TFIPS: A Compact, Low-power Heavy Ion Spectrometer for Space Environments

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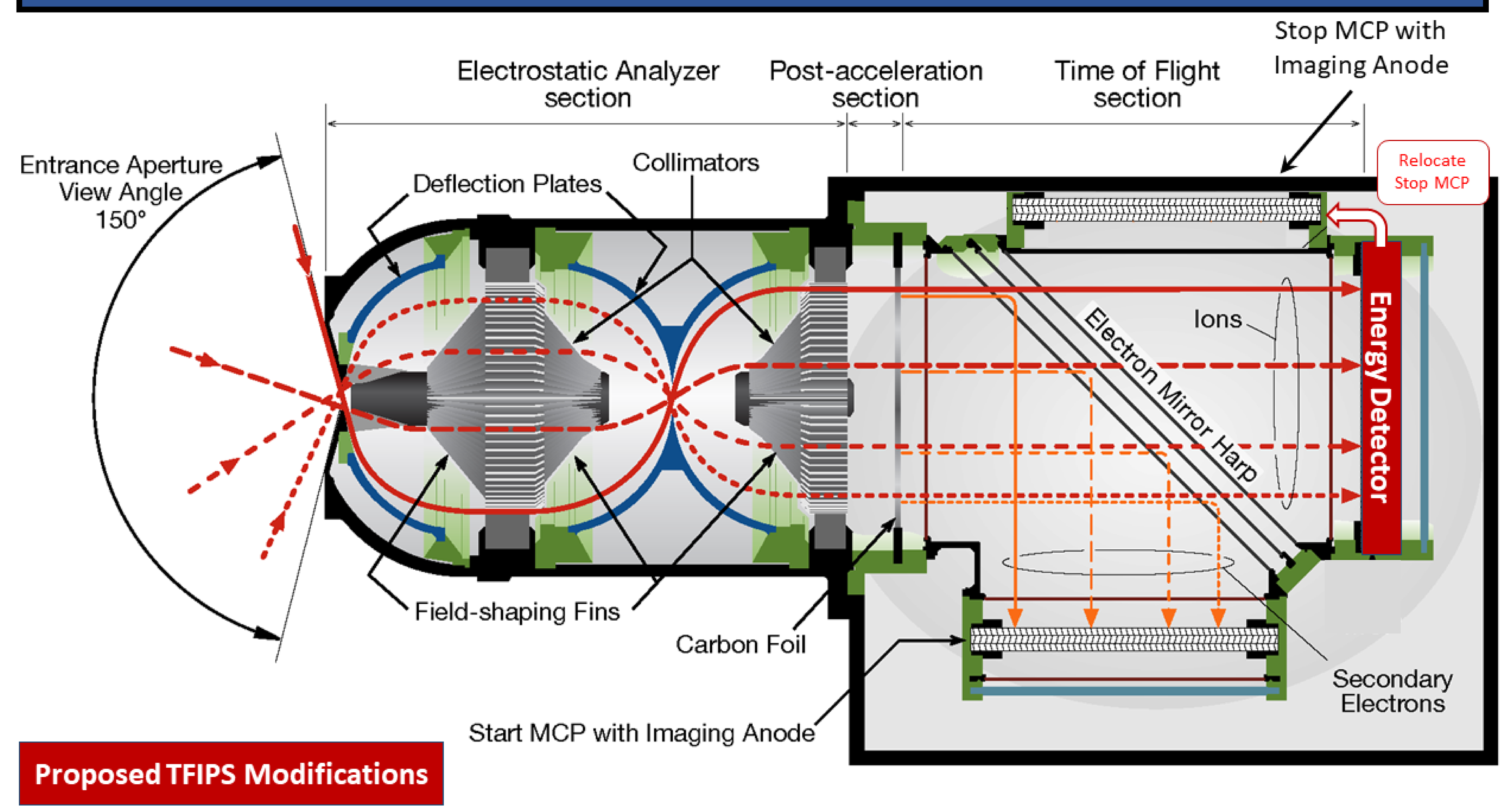
Abstract

