Recent Top Quark Results from CMS

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CMS Collaboration

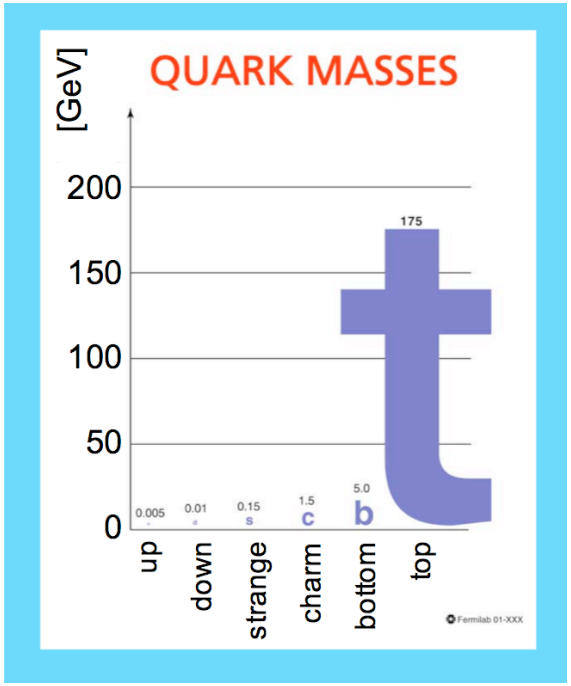
16th February 2015

The Top Quark

- Top is heaviest known fundamental particle

  $m_t = 173.21 \pm 0.51 \pm 0.71$ GeV

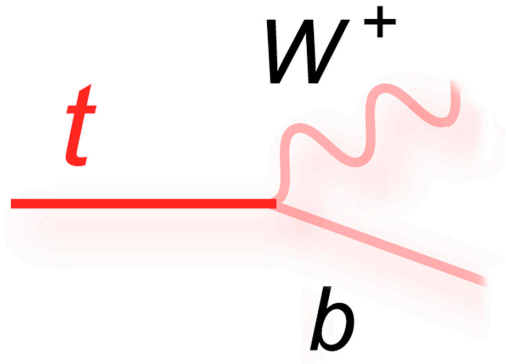
  (PDG value based on Tevatron + LHC measurements)



- Top decays to Wb ~100% of the time ➔ $|V_{tb}| \sim 1$

- Lifetime ~0.5×10^{-24} s
  - Top decays before it can hadronize

- Top quark has large coupling to the Higgs boson



- Plays a special role in many BSM models

Top Pair Production

Cross sections

ttX/multi-top production

Charge asymmetry

Spin correlation/polarisation

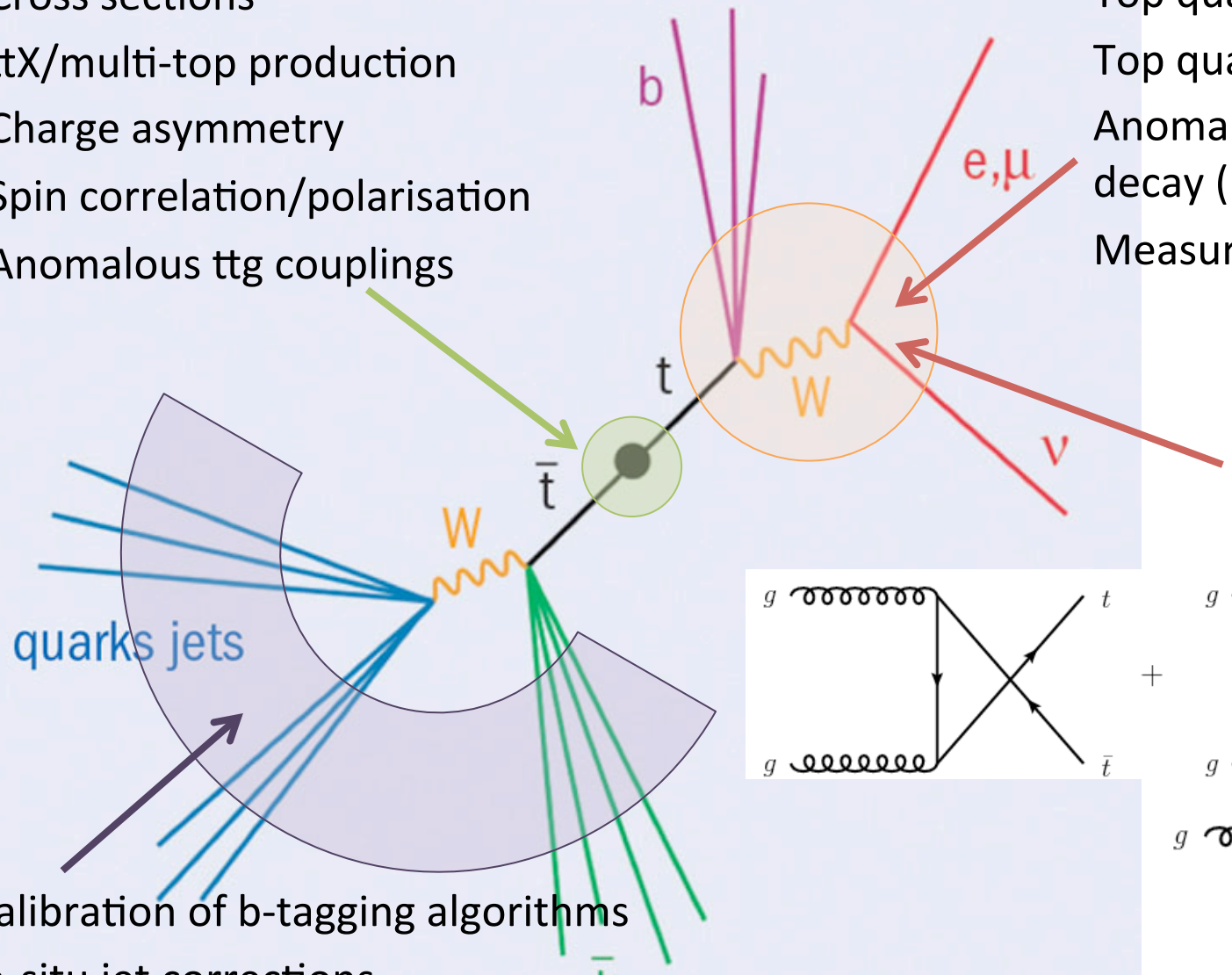
Anomalous ttg couplings

Top quark mass

Top quark charge

Anomalous top quark decay (FCNC/H)

Measurement of R (CKM)



W helicity

Anomalous tWb couplings

Calibration of b-tagging algorithms

In-situ jet corrections

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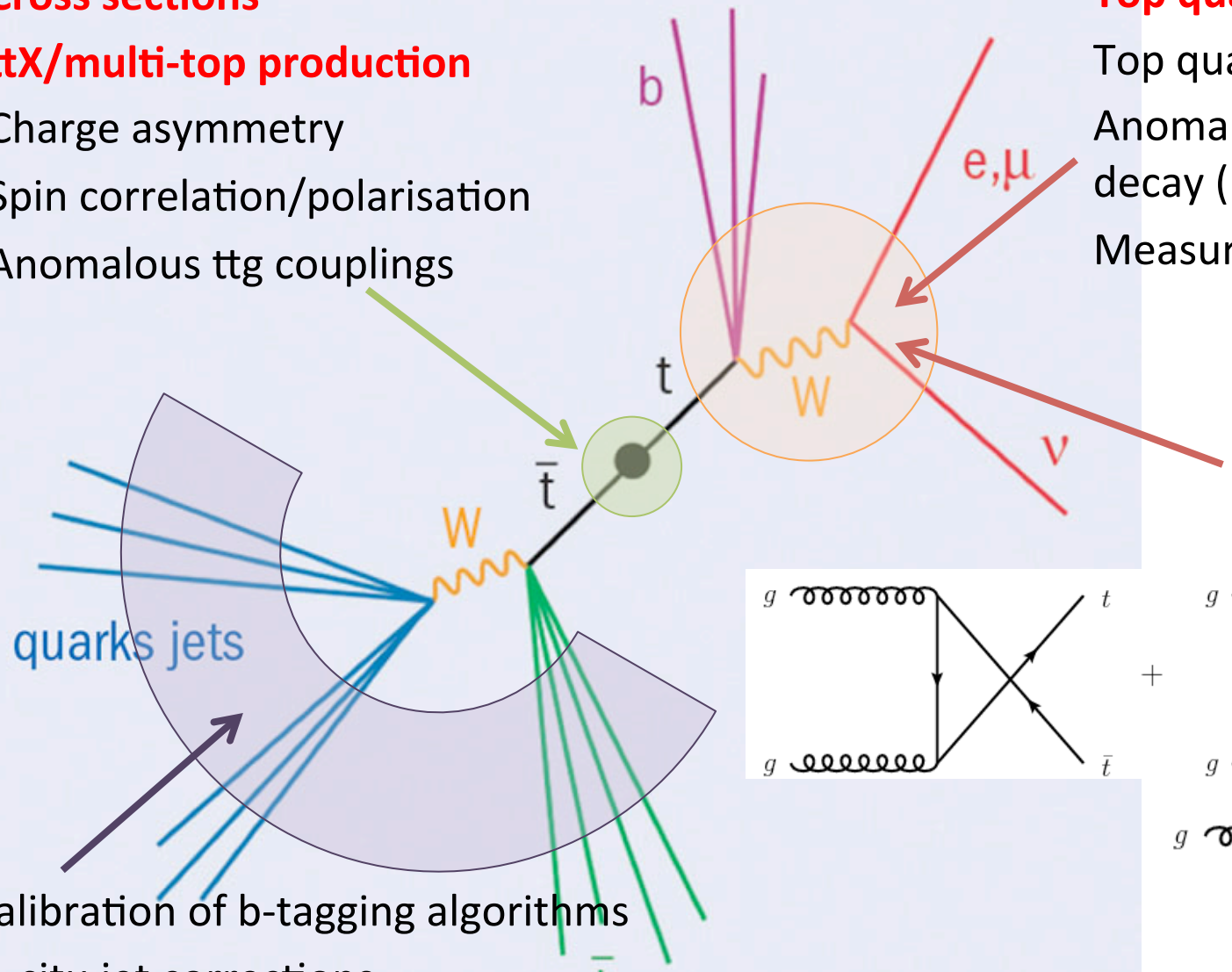

