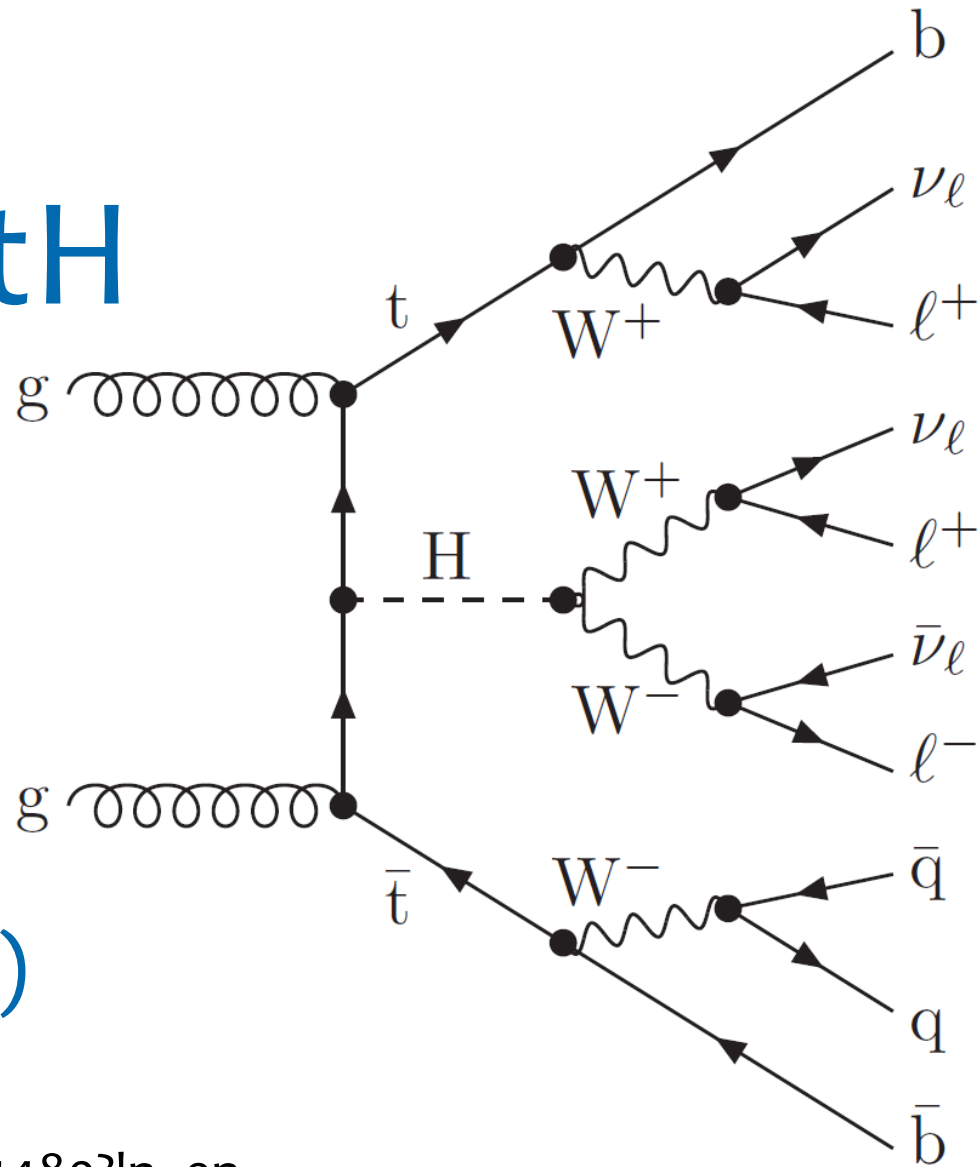




Search for $t\bar{t}H$ in leptonic final states

Cristina Botta (CERN)



PAS: <http://cds.cern.ch/record/1604480?ln=en>

TWIKI: <https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13020TWiki>

Yields after selection

	$\mu\mu$	ee	$e\mu$	3ℓ	4ℓ
$t\bar{t}H, H \rightarrow WW$	2.0 ± 0.3	0.9 ± 0.1	2.7 ± 0.4	3.2 ± 0.6	0.28 ± 0.05
$t\bar{t}H, H \rightarrow ZZ$	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.09 ± 0.02
$t\bar{t}H, H \rightarrow \tau\tau$	0.6 ± 0.1	0.3 ± 0.0	0.9 ± 0.1	1.0 ± 0.2	0.15 ± 0.02
$t\bar{t}W$	8.2 ± 1.5	3.4 ± 0.6	13.0 ± 2.2	9.2 ± 1.9	-
$t\bar{t}Z/\gamma^*$	2.5 ± 0.5	1.6 ± 0.3	4.2 ± 0.9	7.9 ± 1.7	1.25 ± 0.88
$t\bar{t}WW$	0.2 ± 0.0	0.1 ± 0.0	0.3 ± 0.1	0.4 ± 0.1	0.04 ± 0.02
$t\bar{t}\gamma$	-	1.3 ± 0.3	1.9 ± 0.5	2.9 ± 0.8	-
WZ	0.8 ± 0.9	0.5 ± 0.5	1.2 ± 1.3	4.2 ± 0.9	-
ZZ	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.4 ± 0.1	0.45 ± 0.09
rare SM bkg.	1.1 ± 0.0	0.4 ± 0.0	1.5 ± 0.0	0.8 ± 0.0	0.01 ± 0.00
non-prompt	10.8 ± 4.8	8.9 ± 4.5	21.2 ± 8.1	33.2 ± 12.3	0.53 ± 0.32
charge flip	-	1.9 ± 0.6	2.4 ± 0.8	-	-
all signals	2.7 ± 0.4	1.2 ± 0.2	3.7 ± 0.6	4.4 ± 0.8	0.52 ± 0.09
all backgrounds	23.7 ± 5.2	18.0 ± 4.7	45.9 ± 8.6	58.9 ± 12.7	2.28 ± 0.94
data	41	19	51	68	1

Uncertainties from theoretical and experimental systematics

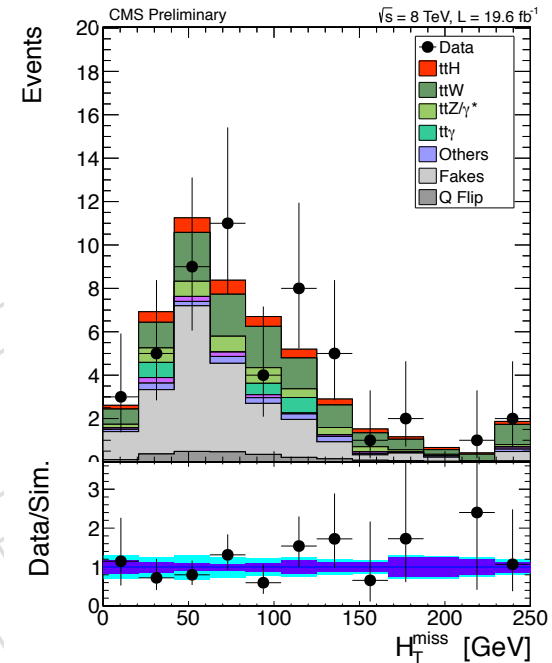
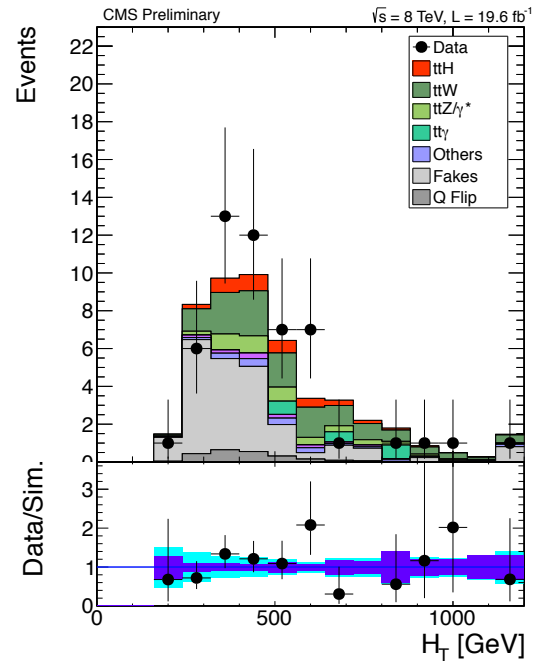
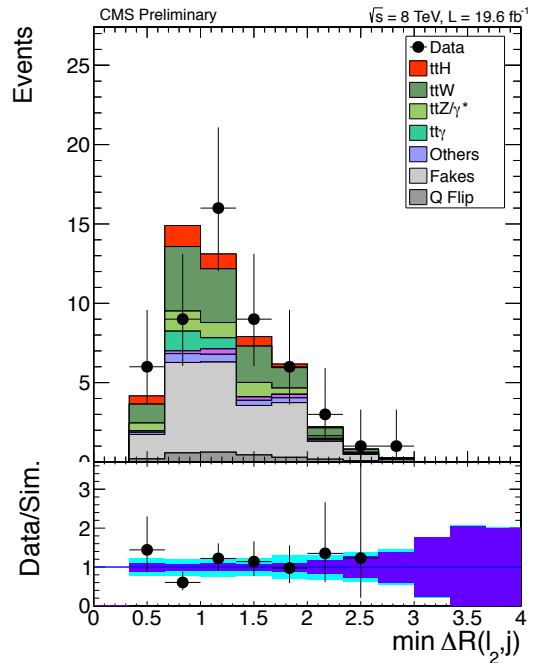
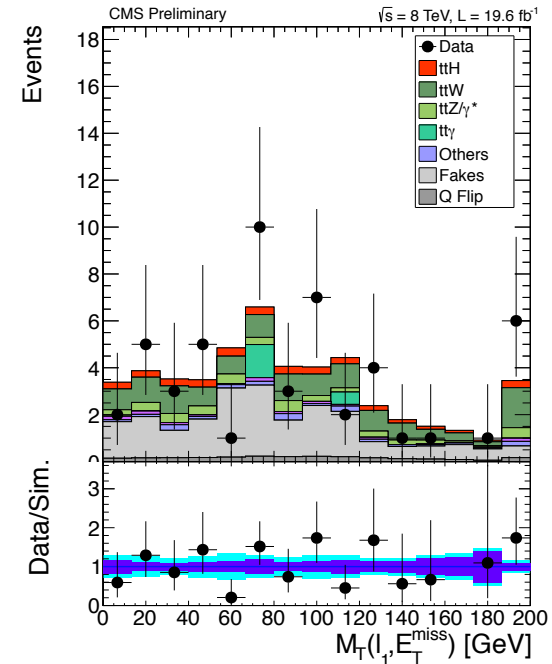
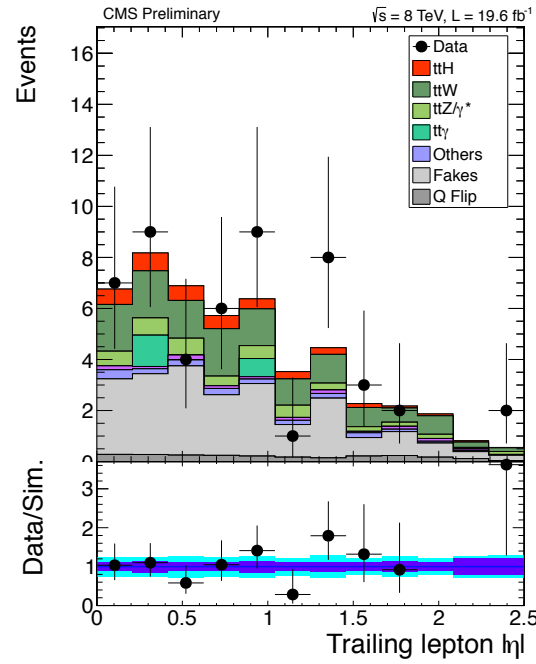
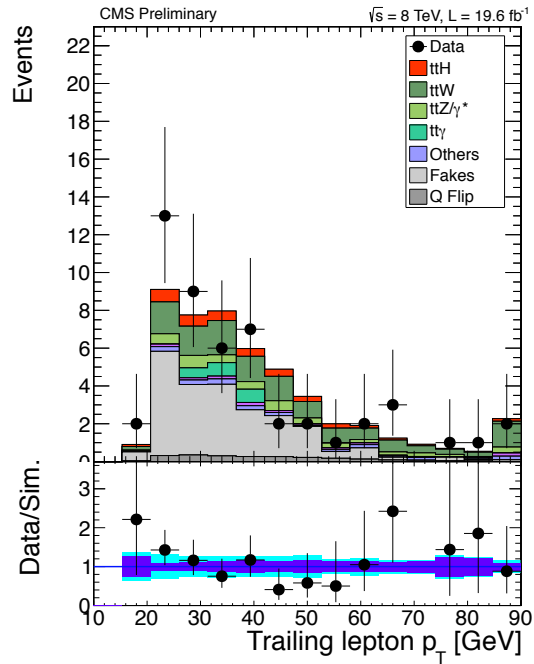
From simulation (with data/MC SF corrections)

