Top results from CMS

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On behalf of the CMS collaboration

Instituto de Física de Cantabria

CMS Compact Muon Solenoid

Physics at LHC 2011

PERUGIA, Italy, June 6-11th, 2011, Congress Center GIO

Top quark measurements with CMS

All presented results are obtained from the full 2010 pp dataset: L = (36 ± 1) pb^{-1}

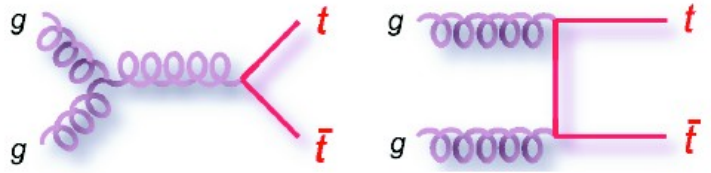
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

- **$t\bar{t}$ Cross Section** Measurement and top Quark Mass Measurement in the Dilepton Channels ***http://arxiv.org/abs/1105.5661***
- $t\bar{t}$ Cross Section Measurement in the Lepton+Jets Channels w/o b-Tagging ***http://arxiv.org/abs/1106.0902***
- $t\bar{t}$ Cross Section Measurement in the Lepton+Jets Channels with b-Tagging (TOP-10-003)
- Combination of $t\bar{t}$ Cross Section Measurements and Comparison with Theory Predictions (TOP-11-001)
- **Single Top Quark Cross Section** Measurement (TOP-10-008)
- **Top Quark Mass** Measurement in the Lepton+Jets Channels (TOP-10-009) ***New result!***
- **Charge Asymmetry** Measurement (TOP-10-010)
- The **m($t\bar{t}$) Spectrum** and Searches for New Physics (TOP-10-007)

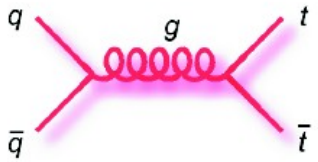
Top quark physics

- **Top quark pairs produced in strong interaction via:**

  - gluon-gluon fusion: dominant mode at LHC



  - quark- antiquark annihilation



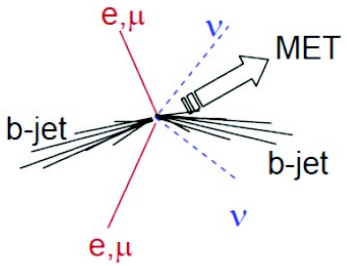
Machine	$\sqrt{s}$ [TeV]	σ [pb]	qq%	gg%
Tevatron	1.96	~ 7	~85	~15
LHC	10	~160	~30	~70

→ 20 times higher than at Tevatron

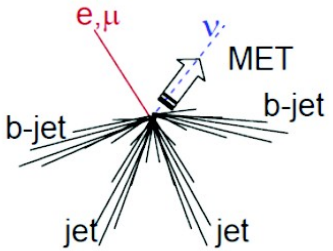
- **In SM top decays to W+b 99.9% of the time**

- **Analysis strategy depends on W decay modes**

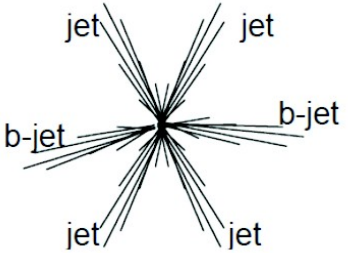
Dileptonic channel
Smaller branching ratio
Very clean

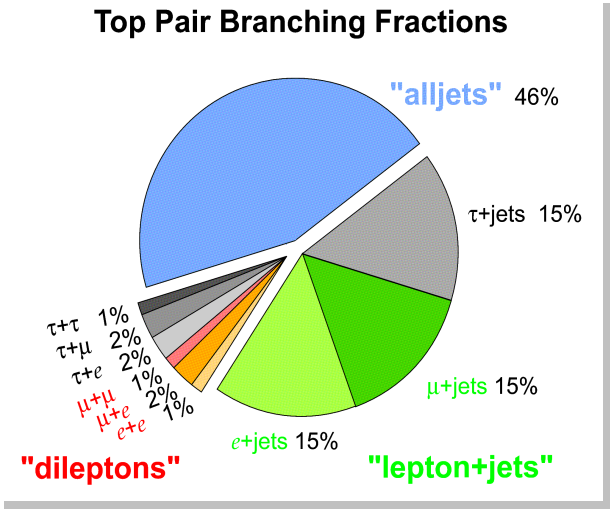


Semileptonic channel
Large branching ratio
Ask for Lepton
forbackground reduction



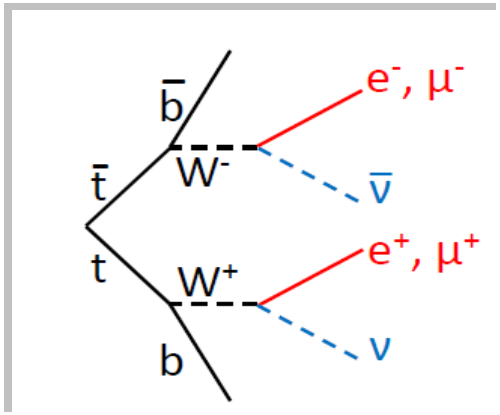
Fully hadronic channel
Largest branching ratio
No high pt leptons
High QCD backgrounds





σ(tt̄) : dilepton channel

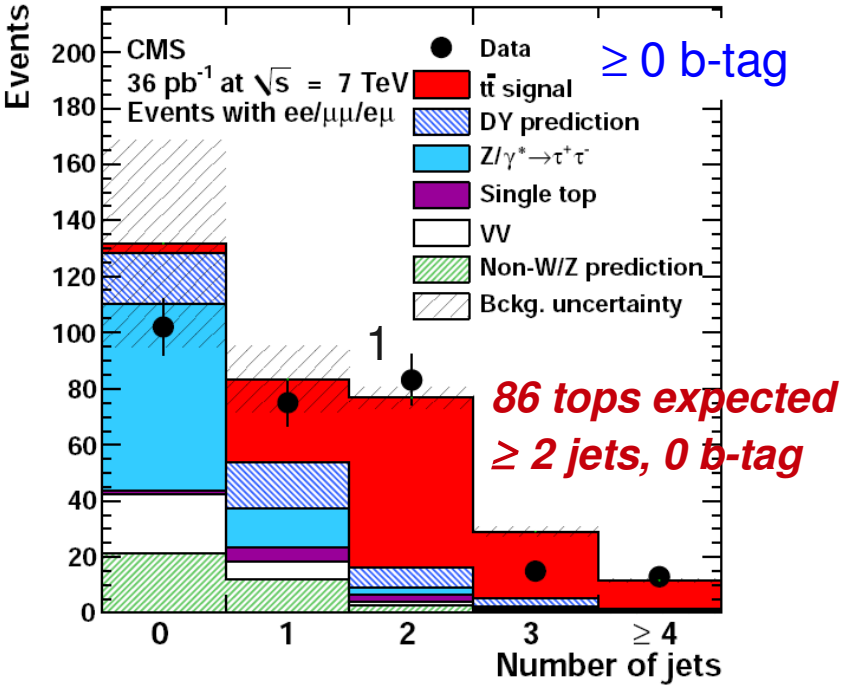
- **Selection in the dilepton channels: *ee, μμ, eμ***

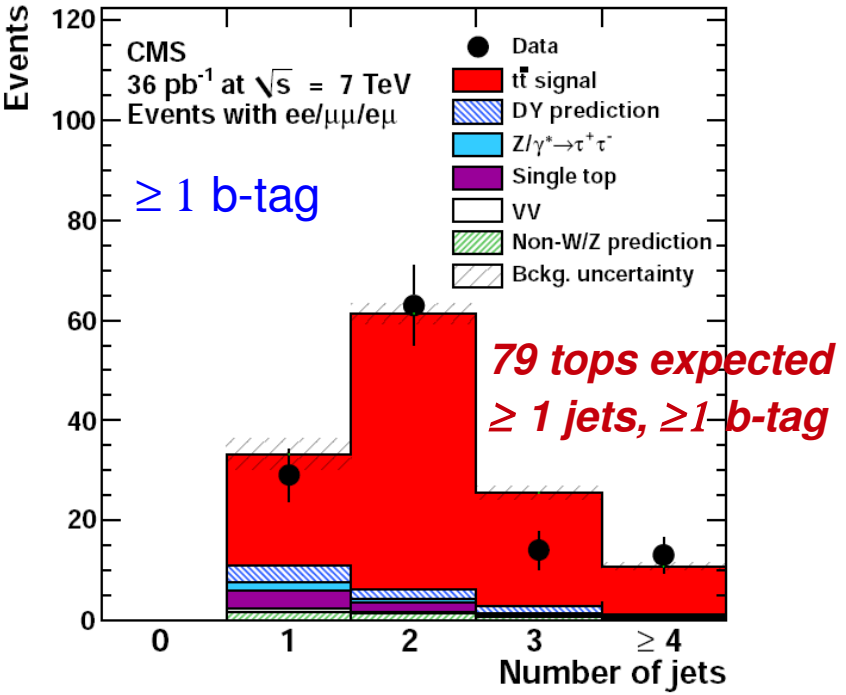


- ✗ **2 isolated, prompt, oppositely charged leptons** (l = e,μ) of good quality
- ✗ **Missing transverse energy** (MET) from the 2 neutrinos
- ✗ Count additional jets: **at least 1 jet typical for ttbar**

Very clean channel, especially with b-tagging

- **Main backgrounds after leptonic selection :**
  - ✗ Drell-Yan: 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**





σ(tt̄) : dilepton channel

- **Simple counting experiment in jet multiplicity bins**
- **Signal includes t→W→lν where l = e, μ, τ→e, μ**

$$\sigma^{t\bar{t}}_{\text{data}} = \sigma^{t\bar{t}}_{\text{theory}} \frac{S_{\text{obs}}}{SF \cdot S_{\text{exp}}} = \frac{S_{\text{obs}}}{SF \cdot \mathcal{L} \cdot A}$$

SF: Data/MC scale factor,
S_{exp}: Expected signal evts from simulation

- **9 cross sections are obtained**

  2 jets, no b-tag

  2 jets, at least 1 b-tag: more precise than without b-tag for the ee and μμ channels (but not for the eμ channel)

