Top quark pair production at the LHC in ATLAS

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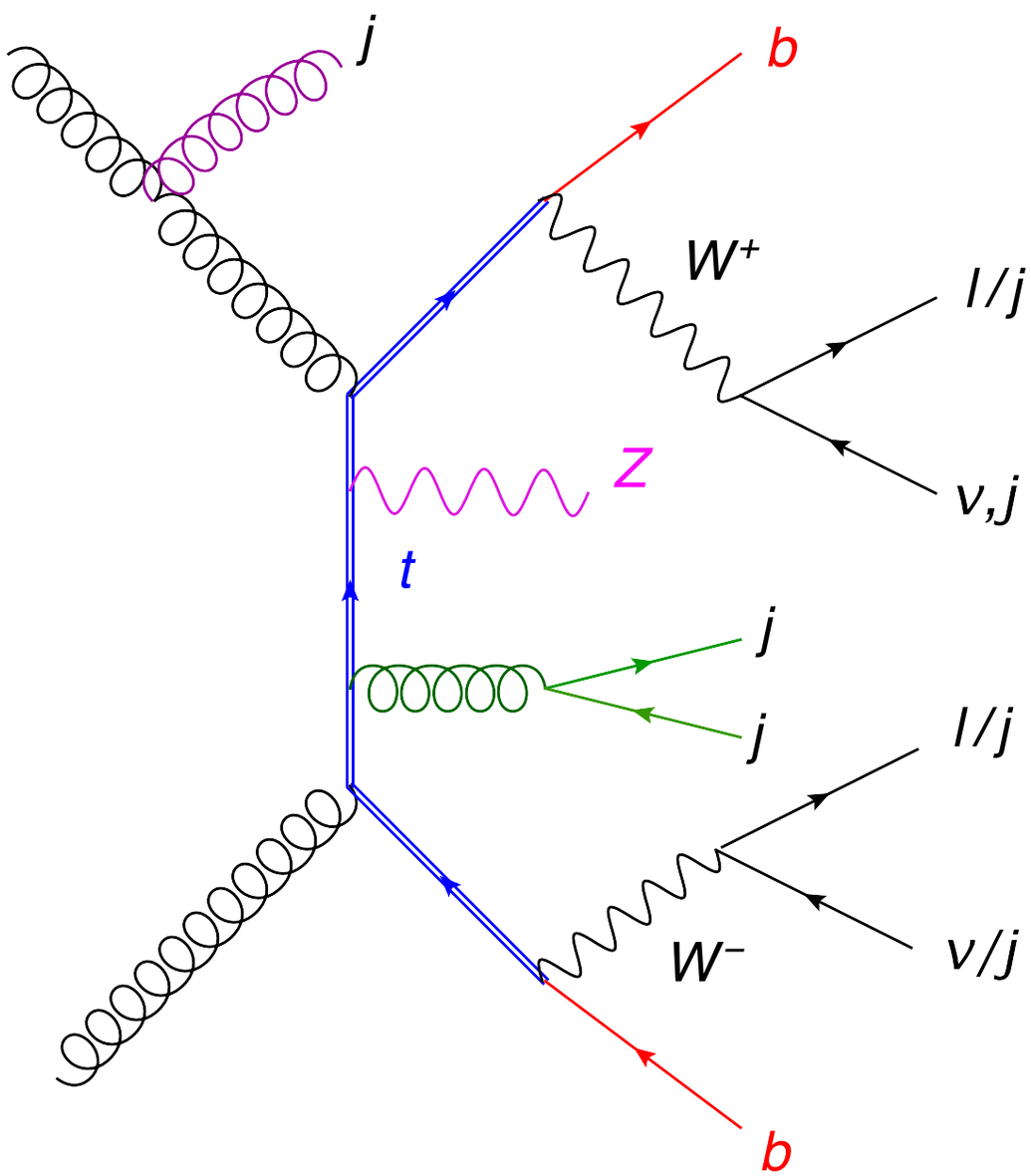
Overview



I. Top quark properties

i. Mass
ii. Charge
iii. Polarization
iv. Charge asymmetry

II. tt+jets differential measurements

III. tt+W/Z

IV. Top decays

i. Spin correlations
ii. W polarization

V. New physics searches

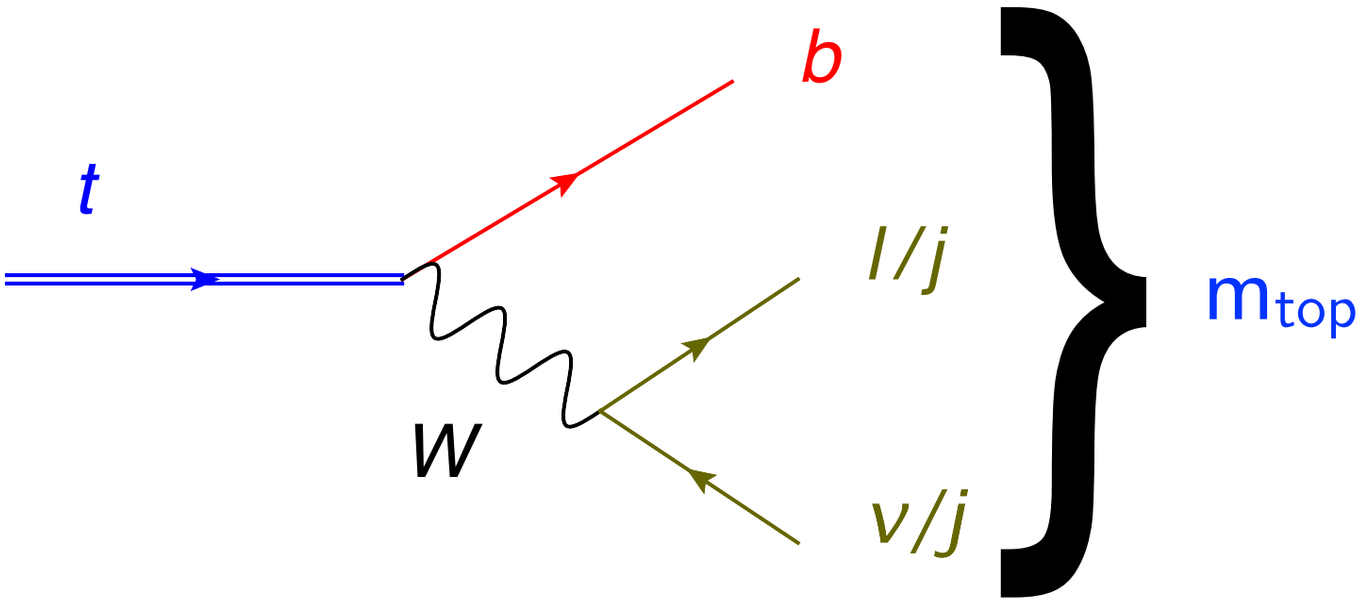
FCNC

Top properties: Mass

- measurements in all decay channels: all hadronic, lepton+jets, dilepton
- different measurement methods with different sensitivities to systematics
- two main classes of measurements:

Direct mass measurement

- Measurement of m_{top} from reconstruction of top system
- usually done with template method using different final state observables
- most recent measurements have precision $< 1\%$

