Top Quark Pair Inclusive Cross Section in the $e\mu$ Channel at 7, 8 and 13 TeV with the CMS Experiment

Carmen Diez Pardos
DESY

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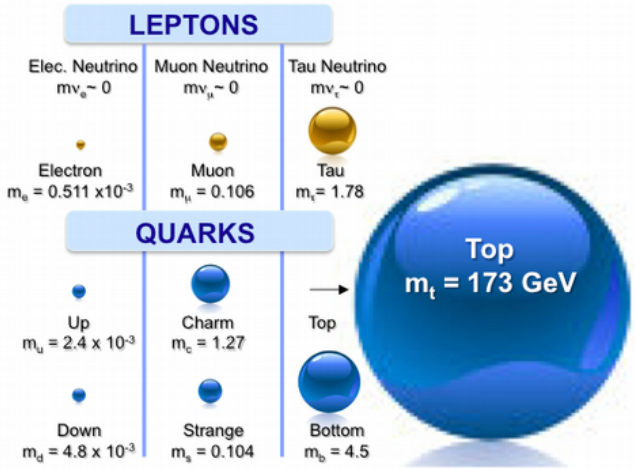
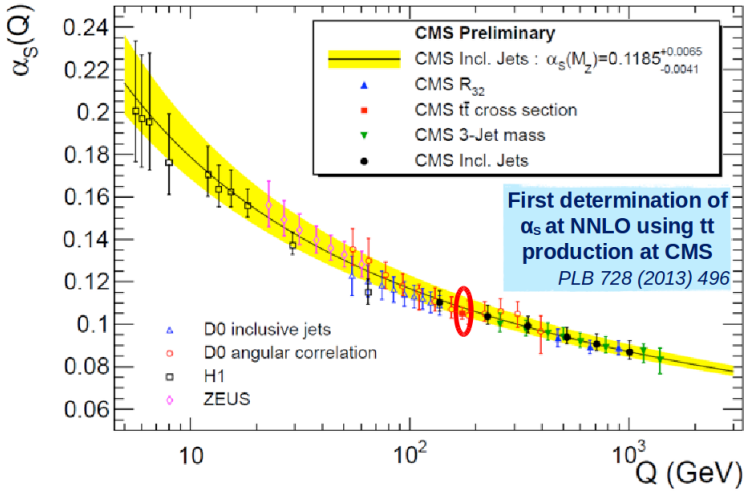
The top quark: key to QCD, EWK, Higgs and new physics

- The most massive known particle
- It decays before hadronisation: study the properties of the bare quark

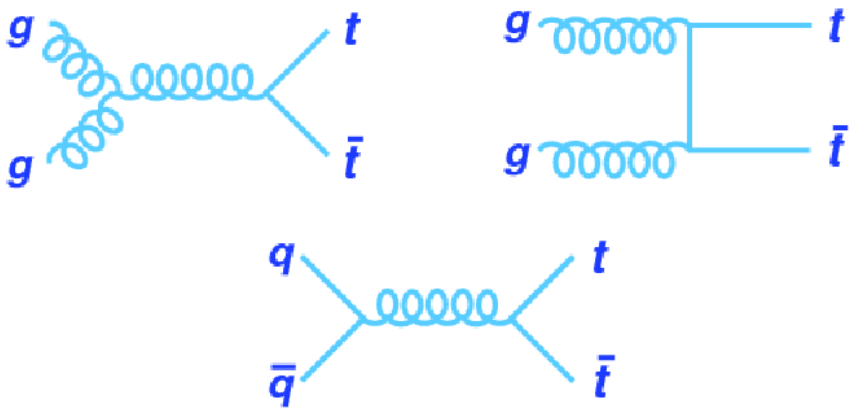
- Measuring $\sigma_{t\bar{t}}$ is the first fundamental step for understanding top physics
- Test QCD predictions and help constraining the PDFs (especially gluon distribution)
- Determination of m_t or α_s
- Main background for Higgs and many searches for New Physics
- May provide insight into physics BSM





Top quark production in pp collisions at the LHC

$t\bar{t}$ production mainly by gluon fusion
($\sim$80% at 7-8 TeV)

