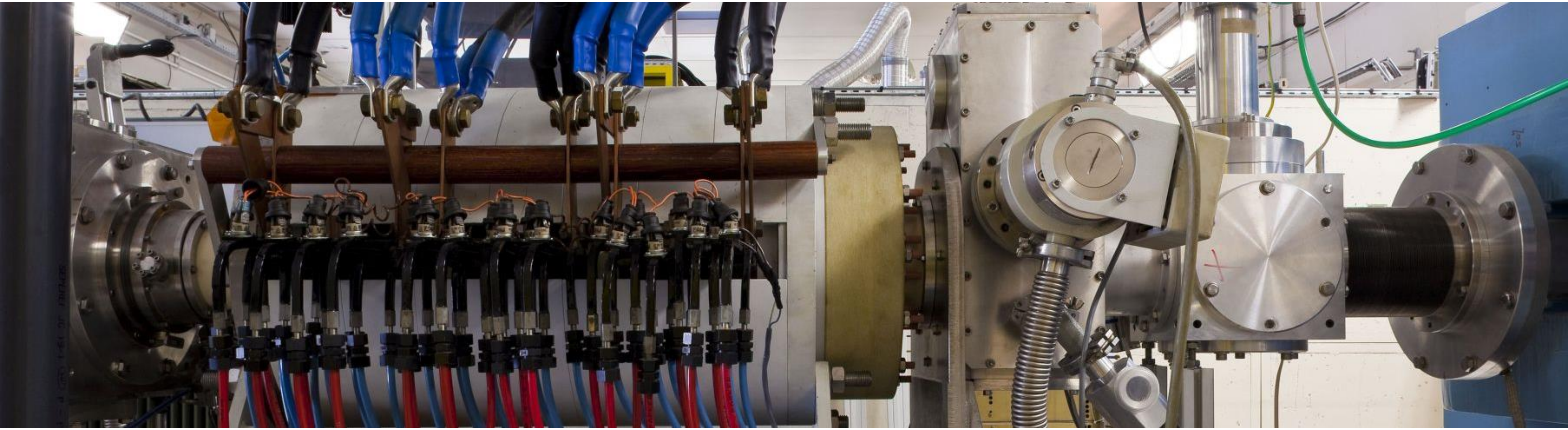
Cyclotron Ion Sources

The capture of injected 1+ ions into an ECRIS CB plasma

J. Angot[1], O. Tarvainen[2], P. Chauveau[3], A. Galatà[4], L. Maunoury[3*], T. Thuillier[1]



1 LPSC GRENOBLE | MODANE

2 UK Research and Innovation

3 GANIL spiral2 laboratoire commun CEA/DRF CNRS/IN2P3

4 INFN LNL Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Legnaro

* Today Normandy Hadrontherapy

Introduction

For more details on this R&D :

OPEN ACCESS
IOP Publishing
Plasma Sources Science and Technology
Plasma Sources Sci. Technol. **31** (2022) 125003 (7pp)
https://doi.org/10.1088/1361-6595/aca713

The capture of injected 1+ ions in charge breeder electron cyclotron resonance ion source plasma

RESEARCH ARTICLE | MAY 06 2024

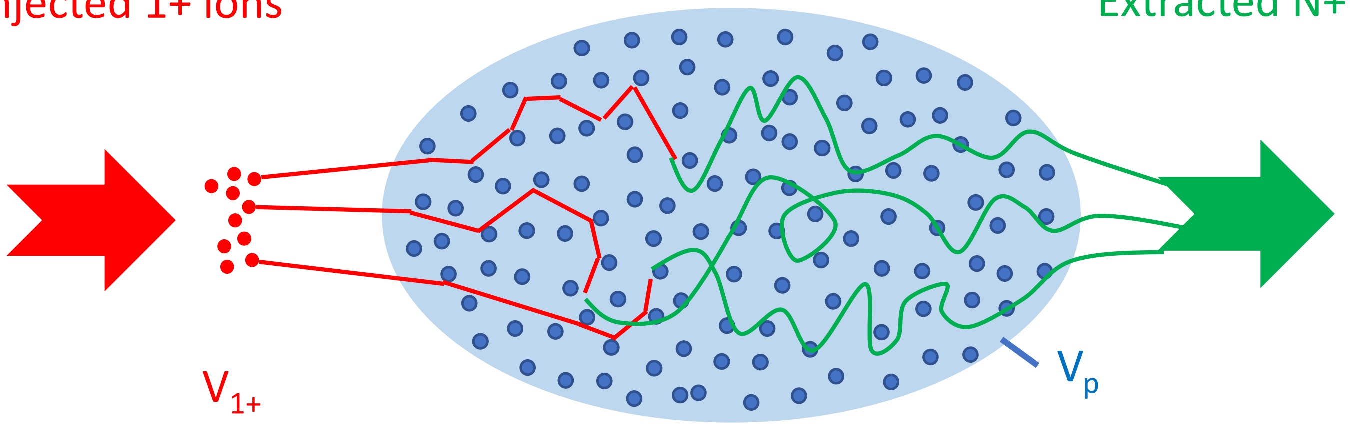
Experimental investigation of electrostatic capture of 1+ ions in charge breeder electron cyclotron resonance ion source plasma

