Simulation of Sputtered Boron Atoms in the Plume of a SPT-70 Hall Thruster

Horatiu C. Dragnea and Iain D. Boyd, Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

Motivation

- Main lifetime limiting factor for Hall thrusters is channel erosion.
- Current lifetime evaluation techniques are expensive and most are intrusive.
- A cavity-ring down spectroscopy technique (CRDS) was developed to identify the line integrated value of boron atom number density near the exit plane [1].


Fig. 1: Xenon Hall thruster [2].

A simulation is prepared to determine boron number density in the plume and compare the results with CRDS. The code MONACO [3], an implementation of the direct simulation Monte Carlo (DSMC) [4] method, is used.

Simulation Setup

Parameters:

- 670,000 total particles
- $\frac{real}{model}$ Xe particles = 10^{10}
- $\frac{real}{model}$ B particles = 1.25 X 10^{10}
- time step: 3 X 10^{-7} s
- simulation time: 0.012 s.
- n_{xenon} = 2.25 X 10^{20} m^{-3}
- n_{boron}^{outer} = 1.45 X 10^{10} m^{-3}
- n_{boron}^{inner} = 4.83 X 10^{10} m^{-3}

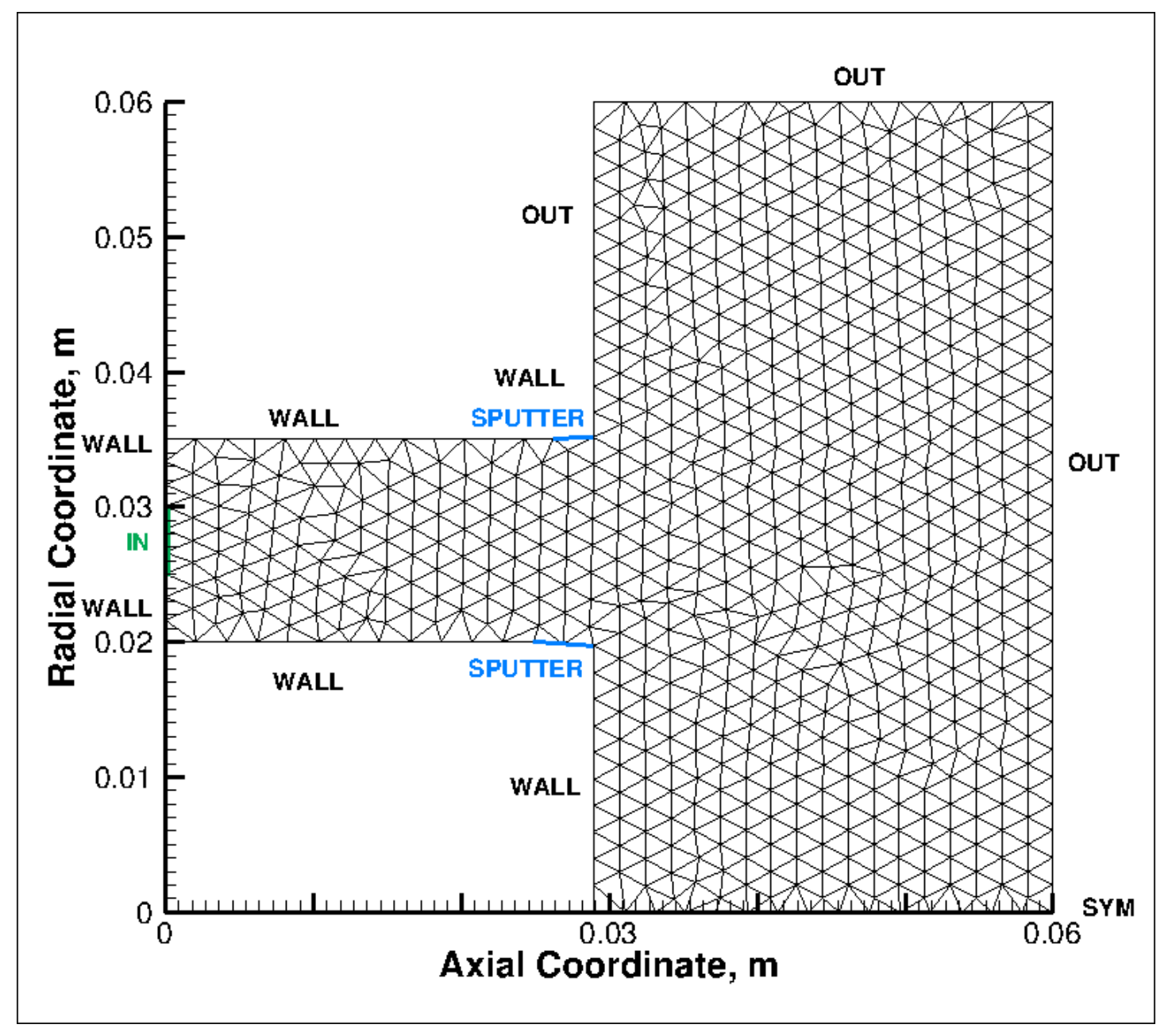

Fig. 2: Computational mesh and boundary conditions.

Eroded boron atom velocities are sampled from the distributions in Figs. 2 (radial) and 3 (tangential).

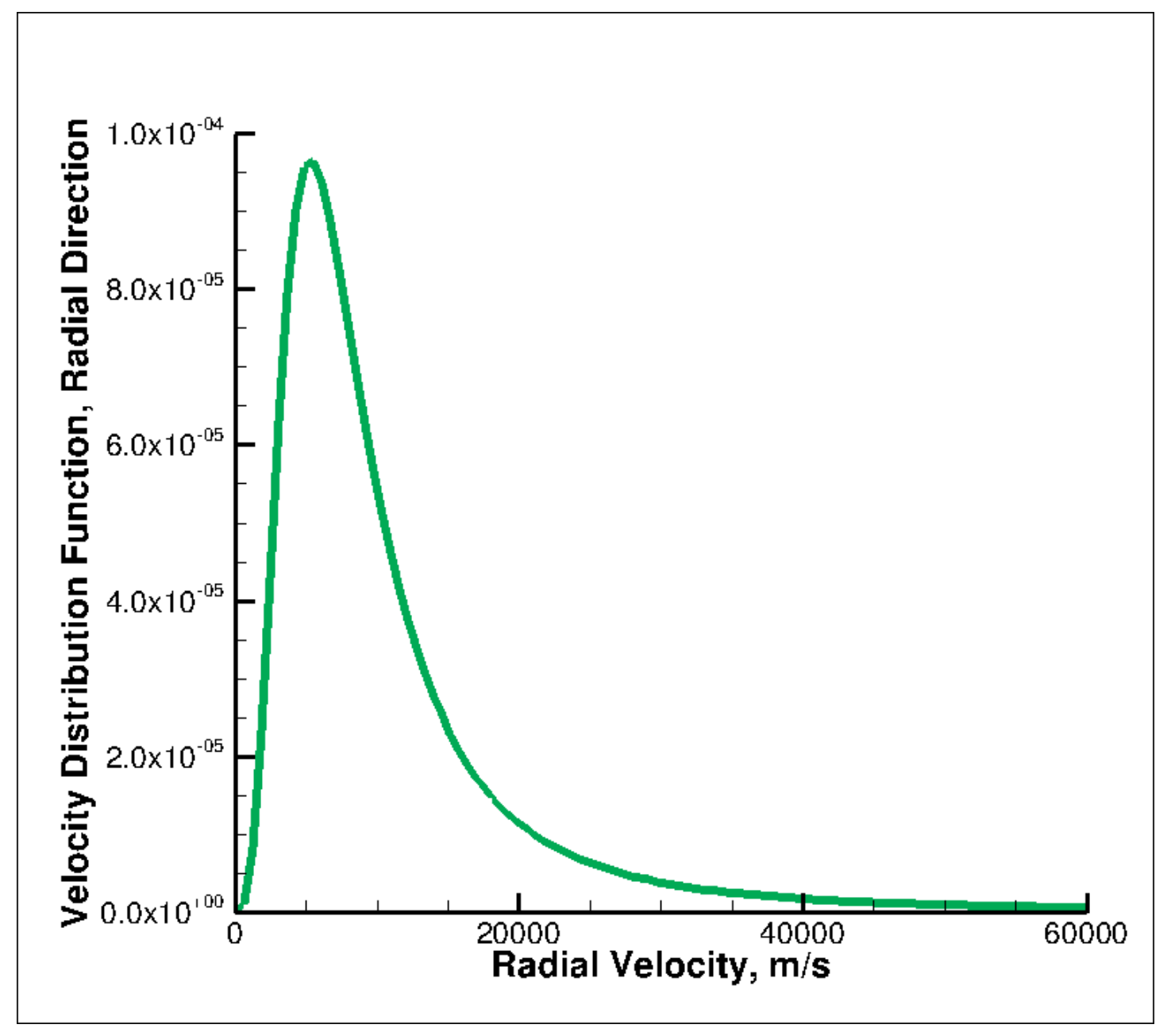

Fig. 3: Sigmund-Thompson distribution [5].

