ATLAS RESULTS ON TOP QUARK PHYSICS

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on behalf of the ATLAS Collaboration

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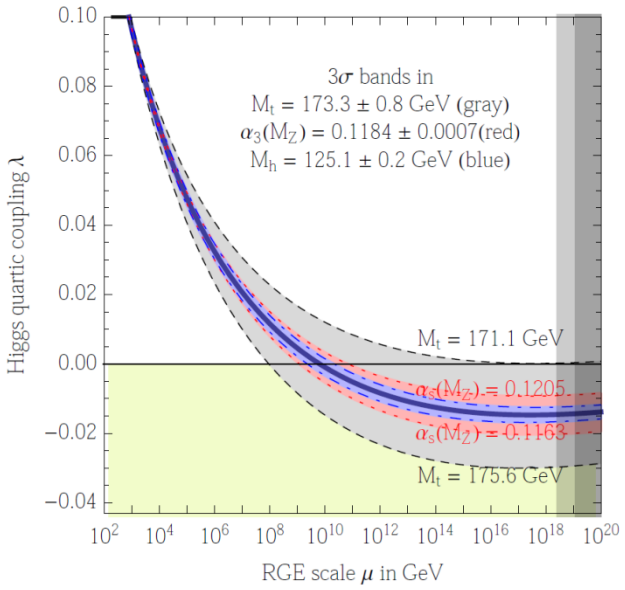
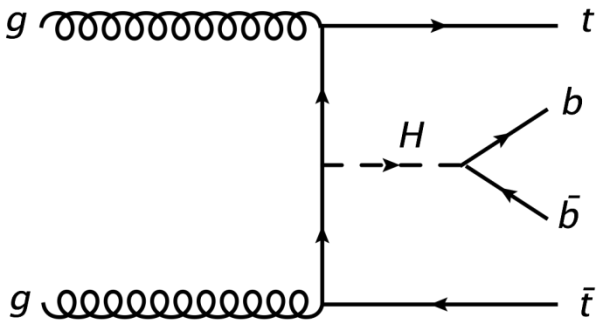
Motivation

- Top quark is expected to play a special role in EWK symmetry breaking because of the very large Yukawa coupling.
  - Production and decay of Higgs
  - Higgs mass
  - Running of the Higgs self-coupling
- BSM physics processes often produce top quarks or happen in decays of top quarks.
  - e.g.: 3rd-gen SUSY
  - Flavor-changing neutral current (FCNC)
  - Top quark pair production is a background to many searches and measurements
- Top quarks are a precise tool to study pQCD and PDFs.
  - Heavy scale
  - Top quark life time, ~ $5 \cdot 10^{-25}$ s., is shorter than the hadronization time of ~ $2 \cdot 10^{-24}$ s.

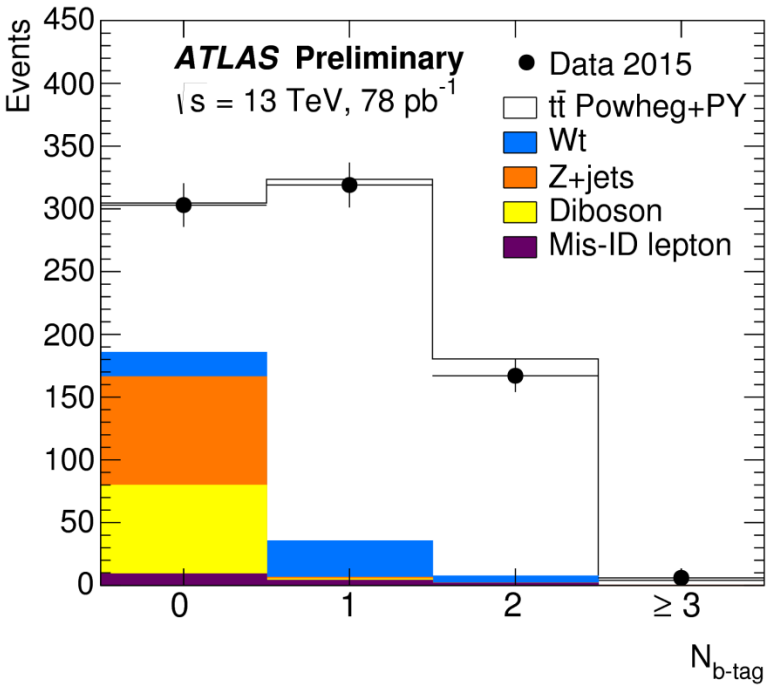




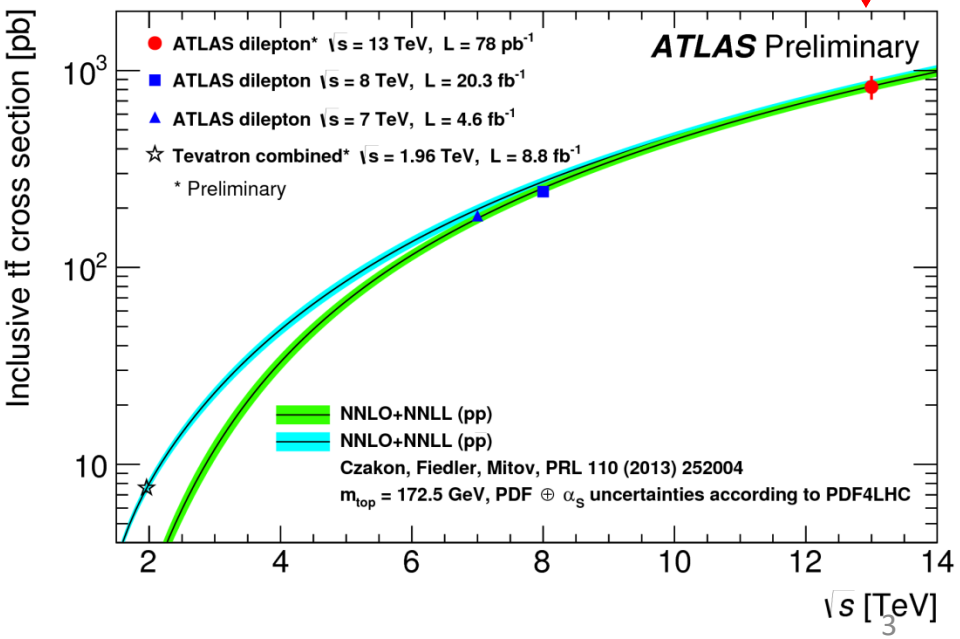
$t\bar{t}$ production at 13 TeV

- The very early ATLAS data reveals plenty of top quarks, enough to observe the top quark pair production!
- The measured cross-section, 825 ± 49 (stat) ± 60 (syst) ± 83 (lumi) pb, is in agreement with the NNLO+NNLL prediction.
- The cross-section is measured in the e-μ channel + 1-2 b-jets.

ATLAS-CONF-2015-033

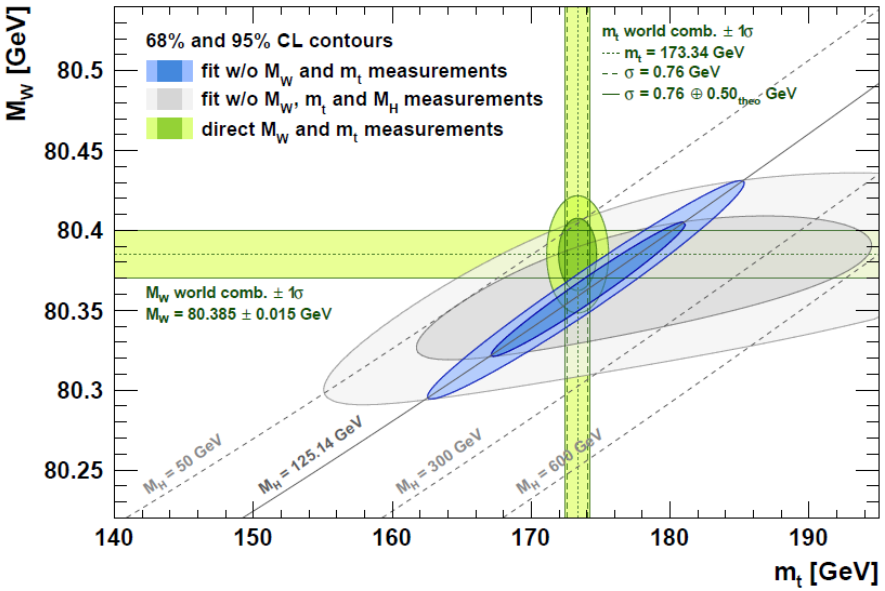


New!

