Measurement of the top quark polarization and $t\bar{t}$ spin correlations using dilepton final states in proton-proton collisions at $\sqrt{s}$ = 13 TeV

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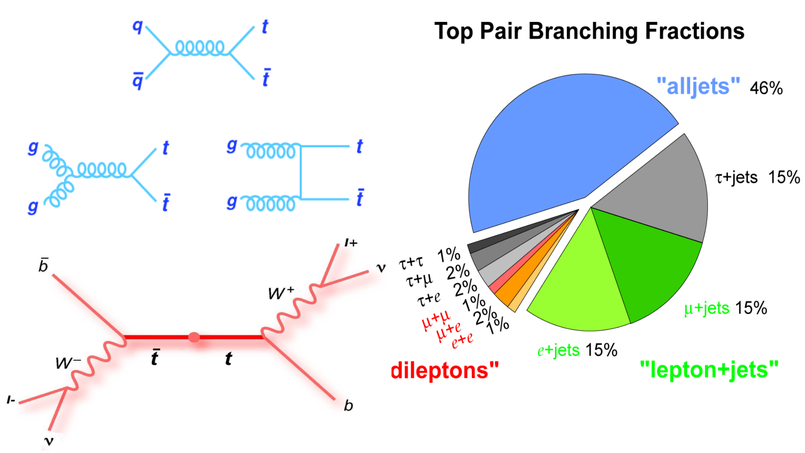
Abstract

Measurements of the top quark polarization and top quark pair ($t\bar{t}$) spin correlations are presented using events containing two oppositely charged leptons (e^+e^-, $e^\pm\mu^\pm$, or $\mu^+\mu^-$) produced in proton-proton collisions at a center-of-mass energy of 13 TeV. The data were recorded by the CMS experiment at the LHC in 2016 and correspond to an integrated luminosity of 35.9 fb^{-1}. A set of parton-level normalized differential cross sections, sensitive to each of the independent coefficients of the spin-dependent parts of the $t\bar{t}$ production density matrix, is measured for the first time at 13 TeV. The measured distributions and extracted coefficients are compared with standard model predictions from simulations at next-to-leading-order (NLO) accuracy in quantum chromodynamics (QCD), and from NLO QCD calculations including electroweak corrections. All measurements are found to be consistent with the expectations of the standard model.

Introduction

The top quark is the heaviest fundamental particle. In the SM, the $t\bar{t}$ pairs are unpolarized but their spins are correlated. The top quark decays before hadronization and its spin information is transferred to its decay products. The precise measurement of polarization of top quark and its spin information provide insights for new physics searches.

$$\underbrace{\frac{1}{m_t}}_{\substack{\text{production}\\ 10^{-27}\ \text{s}}} < \underbrace{\frac{1}{\Gamma_t}}_{\substack{\text{lifetime}\\ 10^{-25}\ \text{s}}} < \underbrace{\frac{1}{\Lambda_{QCD}}}_{\substack{\text{hadronization}\\ 10^{-24}\ \text{s}}} < \underbrace{\frac{m_t}{\Lambda^2}}_{\substack{\text{spin-flip}\\ 10^{-21}\ \text{s}}}$$

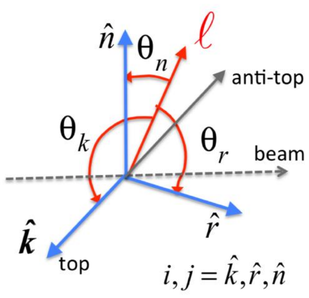


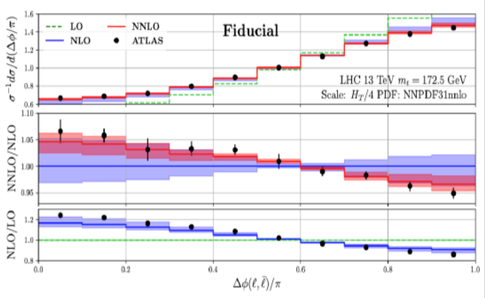
$$|\mathcal{M}(q\bar{q}/gg \to t\bar{t} \to (\ell^+\nu b)(\ell^-\bar{\nu}\bar{b}))|^2$$

