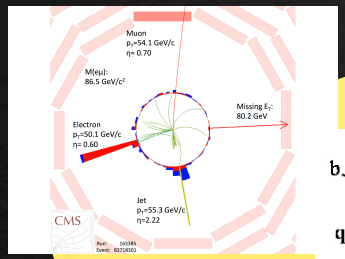
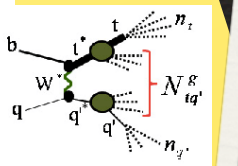
Instituto de Física de Cantabria

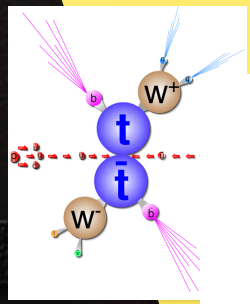
Top at CMS

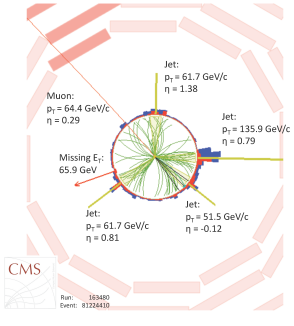
Rocio Vilar for CMS collaboration

Brookhaven Forum 1-3 May 2013









What do we measure at CMS?

Production

- Cross section: Total and differential
- Asymmetries
- Polarizations
- Associated productions
- Resonances
- FCNC single top
- spin correlations

Decays

- BR(t ->Wb)/BR(t->Wq) ⇒CMK $|V_{tb}|$
- W-helicity ⇒anomalous couplings
- t->H^+b
- BSM top decays

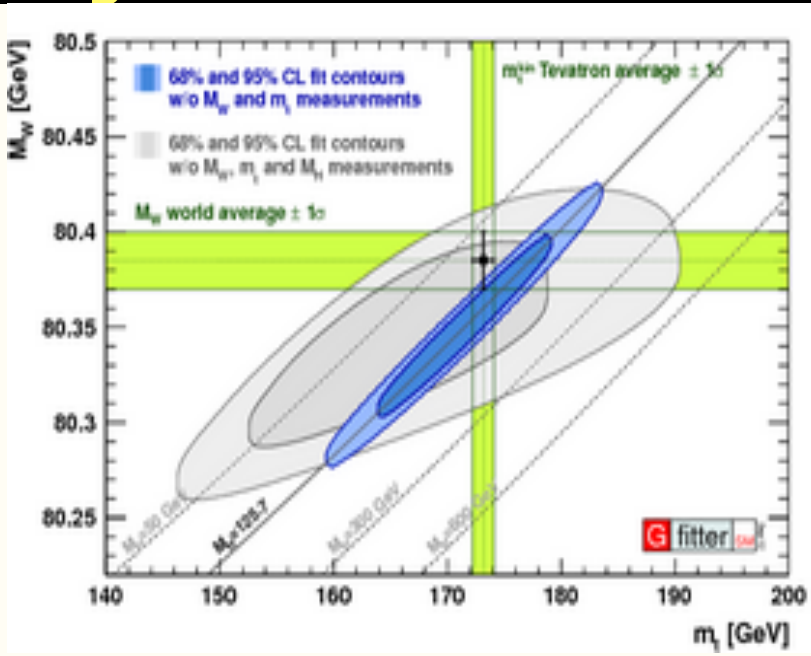
Intrinsic Properties

- Mass
- Charge
- Lifetime, width
- ……

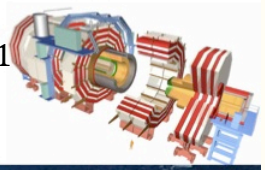
- Top provides a huge spectrum of measurements on SM and BSM
- Many analysis: different analysis per decay/production channel
- At LHC two different cm energies
- NOT ALL COVERED HERE ⇒try to give a representative overview of top in CMS
- Newest analysis are prioritized

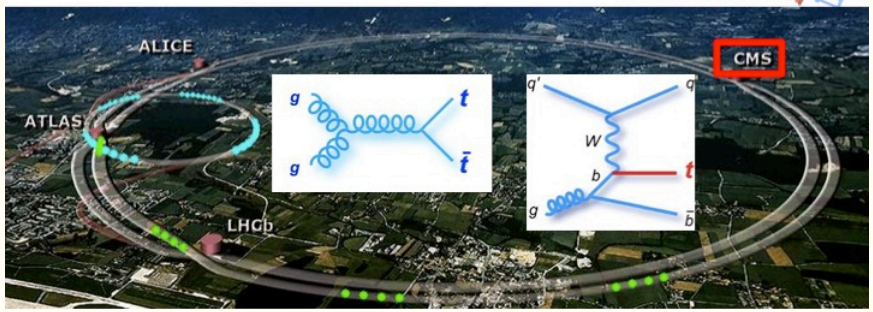
Top Physics

- Heaviest quark ➔maybe special role?
- Does not hadronize before decaying ➔allows to study a free quark
- Decay almost 100% to Wb. top to other decays is < O(10^{-13})
- Total and differential rates are calculated with good precision O(10%)
- Important background for SM higgs and other BSM searches
- Opens a door to new physics search ➔ May reveal non standard contributions and new particles



L(at 7 TeV) = 6.13(5.55) fb^{-1}
L(at 8 TeV)= 23.30(21.79) fb^{-1}





Top Production

Top Pair

[Czakon, Fiedler,Mitov,arXiv:1303.6254]

√s (TeV)	7	8
σ(at NNLO)	$172.0^{+4.4}_{-5.8}{}^{+4.7}_{-4.8}$	$245.8^{+6.2}_{-8.4}{}^{+6.2}_{-6.4}$

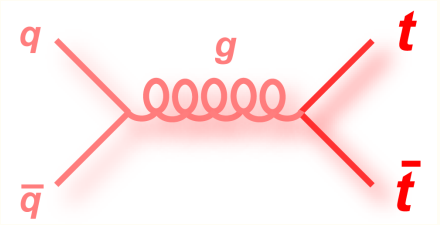
M_{top} = 173 GeV

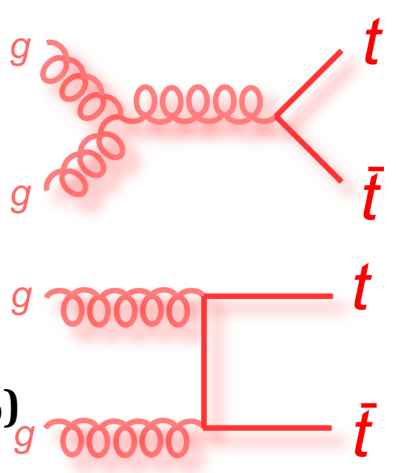
Single Top

N.Kidonakis,arXiv:1205.3453v1

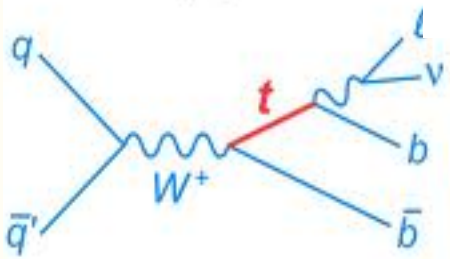
√s (TeV)	7	8
T-channel (pb)	$65.9^{+2.1}_{-0.7}{}^{+1.5}_{-1.7}$	$87.2^{+2.8}_{-1.0}{}^{+2.0}_{-2.2}$
S-channel(pb)	$4.56\pm0.07^{+0.18}_{-0.17}$	$5.55\pm0.08\pm0.21$
Wt-channel(pb)	$15.2\pm0.4^{+1.0}_{-1.2}$	$22.2\pm0.6\pm1.4$

Quark anhilation

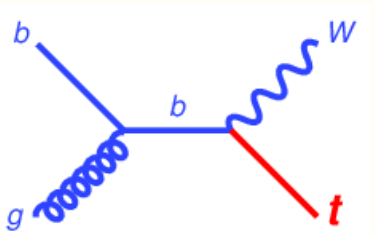


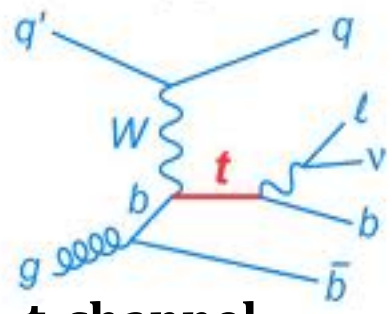


Gluon Fusion
Dominant at LHC (80%)

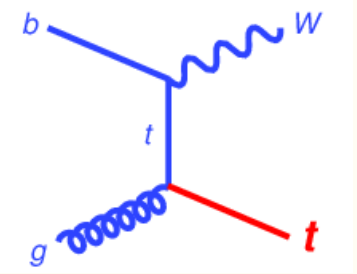


S-channel





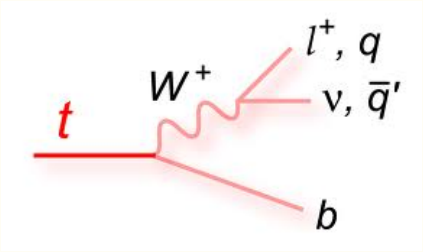
t-channel

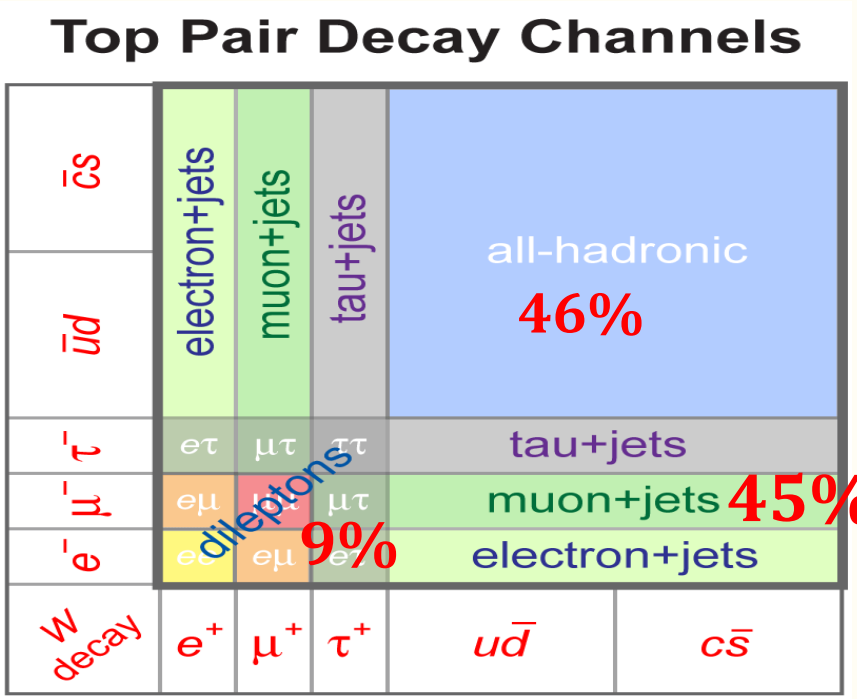


Wt-channel

Top Decay

Top decays ≈100% Wb,
|Vtb|>>|Vtd,|Vts|
Events are classified according to W decay





Signal:

- Triggering on lepton or jets
- Up to two Iso.l high Pt leptons(l+jets or dilepton)
- Missing Transverse energy(l+jets or dilepton)
- Two to six high Et jets(l+jets, dilepton, fully hadronically)
  - Always two b's

Backgrounds

QCD multijet ⇒fully hadronic
W+jets (Wbb/cc) ⇒l+jets
Dibosons⇒l+jets,dileptons
Drell-Yan ⇒dileptons

