Top Quark Physics with CMS

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(on behalf of CMS Collaboration)

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Outline

• Top Physics
• $\bar{t}t$ Cross Section - Dilepton Channel
• $\bar{t}t$ Cross Section – L+jets Channel
• Single Top Cross Section
• $\bar{t}t$ Invariant Mass
• Top Mass
• Charge Asymmetry
• Summary
Top Quark Physics

• Precise Standard Model measurements
  – Heaviest known elementary particle
  – Constraint on Higgs mass

• A Window to new physics
  – Many models couple preferentially to top
  – New particles may decay to top

• Main background in many new physics scenarios (e.g. SUSY)

• Very useful to calibrate detector
  – Jet energy scale
  – b-tagging efficiency
Top Production

- Pair production in 7 TeV pp collisions:
  - BR($t \rightarrow Wb$) $\approx 1$ in Standard Model
  - Analysis strategy depends on W decay modes

- $\approx 85\%$
- $\approx 15\%$
Top Quark Candidate
\( \bar{t}t \) Cross Section at CMS

- First publication: A first measurement at 3.1 pb\(^{-1}\) in the dileptonic channel:
  - TOP-10-001: «First Measurement of the Cross Section for Top-Quark Pair Production in Proton-Proton Collisions at \( \sqrt{s} = 7 \) TeV», *Phys. Lett. B695 (2011) 424*

- In 2010, Results from 2010 data are based on dataset corresponding to \( L = 35.9 \) pb\(^{-1}\) of data at \( \sqrt{s} = 7 \) TeV.
  - TOP-10-002: «Measurement of the \( \bar{t}t \) Pair production Cross Section at \( \sqrt{s} = 7 \) TeV using the Kinematic Properties of Lepton + Jets Events»
  - TOP-10-003: «Measurement of the \( \bar{t}t \) Pair Production Cross Section at \( \sqrt{s} = 7 \) TeV using b-quark Jet Identification Techniques in Lepton + Jets Events»
  - TOP-11-002 (submitted to JHEP, arXiv:1105.5661): «Measurement of the \( \bar{t}t \) production cross section and the top quark mass in the dilepton channel in pp collisions at \( \sqrt{s} = 7 \) TeV»
• Event Selection
  – two opposite charge leptons:
  – $p_T > 20 \text{ GeV/c}$, $|\eta| < 2.5$ ($2.4$) for $e$ (µ), Isolated in tracker and calorimeter
  – invariant mass selection:
    • $M_{ll} > 12 \text{ GeV/c}^2$, $M_{ll} \neq [91 \pm 15]$
  – jets selection:
    • corrected Jet, $p_T > 30 \text{ GeV/c}$, $|\eta| < 2.5$
  – For each channel, for 2 jets no b-tags, 2 jets 1 b-tag and 1 jet no b-tags

• Main backgrounds after leptonic selection:
  – Drell-Yan $\rightarrow ll$: main background,
    • rejected by Z veto, jets and $E_T$, estimated from data
  – W+Jets, semi-lept. $tt$, QCD: from non-W/Z decays, estimated from data
  – Single top $tW$, diboson, $Z\rightarrow\tau\tau$: small cross-sections, estimated from MC

• Very clean channel, thanks to b-tagging
  - Cut and count experiment
• Event counting with dedicated data-driven techniques for the estimation of background contributions in $e^+e^-$, $\mu^+\mu^-$, and $e^\pm\mu^\mp$ channels
• Combination taking correlation into account using Best Linear Unbiased Estimated

$\sigma_{(t\bar{t})} = 168 \pm 18($stat$) \pm 14($sys$) \pm 7($lum$)$ pb

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• Measurement without b-tagging
• Simultaneous binned likelihood fit to
  – Missing ET with 3 jet
    • discriminate QCD from true W decay
  – M3 with ≥ 4 jets
    • M3 is invariant mass of 3 jets with max $\sum P_T$
    • separates top from other events with real W decays
• $M_T(W)$ shows good agreement with data
• Combined measurement
  • $\sigma_{tt} = 173^{+39}_{-32}$ (stat. + syst.) $\pm 7$ (lumi.) pb
• Compatible with other measurement

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\( \bar{t}t \) Cross Section in the Lepton+Jets Channels with b-Tagging

(TOP-10-003)

- **Measurement with b-tagging**
- **Event Selection:**
  - one lepton (with second lepton veto): \( p_T > 30 \) (20) GeV/c, \( |\eta| < 2.5 \) (2.1) for e (\( \mu \)), Isolated in tracker and calorimeter
  - jets selection: corrected Jet, \( |\eta|<2.4 \)
  - \( \not{E}T \) and b-tag selection: \( \not{E}T > 20 \), Secondary Vertex
- **Simultaneous fit of**
  - Secondary Vertex Mass (from tracks associated with the vertex with a pion mass assumption)
  - Number of jets and b-tagged jets

**Combined Measurement:**
\[
\sigma_{\bar{t}t} = 150 \pm 9 \text{ (stat.)} \pm 17 \text{ (syst.)} \pm 6 \text{ (lumi.)} \text{ pb}
\]
**Cross Section Combined**

- Combined measurement has precision of 12%
- Very good agreement with approximation NNLO theory
- Comparable to world average
Single Top Cross Section  
(CMS-PAS TOP-10-008)

- **Event Selection**
  - Trigger: Single $\mu/e$
  - Existence of a good primary vertex
  - Exactly one muon (electron)
  - Exactly two anti-kt 5 Particle Flow jets with
  - Transverse W boson mass > 40 GeV (50 GeV)

