Single top production cross section using the ATLAS detector at the LHC

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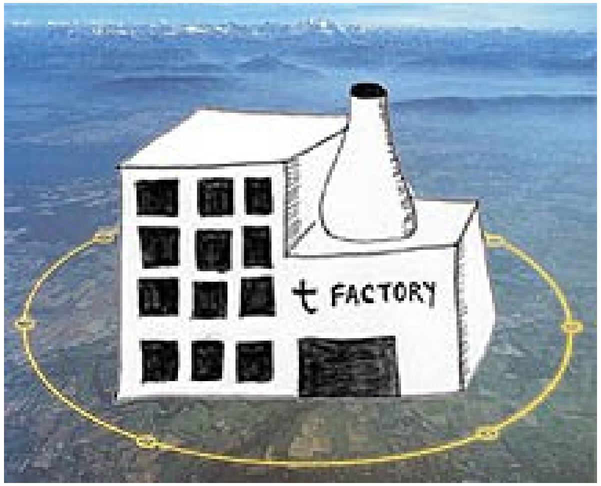
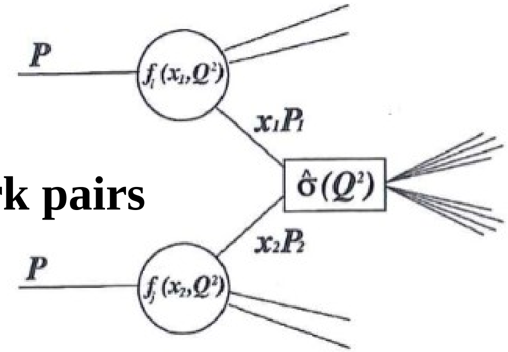
Top production @ the LHC

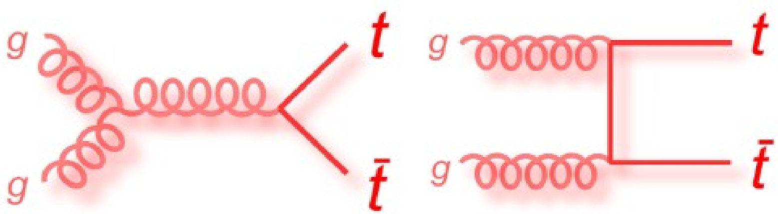


Proton-proton collisions
at sqrt(s)= 7 TeV (2011) and 8 TeV (2012)
generated **more than 5 millions of top quark pairs via strong interaction**

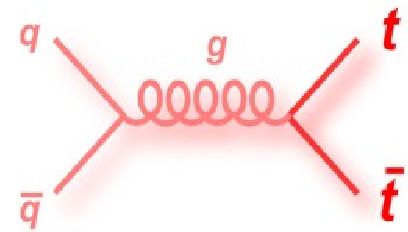


TOP PAIR PRODUCTION

gluon-gluon fusion (90%)



quark-quark annihilation (10%)

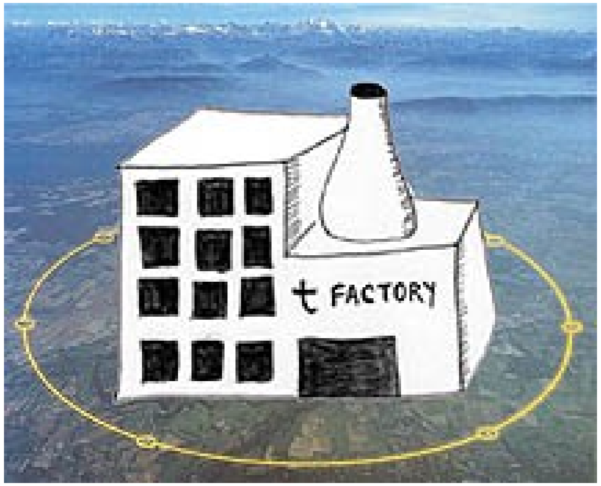


Predicted cross section at NNLO in QCD
including resummation of NNLL soft gluon terms with top++2.0
m(t)c^2=172.5 GeV, uncertainty accounting for PDF and scale variations

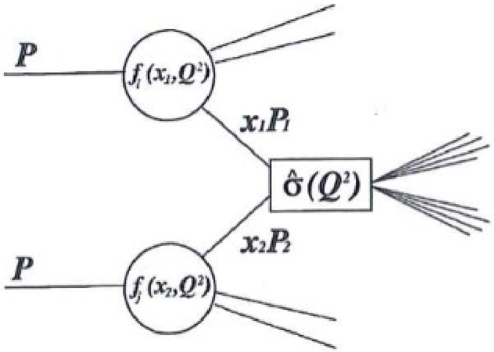
	LHC @ 7 TeV	LHC @ 8 TeV
$\sigma_{t\bar{t}}$	177^{+10}_{-11} pb	253^{+13}_{-15} pb

(Phys Lett B 710, 2012)

Top production @ the LHC

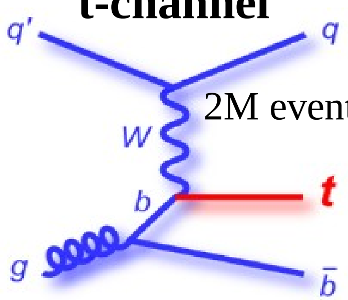


Proton-proton collisions
at sqrt(s)= 7 TeV (2011) and 8 TeV (2012)
generated **more than 2.5 millions of top quarks via electroweak interaction**



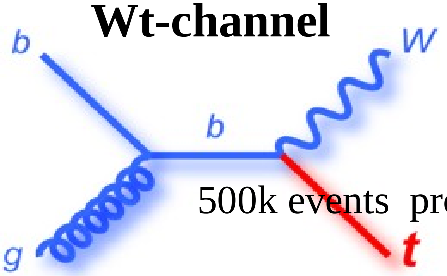
SINGLE TOP PRODUCTION

t-channel



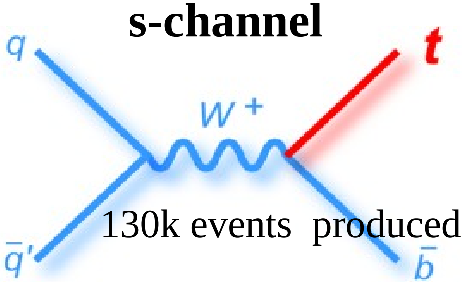
2M events produced

Wt-channel



500k events produced

s-channel



130k events produced

Predicted cross sections at NLO in QCD + NNLO soft-gluon corrections
m(t)c^2=172.5 GeV, uncertainty accounting for PDF and scale variations

	LHC @ 7 TeV	LHC @ 8 TeV
σ_t	$64.57^{+2.63}_{-1.74}$ pb	$87.76^{+3.44}_{-1.91}$ pb
σ_{Wt}	$15.74^{+1.17}_{-1.21}$ pb	$22.37^{+1.52}_{-1.52}$ pb
σ_s	$4.63^{+0.20}_{-0.18}$ pb	$5.61^{+0.21}_{-0.21}$ pb

(Phys. Rev. D 83, 091503(R), 2011)

(Phys. Rev. D 82, 054018, 2010)

(Phys. Rev. D 81, 054028, 2010)

Single top motivation

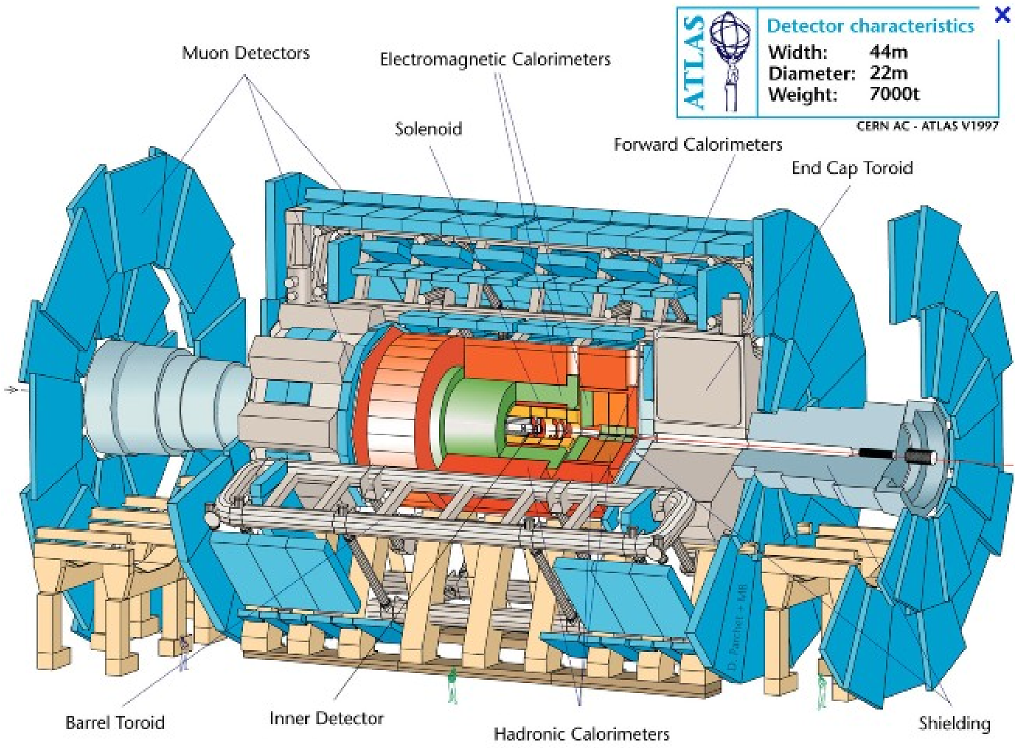
Why looking for single top with the ATLAS detector?

