



# Tuning Static and Dynamic Properties of a Quasi One-Dimensional Bose-Einstein Condensate

**DPG conference 2016**

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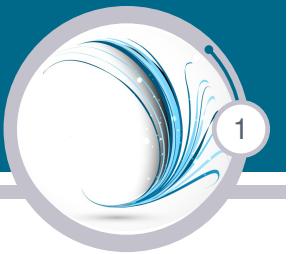
1: BEC with dimple trap Phys. Rev. A 93, 023606 (2016) and  
[arXiv:1510.07138](https://arxiv.org/abs/1510.07138)

2: Impurity in BEC Phys. Rev. A (in press), arXiv:1508.05482

3: BEC in GOST J. Phys. B: At., Mol. Opt. Phys. (in press),  
[arXiv:1509.05987](https://arxiv.org/abs/1509.05987)

# 1.1: Quasi one-dimensional

Gross-Pitaevskii equation



Quasi one-dimensional setting<sup>1</sup>  $(a_B/l_z) \ll \gamma \ll 1$ , here  $\gamma = l_r/l_z$

$$\psi(\mathbf{r}, t) = \psi(z, t)\phi(\mathbf{r}_\perp, t) \quad \text{here } \phi(\mathbf{r}_\perp, t) = \frac{e^{-\frac{x^2+y^2}{2\gamma^2}}}{\gamma\sqrt{\pi}} e^{-i\frac{\omega_r}{\omega_z}t}$$

$$i\frac{\partial}{\partial t}\psi(z, t) = \left\{ -\frac{1}{2}\frac{\partial^2}{\partial z^2} + \frac{z^2}{2} + U_{dT}^{1D}(z) + G_B \|\psi(z, t)\|^2 \right\} \psi(z, t)$$

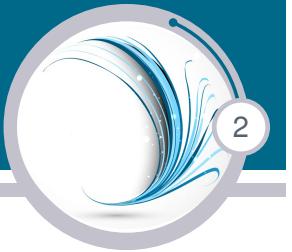
Here  $U_{dT}^{1D}(z) \propto \frac{l(z)}{\Delta}$  with  $\Delta = \omega - \omega_A$ .

For  $N_B = 2 \times 10^5$  atoms of  $^{87}\text{Rb}$   $G_B = 2N_B\omega_r a_B/l_z \omega_z = 11435.9$

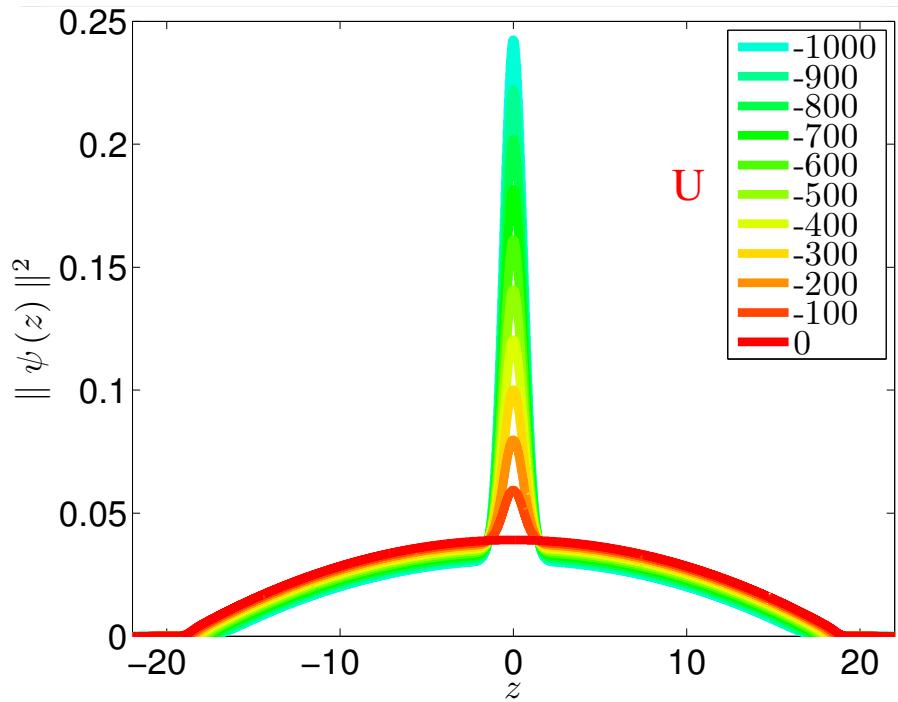
<sup>1</sup>J. Exp. Theor. Phys. **98**, 908 (2003).

