Negative ion studies on the RF plasma device MAGPIE

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1. Introduction

We present results of a study of the **negative ion** population in a helicon plasma device, measuring **H^- densities of over 1 × 10^{18} m^{-3}**.

2. Motivation

Negative ion sources are required for **neutral beam injection** (NBI) systems for tokamaks (e.g. [1, 2]). Negative ions are produced, accelerated and neutralised to form high-energy neutral beams for heating and fuelling the plasma (Figure 1).

- Neutralisation process is more efficient for negative ions than for positive ions
- **However**, formation of negative ions currently needs a caesium catalyst

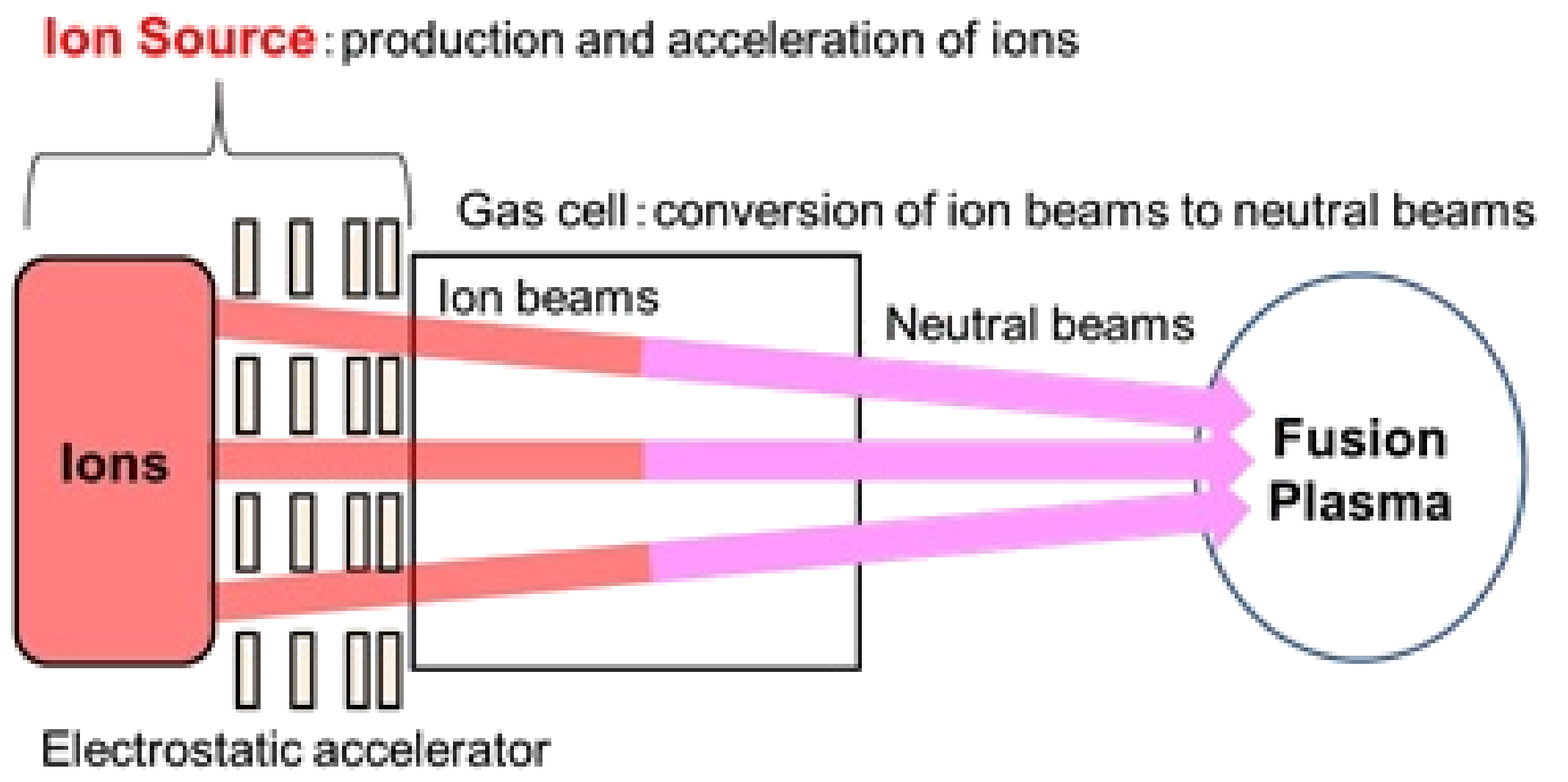

Figure 1: Schematic diagram of a neutral beam injection system. *From https://www.jaea.go.jp/english/news/press/p2015073101/*

Helicon sources have been proposed as an **alternative** method of negative ion production:

- Helicon wave coupling is very **efficient** [3]
- High plasma densities may **remove the need** for the caesium catalyst
- Target for negative ion density **~10^{17} m^{-3}** [4]

Aim: study negative ion populations in hydrogen plasma in the **Magnetised Plasma Interaction Experiment** (MAGPIE)

3. Experimental equipment

MAGPIE is a **linear** machine with a helicon plasma source (shown in Figure 2) [5].

