MENTA

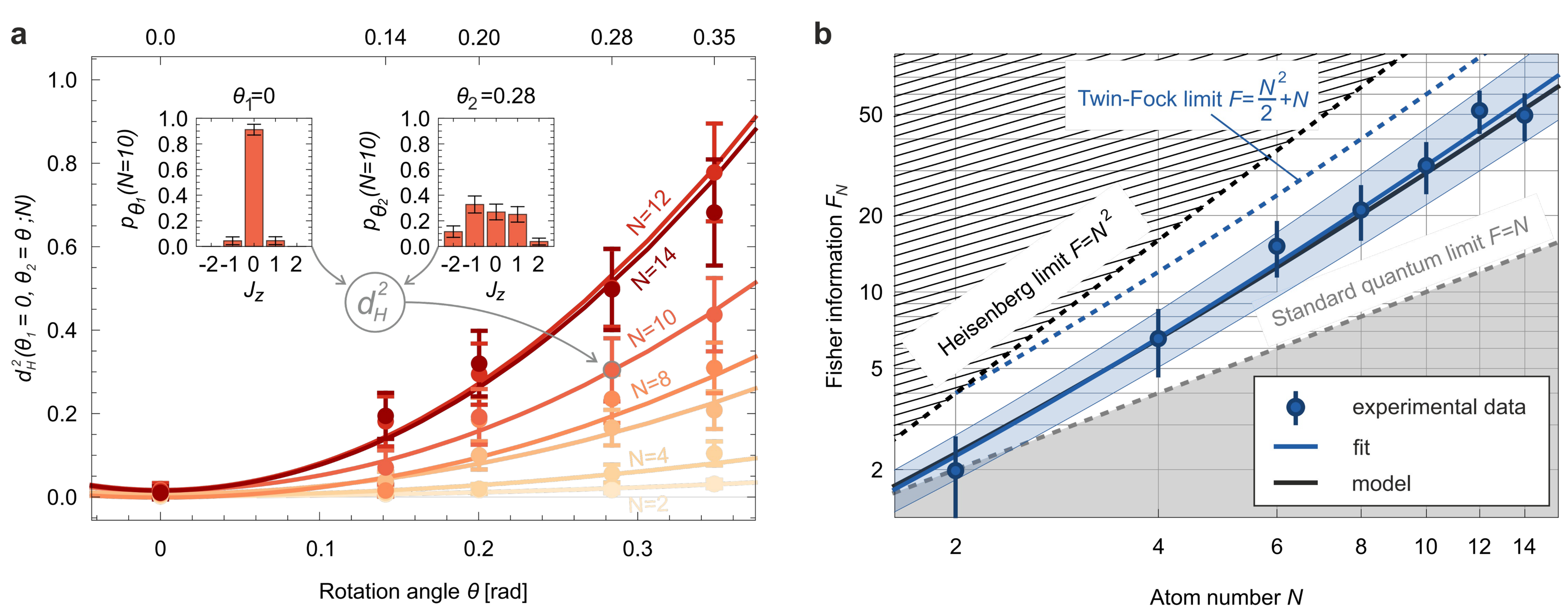
Accessible Quantifiers of Multipartite Entanglement in Atomic Systems

LCF, Palaiseau, France; CNR, Florence Italy; LUH, Hannover, Germany; Univ. of the Basque Country, Bilbao, Spain; TUW, Vienna, Austria

