Recent Results on Top Physics at CMS

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on behalf of the CMS Collaboration

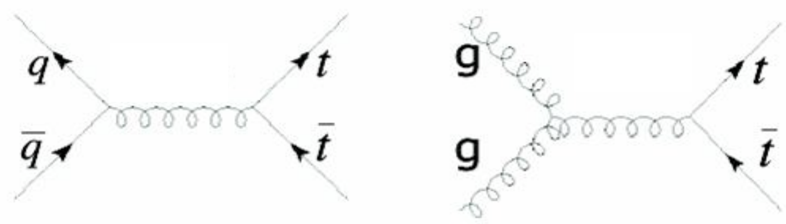
Outline

- Interests for the top-quark physics
- CMS and the LHC
- Inclusive $t\bar{t}$ cross-section measurements
- Charge asymmetry in $t\bar{t}$ pair production
- Search for Z' -> $t\bar{t}$ resonances in the m($t\bar{t}$) spectrum
- Single top production
- Top-quark mass

The Top Quark (I)

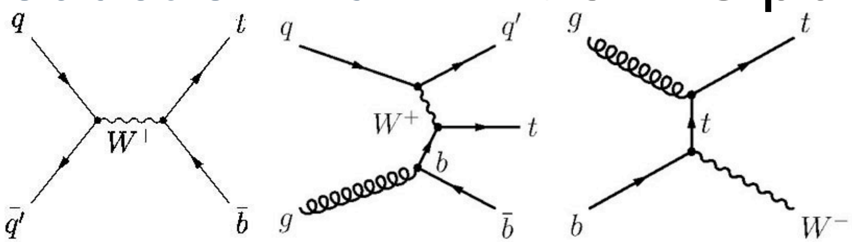
- The heaviest elementary particle known to date
  - m = (173.3±1.1) GeV/c^2*; $\tau < 10^{-25}$ s
  - It decays before hadronization
  - BR(t->Wb) ~ 100%

- $t\bar{t}$ pair production via QCD: $\sigma \approx 158$ pb at 7 TeV



According to the W decay, we can have *semileptonic (42%)*, *dileptonic (10%)* or *hadronic (48%)* $t\bar{t}$ pairs

- Single top production via EWK: $\sigma \approx 78$ pb at 7 TeV

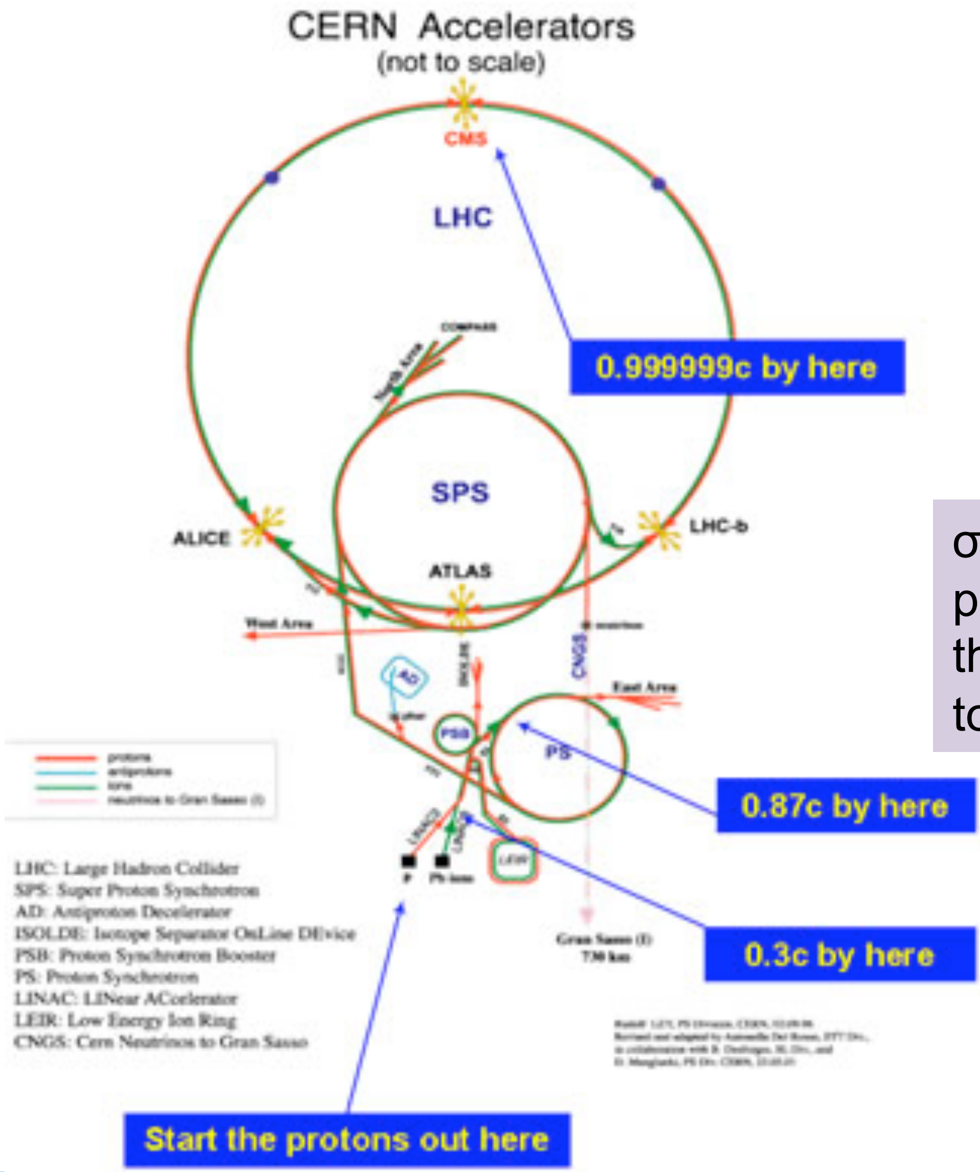


* arXiv:1007.3178

The Top Quark (II)

- The top quark has a paramount importance at the LHC
- Tests of the performances of the detector
  - Almost all subdetectors are involved: final states with leptons, jets, missing energy
- It represents one of the largest backgrounds to other processes
- Important tool to verify SM predictions
  - Verification of QCD calculations at the LHC environment
  - m(top) is a fundamental ingredient of EWK fits
- Search for New Physics beyond the SM
  - Preferential coupling of many NP models to the top sector
  - several « top-like » signatures foreseen in these models

