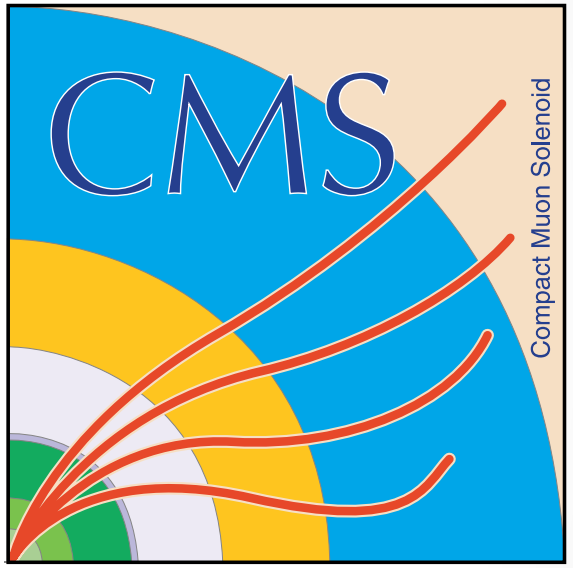
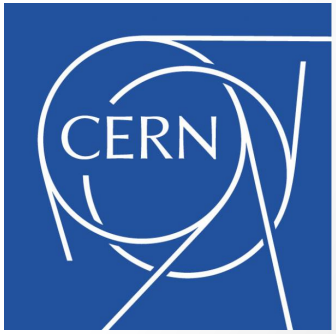
Top Quark Production and Top Quark Properties at LHC



Clement Helsens, CERN

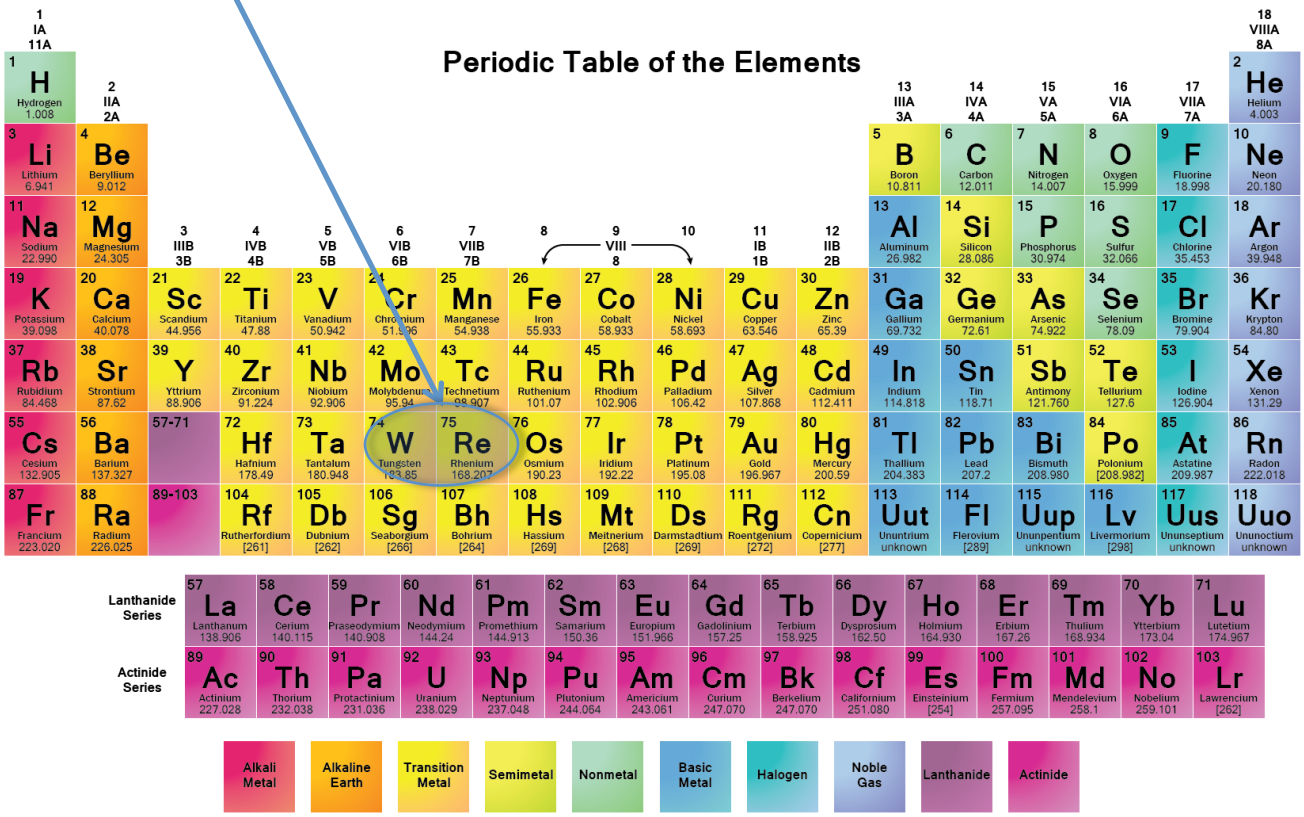
On behalf of the ATLAS and CMS collaborations

Rencontres du Vietnam August 2013, Quy Nhon



Introduction

- If we compare the top quark mass with chemical elements, its mass is ~186 u and would be between Tungsten and Rhenium

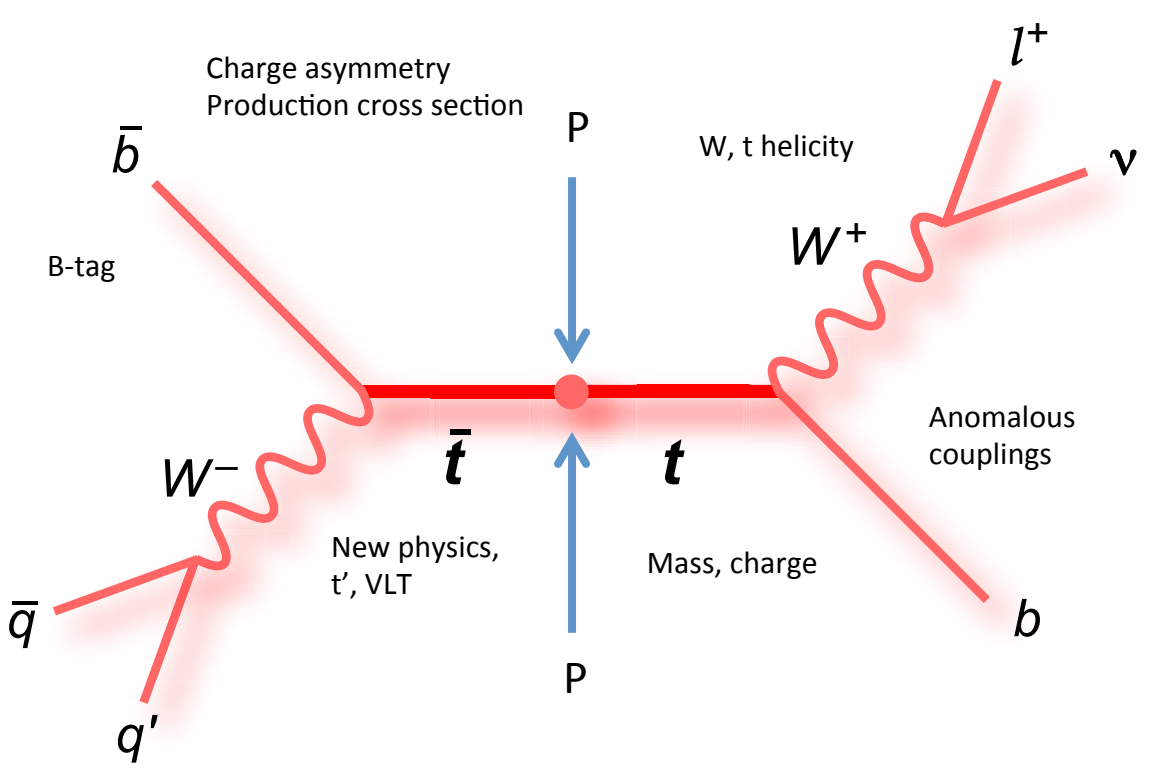


Introduction

- If we compare the top quark mass with chemical elements, its mass is ~186 u and would be between Tungsten and Rhenium
- But we are not doing chemistry at the LHC!
- For particle physicist the top quark is special:
  - It is the most heaviest elementary(?) particle known (to date)
  - It plays a special role in many BSM theories
  - Short-lived, so decays before it hadronized and it is possible to study the properties of the bare quark
  - Main background source in most of the BSM searches
  - Precision test of perturbative QCD
  - Possible window to new physics

Outline

- $t\bar{t}$ production cross section
- Single top production
- Top properties
- Beyond the S.M. searches
- Conclusion



