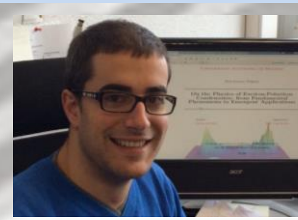
Coherence of polariton condensates in momentum space

C. Antón, **E. Rozas**, M.D. Martín, C. Tejedor, and L. Viña
Depto. de Física de Materiales & Depto. de Física Teórica de la Materia Condensada , UAM, 28049 Madrid, Spain

UNIVERSIDAD AUTONOMA DE MADRID

SEMIC UAM



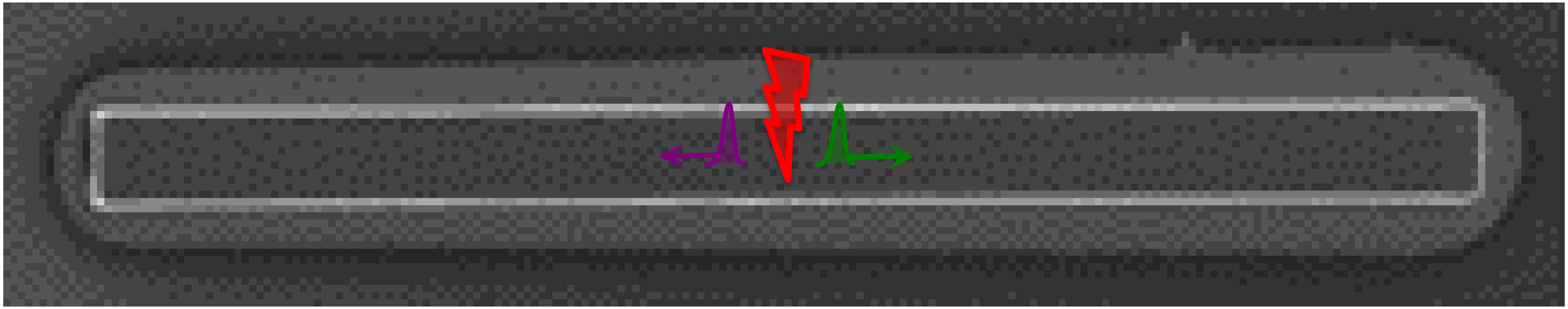
…Samples

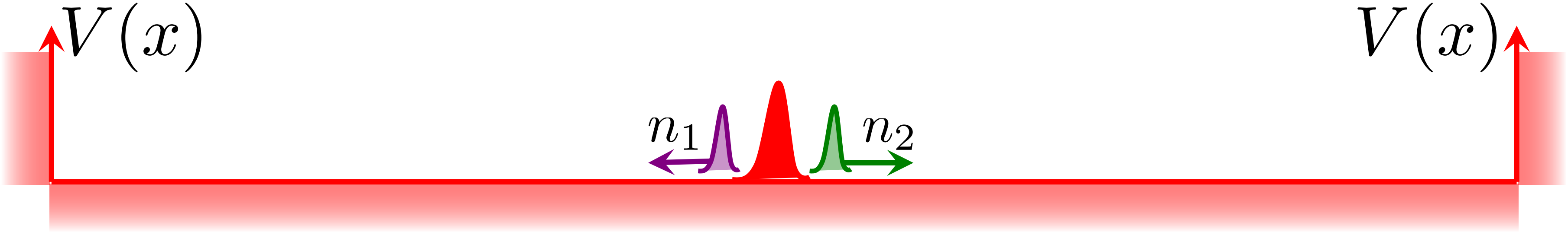
P.G. Savvidis
[5]FORTH-IESL & Department of Physics, University of Crete, 71110 Heraklion, Crete, Greece

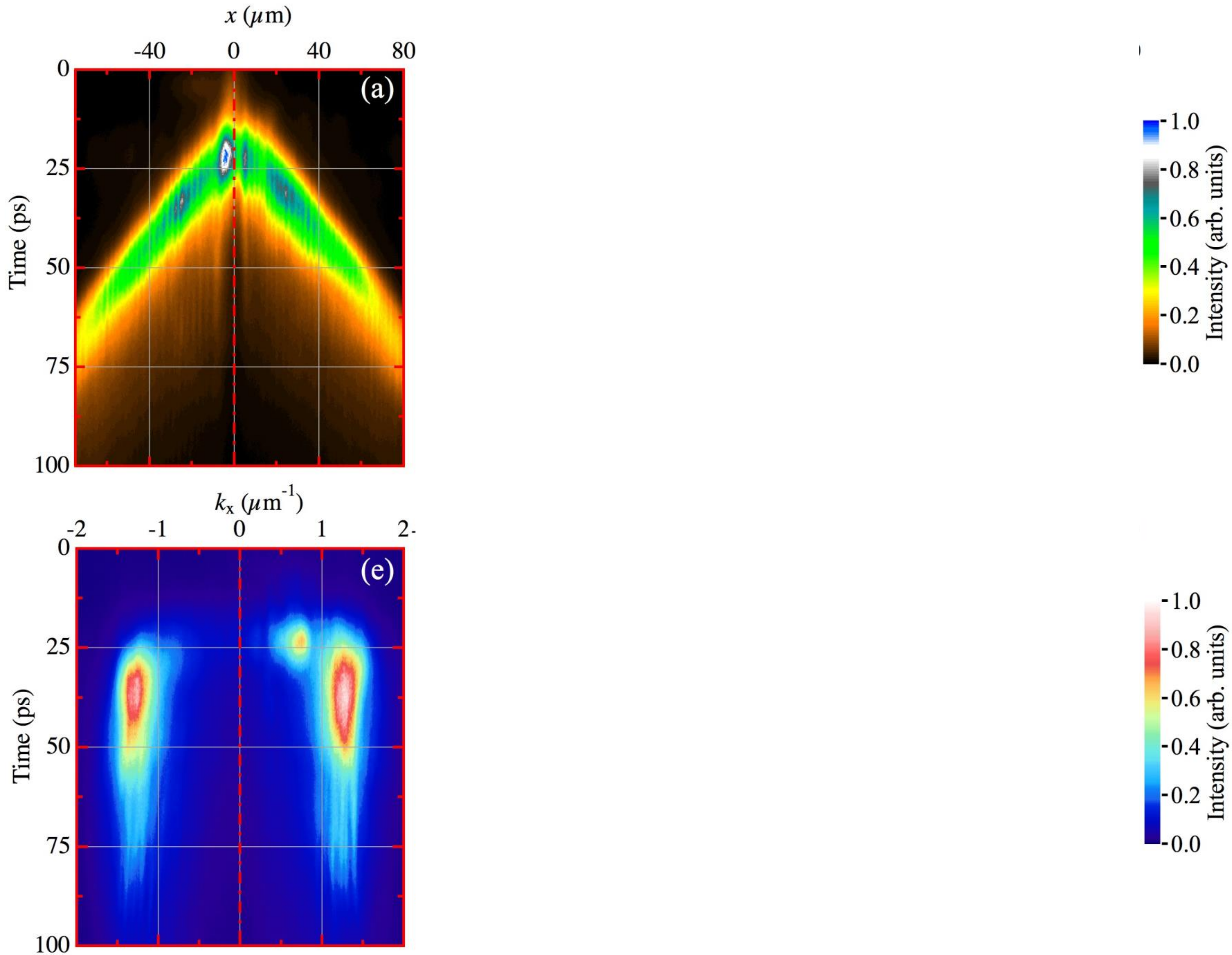
Outline:

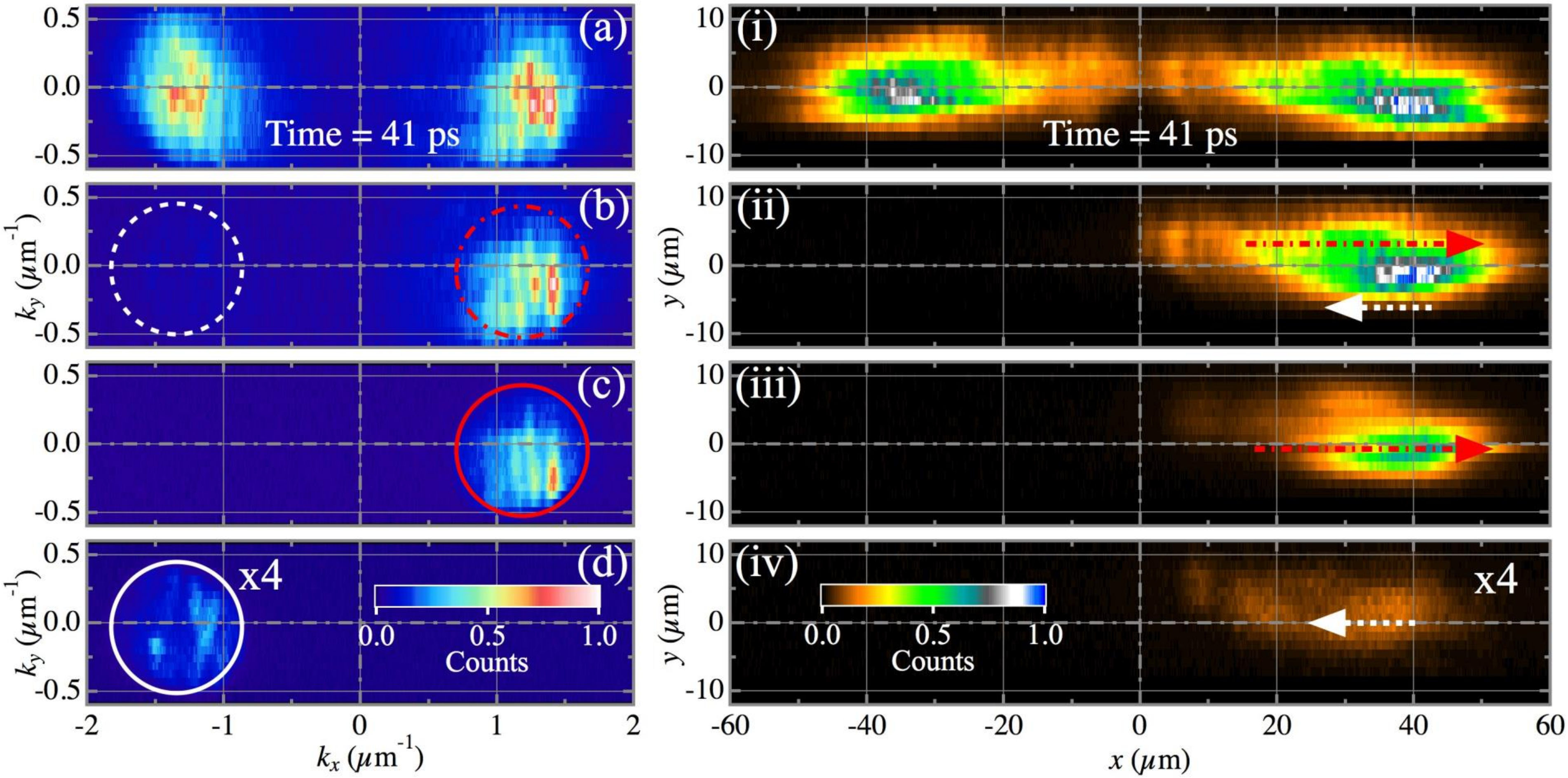
- Interferences
- Atomic Condensates
- Phase locking in momentum (& real) space
- Temperature dependence