From simulation (with data/MC SF corrections) with normalization from data yields in CR

From data-driven (expected mainly $t\bar{t}$ +jets - small amount of Z/W+jets)

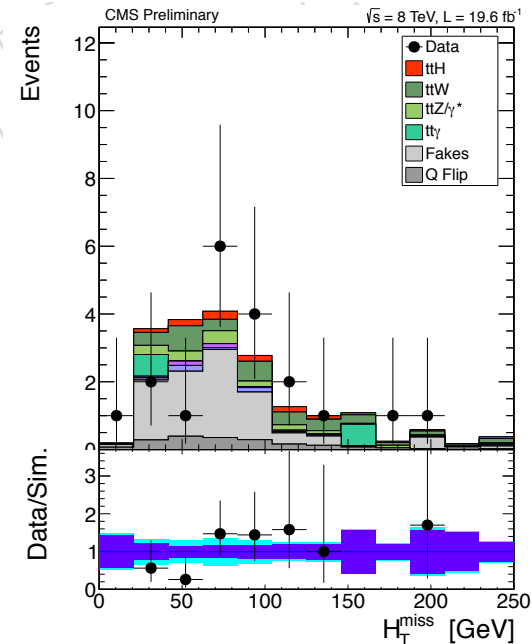
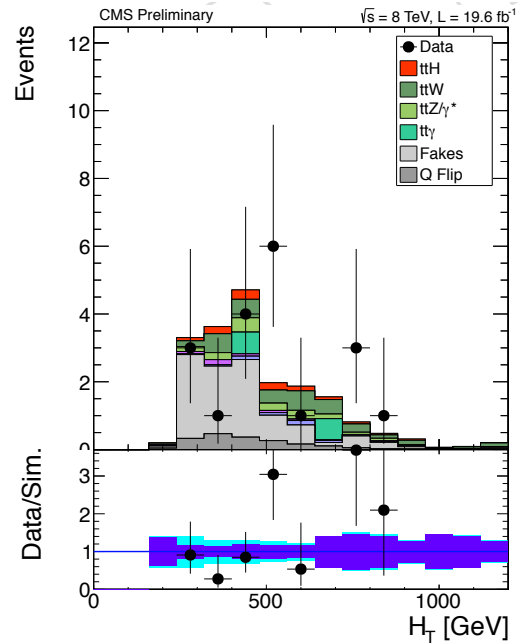
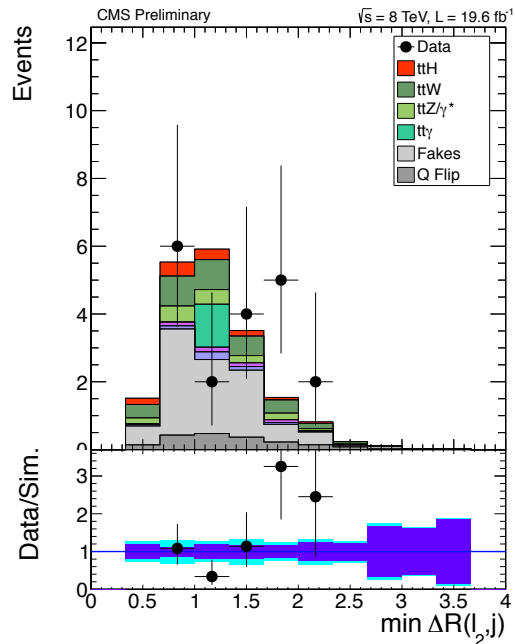
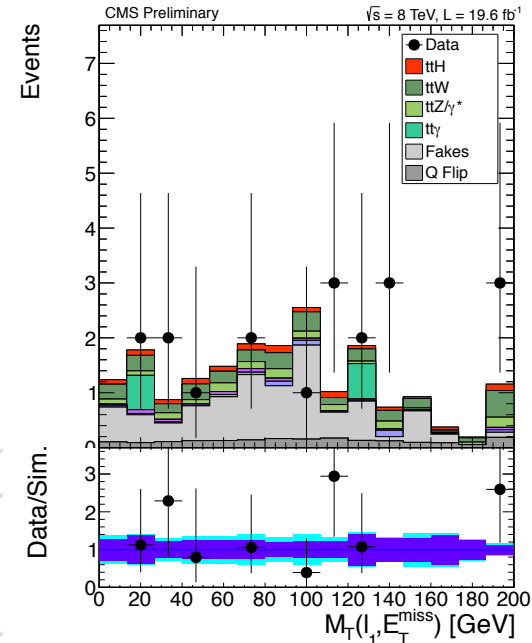
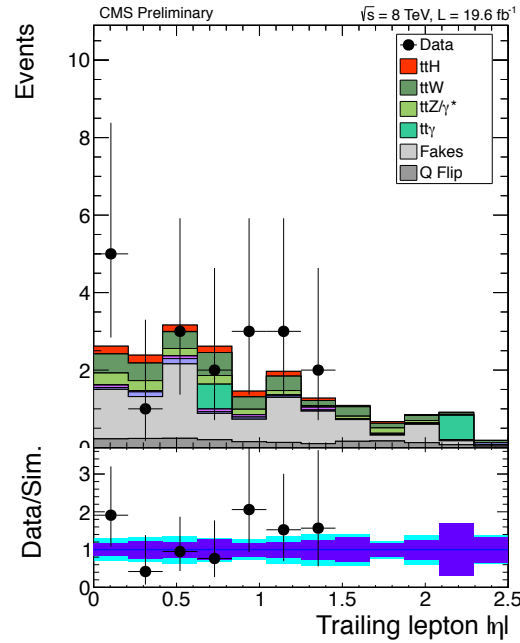
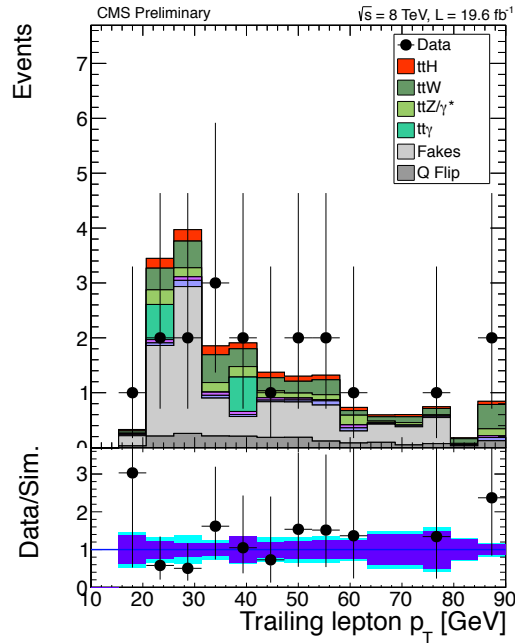
Input variables $e^\pm\mu^\pm$