# 1.2: Stationary condensate wave function

Dimple trap vs HGdT potential

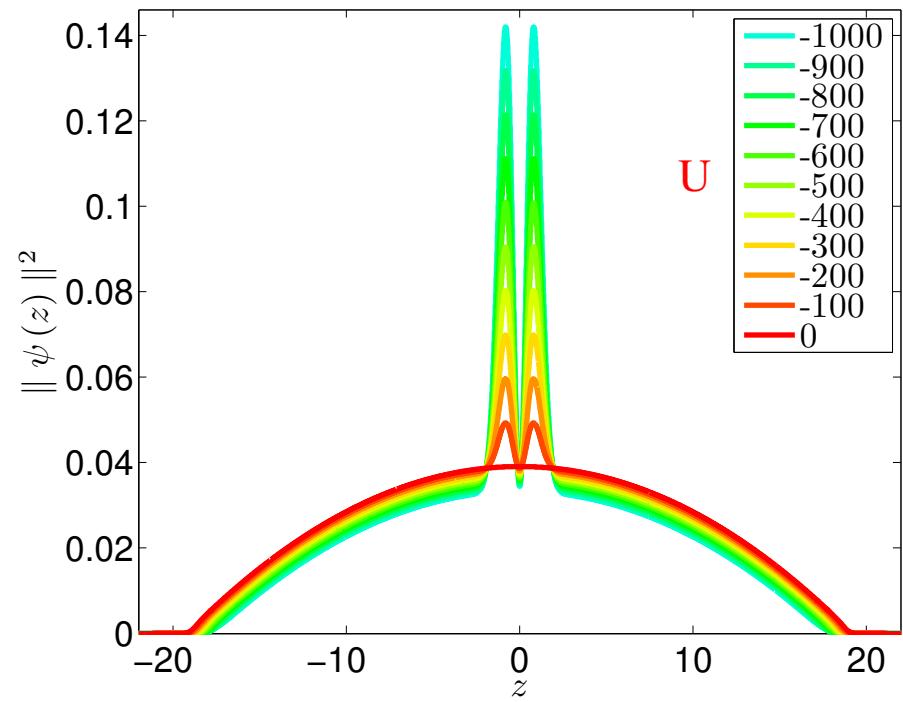


U<0 (Red detuned)



TEM<sub>00</sub> mode dimple trap (dT)

$$U_{dT}^{1D}(z) = U e^{-\frac{z^2}{w^2}}$$



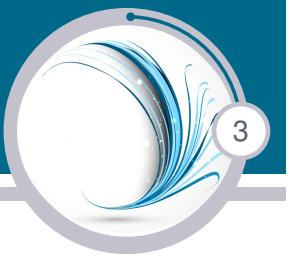
TEM<sub>01</sub> Hermite-Gaussian dimple trap (HGdT)

$$U_{HGdT}^{1D}(r) = U z^2 e^{-\frac{z^2}{w^2}}$$

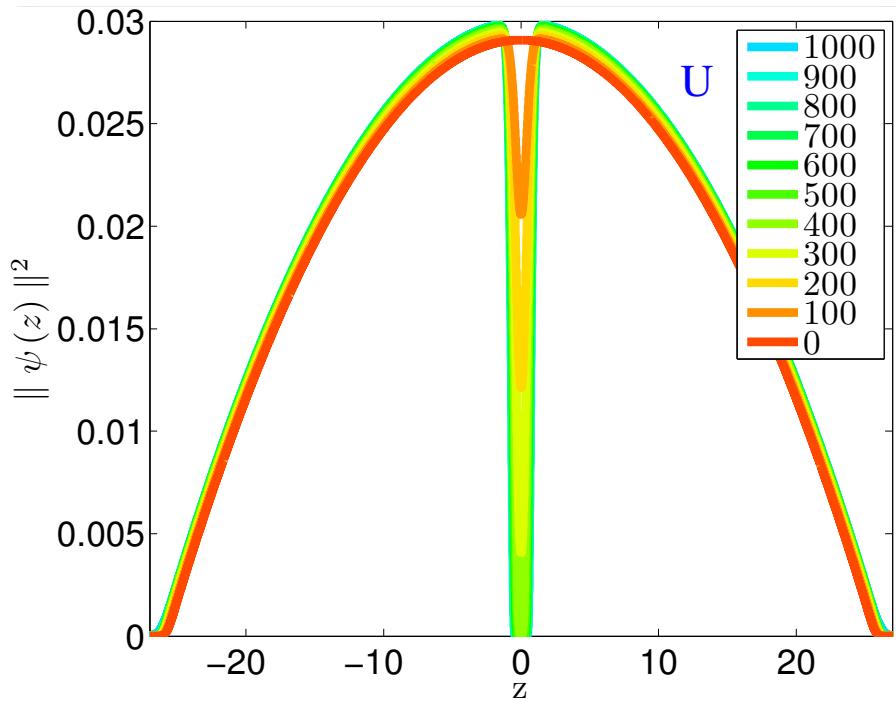
Here  $U \propto \frac{1}{\Delta}$  with  $\Delta = \omega - \omega_A$

# 1.3: Stationary condensate wave function

Dimple trap vs HGdT potential

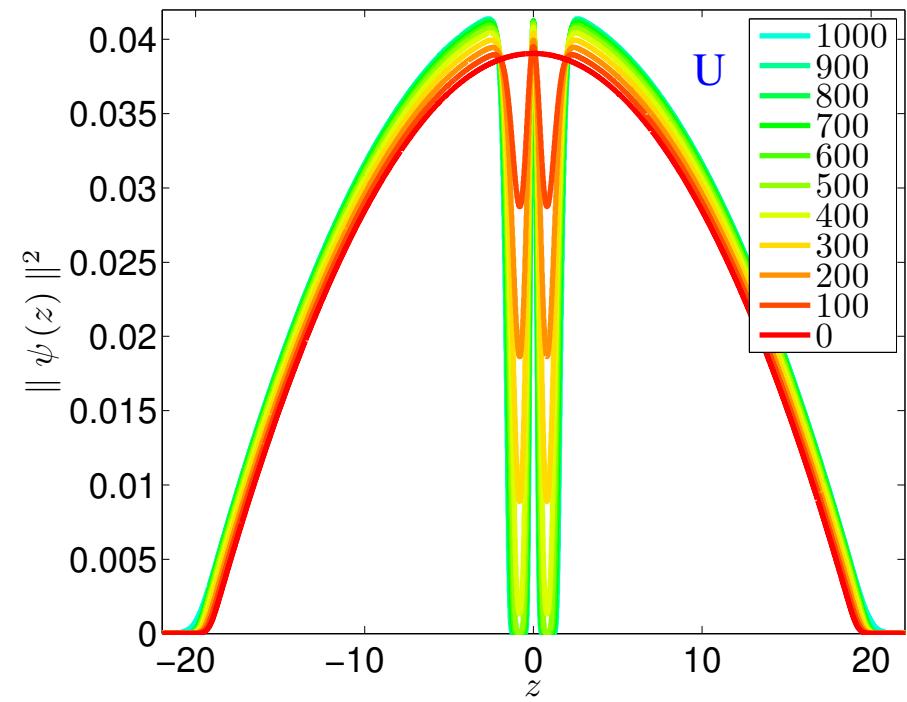


U>0 (blue detuned)