Outline

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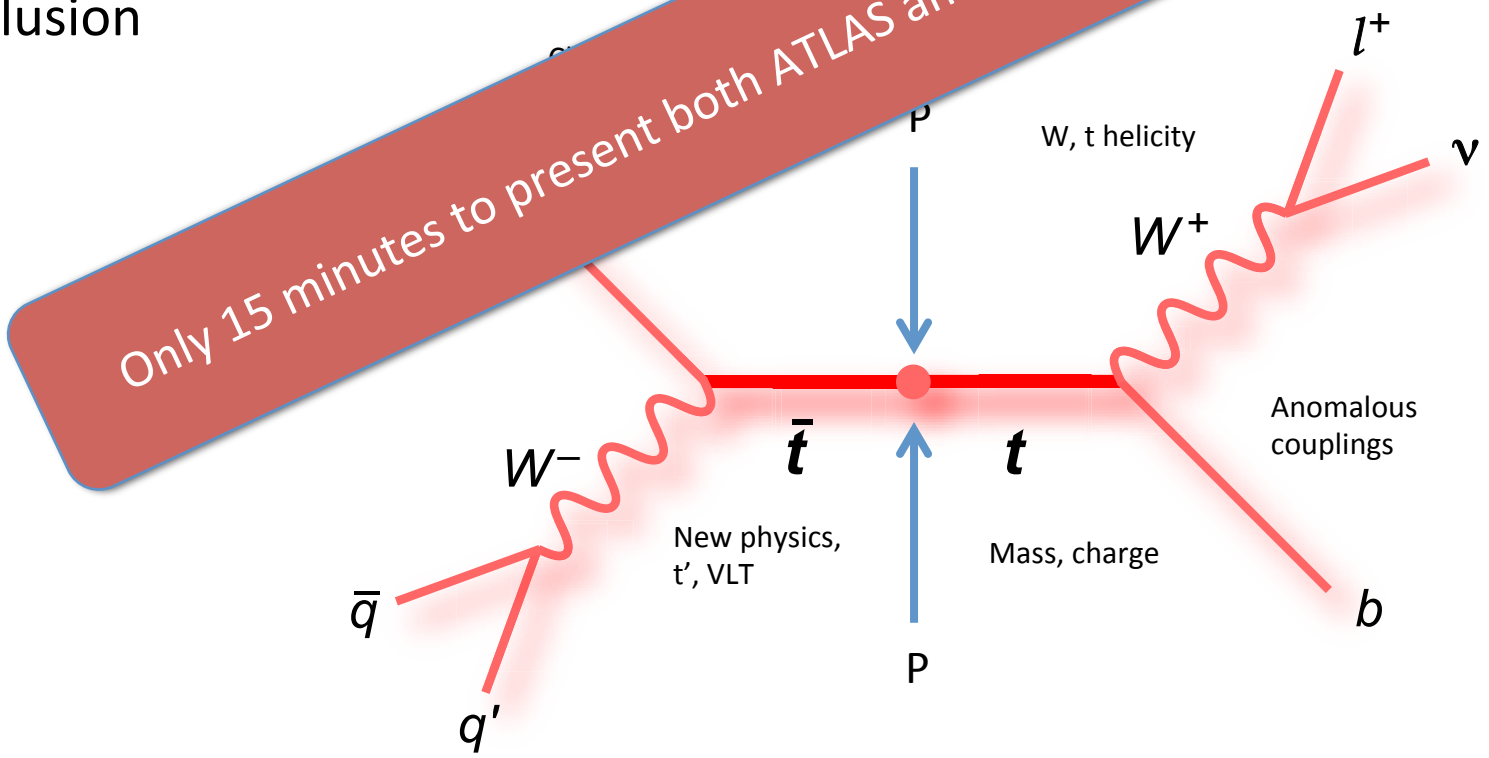
Only 15 minutes to present both ATLAS and CMS results...



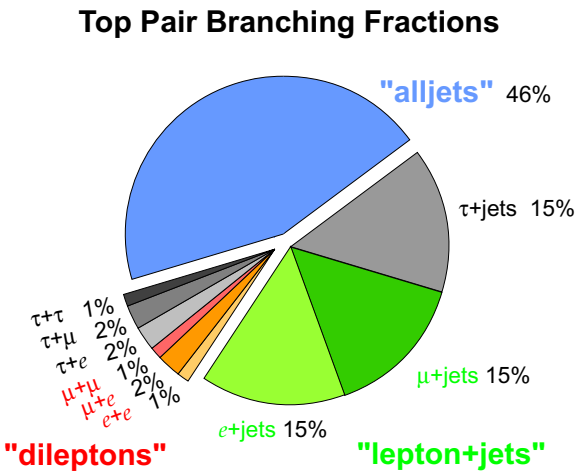
LHC as a top factory!

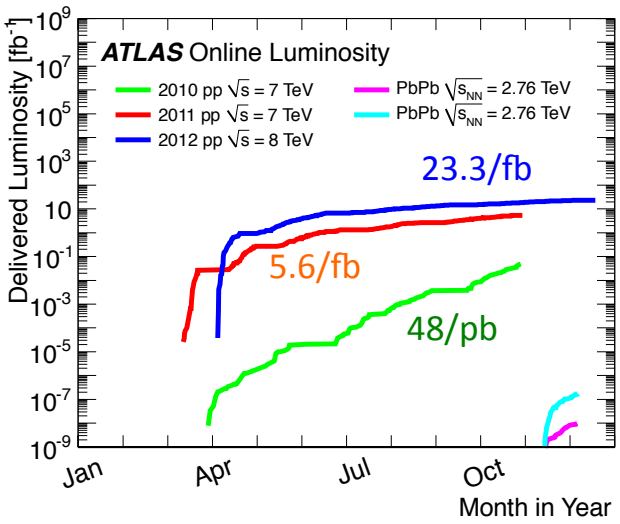
- Top production pair and single production at the LHC
- Leading order contributions

$$q\bar{q} \rightarrow t\bar{t} \cong 15\% \,@\, 7\text{TeV}$$
$$gg \rightarrow t\bar{t} \cong 85\% \,@\, 7\text{TeV}$$

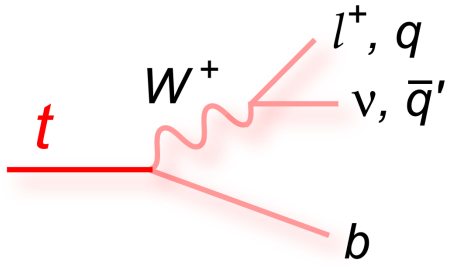
} At the Tevatron $q\bar{q}$ dominates

- Production in ATLAS and CMS
  - 6.6 M top pairs (2012+2011 / 5.7 + 0.9)
  - 3 M single tops (2012+2011 /2.6 + 0.4)

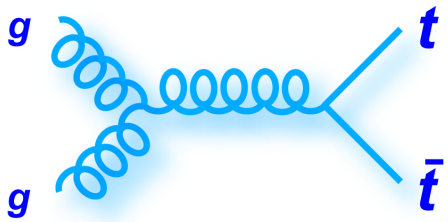


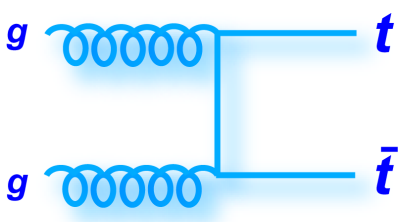


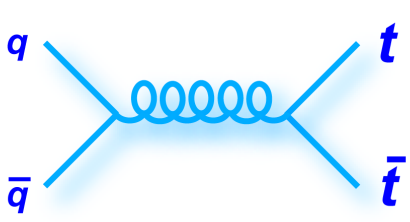
Top Quark Production



- Top decays almost exclusively in a W-boson and a b-quark
- Top pair production, strong interaction

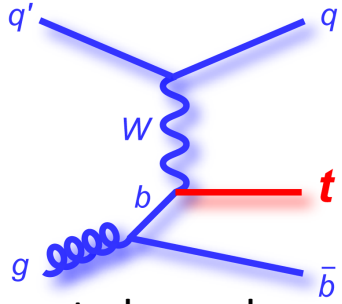






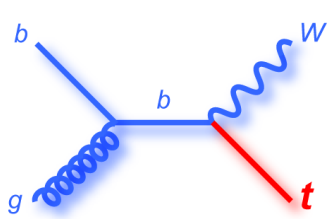
$$\cong 177^{+10}_{-11} / 253^{+13}_{-15}\,\text{pb} \,@\, 7/8\,\text{TeV}\ (m_{top} = 172.5\,\text{GeV})$$

- Single top production, electroweak interaction



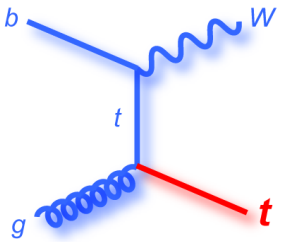
t-channel

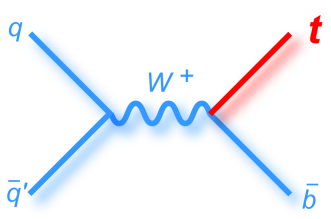
$$\cong 65^{+3}_{-2} / 88^{+3}_{-2}\,\text{pb} \,@\, 7/8\,\text{TeV}$$