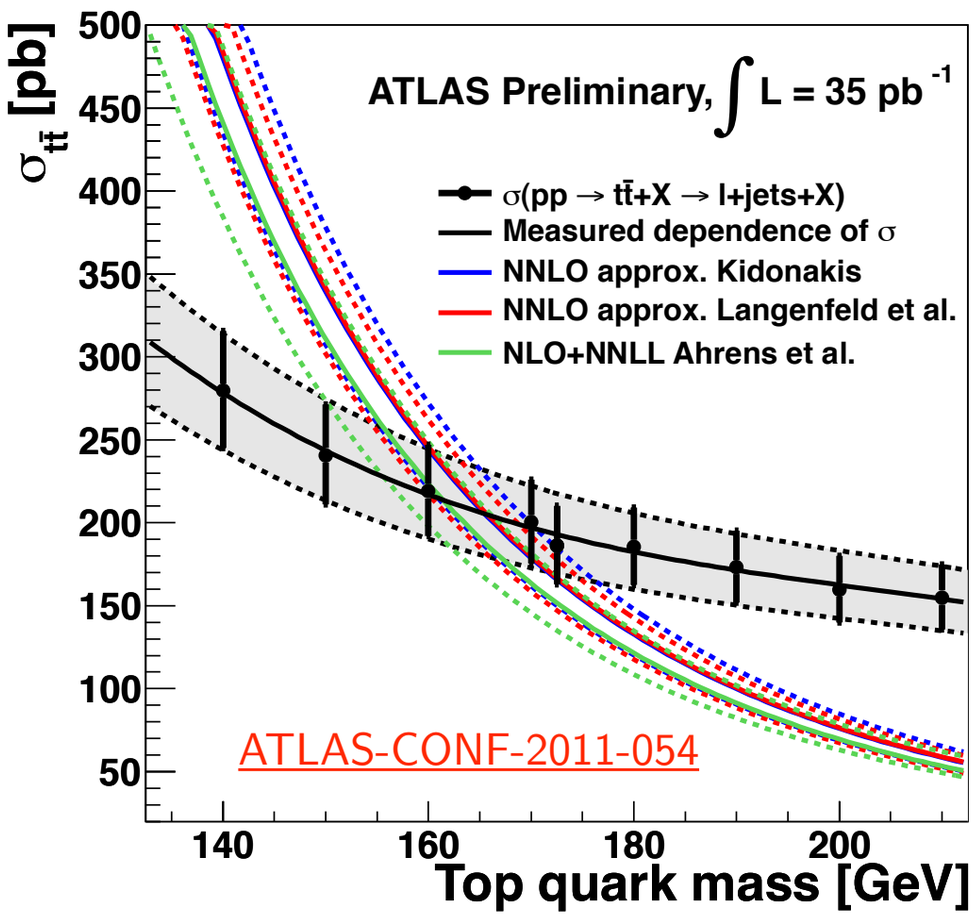


$m_{top} = (172.31 \pm 0.75\ _{stat+JSF+bJSF} \pm 1.35\ _{sys})$ GeV

[ATLAS-CONF-2013-046]

Indirect mass measurement

- from inclusive and tt+jet cross-section (precision < 4.7 %)
- using B-hadron lifetime, J/ψ final states, kinematic endpoints



Top properties: Charge

Motivation

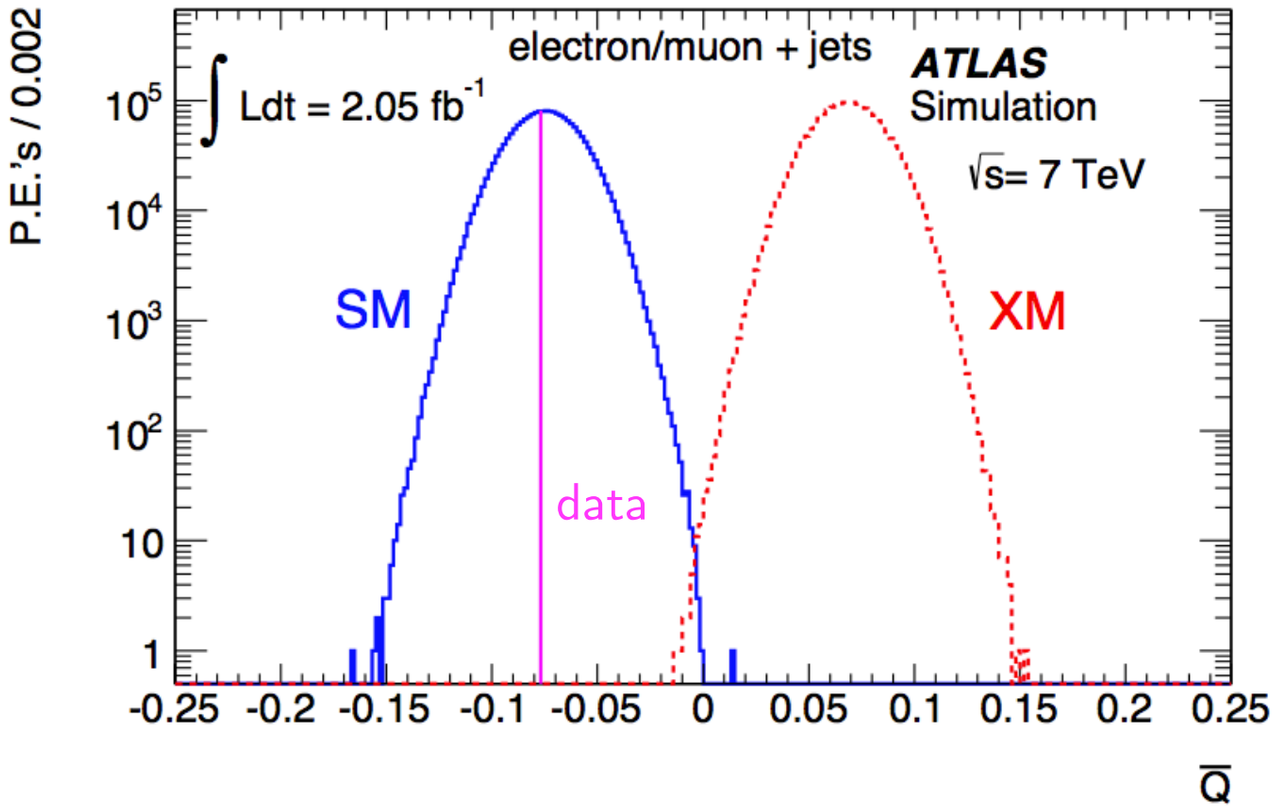
- Model proposing exotic quark with charge -4/3 and mass equal to the SM top mass
- improve Tevatron exclusion limits (2-3 σ)

Measurement

- exploit correlation between charges of top decay products

$$\text{SM}: \quad t^{(2/3)} \to b^{(-1/3)} + W^{(+1)} \qquad \text{XM}: \quad t_X^{(-4/3)} \to b^{(-1/3)} + W^{(-1)}$$

- $Q_b Q_l$ = -1/3 for SM and +1/3 for exotic model
- Q_b defined as a weighted sum of b-jet track charges: $Q_b = \frac{\sum_i Q_i |\vec{j} \cdot \vec{p_i}|^{1/2}}{\sum_i |\vec{j} \cdot \vec{p_i}|^{1/2}}$
- lepton+jet events, 2 fb^{-1} of 7 TeV data



JHEP 11 (2013) 031 [arXiv:1307.4568v2]

