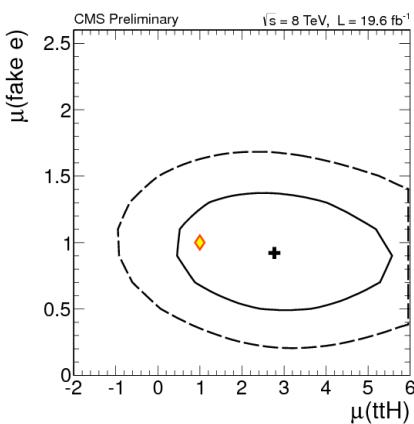
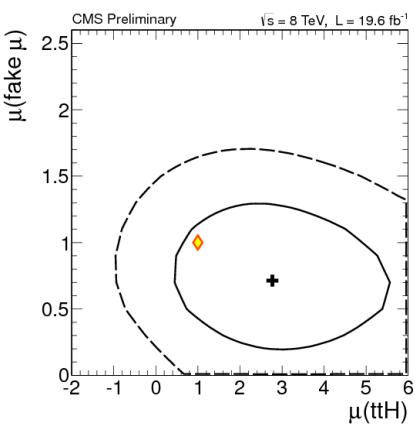
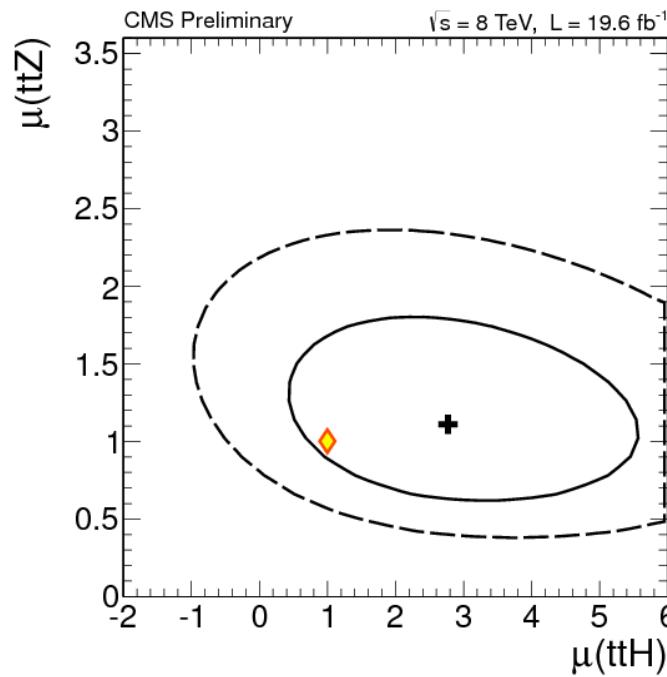
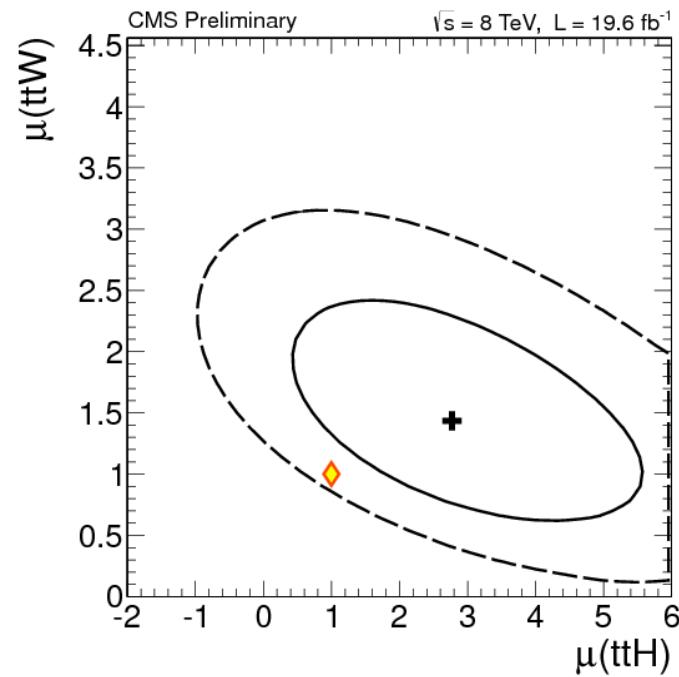
CMS eμ, fail lep. id