O. Tarvainen; J. Angot; P. Chauveau; A. Galatà; T. Thuillier

Check for updates

Phys. Plasmas 31, 053103 (2024)
https://doi.org/10.1063/5.0202875

Introduction



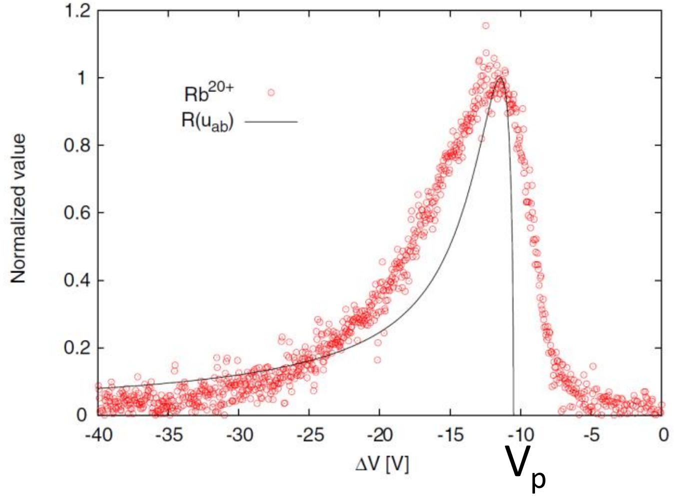
$$S_{ab} = \frac{\langle \Delta v_{a,\parallel} \rangle}{\Delta t} \qquad S_{ab} = -\frac{n_b}{4\pi\epsilon_0^2}\left[\frac{q_a q_b e^2}{m_a \langle v_b \rangle}\right]^2 \left(1+\frac{m_a}{m_b}\right) R(u_{ab}) \ln\Lambda$$

$$R(u_{ab}) = \frac{2}{\pi^{1/2}}\frac{1}{u_{ab}^2}\int_0^{u_{ab}} x^2 e^{-x^2} dx \qquad u_{ab} = \frac{v_{a,\parallel}}{\langle v_b \rangle}$$

$R(u_{ab})$ maximum when $u_{ab}=1$ so when $v_{a,\parallel} = \langle v_b \rangle$

a injected species, b plasma species
n density, q charge, m mass, v velocity, $\ln\Lambda$ Coulomb logarithm

Rb^{20+} ΔV curve, O_2 as support gas



Considering a Maxwellian velocity distribution for the plasma ions :

$$E_{opt,1+} = \frac{4m_{1+}}{\pi m_i} kT_i$$

$$\Delta V = V_{CB} - V_{1+}$$

$$E_{1+} = e(|\Delta V| - V_p)$$

$$|\Delta V|_{opt} = \frac{4m_{1+}}{\pi m_i}\frac{kT_i}{e} + V_p$$

Introduction

$$|\Delta V|_{opt} = \frac{4m_{1+}}{\pi m_i}\frac{kT_i}{e} + V_p$$

From experimental results :

- $m_{1+}/m_i > 5$ for good ECR CB efficiency
- Ion temperature in ECRIS plasma 5 - 28eV (optical spectroscopy measurements)

➢ $|\Delta V|_{opt} > 50V$ for Na^+ injected into an He plasma, even considering $V_p = 0V$

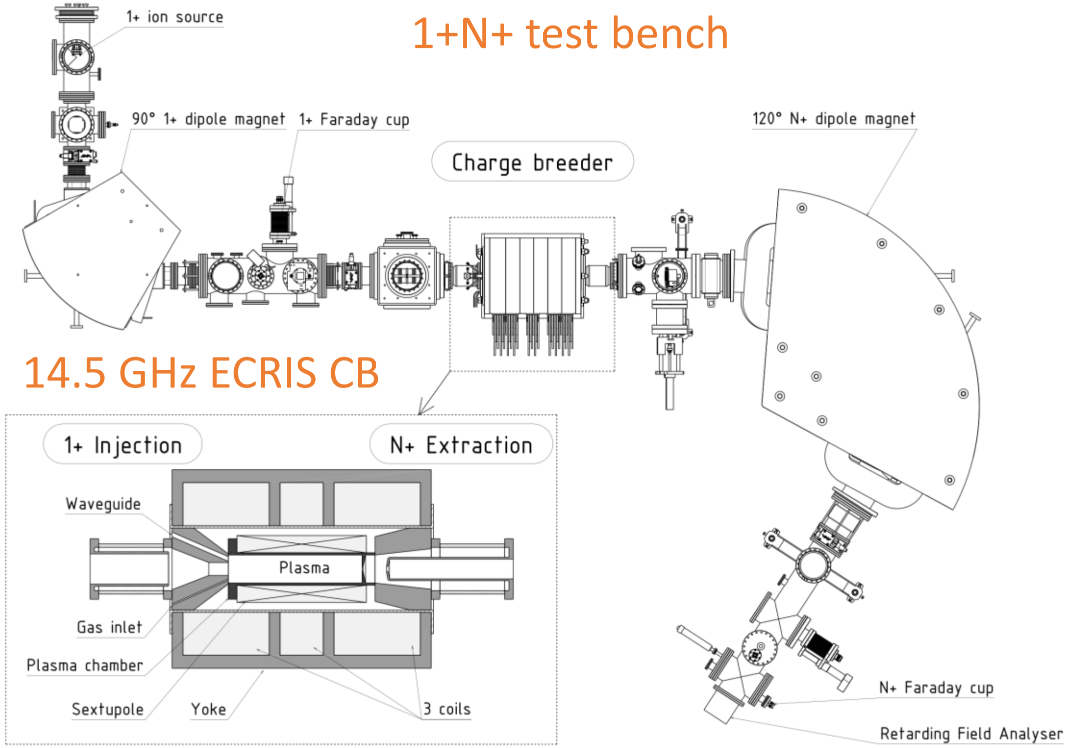
➢ 5 – 15 V values are typically measured

We propose here a revised concept where the slowing down is mainly electrostatic due to V_p

