



Single top quark studies with the CMS detector

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for the CMS collaboration

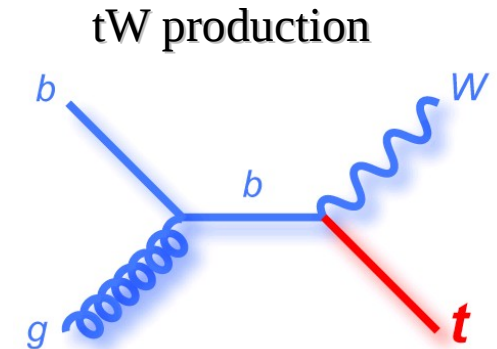
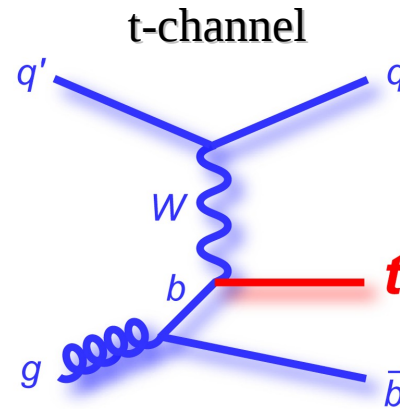
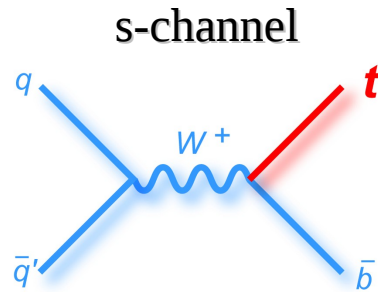
ICSSNP2013
06 November 2013

Outline

- Single top processes and motivation
- Cross section measurements
 - t-channel
 - tW-channel
- Charge asymmetry
- W-helicity measurement
- Top quark polarization
- Summary

Single top

Single top quark production:



LHC @ 7 TeV

4.56 pb

65.9 pb

15.6 pb

LHC @ 8 TeV

5.55 pb

87.2 pb

22.2 pb

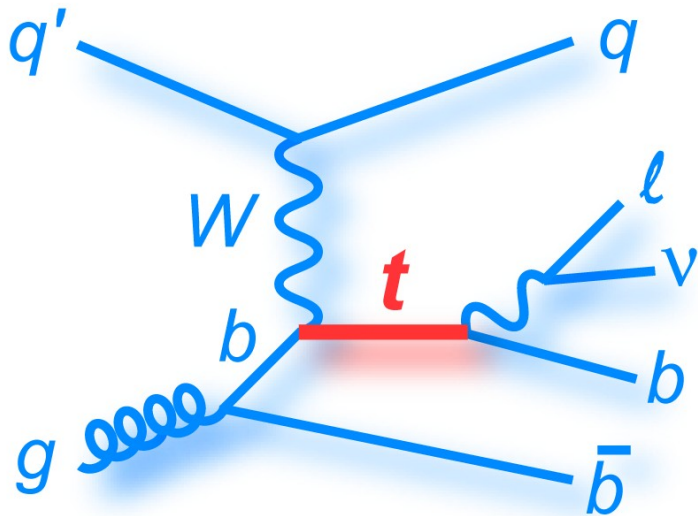
N. Kidonakis

Single top features:

- Cross section proportional to $|V_{tb}|^2 \Rightarrow$ allows direct measurement
- Wtb vertex enables tests of V–A structure
- Test of b-quark structure function, u and d PDF and ratio
- Sensitive to new physics, e.g. anomalous couplings, 4th generation, W' , H^+

t-channel cross section

Signature:



Light jet with high pseudorapidity

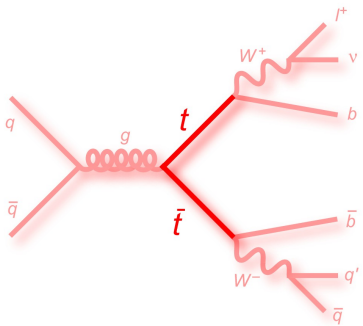
Lepton (muon or electron)

Missing transverse energy

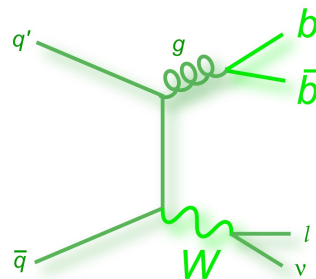
b-jet with high p_T

Additional b-jet with lower p_T

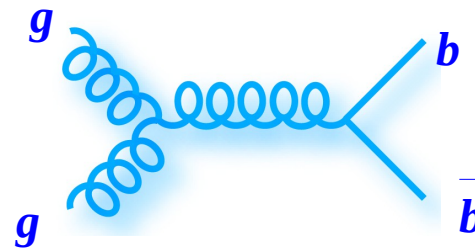
Main backgrounds:



top pairs



W+jets



QCD

t-channel cross section: 7 TeV

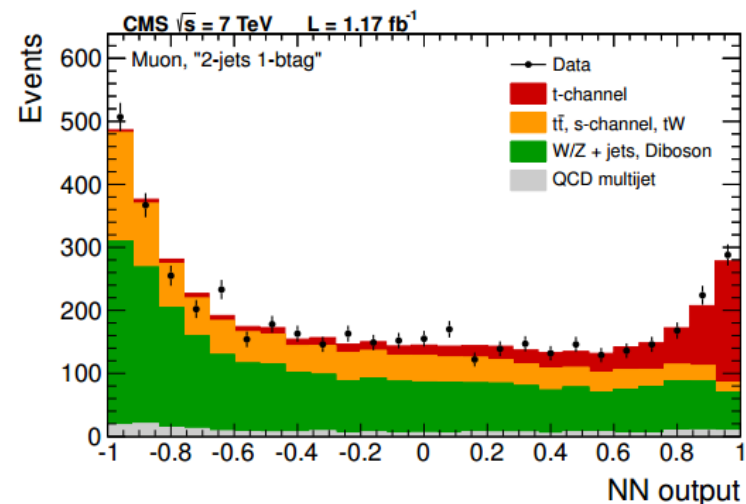
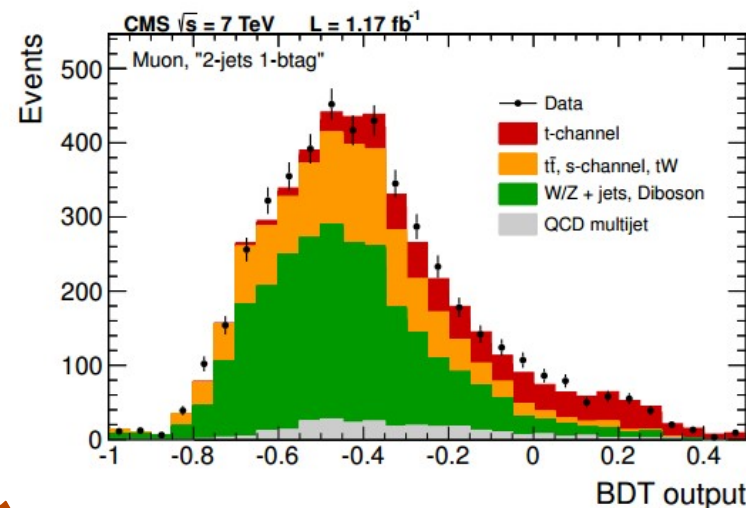
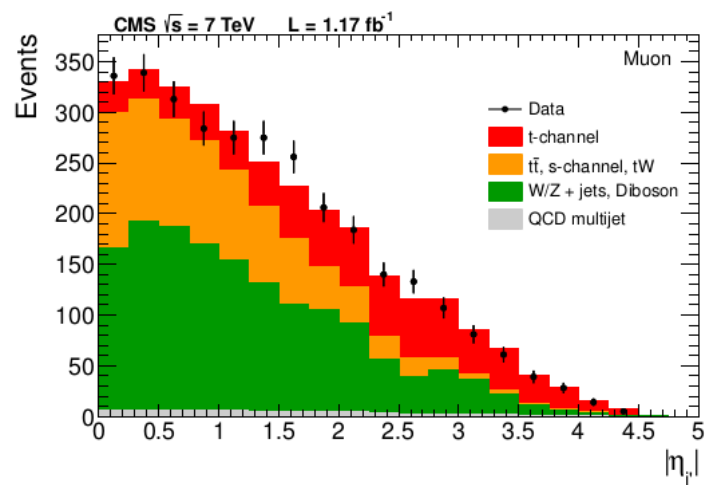
Three analyses provided with $1.17 / 1.56 \text{ fb}^{-1}$ (muon / electron) of Data

Multivariate analyses

use multivariate methods (BDT, NN) to obtain a powerful discriminator between signal and background