CMS 3ℓ, Z peak



CMS cross-check: unconstrained fit



$$\mu(\text{ttH}) = 2.8^{+1.8}_{-1.7}$$

$$\mu(\text{ttW}) = 1.4^{+0.6}_{-0.5}$$

$$\mu(\text{ttZ}) = 1.1^{+0.4}_{-0.3}$$

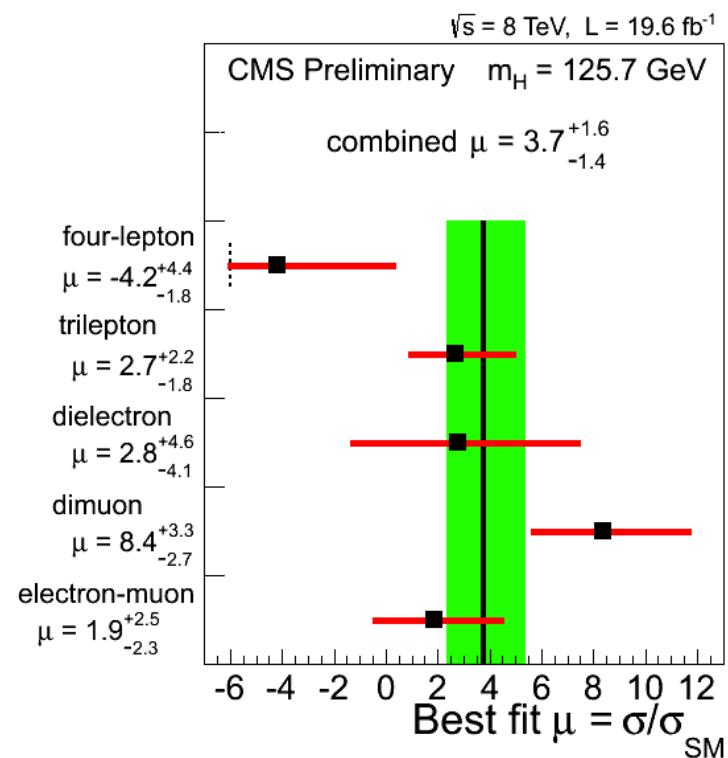
$$\mu(\text{fake } \mu) = 0.7^{+0.4}_{-0.3}$$

$$\mu(\text{fake e}) = 0.9^{+0.3}_{-0.3}$$

Summary of CMS HIG-13-020 result and cross-checks

The result

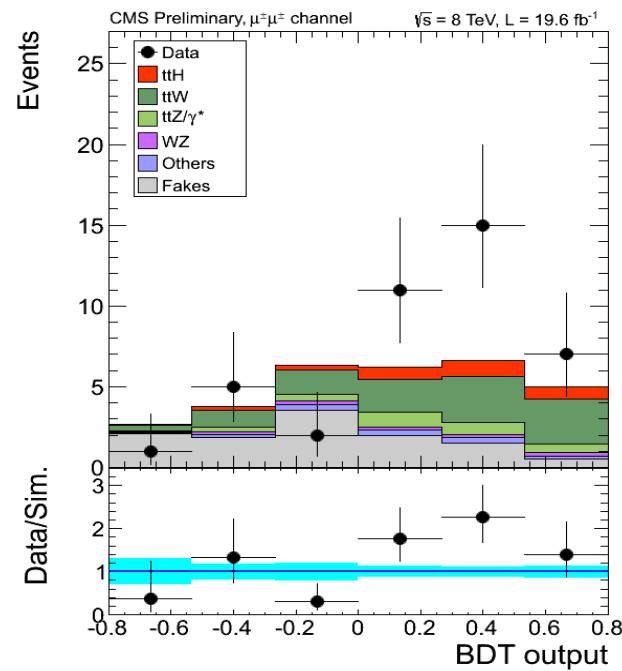
- The results in the different channels are fairly close to the SM Higgs predictions except the $\mu^\pm\mu^\pm$ final state, where an excess is observed
 - The results in the five final states are consistent with a common signal strength at the 16% level.
 - The μ from the combined fit is consistent with the SM Higgs prediction ($\mu = 1$) at the 3% level (1.9σ)



