# HIIPER Space Propulsion Simulation Using AC/DC Module

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## Introduction

- HIIPER: **H**elicon **I**njected **I**nertial **P**lasma **E**lectrostatic **R**ocket
  - An electric space propulsion concept being studied
  - Utilizes helicon source to generate argon ions through RF heating
  - A helicon source can create a denser, more ionized plasma than other methods using similar power levels [1]
- IEC: **I**nertial **E**lectrostatic **C**onfinement
  - Fusion concept applied here for ion acceleration
  - Uses metal grids to accelerate ions, generating a thrust
- COMSOL® simulation
  - Present simulations follow largely from previous HIIPER COMSOL® work [2]
  - Simulations provide an efficient way to improve the design of HIIPER

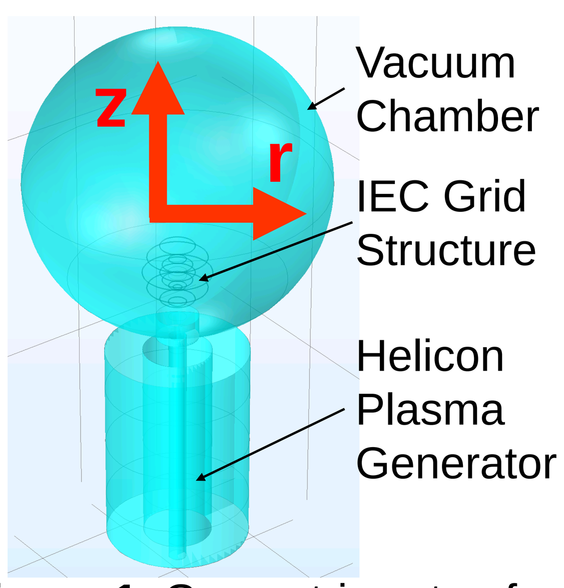


**Figure 1**. Geometric setup for full model simulation

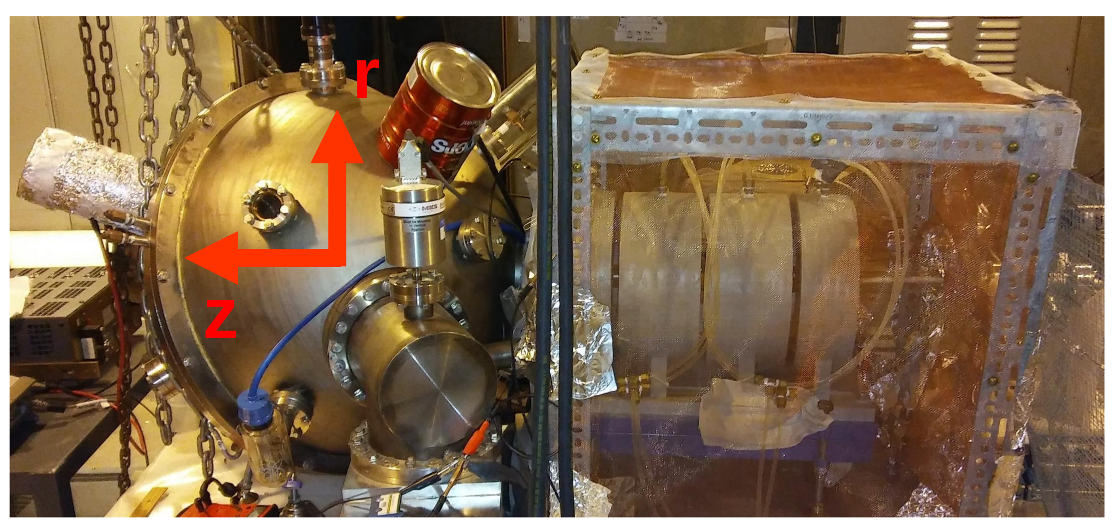


**Figure 2**. Experimental setup

## Computational Methods

### 1. Ion velocity analysis (2D axisymmetric model)

- Ar+ ions injected at helicon bias with initial speed 400 m/s toward IEC grids

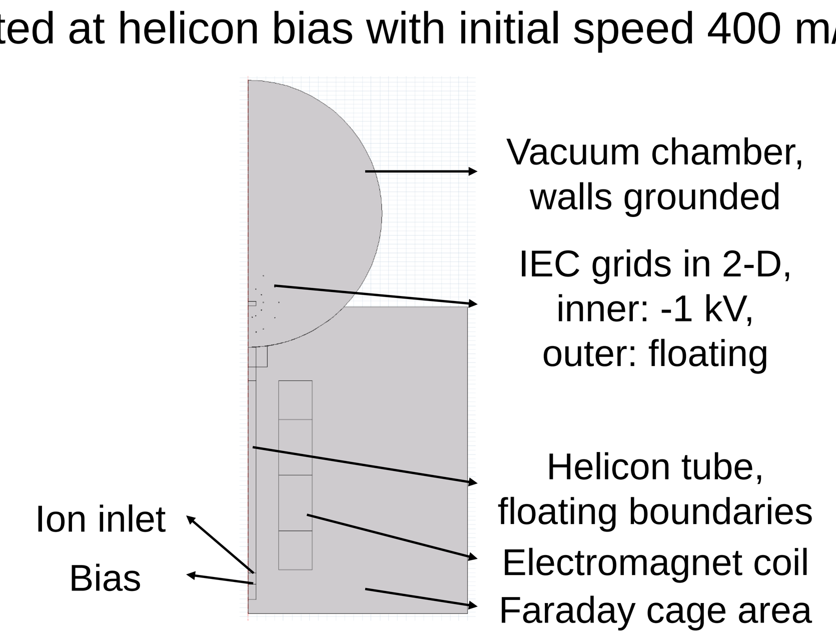


**Figure 3**. Setup for ion velocity study

### 2. Secondary electron preferred direction in IEC grid (3D model)

- Nested grids surrounded by circular faces to measure electron flux from IEC grid
- Electrons randomly distributed along inside edges of inner IEC grid
- Initial KE is 5eV, with initial velocity pointing inward (normal to grid)