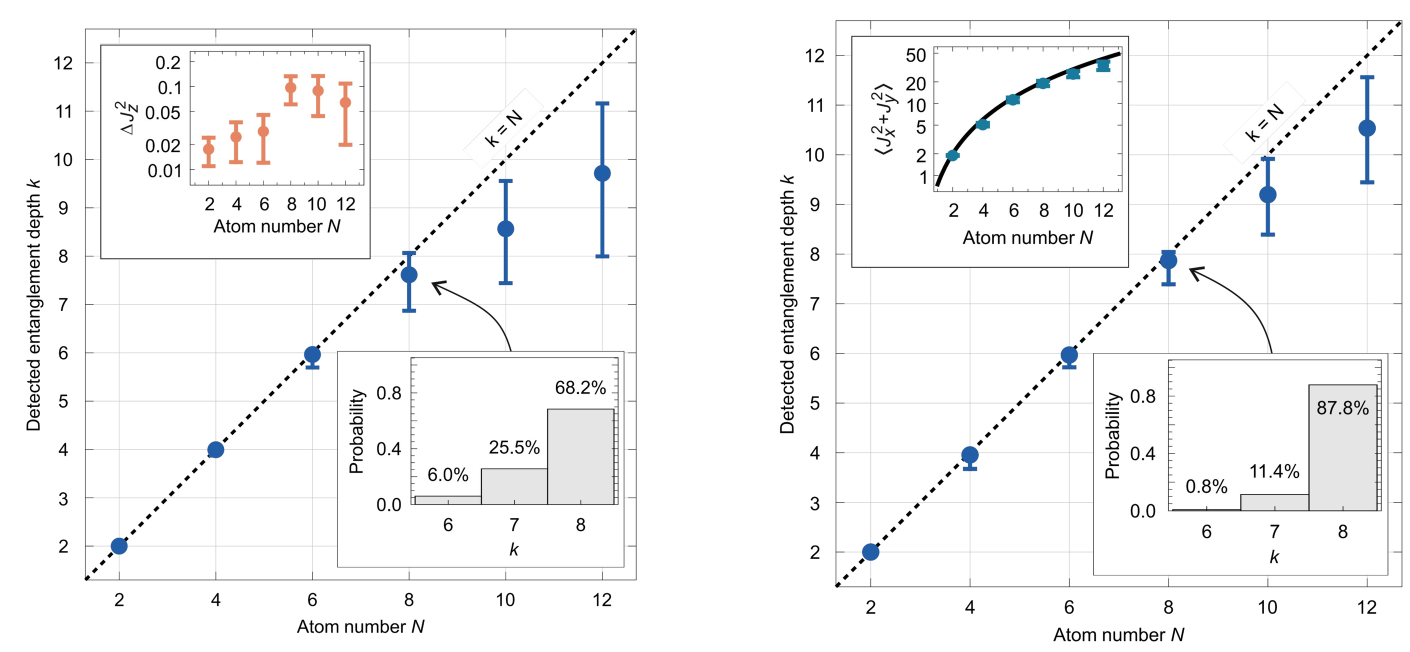
Motivation

The characterization and classification of **multipartite entanglement** is crucial for the investigation of many-body systems, foundational problems and quantum technologies. A central goal is to discover **robust**, **experimentally accessible criteria** to witness and explore the many facets of quantum correlations. Multipartite entanglement provides formidable challenges arising from the exponential increase of the Hilbert space dimension with the number of the quantum system constituents. For instance, the full classification of multipartite entanglement is missing in the literature, and the possibility to witness the classes of entangled states allowing quantum advantages in different quantum information applications is still largely unexplored.

Multipartite Entanglement Concepts (Florence, Bilbao)

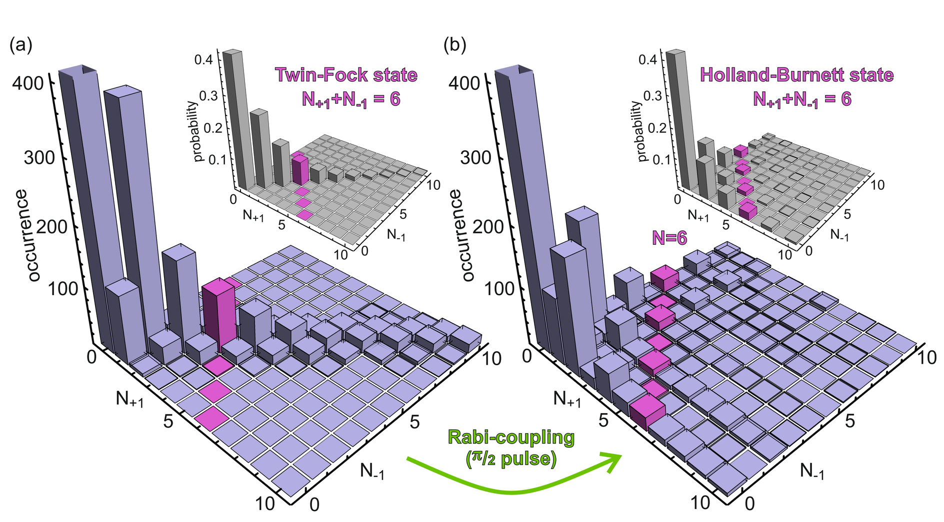


Quantum metrology with Dicke states of two-state atoms, CNR-INO. (a) Probability distributions and Hellinger distance from the initial state for various particle numbers *N*. (b) The **quantum Fisher information**, quantifying the metrological performance of the quantum state, increases rapidly with *N* and demonstrates a Heisenberg scaling.

