Intrinsic top quark properties in ATLAS

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PRISMA Cluster of Excellence
on behalf of the ATLAS collaboration

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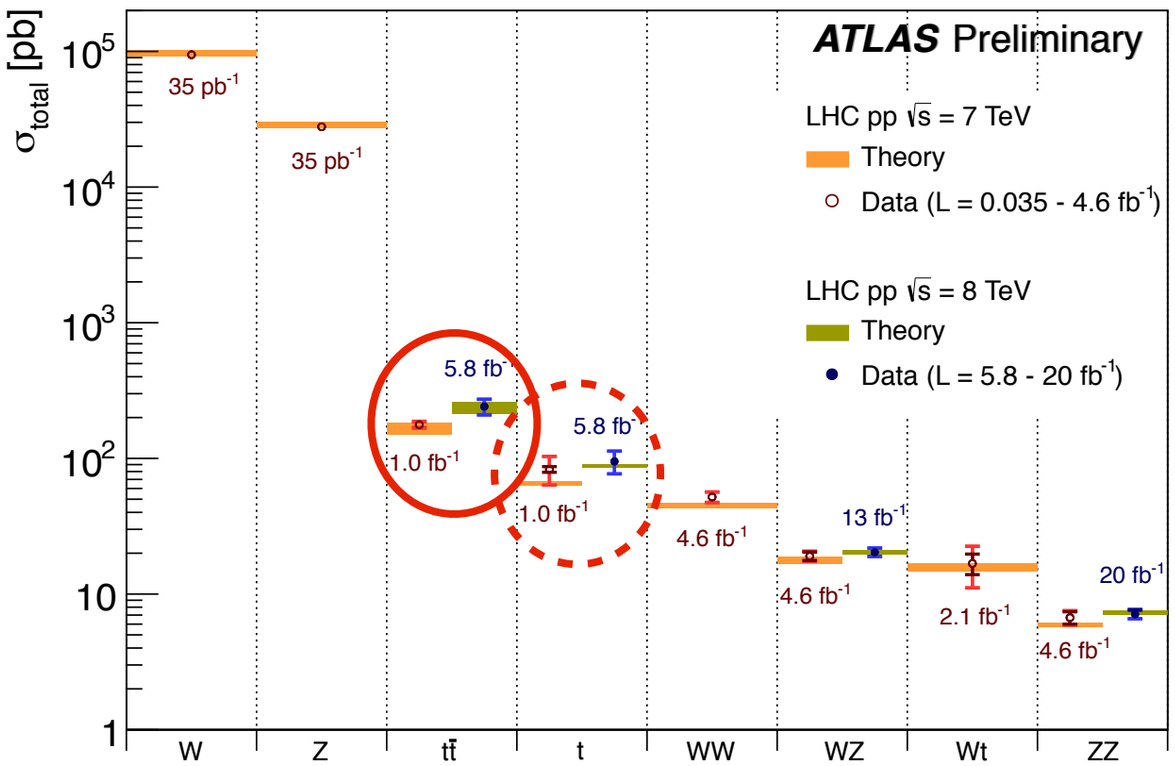
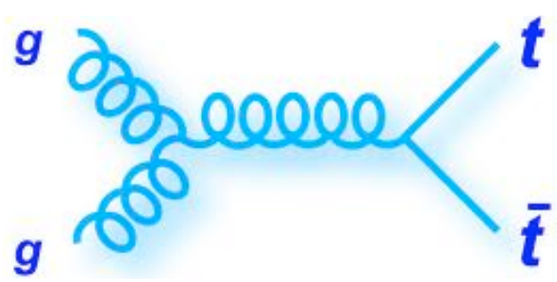
SM Top Quark Production





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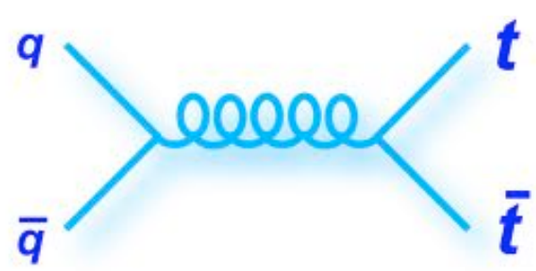

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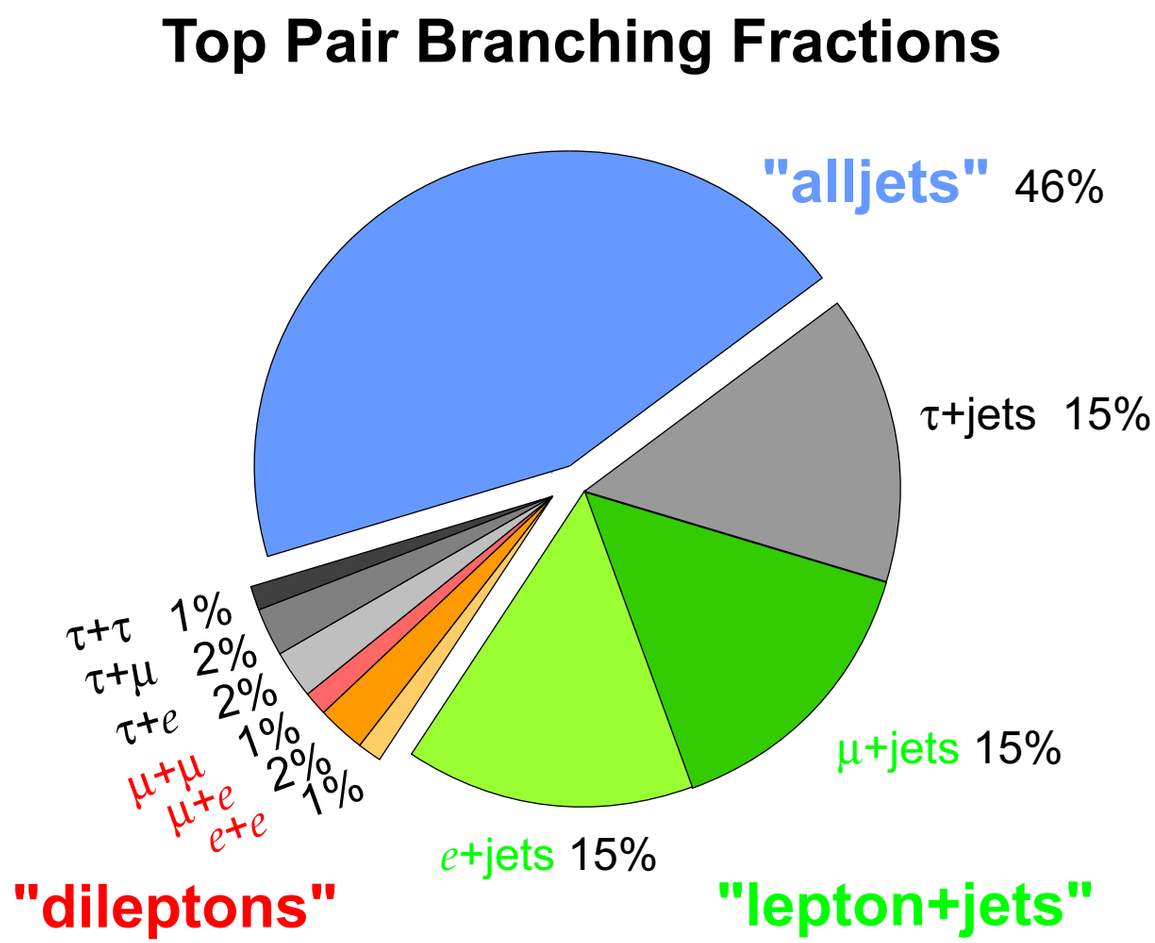
- Measurements of top quark properties presented here are based on **top-antitop events**
- First properties measurements are being performed also on single top events, see talk by Attila Krasznahorkay

