Curved Microchannel Plates for Time-of-Flight Mass Spectrometer

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Abstract

The COmposition and DIstribution Function analyzer (CODIF) is a typical Time-of-Flight (TOF) mass spectrometer that uses thin carbon foils and flat micro-channel plates (MCP) in chevron stacks. To measure TOF of incoming ions a start signal is initiated by secondary electrons from the carbon foil and stop signal is generated by the MCP chevron assembly a known distance away. The purpose of the project was to modify and design an inner bracket system for the existing CODIF instrument to use newly developed curved MCPs. The MCPs are curved to simplify electron steering and accommodate the cylindrical shape of the CODIF. The goal of the bracket system was to secure a curved MCP stack in a modified holder at a desired distance from a toroidal shaped MCP stack. The bracket system created uses vertical rails with standoffs to separate thin plates that hold the start and stop chevron holders. This design allows for improved performance and efficiency of the CODIF instrument and the ability to change flight path length for various testing.

Introduction

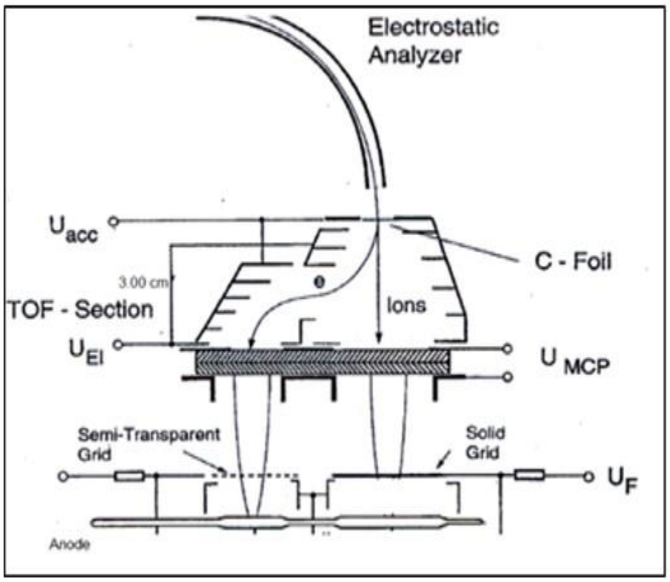
CODIF is a spaceflight mass spectrometer that used to measure the mass/charge ratio of ions. It has been used in missions to the magnetosphere, which is the region around the Earth where the flow of particles is dominated by the magnetic field of the Earth. Outside the magnetosphere, the flow of the solar wind past the Earth strongly affects particle motion. We want to know the mass/charge ratio of ions, because mass and charge are the two key ingredients by which particles engage with electric fields, and therefore either gain or lose energy. They also control how particles move in a magnetic field. Ion energy and motion are important because they affect how the Sun's energy is dissipated in the magnetosphere, particularly when a spectacular solar coronal mass ejection erupts. The aurora is a visible effect of the dissipation, as well as somewhat rare power grid failures. Ions that gain considerable energy can interact with spacecraft, and potentially cause damage to electronics or astronauts. CODIF helps us understand how the whole solar-magnetospheric system works, and how it affects the way we live our lives on Earth and in space. using new MCP configuration and better electronics we will improve the efficiency of the existing CODIF to analyze the new ions both from the ionosphere and the Sun.

Project Goals and Challenges

The objective of this project was to fabricate modified MCP holders to make use of newly developed MCPs to more efficiently steer the secondary electrons to the MCP and apply a lower attraction high voltage to the face of the MCP. These fixtures must clamp the MCPs firmly but without damage and allow MCP output charge to reach a test anode without charging the fixture. The CODIF design change will require design, machine shop time, and vacuum chamber testing. The design effort required electrostatic simulations (SIMION) to determine the ion/electron dynamics in the TOF section and to determine the steering voltages for the deflection electrodes. To limit cost and be resourceful there was an effort made during design to reuse existing CODIF components with limited alterations. The performance of the modified CODIF design will be compared in vacuum chamber testing to the original by including the flat MCP and curved start in one quadrant, and the toroidal MCP and the curved start in another.

