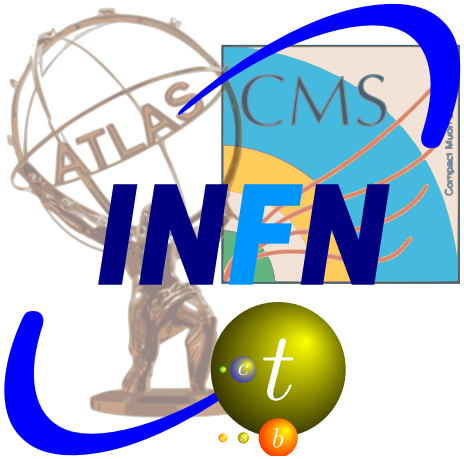
Top Results from ATLAS and CMS

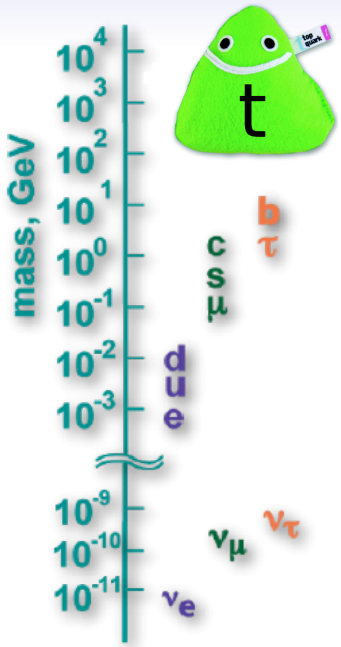


Michele Pinamonti [1] **(ATLAS), Luca Lista** [2] **(CMS)**

1: SISSA Trieste & INFN Udine
2: INFN Napoli

IFAE2013 - Cagliari - April 3-5, 2013

Top Quark @ LHC



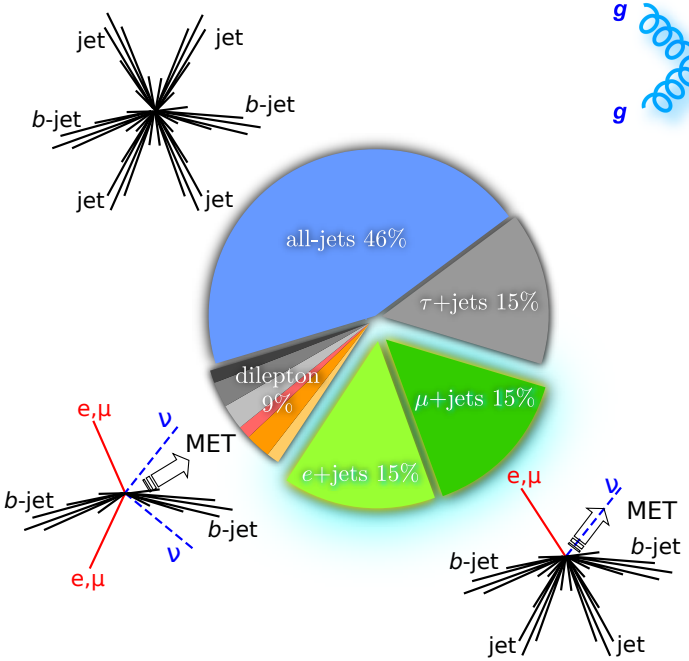
Why is top quark interesting?

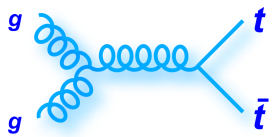
- Huge mass ($\sim$ 40 larger than b quark, $y_t \sim 1$, large coupling to Higgs)
- Plays a role in SM in loop diagrams (check consistency of SM)
- Decays before hadronisation (can study a "free quark")
- Important background for SM (e.g. Higgs) and beyond SM
- Decay product of many "new particles" (e.g. Z' boson, SUSY $\tilde{t}$)
- Can decay into "new particles" (e.g. light H^+)

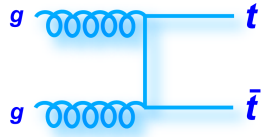
At ATLAS and CMS:

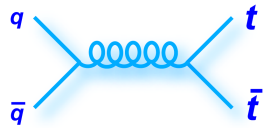
- 5 fb^{-1} @ 7 TeV + 20 fb^{-1} @ 8 TeV per experiment
- 5'600'000 $t\bar{t}$ pairs (vs. 70'000 @ Tevatron)
- 2'700'000 single-t events

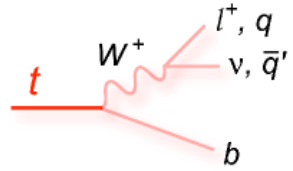
$t\bar{t}$ at the LHC











Backgrounds:

- QCD multi-jets (all-hadronic)
- Z + jets (dilepton)
- W + jets (ℓ+jets)
- single-t

Signal signature(s):

- Triggering lepton and/or multi-jets
- Up to two high p_T leptons
- Missing transverse energy $\not{E}_T$ (ℓ+jets, dilep.)
- 2-6 high p_T jets (2 b-jets)

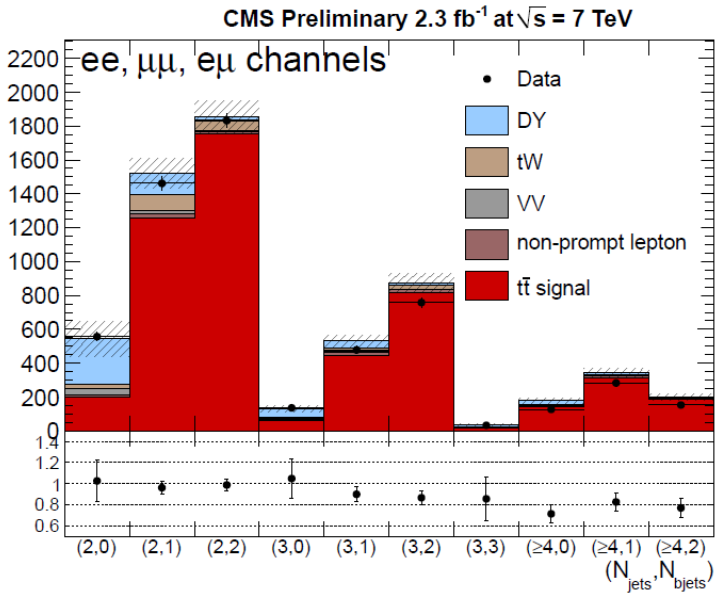
Measurements:

- ℓ+jets and dilep. dominated by systematics (Lumi, JES, b-tagging, MCgen...)
- Profile Likelihood Ratio (PLR) fits to reduce systematics
- Data-driven Bkg determination
- All-hadronic and $\ell+\tau$ results also available

Best Inclusive Cross-Section Measurements

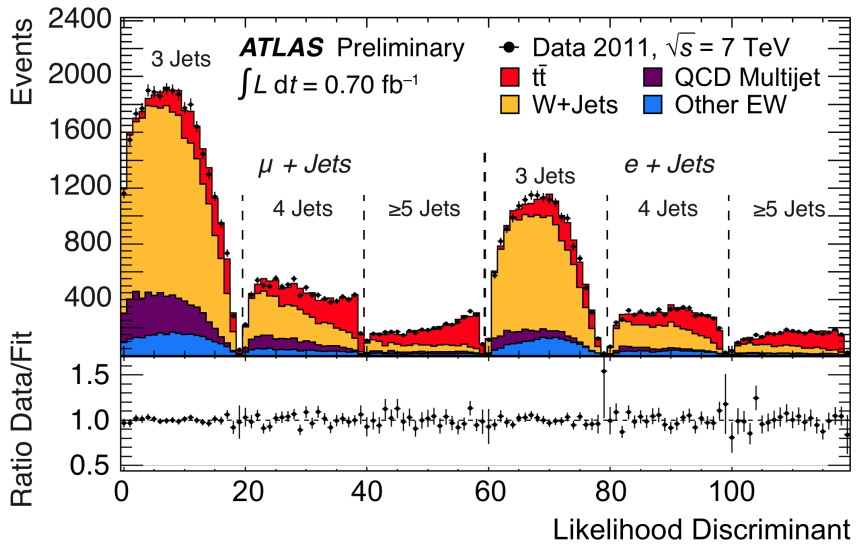
CMS dilepton @ 7 TeV [JHEP 11 (2012) 067]:

