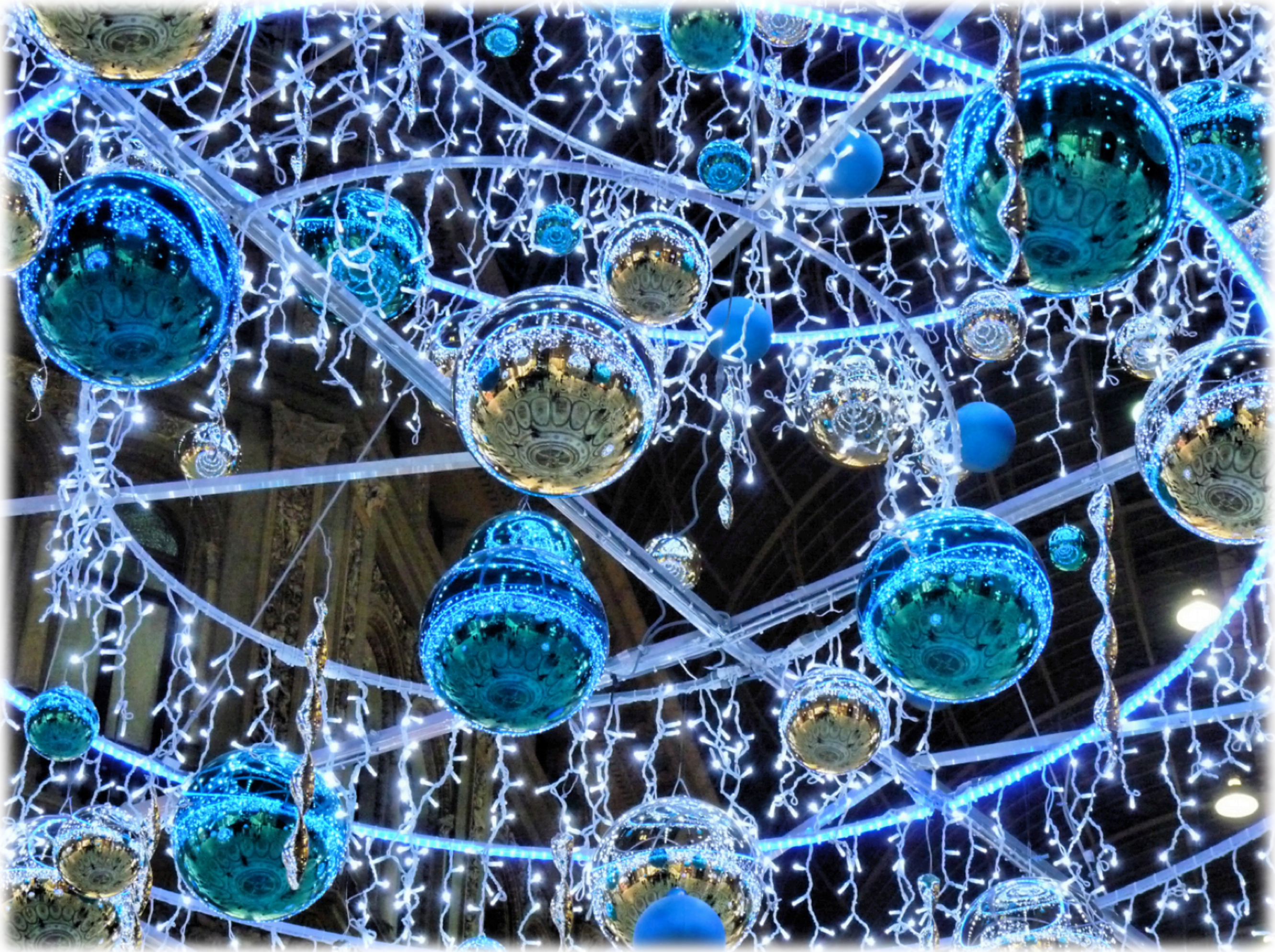
Single top
Experimental summary



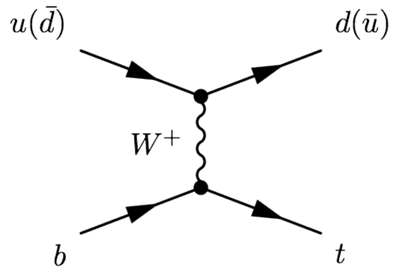
Luca Lista

INFN – Napoli

Outline

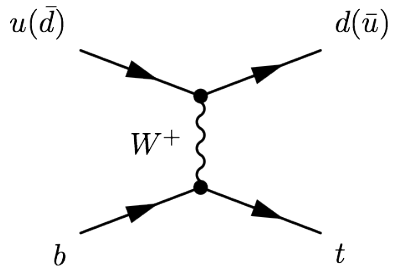
- t channel
  - Cross-section
  - Top-antitop cross-section ratio
  - Differential studies
- tW channel
- s channel
- What will change at 14 TeV

t channel: event selection



- **7 TeV / 8 TeV** requirements:
  - exactly one e or μ / exactly one μ
  - Number of jets and b tags identify signal and control regions
    - Signal: 2 jets, 1 tag
    - Enriched of tt~ or W+jet (heavy, light) varying # of jets and tags
  - Jets: anti-k_T(0.5) $p_T > 30/60$ GeV, $|\eta| < 4.5$
  - Muons: $p_T > 20/26$ GeV, $|\eta| < 2.1$
  - Electrons: $p_T > 30$ GeV, $|\eta| < 2.5$
  - m_T (W) > 40/50 GeV(μ) or ME_T > 25 GeV(e)

t channel: cross section

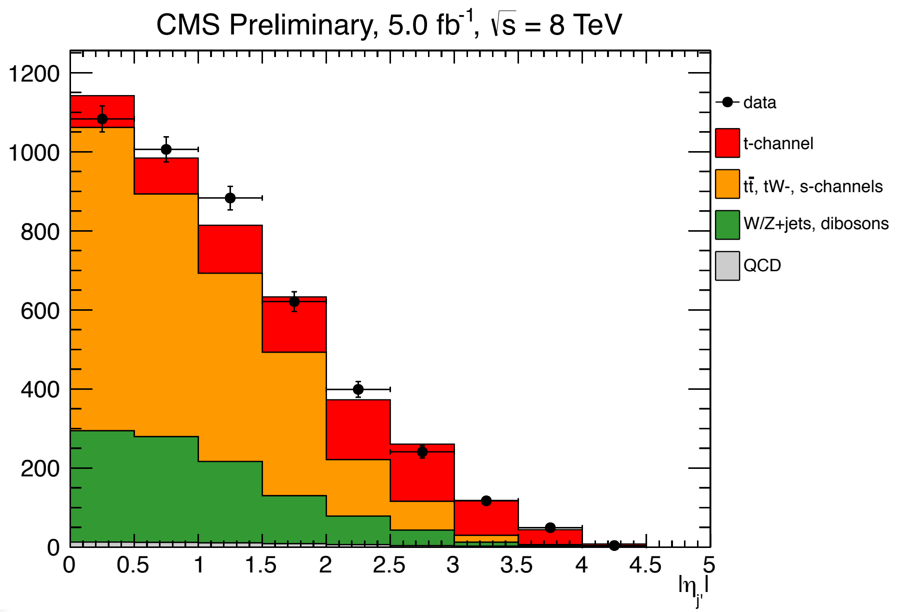


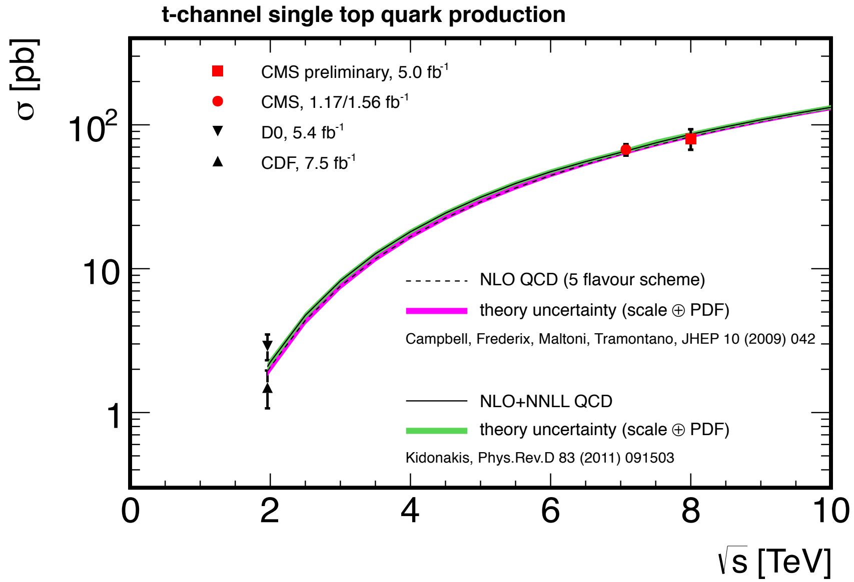
- Inclusive cross section measured at 7 and 8 TeV
- **7 TeV**, 1.17/1.56 fb^{-1}: three analyses combined: NN, BDT and fit to $|\eta_{j'}|$ distribution; exactly one e or μ

$\sigma_{t\text{-ch.}}$ = 67.2±3.7(stat)±3.0(syst)±3.5(th)±1.5(lumi) pb [JHEP12(2012) 035]
$\sigma_{t\text{-ch.}}^{SM}$ = 64.6pb

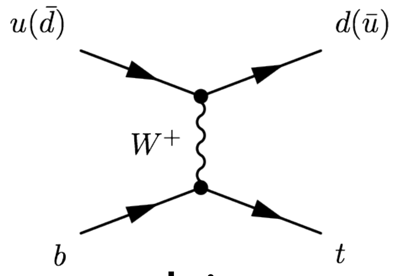
- **8 TeV**, 12.2 fb^{-1}: fit to $|\eta_{j'}|$ distribution in 2jets+1b-tag, signal region from reconstructed top mass. Exactly one μ

$\sigma_{t\text{-ch}}$ = 80.1±5.7(stat)±11.0(syst)±4.0(lumi) pb [TOP-12-011]
$\sigma_{t\text{-ch.}}^{SM}$ = 87.6pb

