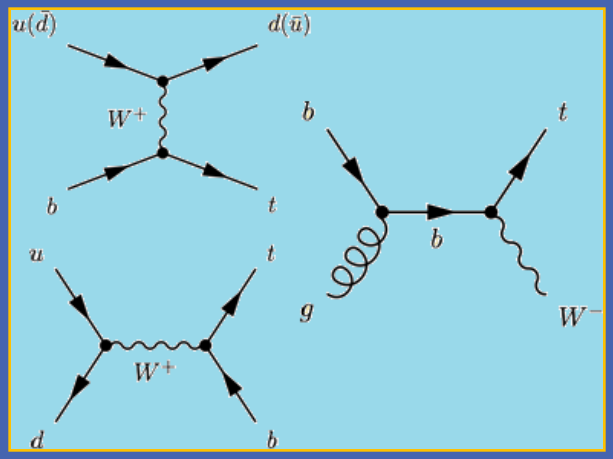
Institute for research in fundamental sciences
SCHOOL OF PARTICLES AND ACCELERATORS

Status of single top measurements in CMS

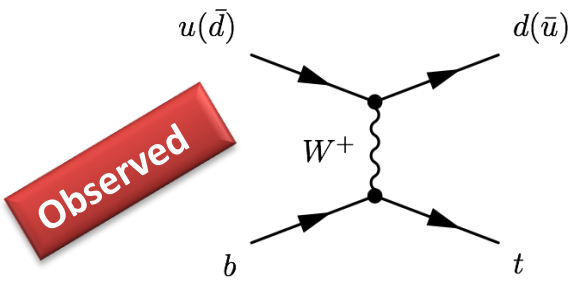


IPMLHC2013
The 2nd IPM meeting on LHC physics
7-12 October
Tehran, Iran

Abideh Jafari
School of particles and accelerators, IPM
On behalf of the CMS collaboration

Introduction

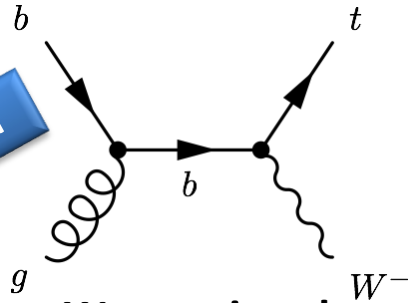
Top quark at LHC: produced mostly in pair via strong interaction
Single-top quark: production via electroweak interaction, involving tWb vertex



Observed

t-channel

>



Just observed

tW-associated

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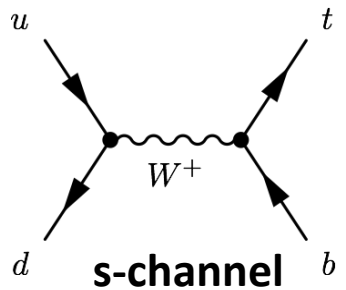


s-channel

In progress …

Why single-top?

- Sensitive to **new physics**!
  - FCNC, Anomalous couplings
  - New particles (W' , charged Higgs)
- Characteristic scenario for **SM measurements**
  - Top polarization, W helicity, top mass, $|V_{tb}|$
- **Background** in searches
  - SUSY, Higgs

We will look at

- Production cross sections of t-channel and tW associated production
- Top/anti-top production ratio
- $|V_{tb}|$
- Top polarization
- W-helicity in single-top

t-channel cross section

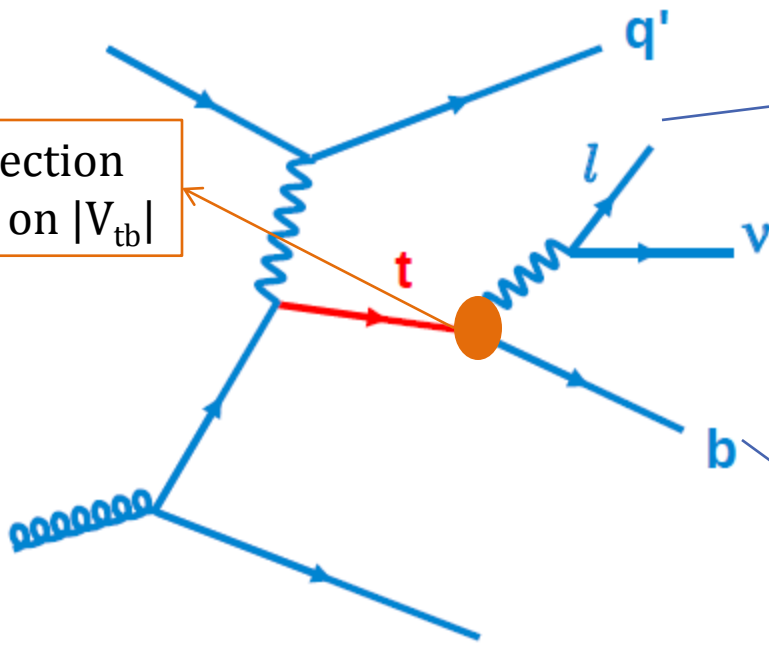
SM expectations (http://arxiv.org/abs/1210.7813v2)

7 TeV

$\sigma_t = 65.9^{+2.1+1.5}_{-0.7-1.7}$ pb

8TeV

$\sigma_t = 87.2^{+2.8+2.0}_{-1.0\ -2.2}$ pb



Light jet (j') with large pseudorapidity, $\eta_{j'}$

High p_T lepton (μ, e)

Cross section depends on $|V_{tb}|$

Missing transverse energy (MET)

