Ions in ERLs

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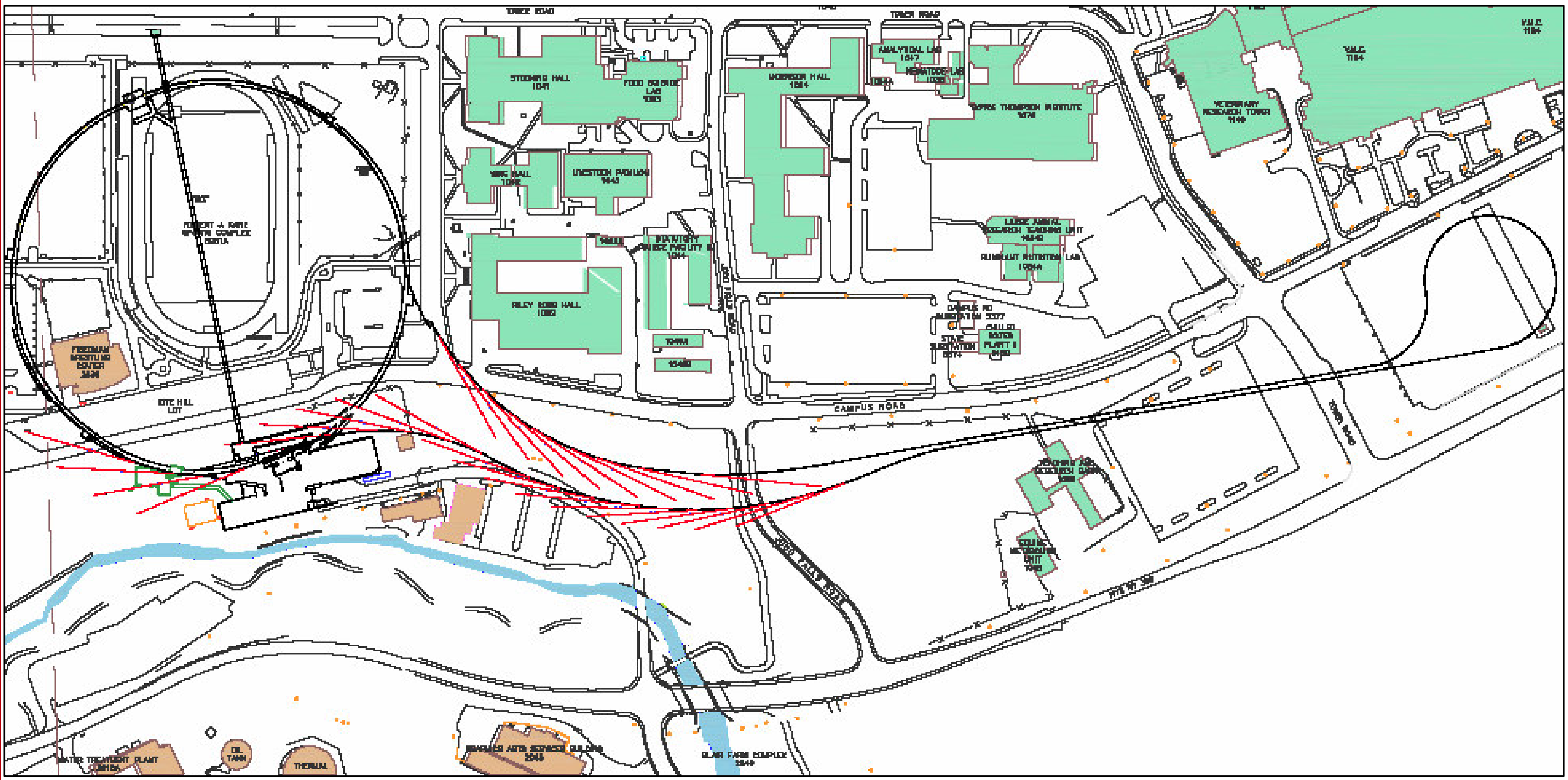

Ions in an ERL beam

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With good gas pressure (5 10^{-10} mbar) it takes a few seconds to neutralize the electron beam with ions.

Ion	Atomic number	σ_{col} (m^2),10MeV	σ_{col} (m^2),5GeV	τ_{col} (s),5GeV
H_2	2	2.0E-23	3.1E-23	5.6
CO	28	1.0E-22	1.9E-22	92.7
CH_4	44	1.2E-22	2.0E-22	85.2

Their field would strongly damage the electron beam. How can the ions be eliminated?

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Ion elimination

Elimination in linacs: When too many ions have accumulated, i.e. after a few 10 mseconds, make a gap to let ions drift out of the beam space, i.e. a few 10 microseconds.

Elimination in rings: Ion clearing gaps are arrange such that the electron bunches between these gaps over focus the ion oscillations, which grow to large amplitudes where they do not disturb the electron beam much.

Ion clearing electrodes: A set of electrodes that draw ions out of the beam potential. They have to be located at the minimums of the electron beam, where the ions would otherwise accumulate.

