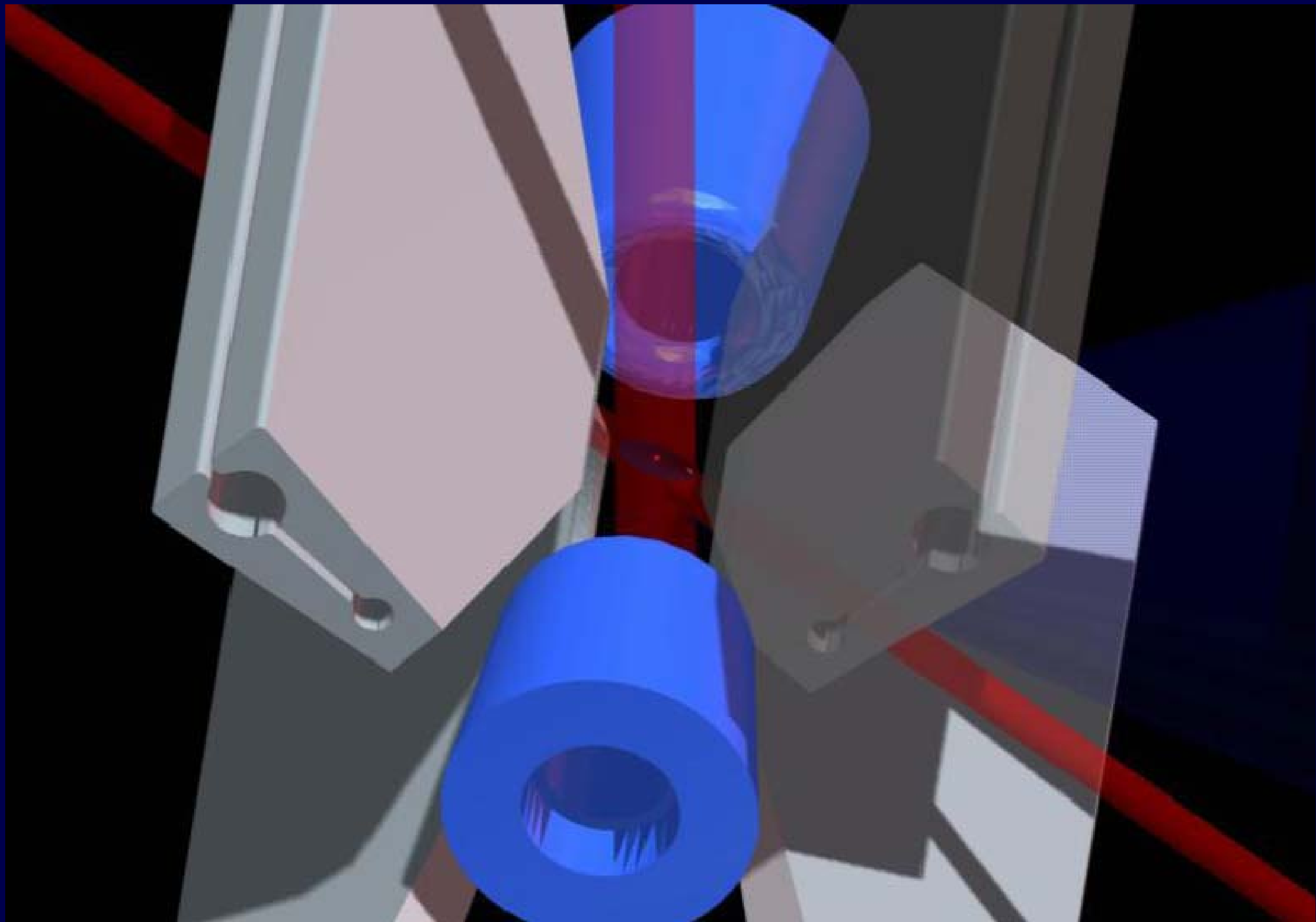
SFB/ TRR21

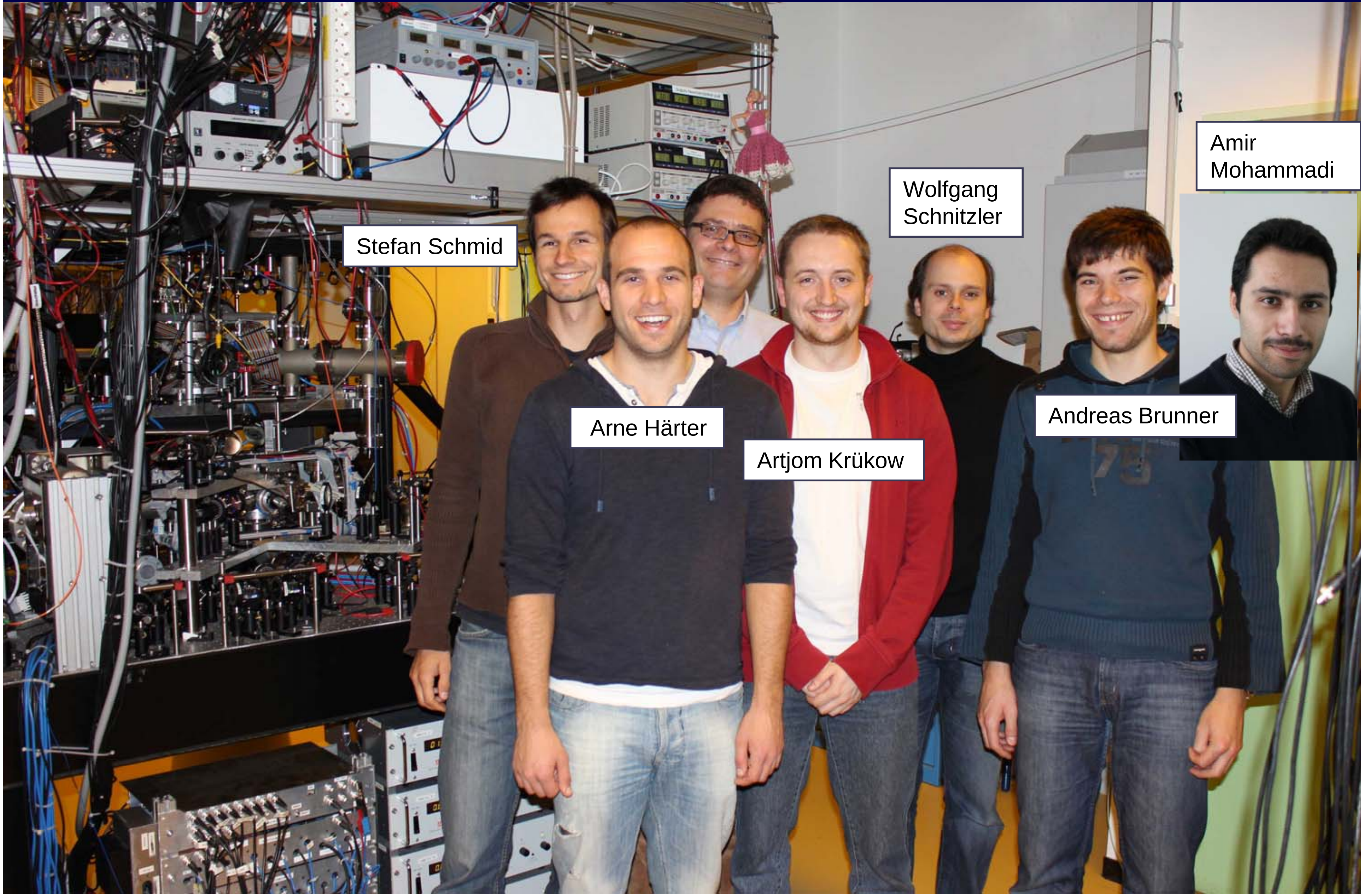
A single ion in an ultracold atomic gas



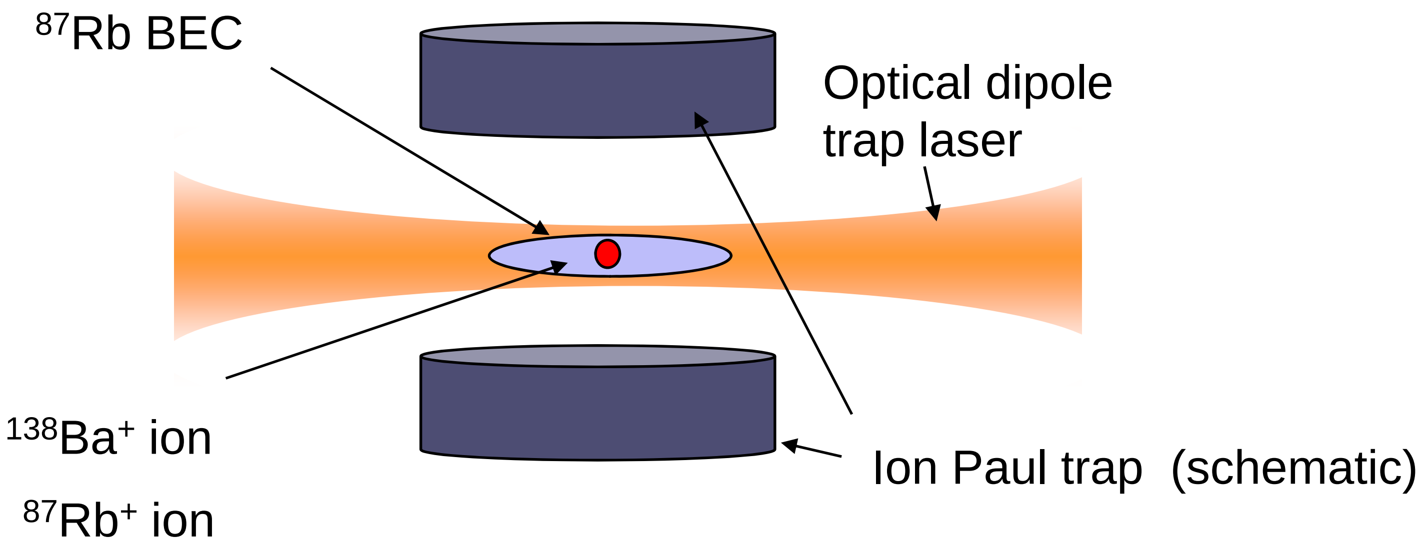
Johannes Hecker Denschlag

European Conference on Trapped Ions, Obergurgl, September 13, 2012

The BaRble-Team



Trapped Ions and Ultracold neutral Atoms



Good compatibility of traps!