- Separate source and target magnetic field coils produce a **tailored mirror field profile**
- **20 kW** of pulsed power at 13.56 MHz

Diagnostic techniques:

- Langmuir probe: *plasma temperature and density*
- Laser photodetachment [6]: *negative ion density*
- B-dot probe: *magnetic field strength*

Pulse parameter	Value
Pulse duration	40 ms
Gas pressure	10 mTorr
Source field current	50 A (~10 mT)
Mirror field current	800 A (~170 mT peak)

4. Results

The electron temperature (T_e) and density (n_e) profiles throughout a pulse are shown in Figures 3 and 4. The negative ion density (n_{H^-}) evolution is shown in Fig. 5.

Figure 6 shows the time evolution of each parameter for an axial position of 500 mm.

- Obtained **n_{H^-} > 1 × 10^{18} m^{-3}**
- Profiles **evolve** throughout the pulse, resulting in a transient peak in n_{H^-} (lasting a few ms)
- n_{H^-} peak corresponds to the region of **low temperature**
- Peak position is around the peak magnetic field (~500 mm)
- As the electron heating region propagates forward, n_{H^-} decreases in front of it

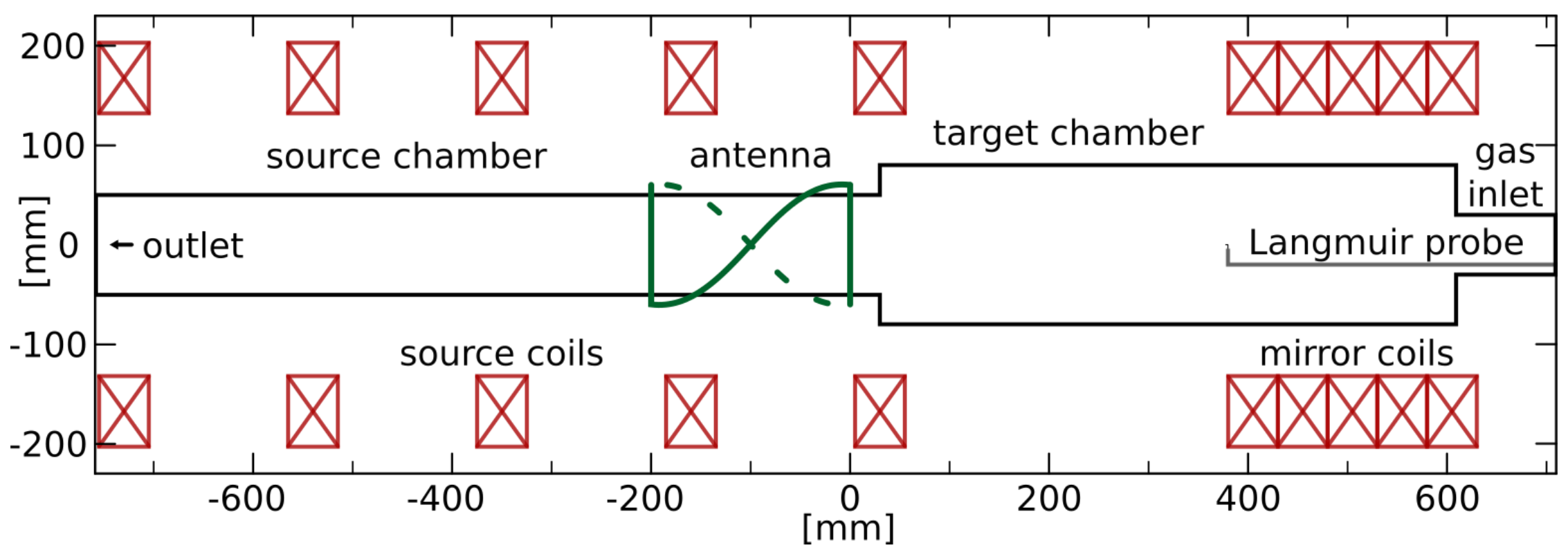

Figure 2: Schematic diagram of MAGPIE.