Dimuon final state

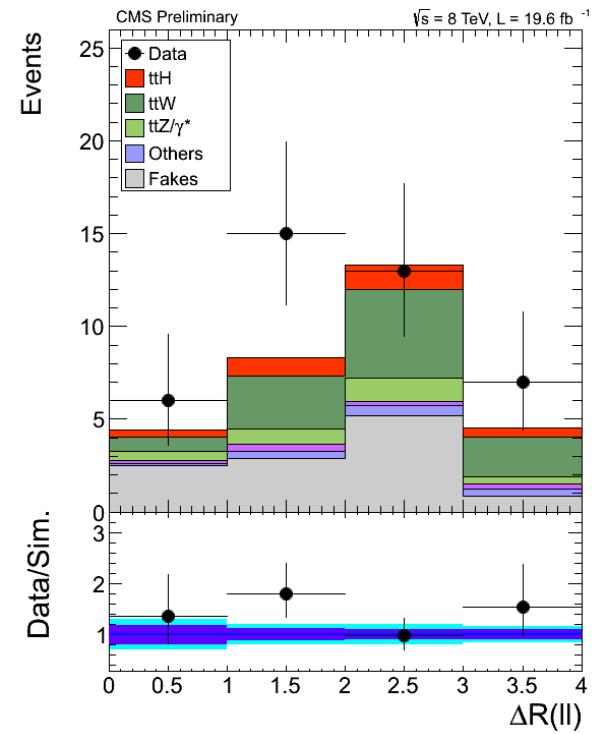
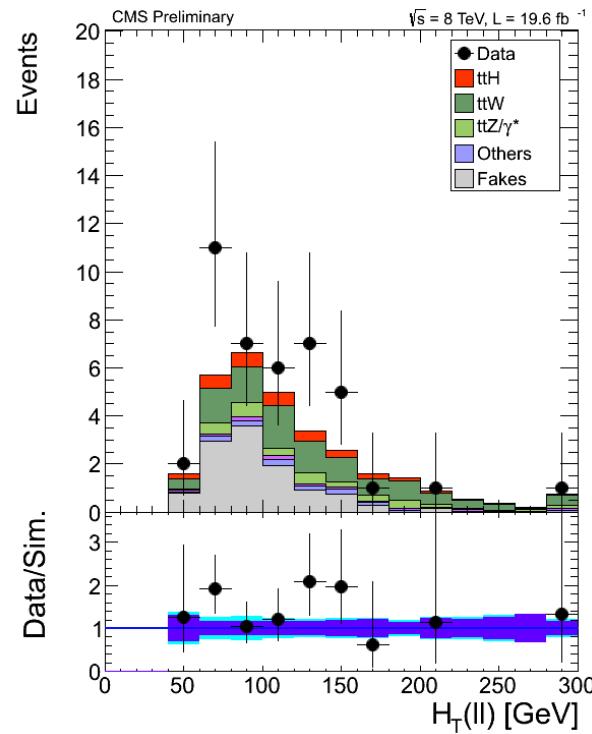
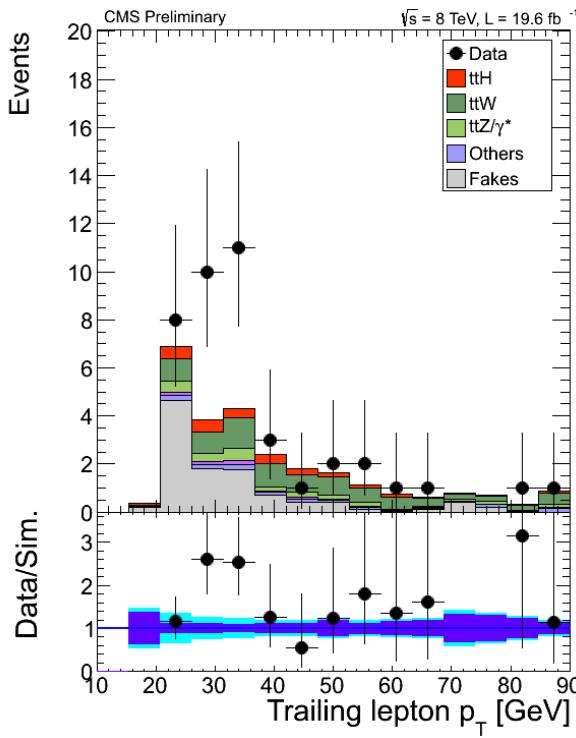
- Excess of events observed, in the signal-like part of the BDT discriminator (trained to separate ttH from the reducible background, on the basis of kinematic variables, not using lepton id variables)

