Negative ion studies on the RF plasma device MAGPIE

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FUSION CDT

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1. Introduction

We present results of a study of the **negative ion** population in a helicon plasma device, and show that it is possible to reach **H^- densities of over 1 × 10^{18} m^{-3}**.

2. Motivation

Negative ion sources are key components of **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 cesium catalyst (highly reactive)

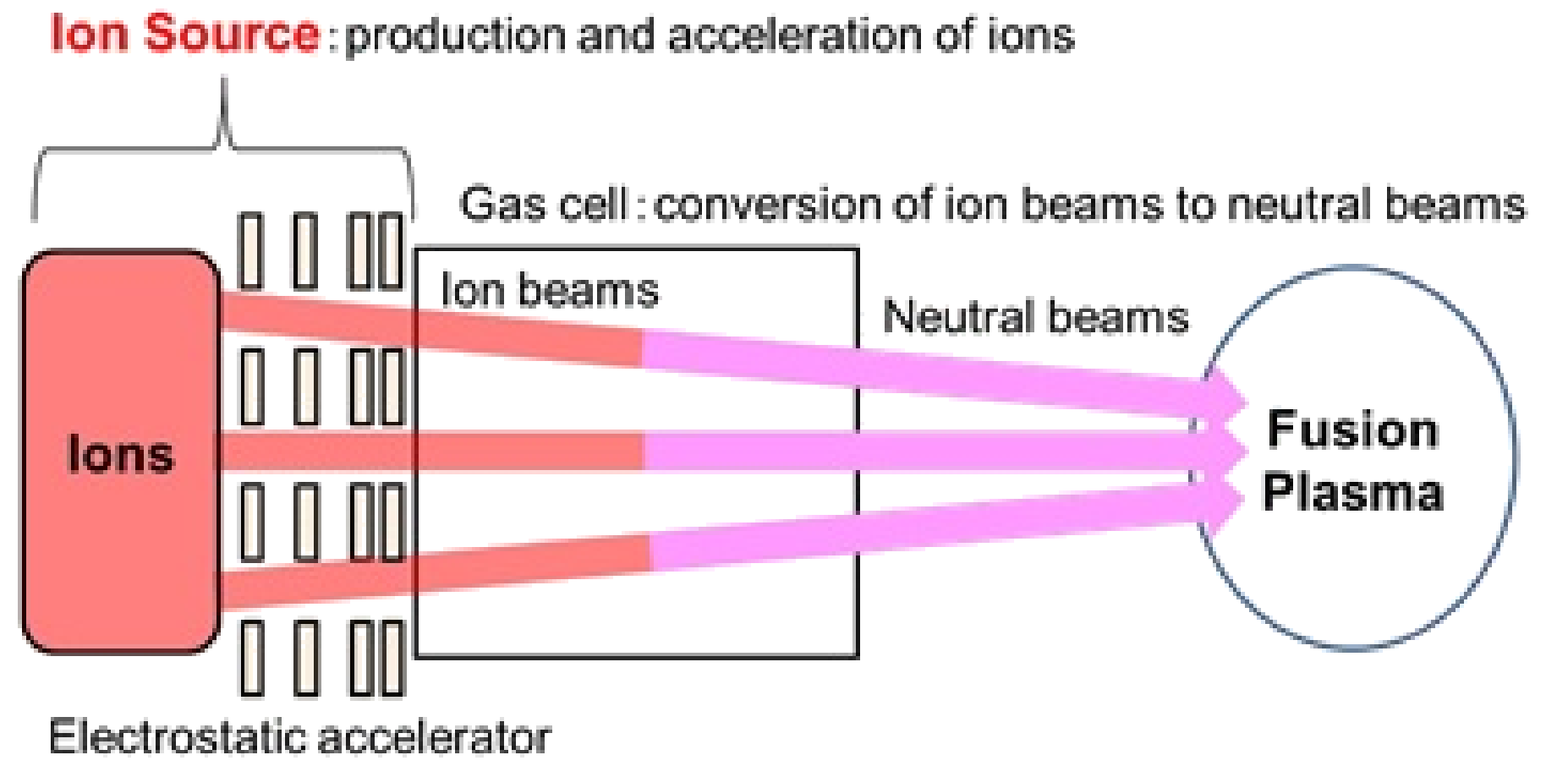

Figure 1: Schematic diagram of a neutral beam injection system. *From https://www.jaea.go.jp/english/news/press/p2015073101/*

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

- Helicon wave coupling is very efficient
    - **Reduce power** required, but maintain high plasma density [3]
    - No cesium required
- 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) at the Australian National University, to increase the **maximum achievable density**.

