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Observing true tauonium at colliders

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The bound state of two tau leptons, called ditauonium or true-tauonium $\mathcal{T}$, is the heaviest and also most compact QED atom, and remains unobserved to date. Its study has several motivations such as precisely extracting properties of the tau lepton, carrying out novel tests of SM and its basic CPT symmetries, and searching for BSM effects impacting the tau lepton. We will first discuss the spectroscopic properties of ditauonium, including energy levels and decay channels. A systematic survey of search strategies at present and future lepton and hadron colliders will then be provided. The spin-triplet state, ortho-ditauonium, can be observed at a future super tau-charm factory (STCF) via $e^+e^- \rightarrow \mathcal{T}_1 \rightarrow \mu^+\mu^-$, where a threshold scan with monochromatized beams can also provide a very precise extraction of the tau lepton mass with $\mathcal{O}(25 \text{ keV})$ uncertainty. Observing $pp \rightarrow \mathcal{T}_1(\mu^+\mu^-) + X$ is possible at the LHC by identifying its displaced vertex with a good control of the combinatorial dimuon background. The spin-singlet state, para-ditauonium, will be observable in photon-photon collisions at the FCC-ee via $\gamma\gamma \rightarrow \mathcal{T}_0 \rightarrow \gamma\gamma$.

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