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Charged Particle Filter for Entrance of IMAP-Lo

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Introduction

The interstellar medium (IM) is defined as the material that lies between stars systems inside galaxies. This material is primarily composed of hydrogen and helium, with trace amounts of heavier elements. Our Sun moves through the interstellar medium with a speed of approximately 70,000 km/hr. The solar wind travels radially outwards with the pressure dropping over distance. The area where the solar wind pressure is similar to the IM impact pressure is called the heliosphere. IMAP is trying to obtain energetic neutral atoms (ENAs) from this boundary region. The neutral atoms are not affected by the solar wind pressure.

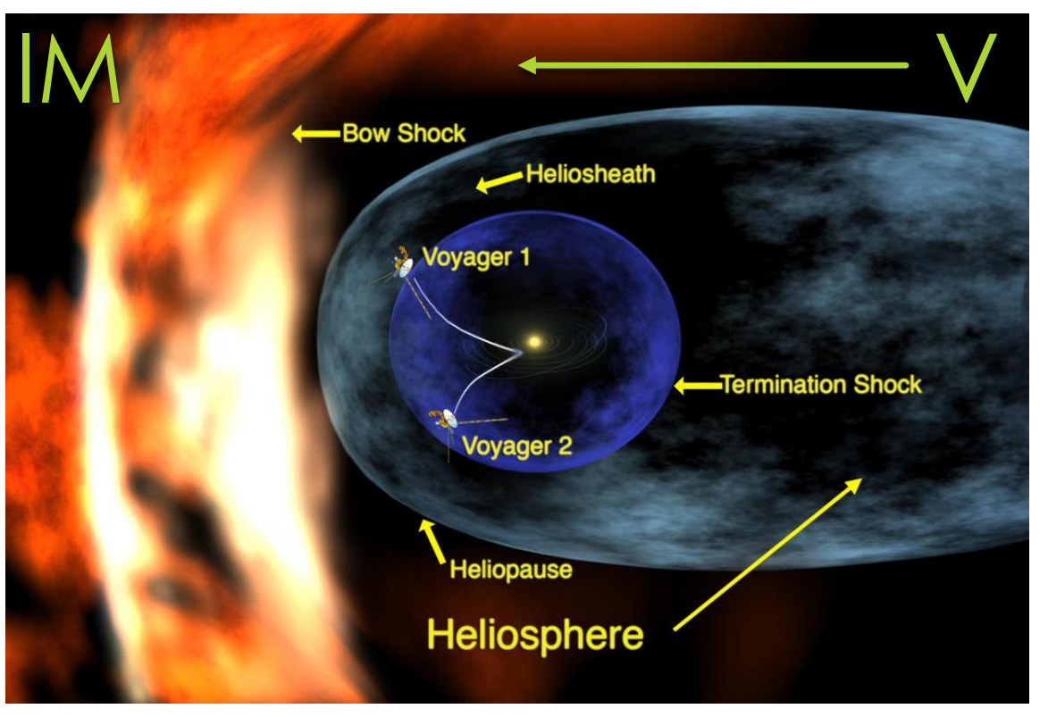

Figure 1: Sun moving through IM

Background

IMAP-Lo's main goal is to detect ENAs at energies ranging from 10eV-1,000eV. The satellite will rotate on an axis that points towards the Sun. IMAP-Lo's field of view is oriented perpendicular to the spin axis and thus traces out a circle on the sky. After half a year, IMAP-Lo will create a complete sky map of ENAs at different energies.

