High Dynamic Range Electrostatic Analyzer for Magnetosphere-Ionosphere Studies

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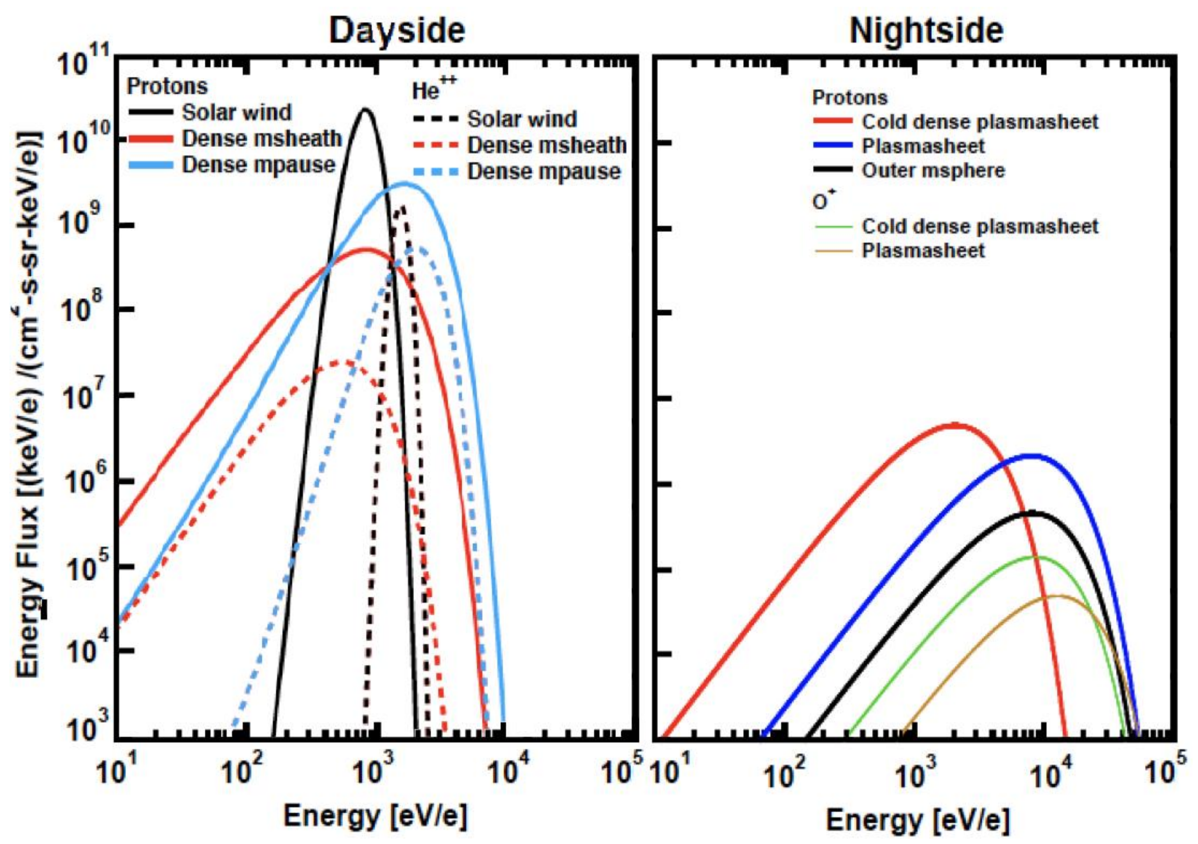
Introduction

Plasmas within the Heliosphere range from fast flowing, cold solar wind to diffuse, hot magnetospheric plasma to cold, dense ionospheric plasma. Covering the dynamic range for the full range of conditions for even one plasma population is challenging, let alone if measured by the same instrument. To study cross-scale phenomena, such as ion outflow from the ionospheric source to the dispersal in the magnetosphere, a wide dynamic range is necessary.

