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Top-Quark Properties Measurements with the ATLAS Detector

1. Top-quark Charge Asymmetry
2. Search for Flavor Changing Neutral Currents (FCNC) in top-quark decays

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On behalf of the ATLAS collaboration

ATLAS

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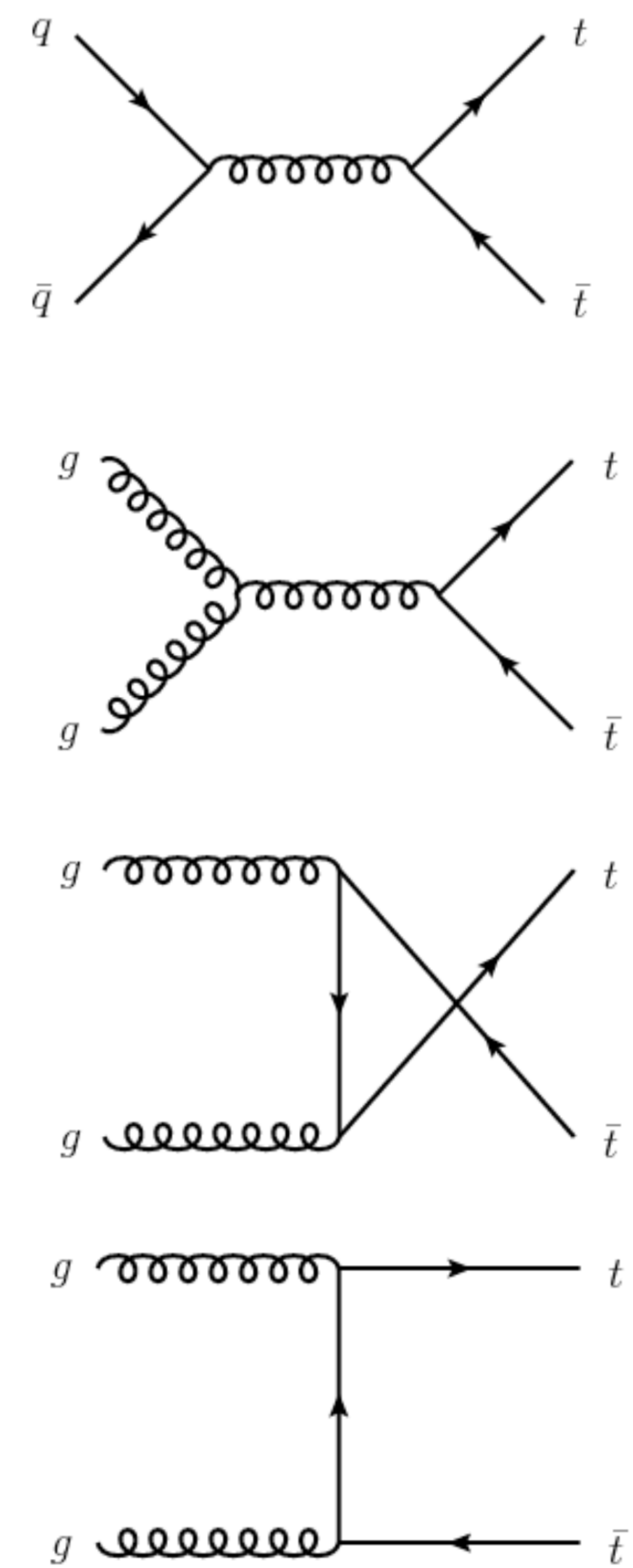
CERN

CoEPP
ARC Centre of Excellence for Particle Physics at the Terascale

Understanding the top-quark @ LHC

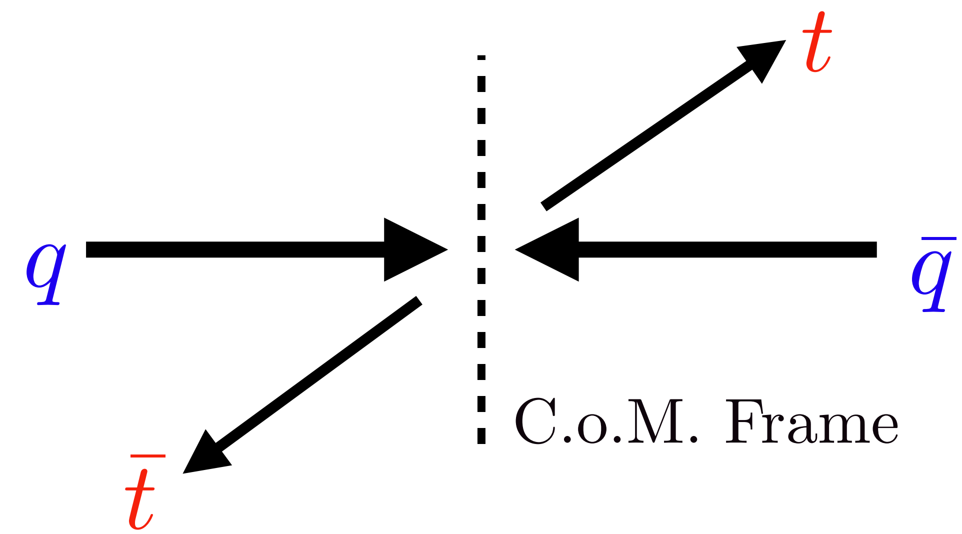
- Heaviest particle, Yukawa coupling~1
- Potential role in electroweak symmetry breaking and beyond standard model physics (BSM)
- Top-quark properties are sensitive probes of BSM
  - **Charge asymmetry** in top-quark products
  - **Flavor Changing Neutral Currents** decays of top quarks
- Today showing results from 8 TeV proton proton collisions collected in Run 1 of the LHC

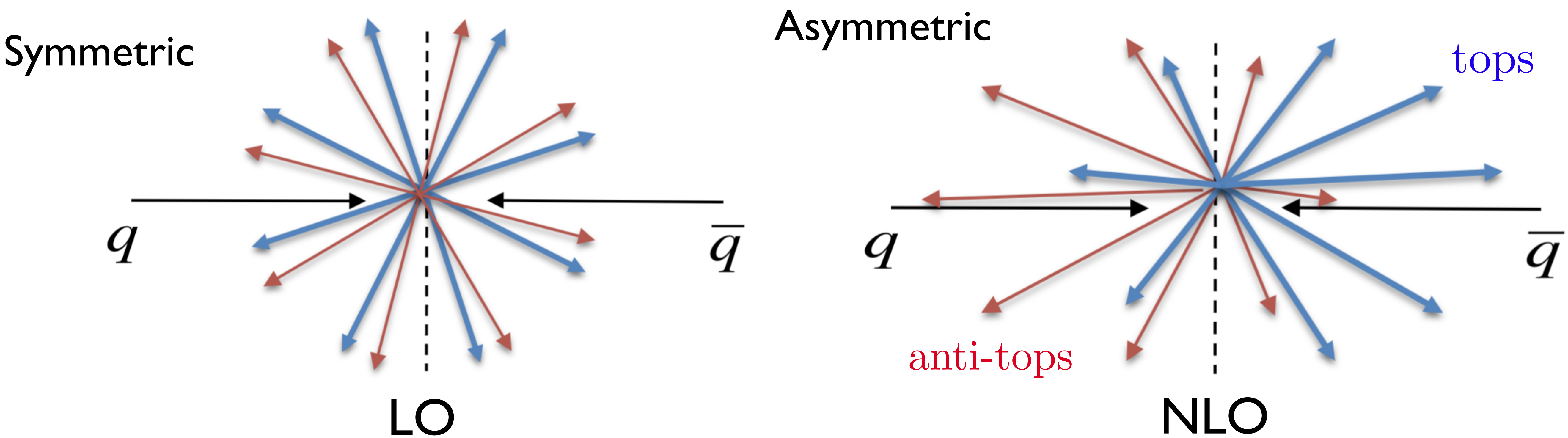
Cross-section @ $\sqrt{s} = 8$ TeV		pb
$\sigma(gg \to t\bar{t})$	$\approx$	212
$\sigma(q\bar{q} \to t\bar{t})$	$\approx$	38
$\sigma(pp \to t\bar{t})$	$\approx$	250



Top Quark Pair Charge Asymmetry

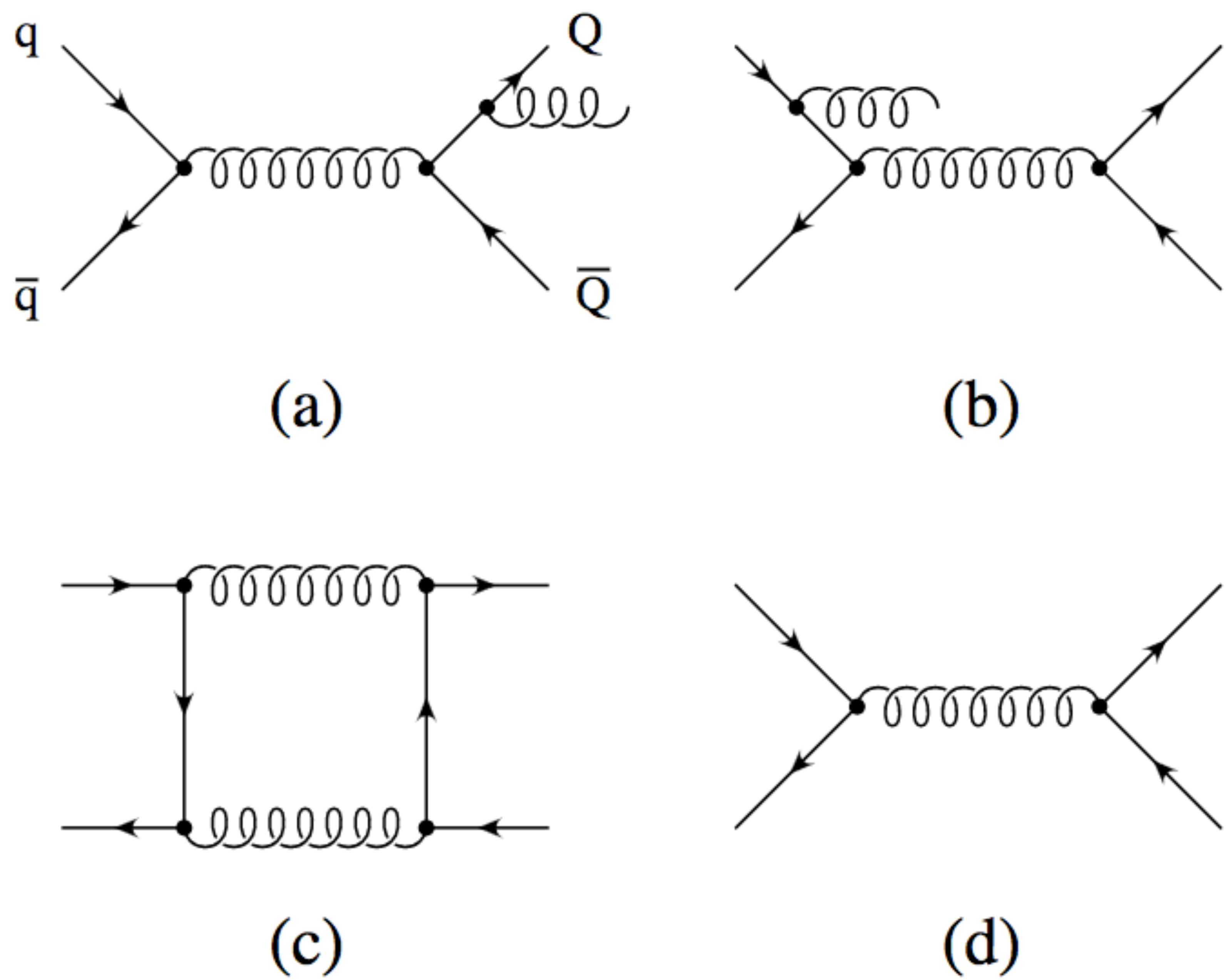
Measure anisotropy in (anti-)top production with respect to incoming (anti-)quark direction





SM Asymmetries

- Standard Model QCD high order processes introduce charge asymmetry (α_s^3)
- Interference
  - (a) & (b) : ISR and FSR
  - (c) & (d) : Box and tree
- Angle between incoming quark and outgoing top sensitive to interference
- Gluon-induced top production induces no asymmetries



