Correlated phonon pairs in a time modulated Bose-Einstein Condensate

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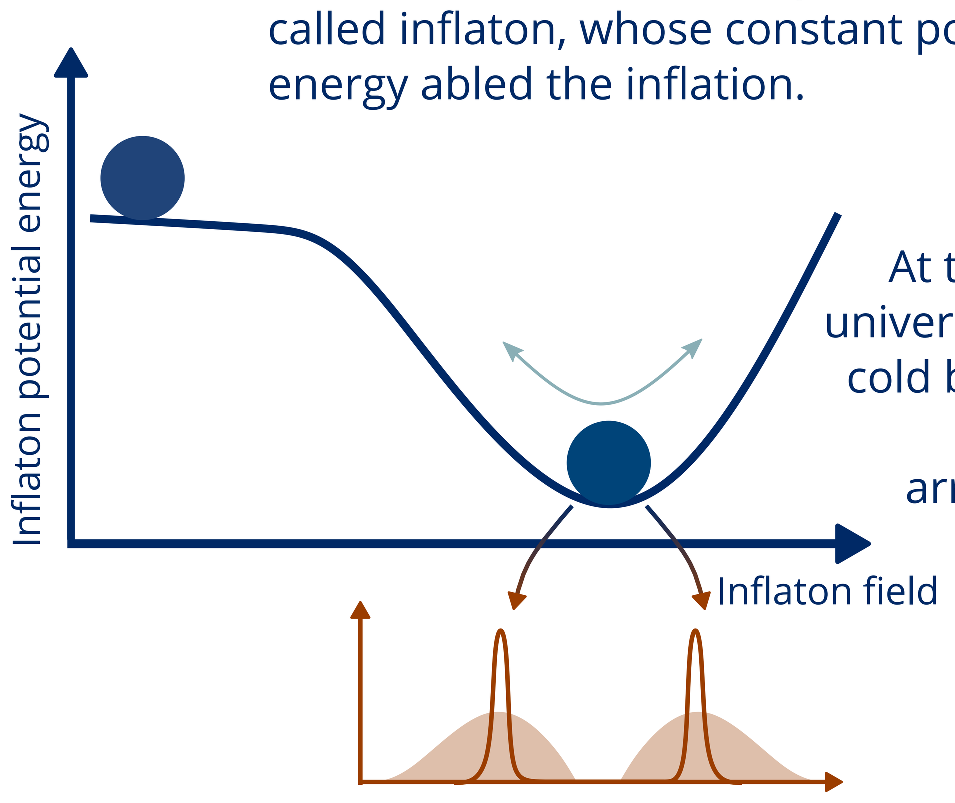
Context and experimental setup

The inflation was driven by a scalar field called inflaton, whose constant potential energy abled the inflation.



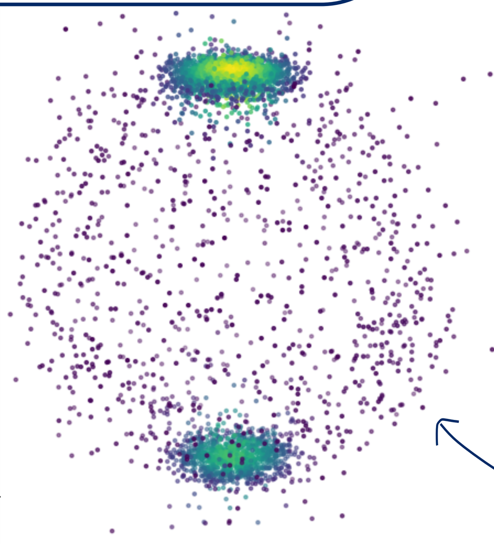
At the end of inflation, the universe is mostly empty and cold but the inflaton reach a minimum of potentials arround which it starts to oscillate.

Its oscillations create pairs of entengled particles through parametric amplification.

