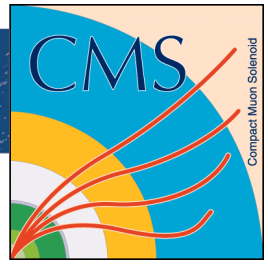


Measurements of Top Quark Properties at CMS

Efe Yazgan (Ghent University, Belgium)

on behalf of the CMS Collaboration

DIS 2013: XXI. International Workshop on Deep-Inelastic Scattering and Related Subjects
24 April 2013 Marseille, France

The Top Quark

- The most massive particle known to date (m_t~173 GeV)
  - very short lifetime

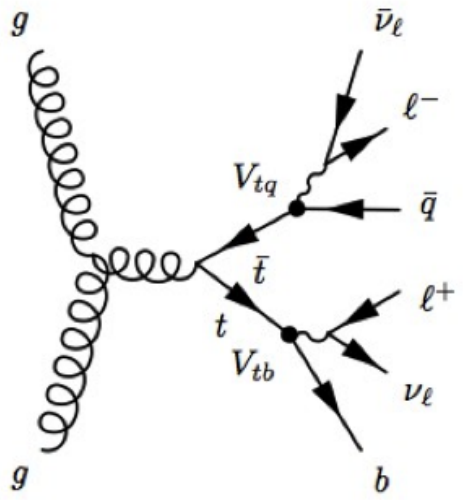
$$\tau_t = \frac{1}{\Gamma_t} \sim 0.5 \times 10^{-24} s < \frac{1}{\Lambda_{QCD}} < \frac{m_t}{\Lambda_{QCD}^2} \sim 3 \times 10^{-21} s << \tau_b \sim 10^{-12} s$$

$$\tau_t < \tau(hadronization) < \tau(spin - decorrelation) << \tau_b$$

No hadronic bound states→ bare quark properties are accessible (mass, V_{tb}, spin, charge, …).

spin effects propagate to decay products.

Top Quark Properties

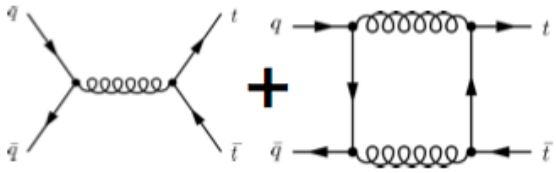


- Top pair charge asymmetry
- Top quark charge
- Top pair spin correlation
- Bottom quark content in top decay, $|V_{tb}|$
- W polarization, anomalous couplings
- ttZ, ttW

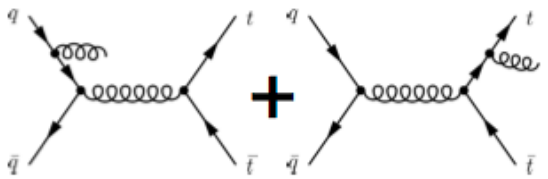
All public results at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Charge Asymmetry

- Interferences between the Born and the box diagram and between ISR & FSR causes the (anti)top direction to be correlated to the initial state (anti)quark

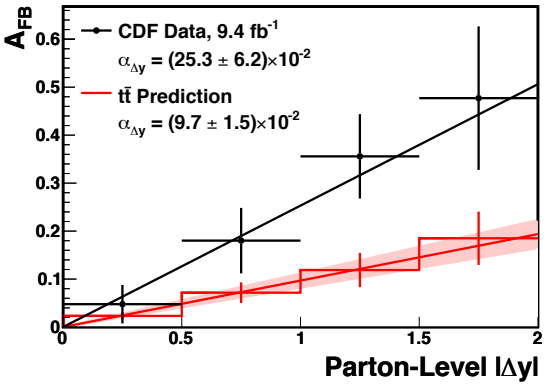


Top quark emitted in the direction of the proton (more forward)



Top quark emitted in the opposite direction of the proton (more backward)

arXiv:1211.1003 (l+jets)



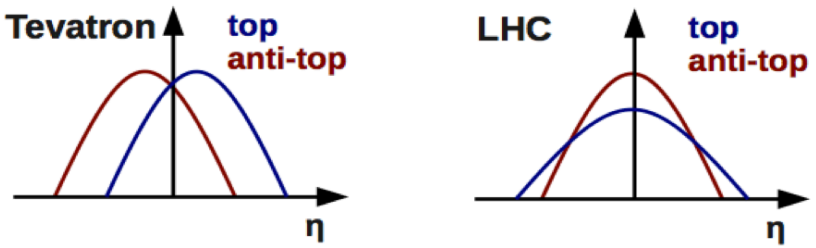
- Small deviation from SM observed at the Tevatron (A_{FB}).
  - $A_C \neq A_{FB}$ but are related in a model dependent way.

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

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

$$or\ \Delta|y| = \Delta|\eta| = |\eta_{\ell^+}| - |\eta_{\ell^-}|\ \ (dilepton)$$

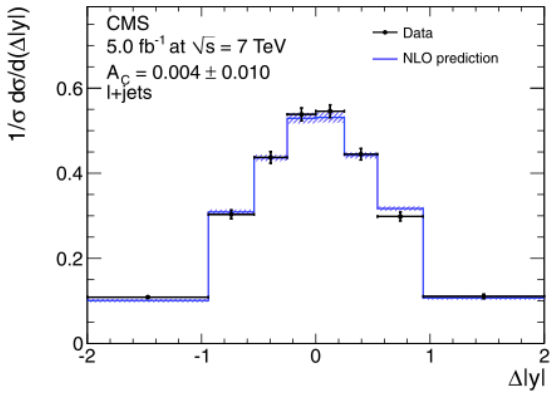
Tevatron: annihilation of two valence quarks
LHC: annihilation of one valence and a sea quark and gluon fusion dominated. → Much smaller asymmetry but tops more forward than anti-tops.