b-quark jet, high p_T, in the central part of the detector

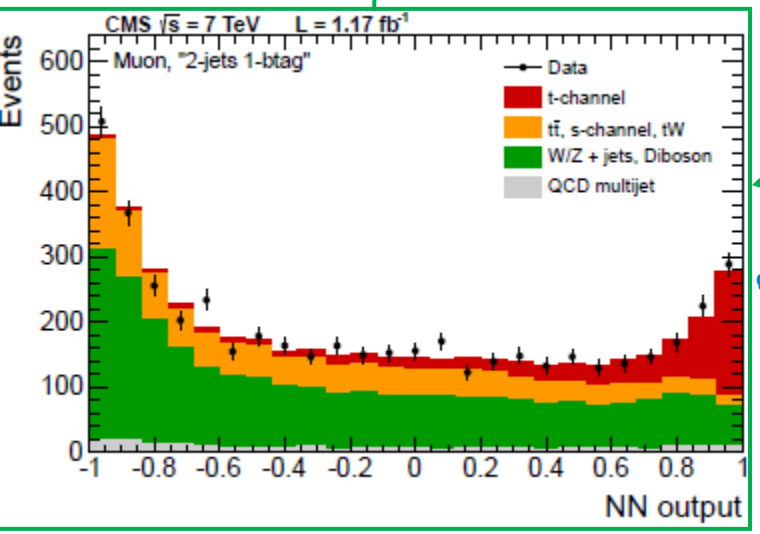
Additional soft b-quark jet

Selection: 1 lepton + 1 jet + 1 b-tagged jet + MET-related requirement

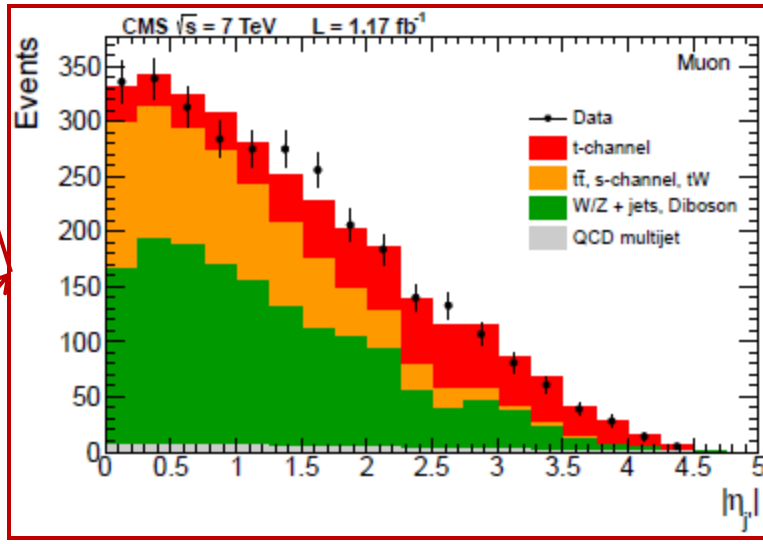
t-channel cross section at 7 TeV

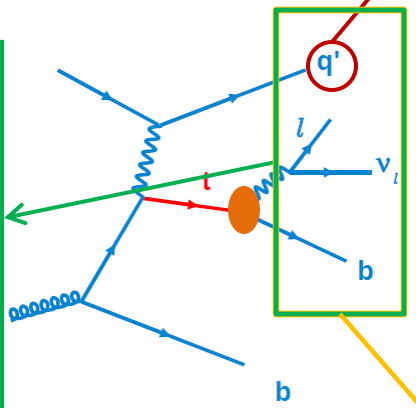
Three different analyses

Neural Network: Backgrounds and systematics as nuisance parameters

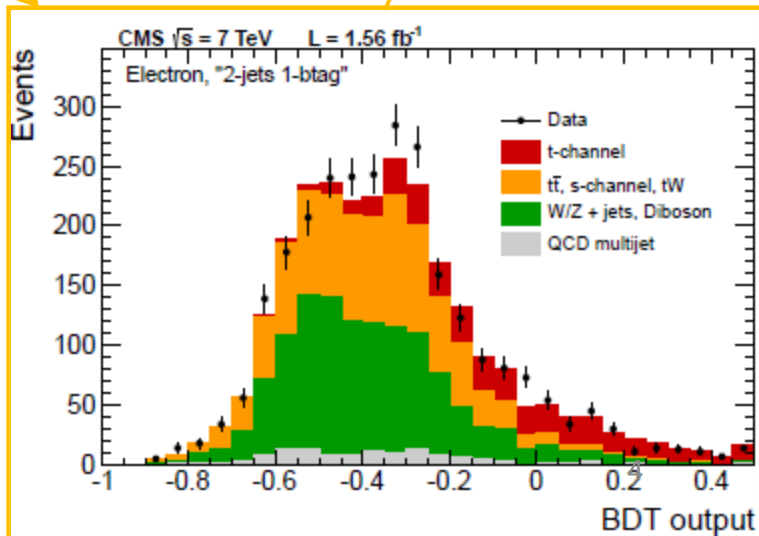


Template fit with data driven backgrounds





Boosted Decision Tree: Backgrounds and systematics as nuisance parameters



Combination of all analyses:

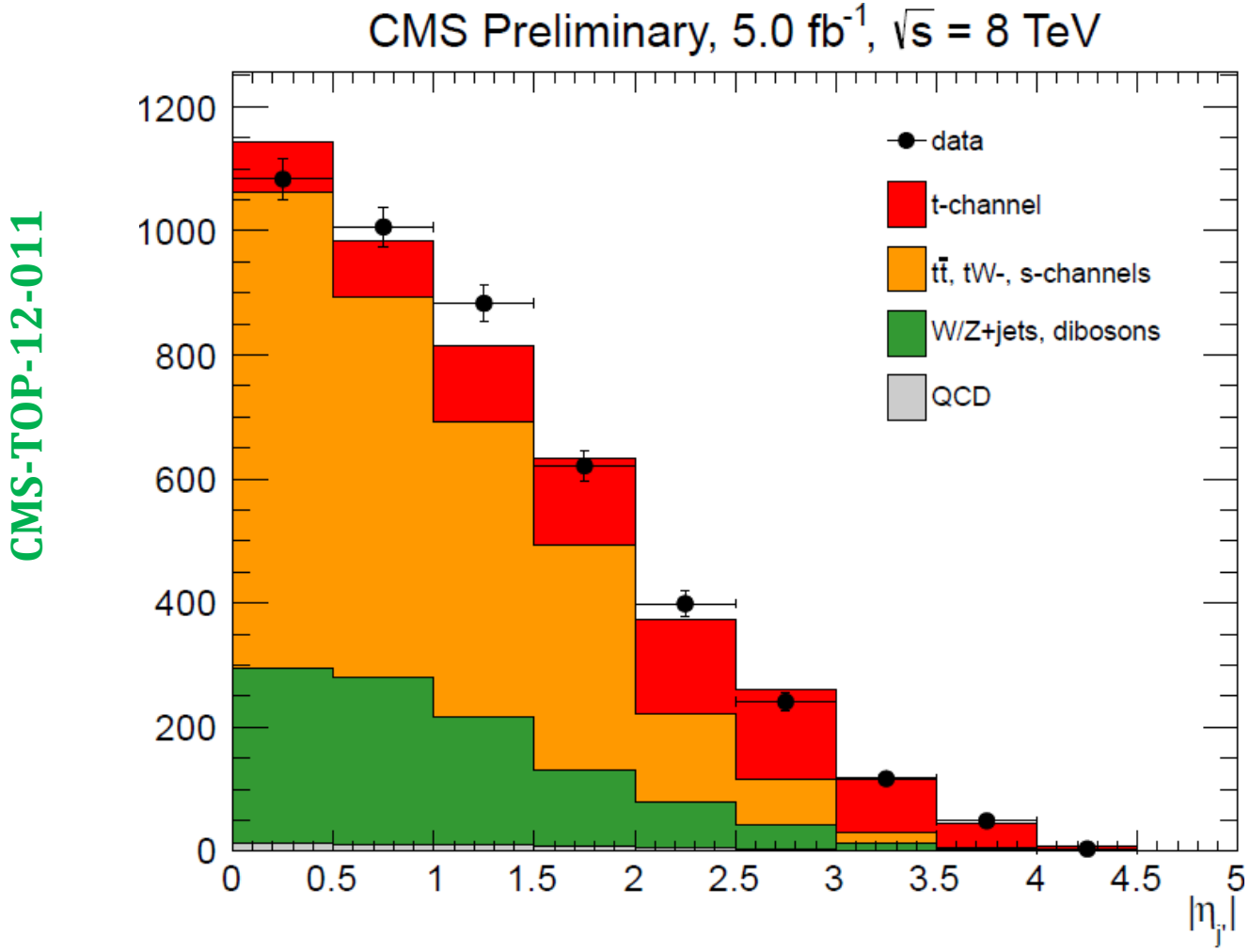
$$\sigma_{t-ch} = 67.2 \pm 3.7(\text{stat.}) \pm 3.0(\text{syst.}) \pm 3.5(\text{th.}) \pm 1.7(\text{lumi.})$$

JHEP12(2012) 035

t-channel cross section at 8 TeV

$|\eta_{j'}|$ analysis ported to 8 TeV (μ+jets)

Also top-pair modeling from data



Result: $\sigma_{t-ch} = 80.4 \pm 5.8(\text{stat.}) \pm 11.0(\text{syst.+ th.}) \pm 4.0(\text{lumi.})$

t-channel cross section overview

Cross sections:

7 TeV: 67.2 ± 6.1 (total)

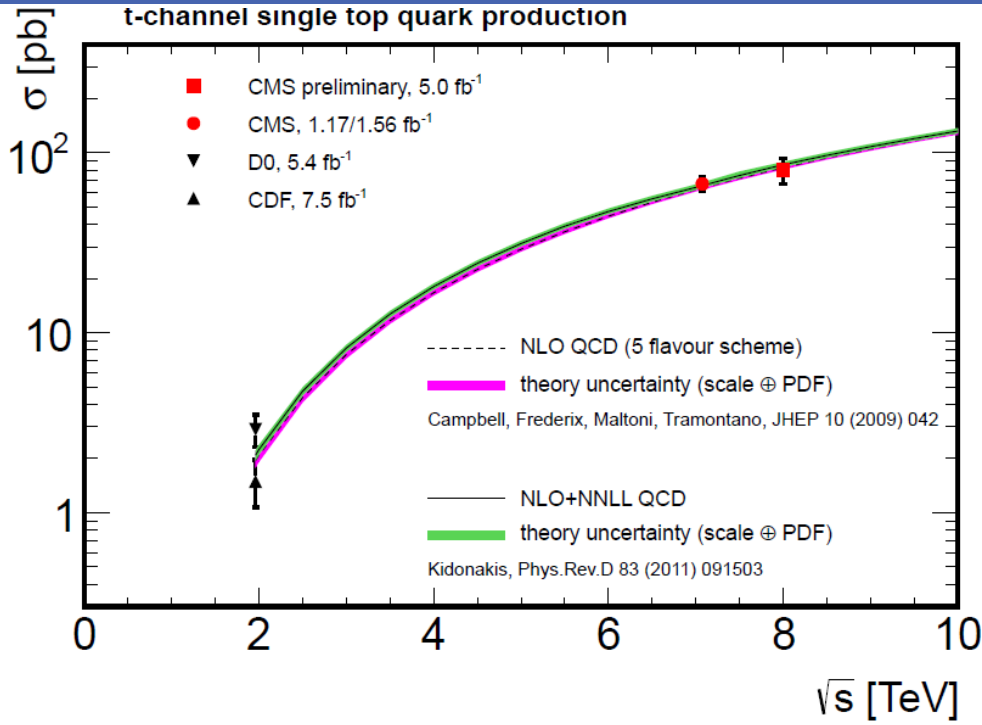
8 TeV: 80.4 ± 13.0 (total)

Cross sections ratio:

$R_{(8/7)} = \sigma_{8TeV} / \sigma_{7TeV} =$

1.14 ± 0.12 (stat.) ± 0.14 (syst.)