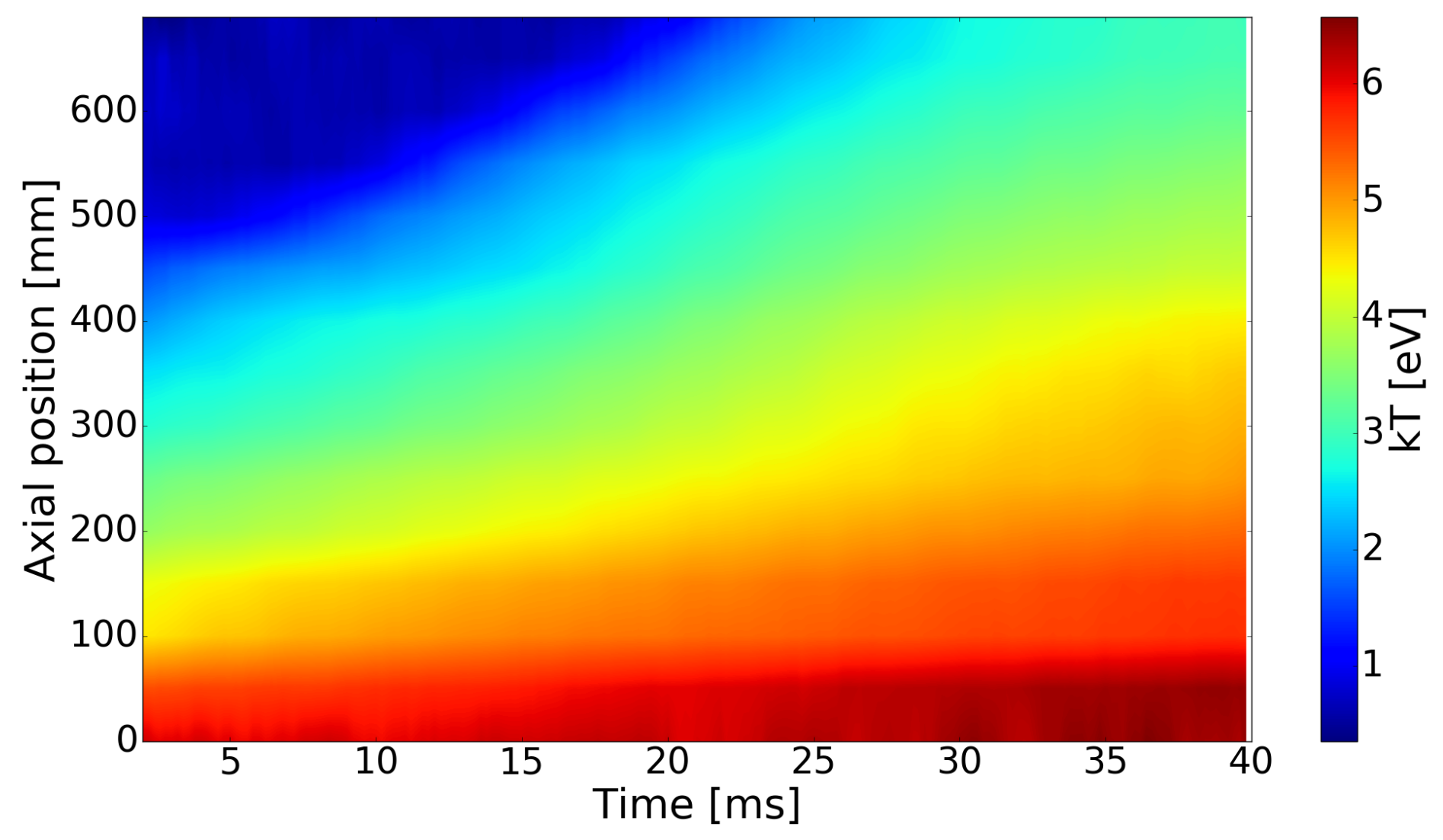

Figure 3: Evolution of the axial **electron temperature** profile during a 40 ms pulse.