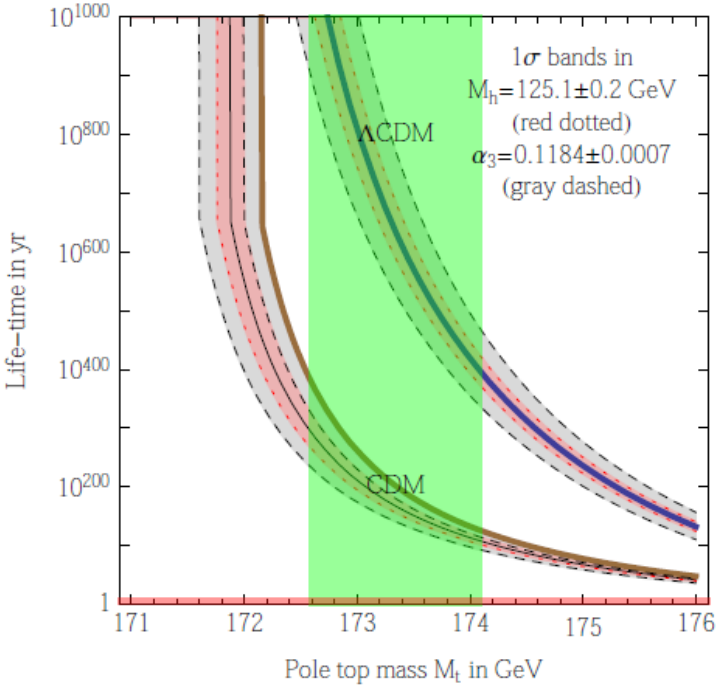


Top Quark Mass

- It is important to know mass of top quark for a variety SM calculations.
  - Ex: The global Standard Model fit to electroweak precision data
  - Higgs couplings (including the self-coupling) → Vacuum stability



Future precision measurements may indicate new physics. See: arXiv:1407.3792

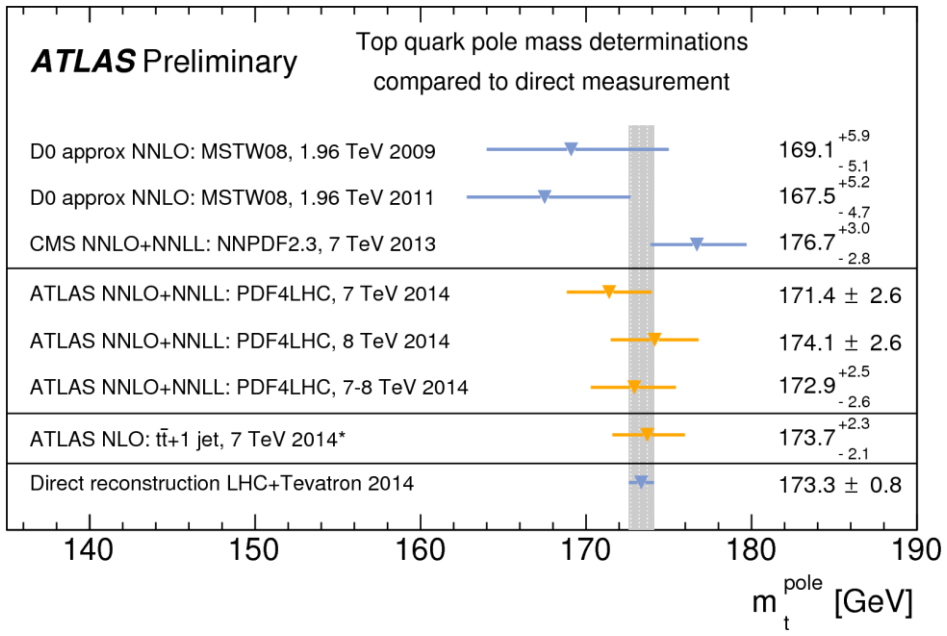


The life-time of the electroweak vacuum, with two different assumptions for future cosmology: universes dominated by the cosmological constant (ΛCDM) or by dark matter (CDM).
See: 10.1007/JHEP12(2013)089

Top Quark Mass. What?

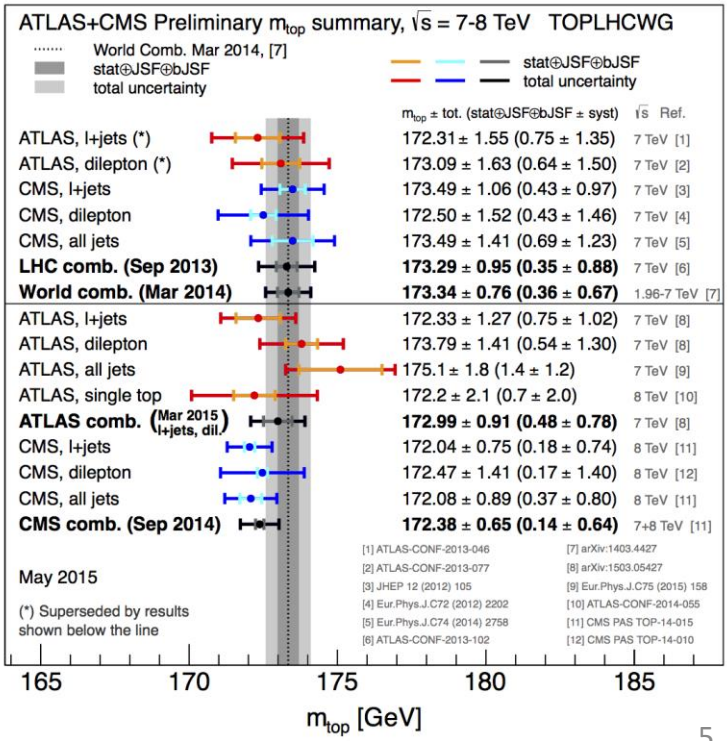
- Two kinds of measurements:
  1. Parameter in a Monte Carlo Event Generator (e.g. PowHeg)
  2. Pole mass (in the propagator)
- The expected difference is of about 1 GeV.
- Both kinds are consistent given the precision of these measurements.

2)



Pole Mass from $t\bar{t} + 1jet$: $173.7^{+2.3}_{-2.1}$ GeV

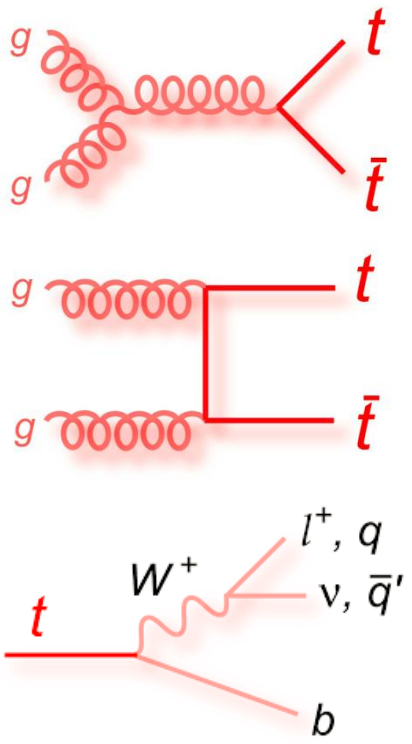
1)



ATLAS combined: 172.99±0.91 GeV

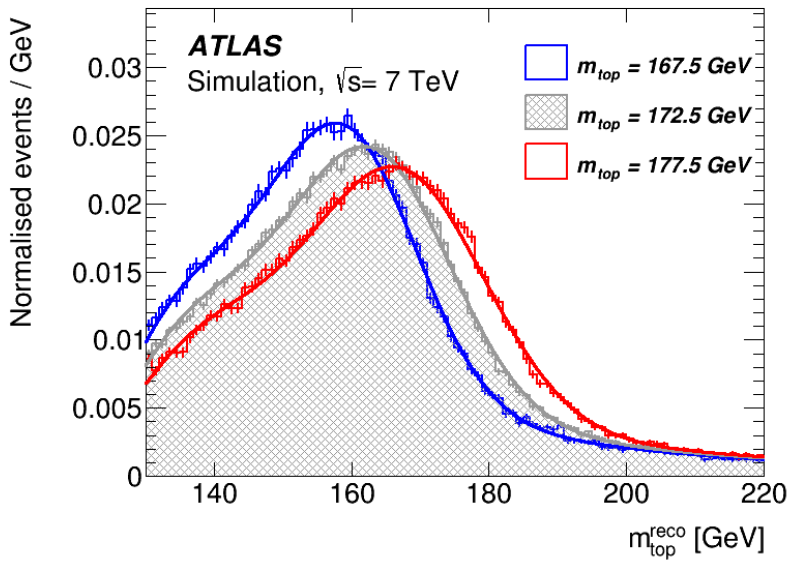
Direct Measurements of Mass

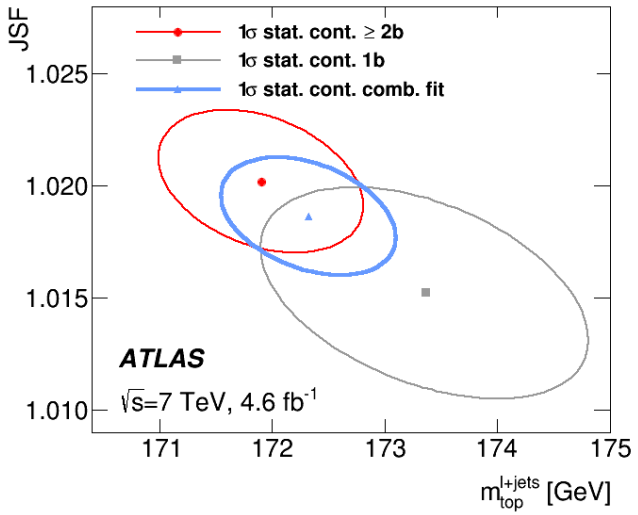
- Calculated mass using kinematic properties of $t\bar{t}$ events, invariant masses of the decay products and kinematic distributions
  - Kinematic fits
  - Matrix element calculations
- Final states: all-hadronic, 1-lepton, 2-lepton
  - Robust measurement



e.g.: arXiv:1503.05427; template fit of 1- and 2- lepton events

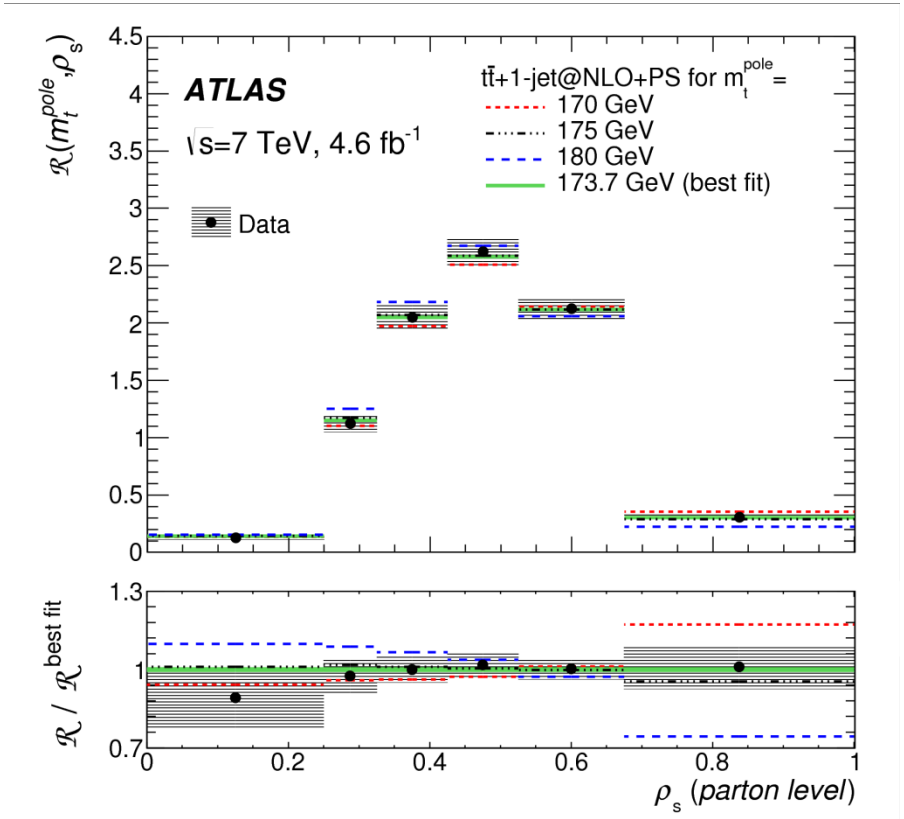
172.99±0.48(stat)±0.78(syst) GeV





Measurements of Top Pole Mass

- The normalized differential cross section for top-quark pair production in association with at least one jet is studied as a function of 1/m($t\bar{t}$+1-jet). This distribution can be used for a precise determination of the top-quark pole mass since gluon radiation depends on the pole mass.



