Periodic beam current oscillations driven by electron cyclotron instabilities in ECRIS plasmas

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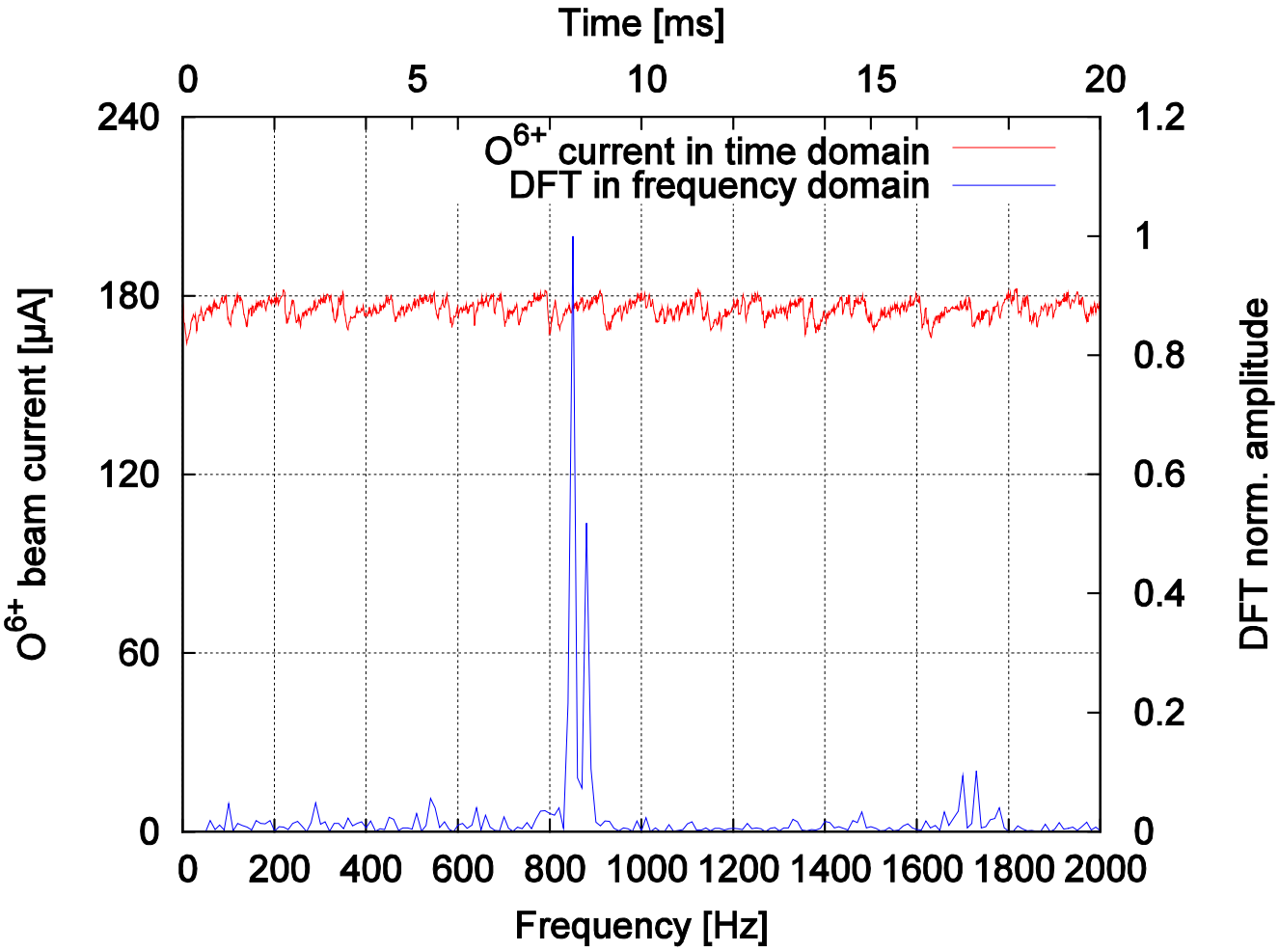
Content

- Stability of ECRIS beams
- Experimental setup
- Results and discussion

Stability of ECRIS beams

- Long-term variation of the beam current
  - Changing gas balance
  - Contamination
- Periodic oscillations in ~ kHz range
  - Driven by plasma mechanisms

Peridoc oscillations of the beam current



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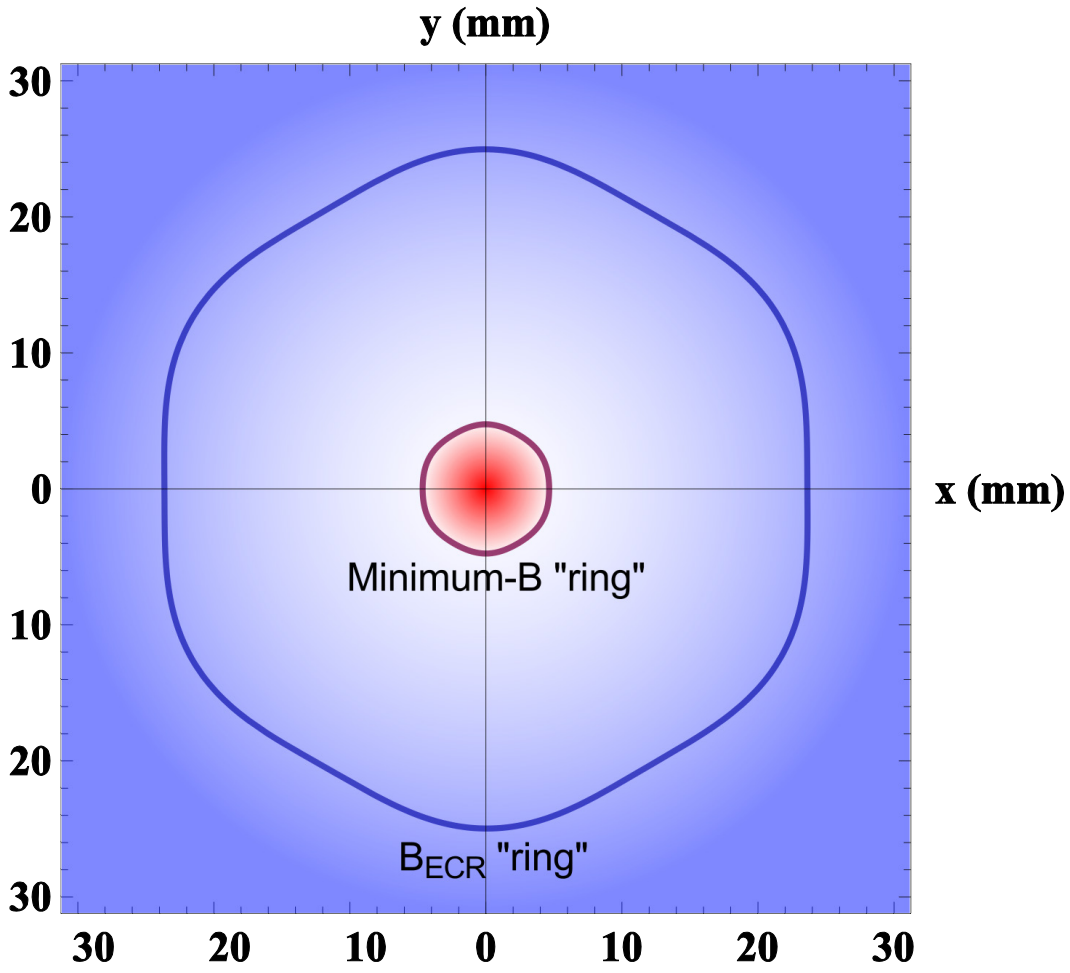
MHD- or kinetic instabilities?

