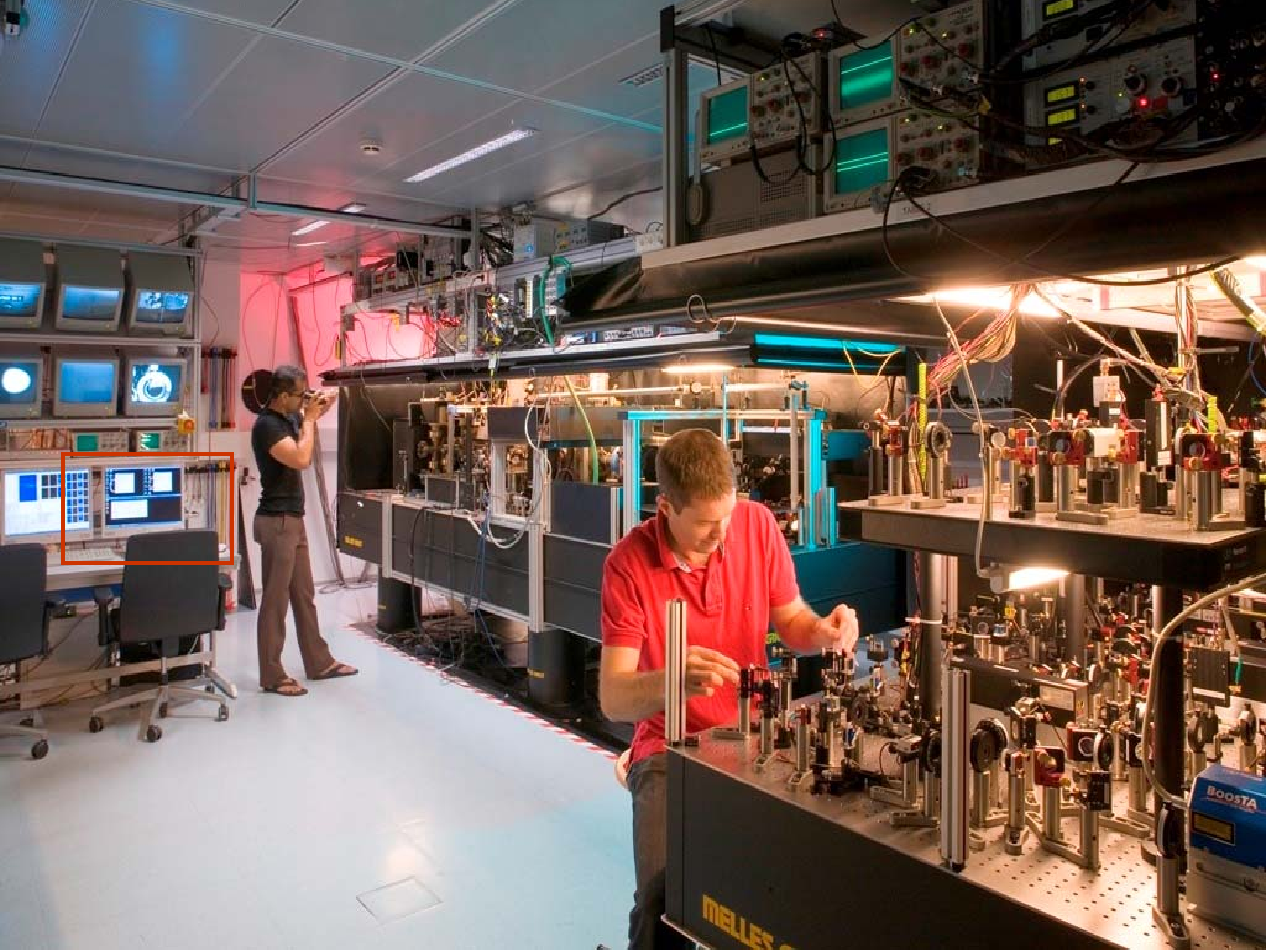
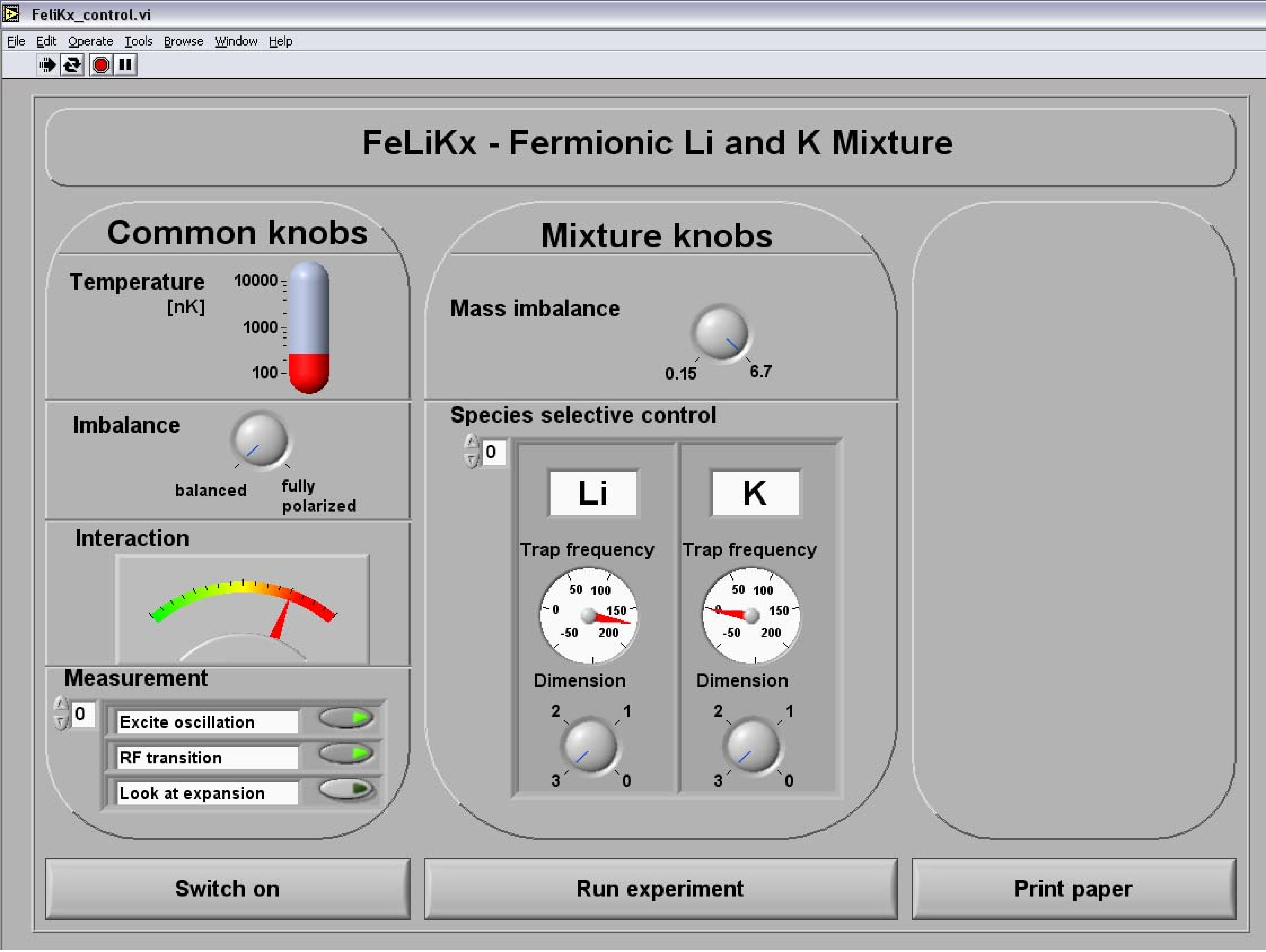
Realization of a Strongly Interacting ^{6}Li ^{40}K Fermi-Fermi mixture

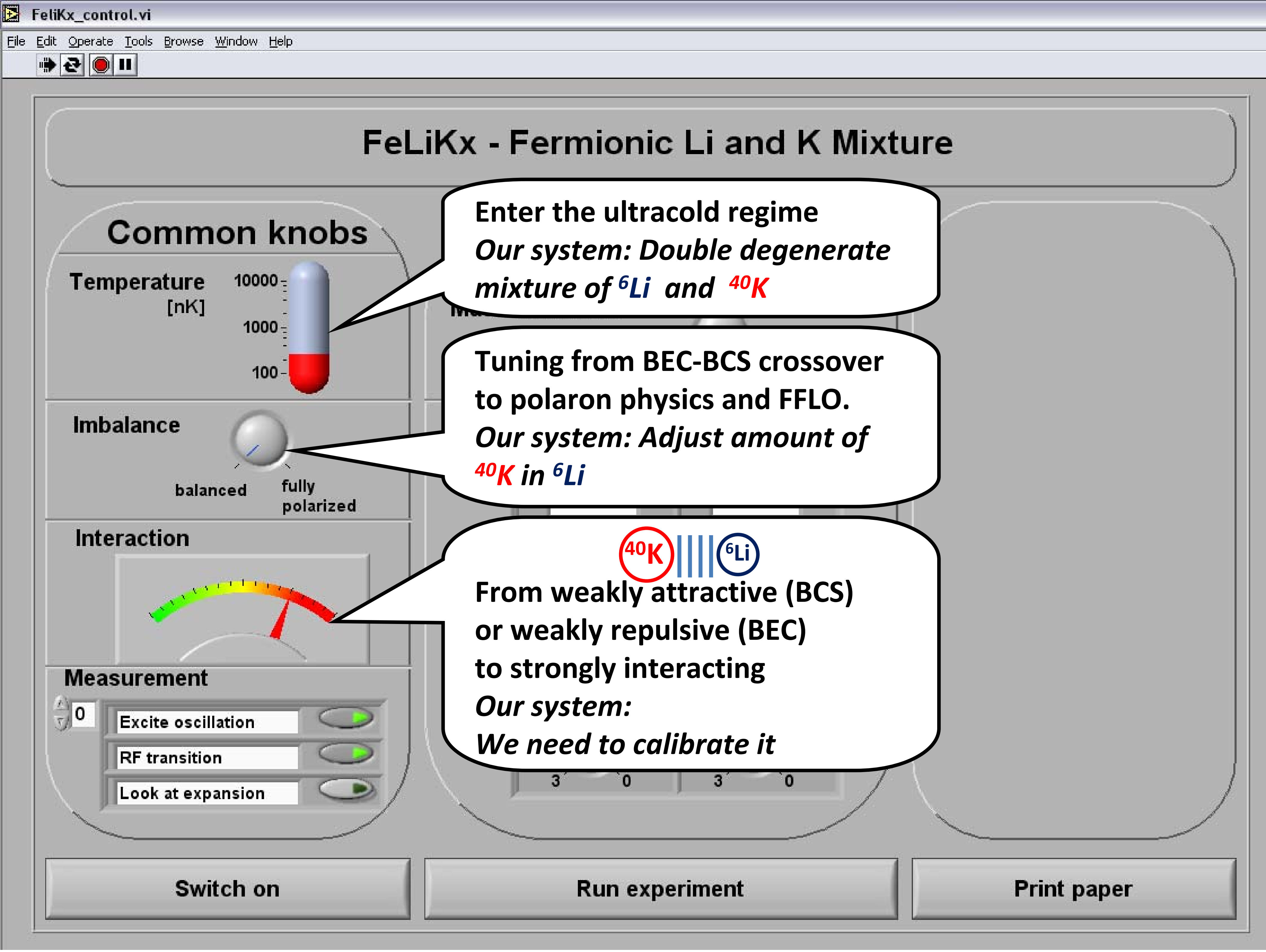
Andreas Trenkwalder, Christoph Kohstall, Matteo Zaccanti, Devang Naik, Gerhard Hendl, Andrei Sidorov, Florian Schreck, and Rudi Grimm