Single top is bkg for top pair and viceversa

Tools

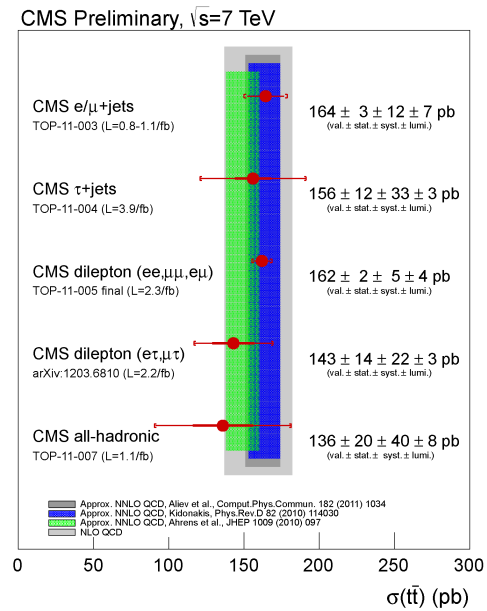
b-tagging
t-tagging

Top Production

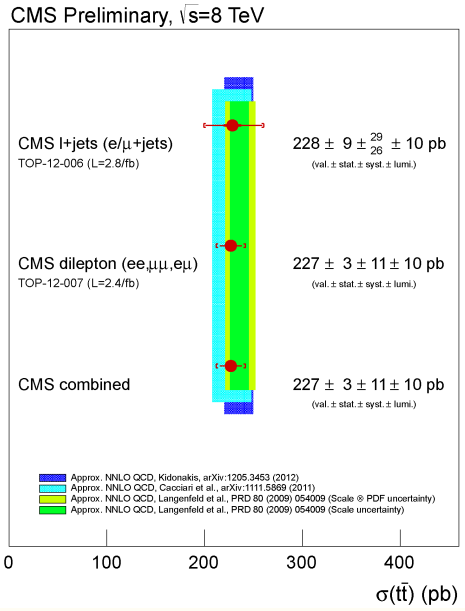
Cross sections: Totals and Differentials
Cross Section Ratios : $\sigma(t)/\sigma(\bar{t})$, $\sigma(t\bar{t}b\bar{b})/\sigma(ttjj)$
Additional jets in $t\bar{t}$ events
Charge asymmetry

Top Pair Cross sections

At $\sqrt{s}$=7 TeV

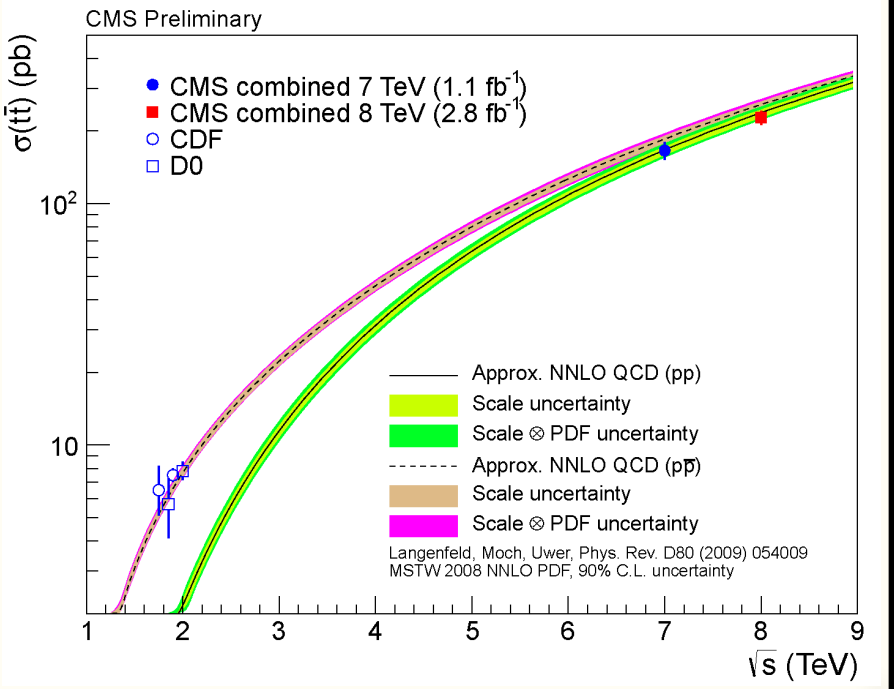


At $\sqrt{s}$=8 TeV



- Measuments are from likelihood fits (l +jets,hadronic) or counting methods (dileptons)
- Data driven estimation for the main back. contributions

Ratio: $\sigma(8\ \text{TeV})/\sigma(7\ \text{TeV})=1.41\pm0.10$



Combination up to 1.1 fb^{-1} **at 7 TeV (CMS PAS TOP-11-024)**

σ=165.8±2.2(stat) ±10.6(syst) ± 7.8(lumi) pb^{-1}

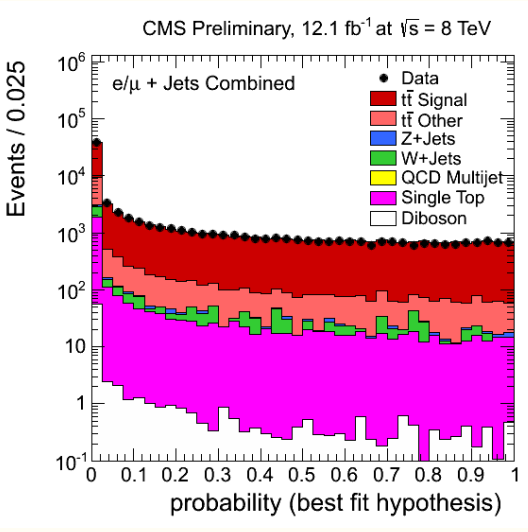
σ=173.8±2.3(stat) ±7.6(syst) ± 6.3(lumi) pb^{-1}
LHC results

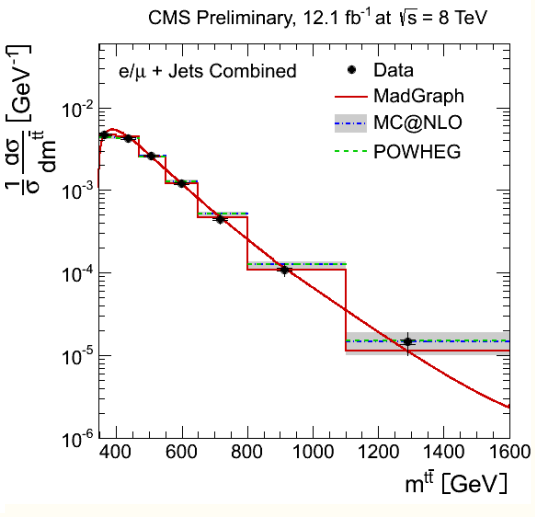
Combination up to 2.8 fb^{-1} **at 8 TeV (CMS PAS TOP-12-007)**

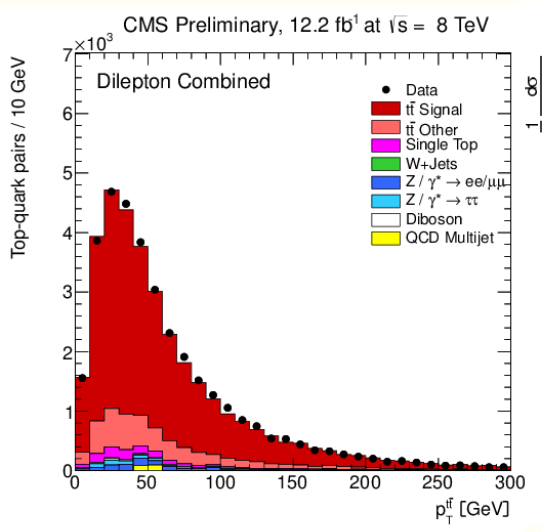
σ=227±3(stat) ±11(syst) ± 10(lumi) pb^{-1}

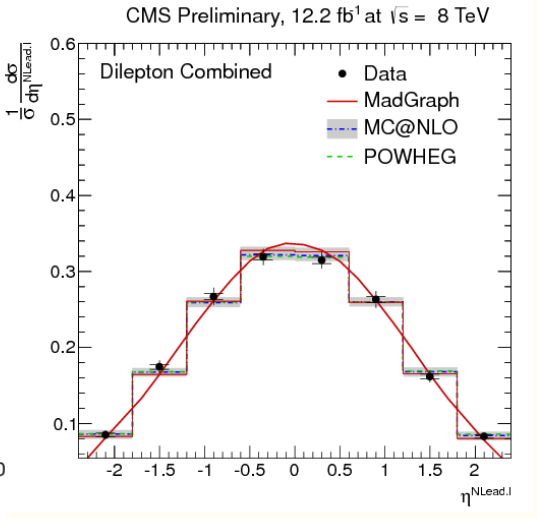
Differential Cross sections

Done at $\sqrt{s}$=7 and $\sqrt{s}$=8 TeV in l+jets and dilepton









Measure as a function of kinematic properties of final state objects(l,b), top and ttbar system

- tt reconstruction:
  - L+jets : constraint kinematic fitter **(CMS PAS TOP-12-027)**
  - Dilepton channel use an alternative kinematic reconstruction with top mass range wider. **(CMS PAS TOP-12-028)**
- 5.4% and 3.9% typical Syst. Uncertainties for l+jets and dilepton channels respectively

- Normalized differential cross sections -> cancels out systematic uncertainties

Good agreement between data and theoretical predictions, no deviation observed

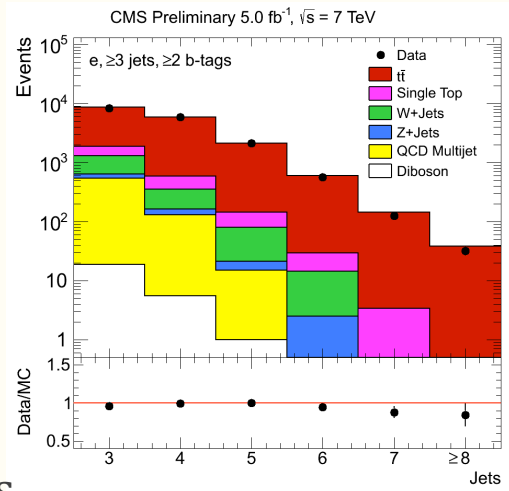
Jet multiplicity in $t\bar{t}$

At $\sqrt{s}$=7 TeV

- This probes the simulation for high jet multiplicity QCD at top scale
- Measure the initial and final state radiation contributions
  - Important for Top, Higgs and many BSM analyses
  - Measurement unfolded at MCs level in visible experimental phase space

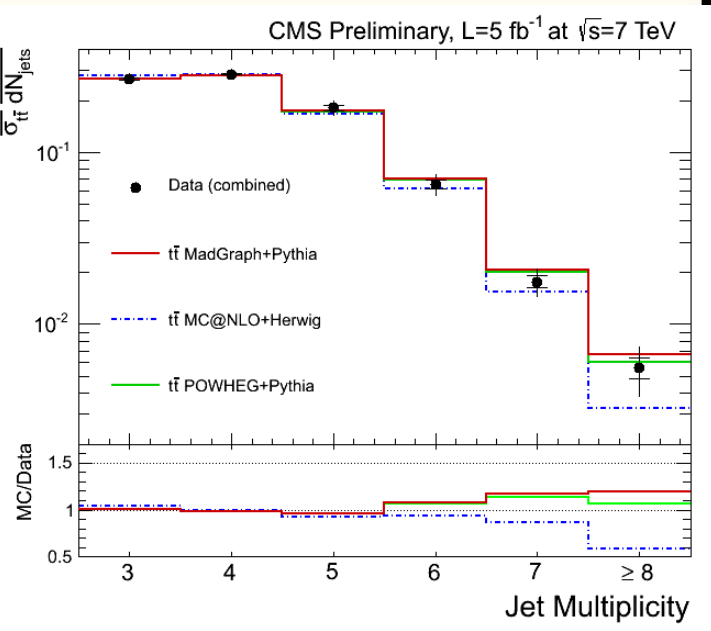
MC@NLO shows some discrepancy in the number of jets at high Pt jets