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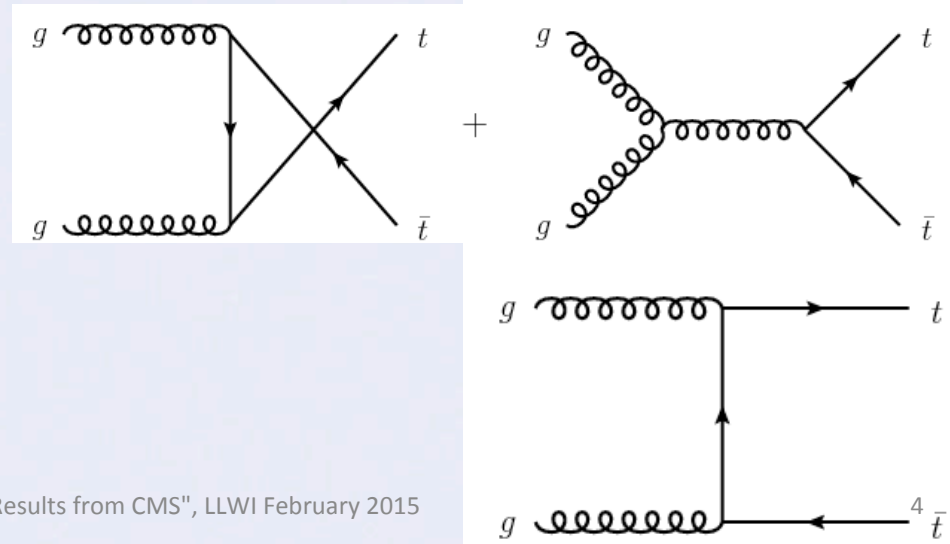

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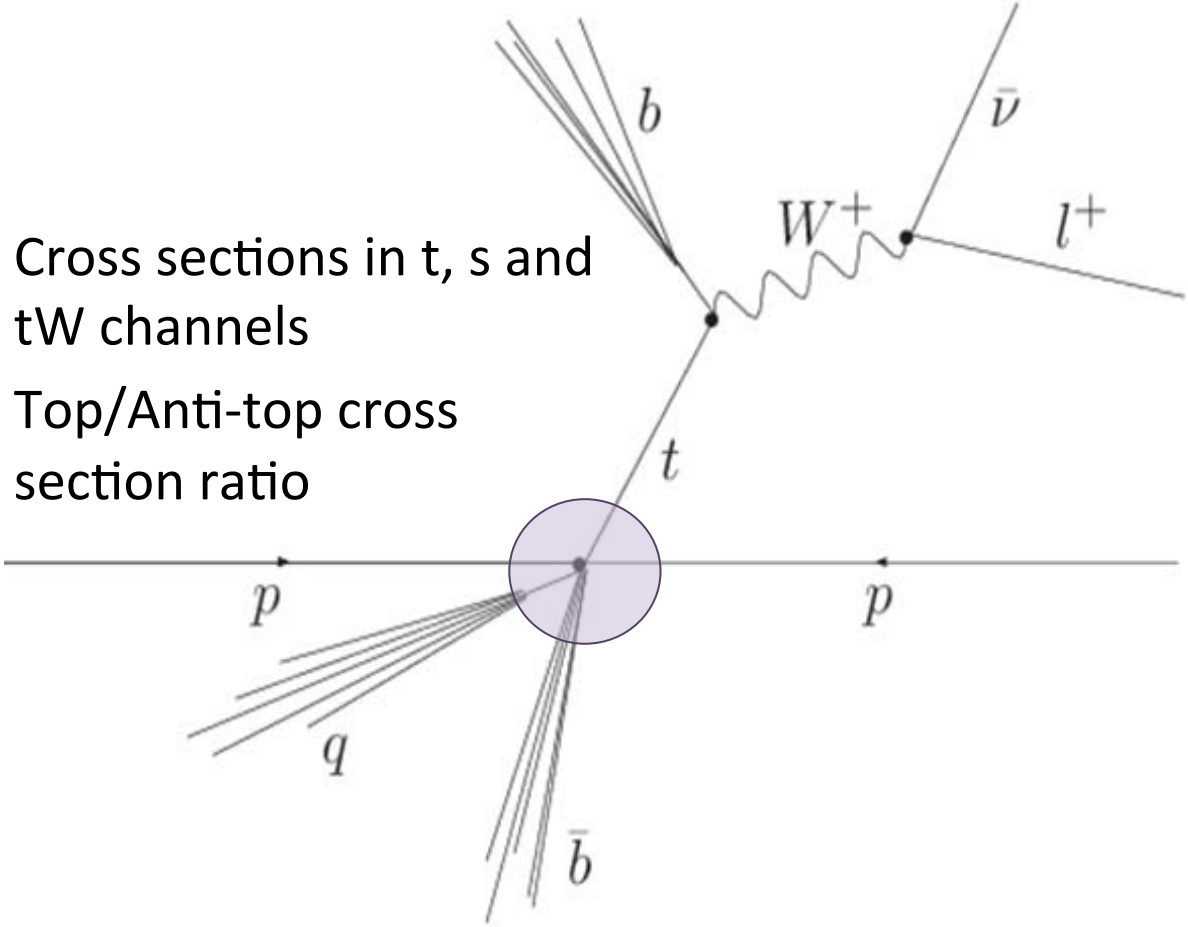
Single Top Production

Cross sections in t, s and tW channels

Top/Anti-top cross section ratio



Top polarization

Anomalous single top quark production (FCNC/H)

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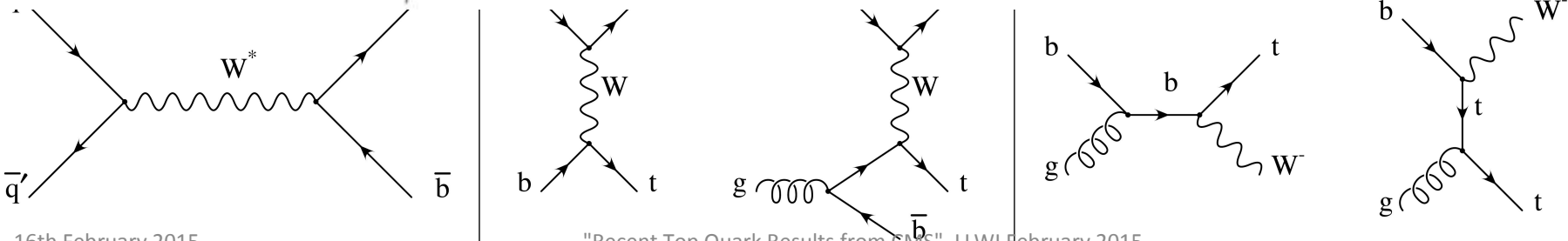