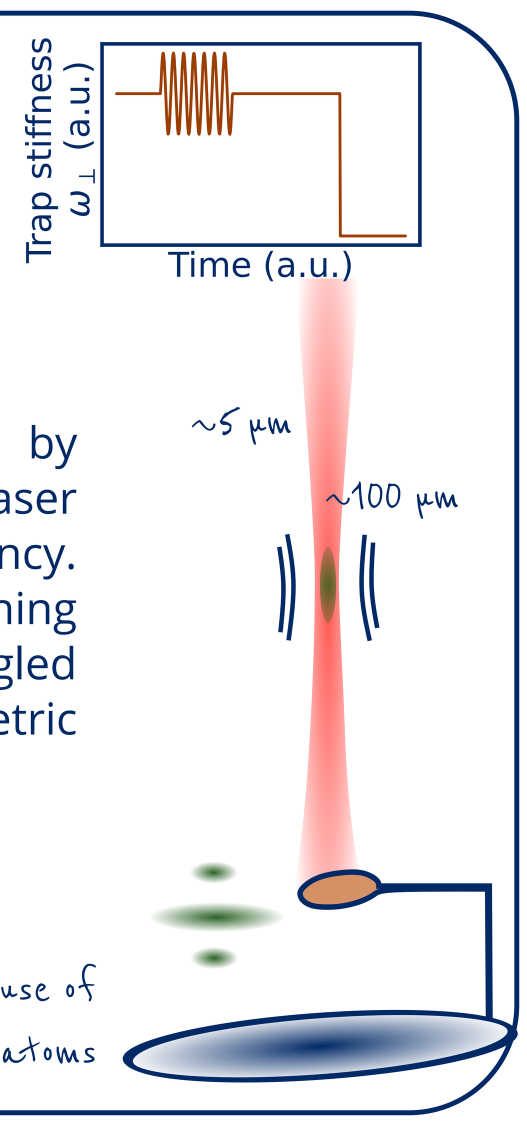
~ 10^{89} particles in just a few oscillations !

Particles interactions lead to decoherence and thermalization.

The idea of analog gravity experiment is to study a system in laboratoriy that exhibits analog behaviour as the one expected by the standard model.



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

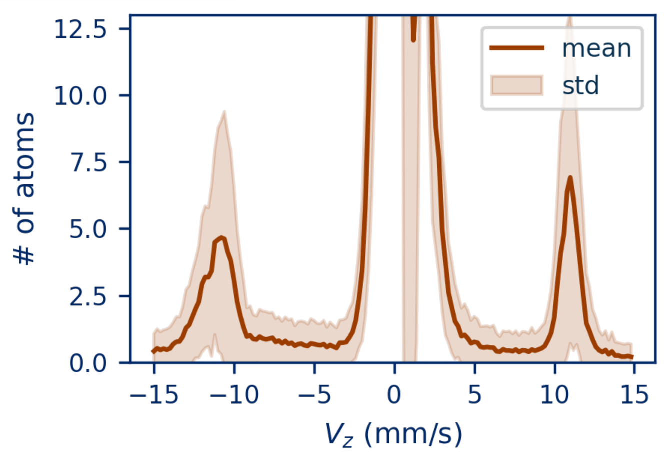


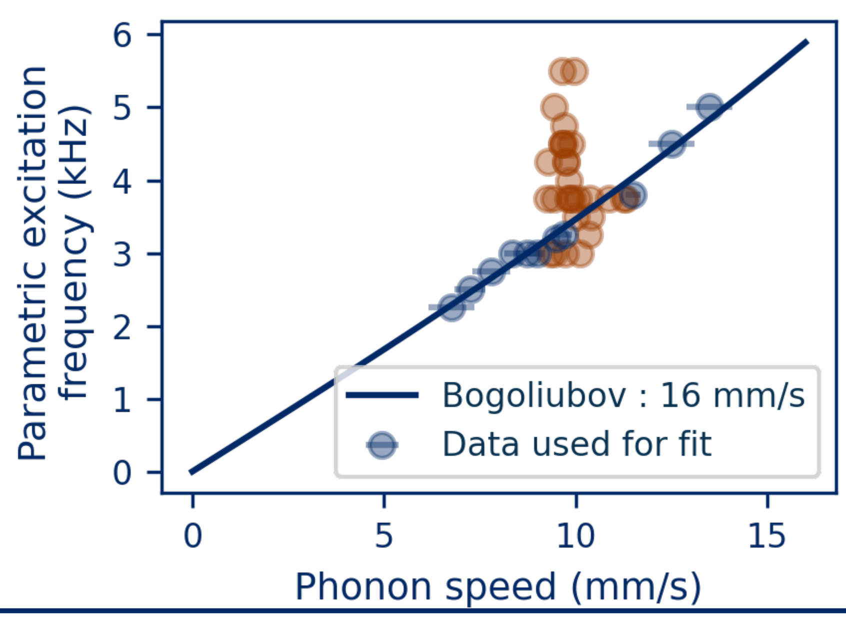
The system is excited by modulating the trapping laser intensity hence the trap frequency. The BEC entered in a breathing mode, producing pairs of entangled particles through parametric resonance.