Interferences



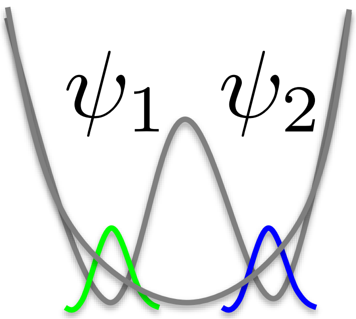



x (μm)
-40
0
40
80
(a)
Time (ps)
0
25
50
75
100
1.0
0.8
0.6
0.4
0.2
0.0
Intensity (arb. units)
k_x (μm^{-1})
-2
-1
0
1
2
(e)
Time (ps)
0
25
50
75
100
1.0
0.8
0.6
0.4
0.2
0.0
Intensity (arb. units)



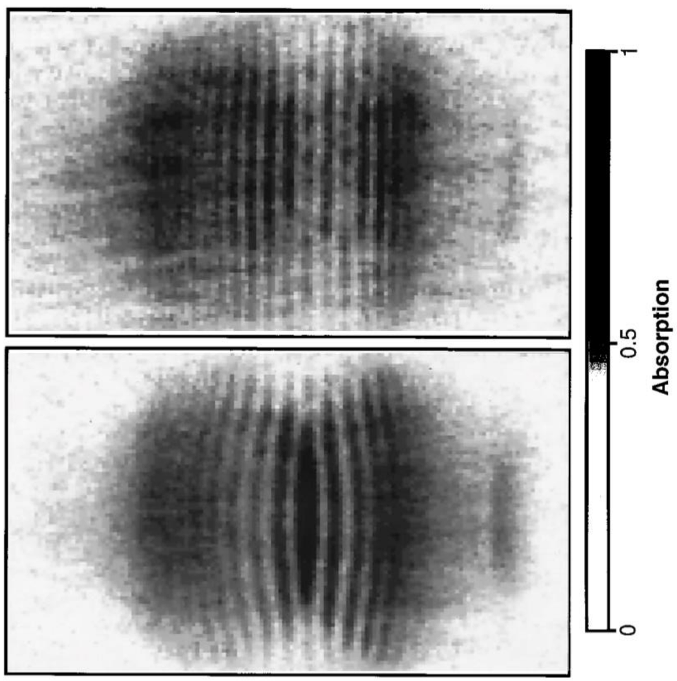
(a)
Time = 41 ps
(b)
(c)
(d)
x4
0.0
0.5
1.0
Counts
k_y (μm^{-1})
k_x (μm^{-1})
(i)
Time = 41 ps
(ii)
(iii)
(iv)
x4
0.0
0.5
1.0
Counts
y (μm)
x (μm)

Observation of Interference Between Two Bose Condensates
M. R. Andrews *et al.*
Science **275**, 637 (1997);
DOI: 10.1126/science.275.5300.637



$$\psi_{1,2}\left(x \pm d/2\right)$$

$$\psi_{1,2}\left(x,t\right) = \left|\psi_{1,2}\left(x,t\right)\right| e^{\pm ikx}$$



$$\Psi^{coh}\left(x,t\right) = \psi_1\left(x,t\right) + e^{i\phi_0}\psi_2\left(x,t\right)$$

$$\rho\left(x,t\right) = f\left(x,t\right) + g\left(x,t\right) cos\left(\phi_0 + \Delta k_x x\right)$$

Interference of Bose-Einstein Condensates in Momentum Space

L. Pitaevskii[1,2] and S. Stringari[1]

Anderson [6] raised the intriguing question: "Do two superfluids which have never *seen* one another possess a definitive phase?"

$$\phi_0$$

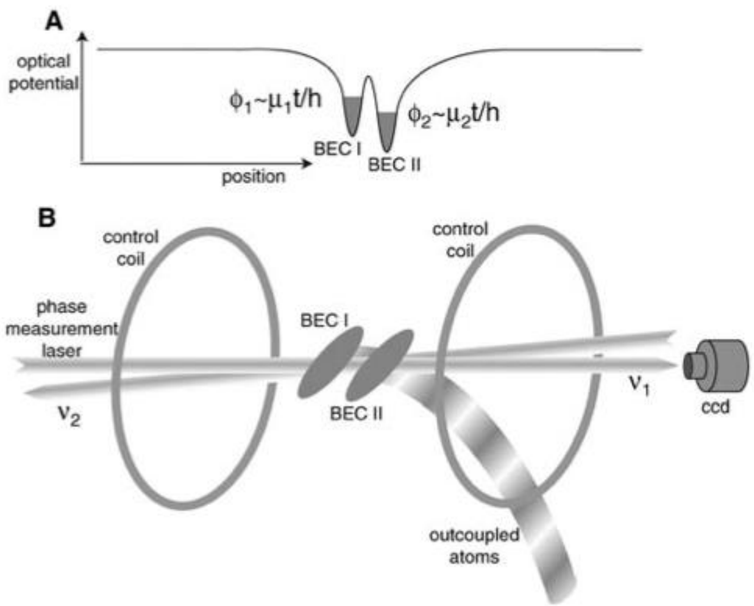
$$\Psi^{coh}(x,t) = \psi_1(x,t) + e^{i\phi_0}\psi_2(x,t)$$

However, measuring fringe patterns in the density profiles requires overlapping of the condensates in coordinate space and one cannot exclude the possibility that interactions among atoms block the relative phase before measurement [10,13].

Light Scattering to Determine the Relative Phase of Two Bose-Einstein Condensates

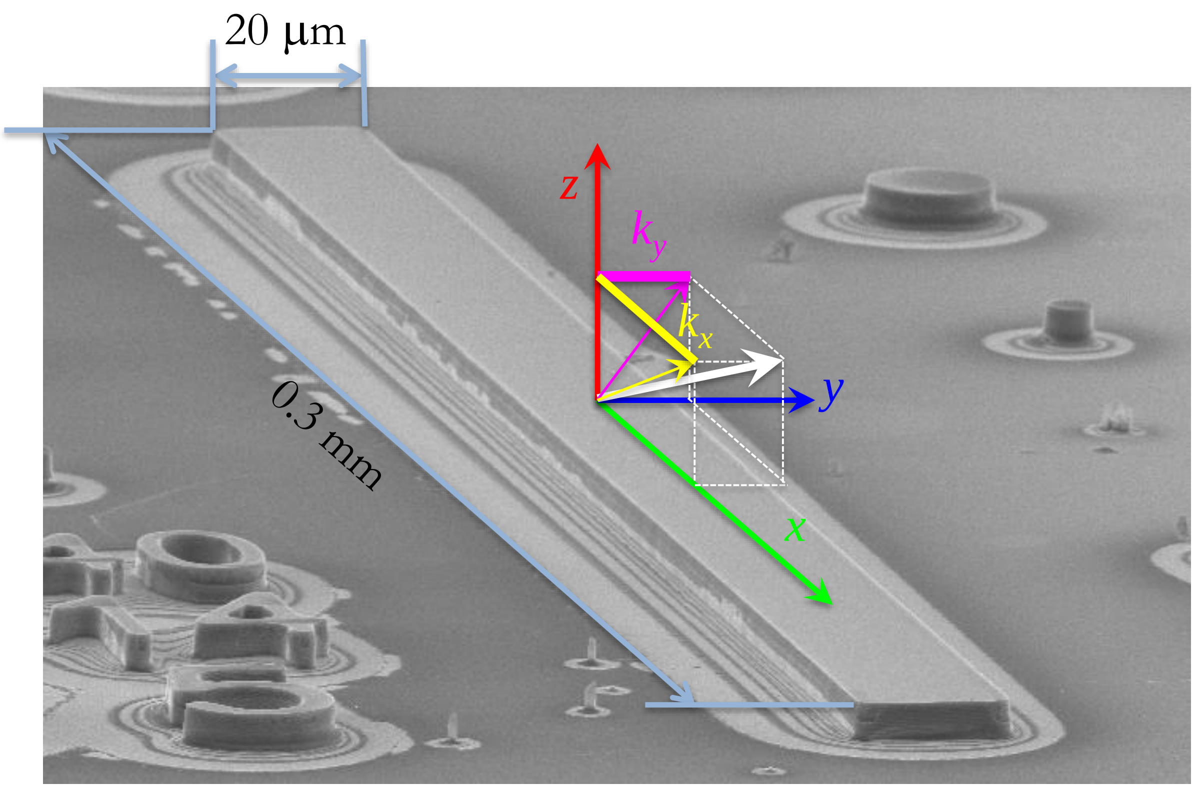
M. Saba *et al.*

Science **307**, 1945 (2005);
DOI: 10.1126/science.1108801



The structure factor is phase-sensitive and shows interference fringes without requiring spatial overlap between the two condensates, as long as the excited states (after light scattering) have spatial overlap. This picture emphasizes that overlap between scattered atoms, as well as scattered photons, is crucial to our method: No phase information can be retrieved from two atomic wavepackets that scatter the same light but whose excited states are disconnected.