$|\eta_j|$ analysis

likelihood fit to pseudorapidity of light jet



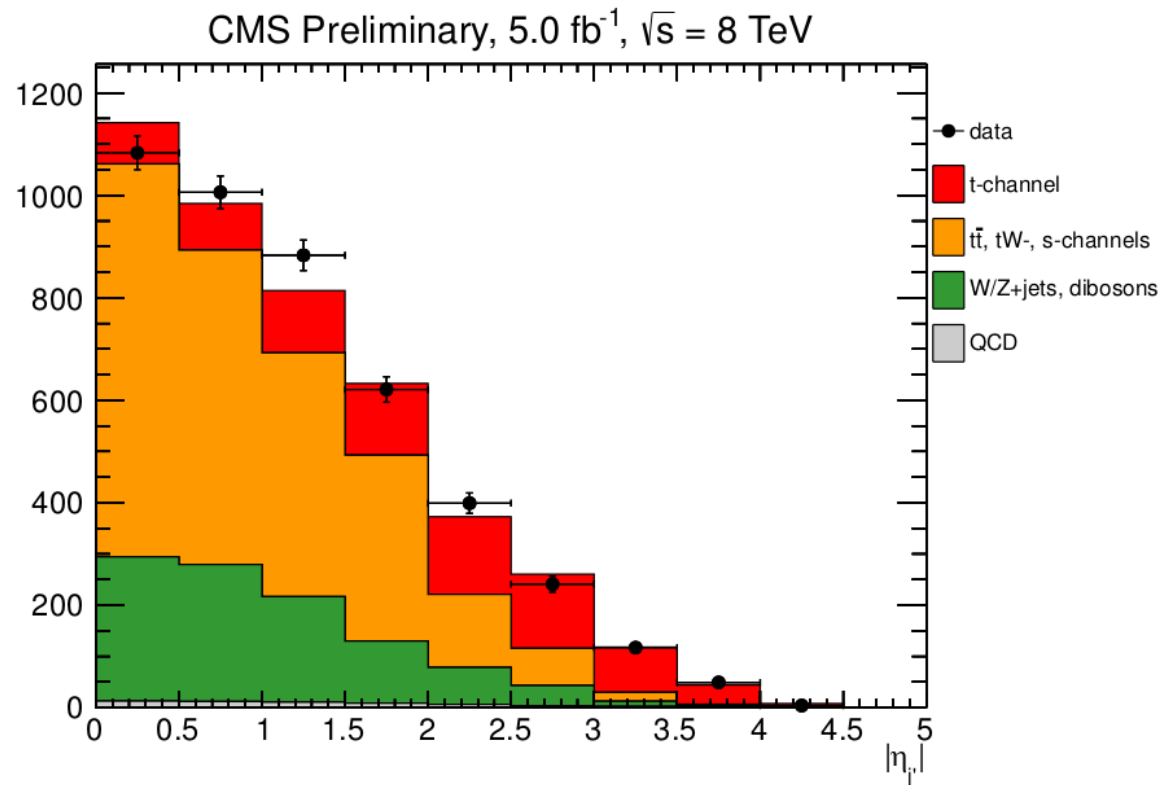
Combination:

$$\sigma_{t\text{-ch.}} = 67.2 \pm 6.1 \text{ pb} = 67.2 \pm 3.7 \text{ (stat.)} \pm 3.0 \text{ (syst.)} \pm 3.5 \text{ (theor.)} \pm 1.5 \text{ (lum.)} \text{ pb}$$

t-channel cross section: 8 TeV

$|\eta_j|$ analysis: the same strategy as for 7 TeV

Provided with 5.0 fb⁻¹ of Data (muon channel)



Result:

$$\sigma_{t\text{-ch.}} = 80.1 \pm 5.7(\text{stat.}) \pm 11.0(\text{syst.}) \pm 4.0(\text{lumi.}) \text{ pb}$$

t-channel cross-section

Cross sections:

7 TeV: $\sigma_{t\text{-ch.}} = 67.2 \pm 6.1 \text{ pb} = 67.2 \pm 3.7 \text{ (stat.)} \pm 3.0 \text{ (syst.)} \pm 3.5 \text{ (theor.)} \pm 1.5 \text{ (lum.) pb}$

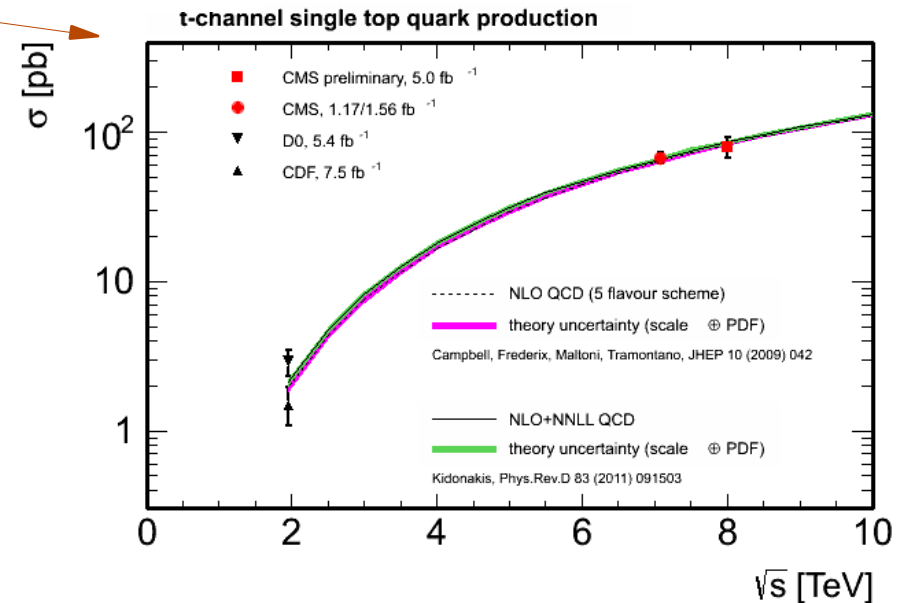
8 TeV: $\sigma_{t\text{-ch.}} = 80.1 \pm 5.7 \text{ (stat.)} \pm 11.0 \text{ (syst.)} \pm 4.0 \text{ (lumi.) pb}$

