Time Evolution of Plasma Potential in Pulsed Operation of ECRIS

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Outline

- Plasma potential of an ECRIS
- Measuring the plasma potential of an ECRIS
  - Continuous mode
  - Pulsed mode
- Results in pulsed mode
- Discussion

Plasma potential of an ECRIS

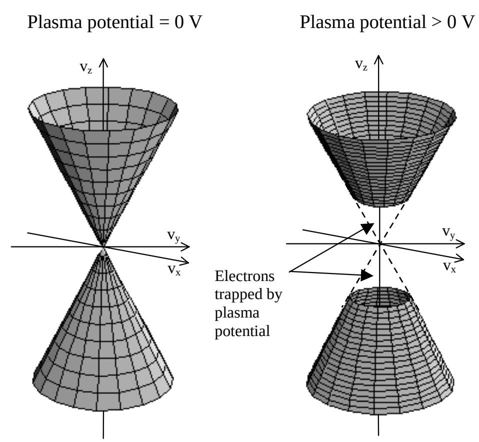
- Diffusive loss rates of electrons and ions are affected by their mobility

→ Ions being heavy diffuse slower than cold (collisional) electrons

$$\mu = \frac{qe}{m\nu_{coll}}$$

- In order to compensate the loss rates of positive and negative charge and to maintain plasma quasineutrality a positive potential builds up retarding the losses of electrons and repelling ions

$$n_e = \sum_i q_i n_i$$



Low energy electrons are trapped by the plasma potential

Ion confinement is weakened

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Plasma potential of an ECRIS

- The plasma potential of an ECRIS can be estimated with*

$$V_p = \frac{kT_{e,cold}}{2e}\left(5.67 - \ln\left(\frac{q_{eff}}{A}\right)\right)$$

$T_{e,cold}$ is temperature of the cold electron population

q_{eff} is the mean charge of ions

A is the mass number of ions

Prediction: during the plasma preglow and afterglow decay the plasma potential is higher than in steady-state due to lower q_{eff} (stepwise ionization and diffusive decay)

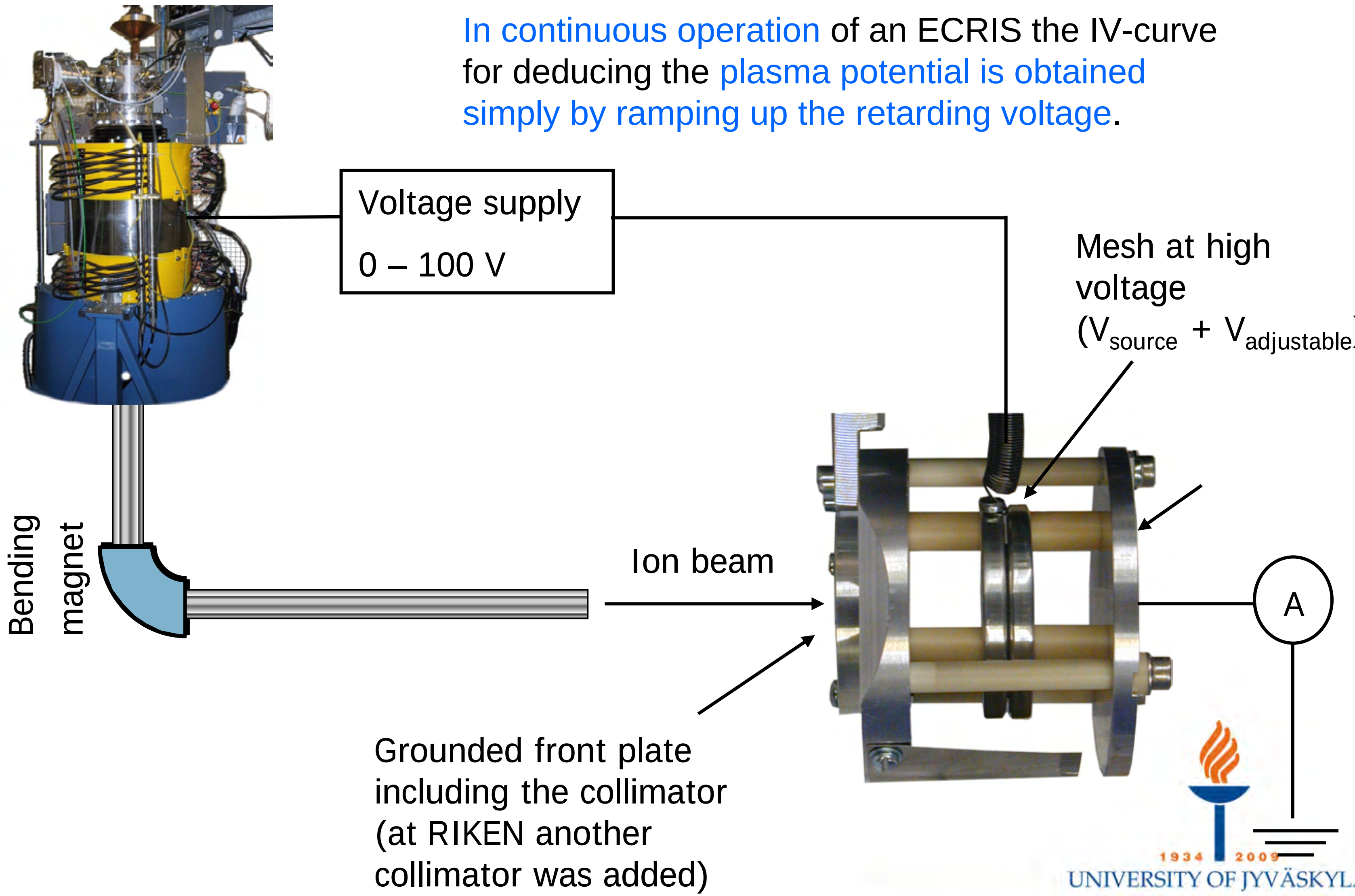
* Bibinov et al. Plasma Sources Sci. Technol., 14, (2005), p. 109.

