



Top quark cross-section measurements with CMS

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on behalf of CMS Collaboration
Physics at the LHC, Perugia, Italia
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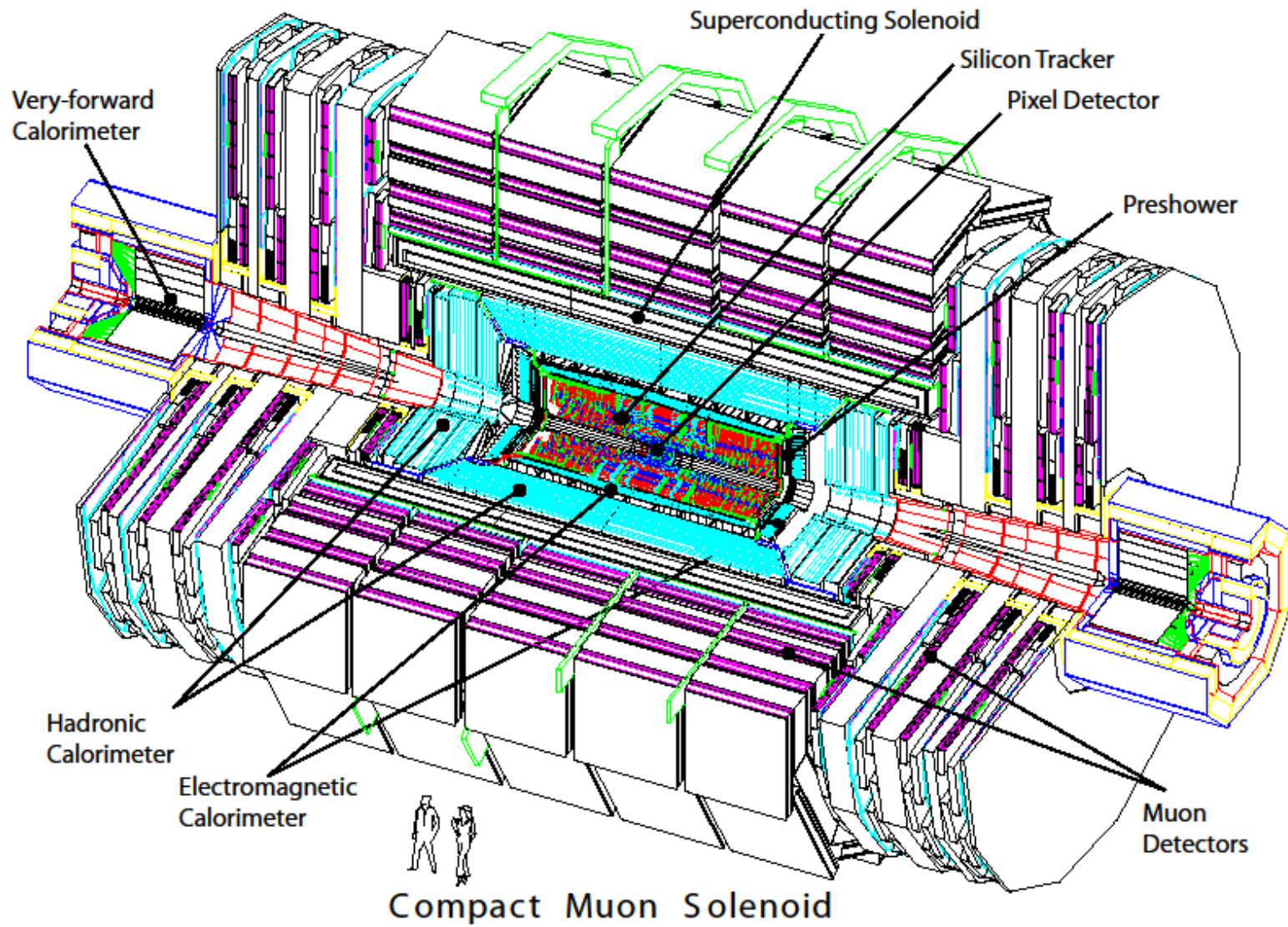
Motivation



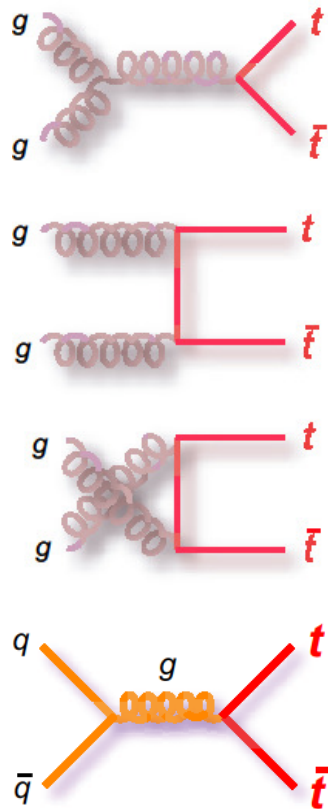
- Probing the dynamics of heavy particle production at the multi-TeV scale:
 - The top quark is the heaviest known particle, with mass close to the natural electroweak scale.
 - New energy scale reachable at the LHC.
- New physics can manifest themselves in the production dynamics of top quarks:
 - Absolute rate / total cross-section.
 - Differential distributions.
- Pave the way toward precision measurements of top quark properties:
 - Mass and width.
 - Branching ratios and non-SM decay modes.
 - Couplings to bosons (W, Z, photons, Higgs).