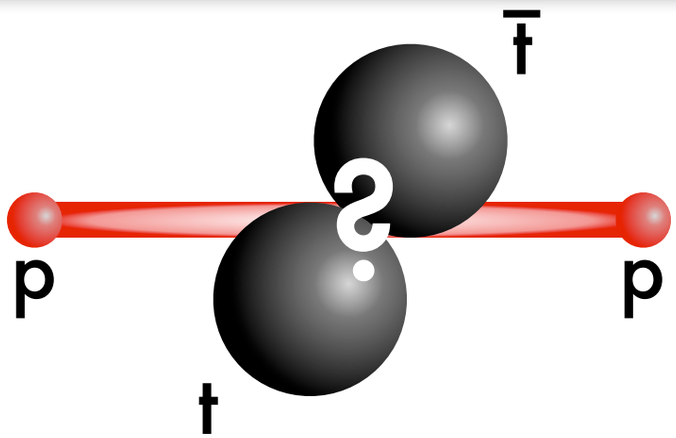
SM Decay

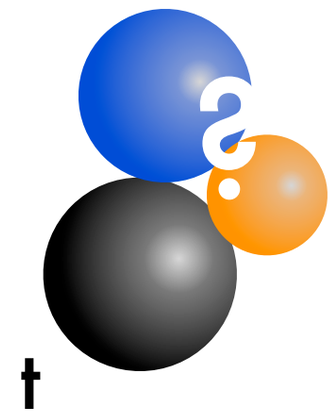
- Top decays to Wb with about 100% BR
- Experimental signatures based on W decay



- High rate, high background, (Multijet)
  not used for the results presented here
- Moderate rate, acceptable background (W+jets)
- Low rate, low background (Z+jets, diboson)

Which properties?





- Charge asymmetry
- Spin correlations
- Top polarisation
- Resonances
- Vector-like quarks
- Stops

- Mass
- Charge

- W polarisation
- Couplings (ttH, ttγ, ttZ)
- FCNC

More top quark properties measurements: see talk by Liza Mijovic
Searches for exotic top pair production: see talks by Diedi Hu and Antonella Succurro

Event selection

- Event topology (lepton+jets, dilepton)
  - Trigger: single lepton
  - 1 or 2 high p_T isolated leptons (p_T > 20 or 25 GeV, $|\eta|$< 2.5)
  - MET > 20 or 35 GeV, > 60 GeV
  - At least 4 or at least 2 anti-k_T (R=0.4) Jets (p_T > 25 GeV, $|\eta|$< 2.5)
  - At least 1 b-tagged jets (70% efficiency for b-quarks)

- Background rejection
  - Multijet: m^T_W > 25 GeV or MET+ m^T_W > 60 GeV
  - Z+jets: m_{ll} veto or H_T > 130 GeV

Background estimate

- Fake leptons: multijet, W+jets
  - Data-driven shape and rate determined with matrix method

- W+jets
  - Shape from MC
  - Data-driven normalisation from charged asymmetry
  - $N_{W^+ + W^-} = (r_{MC}+1)/(r_{MC}-1) \times (D^+ - D^-)$

- Z+jets
  - Shape from MC
  - Data-driven normalisation from m_{ll} around Z mass

Event reconstruction

- Different methods to resolve **combinatorial ambiguities** in jet assignment and to determine **neutrino momenta** in dilepton events
- **Kinematic fit** chooses best combination and reconstructs true momenta
- Example: KLFitter for lepton+jets events

$$L = \underbrace{\mathcal{B}(\widetilde{E}_{\mathrm{p},1}, \widetilde{E}_{\mathrm{p},2} | m_W, \Gamma_W) \cdot \mathcal{B}(\widetilde{E}_{\mathrm{lep}}, \widetilde{E}_{\nu} | m_W, \Gamma_W)}_{\text{Breit-Wigner}} \cdot$$

$$\underbrace{\mathcal{B}(\widetilde{E}_{\mathrm{p},1}, \widetilde{E}_{\mathrm{p},2}, \widetilde{E}_{\mathrm{p},3} | m_t, \Gamma_t) \cdot \mathcal{B}(\widetilde{E}_{\mathrm{lep}}, \widetilde{E}_{\nu}, \widetilde{E}_{\mathrm{p},4} | m_t, \Gamma_t)}_{\text{Breit-Wigner}} \cdot$$

