Photoinjector Beam Dynamics Simulation Using an Improved Quasi-Static Model

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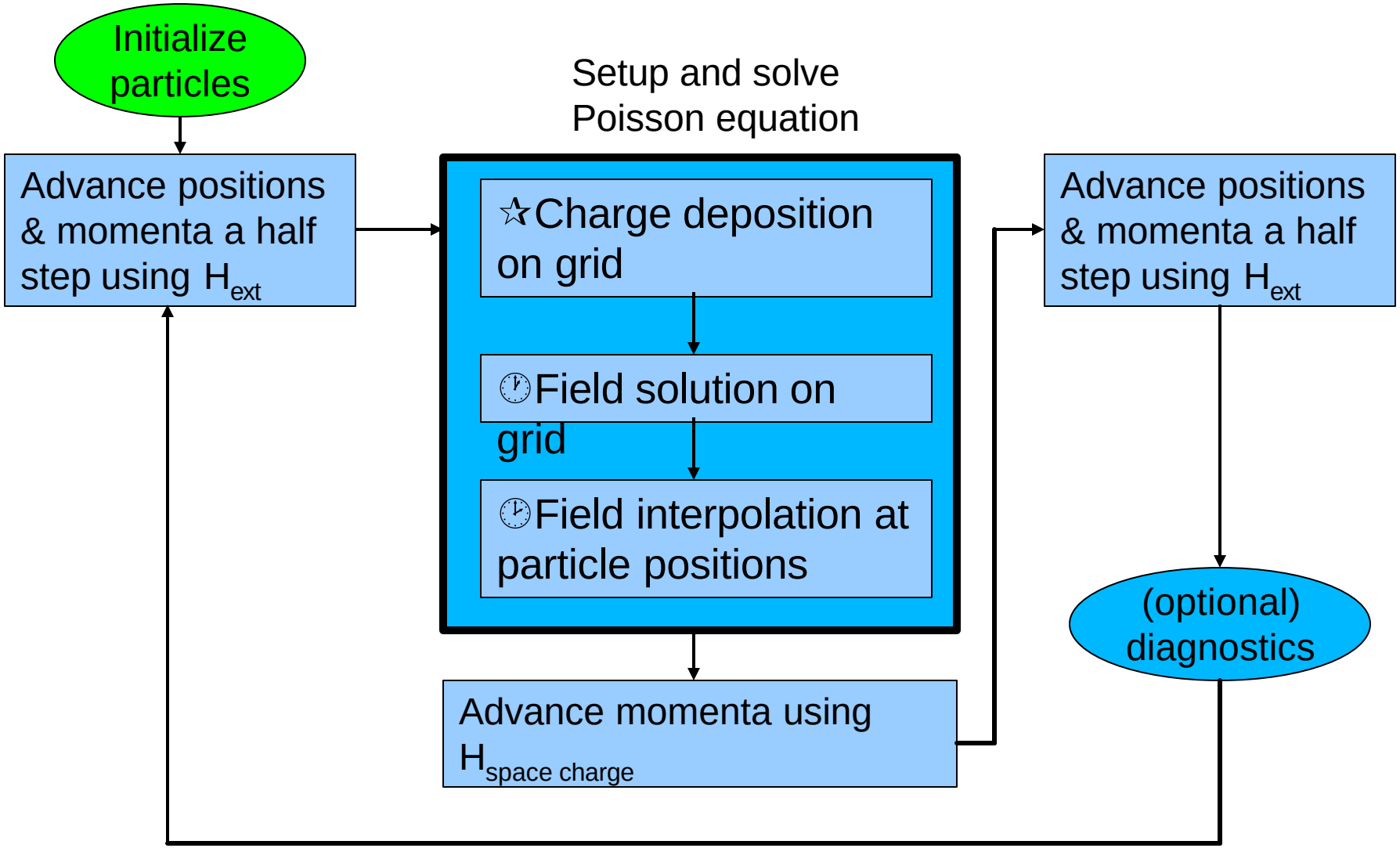
National Energy Research Scientific Computing Center

Particle-In-Cell (PIC) Simulation



Green Function Solution of Poisson's Equation

$$f(r) = \int G(r, r')\, r(r')\, dr' \;;\; r = (x, y, z)$$

$$f(r_i) = h \sum_{i'=1}^{N} G(r_i - r_{i'})\, r(r_{i'})$$

$$G(x, y, z) = 1/\sqrt{(x^2 + y^2 + z^2)}$$

Direct summation of the convolution scales as N^6 !!!!
N – grid number in each dimension

Green Function Solution of Poisson's Equation

Hockney's Algorithm:- scales as $(2N)^3 \log(2N)$

- Ref: Hockney and Easwood, ***Computer Simulation using Particles***, McGraw-Hill Book Company, New York, 1985.

