One, two, three, many: few-body losses in many-body ensembles

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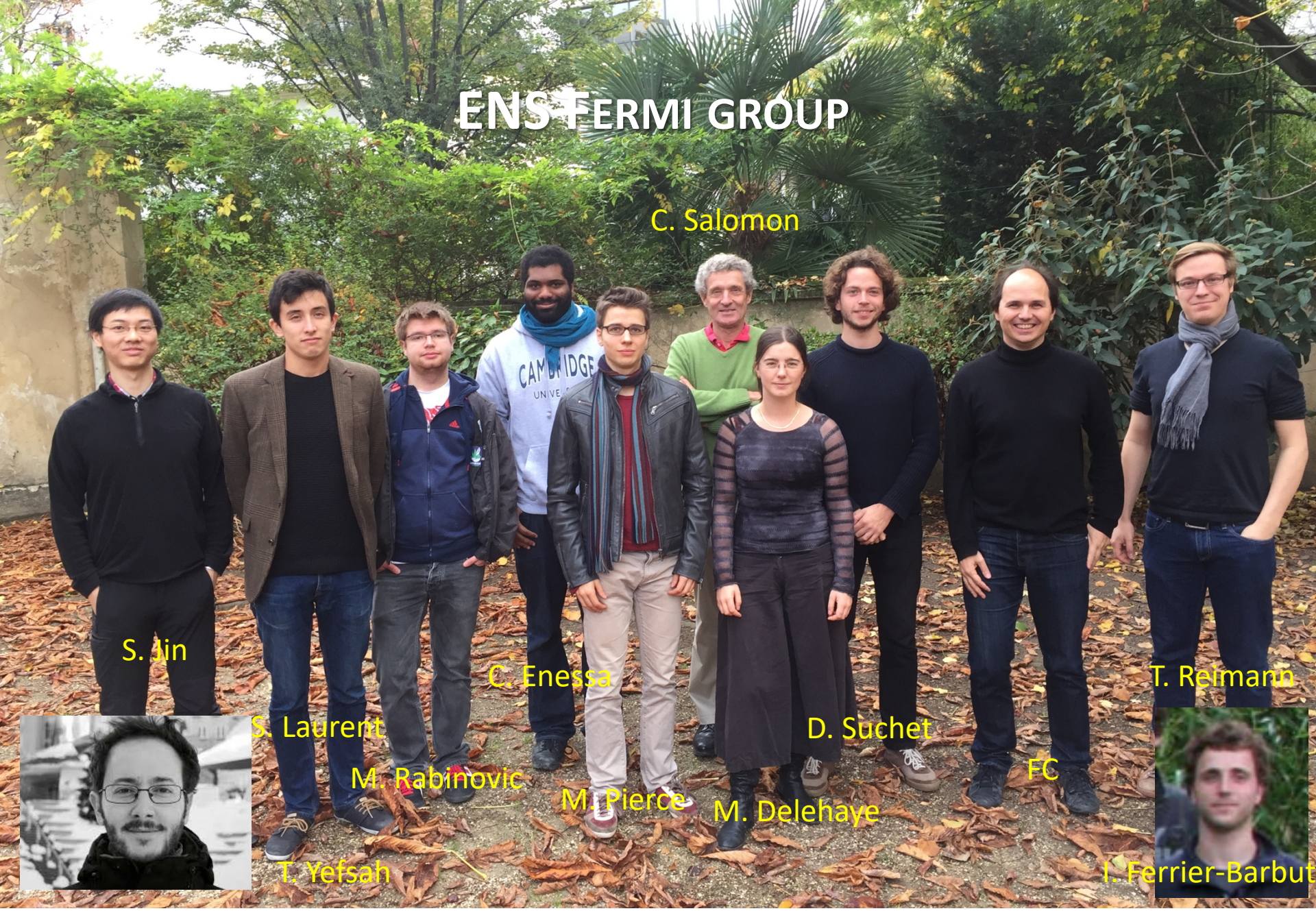
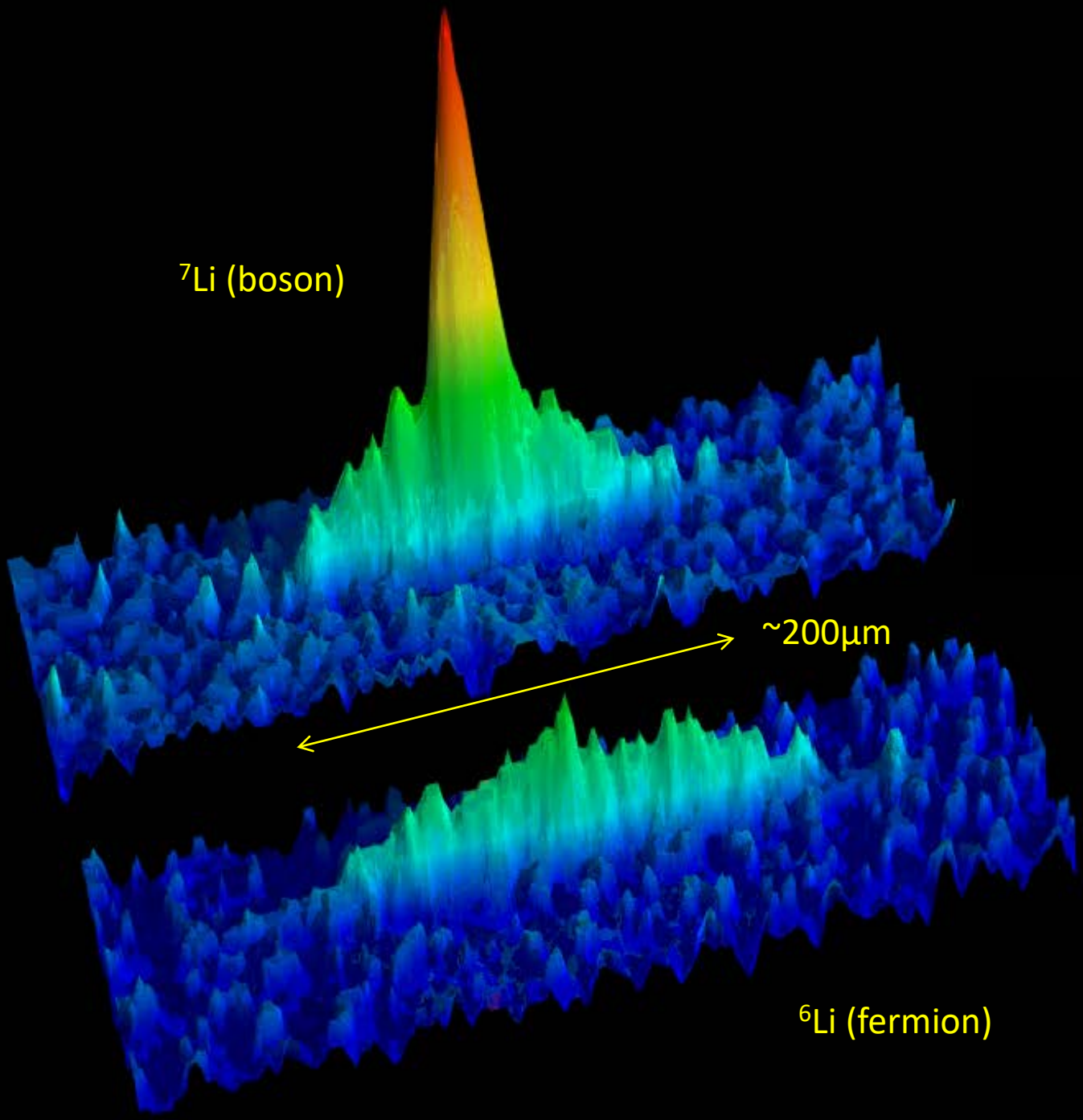
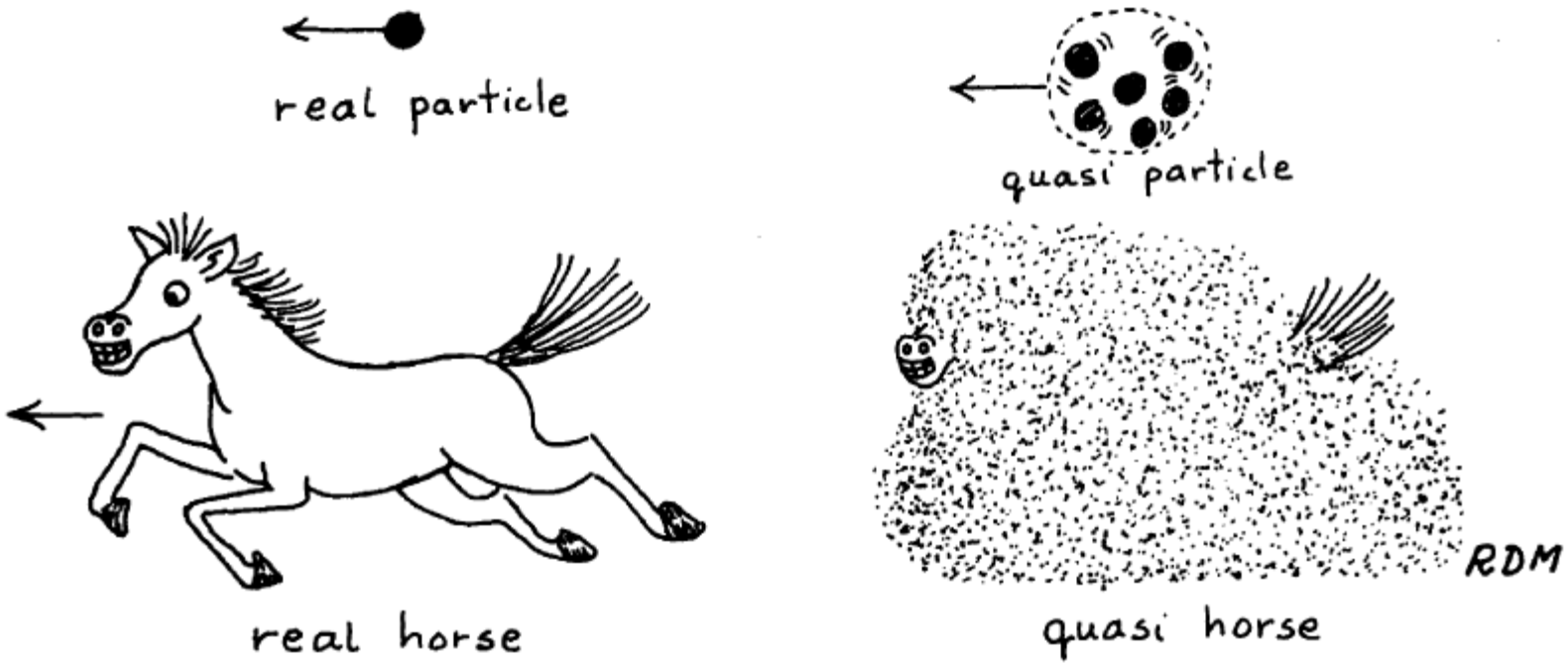
ENS Fermi group



