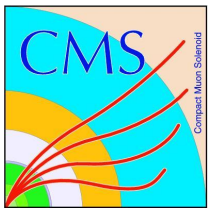
Single top quark production with ATLAS and CMS

Kevin Finelli, on behalf of the ATLAS and CMS collaborations
University of Sydney

DIS2015: Dallas, Texas
27 April 2015 - 1 May 2015

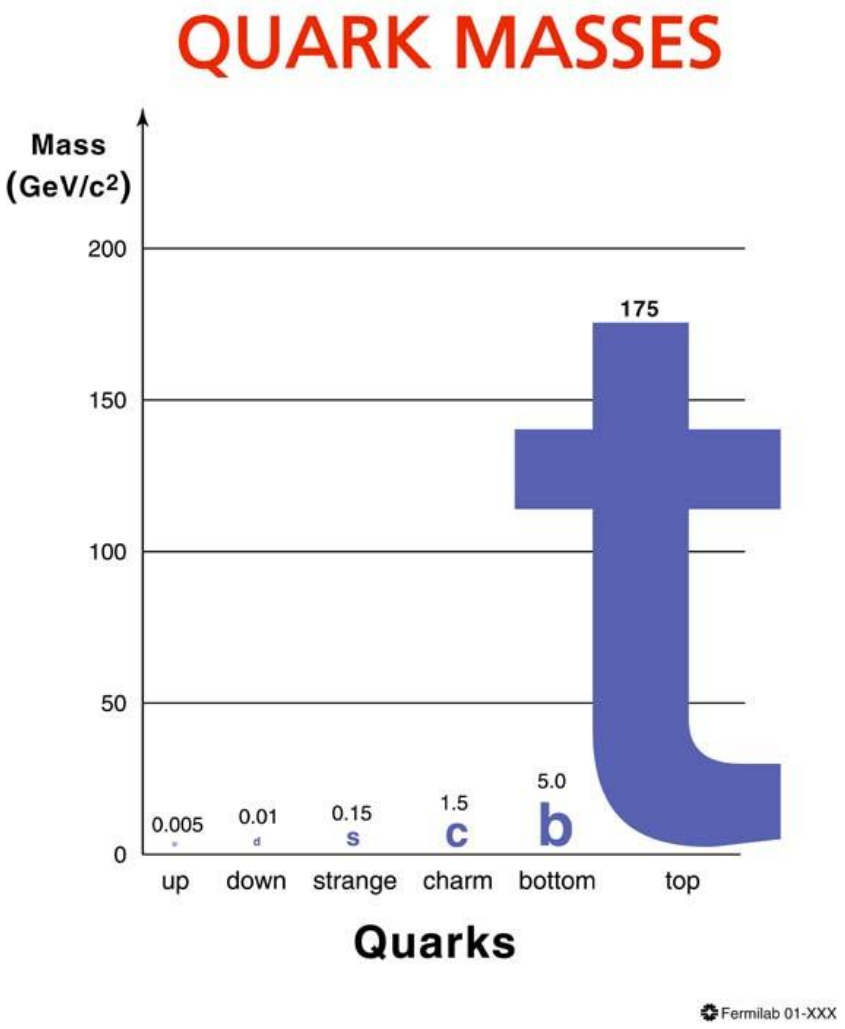


THE UNIVERSITY OF SYDNEY

CoEPP
ARC Centre of Excellence for Particle Physics at the Terascale

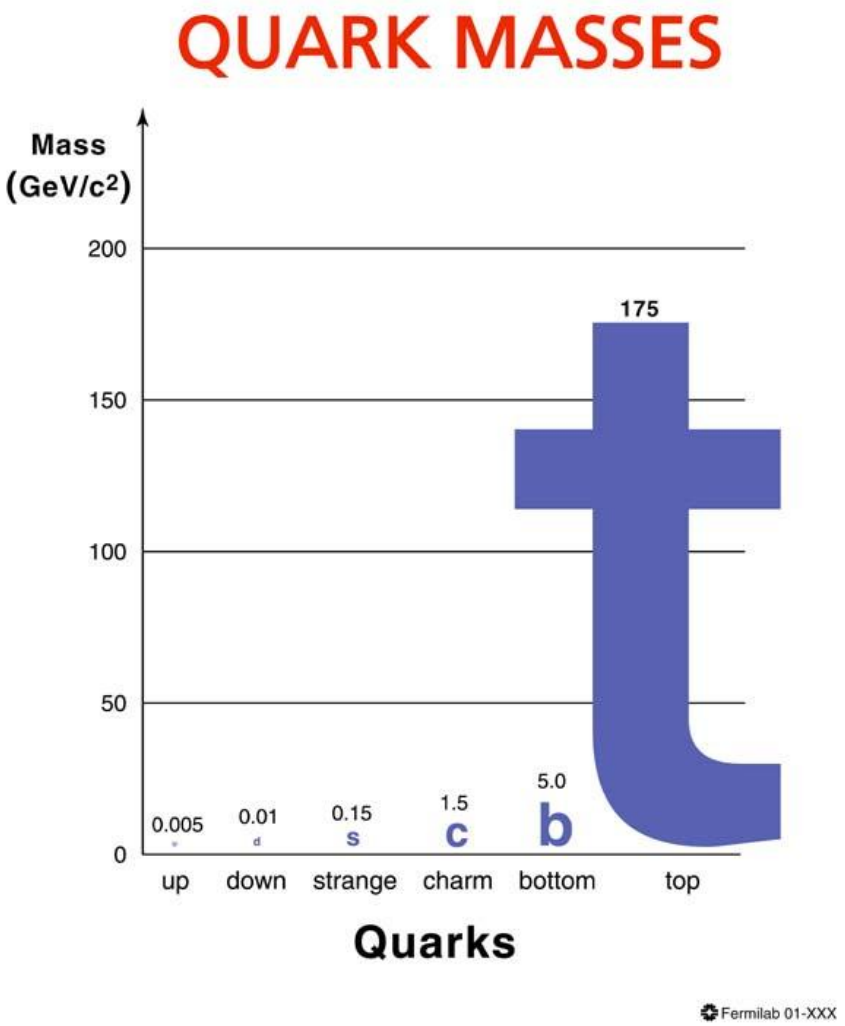
Top quark physics

- Top quark **decays** before it hadronises
  - Only opportunity to look at partons without hadronisation
- The top is very **massive** ($m_{top} \approx 173$ GeV)
  - Important for Higgs mass corrections, hierarchy problem, electroweak symmetry breaking

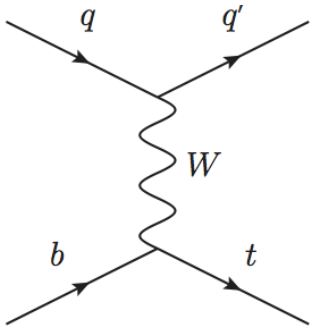


Top quark physics

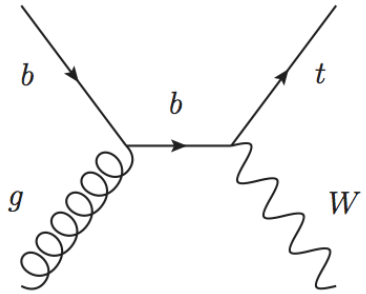
- Single top measurements give unique **test of the SM**
  - CKM V_{tb} matrix element, PDFs, etc.
- Single top final states can be powerful **probe for BSM physics**
  - anomalous *Wtb* coupling, FCNC, *W'* search



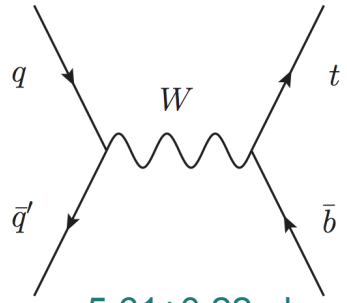
Single top phenomenology



σ=87.76±3.44 pb



σ=22.37±1.52 pb



σ=5.61±0.22 pb

Production diagrams classified (at LO) as *t*-channel, *Wt* channel, or *s*-channel

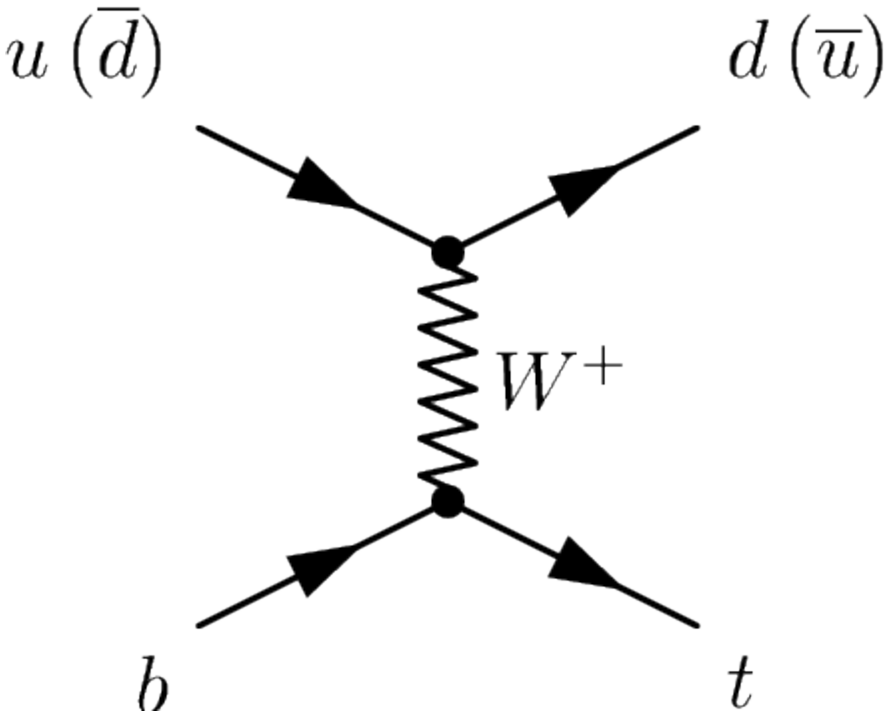
- ***t*-channel**
  - largest production cross-section
  - 1 *b*-jet, 1 forward light jet, 1 isolated lepton, E_T^{miss}
- ***Wt* channel**
  - similar final state to top pair
  - 1 *b*-jet, 2 isolated leptons, E_T^{miss}
- ***s*-channel**
  - small cross-section, challenging at LHC
  - 2 *b*-jets, 1 isolated lepton, E_T^{miss}

Outline

- Cross-sections
  - *t*-channel inclusive and differential cross-sections
  - *Wt* observation/XS
  - *s*-channel search
- *Wtb* vertex properties
  - Anomalous couplings
  - *W* boson helicity
  - Top polarization
- Searches
  - Flavor-changing neutral currents
  - W'->tb
  - Monotop

JHEP 06 (2014) 090

ATLAS-CONF-2014-007



Inclusive measurements of the cross-section of single top quark production in the t-channel at 8 TeV

t-channel inclusive

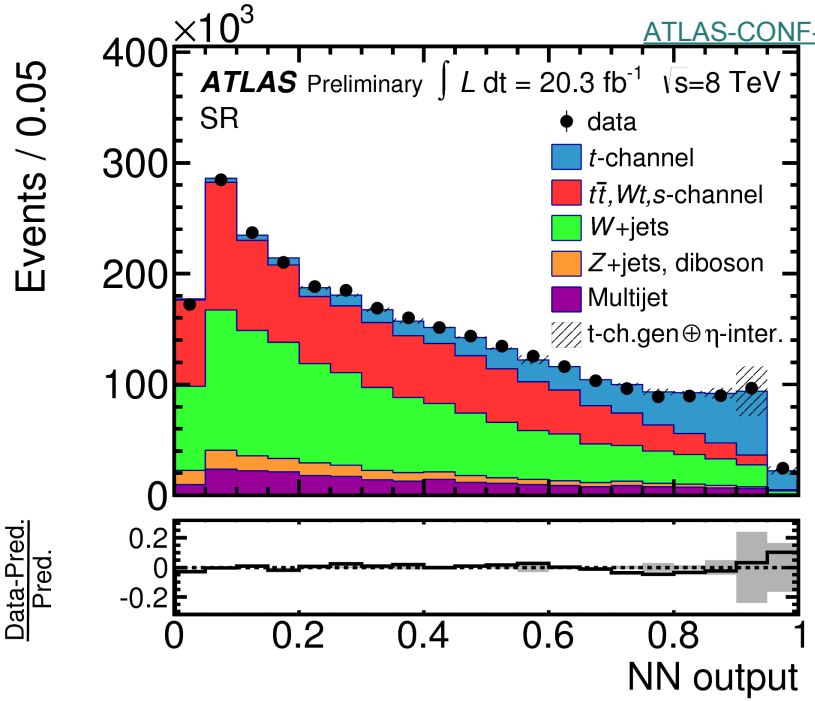
Exactly **2 jets**, 1 *b*-tagged, 1 untagged, with $|\eta|<4.5$

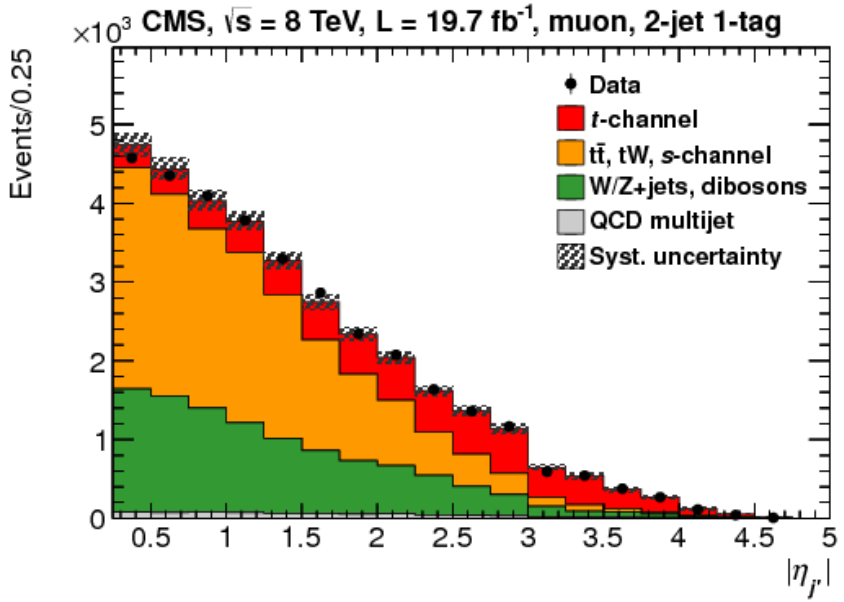
ATLAS: Likelihood fit to **neural network (NN)** discriminant

CMS: Likelihood fits to $|\eta_j|$ **distribution**

JHEP 06 (2014) 090

ATLAS-CONF-2014-007





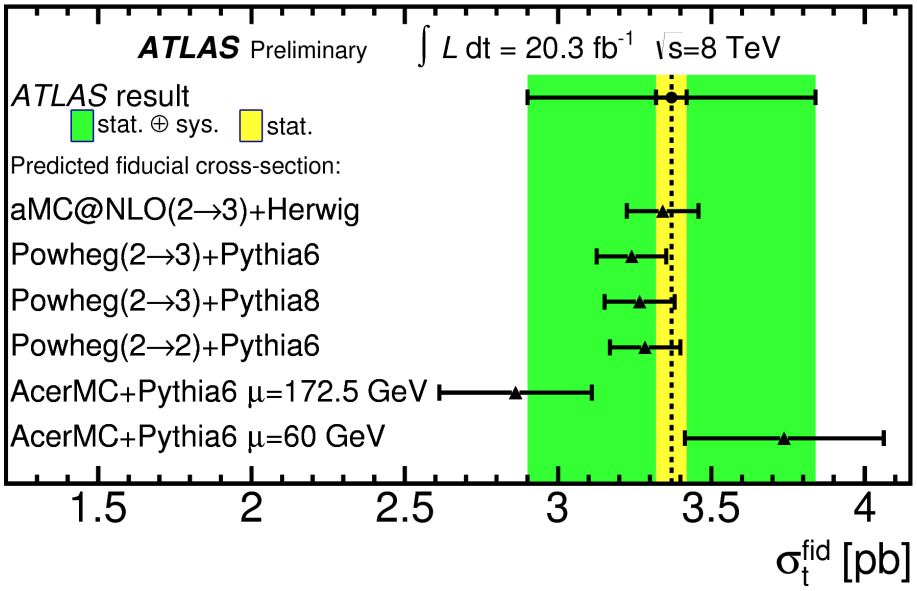
t-channel inclusive - results

Main uncertainties: Jet energy scale (JES), signal model

ATLAS: Full and fiducial cross-sections

$\sigma_{t\text{-ch}}$ = 82.6 ± 1.2 (stat) ± 12.0 (syst.) pb

$\sigma_{t\text{-ch, fid}}$ = 3.37 ± 0.05 (stat) ± 0.48 (syst) pb



JHEP 06 (2014) 090

ATLAS-CONF-2014-007

t-channel inclusive - results

CMS: Full, top, anti-top cross-sections, and ratio

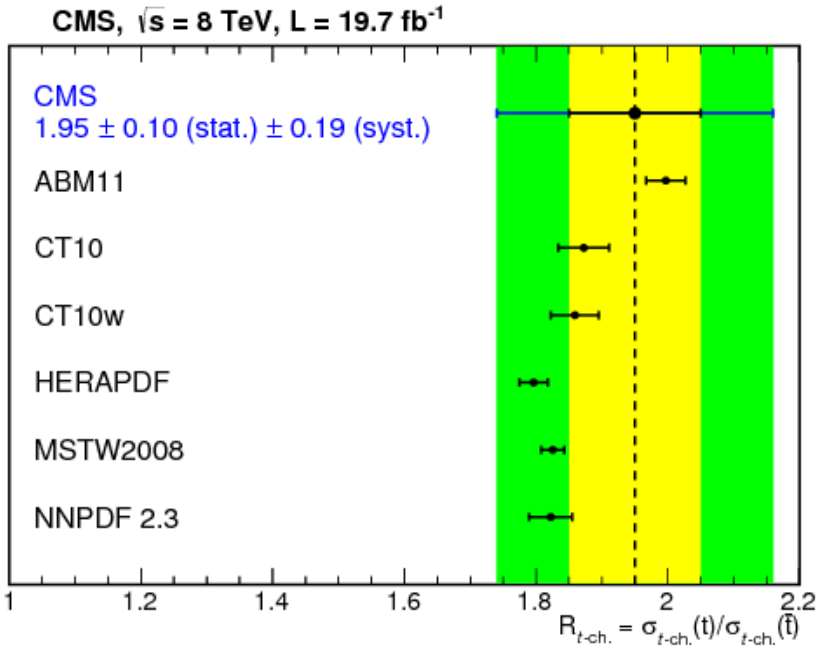
$\sigma_{t\text{-ch}}$ = 83.6 ± 2.3 (stat) ± 7.4 (syst) pb