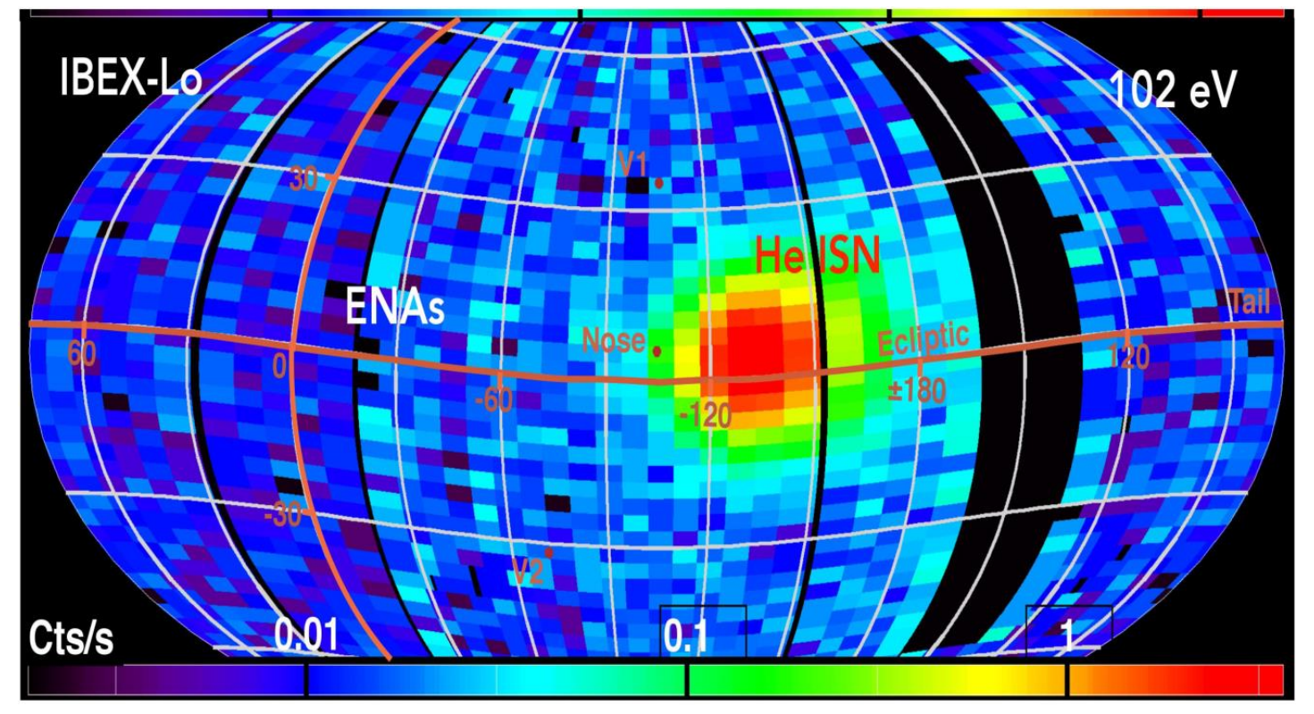

Figure 2: Sky map of the heliosphere made by IBEX-Lo detecting different ENA energies

Problem Statement

The original instrument that was sent out to observe low energy ENAs was IBEX. The incoming neutrals enter through a collimator that filters out certain directions. These ENAs will then impact a conversion surface, where they are converted to negative ions. Then the ions will be directed through an electrostatic analyzer (ESA). With a given voltage across the ESA, only ions with particular energies will be able to make it through the 180° curve. The ions that do make it through to the time-of-flight system have their velocity measured. By determining the energy and velocity, the mass of these ions can be obtained. Since there is such a low rate of incoming neutrals, it is important to reduce any background noise as much as possible. There is a much higher rate of energetic charged particles in space and it is very important to filter out as much of these as possible, hence the purpose of this trade study.

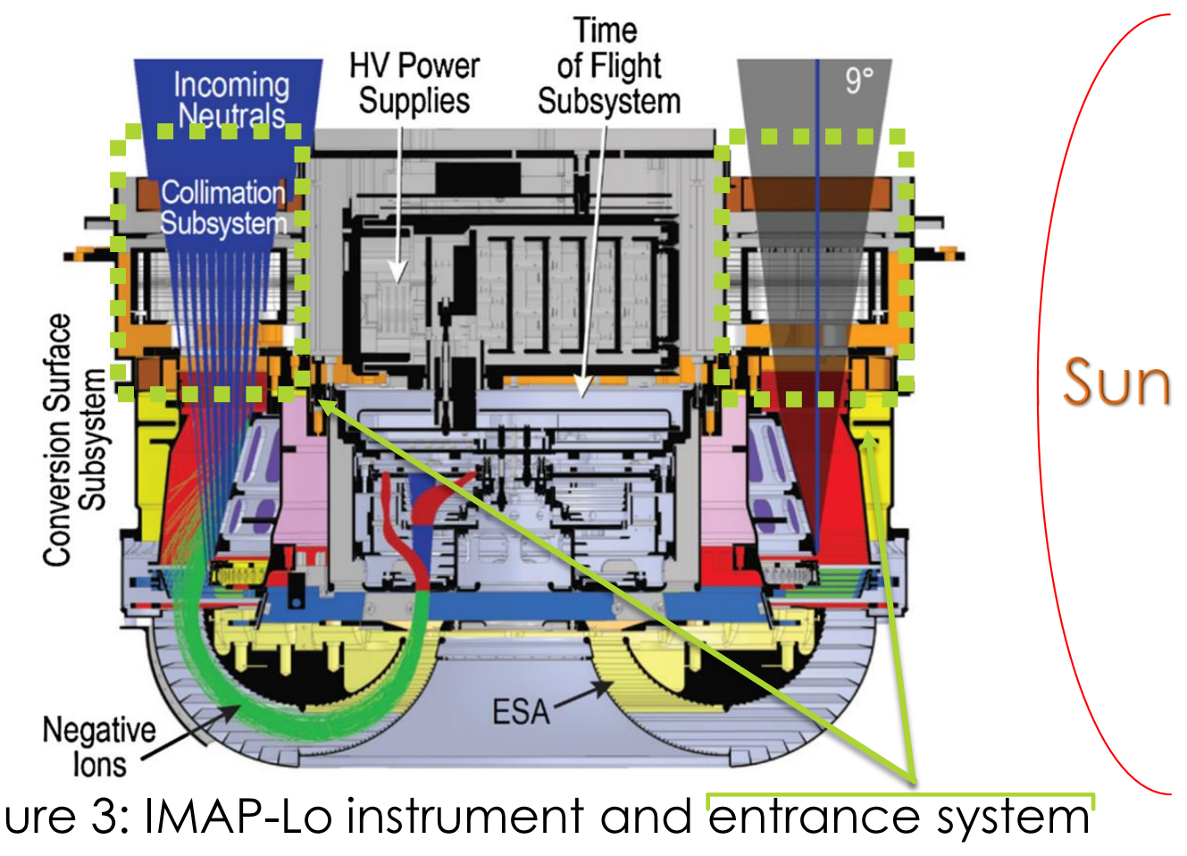

Figure 3: IMAP-Lo instrument and entrance system

Objectives

The original design (Figure 4) rejected incoming ions by setting a +3kV potential to the collimator (rejection design). This design is compared to a new design (Figure 5) in which the incoming ions are deflected away from the conversion surface (deflection design). The rejection design has the disadvantage that it accelerates electrons into the instrument. The deflection design should eliminate this, while also reducing the voltage needed to prevent charged particles from impacting the conversion surface.

