Top quark physics with the CMS experiment

neutrino

light quark jet

b-quark jet

light quark jet

electron

b-quark jet

CMS — Compact Muon Solenoid
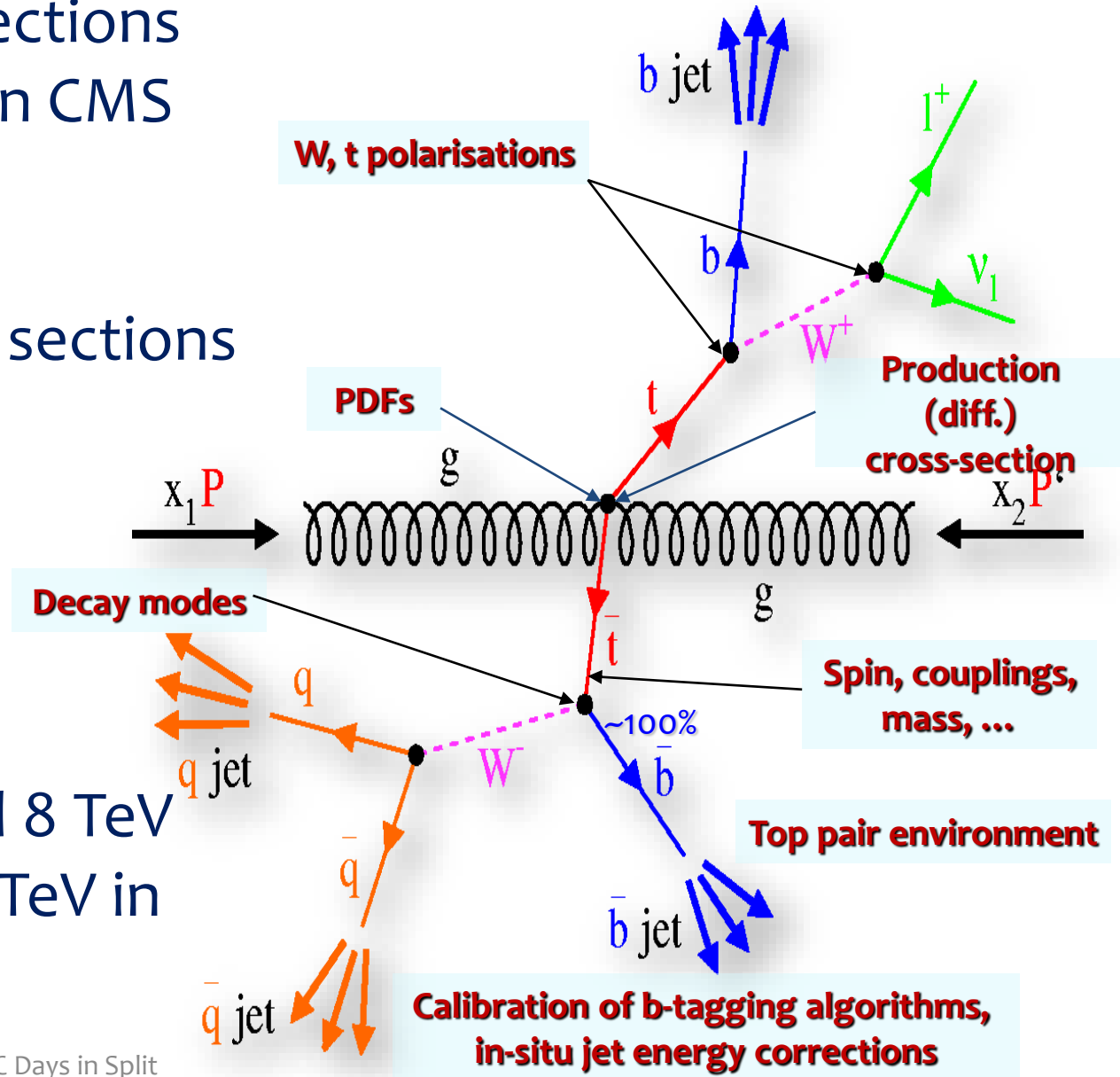
jet
pT=31 GeV/c

b jet
pT=65 GeV/c

μ+
pT=52 GeV/c

b jet
pT=91 GeV/c

jet
pT=47 GeV/c
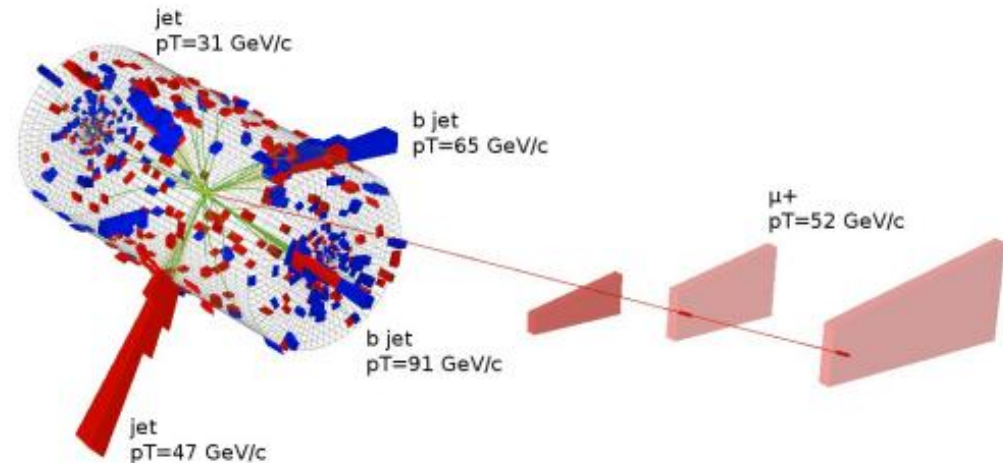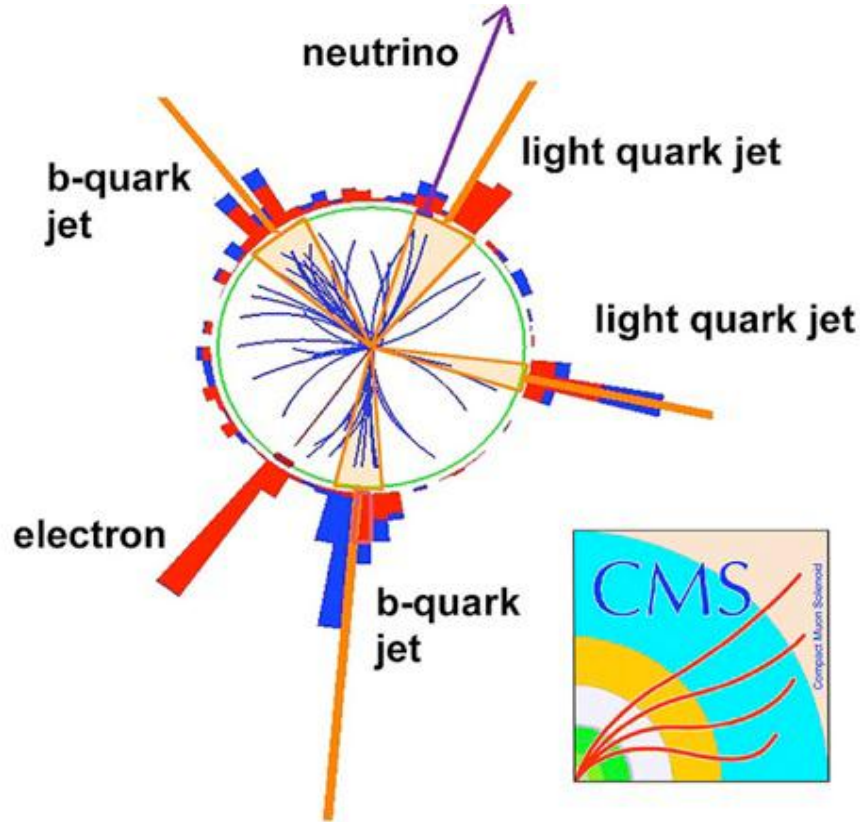
J. Cuevas
U. Oviedo (Spain)
on behalf of the CMS collaboration

Outline

- Top pair cross sections measurements in CMS
  - Inclusive
  - Differential
- Single top cross sections
- Top mass
- Top properties
- Looking for new physics

- Results on 7 and 8 TeV data, some at 8 TeV in the pipeline

b jet

W, t polarisations

l^+

b

ν_l

W^+

Production (diff.) cross-section

PDFs

t

$x_1 P$

g

$x_2 P'$

g

Decay modes

q

$\bar{t}$

Spin, couplings, mass, …

q jet

W

~100%

$\bar{b}$

$\bar{q}$

Top pair environment

$\bar{b}$ jet

$\bar{q}$ jet

Calibration of b-tagging algorithms, in-situ jet energy corrections

A particle with unique characteristics

- Special because of its enormous mass: heaviest known particle
  - Still a point-like particle in our understanding
  - The top and the Higgs are "strongly" coupled $\quad y_t \approx 1 \qquad m_t = y_t \text{v}/\sqrt{2}$
  - The top mass dramatically affects the stability of the Higgs mass
    - If we consider the SM valid up to a certain scale Λ
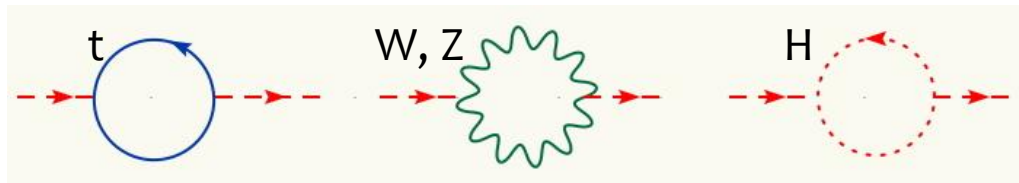
$$m_H^2 = m_{H0}^2 \qquad -\frac{3}{8\pi^2}y_t\Lambda^2 \qquad +\frac{1}{16\pi^2}g^2\Lambda^2 \qquad +\frac{1}{16\pi^2}\lambda^2\Lambda^2$$
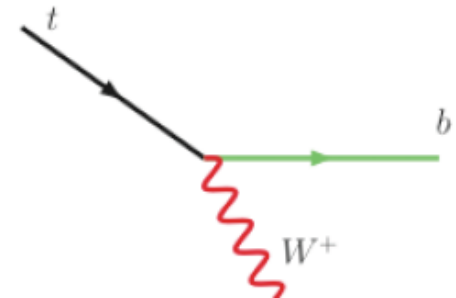
$$(125\,\text{GeV})^2 = m_{H0}^2 + \left[-(2\,\text{TeV})^2 + (700\,\text{GeV})^2 + (500\,\text{GeV})^2\right]\left(\frac{\Lambda}{10\text{TeV}}\right)^2$$
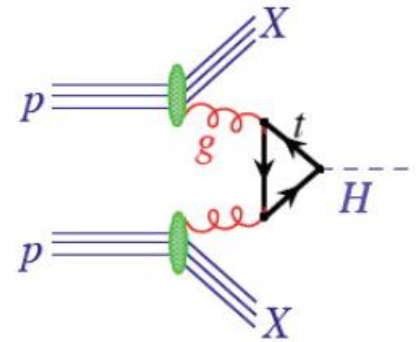
- It is the only quark that does not hadronise
  - $\tau(\text{had})\sim h/\Lambda_{QCD}\sim 2\ 10^{-24}$ s
  - $\tau(\text{top})\sim h/\Gamma_{top}\sim 5\ 10^{-25}$ s
  - Compare with $\tau(b)\sim 10^{-12}$ s
  - Decays before forming a "dressed" top quarks
  - No bound tq states, its spin properties are directly passed to its decay products
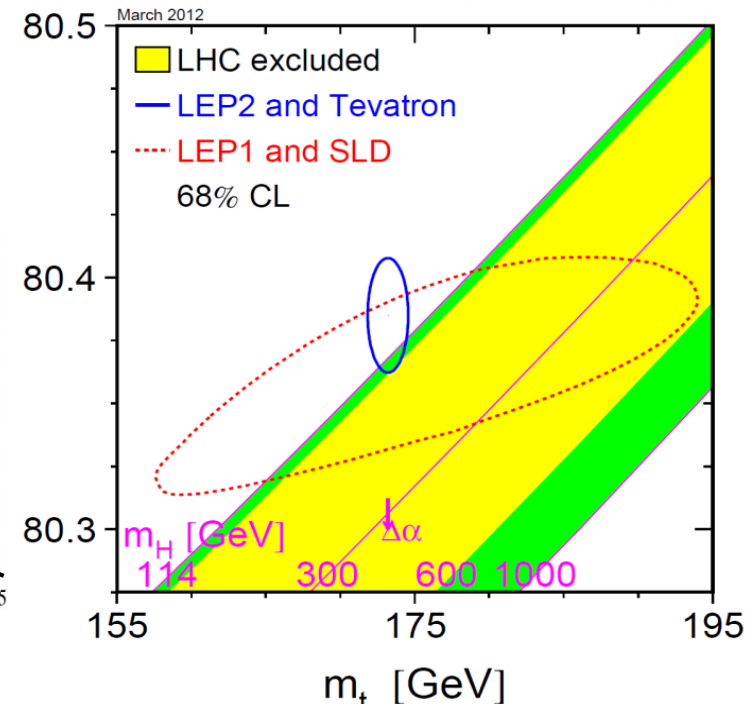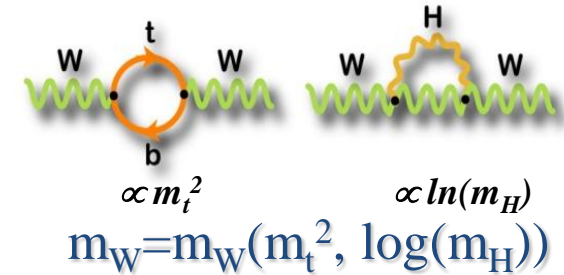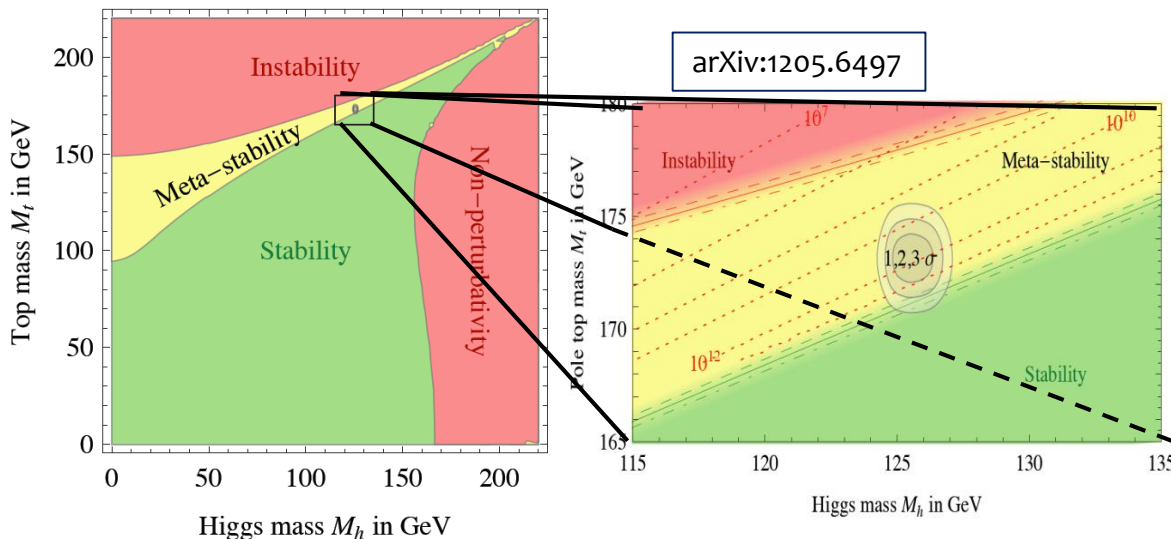 - QCD, Flavor and EWK physics at their best !