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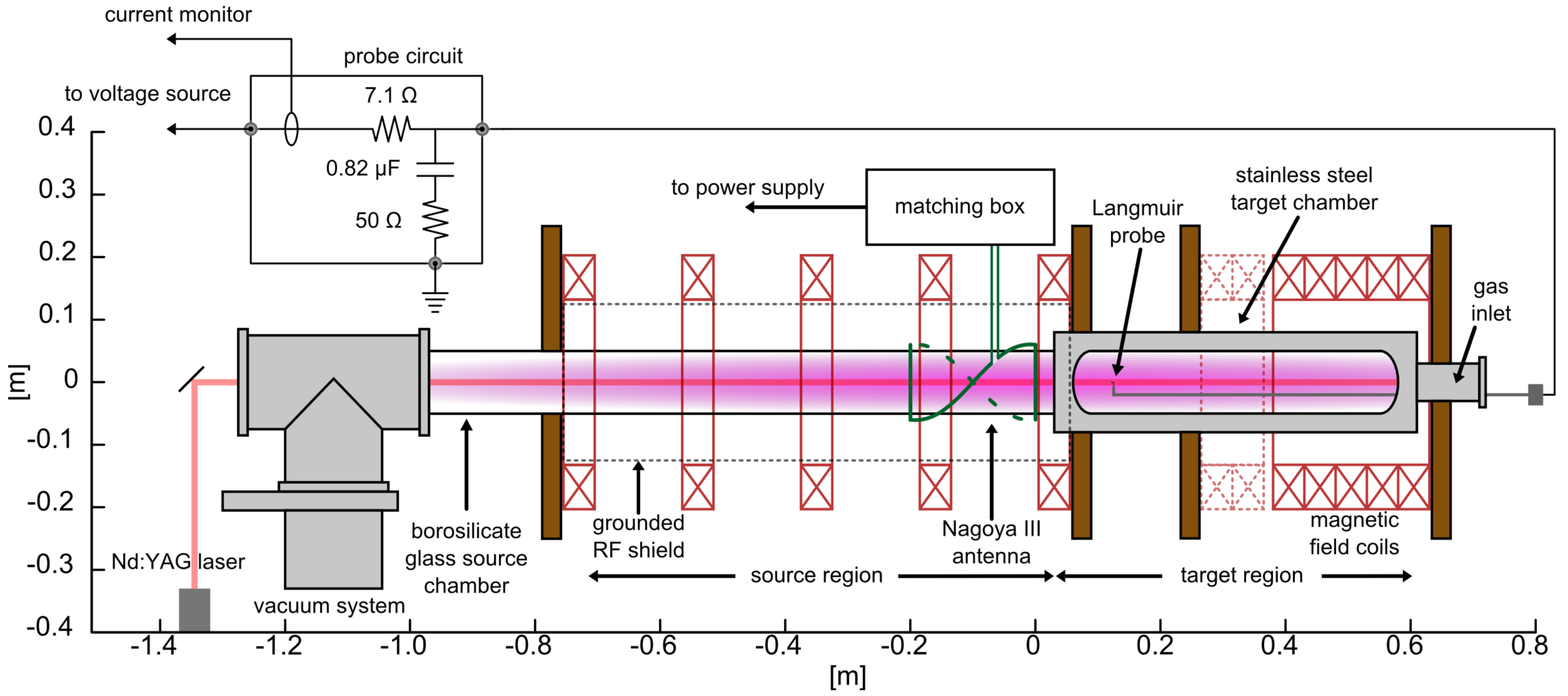

Figure 2: Schematic diagram of the Magnetised Plasma Interaction Experiment (MAGPIE) with laser photodetachment diagnostic [5].

3. Experimental equipment

MAGPIE is a **linear** machine with a helicon plasma source (shown in Figure 2) [6].