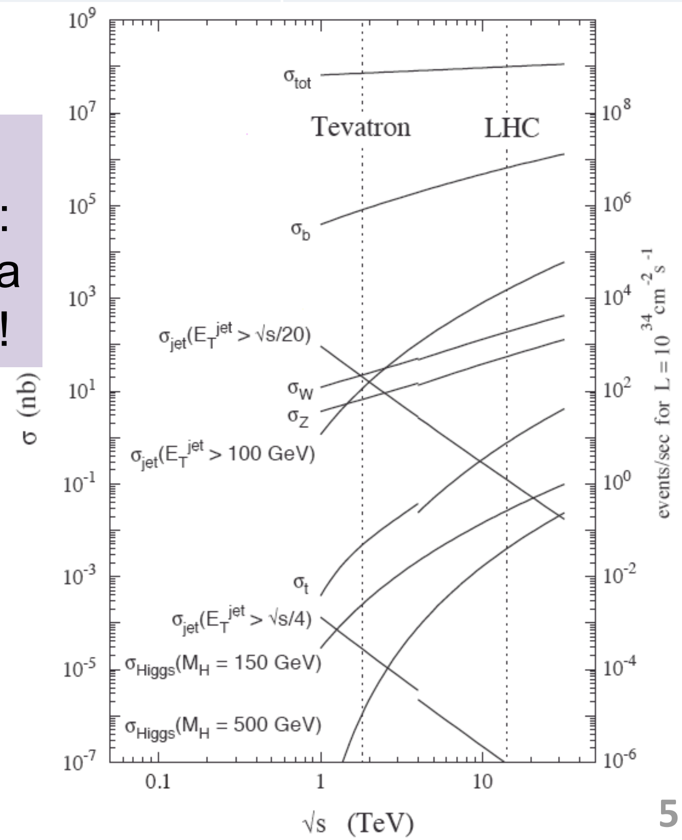
The LHC



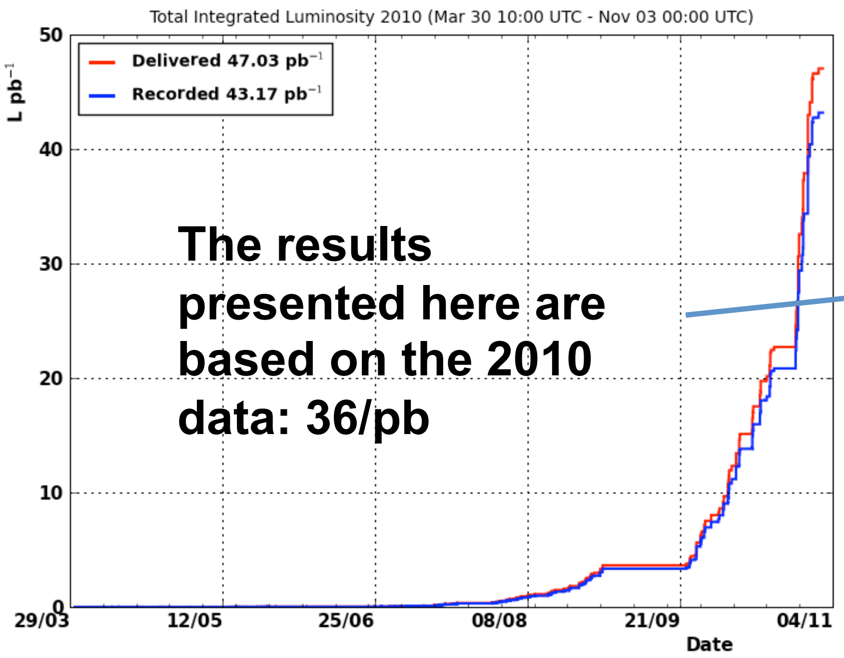
Proton and heavy ion collisions

	Nominal parameters
Center of mass energy	14 TeV
Instantaneous luminosity	10^{34} cm^{-2} s^{-1}
Integrated luminosity	100 fb^{-1}/an
N. bunches	2808

$\sigma(t\bar{t}) \sim 158$ pb at 7 TeV: the LHC is a top-factory !

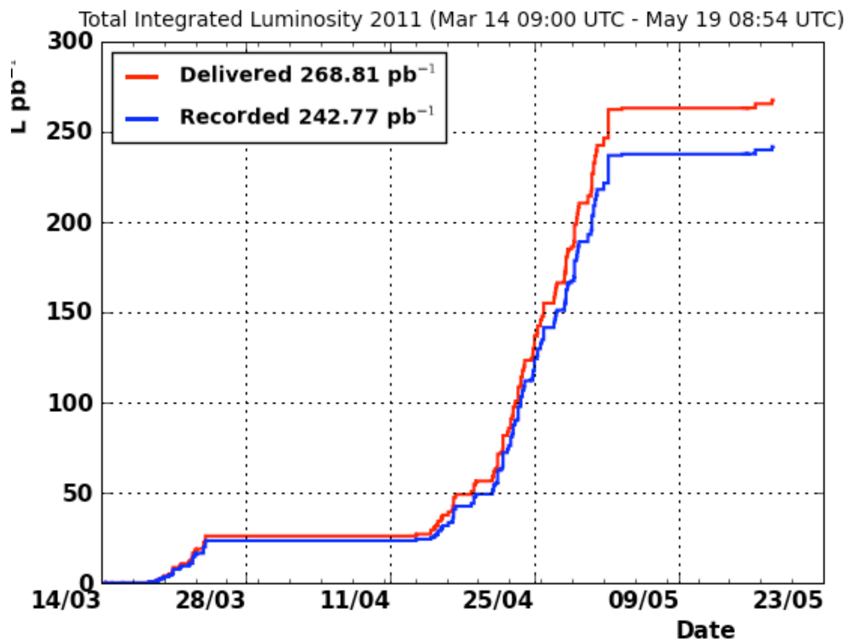


The Data



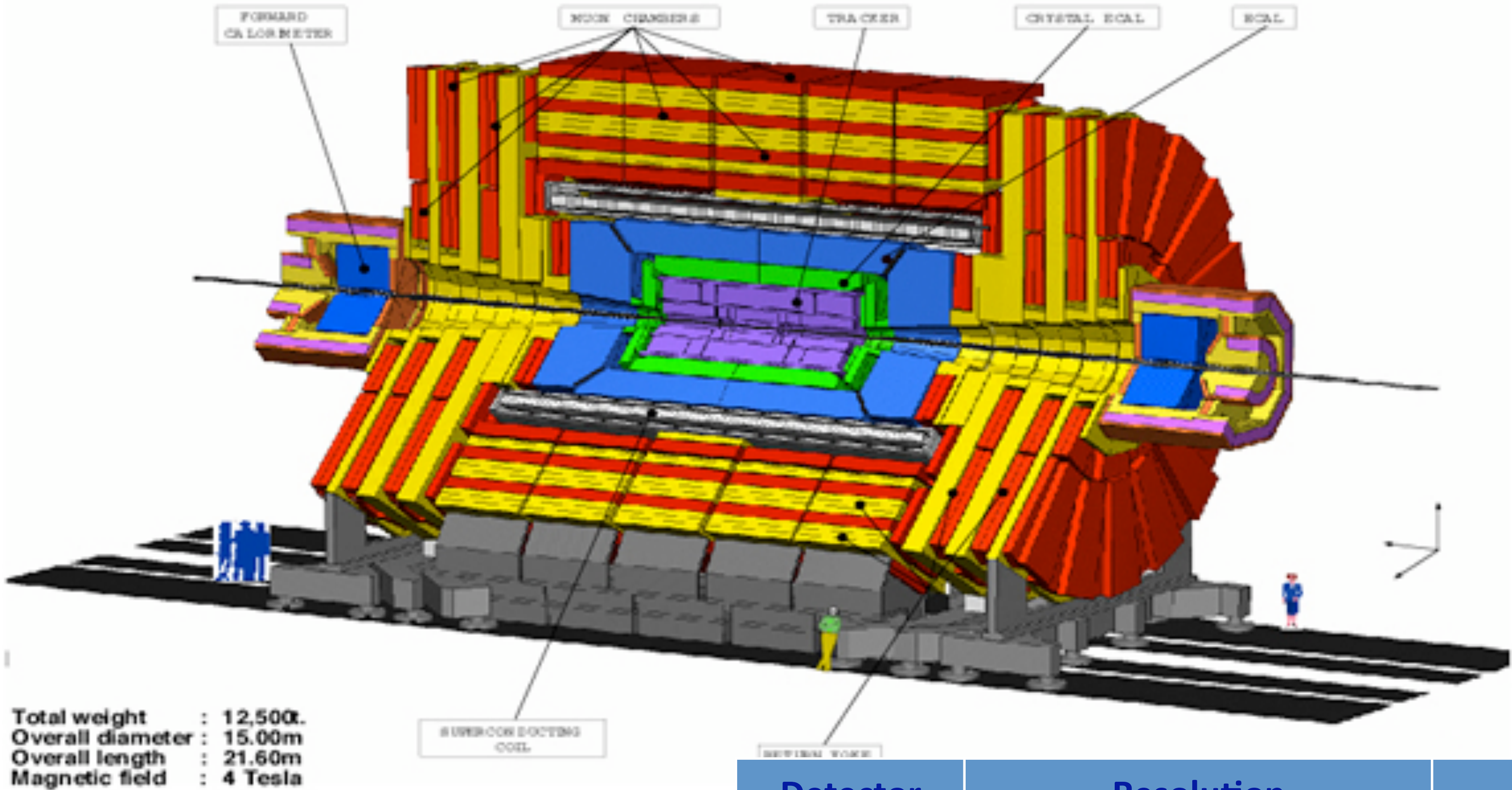
The results presented here are based on the 2010 data: 36/pb

- 2009:
  - 12.5/μb pp at 900 GeV
  - 0.5/μb pp at 2.36 TeV
- 2010:
  - 47.03/pb pp at 7 TeV
  - 8.38/μb heavy ions at 7 TeV



- 2011
  - ~270/pb at 7 TeV so far
- More than 1/fb in 2011?