Tt with veto on extra jets
Constraint QCD radiation

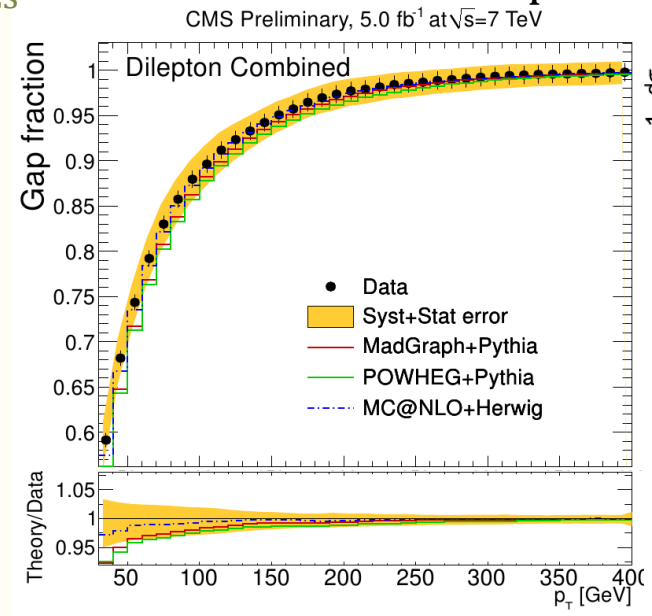


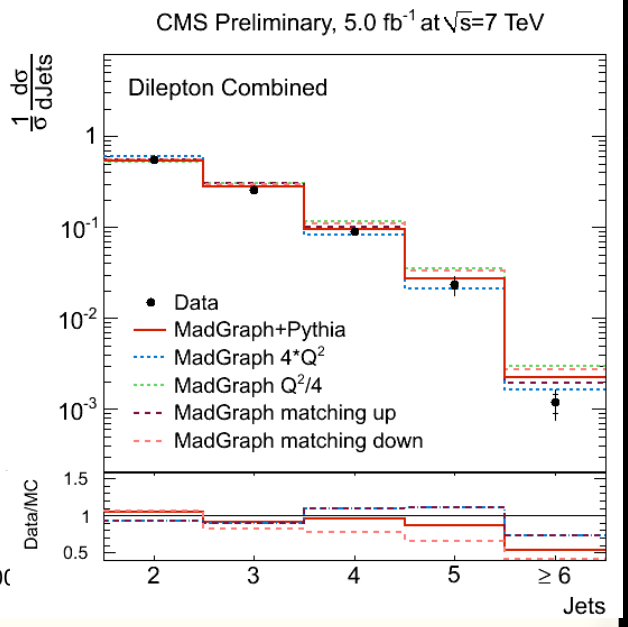
L+jet channel

CMS PAS TOP-12-018



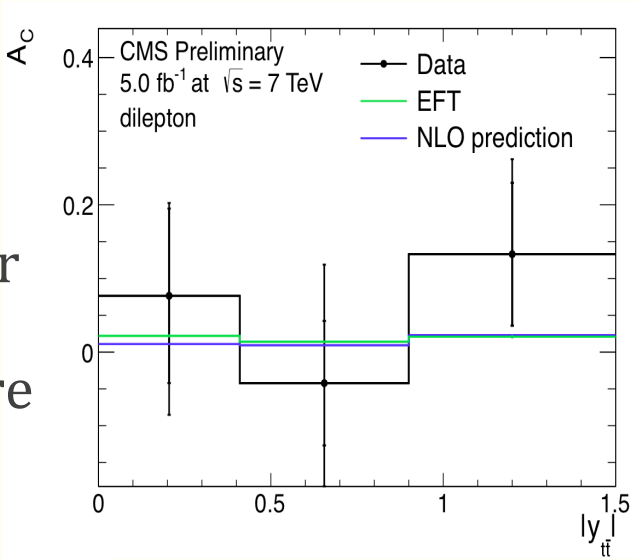
Dilepton channel **CMS PAS TOP-12-023**

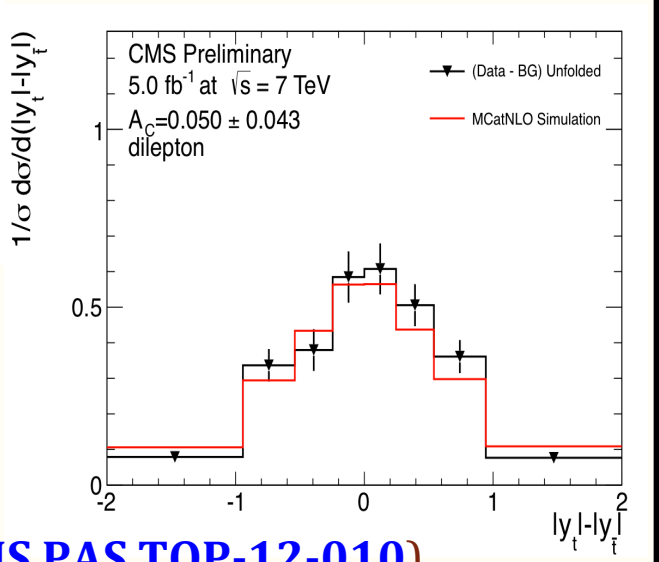


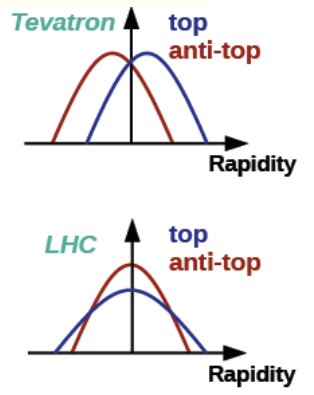


tt charge asymmetry

- NLO correction introduce small asymmetries in t and tbar rapidity distributions at ppbar production
- At LHC initial state are symmetric ⇒ no differences







$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

$$A_c = \frac{N(\Delta|y|>0) - N(\Delta|y|<0)}{N(\Delta|y|>0) + N(\Delta|y|<0)}$$

Dilepton channel (**CMS PAS TOP-12-010**)

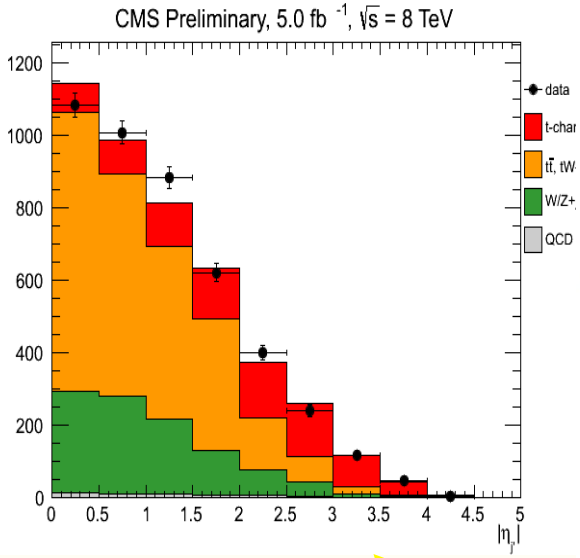
$A_c = 0.050 \pm 0.043(\text{stat})^{+0.010}_{-0.039}(\text{syst})$

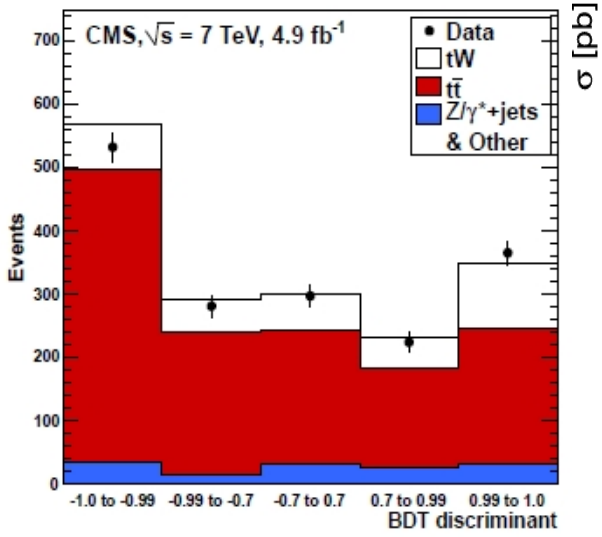
A_{llC}=0.010±0.015(stat) ±0.006(syst)

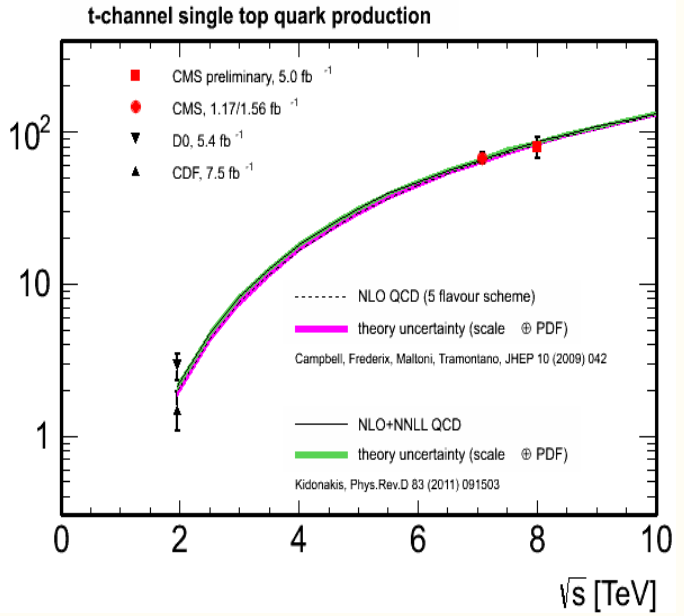
L+jets channel (**Phys. Lett. B717 (2012) 129**)

$A_c = 0.004 \pm 0.010(\text{stat}) \pm 0.011(\text{syst})$

Single Top Cross Section







Ratio: $\sigma(8\ \text{TeV})/\sigma(7\ \text{TeV})=1.14\pm0.12(\text{stat.})\pm0.14(\text{syst})$

	σ(t-channel)[pb] •lepton+MET+b-jet+recoil jet •Signal extraction by fitting, $\lvert\eta_{\text{jrecoil}}\rvert$ distribution	**σ(tW)[pb]** •Two leptons+MET+b-jet •Simultaneous fitting to MVT output in different jet-bin regions	$\lvert V_{tb}\rvert$
7TeV ($L=5.0fb^{-1}$)	**JHEP 12 (2012) 035** $67.2\pm3.7(\text{stat})\pm4.6(\text{syst})\pm2.5(\text{lumi})$	16^{+5}_{-4} (sign. 4σ) **Phys. Rev. Lett. 110 (2013) 022003**	$1.04^{+0.10}_{-0.13}(\text{exp})^{+0.03}_{-0.04}(\text{th})$
8TeV ($L=5.0fb^{-1}$)	$80.1\pm7.5(\text{stat})\pm11.0(\text{syst})\pm4.0(\text{lumi})$ **CMS PAS TOP-12-011**		$1.04^{+0.10}_{-0.11}$

