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ATOMINSTITUT
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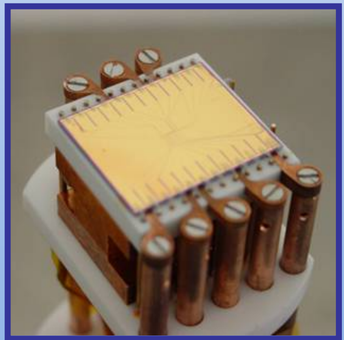
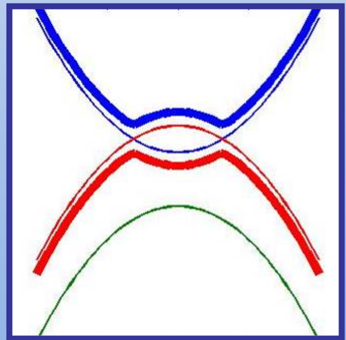
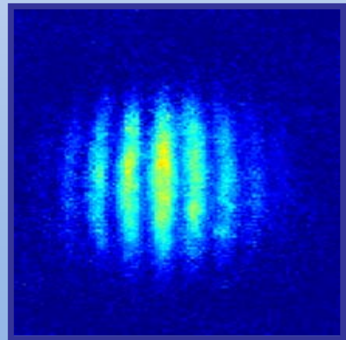
TU WIEN

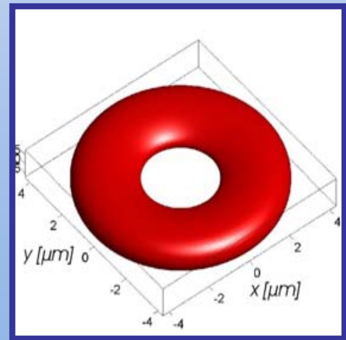
Interference with Bose-Einstein condensates on atom chips

Sebastian Hofferberth, Igor Lesanovsky, Bettina Fischer,
Thorsten Schumm, Jörg Schmiedmayer



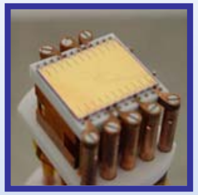




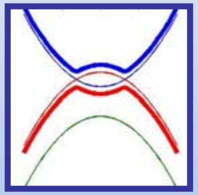


International workshop on
„Advances in precision tests and experimental gravity in space“

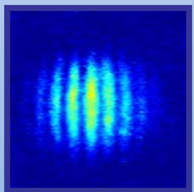
Outline:



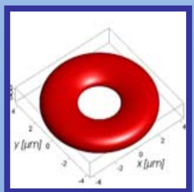
A brief introduction to atom chips: magnetic wire traps



A tunable double well potential based on RF adiabatic potentials



A matter wave interferometer based on dynamic splitting of a BEC



Further experiments and outlook

magnetic wire traps

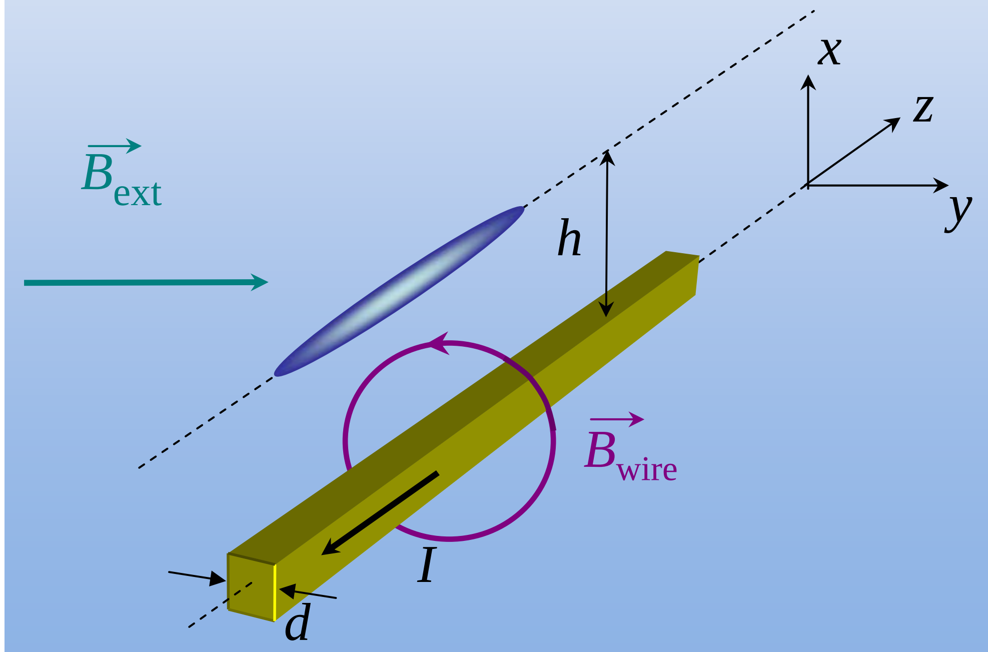
Use the interaction of the magnetic moment of an atom with an external field:

$$V = -\vec{\mu}.\vec{B} \approx g_F \, m_F \, \mu_B \left|\vec{B}\right|$$

trap atoms at minimum of $|B|$

($g_F \, m_F$=1 for ^{87}Rb in m_F=2)

3D trapping needed!



magnetic wire traps: the Z wire trap

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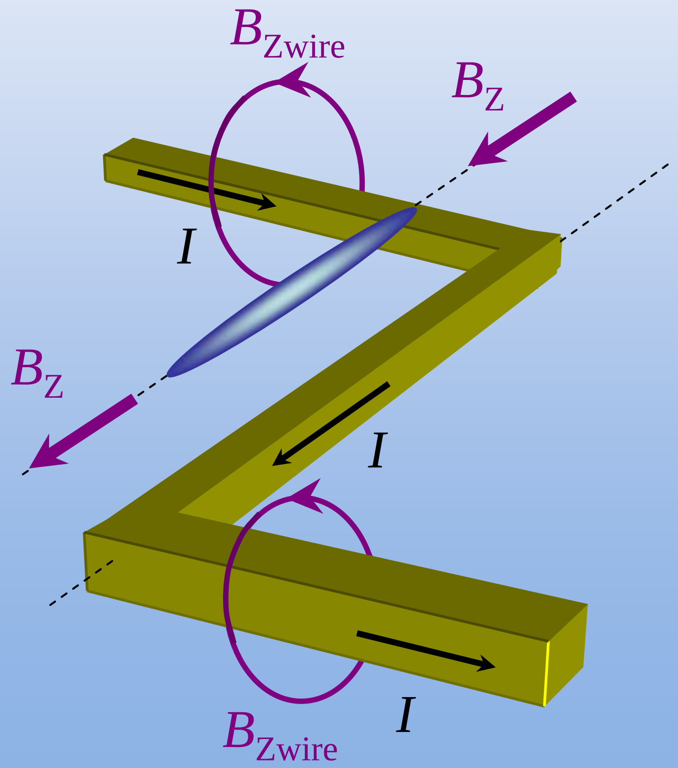
provided by Z wire geometry



magnetic wire traps: the Z wire trap

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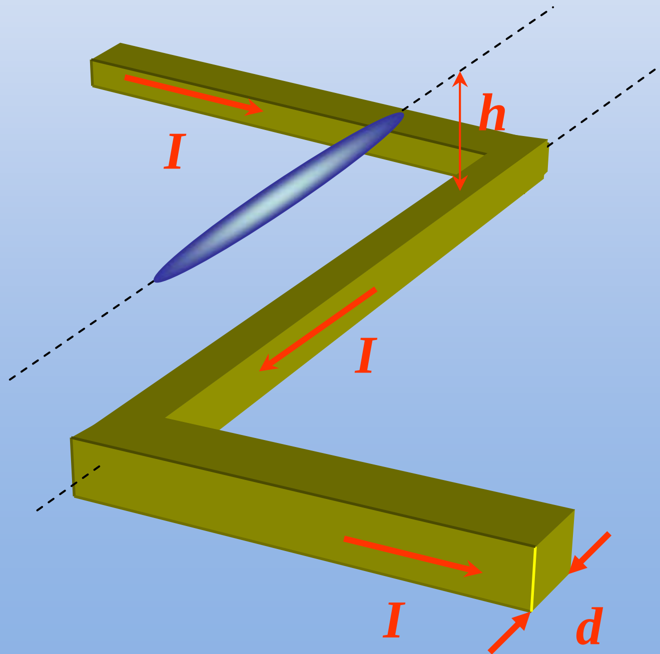
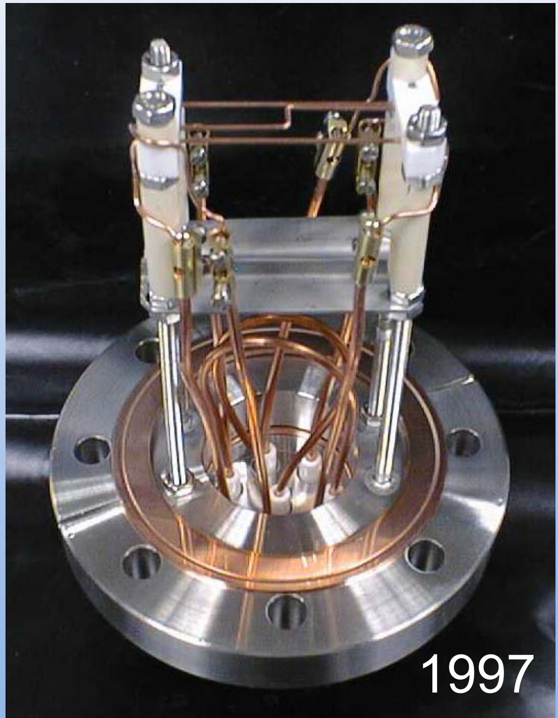


reducing wire size d,
wire current I and
atom–wire separation h
increases the atomic confinement