$$f_c(r_i) = h\sum_{i'=1}^{2N} G_c(r_i - r_{i'})\, r_c(r_{i'})$$

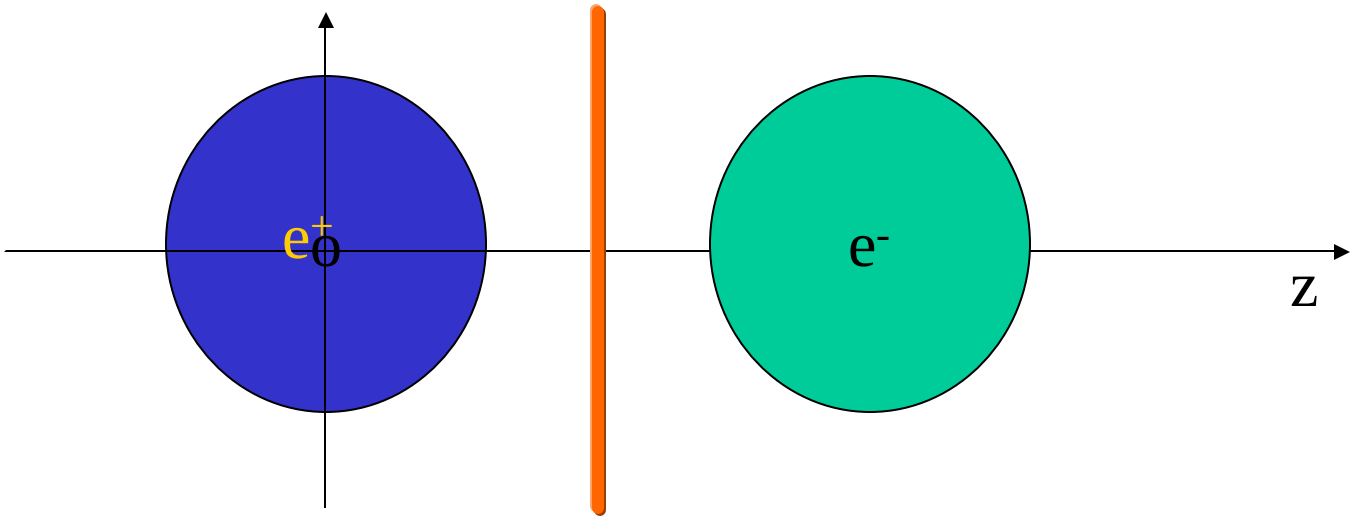
$$f(r_i) = f_c(r_i) \quad \text{for i} \;=\; 1,\ \text{N}$$

Shifted Green function Algorithm:

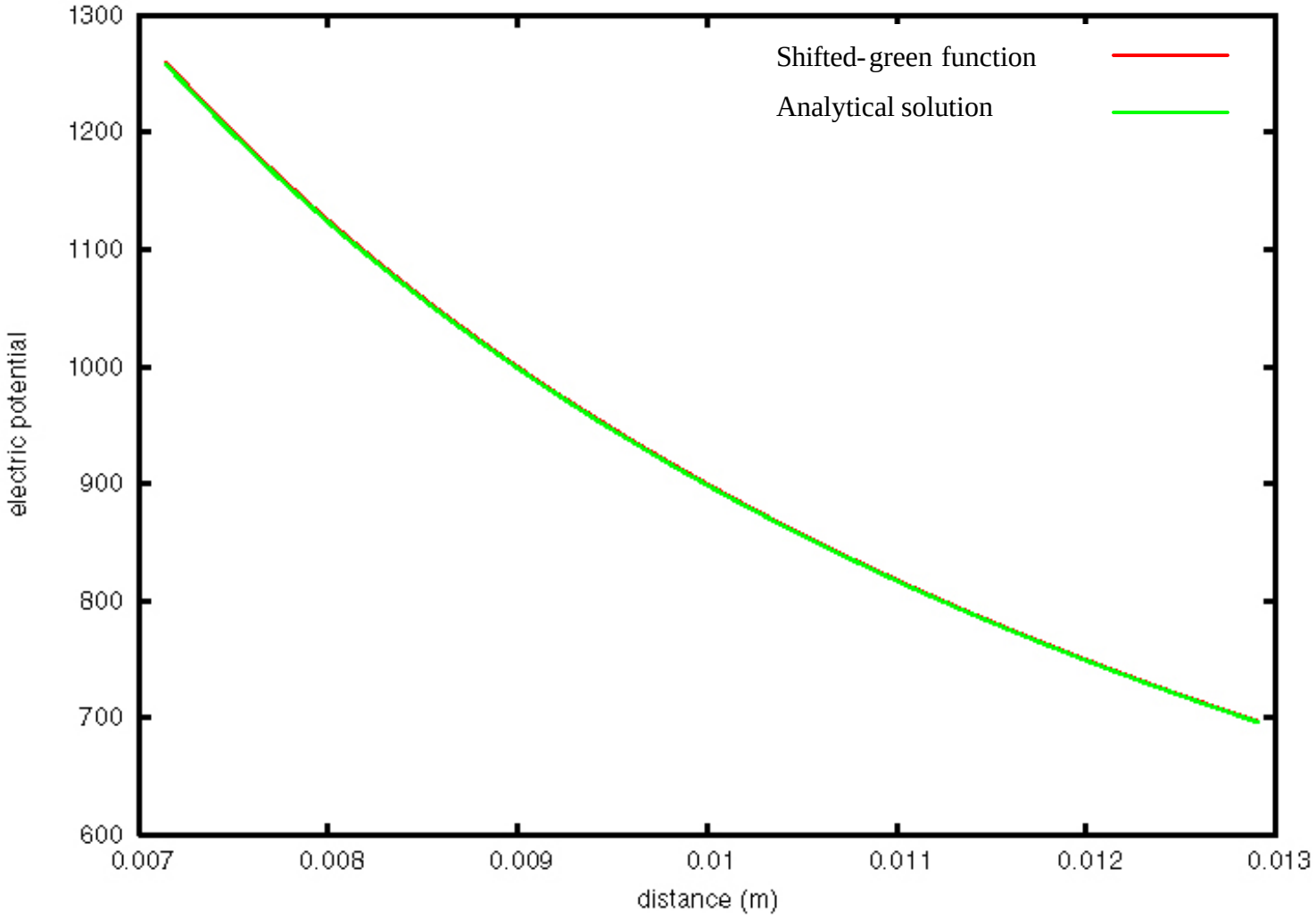
$$f_F(r) = \int G_s(r, r')\, r(r')\, dr'$$