- $\ell^+\ell^-(\ell = e, \mu)$, ≥ 2 jets, $m_{\ell\ell} > 20$ & $\notin$[76,106], $\not\!\!E_T > 40$ GeV (ee and $\mu\mu$)
- PLR fit on #jets vs #b-tags distribution



$$\sigma_{t\bar{t}} = 162 \pm 2(stat) \pm 5(syst) \pm 4(lumi) \text{ pb}$$
$$(4.2\%)$$

ATLAS ℓ+jets @ 7 TeV [ATLAS-CONF-2011-121]:



- e/μ, ≥ 3 jets, $\not\!\!E_T$ and $m_T(W)$ cuts
- Likelihood discriminant built on top of kinematical variables: $t\bar{t}$ vs. W+jets
- PLR fit in 3 jet multiplicity regions per ℓ-flavour

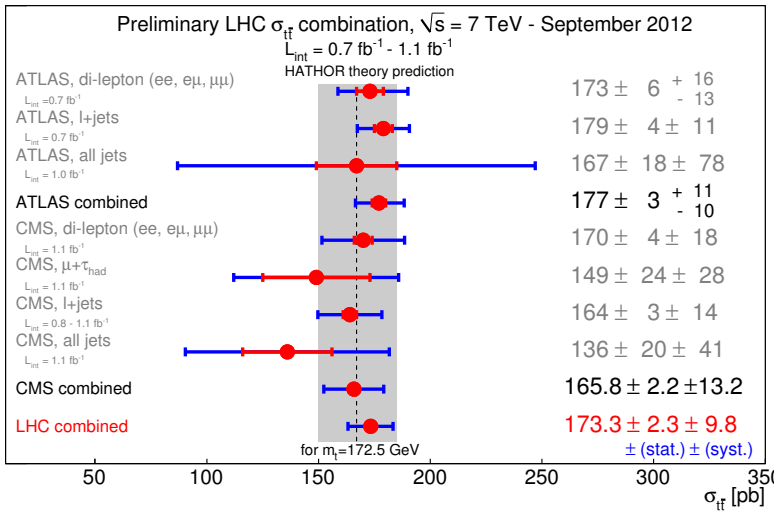
$$\sigma_{t\bar{t}} = 179 \pm 4(stat) \pm 9(syst) \pm 7(lumi) \text{ pb}$$
$$(7\%)$$

Cross-Section Results

ATLAS+CMS Combination

[ATLAS-CONF-2012-134 / CMS-PAS-TOP-12-003]:

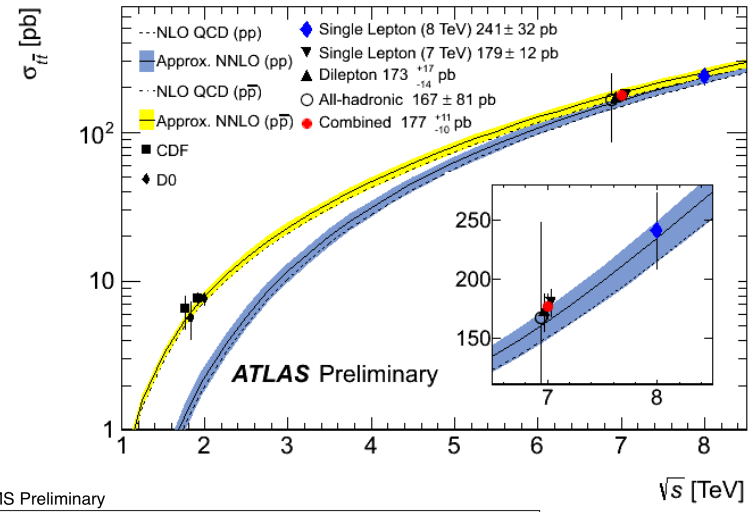
- 7% gain vs. the most precise measurement
- New results not included yet

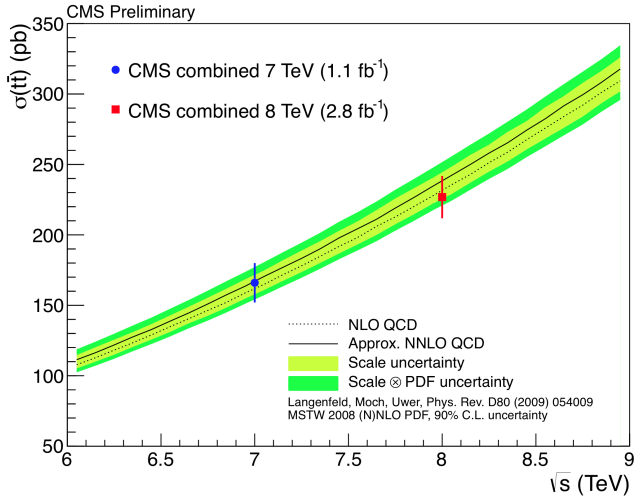


- All results in agreement with SM
- Experimental uncertainty smaller than theoretical one

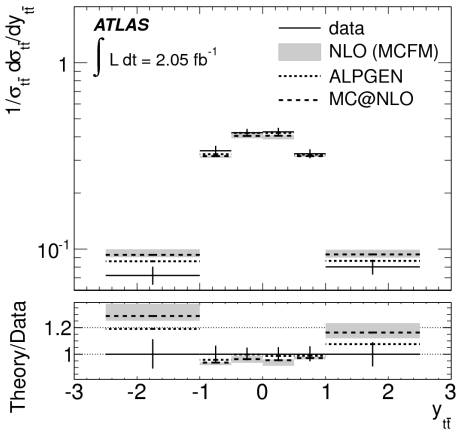
... @ 8 TeV: [ATLAS-CONF-2012-149],

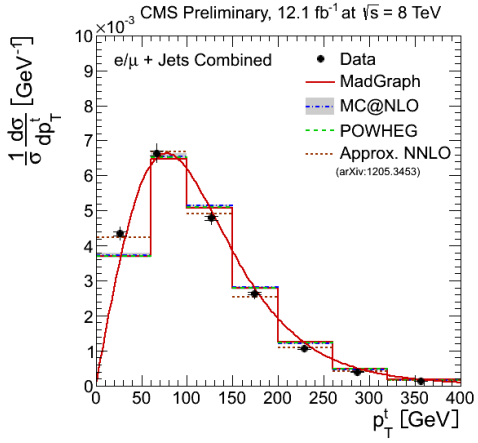
[CMS PAS TOP-12-006], [CMS PAS TOP-12-007]

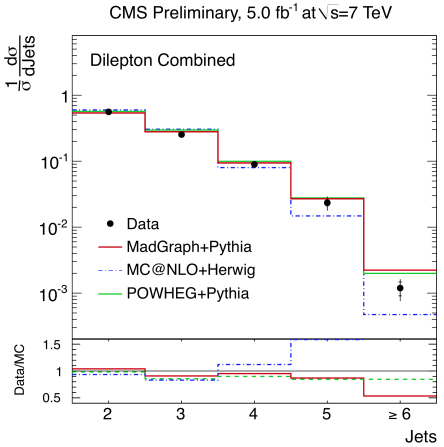


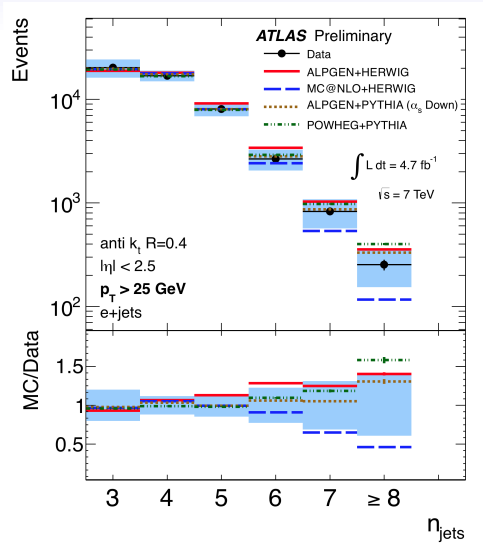


Differential Cross-Section









Large data samples allow for measurement of $\sigma_{t\bar{t}}$ vs.:

- p_T, y, m of $t\bar{t}$ system,
  p_T, y of individual tops,
  p_T, y, m of lepton pairs
  (testing perturbative QCD)

  [CMS PAS TOP-12-027] (l+jets)
  [CMS PAS TOP-12-028] (dilepton)
  [ATLAS: Eur. Pys. J. C (2013)] (l+jets)

- Number of additional jets
  (testing MC prediction for
  non-perturbative QCD, ISR/FSR...
  important background for searches)