Constraining the SM

- Can use the fact that m_t, m_W, m_H are linked at loop level to constrain the SM

  ➤ **The Higgs/symmetry breaking sector can be explored with more insights coming from top physics**

$$V(\phi) = -\mu^2 \phi^+\phi + \lambda (\phi^+\phi)^2 + Y^{ij} \psi_L^i \psi_R^j \phi$$

$\propto m_t^2$ $\propto ln(m_H)$

$$m_W = m_W(m_t^2, \log(m_H))$$

λ now known at NNLO QCD. Vacuum meta-stability when the minimum of $V(\Phi)$ is just local

arXiv:1205.6497

March 2012

- LHC excluded
- — LEP2 and Tevatron
- ⋯ LEP1 and SLD
- 68% CL

m_H [GeV]
114   300   600 1000

m_t [GeV]
155   175   195

- The top quark also provide other direct constraints to the model

  ➤ Direct access to parameters of the SM (m_t, V_{tb})

  ➤ Other stringent tests of SM (QCD in $d\sigma/dX$, couplings, CPT invariance,…)

Top quark production at LHC

process	Events/s 8 TeV, peak lumi	Events/y 8 TeV, 25/fb
bb	~10^6	~3 10^{12}
W→$\ell\nu$	~70	~2.5 10^8
Z→$\ell\ell$	~6	~25 10^6
tt	~1.5	~6 10^6

Top pairs

Single top

t-channel

s-channel

tW-channel

QCD

W+jets

Z+jets

Javier Cuevas, LHC Days in Split
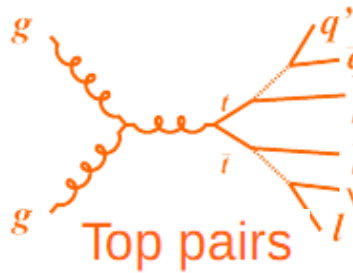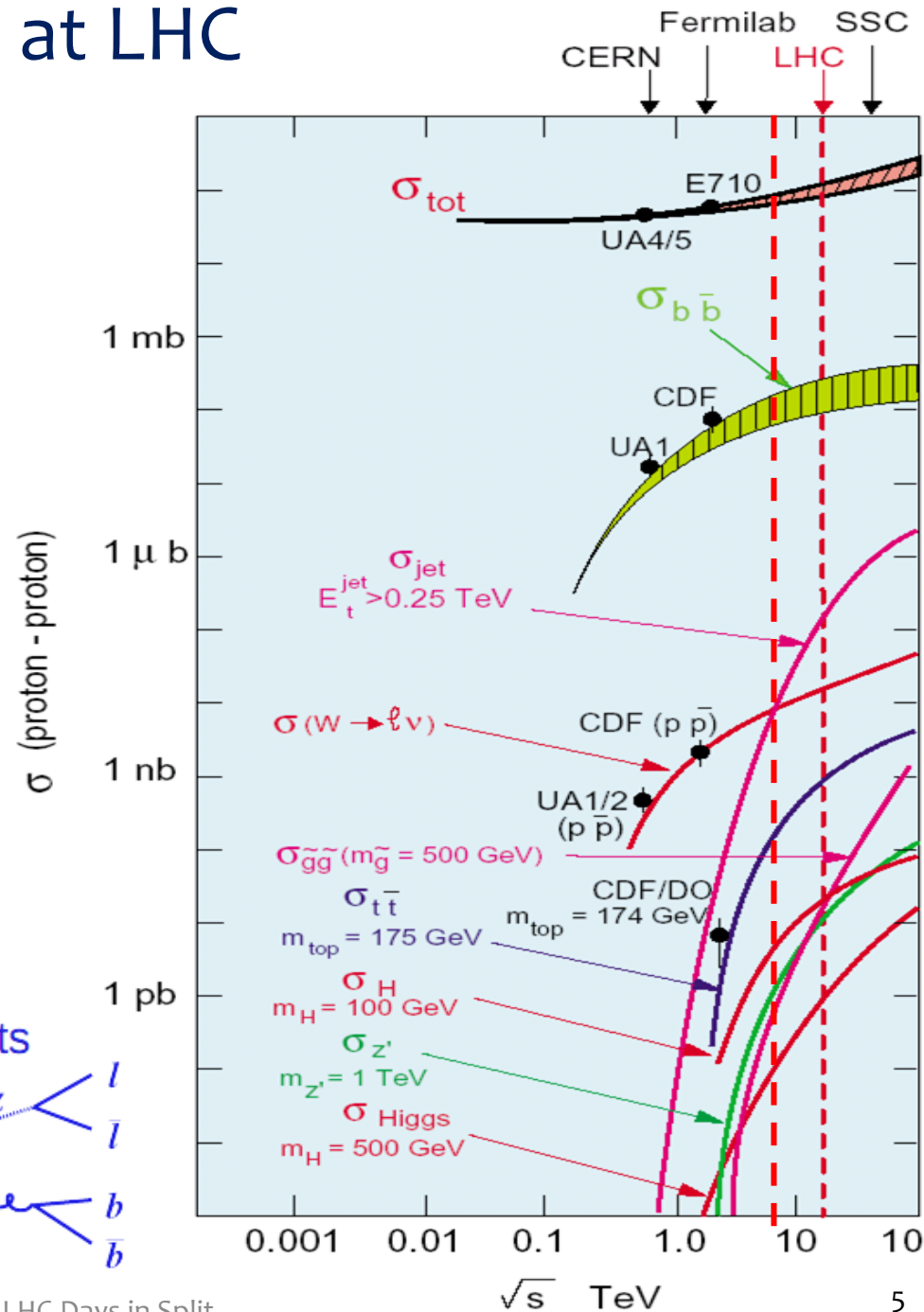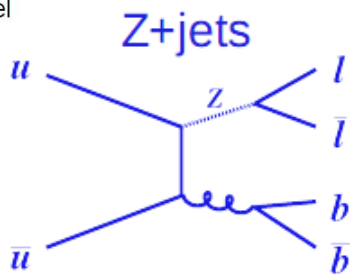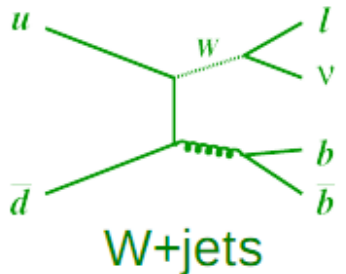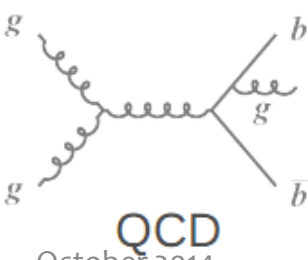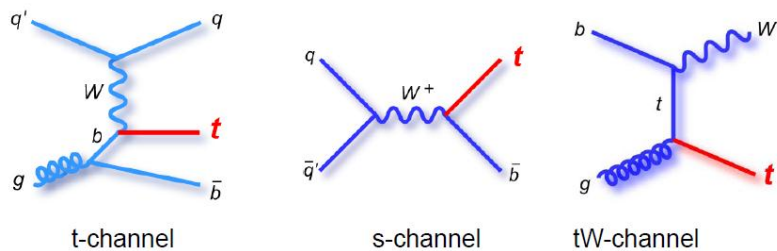
Collected data in CMS

The LHC performed incredibly well (even better than expected) and this was possible thanks to the quality of the design, construction and installation and to the thorough preparation in the injectors which were delivering beams well beyond nominal parameters: **~5/fb** collected in total at **7** TeV and **~20/fb** at **8** TeV

CMS has a dedicated team of experts monitoring the quality of data online and offline, with certification of every collision run

- **Statistics important for top physics**
  - ➤ LHC is the first top factory ever !
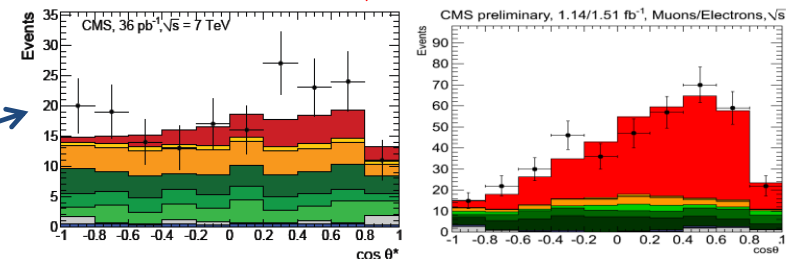   - o O(1M) tt @7TeV, O(10M) @8 TeV
  - ➤ While precision measurements soon limited by systematic errors, many possibilities for other studies open up
    - o Rare processes
    - o Searches for new physics
    - o Constrain of systematic errors and backgrounds by using data
- o With the 2010 run, and a relatively simple analysis, it was sufficient for CMS to compete with Tevatron on an analysis that had taken a decade and the most state-of-the-art analysis techniques to them.

CMS Integrated Luminosity, pp

Data included from 2010-03-30 11:21 to 2012-12-16 20:49 UTC

- 2010, 7 TeV, 44.2 pb^{-1}
- 2011, 7 TeV, 6.1 fb^{-1}
- 2012, 8 TeV, 23.3 fb^{-1}

Peak luminosity: 7.7×10^{33}

Example: how the single top signal improves
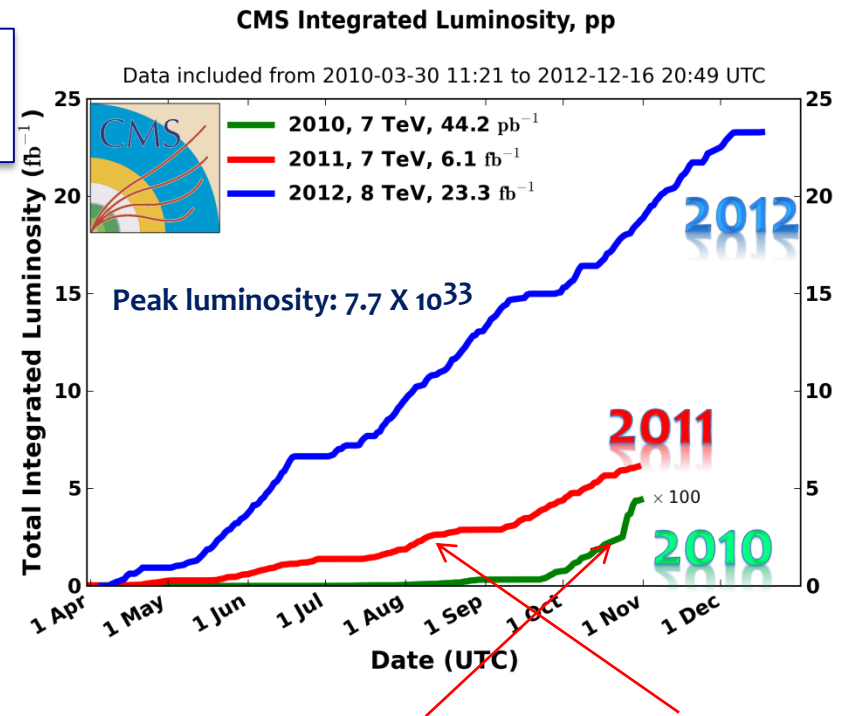
Experimental challenges

b-tagging

b jet

e, μ, τ

l⁺

ν_l

W⁺

Missing E_T

x₁P

g

x₂P'

g

t

t̄

q

q jet

light jets
(energy scale)

q̄ jet

W⁻

q

b̄

b̄ jet
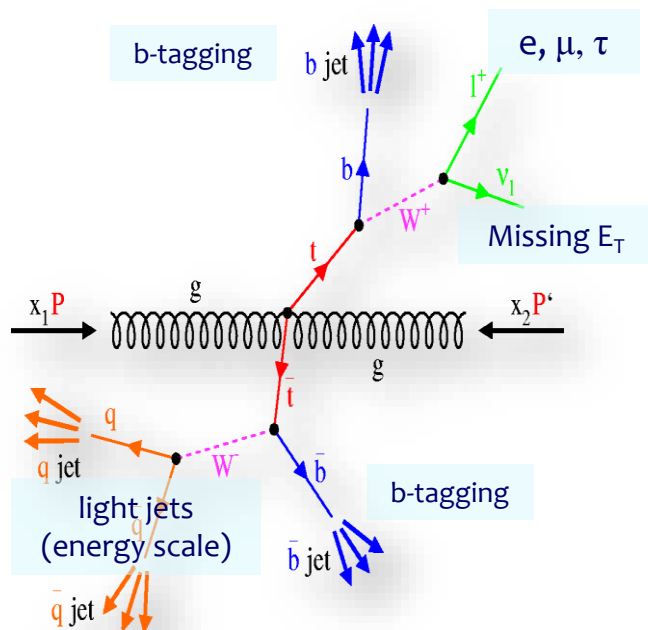
b-tagging

- Top quark studies require **all** components and capabilities of the **CMS** detector to work:
  - Trigger
  - Charged lepton reconstruction, identification and isolation
  - Jet reconstruction
  - Missing transverse energy
  - b-tagging

- important to consider PU conditions at 8 TeV.

- **Optimal use of the detectors...**
  - ➤ Particle Flow reconstruction in CMS
    - ○ Combine all sub-detector information to reconstruct and identify particles, after pile-up substraction

- ... and sophisticated analysis tools:
  - ➤ B-tagging, τ reconstruction, kinematic fitting

CMS: a simple and elegant concept

Key:
- Muon
- Electron
- Charged Hadron (e.g. Pion)
- Neutral Hadron (e.g. Neutron)
- Photon

$\sigma(E)/E \sim 3\%/\sqrt{(E)}$ [GeV] ⊕0.3% $\sigma(E_T)/E_T \sim 100\%/\sqrt{(ET)}$ [GeV] @5%

$\sigma(p_T)/p_T \sim 15\%$ at 1TeV

Silicon Tracker

Electromagnetic Calorimeter

Hadron Calorimeter

Superconducting Solenoid

Transverse slice through CMS

Neutrinos "measured" through missing transverse energy (E_T^miss) in calorimeters.

Iron return yoke interspersed with Muon chambers

No particle should go undetected

Fast detectors: 25-50ns bunch crossing
High granularity: 20-40 overlapping complex events
High radiation resistance: >10 years of operation

$\sigma(p_T)/p_T < 1\%$ @ 100GeV
$\sigma(p_T)/p_T < 10\%$@1 TeV

Top (pair) production at the LHC

- **Top pair** QCD production happens mainly via gluon fusion
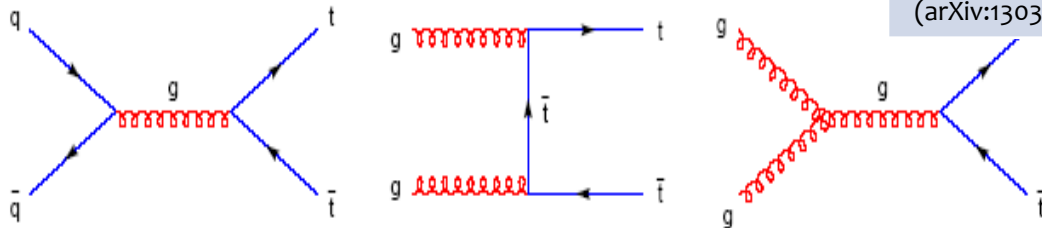
	σ(NNLO+NNLL) ± scales ± PDFs [pb]	
	7 TeV	8 TeV
Czakon, Fiedler, Mitov (arXiv:1303.6254)	$172.0^{+4.4}_{-5.8}{}^{+4.7}_{-4.8}$	$245.8^{+6.2}_{-8.4}{}^{+6.2}_{-6.4}$

- Final states depend on the decay of the W bosons
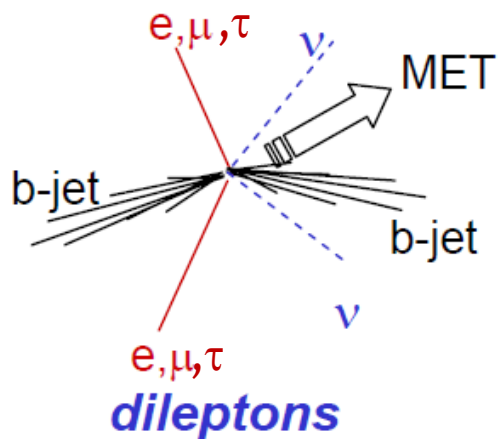
- dileptons
  - BR~10%
- lepton + jets
  - BR~44%
- all hadronic
  - BR~46%

