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Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

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Search for new top-like quarks in CMS experiment

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Search for a Vector-like Top Quark T → tZ at $\sqrt{s}$ = 7 TeV in CMS

Beyond the Standard Model : results with the 7 TeV LHC Collision Data
Sep. 20th (2011), ICTP, Trieste (Italy)

Outline

- **Search for a vector-like top quark**
  - **What's a vector-like top quark?**
  - **Why are we looking for it?**
- **T → tZ analysis in the CMS detector**
  - **Event selection**
  - **Background estimation**
  - **Systematic uncertainties**
  - **Result**
- **Conclusion**

Vector-like Top Quark

- **Chiral fermions in the SM**
  - **All fermions obey chiral symmetry ($u = u_L + u_R$)**

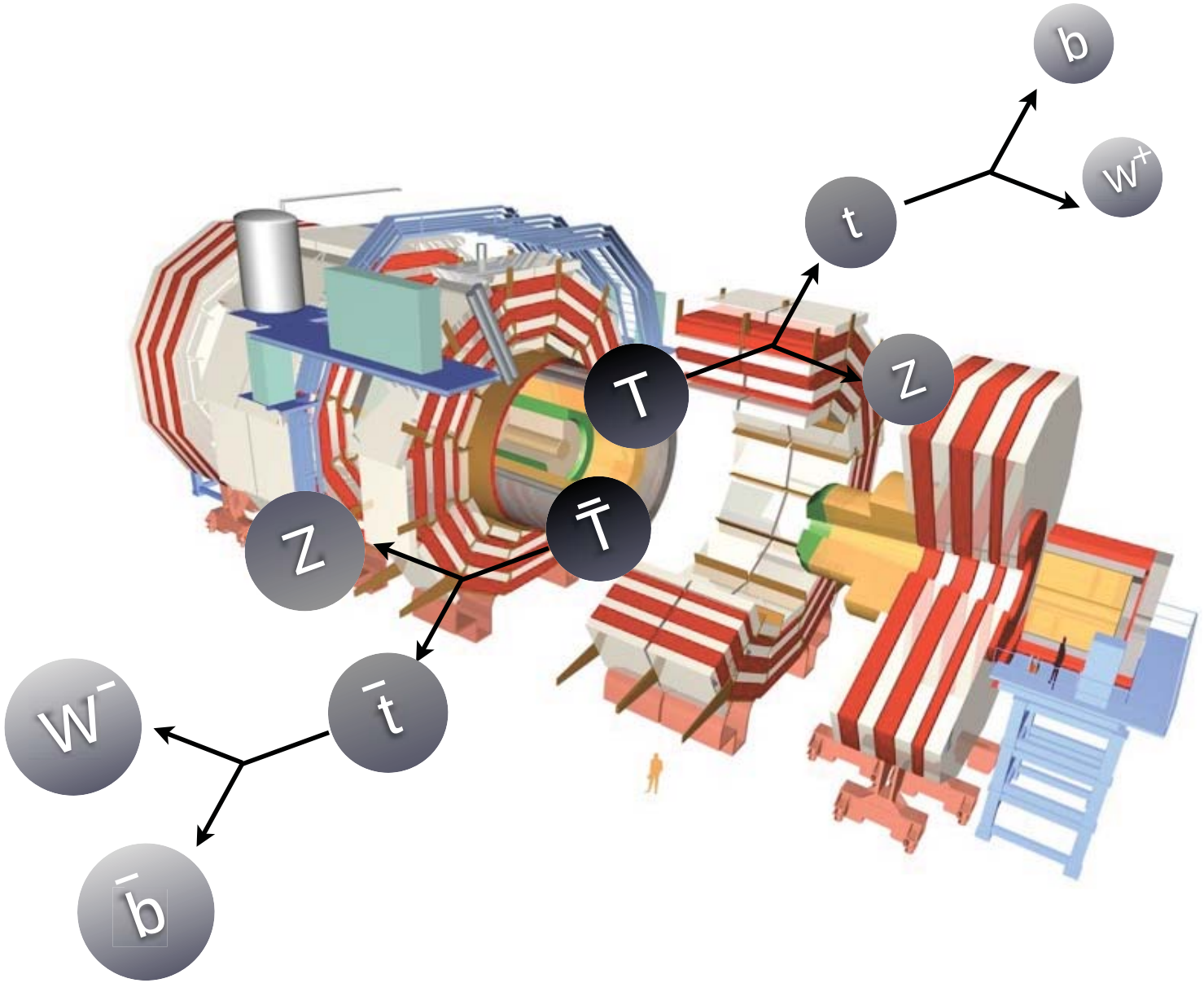
$$u_L \equiv \frac{(1-\gamma^5)}{2}u \qquad u_R \equiv \frac{(1+\gamma^5)}{2}u$$