Measurement of ECRIS plasma potential

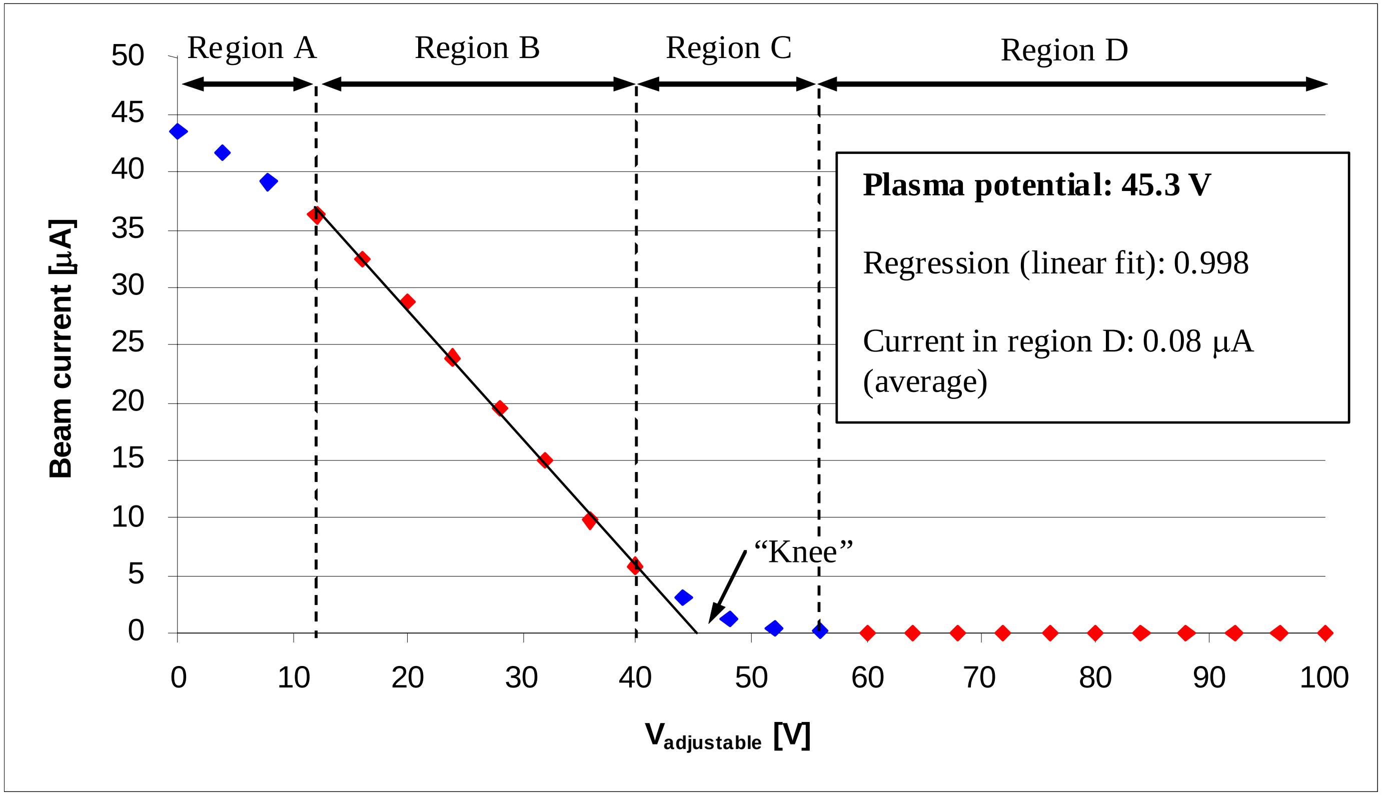
- Langmuir-probe (e.g. Mironov et al. Rev. Sci. Instrum. **73**, 623 (2002))
  - Invasive, plasma properties can be affected
  - Technically challenging
- Measurement of beam energy
  - Magnetic rigidity of the ion beams
    (Z.Q. Xie and C.M. Lyneis Rev. Sci. Instrum. **65**, 2947 (1994)
  - Retarding field analyzer
    - Applicable for time-resolved measurement!

Measurement of ECRIS plasma potential

In continuous operation of an ECRIS the IV-curve for deducing the plasma potential is obtained simply by ramping up the retarding voltage.