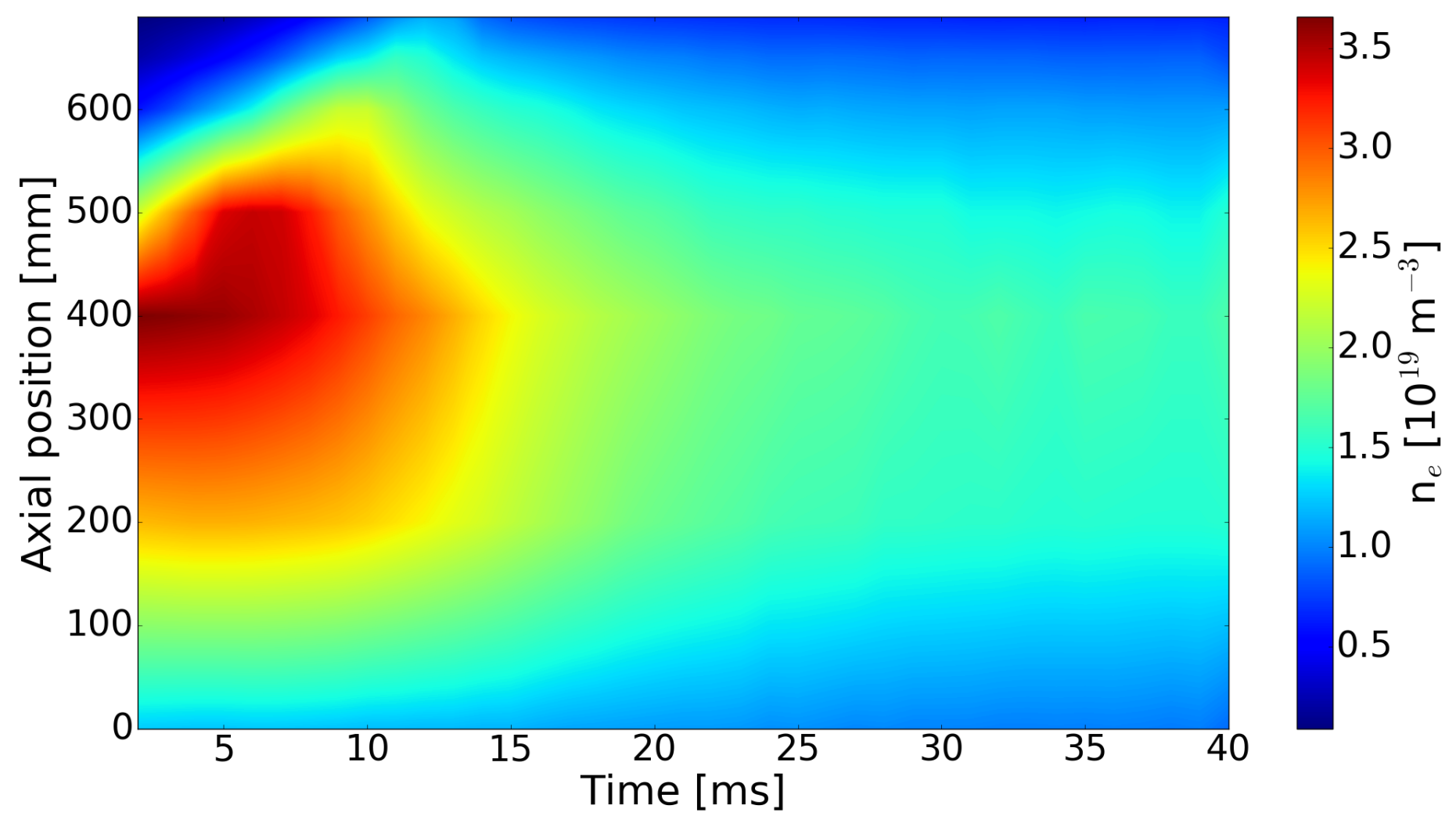

Figure 4: Evolution of the axial **electron density** profile during a 40 ms pulse.

