Top Quark Property Measurements with ATLAS

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for the ATLAS Collaboration

Les Rencontres de
Physique de la
Vallée d'Aoste

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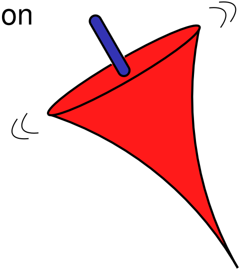


The top quark

- Top quark is an outlier in the Standard Model
- Heaviest fundamental particle – $m_t > 170$ GeV
- Lone quark – lifetime $< 10^{-24}$ s
- Strong potential to be tied to new physics
- Properties measurements are key tests of the Standard Model
- Can be used as indirect and direct searches for new physics

Top properties

Measure:

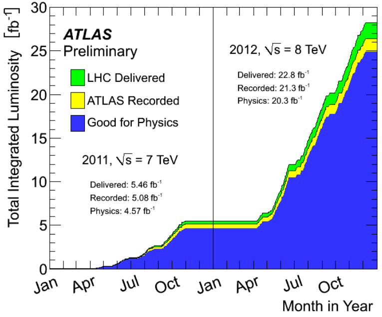
- Mass
- Charge
- Production asymmetries
- Spin

- Properties measureable through decay of the top
- Recent focus on expanding measurements:
  - Complementary measurements
  - Extra observables
  - Examination of new physics models

Data sets

Year	Energy	Luminosity	Total $t\bar{t}$
2011	7 TeV	5 fb^{-1}	850k
2012	8 TeV	20 fb^{-1}	5M

- New results with both 7 and 8 TeV data
- Depend on well understood systematic uncertainties

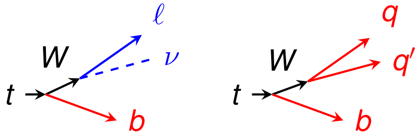


Luminosity summary on atlas.web.cern.ch

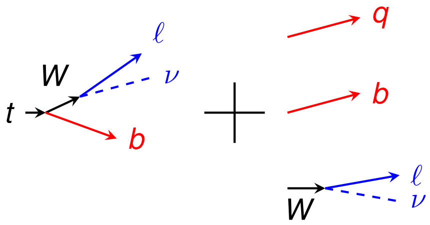
Analysis channels

- $t\bar{t}$ channels
  - Dilepton ($\approx 1/9$)
  - Lepton+jets ($\approx 4/9$)
  - All-hadronic ($\approx 4/9$)

Choose two:



- Single top:
  - *t*-channel
  - *s*-channel
  - *Wt*



Reconstruction

- Many $t\bar{t}$ measurements require full reconstruction:
  - Four-momentum of both top quarks
  - Four-momentum of all daughter particles
- Have to solve for:
  - Momentum of unmeasured neutrinos
  - Assignment of jets to top decay quarks
- Dilepton channel more challenging
- Mass constraints for t and W commonly used

Some different strategies:

- Simple jet choice algorithm
- Kinematic likelihood fit with floating energies
- Dilepton neutrino weighting – test many different η_ν pair hypotheses

Charge asymmetry

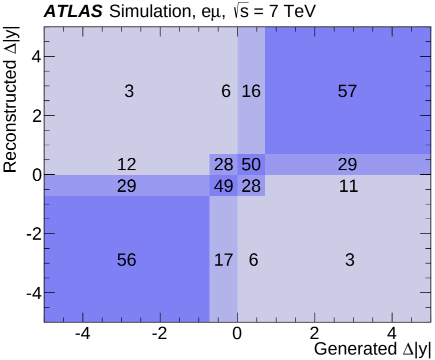
- Measure if top quark is produced more forward than antitop
- Dilepton channel allows lepton-based asymmetry
- Unfold reconstructed distribution to measure asymmetry

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

$$A_C^{\ell\ell} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| > 0) + N(\Delta|\eta| < 0)}, \qquad \Delta|\eta| = |\eta_{\ell+}| - |\eta_{\ell-}|$$

Unfolding

- Correct reconstructed spectrum for detector response and acceptance
- "Invert" the response matrix with regularization to control statistical fluctuations