  [CMS PAS TOP-12-018] (l+jets)
  [CMS PAS TOP-12-023] (dilepton)
  [ATLAS-CONF-2012-155] (l+jets)

- No significant deviation from MC predictions
- MC@NLO shows discrepancies in the number of high p_T jets

$t\bar{t} + W, Z, \gamma, b\bar{b}$

Associated production of $t\bar{t}$ with vector bosons or $b\bar{b}$ also observed:

$t\bar{t} + W/Z$, SS dilepton, trilepton [CMS PAS TOP-12-014], [ATLAS-CONF-2012-126]:

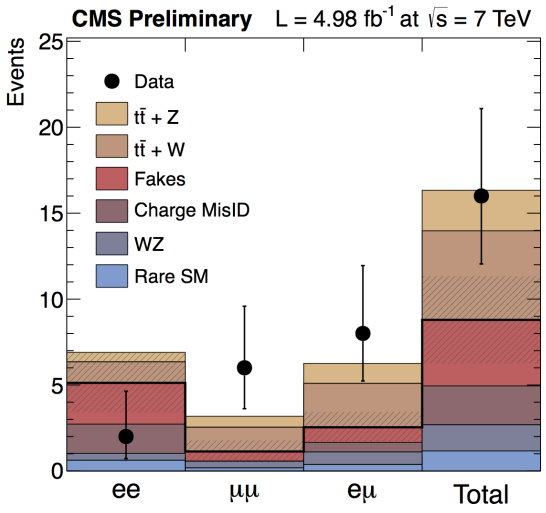
$\sigma_{t\bar{t}Z}=$ (CMS) $0.30^{+0.14}_{-0.11}(\text{stat})^{+0.04}_{-0.02}(\text{syst})$ pb
(ATLAS) < 0.71 pb @ 95% C.L.
(Theory[Campbell, Ellis arXiv:1204.5678]) $0.14 \pm ??$ pb

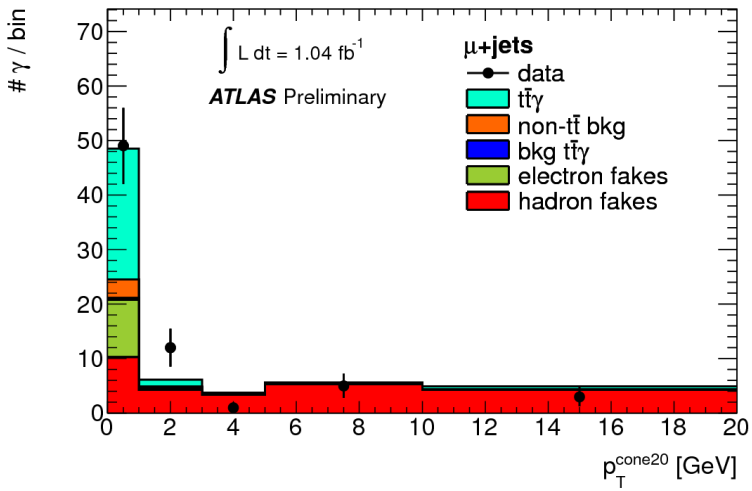
$\sigma_{t\bar{t}W}=$ (CMS) $0.28^{+0.14}_{-0.12}(\text{stat}) \pm 0.04(\text{syst})$ pb (Theory[Kardos et al. PRD85(2012)074022]) $0.17^{+0.03}_{-0.05}$ pb

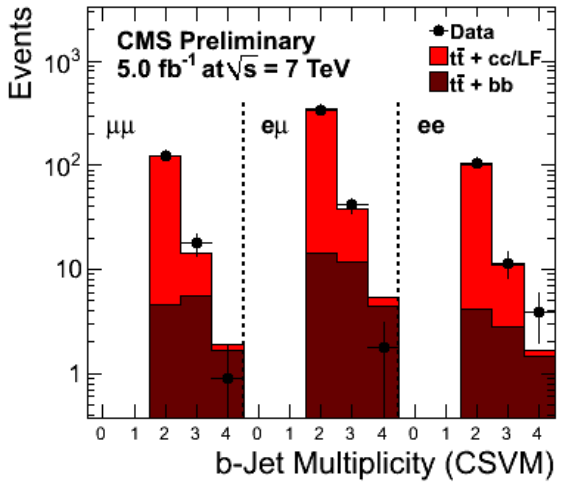
$t\bar{t} + \gamma$ [ATLAS-CONF-2011-153]:

$\sigma_{t\bar{t}\gamma}=$ $2.0 \pm 0.5(\text{stat}) \pm 0.7(\text{syst}) \pm 0.8(\text{lumi})$ pb (Theory [W. Kilian et al. EPJC71(2011)1742]) 2.1 ± 0.4 pb

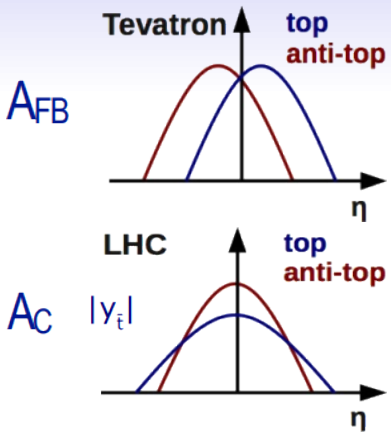
$t\bar{t} + b\bar{b}$ [CMS PAS TOP-12-024]: $\frac{\sigma(t\bar{t}b\bar{b})}{\sigma(t\bar{t}jj)} = 3.6 \pm 1.1(stat) \pm 0.9(syst)\%$







$t\bar{t}$ Charge Asymmetry



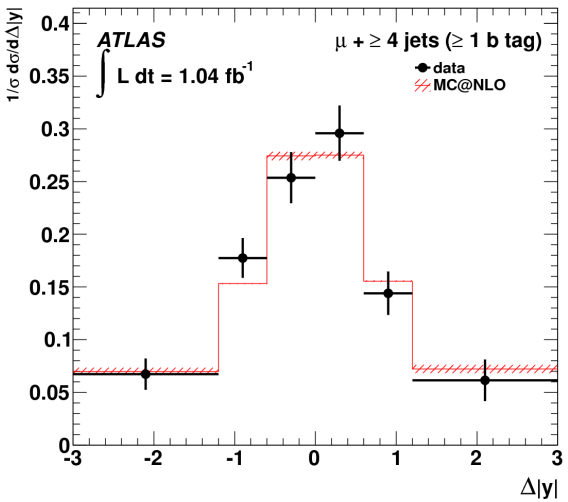
- Forward-Backward Asymmetry (A_{FB}) in $t\bar{t}$ @ Tevatron
  $\rightarrow$ larger than SM expectation
- Related observable @ LHC:

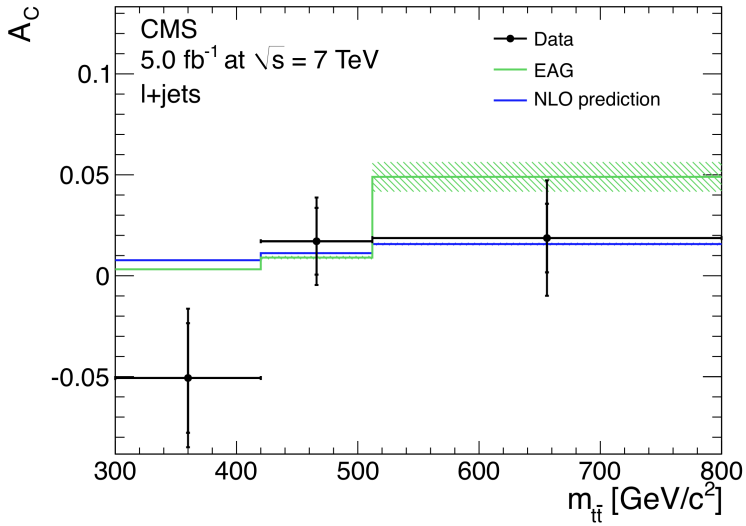
$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}, \quad \Delta|y| = |y_t| - |y_{\bar{t}}|$$