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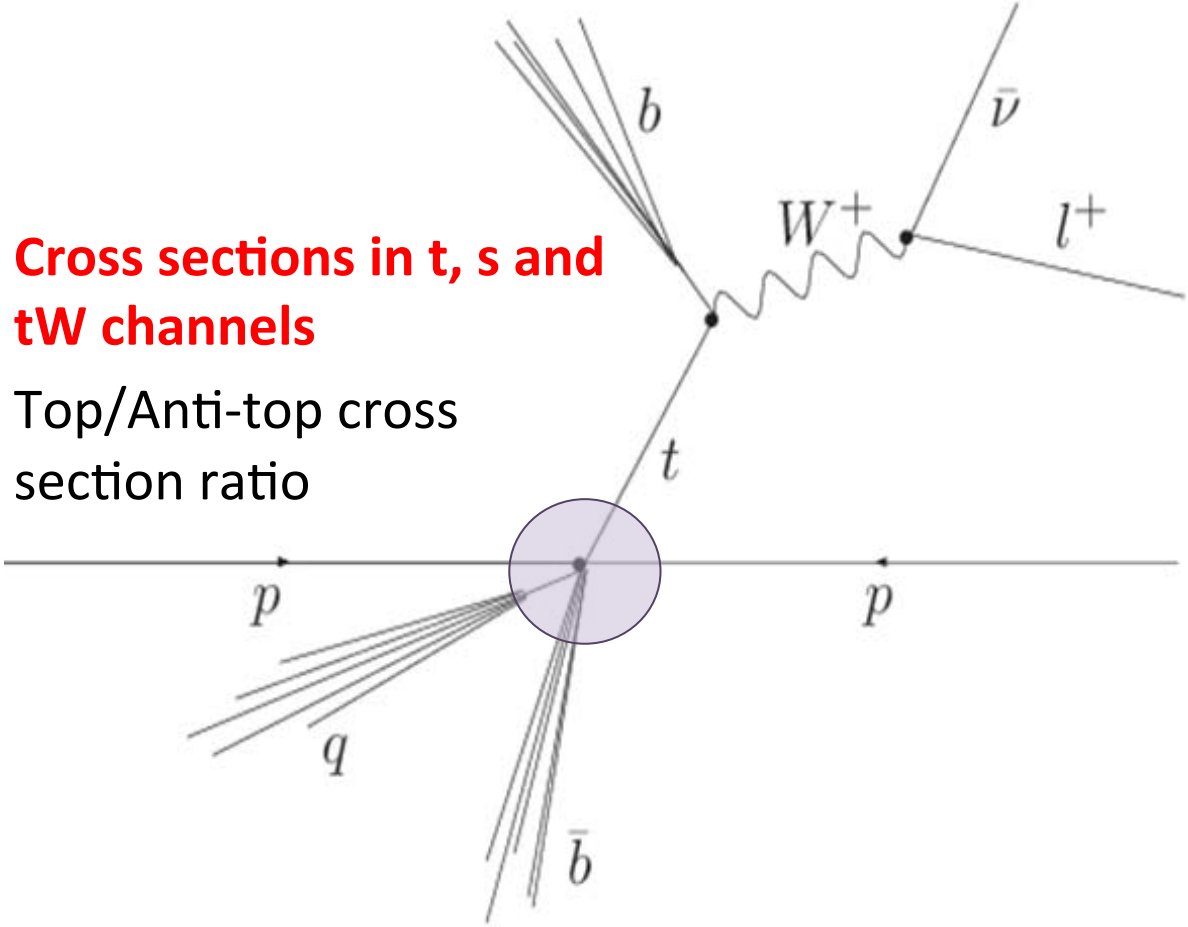

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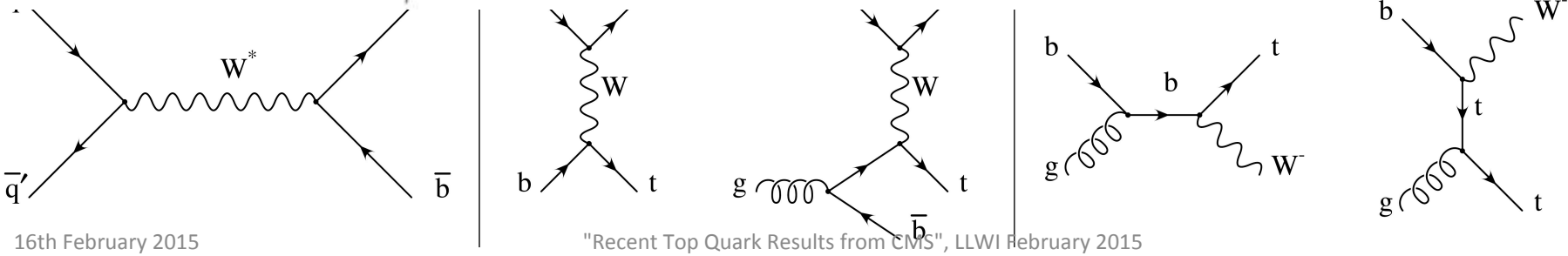
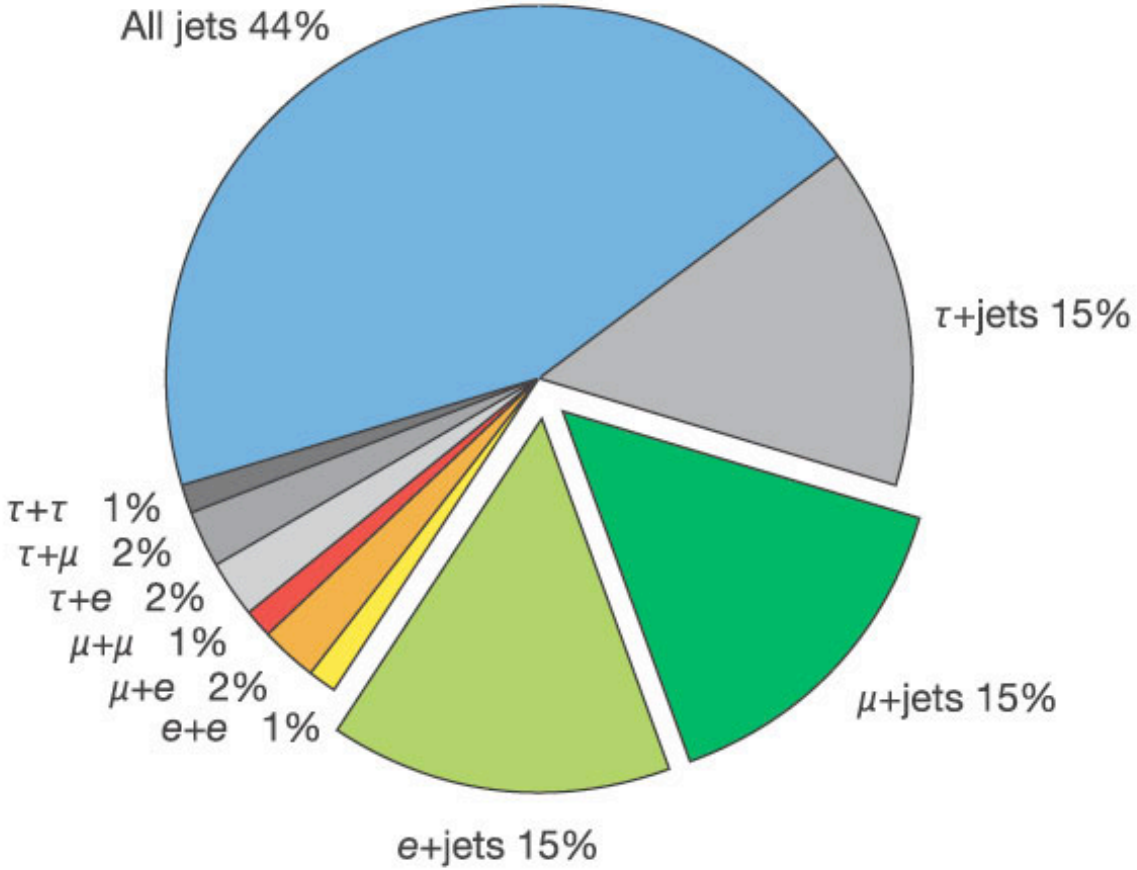
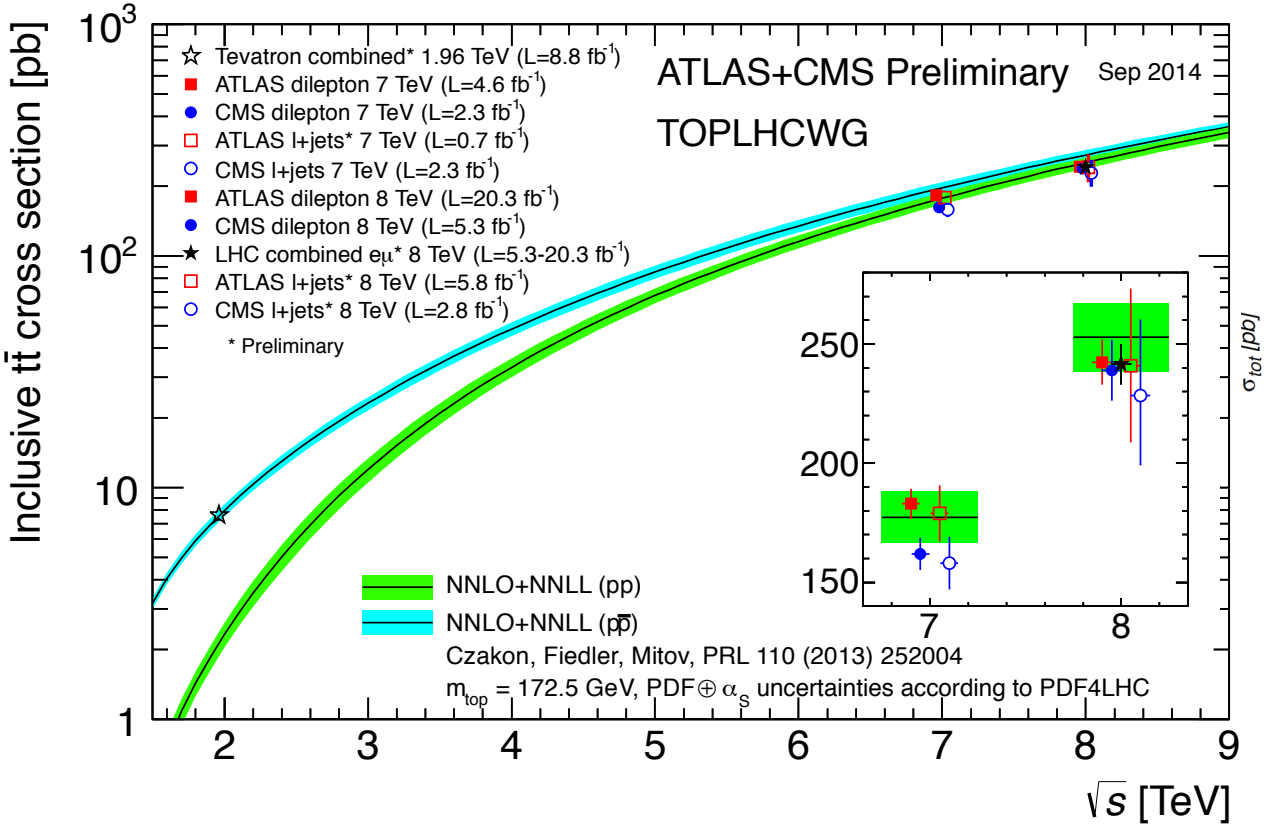