We present the current progress on the design and testing of a novel ESA design capable of a large dynamic range. To reduce incoming flux, a voltage is applied to a plate on the outer hemisphere, called the flux reducer. Electrically controlled, the flux reducer changes particle trajectories such that a smaller fraction are measured. Model results demonstrate the geometric factor can be changed by 3 orders of magnitude.

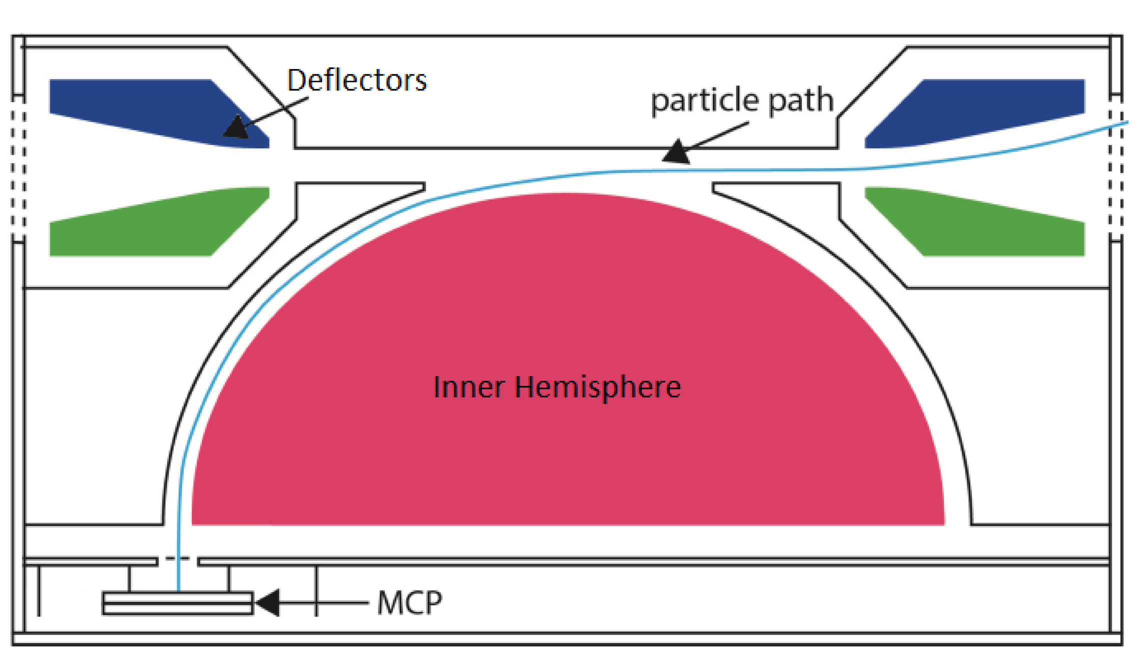
Background



Typical plasma distributions for the dayside (left) and nightside (right) magnetosphere

Magnetospheric Plasma Distributions:

- Day- and nightside energy fluxes vary by ~5 orders of magnitude
- To measure composition, e.g. He^{++} or O^{+}, several orders of magnitude lower than the peak flux are additionally needed
- An example magnetospheric spacecraft mission would need to cover ~8 orders of magnitude in energy flux to cover the regions from the magnetosheath to the nightside plasmasheet