TEM<sub>00</sub> mode dimple trap (dT)

$$U_{dT}^{1D}(z) = U e^{-\frac{z^2}{w^2}}$$



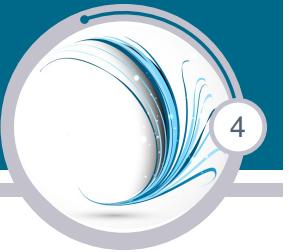
TEM<sub>01</sub> Hermite-Gaussian dimple trap (HGdT)

$$U_{HGdT}^{1D}(r) = U z^2 e^{-\frac{z^2}{w^2}}$$

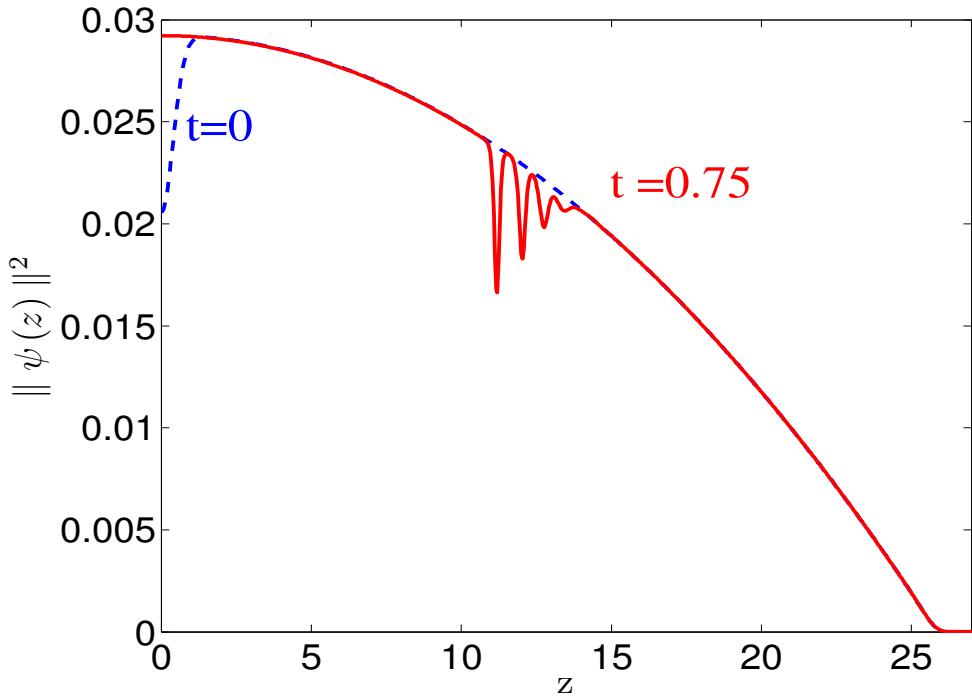
Here  $U \propto \frac{1}{\Delta}$  with  $\Delta = \omega - \omega_A$

# 1.4: Excitation of Solitons

After having switched off the dT or HGdT

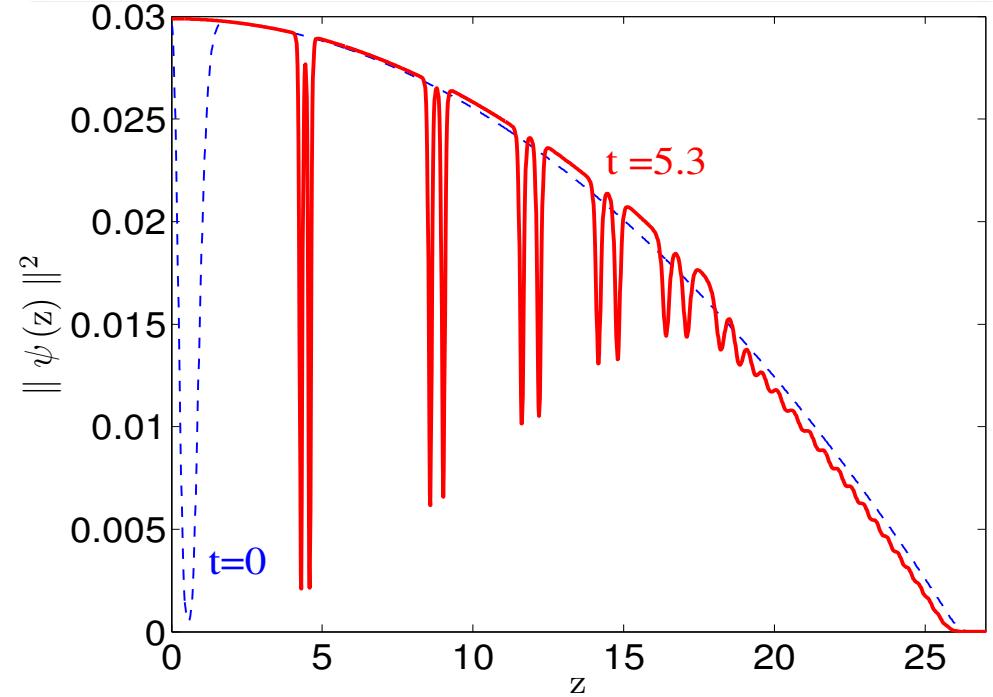


$U>0$  (Blue detuned)