(where u_L and u_R stand for the left-handed and right-handed states)

- **Vector-like fermions**
  - **u_L and u_R have equal behavior under SU(2)**
- **Vector-like charge 2/3 top quark (T)**
  - **Flavor changing neutral current (FCNC) via tree level.**
  - **BF of T→tZ and T→tH can reach to 50% (JHEP 1011:159,2010).**
  - **Assuming BF(T→tZ) close to 100% if $m_h > m_T$.**

Motivation

- **Many theories postulate vector-like quarks, for example :**
  - **Warped extra dimensions scenario : ADD + RS (e.g. Phys.Rev.Lett.83:3370-3373,1999)**
  - **Little Higgs model (e.g. Nucl.Phys.Proc.Suppl.117 (2003)40)**
- **Both models can give a solution to hierarchy problem (SM)**
  - **Hierarchy problem between weak and Planck scale**
  - **Warped extra dimensions (4+n)**
    - **Introduce *vector-like quarks* since chiral quarks can not exist when n is odd.**
  - **Little Higgs model**
    - **Introduce *a vector-like top quark* in order to cancel the divergency from the top loop**


b
W+
t
T
Z
Z
T̄
W−
t̄
b̄

Analysis Strategy

- **The full decay chain : $T\bar{T} \rightarrow t Z \bar{t} Z \rightarrow b\bar{b}W^+W^-ZZ$**

(2 W-bosons + 2 Z-bosons + 2 b-jets)

- **Final states :**

Decay Mode	Branching Fraction
1L+4~8J ($1W_{l\nu}$)	324/900
2L+2~6J ($2W_{l\nu}$)	81/900
2L+6~8J ($1Z_{ll}$)	72/900
3L+4~6J ($1W_{l\nu}$ + $1Z_{ll}$)	72/900
4L+2~4J ($2W_{l\nu}$ + $1Z_{ll}$)	18/900
4L+6J ($2Z_{ll}$)	4/900
5L+4J ($1W_{l\nu}$ + $2Z_{ll}$)	4/900
6L+2J ($2W_{l\nu}$ + $2Z_{ll}$)	1/900

BF~5.4% for e,μ

BF(W → lν) = 1/3
BF(Z → l^+l^-) ~ 1/10

Clean states ⇒ at least 3 leptons (including Z_{ll}) + at least 2 jets

Selection Criteria

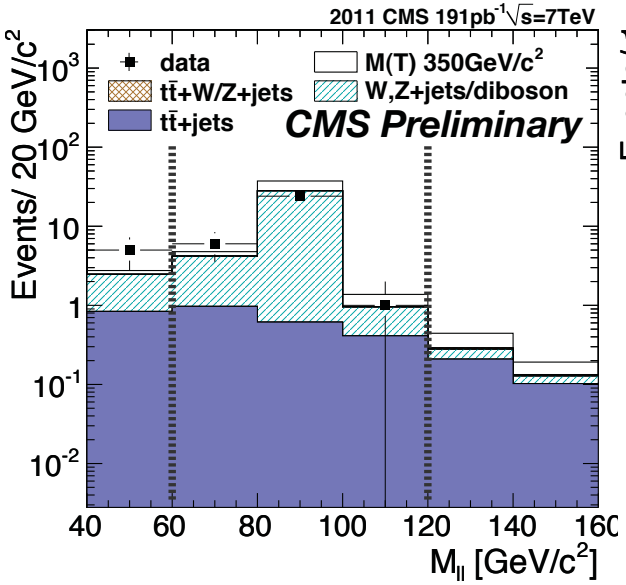
- **Vertex selection:**
  - **degrees of freedom>4, |ρ| < 2 cm, and |z| < 24 cm**
- **Objects selection:**

