Measurement of the Cross Section ratio ttbb/ttjj in pp collisions at 13TeV with the CMS detector

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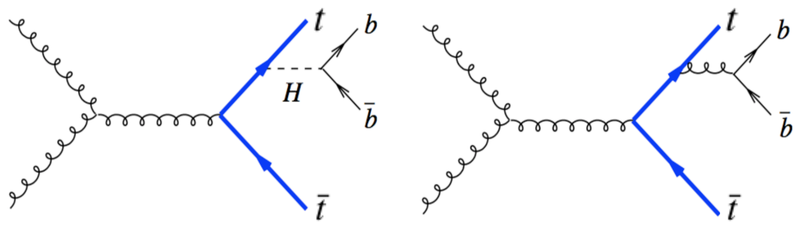
1.Introduction

- $t\bar{t}b\bar{b}$ process is the main irreducible background for $t\bar{t}H(b\bar{b})$.
- Cross section measurement of $t\bar{t}b\bar{b}$ is important in validation of NLO QCD calculation.
- Measured the cross section ratio of $t\bar{t}b\bar{b}/t\bar{t}jj$ using data sample corresponding to an integrated luminosity of 2.3 fb^{-1} collected at $\sqrt{s}$ = 13 TeV in dilepton channel with the CMS detector at the LHC.



Feynman diagrams of ttbb processes

2.Phase space and signal definition

- Object definition
  - Leptons (μ,e) : p_T > 20 GeV, $|\eta|$ < 2.4
  - Gen-jet :
    - Anti-kt algorithm with r=0.4
    - p_T > 20 GeV, $|\eta|$ < 2.5
    - Jet cleaning with leptons with r=0.5
- Full phase space
  - $t\bar{t}jj$: at least 2 additional jets not from top decay
  - $t\bar{t}b\bar{b}$: at least 2 additional b-jets not from top decay
- Visible phase space
  - $t\bar{t}jj$: two leptons and at least 2 b-jets and 4 jets
  - $t\bar{t}b\bar{b}$: $t\bar{t}jj$ + at least 4 b-jets
  - $t\bar{t}bj$: $t\bar{t}jj$ + exactly 3 b-jets
  - $t\bar{t}c\bar{c}$: $t\bar{t}jj$ + at least 2 c-jets
  - $t\bar{t}LF$: $t\bar{t}jj$ - $t\bar{t}b\bar{b}$ - $t\bar{t}bj$ - $t\bar{t}c\bar{c}$

3.Event selection

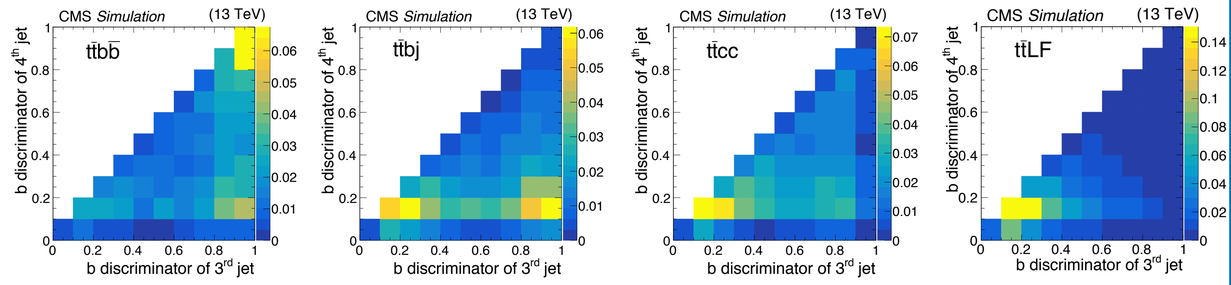
- Object selection
  - Muons : p_T > 30 GeV, $|\eta|$ > 2.1, tight ID, relative PF isolation (r = 0.4) with $\Delta\beta$ < 0.15
  - Electrons : p_T > 30 GeV, $|\eta|$ < 2.1, medium cut-based ID
  - MET : PFMET with type 1 correction
  - Jets : PFJets, Anti-kt with r=0.4, p_T > 30 GeV, $|\eta|$ < 2.4, loose ID, jet cleaning with isolated leptons
  - b-tagged Jets : CSVv2 with medium working point.
- Event selection
  - S1 : a pair of opposite sign isolated leptons
  - S2 : $|M_{ll} - M_Z|$ > 15 GeV (ee, $\mu\mu$ only)
  - S3 : MET > 40 GeV (ee, $\mu\mu$ only)
  - S4 : at least 4 jets
  - S5 : at least 2 b-tagged jets

Process	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$	All
$t\bar{t}b\bar{b}$	6.3 ± 0.4	8.6 ± 0.4	24 ± 1	39 ± 1
$t\bar{t}bj$	16 ± 1	21 ± 1	57 ± 2	95 ± 2
$t\bar{t}c\bar{c}$	7.7 ± 0.4	11 ± 1	27 ± 1	46 ± 1
$t\bar{t}LF$	157 ± 2	220 ± 2	596 ± 3	972 ± 4
$t\bar{t}$ others	18 ± 1	19 ± 1	61 ± 1	99 ± 1
$t\bar{t}$ V	2.5 ± 0.1	3.2 ± 0.2	7.3 ± 0.2	14 ± 1
Single t	6.6 ± 0.8	8.4 ± 0.8	23 ± 2	39 ± 2
Z+jets	$0.8^{+1.0}_{-0.8}$	5.4 ± 1.5	0.6 ± 0.5	6.8 ± 1.9
Total	215 ± 2	297 ± 3	796 ± 4	1311 ± 6
Data	186	288	682	1156

Number of events for each process and for each channel after final selection.