Ratio

cross section (8 TeV) / cross section (7 TeV):

$$R_{8 \text{ TeV} / 7 \text{ TeV}} = 1.14 \pm 0.12 \text{ (stat.)} \pm 0.14 \text{ (syst.)}$$

→ obtained only with $|\eta_j|$ analysis



$|V_{tb}|$ extraction

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

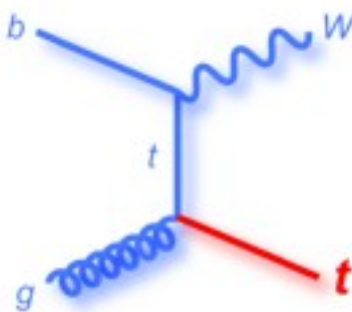
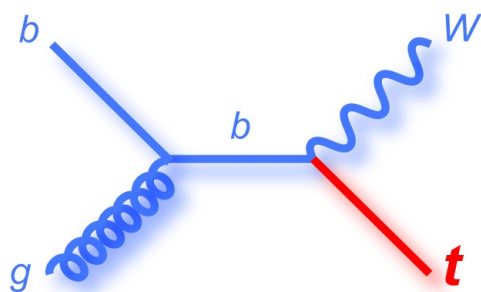
→ calculated with $|V_{tb}|=1$

7 TeV: $|f_{L_V} V_{tb}| = 1.020 \pm 0.046 \text{ (exp.)} \pm 0.017 \text{ (theor.)}$

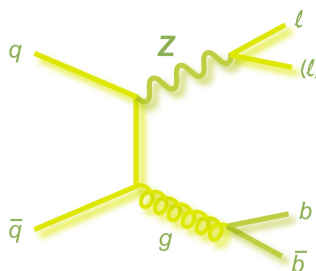
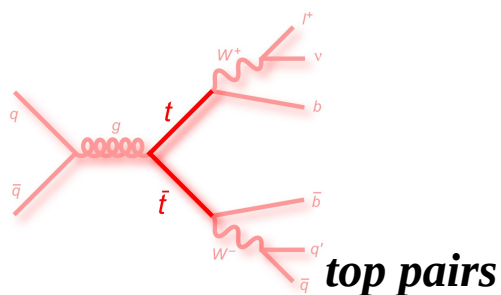
8 TeV: $|f_{L_V} V_{tb}| = 0.96 \pm 0.08 \text{ (exp.)} \pm 0.02 \text{ (theor.)}$

Associated tW production

Signature:



Main backgrounds:



Z+jets

SM predictions:

$$7 \text{ TeV: } \sigma_{tW} = 15.6 \pm 0.4 \pm 1.1 \text{ pb}$$

$$8 \text{ TeV: } \sigma_{tW} = 22.2 \pm 0.6 \pm 1.4 \text{ pb}$$

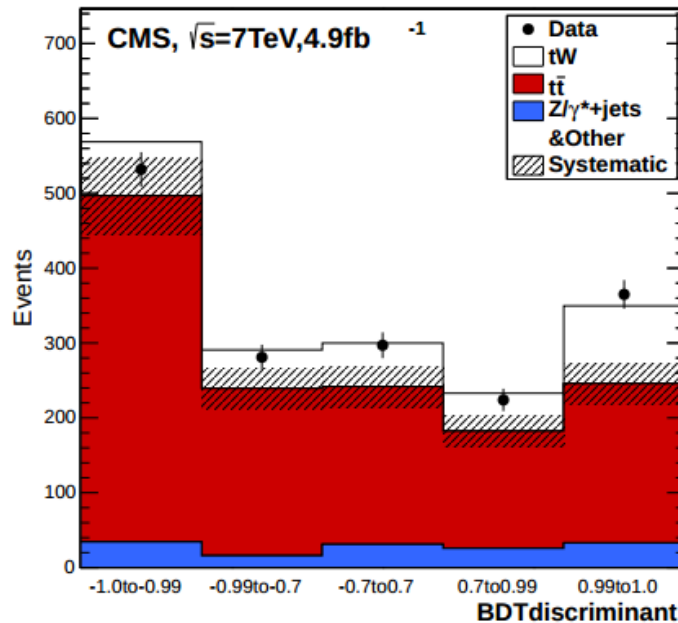
N. Kidonakis:
PRD 82, 054018 (2010)

