Supplementary Information for Manipulation of emergent vortices in swarms of magnetic rollers

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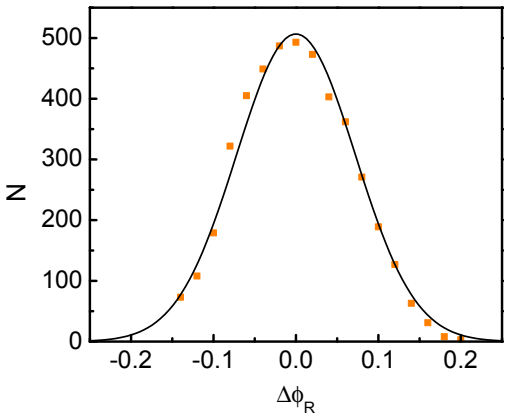
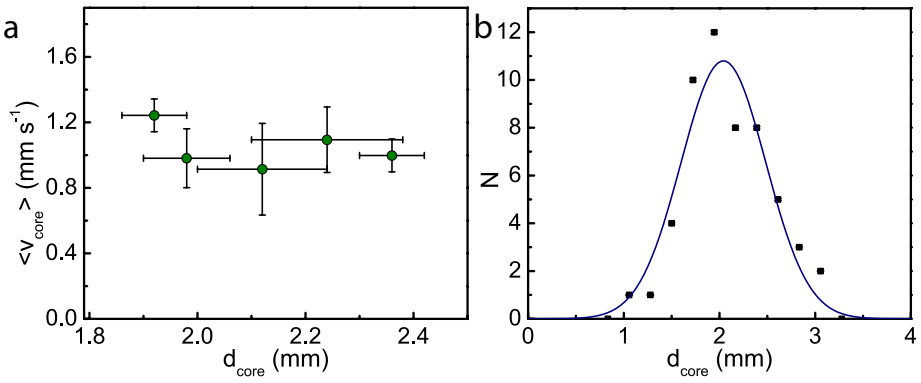
Supplementary Figures



Supplementary Figure 1: Order parameter fluctuations. The probability histogram ($\sum N = 4446$) of order parameter fluctuations $\Delta\phi_{\mathrm{R}}$ displays a normal distribution (the black line is a Gaussian fit).



Supplementary Figure 2: Vortex on a flat surface. **a**, Mean vortex core speed versus roller vortex core diameter. Error bars are the standard deviation of the measurements. **b**, The histogram ($\sum N = 54$) of vortex core diameters d (the blue line is a Gaussian fit) realised on a flat surface.

Supplementary Notes

Supplementary Note 1

The vortex order parameter ϕ_{R} (see main text) fluctuates around a mean value. To characterize these fluctuations we calculate the deviation from the mean value $\Delta\phi_{R_i} = \phi_{R_i} - \frac{1}{N}\sum_{i=1}^{N}\phi_{R_i}$, where i runs over all N vortex realizations. Figure 1 demonstrates the Gaussian distribution of $\Delta\phi_{\mathrm{R}}$. The experiment was carried out in a spherical potential well (radius of curvature 52 mm) with Ni particles (radius $R_{\mathrm{Ni}} = 69\,\mu\mathrm{m}$) subjected to in- and out-of-plane oscillating magnetic field (amplitude $B_0 = 5.78\,\mathrm{mT}$, frequency $f_{\mathrm{B}} = 40\,\mathrm{Hz}$).

Supplementary Note 2

For vortices on a flat surface far from container walls (no confinement) the mean vortex core speed $\langle v_{\mathrm{core}}\rangle$ does not depend on the vortex core diameter d_{core} (Figure 2a), as determined from the peak of radially averaged tangetial velocity (see Figure 1d). The vortex core diameters d_{core} display a wide distribution (Figure 2b). The experiment was carried with Ni particles (radius $R_{\mathrm{Ni}} = 69\,\mu\mathrm{m}$) subjected to in- and out-of-plane oscillating magnetic field (amplitude $B_0 = 5.66\,\mathrm{mT}$, frequency $f_{\mathrm{B}} = 42\,\mathrm{Hz}$).