Wt-channel

$$\cong 16^{+1.2}_{-1.2} / 22.4 \pm 1.5\,\text{pb} \,@\, 7/8\,\text{TeV}$$



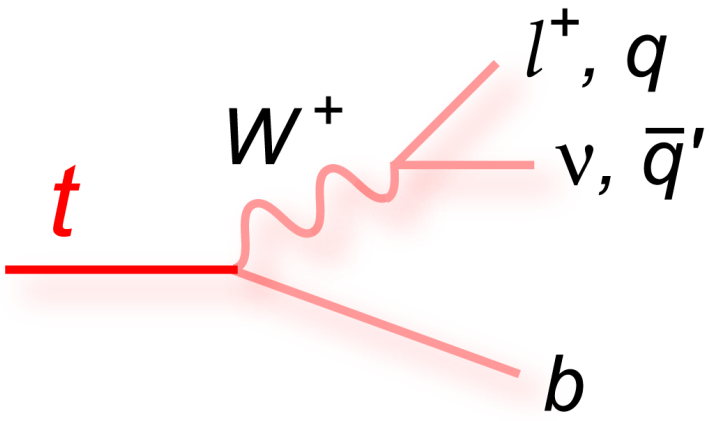


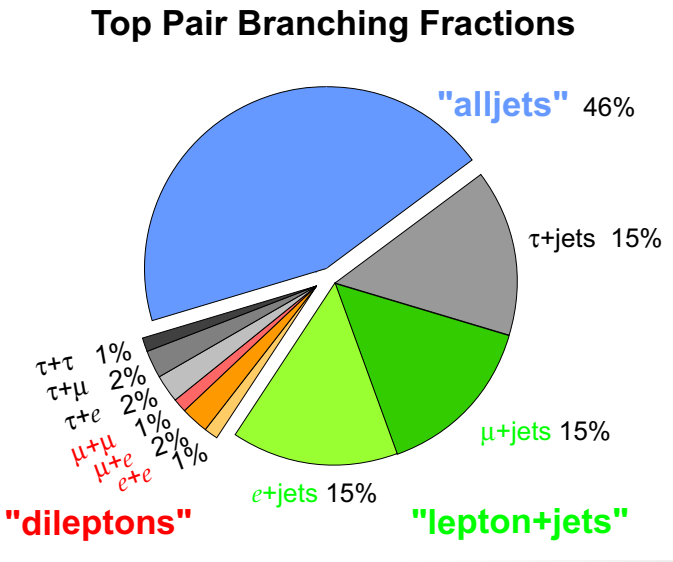
s-channel

$$\cong 4.6^{+0.2}_{-0.18} / 5.6 \pm 0.22\,\text{pb} \,@\, 7/8\,\text{TeV}$$

Top Quark Decay

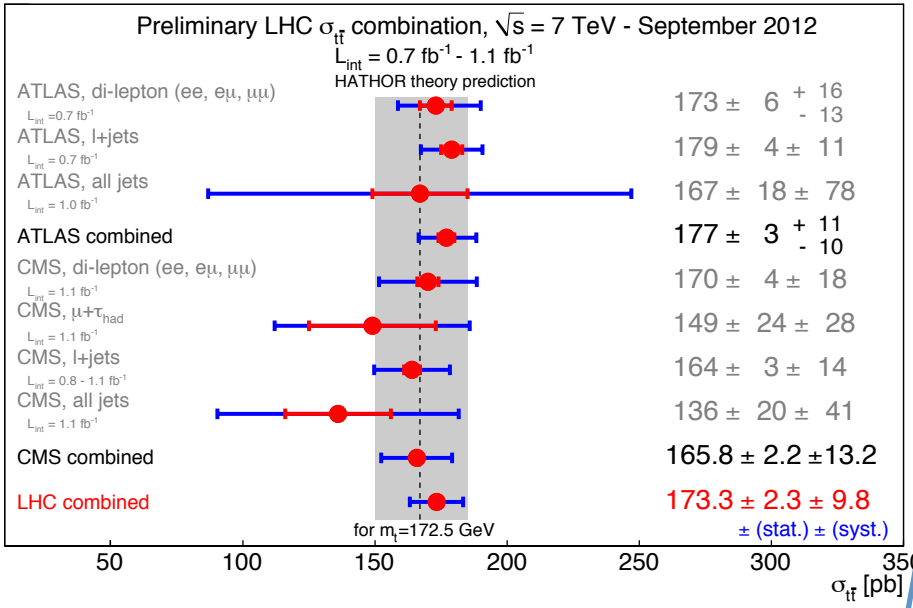
- Top decays almost exclusively in a W-boson and a b-quark
- W-boson decays hadronically (leptonically) ~70 (30)%
- Very rich final states! Jets, b-jets, lepton, neutrino
- All jets: largest BR but also large QCD background
- 1-lepton + jets: large BR and reasonable background
- 2-lepton + jets: smallest BR and background
- Tau lepton treated in dedicated analyses (not presented)

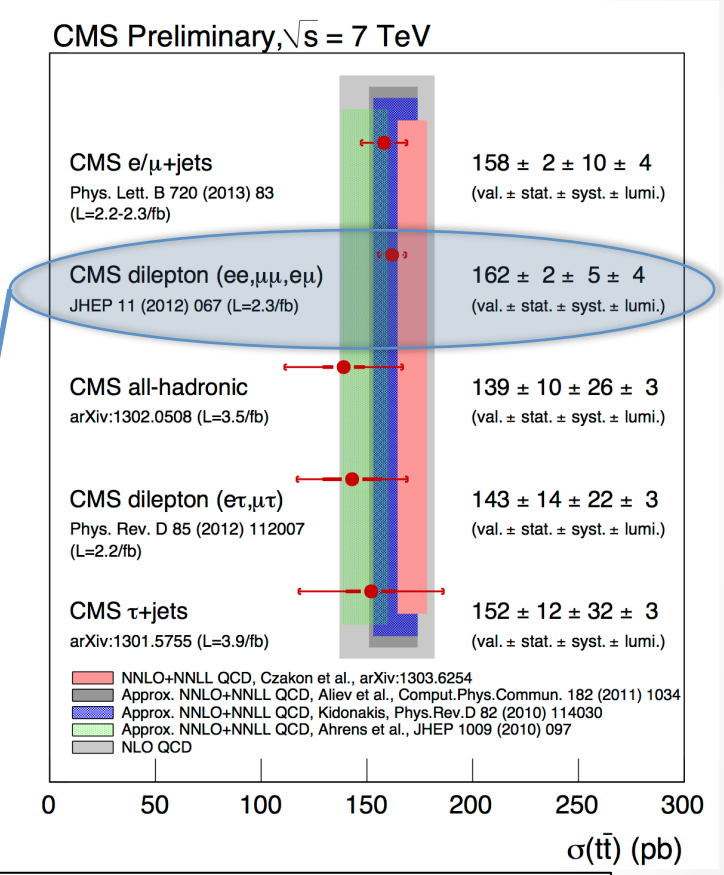




Top Pair Production Cross Section

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





Total LHC combined uncertainties ~6%

CMS dilepton result not used in this combination

$$\sigma_{t\bar{t}} = 161.9 \pm 2.5(stat)^{+5.1}_{-5.0}(syst) \pm 3.6(lumi)\text{pb}\ (4.2\%)\ JHEP11(2012)067$$

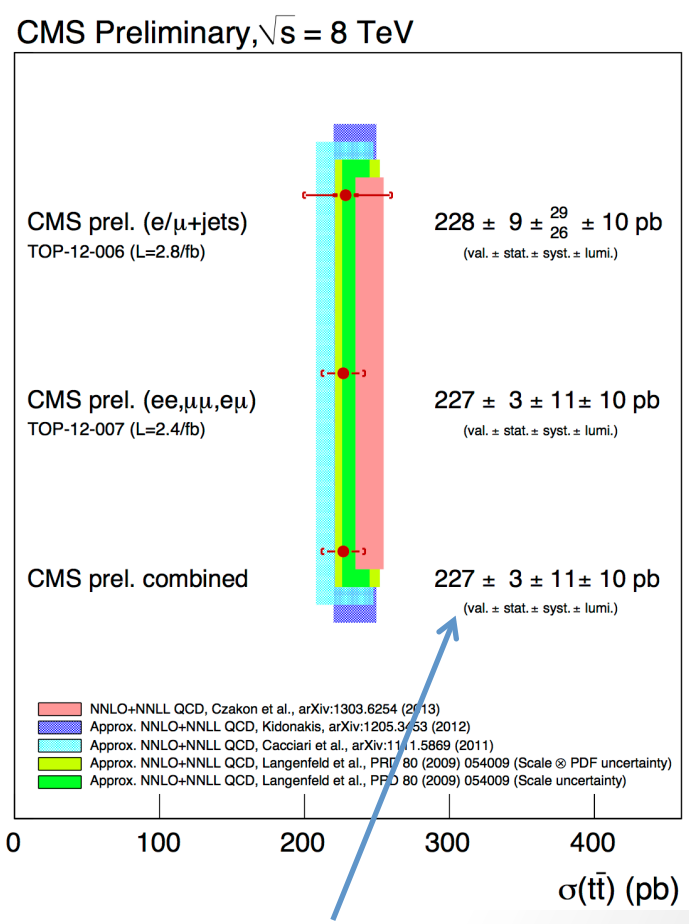
Top Pair Production Cross Section

8TeV results

ATLAS MVA 8TeV Lepton + jets analysis with 5.8 fb^{-1}

$$\sigma_{t\bar{t}} = 232 \pm 2(stat) \pm 31(syst) \pm 9(lumi)\,pb\ (14\%)$$

- Cross section are consistent with theory (full NNLO calculation arXiv:1303.6254)
- Also consistent across channels and experiments
- Systematics dominated measurments

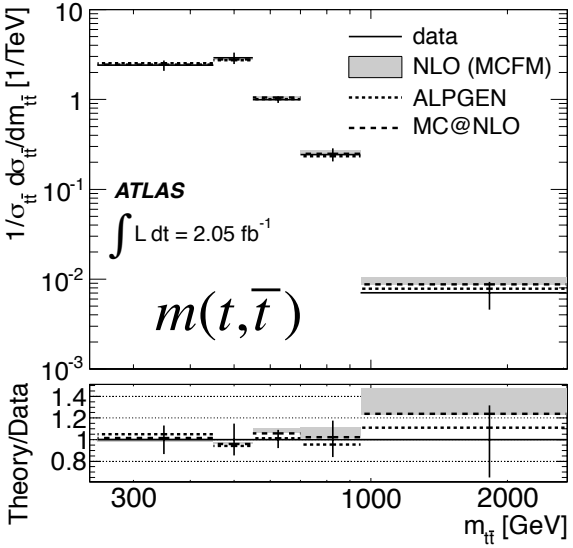


CMS combined (7%)