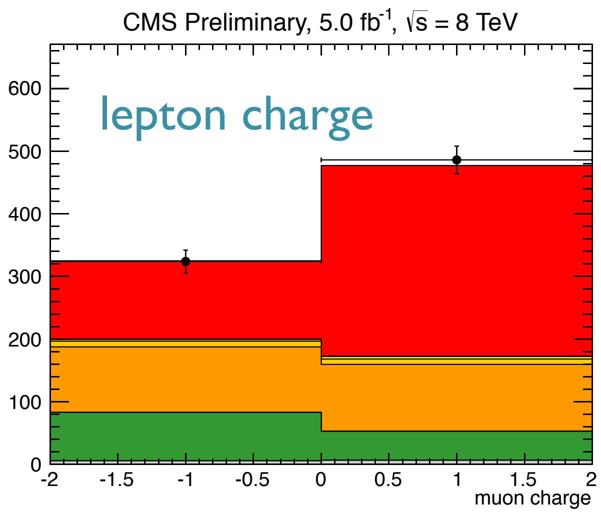


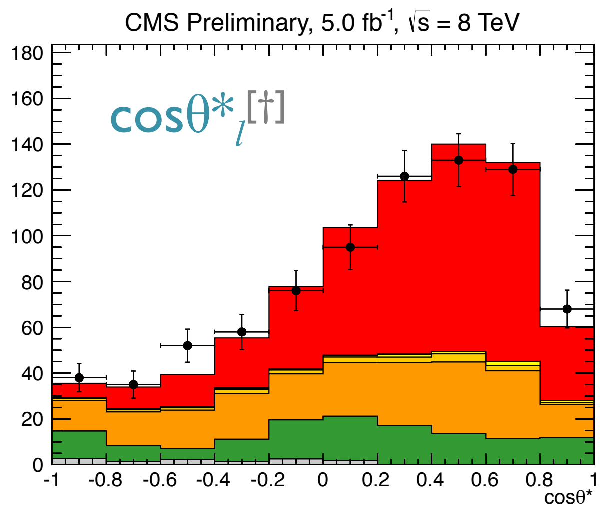


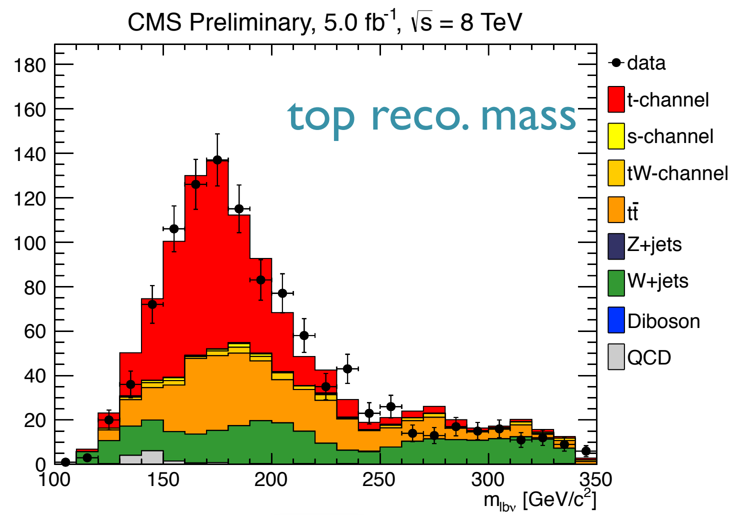
t channel: distributions



- The t-channel data sample is large enough to start studying distributions
  - → differential cross sections
- Signal can be enhanced by requiring large forward jet pseudorapidity, e.g.: $|\eta_{j'}| > 2.0$







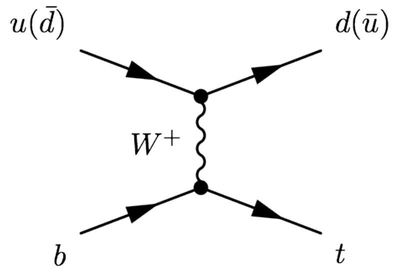
Top/antitop cross-section ratio

Top polarization

Top mass from single top (uncovered so far!)

[†] θ^*_l = angle between lepton in W rest frame and the W in top rest frame.

Systematic uncertainties

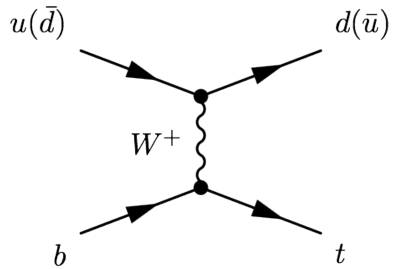


- Main systematics:
  - Jet energy scale, signal generator, muon efficiency, PDF, b tagging
  - Improving on the theory side is important!

8 TeV analysis

Uncertainty source	in pb	relative
Statistical	± 5.7	± 7.2 %
W+jets and $t\bar{t}$ modeling	± 3.6	$\pm$ 4.5 %
JES	$-$ 6.2 / + 4.7	$-$ 7.8 / + 5.8 %
JER	$-$ 0.8 / + 0.3	$-$ 1.0 / + 0.4 %
Unclustered $\not{E}_T$	$-$ 0.8 / + 0.7	$-$ 1.0 / + 0.9 %
Pileup	$-$ 0.5 / + 0.3	$-$ 0.6 / + 0.4 %
Muon trigger + reconstruction	$-$ 4.1 / + 4.0	$-$ 5.1 / + 5.1 %
Q^2	± 2.5	± 3.1 %
$t\bar{t}$, rate	$-$ 1.5 / + 1.7	$-$ 1.9 / + 2.1 %
QCD, rate	± 0.7	± 0.9 %
$t-$channel generator	± 4.4	± 5.5 %
Other backgrounds, rate	± 0.5	± 0.6 %
b-tagging	± 3.7	± 4.6 %
PDF	$\pm$ 3.7	± 4.6 %
Simulation statistics	± 1.8	± 2.2 %
Total systematics	± 11.0	± 13.7 %
Luminosity uncertainty	± 4.0	± 5.0 %
Total	± 13.0	± 16.3%

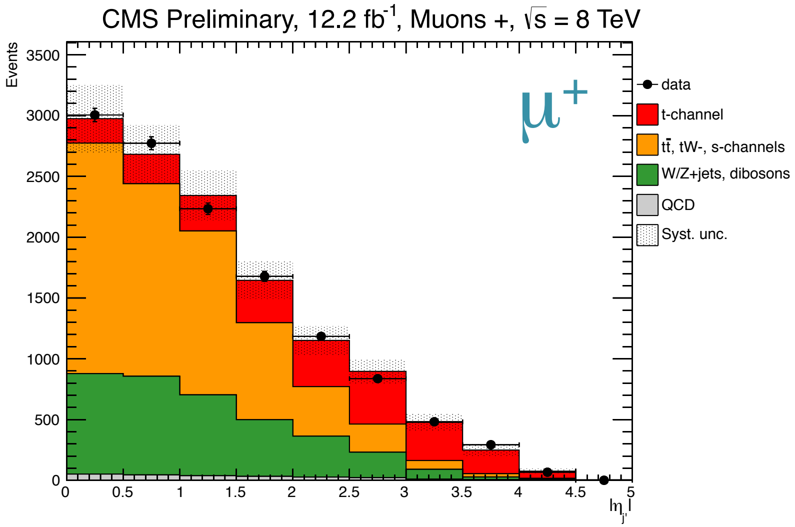
Top antitop, separately

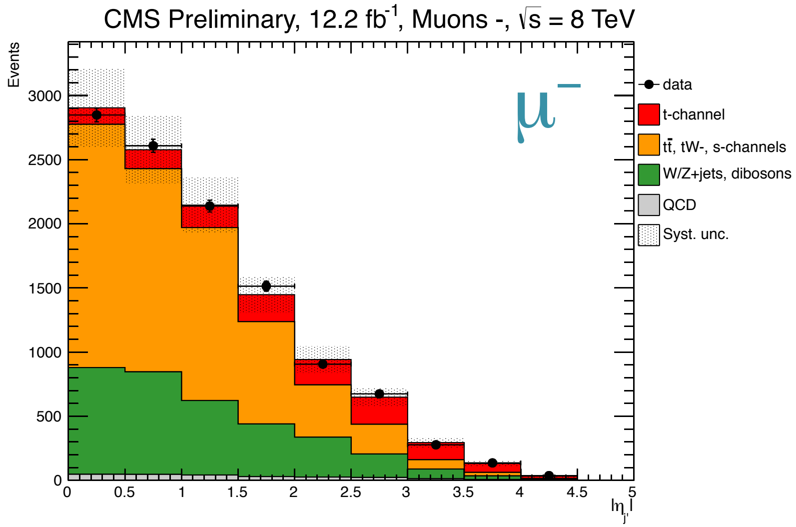


- Top and antitop cross sections can be measured separately, based on the lepton charge [TOP-12-038]
- Their ratio and total cross section can be determined, alternatively
- Slightly different selection with both e and μ, to optimize uncertainty on the ratio; electron channel added to the analysis

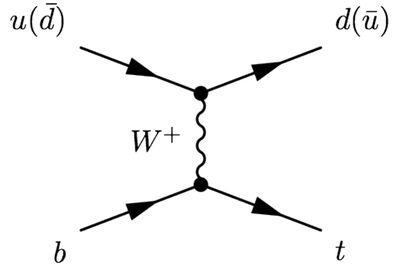
- σ_{top} = 49.9 ± 1.9(stat) ± 8.9(syst) pb
- $\sigma_{anti\text{-}top}$ = 28.3 ± 2.4(stat) ± 4.9(syst) pb

SM expectation
σ_{top} = 43.0 $(^{+1.6}_{-0.2})$ ±0.8 pb $\sigma_{anti\text{-}top}$ = 22.9±0.5 $(^{+0.7}_{-0.9})$ pb
http://arxiv.org/abs/1210.7813v2