Top, anti-top fitted separately:

$\sigma_{t\text{-ch}}(t)$ = 53.8 ± 4.6 pb

$\sigma_{t\text{-ch}}$(anti-t) = 27.6 ± 3.9 pb

$R_{t\text{-ch}}$ = 1.95 ± 0.10 (stat) ± 0.19 (syst)

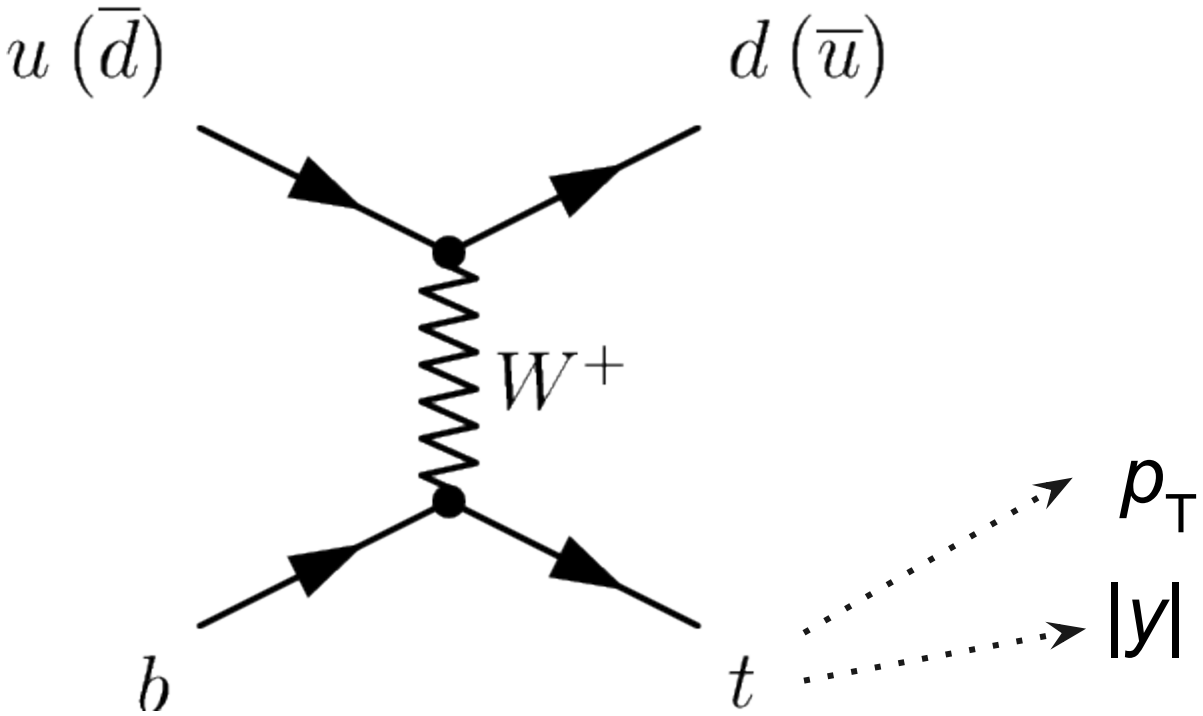


Same trends seen in ATLAS 7 TeV results

JHEP 06 (2014) 090

ATLAS-CONF-2014-007

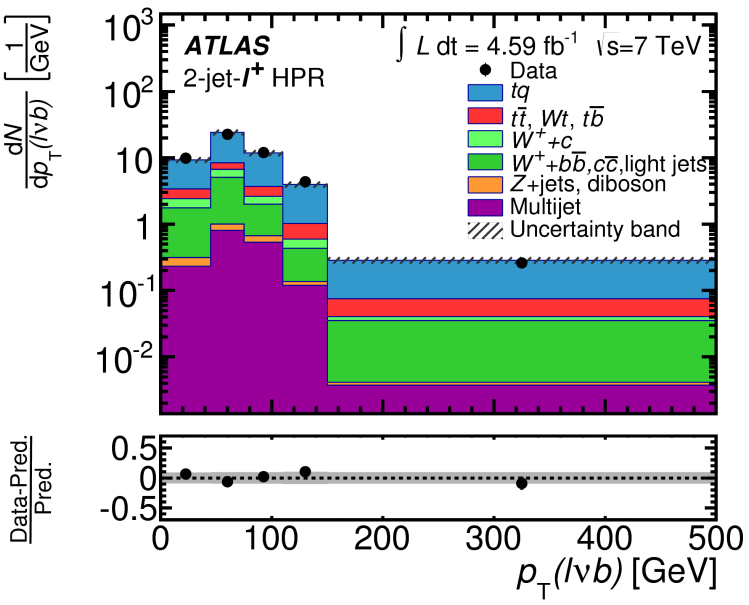
[Phys. Rev. D. 90, 112006 (2014)]
[CMS PAS TOP-14-004]



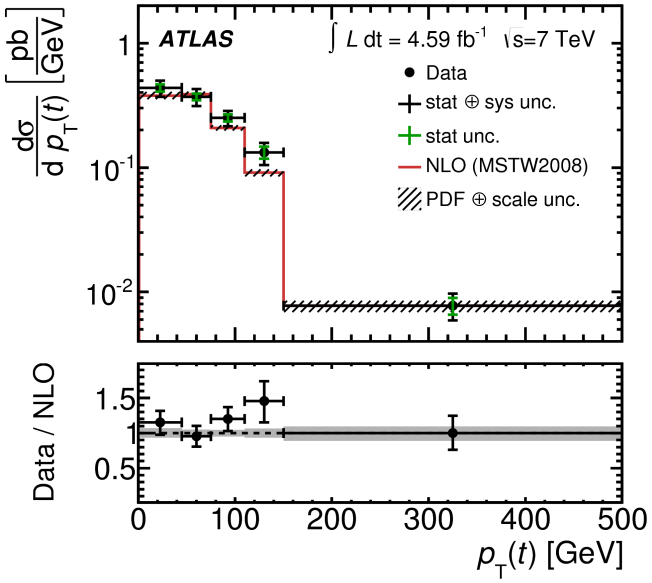
Differential measurements of the cross-section of single top quark production in the t-channel at 7 and 8 TeV

t-channel differential

Distributions of p_T(t) and |y(t)| **unfolded** to compare with parton-level predictions



Reconstruction level

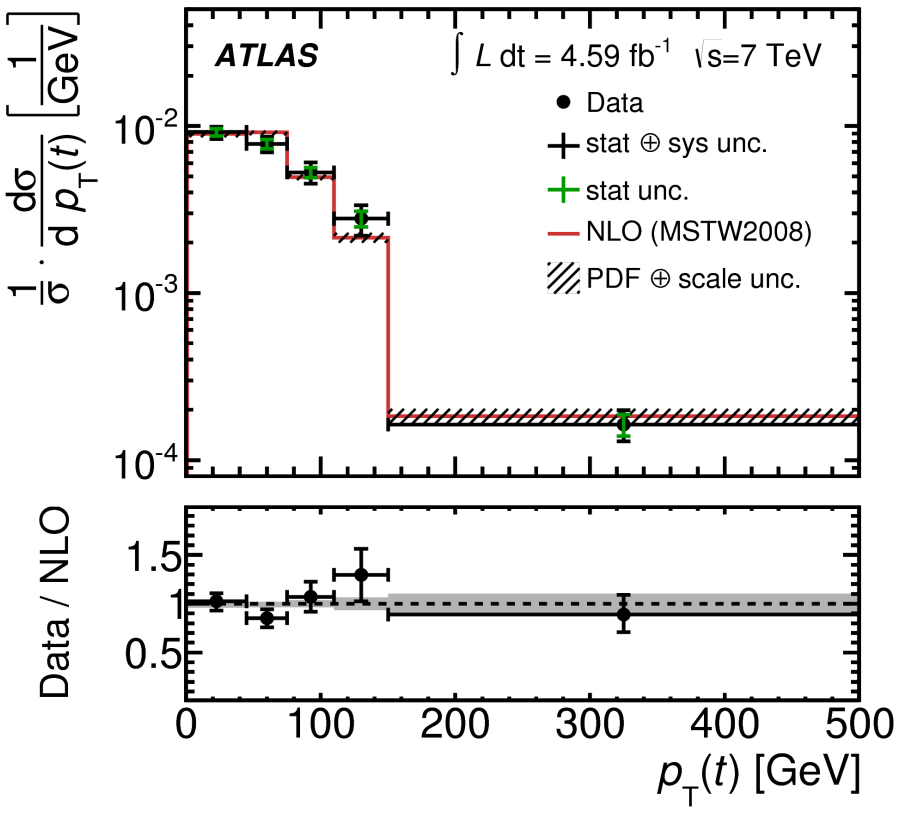


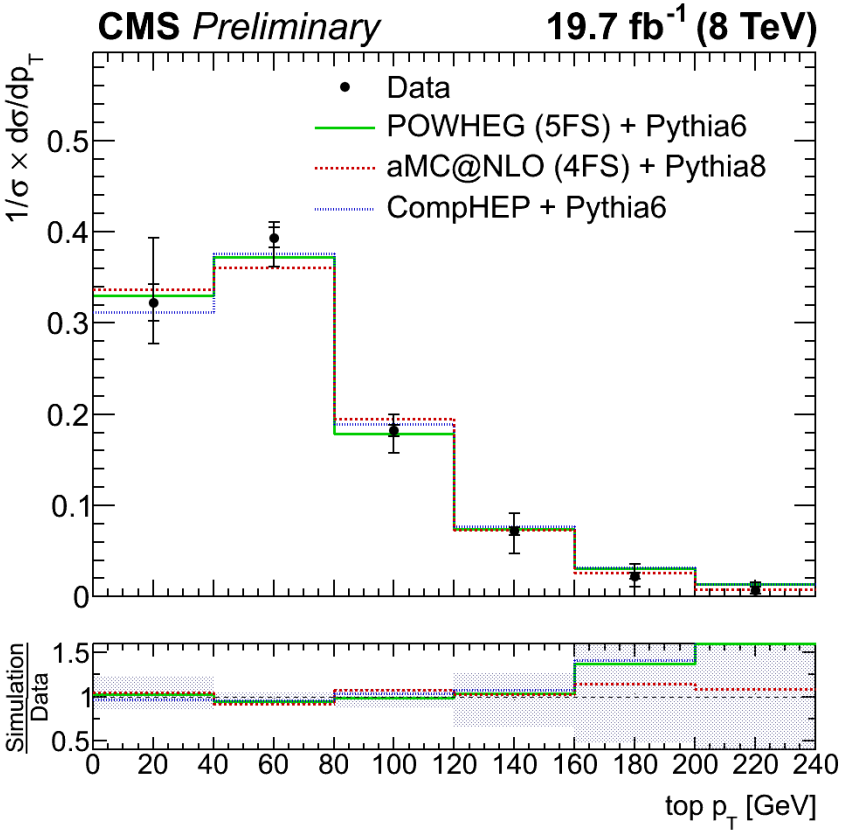
Parton level

Phys. Rev. D. 90, 112006 (2014)

CMS PAS TOP-14-004

t-channel differential: p_T(top)





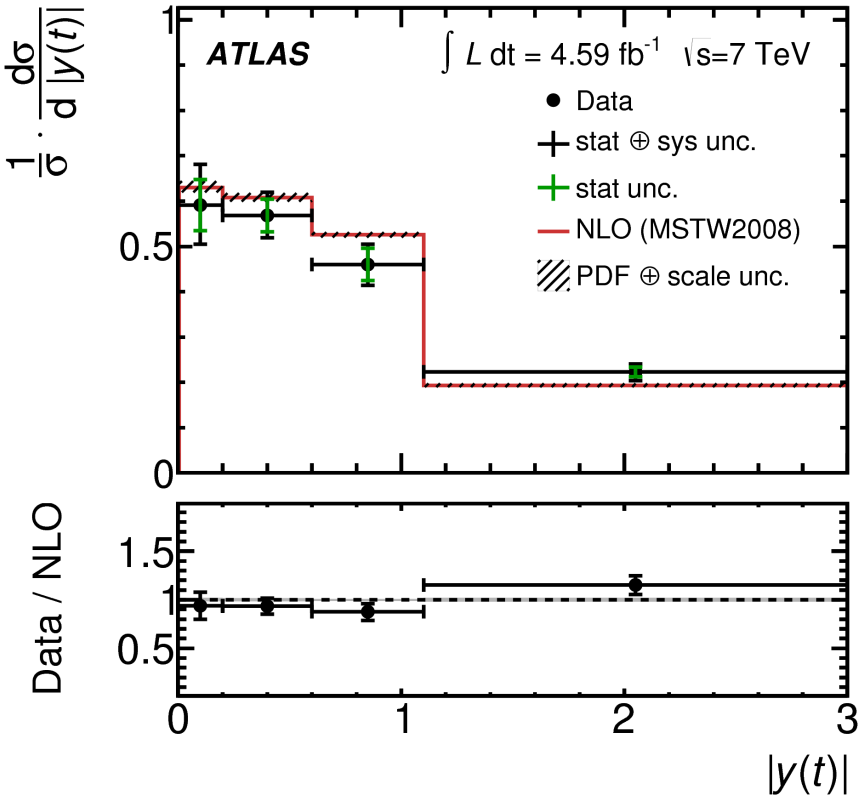
Results generally **agree well** with MC and NLO QCD predictions

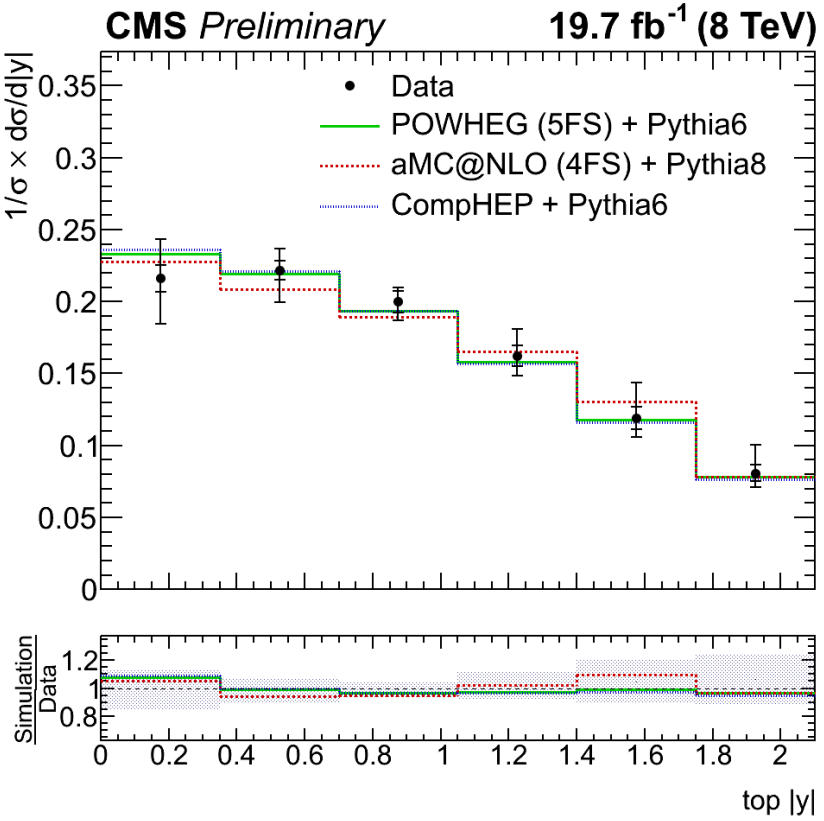
E_T^{miss}, JES, signal model among dominant **systematics**

Phys. Rev. D. 90, 112006 (2014)

CMS PAS TOP-14-004

t-channel differential: |*y*(top)|





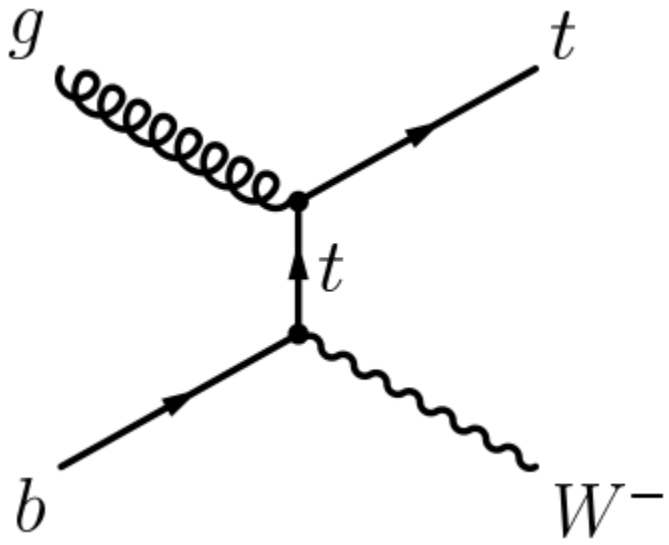
Results generally **agree well** with MC and NLO QCD predictions

E_T^{miss}, JES, signal model among dominant **systematics**

Phys. Rev. D. 90, 112006 (2014)

CMS PAS TOP-14-004

PRL 112 (2014) 231802
ATLAS-CONF-2013-100
CMS PAS TOP-14-009/ATLAS-CONF-2014-052



Inclusive measurements of the cross-section of single top quark production in the *Wt* channel at 8 TeV

