LHC Seminar
Tuesday, 25 February 2014

Recent top physics results from CMS

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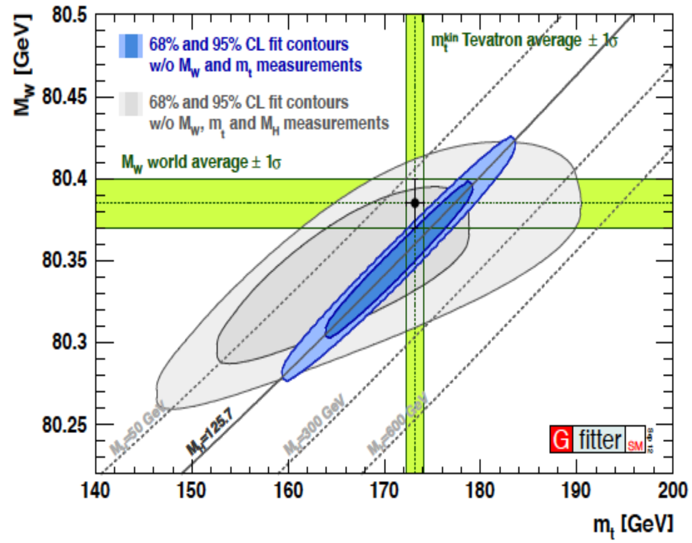
The top quark

- It is the **heaviest elementary particle known**
  - large coupling to the Higgs boson
  - candidate to play a special role in the EW symmetry breaking and in many scenarios of physics beyond the SM (BSM)
  - decays before hadronizing
    - direct access to properties (spin, charge, polarization…)



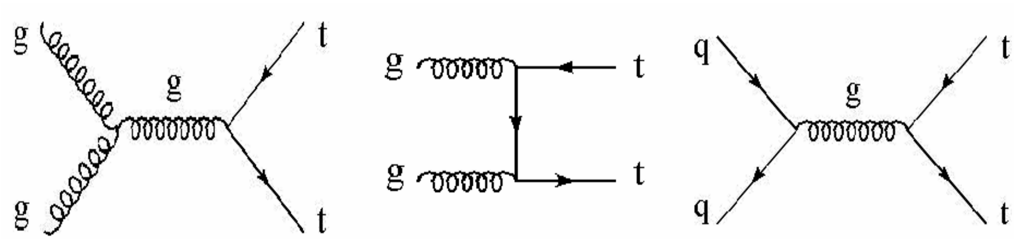
- Discovered by the **Tevatron** experiments (1995) (first collisions on November 30, 1986)

  PRL 74, 2626–2631, PRL 74, 2632–2637

  - **Tevatron legacy** still of main importance in top physics

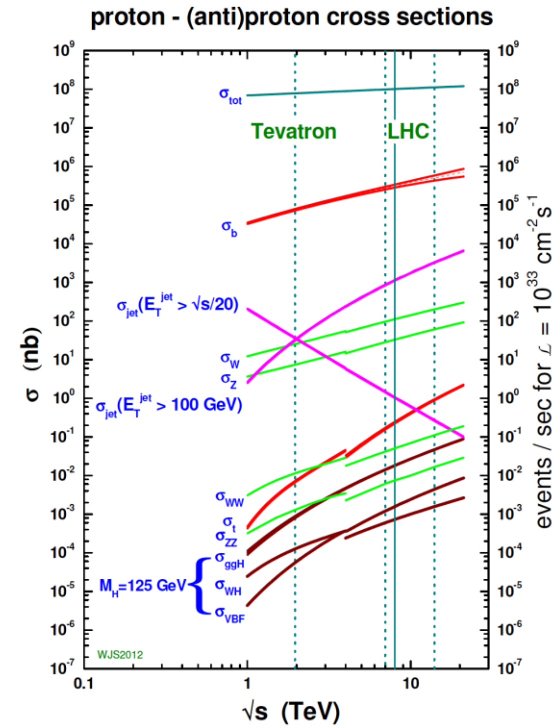
Top quarks at the LHC

- At the **LHC**:
  - top quarks produced at a **much higher rate**

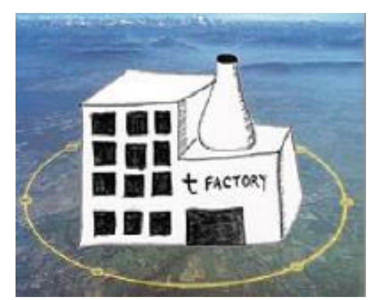


Main production: ttbar pairs, via strong interaction

x-sec (pb)	ttbar
Tevatron	7.08 (+0.00-0.24) (+0.36-0.27) approx. NNLO
LHC @ 7TeV	163 (+7-5)(±9) approx. NNLO
LHC @ 8TeV	234 (+10-7)(±12) approx. NNLO

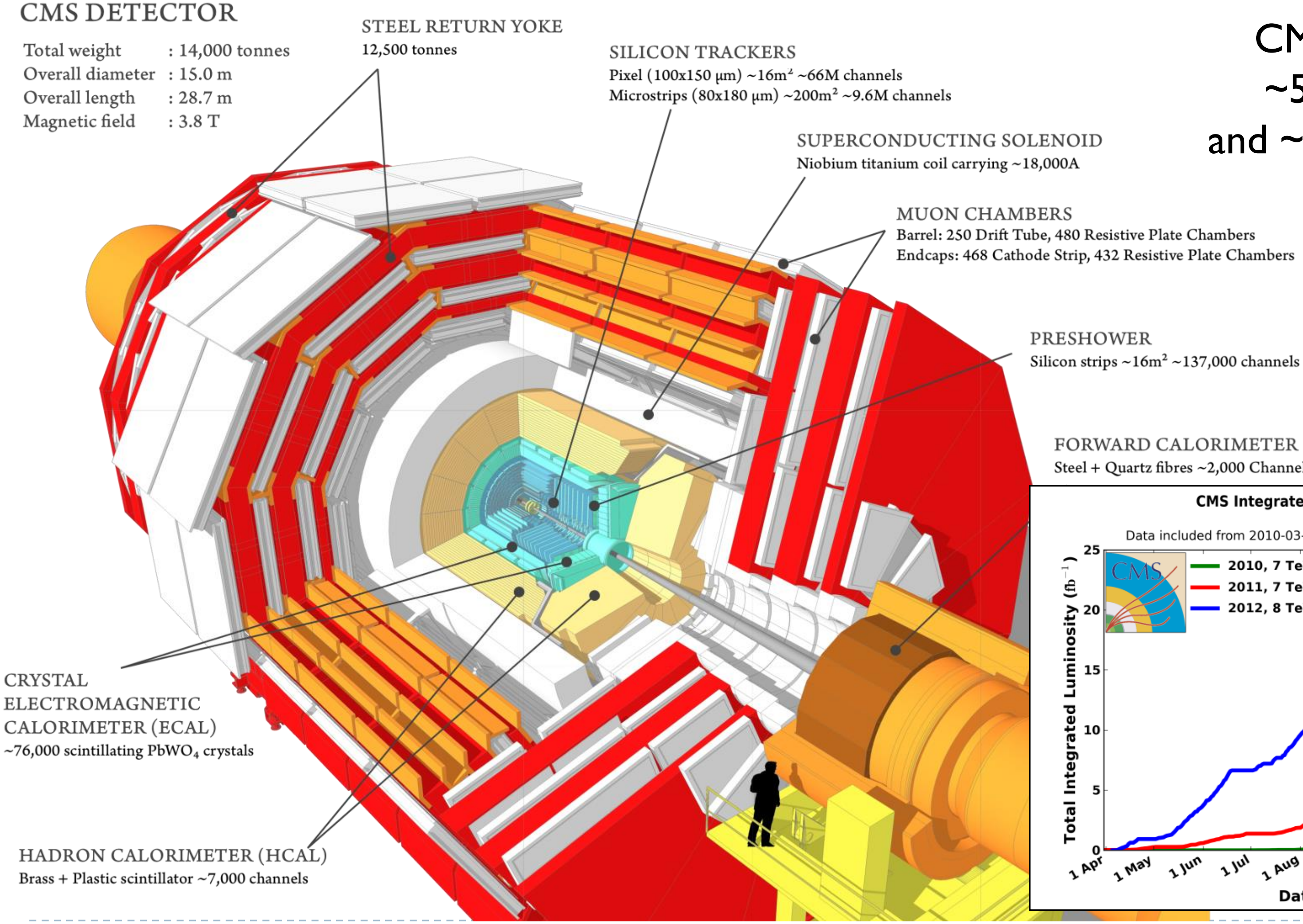


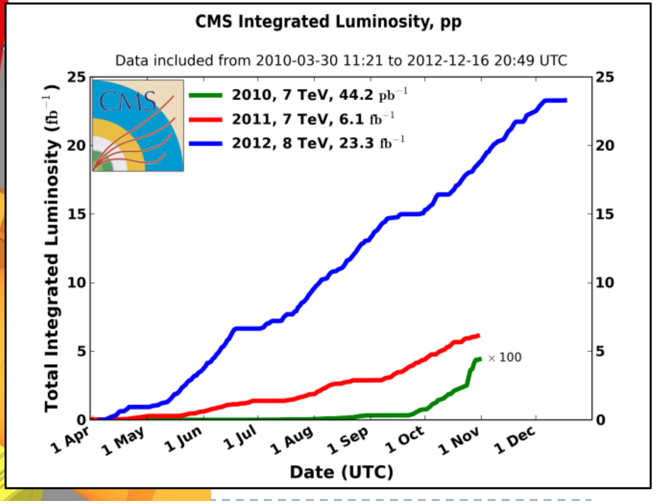
"The LHC is a top quark factory!"



Compact Muon Solenoid (CMS)

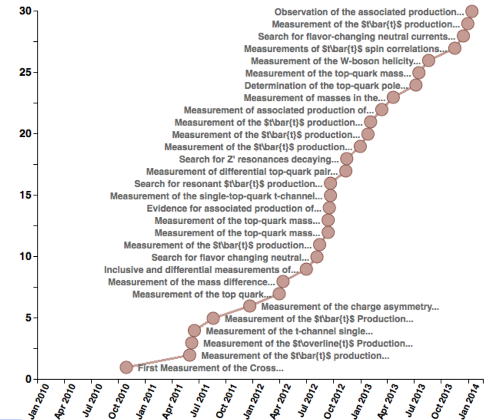
CMS recorded
~5fb^{-1} at 7TeV
and ~20 fb^{-1} at 8TeV





Top Physics in CMS

- Since the start of the data-taking, CMS has measured and studied the **ttbar and single top production** modes in many final states, at 7 and 8TeV
- A variety of top properties have been studied
- 31 papers published in standard model top physics
  - + many preliminary results



This talk will cover recent results concerning:

- Single top production
- A selection of top properties

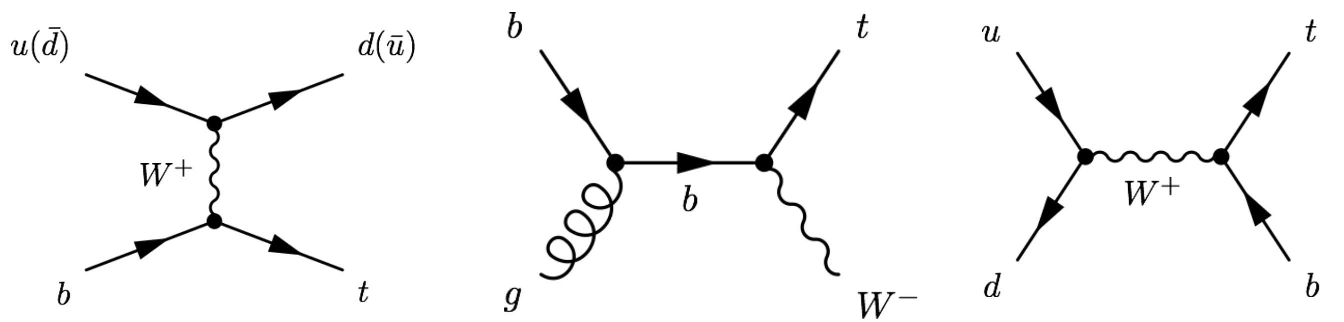
- All the top results summarized in https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Single top results

t-channel, tW associated production, s-channel

Single top production

- Alternative top quark production via electroweak interaction, at a lower rate than pair production, involving a Wtb vertex
- Three main processes: **t-channel, tW associated production, s-channel**



- sensitive to many models of new physics
  - FCNC, Anomalous couplings
  - New particles (W', charged Higgs)
- characteristic scenario in which to perform **SM measurements**:
  - Top polarization, W helicity, top mass, $|V_{tb}|$
- **background** to searches (Higgs, SUSY)

Single top world status

- First observed at the Tevatron (2009) PRL103:092002, PRL.103:092001
- At the Tevatron:
  - t-channel and s-channel were observed (s-channel fresh from last Friday! arXiv:1402.5126), tW associated production was not accessible

σ [pb]	t-channel	tW	s-channel
Tevatron (1.96 TeV)	2.08 Established	0.22 Not accesible	1.046 Established
LHC (7 TeV)	64.6 Established	15.6 Evidence	4.59 … ATLAS
LHC (8 TeV)	87.1 Established	22.2 Established	5.55 … CMS

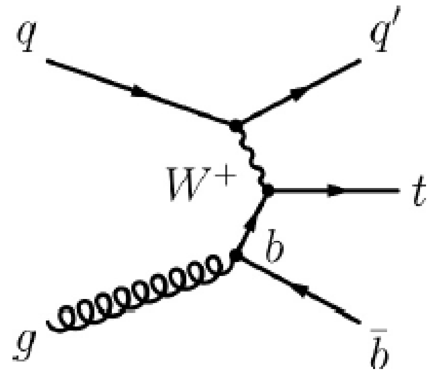
- CMS presented the first t-channel studies with 7TeV data **early 2011**
- Since then, all the main modes have been studied, the t-channel has been used to measure SM properties, the tW has been discovered, and single top related signatures have been explored on the search for new physics

Established: observed with ≥ 5σ significance. Evidence : ≥ 3σ

"The LHC is a SINGLE top quark factory!"

t-channel

- **Dominant process** with the highest cross section at the Tevatron and the LHC



- The final state studied is a **lepton + jets signature**
- Signal events characterized by:
  - One isolated **muon or electron**
  - Missing transverse energy (**MET**)
  - A central **b jet**

  Leptonic top decay

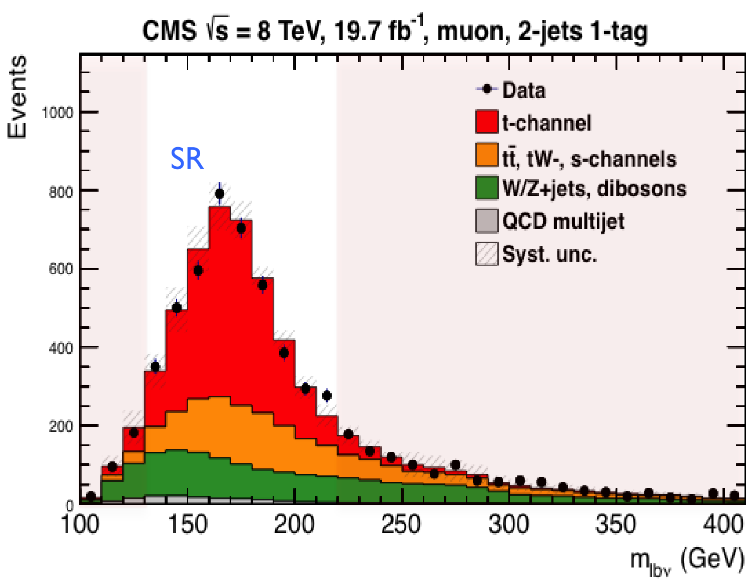
  - light-quark jet from the hard scattering process (often forward)
  - Additionally, a second b jet produced in association to the top quark
- **Main backgrounds: W+jets, ttbar, multijet**

