Measurement of the $t\bar{t}$ Production Cross Section in pp Collisions at $\sqrt{7}$ TeV

(by CMS Collaboration)

(arxiv:1106.0902)

ESHEP 2011, Group F

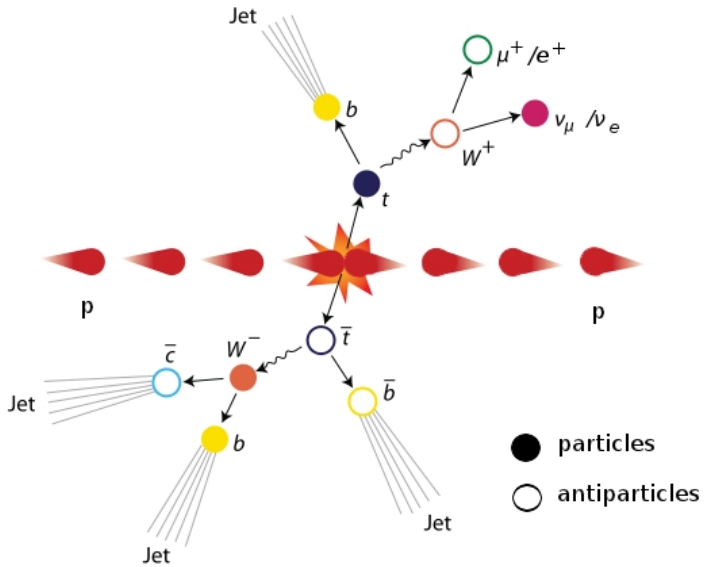
September 18, 2011

Motivation & Event topology

To check the validity of the SM.
Confirmation of the theory prediction $\sigma_{t\bar{t}} = 165^{+11}_{-16}$ pb (NNLO log).

- t discovered in 1995,
- t decays before hadronization,
- test of the CMS detector performance,
- important background in new physics,
- sensitivity to new physics.