CMS

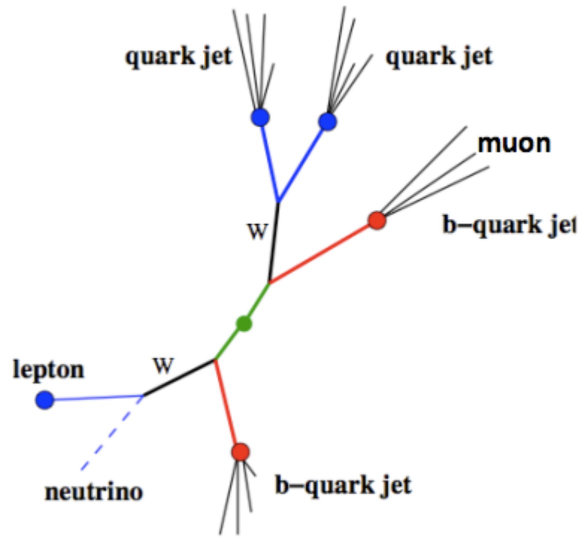


Detector	Resolution	Coverage
Tracker	$\sigma(p_T)/p_T$~1.5%p_T+0.005	$\vert\eta\vert<2.4$
Ecal	$\sigma(E)/E$~3%/$\sqrt{E}$+0.003	$\vert\eta\vert<3$
Hcal	$\sigma(E)/E$~100%/$\sqrt{E}$+0.05 GeV	$\vert\eta\vert<3$ (b) / 5 (f)
Muon	$\sigma(p_T)/p_T$~1-10%p_T	$\vert\eta\vert<2.4$

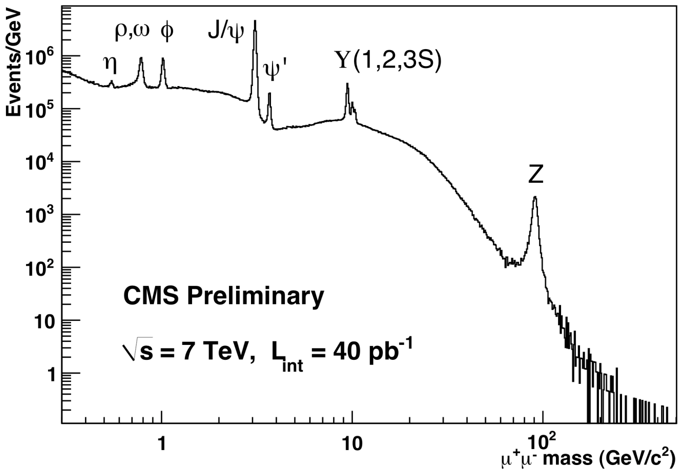
Ingredients for Top Physics (I)

- Several basic objects are involved
- Trigger requirements
  - One electron, with minimum E_T > 10 (22) GeV/c (*), eff ~ 98%
  - One muon, with minimum p_T > 9 (15) GeV/c (*), eff ~ 92%

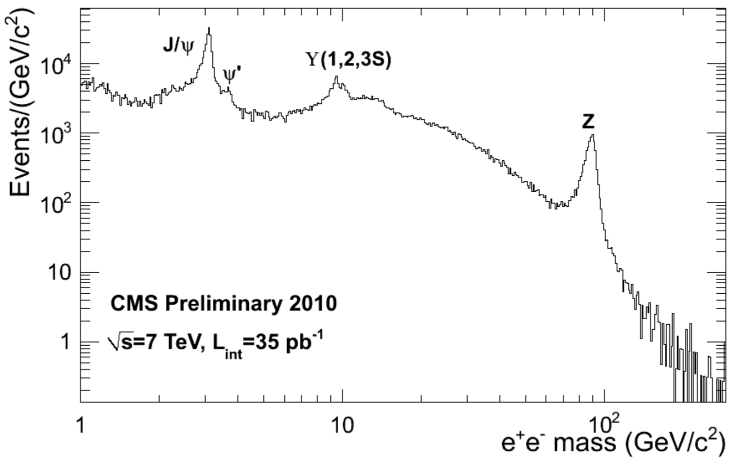
(*) different thresholds according to the data taking period



- Muons
  - Typical eff for an isolated muon ~88%

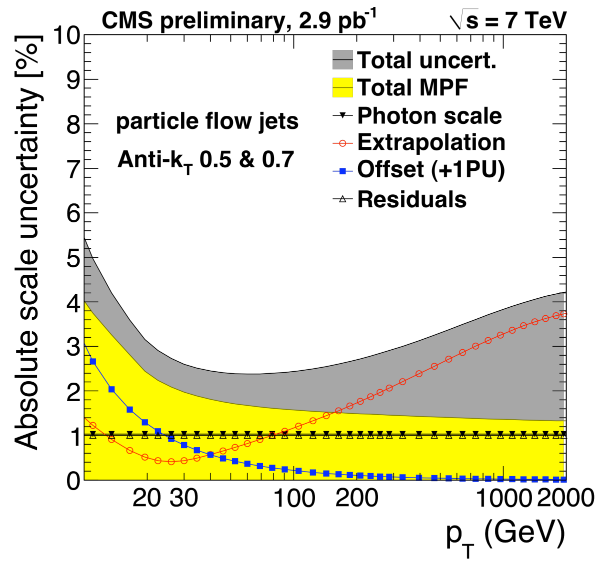


- Electrons
  - Typical eff for an isolated electron ~75%

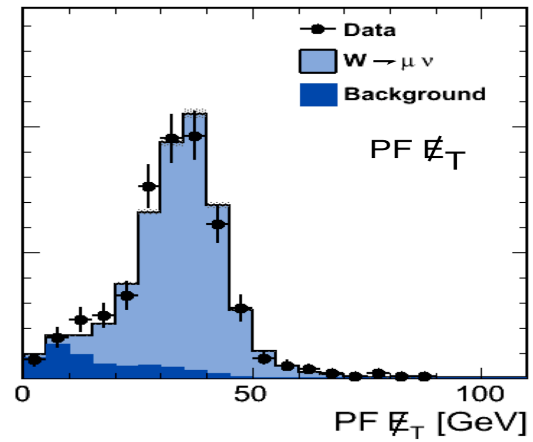


Ingredients for Top Physics (II)

- Particle flow algorithm used for jets and missing energy
  - Usage of the information from all subdetectors to determine the particle content of the events
- Jets
  - Uncertainty on the energy scale depending on p_T/η: 3 to 5%
  - Uncertainty on the energy resolution ~ 10%
- Identification of the b-flavor content of jets (b-tagging)
  - Several algorithms available
    - Typical efficiency ~80% at a misID level of 10%
  - Typical eff uncertainty around 15%