Y. Castin (ENS), S. Stringari (Trento), I. Danaila (Rouen), P. Parnaudeau (Poitiers)


^{7}Li (boson)
~200µm
^{6}Li (fermion)

The Polaron Problem

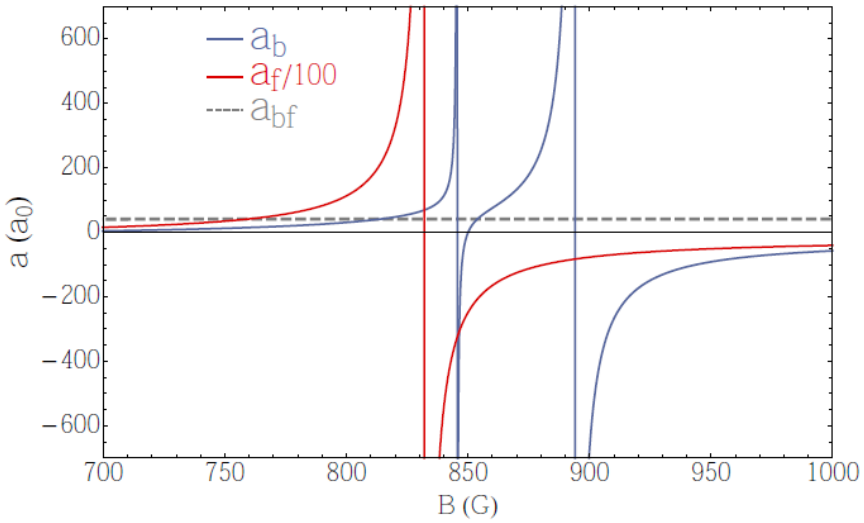


(From R.D. Mattuk)

POLARON PHASE DIAGRAM

Intra medium coupling

Impurity weakly coupled to a strongly correlated medium



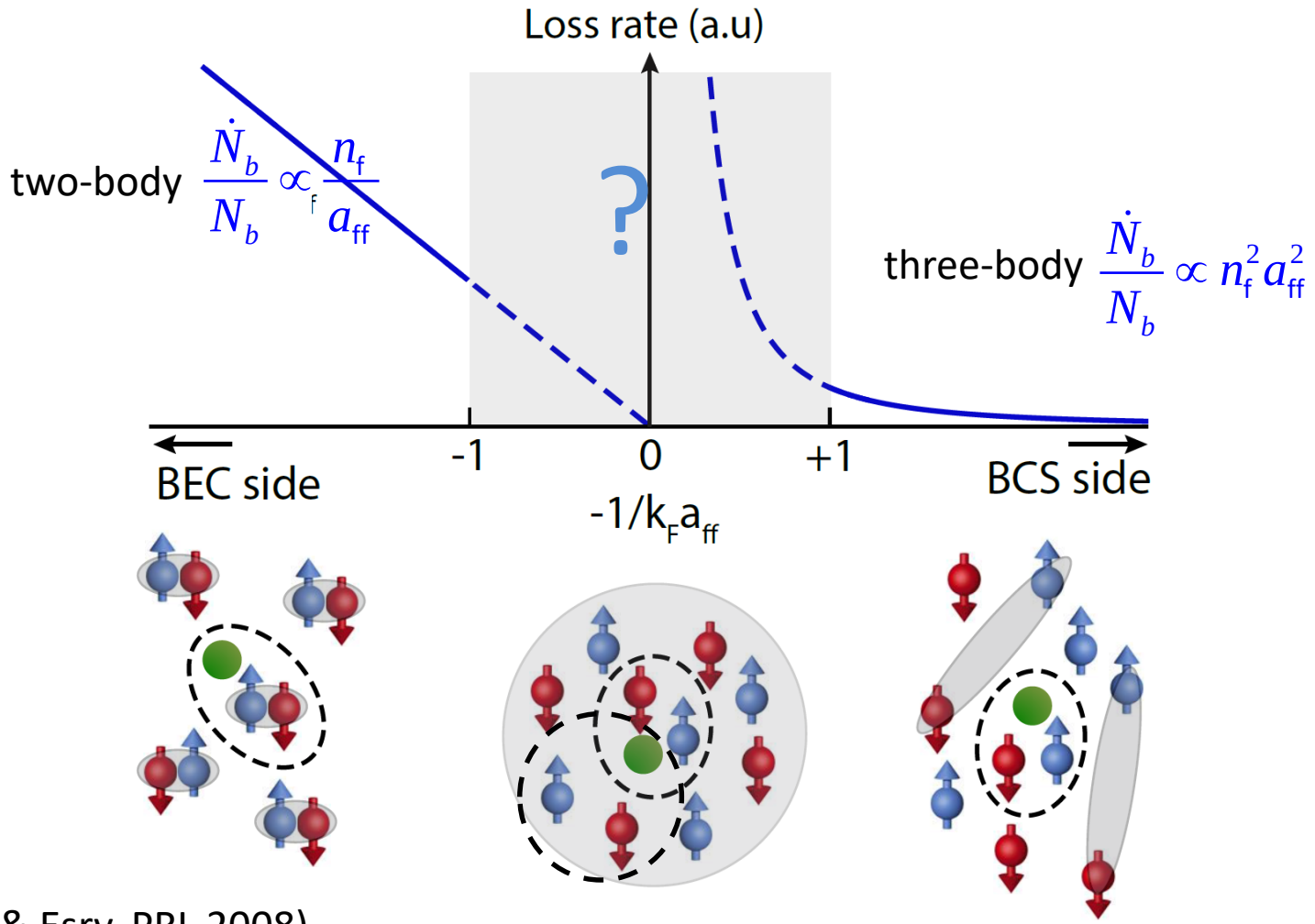
Fermi polaron (ENS, MIT, Innsbruck…); Bose polaron (Aarhus, JILA); Kondo problem…

