Creation and non-separability of phonon pairs in a modulated BEC

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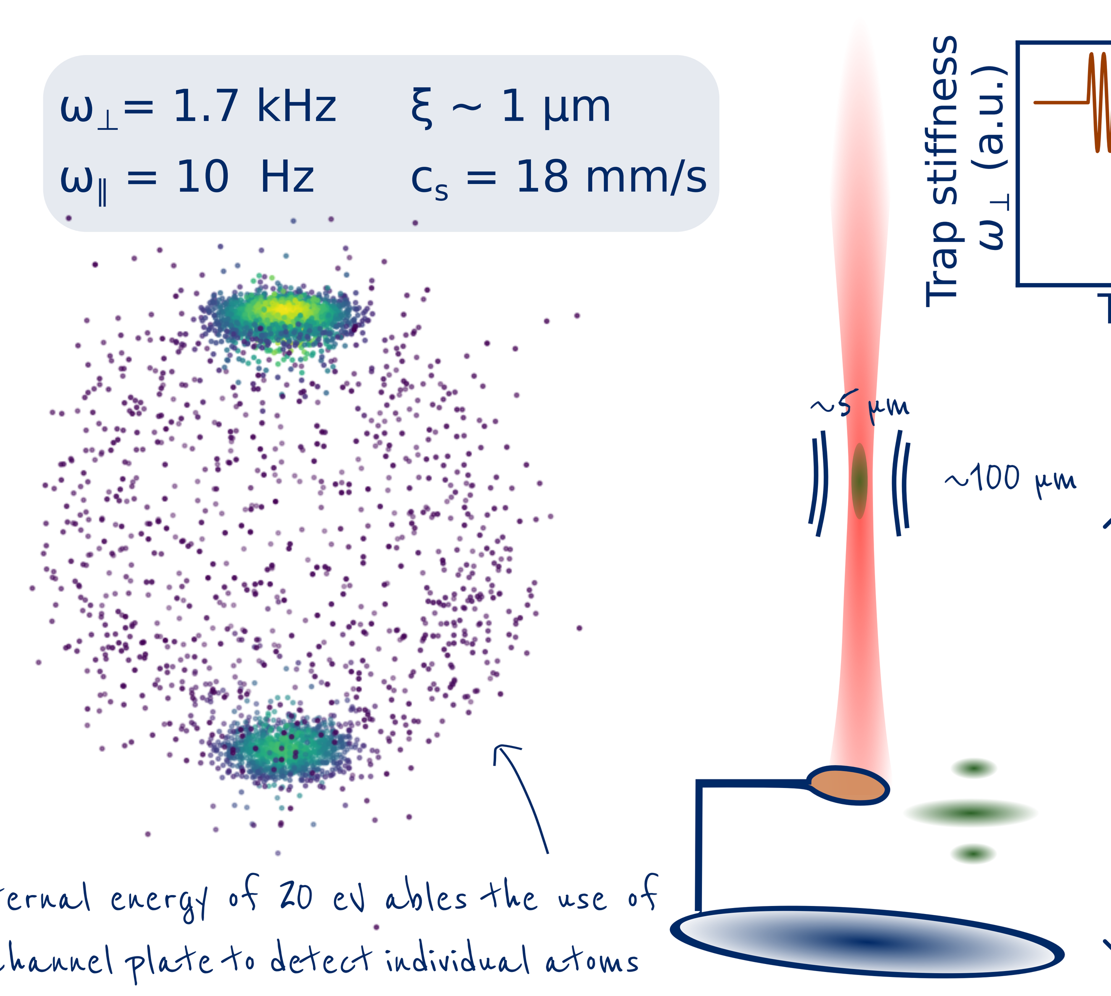
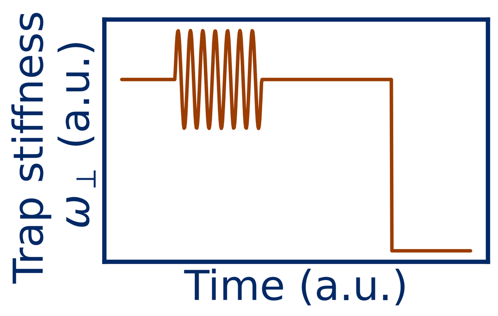
Experimental setup

