Two-Particle Four-Mode Interferometer for Atoms (poster)

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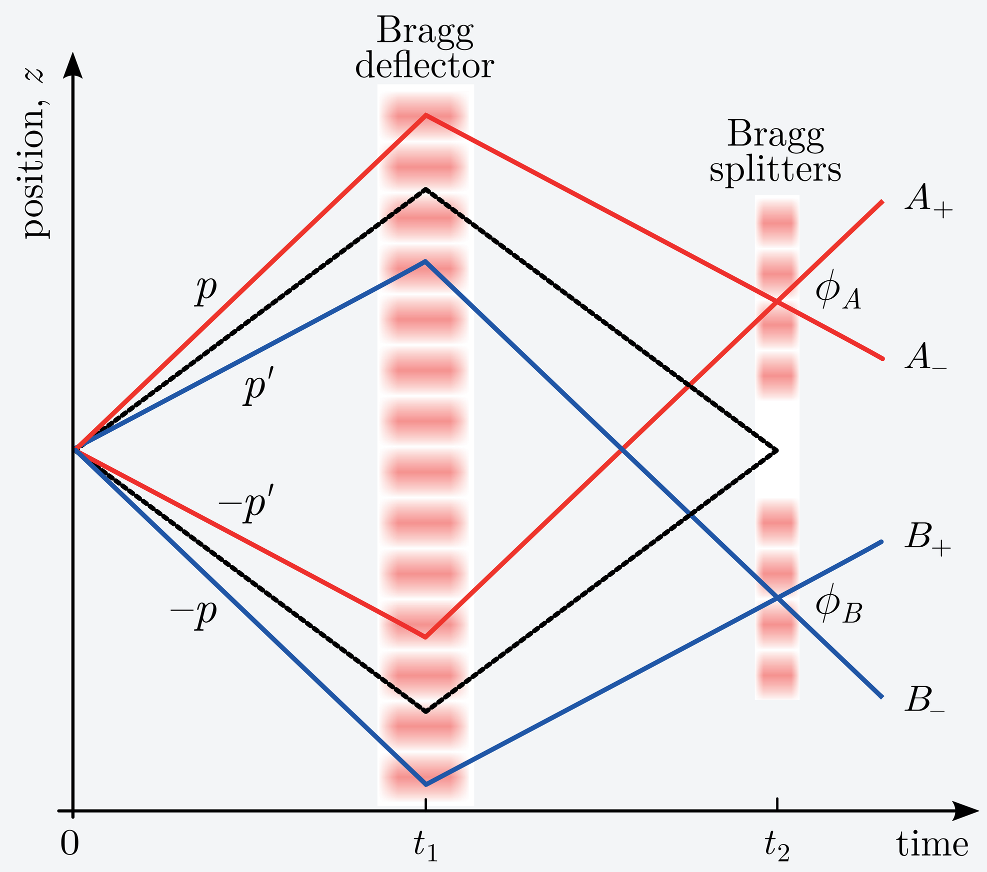
- We present a **free-space interferometer** to observe **two-particle interference of a pair of atoms with entangled momenta**.
- The source of atom pairs is a Bose-Einstein condensate subject to a dynamical instability, and the interferometer is realized using Bragg diffraction on optical lattices.
- **Our observations rule out the possibility of a purely mixed state at the input of the interferometer.**
- **Our current setup can be extended to enable a test of a Bell inequality on momentum observables.**

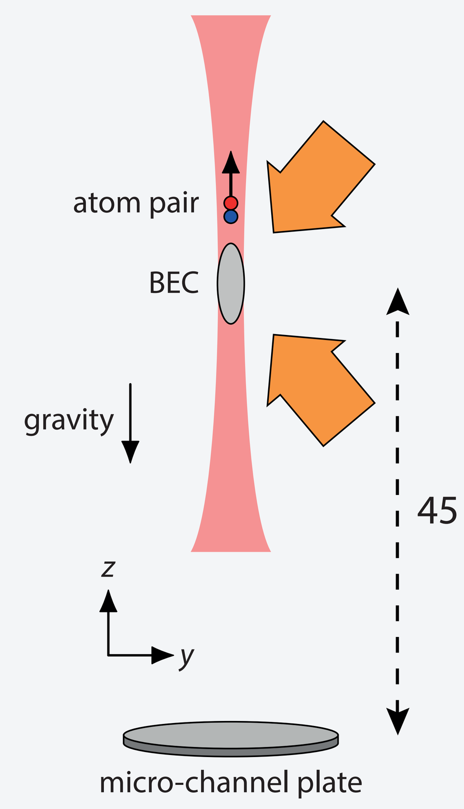
Interferometer diagram

- Input state:
  $|\Psi\rangle = \frac{1}{\sqrt{2}}(|p,-p\rangle + |p',-p'\rangle)$
- Joint detection probabilities:
  $P(A_+,B_+) = P(A_-,B_-) = \frac{1}{2}\cos^2[(\phi_A - \phi_B)/2]$
  $P(A_+,B_-) = P(A_-,B_+) = \frac{1}{2}\sin^2[(\phi_A - \phi_B)/2]$
- Correlation coefficient:
  $E = P(A_+,B_+) + P(A_-,B_-) - P(A_+,B_-) - P(A_-,B_+) = V\cos(\phi_A - \phi_B)$
- Violation of a Bell inequality if $V > 1/\sqrt{2}$