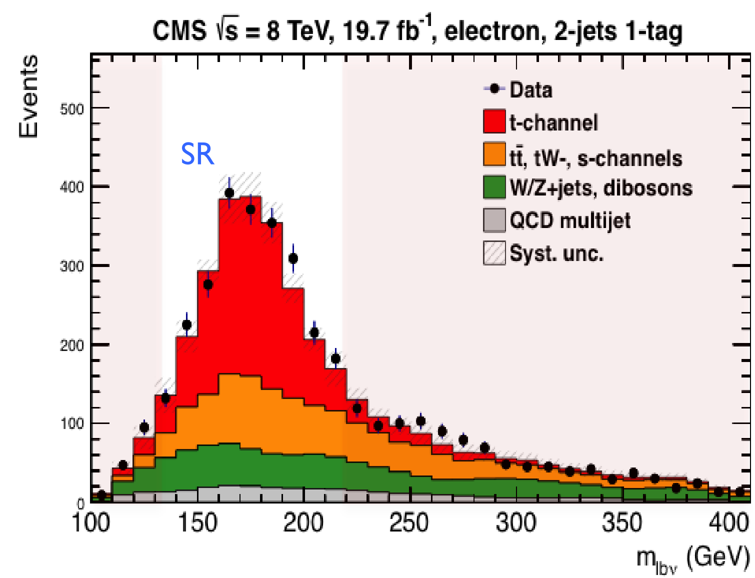
Measurement at 7TeV: JHEP12(2012) 035

Paper TOP-12-038 (to be submitted to JHEP)

t-channel at $\sqrt{s}$ = 8 TeV: Analysis

- Fit on $|\eta_{j'}|$, pseudorapidity of the recoiling light jet exploiting forward kinematics
- Event selection
  - 1 isolated lepton (μ/e)
  - Kinematic cuts (anti QCD): m_T (W) (μ) / MET (e)
- Several exclusive regions using jet and b-tag multiplicity (Njets-Mtag):
  - Signal extraction 2jets-1tag region, divided into "signal region" (SR) and "sideband" (SB) ($130 < m_{l\nu b} < 220$ GeV)

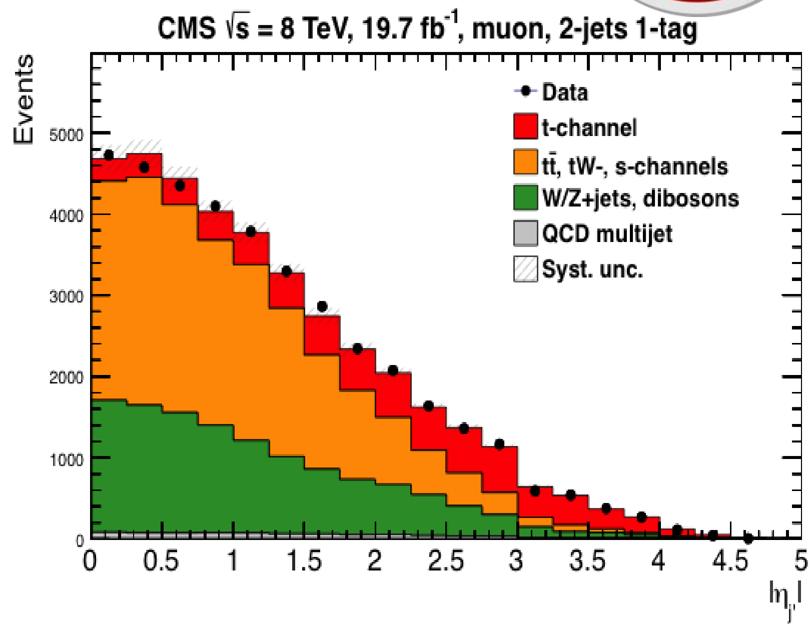




Paper TOP-12-038

t-channel at √s = 8 TeV: Analysis

- Other regions used as **Control Regions**
  - ttbar: 3jets-1tag, 3jets-2tag
  - W/Z+jets: 2jets-0tag
- Background estimation:
  - QCD multijet: Maximum likelihood fit to MET (e) or $m_T(W)(\mu)$ before cut. Template from data, inverting isolation.
  - W/Z+jets: From SB to SR
  - tt: normalization from simulation, template from 3jet-2tag region



$\sigma_{t\text{-channel}}$ **= 83.6±2.3(stat.)±7.4(syst)pb**

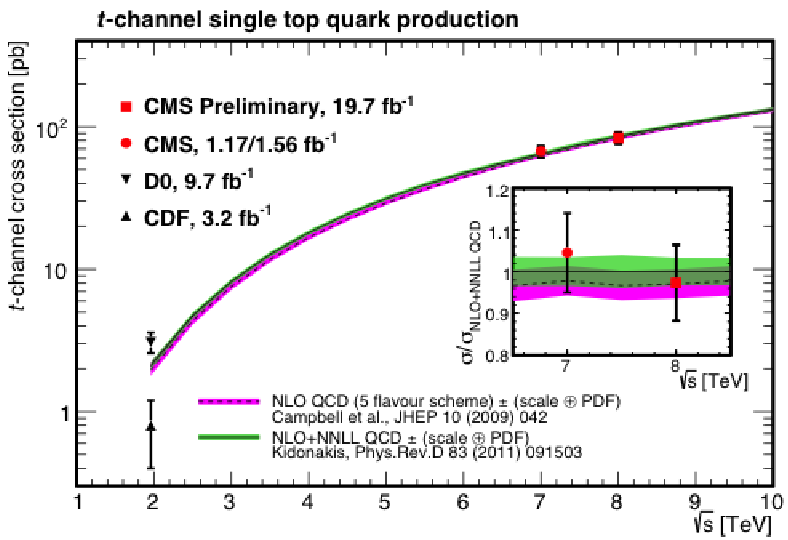
$\sigma^{th}_{t\text{-channel}}$ *= 87.2+2.8-1.0(scale)+2.0-2.2(PDF)pb (app. NNLO)**

$$|V_{tb}| = \sqrt{\frac{\sigma}{\sigma^{th}}} = 0.979 \pm 0.045(\exp.) \pm 0.016(th.) \rightarrow |V_{tb}| \quad > 0.92$$

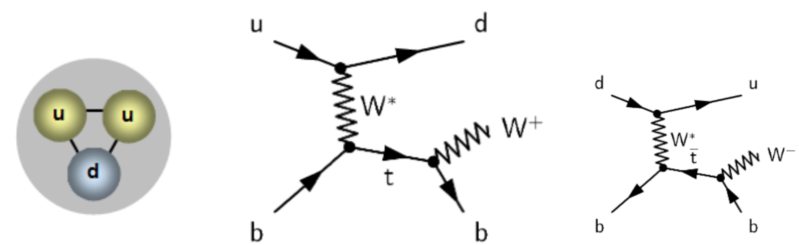
$$|V_{tb}|(7+8TeV \quad combination) = 0.998 \pm 0.038(\exp.) \pm 0.016(th.)$$

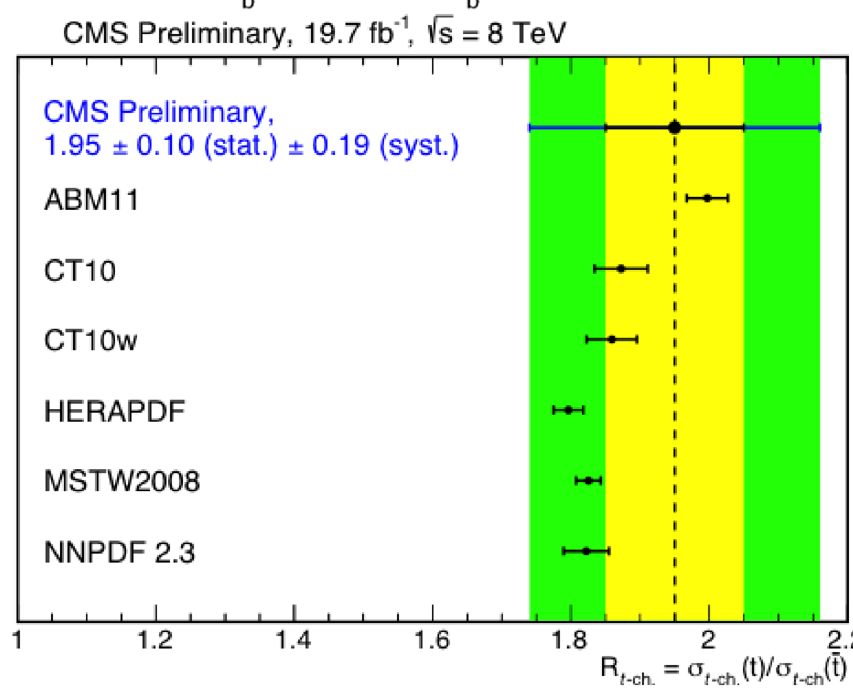
*arXiv:1205.3453

t-channel at √s = 8 TeV: Results



$$\frac{\sigma_{t-ch}(8TeV)}{\sigma_{t-ch}(7TeV)} = 1.24 \pm 0.08(stat.) \pm 0.12(syst.)$$





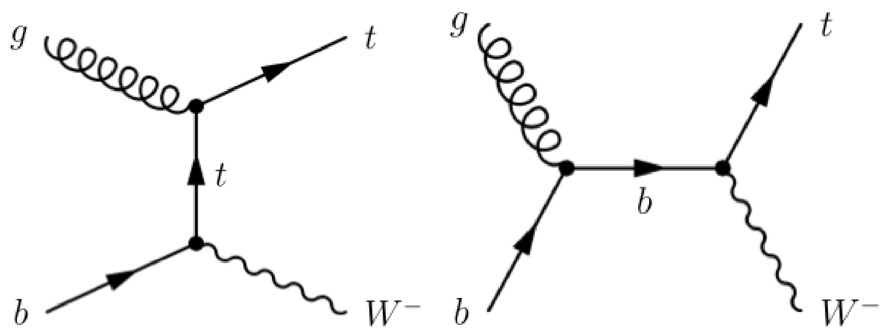
Due to the relative proportion of u and d quarks in the proton, more tops than anti-tops are expected to be produced

σ_{top} = 53.8±1.5(stat.)±4.4(syst)pb *σ^{th}_{top} = 56.4+2.1-0.3(scale)±1.1(PDF)pb*
$\sigma_{anti\text{-}top}$ = 27.6±1.3(stat.)±4.4(syst)pb *$\sigma^{th}_{anti\text{-}top}$ = 30.7±0.7(scale)+0.9-1.1(PDF)pb*

$$R_{t-channel} = 1.95 \pm 0.10(stat.) \pm 0.19(syst.)$$

tW associated production

- Single top process with the second largest cross-section at the LHC, inaccessibly small at the Tevatron
- **ATLAS** showed evidence at 7 TeV quickly followed by **CMS** (first experiments study this process)



- The final state studied is a **dilepton signature**
- Signal events are characterized by:
  - **Two** opposite-sign, isolated **leptons**
  - Missing transverse energy (2 neutrinos in the final state)
  - A jet coming from a **b decay**
- **Backgrounds: ttbar (main challenge), DY**

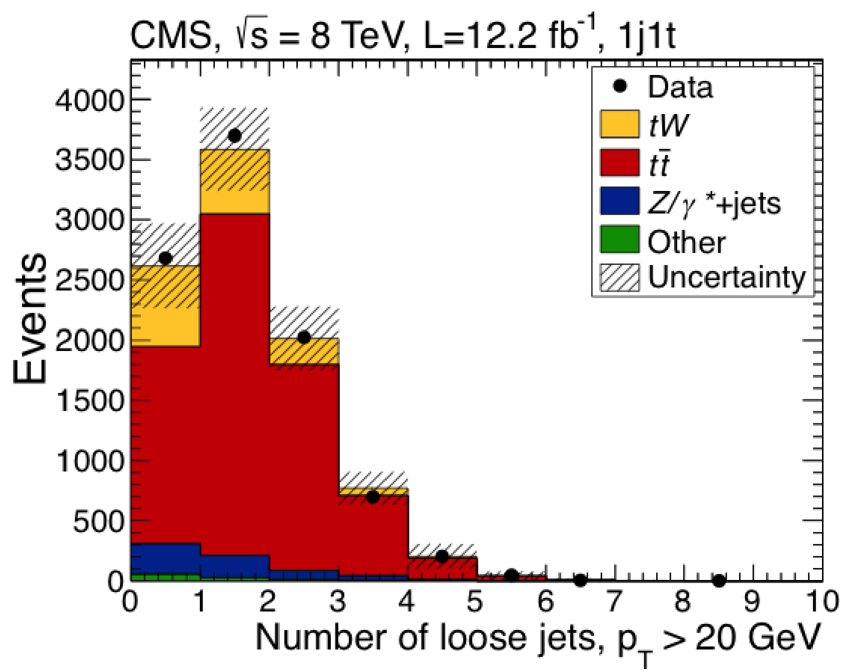
Evidence at 7TeV:
Phys.Rev.Lett 110, 022003 (2013)

arXiv:1401.2942
Submitted to PRL

tW at √s = 8 TeV: Analysis

- $12.2 fb^{-1}$
- Event selection:
  - 2 isolated leptons, opposite charge (e,μ)
  - Vetoing Z mass window (m_{ll}), MET cut
- Regions:
  - Signal: Exactly 1 jet, b-tagged **(1j1t)**
  - Control Regions: Exactly 2 jets either one or both of them b-tagged **(2j1t and 2j2t)**(ttbar)
- Background estimation:
  - ttbar: 2 control regions included in the fit.
  - Z+jets: MET-dependent data-driven scale factors. Inverting Z mass cut

