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Lorentz-2D is a boundary element package developed and marketed by Integrated Engineering Software, which can be used for a variety of charged particle optical analysis. In this paper, the program is used in the analysis of two types of Cs+ sputter ion sources. The results are presented and compared versus some earlier empirical and numerical simulations.

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Lorentz-2D is a boundary element package developed and marketed by Integrated Engineering Software, which can be used for a variety of charged particle optical analysis. In this paper, the program is used in the analysis of two types of Cs+ sputter ion sources. The results are presented and compared versus some earlier empirical and numerical simulations.

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INTRODUCTION

Lorentz [1] is a suite of charged particle ray-tracing packages based on the IES (Integrated Engineering Software) legacy Boundary Element Method (BEM) [2] codes. Currently, Lorentz is being marketed in four different flavors:

Ray-tracing package	***Problem type***	***BEM code***
Lorent-2D	2D (Two dimensional) and RS (Rotational symmetric)	Electro
Lorentz-E	3D (Electrostatic)	Coulomb
Lorentz-M	3D (Magnetostatic)	Amperes
Lorentz-EM	3D (Hybrid Electrostatic & Magnetostatic)	Coulomb & Amperes

Lorentz is supported on all different versions of MS Windows operating system with a GUI (Graphical User Interface), which is quite compatible with Microsoft standard look and feel. All the interactions with the software are done through dialog boxes and menu structures. This is quite in contrast to some of the other packages that will require the user to interact with the program through awkward and error-prone ASCII files. Using the self contained geometrical modeler; the user can define any complicated structures at no time. The library of standard geometrical entities consists of lines, arcs, splines, planes, spheres, etc. Also, sweeping different primitive entities can generate arbitrary surfaces and volumes.

CS+ SPUTTER ION SOURCE

In 1973, Middleton and Adams developed a novel type of ion source, which is based on generating negative ions by sputtering a solid surface with Cs+ ions. This type of design has found its wide spread applications due to the fact that it can generate high intensity ions of practically any element with low energy spread and minimum amount of maintenance. In principle, the positively charged Cesium ions will be extracted from the spherical ionizer at the left, to be accelerated towards the target at the very right end of the structure. Due to the collision of heavy Cesium ions with the target surface, negatively charged Carbon ions will be sputtered off that surface. These sputtered ions will then be accelerated towards the output window located at the very left side of the geometry.

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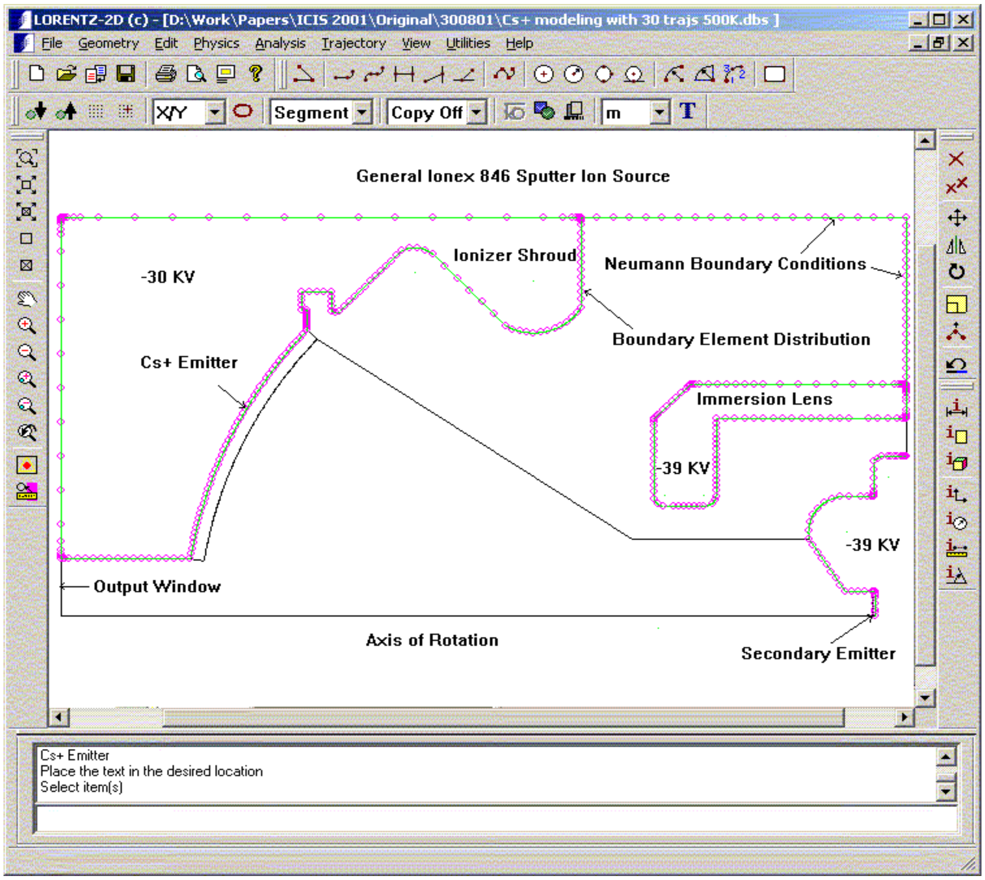
Here, we will concentrate on two designs, which were previously studied by Brown, et al [3]. The first design is an adaptation of General Ionex Corporation 846 Cs sputter ion source acquired by CAMS (Center for Accelerator Mass Spectrometry) in 1989. The second structure is a modified model, which could double the current throughput of the device.

