SYMPATHETIC COOLING OF TRAPPED $^9Be^+$ IONS : A TEST-BED FOR TAMING ANTIMATTER IONS

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Physique quantique et applications

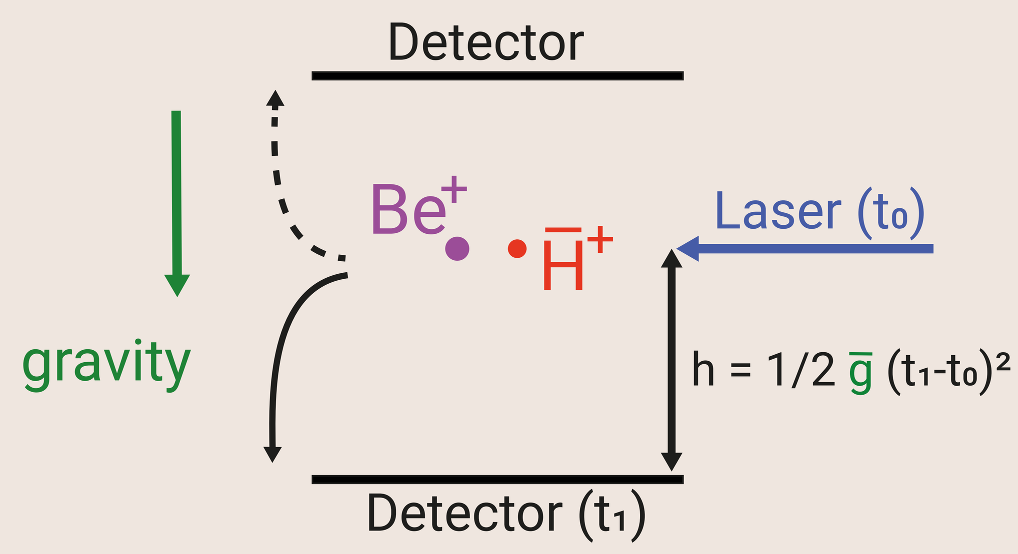
MPQ

Motivations

GBAR experiment at CERN

Concept: Completely stop an a anti-hydrogen atom in order to perform a free fall experiment at rest.

Process:
-Produce $\bar{H}^+$ ions.
-Deccelerate an $\bar{H}^+$ ion from 1keV to 1eV.
-**Capture in a Paul trap and cool down the anti-ion to 10μK.**
-Photodetach a positron at threshold to get $\bar{H}$ at rest.
-Mesure the free fall time to get the $\bar{g}$ constant.



1st cooling step: $\bar{H}^+$ at 1eV (10^7mK) ⟶ 1mK

Adopted solution:
Sympathetically cool the $\bar{H}^+$ ion using a reservoir of laser cooled Be^+ ions in a volumique Paul trap.

N body problem:
Difficult to simulate over long periods of time (> ms).

Our solution:
Perform an experimental simulation.
$\bar{H}^+/^9Be^+$ ⟶ $^9Be^+/^{88}Sr^+$
-mass ratio (88/9≈9.78)
-$^9Be^+$ is laser addressable