Heavy ions provide vital signatures that explain the physical processes taking place in the diverse plasmas of space environments. Measurement of particle mass provides compositional information of plasmas whereas charge state unmasks the physical origins that produce the ions. This translates to solutions to critical science questions anywhere in situ heavy ion detections can be made. For example, it is still unknown which physical processes generate the supersonic outflow of the solar wind from the Sun into the Heliosphere. Likewise, the rapid expulsion of plasma during Coronal Mass Ejections (CMEs) produces heated – high charge-state – plasma concurrent with shock accelerated ions and cold filamentary material that interacts with the ambient solar wind. Similarly, in diverse planetary magnetospheres plasma source identification, transport, and energization must be studied to define and quantify a variety of phenomena e.g., global convection patterns, auroral footpoints, solar wind-magnetosphere coupling, and the ionization of neutral matter such as rings, atmospheres, and moon surfaces via interactions with radiation or plasma. To measure the heavy ions of these environments we are developing a low mass, compact, power-efficient time-of-flight (TOF) mass spectrometer called TFIPS or the Triple Fast-Imaging Plasma Spectrometer. The TFIPS instrument concept utilizes heritage design from the FIPS instrument that flew onboard the MESSENGER mission around Mercury for four years. Modifications have been made to include energy detection for triple-coincidence measurements that provide ion species, charge-state, and 3-D velocity distribution between 0.5 – 25 keV/e. We simulate instrument performance using COMSOL Multiphysics to trace the ion optical path through the electrostatic analyzer and time-of-flight chamber. Finally, we are using the state-of-the-art calibration facilities in the Space Physics Research Laboratory and the Solar and Heliospheric Group's Plasma Instrumentation Lab to protype and calibrate the new time-of-flight chamber.