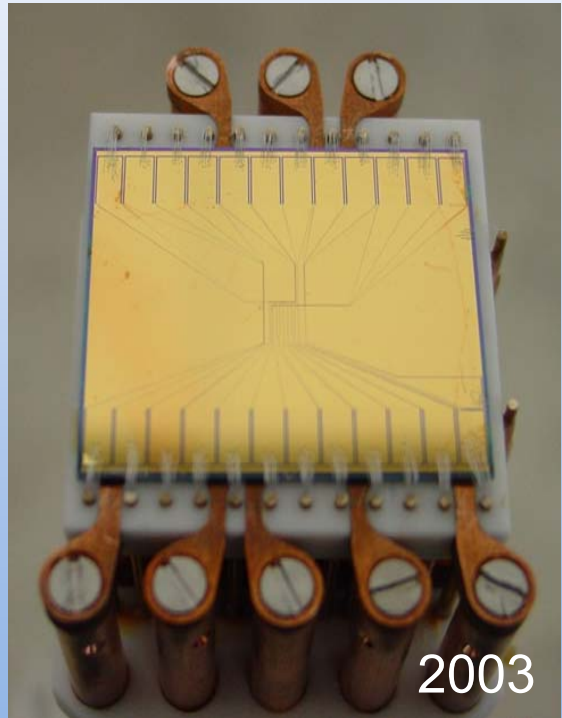
miniaturization of atom chip structures

magnetic atom chip traps: miniaturization

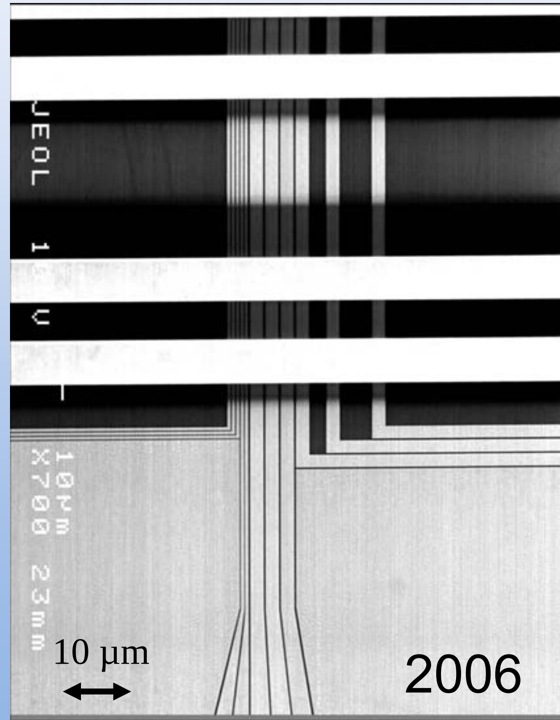
macroscopic wire structures	microfabricated wire structures (optical lithography)	microfabricated wire structures (double layer e-beam lithography)



millimeters



100 – 10 microns



1 micron

miniaturizing wire sizes, reducing wire current, bringing atoms close to wire structures

Integrated atom optics with atom chips ?

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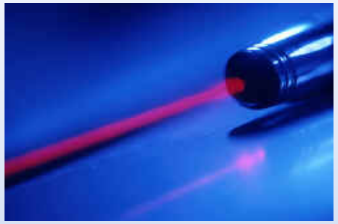
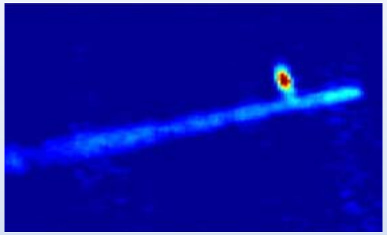
photon optics — atom optics

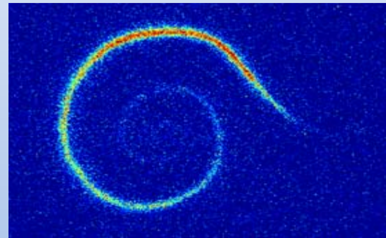
Lasers





on chip BEC production

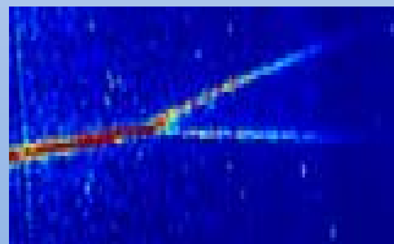
Fibers



monomode guiding, conveyor belts

Beam splitters

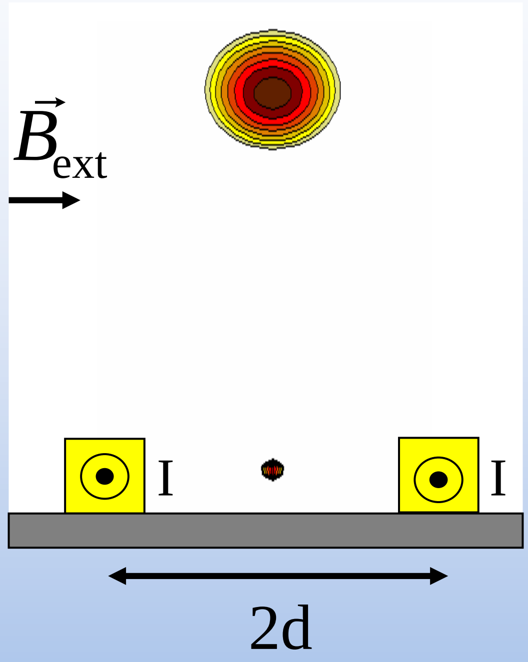
?



coherent beam splitting with BEC?

goal: (portable?) interferometers on atom chips

an atom chip beam splitter: the two wire scheme



Calarco *et al*, PRA **61**, 22304 (2000)
Zobay / Garraway Opt. Com. 178, 93 (2000)
Hinds et al, PRL **86**, 1462 (2001)

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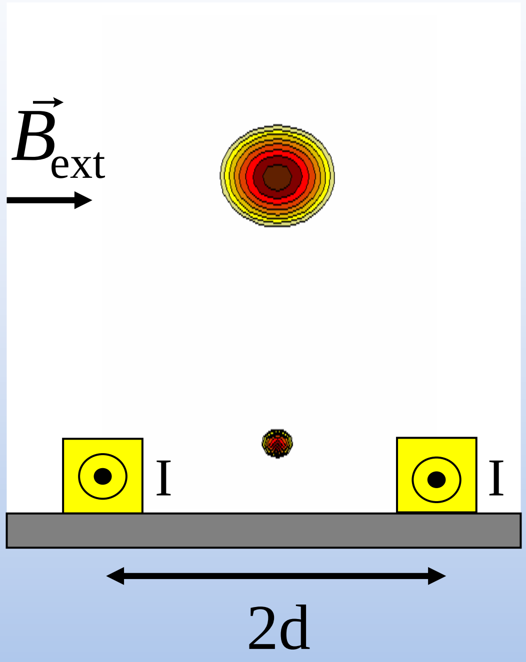

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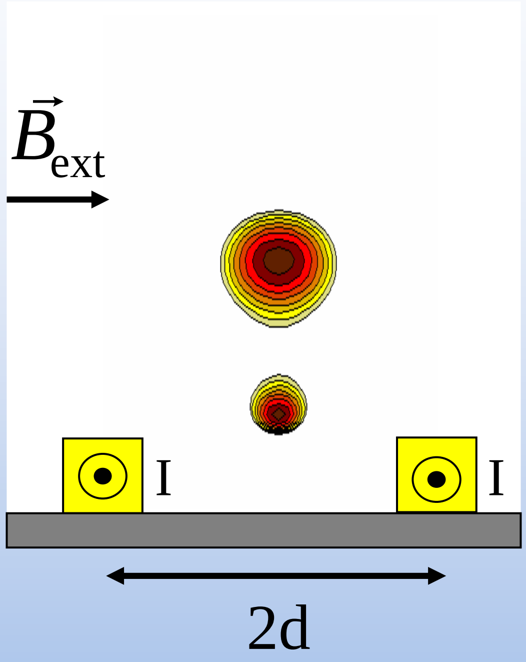

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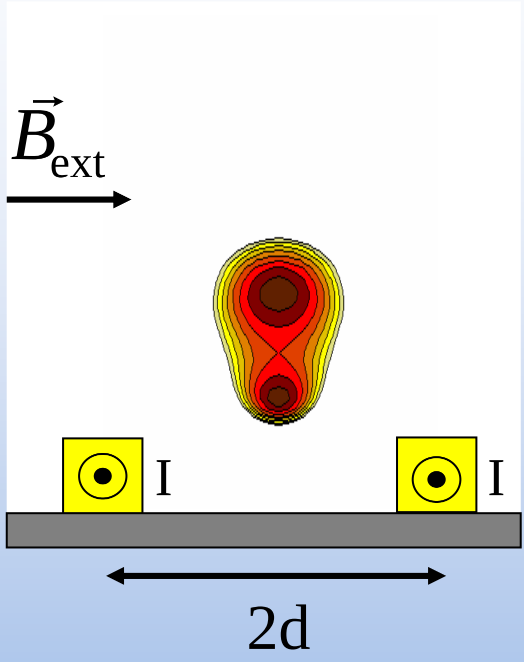

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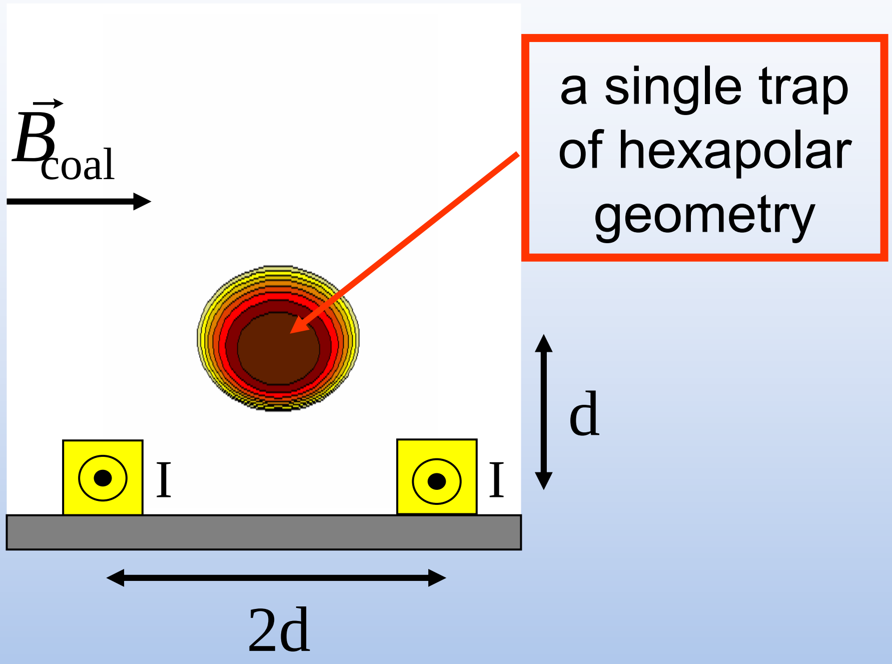