- Separate magnetic field coils around the source and target region produce a **tailored mirror field profile**
- **20 kW** of pulsed power at 13.56 MHz (example pulse power shown in Fig. 3)

Diagnostic techniques:

- Langmuir probe: *plasma temperature and density*
- Laser photodetachment [7]: *negative ion density*

Pulse parameters:

- 40 ms duration
- Gas pressure: 10 mTorr
- Source field: 4 mT (50 A current)
- Mirror field: 57 mT (300 A current)

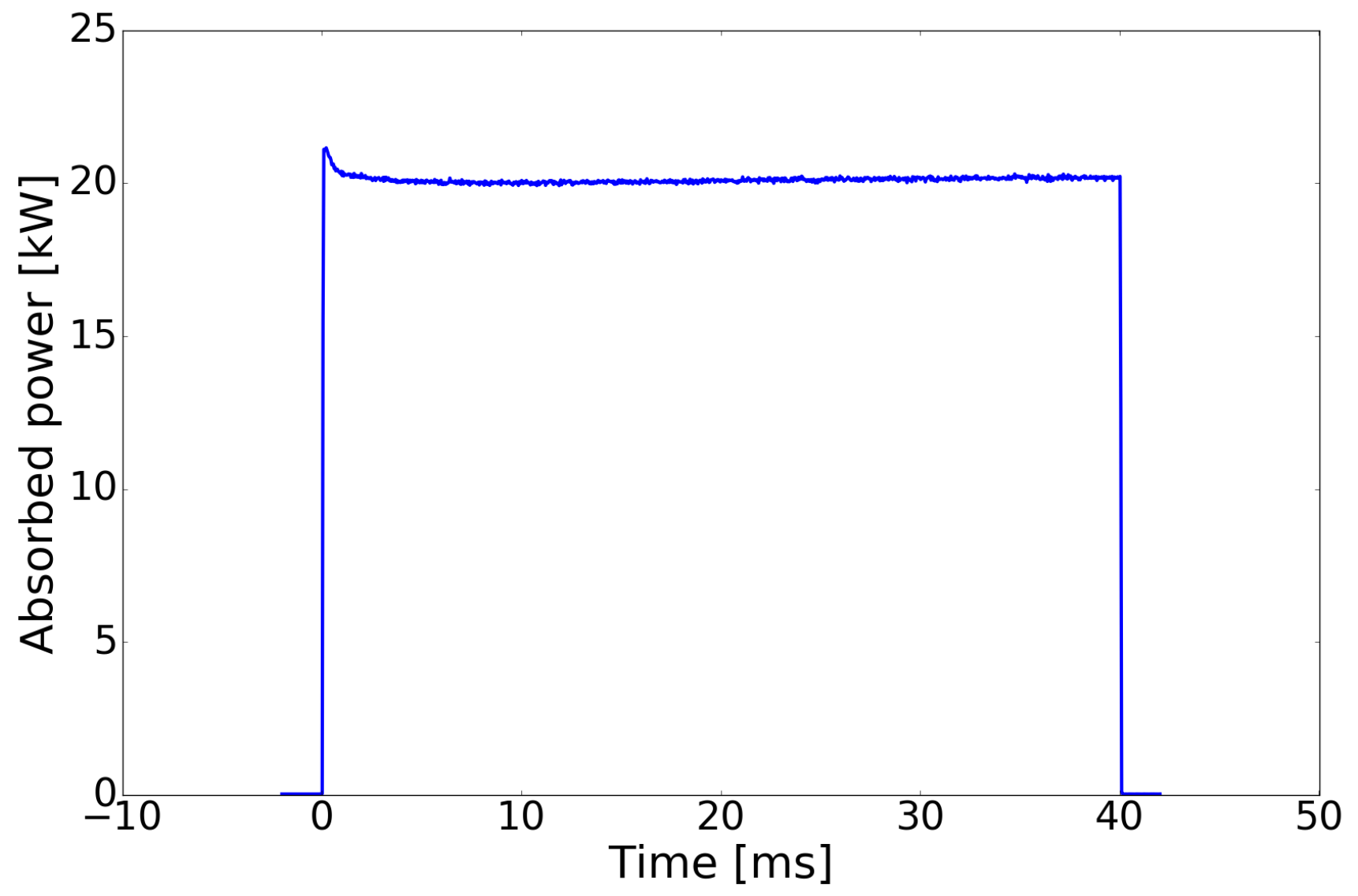

Figure 3: Amplitude of the power absorbed by the plasma throughout a 40 ms pulse.