Methods/Analysis

The first step in this trade study was to simulate the original rejection design versus the new deflection design, using the Simion program. This program is used to simulate particle paths and the influence electric potentials have on those trajectories. Geometries in this program define the shape of objects that these particles can interact with during flight.

First, a geometry is chosen for simulation and will be tested for different voltage steps on the electrodes and collimator (depending on design). Once a geometry and voltages are chosen, a particle population is determined. This population has starting positions (angles of approach) and energies (1keV-2keV) determined from the birth of the particle. After a particle has left its starting point the geometry and electric fields, produced by the voltages, determine its path through the instrument. Once all voltage and energy steps have been simulated for a design, another design is chosen and the process is repeated.

For the deflection design, it is shown that the majority of the ions that were hitting the conversion surface were coming from angles close to 90° from the entrance and from the outer direction (from the upper part of Figure 6). The addition of a shield wall physically blocked an average of 51.58% more ions (Figure 7). The outer shield wall was extended a total of 47.8mm farther out than the original design. For figures 6 and 7, each color represents a population of ions with a specific angular distribution.

The inner electrode was redesigned to fill more space outside of the 9° field of view. Three outer electrode designs (6-prong (48mm), 8-prong (66.8mm), and 10-prong (85.4mm)) were tested to see if any significant difference in deflection results could be determined. The inner electrode was held at a constant length of 38.6mm during the testing for these three designs. A minimum spacing of 3mm (1kv/1mm) was used between the electrodes and any flat surface to prevent strong potential gradients.

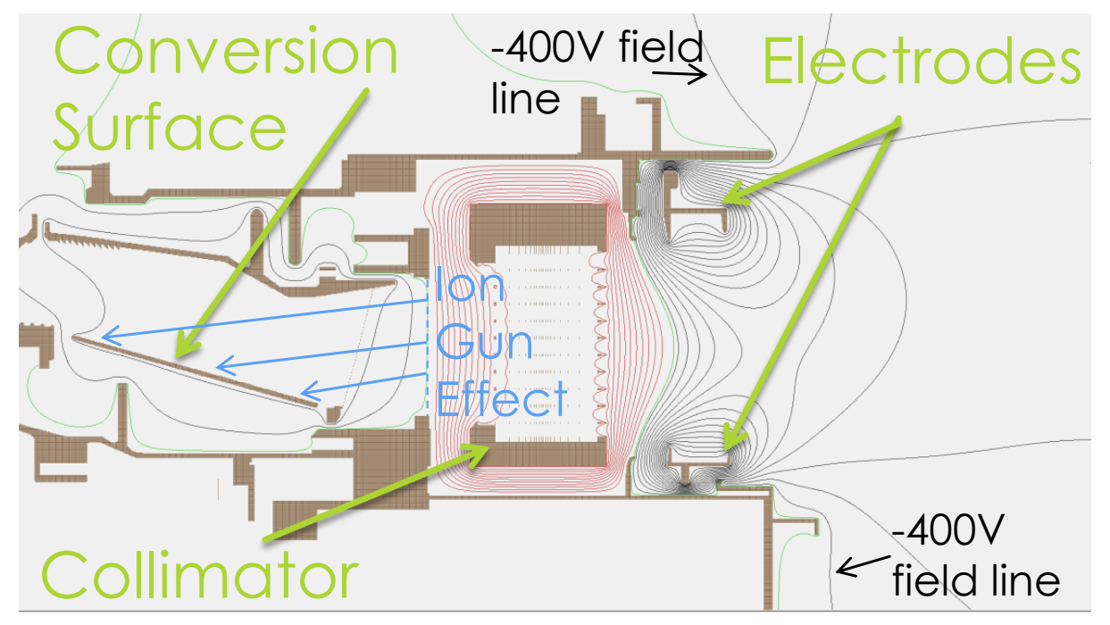

Figure 4: Original rejection design with collimator set to +3kV and electrodes set to -4kV

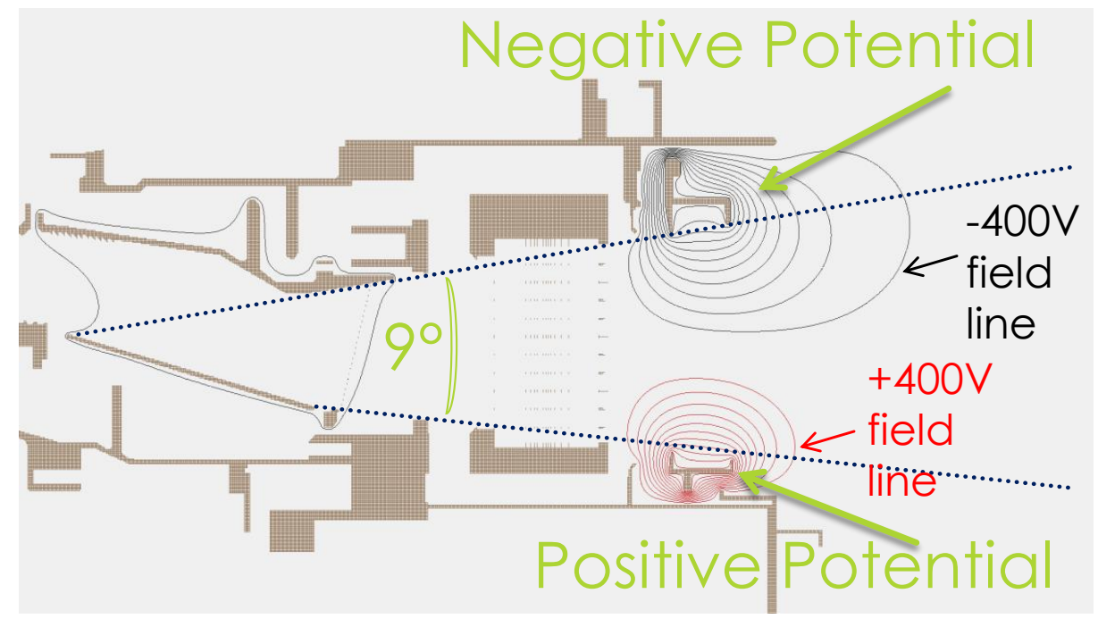

Figure 5: Deflection design with outer electrode set to -3kV and inner electrode set to +3kV