Preliminary results

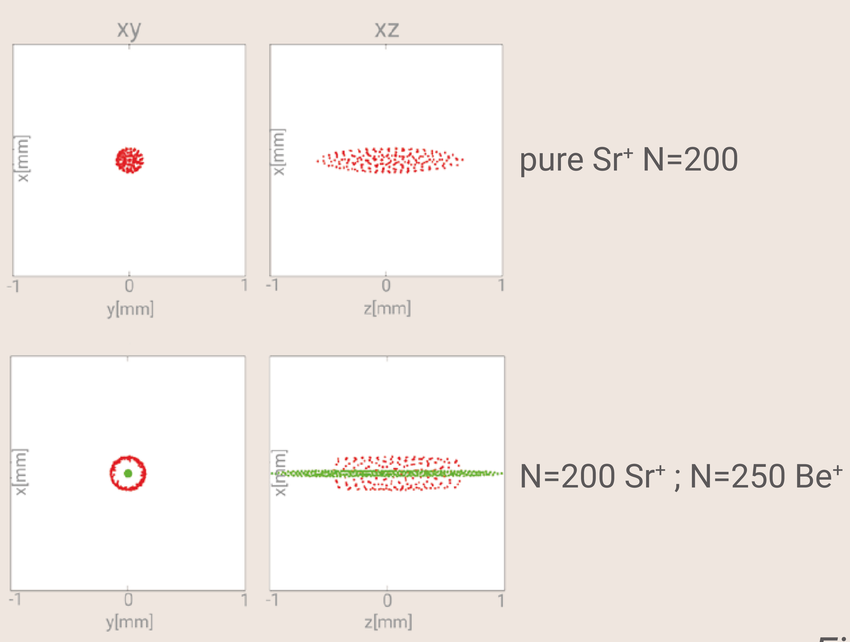


Fig 1: Steady state numerical simulations.

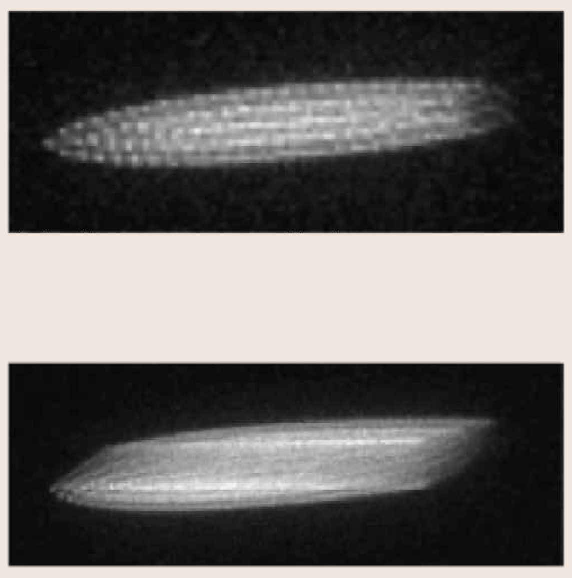


Fig 2: Up, picture of a Sr^+ Coulomb crystal in a 3D linear Paul trap.
Down, fluorescence image of the Sr^+ crystal after the injection of Be^+ ions.

In the experiment (Fig 2, down) the dark core is the signature of the presence of sympathically cooled Be^+ ions. We see in the simulation as well as in the experiment a strong spatial segregation between the Be^+ and Sr^+ ions .

