Single top-quark production cross section at LHC in ATLAS

PASCOS 2013 Conference – Taipei

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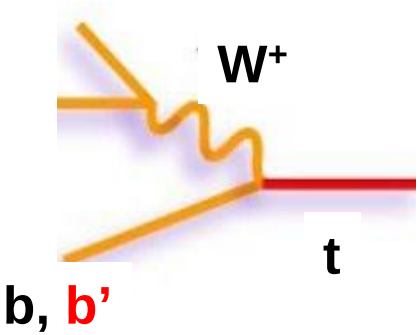
Single top-quark production

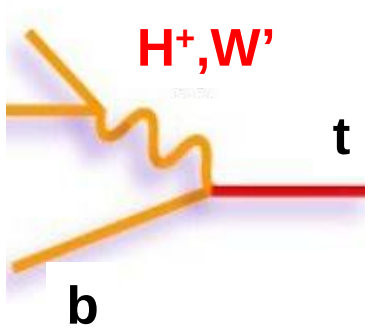
Electroweak production of the top quark

Cross section proportional to $|V_{tb}|^2$

Sensitive to any (new) effect that can modify the top quark weak coupling

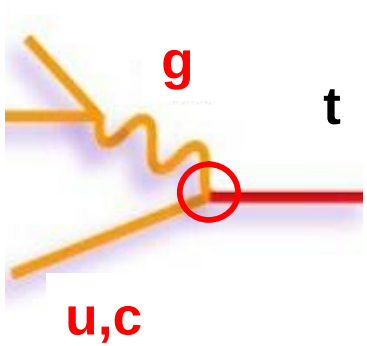


➔ New heavy quarks



➔ New bosons

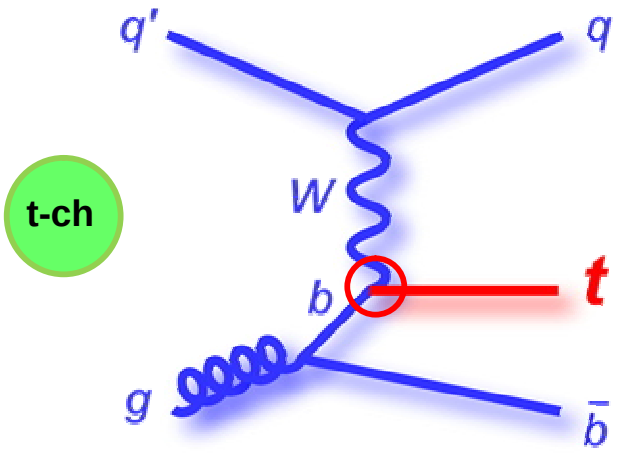
➔ New resonances



➔ Modified couplings

➔ Anomalous polarization

t-channel production



Probe W-t-b vertex

- Constrain V_{tb}
- Search for modified couplings
- Anomalous polarisation

Production mechanisms

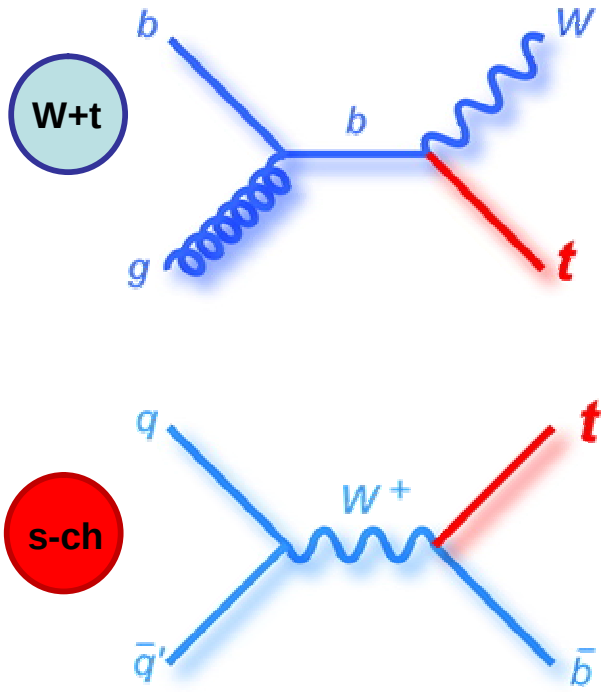
- FCNC single-top production

Determine b-quark PDF

Dominant process: ~1/3 top-pair production ($\sigma_t^{th.}$ = 88 pb @ 8 TeV)
➔ **Observed** at Tevatron (2009), then at LHC (2011) [1]

Measure single-top cross-section as precisely as possible:
➔ Test SM & probe for new physics
➔ But new intermediate particles suppressed as $1/M^2$

Wt and s-channels



Probe W-t-b vertex

- Constrain V_{tb}

New heavy particles

- Excited quarks
- Charged Higgs
- Charged W-like bosons
- Composite models

Wt process (σ_{Wt}^{th} = 22 pb @ 8 TeV) ➔ **Observation** at LHC [2]

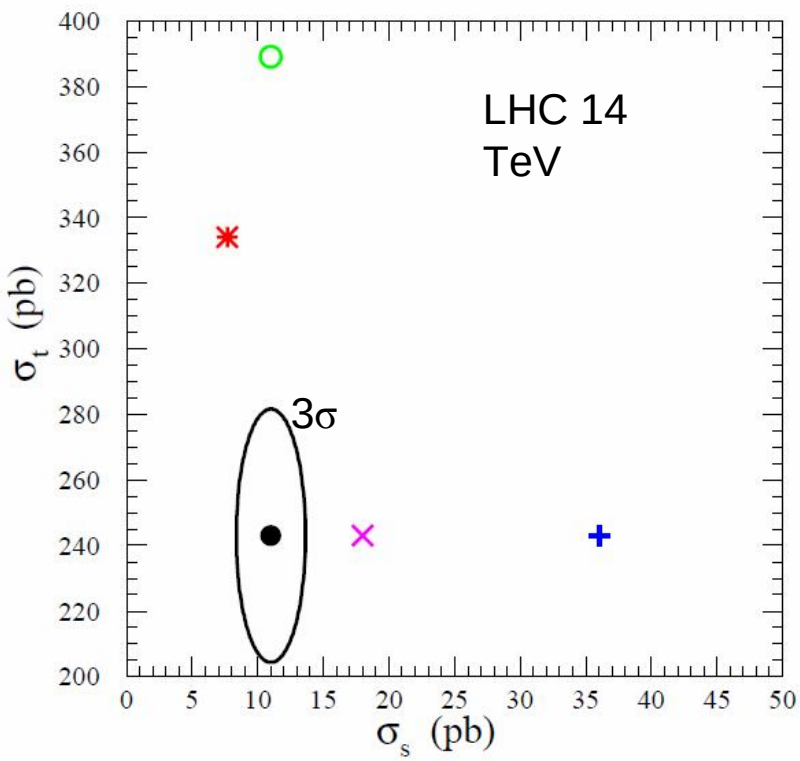
s-channel: smallest cross-section, ~1/15 t-channel ($\sigma_s^{th.}$ = 6 pb @ 8 TeV)

➔ Difficult channel, **Evidence** at Tevatron [3], **Limits** at LHC

Test of the SM in the single-top sector

Tait et al. (2000): “single-top as a window to new physics”

Phys.Rev. D63 (2000) 014018



• LHC SM

x Top-flavor ($m_{Z'}$=1 TeV)

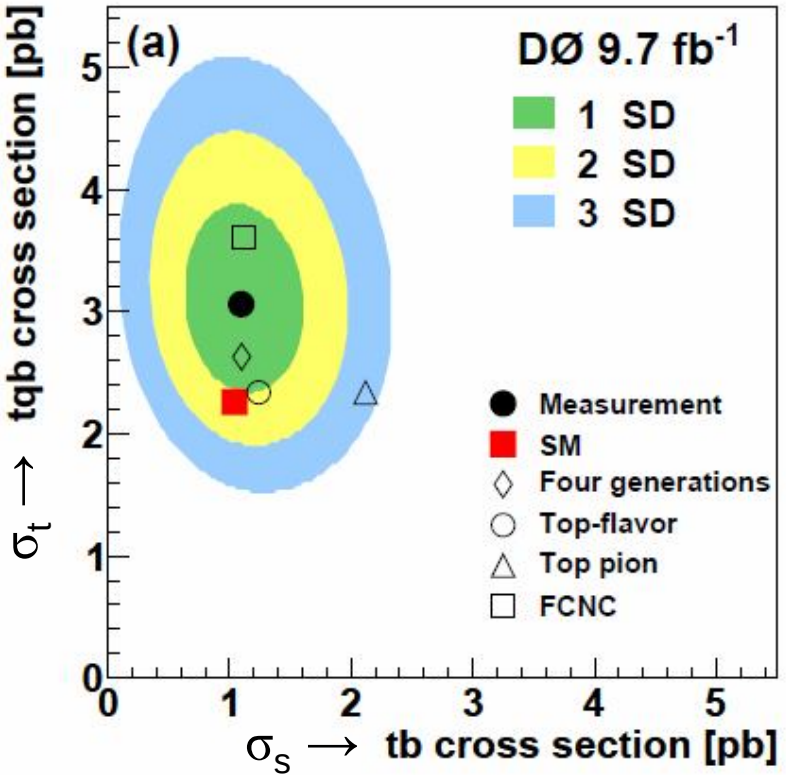
○ FCNC Z-t-c

+ Top-pion (m_π=450 GeV)