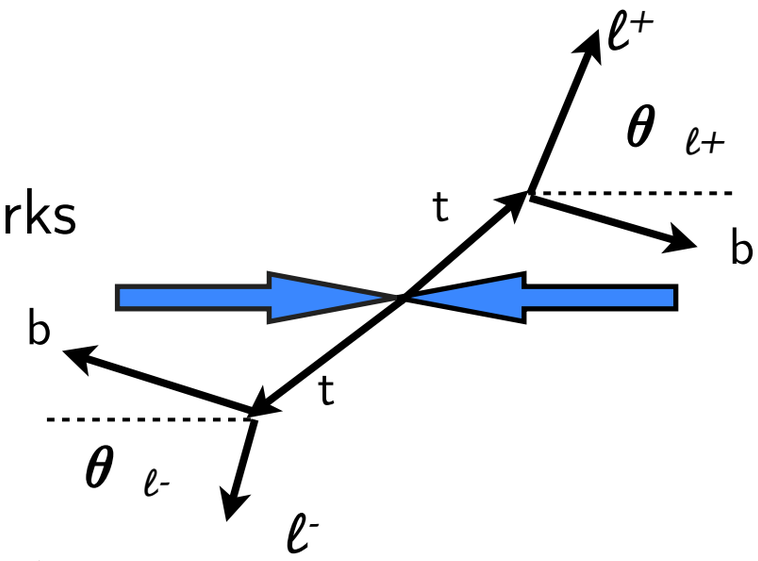
Result

- $Q_t = 0.64 \pm 0.02_{stat} \pm 0.08_{sys}$
- exotic model excluded by more than 8σ

Top properties: Polarization

Motivation

- in SM top quarks are produced with negligible polarization
- BSM models (e.g. axigluon) can generate polarization of top quarks

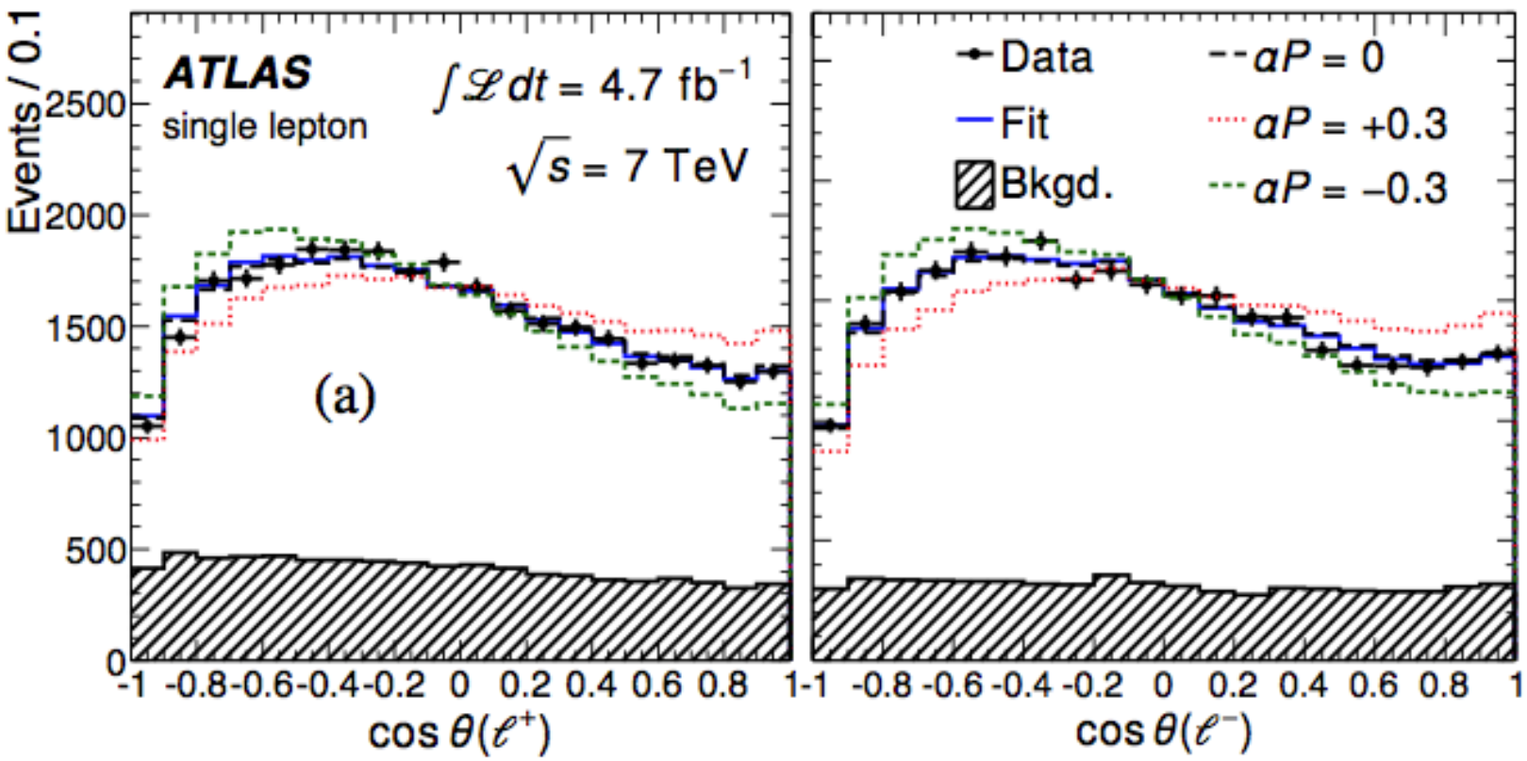


Measurement

- double differential cross-section with respect to polar angles of decay products

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_{\ell+}\, d\cos\theta_{\ell-}} = \frac{1}{4}(1 + P_1\cos\theta_{\ell+} + P_2\cos\theta_{\ell-} - C\cos\theta_{\ell+}\theta_{\ell-})$$

- lepton+jets and dilepton tt events, 4.7fb^{-1} of 7TeV data



PRL, 111 232002 [arXiv:1307.6511v2]

Result

- polarization of top quarks compatible with SM prediction

$$\alpha_\ell P_{\mathrm{CPC}} = -0.035 \pm 0.014_{\mathrm{stat}} \pm 0.037_{\mathrm{sys}}$$

$$\alpha_\ell P_{\mathrm{CPV}} = 0.020 \pm 0.016(\mathrm{stat})\,^{+0.013}_{-0.017}\,(\mathrm{sys})$$

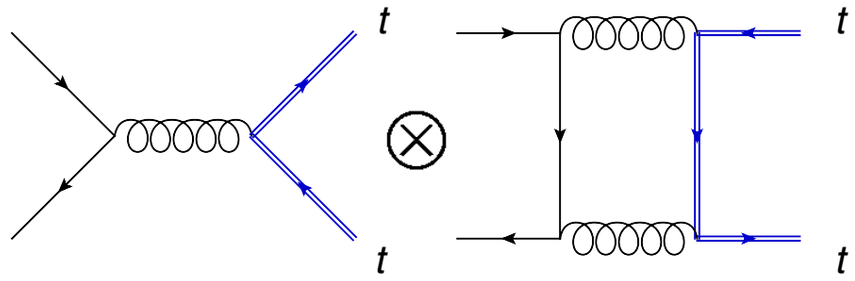
Top properties: Charge Asymmetry

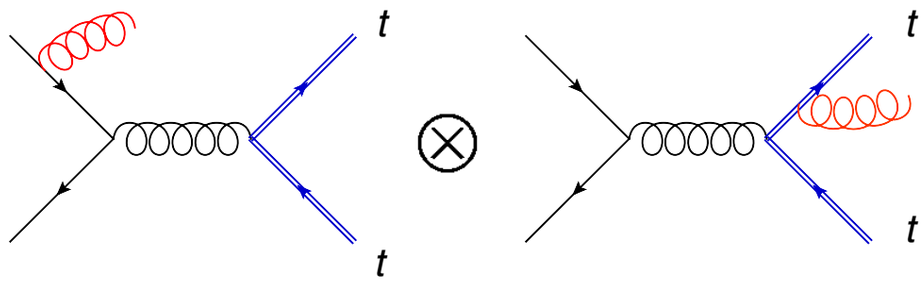
Motivation

- top charge asymmetry is sensitive to new physics
- 2-3σ excess observed by CDF, D0 / growing to 3.4σ for $m_{tt} > 450$ GeV (CDF)

