Prospects of first Top pair cross section measurements at CMS

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- From Tevatron to LHC
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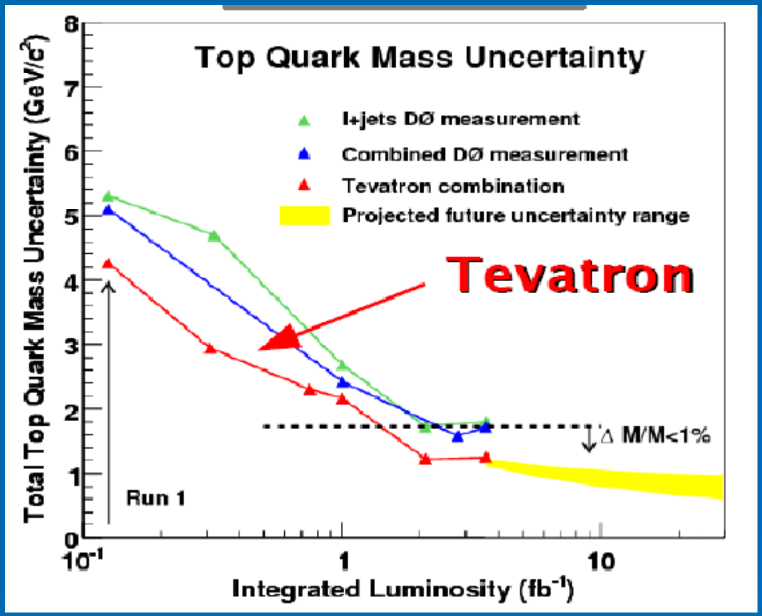
- Summary

Introduction

- Since the discovery of Top quark in 1995, CDF & DØ have contributed to immense progress in the knowledge of its production and properties.
- However, except for mass, precision for most of the measurements is statistically limited.
- LHC experiments will begin a new era of precision measurements in the Top quark sector : ~8M top pairs & ~2M single top events per year expected at the low luminosity at $\sqrt{s}=14$ TeV.
- Focus here on early CMS σ_{ttbar} measurements (10-20 pb^{-1})



$$m_{top} = 173.1 \pm 1.3 \text{ GeV}$$

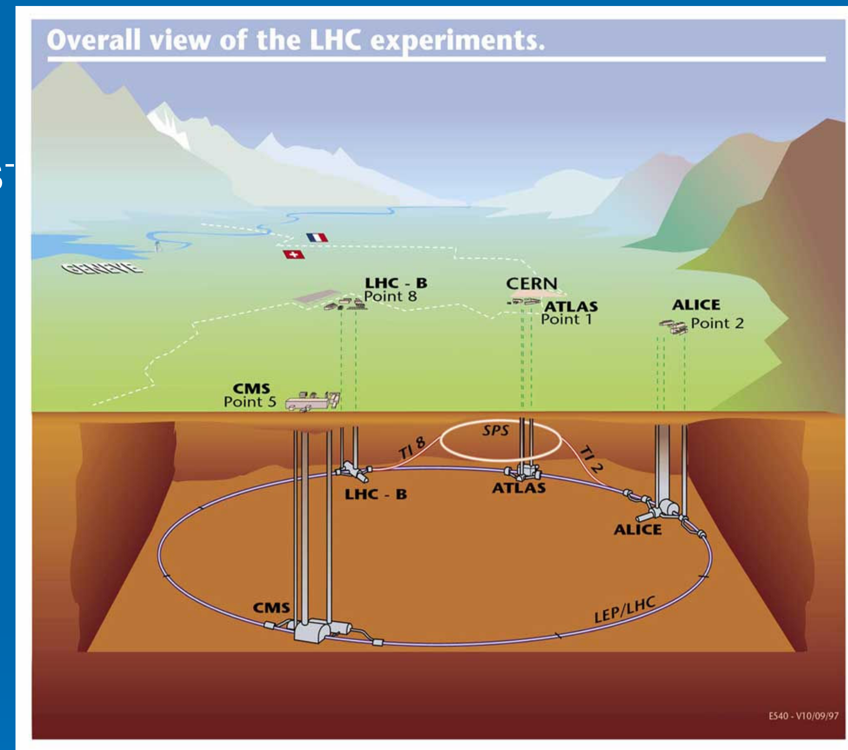
arXiv: 0903.2503

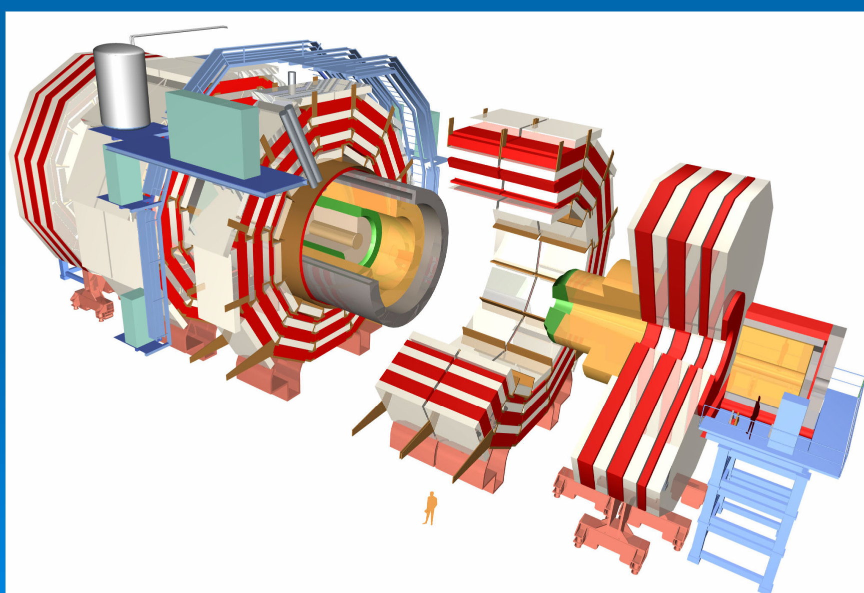
What makes Top Special?