BSM Asymmetries

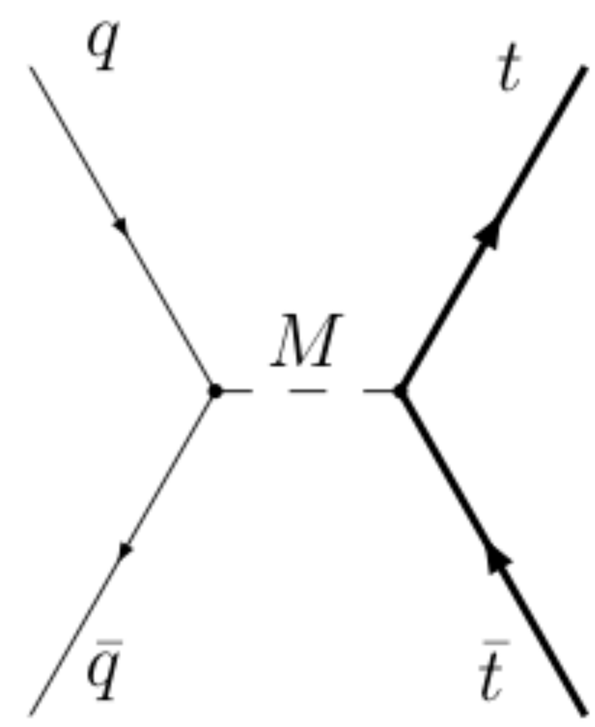
BSM particle contributions to asymmetries

- To be visible in QCD top pair production new particle should couple strongly enough to both the 1st generation quarks and to the top quarks.
- To generate a charge asymmetry new particle should couple differently to left- and right-handed quarks.

s-channel

Axigluon
Zerwekh
Phys.Lett. B704 (2011) 62-65

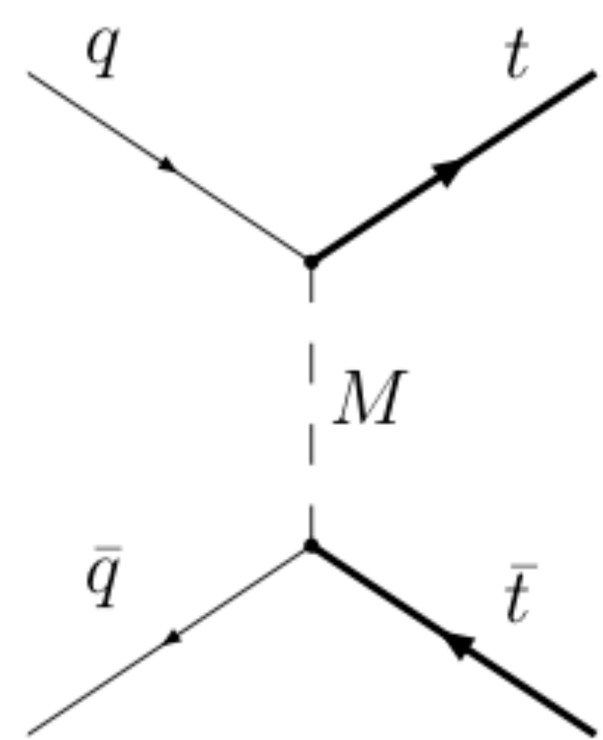
Kaluza-Klein excitation :
Delaunay, Gedalia, Lee, Perez & Ponton
Phys.Lett. B703 (2011) 486-490



t-channel

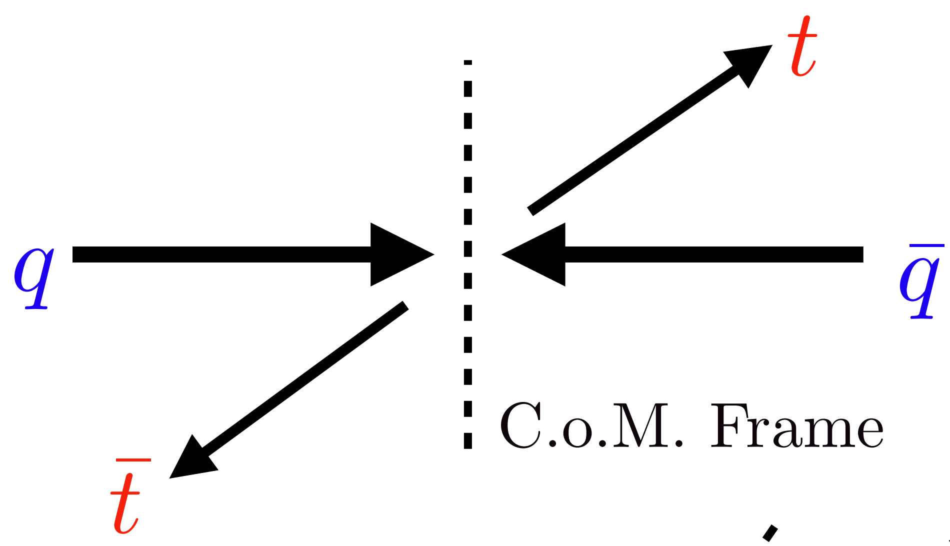
Gauge Boson
Shelton, Zurek
Phys.Rev. D83 (2011) 091701

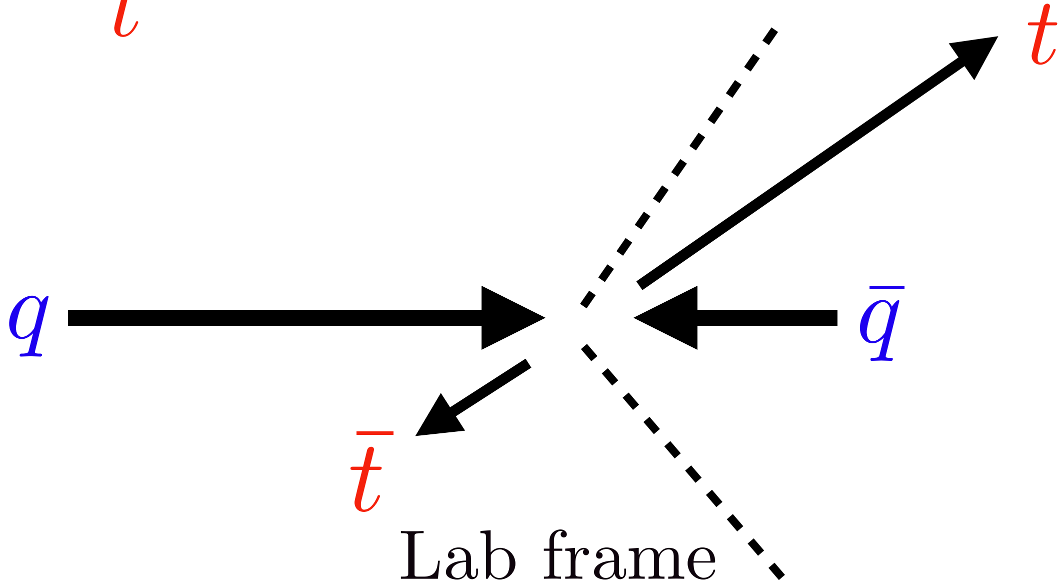
Color triplet
Ligeti, Tavares, Schmaltz
JHEP 1106 (2011) 109



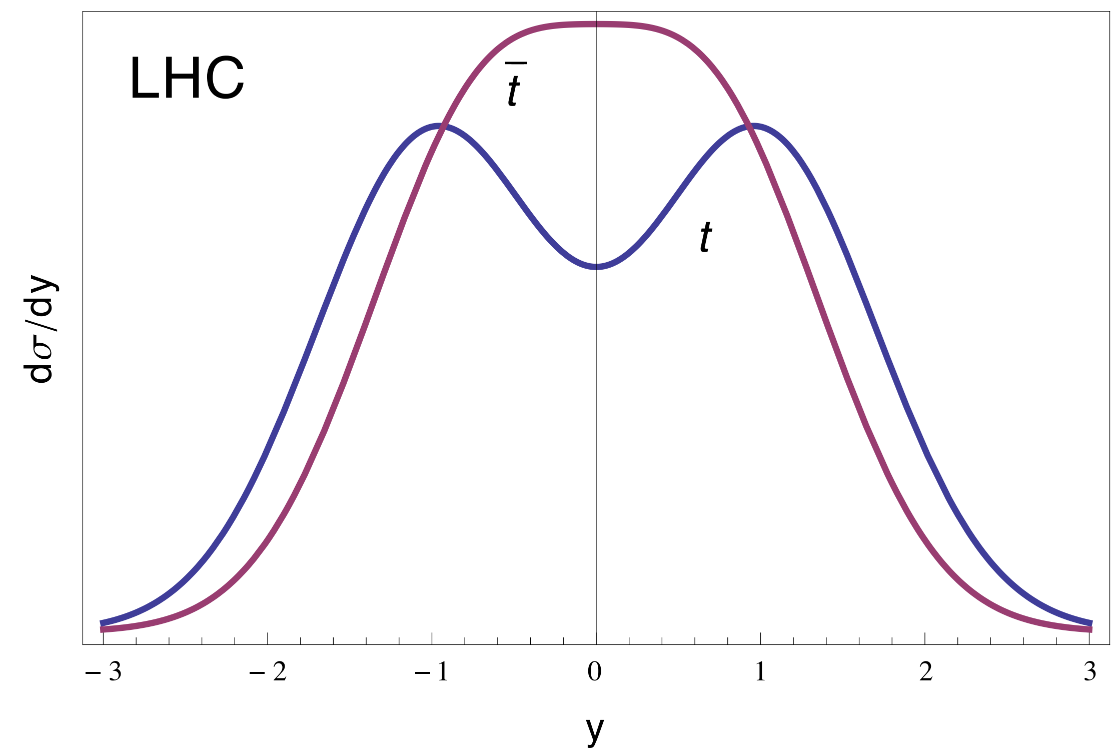
Charge Asymmetry @ LHC

- 15% of collisions are quark and anti-quark
- Incoming quark direction not known in pp collisions
- Valence quarks more likely than sea quarks
- More valence quarks vs sea anti-quarks collisions
- Valence quarks have larger fraction of momentum





Kühn, Rodrigo, JHEP 1201 (2012) 063
Bernreuther, Si, Phys. Rev. Lett. D 86 (2012) 034026