4. Results

The electron temperature (T_e) and density (n_e) profiles throughout the pulse are shown in Figures 4 and 5 respectively. The negative ion density (n_{H^-}) evolution is shown in Fig. 6.

- Obtained **n_{H^-} >1× 10^{18} m^{-3}**
- Profiles **evolve** throughout the pulse, resulting in a transient peak in n_{H^-}

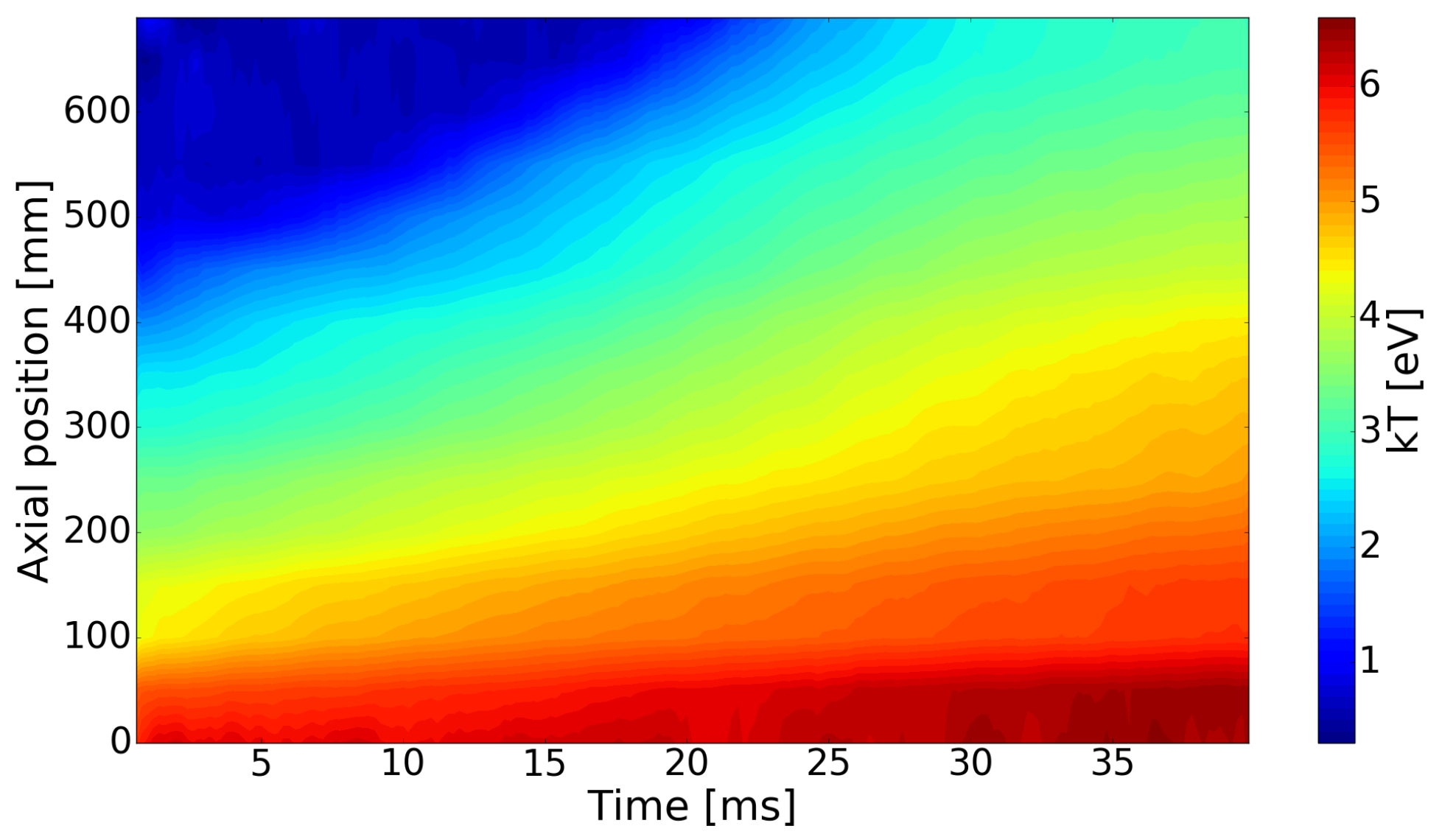

Figure 4: Evolution of the axial electron temperature profile throughout a 40 ms pulse.