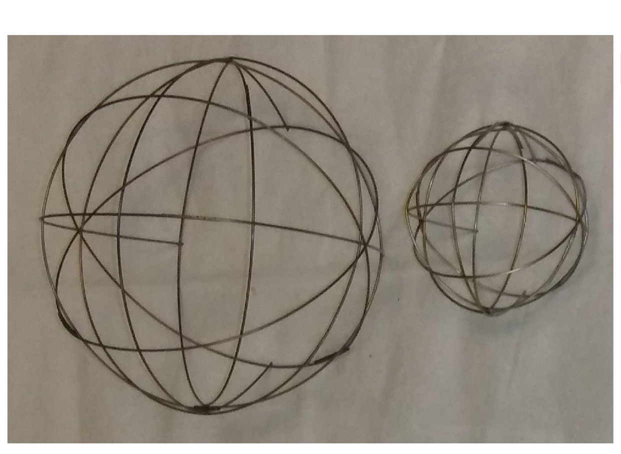

**Figure 4**. IEC grids using in the real experiment

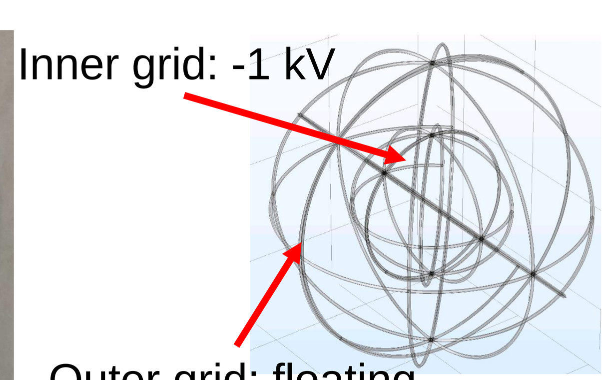


**Figure 5**. Nested grid configuration

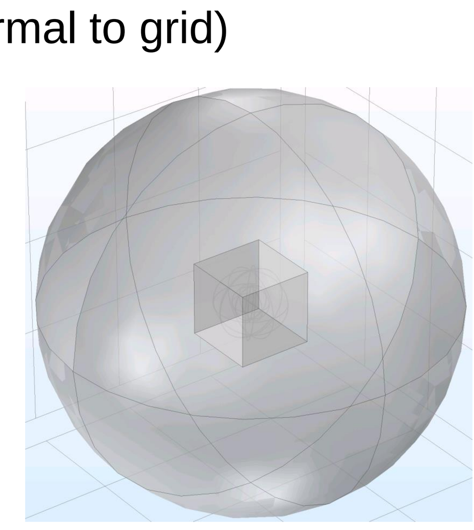

**Figure 6**. Full model

### 3. Retarding potential analyzer (RPA) (2D axisymmetric model)

- 2D axisymmetric model following Christenson [3]
- Electrons randomly distributed along inlet
- 2 studies with different inlet electron energies:
  1) Initial KE of 2 keV (from IEC grid)
  2) Initial KE of 10 eV (secondary electrons)