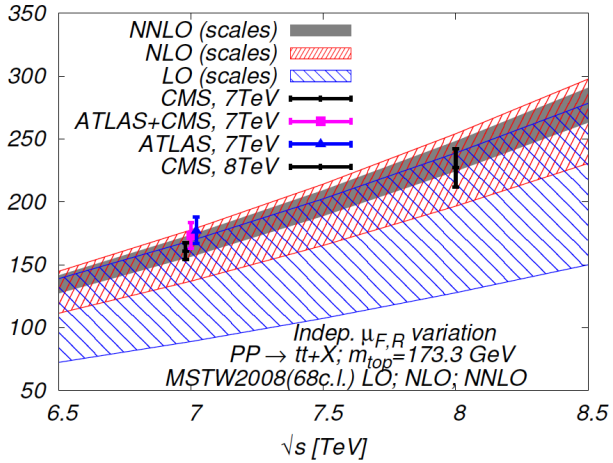
Top Quark Decay



Characterize top pair events according to the decay channels of the two top quarks

Summary of top pair cross sections





A. Mitov, CKM 2014

Good description of production cross sections by theory

Precision of measurements indicates why NNLO QCD is used

Latest cross section measurements

CMS PAS TOP-14-016

- Combination of ATLAS and CMS cross sections
  - Combined using BLUE method

    (NIM A 270 (1988) 110,

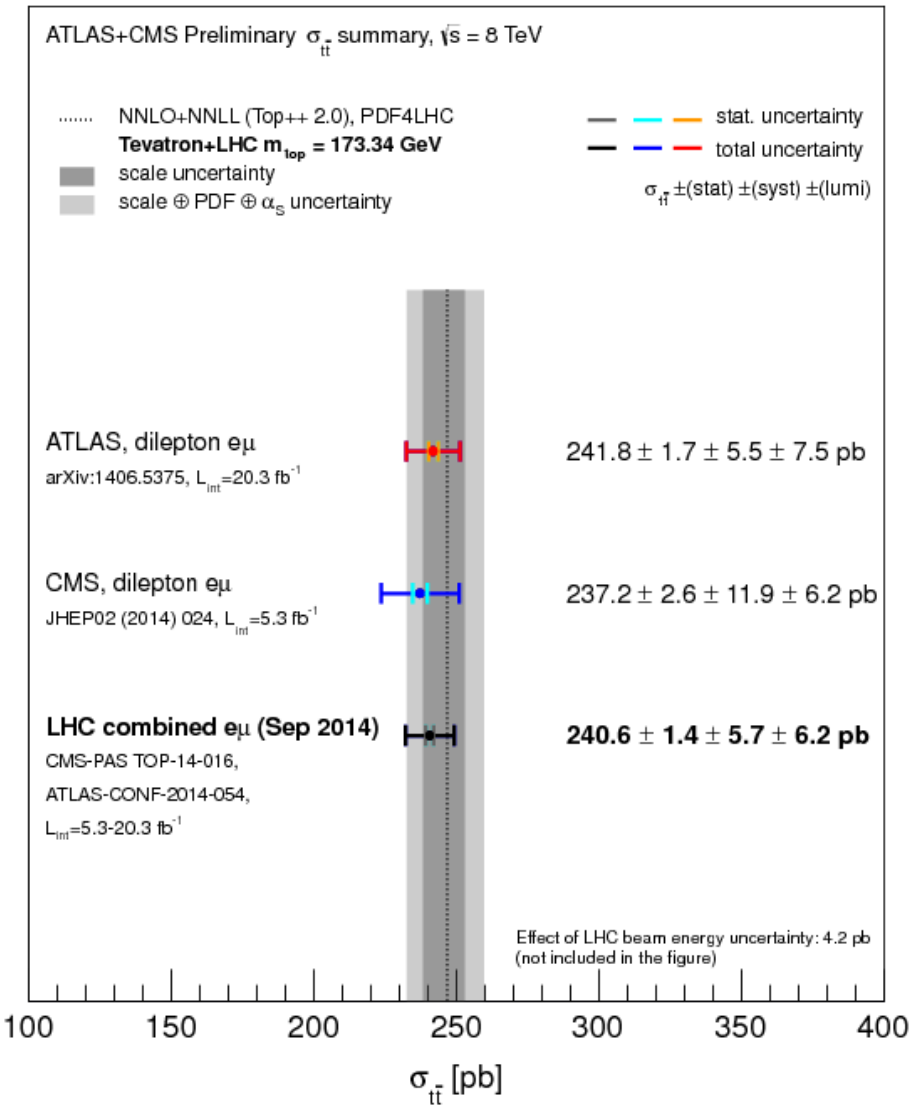
    NIM A 500 (2003) 391)

- Measured in dilepton eμ final state

- Cleanest event selection

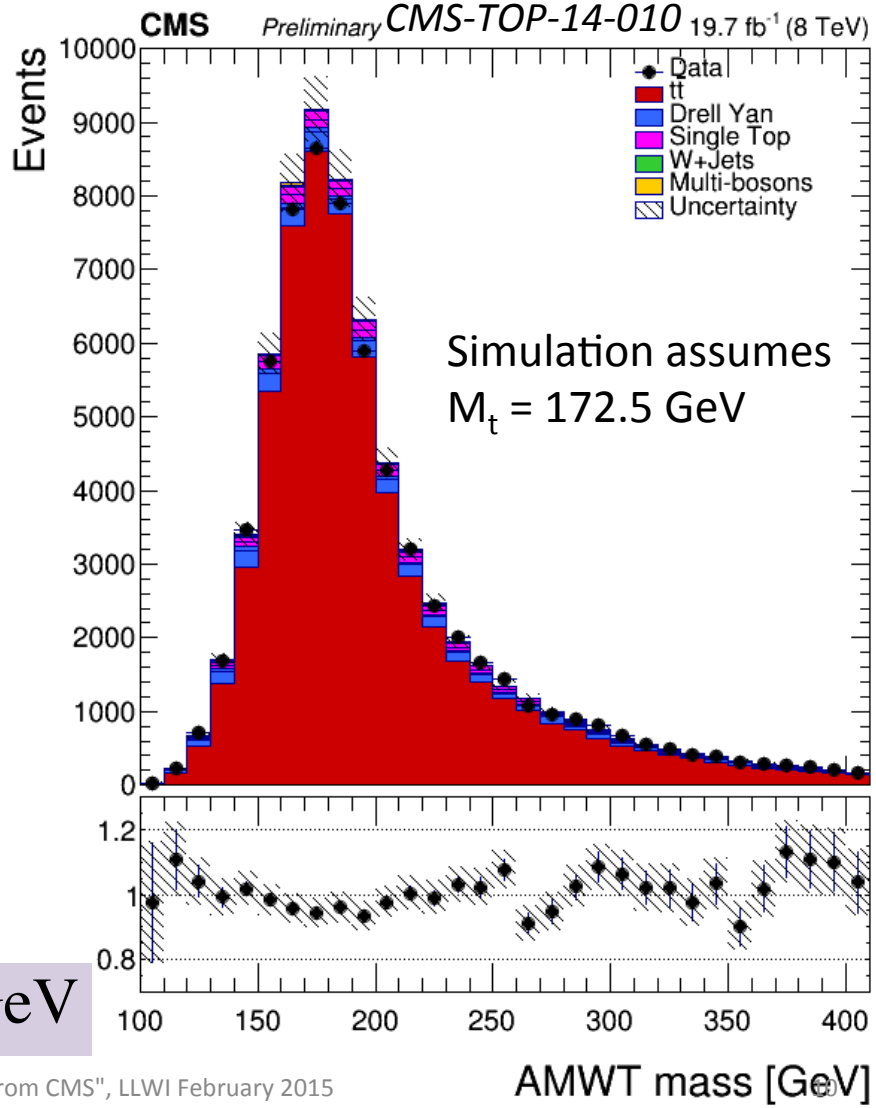
- The most precise cross section measurement so far