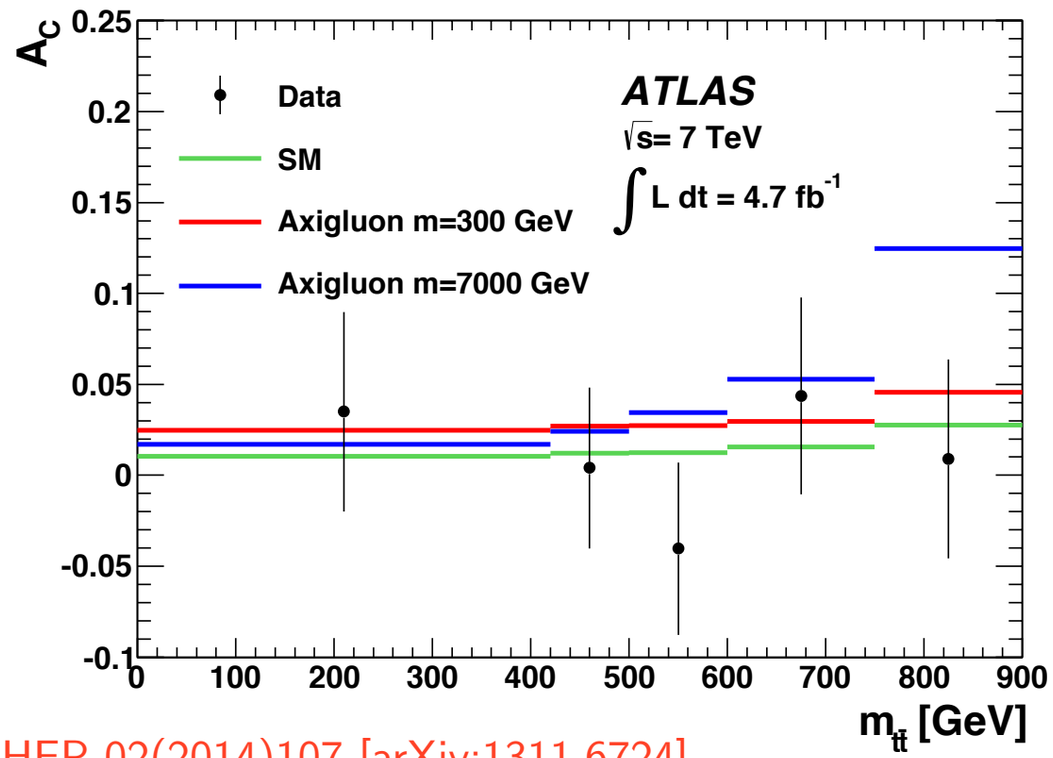
What is measured

- charge asymmetry is a NLO effect arising from the interference of (Born x Box) and (ISR x FSR) diagrams
- asymmetry expected to be small at LHC since the dominant contribution is from gg fusion (C-symmetric)
- measure A_C as a function of m_{tt}, $p_T(tt)$, y_{tt}





$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)} \quad , \quad \Delta|y| \equiv |y_t| - |y_{\bar{t}}|$$



Result

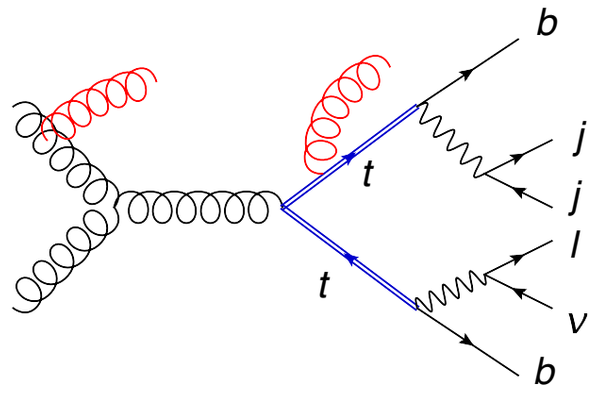
- all measurements compatible with SM prediction
- $A_C = 0.006 \pm 0.010$
  $A_C^{SM} = 0.0123 \pm 0.0005$.

JHEP 02(2014)107 [arXiv:1311.6724]

tt+jets differential measurements

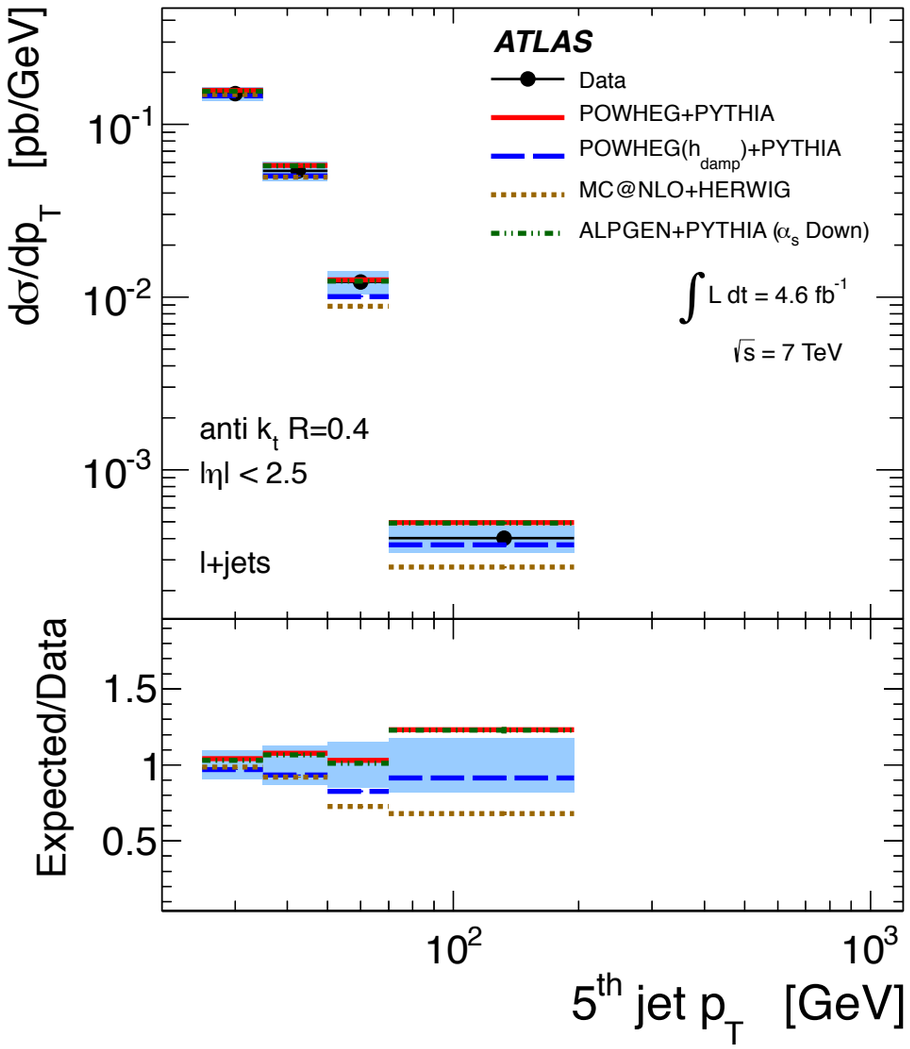
Motivation

- test QCD predictions at hard scales
- important background for SUSY searches
- constrain ISR/FSR in top events and other modeling uncertainties that affect other measurements (top mass, inclusive tt cross-section)