T. Speer's talk: Measurements of top quark mass and properties in CMS

The CMS Detector

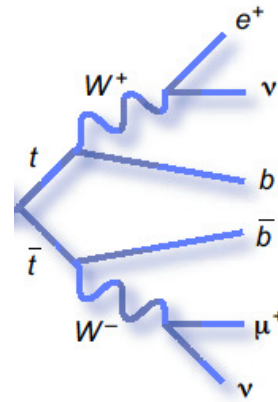


Top quark pair production and decay

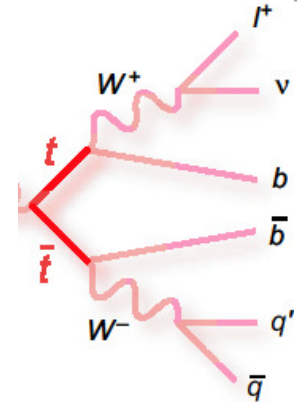


~85 %

~15 %



Dilepton: ~10%



Lepton+jets: ~45%

Produced through QCD processes.

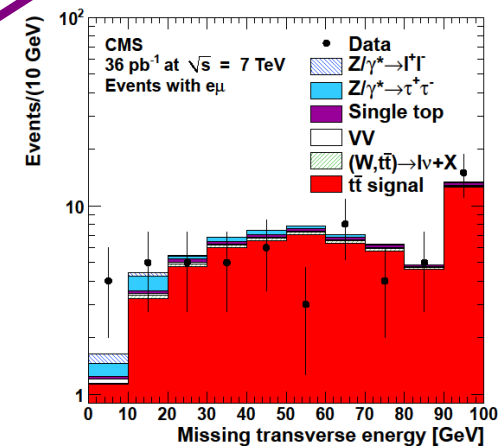
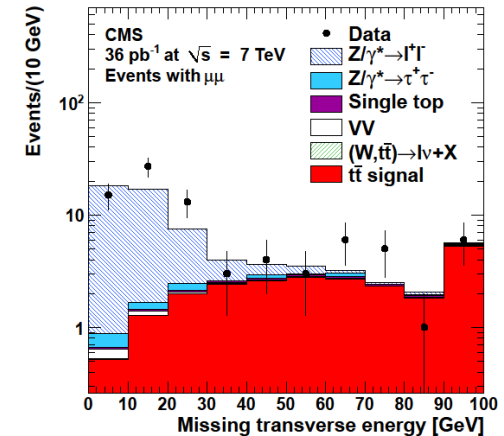
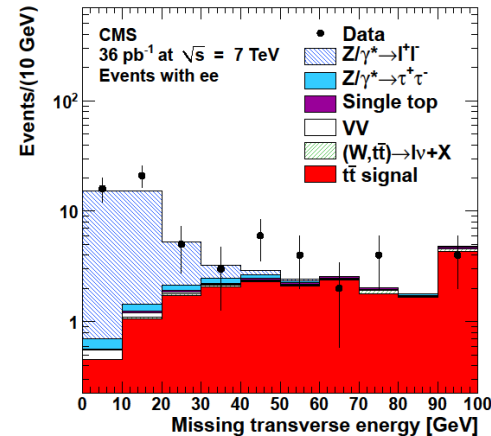
MCFM NLO calculation:

$$\sigma_{t\bar{t}} = 157^{+23}_{-24} \text{ pb}$$

- > All analysis shown used the full 2010 dataset.
 - > Total integrated luminosity is ~36 pb⁻¹.
- > Huge thanks to the LHC Operations Team for a very successful campaign in 2010.

Dilepton channel (i)