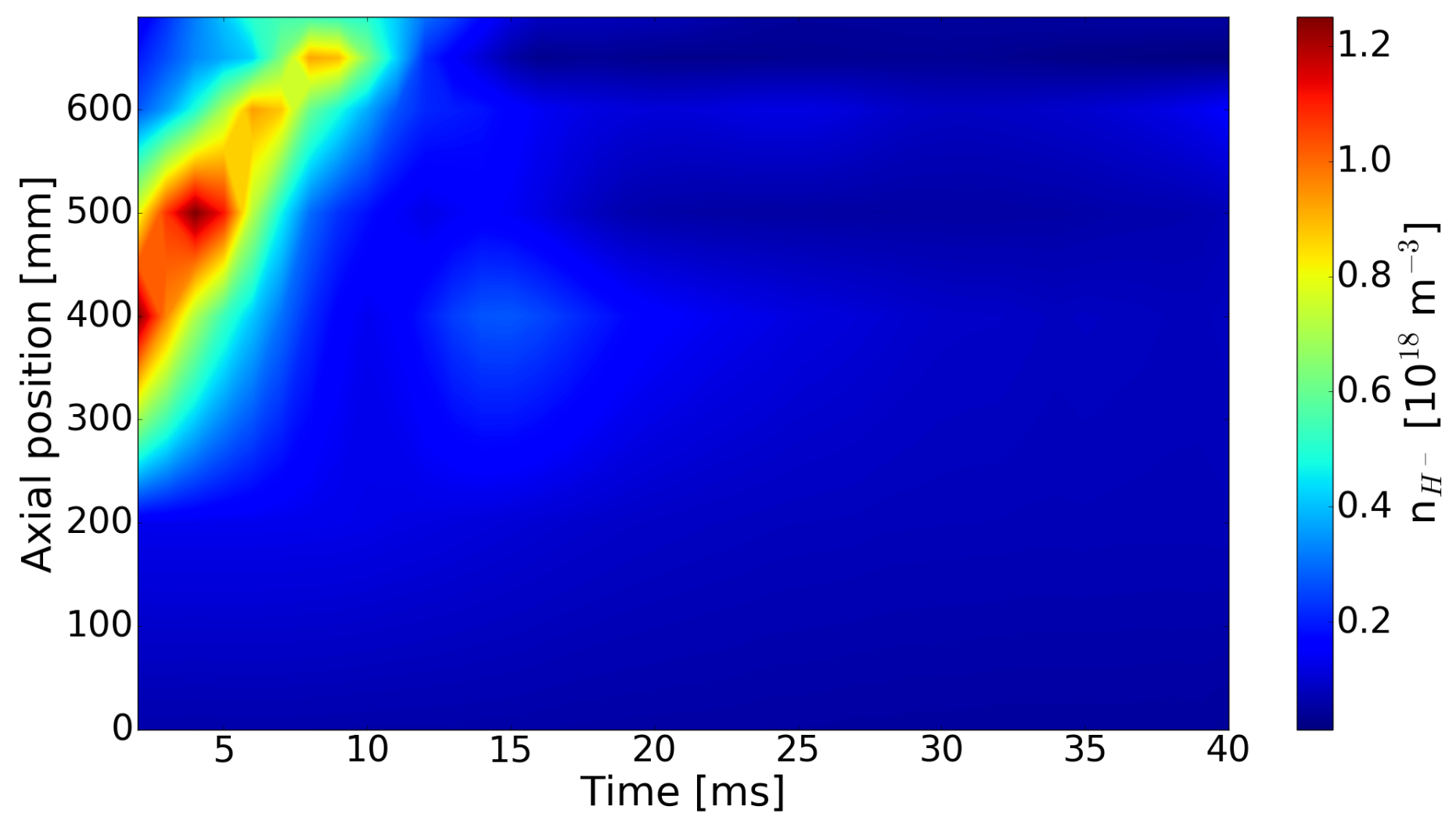

Figure 5: Evolution of the axial **negative ion density** profile during a 40 ms pulse.