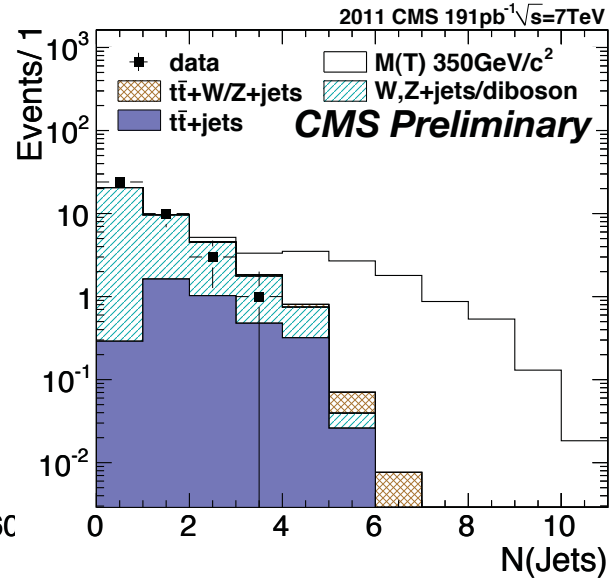
μ selection	*e selection*	*Jet selection*
Global μ pT > 15 GeV |η| < 2.4	pT > 20 GeV |η| < 2.5 ΔR(e,μ)>0.1 Reject γ conversion	Particle flow pT > 25 GeV |η| < 2.4 ΔR(jet,lep)>0.4

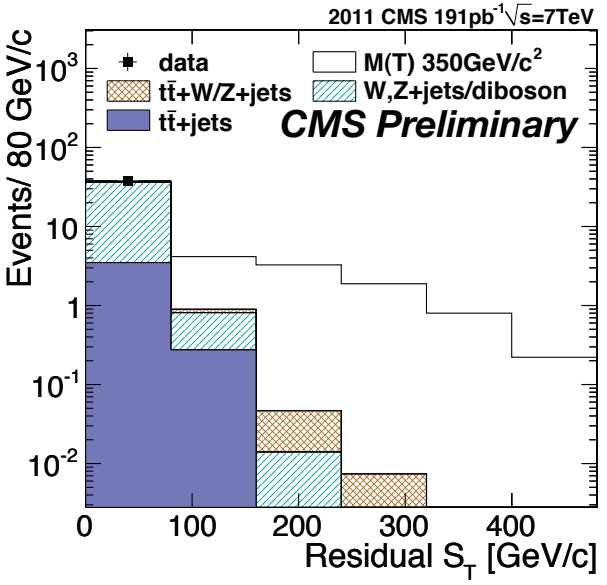
- **N(lep) ≥ 3, Z_{ll} (60GeV~120GeV), and N(jet) ≥ 2**
- ***Residual S_T = Σ(lep+jet pT) - Σ(leading 2lep+2jet pT) > 80GeV***

Plots in a Control Region

- **Selection :**
  - At least 3 leptons
  - $Z \rightarrow ll$
  - ~~N(jet) ≥ 2 + Residual S_T > 80 GeV~~