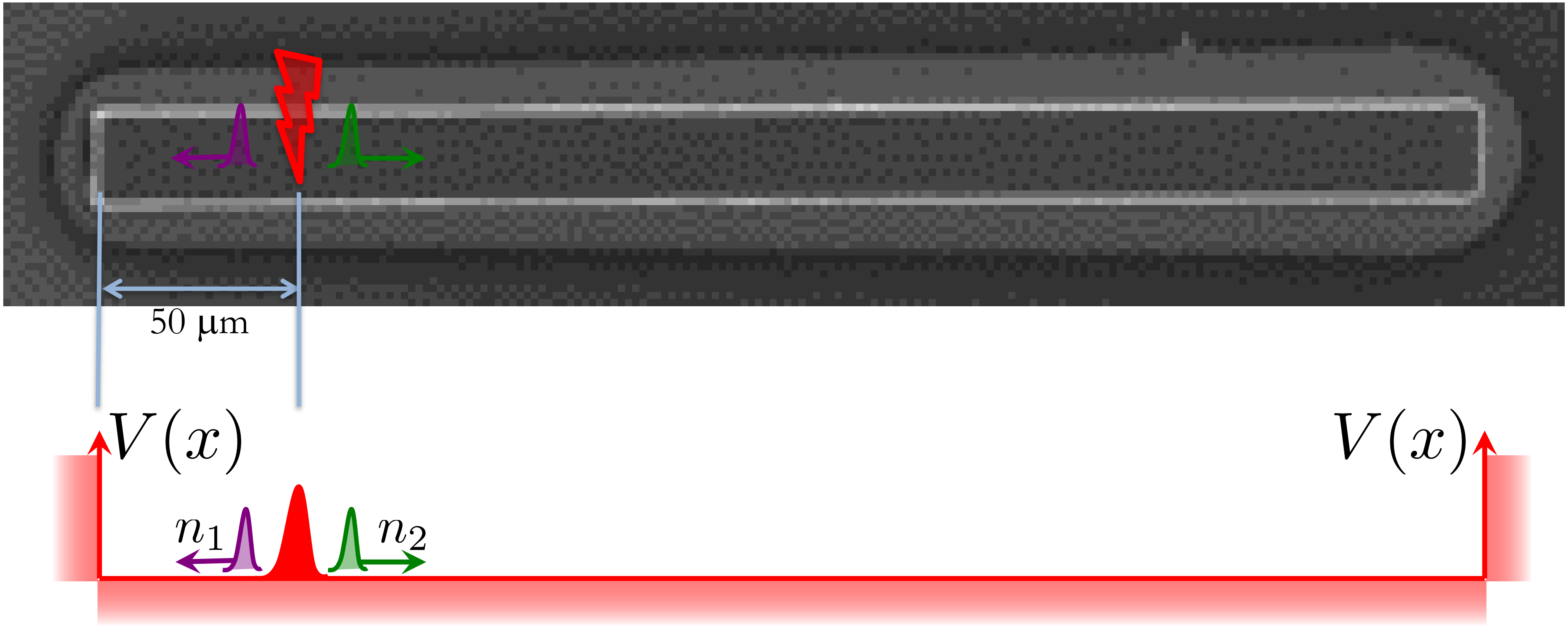
Description of the sample



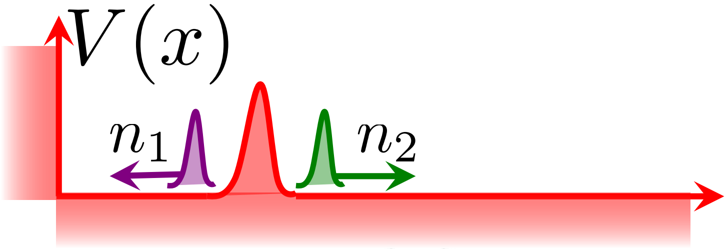
high-quality AlGaAs-based microcavity

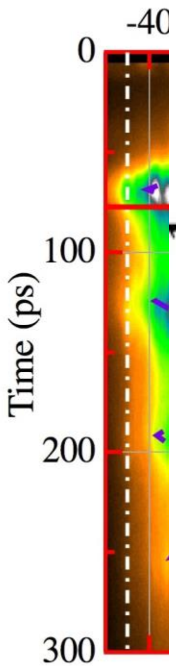
Experimental **results**

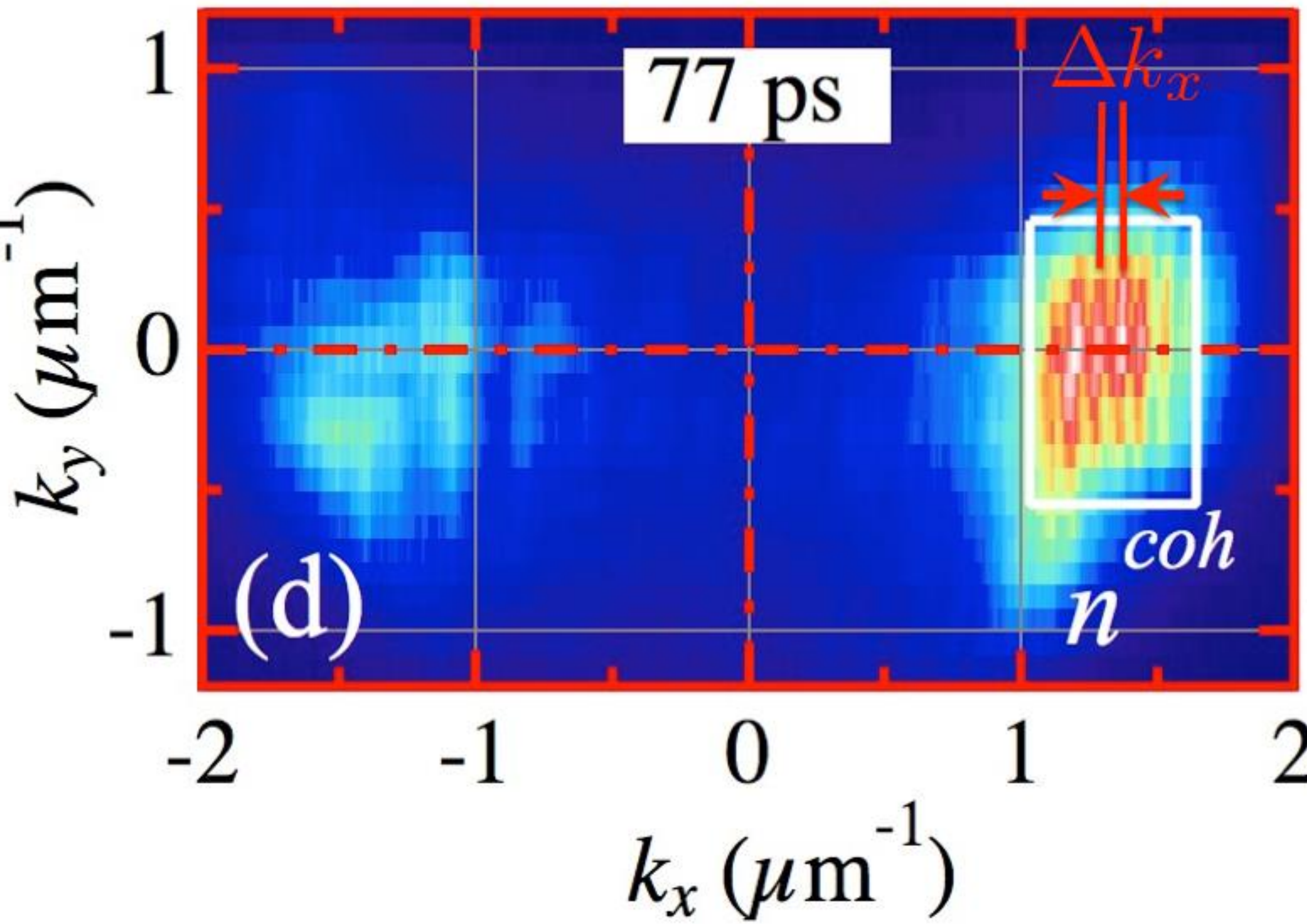
1st **Observation** of phase-locking in momentum space between polariton condensates



1st **Observation** of phase-locking in momentum space between polariton condensates

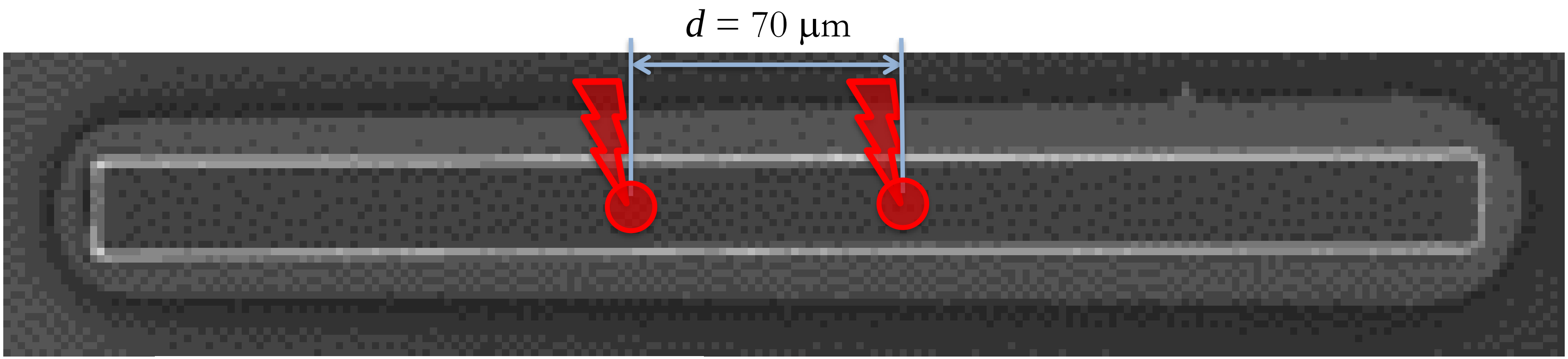


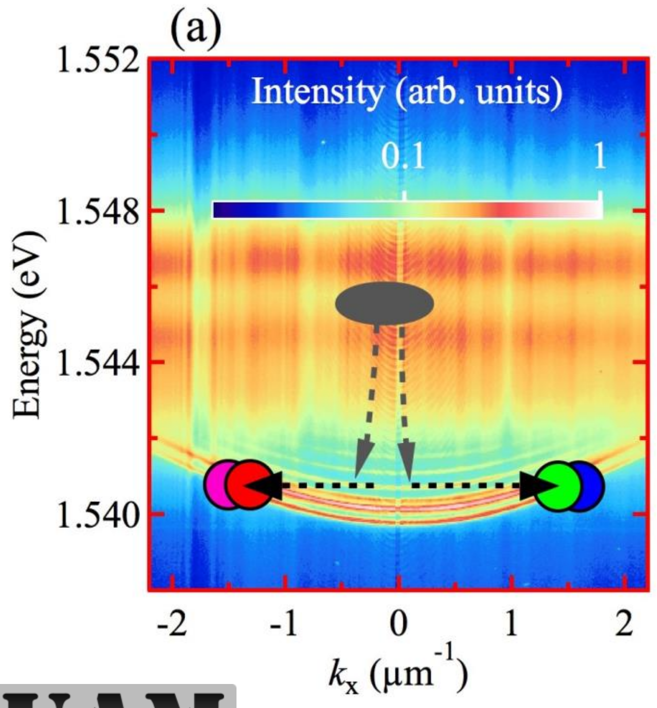


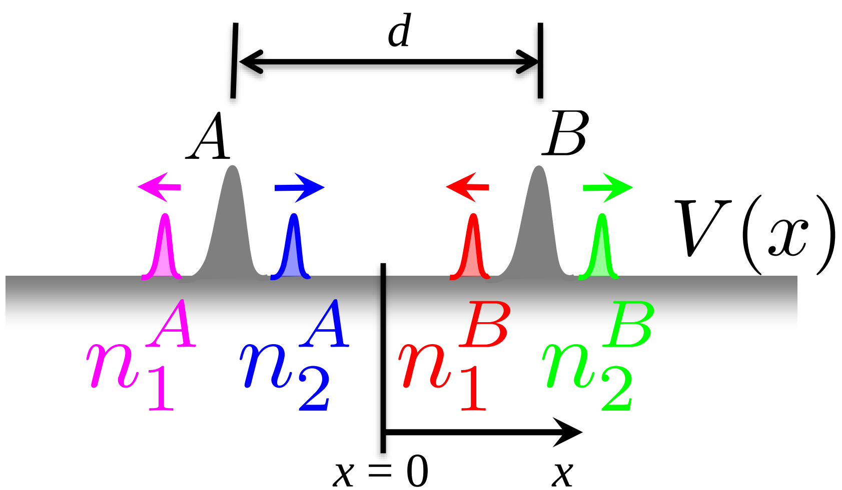


)83 μm^{-1}

Full observation of the phase-locking in momentum space between polariton condensates