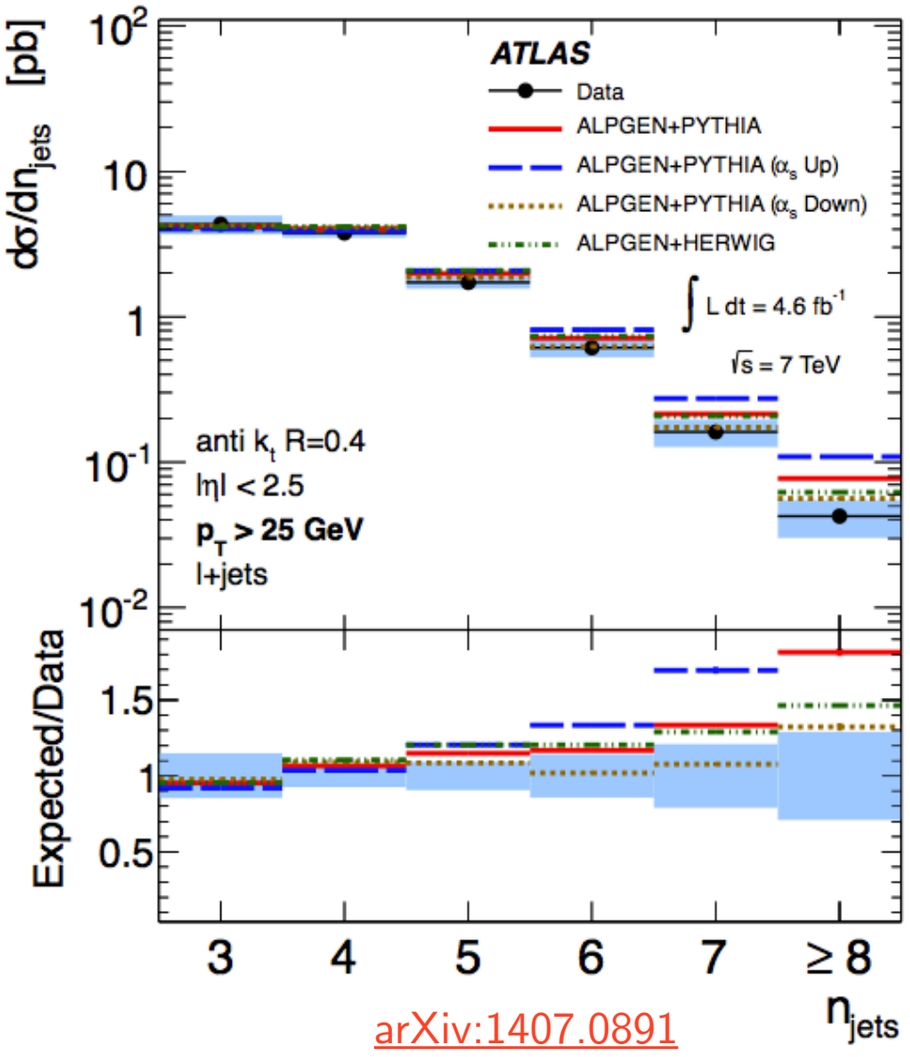
Measurement

- differential cross-section as a function of jet multiplicity and jet p_T (lepton+jet events)
- unfolded to stable particle level



Results

- measurement can distinguish between models
- MC@NLO+Herwig gives too soft spectrum for 5th jet
- data favor lower α_s in Alpgen+Pythia model

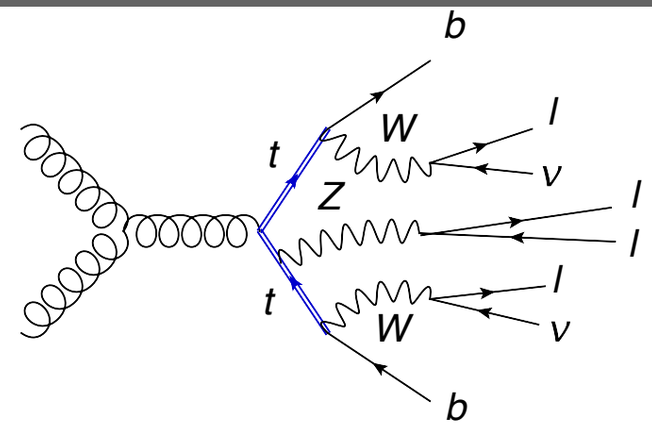


arXiv:1407.0891

tt + W/Z

Motivation

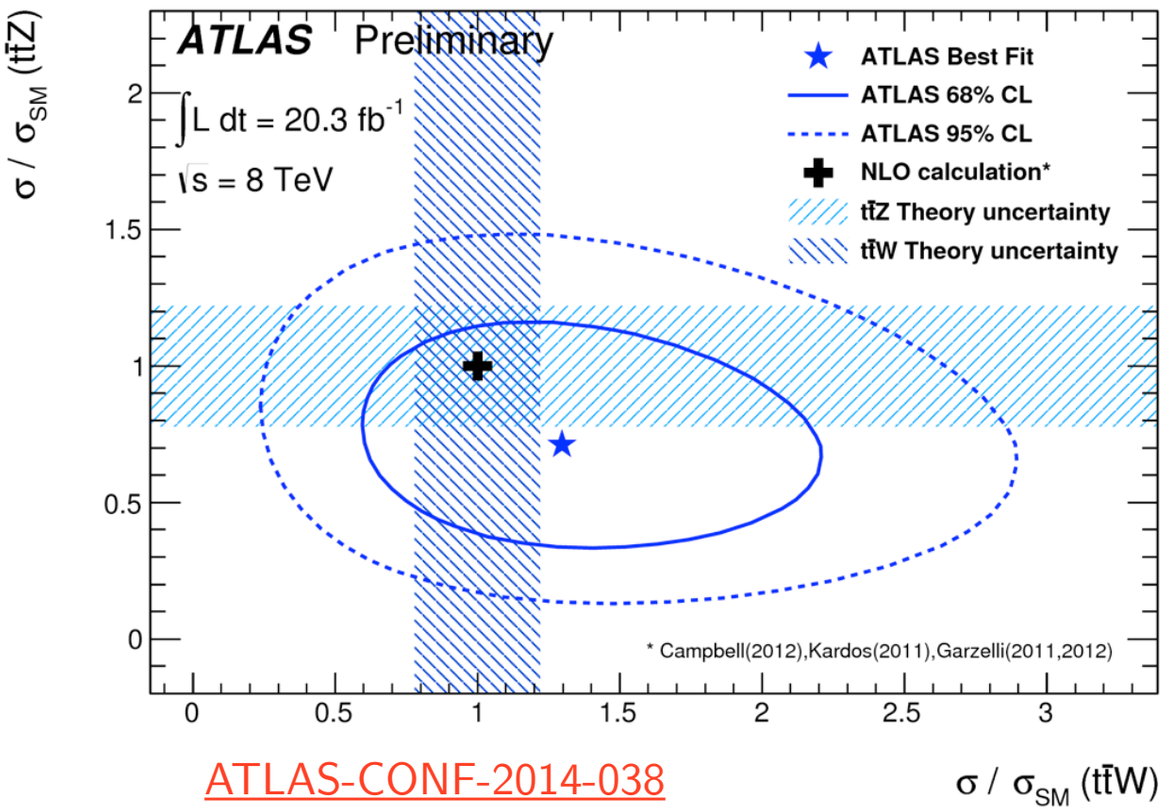
- couplings of top to γ and Z have not been measured
- BSM physics (e.g. technicolor) could modify couplings