ttbar with 1 jet outside acceptance or miss-reconstructed → main background

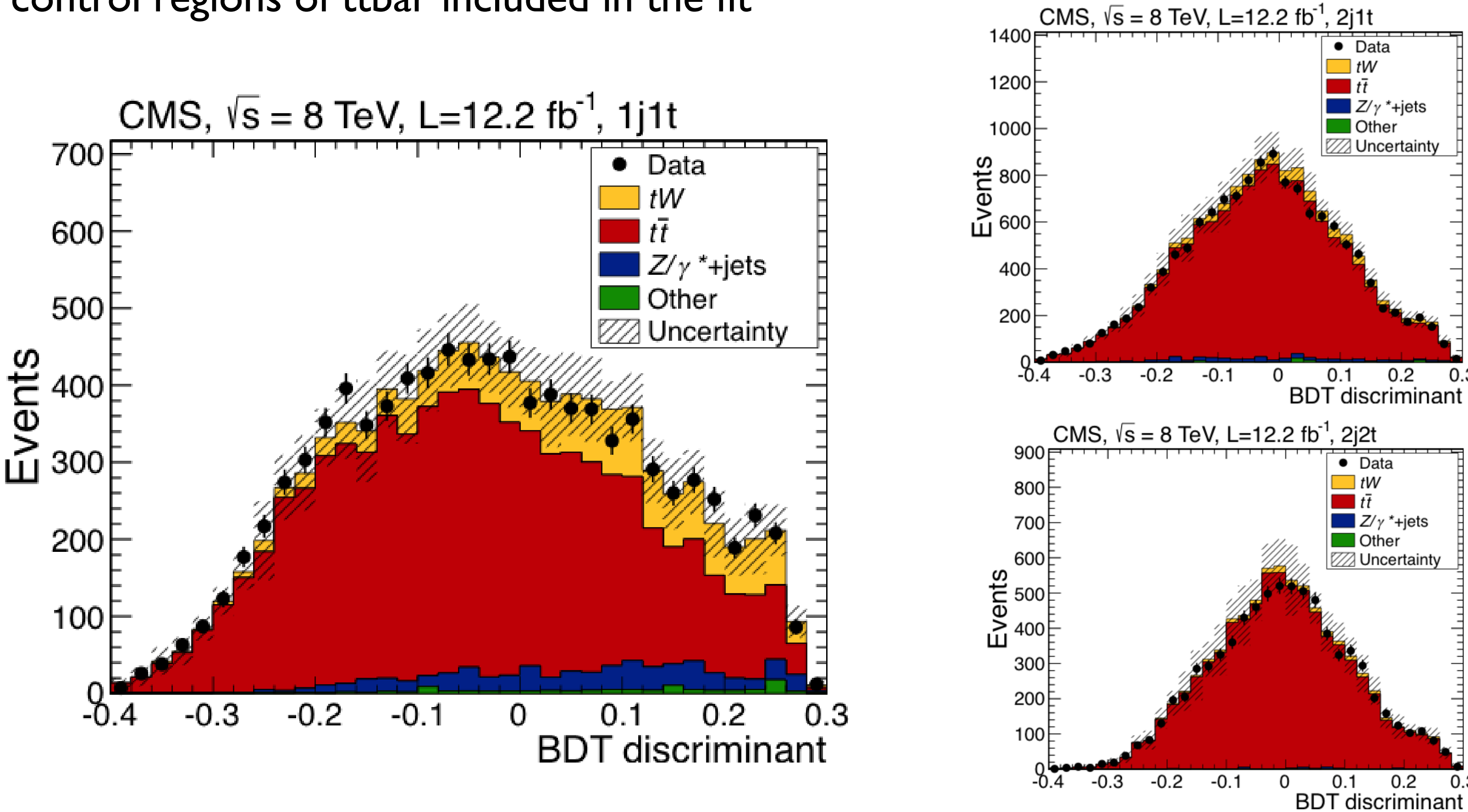


Handle to discriminate tW and ttbar: jets that have not been selected by the main quality criteria (looser pt cut, more open η angle, b-tagging information)

arXiv:1401.2942
Submitted to PRL

tW at √s = 8 TeV: Analysis

- **BDT build with 13 variables** (variables related to loose jets most powerful to discriminate)
- 2 control regions of ttbar included in the fit

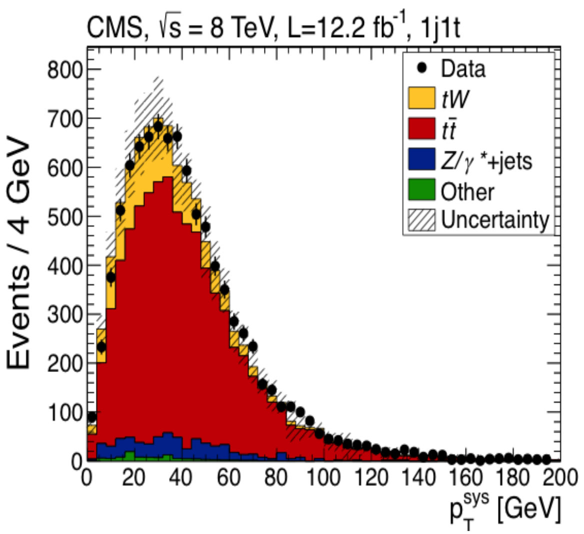


arXiv:1401.2942
Submitted to PRL

tW at √s = 8 TeV: Results

tW signal observed with a significance of 6.1σ (expected significance 5.4±1.4σ)
$\boldsymbol{\sigma_{tW} = 23.4 \pm 5.4}$ **pb** *σ^{th}_{tW} = 22.2±0.6(scale)±1.4(PDF)pb (app. NNLO)**
$|V_{tb}| = 1.03 \pm 0.12(\text{exp.}) \pm 0.04(\text{th.}) \rightarrow |V_{tb}| > 0.78$ (95% CL)

First observation of the process!

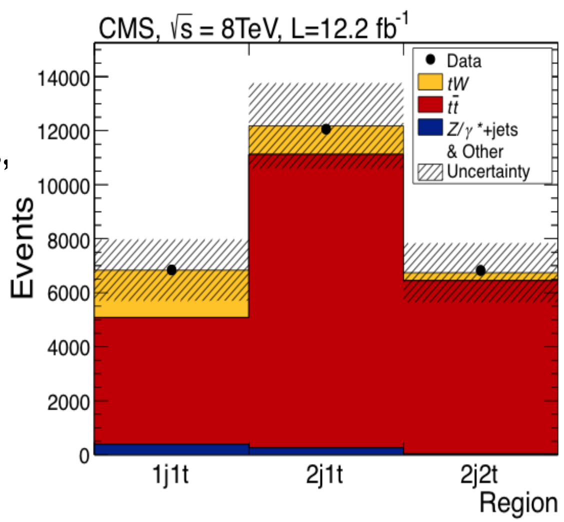


Two cross-check analyses

Same selection + additional cut in eμ

Fit on shape of p_T of the system (leptons, jet, MET), and event counting

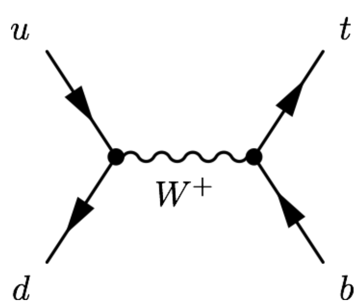
Fit to the p_T of the system	**4.0σ** (3.2+0.4-0.9) σ_{tW} = 24.3+8.6-8.8 pb
Cut-based analysis	**3.6σ** (2.8+0.9-0.8σ) σ_{tW} = 33.9+8.6-8.6 pb



*arXiv:1210.7813

s-channel

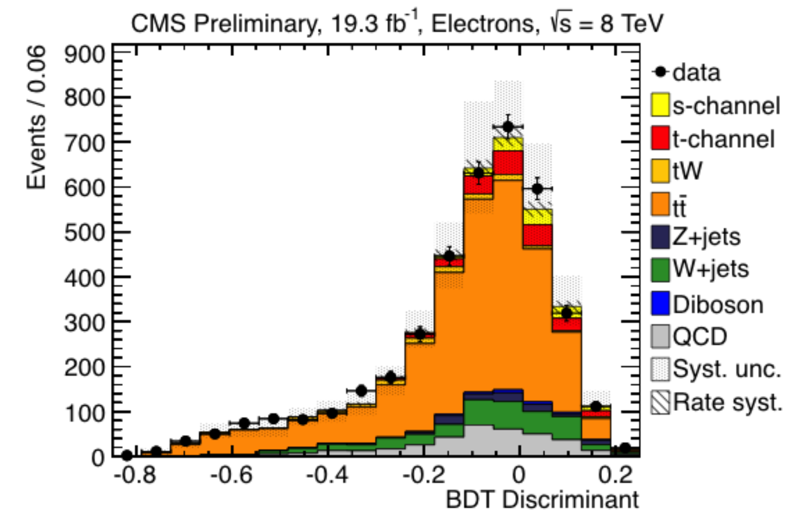
- Lowest cross-section at the LHC, more important at the **Tevatron** (where the study of data after the shutdown allowed for the observation of the process)
- Production mode **sensitive to new physics: W' bosons, charged Higgs bosons**
- **Very challenging final state:** low cross-section, difficult to separate from backgrounds

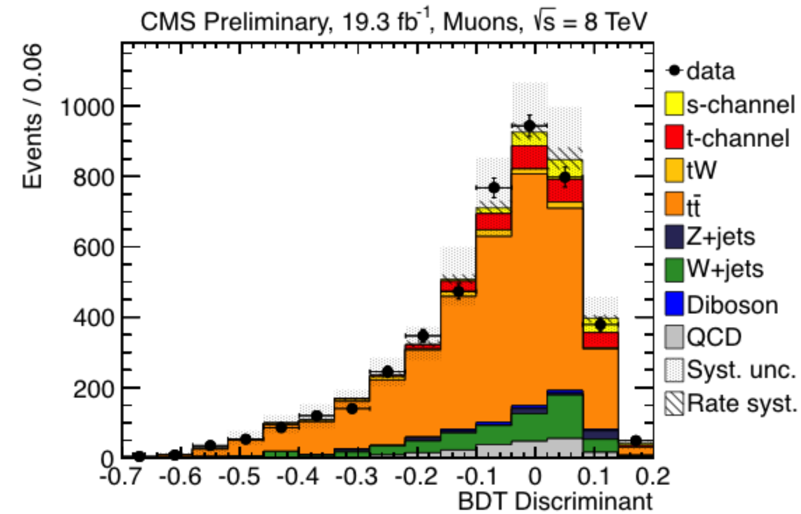


- Signal signature: **lepton + jets**
  - **A lepton** (e,μ) and **MET** from the decay of a W boson
  - **Two jets** with high transverse momentum originating from **b-quarks**
- **Main backgrounds**: W+jets and ttbar, multijet

s-channel at √s = 8 TeV: Analysis

- **First CMS result on this channel**
- Event Selection
  - 1 isolated lepton (μ/e)
  - 2 b-tagged jets
- Background estimation:
  - QCD : data-driven. Maximum likelihood fit to MET (e) or $m_T(W)(\mu)$. Template from data inverting isolation.
  - ttbar: control region included in the fit (3jet-2tag)
- **Multivariate analysis based on a BDT**
- 11 variables (e), 10 (μ); no single "golden" discriminant variable





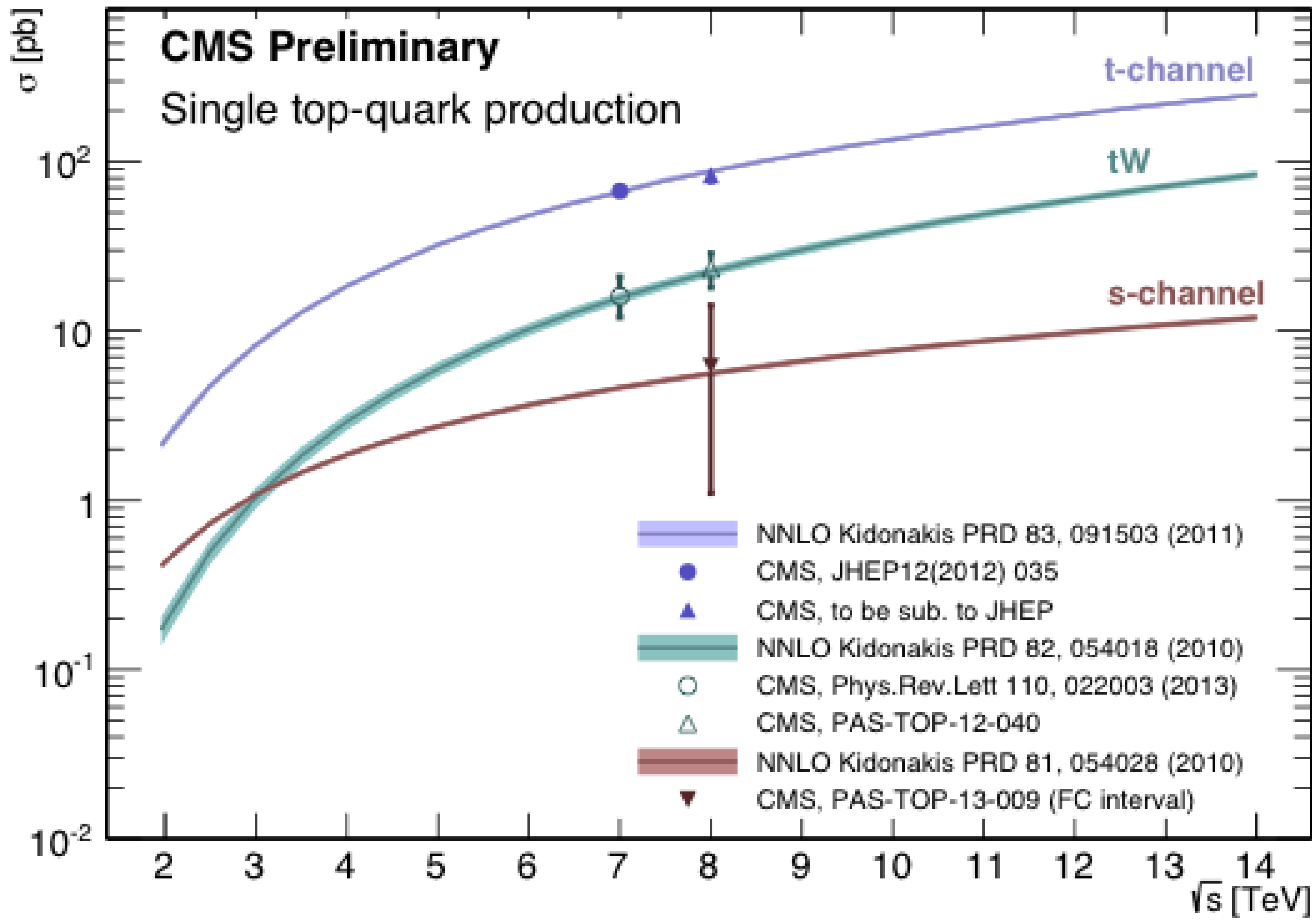
s-channel at √s = 8 TeV: Results

$\sigma_{s\text{-channel}}$ = 6.2±5.4(exp.)±5.9(th)pb = 6.2+8.0-5.1 pb (FC*) $\sigma^{th}_{s\text{-channel}}$ = *5.55 ± 0.08 (scale) ± 0.21(PDF) pb (NNLL)***
Observed significance of the s-channel signal 0.7σ Expected significance 0.9σ
Upper limit of 2.1 (3.1,1.6) times the SM → 11.5 (17.0,9.0) pb

* 68%CL interval using the Feldman-Cousins unified approach which does not reach negative x-sec values

**arXiv:1205.3453

Single top in CMS



Top properties

Top properties

- To fully characterize the top quark, its mass, couplings, and other properties need to be measured and established
  - **Test consistency of SM predictions**
  - Search for hints of new physics in **deviations from SM**
- In CMS many top measurements have been performed
  - The high rate of top production at the LHC allowed competitive measurements since early data taking
- ttbar events have been classically used to study top properties
  - **The single top production at the LHC is large enough to measure top properties**
    - Complementary approach
    - Valuable to get the **full picture**

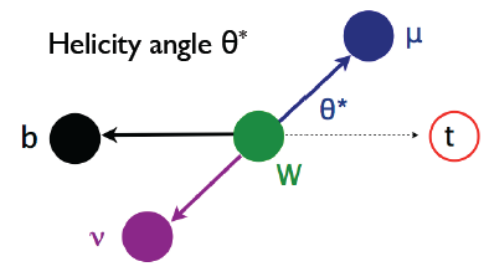
W-helicity fractions

- In the SM, t→Wb (most of the time)
- W (massive, spin 1 boson) can have longitudinal, left- or right-handed helicity states
- Assuming SM couplings:
  - helicity fractions: ~70% longitudinal (F_0), ~30% left-handed (F_L), 0% right-handed (F_R) -due to helicity suppression at LO (unitarity condition: $F_0+F_L+F_R=1$)
- Helicity fractions can be extracted from the angular distributions of the top decay products:

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

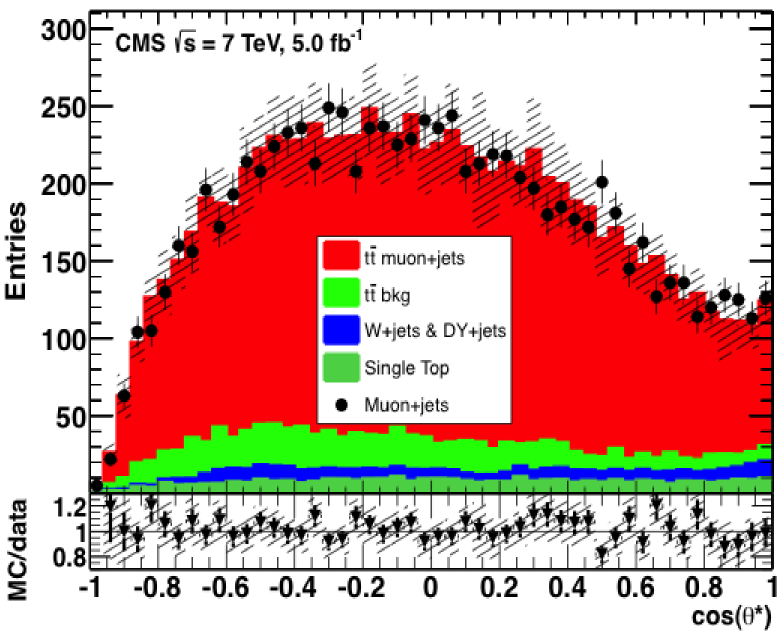
- Helicity angle, θ* : Angle between the momentum of the d-type fermion (lepton in leptonic decays) in the W boson rest frame, and the momentum of the W boson in the top quark rest frame

Direct probe of the Wtb vertex, sensitive to BSM effects



W-helicity in lepton+jets tt events (7TeV)

- Event selection
  - 1 isolated lepton (μ/e); ≥ 4 Jets, at least 2 b-tagged
  - m_T (W) cut against QCD
- ttbar reconstructed using a kinematic fit using W and top mass constraints
- W+jets and Z/γ+jets partially data-driven (normalization by exploiting charge asymmetry and from control region with 1 additional lepton)



Simulation reweighted using generator level cosθ* distribution to obtain any helicity scenario

2D (F_0 free parameter, F_R=0, F_L = 1-F_0) and 3D (F_0, F_L free, F_R constrained as 1-F_0-F_L) fits

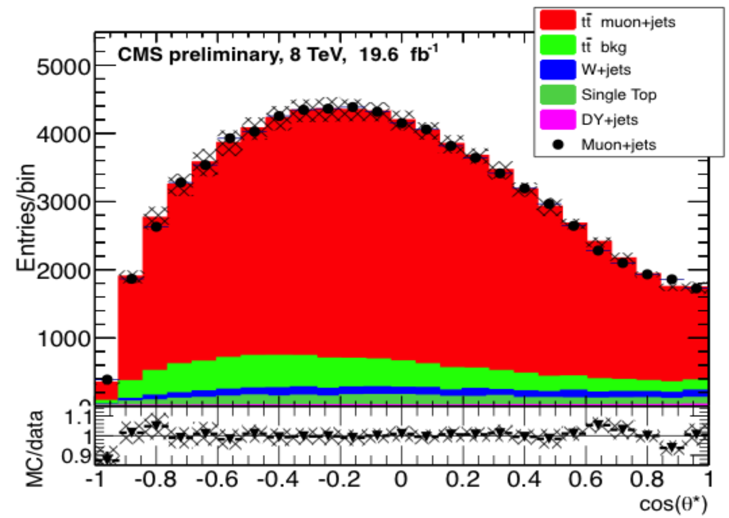
cosθ*$_{lep}$ and cosθ*$_{had}$ considered
Most precise 3D: combined e/μ results, leptonic

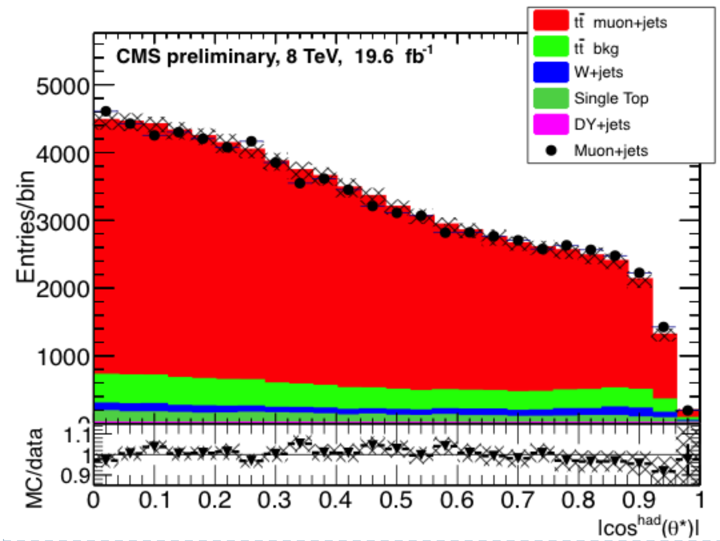
F_L = 0.310 ± 0.022 (stat.) ± 0.022 (syst.)
F_R = 0.008 ± 0.012 (stat.) ± 0.014 (syst.)
F_0 = 0.682 ± 0.030 (stat.) ± 0.033 (syst.)

W-helicity in lepton+jets tt events (8TeV)

- Update of the analysis at 8TeV
  - σ_{tt}(8 TeV) ~ 1.6 σ_{tt}(7 TeV)
  - σ_{Wjets}(8 TeV) ~ 1.2σ_{Wjets}(7 TeV)

    →W-helicity measurement in a purer sample
- Muon channel
- 3D fit





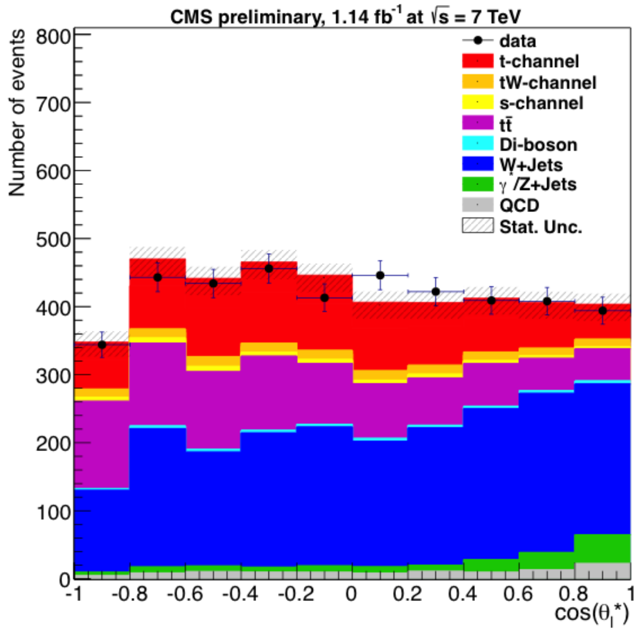
Results:

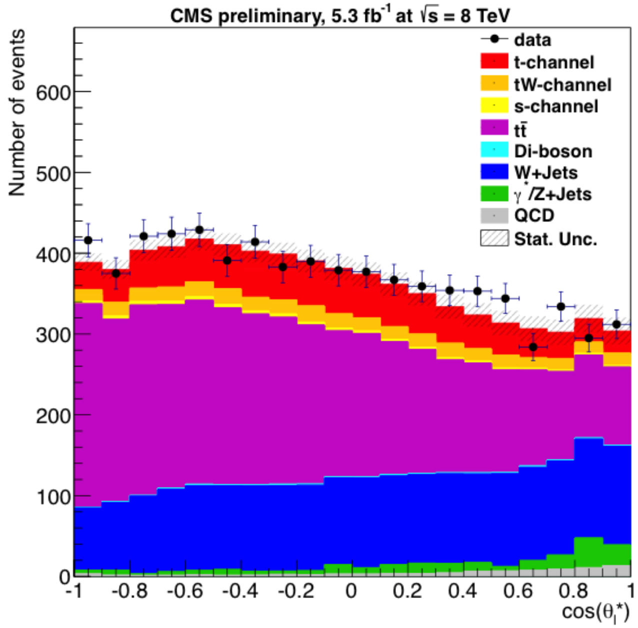
F_L = 0.350 ± 0.010 (stat.) ± 0.024 (syst.)
F_R = -0.009 ± 0.006 (stat.) ± 0.020 (syst.)
F_0 = 0.659 ± 0.015 (stat.) ± 0.023 (syst.)

Leptonic branch

W-helicity in Single top signatures

- First measurement using **single top**
- t-channel standard (cross-section measurement) event selection
- Preliminary result with only muons, 1.14fb^{-1}(7TeV) and 5.3fb^{-1}(8TeV)





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

CMS measurements of F_0, F_L, F_R

	7 TeV	8 TeV
Theory prediction (NNLO)	F_L = 0.311 ± 0.005 F_R = 0.0017 ± 0.0001 F_0 = 0.687 ± 0.005 PRD 81, 111503(R) (2010)	
tt l+jets	F_L = 0.310 ± 0.022 (stat.) ± 0.022 (syst.) F_R = 0.008 ± 0.012 (stat.) ± 0.014 (syst.) F_0 = 0.682 ± 0.030 (stat.) ± 0.033 (syst.) JHEP 10 (2013) 167	F_L = 0.350 ± 0.010 (stat.) ± 0.024 (syst.) F_R = -0.009 ± 0.006 (stat.) ± 0.020 (syst.) F_0 = 0.659 ± 0.015 (stat.) ± 0.023 (syst.) CMS-PAS-TOP-13-008
tt dilepton	F_L = 0.288 ± 0.035(stat) ± 0.040(sys) F_R = 0.014 ± 0.027(stat) ± 0.042(sys) F_0 = 0.698 ± 0.057(stat) ± 0.063(sys) CMS-PAS-TOP-12-015	
Single top t-channel	F_L = 0.293 ± 0.069(stat.) ± 0.030(syst.) F_R = -0.006 ± 0.057(stat.) ± 0.027(syst.) F_0 = 0.713 ± 0.114(stat.) ± 0.023(syst.) CMS-PAS-TOP-12-020	
LHC combination (l+jet and dilep)	F_L = 0.359 ± 0.021 (stat.) ± 0.028 (syst.) F_R = 0.015 ± 0.034 F_0 = 0.626 ± 0.034 (stat.) ± 0.048 (syst.) CMS-PAS-TOP-12-025	

Limits on anomalous couplings

- Deviations on the measured helicity fractions from the SM can be interpreted in terms of anomalous Wtb couplings
- General Wtb vertex lagrangian:

left and right handed vector couplings — left and right handed tensor couplings

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

SM part, $V_L = V_{tb}$ — anomalous couplings (zero in SM)

limits set on real components of g_L and g_R

disfavored by single top cross-section measurements

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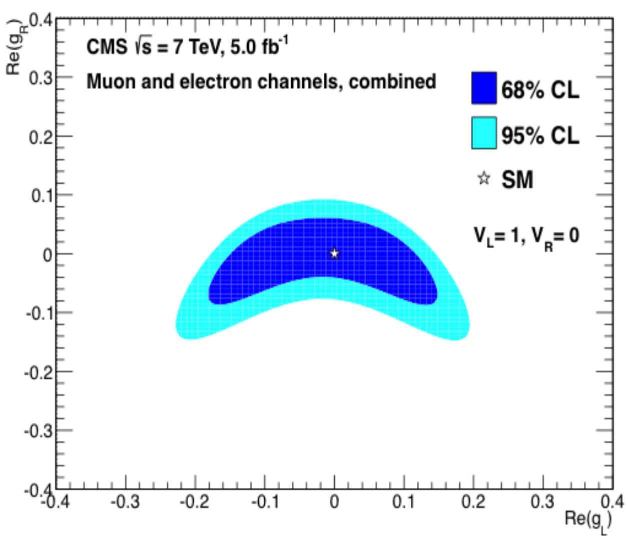
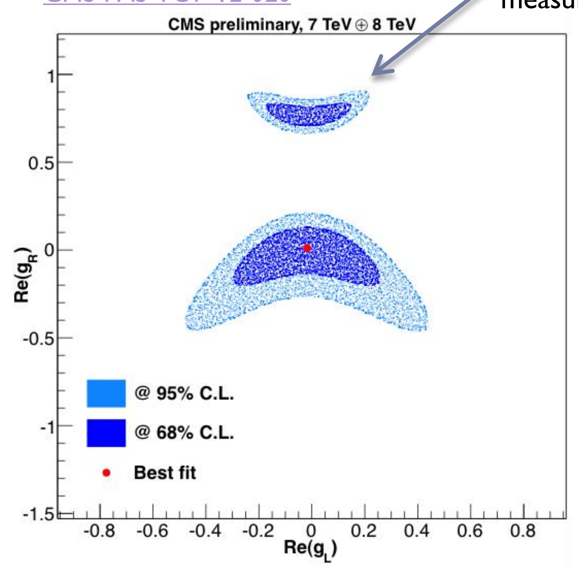
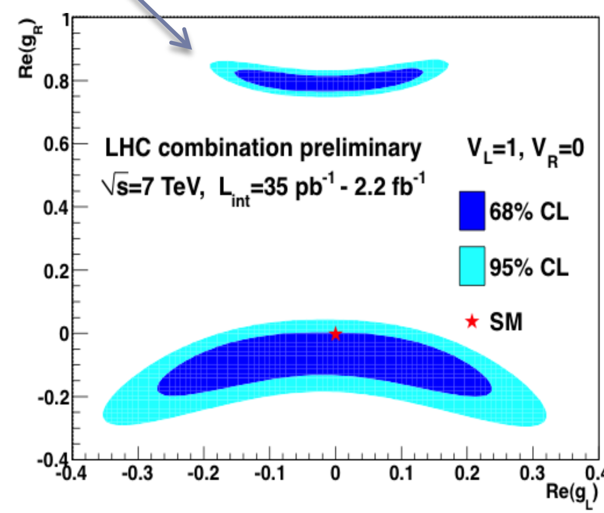


CMS-PAS-TOP-12-020



CMS-PAS-TOP-12-025



Top polarization and spin correlations

- spin of the top in generation → decay products
  - **Information retrieved from angular distributions**
  - Measurements using angular asymmetry variables (unfolded to parton level)
- Top spin studied in ttbar using θ_l (angle of lepton in parent top's rest frame, relative to the direction of the top in the ttbar center of mass frame)
- ttbar → tops unpolarized: polarization **P** given by **$P = 2A_P$**, where **A_P** is

$$A_P = \frac{N(\cos(\theta_\ell) > 0) - N(\cos(\theta_\ell) < 0)}{N(\cos(\theta_\ell) > 0) + N(\cos(\theta_\ell) < 0)}$$

- A_{c1c2}

$$A_{c_1c_2} = \frac{N(c_1 \cdot c_2 > 0) - N(c_1 \cdot c_2 < 0)}{N(c_1 \cdot c_2 > 0) + N(c_1 \cdot c_2 < 0)}$$

Direct measure of spin correlation coefficient C_{hel} using helicity angles of the two leptons in each event: $C_{hel} = -4A_{c1c2}$