ORIGINAL ION SOURCE

Originally, the Ionex 846 Cs sputter source was modeled using a Finite Difference (FD) mesh of $600 \times 300 = 180{,}000$ grid points. FD is based on utilizing a truncated Taylor series expansion in each coordinate direction. Using this expansion, the differential operator is discretized at each point of a rectangular grid covering the entire region of interest. The biggest advantage of this method is its ease of implementation since the differential operators are easily modeled without much preprocessing. Of course, the trade off is paid in less accuracy and speed and poor modeling of the boundaries compared to more sophisticated methods. Lorentz, based on BEM, on the other hand, solves for the charge distribution on the boundaries of the structure. Knowing these charges, the potential and field can be directly computed everywhere in space. If there is no space charge present in the structure, Lorentz will automatically place boundary elements (red dots in Figure 1) on the segments that have a boundary condition assigned to them and that is all that is needed.



Cs+ Emitter
Place the text in the desired location
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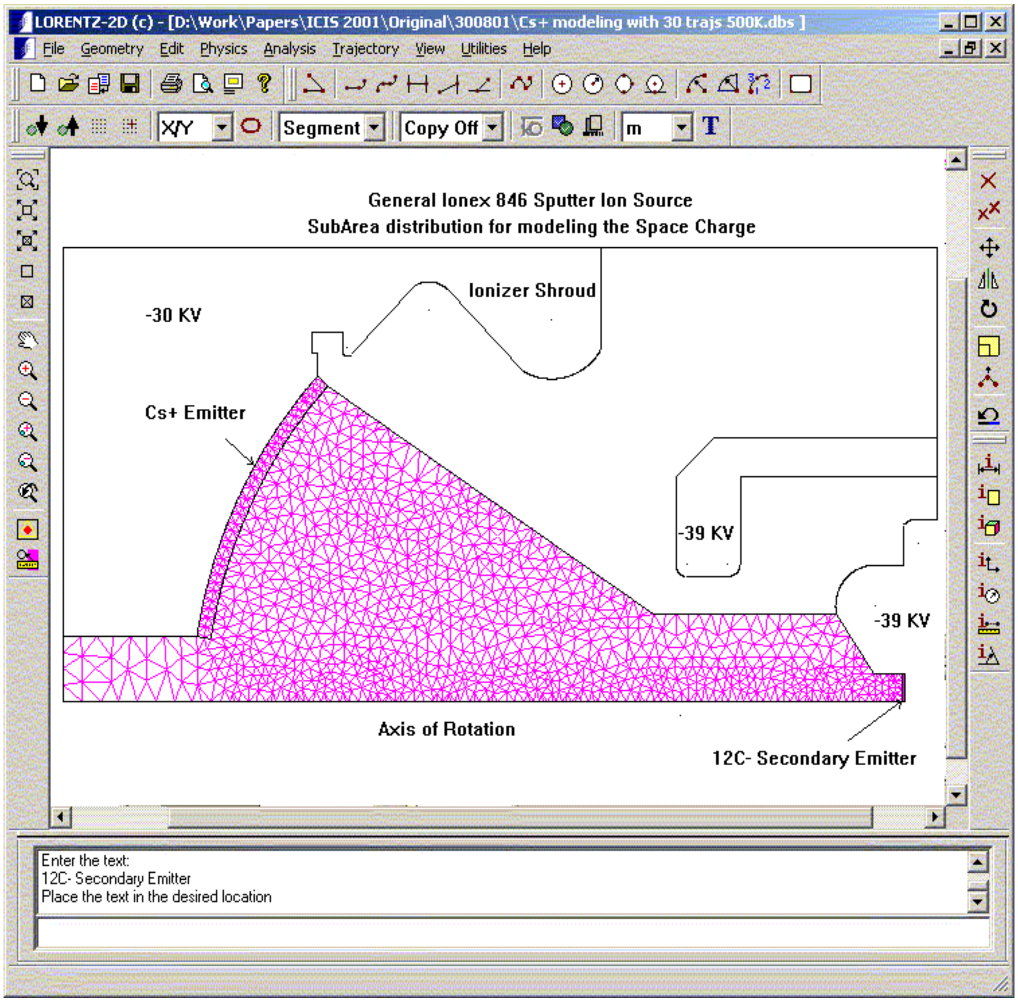
Figure 1: The BEM boundary element distribution of the original ion source

On the other hand, for the situations that space charge analysis is of prime concern, a two dimensional mesh in space is required in order to deposit and store space charge distribution; as shown in **Figure 2**.



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Enter the text:
12C- Secondary Emitter
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Figure 2: The sub area distribution (required for space charge computation) of the original ion source.

Each triangular sub area contains three Gauss points. When a particle trajectory crosses a sub area, it will deposit appropriate amount of charges on these Gauss points based on the relative positioning of these Gauss points with respect to the crossing trajectory.

