Rabi interferometry with ultracold gases

Jan Chwedeńczuk[1], Luca Pezzé[2], Francesco Piazza[3] and Augusto Smerzi[3]

[1]Faculty of Physics, University of Warsaw, Poland
[2]Laboratoire Charles Fabry de l'Institut d'Optique, CNRS and Univ. Paris-Sud
[3]BEC-CNR-INFM and Dipartimento di Fisica, Universita' di Trento

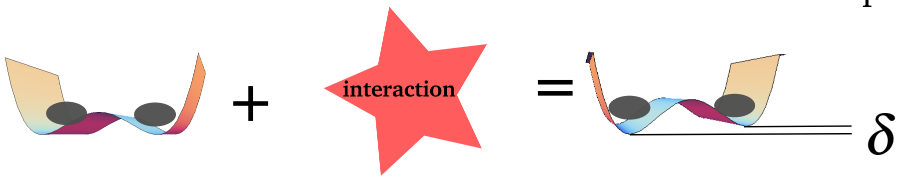
INNOVATIVE ECONOMY NATIONAL COHESION STRATEGY

FNP

EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Idea:

- Take a BEC in a double-well and add small external perturbation



- The atoms will start to perform the **Rabi oscillations**
- Measure the oscillations and deduce δ

How:

- The Hamiltonian (in the absence of interactions) $\hat{H} = -E_J\hat{J}_x + \delta\hat{J}_z$
- Focus on the measurement of the population imbalance after time t

the evolution operator $\hat{U}(t) = e^{-i\alpha\hat{J}_y}e^{i\omega t\hat{J}_x}e^{i\alpha\hat{J}_y}$ gives

$$\omega = \frac{1}{\hbar}\sqrt{E_J^2+\delta^2} \qquad \alpha = \arccos\left(\frac{E_J}{\hbar\omega}\right)$$

$$\hat{J}_z(t,\delta) = \sin\alpha\cos\alpha(\cos\omega t - 1)\hat{J}_x - \cos\alpha\sin\omega t\hat{J}_y + (\cos^2\alpha\cos\omega t + \sin^2\alpha)\hat{J}_z$$

measure the population imbalance at k different times (m repetitions at each point)

$\{n\} = \{n(t_1),\ldots,n(t_k)\}$ distributed according to the CLT

$$p(\{n\}|\delta) = \prod_{i=1}^{k}\left[\frac{1}{\sqrt{2\pi}\Delta\hat{J}_z(t_i,\delta)/\sqrt{m}}e^{-\frac{(n(t_i)-\langle\hat{J}_z(t_i,\delta)\rangle)^2}{2\Delta^2\hat{J}_z(t_i,\delta)/m}}\right]$$

fit a curve to these points using the least squares method

$$\Delta^2\delta(t_i) = \frac{\Delta^2\hat{J}_z(t_i,\delta)}{m\left[\frac{\partial}{\partial\delta}\langle\hat{J}_z(t_i,\delta)\rangle\right]^2}$$

for a coherent state

$$\Delta\delta(t_i) = \frac{1}{\sqrt{mN}}\frac{E_J}{\left|\cos\left(\frac{E_Jt_i}{\hbar}\right)-1\right|}$$

Example:

- Casimir-Polder potential between a dielectric and an atom

$$V_{CP}(x_1;d) = -\frac{0.24\,\hbar\,c\,\alpha_0}{(x_1+\frac{1}{2}l+d)^4}\frac{\varepsilon_0-1}{\varepsilon_0+1} \quad \text{quantum}$$

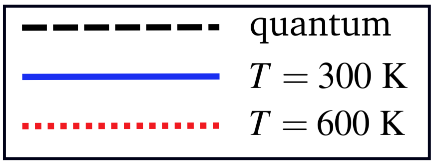
$$V_{CP}^{th}(x_1;d) = -\frac{k_BT\,\alpha_0}{4\,(x_1+l/2+d)^3}\frac{\varepsilon_0-1}{\varepsilon_0+1} \quad \text{thermal}$$

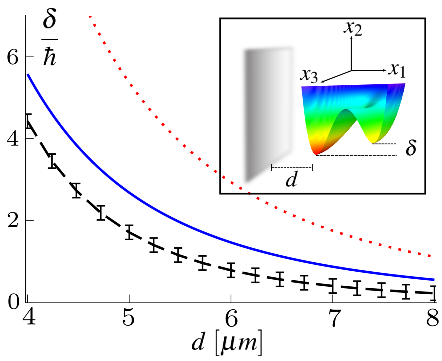
$N = 2500$ ^{87}Rb atoms

$l = 4.8\ \mu m$ well separation

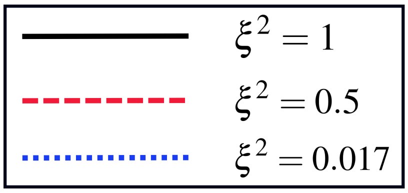
$\frac{E_J}{\hbar} = 52.3\ \frac{1}{s}$ Rabi frequency

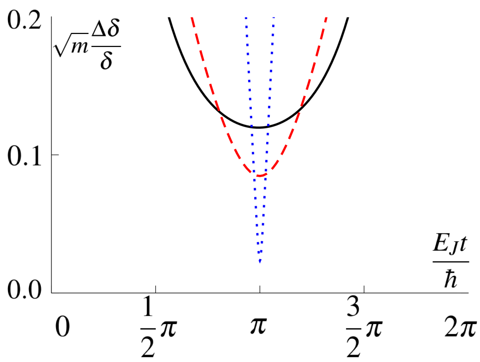
$m = 100$ repetitions





the impact of squeezing $\xi^2 = N\frac{\langle\hat{J}_z^2\rangle}{\langle\hat{J}_x\rangle^2}$





J. Chwedeńczuk, L. Pezzé, F. Piazza and A. Smerzi, Phys. Rev. A 82, 032104 (2010)
M. Antezza, L. P. Pitaevskii, and S. Stringari, Phys. Rev. A **70**, 053619 (2004)
J. M. Obrecht, R. J. Wild, M. Antezza, L. P. Pitaevskii, S. Stringari, and E. A. Cornell, Phys. Rev. Lett. **98**, 063201 (2007)
O. A. Sushkov, W. J. Kim, D. A. R. Dalvit and S. K. Lamoreaux, Nat. Phys. 7, 230 (2011)