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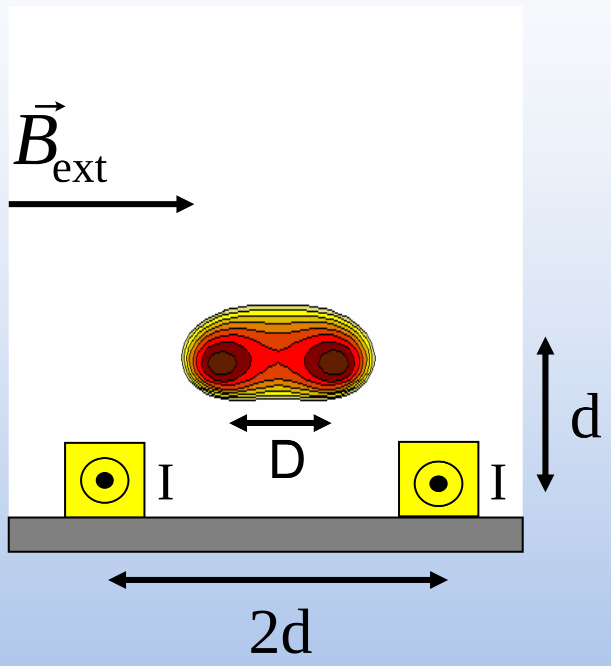
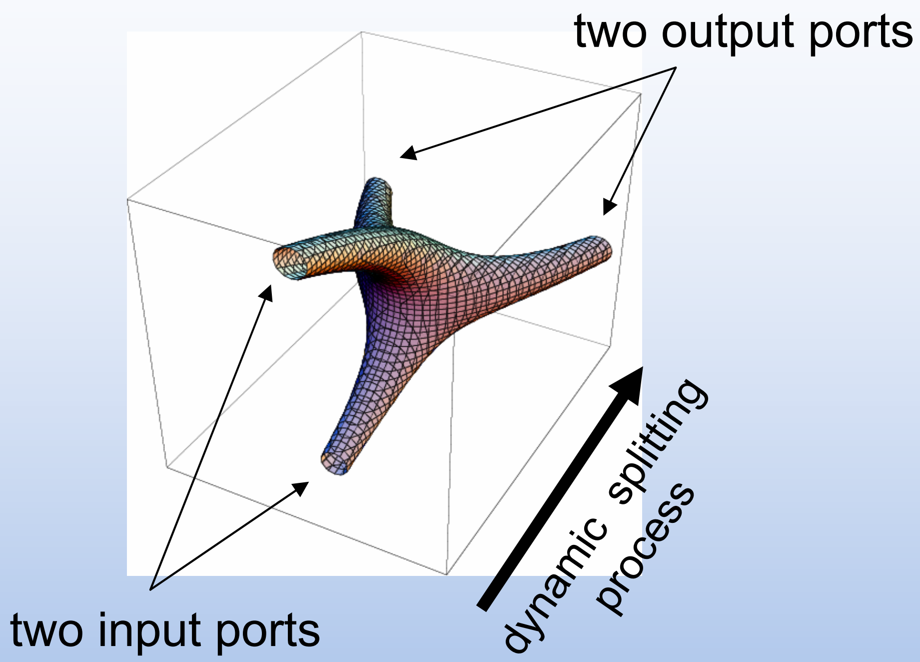




The two wire scheme is extremely sensitive to fluctuations:

- wire size approx. splitting distance (d $\simeq$ D, needs micron size wires)
- atoms very close to surface (heating, fragmentation)
- 10^{-4} stability on external fields (needs magnetic shielding)

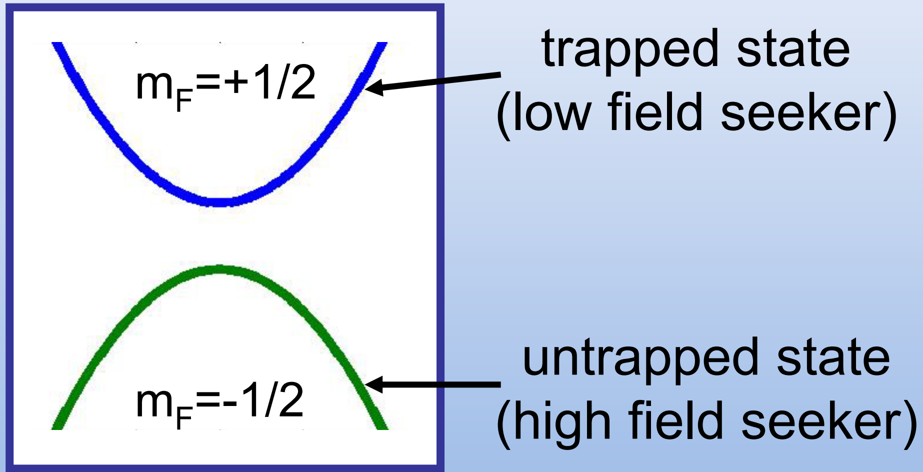
coherent splitting using this scheme failed so far

Y. Shin *et al*, PRA **72**, 21604 (2005)

an atom chip beam splitter: adiabatic dressed rf potentials

Idea: combine static magnetic trap with RF fields to couple different magnetic states → **adiabatic potentials**

bare states



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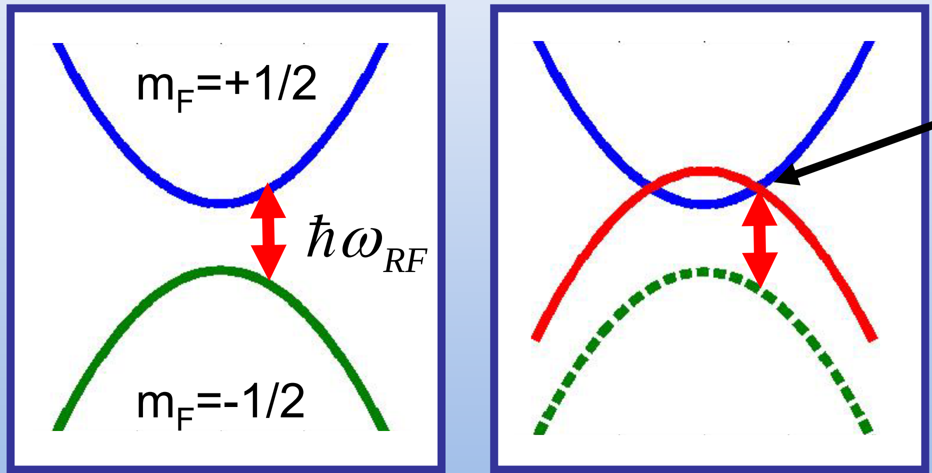

$$\hbar\omega_{RF} = \mu_B \,|\, \vec{B}_{trap}(r) \,|$$

crossing **position** controlled by **RF frequency**

an atom chip beam splitter: adiabatic dressed rf potentials

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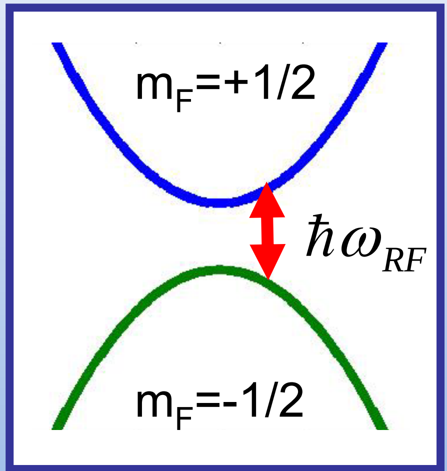
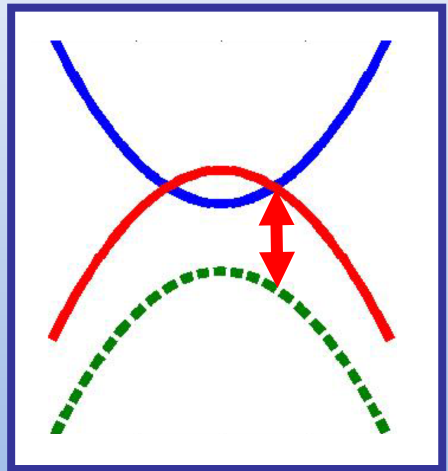
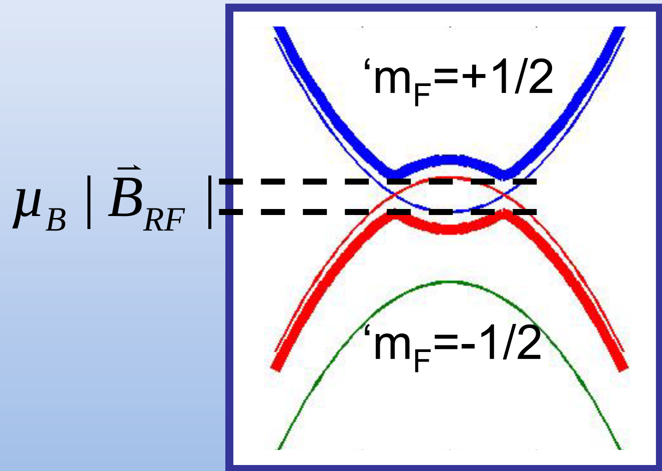




crossing **position** controlled by **RF frequency**

dressed states

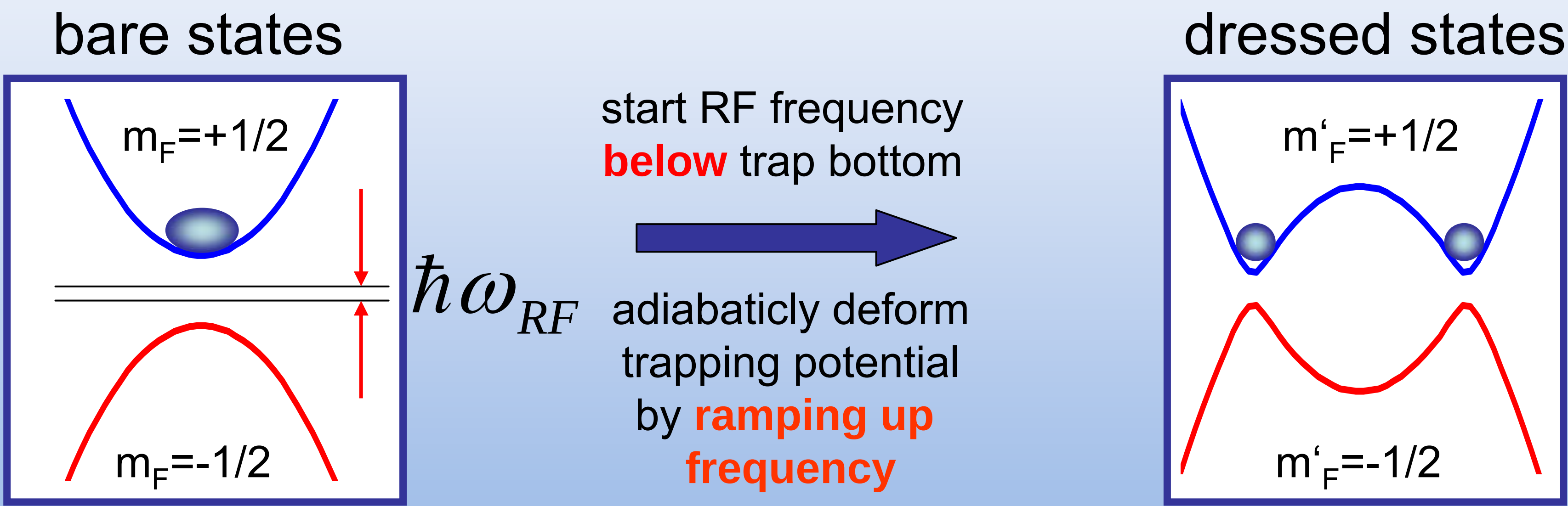


level **repulsion** controlled by **RF amplitude**

Zobay / Garraway PRL **87**, 1195 (2001)
Colombe *et al*, Europhys. Lett. **67** ,593 (2004)