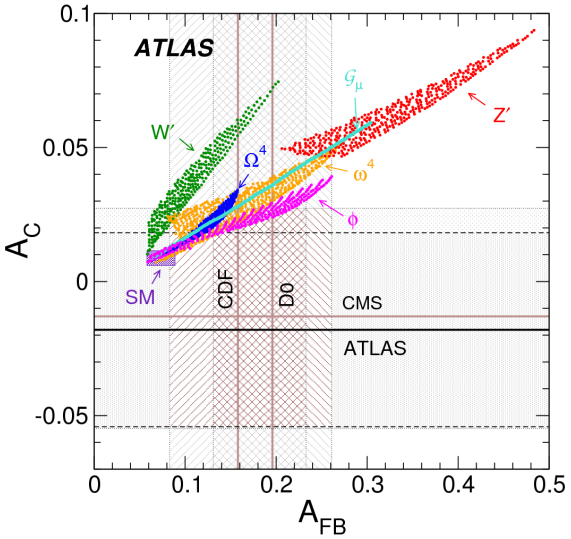
ATLAS (ℓ+jets, dilep): $A_C = 0.029 \pm 0.018_{(stat)} \pm 0.014_{(syst)}$ [Eur.Phys.J. C72 (2012) 2039, ATLAS-CONF-2012-057]

CMS (ℓ+jets): $A_C = 0.004 \pm 0.010_{(stat)} \pm 0.011_{(syst)}$ [PLB717(2012)129, CMS PAS TOP-12-010]

Theory: $A_C = 0.0115 \pm 0.0006$ [J.H. Kuhn and G. Rodrigo, JHEP 1201 (2012)]







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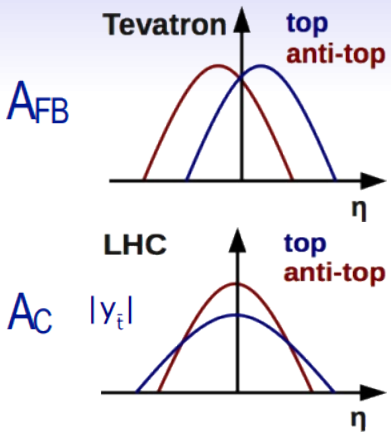

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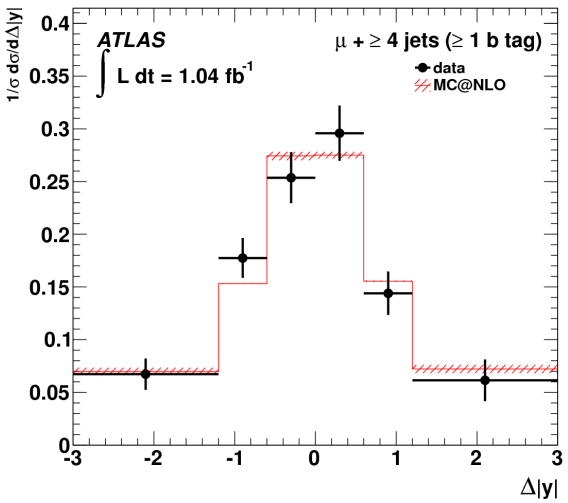
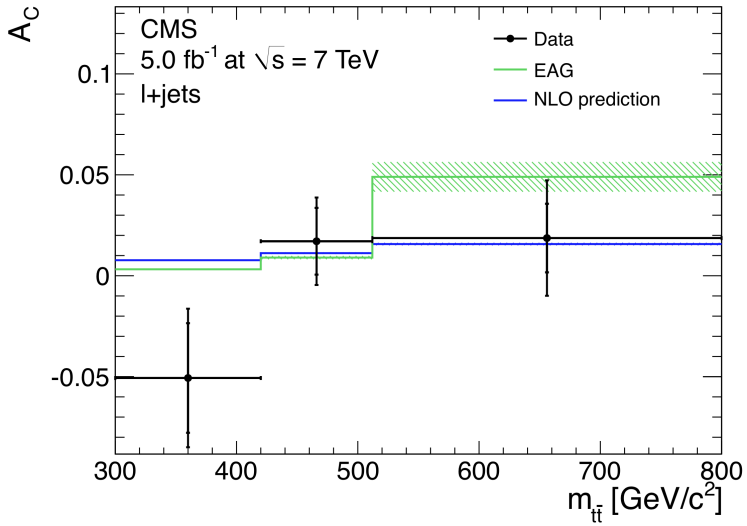
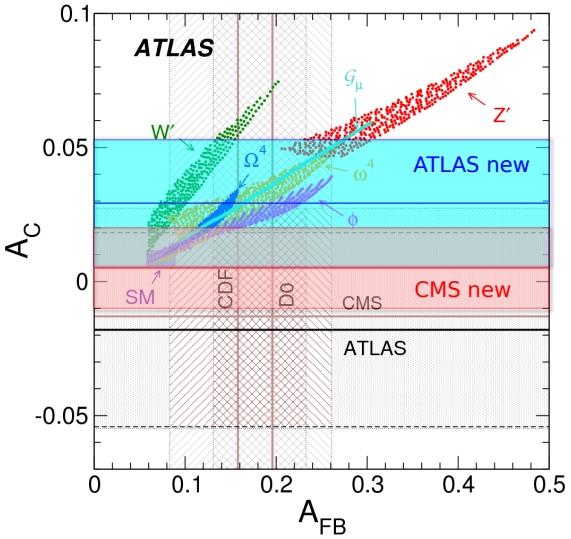
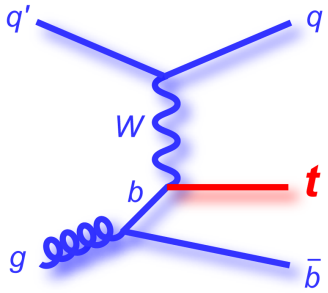




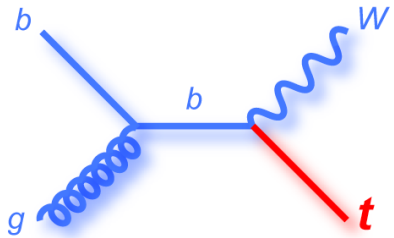


Single Top Production

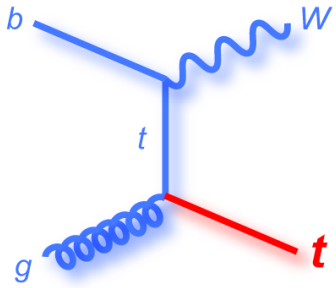
- Electroweak production (first observed in 2009 at the Tevatron)
- Sensitive to new phyisics anomalous couplings, W', H^+, 4^{th} generation
- Direct measurement of $|V_{tb}|$

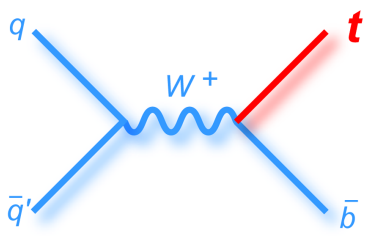


t-channel



Wt-**channel**

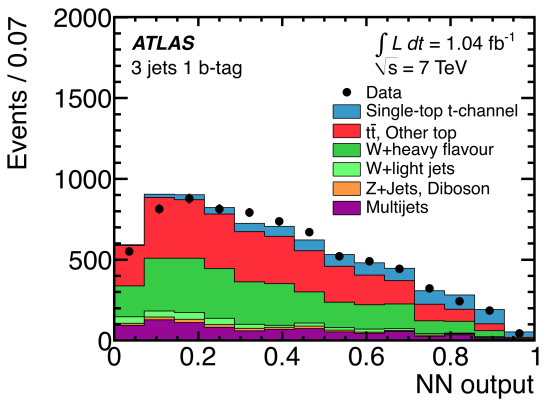


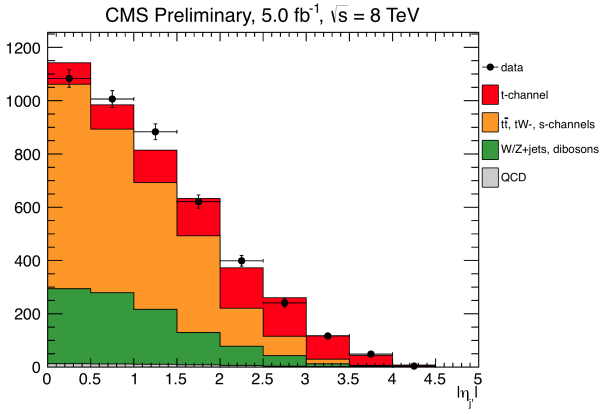


s-channel

t-channel

- Main single-t channel
- ℓ+jets final state, main background is $t\bar{t}$
- Fit on MVA output (NN or BDT)
- Or using single relevant variable ($|\eta|$ of j', first non-b-tagged jet)