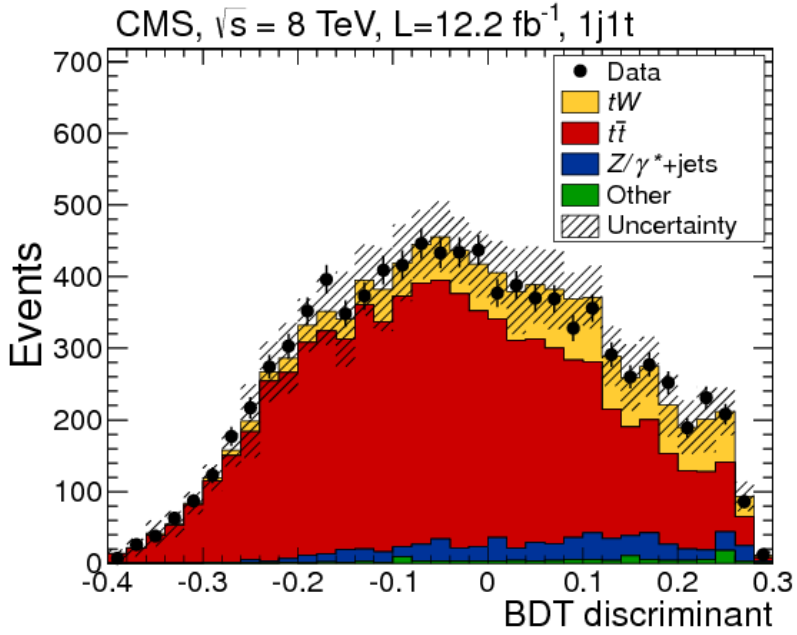
Wt inclusive: procedure

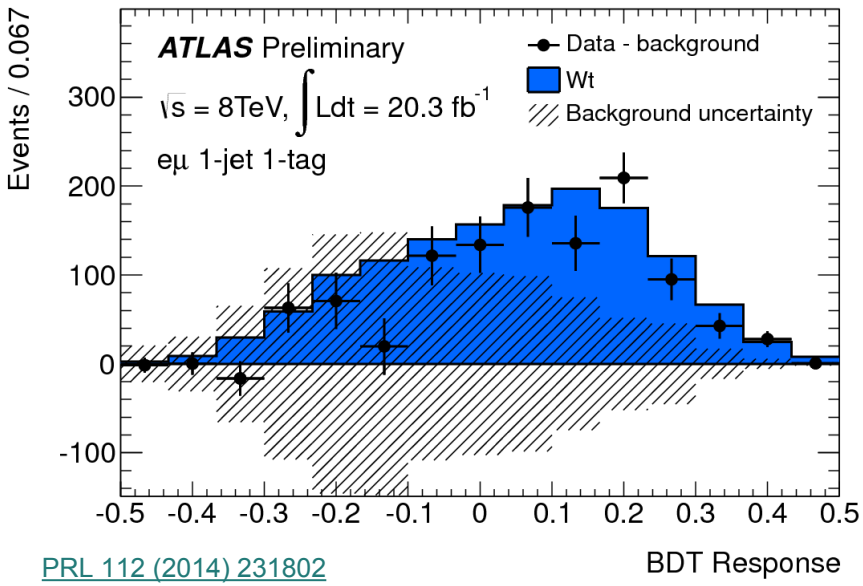
Opposite-sign lepton pair, 1 *b*-tagged jet

Rejecting top pair is the main challenge

CMS: Fit to **BDT** in signal (1j1b) and 2 control regions (2j1b, 2j2b)

ATLAS: Fit to **BDT** for 1-jet, 2-jet events





PRL 112 (2014) 231802

ATLAS-CONF-2013-100

CMS PAS TOP-14-009/ATLAS-CONF-2014-052

Wt inclusive: results

Main uncertainties: **signal** and **top pair** background **model**, **jet energy scale**

Discovery of *Wt* signal at 6.1 σ (combined) significance

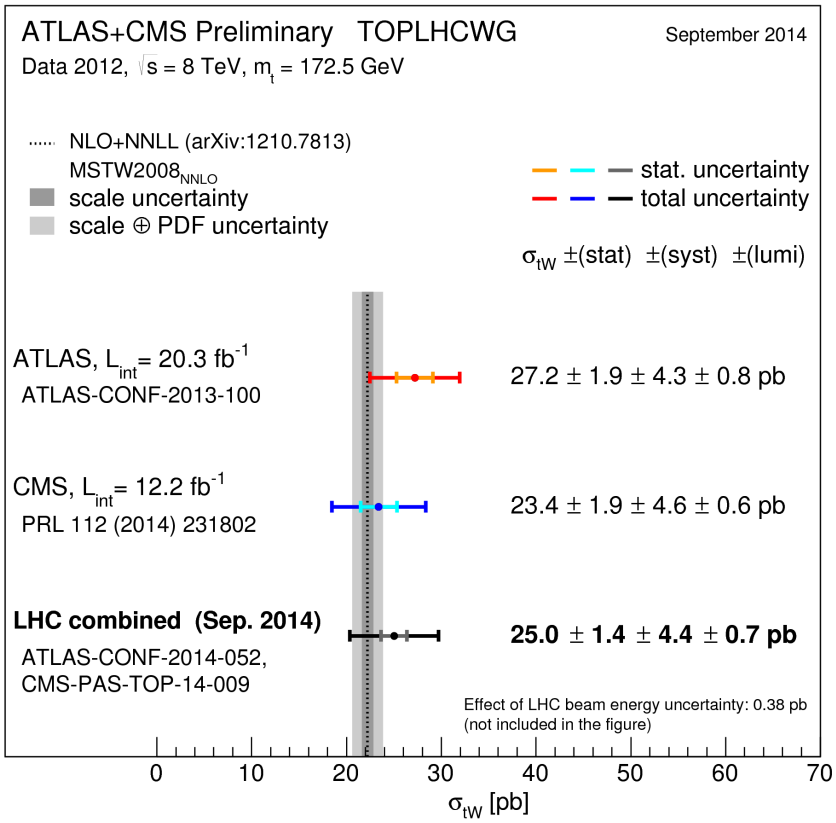
Extraction of $|V_{tb}|$:

CMS: 1.030 ± 0.127

ATLAS: 1.10 ± 0.12

combined: 1.06 ± 0.11

Compatible with $|V_{tb}|$ measured in *t*-channel



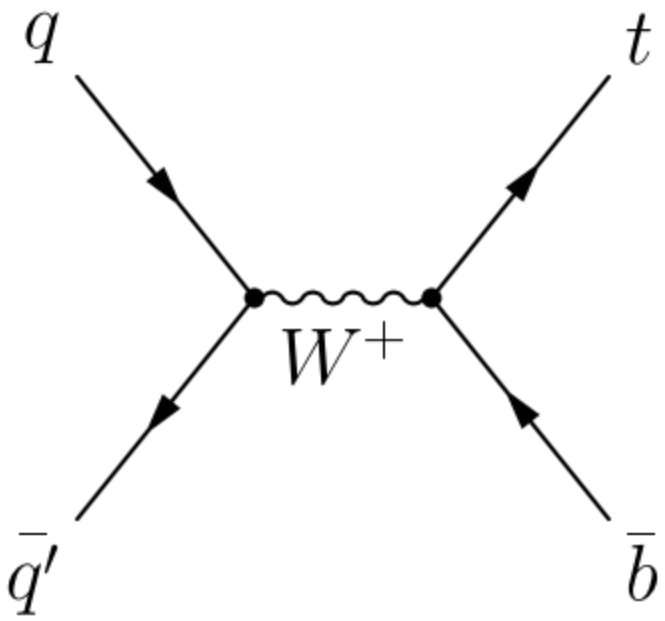
PRL 112 (2014) 231802

ATLAS-CONF-2013-100

CMS PAS TOP-14-009/ATLAS-CONF-2014-052

CMS PAS TOP-13-009

Phys.Lett. B740 (2015) 118



Searches for single top quark production in the *s*-channel at 8 TeV

s-channel searches

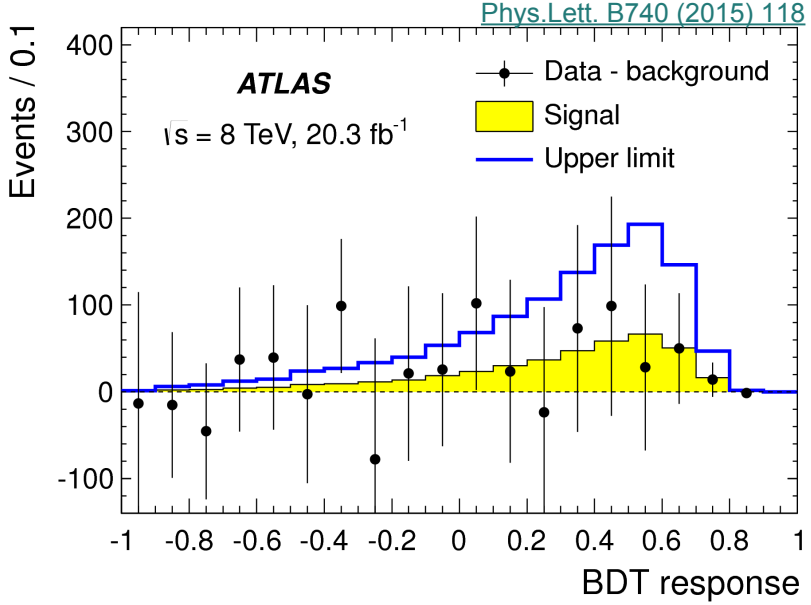
Select events with large E_T^{miss}, 1 lepton, exactly 2 *b*-tagged jets

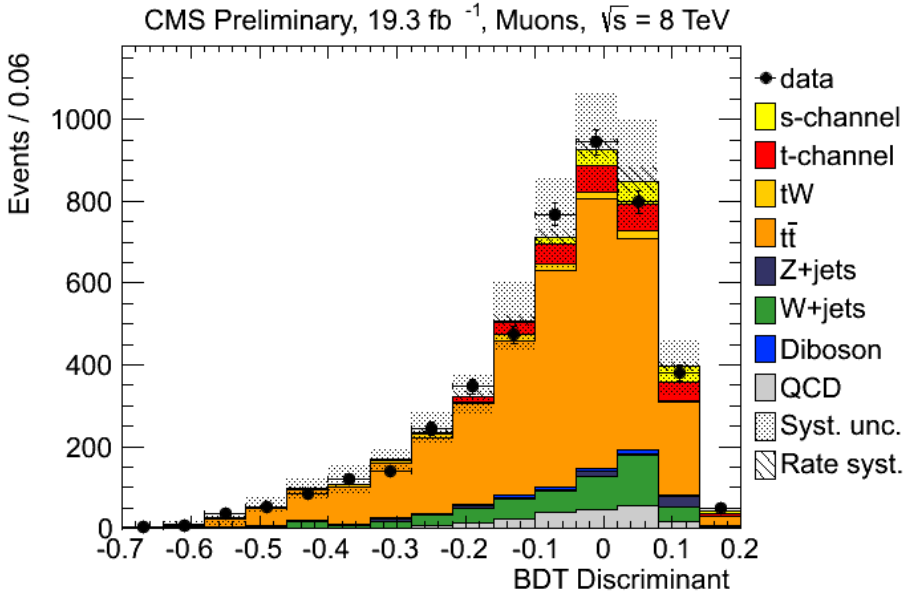
Fit to BDT output

CMS: include 3-jet 2-tag region to **constrain backgrounds**

CMS PAS TOP-13-009

Phys.Lett. B740 (2015) 118





s-channel searches: results

Main systematics: E_T^{miss} scale, JES (ATLAS) MC stat., (CMS) signal model

ATLAS:

$$\sigma_{s\text{-}ch} = 5.0 \pm 1.7 \text{ (stat)} \pm 4.0 \text{ (syst.) pb}$$

1.3σ obs. 1.4σ exp. significance; **14.6 pb** upper limit (95% CL)

CMS:

$$\sigma_{s\text{-}ch} = 6.2 \pm 8.0 \text{ (stat+syst) pb}$$

0.7σ obs. 0.9σ exp. significance; **11.5 pb** upper limit (95% CL)

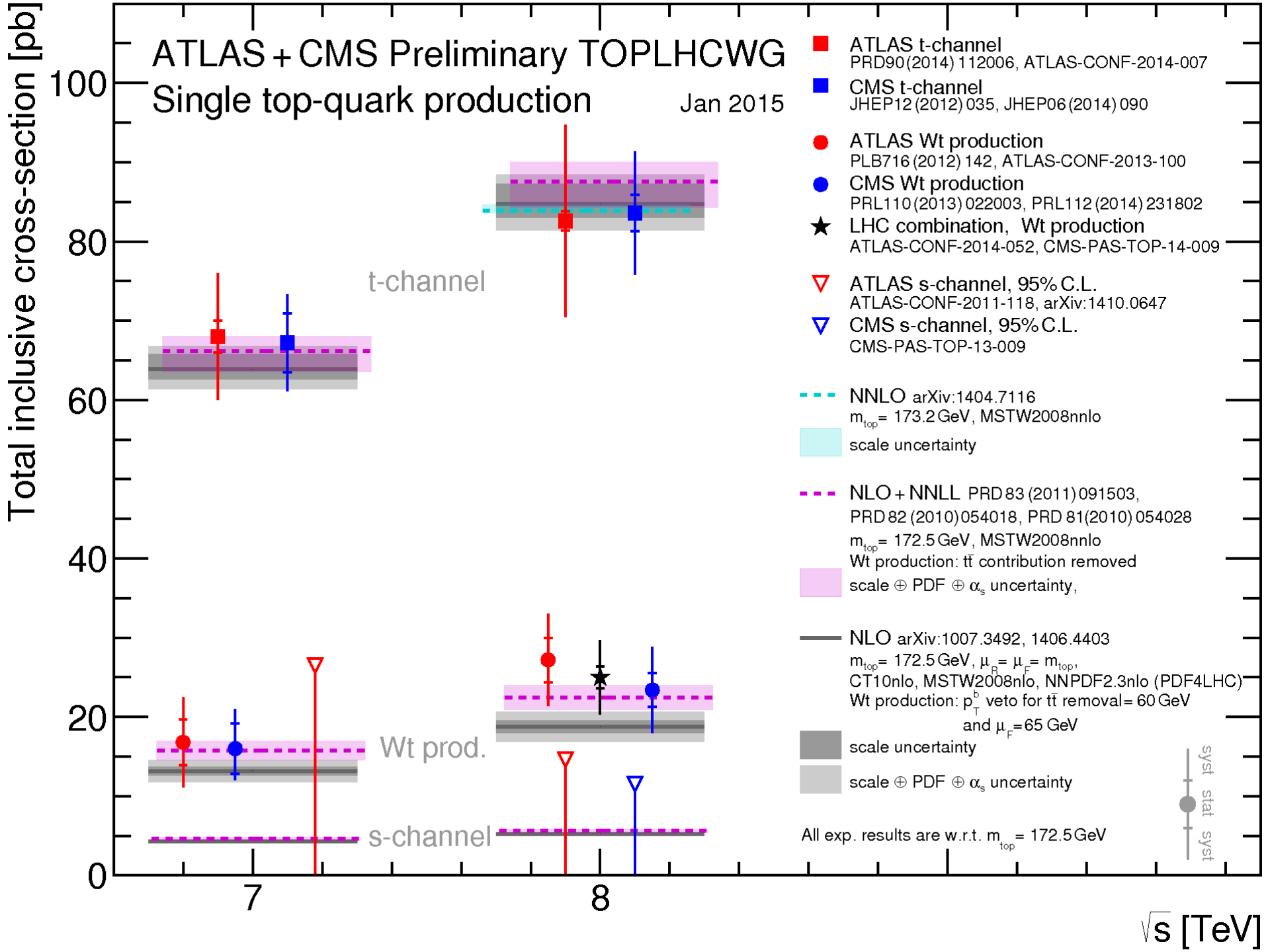
Appx. NNLO+NNLL (Kidonakis, Phys.Rev.D 83(2011) 091503):

$$\sigma_{s\text{-}ch} = 5.61 \pm 0.22 \text{ pb}$$

Results in good agreement with SM predictions

CMS PAS TOP-13-009

Phys.Lett. B740 (2015) 118


ATLAS + CMS Preliminary TOPLHCWG
Single top-quark production
Jan 2015
Total inclusive cross-section [pb]
100
80
60
40
20
0
7
8
√s [TeV]
t-channel
Wt prod.
s-channel
ATLAS t-channel
PRD90(2014) 112006, ATLAS-CONF-2014-007
CMS t-channel
JHEP12(2012) 035, JHEP06(2014) 090
ATLAS Wt production
PLB716(2012) 142, ATLAS-CONF-2013-100
CMS Wt production
PRL110(2013) 022003, PRL112(2014) 231802
LHC combination, Wt production
ATLAS-CONF-2014-052, CMS-PAS-TOP-14-009
ATLAS s-channel, 95% C.L.
ATLAS-CONF-2011-118, arXiv:1410.0647
CMS s-channel, 95% C.L.
CMS-PAS-TOP-13-009
NNLO arXiv:1404.7116
m_top = 173.2 GeV, MSTW2008nnlo
scale uncertainty
NLO + NNLL PRD 83 (2011) 091503,
PRD 82 (2010) 054018, PRD 81(2010) 054028
m_top = 172.5 GeV, MSTW2008nnlo
Wt production: tt̄ contribution removed
scale ⊕ PDF ⊕ α_s uncertainty,
NLO arXiv:1007.3492, 1406.4403
m_top = 172.5 GeV, μ_R = μ_F = m_top,
CT10nlo, MSTW2008nlo, NNPDF2.3nlo (PDF4LHC)
Wt production: p_T^b veto for tt̄ removal = 60 GeV
and μ_F = 65 GeV
scale uncertainty
scale ⊕ PDF ⊕ α_s uncertainty
All exp. results are w.r.t. m_top = 172.5 GeV
syst
stat
syst

Anomalous *Wtb* couplings

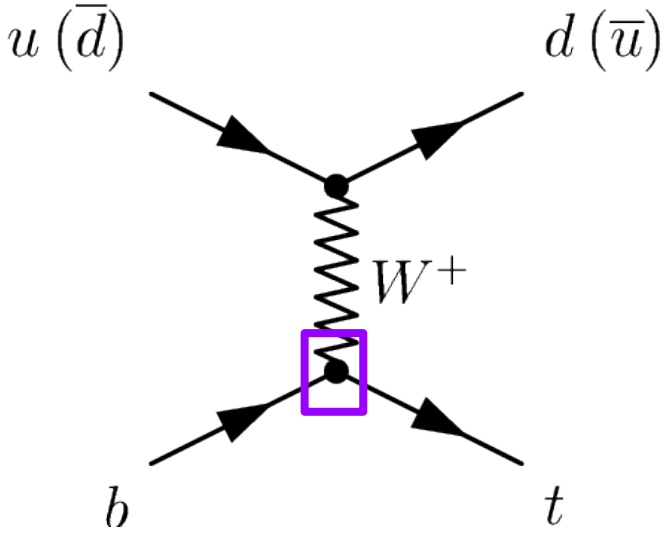
$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_L P_L + V_R P_R\right) t W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}\left(g_L P_L + g_R P_R\right) t W_{\mu}^{-} + \text{h.c.}$$