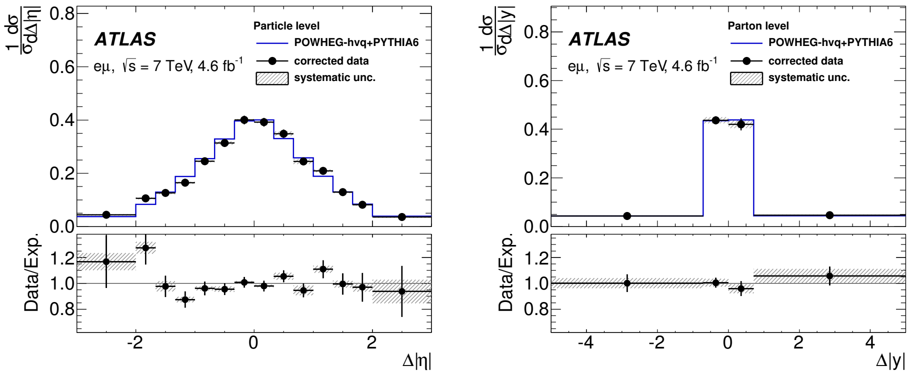


Some methods:

- Bin-by-bin correction
- Singular Value Decomposition (SVD)
- Fully Bayesian Unfolding (FBU)

Charge asymmetry distributions

- Unfolded distributions:

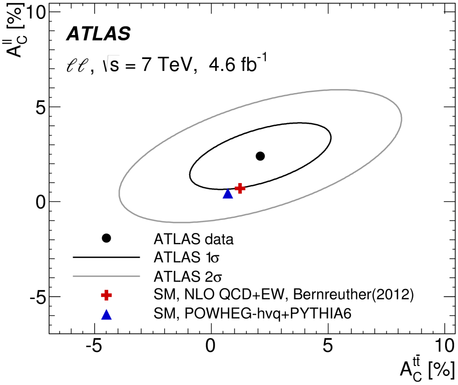


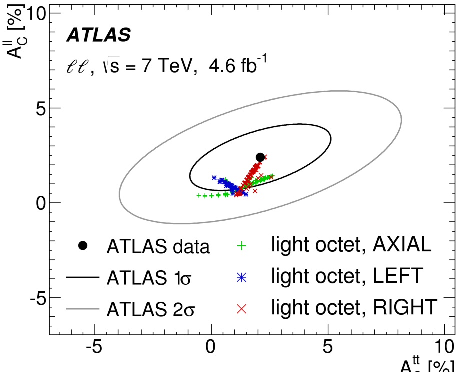
arXiv:1501.07383, submitted to JHEP

Charge asymmetry result

$$A_C^{\ell\ell} = 0.024 \pm 0.015(\text{stat.}) \pm 0.009(\text{syst.})$$
$$A_C^{t\bar{t}} = 0.021 \pm 0.025(\text{stat.}) \pm 0.017(\text{syst.})$$

- Compare to SM and new physics models like a light color octet:





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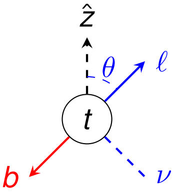
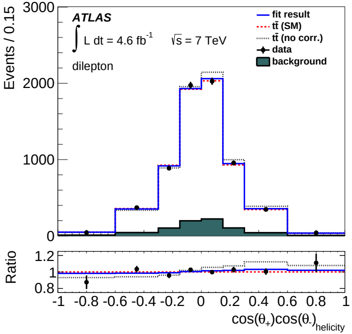
Spin correlation overview

- Spins in $t\bar{t}$ are correlated
- Changes angular distribution of daughter pairs:

$$\frac{d\sigma}{d\cos\theta_1 \, d\cos\theta_2} \propto 1 - A\alpha_1\alpha_2 \cos\theta_1 \cos\theta_2$$



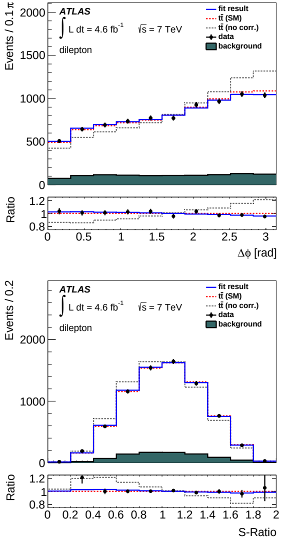
- $\alpha = 1$ for charged leptons
- SM predicts correlation $A \approx 0.3$ in helicity basis