- Top quark mass is a fundamental parameter of the EW theory. In SM, m_{top} and m_W constrain Higgs mass.
- Large mass and short life time ($5x10^{-25}$s) makes top unique. It decays before fragmenting $\rightarrow$ observe "naked" quark.
- Roles of Top quark in the searches beyond the SM at LHC
  --a decay product of new particles thanks to higher $\sqrt{s}$
  --major background to many searches
  How well we understand and control top background defines ultimate sensitivity to new physics in many searches
- Due to distinct experimental signatures and final state topologies, ttbar events will also constitute one of the main benchmark sample in detector commissioning, useful from the very early data taking period
  -- understanding of most physics objects required
  -- jet energy scale determination
  -- measurements of performance of b-tagging and lepton ID tools

CMS at the LHC

pp collisions at LHC
Goal : $\sqrt{s}$ = 14 TeV, L = 10^{34} $cm^{-2}s^{-1}$
2009-10 : $\sqrt{s}$ = 10 TeV, L = 10^{31}-10^{32} $cm^{-2}s^{-}$
: analyzable data O(200 pb^{-1})
σ_{ttbar} reduced by ~1/2 @ 10 TeV
Top physics program still competitive





Multipurpose detector optimized for precise measurements of physics objects in a wide momentum and rapidity range.

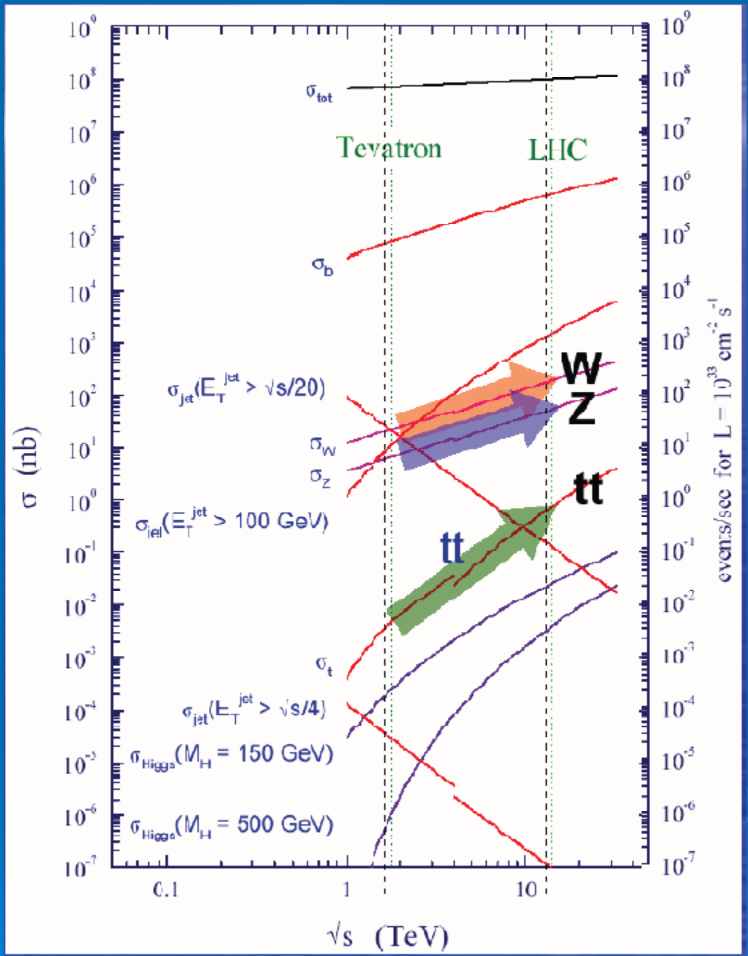
From Tevatron to LHC

LHC opens new regime in energy and hence higher production cross sections.

Low lumi = 10 fb^{-1}/y

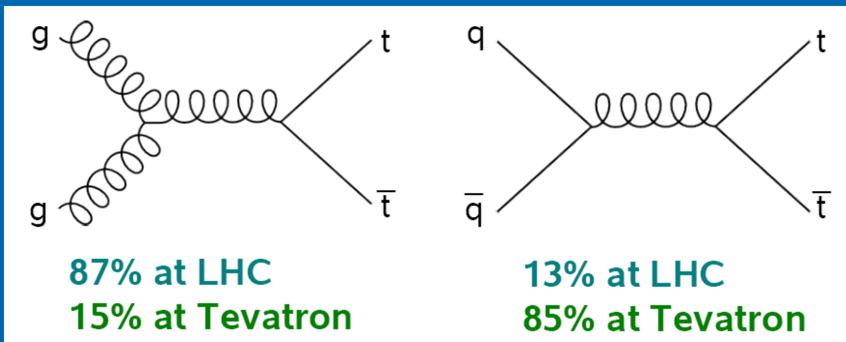
Process	σ(pb)	N/s	N/year
$W \to l\nu$	3×10^4	30	10^9
$Z \to ee$	1.5×10^3	1.5	10^8
t t	830	1	10^7

- σ(ttbar) about x100 than Tevatron $\Rightarrow$ we expect ~ 1Hz of ttbar events.
- Cross-section of the main background, Wjets, grows slower than that of top, though high jet multiplicity states have comparable cross-section gain
- Better signal to background ratio is expected for both ttbar and single top



10 fb^{-1} = 1 year of LHC running at low luminosity 10^{33} $cm^{-2}s^{-1}$ @14 TeV

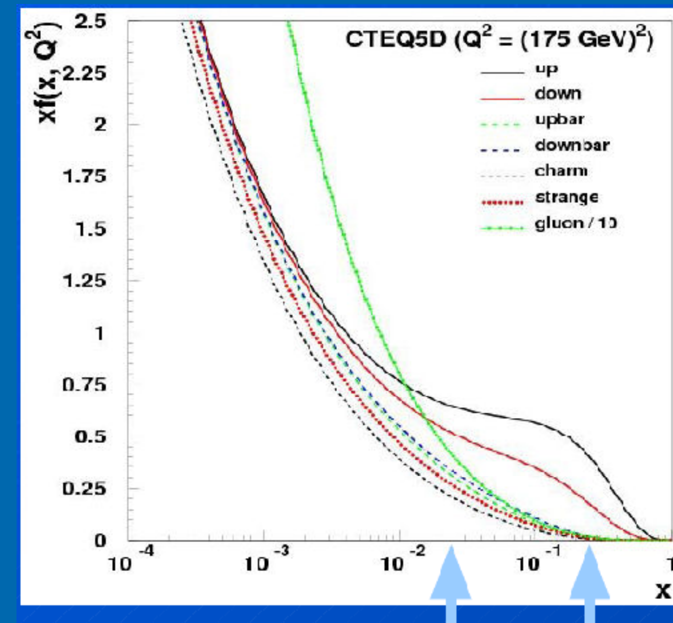
Top Quark Production



LHC: Gluonic production dominates the Top pair production in strong interactions

Predicted
8M evts/yr (10 fb-1 @ 14 TeV)
80k evts/yr in 2009-2010 run
(200 pb-1 @ 10 TeV)