  1 jet, no b-tag: less precise but improves the combined result

- **Major systematics:**

  background modeling from data
  b-tagging efficiency
  JES

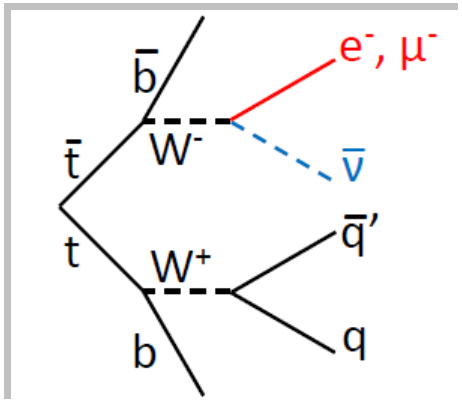
Final state	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
At least two jets, no b-tagging requirement			
Events in data	23	28	60
All backgrounds	5.5 ± 2.3	9.5 ± 4.3	6.7 ± 2.0
Total acceptance, %	0.259 ± 0.021	0.324 ± 0.025	0.928 ± 0.057
Cross section, pb	$189 \pm 52 \pm 29 \pm 8$	$159 \pm 45 \pm 39 \pm 6$	$160 \pm 23 \pm 12 \pm 6$
At least two jets, at least one b-jet			
Events in data	15	24	51
All backgrounds	2.3 ± 1.4	3.8 ± 2.0	3.0 ± 1.4
Total acceptance, %	0.236 ± 0.022	0.303 ± 0.028	0.857 ± 0.068
Cross section, pb	$150 \pm 46 \pm 22 \pm 6$	$186 \pm 45 \pm 25 \pm 7$	$156 \pm 23 \pm 13 \pm 6$
One jet, no b-tagging requirement			
Events in data	8	10	18
All backgrounds	2.1 ± 0.7	7.1 ± 4.3	4.9 ± 1.5
Total acceptance, %	0.058 ± 0.007	0.074 ± 0.008	0.183 ± 0.024
Cross section, pb	$282 \pm 135 \pm 45 \pm 11$	$107 \pm 119 \pm 163 \pm 4$	$200 \pm 65 \pm 35 \pm 8$

The 9 cross sections are combined using the BLUE technique (Best Linear Unbiased Estimator) it takes into account the correlations between different contributions to the measurements

$$\sigma_{t\bar{t}} = 168 \pm 18\ (stat.) \pm 14\ (syst.) \pm 7\ (lumi.)\ pb$$

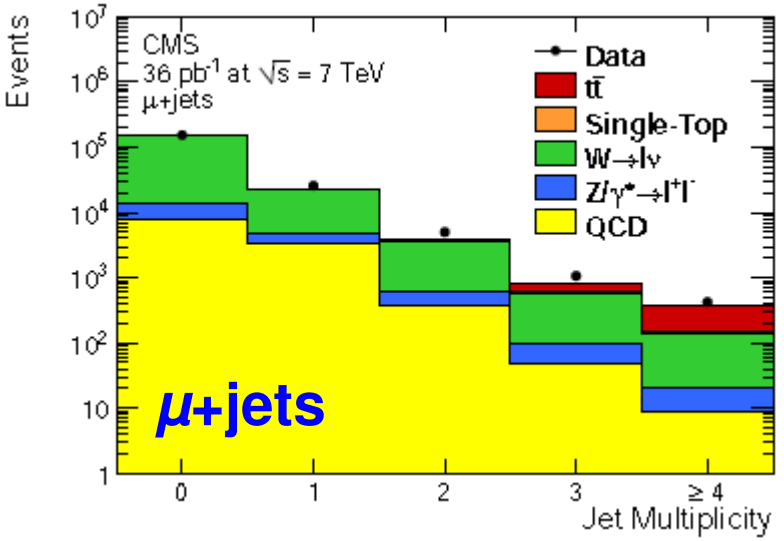
$\sigma(t\bar{t})$: lepton+jets channel

Selection in the lepton+jets channel:
***e*+jets, *μ*+jets**



- ✗ **one isolated, prompt lepton** (l = e,μ) (with second lepton veto) of good quality
- ✗ **Missing transverse energy** (MET) from the neutrino
- ✗ Count additional jets: **≥ 3 jets typical for ttbar**

Higher cross-section but higher background contamination.



- **Main backgrounds after leptonic selection :**
  - ✗ W+jets (divided in b-jets, c-jets and light-jets in the b-tag analysis)
    estimated from data
  - ✗ Z+jets, γ+jets, single top
    estimated from MC
  - ✗ QCD
    estimated from data

- **Cross section measurements :**
  b-tag analysis: a simultaneous fit of
  - Secondary Vertex Mass
  - Number of jets and b-tagged jets

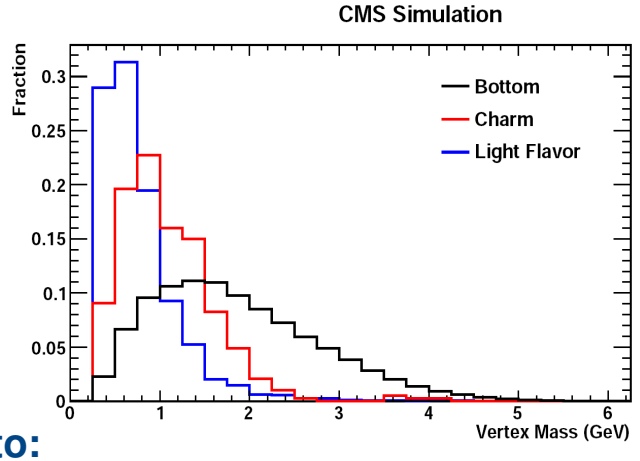
  no b-tags analysis: a fit of
  $\not{E}_T$ for = 3 jets
  M3 for >= 4 jets

$\sigma(t\bar{t})$: lepton+jets channel w/ b-tagging

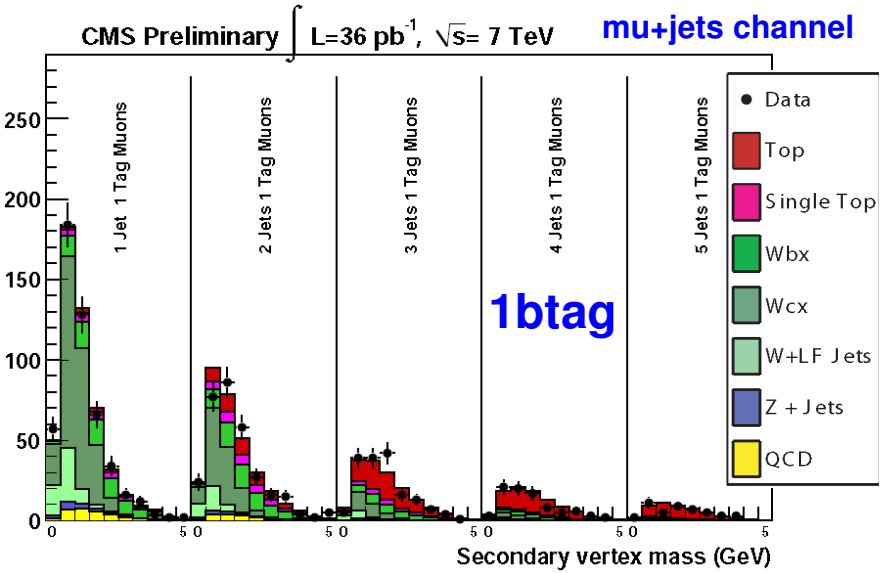
➔ **Only b-tagged events are used**
b-tagging based on displaced secondary vertex

- **Binned Likelihood Fit to the secondary vertex mass**
  in the e+jets, μ+jets channel

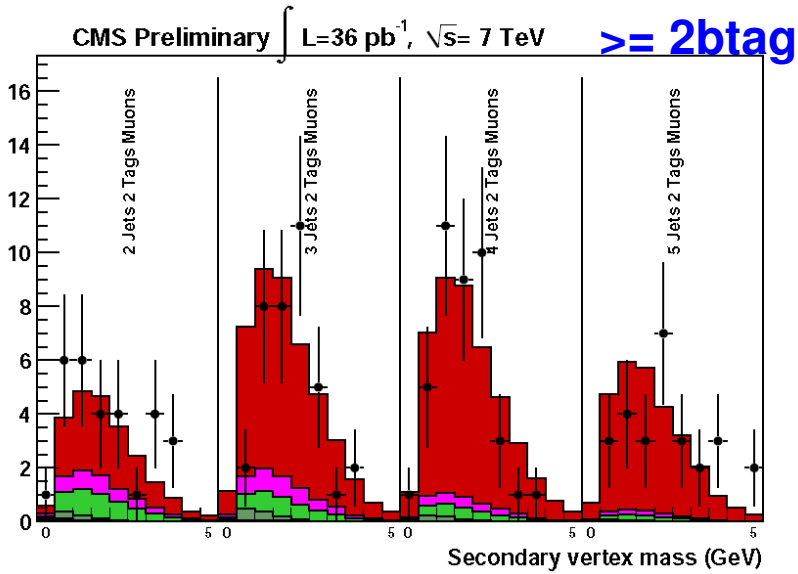
Invariant mass of tracks from same SV
→ **separates light and heavy flavor**



Fitted secondary vertex mass in mu+jets channel



- **Simultaneous fit also to:**
  - largest systematics determined in situ, thus their impact is reduced
  JES, Q^2-scales, b-tag efficiency
  - W+jets and QCD templates estimated directly from data.
- **Measurement in 9 different jet & b-tag multiplicities**



- **Combined cross-section:**

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

σ(tt̄) : lepton+jets channel w/o b-tagging

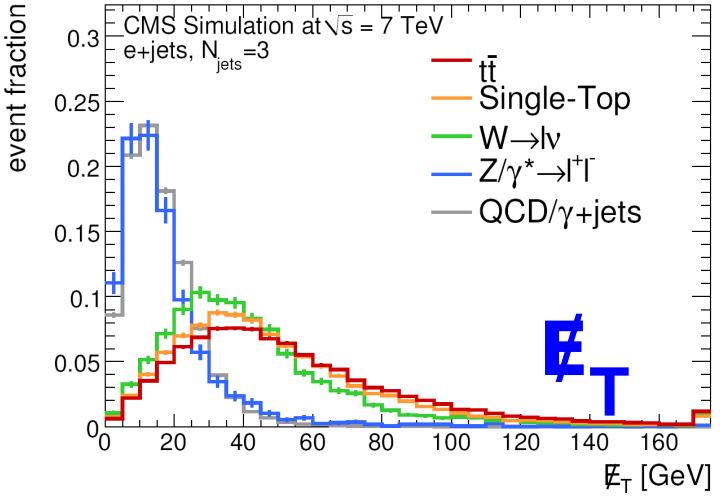
- **Simultaneous binned likelihood fit to:**

$\not\!\!E_T$ with = 3 jets

* Separates QCD from real W decays

M3 with ≥ 4 jets

* M3 is the inv. Mass of the 3 jets with the max $\sum \vec{pt}$
* Separates top from other events with real W decays.