- Missing transverse energy



Measurements of $\sigma(t\bar{t})$

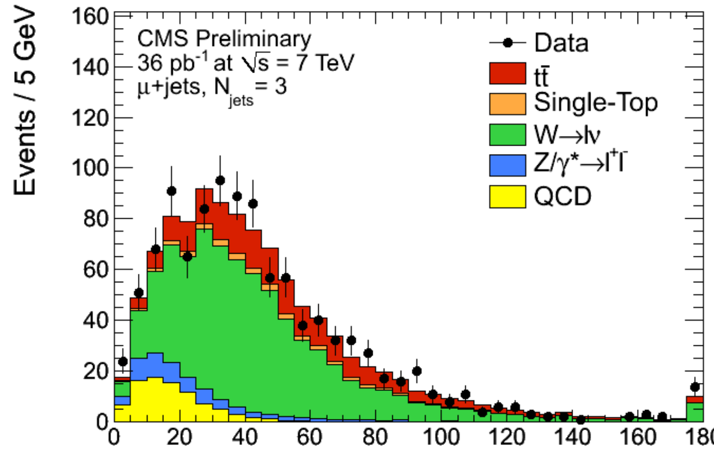
- Inclusive cross section with the semi-leptonic channel
  - CMS-PAS TOP-10-002 without b-tagging
  - CMS-PAS TOP-10-003 with b-tagging
- Inclusive cross section with the dileptonic channel
  - Phys. Lett. B 695, 424 (2011) with 3.1/pb
  - CMS-PAS TOP-11-002 with 36/pb
- Ongoing developments
  - Differential cross-section measurements
  - Channels with taus
  - All-hadronic channel

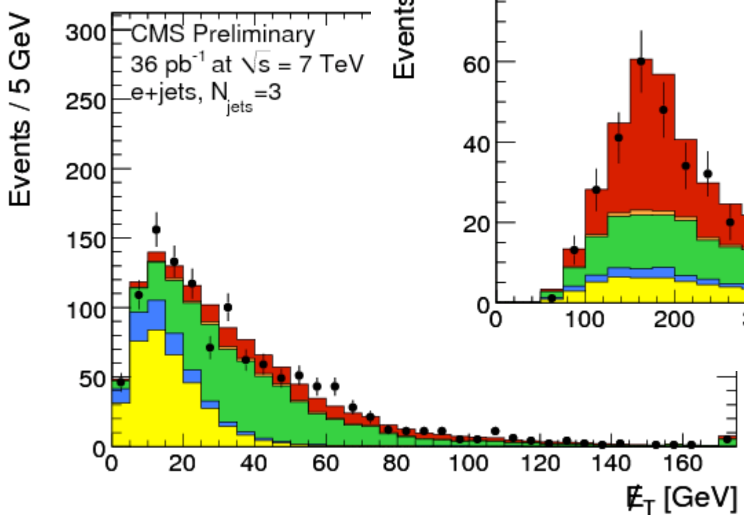
All measurements cross-checked with alternative methods

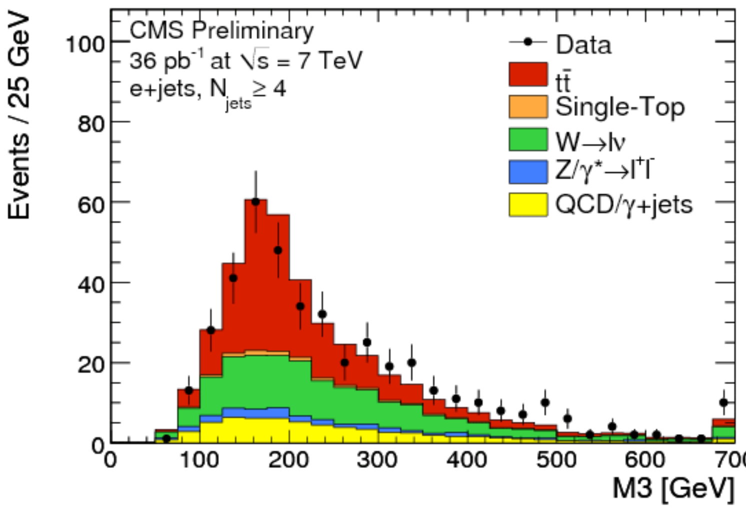
σ(tt̄): Semileptonic Channel Without b-Tagging

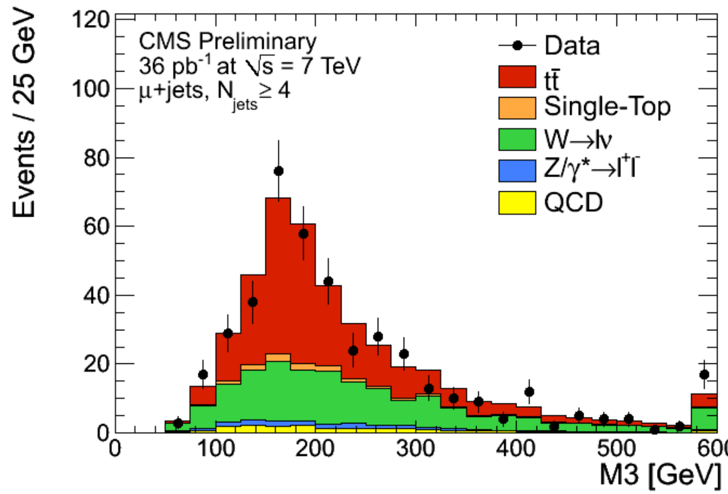
CMS-PAS TOP-10-002

- Binned likelihood template fit to
  - $\not{E}_T$ = missing energy
  - M3 = inv. mass of the 3 jets with largest vectorial summed p_T
- Data-driven QCD template
- Main systematics: jet-energy scale









e+jets and mu+jets combined:

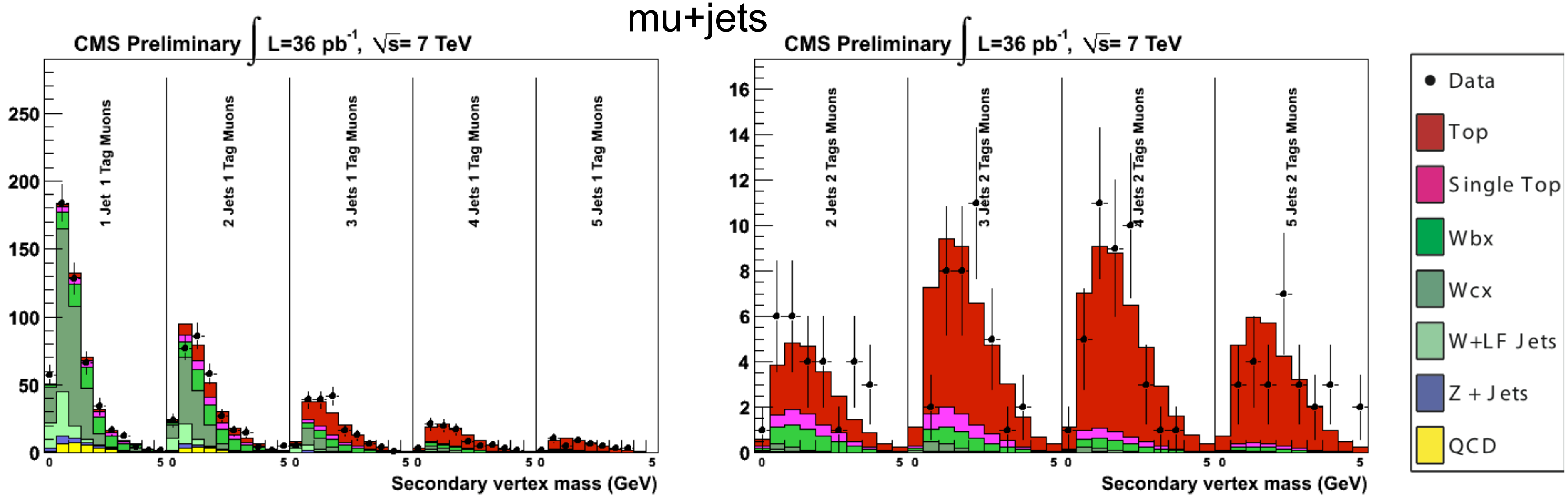
$$\sigma_{t\bar{t}} = 173^{+39}_{-32}(\text{stat} + \text{syst}) \pm 7(\text{lumi})\ \text{pb}$$