- Backgrounds coming from: W/Z+jets, single top (tW), QCD, di-boson

Total cross section measurements

- Monitoring the total production cross section is the first fundamental step for understanding top physics at the LHC
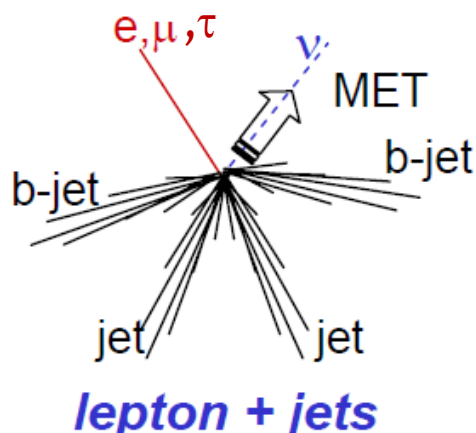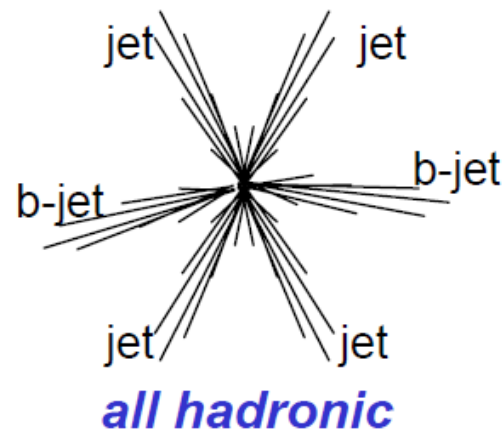 - Test the presence of new production mechanisms
  - In the frame of the SM, test QCD predictions and help constraining the PDFs (especially gluons)
    - Important for Higgs production

$$\sigma_{t\bar{t}}(m_t) = \sum_{i,j} \int_0^1 dx_1 dx_2 \, f_i(x_1) f_j(x_2) \, \hat{\sigma}_{ij}(m_t)$$

  - Indirect determination of m_t or α_s.
  - Constrain a very important background for many searches at the LHC

- **Almost all decay modes are investigated at the LHC**

- The measurements are performed at different level of complexity:
  - Counting experiment in acceptance $\sigma = \dfrac{N_{data} - N_{BG}}{\epsilon_{t\bar{t}} \int \mathcal{L}dt}$
  - Fit to data in several portions of phase space with in situ constraining of various backgrounds
  - Multivariate analyses
  - Selections defined for inclusive cross sections are in general used for the rest of the measurements in that final state

H1 and ZEUS HERA I+II 10 parameter PDF Fit

$Q^2 = 10 \text{ GeV}^2$

HERAPDF1.5 (prel.)
exp. uncert.
model uncert.
parametrization uncert.

xu_v
xg ($\times 0.05$)
xd_v
xS ($\times 0.05$)

March 2011
HERAPDF Structure Function Working Group
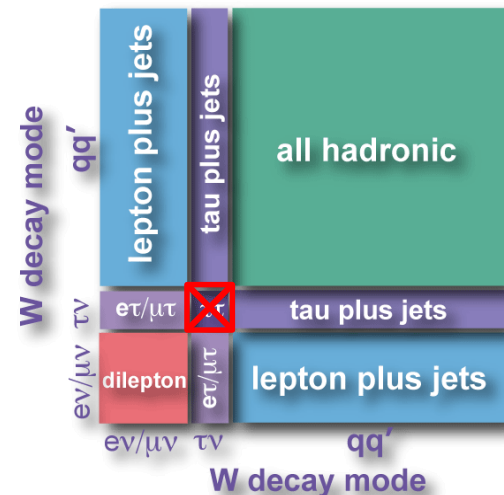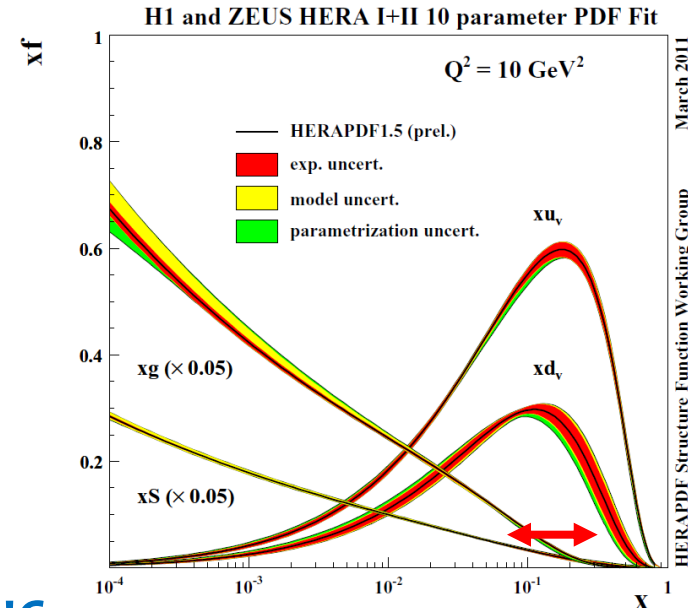
Top pair cross section in the dilepton channel at 8 TeV

- **Selection basically unchanged wrt to 7 TeV analysis (reflecting LHC running conditions)**

- **A cut and count analysis was developed.**

- Signal acceptance is taken from simulation assuming a top mass of 172.5 GeV.

- $t\bar{t}$ cross section is calculated using events passing final selection

	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
ϵ_{total} (%)	0.203 ± 0.012	0.270 ± 0.017	0.717 ± 0.033
$\sigma_{t\bar{t}}$ (pb)	$244.3 \pm 5.2 \pm 18.6 \pm 6.4$	$235.3 \pm 4.5 \pm 18.6 \pm 6.1$	$239.0 \pm 2.6 \pm 11.4 \pm 6.2$

- Dominant systematics: JES (2.1 %), lepton and trigger efficiencies (1.7 %), factorization and renormalization scales (2.3%).

- Compatible results among the three channels **eµ** is the **most precise** due to its **small backgrounds**

- Combined result

JHEP 02 (2014) 024

$$\sigma_{t\bar{t}} = 239.0 \pm 2.1\,(\text{stat.}) \pm 11.3\,(\text{syst.}) \pm 6.2\,(\text{lum.})\ \text{pb}$$
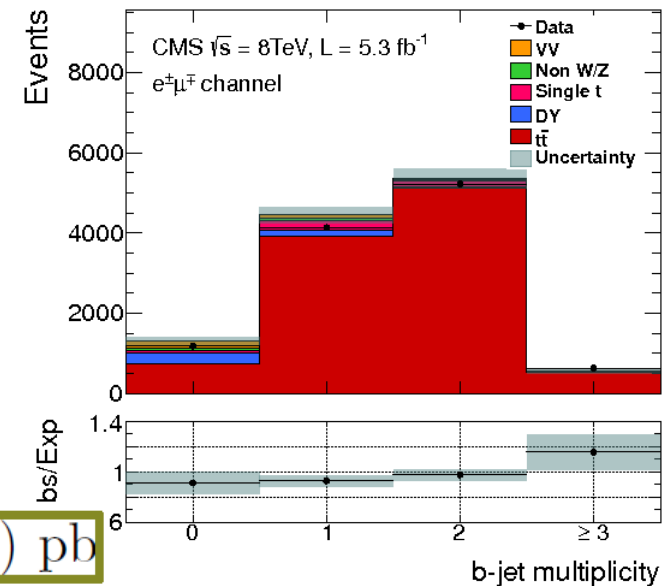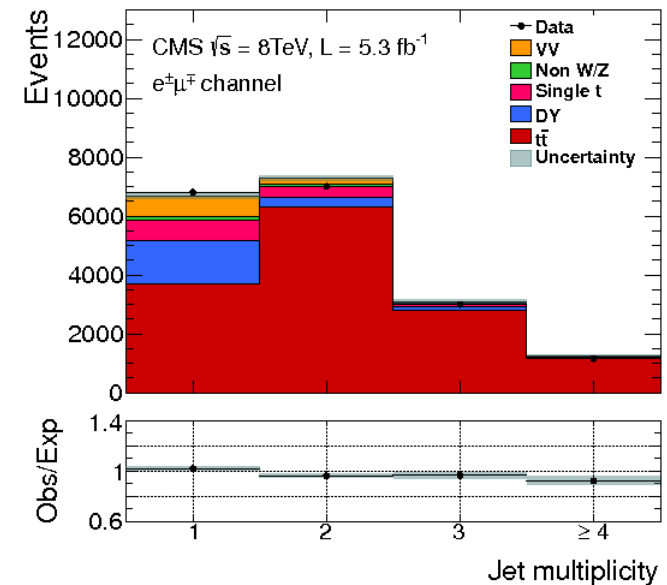
Cross section in dilepton decays with τ at 8 TeV

- Similar selection than in the 7 TeV analysis
- Cut and count analysis
- Backgrounds: Misidentified τ (dominant)
  - Mostly $t\bar{t} \rightarrow$ lepton + jets
  - Misidentification probability is measured in control samples in data and simulation
  - Other backgrounds are taken from simulation
- Data-driven τ-fake background estimation
- Main systematics: τ miss-id background (4%), τ-ID(6%)
- Signal acceptance is taken from simulation assuming a top mass of 172.5 GeV and cross section is calculated using event passing final selection:
  - $\sigma_{t\bar{t}}(e\tau_h)$ = 255 ± 4 (stat.) ± 24 (syst.) ± 7 (lum.) pb
  - $\sigma_{t\bar{t}}(\mu\tau_h)$ = 258 ± 4 (stat.) ± 24 (syst.) ± 7 (lum.) pb
- **$\sigma_{t\bar{t}}$(combined) = 257 ± 3 (stat.) ± 24 (syst.) ± 7 (lum.) pb**
- Precision is limited (mainly by τ mis-ID) but still **~ 10 %**

- At 7 TeV: $\sigma_{t\bar{t}} = 143.0 \pm 14.0(stat.) \pm 22(syst.) \pm 3.0(lum.)pb$

Phys. Rev. D 85 (2012) 112007
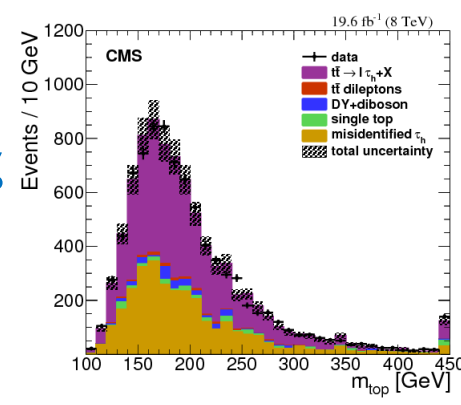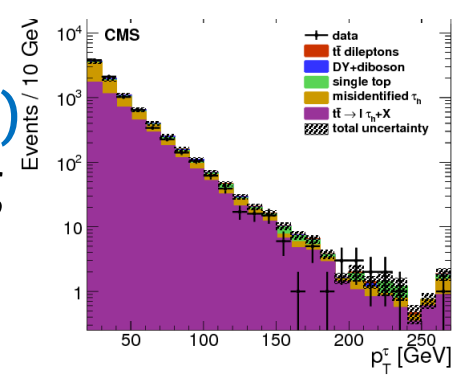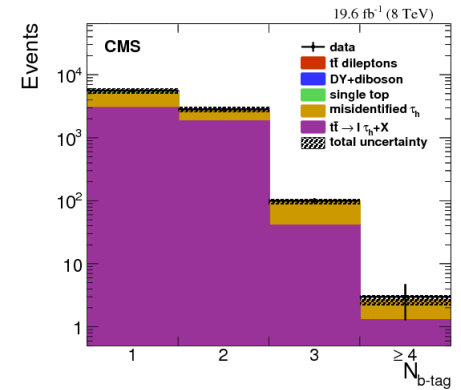
Cross section (inclusive) combination

Most top pair final states investigated

- $\ell(e,\mu,\tau)$+jets, $\ell\ell$ (all but $\tau\tau$)+jets and fully hadronic final states in the combination.
- Highest precision reached in the di-lepton channels
- **All results consistent**

Collider	σ_{tot} [pb]	scales [pb]	pdf [pb]
Tevatron	7.164	+0.110(1.5%) / −0.200(2.8%)	+0.169(2.4%) / −0.122(1.7%)
LHC 7 TeV	172.0	+4.4(2.6%) / −5.8(3.4%)	+4.7(2.7%) / −4.8(2.8%)
LHC 8 TeV	245.8	+6.2(2.5%) / −8.4(3.4%)	+6.2(2.5%) / −6.4(2.6%)
LHC 14 TeV	953.6	+22.7(2.4%) / −33.9(3.6%)	+16.2(1.7%) / −17.8(1.9%)

Combinations performed taking into account correlations between errors
Experimental uncertainty close to 5%
Already challenging the newly available NNLO computations (Current th. errors about 4%)

Javier Cuevas, LHC Days in Split
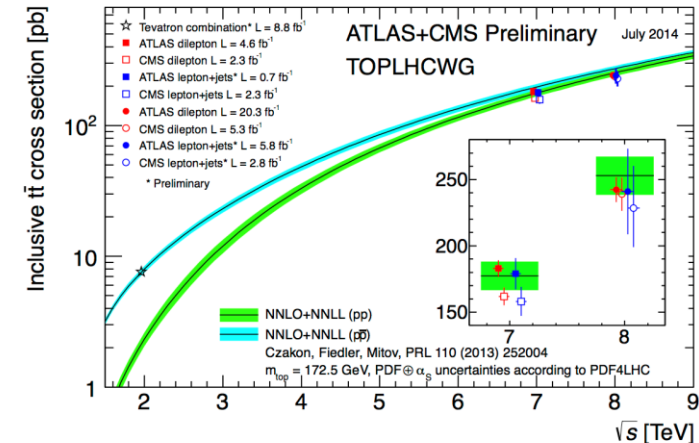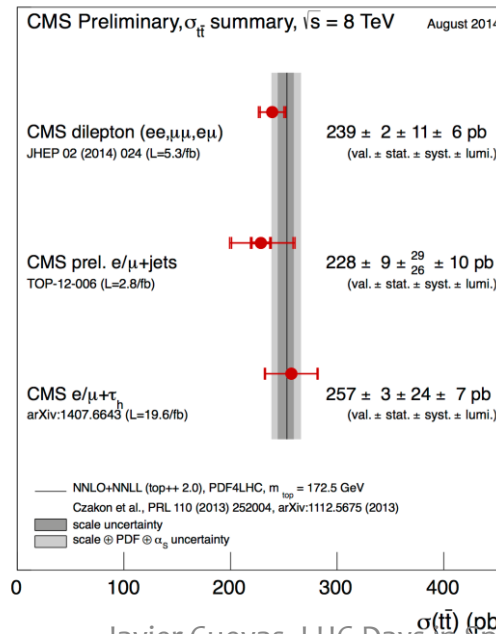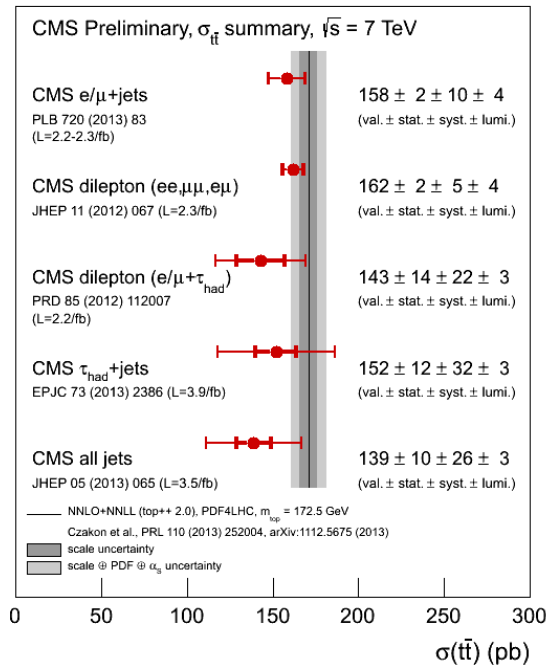
CMS+ATLAS inclusive cross section combination