dT potential

$U=100$

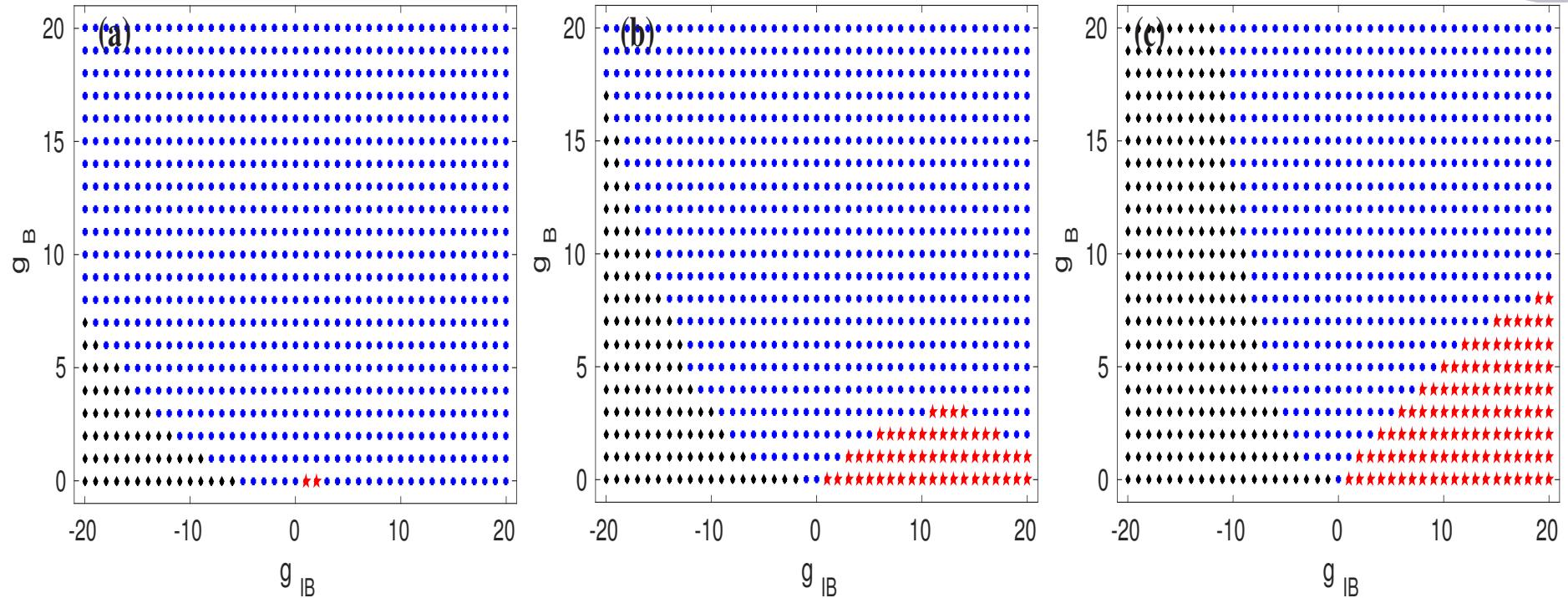


HGdT potential

$U=3500$

## 2.1: Equilibrium phase diagram

Localization of impurity  $^{133}\text{Cs}$

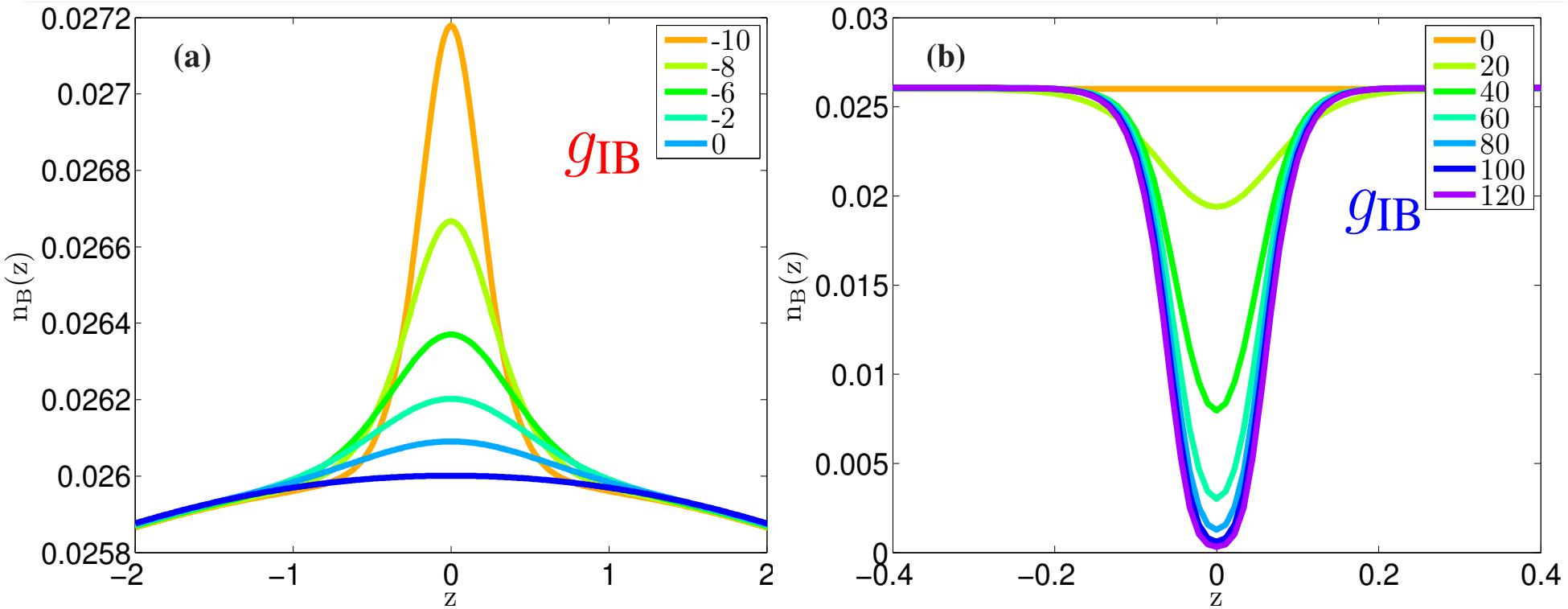
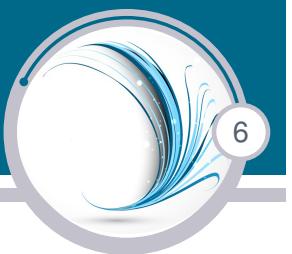