σ(tt̄): Semileptonic Channel With b-Tagging

CMS-PAS TOP-10-003

- Binned likelihood fit to the secondary vertex mass
- Data-driven templates
- Systematics included as nuisance parameters in the fit

mu+jets



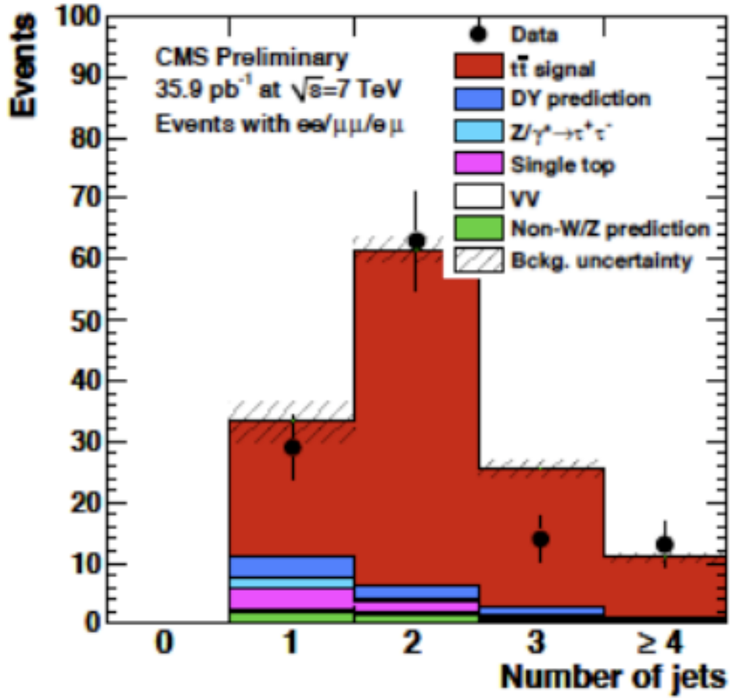
e+jets and mu+jets combined:

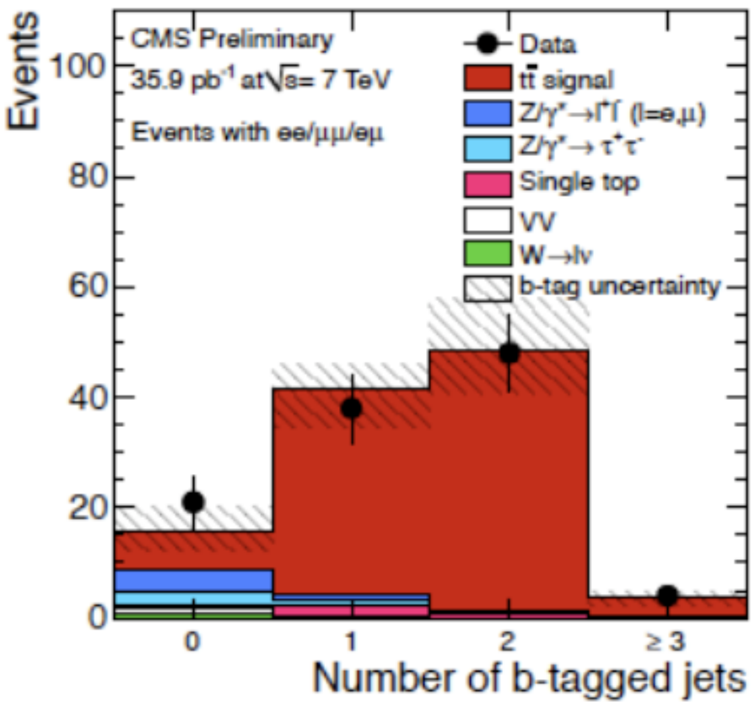
$$\sigma_{t\bar{t}} = 150 \pm 9\,(\text{stat.}) \pm 17\,(\text{syst.}) \pm 6\,(\text{lum.})\ \text{pb}$$

σ(tt̄): Dileptonic Channel

CMS-PAS TOP-11-002

- ee, μμ, eμ channels
- Event counting in jet multiplicity bins
- Major systematics: background modelling and b-tagging efficiency

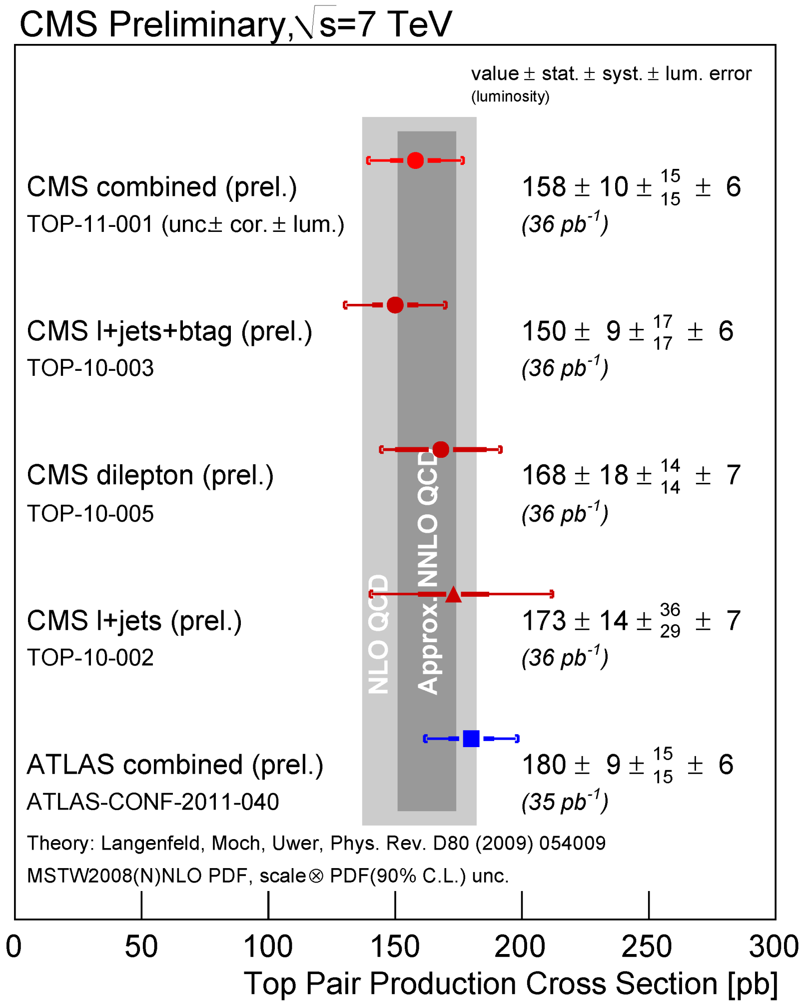


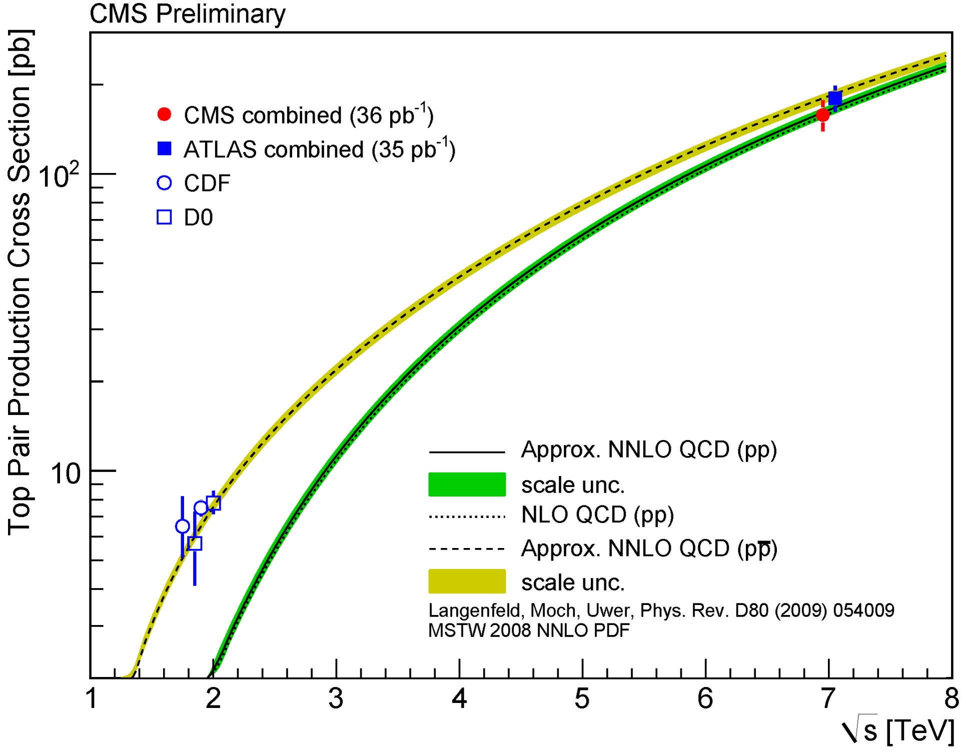


$$\sigma_{t\bar{t}} = 168 \pm 18\,(\mathrm{stat.}) \pm 14\,(\mathrm{syst.}) \pm 7\,(\mathrm{lumi.})\ \mathrm{pb}$$