- Precision test of the Standard Model
  t-channel , Wt associated production, s-channel cross section measurements
  extraction of the CKM matrix element $|V_{tb}|$

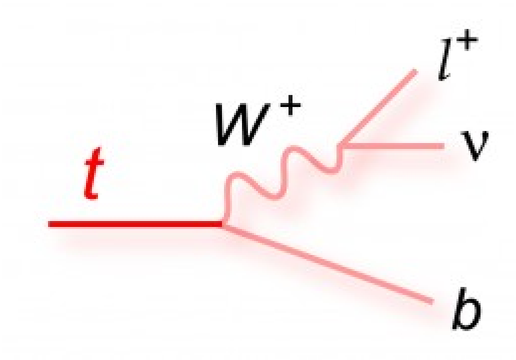
- PDF constraints
  t-$\bar{t}$ cross section ratio

- Direct sensitivity to new physics
  - Flavor Changing Neutral Currents (t-channel final state)
  - Heavy resonances i.e W' boson (s-channel final state)

only analyses reported here are cited



Object modelling



Electrons: isolated electromagnetic calorimeter clusters matched to inner detector tracks

Muons: muon spectrometer p_T associated to ID track

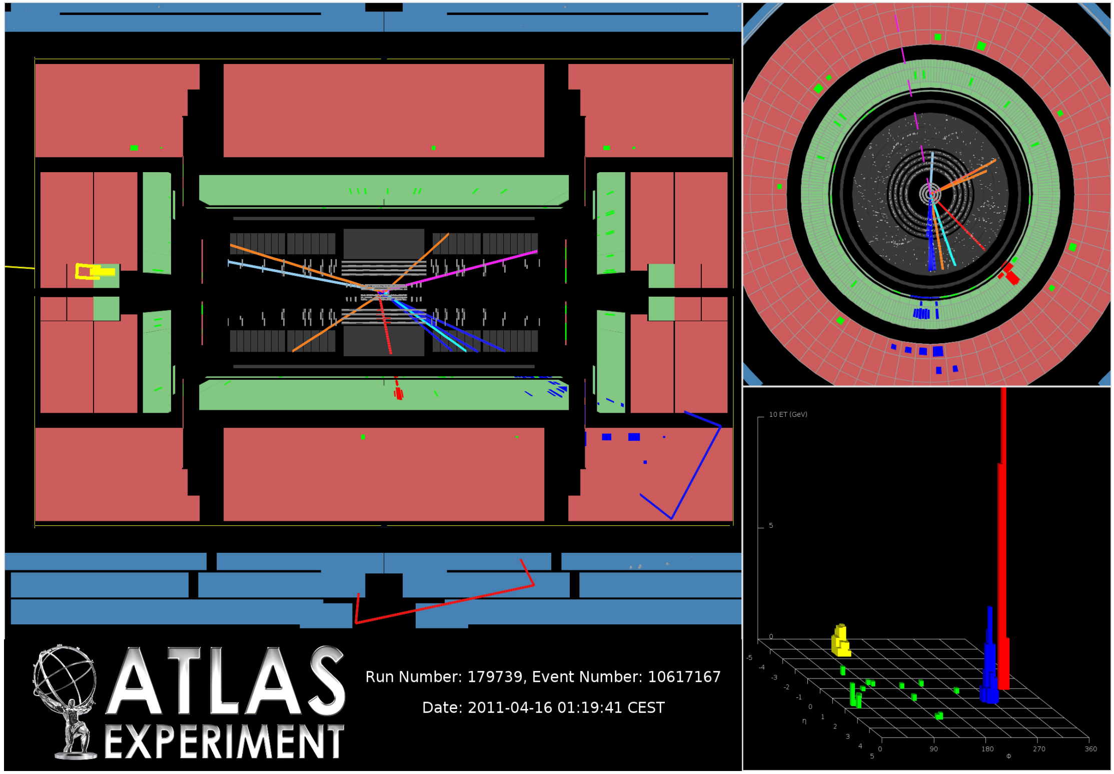
Associated experimental systematic uncertainties:
Lepton energy/momentum scale & resolution
Lepton trigger & ID efficiency

E_T^{miss}: extracted from total energy for particles travelling perpendicular to the beam axis

Missing momentum scale & resolution

b-tagged jets: hadronic calorimeter clusters + multivariate combination of topological variables and b-tagging algorithms

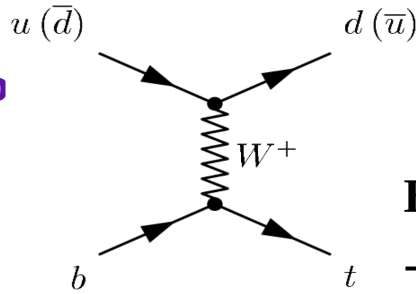
Jet energy scale, several component (JES)
Jet energy resolution, reconstruction efficiency
Jet vertex fraction, b-tagging and mis-tagging efficiency



Precision measurements

t-channel cross section

8 TeV analysis, $\int Ldt$=20.3 fb



(ATLAS-CONF-2014-007)

Event selection

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

Multivariate analysis

t-channel discrimination realized by combining 14 kinematic variables into a Neural Network discriminant

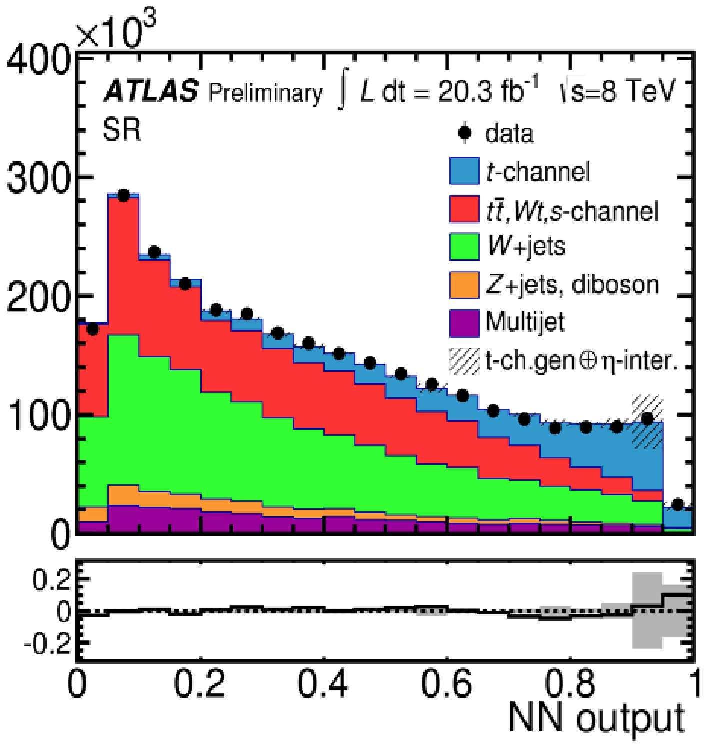
Systematic uncertainty

Pseudo experiments estimate the impact of background normalization, luminosity, object modelling (JES η intercalibration being the greatest), PDF & generator.

New procedure to minimize them

Backgrounds

- Dominant contributions from ttbar and W+jets events, examined in specific control regions
- multijet data driven normalization
  - E_T^{miss} fit for e+jets final state,
  - matrix method for μ+jets final state



t-channel cross section

Fiducial cross section

$$\sigma_{\text{fid}} = \frac{\epsilon_{\text{corr,sel}}}{\epsilon_{\text{corr,fid}}} \cdot \frac{\hat{\nu}}{\mathcal{L}} = R_f \cdot \frac{\hat{\nu}}{\mathcal{L}}$$

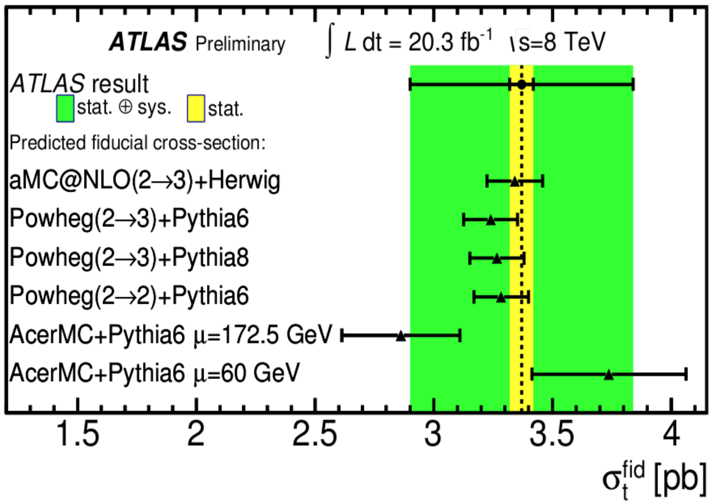
Fraction of events selected by offline selection which are in the fiducial volume (vice-versa)

Fit to the maximum likelihood to the NN output distribution

Fiducial volume within the detector acceptance: stable particles with lifetime>30 ps

Object	Cut
Electrons	$p_T > 25$ GeV and $\lvert\eta\rvert < 2.5$
Muons	$p_T > 25$ GeV and $\lvert\eta\rvert < 2.5$
Jets	$p_T > 30$ GeV and $\lvert\eta\rvert < 4.5$
	$p_T > 35$ GeV, if $2.75 < \lvert\eta\rvert < 3.5$
Lepton (ℓ), Jets (j_i)	$\Delta R(\ell, j_i) > 0.4$
E_T^{miss}	$E_T^{\text{miss}} > 30$ GeV
Transverse W-boson mass	$m_T(W) > 50$ GeV
Lepton (ℓ), jet with the highest p_T (j_1)	$p_T(\ell) > 40\text{ GeV}\left(1 - \frac{\pi - \lvert\Delta\phi(j_1,\ell)\rvert}{\pi - 1}\right)$

Measured fiducial cross-section vs predictions for different MC event generators



$$\boxed{\sigma_{\text{fid}} = 3.37 \pm 0.05\,(\text{stat.}) \pm 0.47\,(\text{syst.}) \pm 0.09\,(\text{lumi.})\ \text{pb}}$$

