



Study of single top quark production with the CMS detector

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for the CMS collaboration

QFTHEP 2013
25 June

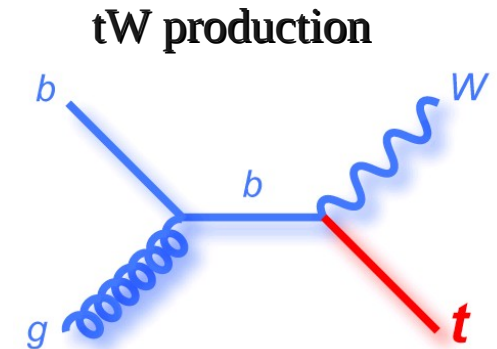
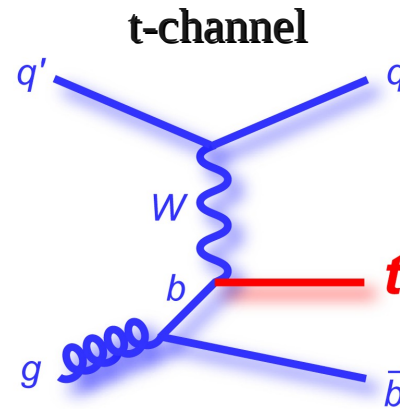
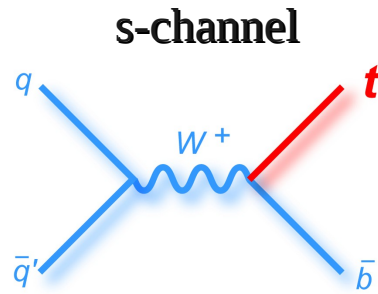
Outline

- **Single top** processes and motivation
- **t-channel** measurements
 - Cross section
 - Charge asymmetry
- Associated **tW** production
- Summary

Single top

Single top quark production:

N. Kidonakis:
 PRD 83, 091503 (2011)
 PRD 81, 054028 (2010)
 PRD 82, 054018 (2010)



LHC @ 7 TeV

4.59 pb

64.57 pb

15.6 pb

LHC @ 8 TeV

5.6 pb

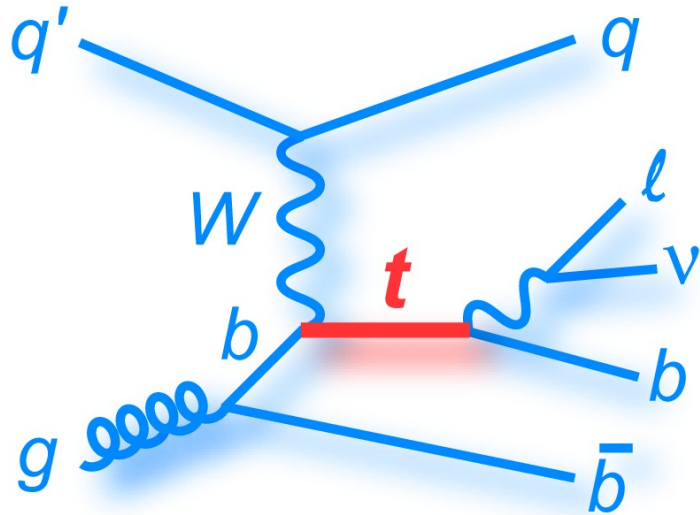
87.8 pb

22.4 pb

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
- Sensitive to new physics, e.g. anomalous couplings, 4th generation, W', H^+

t-channel cross section (7 TeV)

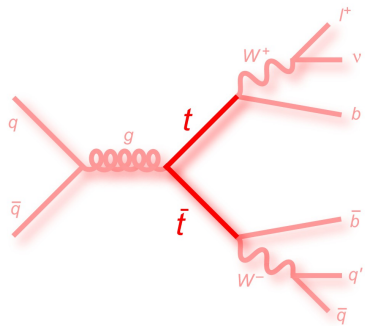


Data: 1.17 / 1.56 fb⁻¹ (muon / electron)