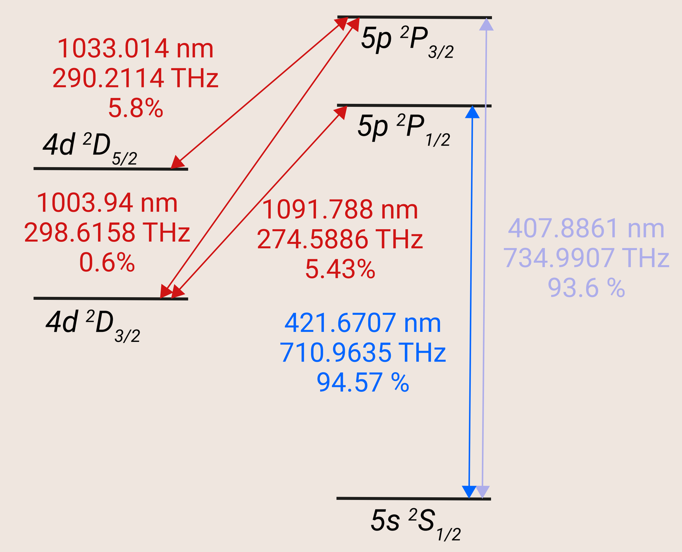
New Experiment

Trapping of individual Be^+

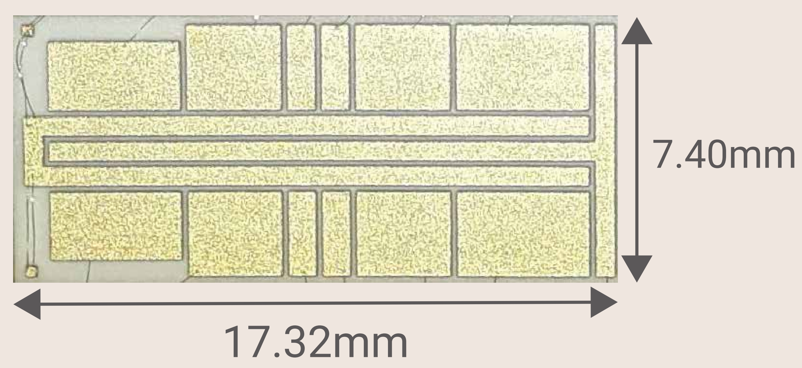
Both species are laser addressable: information about the Be^+ cooling dynamics