  (total uncertainty = 3.5%, excluding beam energy uncertainty)



Top Mass Measurements

- Top mass measurements produced with a number of different methods
  - Ideogram (l+jets, all-hadronic)
  - **Analytical Matrix Weighting method** (dilepton)
  - …
- Method used extensively at the Tevatron
  - Calculate a likelihood for each event as a function of M_t
  - M_t that maximises the likelihood used as an estimator
  - Physical mass determined from template fit



$$m_t = 172.47 \pm 0.17(stat.) \pm 1.40(syst.)\ \text{GeV}$$

Top Mass Measurements

CMS-TOP-14-014

- In leptonic decays: $M_{lb}^2 = \frac{M_t^2 - M_W^2}{2}\left(1 - \cos\theta_{lb}\right)$

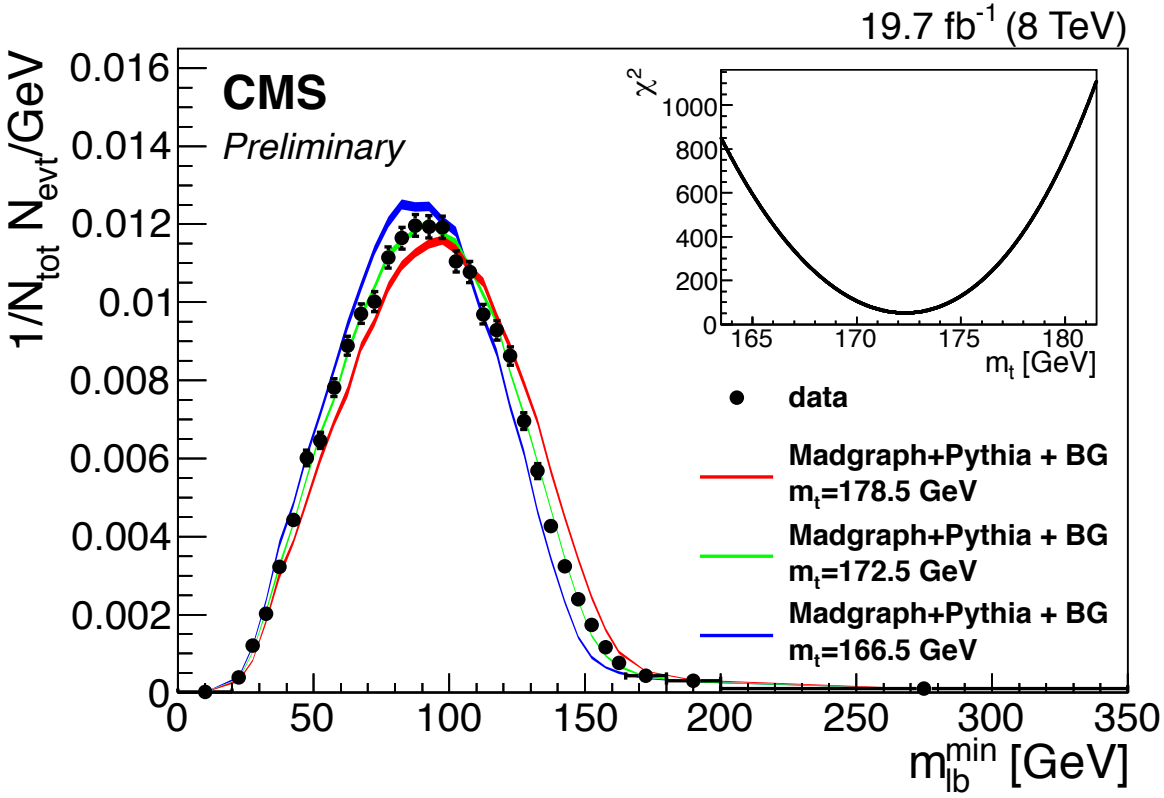
- Reconstruct M_{lb} and fit event yields bin-by-bin based on different M_t

Using MADGRAPH+PYTHIA

$$M_t = 172.3^{+1.23}_{-1.3}\ \text{GeV}$$

Using MCFM
(NLO production, LO t decay)
(fixed-order calculation)

$$M_t = 171.4^{+1.0}_{-1.1}\ \text{GeV}$$



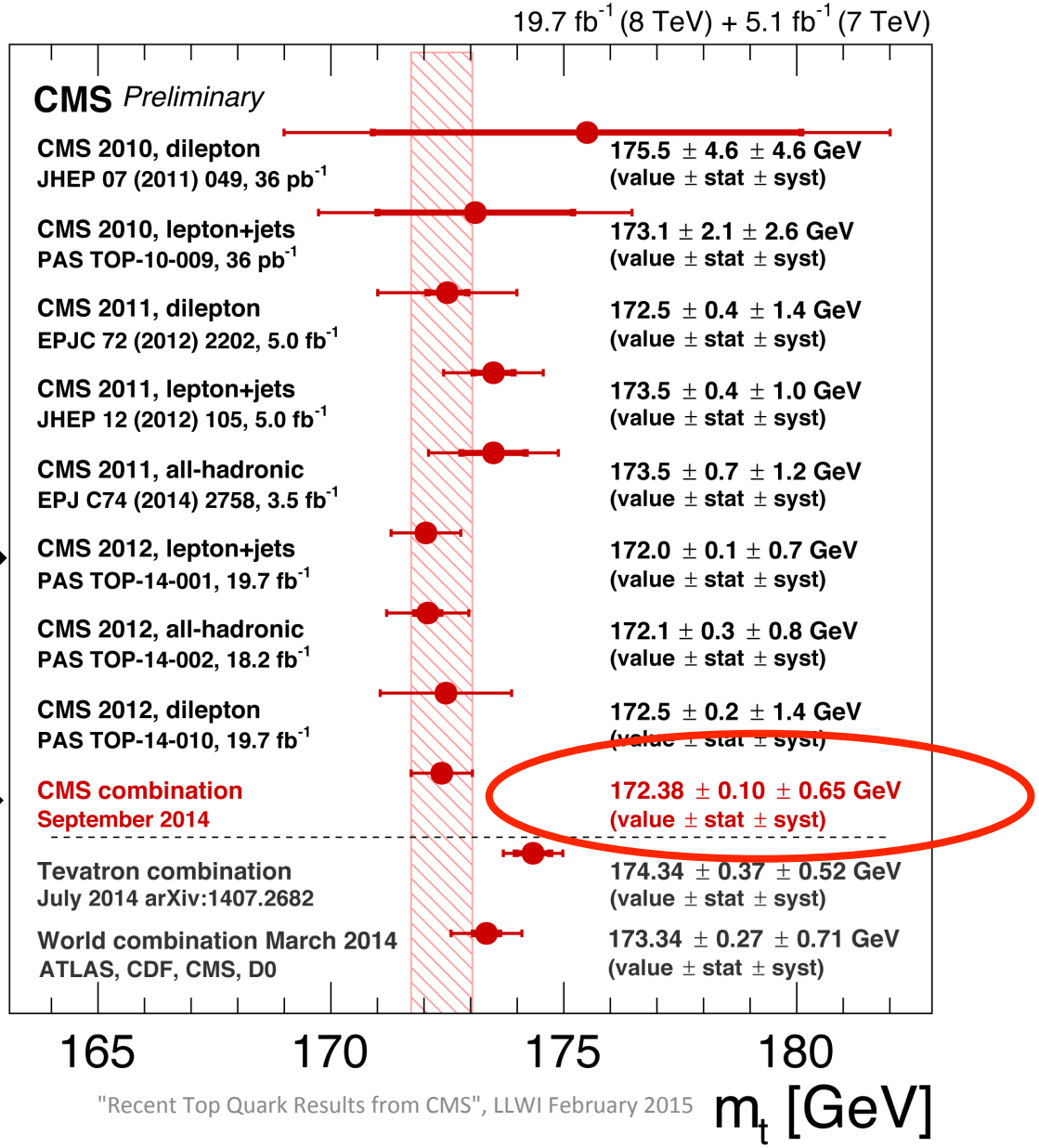
Run 1 CMS top mass summary

CMS-TOP-14-015

Combined using the BLUE method

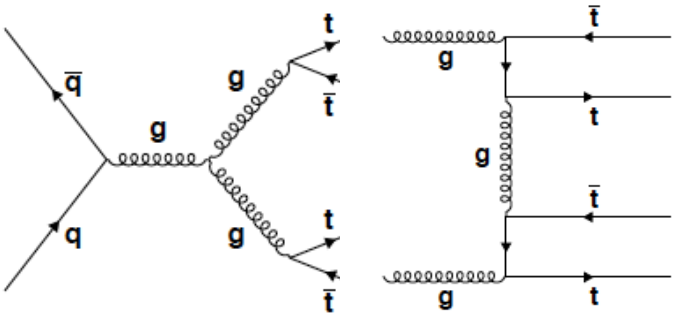
Most precise measurement ➔
Uncertainty 0.41%