- **Still rather small signal to background ratio:**

- **Complementary methods**
  - Exploit two characteristic features of Single top quark production (**2D analysis**)
  - Use MVA technique Boosted Decision Trees for further separation (**BDT analysis**)

- **CMS combined result**
  - $\sigma(t) = 84 \pm 30$ pb

- **Significance observed (expected)**
  - 2D fit: 3.7 (2.1)
  - BDT: 3.5 (2.9)

\[
|V_{tb}| = \sqrt{\frac{\sigma^{exp}}{\sigma^{th}}} = 1.16 \pm 0.22(exp) \pm 0.02(th)
\]

For $0 \leq |V_{tb}|^2 \leq 1$ (flat prior in $|V_{tb}|^2$):

$|V_{tb}| > 0.69$ @95% CL (BDT analysis)
Reconstruction of $m_{\bar{t}t}$ done in 3 steps
- reconstruction of leptonic W (with MET as $p_T(\mu)$)
  - 2 real solutions $\rightarrow$ keep both
  - imaginary solutions $\rightarrow$ modify MET
- jet-parton association by $\chi^2$ minimisation
  - 5 quantities used: $m_{lep}(top)$, $m_{had}(top)$, $m_{had}(W)$, $p_T(\bar{t}t)$, $H_T$
  - correct association in $\sim$ 80% (in simulation)
- kinematic fit to improve resolution
  - $m_{top} = 172.5$ GeV/c²
  - $m_W = 80.4$ GeV/c²

Looking for narrow resonances
- Model independent

Lepton+jets channels
- $e^{\pm}$ + jets
- $\mu^{\pm}$ + jets

No significant signal observed
Top Quark Mass Measurement in the Dilepton Channels
(submitted to JHEP, arXiv:1105.5661)

- Event Selection:
  - Inclusive single lepton trigger
    - muon with $p_T > 15$ GeV/c ($\mu\mu/\epsilon\mu$) or electron with $ET > 17$ GeV (ee/$\epsilon\mu$)
    - $\geq 2$ leptons, $p_T > 20$ GeV/c $|\eta| < 2.5$
      - Isolated and promptly produced
    - $\geq 2$ jets, $p_T > 30$ GeV/c $|\eta| < 2.5$
      - Anti-$k_T$ (R=0.5), particle flow based algorithm
    - MET $> 30$ (20) GeV for the ee/$\mu\mu$ (e$\mu$) channel
  - Evaluated using 2 methods
    - fully kinematic analysis (KINb)
    - analytical matrix weighting technique (AMWT)
  - Largest systematics from jet energy scales
  - CMS combined result
    - $m_{top} = 175.5 \pm 4.6$ (stat) $\pm 4.6$ (syst) GeV/c$^2$
  - Good agreement with world average
    - $m_{top} = 173.1 \pm 1.1$ GeV/c$^2$

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Top Quark Mass Measurement in the Lepton+jets Channels (CMS-PAS TOP-10-009)

- Event Selection:
  - Exactly one high $p_T$ isolated lepton (electron $p_T > 30$ GeV, $\mu$ $p_T > 20$ GeV), loose 2nd lepton veto and four or more PF jets ($p_T > 30$ GeV).
  - Particle flow jets and missing transverse energy are used to achieve the best expected mass resolution.
- Using Ideogram method
  - A constrained kinematic fit is used to reconstruct the complete kinematics of the event under the hypothesis that the event is a $t\bar{t}$ lepton+jets event
  - A likelihood is calculated for each event in the data sample from the output of the kinematic fit
  - The likelihood calculation takes into account all the possible assignments of jets to quarks in the $t\bar{t}$ lepton+jet event hypothesis, and considers the possibility that the event is a $t\bar{t}$ event or a background event
  - A joint likelihood fit over all events in the data sample is then used to extract the value of the top quark mass
'Fresh from the oven: approved yesterday!' 

- Combination e+jets and $\mu$+jets
  
  \[ m_t = 173.1 \pm 2.1 \text{ (stat)}^{+2.4}_{-2.1} \text{ (JES)} \pm 1.4 \text{ (other syst)} \text{ GeV.} \]

  The most precise top mass measurement outside Tevatron

- Combination of dilepton and lepton +jets top mass using the BLUE (Best Linear Unbiased Estimate) method.
  
  \[ m_t = 173.4 \pm 1.9 \text{ (stat)} \pm 2.7 \text{ (syst)} \text{ GeV} \]
Charge Asymmetry
(CMS-PAS TOP-10-010)

• Tevatron
  – Valence (anti-)quarks from certain direction
  – Forward-backward asymmetry

• LHC
  – gg fusion symmetric
  – asymmetry only from small qq fraction

• $A_C = (N^+ - N^-)/(N^+ + N^-)$
  $N^+ / N^-$ are the number of events with positive /negative values of $|\eta_{\text{top}}| - |\eta_{\text{antitop}}|$
  Predicted in SM $A_C = 0.0130(11)$

• Would indicate BSM if there is deviation
e.g. axigluon

• Measured at CMS
  $A_C = 0.060 \pm 0.134(\text{stat}) \pm 0.026(\text{sys})$
Summary

- CMS is a new Top Factory
- With only 36 pb\(^{-1}\) we have:
  - \(t\bar{t}\) cross section (±12%)
  - Single top cross section (±36%)
  - The most precise top mass measurement outside Tevatron
  - \(t\bar{t}\) invariant mass (-> limits for Z\(^{'}\) production)
  - Charge asymmetry (competitive with Tevatron end of 2011?)
- Today, June 2, 2011 we have more than 500 pb\(^{-1}\) and many golden opportunities in Top Physics