Properties of the Top Quark

Phenomenology 2014

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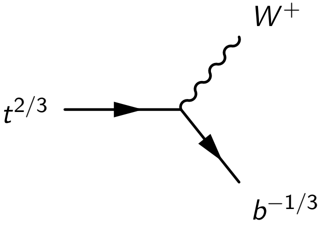
Motivation and introduction

The top quark

- **Heaviest** elementary particle at $\approx 173\,\mathrm{GeV}$. Discovered 1995.
- Lifetime: $\tau = 3 \cdot 10^{-25}$ seconds, decays **without hadronizing**.
- Branching ratio $\mathrm{Br}(t \rightarrow W + b) \approx 1$.

- Top properties enter as important parameters in many BSM theories.
- High precision measurments are important to test SM and BSM.

- LHC acts as a **top factory**, producing $t\bar{t}$ pairs through gluon fusion.
- Final states with $t\bar{t}$, leptons and jets were used for the measurements below.



Top quark mass (1)

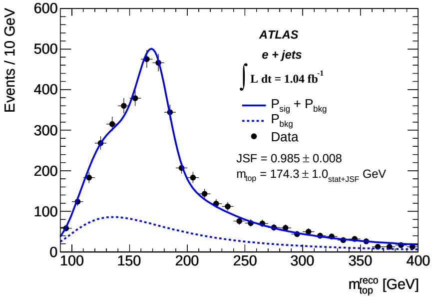
Top mass

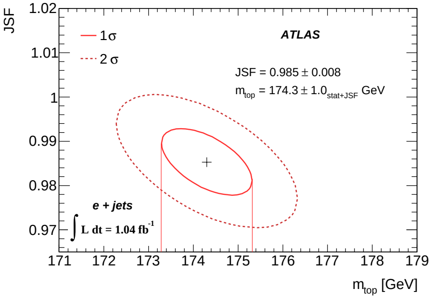
- Test internal consistency of the SM and BSM theories.
- Constrain masses of undiscovered particles in BSM scenarios.

- Selection: lepton+jets from $t\bar{t} \to b\bar{b}l\nu q_1\bar{q}_2$.
- $\sqrt{s} = 7\,\mathrm{TeV}$ at $1.04\,\mathrm{fb}^{-1}$, 2011 data.
- Measure **invariant mass** of decay products, determine top mass using a template method with a likelihood fit.
- MC generated for six different top masses, between 160 and 190 GeV.
- **2d analysis**, optimizing top mass and the JSF simultaneously.

Eur.Phys.J. C72 (2012) 2046, arXiv 1203.5755

Top quark mass (2)





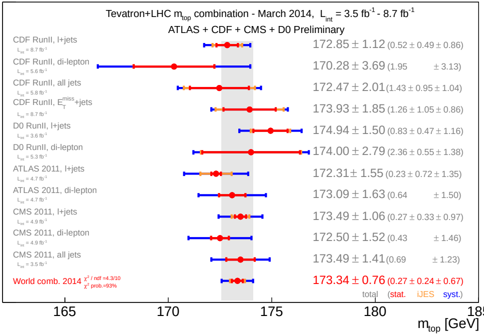
Results

- $m_t = 174.5 \pm 0.6 \pm 2.3\,\mathrm{GeV}$.
- Statistically as precise as Tevatron combined measurement of $m_t = 173.2 \pm 0.6_{\mathrm{stat}} \pm 0.8_{\mathrm{syst}}\,\mathrm{GeV}$, larger **systematic uncertainty**.
- Largest systematic uncertainties: JES and QCD modelling.

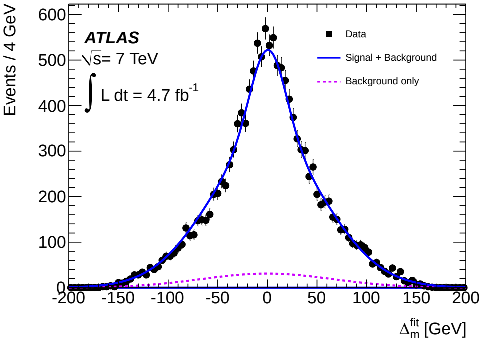
Top quark mass: combination

- First combination of LHC (ATLAS+CMS) and Tevatron (CDF+D0) for the top quark mass.
- Final states: $t\bar{t} \rightarrow$lepton+jets, $t\bar{t} \rightarrow$ dilepton, $t\bar{t} \rightarrow$ jets, $t\bar{t} \rightarrow E_{\mathrm{T}}^{\mathrm{miss}}$.
- Preliminary **results**: $m_t = 173.34 \pm 0.27_{\mathrm{stat}} \pm 0.71_{\mathrm{syst}}\ \mathrm{GeV}$.