Cross-sections @ 7 TeV:

- $\sigma_t = 83 \pm 4_{(\text{stat})} \pm 20_{(\text{syst})}$ pb (ATLAS [Phys. Lett. B 717 (2012) 330-350]) $|V_{tb}| > 0.75$
- $\sigma_t = 67 \pm 4_{(\text{stat})} \pm 5_{(\text{syst})} \pm 1_{(\text{lumi})}$ pb (CMS [JHEP 12 (2012) 035]) $|V_{tb}| > 0.92$
- $\sigma_t = 64.6 \pm 2.4$ pb (Theory [*])

95% C.L. constrained

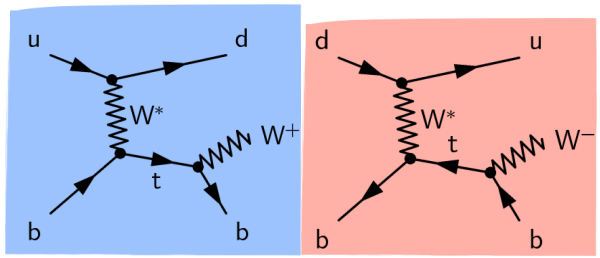
Cross-sections @ 8 TeV

- $\sigma_t = 95 \pm 2_{(\text{stat})} \pm 18_{(\text{syst})}$ pb (ATLAS [ATLAS-CONF-2012-132]) $|V_{tb}| > 0.80$
- $\sigma_t = 80 \pm 6_{(\text{stat})} \pm 11_{(\text{syst})} \pm 4_{(\text{lumi})}$ pb (CMS [CMS PAS TOP-12-011]) $|V_{tb}| > 0.80$
- $\sigma_t = 87.8 \pm 3.4$ pb (Theory [*])

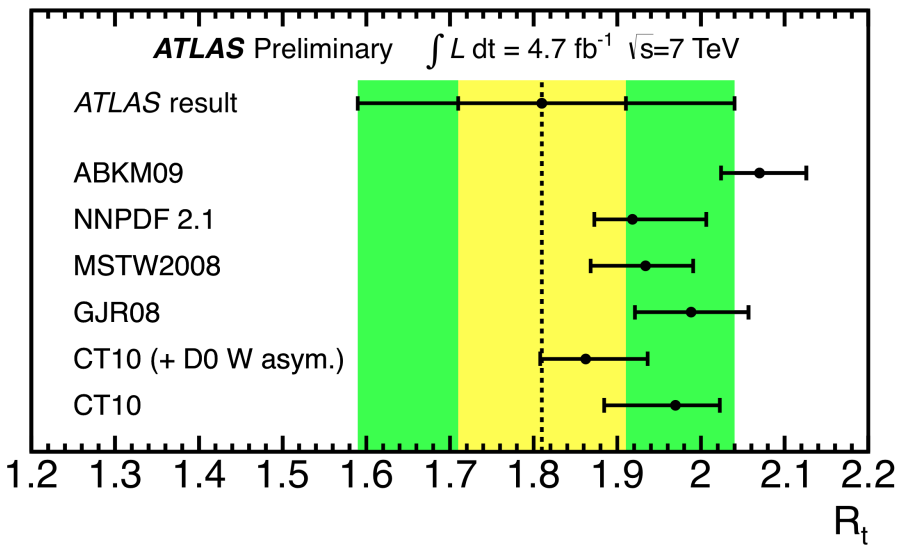
*: N. Kidonakis: PRD83(2011)091503, PRD81(2010)054028 (2010), PRD82(2010)054018, arXiv:1205.3453

t-channel $t/\bar{t}$ Cross-Section Ratio

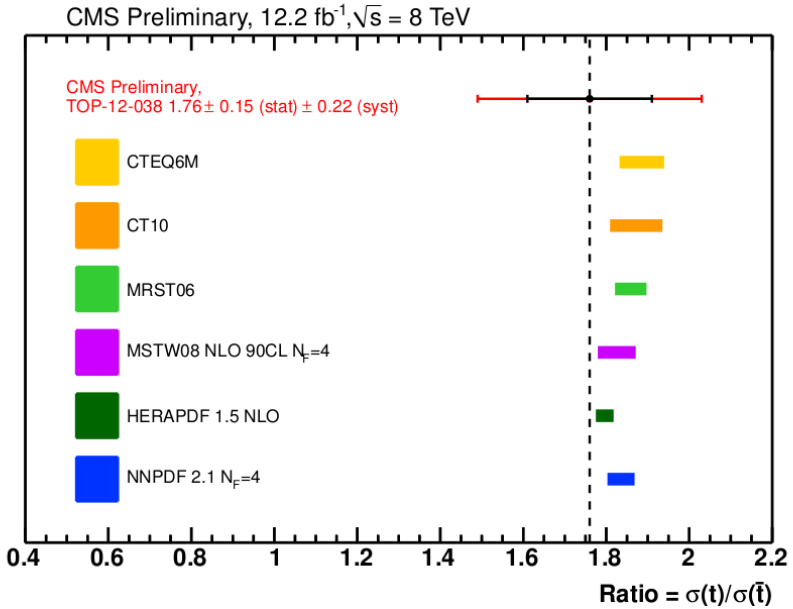
- At LHC single-$t(\bar{t})$ t-channel production mainly via $u(d)$-b W exchange
- and since: in pp collisions u density $\sim$2 d density
- $\Rightarrow$ @LHC $R_t = \sigma_t/\sigma_{\bar{t}}$ in t-channel expected > 1



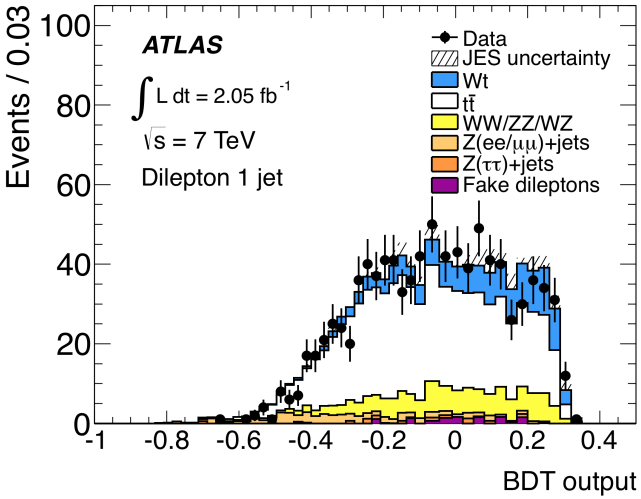
[ATLAS-CONF-2012-056]



[CMS PAS TOP-12-038]

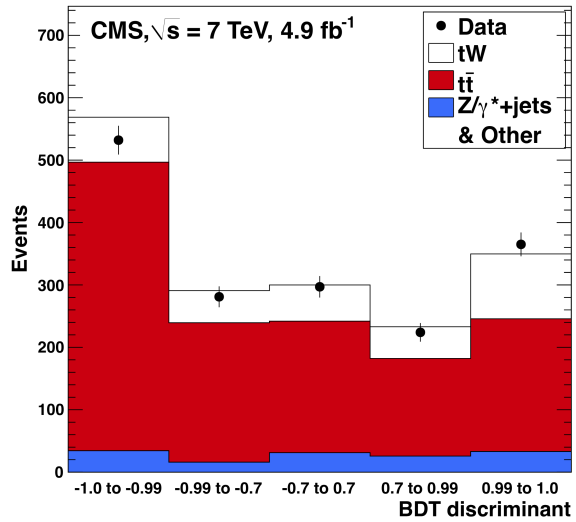


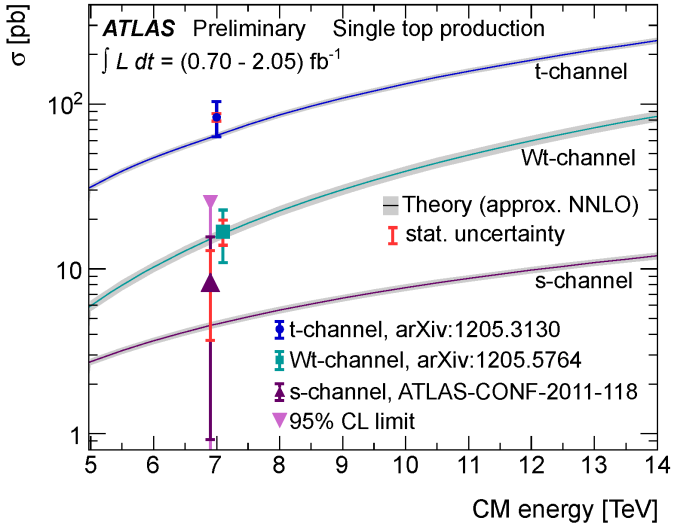
Wt- and s-channel



Wt-channel:

