The Gated Electrostatic Mass Spectrometer GEMS

Fred A. Herrero (fred.herrero@nasa.gov)
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771

18 September 2007

Outline

1. MagCon started it all - why Miniaturize Charged Particle Spectrometers?
2. The Small Deflection Eneregy Analyzer
3. The FLAt Plasma Spectromete FLAPS - APL & USAFA’s Falcon-Sat 3 mission
4. The Gate Electrostatic Mass Spectrometer GEMS and the Free Fall Mass Spectrometer FFMS
5. Ion Source Development
6. MIMMS

Miniaturizing the Electrostatic Energy Analyzer

The MagCon Challenge: Provide an energy analyzer with small mass, operating with a small voltage (large plate factor) that maintains the sensitivity and energy resolution of current analyzers.

↓

NEW ATTITUDE

True miniaturization requires re-definition, not just shrinking of existing devices

↓

The Small Deflection Energy Analyzer (SDEA):

Plasma spectrometer (FLAPS)

Wind and temperature spectrometer (WTS) Gated Electrostatic Mass Spectrometer (GEMS/FFMS).

Introduction

What is a charged particle spectrometer and why does NASA use them?

A charged particle spectrometer determines energies, momenta and/or masses of ions and electrons-has a field of view (FOV) for particles and often determines structure within that FOV.

The data provide a physical picture that tests theoretical models of atmospheres and plasmas to further our understanding of nature:
- Troposphere to thermosphere to exosphere and interplanetary space - must ionize neutrals before analyzing them.
- Ionosphere, magnetosphere, solar wind, heliosphere, interplanetary space.

Example: The Loss Cone Analyzer Parallel Plate energy Analyzer (PPA) on Polar's Hydra Instrument:
- FOV about 30°x30°
- 1024 pixels - resolution about 1°x1°
- Energy range - 0.1 to 10 keV
- Energy scan voltage supply - 0.1 to 10 kV

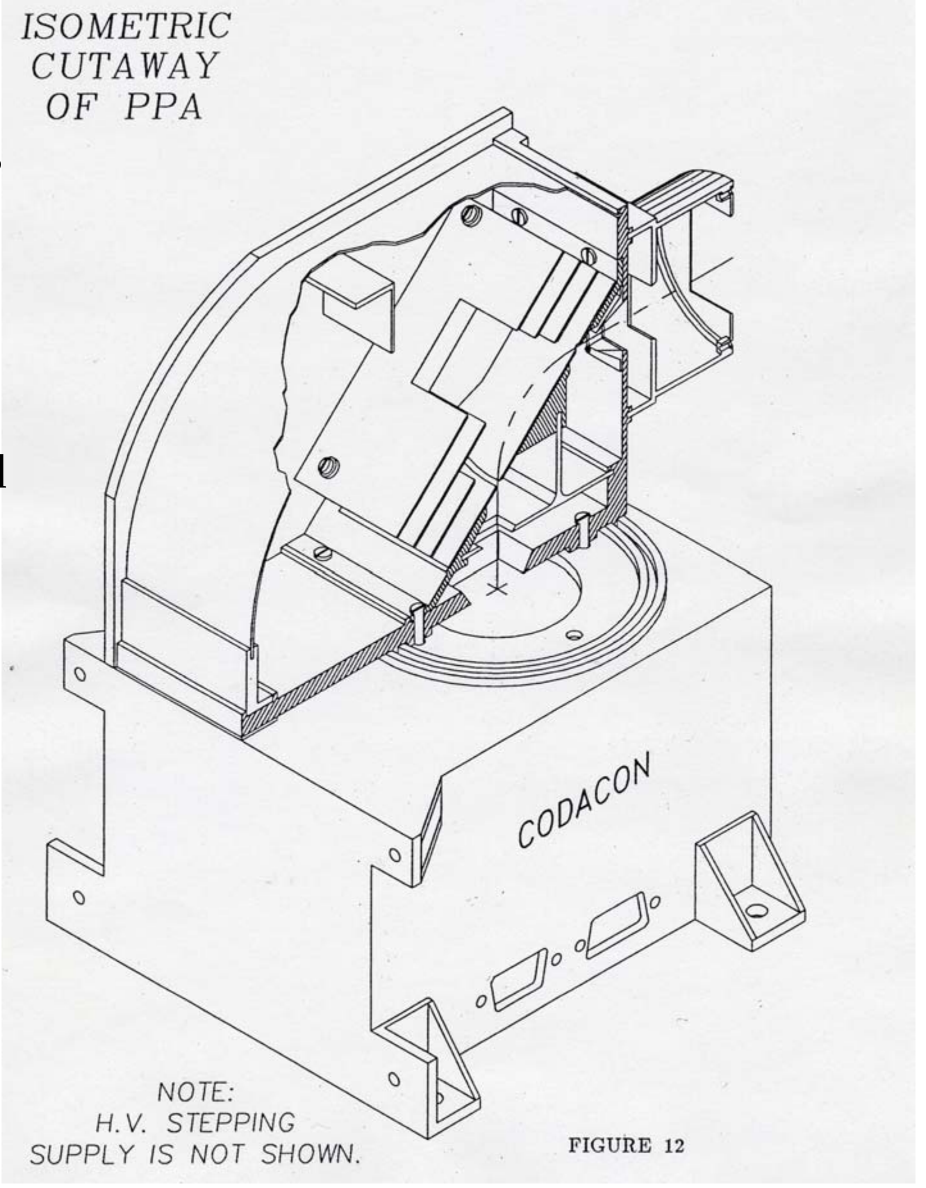
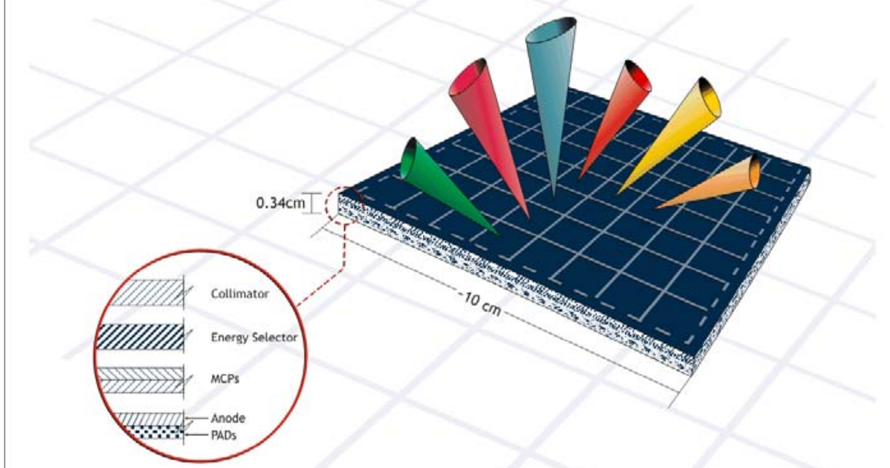