Institute of Quantum Optics and Quantum Information, Innsbruck

University of Innsbruck


BOOSTA


FeliKx_control.vi
File Edit Operate Tools Browse Window Help
FeLiKx - Fermionic Li and K Mixture
Common knobs
Temperature
[nK]
10000
1000
100
Imbalance
balanced
fully polarized
Interaction
Measurement
0
Excite oscillation
RF transition
Look at expansion
Mixture knobs
Mass imbalance
0.15
6.7
Species selective control
0
Li
Trap frequency
50 100 0 150 -50 200
Dimension
2 1 3 0
K
Trap frequency
50 100 0 150 -50 200
Dimension
2 1 3 0
Switch on
Run experiment
Print paper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Common knobs
Temperature [nK]
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1000
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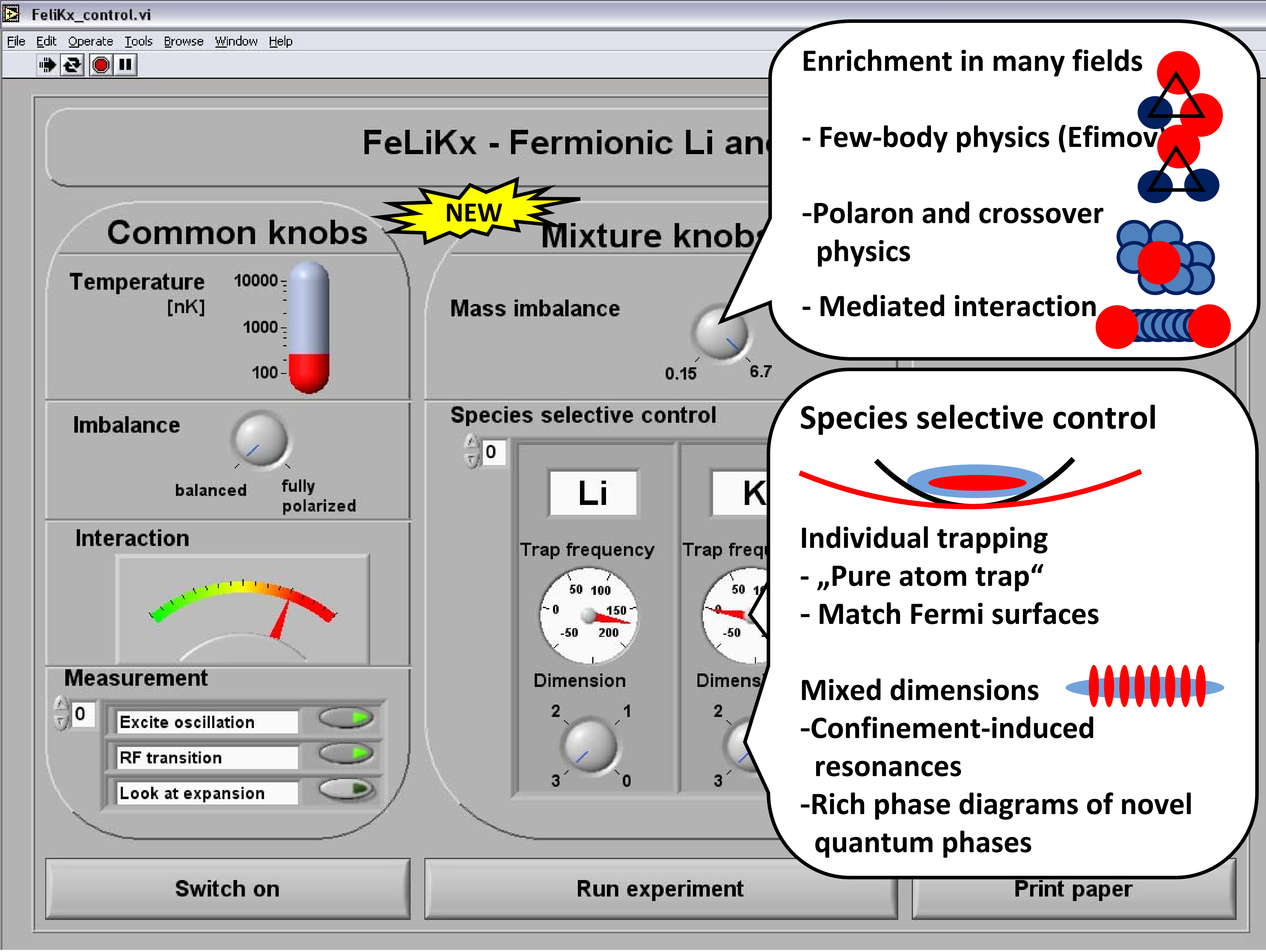
Interaction
Measurement
0
Excite oscillation
RF transition
Look at expansion
Enter the ultracold regime
Our system: Double degenerate mixture of ^{6}Li and ^{40}K
Tuning from BEC-BCS crossover to polaron physics and FFLO.
Our system: Adjust amount of ^{40}K in ^{6}Li
^{40}K
^{6}Li
From weakly attractive (BCS) or weakly repulsive (BEC) to strongly interacting
Our system: We need to calibrate it
Switch on
Run experiment
Print paper