Fakes and Charge-flip lep. contributions from data-driven



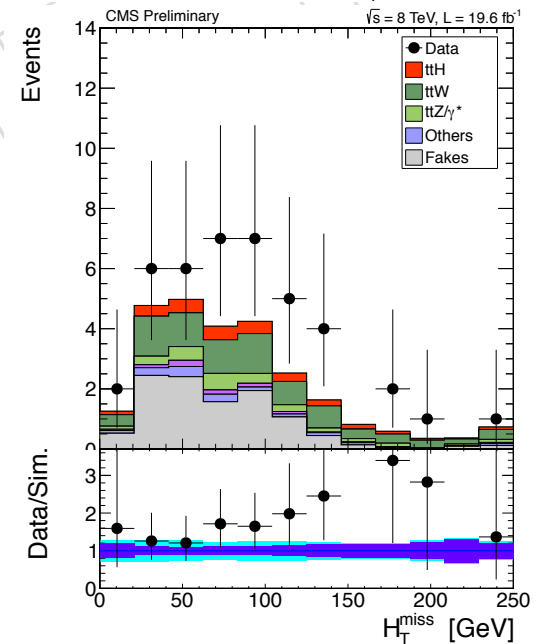
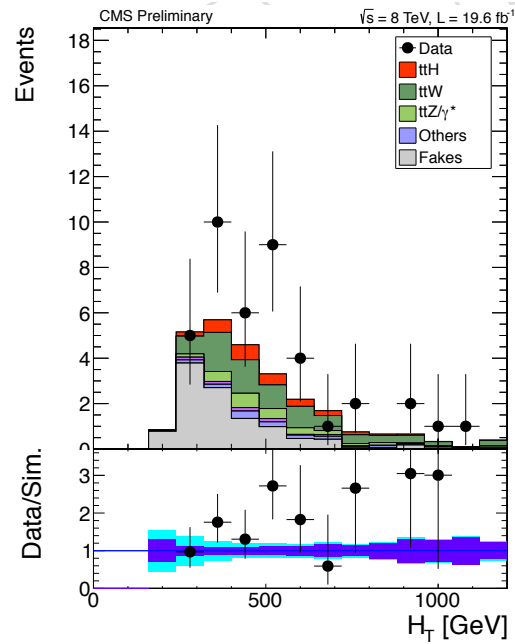
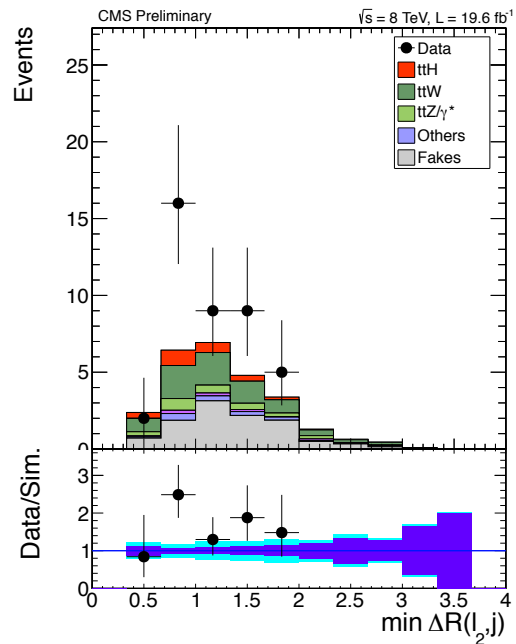
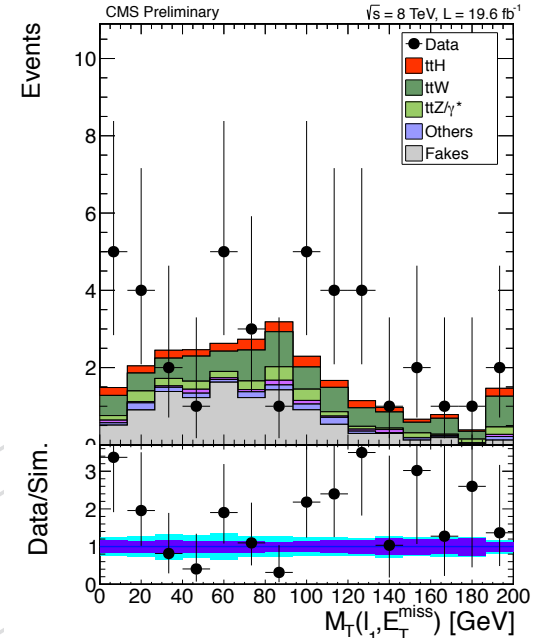
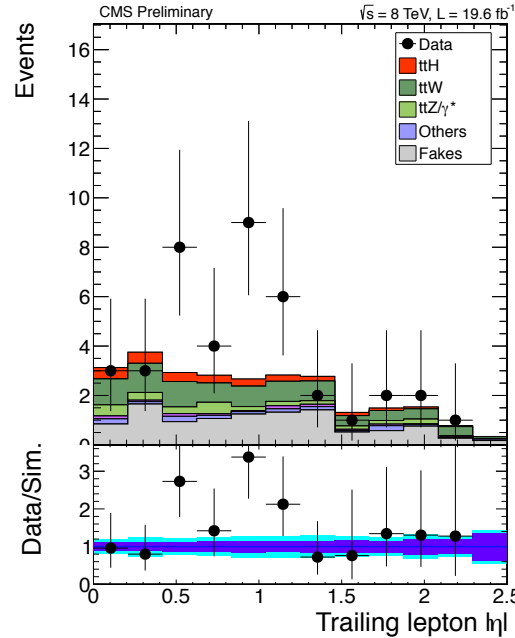
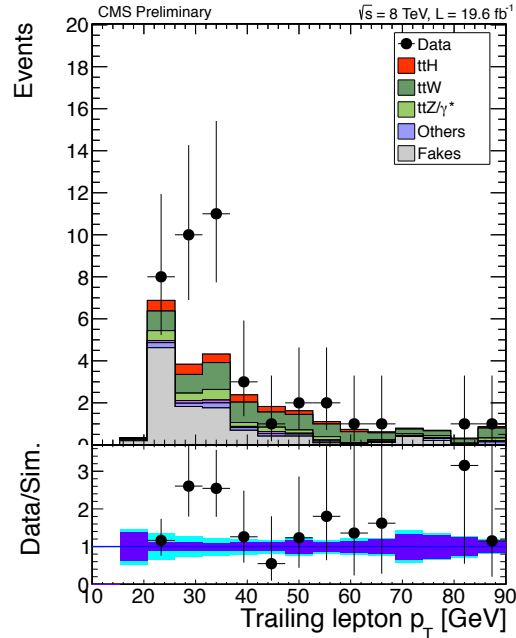
Input variables e^+e^-

Fakes and Charge-flip lep. contributions from data-driven

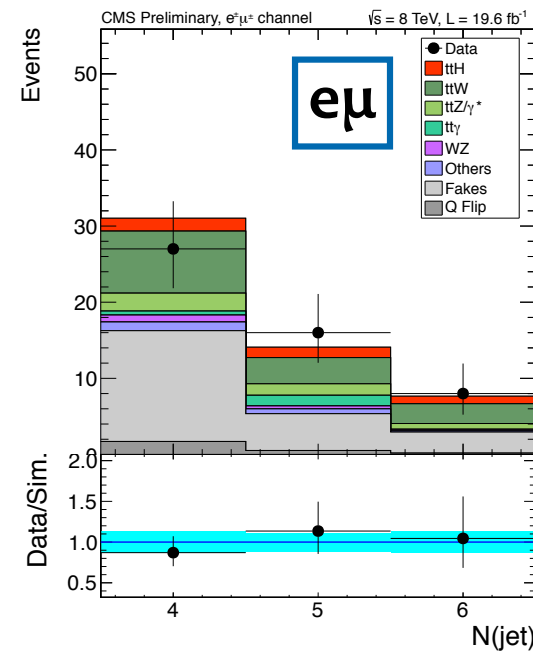
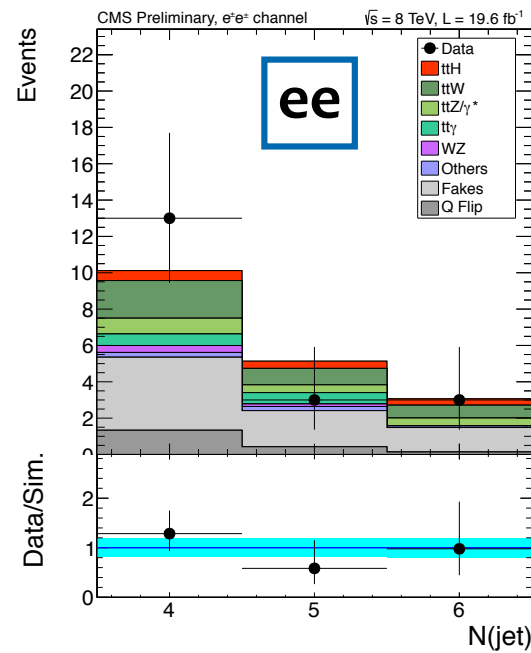
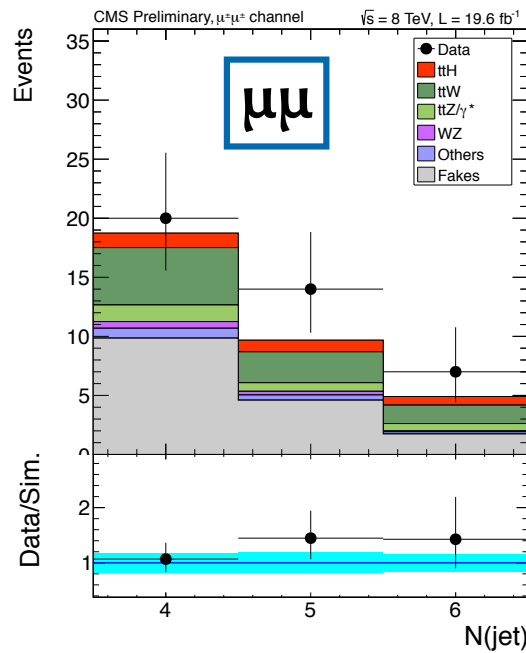