Process	Expected \pm syst.
ttH	2.7 ± 0.4
ttW	8.2 ± 1.4
ttZ/ γ^*	2.5 ± 0.5
WZ	0.8 ± 0.9
Others	1.4 ± 0.1
Reducible	10.8 ± 4.8
Data	41



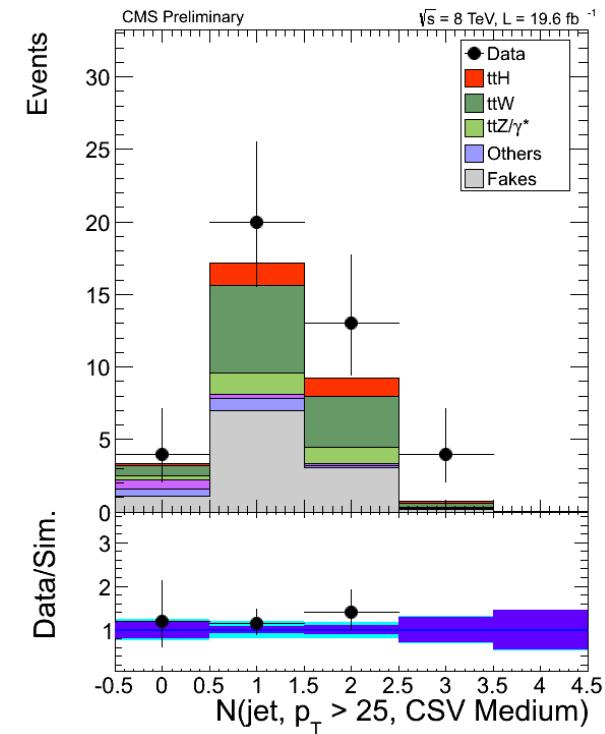
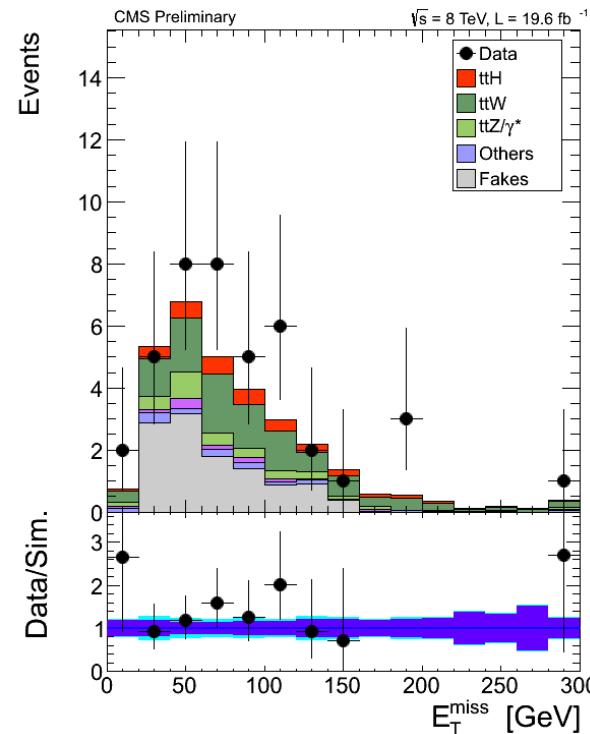
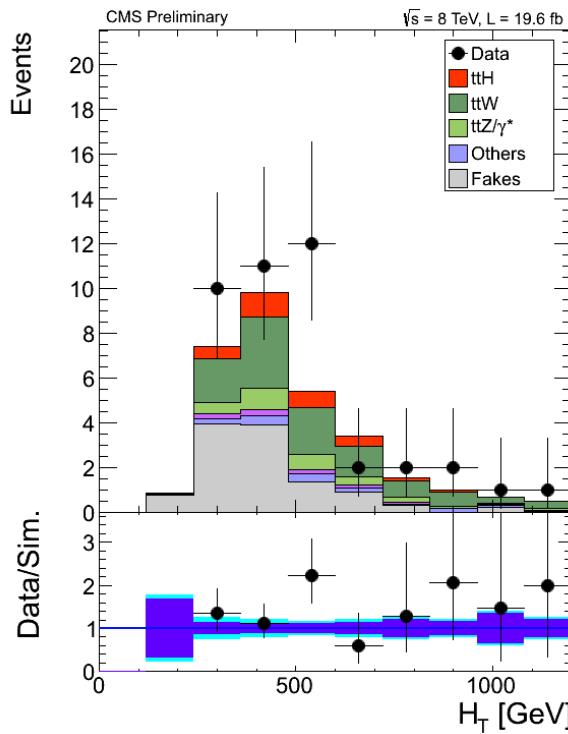
Event kinematics (leptons)