$\rho_s \sim 1/m(t\bar{t} + 1jet)$

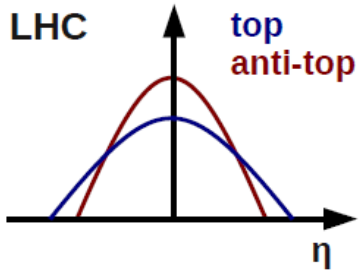
$R \sim d\sigma/d\rho$

Most precise ATLAS measurement of the top-quark pole mass: $173.7^{+2.3}_{-2.1}$ GeV

Another method – extraction of the poll mass from the inclusive $t\bar{t}$ cross-section.

$t\bar{t}$ Charge Asymmetry

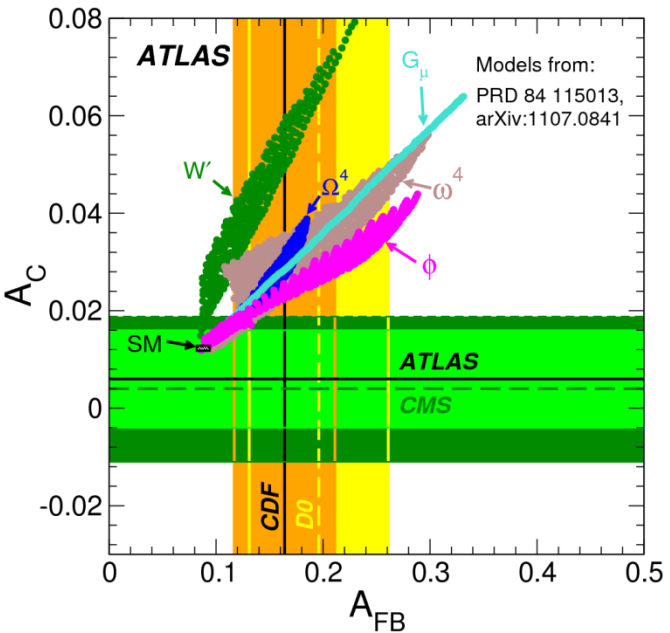
- At leading order you do not expect any charge asymmetry.
- Significant asymmetry may appear in presence of BSM physics.

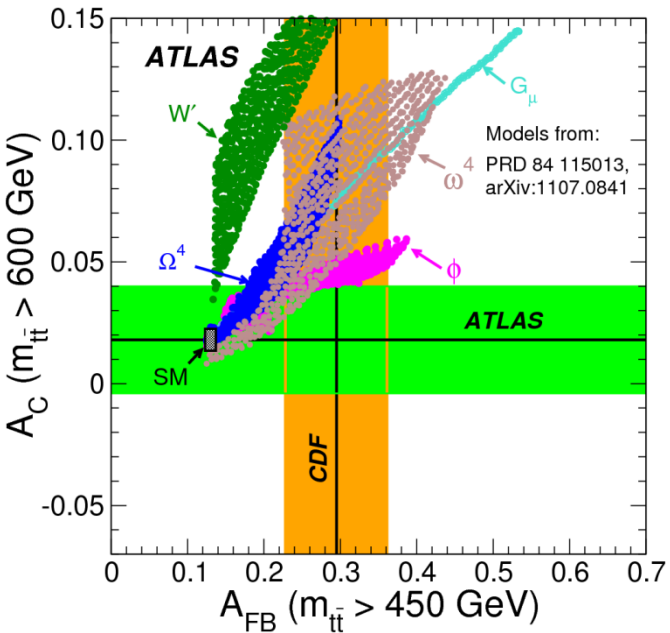


$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

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

- ATLAS finds the charge asymmetry consistent with the SM predictions:

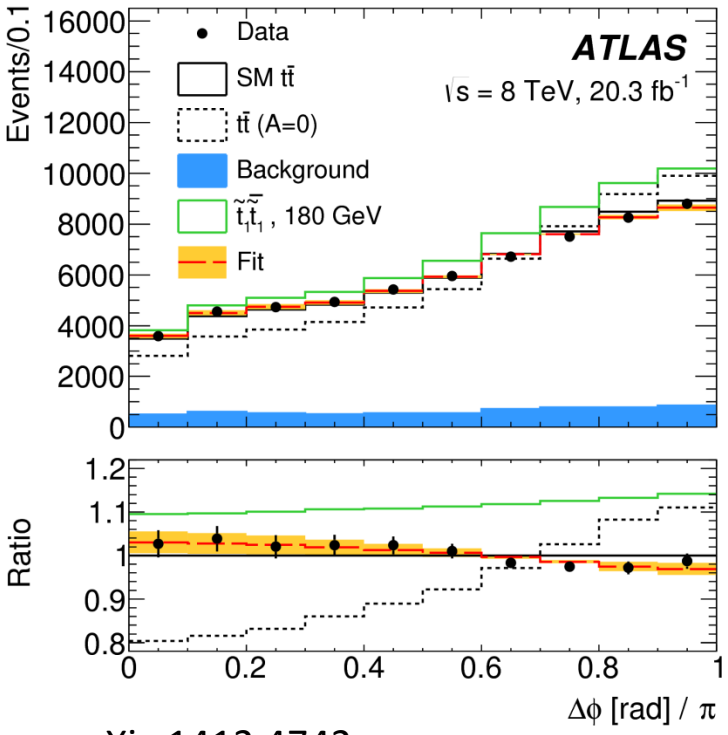




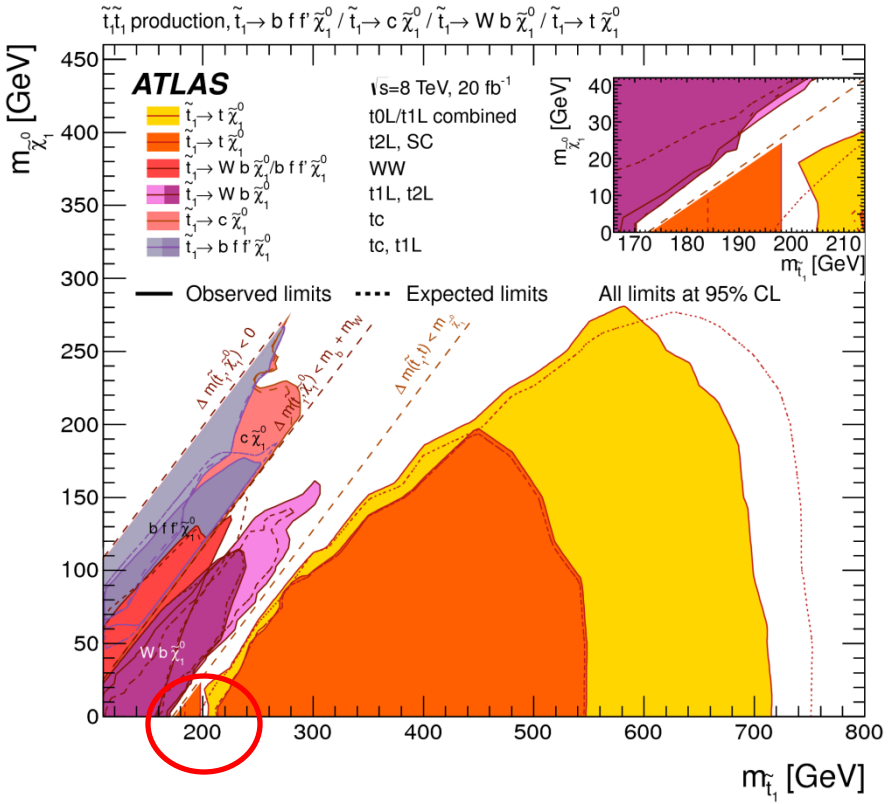
ATLAS has also measured A_c with two-lepton events: arXiv:1501.07383
Less dependent on the reconstruction algorithm.

Top quark Spin Correlations

- Spins of t and $\bar{t}$ are correlated in the pair-production process.
- The correlation is extracted from template fit of the distribution in the angular separation between leptons $\Delta\varphi(l^+l^-)$.
- The measurement is sensitive to SUSY models with top squarks.