Plasma potential from the IV-curve



Plasma potential measurement in pulsed mode

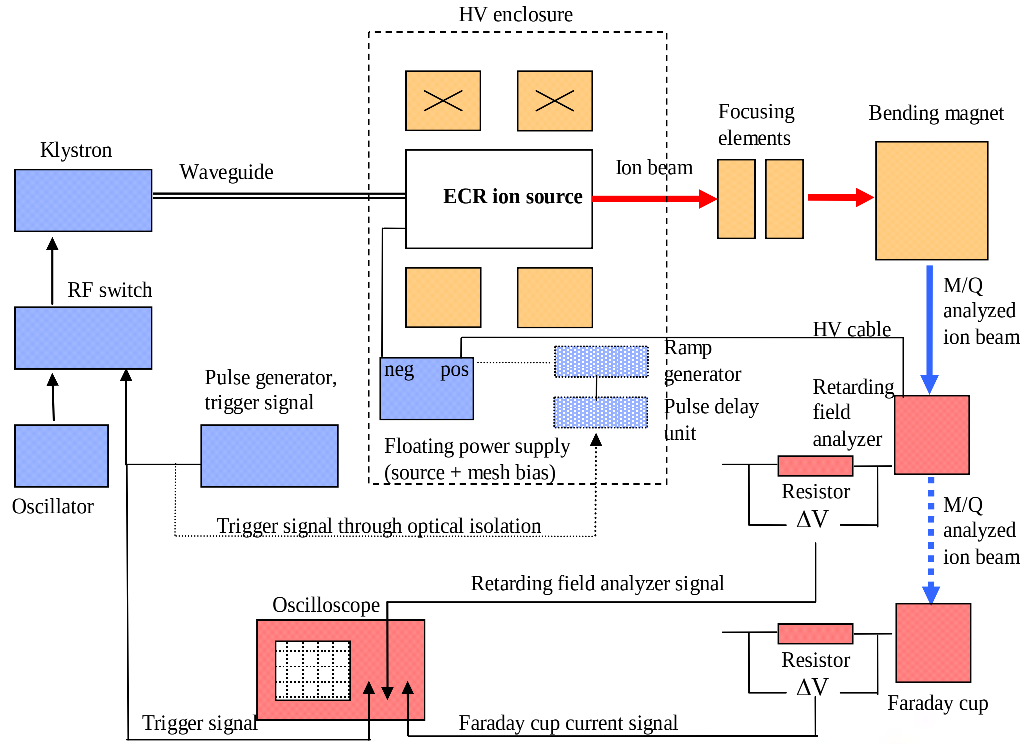
Option #1:

Pulse generator triggering microwave pulse and retarding voltage ramp through pulse delay unit

Ramping time 1 ms

Time window is chosen with the pulse delay unit

Signal from the retarding field analyzer recorded with an oscilloscope



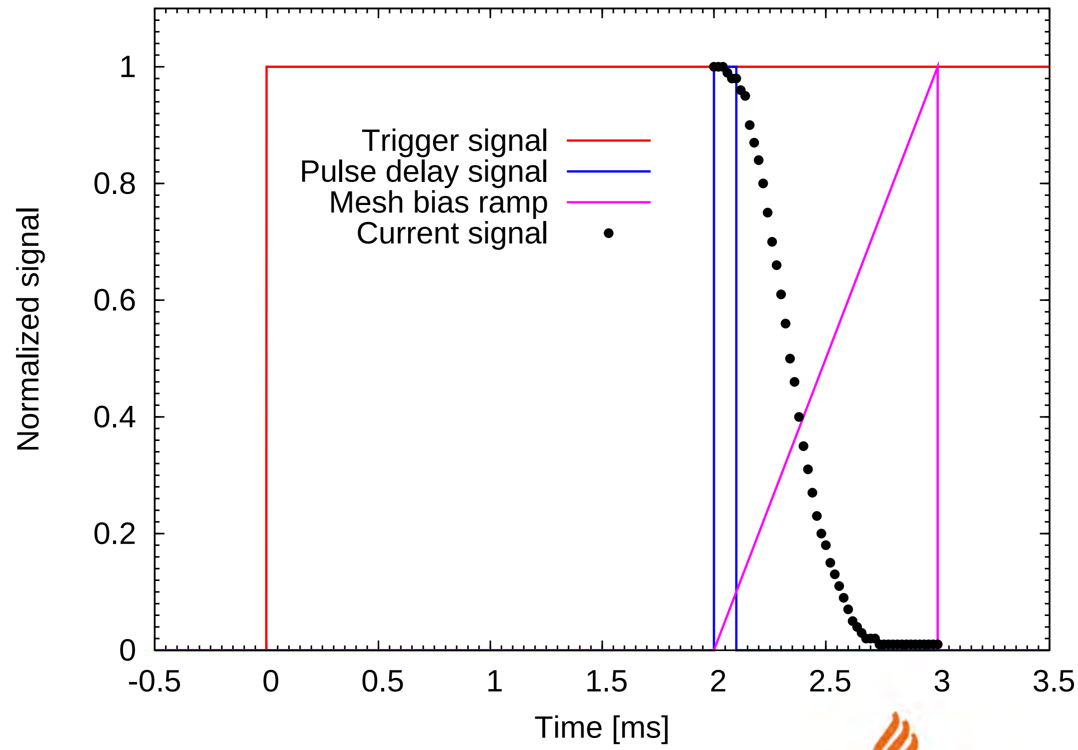
Plasma potential measurement in pulsed mode

Option #1:

An example of recorded IV-curves shown on right

Unfortunately the ramping time of 1 ms is too slow for fast variations of plasma potential during the preglow and afterglow

The method can be applied after ~ 50 – 100 ms (into the microwave pulse) and it was used for measuring the plasma potential in pulsed mode after reaching the saturation



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Plasma potential measurement in pulsed mode