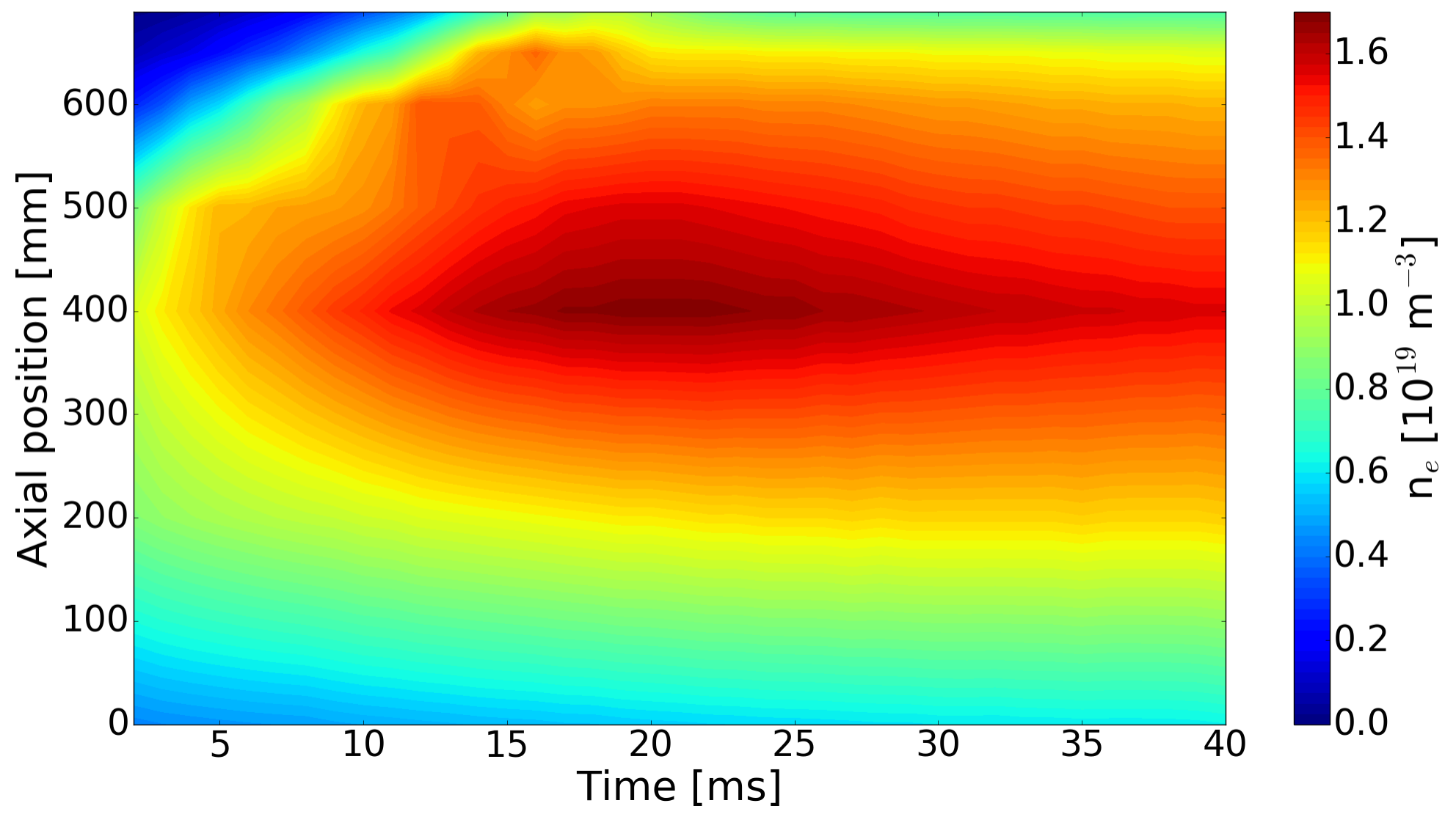

Figure 5: Evolution of the axial electron density profile throughout a 40 ms pulse.

Results cont.