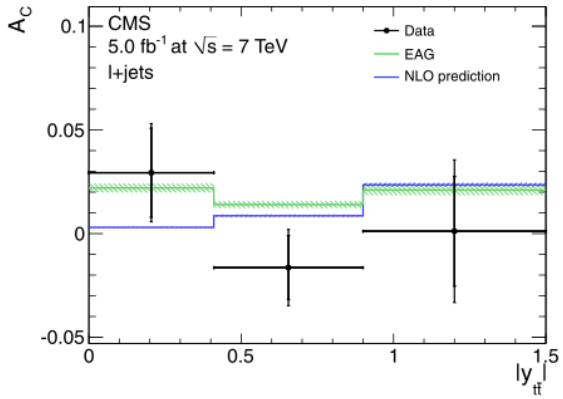


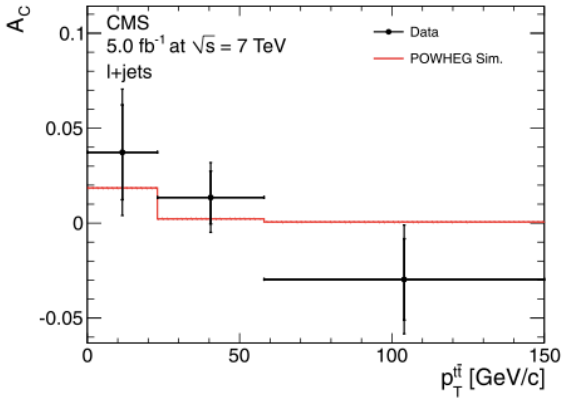
Charge Asymmetry

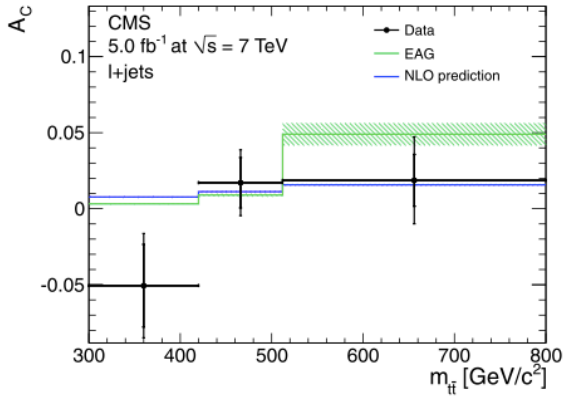
PLB 717 (2012) 129

l+jets









$$A_C^{\Delta|y|} = 0.004 \pm 0.010(stat) \pm 0.011(syst)$$

$$A_C^{\Delta|y|}(NLO) = 0.0115 \pm 0.0006$$

arXiv:1109.6830

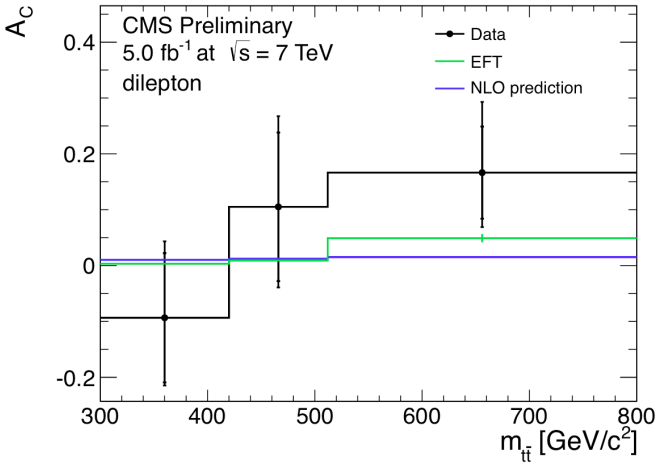
EFT/EAG: A model featuring an effective axial-vector coupling of the gluon that could describe the A_{FB} vs m_{tt} dependence [PRD 8 (2011) 054017].

No deviations from the SM (still large uncertainties)

Charge Asymmetry

CMS-PAS-TOP-12-010

dilepton

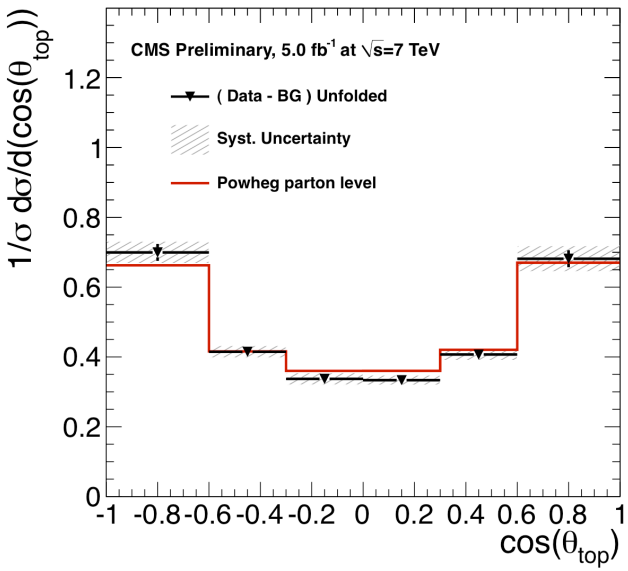


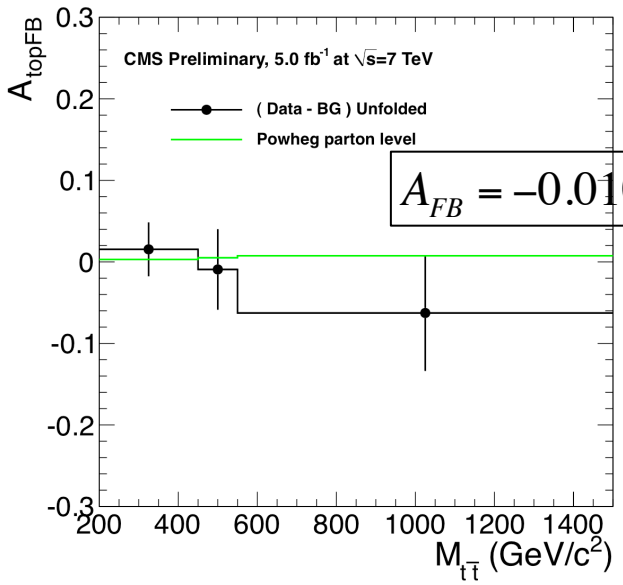
$$A_C^{\Delta|y|} = 0.050 \pm 0.043(stat)^{+0.010}_{-0.039}(syst)$$

$$A_C^{\Delta|y|}(NLO) = 0.0123 \pm 0.0005$$ arXiv:1205.6580

$$A_C^{\Delta|\eta|} = 0.010 \pm 0.015(stat) \pm 0.006(syst)$$

$$A_C^{\Delta|\eta|}(NLO) = 0.0156 \pm 0.0007$$ arXiv:1205.6580





$$A_{FB} = -0.010 \pm 0.034(stat) \pm 0.026(syst)$$

No deviations from the SM (still large uncertainties)