an atom chip beam splitter: adiabatic dressed RF potentials

A single trap can be deformed to a double well potential by controlling RF **frequency** and **amplitude**:



an atom chip beam splitter: adiabatic dressed RF potentials

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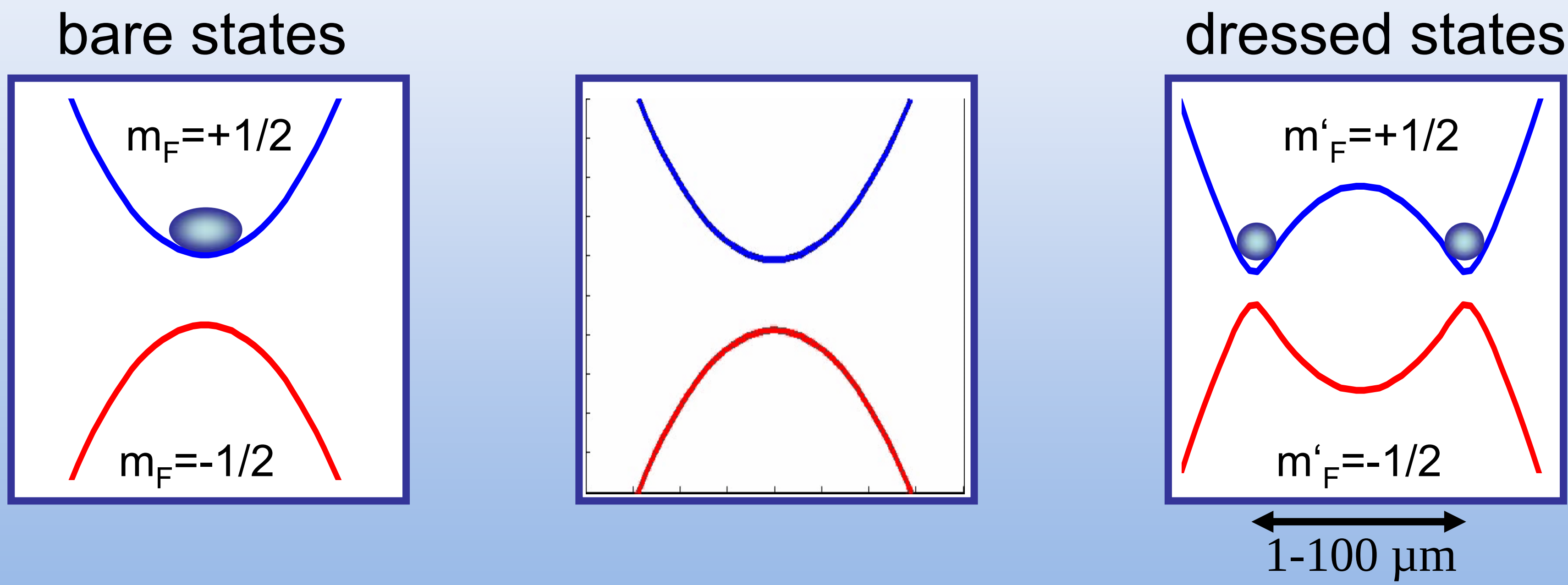

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an atom chip beam splitter: adiabatic dressed RF potentials

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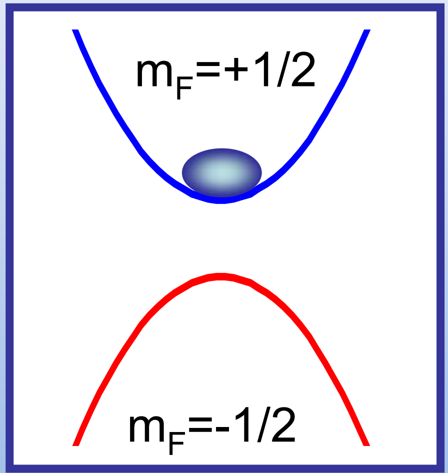
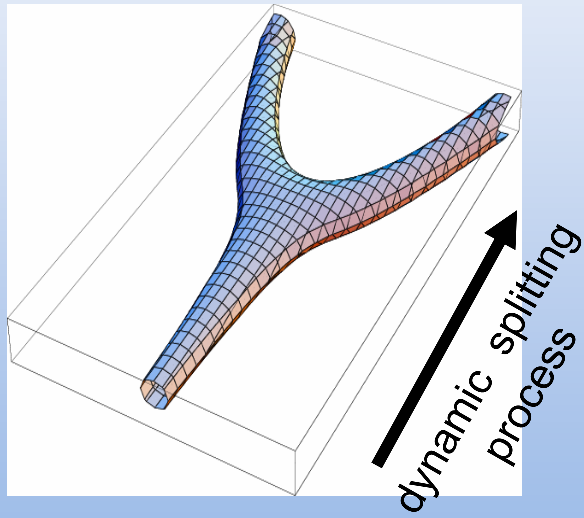
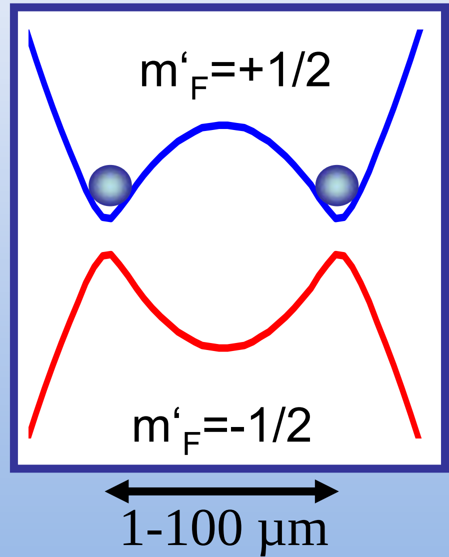
bare states





dressed states

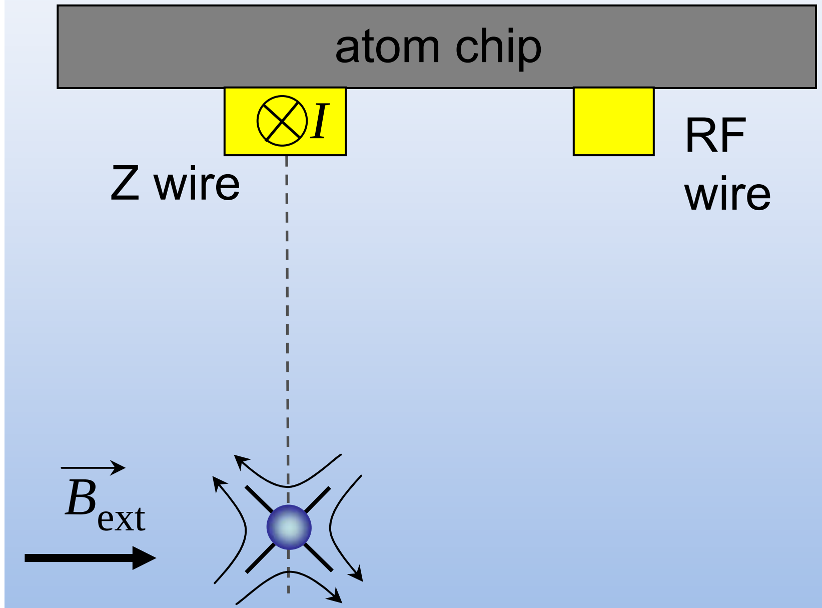


The RF scheme realizes a true 1 to 2 beam splitter:

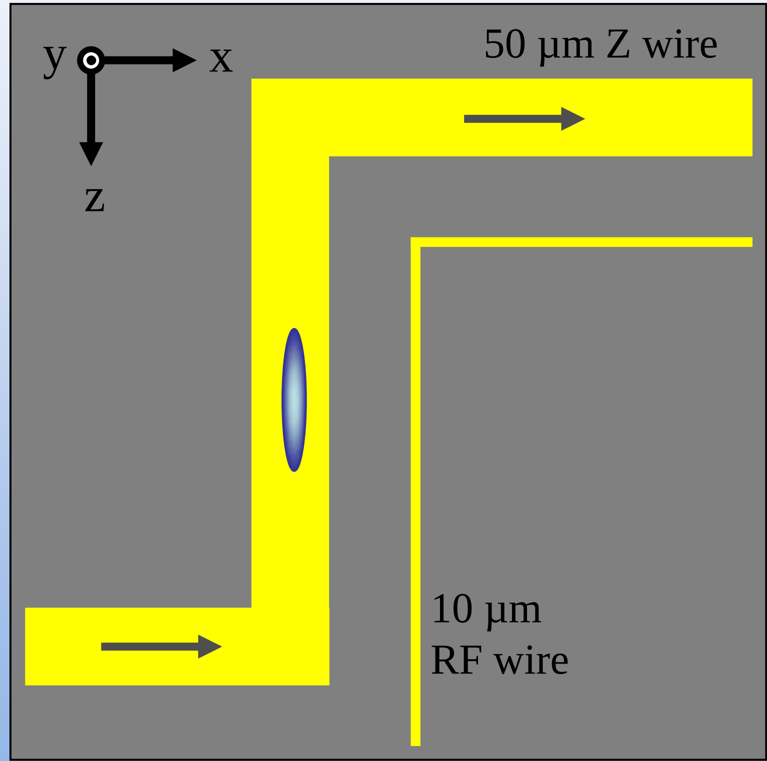
- robust against magnetic field fluctuations (10^{-2} stability on external fields)
- can be performed with large wire structures ($d \simeq 100D$) far from the chip surface