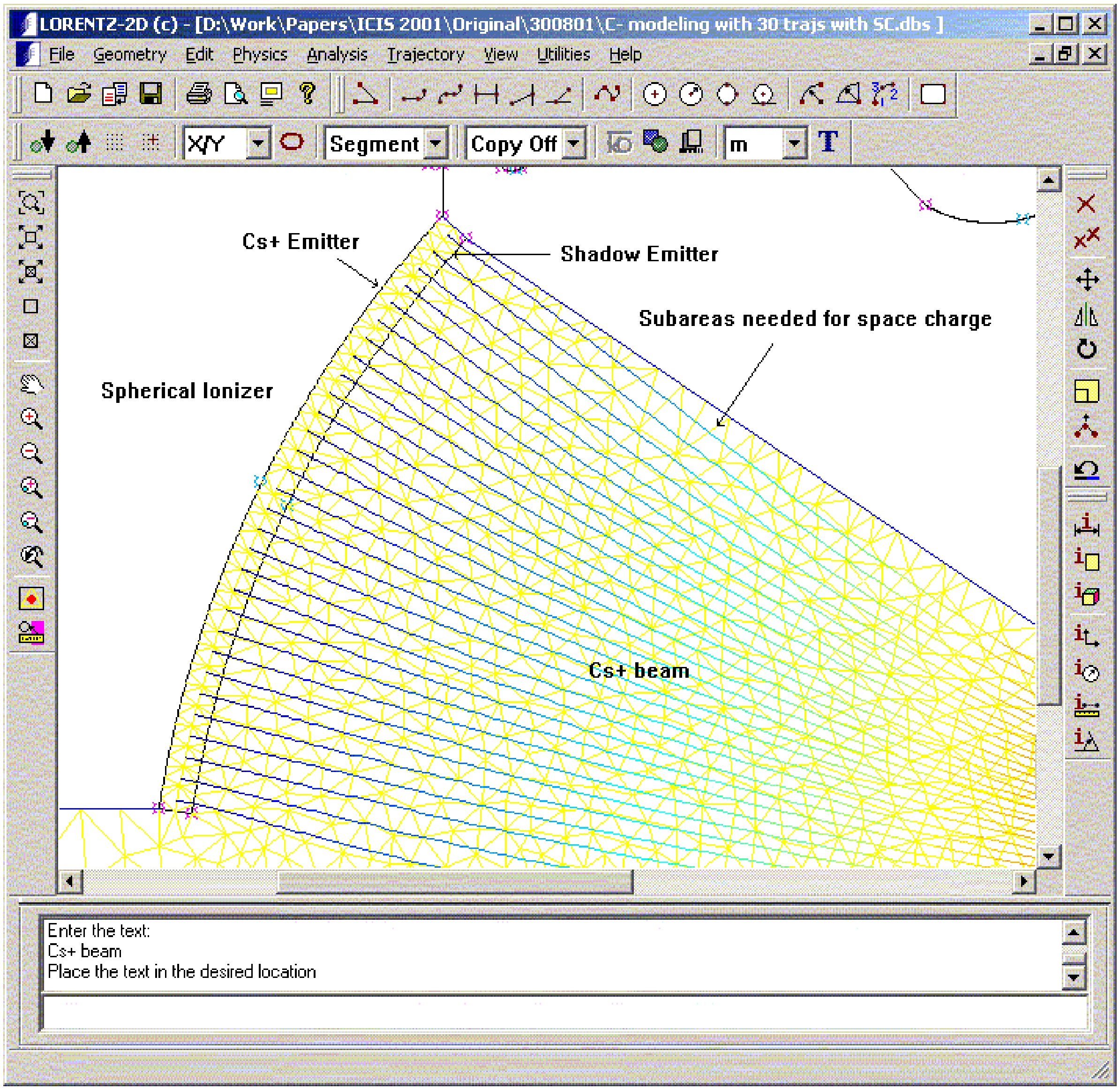
For an ideal planar diode, the space charge distribution will approach infinity, as a point approaches the emitter surface, according to the following equation:

$$\rho(z)=\frac{-4\varepsilon_0 V_0}{9d^{\frac{4}{3}}}\left(\frac{1}{z^{\frac{2}{3}}}\right)$$ in which z is the normal distance to emitter [1]

This, of course, is a natural consequence of applying the Child's law, which by definition requires a space charge distribution to create such a strong opposing field that pushes down the normal component of the electric field at the surface of the emitter to zero.

This discontinuity poses a challenging problem to any numerical analysis, if left untreated.

Lorentz deals with this discontinuity with partitioning the space into two regions: (a) Close and (b) Far from the emitter surface. As it is depicted in Figure 3 and Figure 4, there exists a parallel segment drawn at the vicinity of all the emitters; we call this artificial segment a shadow emitter. Its responsibility is merely dividing the modeling region into two partitions; i.e. close and far from the emitter. Such partitioning is required because of the way program assigns the space charge to subareas.



