Top Quark Physics with CMS

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(on behalf of CMS Collaboration)

The 44th **Fermilab Users Meeting 2011**

Outline

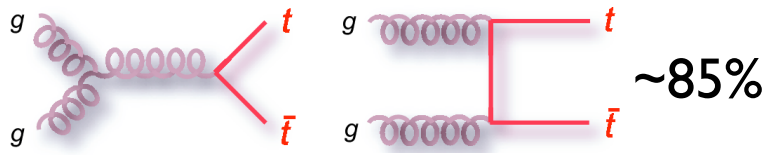
- Top Physics
- $t\bar{t}$ Cross Section - Dilepton Channel
- $t\bar{t}$ Cross Section – L+jets Channel
- Single Top Cross Section
- $t\bar{t}$ Invariant Mass
- Top Mass
- Charge Asymmetry
- Summary

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:



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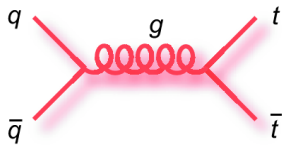

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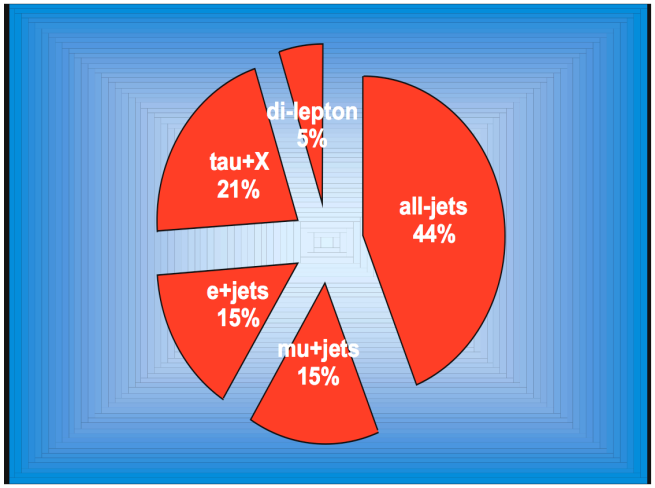
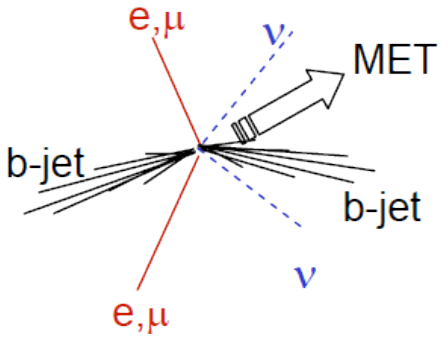
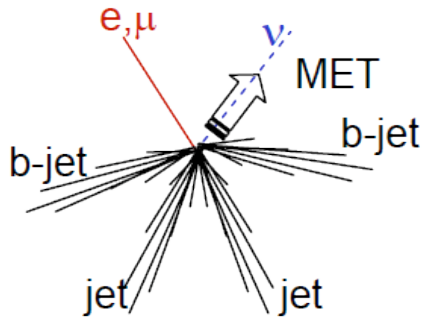
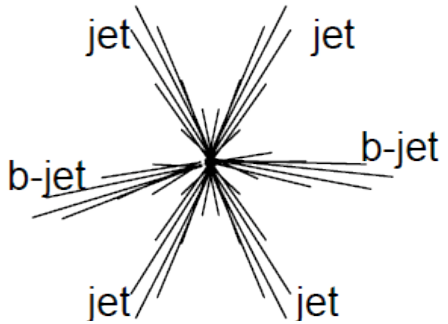