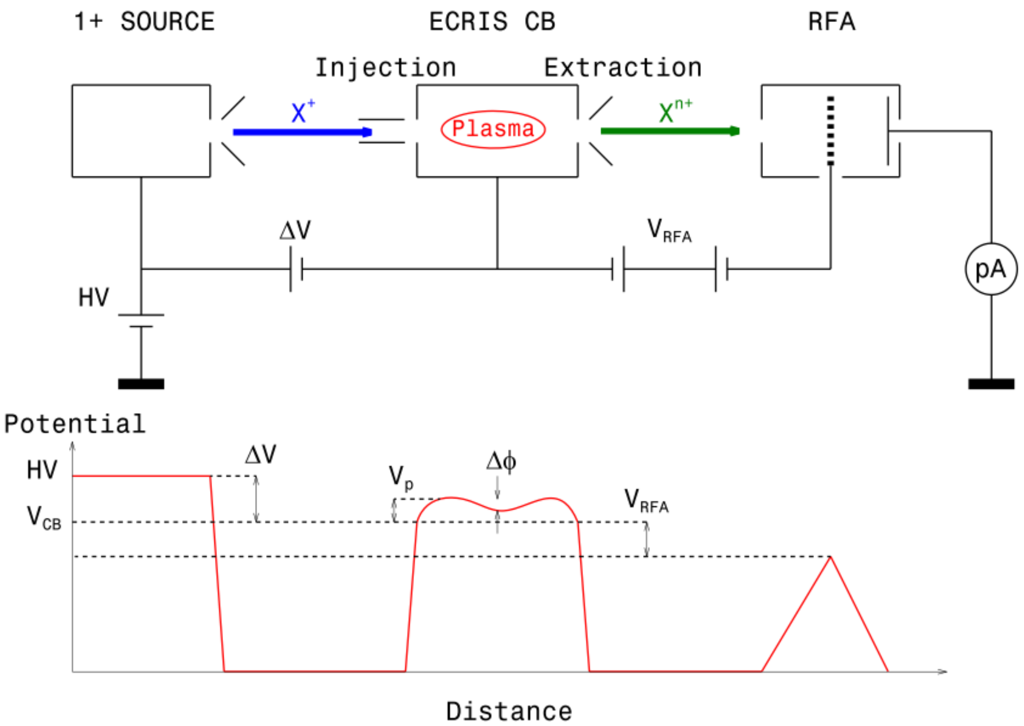
$$E_{opt,1+} = eV_p$$

We did extensive experiments to verify this assumption.

