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Exploring toponium formation at the LHC

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The top quark, the heaviest known elementary particle ($m_t \approx 172.52$ GeV), plays a crucial role in probing the Standard Model (SM) at high energies. At the Large Hadron Collider (LHC), top quark pair production ($t\bar{t}$) is the dominant mechanism for top production. The top quark predominantly decays to a b-quark and a W^+ boson, the latter of which decays either leptonically or hadronically. The dileptonic decay channel ($pp \to t\bar{t} \to b\bar{b}W^+W^- \to b\bar{b}l^+\nu_l l^-\bar{\nu}_l$, with $l = e, \mu$) provides a clean and sensitive probe of the near-threshold region of $t\bar{t}$ production, where the center-of-mass energy is just sufficient to produce the top pair. This threshold region is especially sensitive to key SM parameters such as the top mass, width, and Yukawa coupling. It also offers a unique opportunity to explore the formation of toponium, a relatively unexplored bound state of a top and anti-top quark. Earlier studies indicated discrepancies between theoretical predictions and experimental data in this region, partly due to the absence of toponium effects in standard perturbative calculations. We present an updated and comprehensive study of toponium-induced corrections to various kinematic distributions, including $m_{t\bar{t}}$ and $\Delta\phi(l\bar{l})$ at next-to-next-to-leading order (NNLO) in QCD. Additionally, we incorporate toponium corrections into 2-D differential observables such as $|\Delta\phi^{e\mu}| : m^{e\mu}$, at next-to-leading order (NLO). This analysis compares the improved predictions, now incorporating toponium effects, to LHC data and includes a systematic assessment of theoretical uncertainties.

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