- The kinematic of the leptons in the events does not show anomalies and is compatible with that of signal or ttV events



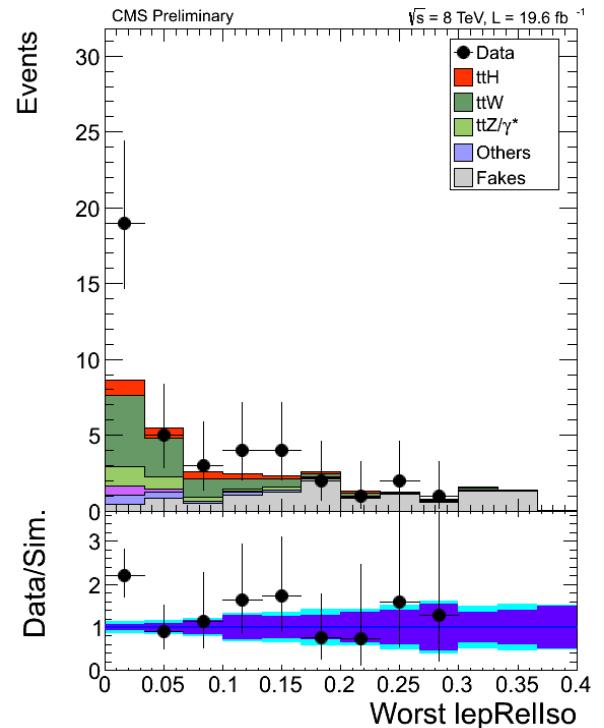
Event kinematics (jets & E_T^{miss})

- Jets and E_T^{miss} are more compatible with signal or ttV.
- The multiplicity of b-tags is also signal-like, while the reducible background has more often only 1 b-tag since the other b-jet is misidentified as a lepton.