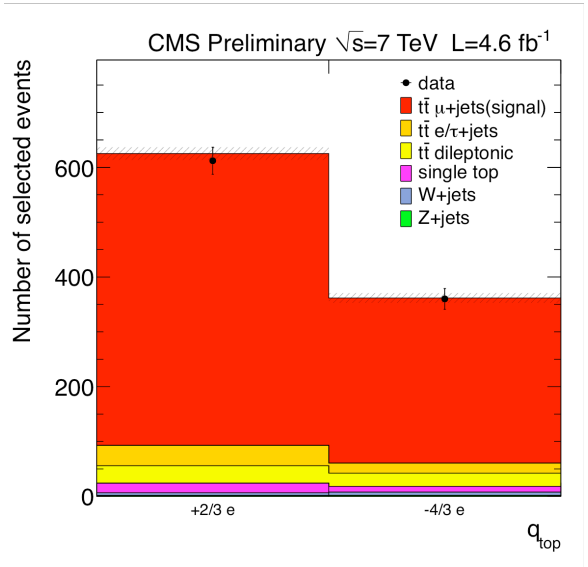
Top Quark Charge

- Muon+jets final state
- Sign of b quark charge from muon within b jet + muons from W
- Wrong charge assignment taken into account with a b-quark enriched data sample.
- Combine b and W charges to obtain top quark charge
- Test q=+2/3e vs q=-4/3e hypotheses

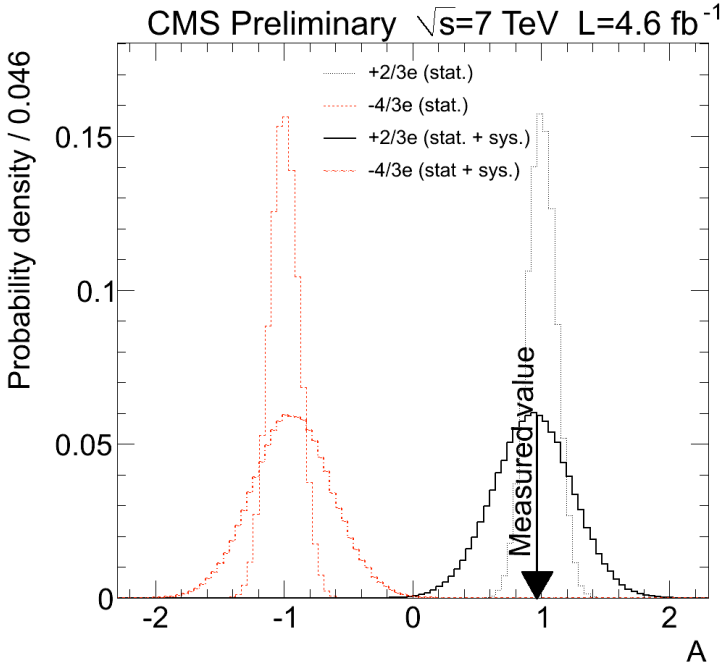
CMS-PAS-TOP-11-031

Test statistics: Asymmetry between the two bins:

$$A = \frac{1}{D_S}\frac{N_{SM} - N_{XM} - \langle N_{BG}\rangle D_B}{N_{SM} + N_{XM} - \langle N_{BG}\rangle}$$



Histogram: predicted distribution for simulated SM (q=2/3 e) events.

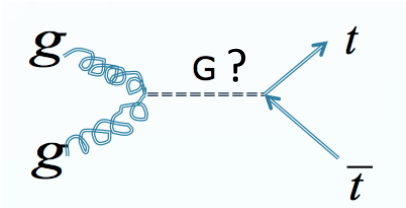


$$A = 0.97 \pm 0.12(stat) \pm 0.31(syst)$$

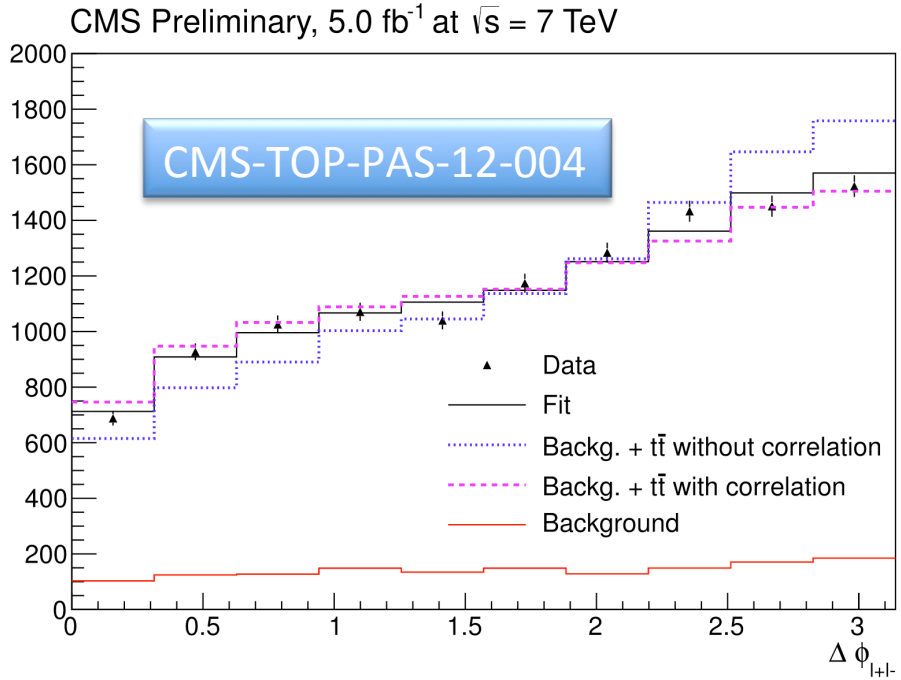
Perfect agreement with the SM and q=4/3e (i.e., A=-1) hypothesis excluded.

tt~ Spin Correlation from Dileptons

- Does the top quark have a new type of strong interaction that would cause a much faster decorrelation?
- Is the spin of the top (1/2) and top-anti-top spin correlation consistent with the SM?
- t→H^+b, … ?



Simultaneous template fit of $e^+e^-, \mu^+\mu^-, e^\pm\mu^\mp$ channels.