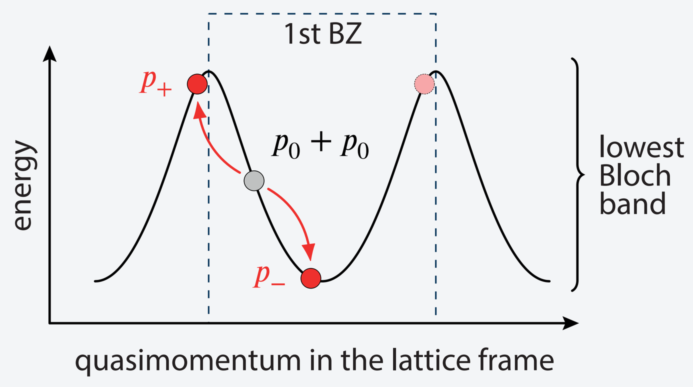
Setup

- Metastable Helium-4 BEC
- Quasi-1D geometry (vertical)
- Pair emission driven by a moving optical lattice (vertical)
- Interferometer realized in free fall
- Bragg mirros and splitters
- Detection after 300 ms time of flight
  → single-atom detection (25% det. eff.)
  → 3D resolution (x-y position + time)



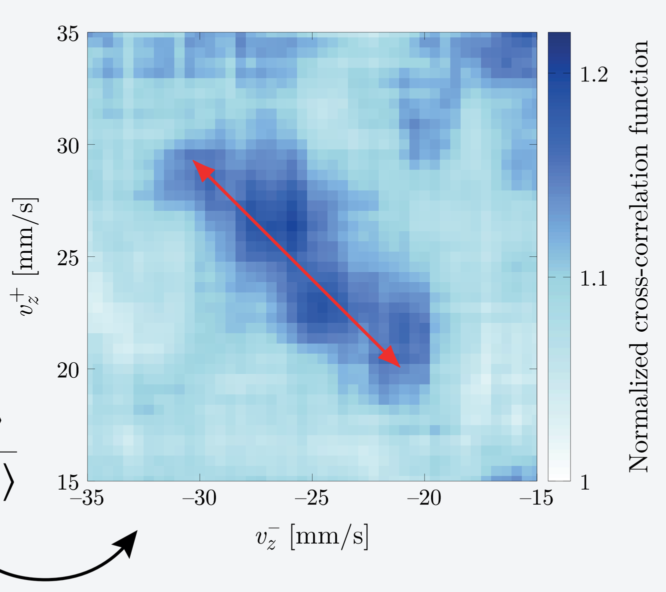
Source of atom pairs

- Dynamical instability driven by moving optical lattice
  → emission of atom pairs with opposite momenta
- Broad resonance
  → several pairs of modes are coherently populated
  $|\Psi\rangle \propto \sum (|p_+,p_-\rangle + |p'_+,p'_-\rangle + |p''_+,p''_-\rangle \dots)$



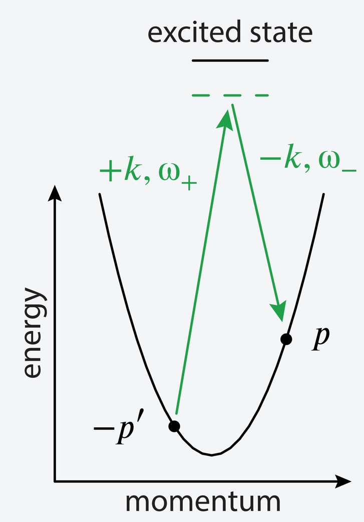
- Filtering the data reduces the state to the desired form:
  $|\Psi\rangle = \frac{1}{\sqrt{2}}(|p_+,p_-\rangle + |p'_+,p'_-\rangle)$
  $|\Psi\rangle = \frac{1}{\sqrt{2}}(|p,-p\rangle + |p',-p'\rangle)$
  center-of-mass frame

$$g^{(2)}(p_+,p_-) = \frac{\langle n(p_+)\,n(p_-)\rangle}{\langle n(p_+)\rangle\langle n(p_-)\rangle}$$