Measurement

- events with 2 or 3 leptons with same or opposite sign

	same sign dimuon	opposite sign dilepton (Z veto)	opposite sign dilepton	trilepton	trilepton (Z veto)
Z-mass selection	-	$\lvert m_{ll}\text{-}m_Z\rvert > 10$ GeV	$\lvert m_{ll}\text{-}m_Z\rvert < 10$ GeV	$\lvert m_{ll}\text{-}m_Z\rvert < 10$ GeV	$\lvert m_{ll}\text{-}m_Z\rvert > 10$ GeV
Signal	ttW dom.	ttZ and ttW	ttZ dom.	ttZ	ttW dom.
Main background	ttZ, ttH, fakes	tt+jets	Z+jets	tZ, WZ, fakes	ttZ, ttH, fakes



ATLAS-CONF-2014-038

Result

- evidence for ttZ and ttW production
- signal strength and cross-section measurements in agreement with SM expectation

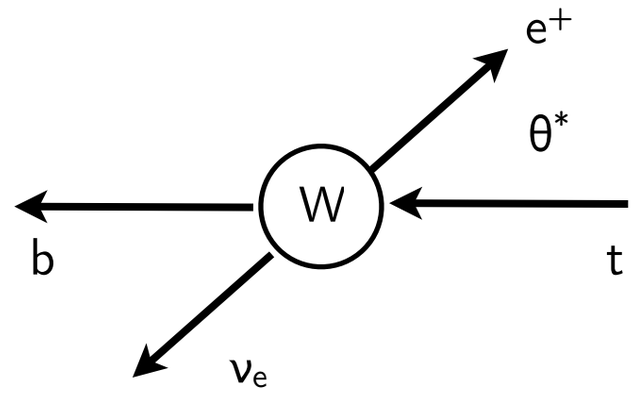
$$\sigma_{t\bar{t}Z} = 150^{+55}_{-50}(\text{stat.}) \pm 21(\text{syst.})\ \text{fb}$$

$$\sigma_{t\bar{t}W} = 300^{+120}_{-100}(\text{stat.})^{+70}_{-40}(\text{syst.})\ \text{fb}$$

Top decays: W polarization

Motivation

- probe Lorentz structure of Wtb vertex
- search for anomalous Wtb couplings

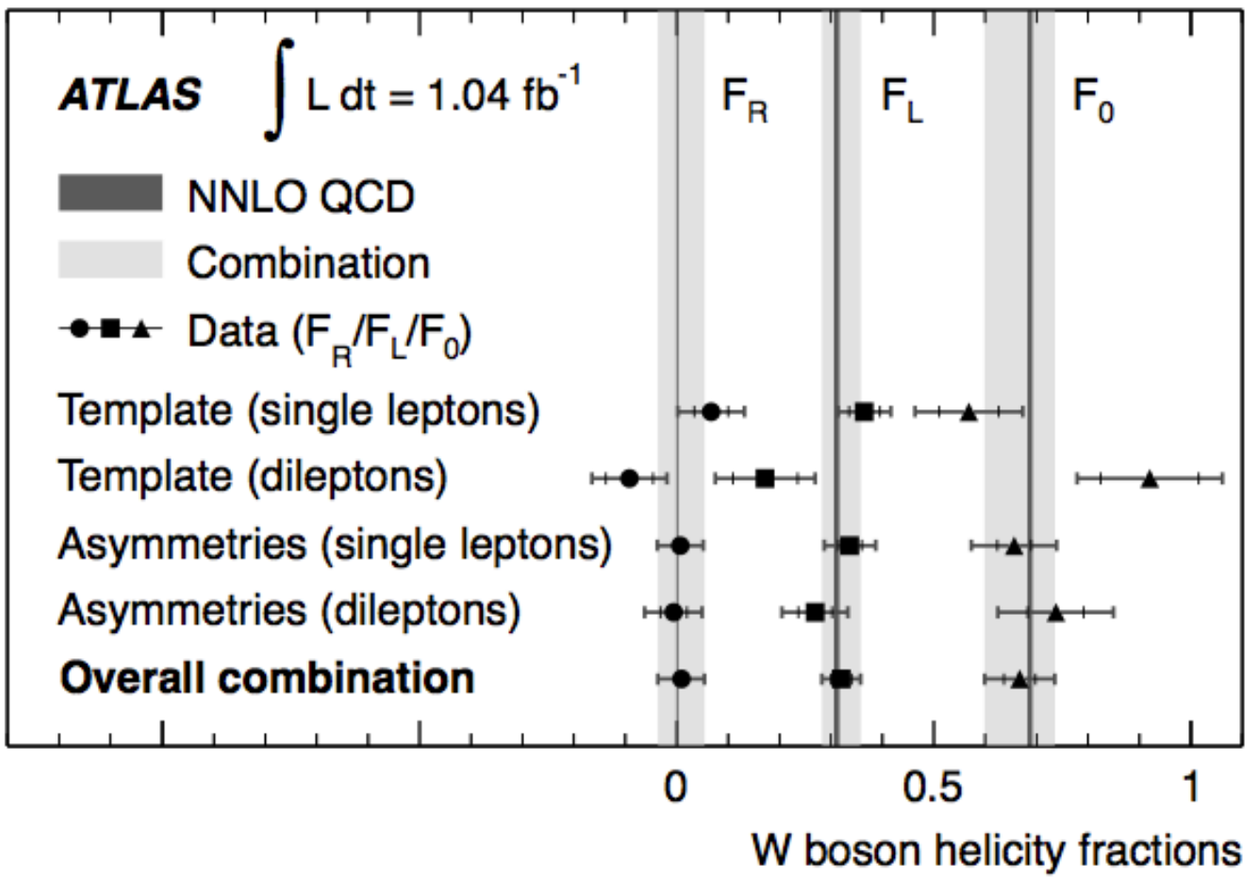


Measurement

- angular distribution of top decay products

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta)F_0 + \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{8}(1+\cos\theta^*)^2 F_R$$

- angular asymmetry $A_\pm = \dfrac{N(\cos\theta^* > \pm(1-2^{2/3})) - N(\cos\theta^* < \pm(1-2^{2/3}))}{N(\cos\theta^* > \pm(1-2^{2/3})) + N(\cos\theta^* < \pm(1-2^{2/3}))}$



JHEP 1206 (2012) 088 [arXiv:1205.2484v1]

Result

- W helicity fractions compatible with SM
- no anomalous Wtb couplings found - improvement of limits set by Tevatron

Top decays: Spin Correlations

Motivation

- probe BSM physics in top production or decay
- top production: MSSM/2HDM Higgs, heavy Z
- top decay: top decaying to MSSM Higgs