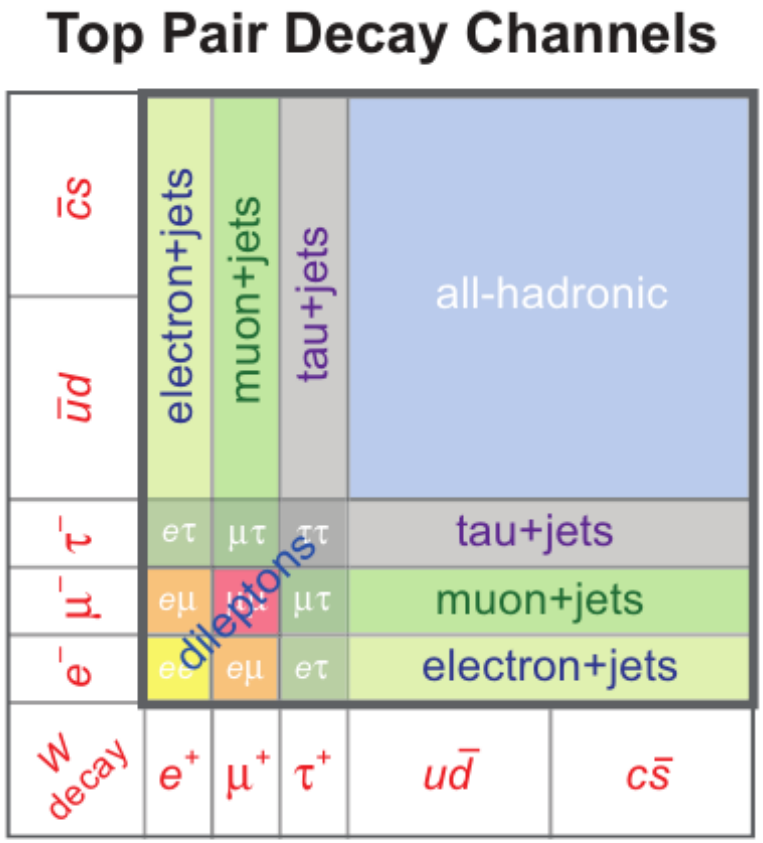


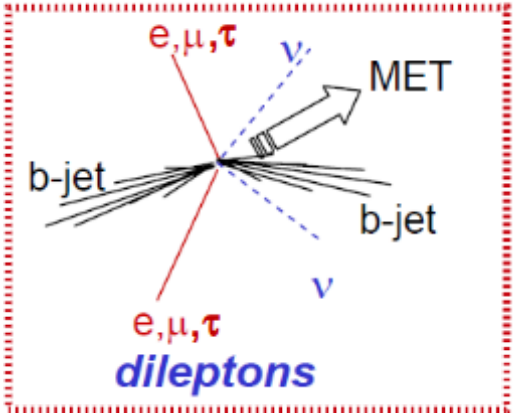
Full NNLO+NNLL calculation
[arXiv:1303.6254]

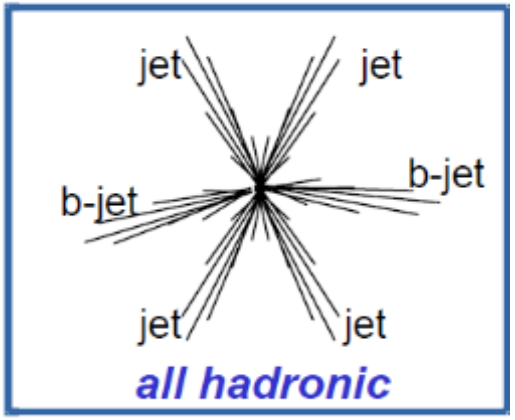
$\sqrt{s}$ (TeV)	$\sigma_{t\bar{t}}(NNLO+NNLL)$ [pb]
	m_t =172.5 GeV
7	$177.3^{+4.7}_{-6.0}(scale) \pm 9.0(PDF+\alpha_s)$
8	$252.9^{+6.4}_{-8.6}(scale) \pm 11.7(PDF+\alpha_s)$
13	$832^{+20}_{-29}(scale) \pm 35(PDF+\alpha_s)$

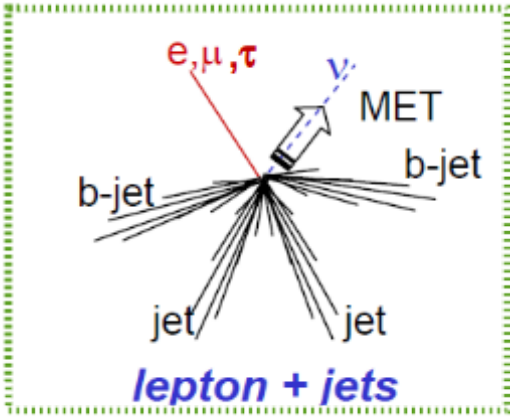
Top quark decay signatures

In the SM $t \to Wb$ almost 100%, W decay defines final state





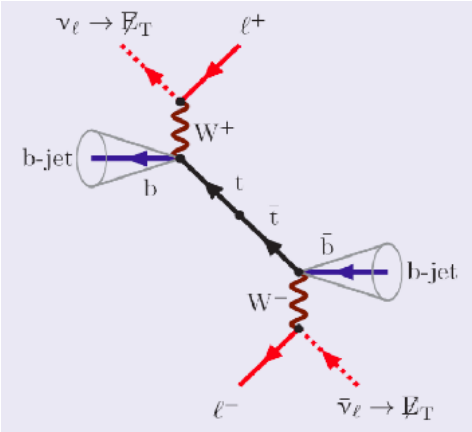




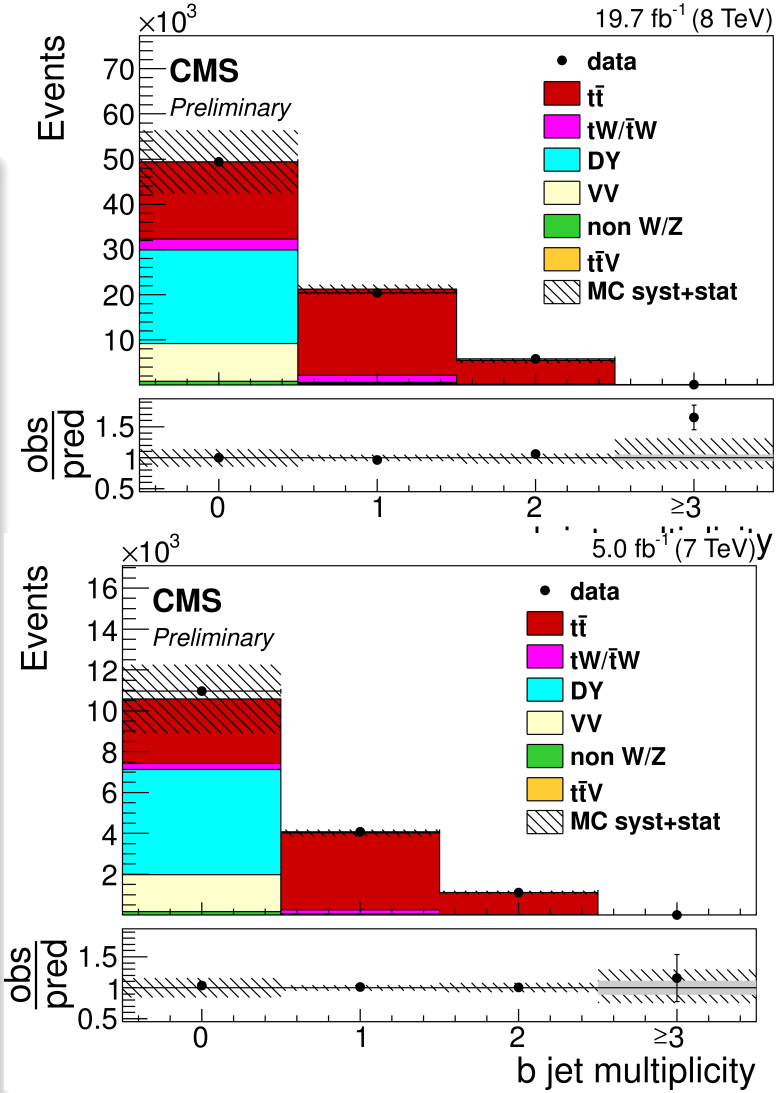
Here: measurements in the $e\mu$ channel at 7, 8 and 13 TeV