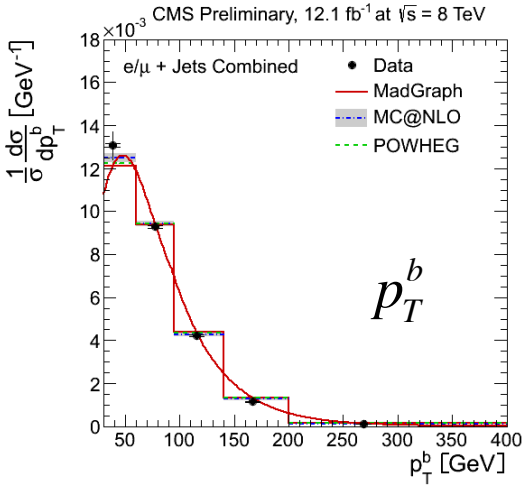
Differential Top Pair Cross Section

- Statistic is enough to study differential $t\bar{t}$ pair production cross section
- Several variables considered: $m(t,\bar{t})$, $p_T(t,\bar{t})$, $Y(t,\bar{t})$
  - sensitive to new physics
- CMS considered also top and top decays kinematics (b-jets, lepton…)
- Generators in good agreement with measurements

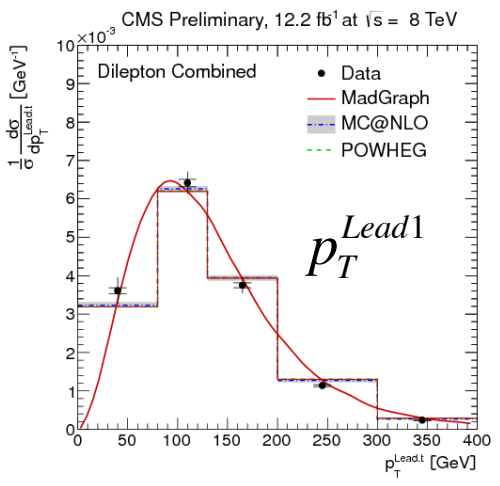
L+Jets



L+Jets



Dilepton



[Eur. Phys. J. C (2013) 73: 2261]

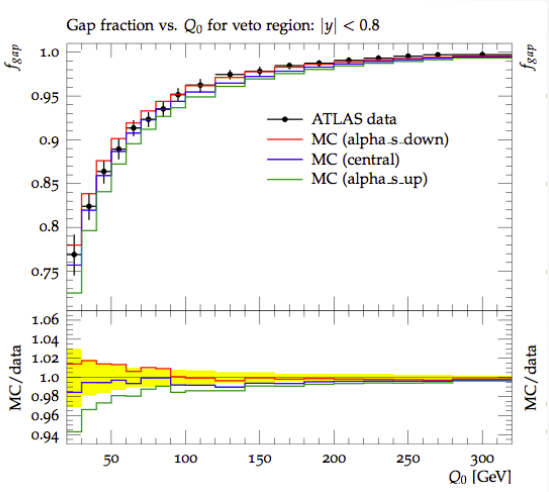
[CMS PAS TOP-12-027], [CMS PAS TOP-12-028]
[Eur. Phys. J. C73 (2013) 2339]

Top Pair Production with jets

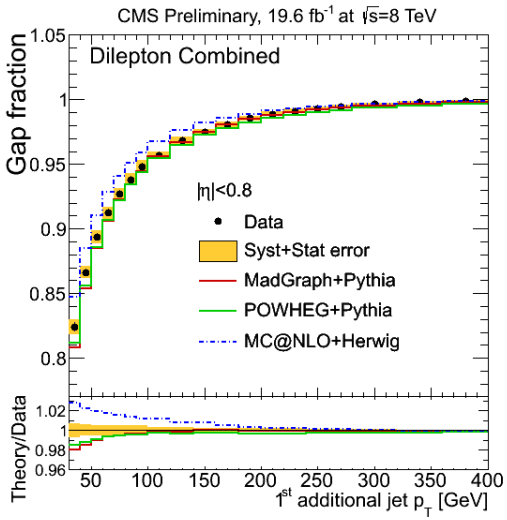
- Allow to study additional jets to test Monte-Carlo generators and QCD
- Reduce the ISR/FSR associated systematic errors
  - Gap fraction

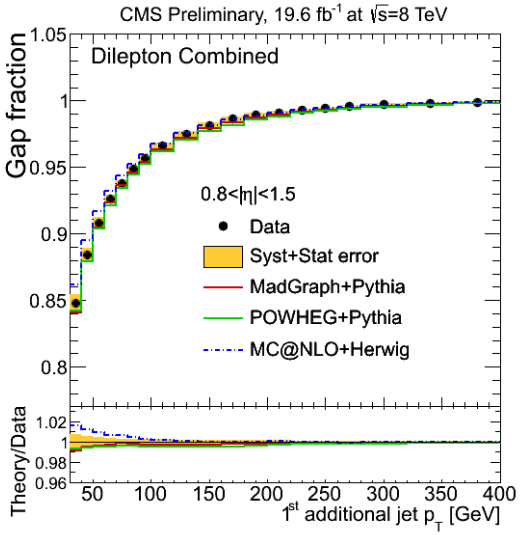
$$f(Q_0) = \frac{n(Q_0)}{N},\ f(Q_{Sum}) = \frac{n(Q_{Sum})}{N}$$

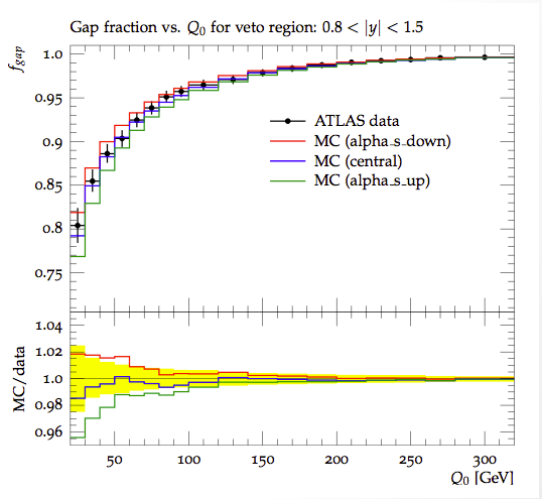
[ATLAS-CONF-2012-155](), [ATL-PHYS-PUB-2013-005]()



[CMS PAS TOP-12-041]()

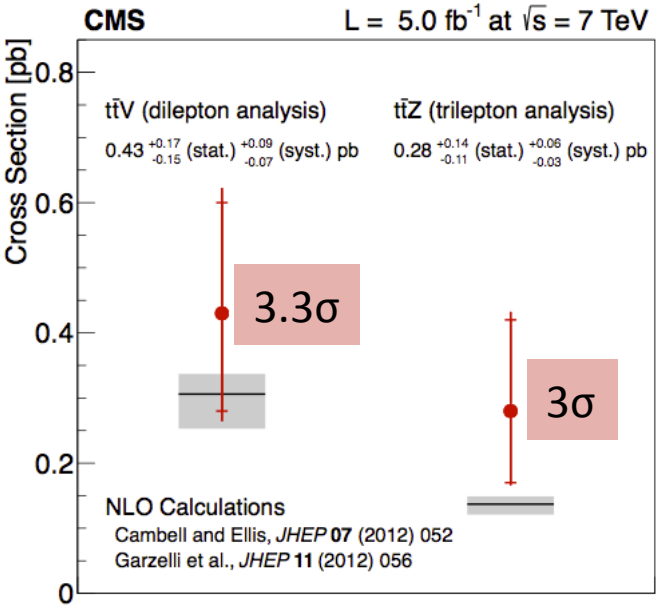


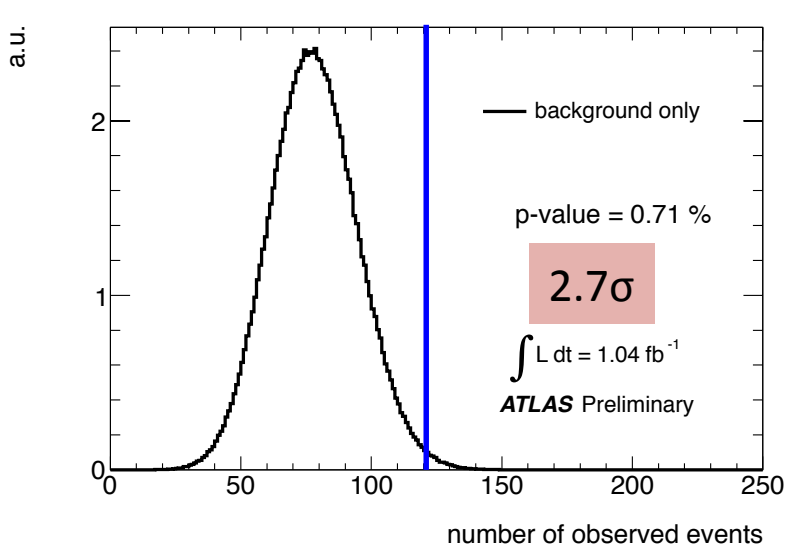




Top Pair Production with W, Z and γ

- Important to measure top pair production cross section in association with vector boson, key test of the SM @ TeV Scale
- New physics may affect the top couplings
- $t\bar{t}Z$ and $t\bar{t}W$: Phys. Rev. Lett. 110 (2013) 172002, ATLAS-CONF-2012-126, Phys. Lett. B 716 (2012) 142-159
- $t\bar{t}\gamma$: ATLAS-CONF-2011-153



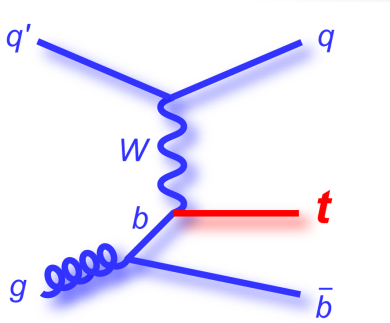


$$\sigma_{t\bar{t}\gamma}(p_T(\gamma) > 8\text{GeV}) = 2.0 \pm 0.5(stat) \pm 0.7(syst) \pm 0.08(lumi)\text{pb}$$