$\sigma(t)/\sigma(\bar{t})$ in t-channel

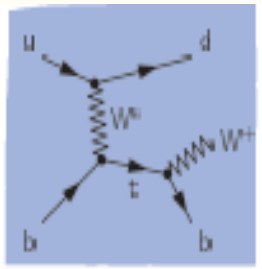
At $\sqrt{s}$=8 TeV

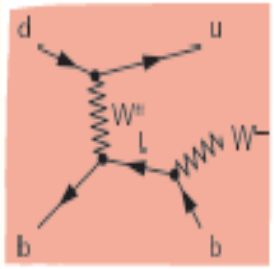
pp collision u density is ≈ 2x d density ⇒ is expected to be larger than 1

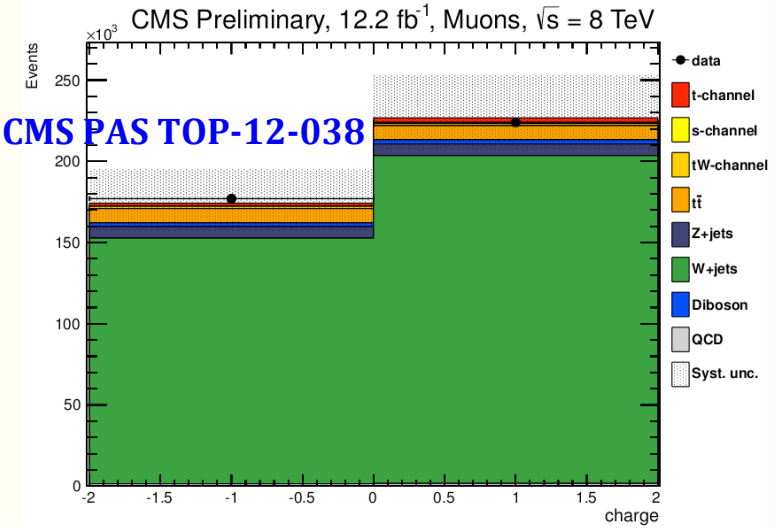
Top decaying leptonically to e or μ

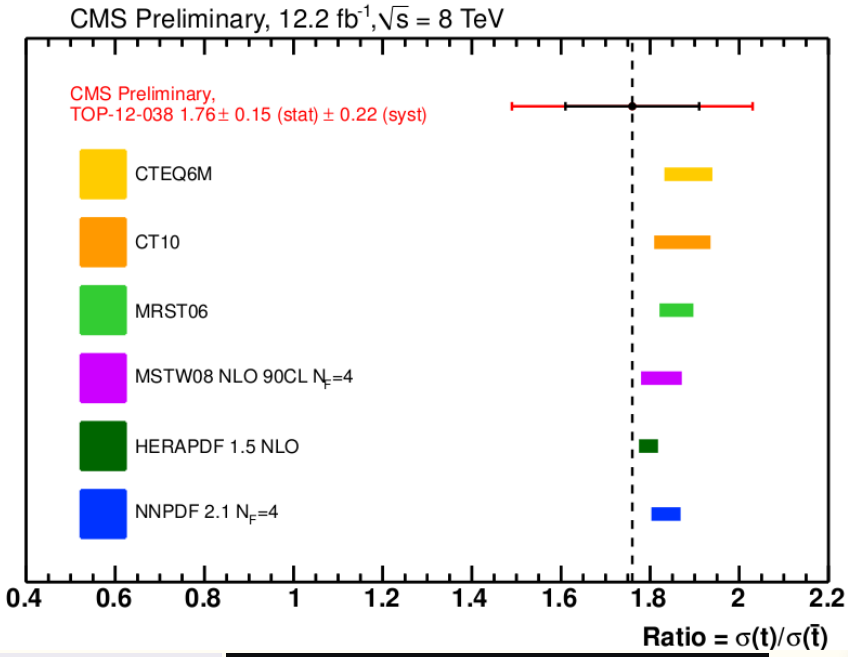
Background estimations through data driven techniques

Performance a fit in the η distribution of the non b-tagged jet for the $l^+(l^-)$ distributions simultaneously





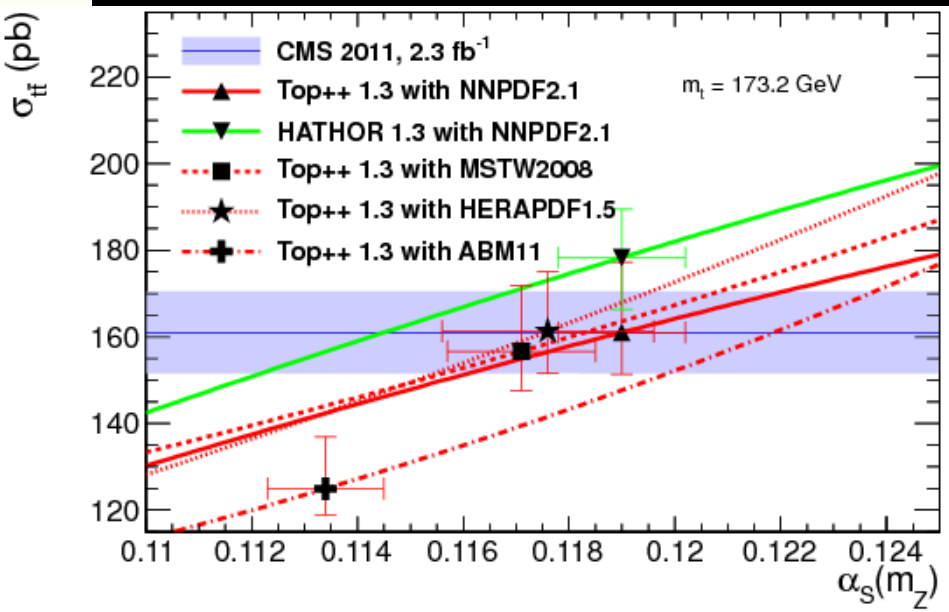




R= 1.76±0.15(stat) ±0.22(syst)
Agrees with predictions
$SF(R_{exp}/R_{SM})$=0.96 ±0.08(stat)±0.12(syst)

σ(top) = 49.9±1.9(stat)±8.9(syst) pb.
σ(anti-top) = 28.3±2.4(stat)±4.9(syst)pb.

Determination of α_s

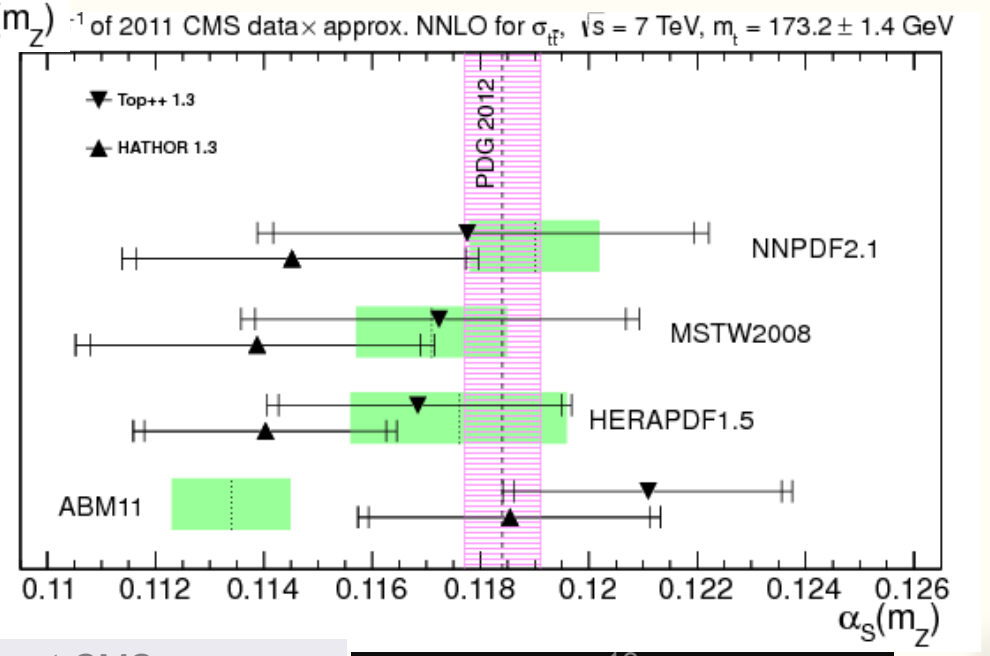


$\alpha_s(m_z)=0.1178^{+0.0046}_{-0.0040}$

In good agreement with the world average (0.1184±0.0007)

CMS-PAS-TOP-12-022

- Using the measurement top cross section at 7 TeV, and approx. NNLO QCD prediction for the cross section with different PDFs ⇨ the α_s is extracted
- Top++ and NNPDF used for extraction of α_s (less assumptions of PDF parametrization)
- Maximum likelihood of the predicted and measured cross sections



Top decays

BR(t->WB)/BR(t->Wq)

W-helicity

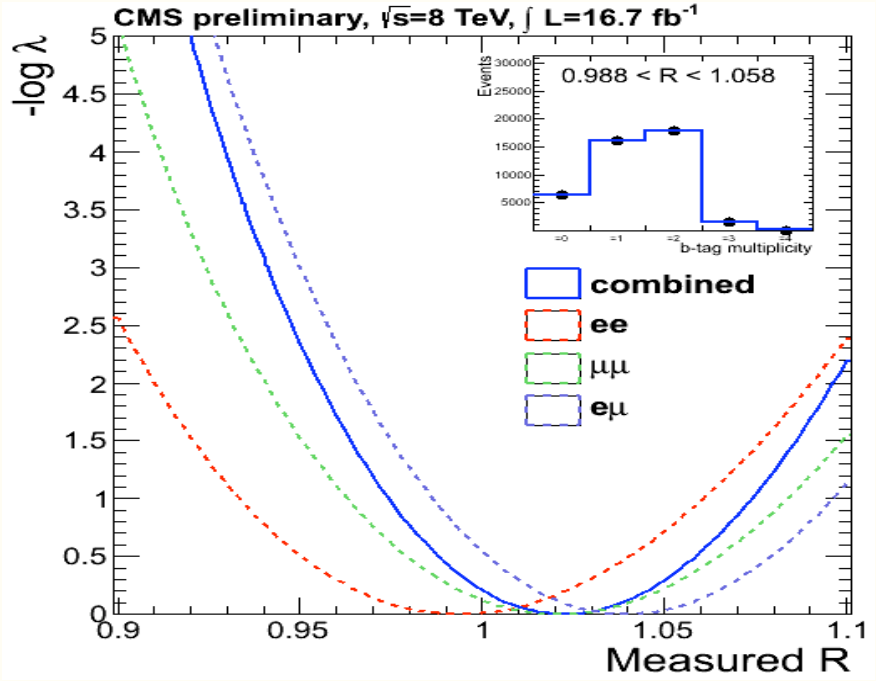
Spin correlations

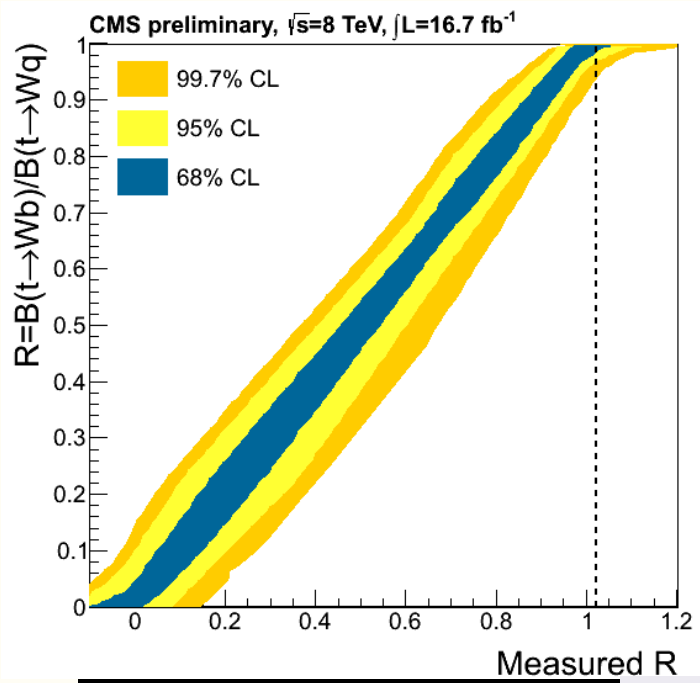
R=BR(tWb)/BR(tWq)