$$G_s(r, r') = G(r + r_s, r')$$

A Schematic Plot of an e^- Beam and Its Image Charge



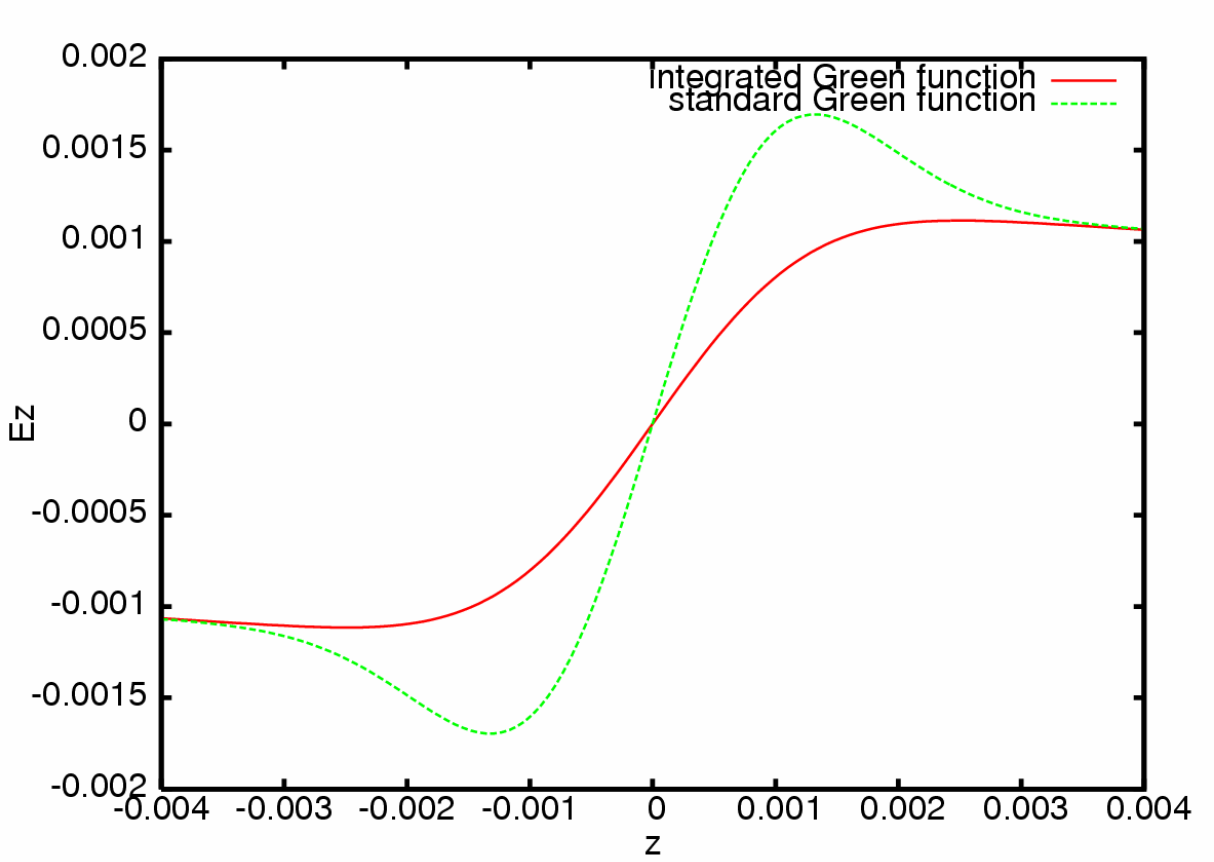
Test of Image Space-Charge Calculation Numerical Solution vs. Analytical Solution