This is a general **effective Lagrangian** for the *Wtb* vertex

There are several analyses probing the **vector** (V_L, V_R) and **tensor** (g_R, g_L) couplings

In the **SM**, $V_L = V_{tb} \approx 1$, the other couplings are **anomalous** (any nonzero coupling is evidence for new physics)

ATLAS-CONF-2013-032
CMS PAS TOP-14-007



$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_{\mathrm{L}}P_{\mathrm{L}} + V_{\mathrm{R}}P_{\mathrm{R}}\right)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}\left(g_{\mathrm{L}}P_{\mathrm{L}} + g_{\mathrm{R}}P_{\mathrm{R}}\right)tW_{\mu}^{-} + \mathrm{h.c.}$$

Search for anomalous *Wtb* couplings in t-channel single top events at 7 TeV

Anomalous *Wtb* couplings

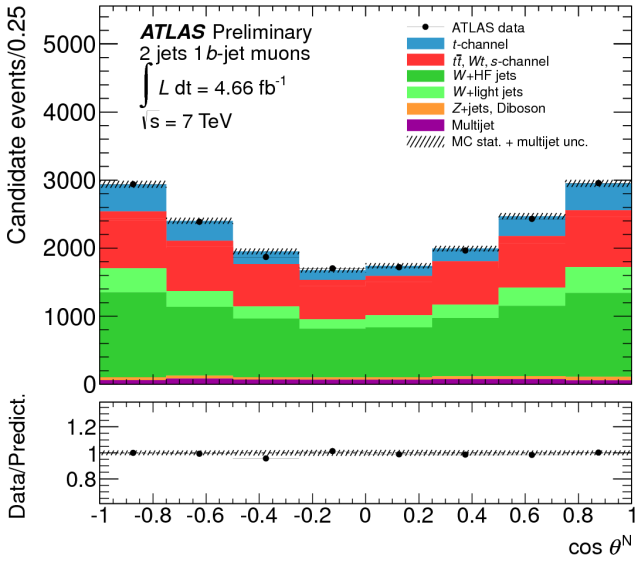
ATLAS:

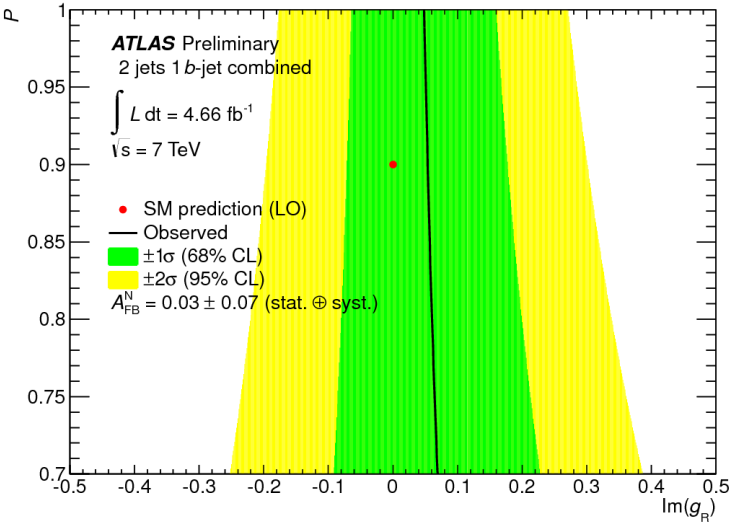
Measurement of A^{N}_{FB}, f^{wd}-b^{kwd} **asymmetry** in normal direction

$$A^{N}_{FB} = 0.64\, P\, \mathrm{Im}(g_R)$$

Decay angle $\cos\theta^{N}$ distribution **unfolded** to parton level

$\mathrm{Im}(g_R) \in [-0.20, 0.30]$ (95% CL), assuming P=0.9



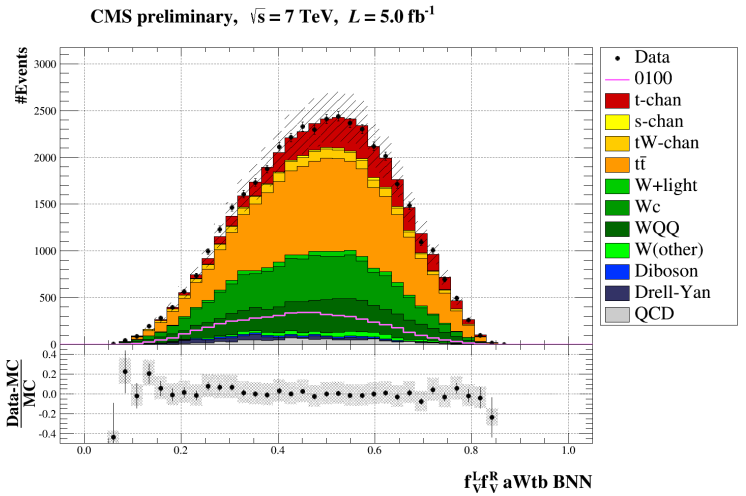


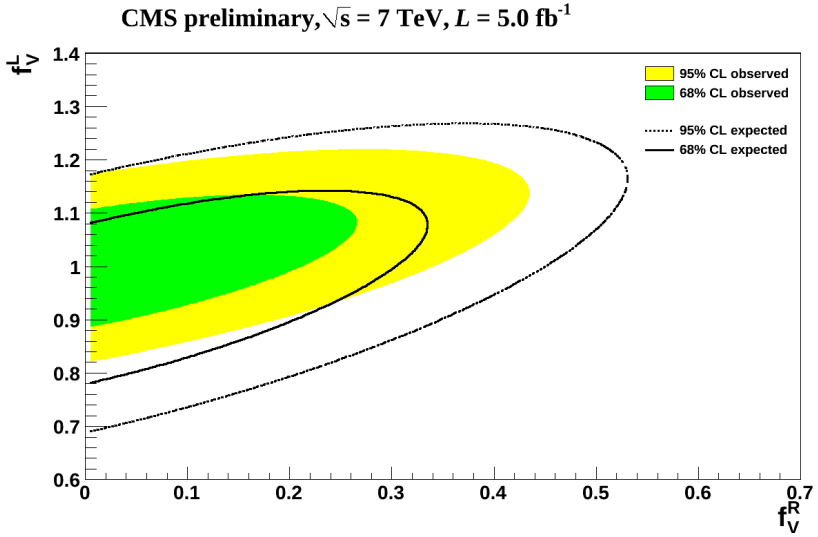
ATLAS-CONF-2013-032

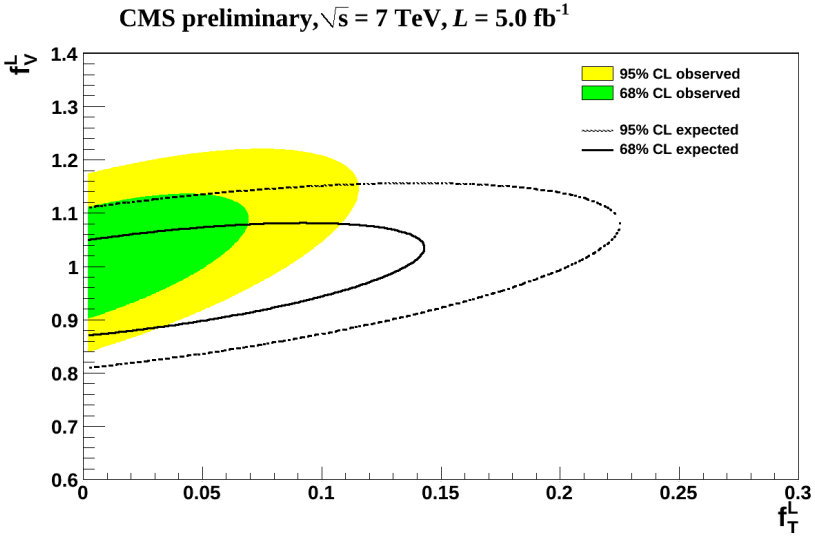
Anomalous *Wtb* couplings

CMS: Series of **Bayesian NN** extracts signal (above)

2D constraints on ($|V_L|$,$|V_R|$) (below, left) and ($|V_L|$,$|g_L|$) (below, right)

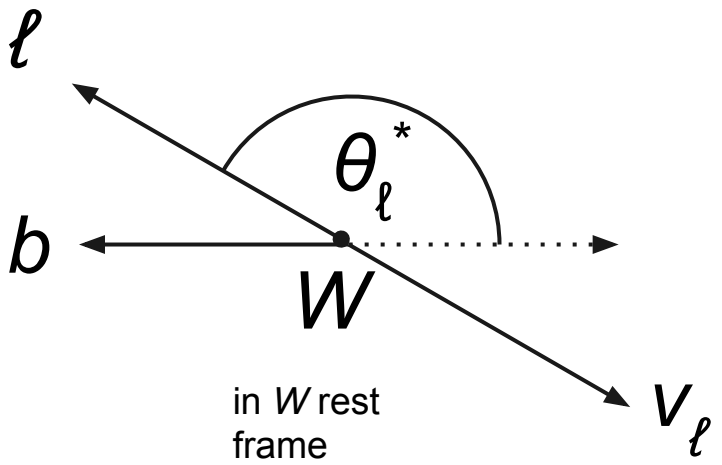






CMS PAS TOP-14-0071

JHEP 01 (2015) 053



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

Measurement of the *W* boson helicity in events with a single reconstructed top quark at 8 TeV

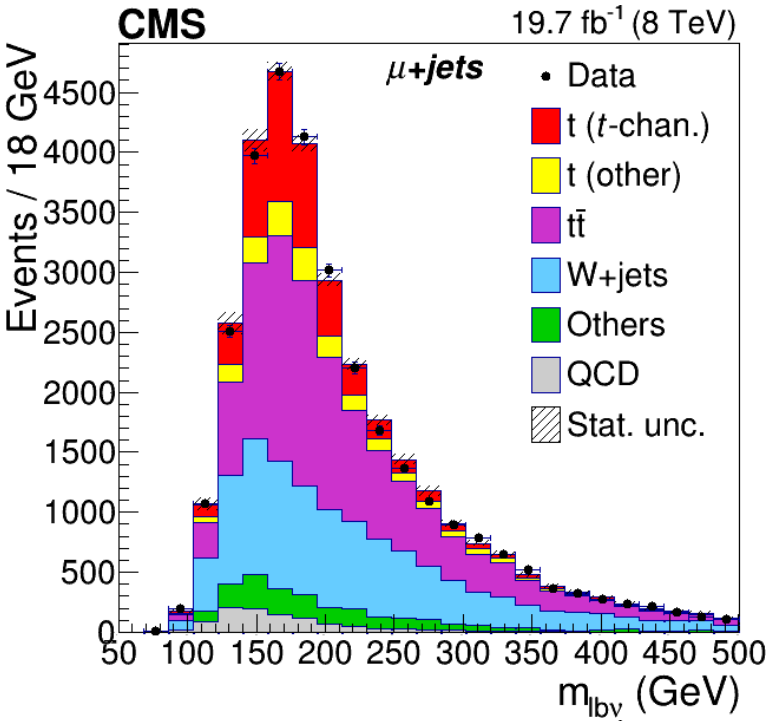
W boson helicity

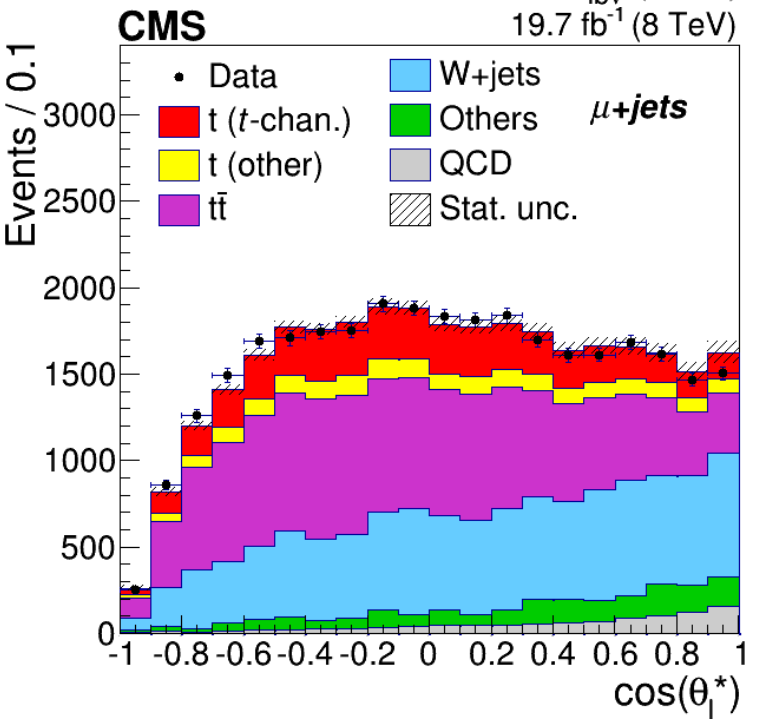
Polarization sensitive to **non-SM *tWb* coupling**

Measurement typically performed in **top pair** events

***t*-channel** events: 1 lepton, 2 jets ($|\eta|<4.7$), 1 *b*-tagged jet

Reconstruct top (from m_W constraint) to compute cos θ_ℓ^*





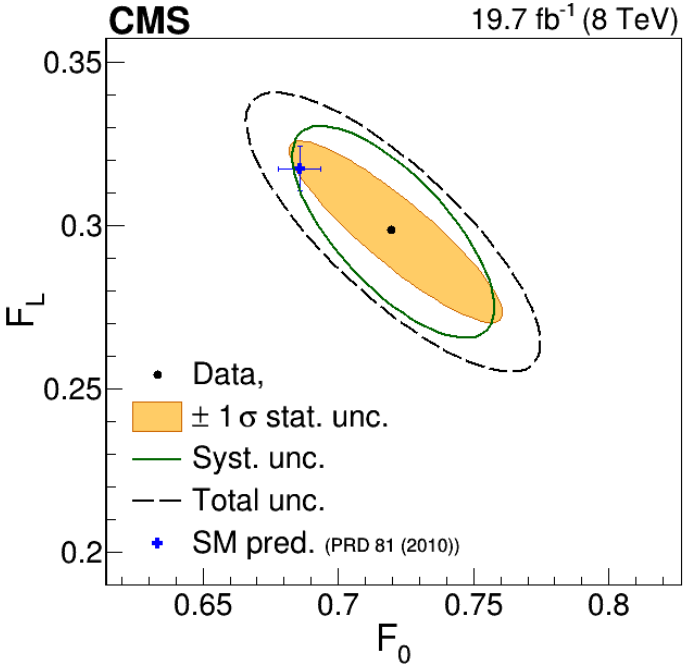
JHEP 01 (2015) 053

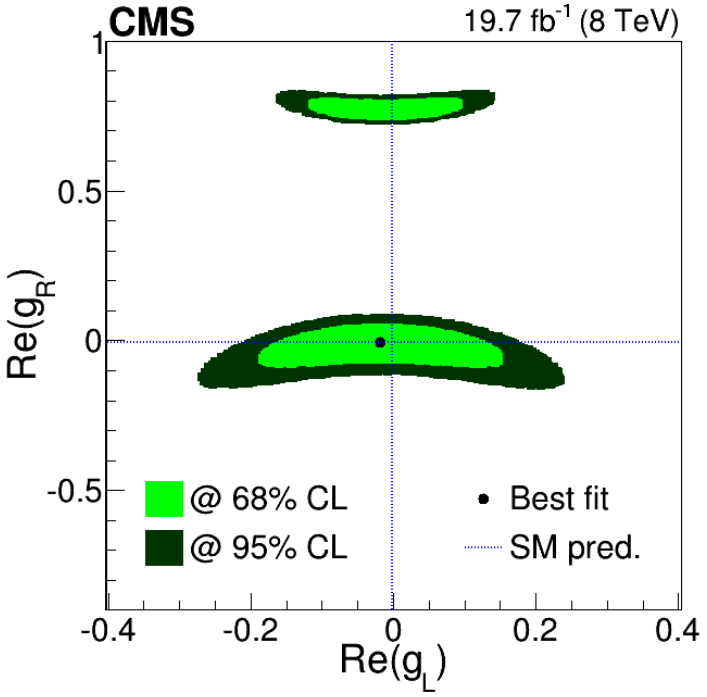
W helicity results

Extract F_0 F_L F_R from **fit to cos θ_ℓ^***

Helicity fractions in **good agreement** with SM

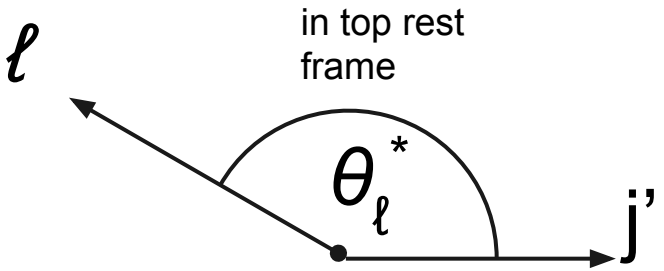
Set exclusion **limits** on *Wtb* anomalous couplings g_L and g_R, assuming V_L=1, V_R=0





JHEP 01 (2015) 053

CMS PAS TOP-13-001



$$\frac{d\Gamma}{d\cos\theta_X} = \frac{\Gamma}{2}(1 + P_t\alpha_\ell\cos\theta_X) \equiv \frac{\Gamma}{2}(1 + 2A_\ell\cos\theta_X)$$