(a)  $N_B = 20$  (b)  $N_B = 200$  and (c)  $N_B = 800$

Unstable region (Black), localized impurity region (Blue) & impurity  
expelled to the condensate border (Red)

## 2.2: Numerical density

Profile of the BEC for  $G_B = 16000$



Interspecies coupling strength,

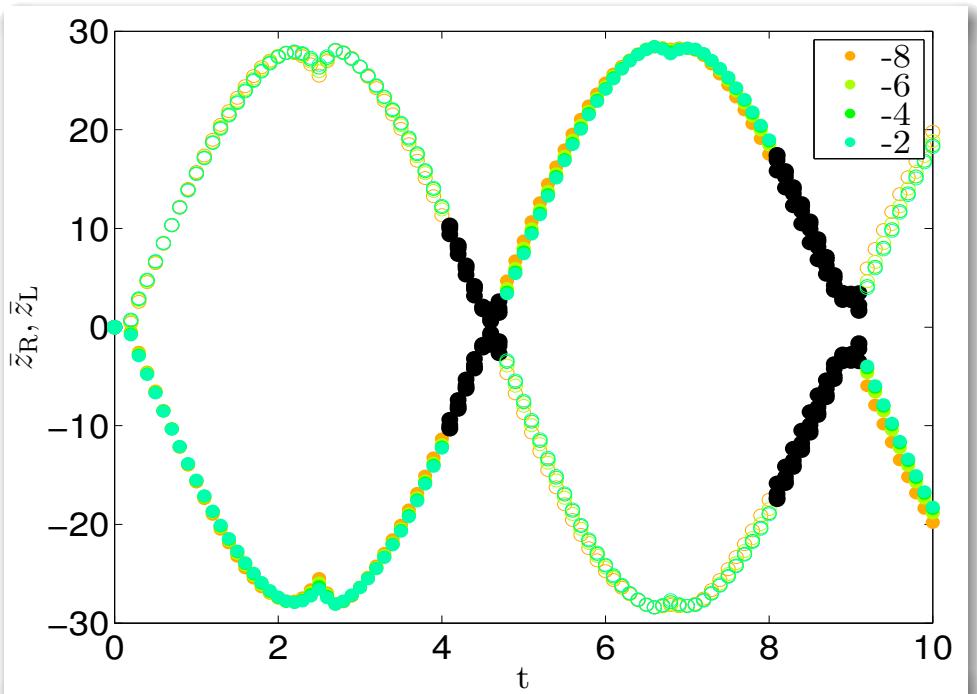
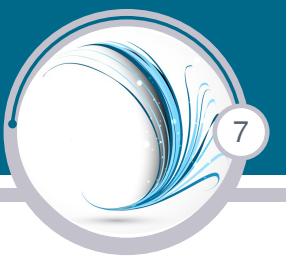
(a) attractive ( $g_{IB} < 0$ )

here  $N_B = 800$  and  $g_{IBc} \approx 110$

(b) repulsive ( $g_{IB} > 0$ )

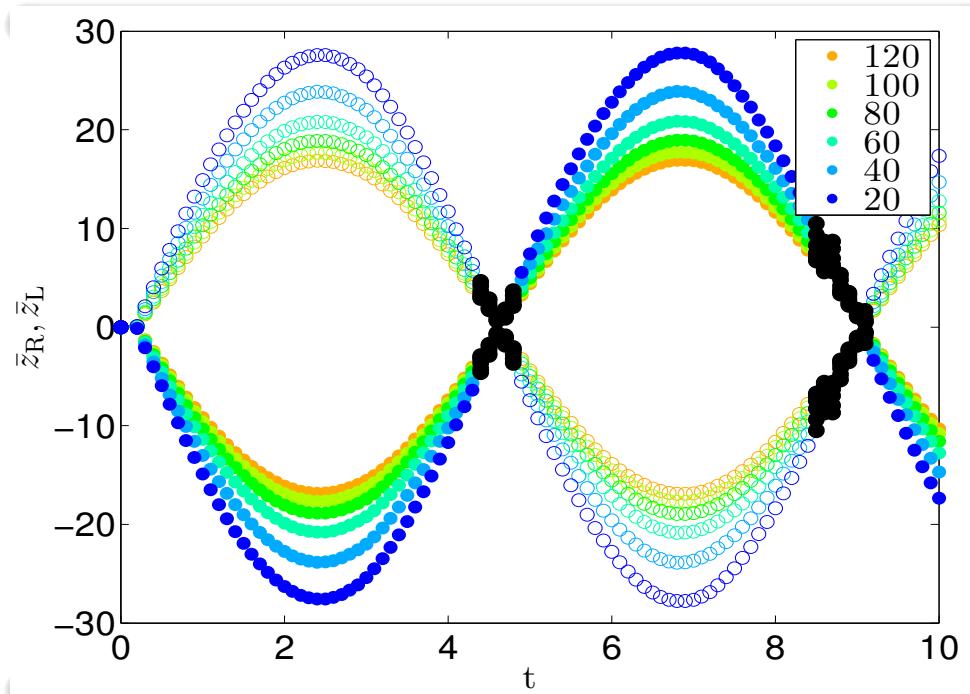
## 2.3: Density profile of the BEC

Interspecies coupling strength switched off i.e.  $g_{IB} = 0$  at  $t = 0$



attractive ( $g_{IB} < 0$ )

$$z(t) = \sqrt{2\mu} \sin\left(t/\sqrt{2}\right)$$



repulsive ( $g_{IB} > 0$ )