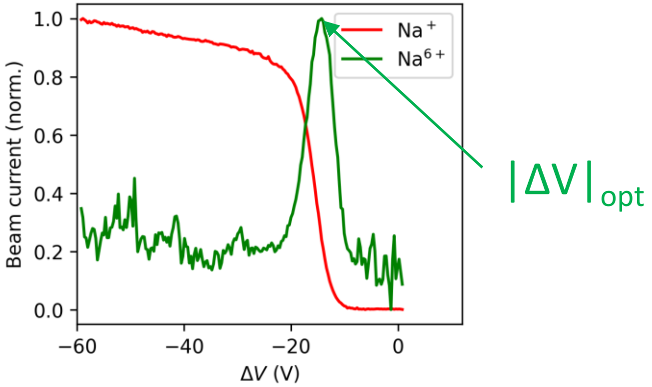
Experimental setup



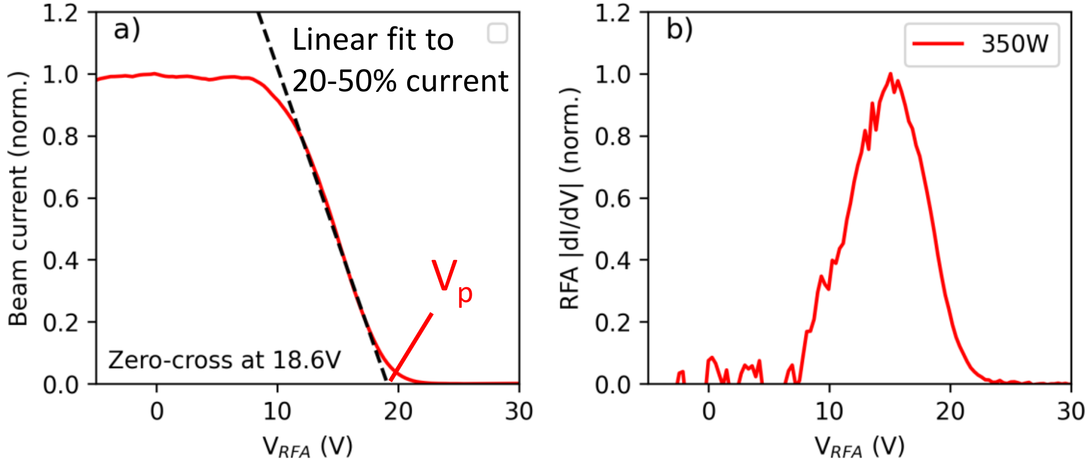
Electrical configuration



ΔV spectrum

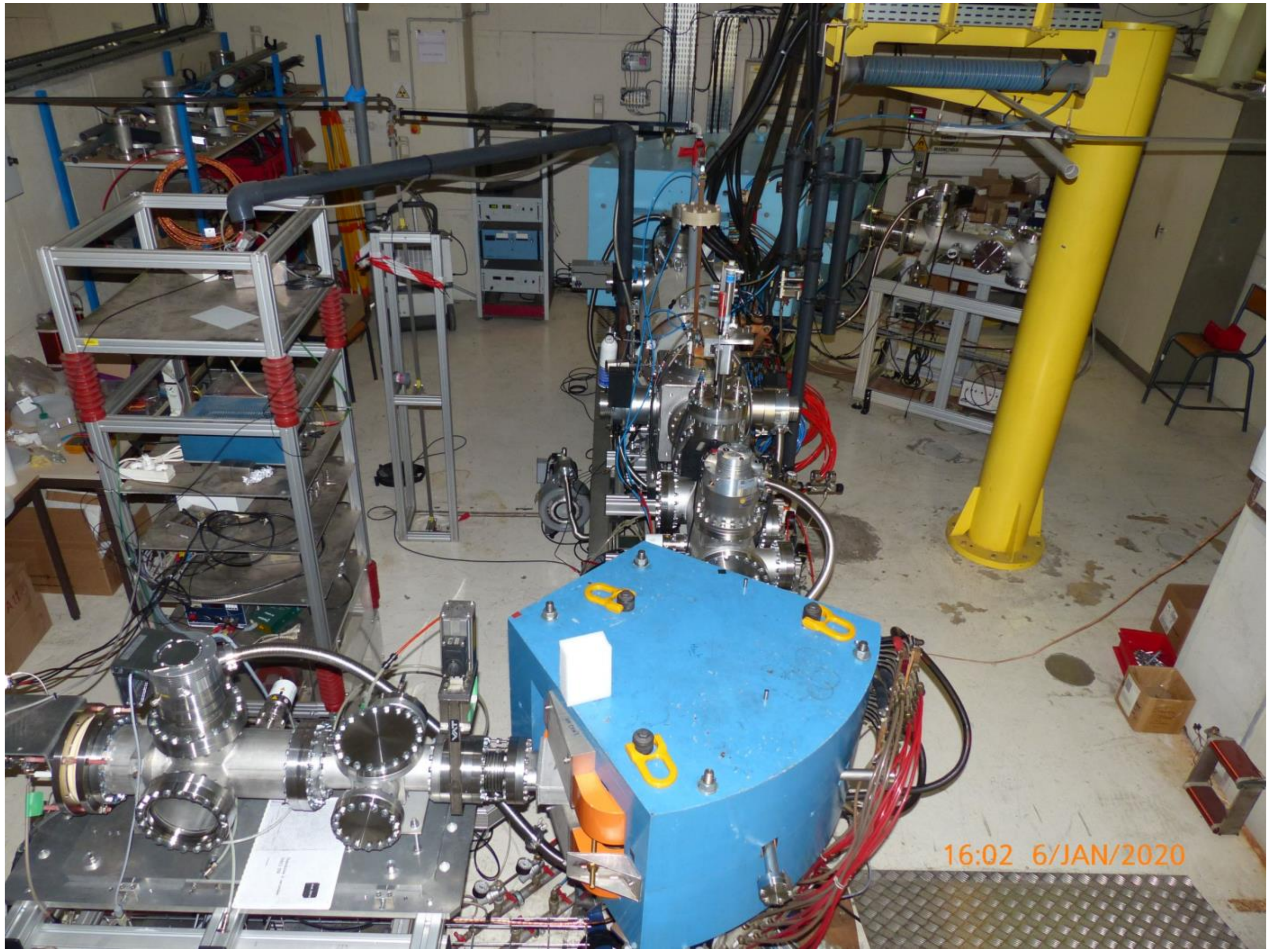


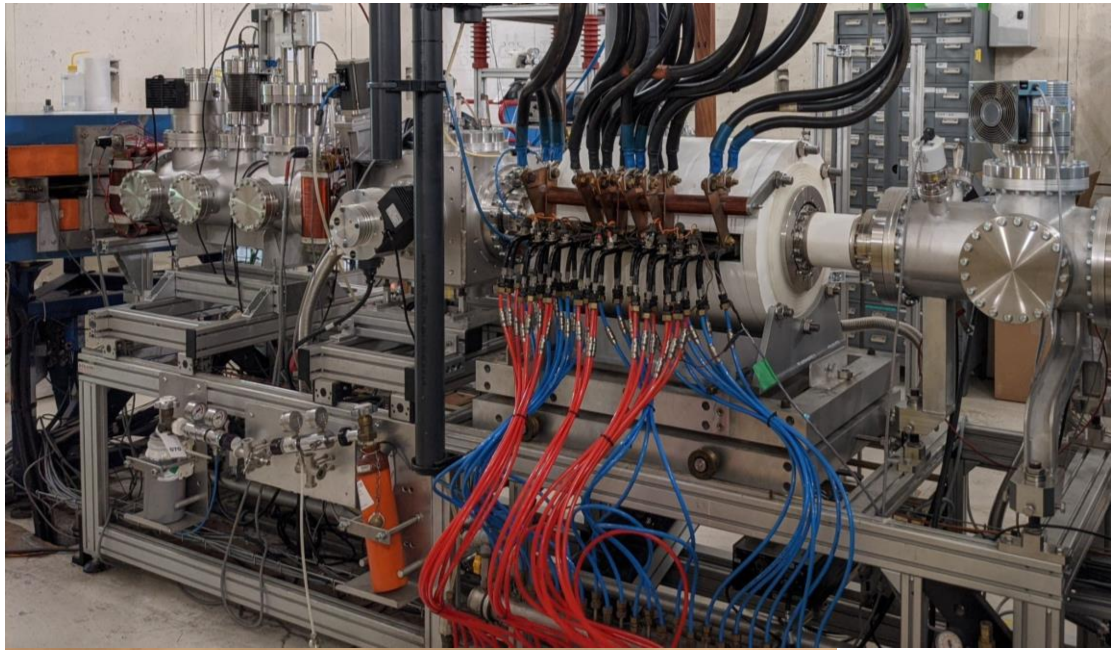
RFA spectrum , with plasma potential assessment