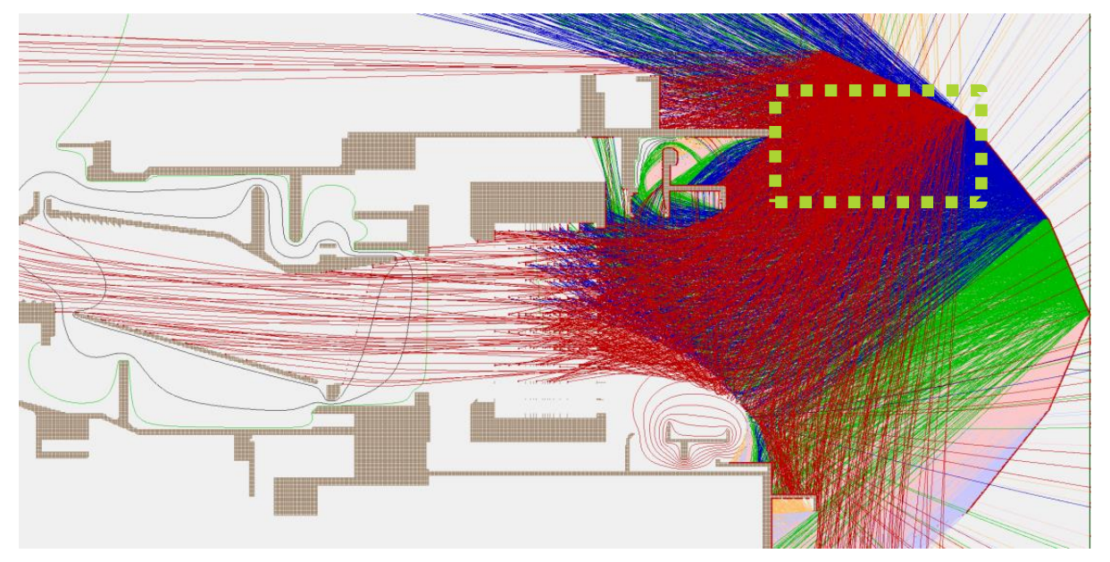

Figure 6: Deflection design with no outer wall extension

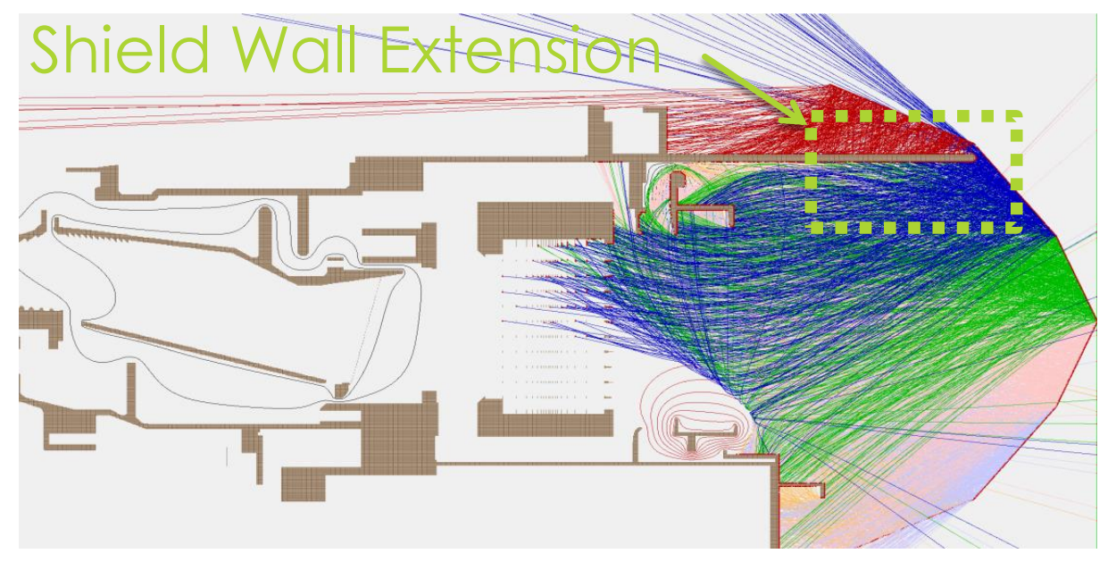

Figure 7: New deflection design with the outer wall extension

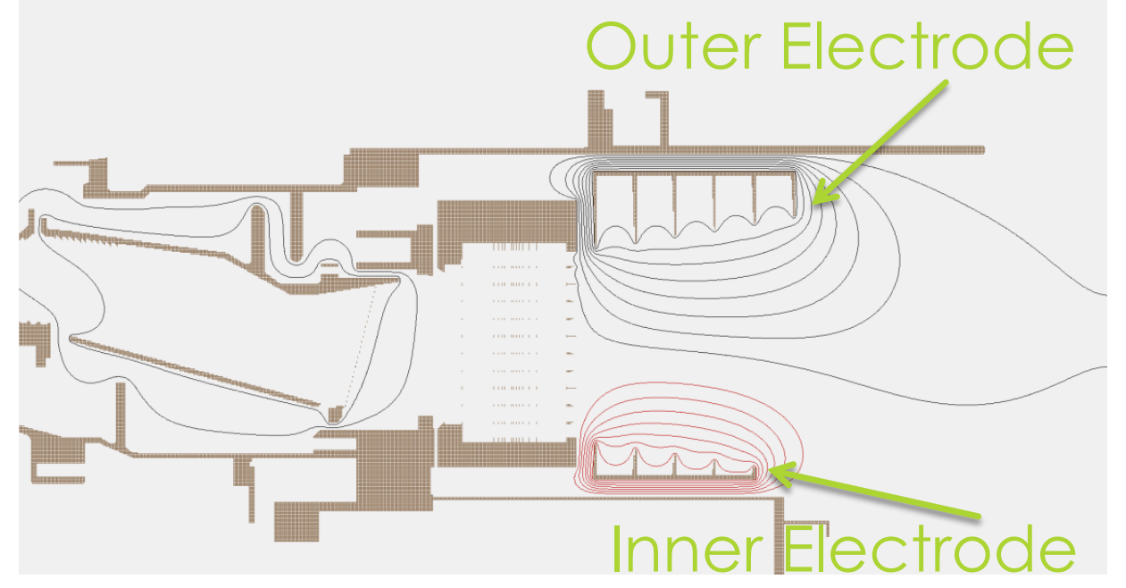