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Cs+ beam
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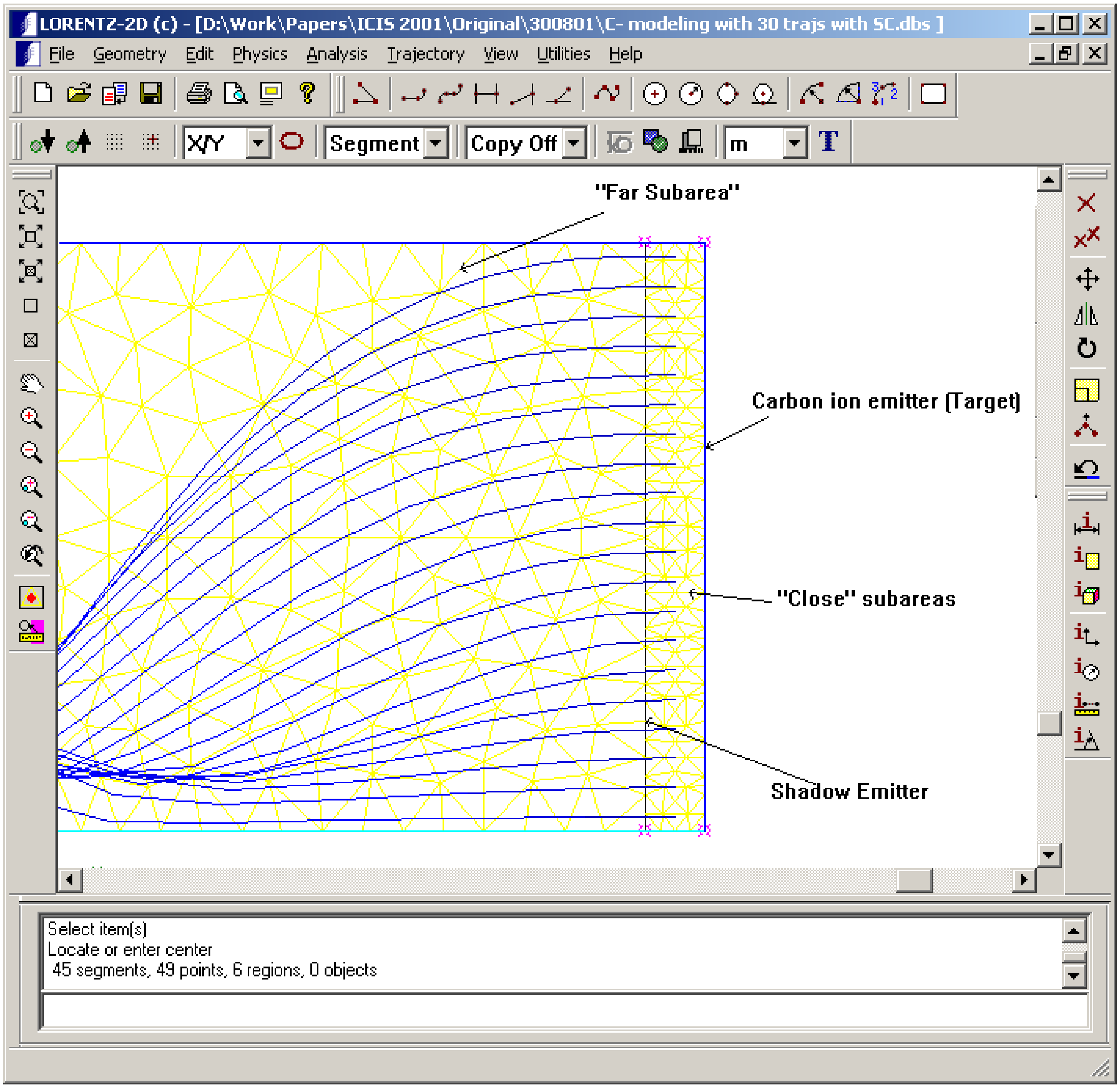
Figure 3 Close up view of the Cs+ spherical ionizer surface.



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Select item(s)
Locate or enter center
 45 segments, 49 points, 6 regions, 0 objects
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Figure 4 Close up view of the C- ion target surface.

A quick hand calculation of Child's law [4] will give us some ideas about the amount of the current that should be expected from this device. It has to be emphasized that, strictly speaking, Child's law is only applicable to planar emitters with Neumann boundary conditions set at the sidewalls. So, using this formula for the problem at hand should be viewed only as an aiding tool, not as the exact analytical solution.

$$J = \frac{4\varepsilon_0\sqrt{2\eta}}{9}\,\frac{V_0^{\frac{3}{2}}}{d^2} \quad \text{in which } \eta = \frac{q}{m} \qquad [2]$$

Ion	q	m	V_0	d	$\tilde{r}$	$I_{flat-diode}$	$I_{Lorentz-2D}$
Cesium	$+e$	133	$9KV$	$26mm$	$7.2mm$	$+0.96mA$	$+1.08mA$

Table 1: Cs+ saturation current

Figure 5 illustrates the trajectories of positive Cesium ions once the saturation is achieved. It turns out that the spherical ionizer is pumping $1.08mA$ of positive current into space. The trajectories are also color shaded based on the local velocity of the corresponding particles.