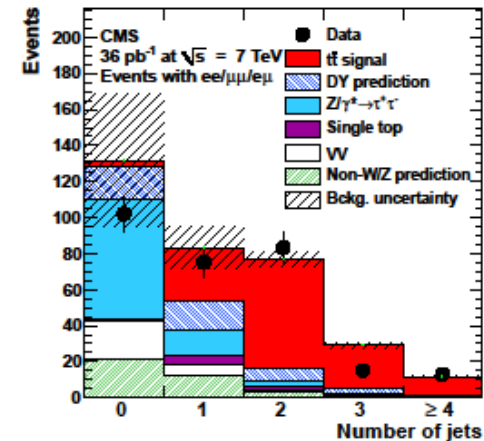
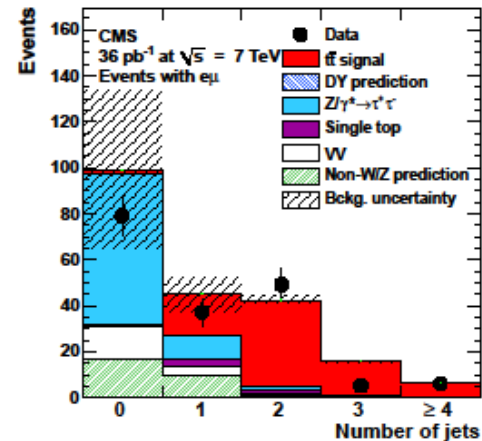
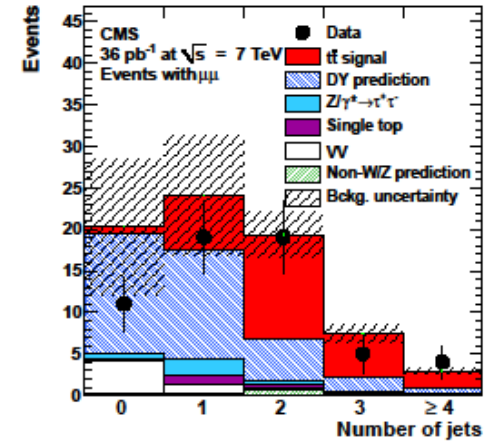
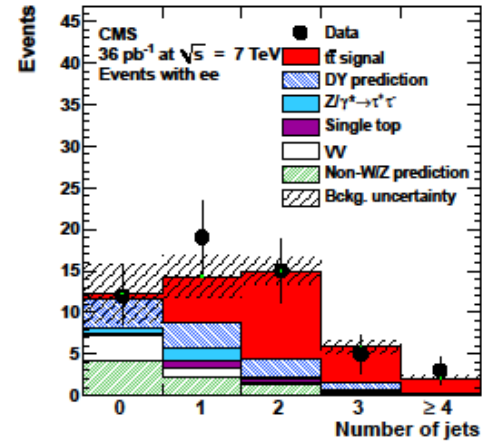
- Events are required to fire single lepton (e,μ) or dielectron triggers.
- Two oppositely charged leptons (e,μ) with $p_T > 20$ GeV.
- One or more jets.
- Veto on dilepton pair mass:
 - $M(l\bar{l}) < 12$ GeV.
 - $M(ee)$ & $M(\mu\mu)$ inside a 15 GeV window centered at Z mass.
- MET cut
 - $MET > 30$ GeV for ≥ 2 jets events.
 - $MET > 50$ GeV for 1 jet events.
- MET & dilepton transverse mass cut in $e\mu$ channel.



Dilepton channel (ii)



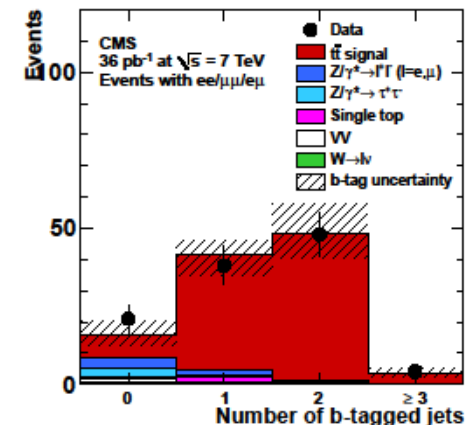
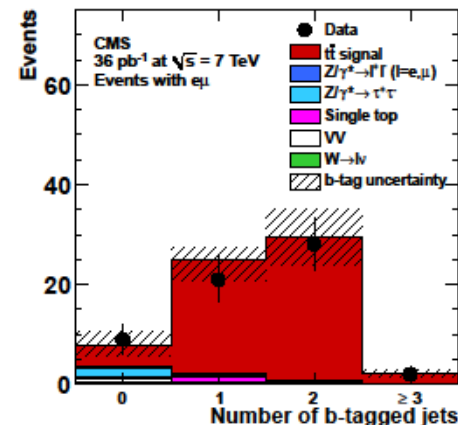
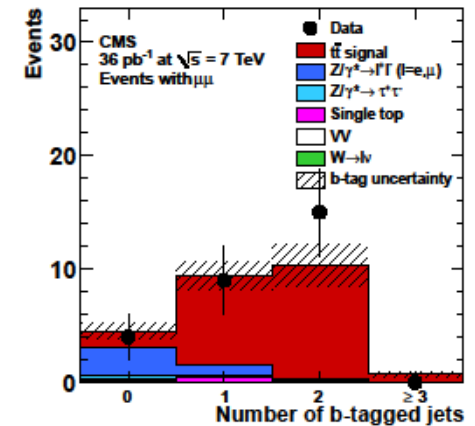
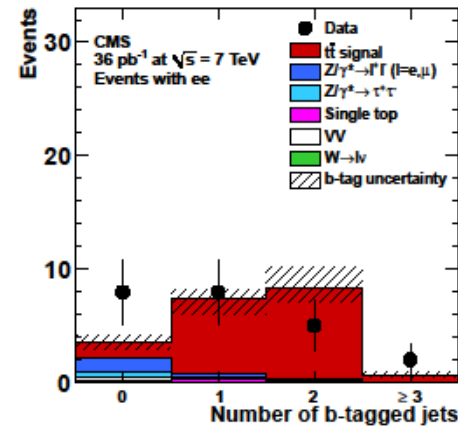
- Background estimation:
 - Drell-Yan/Z: Estimated using data-driven method by normalization to Z peak in ee and $\mu\mu$ channels.
 - W +jets, $t\bar{t}$, and QCD are estimated using data-driven method.
 - Single top, dibosons, and Z to $\tau\tau$ are estimated using MC.
- Measurement without b -tagging, use events with one and two or more jets (Six channels).



Expected and observed yields in data in the non-b-tagged sample.

Dilepton channel (iii)

- Track counting based B-tagging algorithm is used to reduce background.
- Measurement without b-tagging, use events with two or more jets and at least one b-tagged jets (Three channels).
- Cross-section is individually extracted from the 9 channels and then combined using the BLUE method.