- Dilepton selection
- MVA discriminants
- $\sigma_{Wt} = 16.8 \pm 2.9_{(\text{stat})} \pm 4.9_{(\text{syst})}$ pb (ATLAS [PLB716(2012)142])
- $\sigma_{Wt} = 16^{+5}_{-4}$ pb (CMS [Phys. Rev. Lett. 110, 022003 (2013)])





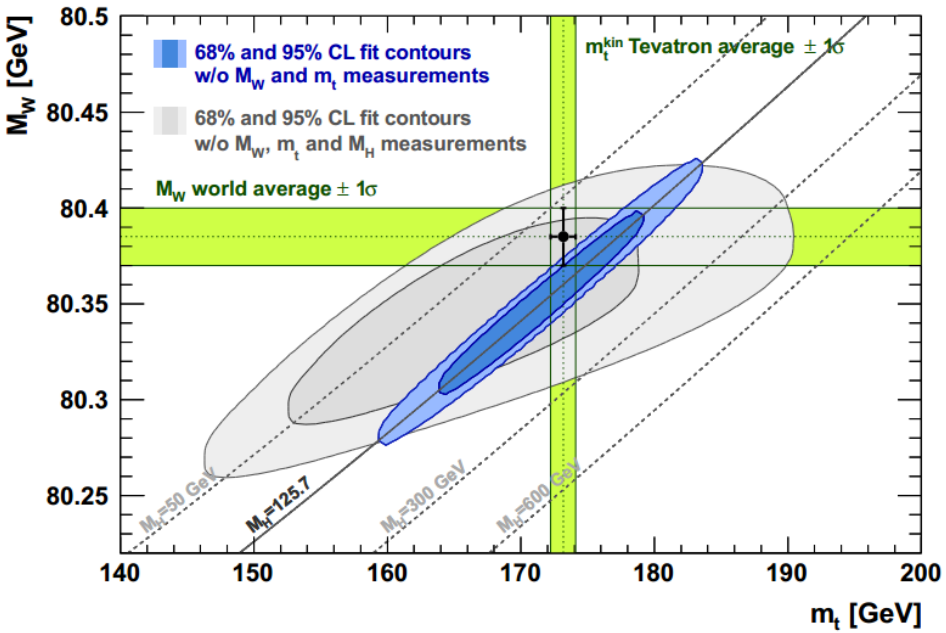
s-channel:

- No evidence yet
- 5.8 × SM excluded by ATLAS @ 95% C.L.
  [ATLAS-CONF-2011-118]

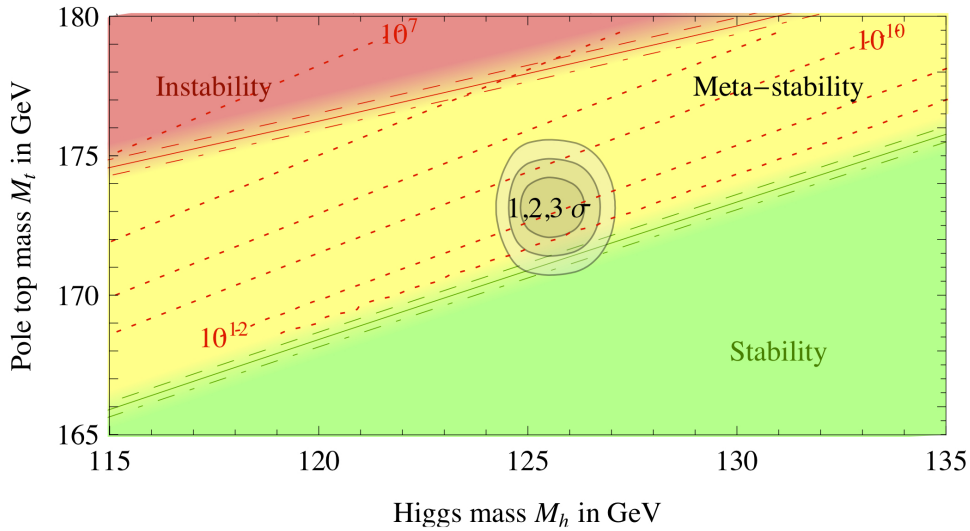
Importance of Top Mass Measurement

Precision needed to test Electroweak theory given a Higgs boson at 125 GeV

[arXiv:1209.2716v2 [hep-ph]]



[Degrassi et al JHEP08(2012)098



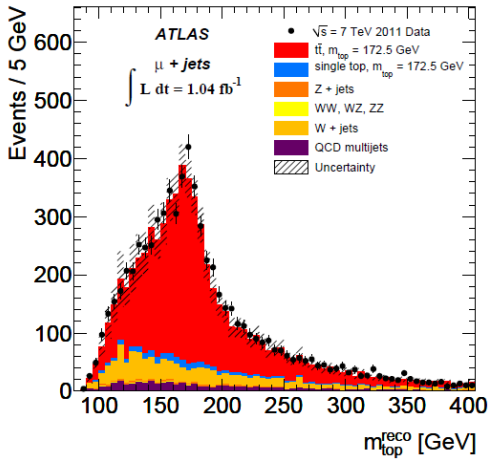
Top Mass Measurement, ℓ+jets

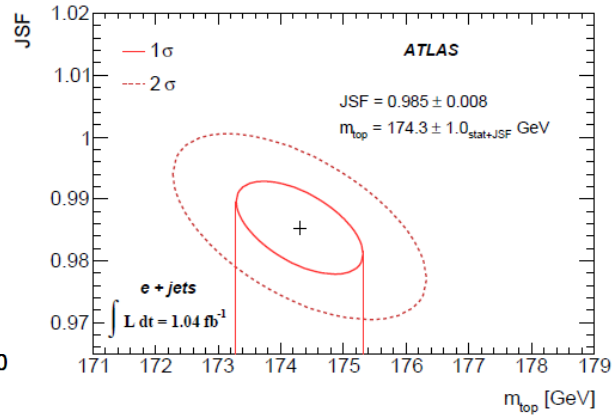
ATLAS - Template Method

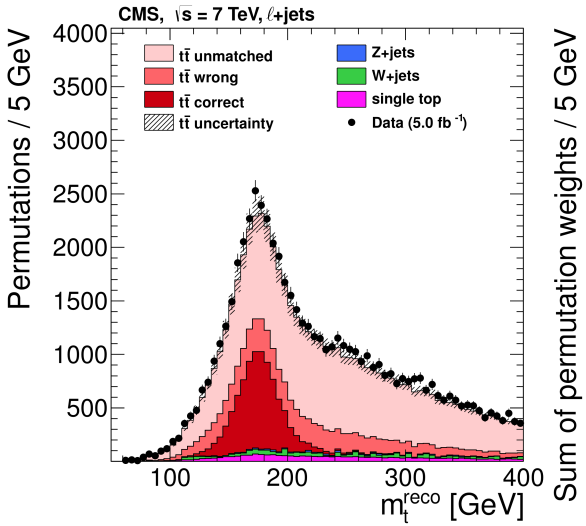
[EPJC72(2012)2046]

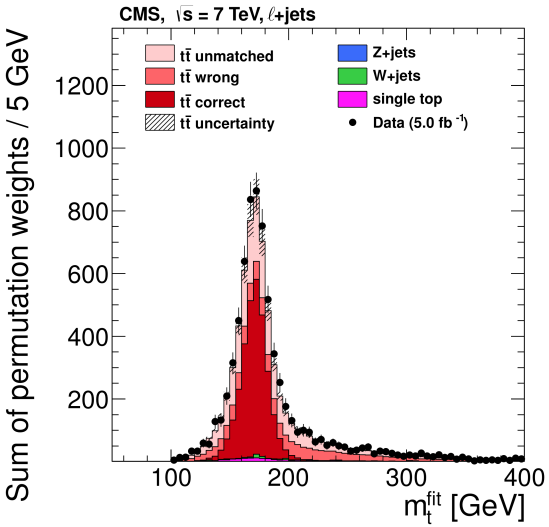
- Kinematical Likelihood method to reconstruct $t\bar{t}$
- 2D m_t^{reco} vs. m_W^{reco} considered
- m_t and JES fitted, m_W fixed

