High Efficiency, High Power Ion Thrusters for Operation at Specific Impulses Greater than 7000 s

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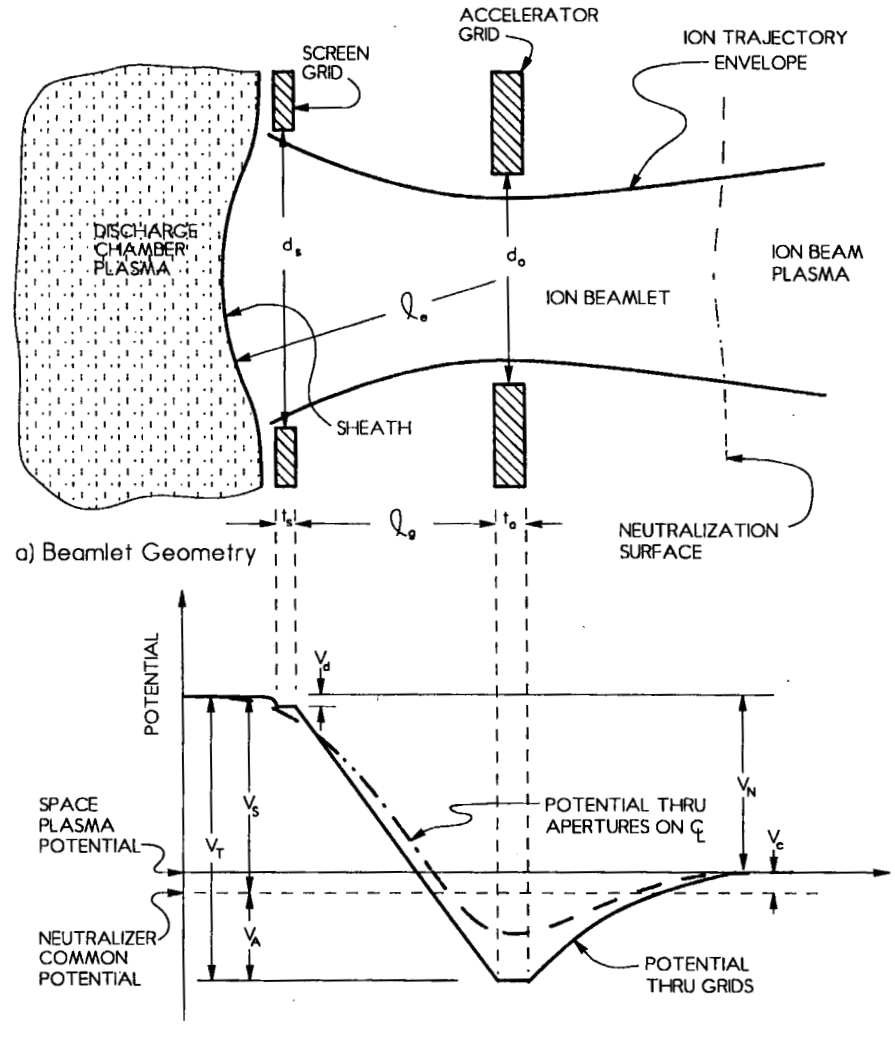
Objective

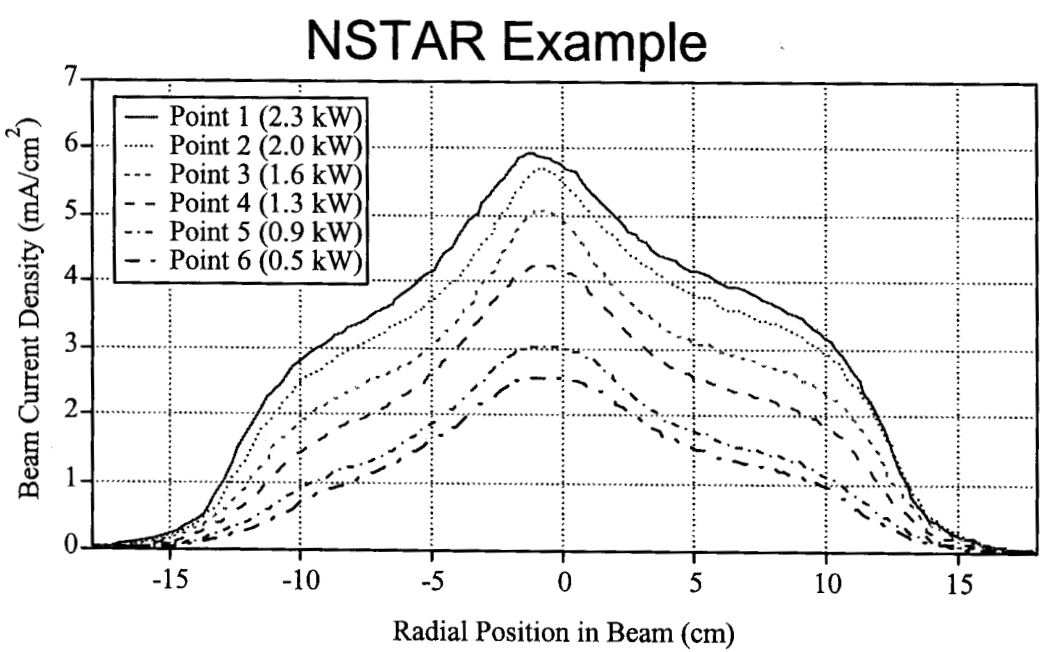
- What design maximizes the accelerator system life for a given:
  - Specific Impulse (*Isp*)
  - Plasma Density Profile