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

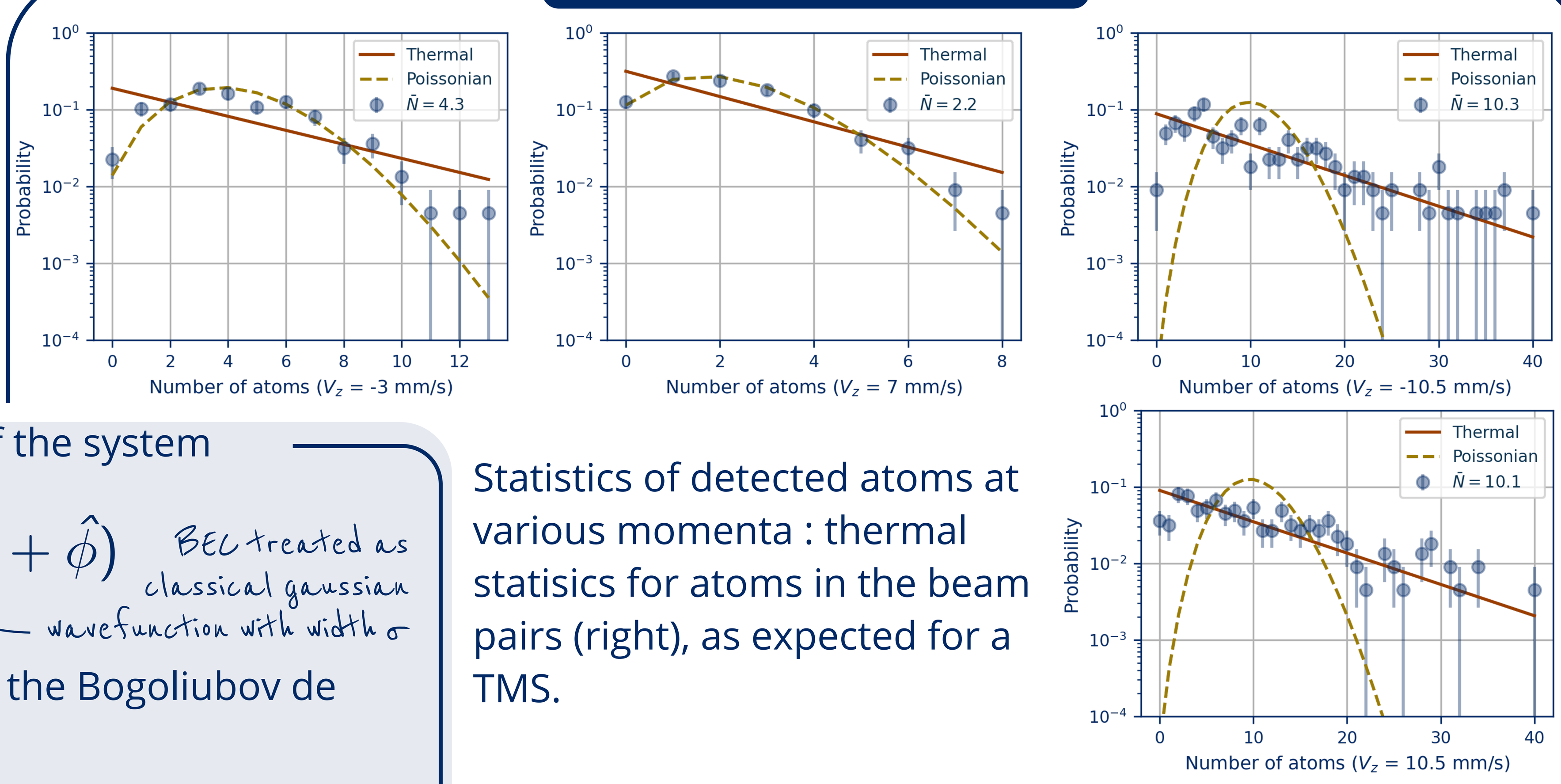
Dispersion relation of excitations

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.





Counting statistics



Statistics of detected atoms at various momenta : thermal statistics for atoms in the beam pairs (right), as expected for a TMS.