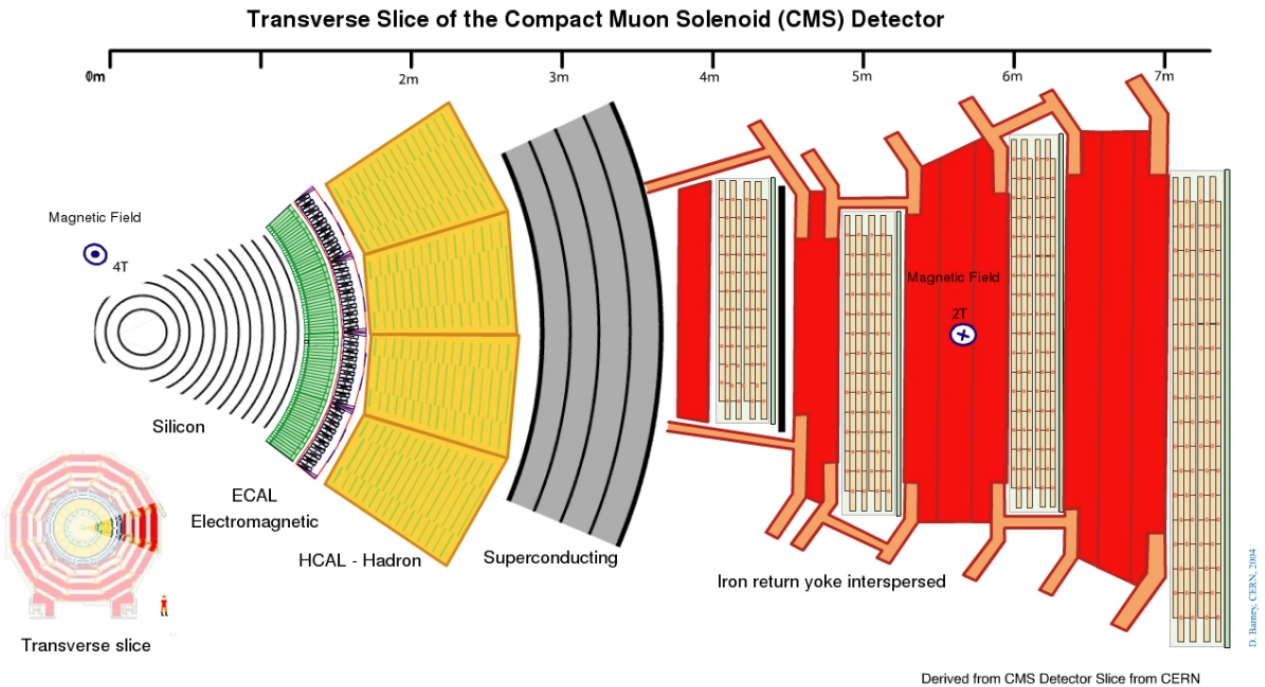
Lepton (μ/e) + jets channel



Signatures:

- lepton with high p_T,
- large $\not{E}_T$ associated with undetected neutrino,
- 4 jets, 2 come from b.

CMS Detector



- Analogue Si tracker in 3.8T magnetic field gives high p_T resolution
- High granularity homogeneous $PbWO_4$ ECAL
- Brass/steel and plastic scintillator HCAL
- Drift tubes and cathode strip chambers detect muon tracks

Event Reconstruction

- **Electrons** - ECAL cluster + associated track + brem clusters
- **Muons** - Must be found by both global (outside in) and track (inside out) algorithms
- **Jets** - Reconstruct charged hadrons, neutral hadrons and photons from particle flow, calibrate calorimeter energy based on particle type, form into jets using anti-kt (cone size of 0.5) algorithm
- **Missing Transverse Energy** - Negative of the vector sum of particles' p_T from particle flow reconstruction

Event Selection

Jet selection

- $p_{\mathrm{T}}^{\mathrm{jet}} > 30\mathrm{GeV}$, $|\eta^{\mathrm{jet}}| < 2.4$
- Remove jets matched to isolated leptons

Event selection

- At least one primary vertex
- Single lepton trigger: $E_{\mathrm{T}}^{e}, p_{\mathrm{T}}^{\mu} > 10\text{-}22, 9\text{-}15\mathrm{GeV}$
- 1 lepton and at least 3 jets
- No requirement on $E_{\mathrm{T}}^{\mathrm{miss}}$
- No b-tagging

Lepton selection

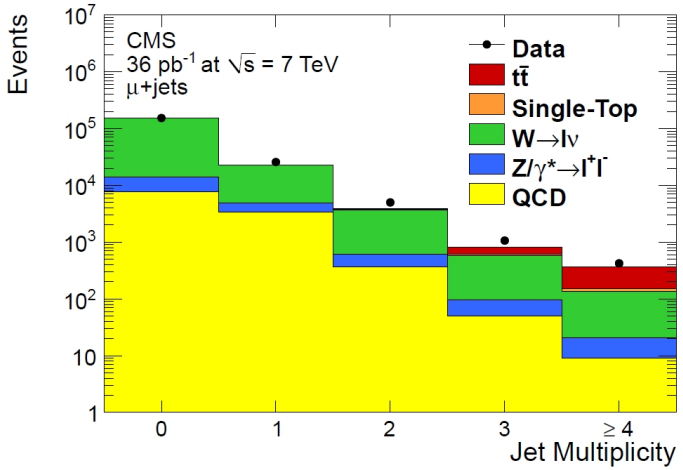
- $E_{\mathrm{T}}^{e} > 30\mathrm{GeV}$, $p_{\mathrm{T}}^{\mu} > 20\mathrm{GeV}$
- $|\eta^{e}| < 2.5$, $|\eta^{\mu}| < 2.1$
- Isolation requirement

Lepton efficiencies

- Account for trigger, ID, isolation
- Extracted using tag-and-probe with Z events
- $\epsilon_{\mathrm{id+iso}}^{e} = 0.75$, $\epsilon_{\mathrm{id+iso}}^{\mu} = 0.88$
- $\epsilon_{\mathrm{trig}}^{e} = 0.982$, $\epsilon_{\mathrm{trig}}^{\mu} = 0.922$