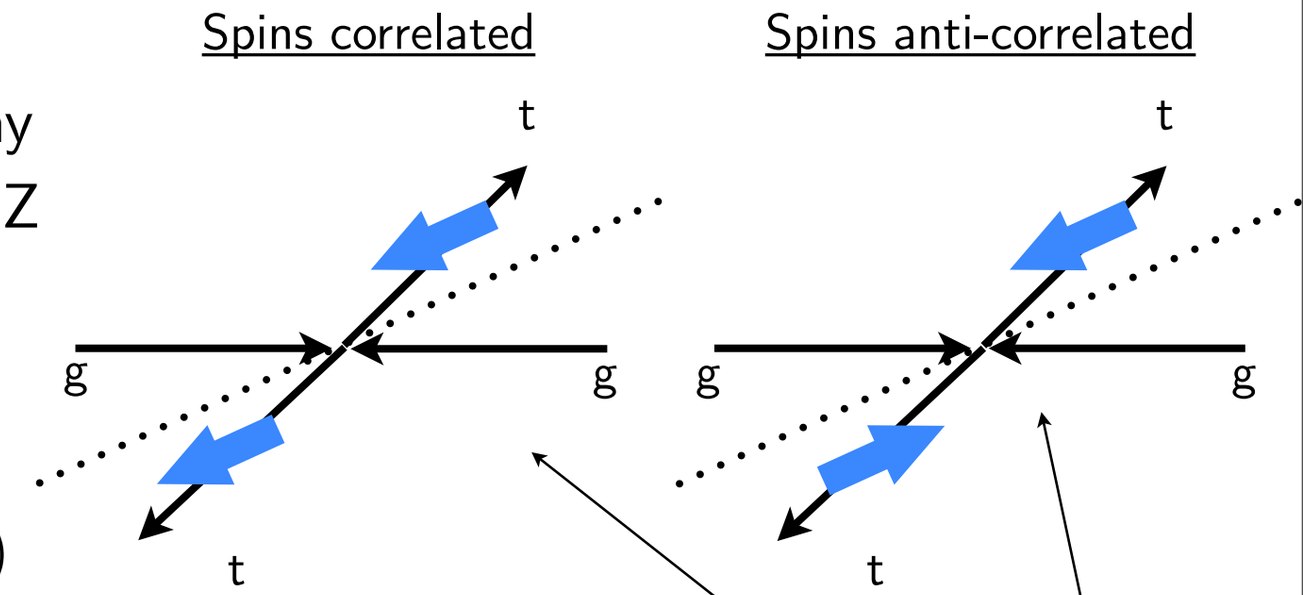
Measurement

- angular distribution of top decay products

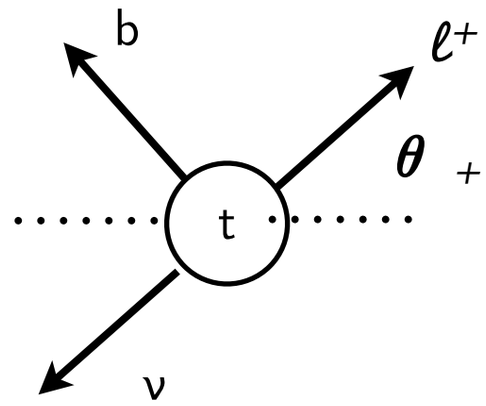
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_{\ell+}\, d\cos\theta_{\ell-}} = \frac{1}{4}(1 - C\cos\theta_{\ell+}\theta_{\ell-})$$

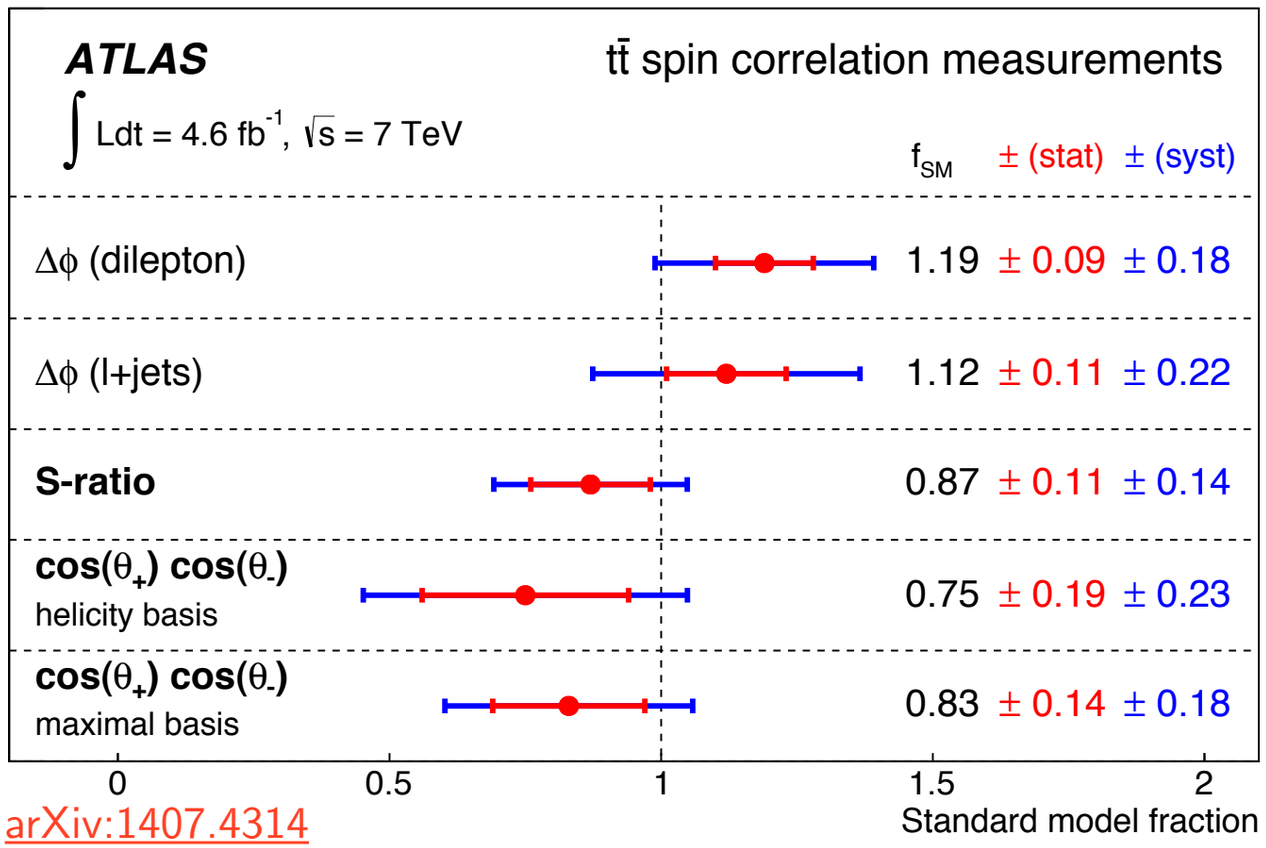
with different quantization axes (requires top reconstruction)

- Matrix element ratio correlation/no-correlation
- azimuthal angles $\Delta\varphi(\ell^+, \ell^-)$, $\Delta\varphi(\ell,\mathrm{d})$, $\Delta\varphi(\ell,\mathrm{b})$



$$C = \frac{(N_{\uparrow\uparrow} + N_{\downarrow\downarrow}) - (N_{\uparrow\downarrow} + N_{\downarrow\uparrow})}{(N_{\uparrow\uparrow} + N_{\downarrow\downarrow}) + (N_{\uparrow\downarrow} + N_{\downarrow\uparrow})}$$