Soliton Freq.<sup>2</sup>  $\Omega/\omega_z = 1/\sqrt{2}$ ,  
Hamburg<sup>3</sup> & Heidelberg Exp.<sup>4</sup>

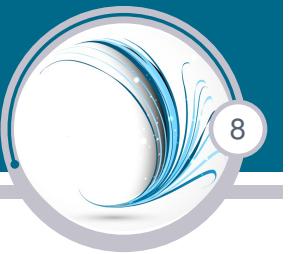
<sup>2</sup>Phys. Rev. Lett. **84**, 2298 (2000).

<sup>3</sup>Nature Phys. **4**, 496 (2008).

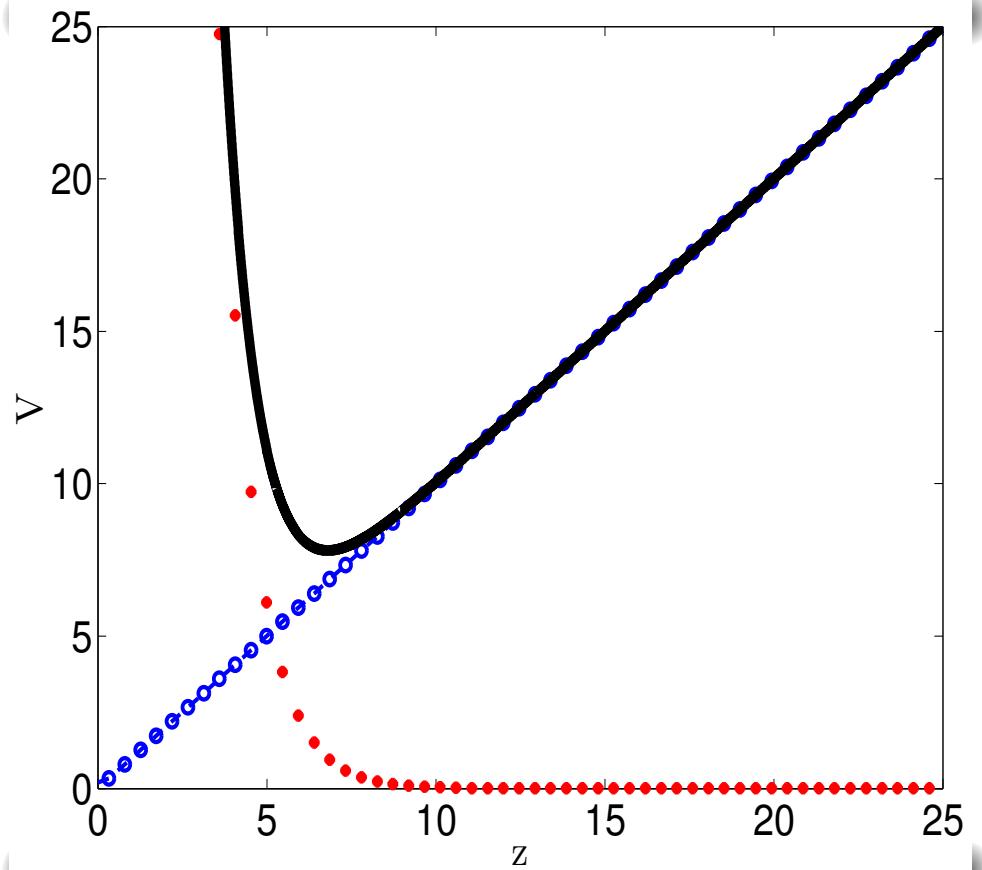
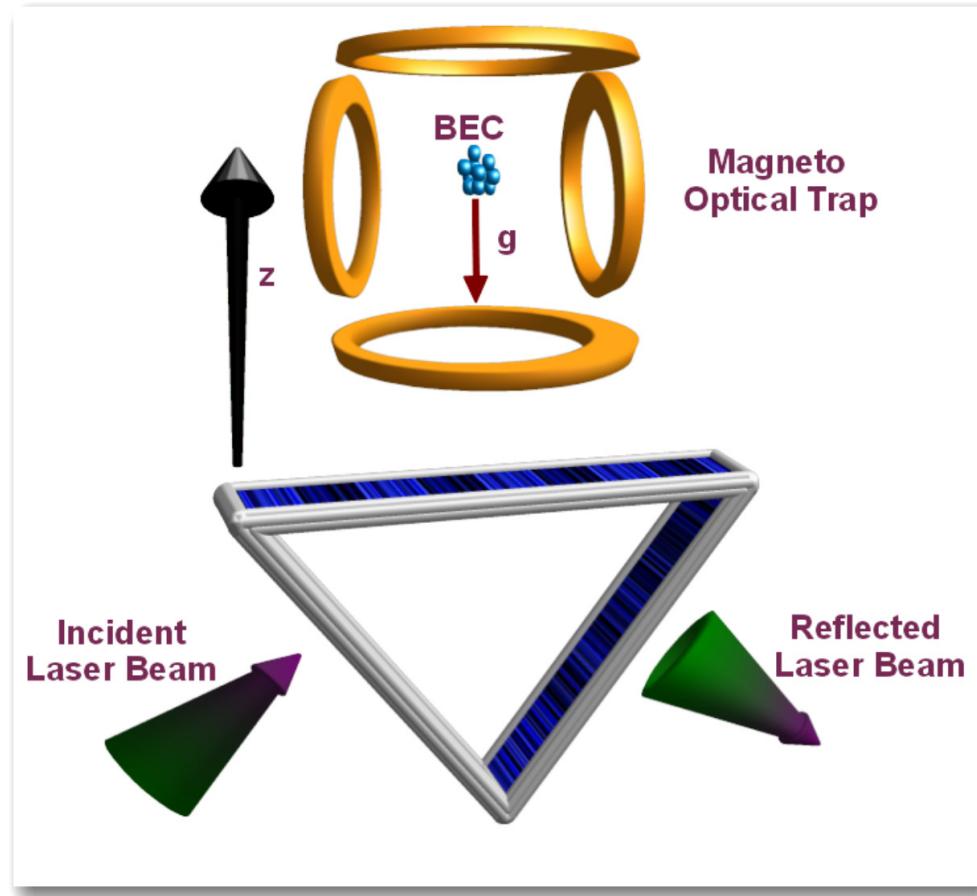
<sup>4</sup>Phys. Rev. Lett. **101**, 130401 (2008).