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

Theoretical description of the system

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

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

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

for which the second order correlation function

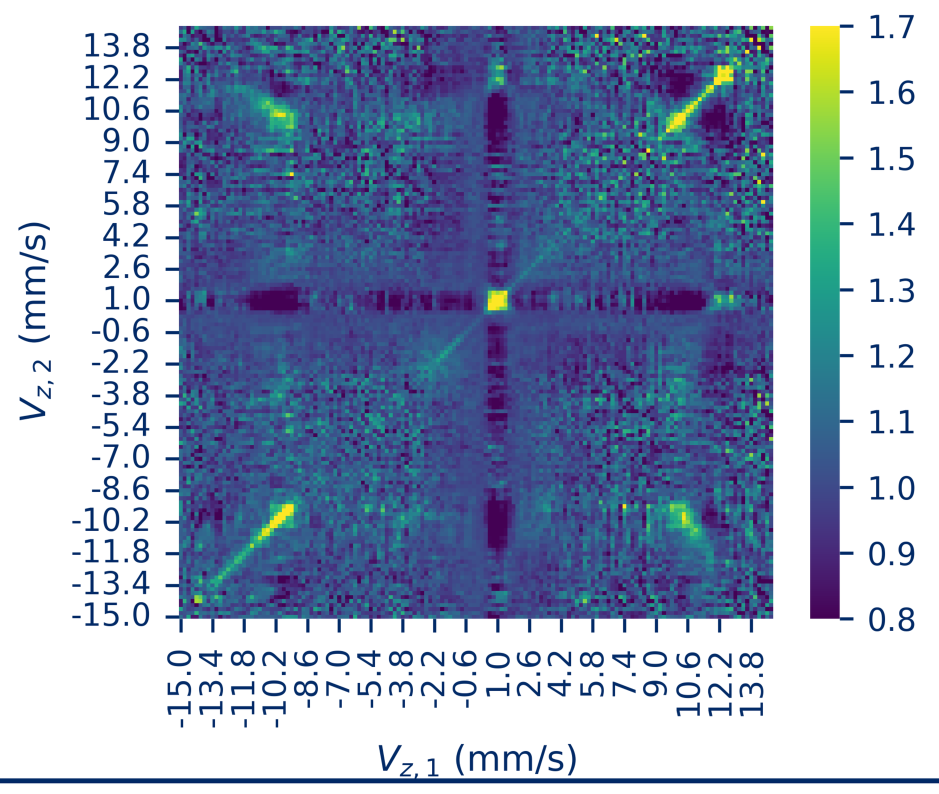
$$g^{(2)}(k_1,k_2) = \langle : \hat{n}_{k_1}\hat{n}_{k_2} : \rangle / \langle \hat{n}_{k_1}\rangle\langle \hat{n}_{k_2}\rangle$$

satisfies

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

Correlations

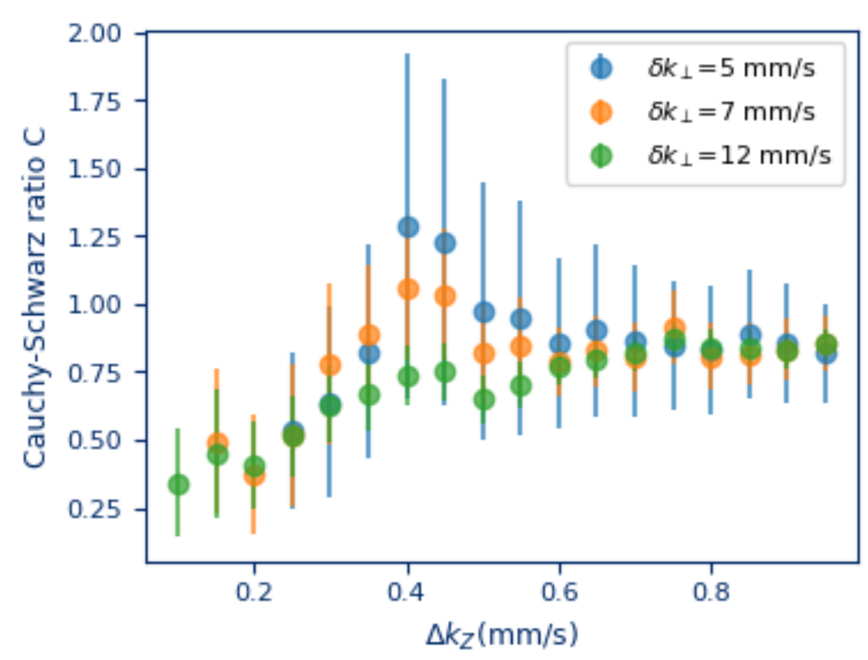
2D colormap of the second order correlation function $g^{(2)}(v_1, v_2)$. On the diagonal lies local correlations while crossed-correlations are visible on the anti-diagonal.