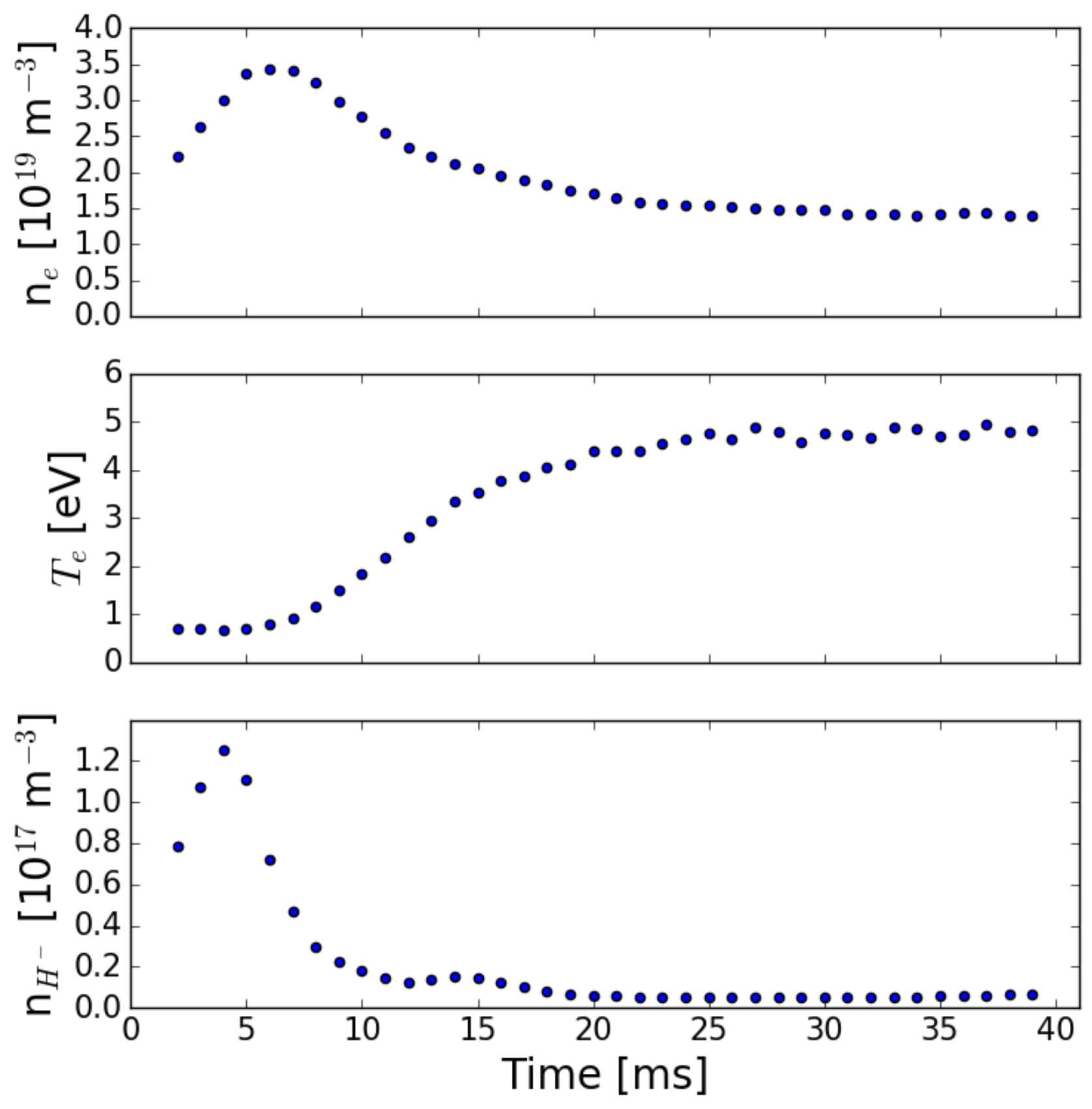

Figure 6: Electron density (n_e), temperature (T_e) and negative ion density (n_{H^-}) throughout a 40 ms pulse. Axial position: 500 mm.

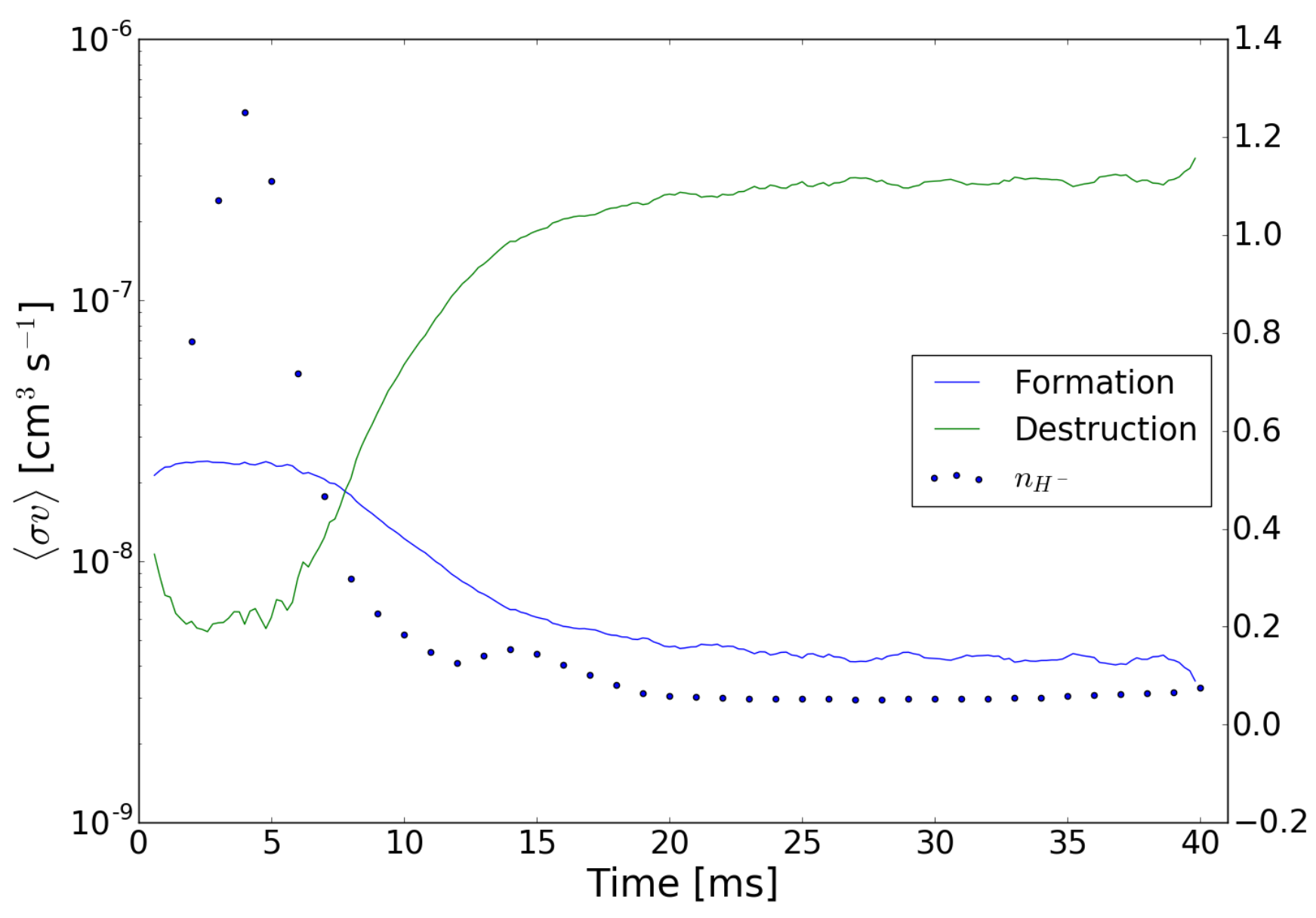

Figure 7: Calculated reaction rate coefficients (solid lines) for negative ion formation and destruction throughout a 40ms pulse, with negative ion density data overlaid. Axial position: 500 mm.

