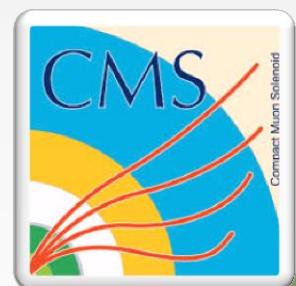
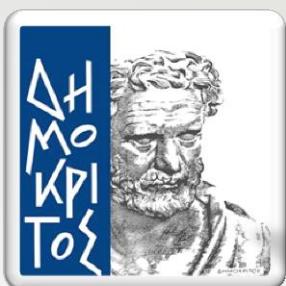


Production cross section measurement of the $t\bar{t} + jj$ channel in the lepton+jets final state

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Motivations & Goals



- The process $pp \rightarrow t\bar{t} + jj$ is an important SM process for testing QCD.
 - At the same time it might be a background for New Physics Searches.
 - Our target is to measure its cross section and compare the measurement with theoretical predictions.
- The absolute cross section and corresponding theoretical errors at one loop order and at 8 TeV is (**G. Bevilacqua et al. hep/ph. 1108.2851 1403.2046**):

$$\sigma_{t\bar{t}jj}^{NLO} = (LHC_{8TeV}, M_t = 173.5 GeV, CT10) = 20.97_{-2.79}^{+3.25} [pb]$$

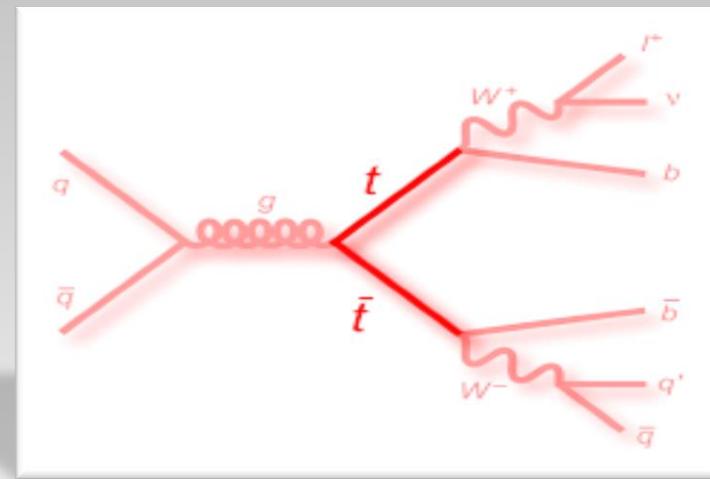


Semi-Leptonic Top Pair Decay



Signature

- At least six jets
- At least two of them b-tagged
- One charged lepton μ/e
- MET



Representative sets of Feynman diagrams for tree and one loop level for the case of $pp \rightarrow t\bar{t} + jj$ (*G. Bevilacqua et al. hep-ph. 1108.2851 1403.2046*)

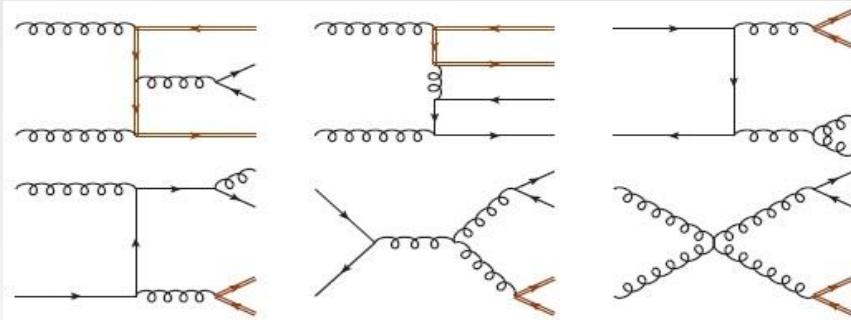


FIG. 1. A representative set of Feynman diagrams contributing to the LO hadronic $t\bar{t}jj$ production at $\mathcal{O}(\alpha_s^4)$. Double brown lines correspond to top quarks, single lines to light quarks and wiggly ones to gluons.

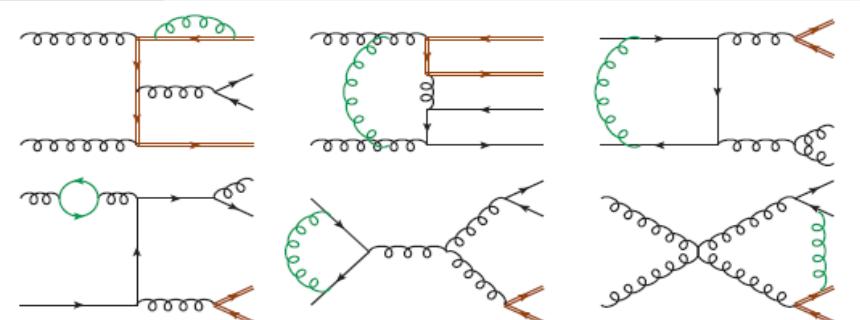


FIG. 2. A representative set of Feynman diagrams contributing to the virtual corrections to hadronic $t\bar{t}jj$ production at $\mathcal{O}(\alpha_s^5)$. Double brown lines correspond to top quarks, single lines to light quarks and wiggly ones to gluons.