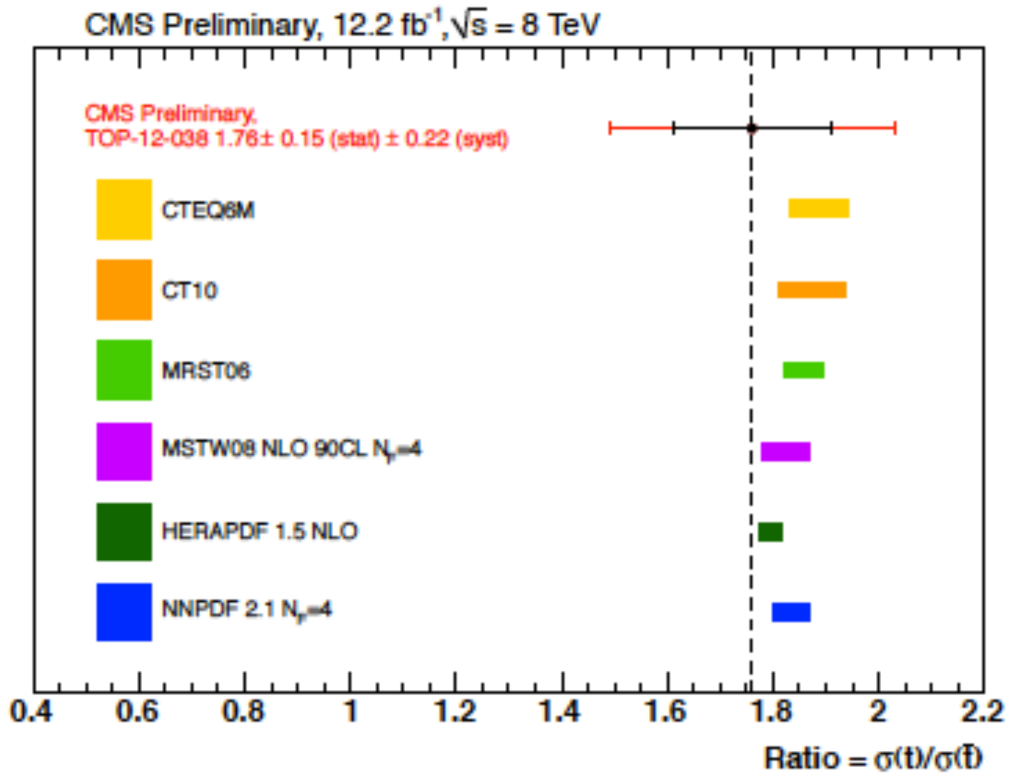
Top-antitop ratio



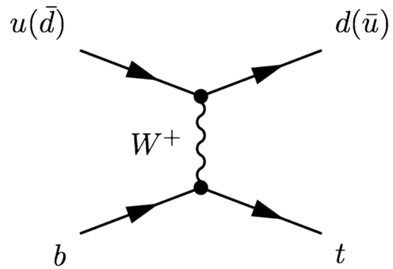
- Top-antitop ratio $R_{t/t\sim}$ probes the different u and d content of the proton
- Potentially sensitive to PDF

- $R_{t/t\sim} = 1.76 \pm 0.15(\text{stat}) \pm 0.22(\text{syst})$

- Uncertainty is still large to discriminate PDF models
- Combination with ATLAS should be pursued, but measurements are available at different √s
- Can we achieve a better sensitivity combining some observables at √s = 7 TeV and 8 TeV (and eventually at 14 TeV)?
- ..or it is a job for PDF global fits?



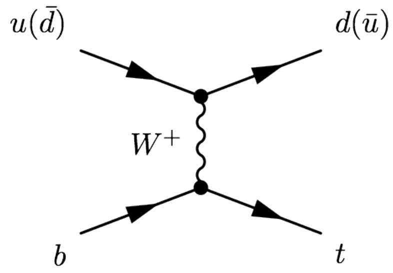
Systematic uncertainties



- Systematics for top and antitop cross sections slightly different from cross section paper (electrons added, different selection)
- In tt~ ratio some uncertainties are reduced (e.g.: b tagging, QCD), but still sizeable PDF, generator

Uncertainty source	$\sigma_{t-ch,antitop}$ (%)	$\sigma_{t-ch,top}$ (%)	$R_{t-channel}$ (%)
stat. uncertainty	$\pm$ 8.6	$\pm$ 3.9	$\pm$ 8.8
JES,JER, and MET	$\pm$ 4.9	$\pm$ 4.2	$\pm$ 2.6
b-tagging and mis-tag	$\pm$ 4.3	$\pm$ 3.7	$\pm$ 0.9
backgrounds ratio	$\pm$ 0.6	$\pm$ 0.5	$\pm$ 1.1
lepton reconstruction/trig.	$\pm$ 1.9	$\pm$ 1.8	$\pm$ 3.6
qcd extraction	$\pm$ 6.4	$\pm$ 3.4	$\pm$ 0.9
W+Jets, $t\bar{t}$ extraction	$\pm$ 5.9	$\pm$ 2.4	$\pm$ 6.8
signal modeling	$\pm$ 11.4	$\pm$ 15.4	$\pm$ 5.4
pdf uncertainty	$\pm$ 5.8	$\pm$ 2.8	$\pm$ 7.5
simulation statistics	$\pm$ 1.1	$\pm$ 0.6	$\pm$ 1.1
luminosity	$\pm$ 4.4	$\pm$ 4.4	-
total systematics	$\pm$ 17.4	$\pm$ 17.8	$\pm$ 12.6
total relative uncertainty	$\pm$ 19.4	$\pm$ 18.3	$\pm$ 15.3
Scale factor w.r.t. SM $\pm$ uncertainty	0.92$\pm$0.18	0.88$\pm$0.16	0.96$\pm$0.15

Differential studies



- Regularized unfolding of cosθ* distribution removes experimental effects
- Top spin asymmetry: A_l = 0.41±0.06(stat)±0.16(syst)
- Top polarization: P_l = 0.82±0.12(stat)±0.32(syst)

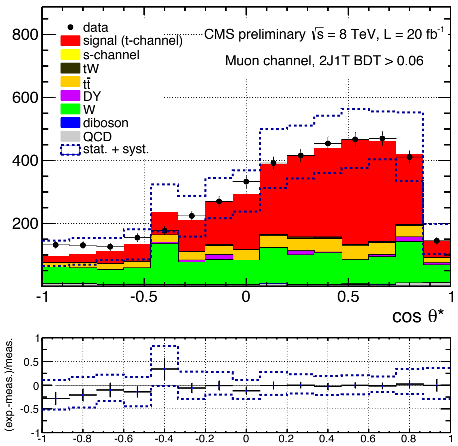
$$A_l \equiv \frac{1}{2} \cdot P_t \, \alpha_l = \frac{N(\uparrow) - N(\downarrow)}{N(\uparrow) + N(\downarrow)}$$

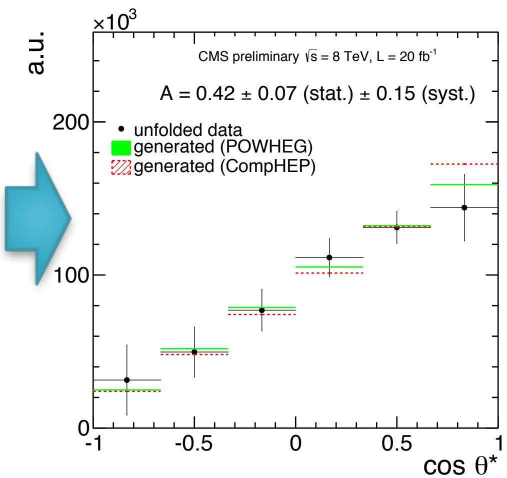
α_l =1 in the SM, modified in case of tWb anomalous coupling

Talk by Matthias Komm later on

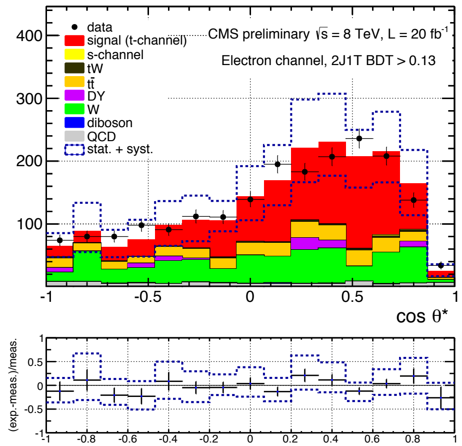
- First of several possible differential cross-section measurements

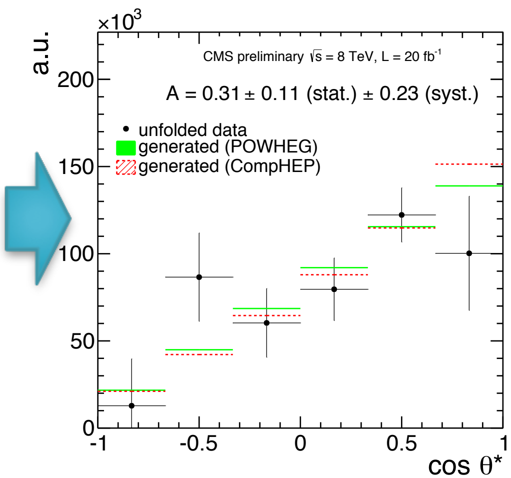
[TOP-13-001]