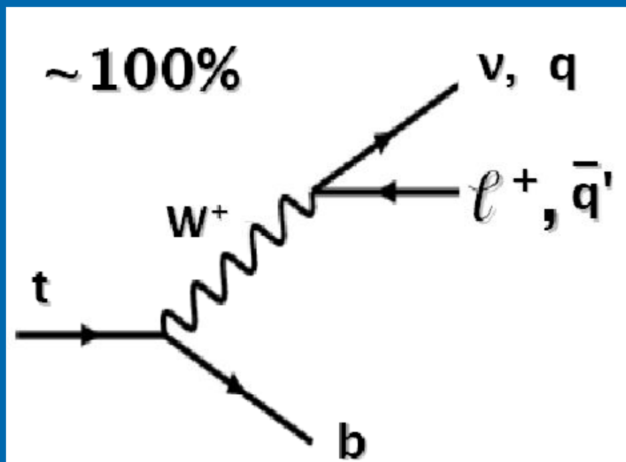
	14 TeV	10 TeV	2 TeV
σ_{ttbar}	833 pb	414 pb	7.6 pb
σ_t	320 pb	~150pb	2.7 pb



LHC Tevatron

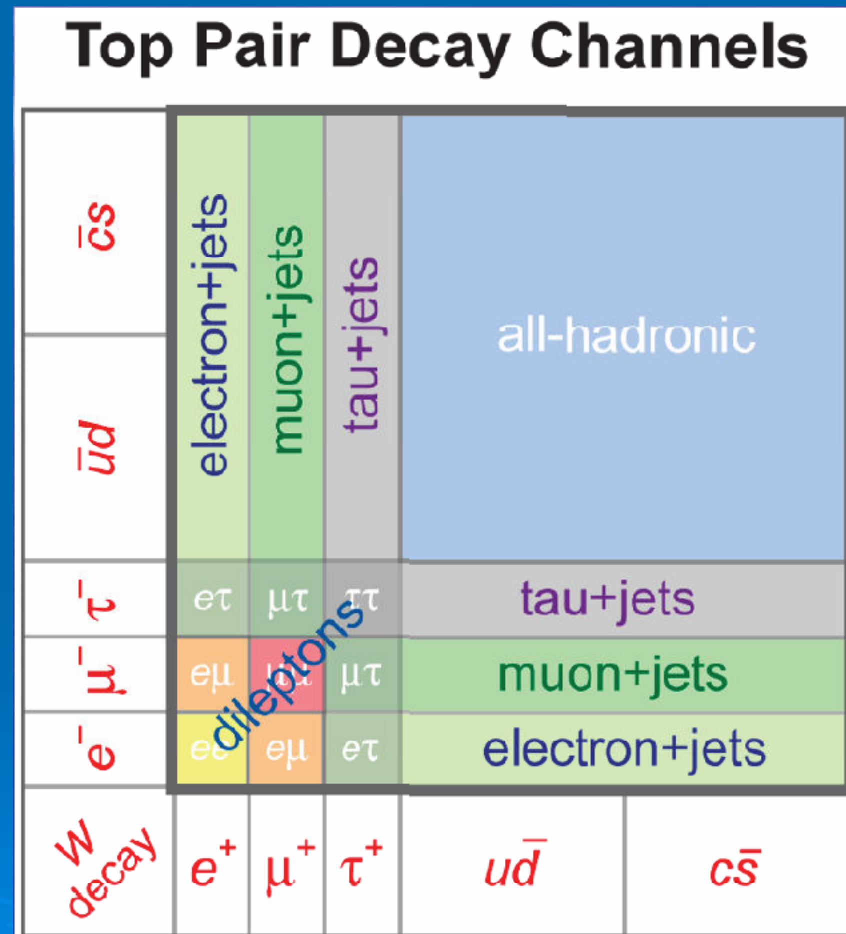
Large difference in momentum fractions of the incoming partons at LHC resulting in strong forward boost of the ttbar system ⇒ event topologies less central and more boosted.

Top Pair Decay Products



$W \rightarrow qq'$: 68%
$W \rightarrow l\nu_l$: 32%

→ hadronic: 44%
semi-leptonic: 45%
dileptonic: 11%

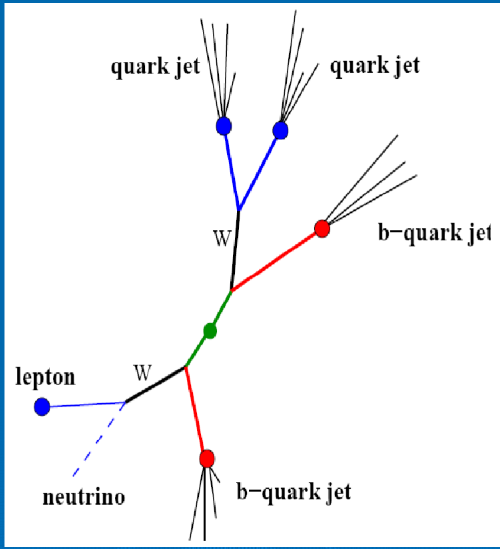


Top Pair Signatures

- Dilepton (ee/$\mu\mu$/eμ) Channel (5%):
  - 2 isolated leptons, 2 b-jets, Missing E_T
  - Cleanest final state, but lowest branching ratio
  - Dominant background: Diboson, DY, W+jets
  - eμ clean channel, not contaminated by DY

→ **Early observation**

- e/μ + jets (30%):
  - Very characteristic signal
  - 1 isolated lepton, 3 light jets, 2 b-jets, Miss E_T
  - Reasonable signal/background ratio
  - Dominant backgrounds: W+jets, QCD
  - Full event reconstruction using Missing E_T



- All hadronic events (44%):
  - 4 light jets and 2 b-jets
  - Dominant decay mode
  - Large background from multi-jet QCD events
- The rest 21% are events with τ+X

Rediscovering Top with early CMS data

- Measurement of top pair production cross section is one of early physics goals. Test the theoretical predictions at the LHC energy.
- During the commissioning phase, the top quark signal will play important role in understanding the detector performance.
- LHC experiments have developed extensive and robust analyses to extract the top signal. In the beginning, focus on channels with leptonic W decay(s) without b-tags and even missing E_T
  --dilepton : simple counting experiment
  --lepton + jets : reconstruct top from 3-jet combination with highest vector sum p_T. Further enhance the signal by finding one of the dijet combinations with mass close to m_W.