$$f^{SM} = 1.0$$
$$A^{SM}_{helicity}(NLO) = 0.31$$

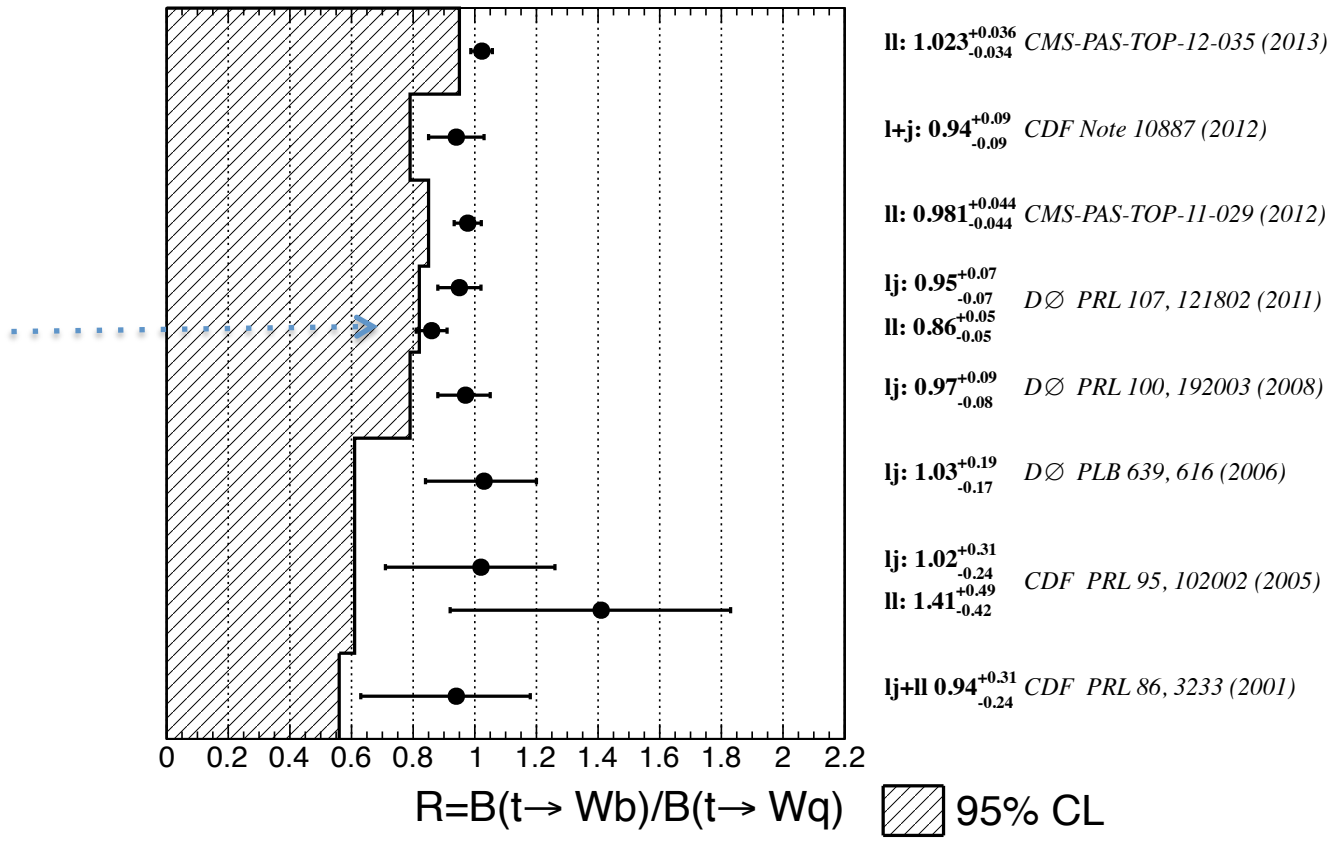
$$f^{SM} = \frac{N_{SM}}{N_{SM} + N_{uncorr}} = 0.74 \pm 0.08(stat) \pm 0.24(syst)$$
$$\rightarrow A^{measured}_{basis} = A^{SM}_{basis} f^{SM}$$
$$A_{helicity} = 0.24 \pm 0.02(stat) \pm 0.08(syst)$$

Results consistent with the SM.

Bottom Quark Content in Top Decay

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

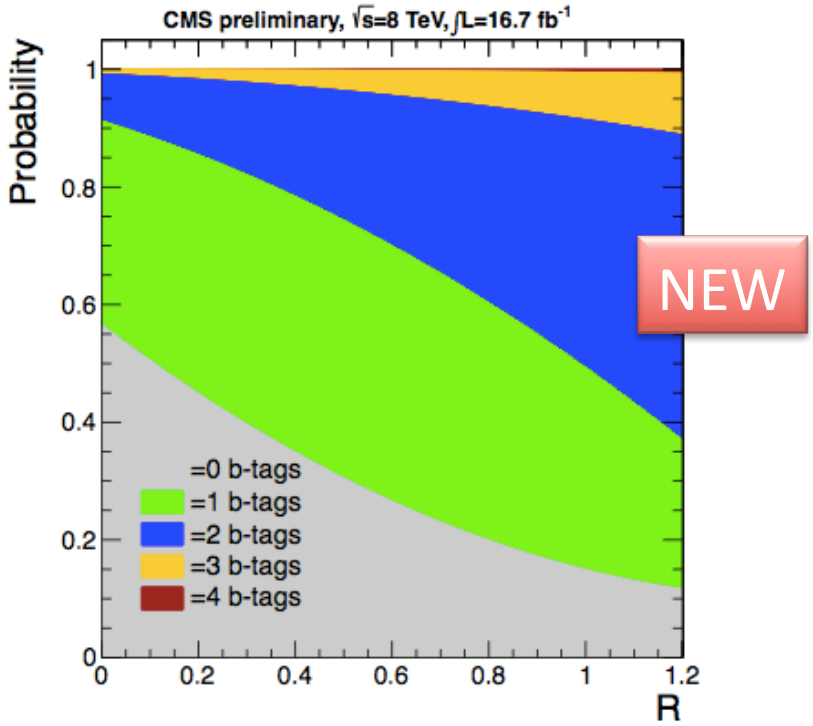
- A deviation from R=1 → a 4th generation quark or a charged Higgs boson, ...



Bottom Quark Content in Top Decay

- tt~ dilepton final state
- Count N(t→Wb) and compare to total N(t→Wq) taking into account
  - the signal purity
    - data-driven estimation of the main bkg (DY)
    - single top from simulation
  - number of reconstructed t→lνj in 0,1 and 2 jet categories.
    - Using M(lj)
  - number of b-tags
    - measure b-tag jet efficiency and mis-identification
    - determine number of b-tags
    - compare to data-driven probability functions vs R.

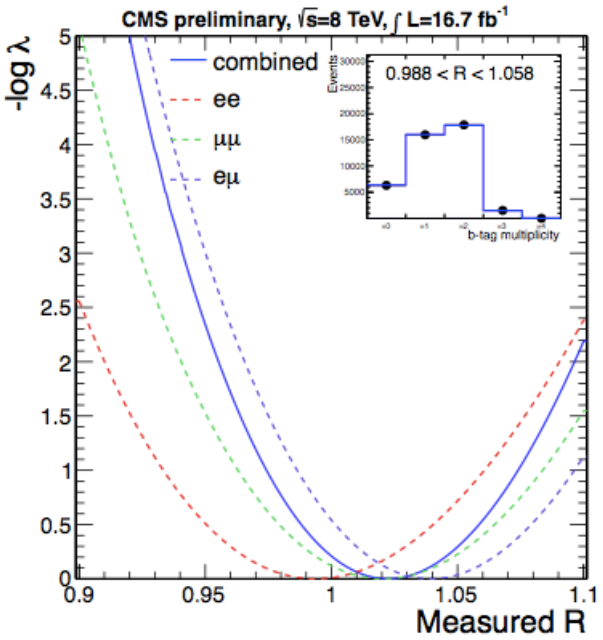
R is extracted from a profile likelihood fit to analytic data-driven analytic probability models for each 36 event category.