Location of ion clearing electrodes

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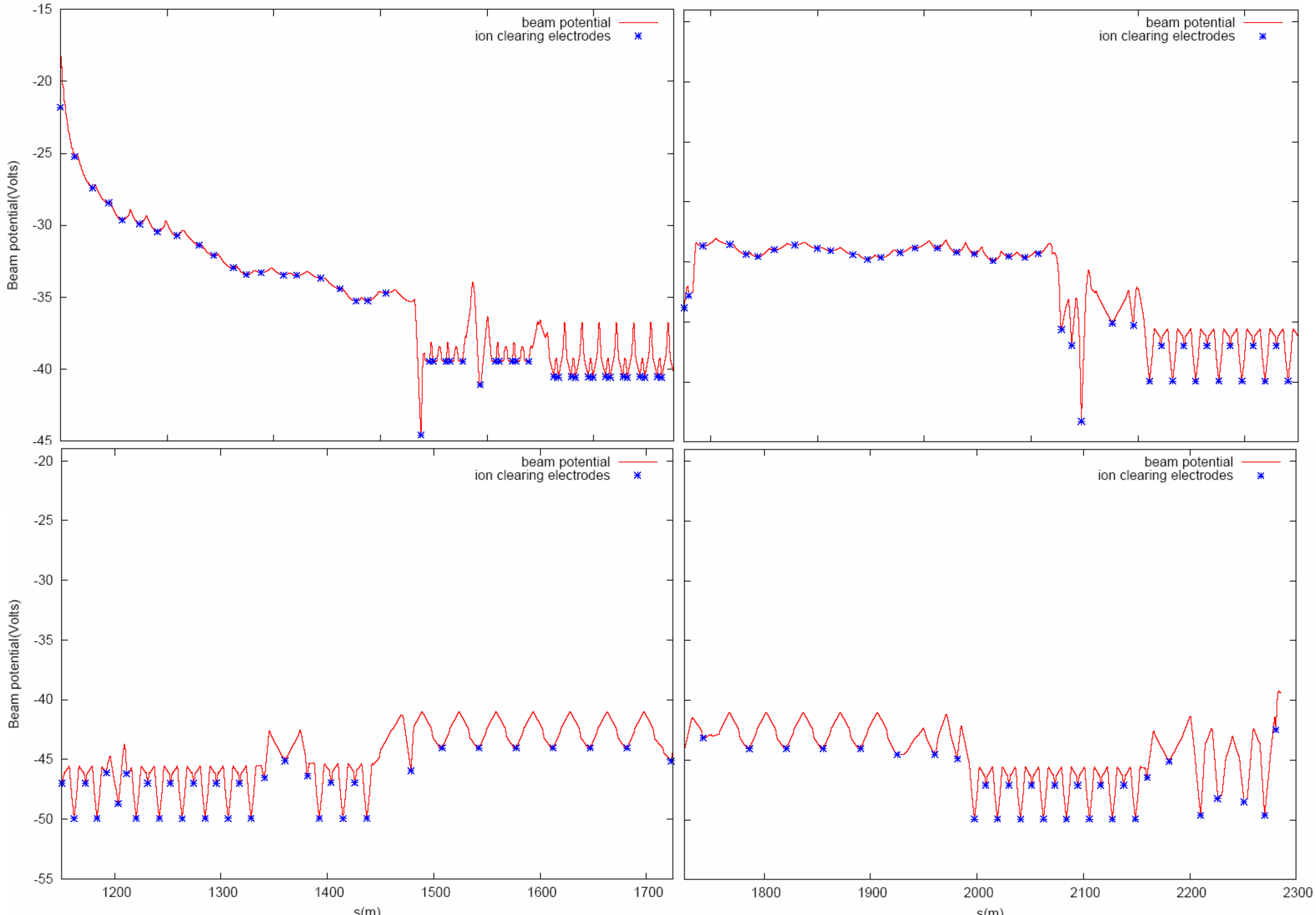

(a) s=1150-1725m (b) s=1725-2300m

Ion - clearing electrodes

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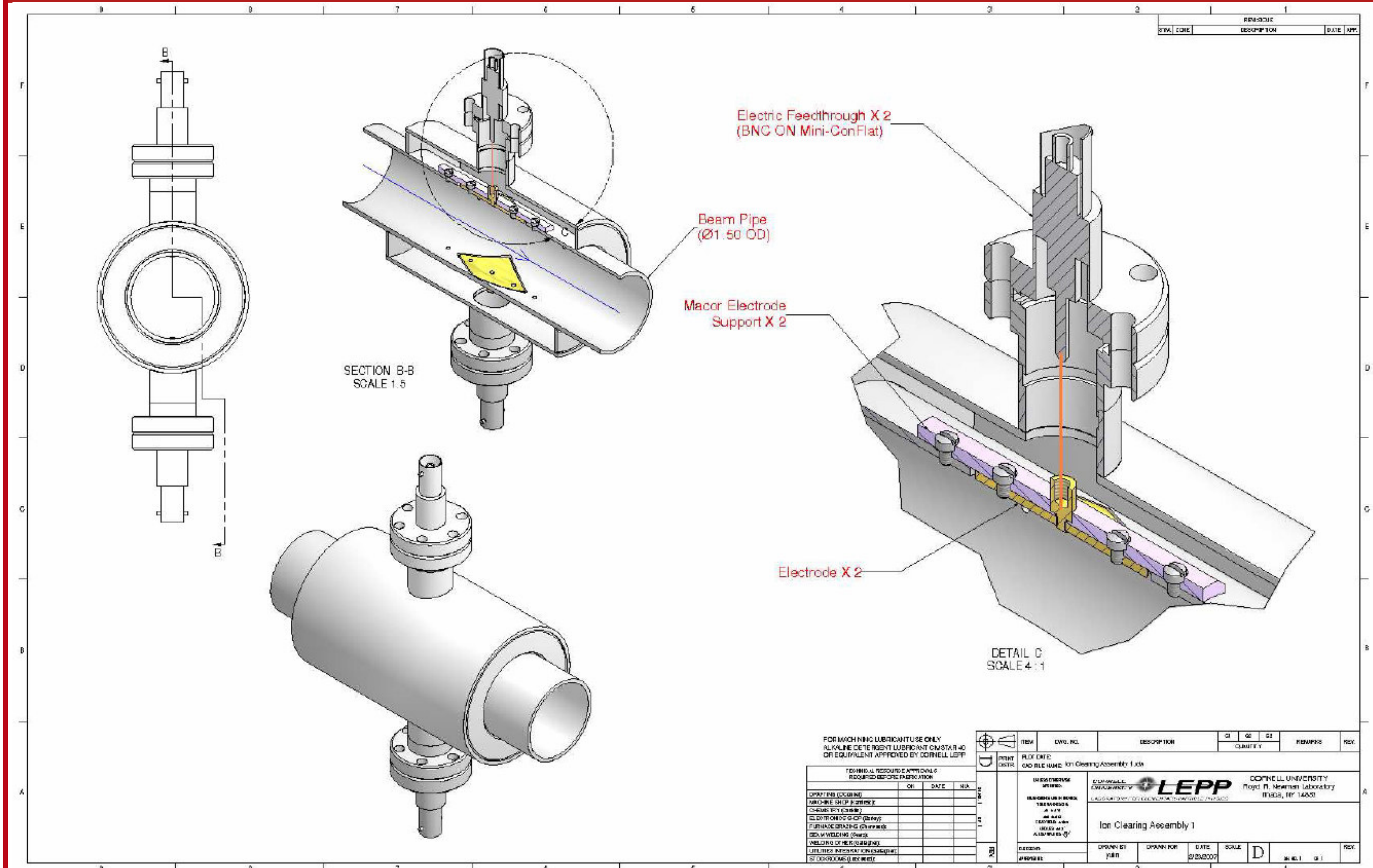