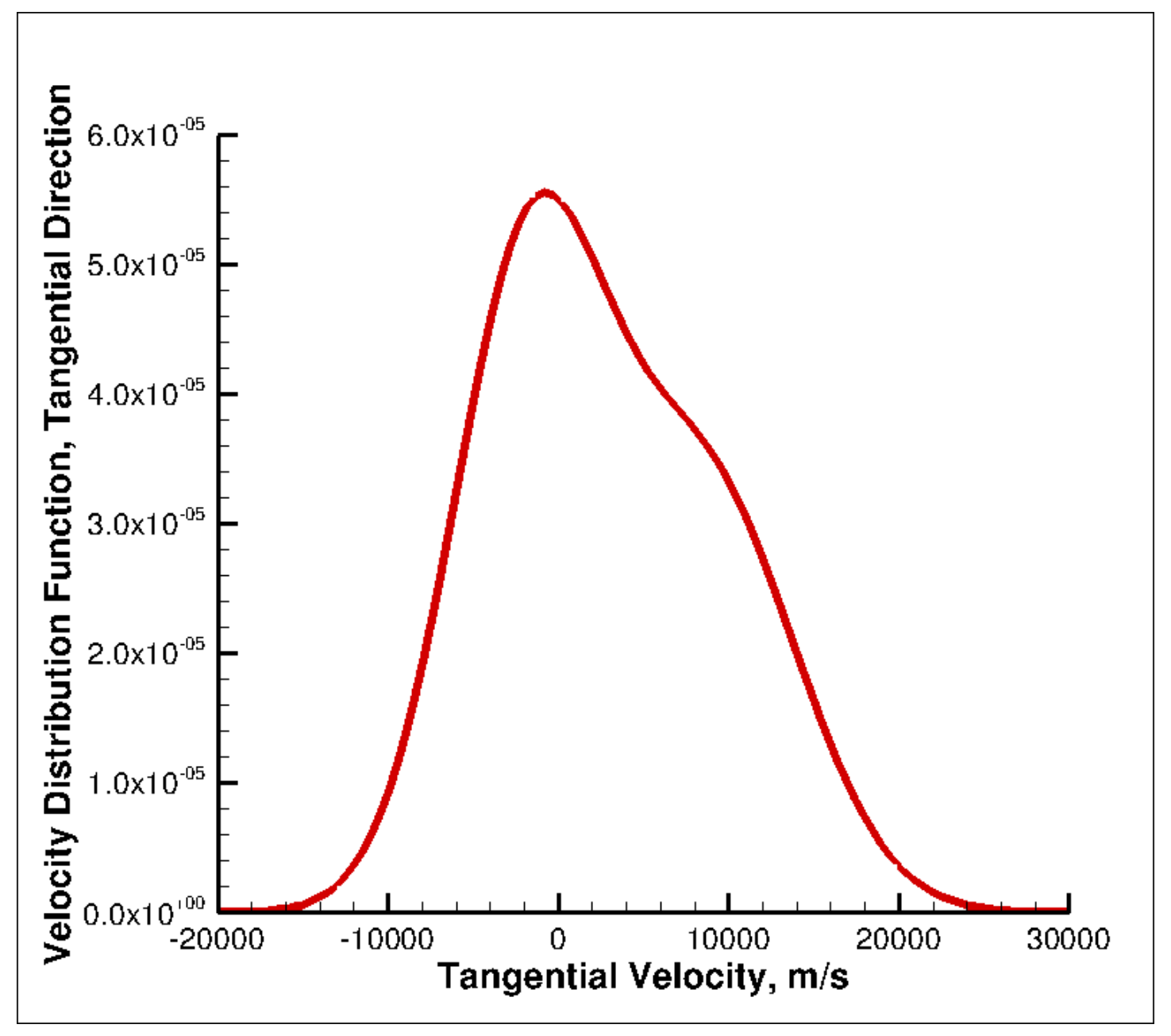

Fig. 4: Bimodal Maxwellian distribution [5].