Figure 8: New 6-prong deflection design with outer wall extension (electrodes set to ±3kV)

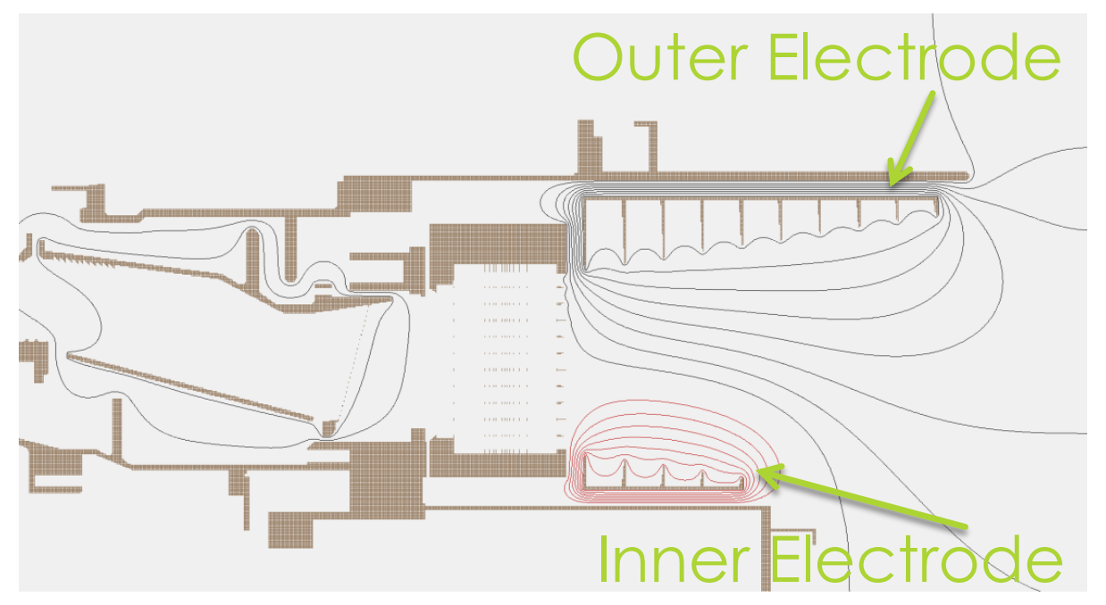

Figure 9: New 10-prong deflection design with outer wall extension (electrodes set to ±3kV)

