

Update on $t\bar{t}t\bar{t}$ Searches in Single Lepton/OS Dilepton Channel Using 2016 Data

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Current Status

- ▶ Aiming at re-preapproval, documentation -
- ▶ We have requested for the production of two new $t\bar{t}$ samples with 9M events each for the two channels(semi-lep and OS dilep), with dedicated cuts at generator level to increase MC stats by a factor of ~ 10 in high multiplicity/discriminant tails. Details on slide 20
- ▶ We are studying the effects of possible background from QCD multi jets with mis-identified leptons.

Data, MC and Objects

Data and MC

- ▶ Run2016 B-H, $35.9 pb^{-1}$
- ▶ Summer 16 MiniAOD MC for Morond 17
 - ▶ signal sample: $t\bar{t}t\bar{t}$ amc@NLO
 - ▶ background samples: $t\bar{t}$ (backup, mass, width), single $t(\bar{t})$, DY, W+jets, $t\bar{t} + Z/H/W/diboson$

Objects

Single Lepton

- ▶ μ : tight ID, $p_T > 26$ GeV,
 $|\eta| < 2.1$, $RelIso < 0.15$
- ▶ e : tight ID, $p_T > 35$ GeV,
 $|\eta| < 1.4442$ or $1.566 < |\eta| < 2.1$
- ▶ jet : loose ID, $p_T > 30$ GeV,
 $|\eta| < 2.1$, $\Delta R > 0.4$

OS Dilepton

- ▶ μ : loose ID, leading(subleading) lep
 $p_T > 25(20)$ GeV, $|\eta| < 2.4$,
 $RelIso < 0.15$
- ▶ e : loose ID, leading(subleading) lep
 $p_T > 25(20)$ GeV, $|\eta| < 1.4442$ or
 $1.566 < |\eta| < 2.4$
- ▶ jet : loose ID, $p_T > 30$ GeV(25
GeV if tagged as b), $|\eta| < 2.4$,
 $\Delta R > 0.4$

Event Selection and MC Re-weighting

Event selection

Single Lepton

- ▶ $N_l^{tight}=1$
- ▶ $N_\mu^{loose} = 0, N_e^{veto} = 0$
- ▶ $N_j \geq 8(7)$ in $e(\mu)$ channel of which $N_{tags}^M \geq 2$
- ▶ $\cancel{E}_T > 50$ GeV
- ▶ $HT \geq 500$ GeV

OS Dilepton

- ▶ Exactly 2 OS leptons
- ▶ $M_{ll} \geq 106$ GeV or $76 \leq M_{ll} \leq 20$ GeV
- ▶ $N_j \geq 4$ of which $N_{tags}^M \geq 2$
- ▶ $HT \geq 500$ GeV

MC Re-weighting

- | | | |
|-----------------|-------------------|----------------------|
| ▶ Trigger eff. | ▶ Pileup Reweight | ▶ b-tagging eff. |
| ▶ Lepton scales | ▶ JER/JEC | ▶ top p_T reweight |

$t\bar{t}t\bar{t}$ Search Method

Binned analysis fitting on event level BDT

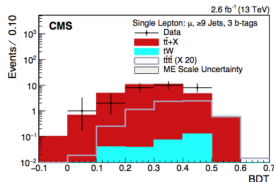


Figure: Single μ event level BDT in ≥ 9 jet 3 btag category

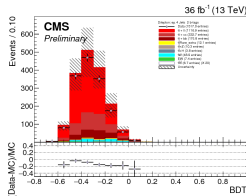


Figure: μe event level BDT in CR

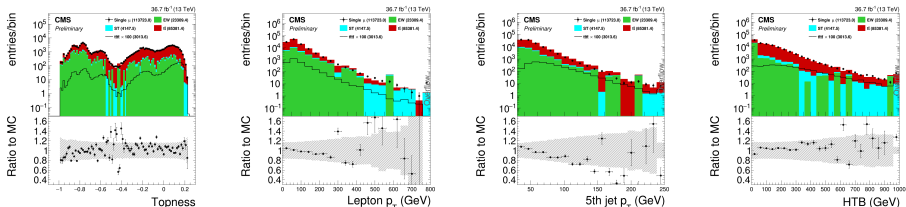
Event categorization in $N_j \otimes N_{tags}^M$ for limit fitting