FIGURE 12

FLAPS for Falcon Sat -3

A MEMS Miniaturized Plasma Spectrometer - with APL



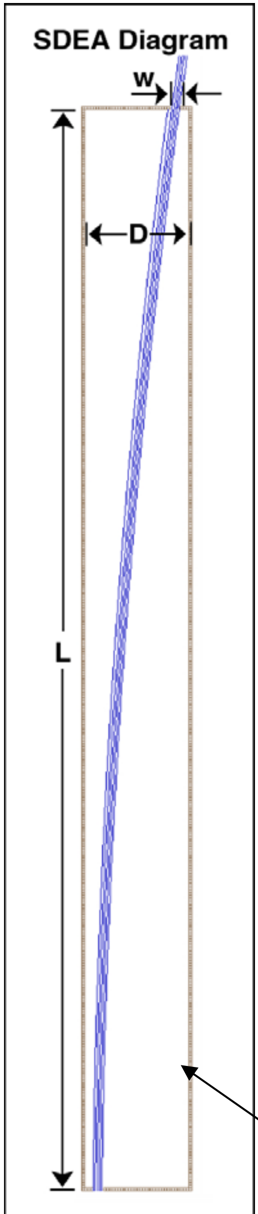
SDEA enables electron/ion spectrometer geometries of small size with large aperture and large and static FOV.

The drawing shows what a flat plasma spectrometer (FLAPS) might look like with 64 (8x8) spectrometer pixels, each with its own look-angle. The overall FOV is set by the collection of look-angles.

Photo of flight prototype unit, a micro-machined version developed at JHU/APL using the electronics built by Space Instruments, Inc. The flight version was built to fly in the USAFA satellite FalconSat-3

Small Deflection Energy Analyzer (SDEA)

True miniaturization requires re-definition, not just shrinking of existing devices



Conventional energy analyzers require deflection angles of 45° or more, and their outer boundaries have complex geometries.

SDEA yields significant gains in a re-definition of the energy analyzer that gives up focusing but retains energy definition

1. Uses small charged-particle deflection (< 45°)
2. Risk of voltage breakdown reduced - high plate factors;
   also static power V^2/R is reduced.
   Plate factors of 25 are practical (e.g. 50keV / 2kv).
1. Simple outer boundaries to enable spectrometer arrays
2. Enables static imaging spectrometer (4Pi sterad FOV).
3. Flexibility in FOV vs. plate factor
4. Light rejection similar to conventional
5. Analyzer capacitance may be large depending on application - energy scan power may thus increase
   $CV(dV/dt)$

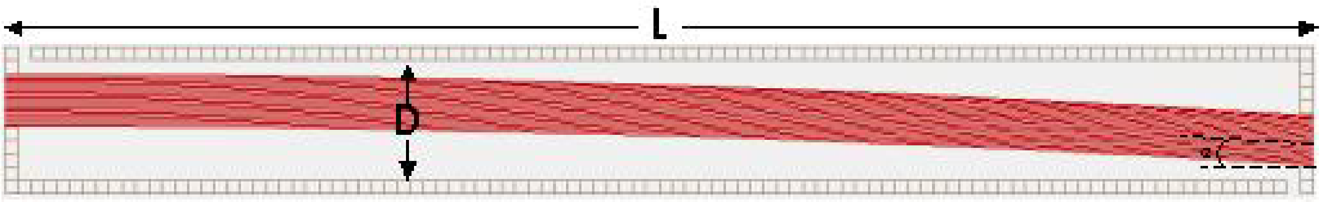
Example shows L/D = 10 and deflection angle < 10°.

Small Deflection Energy Analyzer (SDEA)

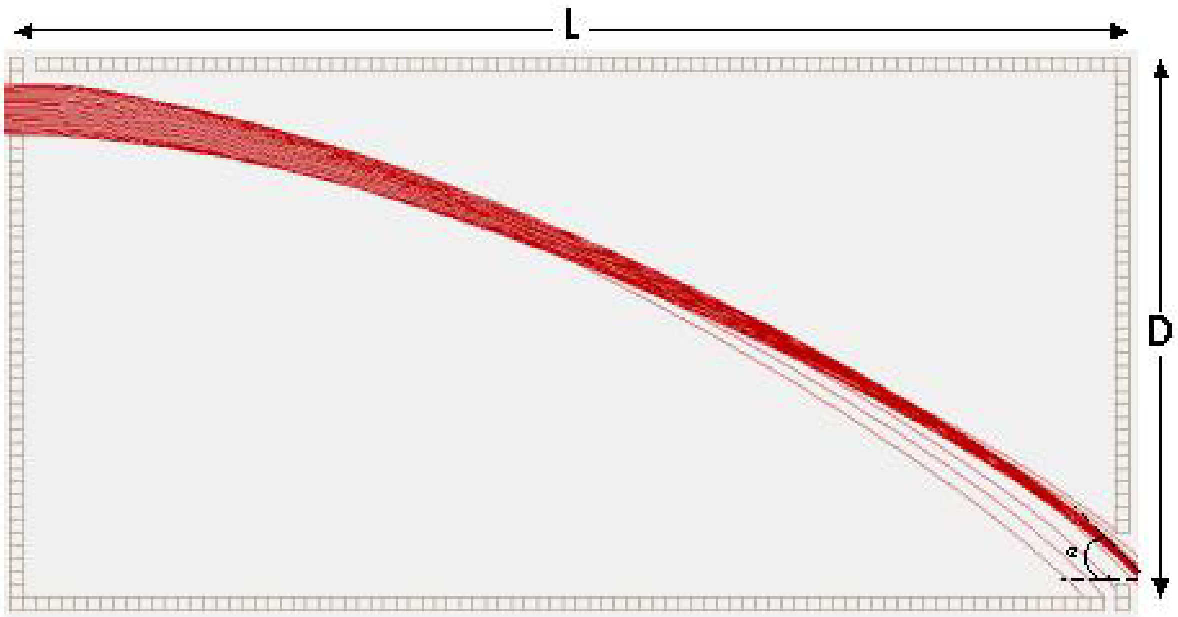
SDEA for both high L/D and low L/D (high and low plate factors)