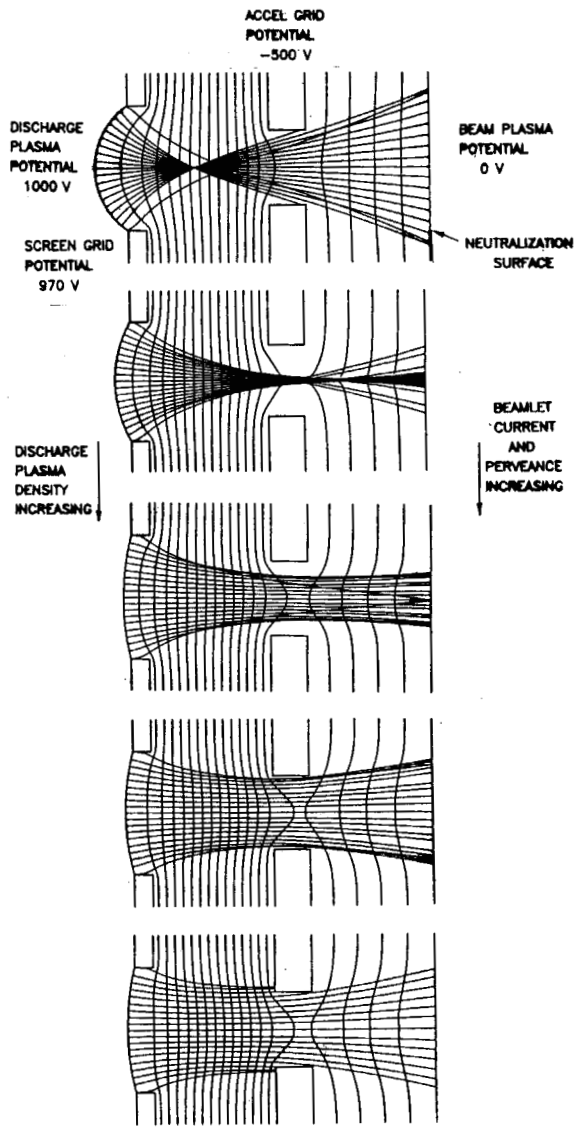
- Free Parameters
  - Screen Grid:
    - *ds*
    - *ts*
    - open area fraction (OAF)
  - Accelerator Grid:
    - *da*
    - *ta*
    - OAF
  - Grid Gap, *lg*



Ion Beam Extraction

- The grid design is complicated by the radial variation in plasma density upstream of the grids

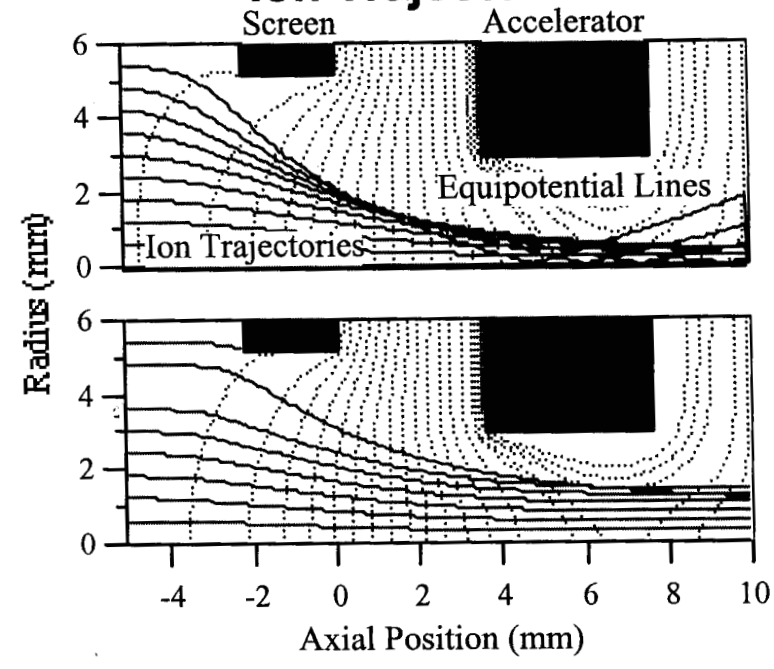




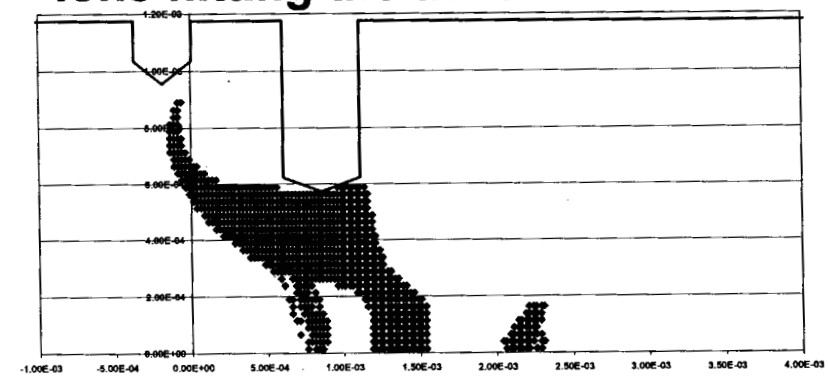
New Toys

- New 2D and 3D ion optics codes have recently been developed with the following features:
  - Fast Execution on a PC
    - As little as 10 minutes in some 2D cases
  - Shape and size of beamlets
  - Energy dependent Charge Exchange (CEX) ion production
  - CEX ion tracking
  - Number, energy, and angle of CEX ions hitting the accelerator grid
  - Can model circular or square holes