adiabatic dressed RF potentials: realization on an atom chip

side view



top view



adiabatic dressed RF potentials: realization on an atom chip

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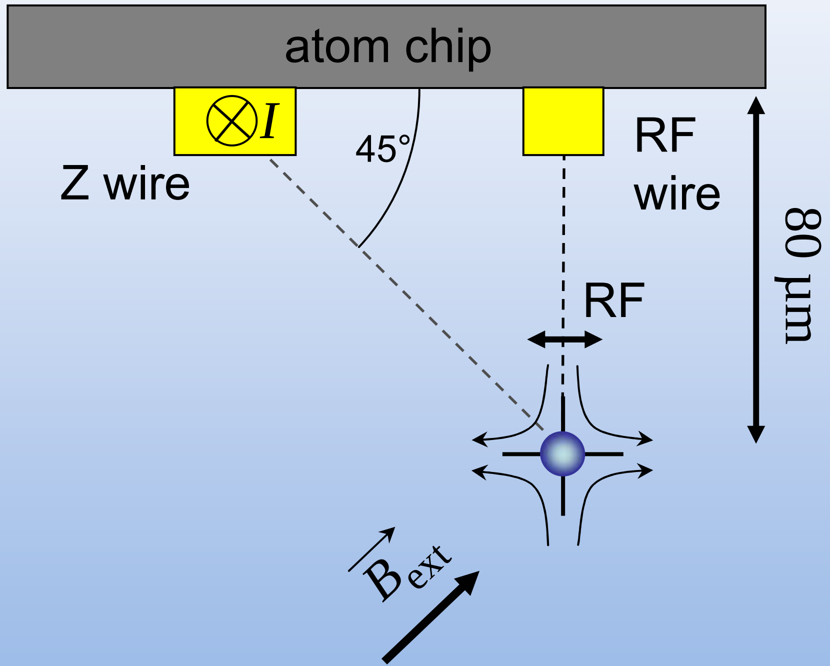

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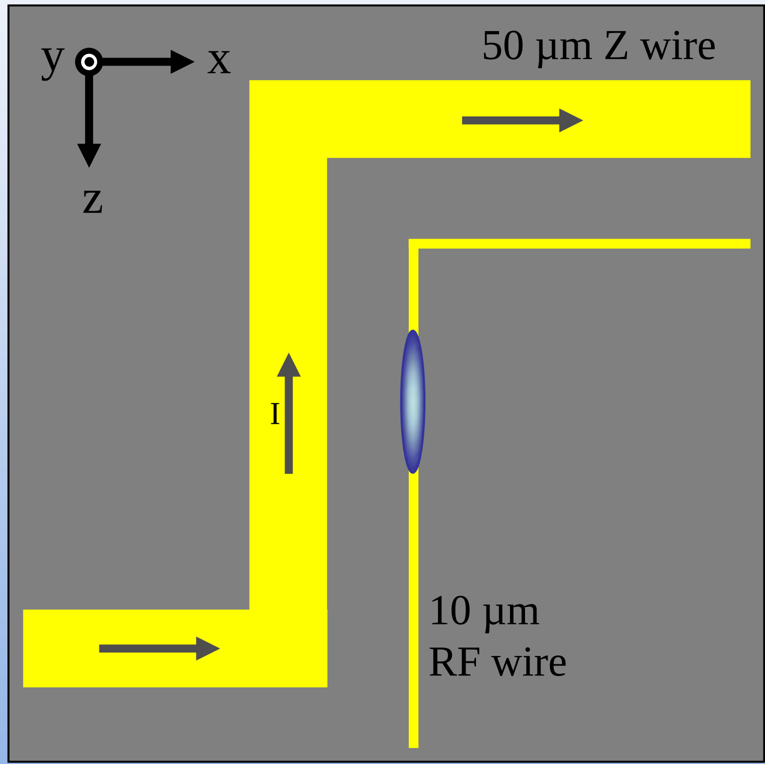

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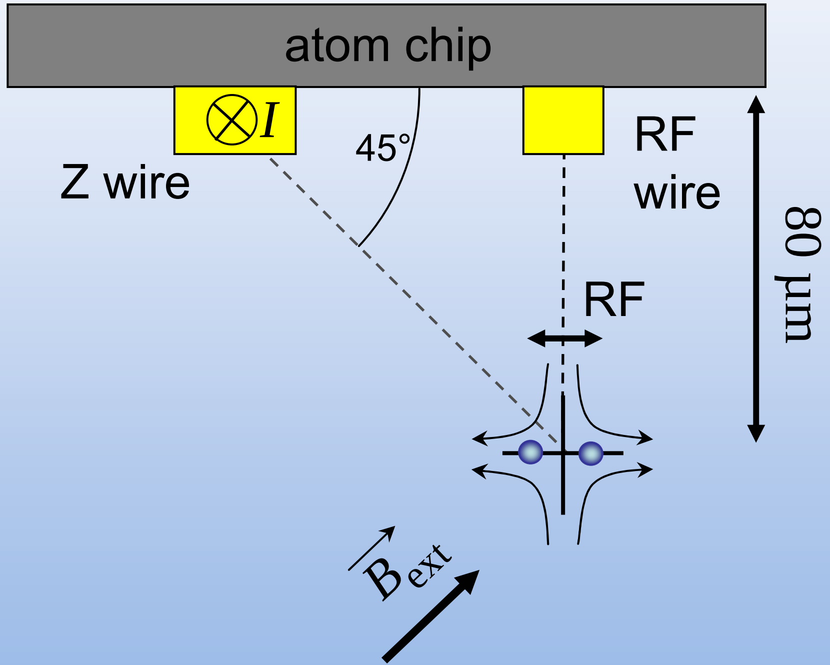

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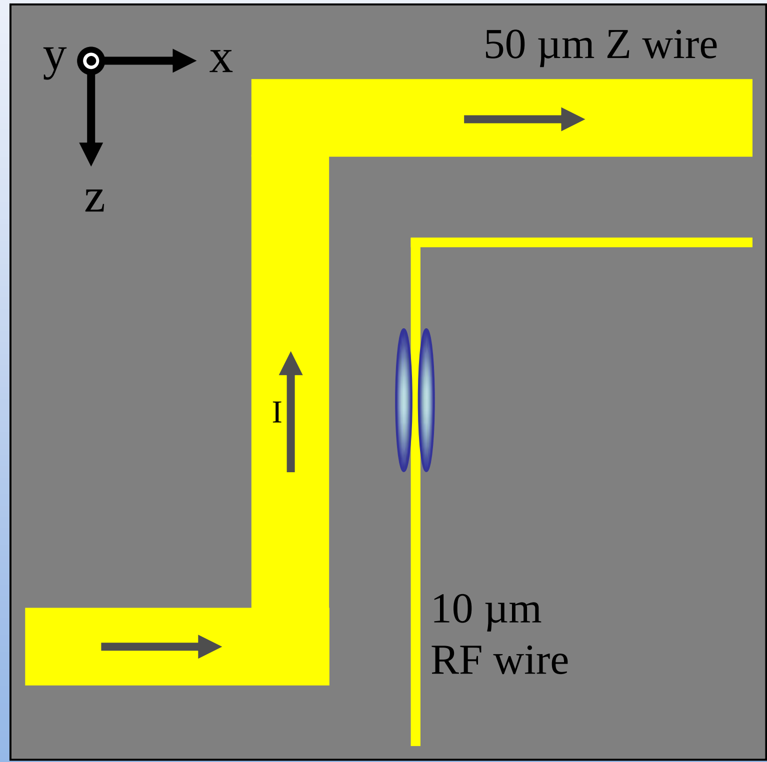

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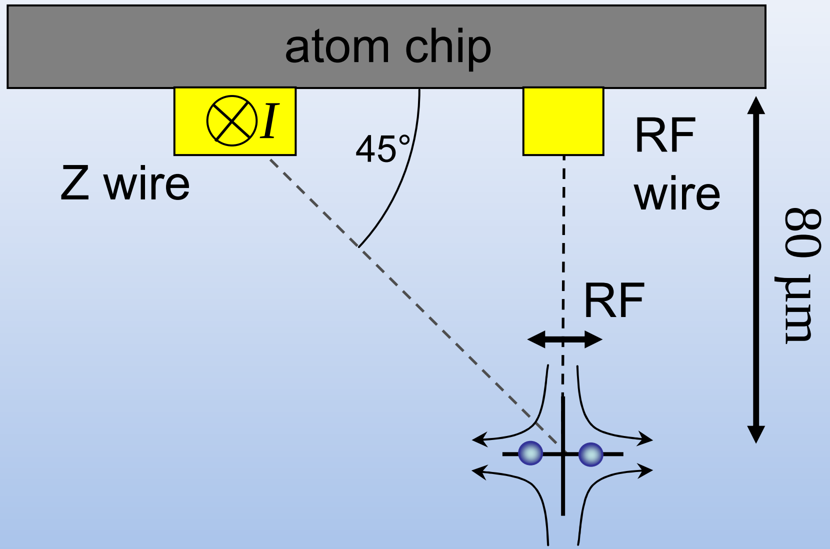
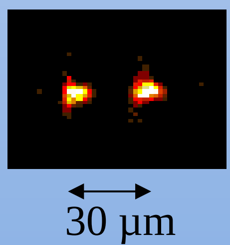
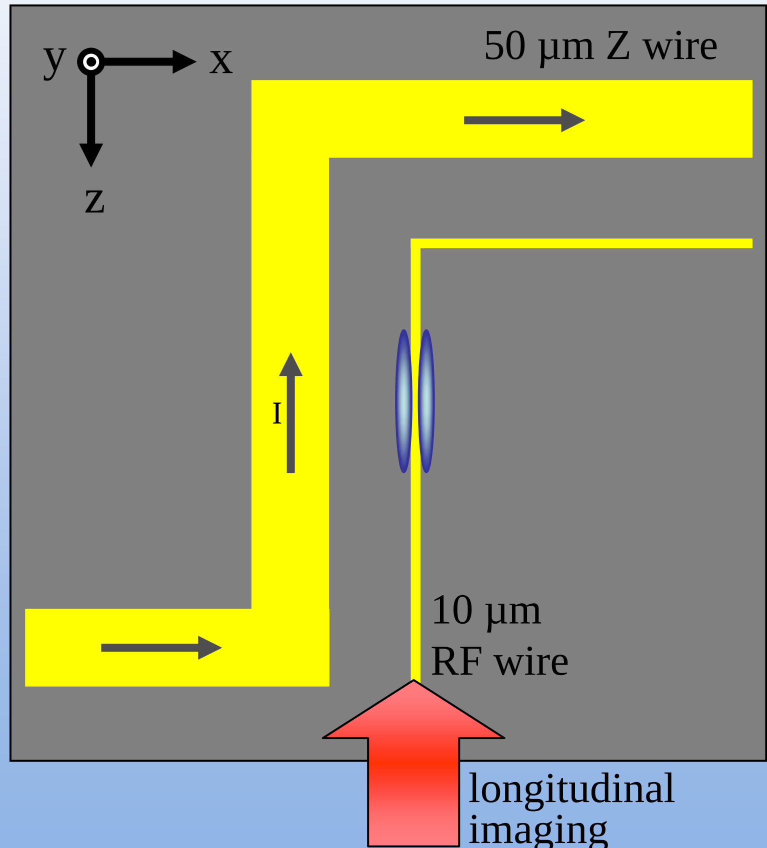