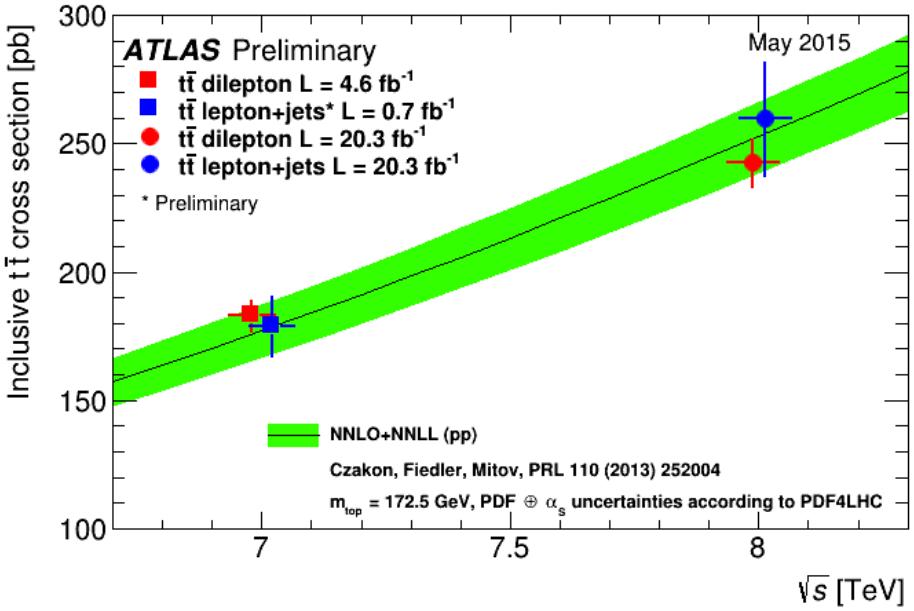


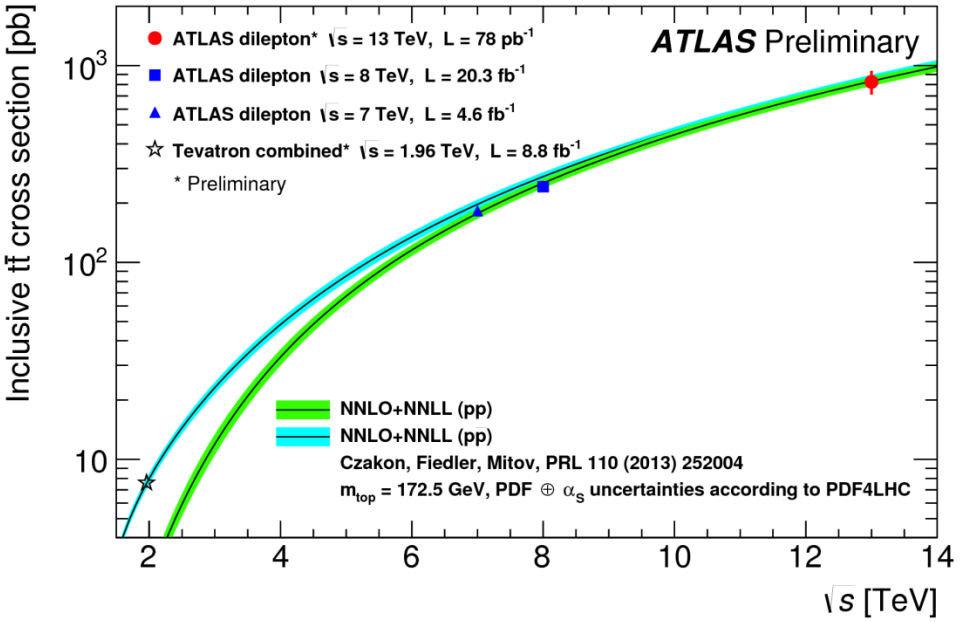
arXiv:1412.4742



Top quark as a tool for pQCD and PDFs

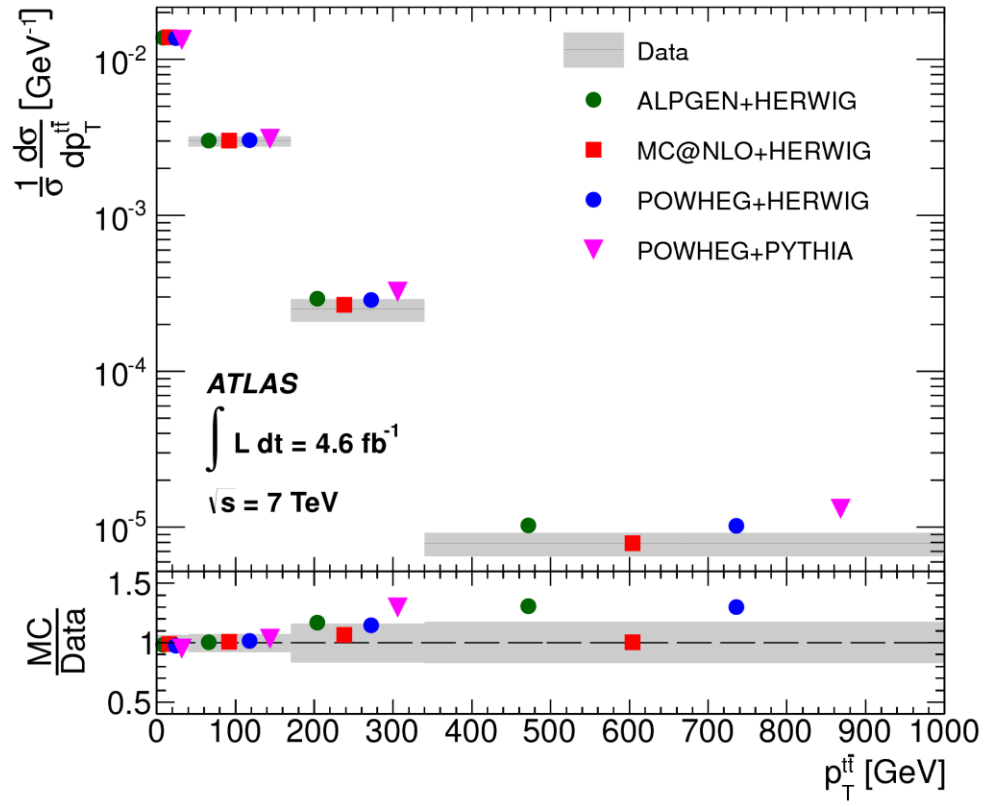
- Top quark pair production is a robust tool for testing pQCD calculations.
- The inclusive cross-sections for $t\bar{t}$ production are calculated at high accuracy, NNLO+NNLL.
- The cross-sections are measured reliably in the 1- and 2-lepton channels.
- Sensitive to gluon pdf at high x.

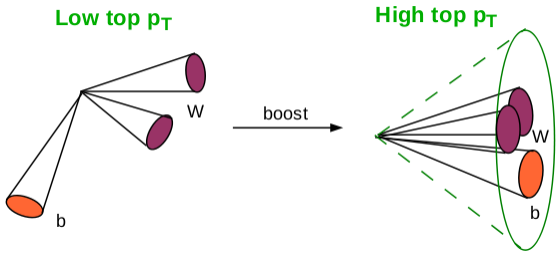


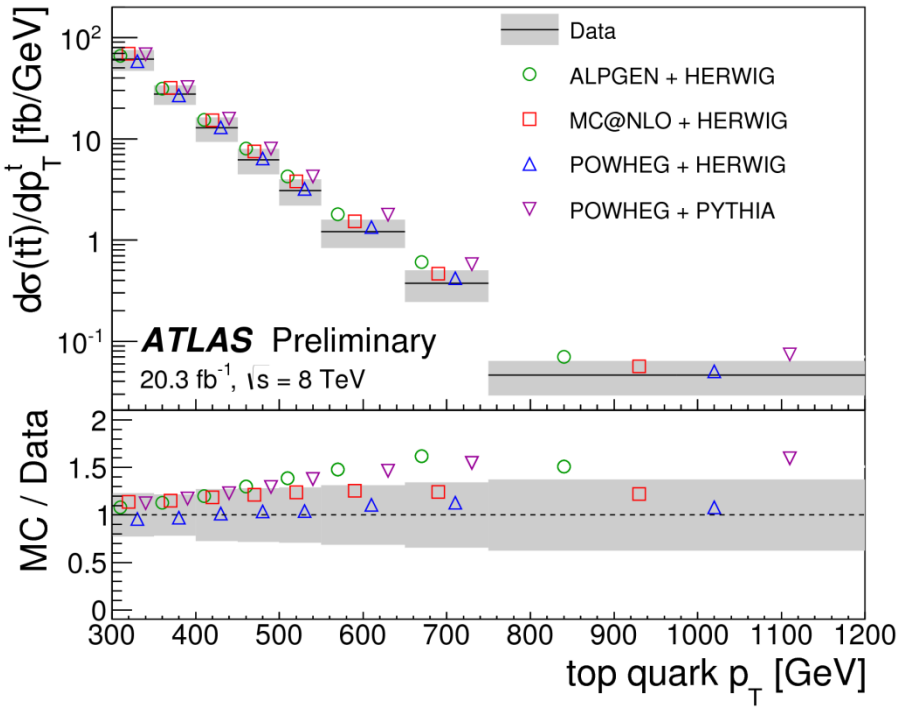


Differential cross-sections

- Top pair production is a major background to a variety of rare and BSM processes. We need to model it well.
- Detailed test of theory predictions

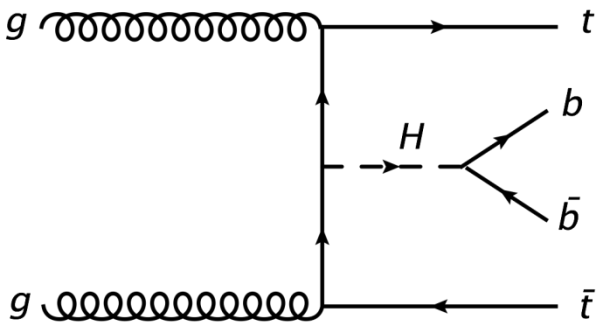




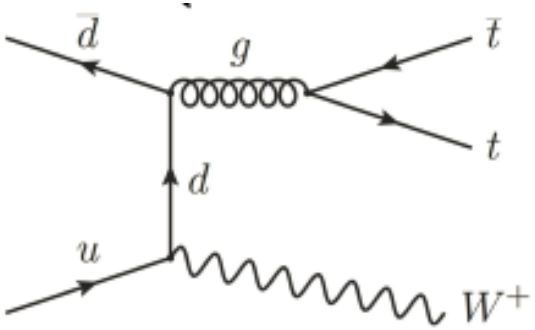


Production of boson in association with $t\bar{t}$

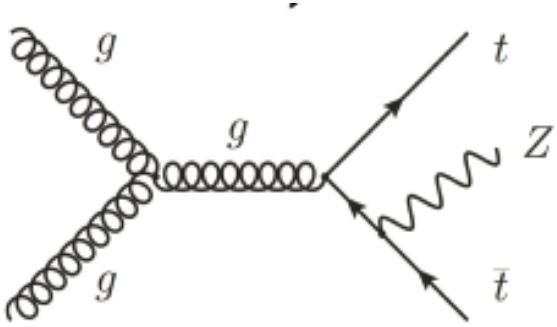
- Measurements of $t\bar{t}W$, $t\bar{t}Z$, and $t\bar{t}\gamma$ cross sections test reliability of the predicted cross section for $t\bar{t}H$.
  - All are known at NLO in α_s
  - Similar scales
- The $t\bar{t}Z$ cross-section is sensitive to the top-to-Z coupling.