Input variables $\mu^\pm\mu^\pm$

Fakes and Charge-flip lep. contributions from data-driven



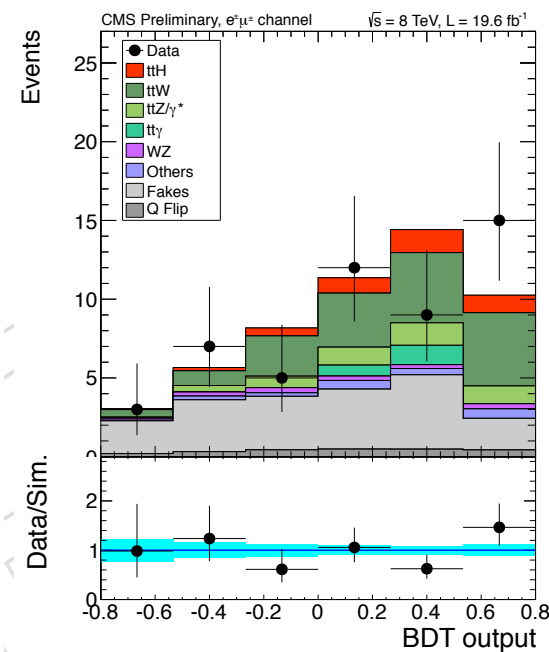
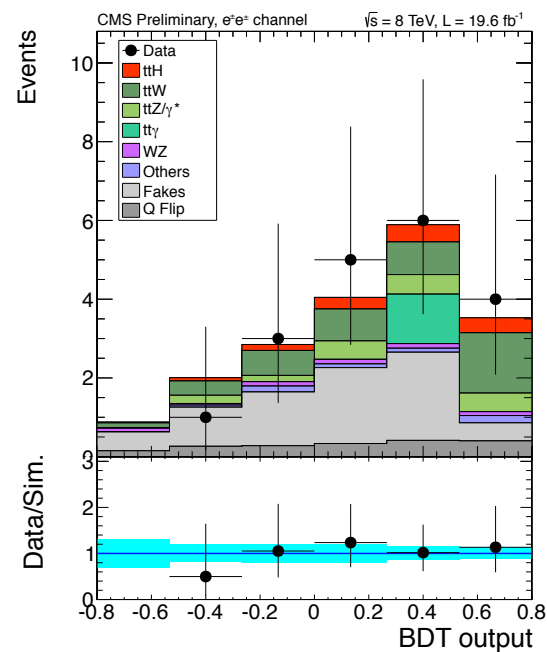
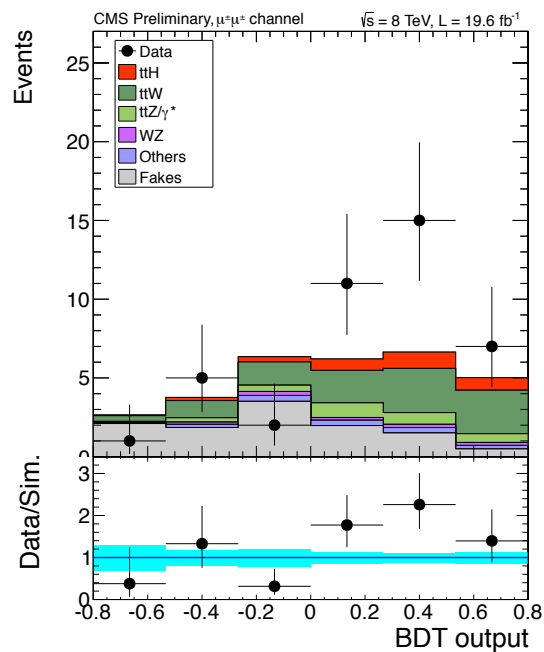
Outputs $2\ell ss$



NJets

Post-fit plots

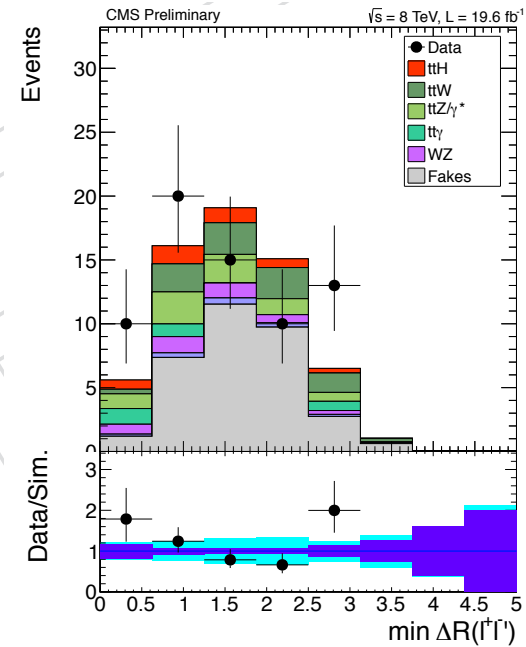
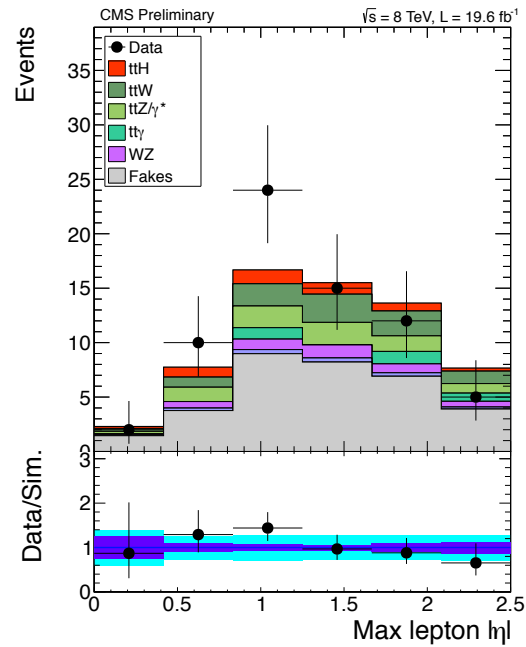
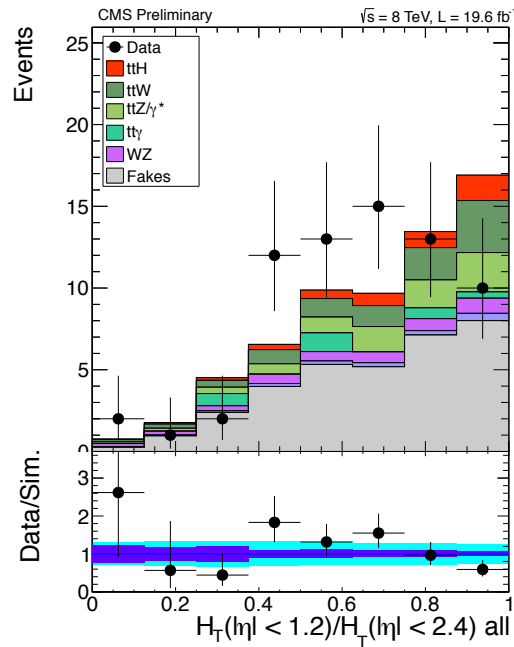
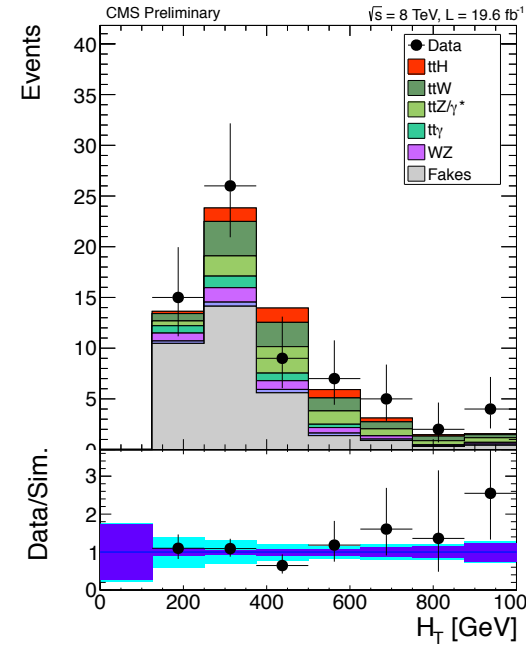
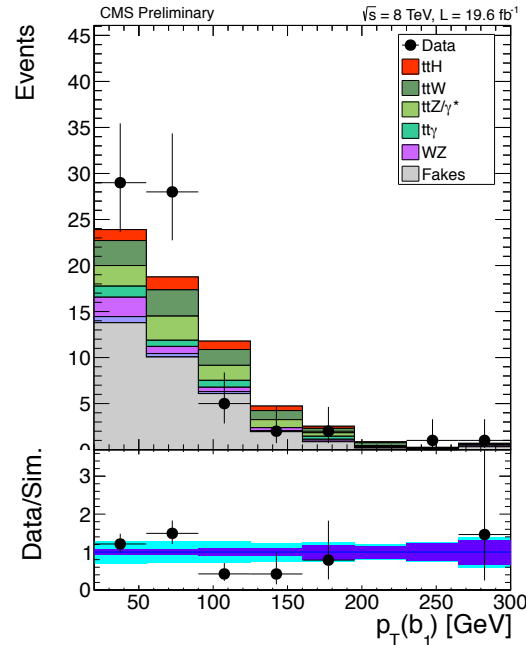
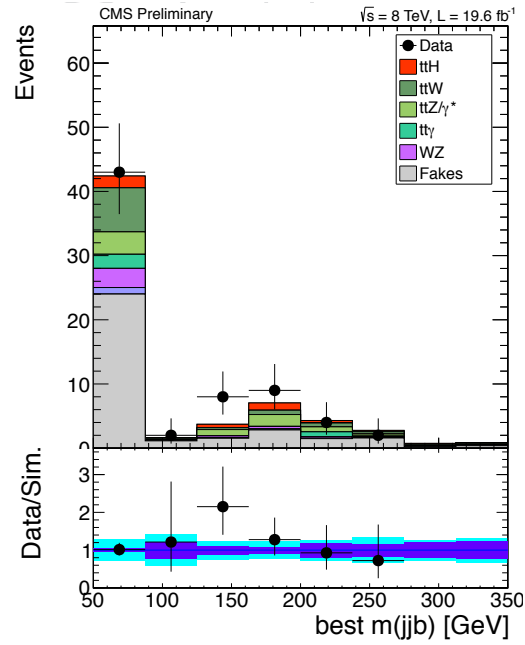
Light-Blue band from stat and syst uncertainties after the fit