$t\bar{t}$ inclusive cross section 7 and 8 TeV [PAS-TOP-13-004]

$$\sigma = \frac{N_{data} - N_{bkg}}{\epsilon_{t\bar{t}} \int \mathbf{L} dt}$$



1. One isolated opposite charge $e\mu$ pair ($m_{e\mu} > 20$GeV)
2. Jets
3. b-tagged jets identified with low mistag rate (0.1%)
4. No minimun requirement on jets, b-jets!



Inclusive cross section (TOP-13-004)

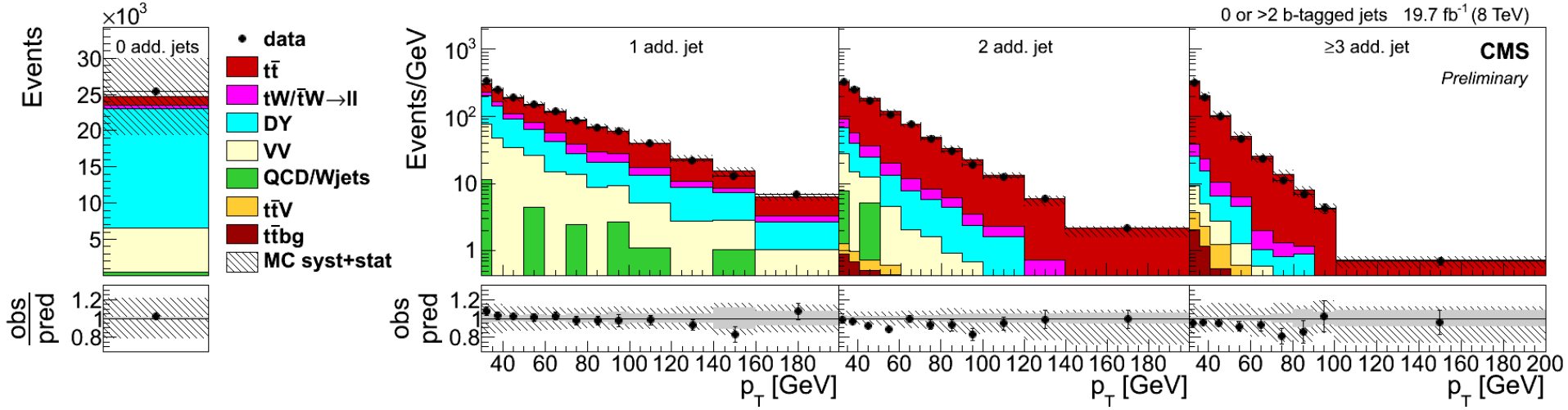
Analysis strategy

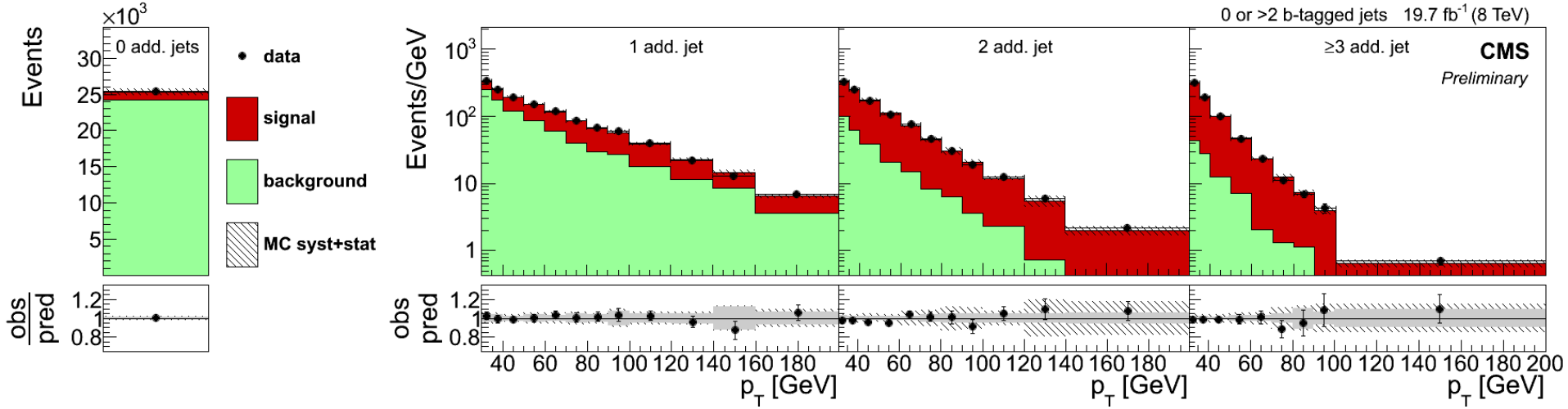
- Measurement of the inclusive cross section using the $e\mu$ channel in visible phase space (within the detector acceptance) and extrapolated to full phase space $\rightarrow$ Aiming for very high precision
- Simultaneous 7 & 8 TeV binned likelihood fit with systematics as nuisance parameters:
  - N b-tagged jet and additional non-tagged Njets categories
  - Fit to the softest non-tagged jet pT distribution in each category
- Cross check analysis: counting approach $\rightarrow$ also useful to compare uncertainties