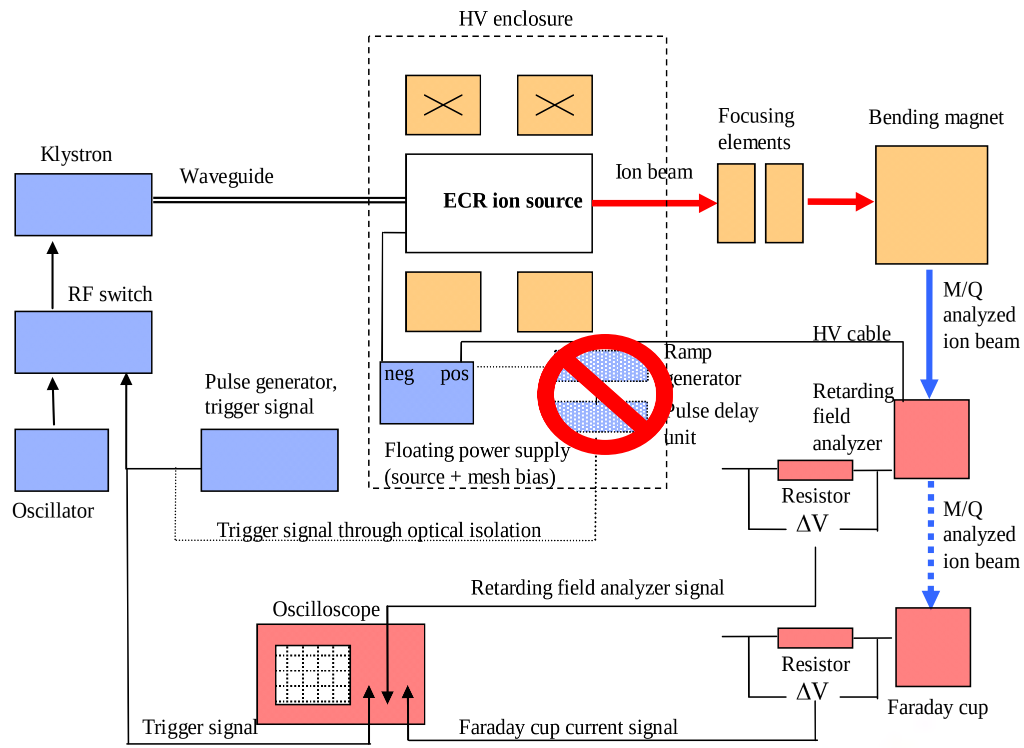
Option #2:

Retarding voltage set to constant value for a complete microwave pulse

Signal from the retarding field analyzer recorded with an oscilloscope (full pulse length)

Retarding voltage stepped up to next value

Signals at different retarding voltages combined to form IV-curve at given time (measured from the leading edge of the microwave pulse)



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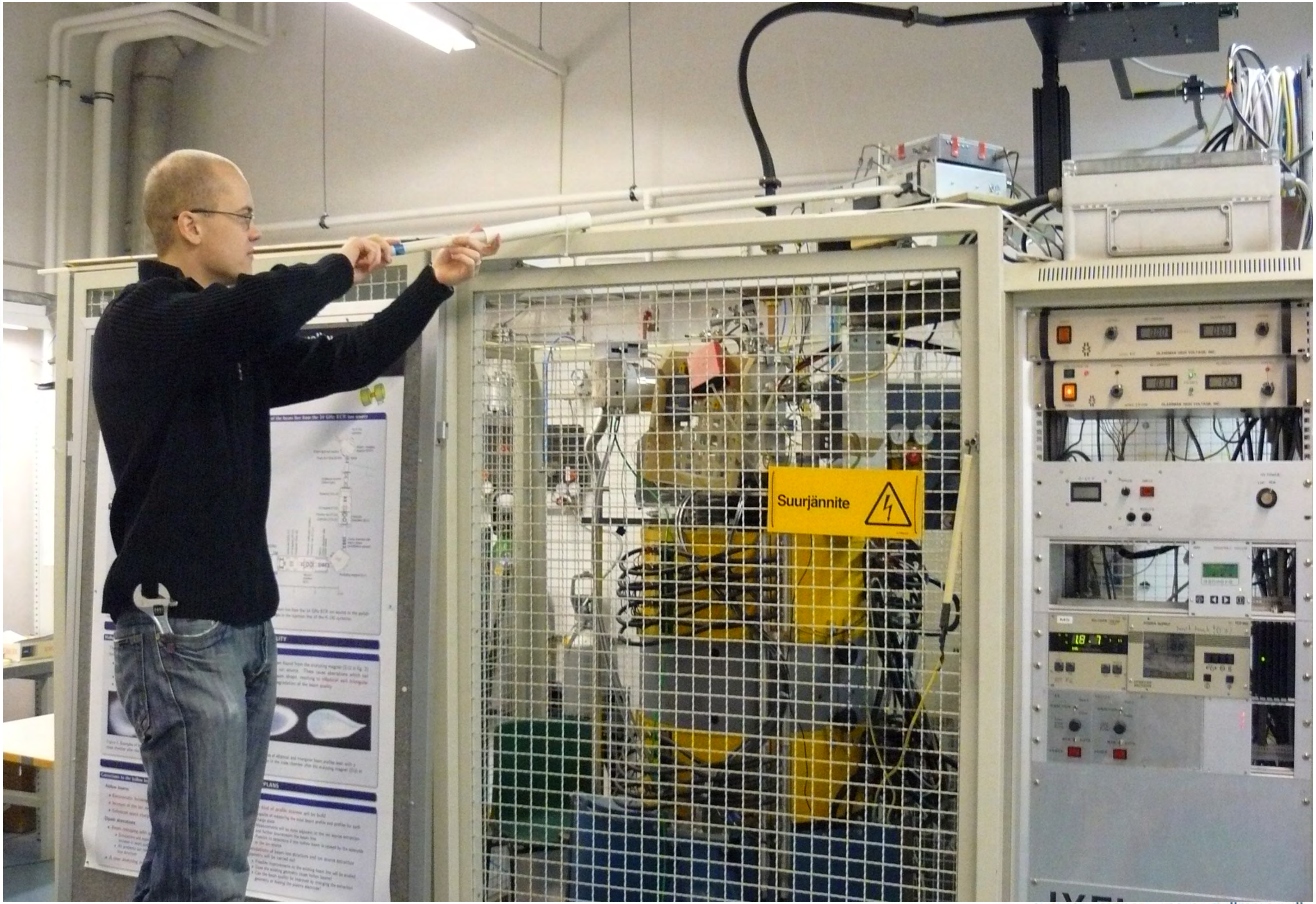