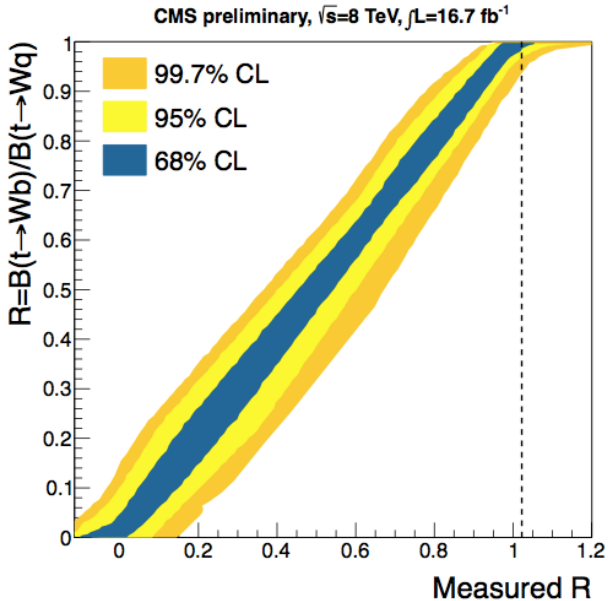


Probability model for different b-tag multiplicities

CMS-TOP-PAS-12-035

Bottom Quark Content in Top Decay





NEW

$$R = 1.023^{+0.036}_{-0.034}\left(stat + syst\right)$$

$$\text{If } R \le 1 \rightarrow R > 0.945 \text{ @ } 95\% \text{ CL}$$

R → $|V_{tb}|$ with the assumption of CKM unitarity and 3 generations.

$$\left|V_{tb}\right| = 1.011^{+0.018}_{-0.017}\left(stat + syst\right)$$

$$if \ \left|V_{tb}\right| < 1 \rightarrow \left|V_{tb}\right| > 0.972 \ @ \ 95\% \ CL$$

Result systematic uncertainty dominated

- mainly b-tagging efficiency, purity, fraction of correct assignments from data.

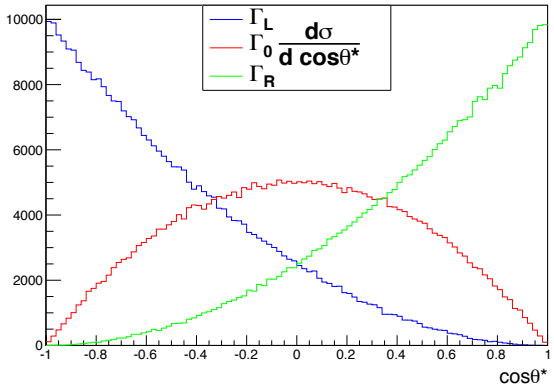
The most precise measurement of R and the most stringent direct lower bound on $|V_{tb}|$.

CMS-TOP-PAS-12-035

W Boson Polarization from tt~ Events

- Parametrization of top quark partial width in terms of W-helicity fractions

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}\left(1-\cos\theta^*\right)^2 F_L + \frac{3}{8}\left(1+\cos\theta^*\right)^2 F_R + \frac{3}{4}\left(\sin\theta^*\right)^2 F_0,\ F_X \equiv \frac{\Gamma_X}{\Gamma},\ F_L + F_R + F_0 = 1$$



θ*: angle between the p(d-type fermion) in W rest-frame and p(W) in top rest-frame.

Wtb: magnitude determined by $|V_{tb}|$.

- BSM contributions to Wtb vertex modify helicity fractions.
- In the effective operative framework Wtb vertex can be parametrized as

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^\mu\left(V_L P_L + V_R P_R\right) t\, W_\mu^- - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_\nu}{M_W}\left(g_L P_L + g_R P_R\right) t\, W_\mu^- + \text{h.c.}$$

EPJ-C 50 (2007) 519

$$SM:\ V_L = V_{tb} \approx 1$$

$$V_R = g_L = g_R = 0$$

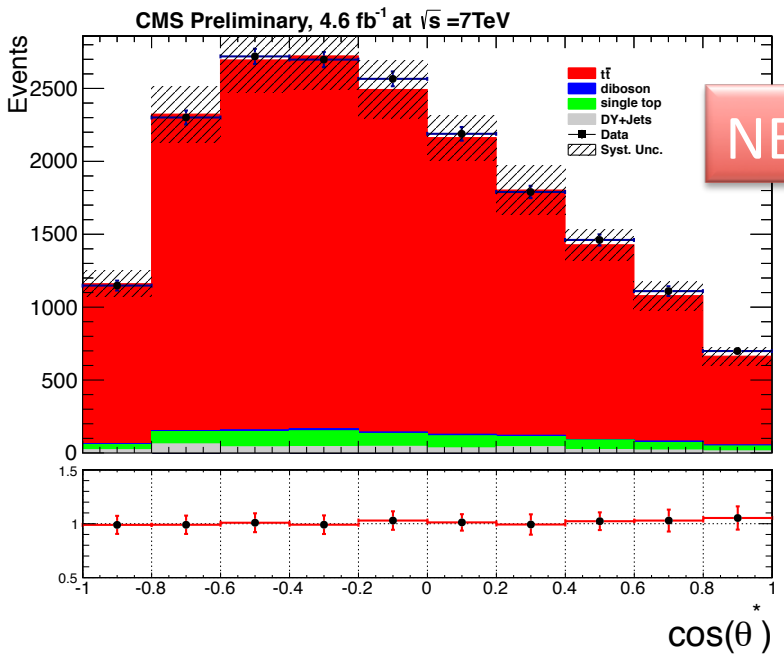
Non-zero anomalous couplings V_R, g_L, g_R can be probed with helicity fractions.

W Boson Polarization from tt~ Events

- Fit based on event-by-event reweighting for resolution and efficiencies.

- *Dilepton channel*
  - Analytical solution for the tt~ system.