The Triple Fast Imaging Plasma Spectrometer Design

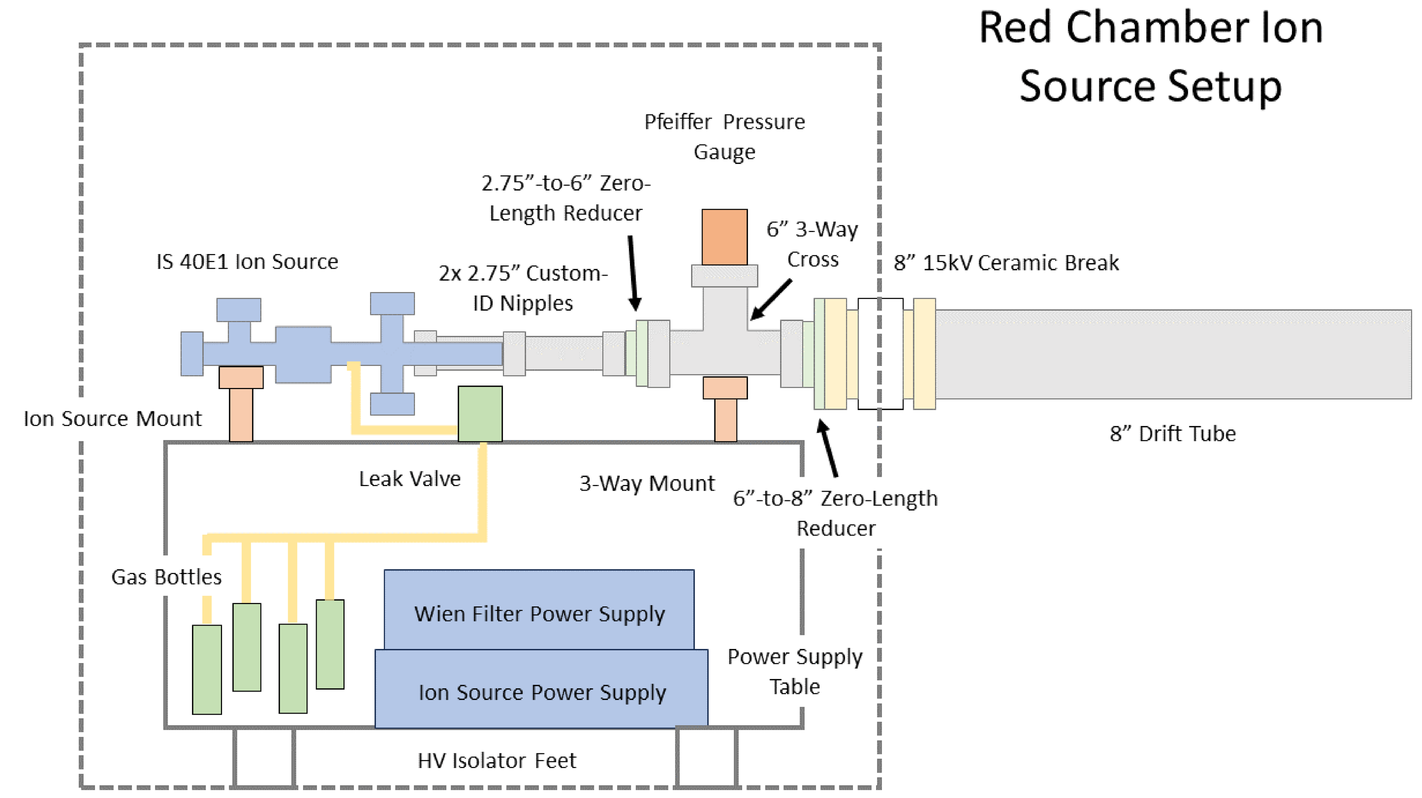


The Triple Fast-Imagine Plasma Spectrometer is an instrument concept being developed by the Solar and Heliospheric Research Group (above). Particles that pass through the electrostatic analyzer on the right are filtered by their energy-per-charge (E/q). Afterwards, the ions enter the time-of-flight chamber which measures their velocity (v) through the production and measurement of electrons along the flightpath. Finally, we propose to add an energy detector to the exit of the time-of-flight chamber to measure the particle's energy. By convolving the three measurements (E/q, v, E) we are able to determine the mass, charge, and 3D velocity distribution of the measured particles. The addition of the energy detector requires significant alterations to the time-of-flight chamber and it is the purpose of this research to explore and characterize any changes that result in the performance.