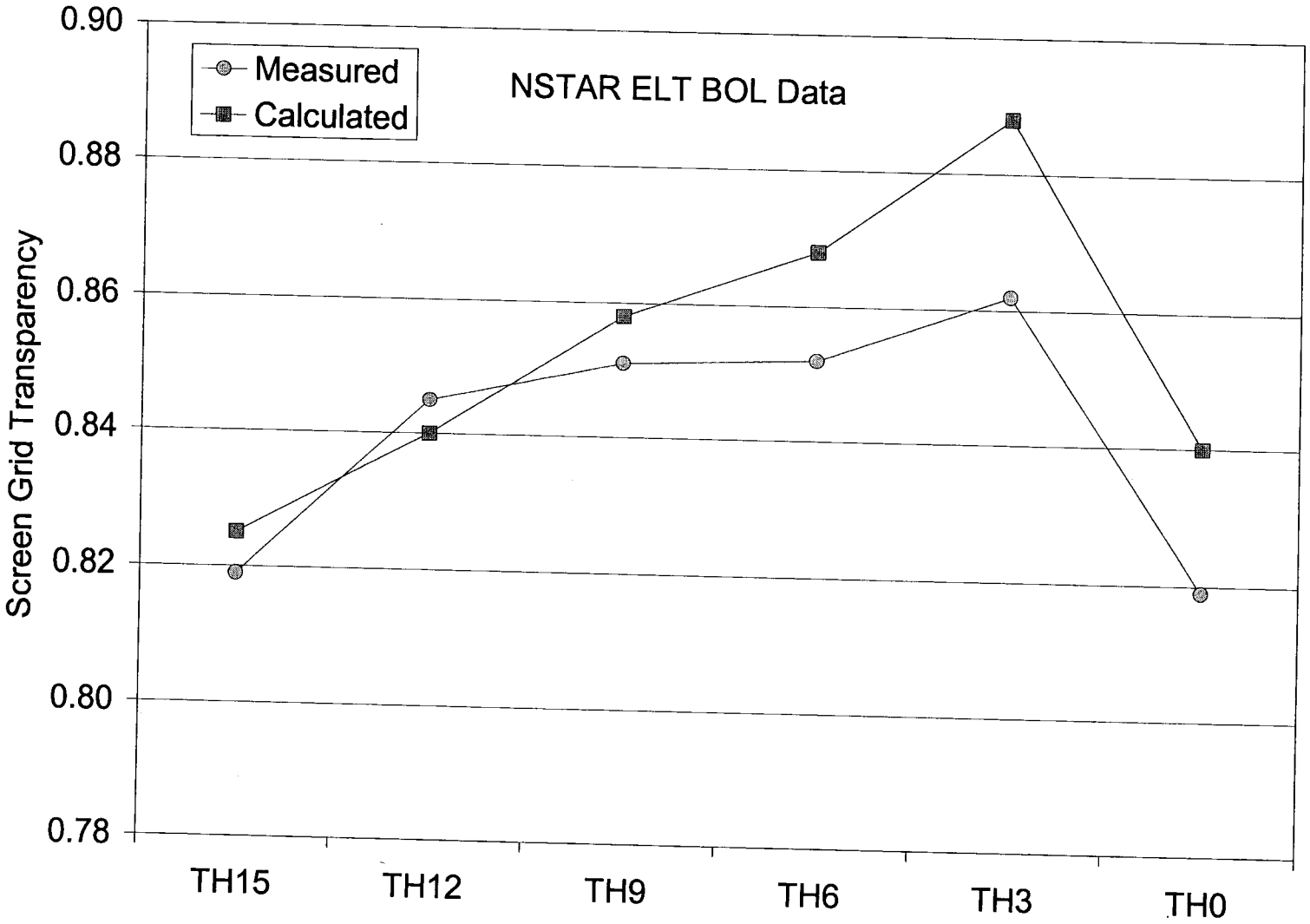
Ion Trajectories



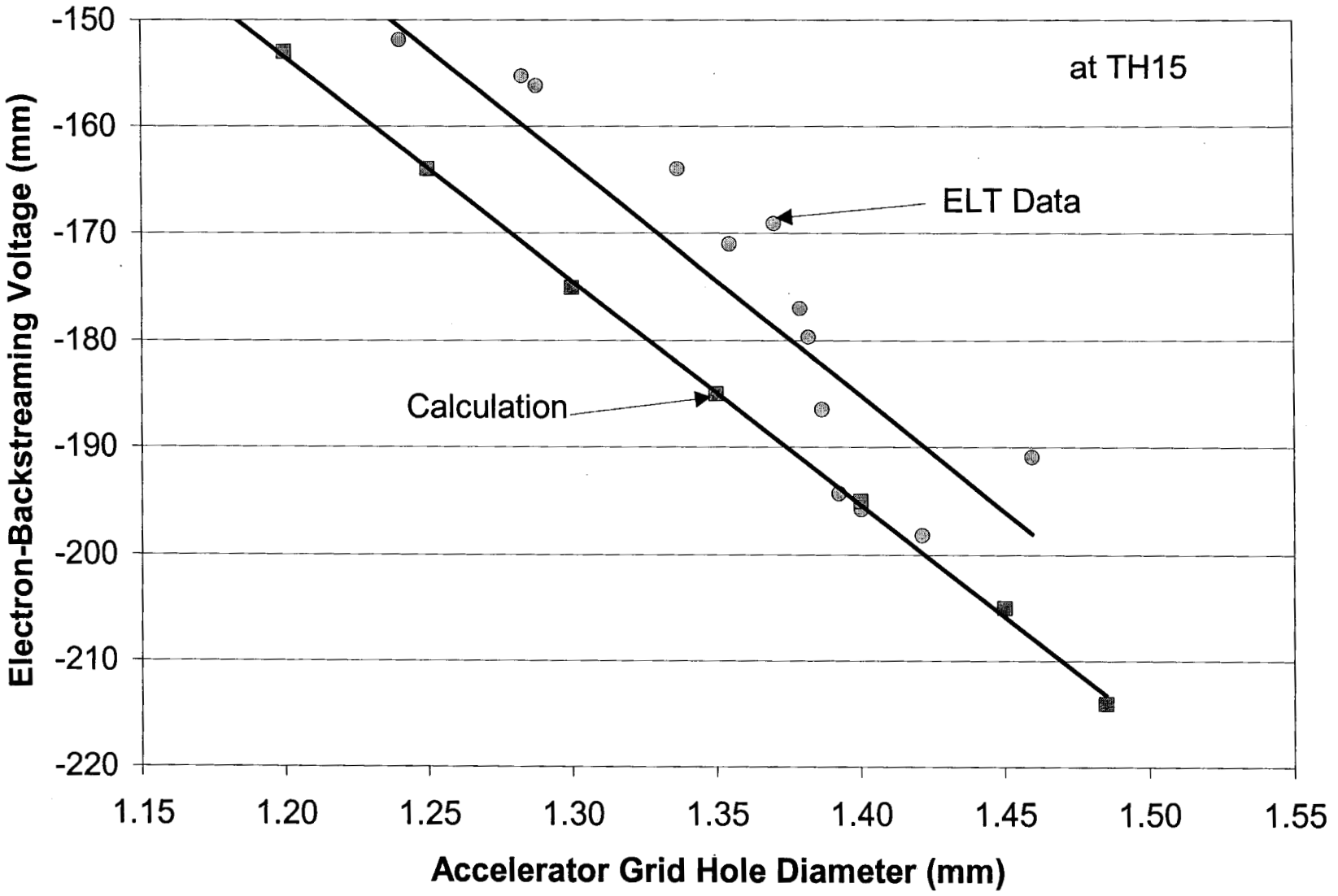
CEX Ions – Birth Locations for Ions hitting the accel. Hole wall