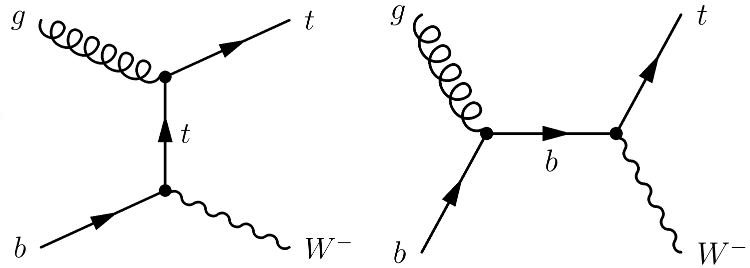
muons





electrons

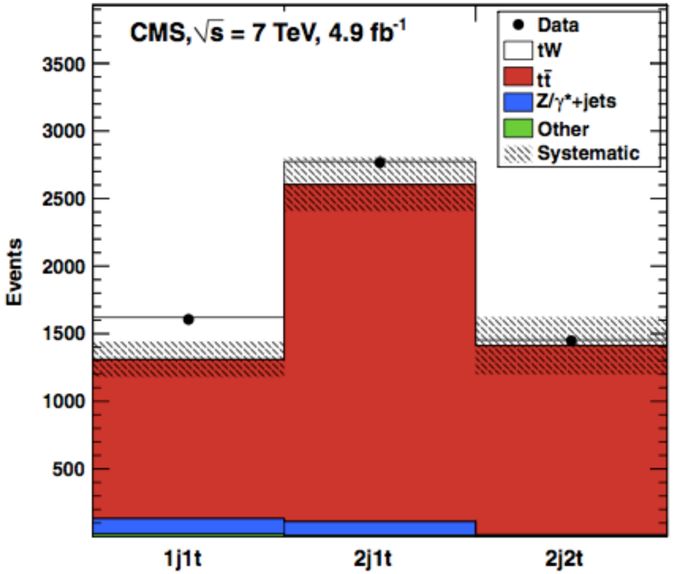
tW evidence, 7TeV

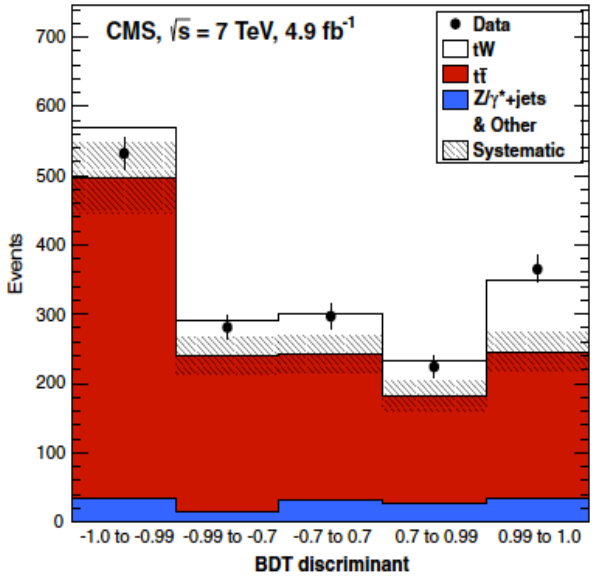


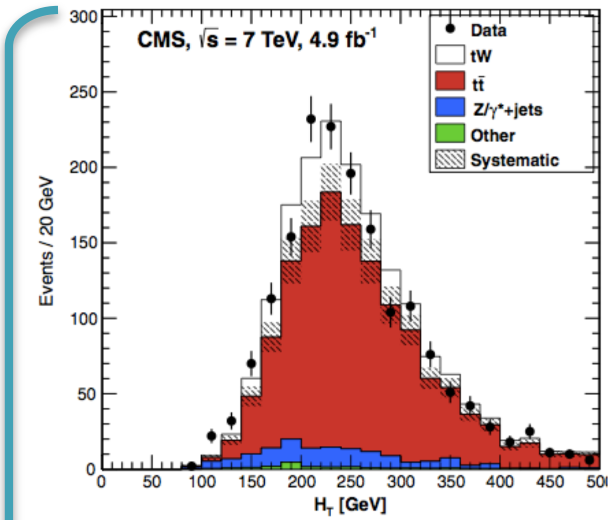
- Cross section measured in dilepton channel
  - Leptons: p_T > 20 GeV, $|\eta|$ < 2.1(μ),2.4(e)
  - Jets: p_T > 30 GeV, $|\eta|$ < 2.4, b tag
  - m_{ll} > 20 GeV
  - Veto (ee/$\mu\mu$): 81< m_{ll} < 101 GeV
  - min(ME_T, Tracker ME_T) > 30 GeV
- BDT adopted to gain sensitivity (4 variables)
- **7 TeV**, 4.9 fb^{-1} [PRL110(2013)022003]:

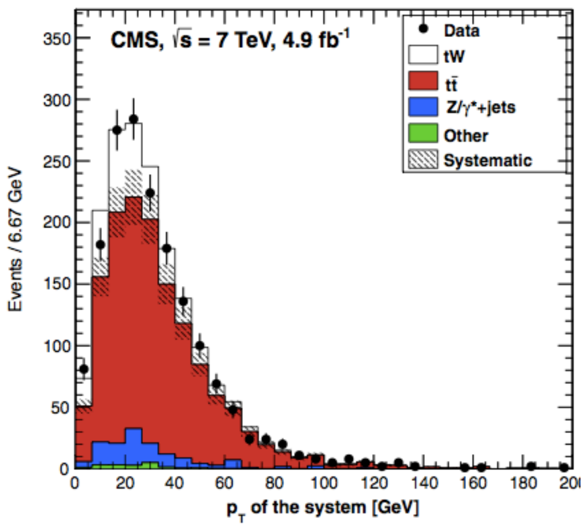
$\sigma_{tW}=16\ ^{+5}_{-4}$ pb (evidence at 4σ)

σ_{tW}^{SM} = 15.6pb



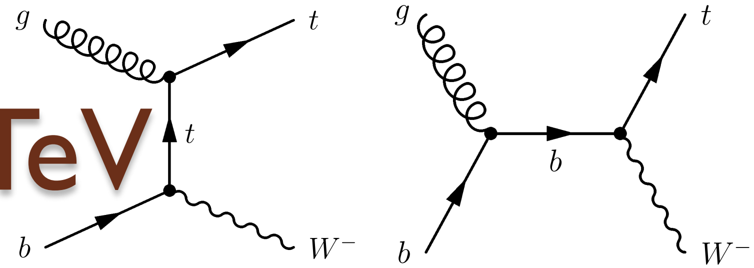






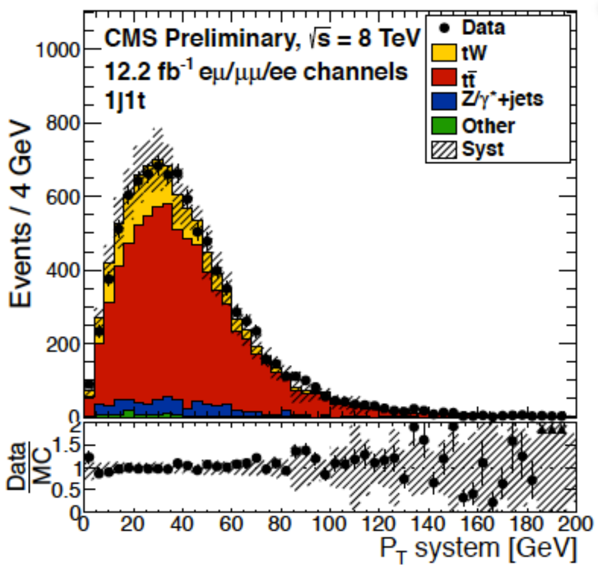
. . . (4 variables)

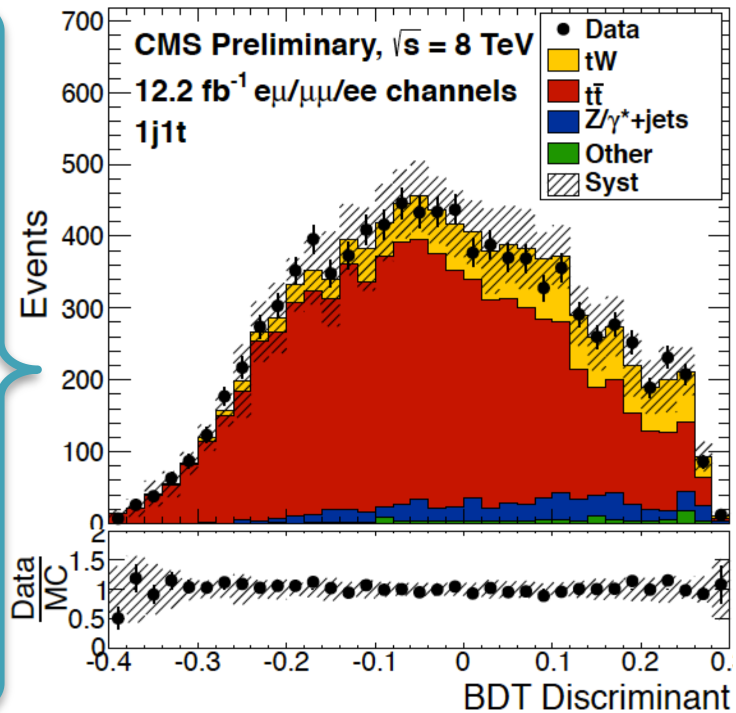
tW observation, 8TeV

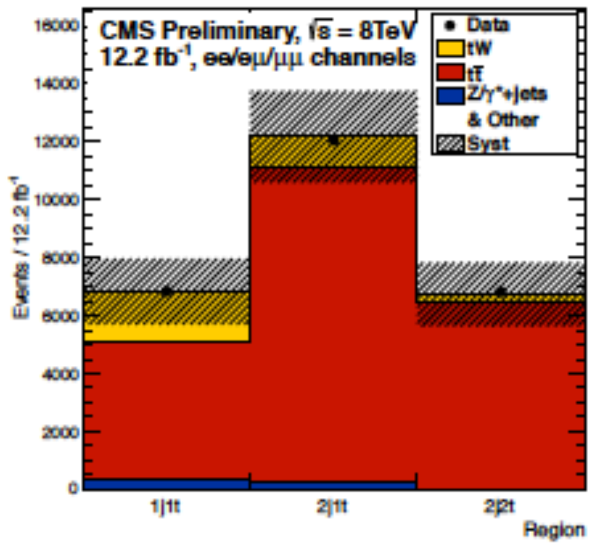


- Very similar selection
- Different BDT training strategy (13 variables)
- **8 TeV**, 12.2 fb^{-1}:

σ_{tW}= 23.4 $^{+5.5}_{-5.4}$ pb (observation at 6σ) [TOP-12-040]
$\sigma_{tW.}^{SM}$ = 22.2pb







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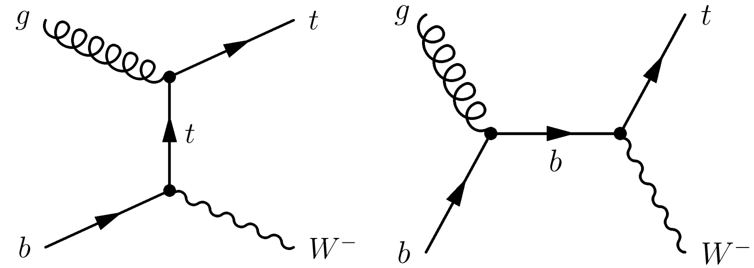
Systematics



- Theory modeling contribute the largest uncertainties: ME/PS matching, ren./fact. scale