Control of the Be^+ launching energy up to 1eV

Energy levels diagram of Sr^+ for Doopler cooling



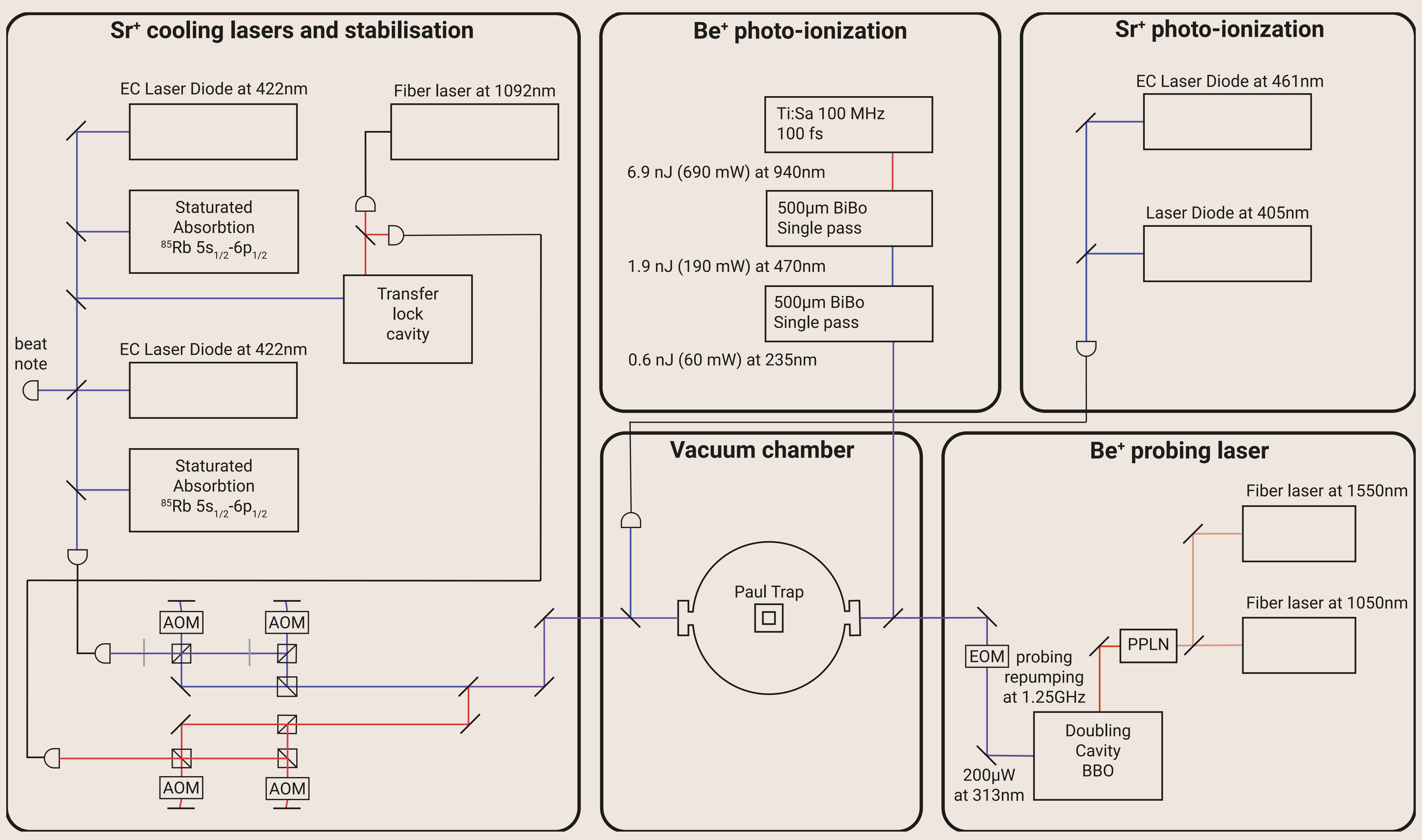
Double Paul trap



Alunina gold-plated PCB
5 wire geometry
1 RF electrode
13 DC electrodes

Trap height : 640μm
RF frequency : 14 to 20MHz
RF amplitude 500-1000Vpp

Experimental Set-up



Ion Launching Simulation

Controlled Be^+ initial kinetic energy

Approach:
- Cooling Be^+ (Ec≈0eV) in one trap (U)
- Apply V_{push} at the end (pink electrodes)
- Apply V_{close} (red electrodes) Δt later

Find the launching parametres:

The potential barrier at the center must be lower than those at the edges.
- Find **DC voltages** corresponding

Simulation :
- Find V_{push} to enter the target trap
  Solve molecular dynamics equations
  - Find **Δt** (on first simulation)
- Finaly compute a new simulation to find V_{close}

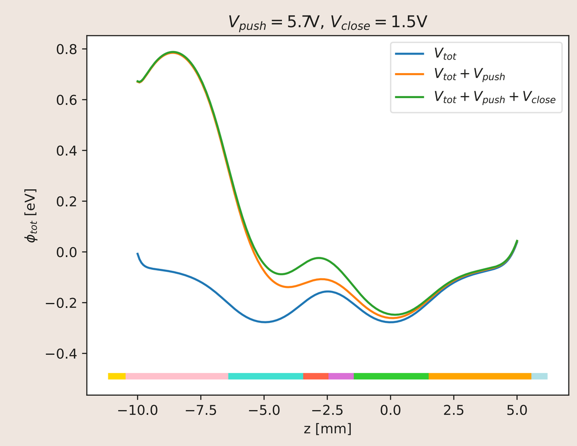


Fig 3: Trapping potential along the longitudinal axis before, during an after the launching of a Be^+ ion.

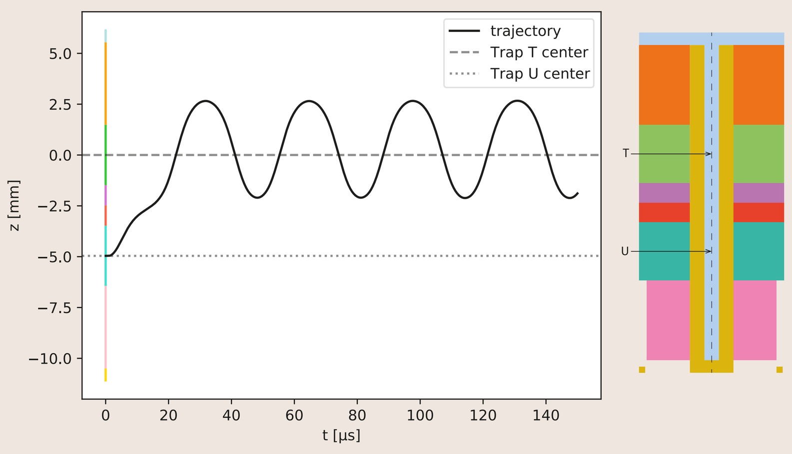


Fig 4: Ion trajectory along the longitudinal axis.