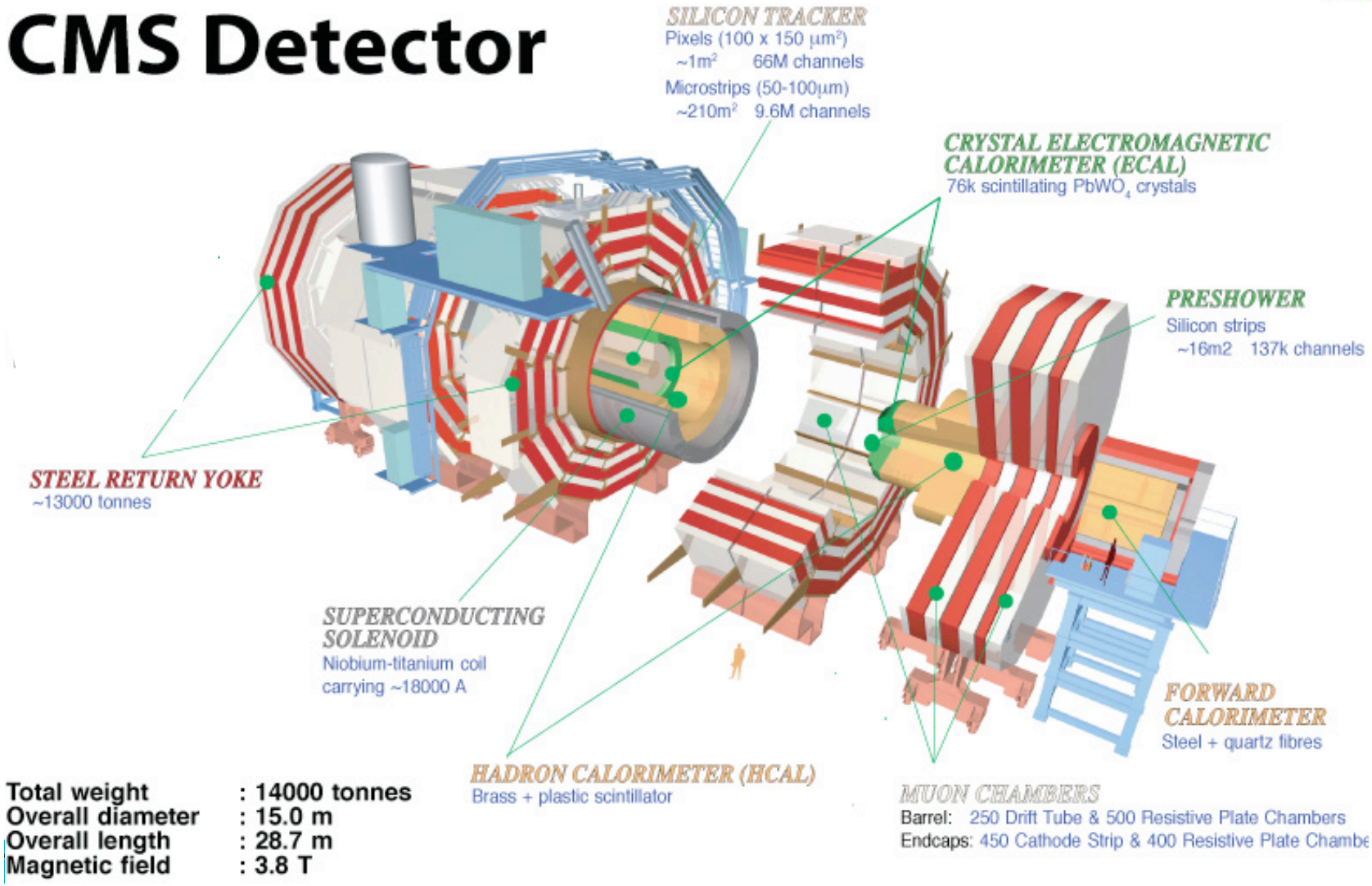
- BR(t->Wb) ≈ 1 in Standard Model
- Analysis strategy depends on W decay modes