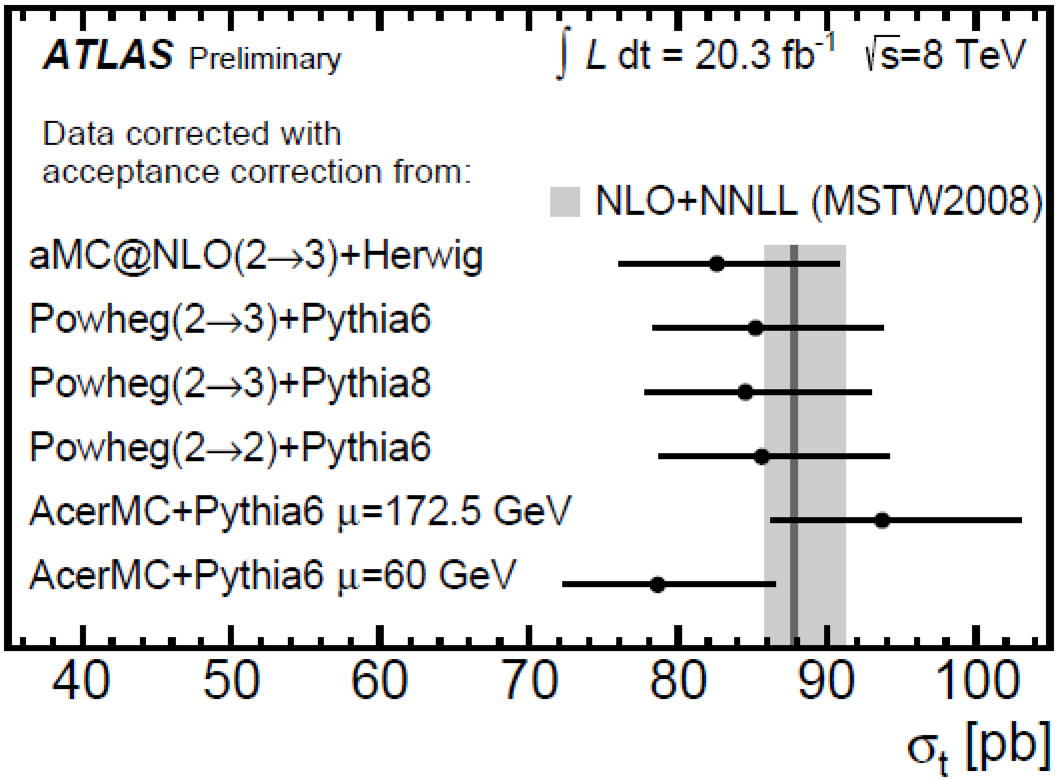
Relative uncertainty: 14% vs 17% using the acceptances referred to the full phase space
Dominant contributions: JES η intercalibration, t-channel generator

t-channel cross section

Extrapolation of the inclusive cross section and Vtb

The fiducial cross section is extrapolated to the full phase space where ϵ_{fid} is the selection efficiency of the particle-level selection

$$\sigma = \frac{1}{\epsilon_{\rm fid}} \cdot \sigma_{\rm fid}$$

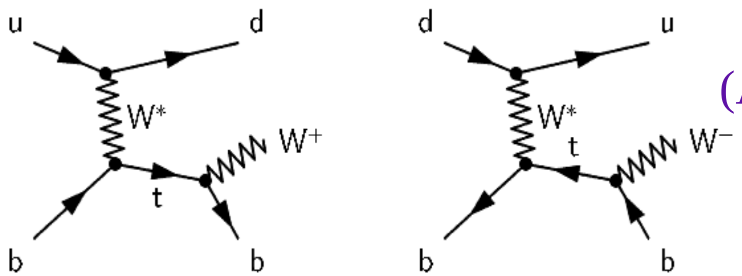


- Vertical line indicates the approximate NNLO cross-section, including the uncertainty
- Extrapolations using the acceptance of several MC generators and renormalization scales
  Uncertainty on the fiducial cross section +PDF

$$\sigma_t \quad = \quad 82.6 \pm 1.2\,(\mathrm{stat.}) \pm 11.4\,(\mathrm{syst.}) \pm 3.1\,(\mathrm{PDF}) \pm 2.3\,(\mathrm{lumi.})\ \mathrm{pb}$$

t-channel cross section ratio

7 TeV analysis, ∫Ldt=4.7 fb^{-1} (ATLAS-CONF-2012-056)



Motivations

- $R_t=\sigma_t(t)/\sigma_t(\bar{t})$ sensitive to the ratio of u-quark to d-quark PDFs in the range 0.02<x<0.5
  → further constraint on PDFs (complementary to W asymmetry)
- Smaller uncertainties than the total cross section because of partial cancellations

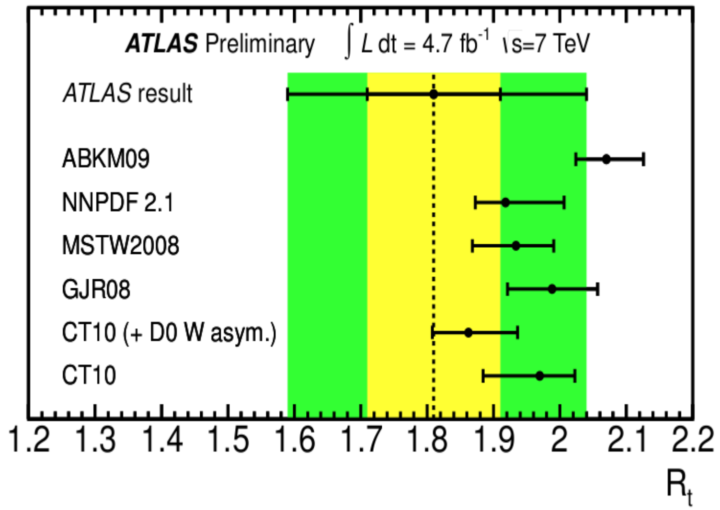
Almost the same strategy than 8TeV t-channel, except:

- Inclusive selection of 2 or 3 jets events, looser cut $m_T(W)>30$ GeV
- Data driven background estimates: multijet & W+jets
- Neural Network training done individually for 4 channels: 2jets+l$^{+/-}$, 3jets+l$^{+/-}$
- 4 NN discriminants fitted simultaneously

Results

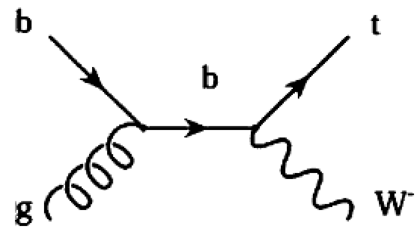
$$\sigma_t(t) = 53.2 \pm 1.7\,(\text{stat.}) \pm 10.6\,(\text{syst.})\,\text{pb} = 53.2 \pm 10.8\,\text{pb}$$
$$\sigma_t(\bar{t}) = 29.5 \pm 1.5\,(\text{stat.}) \pm 7.3\,(\text{syst.})\,\text{pb} = 29.5^{+7.4}_{-7.5}\,\text{pb.}$$
$$R_t = 1.81 \pm 0.10\,(\text{stat.})\,^{+0.21}_{-0.20}\,(\text{syst.}) = 1.81^{+0.23}_{-0.22}$$

Dominant systematic uncertainties: JES, btag, generator



Wt-channel cross section

8 TeV analysis, $\int L dt = 20.3\ fb^{-1}$



(ATLAS-CONF-2013-100)

Event selection

- 2 isolated opposite sign leptons $p_T > 25$ GeV
  eμ final state only (best signal purity)
- 1 or 2 jets, 1 b-tagged, $p_T > 30$ GeV

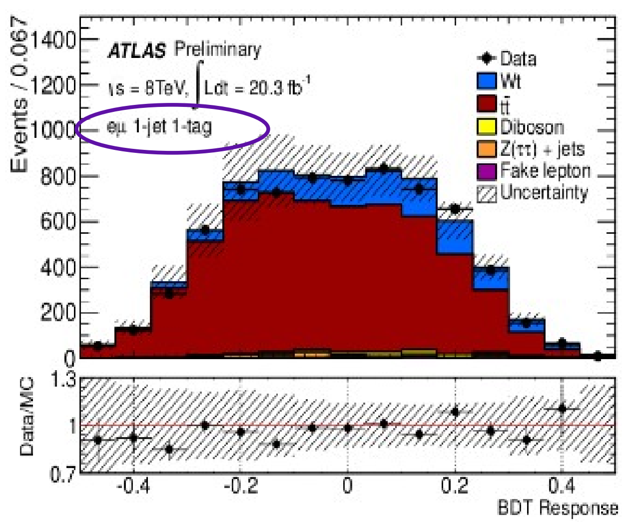
Backgrounds

- Big contribution from top pair production, Z(ττ)+jets & diboson events contribute also
- MC modeling for every source except multijet, estimated via the matrix method

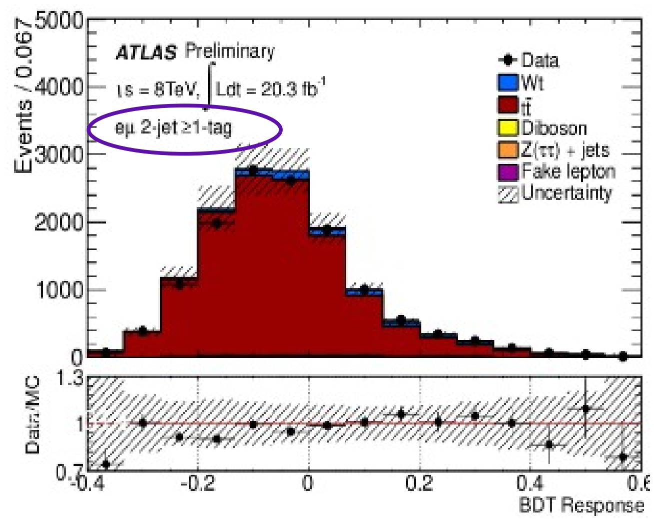
Multivariate analysis

Boosted Decision Trees optimized separately for 1 jet and 2 jets events to account for differences in topology and kinematics

19 variables



20 variables



Wt-channel cross section

Results

Simultaneous maximum likelihood fit to the two BDT output distributions

σ_{wt}=27.2 ± 2.8 (stat) ± 5.4 (syst) pb
Significance = 4.2 σ

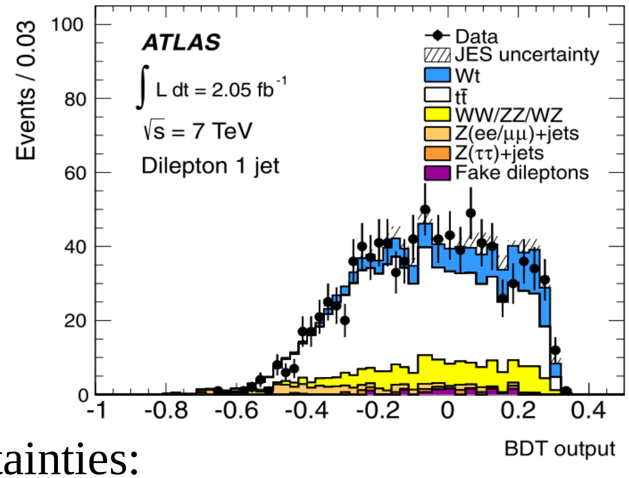
Main systematic uncertainties:
JES detector modelling component, btag, E_t^{miss} scale (all profiled), generator and parton shower

7 TeV analysis, ∫Ldt=4.7 fb^{-1} (Phys.Lett. B 716 2012)

Similar strategy than 8TeV Wt-channel, different selection & background modeling:

- eμ/ee/μμ opposite sign dilepton categories, cuts to reduce Z decays contamination
- 1, 2, ≥ 3 jets events to control the main backgrounds, no b-tagging requirement
- E_T^{miss}>50 GeV
- data-driven estimates for Drell-Yan processes

Simultaneous maximum likelihood fit of 3 BDTs distributions (optimized per jet-bin) → FIRST EVIDENCE!

