Quantum information with top quarks at the LHC

Juan Ramón Muñoz de Nova[1] and Yoav Afik[2]

[1]*Departamento de Física de Materiales, Universidad Complutense de Madrid, Ciudad Universitaria 28040, Madrid, Spain*
[2]*Experimental Physics Department, CERN, 1211 Geneva, Switzerland*

Entanglement is a central subject in quantum mechanics. Due to their genuine relativistic behavior, the exotic character of the interactions and symmetries involved, as well as their fundamental nature, high-energy colliders are attractive systems for the experimental study of quantum information. In particular, top quarks represent unique high-energy systems since their spin correlations can be measured. However, so far, no link between top spin correlations and entanglement has been discussed at the literature. We propose the detection of entanglement between the spins of top–antitop–quark pairs at the LHC [1,2], representing the first proposal of entanglement detection in a pair of quarks, and also the entanglement observation at the highest energy scale so far. We show that entanglement can be observed by direct measurement of the angular separation between the leptons arising from the decay of the top–antitop pair. We analyze the entanglement dependence with the energy of the proton collisions, finding that the detection can be already achieved with high statistical significance using the currently data recorded during Run 2 at the LHC. In addition, we develop a simple protocol for the quantum tomography of the top–antitop pair. This experimental technique reconstructs the quantum state of the system, providing a new experimental tool to test theoretical predictions, as for instance those of New Physics beyond the Standard Model. The explicit implementation of canonical experimental techniques in quantum information in a two-qubit high-energy system paves the way to use high-energy colliders to also study quantum information theory.

[1] Yoav Afik, Juan Ramón Muñoz de Nova, The European Physical Journal Plus 136, 907 (2021).

[2] Yoav Afik, Juan Ramón Muñoz de Nova, arXiv:2203.05582.