# 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 channel(semi-lep and OS dilep), with dedicated cuts at generator level to increase MC stats by a factor of $\backsim 10$ in high multiplicity/discriminant tails. Details on slide 18
- We are studying the effects of possible background from QCD multi jets with mis-identified leptons.

# Data, MC and Objects

<u>Data and MC</u>

- ▶ 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, $t\bar{t} + Z/H/W/diboson$

<u>Objects</u>

*Single Lepton*

- ▶ $\mu$ : 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*

- ▶ $\mu$ : 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

<u>Event selection</u>

### 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 $N_{tags}^M \geq 2$
- $\not{E}_T > 50$ GeV
- $HT \geq 500$ GeV

### OS Dilepton

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

<u>MC Re-weighting</u>

- Trigger eff.
- Lepton scales

- Pileup Reweight
- JER/JEC

- b-tagging eff.
- top $p_T$ reweight

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

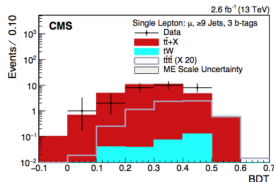**Binned analysis fitting on event level BDT**



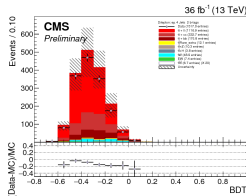Figure: Single $\mu$ event level BDT in $\geq$9 jet 3 btag category



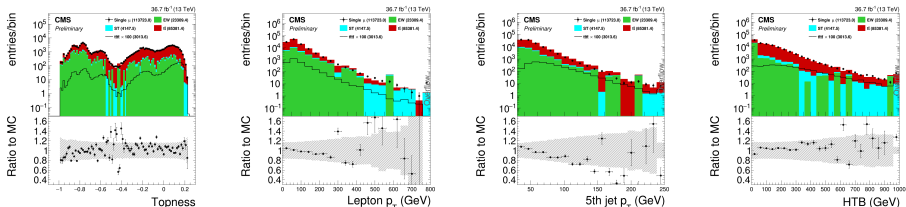Figure: $\mu e$ event level BDT in CR

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

- ▶ Single lepton channel
    - ▶ $\mu$: $N_j$: 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+
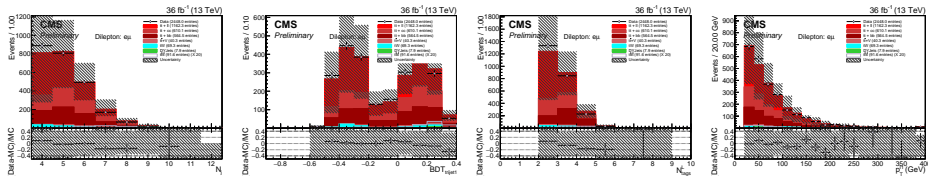
# Control Plots (BDT Input Variables)

▶ 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

$N_j, BDT_{trijet1}, H_T^b, H_T^{2M}, HTH, S, H_T^{Rat}, p_T^{l1}, \eta^{l1}, \Delta R_{ll}, \Delta R_{bb}, N_{tags}^L, N_{tags}^M, p_T^{3rdjet}, p_T^{4thjet}$



▶ 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 & 4+ 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

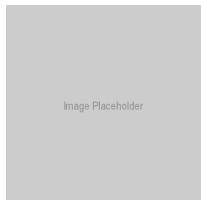| Channel | Expected limit $\times\sigma_{t\bar{t}t\bar{t}}^{SM}$ | Expected xsec $\times fb$ | Expected significance |
|---|---|---|---|
| $e$ | | | |
| $\mu$ | | | |
| combined | | | |

## Postfit BDT distributions
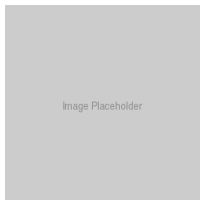


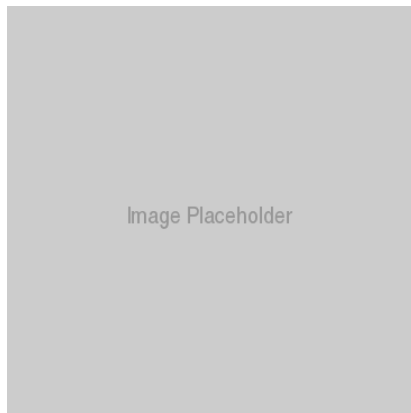Figure: $\mu$ channel



Figure: $e$ channel

► some comments

►

# Fit Diagnostic in Single Lepton Channel

Image Placeholder

- some comments
-

# Impact of Nuisance Parameters

Image Placeholder

- some comments
-

# Template Fit in OS Dilepton Channel

Table: OS dilepton blinded fitting results

| Channel | Expected limit $\times \sigma^{SM}_{t\bar{t}t\bar{t}}$ | 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 |

Highest region blinded postfit BDT distributions



Figure: $\mu\mu$ channel

Figure: $e\mu$ channel

Figure: $ee$ channel

# Fit Diagnostic in OS Dilepton Channel
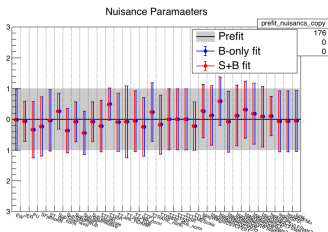


Figure: nuisance pulls in $\mu\mu$



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
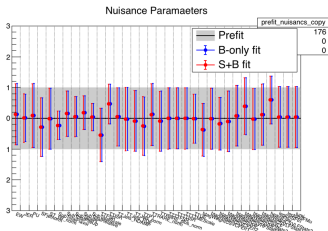
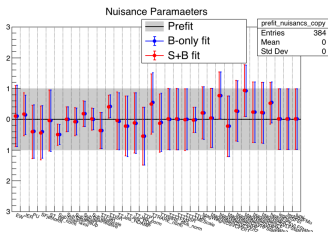# Fit Diagnostic in OS Dilepton Channel