Experimental setup

1+N+ test bench





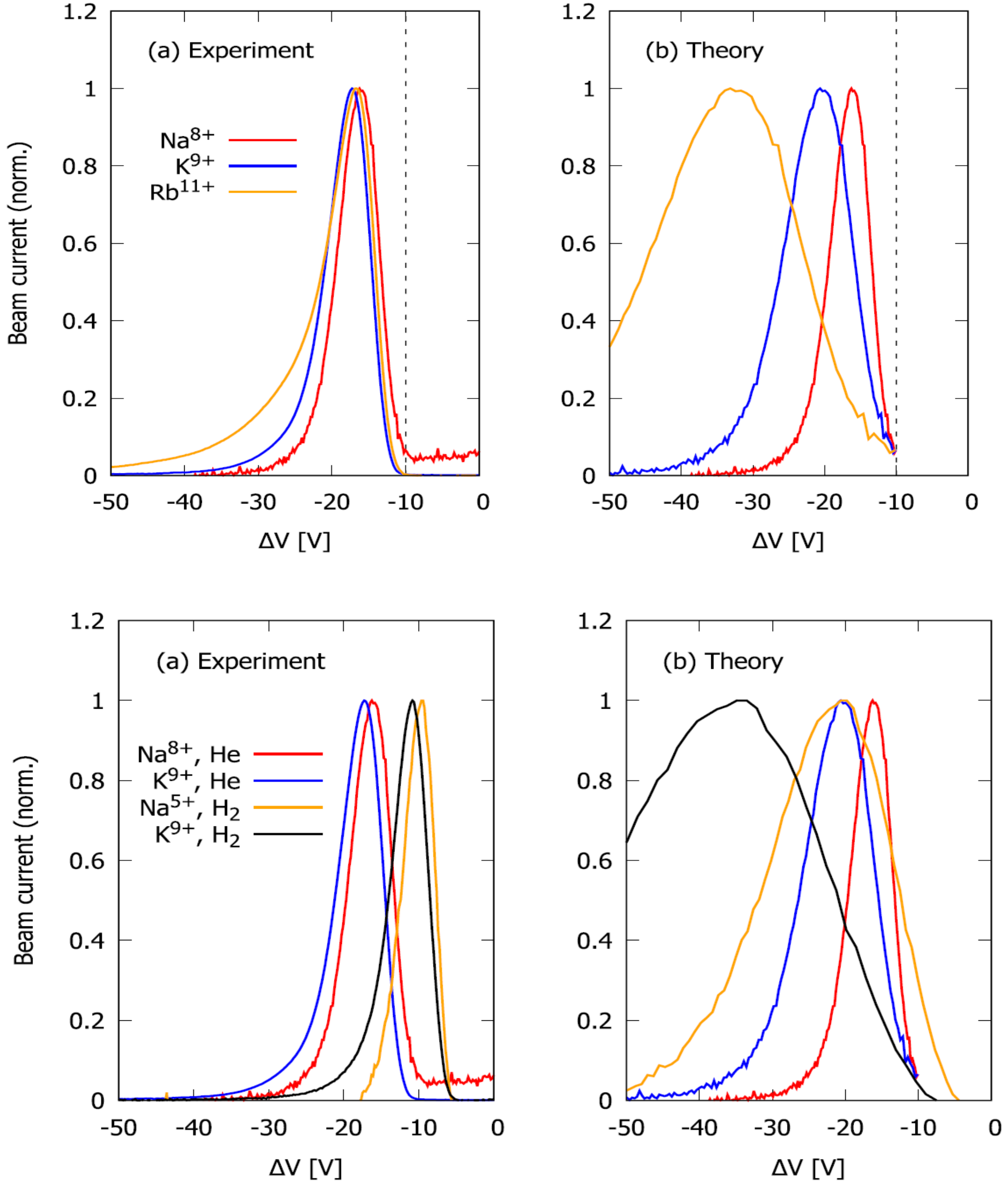
Results

Check the mass dependency of $|\Delta V|_{opt}$:

$$|\Delta V|_{opt} = \frac{4m_{1+}}{\pi m_i}\frac{kT_i}{e} + V_p$$

Mass ratio

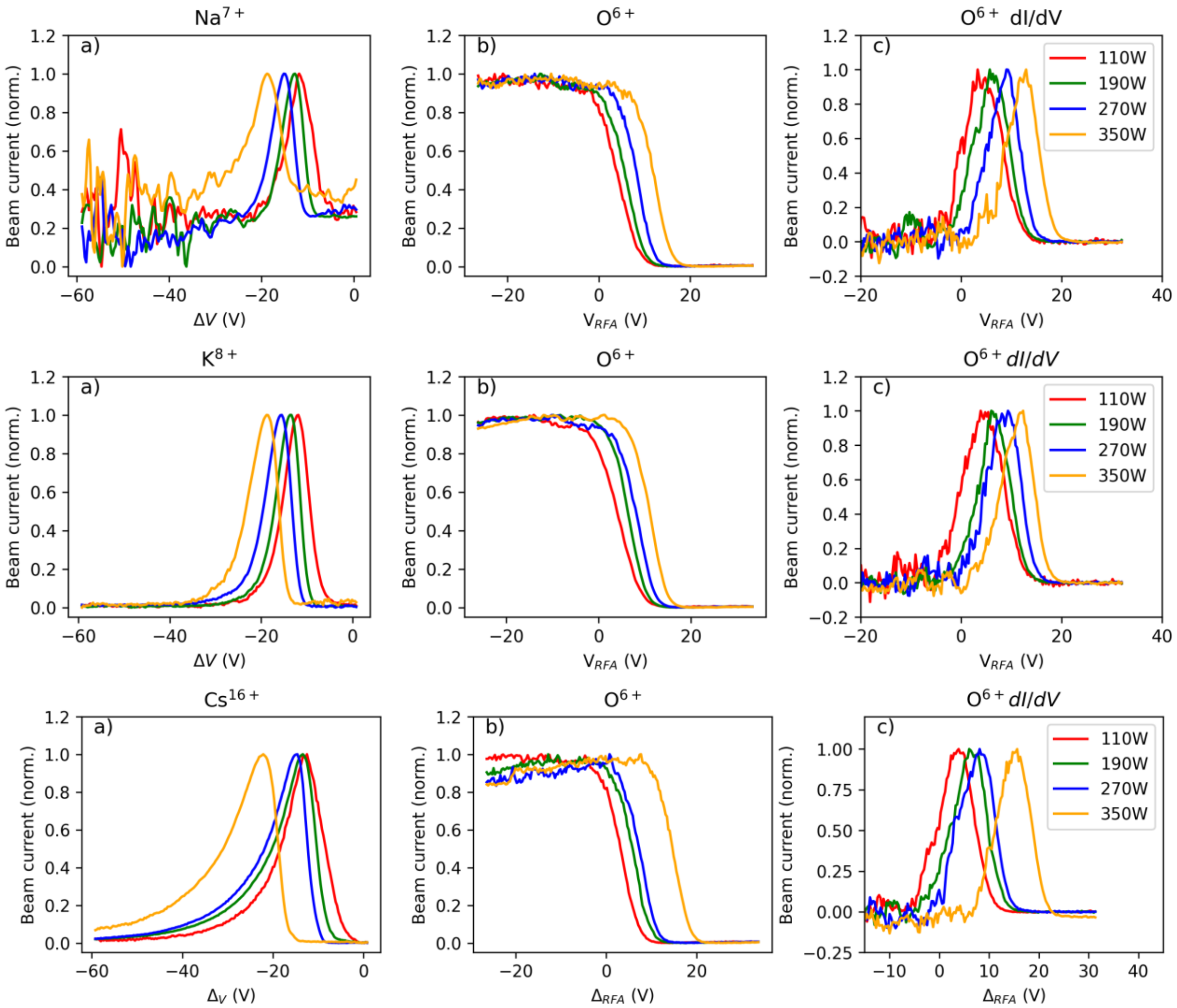
He plasma support gas



Results

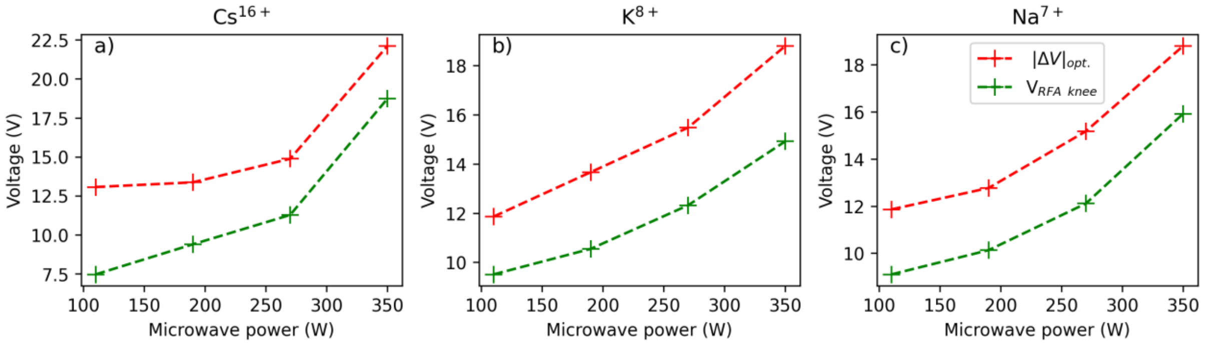
$$|\Delta V|_{opt} = \frac{4m_{1+}}{\pi m_i}\frac{kT_i}{e} + V_p$$

Plasma potential variation with microwave power



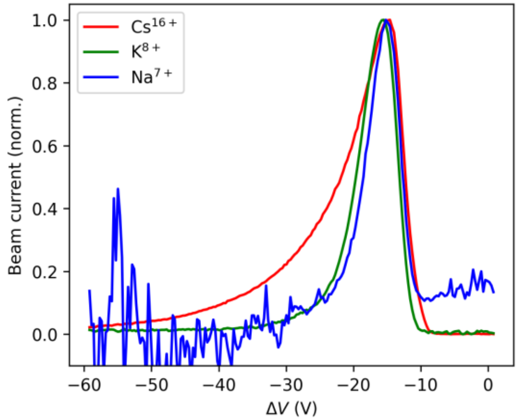
Na+ and K+ injected exactly in the same plasma conditions

Plasma potential and $|\Delta V|_{opt}$ vs microwave power



- $|\Delta V|_{opt}$ follows the plasma potential with an offset

DeltaV curves comparison at 270W microwave power

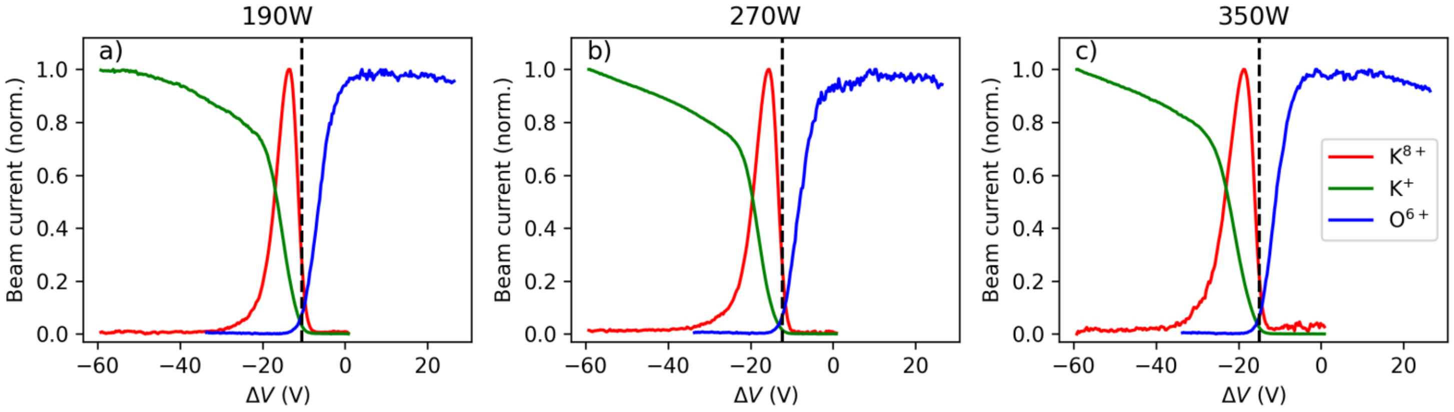


- Same $|\Delta V|_{opt}$ whatever the injected mass
- Larger FWHM for Cs : lower for high mass ?