Phys. Rev. D. 90, 112016 (2014)

Spin correlation at 7 TeV

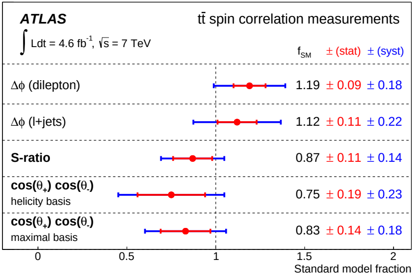
- Expand with four observables that depend in different ways on underlying C and P even correlations:
  - $\Delta\phi$
  - S-ratio
  - $\cos\theta_+ \cos\theta_-$ in helicity
  - $\cos\theta_+ \cos\theta_-$ in "maximal"
- Include lepton+jets for $\Delta\phi$ (between ℓ and b-jet or down-type jet)



Phys. Rev. D. 90, 112016 (2014)

Spin correlation results

- Results in terms of "Standard Model fraction"
- 1 = Standard Model value,
  0 = no correlation



- Can directly extract A from $\cos\theta_+ \cos\theta_-$ for that basis

Comparison with Standard Model:

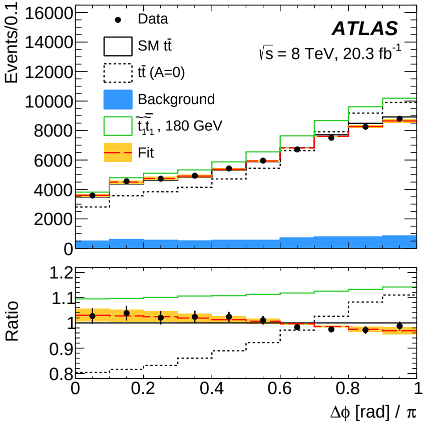
$$A_{\text{helicity}} = 0.23 \pm 0.09 \qquad A^{\text{SM}}_{\text{helicity}} = 0.31$$

$$A_{\text{maximal}} = 0.37 \pm 0.10 \qquad A^{\text{SM}}_{\text{maximal}} = 0.44$$

Phys. Rev. D. 90, 112016 (2014)

Spin correlation and stops

- $\Delta\phi$ measurement at 8 TeV
- Supersymmetric top squark pair production can look like $t\bar{t}$ when $m_{\tilde{t}}$ close to m_t
- Spin correlation of $t\bar{t}$ will be different
- Measure spin correlation and set limit on stop production



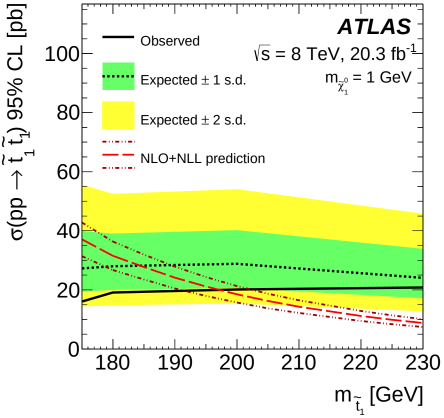
$$f_{\rm SM} = 1.2 \pm 0.05({\rm stat.}) \pm 0.13({\rm syst.})$$

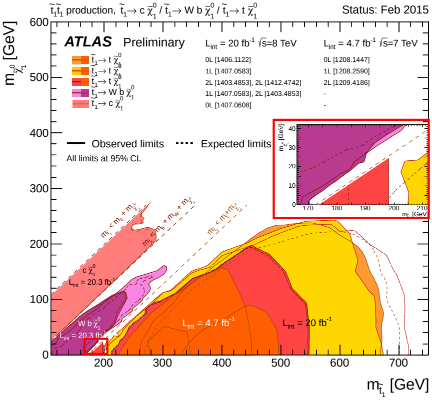
$$A_{\rm helicity} = 0.38 \pm 0.04 \qquad A^{\rm SM}_{\rm helicity} = 0.318$$