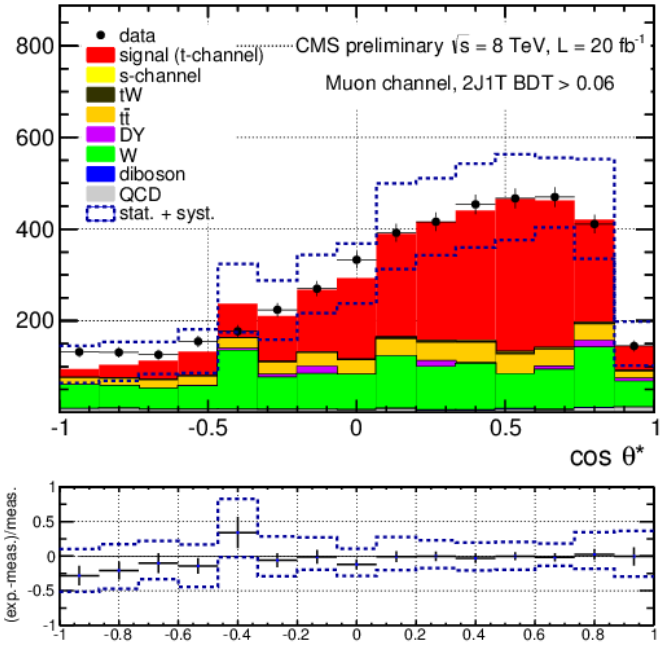
Measurement of top quark polarization in t-channel single top production at 8 TeV

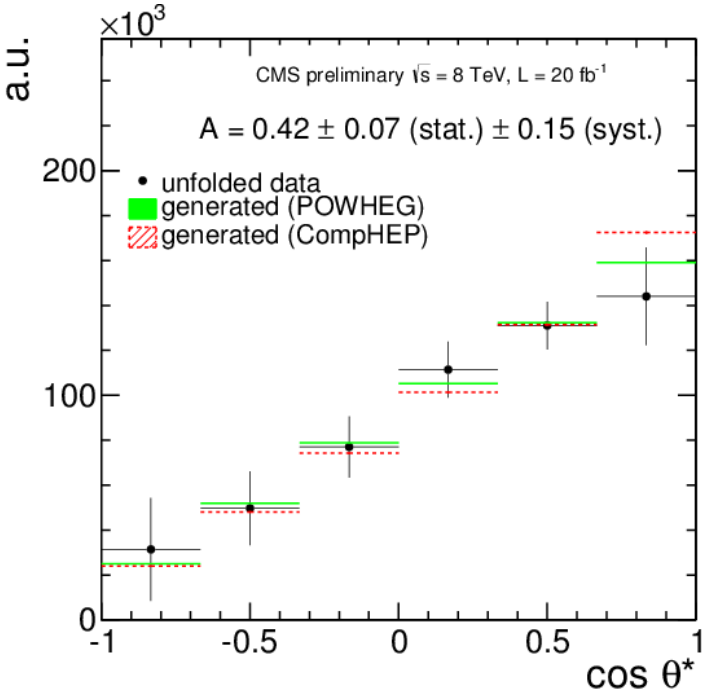
Top quark polarization

BDT selects *t*-channel events

Events **unfolded** to parton-level distribution of cos θ_ℓ^*

Asymmetry A_ℓ of leptons measured to determine polarization





CMS PAS TOP-13-001

Top quark polarization

Measured asymmetry (from BLUE combination)**:**

$$A_l = 0.41 \pm 0.17$$

$$\frac{d\Gamma}{d\cos\theta_X} = \frac{\Gamma}{2}\left(1 + P_t \alpha_\ell \cos\theta_X\right) \equiv \frac{\Gamma}{2}\left(1 + 2A_\ell \cos\theta_X\right)$$

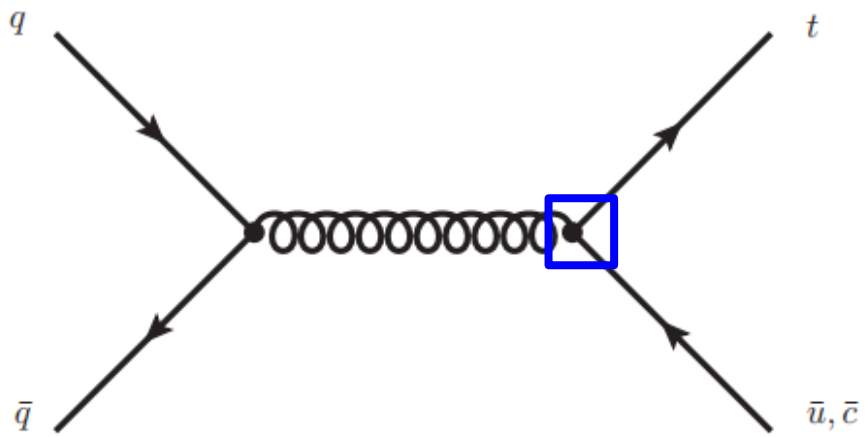
Assuming 100% spin **analyzing power** of charged lepton ($\alpha_\ell = 1$):

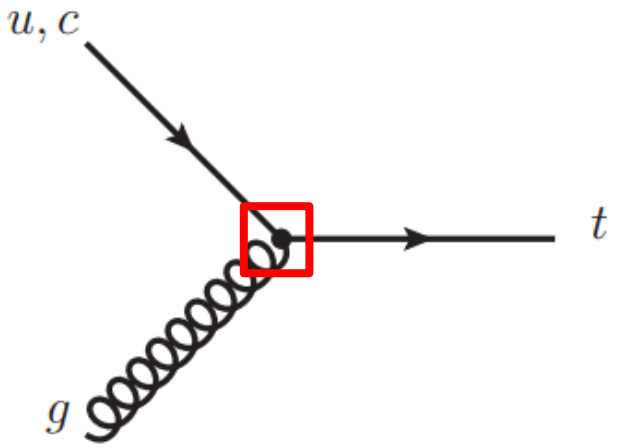
$$P_t = 0.82 \pm 0.34$$

CMS PAS TOP-13-001

ATLAS-CONF-2013-063

CMS PAS TOP-14-007



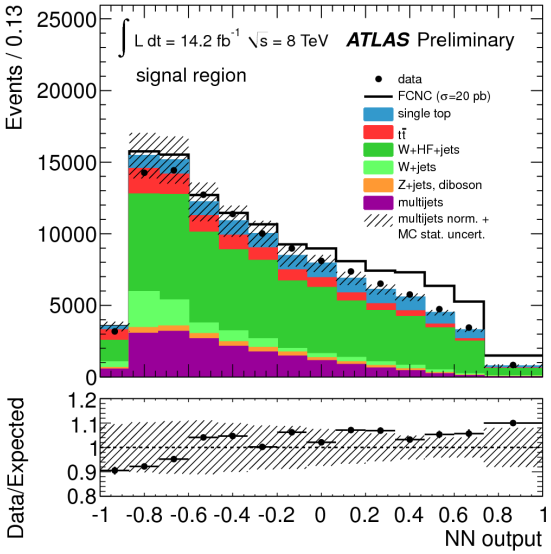


Search for single top quark production via flavor-changing neutral current (FCNC) in strong interactions at 7 and 8 TeV

Flavor-changing neutral currents *tcg* and *tug*

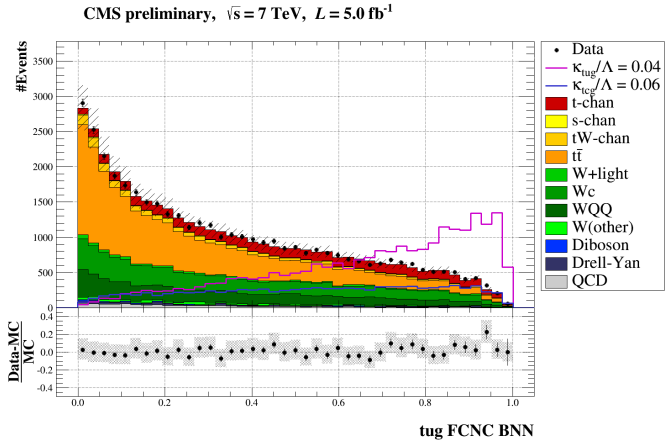
FCNC in top decays predicted in several **BSM theories** (new exotic quarks, new scalars, SUSY, technicolor)

Multivariate classifier separates FCNC in decay vertex (CMS) or production vertex (ATLAS) from SM *t*-channel events



ATLAS-CONF-2013-063

CMS PAS TOP-14-007

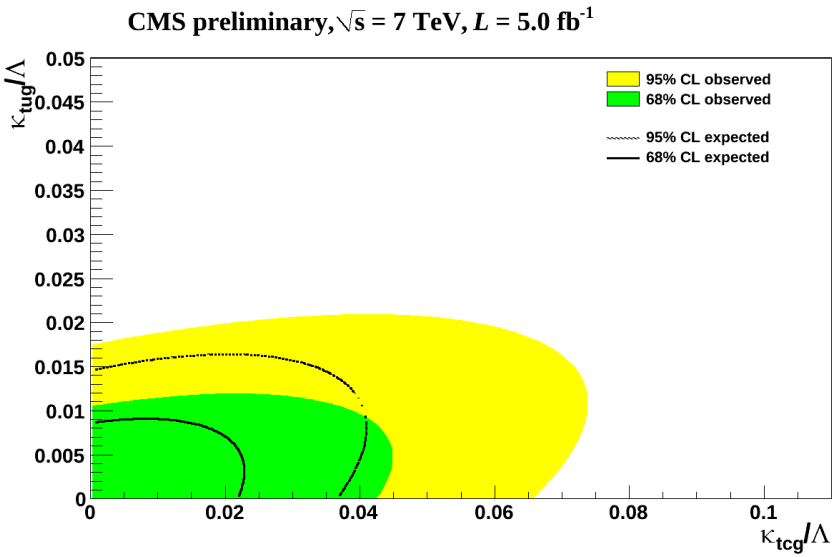


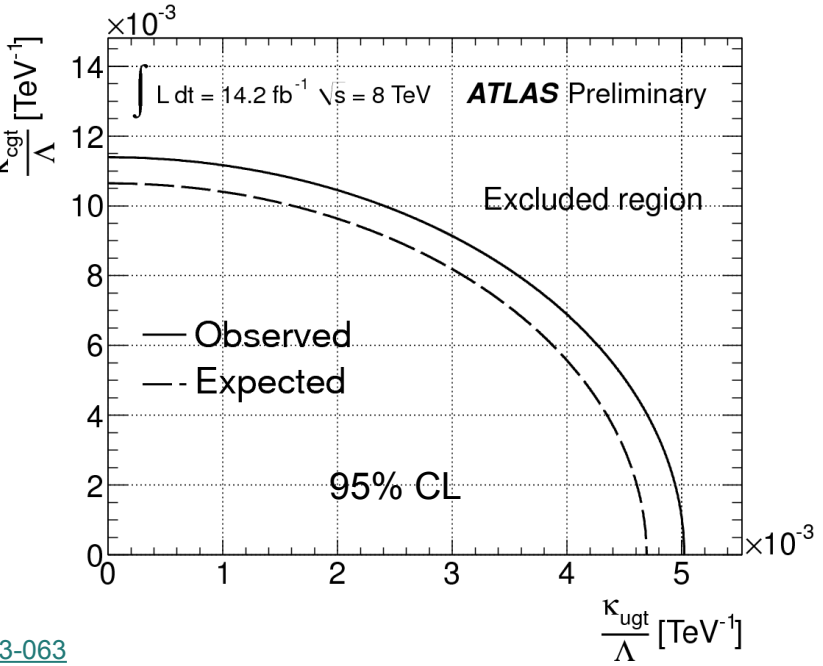
Limits on FCNC

Limits set on coupling parameters κ_{ugt} and κ_{cgt}

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

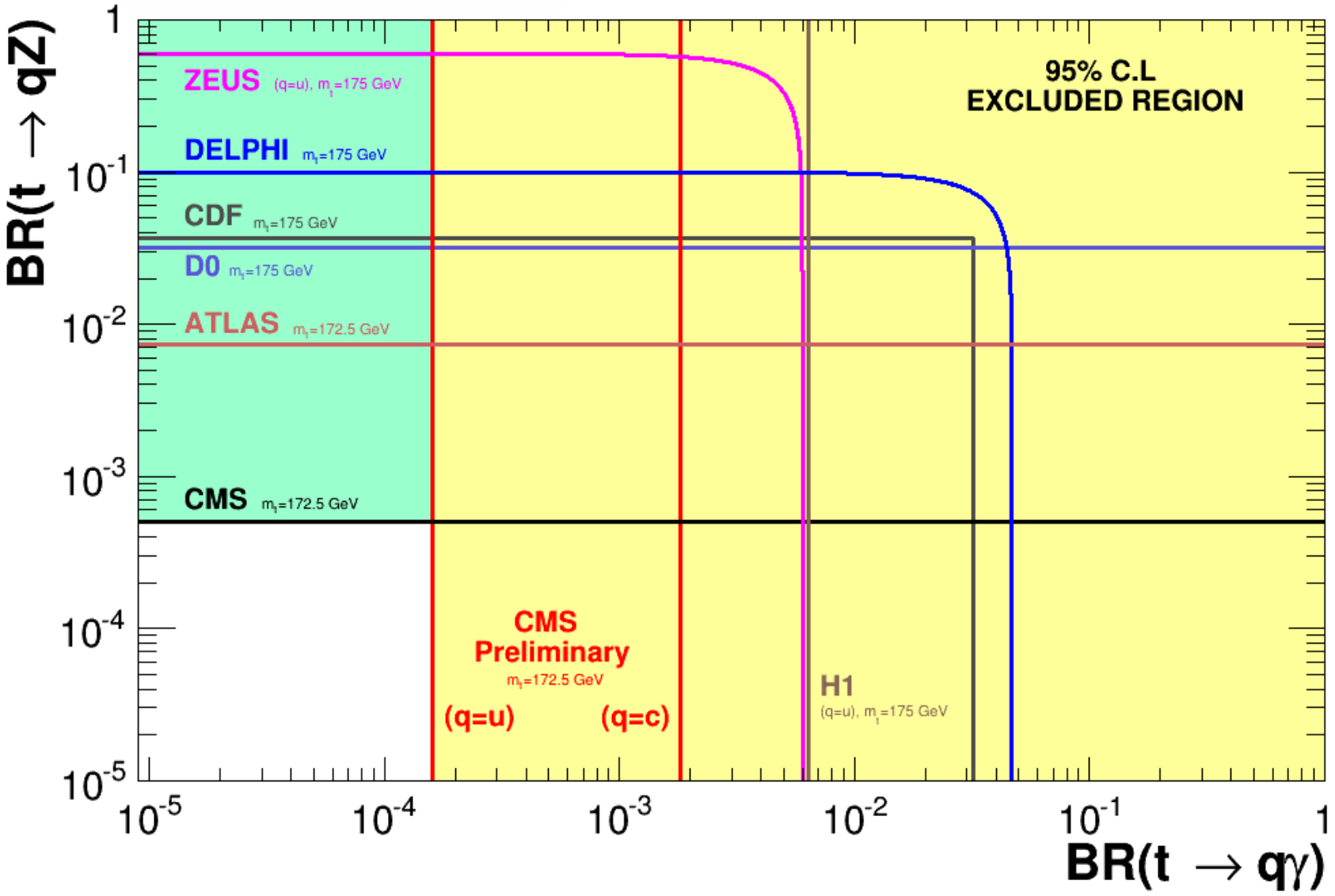
Additional results in *tZ* and *tγ* in backup





ATLAS-CONF-2013-063

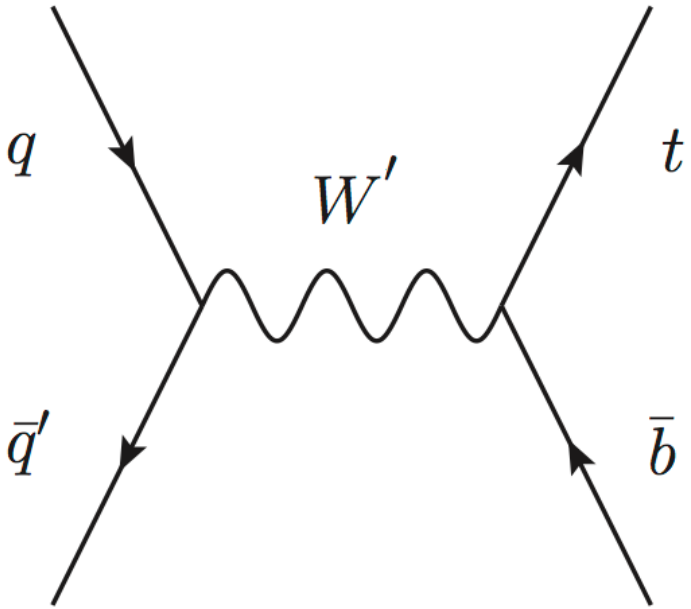
CMS PAS TOP-14-007



Summary of FCNC measurements

Physics Letters B 743 (2015) 235-255

JHEP 05 (2014) 108



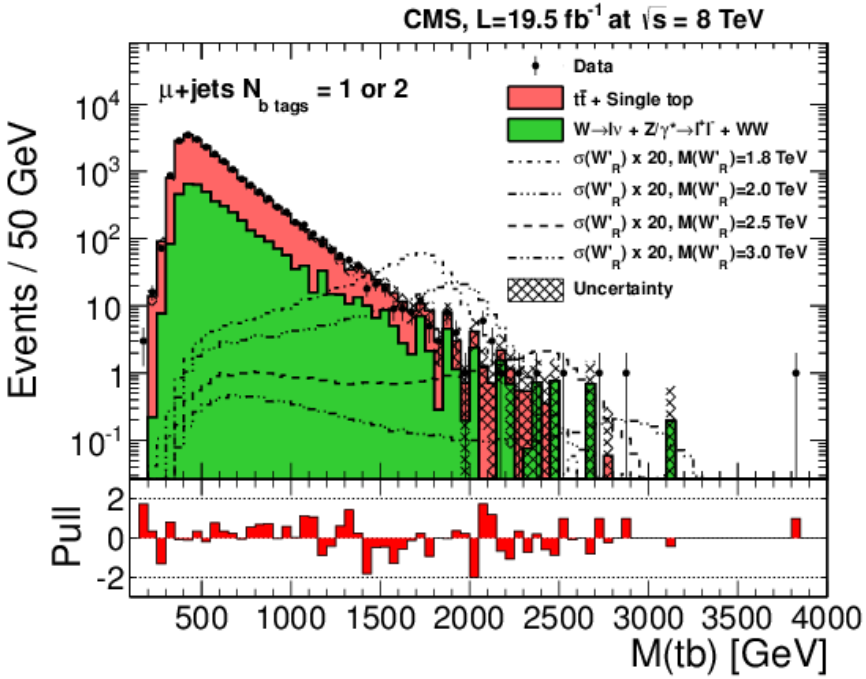
$$\mathcal{L} = \frac{V_{f_i f_j}}{2\sqrt{2}} g_w \overline{f}_i \gamma_\mu \left(a^{\mathrm{R}}_{f_i f_j} (1+\gamma^5) + a^{\mathrm{L}}_{f_i f_j} (1-\gamma^5) \right) \mathrm{W}'^{\mu} f_j + \mathrm{h.c.}$$