Process	NLO cross section
TTbar	0.8 nb
W+Jets	65.2 nb
Z+Jets	6.5 nb
WW	0.11 nb
WZ	0.05 nb
ZZ	0.16 nb

Obtained using MCFM

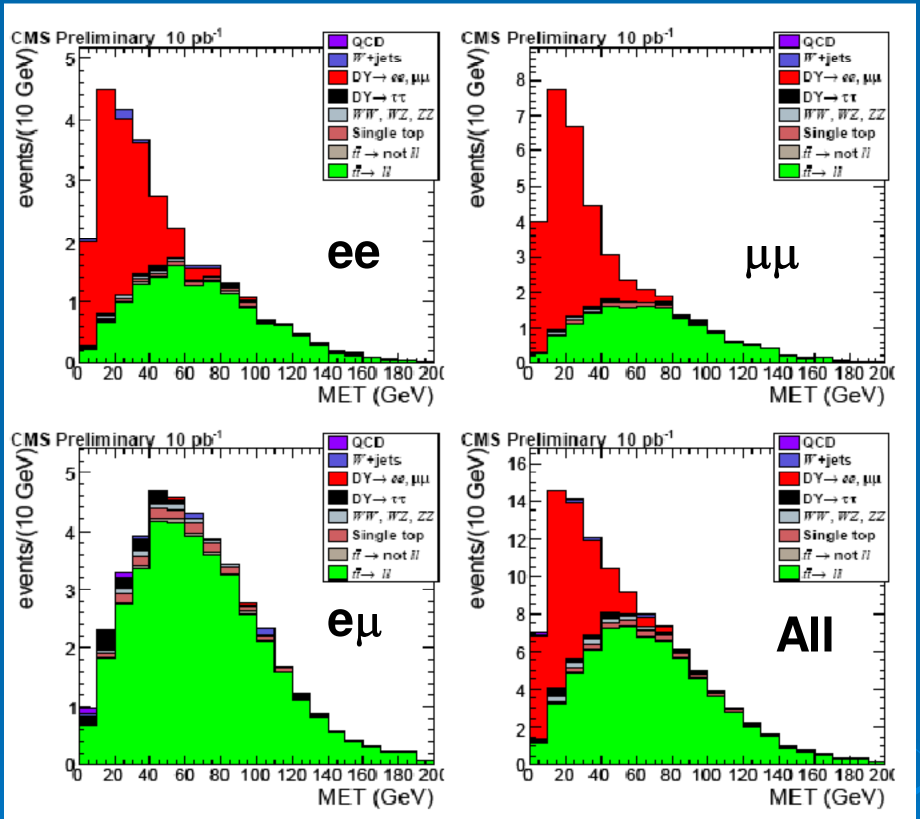
Dilepton Channel : Event Selection

$\int L dt = 10\ pb^{-1}$ @ 10 TeV

- 2 isolated leptons (ee,μμ,eμ) of opposite charge, $p_T > 20$ GeV, $|\eta|<2.4$
- Z-veto $|m_{ll}-m_z|<15$ GeV : reduce the DY background in ee, μμ channels
- $\geq$ 2 jets with high $p_T>30$ GeV
- Further reduce DY background by requiring MET

  >30GeV (ee,μμ), >20 GeV (eμ)

CMS PAS TOP-09-002



DY main background in ee/μμ

Pure eμ channel, can be used alone if bgd (DY) or MET not correctly controlled.

Dilepton Channel : Results

Clear observation of the signal in dilepton final state expected

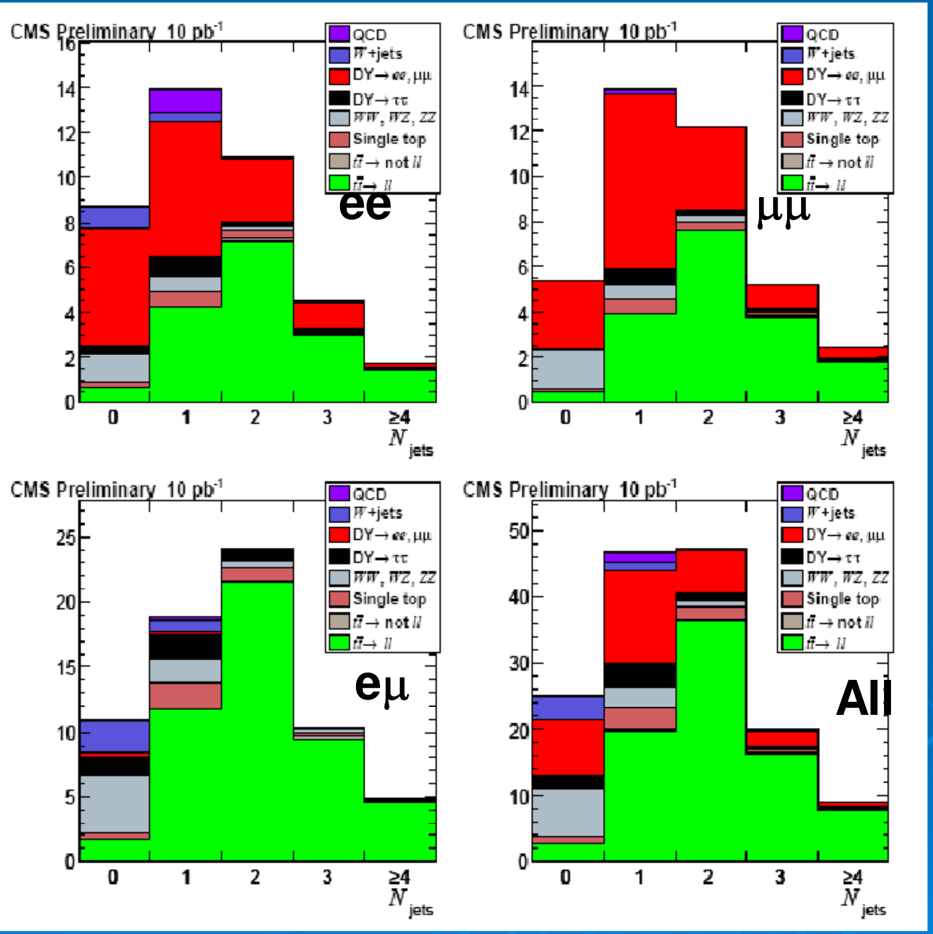
Chan	Sig.	Bgd.
ee	11.6±0.2	5.5±0.4
μμ	13.2 ±0.2	6.6±0.4
eμ	35.6 ±0.4	3.7±0.2
All	60.4±0.6	15.8±0.6