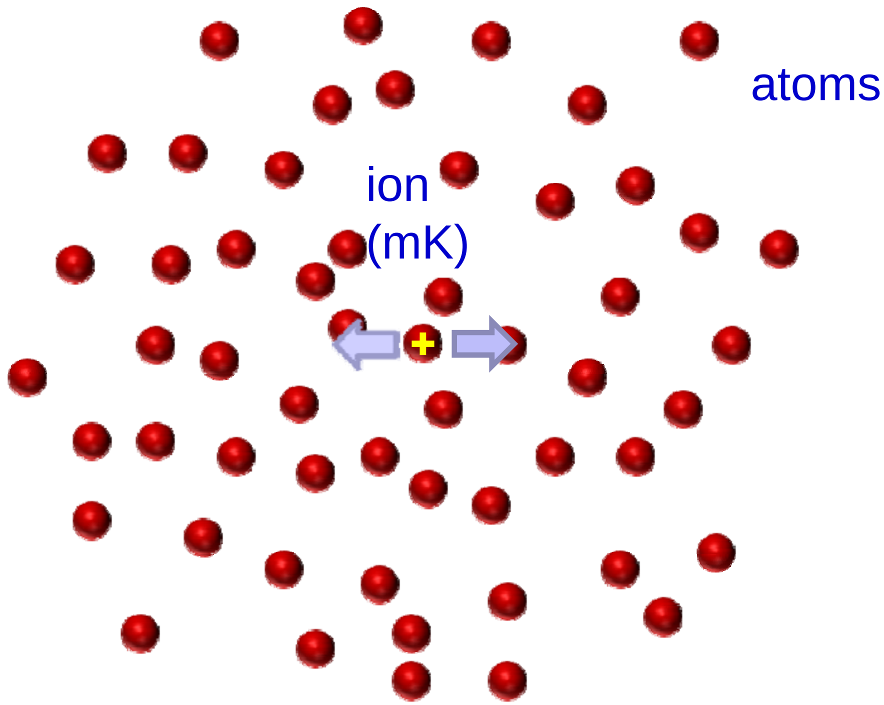
Three stories

1) Putting atoms to work in an ion trap:
cooling and micromotion compensation

2) An ion as a three-body reaction center

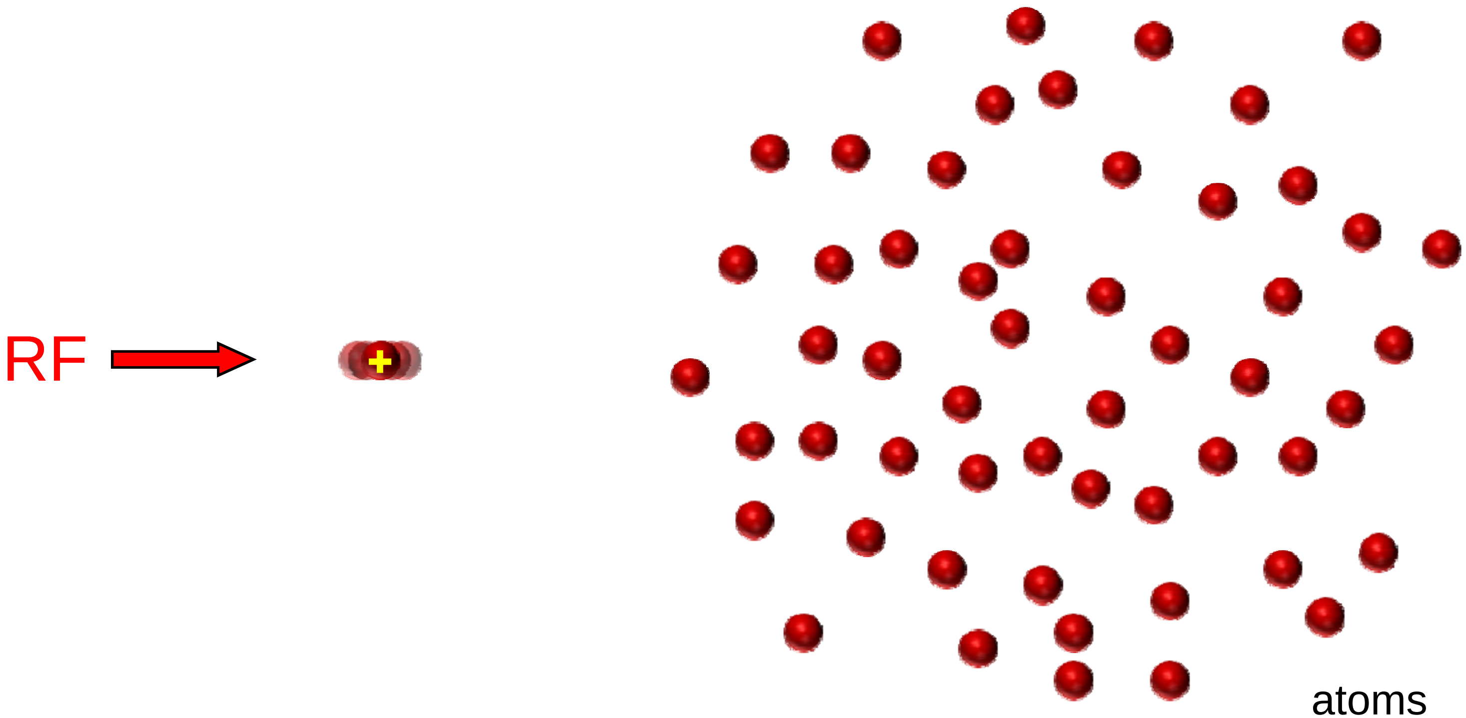
3) A „mysterious“ production of Rb^+ and Rb_2^+ ions

An ion in a cloud of atoms, naive picture



- Thermalization of ion within a few collisions, sympathetic cooling
- Loss of a few Rb atoms
- no further dynamics afterwards….

The role of excess micromotion

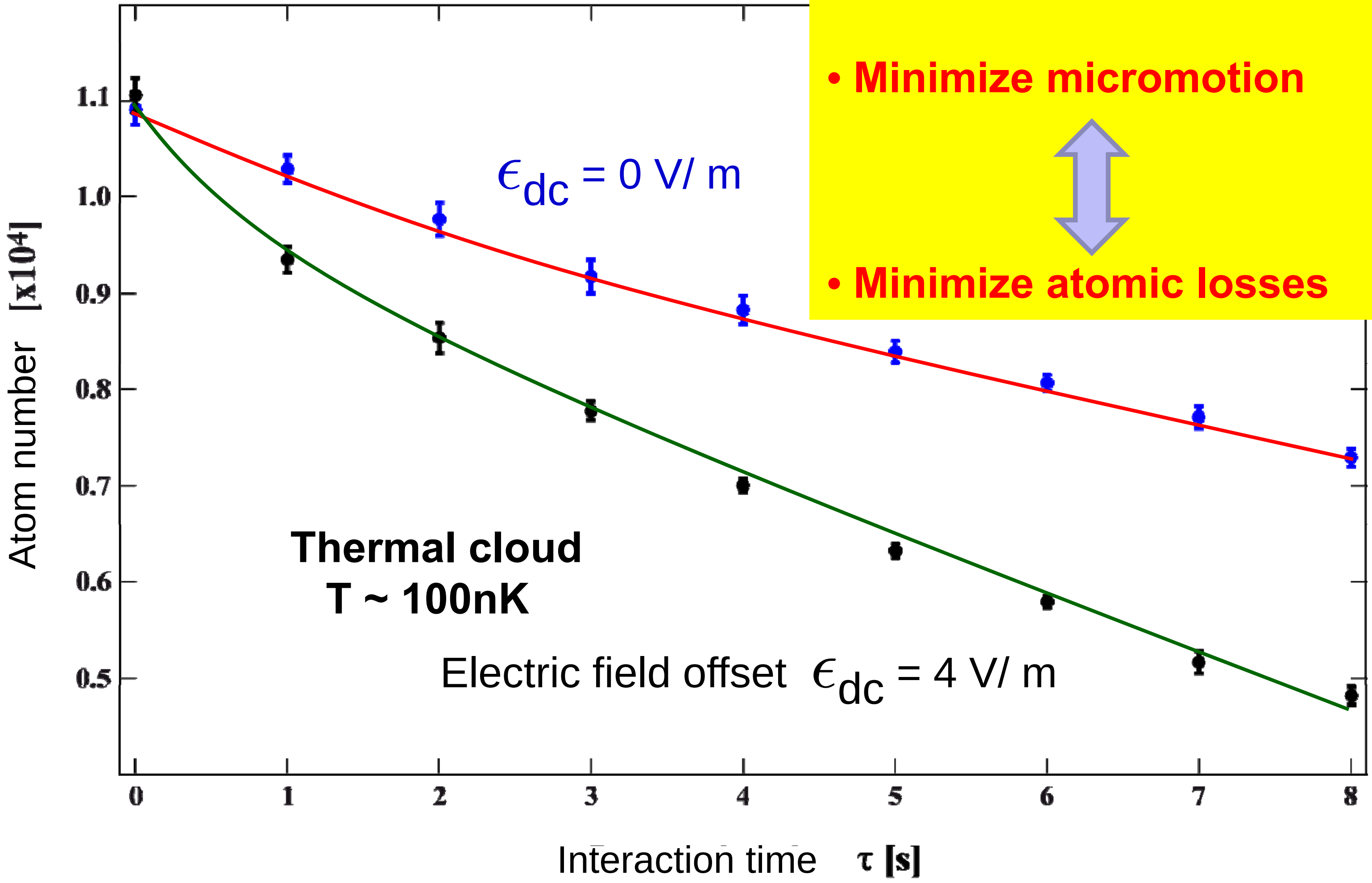


atoms $T \sim 1\,\mu\mathrm{K}$
confined by
shallow dipole trap
$U_{\mathrm{dip}} \sim 10\mu\mathrm{K}$

- coherent trap drive (5MHz) accelerates stopped ion again

- ion energy is set by excess micromotion $E_{\mathrm{ion}} \sim \mathrm{mK}\ \mathrm{k}_{\mathrm{B}}$

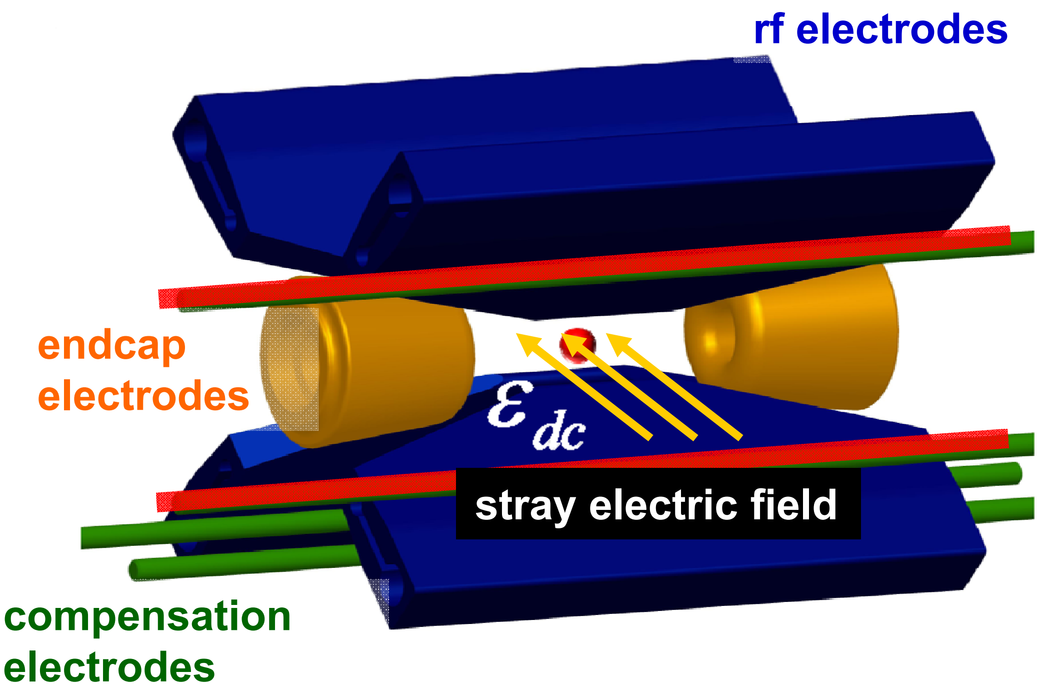
Observed elastic atom-ion collisions



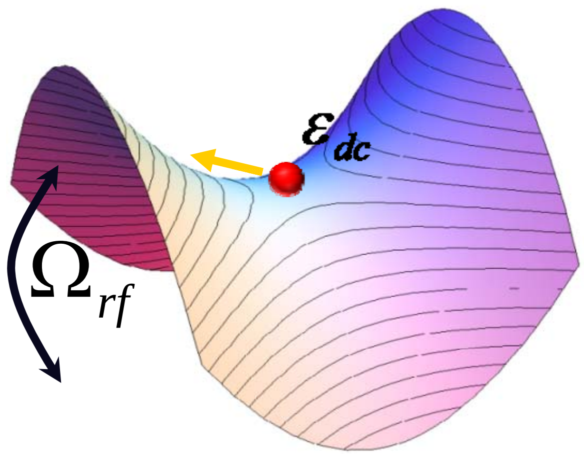
Path to cold ion temperatures:

- **Minimize micromotion**
- **Minimize atomic losses**

Stray electric fields → excess micromotion

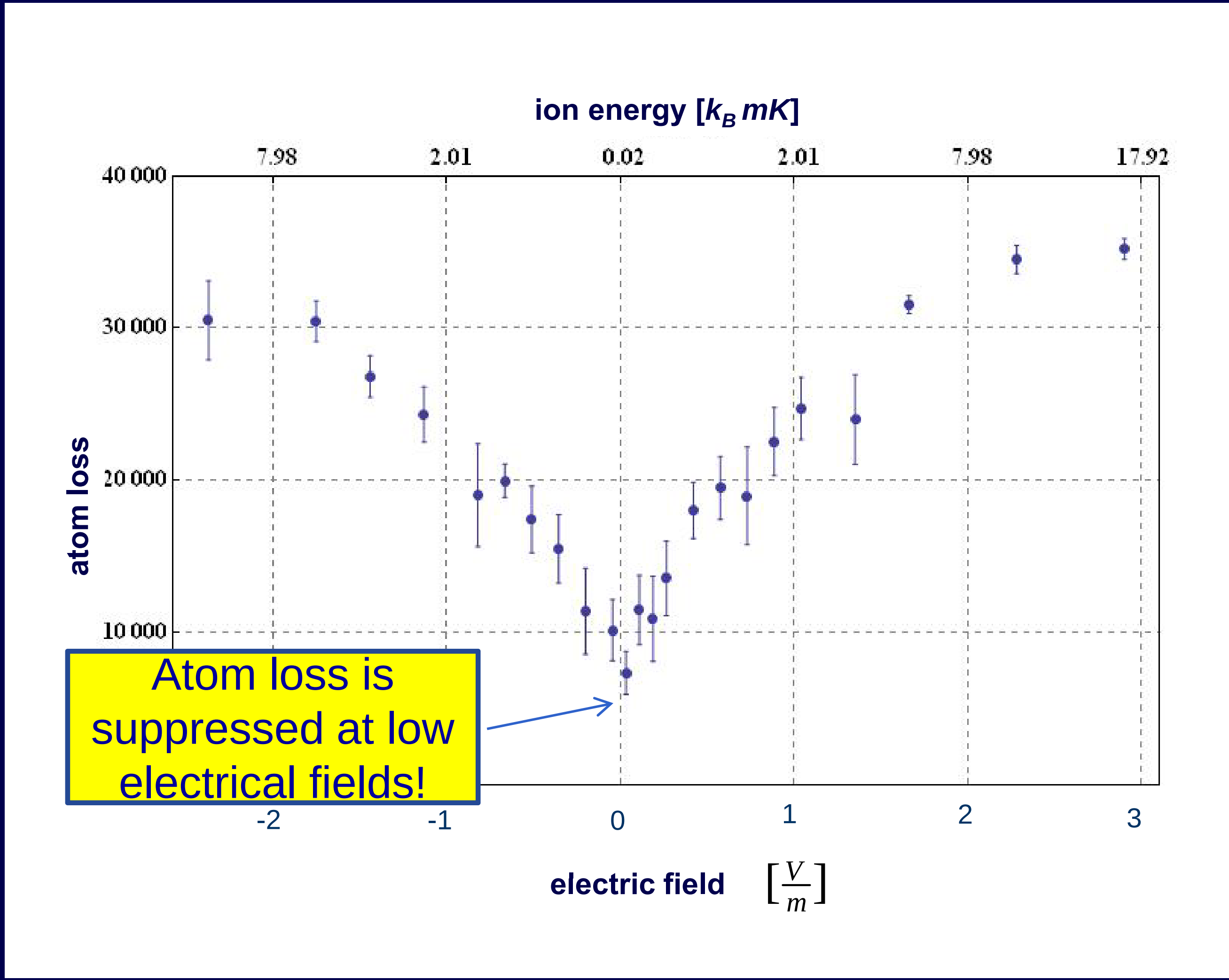


saddle potential



→ driven motion

can be minimized by applying appropriate compensation voltages



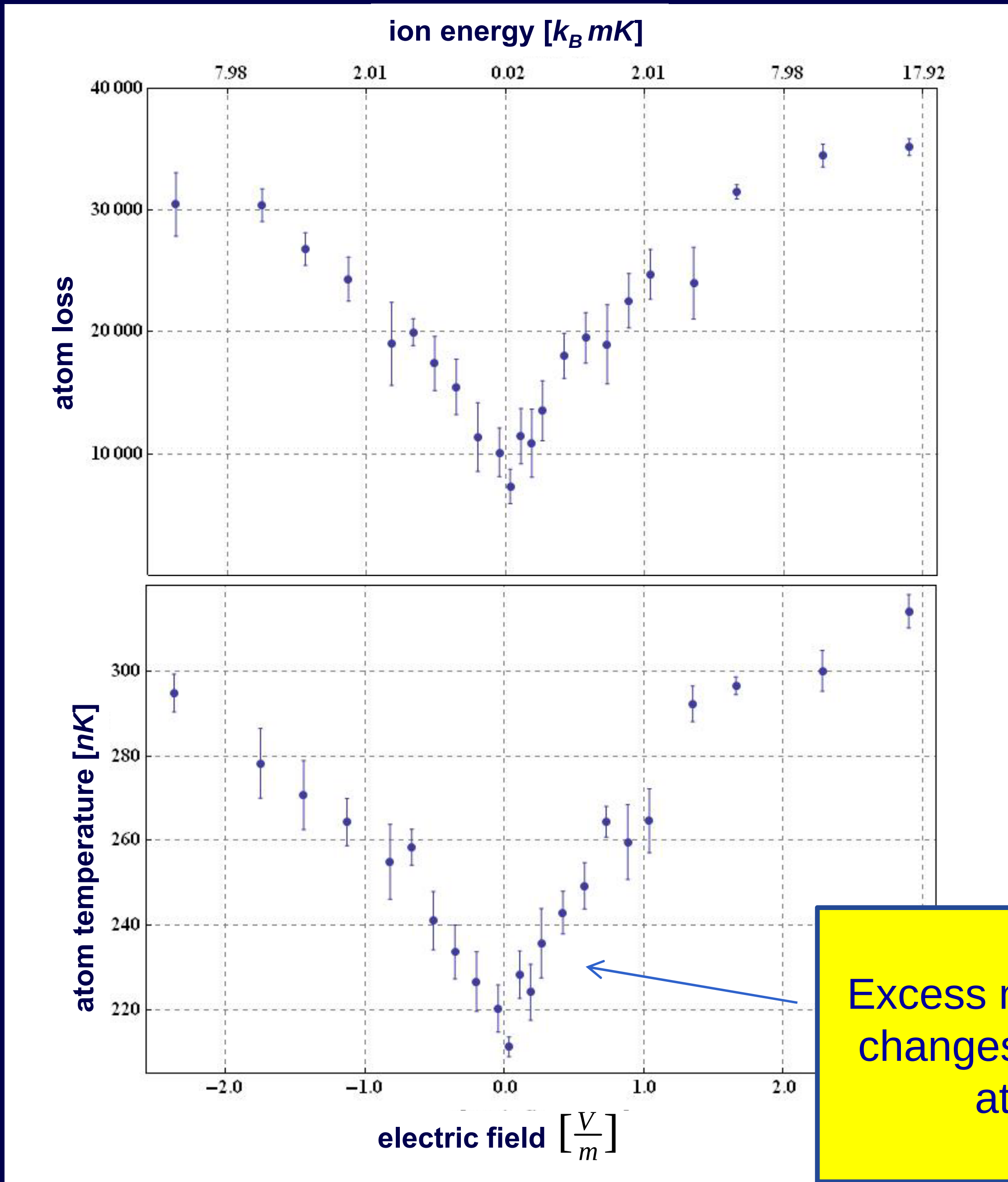
initial conditions

Atom number
N ~ 80000

Temperature
180 nK

Density
n ~ 2.5 10^{12} cm^{-3}

Interaction time
τ = 2 s



initial conditions

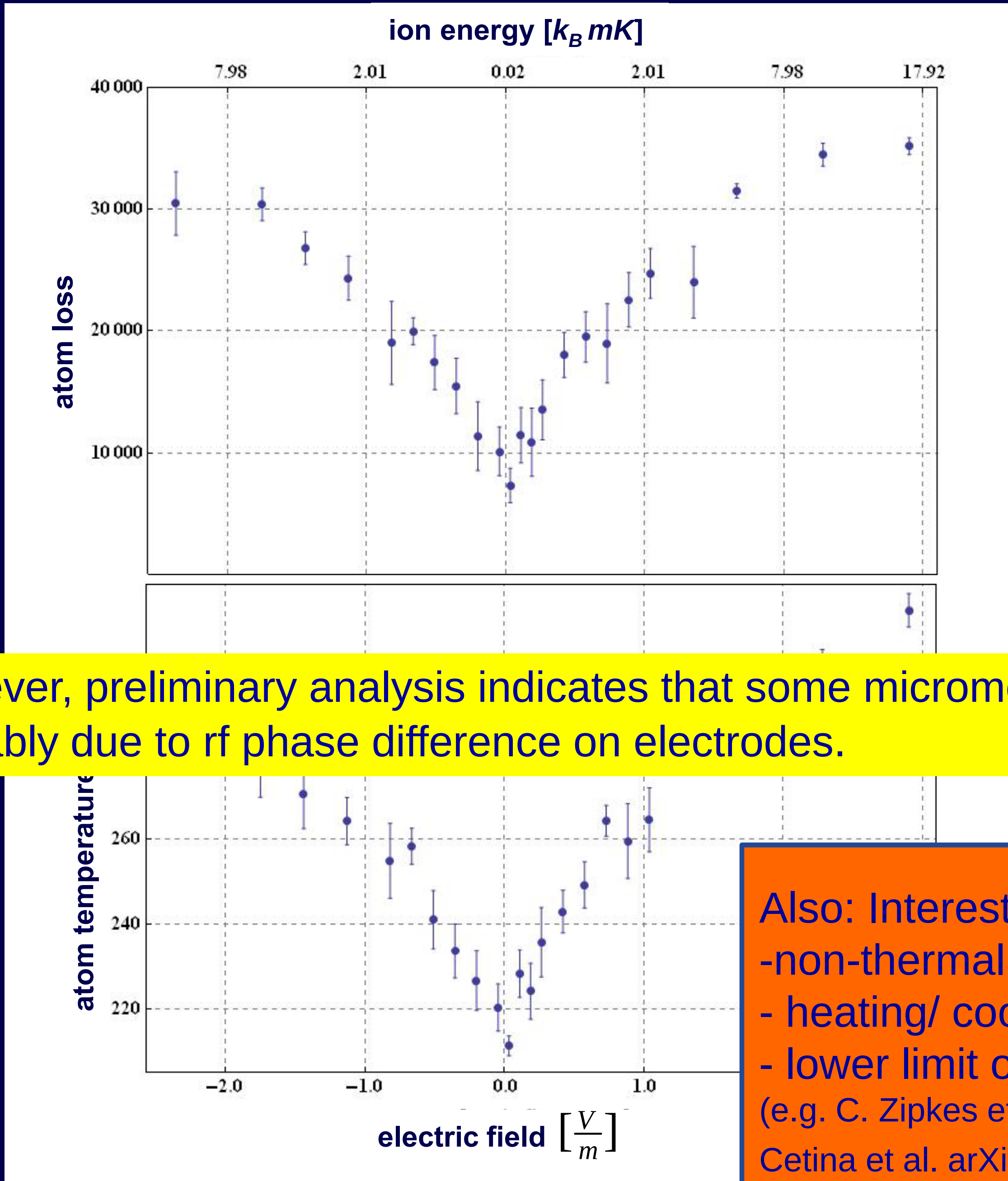
Atom number
N ~ 80000

Temperature
180 nK

Density
n ~ 2.5 10^{12} cm^{-3}

Interaction time
τ = 2 s

Excess micromotion also changes temperature of atom cloud!



You can use cold atoms to compensate micromotion!

Sensitivity down to 0.1 V/m for stray electrical fields
→
micromotion energies ~ 10μK

However, preliminary analysis indicates that some micromotion ~500μK remains, probably due to rf phase difference on electrodes.

Also: Interesting collision dynamics
-non-thermal kinetic distribution
- heating/ cooling depends on m-ratio
- lower limit of sympathetic cooling
(e.g. C. Zipkes et al., New J Phys.(2011), M. Cetina et al. arXiv:1205.2806v1).