Data & Simulated Samples



- All data used for the analysis were collected with single lepton unprescaled triggers in 2012 by the CMS detector @8TeV with the integrated luminosity 19.6 fb^{-1} .
- For our signal we used different top pair monte carlo samples such as madgraph, powheg and mc@nlo each one with pythia for hadronization.
- Special studies for systematics such as normalization & hadronization scale, matrix element & parton shower matching were produced using dedicated mc samples .
- Simulation samples were also used in order to estimate background processes.
 - Single Top
 - Diboson (WW, WZ, ZZ)
 - Drell – Yan
 - W+Jets
 - QCD (multijet)
 - tH, ttW, ttZ



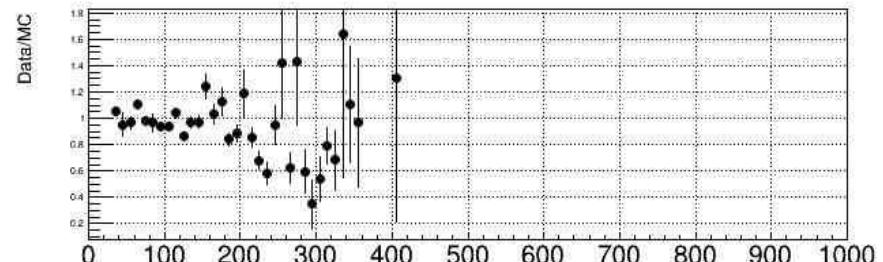
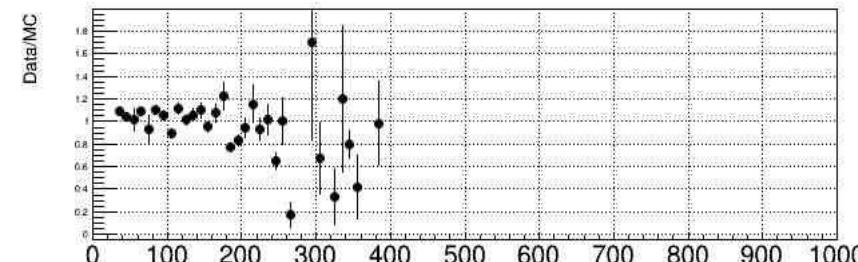
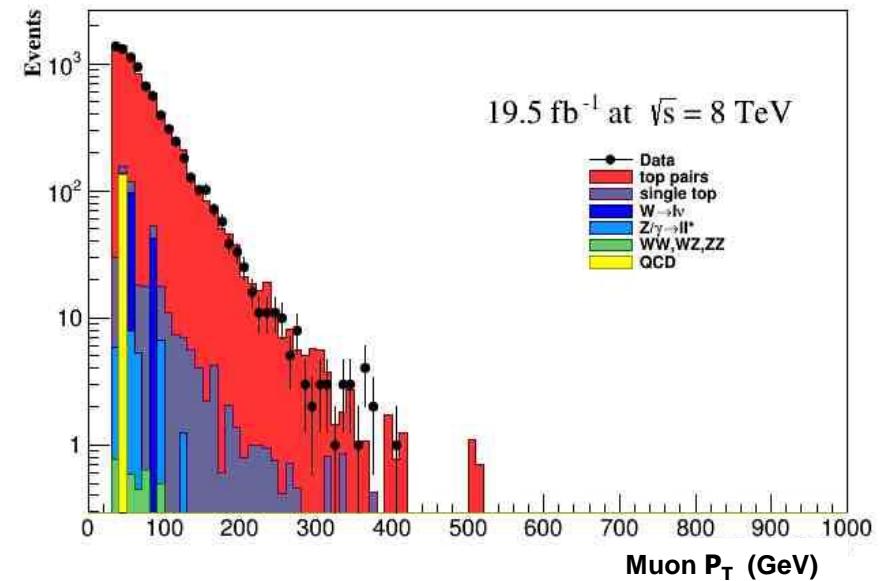
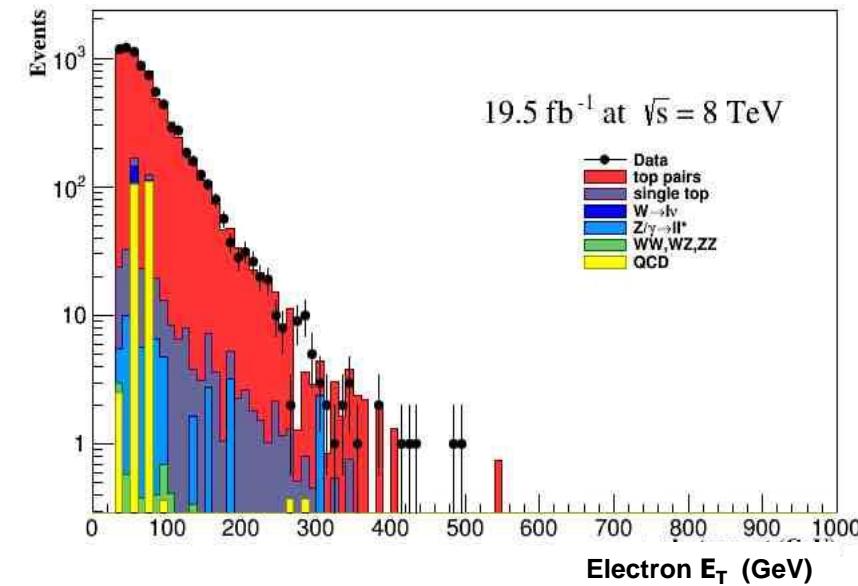
Basic Selection