At √s=8 TeV

CMS PAS TOP-12-035

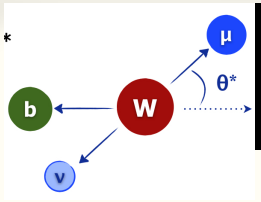
- Dilepton channel: two high iso. Pt leptons, with MET and two jets
- Back. are estimated using Data Driven techniques
- Extract with PRL fit on jet multiplicity that accounts for
  - Fraction of ttbar in sample and single-t
  - Fraction of events with correct jet assignment
  - B-tagging efficiency and misidentification





R	$1.023^{+0.036}_{-0.034}$	Unconstraint
R	>0.945	95%C.L. constraint
$\|V_{tb}\|$	$1.011^{+0.018}_{-0.017}$	Unconstraint
$\|V_{tb}\|$	>0.972	95%C.L. constraint

Most precise measurement



W helicity

V-A SM nature of the tWb is tested with cosθ*

$F_L = 0.311 \pm 0.005$, $F_0 = 0.687 \pm 0.005$, $F_R = 0.0017 \pm 0.0001$

SM: $V_L \neq 0$ and $g_R = g_L = V_R = 0$

Use a likelihood method

CMS PAS TOP-12-020

single-top(l+jets at 7+8 TeV)

$F_L = 0.293 \pm 0.069(\text{stat.}) \pm 0.030(\text{syst})$

$F_0 = 0.713 \pm 0.114(\text{stat}) \pm 0.023(\text{syst})$

$F_R = -0.006 \pm 0.057(\text{stat}) \pm 0.027(\text{syst})$

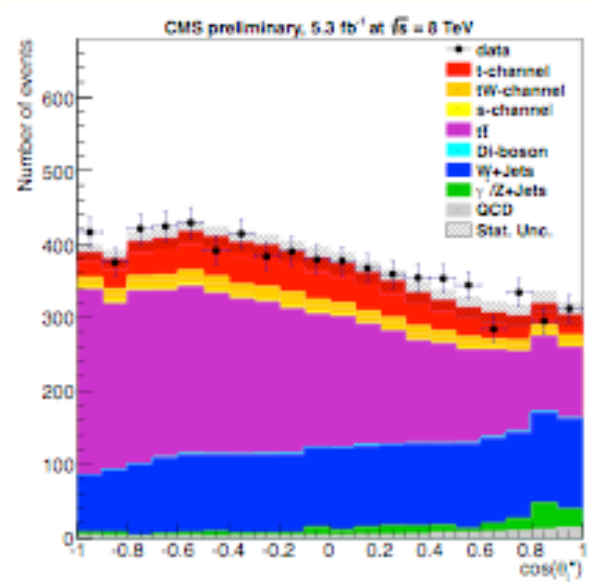
CMS PAS TOP-12-015

ttbar(dilepton at 7 TeV)

$F_L = 0.288 \pm 0.035(\text{stat.}) \pm 0.050(\text{syst})$

$F_0 = 0.698 \pm 0.057(\text{stat}) \pm 0.063(\text{syst})$

$F_R = 0.014 \pm 0.027(\text{stat}) \pm 0.055(\text{syst})$



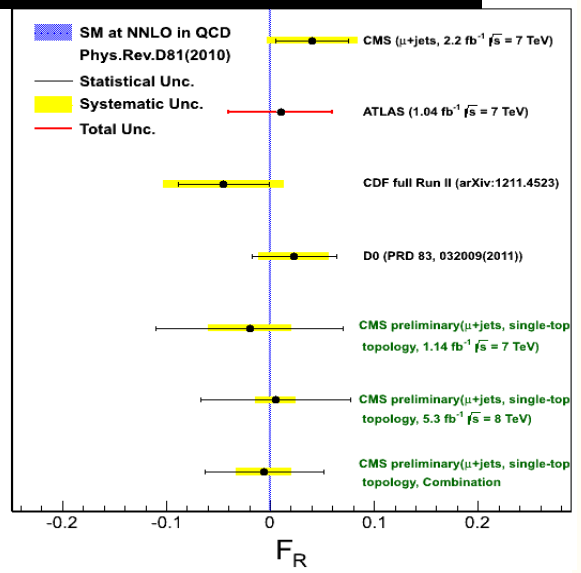
CMS PAS TOP-12-025

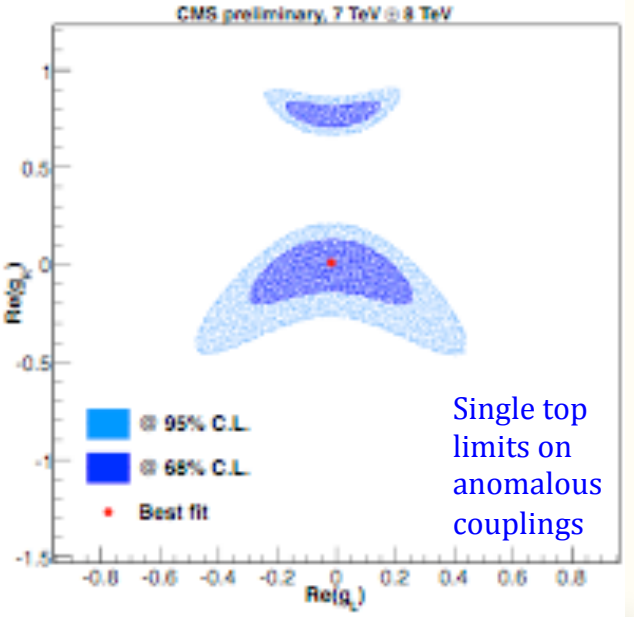
ATLAS+CMS(at 7 TeV)

$F_L = 0.359 \pm 0.021(\text{stat.}) \pm 0.048(\text{syst})$

$F_0 = 0.626 \pm 0.034(\text{stat}) \pm 0.048(\text{syst})$

$F_R = -0.015 \pm 0.034$





Single top limits on anomalous couplings

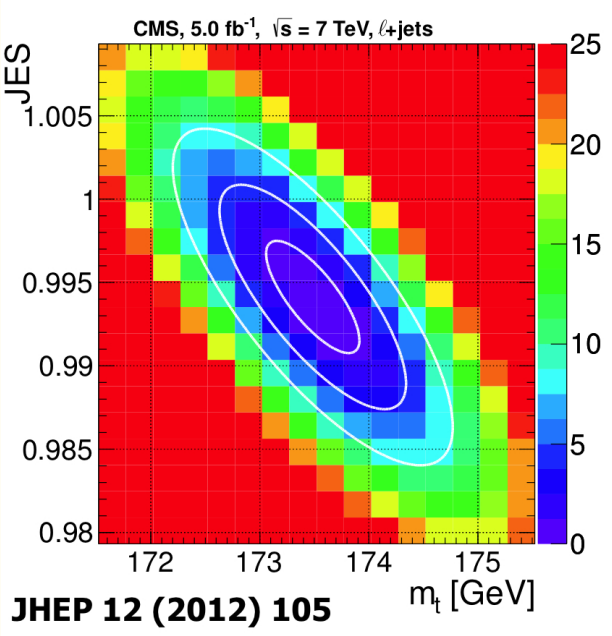
Top Properties

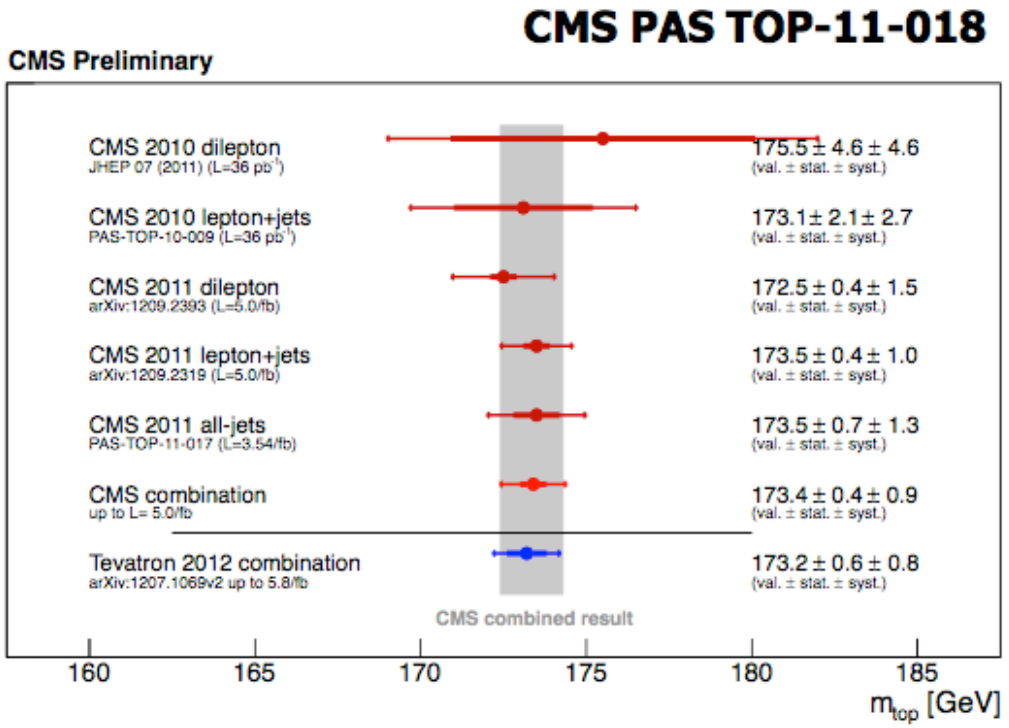
Mass
Mass differences
polarizations

Mass measurements

- Templete Fit Method (j+jets)
- Ideograms Method(l+jets, fully hadronic)
- Analytical Matrix weighting technique(dileptons)
- Full kinematic analysis(dileptons)
- Kinematic endpoints(dileptons)
- In-situ jet energy scale (JES/JSF) calibration