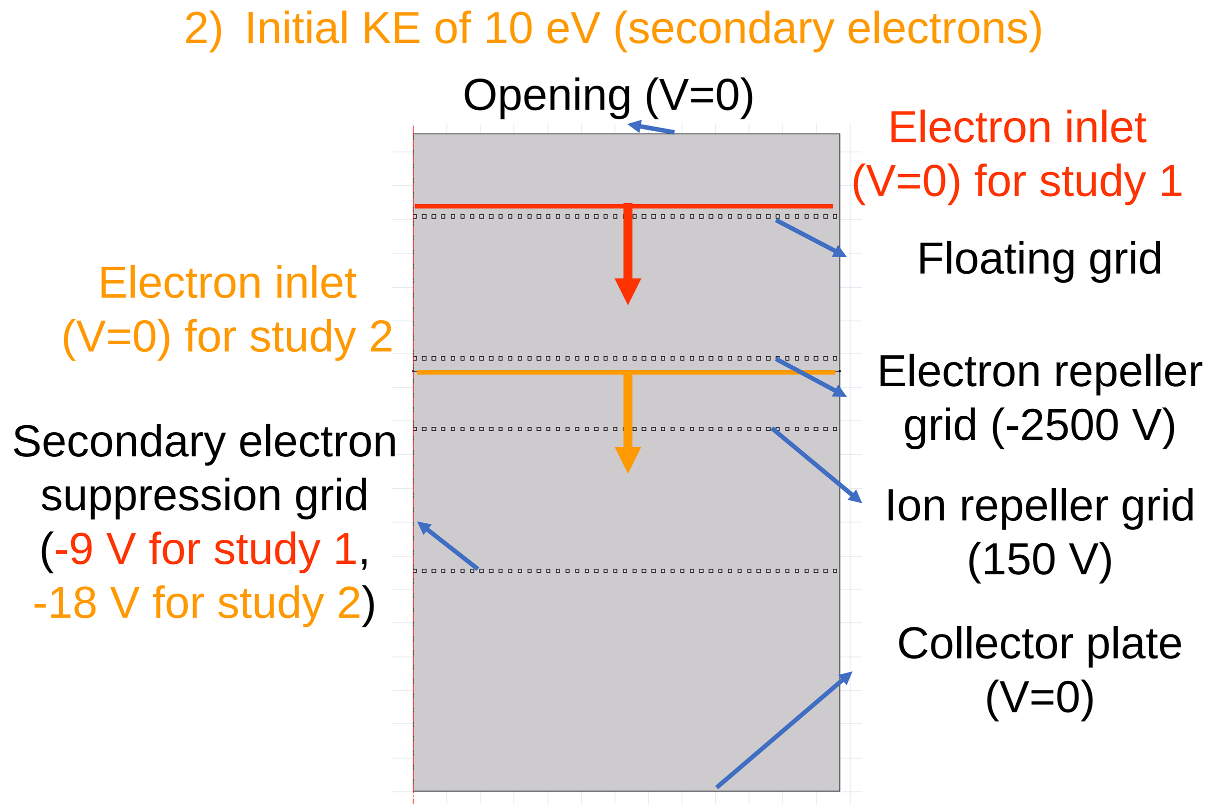


**Figure 7**. Setup for RPA study

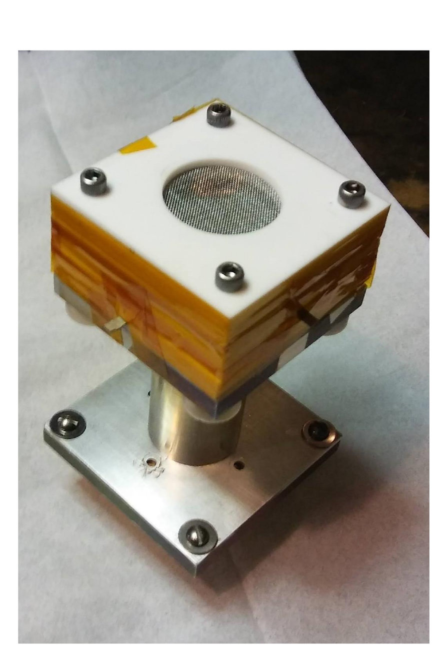

**Figure 8**. RPA used in the real experiment

## Results

### 1. Ion velocity analysis (2D axisymmetric model)

- Simulation shows increase in velocity with higher helicon bias voltage, matching experimental behavior [4]
- Additionally, simulation's magnetic field matches experimental results [5]