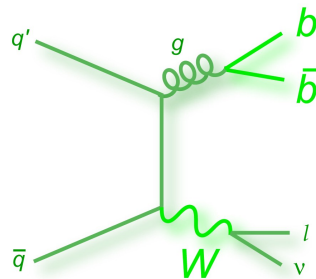
Event selection

- Single isolated **lepton** (muon or **electron**)
 - $p_T > 20$ GeV/c $|\eta| < 2.1$ (muon)
 - $p_T > 30$ GeV/c $|\eta| < 2.5$ (**electron**)
- One central **b-jet** from top decay
- Additional **light-quark jet** often in forward region
- Additional **b-jet** can be present (softer p_T)
- Cut to reduce QCD multijet events:
 - $M_{tW} > 40$ GeV/c² (muon),
 - MET > 35 GeV (**electron**)

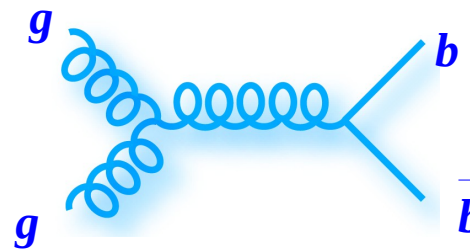
Main backgrounds:



top pair



W+jets

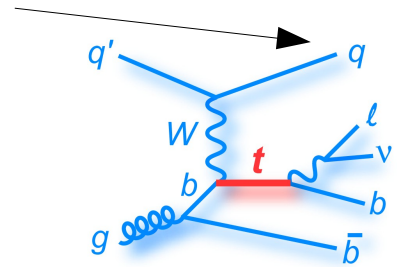


QCD

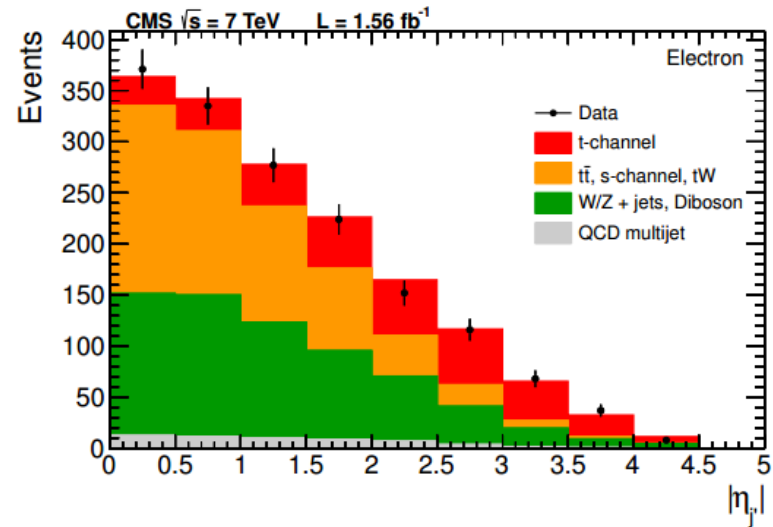
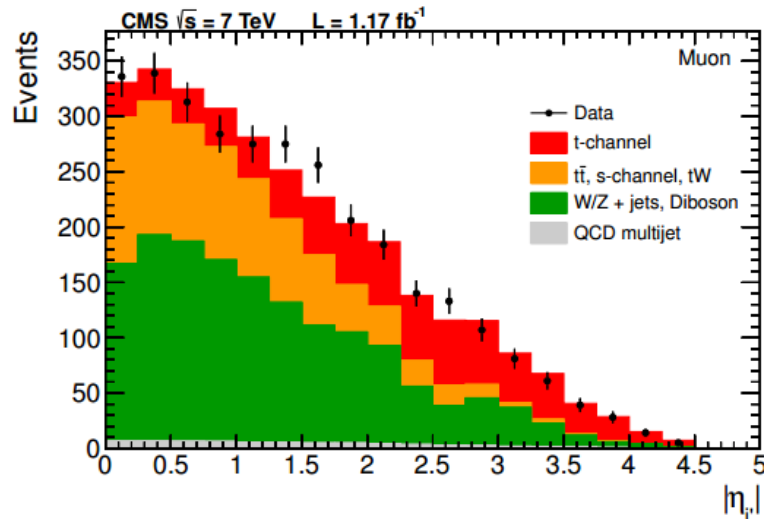
Two approaches: template fit ($|\eta_{j,i}|$ analysis)
multivariate analyses (BDT & NN)