# 3.1: Gravito-optical surface trap (GOST)

Experimental setup and potential

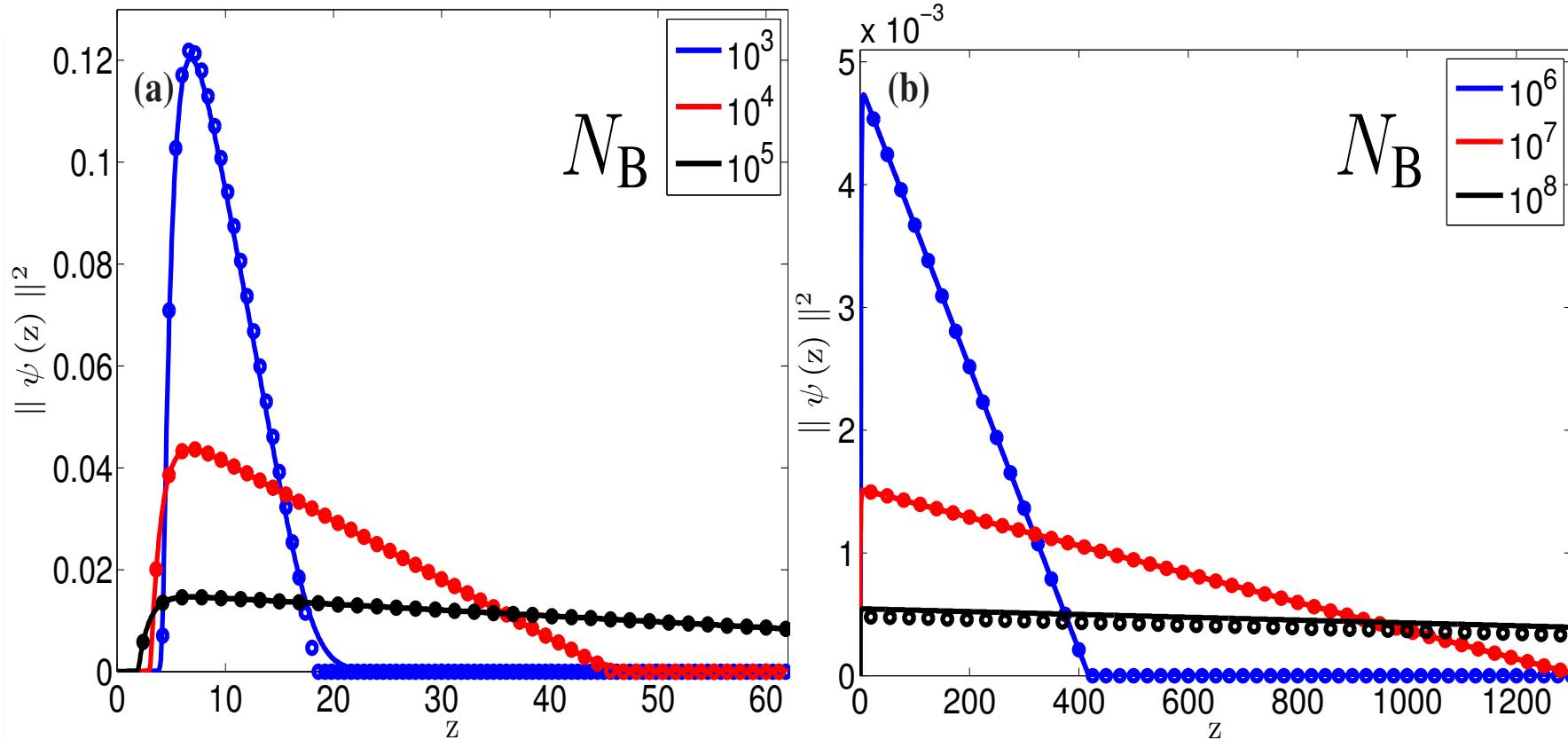
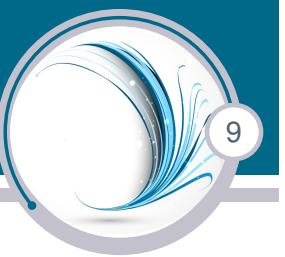


$$V(z) = V_0 e^{-z} + z$$



## 3.2: Stationary mirror solution

Thomas-Fermi approximation for the BEC

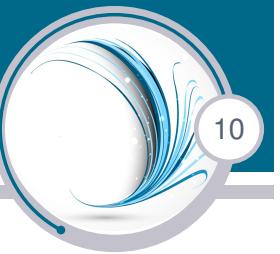


TF solution (circles)