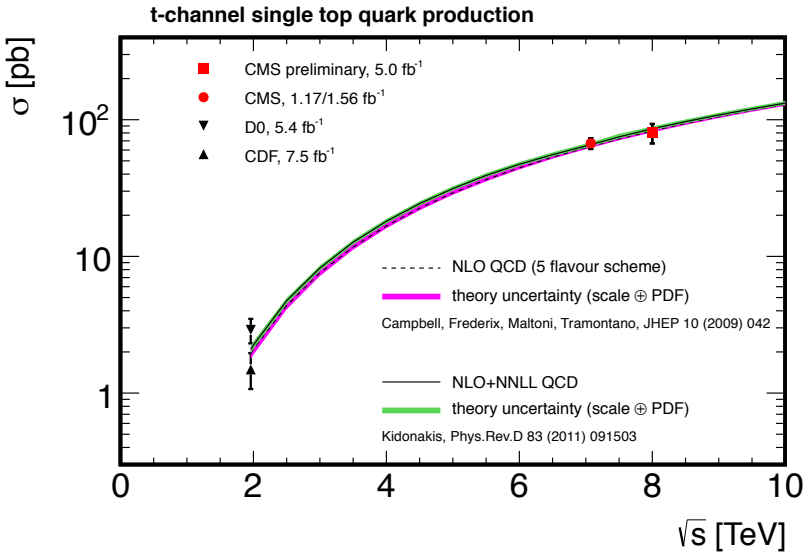
$$SM\ prediction = 2.1 \pm 0.4\text{pb}(LO + LO \rightarrow NLO\ k-factor)$$

t-channel production cross section

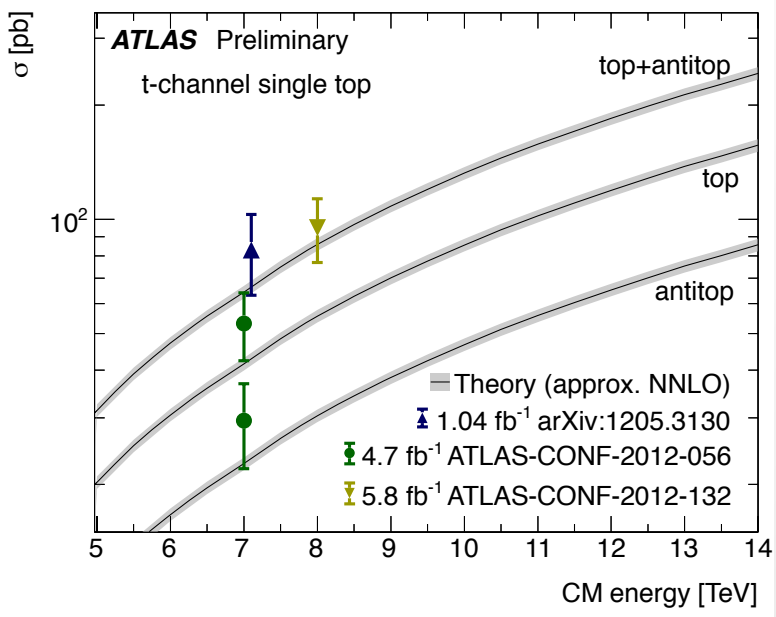
- Single-top
  - Probe the Wtb coupling and Vtb CKM matrix element
  - High background level, MVA technics needed
  - t-channel observed at the LHC (measured to 20%)
  - Observation of W-t channel production (evidence by both experiments)
  - $|V_{tb}| > 0.81$ @ 95% C.L.



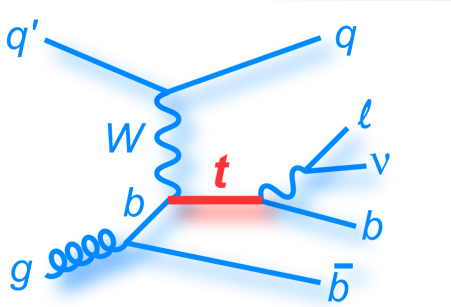
CMS PAS TOP-12-011



ATLAS-CONF-2012-056,
ATLAS-CONF-2012-132

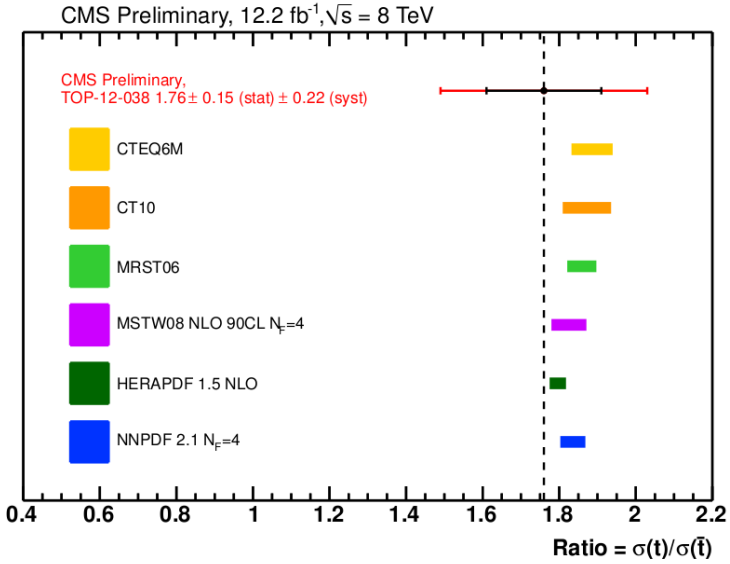


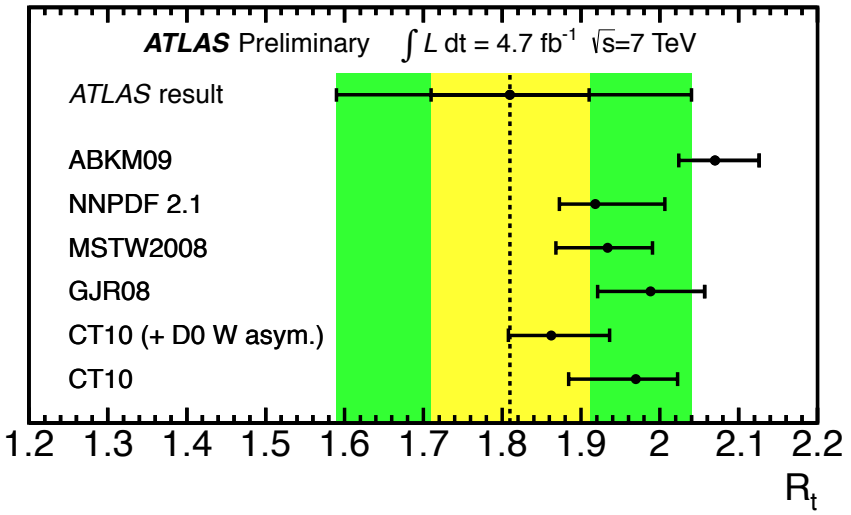
t-channel charge ratio



- Use the lepton charge to build $R_t = \frac{\sigma_t}{\sigma_{\bar{t}}}$ information on proton content's
- Results agrees with Standard Model
- Improving the measurement could lead to better constrain PDF sets

$$R_t = 1.76 \pm 0.14(stat) \pm 0.21(syst) \quad R_t = 1.81 \pm 0.1(stat) \pm 0.21(syst)$$





[CMS PAS TOP-12-038]

[ATLAS-CONF-2012-056]

Observation of W-t channel

- First observation by CMS
- 6σ significance (8TeV)

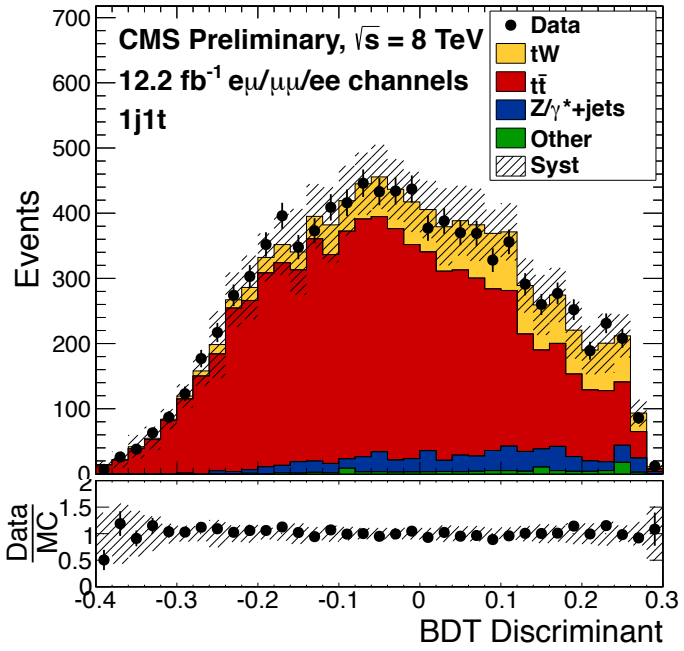
$$\sigma_{W-t} = 23.4^{+5.5}_{-5.4}\,\text{pb}$$

- Evidence by ATLAS
- 3.3σ significance (7TeV)