$c_1 = \cos(\theta_{l+})$, $c_2 = \cos(\theta_{l-})$

- And finally **$A_{\Delta\phi}$** , sensitive to ttbar spin correlations

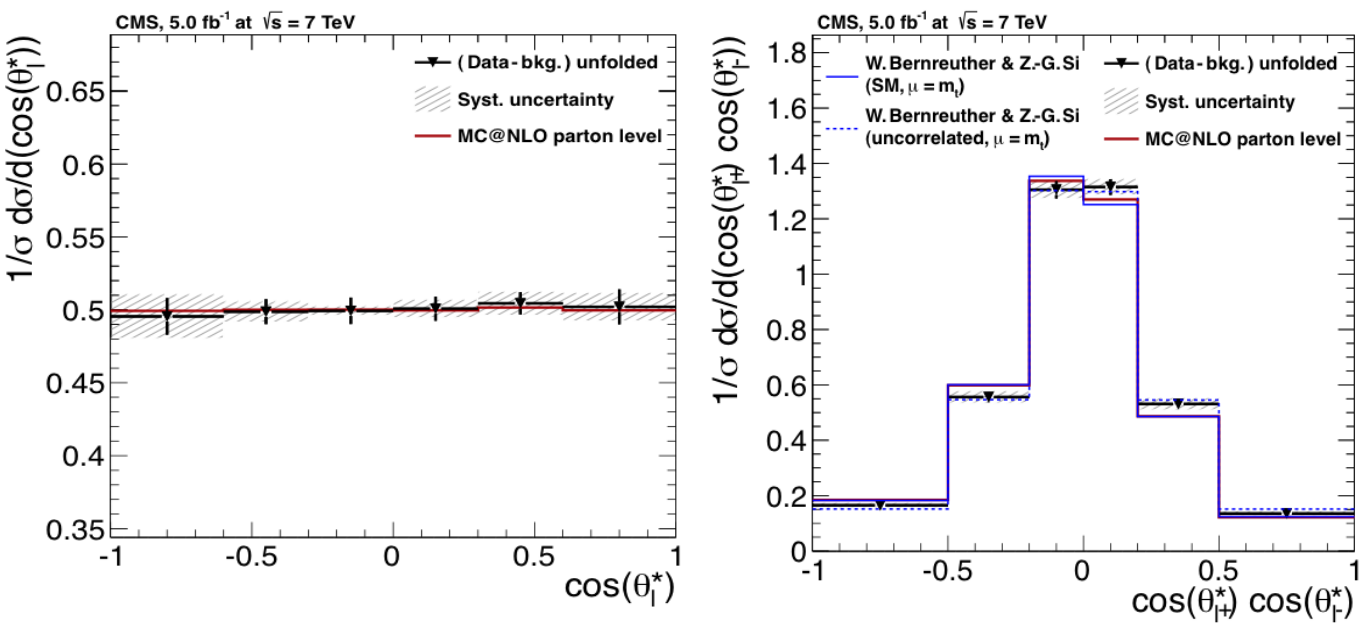
$$A_{\Delta\phi} = \frac{N(\Delta\phi_{\ell+\ell-} > \pi/2) - N(\Delta\phi_{\ell+\ell-} < \pi/2)}{N(\Delta\phi_{\ell+\ell-} > \pi/2) + N(\Delta\phi_{\ell+\ell-} < \pi/2)}$$

discrimination between correlated and uncorrelated top and anti-top spins

arxiv:1311.3924
Submitted to PRL

Polarization and spin in tt dilepton

- 7TeV
- Event selection
  - 2 isolated leptons (e, μ); ≥ 2 jets, ≥1 b-tagged
  - ee/μμ: vetoing Z mass window (m_{ll}), MET cut
- **Analytical matrix weighting technique** (AMWT) to reconstruct ttbar system

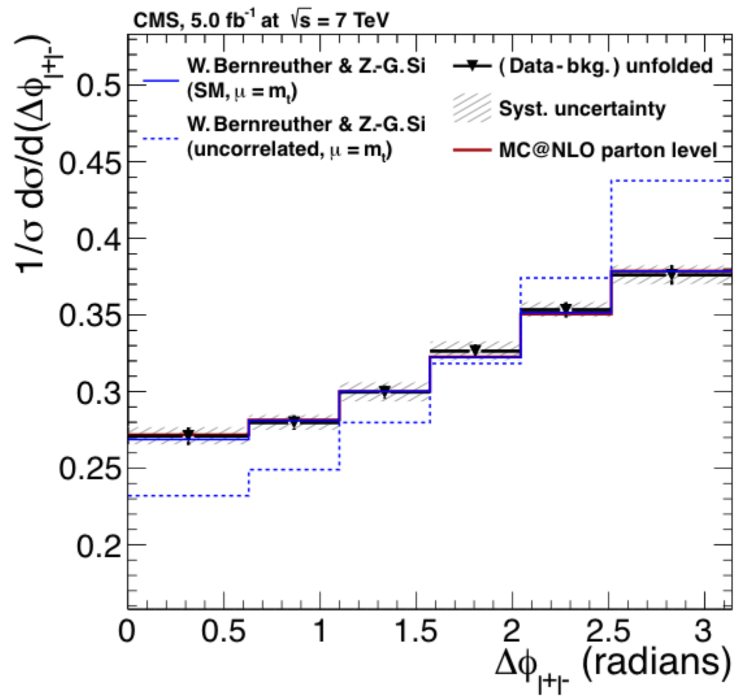


Regularized unfolding algorithm

distributions corrected for detector effects allowing for direct comparison with theoretical predictions

Polarization and spin in tt dilepton

- The **Asymmetries** determined from the unfolded distributions are also at **parton level**
- Uncertainties are statistical, systematic, and from the modeling of the top p_T distribution
- $A_{\Delta\Phi}$ result indicates tt spin correlations, disfavoring the uncorrelated case



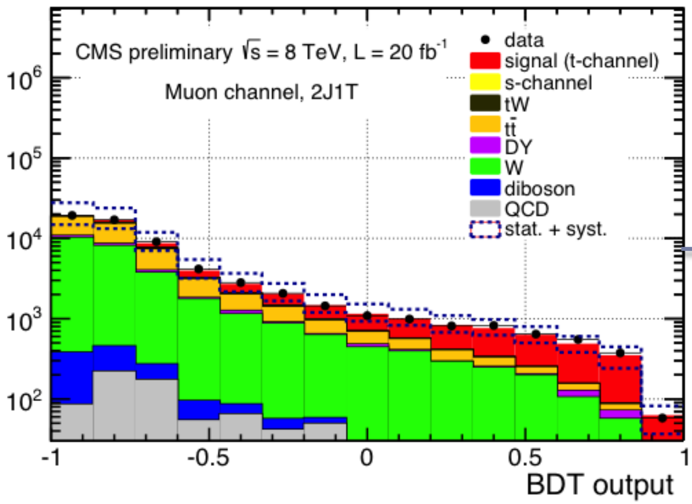
Asymmetry	Data (unfolded)	MC@NLO	NLO (SM, correlated)	NLO (uncorrelated)
$A_{\Delta\phi}$	$0.113 \pm 0.010 \pm 0.007 \pm 0.012$	0.110 ± 0.001	$0.115^{+0.014}_{-0.016}$	$0.210^{+0.013}_{-0.008}$
$A_{c_1c_2}$	$-0.021 \pm 0.023 \pm 0.027 \pm 0.010$	-0.078 ± 0.001	-0.078 ± 0.006	0
A_P	$0.005 \pm 0.013 \pm 0.020 \pm 0.008$	0.000 ± 0.001	N/A	N/A

Top polarization in single top

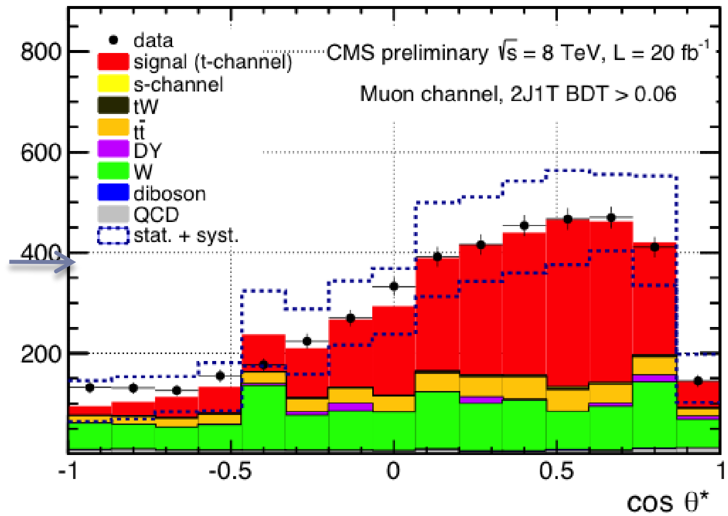
- **Single top quarks → highly polarized**, spin aligned with the recoiling light jet
- Polarization (related to the spin asymmetry) measured from unfolded **cosθ*$_l$ distribution** (angle between the charged lepton and the untagged jet in the top quark rest frame) using the spin asymmetry

$$A_l \equiv \frac{1}{2} \cdot P_t \cdot \alpha_l \qquad A_l = \frac{N(\cos\theta^*_{unfolded} > 0) - N(\cos\theta^*_{unfolded} < 0)}{N(\cos\theta^*_{unfolded} > 0) + N(\cos\theta^*_{unfolded} < 0)}$$

- Analysis performed at 8TeV (e/μ)
- t-channel event selection, BDT discriminant built to obtain a signal enriched sample

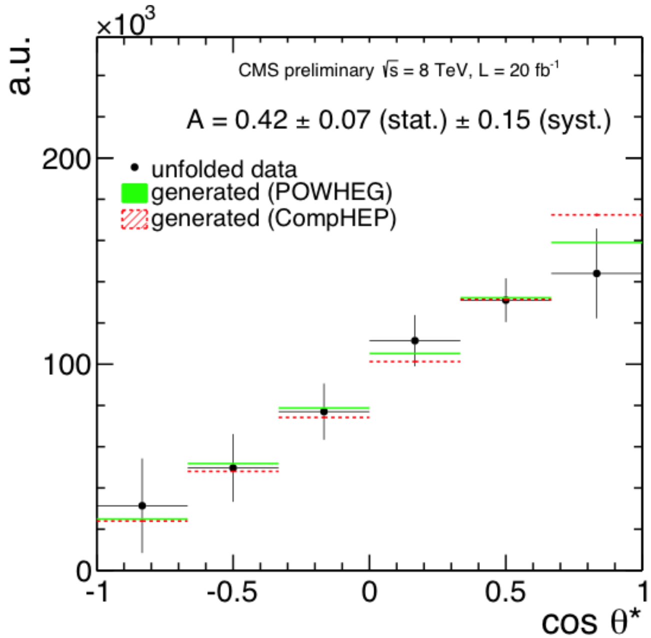


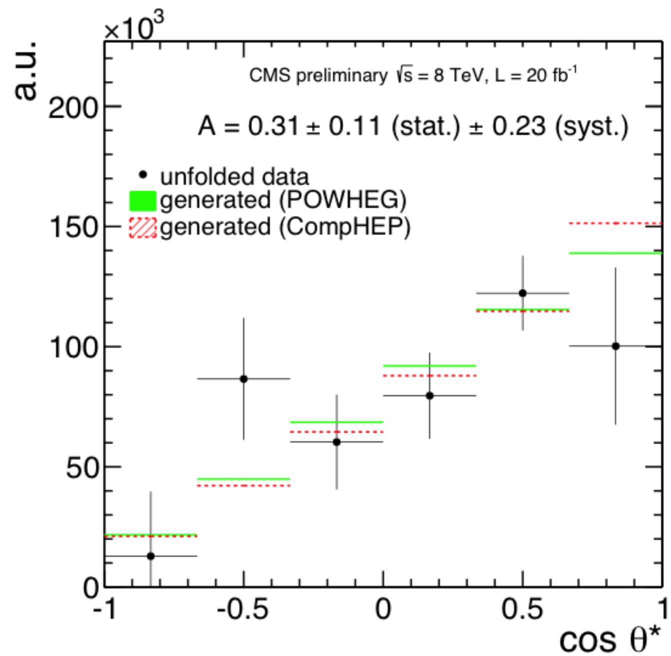
Cut on optimal S/B point



Top polarization in single top: Results

- $\cos\theta_l$ distributions unfolded to parton level, used to extract the top-quark spin asymmetry





e/μ results combined with BLUE

top-quark spin asymmetry A_l=0.41±0.06(stat.)±0.16(syst.)
(SM expectation 0.44)

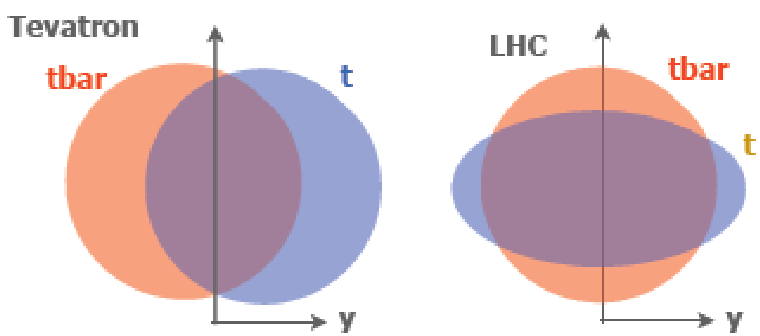
top-quark polarization P_t=0.82±0.12(stat.)±0.32(syst.)
(assuming the spin analyzing power of a charged lepton $-\alpha_l$- is 100% -SM)

Charge asymmetry

- Tevatron found a potential **hint for new physics** in the top quark sector → discrepancy of measured ttbar forward–backward asymmetry with SM expectations (>2σ effect)
- Correlation between the direction of the momentum of the top (anti-top) quark and incoming quark (anti-quark)
  - Forward–backward asymmetry (A_{FB}) at the Tevatron (proton-antiproton collider)
  - Not the case at the LHC (proton-proton)
- At the LHC, larger average momentum fraction of valence quarks → excess of top quarks in the forward and backward directions, anti-top quarks produced more centrally.