Hardware

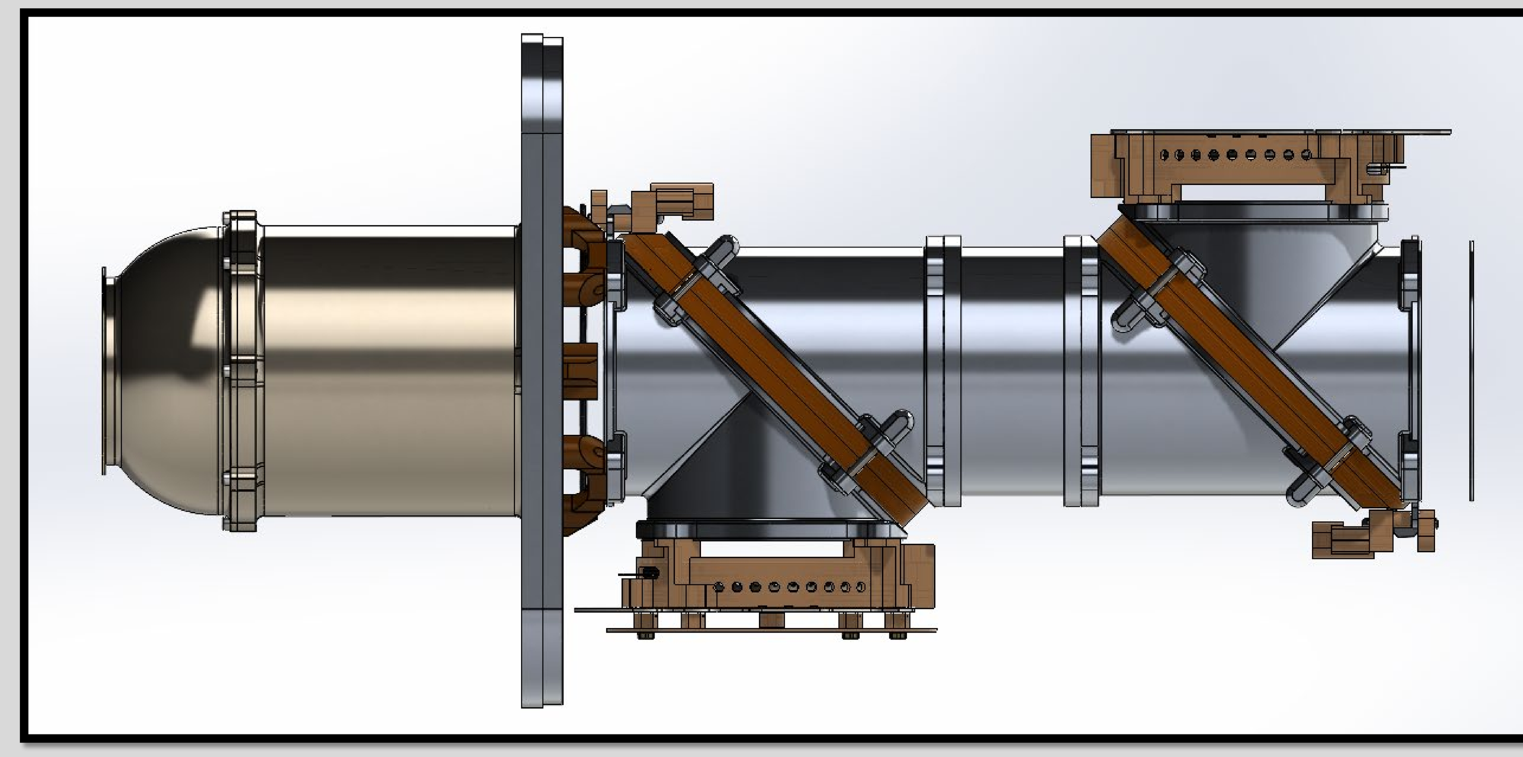
Our final stage of research will be to prototype our existing design using our simulated optimal parameters. To accomplish this new equipment was purchased for our laboratory. To the right shows the current modifications that are underway to install a new Prevac ion source that can generate, refine, and energize plasma to simulate particles of the solar wind and planetary magnetospheres.

Red Chamber Ion Source Setup



Simulations

Through modifications to existing heritage designs we have a developed a high-fidelity computer-aided design (CAD) for structural and performance analyses. The electrostatic analyzer on the left selects particles by E/q whereas the time-of-flight chamber on the right determines velocity before subsequent energy deposition into a solid-state detector. This work was done by Marcello Lara and Charles Via, engineering students in the Climate and Space department.