Impurity-medium coupling

How long does the mixture live?

S. Laurent *et al.*, Phys. Rev. Lett. **118**, 103403 (2017)

LIFETIME OF AN IMPURITY IMMERSED IN A FERMIONIC SUPERFLUID.



(D'incao & Esry, PRL 2008)

THREE-BODY LOSSES AND TAN'S CONTACT PARAMETER

Loss rate $\propto$ probability of having three atoms within a distance R* (size of the final molecule)

Weak Bose-Fermi interaction: $\rho(r_\uparrow, r_\downarrow, r_b) \approx \rho_f(r_\uparrow, r_\downarrow)\rho_b$

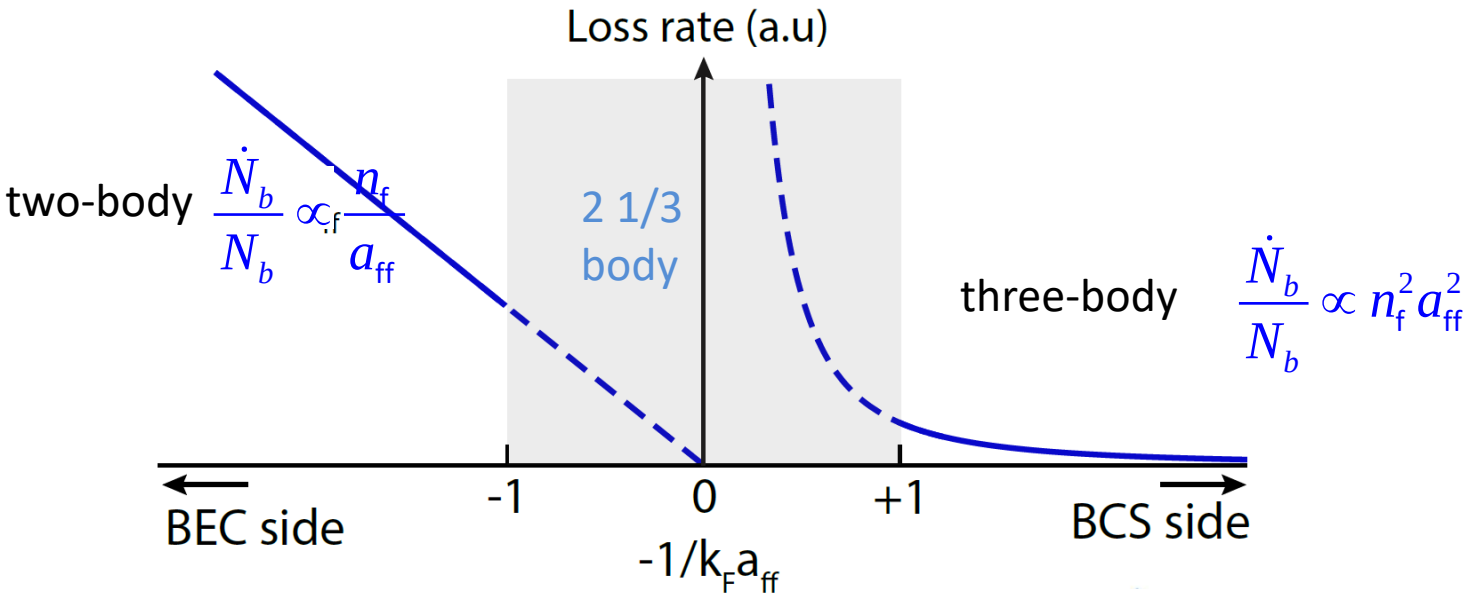
Tans's contact: in the two body problem with contact interaction

$$\rho_f(\mathbf{r}_\uparrow, \mathbf{r}_\downarrow) \sim \frac{C_f}{|\mathbf{r}_\uparrow - \mathbf{r}_\downarrow|^2}$$