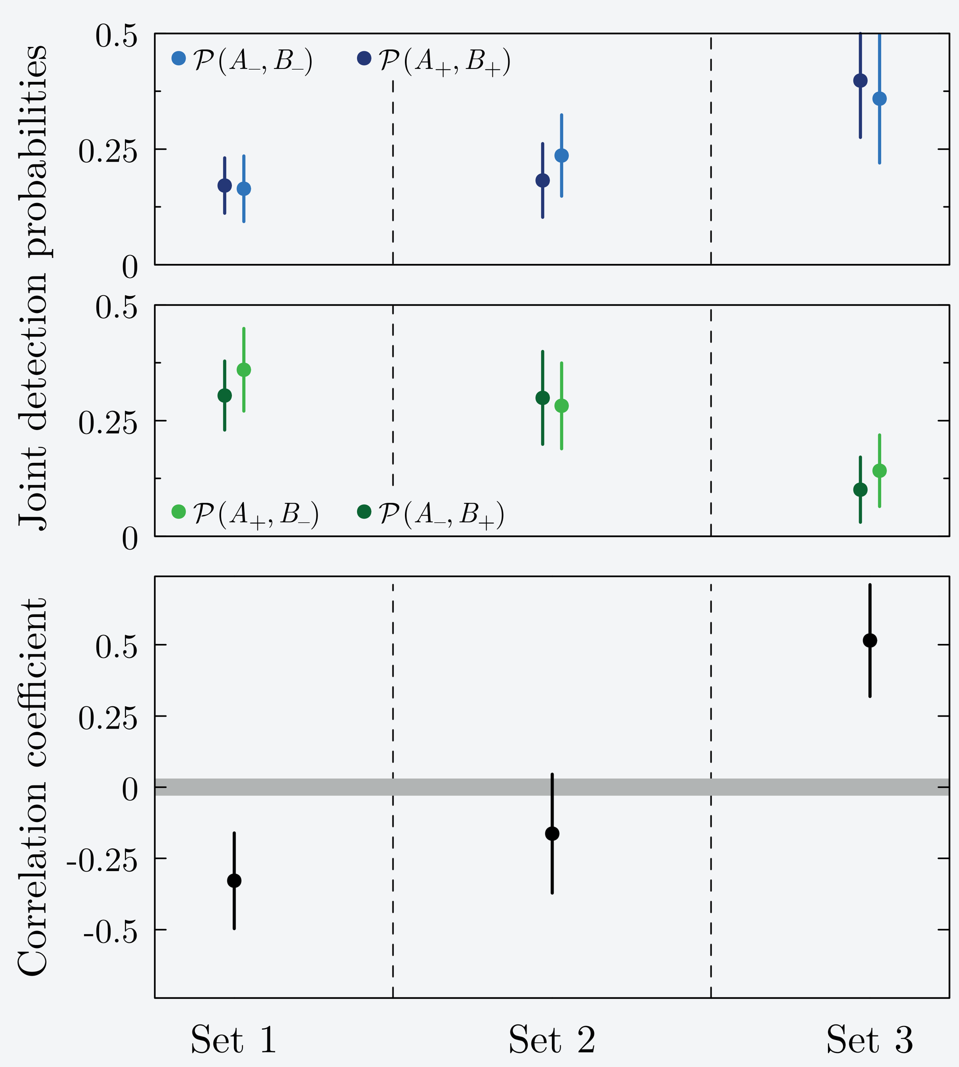
Bragg mirror and splitters

- Mirror: 100 µs pulse (π-pulse)
- Splitter: 50 µs pulse (π/2-pulse)
- The lasers imprint their phase on the atomic modes ($\varphi_{A,B}$)
- Spectral broadening induced by the short interaction time:
  → the same lattice addresses ($p,-p'$) and ($-p, p'$)
  → addition of a velocity-dependent phase away from the energy resonance
- Correlation coefficient: $E = V\cos(\varphi_A - \varphi_B - 2\delta\tau)$



Correlation measurements

- Analysis of 3 different sets of modes
  → access to 3 different phases ($\varphi_A - \varphi_B - 2\delta\tau$)
- Joint detection probabilities correlated 2-by-2
- Correlation coefficient different from zero for one data set
  → E = 0.51(20) for set 3
- Rules out the possibility for a totally mixed state
- Proof of entanglement?
  → need separate Bragg splitters to control the phase
  → work in progress



References

Published in **Dussarrat et al., PRL 119, 173202 (2017)**

- Inspiration for the interferometer:
  → Horne et al, Phys. Rev. Lett. 62, 2209 (1989)
  → Rarity and Tapster, Phys. Rev. Lett. 64, 2495 (1990)
- More details on the atom source:
  → M. Bonneau et al. Phys. Rev. A 87, 061603 (2013)

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