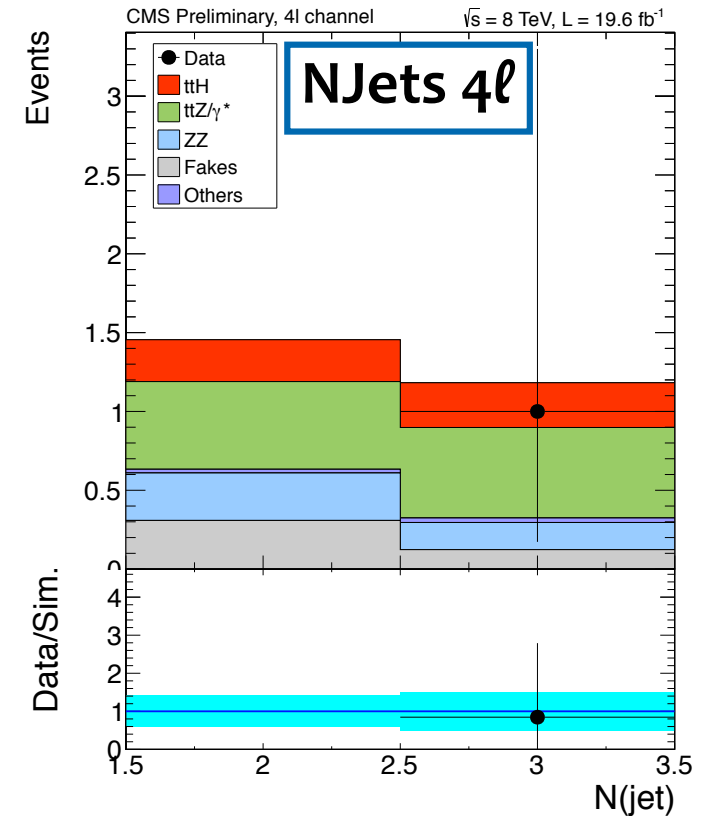
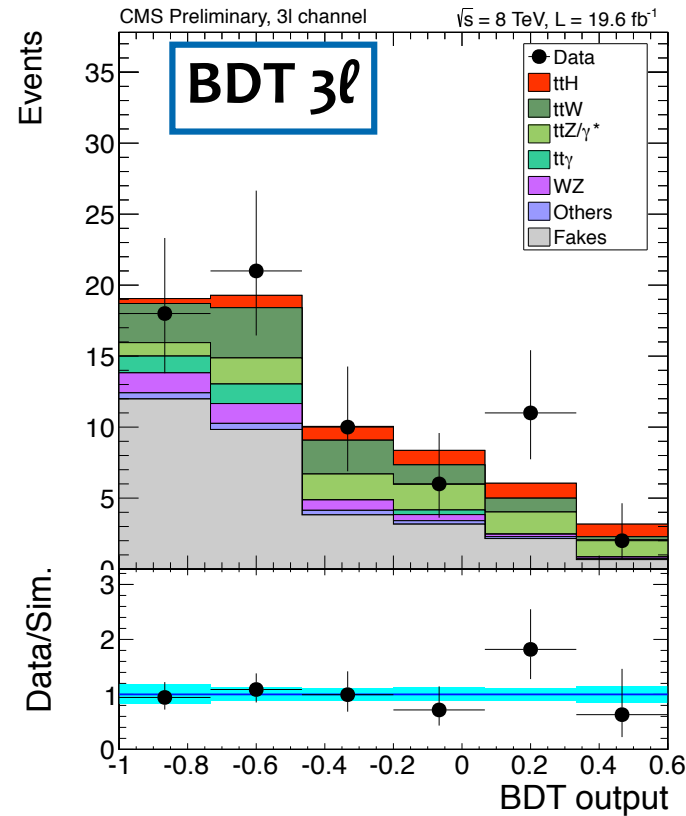
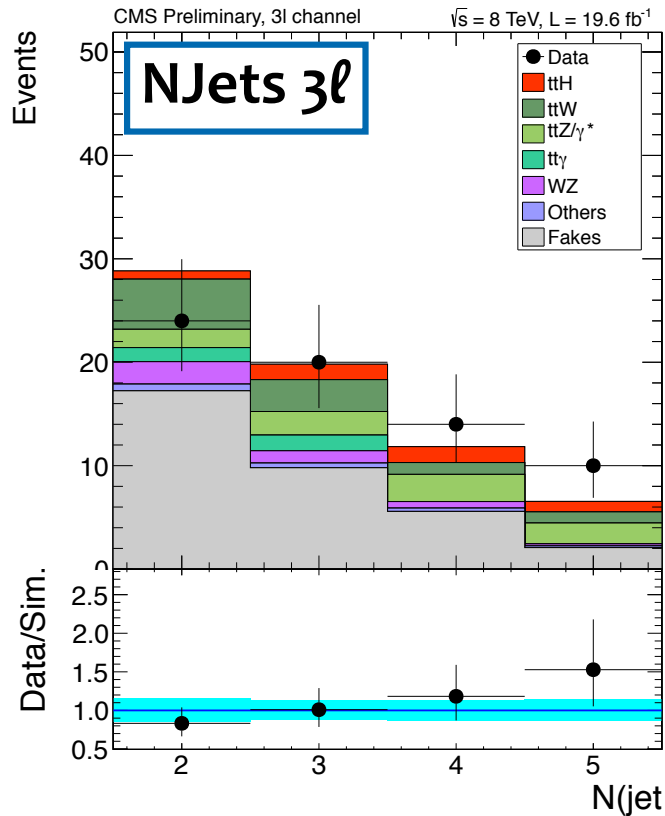
BDT

Input variables 3l

Fakes and Charge-flip lep. contributions from data-driven



Outputs 3ℓ and 4ℓ



Post-fit plots

Light-Blue band from stat and syst uncertainties after the fit



03/10/13

C. Botta (CERN)

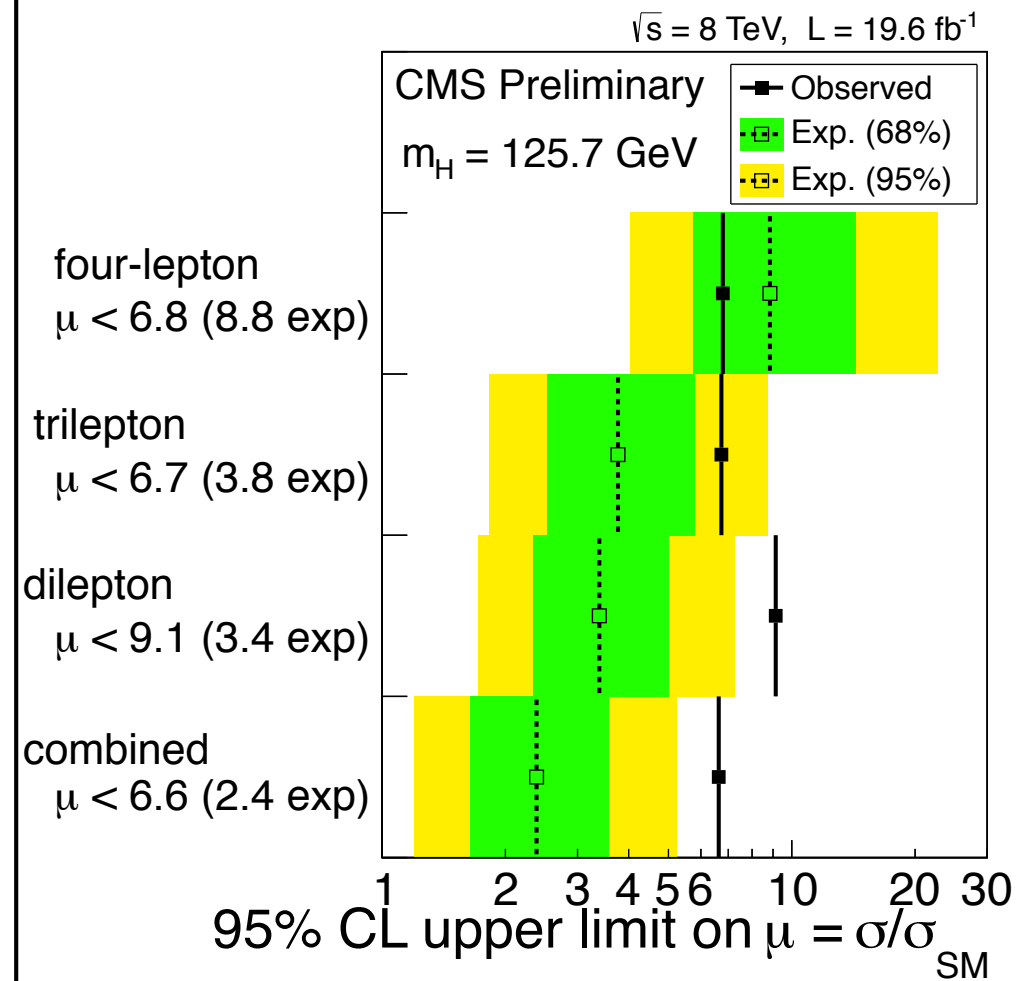
9



Results

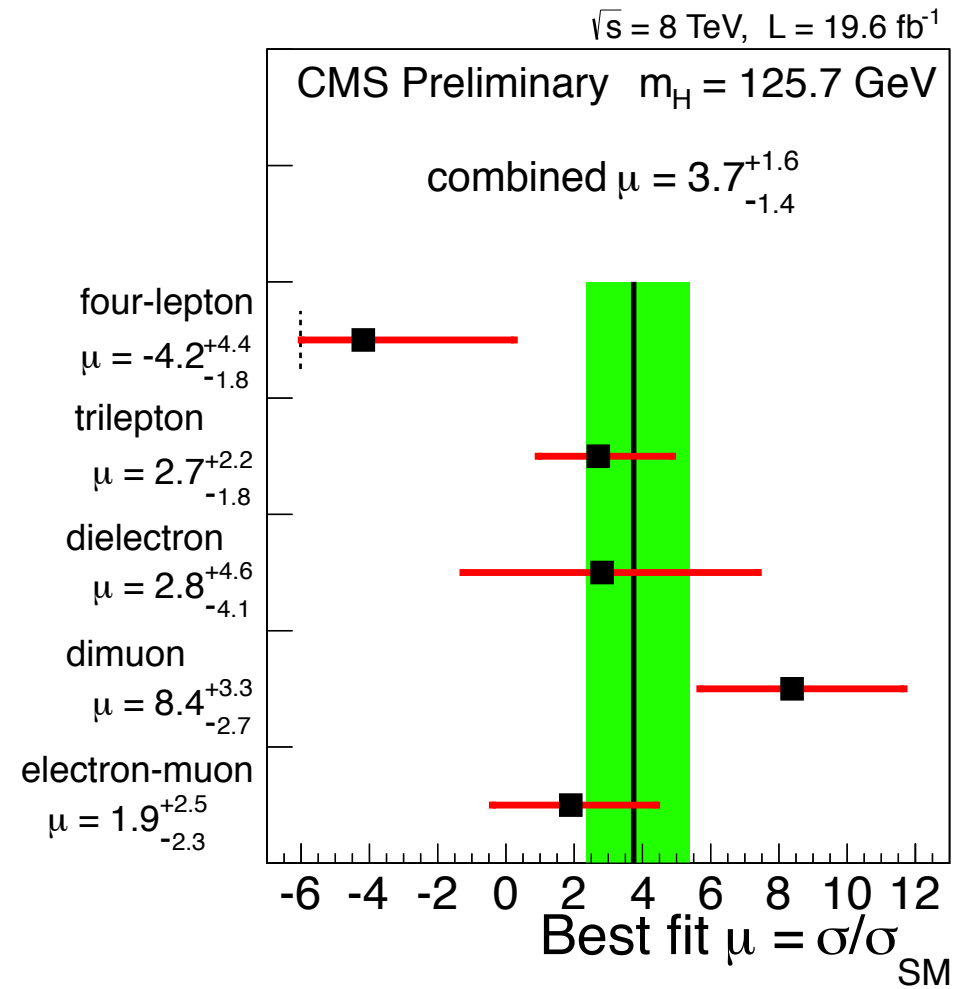
Limits on $\mu = \sigma/\sigma_{SM}$

- Observed yields and distributions are compared to the expectation for a **SM Higgs with $m_H = 125.7$**
- Median expected combined UL:
 - in the absence of ttH signal: **2.4** at 95% CL
 - with the SM ttH production: **3.5** at 95% CL
- Observed UL is **6.6** at 95% CL
mainly driven by the observed excess in the **ss $\mu\mu$ channel**