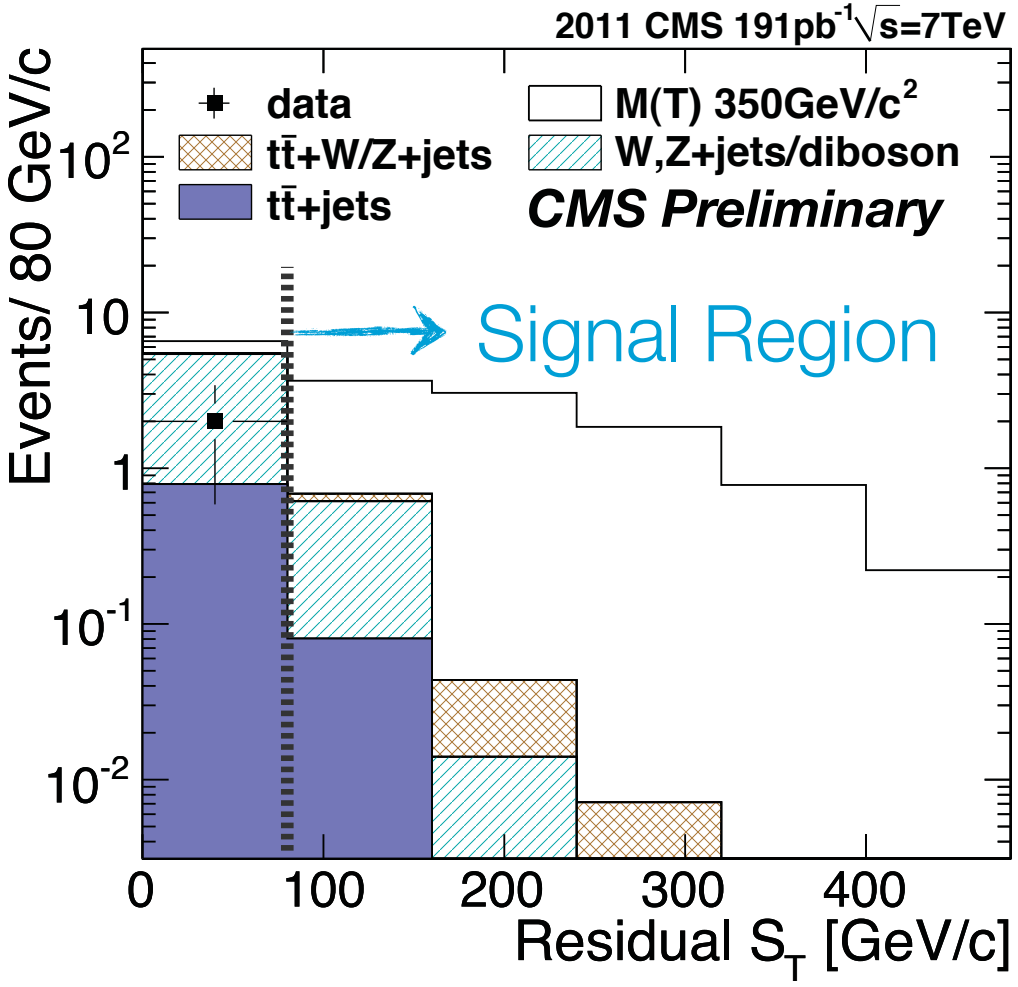




Resulting Plot (Signal Region)

- **Selection :**
- **At least 3 leptons**
- **Z→ll**
- **N(jet) ≥ 2 +**
  Residual S_T > 80 GeV

T(350GeV)	8.99±1.61
Bkg. (estimated)	0.73±0.31
Data	0



Background Classifications

- **≤ 2 prompt leptons ($B_{2\ell}$)**
  - ***Estimated with data-driven method***
  - **Z+jets, $t\bar{t}$+jets... (QCD processes also included in this estimation)**
- **3 prompt leptons ($B_{3\ell}$)**
  - ***Obtained from MC***
  - **$t\bar{t}Z$(W)+jet, WZ, and ZZ**

Data-Driven Bkg. Estimation

Method :

$$N_B = N_{control} \times \varepsilon_f$$

Control region is similar to signal region except for combination of loose and tight leptons

Lepton tight-to-loose ratio is determined from data.

- **Loose and tight leptons :**
  - Tight lepton (T) : Passing lepton selection
  - Loose lepton (L) : Anti-tight lepton
- **Lepton tight-to-loose ratio (ε_f) :**
  - $\frac{N_{T\mu+Le}}{N_{L\mu+Le}}$ and $\frac{N_{L\mu+Te}}{N_{L\mu+Le}}$ in dilepton events

$\varepsilon_{f\mu}$	18.6±0.2%
ε_{fe}	1.9±0.1%

- **$N_{control}$: 2TLep(Z) + 1LLep + ≥2jets + Residual S_T**

	Yields in control region (data)	Scaling ratio	Estimated yields (signal region)
Z + loose μ	2	$\varepsilon_{f\mu}$= 18.6±0.2%	0.45 ± 0.27 (stat. only)
Z + loose e	4	ε_{fe}= 1.9±0.1%	

Systematic Uncertainties

Source	$\Delta\epsilon/\epsilon$[%]	$\Delta B_{2\ell}$	$\Delta B_{3\ell}$	ΔB_{total}
Control region statistics	-	0.27	-	0.27
Luminosity	6	0	0.02	0.02
Trigger efficiency	2.8	-	-	-
Background normalization	-	0.03	0.07	0.08
Lepton (Reconst./ID/Isolation)	19	0.01	0.05	0.06
PDF	0.4-0.8	0.04	0.01	0.05
Jet energy scale	0.5-0.9	0.05	0.05	0.10
Jet resolution	0.1-0.5	0.01	0.01	0.02
Pile-up jets	2.8	0.03	0.04	0.07
Simulated sample statistics	3.4-3.7	-	0.03	0.03
Sum	20	0.28	0.11	0.31

43% uncertainty (relative to B_{total})