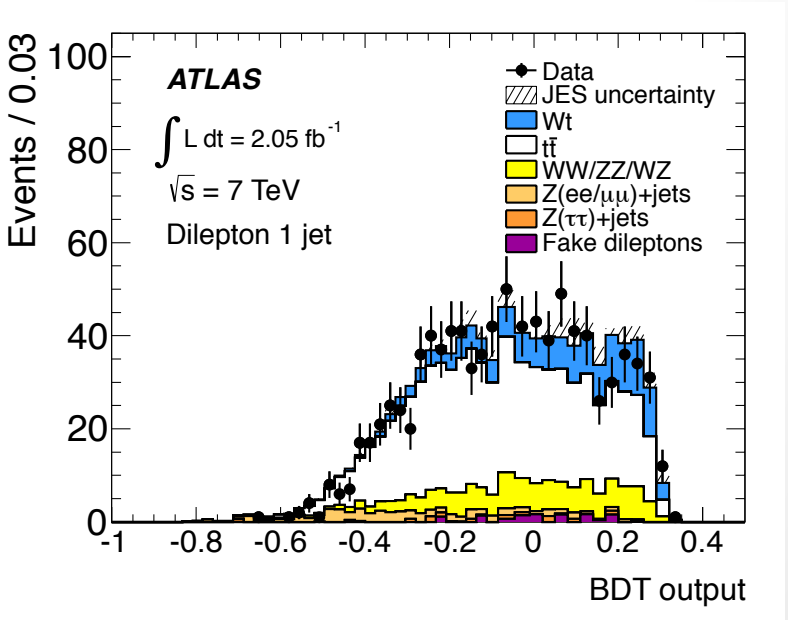
$$\sigma_{W-t} = 16.8 \pm 2.9(stat) \pm 4.9(syst)\,\text{pb}$$

$$\sigma \cong 16^{+1.2}_{-1.2} / 22.4 \pm 1.5\,\text{pb} \;@\; 7/8\,\text{TeV}$$

CMS PAS TOP-12-040



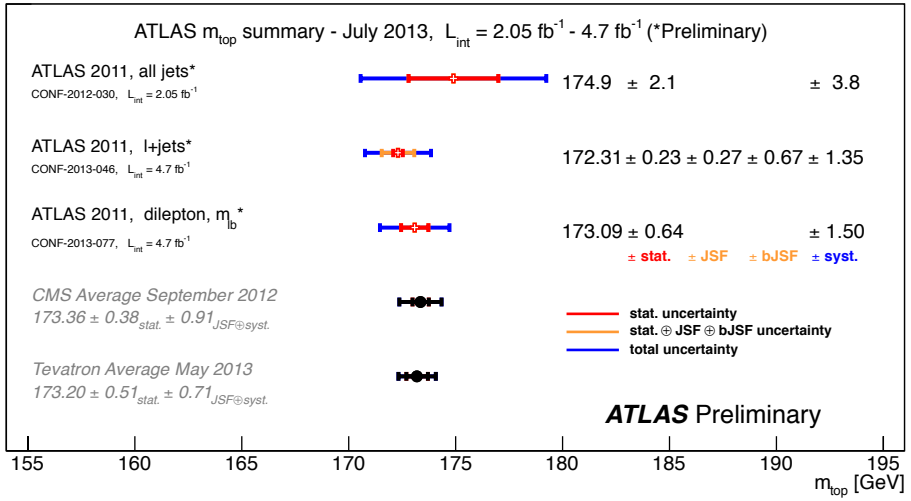
Phys. Lett. B 716 (2012) 142-159



Top Mass

- Essential parameter of SM
- Tevatron legacy: Average dominated by leptons+jets

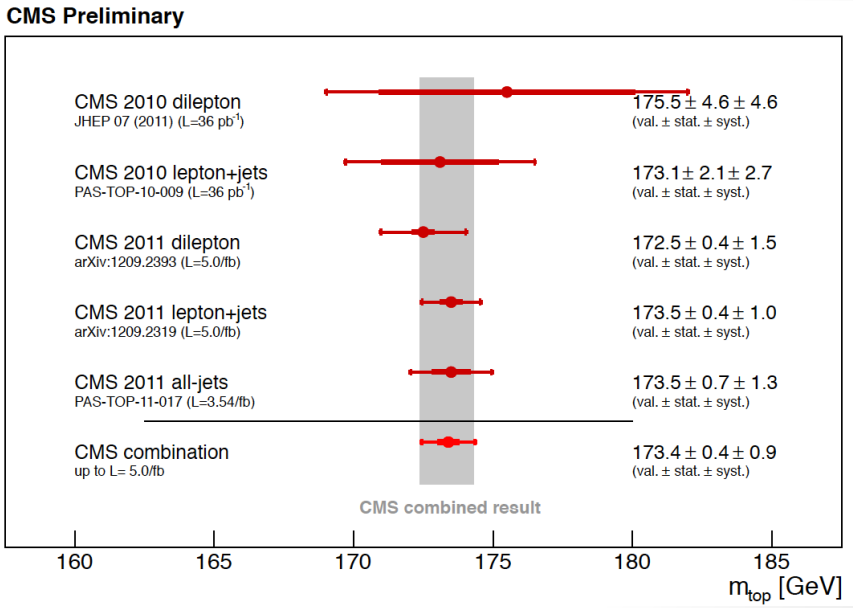
$$m_{top} = 173.2 \pm 0.51(stat) \pm 0.71(syst)\text{GeV}\ (0.5\%)$$



- Average CMS result competitive with Tevatron

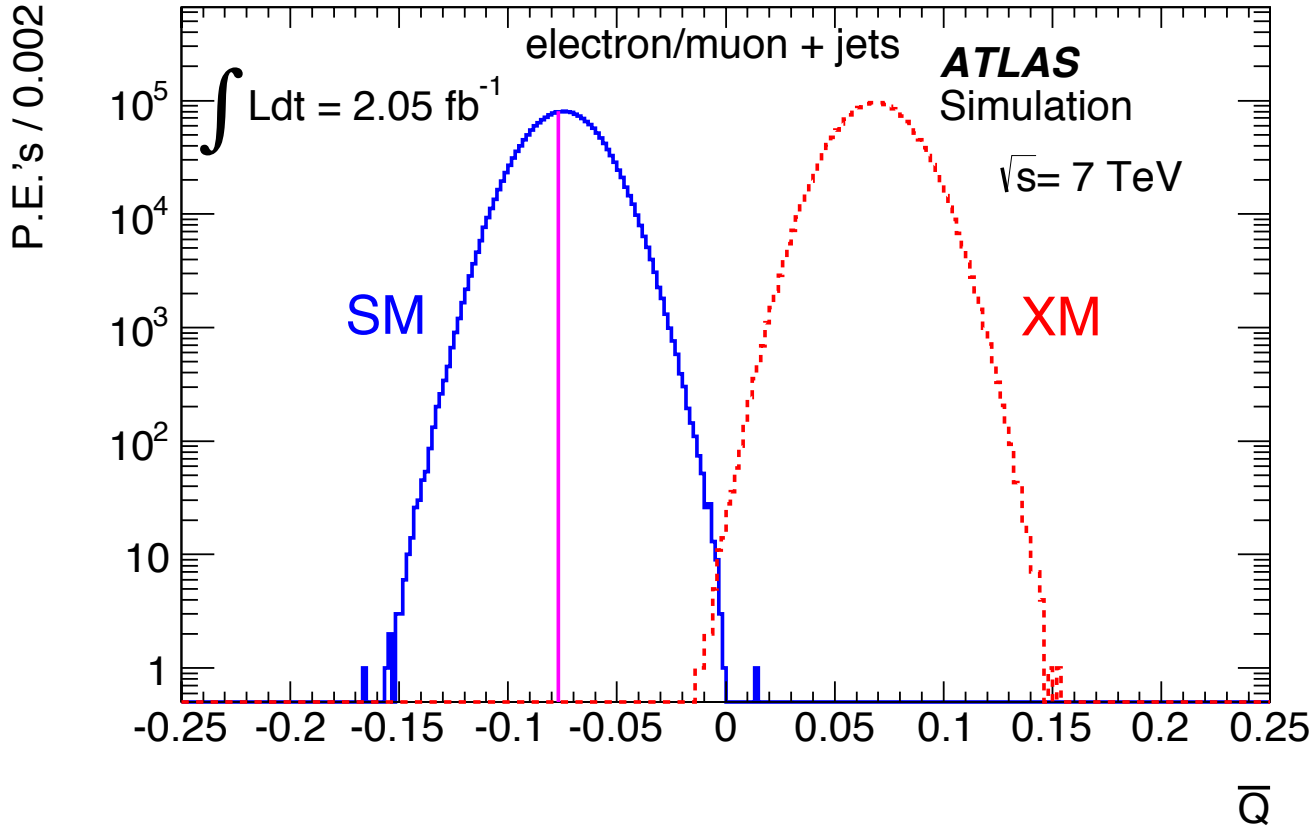
$$m_{top} = 173.4 \pm 0.4(stat) \pm 0.9(syst)\text{GeV}\ (0.57\%)$$