Distributions pre- and post-fit (8 TeV)

Category: 0 or $\geq$2 b-tagged jets

- Jet distributions allow fit to constrain systematics related to gluon radiation, jet energy scale, etc.

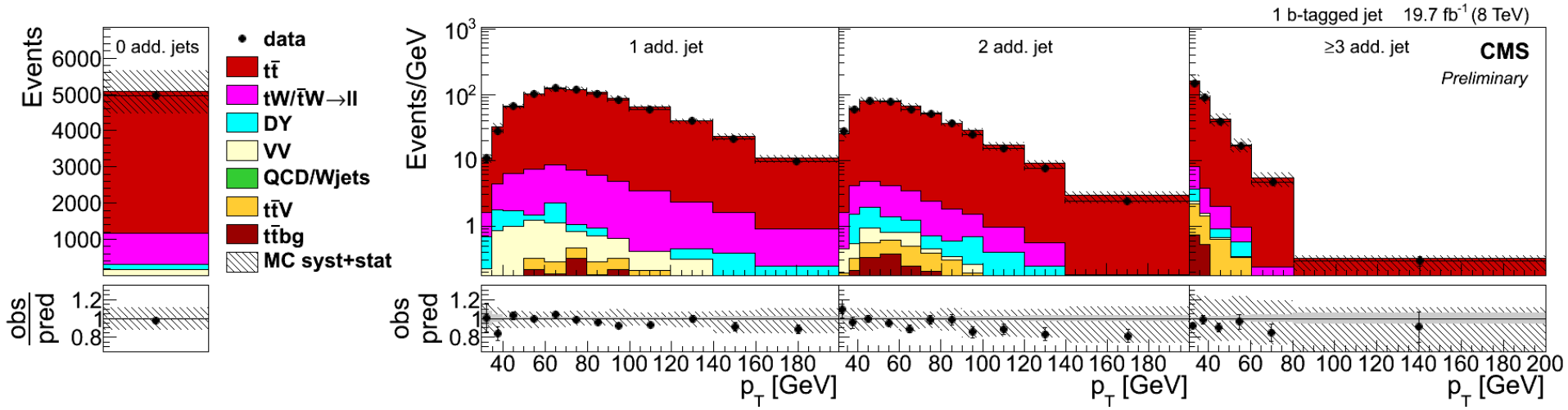


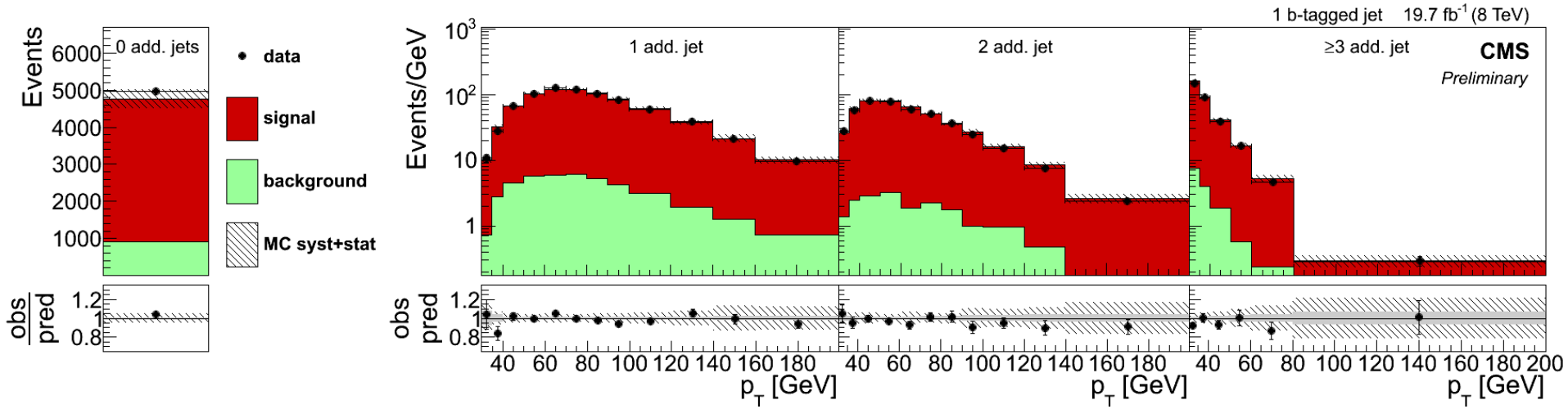


Distributions pre- and post-fit (8 TeV)

Category: 1 b-tagged jets

- Jet distributions allow fit to constrain systematics related to gluon radiation, jet energy scale, etc.





Results: fiducial cross section

$\sigma^{vis}_{t\bar{t}}$ defined with events containing an $e\mu$ pair, with $p_T > 20$ and $\eta < 2.4$.