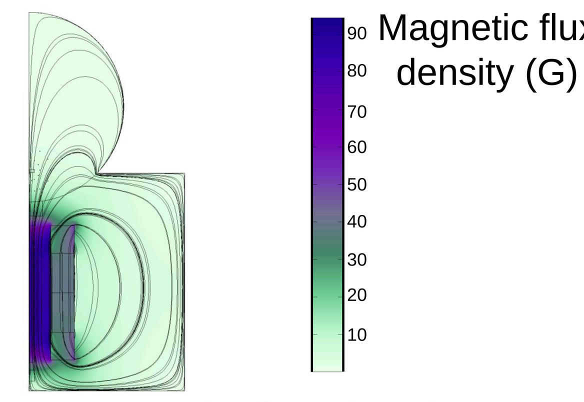


**Figure 9**. Magnetic flux density

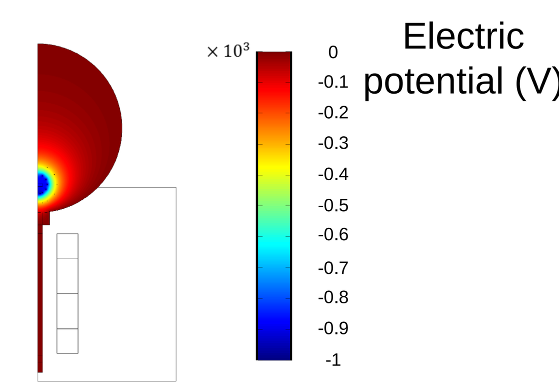


**Figure 10**. Electric potential

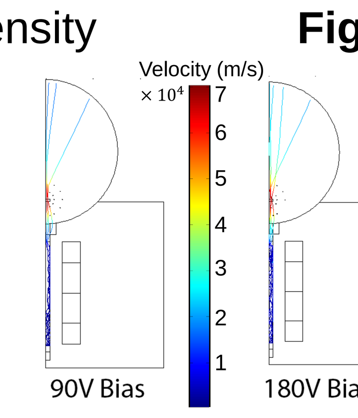


**Figure 11**. Ion velocity

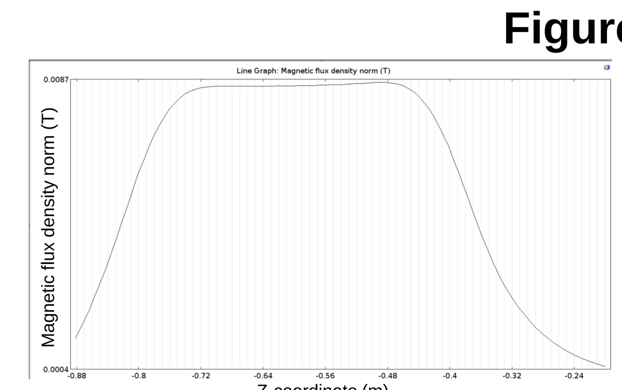


**Figure 12**. Axial applied magnetic field at 3 A

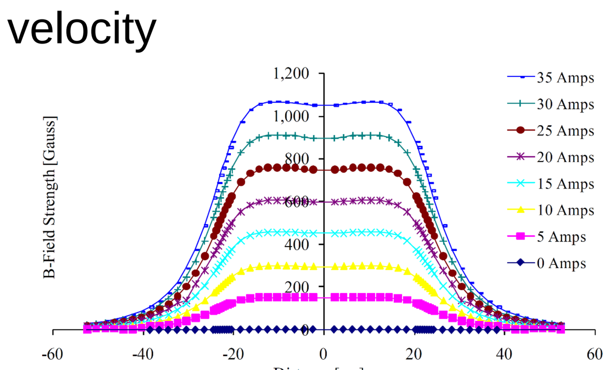


**Figure 13**. Axial applied magnetic field from experimental result [5]

### 2. Secondary electron preferred direction