arXiv:1407.4314

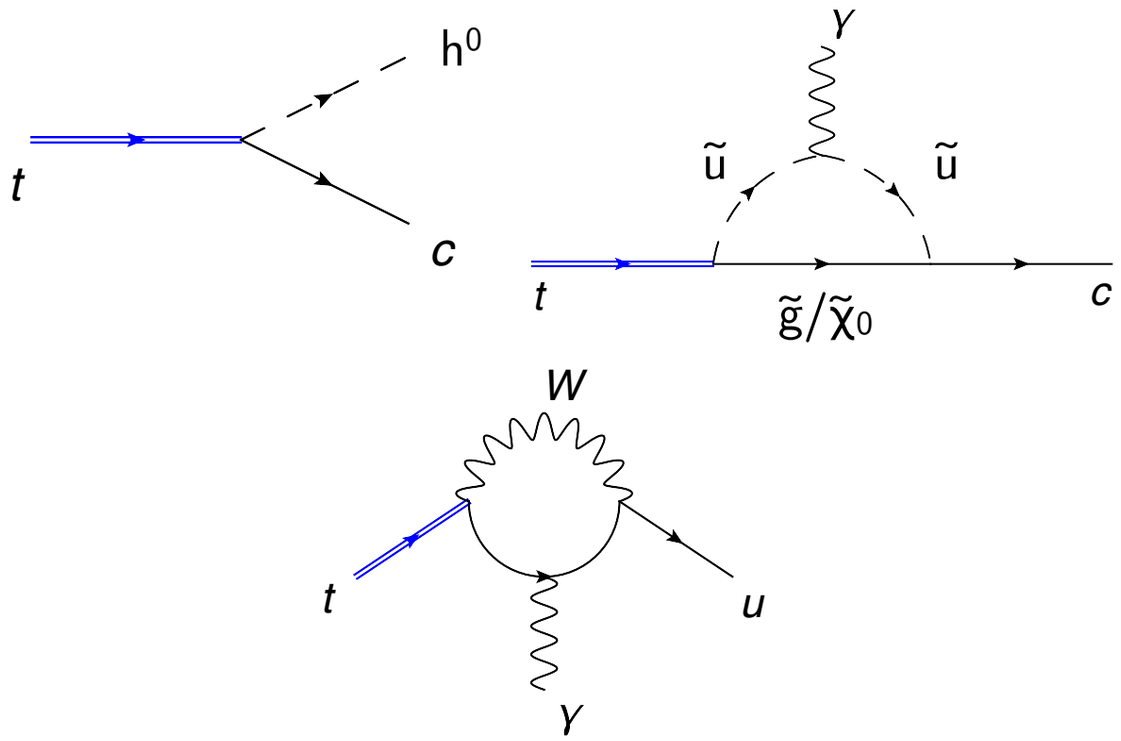
Result

- measurements in agreement with SM prediction

Searches: FCNC in top decays

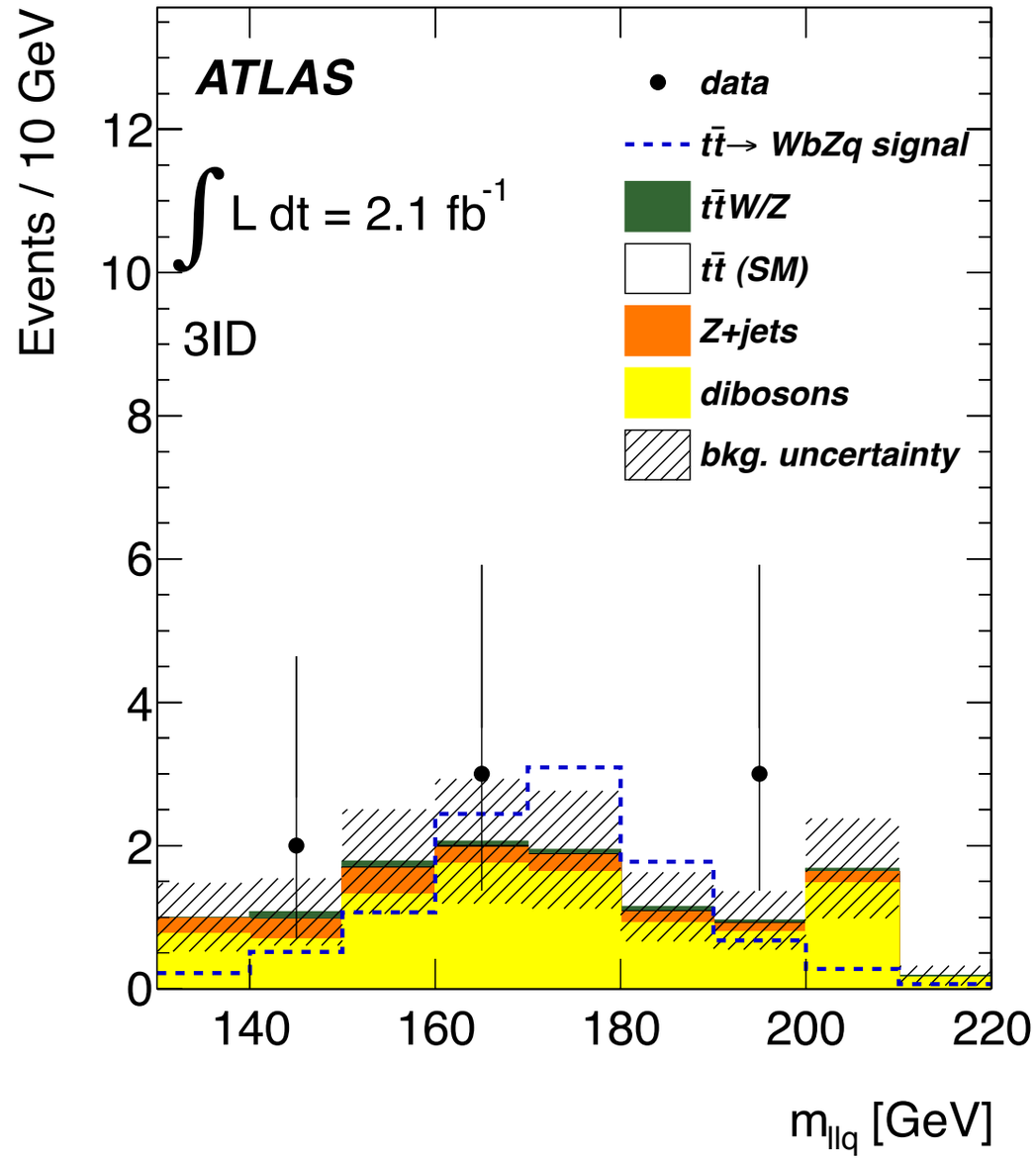
Motivation

- sensitive to physics beyond SM
- MSSM, 2HDM, RPV SUSY, extra dimensions...



SM FCNC
GIM suppressed

$$\mathrm{BR} \sim 10^{-16}$$



Measurement

- signal: $t\bar{t} \to Z(\to \ell^+\ell^-)q\ W^-(\to \ell^-\nu)\bar{b}$
  3 leptons, $>$ 1 jet, MET
- backgrounds: processes with fake leptons or real leptons (WZ,ZZ)
- dominant systematic: diboson modeling

Result

- no evidence for signal
- observed limit $\mathrm{BR}(t \to qZ) < 0.73\%$ compatible with expected sensitivity

JHEP 1209 (2012) 139 [arXiv:1206.0257]

Summary & prospects

Top physics with ATLAS

- rich top physics program with 7 and 8 TeV data related to:
  - top quark properties (mass, charge)
  - properties of top production and decay
  - measurements of associated production with vector bosons
  - searches for new physics phenomena

All measurements are in agreement with SM so far.

Prospects for HL-LHC

- increase of center-of-mass energy to 14 TeV and integrated luminosity to 3 ab^{-1}
- probe rare processes, e.g.
  - di-top resonances: up to 2.4 TeV [ATLAS-PHYS-PUB-2013-003]
  - FCNC expected limits of the order of BR=O(10^{-4}) approaching the BR that certain BSM models predict [ATLAS-PHYS-PUB-2013-012]