Quantum Time Dilation: A New Test of Relativistic Quantum Physics

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At the intersection of quantum mechanics and relativity lies the possibility for a clock to move along a superposition of two distinct classical trajectories — perhaps these trajectories correspond to different speeds or locations in a gravitational field. It is then natural to ask: what time dilation would such a quantum clock observe? Using covariant time observables described as positive operator valued measures, I will introduce a formulation of relational quantum dynamics that allows for a probabilistic formulation of relativistic time dilation and leads to an uncertainty relation between clock mass and proper time. This framework will then be used to describe quantum time dilation effects that occur when a clock moves in a superposition of different relativistic momenta and is at rest in a spatial superposition of an external gravitational field. I will argue that these quantum time dilation effects may be observable with present-day technology and offer a new test of fundamental physics in the regime where quantum coherence and relativistic effects play an essential role.

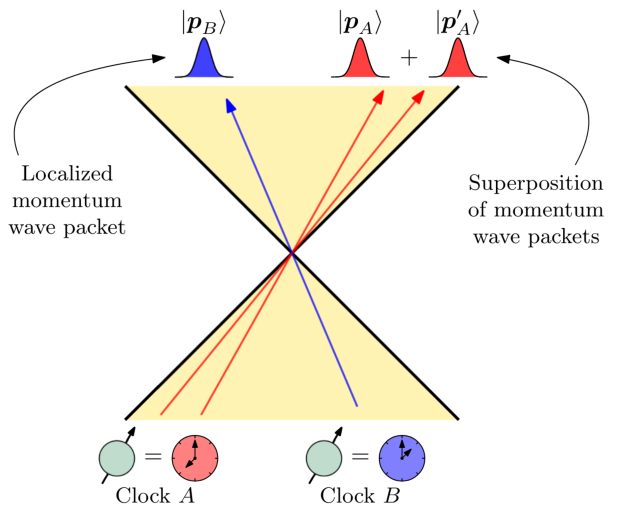

Figure 1: The world lines of clocks A (red) and B (blue) in Minkowski space are depicted. Clock A moves in a superposition of momentum wave packets giving rise to a quantum time dilation effect relative to clock B, which moves in a localized momentum wave packet