

The Quantum Life of the Top Quark: Spin, Entanglement, and quasi-bound states

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The Large Hadron Collider at CERN provides proton-proton collisions at unprecedented center-of-mass energies and is a top quark factory. Lately, the top–antitop quark ($t\bar{t}$) production region has gained significant attention as a unique laboratory for short-distance quantum chromodynamic (QCD) dynamics. In this regime, QCD gives rise to threshold enhancements, i.e. it allows for the formation of a short-lived quasi-bound state: toponium. A sensitive probe and hence, an indicator of such near-threshold effects are observables aimed at measuring spin correlations between the top and the anti-top quark. In practice, measuring correlated angular distributions provides an experimentally accessible way to quantify entanglement and reveal how threshold QCD dynamics shape the coherence of the $t\bar{t}$ system especially to the formation of a pseudo-scalar ground-state of the quasi-bound state toponium spectra. Recent measurements by the CMS collaboration have not only confirmed entanglement in $t\bar{t}$ production seen earlier at threshold by the ATLAS collaboration, but also – for the first time – CMS observed a pseudo-scalar excess at the top quark pair production threshold challenging the current understanding of the theoretical modeling in top quark production. Precision studies in the $t\bar{t}$ production region provide a window into the inner workings of the Standard Model, and moreover provide exciting new probes connected to quantum information science. The talk concludes with an outlook on LHC perspectives into the future including prospects at other proposed future colliders.