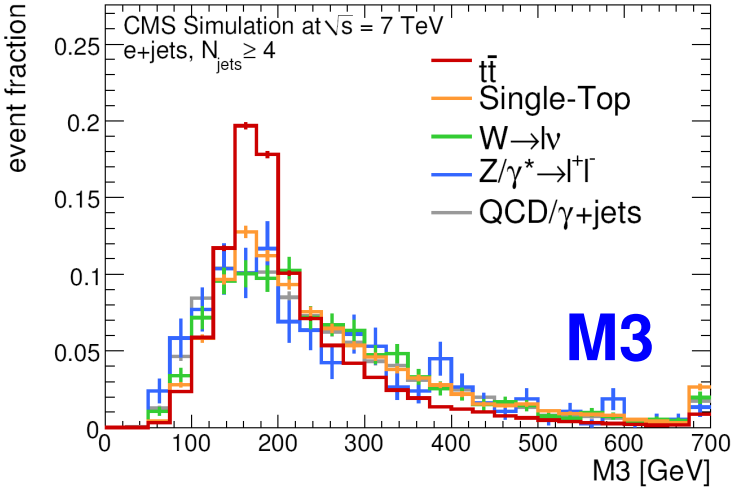


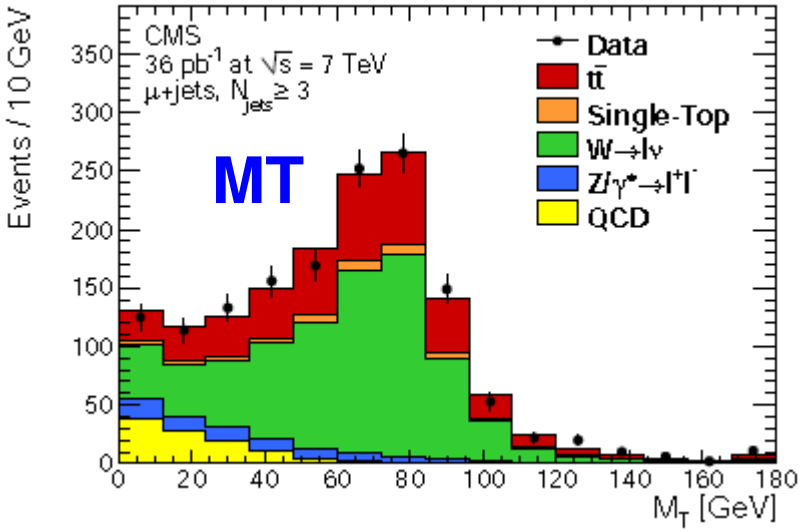
- **Dominant effect:**

JES, followed by W+jets Q^2 scale

- **Good agreement with data after fit**

control: MT (W) (transverse mass)





- **e+jets and mu+jets combined:**

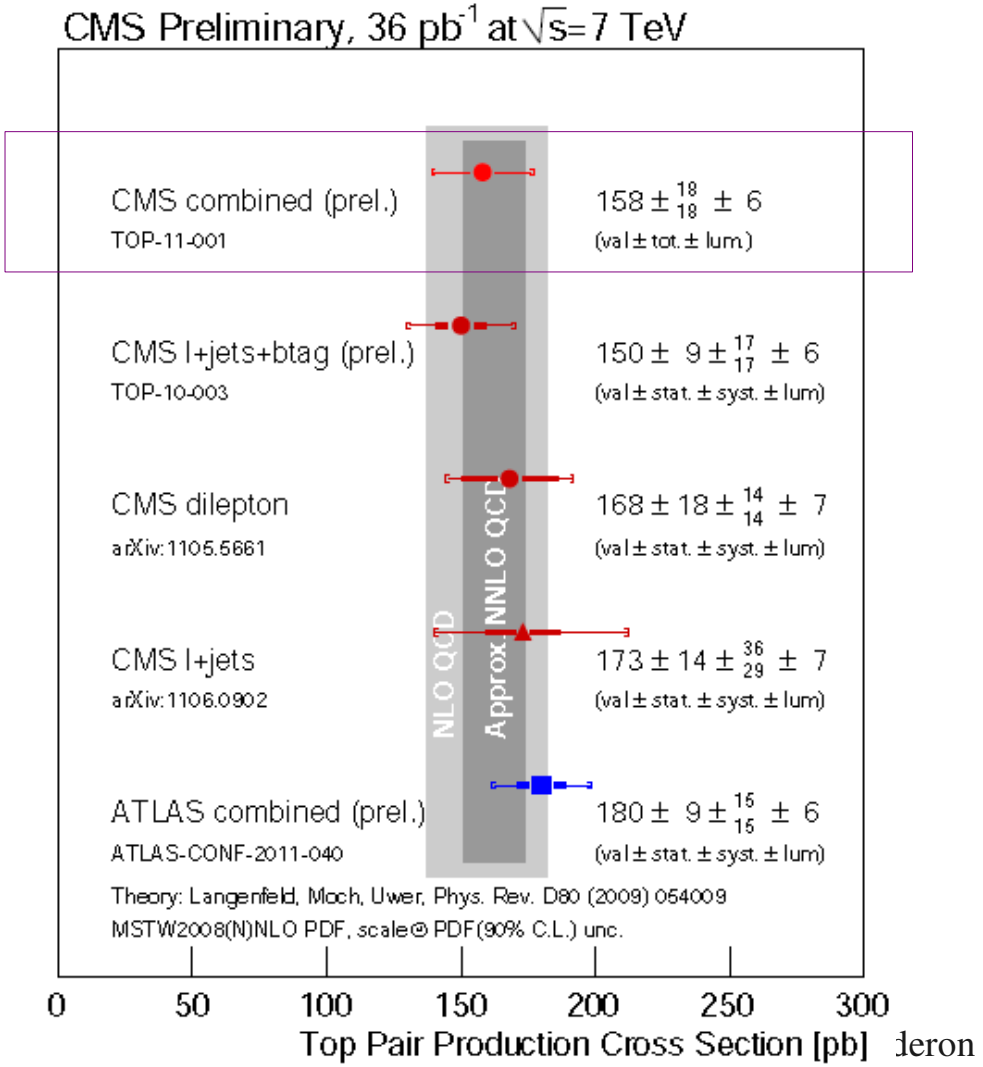
$$\sigma_{t\bar{t}} = 173^{+39}_{-32}\ (stat. + syst.) \pm 7\ (lumi.) pb$$

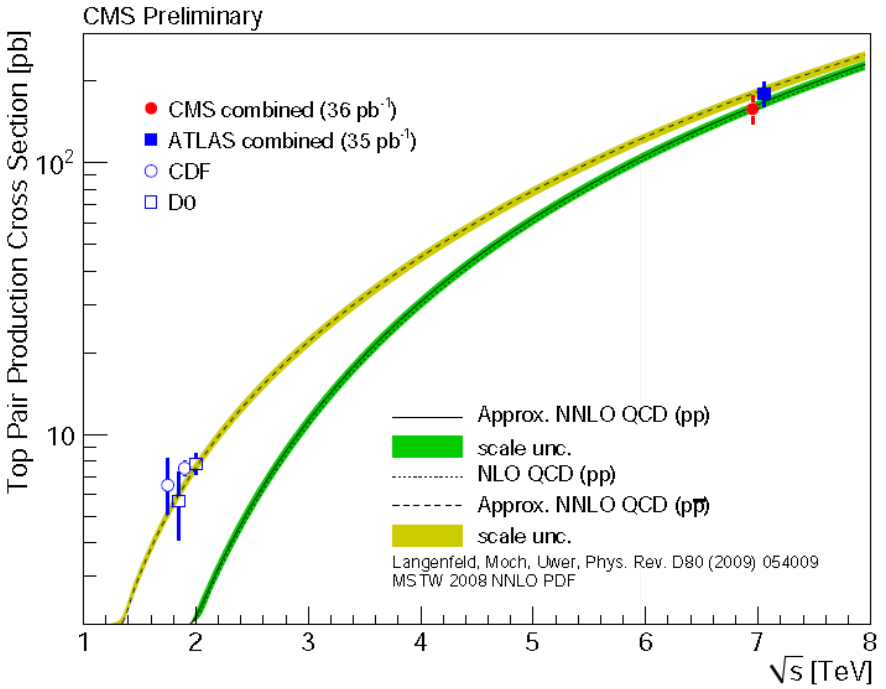
$\sigma(t\bar{t})$: combination

CMS combined result using the BLUE technique:

$$\sigma_{t\bar{t}} = 158 \pm 10\ (unc.) \pm 15\ (cor.) \pm 6\ (lumi.)\ pb$$

12% precision





This result is consistent with the theoretical $t\bar{t}$ cross section at approximate NNLO :

σ_{tt} (HATHOR) = 164^{+10}_{-13} pb

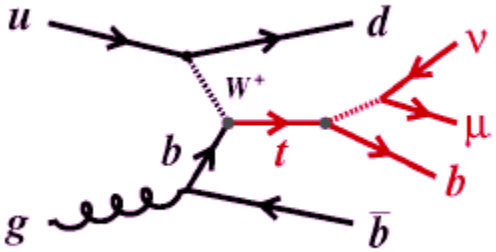
σ_{tt} (Kidonakis) = 163^{+11}_{-10} pb

and more precise than the NLO theory uncertainty

Single top cross-section

Successful example of extraction of a tiny signal with only 36/pb !!