E/M loss factor avoids strong heating

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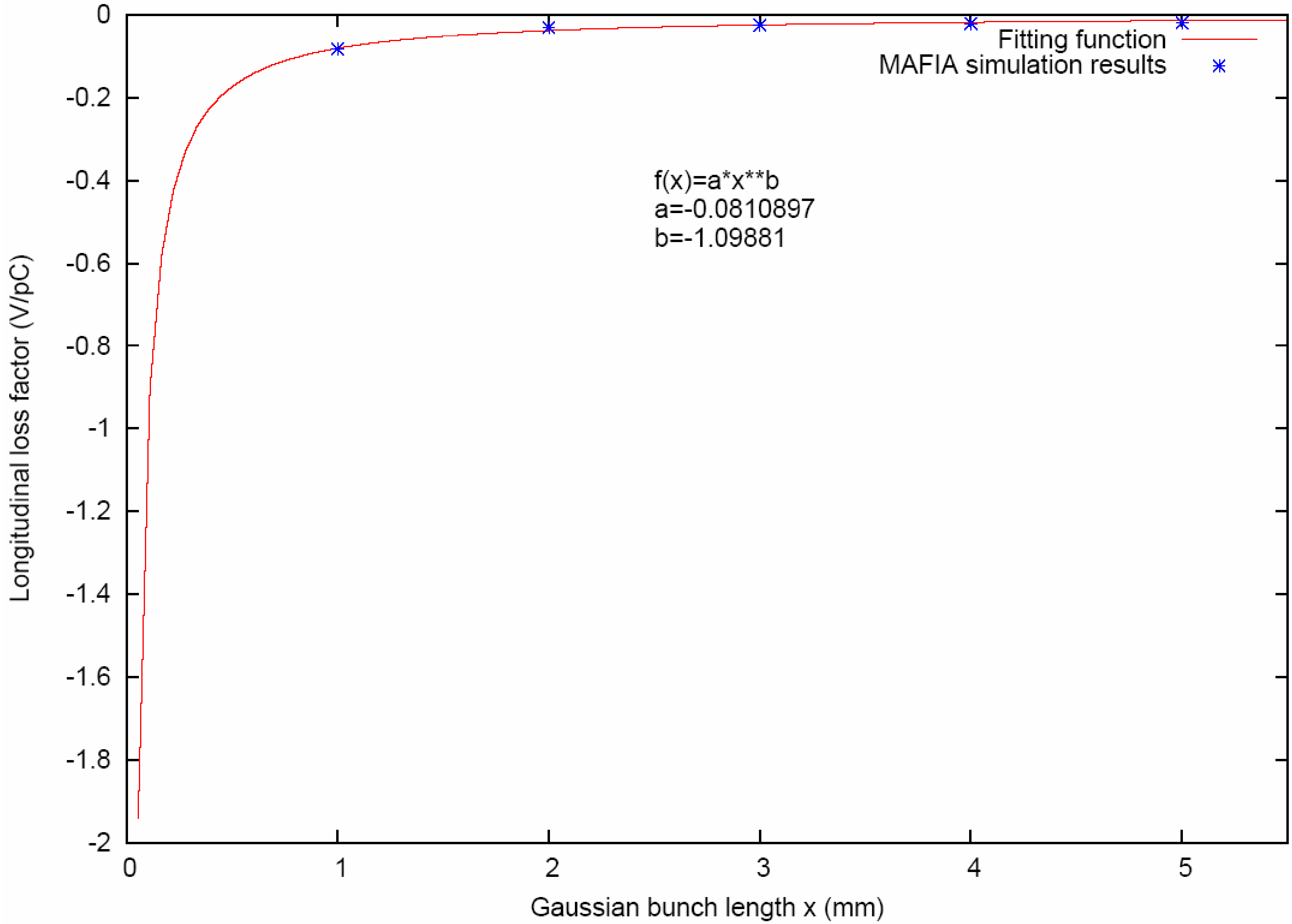