Overall uncertainty ➔
only 0.38%



Multi-top production

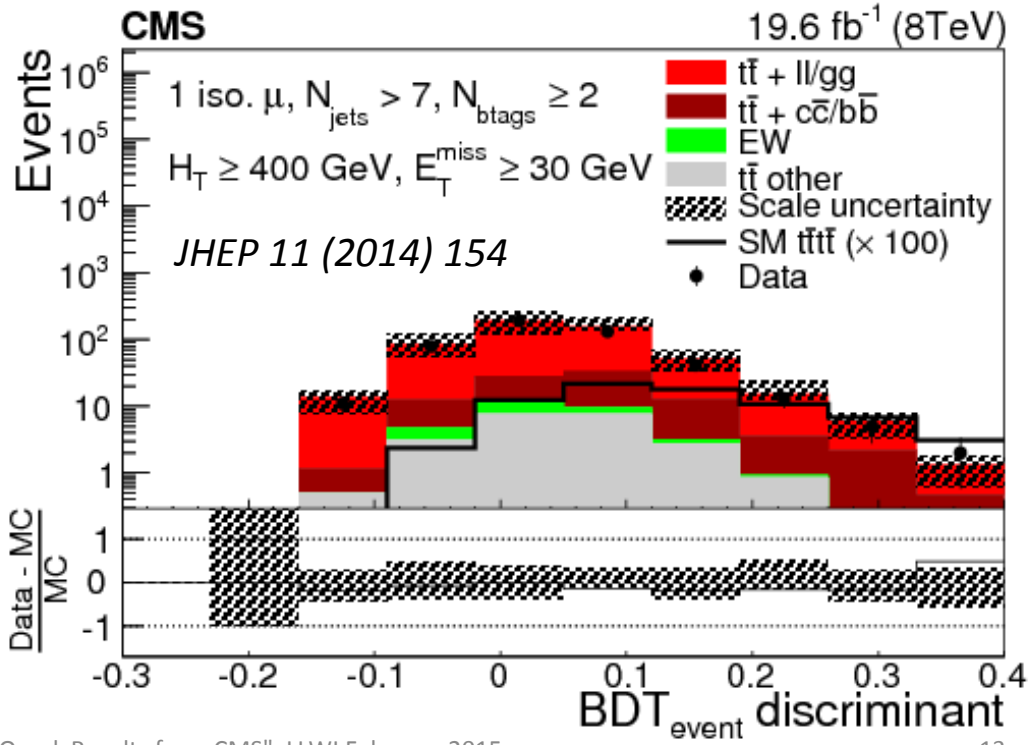
- Increasing lumi and centre-of-mass energy means rare SM processes are becoming accessible … $t\bar{t}t\bar{t}$ is one such prospect



- @ 8 TeV $\sigma_{SM} \approx 1$ fb
- Many BSM models predict enhancement of this cross section (SUSY squark/gluino decays)

- No significant excess observed over SM expectations

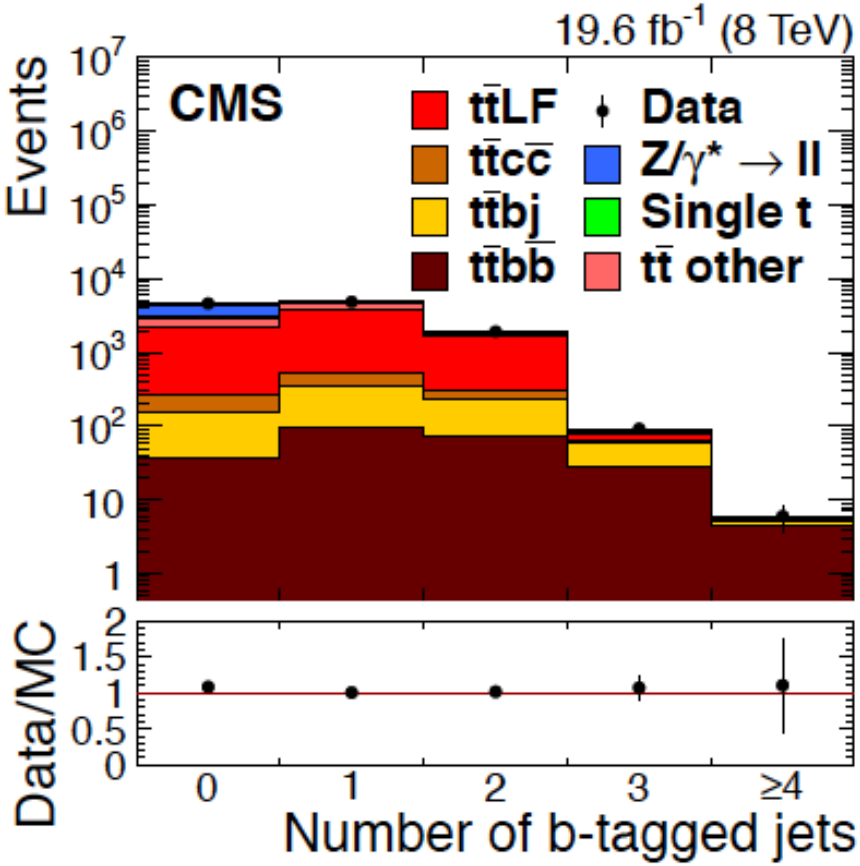
- Cross section limit:
  Observed limit is 32 fb
  Expected limit is 32 ± 17 fb



Top-Higgs Coupling

CERN-PH-EP-2014-249

- High priority for Run 2: Direct measurement of Top Yukawa coupling via ttH ➔ leads to a ttbb final state
- ttbb is an irreducible background
- ttbb and ttjj measurements important tests of NLO QCD
- Ratio extracted via fit to the output of the b-tagging algorithm for the 3rd and 4th jets
- Ratio in full phase space with jet p_T > 40 GeV/c threshold



$$\frac{\sigma_{t\bar{t}b\bar{b}}}{\sigma_{t\bar{t}jj}} = 0.022 \pm 0.004(\text{stat.}) \pm 0.005(\text{syst.})$$

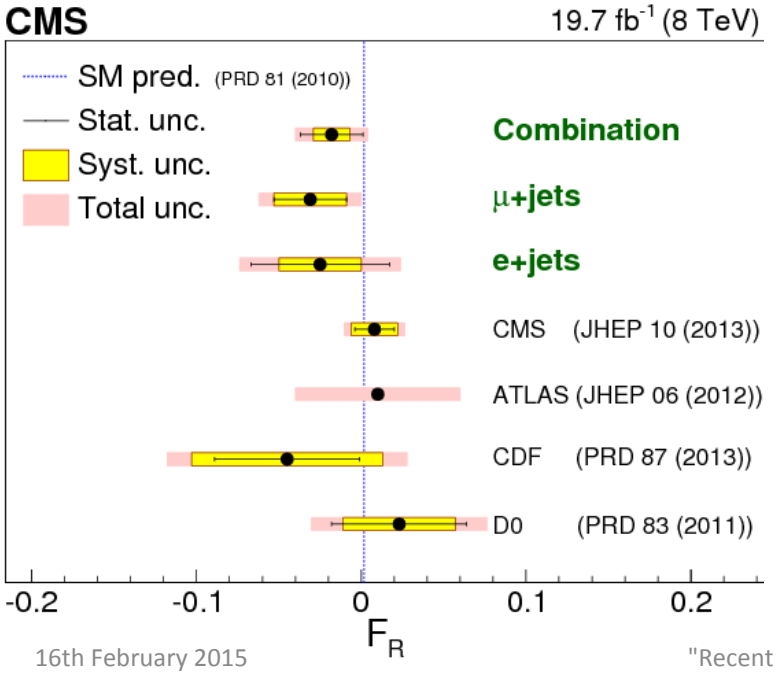
$$\frac{\sigma_{t\bar{t}b\bar{b}}}{\sigma_{t\bar{t}jj}}(\text{NLO QCD}) = 0.011 \pm 0.003$$