  - Systematics dominated by b-JES and color reconnection



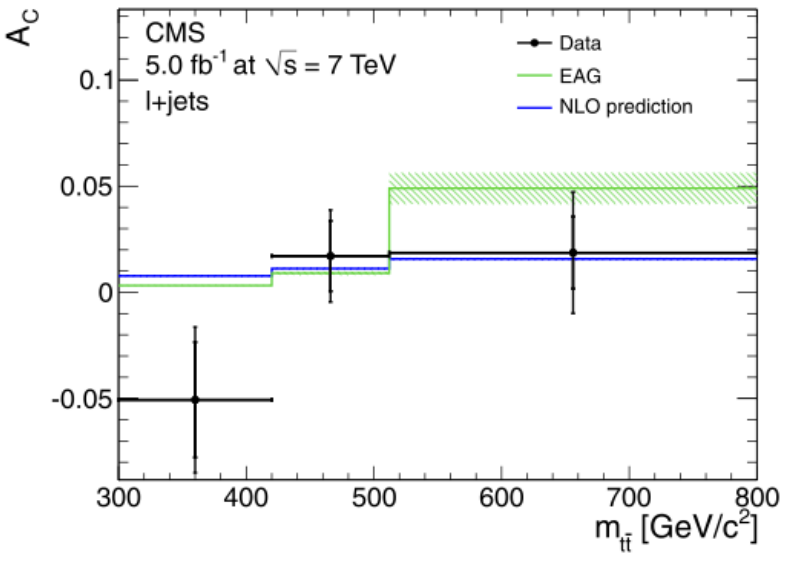
Properties

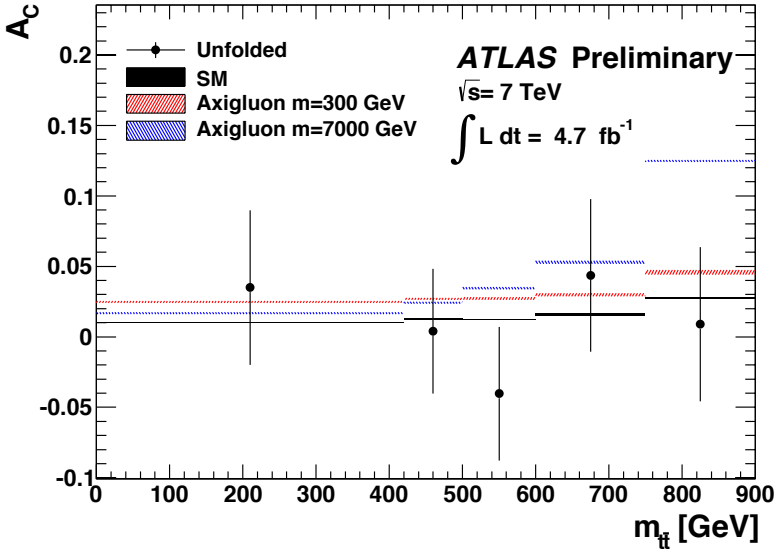
- Charge: $Q = 0.64 \pm 0.02(stat) \pm 0.08(syst)$ (arXiv:1307.4568)



Properties

- Charge: $Q = 0.64 \pm 0.02(stat) \pm 0.08(syst)$ (arXiv:1307.4568)
- Charge asymmetry consistent with SM expectations ATLAS-CONF-2013-078, Phys. Lett. B717 (2012) 129





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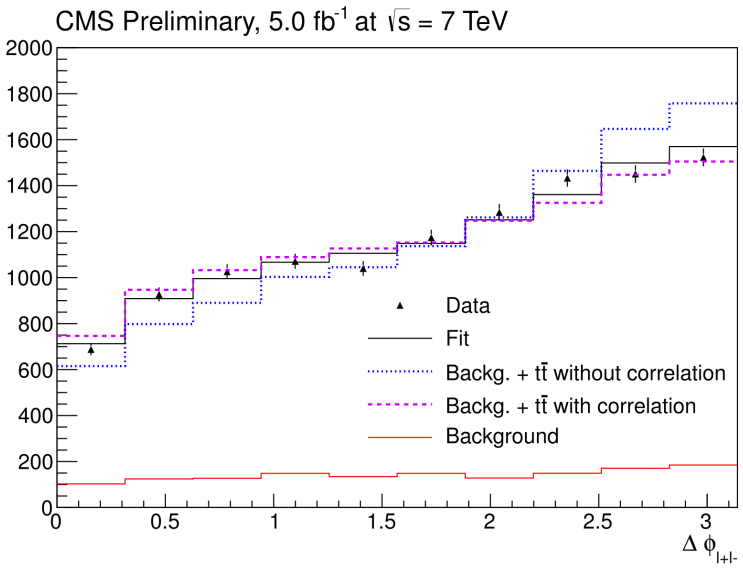
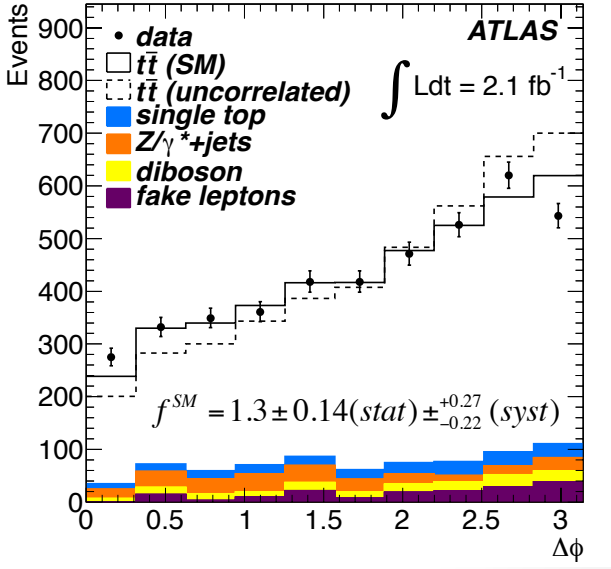
- Charge asymmetry consistent with SM expectations ATLAS-CONF-2013-078, Phys. Lett. B717 (2012) 129
- Spin correlations consistent with SM expectation (f_{SM} = 1 correlations) Phys. Rev. Lett. 108, 212001 (2012) CMS PAS TOP-12-004





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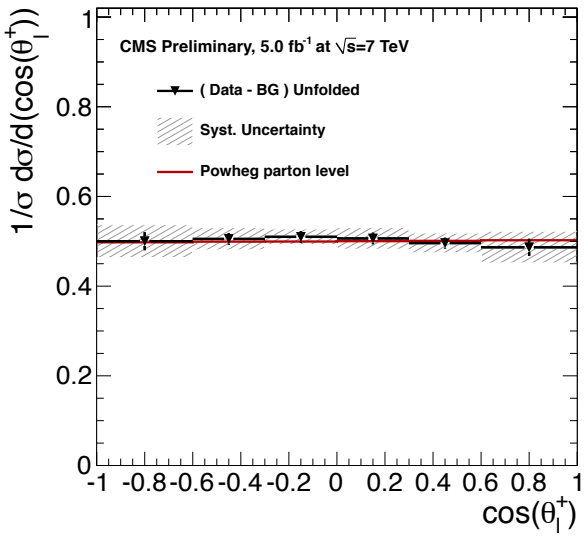

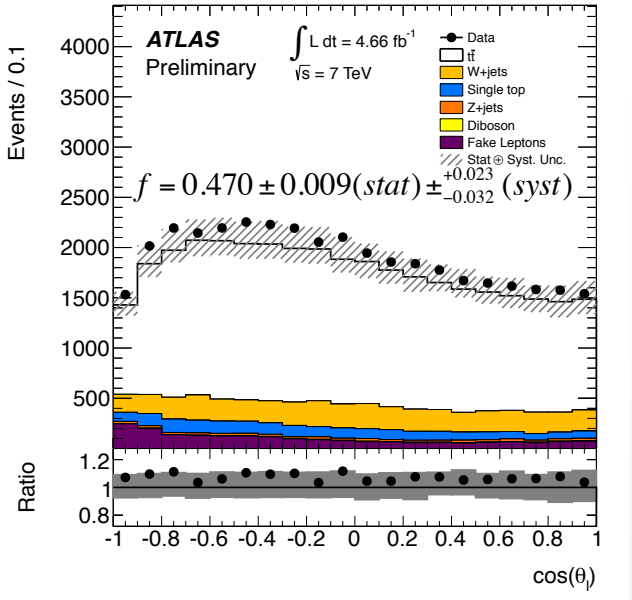

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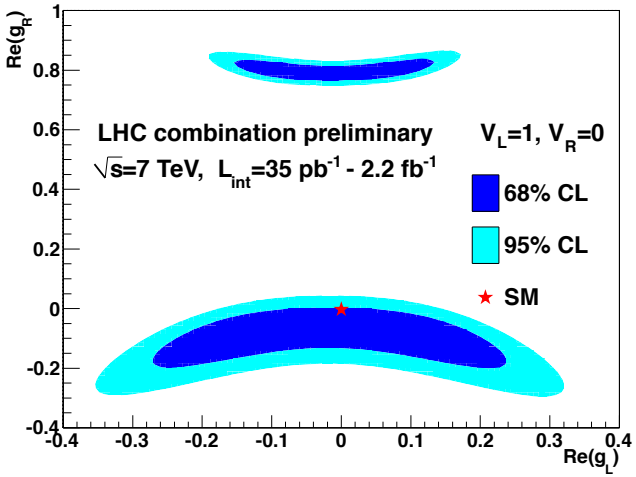
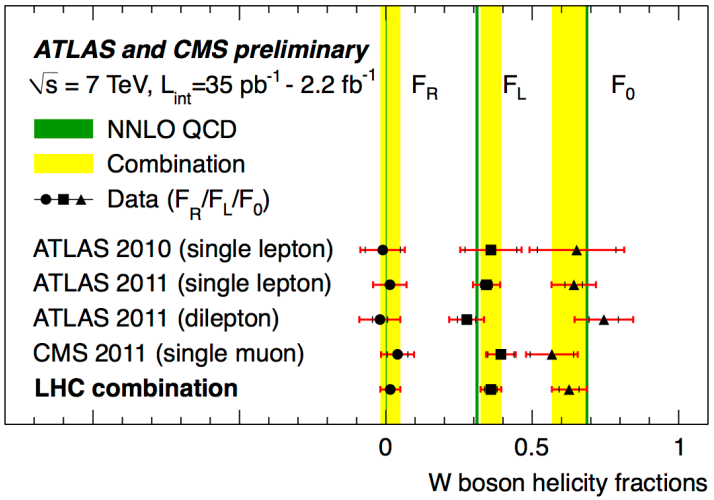
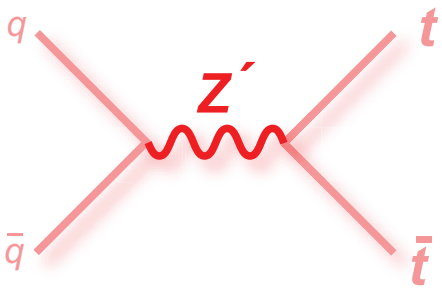
- W helicity fractions in top decays CMS PAS TOP-12-020, CMS PAS TOP-12-027, JHEP 1206 (2012) 088