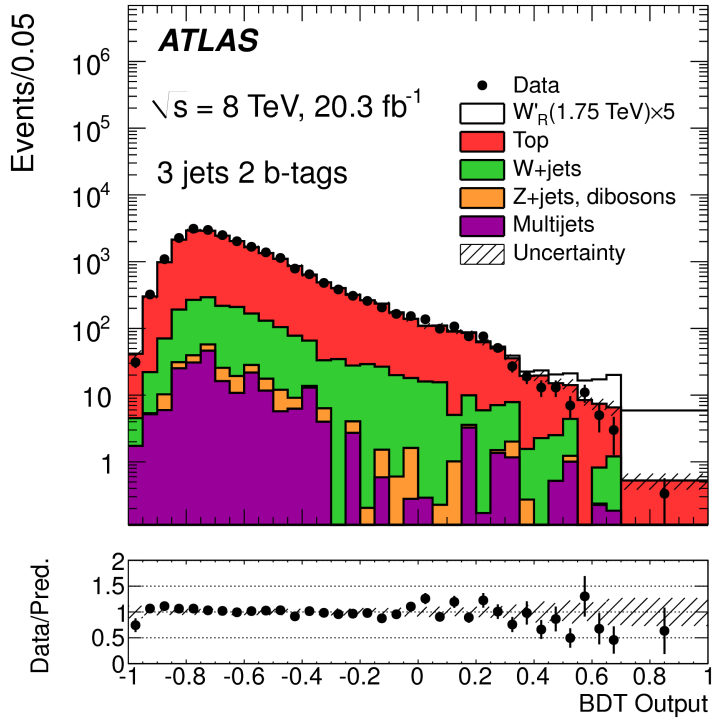
Searches for *W'* to *tb* decays in the lepton + jets final state at 8 TeV

Searches for *W'* to *tb*

Select 2 or more jet, 1 or 2-tag(CMS)/2 or 3-jet, 2-tag (ATLAS) lepton+jets events

Fit to m_{tb} distribution (CMS)/BDT output (ATLAS)





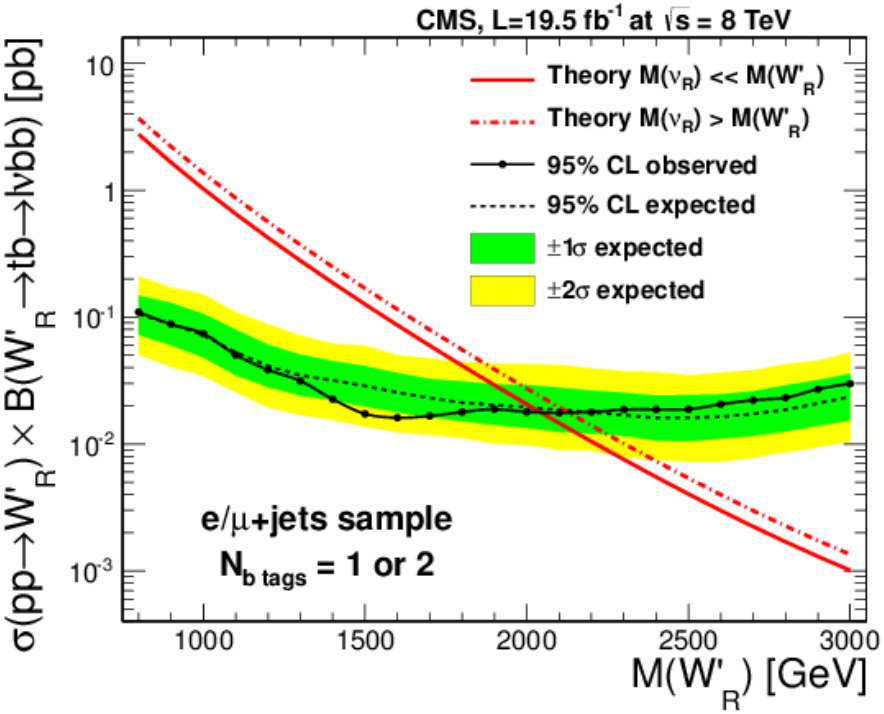
Physics Letters B 743 (2015) 235-255

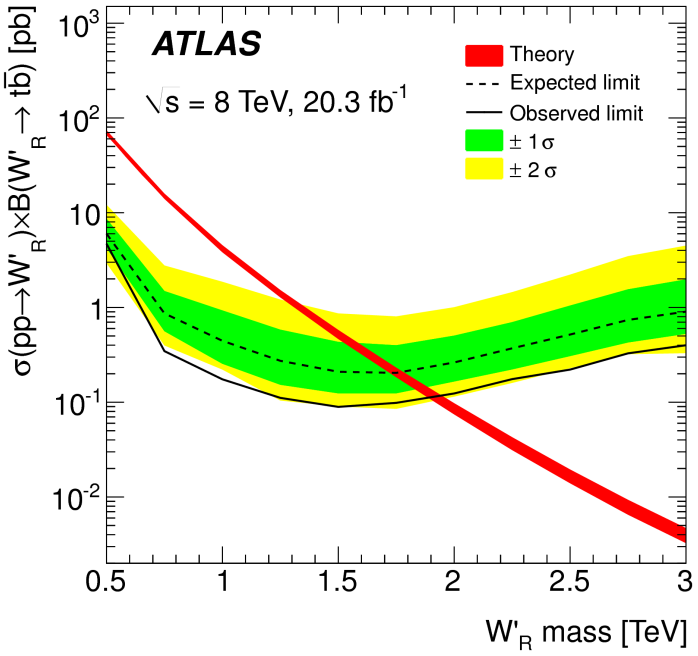
JHEP 05 (2014) 108

W' to *tb* limits

Limits set on $M(W'_R)$ (shown) and $M(W'_L)$ at ≅ 2 TeV

Limits also set in a^L, a^R coupling **plane** (CMS) and as a function of *M (W')*, ***g'/g*** (ATLAS)





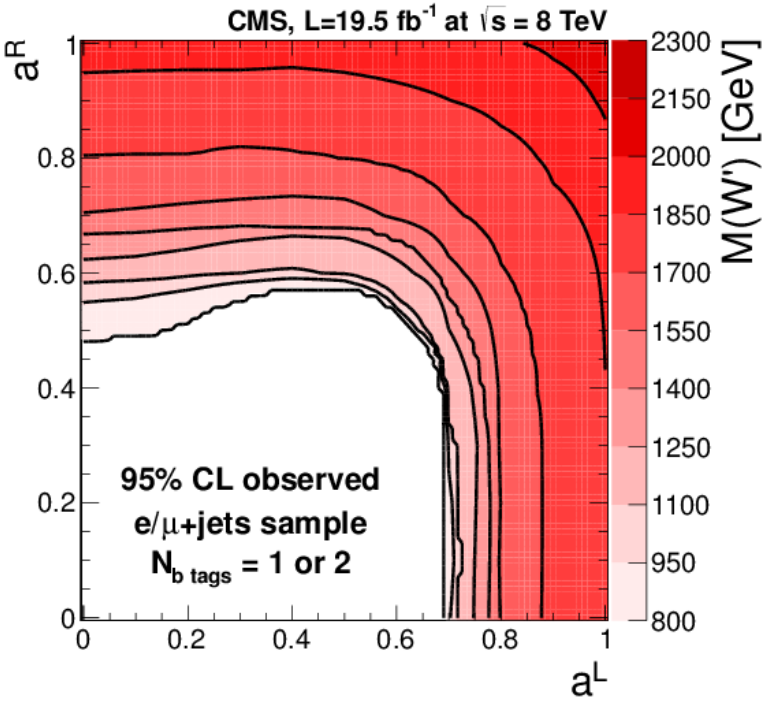
Physics Letters B 743 (2015) 235-255

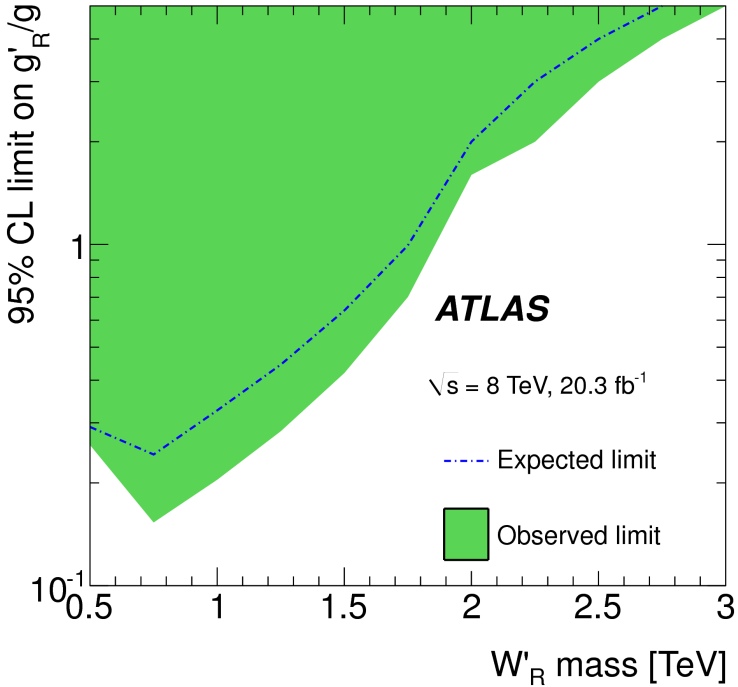
JHEP 05 (2014) 108

W' to *tb* limits

Limits also set in a^L,a^R coupling **plane** (CMS) and as a function of *M (W')*, ***g'/g*** (ATLAS)

Boosted all-hadronic results improve sensitivity at high mass (in backup)

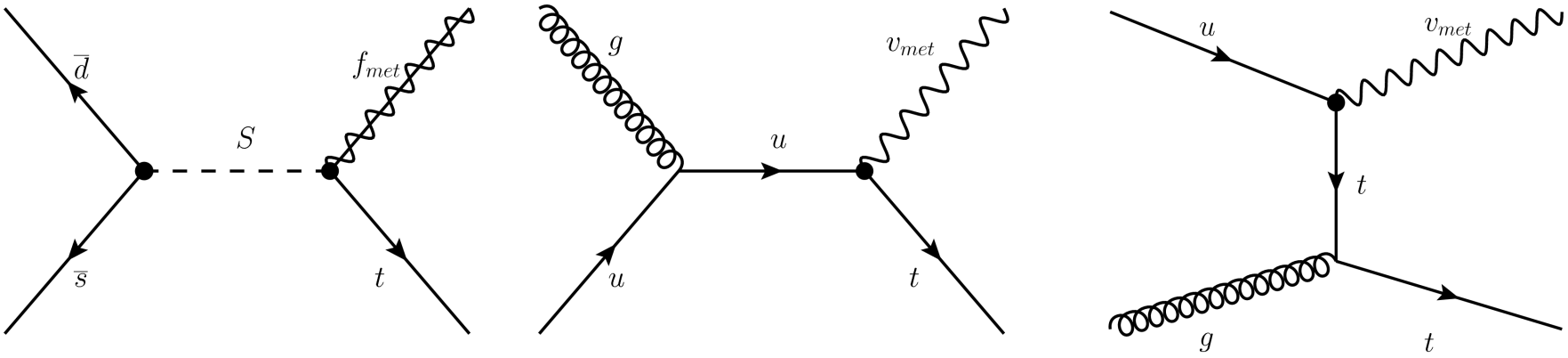




Physics Letters B 743 (2015) 235-255

JHEP 05 (2014) 108

Eur. Phys. J. C (2015) 75:79
hep-ex:1410.1149 (submitted to PRL)



Searches for invisible particles produced in association with single top quarks (monotop) at 8 TeV

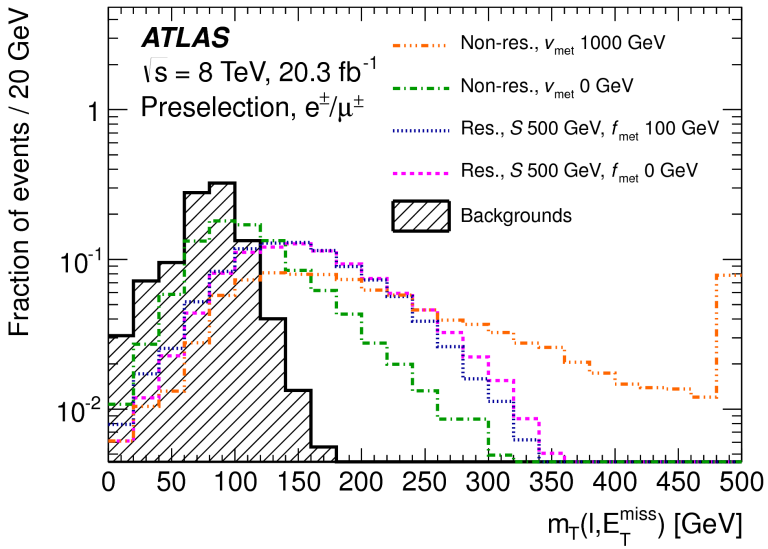
Monotop searches

ATLAS: **Leptonic** top decay

Cut and count, $m_T(\ell, E_T^{miss})$ and $|\Delta\varphi(\ell,b)|$ cuts optimized to **resonant** production and **non-resonant** production models

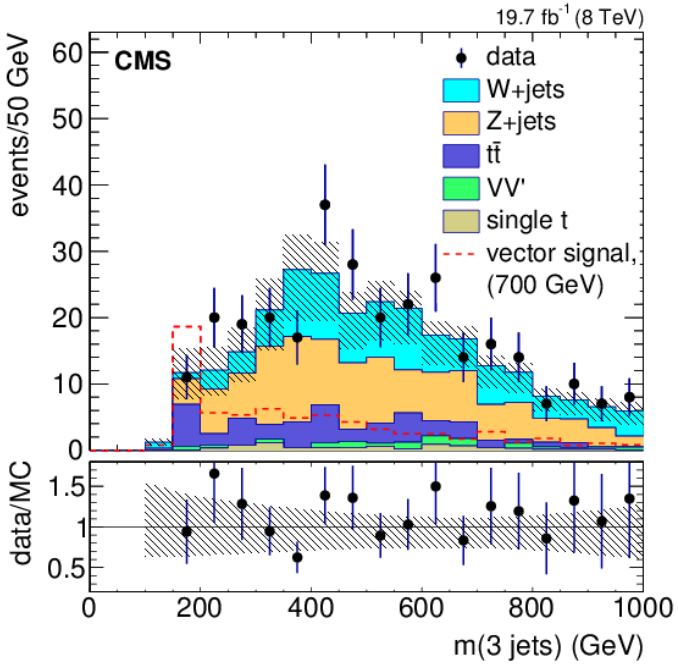
Eur. Phys. J. C (2015) 75:79

hep-ex:1410.1149 (submitted to PRL)



CMS: **Hadronic** top decay

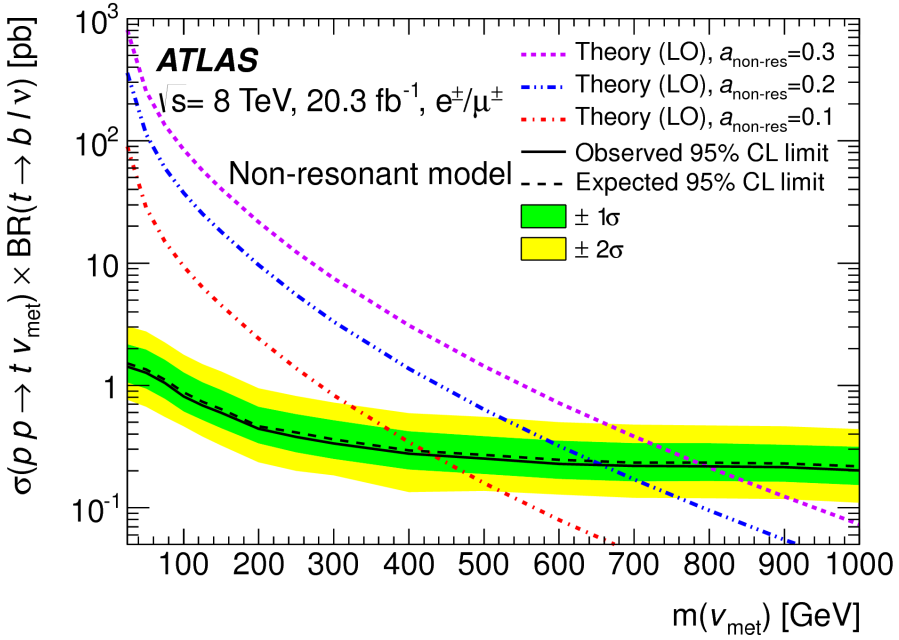
Likelihood fit with 0, 1-tag events to extract signal and QCD background, investigate **scalar** and **vector** DM models

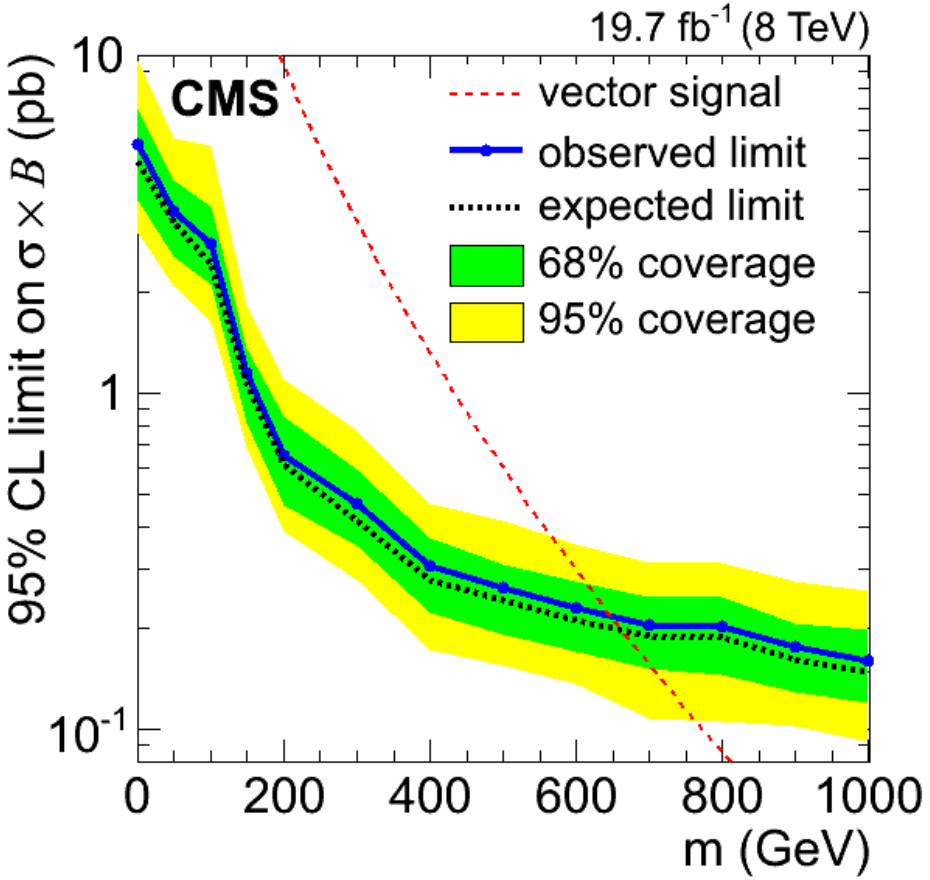


Monotop limits

Eur. Phys. J. C (2015) 75:79

hep-ex:1410.1149 (submitted to PRL)





Summary

ATLAS and CMS have delivered impressive results in **single top** final states with run-1 data

Cross-section measurements, properties measurements, BSM searches **confirm** best **SM** calculations and predictions

Eagerly awaiting **run-2 LHC** data

“And the good Master said: Even now, my Son,
The city draweth near whose name is Dis,
With the grave citizens, with the great throng.”