Suurjännite

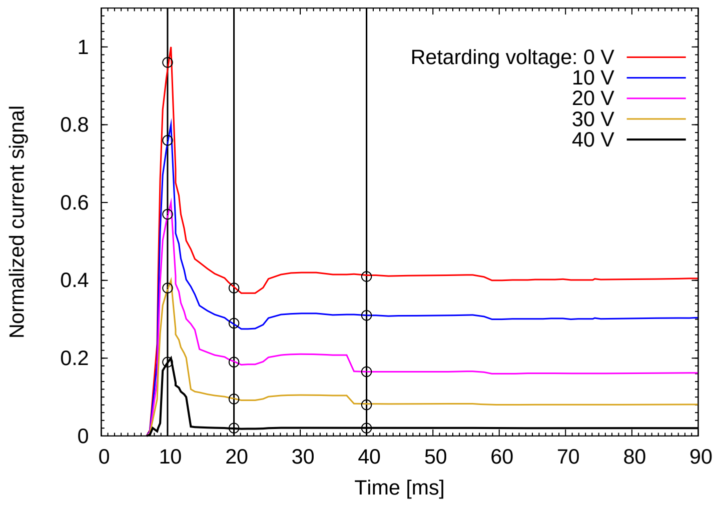
Plasma potential measurement in pulsed mode

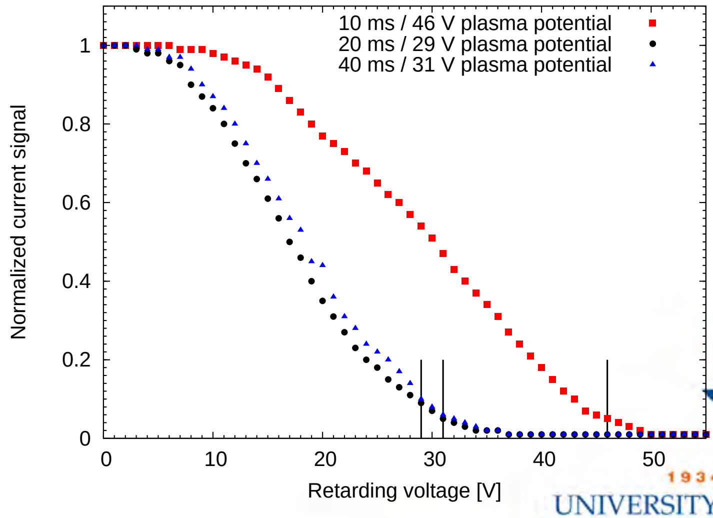
Option #2:

Examples of recorded current signals at different retarding voltages (pulsed) and corresponding IV-curves are shown on right

The method can be applied to measure fast variations of plasma potential.

This method was used to determine the plasma potential during preglow and afterglow plasma decay