Higgs is mostly in FSR



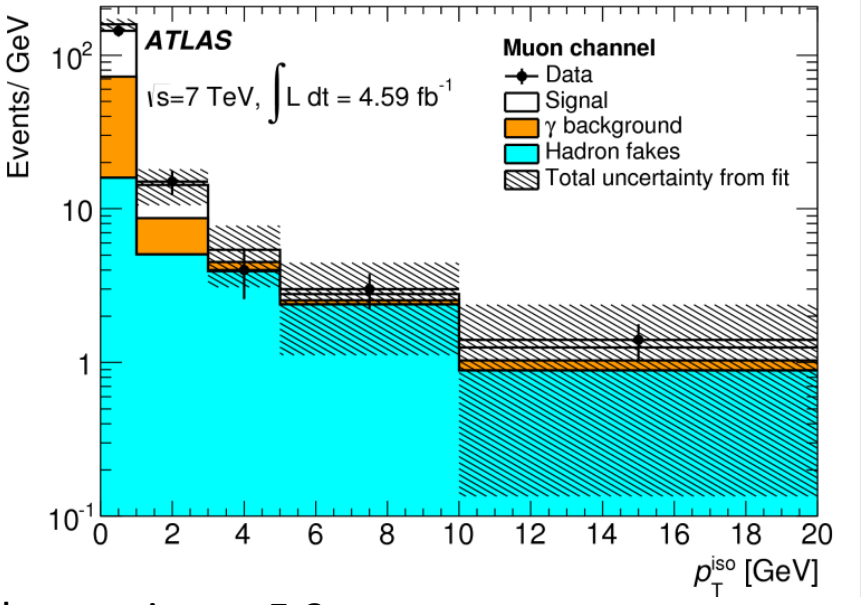
W is only in ISR

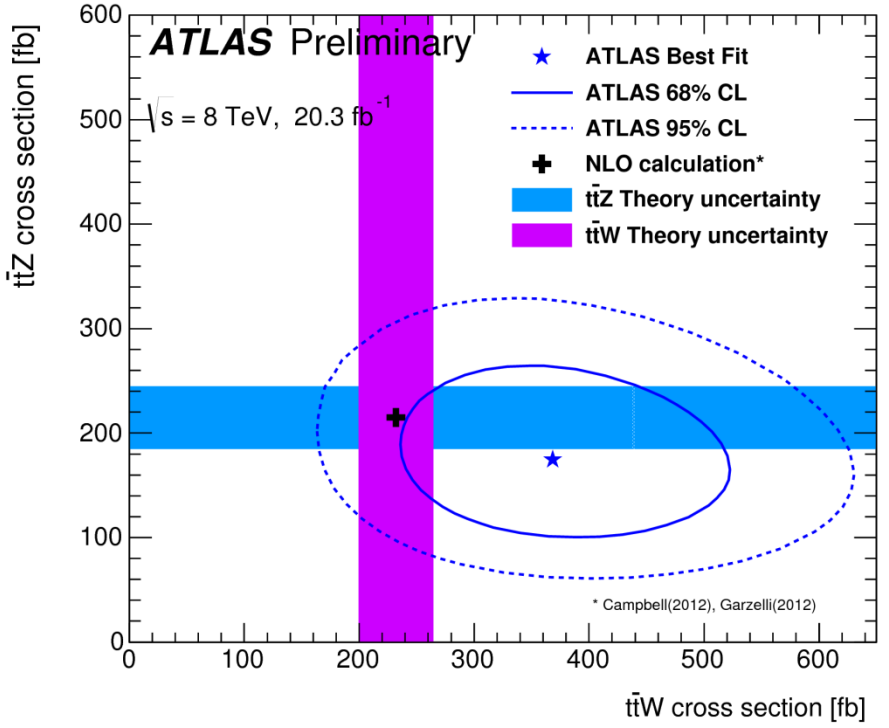


Z and γ can be in ISR and FSR but the couplings are different.

$t\bar{t}W$, $t\bar{t}Z$, and $t\bar{t}\gamma$ cross sections

- ATLAS has measured all these cross sections:





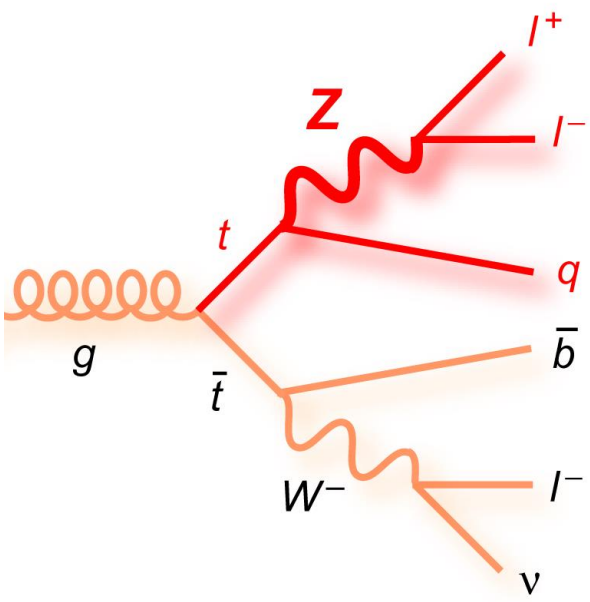
Observation at 5.3σ:
$\sigma(tt\gamma)_{fid} \times BR = 63 \pm 8(stat)\ ^{+17}_{-13}(syst) \pm 1(lumi)$ fb:
good agreement with the LO calculation
normalized to the NLO prediction : 48 ± 10 fb

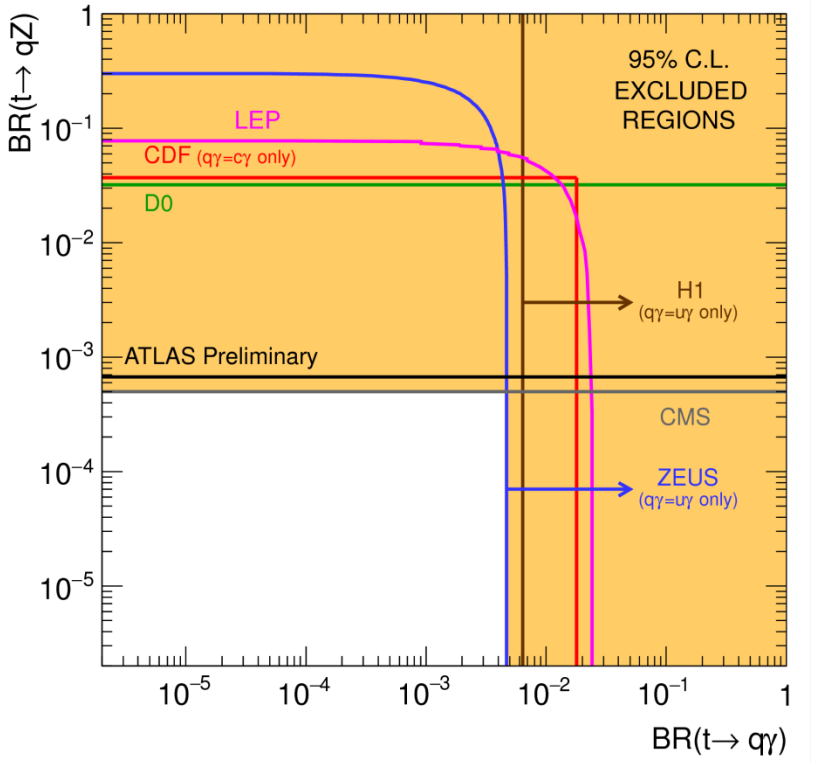
$t\bar{t}W$ is observed at 5.0σ,
$t\bar{t}Z$ is at 4.2σ.
Good agreement with NLO predictions.

So far the cross-sections are in good agreement with theory predictions.
May be enhanced by BSM processes.

Searches for FCNC top decays

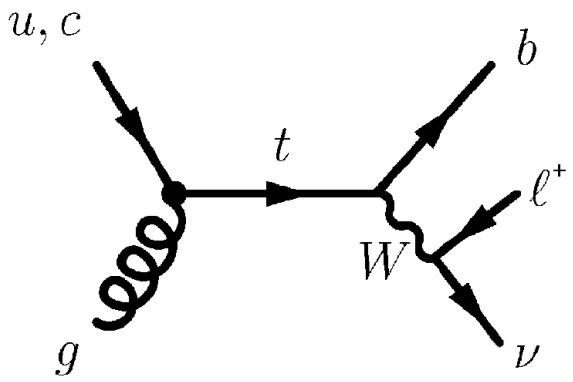
- The flavor-changing neutral current (FCNC) decays of top quarks such as $t \to Zc$ are rare in the SM but may be appear in presence of new physics.
- The analysis, TOPQ-2014-08 , looked for $t\bar{t} \to WbZc \to 3l + jets$ decays.
- No deviation from SM was observed: Br($t \to Zc$)<7·10^{-4} @ 95%Cl.