Low P has some focusing - good for light rejection. Not so for high P

a.) L/D = 10.84, α = 2.45°

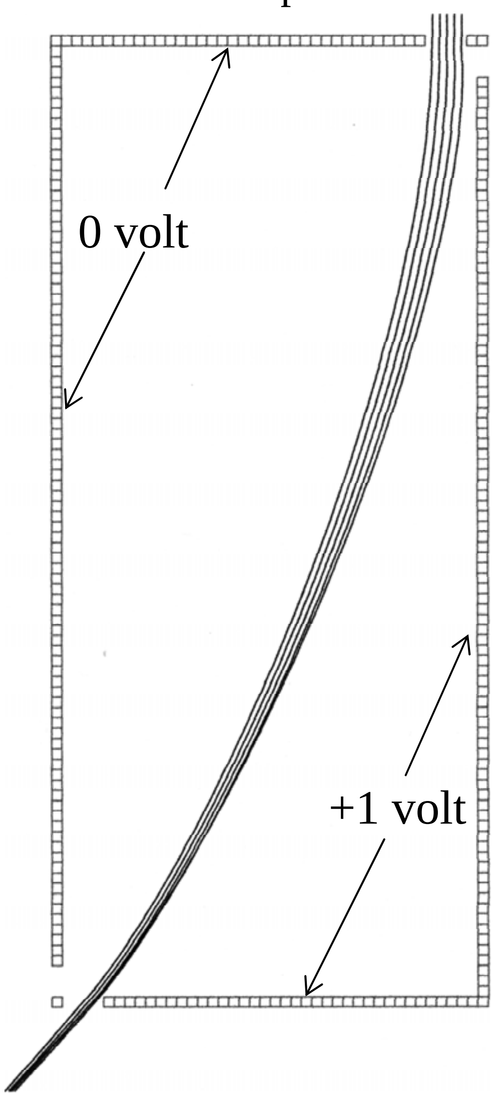


b.) L/D = 2.12, α = 40.0°



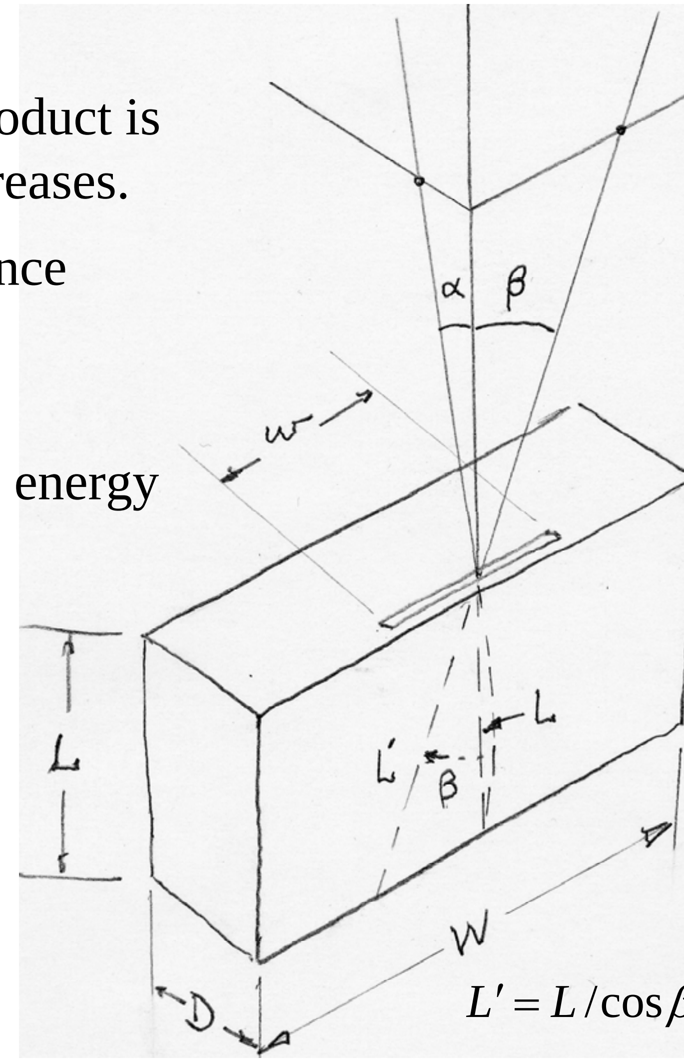
The Two Angles of Incidence in the Small-Deflection Energy Analyzer

SIMION TRAJECTORIES
E = 3.45 eV with
1.00 volts to plates



- Resolution x Aperture product is 3X enhanced as L/D decreases.
- Requires control of entrance angles **(α,β)** for energy definition & resolution.

Small L/D achieves 20 eV energy scan with 0-5 volt scan on analyzer plates.

