Spontaneous Four-Wave Mixing of de Broglie Waves: Beyond Optics

V. Krachmalnicoff[1], J.-C. Jaskula[1], M. Bonneau[1], G. B. Partridge[1], D. Boiron[1], C. I. Westbrook[1], P. Deuar[2], P. Ziń[3], M. Trippenbach[4], and K. V. Kheruntsyan[5]
[1] *Laboratoire Charles Fabry, Institut d'Optique, Univ Paris Sud, CNRS, Palaiseau, France*
[2] *Institute of Physics, Polish Academy of Sciences, Warsaw, Poland*
[3] *The Andrzej Sołtan Institute for Nuclear Studies, Warsaw, Poland*
[4] *Institute of Theoretical Physics, Physics Department, University of Warsaw, Poland*
[5] *School of Mathematics and Physics, ACQAO, UQ*

We investigate the atom-optical analog of degenerate four-wave mixing of photons by colliding two Bose-Einstein condensates (BECs) of metastable helium and measuring the resulting momentum distribution of the scattered atoms with a time and space resolved detector [1, 2]. For the case of photons, phase matching conditions completely define the final state of the system, and in the case of two colliding BECs, simple analogy implies a spherical momentum distribution of scattered atoms. We find, however, that the final momenta of the scattered atoms instead lie on an ellipsoid whose radii are smaller than the initial collision momentum. Numerical and analytical calculations agree well with the measurements, and reveal the interplay between many-body effects, mean-field interaction, and the anisotropy of the source condensate.

In Fig. 1 we show the schematic diagram of the collision geometry in the center-of-mass frame in which we denote the collision axis as Z. The two disks represent the colliding condensates in momentum space. The sphere represents the halo of scattered atoms. The axial direction of the initial, cigar-shaped condensate is along X. We analyze the experimental and theoretical data in the XY-plane. In Fig. 2 (a) we show a slice of the experimentally detected scattering halo in the XY-plane that reveals its annular structure; in Fig. 2 (b) we show the respective theoretical result obtained from the first-principles simulations using the positive-P method.

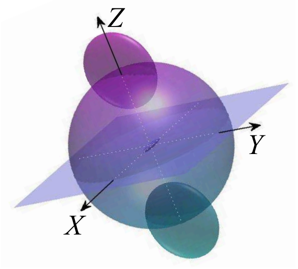

Fig. 1. Schematic diagram of the collision geometry.

Fig. 2 (c) shows the comparison of the experimental (black) and theoretical (red) data for the peak radius of the scattering halo on the equatorial plane versus the azimuthal angle ϕ; as we see the results agree within $\sim$ 2% of accuracy. We have also analyzed the problem using a stochastic implementation of the Bogoliubov approach, which allows us to identify and illustrate the contributions of various mean-field interaction effects in the scattering process.

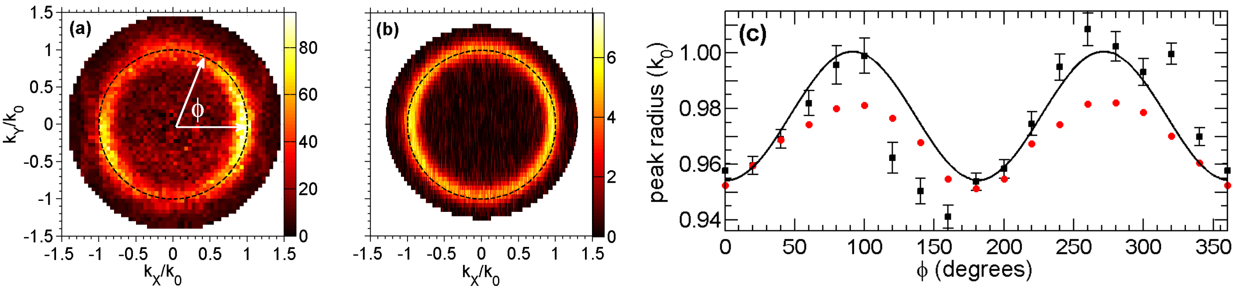

Fig. 2. (a) Momentum space density $n(k_X, k_Y)$ (in arb. units) of the experimentally observed scattering halo on the equatorial plane; (b) Same as in (a) but from the positive-P simulation after 70 μs collision time, in units of 10^{-18} m^3. (c) Peak radius versus the azimuthal angle ϕ.

References

[1] V. Krachmalnicoff, J.-C. Jaskula, M. Bonneau, G. B. Partridge, D. Boiron, C. I. Westbrook, P. Deuar, P. Zin, M. Trippenbach, and K.V. Kheruntsyan, arXiv: 0911.4564 (submitted to Phys. Rev. Lett.).

[2] M. Ögren and K. V. Kheruntsyan, Phys. Rev. A **79**, 021606(R) (2009).