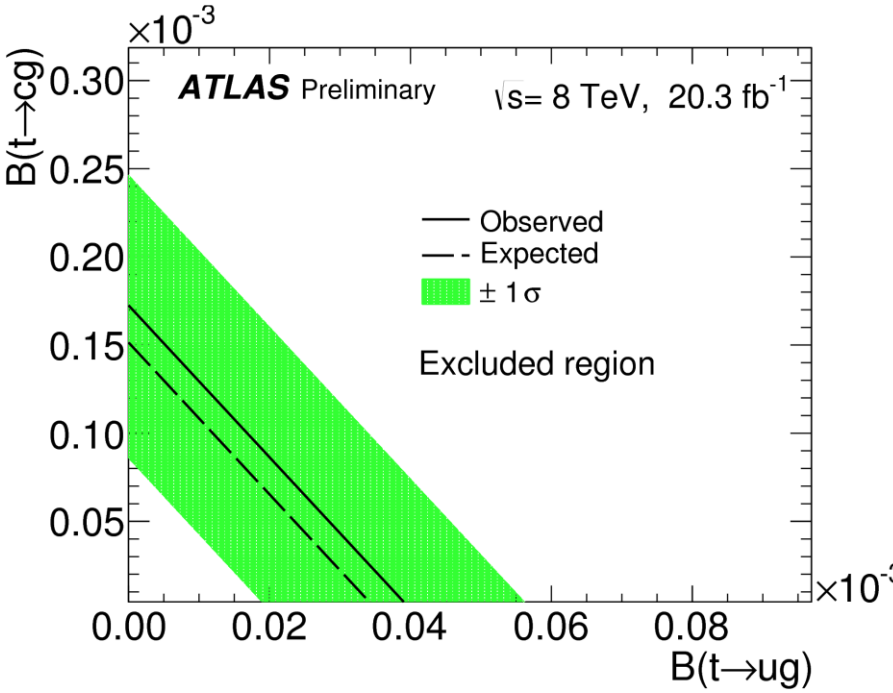




Searches for FCNC top production

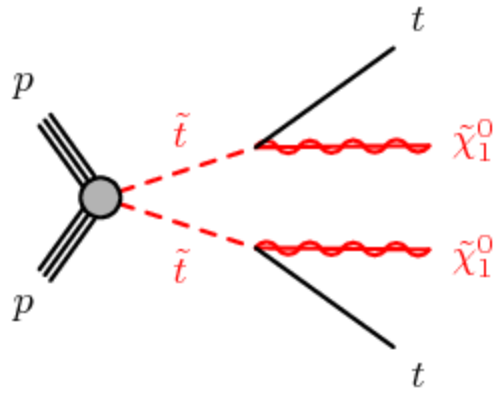
- Production of single top quarks can be greatly enhanced in presence of $t-g-c$ and $t-g-u$ couplings.
- The analysis, TOPQ-2014-13 , did not find any excess in the rate of single top quark decays without additional jets.
- No deviations from SM were observed: Br($t \to ug$)<3.9·10^{-5} and Br($t \to cg$)<18·10^{-5} @ 95%Cl.

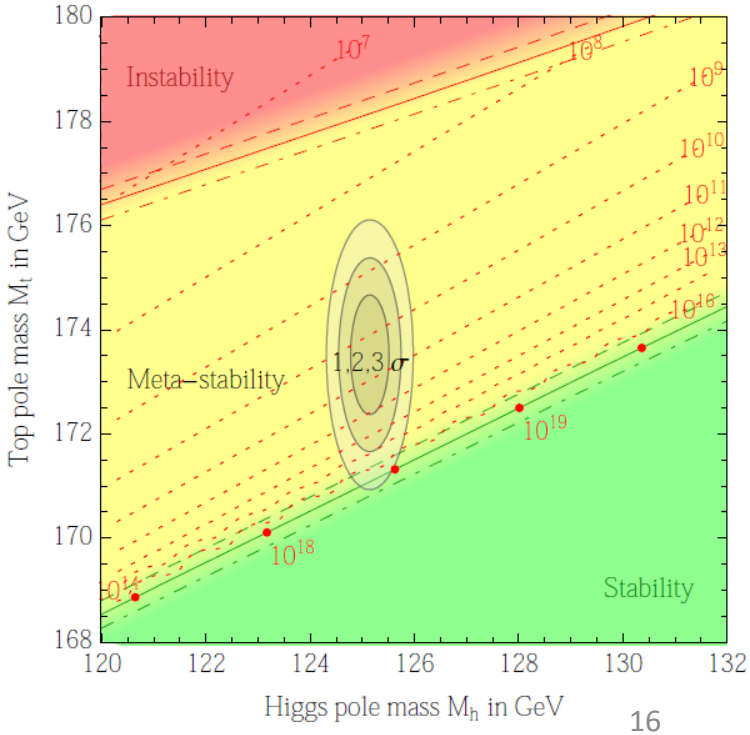




Conclusions and outlook

- The LHC is a top quark factory.
- That enables ATLAS to conduct an extensive set of measurement related to the top quark.
- These results are of great importance for tests of the SM and for the discovery potential of the LHC experiments.
  - Essential for Higgs measurements and searches for BSM
- The future is bright. Data at 13 TeV will greatly enhance the strength of ATLAS' top program.

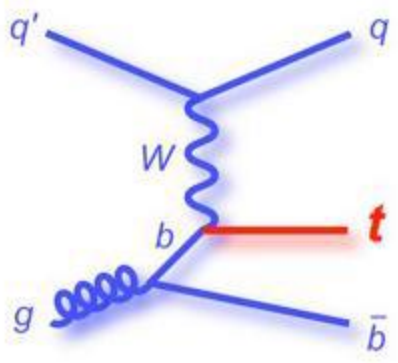


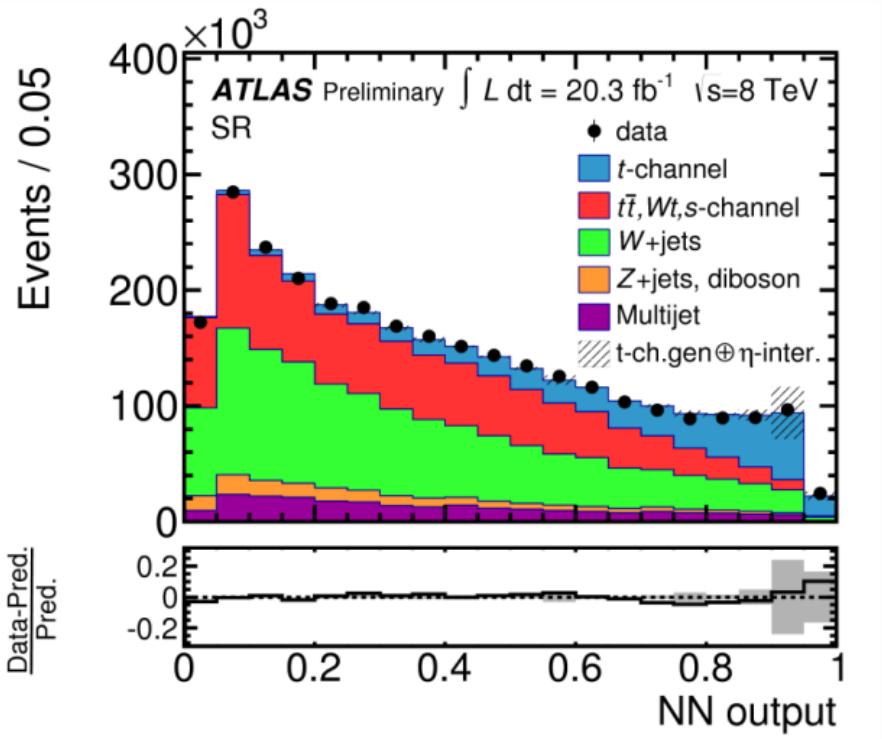


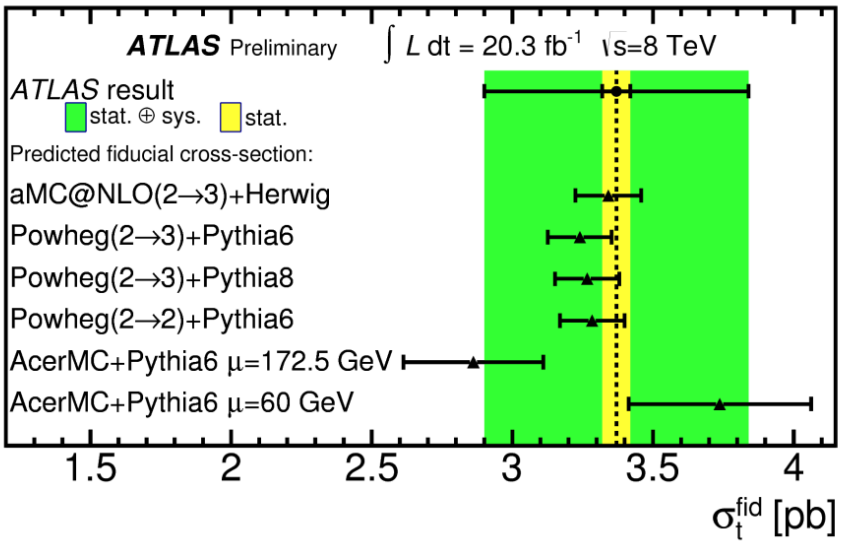
BACKUP

Single Top: t-channel

- 1 lepton & 2 b-jets
- An MVA is used to extract the signal.
- Main uncertainties: JES, signal modelling
- Measured fiducial and inclusive cross sections
- Determined $V_{tb}=0.97^{+0.09}_{-0.10}$