- ▶ Single lepton channel
 - ▶ μ : N_j : 7, 8, 9, 10+; N_{tags}^M : 2, 3, 4+
 - ▶ e : N_j : 8, 9, 10+; N_{tags}^M : 2, 3, 4+
- ▶ OS Dilepton channel: N_j : 4-5, 6-7, 8+; N_{tags}^M : 2, 3+

Control Plots (BDT Input Variables)

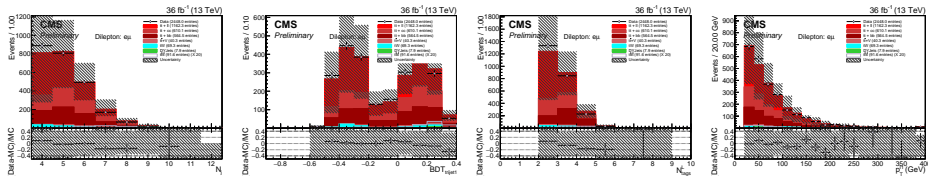
► Single lepton channel

$BDT_{trijet2}$, HTH , H_T^b , H_T^{Rat} , p_T^{5thjet} , p_T^{6thjet} , M_{RE}^H , HT_X , p_T^{lep} , CSV_3 , CSV_4 , CSV_{3rdjet} , CSV_{4thjet}



► OS Dilepton channel

N_j , $BDT_{trijet1}$, H_T^b , H_T^{2M} , HTH , S , H_T^{Rat} , p_T^{I1} , η^{I1} , ΔR_{ll} , ΔR_{bb} , $N_{L_{tags}}$, N_{tags}^M , p_T^{3rdjet} , p_T^{4thjet}



► Overall reasonable distributions agreement within uncertainties.

Sources of Systematic Uncertainties

Experimental Uncertainties

- ▶ Luminosity uncertainty
- ▶ Pileup $\pm 1\sigma$
- ▶ Lepton SFs uncertainty
- ▶ JER $\pm 1\sigma$
- ▶ JES(split)
 - ▶ SubTotalPileUp
 - ▶ SubTotalRelative
 - ▶ SubTotalPt
 - ▶ SubTotalScale
 - ▶ Jet flavor
- ▶ b-tag CSV $\pm 1\sigma$
- ▶ Heavy flavor fraction
- ▶ Top p_T reweight
- ▶ Jet normalization

Theoretical Uncertainties

- ▶ ME scale
- ▶ MC cross sections
- ▶ UE tune
- ▶ PS scale
- ▶ ME-PS matching
- ▶ PDF

Fit Strategy

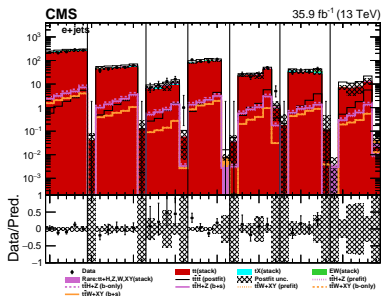
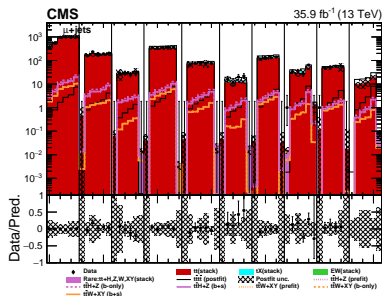
- ▶ Likelihood fit using Combine Tool
- ▶ Event level BDT output discriminator distributions for fit is performed simultaneously in different $N_j \otimes N_{tags}^M$ categories.
- ▶ Blind highest jet/tag multiplicity categories.
 - ▶ single lepton: blind 10+ jets & 3+ tags category
 - ▶ OS dilepton: blind 8+ jets & 3+ tags category
- ▶ Combine results from single lepton channel and OS dilepton channel.