Original CODIF

The original CODIF configuration had ions enter the instrument through a spherical entrance called the Electro-Static Analyzer (ESA), which filters the ions based on their energy per charge ratio. After the ions are filtered, they are given a Post Acceleration voltage (PAC) to go in the TOF section. When the ions interact with the carbon foil they knock out secondary electrons that are steered with an electric field to initiate start and position signal by hitting at one end of the MCP. The ions penetrate through the foil and hits the other end of the MCP giving a stop signal. Ion TOF tails are produced in part by ion energy loss during passage through a carbon foil. Ion trajectories are scattered away from the initial direction and have a longer flight path. Curved target MCPs can equalize the flight path for ions after foil passage, improving TOF resolution by simply changing the shape of the MCP. These MCPS (micro-channel plates) are glass capillary arrays coated in a thin film to establish resistance and secondary emission functions. These new MCPs are curved to simplify electron steering and accommodate the cylindrical shape of the mass spectrometer.



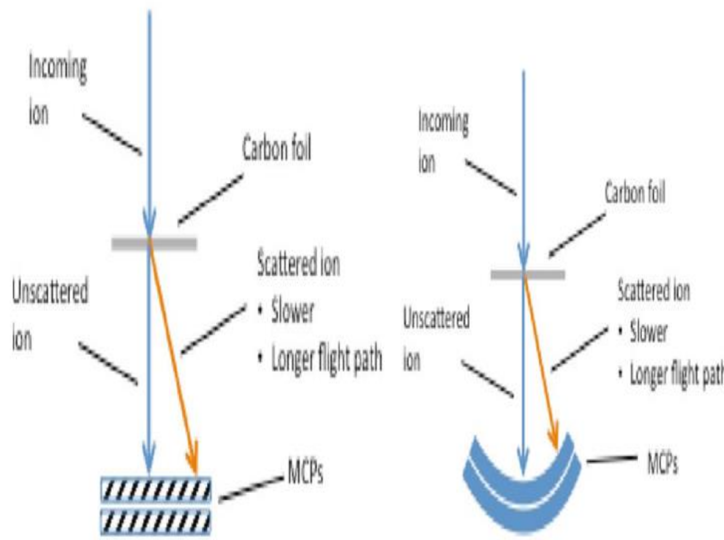
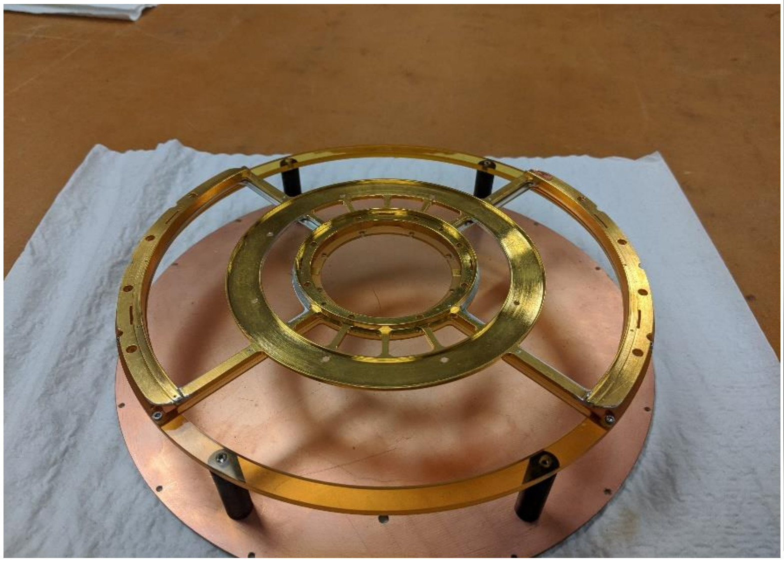


Figure 1: Original CODIF Figure 2: Comparing Ion flight path with flat and curved MCP.

Modified CODIF Design

Bracket system

The internal bracket system created uses four vertical rails with standoffs to separate thin plates that hold the start and stop MCP fixtures. These standoffs are cylindrical metal spacers cut to a measured distance to control flight path length from carbon foil to stop MCP. One modified quadrant will feature a curved Start MCP, and the original flat Stop MCP. The other modified quadrant will include both the curved Start and toroidal Stop MCPs. Electrostatic simulations have evaluated the best radius of curvature for the start MCP and these dimensions were used to determine the best placement of the vertical rails. These rails are connected to a copy of the existing base plate to connect the bracket system to the CODIF shell and carbon foil. The electrical components held below the ToF section were meant to remain unchanged and therefore, were ignored during the design process.