Integrated Green Function Solution of Poisson's Equation

$$f_c(r_i) = \sum_{i'=1}^{2N} G_i(r_i - r_{i'})\, r_c(r_{i'})$$

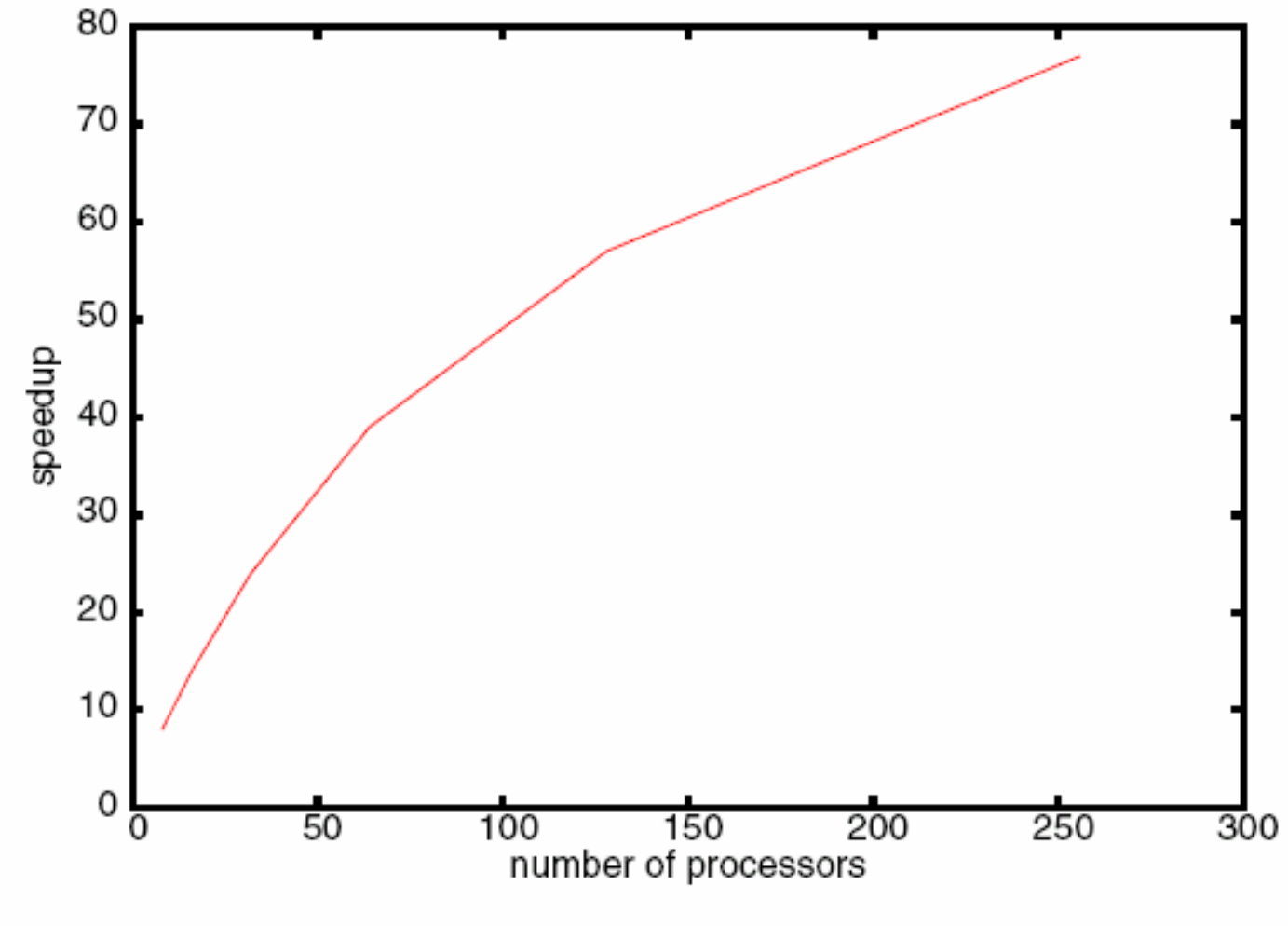
$$G_i(r,r') = \oint G_s(r,r')\, dr'$$



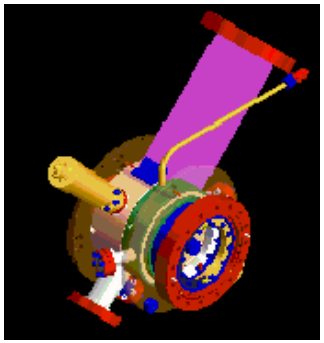
The IMPACT-T code

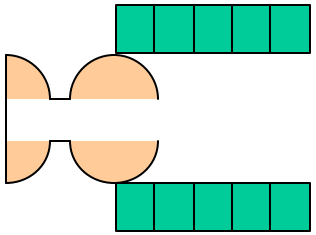
- 3D Integrated Green method to accurately compute the space-charge forces for a beam with large aspect ratio
- 3D Shifted Green method to efficiently compute the space-charge forces from the image charge
- Multiple slices/bins to handle the beam with large energy spread
- Arbitrary overlap of external fields to allow the modeling of both standing wave and traveling wave structure
- Transverse and longitudinal wakefield effects included (in testing)
- Parallel implementation on high performance computer to allow multiple million, high resolution simulation