Ions in an ERL beam

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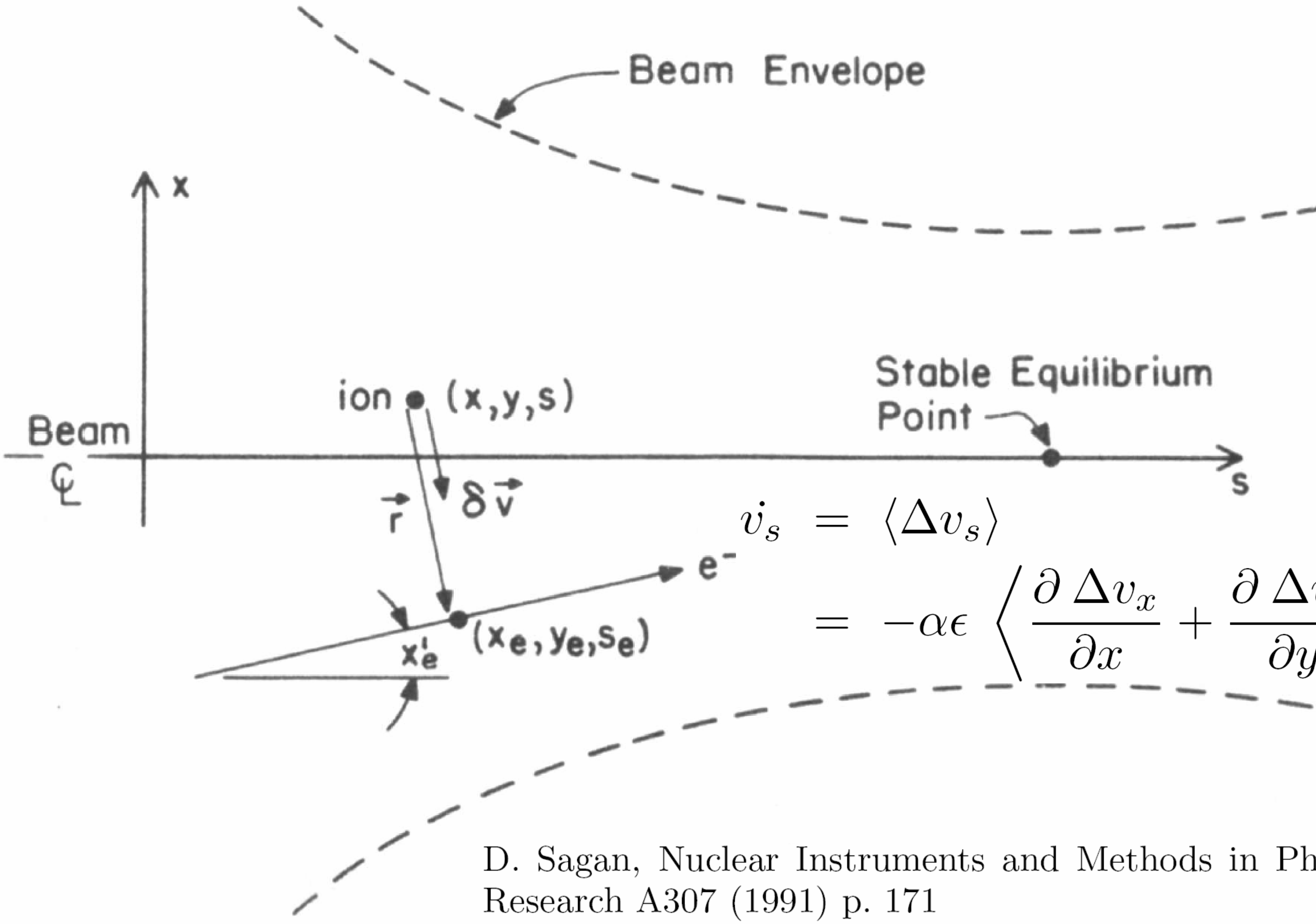

$$\dot{v}_s = \langle \Delta v_s \rangle = -\alpha\epsilon \left\langle \frac{\partial\, \Delta v_x}{\partial x} + \frac{\partial\, \Delta v_y}{\partial y} \right\rangle$$

D. Sagan, Nuclear Instruments and Methods in Physics Research A307 (1991) p. 171

Tracking until equilibrium

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Even for the most simple case of a rotation symmetric electron beam:

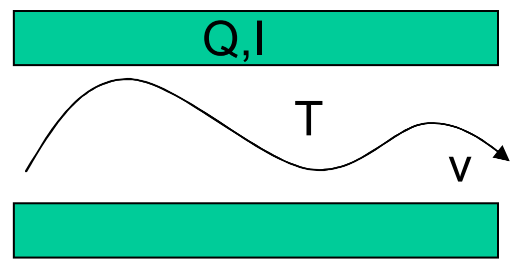
$$\boxed{\begin{aligned} \dot{x} &= p_x \\ \dot{p}_x &= f_x(x,z) \\ \dot{z} &= p_z \\ \dot{p}_z &= f_z(x,z) \end{aligned}}$$

Many ions have to be created proportional to the electron density, and the motion of all have to be computed until each one is eliminated at the clearing electrode.

$$\left.\begin{aligned} \dot{x} &= p_x \\ \dot{p}_x &= f_x(x,z) \end{aligned}\right\} a$$

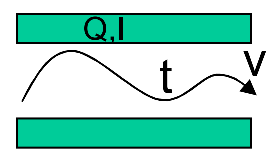
$$\Delta\dot{z} = \langle f_z(x,z) \rangle = f(a,z)$$

1st simplification: Averaging



$$\Delta\dot{z} = \alpha\varepsilon\tfrac{1}{\sigma^2}\, g(a/\sigma)$$

2nd simplification: scaling



$$J = \oint p_x dx \approx const.$$

3rd simplification: Adiabatic invariant

$$\boxed{\Delta\dot{z} = \alpha\varepsilon\tfrac{1}{\sigma^2}\, h(J/\sigma)}$$

h(x) is tabulated for one sigma, and then scaled.
Calculation is speeded up by many orders of magnitude.