Results (cont.)

Rate coefficients for the formation and destruction of negative ions throughout the pulse are shown in Figure 7. Calculations used the measured T_e values, and rate coefficient expressions found in [7].

- Negative ion evolution appears to **correlate** with the expected evolution of the rate coefficients.

Frequency components of the floating potential (V_f) throughout the pulse were tracked (Figure 8).

- The evolution of the first and second harmonics of the Alfvèn frequency was estimated based on B and n_i measurements (overplotted in Fig. 8)
- Strongest peaks in the V_f spectrogram (after 10 ms) appear to show an **Alfvènic nature**
- The modes present may help to explain the evolution of the plasma

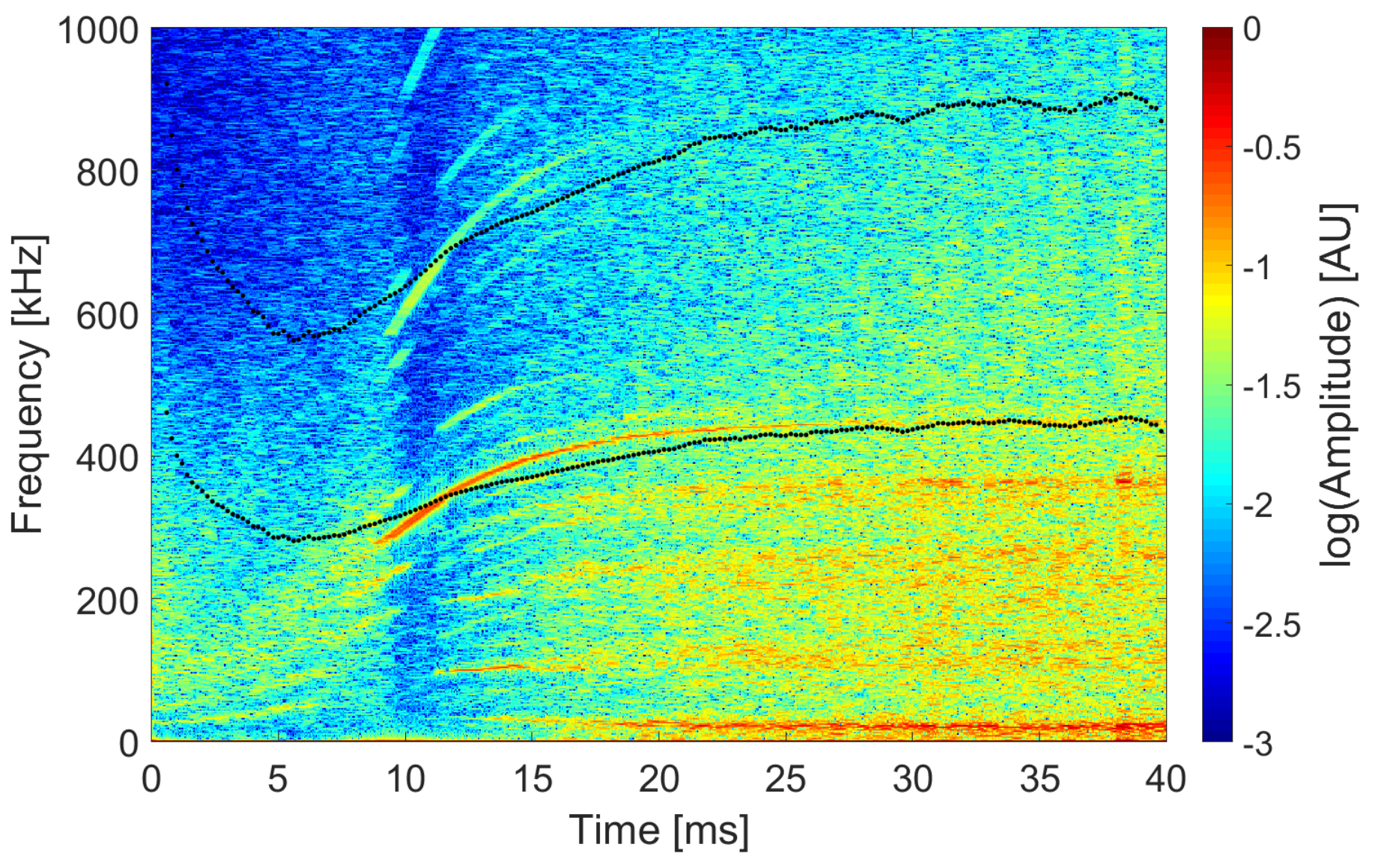

Figure 8: Spectrogram of the frequency components present in V_f through a 40 ms pulse. The estimated Alfvèn wave frequency evolution is overlaid in black. Axial position: 500 mm.