- **Dominant production mode**: t-channel
  Smaller xs and large bkgs → more sophisticated methods needed to extract the signal



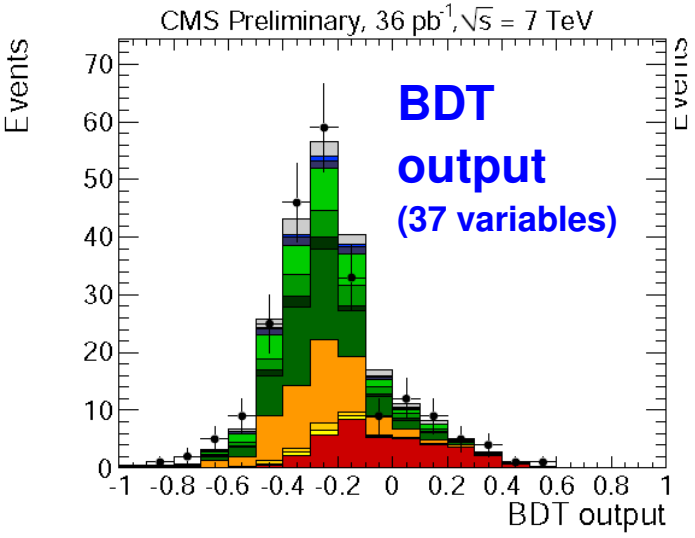
σ=62.3 pb @ 7TeV

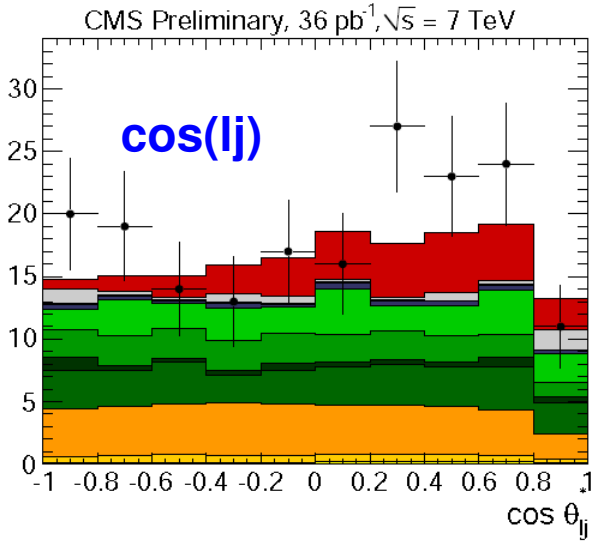
- **Signal:** 1 isolated lepton, MET, 1 light forward hadronic jet, 1 central b-jet
- **Bkgs:** ttbar, W+jets, Wbbar+jets, QCD mutijets (data-driven methods)

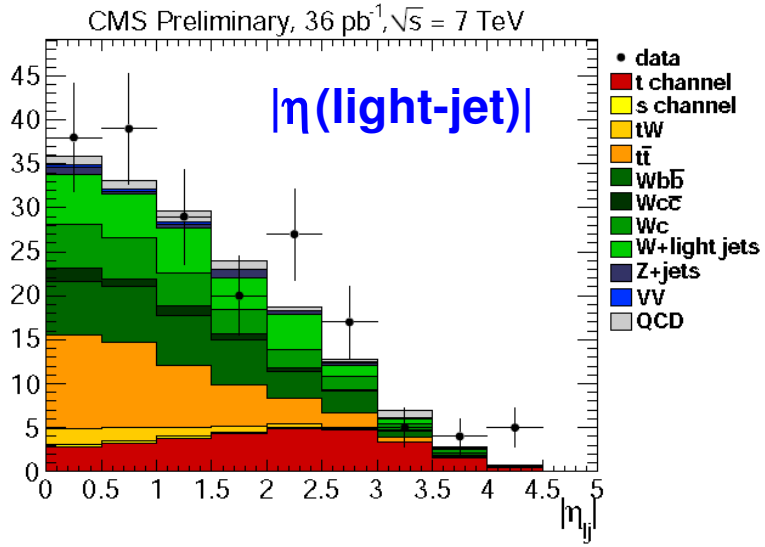
- **Two complementary analyses:**

✗ **A multivariate technique (BDT)**
(Boosted Decision Trees)
Fully exploits signal topology, maximizes significance

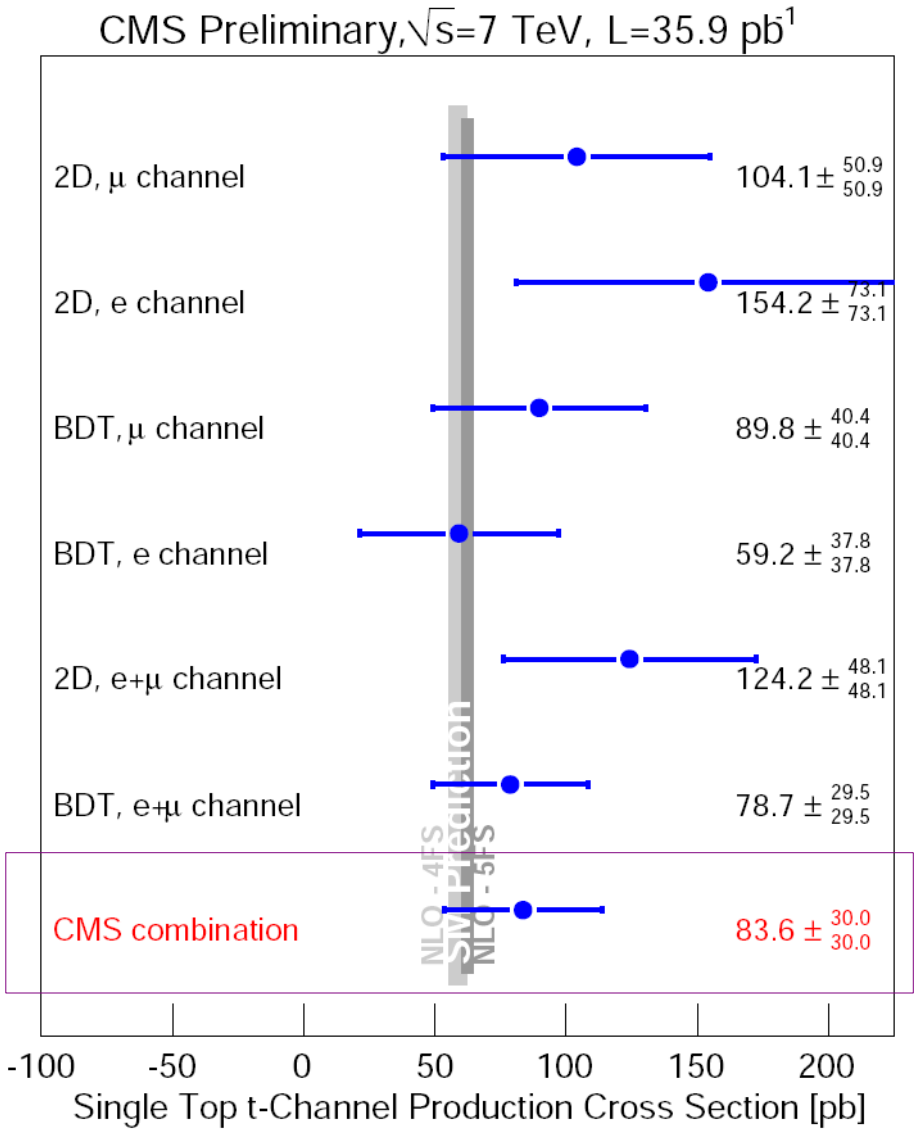
✗ **2D template fit to angular variables**
(characteristic for EWK production of single top quarks)
→ minimal model assumption







Single top cross-section



CMS combined result (using the BLUE method)

almost all systematics fully correlated

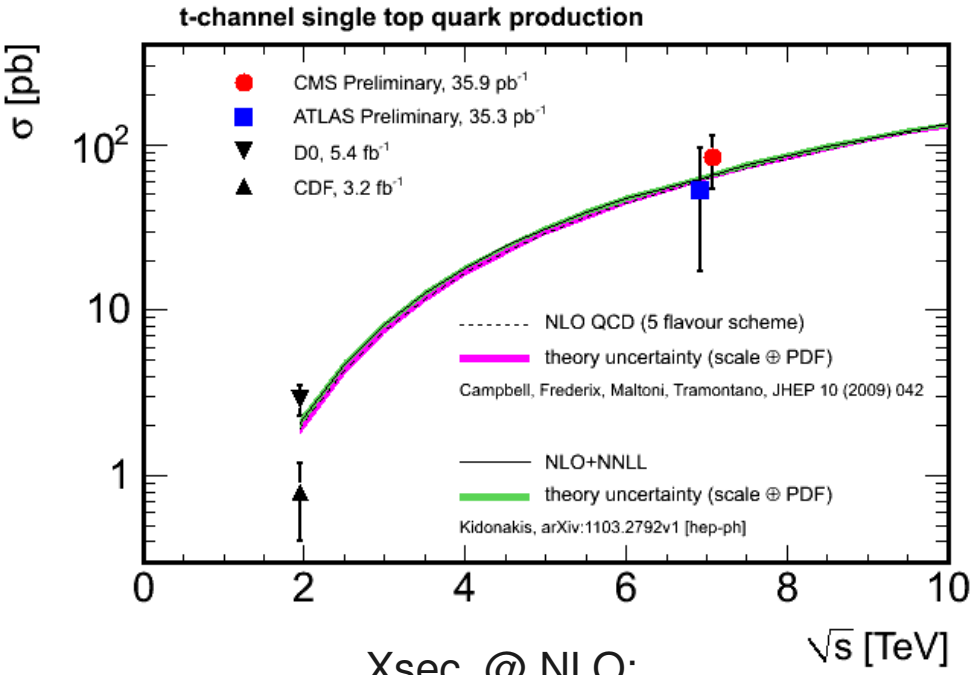
$$\sigma_t = 83.6 \pm 29.8\ (stat. + syst.) \pm 3.3\ (lumi.) pb$$

36% precision

Significance:

2D fit: 3.7σ evidence (2.1σ expected)

BDT: 3.5σ evidence (2.9σ expected)



Xsec. @ NLO:

$$\sigma_t^{4FS} = (59.1^{+3.0}_{-4.0})\ \text{pb}$$

$$\sigma_t^{5FS} = (62.3^{+2.3}_{-2.4})\ \text{pb}$$

Top quark mass in the dilepton channel

- **Two independent methods:**
  - Numerical solutions to the kinematics equations of the ttbar decay: 2 b-jets, 2 charged leptons, 2 neutrinos
  - Likehood fits to data to extract m_t from the mass distributions

Fully kinematics analysis (KINb)

- Using longitudinal invariance $p_z(tt)$ as additional information
- b-tag for l-jet assignment

$$m_{top} = 174.8 \pm 5.5\ (stat.)^{+4.5}_{-5.0}(syst.) GeV/c^2$$

Analytical matrix weighting technique (AMWT)

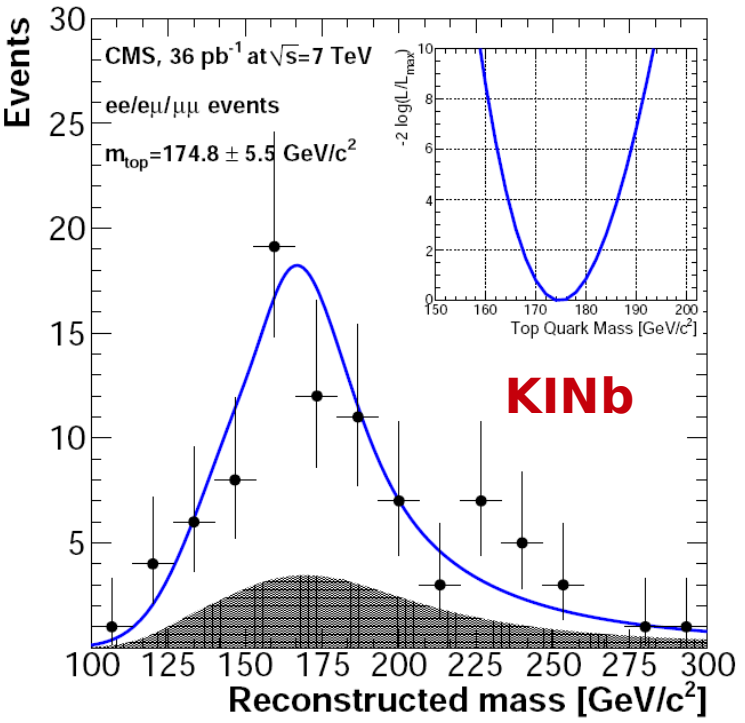
- Scan values of m_t, weight from PDFs and lepton spectra