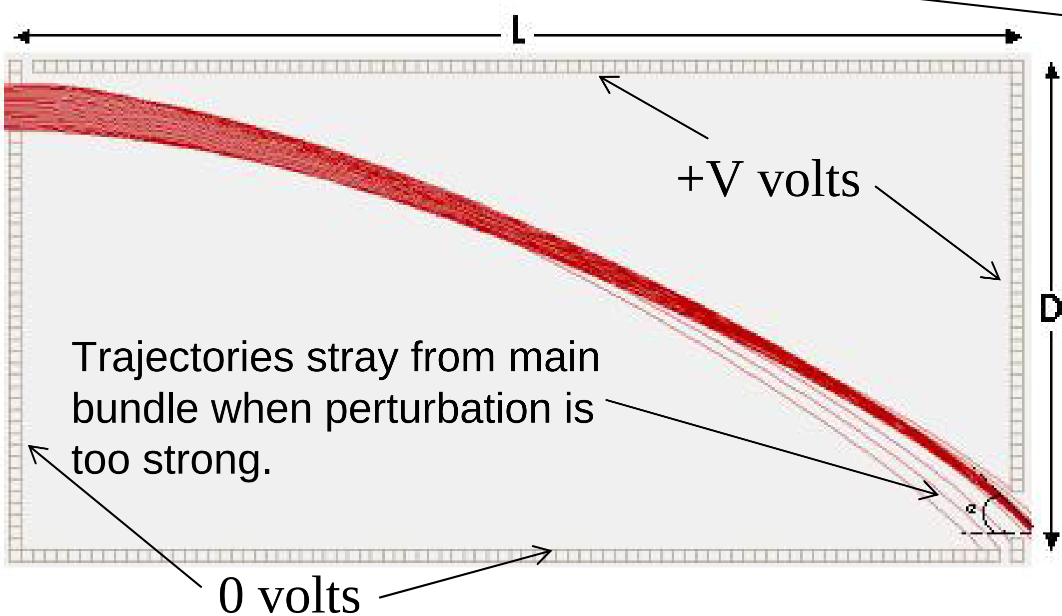


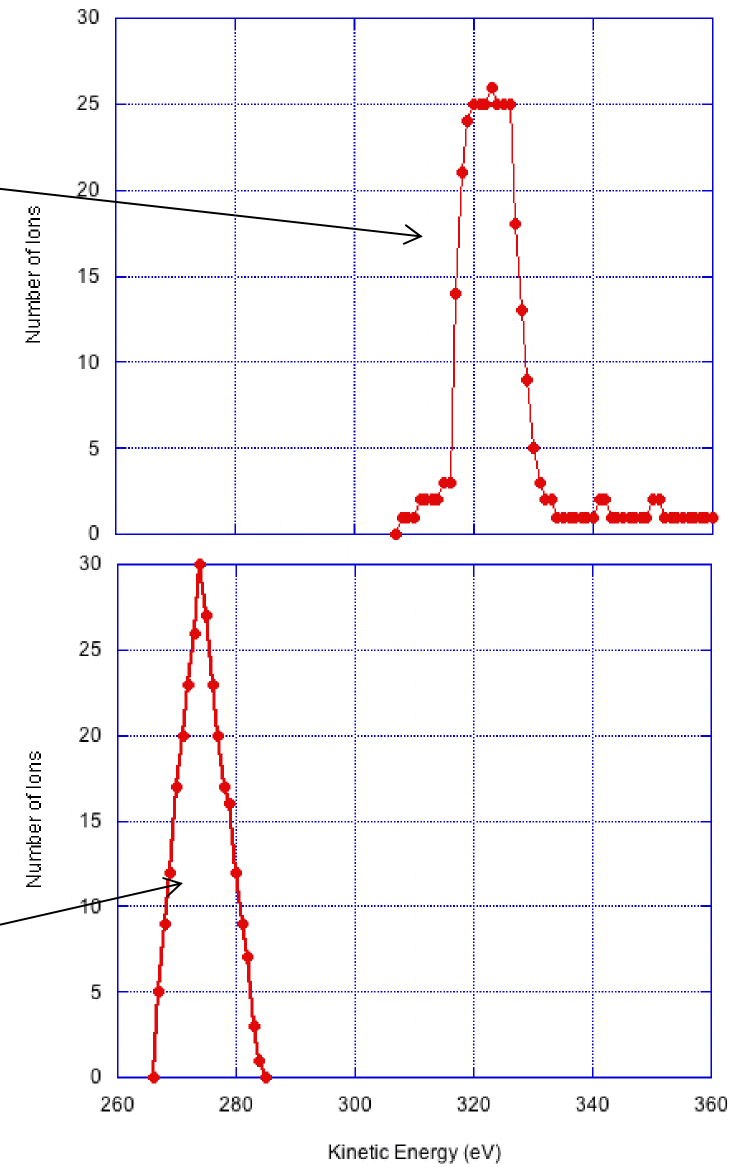
$$L' = L / \cos\beta$$

$$E = V\left(\frac{L'}{D}\right)^2 \frac{1}{4(f\cos^2\alpha + (L/D)\sin\alpha\cos\alpha)}$$

SDEA Performance for Small L/D

SIMION trajectories (incident from the left on L/D = 2.12 SDEA) demonstrate that stray trajectories occur when the entrance slit is too close to the top plate 0.025D, affecting the energy bandpass.





Moving slit down to a distance 0.1D away from top plate removes stray trajectories, giving 100% transmission in a clean triangular shape bandpass.

Motivation for GEMS:

To develop mass spectrometers of large aperture area per unit mass and power to enable unique opportunities in Lunar Exploration, Cometary Science, and in Ionosphere-Thermosphere-Magnetosphere (ITM) Science.