Condition for suppressing MHD-instabilities: $\partial B/\partial r \geq 0$



JYFL 14 GHz ECRIS

$\partial B/\partial r < 0$

$\partial B/\partial r \geq 0$

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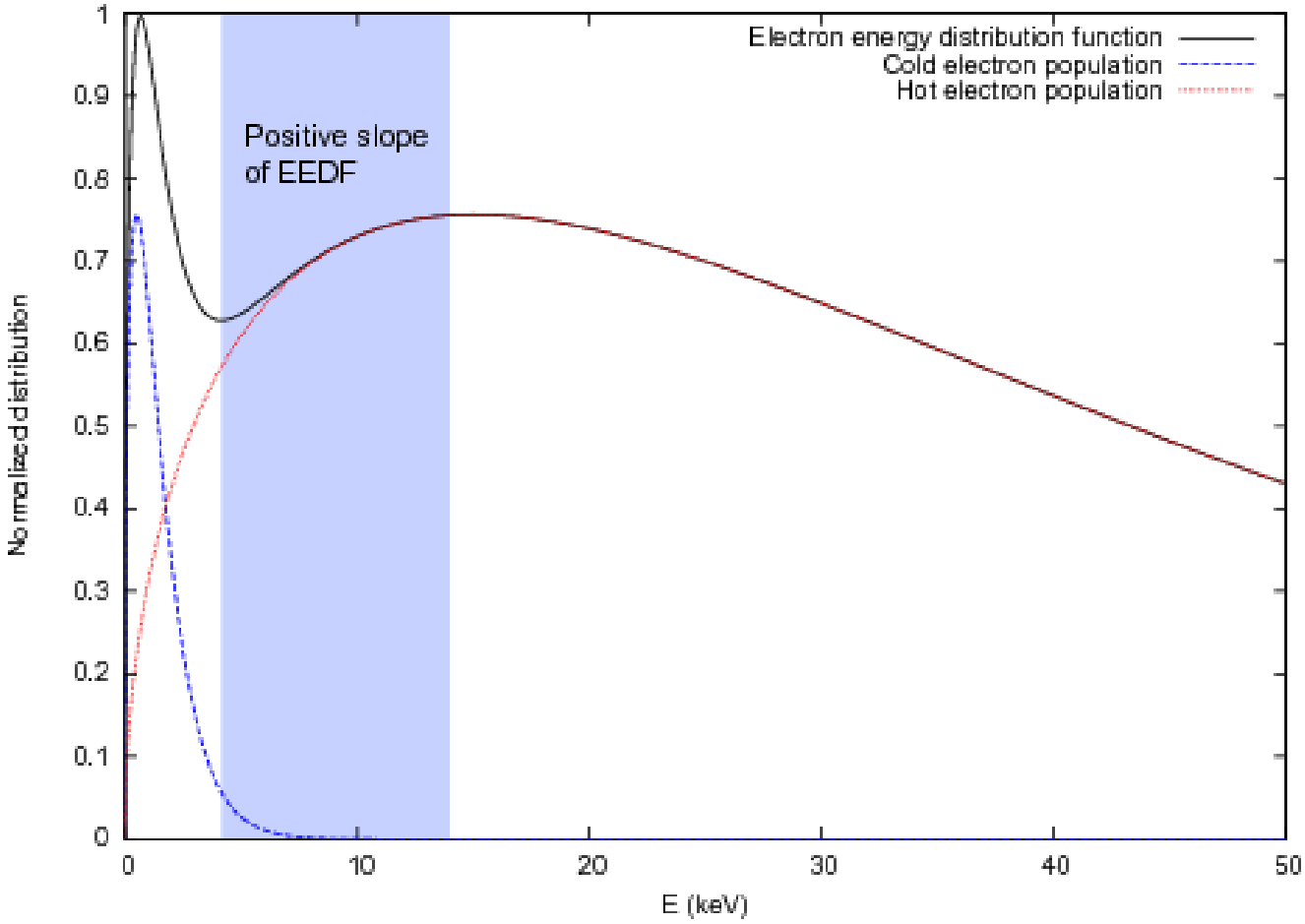
MHD- or kinetic instabilities?



Anisotropy of the EEDF generates kinetic instabilities

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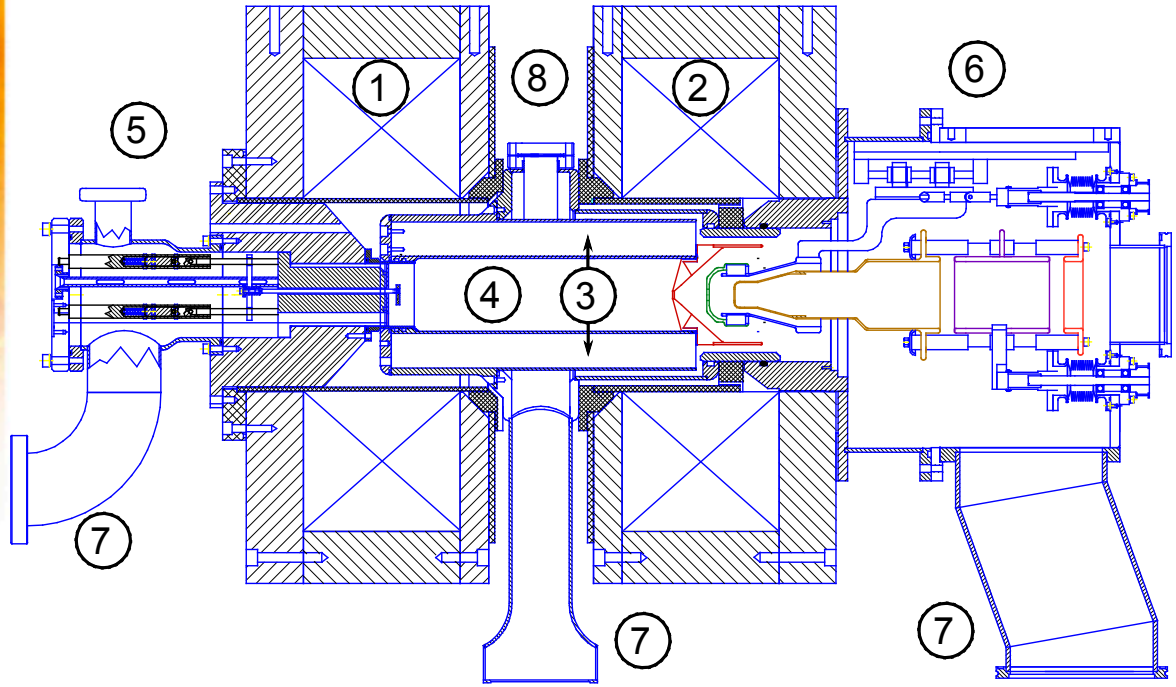
Experimental setup – JYFL 14 GHz ECRIS (A-ECR)



1. Injection coil
2. Extraction coil
3. PM hexapole
4. Plasma chamber
5. Waveguides
6. Extraction
7. Pumping
8. Radial viewport