Summary of measurements of the top-pair production cross-section at 8 TeV compared to the exact NNLO QCD calculation complemented with NNLL resummation (top++2.0). The theory band represents uncertainties due to renormalisation and factorisation scale, parton density functions and the strong coupling. The measurements and the theory calculation is quoted at m_{top}=172.5 GeV
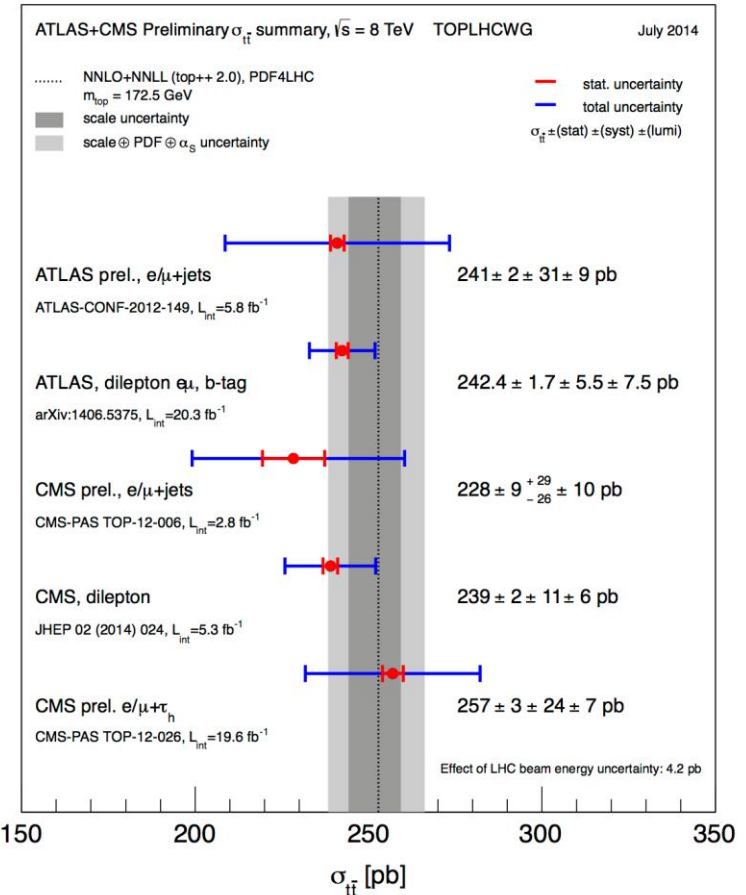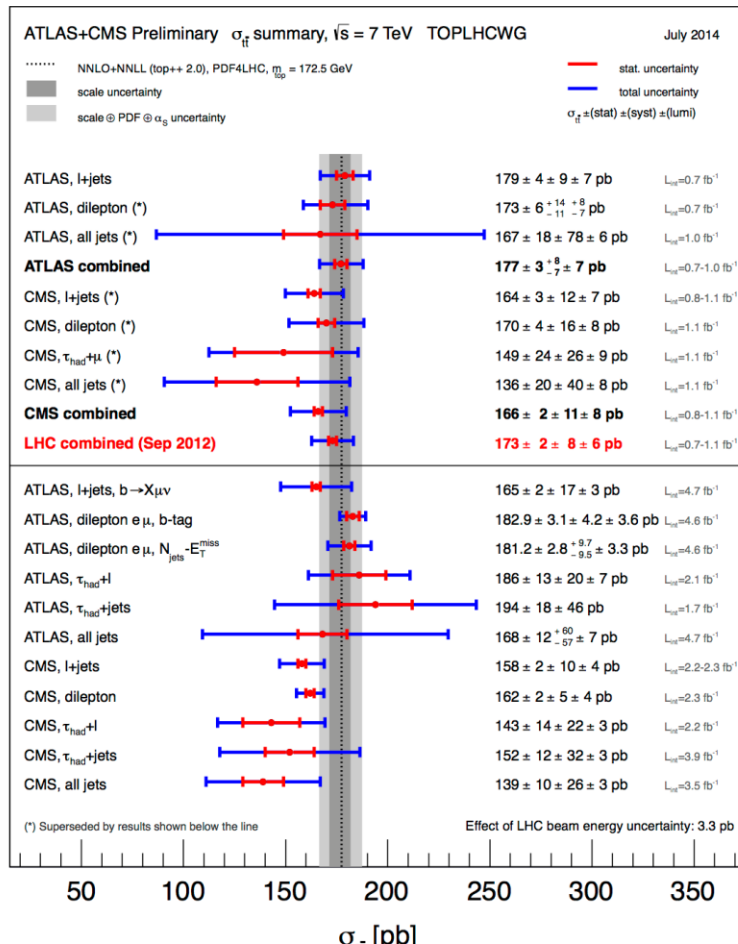
Top pair differential cross sections (7 and 8 TeV)

- Test top physics in different portions of the phase space

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

  - Test of perturbative QCD, constrain of different generators, theory uncertainties, systematic effects. Window to new physics

  - Use unfolding techniques on background-subtracted reconstructed distributions for a direct comparison to theory predictions

  - Propagation of the systematic errors (only shape errors important)

    - Most relevant coming from background knowledge, radiation and hadronization

- Look at lepton, jets, and to more complex variables in top quark final states

  - Need a full reconstruction of top kinematics

  - Compare to reference generators and predictions on differential distribution from theory

Results in agreement with 7 TeV measurement **EPJ C73 (2013) 2339**

p_{Tt} better described by Approx. NNLO prediction

Data start to challenge NLO predictions

Sensitive to resonances and an important background for new searches

$p_T(t)$, ℓ+jets

Javier Cuevas, LHC Days in Split
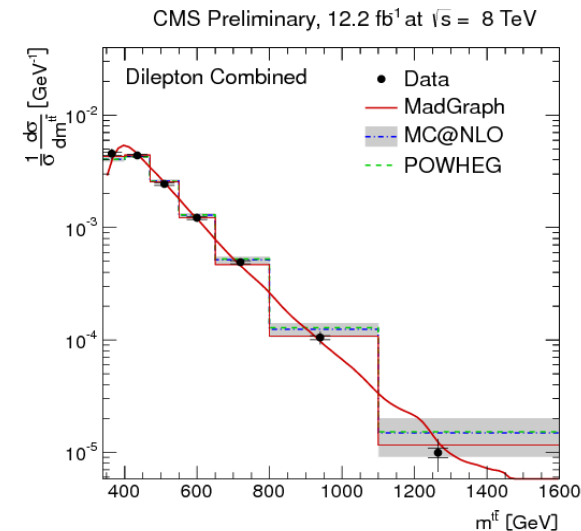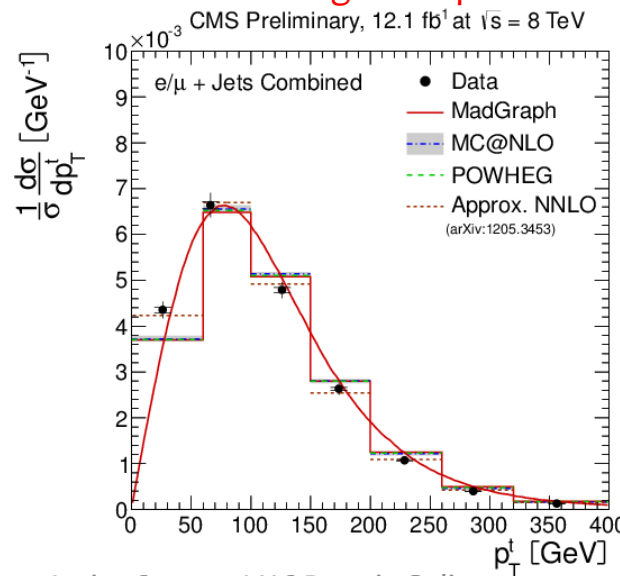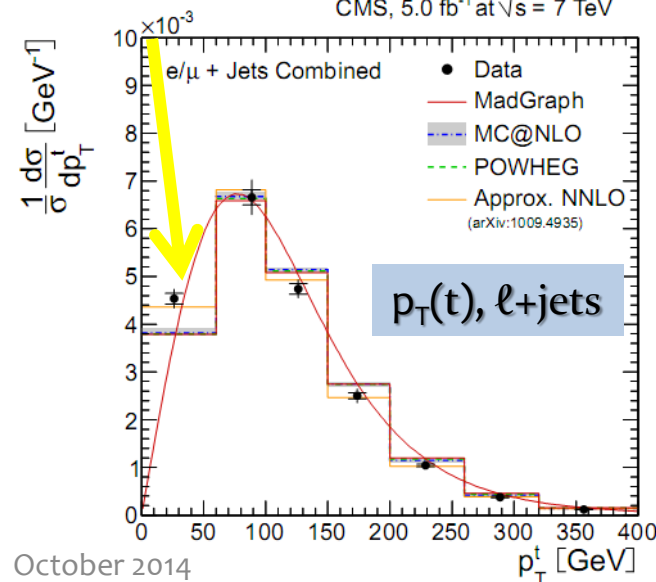
Radiation in top pair production

- At LHC a large fraction of top quark are often produced with extra jets from initial (or final) state radiation
  - Higher energy and high scale of the process
  - Initial state preferentially from gluons (more colour)
- Important to monitor and describe jet production
  - Inclusive jet multiplicities, extra jet p_Ts, ηs,...
  - Constrain generator parameters on radiation
  - Aim also to look for new physics production in tt+jets

CMS, 5.0 fb^{-1} at $\sqrt{s}$ = 7 TeV

$p_T(tt)$, ℓ+jets

- Data
- MadGraph
- MC@NLO
- POWHEG

arXiv:1211:2220
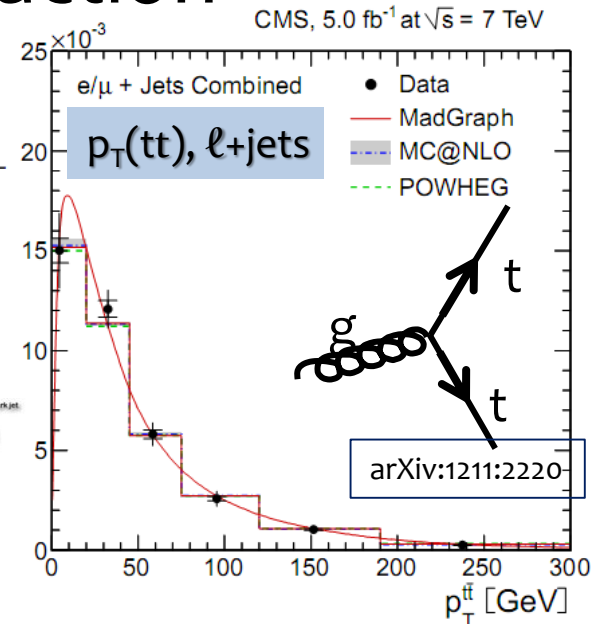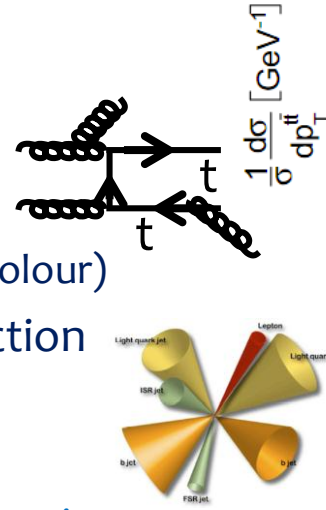
Semileptonic channel: Full 7 TeV dataset, cut and count analysis with data driven BG estimation and bin-by-bin unfolding

CMS-PAS-TOP-12-041

Additional jets defined as those not identified as part of tt system

CMS Preliminary, L=5 fb^1 at $\sqrt{s}$=7 TeV

- Data (combined)
- tt̄ MadGraph+Pythia
- tt̄ MC@NLO+Herwig
- tt̄ POWHEG+Pythia

CMS Preliminary, L=5 fb^1 at $\sqrt{s}$=7 TeV

- Data (combined)
- tt̄ MadGraph+Pythia
- tt̄ MadGraph Q^2 scale up
- tt̄ MadGraph Q^2 scale down
- tt̄ MadGraph match threshold up
- tt̄ MadGraph match threshold down

CMS Preliminary, 19.6 fb^1 $\sqrt{s}$ = 8 TeV

Dilepton Combined p_T^{jet}> 30 GeV

- Data
- MadGraph+Pythia
- MC@NLO+Herwig
- POWHEG+Pythia

CMS Preliminary, 19.6 fb^1 $\sqrt{s}$ = 8 TeV

Dilepton Combined p_T^{jet}> 100 GeV

- Data
- MadGraph+Pythia
- 4*Q^2
- Q^2/4
- Matching up
- Matching down

CMS-PAS-TOP-12-018

Dominant systematics: Jet energy scale (JES), model (Q^2 and Hadronisation)

Extend resultsto higher $p_{T^{jet}}$ thresholds and in $|\eta_{jet}|$ bins
Consistent results with 7 TeV measurement

Associated production of top and bosons at 8 TeV

- Study tt in association with additional leptons

- **Same-sign dilepton** analysis $tt+W$

- **Trilepton** and **Four-lepton** analysis for $tt+Z$ process

- Dominant uncertainty lepton identification

- **Results in agreement with SM predictions**

  $\sigma(\bar{t}tW) = 206 \,_{-23}^{+21}$ *fb.*   arXiv:1204.5678
  $\sigma(\bar{t}t\,Z) = 197 \,_{-25}^{+22}$ *fb.*   arXiv:1208.2665

- **$tt+\gamma$ (8 TeV):**

  – $t\gamma$ -coupling can be studied via $\sigma(tt+\gamma)$
  – Template fit of charged hadron isolation variable in $\mu+jets$ events
  – Discriminate between real and misidentified photons
  – Main uncertainty background modelling

$$\frac{\sigma(t\bar{t}+\gamma)}{\sigma(t\bar{t})} = \left(1.07 \pm 0.07\,(stat.) \pm 0.27\,(syst.)\right) \times 10^{-2}$$

SM prediction

$$\sigma(t\bar{t}+\gamma) = 2.4 \pm 0.2\,(stat.) \pm 0.6\,(syst.)\,pb.$$

$$\sigma(t\bar{t}+\gamma) = 1.8 \pm 0.5\,pb.$$
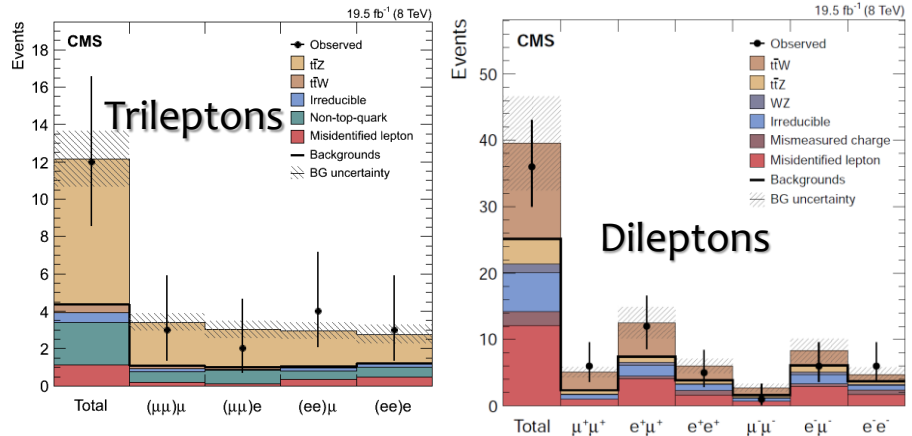
Channels used	Process	Cross section	Significance
2ℓ	$t\bar{t}W$	170_{-80}^{+90} (stat) ± 70 (syst) fb	1.6
$3\ell+4\ell$	$t\bar{t}Z$	200_{-70}^{+80} (stat)$_{-30}^{+40}$ (syst) fb	3.1
$2\ell+3\ell+4\ell$	$t\bar{t}W + t\bar{t}Z$	380_{-90}^{+100} (stat)$_{-70}^{+80}$ (syst) fb	3.7
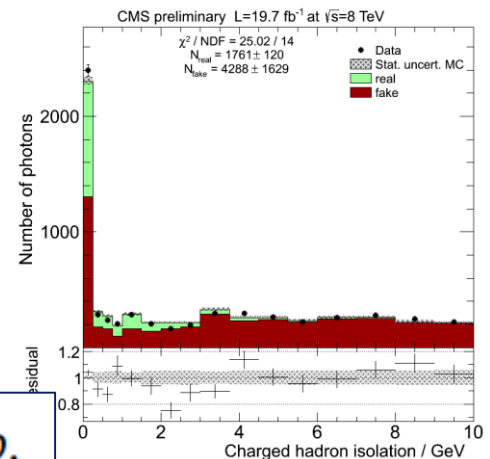
Single top quark production