Results

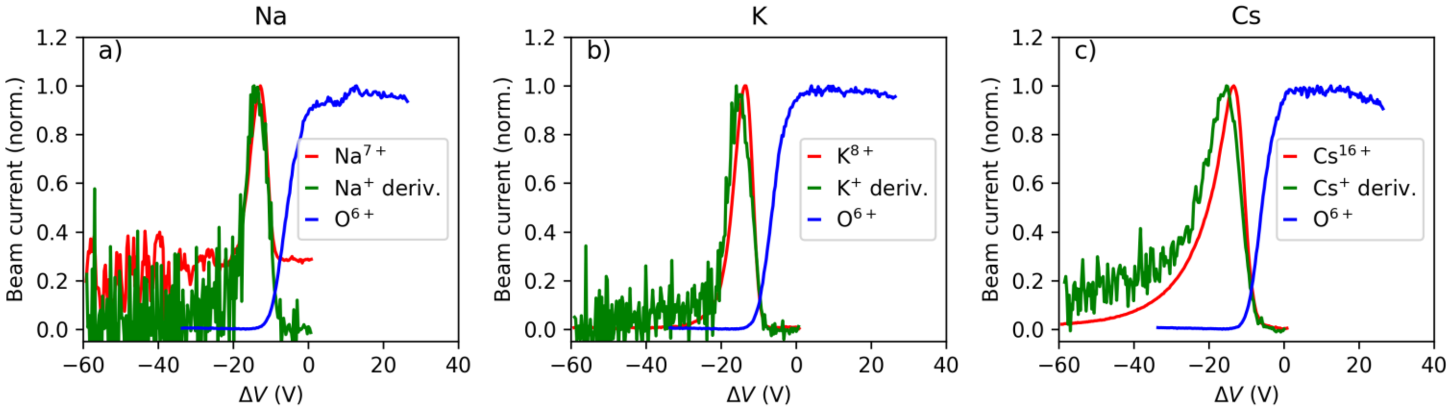
ΔV spectrum of K at different microwave power
With RFA spectrum (inverted voltage) to estimate the plasma potential value (dashed lines) :

- ➢ When the energy of injected ions becomes greater than e.Vp, they can propagate through the CB plasma.



ΔV spectrum of Na K Cs at 190W microwave power, derivative of 1+ (fly through) charge state :

- ➢ Capture optimum corresponds to the most efficient stop of the 1+ ions
- ➢ The 1+ ions stopped are effectively converted to high charge state ions in the energy range
- ➢ Small shift of optimum visible : in flight ionisation to 2+



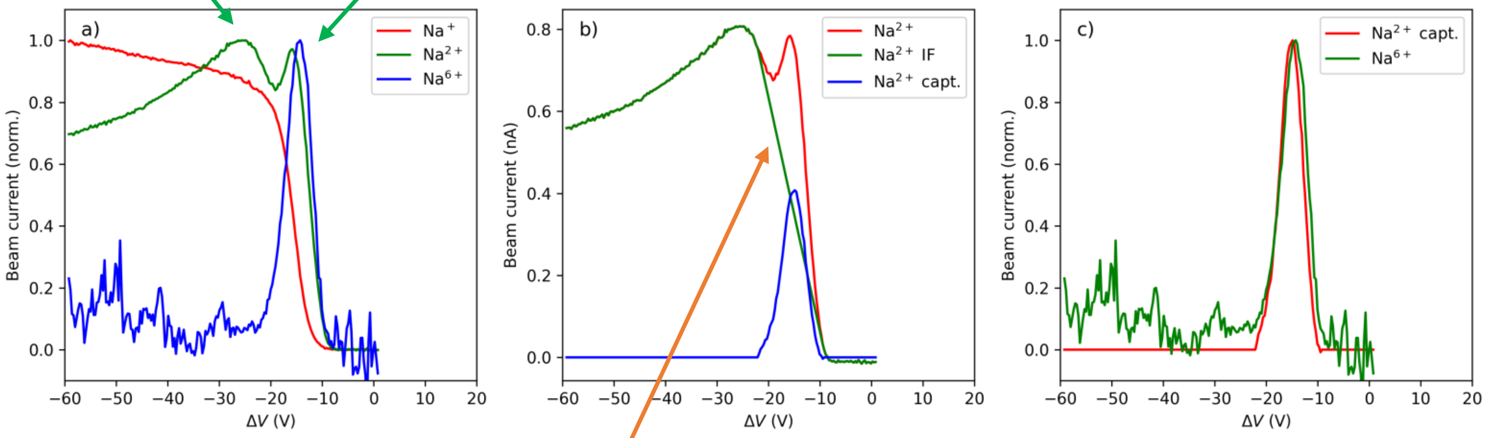
Results

In flight 1+ ➔ 2+ ionisation

Optimum fly through 1+ ➔ 2+ ionisation

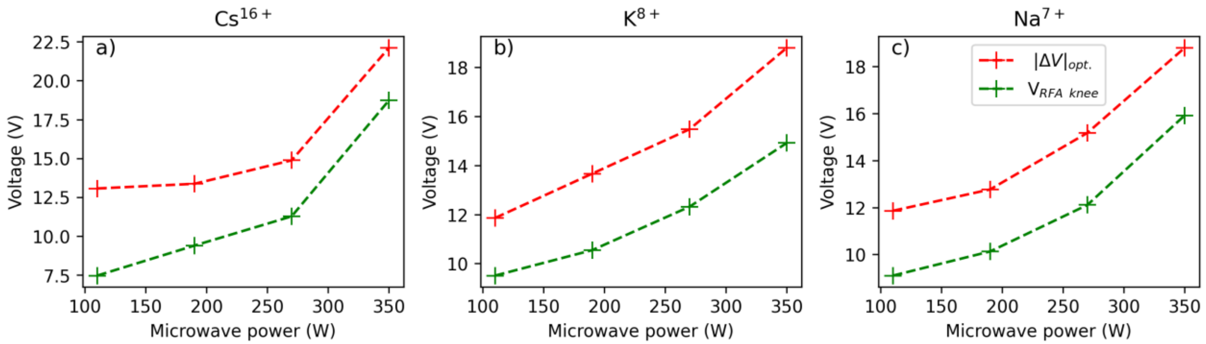
Optimum captured 1+ ➔ 2+ ionisation

Na^+



Higher fly through 1+ ➔ 2+ ionisation at higher energy could lead to « shift » the $|\Delta V|_{opt}$ for high charge state at lower energy