Backup slides

Table 3: Selection cuts of the fiducial volume. Electrons and muons from τ contributes with about 3% to the acceptance.

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

Back to Slide 8: t-channel inclusive - results

ATLAS *t*-channel fiducial region definition

Table 2: The 14 variables which are used in the training of the neural network 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

Back to Slide 7: t-channel inclusive

ATLAS *t*-channel inclusive neural net ranking

TABLE II. Input variables of the NNs in the 2-jet channels and in the 3-jet channels. The definitions of the variables use the term *leading jet* and 2^{nd} *leading jet*, defined as the jet with the highest or 2^{nd} highest p_T, respectively. In the 2-jet channels, exactly one jet is required to be b-tagged. The jet that is not b-tagged is denoted *untagged* jet.

Variables used in the 2-jet channels and the 3-jet channels	
$m(\ell\nu b)$	The invariant mass of the reconstructed top quark.
$m_T(\ell E_T^{miss})$	The transverse mass of the lepton–E_T^{miss} system, as defined in Eq. (1).
$\eta(\ell\nu)$	The pseudorapidity of the system of the lepton and the reconstructed neutrino.
$m(\ell b)$	The invariant mass of the charged lepton and the b-tagged jet.
H_T	The scalar sum of the transverse momenta of the jets, the charged lepton, and the E_T^{miss}.
Variables used in the 2-jet channels only	
$m(jb)$	The invariant mass of the untagged jet and the b-tagged jet.
$\lvert\eta(j)\rvert$	The absolute value of the pseudorapidity of the untagged jet.
$\Delta R(\ell, j)$	ΔR between the charged lepton and the untagged jet.
$\Delta R(\ell\nu b, j)$	ΔR between the reconstructed top quark and the untagged jet.
$\lvert\eta(b)\rvert$	The absolute value of the pseudorapidity of the b-tagged jet.
$\lvert\Delta p_T(\ell, j)\rvert$	The absolute value of the difference between the transverse momentum of the charged lepton and the untagged jet.
$\lvert\Delta p_T(\ell\nu b, j)\rvert$	The absolute value of the difference between the transverse momentum of the reconstructed top quark and the untagged jet.
E_T^{miss}	The missing transverse momentum.
Variables used in the 3-jet channels only	
$\lvert\Delta y(j_1, j_2)\rvert$	The absolute value of the rapidity difference of the leading and 2^{nd} leading jets.
$m(j_2 j_3)$	The invariant mass of the 2^{nd} leading jet and the 3^{rd} leading jet.
$\cos\theta(\ell, j)_{\ell\nu b\ \text{r.f.}}$	The cosine of the angle θ between the charged lepton and the leading untagged jet in the rest frame of the reconstructed top quark.
$\Sigma\eta(j_i)$	The sum of the pseudorapidities of all jets in the event.
$m(j_1 j_2)$	The invariant mass of the two leading jets.
$p_T(\ell\nu b)$	The transverse momentum of the reconstructed top quark.

ATLAS *t*-channel differential neural net ranking

Table 1: List of input variables used in the neural network training, ranked by relevance in the two channels.

variable	rank in channel μ+jets	rank in channel e+jets	variable	rank in channel μ+jets	rank in channel e+jets
η_{lq}	1	1	C	11	12
$m_{\ell,\nu,b}$	2	2	$p_{T,lq}$	12	9
$m_{\mathrm{jet1,jet2}}$	3	3	D	13	17
$m_{\mathrm{T,W}}$	4	4	m_{jet1}	14	5
Q_{ℓ}	5	6	$E_{\mathrm{T}}^{\mathrm{miss}}$	15	14
m_{lq}	6	13	$\Delta\phi[jet2, \vec{\not{E}}_{\mathrm{T}}]$	16	16
η_{W}	7	7	m_{jet2}	17	8
$\Delta\phi[\ell, lq]$	8	11	$\Delta R[jet1, \vec{\not{E}}_{\mathrm{T}}]$	18	15
$m_{b_{top}}$	9	–	$\Delta\phi[jet2, \ell]$	–	10
$\Delta\phi[jet1, \vec{\not{E}}_{\mathrm{T}}]$	10	–	$Aplanarity$	–	18

CMS *t*-channel differential neural net ranking

TABLE I. Variables used for BDT training

Variable Name	Description
# of loose jets	Number of loose jets, $p_T > 20$ GeV, $\|\eta\| < 4.9$
# of central loose jets	Number of loose jets, $p_T > 20$ GeV, $\|\eta\| < 2.4$
# of b-tagged loose jets	Number of loose jets, $p_T > 20$ GeV, q_b-tagged, $\|\eta\| < 2.4$
p_T^{sys}	Vector sum of p_T of leptons, jet, and E_T^{miss}
H_T	Scalar sum of p_T of leptons, jet, and E_T^{miss}
p_T(jet)	p_T of the leading, tight, b-tagged jet
p_T(loose jet)	p_T of leading loose jet, defined as 0 for events with no loose jet present
p_T^{sys}/H_T	Ratio of p_T^{sys} to H_T for the event
m_{sys}	Invariant mass of the combination of the leptons, jet, and E_T^{miss}
Centrality(j$\ell\ell$)	Centrality of jet and leptons, defined as ratio of transverse to total energy
H_T(leptons)/H_T	Ratio of scalar sum of p_T of the leptons to the H_T of full system
p_T(j$\ell\ell$)	Vector sum of p_T of jet and leptons
E_T^{miss}	Missing transverse energy in the event

multivariate data analysis [43]. The BDT analyzer is trained using 13 variables, chosen for their separation power in distinguishing tW and $t\bar{t}$, as well as being well modeled in simulation when checked in control regions. The most powerful variables are those involving loose jets in the event: the number of loose jets, number of central loose jets, and the number of loose jets that are b tagged. Other variables with significant separation power are related to the kinematics of the system comprised of the leptons, jets and E_T^{miss} : the scalar sum of their transverse momenta (H_T), the magnitude of the vector sum of their transverse momenta (p_T^{sys}), and invariant mass of the system. A

return to Slide 15: Wt inclusive: procedure

CMS *Wt* BDT variables

Variable	Description
$p_{\mathrm{T}}^{\mathrm{sys}}$ variables	p_{T} of the vectorial sum of physics objects
$p_{\mathrm{T}}^{\mathrm{sys}}$ (lep1,lep2,$E_{\mathrm{T}}^{\mathrm{miss}}$,jet1)	$p_{\mathrm{T}}^{\mathrm{sys}}$ of leptons, $E_{\mathrm{T}}^{\mathrm{miss}}$ and jet1
$p_{\mathrm{T}}^{\mathrm{sys}}$ (lep1,lep2,jet1)	$p_{\mathrm{T}}^{\mathrm{sys}}$ of leptons and jet1
p_{T}-related variables	
Δp_{T} ((lep1,lep2),($E_{\mathrm{T}}^{\mathrm{miss}}$,jet1))	Difference in p_{T} between the system of leptons and that of $E_{\mathrm{T}}^{\mathrm{miss}}$ and jet
Δp_{T} (lep1,$E_{\mathrm{T}}^{\mathrm{miss}}$)	Difference in p_{T} between lep1 and $E_{\mathrm{T}}^{\mathrm{miss}}$
$\sum E_{\mathrm{T}}$	Visible event transverse energy
H_{T} (lep1,lep2,$E_{\mathrm{T}}^{\mathrm{miss}}$,jet1)	Scalar sum of the p_{T} of all objects
Angular correlations	
$\Delta\phi$ ((lep1,lep2),jet1)	$\Delta\phi$ between the vector sum of leptons and jet1
ΔR ((lep1,lep2),jet1)	ΔR between the vector sum of leptons and jet1
$\Delta\phi$ (lep1,jet1)	$\Delta\phi$ between lep1 and jet1
$\Delta\phi$ ($E_{\mathrm{T}}^{\mathrm{miss}}$,jet1)	$\Delta\phi$ between $E_{\mathrm{T}}^{\mathrm{miss}}$ and jet1
Centrality (lep1,lep2)	(p_{T}(lep1) + p_{T}(lep2))/(p(lep1) + p(lep2))
Thrust	Thrust of all leptons and jets
η (lep1,lep2)	Pseudo-rapidity of the vector sum of leptons
m or m_{T} variables	Mass or transverse mass of the vectorial sum of objects
m_{T} (lep2,$E_{\mathrm{T}}^{\mathrm{miss}}$)	m_{T} of lep2 and $E_{\mathrm{T}}^{\mathrm{miss}}$
m (lep1,lep2,jet1)	m of leptons and jet1
m (lep1,jet1)	m of lep1 and jet1
Object kinematics	
$E_{\mathrm{T}}^{\mathrm{miss}}$	Missing transverse momentum
E_{T} (jet1)	jet1 transverse energy
η (lep2)	lep2 pseudo-rapidity

Table 2: Input variables for the BDT classifier for 1-jet events. The leading lepton in p_{T} is denoted as lep1, the other lepton as lep2 and the jet as jet1. For additional details see the text.

return to Slide 15: Wt inclusive: procedure

ATLAS *Wt* BDT variables

Table 1: Input variables for BDT training in the 2-jets 2-tags sample, ranked by their importance, in the electron channel.

Variable	Description
m_{T}	tranverse W boson mass
$\Delta\Phi_{\mathrm{top,b'}}$	difference in azimuthal angle between top quark and recoiled b-tagged jet
$\not\!\!E_{\mathrm{T}}$	missing transverse energy
$M_{\ell b2}$	invariant mass of the lepton and the second-to-leading b-tagged jet
$\cos\theta^*$	cosine of the angle between the lepton and the b-tagged jet recoiling against the top quark, in the top-quark rest frame
$p_{\mathrm{T}}^{\mathrm{bb}}$	vector sum of p_{T} of the two b-tagged jets
$\Delta R_{\mathrm{bb}}(*)$	angular separation between the two b-tagged jets
p_{T}^{ℓ}	transverse momentum of the lepton
$m_{\ell\nu\mathrm{b}}$-best	invariant mass of lepton, neutrino and one of the b-tagged jets reconstructed with the best-mass top method, as described in Sec.2
$\Delta R_{\mathrm{b'}\ell}$	angular separation between the b-tagged jet recoiling against the top quark and the lepton
H_{T}	scalar sum of p_{T} of all jets

Back to Slide 18: s-channel searches

CMS *s*-channel BDT

defined in Section 5. The two most discriminating variables are the differences in azimuthal angle ($|\Delta\phi|$) between the leading (sub-leading) b-jet and the top-quark candidate reconstructed with the sub-leading (leading) b-jet. The four next-most important variables are the scalar sum of the lepton p_{T} and $E_{\mathrm{T}}^{\mathrm{miss}}$, $E_{\mathrm{T}}^{\mathrm{miss}}$, the W boson transverse mass, and the lepton p_{T}. The other variables, which have a smaller discriminating power, are (grouped according to their type): (*i*) the differences in pseudo-rapidity ($|\Delta\eta|$) between the lepton and the leading (sub-leading) b-jet, the $|\Delta\eta|$ between the leading b-jet and the top-quark candidate reconstructed with the sub-leading b-jet, the $|\Delta\eta|$ between the reconstructed neutrino and the b-jet not associated with the best top-quark candidate, (*ii*) the $|\Delta\phi|$ between the lepton and the missing transverse momentum, the $|\Delta\phi|$ between the two b-jets, (*iii*) the scalar sum of the p_{T} of all objects (lepton, b-jets, neutrino), the magnitude of the vector sum of the p_{T} of the two b-jets, the invariant mass of the two b-jets, and (*iv*) the cosine of the angle ($\cos\vartheta$) between the missing

Back to Slide 18: s-channel searches

ATLAS *s*-channel BDT

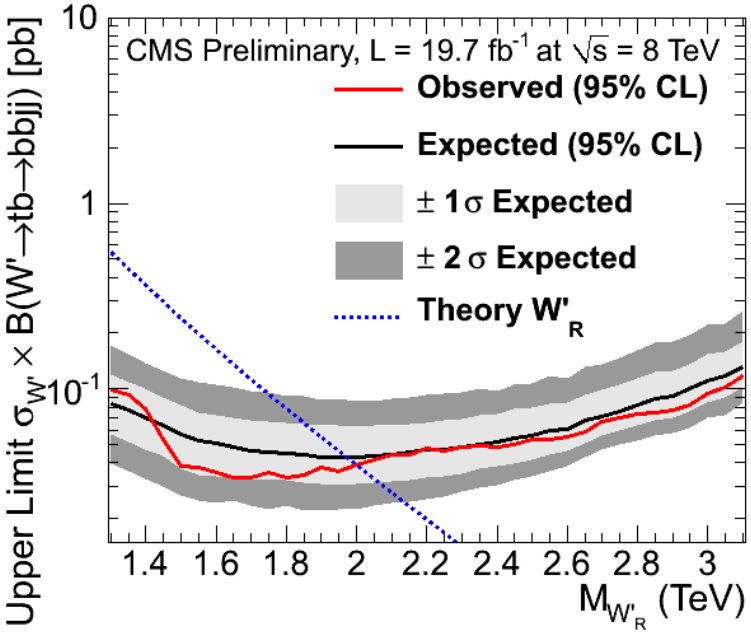
Table 3: Variables used as input to the neural network ordered by their importance, as estimated from the total correlation loss to the target caused by its removal.