Speed up of the IMPACT-T code vs. Number of Processors



A Benchmark Example





1nC

10ps square pulse,

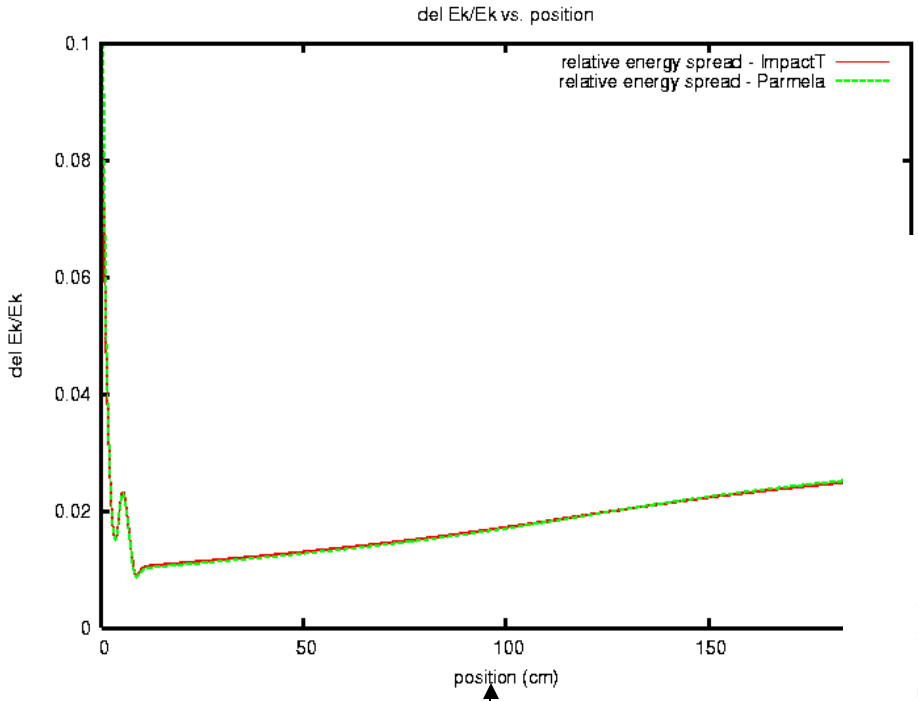
1 mm uniform transverse laser pulse

No Thermal emittance

110MV/m

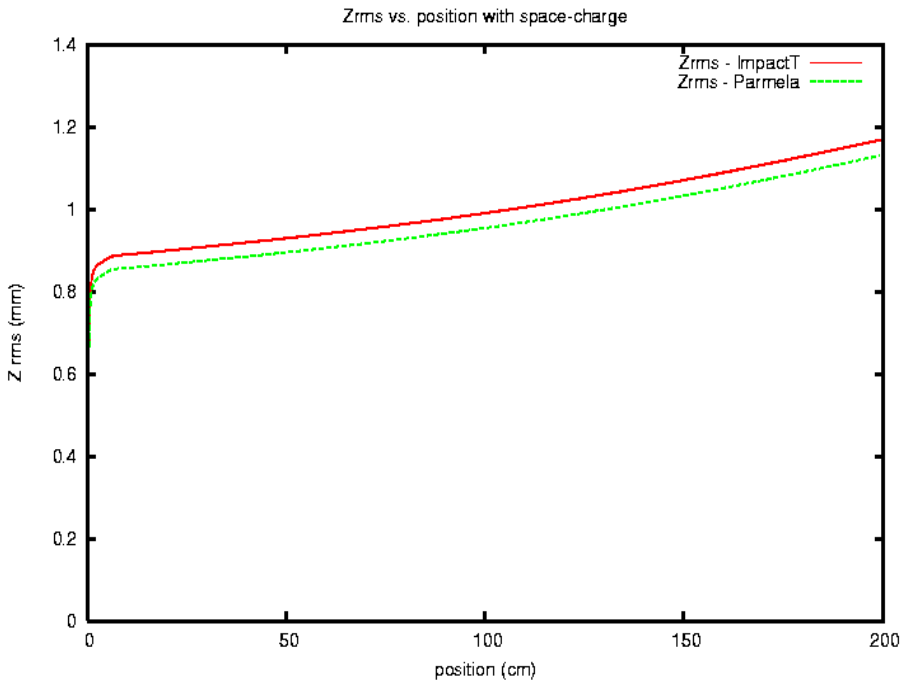
Solenoid 2.541 kG

Zrms and Relative Energy Spread vs. Position

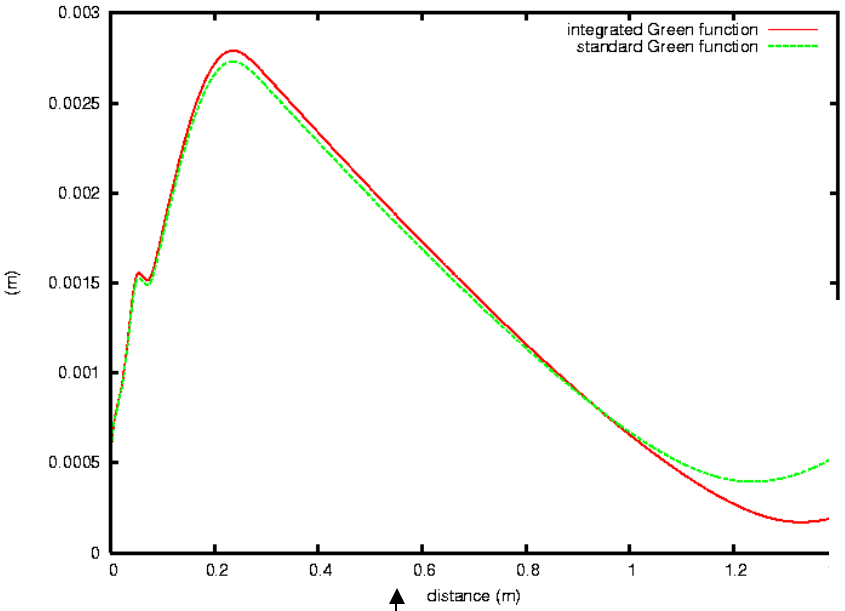


rms energy spread

longitudinal rms size

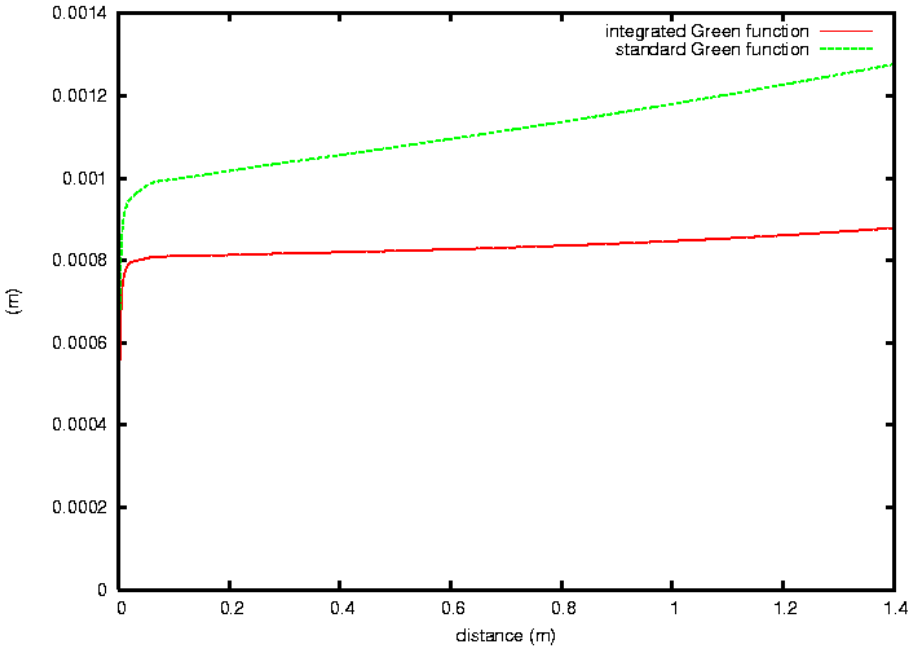


Xrsm vs. Distance with Integrated Green Function and Standard Green Function for Space-Charge Forces Calculation