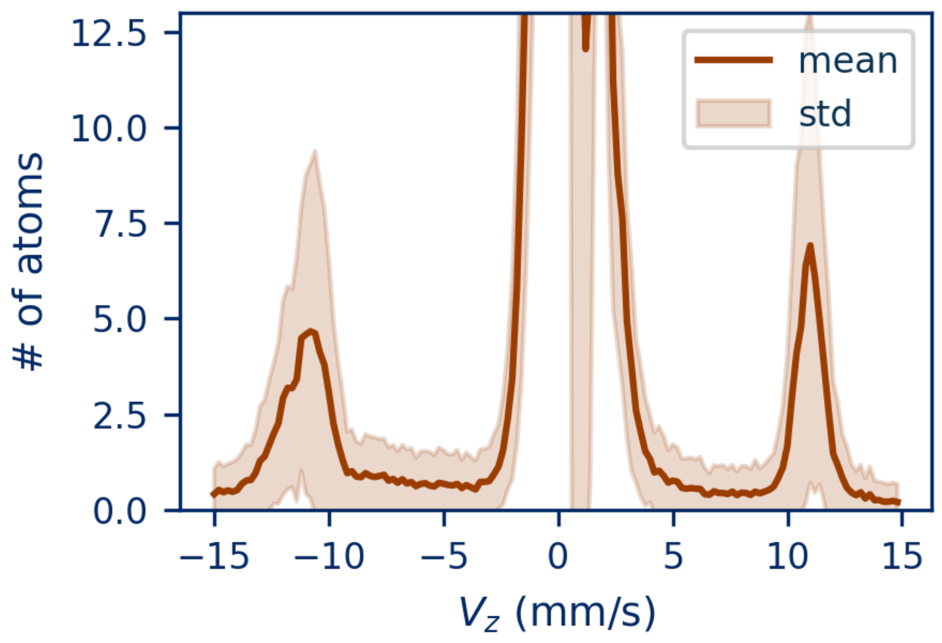
$\omega_\perp$ = 1.7 kHz $\xi \sim 1$ μm
$\omega_\parallel$ = 10 Hz c_s = 18 mm/s



He* internal energy of 20 eV ables the use of micro-channel plate to detect individual atoms



Excite the system by modulating the trapping laser intensity hence the trap frequency. The BEC entered in a breathing mode, producing pairs of entangled particles through parametric resonance.



Describe the system as

$$\hat{\Psi} = \Phi_0(1+\hat{\phi})$$

BEC treated as classical gaussian wavefunction with width σ

Small perturbations obey the Bogoliubov de Gennes equation

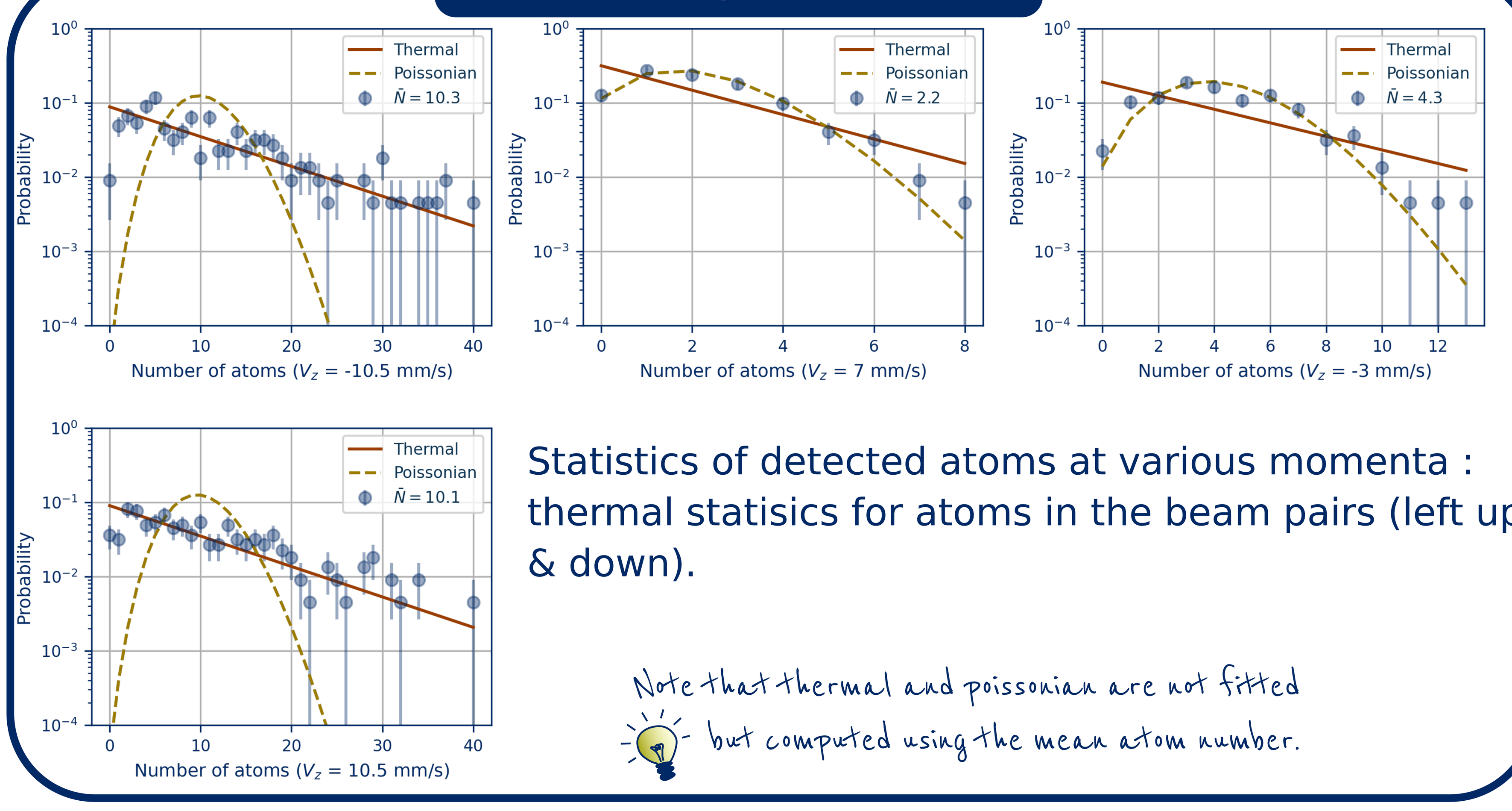
$$i\partial_t\hat{\phi} = \frac{-1}{2m}\partial_{zz}\hat{\phi} + g_1 n_1(z)[\hat{\phi}+\hat{\phi}^\dagger]$$