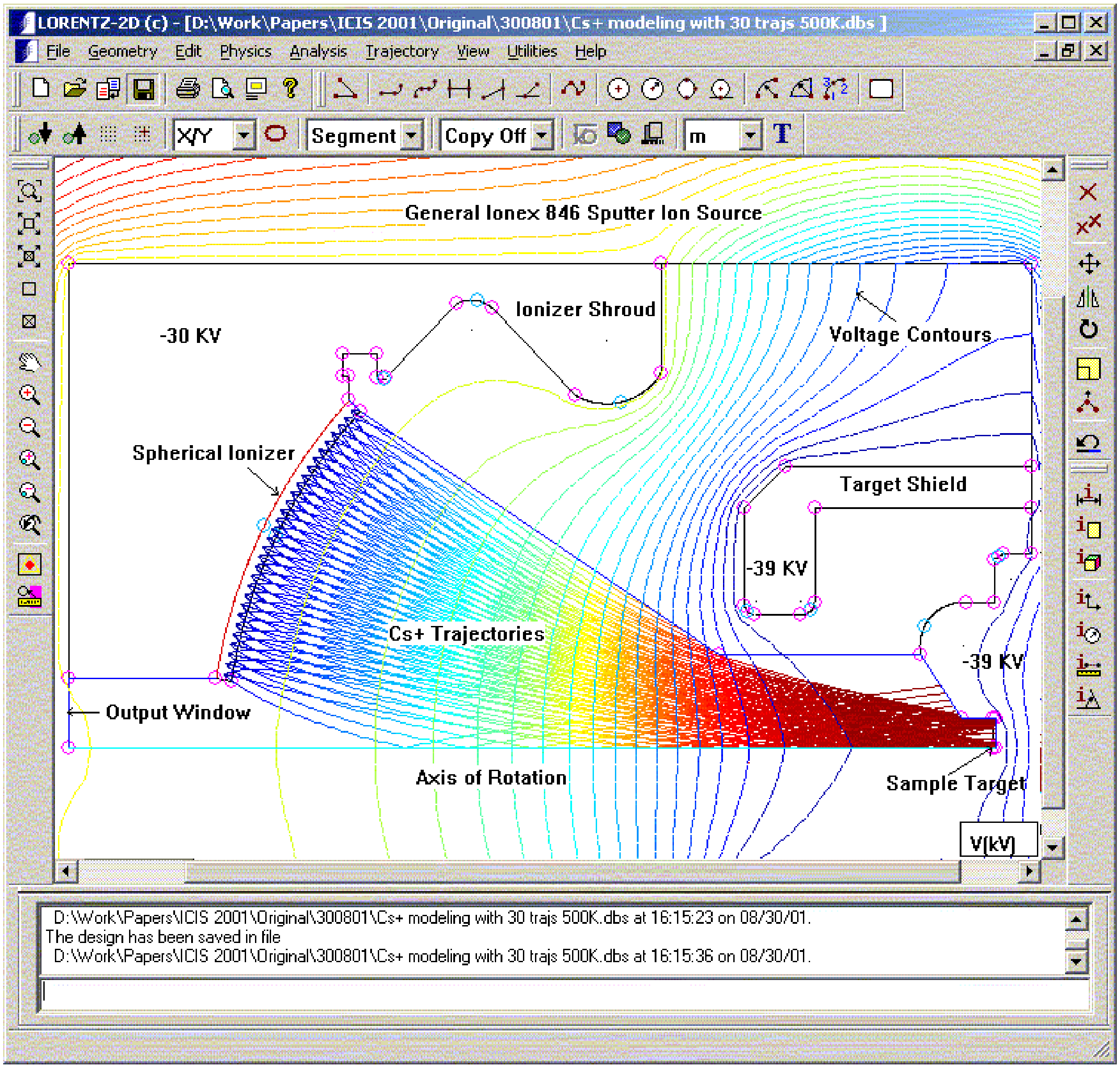

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Figure 5 Trajectory of positive Cesium ions in the saturation regime

In practice, the amount of generated current due to Carbon ions is one order of magnitude smaller than the current carried by Cesium ions. Therefore, it seems reasonable enough to assume that the saturation current for spherical ionizer can be computed regardless of the presence of the space charge due to the Carbon ions. Needless to say, the same assumption cannot be made about the Carbon ions. In other words, any calculation of the saturation current out of the target surface has to be performed in the presence of the space charge due to Cesium ions. The amount of the current produced by negative Carbon ions is calculated as $-135\mu A$ by Lorentz, Figure 6.