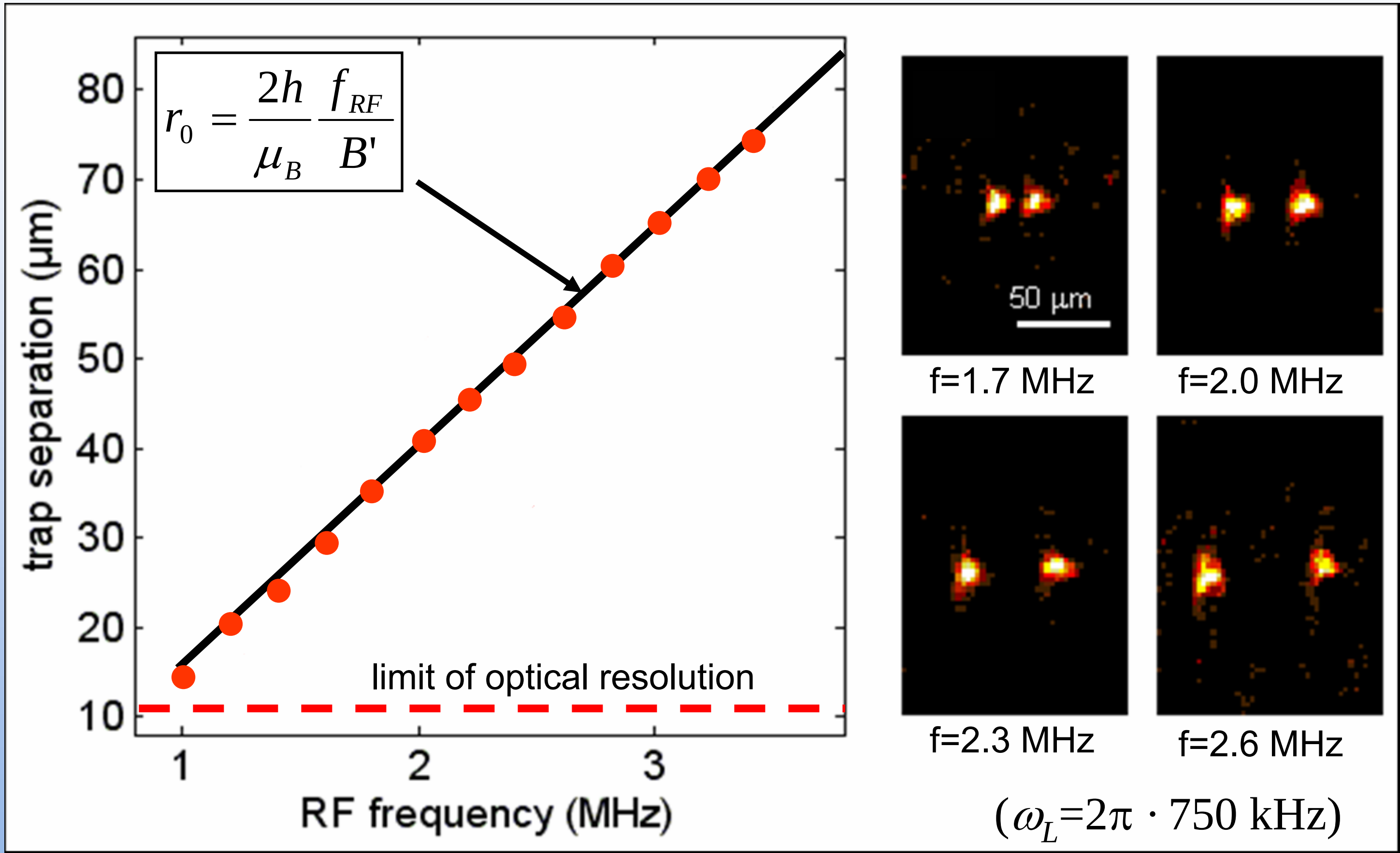
in situ
absorption
image
(BEC)



top view



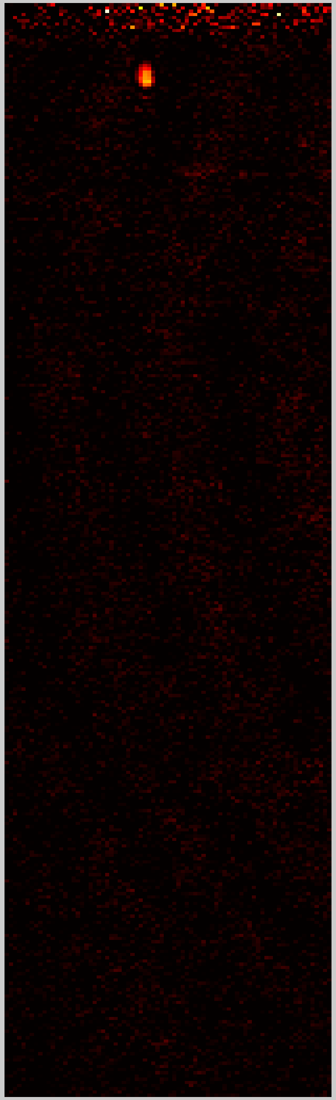
adiabatic dressed RF potentials: dynamic splitting of a BEC



in situ absorption images

- controlled dynamic splitting **BECs** up to 80 µm

adiabatic dressed RF potentials: matter wave interference



adiabatic dressed RF potentials: matter wave interference

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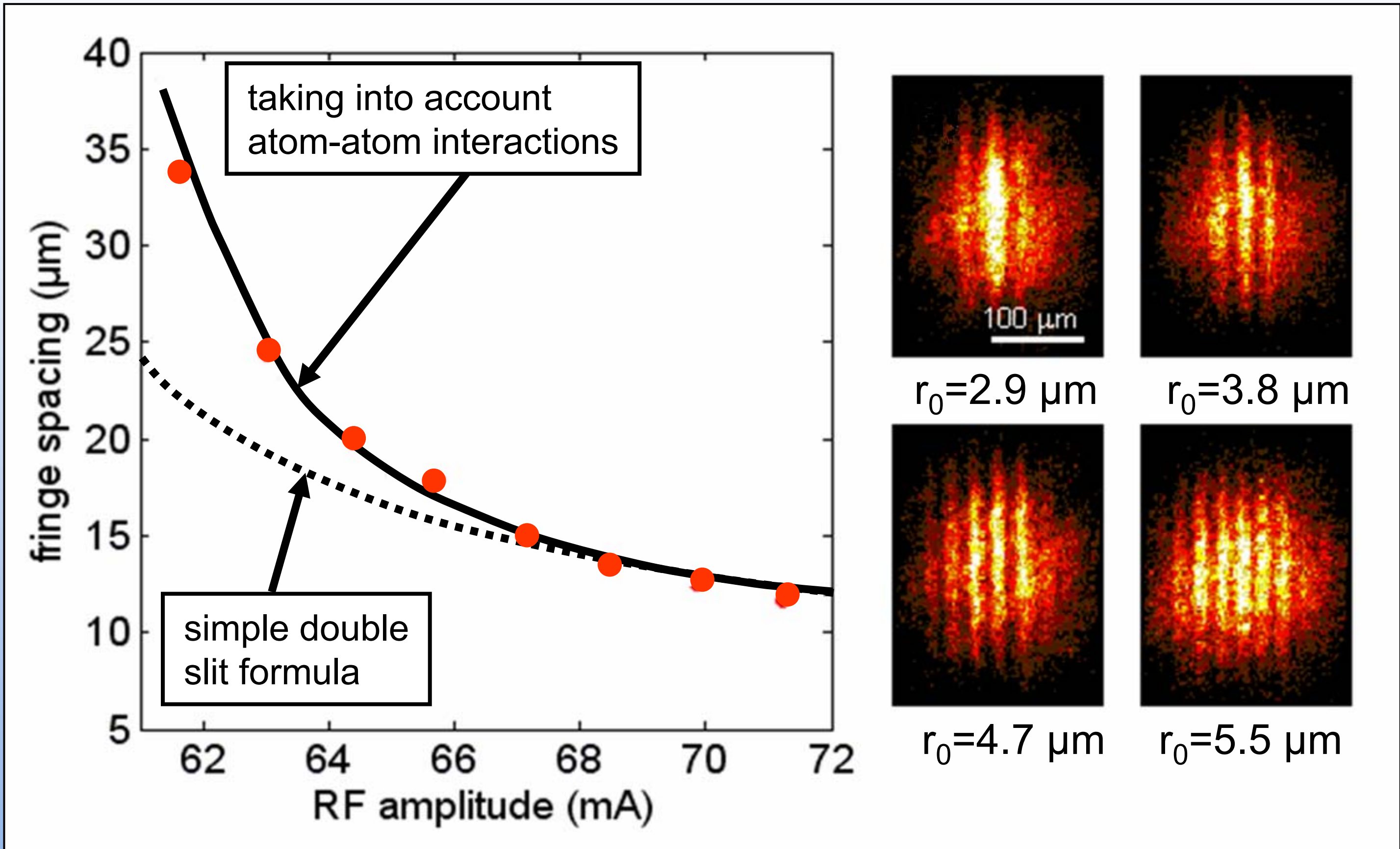
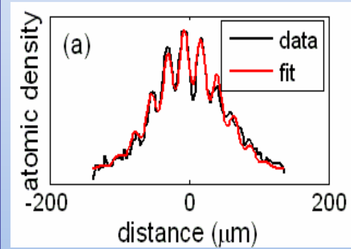