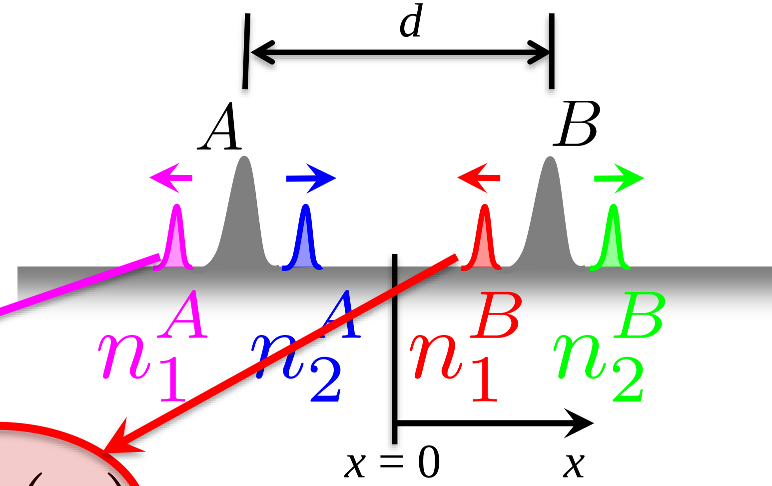




Left propagating wave-trains

$$\psi_1^A\left(x-d/2\right)=\psi_1^B\left(x+d/2\right)=\psi_0\left(x\right)$$

$$\psi_1^A(k_x)e^{-ik_x\frac{d}{2}}=\psi_1^B(k_x)e^{+ik_x\frac{d}{2}}=\psi_0(k_x)$$



$$\Psi_1^{coh}\left(x\right)=\psi_1^A\left(x\right)+e^{i\phi}\psi_1^B\left(x\right)$$

$$\Psi_1^{coh}\left(k_x\right)=\psi_1^A\left(k_x\right)+e^{i\phi}\psi_1^B\left(k_x\right)=$$

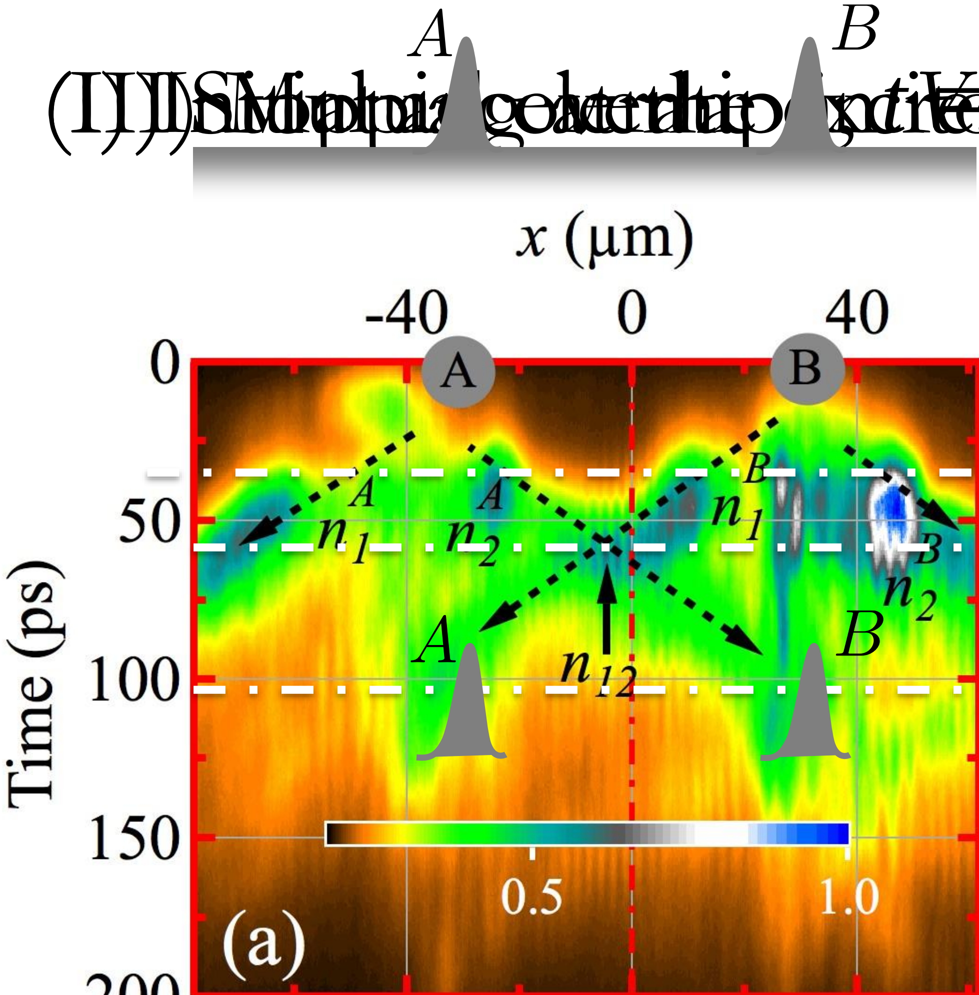
$$e^{-ik_xd/2}\psi_0\left(k_x\right)+e^{i(\phi+k_xd/2)}\psi_0\left(k_x\right)$$

$$n_1^{coh}\left(k_x\right)=\left|\Psi_1^{coh}\left(k_x\right)\right|^2=2\left[1+cos\left(k_xd+\phi\right)\right]\left|\psi_0\left(k_x\right)\right|^2$$

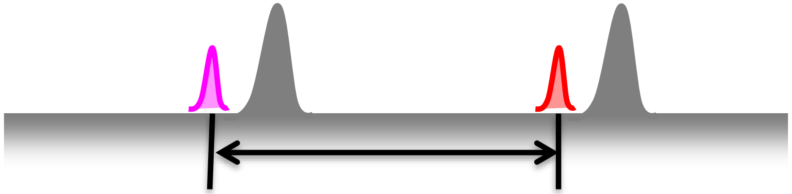
Interferences!

$$\Delta k_x=2\pi/d$$

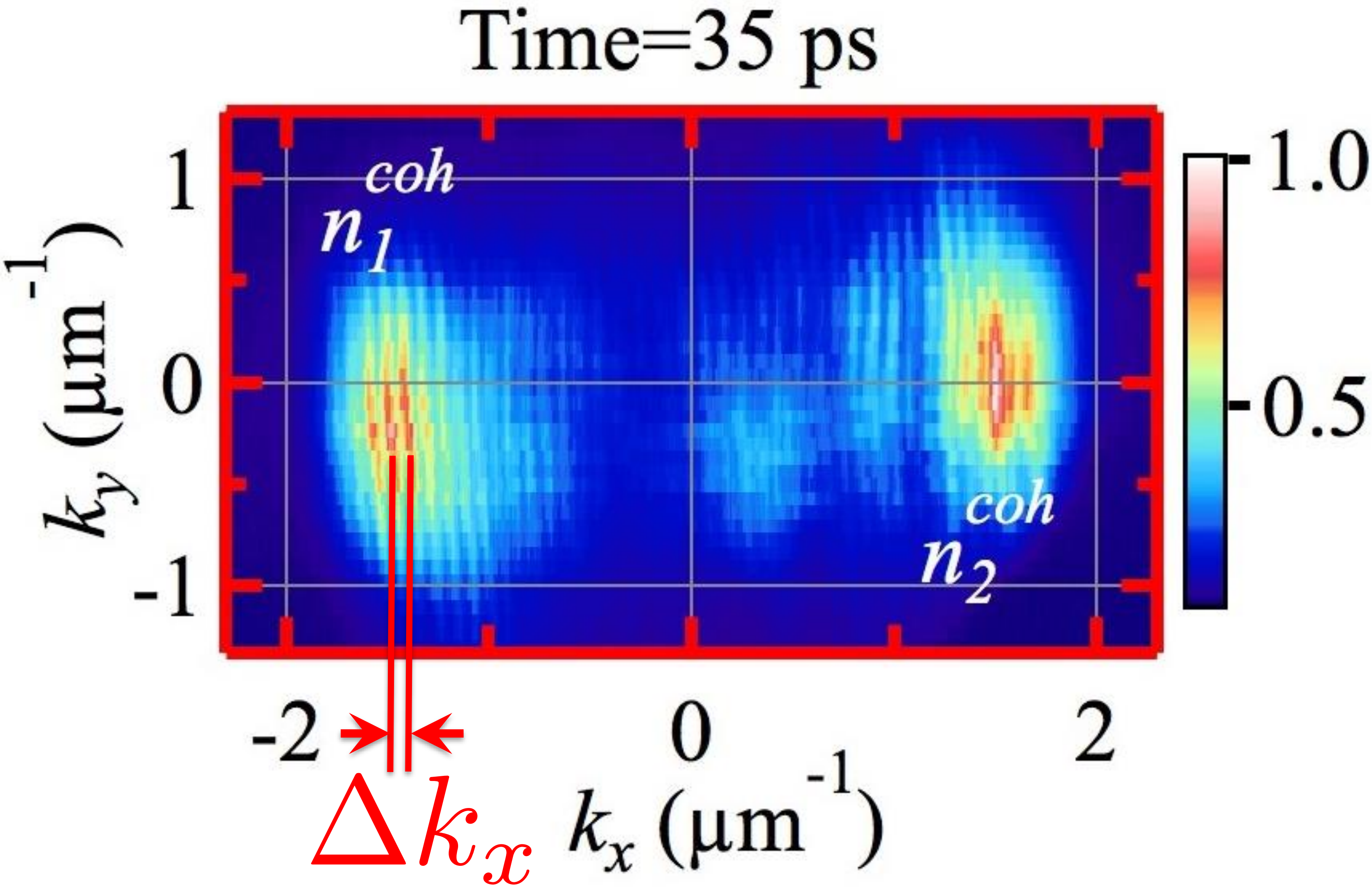
Full observation of the phase-locking in momentum space between polariton condensates