in IEC grid (3D model)

- Majority of electrons preferentially leaving through asymmetry
- 31.3% exit the asymmetry hole vs. 20.5% when there is no asymmetry

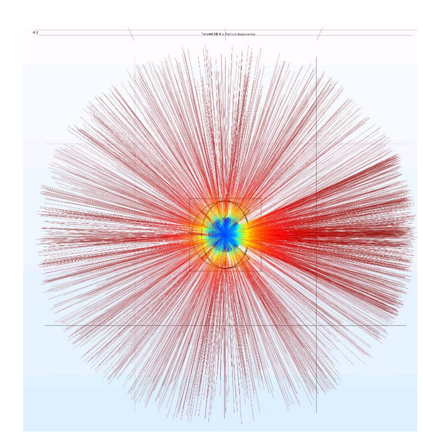

**Figure 14**. Side view of asymmetric grid

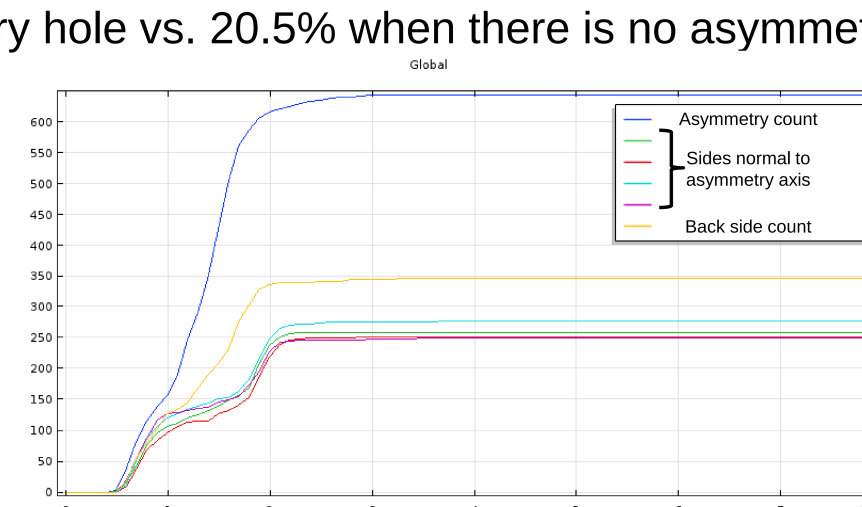


**Figure 15.** Corresponding electron flux

### 3. Retarding potential analyzer (2D axisymmetric model)

- Electrons from IEC grid are repelled
- Secondary electrons are repelled, though some escape