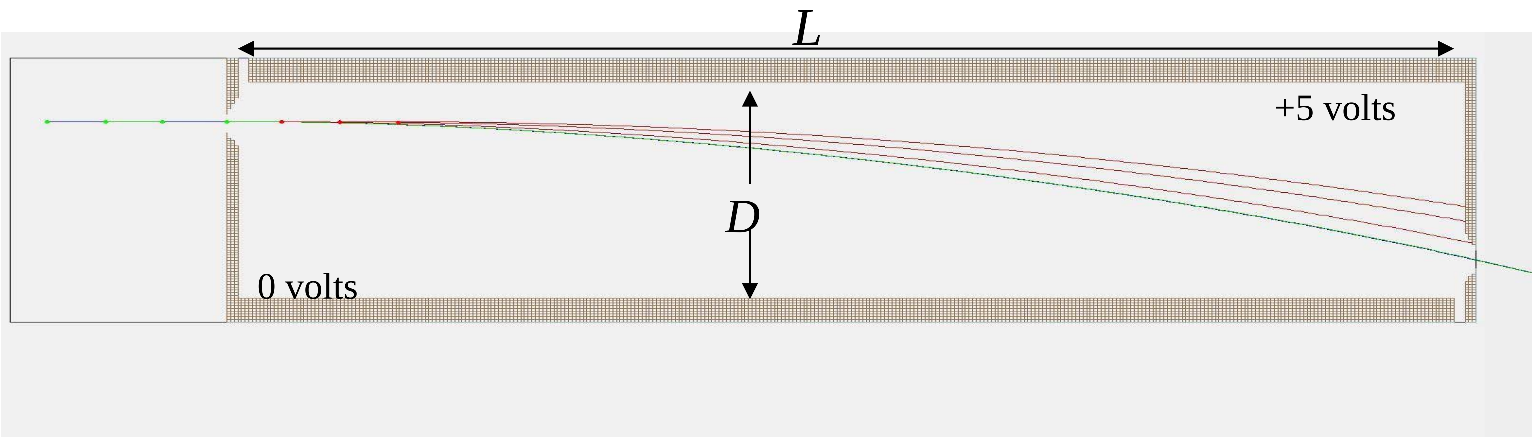
Rationale:

Mass spectrometers with large sensitive areas to broaden the scope of NASA investigations, from missions to map out surface compositions of minerals on the Moon and comets to Science missions for Ionosphere, Thermosphere and Magnetosphere.

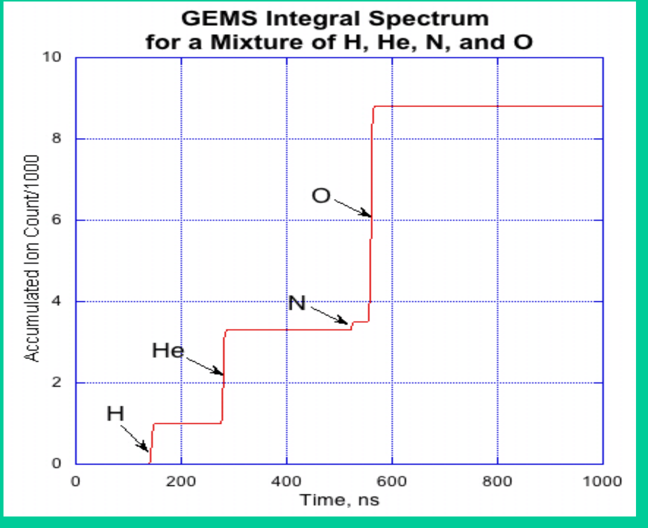
Example: measurements of Lunar surface mineral composition from Lunar orbit, requires a sensitive aperture area exceeding 10 cm^2 – the equivalent of about 1000 conventional mass spectrometers operating simultaneously (current aperture areas are about 10^{-2} cm^2).

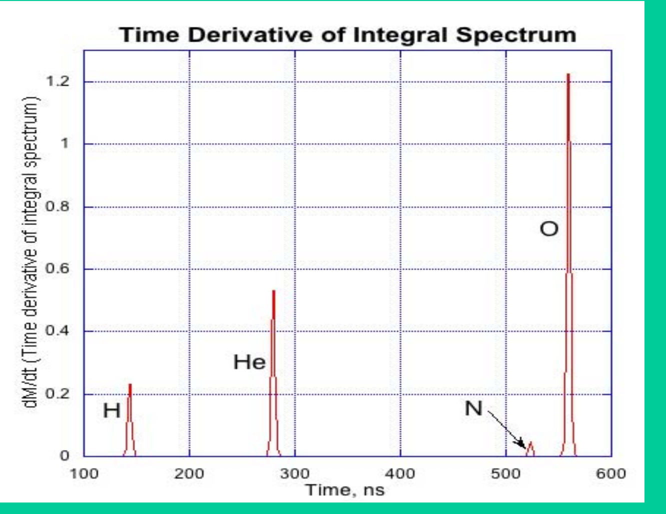
How GEMS works

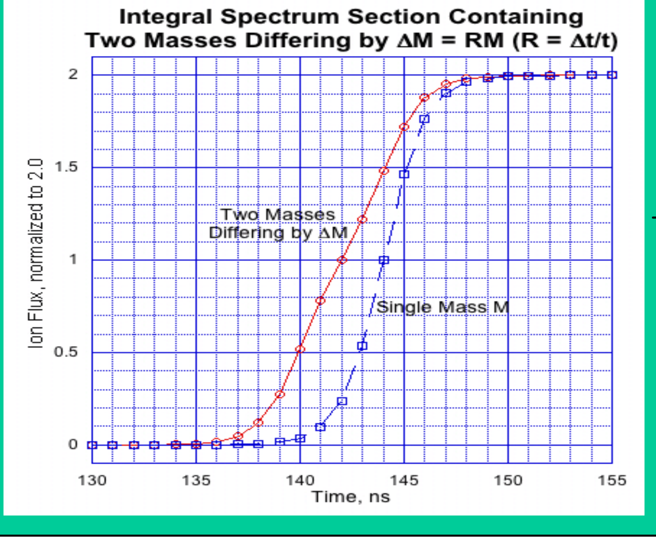
SIMION trajectory simulations of ions incident from the left in a Small Deflection Energy Analyzer (SDEA). Pulsing the top plate voltage at time t = 0 shows the basis for GEMS. Ions at the entrance or to the left (green dots) at t = 0 follow the full SDEA trajectory and exit to the right. Ions to the right of the entrance at t= 0 do not develop the full trajectory and cannot exit SDEA.