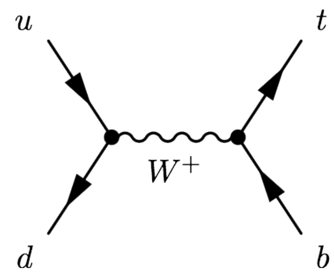
8 TeV analysis

Systematic Uncertainty	$\Delta\sigma$ (pb)	$\frac{\Delta\sigma}{\sigma}$
ME/PS matching thresholds	3.25	14%
Q^2 scale	2.68	11%
Top quark mass	2.28	10%
Statistical	2.13	9%
Luminosity	1.13	5%
JES	0.91	4%
$t\bar{t}$ cross section	0.87	4%
Z+jet data/MC scale factor	0.56	2%
tW DR/DS scheme	0.45	2%
PDF	0.33	1%
Lepton identification	0.31	1%
JER	0.27	1%
B-tagging data/MC scale factor	0.20	$<1\%$
$t\bar{t}$ Spin Correlations	0.12	$<1\%$
Top Pt Reweighting	0.12	$<1\%$
Event pile up	0.11	$<1\%$
E_T^{miss} modeling	0.07	$<1\%$
Lepton energy scale	0.02	$<1\%$
Total	5.58	24%

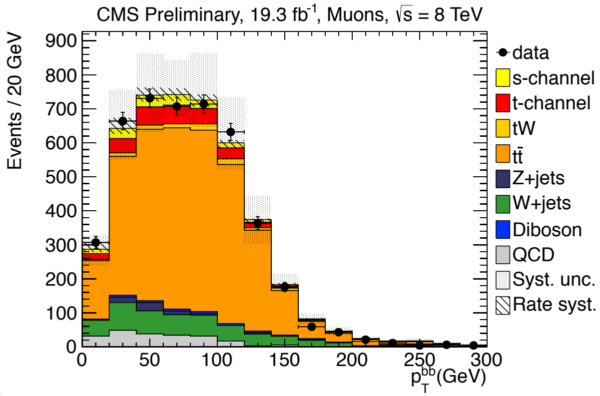
Could be dropped as uncertainty: report the cross section at a given mass, and quote the slope.

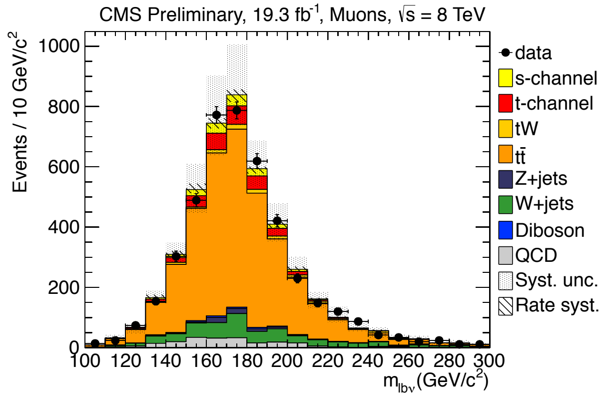
Ongoing discussion with ATLAS for the combination.

s channel



- Most unfavorable cross section and signal/background
- Signal determined using a multivariate approach to increase sensitivity (BDT, 10/11 variables for μ/e)
- Data/simulation agreement was checked for each variable





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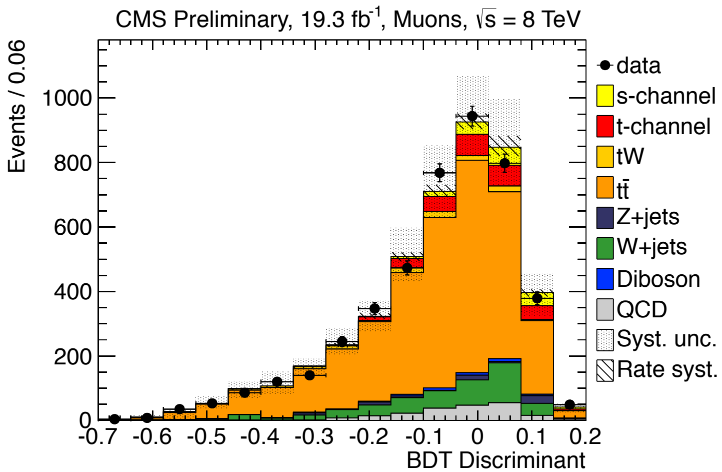
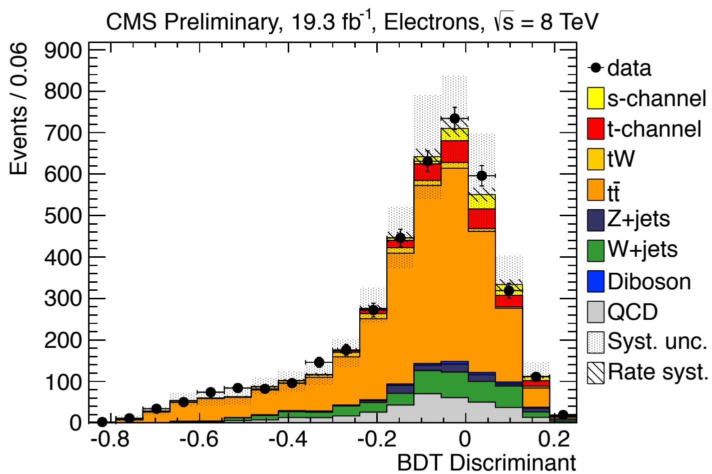
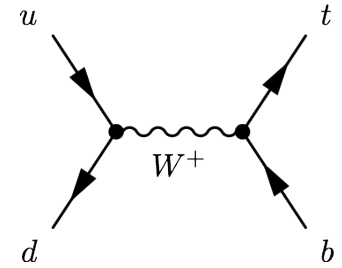




s channel results



- First CMS result approved by PASCOS (**8 TeV**, 19.3 fb^{-1})
- Upper limit: $\sigma_{s\text{-ch.}}$ < 2.1 × SM cross section [TOP-13-009]

exp. w/ signal, exp. w/o signal

$$\sigma_{s\text{-ch.}} < 12.4 \quad (18.4, \quad 10.5)\ \text{pb} \quad \text{muon channel}$$
$$\sigma_{s\text{-ch.}} < 14.7 \quad (23.2, \quad 15.4)\ \text{pb} \quad \text{electron channel}$$
$$\sigma_{s\text{-ch.}} < 11.5 \quad (17.0, \quad 9.0)\ \text{pb} \quad \text{combined}$$

- Sensitivity still limited (0.9σ exp, 0.7σ obs), mainly by theory systematics
- Keeping under control uncertainties like renorm./factor scale (83%!!) would reduce dramatically the uncertainty (➪ TOPLHCWG)
- Cross section determined anyway from fit to data yield ($\sigma_{s\text{-ch.}}^{SM}$ = 5.6pb):

$$\sigma_{s\text{-ch.}} = 5.9 \pm 7.1(\text{exp.}) \pm 5.0(\text{th.})$$
$$\sigma_{s\text{-ch.}} = 6.9 \pm 5.6(\text{exp.}) \pm 6.5(\text{th.})$$
$$\sigma_{s\text{-ch.}} = 6.2 \pm 5.4(\text{exp.}) \pm 5.9(\text{th.})$$

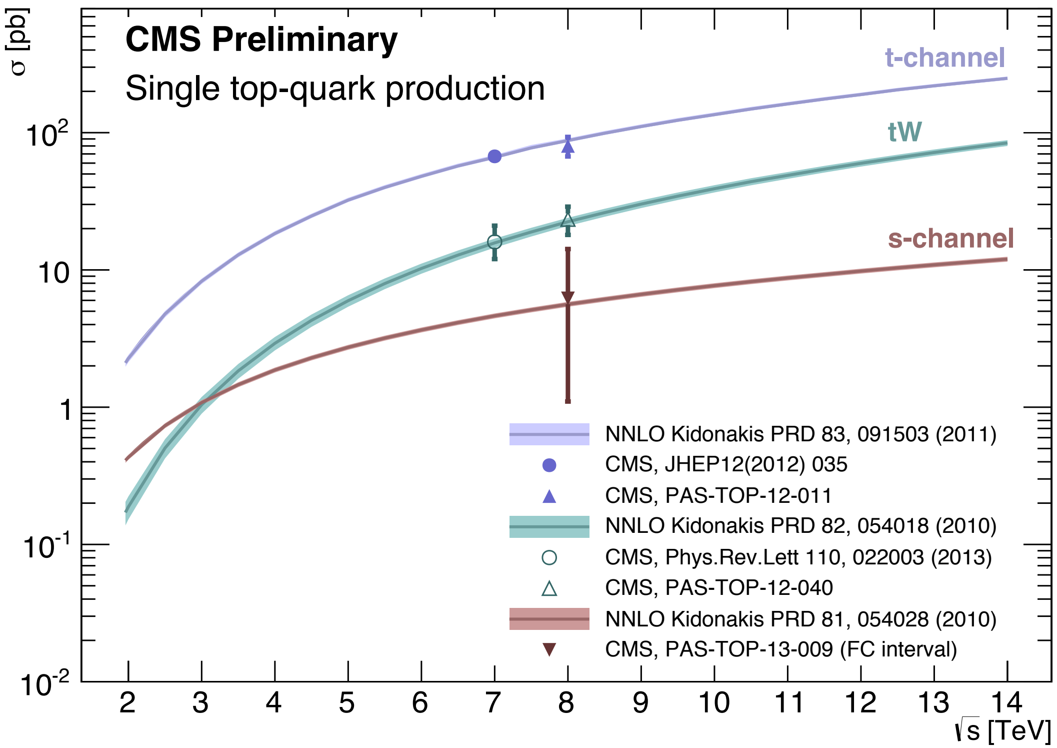
Feldman-Cousins

$$\sigma_{s\text{-ch.}} = 5.9^{+8.6}_{-5.1}\ \text{pb} \quad \text{muon channel}$$
$$\sigma_{s\text{-ch.}} = 6.9^{+8.7}_{-5.7}\ \text{pb} \quad \text{electron channel}$$
$$\sigma_{s\text{-ch.}} = 6.2^{+8.0}_{-5.1}\ \text{pb} \quad \text{combined}$$

- The analysis at 7 TeV is interesting: the better S/B ratio may compensate the smaller data sample
  - ATLAS limit available at 7 TeV, 0.70 fb^{-1}: $\sigma_{s\text{-ch.}}$ < 26.5pb = 5.7 × SM cross section [ATLAS-CONF-2011-118]

