Design Optimization of a Wide Field of View Plasma Spectrometer

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Abstract

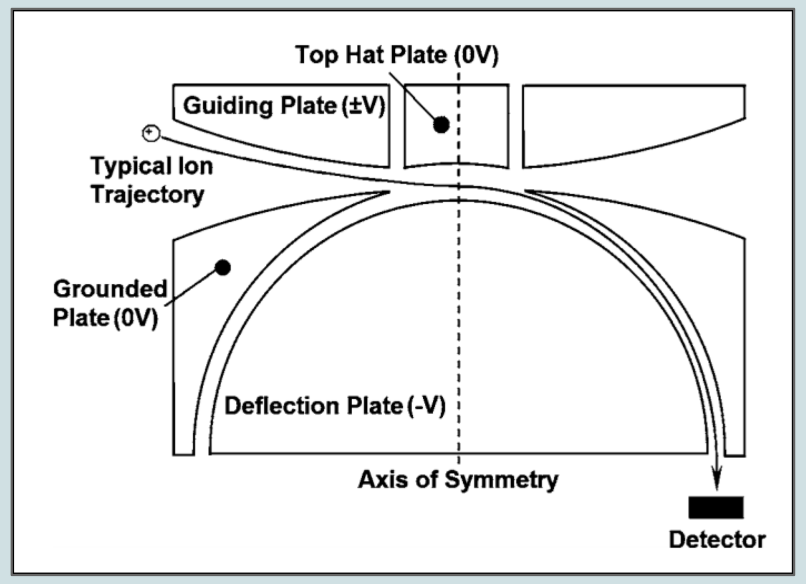
We study a new electrostatic analyzer (EA) geometry that employs two parallel plates to create a uniform electric field where particles are deflected parabolically and filtered through angled slits at defined radii. This detector offers wider simultaneous angle coverage, allowing the instrument to map plasma populations with higher time resolution and considerable resource saving. The cost of this geometry is a reduction in energy resolution, particularly when measuring particles that arrive at steep angles relative to the entrance space. A proposed solution is to add a radial component to the electric field using a cone, held at the same voltage as the filter plate. Numerical simulations have been performed, showing that the cone is effective in increasing the energy resolution of steep angled particles, in addition to reducing the voltage needed to filter a given particle energy.

What are Electrostatic Analyzers?

- Instruments commonly used to study particle distributions in space plasmas.
  - Solar wind
  - Ionosphere
  - Magnetosphere
- Use electric fields to filter particles according to their energies, and to measure their fluxes.

Top Hat Analyzers

- Characteristic EA Geometry (Cluster CODIF, STEREO PLastic)
- Cylindrically symmetric
- consists of two curved plates held at different potentials creating radial force on ions of correct charge
- Solid angle response of about 8°
- Requires scanning energy and angle reducing time resolution
  - On a spinning satellite, the rotation is used for scanning by imaging slivers of the plasma as it rotates
  - On non spinning satellites, additional angular response is added through the use of external deflectors that require additional resources



Main components of a typical top hat analyzer.