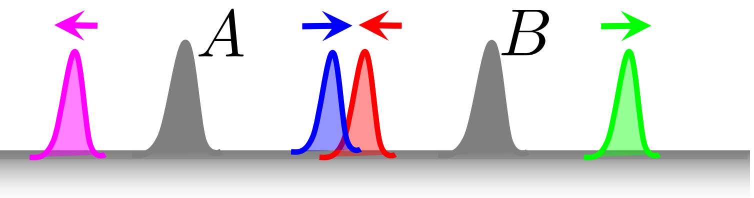
(I) Initial acceleration



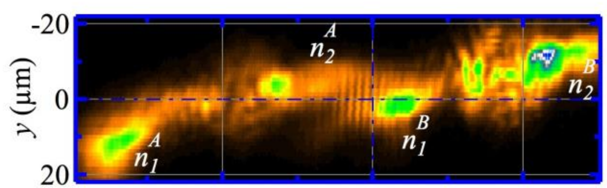
(I) Initial acceleration

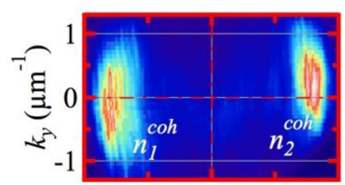


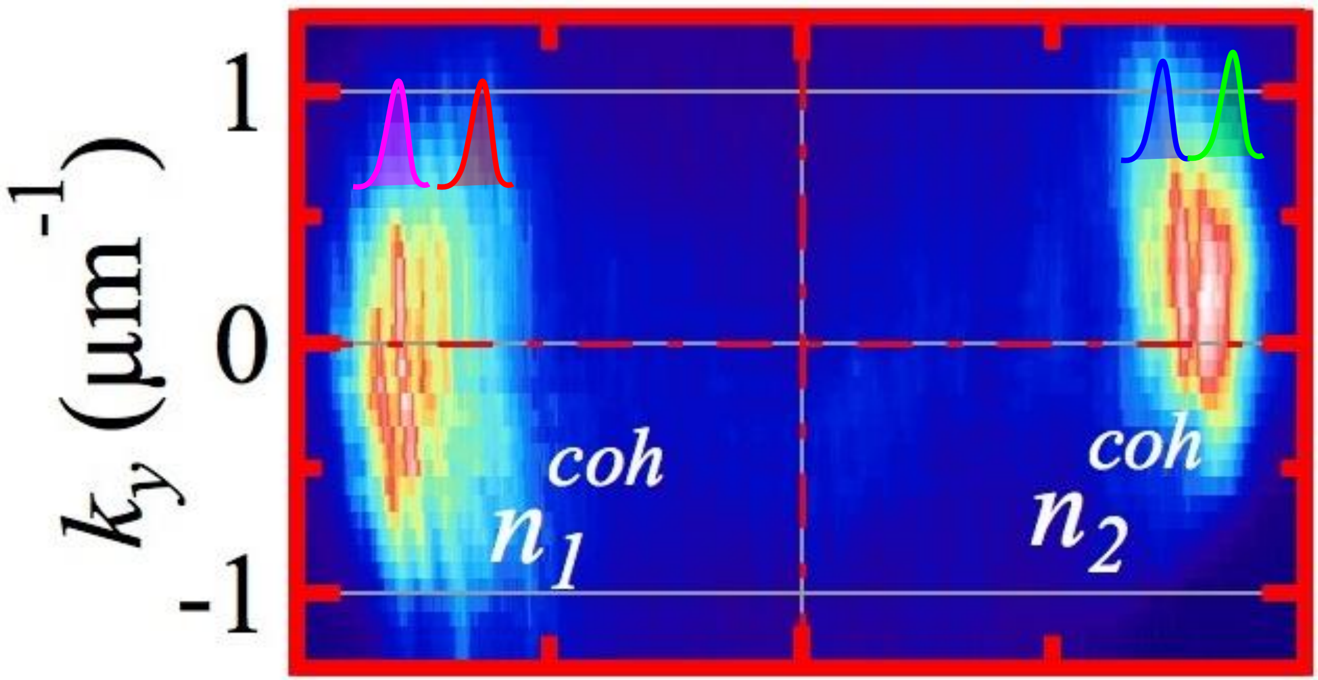
[III] **Checking** the origin of interferences in **k**-space



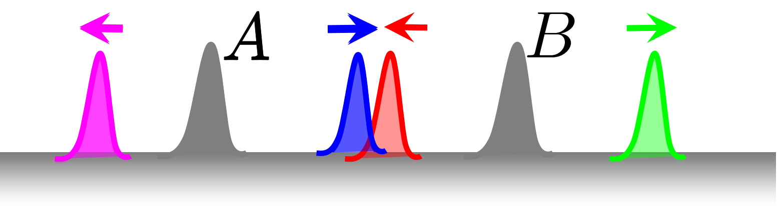
Time = 53 ps

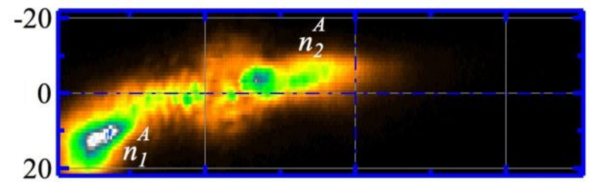


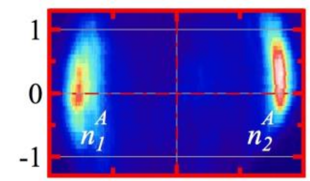


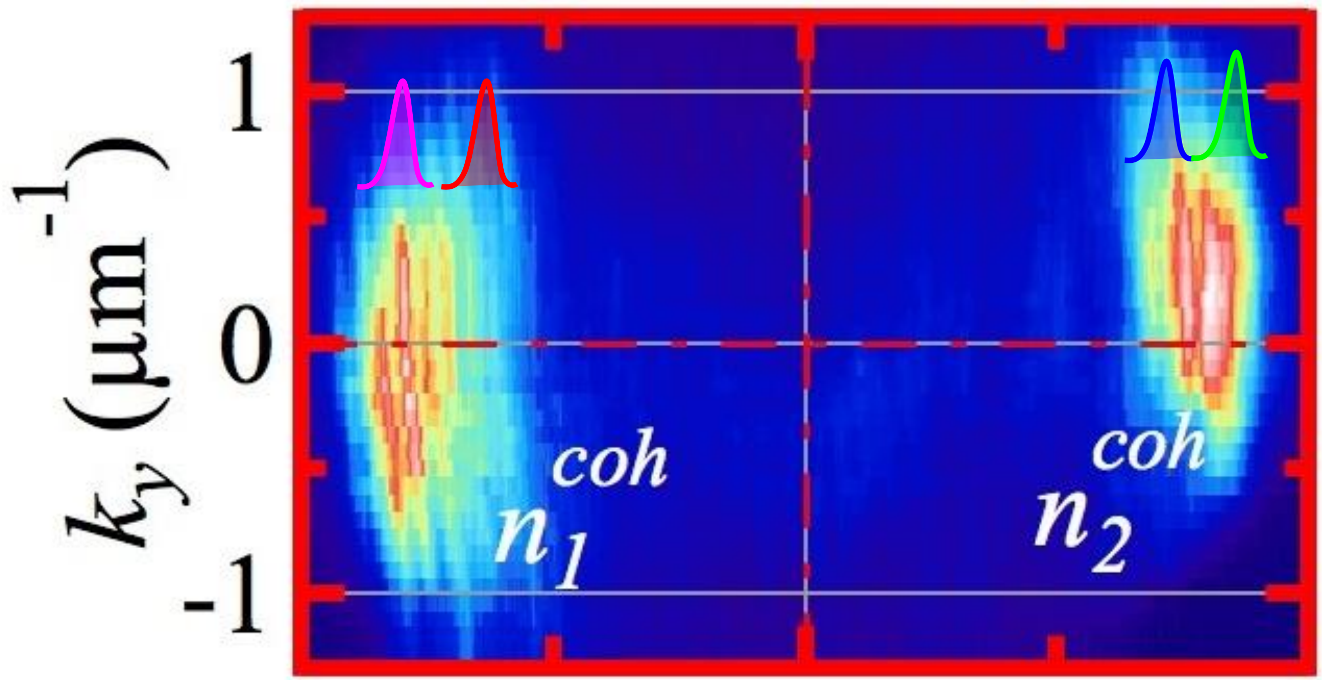


[III] **Checking** the origin of interferences in **k**-space

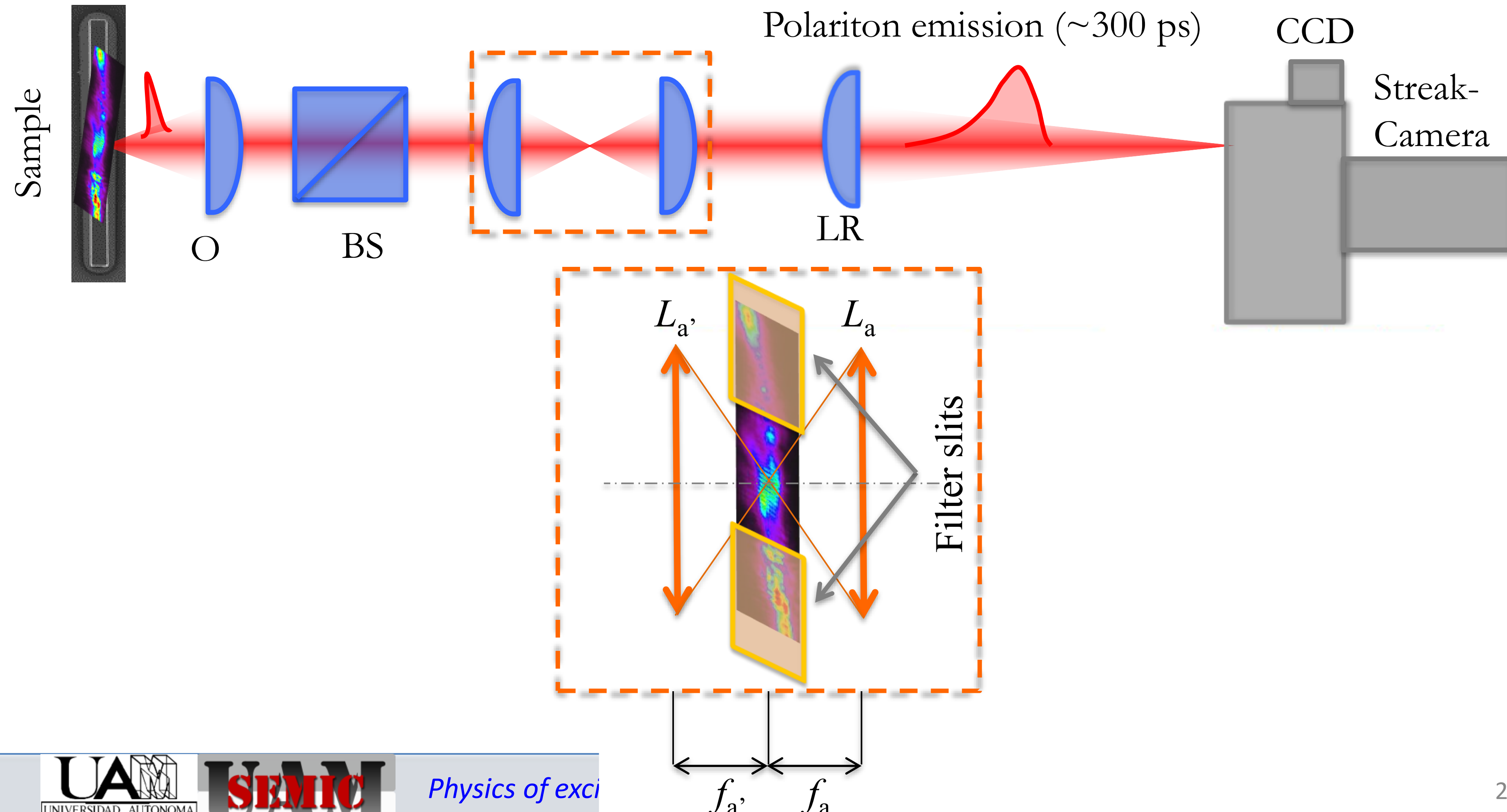




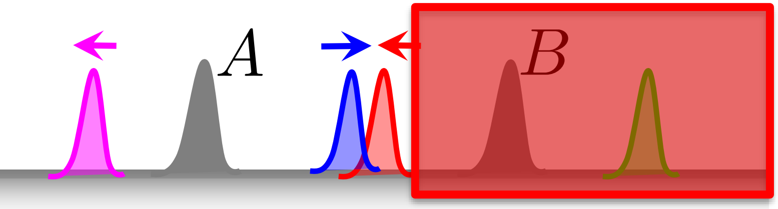


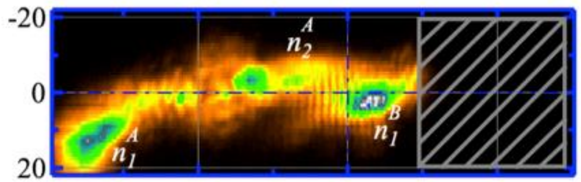


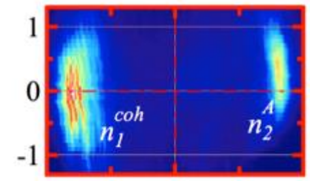
[III] **Checking** the origin of interferences in **k**-space

