Separated entangled ions for sub-picotesla magnetometry

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The creation of entangled states with trapped ions is a well established experimental technique [1]. We create Bell states $\frac{1}{\sqrt{2}}\left(|\uparrow\downarrow\rangle + e^{i\varphi}\,|\downarrow\uparrow\rangle\right)$ consisting of two $^{40}Ca^{+}$ ions stored in a segmented Paul trap, where we separate the ions and move them to any desired positions along the trap axis. As the created Bell states have no net magnetic moment, the accumulated phase φ during a wait time T does not depend on fluctuations of the global ambient magnetic field, but only on the magnetic field difference ΔB between the two ion positions, allowing for precise measurements of inhomogeneous magnetic fields below the noise level of the ambient field. We present magnetic field measurements with accuracies as low as 86 fT and a sensitivity of 2.46 pT/$\sqrt{\text{Hz}}$. To overcome the 2π ambiguity in phase measurements, we employ the Bayesian experimental design method to choose optimal phase accumulation times T [2].

[1] H. Kaufmann et al., Phys. Rev. Lett. 119, 150503 (2017)
[2] T. Ruster et al., Phys. Rev. X 7, 031050 (2017)