Expected and observed yields in data in the b-tagged sample.

Dilepton channel (iv)

› Results

$$\sigma(pp \rightarrow t\bar{t}) = 168 \pm 18 \text{ (stat.)} \pm 14 \text{ (syst.)} \pm 7 \text{ (lumi.) pb.}$$

› Dominant systematic uncertainty: Lepton selection, factorization scale, and b-tagging.

Source	$N_{\text{jet}} = 1$		$N_{\text{jet}} \geq 2$	
	$e^+e^- + \mu^+\mu^-$	$e^\pm\mu^\mp$	$e^+e^- + \mu^+\mu^-$	$e^\pm\mu^\mp$
Lepton selection	1.9/1.3	1.1	1.9/1.3	1.1
Lepton selection model	4.0	4.0	4.0	4.0
Hadronic energy scale	-3.0	-5.5	3.8	2.8
Pileup	-2.0	-2.0	0.8	0.8
b tagging (≥ 1 b tag)			5.0	5.0
Branching ratio	1.7	1.7	1.7	1.7
Decay model	2.0	2.0	2.0	2.0
Event Q^2 scale	8.2	10	-2.3	-1.7
Top quark mass	-2.9	-1.0	2.6	1.5
Jet and \cancel{E}_T model	-3.0	-1.0	3.2	0.4
Shower model	1.0	3.3	-0.7	-0.7
Subtotal without b tagging	11.2/11.1	13.1	8.0/7.9	6.2
Subtotal with b tagging			9.5/9.4	8.0
Luminosity	4.0	4.0	4.0	4.0

SUBMITTED to JHEP
arXiv 1105.5661

Lepton+jets channel: Event selection

- › Events are required to pass either as single electron or single muon trigger.
- › Exactly one isolated high p_T lepton:
 - › electron $p_T > 30$ GeV, μ $p_T > 20$ GeV), loose 2nd lepton veto.
- › Four or more high p_T jets with $p_T > 30$ (25) GeV in the non-btagging (b-tagging) analysis.
- › Jets and missing transverse energy are reconstructed using particle-flow (PF) based algorithms.
 - › Provides the best energy resolution for calculation of missing transverse energy and other kinematic quantities.
- › A secondary-vertex based algorithm is used to discriminate light and heavy flavor jets.

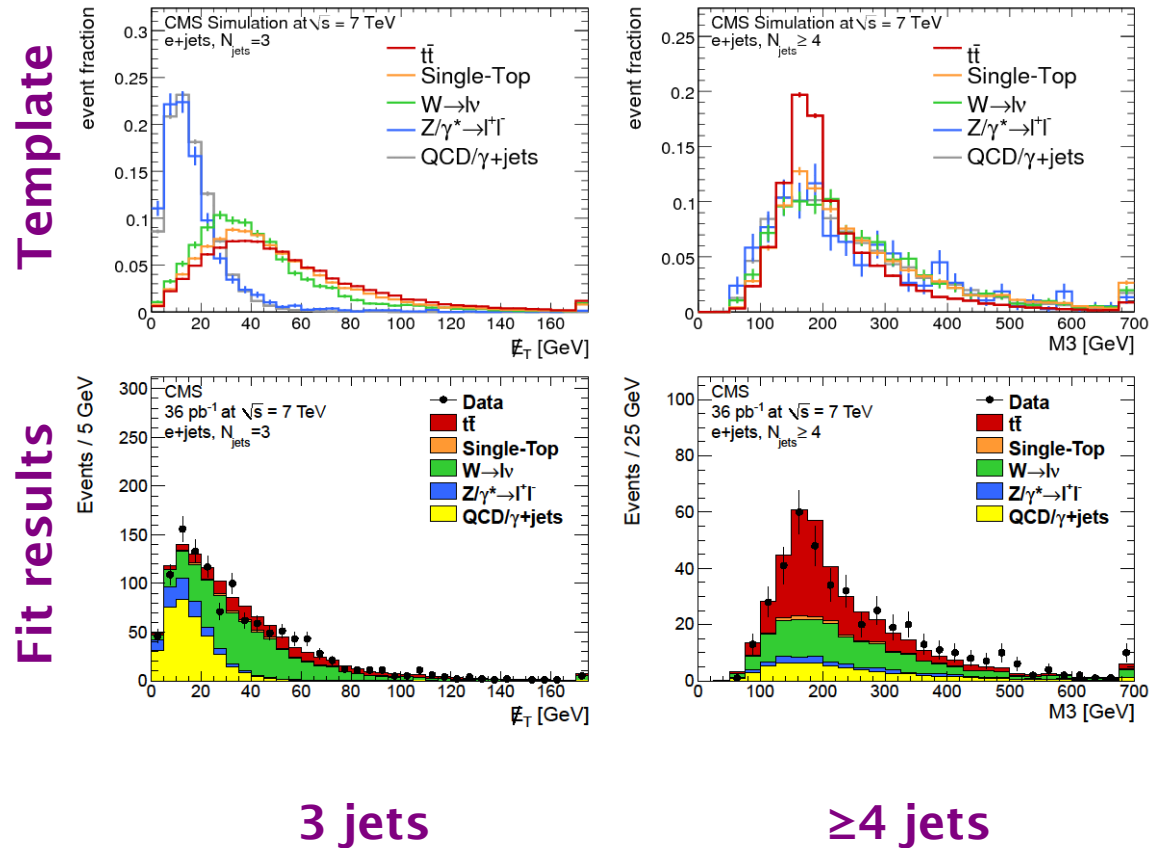
Lepton+jets without b-tagging (i)



- Simultaneous fit of MET in the 3 jets subsample, and M3 in the ≥ 4 jets subsamples.
- SM background templates are taken from MC.
- QCD templates are obtained from data.
- Statistical method:
- Neyman construction with

$$\beta_{t\bar{t}} = \frac{\sigma_{t\bar{t}}^{\text{fit}}}{\sigma_{t\bar{t}}^{\text{theory}}}$$

as test statistic.