$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

$$A_C^{t\bar{t}} = \frac{N(\Delta|y|>0) - N(\Delta|y|<0)}{N(\Delta|y|>0) + N(\Delta|y|<0)}$$

$$A_C^{t\bar{t}} = 0.0111 \pm 0.0004 \text{ (NLO QCD)}$$

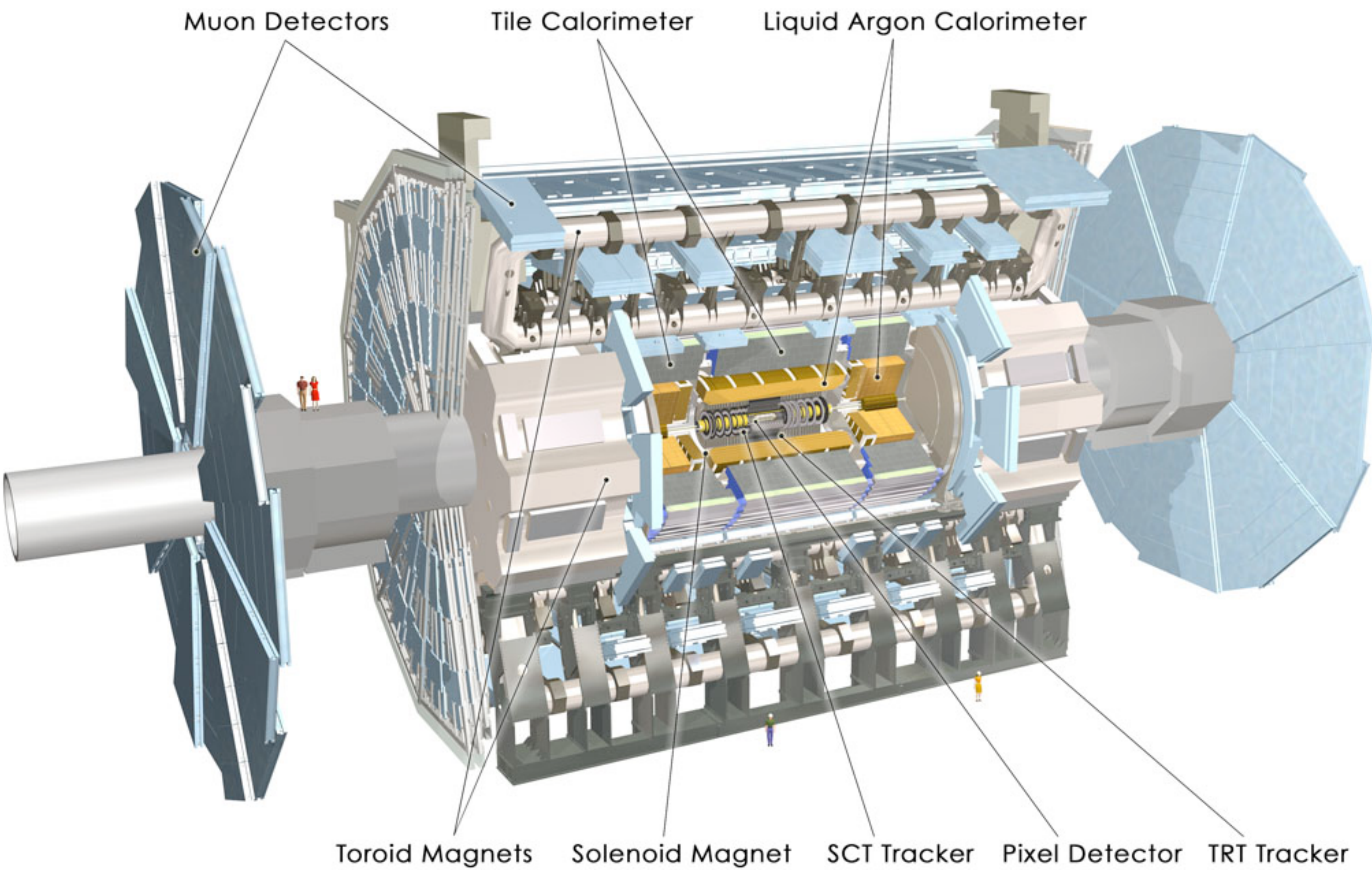
Dilepton

$$\Delta|\eta| = |\eta_{l+}| - |\eta_{l-}|$$

$$A_C^{ll} = \frac{N(\Delta|\eta|>0) - N(\Delta|\eta|<0)}{N(\Delta|\eta|>0) + N(\Delta|\eta|<0)}$$

$$A_C^{ll} = 0.0064 \pm 0.0003 \text{ (NLO QCD)}$$

ATLAS Detector



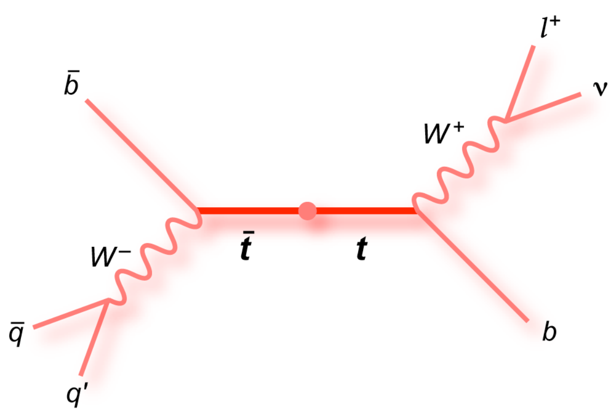
Charge Asymmetry Measurements @ 8 TeV

Channels

lepton+jets $pp \to t\bar{t} \to W(\to l\nu)bW(\to qq)b$

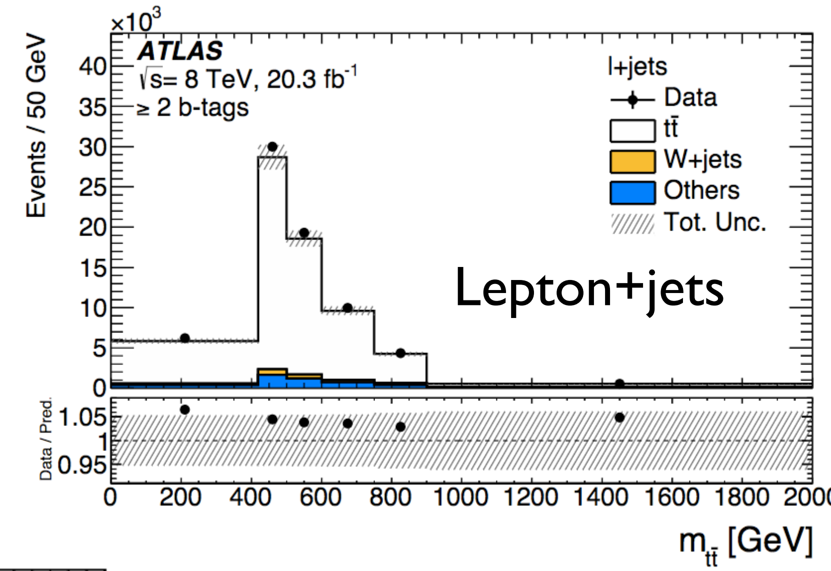
dilepton $pp \to t\bar{t} \to W(\to l\nu)bW(\to l\nu)b$

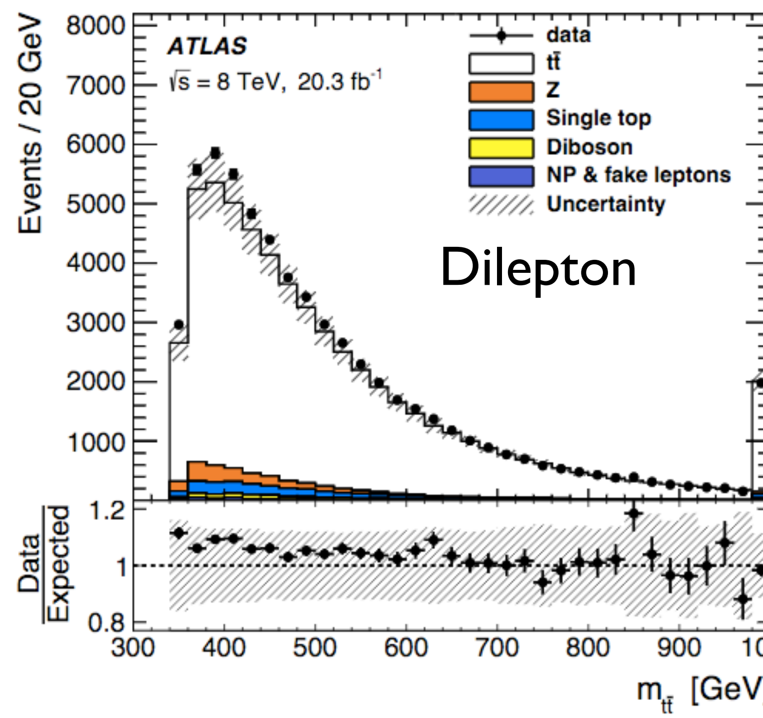
Boosted lepton+jets $m_{t\bar{t}} > 750$ GeV

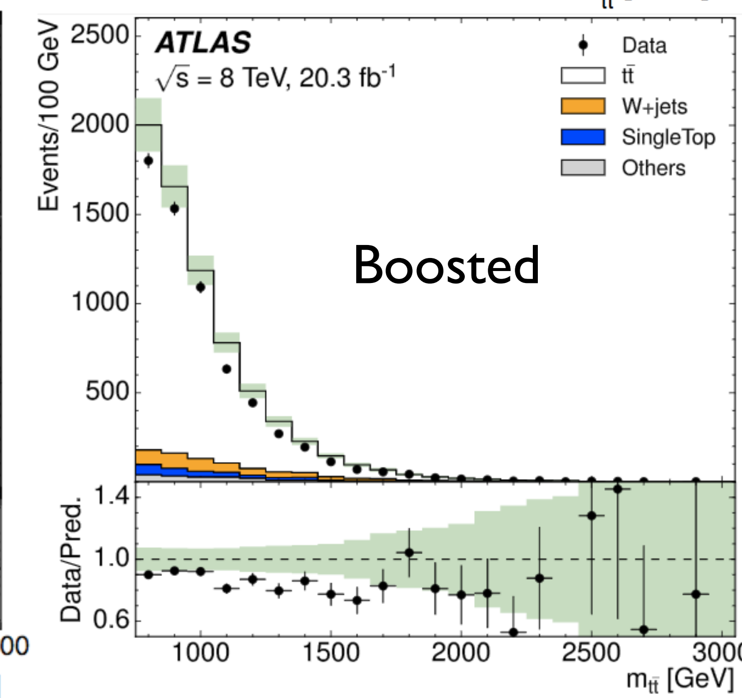


Data
20.3/fb @ 8 TeV

Simulation top-pair
QCD NLO
Powheg-hvq (r2330)
CT10 PDF
h(damp) = 172.5 GeV







Reconstruction methods

lepton+jets Likelihood fit

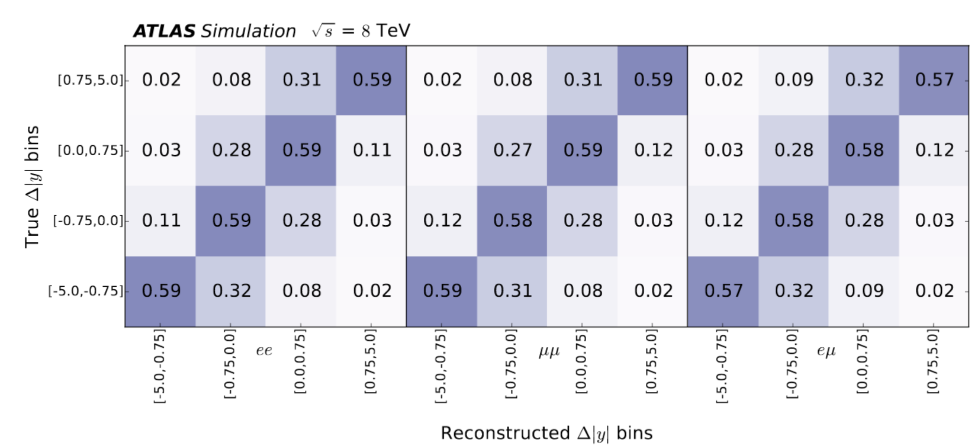
dilepton KIN method

Boosted lepton+jets tailored technique

Interpretation

Iterative Bayesian unfolding to transform back to parton level: Fully Bayesian Unfolding (FBU): https://pypi.python.org/pypi/fbu/0.0.2

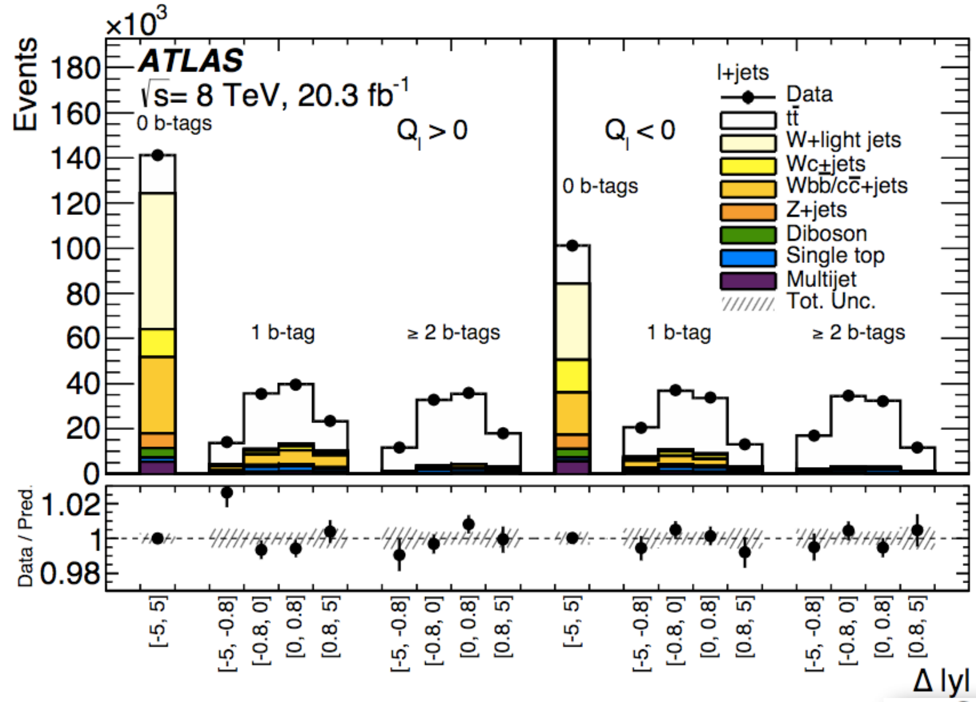
Systematics encoded into nuisance parameters and marginalised and none of the measurements are using regularization