- $\sigma^{vis} = 3.03 \pm 0.04(\mathrm{stat}) \pm^{0.08}_{0.07} (\mathrm{syst}) \pm 0.07(\mathrm{lumi})$ pb at $\sqrt{s} = 7$ TeV
- $\sigma^{vis} = 4.23 \pm 0.02(\mathrm{stat}) \pm^{0.11}_{0.09} (\mathrm{syst}) \pm 0.11(\mathrm{lumi})$ pb at $\sqrt{s} = 8$ TeV

Dominant uncertainties: luminosity, trigger and lepton Id. efficiencies, DY

Source	Uncertainty [%]	
	7 TeV	8 TeV
Trigger	1.2	1.2
Lepton ID/isolation	1.4	1.5
Lepton energy scale	0.1	0.1
Jet energy scale	0.7	0.9
Jet energy resolution	0.1	0.1
Single top	0.9	0.6
DY	1.2	1.2
$t\bar{t}$ other	0.1	0.1
$t\bar{t} + V$	0.0	0.1
Diboson	0.2	0.6
W+jets	0.0	0.0
QCD	0.0	0.0
B-tag	0.5	0.5
Mistag	0.2	0.1
Pileup	0.3	0.3
Q^2 scale	0.3	0.3
ME/PS matching	0.2	0.1
MG+PY $\rightarrow$ PH+PY	0.2	0.4
Hadronization (JES)	0.6	0.8
Top p_T	0.3	0.3
Color reconnection	0.1	0.0
Underlying event	0.0	0.1
PDF	0.2	0.7
Luminosity	2.2	2.6
Statistical	1.2	0.6

Full phase space

- $\sigma = 173.6 \pm 2.1(\mathrm{stat}) \pm^{4.5}_{4.0} (\mathrm{syst}) \pm 3.8(\mathrm{lum})$ **pb** at $\sqrt{s} = 7$ TeV (3.6%)
- $\sigma = 244.9 \pm 1.4(\mathrm{stat}) \pm^{6.3}_{5.5} (\mathrm{syst}) \pm 6.4(\mathrm{lum})$ **pb** at $\sqrt{s} = 8$ TeV (3.7%)

- Model uncertainties cannot be constrained: full variation

- Ratio between 8 and 7 TeV results:

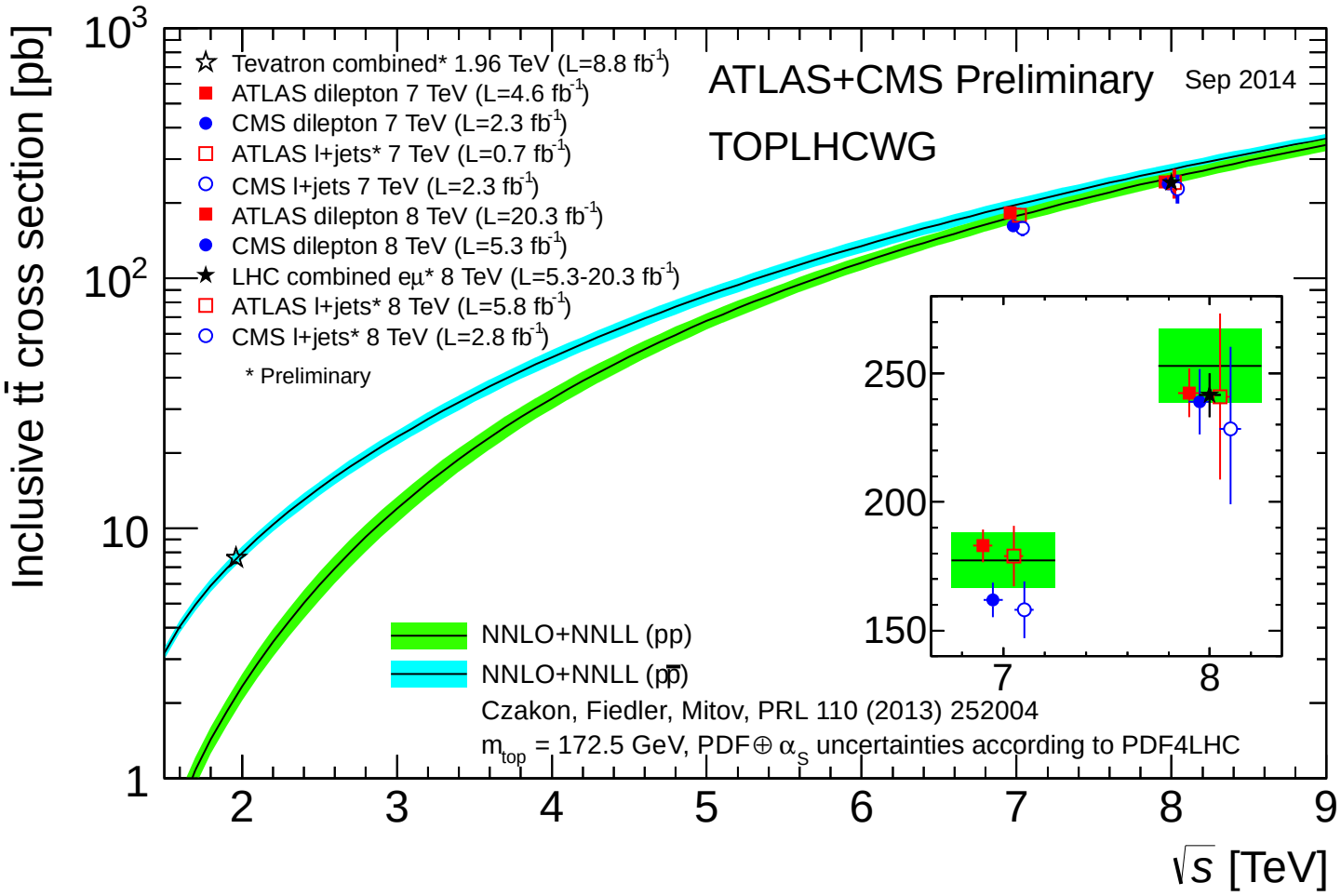
$$\boxed{R_{t\bar{t}} = 1.41 \pm 0.06}$$