Lepton+jets without b-tagging (ii)

› Results

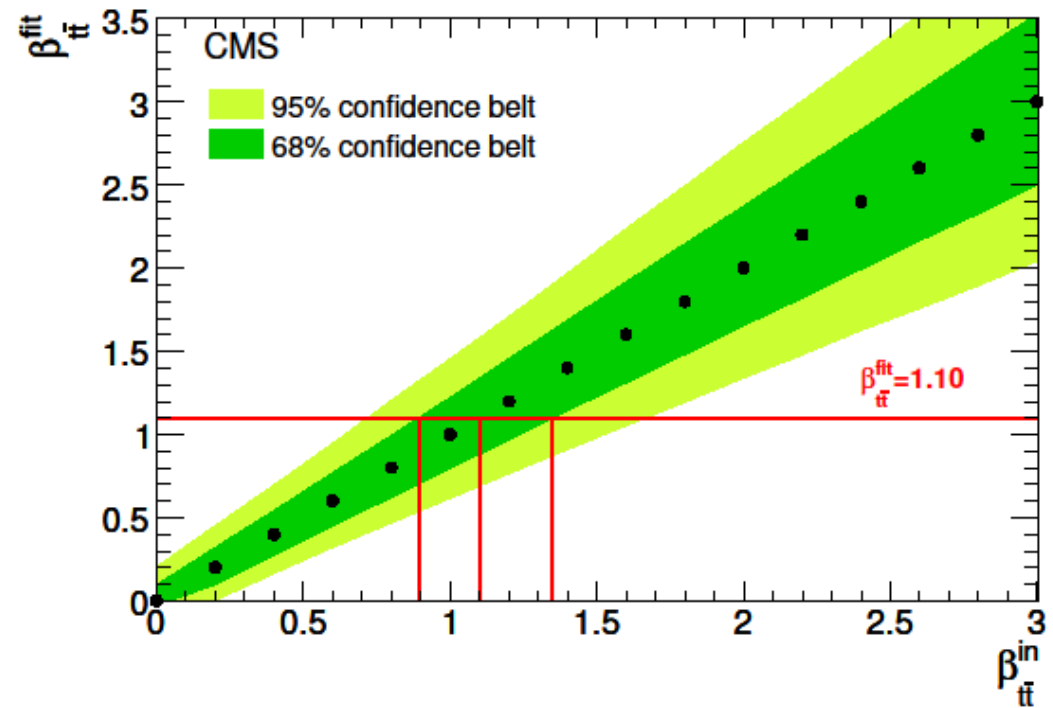
$$e + \text{jets} : \sigma_{t\bar{t}} = 180_{-38}^{+45} (\text{stat.} + \text{syst.}) \pm 7 (\text{lumi.}) \text{ pb}$$

$$\mu + \text{jets} : \sigma_{t\bar{t}} = 168_{-35}^{+42} (\text{stat.} + \text{syst.}) \pm 7 (\text{lumi.}) \text{ pb}$$

$$\ell + \text{jets} : \sigma_{t\bar{t}} = 173_{-32}^{+39} (\text{stat.} + \text{syst.}) \pm 7 (\text{lumi.}) \text{ pb}$$

› Dominant systematics

- › Jet energy corrections
- › Factorization scale



Lepton+jets without b-tagging (iii)