Results

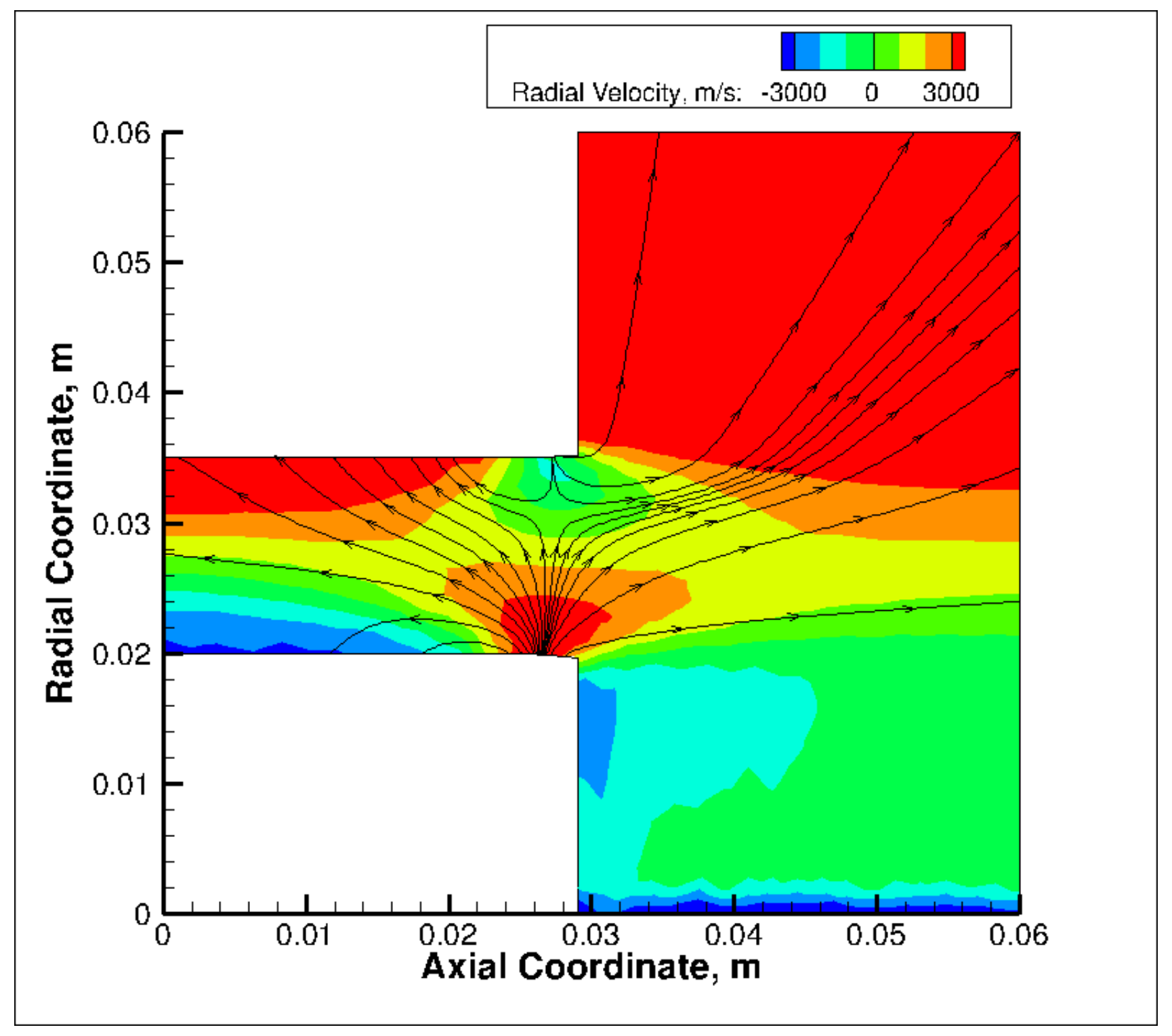

Figure 5: Radial velocity contours.