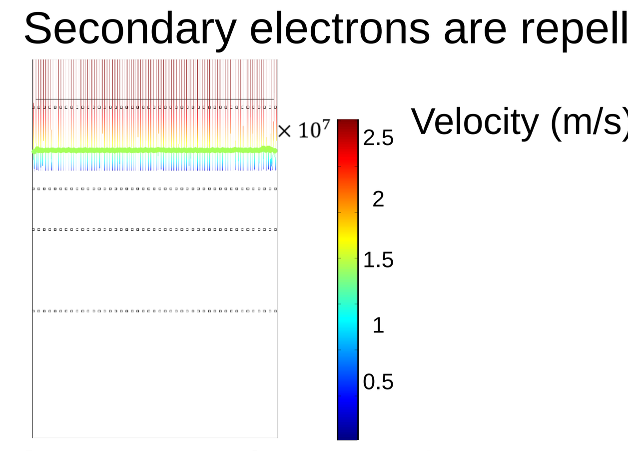


**Figure 16**. Electrons from IEC grid are repelled

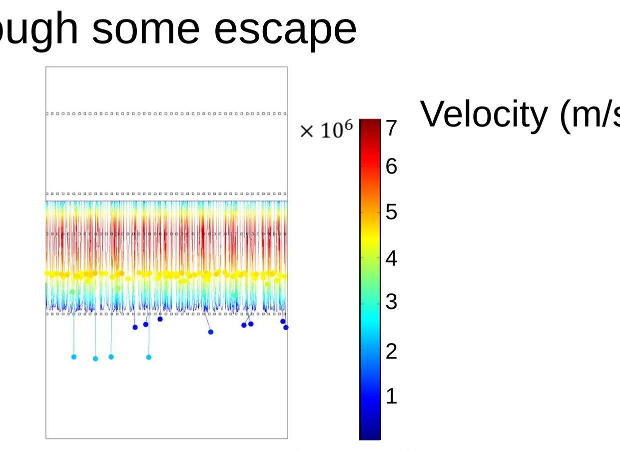


**Figure 17**. Secondary electrons are repelled, but some escape

## Conclusions

- COMSOL® makes it possible to:
  1. Compare and verify experimental data in HIIPER with the simulation data
  2. Understand various characteristics of the experiment
  3. Test and optimize our experimental design
- These techniques might be used for plasma processing studies, plasma deposition, and other plasma manufacturing processes

## References

1. Chen, F. F., "Plasma ionization by helicon waves," Plasma Physics and Controlled Fusion, Vol. 33, No. 4, 1991, pp. 339-364.
2. Ahern, D., Chen, G., Krishnamurthy, A., Ulmen, B., and Miley, G., "Simulating Experimental Conditions of the HIIPER Space Propulsion Device," Proceedings of COMSOL® Conference 2013, Boston, MA, 2013.
3. Christenson, M., "Characterization of Ion Properties in a Linear Pulsed Plasma-Material Interaction Test Stand," M.S. Thesis, Nuclear, Plasma, and Radiological Engineering Dept., University of Illinois at Urbana-Champaign, Champaign, IL, 2015.
4. Ahern, D., et al, "Experimental Studies of the Helicon Injected Inertial Plasma Electrostatic Rocket (HIIPER)," 53rd AIAA/SAE/ASEE Joint Propulsion Conference, Atlanta, GA, 2017.
5. Reilly, M. P., "Three Dimensional Imaging of Helicon Wave Fields via Magnetic Induction Probes," Ph.D. Dissertation, Nuclear, Plasma, and Radiological Engineering Dept., University of Illinois at Urbana-Champaign, Champaign, IL, 2009.