Cross section summary

- t channel and tW measured at 7 and 8 TeV
  - t channel reached 16% precision, 14% if combined with ATLAS
- s channel, upper limit at 8 TeV
  - Fit from data allows to determine the cross section, yet with poor precision so far



$|V_{tb}|$ from single top

- $|V_{tb}|$ from cross section: determined assuming $B(t\to Wb)\cong 1$

$$|V_{tb} f_{L_V}| = \sqrt{\frac{\sigma_{t\text{-ch.}}}{\sigma^{th}_{t\text{-ch.}}}}$$

f_{L_V} =1 in the SM; $\sigma^{th}_{t\text{-ch.}}$: $|V_{tb}|$=1 assumed

  - 7 TeV: $|V_{tb}| = 1.020 \pm 0.046(exp) \pm 0.017(th)$ (t-ch. 4.8%)
    $|V_{tb}| = 1.01^{+0.16}_{-0.13}(exp)^{+0.03}_{-0.04}(th)$ (tW-ch., 14.8%)
  - 8 TeV: $|V_{tb}| = 0.96 \pm 0.08(exp) \pm 0.02(th)$ (t-ch. 8.6%)
    $|V_{tb}| = 1.03 \pm 0.12(exp) \pm 0.04(th)$ (tW-ch. 12.3%)

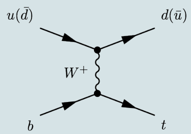
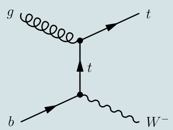
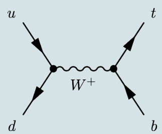
- As comparison, from $B(t\to Wb)/B(t\to Wq)$ in tt~:

  $|V_{tb}|=1.011^{+0.018}_{-0.017}$ (stat.+syst) (tt~ 1.7%) [TOP-12-035]

- By dropping the $B(t\to Wb)=1$ assumption single top may reach competitive precision with tt~: $|V_{tb}| \sim (\sigma_{t\text{-ch.}}/\sigma_{t\text{-ch.}}^{th})^{1/4}$

- Corrections from $|V_{ts}|$, $|V_{td}|$ terms should be applied properly
  - Work in progress: may be a topic for the TOPLHCWG

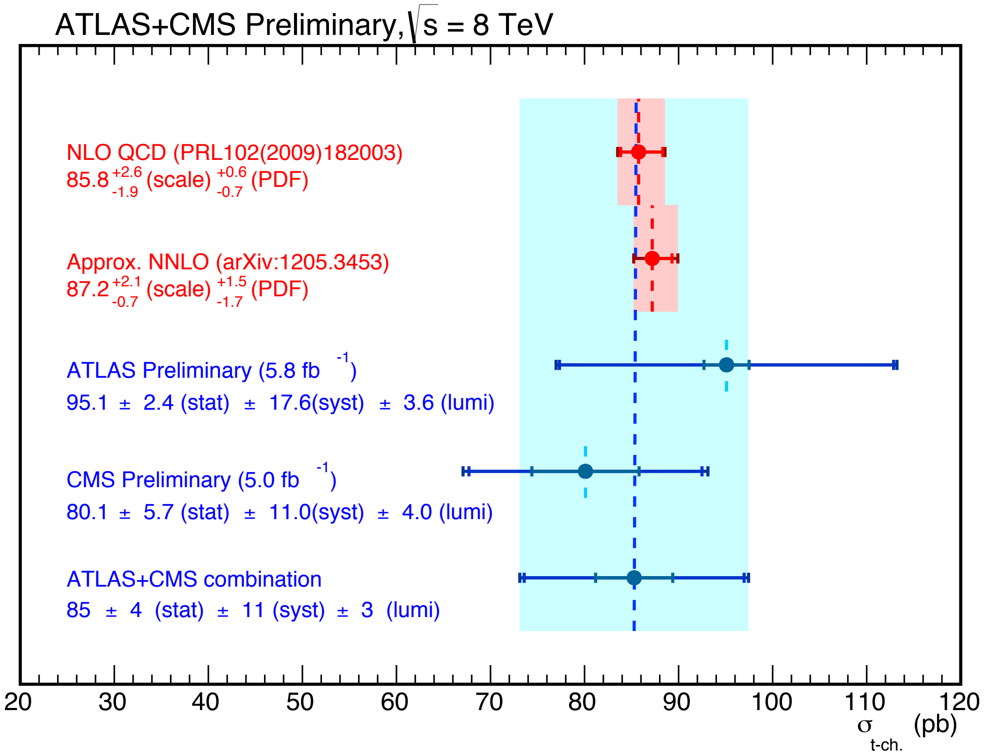
How does CMS compare to ATLAS?

		ATLAS	CMS
t channel 	7 TeV	$\sigma_{t\text{-ch.}}$ = 83±4(stat) $^{+20}_{-19}$(syst) pb = 83 ± 20 pb (24%)	67.2±3.7(stat)±3.0(syst)±3.5(th)±1.5(lumi) pb = 67.2 ± 6.1pb (9.1%)
		$R_{t/t\sim}$ = 1.81±0.10(stat)$^{+0.21}_{-0.20}$(syst) = 1.81$^{+0.23}_{-0.22}$ (12%)	-
	8 TeV	$\sigma_{t\text{-ch.}}$ = 95.1±2.4(stat)±18.0(syst) pb = 95.1 ± 18.1 pb (19%)	$\sigma_{t\text{-ch.}}$ = 80.1±5.7(stat)±11.0(syst)±4.0(lumi) pb = 80.1±13.0 (16%)
		-	$R_{t/t\sim}$ = 1.76±0.15(stat)±0.22(syst) =1.76 ± 0.27 (15%)
tW channel 	7 TeV	σ_{tW} = 16.8 ± 2.9 (stat) ± 4.9 (syst) pb = 16.8 ± 5.7 pb (34%)	σ_{tW} =16$^{+5}_{-4}$ pb (28%)
	8 TeV	σ_{tW} = 27.2±2.8(stat)±5.4(syst) pb = 27.2 ± 6.1 pb (22%)	σ_{tW} = 23.4$^{+5.5}_{-5.4}$ pb (23%)
s channel 	7 TeV	$\sigma_{s\text{-ch.}}$ < 26.5 pb at 95%CL (= 5.7 × SM cross section)	-
	8 TeV	-	$\sigma_{s\text{-ch.}}$ < 11.5pb at 95%CL (= 2.1 × SM cross section)

- Main differences (could evolve in future publications):
  - ATLS has a more conservative approach to theory systematics
  - Some instrumental systematics better under control by CMS (e.g.: b tagging)

Combination with ATLAS

- First single-top combination approved by both collaborations, within the TOPLHCWG
  - $\sigma_{t\text{-ch.}}$ @8 TeV = 85±4(stat)±11(syst)±3(lumi) pb = 85±12 pb
  - Combination @7 TeV dominated by CMS, not approved by ATLAS



[TOP-12-002]

19%

16%

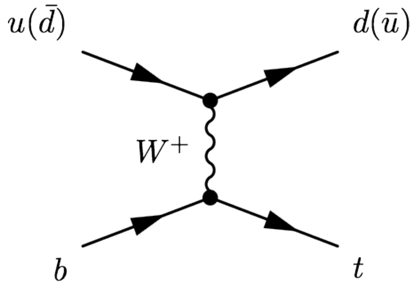
14%

TOPLHCWG single-top items

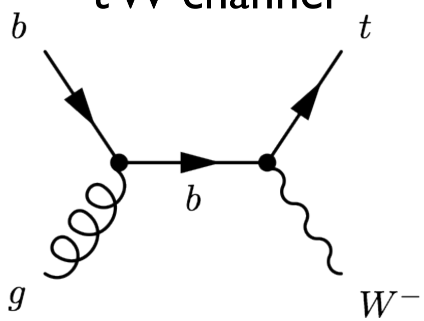
- Ongoing generator studies aiming at attacking theory systematics
  - Goals: move towards common theory systematic treatment in ATLAS and CMS, avoid too "conservative" (=overestimated) uncertainties and move towards the precision regime
  - Using aMC@NLO as new benchmark
  - Generator comparison was performed by Dominic Hirschbühl (ATLAS), non approved for the TOPLHCWG open session in November
- Next steps:
  - Combine tW associated production, work just started
  - Consider possible combination of $|V_{tb}|$, so far dominated by CMS measurement at 7 TeV
  - $R_{t/t\sim}$ measured at different $\sqrt{s}$ so far by ATLAS and CMS
  - s-channel: upper limits only, and at different $\sqrt{s}$

Prospects for run-II

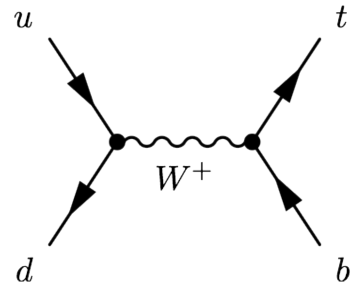
t channel



tW channel



s channel

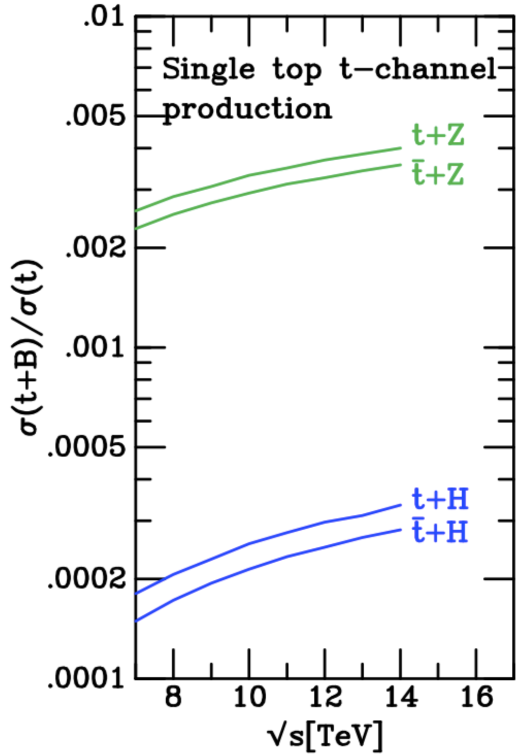


	t ch.	tW ch.	s ch.	tt~
7 TeV	64.6pb	15.6pb	4.59pb	172.0pb
8 TeV	87.6pb	22.2pb	5.55pb	245.8pb
14 TeV	248.1pb (×3.2)	84.8pb (×3.8)	11.86pb (×2.1)	953.6pb (×3.9)

- Life won't be easy: the present data sample has the most favorable signal-to-background ratio
  - tt~ background will increase more than single-top (gg fusion)
  - W+jets not expected to increase more (gq contribution mainly, then q~q')
- We need to use statistics in order to beat the larger background
- The s channel, in particular, will become challenging

Run II: a possible plan

- Plan for the very first data (first on fb^{-1}):
  - Measure the t channel cross section at 14 TeV ("rediscovery"), including charge ratio
  - Study top polarization and differential distributions check the agreement with the Standard Model
  - Look for deviations for SM: FCNC (tZ, tγ)
  - Measure the top mass in single-top events
    - Should be done also at 7, 8 TeV!
- With more data (10 fb^{-1}):
  - Rediscover tW
  - Look for SM tZ, few % of t channel
- With even more data
  - Try again with the s channel
    may require hundreds of fb^{-1}!