Background processes

1. Single Top $\sigma = (21 \pm 1)$ pb , NLO, MCFM
2. W($l\nu$) + jets $\sigma = (31.3 \pm 1.6)$ nb, NNLO, FEWZ
3. Z(ll) + jets $\sigma = (3.05 \pm 0.13)$ nb, NNLO, FEWZ
4. Diboson – neglected
5. QCD (PYTHIA)



Simulation procedure:

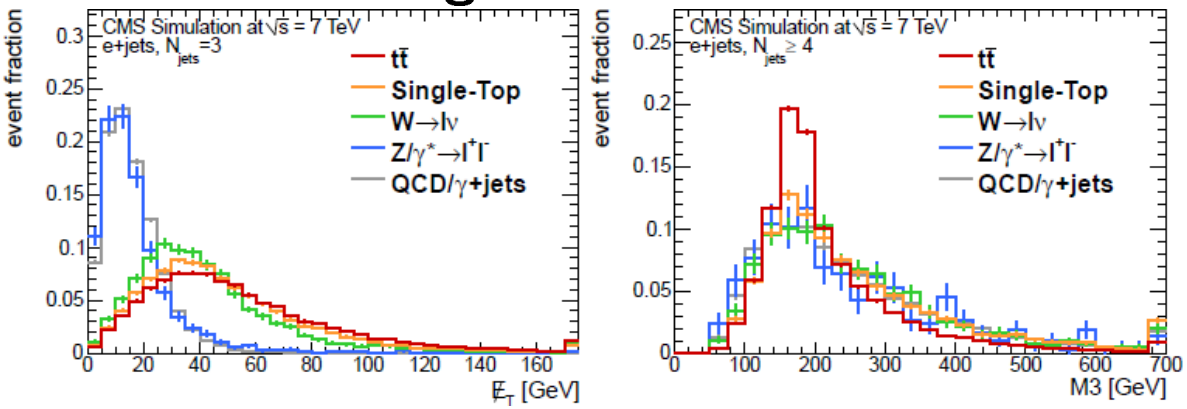
1. MadGraph - parton-level, ME up to 4 jets
2. PYTHIA - showering (MLM matching)
3. GEANT4 based CMS simulation

QCD background:

- Preliminary estimate with Pythia generated events
- From data (using sidebands depleted of W):
  - Electron sample – 2 out of 3 quality criteria fail (IP, isolation, electron PID)
  - Muon sample – sideband in isolation

Cross section measurement

Discriminating variables:



3 jet bin: $\not{E}_T$
4 jet bin: $M3$
$M3$ = inv. mass of 3-jet combination with max p_T

Using templates:

$$\mu_j[i] = \sum_k \beta_k \cdot \alpha_{jk}[i] \Rightarrow$$

Maximum Likelihood fit to get $\beta_k = \sigma_k / \sigma_k^{prediction}$ (for $t\bar{t}$ and all the backgrounds)

Constraints:

- $\sigma^{3-jets}/\sigma^{>=4-jets}$ fixed,
- $\sigma^{single-top}$ and $\sigma^{W+jets}/\sigma^{Z+jets}$ constrained from theory with Gaussian term with $\sigma = 30\%$,
- independent measurements in e and μ channel, then combined.