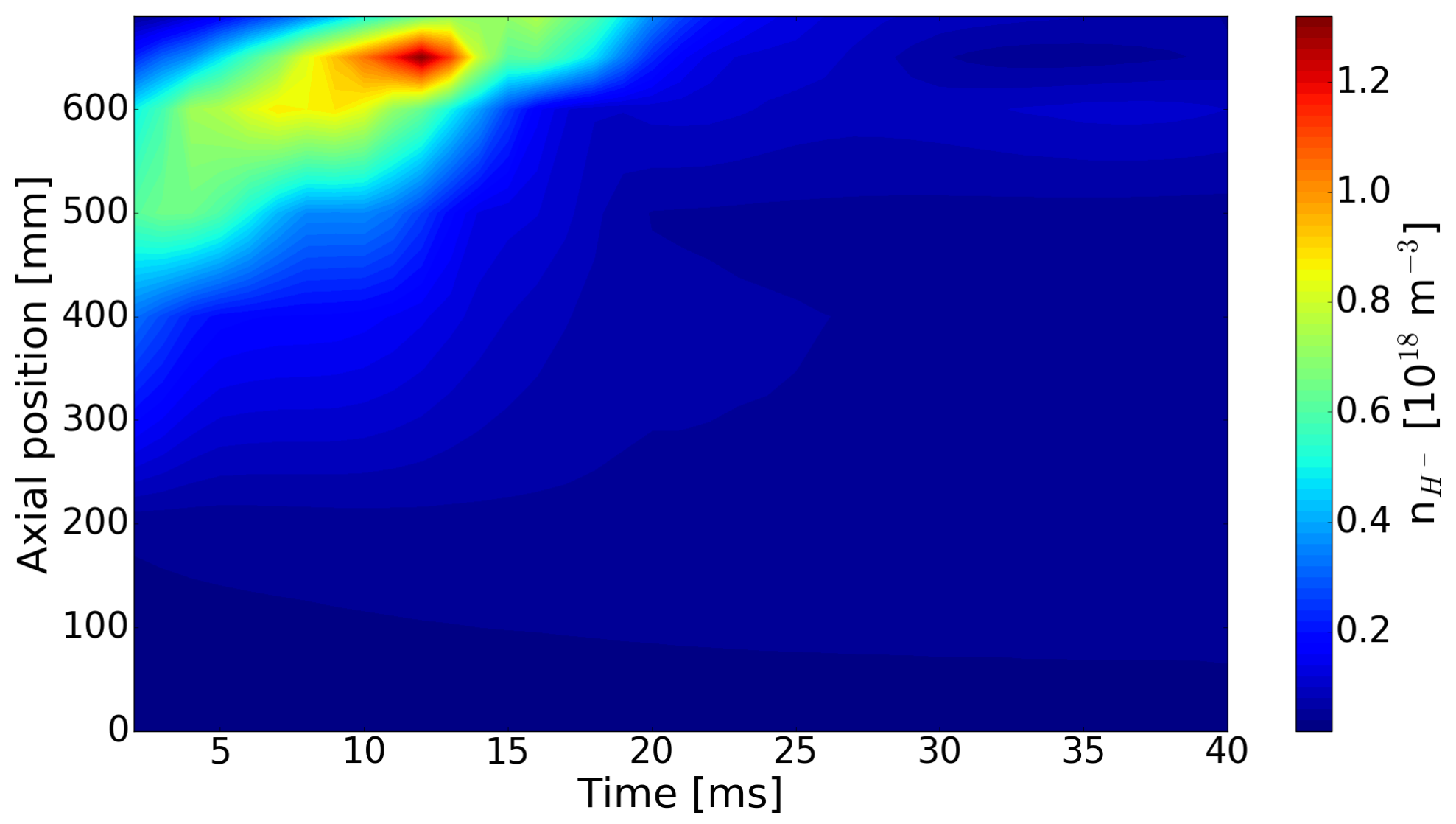

Figure 6: Evolution of the axial negative ion density profile throughout a 40 ms pulse.

Figure 7 shows the time evolution of each parameter for an axial position of 650 mm.