• 4th quark (V_{ts}=0.55)

Tevatron measurements (D0)

http://arxiv.org/abs/1307.0731



At **LHC** we have more **handles** (ex: Wt process)

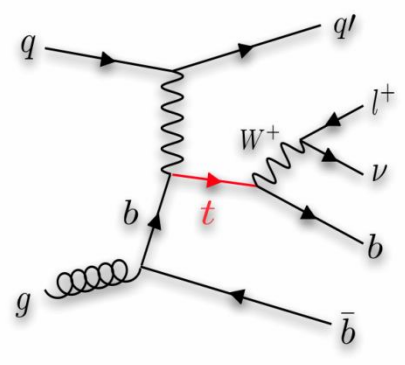
Entering era of **precision** single-top quark measurements

Single Top-Quark Cross Section Measurements

t-channel @ 7 TeV (1.04 fb^{-1})

Phys. Lett. B 717 (2012) 330-350

Signature & selections



1 isolated lepton (e/μ) p_T>25 GeV

2 or 3 jets |η|<4.5, p_T>25 GeV

Exactly 1 b-tagged jet

E_T^{miss}>25 GeV

$m_T(W)$ > (60 GeV – E_T^{miss})

Analysis

Maximum likelihood **fit to NN** distribution

Cut based analysis used as cross-check

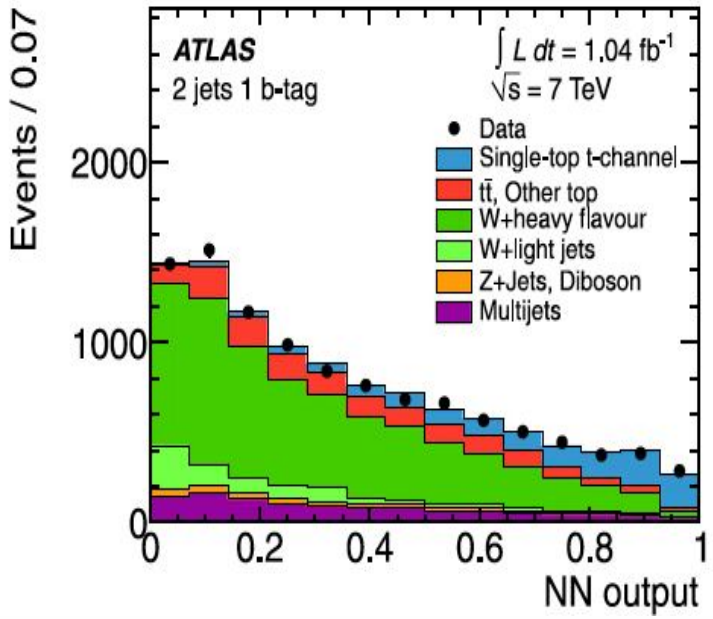
Data-driven multijet and W+jets background rates

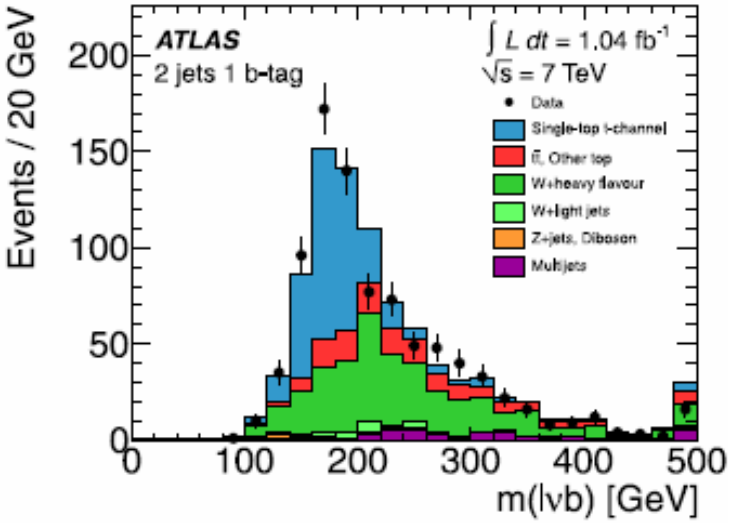
All other backgrounds set to theory predictions

Results

σ_t = 83 ± 4 (stat.) +20 -19 (syst) = 83 ± 20 pb (24%)

Main systematics: ISR/FSR, b-tagging





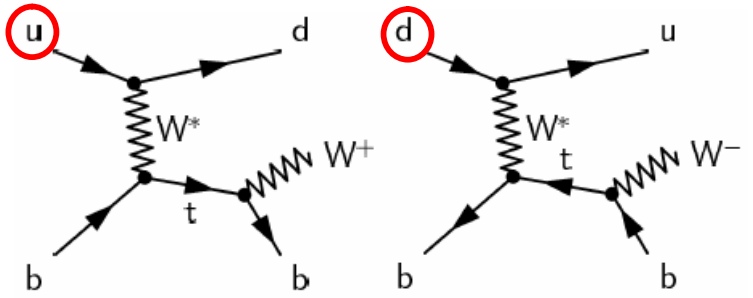
Top/antitop cross section ratio (R_t)

ATLAS-CONF-2012-056

Motivation

$\mathbf{R_t} = \sigma_{top}/\sigma_{antitop}$ sensitive to ratio of u/d quark PDF

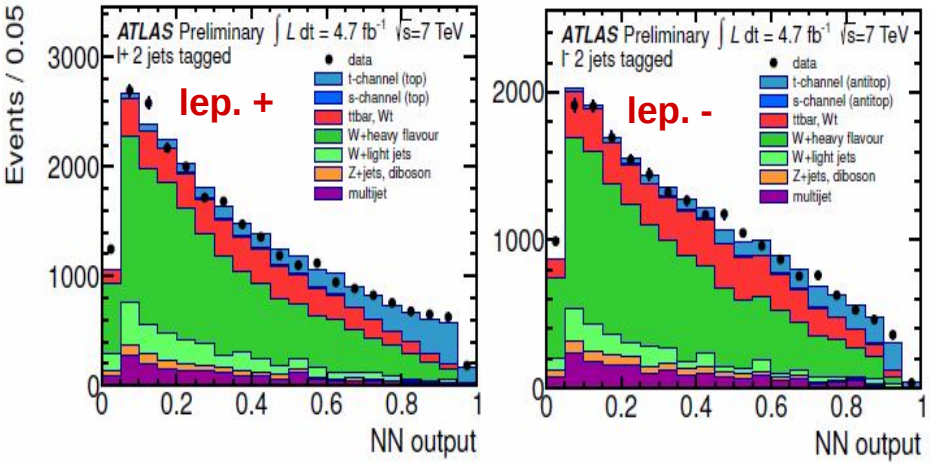
$R_t \sim 1.9$, sizable dependence on PDF sets

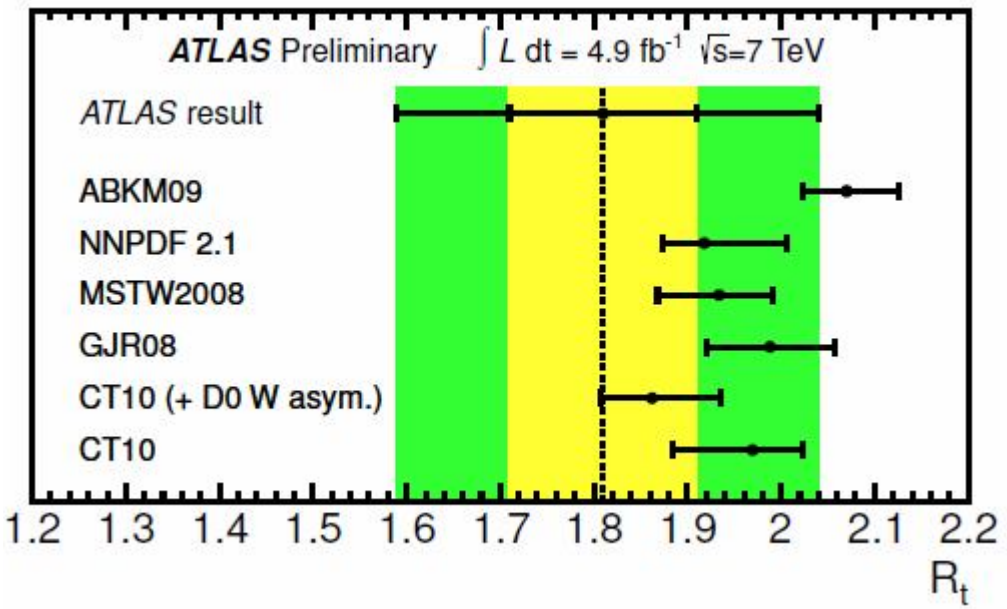


Analysis

NN method similar to xs measurement

Fit separately **+ and - leptons** channels





$R_t = 1.81 \pm 0.10\ (stat) \pm 0.21\ (syst)$

$\sigma_{top} = 53.2 \pm 1.7(stat) \pm 10.6(syst)$ pb

$\sigma_{anti\text{-}top} = 29.5 \pm 1.5(stat) \pm 7.3(syst)$ pb

t-channel @ 8 TeV (5.8 fb^{-1})