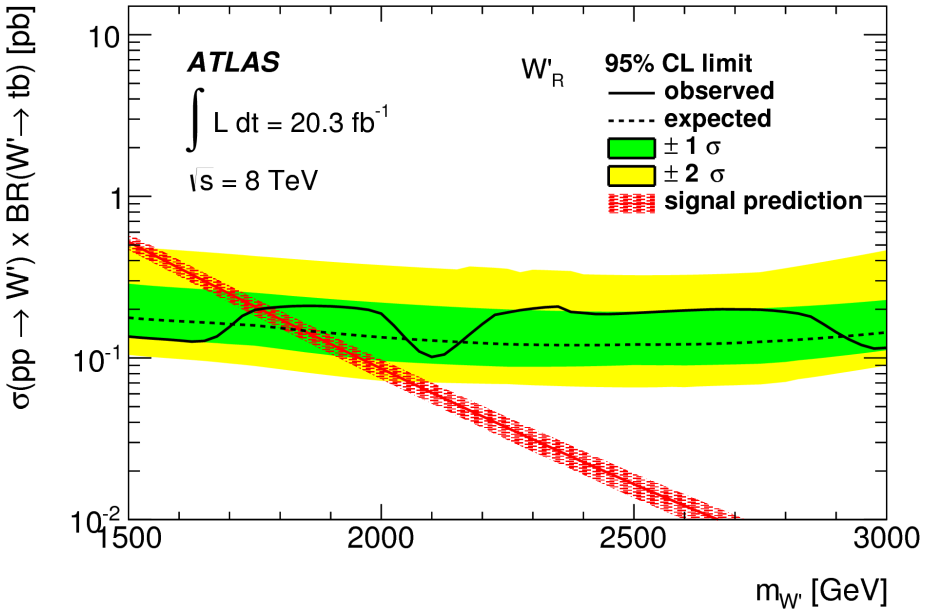
Variable	loss of total correlation (%)	Variable	loss of total correlation (%)
$p_{\mathrm{T}}(b)$	34	$\Delta\phi(\ell, W)$	6
$p_{\mathrm{T}}(W)$	19	$\Delta\phi(b, \ell\nu b)$	5
$\Delta\phi(W, \nu)$ in the top quark rest frame	13	$\Delta R(\ell, \ell\nu b)$	5
Charge of the lepton $q(\ell)$	12	$\Delta\phi(W, \ell\nu b)$	4
$\eta(\ell)$	11	$\eta(\nu)$	4
$\Delta\phi(\ell, b)$	9	$E_{\mathrm{T}}^{\mathrm{miss}}$	4
$\eta(\ell\nu b)$	9		

back to: Slide 32: Flavor-changing neutral currents tcg and tug

ATLAS FCNC neural net ranking

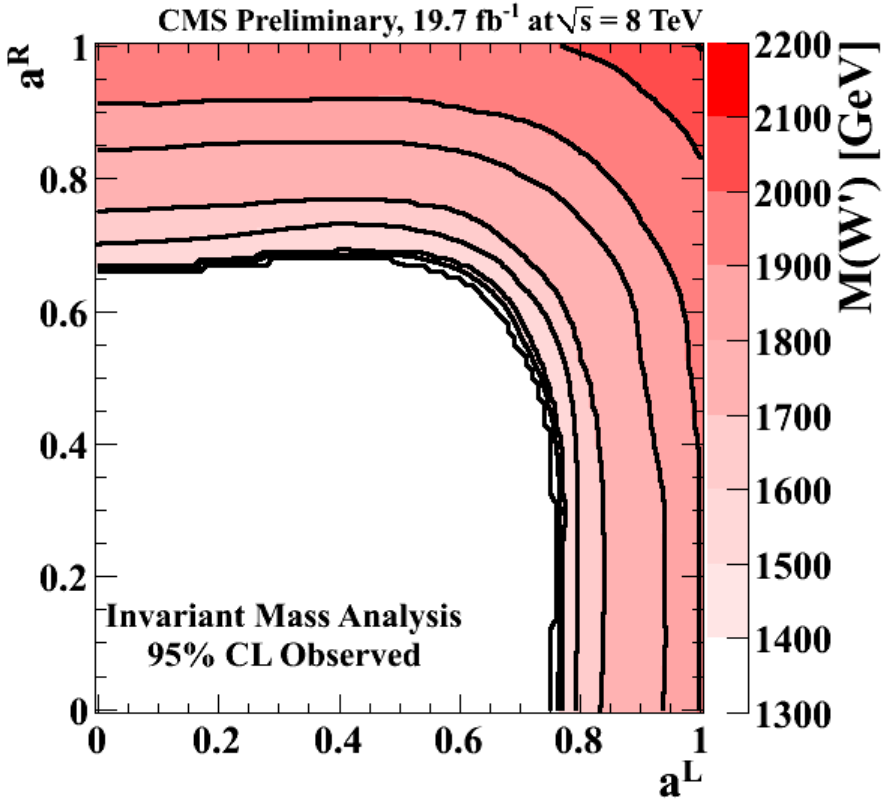
[submitted to EPJ C](#)
[CMS PAS B2G-12-009](#)

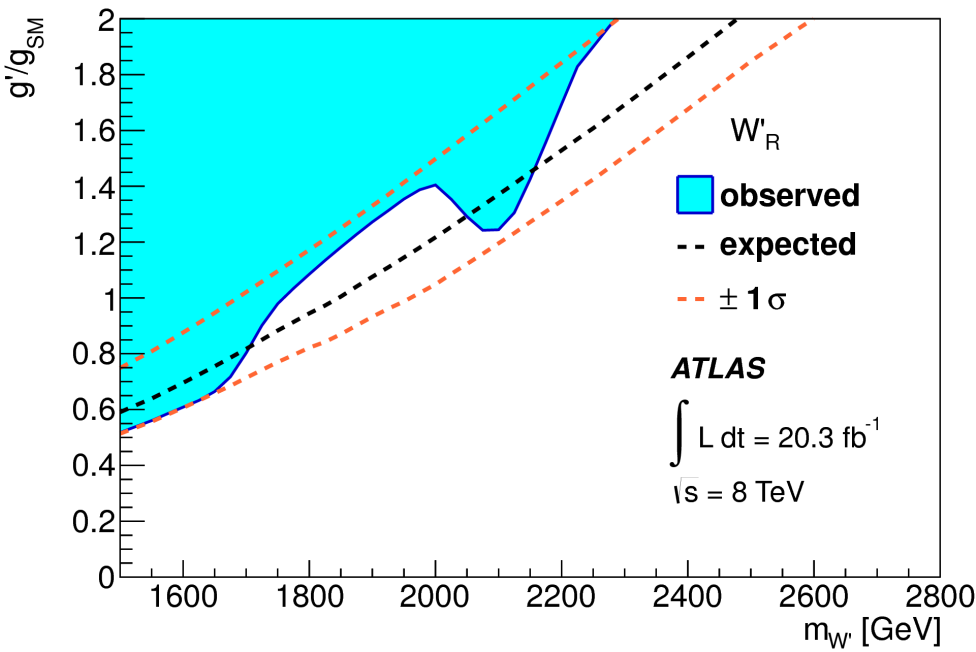




W' resonances in boosted fully-hadronic events

W' hadronic resonances

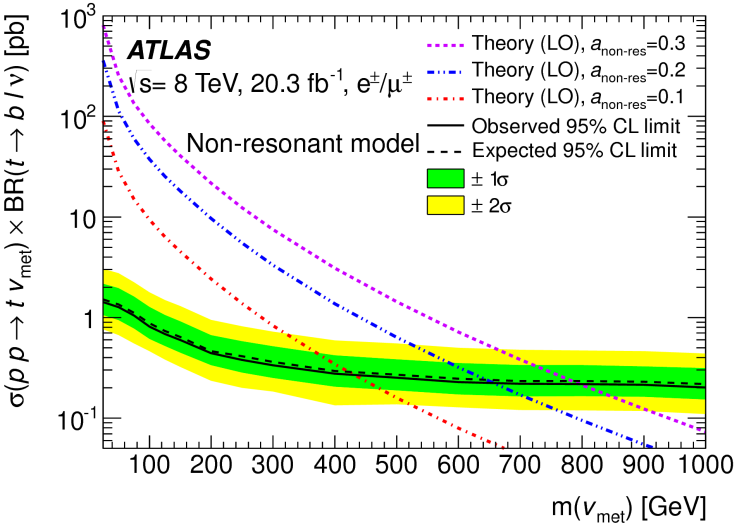


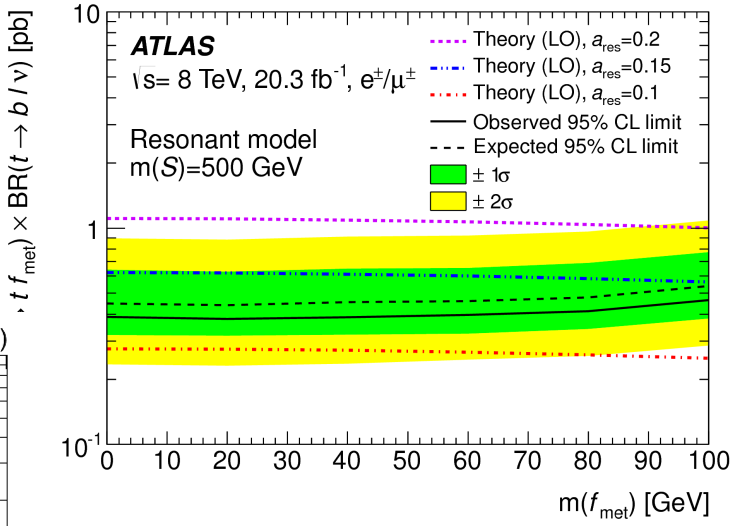


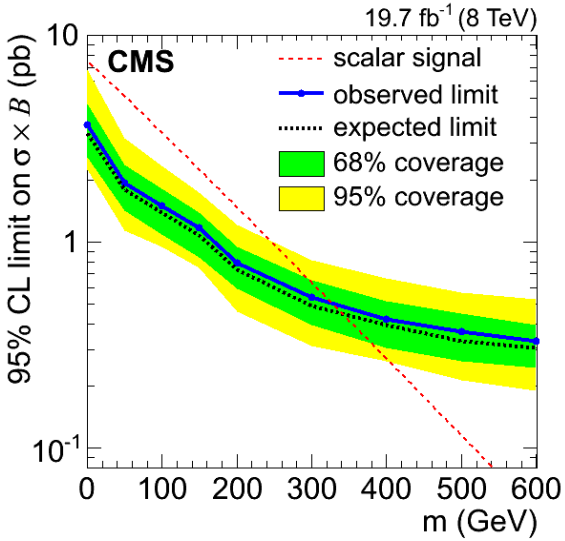
Monotop limits

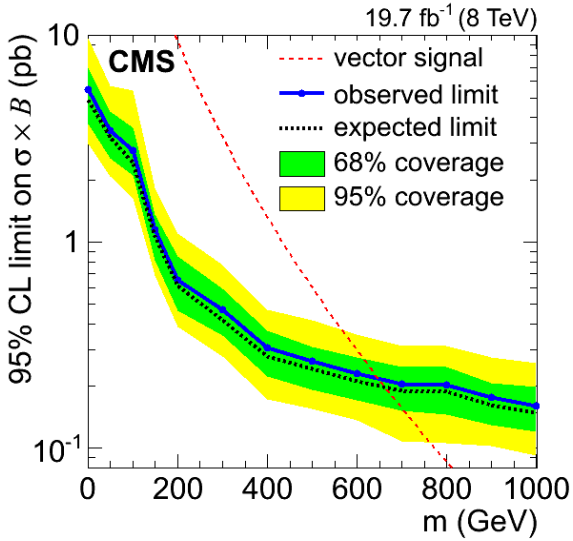
Resonant (top right), non-resonant (right)

Scalar DM (below left), vector DM (below right)





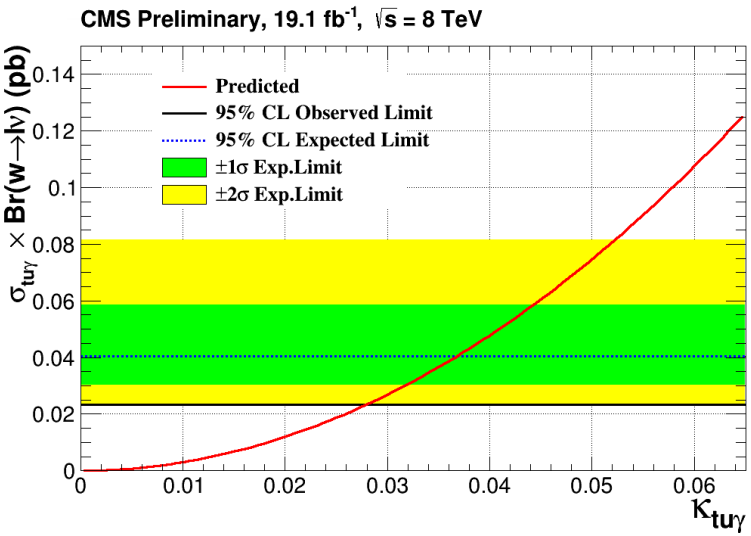


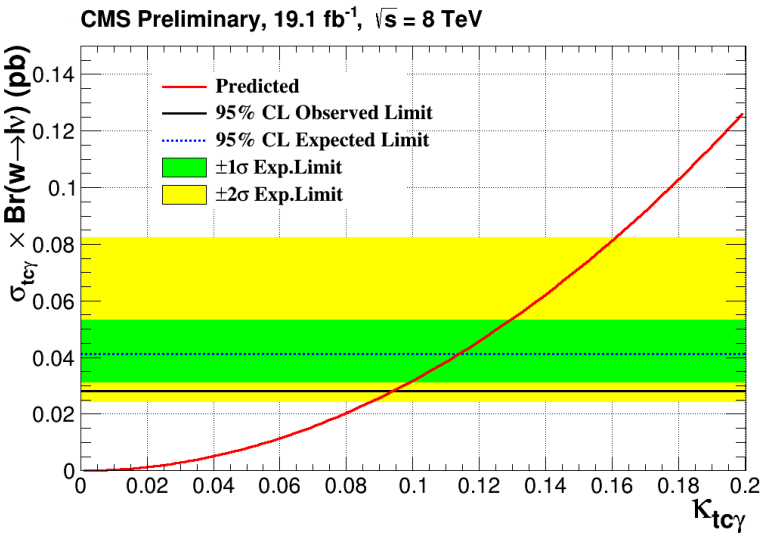


Eur. Phys. J. C (2015) 75:79

hep-ex:1410.1149 (submitted to PRL)

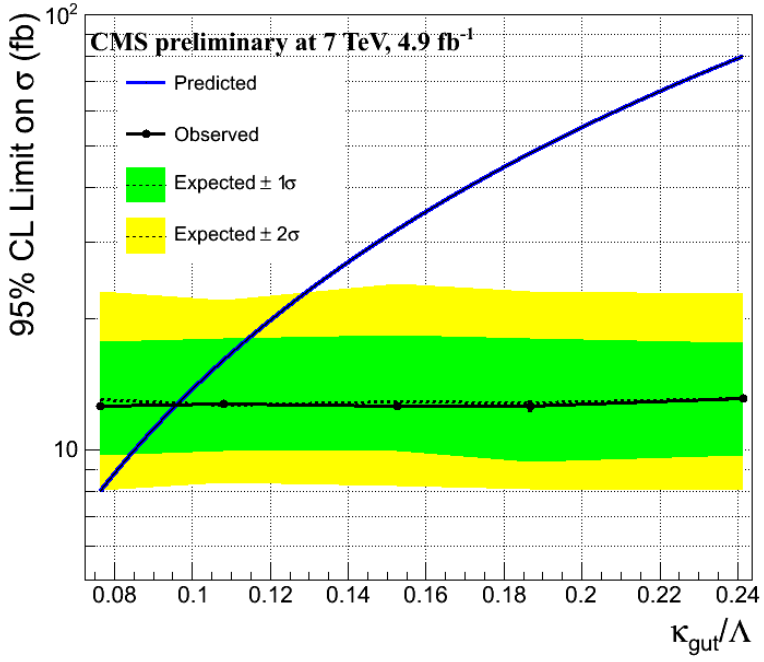
CMS PAS TOP-14-003

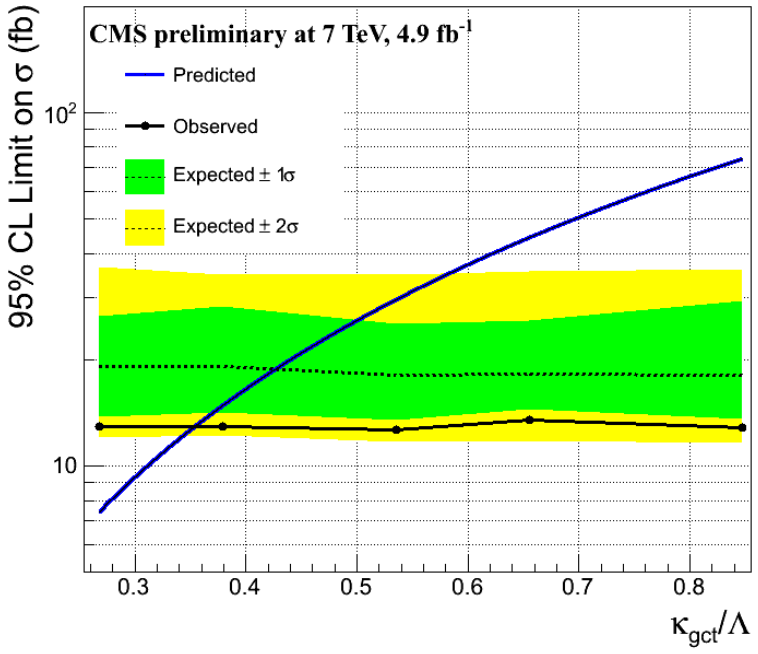




Search for anomalous single top quark production in association with a photon

CMS PAS TOP-12-021





Search for flavor changing neutral currents in *tZ* events in proton-proton collisions at 7 TeV

Anomalous *Wtb* couplings

ATLAS:

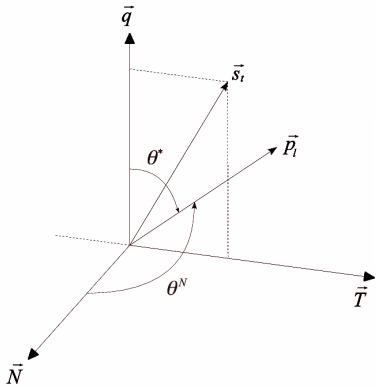
Measurement of A^{N}_{FB}, f
b^{kwd} **asymmetry** in norr
direction:

N = $\mathbf{s}_t$ x **q**

with $\mathbf{s}_t$: spectator quark momentum,

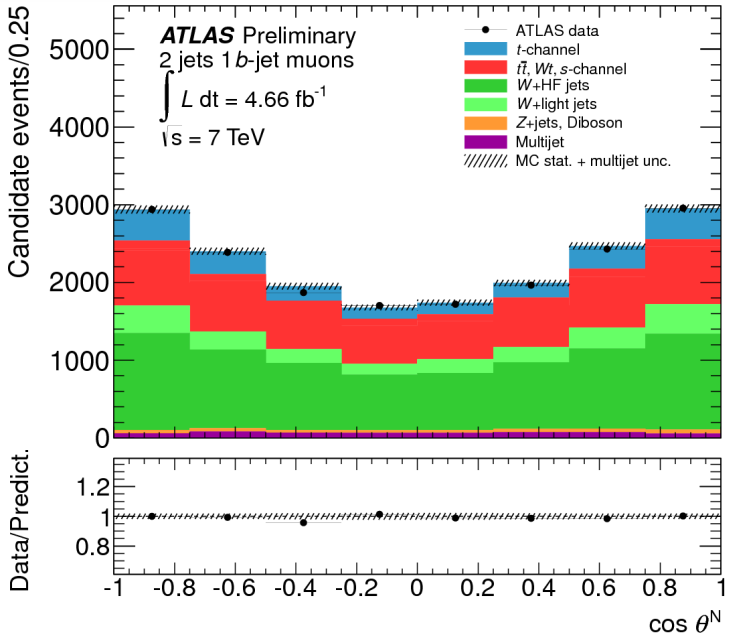
q: *W* momentum

Decay angle cos θ^{N} distribution **unfolded** to parton level



$$A_z \equiv \frac{N_{\text{evt}}(\cos\theta > z) - N_{\text{evt}}(\cos\theta < z)}{N_{\text{evt}}(\cos\theta > z) + N_{\text{evt}}(\cos\theta < z)}$$

ATLAS-CONF-2013-032



Generators

t-chan: ACER (ATLAS) POWHEG+PYTHIA(CMS)

t-chan diff.: POWHEG+PYTHIA

Wt chan: POWHEG+PYTHIA

s-chan: POWHEG+PYTHIA