Associated tW production: 7 TeV

Two analyses provided with 4.9 fb^{-1} of Data

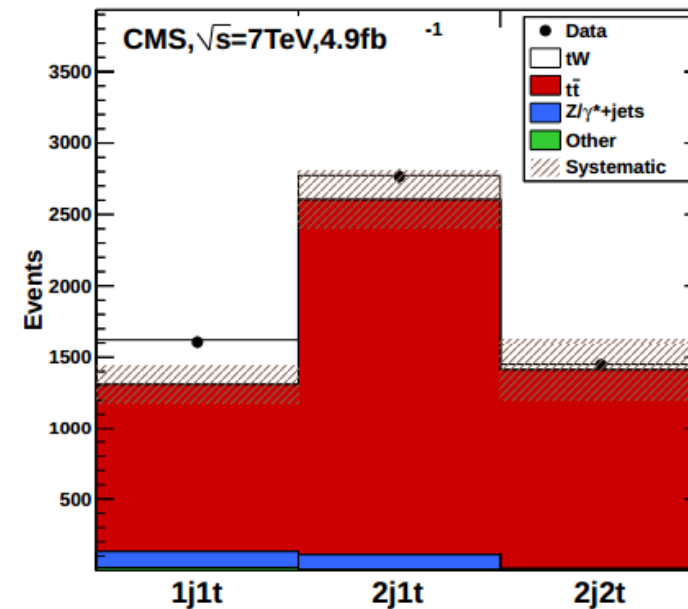
Multivariate analysis

BDT is used to obtain a powerful discriminator between signal and background



Cut-based analysis

as a cross-check



Measured cross-section:

BDT	16 (+5 -4) pb
Cut-based	15 (+-5) pb

Significance:

BDT	4σ
Cut-based	3.5σ

EVIDENCE

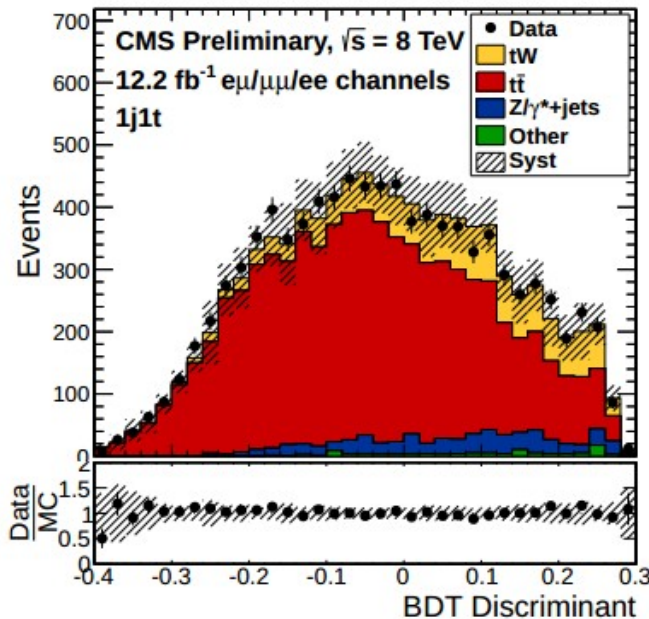
$|V_{tb}|$ extraction: $|V_{tb}| = \sqrt{\frac{\sigma_{tW}}{\sigma_{tW}^{\text{th}}}} = 1.01^{+0.16}_{-0.13}(\text{exp.})^{+0.03}_{-0.04}(\text{th.})$

Associated tW production: 8 TeV

Three analyses provided with 12.2 fb⁻¹ of Data

Multivariate analysis

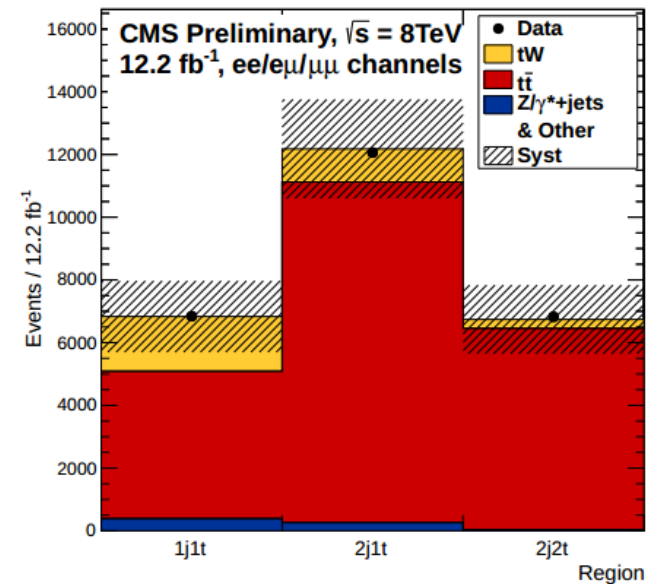
BDT is used to obtain a powerful discriminator between signal and background



Cut-based analysis

Template fit to p_T of the system

as cross-checks



Measured cross-section:

BDT	23.4 (+5.5 -5.4) pb
Cut-based	33.9 (+8.6) pb
Template fit	24.3 (+8.6 -8.8) pb

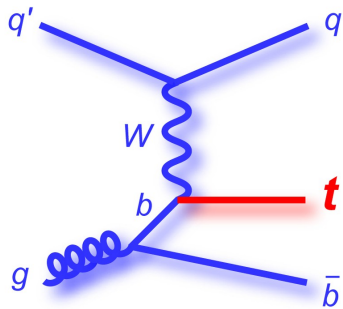
Significance:

BDT	6 σ
Cut-based	3.6 σ
Template fit	4 σ

**FIRST
OBSERVATION**

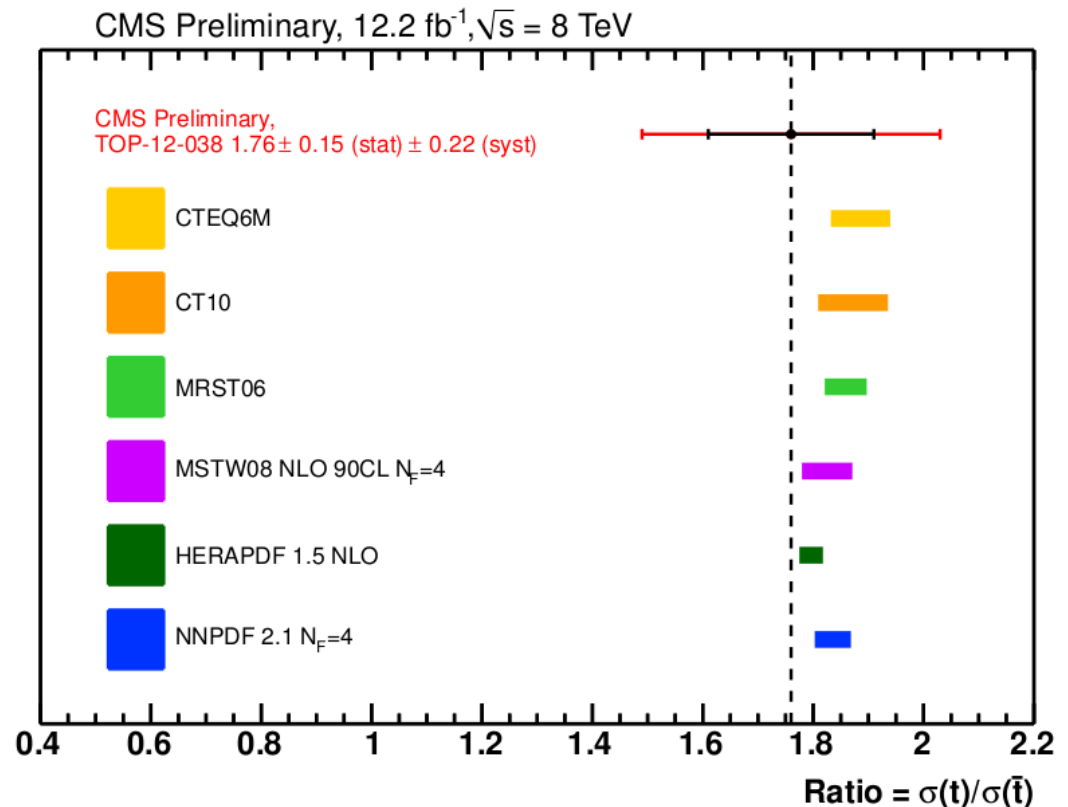
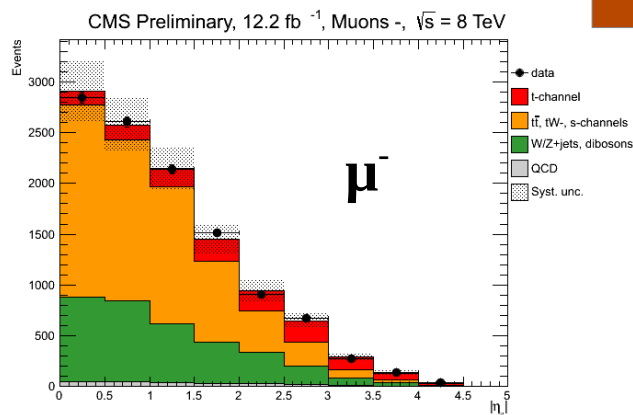
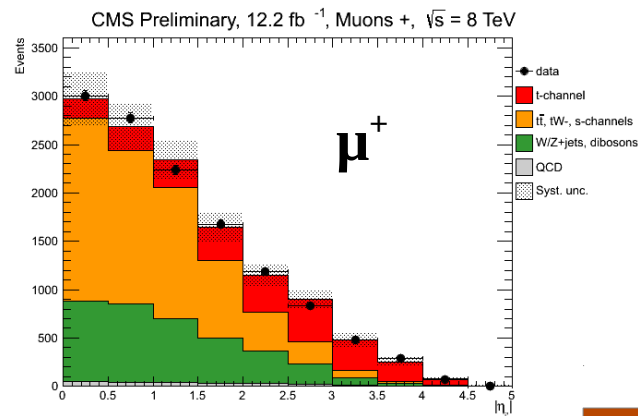
$|V_{tb}|$ extraction: $|V_{tb}| = \sqrt{\frac{\sigma_{tW}}{\sigma_{th}}} = 1.03 \pm 0.12(exp.) \pm 0.04(th.)$