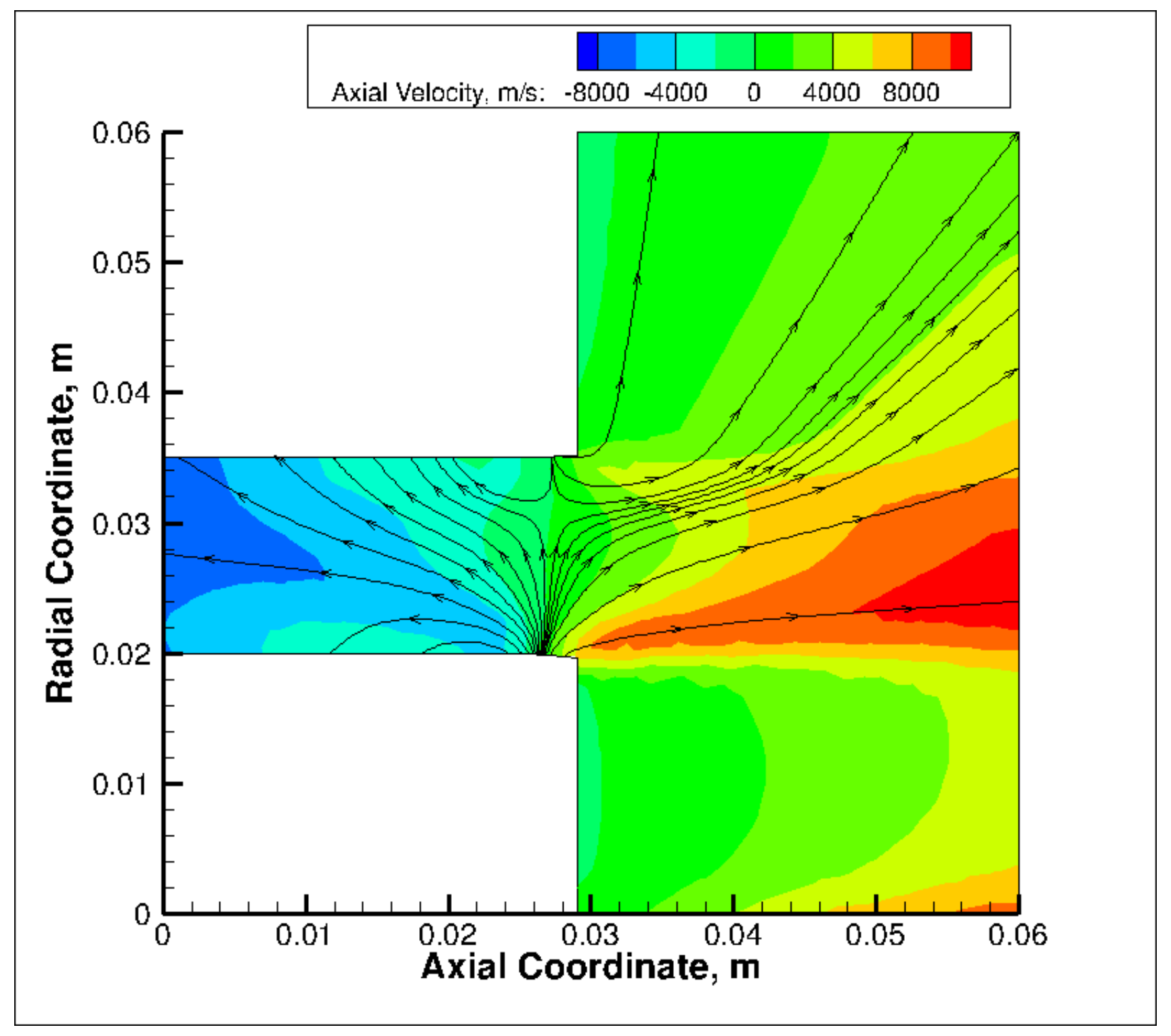

Figure 6: Axial velocity contours.