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FeLiKx - Fermionic Li an
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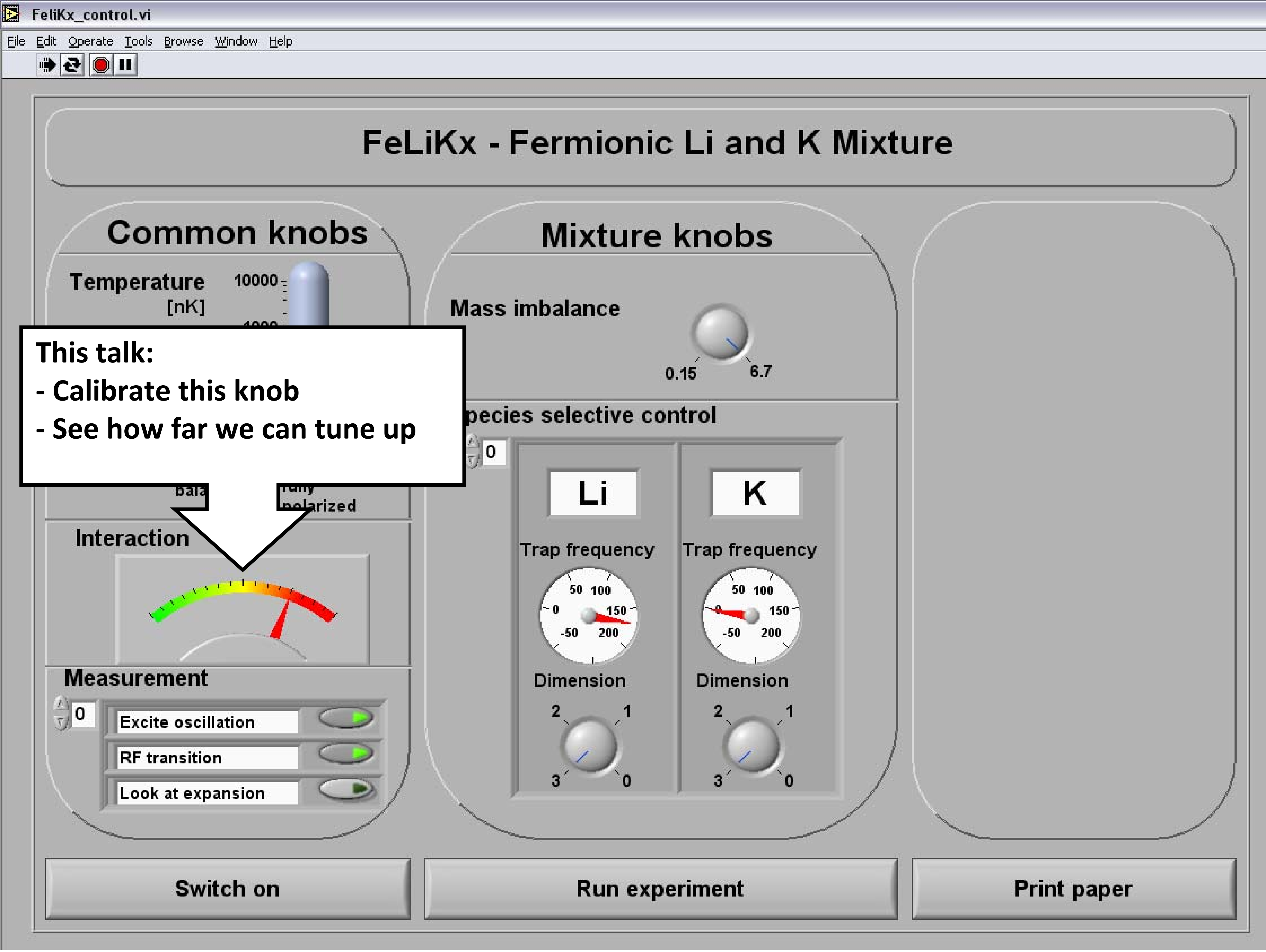
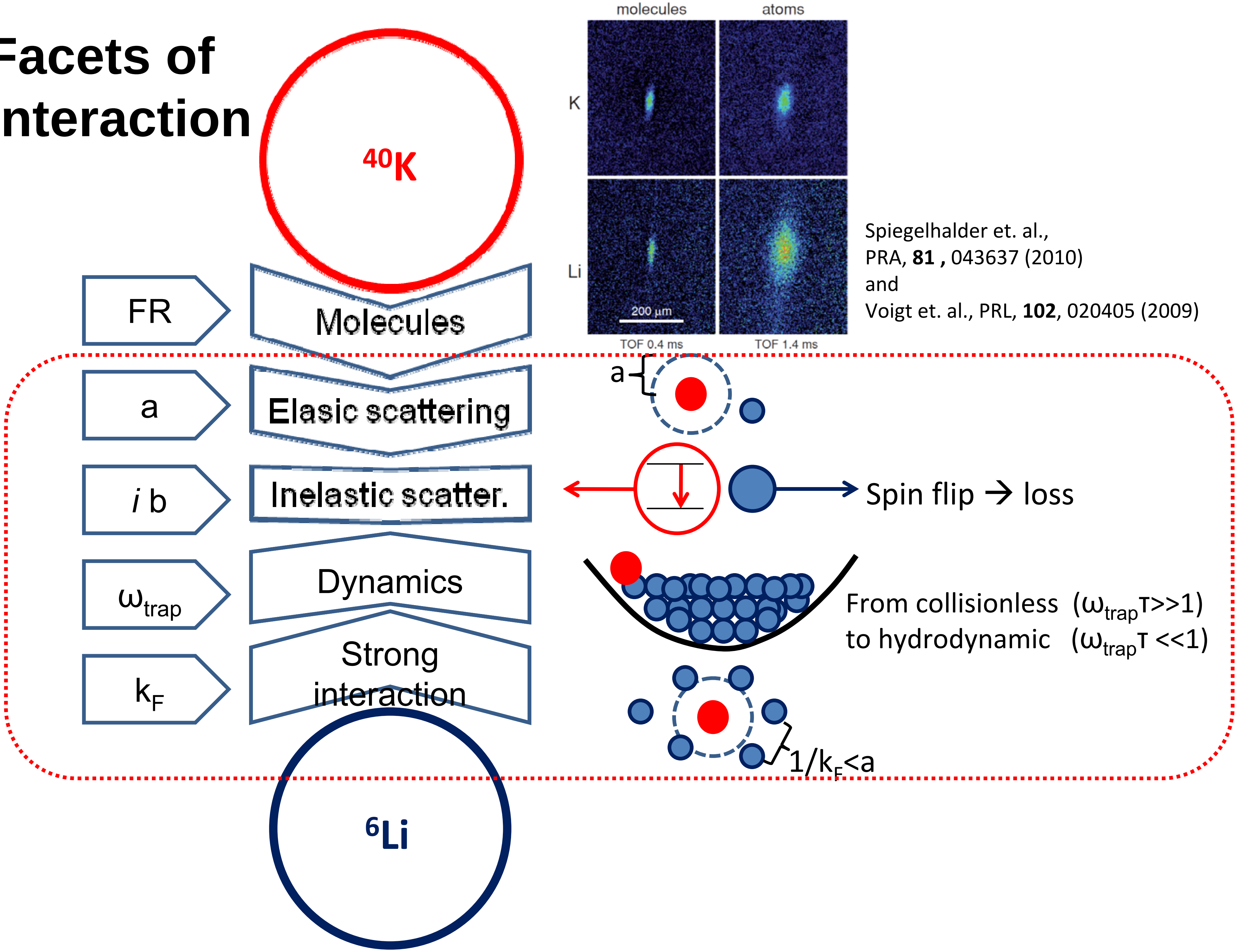
Li
K
Trap frequency
Trap freq
50
100
150
0
-50
200
Dimension
Dimens
2
1
3
0
Switch on
Run experiment
Print paper
Enrichment in many fields
- Few-body physics (Efimov)
-Polaron and crossover physics
- Mediated interaction
Species selective control
Individual trapping
- „Pure atom trap“
- Match Fermi surfaces
Mixed dimensions
-Confinement-induced resonances
-Rich phase diagrams of novel quantum phases



This talk:

- Calibrate this knob
- See how far we can tune up

Facets of interaction



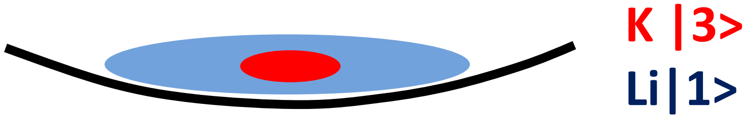
Spiegelhalder et. al.,
PRA, **81 ,** 043637 (2010)
and
Voigt et. al., PRL, **102**, 020405 (2009)

Preparation

time

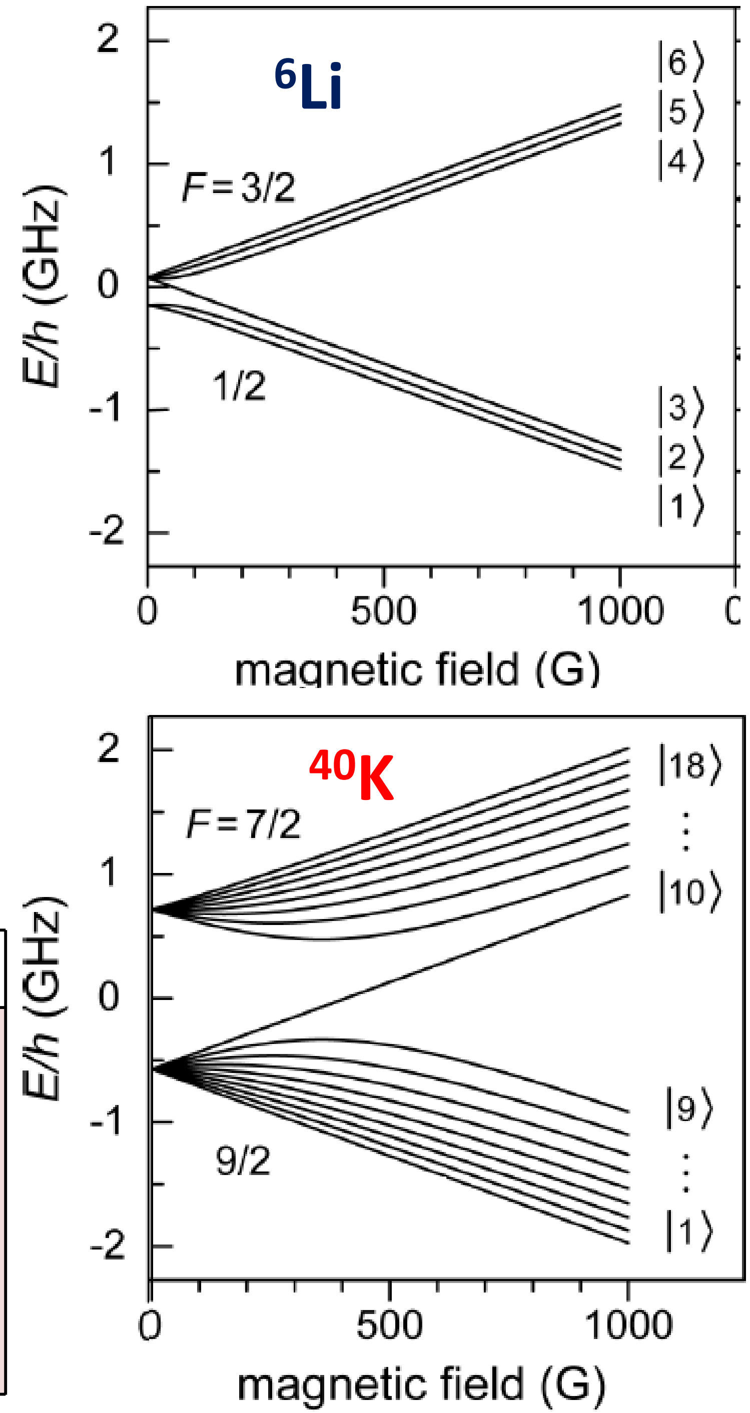
- All optical approach
- Spin mix Li|1> Li|2> is evaporatively cooled
- K is cooled sympathetically

- Kick out one spin state of Li
- Ramp to desired Feshbach field
  - Other resonances are bypassed
- Prepare desired spin states



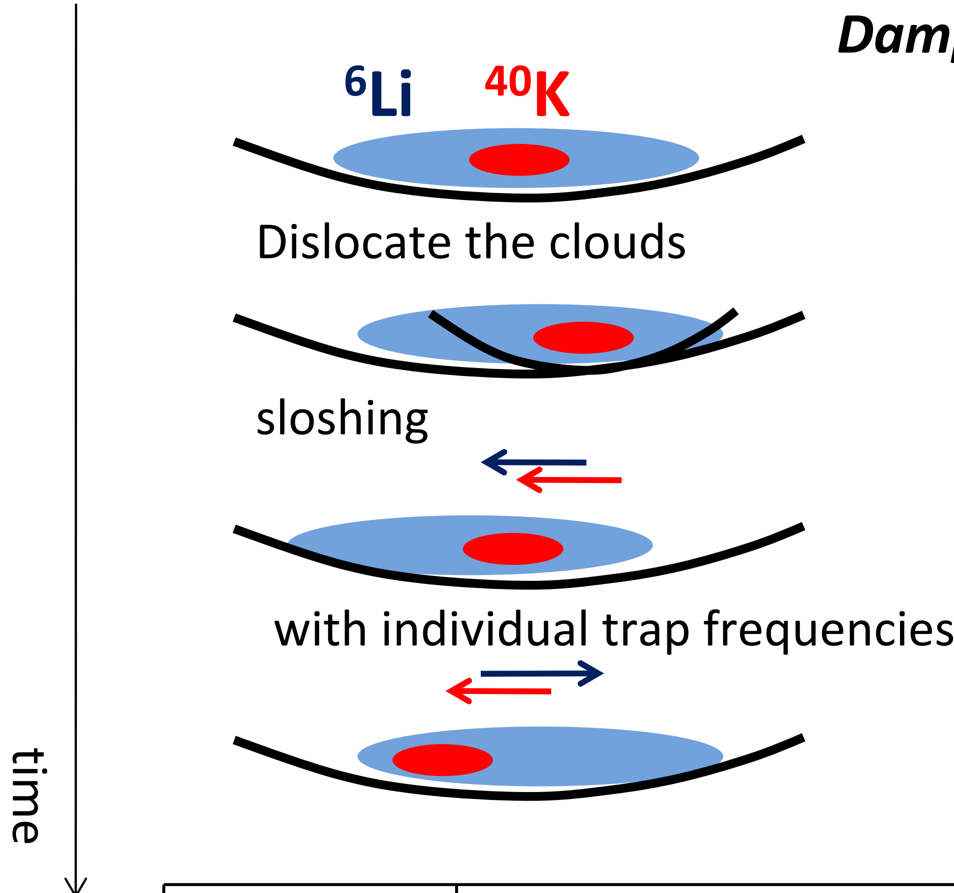
	Li|1>	K|3>	
#	10^5	$2*10^4$	More Li
$\omega_{ax}/2\pi$ /Hz	13	4.5	Cigar shaped
$\omega_{rad}/2\pi$ /Hz	365	210	geometry
T_F /nK	500	140	
T/T_F	**0.3**	**1.1**	**Deg / thermal**