Yields and Efficiency

Process	Cross-section (pb)	ϵ[%]	Yield
$T\bar{T}$, $M(T) = 250\ \mathrm{GeV}/c^2$	20.5 (NLO)	14.5 ± 3.0	30.4
$T\bar{T}$, $M(T) = 300\ \mathrm{GeV}/c^2$	7.29 (NLO)	24.6 ± 5.0	18.4
$T\bar{T}$, $M(T) = 350\ \mathrm{GeV}/c^2$	2.94 (NLO)	29.9 ± 6.8	8.99
$T\bar{T}$, $M(T) = 400\ \mathrm{GeV}/c^2$	1.30 (NLO)	30.3 ± 6.9	4.03
$T\bar{T}$, $M(T) = 450\ \mathrm{GeV}/c^2$	0.617 (NLO)	33.8 ± 7.7	2.13
$T\bar{T}$, $M(T) = 500\ \mathrm{GeV}/c^2$	0.310 (NLO)	34.4 ± 7.9	1.09
$T\bar{T}$, $M(T) = 550\ \mathrm{GeV}/c^2$	0.162 (NLO)	33.6 ± 7.9	0.56

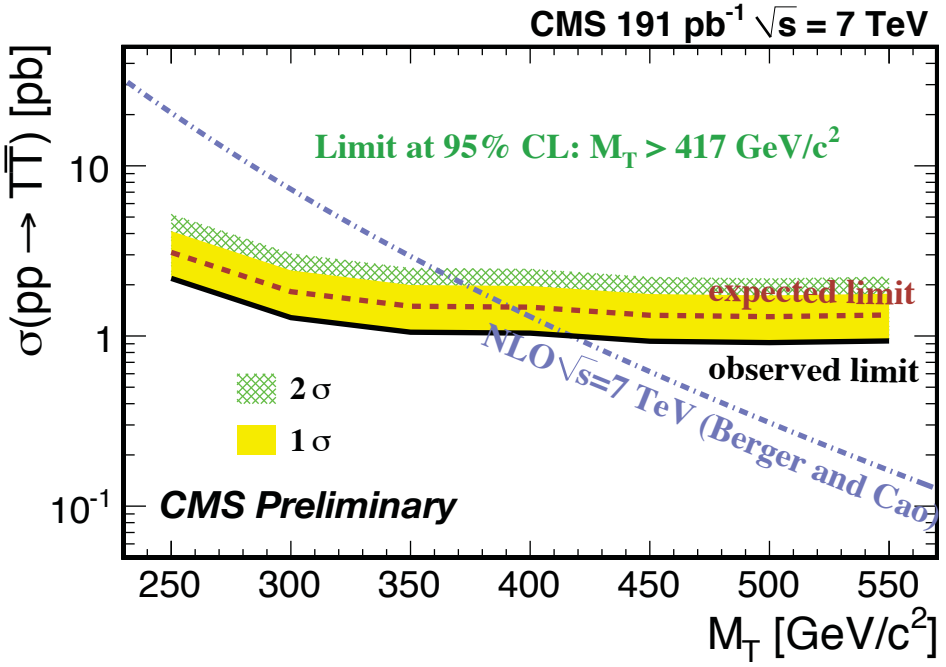
Background with two real leptons (data-driven)	0.45 ± 0.28
Background with three real leptons (simulated)	0.28 ± 0.11
Sum (estimated background)	0.73 ± 0.31
Data ($191\ \mathrm{pb}^{-1}$)	0

Exclusion Limit

- **Observed limits on X-sec using a Bayesian approach at 95% CL**

$M(T)$ [GeV/c^2]	250	300	350	400	450	500	550
Observed limit [pb]	2.18	1.28	1.05	1.04	0.93	0.91	0.94

- **By comparing observed limits to the NLO X-sec :**



Conclusion

- **We report the search for a vector-like charge 2/3 top quark T→tZ in pp collision at 7 TeV**
- **The first result with 191 pb^{-1} CMS data is presented :**
  - **Assuming a 100% branching fraction for the decay T→tZ, we can set T-quark mass limit up to 417 GeV**

Backups

Background Classifications

- $B_{2\ell}$ ***(estimated with data-driven method)***
  - **2 prompt leptons + 1 non-prompt lepton :**