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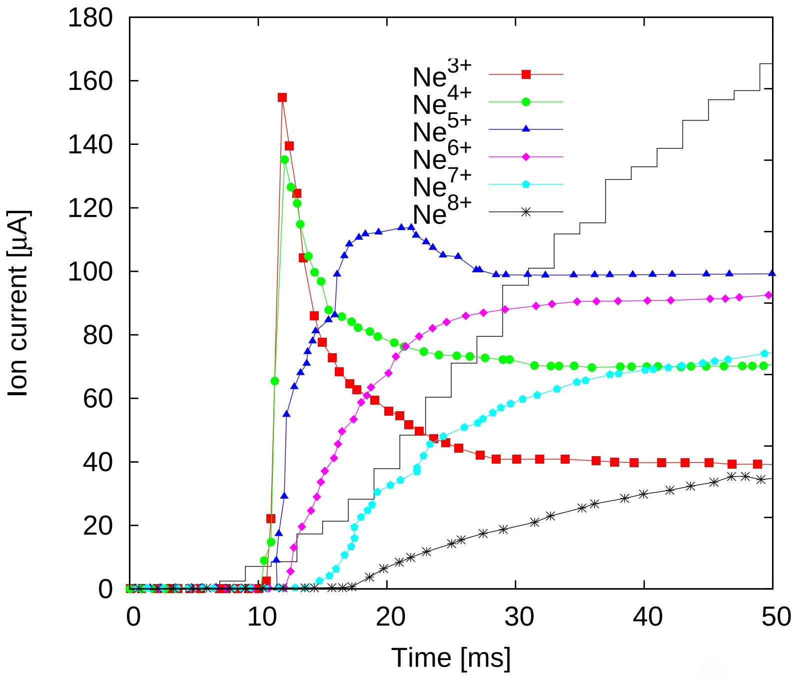
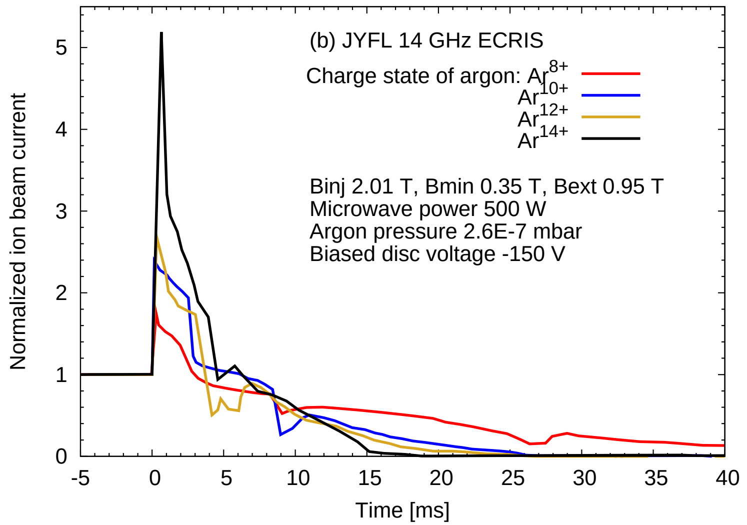
Preglow of ECRIS plasma

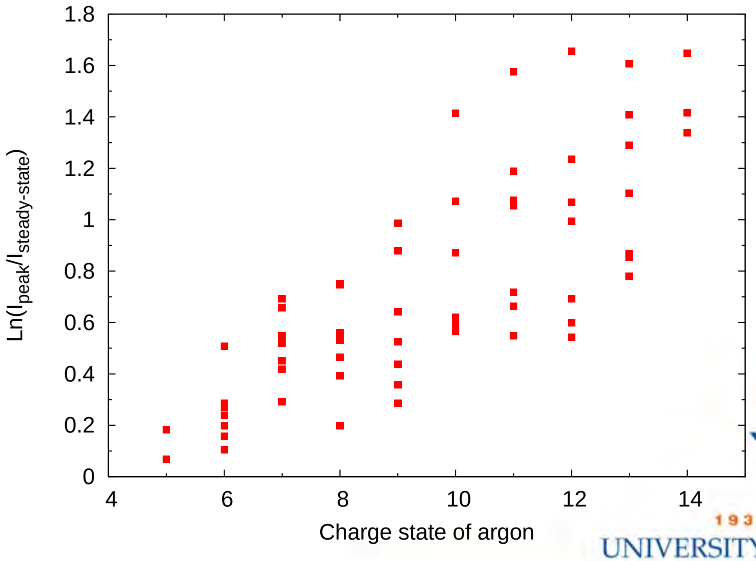
- Preglow is a fast transient peak (a few ms) of extracted currents at the leading edge of the microwave pulse
- Low charge state ions exhibit preglow reflecting the stepwise nature of the ionization process
- Preglow is affected by the ion source tuning parameters, microwave frequency and initial ionization degree (seed electons, pulse pattern)
- Presentation of I. Izotov…



Afterglow of ECRIS plasma

- A transient peak of a few ms
- Initiated by a burst of cold electrons not given a chance to gain perpendicular velocity in resonance and, thus, populating the loss cone after microwave turn-off ("removal of ECR plug")
- The higher the charge state, the stronger the afterglow peak
- Afterglow peak is followed by diffusive plasma decay (several hundreds of ms for the lowest charge states)