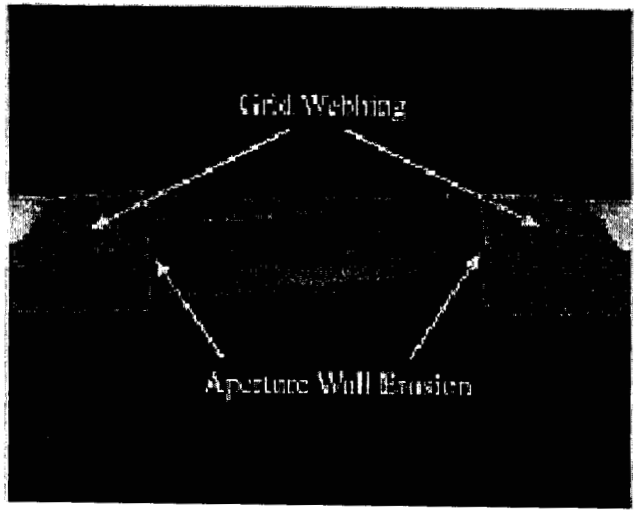
Code Validation – Screen Grid Transparency

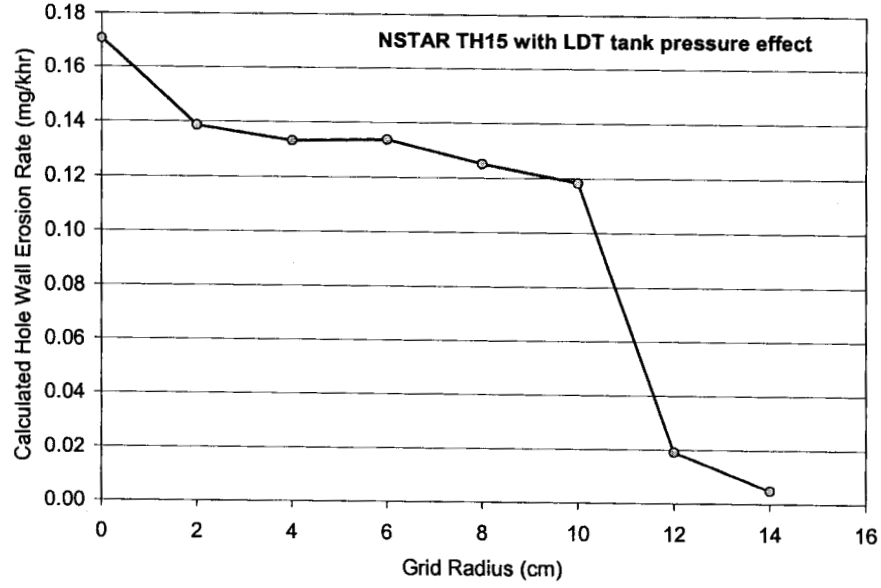


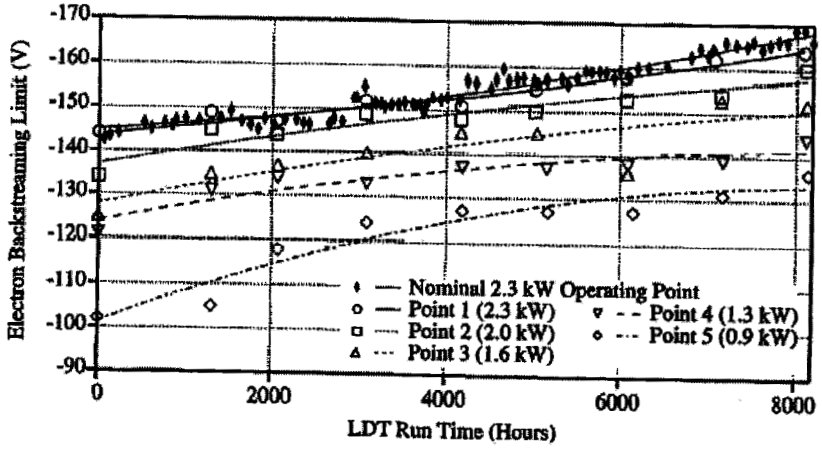
Electron-Backstreaming Variation with Accelerator Grid Hole Diameter