ATLAS-CONF-2012-132

Analysis

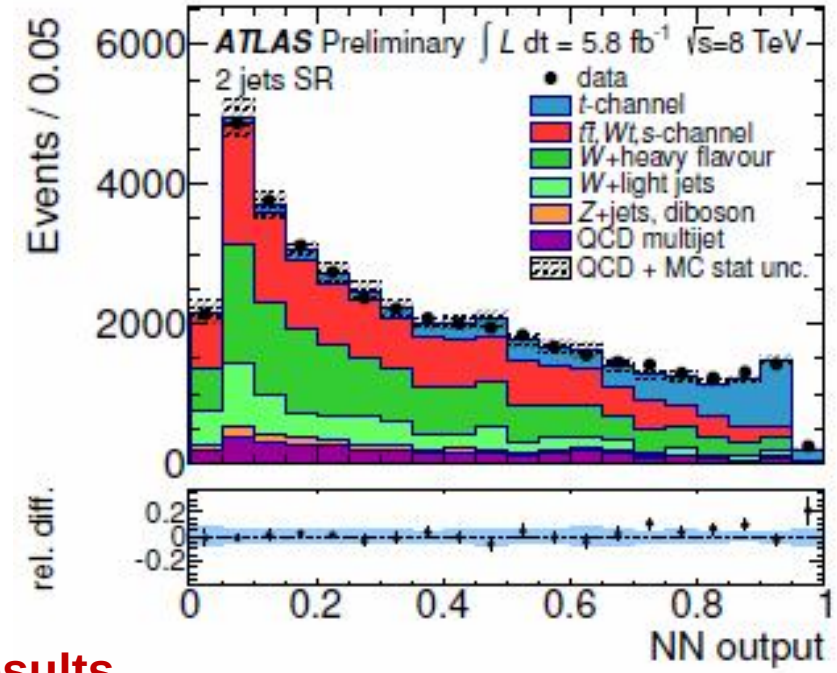
NN method similar to 7 TeV measurement

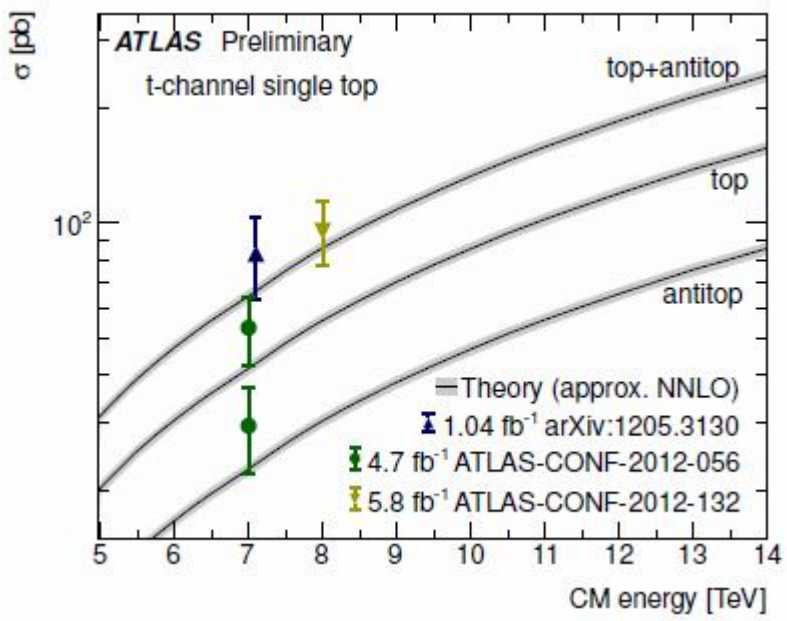
More robust selections vs background and pile-up

Jets selected with p_T>30 GeV

b-tagging: c-quarks jets rejection

E_T^{miss}>30 GeV, m_T(W) > 50 GeV





Results

σ_t = 95 ± 2 (stat.) ±18 (syst) = 95 ± 18 pb (19%)

Main systematics: ISR/FSR, b-tagging, jet energy scale

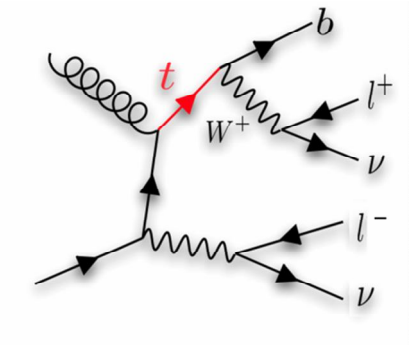
XS measurement combined with CMS

ATLAS-CONF-2013-098

Wt channel @ 7 TeV (2.05 fb^{-1})

Phys. Lett. B 716 (2012) 142-159

Signature & selections



2 opposite sign leptons (ee,eμ,μμ) with p_T>25 GeV

≥1 central jet, p_T>30 GeV

E_T^{miss}>50 GeV

Veto cuts against Z→ll decays

Analysis

Maximum likelihood **fit to BDT** distribution in

- 1-jet signal region
- 2 and 3$^+$ jets background rich (top pairs) regions

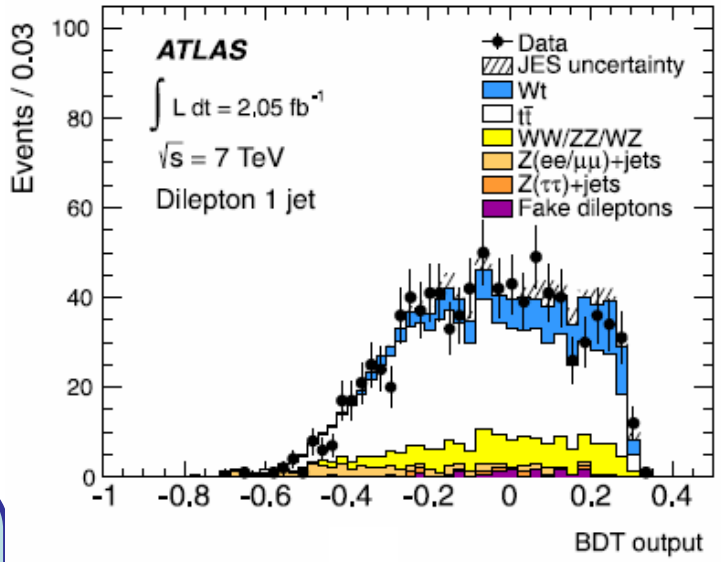
Data driven: DY, "fakes" dilepton and Z→ττ

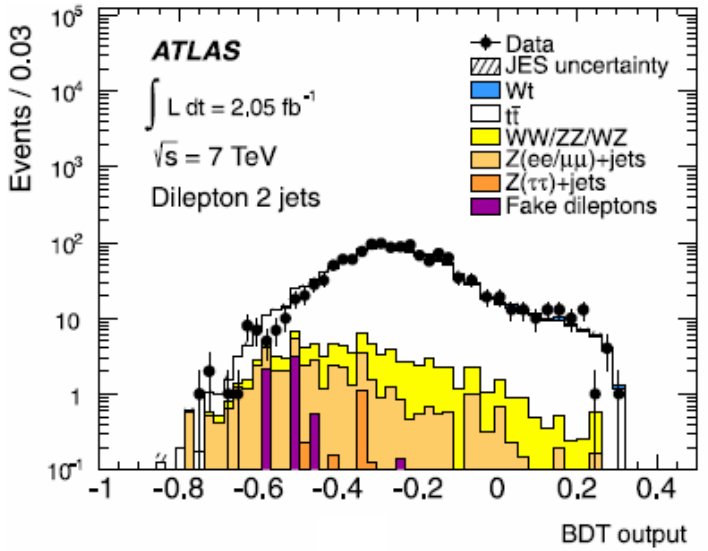
Results

σ_{tW} = 16.8 ± 2.9 (stat.) ± 4.9 (syst) pb

Significance: 3.3σ (3.4σ exp.)