C_f=**Tan's contact parameter**

$$\Rightarrow \frac{\dot{N}_b}{N_b} = \gamma C_f$$

CONTACT SCALING



Adiabatic Sweep Theorem $\Rightarrow C_f = -4\pi \frac{m}{\hbar^2} \frac{1}{V} \frac{dU_f}{d(1/a_{ff})}$

BEC : $U_f = -\frac{N_f}{2} \frac{\hbar^2}{m a_{ff}^2} + g_{mm} \frac{N_f^2}{8V} + \ldots \Rightarrow C_f \sim \frac{N_f}{V a_{ff}}$

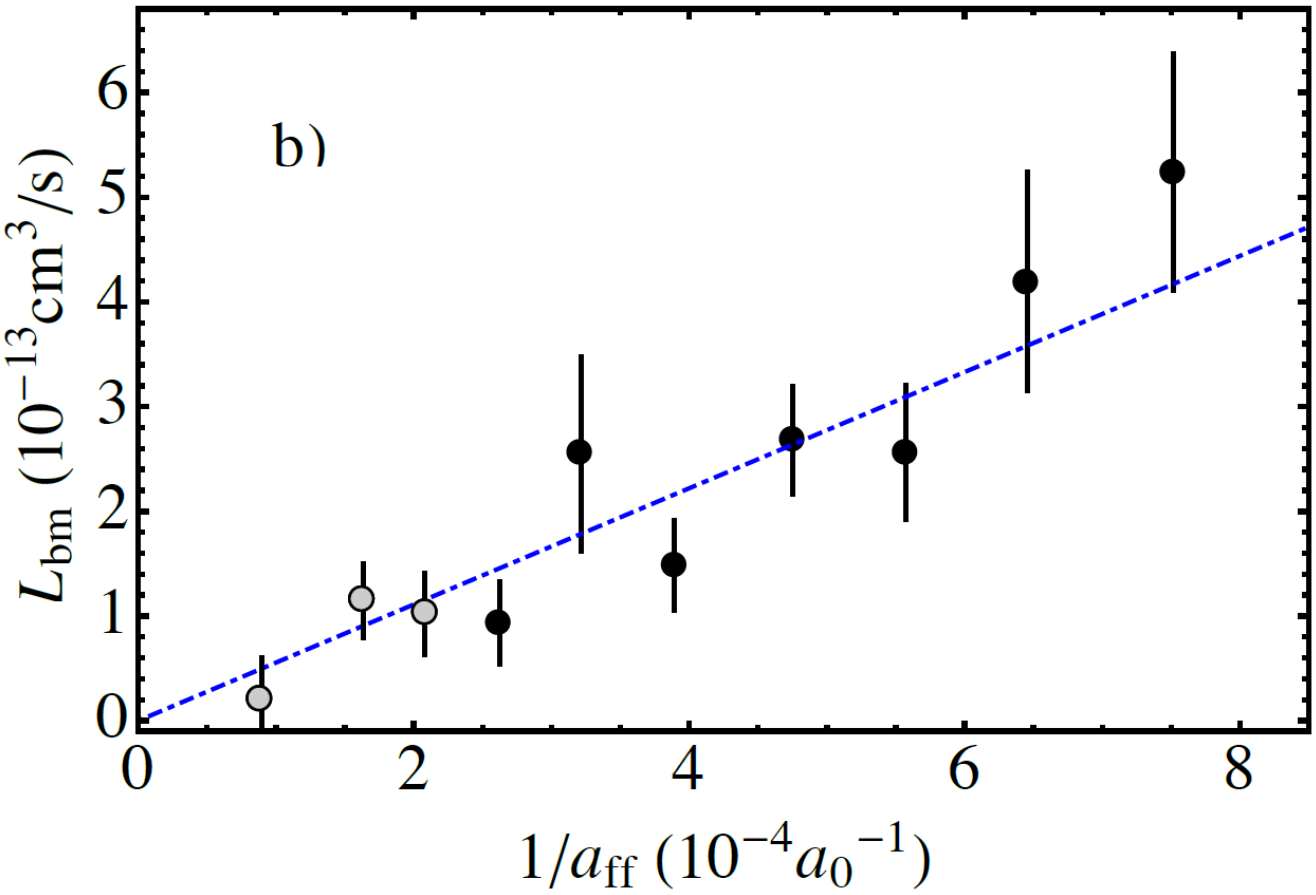
BCS : $U_f = \frac{3}{5} N_f E_F + g_{ff} \frac{N_f^2}{2V} + \ldots \Rightarrow C_f \sim \left(\frac{N_f}{V}\right)^2 a_{ff}^2$