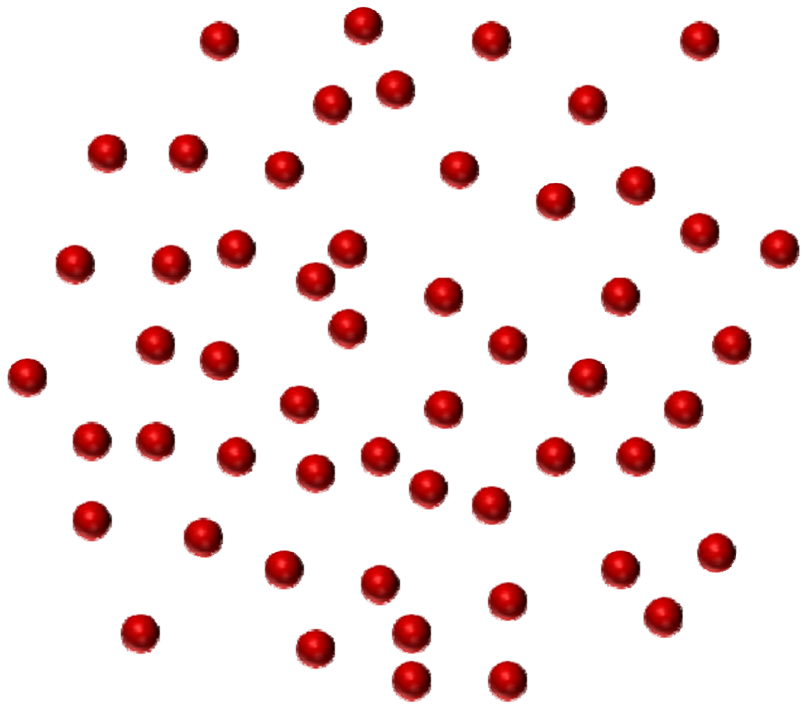
Three stories

1) Putting atoms to work in an ion trap:
cooling and micromotion compensation

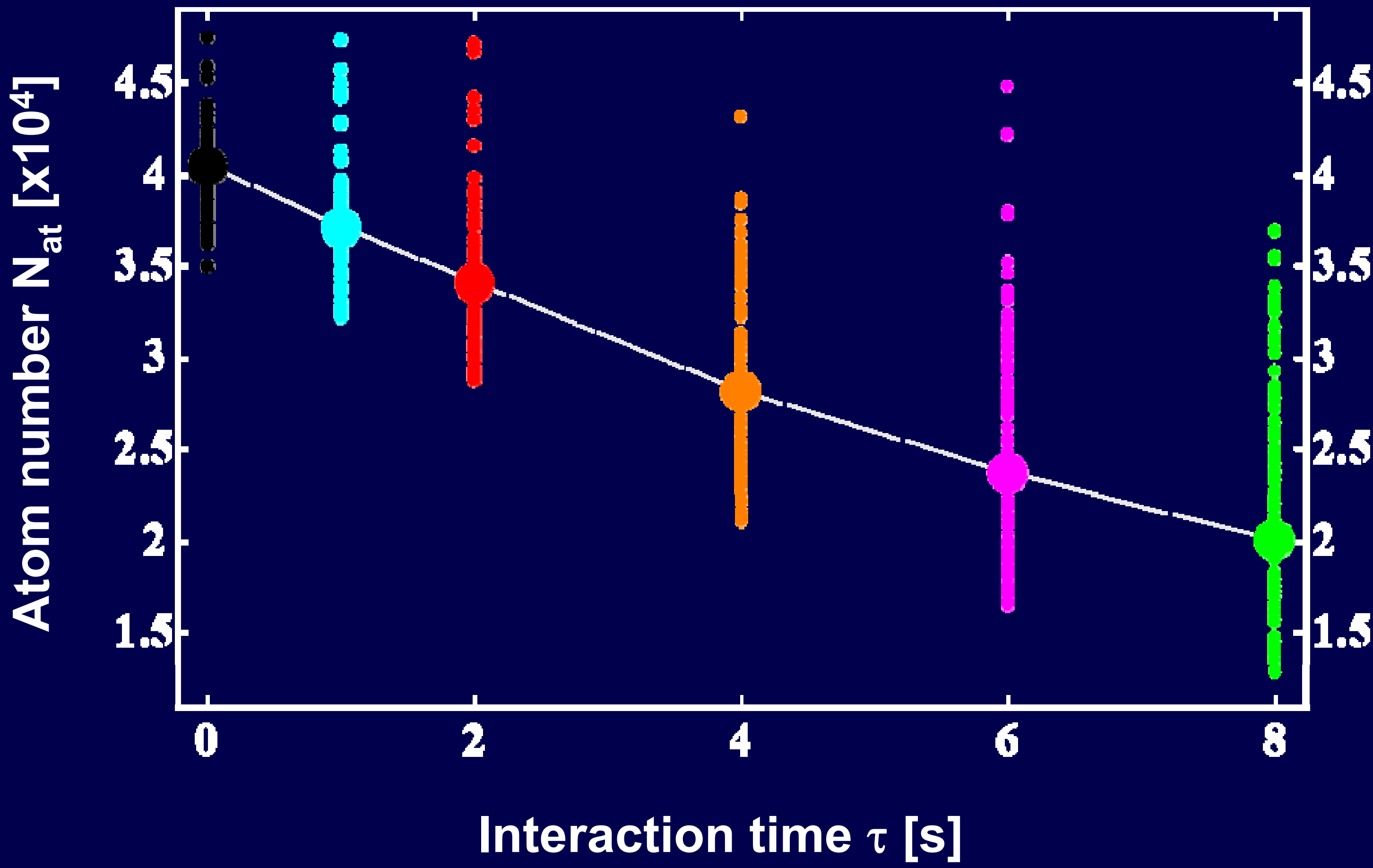
2) An ion as a three-body reaction center