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

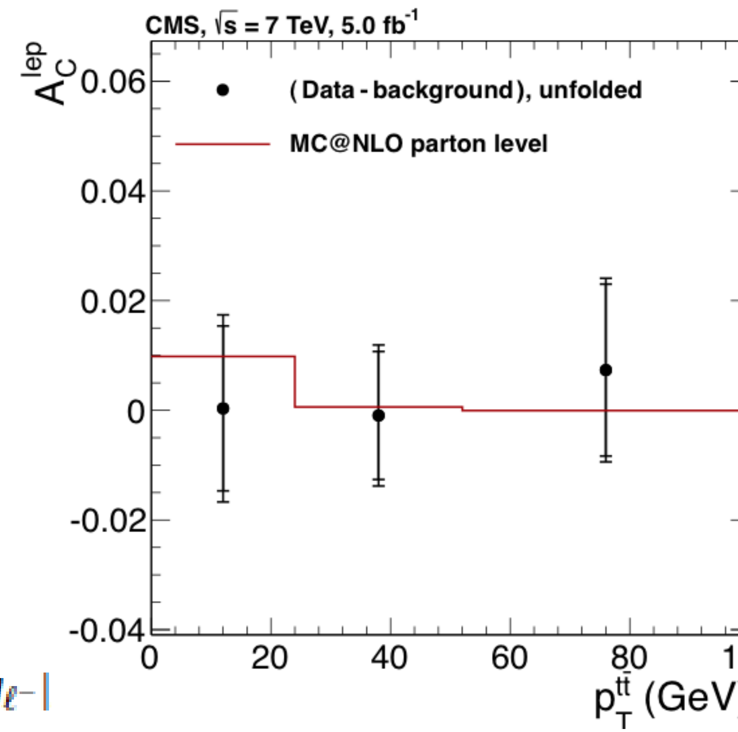
Variable used (y = rapidity)



arXiv:1402.3803
Submitted to JHEP

Charge asymmetry: dilepton tt events

- 7TeV
- Event selection
  - 2 isolated leptons, removing Z mass window (ee/μμ)
  - ≥ 2 Jets; ≥ 1 btag
  - MET cut
- Fake lepton background from data, Z+jets from in/out Z mass window
- ttbar system reconstructed (AMWT)
- **Charge asymmetry and lepton charge asymmetry**

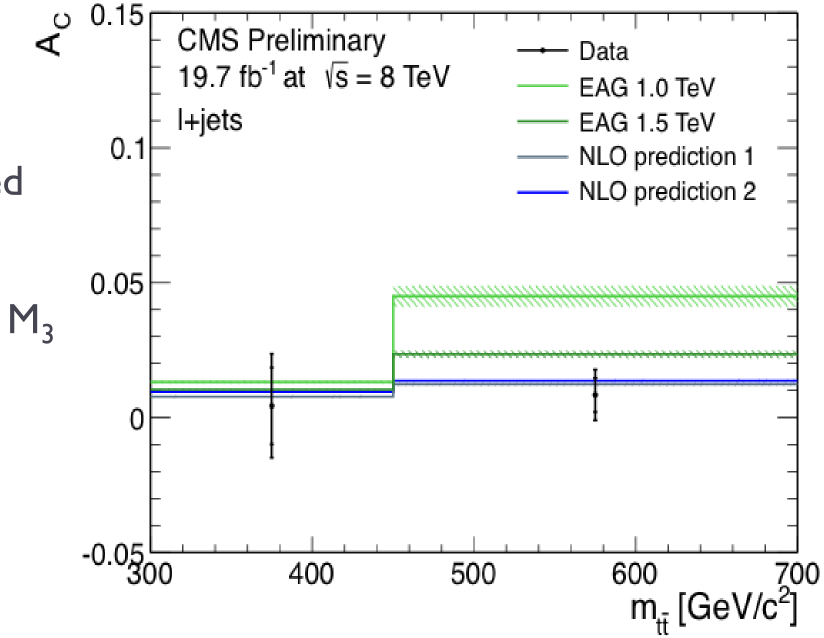


$$A_C^{\mathrm{lep}} = \frac{N(\Delta|\eta_\ell| > 0) - N(\Delta|\eta_\ell| < 0)}{N(\Delta|\eta_\ell| > 0) + N(\Delta|\eta_\ell| < 0)} \qquad \Delta|\eta_\ell| = |\eta_{\ell^+}| - |\eta_{\ell^-}|$$

Variable	Data (unfolded)	MC@NLO prediction	NLO theory
A_C	$-0.010 \pm 0.017 \pm 0.008$	0.004 ± 0.001	0.0123 ± 0.0005
A_C^{lep}	$0.009 \pm 0.010 \pm 0.006$	0.004 ± 0.001	0.0070 ± 0.0003

Charge asymmetry: lepton+jets tt events

- 8 TeV
- Event selection
  - 1 isolated lepton (μ/e) ≥ 4 Jets, at least 1 b-tagged
- Background estimation
  - Fit on regions of $m_T(W)$ (leptonic decay), fitting M_3 (mass of the 3 jets on the hadronic side) simultaneously; QCD from data inverting the isolation
- Reconstructed tt system
- inclusive and differential distributions of Δ|y|



Asymmetry	A_C
Reconstructed	0.003 ± 0.002 (stat.)
BG-subtracted	0.002 ± 0.002 (stat.)
Unfolded	0.005 ± 0.007 (stat.) ± 0.006 (syst.)
Theory prediction [Kühn, Rodrigo] [9, 33]	0.0102 ± 0.0005
Theory prediction [Bernreuther, Si] [34, 35]	0.0111 ± 0.0004

EAG: model featuring an effective axial-vector coupling of the gluon PRD 8 (2011) 054017

CMS measurements of charge asymmetry

	7 TeV	8 TeV
Theory prediction (NLO)	0.0123 ± 0.0005 PRD 86, 034026 (2012)	0.0111 ± 0.0004 PRD 86, 034026 (2012)
tt l+jets	0.004 ± 0.010 (stat.) ± 0.011 (syst.) PLB 717 (2012) 129	0.005 ± 0.007 (stat.) ± 0.006 (syst.) CMS-PAS-TOP-12-033
tt dilepton	-0.010 ± 0.017 (stat.) ± 0.008 (syst.) arXiv:1402.3803	

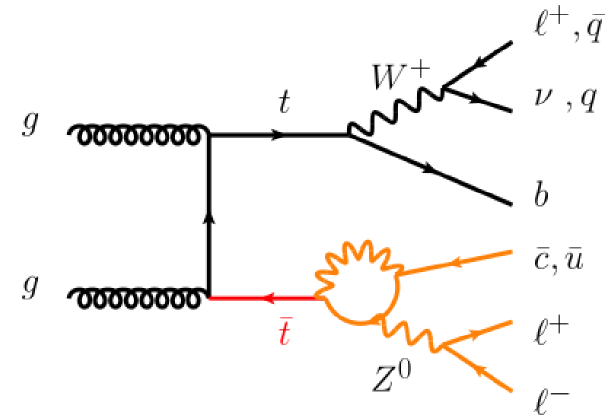
Everything in agreement with SM predictions

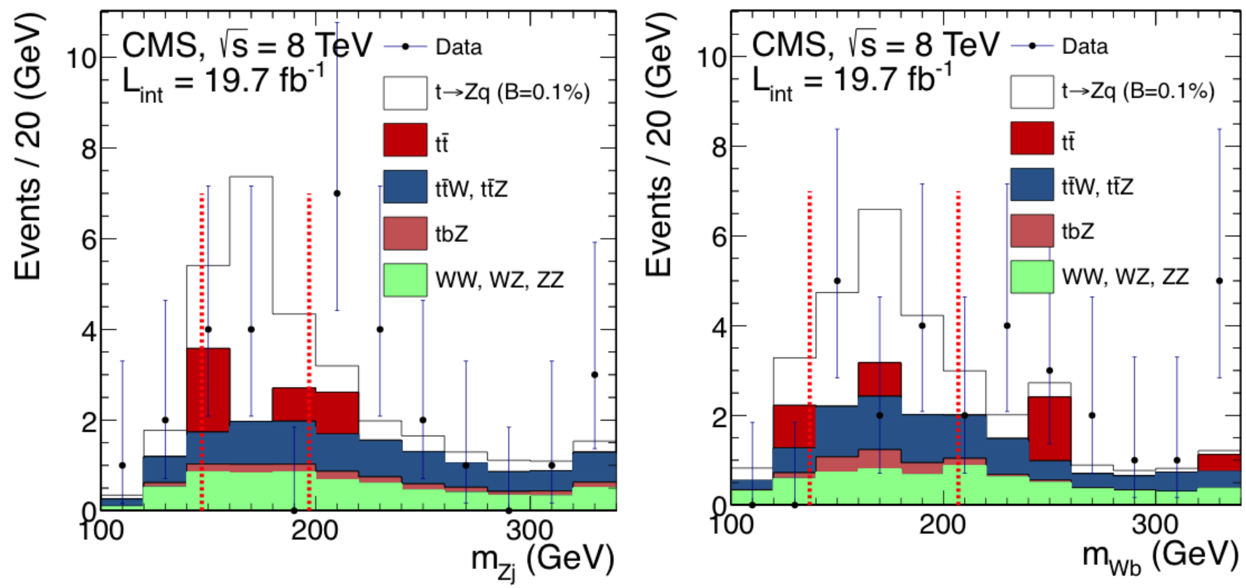
arXiv:1312.4194

Submitted to PRL

FCNC in ttbar events, t→Zq

- Flavor Changing Neutral Currents in top decays using ttbar events, 8TeV
- t→Wb ~100% of the times, t→Zq highly suppressed by the GIM mechanism, predicted B(t →Zq) O(10^{-14})
- Event selection:
  - 3 leptons, (μ, e) (pair compatible with Z decay)
  - ≥2 jets; 1jet b-tagged
  - MET cut
- Background estimation
  - using b-tag information 0,>1 tag samples
- Cuts on m_{Wb} and m_{Zq}





arXiv:1312.4194
Submitted to PRL

FCNC in ttbar events, t→Zq

- **Upper 95% CL limits for B(t→Zq)**
- ~ four times lower than the previous in this channel

$\mathcal{B}(\mathrm{t} \to \mathrm{Zq})$	8 TeV	7 TeV + 8 TeV
Expected upper limit	<0.10%	<0.09%
Observed upper limit	<0.06%	<0.05%
$1\,\sigma$ boundary	0.06–0.13%	0.06–0.13%
$2\,\sigma$ boundary	0.05–0.20%	0.05–0.18%

t →Zq decays at a high rate would indicate BSM physics
Extensions of SM predict enhancement of B(t →Zq) as large as O(10^{-4})

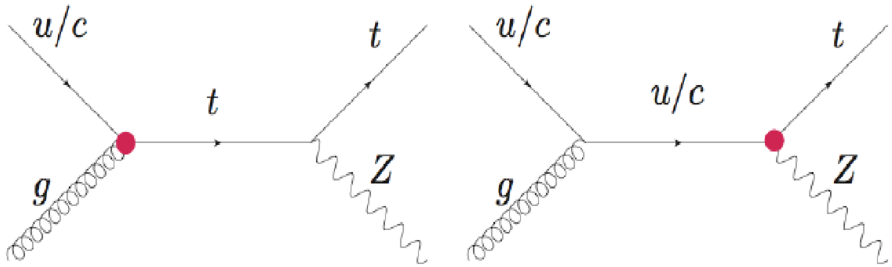
- Projections of the sensitivity of the analysis at high energy and luminosity

$\mathcal{B}(\mathrm{t} \to \mathrm{Zq})$	19.5 fb^{-1} @ 8 TeV	300 fb^{-1} @ 14 TeV	3000 fb^{-1} @ 14 TeV
Exp. bkg. yield	3.2	26.8	268
Expected limit	< 0.10%	< 0.027%	< 0.010%
$1\,\sigma$ range	0.06 – 0.13%	0.018 – 0.038%	0.007 – 0.014%
$2\,\sigma$ range	0.05 – 0.20%	0.013 – 0.051%	0.005 – 0.020%

CMS-PAS-FTR-13-016

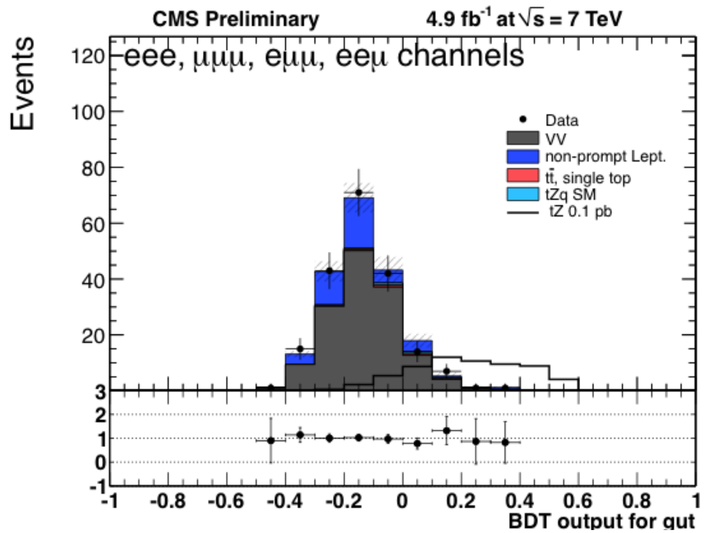
FCNC in single top events, tZ

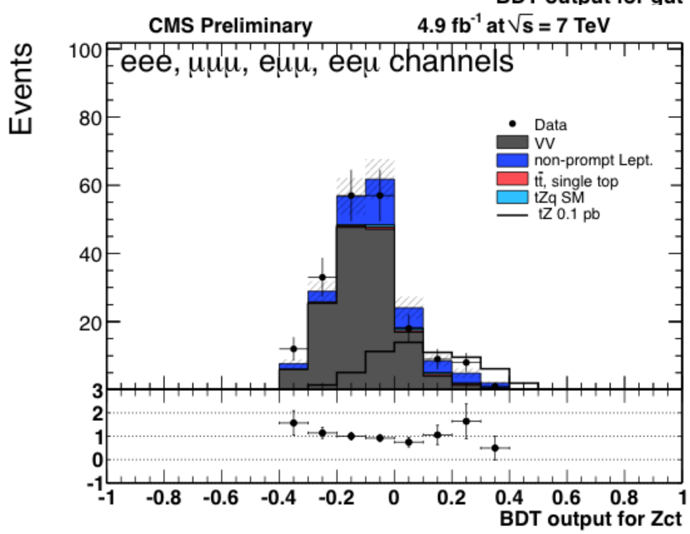
- 7 TeV
- **Single top quark produced in association with a Z (tZ),**
- Signature sensitive to both **Zqt** and **gqt** anomalous vertices



- Event selection:
  - 3 leptons, (e, μ) (one pair compatible with a Z decay), exactly1 b-jet
  - Cut on m_T(W)
- Main background from fake leptons (Z+jets):
  - shapes from data, inverting third lepton isolation + low MET
- Analysis based on a BDT discriminant
  - 11 variables, all the leptonic final states together

FCNC in single top events, tZ





Limits on couplings and branching fractions:

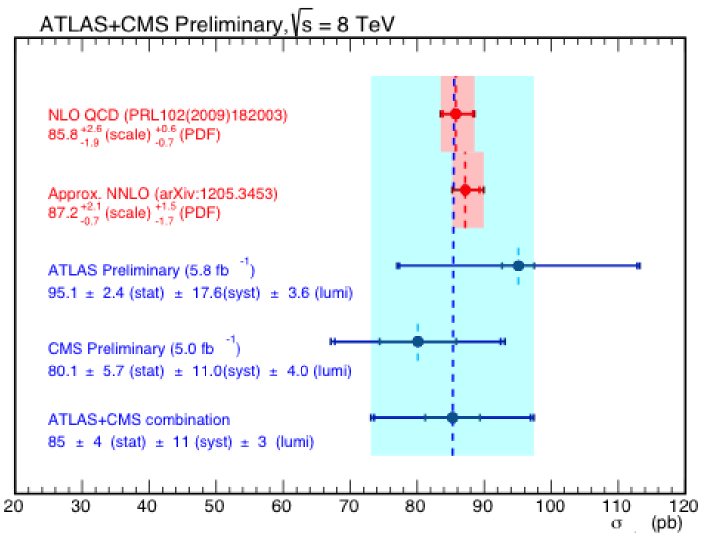
couplings	Expected	Observed	$\mathcal{B}(t \to gq/Zq)$
κ_{gut}/Λ	0.096	0.096	0.56 %
κ_{gct}/Λ	0.427	0.354	7.12 %
κ_{Zut}/Λ	0.492	0.451	0.51 %
κ_{Zct}/Λ	2.701	2.267	11.40 %

Ztq promising

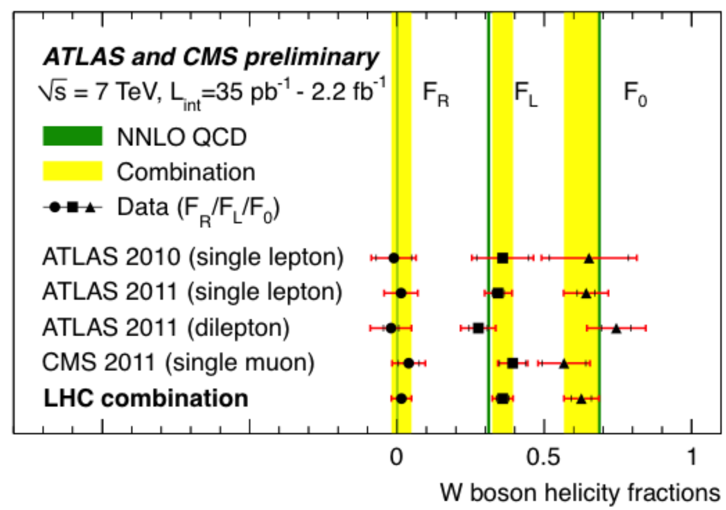
TOP LHC Working Group

- There's an open dialogue between the LHC experiments and the theory community in the context of the TOP LHC working group

- ATLAS and CMS coordinate efforts in top physics to provide combination of experimental results
- 5 preliminary results (top cross-section, mass, single top, W-helicity)



CMS-PAS-TOP-12-002, ATLAS-CONF-2013-098



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

Summary I

- Single top quark production was observed for the first time in 2009 by the Tevatron
- It has been studied in CMS in the three main production modes
  - **t-channel:** observed in early data, well established at 7 and 8TeV
  - **tW associated production:** never accessible before, CMS has the first observation of the process at 8TeV, evidence was found at 7TeV
  - **s-channel:** extremely challenging signature, work is in progress, with a first result in this channel at 8TeV
- Search for new physics (Anomalous couplings, FCNC) also performed in single top events

- The t-channel sample is so large that it can already be exploited to perform **measurements of top properties**
  - $|V_{tb}|$, W-helicity fractions, top polarization (more to come)
  - Moving towards a full characterization of the top quark using all its production modes

Summary II

- For the full characterization of the top quark, the measurement of top properties is necessary
  - Is the top a SM one?
  - Will we find surprises?