ATLAS-CONF-2014-008



- First ATLAS measurement of $\Delta m = m(t) - m(\bar{t})$.
- By **CPT invariance**, $\Delta m = 0$, condition for a local field theory.
- Selection: lepton+jets from a $t\bar{t}$ decay.
- 15 samples simulated with $\Delta m : [-15, 15]\,\mathrm{GeV}$, $\frac{m_t + m_{\bar{t}}}{2} = 172.5\,\mathrm{GeV}$.
- Results: $\Delta m = 0.67 \pm 0.61_{\mathrm{stat}} \pm 0.41_{\mathrm{syst}}\,\mathrm{GeV}$, consistent with SM.

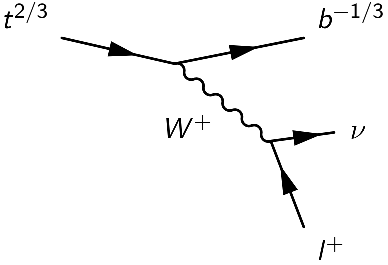


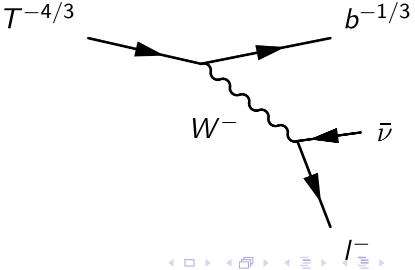
Physics Letters B 728C (2014), pp. 363-379, arXiv 1310.6527

Top Quark Charge

- Test whether the **charge** Q of the top quark is $2/3\,e$ (SM) or $-4/3\,e$.
- Data taken at $2.05\,\mathrm{fb}^{-1}$ and $\sqrt{s} = 7\,\mathrm{TeV}$.
- Selection: $t\bar{t}$ with a single charged lepton, $t\bar{t} \to l^{\pm}\nu jjbb$.
- SM top can decay to l^{+}, $b^{-1/3}$, an exotic T to l^{-}, $b^{-1/3}$.
- Results: $Q = 0.64 \pm 0.02_{\mathrm{stat}} \pm 0.08_{\mathrm{syst}}\,e$. $Q = -4/3\,e$ excluded at 8σ.

JHEP11(2013)031, arXiv 1307.4568





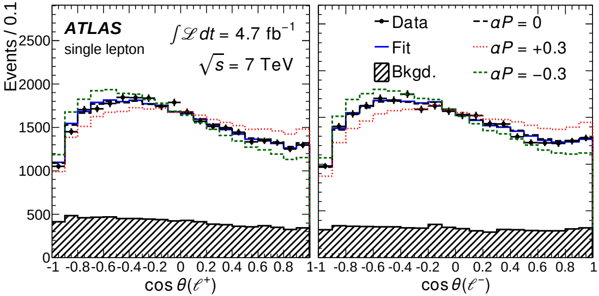
Top polarization

- CP conservation of the strong force results in negligible longtitudional polarization of $t\bar{t}$ pairs. Small contribution from weak processes.
- Some BSM theories predict enhanced polarization.
- Measure spin state using **angular distributions** of the decay products.
- Data taken at $\sqrt{s} = 7\,\mathrm{TeV}$, $L = 4.66\,\mathrm{fb}^{-1}$.
- Final states: one or two isolated leptons + jets.

Phys. Rev. Lett 111, 232002 (2013), arXiv: 1307.6511

Top polarization (2)

- Measure $\alpha_l P$: leptonic spin analyzing power x top polarization.
- $\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta_1 \mathrm{d}\cos\theta_2} = \frac{1}{4}(1 + \alpha_1 P_1 \cos\theta_1 + \alpha_2 P_2 \cos\theta_2 - C\cos\theta_1\cos\theta_2)$
- Two measurements under the hyptoheses: polarization caused by CP conserving or maximally CP violating processes.
- $\alpha_l P_{\mathrm{CPC}} = -0.035 \pm 0.014 \pm 0.037$, $\alpha_l P_{\mathrm{CPV}} = 0.020 \pm 0.016^{+0.013}_{-0.017}$.
- Agreement with SM prediction: top polarization compatible with zero.