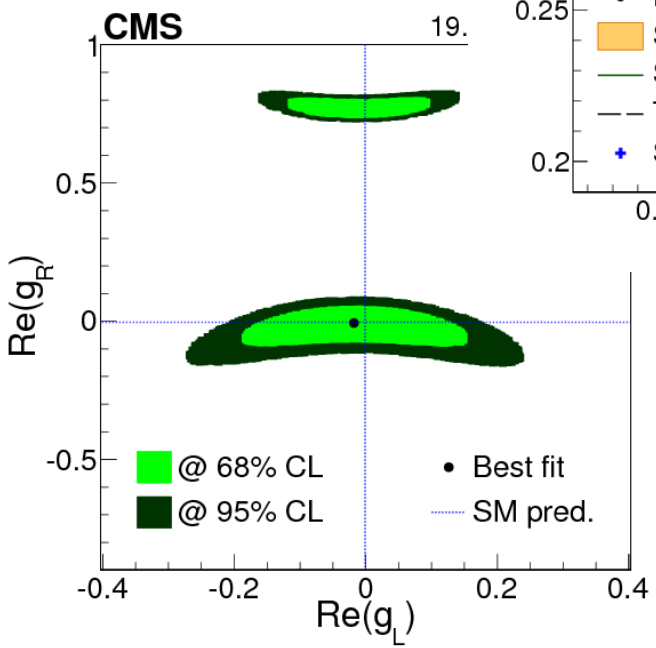
W helicity in top production

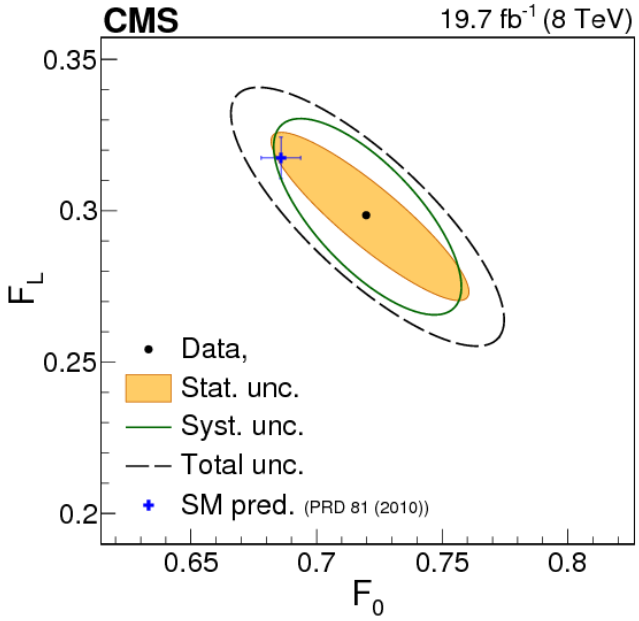
JHEP 01 (2015) 053

- W polarisation sensitive to non-SM tWb couplings
  - W can be produced with left-handed, longitudinal or right-handed helicity ➔ measure the ***helicity fractions***

- First measurement using events containing a single top quark (~⅔ lepton+jets tt events, ~⅓ single top events)