Only $|\eta_{j'}|$ analysis is considered from 7 TeV



Measurement of $|V_{tb}|$

With tWb vertex in production ⟶ cross section depends on $|V_{tb}|$

Assuming $|V_{td}|$, $|V_{ts}| << |V_{tb}|$ ⟶ $|V_{tb}| = \sqrt{\frac{\sigma_{obs.}}{\sigma_{the.}}}$

7 TeV: $|V_{tb}| = 1.02 \pm 0.046$ (exp.) ± 0.017 (theo.)

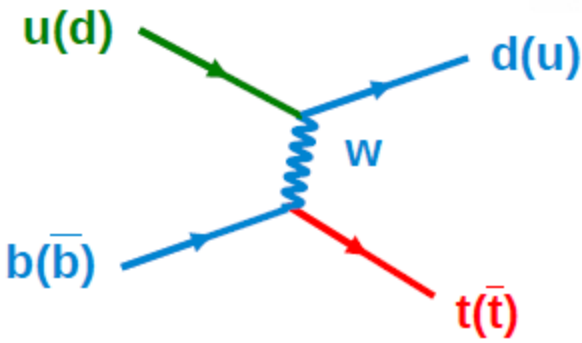
If $|V_{tb}| < 1$ ⟶ $0.92 < |V_{tb}| <= 1$ @ 95% C.L.

8TeV: $|V_{tb}| = 0.96 \pm 0.08$ (exp.) ± 0.02 (theo.)

t-channel top/anti-top at 8 TeV

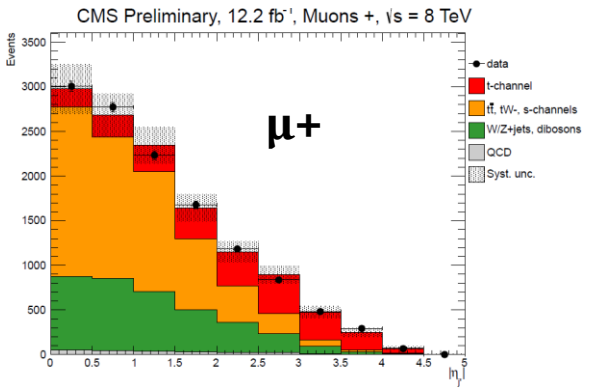
t-channel top quark charge: inherited from the quark in initial state
Valence *u* and *d* quarks contribution generates difference in top-antitop cross section

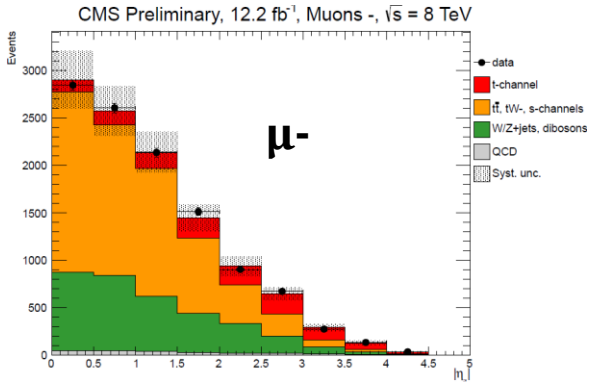
⟶ depends on proton parton distribution function

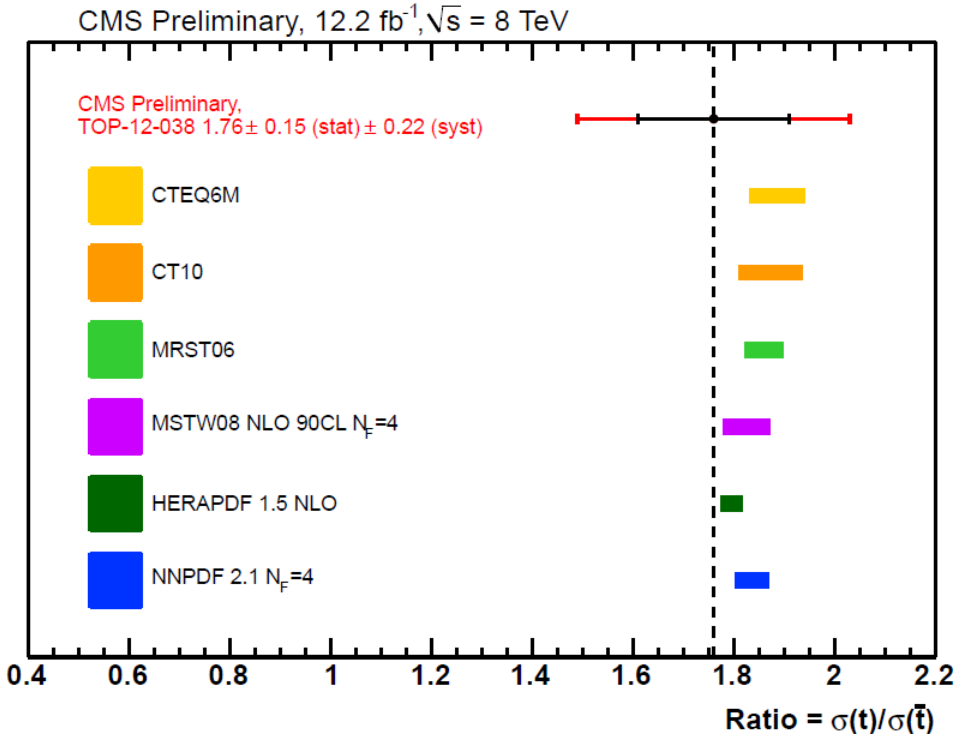


$|\eta_{j'}|$ analysis: fit performed on positive and negative charge leptons simultaneously:

$$\frac{\sigma_{top}}{\sigma_{antitop}}$$







CMS-TOP-12-038

W-helicity measurement

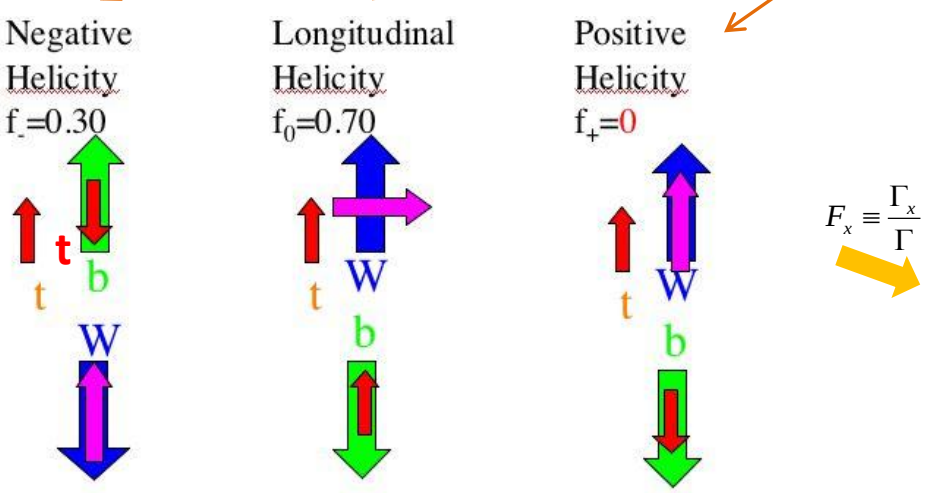
- Probes the **anomalous couplings** in tWb interaction

$$L = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)tW_{\mu}^{-} + -\frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)tW_{\mu}^{-} + h.c.$$

- Anomalous couplings are reflected in angular decay distribution $\cos(\theta_l^*)$

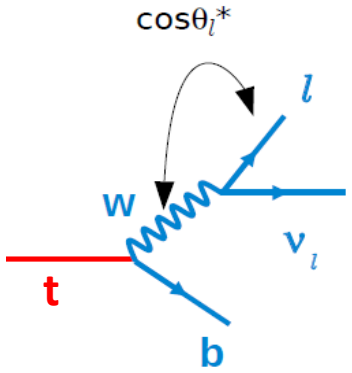
- **Partial decay of top quark**

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



SM at tree level

$$F_x \equiv \frac{\Gamma_x}{\Gamma}$$



$$\Gamma_0 \propto \frac{m_t^2}{m_W^2}[|V_L|^2 + |V_R|^2](1 - x_W^2 - 2x_b^2 - x_W^2 x_b^2 + x_b^4)$$
$$- 4x_b^2\,\mathrm{Re}\,V_L V_R^* + [|g_L|^2 + |g_R|^2](1 - x_W^2 + x_b^2)$$
$$- 4x_b^2\,\mathrm{Re}\,g_L g_R^* + \ldots$$

$$\Gamma_{L,R} \propto [|V_L|^2 + |V_R|^2](1 - x_W^2 + x_b^2) - 4x_b^2\,\mathrm{Re}\,V_L V_R^*$$
$$- \frac{m_t^2}{m_W^2}[|g_L|^2 + |g_R|^2](1 - x_W^2 - 2x_b^2 - x_W^2 x_b^2 + x_b^4)$$
$$- 4x_b^2\,\mathrm{Re}\,g_L g_R^* + \ldots$$