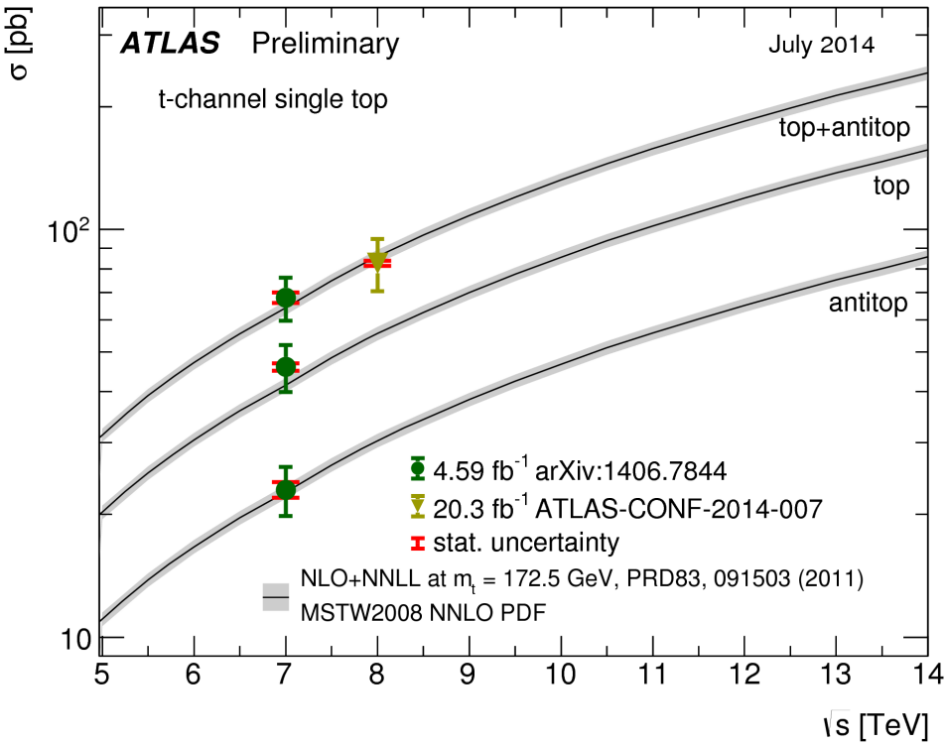


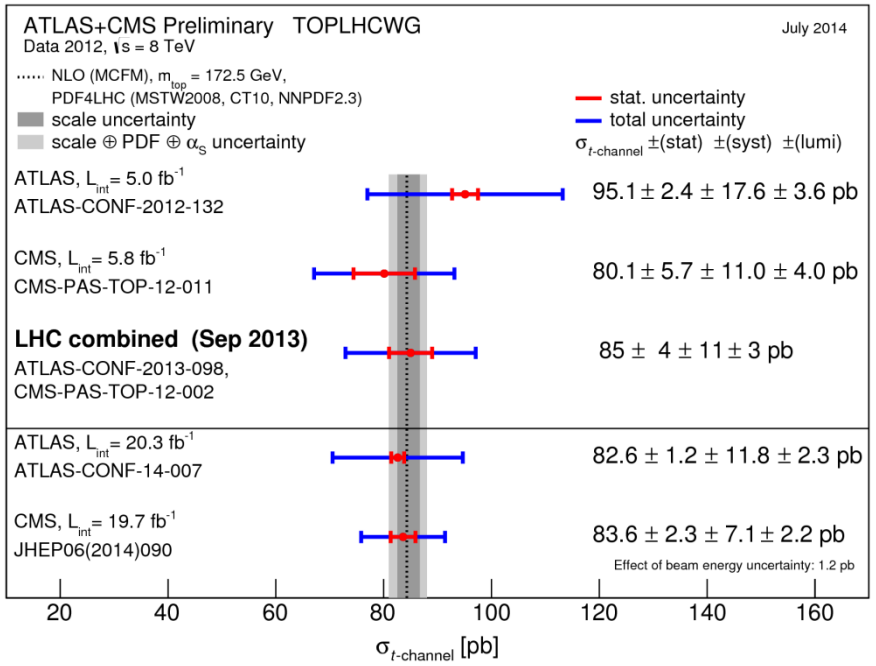


See: ATLAS-CONF-2014-007

Single Top: t-channel

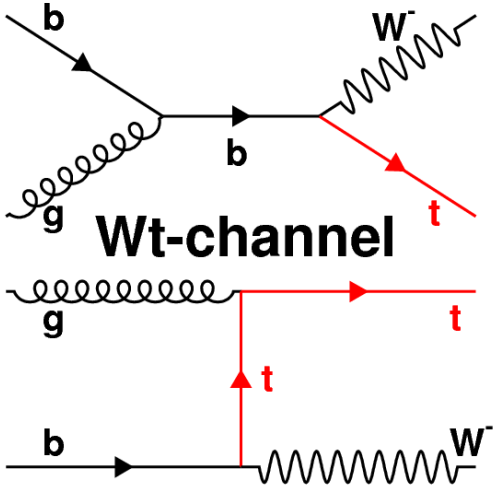
- In good agreement with theory predictions:

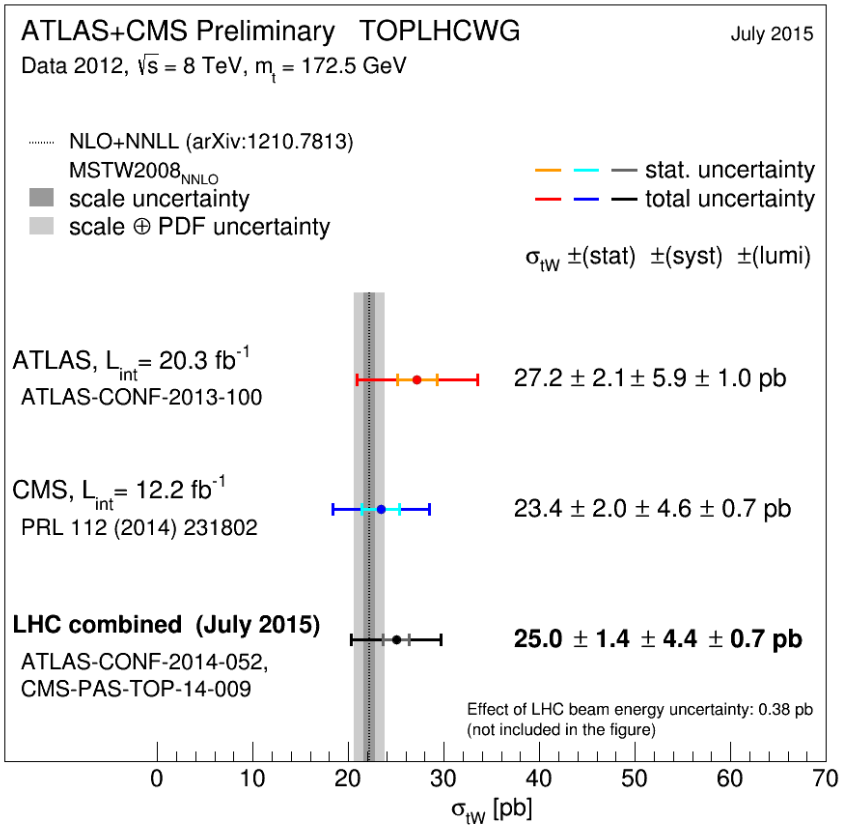




Single Top: Wt channel

- Measured in e-μ events with 1- or 2- b-jets
- Used MVA to extract signal





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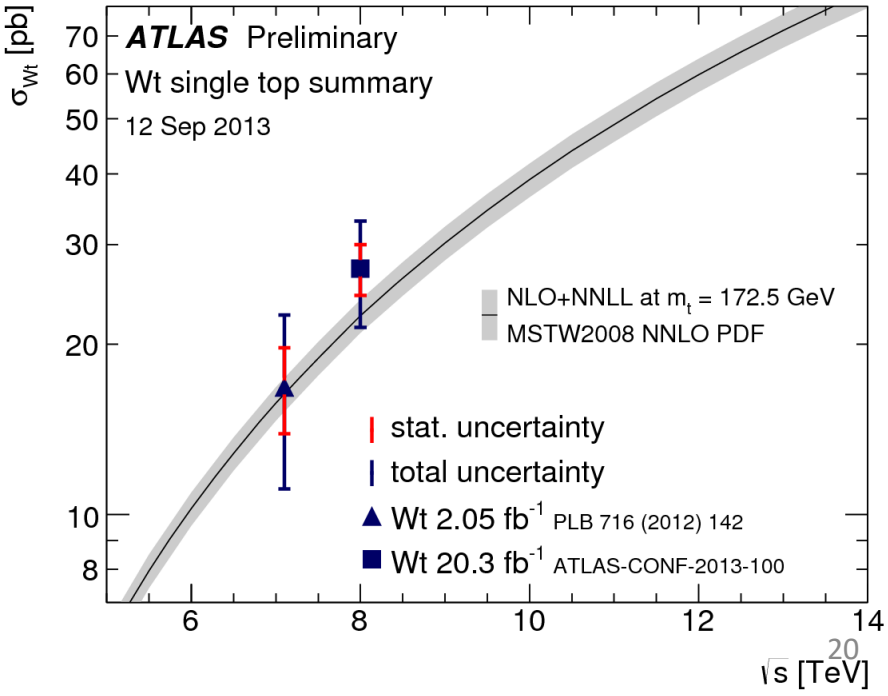
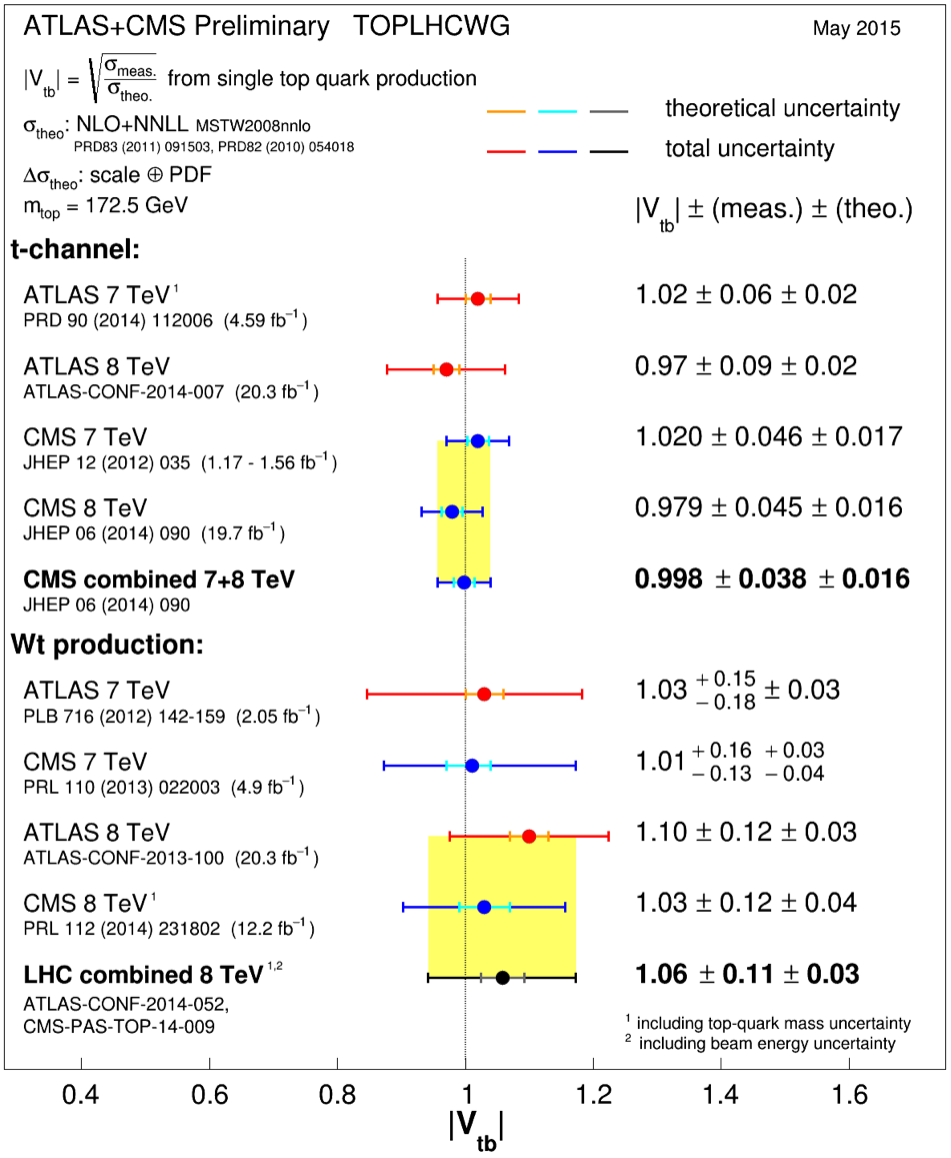
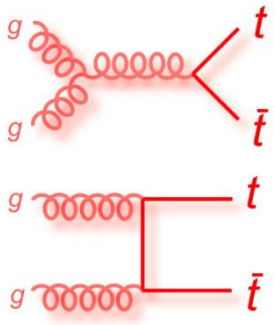