Conclusions (i)

- Single-top processes have been measured in the three channel t, s and tW
  - Systematics due to signal modeling being revised in agreement with ATLAS with feedback from the theory community
- The t channel sample offers the opportunity to perform differential studies
  - Top polarization, W helicity, more to come
  - With run-II data the larger data sample will allow better precision

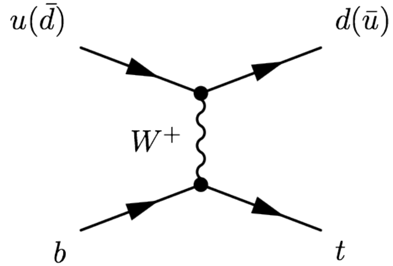
Conclusions (ii)

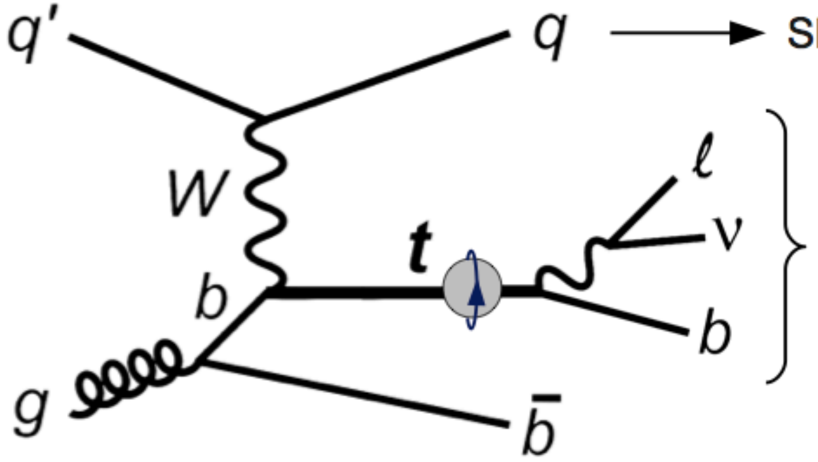
- tW has been observed, though the background contamination is high
  - Probably hard to extract differential distributions, due to the large background
- s channel is tough, we need to attack theory systematics and add 7 TeV data to gain in significance
- Run II will open the way to a larger data sample at the cost of a larger tt~ background, that will make some measurements challenging, in particular the s channel

Backup

- The following material will be covered by other talks is here just as reference

Differential measurements and top polarization





SM: top ~100% polarized along light quark

Wtb coupling structure encoded in kinematics of decay products (SM: V-A coupling structure)

- Selection very similar to cross section measurement
- Extract distribution of angle between light quark & lepton in the top-quark rest frame:

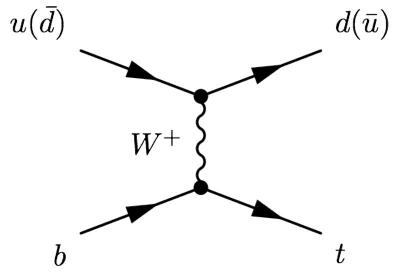
$$\cos\theta^* = \frac{\vec{p}^{\,*}_{\ell} \cdot \vec{p}^{\,*}_{\ell q}}{|\vec{p}^{\,*}_{\ell}| \cdot |\vec{p}^{\,*}_{\ell q}|}$$

- Determine the asymmetry

$$A = \frac{N(\cos\theta^* > 0) - N(\cos\theta^* < 0)}{N(\cos\theta^* > 0) + N(\cos\theta^* < 0)}$$

- Probe coupling structure

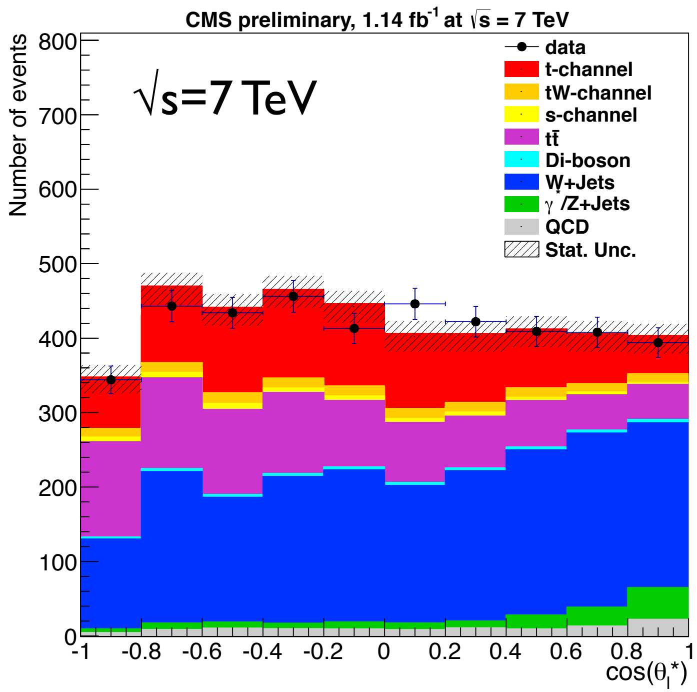
W helicity

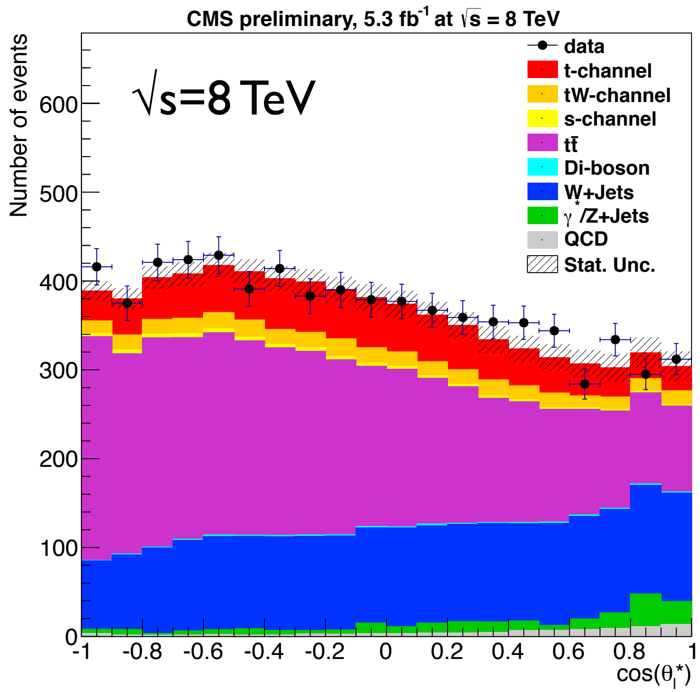


- W helicity from top decay studied from $\cos\theta^*_l$ [†] distribution
  [†] θ^*_l = angle between lepton in W rest frame and the W in top rest frame.

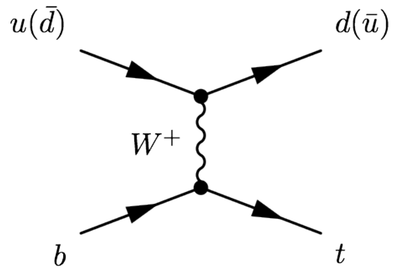
$$\rho(\cos\theta^*_\ell) = \frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta^*_\ell} = \frac{3}{8}(1+\cos\theta^*_\ell)^2 F_R + \frac{3}{8}(1-\cos\theta^*_\ell)^2 F_L + \frac{3}{4}\sin^2{}^*_\ell F_0$$

- Single-top selection provides a sample enriched in single-top event, where the tt~ fraction is anyway sizable, in particular at 8 TeV
- Orthogonal selection w.r.t. W helicity analysis in tt~, suitable for a possible combination





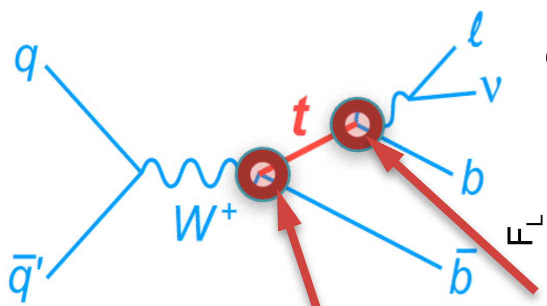
W helicity



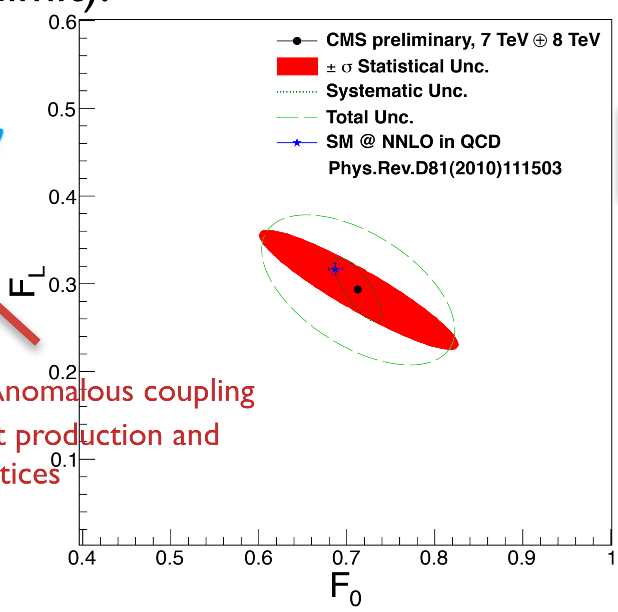
- Preliminary result with **7+8 TeV** (1.14fb^{-1} + 5.3fb^{-1}, μ only) [TOP-12-020]:
  - $F_L = 0.293 \pm 0.069(\text{stat}) \pm 0.030(\text{syst})$
  - $F_0 = 0.713 \pm 0.114(\text{stat}) \pm 0.023(\text{syst})$
  - $F_R = -0.006 \pm 0.057(\text{stat}) \pm 0.027(\text{syst})$
- Limits set on anomalous tWb couplings