14 ms time-of-flight absorption images

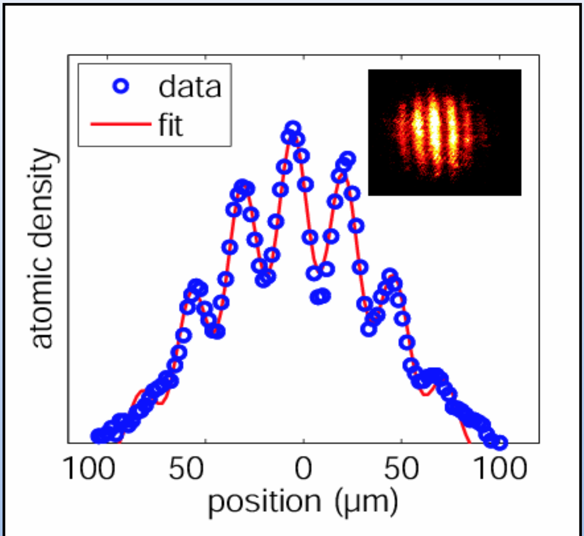


extract fringe spacing Δz

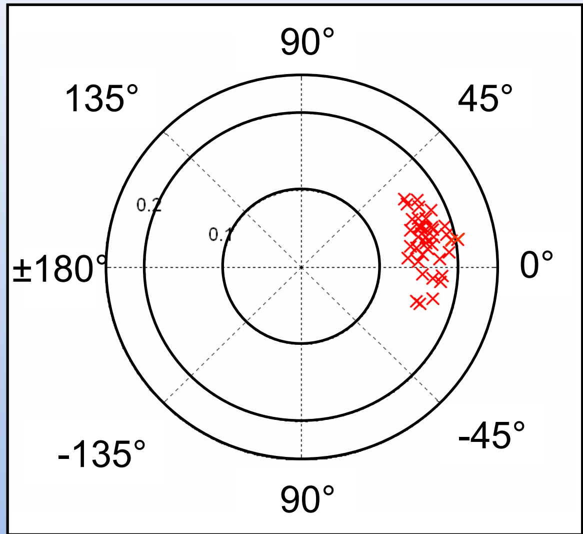
- split **BECs** show interference when recombined in expansion
- atom **interactions** have to be considered to understand interference patterns

adiabatic dressed RF potentials: coherent beam splitter for BEC

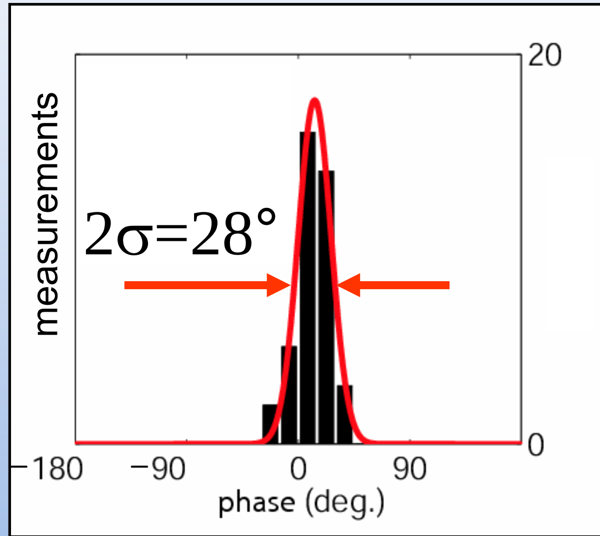
The relative phase between two fully split BECs is measured in many realizations (40) of an interference experiment:



relative condensate phase is extracted from each fit



obtained relative phases in a polar diagram

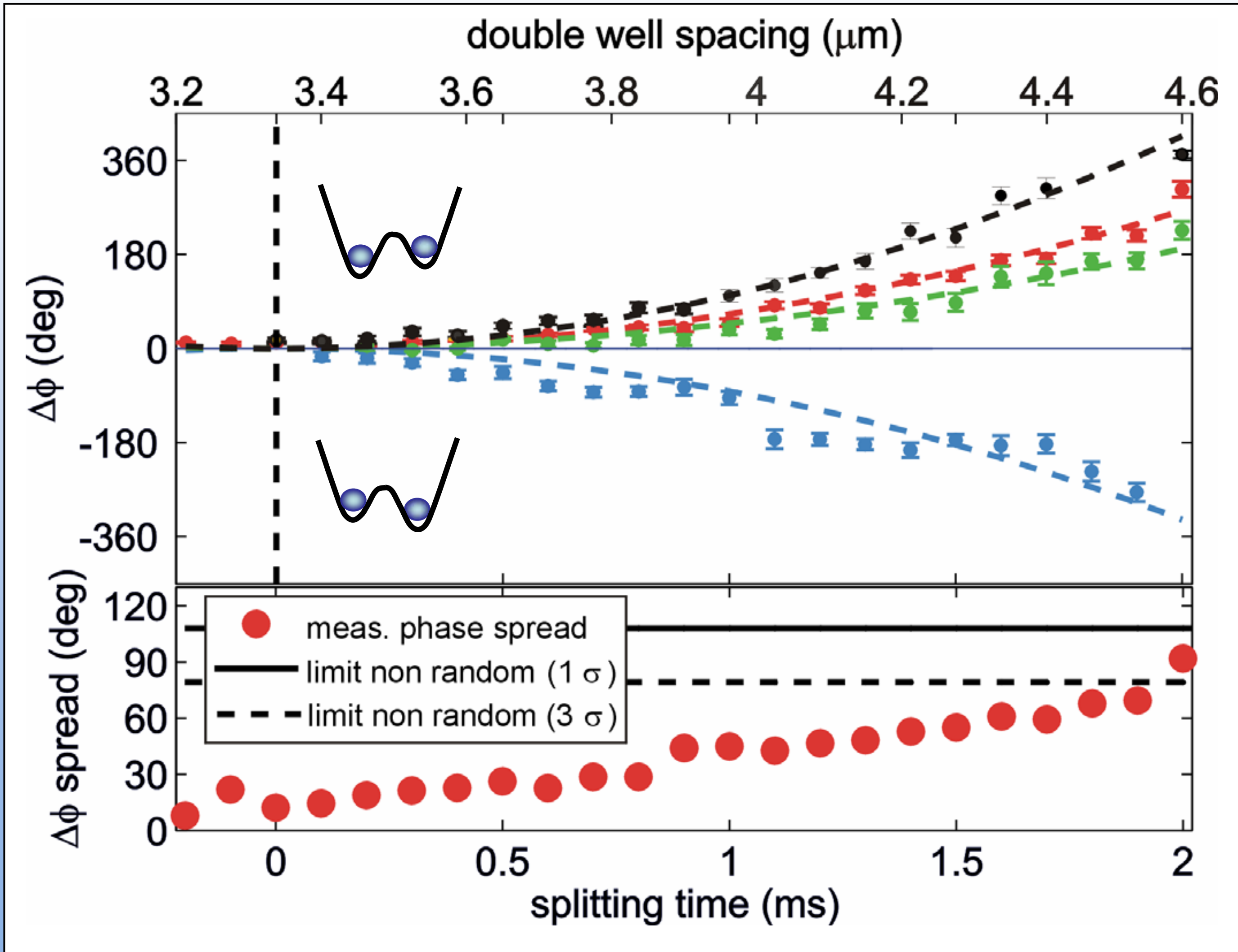


obtained relative phases in a histogram

Result: a phase preserving beam splitter for BEC

Schumm *et al*, Nature Physics **1**, 57 (2005)

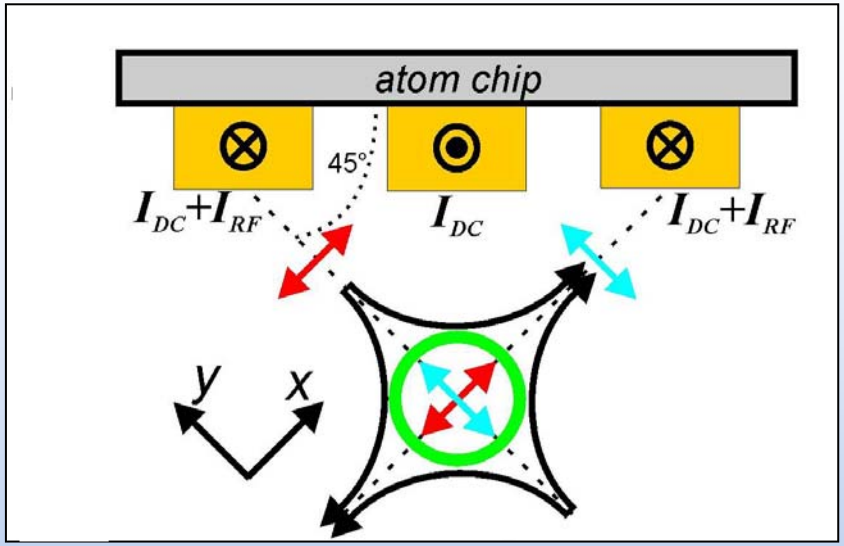
adiabatic dressed RF potentials: evolution of the relative phase



Phase evolution can be controlled by deliberately tilting the double well potential. For connected condensates, the relative phase is locked to zero

Phase spread remains non-random even for larger splitting, but increases with split time (1d phase diffusion!)

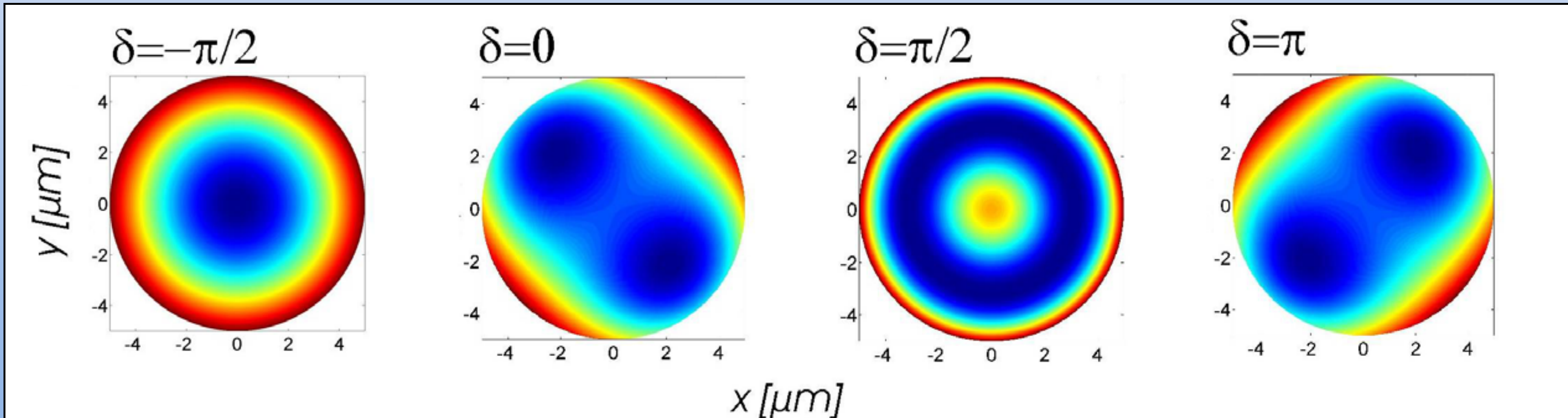
adiabatic dressed RF potentials: arbitrary RF polarization