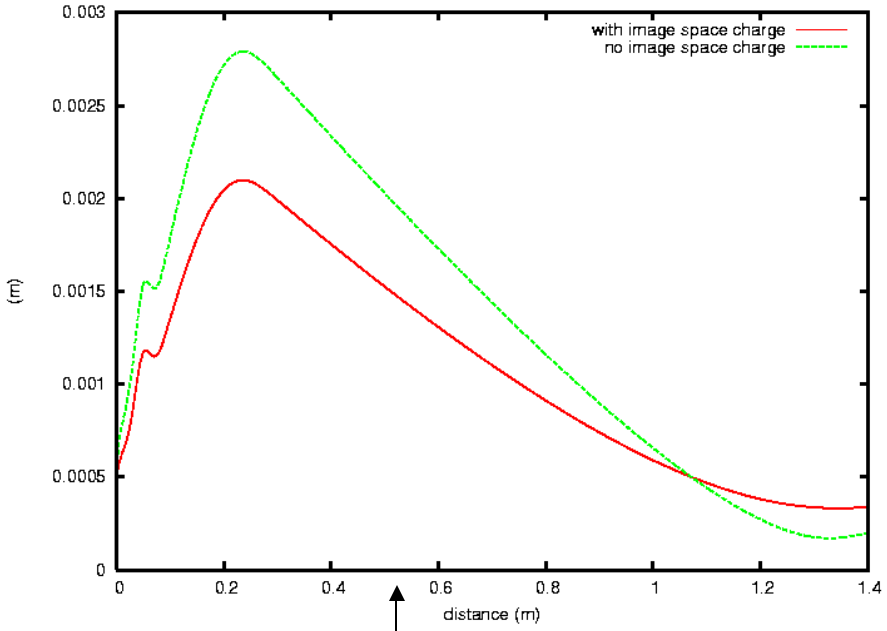


transverse

longitudinal

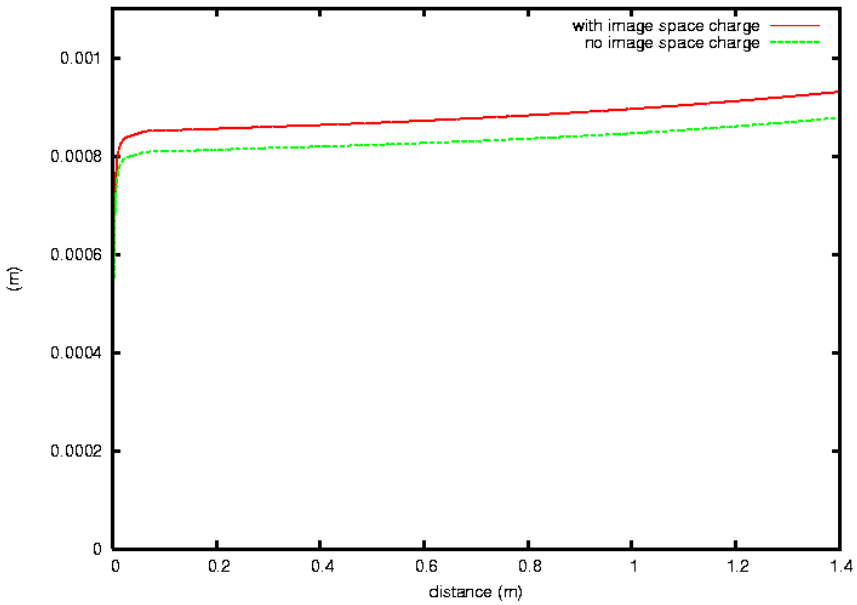


Xrsm vs. Distance with/without Image Charge Effect of Cathode