CMS-PAS-TOP-12-015

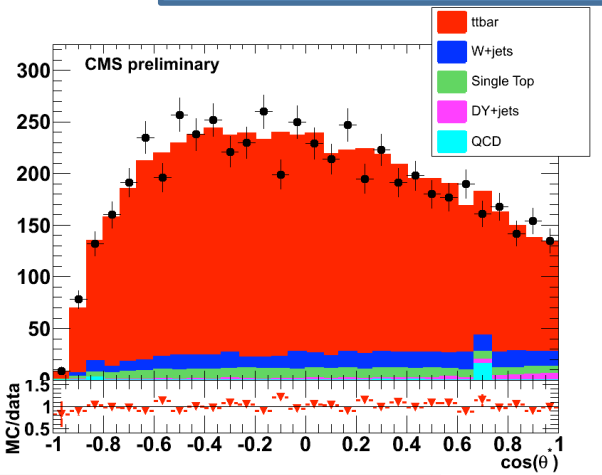


NEW

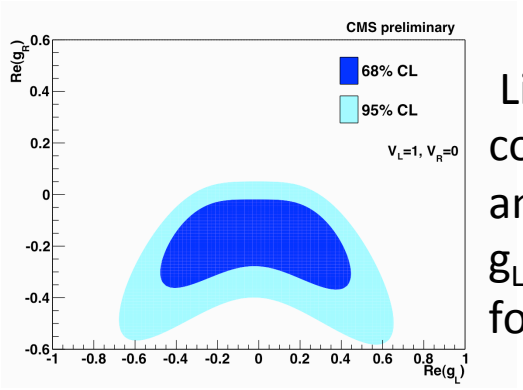
All results consistent with each other and SM predictions.

- *Lepton+jets*
  - Kinematic fit with m_t and m_W constraints.

CMS-PAS-TOP-11-020



2.2 fb^{-1}

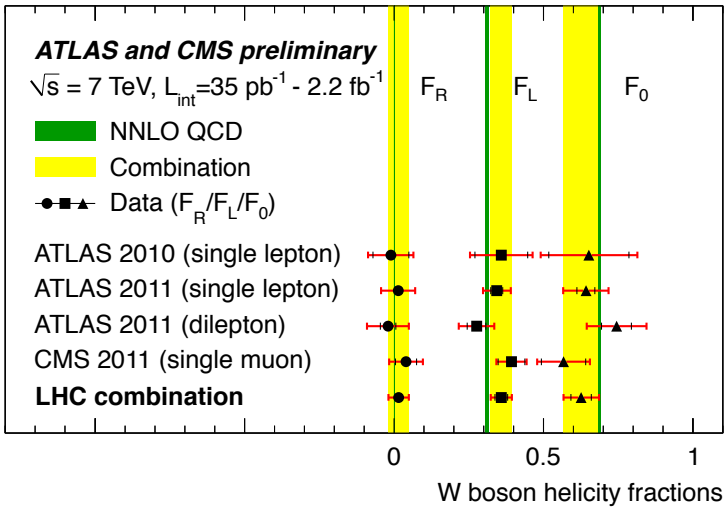


Limits on the real components of the anomalous couplings g_L, g_R at 68 and 95% CL, for VL=1 and VR=0.

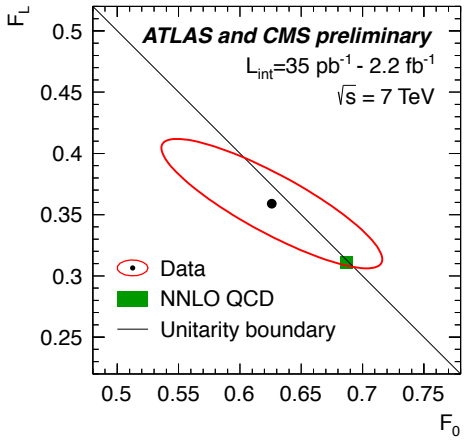
W Boson Polarization - LHC Combination

ATLAS-CONF-2013-033 & CMS-PAS-TOP-12-025

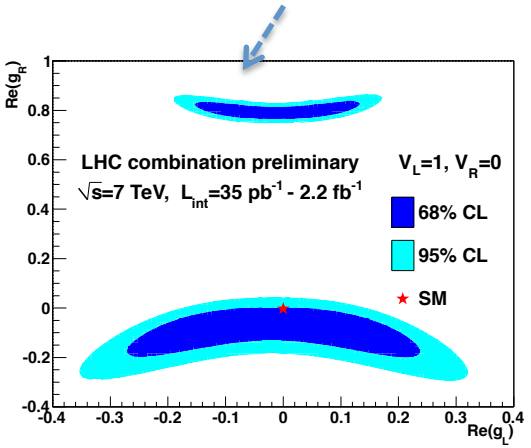
NEW



- All measurements utilize cos(θ*)
- Unitarity constraint: $F_L+F_R+F_0=1$ in each measurement and the combination



Strongly constrained by the single-top cross section measurements.



contours from profile likelihood method

- BLUE (Best Linear Unbiased Estimator) method for the combination
  - Results stable against wrong correlation hypotheses.

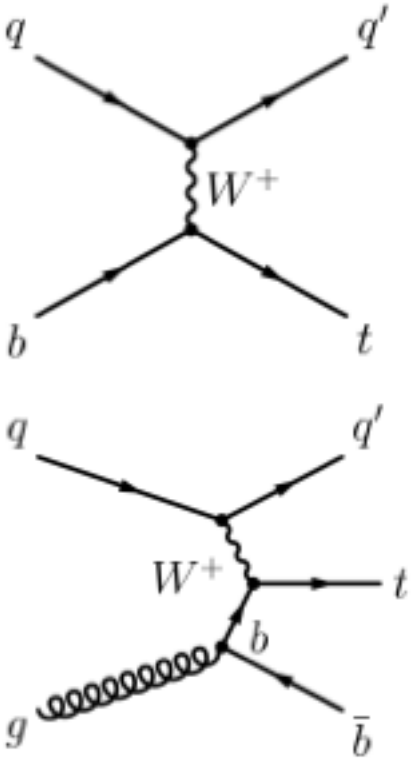
$$F_0 = 0.626 \pm 0.034(stat) \pm 0.048(syst)$$
$$F_L = 0.359 \pm 0.021(stat) \pm 0.028(syst)$$
$$F_R = 0.015 \pm 0.034(stat + syst)$$

SM prediction: $F_0 = 0.687(5)$, $F_R = 0.0017(1)$, and $F_L = 0.311(5)$ [assuming m_t: 172.8+/-1.3 GeV]