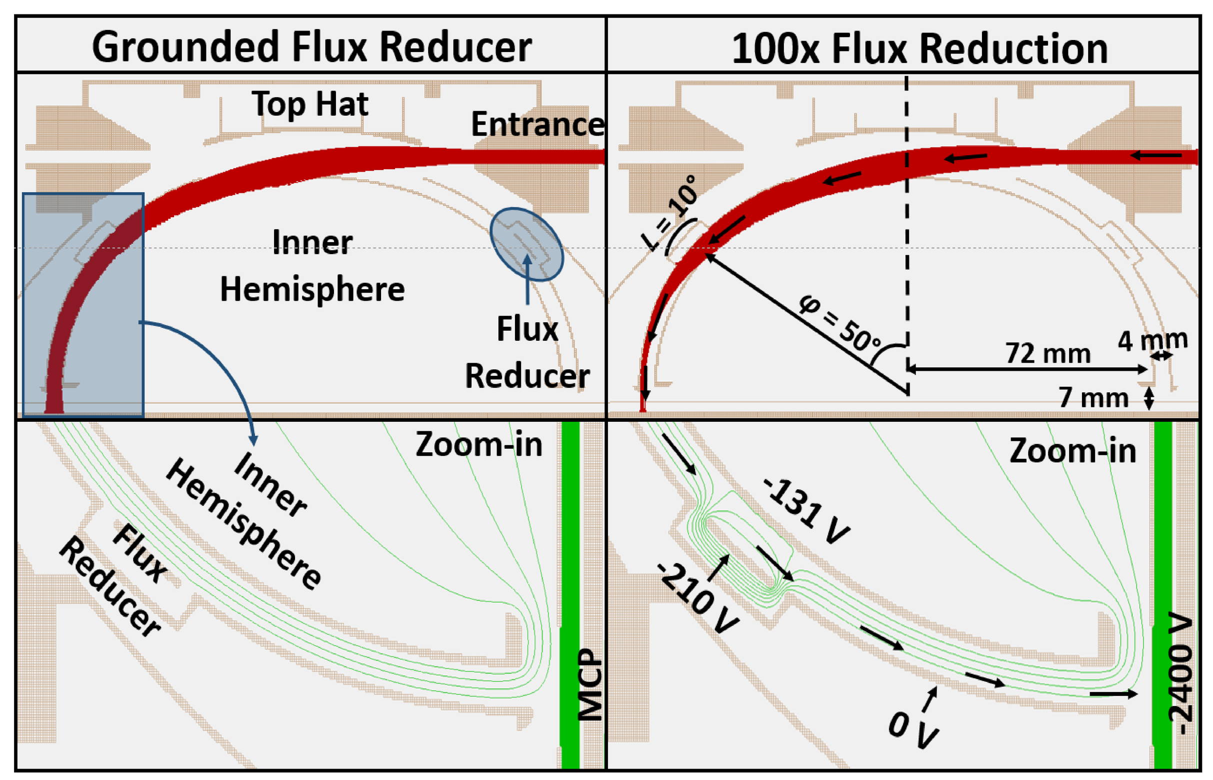


Conceptual diagram of a typical top-hat ESA. Particles enter and are guided by fields generated by the inner hemisphere to be measured by a detector system, like MCPs/Anode

Electrostatic Analyzer Design

Design Description:

- Top-hat ESA design with heritage from Cluster's CODIF [1] and STEREO's PLASTIC [2]
- 360° field of view – can be subtended as needed
- Target energy range of ~20 eV to 35 keV
- Flux reducer is on the outer wall, halfway down the ESA tunnel
- When voltage is applied to the flux reducer, less particles are selected and measured by the MCP due to changed trajectories