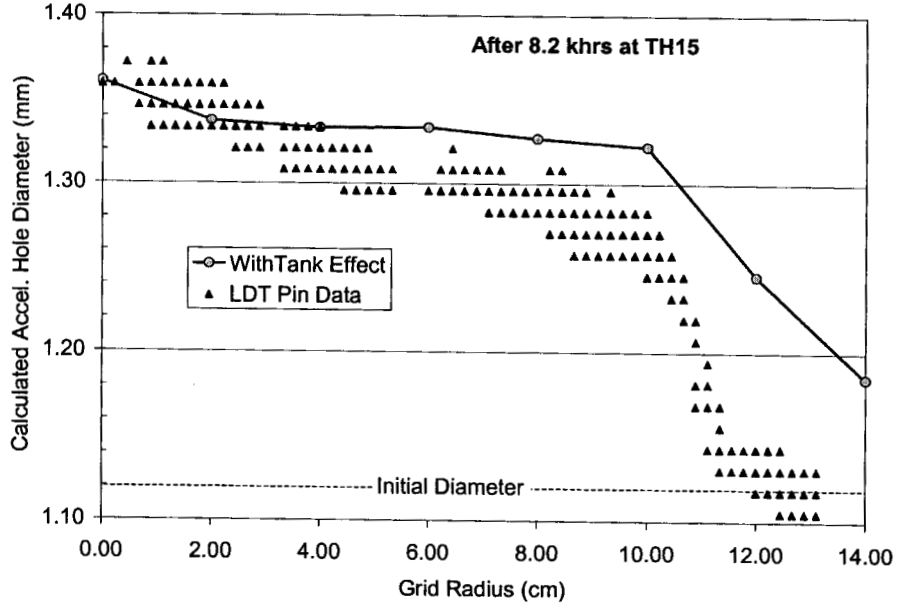


Accelerator Grid Aperture Enlargement is a Major Life Limiting Wear Mechansim



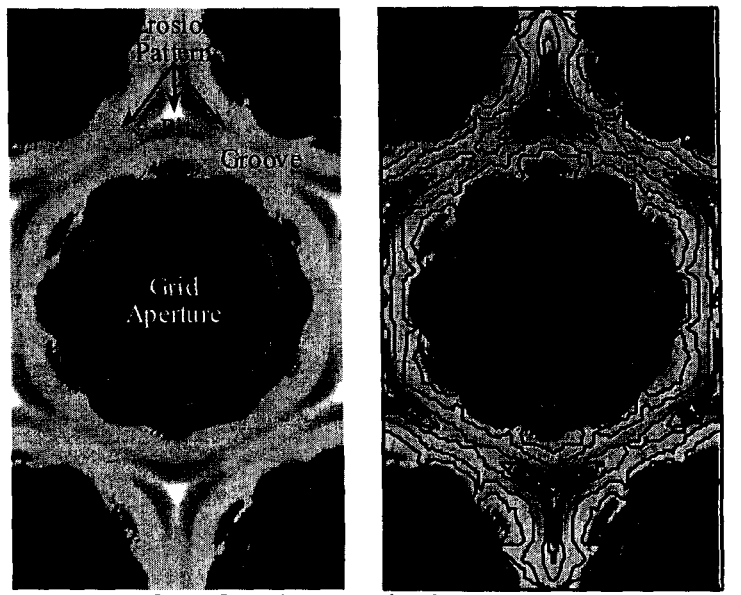






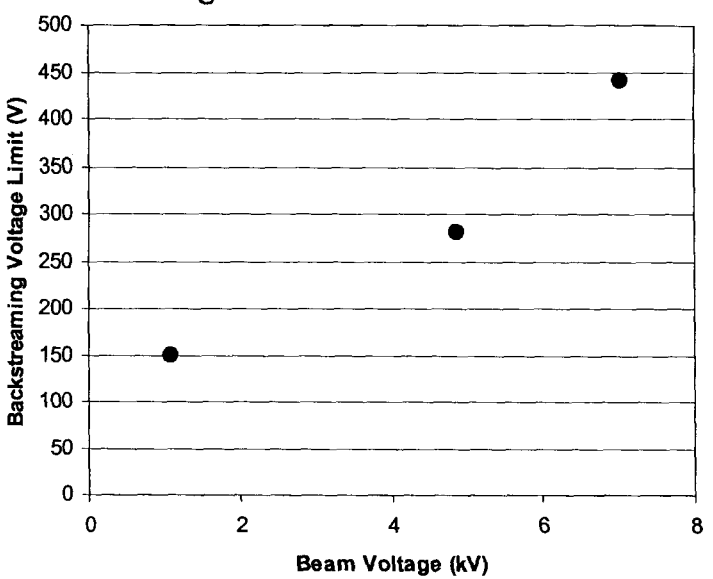
Erosion on the Downstream Side of the Accelerator Grid is Less Important at High *Isp*

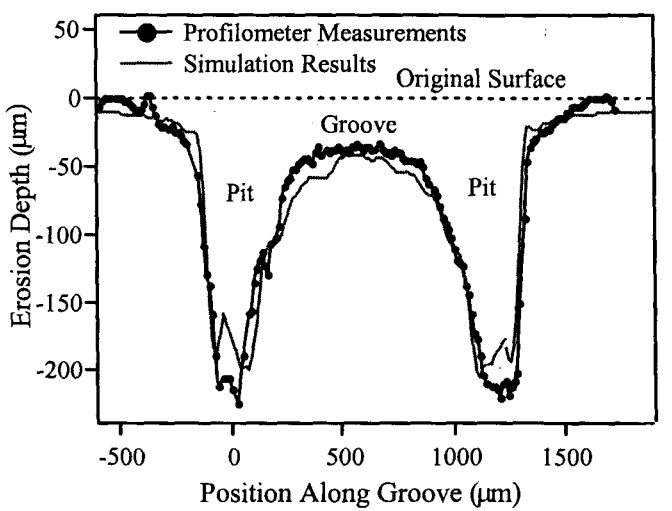
- Scaling to High *Isp* – The Good News
  - Keep all ratios constant
    - *lg/ds, ts/ds, da/ds, ta/ds*
  - Keep electric field constant
    - $E = V_T / l_g$
    - As the total voltage, V_T, increases so does l_g
    - Increasing the grid gap, lg, increases all the other grid parameters resulting in:
      - Thicker Grids
      - Larger Holes
    - The accelerator grid voltage does not increase as fast as the beam voltage and accel. grid thickness



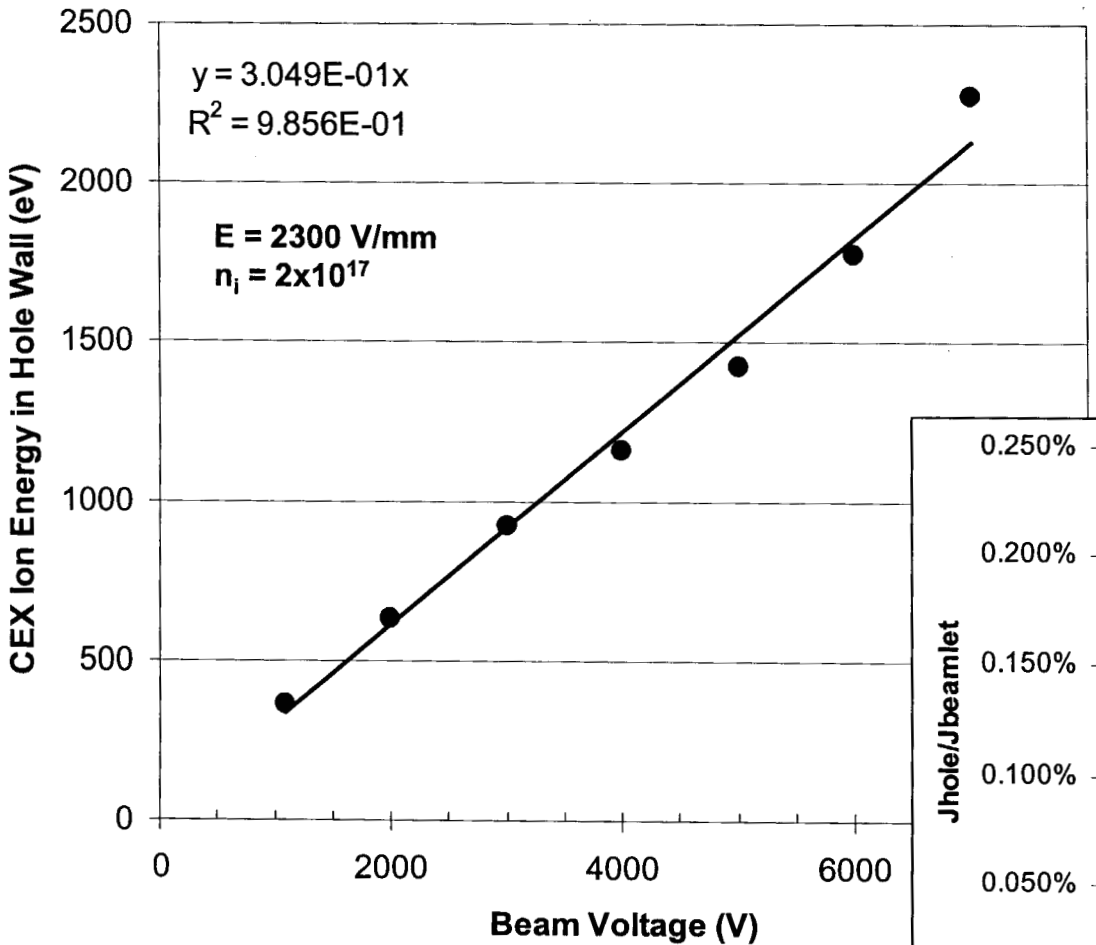
Downstream face of accelerator grid after 8200 hours at 2.3 kWe