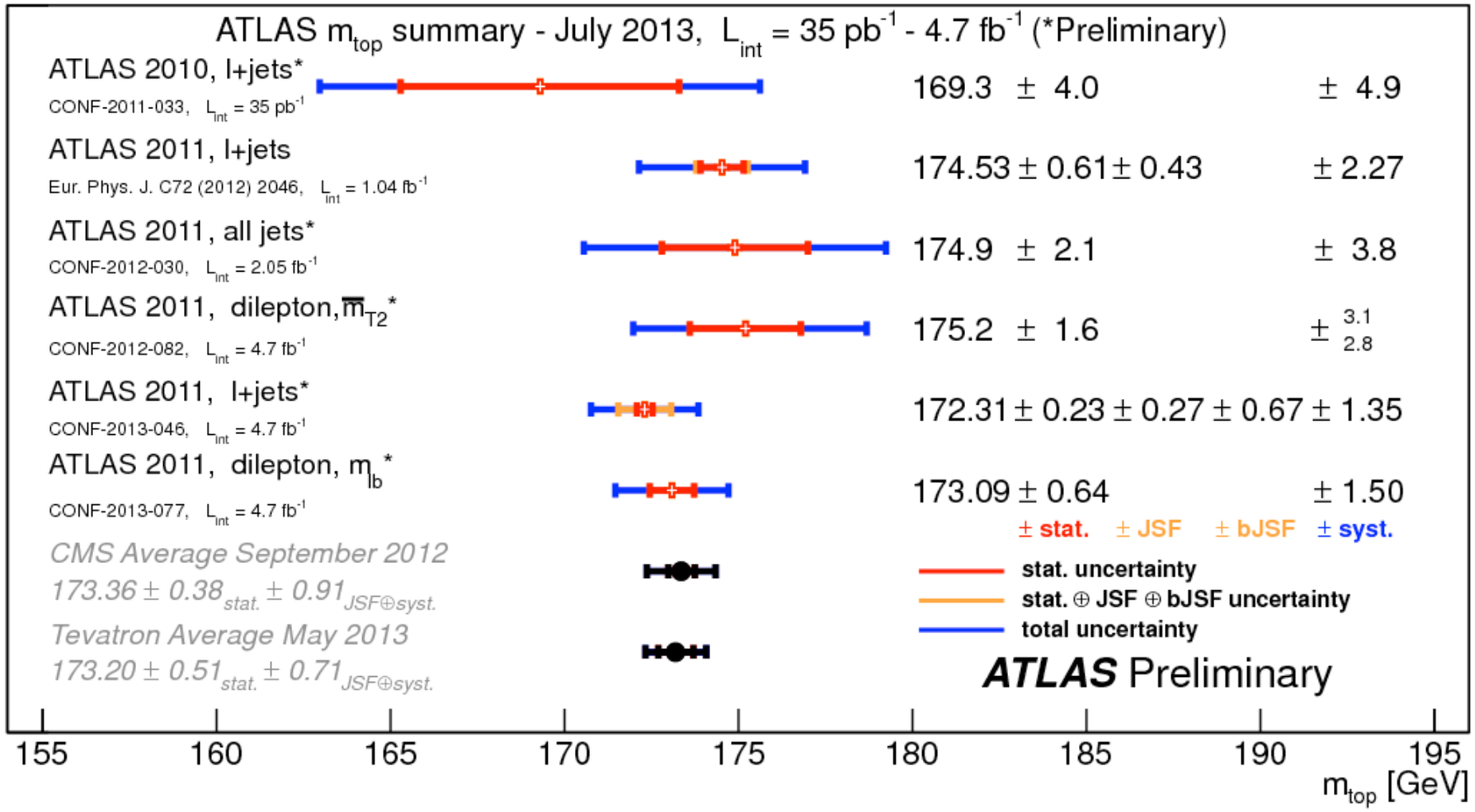
$$\underbrace{\mathcal{W}(\hat{E}_x^{\mathrm{miss}} | \widetilde{p}_{x,\nu}) \cdot \mathcal{W}(\hat{E}_y^{\mathrm{miss}} | \widetilde{p}_{y,\nu}) \cdot \mathcal{W}(\hat{E}_{\mathrm{lep}} | \widetilde{E}_{\mathrm{lep}})}_{\text{Transfer functions}} \cdot$$

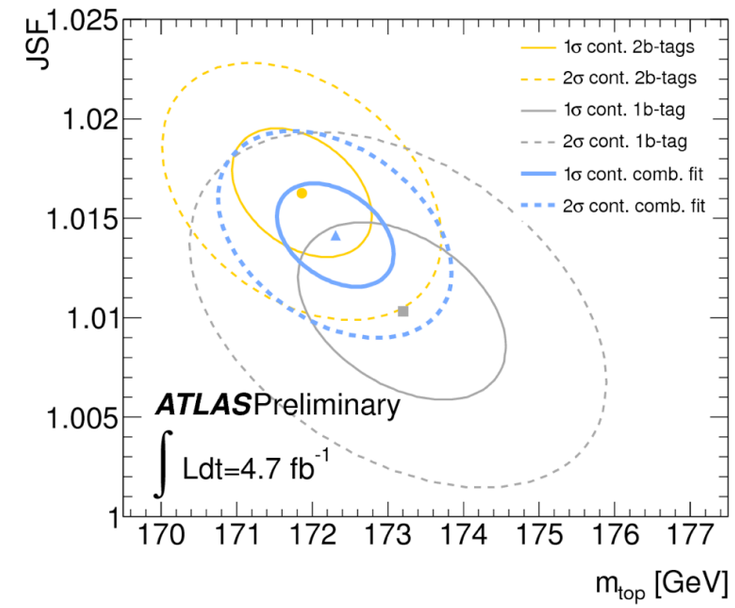
$$\underbrace{\prod_{\mathrm{i}=1}^{4} \mathcal{W}(\hat{E}_{\mathrm{jet,i}} | \widetilde{E}_{\mathrm{p,i}})}_{\text{Transfer functions}} \cdot \underbrace{\prod_{\mathrm{i}=1}^{4} P(\text{tagged} \mid \text{parton flavour})}_{\text{b-tagging}}$$