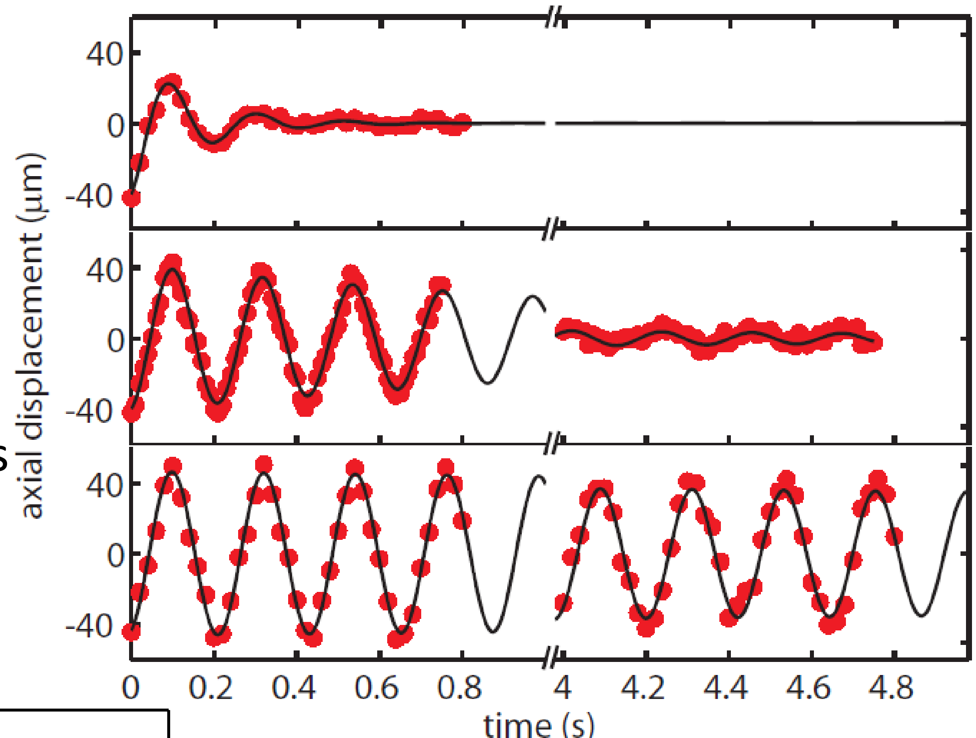
Zeeman diagrams



Elastic scattering *via* damping

Damping ~ collisions ~ cross section ~ a^2





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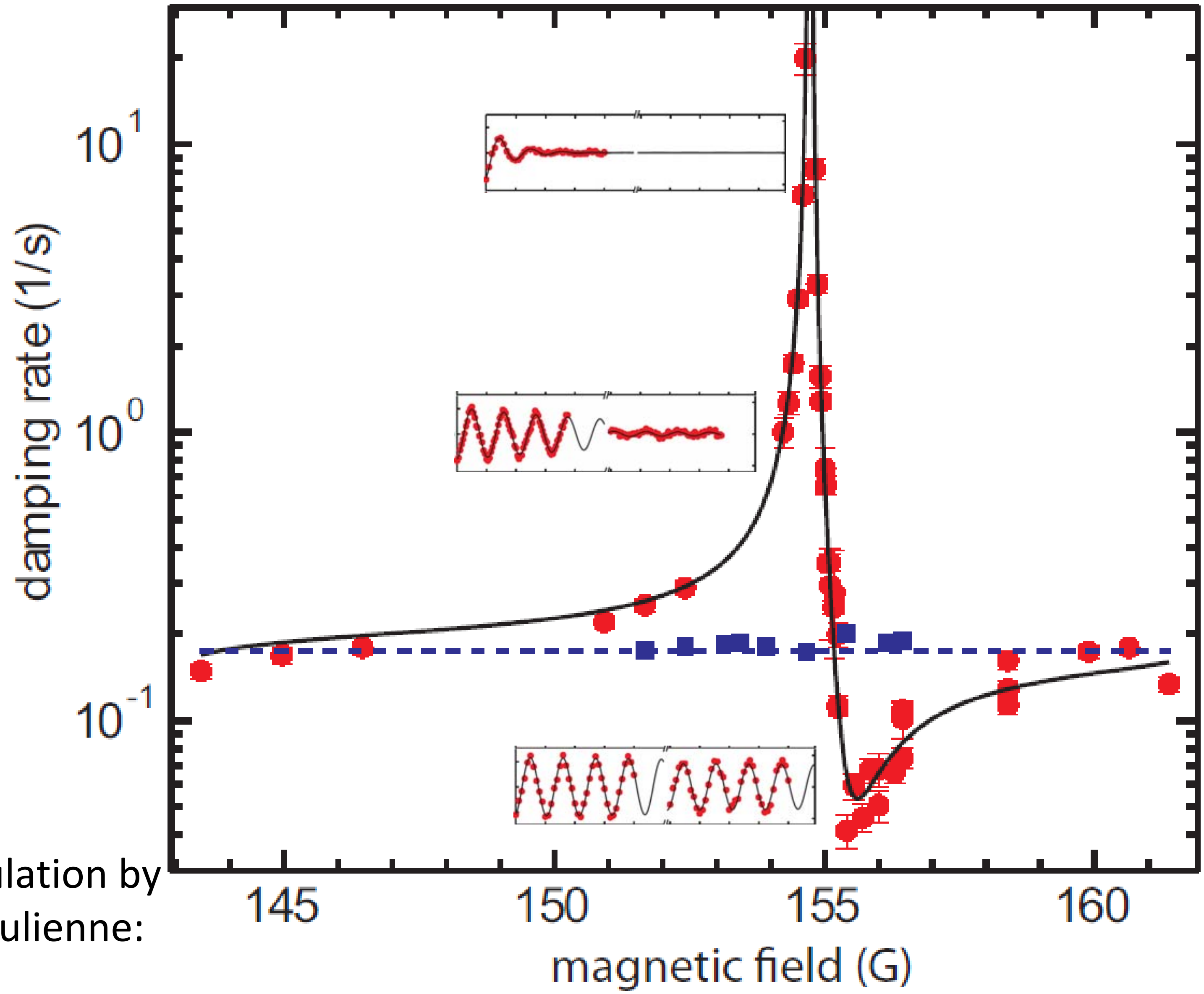
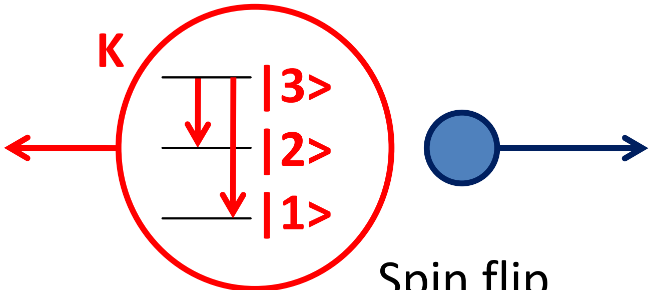
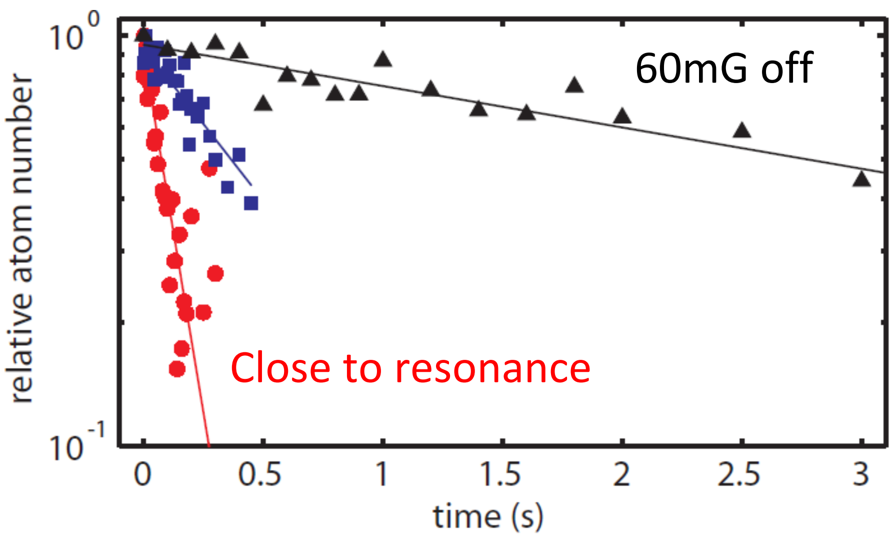


We extract:
ΔB = 920(50) mG
Coupled channel calculation by Tom Hanna and Paul Julienne:
ΔB = 880 mG