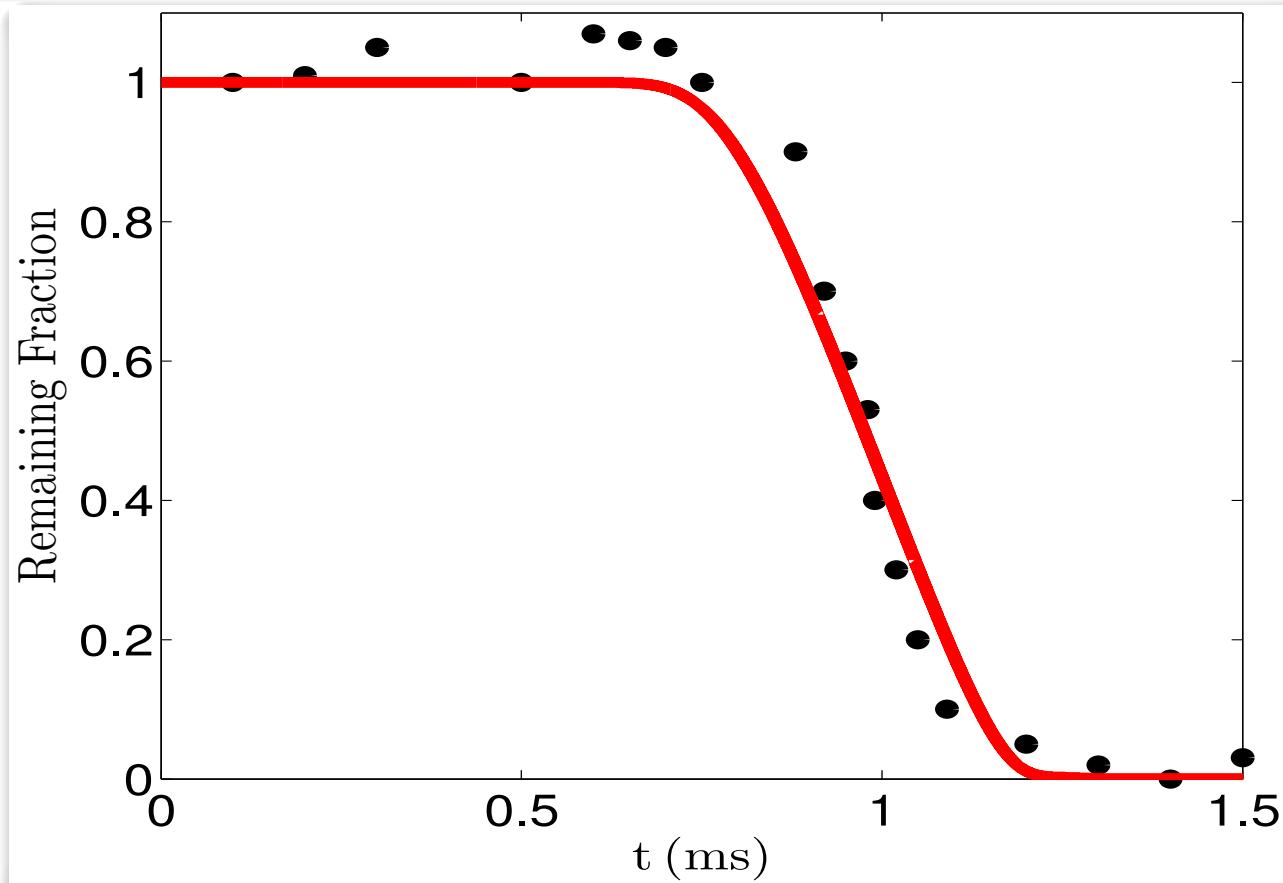
Numerical solution (solid lines)

### 3.3: Innsbruck experiment

Fraction of remaining atoms during time-of-flight



Innsbruck Exp.<sup>5</sup> (black-circles) & our numerical results  
(red-solid line)  $V_0 = 453$  and  $N_B = 2400$   $^{133}\text{Cs}$  atoms



<sup>5</sup>Phys. Rev. Lett. **92**, 173003 (2004).

# **Announcement**

## **616th Wilhelm and Else Heraeus Seminar**

**Ultracold Quantum Gases -**

**Current Trends and Future Perspectives**

**organized by Carlos Sá de Melo and Axel Pelster**

**Bad Honnef (Germany); May 9 – 13, 2016**

**Invited Speakers:** Eugene Demler (USA), Rembert Duine (Netherthelands), Tilman Esslinger (Switzerland), Michael Fleischhauer (Germany), Thierry Giamarchi (Switzerland), Rudi Grimm (Austria), Johannes Hecker-Denschlag (Germany), Andreas Hemmerich (Germany), Jason Ho (USA), Walter Hofstetter (Germany), Randy Hulet (USA), Massimo Inguscio (Italy), Corinna Kollath (Germany), Stefan Kuhr (UK), Kazimierz Rzazewski (Poland), Anna Sanpera (Spain), Luis Santos (Germany), Jörg Schmiedmayer (Austria), Dan Stamper-Kurn (USA), Sandro Stringari (Italy), Leticia Tarruell (Spain), Jacques Tempere (Belgium), Päivi Törmä (Finland), Matthias Weidemüller (Germany), Eugene Zaremba (Canada), Peter Zoller (Austria)

<http://www-user.rhrk.uni-kl.de/~apelster/Heraeus4/index.html>