3) A „mysterious“ production of Rb^+ and Rb_2^+ ions

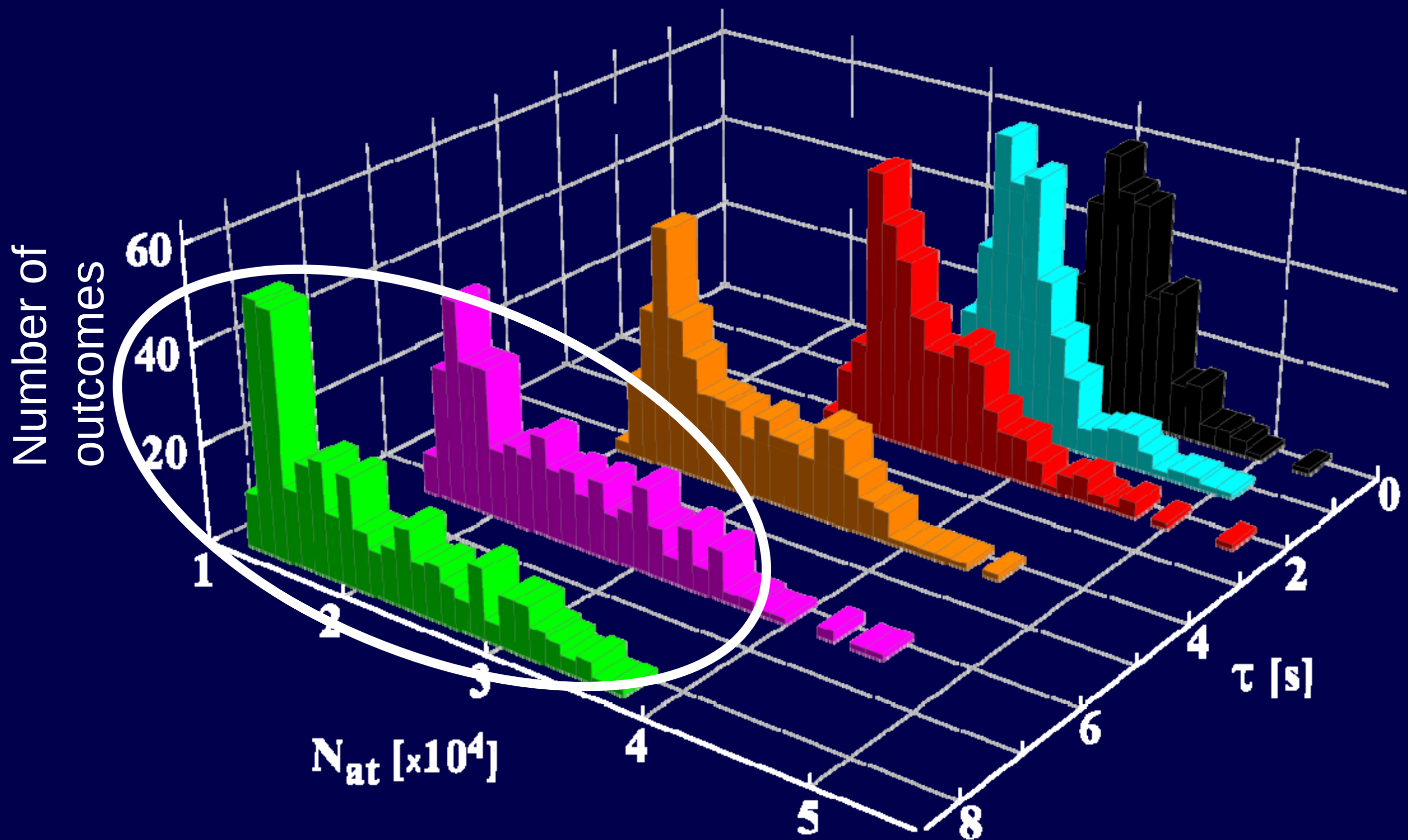
The role of excess micromotion



Ion-induced atom loss

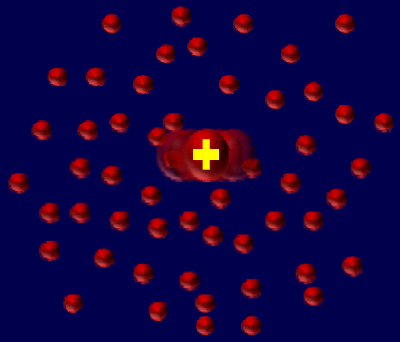


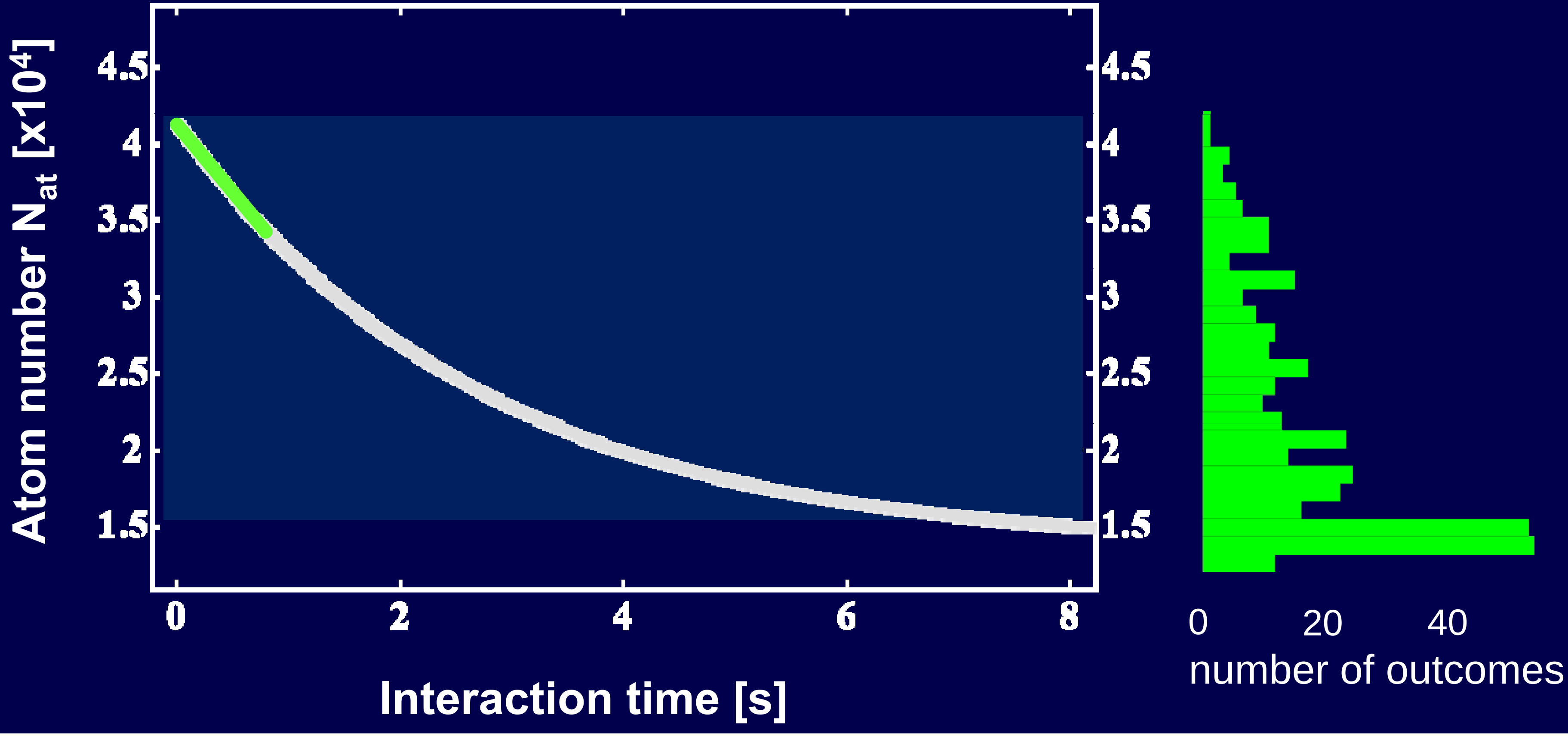
Atom number distributions



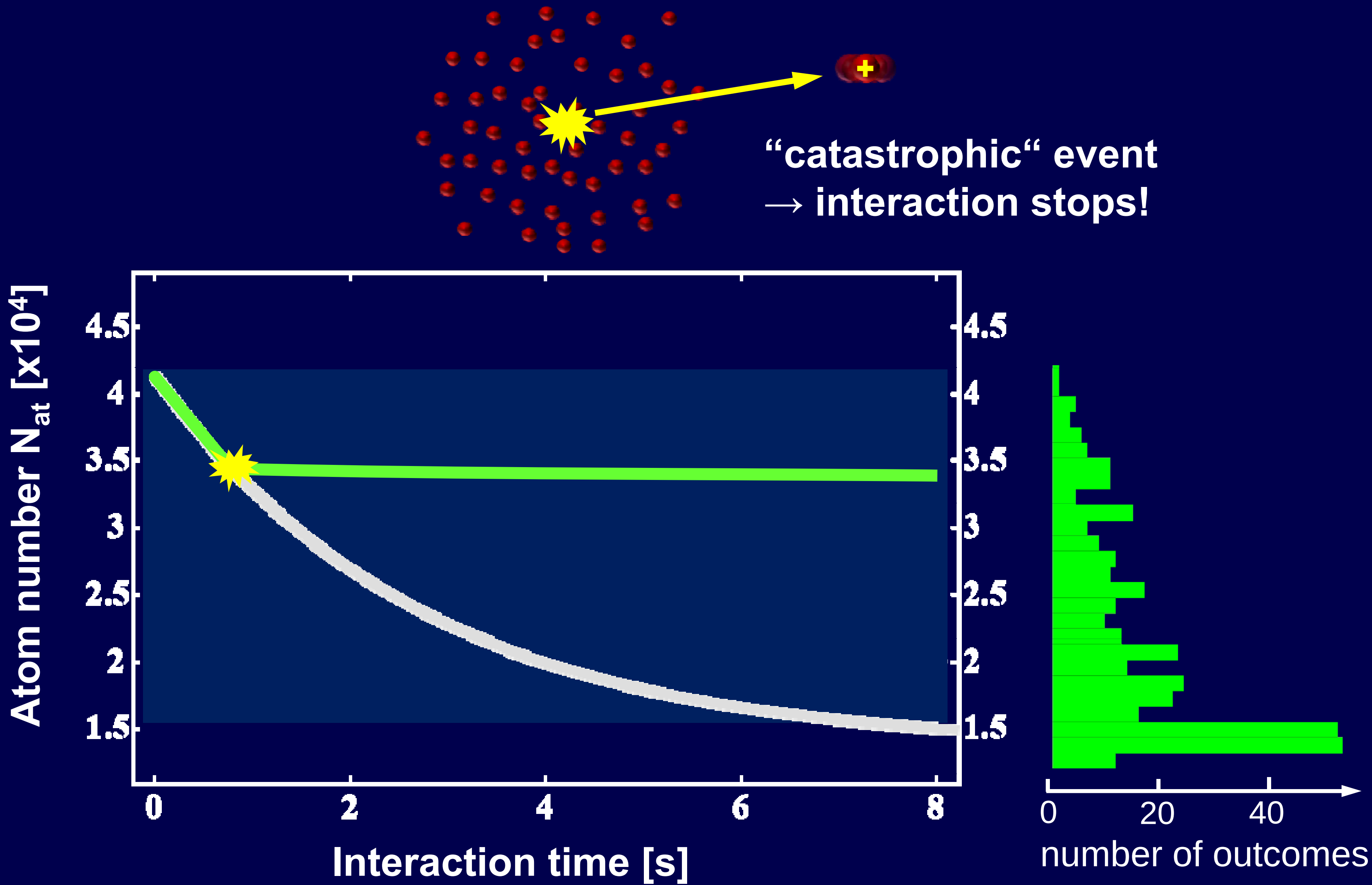
A. Härter et al. PRL 2012, in press

Collision dynamics

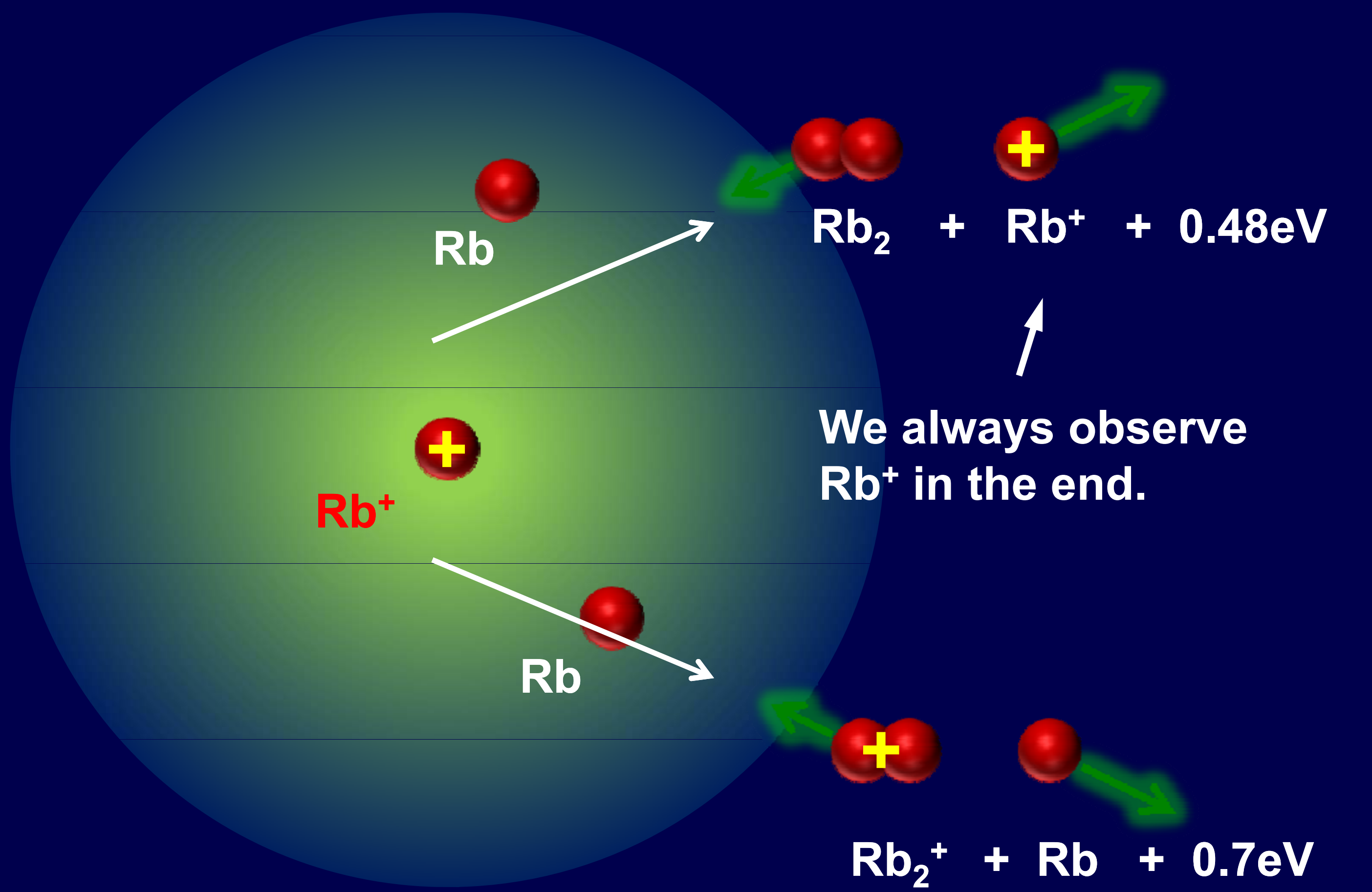




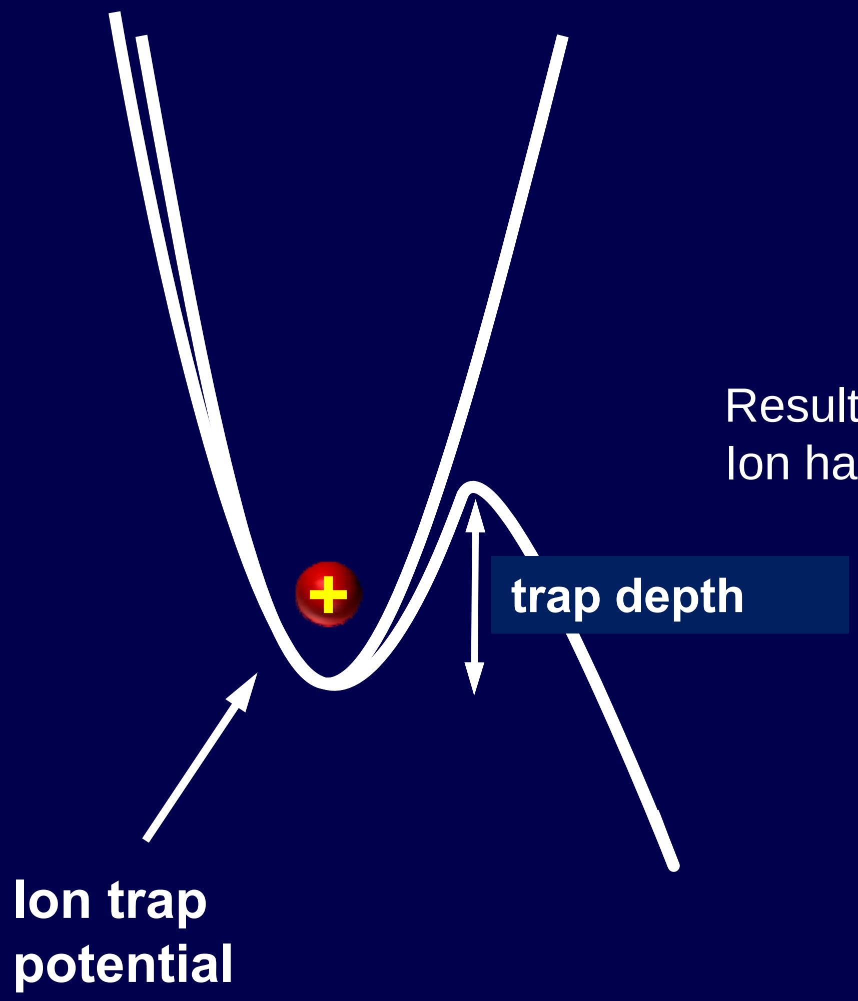
Collision dynamics



Atom-atom-ion three-body recombination

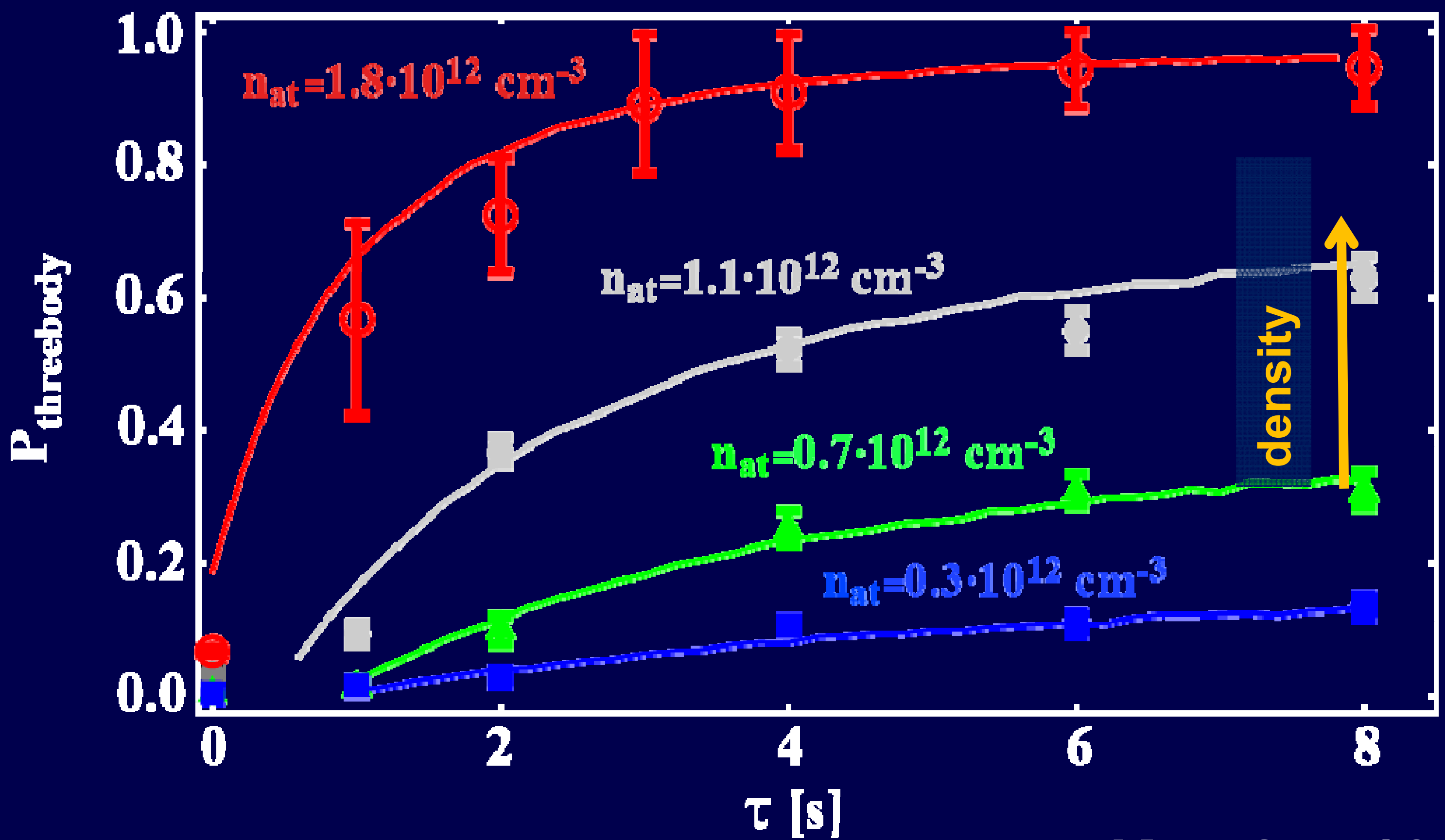


Measurement of the reaction energy



Result:
Ion has typical energy of a few 0,1 eV.

Data well described by three-body recombination dynamics



$K_3 \sim 3 \times 10^{-25}$ cm^6 s^{-1}

quadratic density dependence
→ atom-atom-ion three-body coefficient