Main systematics: jet energy scale, parton shower





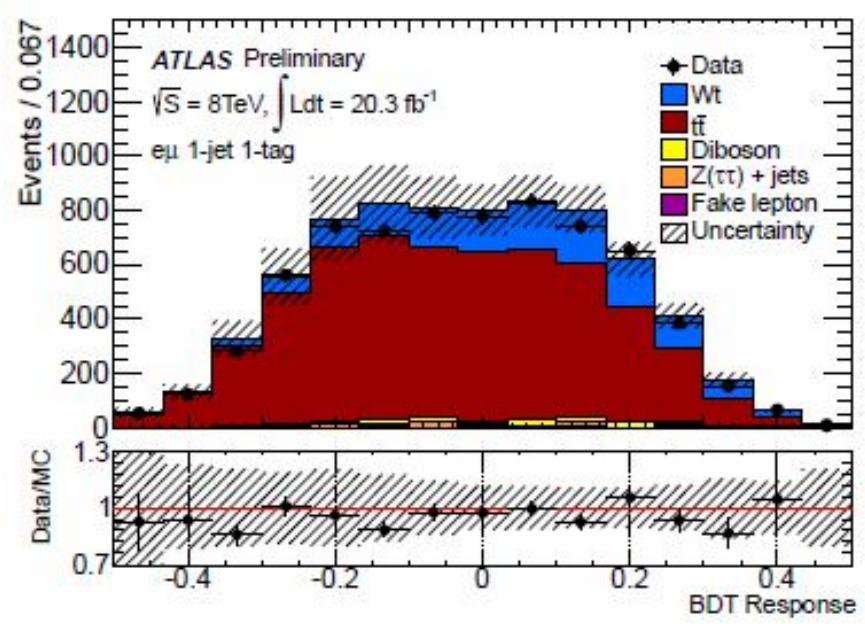
Wt channel @ 8 TeV (20.3 fb^{-1})

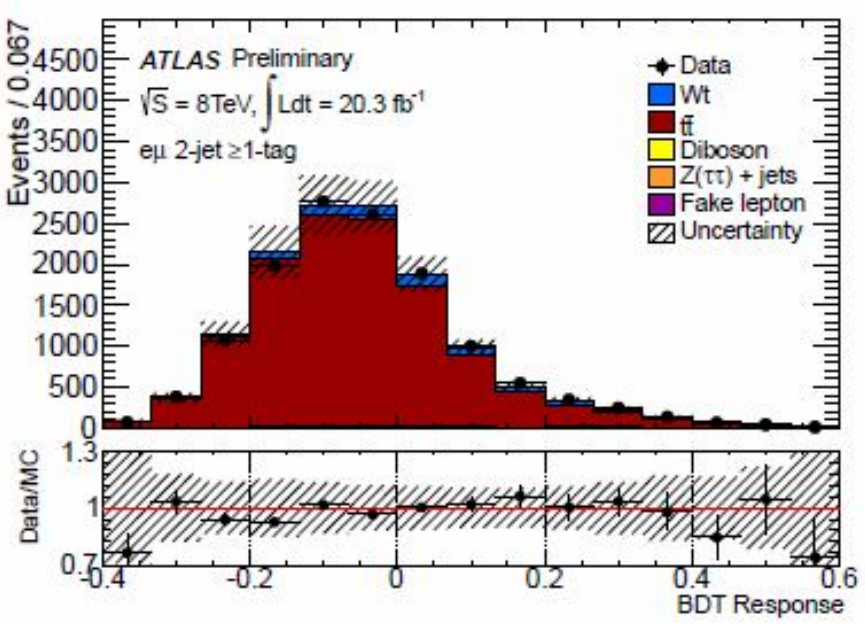
ATLAS-CONF-2013-100

Analysis

Maximum likelihood **fit to BDT** distribution
Data driven: “fakes” dilepton
Validation of diboson and Z→ττ in CR

Only eμ channel (opposite charge)
1 or 2 central jets, at least 1 b-tag





σ_{tW} = 27.2 ± 2.8(stat) ± 5.4(syst) pb
Significance: 4.2σ (4.0σ exp.)

Main systematics: jet energy scale, b-tagging, generators

Direct $|V_{tb}|$ measurement

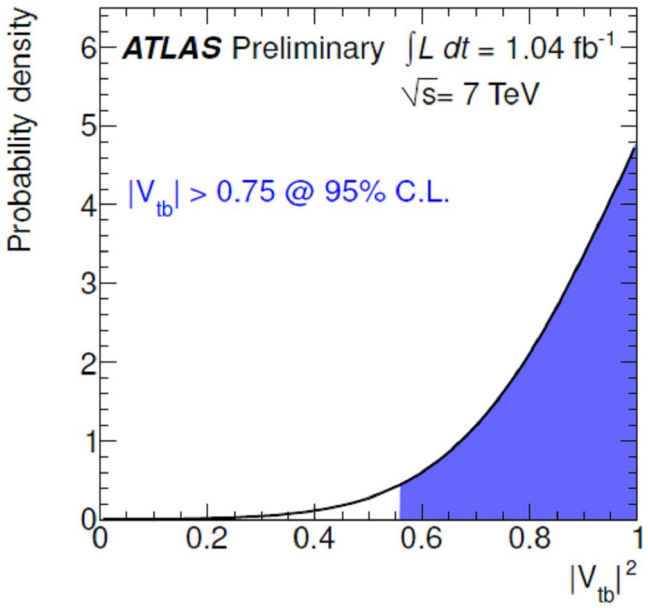
$|V_{tb}|$ Measurement

- Cross section in t and Wt channels proportional to: $|V_{tb} \times f|^2$ (with f = 1 in SM)
- Independent of N_{quark} generations or CKM unitarity

Assumptions

- $|V_{tb}| >> |V_{td}|, |V_{ts}|$
- Left-handed SM-like W-t-b interaction
- Negligible contributions from other single-top processes

$|V_{tb} \times f|^2 = \sigma_t$ (obs.) / σ_t (theory)



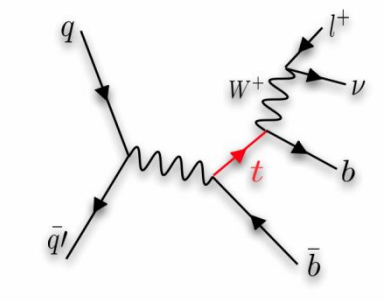
$\|V_{tb}\|$	7 TeV	8 TeV
t-ch	$\|V_{tb}\| = 1.13 \pm 0.14$ > 0.75 (95% CL)	$\|V_{tb}\| = 1.04 \pm 0.11$ > 0.80 (95% CL)
Wt	$\|V_{tb}\| = 1.03\ ^{+0.16}_{-0.19}$	$\|V_{tb}\| = 1.10 \pm 0.12$ > 0.72 (95% CL)

Best precision on $|V_{tb}|$: 10% (t-channel at 8 TeV)

Search for s-channel @ 7 TeV (0.7 fb^{-1})

ATLAS-CONF-2011-118

Signature & selections



1 isolated lepton (e/μ) p_T>25 GeV

2 b-tagged jets, p_T>25 GeV

E_T^{miss}>25 GeV

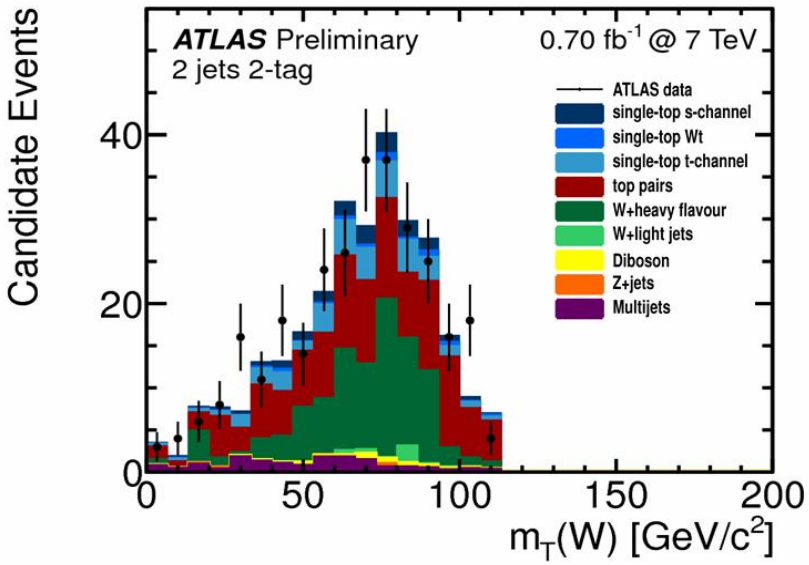
$m_T(W) > (60\ GeV - E_T^{miss})$

	Final Selection
s-channel	16 ± 6
t-channel	33 ± 13
Wt	5 ± 3
$t\bar{t}$	111 ± 47
W+jets	4 ± 5
Wc+jets	10 ± 8
$Wc\bar{c}$+jets	14 ± 12
$Wb\bar{b}$+jets	70 ± 51
Z+jets	1 ± 1
Diboson	4 ± 1
Multijets	17 ± 10
TOTAL Exp	285 ± 17
$S/\sqrt{B}$	0.98
DATA	296