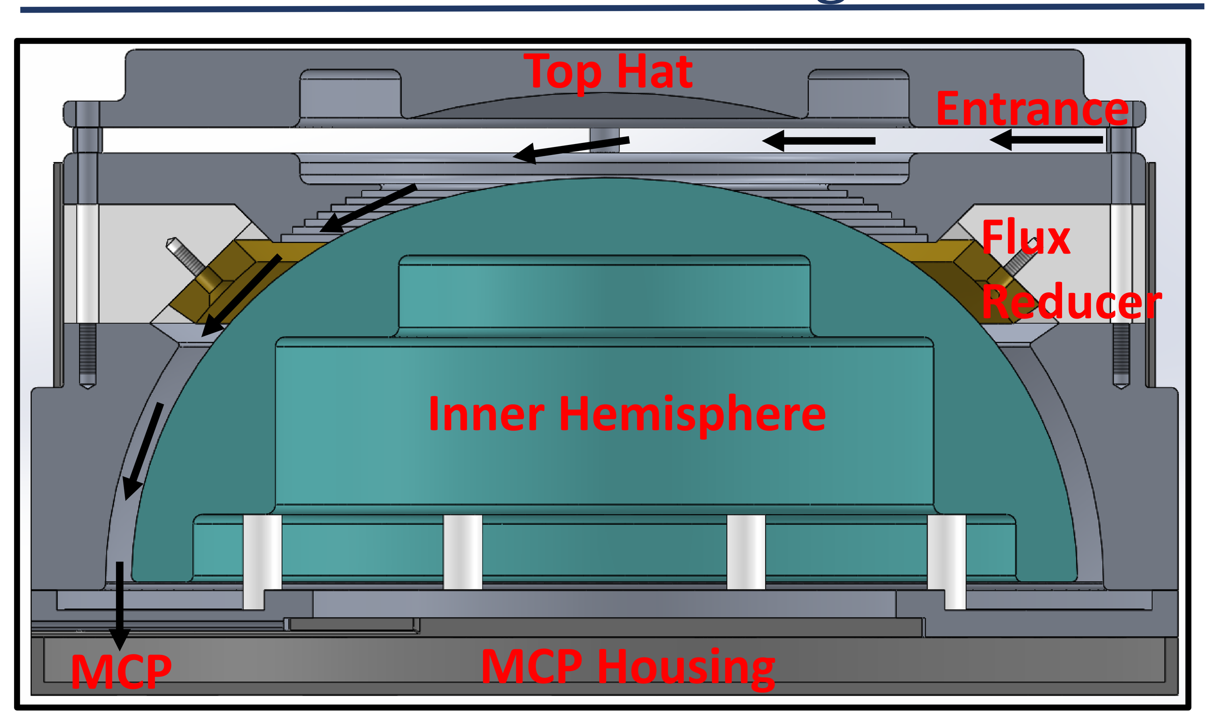


Modeled design of flux reducer ESA with particle trajectories and potential contours for 1x and 100x flux reduction factors

Exploration of Flux Reducer Design:

- Smaller flux reducer sizes, *L*, provide better control of the reduction factor but at the cost of requiring higher voltages
- Smaller *φ* (nearer the entrance) provide more controlled behavior but more significant changes in instrument parameters
- Model results suggest fluxes can be reduced by a factor of 1000x smoothly and consistently

Mechanical Design



Mechanical design for the lab prototype flux reducer ESA

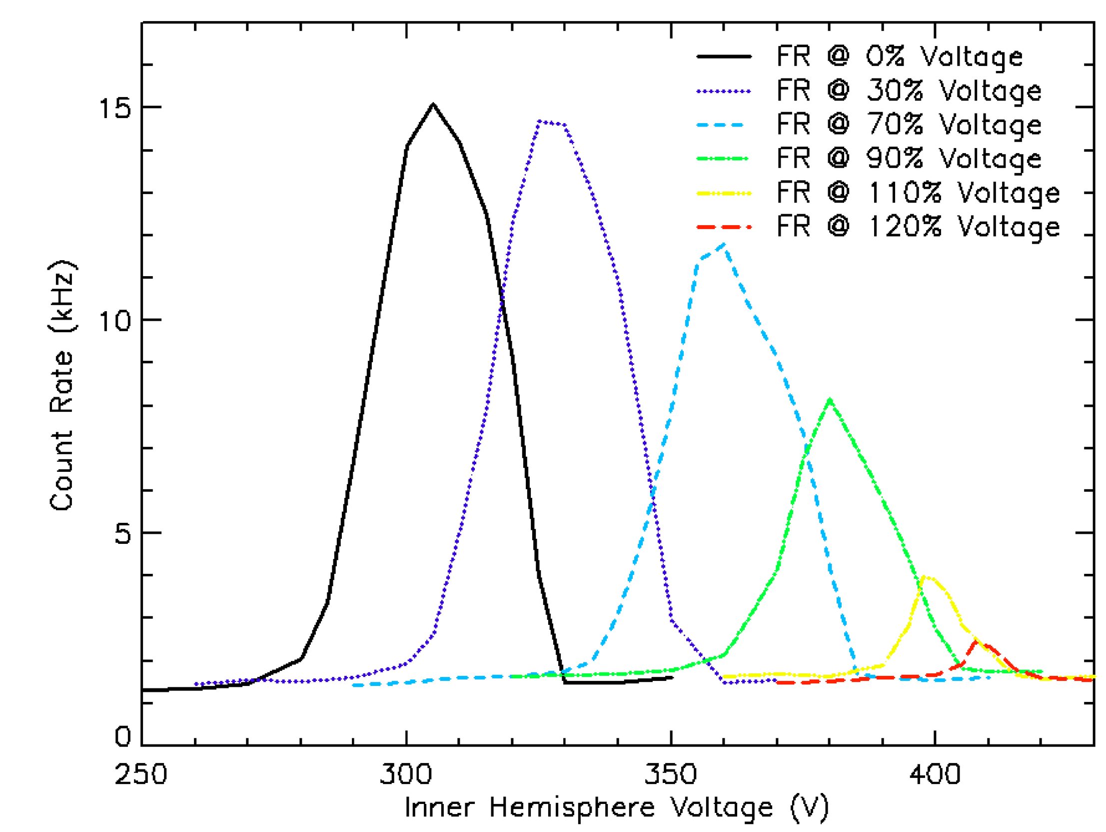
Mechanical Design:

- Particles enter from the entrance and travel along potential field lines due to voltage applied to the Inner Hemisphere
- Selected particle energies are measured by an MCP or other detection system at the end of the ESA tunnel
- Flux Reducer (gold) and Inner Hemisphere (teal) are isolated from ground by insulators (white)

Initial Laboratory Testing

dE/E is the ratio of the FWHM of the measured energy distribution to the peak energy – the instrument's energy resolution

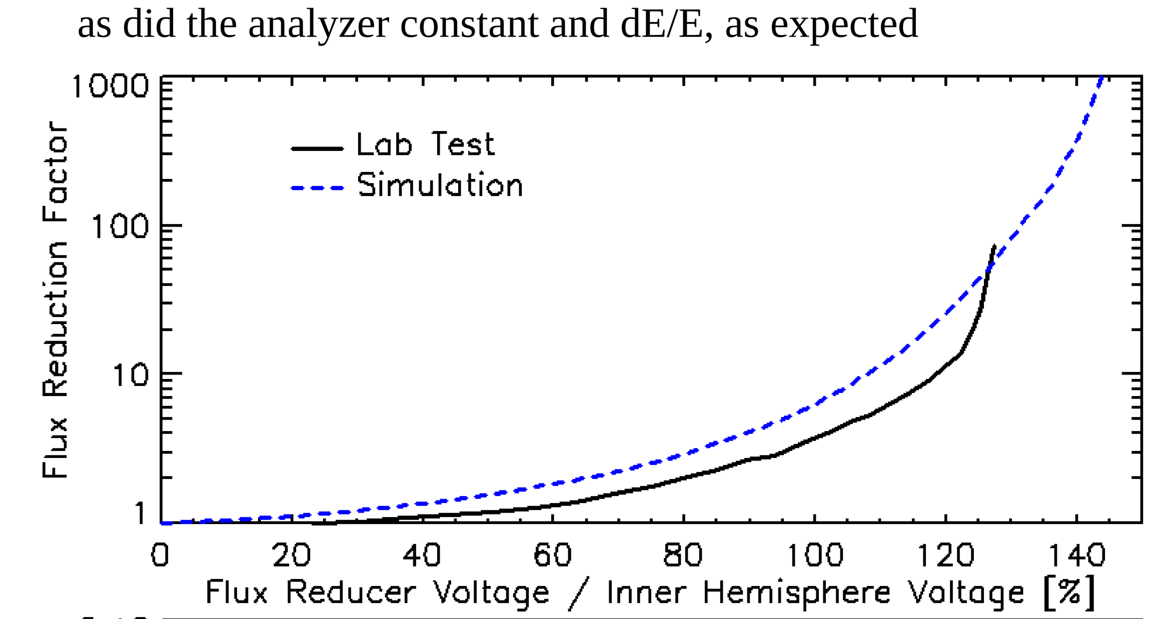
The **Analyzer Constant** is the ratio of the peak energy to the inner hemisphere voltage – intrinsic parameter to the instrument