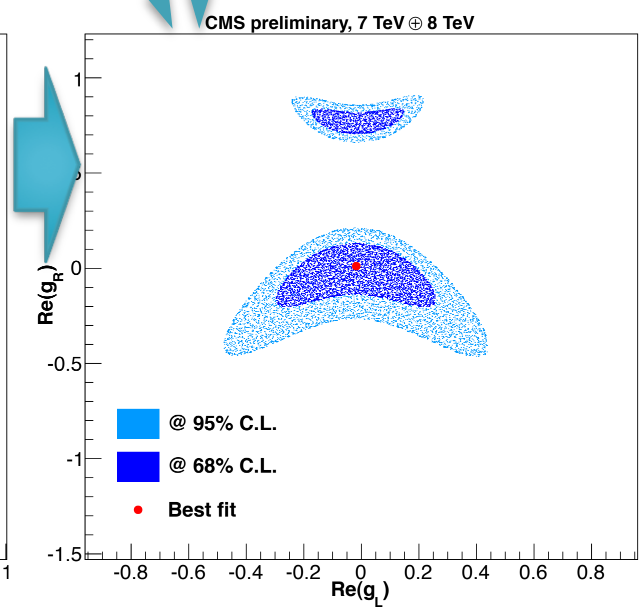
$$\mathcal{L}_{tWb}^{anom.} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}(g_L P_L + g_R P_R)tW_{\mu}^{-} + H.C,$$

- Anomalous coupling at production vertex not taken into account explicitly in the analysis method, but effects on the measurement determined with dedicated simulated samples: null (V_R=0) or negligible bias, if V_L = 1 and $|V_R|^2 < 0.3$ (D0 limit).



Anomalous coupling both at production and decay vertices



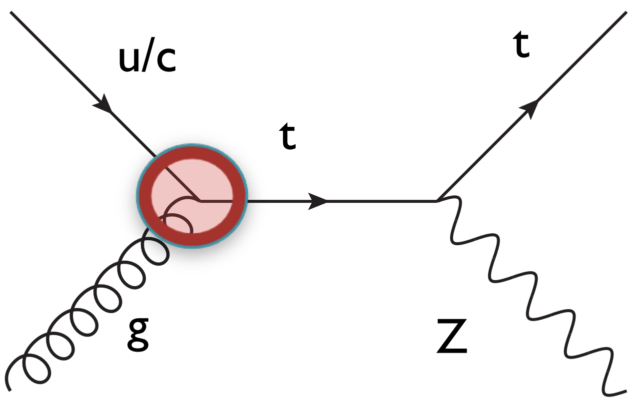


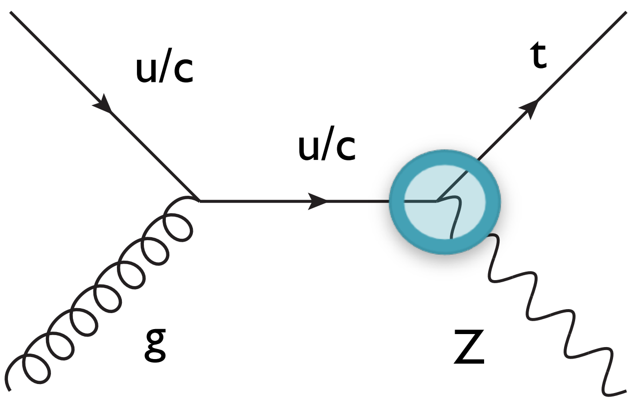
FCNC in single top

- tZ production via 2 types of anomalous couplings [arXiv:1304.5551]
- Signature: 3 leptons + 1 b tab + ME_T

$$\mathcal{L} = \sum_{q=u,c} \left[\sqrt{2} g_s \frac{\kappa_{gqt}}{\Lambda} \bar{t} \sigma^{\mu\nu} T_a (f_q^L P_L + f_q^R P_R) q \, G^a_{\mu\nu} \right. \quad \text{gut, gct}$$

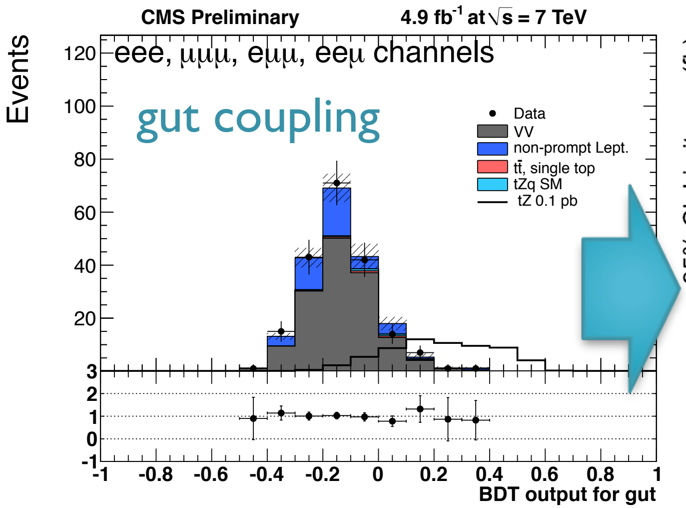
$$\left. + \frac{g}{\sqrt{2} c_W} \frac{\kappa_{Zqt}}{\Lambda} \bar{t} \sigma^{\mu\nu} (\hat{f}_q^L P_L + \hat{f}_q^R P_R) q \, Z_{\mu\nu} \right] + \text{h.c.} \quad \text{Zut, Zct}$$

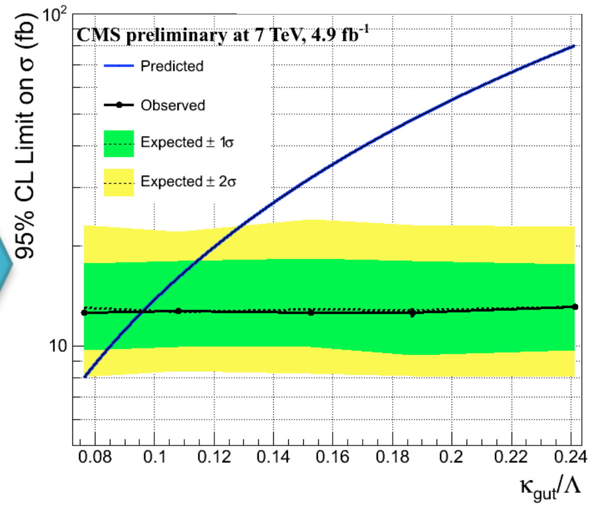




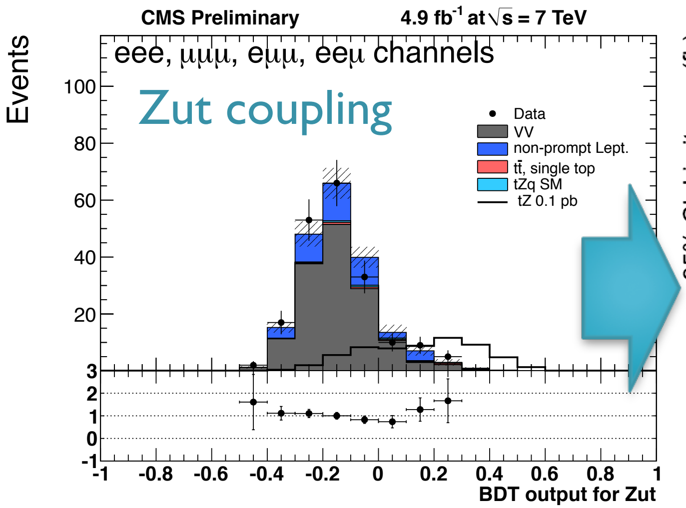
New physics with single top!

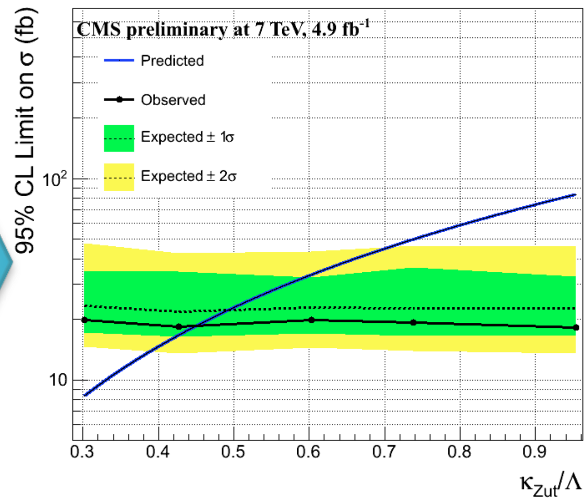
- Limits set to coupling strength (7 TeV with $5 fb^{-1}$) [TOP-12-021]
- Limit to FCNC branching ratio using: $Br(t \to gq/Zq) = \frac{\Gamma_{t\to gq/t\to Zq}}{\Gamma_{t\to gq/t\to Zq} + \Gamma_{top}}$





$\kappa_{gut}/\Lambda < 0.10\ TeV^{-1}$
$\kappa_{gct}/\Lambda < 0.35\ TeV^{-1}$
$\kappa_{Zut}/\Lambda < 0.45\ TeV^{-1}$
$\kappa_{Zct}/\Lambda < 2.27\ TeV^{-1}$





$B(t\to gu) < 0.56\%$
$B(t\to gc) < 7.12\%$
$B(t\to Zu) < 0.51\%$
$B(t\to Zc) < 11.40\%$
(95% CL)