- **Un-prescaled single lepton Triggers**
 - Single electron with $E_T > 27 \text{ GeV}$
 - Single muon with $P_T > 24 \text{ GeV}$
- **1 electron** with $E_T > 30.0 \text{ GeV}$, isolated, $|\eta| < 2.5$ excluding $1.44 < |\eta| < 1.56$, electron ID based on MultiVariate Analysis
 - OR**
 - 1 muon** with $P_T > 30.0 \text{ GeV}$, isolated, $|\eta| < 2.1$, muon ID tight
- Veto second lepton
- **At least 6 PF-jets** ($\text{anti-}K_T$ $\Delta R = 0.5$)
 - AND**
 - At least 2 of them tagged as b-jets**
with $P_T > 30.0 \text{ GeV}$, $|\eta| < 2.4$, Particle Flow Jet ID,
b-tagged with a tagger (CSV) which has 60-70% efficiency and 1% mistag prob.



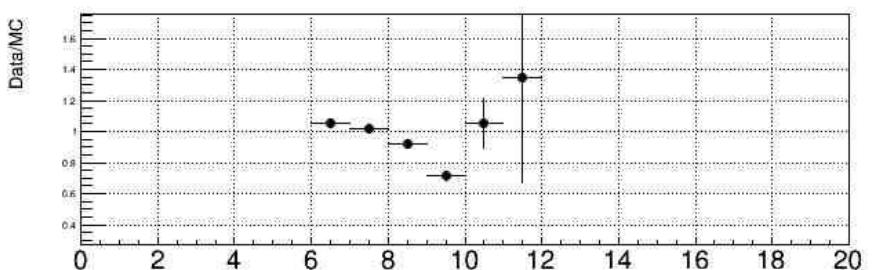
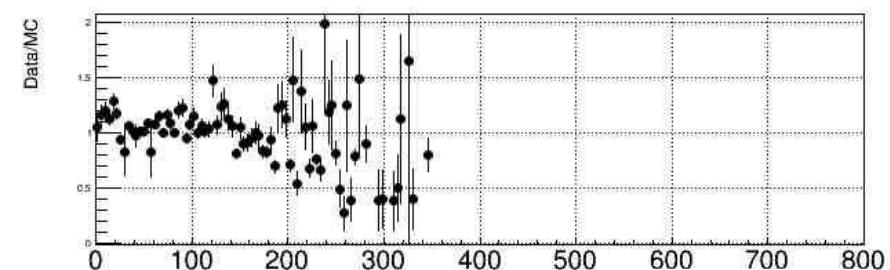
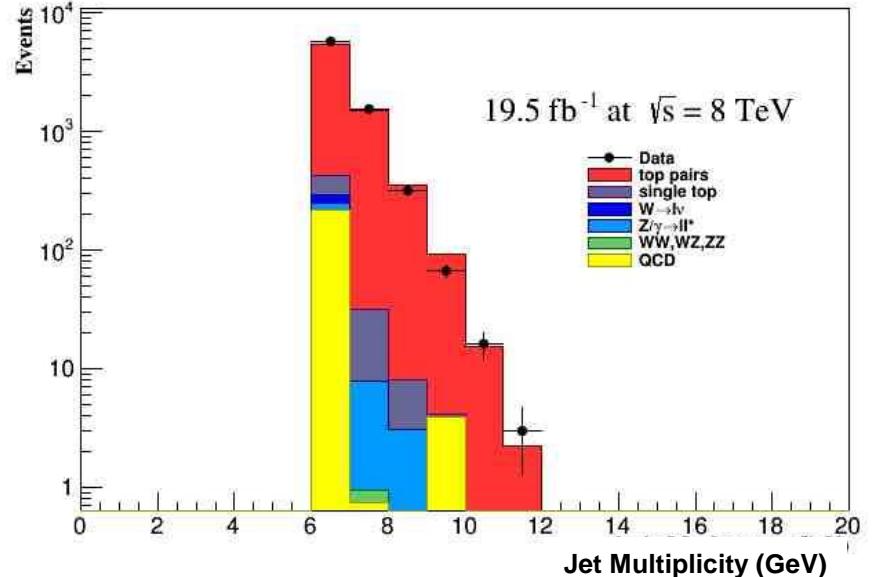
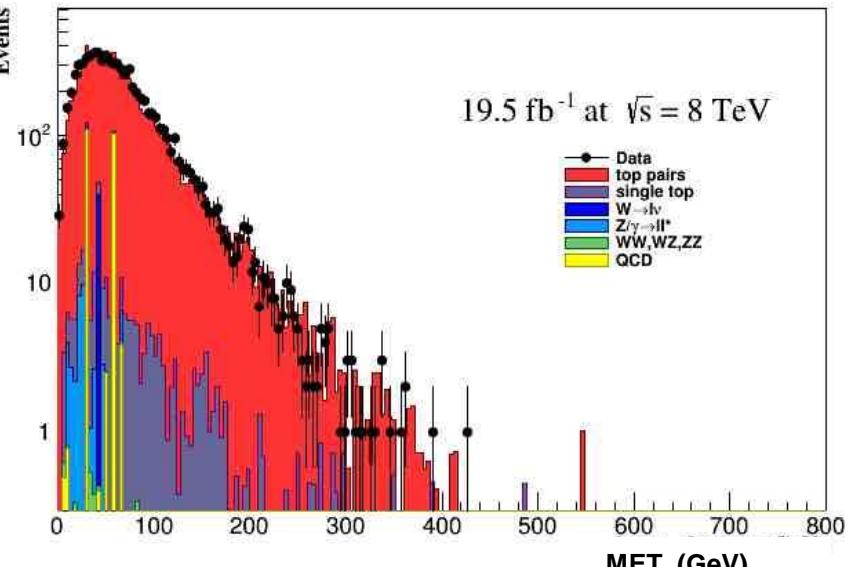
Electron & Muon Events