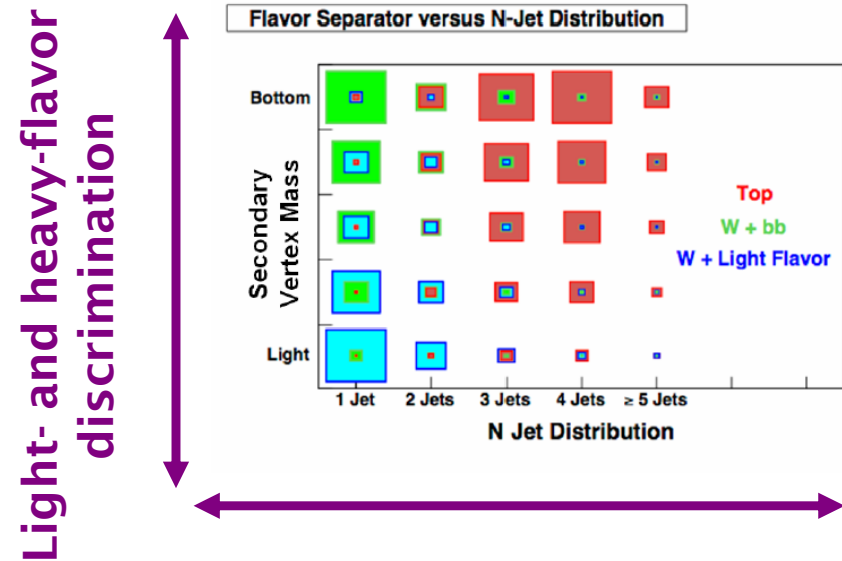
	electron+jets channel		muon+jets channel		combined result	
	stat.+syst. uncertainty	syst. only	stat.+syst. uncertainty	syst. only	stat.+syst. uncertainty	syst. only
Stat. uncertainty	+14.0% -13.1%	–	+11.4% -10.8%	–	+8.7% -8.4%	–
JES	+23.5% -20.4%	+18.9% -15.6%	+21.9% -18.8%	+18.7% -15.4%	+20.3% -17.6%	+18.3% -15.5%
Factorization scale	+15.5% -14.3%	+6.7% -5.7%	+13.8% -12.9%	+7.8% -7.1%	+11.2% -10.6%	+7.1% -6.5%
Matching threshold	+15.0% -14.0%	+5.4% -4.9%	+14.1% -12.9%	+8.3% -7.1%	+10.5% -9.8%	+5.9% -5.0%
Pileup	+14.4% -13.8%	+3.4% -4.3%	+11.7% -11.3%	+2.6% -3.3%	+9.3% -9.3%	+3.3% -4.0%
ID/reconstruction	+14.5% -13.6%	+3.8% -3.7%	+11.9% -11.2%	+3.4% -3.0%	+9.2% -8.7%	+3.0% -2.3%
QCD rate & shape	+14.7% -14.8%	+4.5% -6.9%	+11.4% -10.9%	+0.0% -1.5%	+9.1% -8.9%	+2.7% -2.9%
ISR/FSR variation	+14.0% -13.3%	+0.0% -2.3%	+11.9% -11.3%	+3.4% -3.3%	+9.0% -8.6%	+2.3% -1.8%
JER	+14.0% -13.1%	+0.0% -0.0%	+11.4% -10.8%	+0.0% -0.0%	+8.8% -8.4%	+1.3% -0.0%
PDF uncertainty	+14.0% -13.1%	+0.0% -0.0%	+11.4% -10.9%	+0.0% -1.5%	+8.7% -8.5%	+0.0% -1.3%
Total	+26.6% -22.2%	+22.6% -17.9%	+25.3% -20.9%	+22.6% -17.9%	+23.5% -19.3%	+21.8% -17.4%

SUBMITTED to EPJC

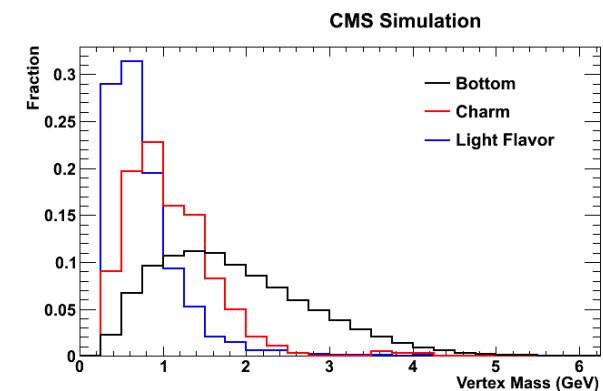
arXiv: 1106.0902

Lepton+jets with b-tagging (i)

- Problems with simple fit or counting:
 - Large uncertainties on W+heavy flavors normalization.
 - Large systematic uncertainties on b-tagging and JES.
- Solutions:
 - Look over many jet bins.
 - Split up 1 tag and ≥ 2 tags events.
- Extra event selection criteria:
 - Requires missing transverse energy (MET) > 20 GeV.
- Use the secondary vertex mass of the leading b-jet as flavor-discriminating variables.



Top and W discrimination.