$\rho / \bar{\rho}$: top decay density matrices

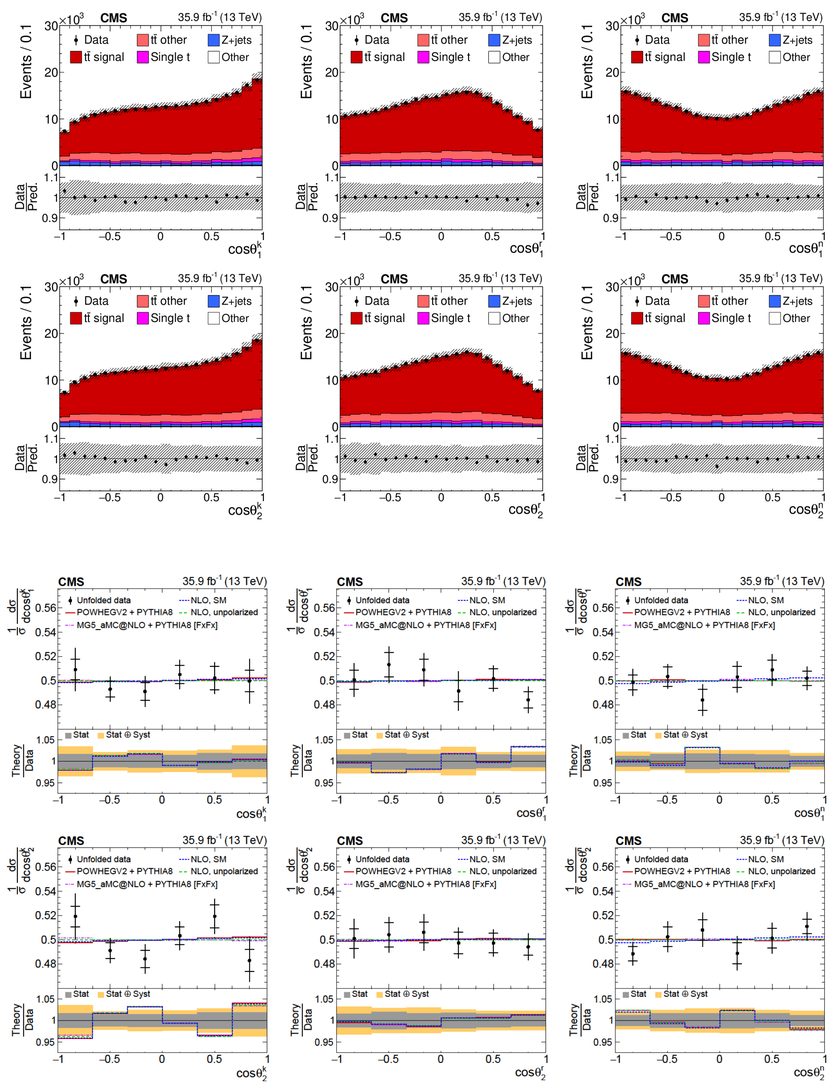
R : Spin density matrix

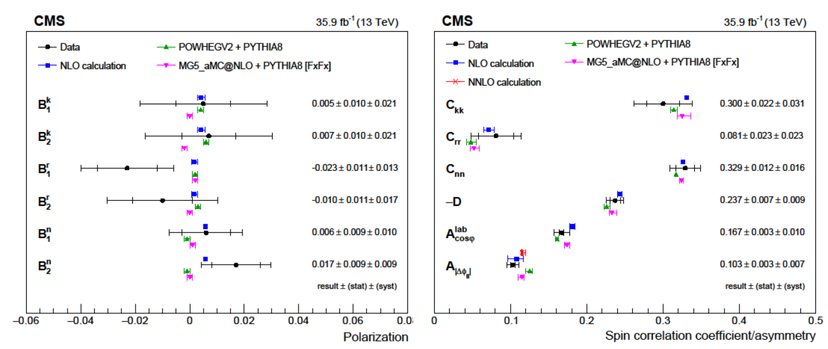
$$R \propto \Big[\underbrace{\tilde{A}\,\mathbb{I}\otimes\mathbb{I}}_{\substack{\text{total cross-section}\\ \text{and top kinematics}}} + \underbrace{\tilde{B}_i^+\,\sigma^i\otimes\mathbb{I} + \tilde{B}_i^-\,\mathbb{I}\otimes\sigma^i}_{\substack{\text{3 – vectors of functions}\\ \text{characterizing } t\bar{t} \text{ polarization}\\ \text{along each axis}}} + \underbrace{\tilde{C}_{ij}\,\sigma^i\otimes\sigma^j}_{\substack{\text{3x3 matrix of functions}\\ \text{characterizing spin}\\ \text{correlation of } t\bar{t}}}\Big]$$