Unitary limit: $[C]$=length^{-4} $\Rightarrow$ $C_f \sim \left(\frac{N_f}{V}\right)^{4/3} = \frac{2\zeta}{5\pi} k_F^4$

$\zeta = 0.87(3)$

(Melbourne, JILA, ENS)

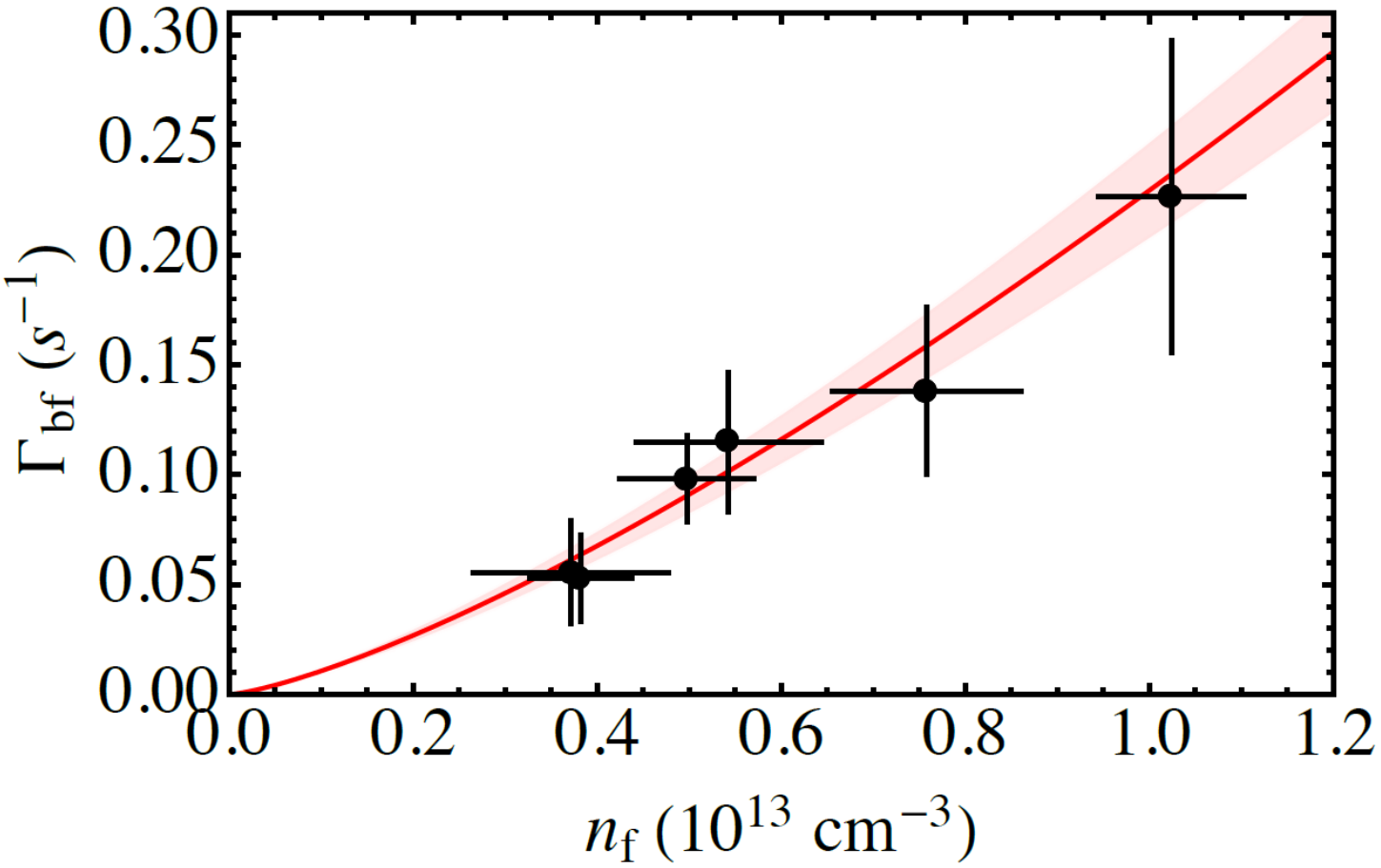
THREE-BODY DECAY IN THE BEC REGIME



Calibration of the proportionality constant $\gamma = 1.17(11)\times10^{-27}\,\mathrm{m}^4.\mathrm{s}^{-1}$