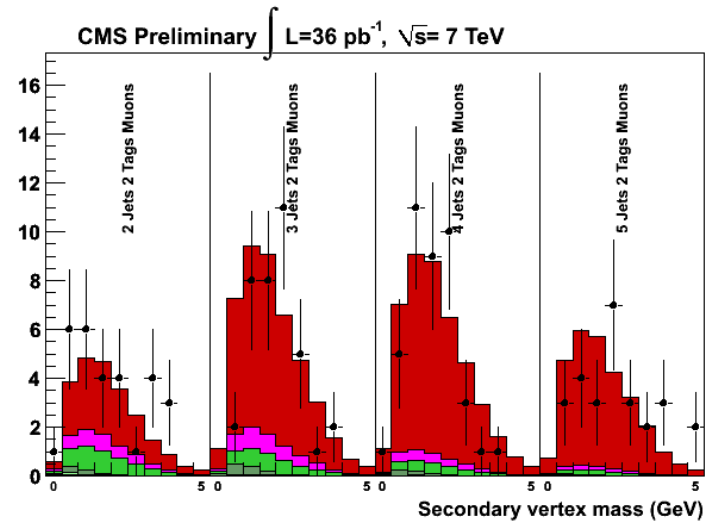
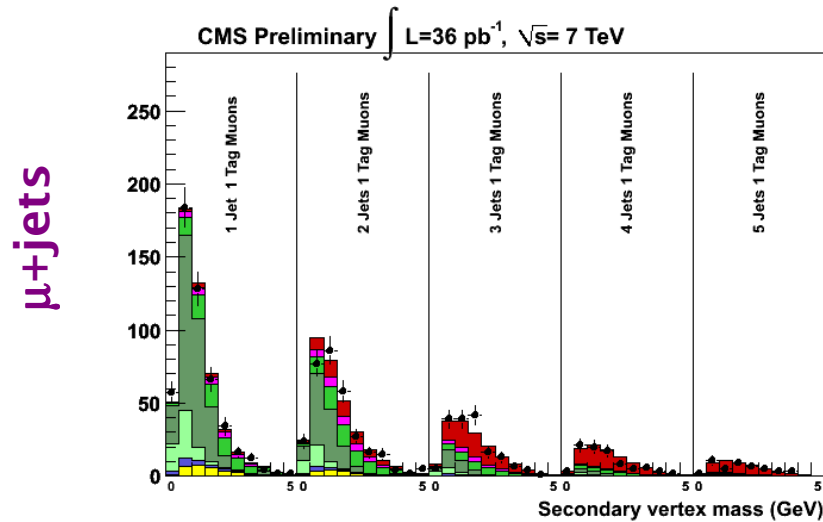
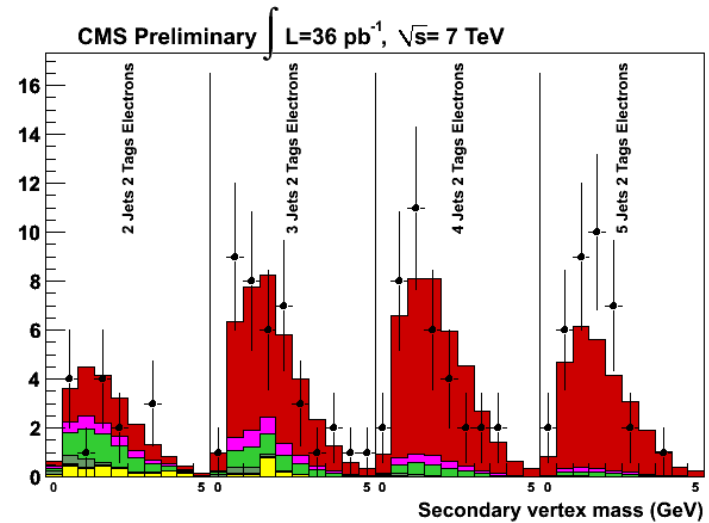
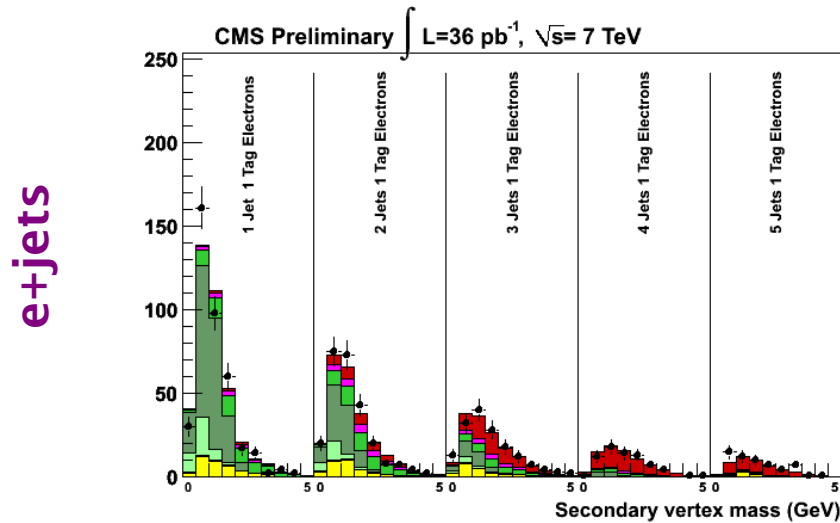
Templates of SV mass

Lepton+jets with b-tagging (ii)

- Simultaneous profile likelihood fit in 18 subsample:
 - 2 lepton flavors (electron + muon).
 - [1-5] jets for events with 1 b-tag.
 - [1-4] jets for events with ≥ 2 b-tags.
- Constrain the normalization of some background processes to be within the large range around of theoretical predictions.
- Treat some of the systematic uncertainties as nuisance parameters:

$$-2 \ln L = -2 \left\{ \sum_{i,j}^{tag,jet \text{ bins}} \sum_k (\ln \mathcal{P}(N_k^{obs}(i,j), N_k^{exp}(i,j))) - \frac{1}{2} \sum_l^{constraints} \frac{(C_X - \hat{C}_X)^2}{\sigma_{C_X}^2} \right\}$$

Lepton+jets with b-tagging (iii)



[1-5] jets, 1 b-tag

[1-4] jets, ≥ 2 b-tags

Lepton+jets with b-tagging (iv)

> Results

$$\sigma_{t\bar{t}} = 150 \pm 9 \text{ (stat.)} \pm 17 \text{ (syst.)} \pm 6 \text{ (lum.) pb.}$$

> Dominant systematics: B-tagging efficiency, jet energy corrections, factorization scale for W+jets Monte Carlo

Table 6: List of systematic uncertainties for the combined electron and muon analysis. Due to the correlation between parameters in the fit, the combined number is not the sum of the squares of the contributions.