Tracking until equilibrium

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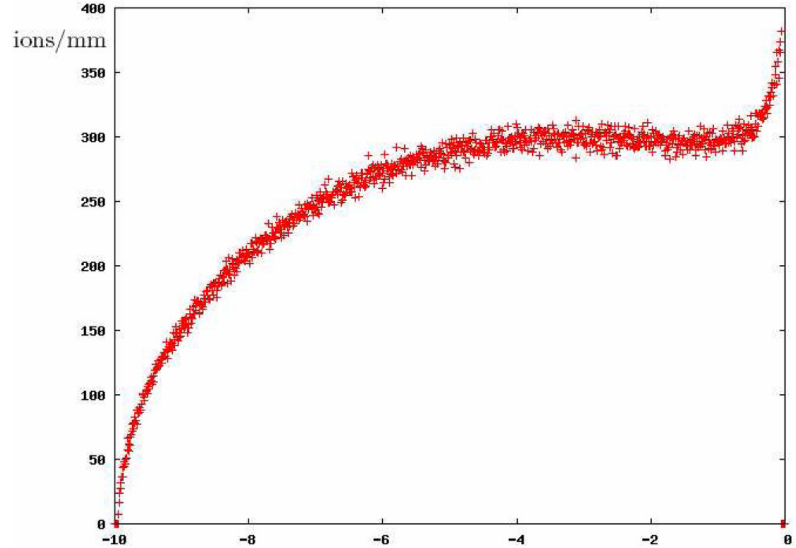
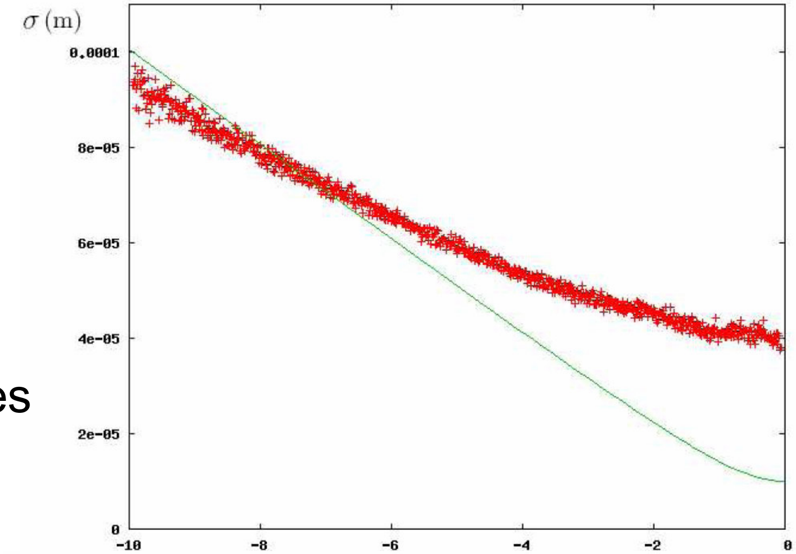
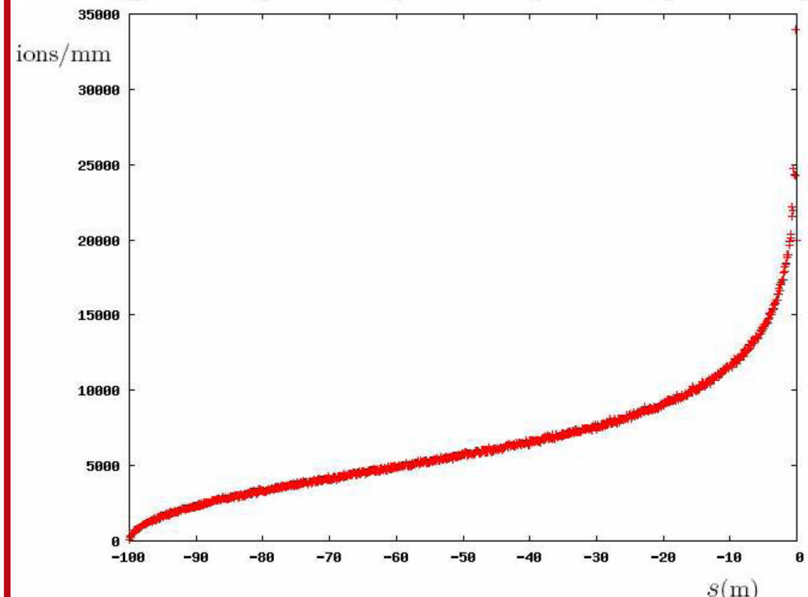
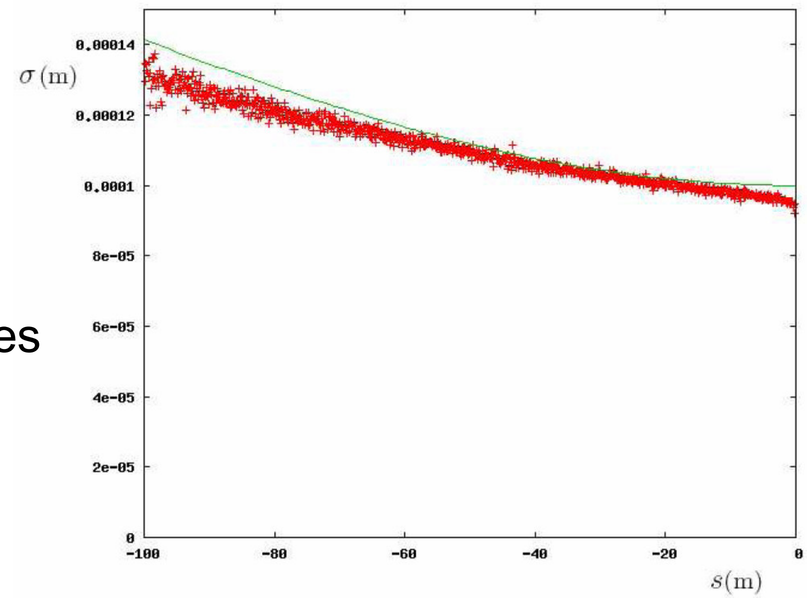