S/B = 4 (all channels)
S/B = 9 (eμ) alone

Signal production cross section is expected to be measured with an uncertainty of

$15\%_{(stat)} \pm 10\%_{(syst)} \pm 10\%_{(lumi)}$

CMS PAS TOP-09-002



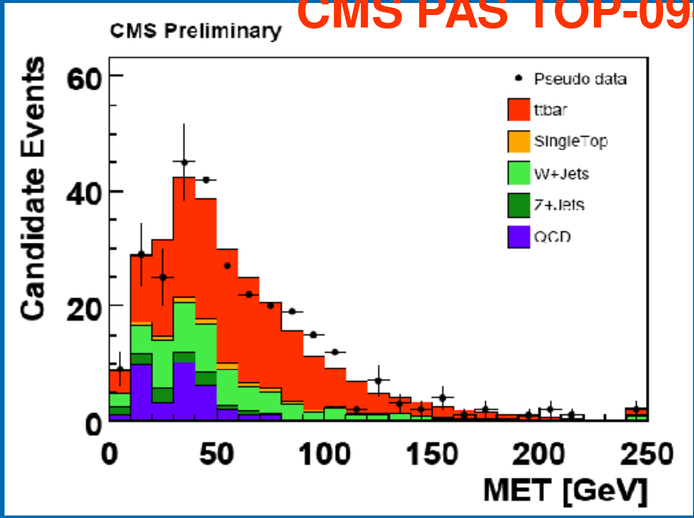
ttbar→e+jets : Event Selection

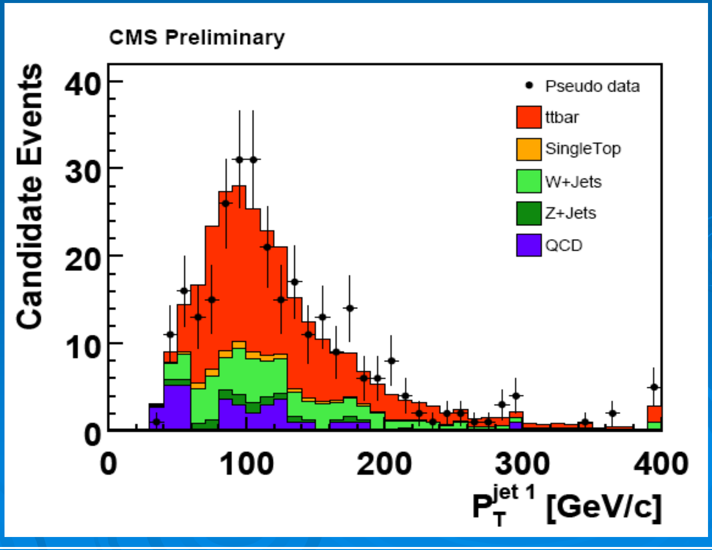
CMS PAS TOP-09-004

$\int Ldt = 20\ pb^{-1}$ @ 10 TeV

- 1 isolated electron : p_T>30 GeV, $|\eta|$<2.5
- reject events containing μ's
- ≥4 jets with p_T>30 GeV, $|\eta|$<2.4
- Loose electron veto to reduce Z+jets
- tightening to barrel-region of $|\eta|$<1.442 to reduce fake electrons from multi-jet events.
- No b-tagging, no cut on MET

signal	172±1
Bgd	108 ±10.3
W+Jets	57 ±2
Z+Jets	12 ±1
QCD	31 ±10
Single Top	8 ±0





ttbar→e+jets : Results

In the absence of b-tagging, rely on kinematic information to extract the top signal. To estimate background, employ template fit method which relies on a discriminating variable that has different shape in signal & background.

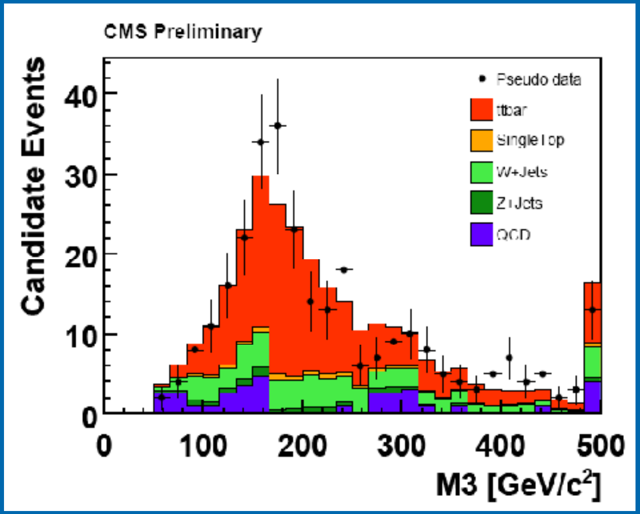
M3: invariant mass of 3-jet combination giving highest vector sum of jet p_T's

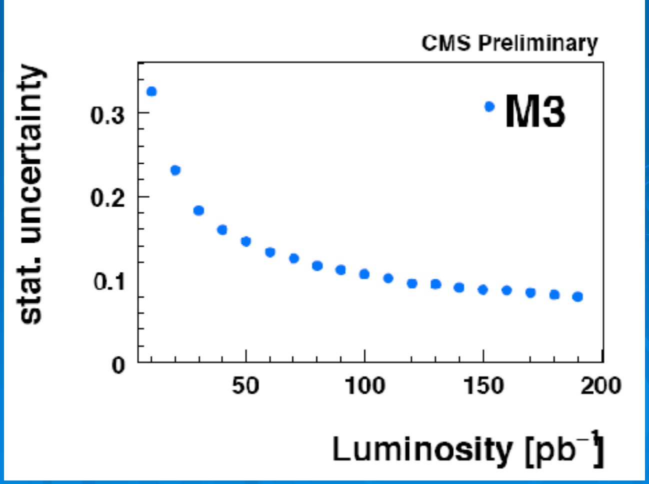
$$\sigma_{t\bar{t}} = \frac{N_{t\bar{t}}^{\rm fit}}{A \cdot \varepsilon_{t\bar{t}} \times \int \mathcal{L} dt}$$

With 20 pb^{-1} of data @ 10 TeV, it is possible to measure the top pair cross section