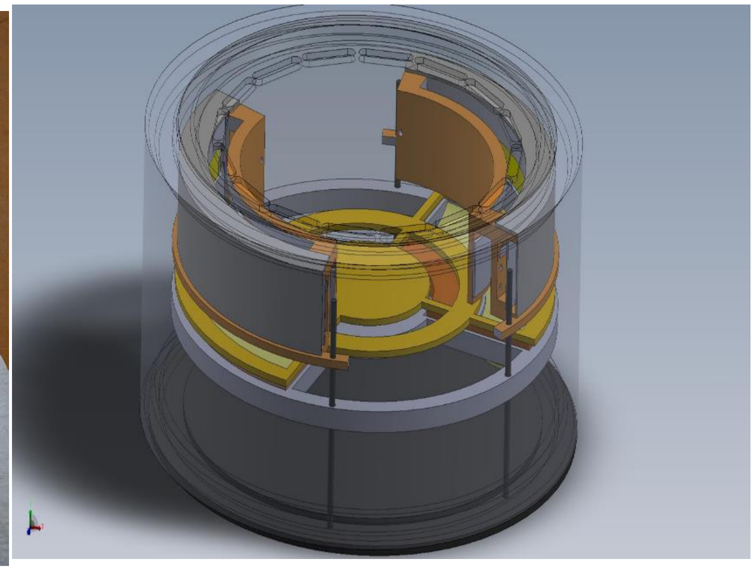


Figure 3 (left): photo shows the created rail-baseplate system with the modified stop butterfly. Figure 4 (right): the complete modified CODIF assembly with the shell and carbon foil made transparent.

Start Fixture

The first step in the start holder design was to determine the best placement and radius of curvature for the start MCP with SIMION simulations of the CODIF instrument. The earliest simulations of the curved MCP and anode placement, shown below, concluded that start MCP secondary collection is better closer to the exit MCP stack. However, proximity to the detection of ions could cause large angle scattering.

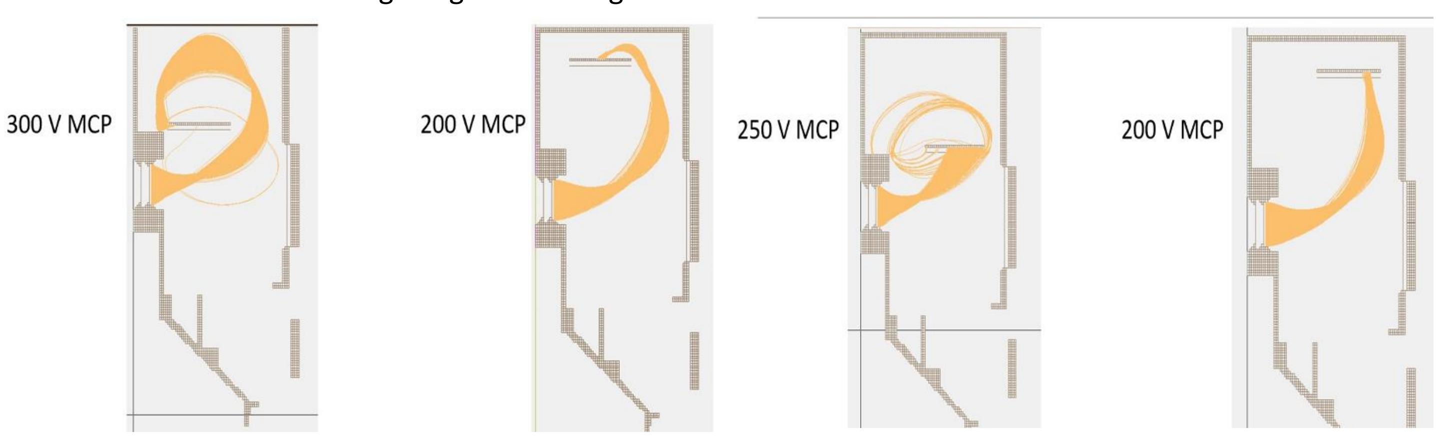


Figure 5: SIMION simulations of curved MCP and anode structure in modified CODIF.

The curved MCP and anode structure was shown to be capable of working in the CODIF but with larger required voltages than desired and potential ion scattering. A solution to improve scattered electron steering and reduce risk of potential ion scattering was to accompany the curved MCP with a cylindrical steering electrode. SIMION simulations confirmed that the curved MCP accompanied with a mirrored electrode allowed for nearly total electron collection and no risk of ion scattering. The simulations showed that closer to the carbon foil the better, but this distance is physically limited by the start holder dimensions. This limitation made the asymmetrical separation between the MCP and mirror critical to voltage range and efficiency.