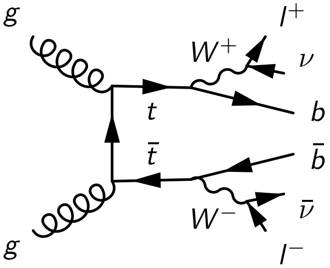


Spin correlation (1)

- The **spin correlation** in $t\bar{t}$ pairs is measured.
- Measurement at $L = 2.1\,\mathrm{fb}^{-1}$, $\sqrt{s} = 7\,\mathrm{TeV}$.
- Selection: 2 leptons, 2 jets and missing E_T, targeting $t\bar{t} \to W^+W^-b\bar{b} \to l^+\nu l^-\bar{\nu}b\bar{b}$.

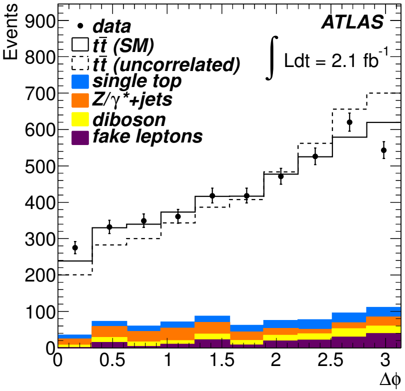
- At low invariant mass, $t\bar{t}$ is produced from gluons with like helicity
- Predicted spin correlation in $t\bar{t}$ pairs.
- No top hadronization - spin **transferred** to **decay products**, measured in l^+l^-.

Phys. Rev. Lett. 108, 212001 (2012), arXiv:1203.4081



Spin correlation (2)

- Spin correlation:
  $A = (N_{\uparrow\uparrow,\downarrow\downarrow} - N_{\uparrow\downarrow,\downarrow\uparrow})/N_{tot}$
- Two hypotheses: A_{SM}, $A = 0$.
- BSM process that could reduce spin correlation: $t \to H^+ b$.
- A is extracted from **angular distribution** $\Delta\phi$ of lepton pairs using fits to templates.
- Correlation measure f, with $f = 1$ being the SM prediction.



Results

- $f_{SM} = 1.30 \pm 0.14_{stat}$, $A_{\textbf{helicity}} = 0.40^{+0.09}_{-0.08}$.
- Results are compatible with SM $A^{SM}_{helicity} = 0.31$.
- 0 spin correlation hypothesis excluded at 5.1σ.

Charge asymmetry

- Motivation: test QCD. Probe BSM processes with anomalous vector or axial-vector couplings.
- SM asymmetry sources: interference of gluon emission state at NLO in $q\bar{q}g \rightarrow t\bar{t}g$ + interference of tree and box diagrams.
- Shown in pseudorapidity η distribution of $t\bar{t}$.

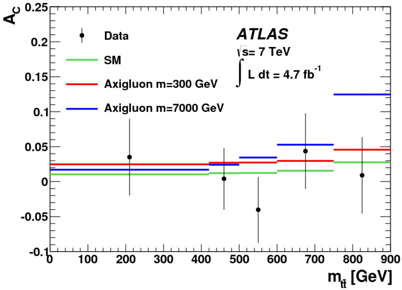
The measurement

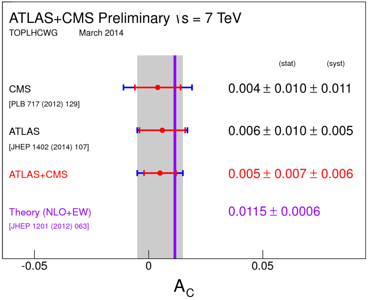
- Data taken at $\sqrt{s} = 7\,\mathrm{TeV}$, $L = 4.7\,\mathrm{fb}^{-1}$.
- Selection: 1 lepton, $\geq$4 jets, one b-tag and large missing transverse momentum.

JHEP02(2014)107, arXiv 1311.6724

Charge asymmetry (2)

- SM prediction at the LHC: $AC_{SM} = 0.0123 \pm 0.0005$.
- Results: $AC = 0.006 \pm 0.010$, consistent with the SM prediction.





- Combination of ATLAS+CMS. Preliminary results: $0.005 \pm 0.007 \pm 0.006$, in agreement with the SM.

Conclusions

- Top properties have been measured at ATLAS in $\sqrt{s} = 7\,\mathrm{TeV}$ data.
- Measurements of the top mass, charge and polarization were presented as well as spin correlation in $t\bar{t}$ pairs the charge asymmetry and the mass difference between t and $\bar{t}$.
- No inconsistencies with the SM were found.
- Several BSM scenarios excluded, such as $Q = -4/3e$ and 0 spin correlation i $t\bar{t}$ pairs.
- The Standard Model prevails.