See also Zierbel *et al.*, PRL 2008; Spiegelhalder *et al.*, PRL 2009

TEST OF THE ANOMALOUS SCALING

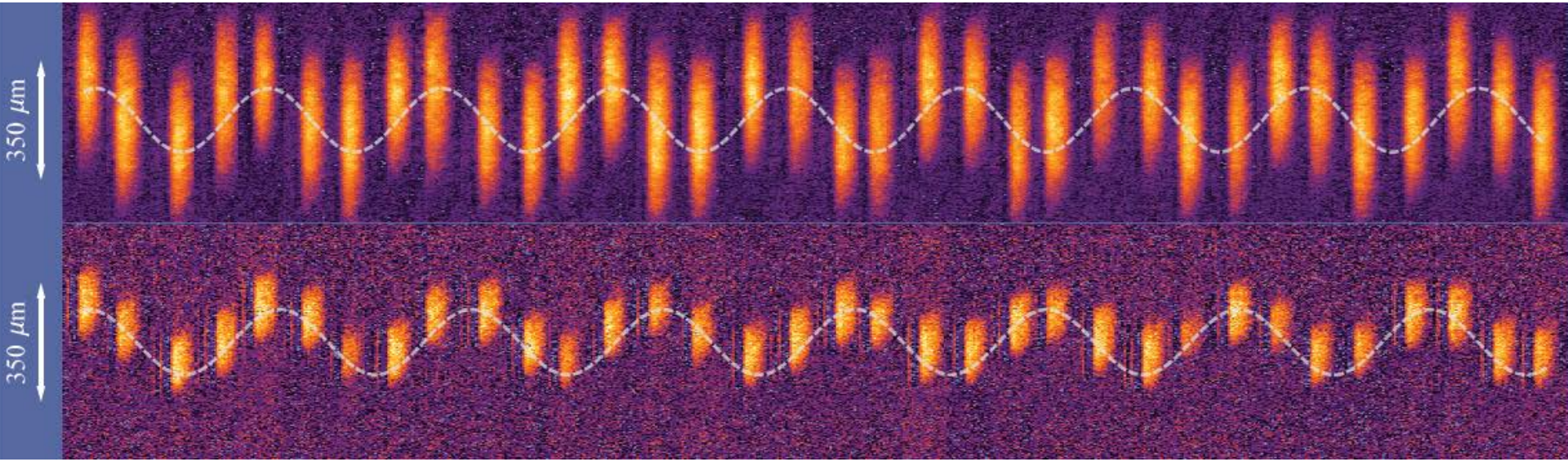


$R_b \ll R_f \Rightarrow$ Local probe of the fermionic contact.

Dynamics of the impurity

I. Ferrier-Barbut *et al.*, Science **345**, 1035 (2014)

Dynamics of the Mixtures



$$\omega_6 = 2\pi \times 16.80(2)\text{Hz} \qquad \tilde{\omega}_6 = 2\pi \times 16.80(1)\text{Hz}$$

$$\omega_7 = 2\pi \times 15.27(2)\text{Hz} \qquad \tilde{\omega}_7 = 2\pi \times 15.00(1)\text{Hz}$$

Single Superfluid

Ratio = $(7/6)^{1/2} = (m_7/m_6)^{1/2}$

Coupled Superfluids

See also C. Hammer *et al* Phys. Rev. Lett. **106**, 065302 (2011) for boson-boson superfluid counterflow

FREQUENCY SHIFT

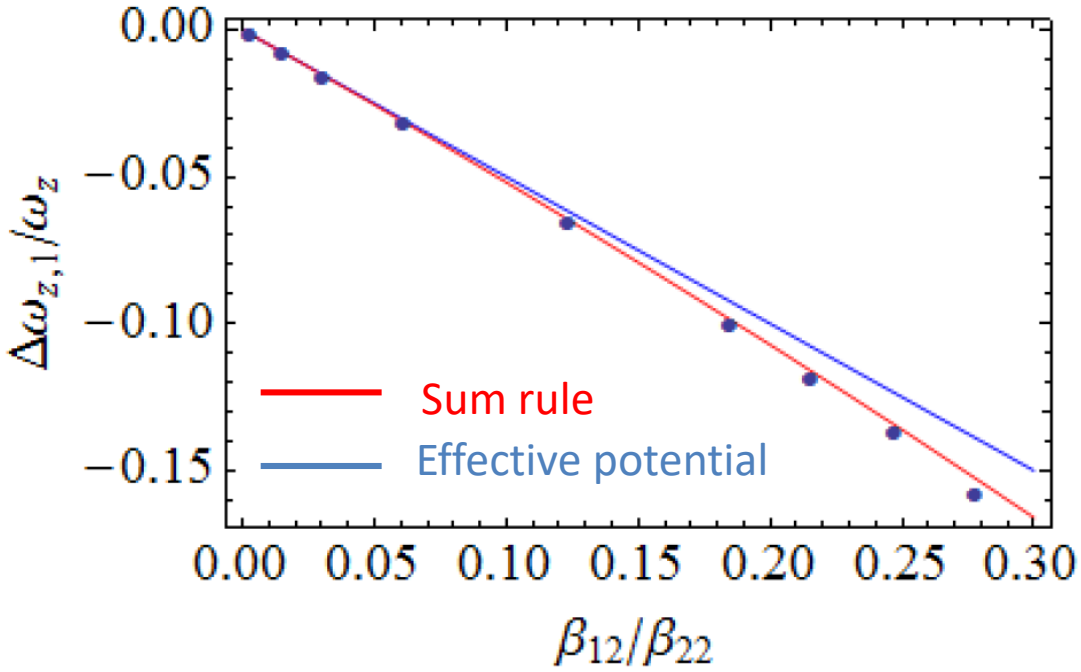
$$V_{\mathrm{eff},7} = V(\mathbf{r}) + g_{67} n_6(\mu_6(\mathbf{r})) \qquad \mu_6(\mathbf{r}) = \mu_6^0 - V(\mathbf{r})$$