Analysis

Cut based analysis

Data-driven multijet background rates



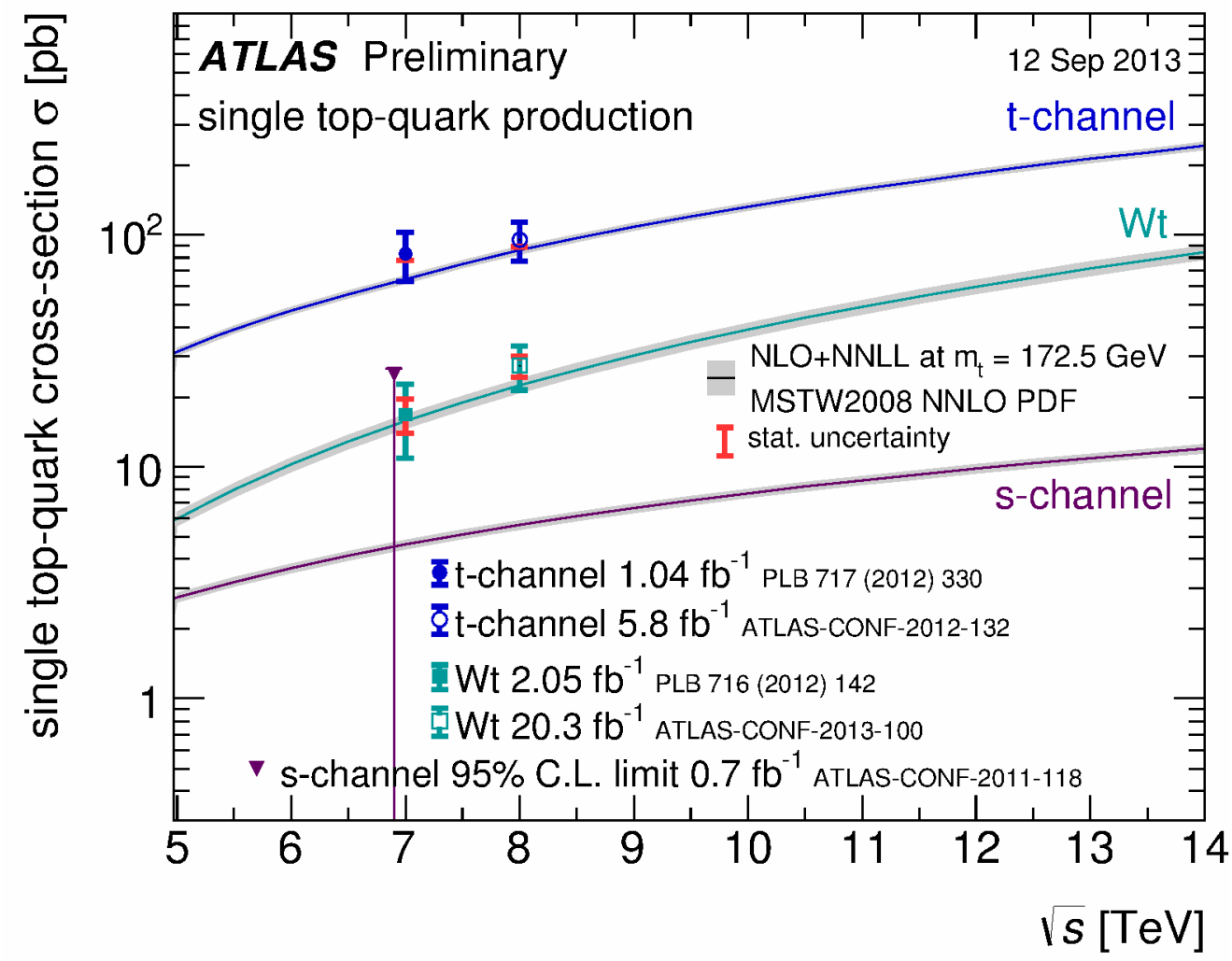
Results

σ_s < 26.5 pb (20.5 pb exp.) @ 95% C.L.

SM: 4.56 ± 0.19 pb (arXiv:1210.7813)

Measurement statistically limited

Single top-quark cross-section summary



Measurements are in good agreement with theoretical predictions

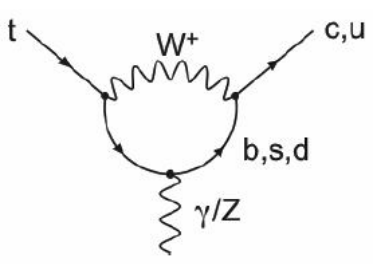
BSM Searches
in Single Top-Quark Signatures

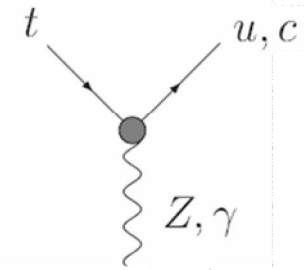
Search for single-top FCNC production

Phys. Lett. B 712 (2012) 351-369 (7 TeV)
ATLAS-CONF-2013-063 (8 TeV)

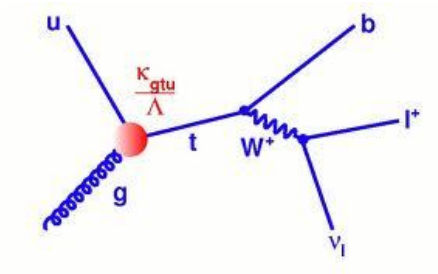
Motivation

FCNC in top-decays B(t → qV) with V = H,Z,γ,g
SM: highly suppressed: B ~ 10^{-17}-10^{-12}
BSM: can be enhanced up to B ~ 10^{-3}





t → qg mode difficult to distinguish from background
Anomalous **qg → t** production: better sensitivity



Model

Effective Lagrangian

$$\mathcal{L}_{\text{eff}} = g_s \sum_{q=u,c} \frac{\kappa_{qgt}}{\Lambda} \bar{t}\sigma^{\mu\nu} T^a \left(f_q^L P_L + f_q^R P_R\right) q G^a_{\mu\nu} + \text{h.c.}$$

K_{qgt}: new coupling strength
Λ: new physics scale

Signature & selections

1 isolated lepton (e/μ) p_T>25 GeV
1 b-tagged jet, p_T>30 GeV
E_T^{miss}>30 GeV
$m_T(W)$ > 50 GeV

FCNC production @ 8 TeV (14.2 fb^{-1})

ATLAS-CONF-2013-063 (8 TeV)

Analysis

Bayesian **fit to NN** distribution

- CR: loose b-tagging
- SR: tight b-tagging

Data driven multijet rates

Results

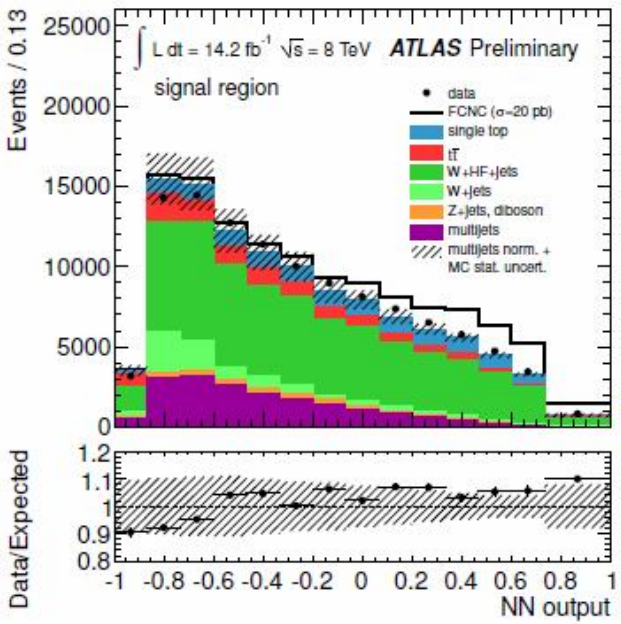
No excess is observed:

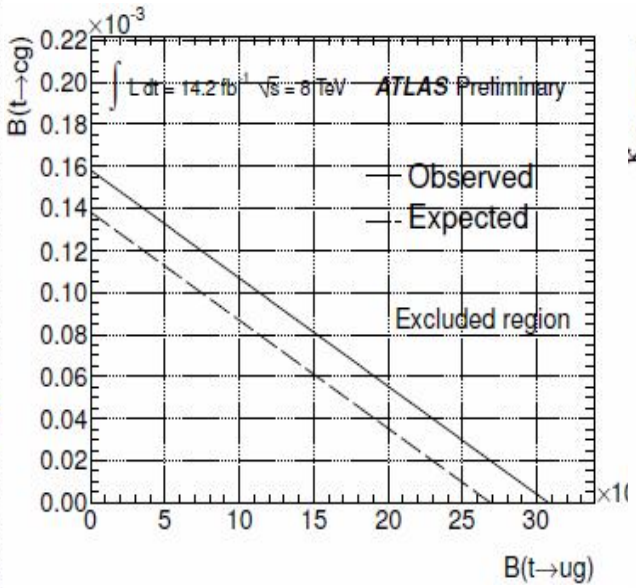
σ_{FCNC} < 2.5 pb @ 95% C.L. (2.2 pb exp.)