Modulated effective 1D two-atoms coupling constant $g_1 = g/2\pi\sigma$

Expect a two-modes squeezed state

$$|\phi_k\rangle = \sqrt{1-|\alpha|^2}\sum_n \alpha^n |n_k, n_{-k}\rangle$$

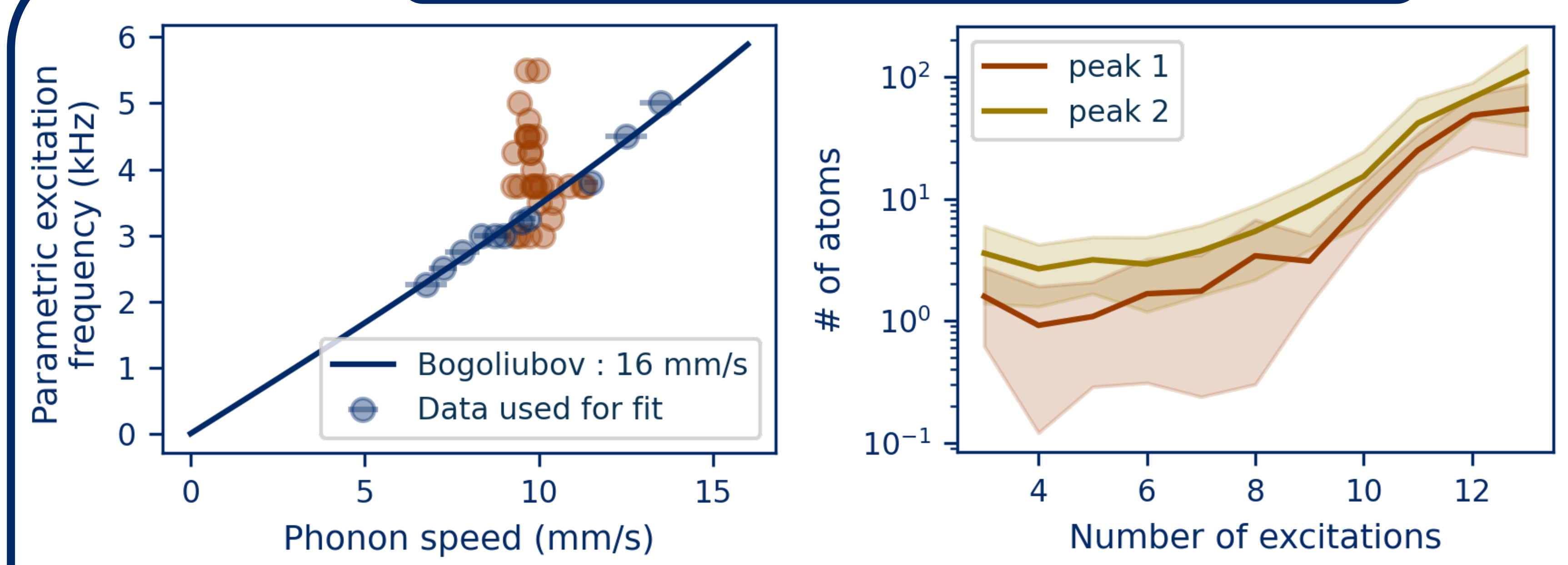
Counting statistics