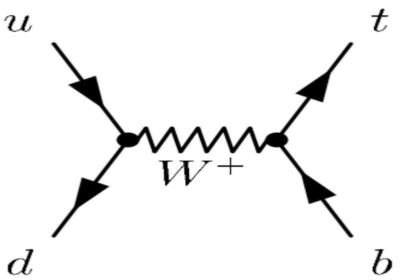


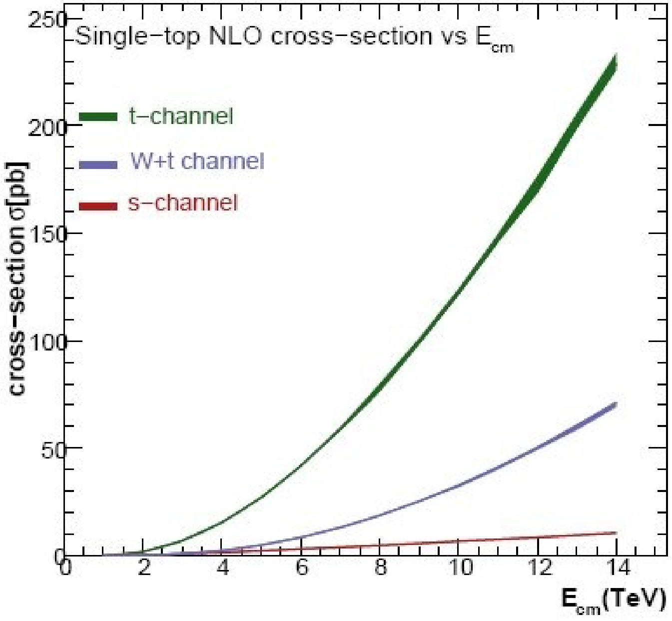
σ_{wt}=16.8 ± 2.9 (stat) ± 4.9 (syst) pb
Significance = 3.4 σ

Main systematic uncertainties:
JES, btag, pile-up, generator and parton shower

s-channel cross section

s-channel is the most challenging production mode at the LHC since it proceeds via q-$\bar{q}$ annihilation





7 TeV analysis, $\int Ldt=0{,}7\ fb^{-1}$ (ATLAS-CONF-2011-118)

Event preselection

- 1 isolated e/μ, p_T>25 GeV
- 2 central jets, both b-tagged, p_T>25 GeV
- E_T^{miss}>30 GeV, $m_T(W)$ > 60 GeV - E_T^{miss}

Cut-based analysis

Most discriminating variables [$m_T(W)$, p_T(jet1,jet2), m(top, jet1/2), ΔR(jet1, jet2), ΔR(jet1, l)] employed to increase S/√B from 0.26 to 0.98

Backgrounds

- huge contamination from top pair production and W+jets

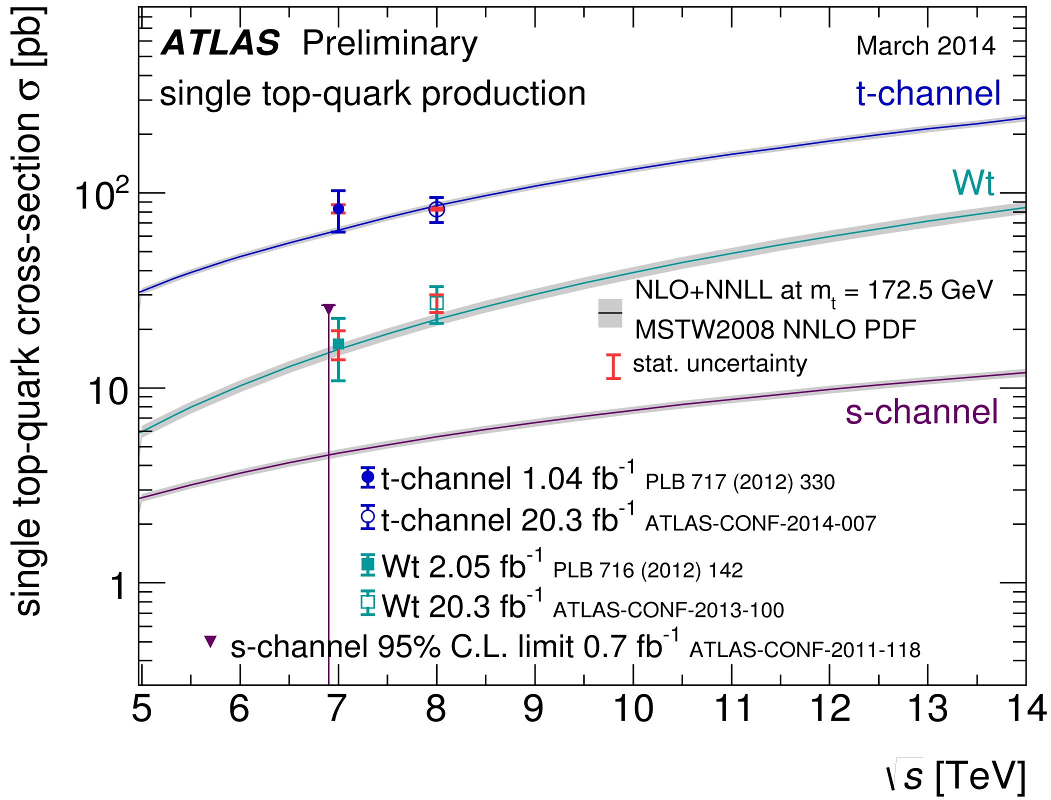
- data-driven estimates for multijet and W+jets events

Results

Counting experiment modelled by a likelihood function fitted to the data

→ $\boxed{\text{upper limit @ 95\% CL: } \sigma_s < 26.5 \text{ pb}}$

single top measurements



Cross section measurements for the 3 channels:

→ no deviation wrt SM expectations

→ constraints on BSM physics, since the production mechanisms are separately susceptible to new physics scenarios

→ constraints on W-t-b vertex, which appears in the production and decay

Direct $|V_{tb}|$ measurement, assuming it is >> $|V_{ts}|$, $|V_{td}|$ independently on the number of quark generations & the CKM matrix unitarity:

$|V_{tb}f|^2 = \sigma_{measured} / \sigma_{predicted}$
with f=1 in the SM

$\lvert V_{tb}\rvert$	t-channel	Wt-channel
$\sqrt{s}$=7 TeV	$1.13^{+0.14}_{-0.13}$ (11.9 %)	$1.03^{+0.16}_{-0.19}$ (17.0 %)
$\sqrt{s}$=8 TeV	$0.97^{+0.09}_{-0.10}$ (9.8 %)	1.10 ± 0.12 (11.2 %)

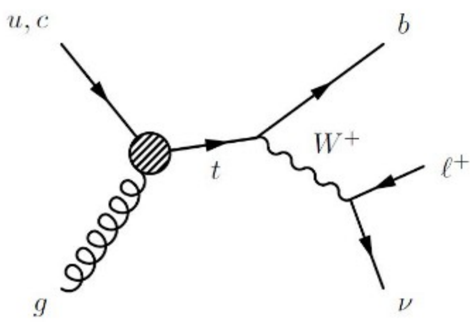
BSM Physics

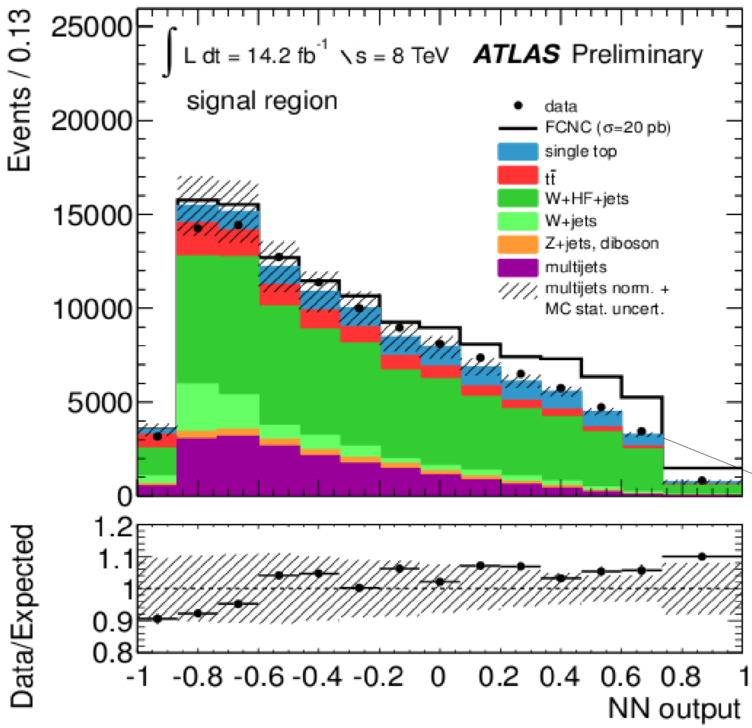
FCNCs in single top production

8 TeV analysis, $\int L dt = 14.2\ \text{fb}^{-1}$ (ATLAS-CONF-2013-063)

Motivations

- FCNC higly suppressed by SM, but enhanced in many BSM scenarios
- $qg \rightarrow t \rightarrow l\nu b$ single top production has good sensitivity
  and distinct kinematical properties from the SM process:
  softer top-quark p_T, higher W p_T, strongly charge asymmetric production