A. Härter et al. PRL 2012, in press

Three stories

1) Putting atoms to work in an ion trap:
cooling and micromotion compensation

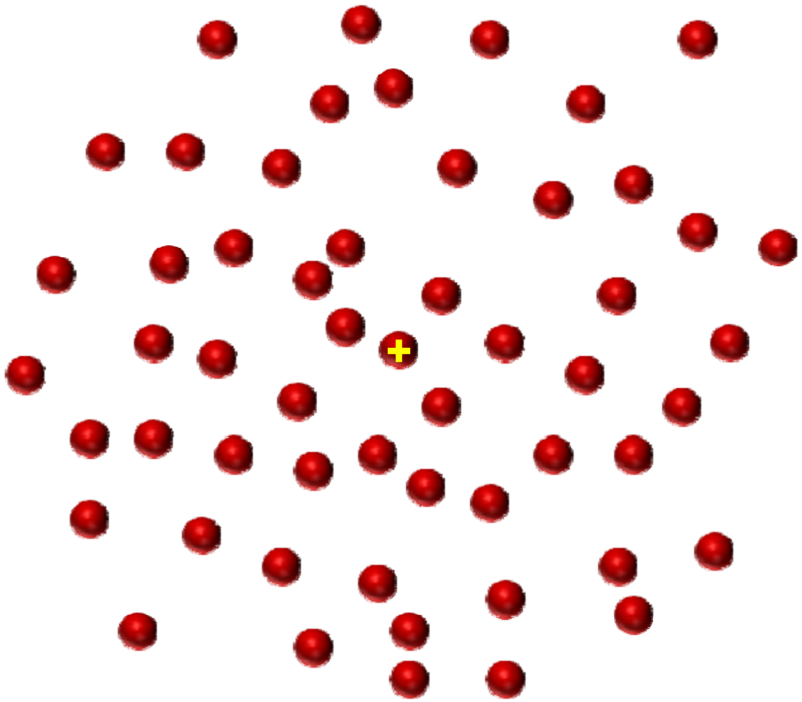
2) An ion as a three-body reaction center

3) A „mysterious“ production of Rb^+ and Rb_2^+ ions

A „mysterious" production of Rb^+ / Rb_2^+ ions

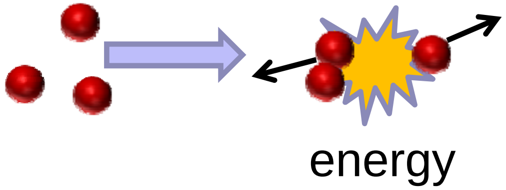
4×10^4 ^{87}Rb atoms
in an optical dipole trap
at 1064nm;
~1μK temperature;
density ~ 10^{13} cm^{-3} ;

After a few seconds…
there is a Rb^+ ion
(or even a Rb_2^+ ion)

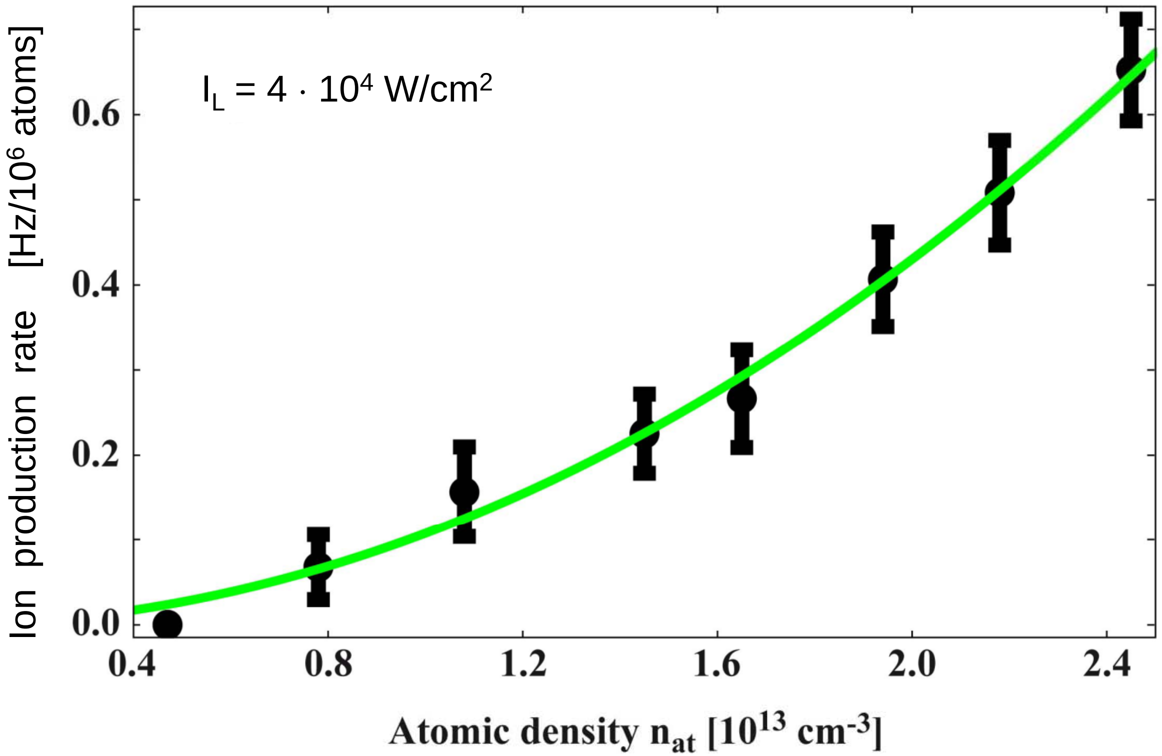


Not a background effect, i.e. no charge transfer collisions of hot ions!

Ion production rate is quadratic in atomic density!
→ 3-body recombination process of Rb atoms!

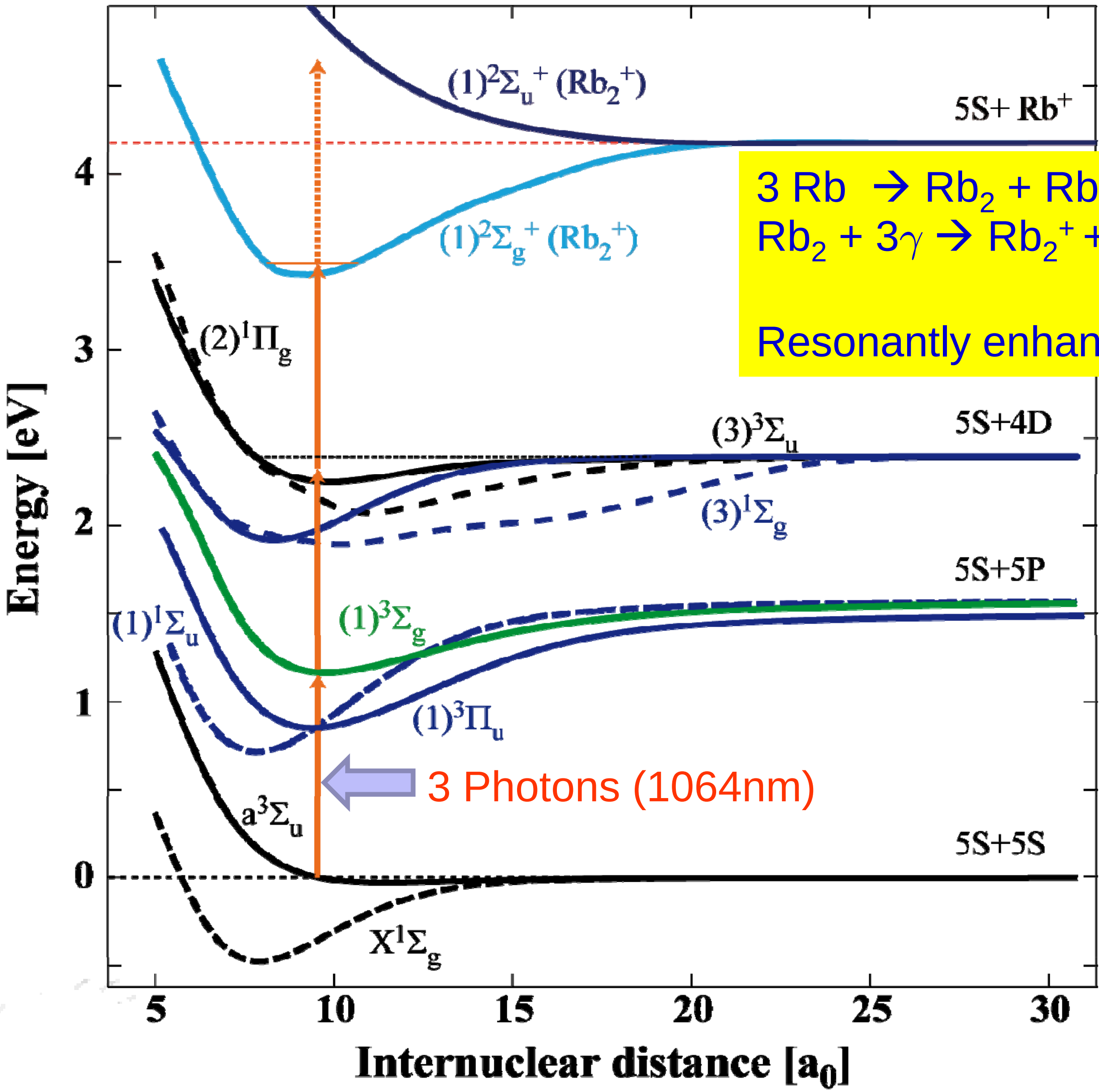


But that is not nearly enough energy to ionize Rb!!