Charge Asymmetry @ 8 TeV l+jets

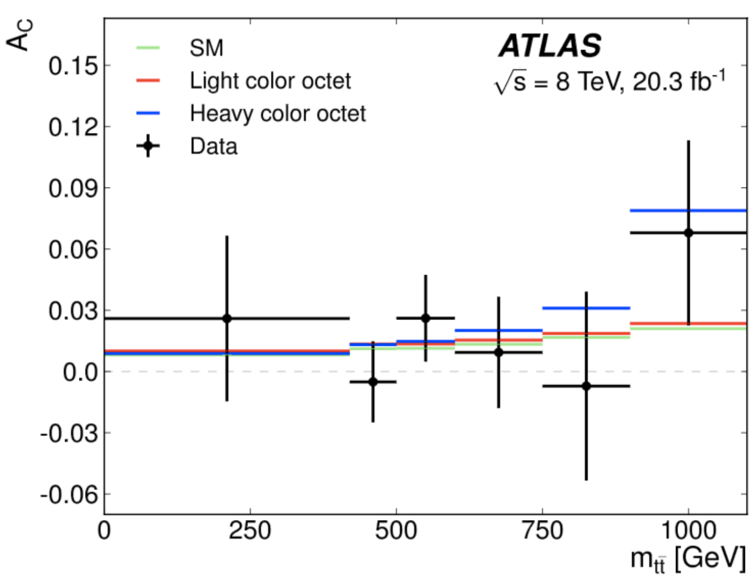
Eur. Phys. J. C76 (2016) 87

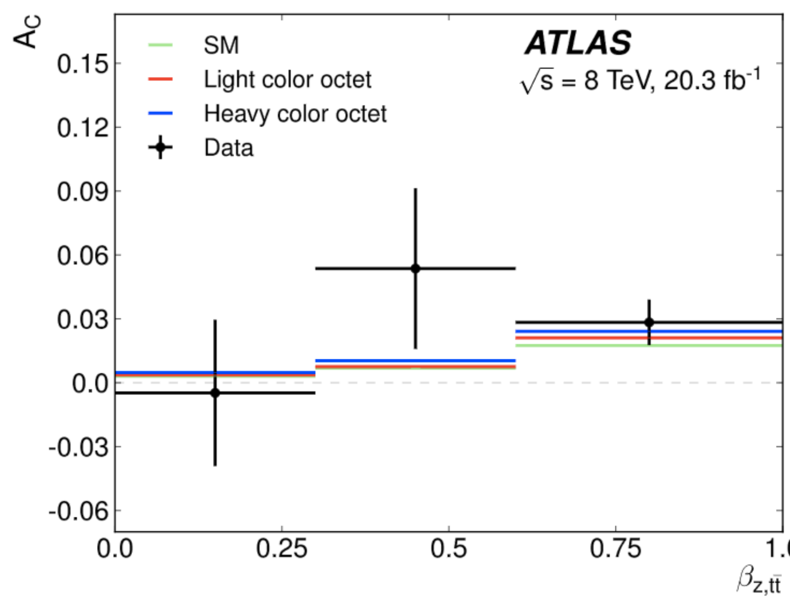
- Inclusive and differential measurements of the top-pair system in
  - invariant mass,
  - p_T and
  - longitudinal boost β_z

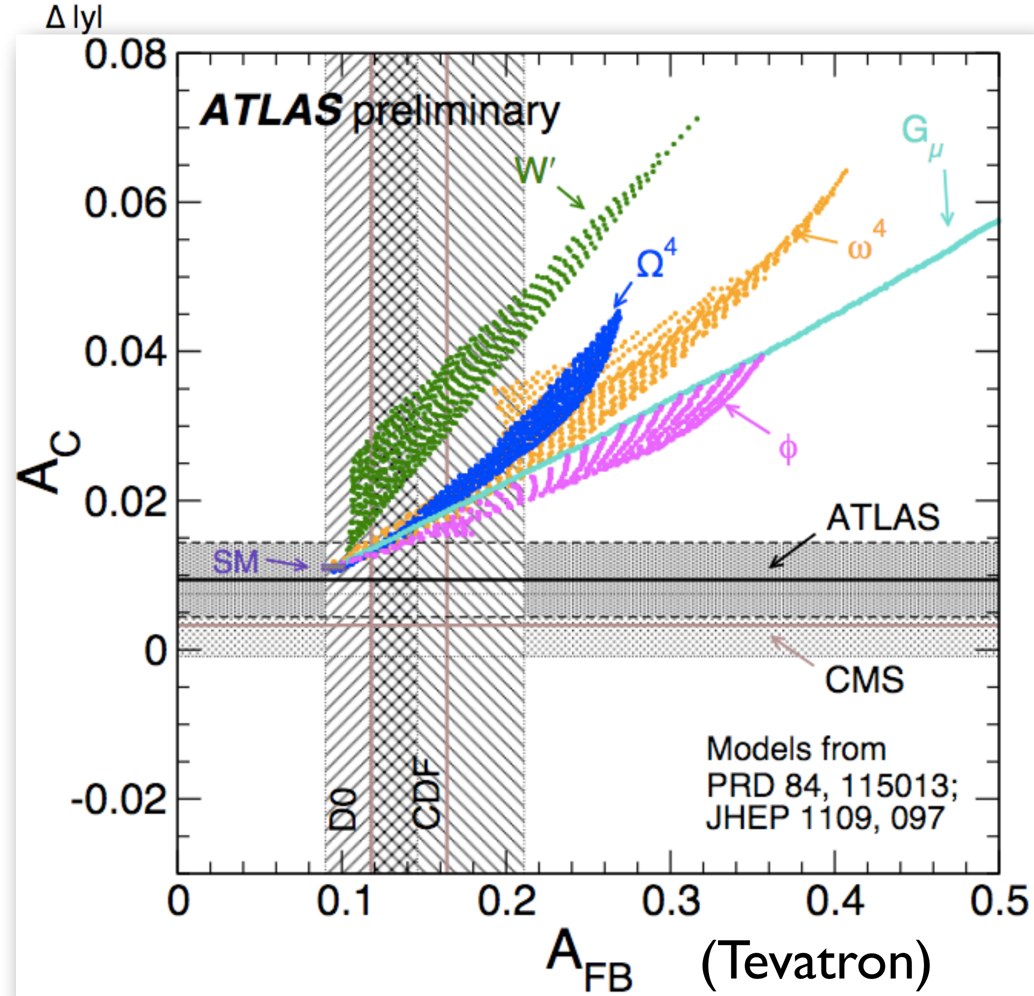


$A_C = 0.009 \pm 0.005$ (stat. + syst.)

- Statistical uncertainty dominates
- Leading systematic is signal modelling





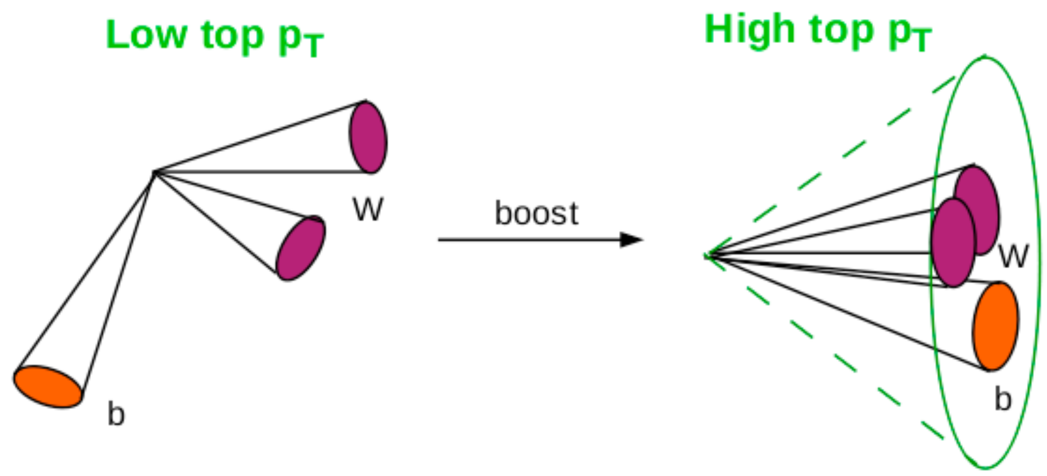


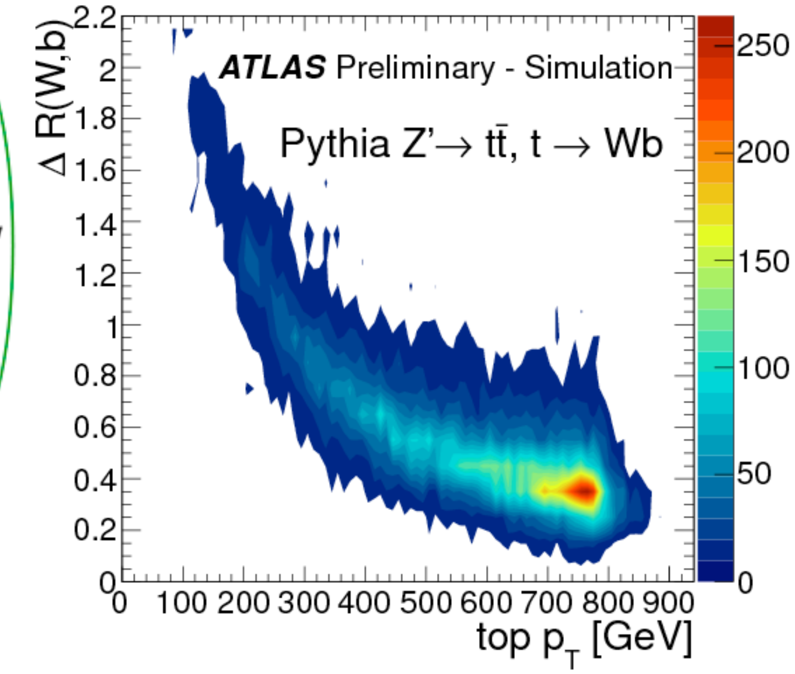
- Consistent with SM expectations
- Constraining many BSM scenarios : W′ boson, a heavy axigluon (G_μ), scalar isodoublet (φ), colour-triplet scalar (ω^4), and colour-sextet scalar (Ω^4)