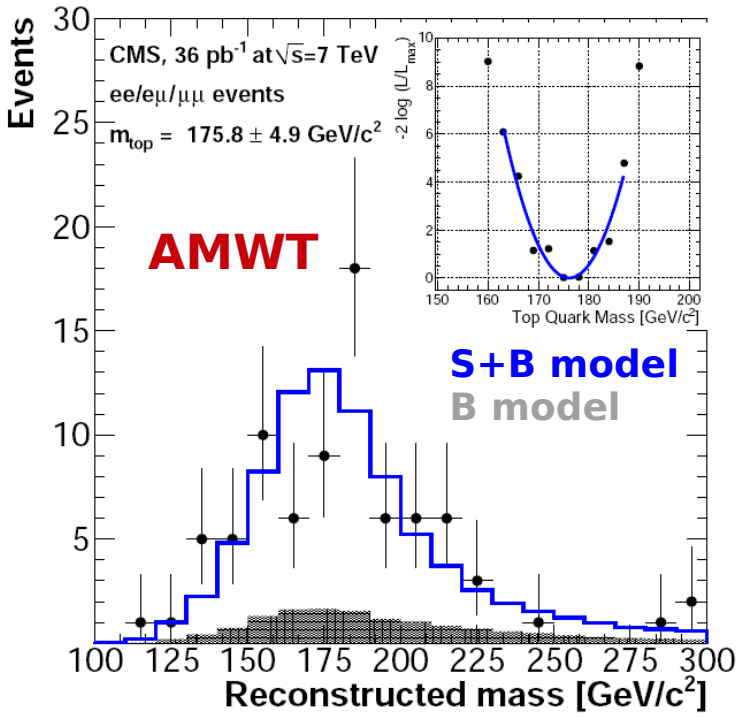
$$m_{top} = 175.8 \pm 4.9\ (stat.) \pm 4.5\ (syst.) GeV/c^2$$

- **CMS combined result (using the BLUE method):**

$$m_{top} = 175.5 \pm 4.6\ (stat.) \pm 4.6\ (syst.) GeV/c^2$$

4% precision





Top quark mass in the lepton+jets channel

Ideogram technique

New result!

- **Constrained kinematic fit of tt lepton+jets events**
  (using 1 lepton, 4 jets and MET)
  - Jets-to-quark assigment: 12 ways to pair the 4 jets with the quark
  - Coinstraint the fit by $m_{\bar{t}} = m_t$

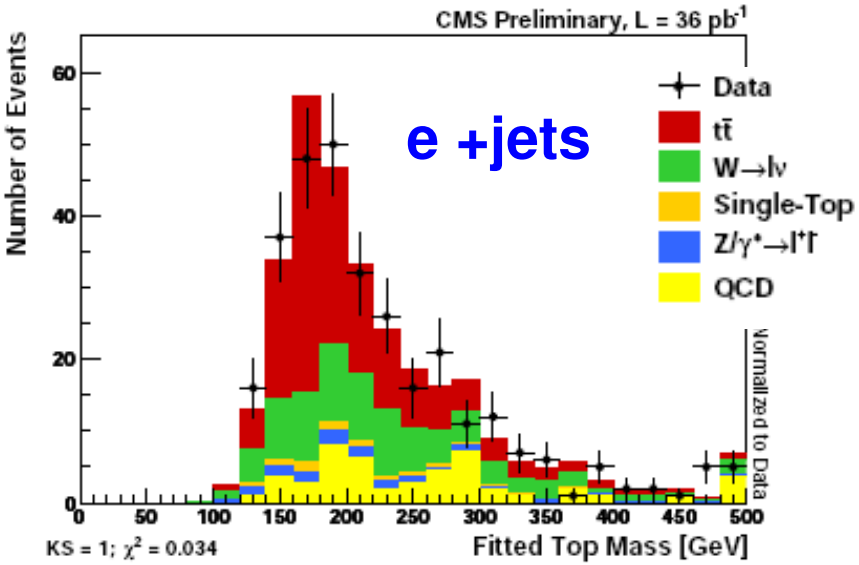
- **Event likelihood as a function of the top quark mass hypothesis**
  - takes into account all possible assignments of jets to quark (each permutation weighted by χ^2)
  - Include probability density to be a signal or a background event
  - b-tagging information

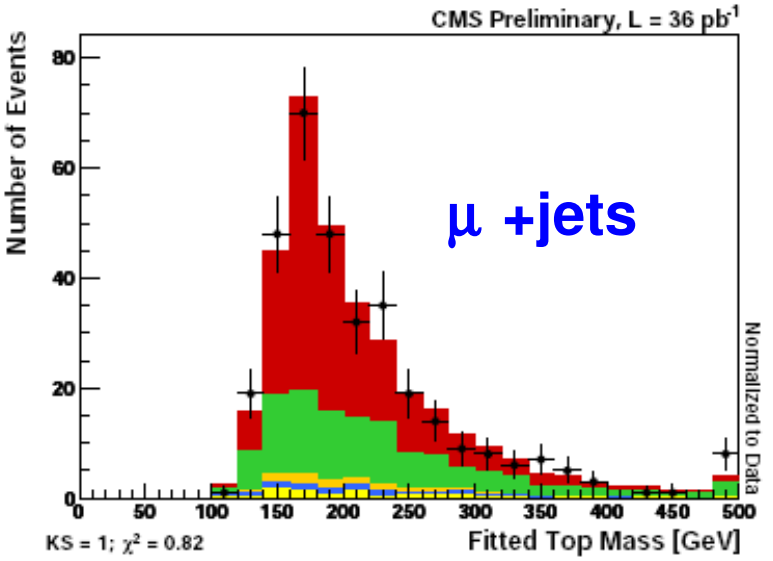
- **A joint likelihood fit over all events is then used to the extract the value of the top quark mass.**

- **CMS combined result: μ+jets, e+jets**

$$m_{top} = 173.1 \pm 2.1\ (stat.)^{+2.8}_{-2.5}(syst.) GeV/c^2$$

2% precision





Top quark mass combination

Performed using the BLUE (Best Linear Unbiased Estimate) method:
Statistical uncertainty not correlated, almost all systematics correlated

- **Dilepton channel:**
  Results from the two methods used to reconstruct the mass: KINb and AMWT

$$m_{top} = 175.5 \pm 4.6\ (stat.) \pm 4.6\ (syst.) GeV/c^2$$

- **Lepton+jets channel:**
  Ideogram method

$$m_{top} = 173.1 \pm 2.1\ (stat.)^{+2.8}_{-2.5} (syst.) GeV/c^2$$

- **CMS combination using the BLUE method**

$$m_{top} = 173.4 \pm 1.9\ (stat.) \pm 2.7\ (syst.) GeV/c^2$$

2% precision

Good agreement with world average
M_{top} = 173.3 ± 1.1 GeV/c²

Top quark charge asymmetry

Any deviation from SM prediction would be a possible indicator of BSM top production (Z', axigluons …)

- **Lepton+jets channel μ+jets, e+jets**
- **Tevatron: proton-anti proton collider**

  valence (anti-)quarks from certain direction

  → forward-backward asymmetry

Deviation > 3σ from SM predicted A_{FB} ~ 5%

- **LHC: proton-proton collider**

  gg fusion FB symmetric

  → asymmetry only from small qq fraction

  no valence antiquarks

  → quarks have higher x on average

asymmetry in $|\eta_t| - |\eta_{\bar{t}}|$ → $A_C = \dfrac{N^+ - N^-}{N^+ + N^-}$

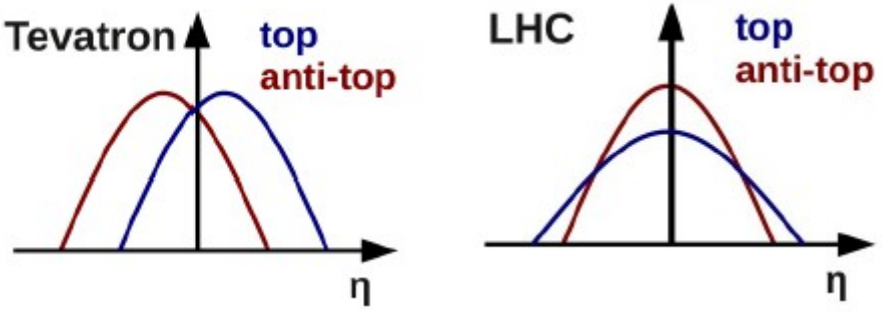
- **Predicted in SM is small**

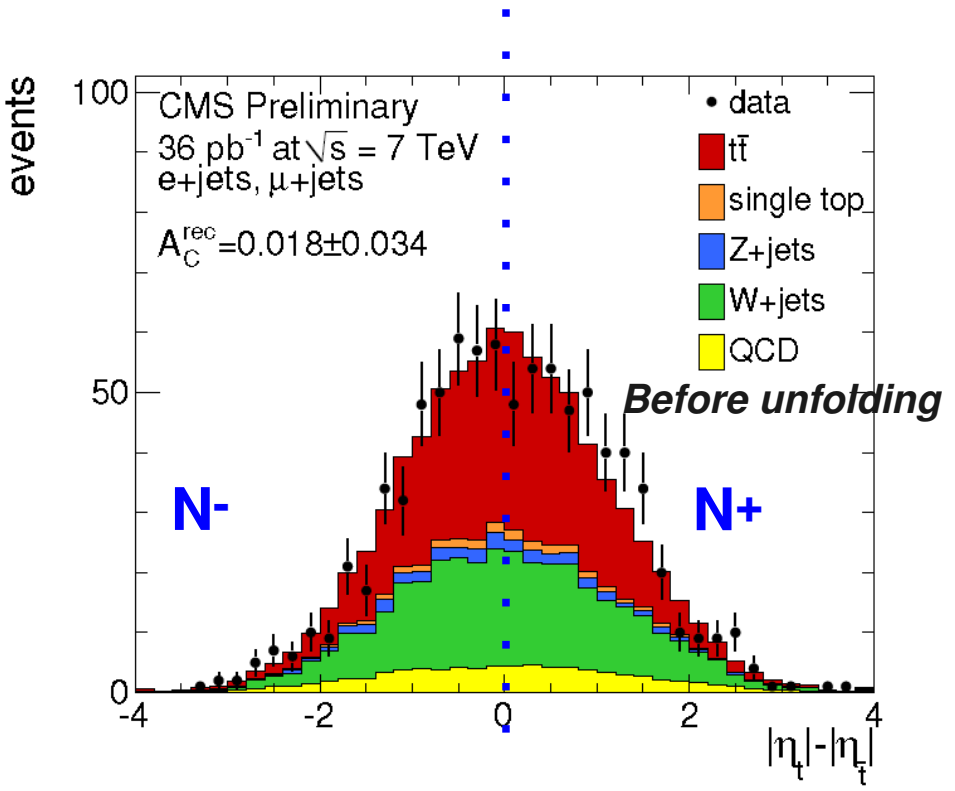
$$A_C = 0.0130 \pm 0.0011$$

- **CMS measurement:** After correction for smearing and selection effects using unfolding techniques.