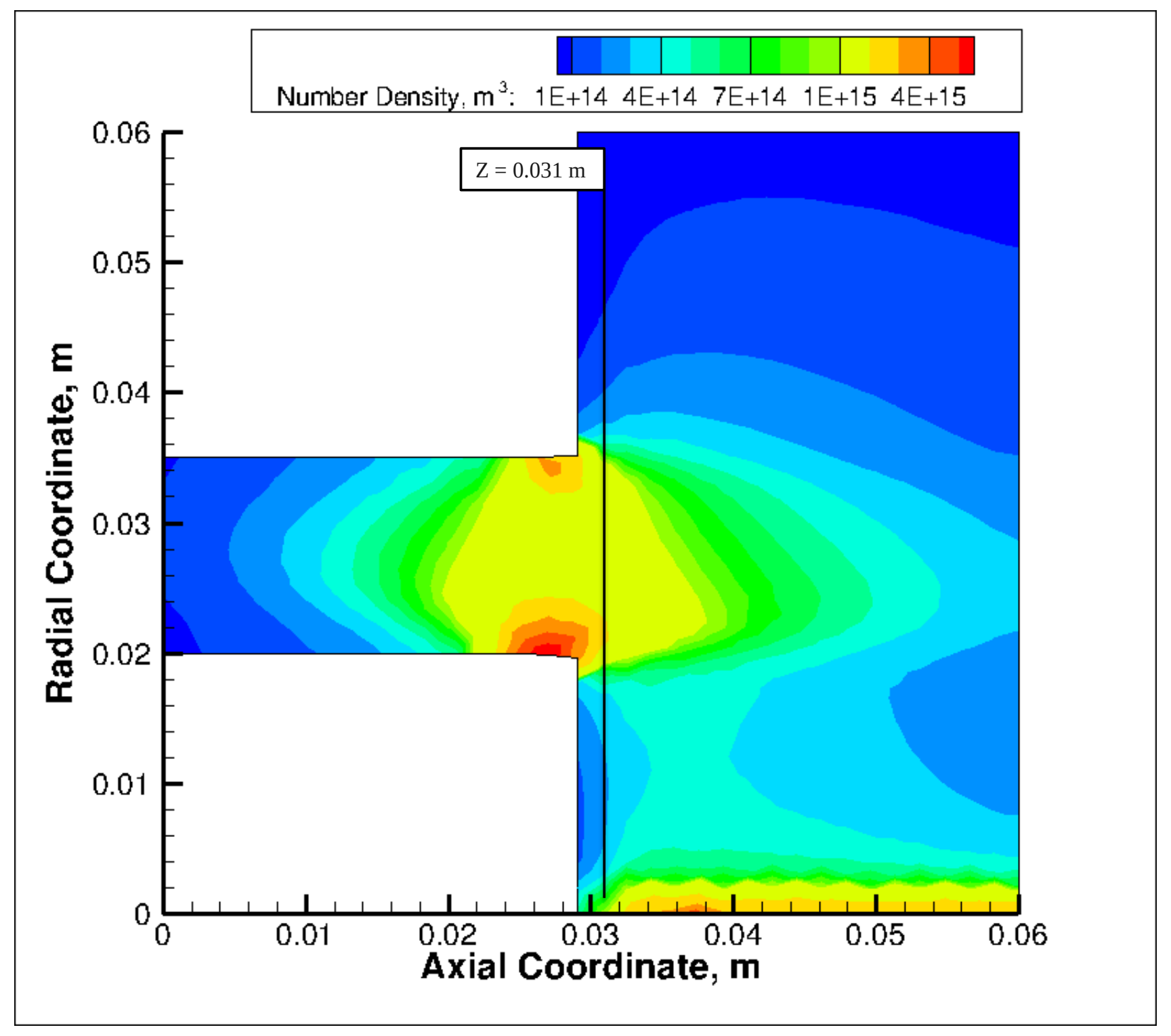

Figure 7: Number density contours, entire domain.