σ(tt̄): Combination

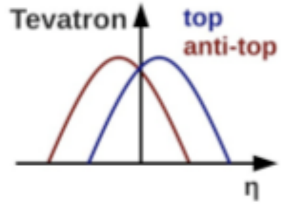
CMS-PAS TOP-11-001



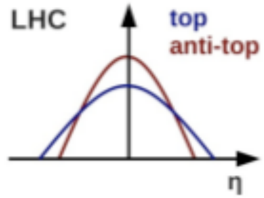


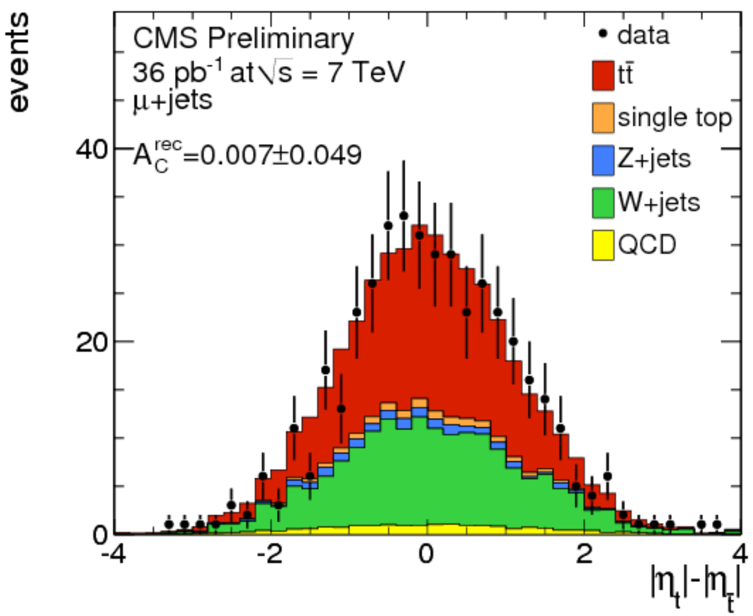
Charge Asymmetry

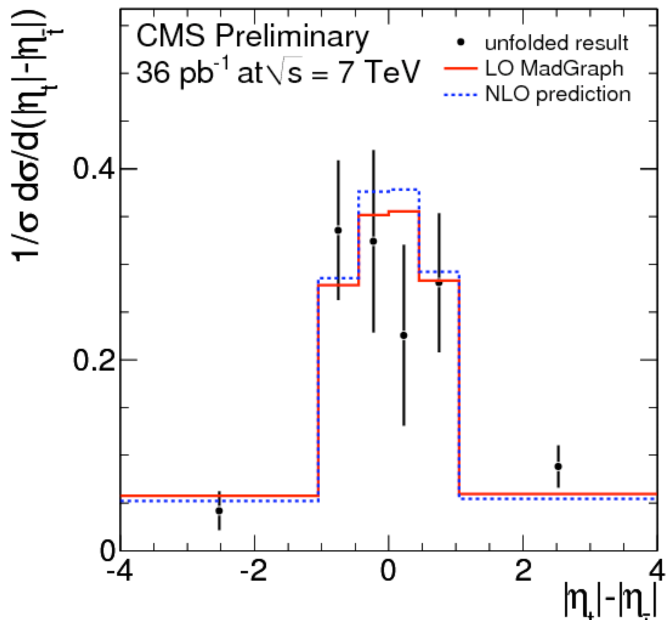
CMS-PAS TOP-10-010



- $t\bar{t}$ pair production is symmetric (at the LO) in the SM
- NP can induce asymmetries!
- Tevatron reported a deviation from SM predictions (*)







$$A_C = \frac{N_+ - N_-}{N_+ + N_-}$$

N_+ (N_-)= n. events with positive (negative) values of $|\eta(t)| - |\eta(\bar{t})|$

$$A_C = 0.060 \pm 0.134\,(\text{stat.}) \pm 0.026\,(\text{syst.})$$

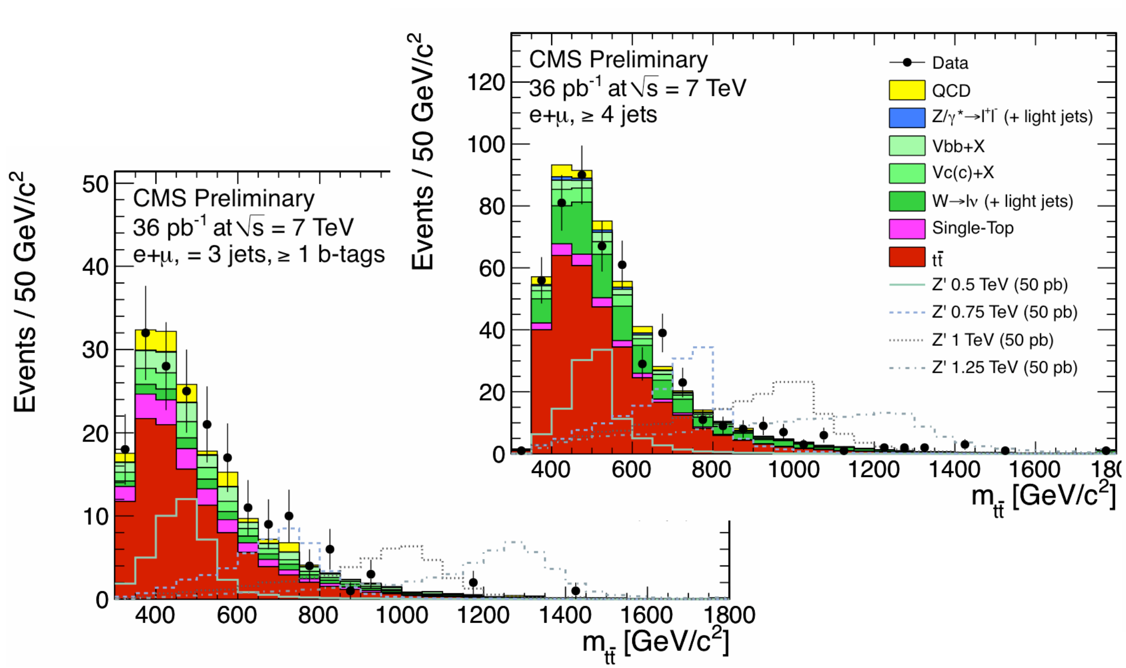
Competitive with Tevatron with ~1/fb of data