arXiv:1412.4742, submitted to PRL

Stop exclusion

- Exclude region out of reach for standard searches





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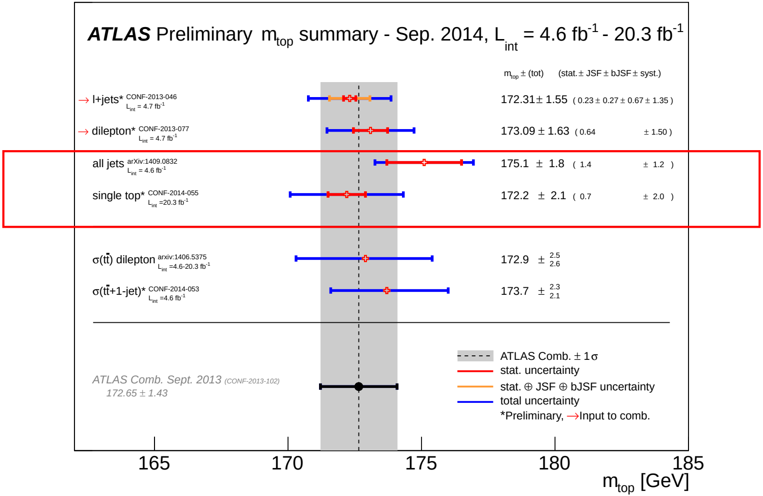
ATLAS SUSY summary plot on atlas.web.cern.ch

Top quark mass

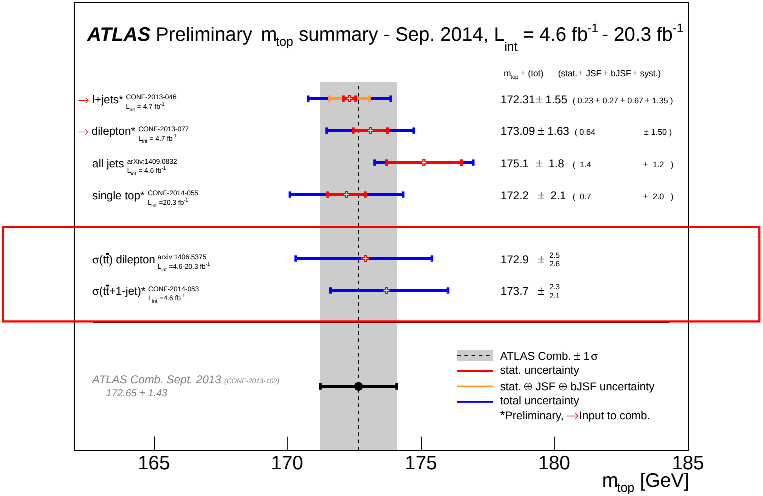
- Complement with new channels
- Pole mass



ATLAS top summary plot on atlas.web.cern.ch

Top quark mass

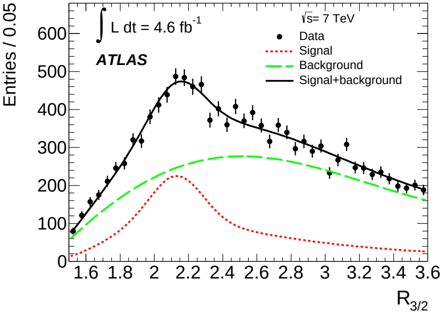
- Complement with new channels
- Pole mass



ATLAS top summary plot on atlas.web.cern.ch

All hadronic mass

- Use ratio of the 3-jet (t) to 2-jet (W) mass
- Estimate of large multi-jet background essential
- Template fit to extract m_t

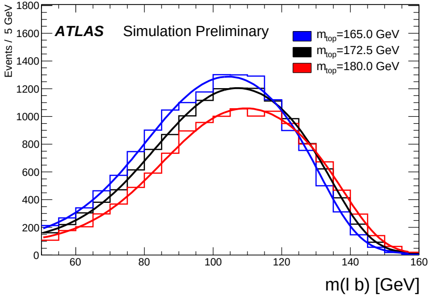


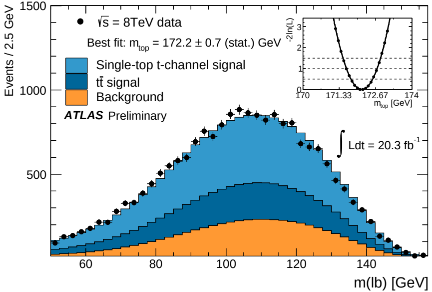
$$m_t = 175.1 \pm 1.4(\text{stat.}) \pm 1.2(\text{syst.})$$