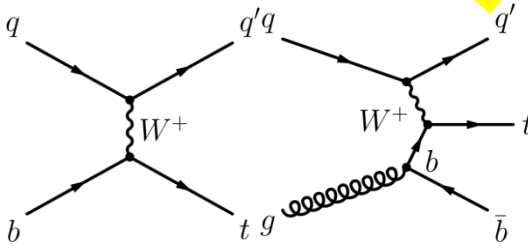
W-helicity measurement (single-top topology)

μ+jets

First measurement of W-helicity fractions in single-top

A reweighting method employed in a binned likelihood fit using $\cos(\theta^*)$ variable

Simultaneous measurement of W+jets and W-helicities



Only t-channel with highest rate

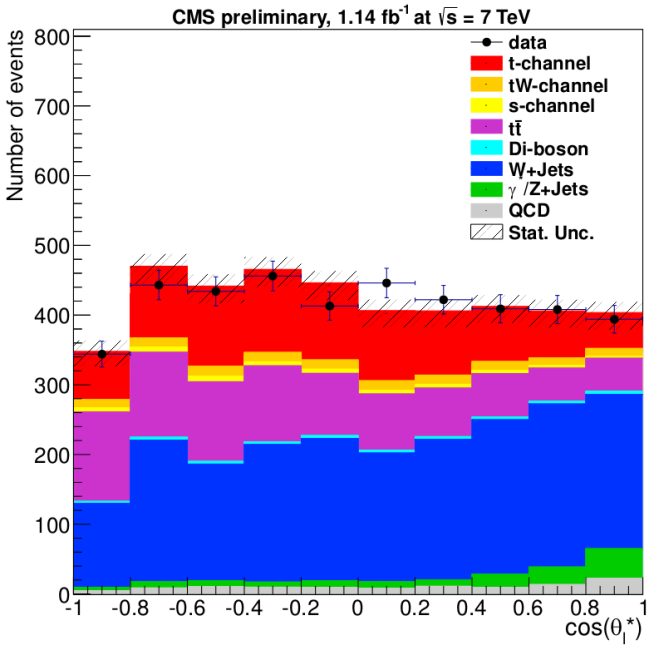
Signal is every process that includes $t \to b\mu\nu$

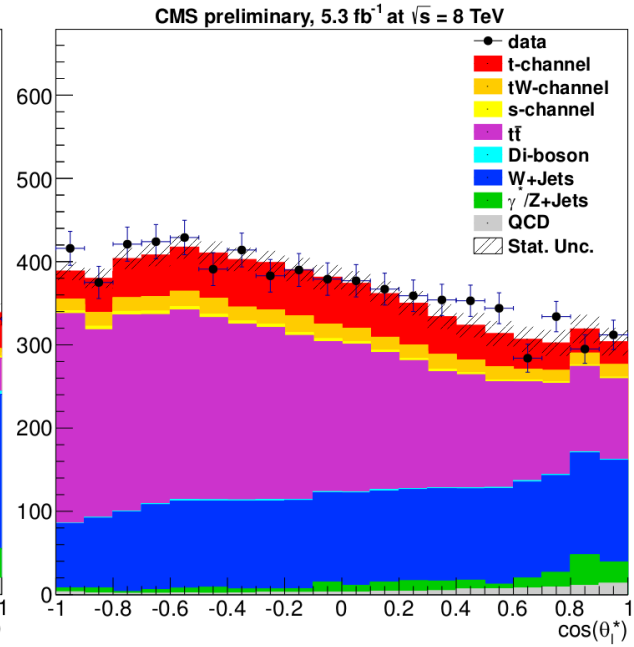
Contributions from top-pair events are taken into account

W boson is reconstructed using W-mass constrained solutions for $p_{z,\nu}$

Results at 7 and 8 TeV are combined using their likelihoods

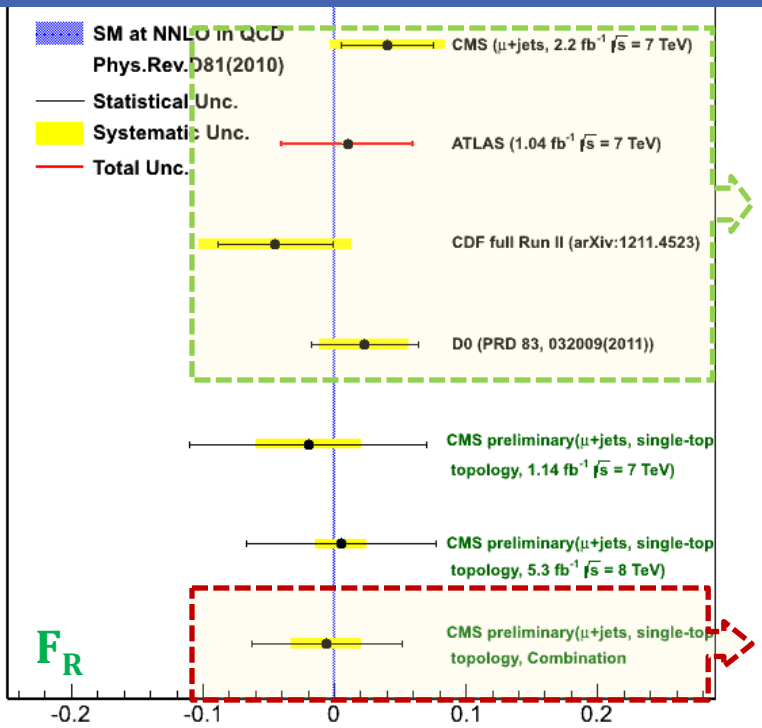
CMS-TOP-12-020





W-helicity measurement (single-top topology)

μ+jets



performed in top-pair

7 + 8 TeV: consistent with SM

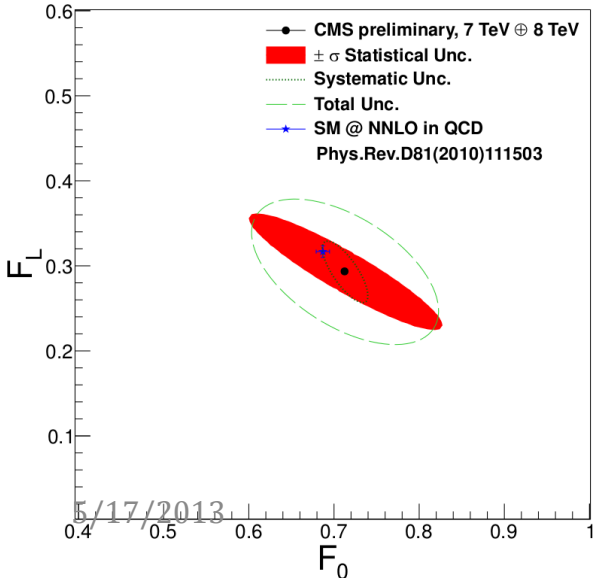
$$F_L = 0.293 \pm 0.069(stat.) \pm 0.030(syst.)$$

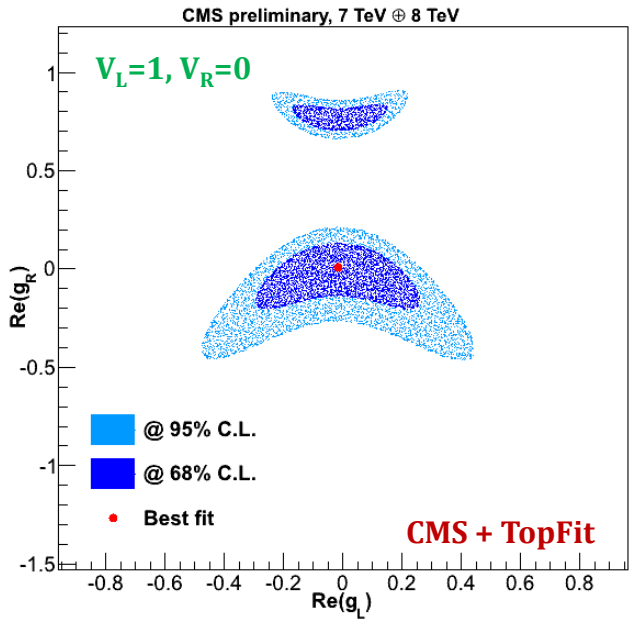
$$F_0 = 0.713 \pm 0.114(stat.) \pm 0.023(syst.)$$

$$F_R = -0.006 \pm 0.057(stat.) \pm 0.027(syst.)$$

Results from single-top are competitive, despite smaller statistics
Single-top and top-pairs: independent datasets: gain in combination.