- **The production cross section gives direct access to the CKM matrix element |V|$_{tb}$**
  - May also test the presence of a possible 4th generation quark
  - Check for presence of FCNC
  - Important background for Higgs searches in associated production W/ZH→qqbb

t-channel   s-channel   tW-channel
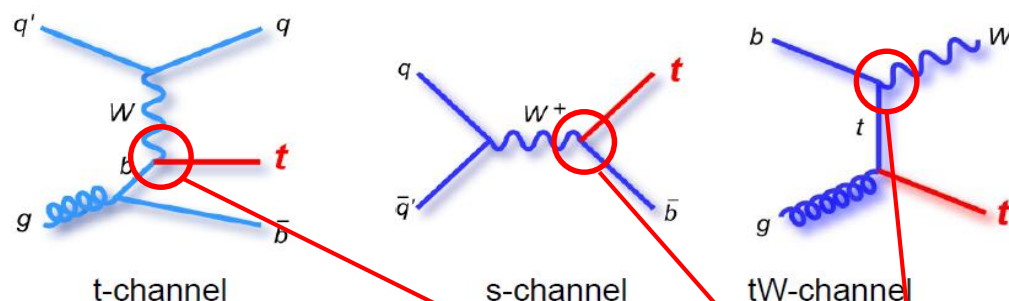
	LHC [pb] $\sqrt{s}=7$ TeV	LHC [pb] $\sqrt{s}=8$ TeV
s-channel	5	6
t-channel	65	87
tW	16	22

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & \mathbf{V_{tb}} \end{pmatrix}$$

Kidonakis, NLO+NNLL
t-channel: PRD 83 (2011) 091503
s-channel: PRD 81 (2010) 054028
tW-channel: PRD 82 (2010) 054018

- **Investigate t-channel and tW production**
  - ➢ s-channel still out of range for an observation
  - ➢ **t-channel:** 1 isolated e or μ, one b-tagged jet, one forward jet, missing E$_T$
  - ➢ **tW channel:** 2 isolated charged leptons (e, μ), one b-tagged jet, missing E$_T$

Kidonakis NNLO arxiv 1311.0283

- **Main backgrounds** from top-pair production (both semileptonic and di-leptonic topologies), Z(ll)/W(lν)+jets, Multijet QCD (reduced to extreme kinematic regions by selection cuts)
  - ➢ Use data whenever possible to constrain the backgrounds

Single top cross sections t-channel

σ(t-ch.,7 TeV)= 67.2 ± 6.1 pb (total)
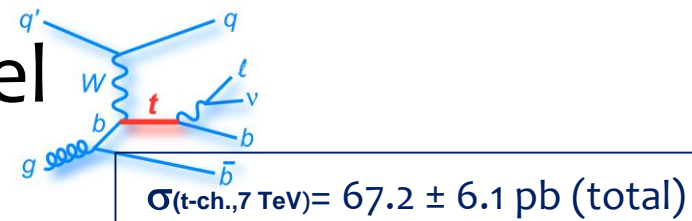
- Robust analysis based on data-driven methods

- Use of multivariate techniques (NN, BDT)
  - Optimize S/B separation using full event properties, constrain systematic effects by simultaneously analyzing signal and background dominated regions

JHEP 12(2012) 035

- Cross sections in agreement with the SM expectations, $|V_{tb}|$ can be derived $|V_{td}|, |V_{ts}| << |V_{tb}|$

$$|V_{\rm tb}| = \sqrt{\frac{\sigma_{t-ch.}}{\sigma^{th}_{t-ch.}}} = 1.020 \pm 0.046\,(\text{exp.}) \pm 0.017\,(\text{theor.})$$

$$0.92 < |V_{\rm tb}| \le 1 \quad @ \text{ 95\% C.L.}$$

JHEP06(2014) 090
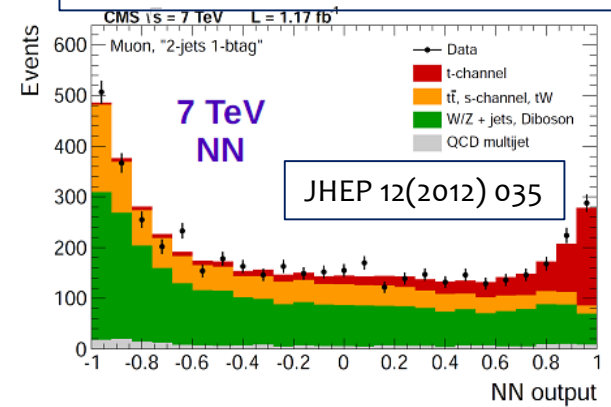
- Analysis ported to 8 TeV (template fit to $|\eta_j|$)
  - fit to the pseudorapidity of the recoil jet in the signal region 130 < m_{top} < 220 GeV
  - **W/Z+jets** and **tt** background shapes are estimated from data (from top mass sidebands and 3 jets 2 b-tags event category, respectively)
  - **QCD multijet** background is fixed with a fit to the W transverse mass (muon channel) / transverse missing energy (electron channel)

f_{LV}, anomalous form factor in the Wtb coupling

$|f_{LV}\,\mathbf{V_{tb}}|$= 0.979 ± 0.045(exp.) ± 0.016(theo.)

$|f_{LV}\,\mathbf{V_{tb}}|$= 0.998 ± 0.038(exp.) ± 0.016(theo.) (7+8 TeV) combined (BLUE)

σ(t-ch.,8 TeV)= 83.6 ± 2.3 (stat) ± 7.4 (syst) pb

Observation of single top **tW** channel

- **tW production observed at LHC for the first time**
  - Interesting topology (background to Higgs->WW searches), only leptonic (e, μ) decays of W considered
  - In the dilepton topology: two isolated leptons, MET and one b-jet, main backgrounds: Top pairs and Z+jets, all other processes easily reducible
  - tW mixing with top pair at NLO: Diagram Removal vs. Diagram Subtraction (DR/DS)

- **BDT based on 13 kinematic input variables chosen based on:**
  - signal/background separation
  - data/MC agreement in several control regions (2j1b, 2j2b, 2j0b,1j0b)
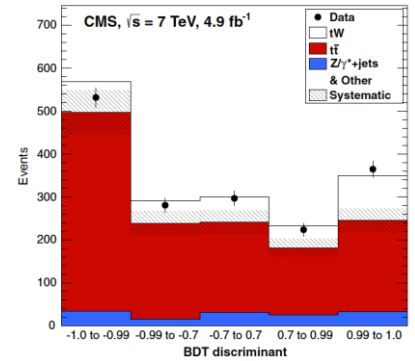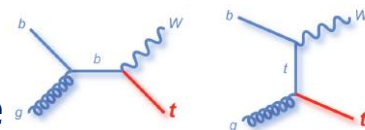
First evidence at 7 TeV
PRL 110, 022003 (2013)

Systematic Uncertainty	$\Delta\sigma$ (pb)	$\frac{\Delta\sigma}{\sigma}$
ME/PS matching thresholds	3.25	14%
Q^2 scale	2.68	11%
Top quark mass	2.28	10%
Statistical	2.13	9%
Luminosity	1.13	5%

the choice of the control regions allows also to constrain b-tag efficiency in situ in the same likelihood fit, and reduce that systematic that would be overwhelming otherwise
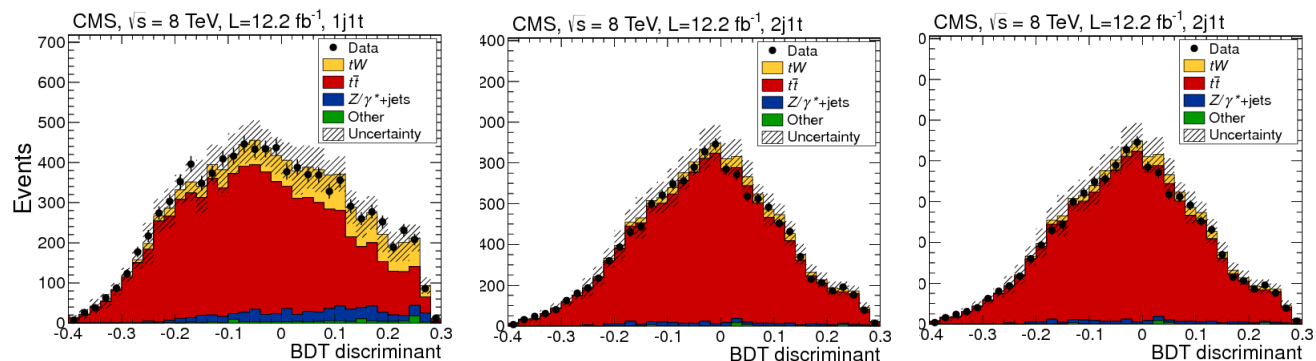
- Observed significance **6.1 σ**/Expected significance: **5.4 ± 1.4σ**.
- Cross-section estimated using profile likelihood: **σ$_{tW}$ = 23.4 ± 5.4 pb at 8TeV**
  - Theoretical value (m$_{top}$=173GeV): σ$_{tW}$ = 22.2 ± 0.6(scale) ±1.4(PDF) pb
- V$_{tb}$ matrix element estimate (|V$_{tb}$|>>|V$_{td}$|,|V$_{ts}$|): $|V_{tb}| = \sqrt{\frac{\sigma_{tW}}{\sigma_{tW}^{th}}} = 1.03 \pm 0.12(exp.) \pm 0.04(th.)$
|V$_{tb}$|>0.78 at 95% C.L. (0≤|V$_{tb}$|²≤1)

PRL 112, 231802 (2014)

Single top cross sections s-channel
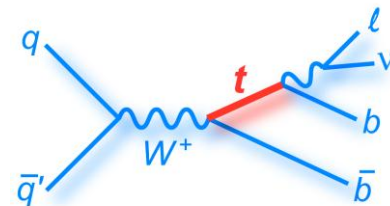
- **Smallest cross section at the LHC** among the single top processes

- **Observation at Tevatron** (March 2014, arXiv:1402.5126); **ATLAS** set an upper limit at 7 TeV of $\sigma_{s\text{-ch.}}$< 26.5 (20.5) pb @ 95% CL (SM expectation: 4.6 pb)
  - **1 muon or electron** p_T^μ > 26 GeV, p_T^e > 30 GeV
  - **2 jets 2 b-tagged** p_T > 40 GeV
  - **additional cuts (tt background rejection)** veto - other jets with pT > 30 GeV

- Choice of b-jet for the top quark reconstruction

- Use of multivariate techniques (BDT)

- **Signal extraction:** binned maximum likelihood fit to th BDT discriminant distribution, simultaneously in the signal region (2j2t) and in the tt enriched control sample (3j2t). tt and W+jets backgrounds constrained in the fit as well.

- **Upper limit:** $\sigma_{s\text{-chan}}$ < 11.5 (17.0, 9.0) pb @ 95% CL,
  $\sigma_{s\text{-channel}}$= 5.55 ±0.08±0.21 pb, SM expectation

- **Main uncertainties:** tt ren./fact. scales (~80%) could be improved with NLO tt generators, JES (~50%)
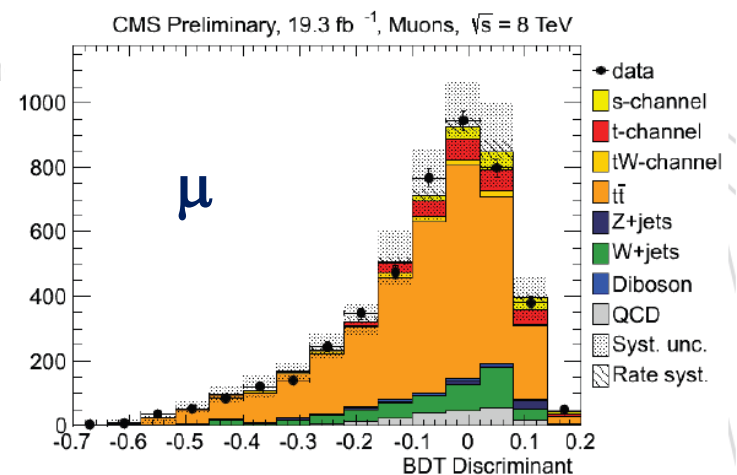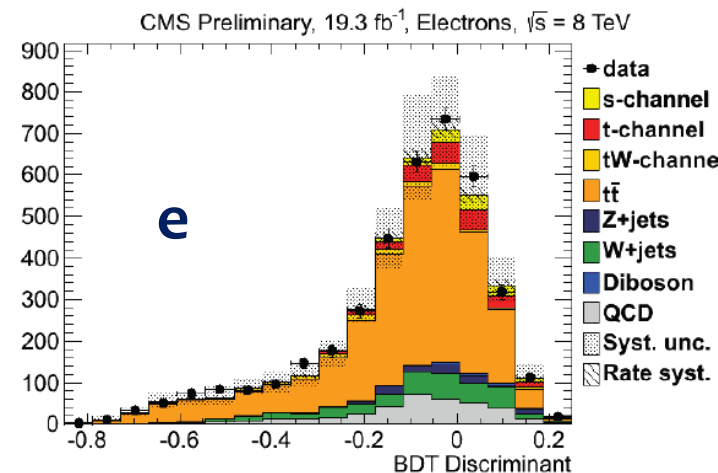
Summary of single top quark measurements

- Charge asymmetry in single top anti-top production,
  - related to u and d parton distribution functions (PDFs), fit to $|\eta_{j'}|$ by lepton charge
    - $R_t = \sigma(t) / \sigma(t)$ sensitive to different PDF models
- Cross section precision measurement: observation established for t-channel and tW associated production
  - $|Vtb|$ precise determination
- s-channel production upper limit

σ_{top} = 53.8 ±1.5(stat) ±4.4(syst) pb
$\sigma_{anti\text{-}top}$= 27.6 ±1.3(stat) ±3.7(syst) pb
R_t = 1.95 ±0.10(stat) ±0.19(syst)

CMS, √s = 8 TeV, L = 19.7 fb⁻¹

CMS
1.95 ± 0.10 (stat.) ± 0.19 (syst.)
ABM11
CT10
CT10w
HERAPDF
MSTW2008
NNPDF 2.3

$R_{t\text{-ch.}} = \sigma_{t\text{-ch.}}(t)/\sigma_{t\text{-ch.}}(\bar{t})$

CMS Preliminary
Single top-quark production

t-channel
tW
s-channel

Approx. NNLO Kidonakis, PRD 83, 091503 (2011)
CMS, JHEP12(2012) 035
CMS, JHEP06(2014) 090
Approx. NNLO Kidonakis, PRD 82, 054018 (2010)
CMS, Phys.Rev.Lett 110, 022003 (2013)
CMS, Phys.Rev.Lett.112, 231802 (2014)
Approx. NNLO Kidonakis, PRD 81, 054028 (2010)
CMS, PAS-TOP-13-009 (FC interval)

$\sqrt{s}$ [TeV]

CMS Preliminary   August 2014

CMS tW, 7 TeV, 4.9 fb⁻¹, PRL110 (2013) 02203
$1.010 ^{+0.160}_{-0.130}$ (exp) $^{+0.030}_{-0.040}$ (th)

CMS tW, 8 TeV, 12.2 fb⁻¹, PRL 112 (2014) 231802
1.030 ± 0.120(exp) ± 0.040(th)

CMS t-ch., 7 TeV, 1.17/1.56 fb⁻¹, JHEP12 (2012) 035
1.029 ± 0.046(exp) ± 0.017(th)

CMS t-ch., 8 TeV, 19.7 fb⁻¹, JHEP06 (2014) 090
0.979 ± 0.045(exp) ± 0.016(th)

CMS t-ch., 7 and 8 TeV combined, JHEP06 (2014) 090
0.998 ± 0.038(exp) ± 0.016(th)

CMS $t\bar{t}$ R_b, 8 TeV, 19.7 fb⁻¹, PLB 736 (2014) 33
1.007 ± 0.016(stat+syst)