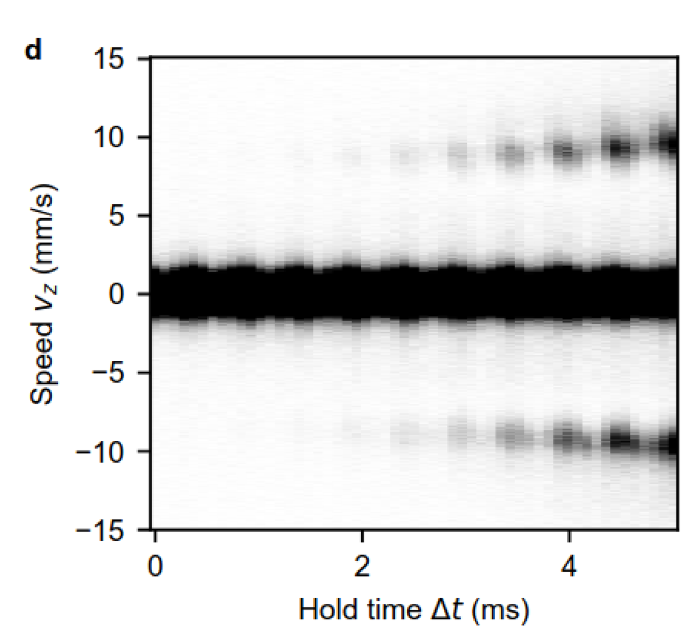


Entanglement in Dicke states realized with up to 12 cold two-state atoms, BILBAO. (a) **Entanglement depth** detected by measuring second-order moments of collective observables. (b) Entanglement depth detected by measuring *N*-partite correlations, requiring **single-particle resolution**. The success of the approach demonstrates the high quality of the prepared quantum state.

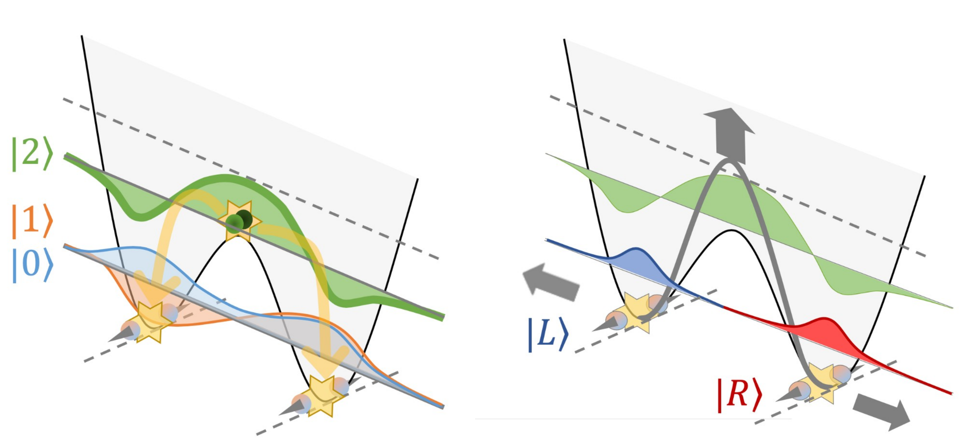
Experimental Platforms (Hannover, Vienna, Palaiseau, Florence)



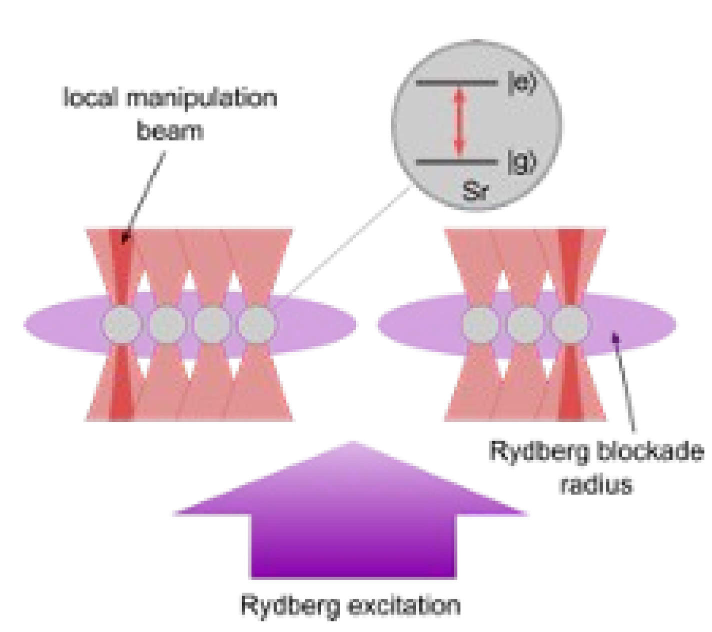
Tomography of the two-mode quantum state at LUH. The Twin-Fock state and the Holland-Burnett state are shown. Demonstrating the absence of odd occupation numbers in the final state is a primary goal of our experiments and requires single-atom-resolved counting.



Entangled phonon pairs at the LCF. The figure shows the time evolution of a BEC whose density is modulated sinusoidally. Slices of the velocity distribution are shown for different durations of modulation. Short modulation times show only a BEC, positioned at $v = 0$. At later times sidebands develop on each side of the BEC. The corresponding phonon modes are entangled in a way analogous to a two mode squeezed state.



Correlated pair production scheme at TUW. Atoms are trapped on an atom chip in a one-dimensional geometry. They are then excited transversely and decay as correlated pairs. Correlations, and entanglement are probed by manipulation of the trapping potential.



Optical tweezer arrays for Sr Rydberg atoms at CNR-INO. Rydberg-based entanglement is created between Sr atoms trapped in optical tweezers within the Rydberg blockade radius. Separated ensembles with variable number of parties are realized.