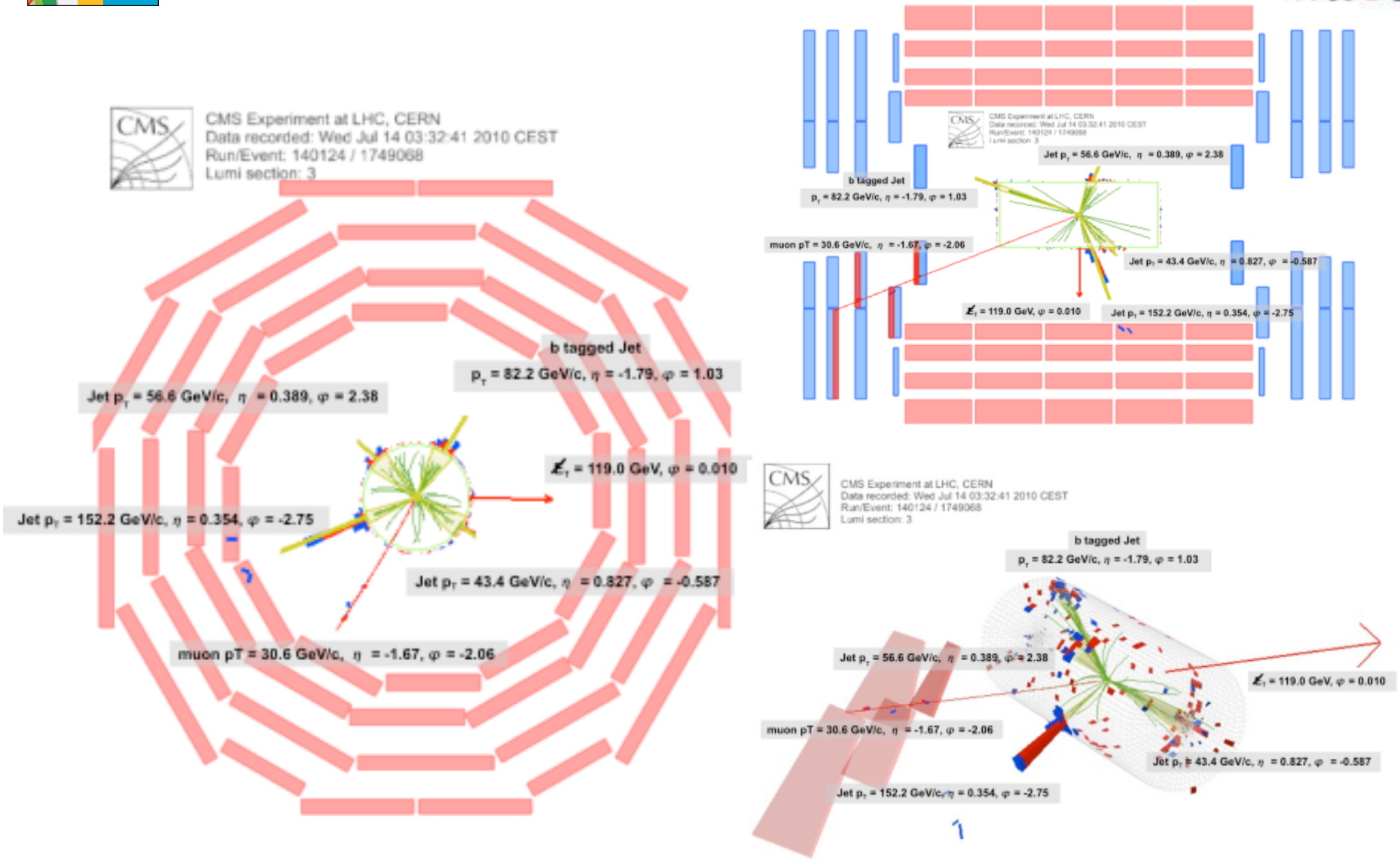


CMS Detector



Total weight	: 14000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T

Top Quark Candidate



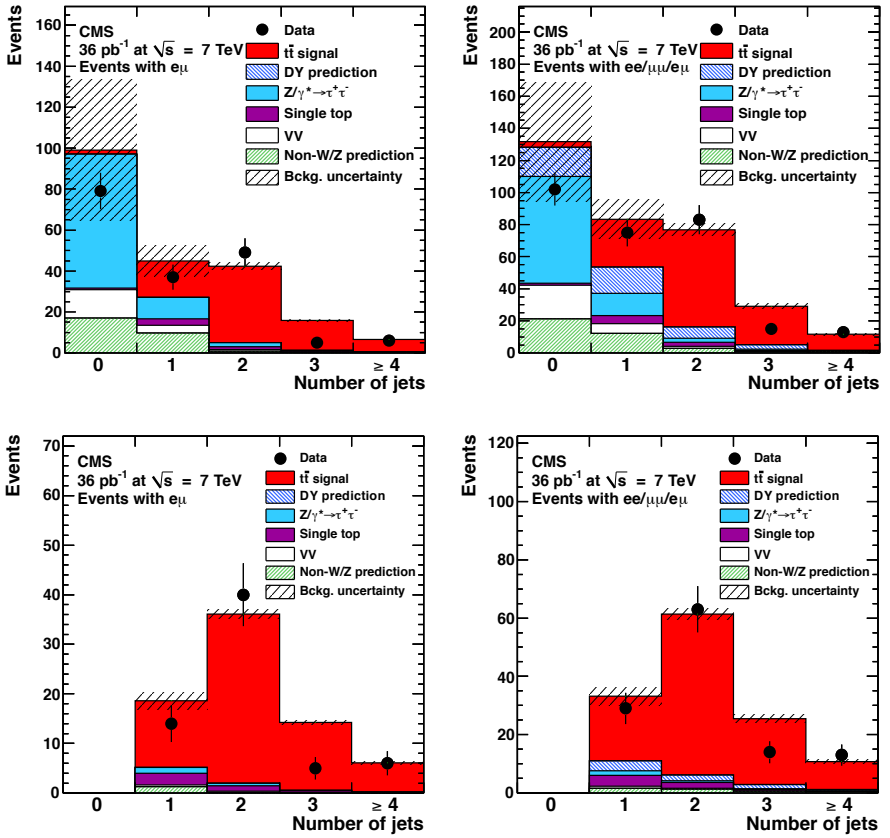
$t\bar{t}$ Cross Section at CMS

- 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 √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 √s = 7 TeV.
  - TOP-10-002: «Measurement of the tt Pair production Cross Section at √s = 7 TeV using the Kinematic Properties of Lepton + Jets Events»
  - TOP-10-003: «Measurement of the tt Pair Production Cross Section at √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 tt production cross section and the top quark mass in the dilepton channel in pp collisions at√s = 7 TeV»

$t\bar{t}$ Cross Section - Dilepton Channel (submitted to JHEP, arXiv:1105.5661)