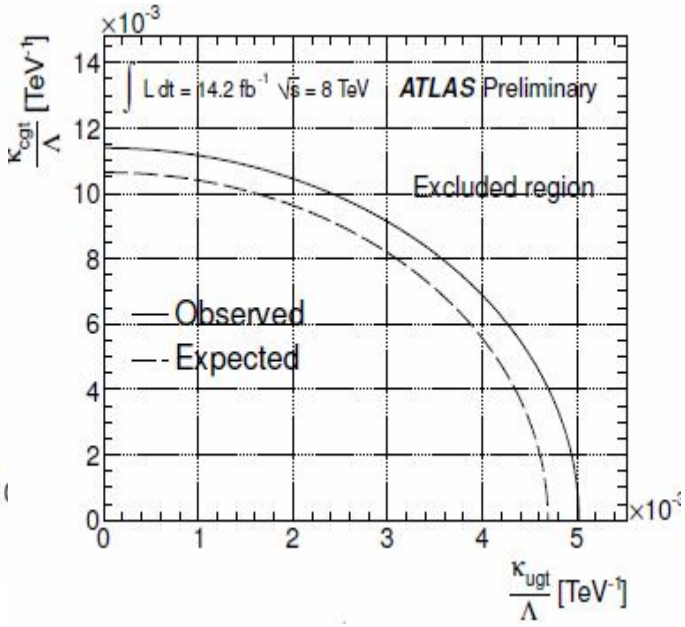
B(t → ug) < 3.1 10^{-5} for B(t → cg) = 0

B(t → cg) < 1.6 10^{-4} for B(t → ug) = 0

Most stringent limits on FCNC single-top prod.





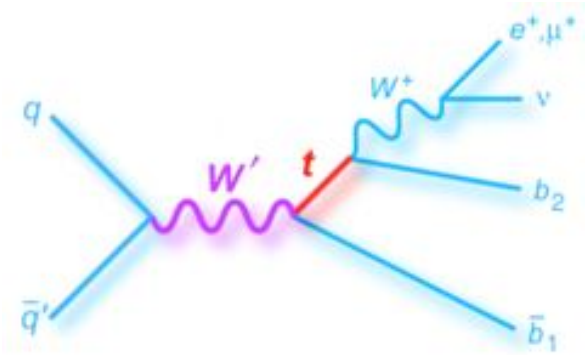


Search for W' bosons

ATLAS-CONF-2013-050 (8 TeV)

Motivation

W' bosons appear in many extensions of the SM
L/R models, KK excitations, Little Higgs, …
Search for W' → tb decays
- More model independent than leptonic decay
- Probe leptophobic sector
- BSM dynamics could explain high top mass



Model independent approach
Effective Left-Right model (arXiv:1208.4858v1)
W' with left-handed, right-handed or mixed couplings

$$\mathcal{L} = \frac{V'_{ij}}{2\sqrt{2}} \bar{f}_i \gamma_\mu \left(g'_{R_{i,j}} (1+\gamma^5) + g'_{L_{i,j}} (1-\gamma^5) \right) W'^{\mu} f_j + h.c.$$

$g'_{R/L}$: right/left-handed coupling

Signature & selections

Similar to s-channel analysis
1 lepton (e/μ) p_T>30 GeV
2 or 3 central jets, p_T>25 GeV
Exactly 2 b-tagged jets
E_T^{miss}>35 GeV
$m_T(W) > (60\ GeV - E_T^{miss})$
m_{tb} > 270 GeV

Search for W' bosons @ 8 TeV (14.3 fb^{-1})

ATLAS-CONF-2013-050 (8 TeV)

Analysis

Fit to BDT spectrum

Data driven W+jets/ multijet rates from CR

Results

No excess is observed

Exclusion 95% CL limits on

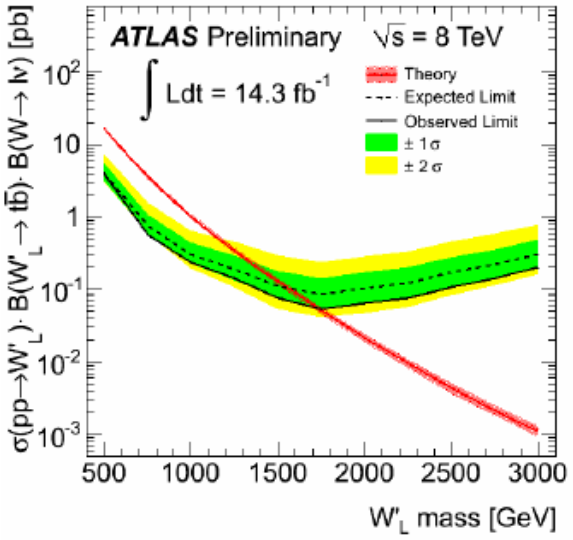
- W'$_{L/R}$ cross section
- g'/g coupling ratio

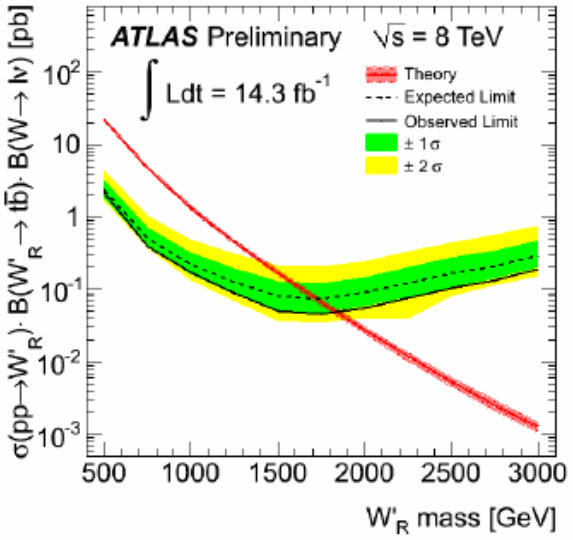
Using CLs method

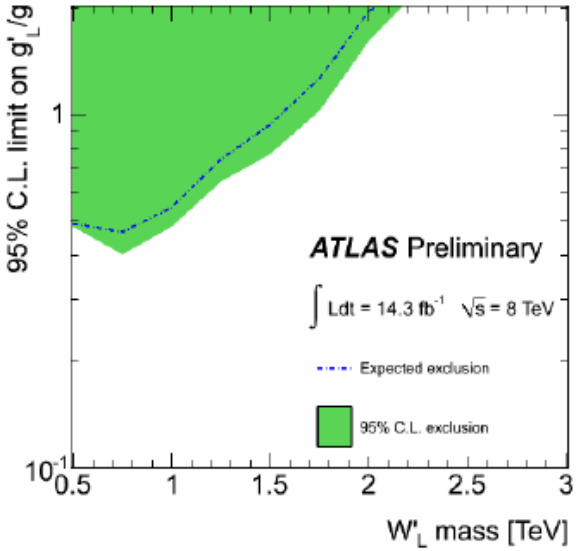
Limits on W' mass:

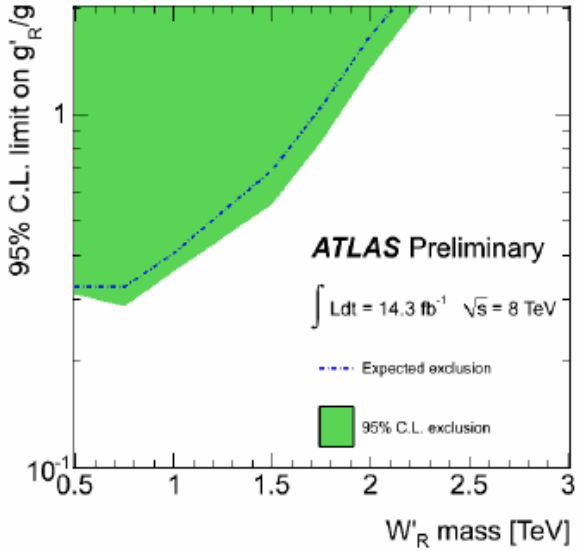
$m_{W'} < 1.74$ TeV for W'$_L$

$m_{W'} < 1.84$ TeV for W'$_R$









Conclusion and outlook

Rich field of study, several public results by ATLAS

➔ 5 published papers, 7 CONF notes

7 & 8 TeV
7 TeV
8 TeV

Cross section

t-channel
Wt channel
s-channel
$|V_{tb}|$
R_t
LHC combination

Properties

FCNC
CP violation

See talk
Y. Peters

BSM

W'
b^*

See backup slides

Prospects

Effort on boosted top topologies
Investigate full hadronic searches
Even more interesting at higher pp energy

Many new interesting results ahead !