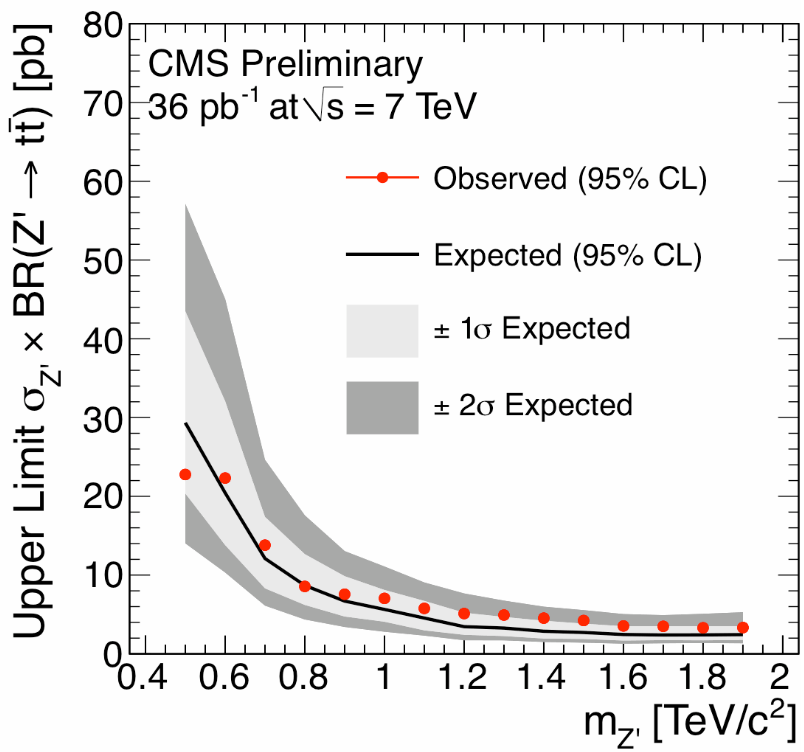
(*) CDF note 10185, D0 note 6062

Search for $t\bar{t}$ Resonances

CMS-PAS TOP-10-007

- Resonances decaying to $t\bar{t}$ (*) can modify the $m(t\bar{t})$ spectrum from SM predictions
- Tevatron excluded resonances up to 820 GeV in the « top-color assisted technicolor» model (**)
- Likelihood template fit to $m(t\bar{t})$





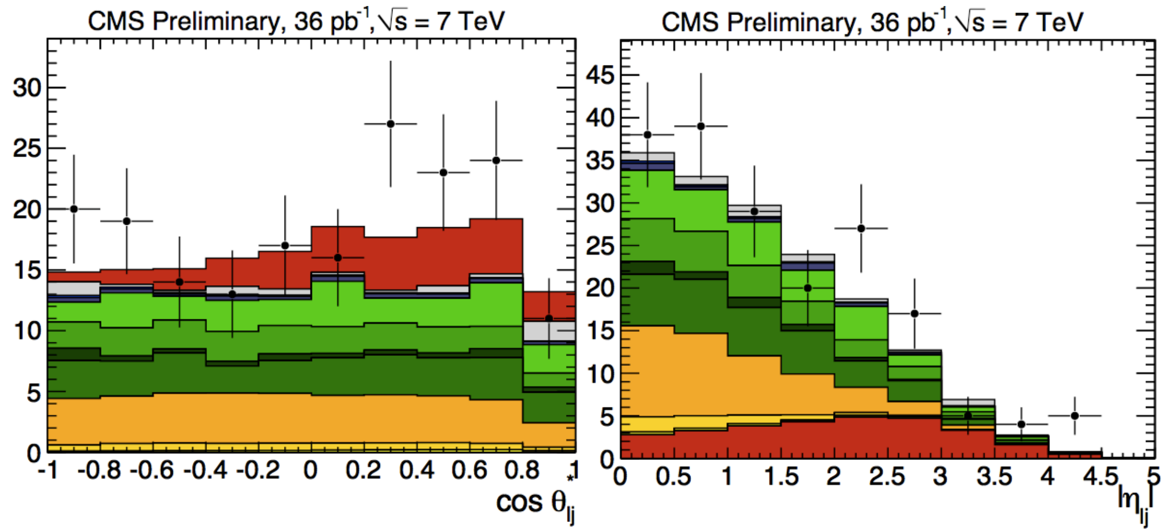
No Z' signal is observed

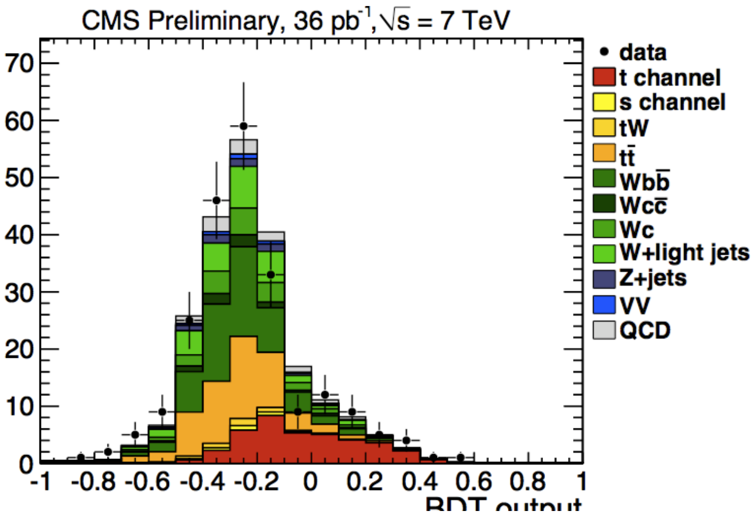
(*) many models, e.g. hep-ph/9911288 (**) D0 note 5882

Single Top

CMS-PAS TOP-10-008

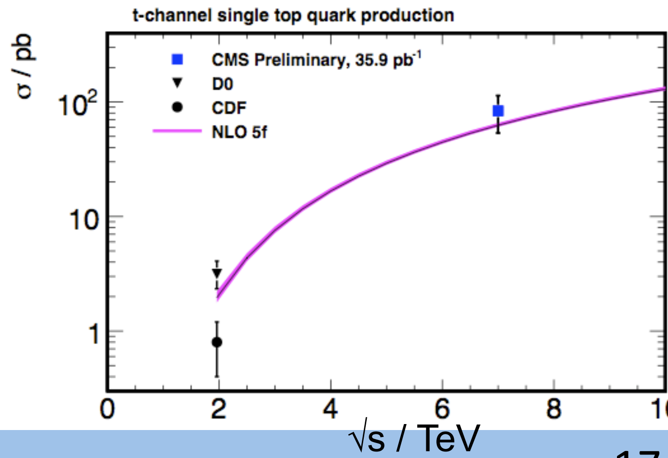
- Successful example of extraction of a tiny signal!
- Two complementary analyses
  - ○ Template 2D fit to $\cos(\vartheta^*_{lj})$ and $|\eta_{lj}|$
  - ○ Multivariate BDT techinque





- > 3σ evidence in both analyses
- Combination of the two analyses:

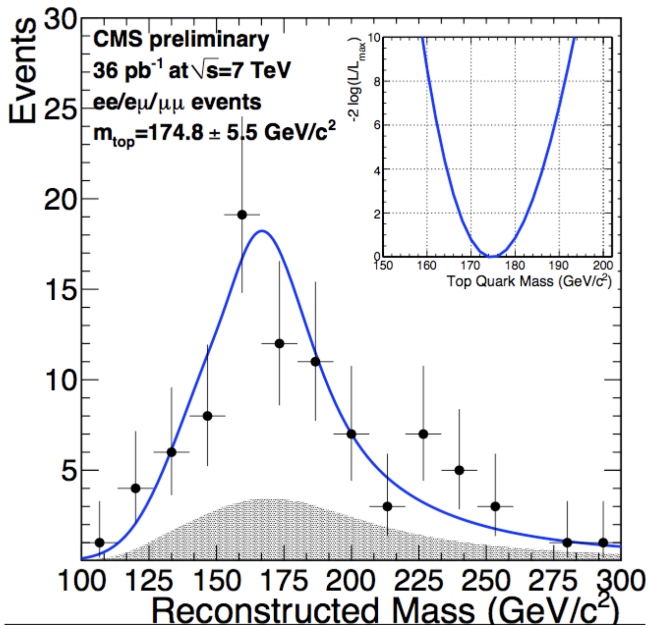
$$\sigma_t = 83.6 \pm 29.8\,(\mathrm{stat.} + \mathrm{syst.}) \pm 3.3\,(\mathrm{lumi.})\ \mathrm{pb}$$