arXiv:1409.0832. submitted to EPJC

Single top mass

- Single top t-channel complementary to $t\bar{t}$ measurements
- Template fit of mass of ℓ and b to extract m_t





$$m_t = 172.2 \pm 0.7(\text{stat.}) \pm 2.0(\text{syst.})\ \text{GeV}$$

ATLAS-CONF-2014-055

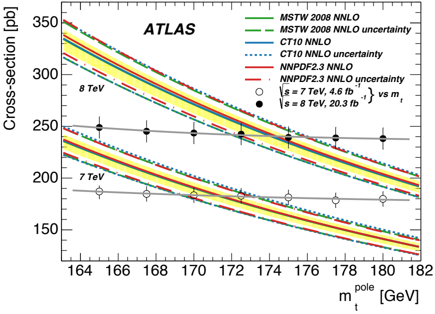
Pole mass measurements

- Directly measured mass theoretically unclear
- May differ from pole mass by $\mathcal{O}(1\text{GeV})$
- Can measure m_t^{pole} from production measurements

Using $e\mu$ dilepton channel cross section:

$$m_t^{\text{pole}} = 172.9^{+2.5}_{-2.6}\ \text{GeV}$$

- Theory uncertainty $\approx$ 2 GeV



Eur.Phys.J. C74 (2014) 3109

$t\bar{t}$+jet pole mass

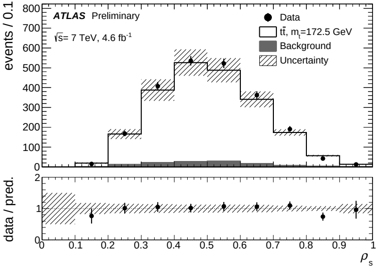
- Dependence of $t\bar{t}$+jet cross section on invariant mass:

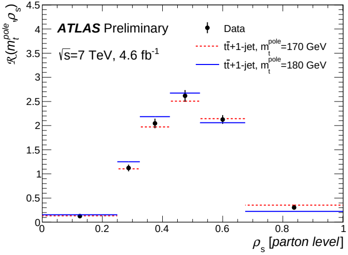
$$\rho_s = \frac{2 \cdot 170\ \text{GeV}}{\sqrt{s_{t\bar{t}j}}}$$

Unfold and extract:

$$m_t^{\text{pole}} = 173.7^{+2.3}_{-2.1}\ \text{GeV}$$

- Theory uncertainty $^{+1}_{-0.5}$ GeV





ATLAS-CONF-2014-053

Conclusions

- Top properties are an important probe of potential new physics
- ATLAS producing new results with 7 and 8 TeV data:
    - Complement previous analyses
    - Expand scope with new observables
- Are in agreement with Standard Model predictions
- Using properties measurements to constrain specific new physics models:
    - SUSY stops
    - New colored bosons
- For all the latest results see this page

Backup

Spin correlation observables

S-Ratio

- Ratio of matrix elements of like-helicity gluon fusion with spin correlation to without correlation

$$S = \frac{\left(|\mathcal{M}|^2_{\mathrm{RR}} + |\mathcal{M}|^2_{\mathrm{LL}}\right)_{\mathrm{corr}}}{\left(|\mathcal{M}|^2_{\mathrm{RR}} + |\mathcal{M}|^2_{\mathrm{LL}}\right)_{\mathrm{uncorr}}} = \frac{m_t^2\left[(t \cdot \ell^+)(t \cdot \ell^-) + (\bar{t} \cdot \ell^+)(\bar{t} \cdot \ell^-) - m_t^2(\ell^+ \cdot \ell^-)\right]}{(t \cdot \ell^+)(\bar{t} \cdot \ell^-)(t \cdot \bar{t})}$$

Maximal basis

- Choose an axis event-by-event to maximize correlation for *gg* fusion
- Choose eigenvector of largest eigenvalue of correlation matrix derived from beam direction and top momentum
- More info in P. Uwer, Phys. Lett. B 609, 271 (2005)