Charge asymmetry: 8 TeV



- The top quark inherits the sign of the charge from the light quark q'
- The cross section ratio depends on light quark PDF, sensitive to new physics (due to Wtb vertex presence)
- An effective handle to constrain different parton distribution function models

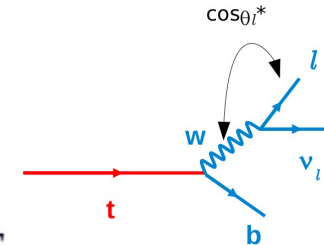
$|\eta_{j,}|$ analysis: template fit to pseudorapidity of the light jet provided with 12.2 fb^{-1} of Data



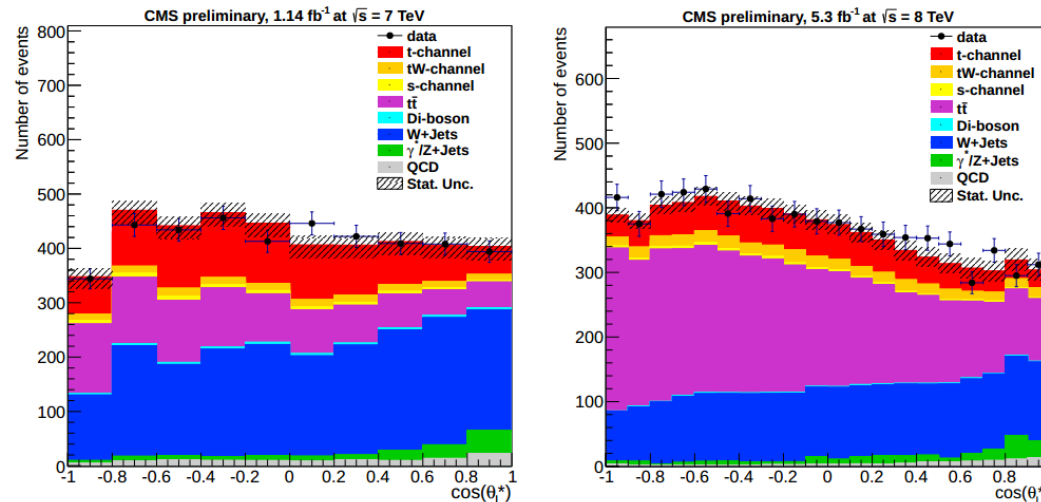
W-helicity measurements

- W boson from top quark decay is polarized
- Fractions are involved in the distribution of $\cos(\theta^*)$

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



The measurement of W-helicity fractions is provided in t-channel for **7 and 8 TeV** with 1.14 fb^{-1} and 5.3 fb^{-1} of Data: *likelihood fit to $\cos(\theta^*)$*



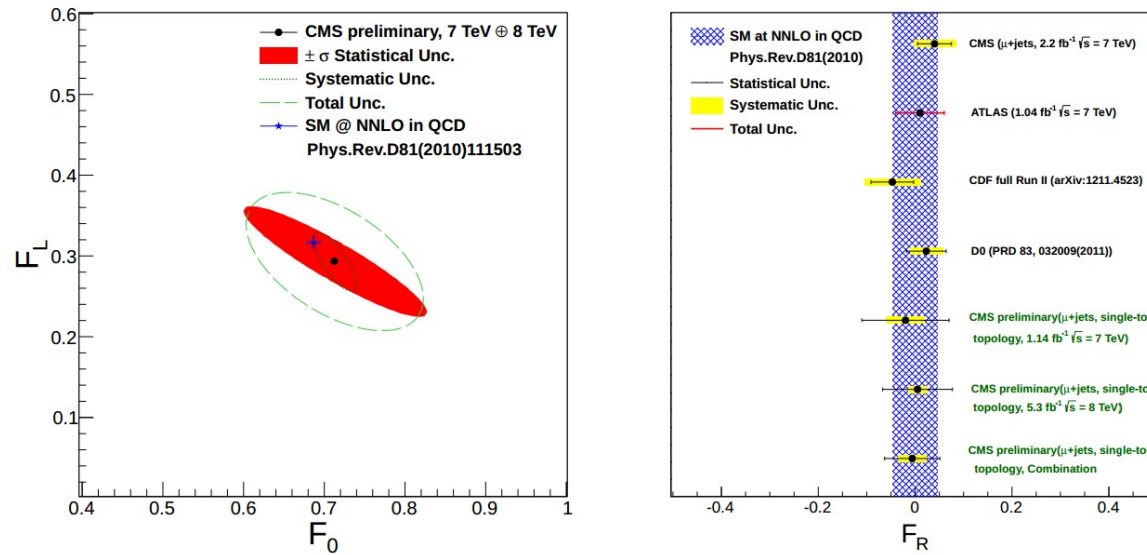
SM prediction: $F_L \approx 0.30$, $F_R \approx 0$, $F_0 \approx 0.70$