$|V_{tb}|$
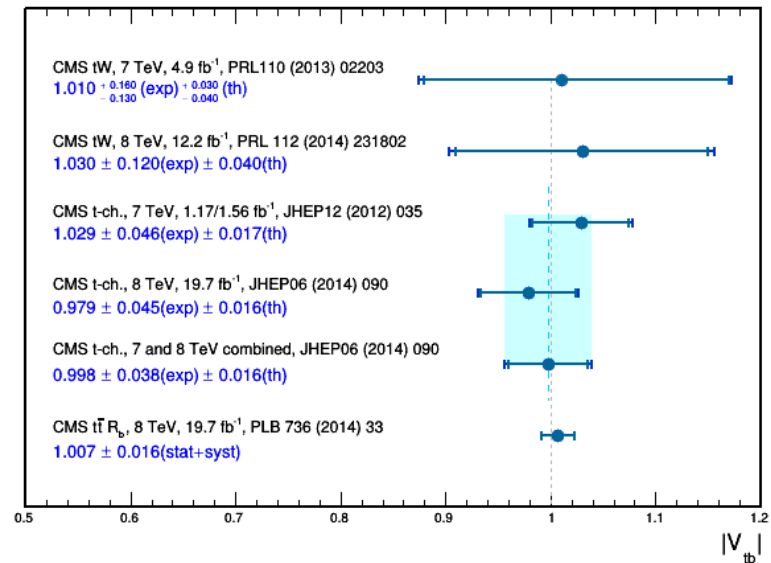
CMS-ATLAS combined results on single top quark measurements
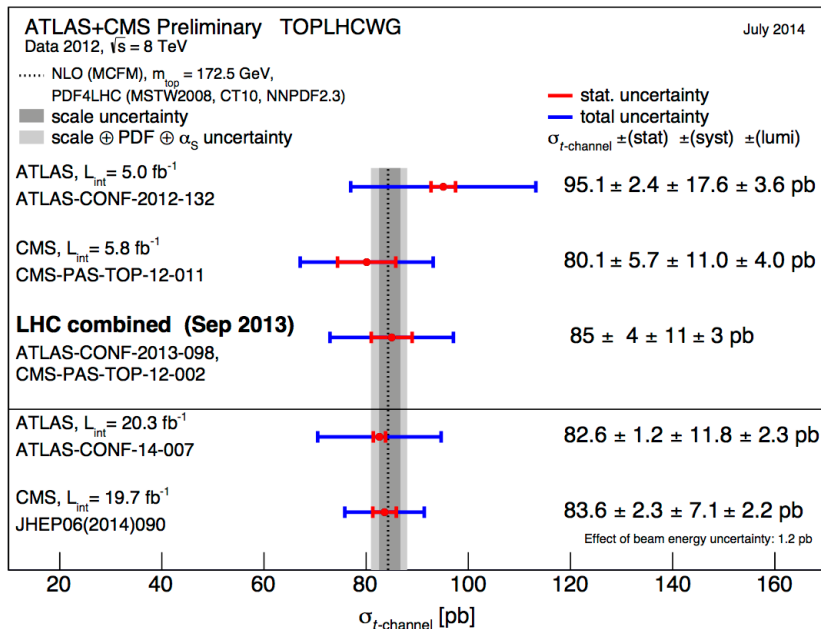
Summary of the ATLAS and CMS Collaboration measurements of the single top production cross-sections in **the t-channel** at 8 TeV. The measurements are compared to a theoretical calculation based on NLO QCD complemented with NNLL resummation computed assuming a top mass of 172.5 GeV.
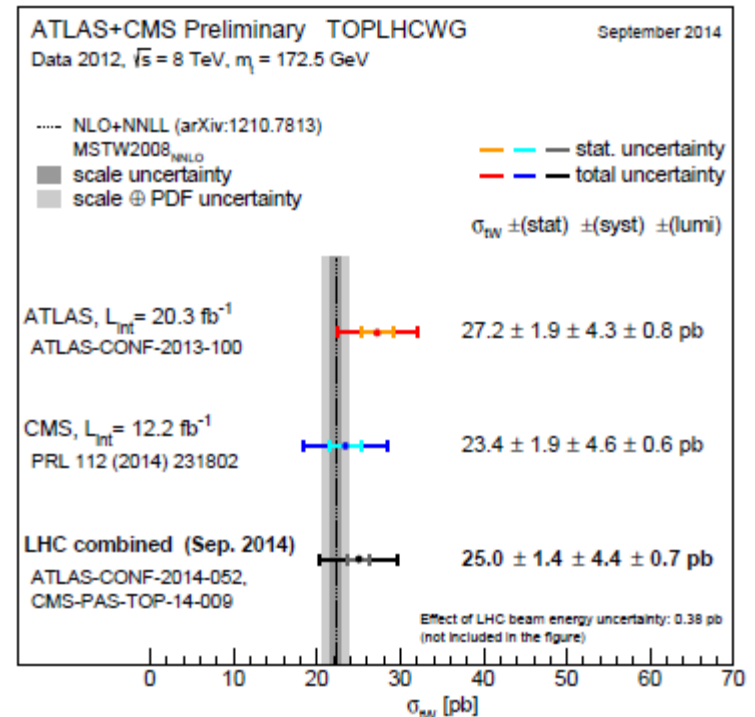
Cross-section measurements for the **associated production of a top quark and a W boson** performed by ATLAS and CMS, and combined result compared with the NLO+NNLL prediction. The uncertainties in the theoretical prediction are represented by dark and light gray bands for renormalisation/factorisation scale and PDF (evaluated using MSTW2008), respectively.

Differential measurement of the cross section of single top-quark production in the t-channel at 8 TeV
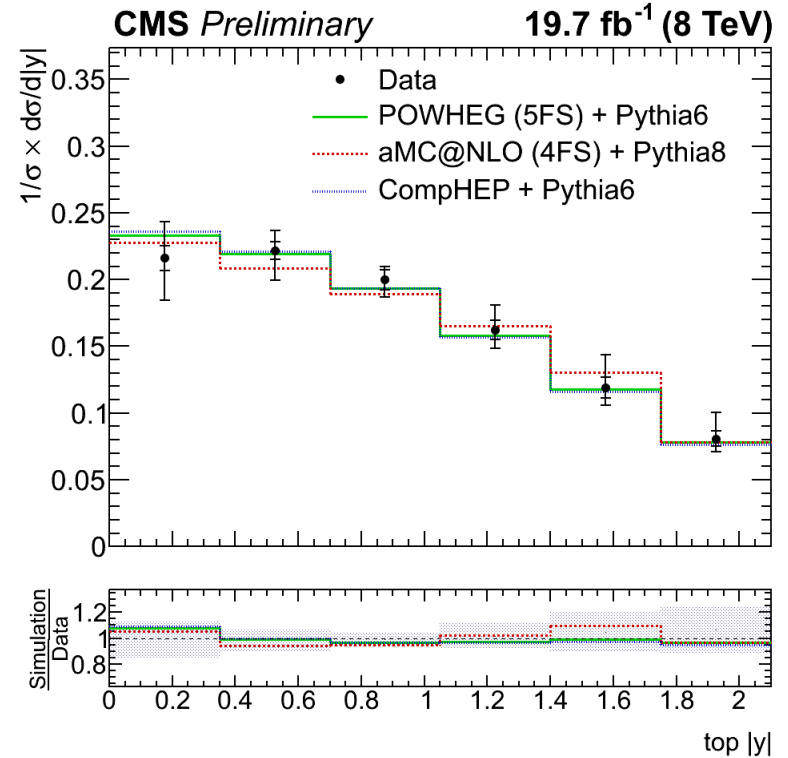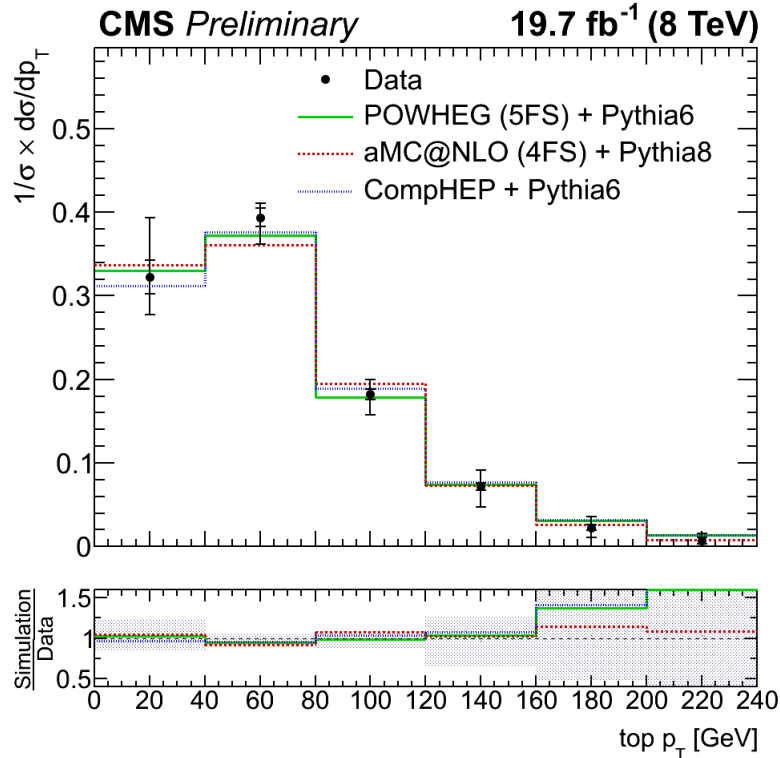
Unfolded pT and abs(y) spectrum of the top quarks in the combined lepton+jets channel compared with the predictions from PowHeg+Pythia (solid), aMC@NLO+Pythia (dotted), and CompHEP (dashed). The inner error bars indicate the statistical uncertainty while the outer error bars indicate the full (stat. + syst.) uncertainty

Ratio: R=B(t→Wb)/B(t→Wq) q=b,s,d

- Extract R from b-tag multiplicity distribution in the dilepton channel
- Key issues : correctly identify b/light-quark jets and its parent top
  - b-tagging efficiency and mistags measured in data
    - correctly identifying b-jets using btag (ε_b, ±~1-3%)
    - accepting light jets passing btag (mistags: ε_q~14%,±~11%)
  - Jet assignment to its parent top:
    - use invariant mass (lepton-jet)
    - normalize at high mass region
- V_{tb} from R assuming 3-family CKM

At 7 TeV
(CMS-PAS-TOP 11-029)
with 2.2 fb^{-1}:
R=0.98±0.04,
R>0.85 @95%CL

CMS simulation, √s = 8 TeV

correct pairs
misassigned pairs

$\sqrt{m_t^2 - m_W^2} \approx 153$ GeV

Lepton-jet invariant mass [GeV]

CMS (unpublished), √s=8 TeV, ∫L dt = 19.7 fb^{-1}

combined
ee
µµ
eµ

$|V_{tb}|$

CMS, √s = 8 TeV, ∫L dt = 19.7 fb^{-1}

- Data
- tt̄
- Single top quark
- Z→ ll (data)
- VV
- W, multijets, other tt̄

ee events   µµ events   eµ events

b-tagged jet multiplicity

ll: 1.014$^{+0.032}_{-0.032}$ CMS TOP-12-035 (2014)

ll: 0.87±0.07 CDF arXiv:140?.3392

lj: 0.94$^{+0.09}_{-0.09}$ CDF PRD 87, 111101 (2014)

lj: 0.95$^{+0.07}_{-0.07}$ DØ PRL 107, 121802 (2011)
ll: 0.86$^{+0.05}_{-0.05}$

lj: 0.97$^{+0.09}_{-0.08}$ DØ PRL 100, 192003 (2008)

lj: 1.03$^{+0.19}_{-0.17}$ DØ PLB 639, 616 (2006)

lj: 1.02$^{+0.31}_{-0.24}$ CDF PRL 95, 102002 (2005)

ll: 1.41$^{+0.49}_{-0.42}$

lj+ll: 0.94$^{+0.31}_{-0.24}$ CDF PRL 86, 3233 (2001)

R=B(t→ Wb)/B(t→ Wq)   95% CL

R=1.014±0.003(stat.)± 0.032 (syst.)
R>0.955 @95 %CL

$V_{tb} > 0.975$ @ 95% CL

PLB 736 (2014) 33

Constraining the SM with the **top mass**

- **The top mass, the W mass and the Higgs mass depend on each other**

- **Direct mass measurement at Tevatron** m(top) = 173.18 ± 0.94 GeV

- **Not an observable, i.e. scheme-dependent**

- Pole-mass: viewing top quark as a free parton

- MS scheme ("running mass"):

- "MC mass": (N)LO+PS yet different from pole or MS mass

- **Colour Reconnection:**
  - Soft interactions not calculable in pQCD
  - Present model uncertainties: 0.5 ... 1 GeV
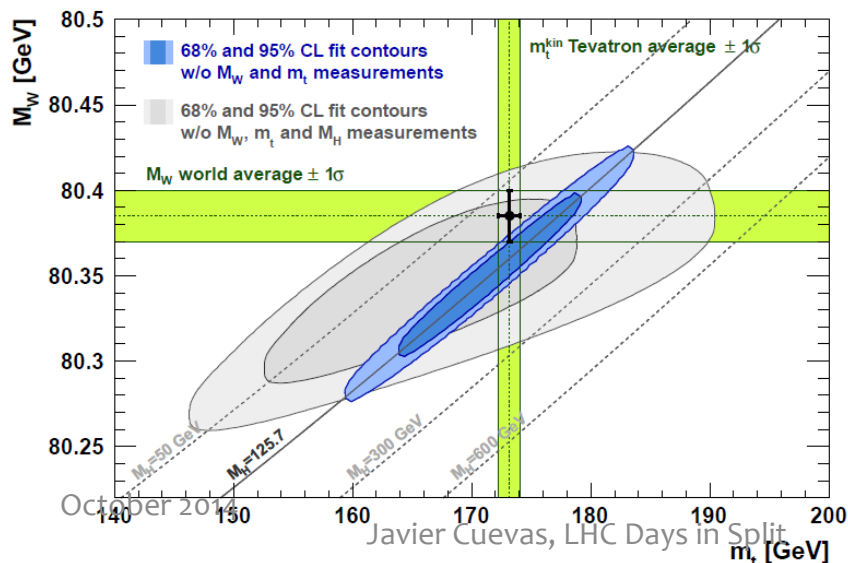
- Direct reconstruction methods
  - ➢ Full reconstruction by resolving the pairing ambiguities (all channels studied)
  - ➢ Use kinematic constrained fitting to improve the mass resolution
    - o Constrain the light jet energy scale in situ by using the W mass constraint
  - ➢ Fit the mass with MC template fits or event by event likelihood fits
    - o Methods very sensitive to the description of radiation and JES uncertainties

- Indirect methods
  - Use the dependence on the top mass on other variables
    - o Top pair cross section
    - o Lepton p_T and end-point methods
    - o Invariant mass of the system J/Ψ+lepton from W
    - o Decay length of the b hadron
  - ➢ Main issue: need of a lot of statistics

Top mass direct reconstruction, ℓ+jets:

- **ℓ+jets**: 90% $t\bar{t}$, 3% W+jets, 4% single top, 3% other

- Kinematic fit:
  - two untagged jets: $m_{jj} = 80.4$ GeV

- lepton and neutrino (MET)
  - $m_{l\nu} = 80.4$ GeV

- combine with two b-tagged jets:
  - $m_{Pjjb1} = m_{l\nu b2}$

- **Ideogram method:**

- fitting JES in situ and constraining radiation from data, simultaneous measurement of the top quark mass and JES
  - no dependence on $m_{t,gen}$

- Dominated by systematic errors
  - Dominant sources are JES and TH uncertainties (scale, color rec.)