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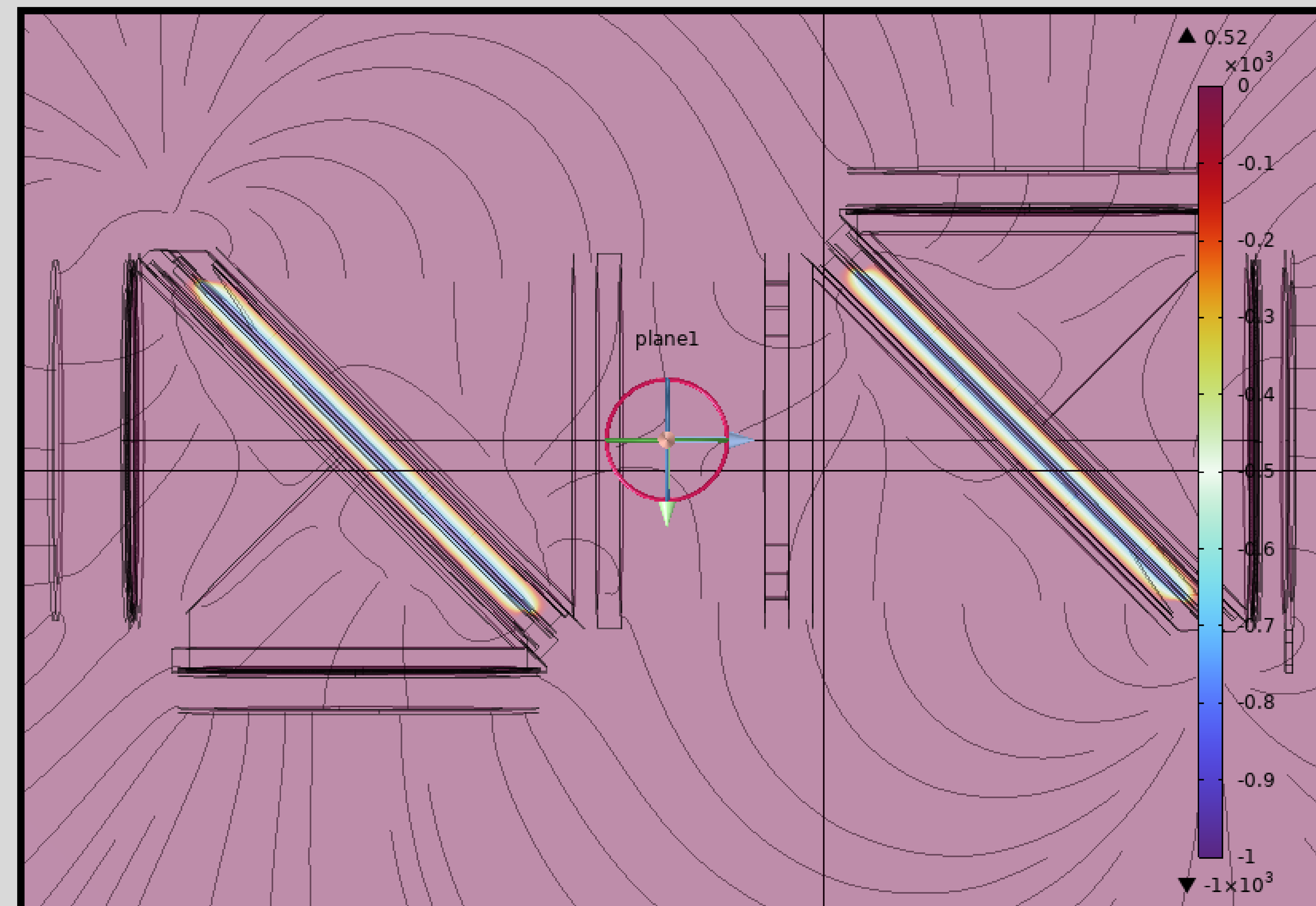
We construct our performance simulations by importing the high-fidelity CAD (above) into the COMSOL simulation environment. COMSOL first simulates the electromagnetic fields by solving the Laplace equation for regions surrounding the structures designated as electrodes (right). After the fields are determined the particle trajectories are traced out by stepping through their dynamic equations. The highest voltages (approximately 1 kV) shown here are applied to the harps which allow the passage of ions through the time-of-flight chamber whereas lighter electrons are easily deflected above and below to stop and start detectors.