Best fit $\mu = \sigma/\sigma_{SM}$

- Observed yields and distributions are compared to the expectation for a **SM Higgs with $m_H = 125.7$**
- The internal consistency of the 5 best-fit signal-strengths with a common value: **16%**
- The fit to the combination yields: **$\mu = 3.7^{+1.6}_{-1.4}$**
- The combined μ is compatible with the SM Higgs boson prediction $\mu = 1$ at the **3%** level (1.9σ)

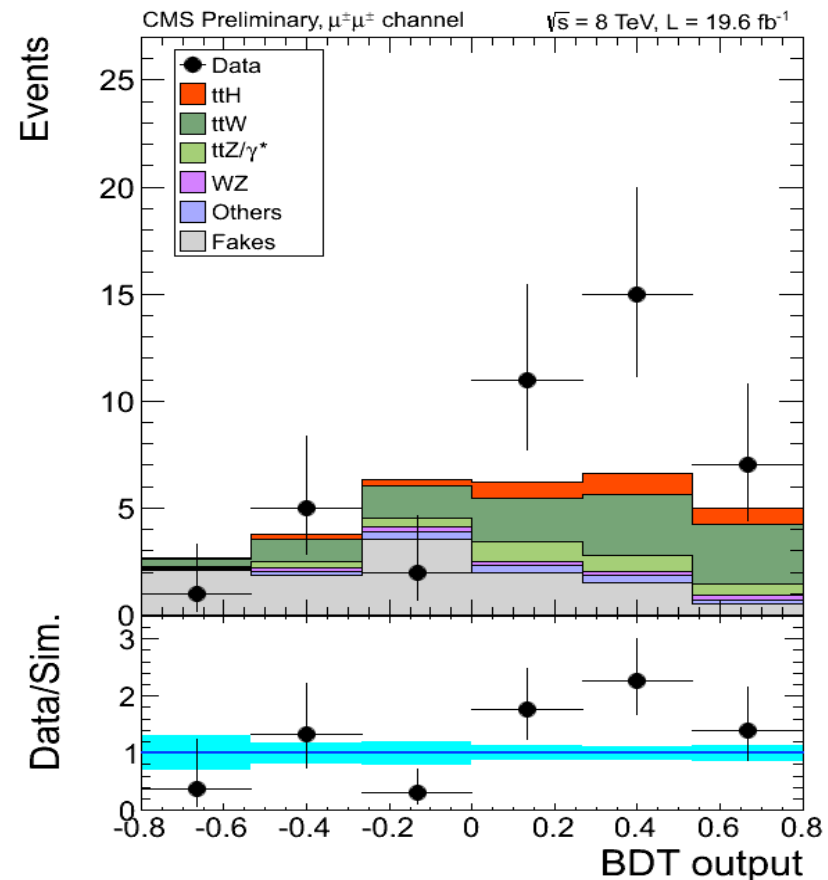


Anatomy of the $\mu^\pm\mu^\pm$ excess

Dimuon final state

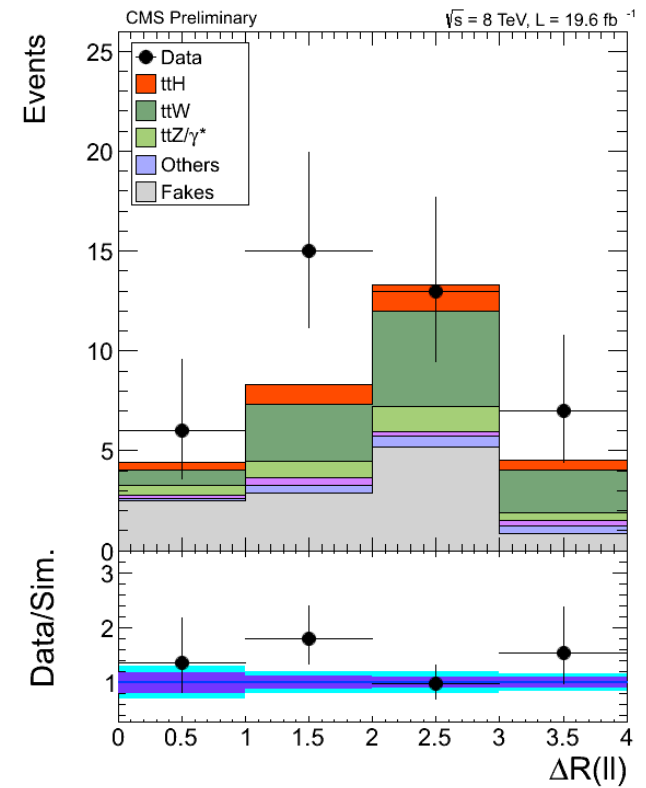
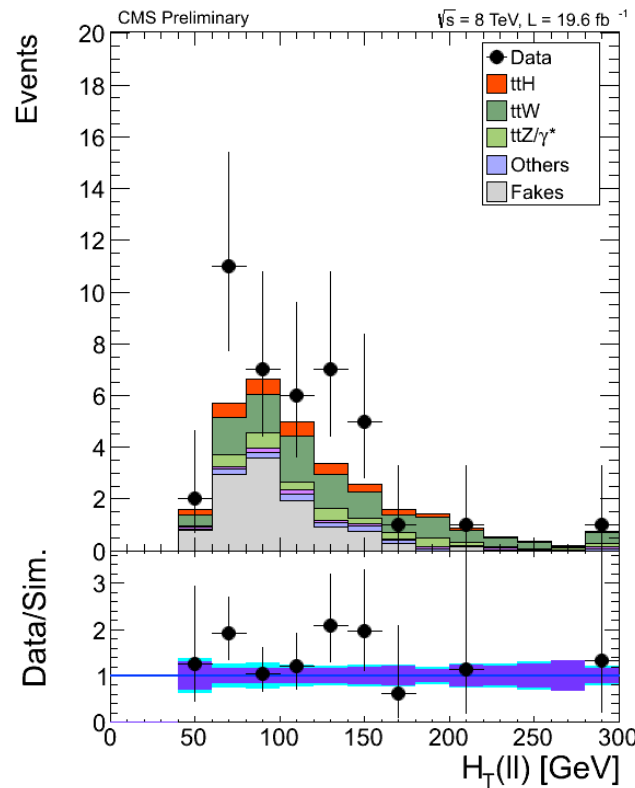
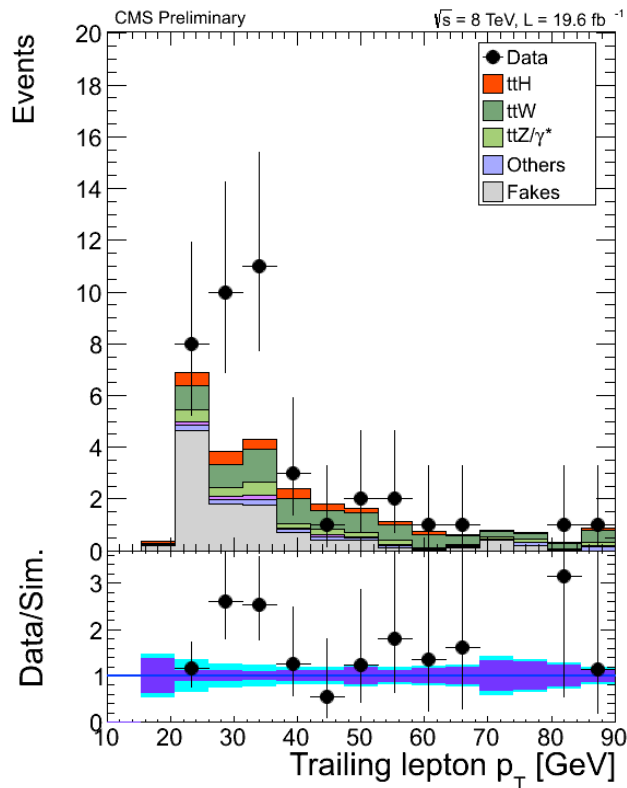
- An excess of events is observed, in the signal-like part of the BDT discriminator (trained to separate ttH from the reducible background on the basis of kinematic variables, not using lepton ID variables)