Results

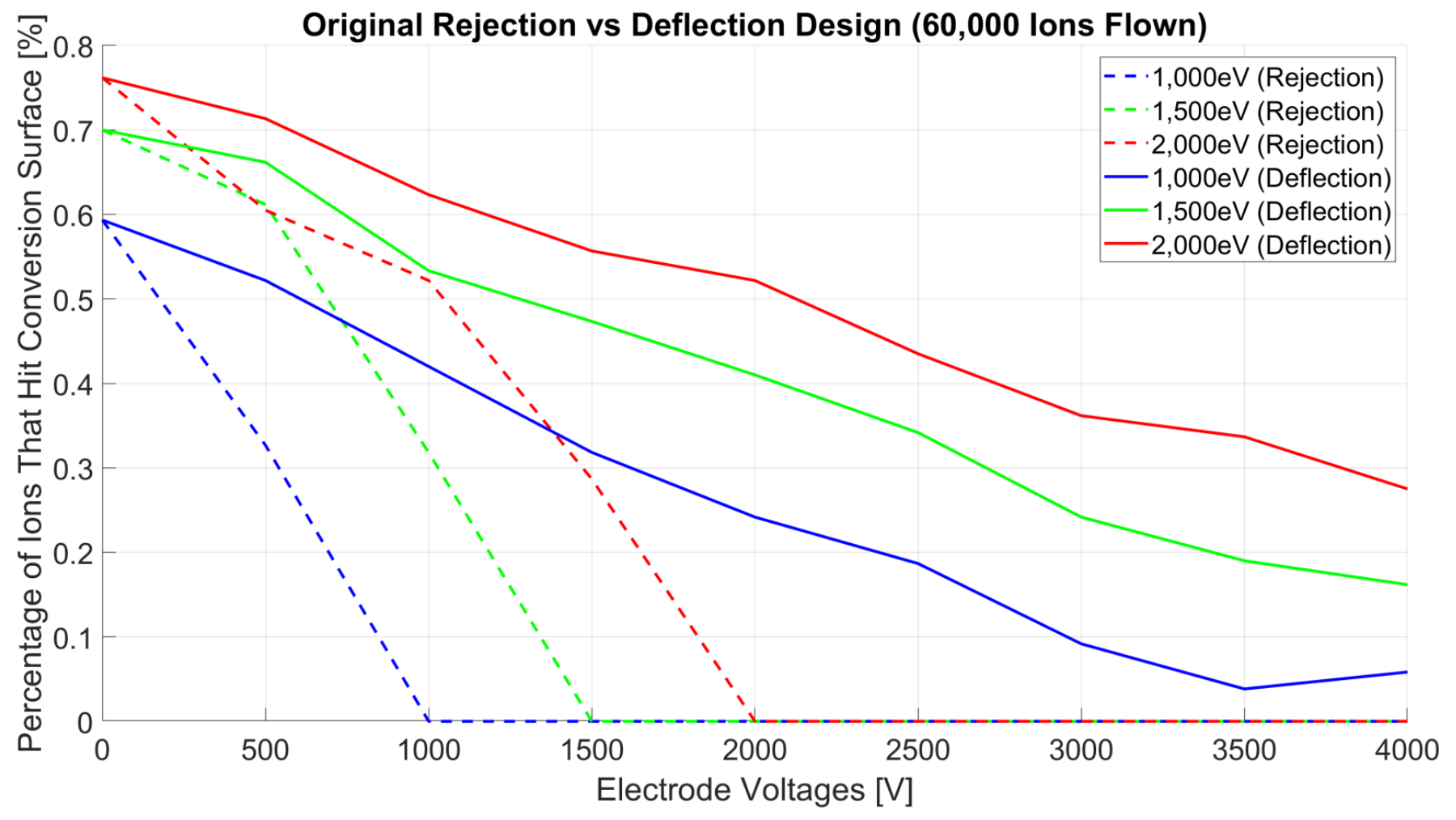

Figure 10: The graph above shows the fraction of ions that hit the conversion surface as a function of voltage. This simulation was run for two different design and three incoming ion energies.