- Highest n_{H^-} values occur only for a few milliseconds
- n_{H^-} peak corresponds to the region of **low temperature**
- Peak position is **downstream** of the peak magnetic field (~500 mm)
- As electron heating region propagates forward, n_{H^-} decreases in front of it

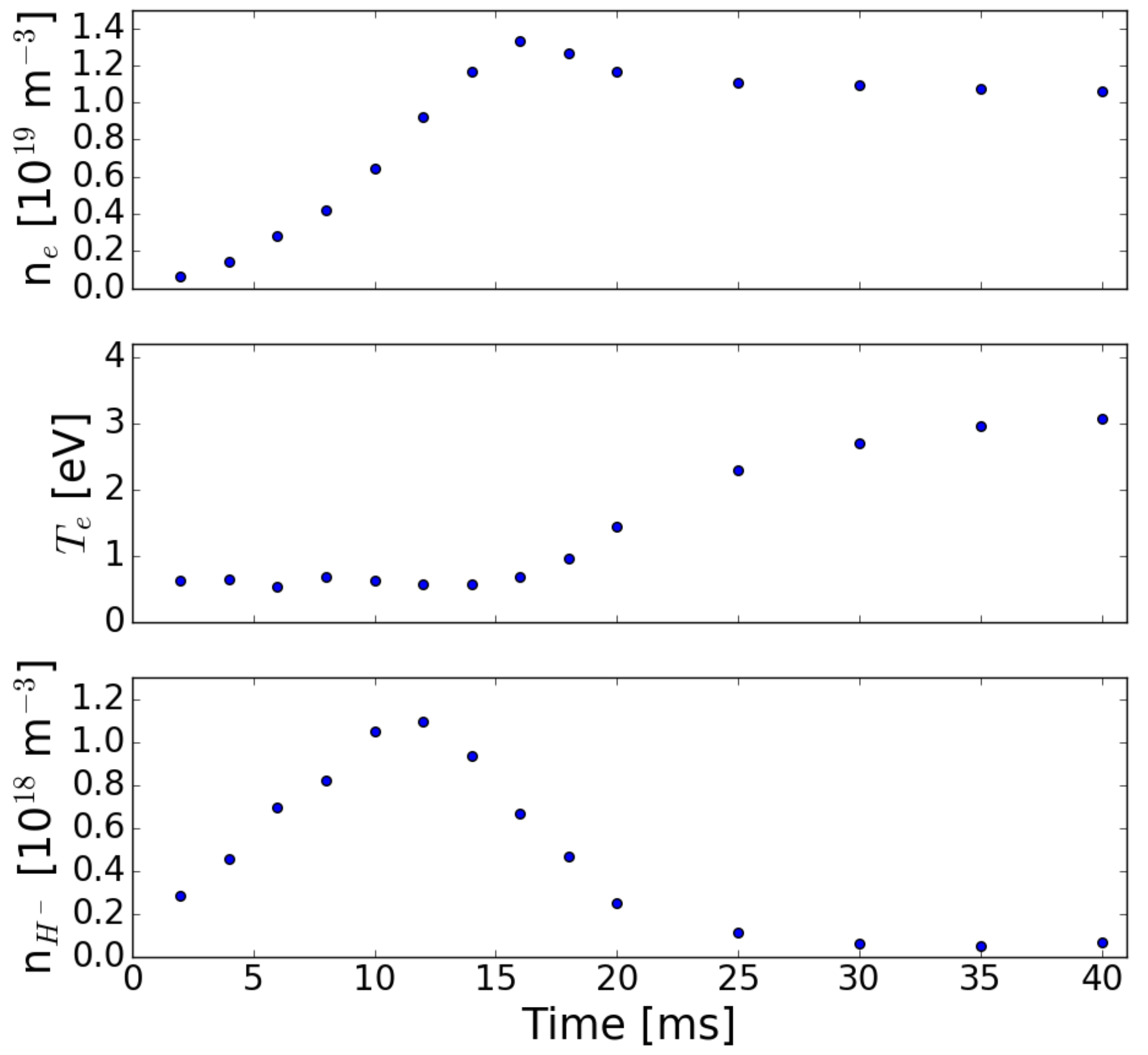

Figure 7: Electron density (n_e), temperature (T_e) and negative ion density (n_{H^-}) throughout a 40ms pulse in MAGPIE. Axial position: 650 mm.

Rate coefficients for the formation and destruction of negative ions throughout the pulse are shown in Figure 8. Calculations used the measured T_e values, and rate coefficient expressions found in [8].

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

Results cont.