Status of the Experiment

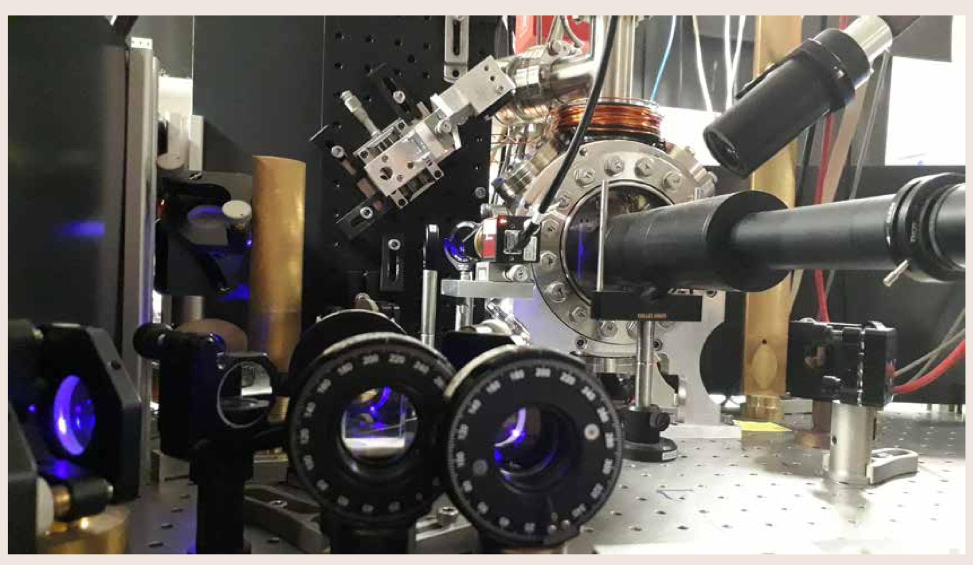


Fig 5: Picture of the experiment (vacuum chamber and optics)

Sr^+ launching achive with initial kinetic energy superior to 100meV and a success rate of 80%

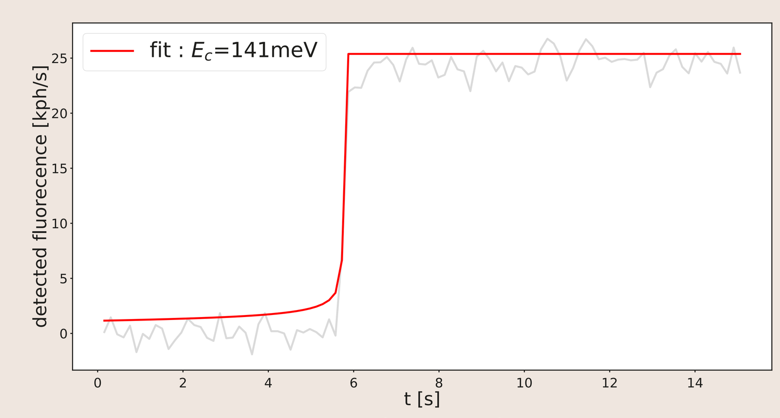


Fig 6: Fluorecence of Sr^+ after lauching, the fit give the initial kinetic energy which is the only ajustable parameter.

Next steps:
-Trapping large Sr^+ crystals.
-Trap both Be^+ and Sr^+.
-Test launching protocol with Be^+.
-Sympathetic cooling of Be^+.

Perspectives:
-Ground state cooling of an Be^+/Sr^+ pair.
-Add Ca^+ ions in the Sr^+ Coulomb crystal

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