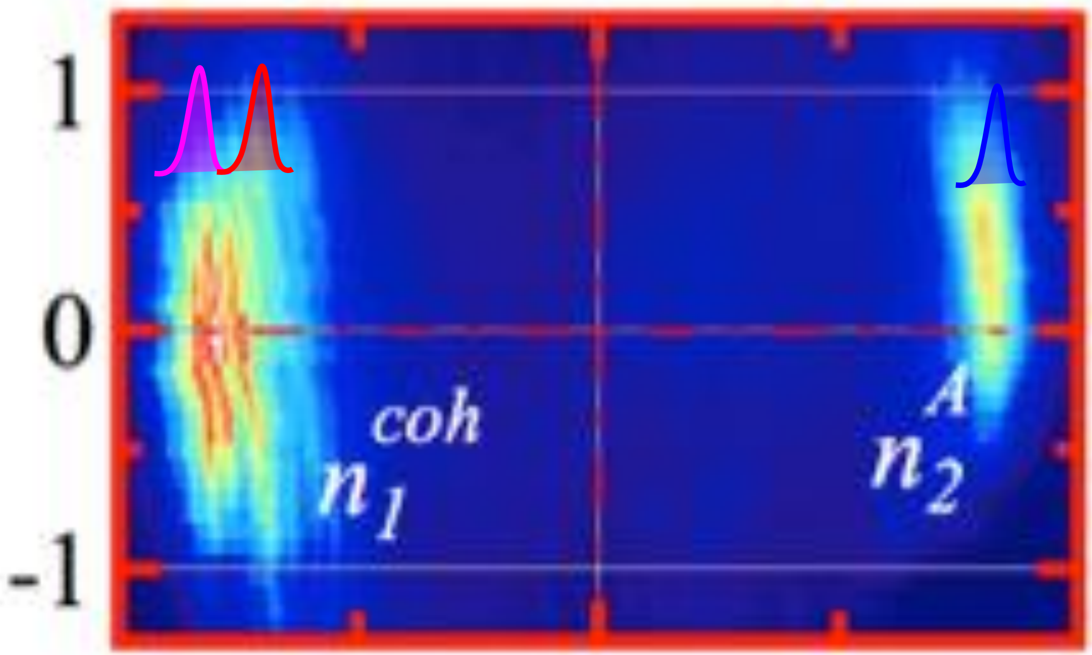


[III] **Checking** the origin of interferences in **k**-space

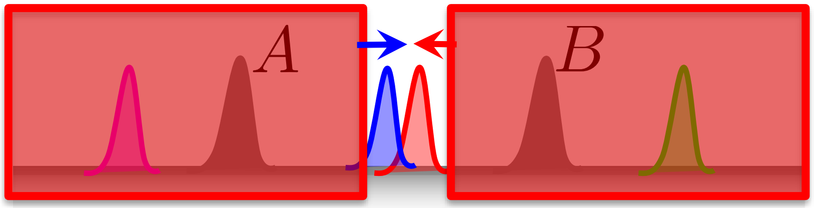


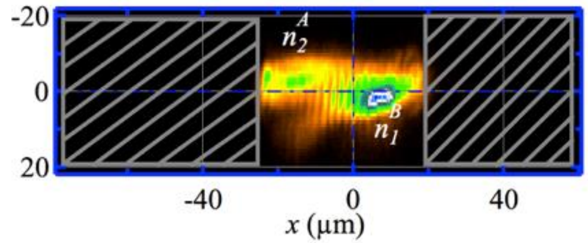


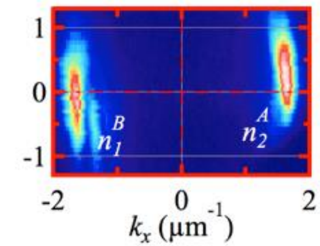


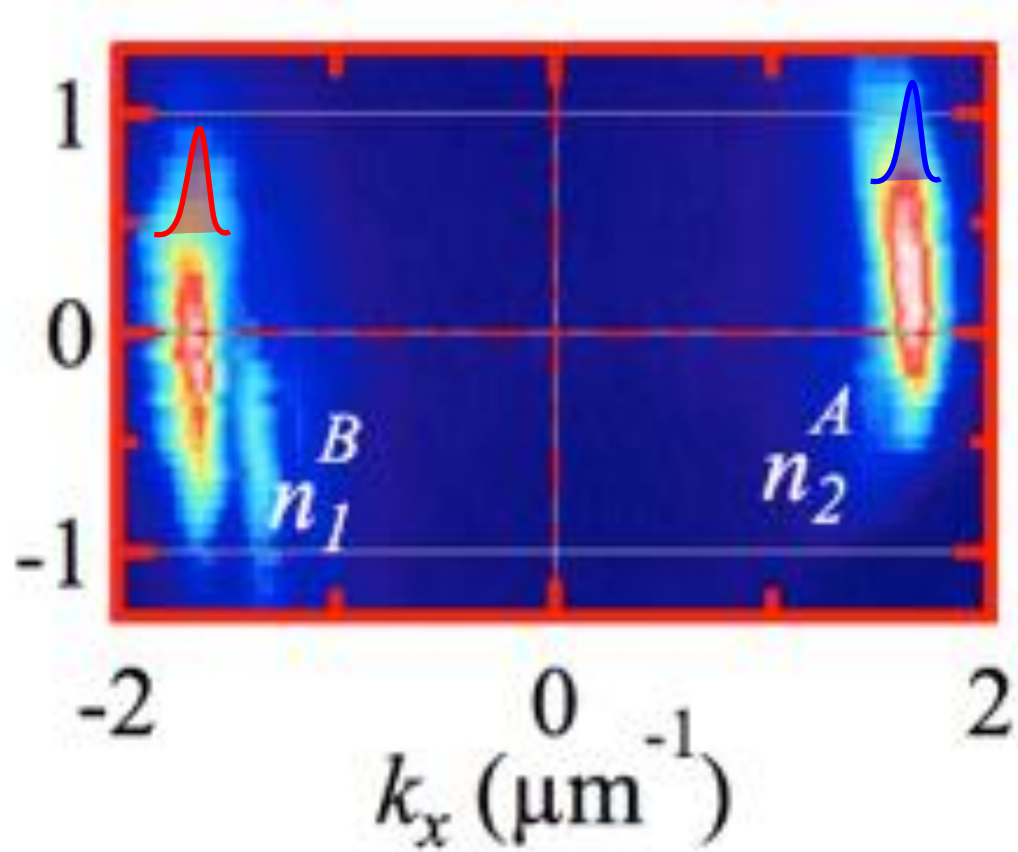


[III] **Checking** the origin of interferences in **k**-space

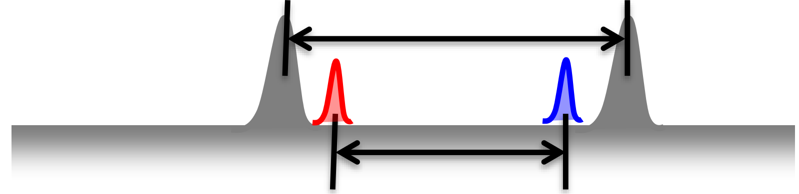


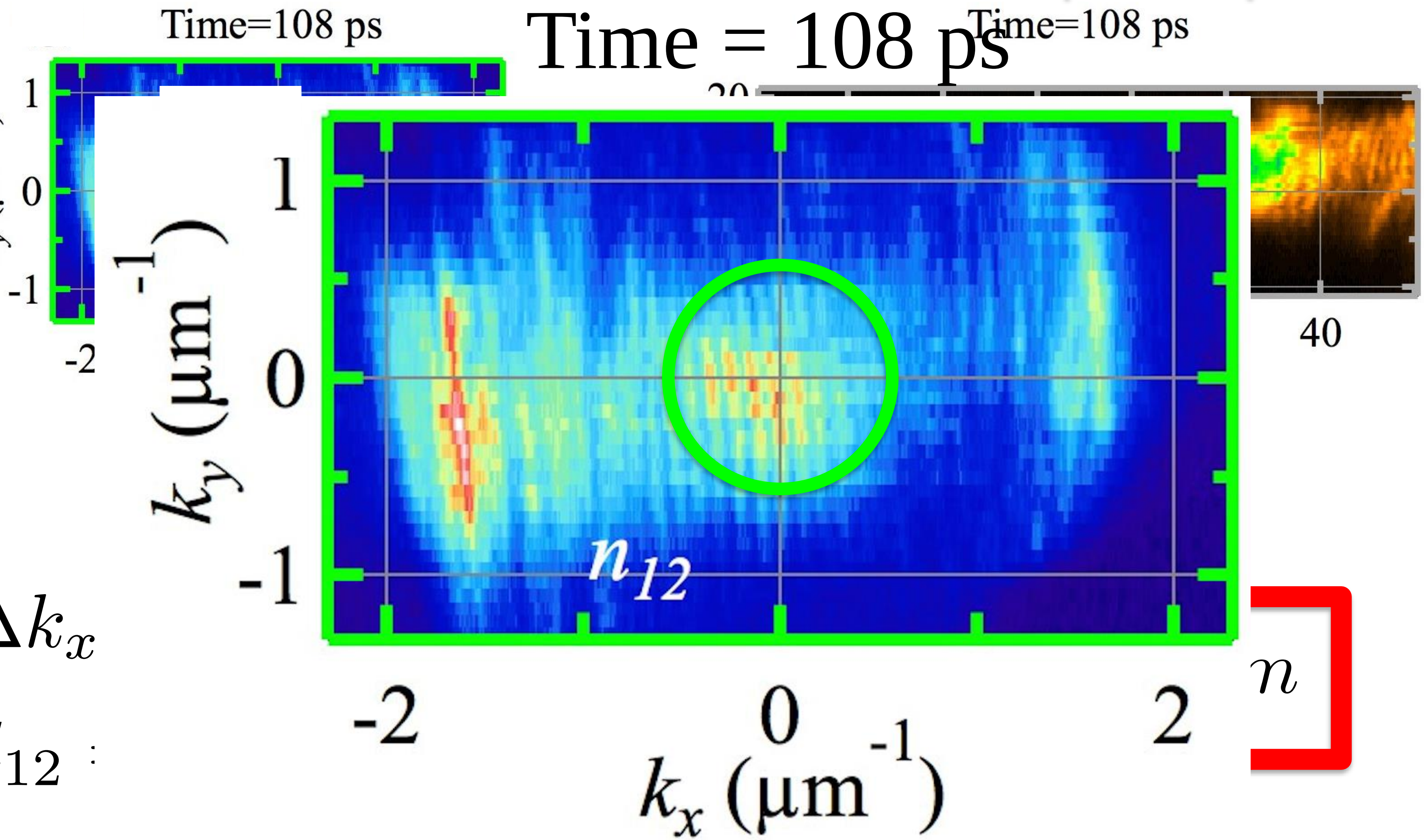






(II) Stopping at the barriers

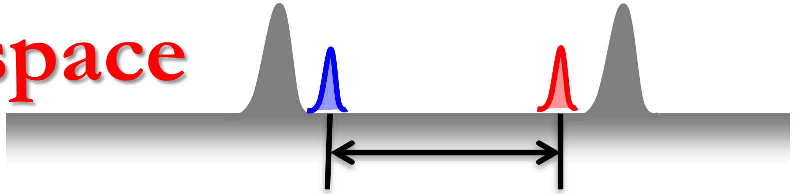




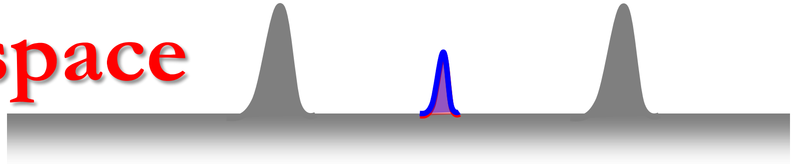
Δk_x

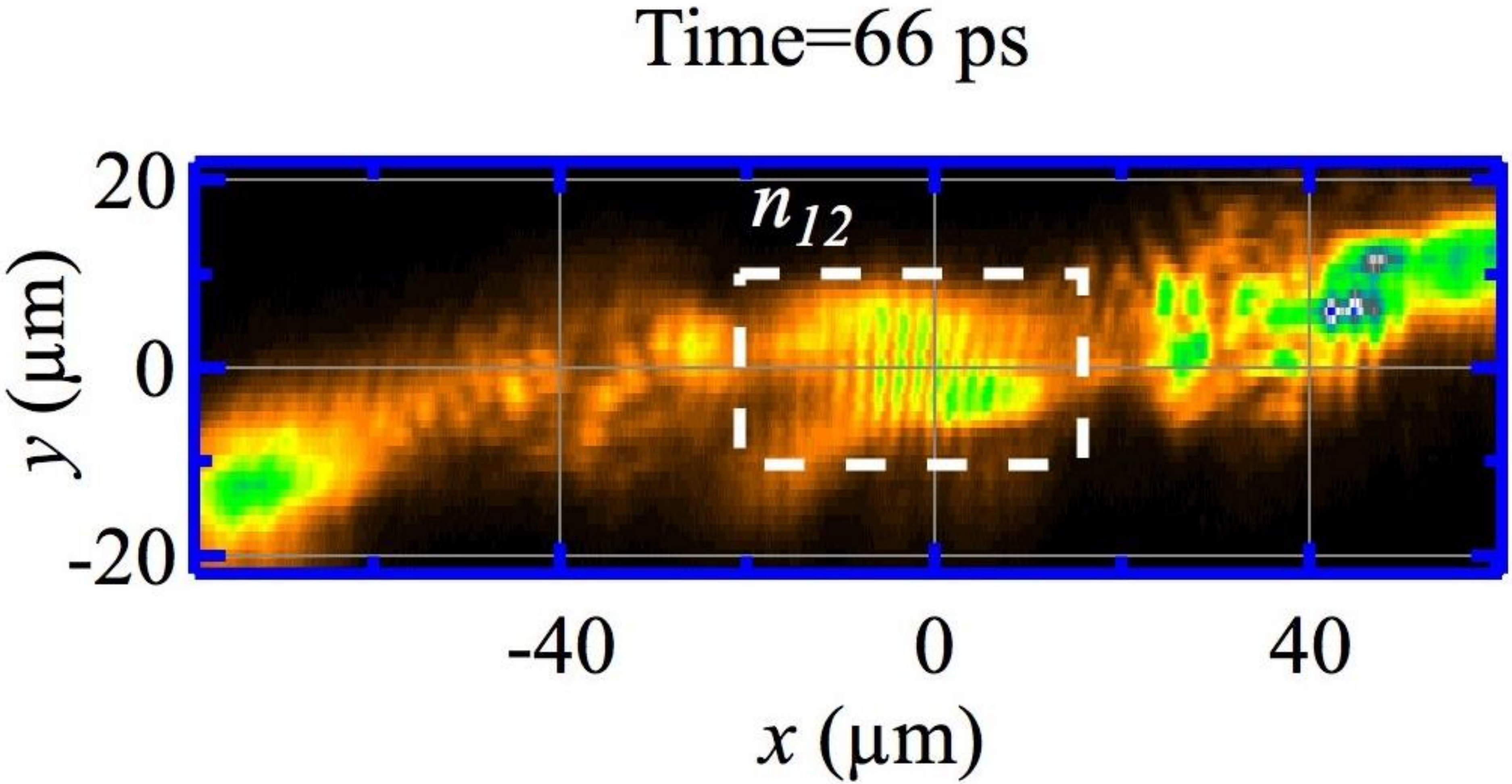
d_{12} :