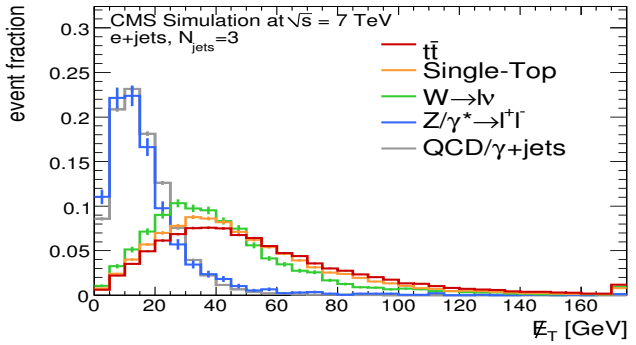
- Event Selection
  - two opposite charge leptons:
  - p_T > 20 GeV/c, |η| < 2.5 (2.4) for e (μ), Isolated in tracker and calorimeter
  - invariant mass selection:
    - $M_{\ell\ell}$ > 12 GeV/c2, $M_{\ell\ell} \neq [91 \pm 15]$
  - jets selection:
    - corrected Jet, p_T> 30 GeV/c, |η|<2.5
  - For 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 → ll: main background,
    - rejected by Z veto, jets and $\not{E}_T$, estimated from data
  - W+Jets, semi-lept. tt, QCD: from non-W/Z decays, estimated from data
  - Single top tW, diboson, Z→ττ: 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

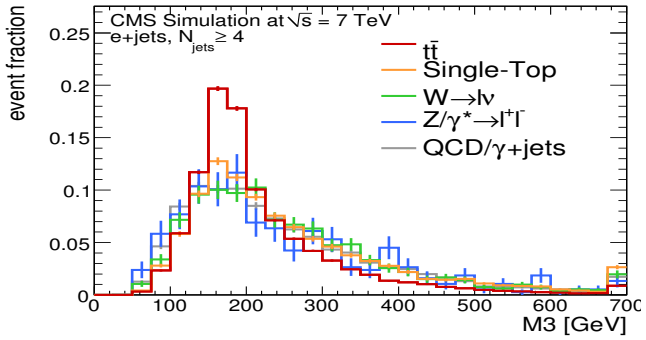
$\sigma_{(t\bar{t})}$ = 168 ± 18(stat) ± 14(sys) ± 7(lum) pb

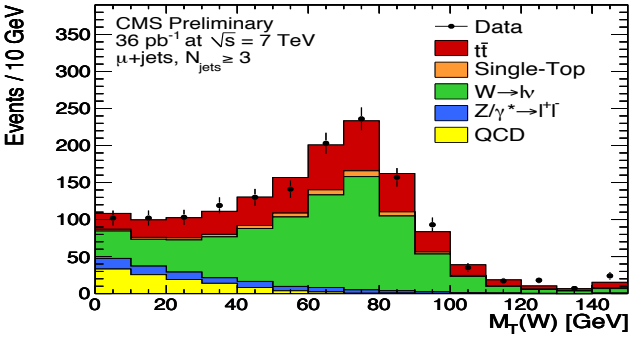


$t\bar{t}$ Cross Section - Lepton+Jets Channel (CMS TOP-10-002)

- 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
  - $\sigma_{tt} = 173^{+39}_{-32}(\text{stat.} + \text{syst.}) \pm 7(\text{lumi.})$ pb
- Compatible with other measurement



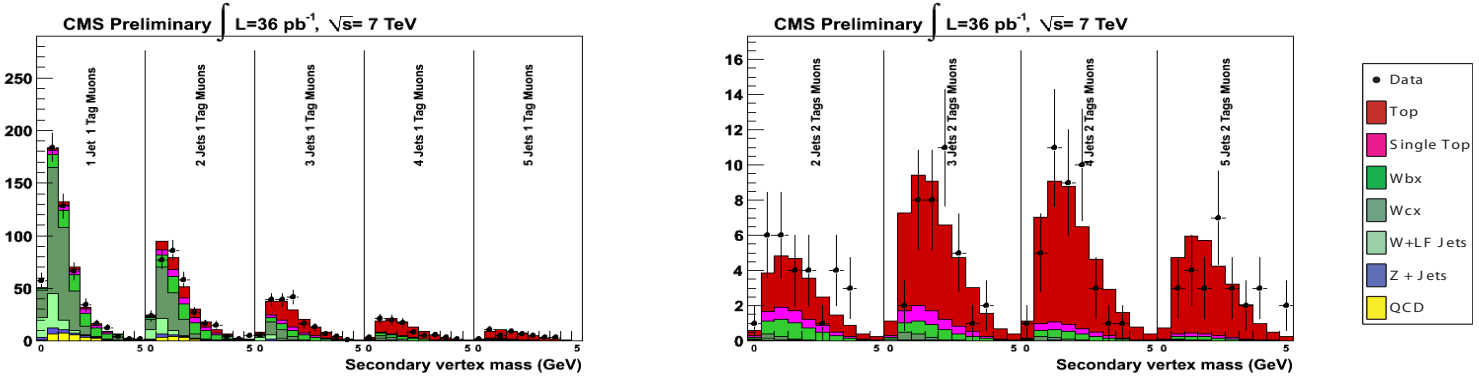




$t\bar{t}$ Cross Section in the Lepton+Jets Channels with b-Tagging (TOP-10-003)