$\Delta\sigma/\sigma = 23\%_{(stat)} \pm 20\%_{(syst)} \pm 10\%_{(lumi)}$

CMS PAS TOP-09-004





ttbar→μ+jets : Event Selection

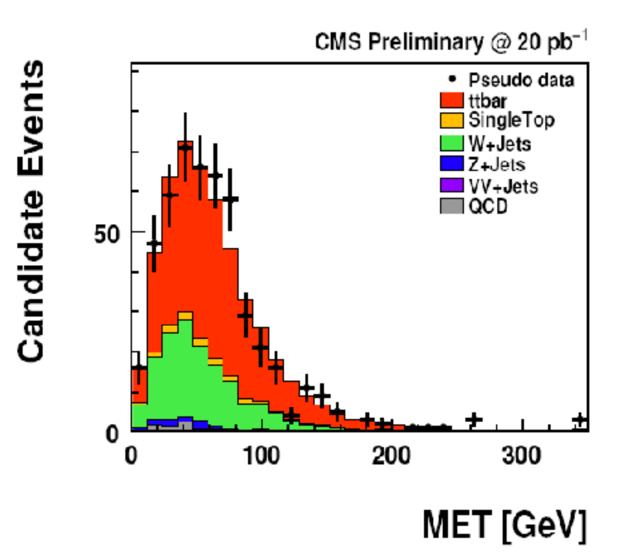
$\int L dt = 20\ pb^{-1}$ @ 10 TeV

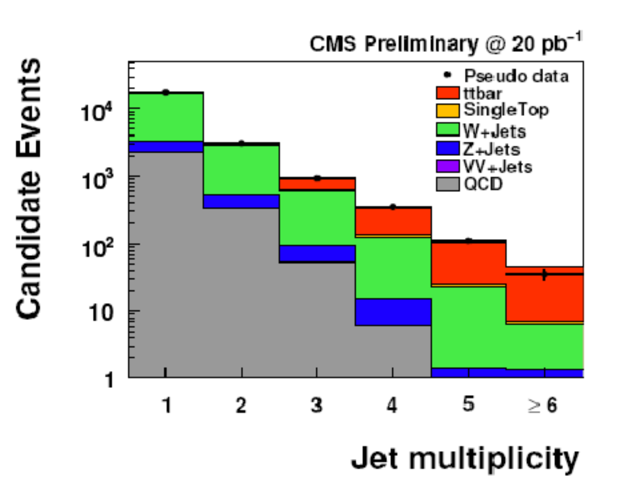
- select exactly 1 isolated μ: $p_T > 20$ GeV, $|\eta| < 2.1$
- veto events with >1 μ to reduce contamination from ttbar→μμ, Z+jets and diboson events
- reject events with an isolated electron with pT>30 GeV
- ≥4 jets with $p_T > 30$ GeV, $|\eta| < 2.4$
- No b-tagging and cut on MET

signal	320
Bgd	171
W+Jets	140
Z+Jets	10
QCD	7
Single Top	14

S/B=1.9

CMS PAS TOP-09-003





ttbar→μ+jets : Results

Identify the 3 jets originating from hadronic top decay

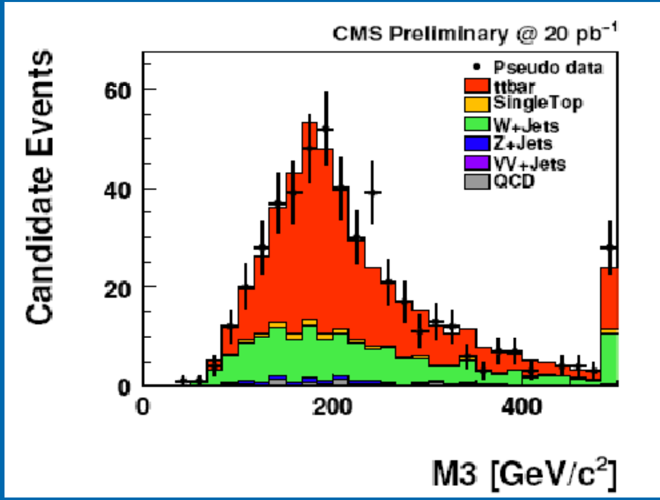
Cross section is extracted by template fits to discriminating variables.

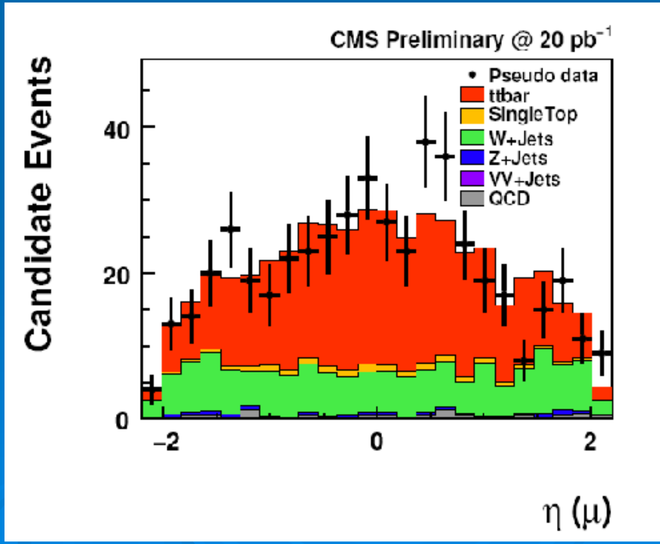
M3: invariant mass of 3-jet combination giving highest vector sum of jet p_T's

With 20 pb-1 of data, σ(ttbar) can be measured with ~20% (stat) & ~25% (syst) uncertainties.

-- syst. uncertainty dominated by jet energy scale.

CMS PAS TOP-09-003





Conclusions

- Early observation of ttbar events is essential part of the detector commissioning.
- Rich program of Top physics at CMS.
- Top rediscovery possible with early LHC data.

  dilepton channel (10 pb^{-1} of data @ $\sqrt{s}$ = 10 TeV)

  $\Delta\sigma/\sigma$ = 15% (stat) ±10%(syst) ± 10%(lumi)

  e+jets channel (20 pb^{-1} of data @ $\sqrt{s}$ = 10 TeV)

  $\Delta\sigma/\sigma$ = 23%(stat) ± 20%(syst) ± 10%(lumi)

  μ+jets channel (20pb-1 of data @ $\sqrt{s}$ = 10 TeV)

  $\Delta\sigma/\sigma$ = ~20%(stat) ± ~25%(syst) ± 10%(lumi)

Backup Slides

Dilepton Channel

Data sample	Main selection e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
$t\bar{t} \to \ell\ell$	11.6 ± 0.2	13.2 ± 0.2	35.6 ± 0.4
other $t\bar{t}$	0.21 ± 0.03	0.04 ± 0.01	0.46 ± 0.04
Single top	0.46 ± 0.03	0.56 ± 0.03	1.40 ± 0.06
$WW/WZ/ZZ$	0.26 ± 0.02	0.33 ± 0.03	0.71 ± 0.05
DY$\to \tau\tau +$jets	0.3 ± 0.1	0.3 ± 0.1	0.7 ± 0.2
DY$\to ee/\mu\mu +$jets	4.1 ± 0.4	5.3 ± 0.4	0.08 ± 0.05
$W +$jets	0.2 ± 0.1	< 0.1	0.3 ± 0.1
QCD	< 1	< 0.4	< 0.4
Total backgrounds	5.5 ± 0.4	6.6 ± 0.4	3.7 ± 0.2
Data driven fakes	1.1 ± 0.6	0.8 ± 0.4	2.5 ± 1.2
Data driven DY	4.0 ± 1.3	5.1 ± 1.6	

Table 3: Summary of uncertainties reported in percent relative to the expected number of signal events. The uncertainties in e^+e^- and $\mu^+\mu^-$ final states are similar and thus combined.