Combination done with BLUE
Mt= 173.4±0.4(stat) ±0.9(syst) GeV





Top mass dependence with top kinematics

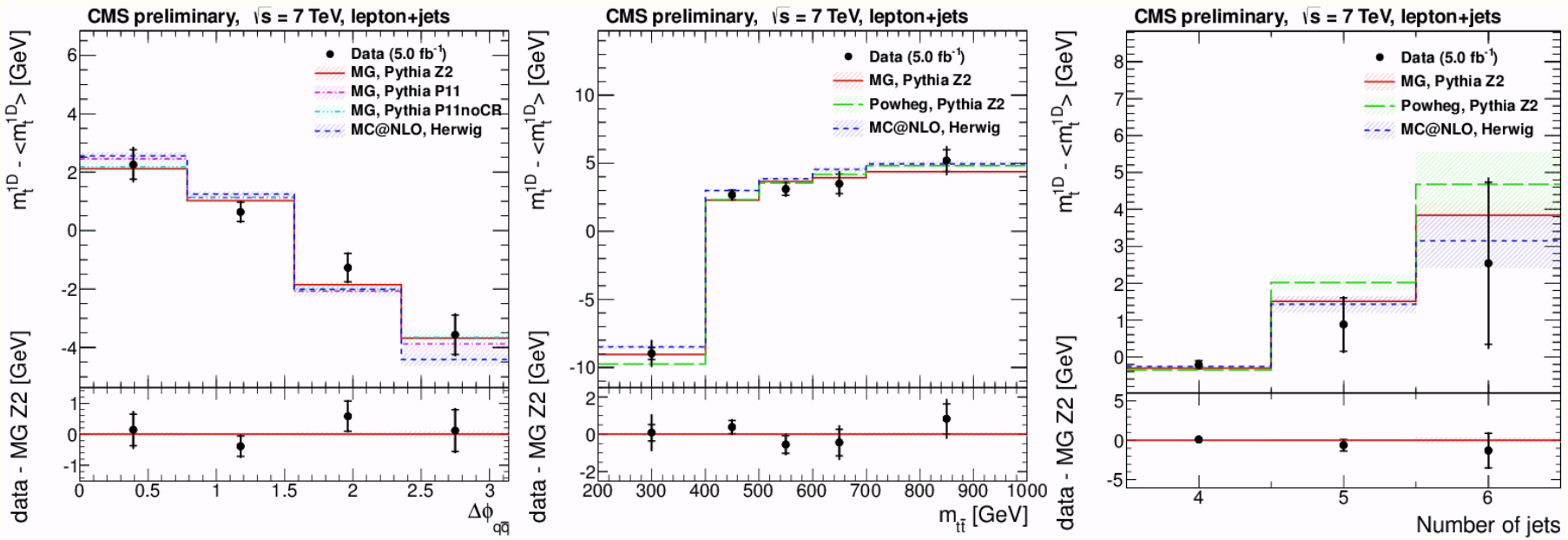
CMS PAS TOP-12-029

Relation contains (non)perturbative corrections, expected to depend on event kinematics

Check the mass dependence with kinematic variables

test for color conections effects, ISR/FSR and b-quark kinematics

Precision does not allow to distinguish between different tuning ⇨ data/MC agreement rule out significant biases

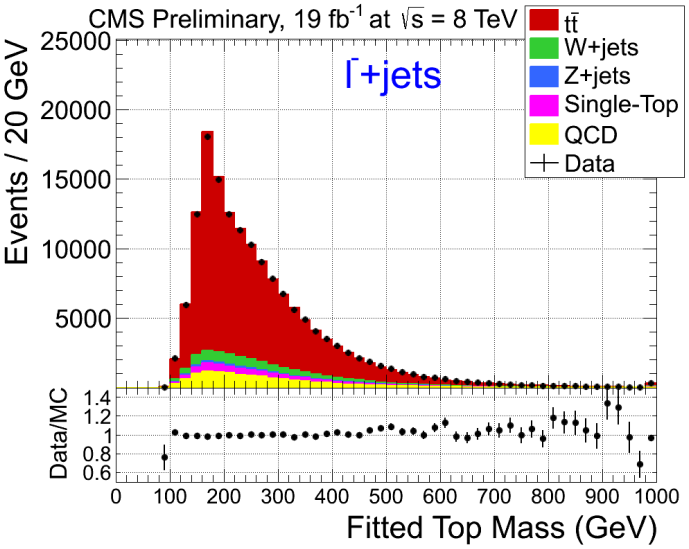


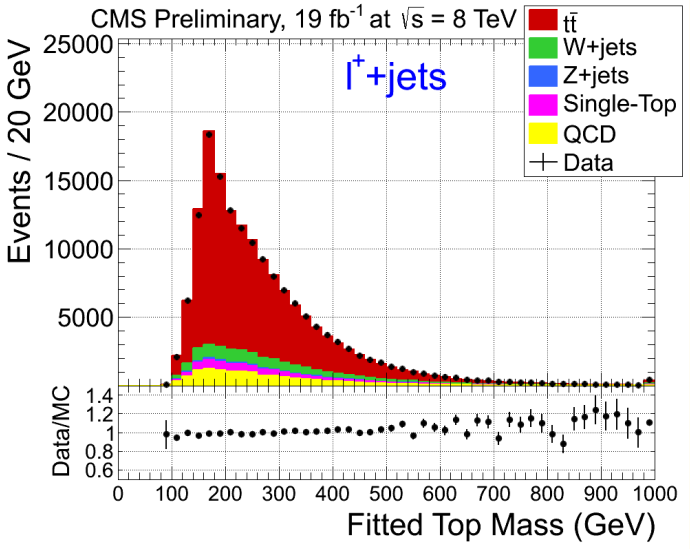
Top –anti top mass difference

- CPT predicts equal mass for top-antitop quarks⇨ deviation from this hypothesis deep impact on SM
- Using l+jets channel, data is divided in l^+ or l^- plus 3 jets to obtained the top decays. The ideogram methods is used to obtained the mass for top or anti-top and finally

CMS PAS TOP-12-031

$\Delta m_{top}(\mu)$ (MeV)	$\Delta m_{top}(e)$ (MeV)	$\Delta m_{top}(\mu+e)$ (MeV)
$-230\pm264_{(stat)}$	$-325\pm294_{(stat)}$	$-272\pm196_{(stat)}\pm122_{(syst)}$





$$\Delta m_{top} = m_t - m_{\bar{t}}$$

Results consistent with SM, precision higher than existing measurement

Many more analysis done in CMS

They compress production, decays, propeties, search for new physics with top

- Top spin correlations
- ttV production
- Top polarization
- Search for FCNC in top decays
- Search for resonances in ttbar production
- Search for pair production of new physics resonances decaying into ttbar
- Search for tb resonances
- Search for top partners with 5/3 charged
- Search for b' and t'
- Search for Z' into top pairs
- Etc…

More results into :
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G (for search of NP with tops)

Conclusions

- Top is still a very exciting topic at colliders
- High precision measurements at LHC are reached now
- Large statistics samples allows to perform detailed studies of the characteristic of this quark
- So far everything agrees with SM prediction for this quark.
- Finalizing the results with 8 TeV trying to include the full statistics. More results and better precision expected before the beginning of the LHC again.
- Very good Top quark physics understanding is essential for the CMS search of new physics program
  - Full CMS potential for top physics is still underway, stay tune for more news

Additional material

More information about the talk

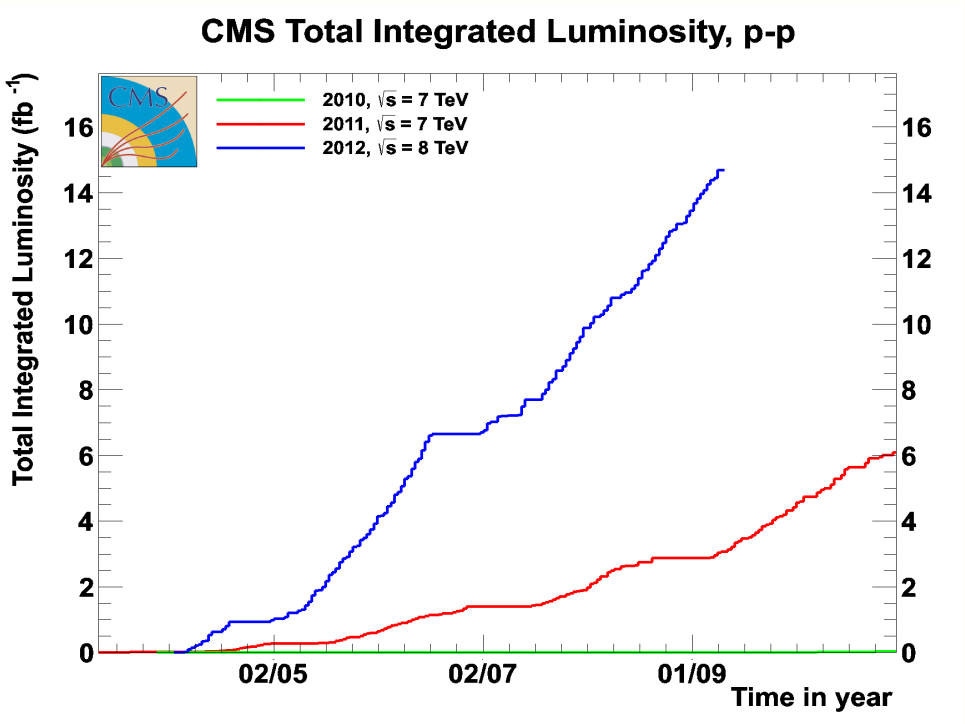
LHC performance

Spectacular performance of the LHC, CMS and ATLAS!

- Over 20 fb^{-1} data in pp collisions recorded in experiments in 2011 and 2012:

~ 5 fb^{-1} @ 7 TeV: luminosity 3 10^{33} cms^{-2} s^{-1} → ~ 0.8M tt events
~ 14 fb^{-1} @ 8 TeV: luminosity 7 10^{33} cms^{-2} s^{-1} → ~ 3.0M tt events