**Electron E_T (left) & Muon P_T (right)
with $N\text{jets} >= 6$ & $N\text{bjets} >= 2$**



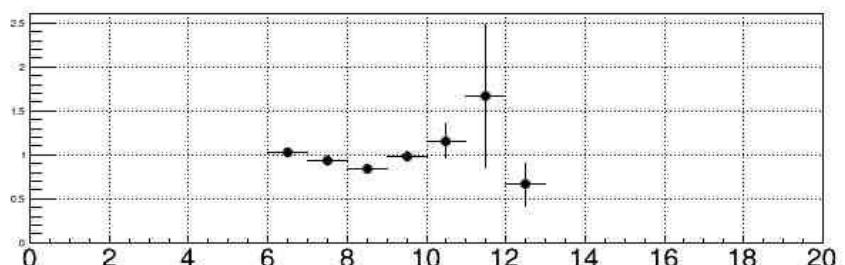
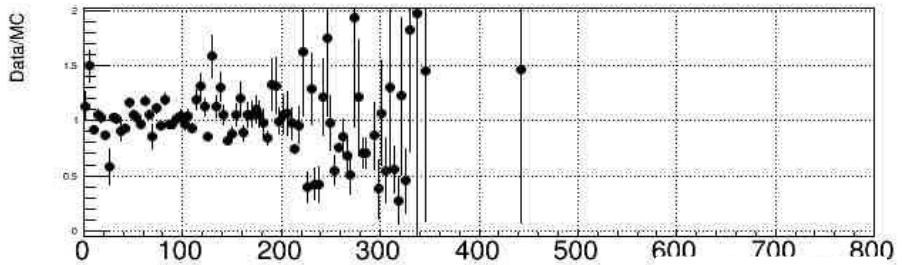
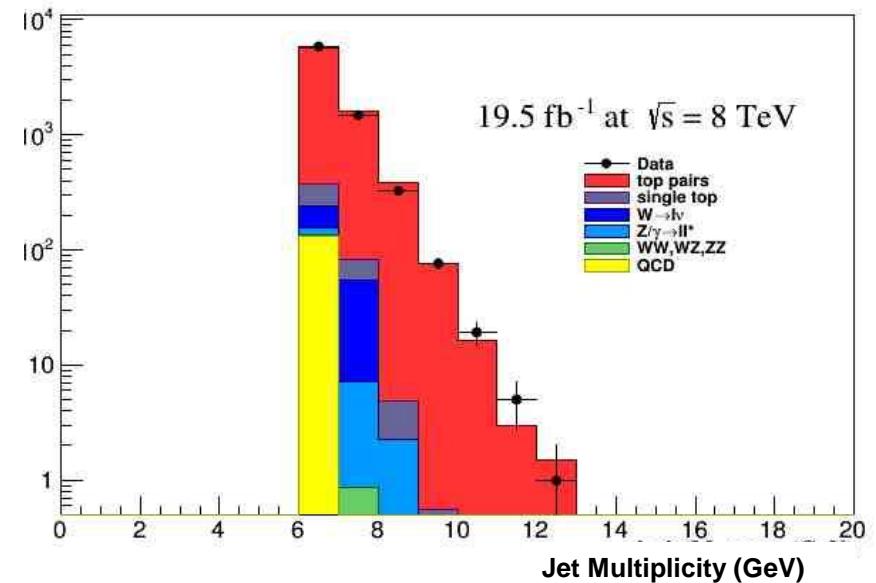
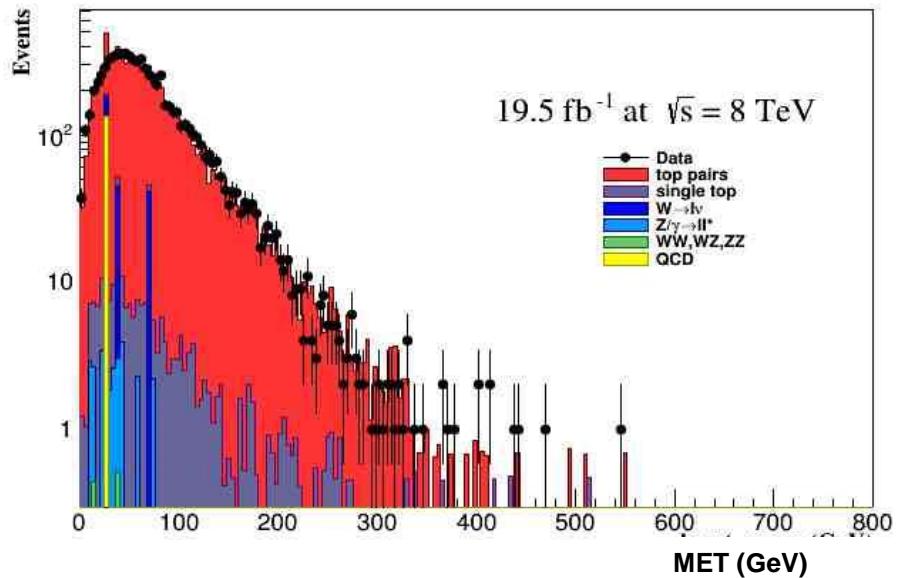
Electron Events