Additional references

[1] t-channel observation

- D0: Phys. Rev. Lett. 103, 092002 (2009)
- CDF: Phys. Lett. B 682, 363 (2010)
- CMS: Phys. Rev. Lett. 107 (2011) 091802
- ATLAS: Phys. Lett. B 717 (2012) 330 – 350

[2] Wt observation

- CMS: CMS PAS TOP 12040

[3] Evidence for s-channel

- D0: Phys. Lett. B **726**, 656 (2013)

Backup material

Single-top LHC combination

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

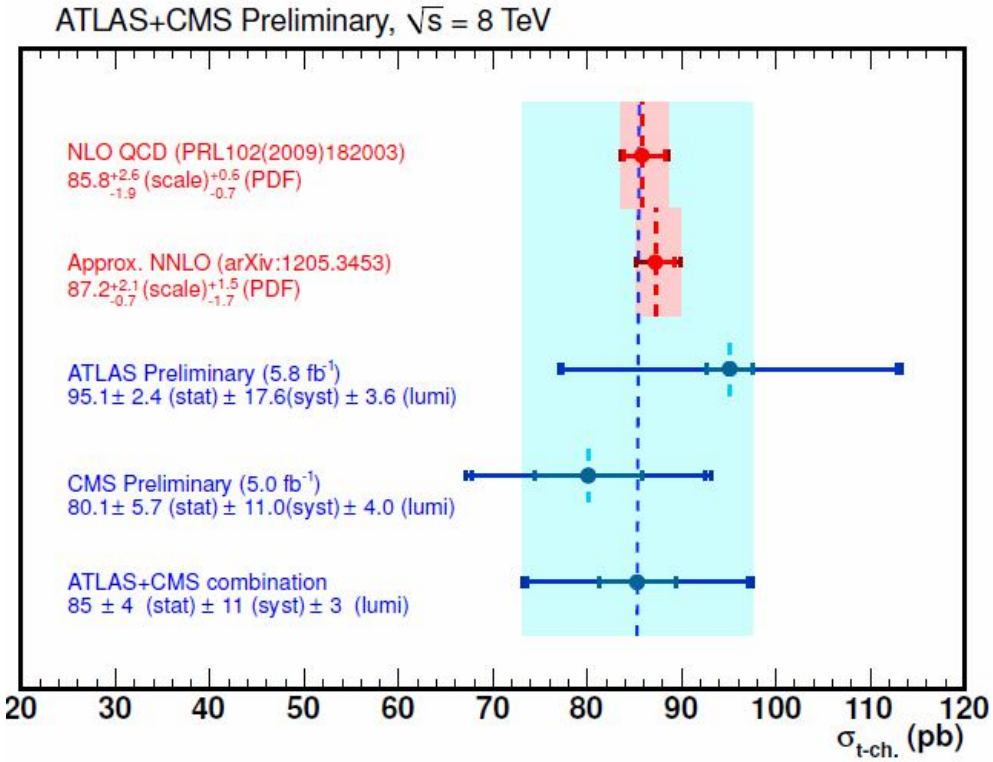
Method

Iterative BLUE (Best Linear Unbiased Estimator)

Mapping of uncertainty contributions in separate categories

Assumption of correlation factors of different categories

Stability of the combined result tested varying correlation factors



Source	Uncertainty (pb)
Statistics	4.1
Luminosity	3.4
Simulation and modelling	7.7
Jets	4.5
Backgrounds	3.2
Detector modelling	5.5
Total systematics (excl. lumi)	11.0
Total systematics (incl. lumi)	11.5
Total uncertainty	12.2

Largest uncertainties: simulation and modeling systematics

FCNC in BSM

Aguilar - Saavedra, ACTA Phys. Pol. B 35 (2004)

	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY
$t \to uZ$	8×10^{-17}	1.1×10^{-4}	–	–	2×10^{-6}	3×10^{-5}
$t \to u\gamma$	3.7×10^{-16}	7.5×10^{-9}	–	–	2×10^{-6}	1×10^{-6}
$t \to ug$	3.7×10^{-14}	1.5×10^{-7}	–	–	8×10^{-5}	2×10^{-4}
$t \to uH$	2×10^{-17}	4.1×10^{-5}	5.5×10^{-6}	–	10^{-5}	$\sim 10^{-6}$
$t \to cZ$	1×10^{-14}	1.1×10^{-4}	$\sim 10^{-7}$	$\sim 10^{-10}$	2×10^{-6}	3×10^{-5}
$t \to c\gamma$	4.6×10^{-14}	7.5×10^{-9}	$\sim 10^{-6}$	$\sim 10^{-9}$	2×10^{-6}	1×10^{-6}
$t \to cg$	4.6×10^{-12}	1.5×10^{-7}	$\sim 10^{-4}$	$\sim 10^{-8}$	8×10^{-5}	2×10^{-4}
$t \to cH$	3×10^{-15}	4.1×10^{-5}	1.5×10^{-3}	$\sim 10^{-5}$	10^{-5}	$\sim 10^{-6}$

Table 1: Branching ratios for top FCN decays in the SM, models with $Q = 2/3$ quark singlets (QS), a general 2HDM, a flavour-conserving (FC) 2HDM, in the MSSM and with R parity violating SUSY.

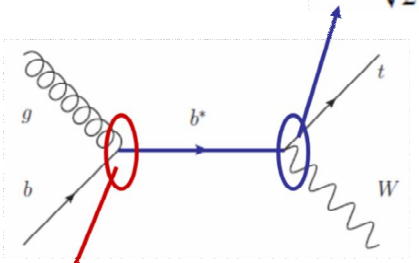
b* search @ 7 TeV (4.7 fb^{-1})

Phys. Lett. B 721 (2013) 171-189

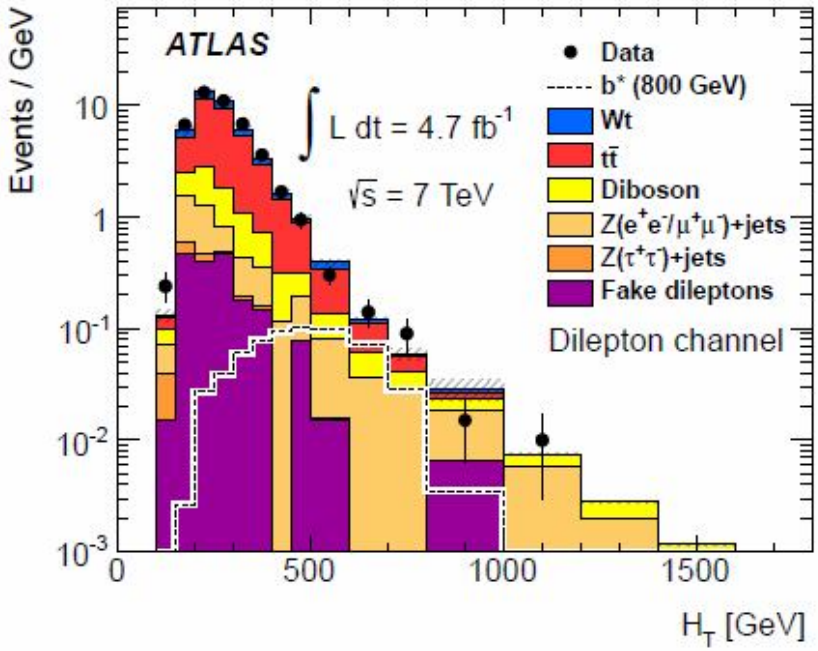
Single b*-quark produced through chromomagnetic interaction and decays to a W+t