Template Fit in Single Lepton Channel

Table: Single lepton blinded fitting results

Channel	Expected limit $\times \sigma_{t\bar{t}t\bar{t}}$ SM	Expected xsec <i>fb</i>	Expected significance
<i>e</i>	$23.5^{+7.0}_{-6.5}$	216.2^{+64}_{-60}	0.09
μ	$16.0^{+7.0}_{-4.7}$	147.2^{+64}_{-43}	0.12
combined	$9.4^{+4.0}_{-2.7}$	86.5^{+37}_{-25}	0.25

Postfit BDT distributions



- Equiprobable binning scheme
- Blind signal rich $10+/3+$ category
- Reasonable description of the data in CRs

Fit Diagnostic in Single Lepton Channel

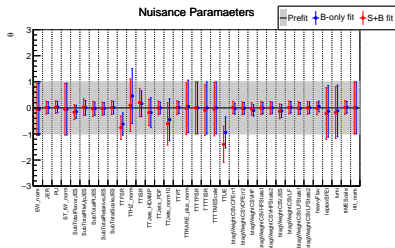


Figure: μ +jets channel

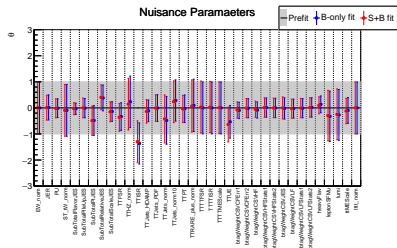
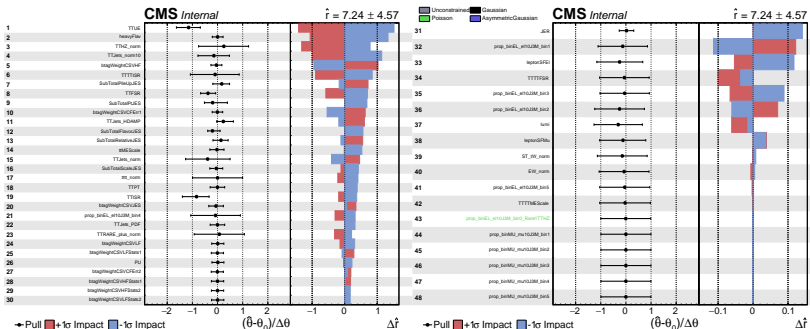


Figure: $e^+ \text{jets}$ channel

- ▶ Post-fit uncertainty reduction is under investigation

Impact of Nuisance Parameters



- Dominant sources of systematic uncertainty:
 - UE variation. Affects jet multiplicity spectrum (Sample has low statistics)
 - $t\bar{t}b\bar{b}$ normalization
 - Normalization of $t\bar{t}Z, H \rightarrow b\bar{b}$
 - Reweighting of HF component in CSV discriminant

Postfit BDT distributions

- ▶ high BDT region in signal sensitive regions is blinded
- ▶ Obvious excess in the distribution tails within all three channels, partially due to lack of MC stats

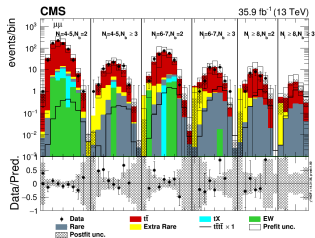


Figure: $\mu\mu$ channel

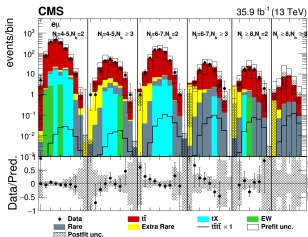


Figure: $e\mu$ channel

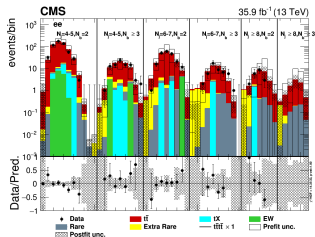


Figure: ee channel

Template Fit in OS Dilepton Channel

Table: OS dilepton blinded fitting results

Channel	Expected limit $\times \sigma_{t\bar{t}t\bar{t}}^{SM}$	Expected xsec $\times fb$	Expected significance
$\mu\mu$	$14.56^{+9.64}_{-5.24}$	134^{+89}_{-48}	0.19
$e\mu$	$9.88^{+6.53}_{-3.53}$	91^{+60}_{-32}	0.37
ee	$17.56^{+11.34}_{-6.19}$	162^{+104}_{-57}	0.29
combined	$6.88^{+4.44}_{-2.42}$	63^{+41}_{-22}	0.52