- **Single most precise top mass measurement to date at this energy.**

CMS preliminary, 4.7 fb^{-1}, $\sqrt{s}$=7 TeV
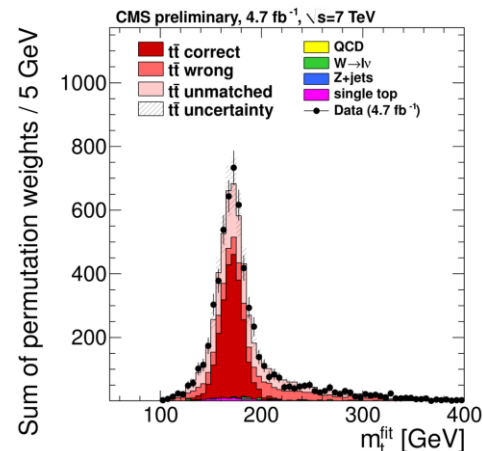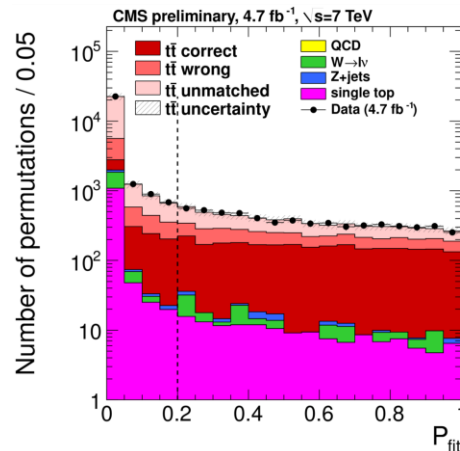
Lepton + Jets	
Systematic Source	Δm_t (Ge
Calibration	0.06
b-JES	0.61
p_T and η dependent JES	0.28
Lepton energy scale	0.02
Missing transverse energy	0.06
Jet energy resolution	0.23
b-tagging	0.12
Pile-up	0.07
Non-$t\bar{t}$ background	0.13
PDF	0.07
μ_R, μ_F	0.24
ME-PS matching threshold	0.18
Underlying event	0.15
Color reconnections	0.54
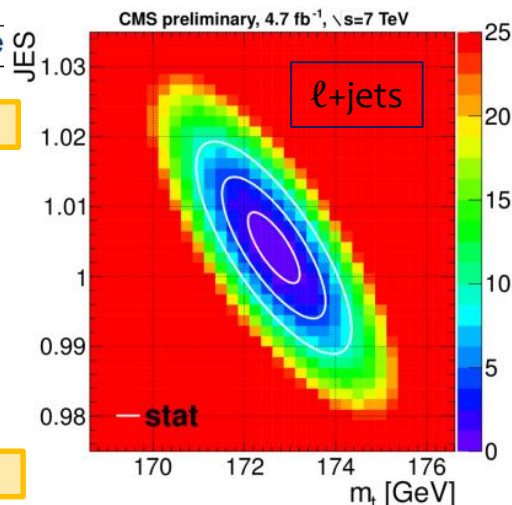
JHEP **12**, 105 (2012)

$m_t = 173.49 \pm 0.43$ (stat.+JES) ± 0.98 (syst.) GeV
JES = 0.994 ± 0.003 (stat.) ± 0.008 (syst.)

Top mass, other channels, 7/8 TeV

Dilepton channel: Analytical Matrix Weighting Technique:

- scan different m_t hypotheses: smear jets and solve kin. equations of tt system, hypothesis with maximum weight -> reconstructed mass
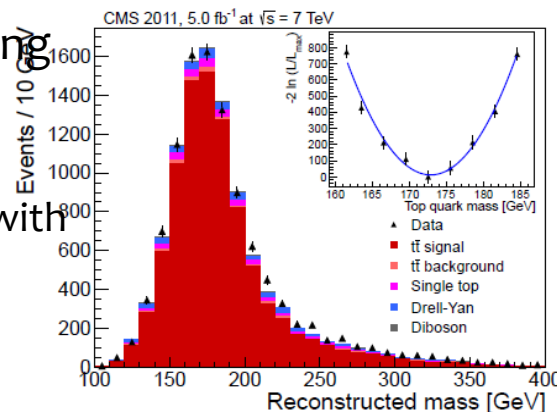
At 7 TeV:

- m_t = 172.5 ± 0.4 (stat.) ± 1.5 (syst.) GeV

At 8 TeV NEW (TOP-14-010):

m_t =172.47 ± 0.17 (stat) ± 1.4 (syst) GeV

All jets channel:

2 x 2 untagged jets: m_{jj} = 80.4 GeV combine with two b-tagged jets: m_{jjb1} = m_{jjb2}

Background modeled by mixing jets from selected data events

- m_t = 173.49 ± 0.69 (stat.) ± 1.21 (syst.) GeV

CMS 2011, 5.0 fb⁻¹ at √s = 7 TeV
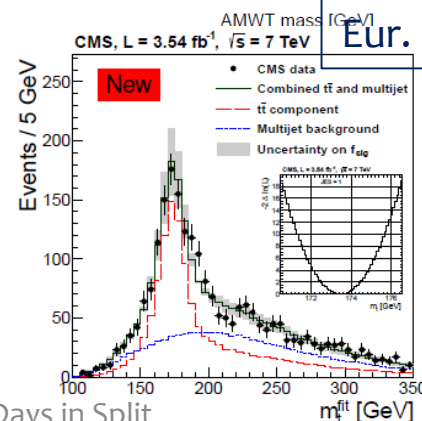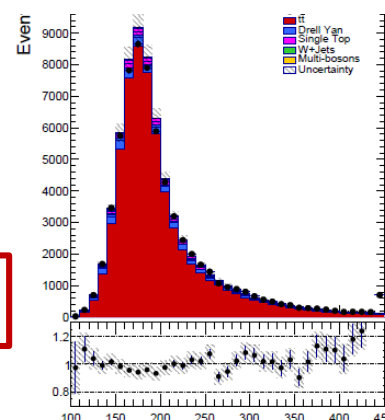
Source	δ_{m_t} (GeV)
Fit calibration	±0.40
Jet energy scale	+0.90 / −0.97
b-JES	+0.76 / −0.66
Lepton energy scale	±0.14
Unclustered E_T	±0.12
Jet energy resolution	±0.14
b-tagging	±0.09
Pileup	±0.11
Background normalization	±0.05
Parton distribution functions	±0.09
μ_R and μ_F scales	±0.55
ME-PS matching threshold	±0.19
Underlying event	±0.26
Color reconnection effects	±0.13
Monte Carlo generator	±0.04
Total	1.48

Source of uncertainty	δm_t(GeV)
Experimental uncertainties	
Fit calibration	0.03
p_T- and η-dependent JES	0.61
Lepton energy scale	0.12
Unclustered E_T	0.07
Jet energy resolution	0.09
b tagging	0.04
Pile-up	0.15
Non-tt background	0.02
Modeling of hadronization	
Flavor-dependent jet energy scale	0.28
b fragmentation	0.67
Semi-leptonic b hadron decays	0.18
Modeling of the hard scattering process	
PDF	0.18
Renormalization and factorization scales	0.87
ME-PS matching threshold	0.13
ME generator	0.37
Modeling of non-perturbative QCD	
Underlying event	0.04
Color reconnection modeling	0.16
Total	1.40

CMS, L = 3.54 fb⁻¹, √s = 7 TeV

	δ_{m_t} (GeV)
Fit calibration	0.13
Jet energy scale	0.97
b-JES	0.49
Jet energy resolution	0.15
b tagging	0.06
Trigger	0.24
Pileup	0.06
Parton distribution functions	0.06
μ_R and μ_F scales	0.22
ME-PS matching threshold	0.24
Underlying event	0.20
Color reconnection effects	0.15
Multijet background	0.13
Total	1.21

Top mass with lepton+jets events, 8TeV
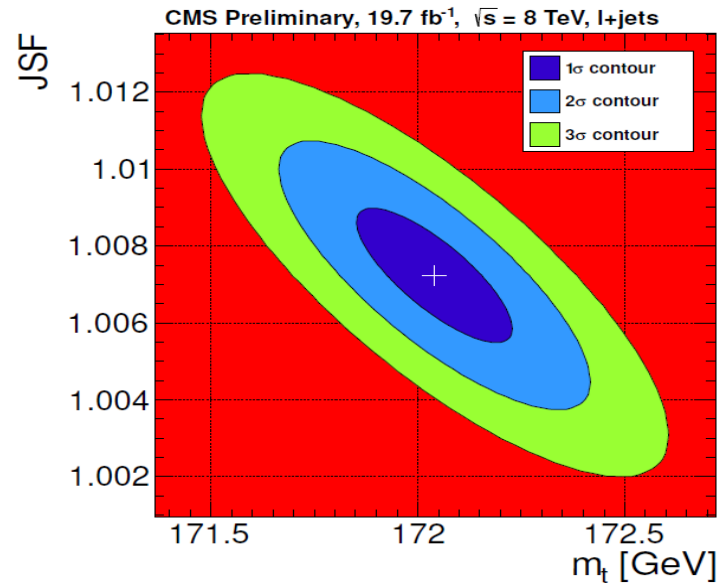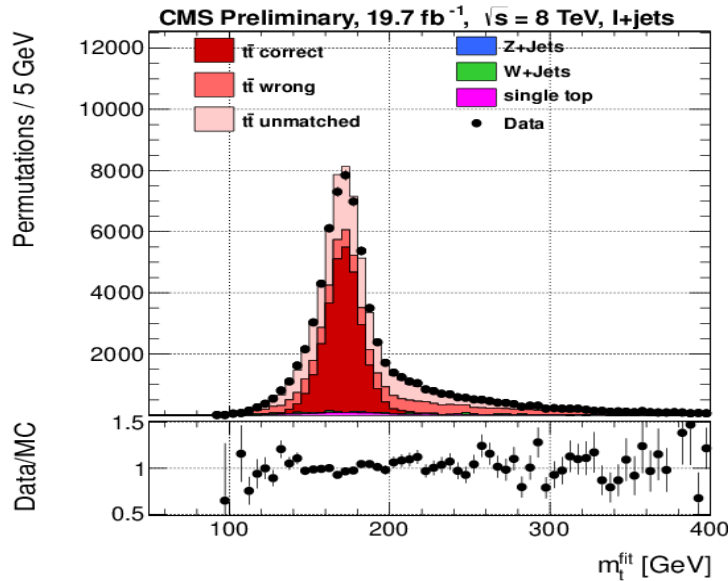
	δm_t^{2D} (GeV)	δJSF	δm_t^{1D} (GeV)
Experimental uncertainties			
Fit calibration	0.10	0.001	0.06
p_T- and η-dependent JES	0.18	0.007	1.17
Lepton energy scale	0.03	<0.001	0.03
MET	0.09	0.001	0.01
Jet energy resolution	0.26	0.004	0.07
b tagging	0.02	<0.001	0.01
Pileup	0.27	0.005	0.17
Non-$t\bar{t}$ background	0.11	0.001	0.01
Modeling of hadronization			
Flavor-dependent JSF	0.41	0.004	0.32
b fragmentation	0.06	0.001	0.04
Semi-leptonic B hadron decays	0.16	<0.001	0.15
Modeling of the hard scattering process			
PDF	0.09	0.001	0.05
Renormalization and factorization scales	0.12±0.13	0.004±0.001	0.25±0.08
ME-PS matching threshold	0.15±0.13	0.003±0.001	0.07±0.08
ME generator	0.23±0.14	0.003±0.001	0.20±0.08
Modeling of non-perturbative QCD			
Underlying event	0.14±0.17	0.002±0.002	0.06±0.10
Color reconnection modeling	0.08±0.15	0.002±0.001	0.07±0.09
Total	0.75	0.012	1.29

$$m_t = 172.04 \pm 0.19\,(\text{stat.+JSF}) \pm 0.75\,(\text{syst.})\ \text{GeV},$$
$$\text{JSF} = 1.007 \pm 0.002\,(\text{stat.}) \pm 0.012\,(\text{syst.}).$$

σ_{tot} = 0.77 GeV

2D fit uncertainty comparable to world average

1D m_t =172.66 ± 0.11 (stat) ± 1.29 (syst) GeV

Top mass all hadronic, 8TeV

CMS Preliminary, 18.2 fb⁻¹, √s = 8 TeV

√s = 8 TeV — 1σ contour, 2σ contour, 3σ contour

	δm_t^{2D} (GeV)	δJSF	δm_t^{1D} (GeV)
Experimental uncertainties			
Fit calibration	0.06	<0.001	0.06
p_T- and η-dependent JES	0.28	0.006	0.86
Jet energy resolution	0.10	0.001	0.01
b tagging	0.02	<0.001	<0.01
Pileup	0.31	0.001	0.30
Calorimeter JES of trigger confirmation	0.18	0.003	0.07
Non-$t\bar{t}$ background	0.22	0.002	0.08
Modeling of hadronization			
Flavor-dependent JSF	0.36	0.004	0.30
b fragmentation	0.07	0.001	0.03
Semi-leptonic B hadron decays	0.12	<0.001	0.12
Modeling of the hard scattering process			
PDF	0.02	<0.001	0.01
Renormalization and factorization scales	0.19±0.19	0.004±0.002	0.18±0.14
ME-PS matching threshold	0.20±0.19	0.002±0.002	0.09±0.14
ME generator	0.09±0.21	0.003±0.002	0.17±0.15
Modeling of non-perturbative QCD			
Underlying event	0.13±0.28	0.000±0.002	0.11±0.20
Color reconnection modeling	0.00±0.25	0.000±0.002	0.03±0.18
Total	0.83	0.011	1.05

all-hadronic channel competitive with lepton+jets channel
high statistics → tighter selecti[on]
no neutrinos in final state
full kinematics available

2D m$_t$ =172.08 ± 0.36 (stat+JSF) ± 0.83 (syst) GeV
JSF = 1.007 ± 0.003 (stat) ± 0.011 (syst)

1D m$_t$ =172.59 ± 0.27 (stat) ± 1.05 (syst) GeV

CMS m$_{top}$ combination

- **BLUE combination of CMS top quark mass measurements:**
  - 2010,2011,2012 data samples
  - dilepton,lepton+jets,all-hadronic
  - most systematics taken as fully correlated
    - data-driven determinations taken as correlated for same data samples, uncorrelated for different years
  - *in situ* JSF taken as uncorrelated
  - $\chi 2$=4.1/5 d.o.f. (54% C.L.)

- **CMS Combination March 2014:**

  m$_t$ =172.22 ± 0.14 (stat) ± 0.72 (syst) GeV

- improves CMS 7 TeV (EPJC 74 (2014) 2758) combination by ~25%
  - all-hadronic 8 TeV result not yet included

CMS Preliminary

CMS 2010, dilepton JHEP 07 (2011) 049, 36 pb^{-1}	175.5 ± 4.6 ± 4.6 GeV (value ± stat ± syst)
CMS 2010, lepton+jets PAS TOP-10-009, 36 pb^{-1}	173.1 ± 2.1 ± 2.6 GeV (value ± stat ± syst)
CMS 2011, dilepton EPJC 72 (2012) 2202, 5.0 fb^{-1}	172.5 ± 0.4 ± 1.4 GeV (value ± stat ± syst)
CMS 2011, lepton+jets JHEP 12 (2012) 105, 5.0 fb^{-1}	173.5 ± 0.4 ± 1.0 GeV (value ± stat ± syst)
CMS 2011, all-hadronic arXiv:1307.4617, 3.5 fb^{-1}	173.5 ± 0.7 ± 1.2 GeV (value ± stat ± syst)
CMS 2012, lepton+jets PAS TOP-14-001, 19.7 fb^{-1}	172.0 ± 0.2 ± 0.8 GeV (value ± stat ± syst)
CMS combination March 2014	172.2 ± 0.1 ± 0.7 GeV (value ± stat ± syst)
CMS 2012, all-hadronic PAS TOP-14-002, 19.7 fb^{-1}	172.1 ± 0.4 ± 0.8 GeV (value ± stat ± syst)
Tevatron combination (2014) arXiv:1407.2682	174.3 ± 0.4 ± 0.5 GeV (value ± stat ± syst)
World combination 2014 ATLAS, CDF, CMS, D0	173.3 ± 0.3 ± 0.7 GeV (value ± stat ± syst)

CMS, √s = 7 TeV

CMS 2010, dilepton JHEP 07 (2011) 049, L=36 pb^{-1}	175.50 ± 4.60 ± 4.52 GeV (value ± stat ± syst)
CMS 2011, dilepton EPJC 72 (2012) 2202, L=5.0 fb^{-1}	172.50 ± 0.43 ± 1.48 GeV (value ± stat ± syst)
CMS 2011, lepton+jets JHEP 12 (2012) 105, L=5.0 fb^{-1}	173.49 ± 0.27 ± 1.03 GeV (value ± stat ± syst)
CMS 2011 all-jets This analysis, L=3.54 fb^{-1}	173.49 ± 0.69 ± 1.21 GeV (value ± stat ± syst)
CMS combination up to L=5.0 fb^{-1}	173.54 ± 0.33 ± 0.96 GeV (value ± stat ± syst)
Tevatron combination Phys. Rev. D 86 (2012) 092003, up to L=5.8 fb^{-1}	173.18 ± 0.56 ± 0.75 GeV (value ± stat ± syst)