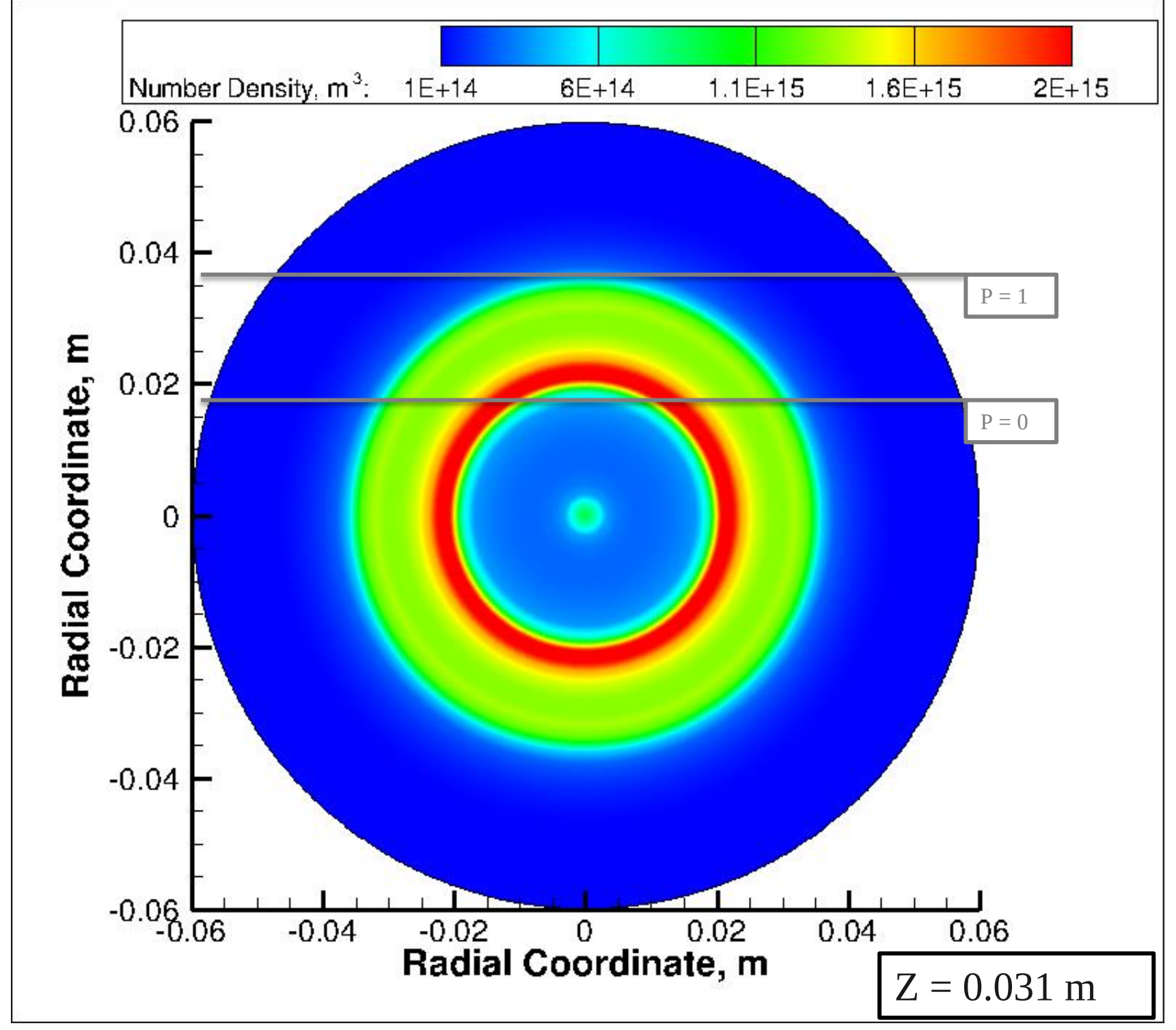

Figure 8: Number density contours, CRDS plane.

Azimuthal plane data is extracted at axial coordinate Z = 0.031 m (CRDS plane) from Fig. 7 and displayed in Fig. 8.

The number density data is integrated over 1000 lines in between P = -1 and P = 2.5 and plotted in Fig. 9, where:

$$P = \frac{r - r_{inner}}{r_{outer} - r_{inner}}$$

The MONACO simulation results are higher than the CRDS measurements by a factor of 3-4.