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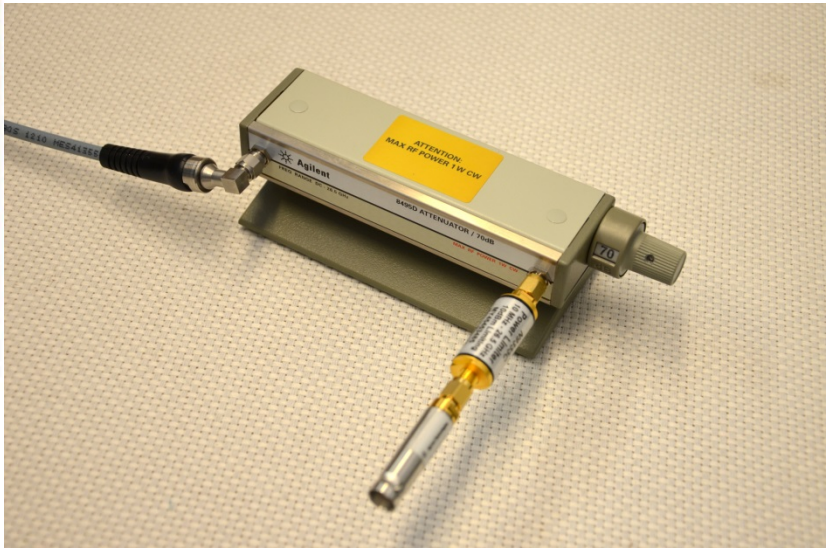
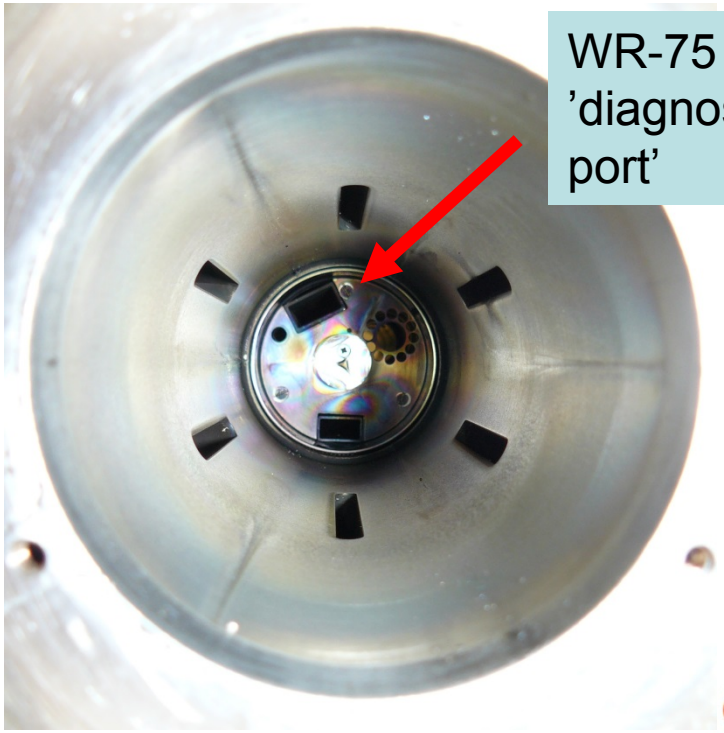
Experimental setup – diagnostics

10 MHz – 50 GHz microwave detector diode connected to WR-75 waveguide





WR-75 'diagnostics port'

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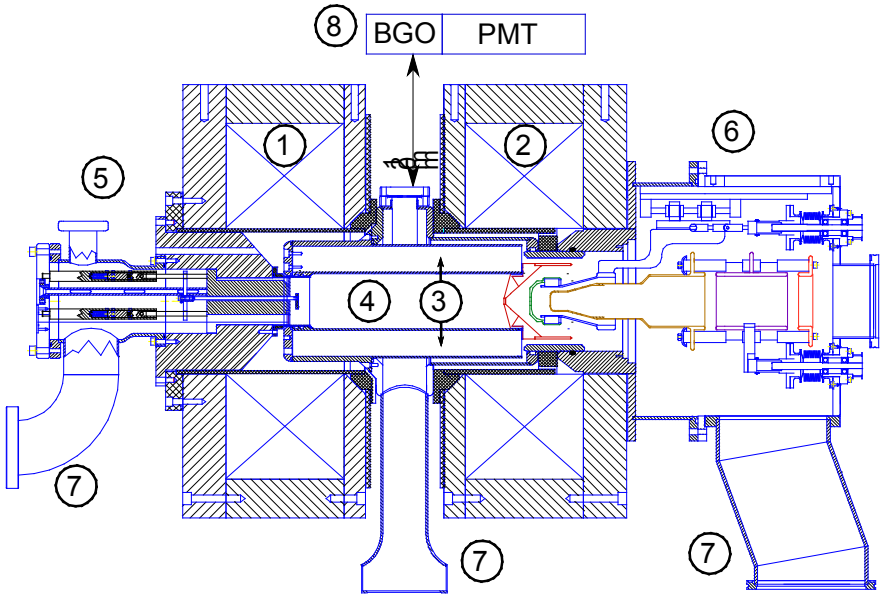
Experimental setup – diagnostics

Current-mode BGO scintillator + PMT measuring the bremstrahlung power flux



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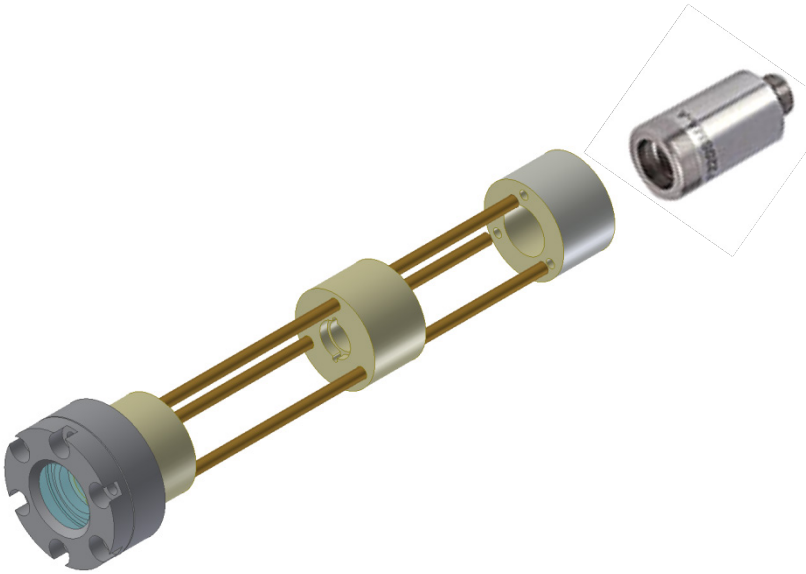
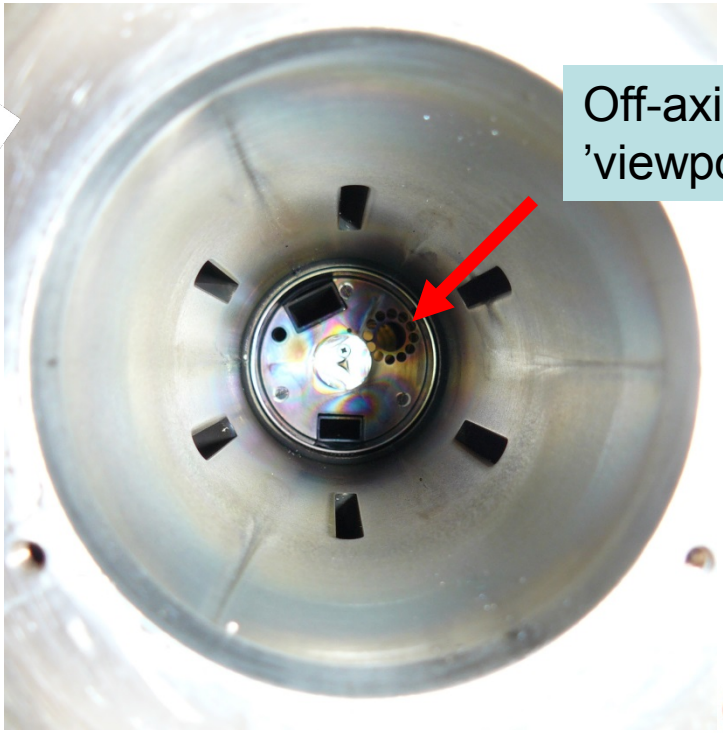
Experimental setup – diagnostics