$$A_C = 0.060 \pm 0.134(stat.) \pm 0.026(syst.)$$

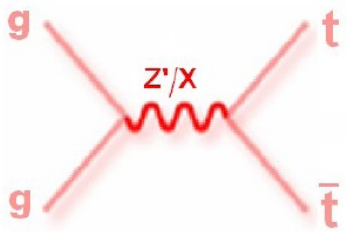
Competitive with Tevatron with ~1fb^{-1} of data

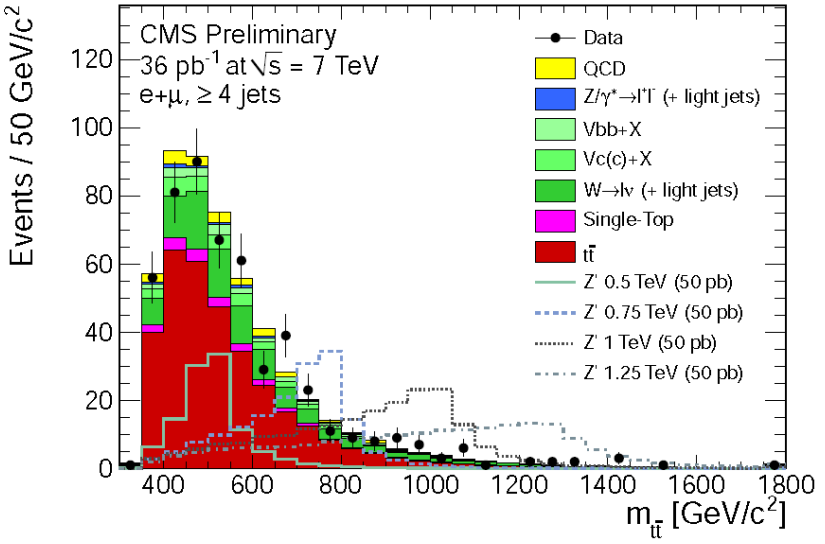




Search for $t\bar{t}$ resonances

- **Search for heavy narrow resonances decaying into a tt pair with e/μ+jets in the final state**
  → can modify the m(tt) spectrum from SM predictions

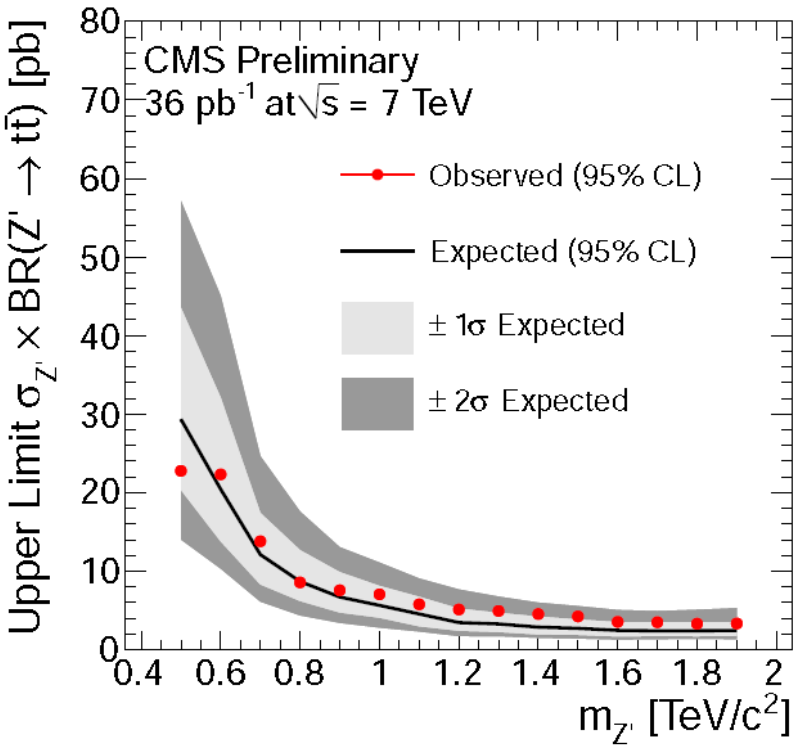




- ✗ **Reconstruction of the m(tt) system**
  → with help of kinematic fit to improve the resolution
- ✗ **Separate in different lepton flavors and jet /b-tag multiplicities** (8 categories)
- ✗ For all relevant processes, use **data-driven & MC templates**
- ✗ **Likelihood template fit to m(tt)**

- **Good agreement in m(tt) with SM**
  Upper limits set for model-independent narrow-width Z' resonancies production at 95% CL

- **Already competitive with Tevatron, particularly at higher masses**



Summary

- **A lot of interesting results in the top sector with only 36 pb^{-1} !!**

  - Measurement of the t t-bar production cross section and the top quark mass in the dilepton channel in pp collisions at sqrt(s) =7 TeV

  Submitted to the Journal of High Energy Physics ***http://arxiv.org/abs/1105.5661***

  - Measurement of the t t-bar production cross section in the lepton+jets channel.

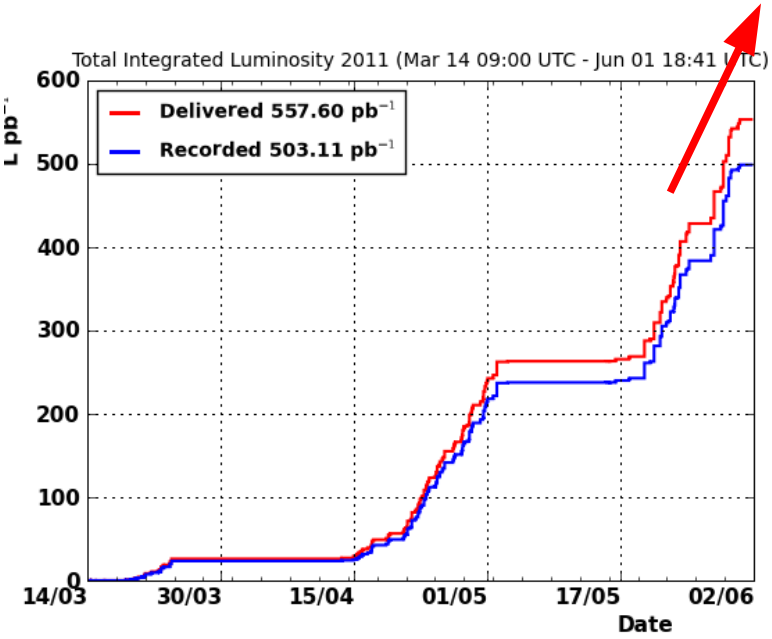
  Submitted to the European Physical Journal C ***http://arxiv.org/abs/1106.0902***

  - Single top cross section production **(36% precision)**
  - Top-pair invariant mass → **limits for Z' production**
  - Charge asymmetry → **competitive with Tevatron before end of 2011**

- **But we have just started ! More results expected soon...**

More decay channels (all-hadronic, with taus)
Differential cross sections
More top-pair and single top properties

2011 data is coming in
(already exceeds 2010 luminosity in a single fill !!)
→ statistical (and also systematic)
uncertainties will drop



More on Top physics with CMS

☐	106	09-Jun-2011 17:00	Top quark pair production cross section measurements in the single-lepton and di-lepton channels with ATLAS (15' + 5')	ROE, Adam	
☑	107	09-Jun-2011 17:20	Top quark cross section measurements with CMS (15' + 5')	SUMOWIDAGDO, Haryo	4F Parallel - top
☐	108	09-Jun-2011 17:40	The third generation quark sector in warped models LHC predictions from LEP/Tevatron anomalies (15' + 5')	MOREAU, Gregory	4F Parallel - top
☐	109	09-Jun-2011 18:00	Searches for Single Top-Quark Production with the ATLAS Detector in pp Collisions at sqrt(s) = 7 TeV (15' + 5')	SCHWIENHORST, Reinhard	4F Parallel - top
☑	111	09-Jun-2011 18:20	Single top quark production with CMS (15' + 5')	SENGHI SOARES, Mara	4F Parallel - top
☐	112	09-Jun-2011 18:40	Top quark property measurements at ATLAS (15' + 5')	DAO, Valerio	4F Parallel - top
☑	113	09-Jun-2011 19:00	Top quark mass and other properties measurements with CMS (15' + 5')	SPEER, Thomas	4F Parallel - top

Backup slides

$\sigma(t\bar{t})$: dilepton channel systematics

Table 3: Summary of systematic uncertainties relative to the rate of selected signal events estimated for the full signal selection. All values are in per cent. Systematic uncertainties on the lepton selection are treated separately for e^+e^- and $\mu^+\mu^-$ final states. Except for the lepton selection, values for all modes of a single source are treated as 100% correlated: the negative sign denotes anti-correlation. Different sources are treated as uncorrelated.

	$N_{jet} = 1$		$N_{jet} \geq 2$	
Source	$e^+e^- + \mu^+\mu^-$	$e^\pm\mu^\mp$	$e^+e^- + \mu^+\mu^-$	$e^\pm\mu^\mp$
Lepton selection	1.91/1.30	1.11	1.91/1.30	1.11
Energy scale	−3.0	−5.5	3.8	2.8
Lepton selection model	4.0	4.0	4.0	4.0
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 $\not{E}_T$ model	−3.0	−1.0	3.2	0.4
Shower model	1.0	3.3	−0.7	−0.7
Pileup	−2.0	−2.0	0.8	0.8
Subtotal (before tags)	11.2/11.1	13.1	8.0/7.9	6.2
b tagging (≥ 1 b tag)			5.0	5.0
Subtotal with tags			9.5/9.4	8.0
Luminosity	4	4	4	4

$\sigma(t\bar{t})$: lepton+jets channel systematics

Analysis with b-tag

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 squres of the contributions.