Simulated erosion contours overlaid on measured erosion pattern

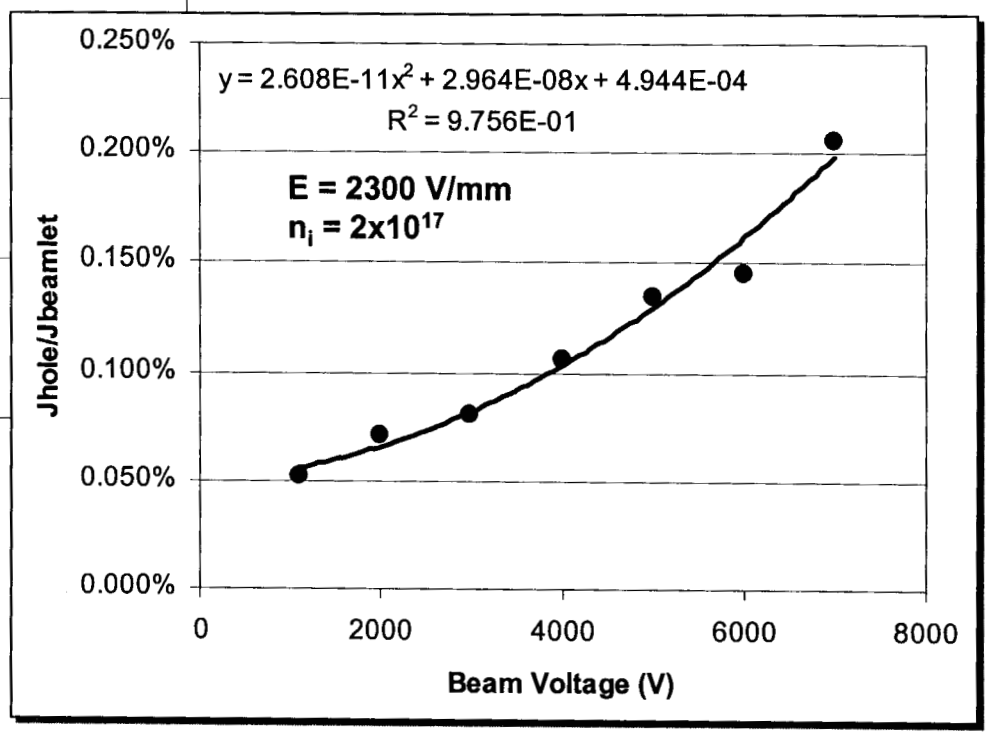




Scaling to High *Isp* – The Bad News



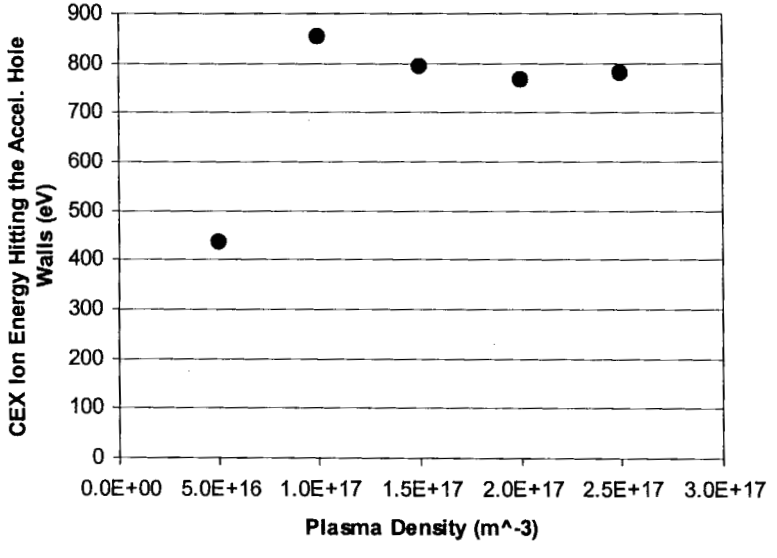
Operation at higher *Isp* (greater beam voltage) increases both the energy and number of CEX Ions hitting the hole walls