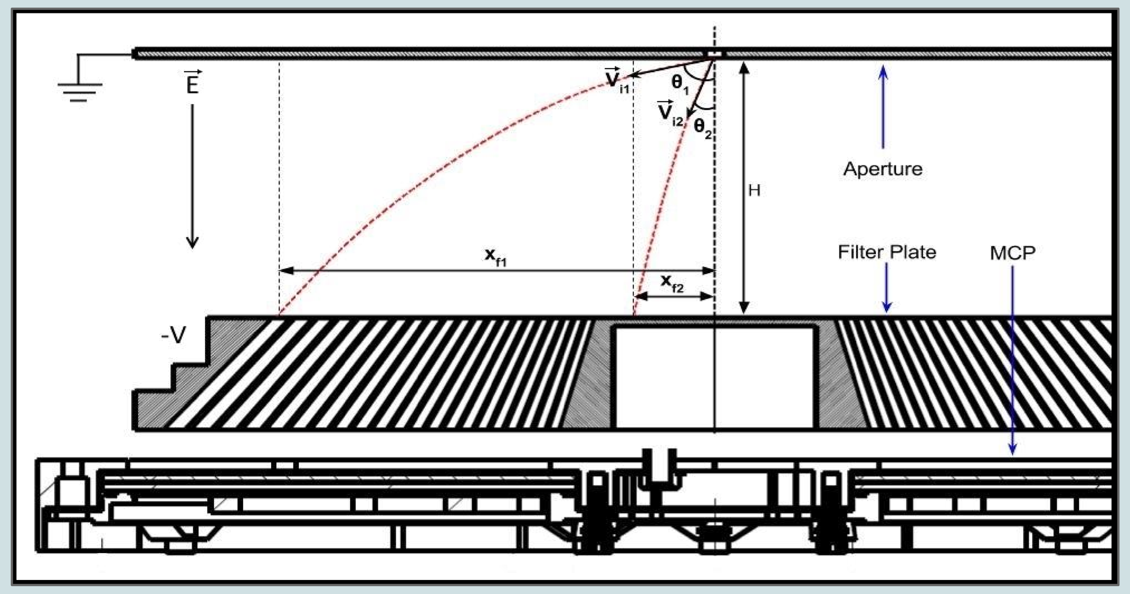
Goals of New Geometry

Developed in collaboration between UNH and Los Alamos National lab

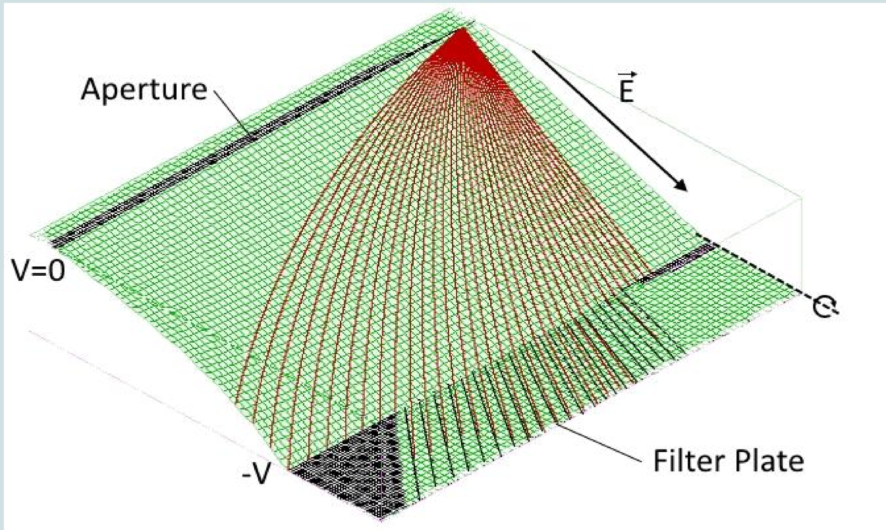
- Achieve large simultaneous solid angle acceptance
- Maintain reasonable angular and energy resolution
- Filter higher energy particles that enter the detector at low angles

Planar Geometry

- Uses two parallel plates to create a uniform electric field deflecting particles parabolically
- Particles can be modeled using basic ballistic kinematics
- Energy selection is performed in a filter plate with channels set at the particle arrival angle