**MET & Jet Multiplicity
with $\text{Njets} \geq 6$ & $\text{Nbjets} \geq 2$**



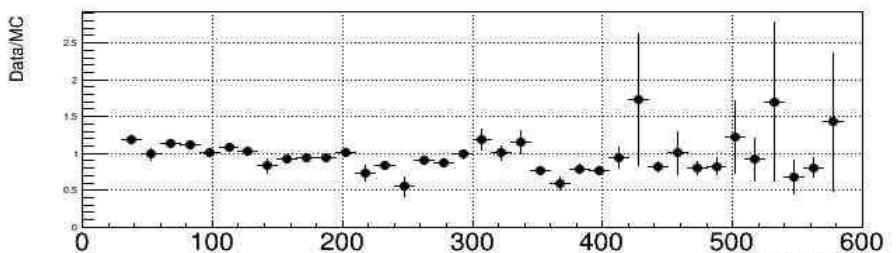
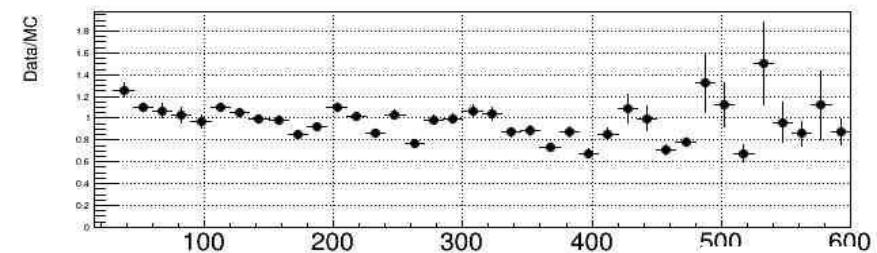
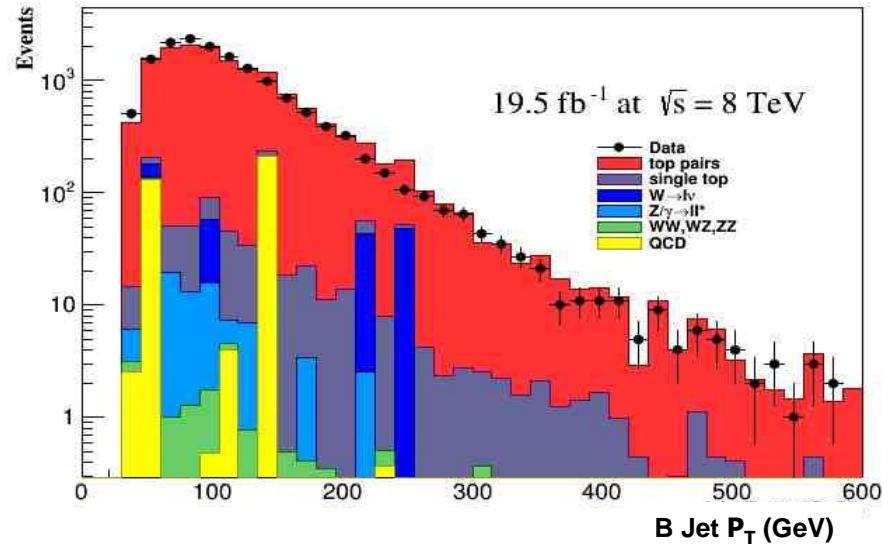
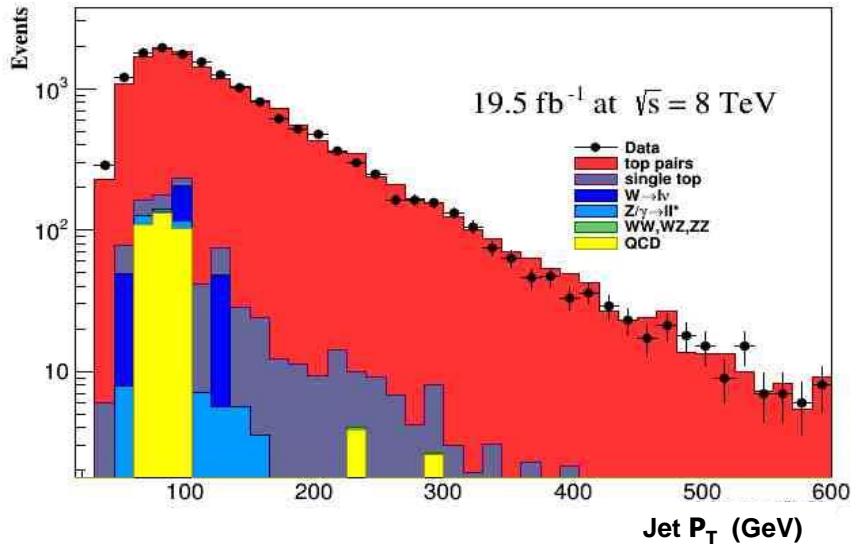
Muon Events



**MET & Jet Multiplicity
with $\text{Njets} \geq 6$ & $\text{Nbjets} \geq 2$**



Leading Jets



**P_T of the Leading non-b-tagged Jet (left) & b-tagged Jet (right)
with $\text{Njets} \geq 6$ & $\text{Nbjets} \geq 2$**