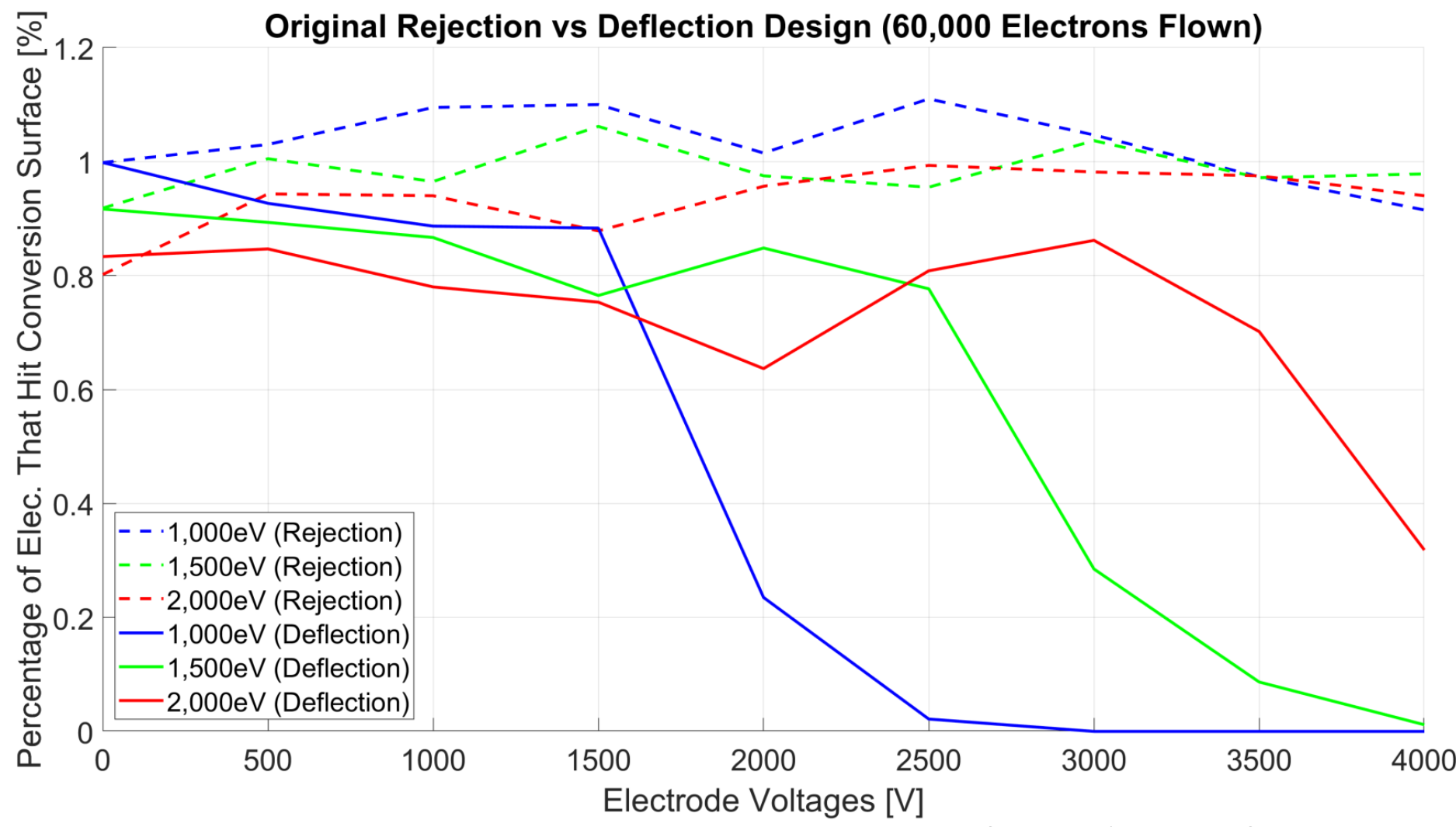

Figure 11: The graph above shows the fraction of electrons that hit the conversion surface as a function of voltage. This also shows a reduction of the "ion gun" effect for the deflection design.

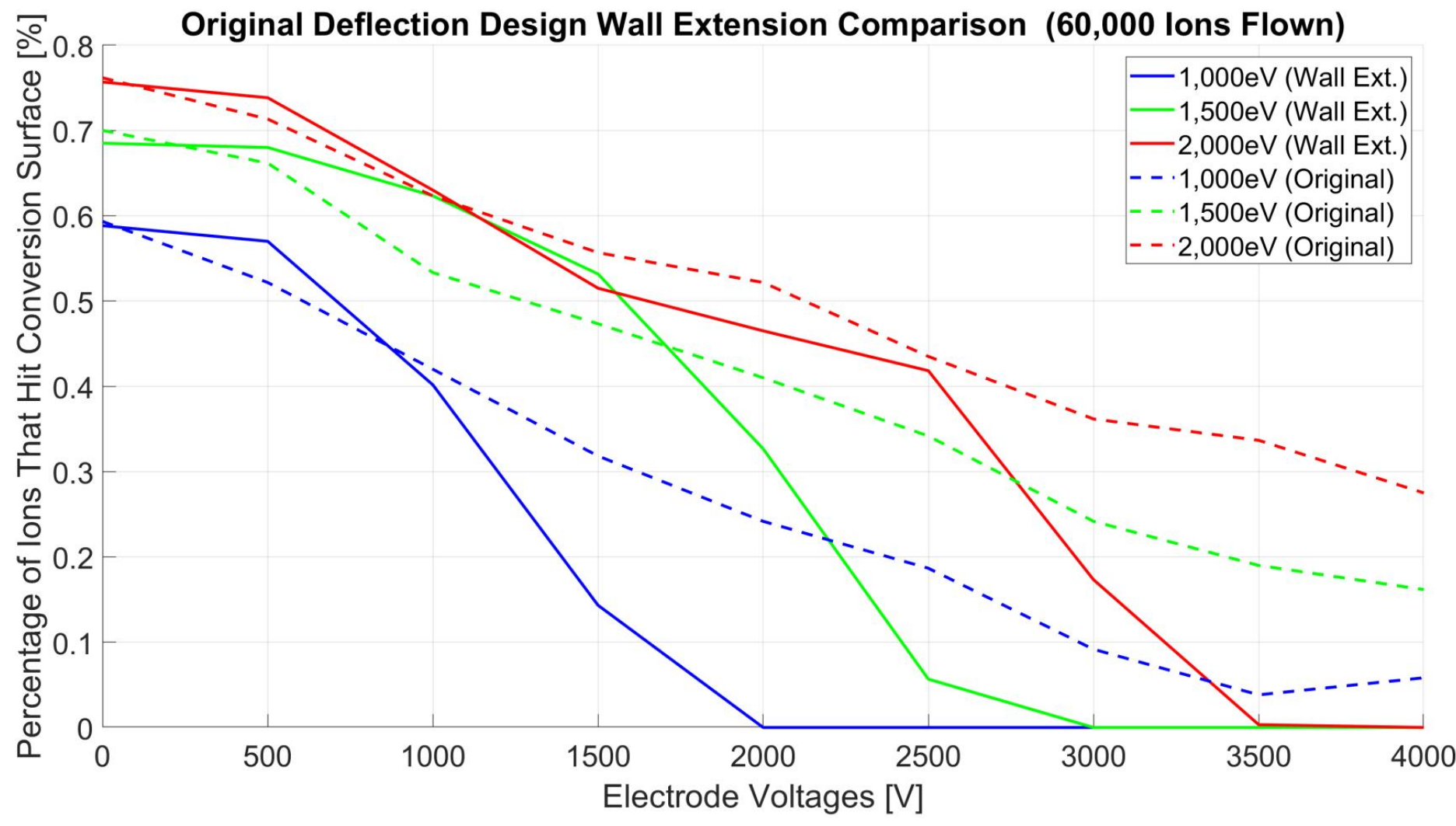

Figure 12: The graph above shows the fraction of ions that hit the conversion surface as a function of voltage. This simulation tests the effectiveness of the shield wall extension.