$m_t = 174.5 \pm 0.6_{(stat)} \pm 2.3_{(syst)}$ GeV









CMS - Ideogram Method

[JHEP12(2012)105]

- Weight permutations by χ^2 prob.
- Extract (m_t,JES) by maximizing Likelihood built with weighted distribution

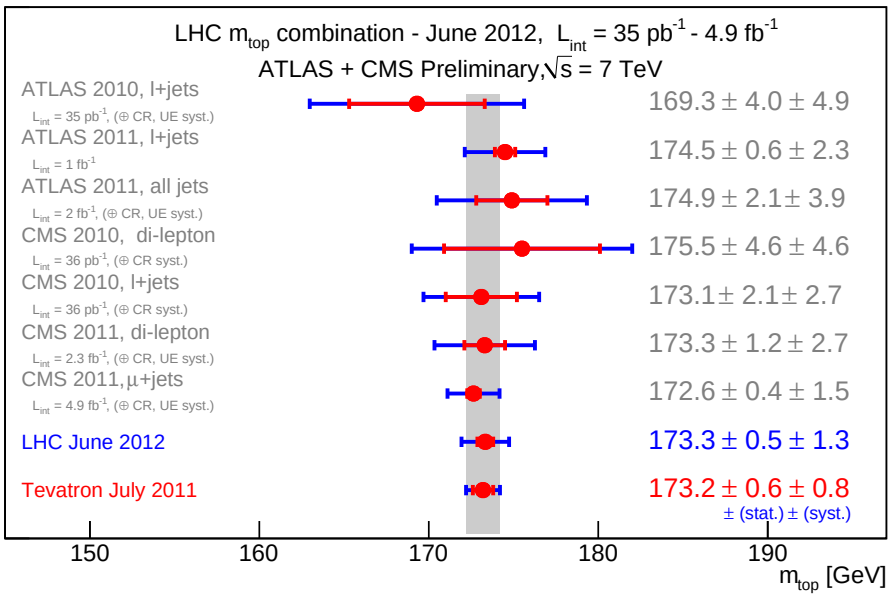
$m_t = 173.5 \pm 0.4_{(stat+jes)} \pm 1.0_{(syst)}$ GeV

Top Mass Measurement Results

ATLAS+CMS Combination

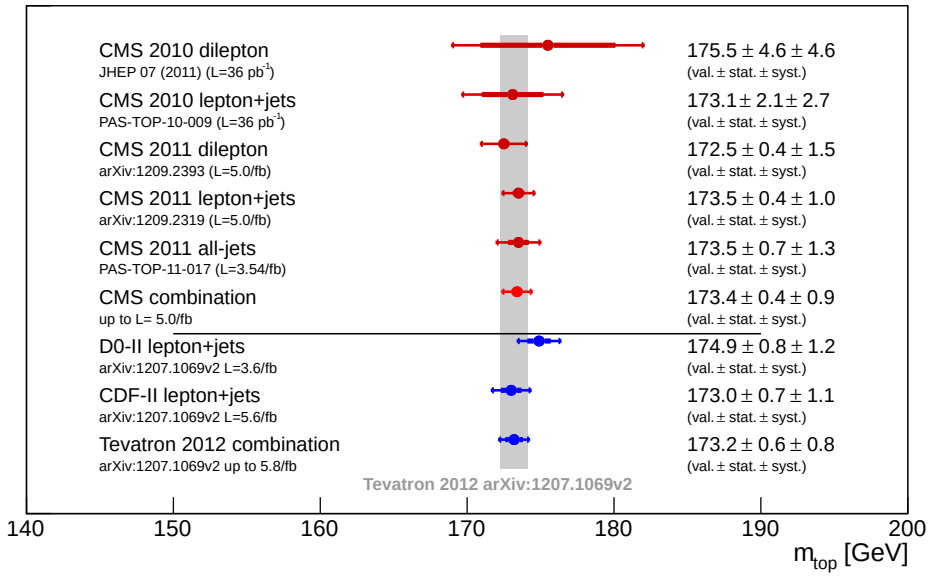
[CMS PAS TOP-12-001 / ATLAS-CONF-2012-095]

Important exercise but outdated



Latest CMS Combination

[CMS PAS TOP-11-018]



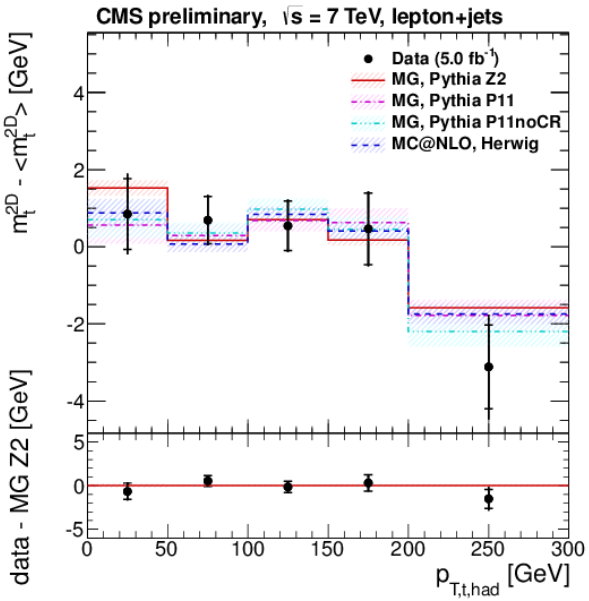
- Most precise single mesurement
- Reaching Tevatron Precision
- Perfect agreement with Tevatron

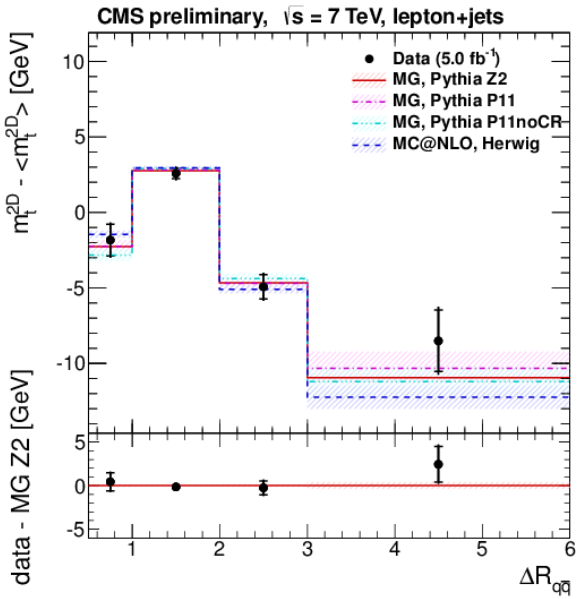
Top mass differential measurement

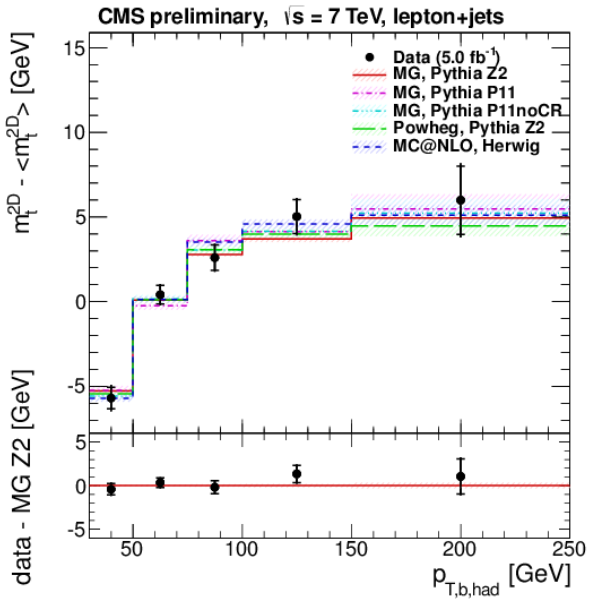
How does the measured m_t relate to the one needed for theoretical calculations?