20m between electrodes





200m between electrodes



Ions in an ERL beam

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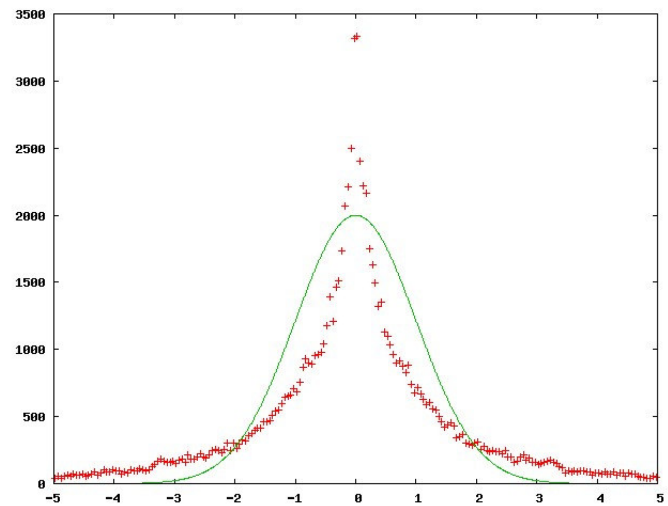

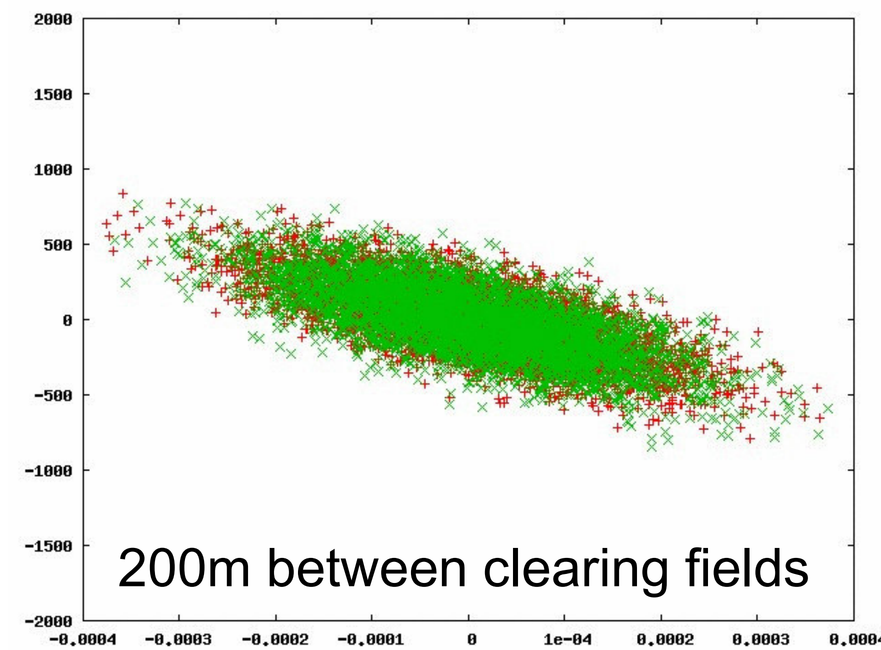

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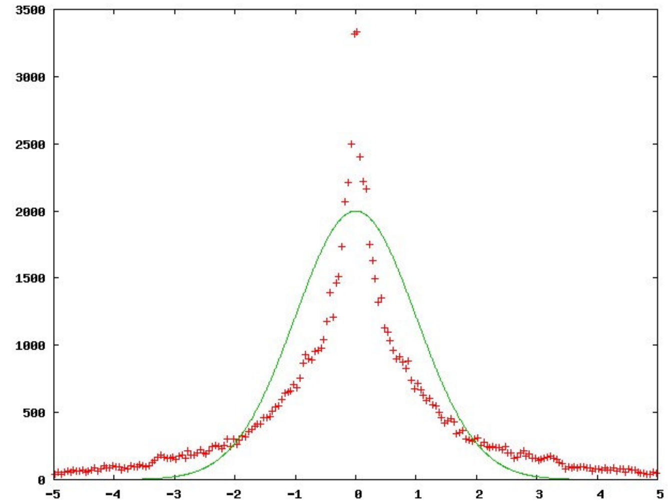