Potential energy curves for Rb_2

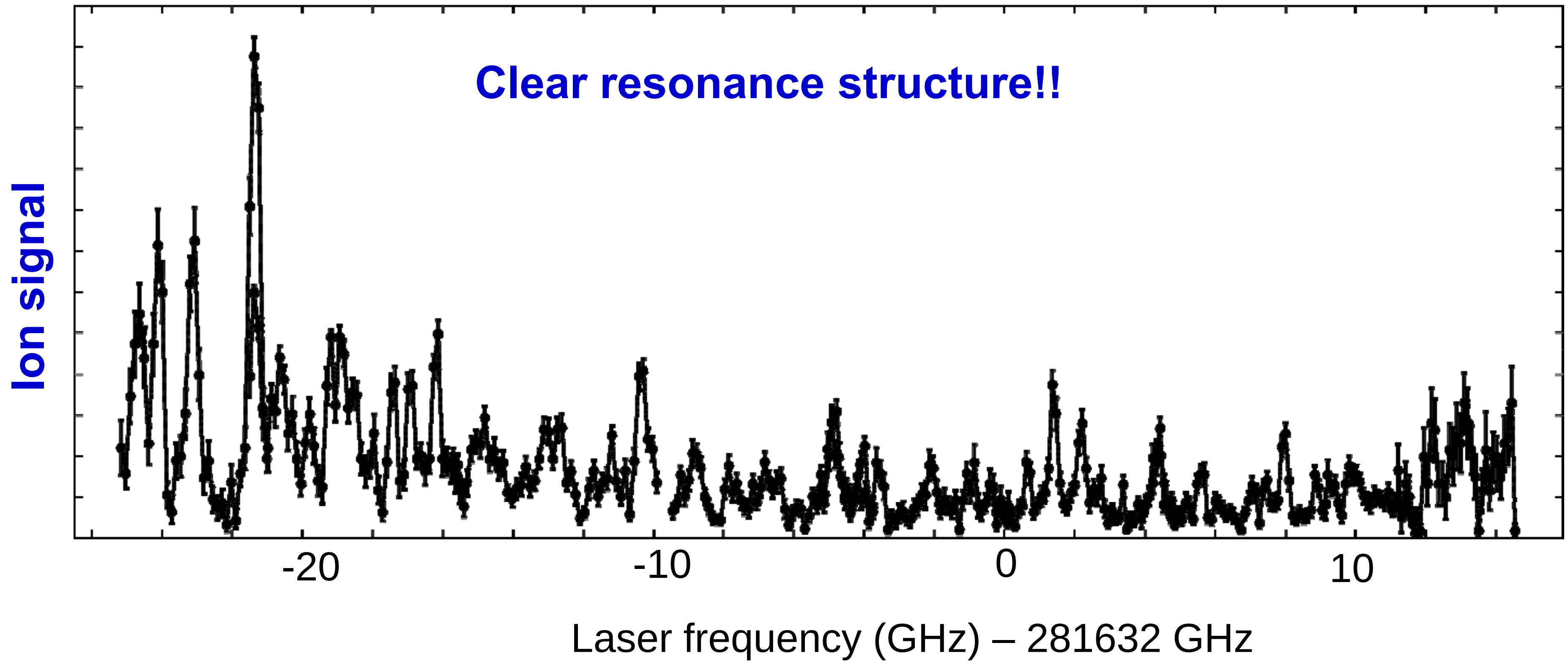
You need 3 or 4 1064nm photons!



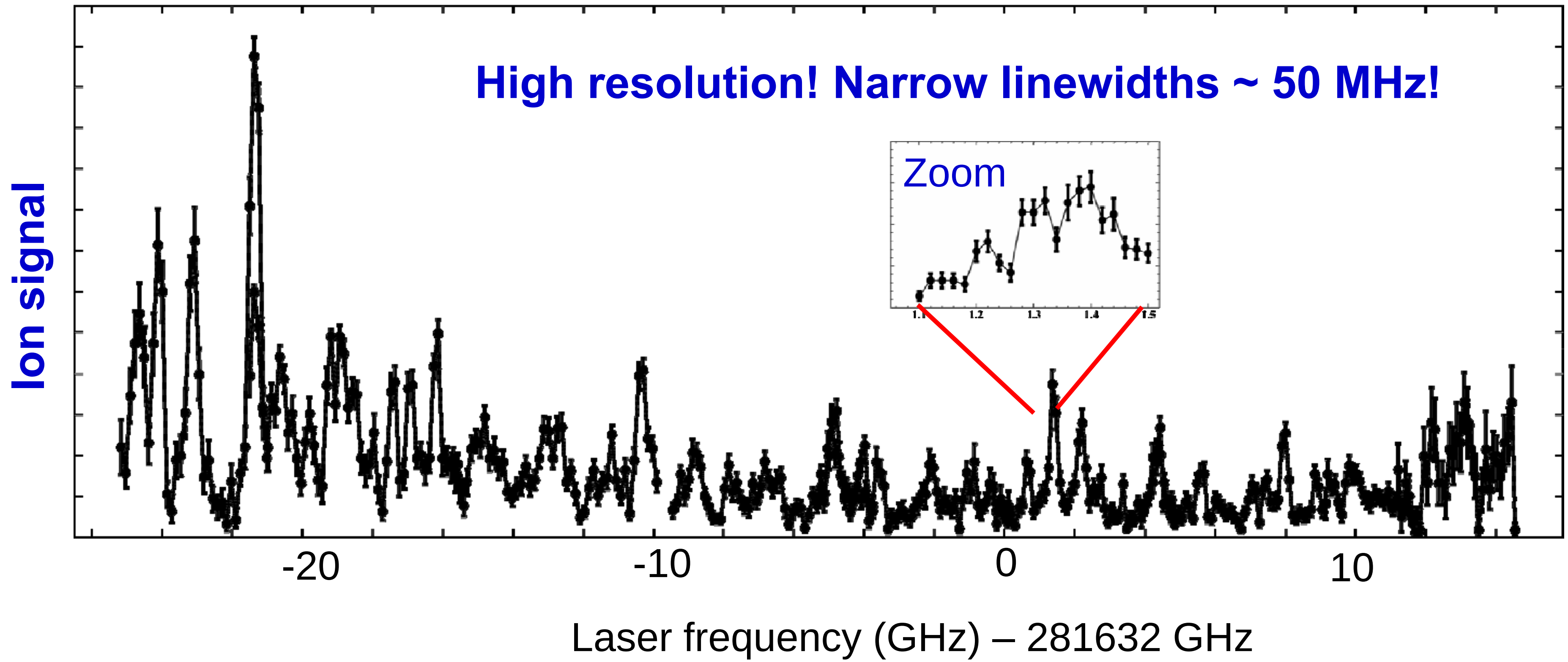
3 Rb → Rb_2 + Rb
$Rb_2 + 3\gamma \rightarrow Rb_2^+ + e^-$

Resonantly enhanced?

1064nm laser plays a crucial role!

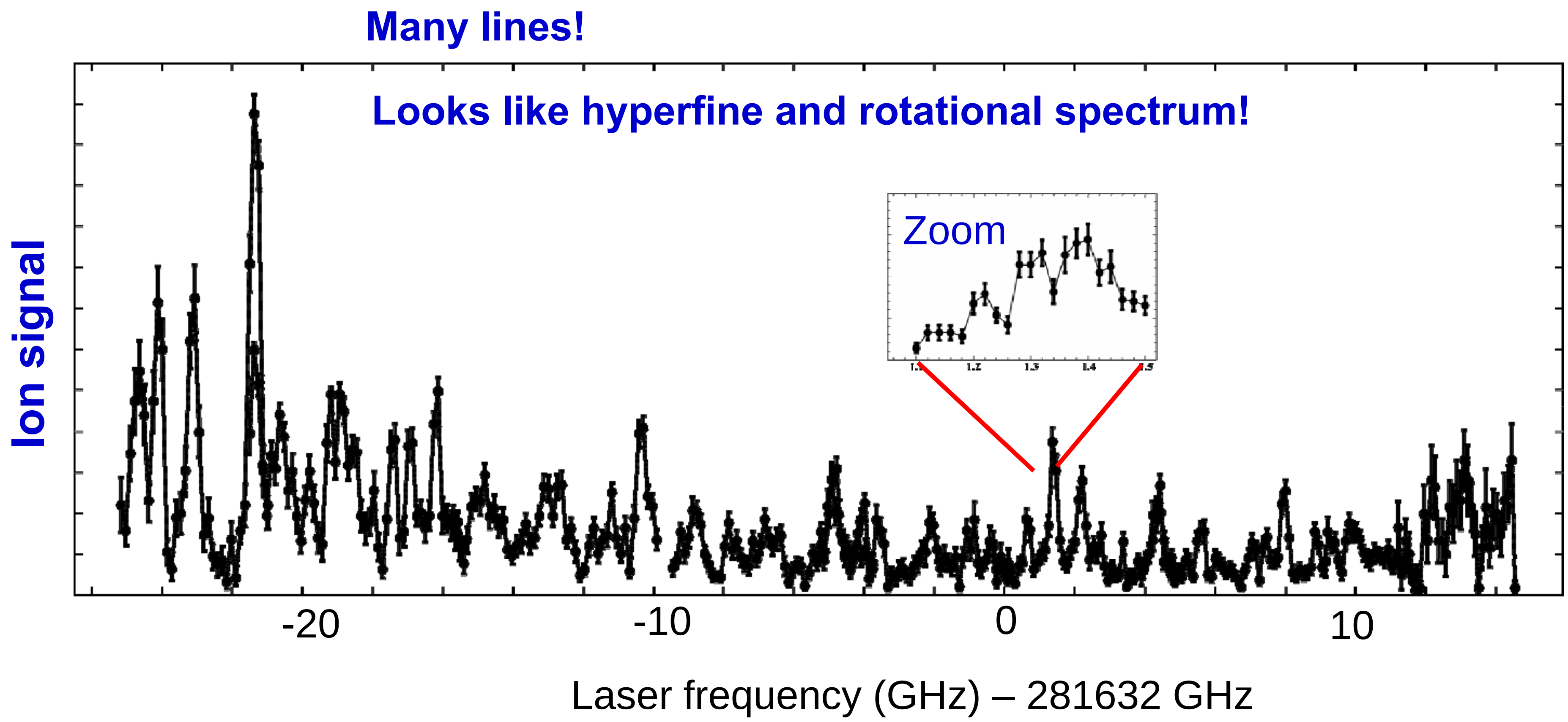


1064nm laser plays a crucial role!



- small Doppler broadening
- Rb_2 molecules slow after three-body recombination
- energy released in three body-recombination is not large (< 0.01 eV)

1064nm laser plays a crucial role!



