Entanglement generation for a spin-squeezed atomic clock on a chip

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Entangled and spin-squeezed states [1] can enable metrology beyond the standard quantum limit (SQL). This fundamental limit is now being reached in state-of-the-art atomic clocks, and it is becoming the limiting noise source of their performances. Spin squeezing is one possible way to mitigate this noise. These states can be produced via quantum non-demolition (QND) measurements of the collective spin states [2]. These measurements can be implemented, for instance, using atom-light interactions in the cavity-QED coupling regime [3]. In addition, QND measurements can also be tailored to remove the dead-time between consecutive measurements, reducing in this way the Dick effect impact on the clock or sensor stability [4]. However, implementing these protocols in metrology-grade platforms is challenging. In our experiment, we have realized a cavity-QED configuration by integrating fiber Fabry-Pérot cavities on the chip [5]. We have thus explore QND measurements and spin-squeezing at a metrologically relevant level of precision for time and frequency measurements, observing spin squeezing lifetime of up to 0.6 s [6]. This significantly relevant lifetime is compatible with typical Ramsey times of state-of-the-art microwave frequency standards. Moreover, in our experiment we also observed an interplay between the spin and the external degree of freedom dynamics of atoms, due to collisions at relatively low temperatures. Remarkably, this spin dynamics produces an effective amplification of the spin differential population determined via cavity transmission measurements [7].

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