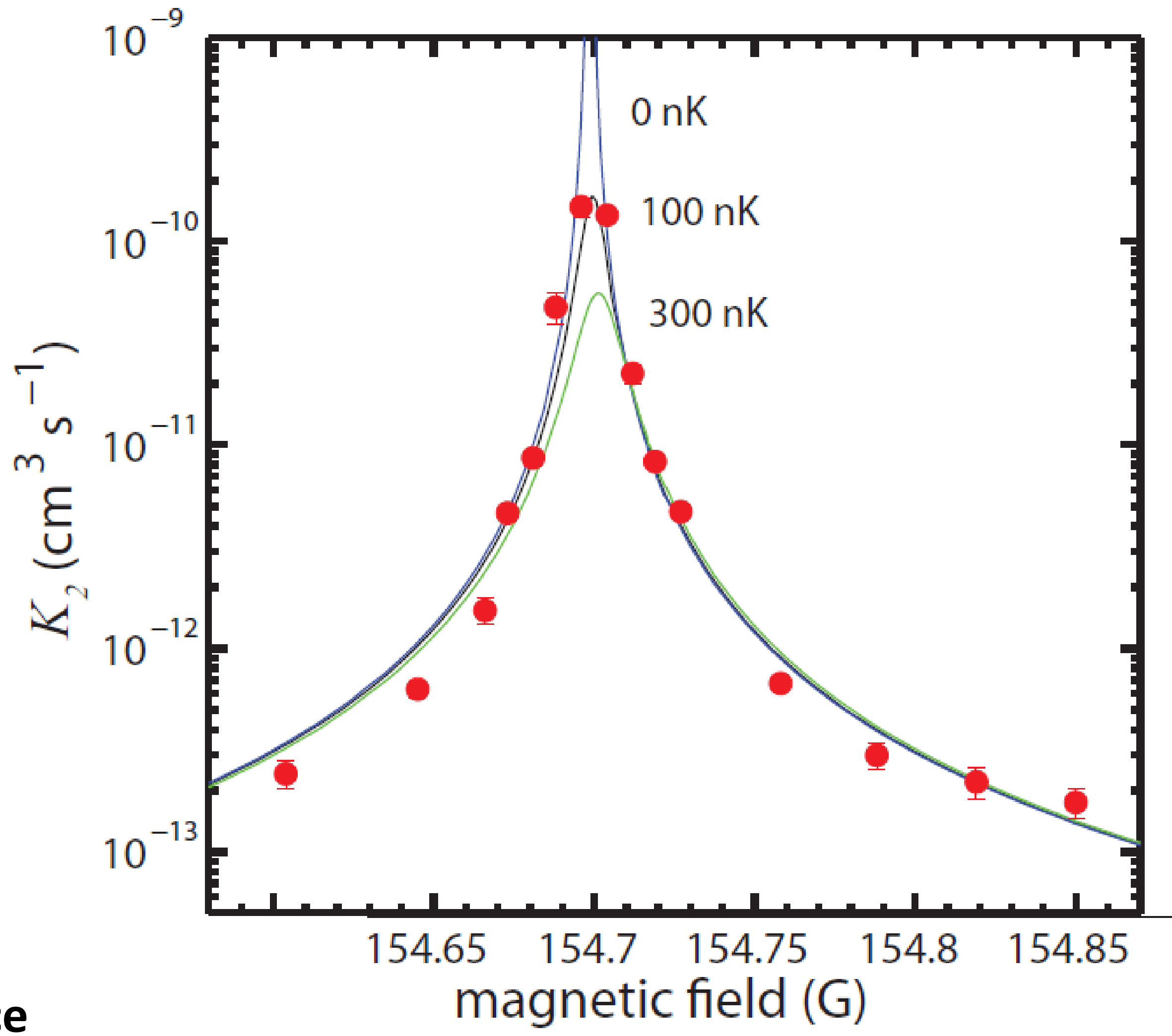
Inelastic collisions



Spin flip
→ loss from trap



Little adjustment of center
No other fit parameter
B_0 = 154.703(5) G



- **two-body loss fits well**
- **tens of ms lifetime on resonance**

→ hard to reach equilibrium ($1/\omega_{trap}$)

Possible measurements: expansion , RF spectroscopy,...

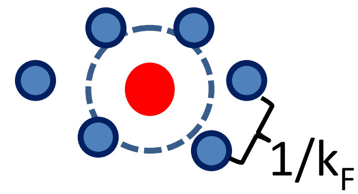
You can choose

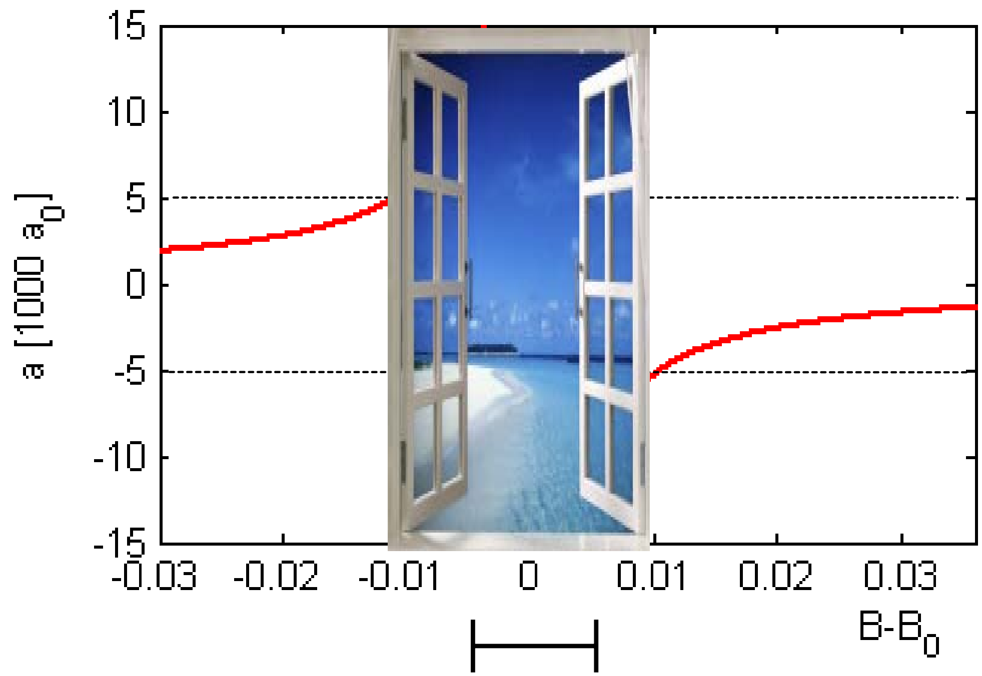
			Experiment			Coupled channels						
	Channel	M_{tot}	B_0 (G)	Δ (G)	Ref.	B_0 (G)	Δ (G)	a_{bg}/a_0	$\delta\mu/h$ (MHz/G)	a_{res} ($10^6\ a_0$)	s_{res}	γ_B (μG)
	ba	-5	215.6		[4]	215.52	0.27	64.3	2.4	19	0.0048	0.91
	aa	-4	157.6		[4]	157.50	0.14	65.0	2.3		0.0024	0
K|1> Li|1>			168.217(10)		[8]	168.04	0.13	63.4	2.5		0.0023	0
	ab	-3	149.2		[4]	149.18	0.23	67.0	2.1	18	0.0037	0.86
			159.5		[4]	159.60	0.51	62.5	2.4	5.3	0.0086	6.0
			165.9		[4]	165.928	2×10^{-4}	58	2.5	0.01	3.3×10^{-6}	1.2
	ac	-2	141.7		[4]	141.46	0.25	67.6	2.1	7.5	0.004	2.3
K|3> Li|1>			154.745(5)	0.92(5)	this work	154.75	0.88	63.0	2.3	3.7	0.014	15
			162.7		[4]	162.89	0.09	56.4	2.5	0.61	0.0014	8.3
	ad	-1				134.08	0.24	68.7	2.0	4.4	0.0037	3.7
						149.40	1.06	63.8	2.2	3.1	0.017	22
						159.20	0.33	55.8	2.45	2.1	0.0051	8.8
	ae	0				127.01	0.22	68.5	2.05	3.0	0.0035	5.0
						143.55	1.20	65.7	2.2	2.8	0.020	28
						154.81	0.69	55.1	2.4	1.5	0.010	25
	af	1				120.33	0.20	66.8	2.1	1.9	0.0032	7.0
						137.23	1.19	65.3	2.2	2.3	0.019	34
						149.59	1.14	53.6	2.4	2.5	0.017	24
	ag	2				114.18	0.14	67.4	2.1	1.2	0.0022	7.9
						130.49	1.07	66.4	2.2	2.0	0.018	36
						143.39	1.57	54.4	2.4	1.6	0.023	53
	ah	3				108.67	0.098	66.6	2.2	0.60	0.0016	11
						123.45	0.86	68.4	2.3	1.5	0.015	39
						135.9	1.87	55.9	2.45	2.0	0.029	52
	ai	4				104.08	0.06	65.9	2.25	0.24	0.0010	16
						116.38	0.54	68.6	2.4	0.61	0.010	61
						126.62	1.97	54.7	2.6	1.26	0.032	86
	aj	5				100.9	0.02	64.3	2.3	0.035	$3.3 \times 10^{-[illegible]}$	37
K|10> Li|1>			114.47(5)	1.5(5)	[7]	114.78	1.81	57.3	2.3	1.06	0.027	98

[redacted]

Homework done.
Our goal: Strongly interacting Fermi-Fermi mixture

- Strong interaction $a > 1/k_F \approx 5000\ a_0$





Standard FR formula

- Resonance position $\approx$ +/- 5 mG
- B-field stability $\approx$ +/- 5 mG

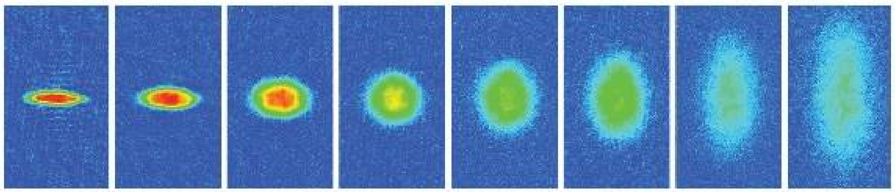
Hunting for a signature of strong interaction

2002 — 2010

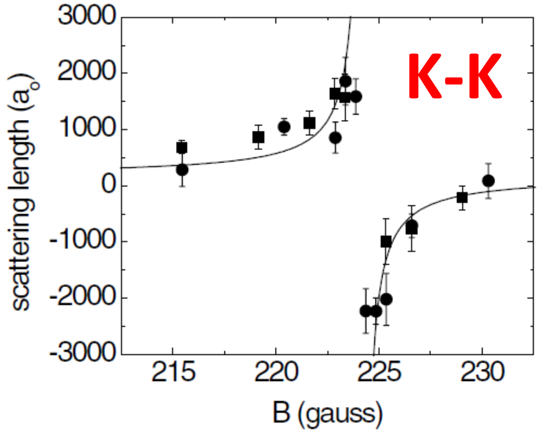
Strong interaction in homonuclear quantum gases