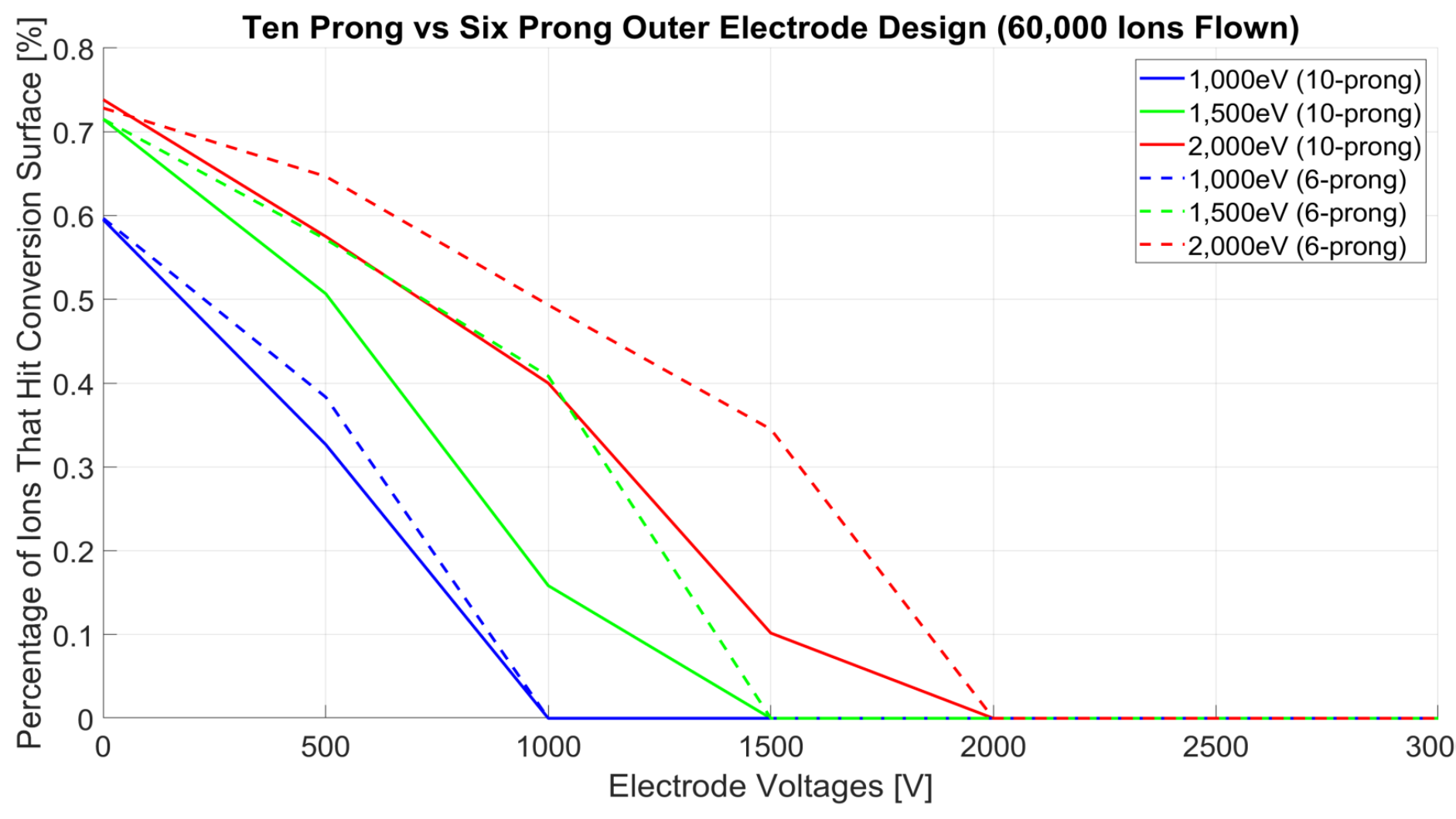

Figure 13: The graph above shows the fraction of ions that hit the conversion surface as a function of voltage. This simulation tests the six prong design against the ten prong design.

Result Analysis

- To quantitatively assess the results, the equation $r = 1 - \left(\frac{n_1}{n_2}\right)$ was used. r is the ratio of effectiveness between two designs. n_1 is the number of particles that hit the conversion surface from the more effective design while n_2 is from the less effective design.
- The ratio (r) was obtained for each voltage step was gained and then averaged for a single particle energy. The ratios for all three energies for each design were then averaged to obtain the final ratio.
- The dipole fields of the deflection design fall off faster away from the instrument compared to the original deflection design. This is better for both IMAP-Lo and any surrounding sensitive instruments.
- The shield wall extension would have been a problem due to physically sticking out farther on IBEX. IMAP-Lo does not have this space constraint, making it a viable option.

Conclusions

- The "ion gun" effect is completely eliminated due to the collimator being set to ground and not accelerating positive ions toward the conversion surface.
- The original ceramic insulators for the collimator can be eliminated because due to the grounded collimator as well.
- The ten prong deflection design eliminates ions up to 2keV with a ±2kV potential on the electrodes. This, combined with the collimator on ground, greatly reduces the voltage compared to the original rejection design.
- Overall, the new deflection design, combined with the shield wall extension, outperforms the original rejection design and should be favored for the final design.

Future Work

- One choice would be to choose a larger source population for both electrons and ions to reduce error and cover more incoming angles. Source populations should be moved outside the influence of the electric fields to create a more accurate simulation of their approach.
- A logarithmic energy scale should be used instead of a linear scale to reduce redundancy in simulations.
- A "wrap around" design of the shield wall at the front end of the electrodes should be tested to reduce the reach of field lines even further.

Bibliography

1. Zell, Holly. "The Heliosphere." *NASA*, NASA, 2 Mar. 2015, www.nasa.gov/mission_pages/sunearth/science/Heliosphere.html.
2. McComas, D. J., et al. "Interstellar Mapping and Acceleration Probe (IMAP): A New NASA Mission." *SpringerLink*, Springer Netherlands, 22 Oct. 2018, link.springer.com/article/10.1007%2Fs11214-018-0550-1.