Fit Diagnostic in OS Dilepton Channel

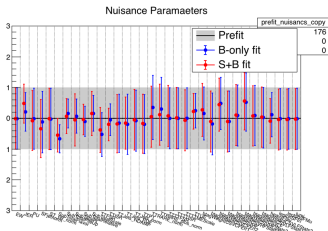


Figure: nuisance pulls in $\mu\mu$

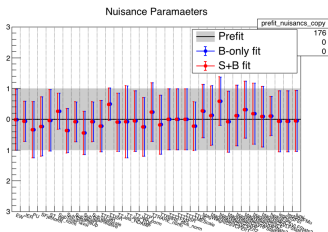


Figure: nuisance pulls in $e\mu$

- ▶ Most signal sensitive region is blinded
- ▶ No extreme pulls or constraints.
- ▶ Reasonable behavior for all the NPs
- ▶ Results are consistent between three sub-channels

Fit Diagnostic in OS Dilepton Channel

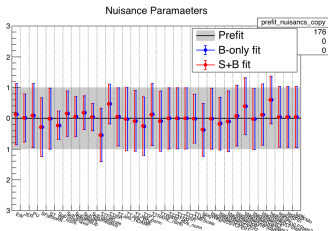


Figure: nuisance pulls in ee

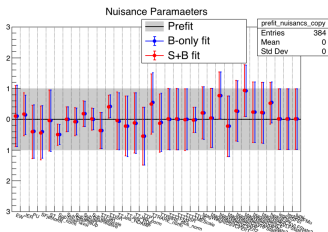


Figure: nuisance pulls in OS dilep

- ▶ Mainly the sub-components of JES are constrained
 - ▶ Statistic fluctuation
 - ▶ Correlated with other NPs

Nuisance Parameters with highest impact in OS dilep combined fit

- ▶ Signal systematics and TTRare have the largest impacts, as we are very close to the expected signal strength.
- ▶ Jet energy scale uncertainties and MC stats in signal enriched bins dominate.
- ▶ All nuisance parameters behave reasonably.
- ▶ Full list of nuisance impacts are on backup slides 22 to 23

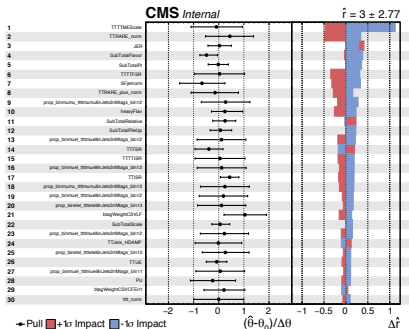


Figure: Impact of nuisance parameters on the parameter of interest

Combined Results

Table: Single lepton + OS dilepton blinded combined results

Channel	Expected limit $\times \sigma_{t\bar{t}t\bar{t}}^{SM}$	Expected limit $\times fb$	Expected significance
l+jets	$9.4^{+4.0}_{-2.7}$	86.5^{+37}_{-25}	0.25
OS ll+jets	$6.9^{+4.4}_{-2.4}$	63^{+41}_{-22}	0.52
combined	$5.2^{+2.6}_{-1.7}$	48^{+24}_{-16}	0.58

- Signal sensitivity is driven by the OS ll+jets channel

Conclusion

Current status:

- ▶ Analysis blinded in order to optimize search regions/binning taking into account limited MC statistics
- ▶ Expecting $\times 10$ more $t\bar{t}$ background MC with dedicated filters in signal rich search regions that have large statistical uncertainty
 - ▶ New high jet multiplicity, high- H_T filter was optimized for the analysis
 - ▶ MC requests are added to the system

Plans for coming weeks:

- ▶ Finalize QCD background estimation
- ▶ Include new MC samples when they are ready
- ▶ Update ANs and paper draft

Backups

Filter optimized for l+jets channel

- Preferred configuration: $HT > 500$, $n\text{Jets} + n\text{Lep} \geq 9$, $n\text{Lep} = 1$ (9M)