Summary of V_{tb} measurements



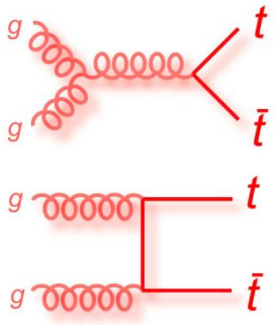
Top Quark Properties

- Mass
- Charge asymmetry
- Spin correlation
- Measurement of color flow



Measured in final states with top and anti-top quarks, $t\bar{t}$.

- V_{tb} → Measured in final states with a single Top
- (Charge)
- Decay modes
- Polarization
- Lifetime



Single Top production and V_{tb}

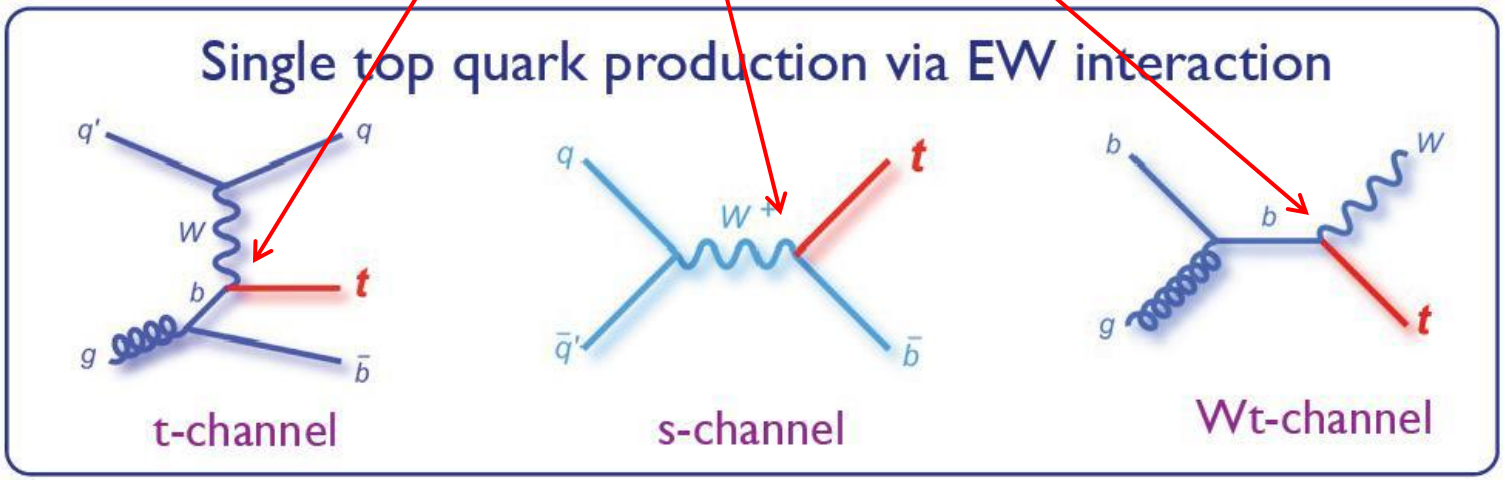
- By definition of the CKM Matrix:

$$V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} = \begin{bmatrix} 0.974 & 0.225 & 0.004 \\ 0.225 & 0.973 & 0.041 \\ 0.009 & 0.041 & 0.999 \end{bmatrix}$$

- Assuming unitarity of the matrix:

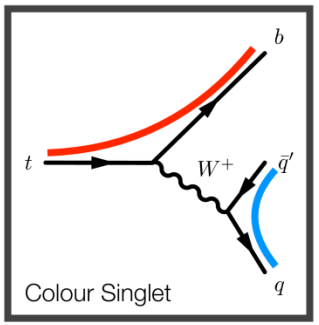
$$\mathcal{R} = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)} \qquad q = (b, s, d) \qquad \mathcal{R} = |V_{tb}|^2$$

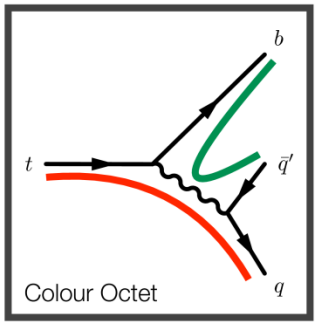
- The production mechanisms are classified as following:



Measurement of Color Flow

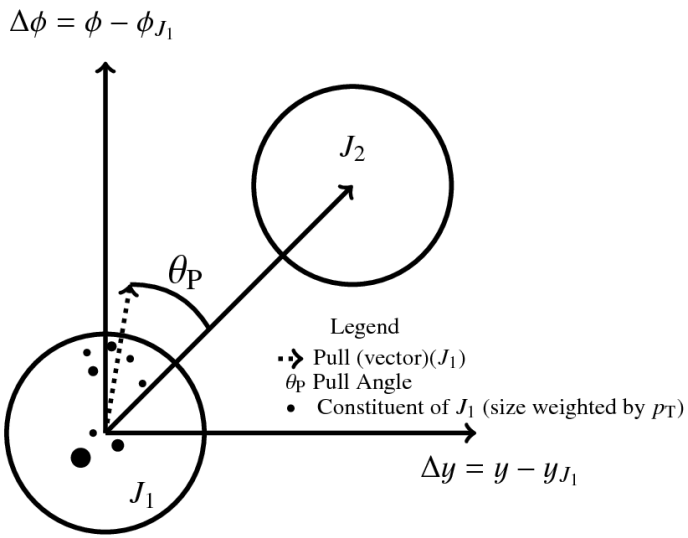
- The distribution and orientation of energy inside jets is predicted to be an experimental handle on colour connections between the hard–scatter quarks and gluons initiating the jets.
- The pull angle, Θ_p, is measured for jets produced in $t\bar{t}$ events with one W boson decaying leptonically and the other decaying to jets.

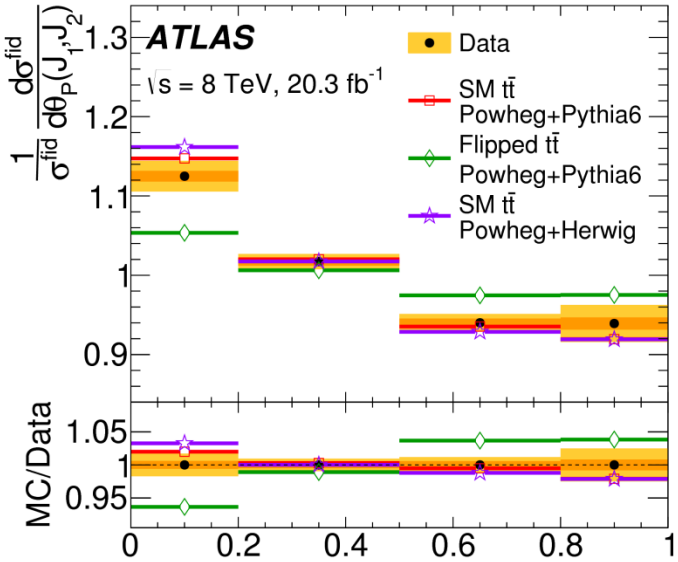




The pull vector is defined using jet constituents:

$$\vec{v}_p^{\,J} = \sum_{i \in J} \frac{p_{\mathrm{T}}^i |r_i|}{p_{\mathrm{T}}^J} \vec{r}_i.$$





← **Non-b-tagged jets**