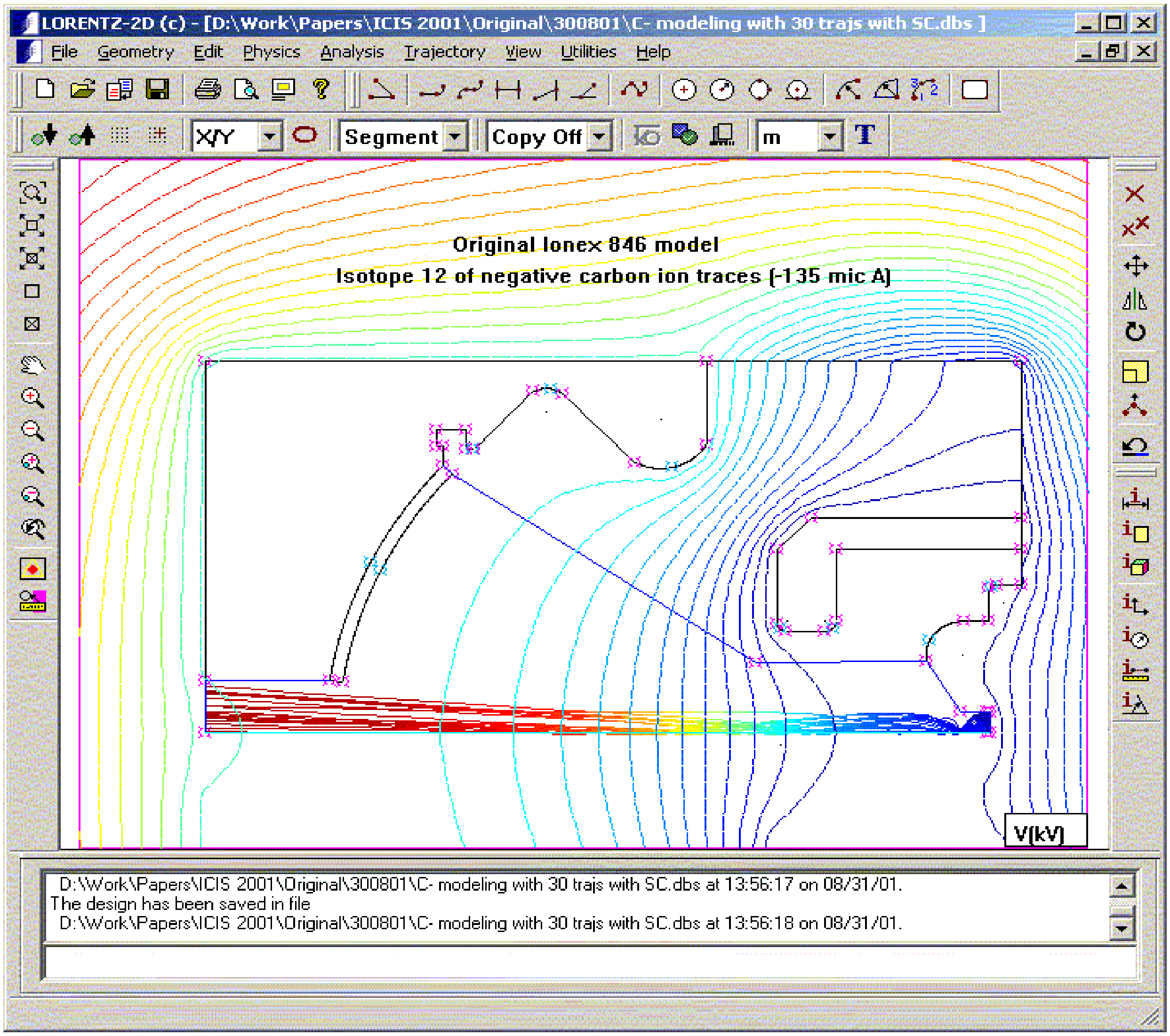

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Figure 6: Trajectories of the negative Carbon ions sputtered off the target.

MODIFIED ION SOURCE

Part of the efforts at Center for Accelerator Mass Spectrometry in analyzing the General Ionex 846 model, was finding ways to improve the performance of these devices. This is achieved by changing the topology of the target shied as well as connecting it to an extra power supply with a voltage of $-38.25KV$. The result of such a simulation using Lorentz-2D is depicted in Figure 7. The total amount of extracted current turns out to be $2.06mA$, which is almost double the amount achievable using the original 846 model. Beam shape seems to be better formed too.