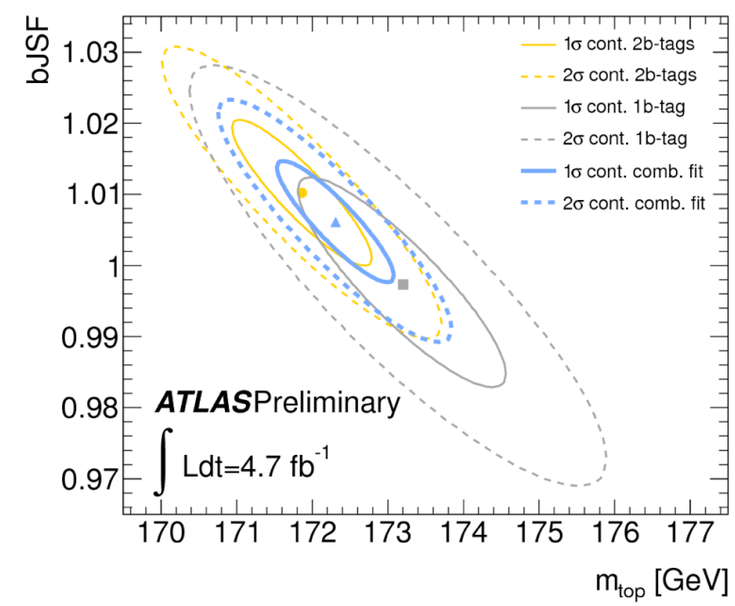
Systematic uncertainties

- Following categories considered for all analyses
- Detector modelling
  - Efficiency and resolution of object identification and reconstruction (e.g. Jet Energy Scale for light and b-jets)
  - Luminosity and pile-up dependence
- Signal and background modelling
  - QCD radiation, MC generators, top quark mass and PDF
  - Background normalisation and shape (cross section expectations, heavy flavour fraction, statistics of data control sample)
- Analysis specific uncertainties
  - e.g. MC statistics for templates, charge mis-id

Mass: summary







See talks by Gabriele Compostella and Markus Cristinziani for details

Charge: method

- Top (or exotic) quark charge determined from **correlation with charge of decay products**

$$t^{(2/3)} \to b^{(-1/3)} + W^{(+1)}$$
$$t_X^{(-4/3)} \to b^{(-1/3)} + W^{(-1)}$$

- Charge of b-jet from **weighted sum of tracks** associated to the jet

$$Q_{b-\mathrm{jet}} = \frac{\sum_i Q_i |\vec{j} \cdot \vec{p}_i|^\kappa}{\sum_i |\vec{j} \cdot \vec{p}_i|^\kappa}$$

- Combined charge of lepton and **paired b-jet**

$$Q_{\mathrm{comb}} = Q^{\ell}_{b-\mathrm{jet}} \cdot Q_\ell$$

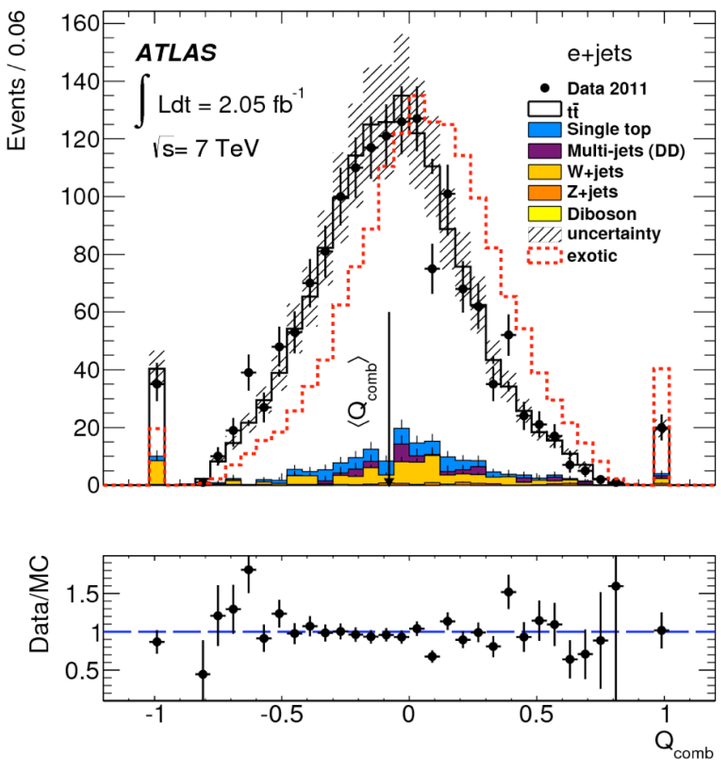
- Lepton+jets events with 2 b-tags + cleaning cuts for high purity of correctly paired events

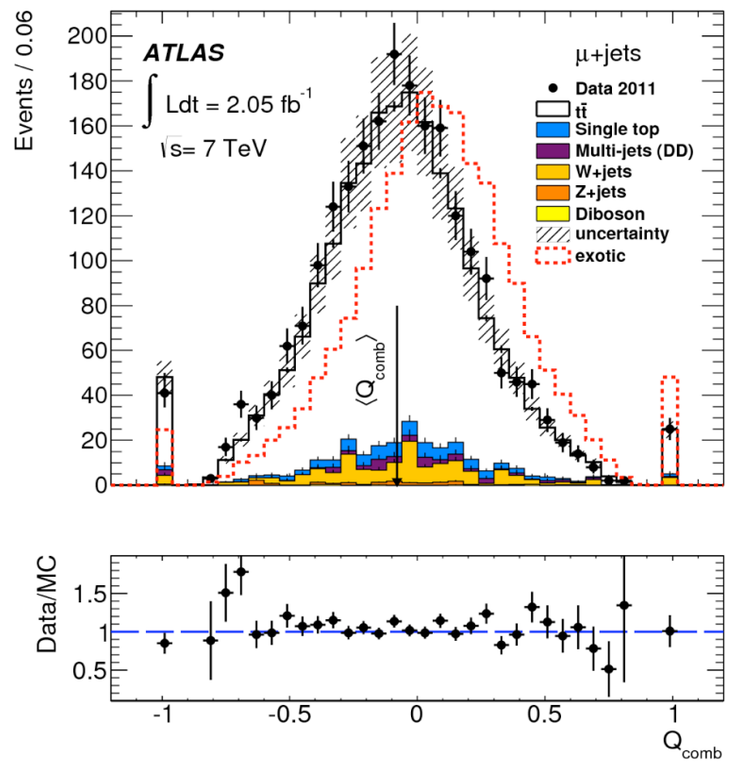
$$m(\ell, b\text{-jet}(1,2)) < m_{\mathrm{cr}}$$
$$m(\ell, b\text{-jet}(2,1)) > m_{\mathrm{cr}}$$
$$m_{\mathrm{cr}} = 155\ \mathrm{GeV}$$