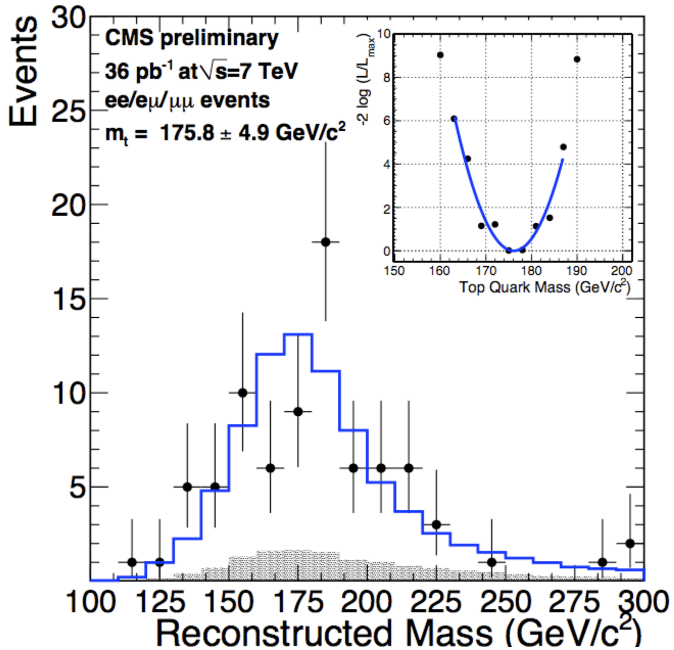


Top Quark Mass

CMS-PAS TOP-11-002

- Important ingredient of SM tests!
- Only ee/eμ/μμ so far. Result with semi-leptonic decays ready soon
- Two techniques
  - Fully kinematic analysis
  - Analytical matrix weighting





- Combination of the two methods:

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

Conclusions

- A lot of interesting results in the top sector!
- But we have just started !
- More results expected soon
  - More decay channels (all-hadronic, with taus)
  - Differential cross sections
  - Measurement of several properties of the top quark and of $t\bar{t}$ pairs
- Becoming competitive with the Tevatron
- No major surprises wrt SM predictions so far… But a lot more data are already available for scrutiny!

BACKUP

Top Mass: Additional Info

Source	KINb	AMWT	Correlation factor	Combination
jet energy scale	+3.1/-3.7	3.0	1	3.1
b-jet energy scale	+2.2/-2.5	2.5	1	2.5
Underlying event	1.2	1.5	1	1.3
Pileup	0.9	1.1	1	1.0
Jet-parton matching	0.7	0.7	1	0.7
Factorization scale	0.7	0.6	1	0.6
Fit calibration	0.5	0.1	0	0.2
MC generator	0.9	0.2	1	0.5
Parton density functions	0.4	0.6	1	0.5
b-tagging	0.3	0.5	1	0.4

Method	Measured m_{top} (in GeV/c^2)	Weight
AMWT	$175.8 \pm 4.9(stat) \pm 4.5(syst)$	0.65
KINb	$174.8 \pm 5.5(stat)^{+4.5}_{-5.0}(syst)$	0.35
combined	$175.5 \pm 4.6(stat) \pm 4.6(syst)$	$\chi2/N_{\rm dof}$=0.040 (p-value=0.84)

tt Cross Section (Semileptonic channel): Systematics

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_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

$t\bar{t}$ Cross Section (Dileptonic channel): Systematics

Table 1: Summary of systematic uncertainties relative to the rate of selected signal events estimated for the full signal selection. All values are in percent. Systematic uncertainties on the lepton selection are treated separately for e^+e^- and $\mu^+\mu^-$ final states. Except for the lepton selection uncertainty, correlated only in the same mode, values for a given source are 100% (anti)correlated among all modes, as reported with the same (opposite) sign. Different sources are treated as uncorrelated. The subtotal values are for sums in quadrature of all corresponding values in the same column.

	$N_{jet} = 1$		$N_{jet} \geq 2$	
Source	$e^+e^- + \mu^+\mu^-$	$e^\pm\mu^\mp$	$e^+e^- + \mu^+\mu^-$	$e^\pm\mu^\mp$
Lepton selection	1.9/1.3	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 ($\geq$ 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 $\not{E}_T$ 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

Single top: systematics

uncertainty	correlation	impact on 2D −	impact on 2D +	impact on BDT −	impact on 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	—	—

Charge Asymmetry: Systematics

Table 2: List of systematic uncertainties taken into account in the measurement of A_C. Listed are the positive and negative shifts induced by systematics in ensemble tests. For systematics uncertainties which shift A_C in only one direction only the maximal shift in this direction is quoted.

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	±0.026	

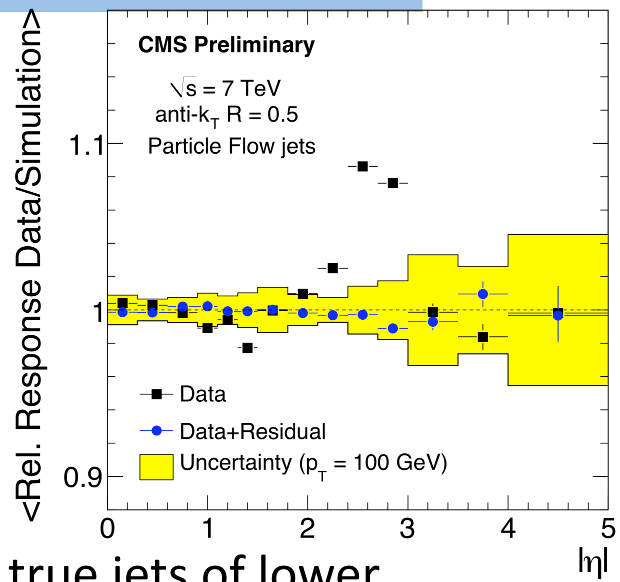
Z' Searches: Systematics

Uncertainty	Variation	Type
Luminosity	4%	rate
Electron efficiency (trigger + ID + isolation)	5%	rate
Muon efficiency (trigger + ID + isolation)	5%	rate
$t\bar{t}$ cross section	20%	rate
Single top cross section	30%	rate
W+jets cross section	50%	rate
Ratio Drell-Yan to W cross section	30%	rate
Ratio W/Z+HF to σ(W)	100%	rate
Muon QCD yield	100%	rate
Electron QCD yield	100%	rate
Jet energy scale	p_T,η dependent	shape
Jet energy resolution	10%	shape
Unclustered energy	10%	shape
b tagging efficiency (b jets)	15%	shape
b tagging efficiency (c jets)	30%	shape
Q^2 scale for W and Drell-Yan events	$\pm 1\sigma$ generator parameters	shape
$t\bar{t}$ modelling	$\pm 1\sigma$ generator differences	shape
Q^2 scale for $t\bar{t}$ events	$\pm 1\sigma$ generator parameters	shape
Amount of ISR/FSR for $t\bar{t}$ events	$\pm 1\sigma$ generator parameters	shape
Matching scale for $t\bar{t}$ events	$\pm 1\sigma$ generator parameters	shape

Table 4: Summary of relative systematic uncertainties and whether they are rate- or shape-changing.

Jet Calibration

$$R(\eta^{probe}, p_T^{dijet}) = \frac{2 + \langle B \rangle}{2 - \langle B \rangle} \qquad B = \frac{p_T^{probe} - p_T^{barrel}}{p_T^{dijet}}$$



- MC response should ideally be ~ 1
- Deviations are due to a resolution bias effect intrinsic in the dijet balancing method.
  - Each reconstructed jet pt bin is contaminated with true jets of lower pt whose detector response fluctuated high
  - The effect is larger at larger eta
- Data agree well with simulation.
- A 10% deviation in data at high eta: this is due to higher single particle response in data:
  - corrected for by using residuals
  - residuals are defined as the difference between data and MC after extrapolating to 0 the third jet activity

LHC latest performances

- Technical stop ended a week ago
- Go to 768 soon and later 912 bunches
- Expect 1400 bunches by mid June
  - L ~ $1.7\ 10^{33}$!