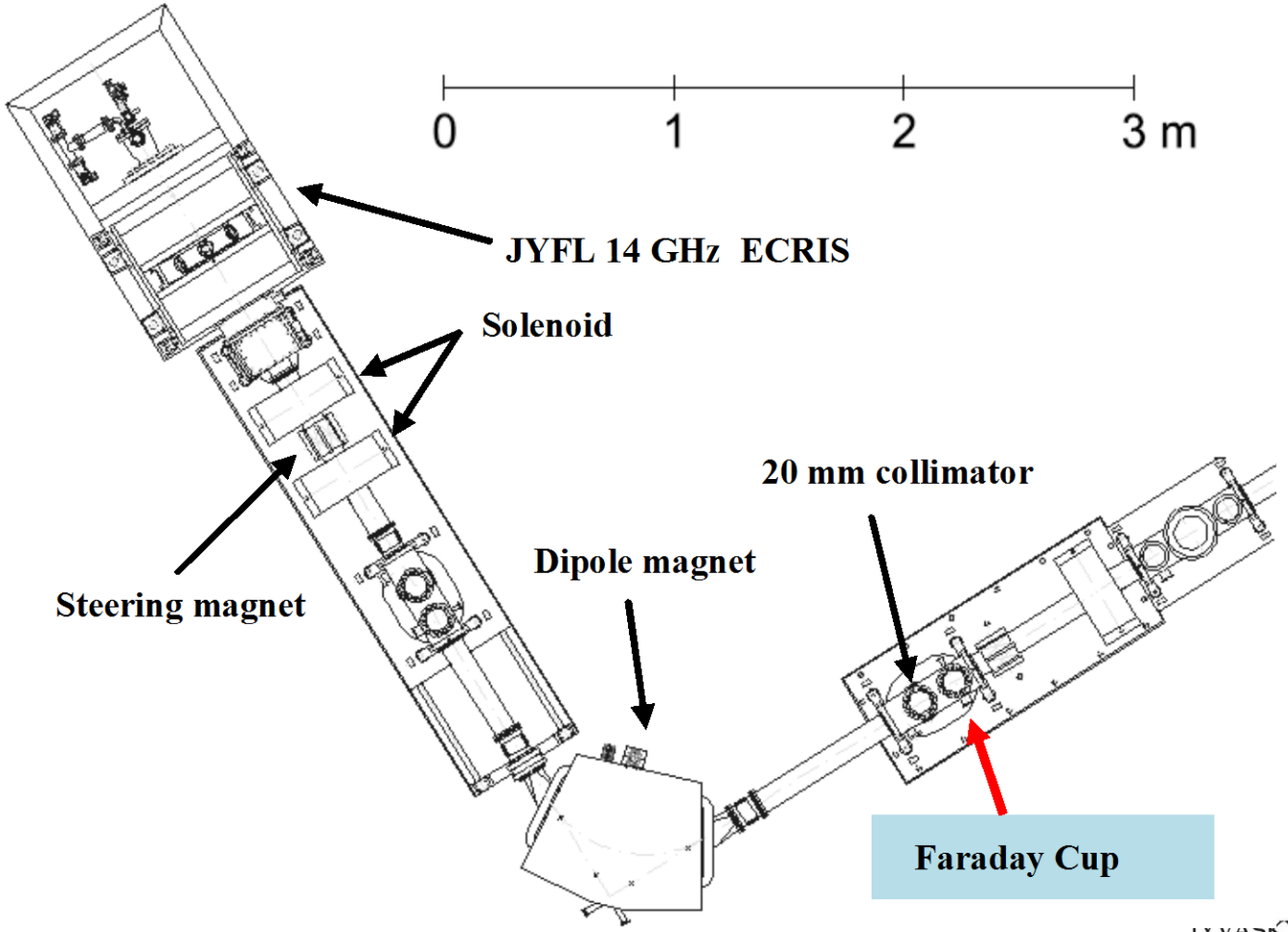
Visible light collector coupled with Na-doped CsI PMT (300-600 nm)





Experimental setup – diagnostics

Faraday cup ~ 5 m downstream in the beam line



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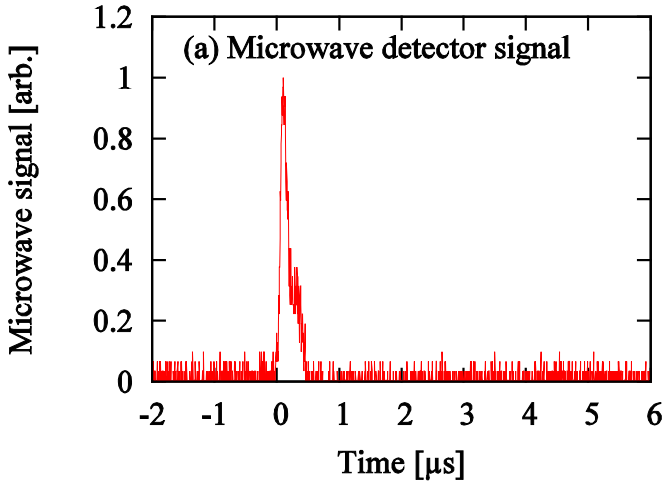
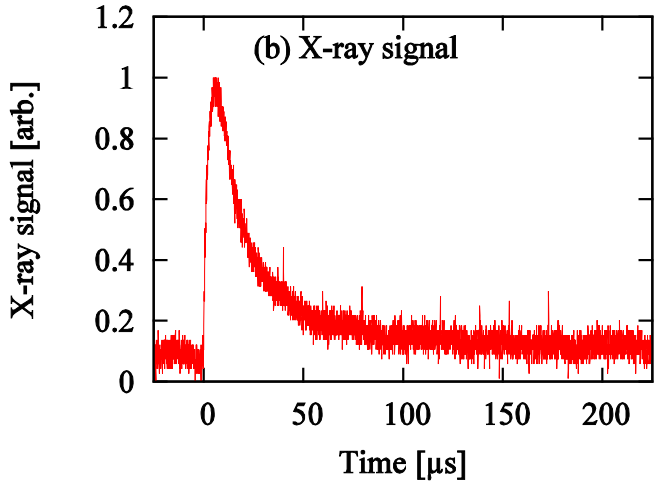
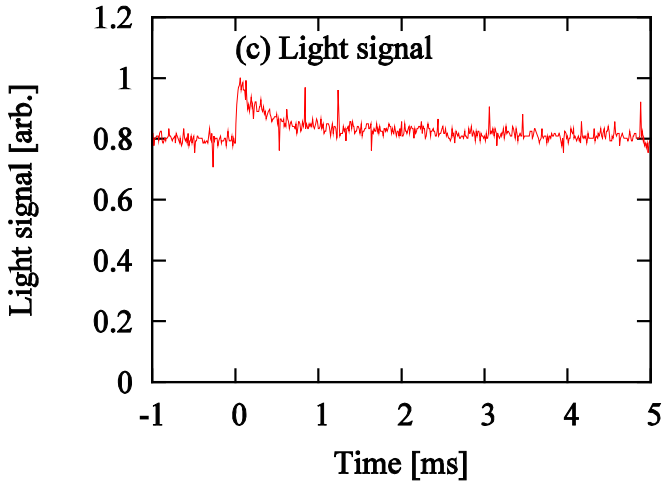
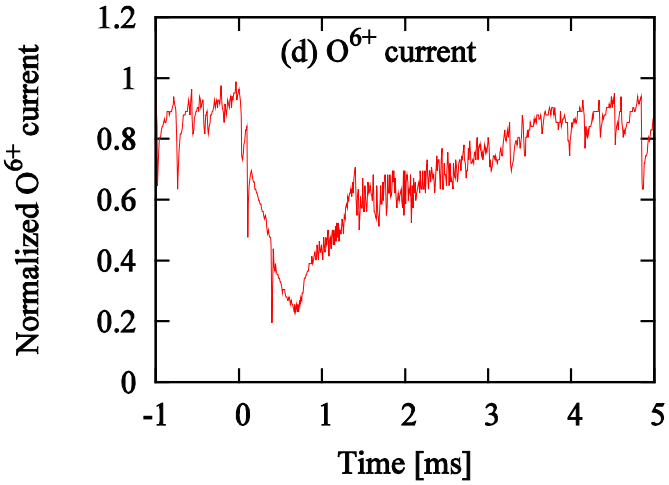
O. Tarvainen et al. Plasma Sources Science and Technology, 23, 025020, (2014).