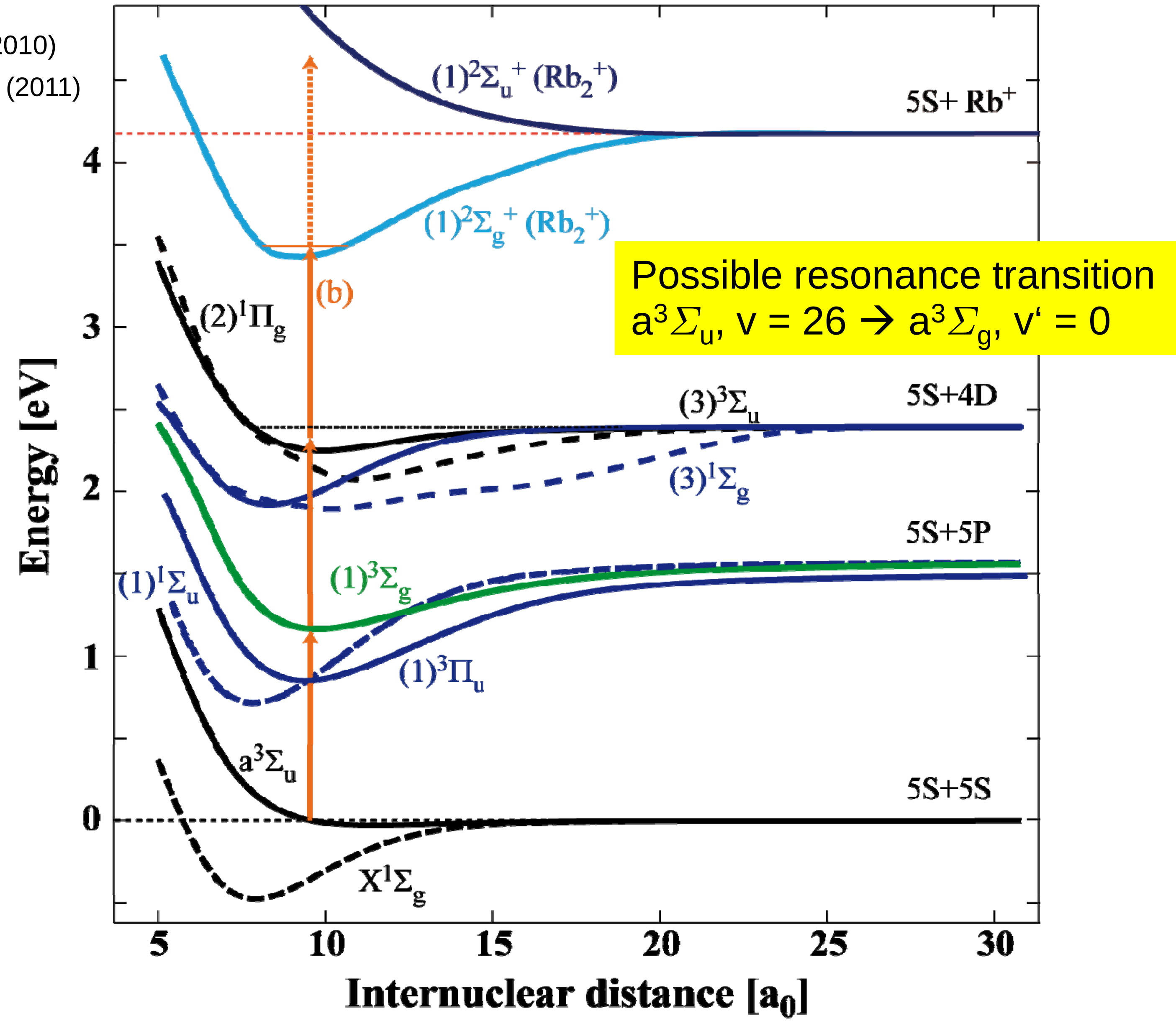
Can we understand the spectrum? Perhaps part of it!

From recent spectroscopy we know several spectra quite well!! (~200 MHz precision!)

Strauss et al., PRA (2010)

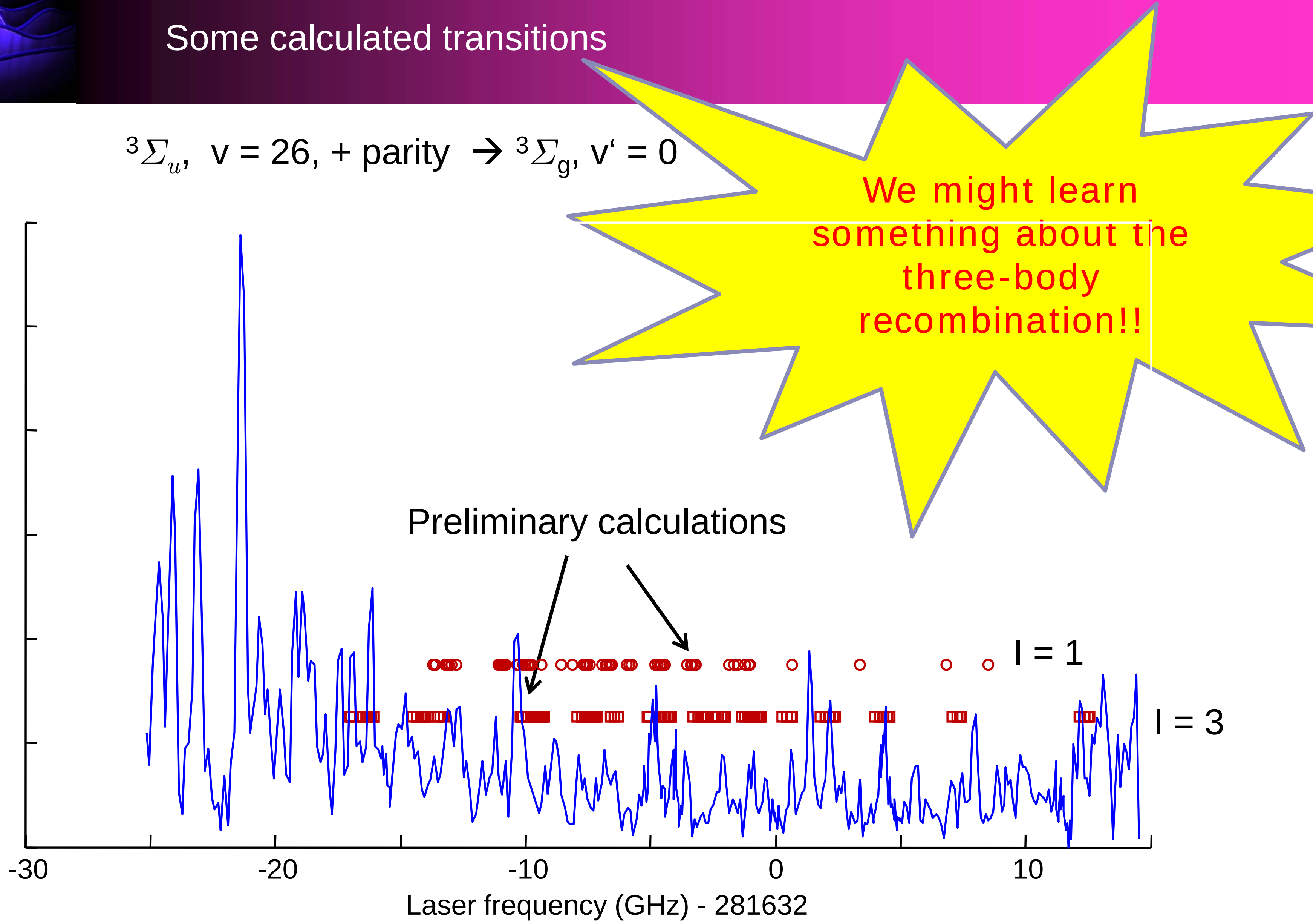
Takekoshi et al., PRA (2011)

collaboration
with E. Tiemann



Some calculated transitions

$^3\Sigma_u$, v = 26, + parity → $^3\Sigma_g$, v' = 0



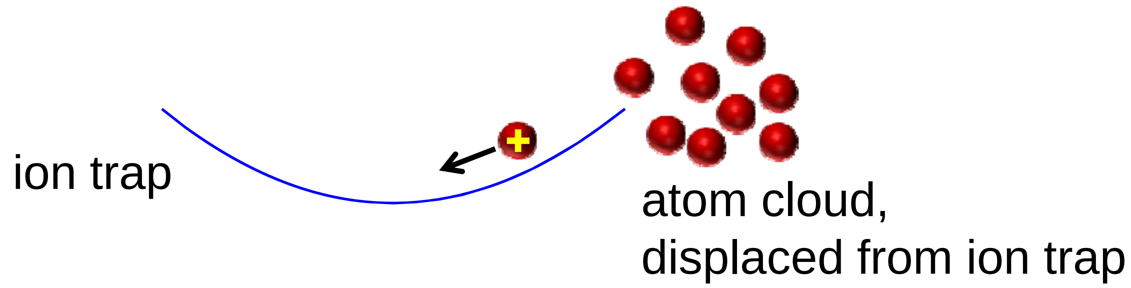
Calculations from E. Tiemann, Hannover

Branching ratio between Rb^+ and Rb_2^+

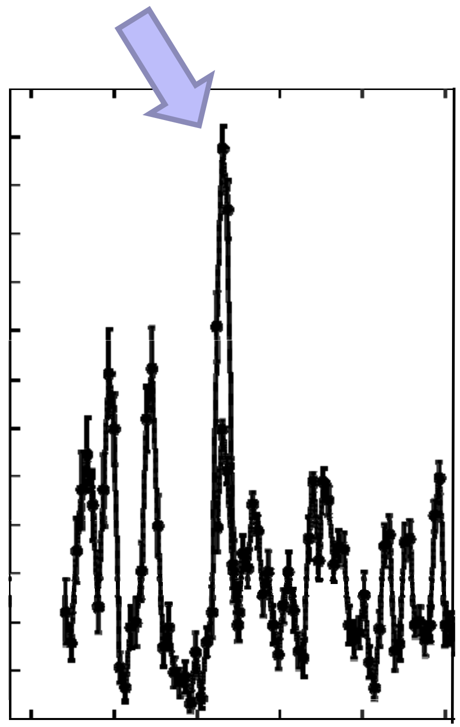
What do we produce more of:
Rb^+ and Rb_2^+ ?

This depends!

If we extract the ion quickly from the atom cloud (~μs), then we get mostly Rb_2^+ (55%) otherwise mostly Rb^+ (~97%).

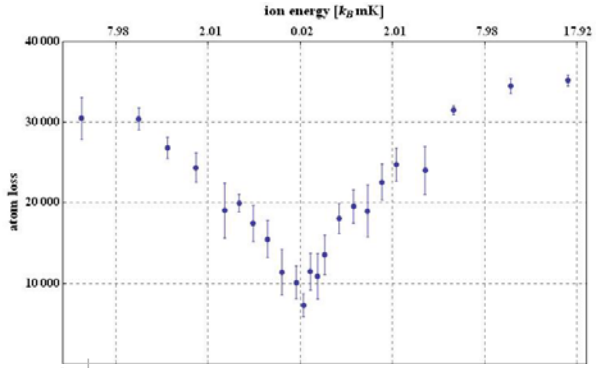


Sit on top of this line

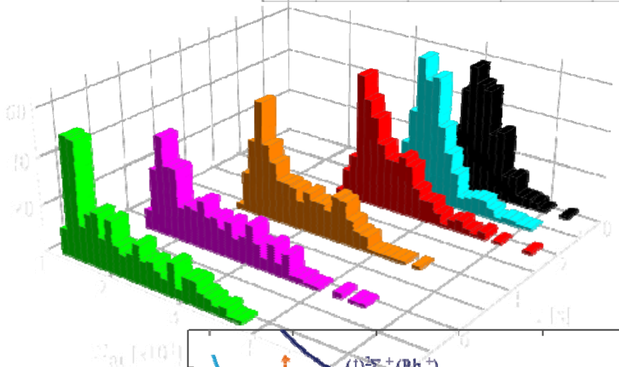


Possibly:
a) Ionization always produces Rb_2^+
b) Afterwards
$Rb_2^+ + Rb + \gamma\ (?) \rightarrow Rb^+ + 2\ Rb\ \ (?)$

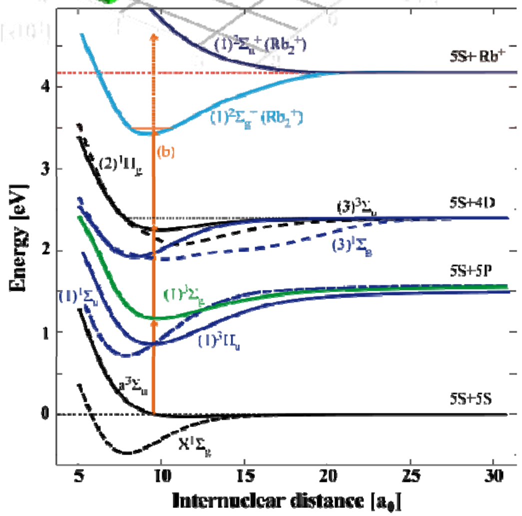
Three stories



1) Use atoms
   - cool ion
   - micromotion compensation



2) An ion as a three-body reaction center
   $Rb^+ + 2Rb \rightarrow Rb^+ + \text{energy} + (2Rb)$



3) A „mysterious“ production of Rb ions
   $3\,Rb + 3\gamma \rightarrow Rb_2^+ + e^- + Rb$

   $3\,Rb + 4\gamma \rightarrow Rb^+ + e^- + (2Rb)$