- Data taking efficiency > 90%
- Plans: to get 30 fb^{-1} before end of 2012

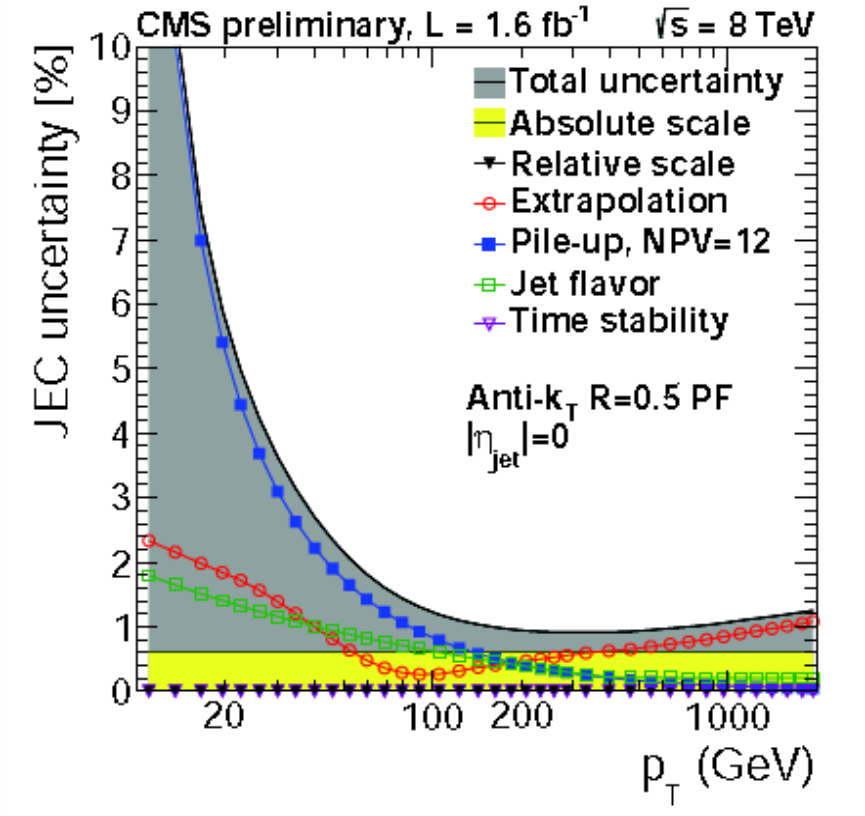


Experimental techniques

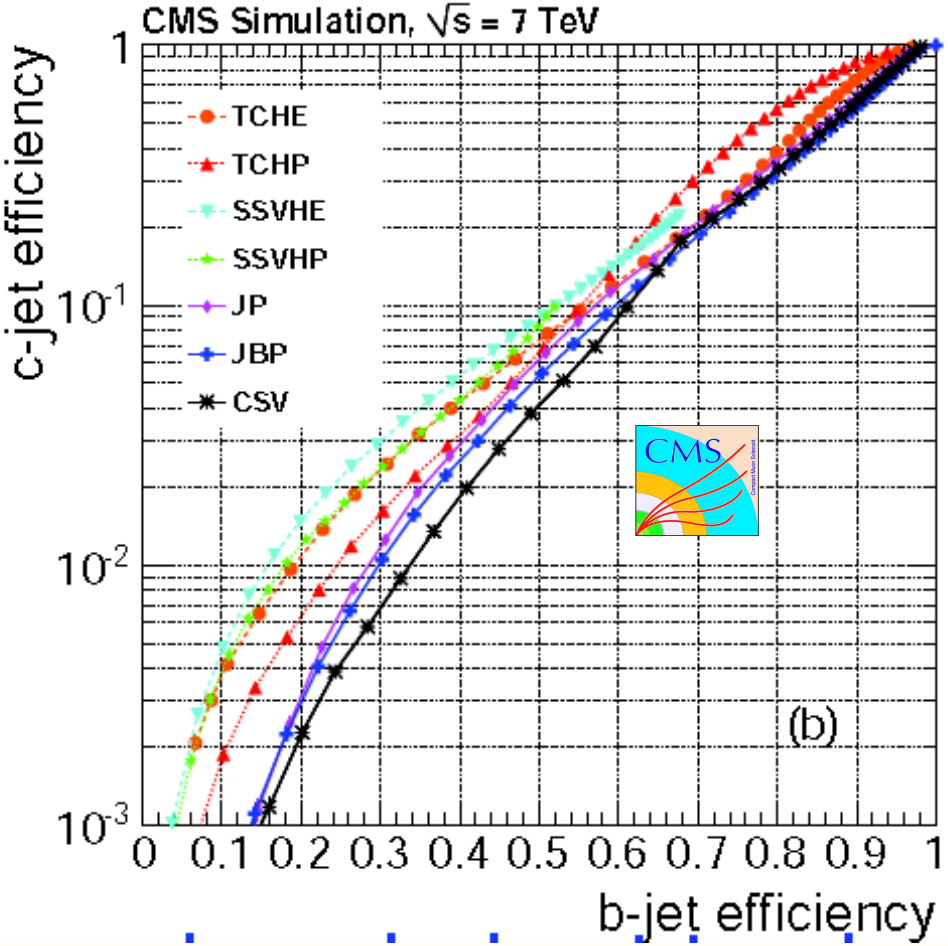
- **Isolated Leptons (e, μ or tau)**
  - isolation cuts against QCD backgrounds
- **Pile-up subtraction**
  - based on charged component
  - Residual area based correction for neutral
- **Jet (and missing ET)**
  - CMS: particle flow (track/calo combination)
  - optimal resolution and scale uncertainties
  - minimal flavour response diferentes
- **B-tagging**
  - combination of several techniques (vertex, impact parameter, track distributions within jets)

Top quarks require high precision calibration of jets and b-tagging

CMS Uncertainties comparable to 2010, 2011.



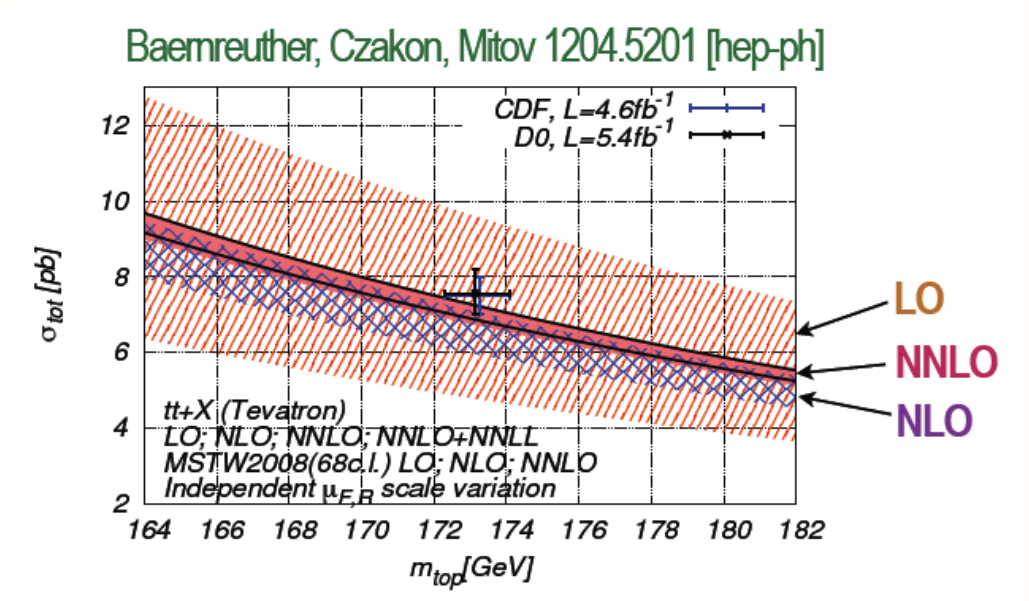
Experimental technique



b-tagging

efficiencies of the light quarks versus the b's
For the different algorithms

MC simulations



full NNLO now available for qq → tt

■ Calculations

NLO
NLO+NNLL and approx. NNLO
full NNLO (available for qq)

■ Event generators

NLO+PS
MC@NLO
POWHEG
Tree-level (+ HO) matched PS
MADGRAPH
ALPGEN
SHERPA
PYTHIA (LO)

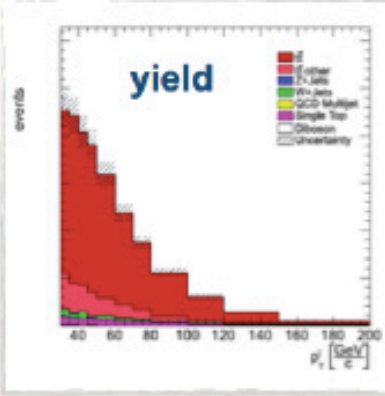
MADGRAPH
CTEQ6 PDF
M_t = 172.5 GeV

ttbar sample tipically normalized according to one of the existing approximate NNLO cross sections

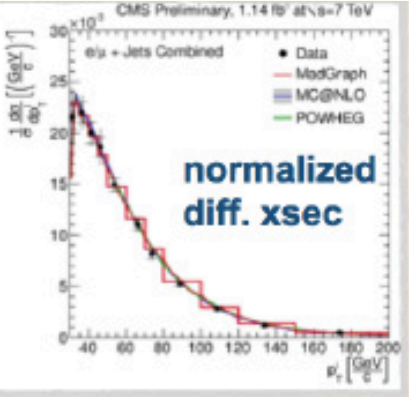
Modeling uncertanties

- ttbar signal compared with different MC generators to access differences netween the NLO+PS generators, as well compare ME+PS with NLO+PS event generators.
- Compare PYTHIA and HERWIG to access variations in the PS and hadronization description.
- Study the impact of the choice of scales: vary the renormalization and factorization scales by 0.5 and 2.0 w.r.t. The different default values, both for signal and the most important backgrounds (V+jets)
- Effect of increasing or decreasing the amount of ISR and FSR is evaluated with dedicated samples: PYTHIA (for CMS) and ACERMC (for ATLAS).
- For those samples with ME+PS: study the choice of matching scale by varying the scale w.r.t the default value some amount.
- PDF choice: using error PDF sets (LHAPDF for CMS) or PDF4LHC prescription in case of ATLAS.

Differential xs



$$\frac{1}{\sigma}\frac{d\sigma^i}{dX} = \frac{1}{\sigma}\frac{N^i_{\mathrm{Data}} - N^i_{\mathrm{BG}}}{\Delta^i_X \epsilon^i L}$$



Cut and count approach

Data driven corrections

- Drell-Yan background (dileptons)
- Trigger efficiencies
- Lepton identification and isolation

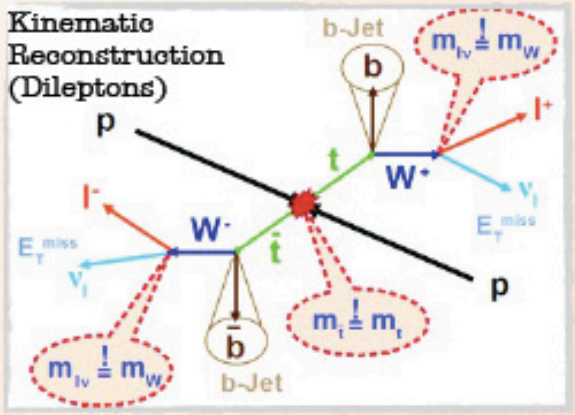
Corrected to parton or particle level and for detector effects

- Purity & stability typically > 50%
- Regularised (SVD) unfolding (MadGraph+Pythia MC)

Normalised to in-situ cross section

Top recontruction

- Dileptons
  - Kinematic reconstruction
  - Underconstrained
  - Input
    - 2 leading jets
    - 2 leptons
    - MET
  - Constraints
    - m_W
    - MET = $\sum$(neutrino p_T)
    - $m_t = m_{\bar{t}}$ [100 GeV, 300 GeV]
  - Chose solution by comparing neutrino energy spectrum to prediction
  - For m_{tt} only: 4-vector sum of 2 leading jets, MET, 2 leptons



- Lepton + jets
  - Kinematic fit
  - Input
    - Lepton
    - up to 5 leading jets
    - Neutrino momentum = MET (initally)
  - Vary 4-Vectors within Resolution
    - $m_t = m_{\bar{t}}$
    - m_W
  - Chose solution with minimum χ^2

Lepton (τ) + jets channel

Relative uncertainty [%]	
Jet energy correction	± 10.5
Jet energy resolution	± 1.9
Unclustered E_T^{miss}	± 6.6
Tau energy correction	± 6.6
Tau identification	± 9.0
Tau trigger leg	± 7.4
B-tagging	± 2.8
Pileup	+4.9 -1.4
Top quark mass	±2.8
Q^2 scale	±2.2
Parton matching	±3.0
PDF	± 5.2
Theoretical cross section	± 2.8
Systematic	± 20.0
Statistical from fit and MC	±7.7
Statistical from trigger	±1.4
Total statistical	± 7.8

- **Main systematics:**
  τ identification (~ 9%), JES (~ 10%)

Xs All hadronic channel

Main systematics: b-tagging eciencies (~ 16%), jet energy scale (~ 14%), and background estimation (~ 12%)

Source	Relative Uncertainty (%)
B-Tagging	15.7
Jet Energy Scale	13.5
Background	12.2
Q^2 Scale	8.7
Tune	8.1
ISR/FSR	5.6
Top Quark Mass	5.3
Parton Shower Matching	5.2
Jet Energy Resolution	4.8
Trigger	4.5
Pile-Up	0.6
Systematic	29.1
Statistical	14.3
Luminosity	6.0
Total Uncertainty	33.0

Xs Lepton (e/μ) + jets channel

@ 7TeV **1.1 fb^{-1}** **@ 8TeV** **2.8 fb^{-1}**

Source	Muon Analysis	Electron Analysis	Combined Analysis
Quantity	Uncertainty (%)		
Lepton ID/reco/trigger	3.4	3	3.4
$\not{E}_T$ resolution due to unclustered energy	< 1	< 1	< 1
$t\bar{t}$+jets Q^2 scale	2	2	2
ISR/FSR	2	2	2
ME to PS matching	2	2	2
Pile-up	2.5	2.6	2.6
PDF	3.4	3.4	3.4
Profile Likelihood Parameter	Uncertainty (%)		
Jet energy scale and resolution	4.2	4.2	3.1
b-tag efficiency	3.3	3.4	2.4
W+jets Q^2 scale	0.9	0.8	0.7
Combined	7.8	7.8	7.3

TABLE 1. Overview of the systematic uncertainties on the cross section measurement. Uncertainties marked with (*) are obtained from 7 TeV.