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



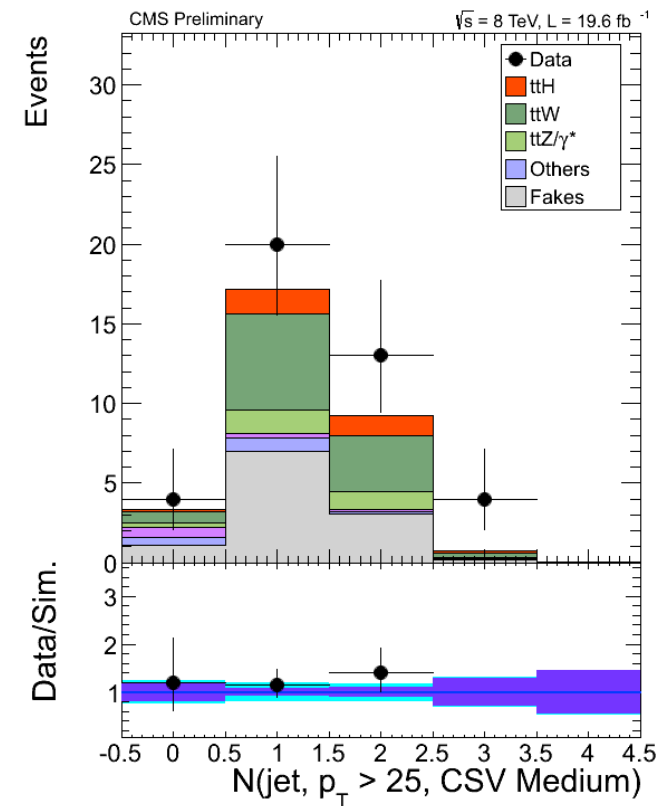
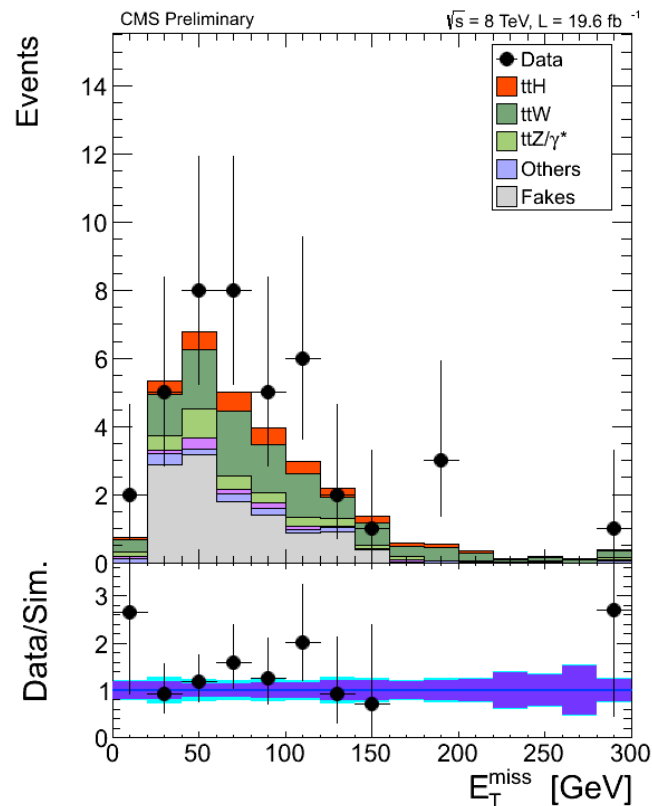
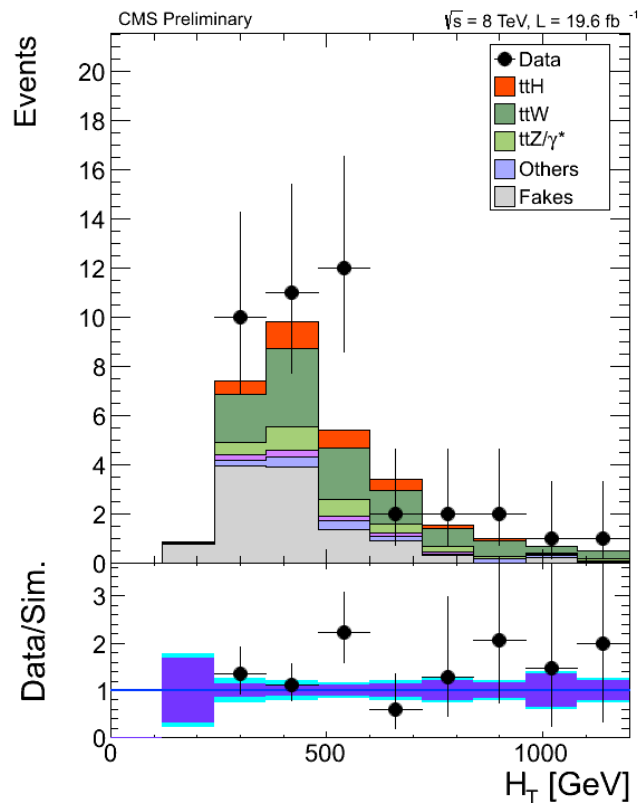
Event kinematic (leptons)

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



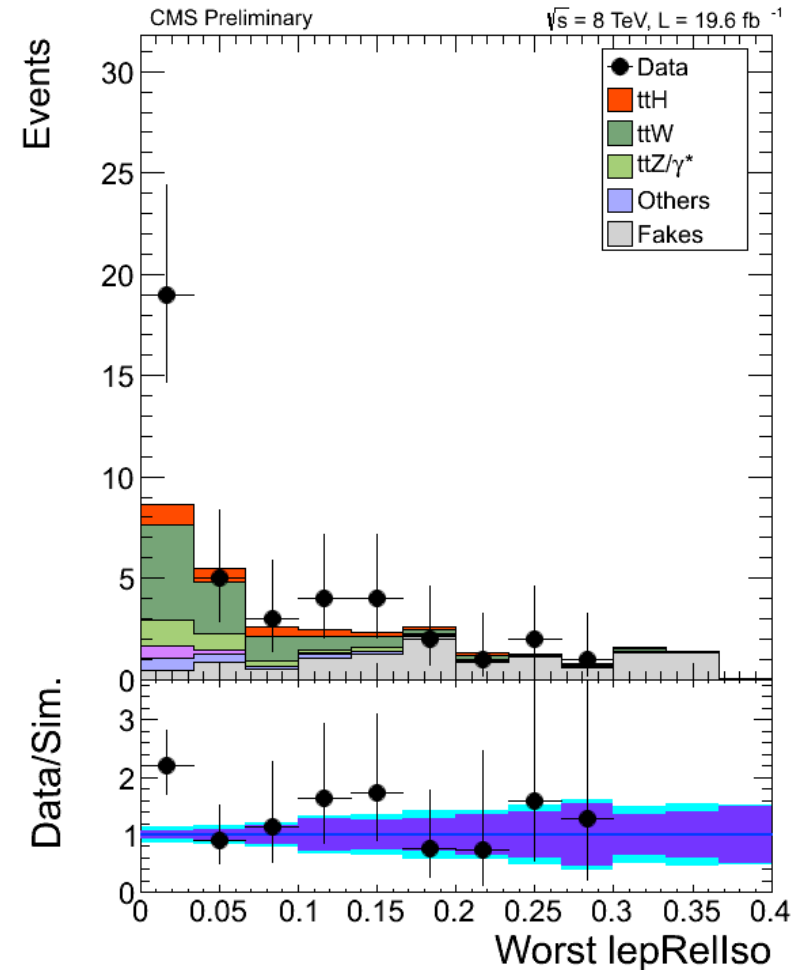
Event kinematic (Jets and E_T^{miss})

- 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 lepton



Leptons

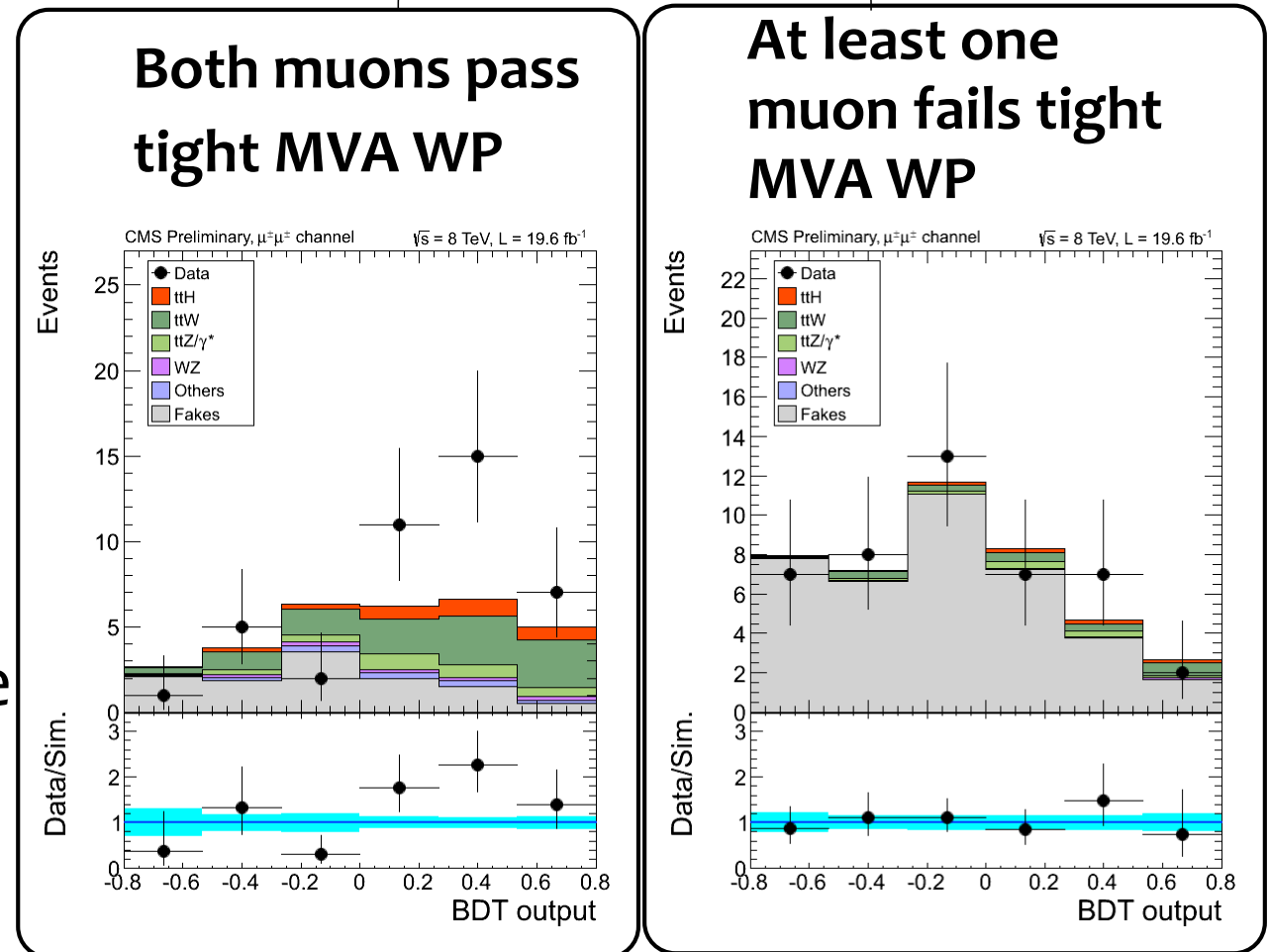
- The events in excess are characterized by having both leptons very well isolated
- Scrutiny of the events also confirms that both leptons are well reconstructed in the tracker and muon system, and that their charge is correctly assigned