$|\eta_{j,l}|$ analysis: likelihood fit to $|\eta_{j,l}|$ distribution (pseudorapidity of light jet)

- Specific **signal region**: 2 jets 1 b-tag category
 $130 \text{ GeV}/c < \text{TopMass} < 220 \text{ GeV}/c$
- Data-driven **W+jets modelling**:



yield and $|\eta_{j,l}|$ -template extracted from data from sideband region of TopMass



$$\sigma_{t\text{-ch.}} = 73.3 \pm 10.4 \text{ (stat. + syst. + lum.)} \pm 4.0 \text{ (theor.) pb (muons),}$$

$$\sigma_{t\text{-ch.}} = 61.6 \pm 13.9 \text{ (stat. + syst. + lum.)} \pm 3.5 \text{ (theor.) pb (electrons)}$$

Combination:

$$\sigma_{t\text{-ch.}} = 70.0 \pm 6.0 \text{ (stat.)} \pm 6.5 \text{ (syst.)} \pm 3.6 \text{ (theor.)} \pm 1.5 \text{ (lum.) pb}$$

t-channel cross section (7 TeV)

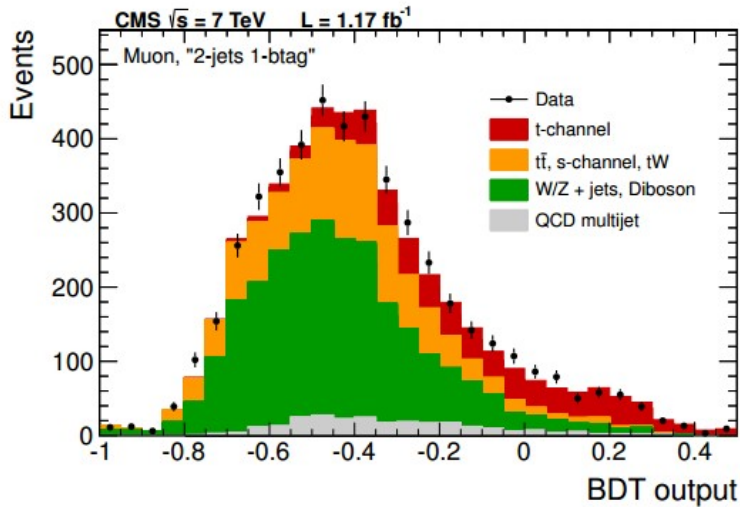
Multivariate analyses: use multivariate methods (BDT, NN) to obtain a powerful discriminator between signal and background processes

<i>jets</i>	2	3	4
0 b-tag	<i>W+jets</i>		
1 b-tag	<i>Signal</i>		<i>Top pairs</i>
2 b-tags			

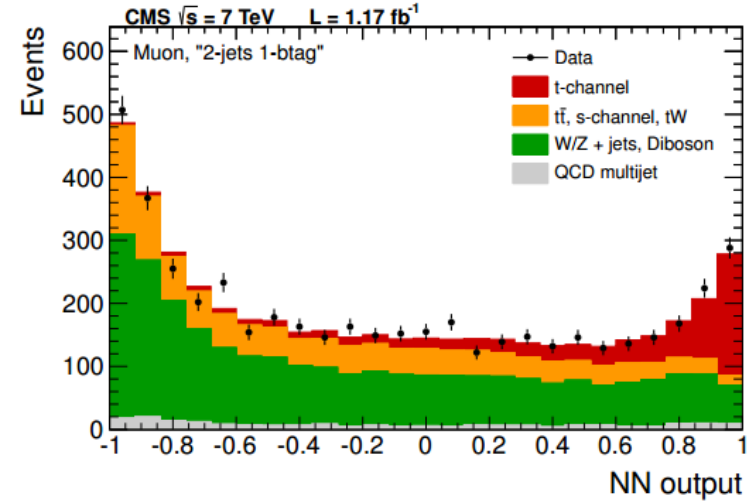
Used to check of modeling of input variables

Used for cross section measurement

BDT



NN



The measured cross section:

$$\sigma_{t\text{-ch.}} = 66.6_{-6.6}^{+7.0} \text{ (stat. + syst. + lum.)}_{-3.5}^{+6.4} \text{ (theor.) pb (muons),}$$

$$\sigma_{t\text{-ch.}} = 66.4_{-7.9}^{+8.4} \text{ (stat. + syst. + lum.)}_{-5.4}^{+5.4} \text{ (theor.) pb (electrons)}$$