Systematic	Combined fit $\delta\sigma_{t\bar{t}}$ (%)
Jet Energy Scale	+4.3 -5.0
Jet Energy Resolution	+0.5 -1.1
Pileup	-0.7 +0.7
Background Composition	-0.1 +0.1
W+Jets template shape from unweighted 7TeV	0.9
Normalisation of data-driven multijet shape	0.9
b tagging efficiency measurement	8.0
Trigger Efficiency	-2.8 +3.2
Lepton selection	-2.4 +2.8
Factorization scale (*)	+6.2 -2.1
ME-PS Matching threshold (*)	+4.6 -3.1
PDF uncertainties (*)	+1.6 -2.0
Top Quark Mass (*)	+0.3 +1.4
Luminosity	4.4
Total	+12.7 -11.4

Xs Dilepton (e, μ) channel

@ 7TeV **2.3 fb^{-1}**

Source	Uncertainty on $\sigma_{t\bar{t}}$(pb)
Diboson	0.4
Single top	2.3
Drell-Yan	1.0
Non-W/Z leptons	0.6
Lepton Efficiencies	1.7
Lepton Energy Scale	0.5
Jet Energy Scale	2.8
Jet Energy Resolution	0.5
$\not\!\!E_T$ Efficiency	1.9
b-tagging	1.1
Pileup	0.7
W Branching Ratio	2.7
Q^2 scale of QCD	1.0
Matching partons to showers	1.0
Total systematic	5.6
Integrated luminosity	3.6
Statistical	2.6

@ 8TeV **2.4 fb^{-1}**

Source	Cont. to the $\sigma_{t\bar{t}}$(pb)	Cont. to the $\sigma_{t\bar{t}}$(%)
VV	0.3	0.1
Single top - tW	2.2	1.0
Non W/Z leptons	3.2	1.4
Drell-Yan	1.6	0.7
Lepton efficiencies	4.0	1.8
LES	0.7	0.3
JES	5.7	2.5
JER	3.8	1.7
B-tagging	2.0	0.9
Pile-up	3.3	1.5
Branching ratio	3.9	1.7
Event Q^2 scale	1.6	0.7
Matching	1.6	0.7
Total Systematic	10.7	4.7
Luminosity	10.0	4.4
Statistics	3.1	1.4

LHC combination @ 7TeV

- LHC combination from TOPLHCWG working group : combination of the ATLAS and CMS combinations (ATLAS-CONF-2012-134, CMS PAS TOP-12-003).
- BLUE method used : simple and compatible results with likelihood based methods.
- Type of uncertainties and their correlations :
  - Detector modeling : uncorrelated.
  - JES : uncorrelated (assumption tested).
  - Signal modeling : fully correlated (assumption tested).
  - Backgrounds estimated from data : uncorrelated.
  - Backgrounds estimated from simulation : fully correlated.
  - Luminosity : partially correlated, bunch charge uncertainty (fully correlated, 3% for ATLAS, 3.1% for CMS) or detector related uncertainty (uncorrelated 2.4% for ATLAS, 3.6% for CMS).

LHC combination @ 7TeV

ATLAS-CONF-2012-134, CMS PAS TOP-12-003

	ATLAS	CMS	Correlation	LHC combination
Cross-section	177.0	165.8		173.3
Uncertainty				
Statistical	3.2	2.2	0	2.3
JES	2.7	3.5	0	2.1
Detector model	5.3	8.8	0	4.6
Signal model				
Monte-Carlo	4.2	1.1	1	3.1
Parton shower	1.3	2.2	1	1.6
Radiation	0.8	4.1	1	1.9
PDF	1.9	4.1	1	2.6
Background from data	1.5	3.4	0	1.6
Background from MC	1.6	1.6	1	1.6
Method	2.4	n/e	1	1.6
W leptonic branching	1.0	1.0	1	1.0
Luminosity				
Bunch current	5.3	5.1	1	5.3
Detector effects	4.3	5.9	0	3.4
Total systematic	10.8	14.2		9.8
Total	11.3	14.4		10.1

Mass systematic unc.

	Dileptons 2010	Lepton+jets 2010	Dileptons 2011	Lepton+jets 2011	All jets 2011
Measured m_t	175.50	173.10	172.50	173.49	173.49
JES	4.0	2.3	1.2	0.75	1.1
Lepton energy scale	0.30	—	0.14	0.02	—
MC generator	0.50	—	0.04	—	—
ISR/FSR	0.20	0.20	—	—	—
PDF	0.50	0.10	0.09	0.07	0.06
Factorization scale	0.60	1.10	0.55	0.24	0.22
ME-PS matching threshold	0.70	0.40	0.19	0.18	0.24
Signal					
Jet energy resolution	0.50	0.10	0.14	0.23	0.15
b-tagging	0.40	0.10	0.09	0.12	0.06
MET scale	0.10	0.40	0.12	0.06	—
Detector Modeling					
Underlying event	1.30	0.20	0.05	0.15	0.32
Background MC	0.10	0.20	0.05	0.13	—
Background Data	—	0.40	—	—	0.20
Fit calibration and MC	0.20	0.10	0.40	0.06	0.13
Pile-up	1.00	0.10	0.11	0.07	0.06
Color reconnection	n/e	n/e	0.13	0.54	0.15
Trigger	—	—	—	—	0.24
Total Systematic Uncertainty	4.52	2.63	1.41	1.03	1.25

Systematic unc diff xs

- Global uncertatintiesdue to normalisation
- Remaining shape uncertainties evaluated individually for each bin:
  - Jet energy scale and resolution
  - Lepton identification and isolation efficiencies
  - Trigger efficiencies
  - B-tagging efficiencies
  - Pile up modelling

  - Top mass uncertainties
  - Scale and matching scale variations (dominant)
  - Hadronisation (POWHEG+Pythia, MC@NLO+Herwig)
  - PDF variations

T-channel cross section

7TeV

		Uncertainty source	NN	BDT	$\eta_{j'}$
Marginalised (NN, BDT)	Experimental uncert.	Statistical	−6.1/+5.5%	−4.7/+5.4%	±8.5%
		Limited MC data	−1.7/+2.3%	±3.1%	±0.9%
		Jet energy scale	−0.3/+1.9%	±0.6%	−3.9/+4.1%
		Jet energy resolution	−0.3/+0.6%	±0.1%	−0.7/+1.2%
		b tagging	−2.7/+3.1%	±1.6%	±3.1%
		Muon trigger + reco.	−2.2/+2.3%	±1.9%	−1.5/+1.7%
		Electron trigger + reco.	−0.6/+0.7%	±1.2%	−0.8/+0.9%
		Hadronic trigger	−1.3/+1.2%	±1.5%	±3.0%
		Pileup	−1.0/+0.9%	±0.4%	−0.3/+0.2%
		MET modeling	−0.0/+0.2%	±0.2%	±0.5%
	Backg. rates	W+jets	−2.0/+3.0%	−3.5/+2.5%	±5.9%
		light flavor (u, d, s, g)	−0.2/+0.3%	±0.4%	n/a
		heavy flavor (b, c)	−1.9/+2.9%	−3.5/+2.5%	n/a
		$t\bar{t}$	−0.9/+0.8%	±1.0%	±3.3%
		QCD, muon	±0.8%	±1.7%	±0.9%
		QCD, electron	±0.4%	±0.8%	−0.4/+0.3%
		s-, tW ch., dibosons, Z+jets	±0.3%	±0.6%	±0.5%
	Total marginalised uncertainty		−7.7/+7.9%	−7.7/+7.8%	n/a
Not marginalised		Luminosity		±2.2%	
	Theor. uncert.	Scale, $t\bar{t}$	−3.3/+1.0%	±0.9%	−4.0/+2.1%
		Scale, W+jets	−2.8/+0.3%	−0.0/+3.4%	n/a
		Scale, *t*-, *s*-, tW channels	−0.4/+1.0%	±0.2%	−2.2/+2.3%
		Matching, $t\bar{t}$	±1.3%	±0.4%	±0.4%
		t-channel generator	±4.2%	±4.6%	±2.5%
		PDF	±1.3%	±1.3%	±2.5%
		Total theor. uncertainty	−6.3/+4.8%	−4.9/+5.9%	−5.6/+4.9%
Syst. + theor. + luminosity uncert.			−8.1/+7.8%	−8.1/+8.4%	±10.8%
Total (stat. + syst. + theor. + lum.)			−10.1/+9.5%	−9.4/+10.0%	±13.8%

8TeV

Uncertainty source	in pb	relative
Statistical	±5.7	±7.2 %
W+jets and $t\bar{t}$modeling	±3.6	± 4.5 %
JES	− 6.2 / + 4.7	− 7.8 / + 5.8 %
JER	− 0.8 / + 0.3	− 1.0 / + 0.4 %
Unclustered $\not{E}_T$	− 0.8 / + 0.7	− 1.0 / + 0.9 %
Pileup	− 0.5 / + 0.3	− 0.6 / + 0.4 %
Muon trigger + reconstruction	− 4.1 / + 4.0	− 5.1 / + 5.1 %
Q^2	±2.5	±3.1 %
$t\bar{t}$, rate	− 1.5 / + 1.7	− 1.9 / + 2.1 %
QCD, rate	±0.7	±0.9 %
$t-$channel generator	±4.4	±5.5 %
Other backgrounds, rate	±0.5	±0.6 %
b-tagging	±3.7	±4.6 %
PDF	± 3.7	±4.6 %
Simulation statistics	±1.8	±2.2 %
Total systematics	±11.0	±13.7 %
Luminosity uncertainty	±4.0	±5.0 %
Total	±13.0	±16.3%

Systematic unc. W helicity

	$\sqrt{s} = 8$ TeV		$\sqrt{s} = 7$ TeV	
Systematic source	ΔF_L	ΔF_0	ΔF_L	ΔF_0
JES	0.006	0.006	0.020	0.020
JER	0.008	0.003	0.015	0.010
unclustered energy	0.013	0.003	0.015	0.015
pileup	0.002	0.003	0.004	0.000
b-flavored scale factor	0.004	0.006	0.009	0.009
non-b-flavored scale factor	0.004	0.007	0.002	0.001
single-top generator	0.008	0.014	0.004	0.004
Q^2 scale	0.009	0.012	0.040	0.007
m_{top}	0.005	0.006	0.010	0.010
PDF	0.005	0.005	0.000	0.000
$t\bar{t}$ normalization	0.002	0.003	0.008	0.008
QCD shape	0.002	0.002	0.004	0.004
W+jets shape	0.008	0.010	0.010	0.010
integrated luminosity	0.003	0.003	0.007	0.007
SM W-helicity reference	0.004	0.003	0.001	0.002
stematic uncertainty (w/o generator)	0.022	0.021	0.054	0.035
total systematic uncertainty	0.024	0.026	0.054	0.035

Systematic source	ΔF_L	ΔF_0
JES	0.007	0.007
JER	0.011	0.003
unclustered energy	0.018	0.010
pileup	0.002	0.002
b-flavored scale factor	0.003	0.001
non-b-flavored scale factor	0.001	0.002
single-top generator	0.005	0.009
Q^2 scale	0.006	0.008
m_{top}	0.001	0.001
PDF	0.003	0.003
$t\bar{t}$ normalization	0.003	0.002
QCD shape	0.003	0.003
W+jets shape	0.012	0.011
integrated luminosity	0.010	0.010
SM W-helicity reference	0.002	0.001
total systematic uncertainty	0.030	0.023