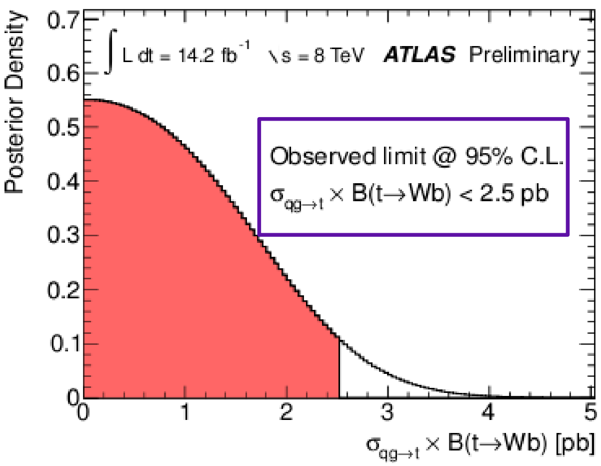
Analysis strategy

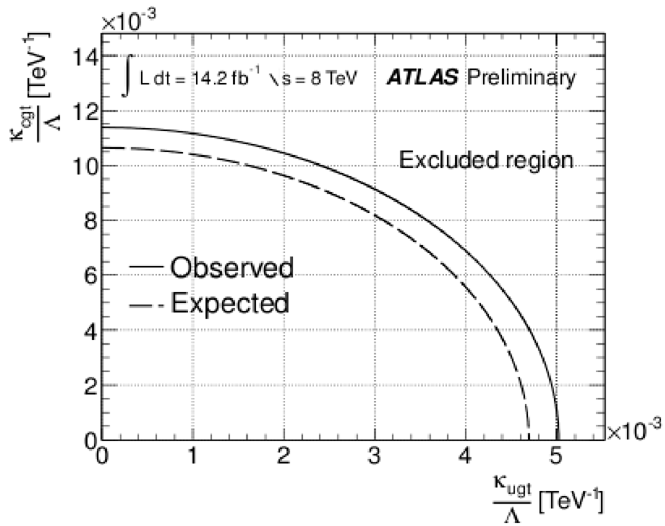
- Same event selection & background modelling of the t-channel cross section analysis @ 8 TeV
- NLO generator (METOP) simulates strong FCNC processes
- Neural Network classifier built from 13 variables
- Binned likelihood fit to the NN output distribution to extract the FCNC contribution

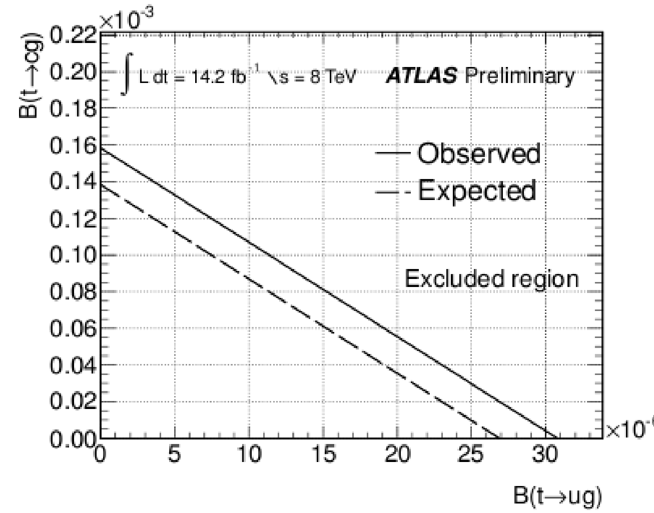
No excess observed,
here signal shape scaled to 20 pb

FCNCs in single top production

Results (A) (B) (C)







(A) Upper limit on cross section * branching fraction

(B) With the hypotheses of pure left-handed coupling & B(t→Wb)=1
⇒ limits on the coupling strength $\sigma_{qg\to t} = 100351.97\left(\frac{\kappa_{ugt}}{\Lambda}\right)^2 + 19496.79\left(\frac{\kappa_{cgt}}{\Lambda}\right)^2$ pb

(C) For small coupling constants (k<0.1)
⇒ limits on the branching fractions $\mathcal{B}(t\to qg) = \frac{\Gamma_{t\to qg}}{\Gamma_{t\to bW}} = 1.2205 \times \left(\frac{\kappa_{gqt}}{\Lambda}\right)^2$

7 TeV analysis, ∫LdL=4.7 fb^{-1} (Phys.Lett. B 712 2012)

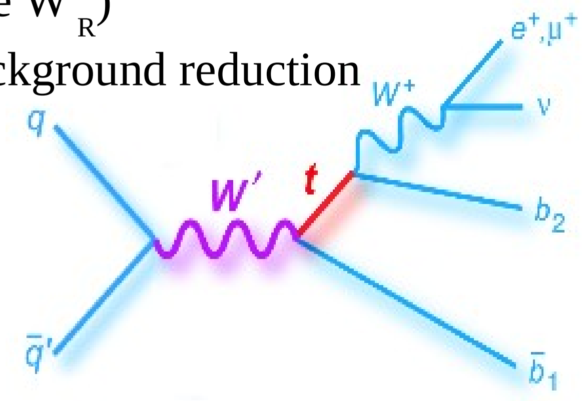
Analogous analysis, less stringent limits [by a factor 3 on (A) and (C), by a factor 2 on (B)]

W' boson search

8 TeV analysis, $\int Ldt=14.2\ fb^{-1}$ (ATLAS-CONF-2013-050)

Motivations

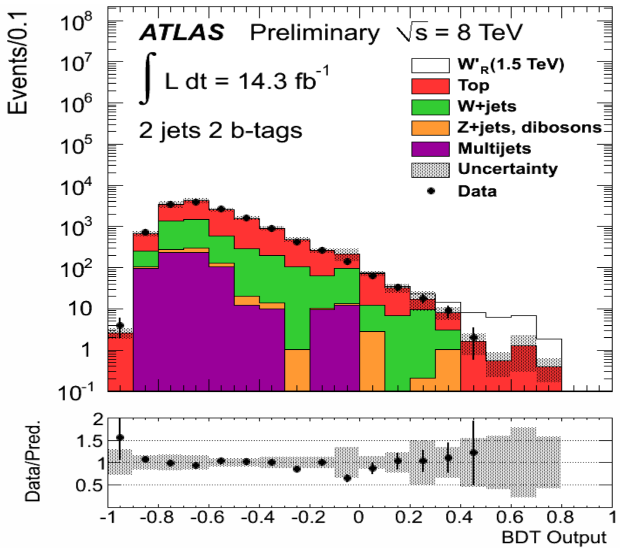
- Predicted by many BSM theories
- W' → tb signature allows to assess models with leptophobic W' (i.e W'_R)
- Semileptonic final state ⇒ cleaner experimental signature and background reduction



Analysis strategy

- Almost same event selection & background modelling than s-channel cross section analysis @ 7 TeV + m(tb)>270 GeV
- LO generator (MADGRAPH) rescaled to NLO XS calculations (Sullivan Phys. Rev. D 86, 075018) provided for various W' chiralities and masses (0.5 - 3 TeV, steps of 250 GeV)
- Signal discrimination via two Boosted Decision Trees with 2-jets & 3-jets events. In the training: W'_R (1.75 TeV), which minimizes the expected limit
- Simultaneous fit of the BDT output distribution in 2 channels for each value of the hypothesized $W_{R/L}'$ mass

  ⇒ CLs limit @ 95% CL

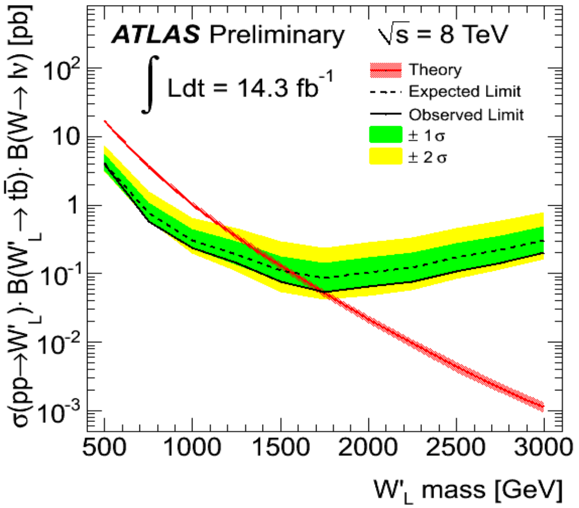


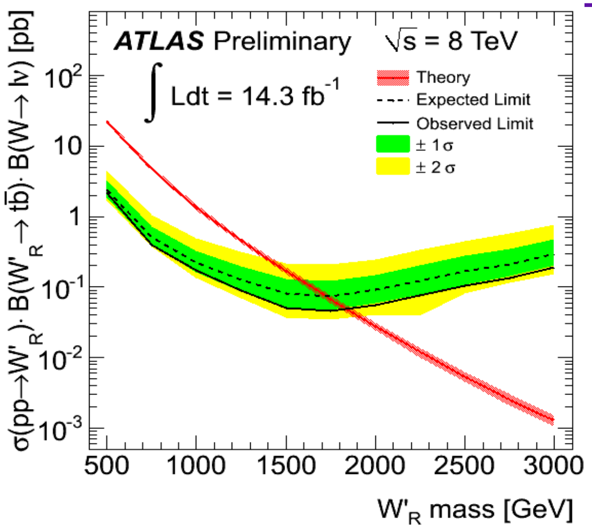
W' boson search

Results

Exclusion limits on W' cross section and mass:

$m(W'_R)>1.84$ TeV $m(W'_L)>1.74$ TeV

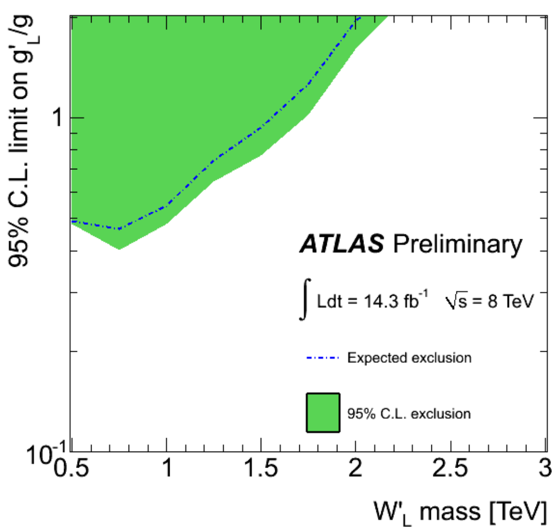


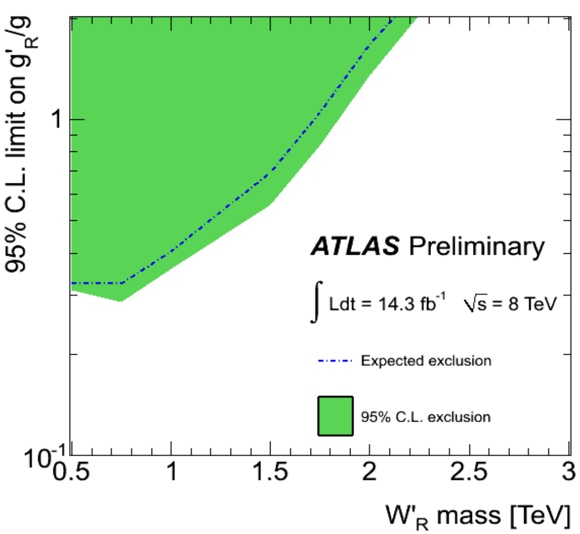


$\sigma(W') \sim (g'/g_{SM})^2$

The hypothesis g' for the mass $m_{W'}$ is excluded if $\sigma(g',m_{W'})>\sigma(m_{W'})$ for a given W' chirality

Exclusion limits on W' couplings (model-independent):





Limits are shown up to a g'/g_{SM} value of 2, for which the approximation holds

Conclusion

- Single top production in ATLAS:
  - observed with high precision in the t-channel
  - evidence in the Wt associate production
  - upper limit for the s-channel

- All the measured cross section are in overall agreement with Standard Model NLO QCD + NNLL predictions and, thus, help to constrain new physics

- BSM searches sharing single top final states show no evidence for W' bosons or FCNCs

...Next LHC phase will push the energy frontier upward,

and the higher luminosity will enlarge the statistics

$\Rightarrow$ improvement of the precision of the analyses involving t-channel and Wt final states !

Backup slides

Data driven bkg estimates

Multijet: MATRIX METHOD

Modelled from tight and loose data samples merged with the MM weight (derived from the efficiencies and fake rates measured on data)

$$N^{tight}_{fake} = \frac{\epsilon_{fake}}{\epsilon_{real} - \epsilon_{fake}} (N^{loose}\epsilon_{real} - N^{tight})$$

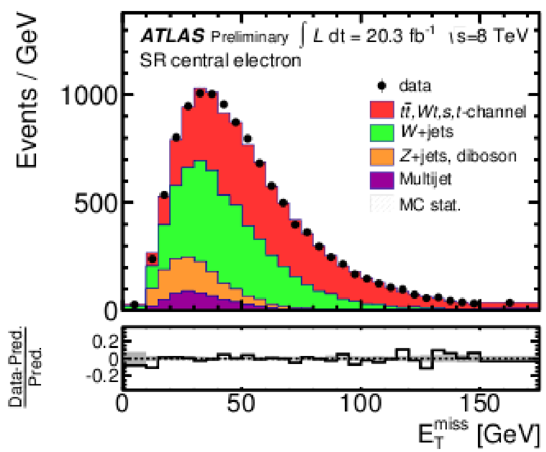
gives the normalization

$$w_{tight} = \epsilon_{fake} \frac{\epsilon_{real} - 1}{\epsilon_{real} - \epsilon_{fake}}$$

is applied for the shapes

Multijet: E_T^{miss} FIT

Normalization: binned maximum likelihood fit on the observed $\mathbf{E_T^{miss}}$ in a control region



- Simulated multijet events with jet-electron model for e+jets final states
- Data driven multijet events with anti-muon method in μ+jets final states

W+jets:

Monte Carlo template with data driven normalization:

- Fit to the discriminant output distribution ($t\text{-}\bar{t}$ ratio)

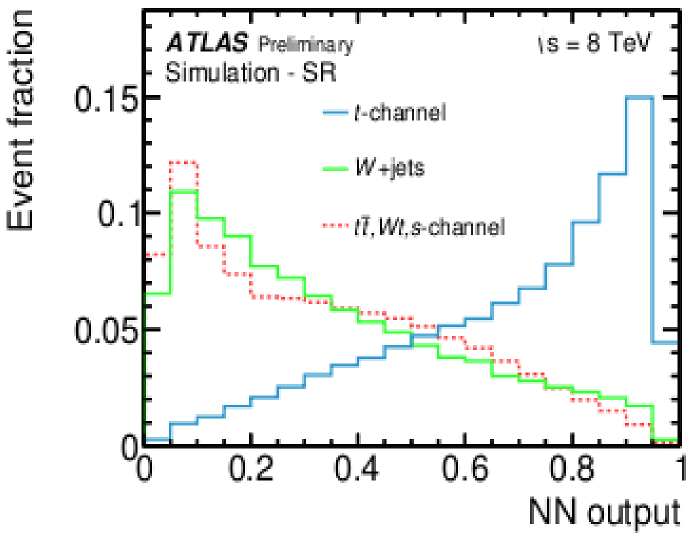
- Overall scale factor (W') obtained per jet-bin and lepton selection in a CR defined by events containing 2 b-tag jets & m(tb)<270 GeV

$$\mathrm{SF}_i = \frac{N^{CR}_{\mathrm{Data},i} - N^{CR}_{\mathrm{other},i}}{N^{CR}_{Wjets,i}}.$$

t-channel cross section

Input variables used for the NN ordered by their importance:

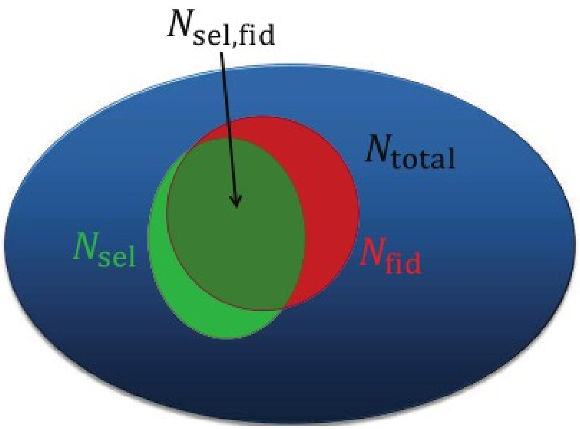
Variable	Definition
$\|\eta(j)\|$	pseudorapidity of the light quark (untagged) jet (j)
$m(\ell\nu b)$	top-quark mass reconstructed from the charged lepton, neutrino and b-quark jet
$m(jb)$	invariant mass of the tagged (b) and light quark jet (j)
$m_{\mathrm{T}}(W)$	transverse mass of the reconstructed W boson
$m(\ell b)$	invariant mass of the lepton (ℓ) and the tagged jet (b)
$\eta(l\nu)$	pseudorapidity of the reconstructed W-boson
$\cos\Theta(\ell, j)_{\ell\nu b\,\mathrm{r.f.}}$	cosine of the angle θ between the charged lepton and the light quark (untagged) jet (j) in the rest frame of the reconstructed top quark
$H_T(l, \mathrm{jets}, E_{\mathrm{T}}^{\mathrm{miss}})$	scalar sum of the transverse momenta of the jets, the charged lepton and the missing transverse momentum
$E_{\mathrm{T}}^{\mathrm{miss}}$	transverse missing momentum
$\Delta R(\ell\nu b, \ell)$	ΔR of the reconstructed top quark and the charged lepton
$p_{\mathrm{T}}(\ell\nu)$	transverse momentum of the reconstructed W-boson
$\eta(\ell\nu b)$	pseudorapidity of the reconstructed top quark
$\eta(b)$	pseudorapidity of the b-quark jet (b)
$p_{\mathrm{T}}(\ell\nu b)$	transverse momentum of the reconstructed top quark



$$\sigma = \frac{\hat{\nu}}{\epsilon\mathcal{L}} = \frac{1}{\epsilon_{\mathrm{fid}}} \cdot \frac{\epsilon_{\mathrm{corr,sel}}}{\epsilon_{\mathrm{corr,fid}}} \cdot \frac{\hat{\nu}}{\mathcal{L}} = \frac{1}{\epsilon_{\mathrm{fid}}} R_f \sigma_{\mathrm{fid}}$$

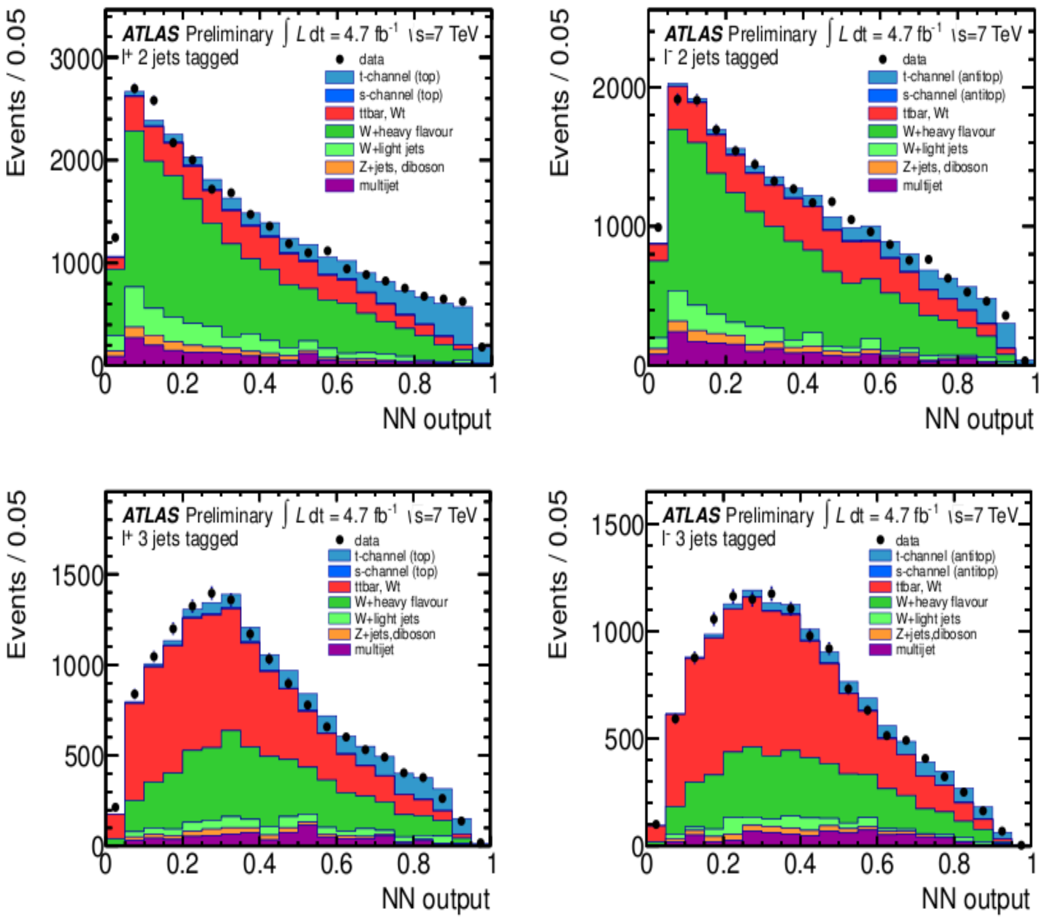
$$\Rightarrow \sigma_{\mathrm{fid}} = \frac{\epsilon_{\mathrm{corr,sel}}}{\epsilon_{\mathrm{corr,fid}}} \cdot \frac{\hat{\nu}}{\mathcal{L}} = R_f \frac{\hat{\nu}}{\mathcal{L}}$$