OR

?

- Wide catalog of top properties measured in CMS
- Reported today:
  - **W-helicity fractions**
    - Related to the angular distribution of the top decays, used to set limits on Anomalous Couplings
  - **Top polarization and spin correlations**
    - From the angular correlations of the decay products in tt events
  - **Charge asymmetry**
    - Using the kinematics of the top and anti-top quarks (Tevatron has a 2σ effect with respect to the SM)
  - **Flavor Changing Neutral Currents** in top decays and production

Backup slides

t-channel at √s = 8 TeV: Systematics

Uncertainty source	$\sigma_{t\text{-ch.}}$ (%)
Stat. uncertainty	± 2.7
JES, JER, MET, and pileup	± 4.3
b-tagging and mis-tag	± 2.5
Lepton reconstruction/trig.	± 0.6
QCD multijet extraction	± 2.3
W+jets, $t\bar{t}$ extraction	± 2.2
Other backgrounds ratio	± 0.3
Signal modeling	± 5.7
PDF uncertainty	± 1.9
Simulation statistics	± 0.7
Luminosity	± 2.6
Total systematic	± 8.9
Total uncertainty	± 9.3
Measured cross section	83.6 ± 7.8 pb

Uncertainty source	$\sigma_{t\text{-ch.}}(\text{t})$ (%)	$\sigma_{t\text{-ch.}}(\bar{\text{t}})$ (%)	$R_{t\text{-ch.}}$ (%)
Stat. uncertainty	± 2.7	± 4.9	± 5.1
JES, JER, MET, and pileup	± 4.2	± 5.2	± 1.1
b-tagging and mis-tag	± 2.6	± 2.6	± 0.2
Lepton reconstruction/trig.	± 0.5	± 0.5	±0.3
QCD multijet extraction	± 1.6	± 3.5	±1.9
W+jets, $t\bar{t}$ extraction	± 1.7	± 3.6	± 3.0
Other backgrounds ratio	± 0.1	± 0.2	± 0.6
Signal modeling	± 4.9	± 9.4	± 6.1
PDF uncertainty	± 2.5	± 4.8	± 6.2
Simulation statistics	± 0.6	± 1.1	± 1.2
Luminosity	± 2.6	± 2.6	-
Total systematic	± 8.2	± 13.4	± 9.6
Total uncertainty	± 8.7	± 14.2	± 10.9
Measured cross section or ratio	53.8 ± 4.7 pb	27.6 ± 3.9 pb	1.95 ± 0.21

arXiv:1401.2942
Submitted to PRL

tW at √s = 8 TeV: BDT Variables

Table 2: Variables used for BDT training

Variable Name	Description
# of loose jets	Number of loose jets, $p_{\mathrm{T}} > 20\,\mathrm{GeV}$, $\lvert\eta\rvert < 4.9$
# of central loose jets	Number of loose jets, $p_{\mathrm{T}} > 20\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.4$
# of b-tagged loose jets	Number of loose jets, $p_{\mathrm{T}} > 20\,\mathrm{GeV}$, q_b-tagged, $\lvert\eta\rvert < 2.4$
$p_{\mathrm{T}}^{\mathrm{sys}}$	Vector sum of p_{T} of leptons, jet, and $E_{\mathrm{T}}^{\mathrm{miss}}$
H_{T}	Scalar sum of p_{T} of leptons, jet, and $E_{\mathrm{T}}^{\mathrm{miss}}$
$p_{\mathrm{T}}(\mathrm{jet})$	p_{T} of the leading, tight, b-tagged jet
$p_{\mathrm{T}}(\mathrm{loose\ jet})$	p_{T} of leading loose jet, defined as 0 for events with no loose jet present
$p_{\mathrm{T}}^{\mathrm{sys}}/H_{\mathrm{T}}$	Ratio of $p_{\mathrm{T}}^{\mathrm{sys}}$ to H_{T} for the event
m_{sys}	Invariant mass of the combination of the leptons, jet, and $E_{\mathrm{T}}^{\mathrm{miss}}$
Centrality$(\mathrm{j}\ell\ell)$	Centrality of jet and leptons, defined as ratio of transverse to total energy
$p_{\mathrm{T}}(\mathrm{leptons})/H_{\mathrm{T}}$	Ratio of scalar sum of p_{T} of the leptons to the H_{T} of full system
$p_{\mathrm{T}}(\mathrm{j}\ell\ell)$	Vector sum of p_{T} of jet and leptons
$E_{\mathrm{T}}^{\mathrm{miss}}$	Missing transverse energy in the event

arXiv:1401.2942
Submitted to PRL

tW at √s = 8 TeV: Systematics

Table 3: Contributions to the systematic uncertainty in the measured cross section. The values are estimated by fixing each source one at a time and evaluating the change in the measured cross section uncertainty. Systematic uncertainties apply to all processes unless specifically noted.

Systematic uncertainty	$\Delta\sigma$ (pb)	$\Delta\sigma/\sigma$	Notes
ME/PS matching thresholds	3.3	14%	Matching threshold 2× and 1/2× nominal 20 GeV value in $t\bar{t}$ simulation
Renormalization/factorization scale	2.9	12%	Scale value 2× and 1/2× nominal value of $m_t^2 + \sum p_T^2$ in $t\bar{t}$ and tW simulation
Top-quark mass	2.2	9%	m_t varied in tW and $t\bar{t}$ simulation by ±2 GeV
Fit statistical	1.9	8%	Remaining uncertainty in fit when all other systematic uncertainties are removed
Jet energy scale	0.9	4%	Jet energy scale varied up/down
Luminosity	0.7	3%	2.6% uncertainty in the measured luminosity
Z+jets data/simulation scale factor	0.6	3%	Varying scale factors used for correcting Z+jets E_T^{miss} simulation
tW DR/DS scheme	0.5	2%	Difference between DR and DS scheme used for defining tW signal
$t\bar{t}$ cross section	0.4	2%	Uncertainty in the cross section of $t\bar{t}$ production
Lepton identification	0.4	2%	Uncertainty in scale factors for lepton efficiencies between data/simulation
PDF	0.4	2%	From choice of PDF
Jet energy resolution	0.2	1%	Energy resolution for jets varied up/down
b-tagging data/simulation scale factor	0.2	<1%	Variations in scale factors
$t\bar{t}$ spin correlations	0.1	<1%	Difference between $t\bar{t}$ simulation with/without spin correlations
Pileup	0.1	<1%	Varying effect of pileup
Top-quark p_T reweighting	0.1	<1%	Uncertainty due to differences in top quark p_T between data and $t\bar{t}$ simulation
E_T^{miss} modeling	0.1	<1%	Uncertainty in amount of unclustered E_T^{miss}
Lepton energy scale	0.1	<1%	Uncertainty in energy of leptons
Total	5.5	24%	

s-channel at √s = 8 TeV: Variables

Variable	Description
m_T	tranverse W boson mass
$\Delta\Phi_{top,b'}$	difference in azimuthal angle between top quark and recoiled b-tagged jet
$\not{E}_T$	missing transverse energy
$M_{\ell b2}$	invariant mass of the lepton and the second-to-leading b-tagged jet
$\cos\theta^*$	cosine of the angle between the lepton and the b-tagged jet recoiling against the top quark, in the top-quark rest frame
p_T^{bb}	vector sum of p_T of the two b-tagged jets
$\Delta R_{bb}(*)$	angular separation between the two b-tagged jets
p_T^{ℓ}	transverse momentum of the lepton
$m_{\ell\nu b}$-best	invariant mass of lepton, neutrino and one of the b-tagged jets reconstructed with the best-mass top method, as described in Sec.2
$\Delta R_{b'\ell}$	angular separation between the b-tagged jet recoiling against the top quark and the lepton
H_T	scalar sum of p_T of all jets

(*) $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$

2jet-2tag electron channel

Variable	Description
p_T^{bb}	vector sum of p_T of the two b-tagged jets
$m_{\ell\nu b}$-best	invariant mass of lepton, neutrino and one of the b-tagged jets reconstructed with the best-mass top method, as described in Sec.2
m_T	tranverse W boson mass
$M_{\ell b2}$	invariant mass of the lepton and the second-to-leading b-tagged jet
$\not{E}_T$	missing transverse energy
$\Delta\Phi_{top,b'}$	difference in azimuthal angle between top quark and the recoiled b-tagged jet
$\cos\theta_l$	cosine of the angle between the lepton and the beam axis in top-quark rest frame
ΔR_{bb}	angular separation between the two b-tagged jets
H_T	scalar sum of p_T of all jets
p_T^{ℓ}	transverse momentum of the lepton

2jet-2tag muon channel

W-helicity in lepton+jets tt events (7TeV)

Systematic	μ+jets ($\cos\theta^*$)			e+jets ($\cos\theta^*$)			ℓ+jets ($\cos\theta^*$)		
	3D fit		2D fit	3D fit		2D fit	3D fit		2D fit
Uncertainties	$\pm\,\Delta F_0$	$\pm\,\Delta F_L$	$\pm\,\Delta F_0$	$\pm\,\Delta F_0$	$\pm\,\Delta F_L$	$\pm\,\Delta F_0$	$\pm\,\Delta F_0$	$\pm\,\Delta F_L$	$\pm\,\Delta F_0$
JES	0.005	0.003	0.001	0.006	0.002	0.003	0.006	0.003	0.001
JER	0.009	0.005	0.001	0.014	0.009	0.003	0.011	0.007	0.001
Lepton eff.	0.001	0.001	0.001	0.009	0.012	0.015	0.001	0.002	0.002
b-tag eff.	0.001	0.001	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	0.001	0.001	$< 10^{-3}$	$< 10^{-3}$
Pileup	0.013	0.011	0.008	0.008	0.007	0.005	0.002	$< 10^{-3}$	0.008
Single-t bkg.	0.004	$< 10^{-3}$	0.003	0.004	$< 10^{-3}$	0.004	0.004	0.001	0.003
W+jets bkg.	0.019	0.007	0.006	0.009	0.006	0.022	0.013	0.004	0.006
DY+jets bkg.	0.002	0.001	0.001	0.001	$< 10^{-3}$	0.001	0.001	$< 10^{-3}$	0.001
MC statistics	0.016	0.012	0.009	0.019	0.015	0.012	0.016	0.012	0.010
Top-quark mass	0.011	0.008	0.007	0.025	0.018	0.014	0.016	0.011	0.019
$\mathrm{t\bar{t}}$ scales	0.013	0.009	0.007	0.015	0.018	0.030	0.009	0.009	0.011
$\mathrm{t\bar{t}}$ match. scale	0.004	0.001	0.006	0.010	0.013	0.016	0.011	0.010	0.008
PDF	0.002	0.001	0.003	0.004	0.002	0.002	0.002	$< 10^{-3}$	0.003

Table 2. Summary of the systematic uncertainties for the analysis using only the leptonic branch of the event, for the 3D fit, fitting F_0, F_L, and $\mathcal{F}_{\mathrm{t\bar{t}}}$ (columns 2–3 for muon+jets analysis, 5–6 for electron+jets analysis, and 8–9 for the combination of both decay modes); and the 2D fit, fitting F_0 and $\mathcal{F}_{\mathrm{t\bar{t}}}$ only (column 4 for muon+jets analysis, 7 for electron+jets analysis, and 10 for the combination of both decay modes). The numbers given correspond to the absolute uncertainty with respect to the central analysis: $\Delta F = (F^{\mathrm{central}} - F^{\mathrm{check}})$.

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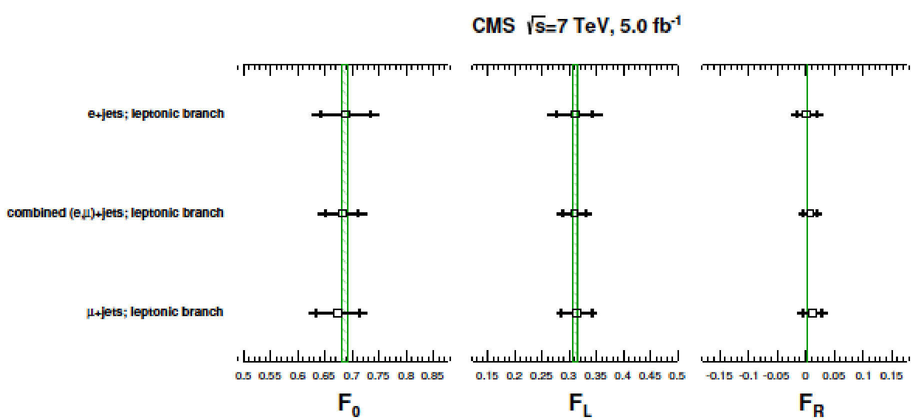
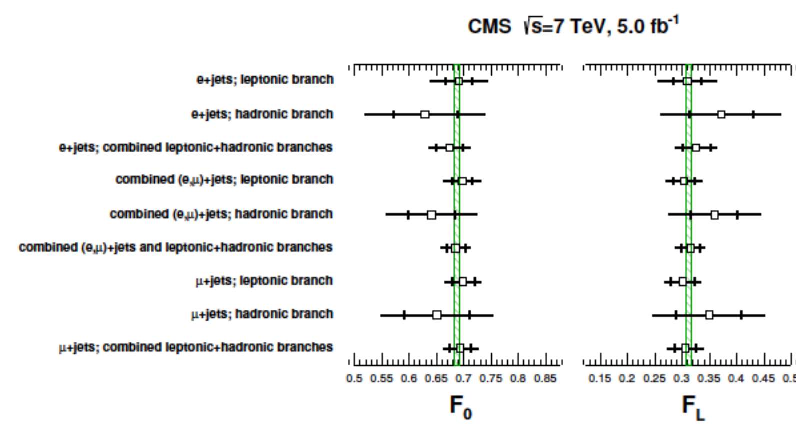
W-helicity in lepton+jets tt events (7TeV)