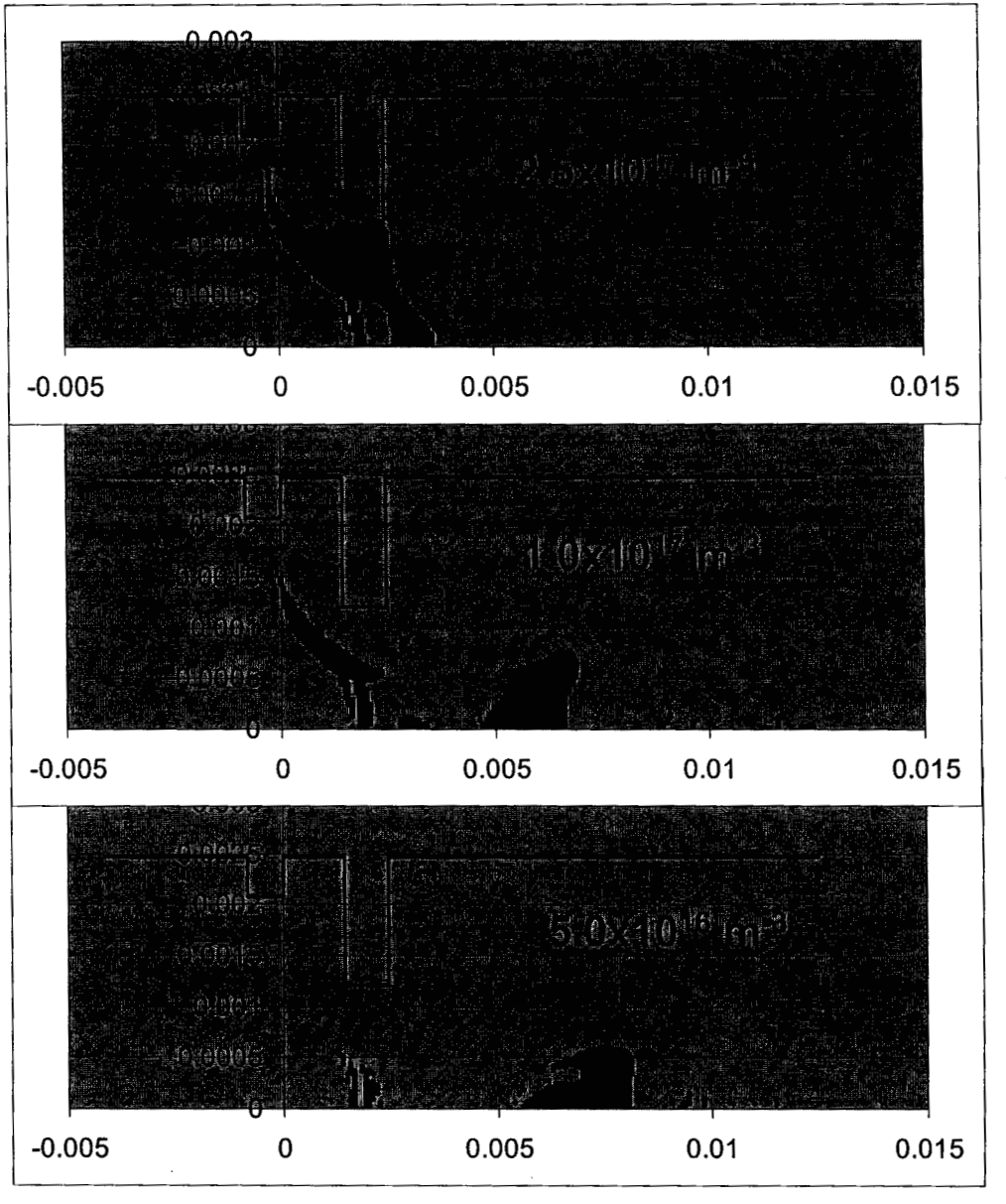


This effect has a major impact On the grid design for long life

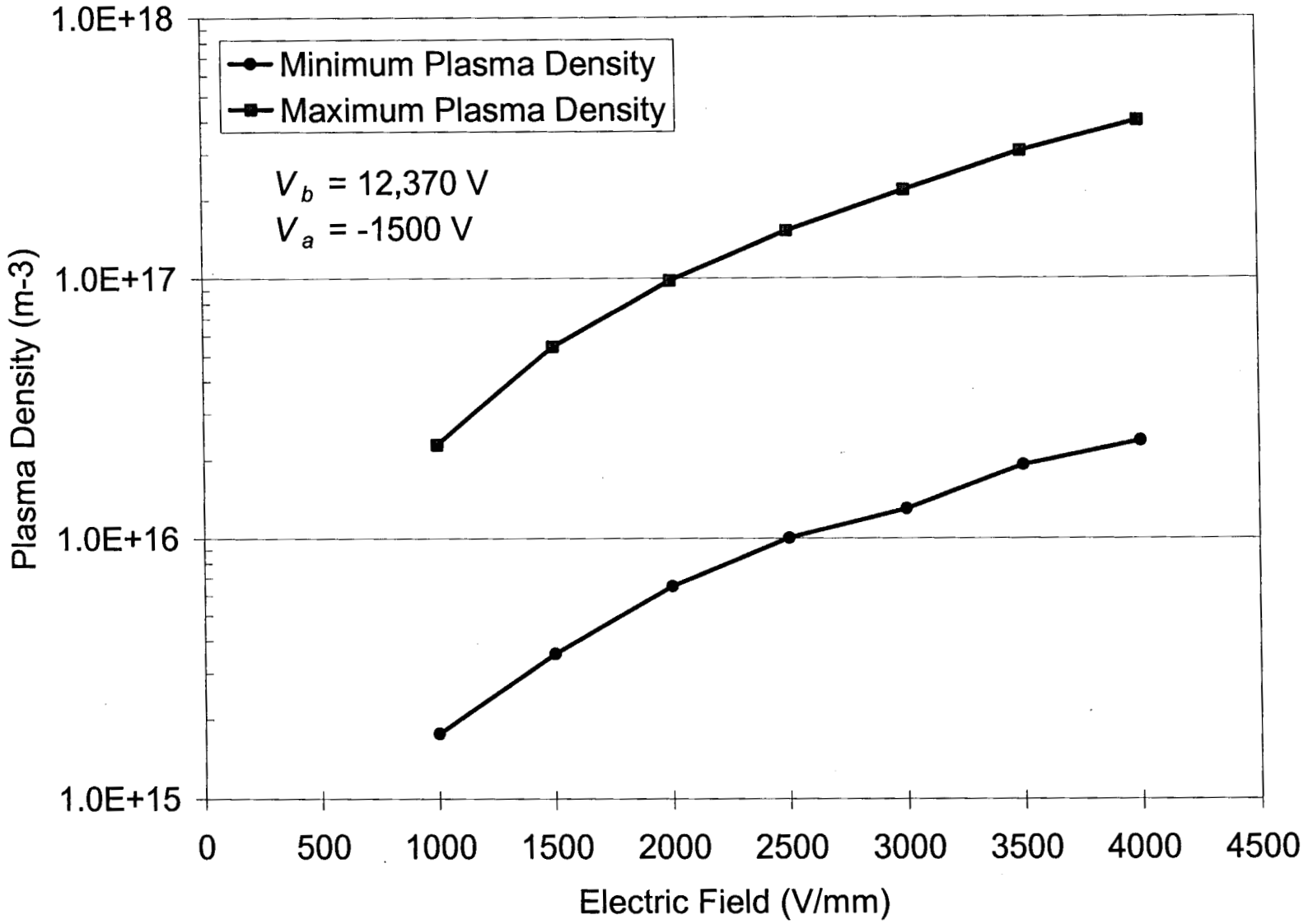
Effect of Plasma Density on CEX Ions

At sufficiently low current densities all of the CEX ions produced between the grids get focused out through the accelerator grid aperture