(III) Mutual overlap in real space

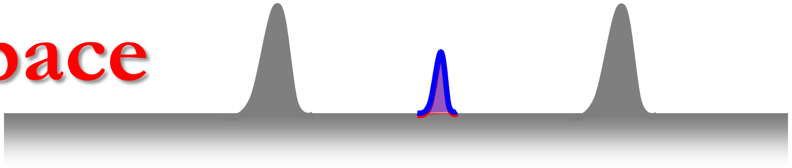


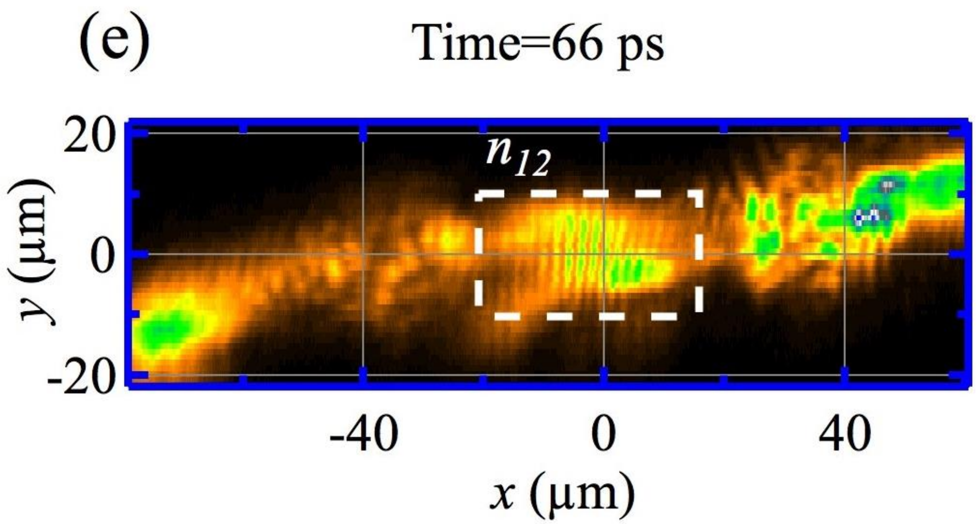
(III) Mutual overlap in real space





(II) Mutual overlap in real space

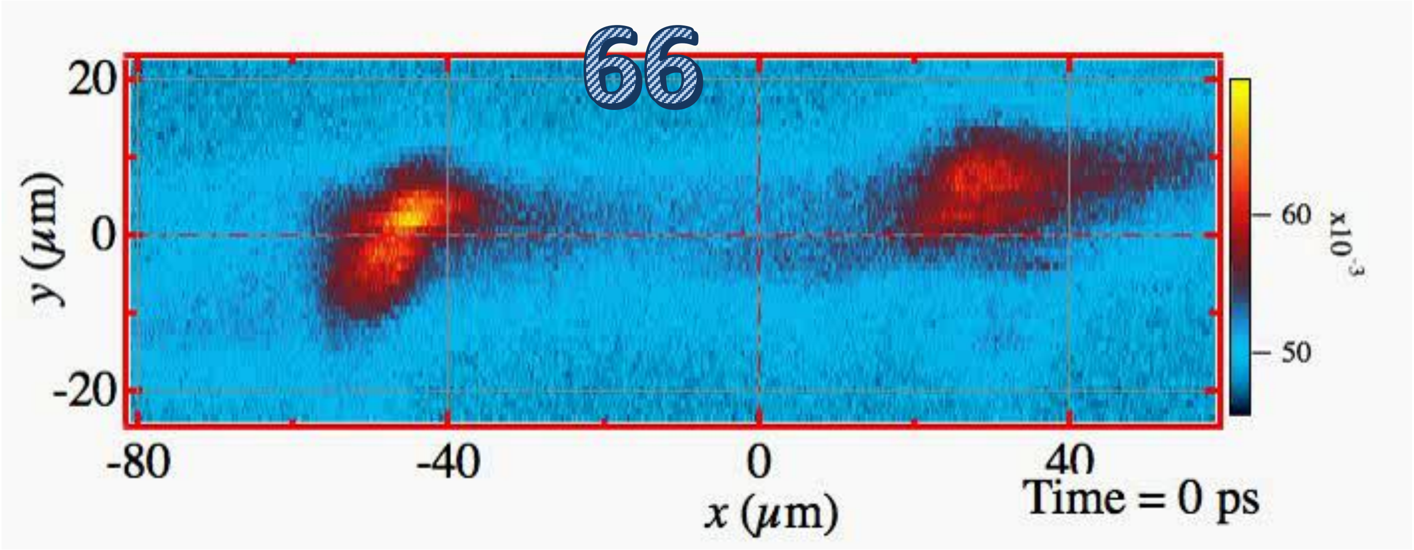


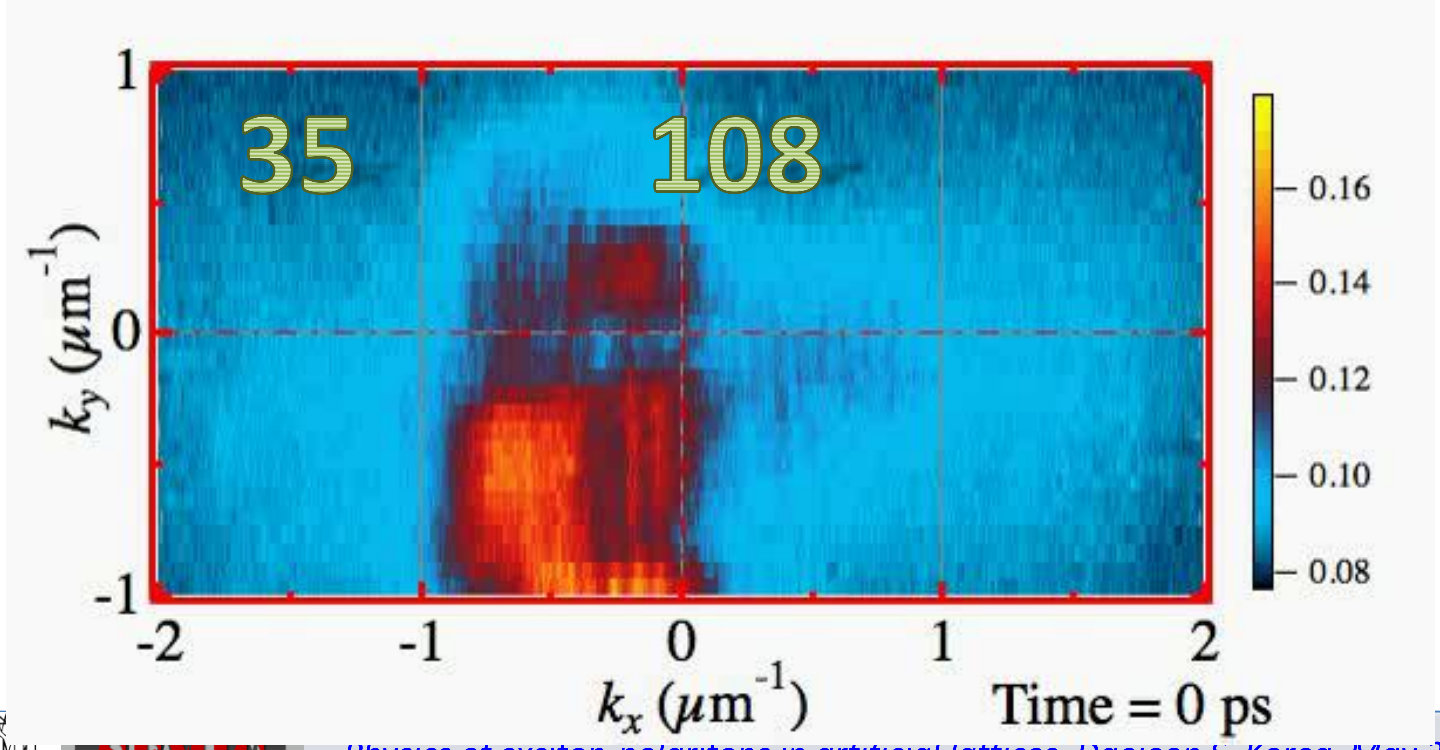


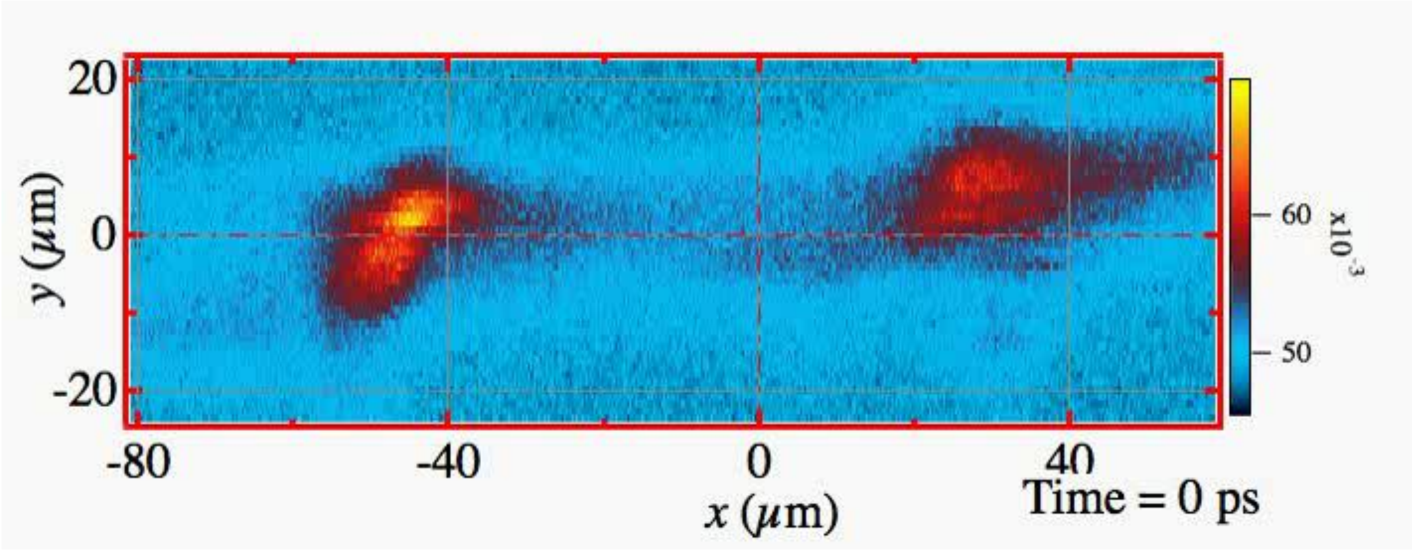
$$\Delta x = 1.99\ \mu m$$

$$\Delta x = 2\pi/\kappa$$

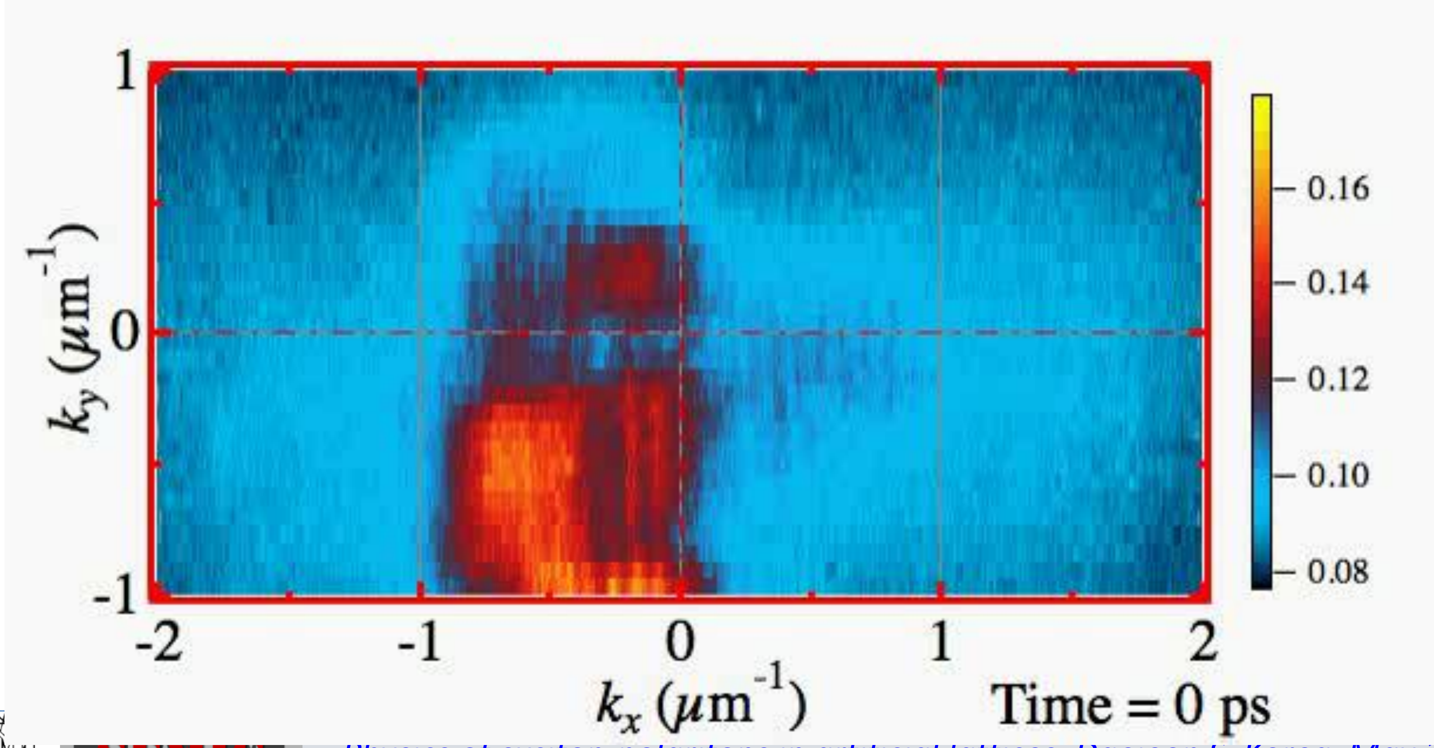
$$\kappa = 3.2\ \mu m^{-1}$$


66
20
0
-20
y (μm)
-80
-40
0
40
x (μm)
Time = 0 ps
60
50
x10^{-3}


35
108
1
0
-1
k_y (μm^{-1})
-2
-1
0
1
2
k_x (μm^{-1})
Time = 0 ps
0.16
0.14
0.12
0.10
0.08



20
0
-20
y (μm)
-80
-40
0
40
x (μm)
Time = 0 ps
60
50
x10^-3



1
0
-1
k_y (μm^-1)
-2
-1
0
1
2
k_x (μm^-1)
Time = 0 ps
0.16
0.14
0.12
0.10
0.08

What fixes the phase ϕ in a multi-shot experiment?

$$n_1^{coh}(k_x) = \left|\Psi_1^{coh}(k_x)\right|^2 = 2\left[1+\cos(k_x d + \phi)\right]\left|\psi_o(k_x)\right|^2$$

PHYSICAL REVIEW B **85**, 121301(**R**) (2012)

Radiative coupling and weak lasing of exciton-polariton condensates

I. L. Aleiner,[1] B. L. Altshuler,[1] and Y. G. Rubo[2]

.....radiative coupling caused by the interference of the light emitted by different centers

arXiv.org > cond-mat > arXiv:1406.6377

Condensed Matter > Other Condensed Matter

Dissipative phase locking of exciton-polariton condensates

H. Ohadi, R. L. Gregory, T. Freegarde, Y. G. Rubo, A. V. Kavokin, P. G. Lagoudakis

PHYSICAL REVIEW X **6**, 031032 (2016)

Nontrivial Phase Coupling in Polariton Multiplets

H. Ohadi,[1] R. L. Gregory,[1] T. Freegarde,[1] Y. G. Rubo,[2] A. V. Kavokin,[1,3] N. G. Berloff,[4,5,*] and P. G. Lagoudakis[1,4,†]

...for two spatially separated condensates the dissipative coupling leads to the phase locking, either in-phase or out-of-phase, between the condensates

Conclusions:

- Remote phase locking in momentum space
- Temperature dependence of phase transition