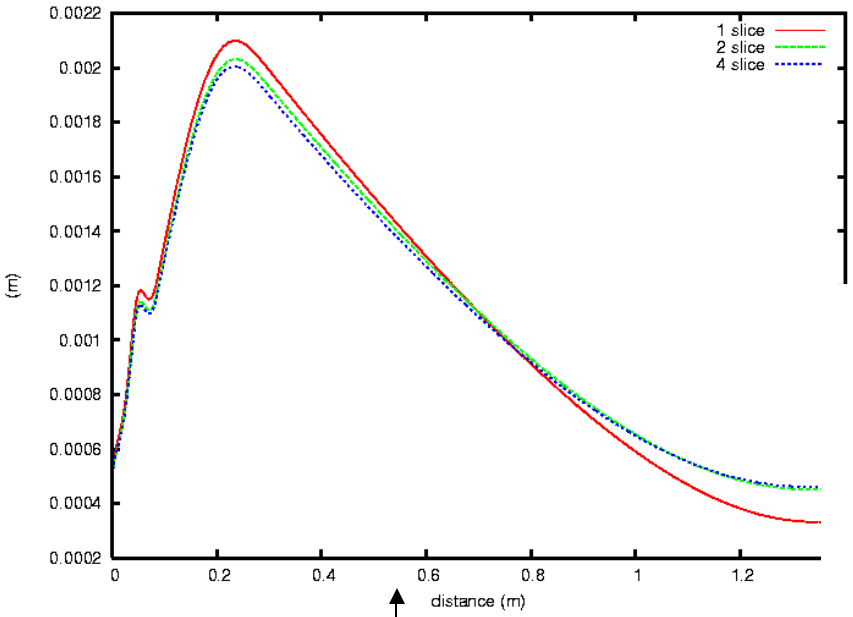


transverse

longitudinal

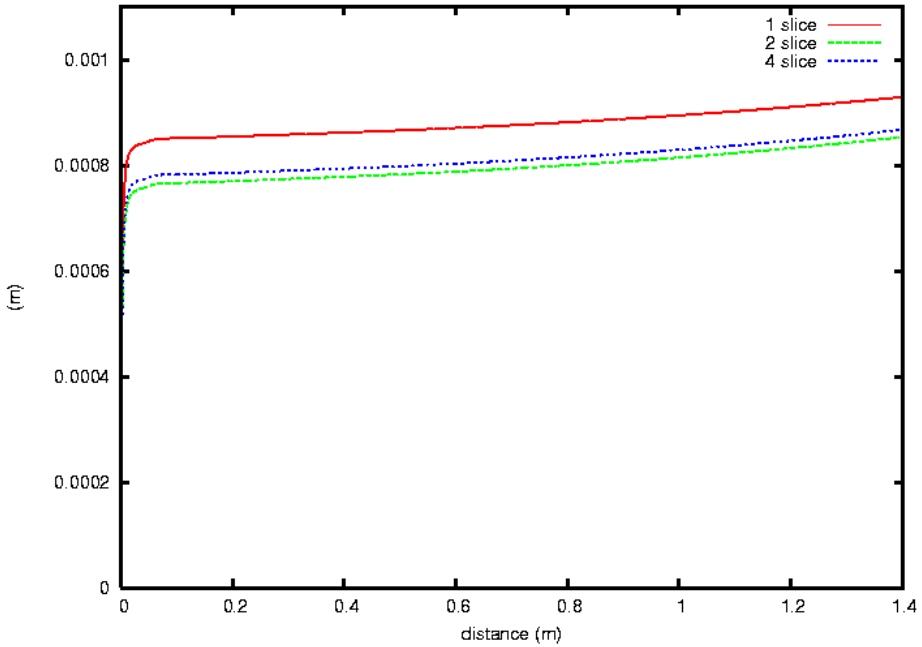


Transverse and Longitudinal RMS Size with 1, 2, and 4 Slices