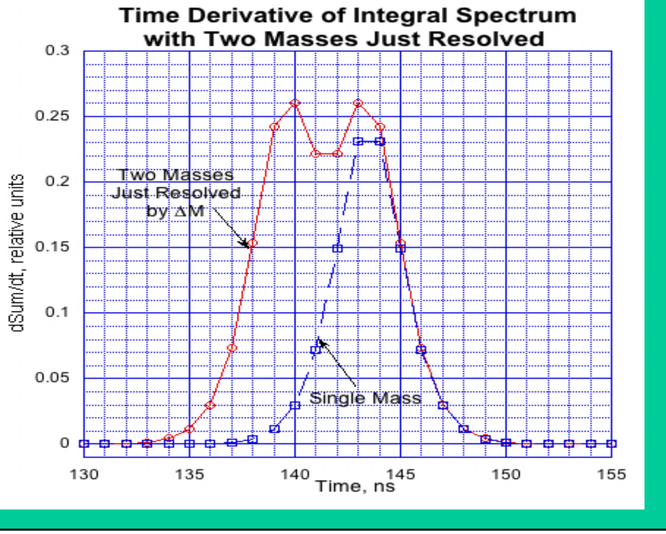


Expected Performance: Mass Spectra and Mass Resolution

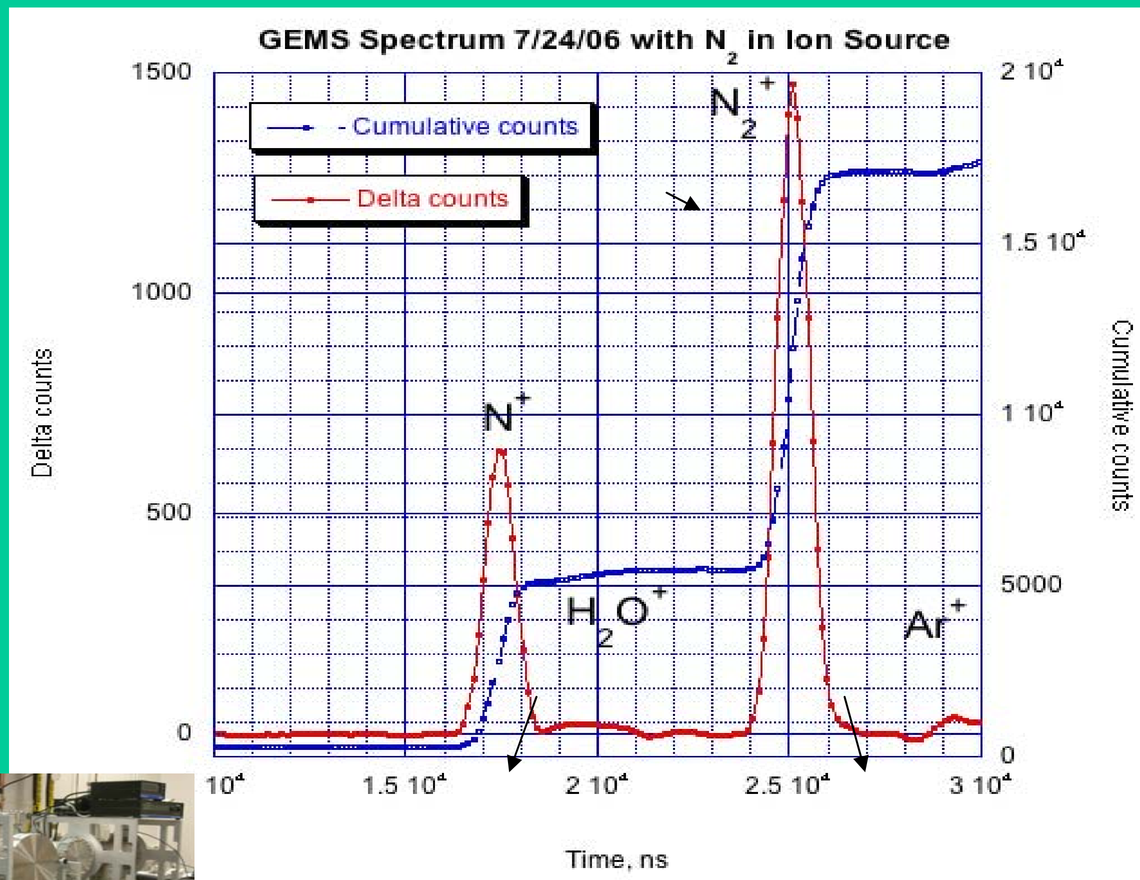


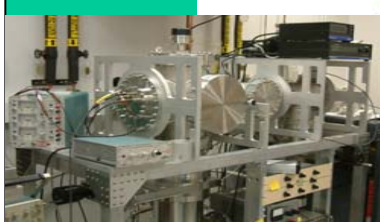






Mass Spectrum Obtained with the GEMS Lab Prototype





Mass Resolution Decreases with L, but…

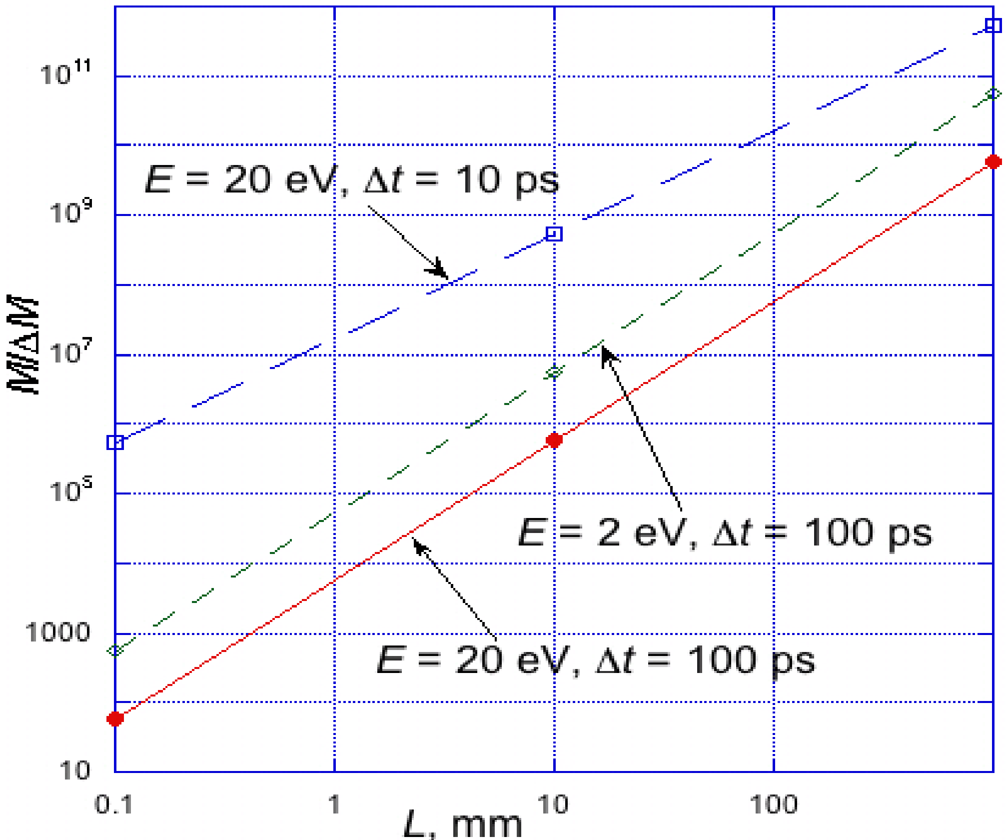
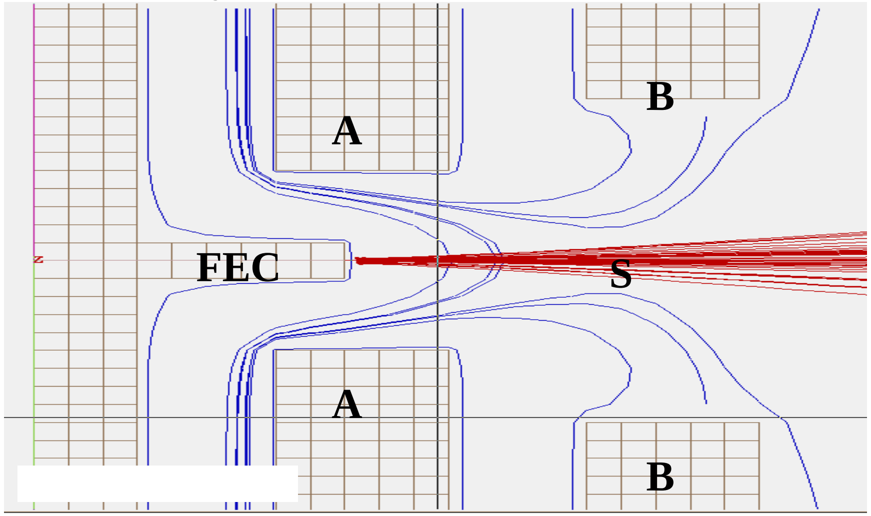