W Helicity in Single Top Topologies

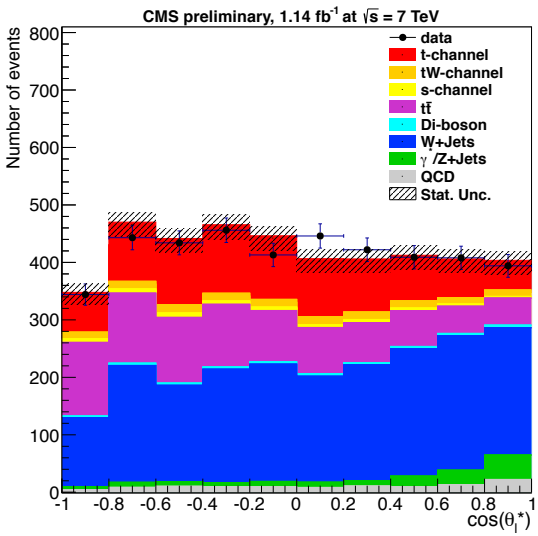
NEW

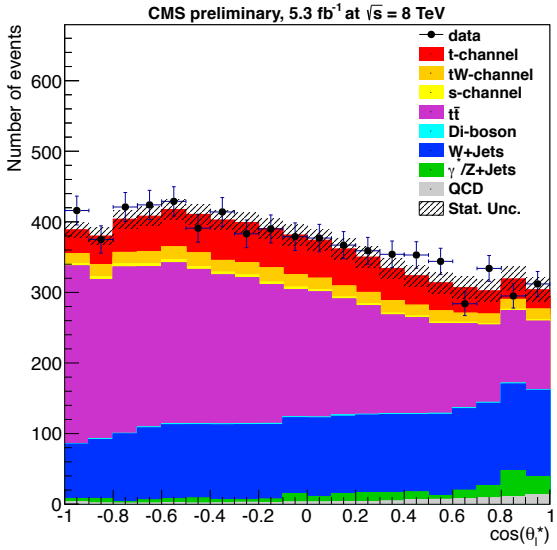
CMS-PAS-TOP-12-020



t-channel has
the highest cross-section

- First measurement of the W-helicity fractions in single-top events.
  - μ+jets final state
- Helicities obtained from likelihoods with reweighted signals.
  - including all processes involving the top quark (t-,s-,tW-channels, and tt~ semileptonic and dileptonic final states)
  - Helicity fractions and W+jets contribution simultaneously extracted.
- 7 and 8 TeV results combined by combining the two likelihoods.





→ p(z,v) calculated using the W-mass constraint and energy conservation.
→ Real solutions: lower value is taken
→ Imaginary solutions: W-mass smeared within its width (2.1 GeV) → a real solution.

W Helicity in Single Top Topologies

NEW

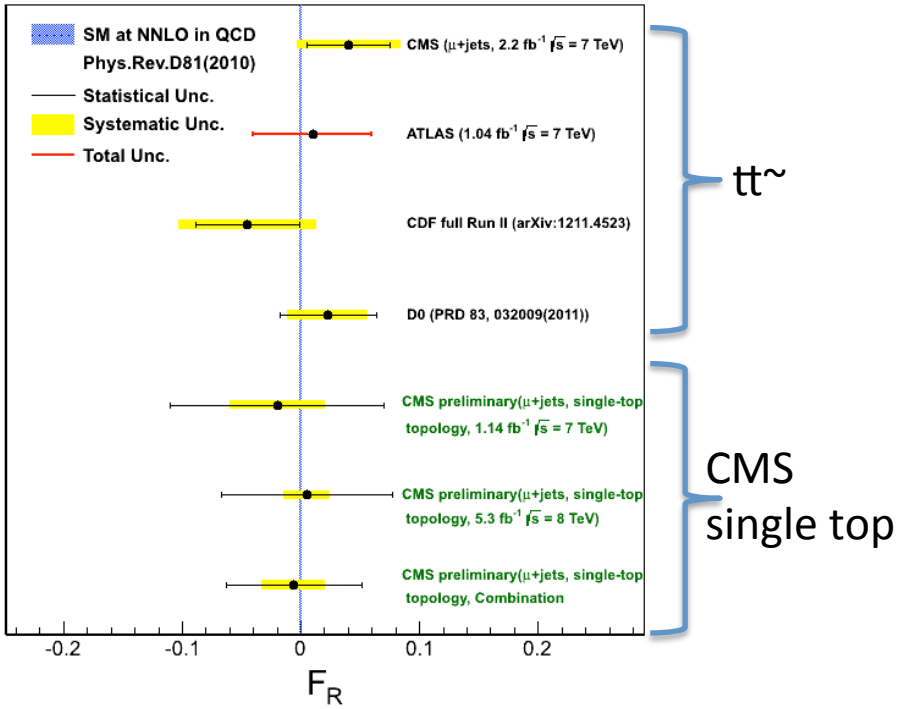
CMS-PAS-TOP-12-020

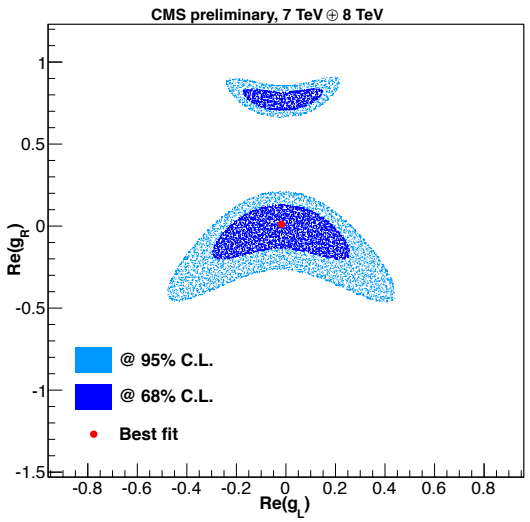
7+8 TeV combined results

$$F_L = 0.293 \pm 0.069(stat.) \pm 0.030(syst.)$$
$$F_0 = 0.713 \pm 0.114(stat.) \pm 0.023(syst.)$$
$$F_R = -0.006 \pm 0.057(stat.) \pm 0.027(syst.)$$

Results consistent with the SM and measurements in tt~ channels.

- Dominant systematic uncertainties
  - MET uncertainty from the fluctuations in un-clustered energy, JES/JER
  - Q2 and simulation
  - W+jet shape