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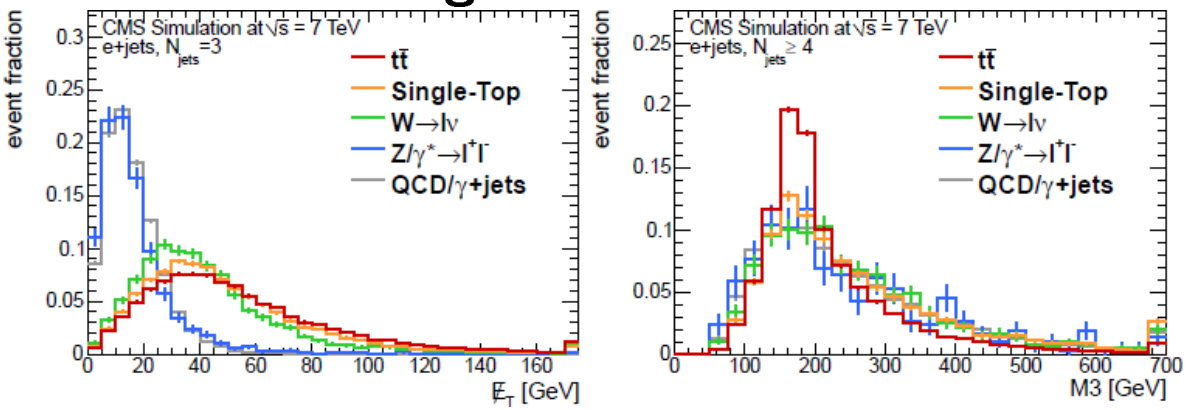

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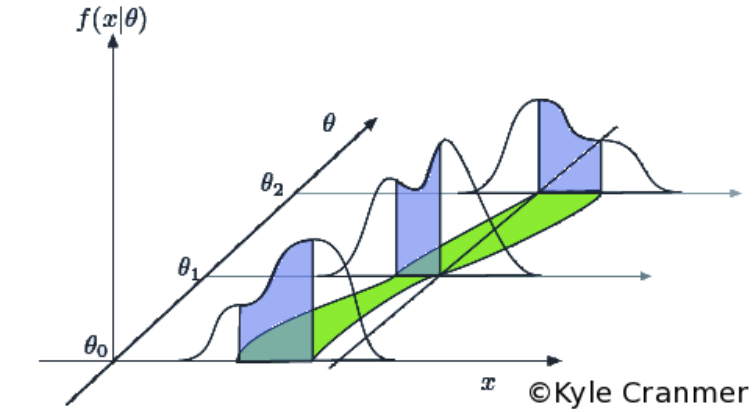
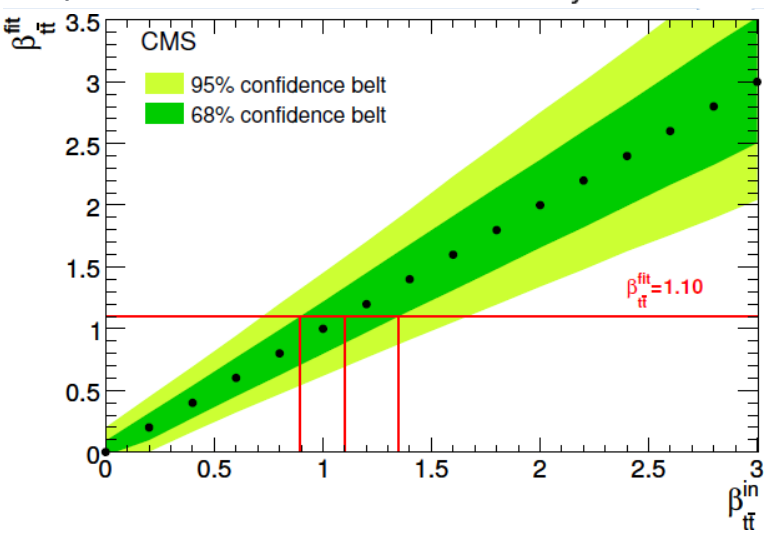
Cross-Section Measurement II

Use of Neyman Construction to obtain the confidence level of $\sigma^{t\bar{t}}$





Neyman Construction for the combined measurement

- 50 000 pseudo-experiments drawn for each value
- changing randomly each background normalization (gaussian with $\mu = 1$, σ 30% or 50% for QCD)
- and changing each bin content following Poisson distribution
- for each $\beta_{t\bar{t}}$ value $\rightarrow$ median value ($\beta_{t\bar{t}}^{fit}$) and 68% (and 95%) quantiles (confidence belt)
- from the confidence belt $\rightarrow$ $\beta_{t\bar{t}}^{measured}$ with $\pm 1\sigma$ uncertainty is extracted