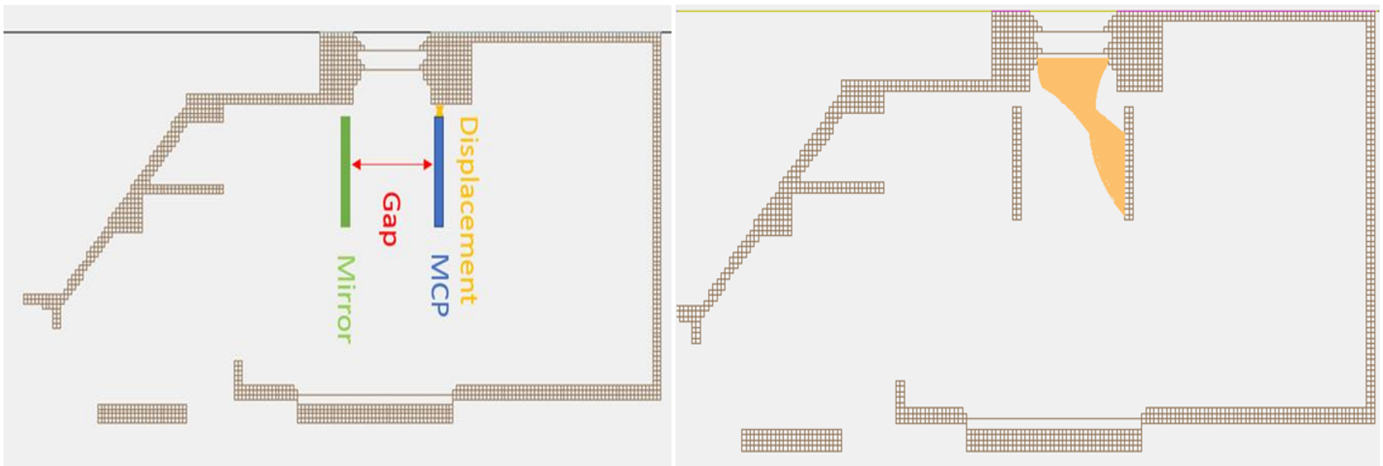


Figure 6: SIMION simulations to find critical MCP and mirror gap distance and desired proximity to the carbon foil.

While MCP placement was being determined, related design modifications were made to an existing curved MCP holder. The prototype ultem (vacuum-safe plastic) holder was originally made by UNH to test the feasibility of curved MCPs. The basic design of the holder was kept but with modifications made to hold a larger curved MCP and a grounded platform to keep the critical mirror gap distance constant. The same brass spring clamping is used for both holders.