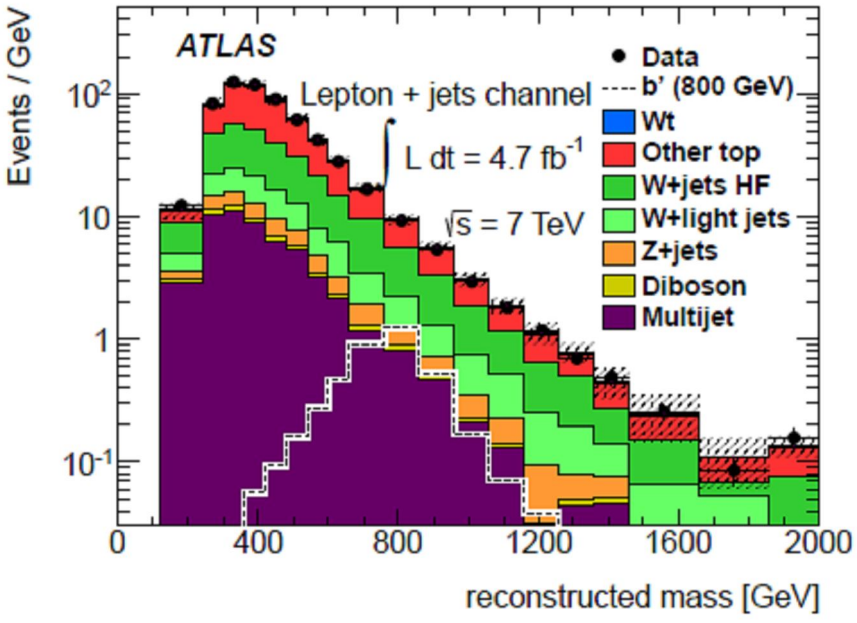
ATLAS: search performed in dilepton and lepton+jets final states and combined

$$\mathcal{L} = \frac{g_2}{\sqrt{2}} W_\mu^+ \bar{t}\gamma^\mu \left(g_L P_L + g_R P_R\right) b^* + \text{h.c}$$



$$\mathcal{L} = \frac{g_s}{2\Lambda} G_{\mu\nu}\, \bar{b}\, \sigma^{\mu\nu} \left(\kappa_L^b P_L + \kappa_R^b P_R\right) b^* + \text{h.c.}$$

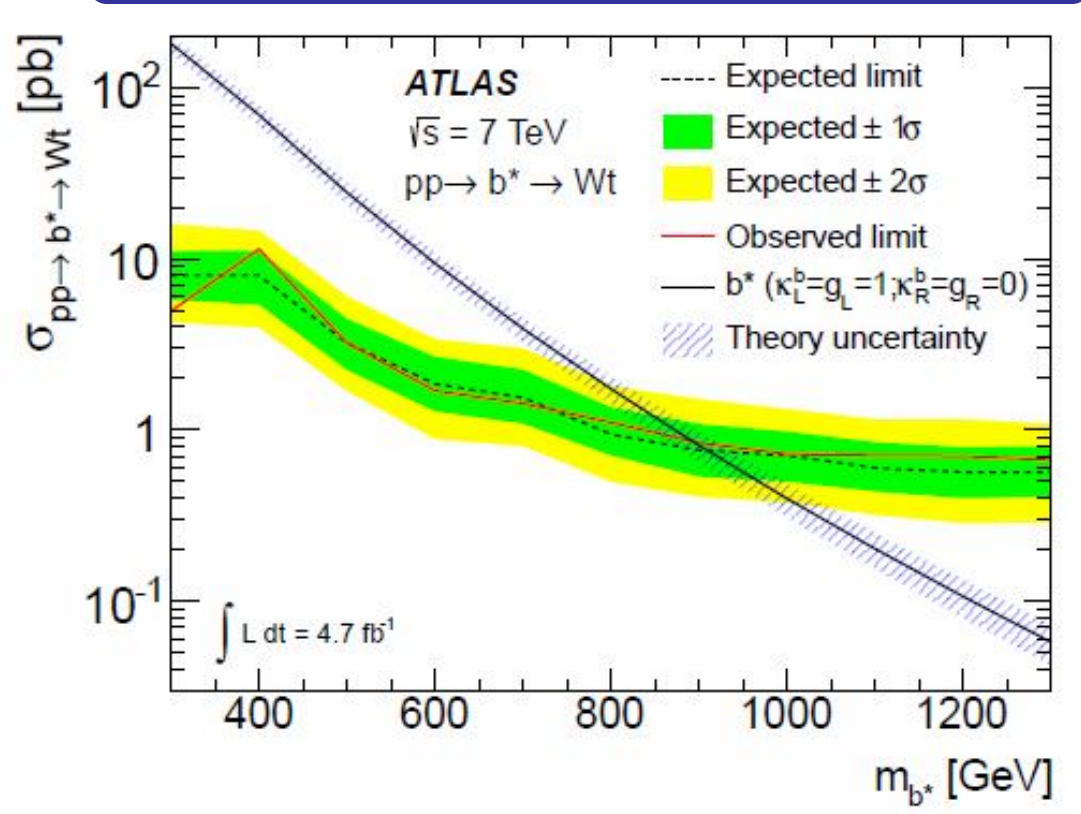




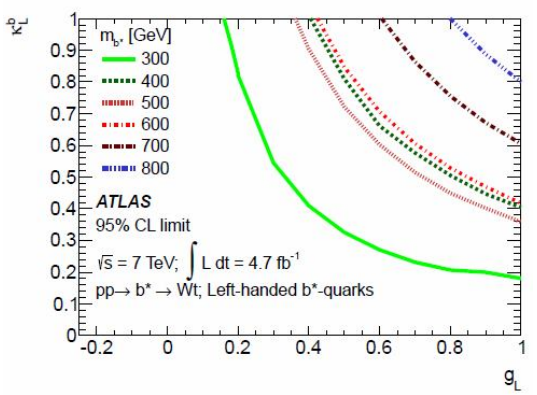
b* search

Phys. Lett. B 721 (2013) 171-189

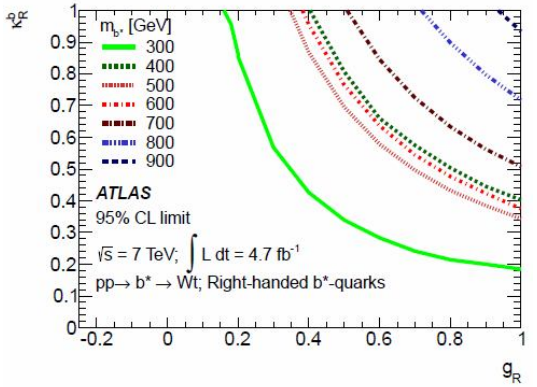
Limits on b* mass and couplings: $K_{L,R}$, $g_{L,R}$



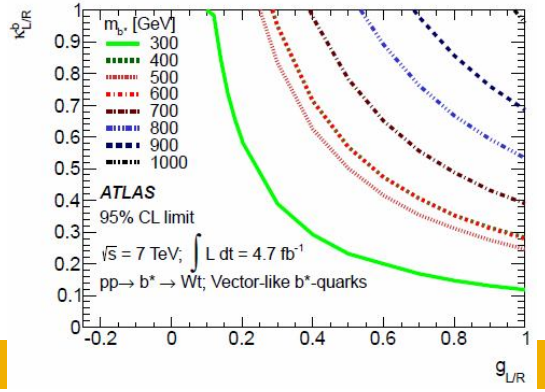
m(b*)>870 GeV at 95% C.L
(benchmark scenario)



(a)



(b)



CP Violation @ 7 TeV (4.7 fb^{-1})

ATLAS-CONF-2013-032

In the Standard Model the couplings of the *Wtb* vertex are reduced to $V_L \simeq 1$ and $V_R = g_{R,L} = 0$ at leading order.

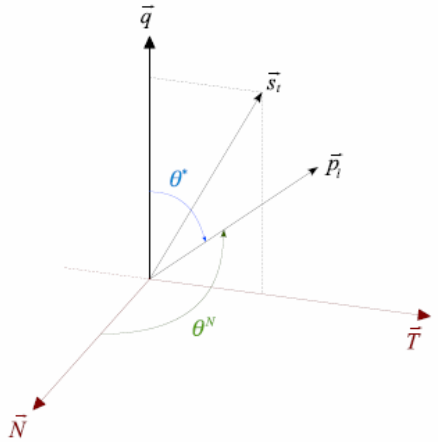
A forward-backward asymmetry with respect to the normal to the plane defined by the *W* momentum and the top quark polarization, A^N_{FB}, is used to probe the complex phase of g_R.

A non-zero value of this asymmetry signals a CP violating contribution to the *Wtb* vertex not expected in the Standard Model.

$$A_{FB}^{N} = \frac{N_{evt}(\cos\theta^{N}>0) - N_{evt}(\cos\theta^{N}<0)}{N_{evt}(\cos\theta^{N}>0) + N_{evt}(\cos\theta^{N}<0)}$$

Very sensitive to the imaginary part of the anomalous coupling g_R $\quad A_{FB}^{N} = 0.64\, P\, \mathbb{I}(g_R)$

$$A_{FB}^{N} = 0.031 \pm 0.065(\text{stat.})^{+0.029}_{-0.031}(\text{syst.})$$



CP Violation @ 7 TeV (4.7 fb^{-1})

ATLAS-CONF-2013-032