Cauchy-Schwarz Inequality

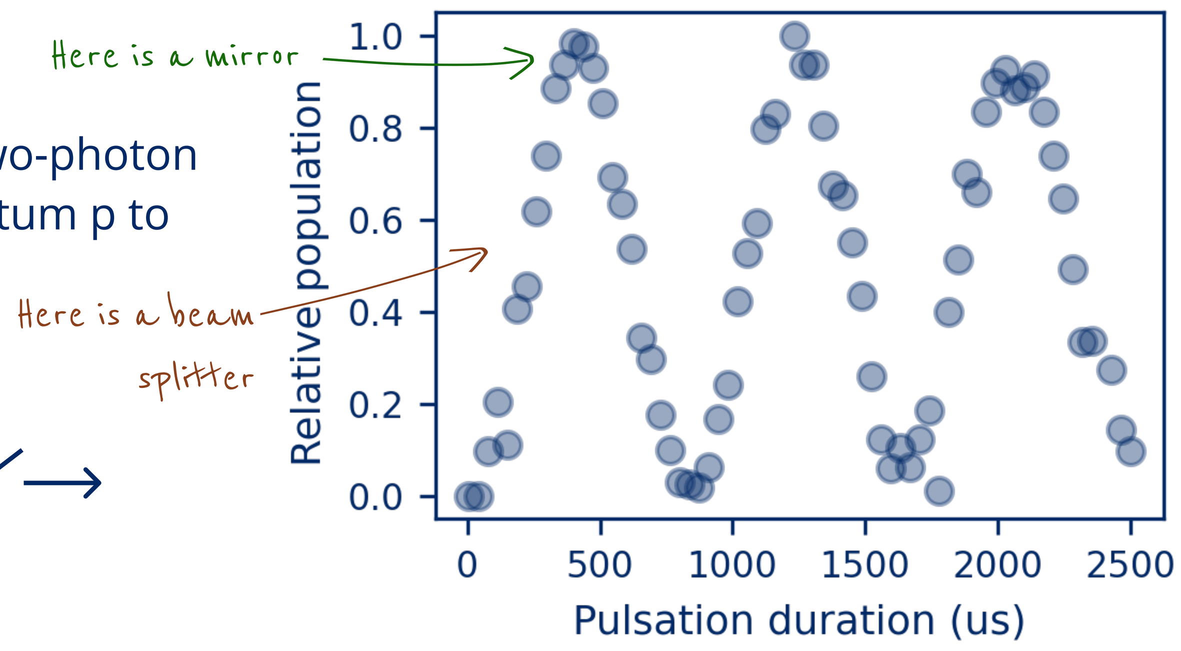
Define the following ratio C for which value above 1 should emphases non-separabilty of the state :

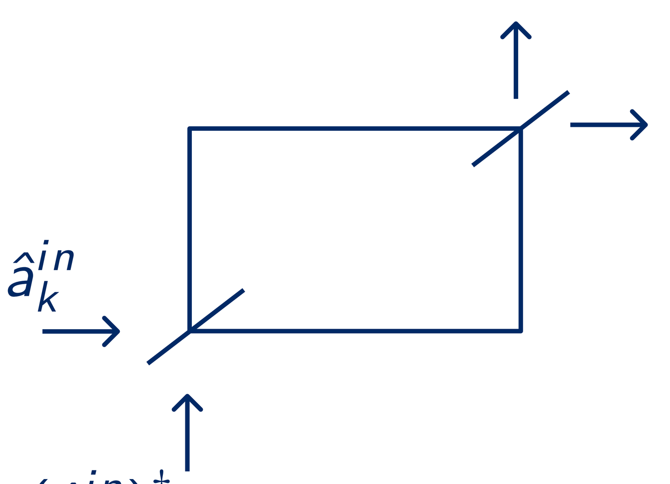
$$C \equiv G^{(2)}(k_1,k_2)/\sqrt{G^{(2)}(k_1,k_1)\times G^{(2)}(k_2,k_2)}$$



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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