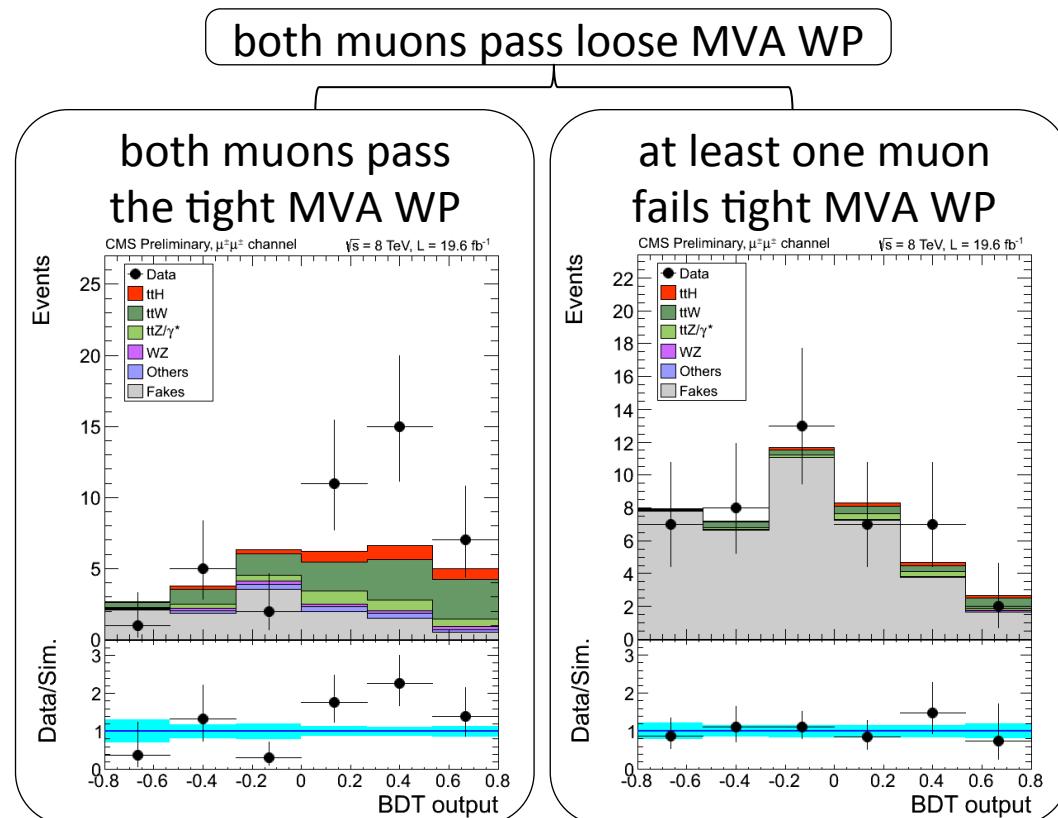
Leptons

- The events in excess are characterized by having both leptons very well isolated.
- Scrutiny of the events also confirms that both leptons are well reconstructed in the tracker and muon system, and that their charge is correctly assigned.



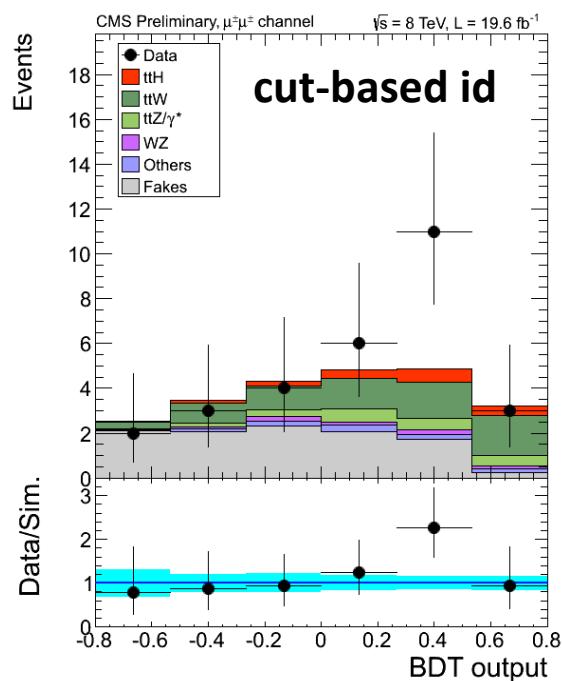
Lepton ID checks: looser MVA

- The analysis was also repeated using a looser working point of the lepton MVA:
 - The excess is visible only when both leptons pass the tight MVA WP.
 - The rest of the sample is well described by the background model