CMS-TOP-12-020



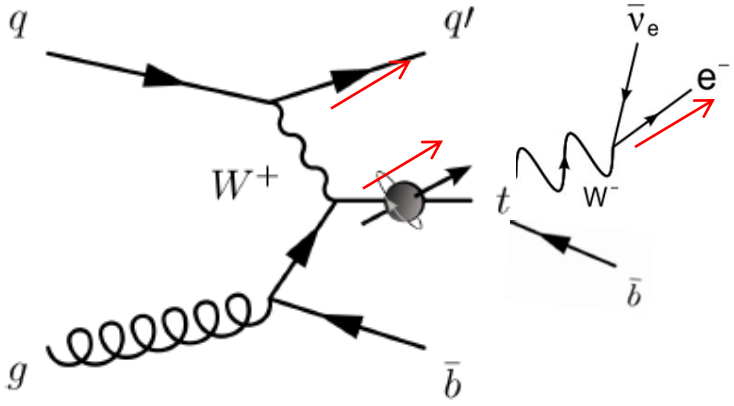


Assuming $V_L=1$, $V_R=0$, limits are set on the tensor couplings.

Best fit values:

$g_L = -0.014$, $g_R = 0.007$

Top quark polarization



New physics in tWb vertex alters the top polarization

Single-top quark in t-channel: produced 100% polarized in the direction of down-type fermion due to V-A coupling

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_l} = \frac{1}{2}(1 + P_t \alpha_l \cos\theta_l)$$

top polarization

$\theta_l \equiv \measuredangle(l, q')$ in top rest frame

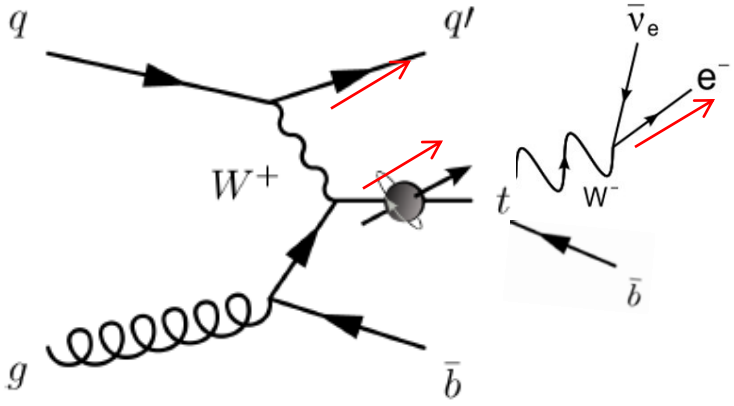
Correlation degree or spin analyzing power
SM: $\alpha_l \approx 1$ for d-fermion

- The sample is statistically a mix of ↑ and ↓ top quarks
- We measure the spin asymmetry:

$$A_l \equiv \frac{N(\uparrow) - N(\downarrow)}{N(\uparrow) + N(\downarrow)} = \frac{1}{2} \cdot P_t \cdot \alpha_l$$

CMS-TOP-13-001

Top quark polarization



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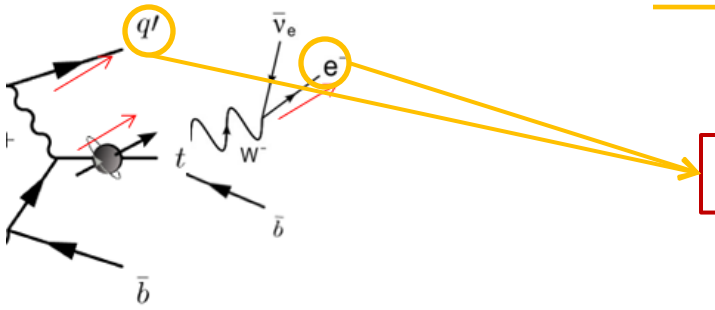
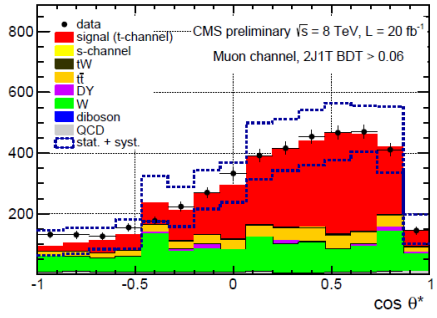
CMS-TOP-13-001

Experimentally:
we select the t-channel event: 1 lepton + 1 light jet + 1 b-tagged jet + …



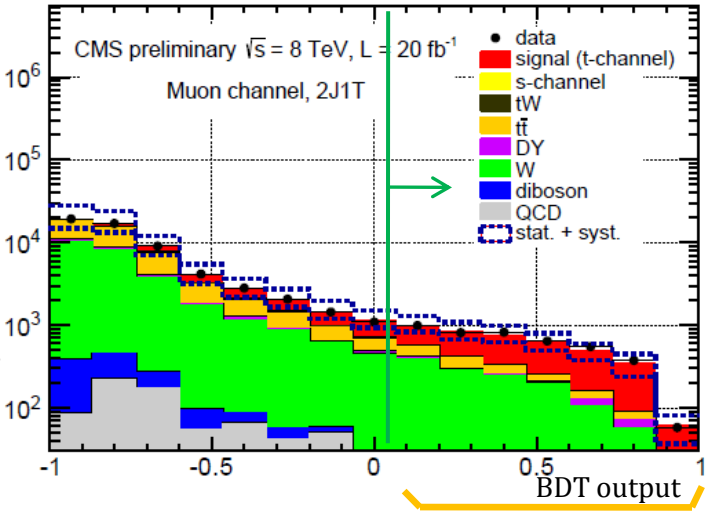
$\theta_l \equiv \measuredangle(l, q')$



Top quark polarization

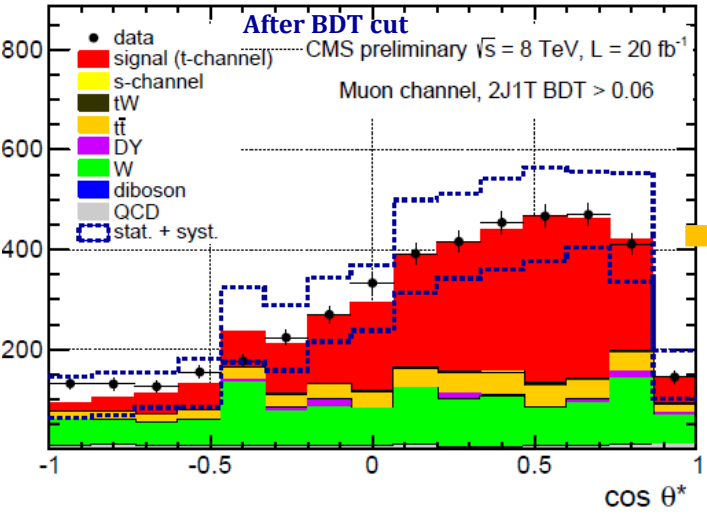
The output of a Boosted Decision Tree is used to

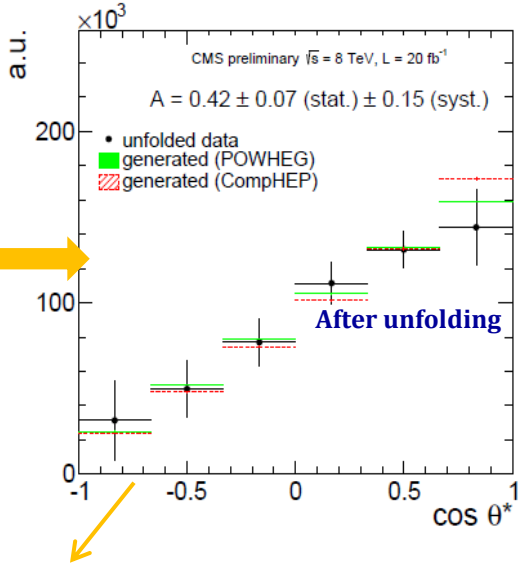
1. Determine the background contributions
2. Enrich the signal sample