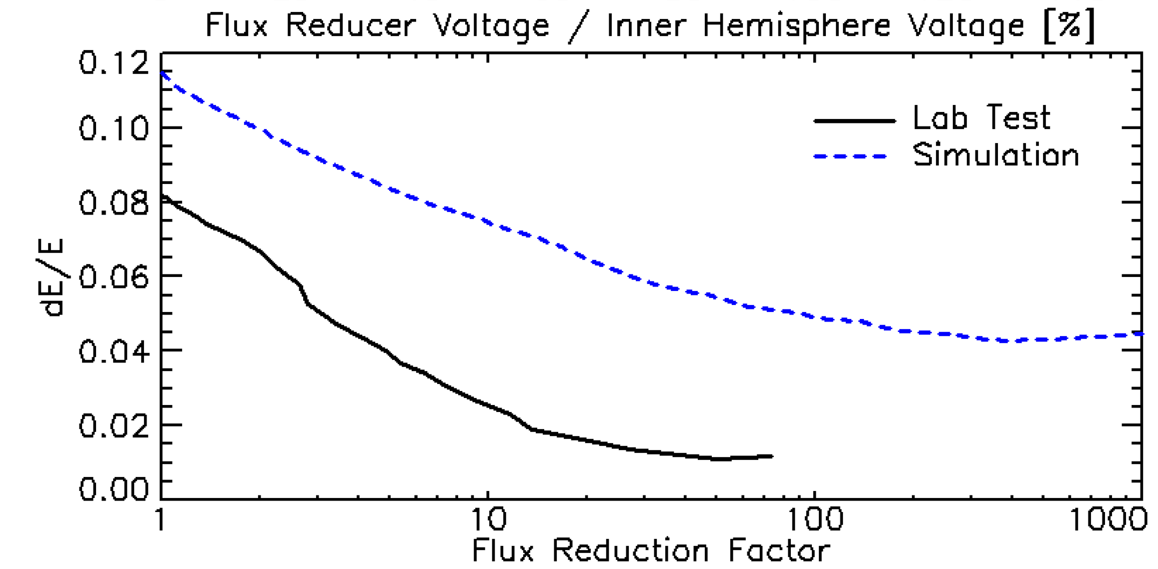


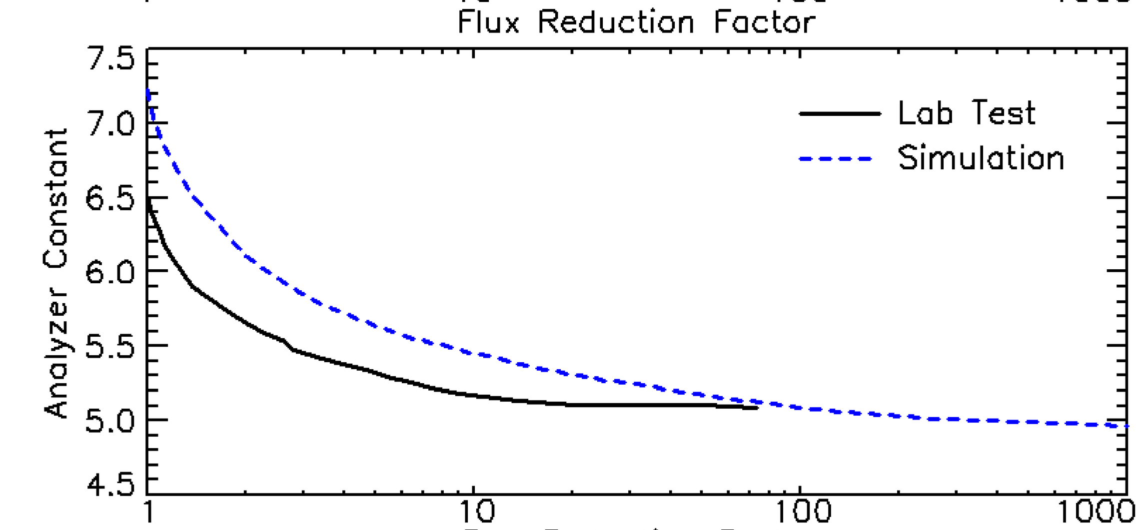
Inner Hemisphere voltage scans for a 2.1 keV ion beam for different voltages on the flux reducer (FR)