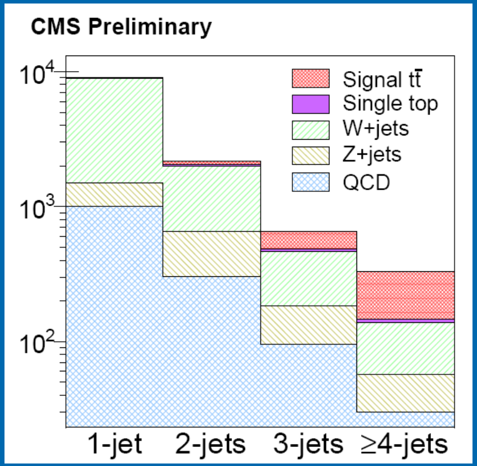
Source	e^+e^- and $\mu^+\mu^-$	$e^\pm\mu^\mp$
Statistical	25	18
Lepton ID	5	5
Lepton isolation	3	3
Jet energy scale	8	5
Theory	4	4
DY$\to ee, \mu\mu$ method	10	
Fake leptons method	4	4
Residual background	5	4
Integrated luminosity	10	10

The main sources of systematic uncertainties arise from the imperfect knowledge of the lepton reconstruction efficiencies, the background subtraction, the jet energy scale, the prediction of the jet multiplicity spectrum, the modeling of the $t\bar{t}$ production, and the luminosity normaliza-

ttbar→e+jets

	Cuts	$t\bar{t}$	W+jets	Z+jets	QCD	Single Top
	-	8280 ± 6	9.1E5 ± 265	8.4E+04 ± 60	1.7E8 ± 3.4E4	1455 ± 2
	Trigger	4727 ± 5	2.0E5 ± 175	2.7E+04 ± 42	3.4E7 ± 1.9E4	669 ± 2
	≥1 Iso e	654 ± 2	6.4E4 ± 102	1.2E+04 ± 29	9030 ± 318	148 ± 1
	=1 Iso e	640 ± 2	6.4E4 ± 102	8672 ± 25	9030 ± 318	146 ± 1
	Muon Veto	590 ± 2	6.4E4 ± 102	8664 ± 25	9030 ± 318	143 ± 1
	≥ 4 jet	215 ± 1	95 ± 4	46 ± 2	76 ± 20	10 ± 0
Option 1	Loose e Veto	208 ± 1	95 ± 3	20 ± 1	76 ± 13	10 ± 0
	$\|\eta\| < 1.442$	172 ± 1	57 ± 2	12 ± 1	31 ±10	8 ± 0
Option 2	$\not{E}_T$> 20 GeV	188 ± 1	83 ± 4	34 ± 2	48 ± 15	9 ± 0
	Z Veto	186 ± 1	83 ± 4	29 ± 2	48 ± 15	9 ± 0
	Conv. Veto	183 ± 1	80 ± 4	28 ± 1	30 ± 14	9 ± 0

Table 1: Number of events passing each stage of the event selection normalized to 20 pb^{-1} as estimated from Monte Carlo Simulation. The uncertainties are the statistical errors from the corresponding Monte Carlo samples.



	Relative Systematic Uncertainty
Jet Energy Scale	15%
$t\bar{t}$ MC Generator	10%
$t\bar{t}$ ISR/FSR uncertainty	3%
W+jets MC Factorization Scale	1%
W+jets MC Matching threshold	5%
Shape uncertainty of Single Top	1%
Shape uncertainty of QCD	2%
PDF uncertainty	5%
Total	20%

Table 3: Systematic uncertainties on the estimation of the cross section. For each uncertainty we symmetrized the effect on the cross section by quoting the larger deviation. The total uncertainty is calculated as the square root of the quadratic sum of the single uncertainties.

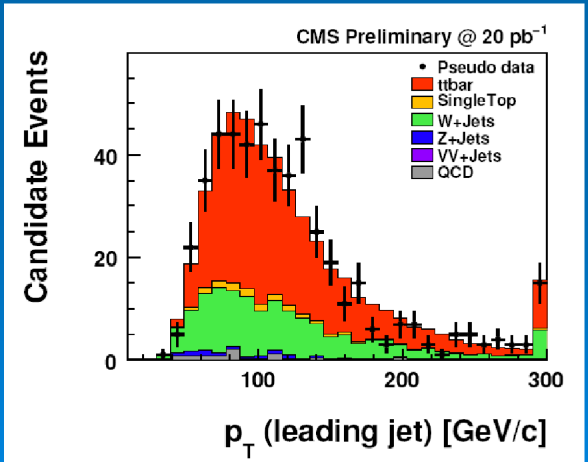
ttbar→μ+jets

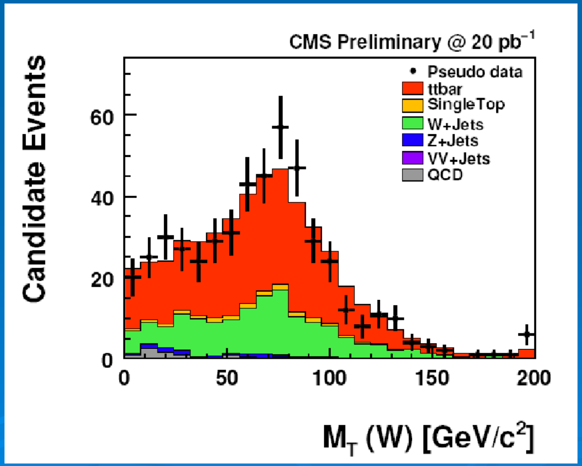
Table 2: Cut-flow table. Event yields normalized to an integrated luminosity of 20 pb^{-1}, where cuts are sequentially applied. The second row, labelled 'Trigger', corresponds to the number of all generated events which satisfy the trigger requirement.