- 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 (μ), 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

μ+jets channel:

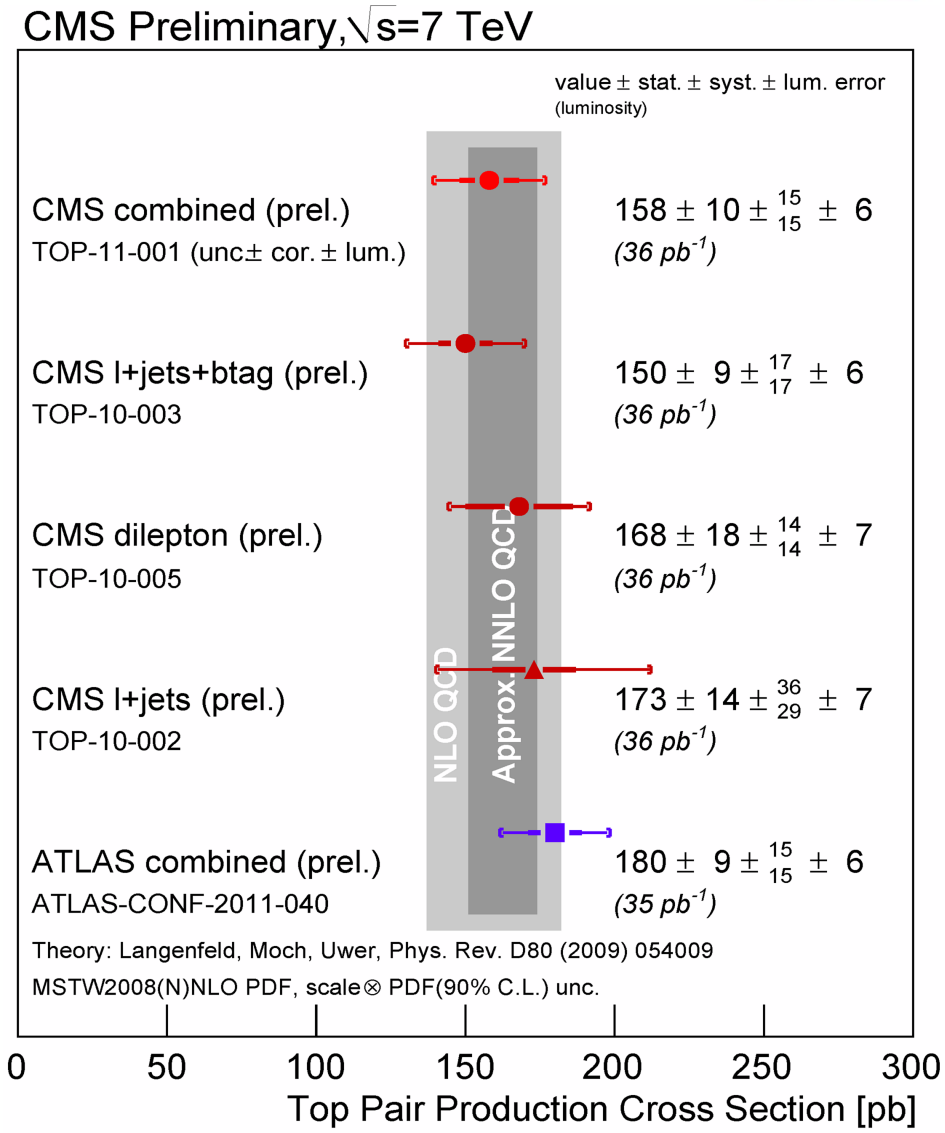


Combined Measurement:

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

$t\bar{t}$ Cross Section Combined

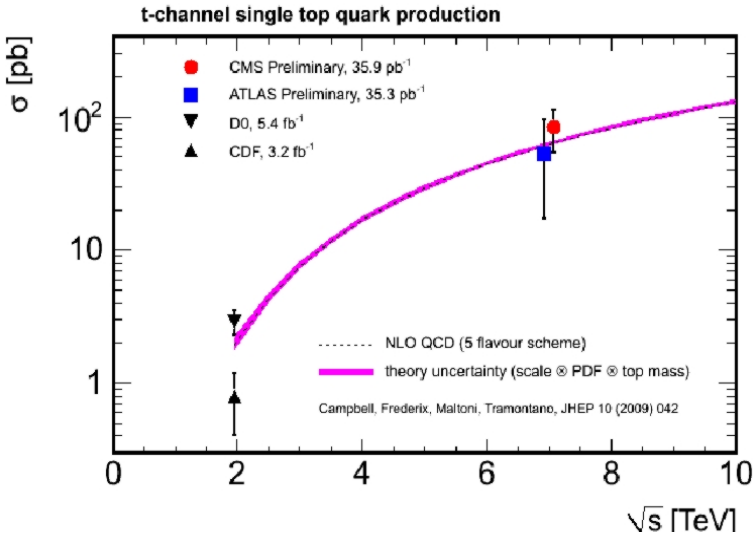
- Combined measurement has precision of 12%
- Very good agreement with approximation NNLO theory
- Comparable to world average



