A pencil beam model for charged particles

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The use of X-rays for radiation therapy began a few days after their discovery. Wilhelm Röntgen announced the discovery of X-rays on December 28, 1895, and Emil Grubbe used them for radiation therapy on January 12, 1896. X-rays are still the most common form of radiation treatment, but beams of electrons, protons, photons, neutrons, and other particles are used as well.

Radiation therapy planning requires the study of radiation penetrating a background. Both the radiation and the background are, of course, made up of particles. *Background particles* can be set in rapid motion as a result of interactions with *radiation particles*, thereby becoming radiation particles themselves. The transport of the radiation particles through the background can be modelled by a system of coupled kinetic equations. A solution of this system is the number of radiation particles per unit volue in *phase-space*, (position-direction-energy space), which characterizes the *dose* (amount of energy deposited per unit volume in phase-space). To adjust the dose intensity is the basic goal in radiation treatment. We shall focus on modelling of a particle beam described below:

A monodirectional "pencil beam" of electrons is incident on the boundary of a system (in our considerations, a slab of width L). For electrons, the mean distance between collisions is small and the mean scattering angle is *very* small. How does the beam "spread" or "diffuse" as it interacts with the material in the system?

The problem is to obtain a formula quantitatively describing the spreading of the beam. These formulas are useful in electron dose calculations. A systematic approach may be outlined as follows:

(a) Construct a kinetic model describing a steady-state, mono-energetic transport of electrons.

(b) Use asymptotic expansions to derive pencil beam equations from the kinetic model, with asymptotic corrections.

(c) Derive the solution of pencil beam equations with asymptotic corrections.

(d) Compare the results with numerical simulations.