Leptonic branch: $\cos\theta^*$					
Fit	Channel	$F_0 \pm$ (stat.) $\pm$ (syst.)	$F_L \pm$ (stat.) $\pm$ (syst.)	$F_R \pm$ (stat.) $\pm$ (syst.)	ρ_{0L}^{stat}
3D	μ+jets	0.674 ±0.039±0.035	0.314 ±0.028±0.022	0.012 ±0.016±0.020	−0.95
3D	e+jets	0.688 ±0.045±0.042	0.310 ±0.033±0.037	0.002 ±0.017±0.023	−0.95
2D	μ+jets	0.698 ±0.021±0.019	0.302 ±0.021±0.019	fixed at 0	−1
2D	e+jets	0.691 ±0.025±0.047	0.309 ±0.025±0.047	fixed at 0	−1
Hadronic branch: $\lvert\cos^{\text{had}}\theta^*\rvert$					
Fit	Channel	$F_0 \pm$ (stat.) $\pm$ (syst.)	$F_L \pm$ (stat.) $\pm$ (syst.)	$F_R \pm$ (stat.) $\pm$ (syst.)	ρ_{0L}
2D	μ+jets	0.651 ±0.060±0.084	0.349 ±0.060±0.084	fixed at 0	−1
2D	e+jets	0.629 ±0.060±0.093	0.371 ±0.060±0.093	fixed at 0	−1





W-helicity in lepton+jets tt events (8TeV)

Systematics	$\pm \Delta F_0$	$\pm \Delta F_L$
JES	0.002	<0.001
JER	0.004	0.003
Lepton eff.	0.001	<0.001
b-tag eff.	0.001	<0.001
Pileup	<0.001	0.001
Single-t bkg.	0.002	<0.001
DY+jets bkg.	0.001	<0.001
W+jets bkg.	0.009	<0.001
MC statistics	0.003	0.002
Top-quark mass	0.012	0.008
$t\bar{t}$ scales	0.012	0.012
$t\bar{t}$ match. scale	0.012	0.008
$t\bar{t}$ p_T reweig.	0.001	<0.001
E_T^{miss} shape	0.004	0.018
Total syst.	0.023	0.024

W-helicity in Single top signatures

Systematic source	$\sqrt{s} = 8$ TeV ΔF_L	$\sqrt{s} = 8$ TeV ΔF_0	$\sqrt{s} = 7$ TeV ΔF_L	$\sqrt{s} = 7$ TeV ΔF_0
JES	0.006	0.006	0.020	0.020
JER	0.008	0.003	0.015	0.010
unclustered energy	0.013	0.003	0.015	0.015
pileup	0.002	0.003	0.004	0.000
b-flavored scale factor	0.004	0.006	0.009	0.009
non-b-flavored scale factor	0.004	0.007	0.002	0.001
single-top generator	0.008	0.014	0.004	0.004
Q^2 scale	0.009	0.012	0.040	0.007
m_{top}	0.005	0.006	0.010	0.010
PDF	0.005	0.005	0.000	0.000
$t\bar{t}$ normalization	0.002	0.003	0.008	0.008
QCD shape	0.002	0.002	0.004	0.004
W+jets shape	0.008	0.010	0.010	0.010
integrated luminosity	0.003	0.003	0.007	0.007
SM W-helicity reference	0.004	0.003	0.001	0.002
total systematic uncertainty (w/o generator)	0.022	0.021	0.054	0.035
total systematic uncertainty	0.024	0.026	0.054	0.035

Table 2: Summary of systematics.

$$F_L = 0.24 \pm 0.11(\text{stat.}) \pm 0.05(\text{syst.}),$$
$$F_0 = 0.78 \pm 0.17(\text{stat.}) \pm 0.03(\text{syst.}),$$
$$F_R = -0.02 \pm 0.09(\text{stat.}) \pm 0.04(\text{syst.}).$$

7TeV

$$F_L = 0.327 \pm 0.089(\text{stat.}) \pm 0.024(\text{syst.}),$$
$$F_0 = 0.668 \pm 0.149(\text{stat.}) \pm 0.026(\text{syst.}),$$
$$F_R = 0.005 \pm 0.072(\text{stat.}) \pm 0.020(\text{syst.}).$$

8TeV

Systematic source	ΔF_L	ΔF_0
JES	0.007	0.007
JER	0.011	0.003
unclustered energy	0.018	0.010
pileup	0.002	0.002
b-flavored scale factor	0.003	0.001
non-b-flavored scale factor	0.001	0.002
single-top generator	0.005	0.009
Q^2 scale	0.006	0.008
m_{top}	0.001	0.001
PDF	0.003	0.003
$t\bar{t}$ normalization	0.003	0.002
QCD shape	0.003	0.003
W+jets shape	0.012	0.011
integrated luminosity	0.010	0.010
SM W-helicity reference	0.002	0.001
total systematic uncertainty	0.030	0.023

Table 3: Summary of systematics in combined likelihood.

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Submitted to PRL

Polarization and spin in tt dilepton

Table 1: Systematic uncertainties in the background-subtracted and unfolded values of $A_{\Delta\phi}$, $A_{c_1c_2}$, and A_P.

Asymmetry variable	$A_{\Delta\phi}$	$A_{c_1c_2}$	A_P
Jet energy scale	0.002	0.012	0.009
Lepton energy scale	0.001	0.001	0.001
Background	0.003	0.001	0.006
Fact. and renorm. scales	0.001	0.010	0.004
Top-quark mass	0.002	0.009	0.016
Parton distribution functions	0.002	0.002	0.001
Jet energy resolution	< 0.001	< 0.001	< 0.001
Pileup	0.002	0.002	0.004
b-tagging scale factor	< 0.001	< 0.001	0.001
Lepton selection	< 0.001	< 0.001	< 0.001
τ decay polarization	0.001	0.002	0.001
Unfolding	0.004	0.020	0.002
Total systematic uncertainty	0.007	0.027	0.020
Top p_T reweighting uncertainty	0.012	0.010	0.008

Top polarization in single top

Uncertainty source	δA_l^μ	δA_l^e
generator	0.025	0.009
Q^2 scale t-channel	0.024	0.055
Q^2 scale, $t\bar{t}$	0.015	0.005
Q^2 scale, W+jets	0.036	0.038
top quark mass	0.058	0.042
W+jets shape	0.016	0.007
W+jets flavour	0.005	0.008
top p_T, $t\bar{t}$	0.010	0.025
matching, $t\bar{t}$	0.028	0.052
matching, W+jets	0.025	0.038
PDF	0.013	0.014
JES	0.074	0.074
JER	0.016	0.179
unclustered $\not{E}_T$	0.013	0.006
lepton ID and isolation	0.001	0.002
lepton trigger	0.001	0.002
pileup	0.015	0.002
b tagging	0.007	0.009
mistagging	0.001	0.003
lepton weight	0.001	0.009
anti-isolation range of QCD	0.010	0.053
QCD fraction	0.092	0.028
background fractions	0.007	0.018
unfolding bias	0.002	0.003
total systematics	0.15	0.23
statistical	0.07	0.11
total	0.17	0.26

Table 3: List of systematic uncertainties and their impact to the measurement of A_l for the muon (δA_l^μ) and electron channel (δA_l^e).

$$A_l^\mu = 0.42 \pm 0.07(stat.) \pm 0.15(syst.)\,,$$
$$A_l^e = 0.31 \pm 0.11(stat.) \pm 0.23(syst.)\,.$$

Charge asymmetry

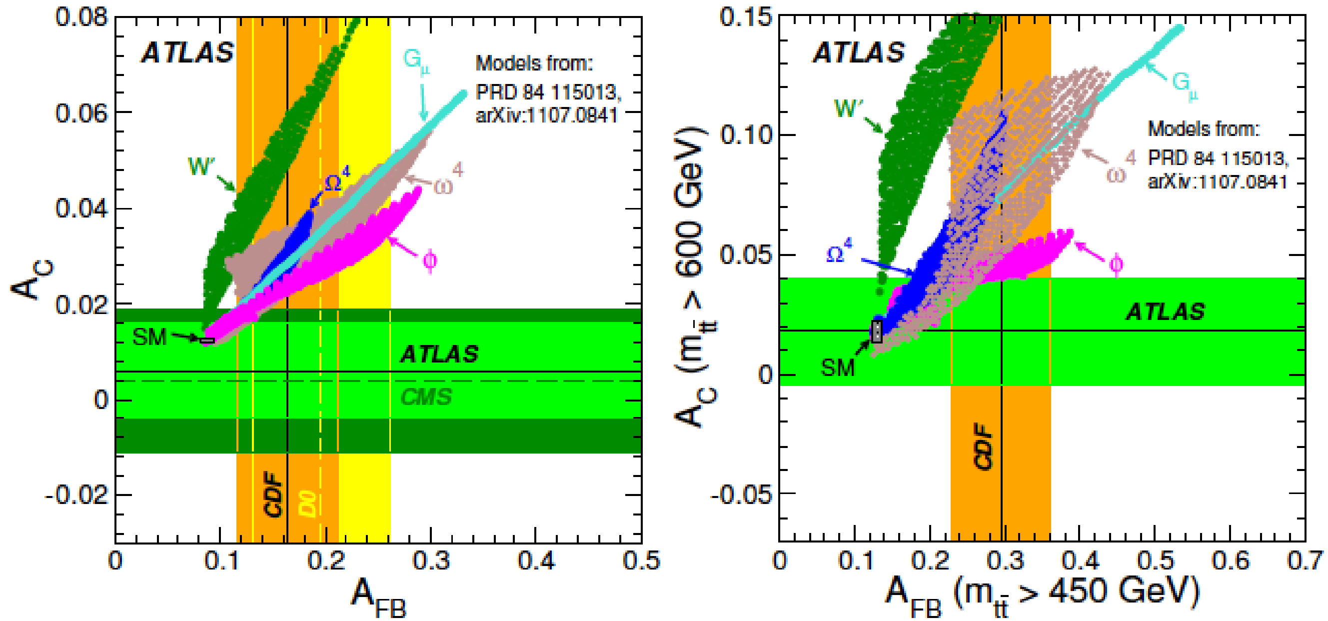

Figure 3. Measured forward–backward asymmetries A_{FB} at Tevatron and charge asymmetries A_{C} at LHC, compared with the SM predictions (black box) as well as predictions incorporating various potential new physics contributions (as described in the figure) [8, 60]. In both plots, where present, the horizontal bands and lines correspond to the ATLAS (light green) and CMS (dark green) measurements, while the vertical ones correspond to the CDF (orange) and D0 (yellow) measurements. The inclusive A_{C} measurements are reported in the left plot. In the right plot a comparison is reported between the A_{FB} measurement by CDF for $m_{t\bar{t}} > 450$ GeV and the A_{C} measurement for $m_{t\bar{t}} > 600$ GeV.

arXiv:1402.3803
Submitted to JHEP

Charge asymmetry: dilepton tt events

Table 3: Systematic uncertainties in the unfolded values of A_C and A_C^{lep} from the sources listed.

Variable	A_C	A_C^{lep}
Experimental uncertainties		
Jet energy scale	0.003	0.001
Lepton energy scale	<0.001	<0.001
Background	0.001	0.001
Jet energy resolution	<0.001	<0.001
Pileup	<0.001	0.001
Scale factor for b tagging	<0.001	<0.001
Lepton selection	<0.001	<0.001
$t\bar{t}$ modelling uncertainties		
Fact. and renorm. scales	0.004	0.005
Top-quark mass	0.001	0.001
Parton distribution functions	<0.001	<0.001
τ-lepton decay	<0.001	<0.001
Top-quark p_T reweighting	0.001	<0.001
Unfolding	0.006	0.001
Total systematic uncertainty	0.008	0.006

 Rebeca Gonzalez Suarez (UNL) 25/02/2014

Charge asymmetry: lepton+jets tt events

Table 2: Systematic uncertainties for the inclusive measurement of A_C and ranges of systematic uncertainties for the differential measurements.

Systematic uncertainty	shift in inclusive A_C	range of shifts in differential A_C
JES	0.001	0.001 – 0.005
JER	0.001	0.001 – 0.005
Pileup	0.001	0.000 – 0.003
b tagging	0.000	0.001 – 0.003
Lepton ID/sel. efficiency	0.002	0.001 – 0.003
Generator	0.003	0.001 – 0.015
Hadronization	0.000	0.000 – 0.016
p_T weighting	0.001	0.000 – 0.003
Q^2 scale	0.003	0.000 – 0.009
W+jets	0.002	0.001 – 0.007
Multijet	0.001	0.002 – 0.009
PDF	0.001	0.001 – 0.003
Unfolding	0.002	0.001 – 0.004
Total	0.006	0.007 – 0.022

arXiv:1312.4194
Submitted to PRL

FCNC in ttbar events, t→Zq

Table 3: Summary of the systematic uncertainties for the signal selection acceptance. An additional 2.6% uncertainty is due to the luminosity measurement.

Source	Uncertainty %
Renormalization/factorization scales	12
Parton distribution functions	7
$t\bar{t}$ cross section	7
Parton matching threshold	6
Lepton selection	6
Trigger efficiency	5
b-tagging	5
Top-quark mass	4
Jet energy scale	4
Missing transverse energy resolution	3
Pileup modeling	3
Total	20

Event selections

- t-channel 8TeV (paper TOP-12-038)
  - 1 isolated lepton, **μ(e)** p_T > 26 (30) GeV; |η| < 2.1 (2.4)
  - Jets: Anti-kt (0.5) p_T > 40 GeV, |η|< 4.5; b-tagging
  - m_T (W) > 50 GeV (μ) / MET > 45 (e)
- tW observation (arXiv:1401.2942)
  - 2 leptons, opposite charge μ(e) p_T> 20 GeV, |η| < 2.4(2.5), isolated
  - 1or 2 jets: p_T > 30 GeV, |η| <2.4 corrected

    (+ loose jets: failing p_T/|η| ; p_T > 20 GeV, |η|< 4.9), b-tag
  - m_{ll} > 20 GeV
  - ee/μμ: veto events with 81 < m_{ll} < 101 GeV

    MET > 50 GeV
- s-channel (CMS-PAS-TOP-13-009)
  - 1 isolated μ(e) p_T (E_T) > 26 (30) GeV, |η| < 2.1 (2.4)
  - 2 b-tagged jets p_T > 40 GeV, |η| < 4.5

Event selections (II)

- W-helicity (7TeV) JHEP 10 (2013) 167
  - 1 isolated lepton μ (e) with p_T > 25 (30) GeV; |η| < 2.1 (2.5)
  - ≥ 4 Jets p_T > 30 GeV, |η| < 2.5; at least 2 b-tagged
  - m_T (W) > 30
- Spin asymetries (tt dilep) arxiv:1311.3924
  - 2 leptons, e (μ) with p_T > 20 GeV |η|< 2.5 (2.4), isolated (vetoing Z mass window for ee/μμ)
  - ≥ 2 jets p_T > 30 GeV |η|< 2.5; ≥1 b-tagged
  - MET > 40GeV ee/μμ
- Charge asymmetry arXiv:1402.3803
  - 2 isolated leptons p_T> 20, |η| < 2.4, removing Z mass window (ee/μμ)
  - ≥ 2 Jets p_T > 30, |η| < 2.4; ≥ 1 btag
  - MET > 40

Event selections (III)

- Charge Asymetry CMS-PAS-TOP-12-033
  - 1 isolated lepton: μ (e) p_T > 26 (30) GeV; |η| < 2.1 (2.5)
  - ≥ 4 Jets p_T > 30 GeV, |η| < 2.5; at least 1 b-tagged
- FCNC tt
  - 3 leptons, e (μ) p_T > 20 GeV, |η|< 2.5 (2.4) (pair compatible with Z decay)
  - ≥2 jets p_T > 30 GeV, |η|< 2.4; 1 b-tagged
  - MET > 30GeV
- FCNC tZ
  - 3 leptons, e (μ) p_T > 20 GeV |η|< 2.5 (2.4) (one pair compatible with a Z decay)
  - Jets p_T > 30 GeV and |η|< 2.4; exactly1 b-jet
  - m_T(W) > 20GeV