Filter cuts	Filter eff.	Acceptance loss in different jet multiplicity regions ¹		
		SL ($N_{f^{\text{ec}}} = 9$)	SL ($N_{f^{\text{ec}}} > 9$)	Ext ($\times 10$)
$HT > 500$ $n\text{Jets} + n\text{Lep} \geq 8$ 1 lepton	0.005 ± 0.0002	0.11	0.08	21.8 M
$HT > 500$ $n\text{Jets} + n\text{Lep} \geq 9$ 1 lepton	0.002 ± 0.0001	0.19	0.10	8.7M
$HT > 500$ $n\text{Jets} + n\text{Lep} \geq 10$ 1 lepton	$0.0007 \pm 6.5 \times 10^{-5}$	—	0.19	3M

¹Fraction of events passing offline cuts but rejected by gen filter

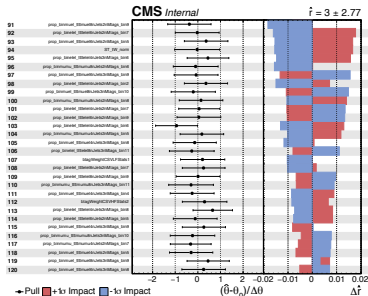
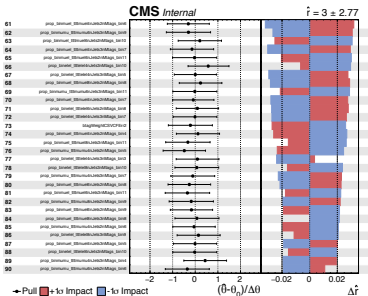
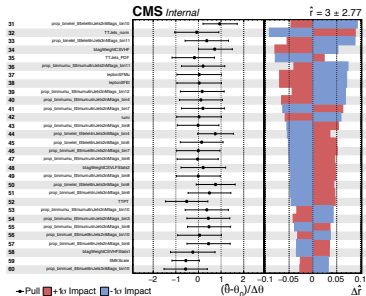
Filter optimized for OS dilepton channel

- Preferred configuration: $HT > 500$, $n\text{Jets} + n\text{Lep} \geq 7$, $n\text{Lep} = 2$ (9M)

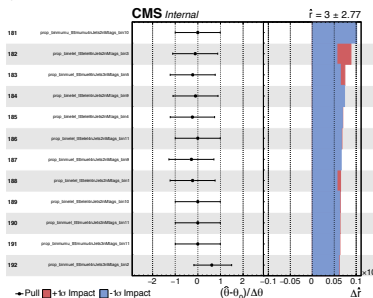
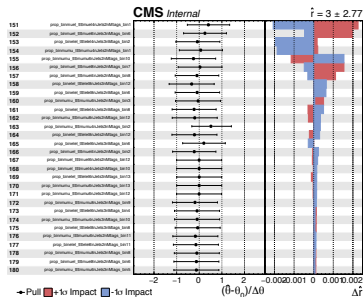
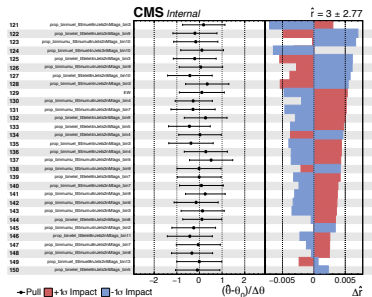
Filter cuts	Filter eff.	Acceptance loss in different jet multiplicity regions ²		
		OS ($N_J^{\text{rec}} = 7$)	OS ($N_J^{\text{rec}} \geq 8$)	Ext ($\times 10$)
$HT > 500$ $n\text{Jets} + n\text{Lep} \geq 5$ 2 lepton	$0.0046 \pm 5.5e - 05$	0.21	0.23	20 M
$HT > 500$ $n\text{Jets} + n\text{Lep} \geq 6$ 2 lepton	$0.0033 \pm 4.7e - 05$	0.21	0.23	14.4 M
$HT > 500$ $n\text{Jets} + n\text{Lep} \geq 7$ 2 lepton	$0.0020 \pm 3.6e - 05$	0.23	0.24	8.7 M
$HT > 500$ $n\text{Jets} + n\text{Lep} \geq 8$ 2 lepton	$0.0009 \pm 2.4e - 05$	0.31	0.25	3.9 M

²Fraction of events passing offline cuts but rejected by gen filter

impacts of nuisance parameters



impacts of nuisance parameters



Maybe some more control plots?