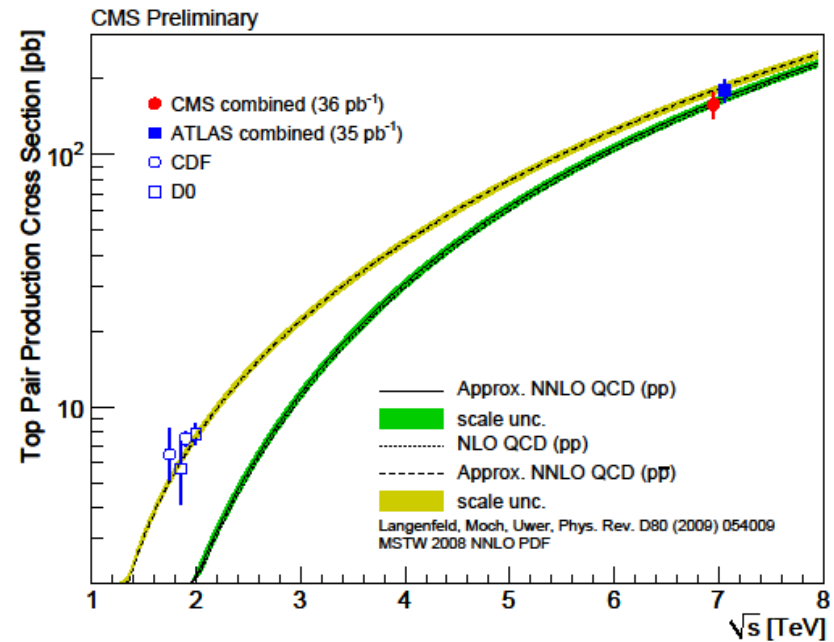
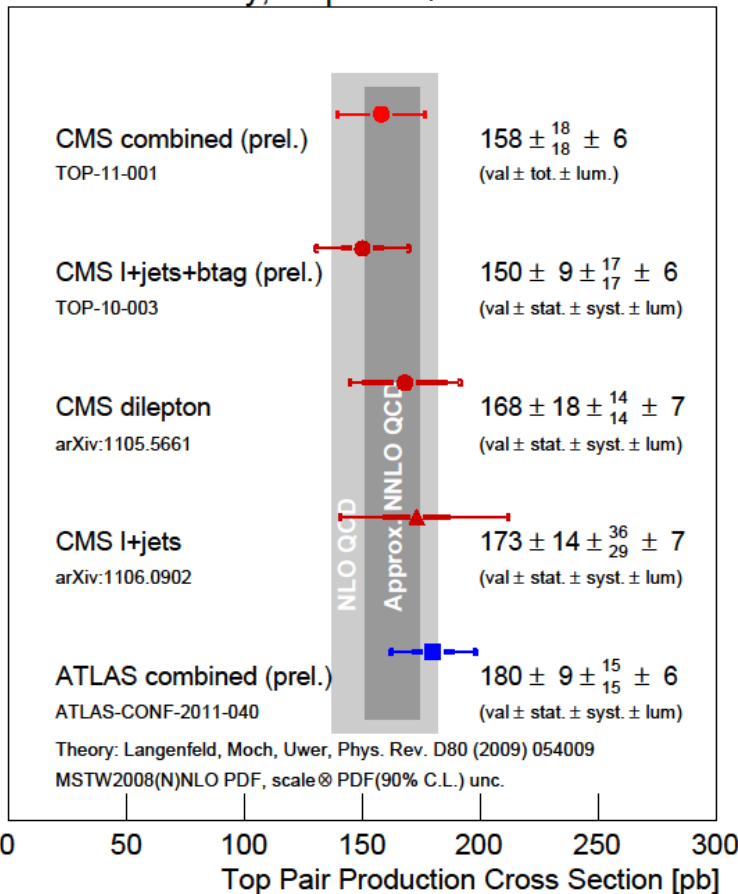
Source	Uncertainty (%)
Systematic uncertainties	
Lepton ID/reco/trigger	3
Unclustered E_T^{miss} resolution	< 1
$t\bar{t}$ + Jets Q^2 -scale	2
ISR/FSR	2
ME to PS matching	2
PDF	3.4
Profile likelihood parameters	
Jet energy scale and resolution	7.0
b tag efficiency	7.5
W+Jets Q^2 -scale	9.1
Combined	11.6

Dilepton and lepton+jets

- BLUE method is used to combine dilepton and lepton+jets with b-tagging results

$$\sigma_{t\bar{t}} = 158 \pm 10 \text{ (stat.)} \pm 15 \text{ (syst.)} \pm 6 \text{ (lumi.) pb.}$$

CMS Preliminary, 36 pb⁻¹ at $\sqrt{s}=7$ TeV



Approximate NNLO calculation

HATHOR: 164^{+10}_{-13} pb

Kidonakis: 163^{+11}_{-10} pb

Summary and conclusions



- Measurements of top quark pair production cross section has been performed in CMS using the full 2010 dataset.
 - Performed in multiple channels: dilepton, lepton+jets.
 - Utilized different techniques: counting, template fit, b-tagging.
- Results are in good agreements with theoretical calculations.
 - Experimental uncertainties are already near theoretical uncertainties.
- Update on the measurements with 2011 data, and inclusion of more channels are ongoing.

Backup slides

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