Lepton ID checks: looser MVA

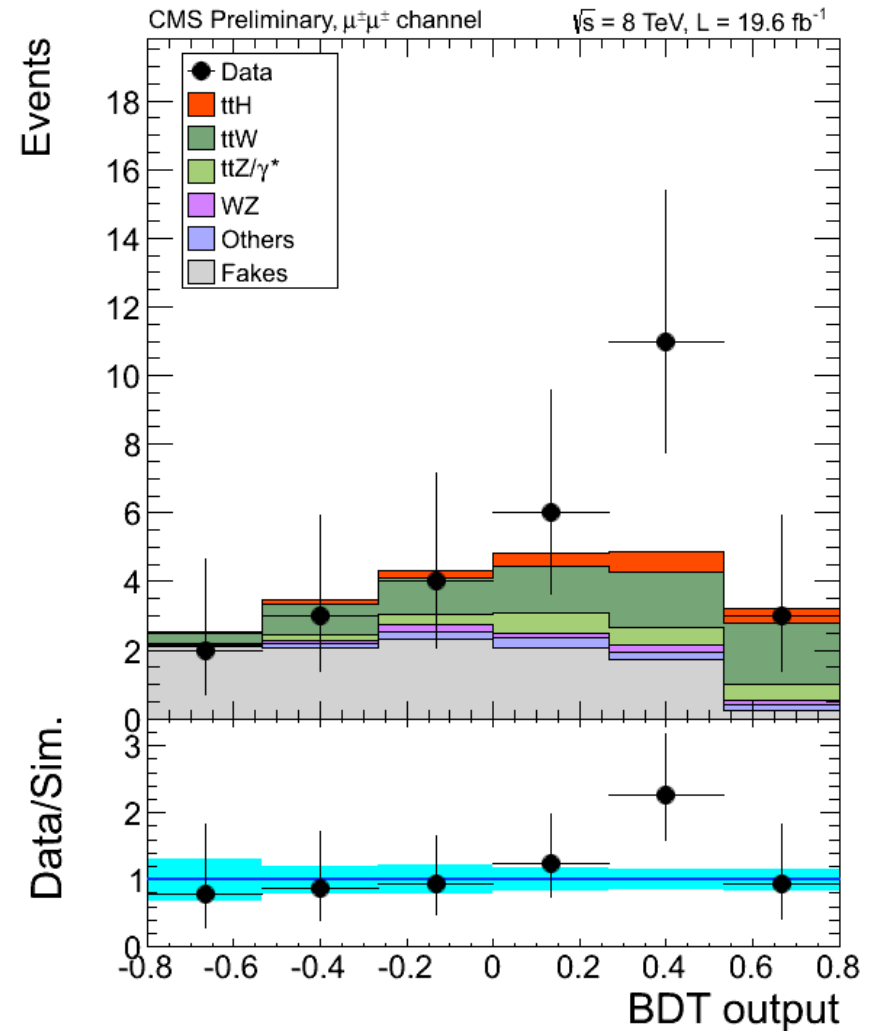
- The analysis was also repeated using a looser working point of the lepton MVA
 - the excess is visible only when both leptons pass the tight MVA WP.
 - the rest of the sample is well described by the background model

Both muons pass loose MVA WP



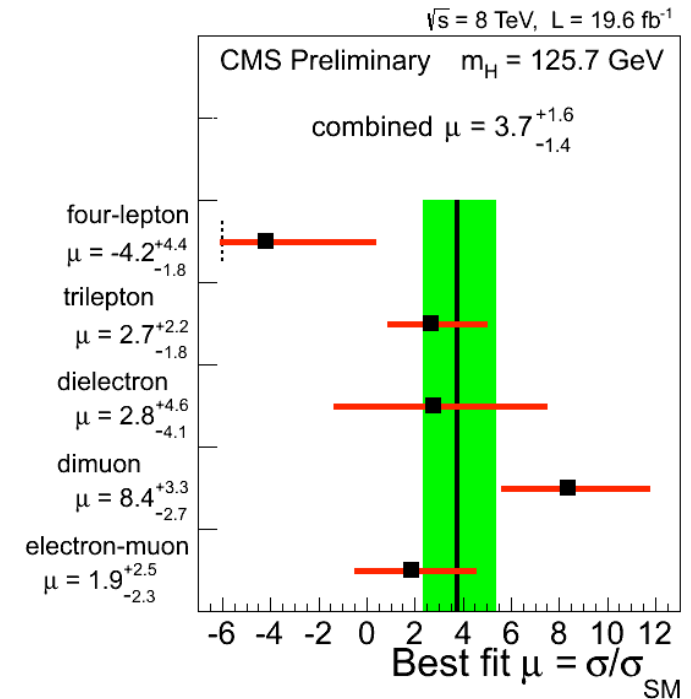
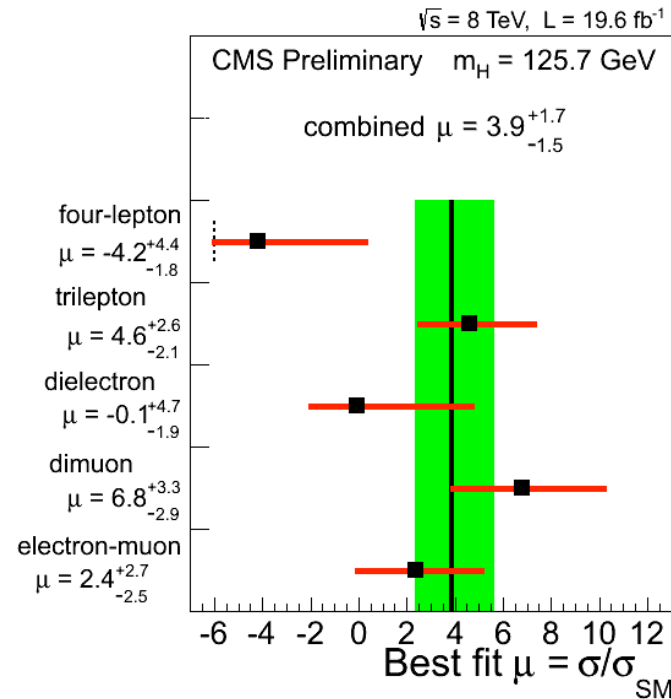
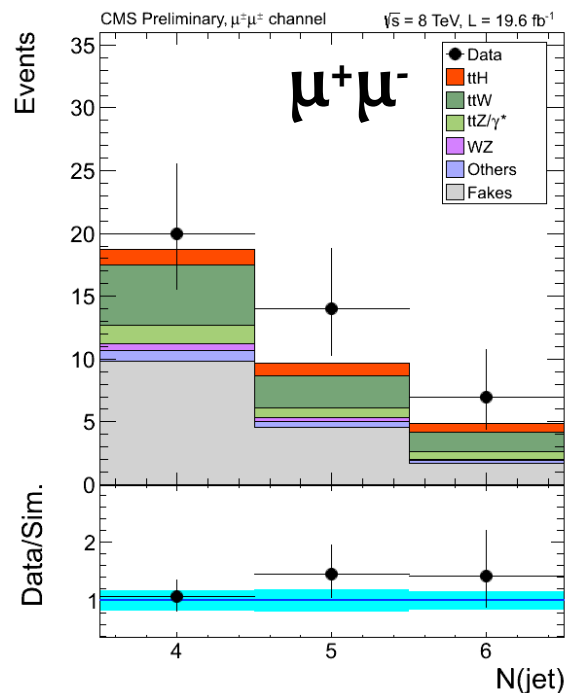
Lepton ID checks: cut based

- 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

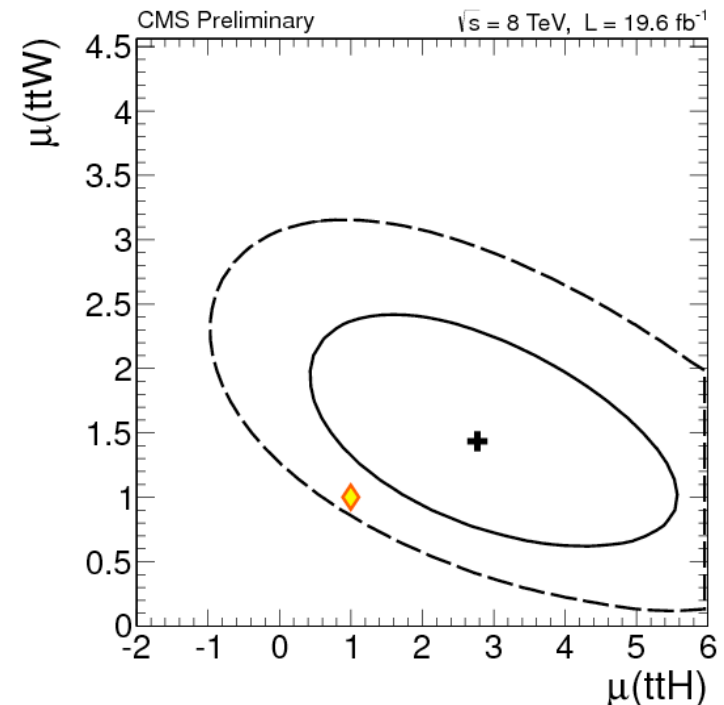
- A more general fit is performed:
 - leaving unconstrained the yields of ttW, ttZ, and reducible background (for fake e, μ separately)
 - including additional control regions in the fit: trilepton events with one Z candidate (mostly ttZ), and dilepton events with 3 jets (ttW & red. bkg.)
- Results compatible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

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

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

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

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



Charge Asymmetry

- Observed 21 m^+m^+ events and 20 m^-m^- 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 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

- $tt+bb$ (or $tt+cc$) with $b/c \rightarrow \mu$:
 - excess should be even more visible with the looser lepton MVA and it's not.
- $tt \rightarrow \mu$ +jets plus a muon from pile-up, or
- $tt \rightarrow \mu$ +jets plus a cosmic ray muon:
 - given the observed d_{xy} , d_z , distribution 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 $tt+X$, $X \rightarrow \mu$ should also contribute in the $3l$ final state)

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 are 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)