Combination:

$$\sigma_{t\text{-ch.}} = 66.6 \pm 4.0 \text{ (stat.)} \pm 3.3 \text{ (syst.)}_{-3.3}^{+3.9} \text{ (theor.)} \pm 1.5 \text{ (lum.) pb}$$

$$\sigma_{t\text{-ch.}} = 69.7_{-7.0}^{+7.2} \text{ (stat. + syst. + lum.)} \pm 3.6 \text{ (theor.) pb (muons),}$$

$$\sigma_{t\text{-ch.}} = 65.1_{-8.9}^{+9.2} \text{ (stat. + syst. + lum.)} \pm 3.5 \text{ (theor.) pb (electrons)}$$

$$\sigma_{t\text{-ch.}} = 68.1 \pm 4.1 \text{ (stat.)} \pm 3.4 \text{ (syst.)}_{-4.3}^{+3.3} \text{ (theor.)} \pm 1.5 \text{ (lum.) pb}$$

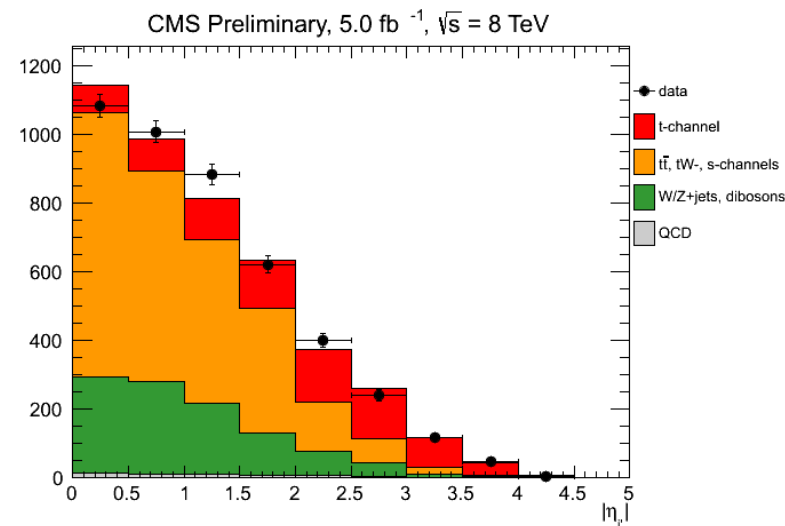
t-channel cross section (8 TeV)

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

- **Data:** 5.0 fb⁻¹ (muon channel only)
- Signal region: 2 jets 1 b-tag category
130 GeV/c < TopMass < 220 GeV/c
- Jet $p_T > 60$ GeV/c
- Cut to reduce QCD multijet events: MtW > 50 GeV/c²
- Data-driven **top pair modelling**

$|\eta_j|$ -template is obtained using the 3-jets 2-tags data sample

- Data-driven **W+jets modelling:**
as for 7 TeV from data from sideband region of TopMass



Likelihood fit to $|\eta_j|$ distribution results in

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

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

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

t-channel cross-section

7 TeV: $|\eta_{..}|$, BDT and NN analyses combined with BLUE method:

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

8 TeV:

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

$|V_{tb}|$ extraction

Assuming $|V_{td}|, |V_{ts}| \ll |V_{tb}|$:

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

calculated with $|V_{tb}|=1$

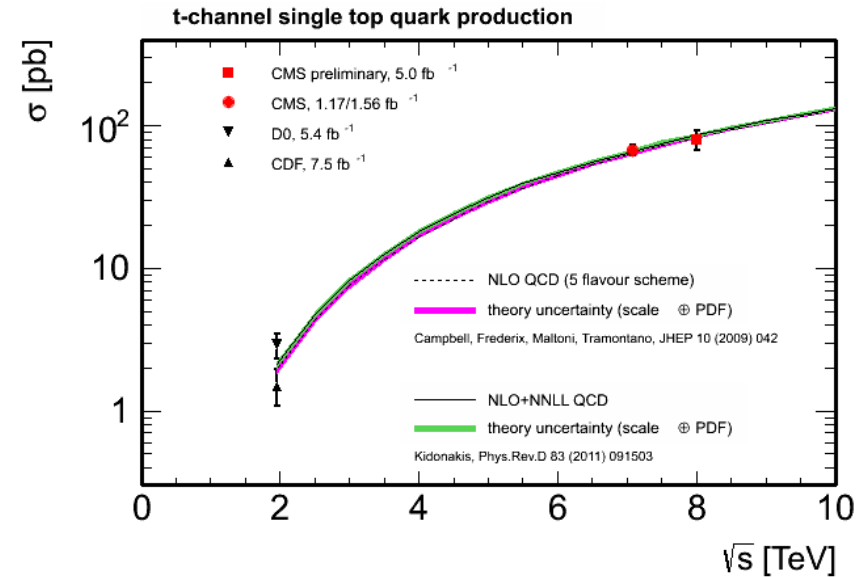
$$7 \text{ TeV: } |f_{LV} V_{tb}| = 1.020 \pm 0.046 \text{ (exp.)} \pm 0.017 \text{ (theor.)}$$

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

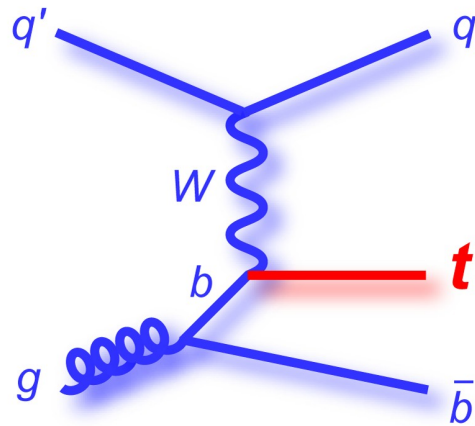
f_{LV} is a left-handed vector coupling, $f_{LV}=1$ in SM

Constraining $|V_{tb}|$ to the interval $[0, 1]$ and setting $f_{LV} = 1$ yields:

$$0.92 < |V_{tb}| \leq 1 \text{ (7 TeV)} \text{ and } 0.81 < |V_{tb}| \leq 1 \text{ (8 TeV) @ 95\% CL}$$



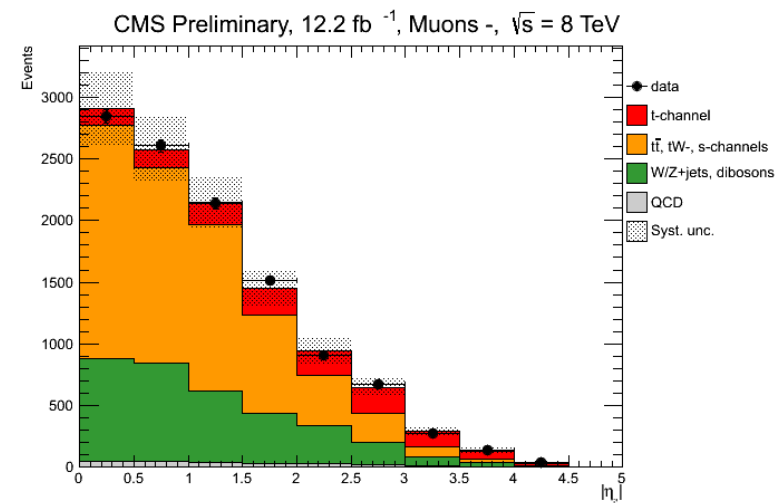
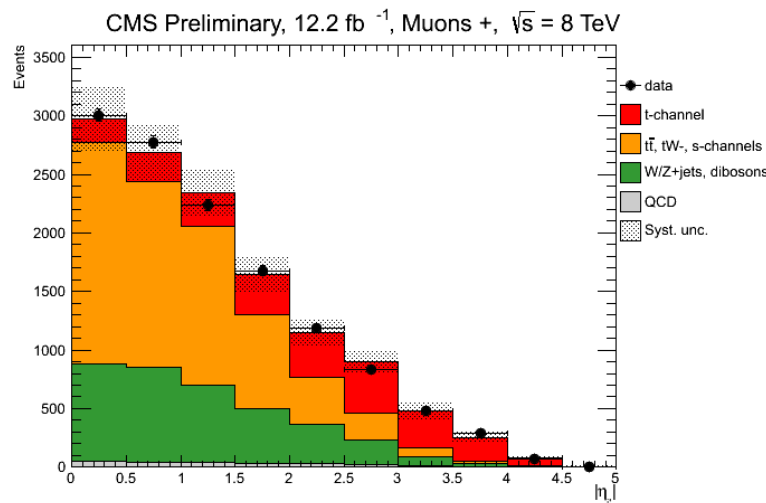
Charge asymmetry (8 TeV)