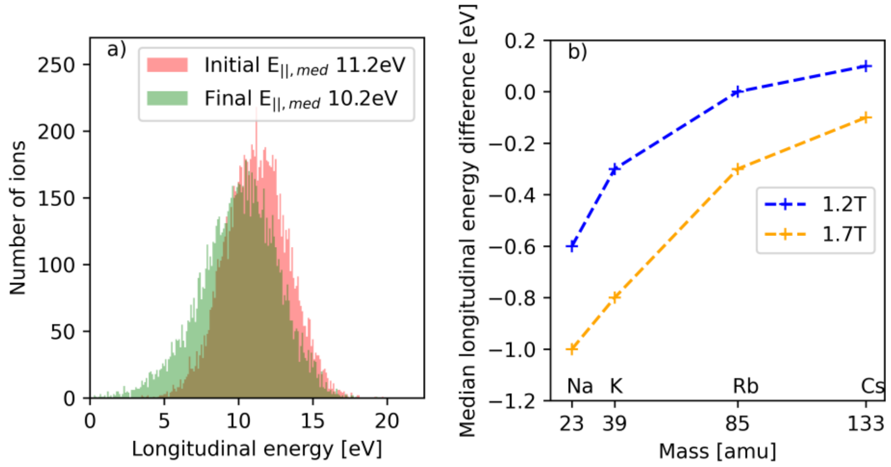
Discussion



Injection optics

CB

ΔV =-12V, Initial energy spread = 2eV

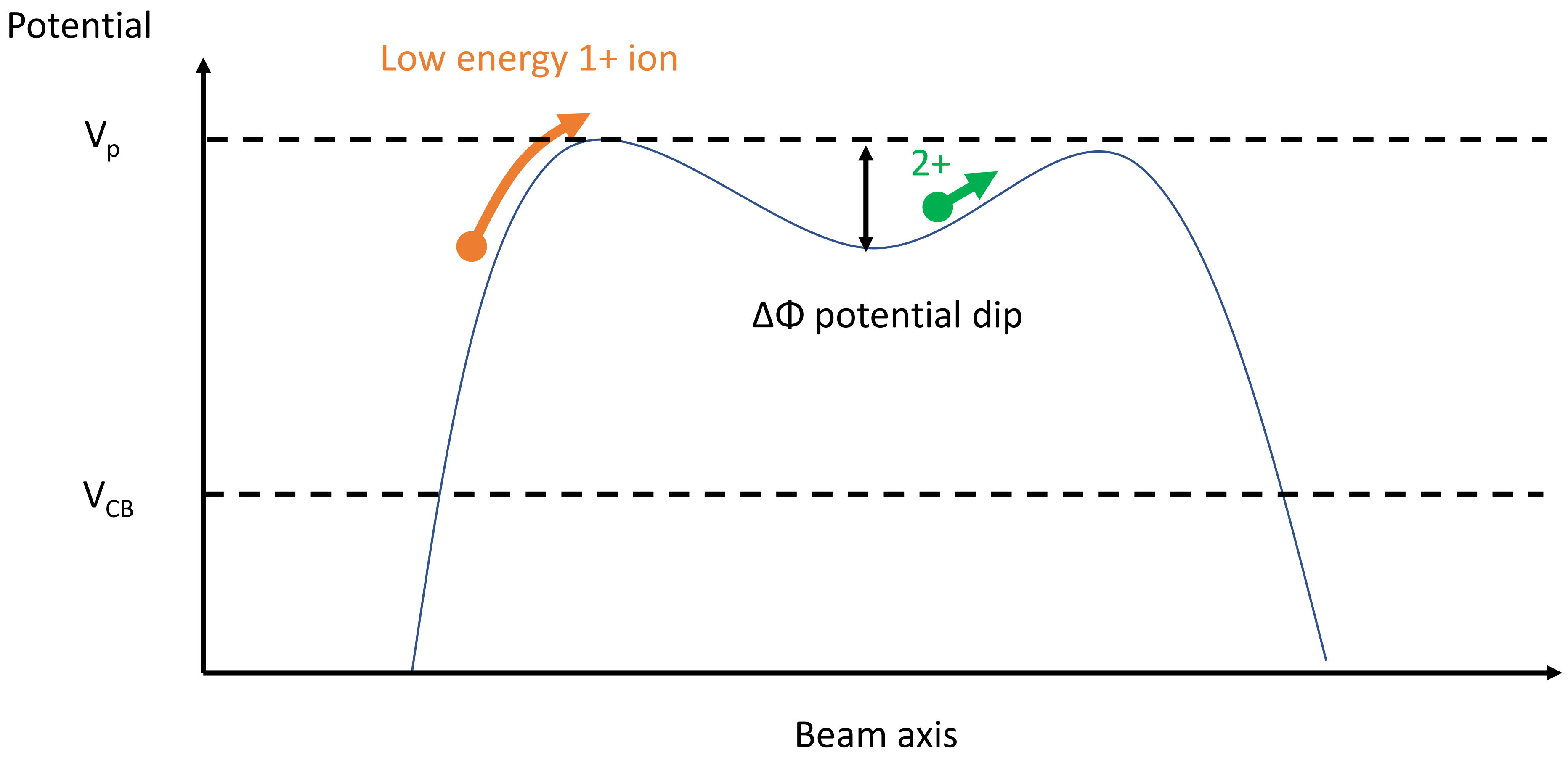


Possible explanation of the difference between $|\Delta V|_{opt}$ and plasma potential value
It is in the range 2.4 V < Offset < 5.6 V

- Injection magnetic field : converts longitudinal energy to transverse
  Study of the effect by simulation with Simion
- Plasma potential (peak value) not symmetric at injection vs extraction
- Coulomb interactions before the injected ions reach the plasma potential peak value
- Injection with an excess of energy balancing the effect of inflight ionisation to 2+ and reflection at injection side

Discussion

Electron impact ionisation to 2+
- ➢ Enhanced friction (proportional to q^2)
- ➢ Electrostatic trapping in plasma potential dip (required energy doubles)



Conclusion

Experiments have demonstrated that the capture of 1+ ions injected into an ECR charge breeder plasma is dominated by the electrostatic forces :

- No direct mass dependency can be observed on the $|\Delta V|_{opt}$ parameter
- $|\Delta V|_{opt}$ follows the plasma potential value with a small offset

$$E_{opt,1+} = eV_p$$

In the proposed model, the capture doesn't depend on the plasma ion temperature

Thank you for your attention