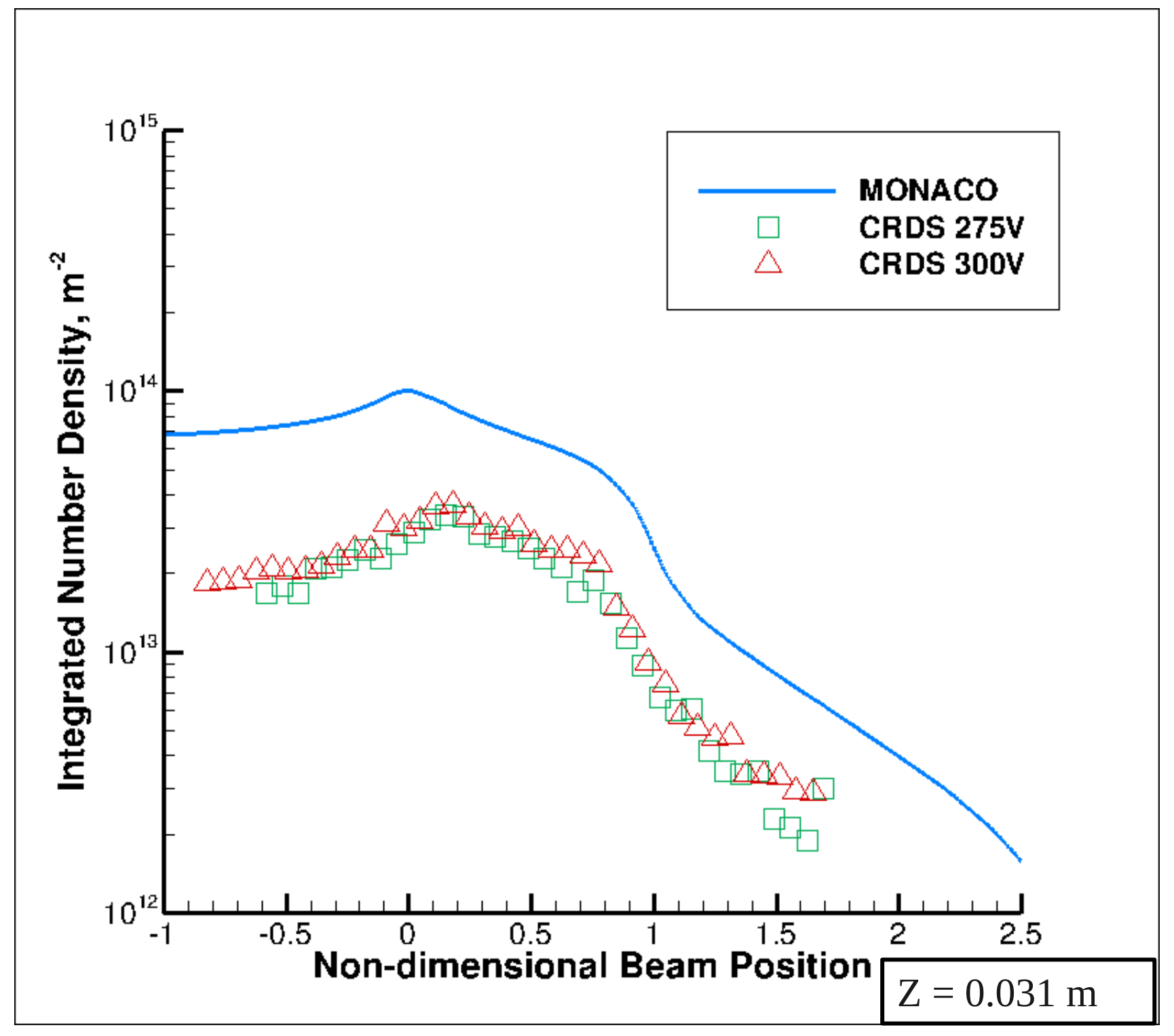

Figure 9:Comparison of integrated values of number density.

Conclusions

- Good qualitative agreement is observed between DSMC and CRDS.
- The values differ in magnitude by a factor of 3-4
- This discrepancy may arise because of the following:
  1. CRDS only accounts for boron atoms in the ground electronic state. Atoms that are excited to higher electronic levels are omitted, and so are atoms that become ionized.
  2. Uncertainty (+/- 50%) in the thruster operation time introduces uncertainty in the initial number density for eroded boron.
  3. The boron VDFs were obtained from a molecular dynamics (MD) simulation [5] under specific sputter conditions which may not apply to the present case (100 eV energy and 45° angle of incidence).

Future Work

- Further MD studies must be performed to characterize the dependence of the sputtered VDFs on the incident ion properties, along with comparisons against experimental data.
- The thruster will be operated at a fixed point for several hours, to reduce the uncertainty in boron number density.
- A full plasma simulation will be prepared in order to account for the electromagnetic interactions that occur in the thruster channel and plume, which have been neglected in the present study.

References

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4.Bird, G. A., Molecular Gas Dynamics and the Direct Simulation of Gas Flows, Oxford Univ. Press, Oxford, England, UK, 1994
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Acknowledgments

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