Show strong interaction in heteronuclear gases

Li-Li



O'Hara et. al., *Science*, **298**, 2179-2182 (2002)

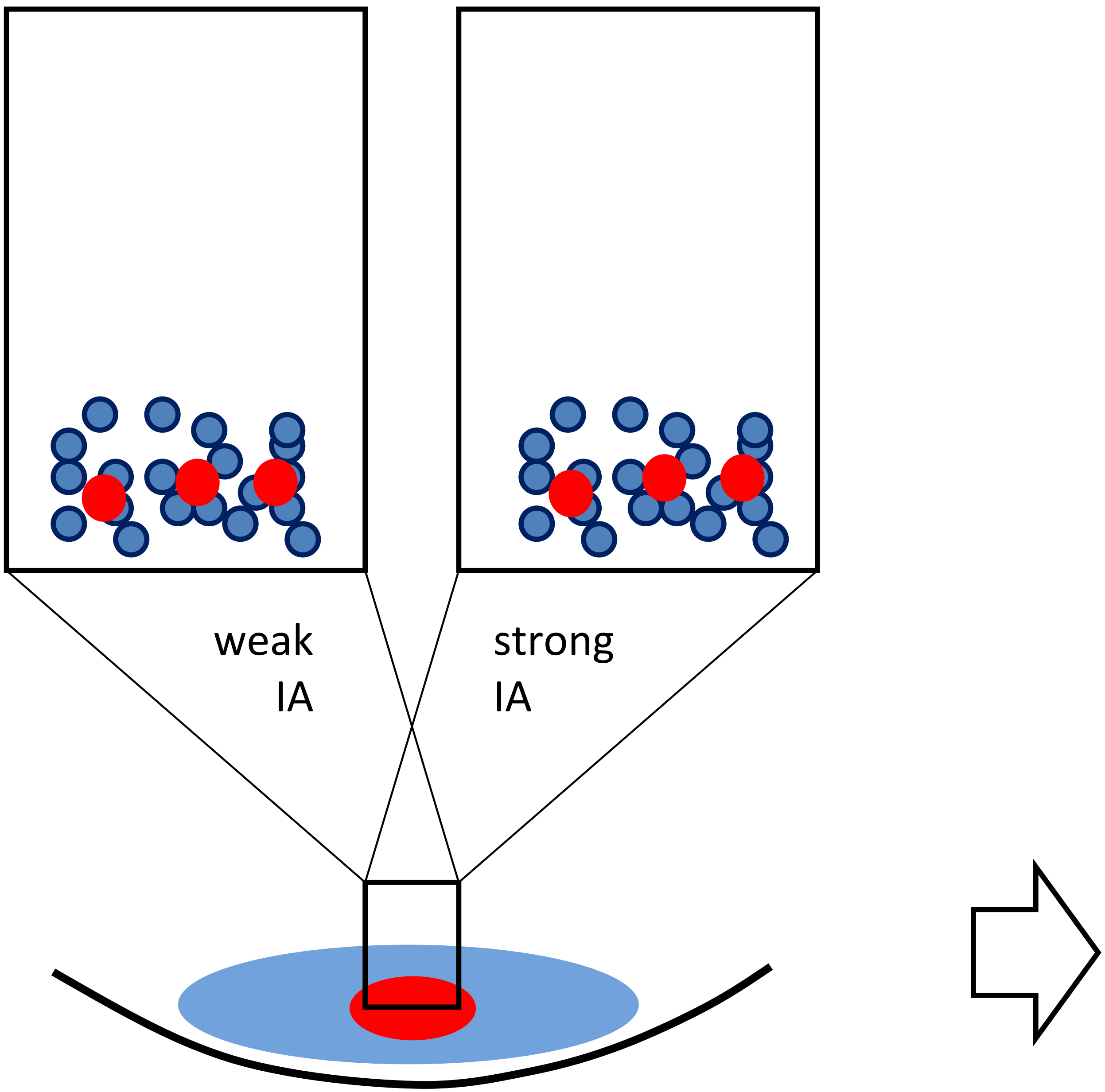


Regal et. al., *PRL*, **90**, 230404 (2003)

Hydrodynamics
(macroscopically)
pressure gradient
→***Inversion of aspect ratio*** (AR)

Energetics
→***Mean field and more***

One more effect



Hydrodynamics
(macroscopically)
pressure gradient
→***Inversion of aspect ratio*** (AR)