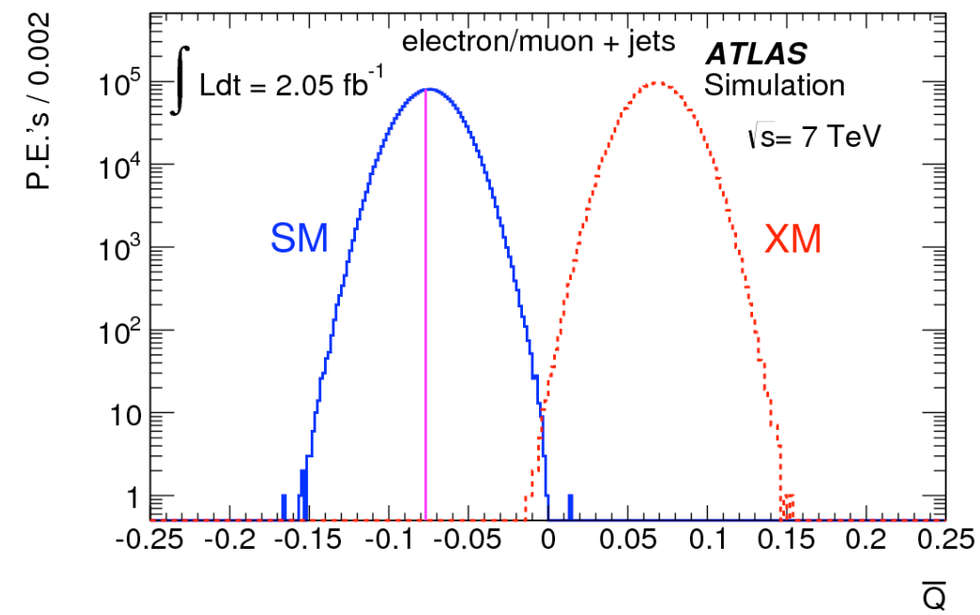
- **Compatibility** with top or exotic quark from pseudo-experiments
- **Charge value** from calibrated b-jet charge

$$Q_{\mathrm{top}} = 1 + Q^{(\mathrm{data})}_{\mathrm{comb}} \times C_b$$

Charge: result







arXiv:1307.4568

$$Q_{\text{top}} = 0.64 \pm 0.02\ (\text{stat.}) \pm 0.08\ (\text{syst.})$$

channel	p_{SM}	p_{XM}	σ_{XM}(S.D.)
e	0.715	$< 10^{-7}$	8.7
μ	0.960	$< 10^{-7}$	8.3
$e+\mu$	0.852	$< 10^{-7}$	8.8

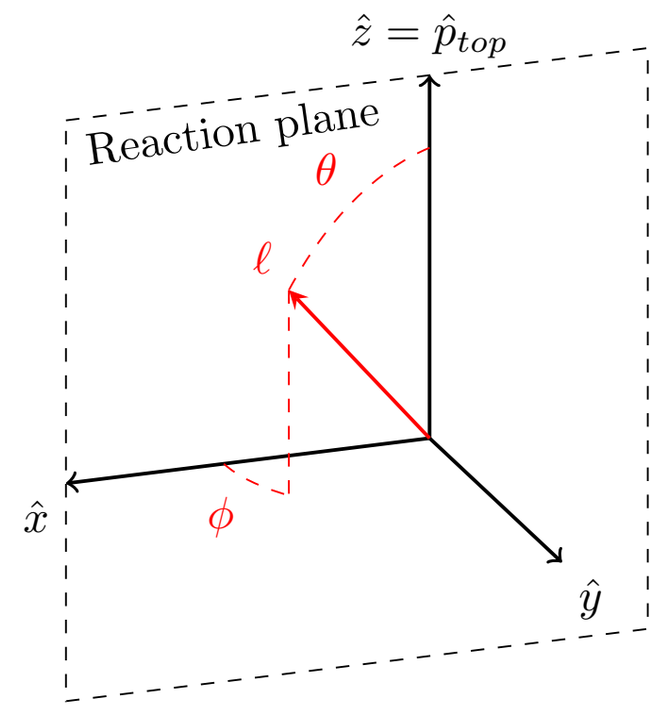
Charge compatible with SM top quark
Exotic model excluded at more than 8 sigma