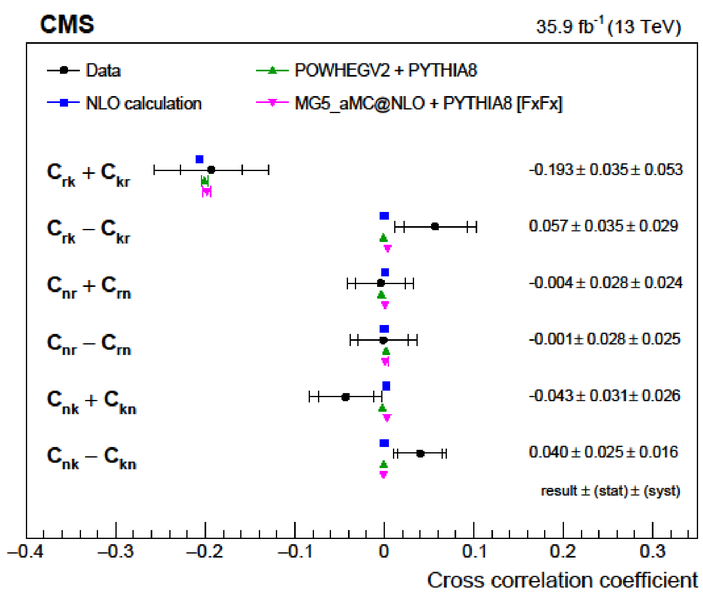




Measurements



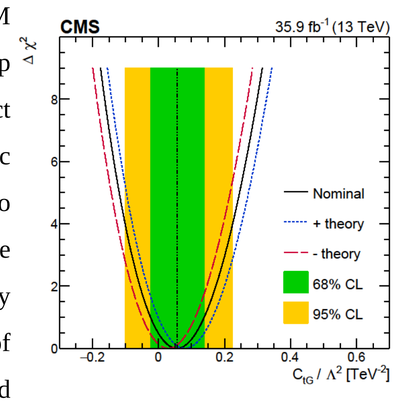


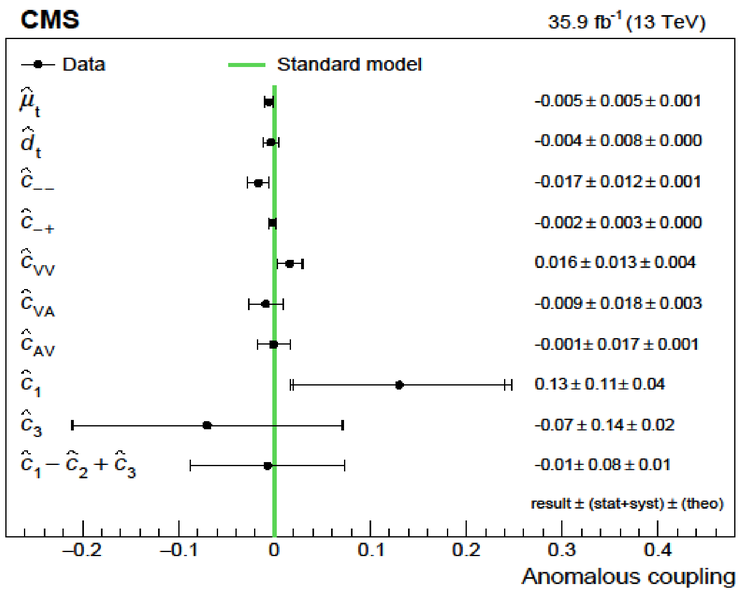


Measured values of polarization, spin correlation, cross spin correlation and asymmetries are compared with predictions of MC simulations. The inner vertical bars on the circles give the statistical uncertainty in the data and the outer bars the total uncertainty. The vertical bars on the values from simulation represent the combination of statistical and scale uncertainties, while for the calculated values they represent the scale uncertainties.

EFT Interpretation

Several BSM models, such as 2HDM (e.g., SUSY), technicolor and top quark compositeness models predict an anomalous chrome magnetic dipole moment (CMDM), leading to modifications of the $t\bar{t}$ production rate and spin structure. The spin density matrix represents a powerful probe of the top quark CMDM and can be used to search for BSM phenomena.





Measured values of and uncertainties in the fitted anomalous couplings, assuming other anomalous couplings to be zero. The first and second quoted uncertainties are from experimental (statistical and systematic, at 68% CL) and theoretical sources, respectively, and are shown by the vertical line.

Conclusion

The measured normalized differential cross sections and coefficients were compared with standard model predictions from simulations with next-to-leading order (NLO) accuracy in quantum chromodynamics (QCD) and from NLO QCD calculations including electroweak corrections. All of the measurements were found to be consistent with the expectations of the standard model. The normalized differential cross sections are used in fits to constrain the anomalous chromomagnetic and chromoelectric dipole moments of the top quark to $-0.24 < C_{tG}/\Lambda^2 < 0.07$ TeV^{-2} and $-0.33 < C^I_{tG}/\Lambda^2 < 0.20$ TeV^{-2}, respectively, at 95% confidence level.

References

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