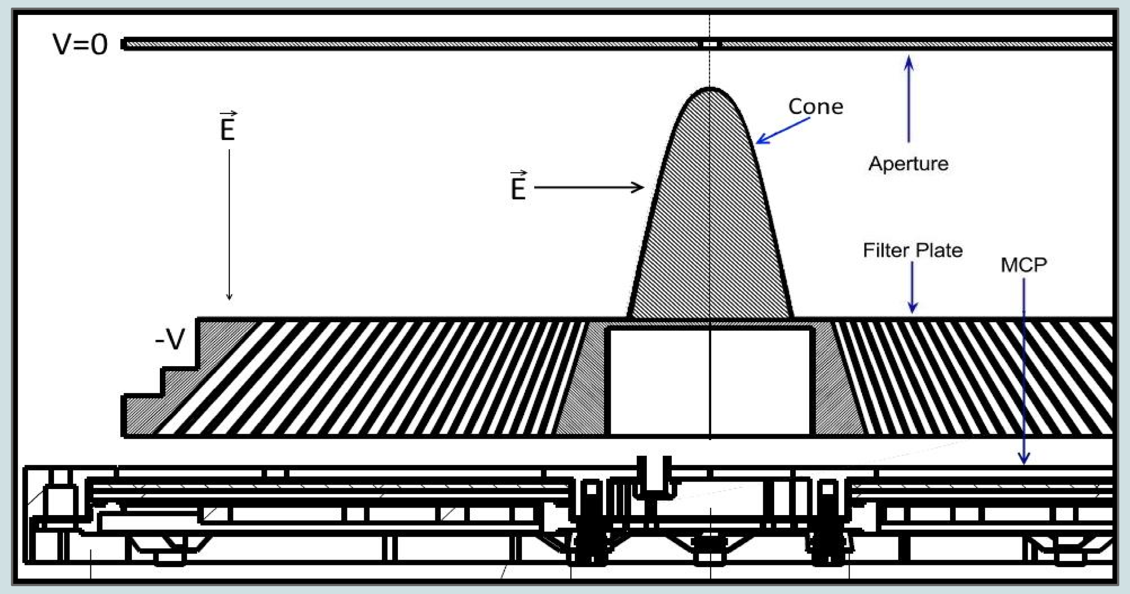
Vanilla design cross sectional geometry



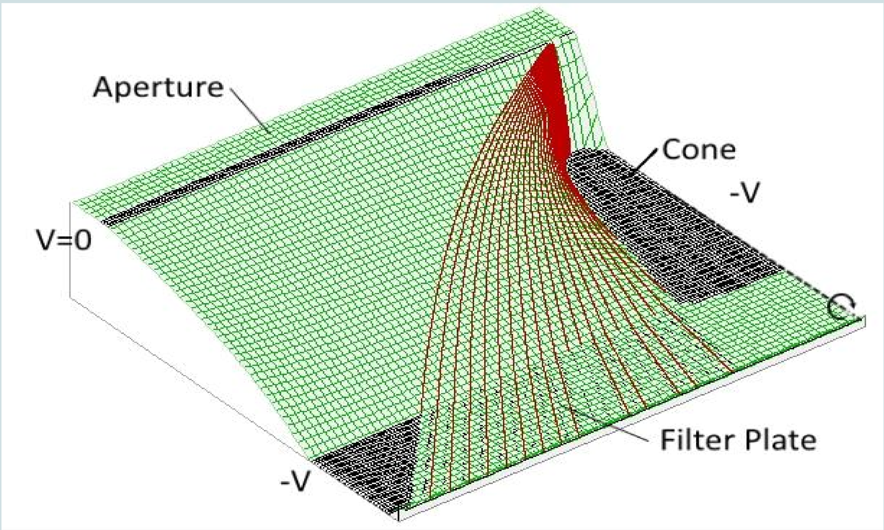
Equipotential lines of the vanilla design. Sample particle trajectories in red

Cone Geometry

The addition of a cone at the filter plate potential adds a radial component to the electric field, separating the trajectories of desired particles from extremely high energy particles.