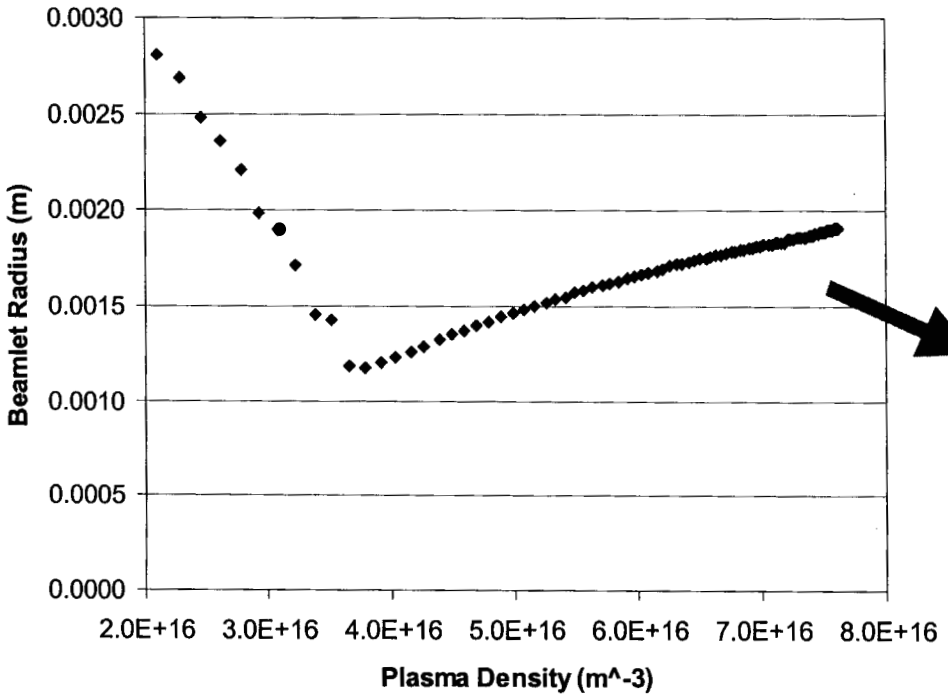


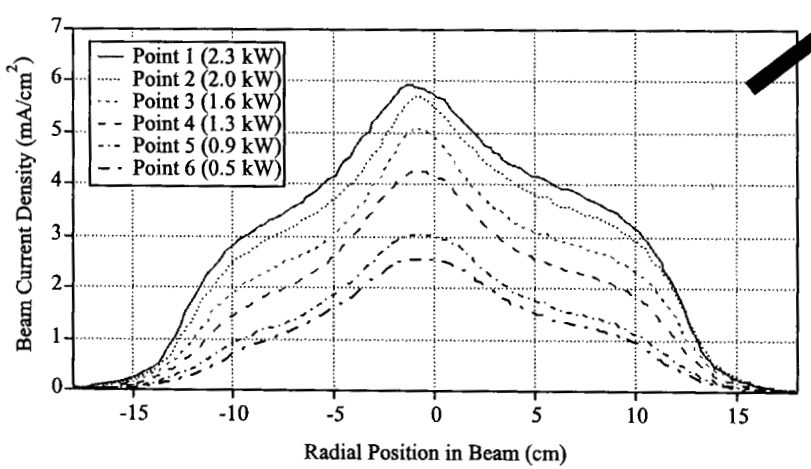


The Ratio of Maximum to Minimum Plasma Densities is Independent of the Electric Field

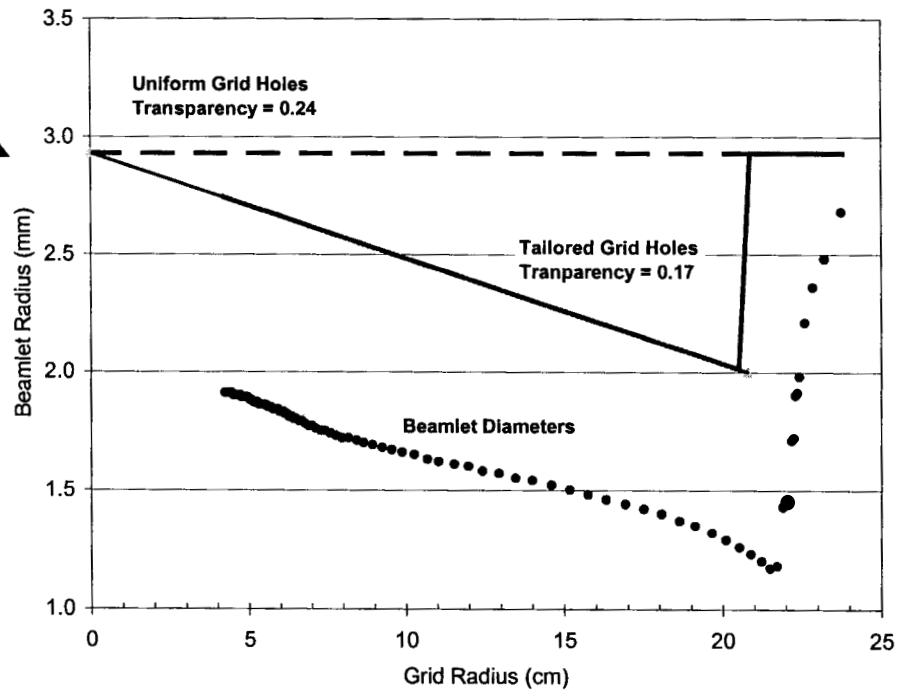


Accelerator Grid Hole Tailoring





Change hole diameters to follow the beamlet size



May enable operation a high propellant efficiencies and high overall thruster efficiencies

Summary

- New computer simulations of the ion accelerator system will enable the development of long-life, high *Isp* ion engines

- The energy of CEX ions hitting the accelerator grid hole walls is a function of the beam voltage
  - Higher *Isp* thrusters will see much greater accelerator grid erosion even if the accelerator grid voltage doesn't change much

- Tailoring of the accelerator grid apertures to follow the beamlet diameters will enable the development of very high efficiency ion thrusters