Systematics

- 9 sources of systematics taken into account. JES is largest.
- Two templates $\alpha_{jk}^{u,\pm}[i]$ are created corresponding to a $\pm 1\sigma$ deviation for every source of systematics uncertainty (eg. JES up, JES down).
- Systematics taken into account in the pseudo experiments using bin-per-bin interpolated templates, with random parameters δ_u extracted by a gaussian distribution with unit width.

	combined result	
	stat.+syst. uncertainty	syst. only
Stat. uncertainty	$^{+8.7\%}_{-8.4\%}$	–
JES	$^{+20.3\%}_{-17.6\%}$	$^{+18.3\%}_{-15.5\%}$
Factorization scale	$^{+11.2\%}_{-10.6\%}$	$^{+7.1\%}_{-6.5\%}$
Matching threshold	$^{+10.5\%}_{-9.8\%}$	$^{+5.9\%}_{-5.0\%}$
Pileup	$^{+9.3\%}_{-9.3\%}$	$^{+3.3\%}_{-4.0\%}$
ID/reconstruction	$^{+9.2\%}_{-8.7\%}$	$^{+3.0\%}_{-2.3\%}$
QCD rate & shape	$^{+9.1\%}_{-8.9\%}$	$^{+2.7\%}_{-2.9\%}$
ISR/FSR variation	$^{+9.0\%}_{-8.6\%}$	$^{+2.3\%}_{-1.8\%}$
JER	$^{+8.8\%}_{-8.4\%}$	$^{+1.3\%}_{-0.0\%}$
PDF uncertainty	$^{+8.7\%}_{-8.5\%}$	$^{+0.0\%}_{-1.3\%}$
Total	$^{+23.5\%}_{-19.3\%}$	$^{+21.8\%}_{-17.4\%}$

$$\alpha_{jk}^{\mathrm{syst}}[i] = \alpha_{jk}[i] + \sum_u |\delta_u| \cdot (\alpha_{jk}^{u,\mathrm{sign}(\delta_u)}[i] - \alpha_{jk}[i])$$

Results

Electron + Jets	$\sigma_{t\bar{t}} = 180^{+45}_{-38}(\text{stat.+syst.}) \pm 7(\text{lumi.})$ pb.
Muon + Jets	$\sigma_{t\bar{t}} = 168^{+42}_{-35}(\text{stat.+syst.}) \pm 7(\text{lumi.})$ pb.
Total	$\sigma_{t\bar{t}} = 173^{+39}_{-32}(\text{stat.+syst.}) \pm 7(\text{lumi.})$ pb.
Prediction	$\sigma_{t\bar{t}} = 163^{+7}_{-5}$ pb. (NNLO)

Cross checks

- Count events with isolated muon and $\geqslant 4$ jets with a more robust selection criteria.
- Use p_T^{μ} and N_{jets} instead of $\not\!\!E_T$ and $M3$.
- Fit η^{μ} and use asymmetry between W^+ and W^- production to determine background.
- Use main method with different selection criteria.

All four cross check are consistent with the main result.

Results: CMS vs ATLAS comparison

CMS $\sigma_{t\bar{t}} = 173^{+39}_{-32}(\text{stat.+syst.}) \pm 7(\text{lumi.})$ pb.
Relative Uncertainty $= +23.5\% \ / \ -19.3\%$

ATLAS $\sigma_{t\bar{t}} = 171 \pm 17(\text{stat.})^{+20}_{-17}(\text{syst.}) \pm 6(\text{lumi.})$ pb.
Relative Uncertainty $= +15.5\% \ / \ -14.5\%$

- Jet energy scale is the largest contribution to relative systematic uncertainty.
- For the CMS result the contribution is $(+18.3\% \ / \ -15.5\%)$.
- For the ATLAS result the contribution is $(+5.7\% \ / \ -6.1\%)$.

Back-up slides