- 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

- **Data:** 12.2 fb^{-1}
- the same event selection as for t-channel cross-section measurement
- signal region: 2 jets 1 b-tag category
 $130 \text{ GeV}/c < \text{TopMass} < 220 \text{ GeV}/c$



Charge asymmetry (8 TeV)

Measurements:

$$\sigma_{t\text{-ch.,top}} = 49.9 \pm 1.9(\text{stat.}) \pm 8.9(\text{syst.}) \text{ pb}$$

$$\sigma_{t\text{-ch.,anti-top}} = 28.3 \pm 2.4(\text{stat.}) \pm 4.9(\text{syst.}) \text{ pb}$$

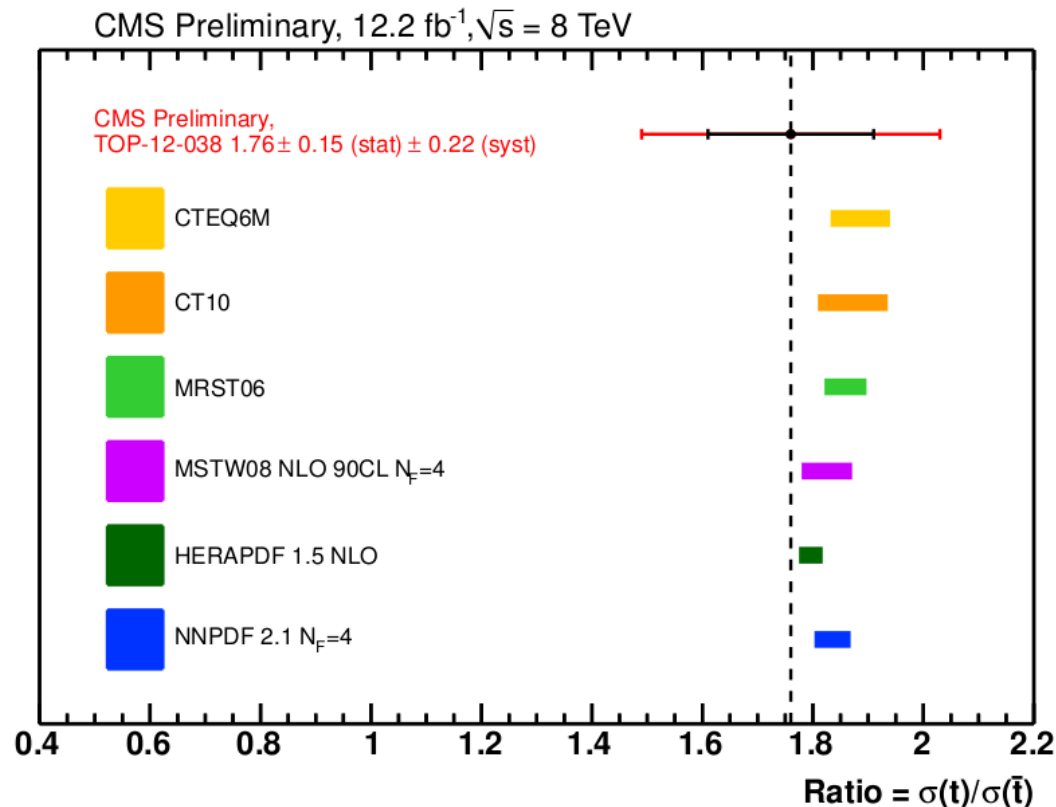
$$R_{t\text{-ch.}} = 1.76 \pm 0.15(\text{stat.}) \pm 0.22(\text{syst.})$$

SM predictions (Kidonakis):