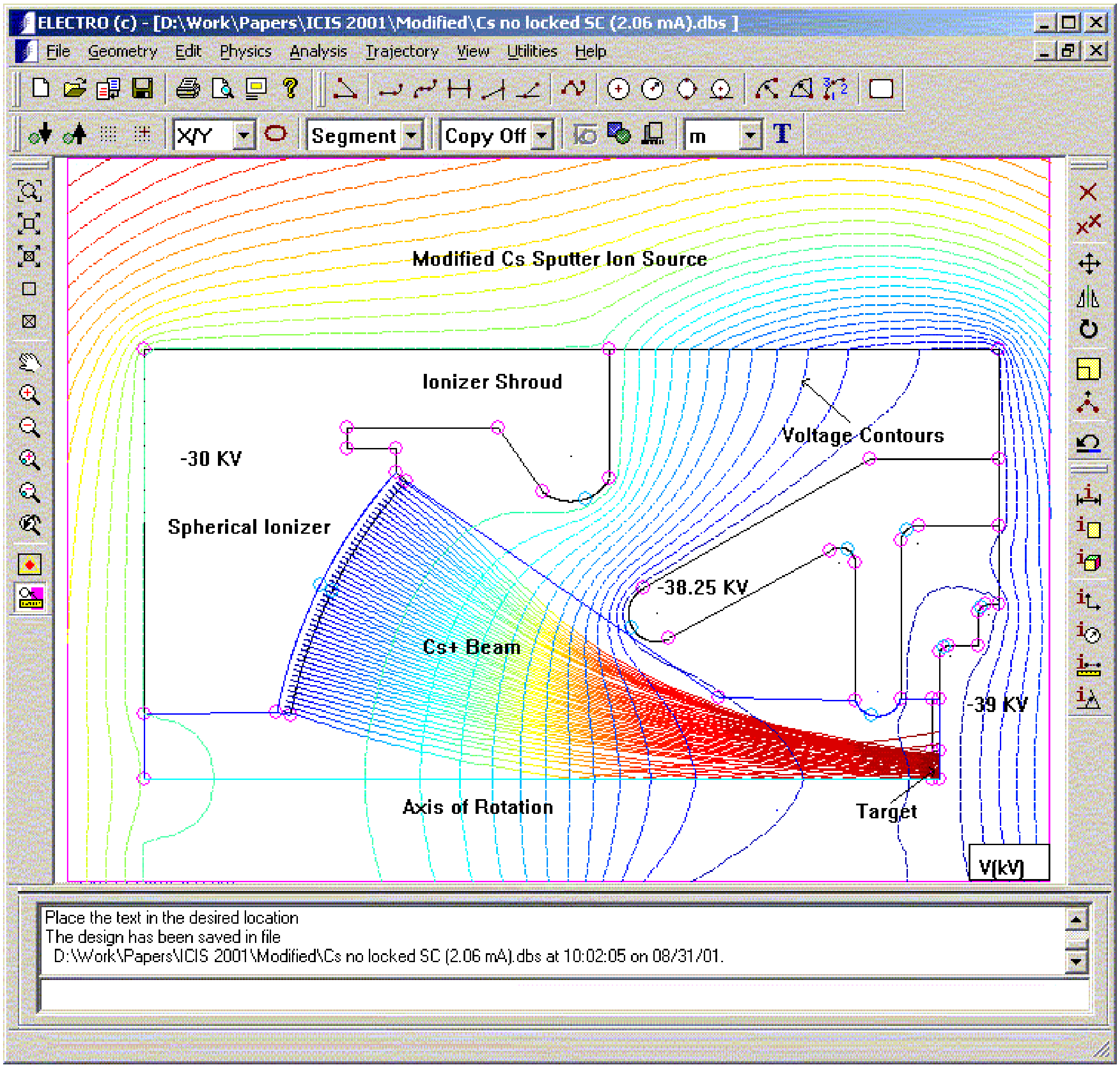

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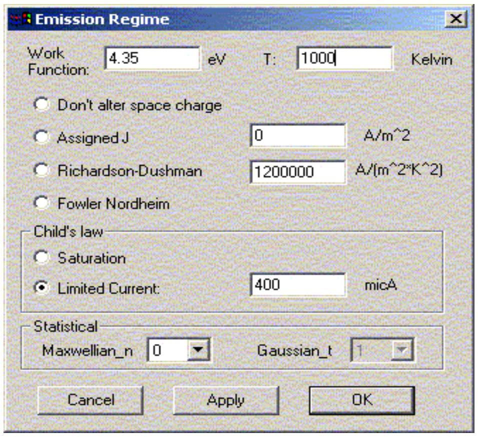
Figure 7: The Cs+ trajectories emitter from the modified spherical ion source.

One of the difficulties that Brown's team reported during their simulation was the observed instability in their finite difference solution whenever they were trying to apply Child's law to the Carbon ion emitter (target). Using Lorentz-2D, the simulation can be executed in several different modes, as illustrated in Figure 8.



Work Function: 4.35 eV T: 1000 Kelvin

○ Don't alter space charge

○ Assigned J 0 A/m^2

○ Richardson-Dushman 1200000 A/(m^2*K^2)

○ Fowler Nordheim

Child's law

○ Saturation

● Limited Current: 400 micA

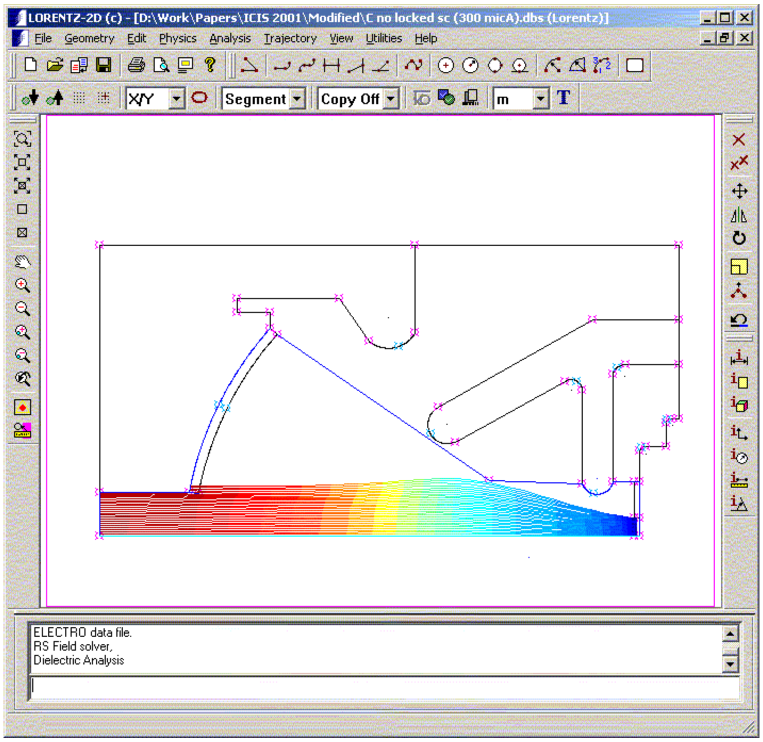
Statistical

Maxwellian_n 0 Gaussian_t 1

Figure 8 Emission regime dialog box from Lorentz.

In fact, in order to show the effect of different settings, the results of a variety of simulations will be presented here.