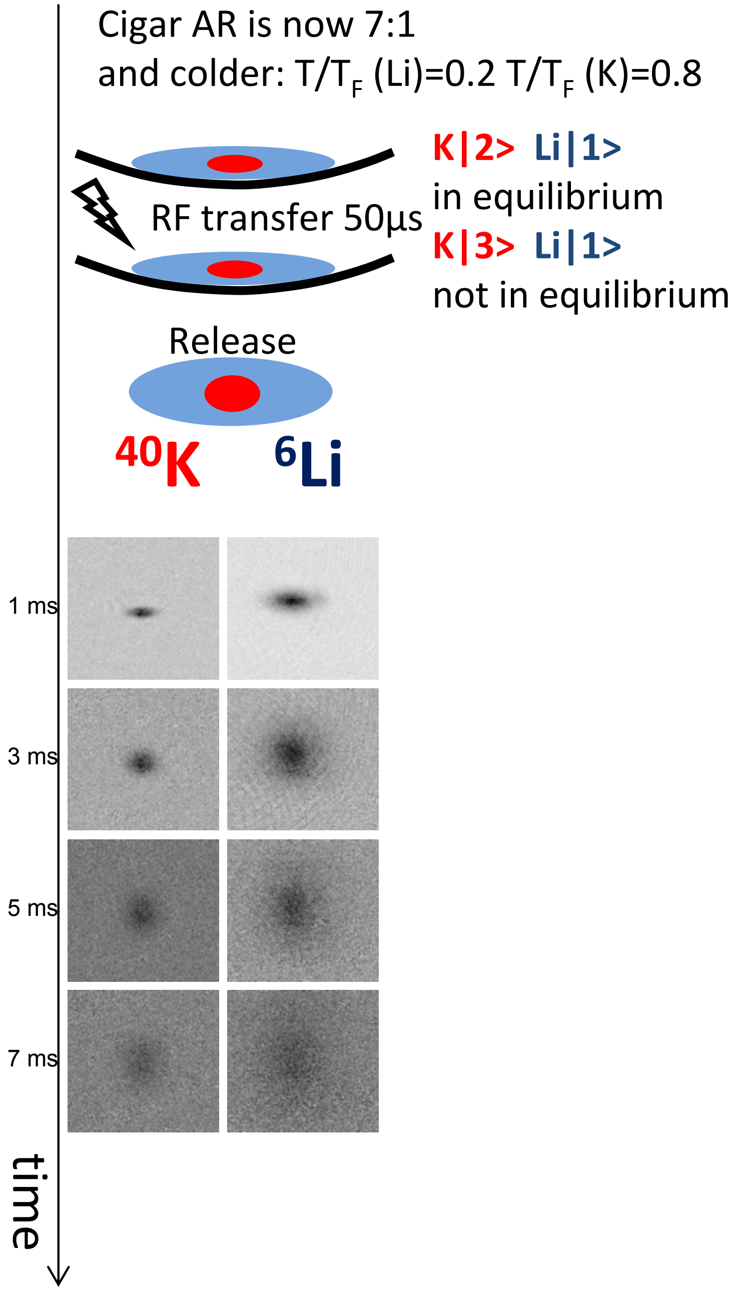
Energetics
→***Mean field and more***

Hydrodynamics
(microscopically)
→***„Dragging“ effect***

Like hd regime in buffer gas cooling

Expansion measurement

Cigar AR is now 7:1
and colder: T/T_F (Li)=0.2 T/T_F (K)=0.8

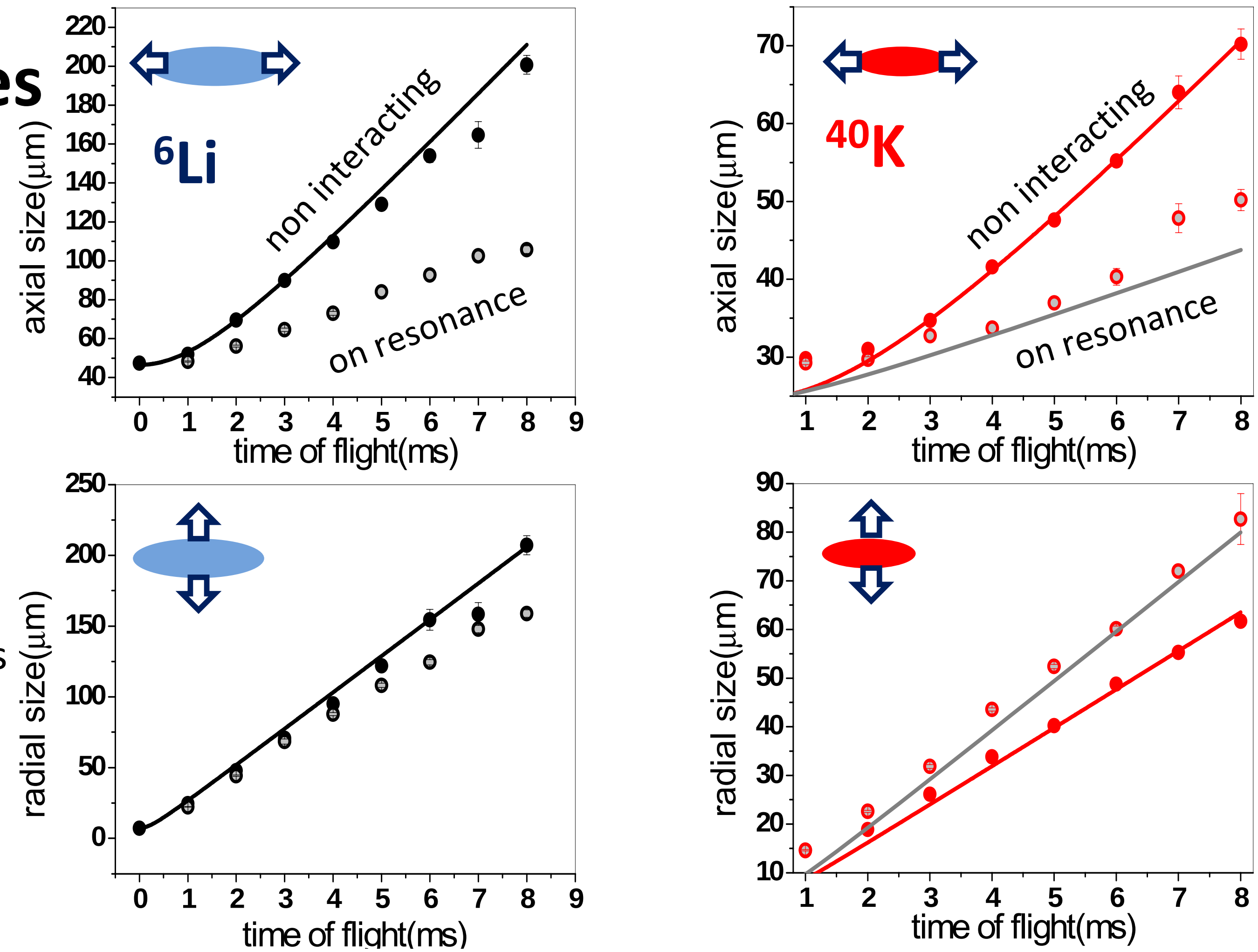


Hydrodynamics
(macroscopically)
pressure gradient
→***Inversion of aspect ratio*** (AR)

Energetics
→***Mean field and more***

Hydrodynamics
(microscopically)
→***„Dragging“ effect***

Expansion curves



No interaction

On resonance

Expansion of Fermi gas

Expansion of thermal gas

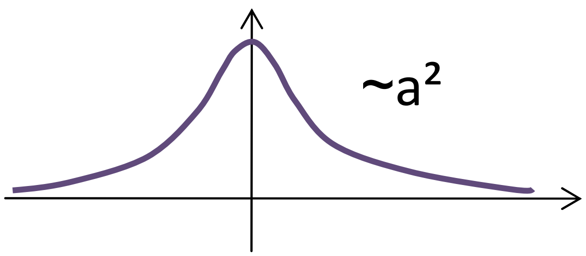
Scaling law for
hydrodynamic gas
(Orso et. al. PRA **77** 033611)