Single Top Cross Section (CMS-PAS TOP-10-008)

- Event Selection
  - Trigger: Single μ/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
  - $\sigma(t) = 84 \pm 30\,\text{pb}$
- Significance observed (expected)
  - 2D fit: 3.7 (2.1)
  - BDT: 3.5 (2.9)



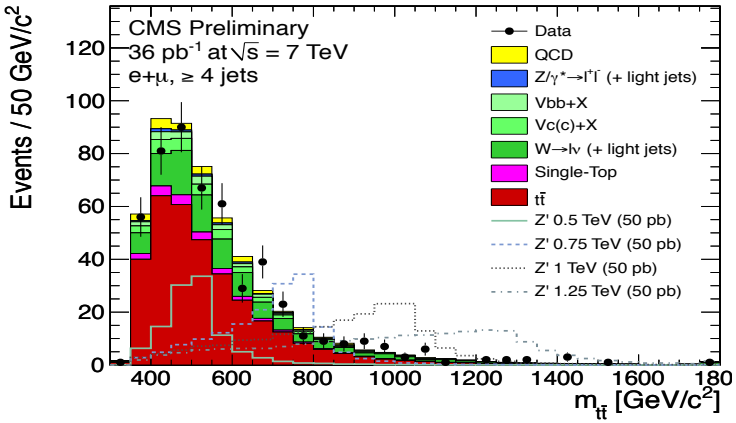
$$|V_{tb}| = \sqrt{\frac{\sigma^{exp}}{\sigma^{th}}} = 1.16 \pm 0.22(exp) \pm 0.02(th)$$

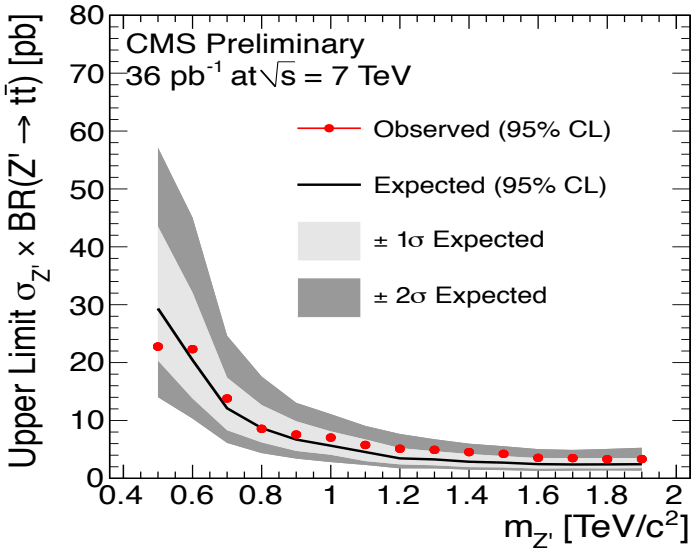
For $0 \leq |V_{tb}|^2 \leq 1$ (flat prior in $|V_{tb}|^2$):

$|V_{tb}| > 0.69$ @95% CL (BDT analysis)

$t\bar{t}$ Invariant Mass (CMS-PAS TOP-10-007)

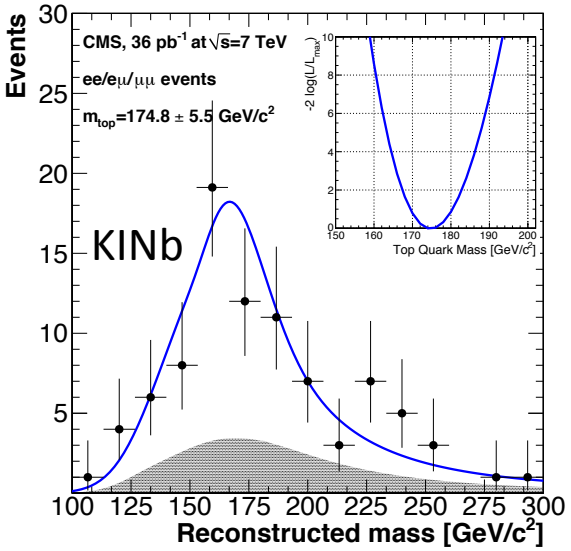
- Reconstruction of $m_{t\bar{t}}$ done in 3 steps
  - reconstruction of leptonic W (with MET as p_T (μ))
    - 2 real solutions → keep both
    - imaginary solutions → modify MET
  - jet-parton association by χ^2 minimisation
    - 5 quantities used: m_{lep} (top), m_{had} (top), m_{had} (W), p_T ($t\bar{t}$), H_T fraction
    - correct association in ~ 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