Control samples used to validate backgrounds
MadGraph **W+jets shape** is corrected with **SHERPA**

The detector effects are resolved via **unfolding**





Combination

$$A_l = 0.41 \pm 0.06(\text{stat.}) \pm 0.16(\text{syst.})$$

$$A_l \equiv \frac{1}{2} P_t \cdot \alpha_l \quad \text{and} \quad \alpha_l \approx 1$$

Muon $A_l = 0.42 \pm 0.07(\text{stat.}) \pm 0.15(\text{syst.})$

Electron $A_l = 0.31 \pm 0.11(\text{stat.}) \pm 0.23(\text{syst.})$

$$P_t = 0.82 \pm 0.12(\text{stat.}) \pm 0.32(\text{syst.})$$

CMS-TOP-13-001

tW-channel cross section: selection

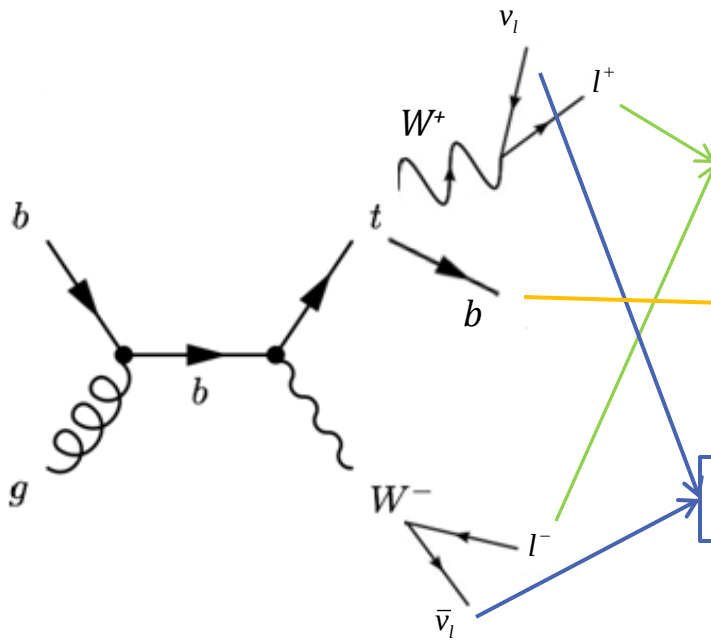
SM expectations (http://arxiv.org/abs/1210.7813v2)

7 TeV

σ_{tW}= 15.6±0.4±1.1 pb

8TeV

σ_{tW}= 22.2±0.6±1.4 pb



Two isolated leptons (μμ, eμ, ee)

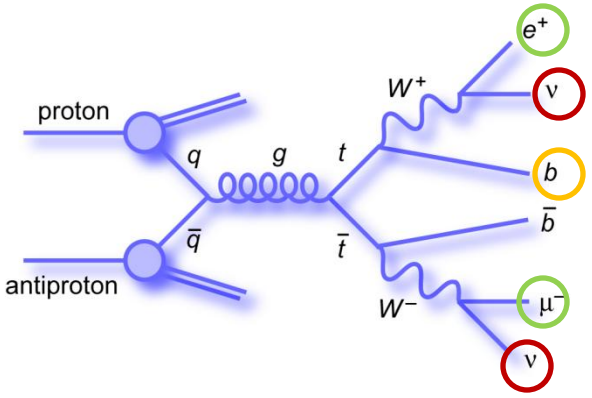
One b-jet from top decay b-quark (1j1t)

Missing energy from two neutrinos (MET)

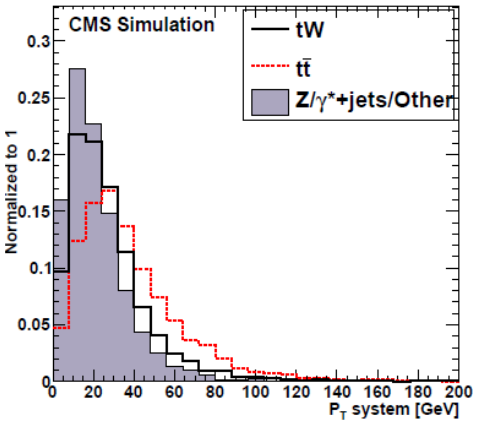
MET ambiguity: Not possible to fully reconstruct the top quark or W-boson

tW-channel cross section: main backgrounds

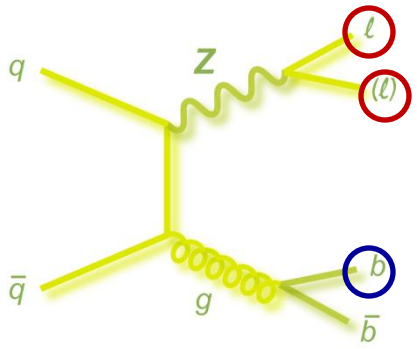
Top pairs



- Veto the second b-quark jet (7 TeV)
- Looking at p_T(system): p_T of $(\vec{p}_{vis} + \vec{E}_T^{miss})$
- Using control regions with 2 jets and 1 or 2 b-tagged to constrain the top-pair normalization in the fit (2j2t, 2j1t)



Z + jets for ee and μμ channels



- Veto lepton pairs under the Z-mass peak, 90-x GeV < m_{ll} < 90+x GeV
- Cut on missing energy, E_t^{miss} > 50 (30) GeV at 8 (7) TeV
- Normalization is corrected by a data-driven factor
  - Correction is extracted using events inside Z-mass peak

Others are negligible

tW-channel cross section at 7 TeV

A **Likelihood fit** is performed on a **BDT (4 var.)** output over all three channels (μμ, eμ, ee) and all three regions (1j1t, 2j1t, 2j2t)

Templates for signal and background taken from **simulation**

Uncertainties included in the fit as nuisance parameters

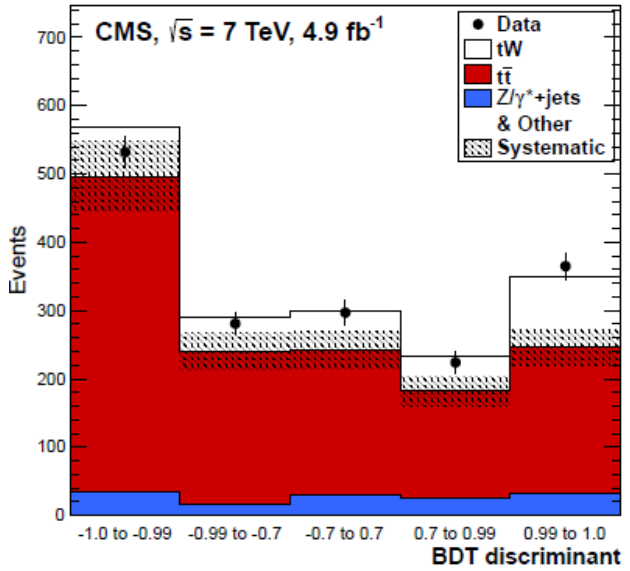
CMS showed EVIDENCE at 7 TeV

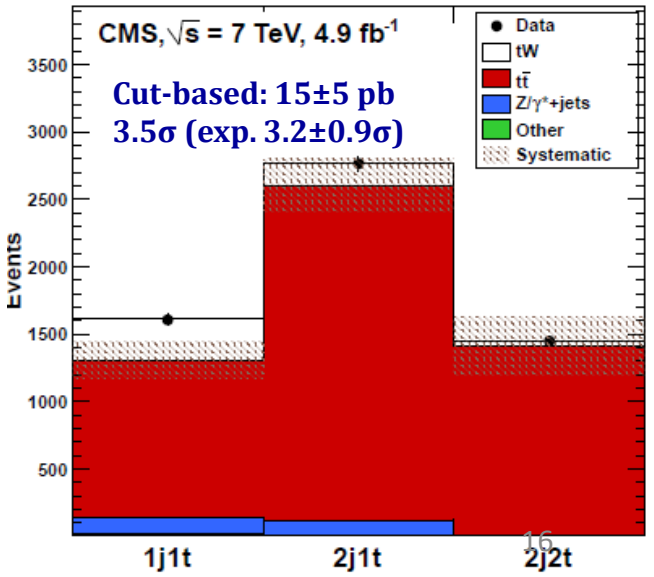
Significance: 4.0σ (expected: $3.6^{+0.8}_{-0.9}$)

Cross section: 16^{+4}_{-5} pb

$|V_{tb}|$: $1.01^{+0.16}_{-0.13}(\text{exp.})^{+0.03}_{-0.04}(\text{th.})$

Constrained $|V_{tb}| < 1$: $|V_{tb}| > 0.79$ @90% C.L.