4.Strategy and measurement

- Rearrangement of jets in a decreasing CSVv2 discriminant order.
- Likelihood fit using CSVv2 shapes of 3rd and 4th jets as the additional 2 jets on data.
- Good fit performance using distinctive shape of $t\bar{t}b\bar{b}$ from other processes.

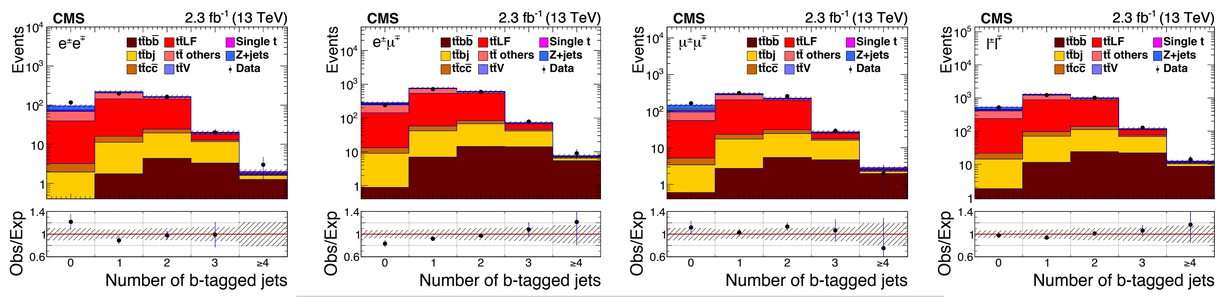


2D templates of b discriminator of 3rd, 4th jets for each process

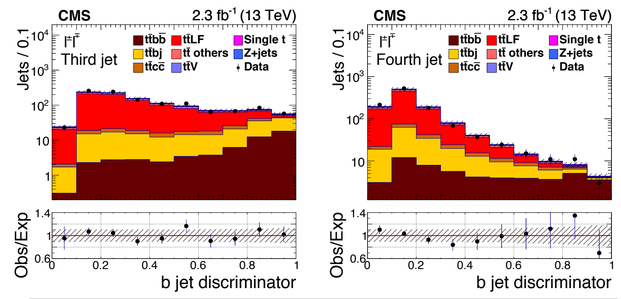
- Fit formula with 2 free parameters R and N_{ttjj} :

$$M(N_{ttjj}, R) = N_{ttjj}[R \cdot F^{norm}_{ttbb} + R' \cdot F^{norm}_{ttbj} + (1 - R - R') \cdot F^{norm}_{ttcc+ttLF}] + \frac{N_{ttjj}}{N^{MC}_{ttothers}} \cdot F_{ttothers} + F_{bkg}$$

- N_{ttjj} = 950 ± 30, R = 0.056 ± 0.008 from the fit.
- Results in visible and full phase spaces using efficiency(ϵ) and acceptance(A) from MC.
  - $\sigma_{vis} = N/(\epsilon L)$
  - $\sigma_{full} = \sigma_{vis}/A$



Distributions of number of b-tagged jets for each channel after fit



Distributions of b jet discriminator of 3rd and 4th jets after fit

5.Systematic uncertainty

Source	$\sigma_{t\bar{t}b\bar{b}}$	$\sigma_{t\bar{t}jj}$	$\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$
b tag (b quark flavour)	19	4.7	19
b tag (c quark flavour)	14	1.3	14
b tag (light flavour)	14	9.8	9.7
JES & JER	7.8	7.4	2.6
Ratio of $t\bar{t}b\bar{b}$ and $t\bar{t}bj$	2.6	0.5	2.6
Background modelling	3.8	3.5	1.6
$t\bar{t}c\bar{c}$ fraction in the fit	5.2	1.9	4.8
Lepton trigger/identification	3.0	3.0	0
Pileup	0.4	<0.1	0.4
MC generator	9.4	6.2	3.0
μ_F and μ_R scale	2.0	2.0	1.0
scale in PS	13	9.9	10
PDFs	0.5	0.5	<0.1
Efficiency ($t\bar{t}c\bar{c}$ fraction)	0	1.3	1.3
Jet multiplicity modelling	5.0	5.0	5.0
Simulation (statistical)	1.5	1.5	1.5
Top quark p_T modelling	0.8	0.3	0.5
Integrated Luminosity	2.3	2.3	0
Total uncertainty	34	19	28

Table of systematic uncertainties

- Uncertainties from b-tagging are dominant.
- Uncertainties from MC predictions can be reduced with more statistics.
- Total uncertainty of cross section ratio of $t\bar{t}b\bar{b}/t\bar{t}jj$ in visible phase space : 28%.

6.Summary

- Measured cross section of $t\bar{t}b\bar{b}$ and also its ratio to $t\bar{t}jj$ in visible and full phase spaces at 13 TeV at CMS.
- $t\bar{t}b\bar{b}$ is one of the main background for many new physics searches and this measurement can give important information for the future discovery.

Phase space		$\sigma_{t\bar{t}b\bar{b}}$ [pb]	$\sigma_{t\bar{t}jj}$ [pb]	$\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$
Visible	Measurement	$0.088 \pm 0.012 \pm 0.029$	$3.7 \pm 0.1 \pm 0.7$	$0.024 \pm 0.003 \pm 0.007$
	SM (POWHEG)	0.070 ± 0.009	5.1 ± 0.5	0.014 ± 0.001
Full	Measurement	$4.0 \pm 0.6 \pm 1.3$	$184 \pm 6 \pm 33$	$0.022 \pm 0.003 \pm 0.006$
	SM (POWHEG)	3.2 ± 0.4	257 ± 26	0.012 ± 0.001

Table of results