Figure 9 shows the traces of Carbon ions launched in the presence of its own space charge. There is no space charge resulted from Cs+ ions present in the space. The value of the saturation current is also being computed to be $-298\mu A$. Intuitively, one expects that introducing the positive Cs+ ion charges would increase the amount of negative current to be extracted from the target and in fact this is exactly what happens. Next, we will try to examine the effect of positive Cs+ ion charges on overall extracted current from the target. Since Brown's team had reported a negative current of around $400\mu A$, we will try to clip the amount of negative current to this much for the next run. Figure 10 illustrates the result of such a simulation. As it can be seen, the negative Carbon ions are well confined within the output window. Also, it seems that the presence of the positive ions helped to cancel out some of the repelling effects of the negative space charges. And that seems to be the reason why the beam in Figure 10 is more closely packed than the beam in Figure 9, which is carrying even a smaller current. Finally, Figure 11 shows the result of the same simulation; i.e. both Cs+ and C- are present, with the distinction that this time there would be no clipping of the total current. In this run, device is being driven into saturation by the maximum current permissible under Child's law. This time a saturation current of $-841\mu A$ is obtained, which is six times more than the one achievable by original 846 model. This may seem like a lot of improvement, but one has to bear in mind that one of the main factors on how much negative current in a device like this can be extracted, is determined by the process of sputtering. Nevertheless, regardless of the exact figure of the total negative current, one conclusion can be made and that is the new design is much more capable of generating high intensity negative ions than the original one.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ELECTRO data file.
RS Field solver,
Dielectric Analysis
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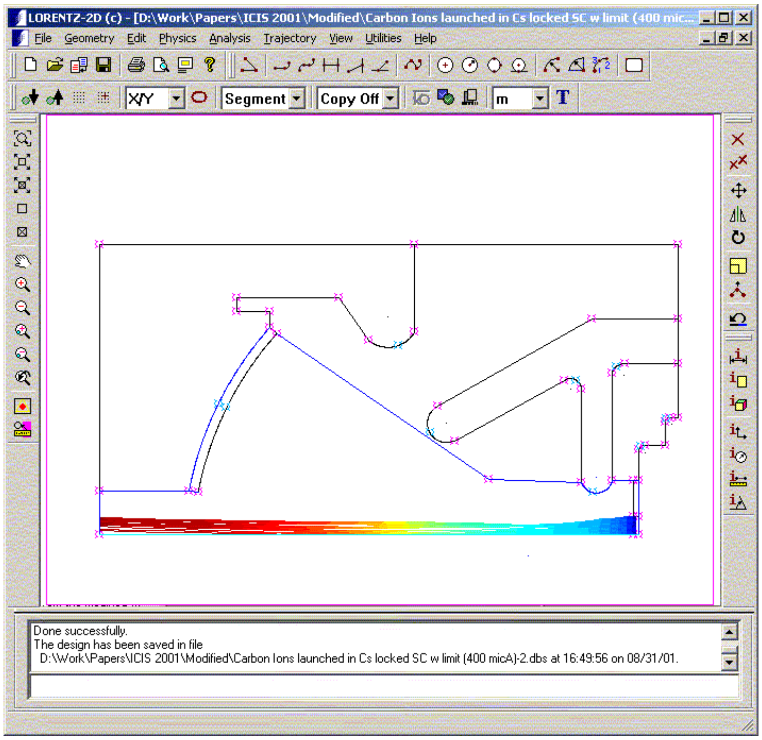
Figure 9 Traces of Carbon ions in the presence of the C- space charge only (no Cs+ space charge).

The total negative current is only limited by Child's law, $-298\mu A$ **.**


LORENTZ-2D (c) - [D:\Work\Papers\ICIS 2001\Modified\Carbon Ions launched in Cs locked SC w limit (400 mic...

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  D:\Work\Papers\ICIS 2001\Modified\Carbon Ions launched in Cs locked SC w limit (400 micA)-2.dbs at 16:49:56 on 08/31/01.
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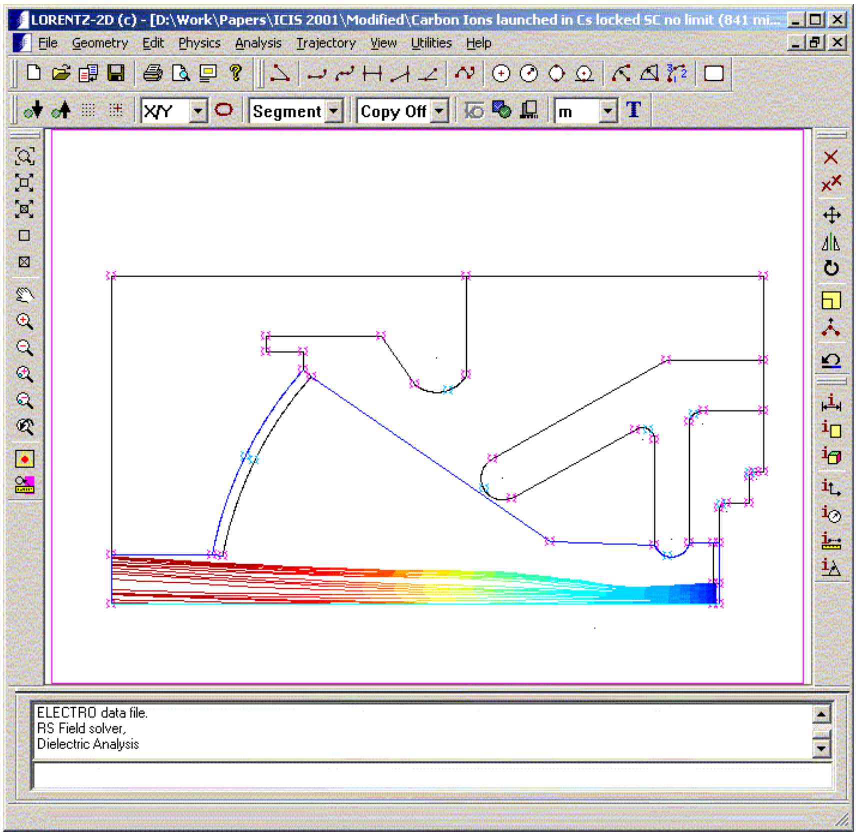
Figure 10 Traces of Carbon ions in the presence of the Cs+ and C- space charge.

The total negative current is limited to $400\mu A$ **.**



ELECTRO data file.
RS Field solver,
Dielectric Analysis

Figure 11 Traces of Carbon ions in the presence of the Cs+ and C- space charge.

The total negative current is only limited by Child's law, $-841\mu A$.

ACKNOWLEDGEMENTS

I would like to gratefully acknowledge the help and contributions made by all my colleagues at Enginia Research Inc. without their help this work would have been impossible. Special thanks goes to D. Craigen for scanning the original geometries into Lorentz. I also feel indebted to T. Brown from Center for Accelerator Mass Spectrometry and F. Osswald from Institut de Recherches Subatomiques for their invaluable input and suggestions.

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