- Relation contains (non)perturbative corrections, expected to depend on event kinematics
- Is this kinematic dependence properly modelled by MC?
- Many kinematic variables (12) checked
- Data/MC agreement rules out dramatic effects

[CMS PAS TOP-12-029]







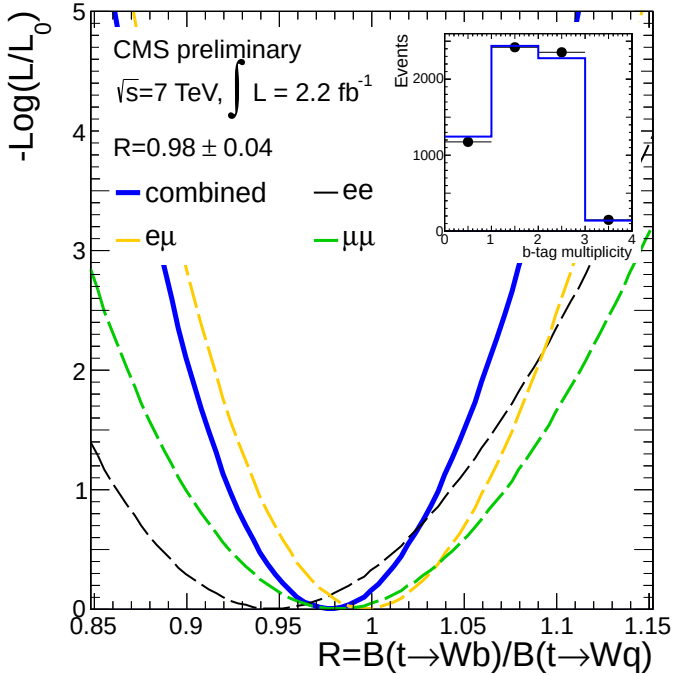
R = BR(tWb)/BR(tWq)

Evaluate branching ratio of $t \to Wb$ w.r.t. branching ratio of $t \to Wq$:

- Validate the SM prediction of $|V_{tb}| = 0.999146^{+0.000021}_{-0.000046}$
- Can probe new physics (as 4^{th} generation or charged Higgs boson)

Computed in dilepton channel using a likelihood fit on b-tag multiplicity that accounts for:

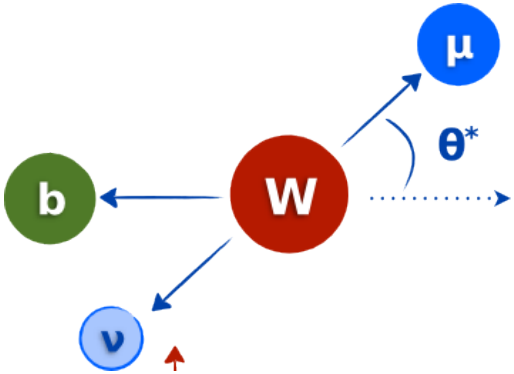
- fraction of $t\bar{t}$ and single-t in sample
- fraction of events with correct jet assignment
- b tagging efficiency and mis-identification



Results [CMS PAS TOP-12-035]:

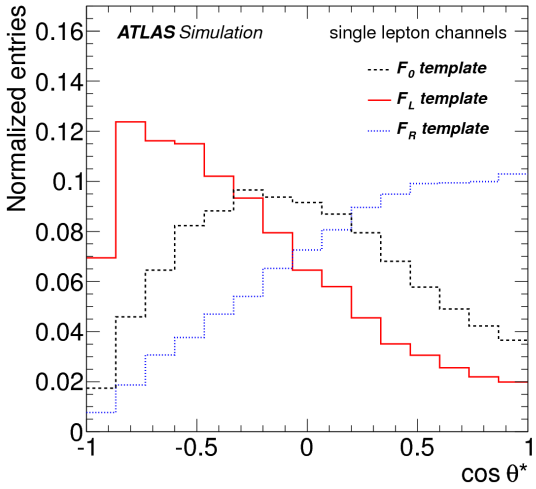
- $R = 1.023^{+0.036}_{-0.034}$
- $|V_{tb}| > 0.972$ @ 95% C.L.
- World most precise measurement!

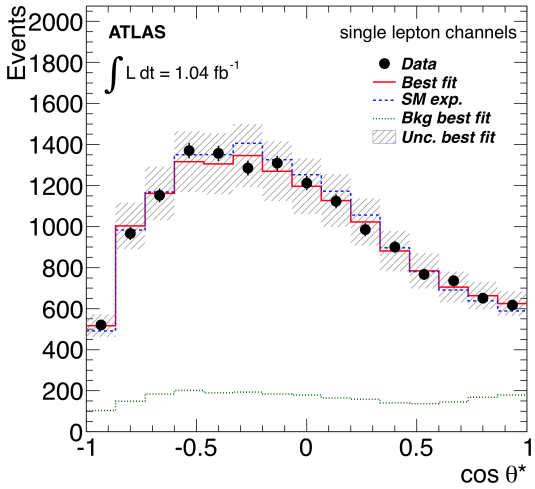
W Polarization in top decay

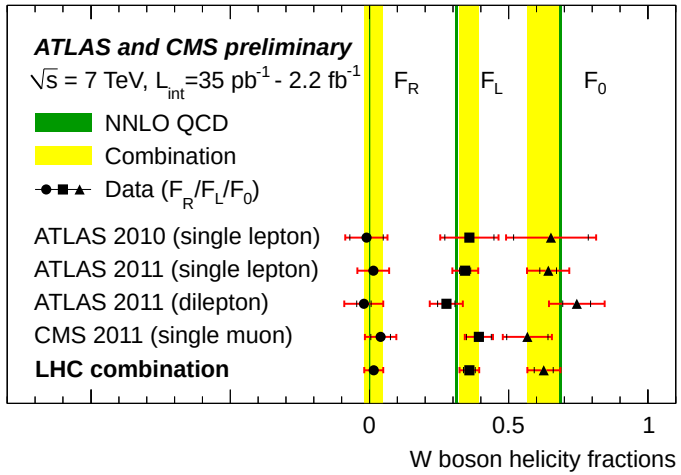


- W polarization in $t \to Wb$ probes the V-A structure of weak charge
- Possible deviations from SM predictions and limits on anomalous Wtb couplings are determined
- ATLAS+CMS combination

  [CMS PAS TOP-12-025 / ATLAS-CONF-2013-033]





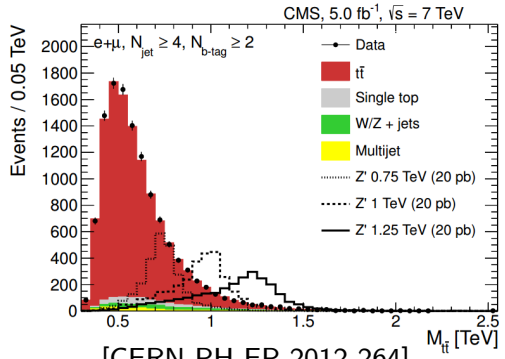


(Measured in single-t topology as well [CMS-PAS-TOP-12-020])

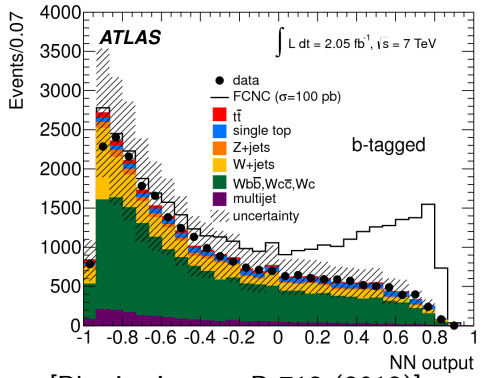
More Measurements...

Many other measurements not reported here, including:

- $t\bar{t}$ cross-section: all-hadronic, final states with τ...
- Higgs searches: ttH, tH^+
- FCNC in t decay
- Top mass: dilepton, all-hadronic, mass from $\sigma_{t\bar{t}}$ ...
- BSM Searches: $t\bar{t}$ resonances, t', $b' \to tW$, $t\bar{t}+\not{E}_T$...
- t charge, $t\bar{t}$ spin correlation, t polarization



[CERN-PH-EP-2012-264]



[Physics Letters B 712 (2012)]

More results are available here:

`https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults`
`https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP`

Conclusions

- 18 years after top discovery (@ Tevatron in 1995), top quark physics still fascinating topic in HEP
  - LHC is a top factory: $t\bar{t}$ cross-section became a precision measurement, single-t cross-section on the way too, differential measurements available ...
  - High precision measurements @ LHC start to be on par (*e.g.* mass), or better (*e.g.* limits on $|V_{tb}|$) than @ Tevatron
  - Many published analyses still based on 7 TeV datasets, not yet including the full 8 TeV sample: more (and better) results expected before LHC starts back @ 14 TeV
  - So far no BSM effects observed in Top physics @ LHC