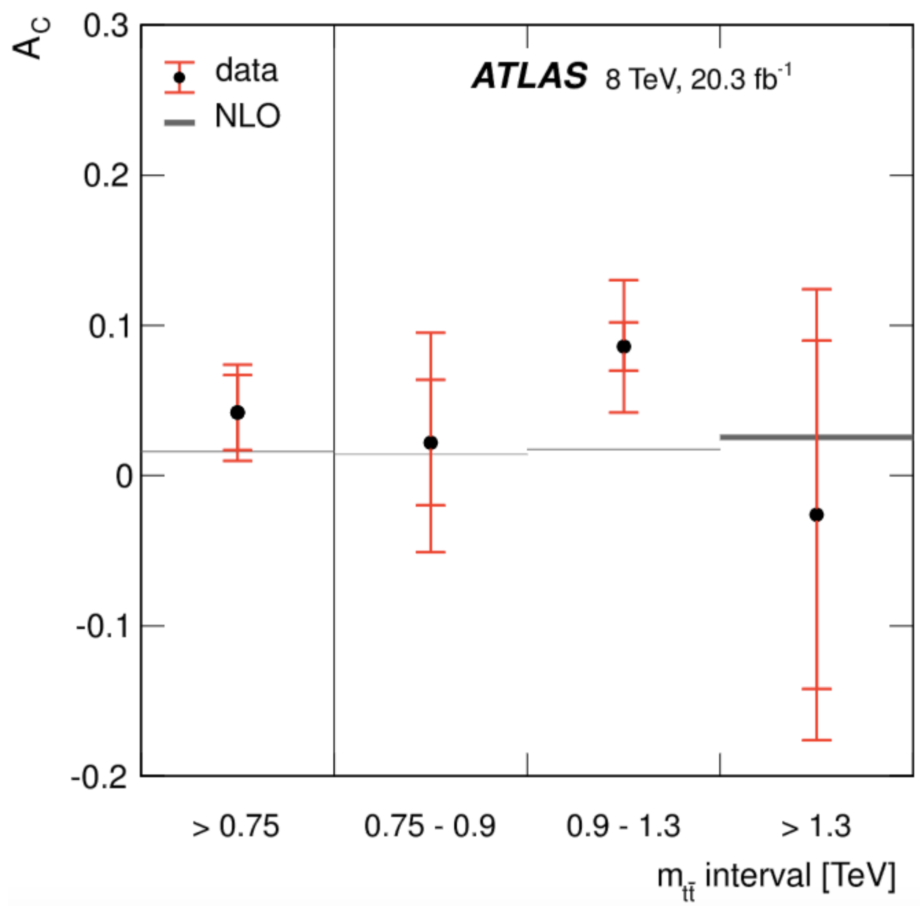
Boosted Tops @ 8 TeV l+jets

Phys. Lett. B (2016) 756

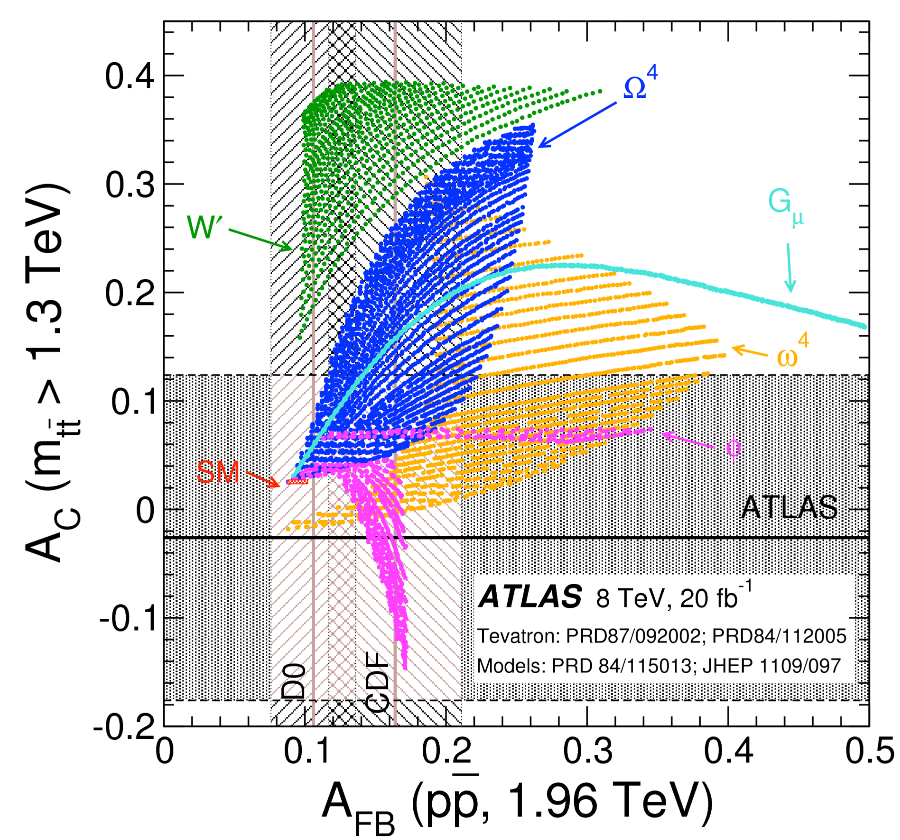
- Boosted tops where top quark pair invariant mass > 750 GeV
- Boost favours qq’ top pair production providing higher sensitivity to SM asymmetry and BSM heavy particles
- Single large-R jet and tagged using jet substructure variables.
- Hadronically decaying top quark is reconstructed as a single trimmed jet with $R = 1.0$.
- Selected jet must have $p_T > 300$ GeV, must be well separated from both the charged lepton($\varphi(l, jet_{R=1.0}) > 2.3$)
- Top-quark pair mass resolution is approximately 6% above 1 TeV
- Measurement agrees with SM
- Precision limited by signal modelling systematic uncertainty. Challenge to improve them in Run 2.







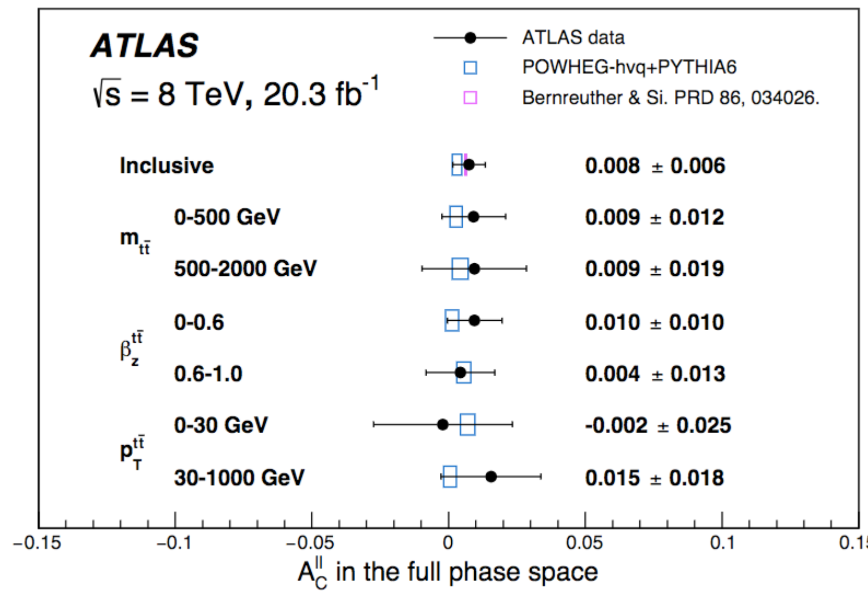
$$m_{t\bar{t}} > 0.75 \text{ GeV}$$
$$-2 < \Delta|y| < 2$$
$$A_C = (4.2 \pm 3.2)\%$$
$$\text{SM: } (1.60 \pm 0.04)\%$$



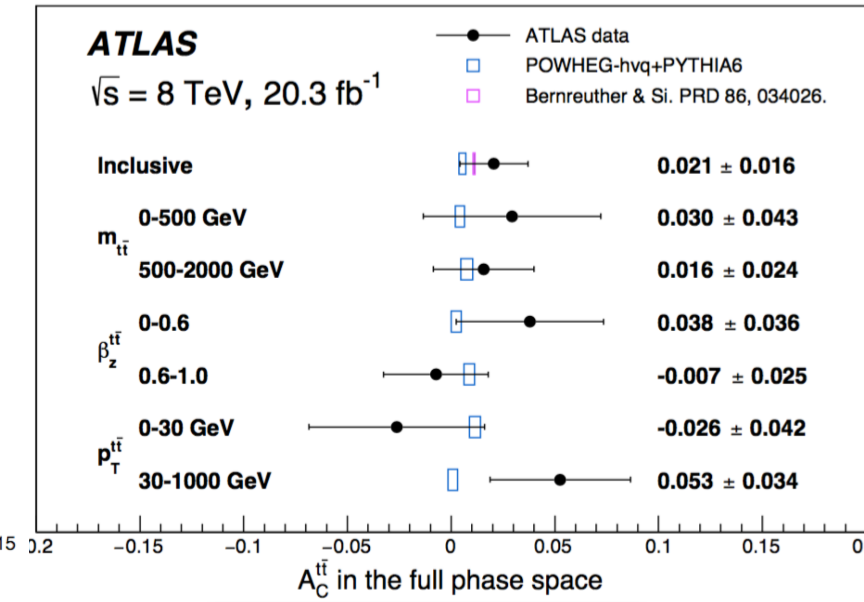
Dilepton @ 8 TeV

arXiv:1604.05538

- Two sets of observables
  - selected leptons
  - reconstructed top-quark pair system
- Inclusive and differential measurements in invariant mass, p_T and longitudinal boost β_z
- Full phase space for comparisons at parton level
- Fiducial region using particle level objects (less model dependent by avoiding extrapolation)