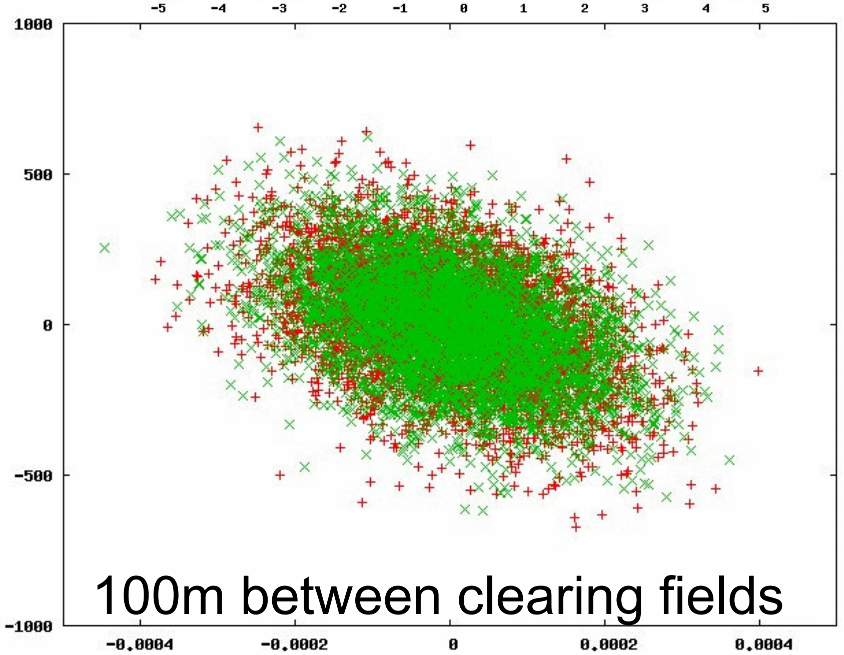
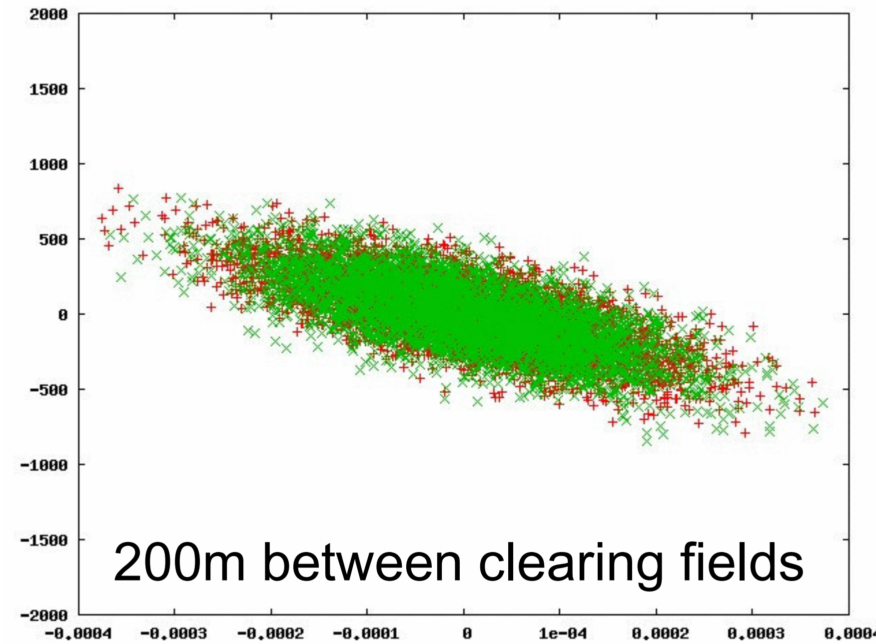




100m between clearing fields



200m between clearing fields

Ions in an ERL beam

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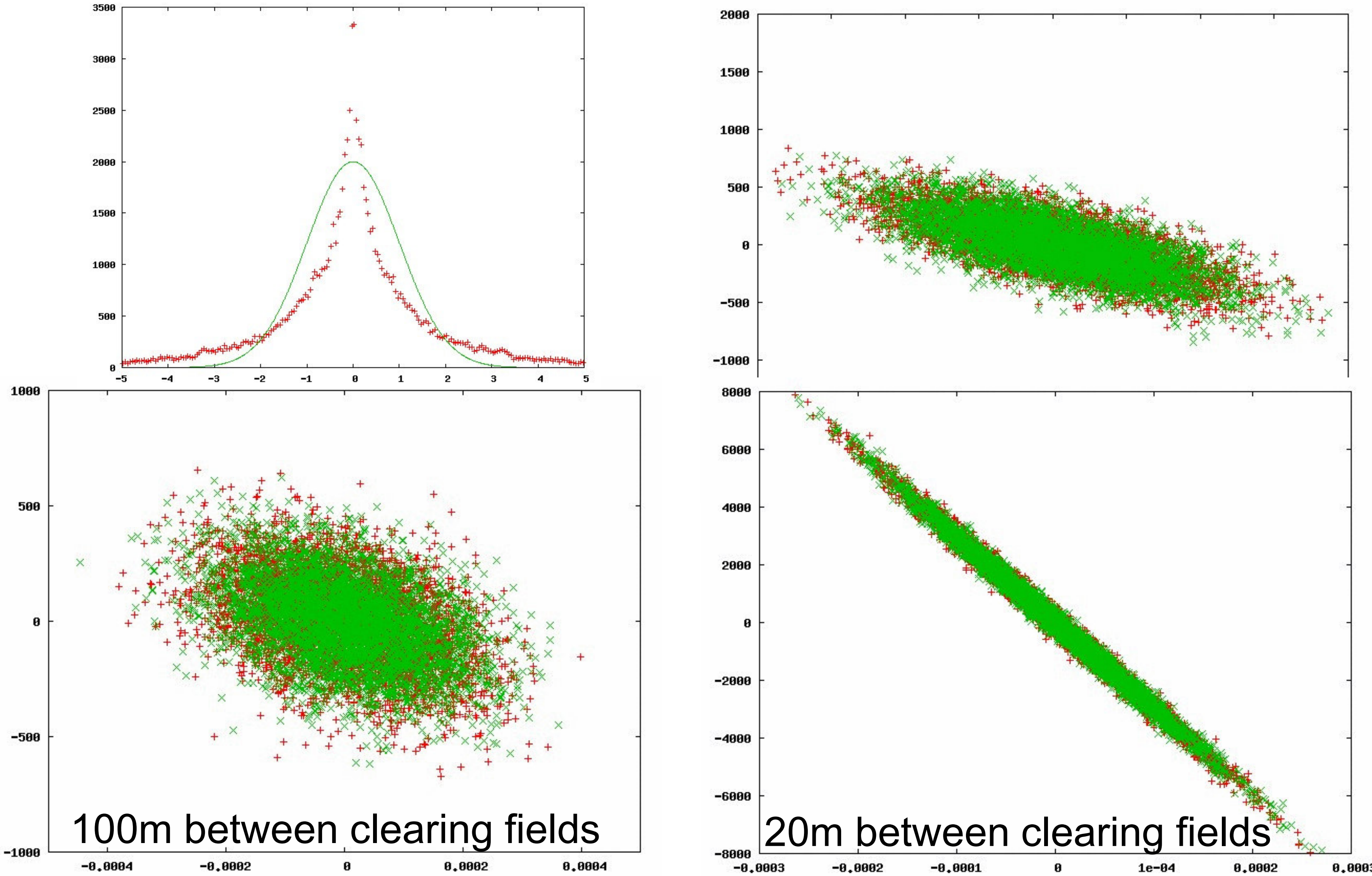