Top polarisation: method

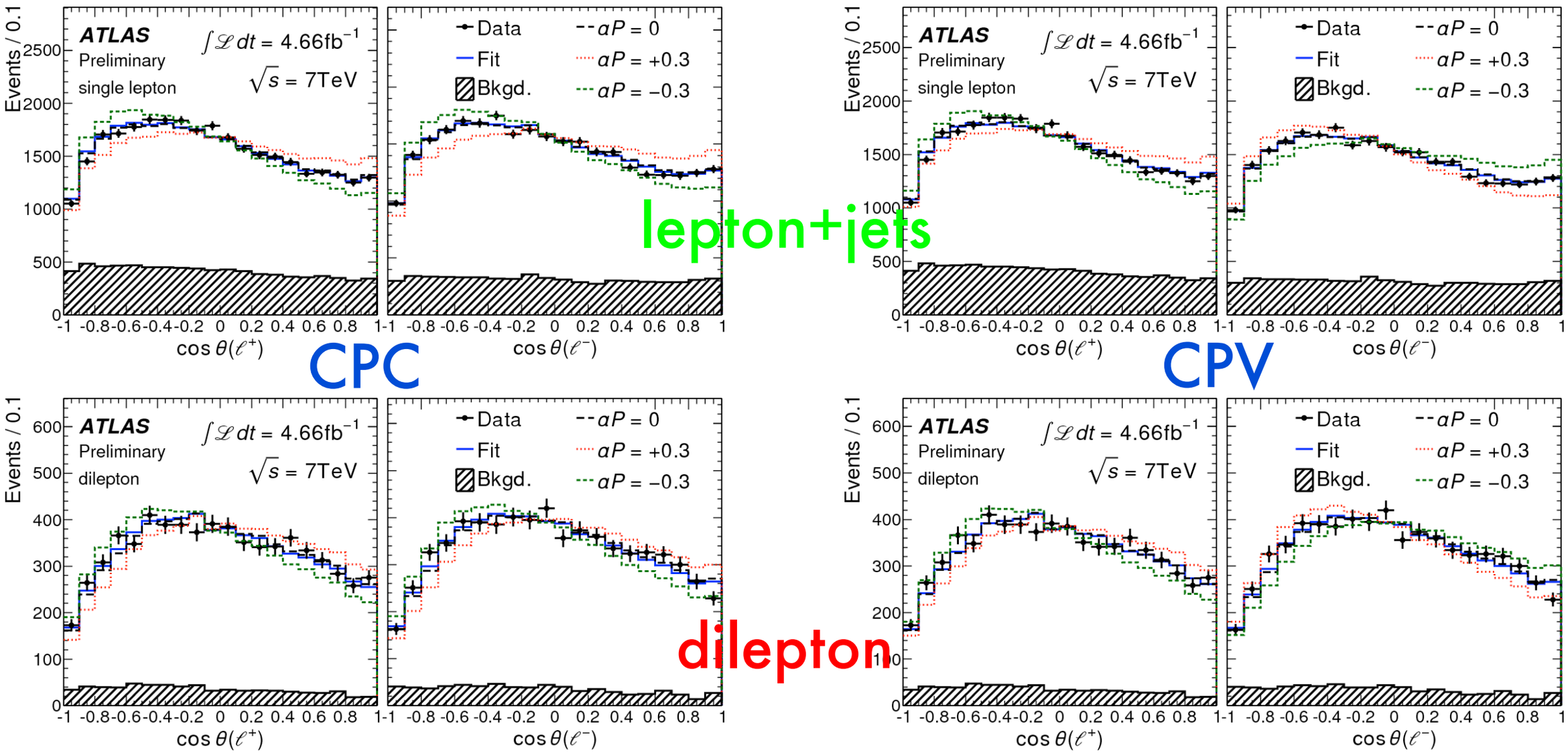
- Top quarks produced unpolarised in the SM
- Lepton+jets and dilepton events selected
- Full reconstruction to determine the top quark centre of mass frame
- Decay product distribution wrt quantisation axis:

$$W(\cos\theta_i) = \frac{1}{2}(1 + \alpha_i P \cos\theta_i)$$

  - P is the degree of polarisation
  - α is the analysing power (=1 for lepton at tree level)
- Template fit of $\cos\theta_l$ distribution (in the helicity basis)
  - f fraction of positively polarised top quarks $\alpha_\ell P = 0.6f - 0.3$ (templates have αP = 0.3)
  - CP conserving and CP violating hypotheses considered



Top polarisation: results



$$\alpha_\ell P_{\text{CPC}} = -0.035 \pm 0.014(\text{stat}) \pm 0.037(\text{syst})$$