Two perpendicular RF fields give additional parameters:

- phase shift δ between RF sources
- ratio of amplitudes of AC currents

allows the realization of any RF polarization:

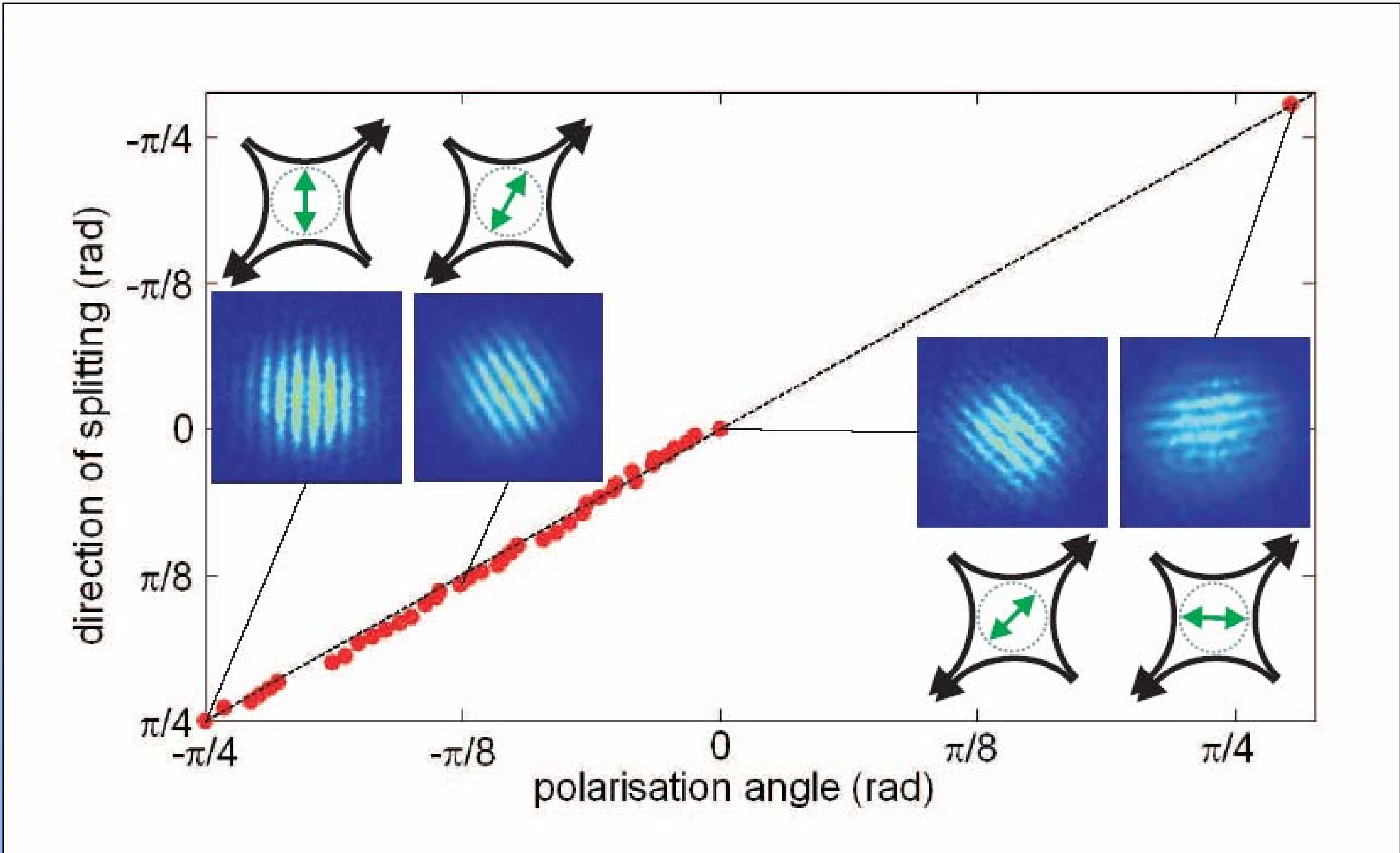


sigma minus　　linear +45°　　sigma plus　　linear -45°

state dependent potentials!

Lesanovsky *et al* , PRA **73**, 033619 (2006)

linear RF polarization: turning the double well



Hofferberth *et al*, quant-ph/0608228

circular RF polarization: a ring potential (current project)

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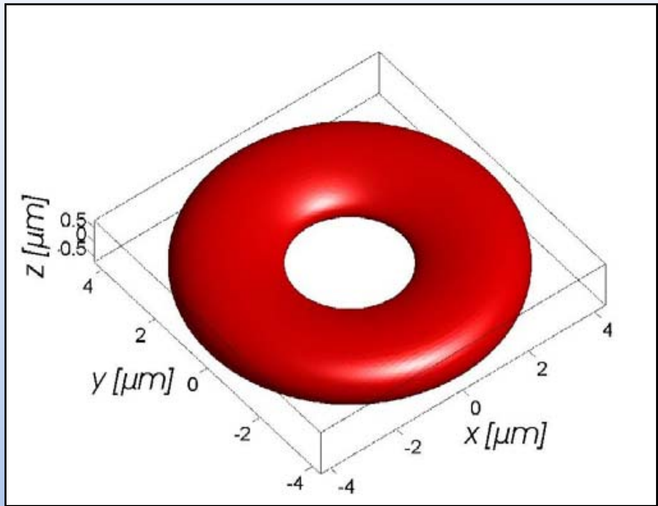
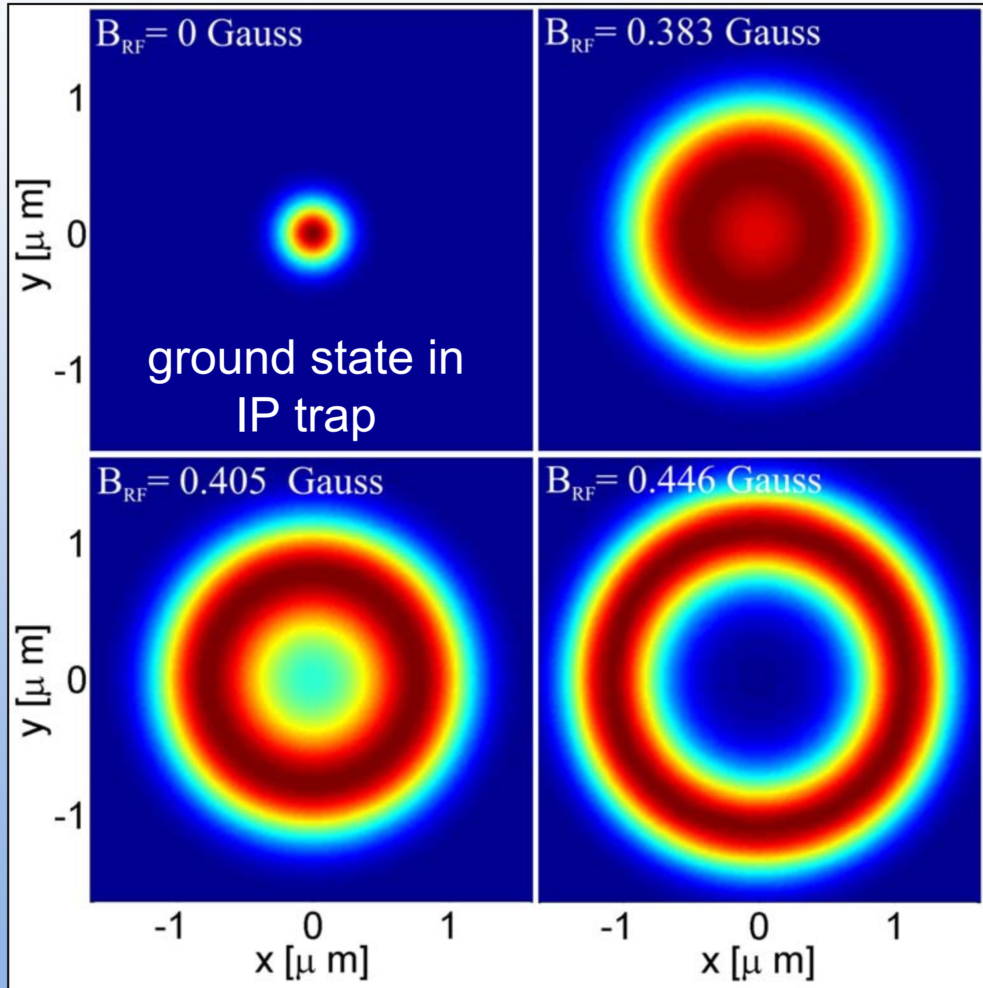
phase shift $\delta = \pi/2$
$\Rightarrow$ circular polarization



Numeric wavepacket propagation



Parameters

G=20 T/m
$\omega=2\pi$ x 500 kHz
B_I= 0.75 Gauss
$\delta=\pi/2$

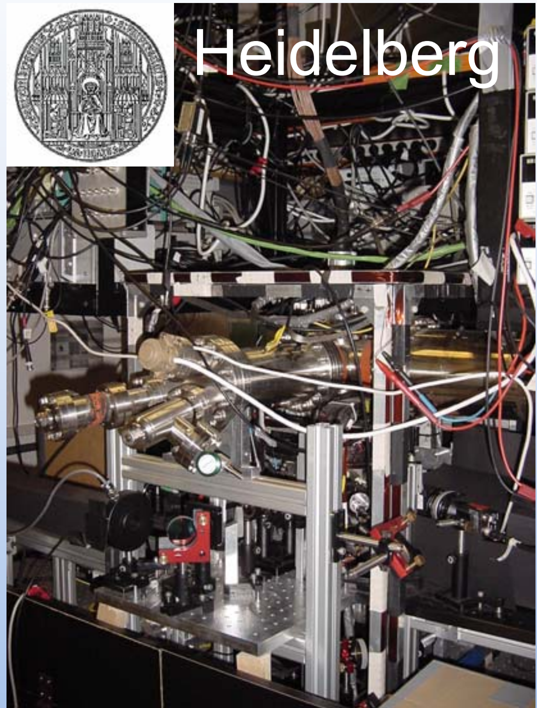
work in progress…

Conclusions:

- Coherent beamsplitting of BEC using dressed adiabatic potentials
- Some control over the evolution of the relative phase
- Need to characterize the BEC:
  - Phase coherence of the initial (1D) BEC
  - Role of interactions (phase evolution, expansion)
  - Phase diffusion (Fermions?)
- More complex adiabatic potentials using arbitrary polarization of the RF field (ring potential)
- portable devices…?

Towards (trans)portable atom chip setups?

Innsbruck
1999



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Moving
October 2007

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