(typical) Diagnostics signals









Electron cyclotron instabilities

The energy of the microwave emission, E_μ, is described by mode- dependent growth and damping rates, γ and δ

$$\frac{\mathrm{d}E_\mu}{\mathrm{d}t} \approx \langle \gamma - \delta \rangle E_\mu$$

Exponential growth of the instability amplitude when $\gamma > \delta$

Electron cyclotron instabilities – growth rate

The growth rates for Whistlers and X-mode are proportional to the hot electron (number) density

$$\gamma_{\mathrm{W}} \propto \omega_{\mathrm{ce}} \frac{N_{\mathrm{e,hot}}}{N_{\mathrm{e,cold}}} \left(\frac{\langle E_{\perp} \rangle}{\langle E_{\parallel} \rangle} - 1 \right) \mathrm{e}^{-\xi \frac{B^2}{\langle E_{\parallel} \rangle N_{\mathrm{e,cold}}}}$$

$$\gamma_{\mathrm{X}} \propto \omega_{\mathrm{ce}} \frac{N_{\mathrm{e,hot}}}{N_{\mathrm{e,cold}}} \left(\frac{\langle E_{\parallel} \rangle^2}{\langle E_{\perp} \rangle m_{\mathrm{e}} c^2} \right),$$

Electron cyclotron instabilities – damping rate

The damping rates for Whistlers and X-mode are proportional to the electron collision frequency ν_e as

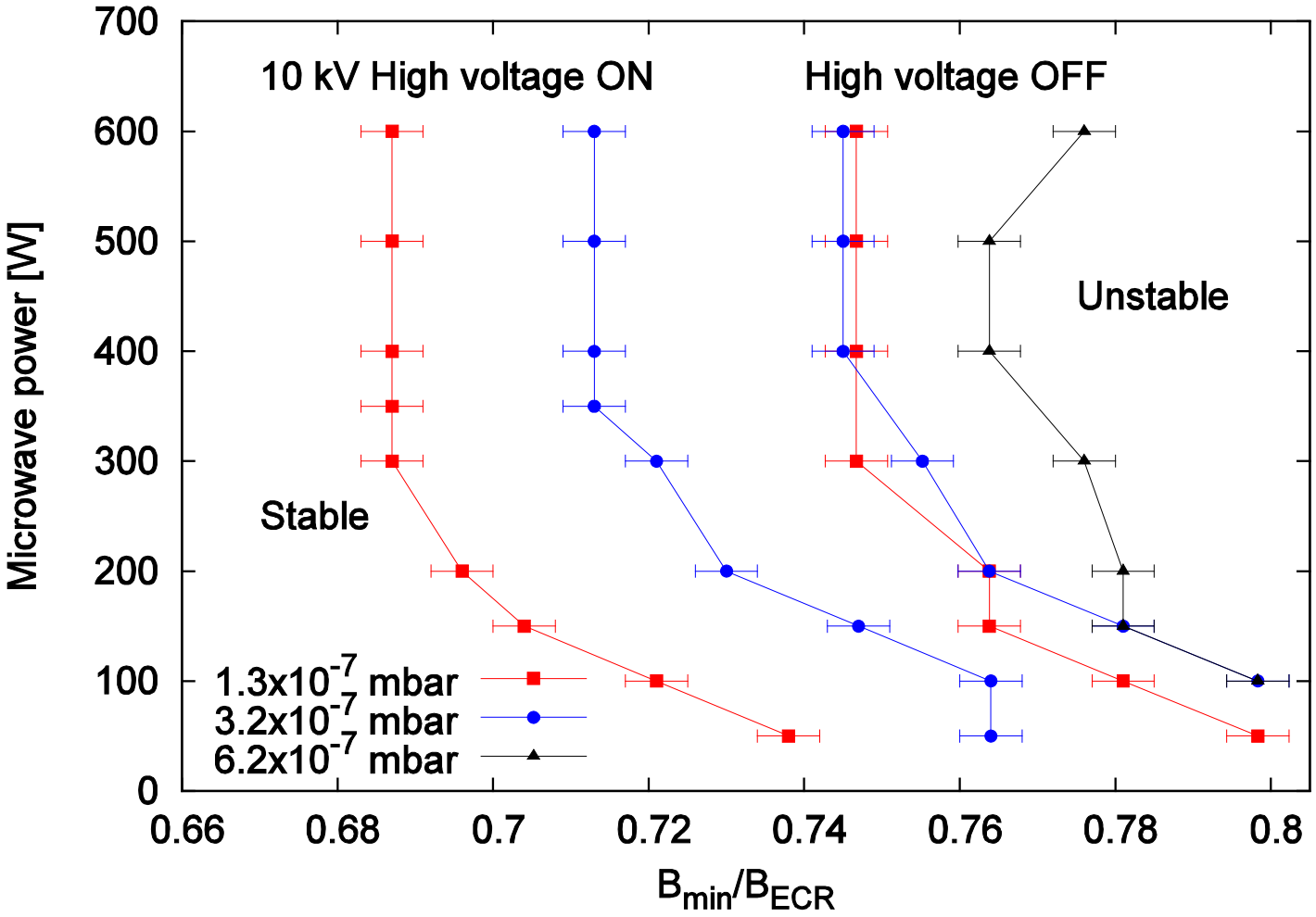
$$\delta_W \approx \frac{\omega}{\omega_{ce}}\nu_e + \frac{v_g\,|\ln R|}{L}$$

$$\delta_X \approx \nu_e + \frac{v_g\,|\ln R|}{L},$$

Electron cyclotron instabilities

- ECRIS parameters affecting the growth and damping rates
  - B-field affects the electron heating rate (resonance gradient) and confinement
  - Power affects the electron heating rate
  - Neutral gas pressure affects the collision frequency
  - Plasma species affects the energy loss in inelastic collisions