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

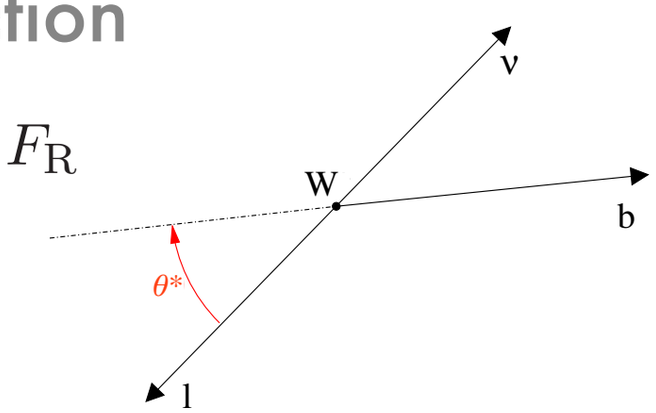
Compatible with unpolarised top quarks

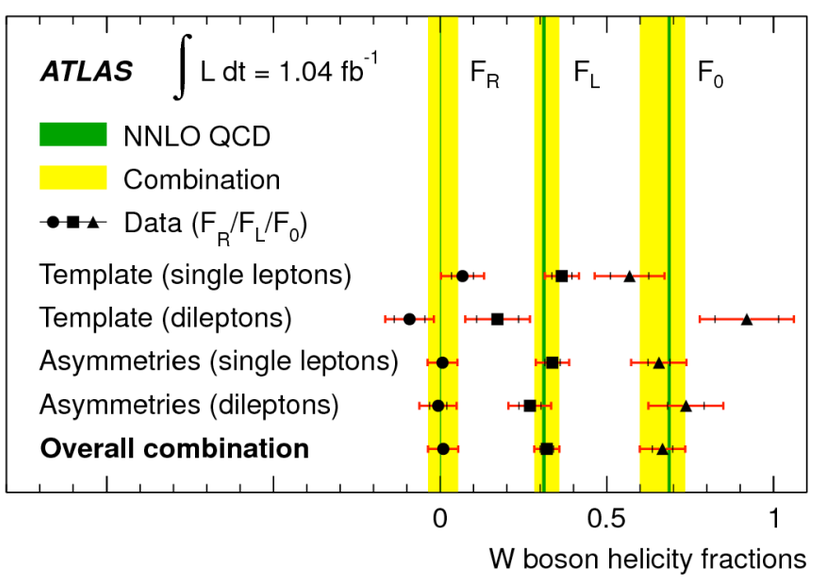
W helicity: measurement

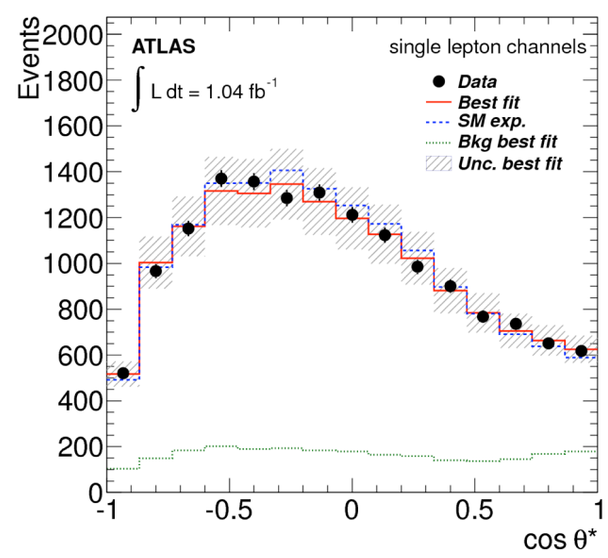
- Fractions of longitudinally, left- and right-handed polarised W's
- Template fit and asymmetry measurement in angular distribution
  - Lepton+jets and dilepton channels, full reconstruction

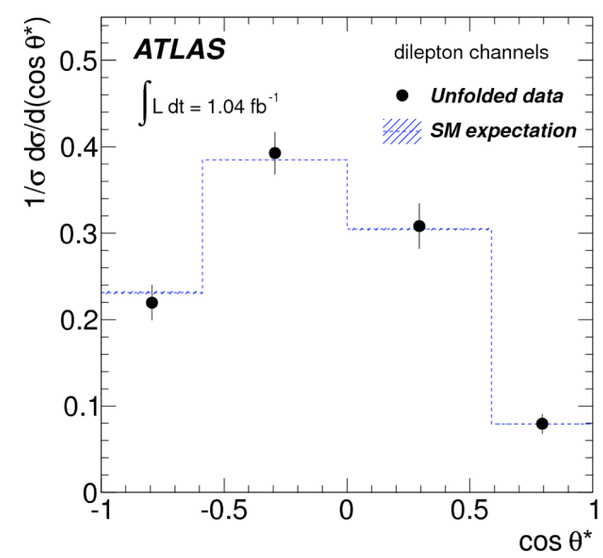
$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*} = \frac{3}{4}\left(1-\cos^2\theta^*\right)\,F_0 + \frac{3}{8}\left(1-\cos\theta^*\right)^2\,F_\mathrm{L} + \frac{3}{8}\left(1+\cos\theta^*\right)^2\,F_\mathrm{R}$$

$$A_\pm = \frac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)} \qquad z = \pm(1-2^{2/3})$$