Data Driven Background Estimation Methods



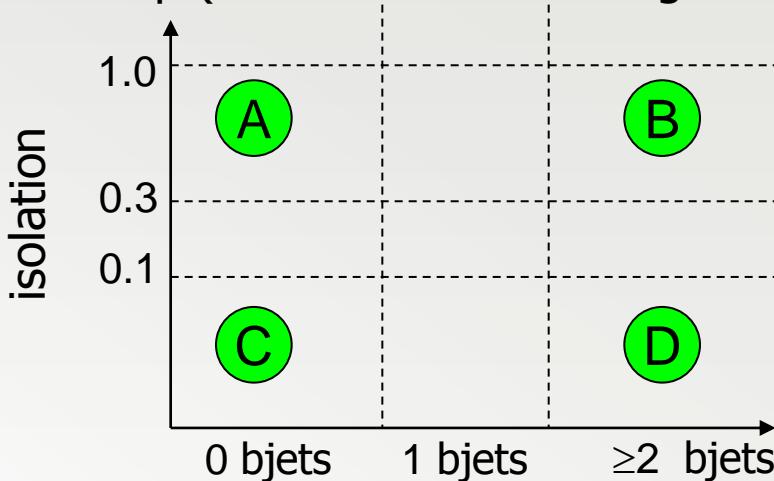
W+jets Estimation

It is based on the charge asymmetry ($W^+ / W^- > 1$) and by correcting for all other charge asymmetric processes like WZ, single top s- & t- channels. We calculate the Wjets for 6-jet final state by extrapolating from a lower number of selected jets. We get: **72 ± 34** (**100 ± 50**) for electrons (muons) with fit uncert.