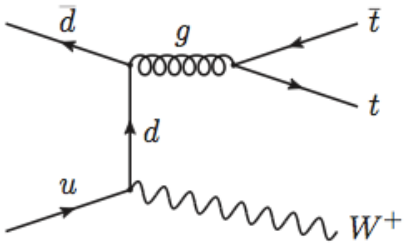


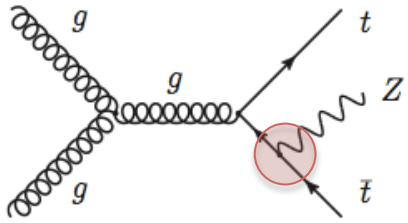


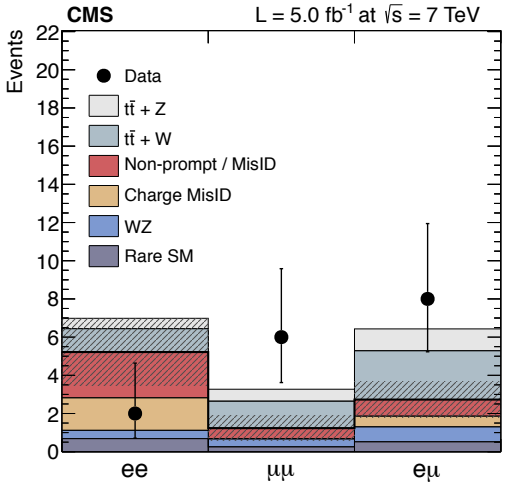
ttW and ttZ Production

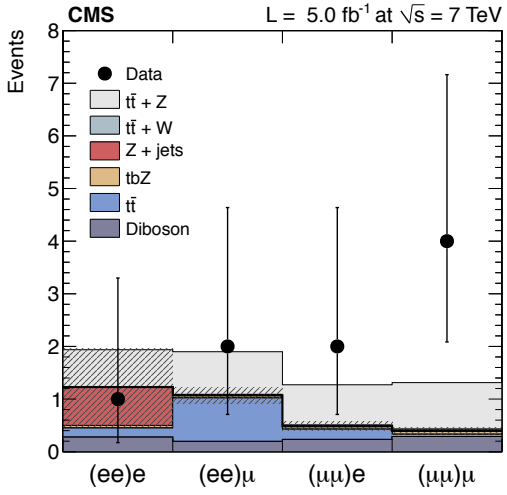
- ttV measurement → test SM top-vector boson coupling.
- Important background in new physics searches and ttH $\sigma(ttH) \approx \sigma(ttV)$
- The first cross section measurement of ttV.
  - Same-sign dilepton signature for ttV (V=W,Z)
  - Trilepton signature for ttZ

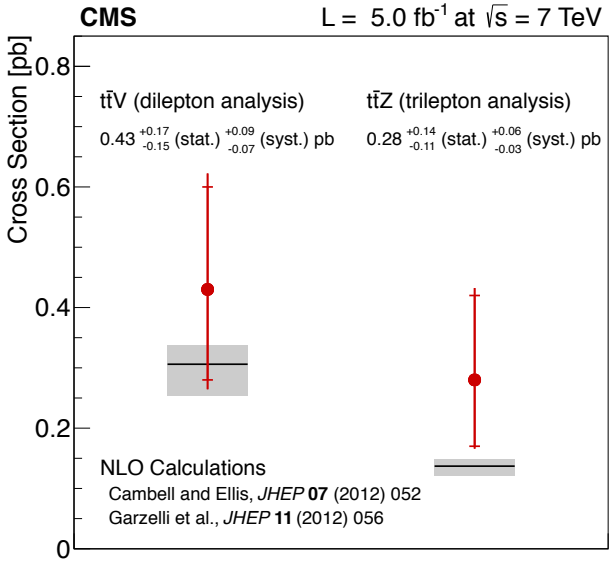
CMS-PAPER-TOP-12-014
Accepted by PRL











First direct measurements of top-Z coupling.

Measurements are compatible with the SM NLO predictions.

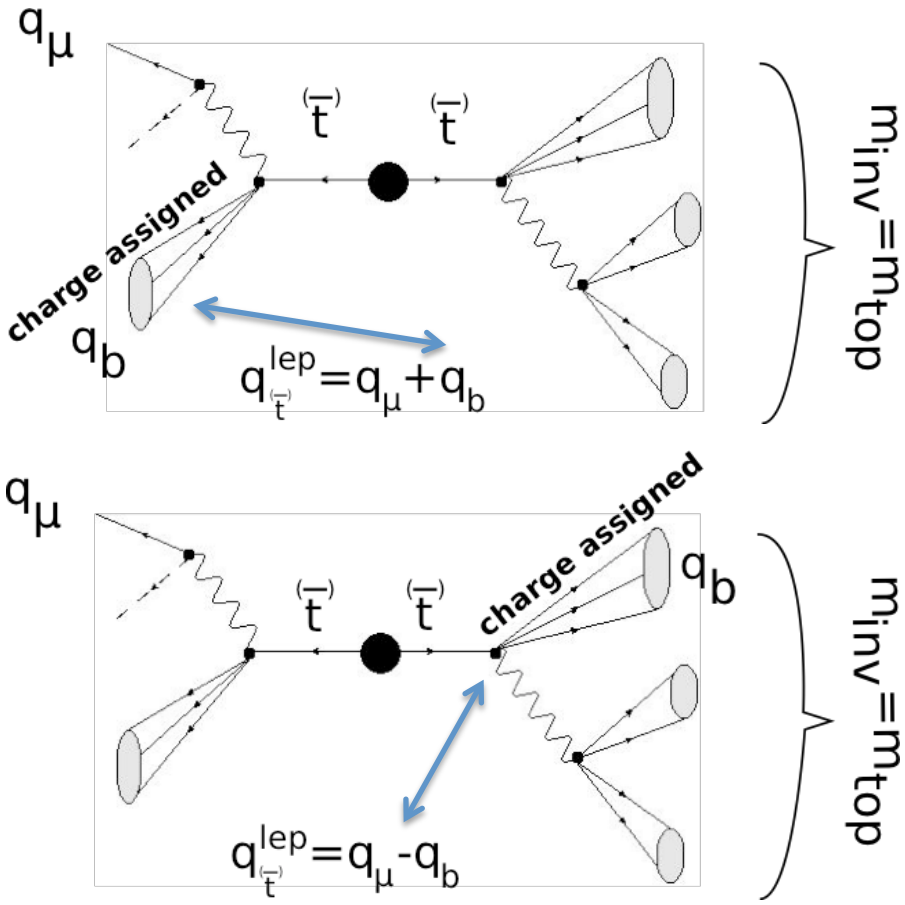
Conclusions

- Measurements of top quark properties at CMS are providing thorough tests of the standard model.
- So far, all top quark properties measurements show good agreement with the standard model predictions (and no signs of new particles from direct searches).
- Many new and more precise top quark measurements to come from 8 TeV data.

All public results at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Backup

Top Charge – Assignment of Charge



- The two jets with highest b-tag are considered to originate from the top quark decays.
- q_b from the jet that fulfills all charge requirements.
- If both jets allow for charge reconstruction the jet with higher b-tag is considered.

W Boson Polarization - LHC Combination

ATLAS-CONF-2013-033 & CMS-PAS-TOP-12-025

	Coefficient [%]	
Measurement	w_{F_0}	w_{F_L}
F_0 ATLAS 2010 (single lepton)	12.4	7.2
F_L ATLAS 2010 (single lepton)	19.4	11.4
F_0 ATLAS 2011 (single lepton)	39.7	- 8.5
F_L ATLAS 2011 (single lepton)	-15.5	35.2
F_0 ATLAS 2011 (dilepton)	13.2	2.7
F_L ATLAS 2011 (dilepton)	5.2	15.0
F_0 CMS 2011 (single lepton)	34.7	- 1.4
F_L CMS 2011 (single lepton)	- 9.1	38.4
Total weight:	100.0	100.0

- The negative weights occur due to the large anti-correlations between *F*0 and *FL* .