Phys.Rev.Lett 110, 022003 (2013)

tW-channel cross section at 8 TeV

A **Likelihood fit** is performed on a **BDT (13 var.)**output over all three channels (μμ, eμ, ee) and all three regions (1j1t, 2j1t, 2j2t)

Templates for signal and background taken from **simulation**

Uncertainties included in the fit as nuisance parameters

CMS showed the FIRST OBSERVATION at 8 TeV

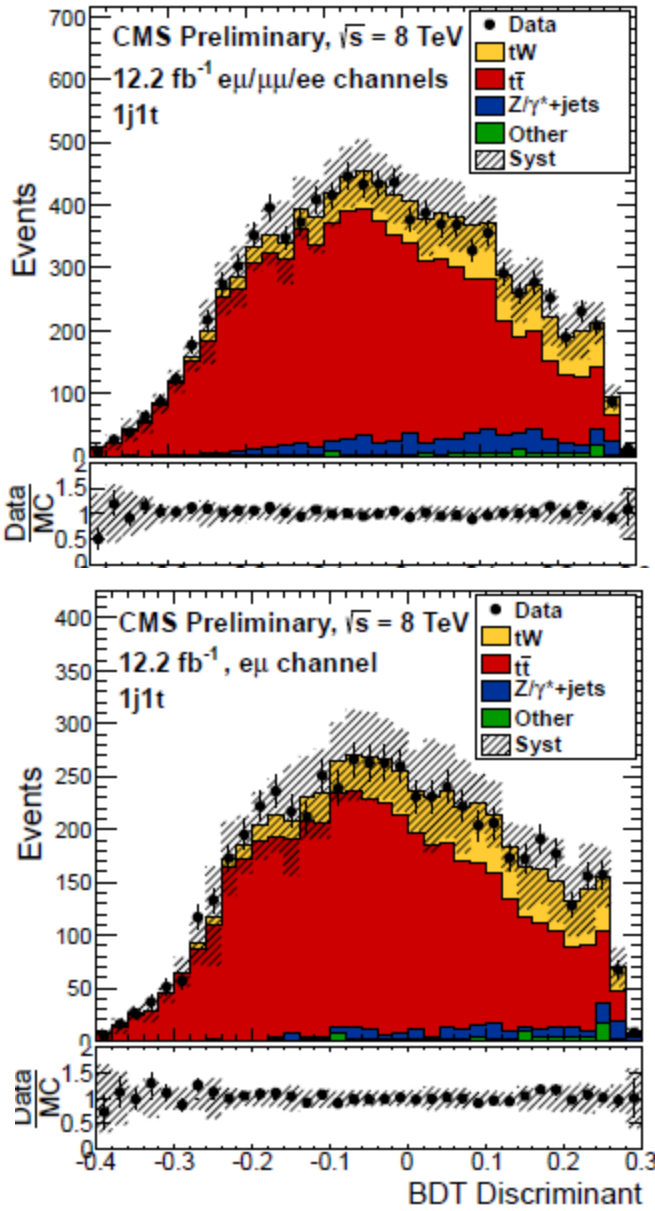
Significance: 6.0σ (expected: $5.4^{+1.5}_{-1.4}$)

Cross section: $23.4^{+5.5}_{-5.4}$ pb

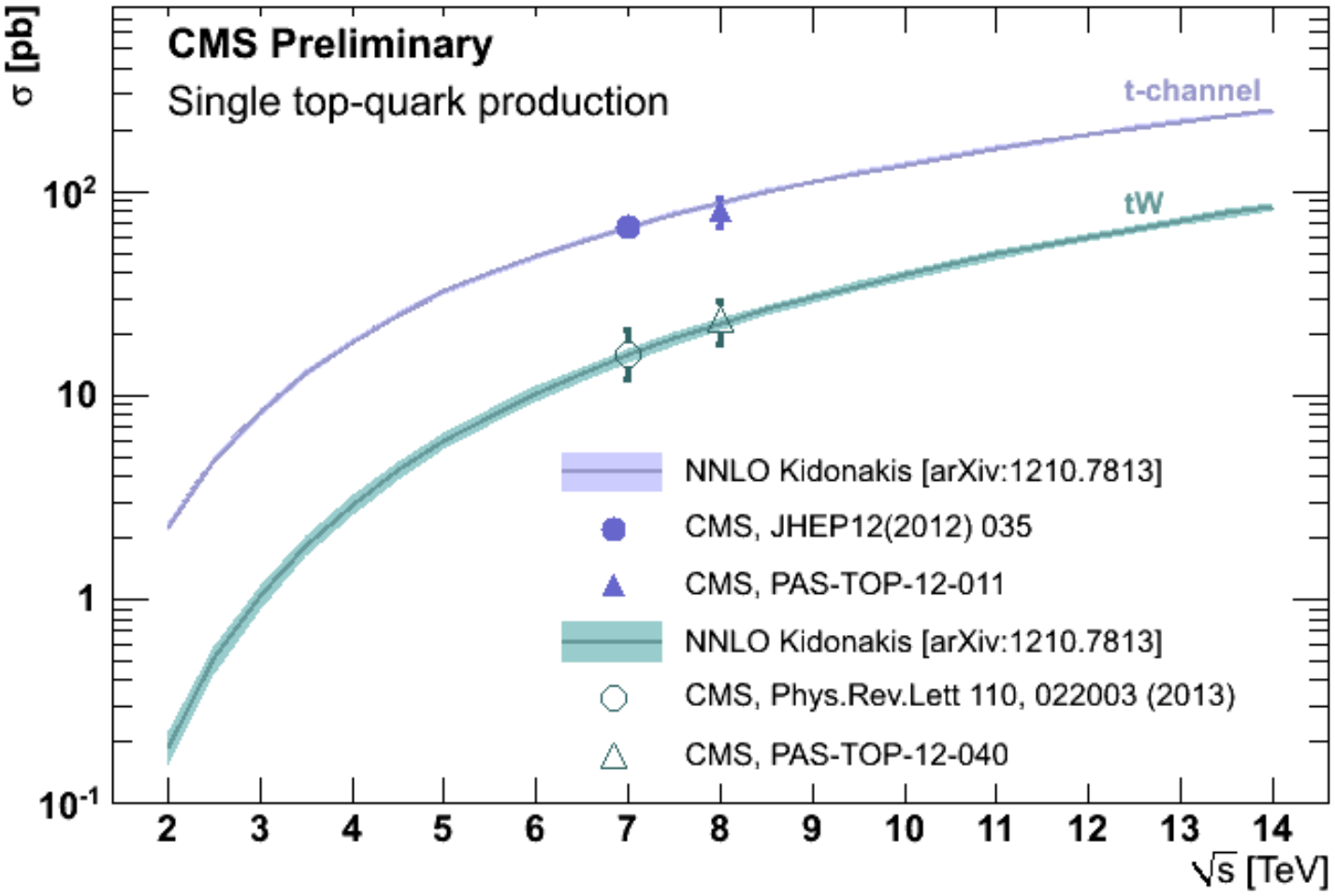
$|V_{tb}|$: $1.03 \pm 0.12(\text{exp.}) \pm 0.04(\text{th.})$

Constrained $|V_{tb}| < 1$: $|V_{tb}| > 0.78$ @95% C.L.

CMS-TOP-12-040

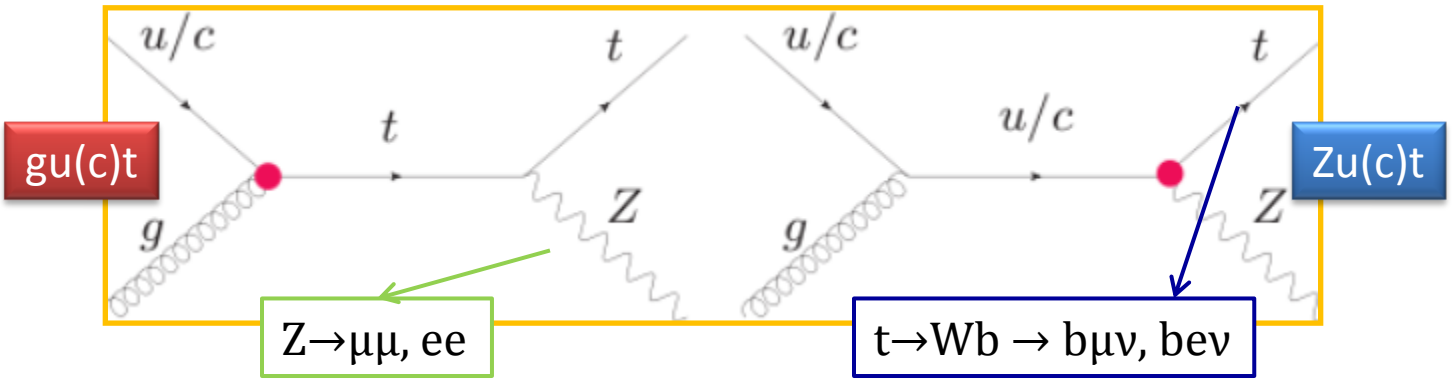


Summary on CMS single-top cross sections



Search for FCNC in tZ events

tZ final state is **sensitive** to two types of **anomalous couplings**



Rare signature (low statistics) : 3 lepton (eeμ, μμμ, μμe, eee) + 1 b-jet + rejecting low m_T^W