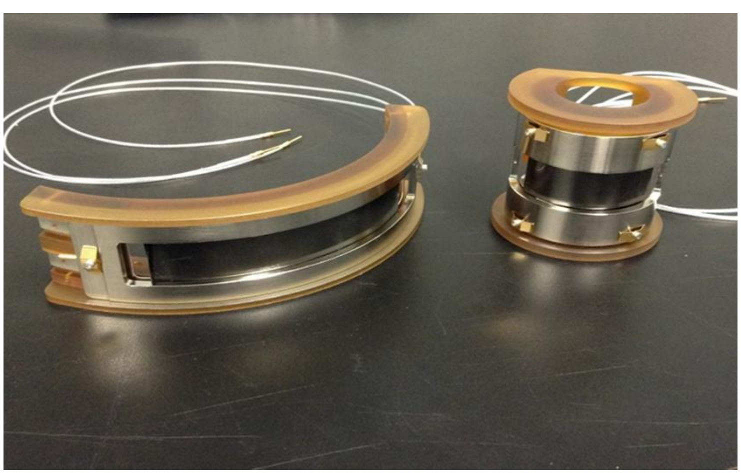


Figure 7: Prototype MCP holder

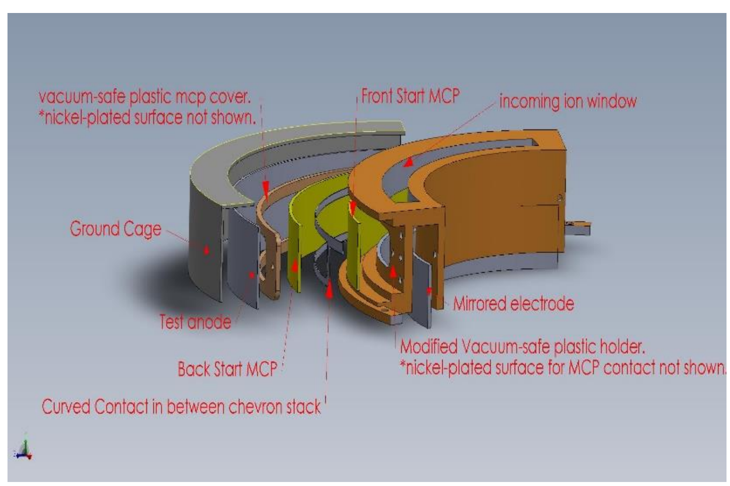


Figure 8: Modified MCP holder

The modified holder was made for a wider MCP to increase the size of the active area window and allowed wider contact surfaces for applying voltage. The start MCP is held at a positive high voltage using the modified nickel-plated holder and a thin curved nickel contact in between the MCP stack. A rear anode was also added to the start fixture to assist in steering scattered electrons but now a ground cage is required because of high voltages and proximity to the CODIF shell.

Stop Fixture

The goal of the toroidal shaped stop MCP was to keep the length of ion flight paths the same so the position of the toroidal MCP was intended to be the same as the original flat MCPs. By modifying the existing butterfly clamp to use the toroidal MCPs we were able to keep the flat MCP quadrant relatively unaffected and the flight path length the same. It was important to have the same ToF distance for both quadrants to allow for reliable testing and comparisons of the flat and toroidal MCPs. To give the same TOF distance as the flat MCP, the toroidal MCP and anode are held in a fabricated ultem fixture that sits in the butterfly clamp. The ultem fixture uses angled surfaces on each curved side to raise the trench of the toroidal MCP to equal the flat MCP position. SIMION simulations were used to determine that a toroidal anode was needed to maximize collection angle uniformity. The toroidal anode was able to be secured on the ultem fixture by adding a curved surface to the bottom of the fixture. A thick ultem gasket in the flat MCP stack is used to accommodate for height offset of the butterfly clamp caused by the toroidal MCP. Voltage is applied to the toroidal MCP with nickel-plated gasket and thin toroidal nickel contact in the middle of the stack. The designed toroidal assembly was able to maintain the same radial active area as the flat stack but the ultem cover on top of the MCP stack did not allow for the same 90-degree active area.

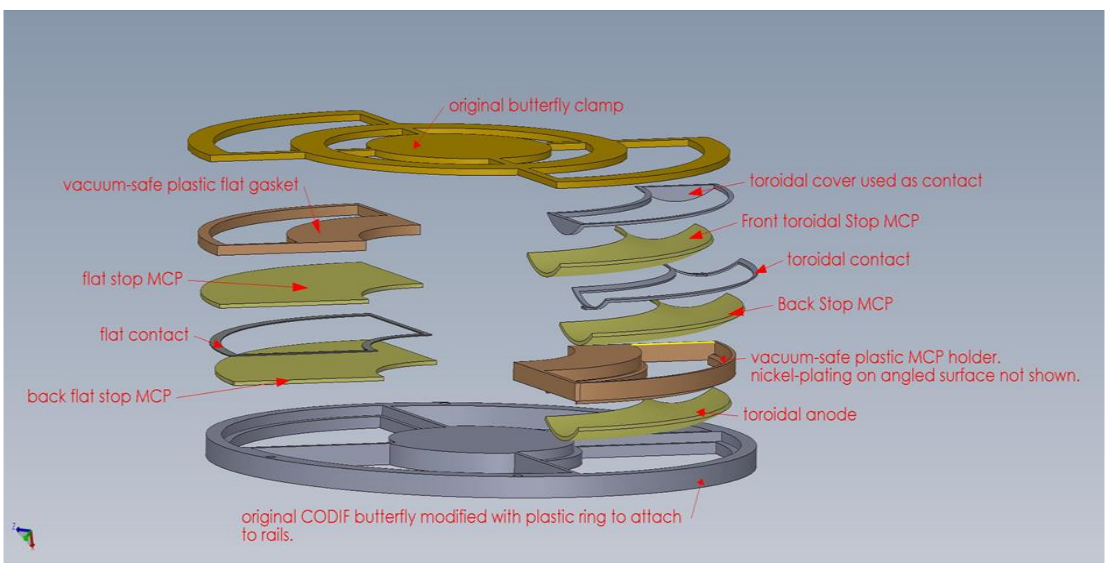


Figure 9: modified stop MCP butterfly clamp with the designed ultem fixtures and contacts.