Lab Testing:

- Initial testing showed results behaviorally consistent with simulation predictions
- As the flux reducer voltage increased, the count rate decreased, as did the analyzer constant and dE/E, as expected

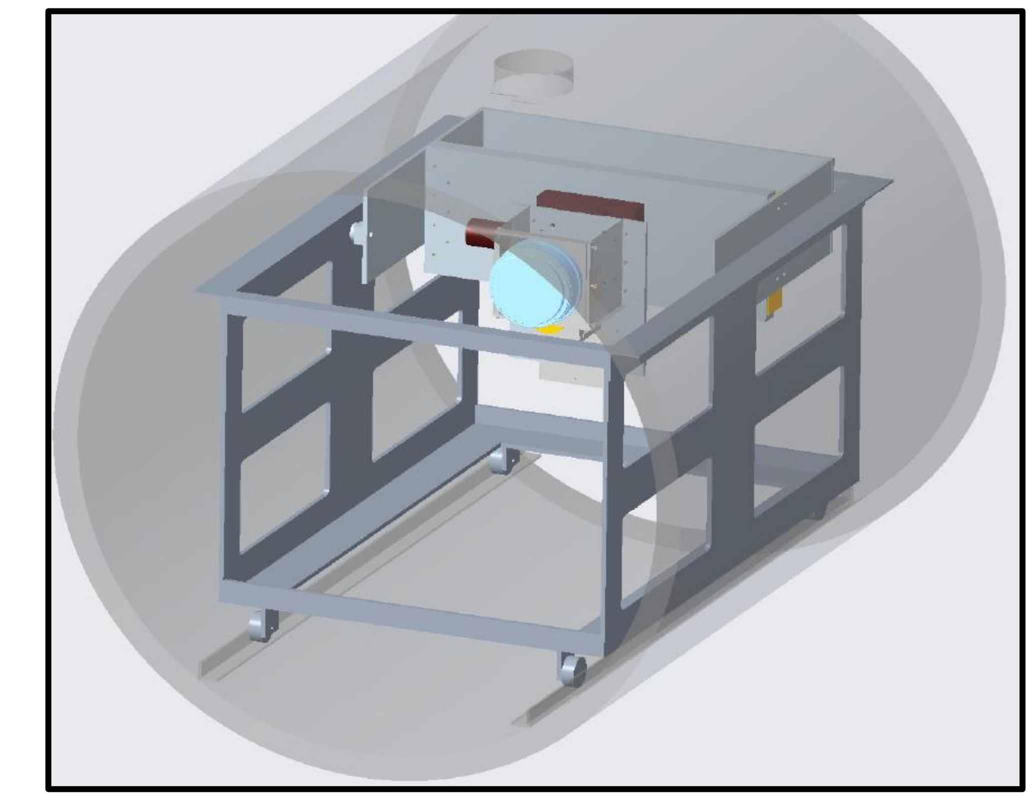




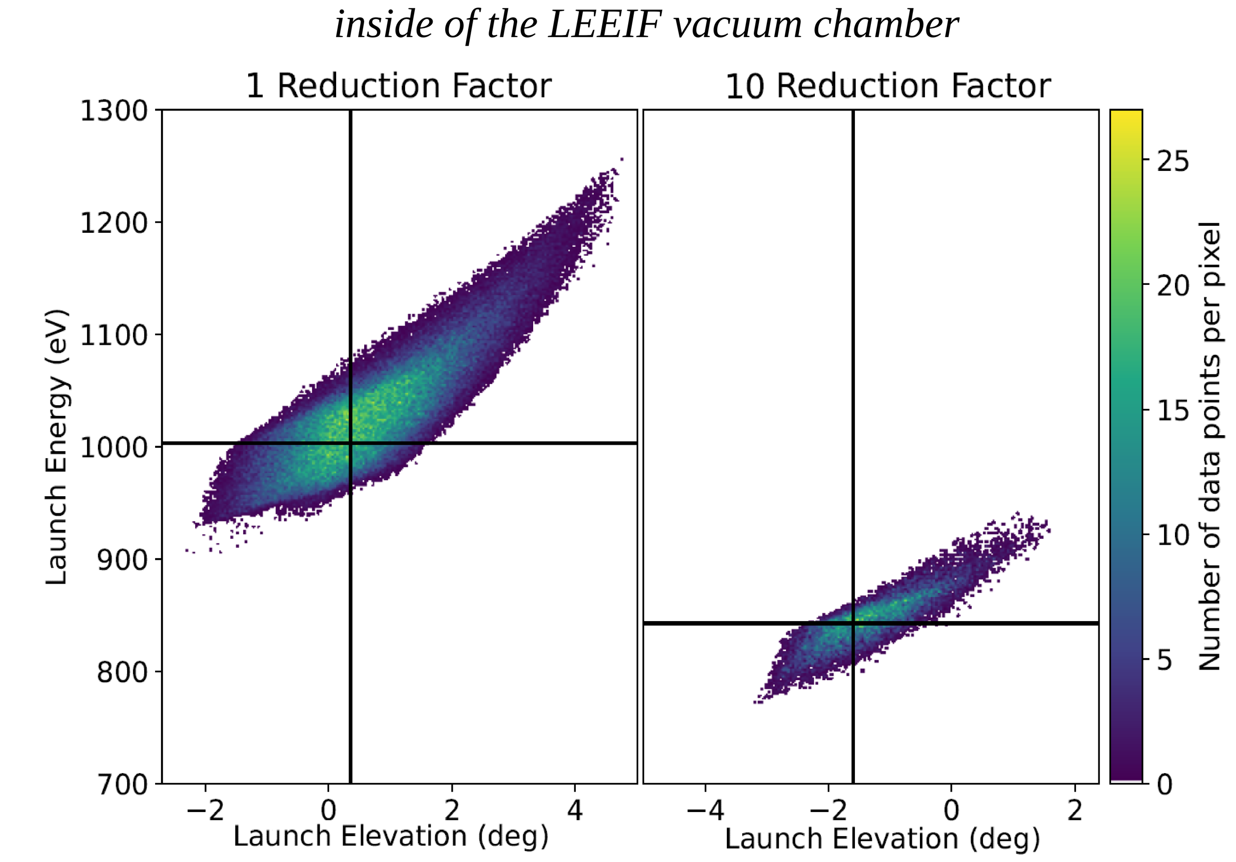


Future Calibration at NASA Marshall

Calibration of the prototype design will take place at NASA Marshall Space Flight Center using the Low Energy Electron and Ion Facility (LEEIF). This facility has a long heritage of developing and testing many charged particle detectors, such as helping calibrate the Dual Ion Spectrometer sensors for the Magnetospheric Multiscale (MMS) mission.



Model of the prototype ESA mounted on a position table inside of the LEEIF vacuum chamber



Simulated measured particle distributions for a 1 keV centered source for flux reduction factors of 1x and 10x

Summary

Key Points:

- New ESA model design with a variable geometric factor spanning 3 orders of magnitude
- ESA prototype components have been designed and assembled
- Initial lab testing demonstrates feasibility of the concept

Future Work:

- Continue lab testing to higher flux reduction factors
- Thorough calibration at the LEEIF at NASA Marshall
- Review of ESA prototype design and potential improvements

References

[1] Rème, H. et al., 2001, doi:10.5194/angeo19-1303-2001

[2] Galvin, A. B., et al., 2008, doi:10.1007/s11214-007-9296-x