Figure 9 shows the radial magnetic wavefield from the helicon antenna. The amplitude is **low** in the region of high n_{H^-}.

- Plasma evolution **unlikely** to be directly related to helicon wave heating

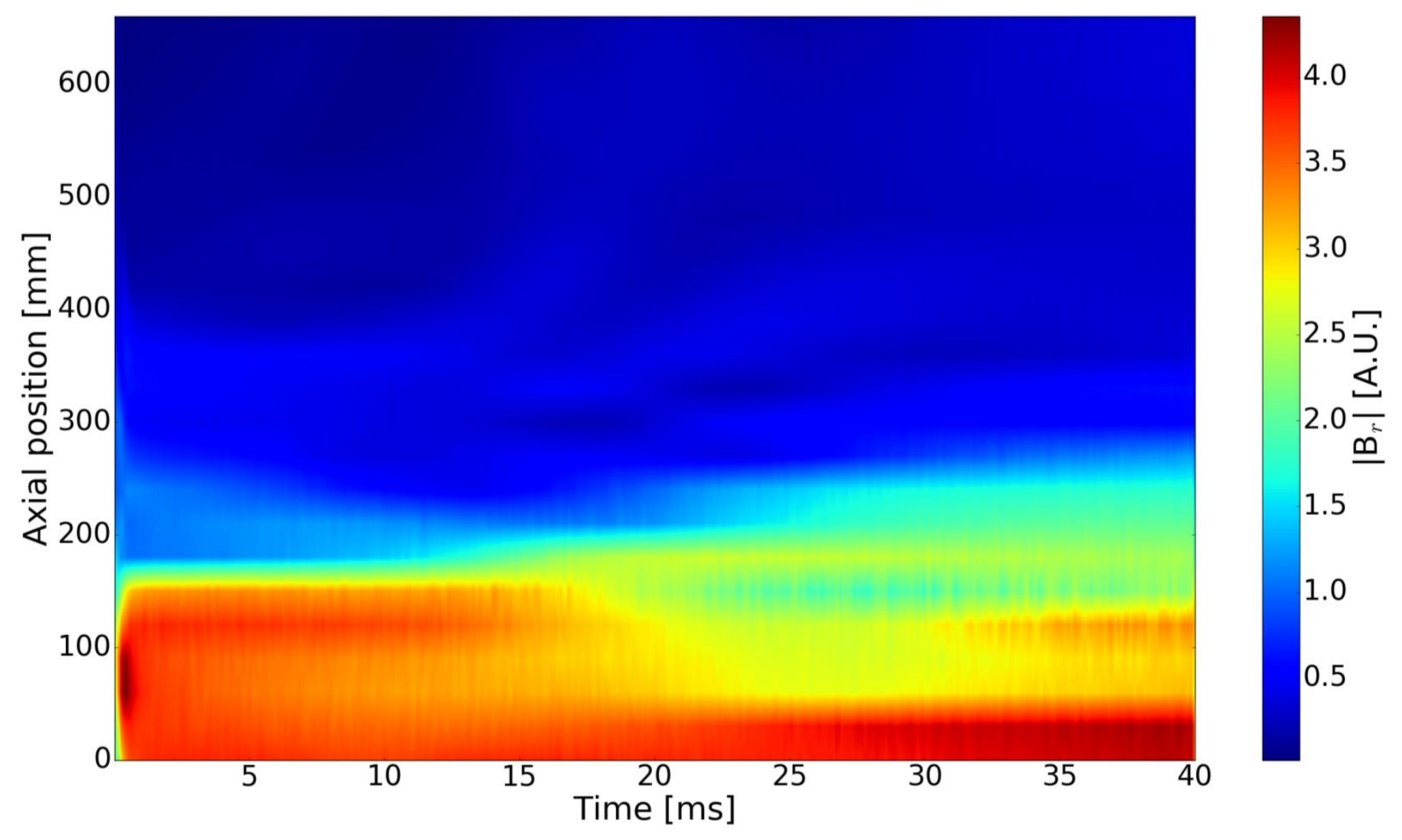

Figure 9: Evolution of the radial magnetic field strength due to the antenna during a 40 ms pulse.

5. Conclusions

Promising results for the future of negative ion sources for NBI systems:

- Observed negative ion densities of above **1 × 10^{18} m^{-3}** (factor of ten higher than the estimated level required)
- Negative ion evolution throughout the pulse **correlates well** with the rate coefficients expected from the electron temperature measurements
- Possible **Alfvènic wave modes** identified after n_{H^-} has peaked

Further work:

- Develop an operation regime with aims to **maintain** high negative ion densities
- Investigate n_{D^-} production in **deuterium** [3]

6. References

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