Source	Uncertainty (%)
Systematic uncertainties	
Lepton ID/reco/trigger	3
Unclustered $E_{\mathrm{T}}^{\mathrm{miss}}$ 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

Analysis without b-tag

	stat.+syst. uncertainty	
Stat.+bkg. uncertainty	−8.4%	+8.7%
JES	−17.6%	+20.3%
JER	−8.4%	+8.8%
ISR/FSR variation	−8.6%	+9.0%
Factorization scale	−10.6%	+11.2%
Matching threshold	−9.8%	+10.5%
Branching ratio	−8.6%	+8.9%
Efficiencies (from T&P)	−8.7%	+9.2%
QCD rate & shape	−8.9%	+9.1%
Lepton scale	−8.4%	+8.7%
PDF uncertainty	−8.5%	+8.7%
Pile-up	−9.3%	+9.3%
Total	−19.3%	+23.5%

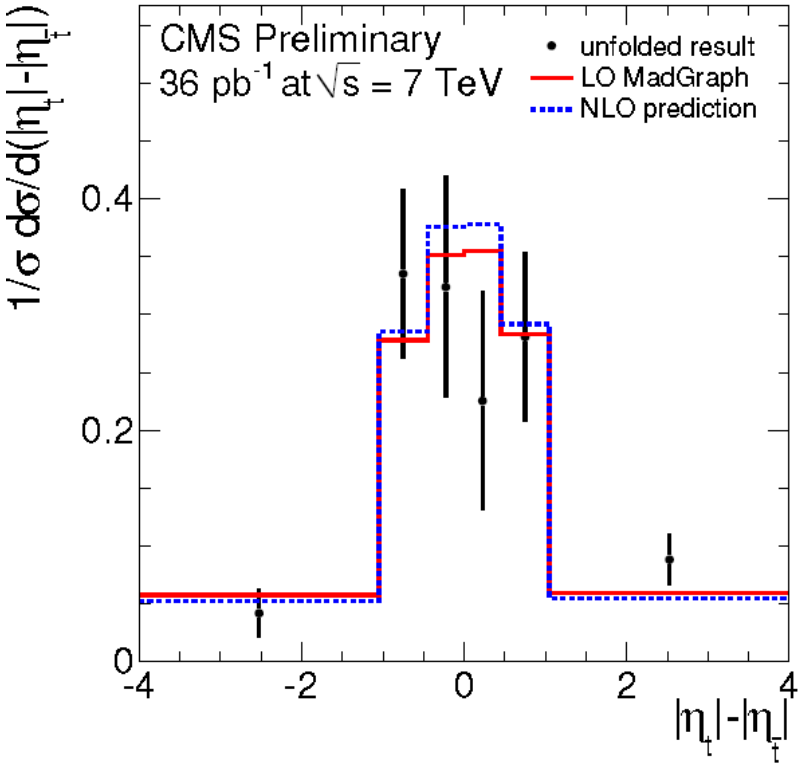
Single top cross-section systematics

uncertainty	correlation	impact on 2D −	2D +	BDT −	BDT +
statistical only	60	52		39	
shared shape/rate uncertainties:					
ISR/FSR for $t\bar{t}$	100	−1.0	+1.5	< 0.2	< 0.2
Q^2 for $t\bar{t}$	100	+3.5	−3.5	+0.3	−0.4
Q^2 for V+jets	100	+5.7	−12.0	+2.6	−4.5
Jet energy scale	100	−8.8	+3.6	−5.1	+1.2
b tagging efficiency	100	−19.6	+19.8	−15.2	+14.6
MET (uncl. energy)	100	−5.7	+3.7	−3.9	−0.5
shared rate-only uncertainties:					
$t\bar{t}$ (±14%)	100	+2.0	−1.9	+0.5	−0.6
single top s (±30%)	100	−0.4	+0.5	−0.4	+0.4
single top tW (±30%)	100	+1.1	−1.0	< 0.2	< 0.2
$Wb\bar{b}$, $Wc\bar{c}$ (±50%)	100	−3.0	+2.9	+1.7	−1.9
Wc ($^{+100\%}_{-50\%}$)	100	−3.0	+6.1	−2.4	+4.4
Z+jets (±30%)	100	−0.6	+0.7	+0.4	−0.2
electron QCD (BDT: ±100%, 2D: $^{+130\%}_{-100\%}$)	50	+2.9	−3.7	−1.7	+1.7
muon QCD (BDT: ±50%, 2D: ±50%)	50	< 0.2	< 0.2	−2.1	+2.1
signal model	100	−5.0	+5.0	−4.0	+4.0
BDT-only uncertainties:					
electron efficiency (±5%)	0	—	—	−1.4	+1.4
muon efficiency (±5%)	0	—	—	−3.6	+3.5
V+jets (±50%)	0	—	—	−1.5	< 0.2
2D-only uncertainties:					
muon W+light (±30%)	0	−1.4	+1.4	—	—
electron W+light (±20%)	0	−0.6	+0.7	—	—
W+light model uncertainties	0	−5.4	+5.4	—	—

Table 3: Relative impact of the uncertainties on the combined cross section measurement ($e + \mu$) in the two analyses, in percent of the standard model cross section, estimated with pseudo-data. The table includes the correlation assumed for the final combination.

Single top cross-section systematics

Unfolded spectrum compared to predictions

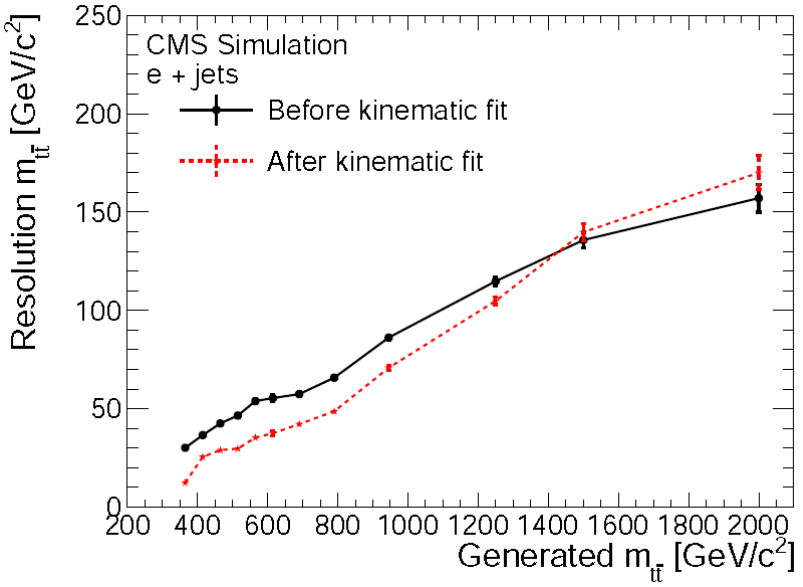


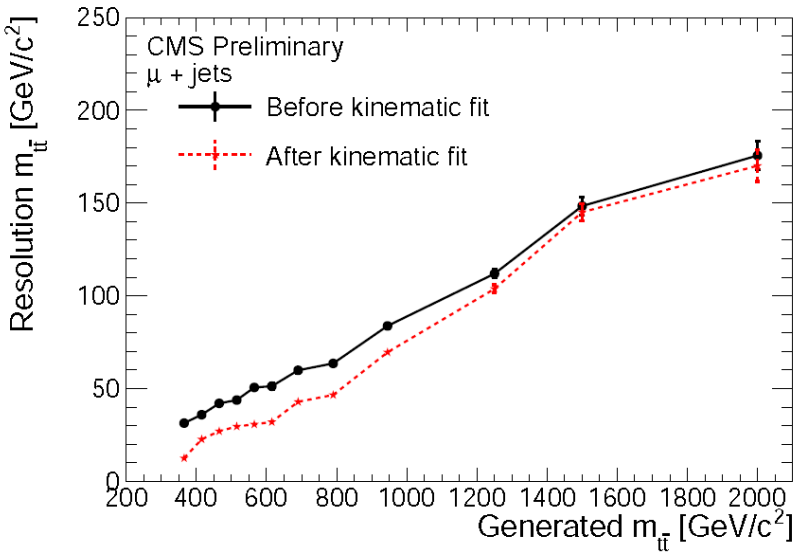
Systematic uncertainties

source of systematic	positive shift in A_C	negative shift in A_C
jet energy scale	0.017	-
jet energy resolution	0.007	-0.006
Q^2 scale	0.003	-0.007
ISR/FSR	0.005	-0.0006
matching threshold	0.004	-0.006
PDF	0.004	-0.011
b tagging	0.007	-
lepton efficiency	0.017	-0.018
QCD model	0.005	-0.005
overall	$\pm$0.026	

Search for $t\bar{t}$ resonances

- **Reconstruction of m(tt) done in 3 steps**
  - **reconstruction of leptonic W (with MET as pT(ν))**
    - 2 real solutions → keep both
    - imaginary solutions → modify MET
  - **jet-parton association by χ2 minimisation**
    - 5 quantities used: m^{lep} (top), m^{had} (top), m^{had} (W), pT (tt), HT fraction
    - correct association in 80% (in simulation)
  - **kinematic fit to improve resolution**
    - mtop = 172.5 GeV/c2, mW = 80.4 GeV/c2





Top quark mass

Fully Kinematic Analysis

- **Reconstruction of top quarks**
  - solve equations of tt system many times per event
  - scanning the kinematic phase space varying p_T(jet), MET and $p_z(t\bar{t})$ independently according to resolution
  - accept solutions with lowest $m_{t\bar{t}}$ if $|m_t - m_{\bar{t}}| j < 3$ GeV/c^2
  - lepton-jet combination with largest number of solutions is chosen
  - m_{KIN} is outcome of Gaussian fit around most probable value (MPV±50 GeV)
  - in MC signal efficiency: 98%, background efficiency:80%
  - in MC right lepton-jet matching: 75%

- **Top mass determination**
  - unbinned likelihood fit to m_{KIN}
  - free parameters: m_{top} , n_{sig} , n_{bkg}
  - background templates from simulation (shape fixed)
  - signal template (Gaussian+Landau) from fit of simulated tt samples
    - 151GeV/c^2 < m_{top} < 199GeV/c^2 (in 3 GeV/c^2 steps)
    - linear dependence on m_{top}

Top quark mass: dilepton channel

Analytical Matrix Weighting Technique

- **Reconstruction of top quarks**
  - solve equations of tt system many times per event
  - 8 solutions per event (4 for each of the 2 lepton-jet combinations)
  - scanning m_{top} in 1 GeV/c2 steps ($100\text{GeV}/c^2 < m_{top} < 300\text{GeV}/c^2$)
  - each solution gets weight, that depends on:
    PDF (summation over u,d,g)
    probability finding lepton with energy E in top rest frame by given m_t
  - add weights for all solutions
  - average weights for different pT (jet) varied within resolution
  - take m_{top} with maximum averaged weight as m_{AMWT}