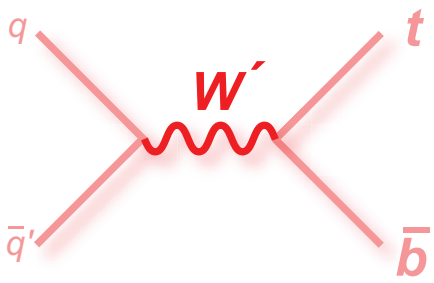


BSM and top quarks

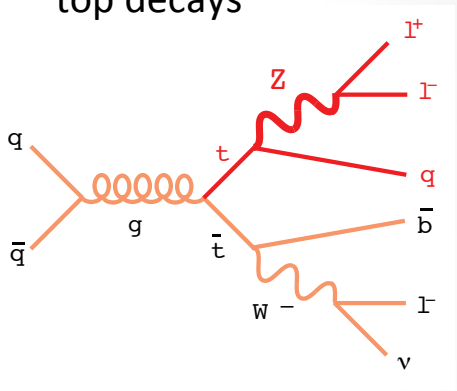
Search for tt resonance (Z' or KK gluons)



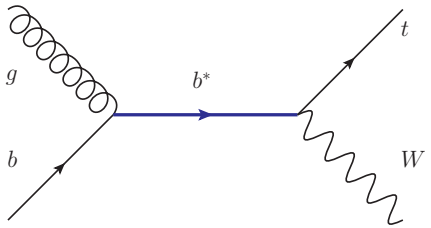
Search heavy vector boson



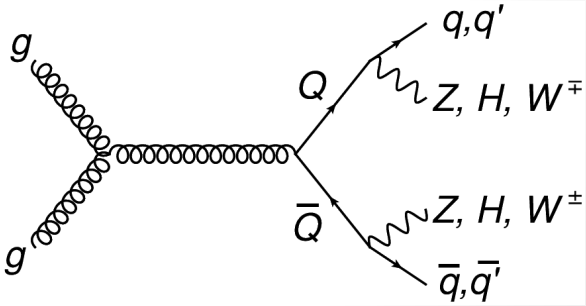
Search for FCNC in top decays



Search for excited states (t*, b*)



Search for heavy quarks
T -> Wb, Ht, Zt
B-> Wt,Hb,Zb



BSM and top quarks

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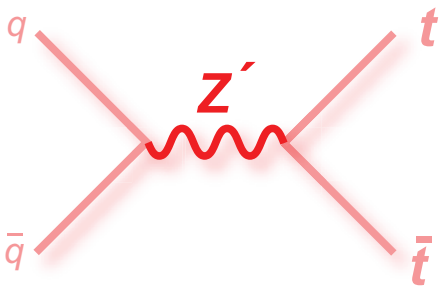

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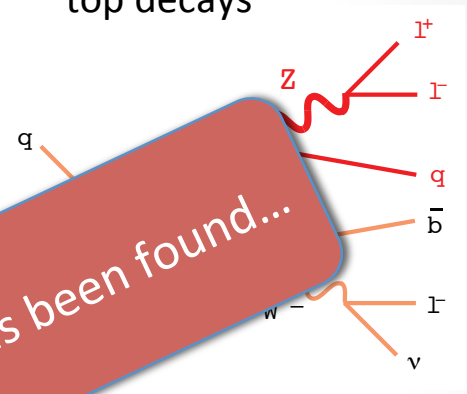
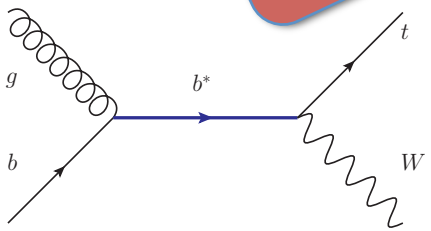


Search heavy vector boson

No significant deviation from standard model has been found...

Search for e



See Gustaaf Brooijmans and Marco Cardaci talks

Search for heavy quarks
T -> Wb, Ht, Zt
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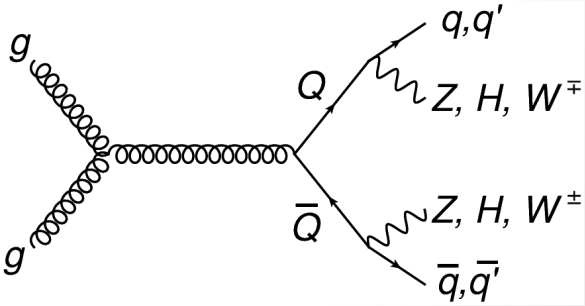


Conclusions

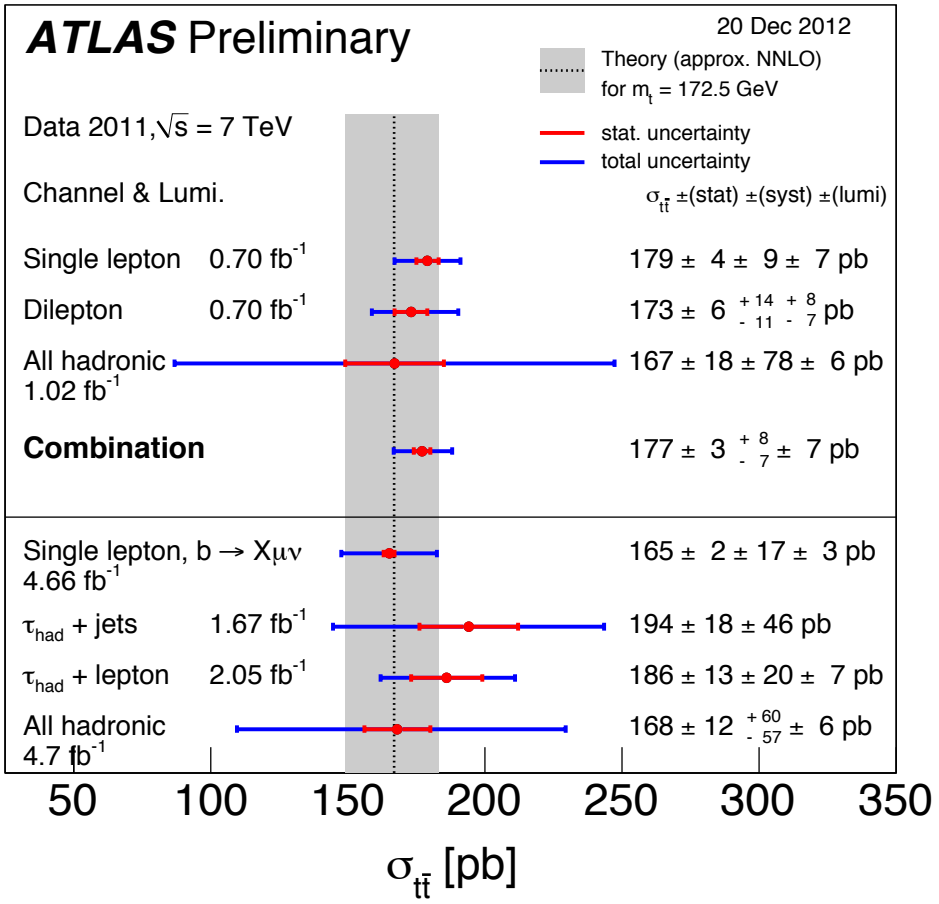
- LHC top physics program is well advanced!
- Many analyses are systematically limited
- Production:
  - Pair production cross section within 4-6% uncertainties
  - Single top t-channel cross section within 20% uncertainty
  - W-t-channel production observed
  - Differential cross section
  - Associated production $t\bar{t}\gamma, t\bar{t}V, t\bar{t}j$
- Properties:
  - Top mass uncertainty 0.57% (0.98GeV)
  - Polarization, asymmetry and couplings consistent with SM
  - No spin correlation hypothesis excluded
- Beyond Standard Model:
  - No new physics observed yet but stringent limits!
- Full set of top results:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

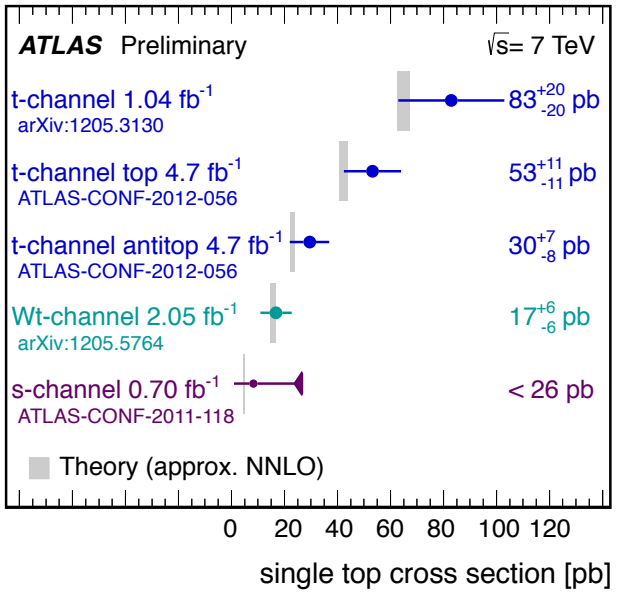
Feynman's diagrams from:
http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_feynman_diagrams.html

Bonus

Top cross section

- All ATLAS results



Single Top

- Probe the Wtb coupling and Vtb CKM matrix element
- High background level, MVA technics needed
- T-channel observed at the LHC
- Observation of W-t channel production (evidence by both experiments)