Statistics of detected atoms at various momenta : thermal statisics for atoms in the beam pairs (left up & down).

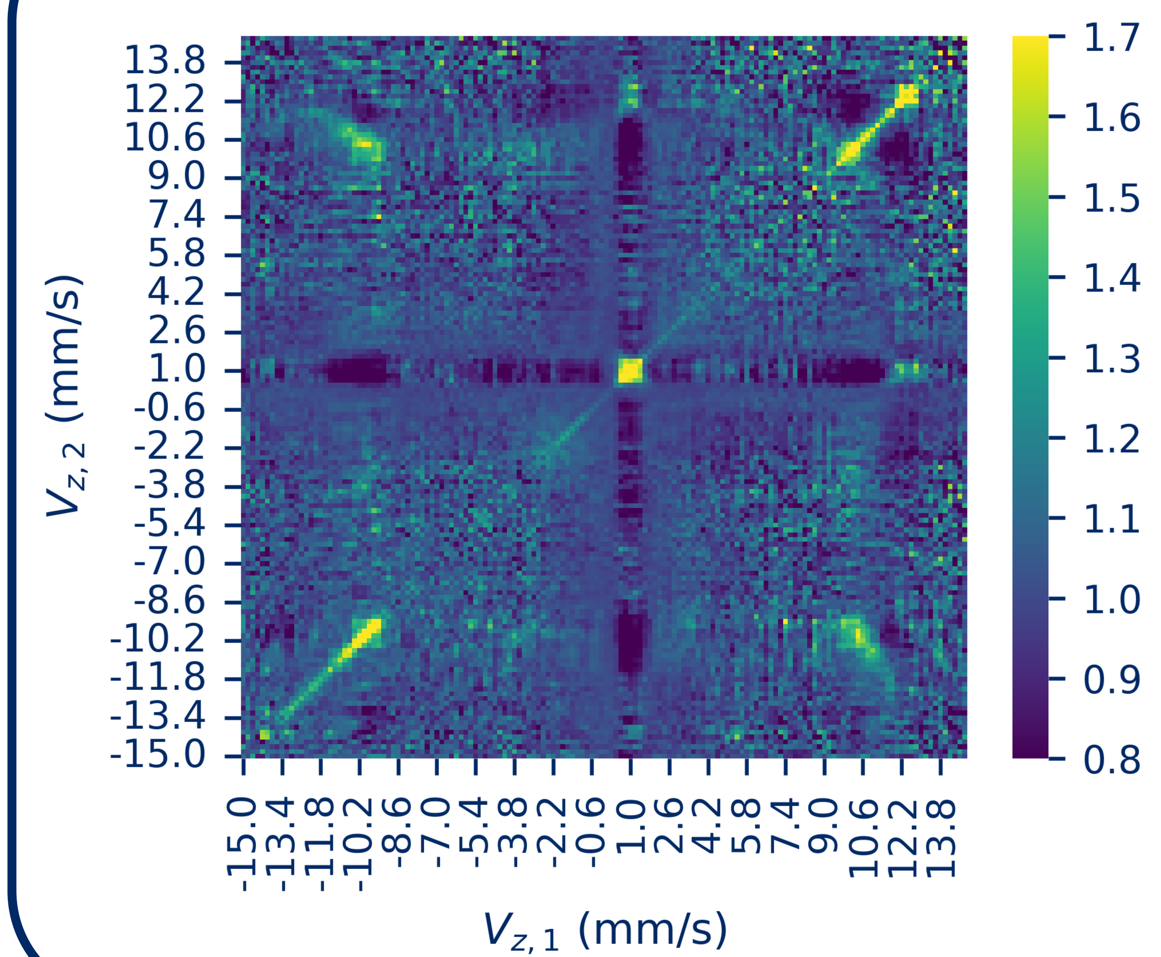
Note that thermal and poissonian are not fitted but computed using the mean atom number.