- **Top mass determination**
  - calculate likelihood for different m_{top}
    $151\text{GeV}/c^2 < m_{top} < 199\text{GeV}/c^2$ (in 3 GeV/c^2 steps)
  - Z+jet background template from data in Z mass window (fixed)
  - other templates from simulation

Top quark mass: lepton+jets channel

Ideogram method

- **Reconstruction of top quarks**
  - Kinematic fit to reconstruct each $t\bar{t}$ event: lepton, 4jets, MET, resolutions
    - Jets-to-quark assigment: 12 ways to pair the 4 jets with the quark
    - Jet corrected to parent parton energy
    - Coinstraint the fit by $m_{\bar{t}} = m_t$
  - 24 possible combinations: for each, if a minimum is found, compute the χ^2
  - Require at least one solution with $\chi^2 < 10$ (88% eff. for tt; 80% eff. Wjets/QCD)

- **Top mass determination**
  - For each event calcula a likelihood as a function of the m_t, containing the probability on the event to be a tt or a background event. Also include:
    - Number b-tagged jets
    - Mass information from the kinematic fit

Top quark mass: lepton+jets channel

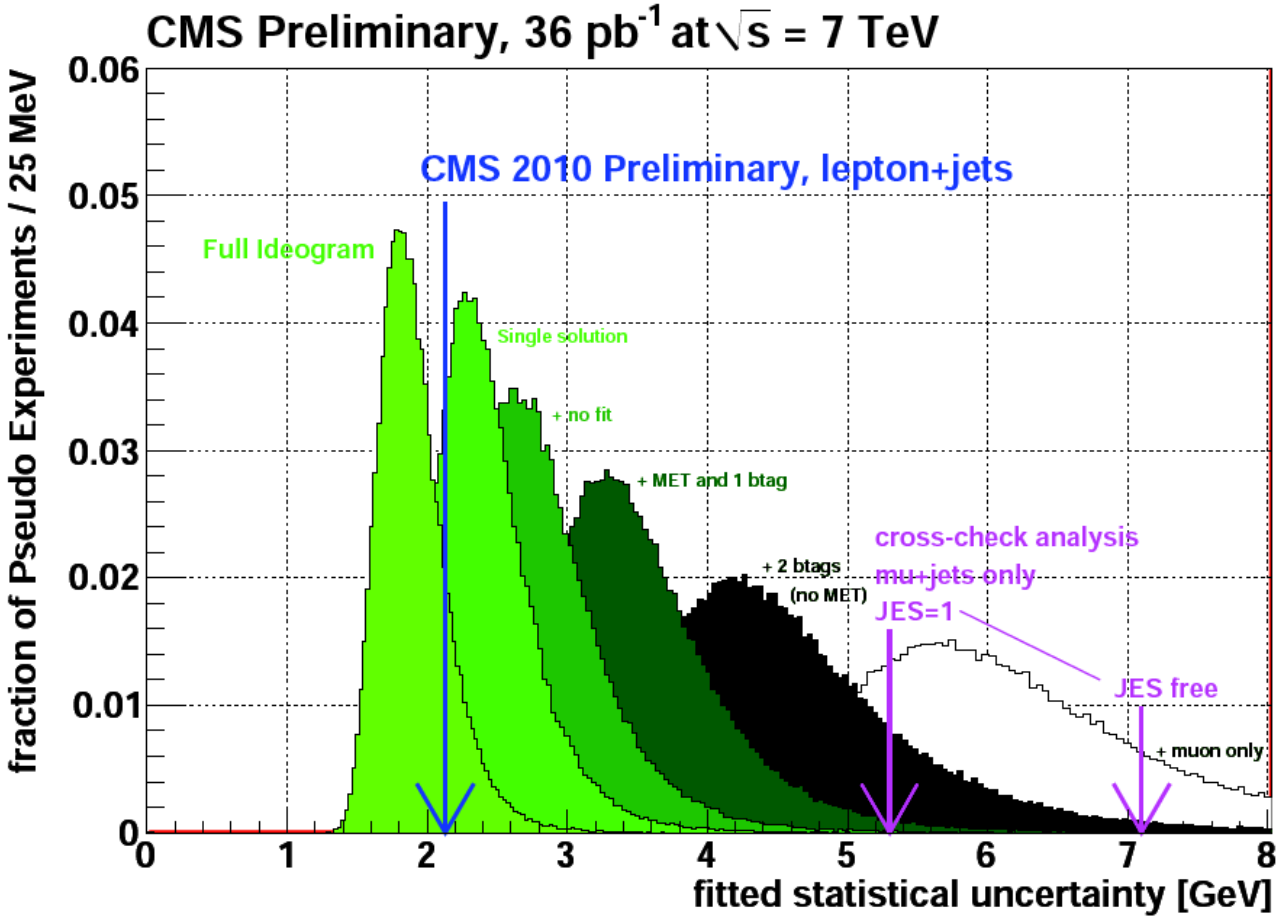


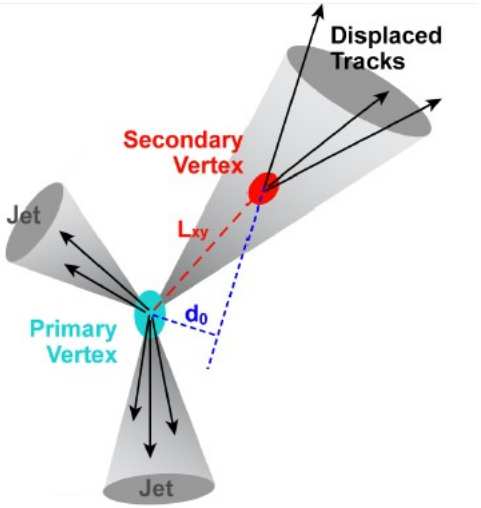
Figure 9: Comparison of the expected statistical uncertainty of the ideogram analysis, applying successively the modifications described in the text, with the statistical uncertainties observed in data for the baseline ideogram and the cross-check analysis.

Top quark mass: combination

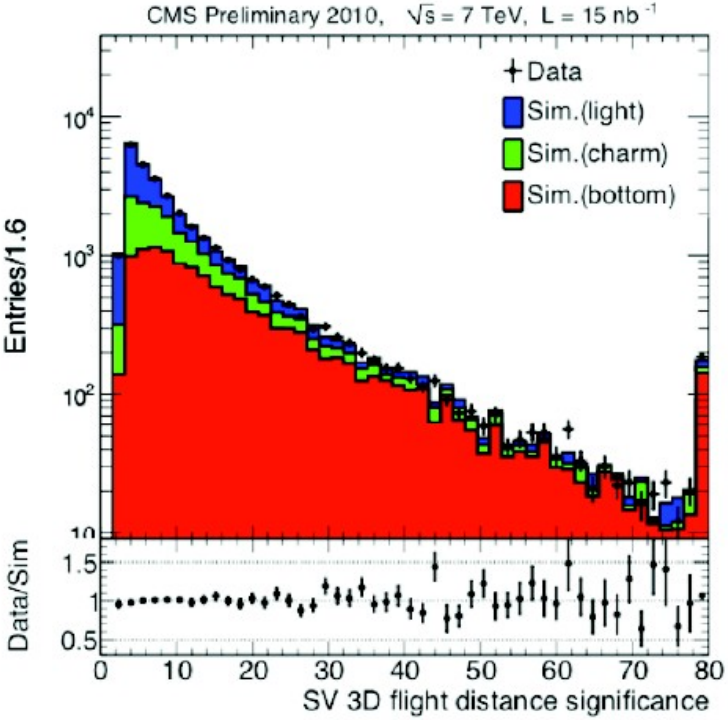
Measured m_t and uncertainties for the two measurements and combination in GeV/c^2

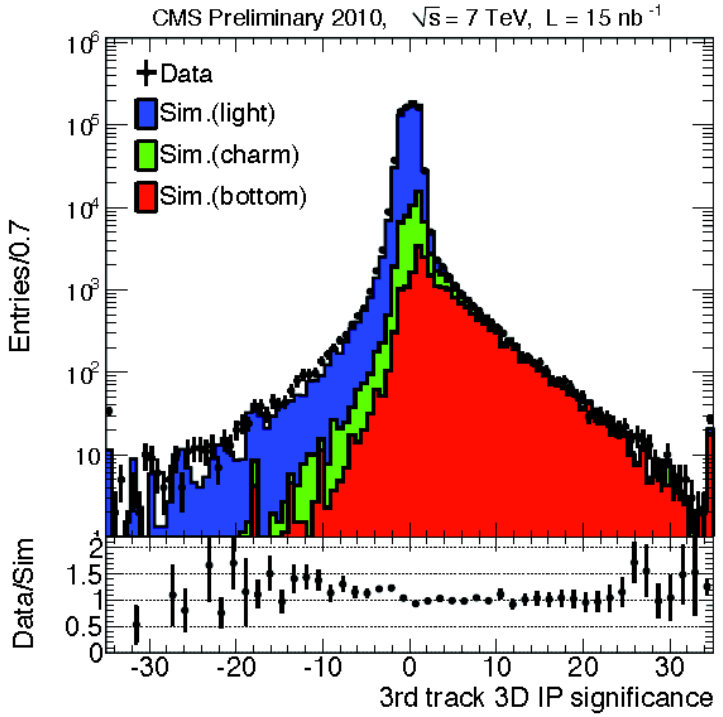
	Dileptons	Lepton+jets	Correlation factor	Combination
Measured m_t	175.5	173.1		173.4
Statistical Uncertainty	4.6	2.1	0	1.9
Breakdown of Systematic Uncertainty:				
Jet energy scale (correlated part)	2.25	2.25	1	2.3
Jet energy scale (uncorrelated part)	3.28	n/a	0	0.4
Jet energy resolution	0.5	0.1	1	0.1
Lepton energy scale	0.3	n/a	0	0.0
Missing p_T scale	0.1	0.4	1	0.4
Pile-up	1.0	0.1	1	0.2
b-tagging	0.4	0.1	1	0.1
Background	0.1	0.5	0	0.4
Parton density function	0.5	0.1	1	0.2
MC generator	0.4	n/a	0	0.0
Underlying event	1.4	0.2	1	0.3
ISR/FSR	0.2	0.2	1	0.2
Jet-parton scale	0.7	0.4	1	0.4
Factorization scale	0.6	1.1	1	1.0
Fit calibration and MC statistics	0.3	0.1	0	0.1
Total Systematic Uncertainty	4.6	2.7		2.7
Combination weight	12%	88%		

B-tagging in CMS



Secondary vertex tagger
Discriminator based on 3D flight distance





"Track counting" tagger
Discriminator: IP significance of the n_{th} track