Figure 4. The change of mass resolution $M/\Delta M$ with drift distance L for 2 and 20 eV and time resolutions of 10 and 100 ps. As energy increases, resolution decreases with L.

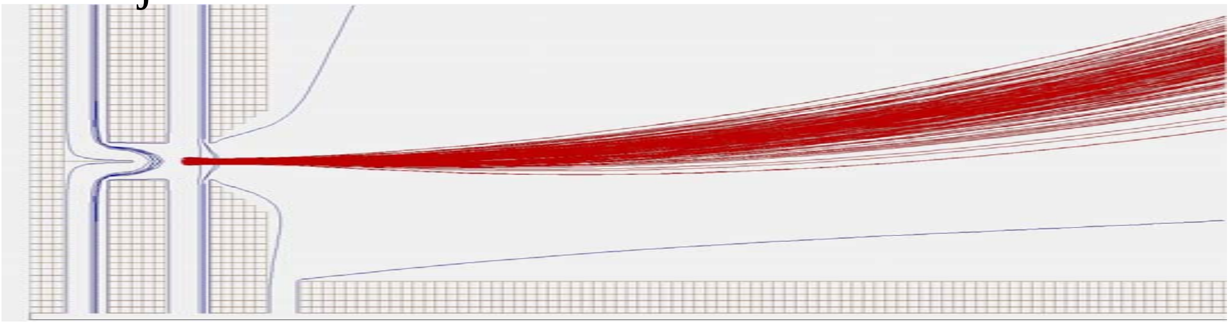
Making a MEMS Mass Spectrometer:

Preliminary proposal for shallow ion source of low energy spread and narrow angular divergence