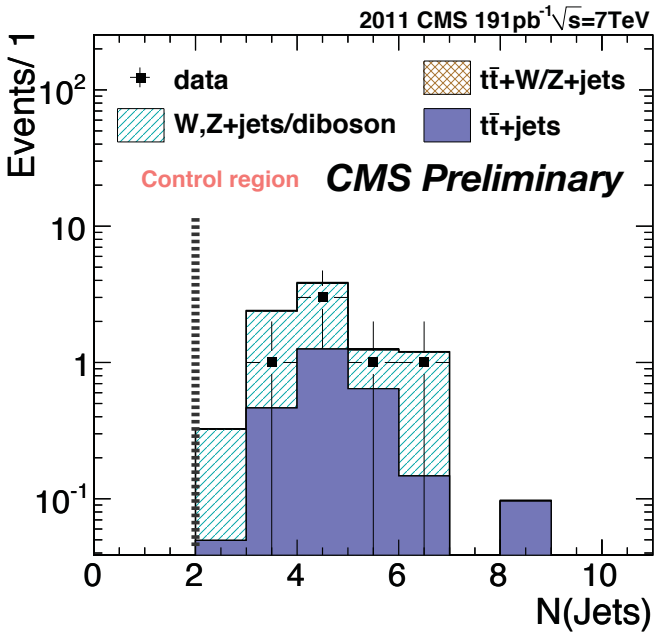
    Z+jets (49%) and $t\bar{t}$+jets (11%)
  - **3 non-prompt leptons :**

    QCD processes (Also included in this estimation)
- $B_{3\ell}$ ***(obtained from MC)***
  - **3 prompt leptons :**

    $t\bar{t}$Z(W)+jet (14%), WZ(17%), and ZZ(9%)

Data-Driven Bkg. Estimation (Cont.)

- **$B_{2\ell}$ (for Z+jets and tt+jets) estimation :**
  - **Bkg. control region :**
    additional LL + 2TL(Z) and keep other selections



Z/tt +jets MC truth value : 0.43
→ Within statistical error

	Yields in control region (MC)		Scaling ratio	Estimated yields (signal region)
	Z/tt +jets	Rest bg.		
Z + L μ	1.8	0.10	$\varepsilon_{f\mu}$= 18.0±3.1%	0.47 ± 0.10
Z + L e	7.0	0.19	ε_{fe}= 1.8±0.6%	

	Yields in control region (data)	Scaling ratio	Estimated yields (signal region)
Z + L μ	2	$\varepsilon_{f\mu}$= 18.6±0.2%	0.45 ± 0.27
Z + L e	4	ε_{fe}= 1.9±0.1%	

Control region stat.

Systematic Uncertainties

- ***Control region statistics:***
  - **Observed data events in control region**
- ***Luminosity & Xsec :***
  - **Vary the values (lumi±4.5%, tt±11.4%, ttX±50%, W+jets±4%, Z+jets±3%, WW±35%, WZ ±42%, ZZ±27%) in calculation**
- ***Lepton ID, Isolation, etc :***
  - **100% difference for MC&data from Z tag&probe + 50% difference of Z & T from GenInfo → 7.7% for each electron and 7.2% for each muon**
- ***PDF (hep-ph/0508110) :***
  - **Using 40 uncertainty sets (CTEQ61) to re-weight event**
- ***Jet energy scale :***
  - **Uncertainty associated with Jet pT and η.**
- ***Jet resolution :***
  - **Increasing 10% of Jet's pT resolution**
- ***Pile up :***
  - **By varying the data pile-up number with ±1 RMS of the distribution. The uncertainties in signal and bkg estimation are 2.8% and 9.8%, respectively.**
- ***MC statistics :***
  - **Error propagation with actual MC counts**

Yields and Efficiency

Process	Cross-section (pb)	ϵ[%]	Yield
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$T\bar{T}$, $M(T) = 550\ \mathrm{GeV}/c^2$	0.162 (NLO)	33.6 ± 7.9	0.56
$t\bar{t}$ + jets	158 (CMS)	$(2.6 \pm 2.0) \times 10^{-4}$	0.08
Z + jets	2.9×10^3 (CMS)	$(6.3 \pm 5.4) \times 10^{-5}$	0.35
WZ inclusive	18.0 (NLO)	$(3.3 \pm 0.5) \times 10^{-3}$	0.12
ZZ inclusive	5.9 (NLO)	$(5.9 \pm 0.6) \times 10^{-3}$	0.07
$t\bar{t}$ + W + jet	0.144 (LO)	$(1.3 \pm 1.3) \times 10^{-2}$	0.004
$t\bar{t}$ + Z + jet	0.094 (LO)	$(5.4 \pm 1.3) \times 10^{-1}$	0.10
Expected background from simulated samples			0.71
Background with two real leptons (data-driven)			0.45 ± 0.28
Background with three real leptons (simulated)			0.28 ± 0.11
Sum (estimated background)			0.73 ± 0.31
Data (191 pb^{-1})			0