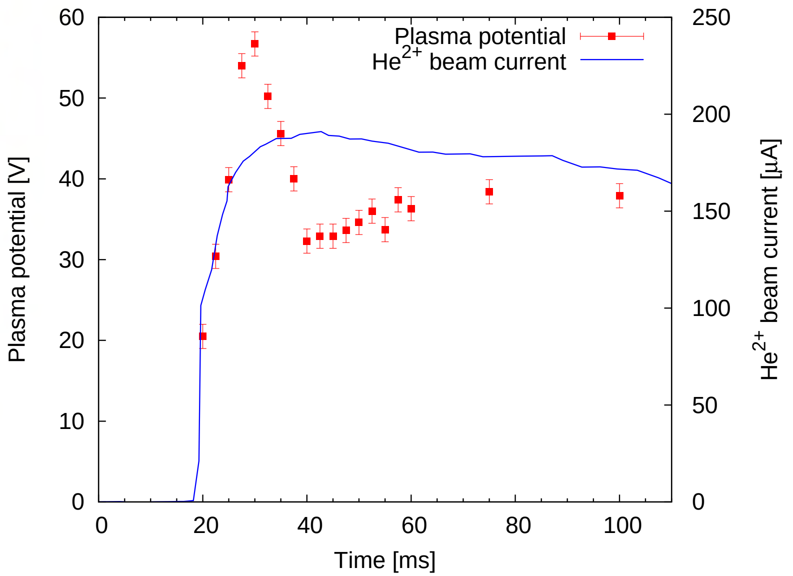


Experiments

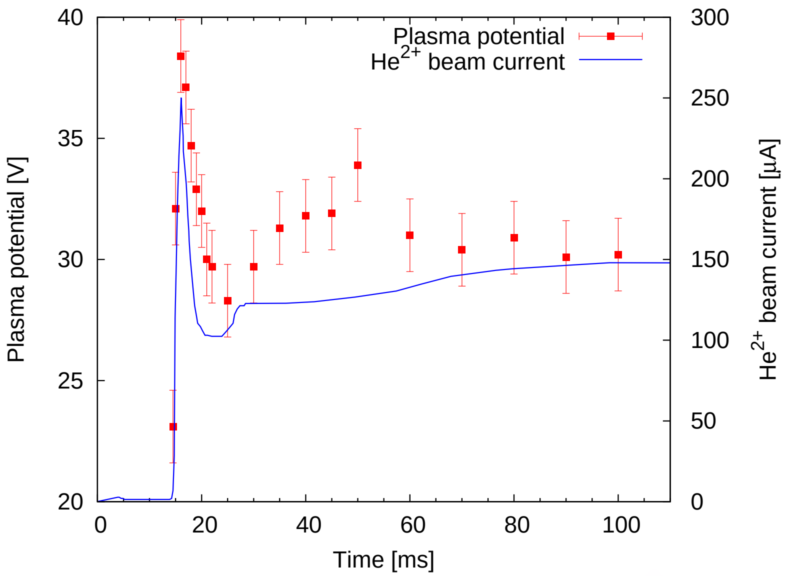
- Three ion sources were used for the experiments
  – JYFL 6.4 GHz ECRIS
  – JYFL 14 GHz ECRIS
  – Room temperature 18 GHz ECRIS at RIKEN
- Helium and Argon plasmas
- The focus of the experiments was to compare plasma potential during preglow and afterglow to steady-state value
  → More experiments required for a full-scale parametric study

Experimental results – preglow plasma potential of JYFL ion sources

JYFL 6.4 GHz ECRIS (He^{2+})



JYFL 14 GHz ECRIS (He^{2+})



Plasma potential peaks during the preglow!

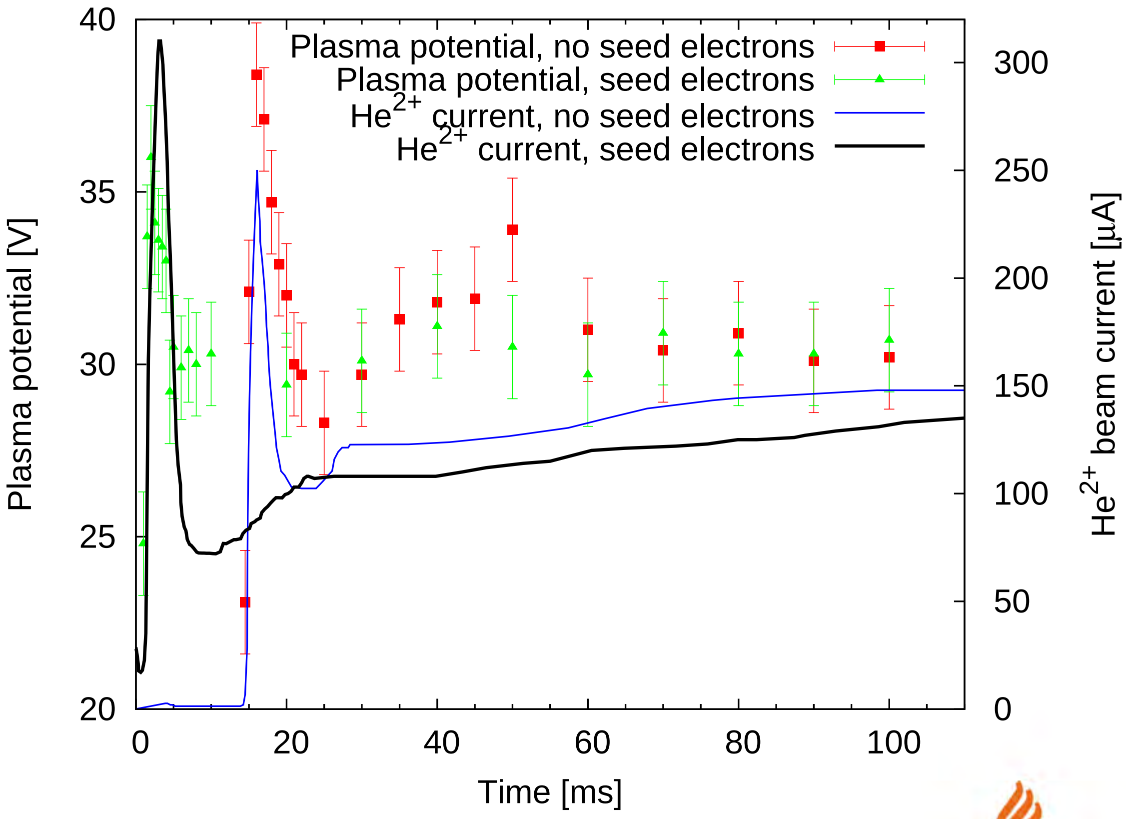
With 6.4 GHz the preglow is virtually non-existent for He^{2+}