165   170   175   180   185
m [GeV]

CMS Combination (Sep-14) CMS-PAS-TOP-14-015

19.7 fb⁻¹ (8 TeV) + 5.1 fb⁻¹ (7 TeV)

CMS Preliminary

Measurement	Value
CMS 2010, dilepton JHEP 07 (2011) 049, 36 pb⁻¹	$175.5 \pm 4.6 \pm 4.6$ GeV (value ± stat ± syst)
CMS 2010, lepton+jets PAS TOP-10-009, 36 pb⁻¹	$173.1 \pm 2.1 \pm 2.6$ GeV (value ± stat ± syst)
CMS 2011, dilepton EPJC 72 (2012) 2202, 5.0 fb⁻¹	$172.5 \pm 0.4 \pm 1.4$ GeV (value ± stat ± syst)
CMS 2011, lepton+jets JHEP 12 (2012) 105, 5.0 fb⁻¹	$173.5 \pm 0.4 \pm 1.0$ GeV (value ± stat ± syst)
CMS 2011, all-hadronic EPJ C74 (2014) 2758, 3.5 fb⁻¹	$173.5 \pm 0.7 \pm 1.2$ GeV (value ± stat ± syst)
CMS 2012, lepton+jets PAS TOP-14-001, 19.7 fb⁻¹	$172.0 \pm 0.1 \pm 0.7$ GeV (value ± stat ± syst)
CMS 2012, all-hadronic PAS TOP-14-002, 18.2 fb⁻¹	$172.1 \pm 0.3 \pm 0.8$ GeV (value ± stat ± syst)
CMS 2012, dilepton PAS TOP-14-010, 19.7 fb⁻¹	$172.5 \pm 0.2 \pm 1.4$ GeV (value ± stat ± syst)
CMS combination September 2014	$172.38 \pm 0.10 \pm 0.65$ GeV (value ± stat ± syst)
Tevatron combination July 2014 arXiv:1407.2682	$174.34 \pm 0.37 \pm 0.52$ GeV (value ± stat ± syst)
World combination March 2014 ATLAS, CDF, CMS, D0	$173.34 \pm 0.27 \pm 0.71$ GeV (value ± stat ± syst)

m_t [GeV]

19.7 fb⁻¹ (8 TeV) + 5.1 fb⁻¹ (7 TeV)

CMS Preliminary

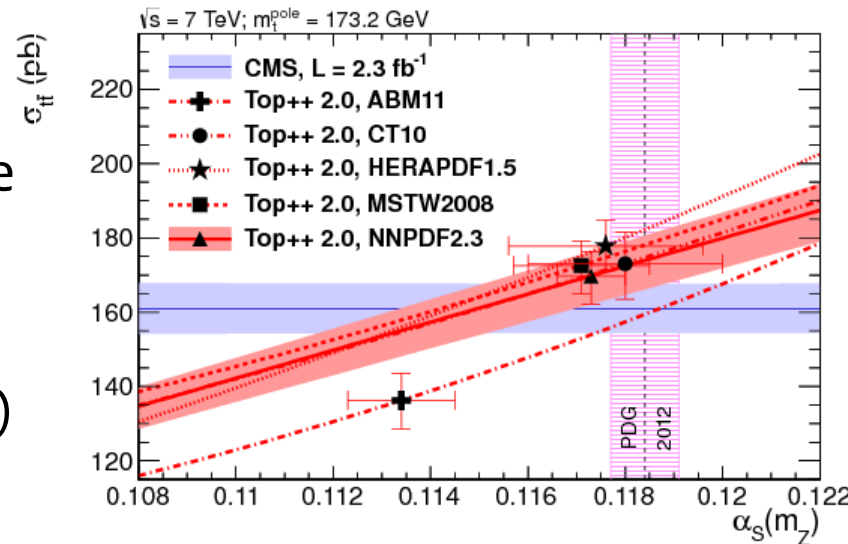| Measurement	Value
CMS combination, dilepton September 2014	$172.51 \pm 0.22 \pm 1.14$ GeV (value ± stat ± syst)
CMS combination, lepton+jets September 2014	$172.38 \pm 0.11 \pm 0.70$ GeV (value ± stat ± syst)
CMS combination, all-hadronic September 2014	$172.40 \pm 0.26 \pm 0.79$ GeV (value ± stat ± syst)
CMS combination September 2014	$172.38 \pm 0.10 \pm 0.65$ GeV (value ± stat ± syst)
Tevatron combination July 2014 arXiv:1407.2682	$174.34 \pm 0.37 \pm 0.52$ GeV (value ± stat ± syst)
World combination March 2014 ATLAS, CDF, CMS, D0	$173.34 \pm 0.27 \pm 0.71$ GeV (value ± stat ± syst)

m_t [GeV]

CMS top-quark mass, RUN I full statistics
m_t =172.38 ± 0.10 (stat) ± 0.66 (syst) GeV

$\alpha_S(m_Z)$ and m_t^{pole} extraction from $\sigma(t\bar{t})$ at 7 TeV

- Cross section prediction depends on α_S and m_t^{pole}
  - Turning this into measurements
- Constrain either α_S or m_t^{pole} and measure the other one
  - m_t^{pole}= 173.2 ± 1.4 GeV (Tevatron average)
  - $\alpha_S(m_Z)$ = 0.1184 ± 0.0007 (world average)
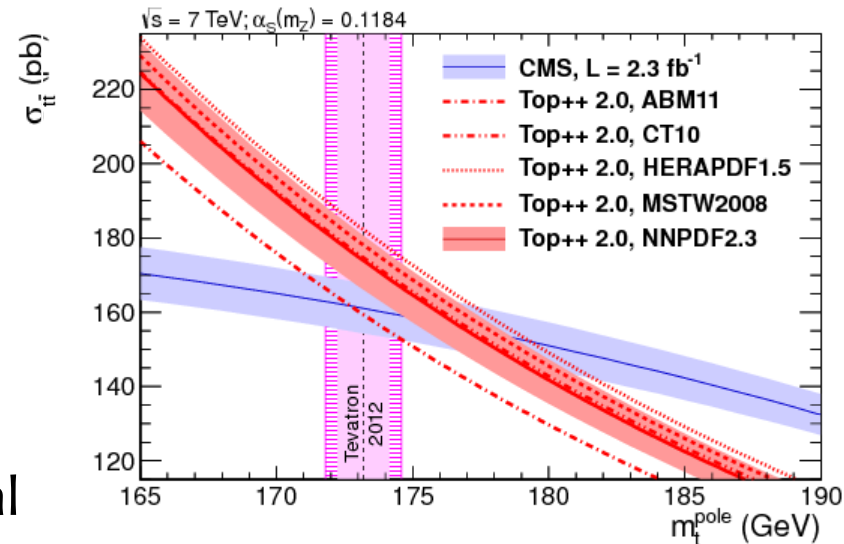 - Using the most precise CMS σ_{tt} measurement (dilepton)
- Compare to **NNLO** predictions as function m_t^{pole} or α_S
- Most probable result from joint likelihood theory $\otimes$ experiment (using NNPDF2.3)

  m_t^{pole} = 176.7 $^{+3.0}_{-2.8}$ GeV

- First determination of α_S from σ_{tt}:

  $\alpha_S(m_Z)$ = 0.1151 $^{+0.0028}_{-0.0027}$

- High precision due to small experimental uncertainty and available **NNLO predictions**

m_t^{obs} and event kinematics

- Measure m_t^{1D}, m_t^{2D}, JES (stat syst) in bins of kinematic variables
  - Results for 14 kinematic variables
  - First binned m_t^{obs} measurement
  - Good agreement between Data and 'standard' MadGraph TuneZ2
  - m_t^{obs} not heavily affected by diferent tunes / generators
  - Precision does not yet allow to distinguish between different models
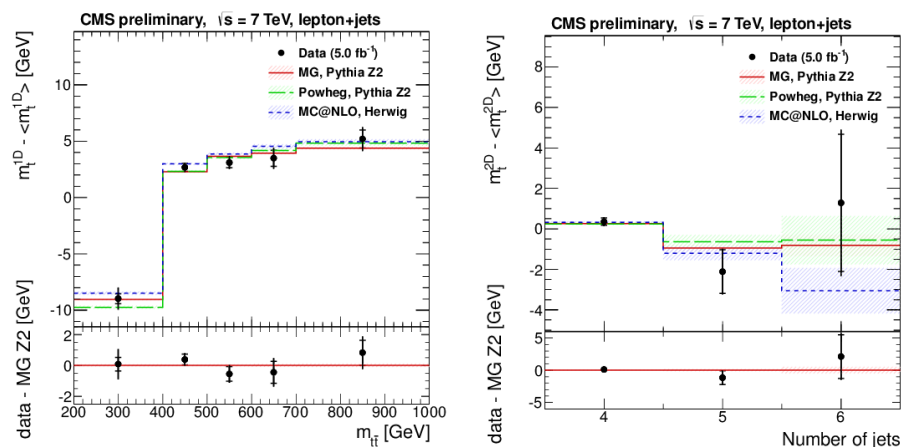
- $m_t^{endpoint}$ via kinematic endpoints
  - M_{T2}-type variables designed to measure SUSY masses via endpoints.
  - Exploit analytic relations between $M_{T2}^{endpoint}$ and underlying masses
  - Independent of assumptions on shapes, measurement independent of m_t^{MC}
  - Doubly-constrained fit ($m_\nu = 0$, $m_W = 80.4$ GeV)
    - $m_t^{endpoint} = 173.9 \pm 0.9(stat)\ ^{+1.6}_{-2.0}$ (syst) GeV
    - In agreement with other measurements
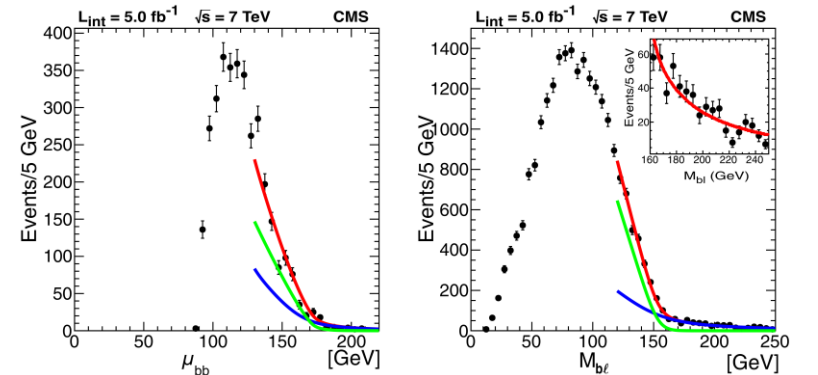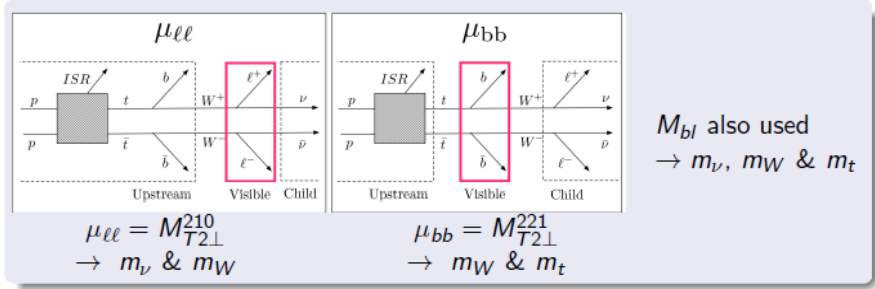
- m_t^{MC} via b-hadron lifetime

  - Diferent sensitivity to systematics, Decay length $L_{b\text{-hadron}}$ correlated with m_t Use Lxy : transverse decay length of secondary vertex (same as in CDF)

$m_t^{MC} = 173.5 \pm 1.5(stat) \pm 1.3$ (syst) ± 2.6 (p_T^{top}) GeV

Top polarization and spin correlations

- The decay time of the top is short so that the decay products should contain information about the spin of the top quark. Can be measured from angular distributions of the top decay products

  - A: correlation strength at production

  - α_i: amount of spin information from each probe

  - Measuring the difference in the azimuthal angle between the leptons in the lab frame gives information about spin correlation

    - Just the lepton information is needed

    - No full reconstruction and associated error!

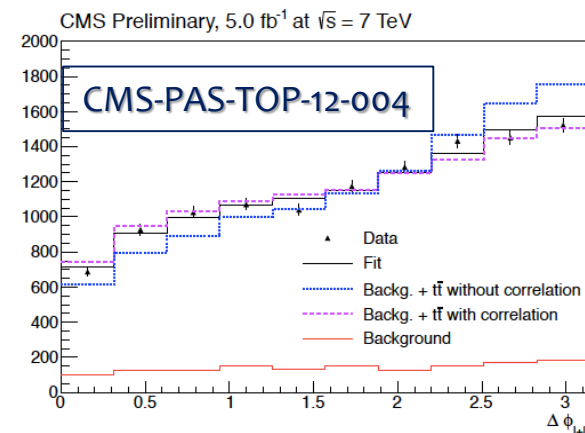   - Compared with the SM expectation $A^{SM}_{hel} = 0.31$

- Similarly the polarization of the top quark can be measured with the daughter particles

$$\frac{1}{\Gamma}\frac{d\Gamma}{\cos\theta_{l,n}} = \frac{1}{2}\left(1 + 2\alpha_l P_n \cos\theta_{l,n}\right) \quad P_n = \frac{N(\cos(\theta_l^+) > 0) - N(\cos(\theta_l^+) < 0)}{N(\cos(\theta_l^+) > 0) + N(\cos(\theta_l^+) < 0)}$$
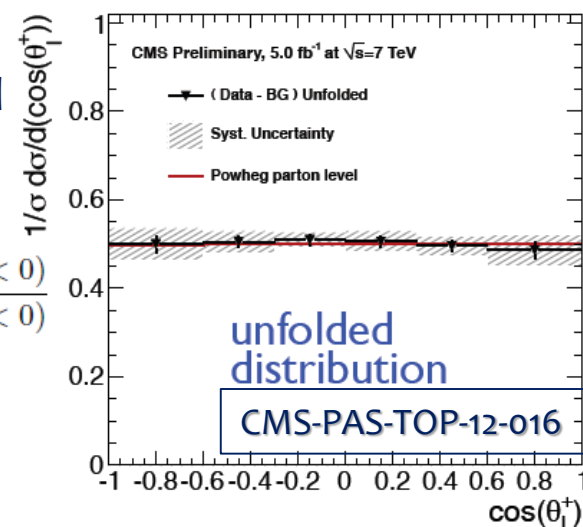
- From QCD, top pairs unpolarized, but EWK corrections provide small polarization that is **enhanced by new physics**

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_1\, d\cos\theta_2} = \frac{1}{4}\left(1 - C\cos\theta_1\cos\theta_2\right)$$
$$\text{where } C = A\,\alpha_1\,\alpha_2$$

CMS Preliminary, 5.0 fb⁻¹ at √s = 7 TeV

CMS-PAS-TOP-12-004

Data
Fit
Backg. + t̄t without correlation
Backg. + t̄t with correlation
Background

$A^{meas}_{hel} = 0.24 \pm 0.02(stat.) \pm 0.08(syst)$

CMS Preliminary, 5.0 fb⁻¹ at √s=7 TeV
(Data - BG) Unfolded
Syst. Uncertainty
Powheg parton level

unfolded distribution

CMS-PAS-TOP-12-016

$P_n = 0.009 \pm 0.029(stat) \pm 0.041(syst)$

Summary

- **Top quark physics is a pillar of the current research program in HEP**

- **The CMS collaboration covers a wide range of top-related topics**

- Key to QCD, electro-weak and New Physics
  - ➢ Ideal probe for constraining (directly + indirectly) the symmetry breaking of the SM
    - o The top is way heavy → the Higgs scalar mostly couples to tops
  - ➢ Ideal probe for looking for new physics beyond the model itself
    - o Via precision measurements
    - o Via direct searches for new signals

- Results in agreement with SM predictions
  - ➢ No hints of new physics
  - ➢ Precision regime: $\sigma_{tt} < 5\%$, m(top) $\lesssim 1$ GeV, …
    - ➢ Inclusive cross section prediction available up to full NNLO, same precision as data
- ➢ New top processes might be accessible with collisions at 13 TeV in the Run II of the LHC
  - ➢ High precision at higher energy and luminosity