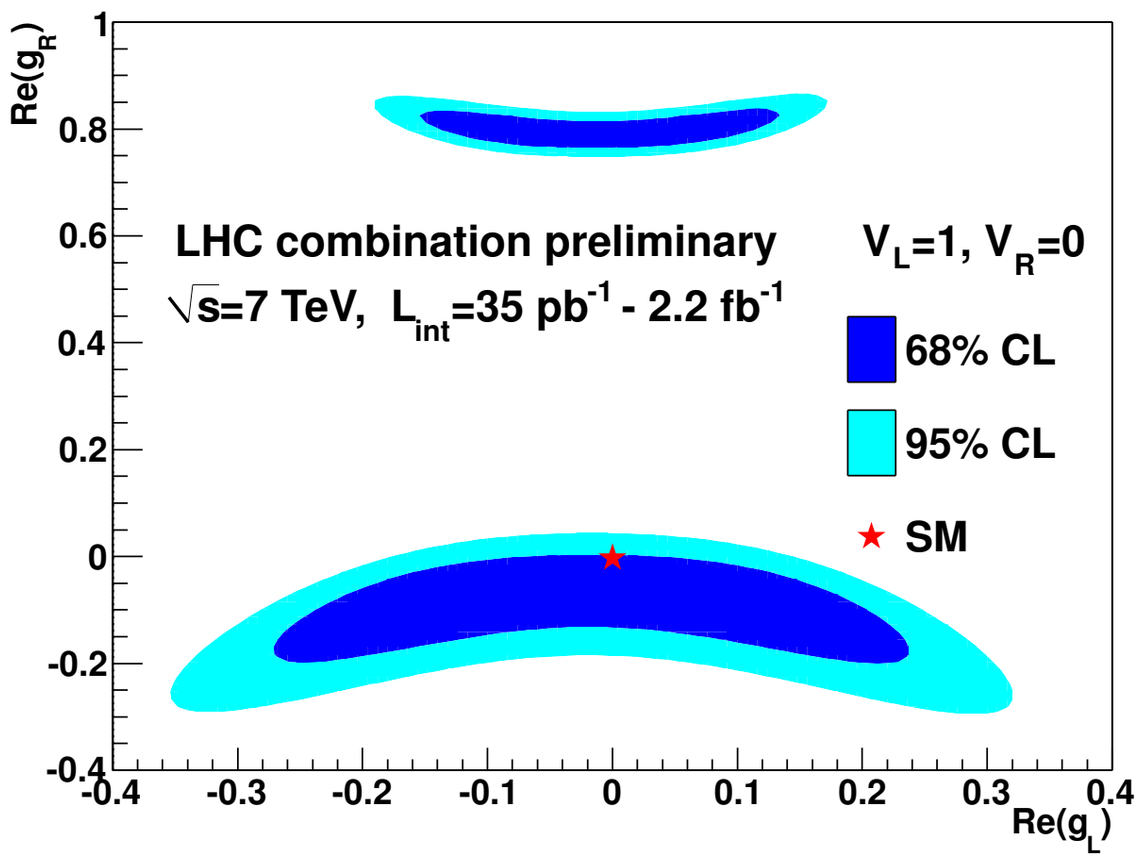


arXiv:1205.2484

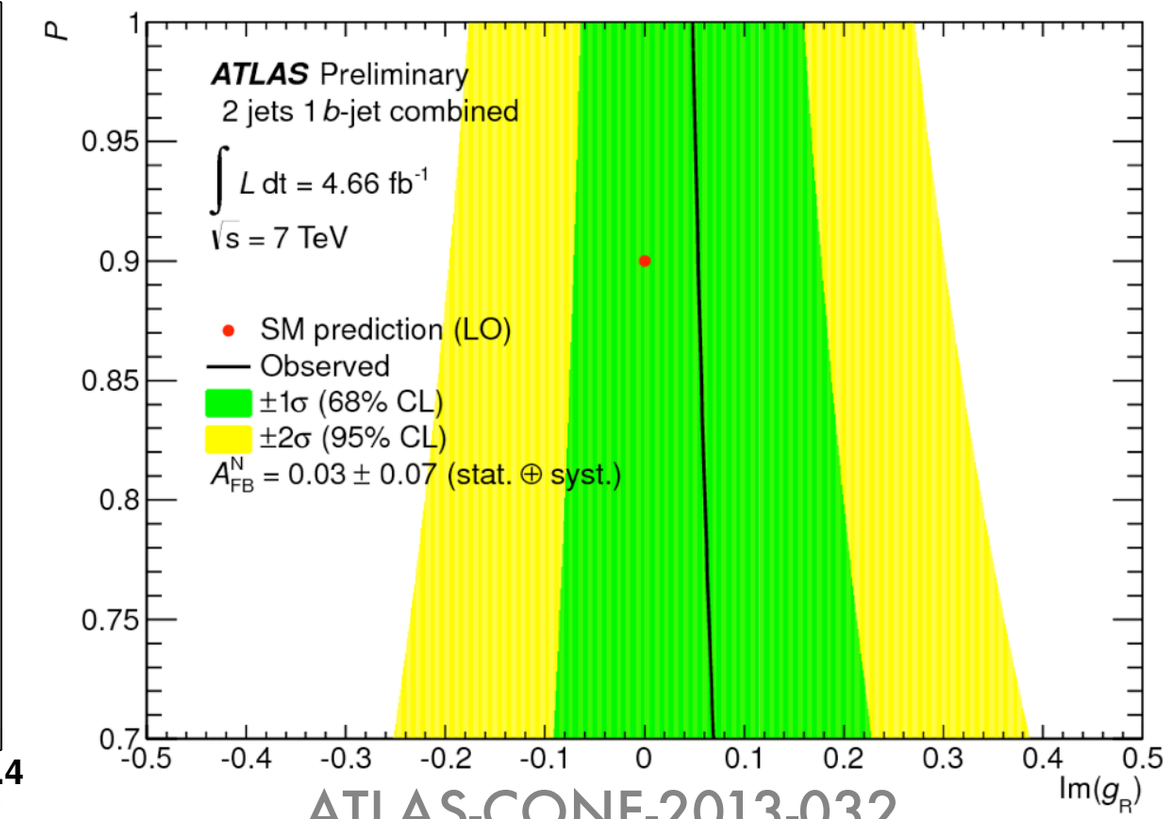
W helicity: interpretation

- Original ATLAS result and combination with CMS interpreted in terms of anomalous couplings in the effective Lagrangian

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



ATLAS-CONF-2013-033

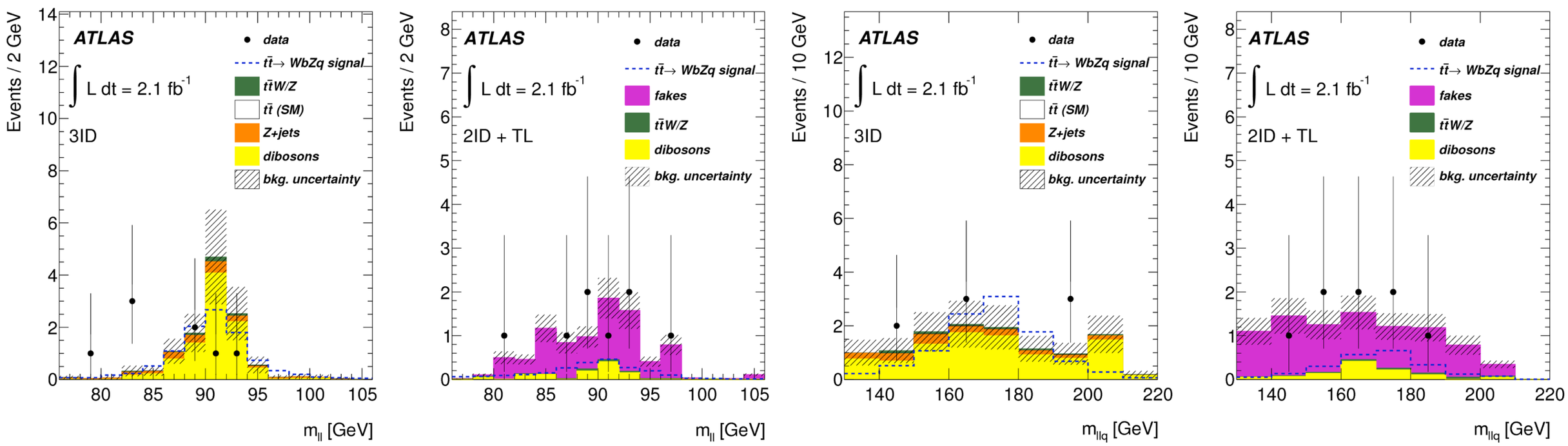


ATLAS-CONF-2013-032
(polarisation vs. anomalous coupling in single top events)

FCNC decays

- Search for $t \to Zq$ FCNC decay (trilepton)
- Expected BR in the SM: $O(10^{-14})$
- Highest expected BR in BSM models: $O(10^{-4})$

channel	observed	(-1σ)	expected	$(+1\sigma)$
3ID	0.81%	0.63%	0.95%	1.4%
2ID+TL	3.2%	2.15%	3.31%	4.9%
Combination	0.73%	0.61%	0.93%	1.4%



arXiv:1203.0529

95% CL limit on FCNC BR: 0.73%

Summary

- Many measurements of top quark properties performed at ATLAS
- Exploiting different decay channels and full kinematic reconstruction
- Data-driven estimate of major backgrounds
- All results compatible with SM predictions
  - Top quark charge and decay vertex as predicted by theory
- Precision limited by systematics in many measurements
- More and more sophisticated mass measurement methods used to reduce effect of systematic uncertainties