Experimental results – effect of seed electrons on the preglow plasma potential

JYFL 14 GHz ECRIS

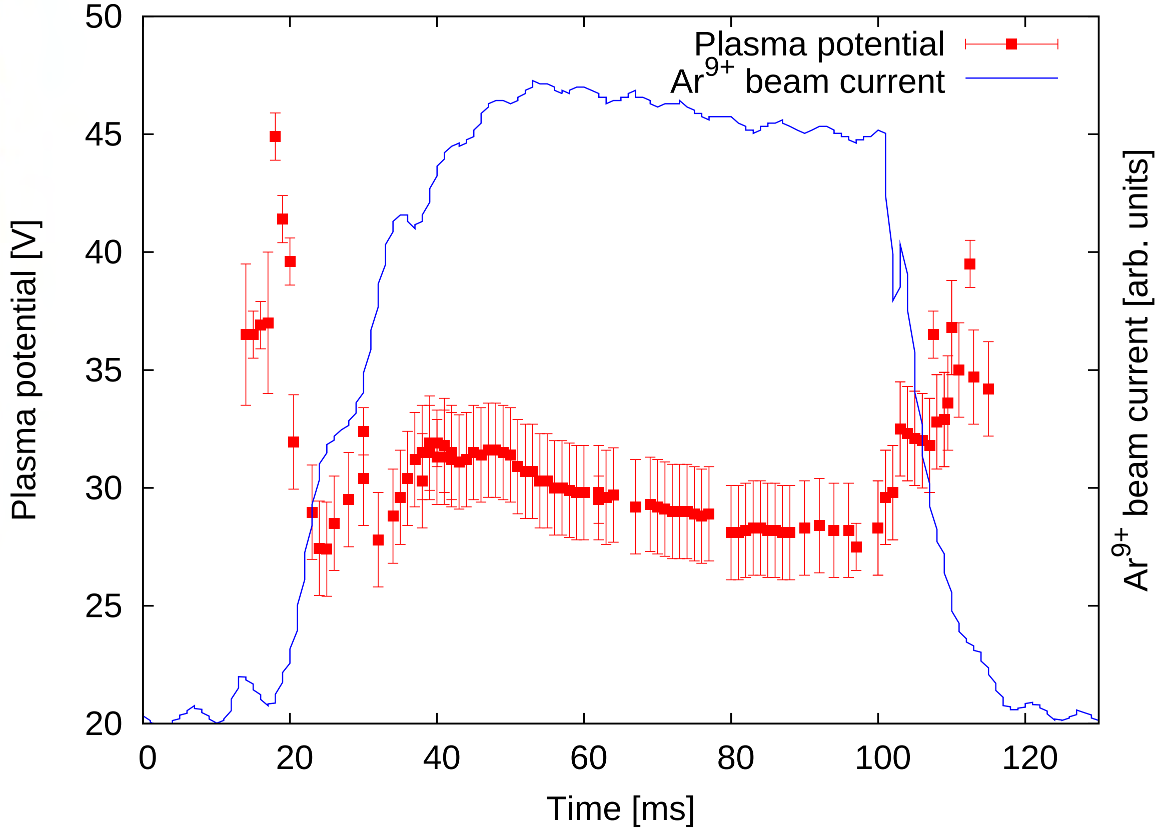
Seed electrons provided by sustaining a low density plasma with TWT amplifier

(5 W of continuous microwave power at 11.53 GHz between the main pulses at 14 GHz)



Faster plasma breakdown and enhanced preglow current but plasma potential is unaffected!

Experimental results – preglow and afterglow plasma potential of 18 GHz ECRIS at RIKEN



Plasma potential peaks during the preglow and afterglow (plasma decay).

Similar behavior was observed with the JYFL ion sources

Comparison of preglow and afteglow plasma potentials with the steady state value

Ion Source	Preglow / cw plasma potential	Afterglow / cw plasma potential
JYFL 6.4 GHz	1.06 – 1.12	1.09 – 1.14
JYFL 14 GHz	1.13 – 1.47	1.17 – 1.28
RIKEN 18 GHz	1.13 – 1.66	1.04 – 1.34

Compared to steady-state (cw) plasma potential

Preglow plasma potential is 10 – 70 % higher

Afterglow plasma potential is 10 – 30 % higher

Difference between preglow and afterglow peaks of plasma potential seems to increase with frequency (average charge state in cw)

Discussion - preglow

- The preglow peak is caused by a burst of electrons (exponentially increasing density and drop of average energy)
- Due to lower mobility, the loss rate of ions cannot match the loss rate of electrons
- Plasma potential builds up and peaks to compensate the difference
- During the preglow the average charge state is lower, which suggests higher plasma potential
- The energy spread of the ion beams is higher and their space charge compensation degree is lower during the preglow

  → effect on beam optics (bending and focusing) as observed at JYFL

Discussion - afterglow

- Afterglow is initiated by increased losses of cold electrons (interruption of ECR heating)
- Loss rate of ions is lower
- Plasma potential builds up and peaks to compensate the difference
- It has been suggested that the spatial profile of the plasma potential is different for cw and afterglow (potential dip improving ion confinement in cw)
- These effects reduce the ion confinement time → afterglow peak
- A difference between preglow and afterglow is the charge state distribution, which could help explaining the difference between the magnitude of plasma potential peaks

Thank you for your attention!