Inversion of AR←

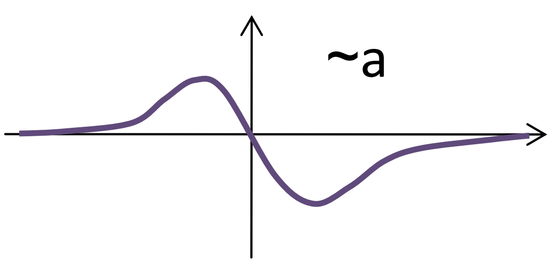
Expansion *vs* B-field

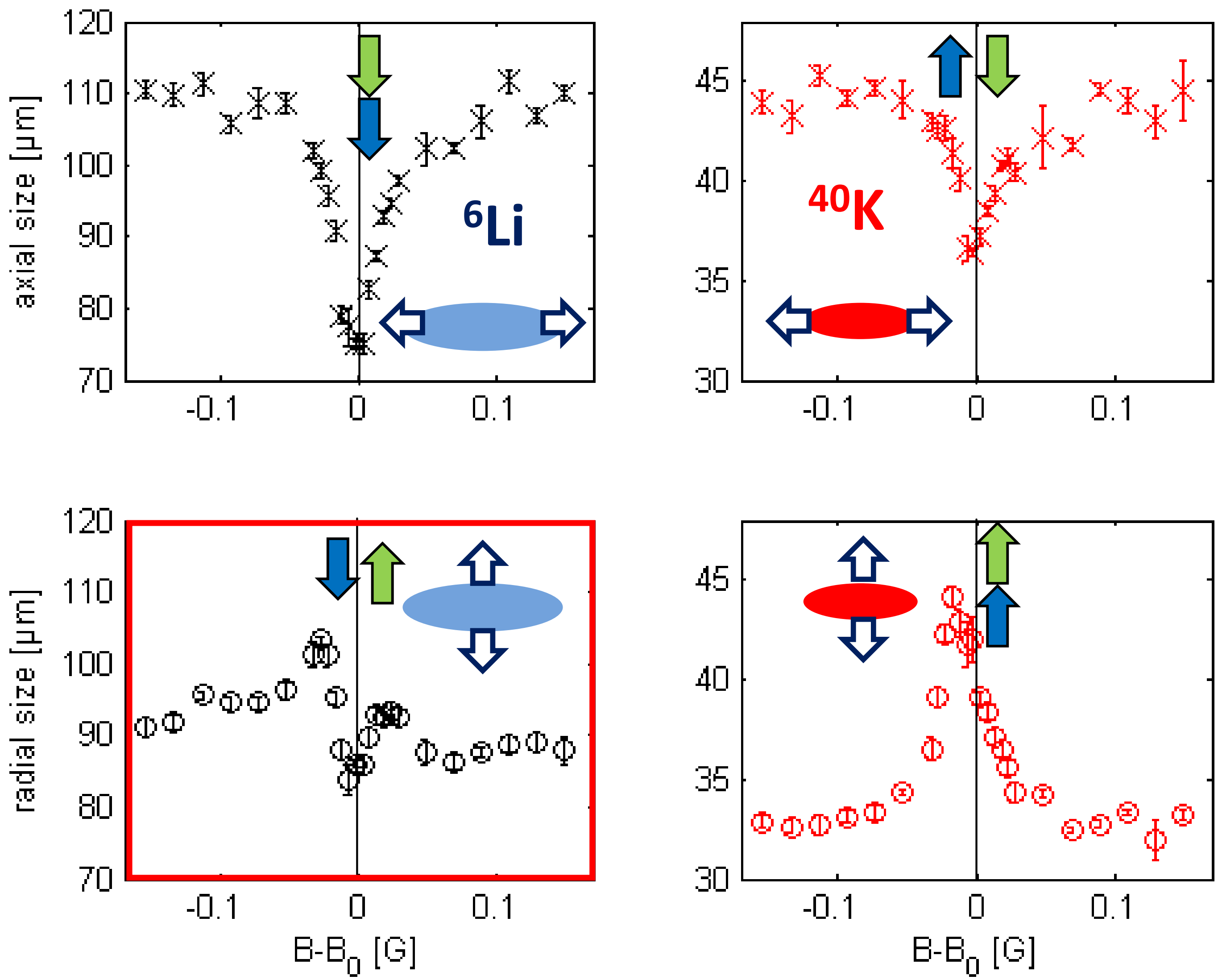
pressure gradient
inversion of AR

„Dragging“ effect



Mean field





The width of the feature is tens of mG

Closer look

to tell the 3 effects from each other

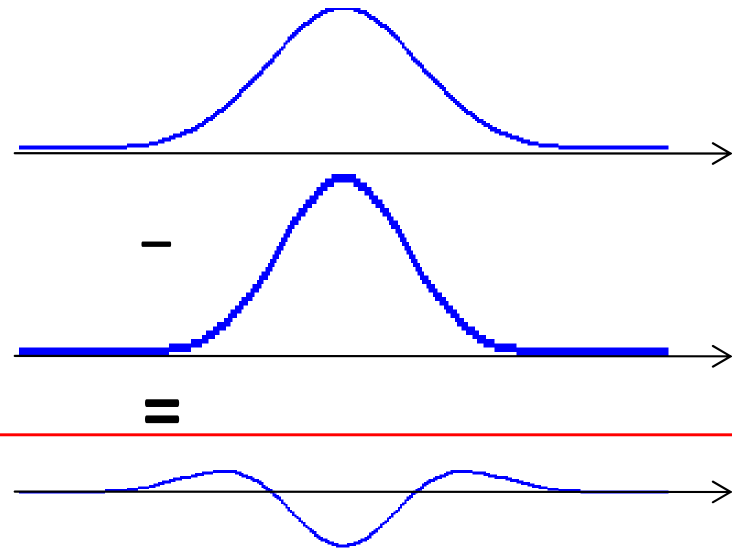
Image of gas **with IA**

minus

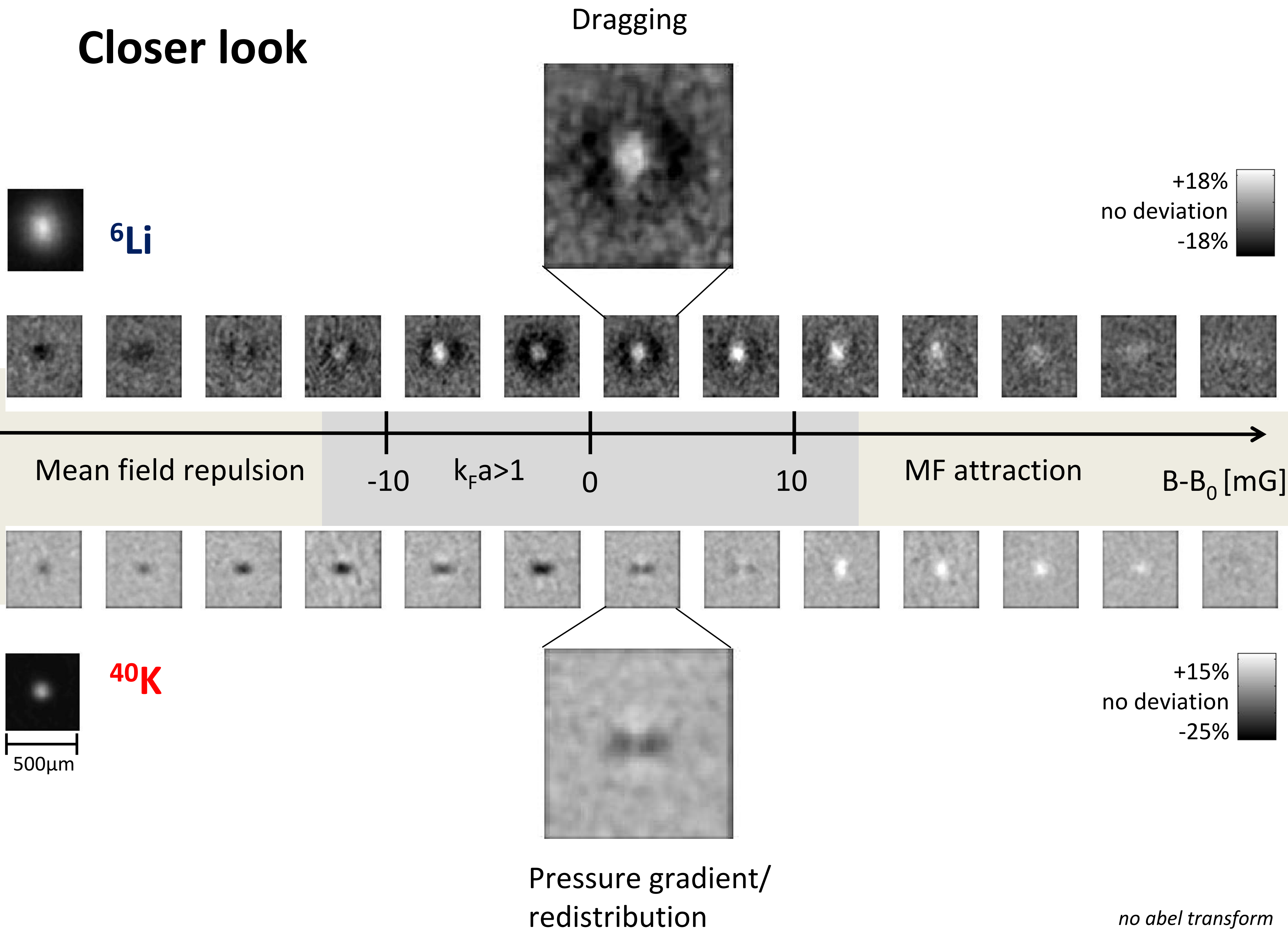
image of gas **without IA**

gives

insights on **redistribution**

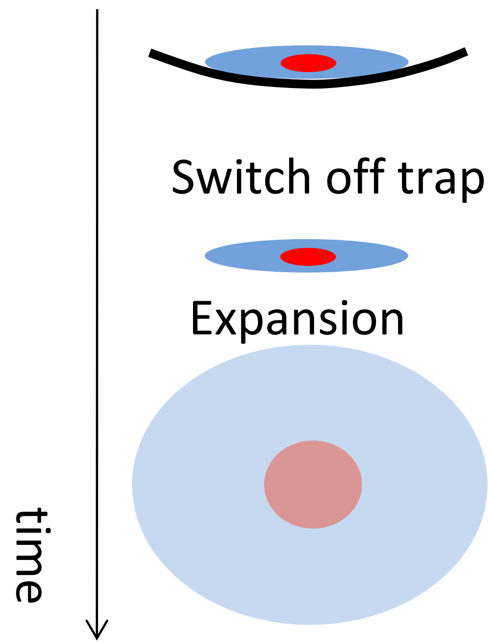


Closer look



no abel transform

Extracting interaction energy (effective scattering length)



$E_{kin\,0}$ $+E_{pot}$

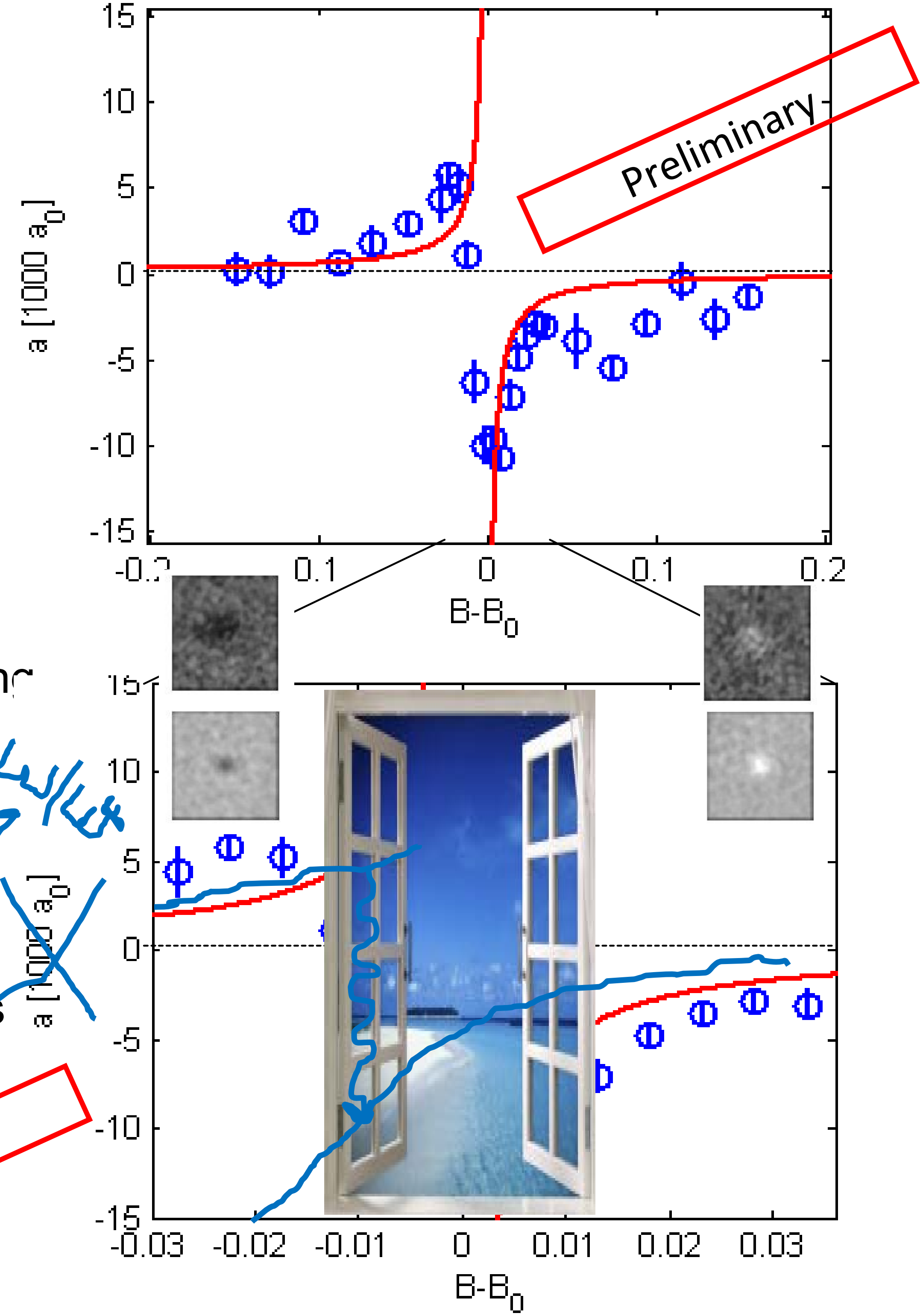
$E_{pot} = 0$

$E_{kin\,0}$ → E_{kin}

E_{IA} /overlapintegral
→interaction parameter
→a_{eff}

Issues
- Not fully farfield
- Complicated Li cloud shape

Interaction energy alias a_{eff}

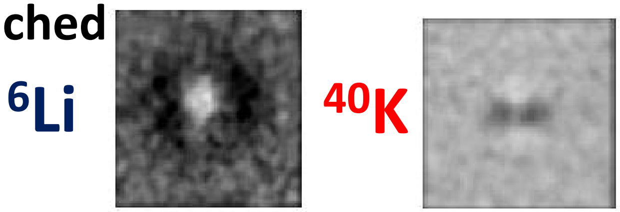


- We find
  - Transition coincides with strong IA regime
  - attraction on resonance
- RF measurements
  - Measure directly energy shifts
  - Distinguish different branches
  - Adiabatic preparation

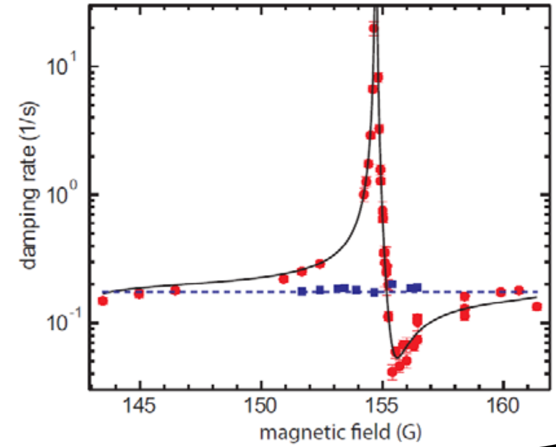
ongoing

Conclusion

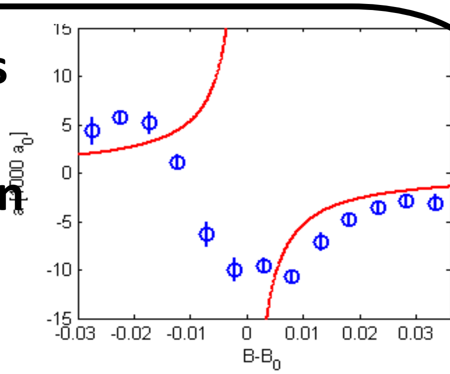
Hydrodynamics shows that the strongly interacting regime is reached



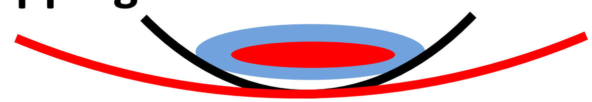
Li-K interactions are well modeled and well under control



Energy shifts are under investigation



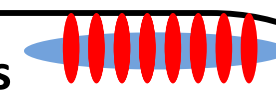
Species selective control
- Bragg spectroscopy
- mode excitation
- trapping



Outlook

Polaron and crossover physics:
RF spectroscopy
→interaction energies
Collective oscillations
→effective mass
→self energy

Mixed dimensions



-Find confinement induced resonances
-Rich phase diagrams of novel quantum phases

Thank you!

In collaboration with:
Tom Hanna and
Paul Julienne

Davang Naik Matteo Zaccanti Florian Schreck Andrei Sidorov
Gerhard Hendl Andreas Trenkwalder Rudi Grimm Christoph Kohstall Frederik Spiegelhalder

FWF Der Wissenschaftsfonds.
SFB FoQuS Foundations and Applications of Quantum Science

European Science Foundation
SETTING SCIENCE AGENDAS FOR EUROPE

European Network
EuroQUAM
Collaborative Research Project
FerMix