Source	Uncertainty [%]	
	7 TeV	8 TeV
Total (vis)	$\pm^{3.6}_{3.4}$	$\pm^{3.7}_{3.4}$
Q^2 scale (extrapol.)	$\mp^{0.0}_{0.4}$	$\pm^{0.2}_{0.1}$
ME/PS matching (extrapol.)	$\pm^{0.1}_{0.1}$	$\pm^{0.3}_{0.3}$
Top p_T (extrapol.)	$\pm^{0.5}_{0.3}$	$\pm^{0.6}_{0.3}$
PDF (extrapol.)	$\pm^{0.2}_{0.1}$	$\pm^{0.2}_{0.1}$
Total	$\pm^{3.6}_{3.5}$	$\pm^{3.7}_{3.5}$

Summary of $t\bar{t}$ inclusive cross sections

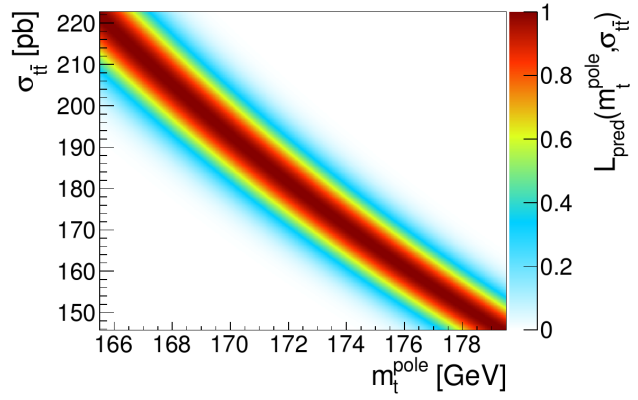
- Good agreement between channels and with the predictions NNLO + NNLL

  Experimental precision limited by systematics



Top quark pole mass extraction

- Mass dependence of predicted σ allows determining m_t from measured $\sigma(t\bar{t})$
  - m_t^{pole} extracted by comparing the most precise predicted and measured cross sections
  - Final result: combination of 7 and 8 TeV



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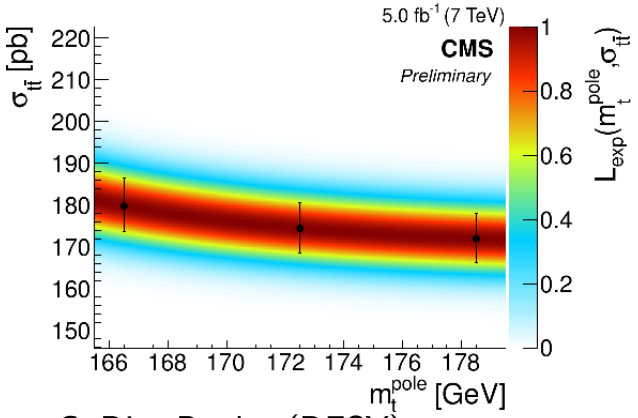
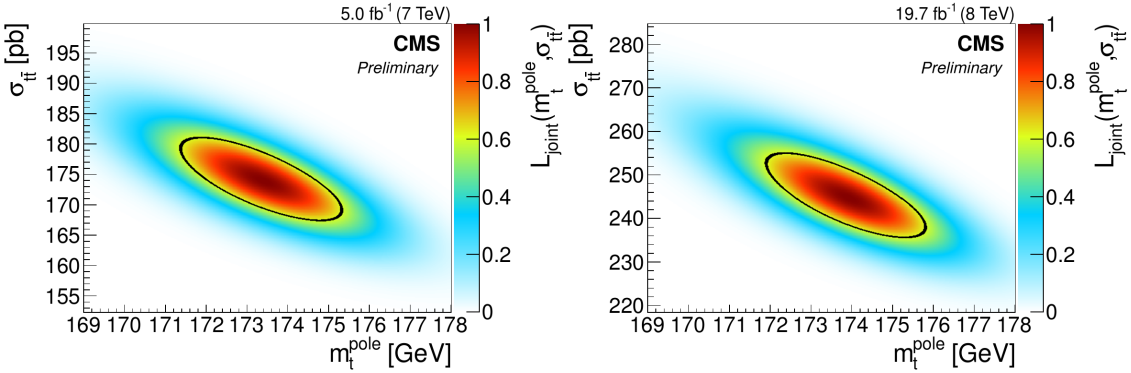




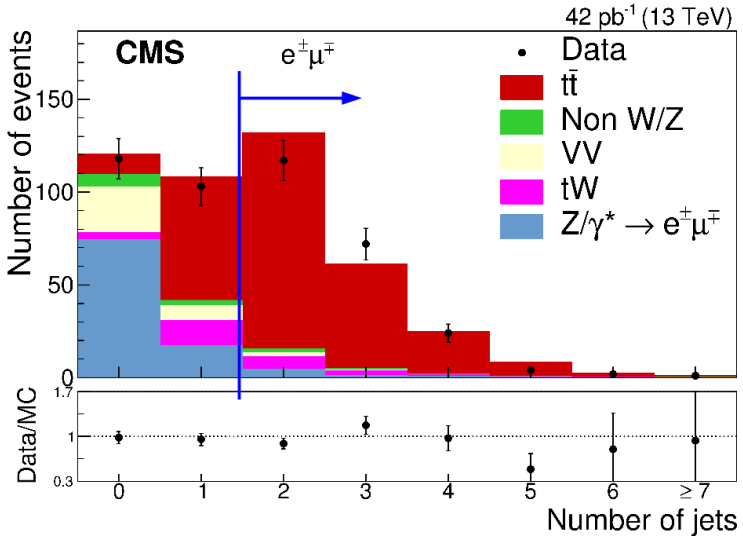
Combined:

	m_t
NNPDF3.0	$173.6 \pm^{1.7}_{1.8}$ GeV
MMHT2014	$173.9 \pm^{1.8}_{1.9}$ GeV
CT14	$174.1 \pm^{2.1}_{2.2}$ GeV