Monitoring the number of created phonons



Left : Excitation frequency of the laser as a function of the speed of the phonon pairs creates. When one is able to excite non-resonnant modes, the frequency of excitation is twice the energy of one Bogolibubov mode, as phonons are created by pairs. Right : the number of created pairs increases exponentially until saturation with the excitation duration.

Correlations



$$g^{(2)}(k_1,k_2) = \langle : \hat{n}_{k_1}\hat{n}_{k_2} : \rangle / \langle \hat{n}_{k_1}\rangle\langle \hat{n}_{k_2}\rangle$$

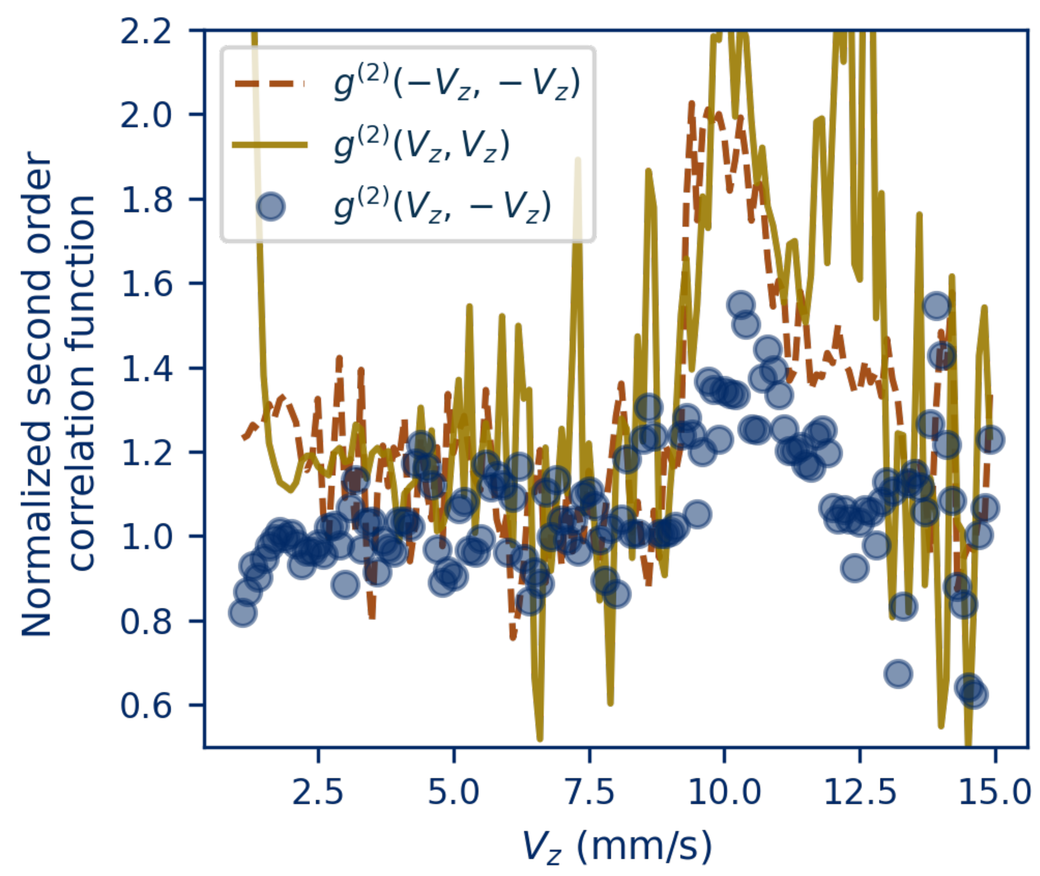
For a TMS, one expects

$$g^{(2)}(k,k) = 2 \qquad g^{(2)}(k,-k) = 2 + 1/\bar{n}_k$$

and therefore a violation of the Cauchy-Schwarz inequality

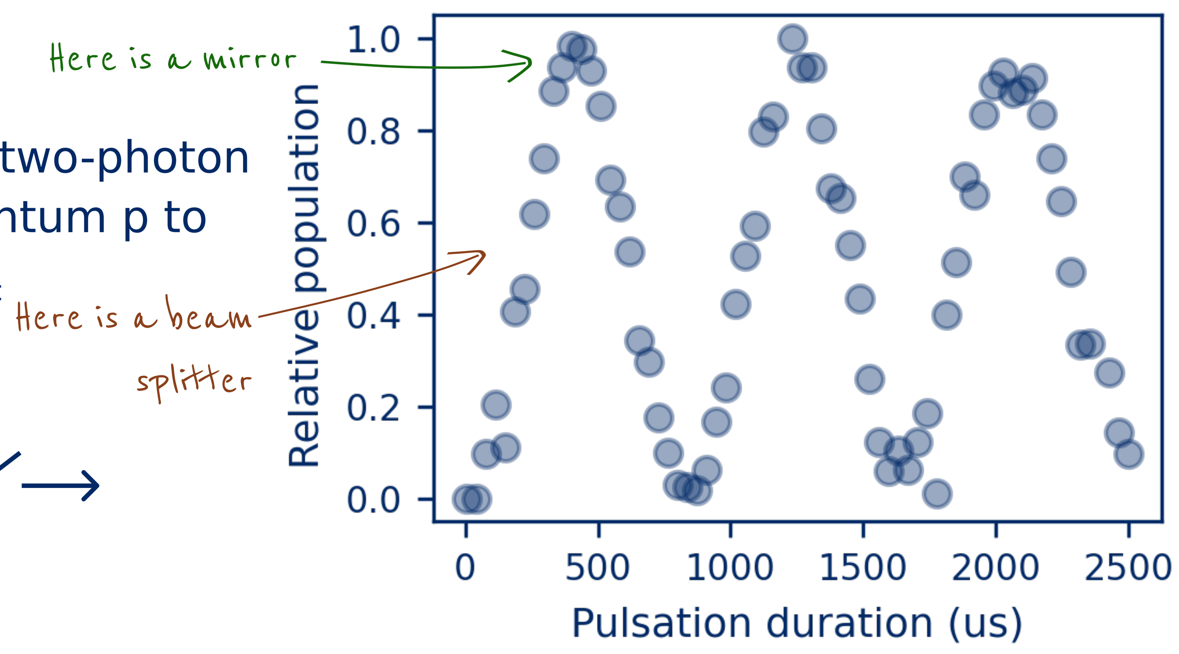
$$G^{(2)}(k_1,k_2) \leq \sqrt{G^{(2)}(k_1,k_1)\times G^{(2)}(k_2,k_2)}$$

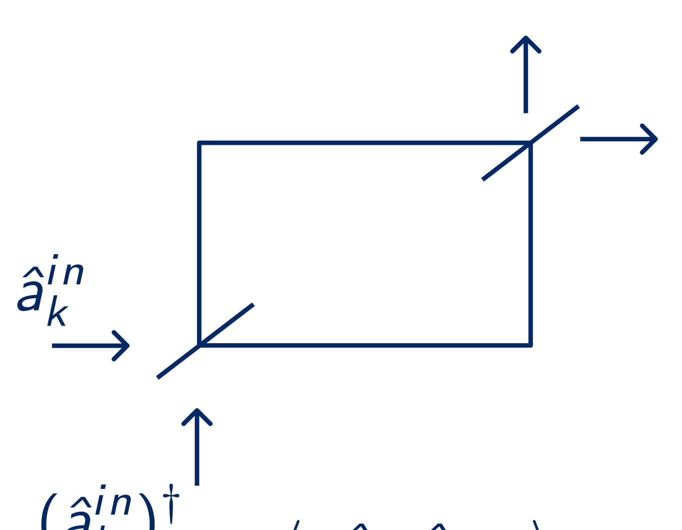
	Local correlation	Crossed correlation
Amplitude	1	0.4
Width	0.3 mm/s	1 mm/s



Bragg diffraction for atomic interferometry

Bragg diffraction is a two-photon transition from momentum p to momentum p + $2\hbar k_{rec}$





Assuming the state is Gaussian, one can measure the ''zero'' term in Cauchy-Schwarz inequality.

$$\langle : \hat{n}_{k_1}\hat{n}_{k_2} : \rangle = n_{k_1}n_{k_2} + \underbrace{|\langle \hat{a}_{k_1}\hat{a}_{k_2}\rangle|^2}_{\leq n_{k_1}n_{k_2}} + \underbrace{|\langle \hat{a}_{k_1}^\dagger\hat{a}_{k_2}\rangle|^2}_{0\ ?}$$

Perspectives, bibliography and fundings

- ☐ Decrease the mean number of particles per mode to violate the Cauchy-Schwarz inequality
- ☐ Check the non-separability criteria using Bragg diffraction
- ☐ Study the thermalization of the quasi-particles.

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