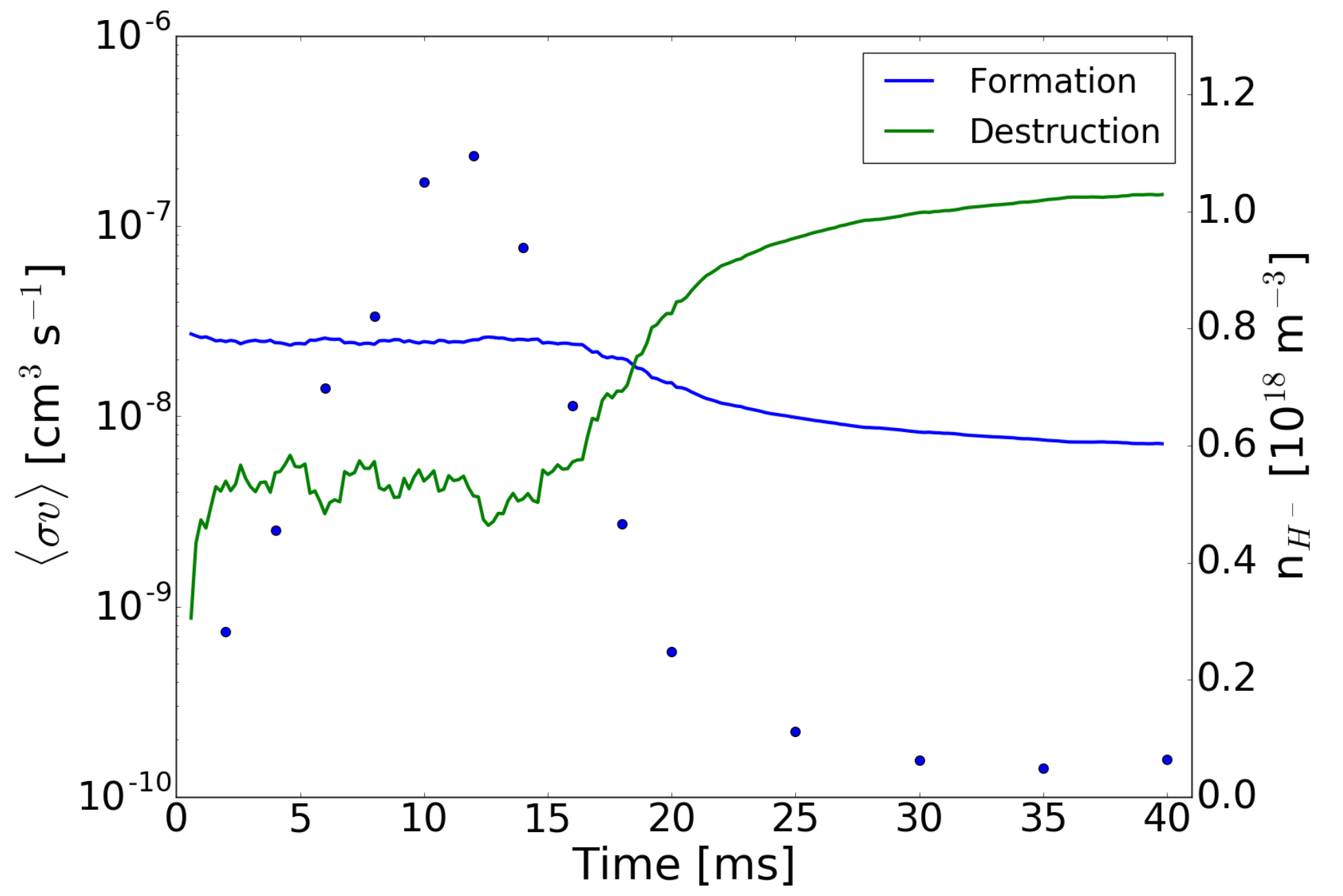

Figure 8: Calculated reaction rate coefficients (solid lines) for negative ion formation and destruction throughout a 40ms pulse in MAGPIE, with negative ion density data points overlaid. Axial position: 650 mm

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

Further work:

- Examine effects of pulse parameters (e.g. RF frequency, pressure, field strength)
- Develop an operation regime which aims to **maintain** high negative ion densities
- Operate using **deuterium** (the relevant isotope for fusion)

6. References

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