Electron trajectories

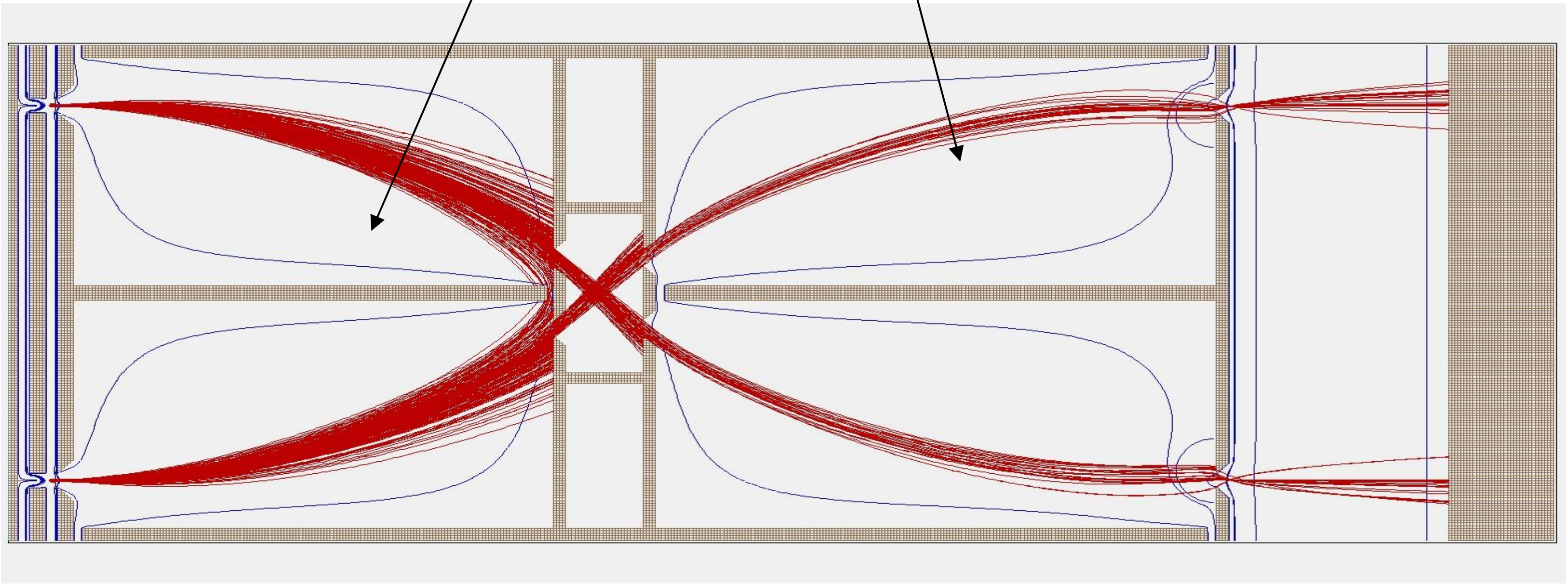


Ion trajectories

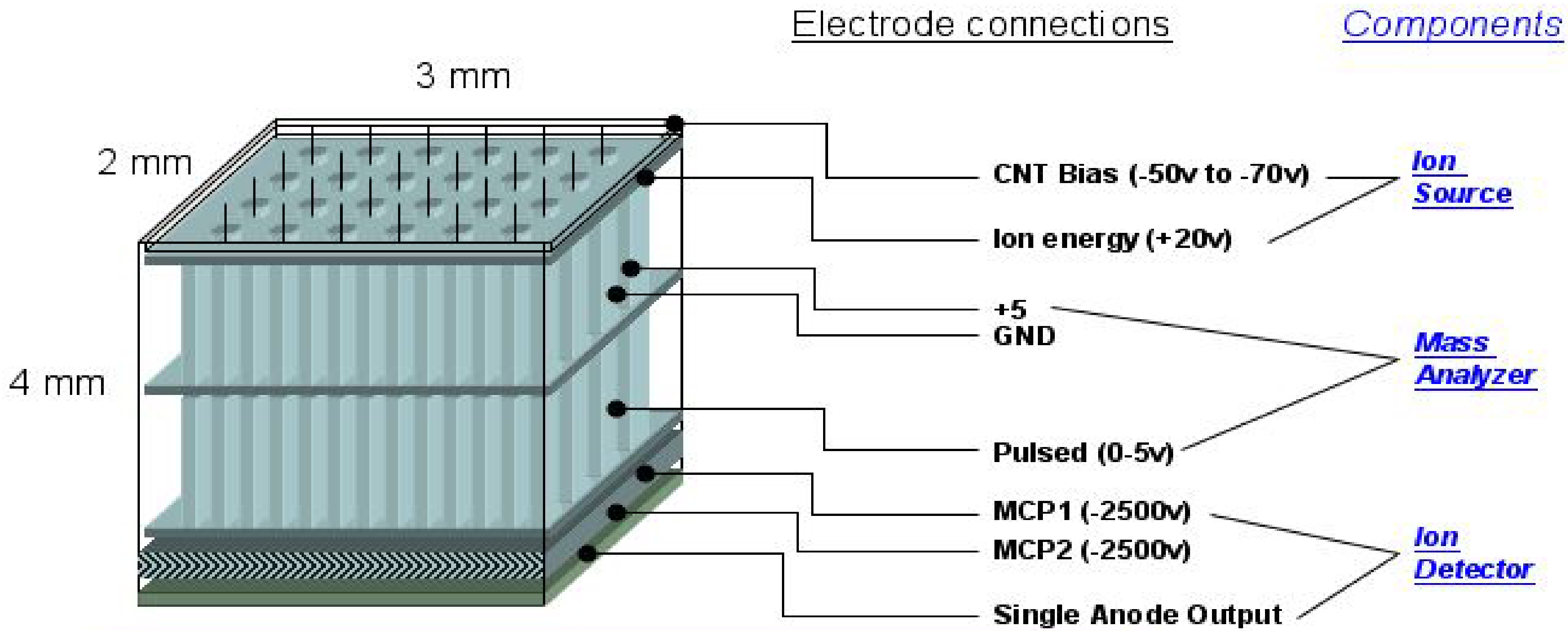


Simulation illustrates double cavity two-stage GEMS with proposed ion sources:

ions pass monochromator-collimator stage on the left and proceed on to the mass analyzer GEMS on the right.



Multiple Ion Sources on Multiple Mass Spectrometers (MIMMS)



4X6 Mass Spectrometer Array = 24 individual mass specs
Total volume = 24 micro-liters
8 total low voltage electrode connections