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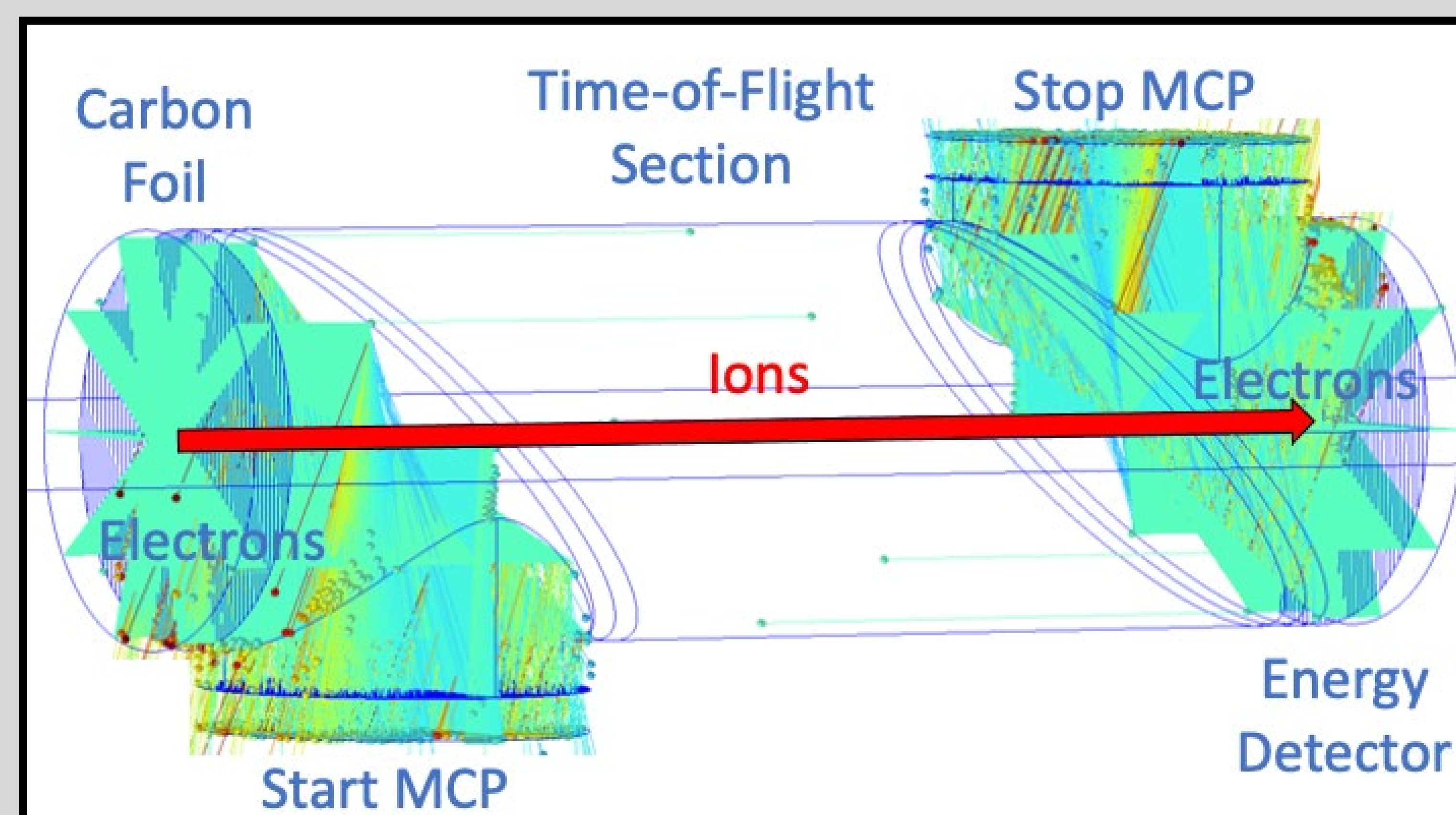
As the ions pass through the carbon foil at the entrance and strike the gold-plated solid-state detector at the exit they produce electrons that once measured designate the initial and final time of the ion's known flightpath (right). Thus, the derived speed combined with trajectory information preserved during the detection provide 3D velocity distributions of particle populations in diverse space environments. By implementing energy detectors to the heritage design we have upgraded a double-coincidence detector that provides mass-over-charge to a triple-coincidence which is capable of unambiguously identifying particle species and charge states.



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