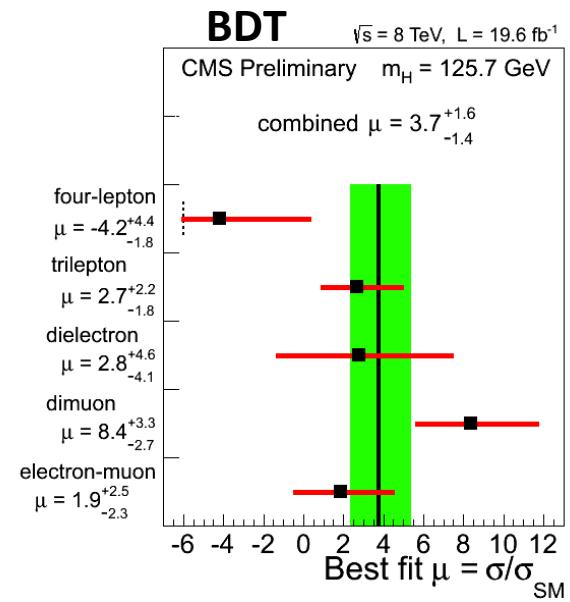
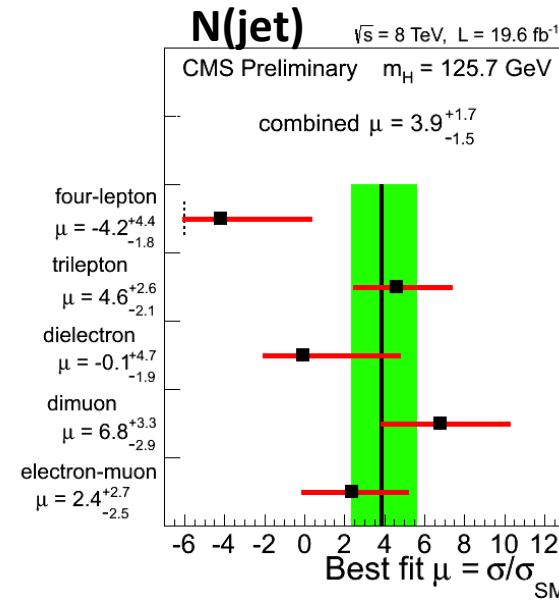
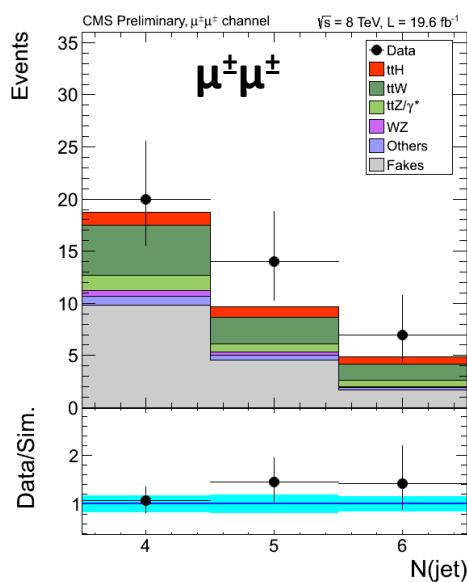
Lepton ID checks: cut-based

- As a cross-check, the analysis was repeated with a cut-based muon selection, instead of the lepton MVA.
- The result with the cut-based selection is compatible with the nominal one, but the sensitivity is worse.