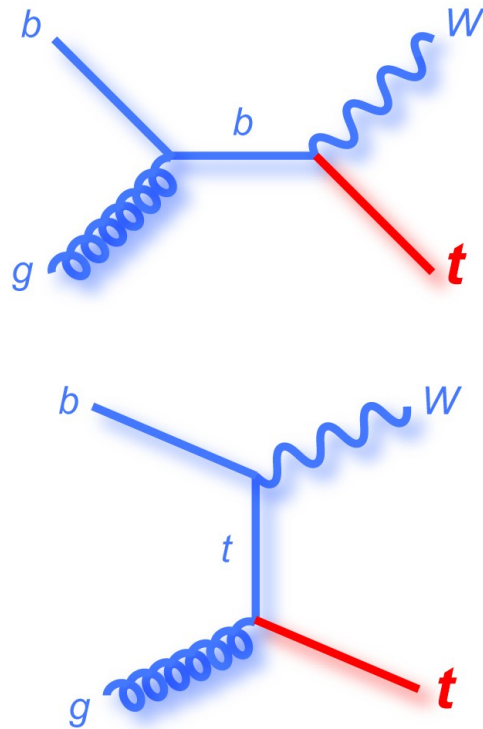
$$\sigma_{t\text{-ch.,top}}^{\text{th}} = 56.4_{-0.3}^{+2.1} (\text{scale})_{-1.1}^{+1.1} (\text{PDF}) \text{ pb}$$

$$\sigma_{t\text{-ch.,anti-top}}^{\text{th}} = 30.7_{-0.7}^{+0.7} (\text{scale})_{-1.1}^{+0.9} (\text{PDF}) \text{ pb}$$

$$R_{t\text{-ch.}} = \sigma_{t\text{-ch.,top}} / \sigma_{t\text{-ch.,anti-top}} = 1.84$$



Associated tW production (7 TeV)

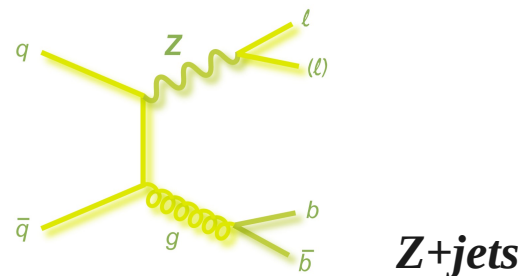
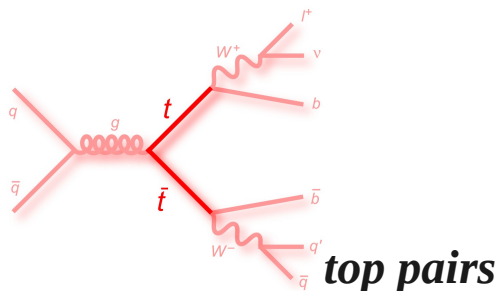


Data: 4.9 fb⁻¹

Event selection

- 2 leptons with opposite charge
 - $p_T > 20$ GeV/c $|\eta| < 2.4$ (muon)
 - $p_T > 20$ GeV/c $|\eta| < 2.5$ (electron)
- One or two jets with $p_T > 30$ GeV/c and $|\eta| < 2.4$, at least one jet is b-tagged
- MET > 30 GeV
- Additional cuts:
 - $m_{ll} > 20$ GeV/c²
 - veto events with $81 \text{ GeV/c}^2 < m_{ll} < 101 \text{ GeV/c}^2$
- $H_T > 60$ GeV (specific cut in cut-based analysis)

Main backgrounds:



H_T : scalar sum of the p_T of the leptons, jets, and MET

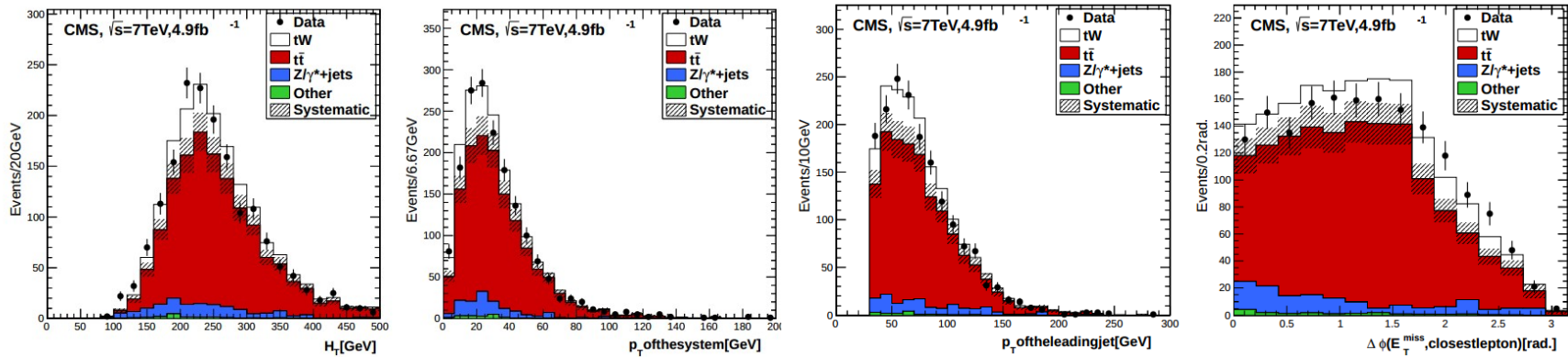
Two complementary approaches:

multivariate analysis (BDT)
cut-based analysis as a cross-check

Associated tW production (7 TeV)

BDT analysis: combine 4 variables in a BDT to increase $t\bar{t}$ / tW separation power

Input variables: H_T , p_T of the system, p_T of jet, angle between MET and the closest lepton

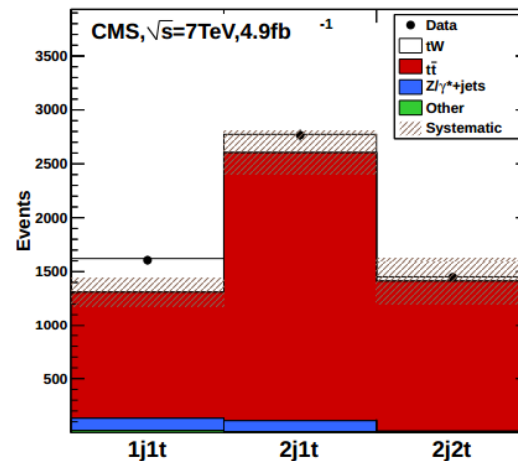
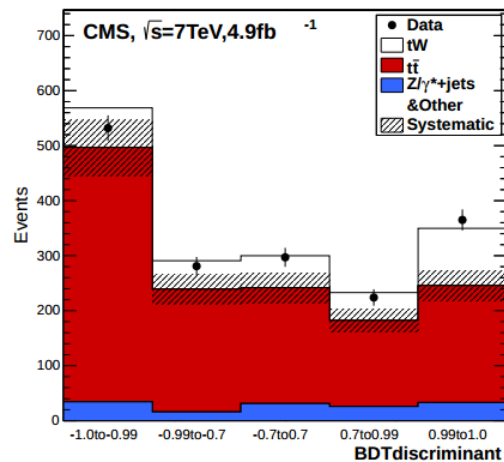


3 categories considered: 1 jet 1 tag, 2 jets 1 tag, 2 jets 2 tags

Simultaneous fit: three categories in the three final states (ee , $e\mu$ and $\mu\mu$)

Binned likelihood fit to BDT output simultaneously in all channels (ee , $e\mu$, $\mu\mu$)

Cross-check with count-based analysis



Associated tW production (7 TeV)

Measured cross-section:

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

Significance:

BDT	4σ
Cut-based	3.5σ

$|V_{tb}|$ extraction

Assuming $|V_{td}|, |V_{ts}| \ll |V_{tb}|$:

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

calculated with $|V_{tb}|=1$

Confidence interval assuming $|V_{tb}| \leq 1$ and $f_{LV}=1$:

$$0.79 < |V_{tb}| \leq 1 \quad @ \quad 90\% \text{ C.L.}$$

Summary

- The **first measurements** of single top production properties are published: t-channel and associated tW production cross sections, $|V_{tb}|$, charge asymmetry
- The **next round** of analyses are in progress: differential cross sections, top mass and rare s-channel production
- Searches for the **deviation from SM** prediction in single top are in progress