Extension to non-round beams

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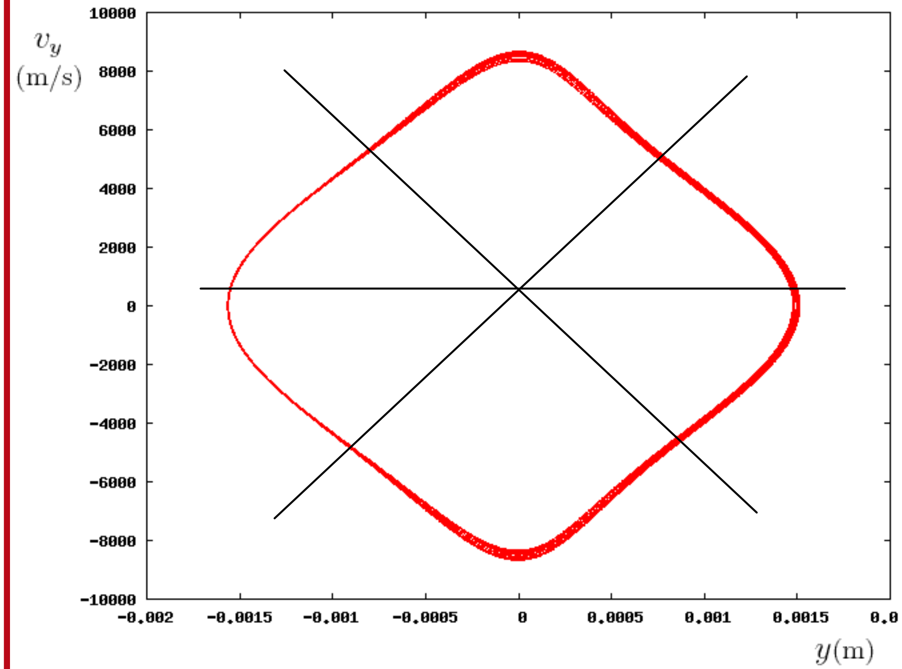

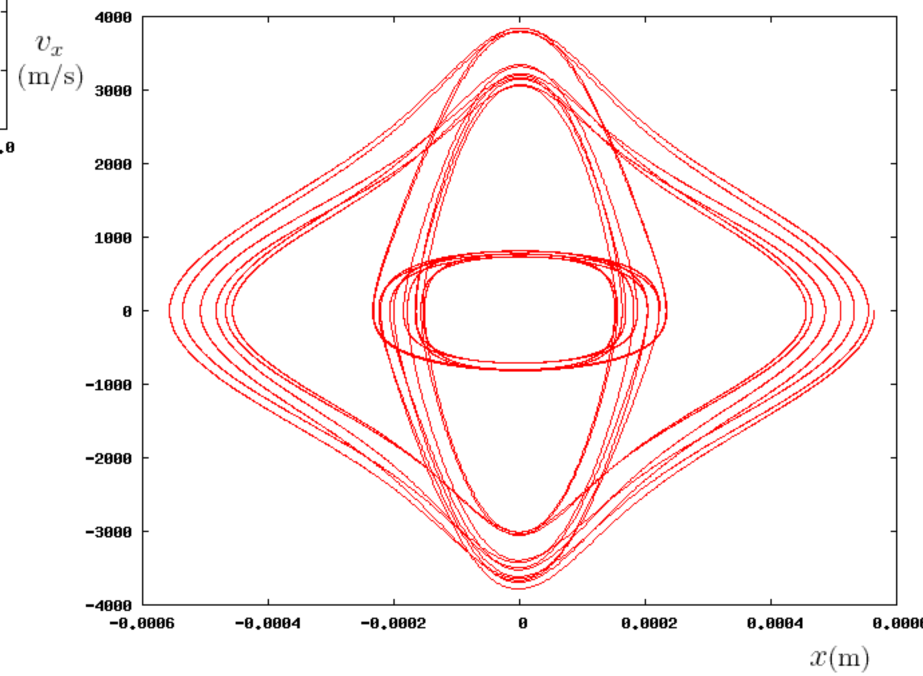

Unique ways to describe a 4D phase space torus by looking at the 2D projections is needed to extend the technique to non round beams.

Conclusions

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1. Conventional methods of ion removal except ion – clearing electrodes do not seem to work.

2. Three are about 200 minimums in the potential where clearing electrodes should be.

3. An electrode shape was designed that causes sufficiently small heating.

4. Even with clearing electrodes there is an equilibrium density of ions that move from their place of creation to the absorbing electrodes.

5. The damage from this density can be made acceptably small by spacing clearing electrodes close enough together (about 10m).

6. An extension to non-circular symmetric beams is needed.