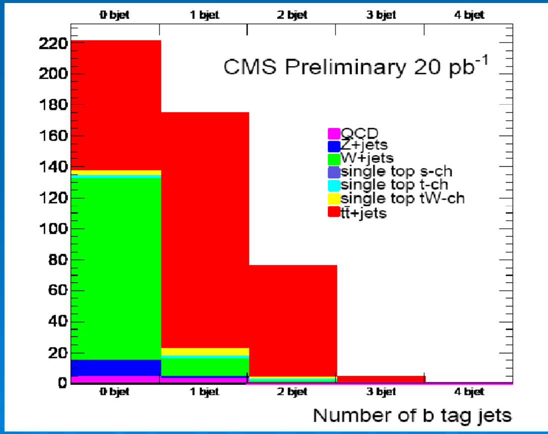
	$t\bar{t}$+jets	$t\bar{t}$+jets	Single top			W+jets	Z+jets	VV+jets	QCD
	s.l. μ	other	s-Ch.	t-Ch.	tW				
AllEvents	1,220	7,060	32	832	580	912,000	76,240	236	2,546,279
Trigger	978	1,418	10	260	147	168,633	20,952	100	2,032,021
≥ 1 tight μ	620	345	5	140	69	110,509	15,296	73	7,200
< 2 tight μ	620	309	5	140	66	110,509	9,300	62	7,200
no tight e	620	264	5	140	62	110,508	9,292	53	7,200
veto on loose μ	618	228	5	140	60	110,503	5,492	44	7,192
veto no loose e	616	183	5	140	56	110,469	5,415	34	7,188
≥ 1 jet	614	180	4	125	55	16,998	1,325	18	2,701
≥ 2 jets	593	158	3	63	47	3,076	256	5	387
≥ 3 jets	489	99	1	18	27	651	51	1	60
≥ 4 jets	277	43	0	5	9	140	10	0	7

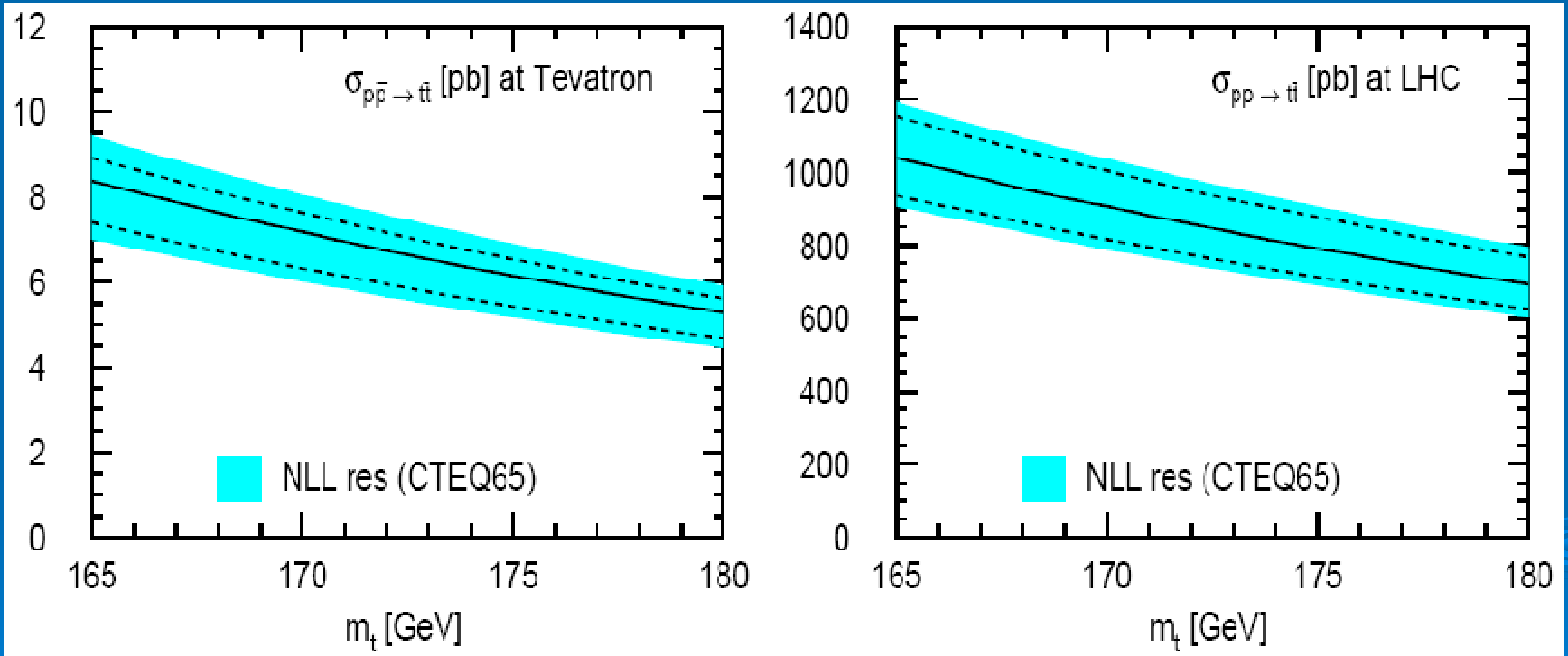
Table 5: Summary of statistical and systematic uncertainties in the template fits to the $\eta(\mu)$, M3 and M3′ variables.

Source	Uncertainty [%]		
	Fit to $\eta(\mu)$	Fit to M3	Fit to M3′
Statistical Uncertainty (20 pb^{-1})	17.7	16.3	11.5
Jet Energy Scale	16.7	15.1	19
$t\bar{t}$ MC Generator	1.9	14.9	14
$t\bar{t}$ ISR/FSR	3.3	7.7	2
W+jets Factorization scale	4.4	4.7	4
W+jets Matching threshold	5.5	2.8	4
Single Top Shape	0.1	0.8	1
PDF Uncertainty	5.0	5.0	5.0
Total Systematic Error	19.2	23.8	25.0
Luminosity Error	10.0	10.0	10.0









$\sigma_{p\bar{p}\to t\bar{t}}$ [pb] at Tevatron
NLL res (CTEQ65)
12
10
8
6
4
2
0
165
170
175
180
m_t [GeV]
$\sigma_{pp\to t\bar{t}}$ [pb] at LHC
NLL res (CTEQ65)
1400
1200
1000
800
600
400
200
0
165
170
175
180
m_t [GeV]