13 TeV measurement [arXiv:1510.05302, submitted to PRL]

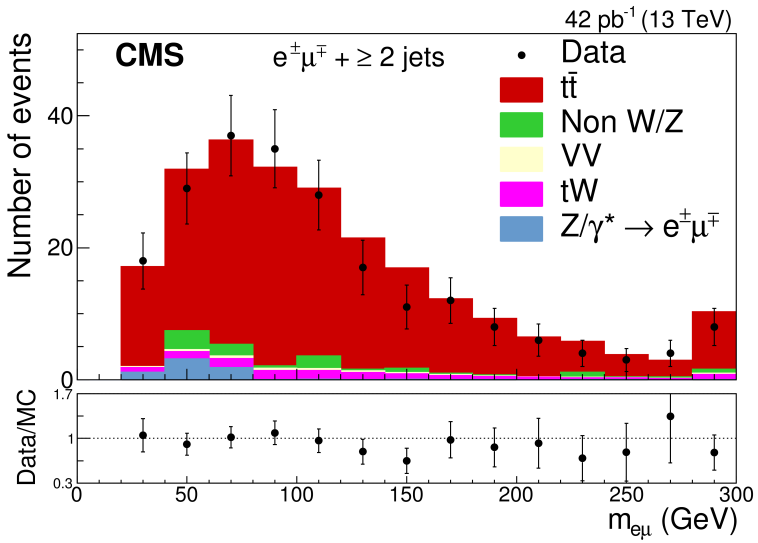
- Goals of this Analysis: Provide a robust first measurement
- Counting experiment

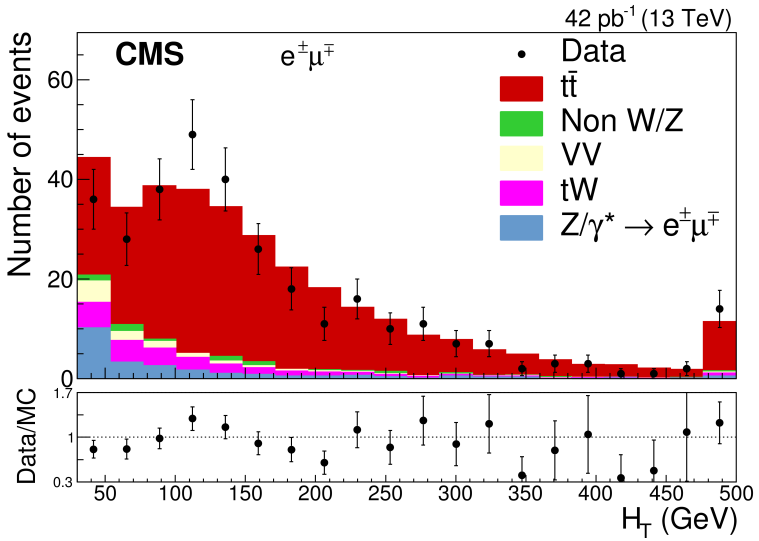
- Luminosity: 42pb^{-1} (50 ns run, July 2015)
- Selection:
  - One isolated opposite charge $e\mu$ pair ($m_{e\mu} > 20$GeV)
  - $\geq$2 jets
- Background estimation (single top and diboson from MC)
  - DY MC prediction normalized to Z peak in data
  - Non W/Z: estimated from same-sign control region with scale factor from MC

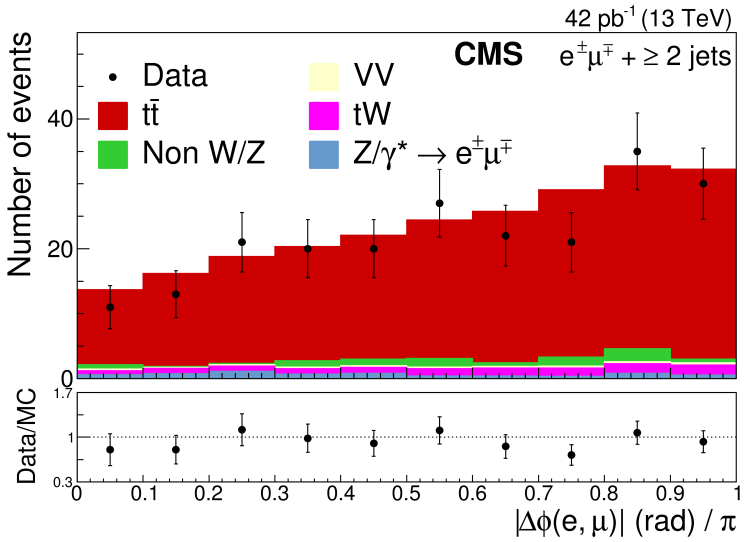


Source	Number of events $e^{\pm}\mu^{\mp}$
Drell–Yan	6.9 ± 1.2
Nonprompt leptons	8.6 ± 4.4
tW	10.6 ± 3.3
VV	2.7 ± 0.9
Total background	28.8 ± 5.7
Data	220

Kinematic distributions: New Physics?







- First look at observables potentially sensitive to new physics → No hints yet, but very low statistics
  - E.g. $m_e\mu$ and $|\Delta\Phi(e,\mu)$ (spin correlations)
  - No hints yet... but very low statistics!