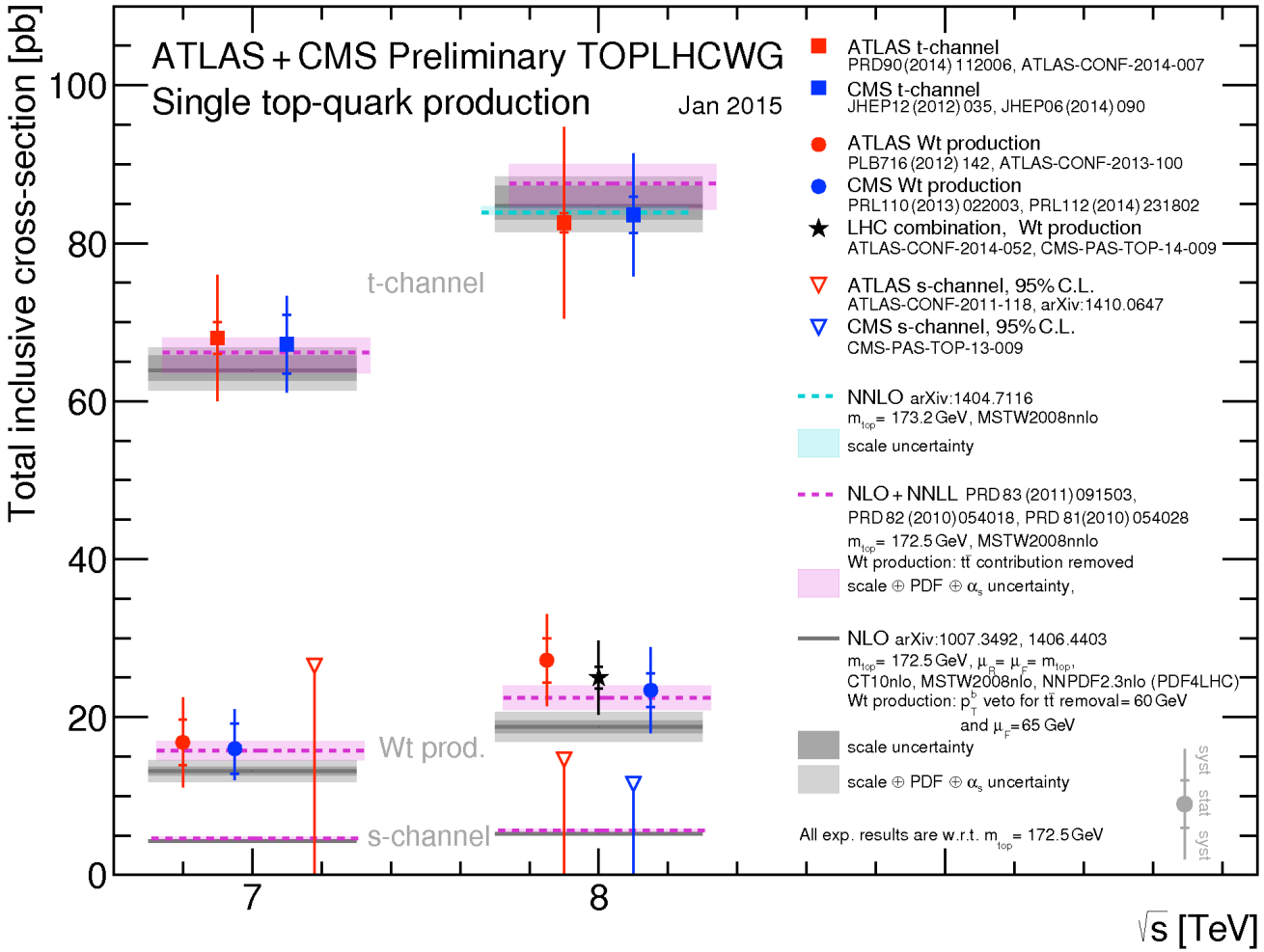






g_L, g_R ➔ the anomalous tWb couplings

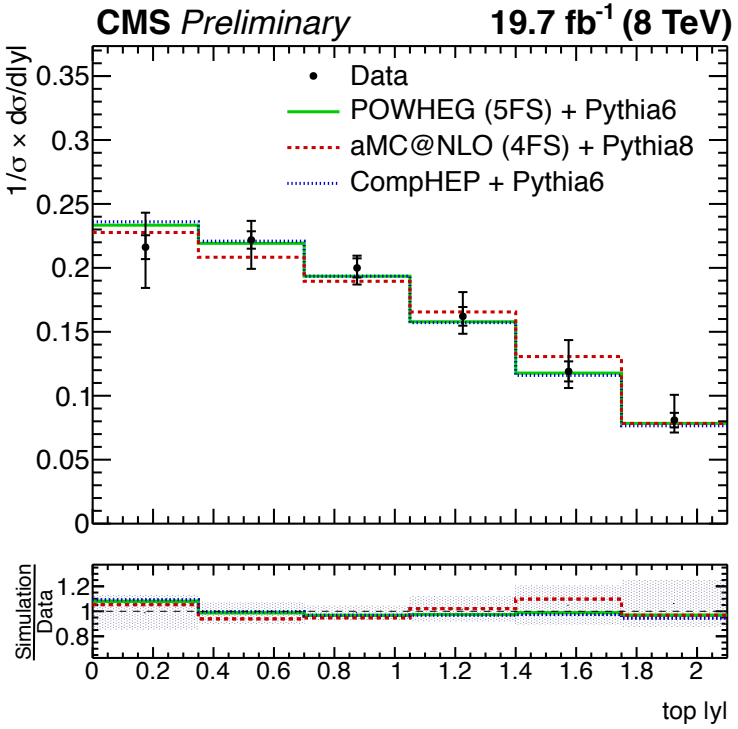
Summary of single top cross sections

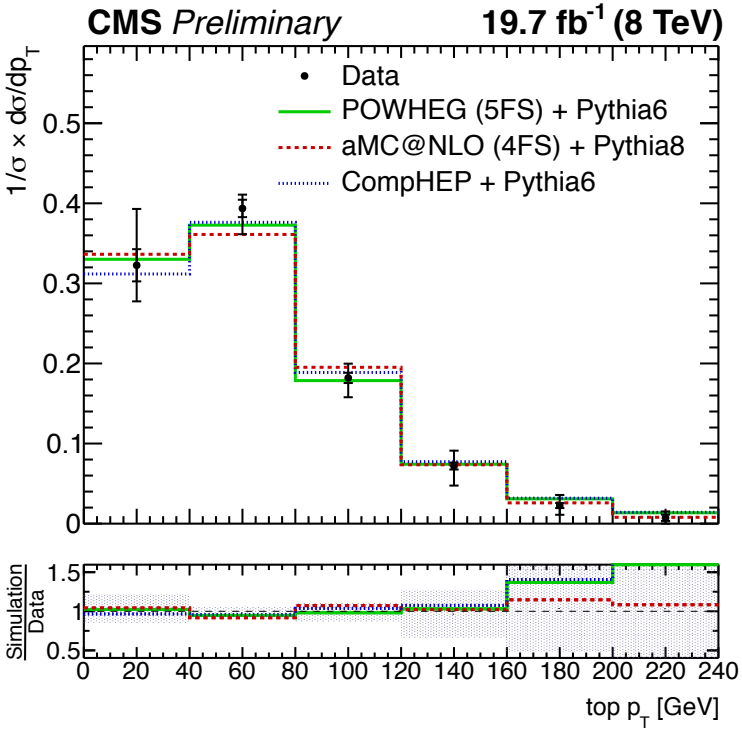


- Three different processes sensitive to different new physics mechanisms
- Good description of t-channel and tW production cross sections by theory

Single top t-channel cross sections

- Differential cross sections as functions of top transverse momentum and rapidity
- Comparison with MC using different modelling for b quarks, showering/ hadronization





- Top decay kinematics hard to simulate in single top *CMS PAS TOP-14-004*
- Good description of the data by all three MC predictions

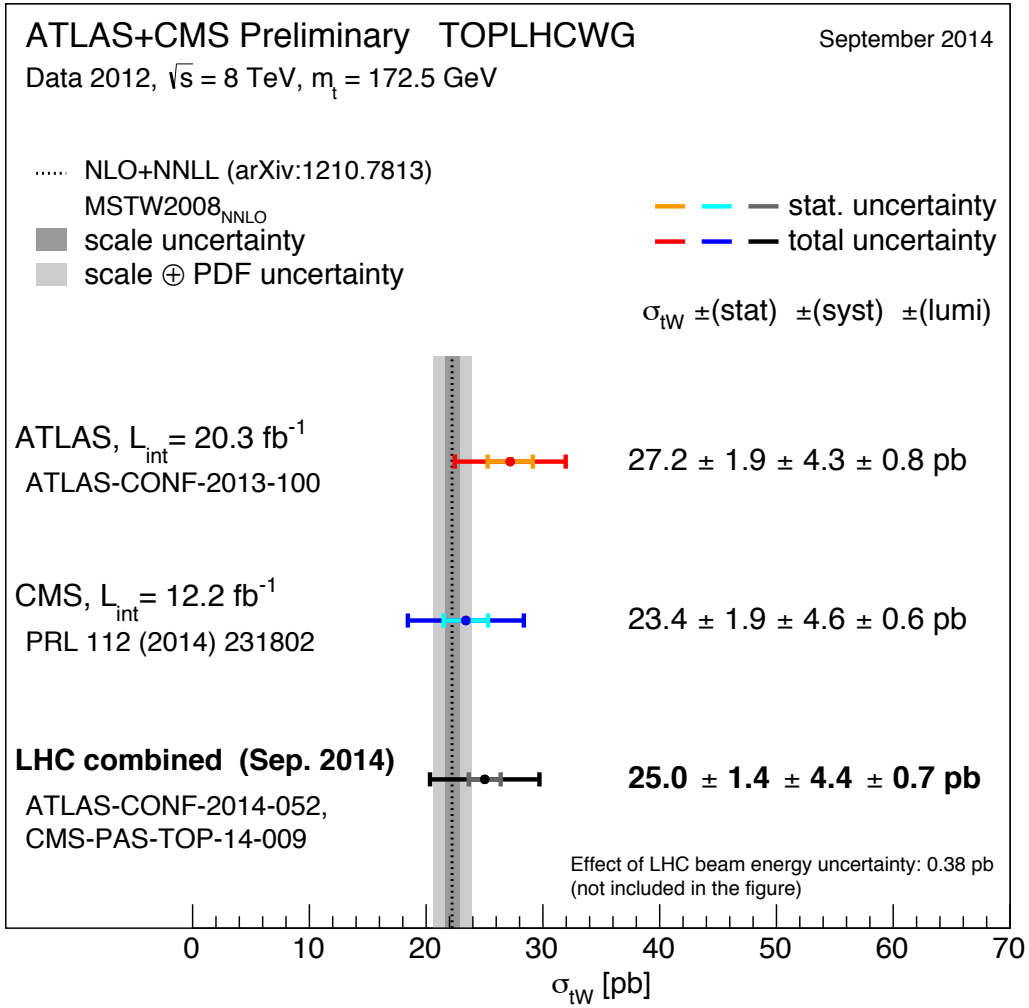
Latest cross section measurements

CMS PAS TOP-14-009

- Combination of ATLAS and CMS tW cross section measurements (BLUE method)
- tW sensitive to new physics that modifies the tWb vertex
- Insensitive to FCNCs
- Sensitive to some new particle types, eg. b*

$$|V_{tb}|^2 = 1.12 \pm 0.23$$

$$|V_{tb}| > 0.75 \text{ at } 95\% \text{ CL}$$



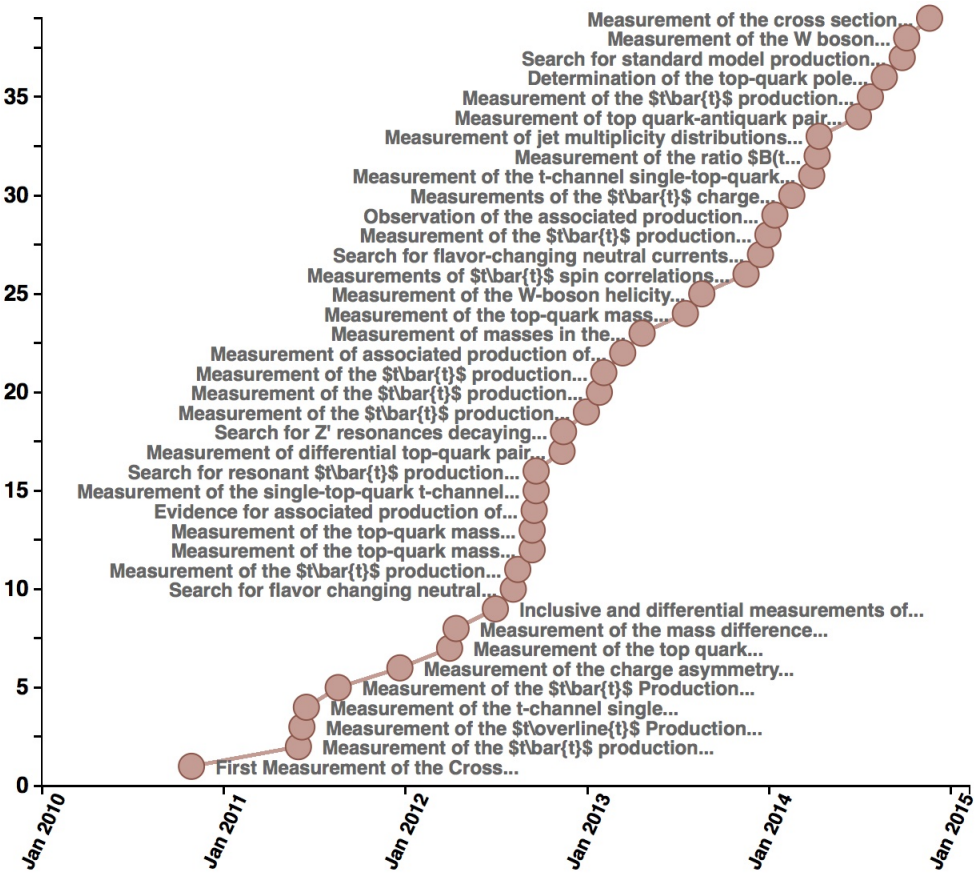
Corresponding result from the t-channel ➔ $|V_{tb}| = 0.998 \pm 0.038\ (\text{exp.}) \pm 0.016\ (\text{theory})$

Summary

- CMS has studied a wide variety of top quark-related topics in Run 1
- 39 papers published so far

- Many more still to come in Run 2:

- More precision measurements
- Observation of rare processes (tttt, tqZ, single top s-channel production, …)



- Running @ 13 TeV extends the reach for new physics (FCNC, anomalous couplings, something new …)
- ***Watch this space!*** ☺

Back-up Slides

The CMS Detector