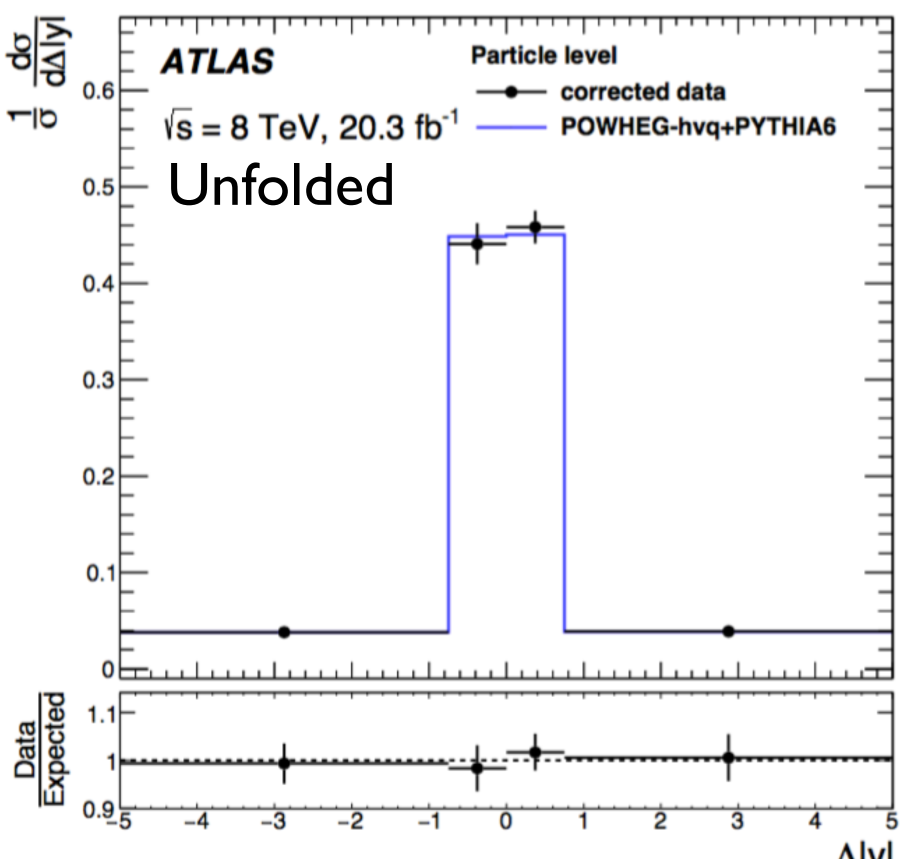


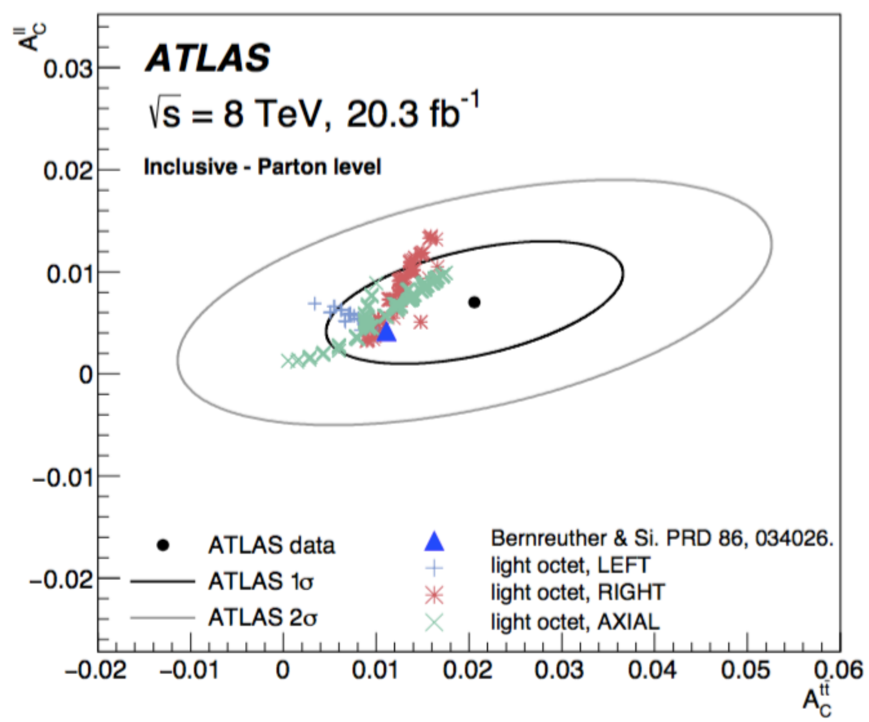
$$A_C^{\ell\ell} = 0.008 \pm 0.006$$

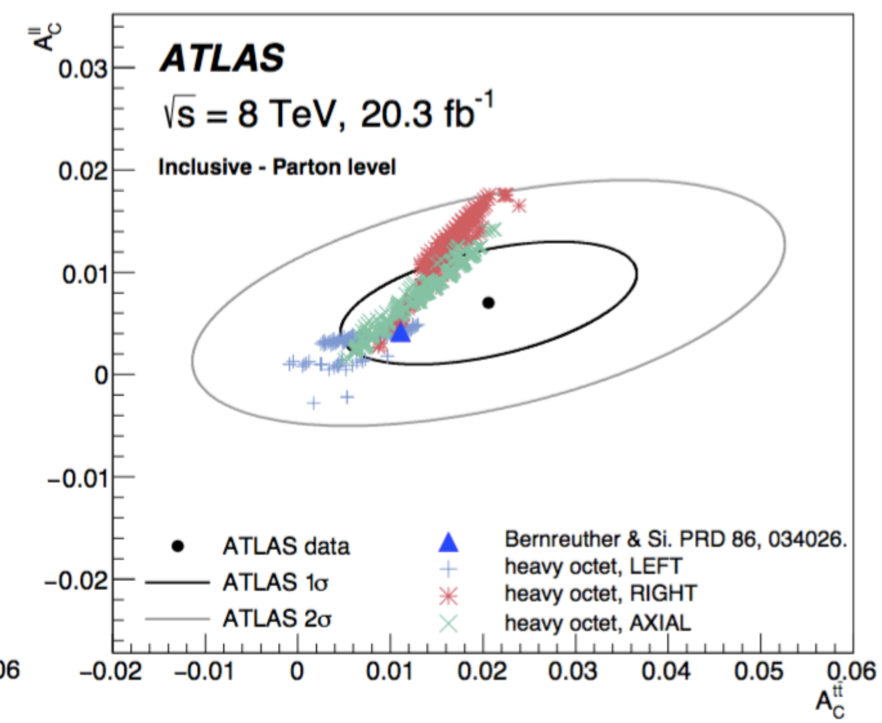


$$A_C^{t\bar{t}} = 0.021 \pm 0.016$$

- Precision is dominated by statistical uncertainty
- Measurements are compatible with the SM and do not exclude the two sets of BSM models considered

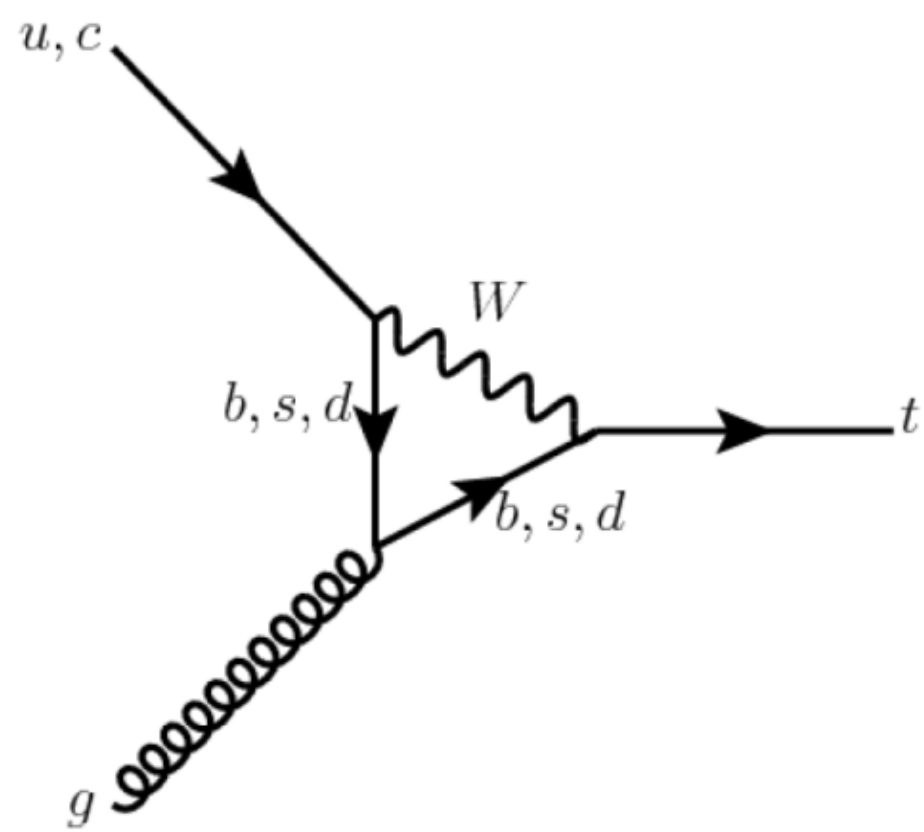




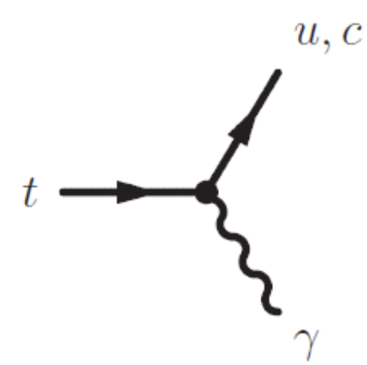


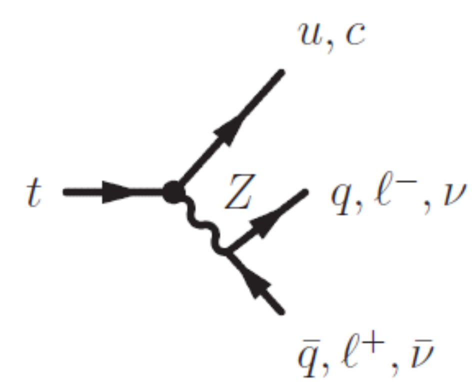
Flavour Changing Neutral Currents in Top

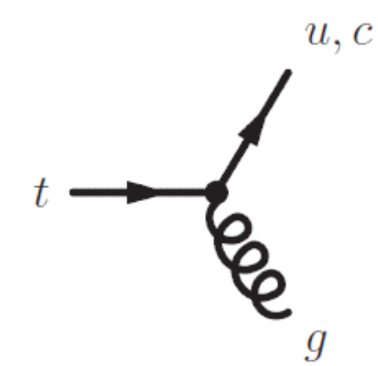
- In SM forbidden at tree level and highly suppressed O(10^{-14}) due to GIM mechanism
- BSM with new sources of flavour predict higher rates



Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$







arXiv:1311.2028v1

FCNC t→Hq @ 8 TeV

JHEP 12 (2015) 061

- Isolated electron or muon, at least 4 jets

$$t\bar{t} \rightarrow W(\rightarrow l\nu)bH(\rightarrow bb)q$$

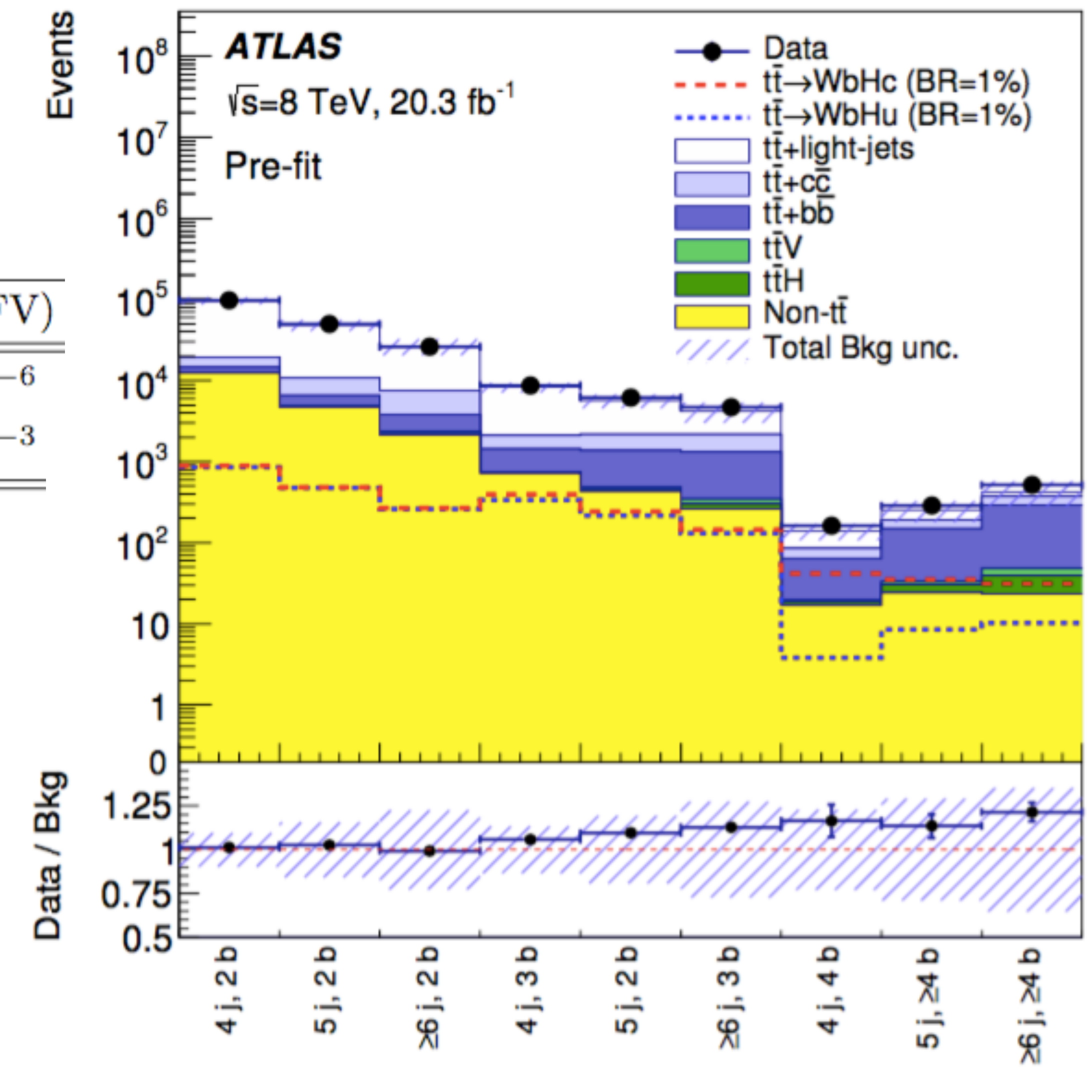
- Exploit high b-quark jet multiplicity

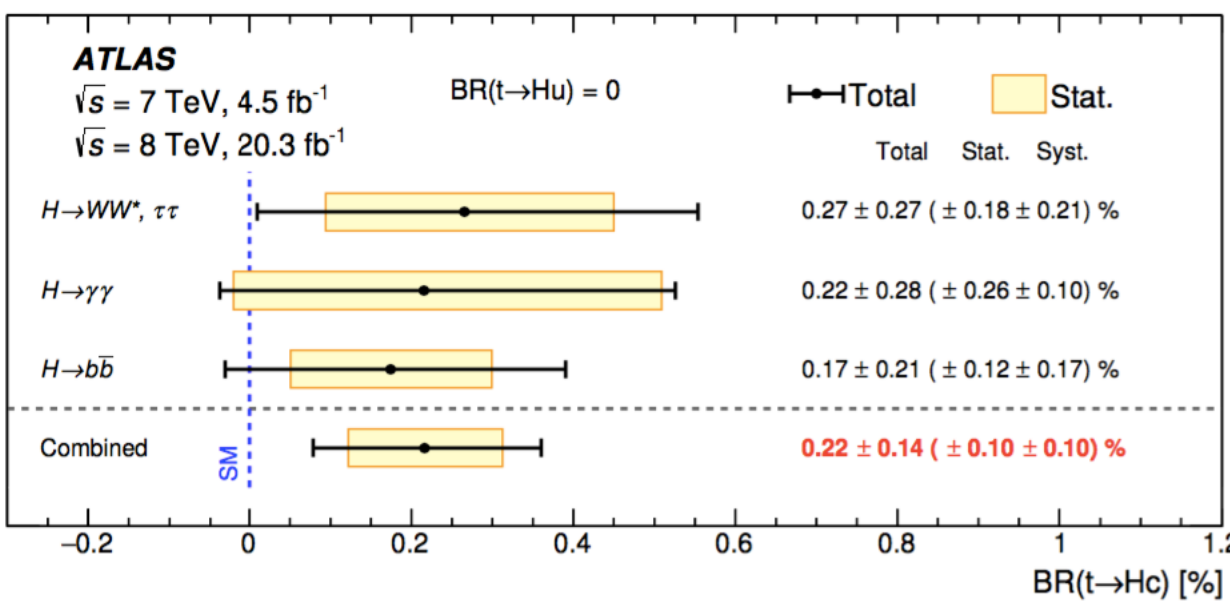
Process	SM	2HDM(FV)
$t \rightarrow hu$	2×10^{-17}	6×10^{-6}
$t \rightarrow hc$	3×10^{-15}	2×10^{-3}

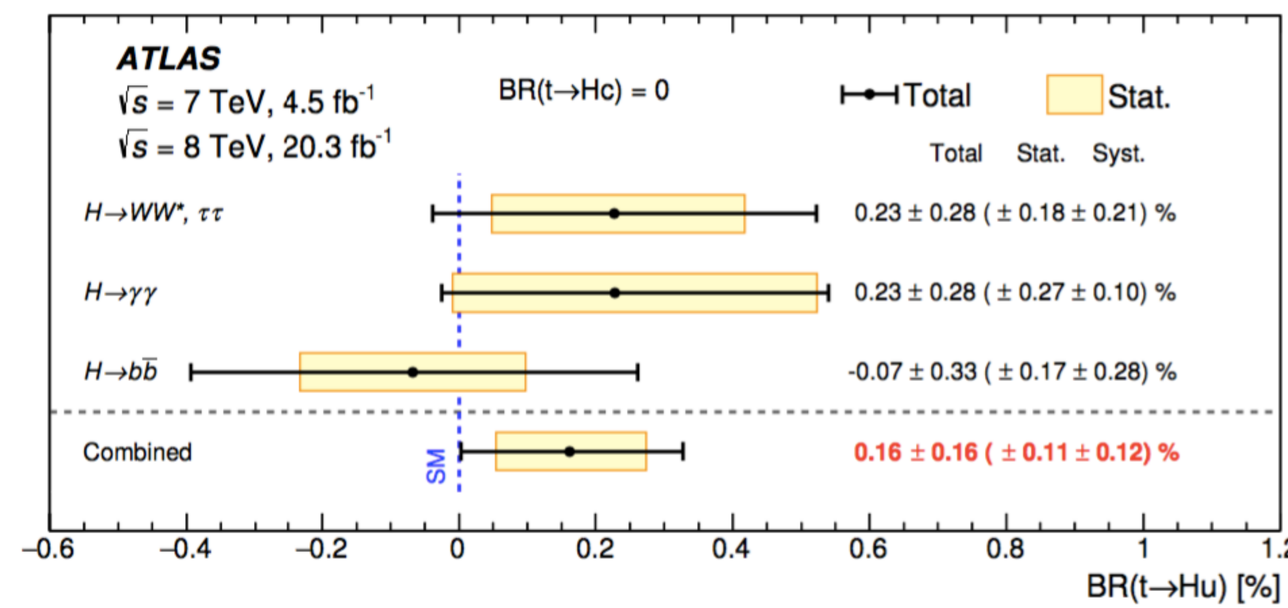
- Likelihood discriminant to suppress

$$t\bar{t} \rightarrow W(\rightarrow l\nu)bW(\rightarrow qq)b$$

- Define event categories based on jet, b-jet multiplicity
- No significant excess of events above background
- Br(t→Hc) < 5.6 (4.2) x 10^{-3} observed(expected)
- Br(t→Hu) < 6.1 (6.4) x 10^{-3} observed(expected)







FCNC t→Zq @ 8 TeV

Eur. Phys. J. C (2016) 76:12

QS - quark singlet

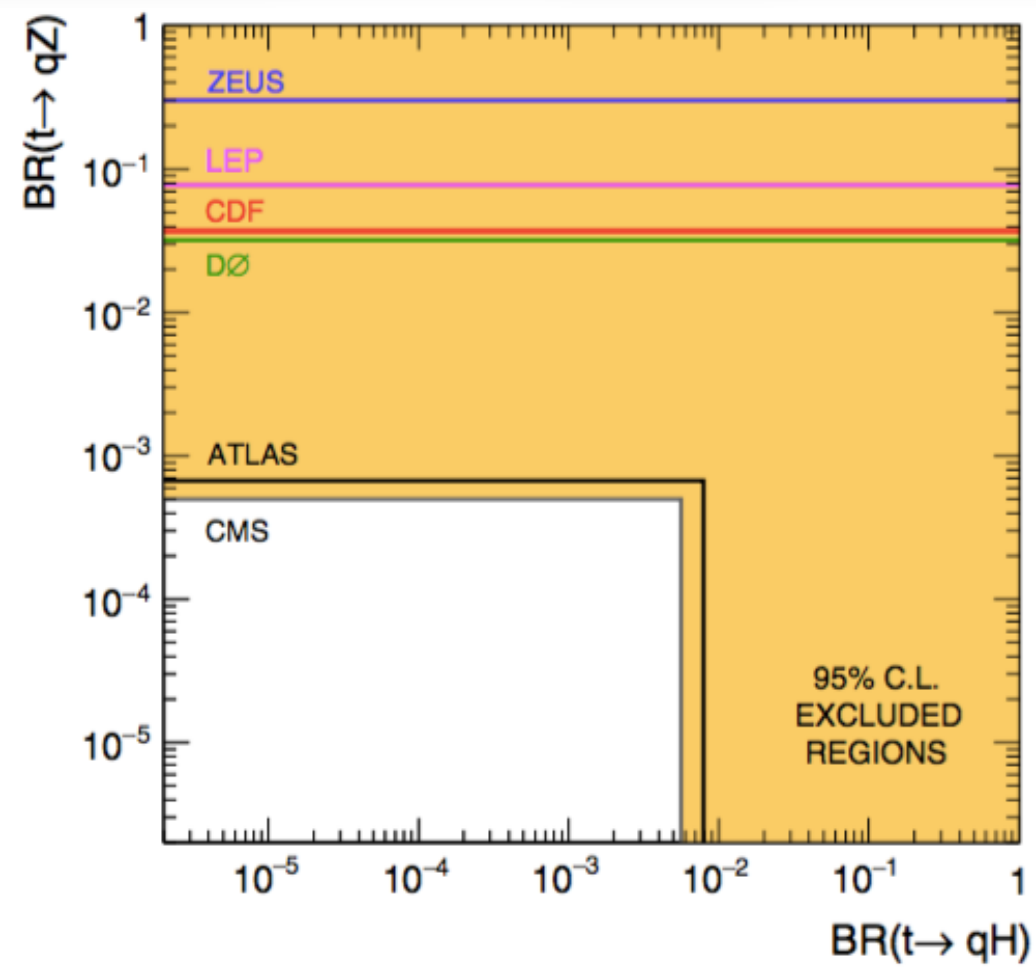
Model:	SM	QS	2HDM	FC 2HDM	MSSM	R̸ SUSY	RS
BR($t \to qZ$):	10^{-14}	10^{-4}	10^{-6}	10^{-10}	10^{-7}	10^{-6}	10^{-5}

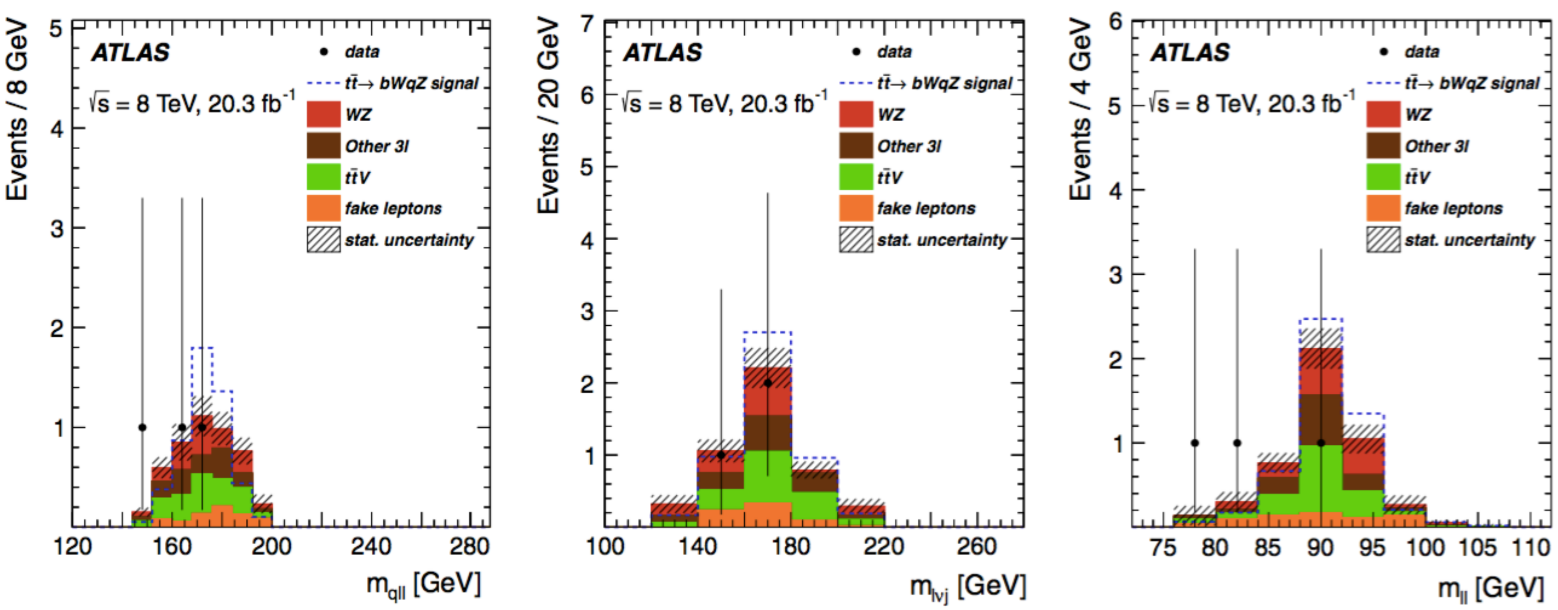
$$t\bar{t} \to W(\to l\nu)bZ(\to ll)q$$

- 3 isolated electrons or muons, at least 2 jets, some missing transverse energy
- One or two b-tagged jets (mis-identified c from t→Zc)
- Two or three reconstructed jets (third from ISR/FSR)
- Kinematics of the top quarks can be reconstructed from the corresponding decay particles; Form χ^2 to determine neutrino p_z
- Control regions used to assign background modelling uncertainties, which are the dominant systematics.