Systematic uncertainties

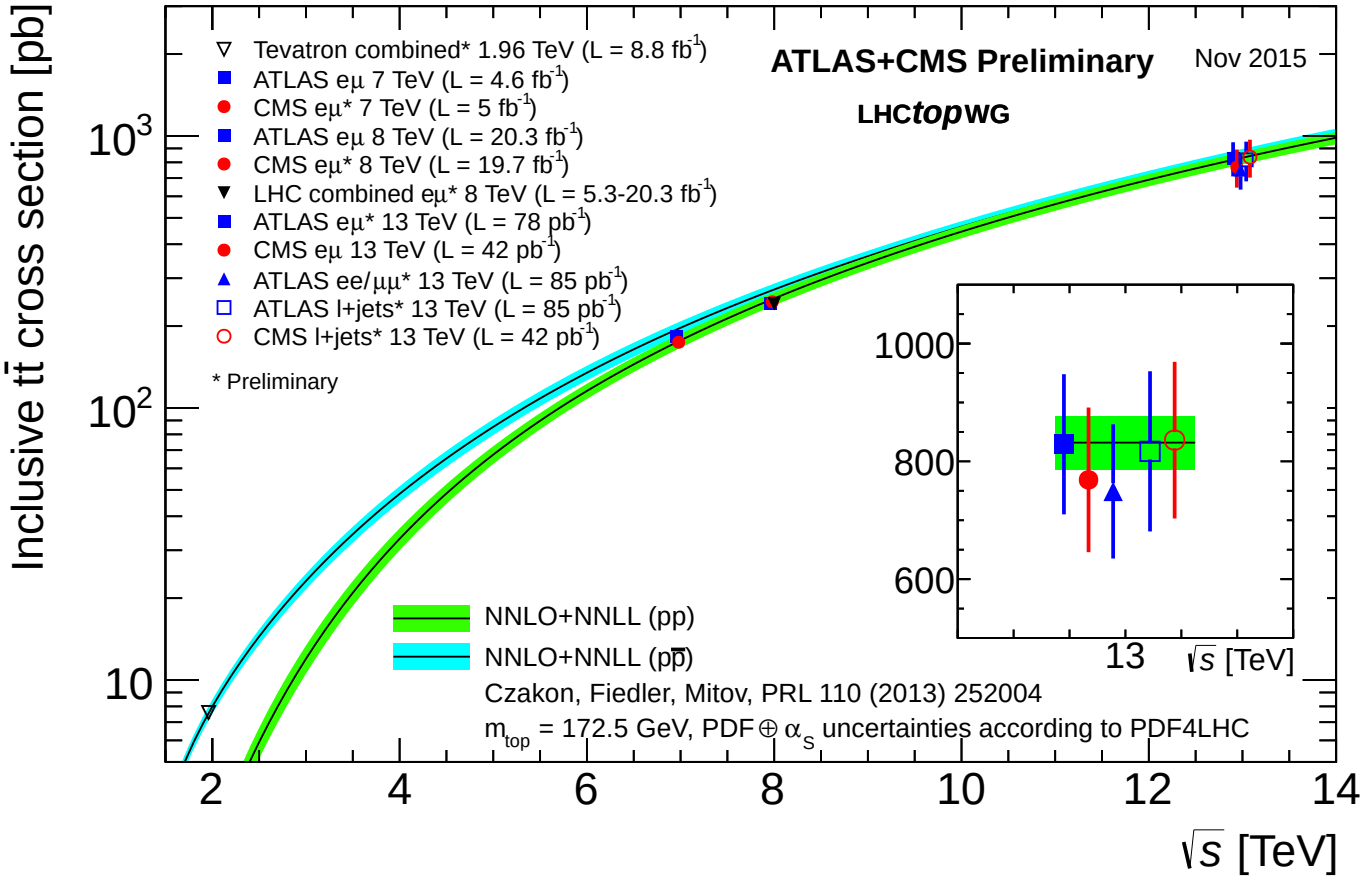
- Statistical uncertainty on same order as systematic uncertainty (without luminosity)
- Dominant Systematic uncertainties:

Source	$\Delta\sigma_{t\bar{t}}$ (pb)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Trigger efficiencies	34	4.4
Lepton efficiencies	26	3.4
Lepton energy scale	<1	≤0.1
Jet energy scale	12	1.5
Jet energy resolution	<1	≤0.1
Pileup	5.4	0.7
QCD scales	1.5	0.2
NLO generator of $t\bar{t}$ signal	15	1.9
Modeling of $t\bar{t}$ signal	14	1.8
PDF	18	2.4
Single top tW background	13	1.7
VV background	3.5	0.5
Drell-Yan background	4.2	0.5
Nonprompt leptons background	7.9	1.0
Total systematic (w/o luminosity)	55	7.2
Integrated luminosity	92	12
Statistical uncertainty	60	7.8
Total	123	16

- Luminosity (preliminary, results from VdM scan expected soon)
- All main contributions expected to be reduced

Grand summary $t\bar{t}$ cross sections

$\sigma_{t\bar{t}} = 769 \pm 60(\mathrm{stat}) \pm 55(\mathrm{syst}) \pm 92(\mathrm{lumi})$ pb (16% precision)



Good agreement among all measurements, also with NNLO+NNLL theory

Summary

From Run I: first ever top quark factory

- Precision regime: $\Delta\sigma_{t\bar{t}}$ <4% (full NNLO same precision as data)
- Measurement in the fidual phase space $\Delta\sigma_{t\bar{t}}$ <3%
- Determined ratio of full phase space cross sections
- Top-quark pole-mass extraction (also constrains on SUSY models)

... to Run II

- First measurements of the cross section with 42 pb^{-1}, precision dominated by luminosity

Agreement between experiments and NNLO+NNLL predictions

CMS public Physics results available from:

http://cms-results.web.cern.ch/cms-results/public-results