QCD Estimation

We try an ABCD method assuming that there is no correlation between the lepton isolation variable and the number of b-tagged jets in the event.

$QCD_D = QCD_C * (QCD_B / QCD_A)$ Then we fix the shapes of the QCD (from region A) & top-antitop (from simulation at region D) and try to extract their yields for all regions.



# of jets	QCD	QCD/(QCD + signal)
3	5200 ± 100	5.1%
4	960 ± 60	1.6%
5	140 ± 20	0.6%
6	3 ± 3	0.04%



Data & MC yields after selection



electrons	
DATA:	7604
other $t\bar{t}$:	932 ± 11
single top:	168 ± 8
TTH+TTV:	94 ± 1
Wjets:	72 ± 34
Zjets:	40 ± 9
VV:	3.8 ± 0.5
QCD:	3.0 ± 3.0
SIGNAL:	$6292 \pm 95(\text{stat})$

muons	
DATA:	7698
other $t\bar{t}$:	897 ± 10
single top:	171 ± 8
TTH+TTV:	98 ± 1
Wjets:	100.0 ± 50
Zjets:	28 ± 10
VV:	4.9 ± 0.7
QCD:	-
SIGNAL:	$6400 \pm 102(\text{stat})$



Visible and Full Cross Section



$$\sigma^{\text{VIS}} = (N_{\text{measured}} - N_{\text{bckgd}}) / (L \times \text{Eff}_{\text{data}})$$

- **Yield** = $N_{\text{measured}} - N_{\text{bckgd}}$
- **Eff_{data}** = $\text{Eff}_{\text{MC}} \times R(\text{data}/\text{MC})$, $R(\text{data}/\text{MC})$ counts for possible differences btw data & MC
- **Eff_{MC}** = (reco events that pass selection) / (particle level events that pass fiducial cuts)
- The **fiducial cuts** are defined as:
electron with $E_T > 30 \text{ GeV}$ in $|\eta| < 2.5$ excluding $1.44 < |\eta| < 1.56$ volume,
muon with $P_T > 30 \text{ GeV}$, $|\eta| < 2.1$,
at least 6 jets with $P_T > 30 \text{ GeV}$, $|\eta| < 2.4$

$$\sigma^{\text{FULL}} = (N_{\text{measured}} - N_{\text{bckgd}}) / (L \times A \times \text{Eff}_{\text{data}})$$

- **Yield, Eff_{data}** as above
- **A × Eff_{MC}** = (reco events that pass selection) / (particle/parton level events in “full” phase space)
- The **particle/parton level events** in “full” phase space are defined as:
Top pair events with undecayed top quarks and at least 2 additional GenJets with $P_T > 40 \text{ GeV}$,
 $|\eta| < 2.5$, $\Delta R(j,j) > 0.5$.



Systematic Uncertainties



Experimental	Electrons (%) Yield / Efficiency	Muons (%) Yield / Efficiency
JES	0.29 / 9.99	0.32 / 9.25
JER	0.04 / 1.15	0.04 / 1.31
B-tagging	0.11 / 3.63	0.11 / 3.63
Mis-tagging	0.06 / 0.97	0.08 / 0.92
Lepton energy scale & ID	0.02 / 0.59	0.01 / 0.29
Trigger	0.03 / 1.17	0.00 / 0.05
Pileup	0.03 / 0.03	0.02 / 0.03
Theoretical	Acceptance (%) (visible / full)	
Q^2 scale	3.7 / 3.0	
ME/PS matching	3.3 / 3.3	
PDF (*)	1.2 / 2.1	
M_{top}	2.0 / 4.6	

(*) PDF4LHC recipe with CT10nlo, NNPDF23nlo, MSTW2008nlo



Visible Cross Section



$$\sigma^{\text{VIS}} = (N_{\text{measured}} - N_{\text{bckgd}}) / (L \times \text{Eff}_{\text{data}})$$

- ❖ The ingredients of the measurement for **electrons** are:
 $L = 19.6 \pm 2.6\% \text{ fb}^{-1}$, $R(\text{data/MC}) = 0.87 \pm 10.8\% \text{ (syst)}$, $\text{Eff}_{\text{MC}} = 0.336(5) \pm 5.5\% \text{ (syst)}$

$$\sigma^{\text{VIS}}(\text{electrons}) = 1.102 \pm 0.023 \text{ (stat)} \pm 0.140 \text{ (syst)} \pm 0.029 \text{ (lumi)} \text{ pb}$$