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.
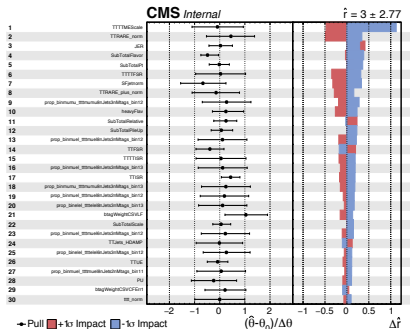- ▶ Full list of nuisance impacts are on backup slides 20 to 21



Figure: Impact of nuisance parameters on the parameter of interest

# Combined Results

Table: Single lepton + OS dilepton blinded combined results

| Channel | Expected limit $\times \sigma^{SM}_{t\bar{t}t\bar{t}}$ | Expected xsec $\times fb$ | Expected significance |
|---|---|---|---|
| l+jets | | | |
| OS ll+jets | | | |
| combined | | | |

# Conslusion

# Backups

# Filter optimized for l+jets channel

▶ Preferred configuration: $HT > 500$, $\mathrm{nJets} + \mathrm{nLep} \geq 9$, $\mathrm{nLep} = 1$ (9M)

| | | Acceptance loss in different jet multiplicity regions[1] | | |
| --- | --- | --- | --- | --- |
| Filter cuts | Filter eff. | SL ($N_j^{rec} = 9$) | SL ($N_j^{rec} > 9$) | Ext ($\times 10$) |
| HT>500 nJets+nLep $\geq$8 1 lepton | $0.005 \pm 0.0002$ | 0.11 | 0.08 | 21.8 M |
| HT $> 500$ nJets+nLep $\geq$ 9 1 lepton | $0.002 \pm 0.0001$ | 0.19 | 0.10 | 8.7M |
| HT>500 nJets+nLep>=10 1 lepton | $0.0007 \pm 6.5 \times 10^{-5}$ | — | 0.19 | 3M |

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

# Filter optimized for OS dilpeton channel

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

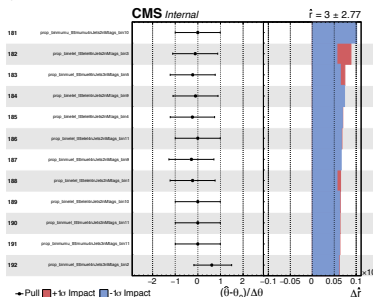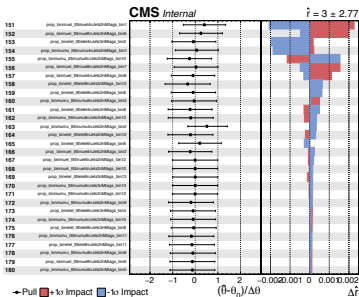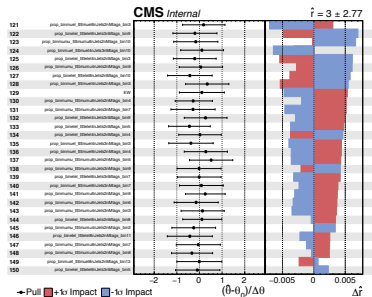| Filter cuts | Filter eff. | Acceptance loss in different jet multiplicity regions[2] | | |
| :---: | :---: | :---: | :---: | :---: |
| | | OS ($N_J^{rec} = 7$) | OS ($N_J^{rec} \geq 8$) | Ext ($\times 10$) |
| HT>500 nJets+nLep>=5 2 lepton | $0.0046 \pm 5.5e - 05$ | 0.21 | 0.23 | 20 M |
| HT>500 nJets+nLep>=6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

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

# impacts of nuisance parameters
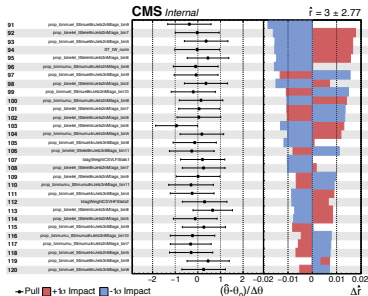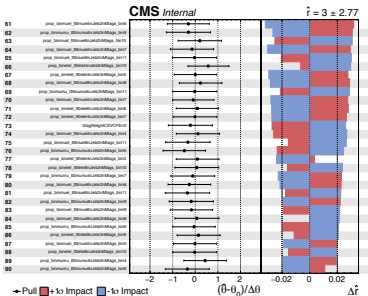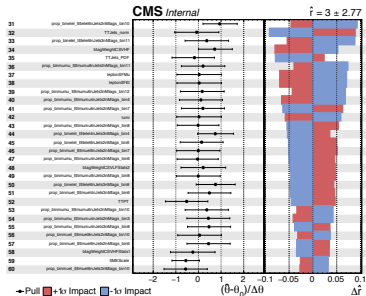
# impacts of nuisance parameters

# Maybe some more control plots?