Results:

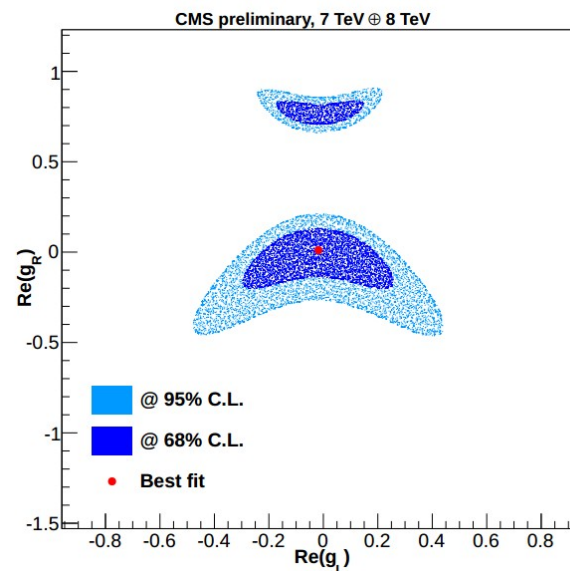
$$\begin{aligned} F_L &= 0.293 \pm 0.069(\text{stat.}) \pm 0.030(\text{syst.}), \\ F_0 &= 0.713 \pm 0.114(\text{stat.}) \pm 0.023(\text{syst.}), \\ F_R &= -0.006 \pm 0.057(\text{stat.}) \pm 0.027(\text{syst.}). \end{aligned}$$

W-helicity measurements

- Results are consistent with SM predictions



- Limits on anomalous tensor couplings from this measurement



Top quark polarization

The measurement is provided for **8 TeV** with 19.7 fb^{-1} of Data:

- In t-channel production the top quark is 100% polarized
- Spin asymmetry:

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

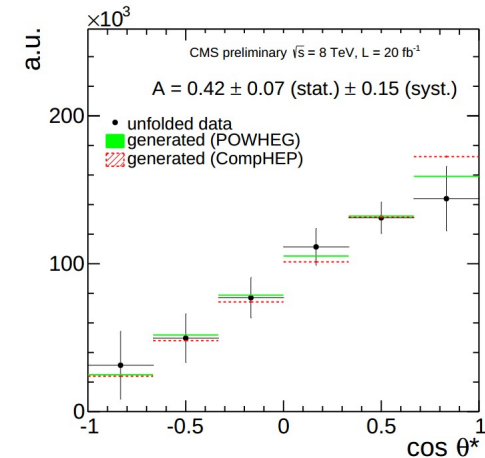
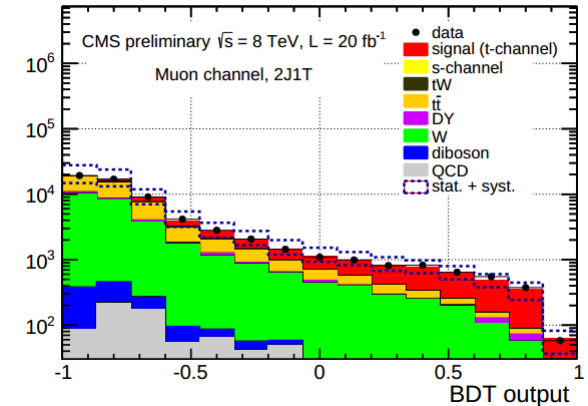
- **likelihood fit to BDT discriminator**
to obtain signal and background yields
- **$\cos(\theta^*)$** (angle between lepton and light quark)
to measure the spin asymmetry

$$A_l = \frac{N(\cos \theta_{unfolding}^* > 0) - N(\cos \theta_{unfolding}^* < 0)}{N(\cos \theta_{unfolding}^* > 0) + N(\cos \theta_{unfolding}^* < 0)}$$

Results:

$$A_l = 0.41 \pm 0.06(stat.) \pm 0.16(syst.) = 0.41 \pm 0.17$$

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



Summary

- The **first measurements** of single top production and properties are published: t-channel and associated tW production cross sections at 7 and 8 TeV, $|V_{tb}|$, charge asymmetry, W helicities, polarization
- The **next round** of analyses are in progress: differential cross sections, top mass and rare s-channel production
- Further searches for **deviations from SM** predictions in single top are in progress