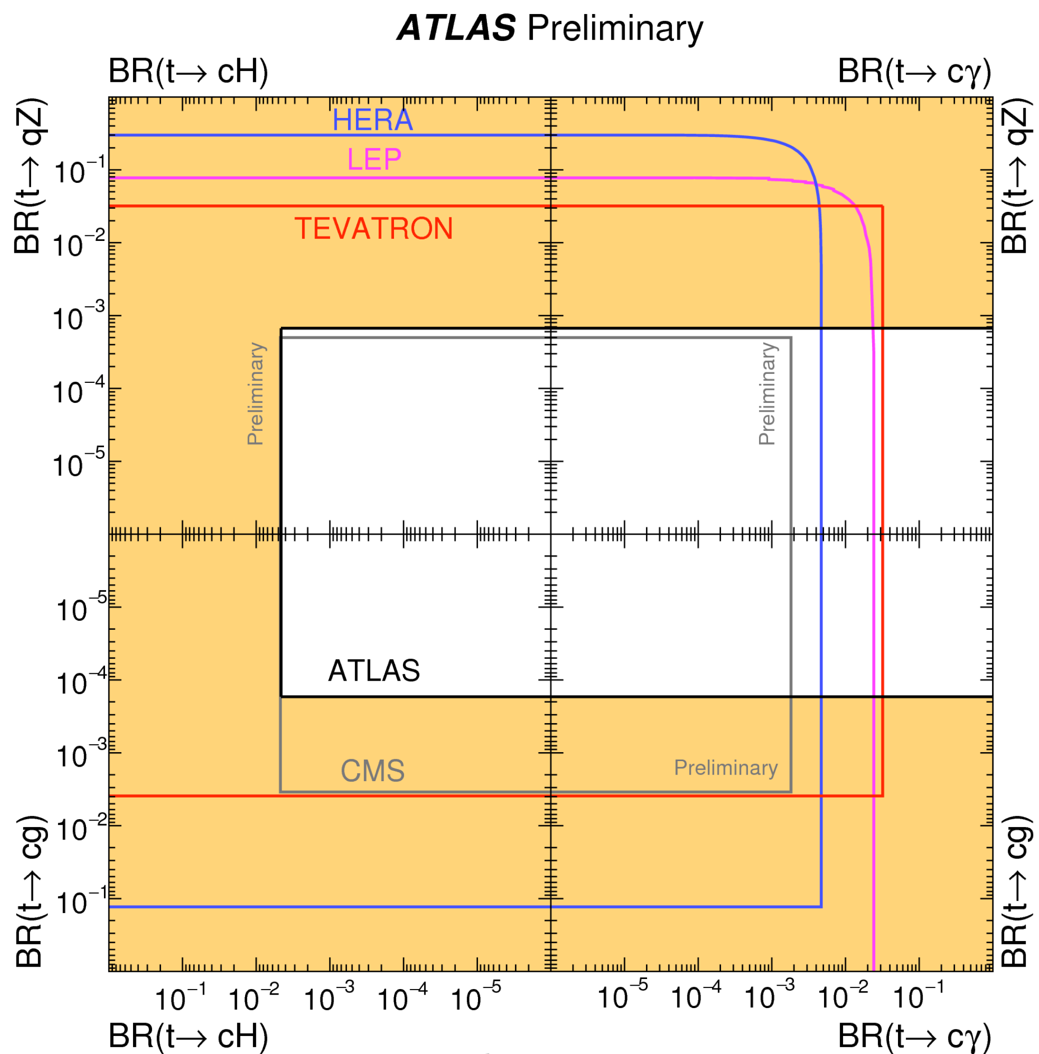
Sample	Yields
WZ	$1.3 \pm 0.2 \pm 0.6$
$t\bar{t}V$	$1.5 \pm 0.1 \pm 0.5$
tZ	$1.0 \pm 0.1 \pm 0.5$
Fake leptons	$0.7 \pm 0.3 \pm 0.4$
Other backgrounds	$0.2 \pm 0.1 \pm 0.1$
Total background	$4.7 \pm 0.4 \pm 1.0$
Data	3
Signal efficiency ($\times 10^{-4}$)	$7.8 \pm 0.1 \pm 0.8$

95% CL limits Observed 7 x 10^{-4} Expected 8^{+4}_{-2} x 10^{-4}

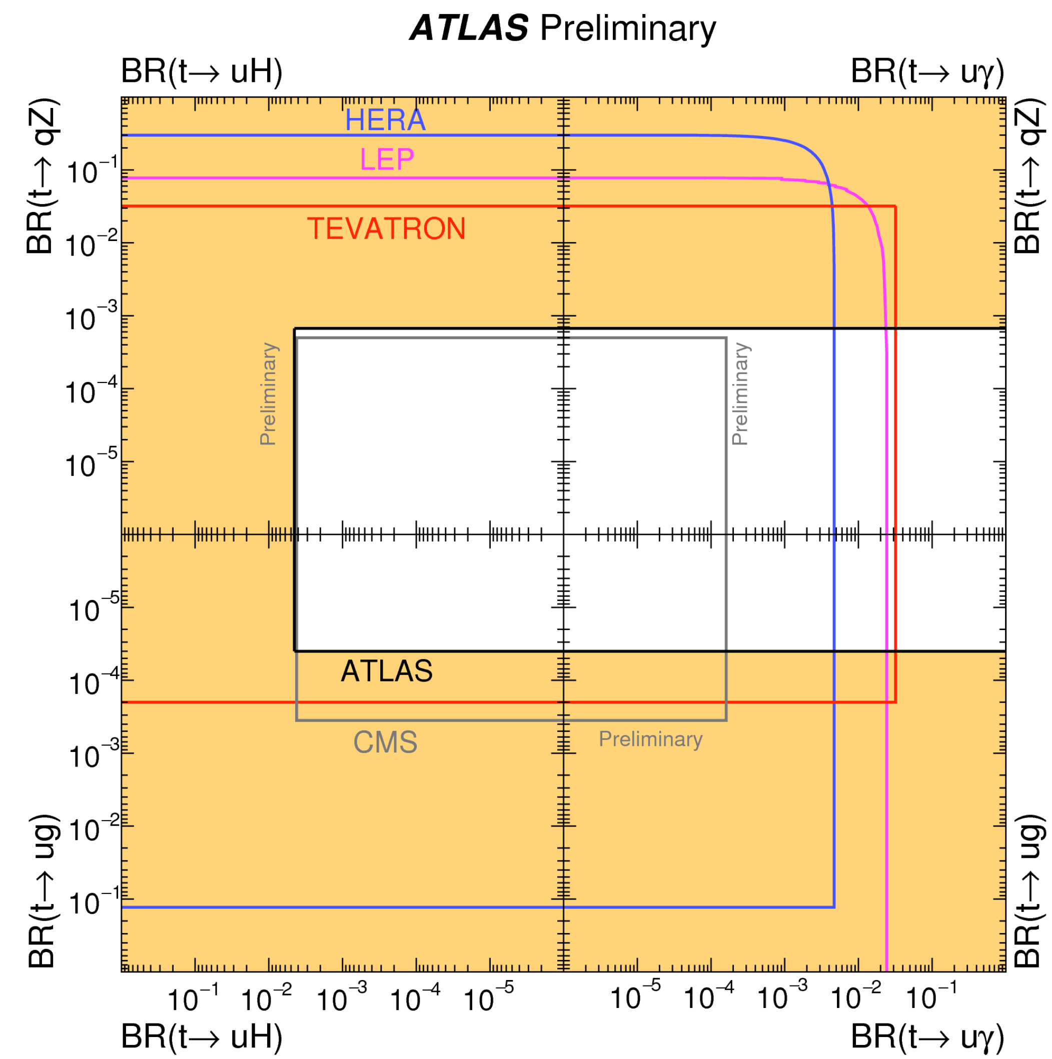




FCNC tops



charm



up

Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

t→qg coupling is also sensitive to 2HDMs

Summary

- ATLAS Charge asymmetry measurements consistent with SM, yet ruling out parameter space in many BSM scenarios

- ATLAS FCNC top decays providing improved upper limits and beginning to reach sensitivity of ruling out BSM scenarios

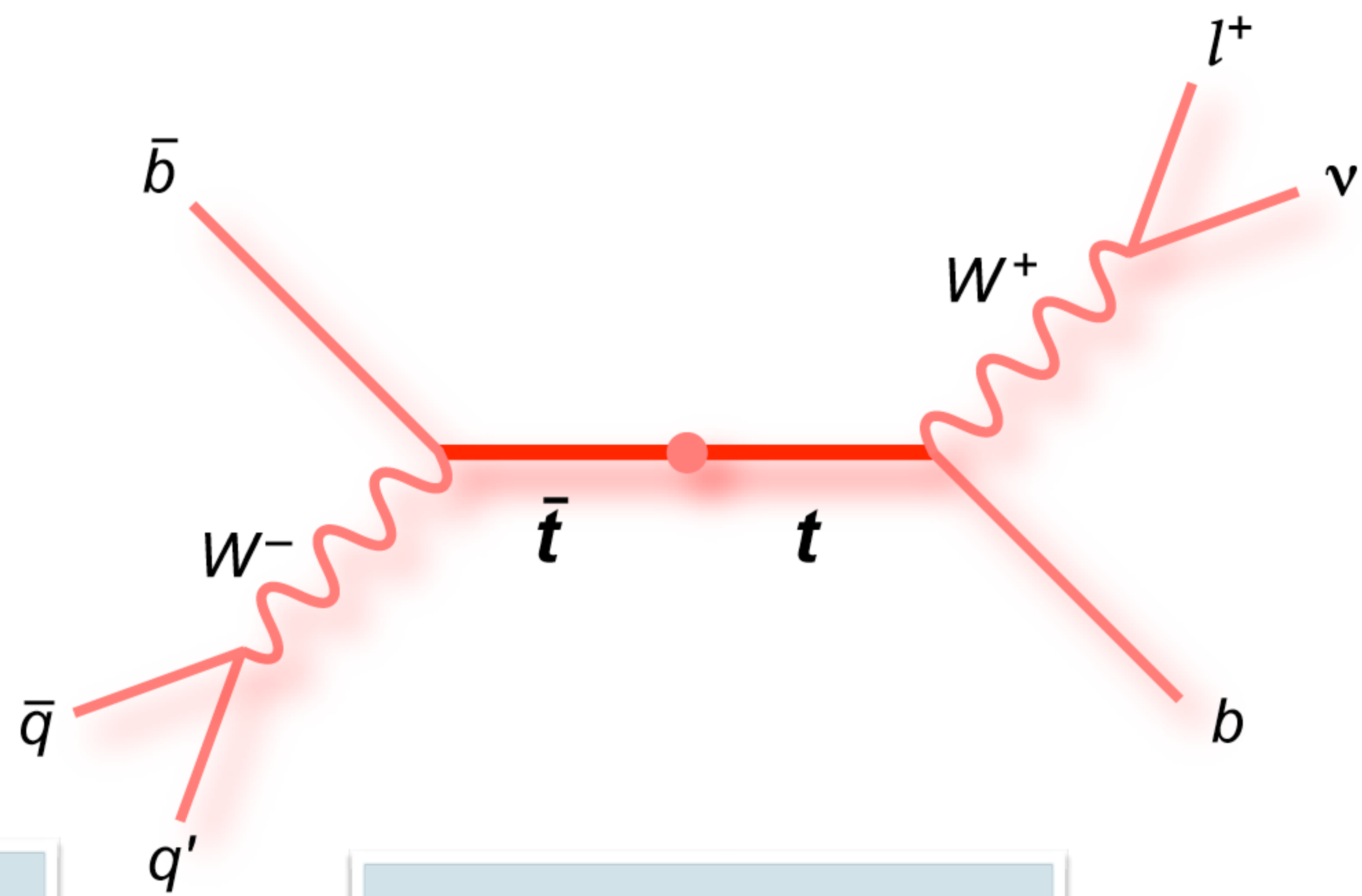
- Most run 1 measurements limited by statistics, look forward to Run 2 results, in particular with more highly boosted top-quarks

Backup

Top-pair Production Event

Objects

- Single lepton trigger
- Isolated lepton
- W using E_T^{miss}
- Anti-k_T R=0.4 jets
- At least one b-tagged jet



Backgrounds

- W + jets (data driven)
- QCD Multijet (data driven)
- Single Top, Z+jets, Diboson (MC)

Requirements for top charge measurement

- Measure b-jet charge
- Measure lepton charge
- Pair lepton and b-jet