Backgrounds

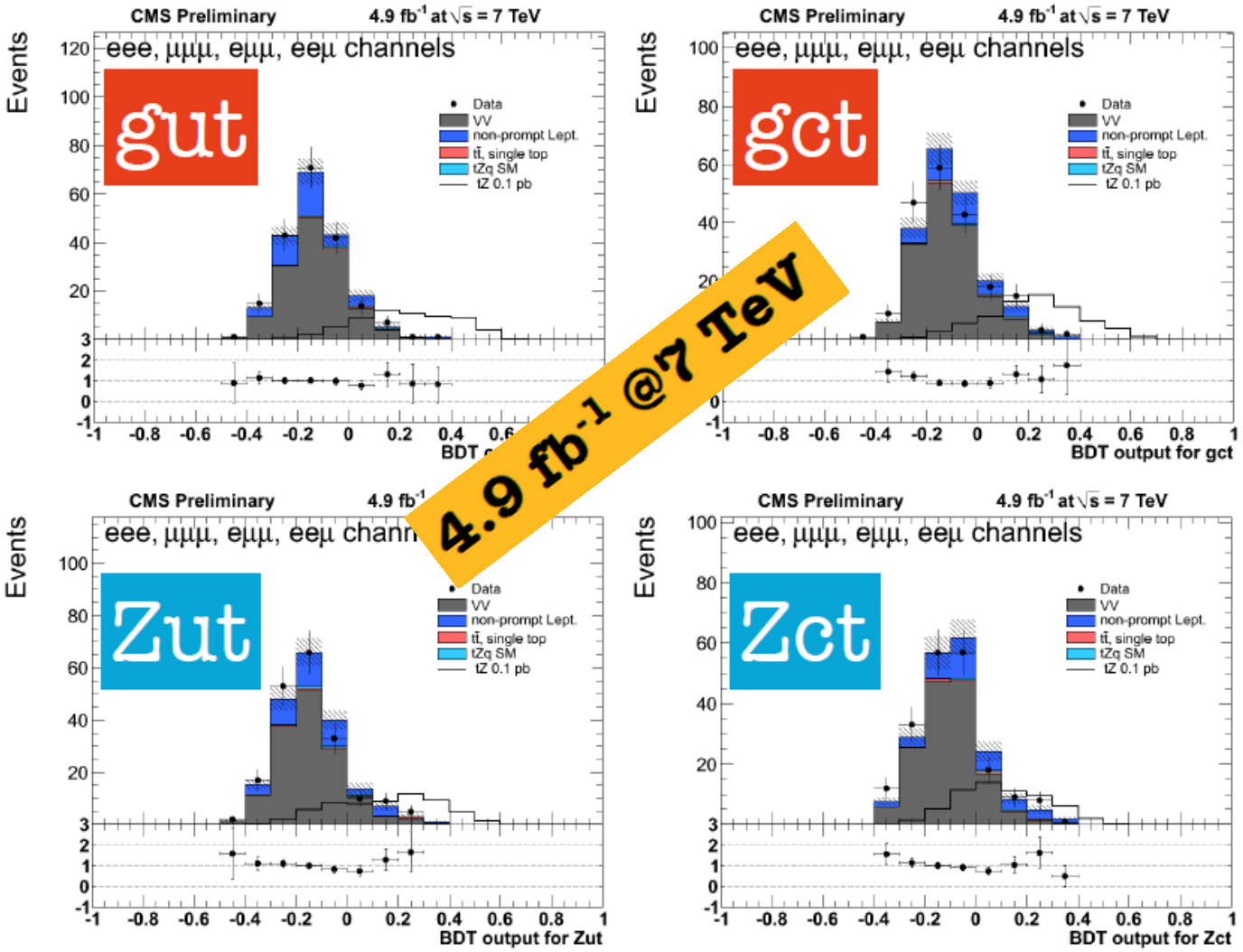
- *Fake leptons in Z+jets:* Normalization from template fit on m_T^W , shape from Z+jets data
- *WZ+jets:* Normalization is left free in limit calculations
- *Others (sub-dominant):* ZZ+jets, top-pairs, tZq

Limits: obtained based on a likelihood fit on the BDT (11 var.)discriminant after selection

CMS-TOP-12-021

Search for FCNC in tZ events

Likelihood fit on BDT output to obtain the limit on cross section @ 95% C.L.



CMS-TOP-12-021

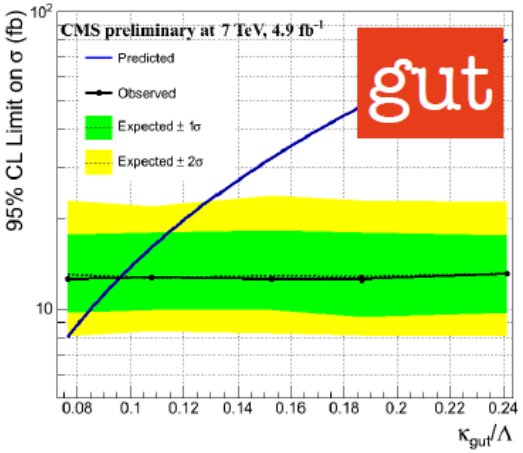
Search for FCNC in tZ events

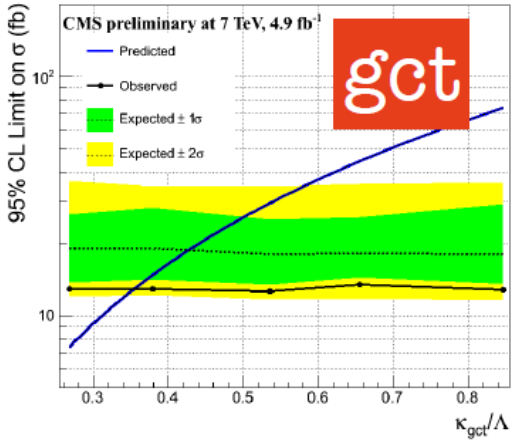
No New Physics

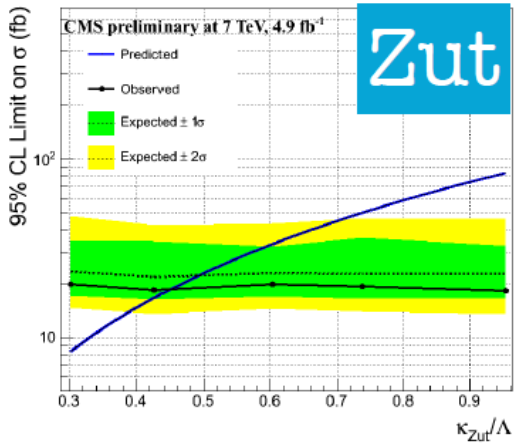
Limits set on the anomalous couplings at 95% C.L.

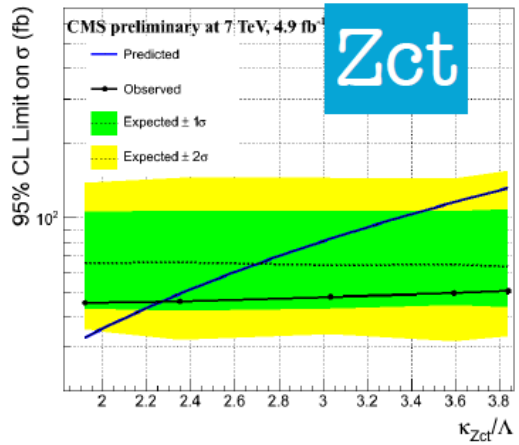
Anomalous *Brs*
Coupling strength results translated to top quark anomalous branching fractions

Improved results
Expected at 8 TeV









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 %

CMS-TOP-12-021

Summary

- **CMS** is performing extensive searches and measurements in single-top events
- The first observation of single-top in tW-channel is reported
- All measurements so far are consistent with the SM predictions
- No sign of new physics yet
- More measurements and updates with the full CMS dataset is underway
- Stay tuned
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Thanks for your attention