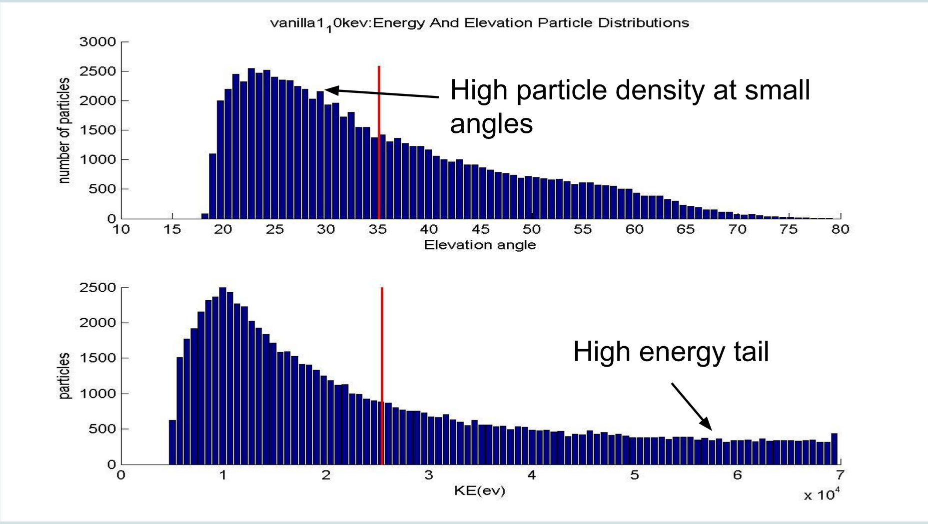
Cone design cross sectional geometry

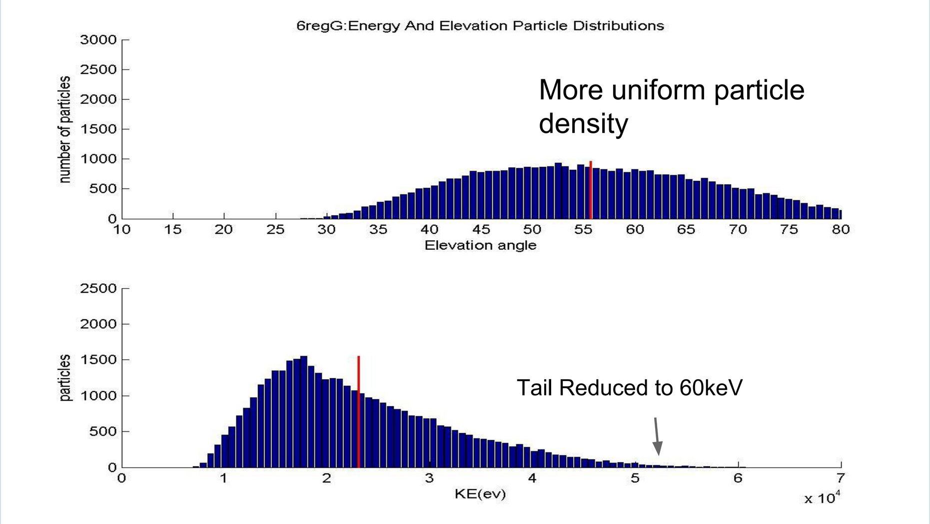


Equipotential lines of the Cone design. Sample particle trajectories in red

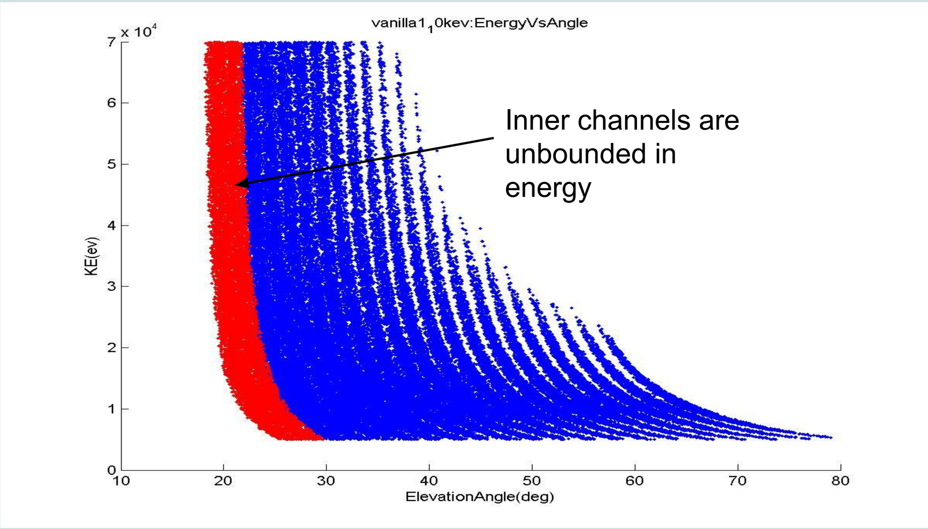
Sample Data

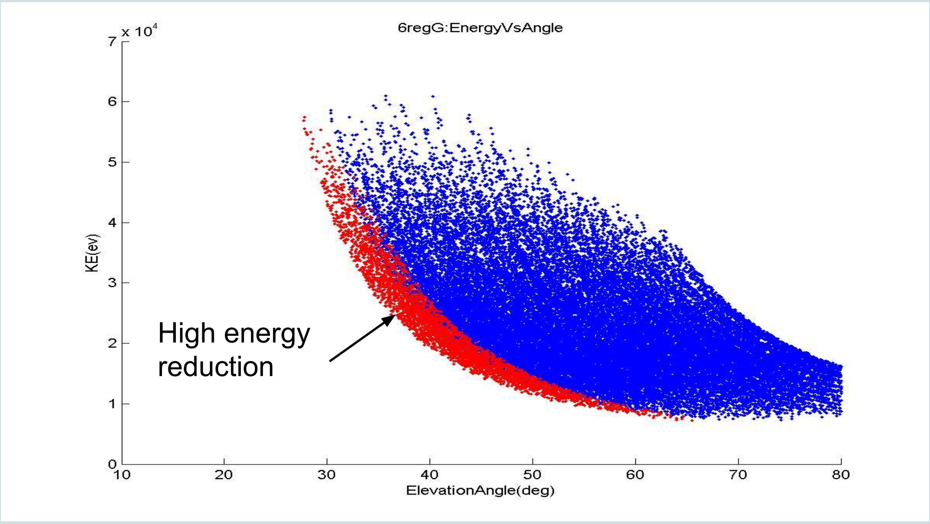
Integrated Angle and Energy Distributions:





Energy and Angle Phase Space





Analysis

Simulations

- 500000 particles
- uniform energy distribution (5-70 keV)

Planar Geometry

- 15% throughput (particles Input/Detected)
- Energy range: 5-70keV
- Angular range: 17°-80°
- 25% of particle energies beyond 2 standard deviations of the gaussian

Problems

Detector has a fundamentally large solid angle, but particles that enter the detector at small angles from the normal are only minimally deflected by the electric field. This causes the innermost channels to pass particles over a wide range of energies (1-100kev).

Cone Geometry

- 8% throughput
- Energy range: 10-55keV
- Angular range: 30°-80°
- 7% of particle energies beyond 2 standard deviation of the gaussian

Initial Impact of Cone:

The radial component of the electric field functioned as expected. It reduced the high energy tail of particles that pass through the filter. The needed deflection voltage for a given energy is reduced from 1keV/kV to 2.2 keV/kV, thus reducing the detector's resource cost. The only drawback is a reduction in viewing angle of about 10°.

After the addition of the cone, the instrument resolution can be fine tuned by changing the channel widths in the filter plate. Decreasing the channel widths will give the individual channels a higher resolution, but at the cost of particle throughput. Once the exact relationship between throughput and resolution is found the exact filter plate geometry can be selected to fit the experimental need.

Conclusion

Simulation has confirmed that the addition of a radial component to the electric field can be successful in increasing the energy resolution of particles at low energies at the cost of some angular viewing range. This view angle of this detector is comparable to that of a tophat analyzer with a deflector system. The major benefit is that this detector only needs one high voltage power supply. Limited resources on satellites have led detector efficiency to be of paramount importance. Further simulation is required to see if this detector could be comparable in resolution to the top hat designs, If higher resolution is achieved this detector is viable as an extremely efficient flight instrument.

References & Acknowledgements

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References:

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