Signal extraction check

- The signal extraction is repeated using just the multiplicity of hadronic jets as discriminating variable instead of the kinematic BDT.
- The result is compatible with the nominal one, but the sensitivity is worse (as expected)

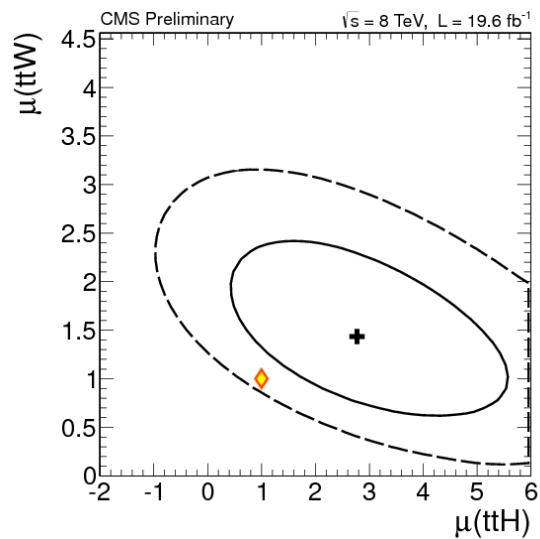


Irreducible background check

- A more general fit is performed:
 - leaving unconstrained the yields of ttW, ttZ, and reducible background (for fake e, μ separately)
 - including additional control regions in the fit: trilepton events with one Z candidate (mostly ttZ), and dilepton events with 3 jets (ttW & red. bkg).
- Results compatible with the nominal ones (but $\sim 20\%$ worse sensitivity).
- All backgrounds yields remain within 1σ from their input value: no indication of issues with ttW & ttZ

$$\begin{aligned}\mu(\text{ttH}) &= 2.8^{+1.8}_{-1.7} \\ \mu(\text{ttW}) &= 1.4^{+0.6}_{-0.5} \\ \mu(\text{ttZ}) &= 1.1^{+0.4}_{-0.3}\end{aligned}$$

Results for ttH and ttW are correlated, all the others are well resolved.



Charge asymmetry

- Observed 21 $\mu^+\mu^+$ events and 20 $\mu^-\mu^-$ events, i.e. $N(++)/N(\text{tot}) = 0.51 \pm 0.09$
- This is compatible with the expectations for SM Higgs + background, $N(++)/N(\text{tot}) = 0.55$
- Within 1σ the excess events are compatible with any charge asymmetry between zero and the one of ttW, $N(++)/N(\text{tot}) = 0.69$
- Note that in the signal extraction in the 2ℓ and 3ℓ final state the events are categorized by charge, to discriminate ttW from ttH.

Other hypotheses

- $t\bar{t}+bb$ (or $t\bar{t}+cc$) with $b/c \rightarrow \mu$:
 - Excess should be even more visible with the looser lepton MVA working point, and it's not.
- $t\bar{t} \rightarrow \mu + \text{jets}$ plus a muon from pile-up, or $t\bar{t} \rightarrow \mu + \text{jets}$ plus a cosmic ray muon:
 - given the observed d_{xy} , d_z distributions the estimated yields are by far too small compared to the excess.
- in general, SM backgrounds producing $\mu^\pm\mu^\pm$ should also produce $e^\pm\mu^\pm$ (and any $t\bar{t}+X$, $X \rightarrow \mu$ should also contribute to the 3ℓ final states)

Conclusions

- Several studies have been performed to investigate the excess in the $\mu^\pm\mu^\pm$ final state
 - no anomalies seen in the properties of the selected events
 - no indication of any issue in the lepton MVA ID and in the reducible background estimation
 - no evidence for unaccounted backgrounds
- More in general, for this analysis:
 - compatible results obtained in cross-check without using multivariate methods for lepton IDs or signal extraction
 - ttW and ttZ yields also fitted as cross-check, and found in good agreement with the theoretical predictions (i.e. no indication of problems there, nor in the signal efficiencies)