Results – threshold B-field



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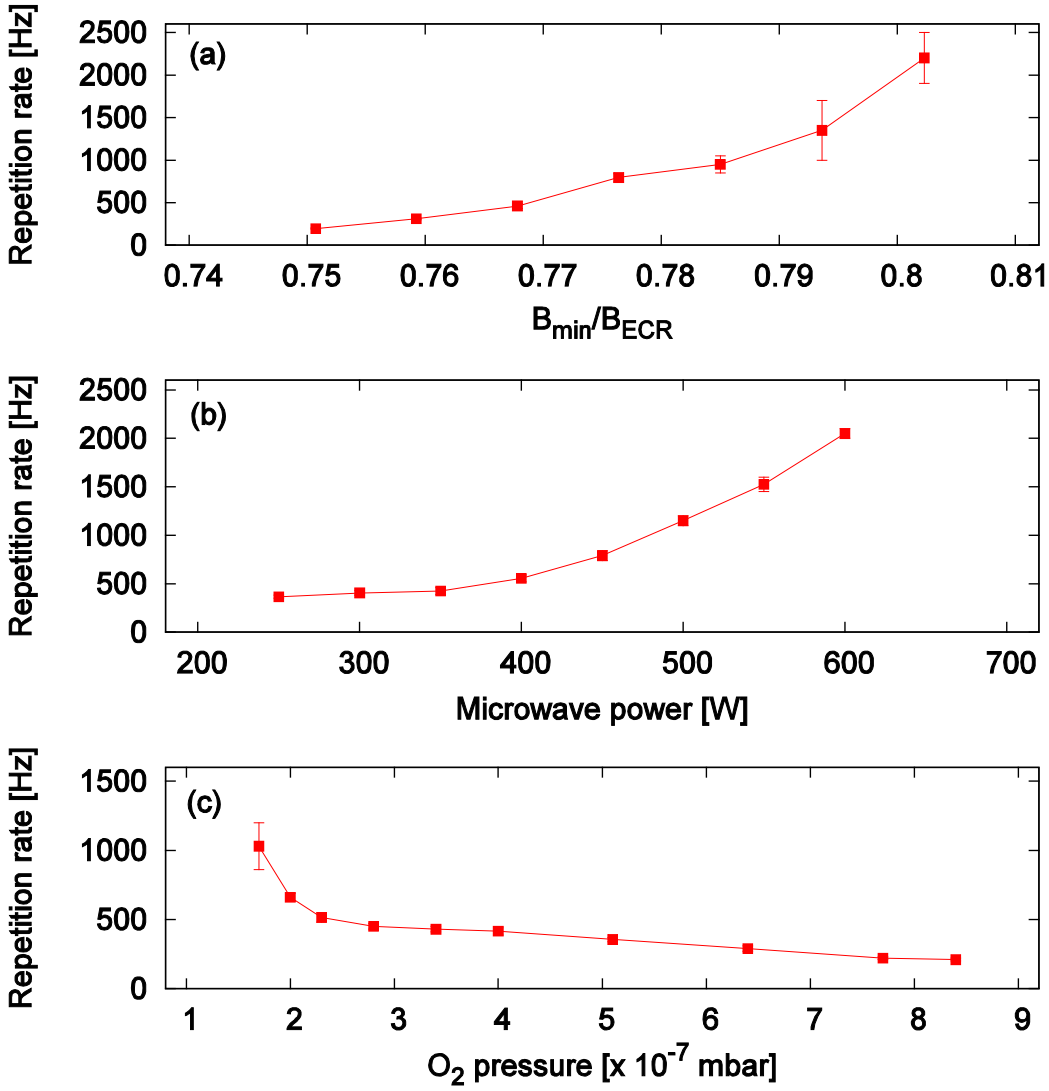
Results – repetition rate



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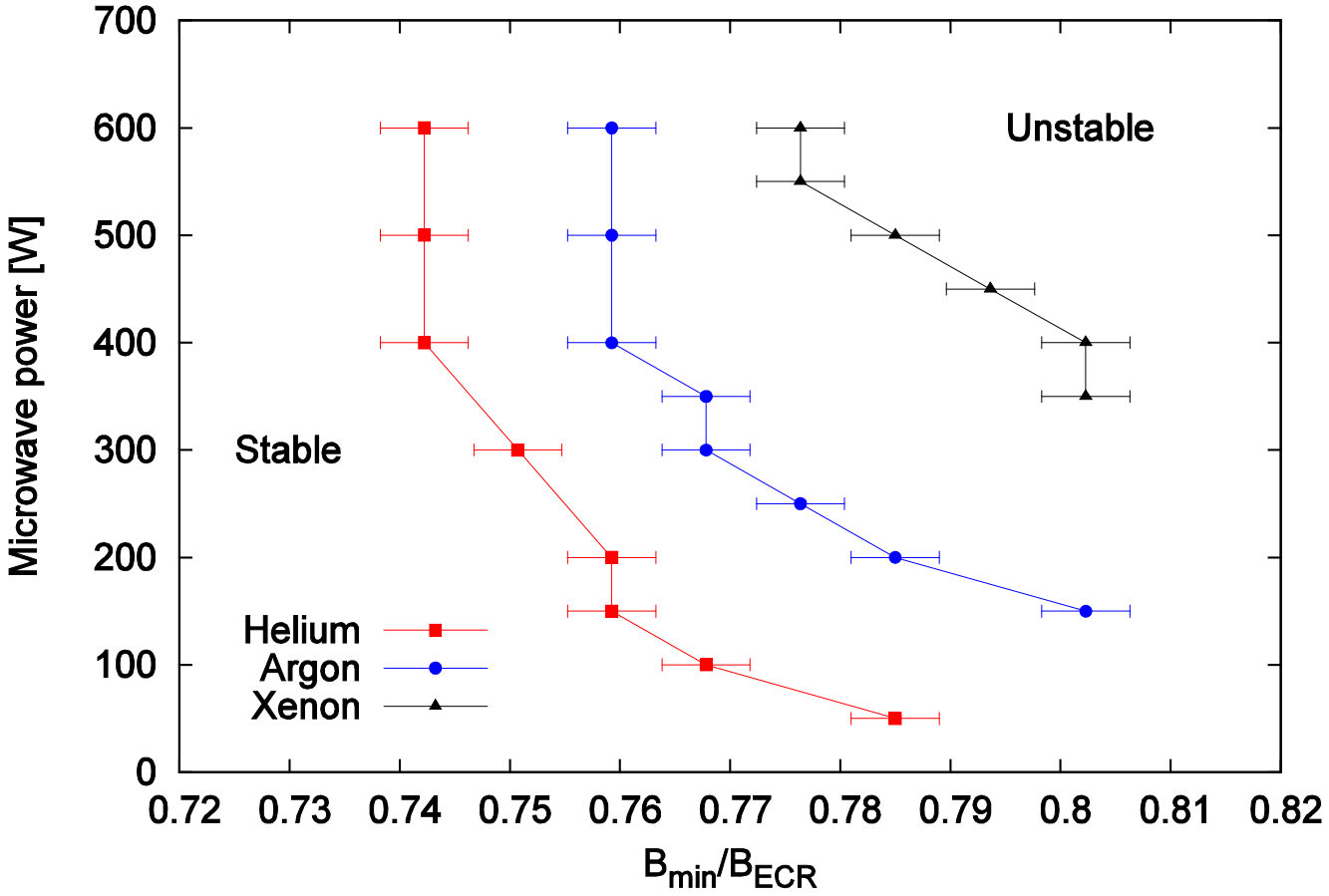
Results – plasma species