$$\epsilon = \frac{N_{\mathrm{sel}}}{N_{\mathrm{total}}}, \quad \epsilon_{\mathrm{fid}} = \frac{N_{\mathrm{fid}}}{N_{\mathrm{total}}}, \quad \epsilon_{\mathrm{corr,sel}} = \frac{N_{\mathrm{sel,fid}}}{N_{\mathrm{sel}}}, \quad \epsilon_{\mathrm{corr,fid}} = \frac{N_{\mathrm{sel,fid}}}{N_{\mathrm{fid}}},$$



t-channel cross section ratio

NN distributions:

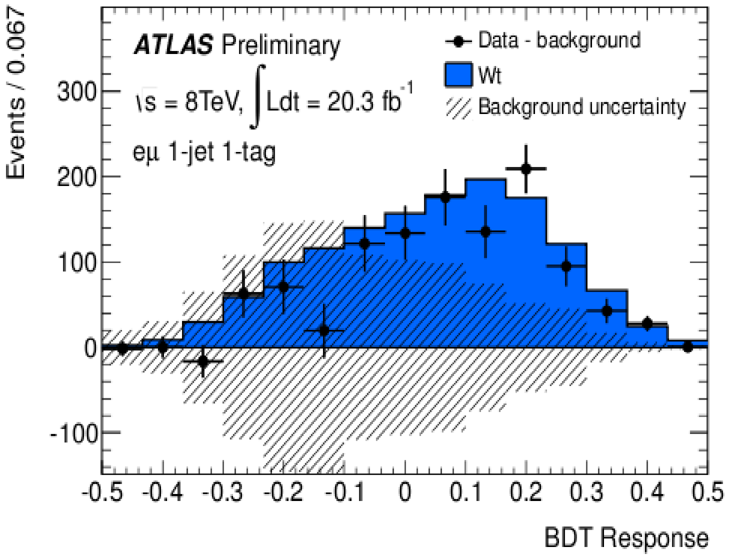


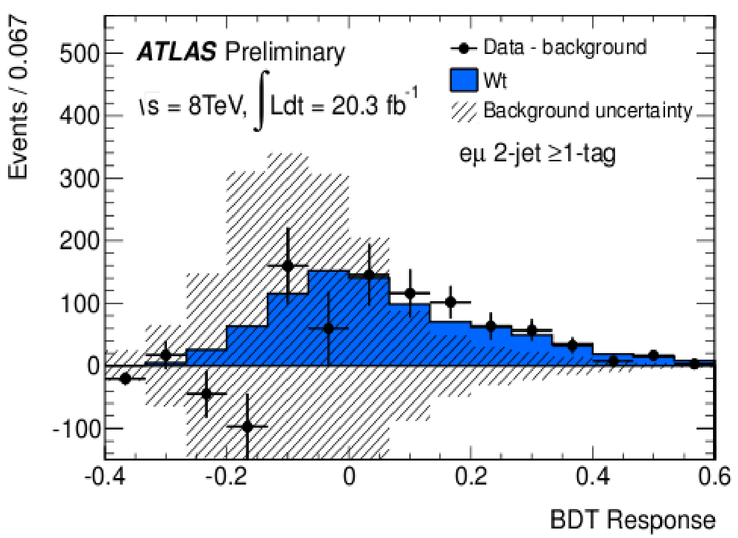
Systematic breakdown:

Source	$\Delta\sigma_t/\sigma_t(t)$ [%]	$\Delta\sigma_t/\sigma_t(\bar{t})$ [%]	$\Delta R_t/R_t$ [%]
Data statistics	±3.2	±5.0	±5.5
MC statistics	±2.4	±3.7	±3.7
Multijet normalisation	+1.1 / -2.0	+3.1 / -4.2	+3.9 / -3.7
Other background normalisation	±3.4	±1.3	±4.5
Jet energy scale	±16.4	±19.5	+3.7 / -3.6
Jet energy resolution	±3.4	±4.3	±0.8
Jet reconstruction efficiency	+0.7 / -0.4	±0.3	+0.8 / -0.5
b-tagging efficiency scale-factor	±5.9	±8.5	±2.5
Mistag efficiency scale-factor	±0.8	±2.0	±2.7
$b/\bar{b}$ acceptance	±1.0	±1.0	±0.4
$E_{\mathrm{T}}^{\mathrm{miss}}$ modeling	+0.6 / -0.9	+0.9 / -1.3	+0.8 / -0.7
Lepton efficiencies	±2.9	±2.9	±0.3
Lepton energy resolution	+0.5 / -0.8	+1.1 / -1.4	+1.0 / -1.1
Electron energy scale	+0.3 / -0.5	+0.7 / -0.8	±0.6
PDF	±3.3	±4.5	+1.1 / -1.2
W+jets shape variation	+0.6 / -0.5	±0.5	±0.7
Top MC generator	±7.1	±7.1	±0.7
ISR / FSR	±0.7	±3.5	±4.2
Luminosity	±3.9	±3.9	±0.4
Total Systematic	±20.0	+24.7 /-24.9	+11.5 /-11.1
Total	±20.2	+25.2 /-25.4	+12.8 /-12.4

Wt-channel cross section

BDT distributions, bkg substraction:





Systematic breakdown:

Source	$\Delta\sigma/\sigma$ [%] **observed**	**expected**
Data statistics	7.1	8.6
MC statistics	2.8	3.5
Experimental uncertainties		
Lepton modeling	2.4	2.4
Jet identification	0.2	0.6
Jet energy scale	10	12
b-jet energy scale	5.0	6.3
Jet energy resolution	0.7	0.2
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale	4.1	5.0
$E_{\mathrm{T}}^{\mathrm{miss}}$ resolution	4.5	5.3
Flavor tagging	8.4	9.4
Theory uncertainties		
$Wt/t\bar{t}$ overlap modeling	1.4	1.6
PDF	2.5	3.2
Background normalization	3.6	4.4
ISR/FSR	5.9	6.0
Wt generator and PS	11	11
$t\bar{t}$ generator and PS	7.5	9.2
Luminosity	3.7	3.9
Total (syst)	20	23
Total (syst+stat)	21	24

s-channel cross section

Cut-based analysis:

Selection	Signal	Background	$S/\sqrt{B}$
Preselection Only	104	153802	0.26
Number of tagged jets=2	18	415	0.88
30< $m_{top,jet2}$ <247 GeV/c^2	17	349	0.91
$p_T(jet1, jet2)$ <189 GeV/c	17	346	0.91
$m_T(W)$ <111 GeV/c	17	318	0.95
0.43< $\Delta R(b-jet1, lepton)$ <3.6	17	308	0.97
123< $m_{top,jet1}$ <788 GeV/c^2	17	302	0.98
0.74< $\Delta R(b-jet1, b-jet2)$ <4.68	16	269	0.98

Systematic breakdown:

Source	$\Delta\sigma/\sigma$ [%] cut-based
Data statistics	$\pm$100
MC statistics	$\pm$70
b-tagging	-30/+20
Jet and lepton modeling	-20/+10
MC generator modeling	-60/+20
Multijets normalization	$\pm$40
Others	-10/+30
Luminosity	$\pm$50
All systematics	-110/+90
Total uncertainty	-160/+150

W' boson search

Theories predicting massive spin-1 charged bosons

- extra-dims : KK excitations of the W
- technicolor : EWSB without scalars but new bosons
- L-R symmetry : right-handed counter-part of the W
- little-Higgs : cancels mH divergence, several new particles including a W

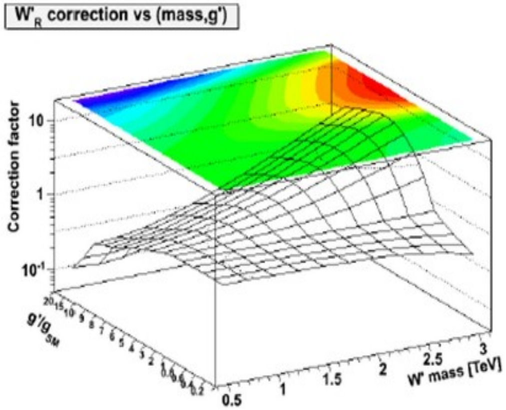
• Effective operator formalism: model independent description

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

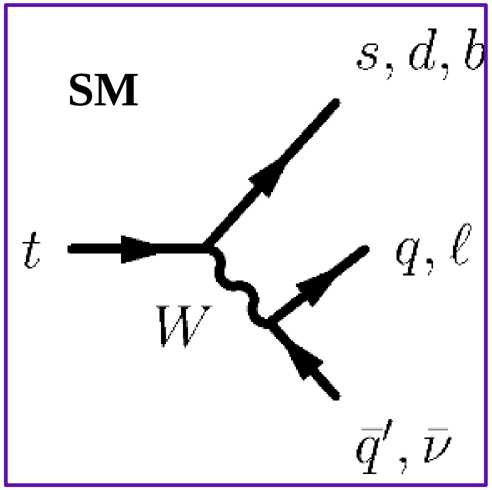
• In this effective theory m(W') independent of g,
which can differ a lot from the SM g (model renormalisable up to g'=5g)