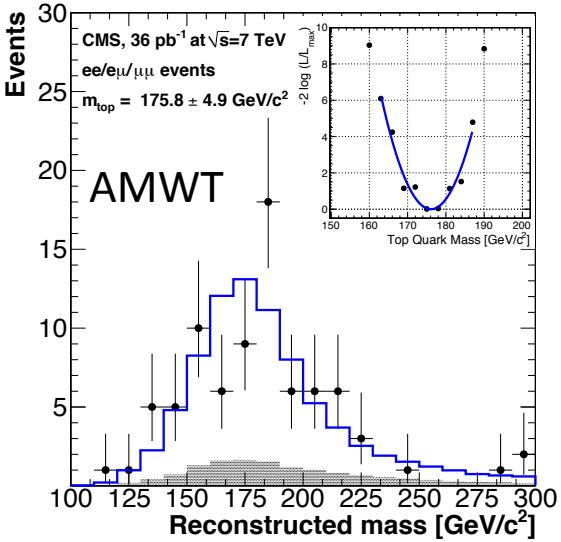




Top Quark Mass Measurement in the Dilepton Channels (submitted to JHEP, arXiv:1105.5661)

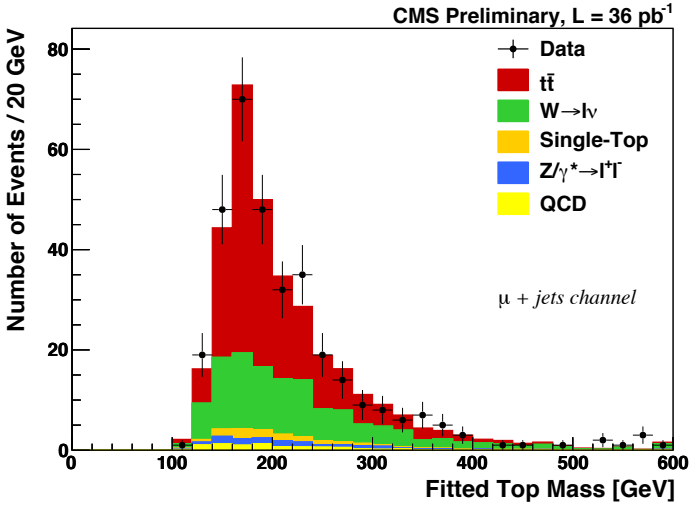
- Event Selection:
  - Inclusive single lepton trigger
    - muon with p_T>15 GeV/c ($\mu\mu$/eμ) or electron with ET>17 GeV (ee/eμ)
  - ≥ 2 leptons, p_T>20 GeV/c $|\eta|$<2.5
    - Isolated and promptly produced
  - ≥ 2 jets, p_T>30 GeV/c $|\eta|$<2.5
    - Anti-kT (R=0.5), particle flow based algorithm
  - MET > 30 (20) GeV for the ee/$\mu\mu$ (eμ) 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 ± 4.6(stat) ± 4.6(syst) GeV/c^2
- Good agreement with world average
  - m_{top} = 173.1 ± 1.1 GeV/c^2

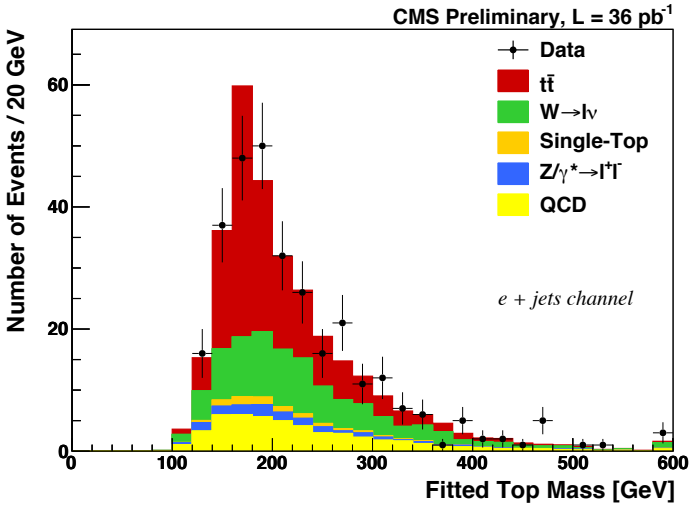




Top Quark Mass Measurement in the Lepton+jets Channels (CMS-PAS TOP-10-009)

- Event Selection:
  - Exactly one high p_T isolated lepton (electron p_T > 30 GeV, μ 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





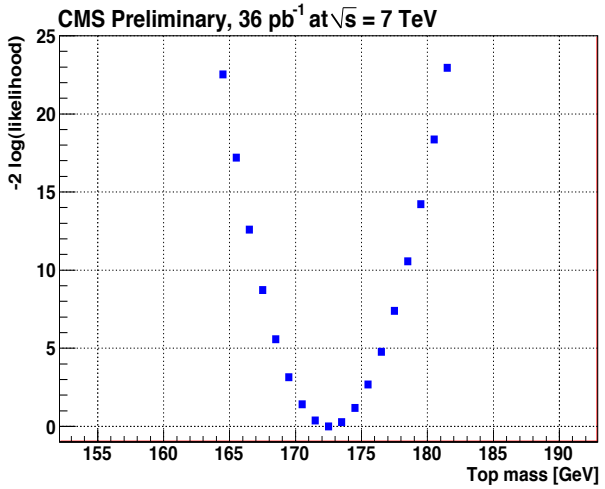
'Fresh from the oven: approved yesterday!'