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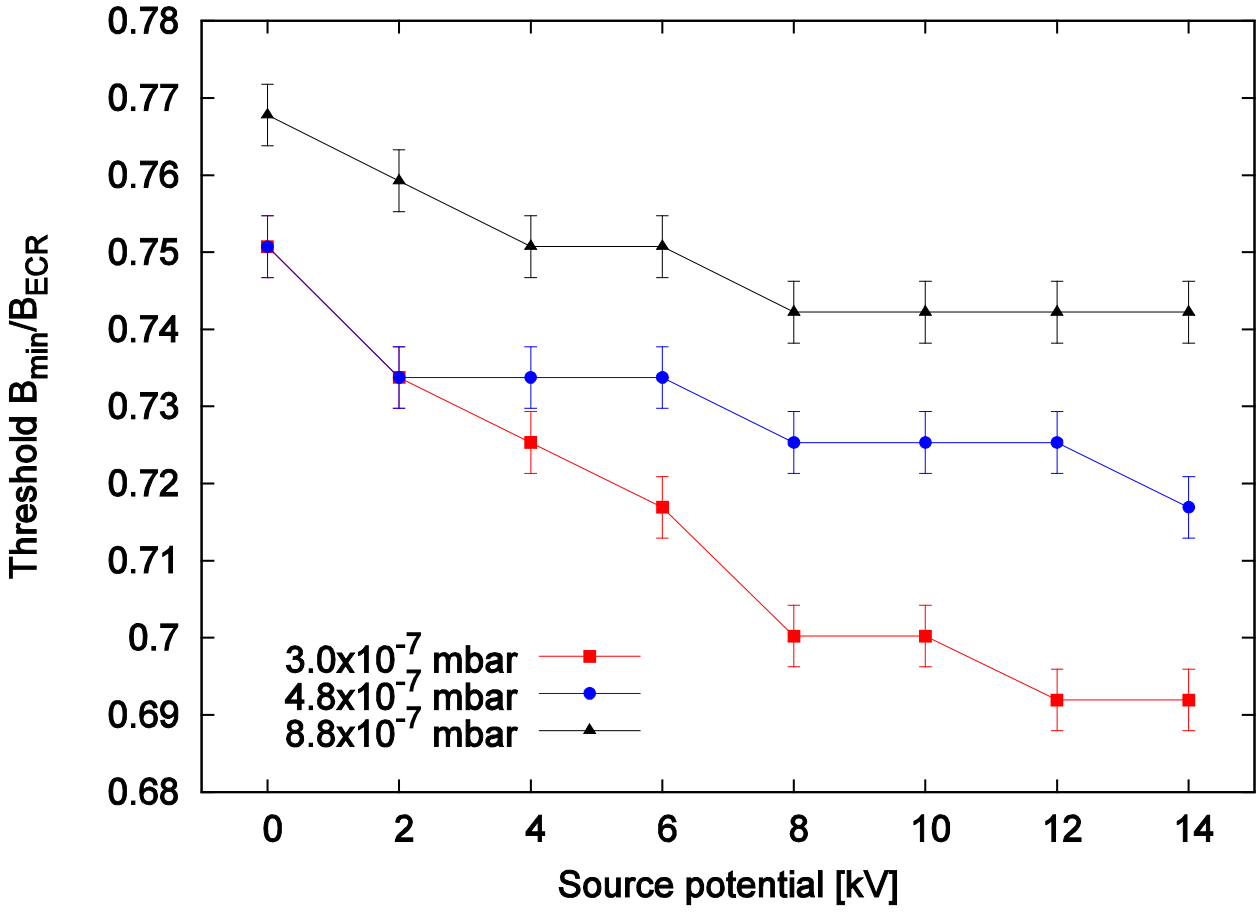
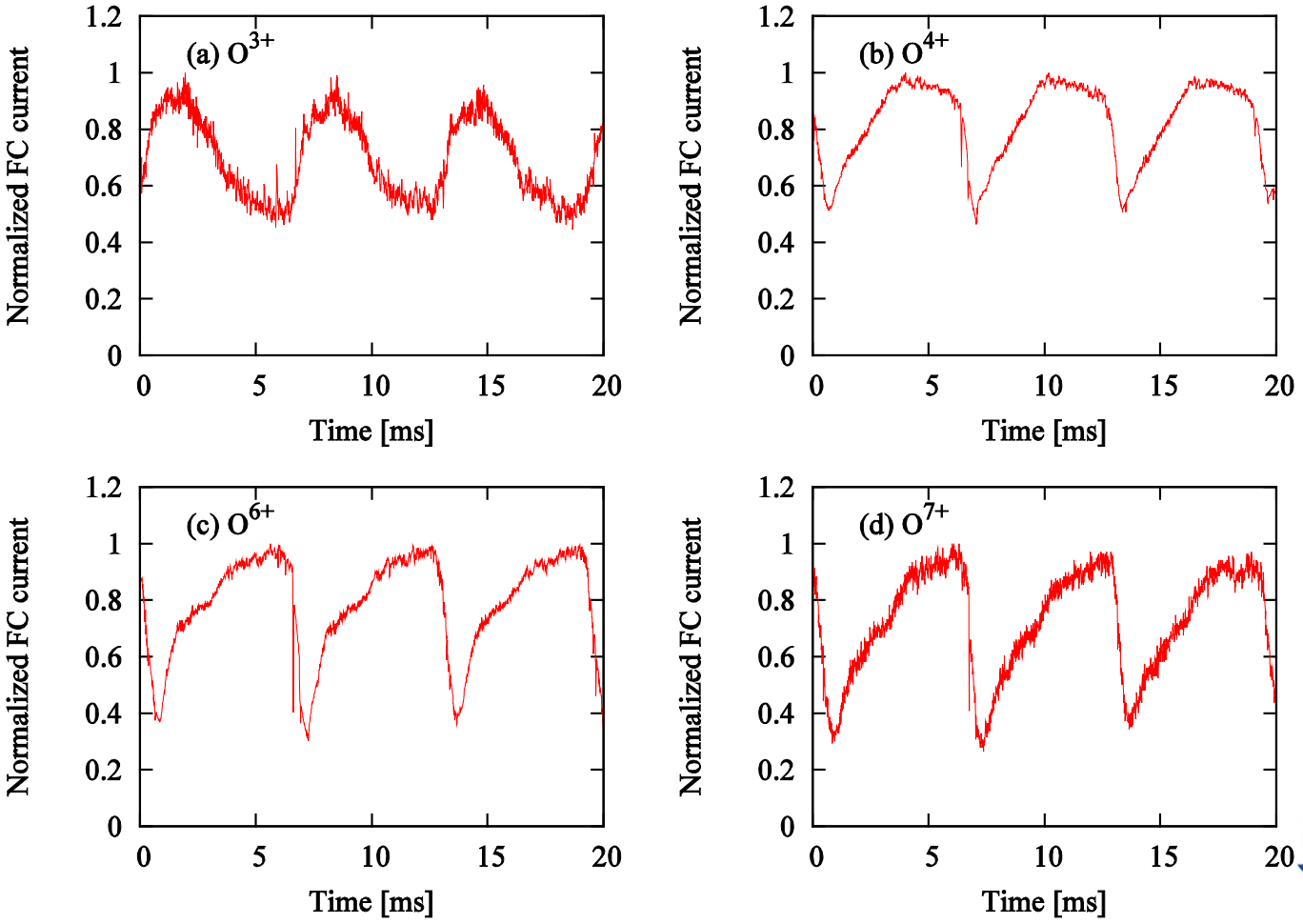
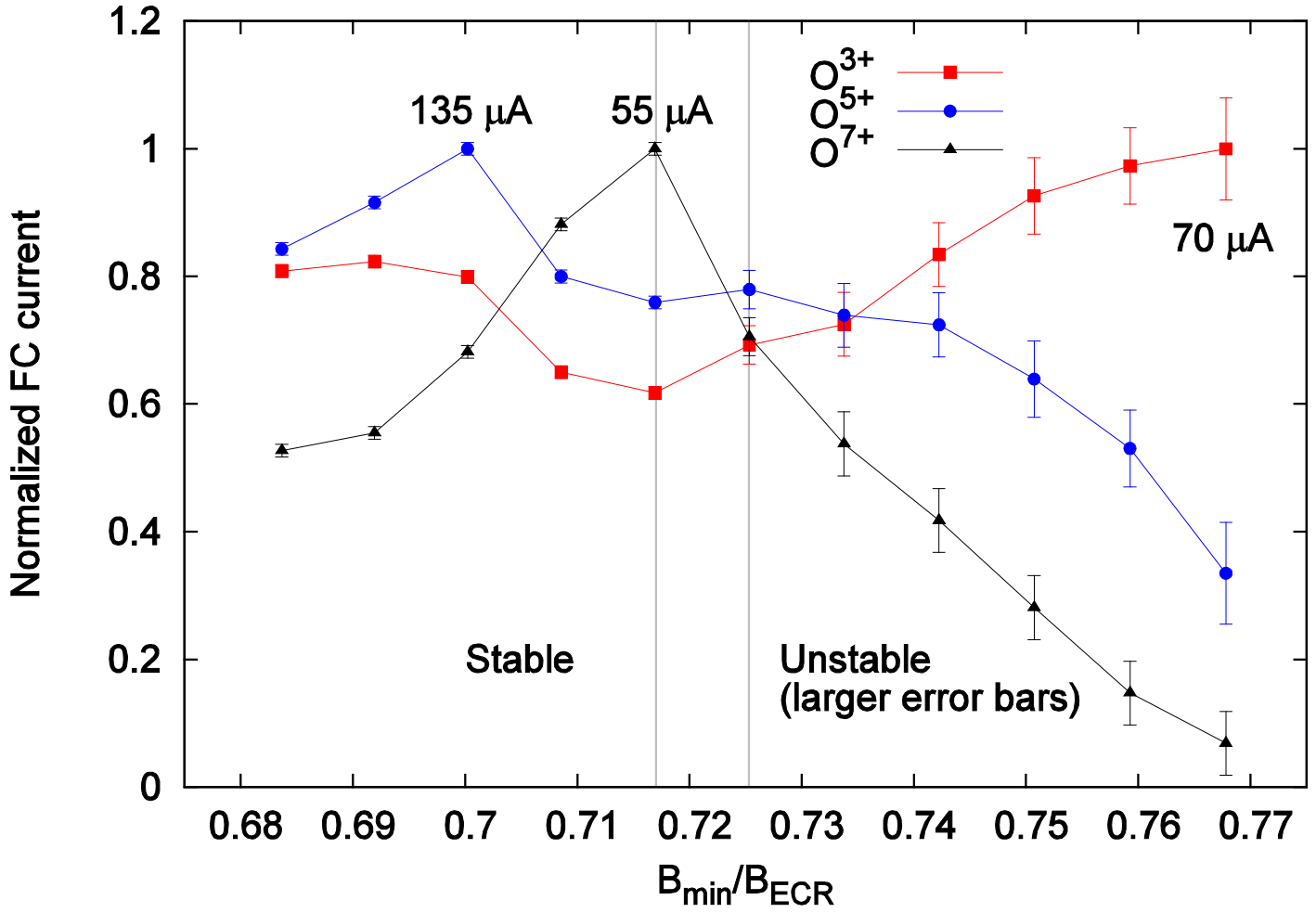
Results – source potential