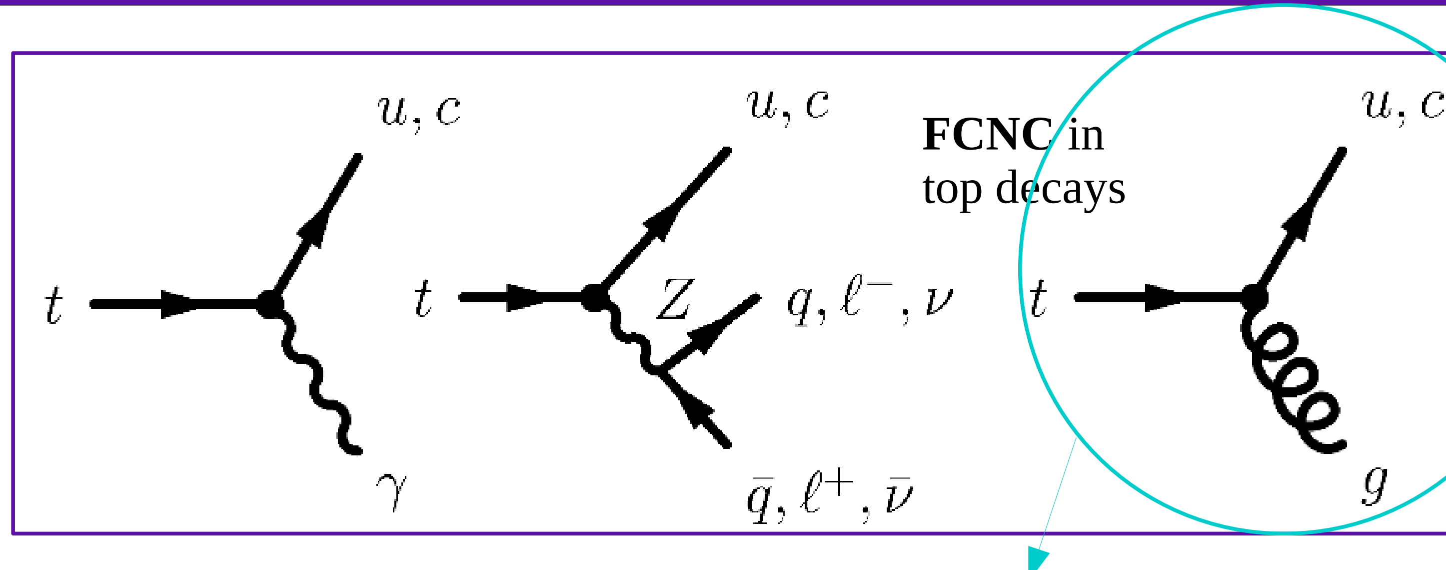
• W' $\rightarrow$ tb cross section roughly scales as ~(g'/g)^2
+ correction factor due to W' width effects
more important for high masses and high g'/g

⇒ limit studied up to g'/g=2, safe since
signal with = 4 * standard width,
still lower than experimental resolution



FCNCs in single top production



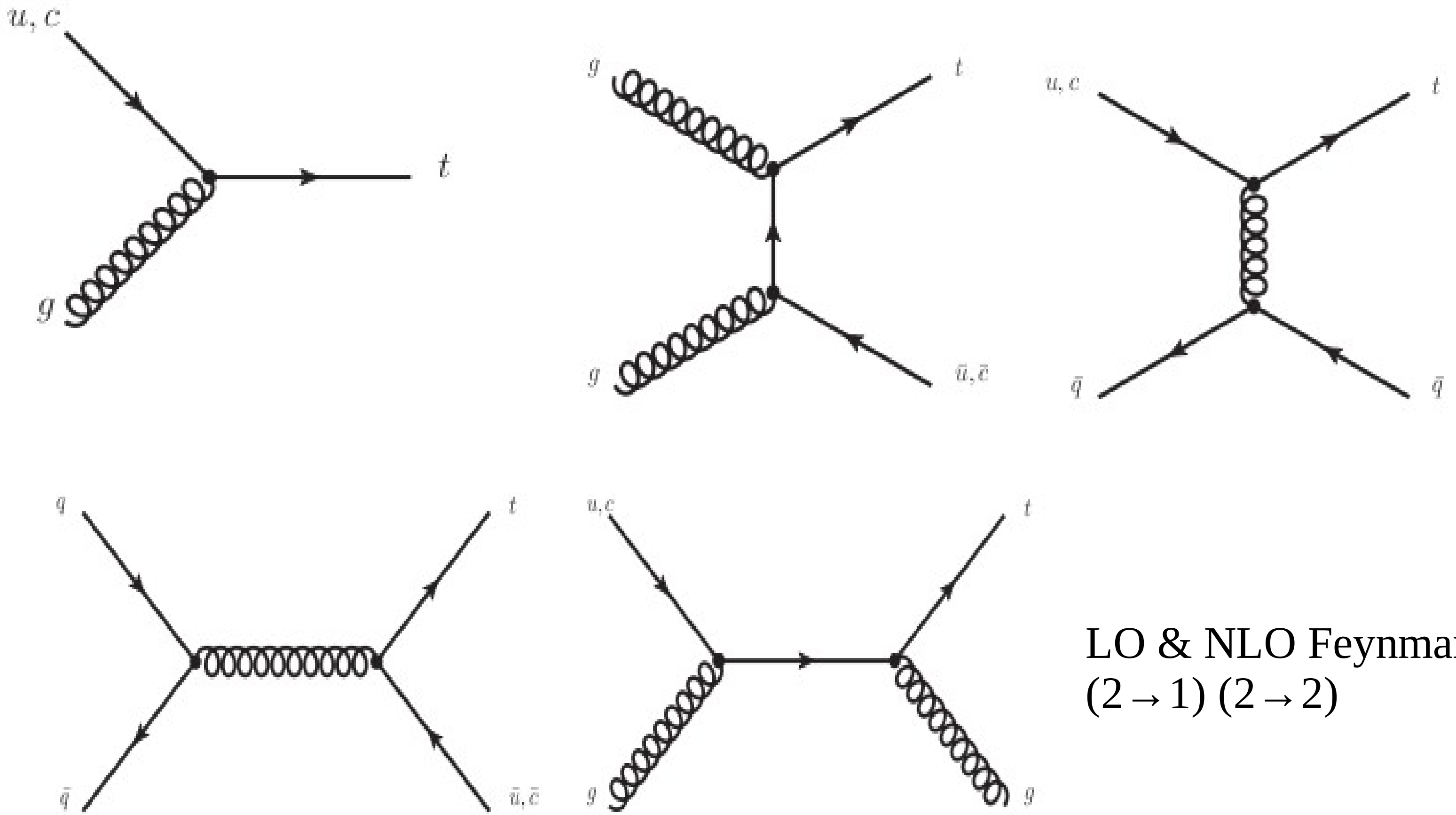


T-g-q coupling better studied in production mechanism,
Since final state signatures dominated by multijet background

Table 1: Theoretical values for the branching fractions of FCNC top quark decays as predicted by the SM, the quark-singlet model (QS), two-Higgs doublet models with (2HDM II) or without flavour-conservation (2HDM III), minimal supersymmetric model (MSSM), SUSY with R-parity violation ($\not{R}$ SUSY), models with extra quarks (Extra q) and Topcolour-assisted Technicolour model (TC2) [29,30].

Process	SM	QS	2HDM II	2HDM III	MSSM	$\not{R}$ SUSY	Extra q	TC2
$t \to u\gamma$	3.7×10^{-16}	$\sim 10^{-8}$	—	—	2×10^{-6}	1×10^{-6}	—	—
$t \to uZ$	8×10^{-17}	$\sim 10^{-4}$	—	—	2×10^{-6}	3×10^{-5}	—	—
$t \to ug$	3.7×10^{-14}	$\sim 10^{-7}$	—	—	8×10^{-5}	2×10^{-4}	—	—
$t \to c\gamma$	4.6×10^{-14}	$\sim 10^{-8}$	$\sim 10^{-7}$	$\sim 10^{-7}$	2×10^{-6}	1×10^{-6}	$\sim 10^{-8}$	$\sim 10^{-7}$
$t \to cZ$	$\sim 1 \times 10^{-14}$	$\sim 10^{-4}$	$\sim 10^{-8}$	$\sim 10^{-6}$	2×10^{-6}	3×10^{-5}	$\sim 10^{-4}$	$\sim 10^{-5}$
$t \to cg$	4.6×10^{-12}	$\sim 10^{-7}$	$\sim 10^{-5}$	$\sim 10^{-4}$	8×10^{-5}	2×10^{-4}	$\sim 10^{-7}$	$\sim 10^{-5}$

FCNCs in single top production



LO & NLO Feynman diagrams
(2 → 1) (2 → 2)

FCNCs in single top production

- Effective operator formalism: model independent description

$$\mathcal{L} = \mathcal{L}^{SM} + \cancel{\frac{1}{\Lambda}\mathcal{L}^{(5)}} + \frac{1}{\Lambda^2}\mathcal{L}^{(6)} + O\left(\frac{1}{\Lambda^3}\right)$$

$L^{(\mathrm{eff})} \rightarrow L^{(\mathrm{SM})}$ in the low energy limit

- For calculating branching fractions, FCNCs considered as additional channels for top decay:

$$\mathcal{B}(t \to qg) = \frac{\Gamma_{t\to qg}}{\Gamma_{t\to bW} + \Gamma_{t\to qg}} \quad q = u, c$$

for small coupling constants (k<0.1): $\mathcal{B}(t \to qg) = \dfrac{\Gamma_{t\to qg}}{\Gamma_{t\to bW}}$ $\longrightarrow$ result (C)

- Production cross section:

$$\sigma_{qg\to t} = \sum_{q=u,c} \left(\frac{\kappa_{gqt}}{\Lambda}\right)^2 (b_{qL}|f_q^L|^2 + b_{qR}|f_q^R|^2)$$

assuming only a pure left-handed coupling (f_q^L=1, f_q^R=0) and considering the $l^{+,-}$ together:

$$\sigma_{qg\to t} = 100351.97\left(\frac{\kappa_{ugt}}{\Lambda}\right)^2 + 19496.79\left(\frac{\kappa_{cgt}}{\Lambda}\right)^2 \mathrm{pb}$$

$\longrightarrow$ result (B)