- ❖ The ingredients of the measurement for **muons** are:
 $L = 19.6 \pm 2.6\% \text{ fb}^{-1}$, $R(\text{data/MC}) = 0.91 \pm 10.1\% \text{ (syst)}$, $\text{Eff}_{\text{MC}} = 0.355(5) \pm 5.5\% \text{ (syst)}$

$$\sigma^{\text{VIS}}(\text{muons}) = 1.011 \pm 0.022 \text{ (stat)} \pm 0.123 \text{ (syst)} \pm 0.026 \text{ (lumi)} \text{ pb}$$



Full Phase Cross Section



$$\sigma^{\text{FULL}} = (N_{\text{measured}} - N_{\text{bckgd}}) / (L \times A \times \text{Eff}_{\text{data}})$$

- ❖ The ingredients of the measurement for **electrons** are:

$L = 19.6 \pm 2.6\% \text{ fb}^{-1}$, $R(\text{data/MC}) = 0.87 \pm 10.8\% \text{ (syst)}$, $A \times \text{Eff}_{\text{MC}} = 0.0128(2) \pm 6.7\% \text{ (syst)}$

$$\sigma^{\text{FULL}}(\text{electrons}) = 25.1 \pm 0.5 \text{ (stat)} \pm 3.1 \text{ (syst)} \pm 0.7 \text{ (lumi)} \text{ pb}$$

- ❖ The ingredients of the measurement for **muons** are:

$L = 19.6 \pm 2.6\% \text{ fb}^{-1}$, $R(\text{data/MC}) = 0.91 \pm 10.1\% \text{ (syst)}$, $A \times \text{Eff}_{\text{MC}} = 0.0138(2) \pm 6.7\% \text{ (syst)}$

$$\sigma^{\text{FULL}}(\text{muons}) = 23.7 \pm 0.5 \text{ (stat)} \pm 2.7 \text{ (syst)} \pm 0.6 \text{ (lumi)} \text{ pb}$$

- The ratio $\sigma^{\text{FULL}}(\text{electrons})/\sigma^{\text{FULL}}(\text{muons}) = 1.060 \pm 0.030 \text{ (stat)}$ using only stat. uncert.

G. Bevilacqua et. al., hep-ph. 1108.2851 1403.2046: $\sigma^{NLO}_{t\bar{t}jj} = 20.97^{-3.25}_{-2.79} \text{ pb}$



Conclusions

- ✓ We presented preliminary results of $t\bar{t} + jj$ cross section in the semileptonic channel.
- ✓ We measured the visible and full cross-section of this case.
- ✓ There is a good agreement between our calculation and the theoretical value.
- ✓ The work is still ongoing.

Thank you for your attention



Back Up Slides - Data



Data (JanReReco CMSSW_5_3_9_patch1) :

SingleElectron_Run2012A-22Jan2013-v1

SingleElectron_Run2012B-22Jan2013-v1

SingleElectron_Run2012C-22Jan2013-v1

SingleElectron_Run2012D-22Jan2013-v1

SingleMu_Run2012A-22Jan2013-v1

SingleMu_Run2012B-22Jan2013-v1

SingleMu_Run2012C-22Jan2013-v1

SingleMu_Run2012D-22Jan2013-v1

Luminosity = 19624.4 pb⁻¹



Back Up Slides - MC

TT_CT10_TuneZ2star_8TeV-powheg-tauola

TTJets_MassiveBinDECAY_TuneZ2star_8TeV-madgraph-tauola

TTJets_MSDecays_central_TuneZ2star_8TeV-madgraph-tauola

TTH_Inclusive_M-110_8TeV_pythia6

TTH_Inclusive_M-115_8TeV_pythia6

T_s-channel_TuneZ2star_8TeV-powheg-tauola,

T_t-channel_TuneZ2star_8TeV-powheg-tauola

T_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola

Tbar_s-channel_TuneZ2star_8TeV-powheg-tauola,

Tbar_t-channel_TuneZ2star_8TeV-powheg-tauola

Tbar_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola

WJetsToLNu_TuneZ2Star_8TeV-madgraph, WxJetsToLNu_TuneZ2Star_8TeV-madgraph (x=1,2,3,4)

DYJetsToLL_M-10To50filter_8TeV-madgraph

DYJetsToLL_M-50_TuneZ2Star_8TeV-madgraph-tarball

DYToMuMu_M-20_CT10_TuneZ2star_v2_8TeV-powheg-pythia6

WW_TuneZ2star_8TeV_pythia6_tauola,

WZ_TuneZ2star_8TeV_pythia6_tauola

ZZ_TuneZ2star_8TeV_pythia6_tauola

QCD_Pt_20_MuEnrichedPt_15_TuneZ2star_8TeV_pythia6

QCD_Pt_*_EMEnriched_TuneZ2star_8TeV_pythia6,

QCD_Pt_*_BCtoE_TuneZ2star_8TeV_pythia6