Results

The performed SIMION simulations of the CODIF instrument determined the best radius of curvature and width of the start MCP will be 130 mm long and 17 mm wide. They will be bent into a cylindrical shape with an 83 mm radius of curvature. The best parameters calculated for the start MCP fixture is 3 ± 1 mm displacement from the carbon foil to the top of the MCP, a 15.5 ± 2 mm gap between MCP and mirror. The location of the MCP close to the carbon foil window means that the voltage can be much lower than in the earlier design of the instrument: 200 volts instead of the more typical 1000 volts. This improves high voltage stability. The lower attraction voltage relieves the power budget and facilitates the collection of the MCP signal to electronics located at ground. The geometry of the CODIF butterfly allows for a Stop curved MCPs with a toroidal shape, with a large radius of curvature of 75 mm, and a small one of 30 mm. Simulations predict a time of flight for secondary electrons from the carbon foil to the start MCP of 6.8 nS, with a 1.2 nS FWHM (figure 10), which is smaller than the flight times of ions. The benefit of a small variation in the flight times is better precision in the ToF measurement of the ion.

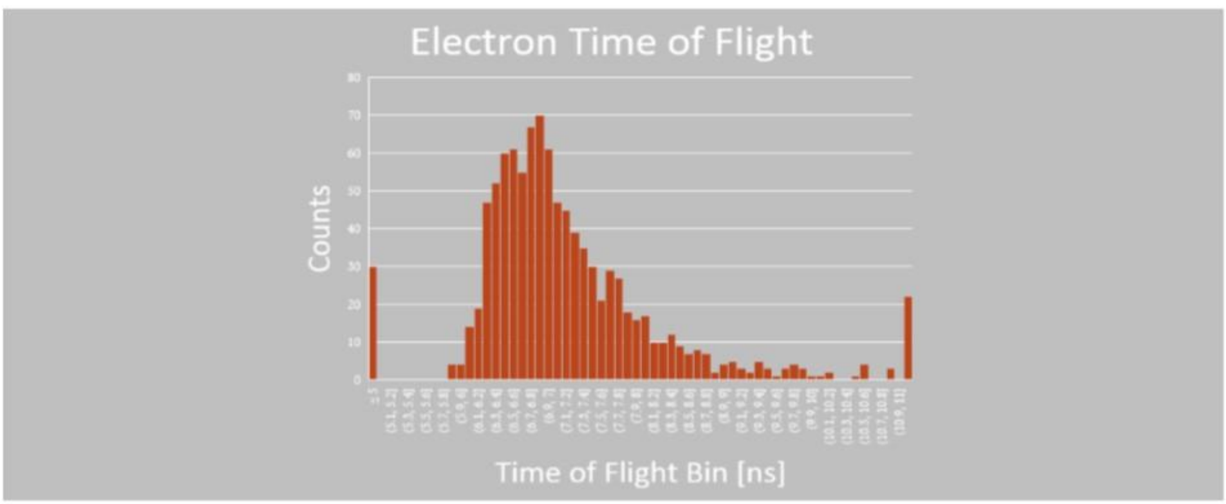


Figure 10: distribution of flight times for carbon foil electrons to reach start MCP

The UNH machine shop has made the rail baseplate system and has begun fabrication of the modified plastic start and stop MCP holders. The thin nickel contacts are being fabricated by Incom. Once the start and stop fixtures are completed nickel-plating will be applied by an independent company. When the fixtures are finished time of flight testing in vacuum chamber will be performed comparing the toroidal MCP quadrant with the original flat quadrant.

Acknowledgements

- Electrostatic simulations performed by Nick Lubinsky.
- Original MCP holder created by Mark Granoff.
- UNH Machine Shop members: Phillip Demaine and Aaron Bolton.
- Abbas, Zain, "Improving the Efficiency and Resolution of Time of Flight (TOF) Mass Spectrometer for Magnetospheric Applications." (2016).Honors Theses and Capstones. 309.