Results – beam current oscillations



Instabilities limiting the source perfomance



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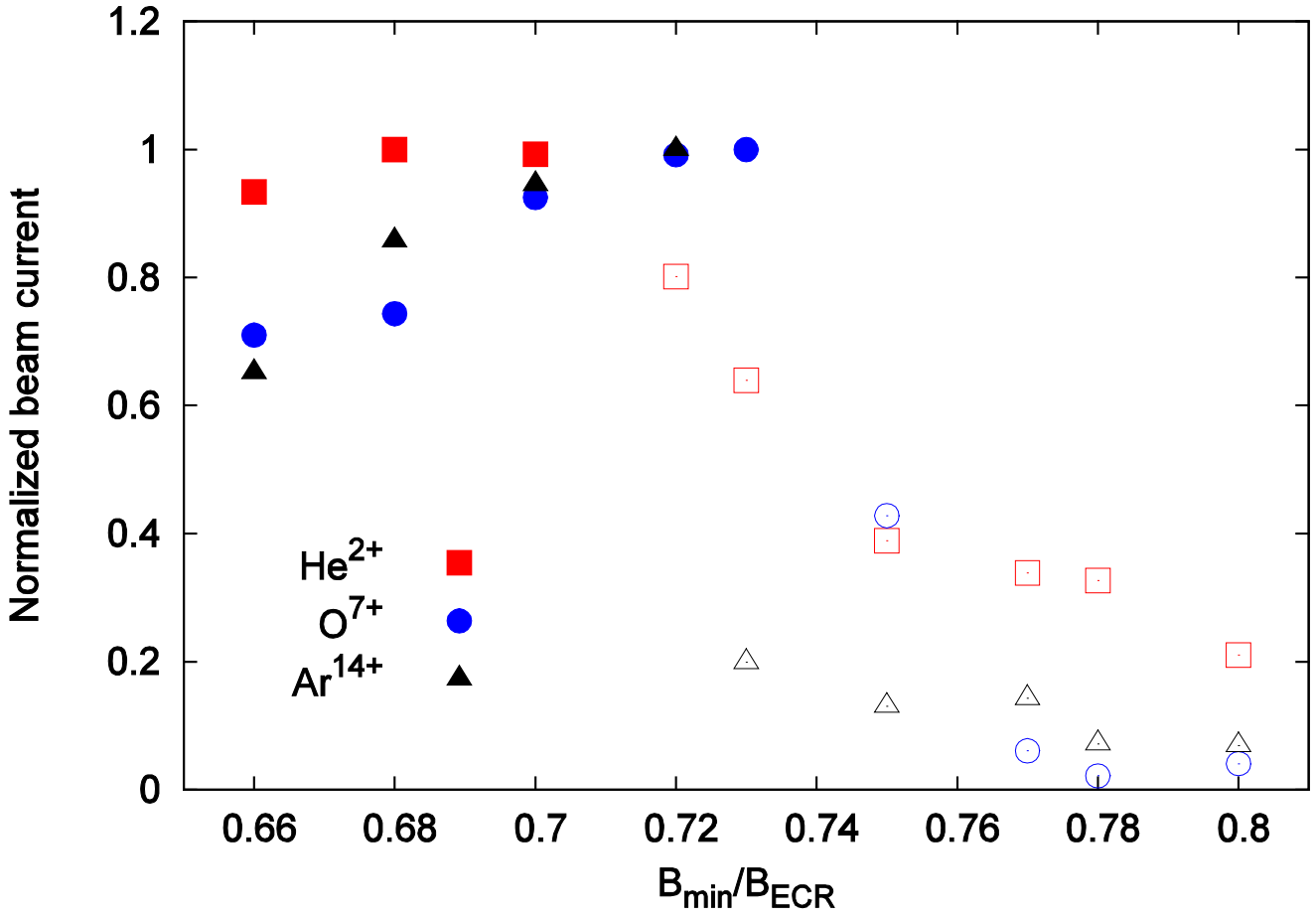

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Future plans

- A comprehensive study of cyclotron instabilities vs. extracted beam currents of different charge states of various elements
- Measurement of the ion beam energy spread in unstable operation mode
- Analysis of the microwave frequencies emitted by the instabilities

Thank You!

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