(Local Density Approximation)

$$\approx g_{67} n_6(\mu_6^0) + V(\mathbf{r})\left(1 - g_{67}\frac{\partial n_6}{\partial \mu_6}\right)$$

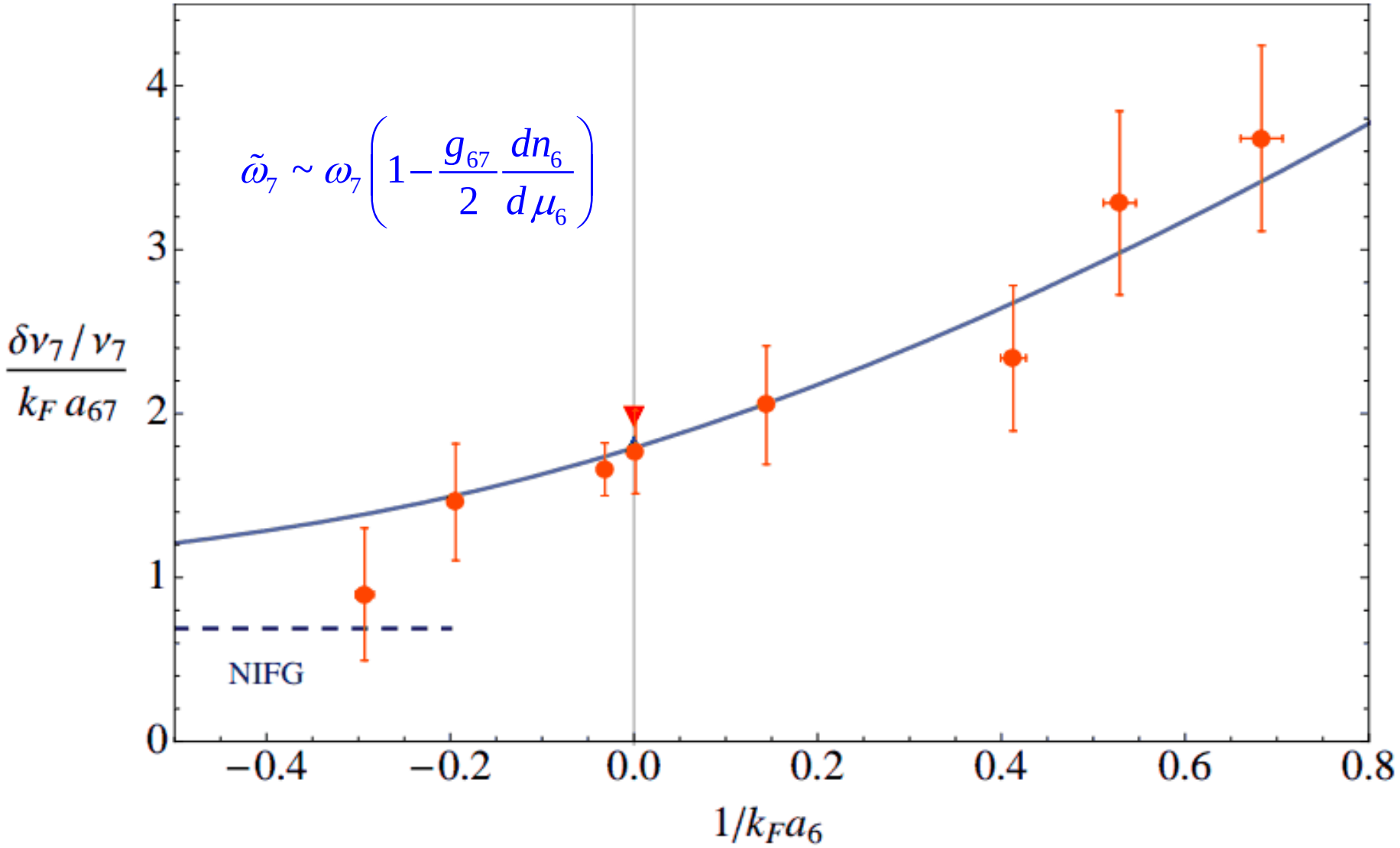
Harmonic trap: $$\frac{\Delta\omega_7}{\omega_7} \approx -\frac{g_{67}}{2}\frac{\partial n_6}{\partial \mu_6}$$

Benchmark: Numerical solution of GPE (P. Parnaudeau/I. Danaila/A. Suzuki)



Oscillation Frequency of the BEC

Weak frequency shift (few percents) of the bosons due to the fermions



CONCLUSION AND OUTLOOK

- Weakly coupled impurities can be used as probes of the properties of strongly correlated many-body systems
- Quantitative analysis of three-body decay can be used as a probe of ***local correlations*** of a strongly interacting systems.
- Oscillation frequency shift gives access to the equation of state of the medium.

POLARON PHASE DIAGRAM