NEW!

- Combination e+jets and μ+jets

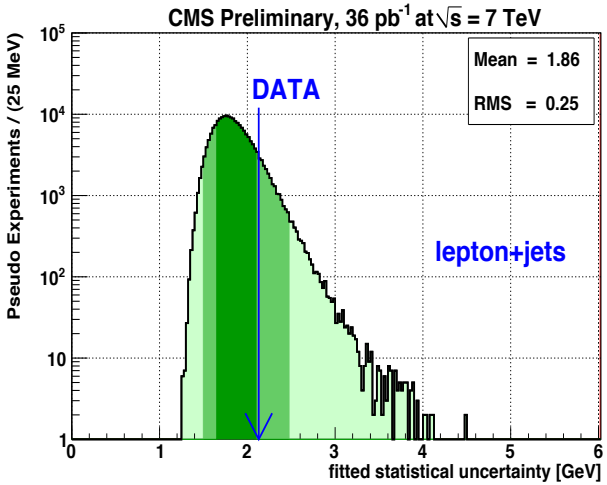
$$m_{\mathrm{t}} = 173.1 \pm 2.1(\mathrm{stat})^{+2.4}_{-2.1}(\mathrm{JES}) \pm 1.4(\mathrm{other\ syst})\ \mathrm{GeV}.$$

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(stat) $\pm$ 2.7 (syst) GeV



Charge Asymmetry (CMS-PAS TOP-10-010)

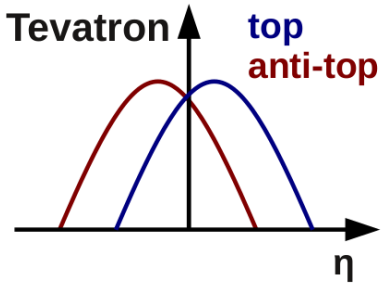
- Tevatron
  - Valence (anti-)quarks from certain direction
  - Forward-backward asymmetry
- LHC
  - gg fusion symmetric
  - asymmetry only from small qq fraction
- $A_C = (N^+ - N^-)/ (N^+ + N^-)$

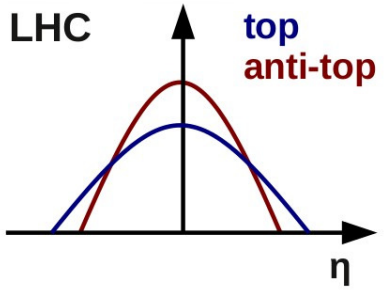
  N^+ / N^- are the number of events with positive /negative values of $|\eta_{top}| - |\eta_{antitop}|$

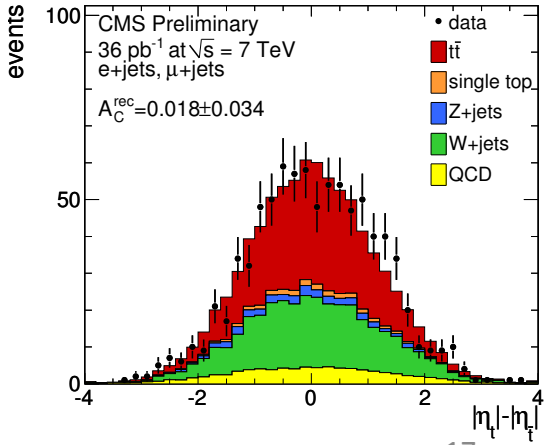
  Predicted in SM $A_C = 0.0130(11)$
- Would indicate BSM if there is deviation

  e.g. axigluon
- Measured at CMS

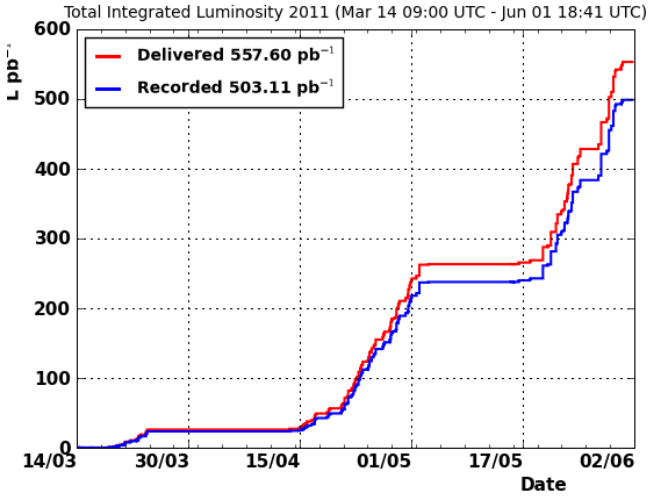
  $A_C = 0.060 \pm 0.134(\text{stat}) \pm 0.026(\text{sys})$







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