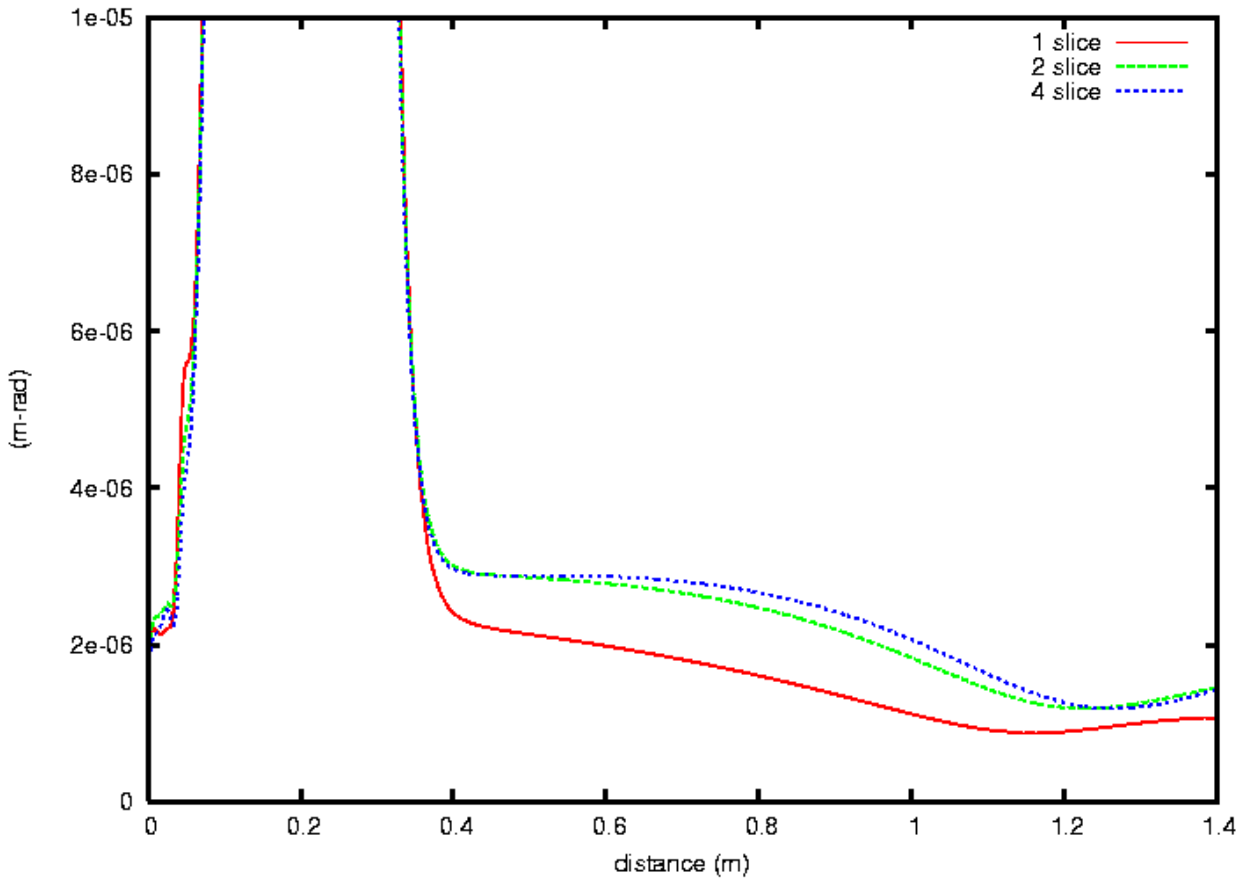


transverse

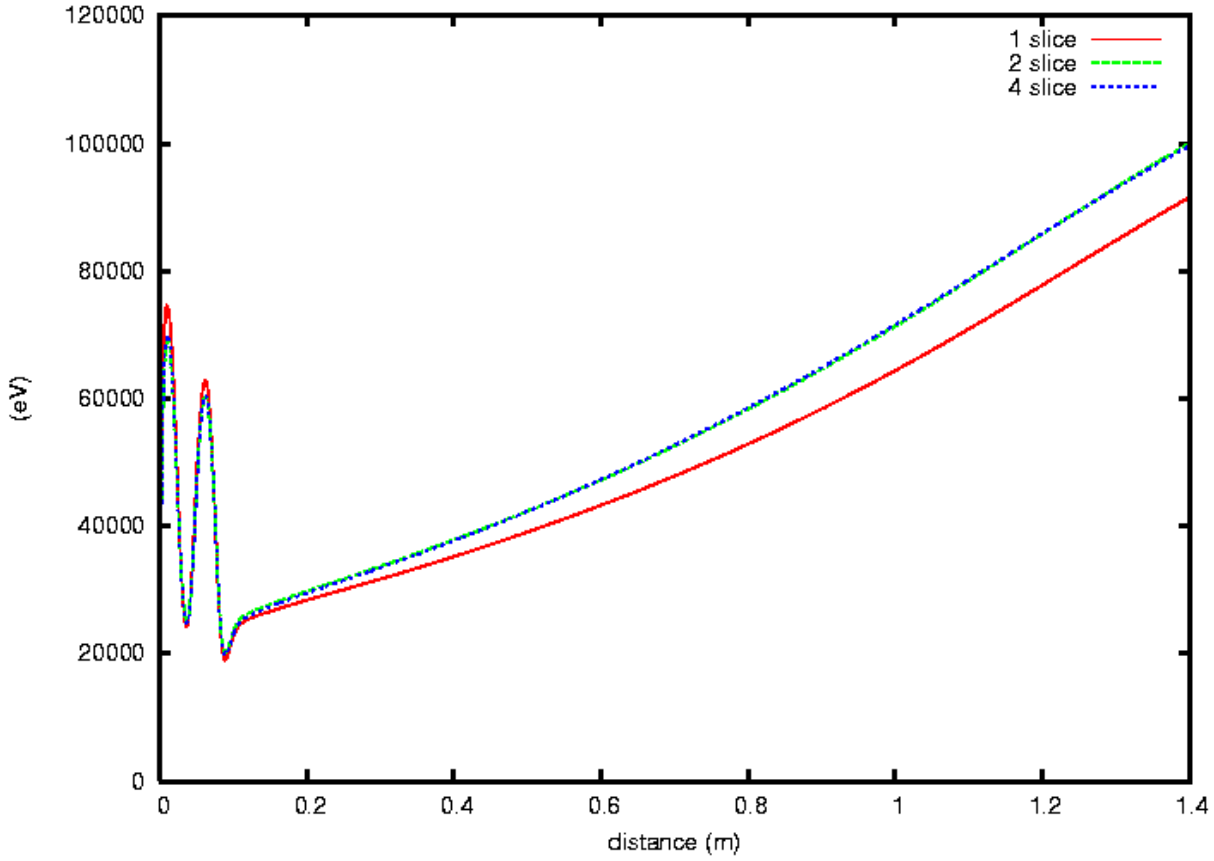
longitudinal



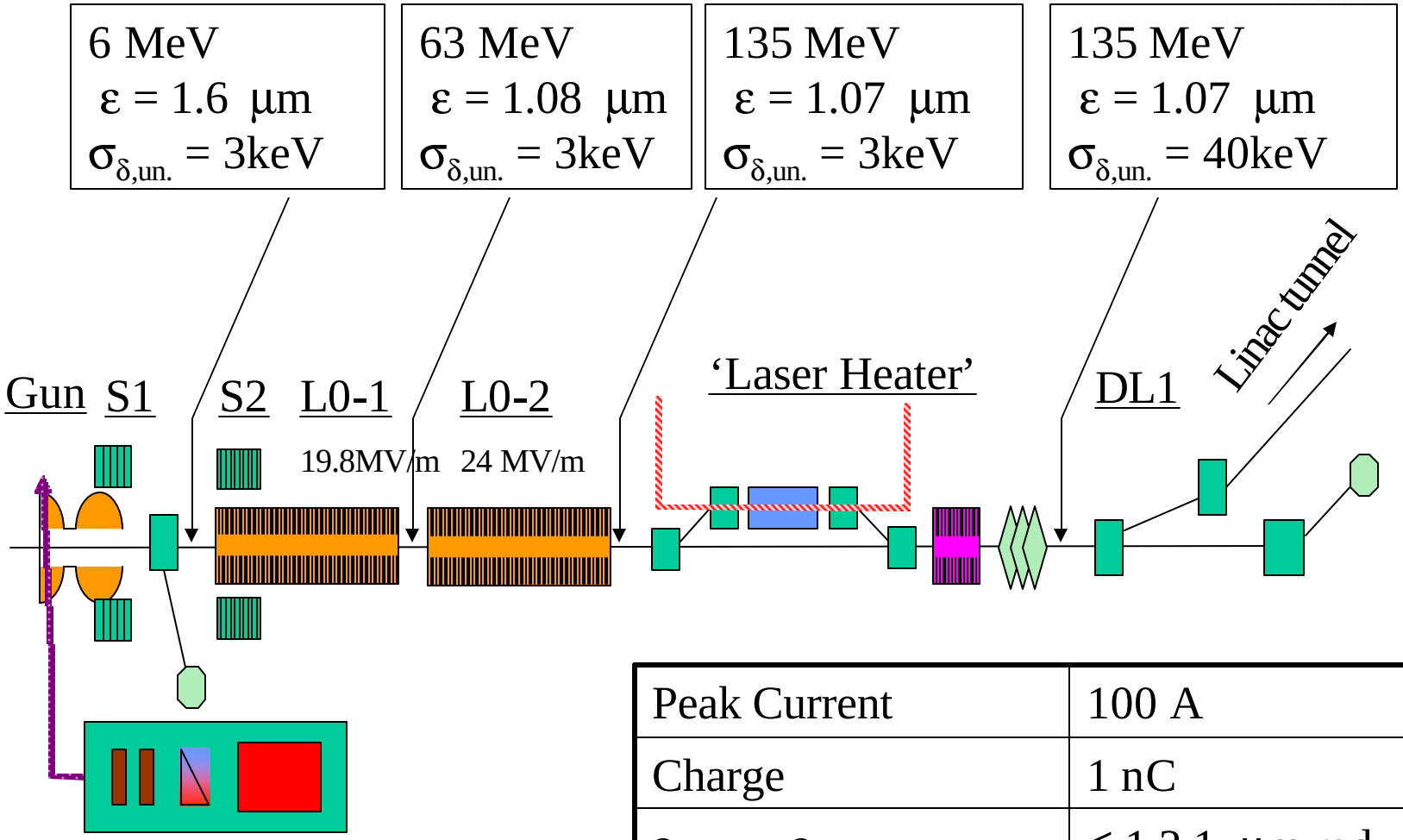
Transverse RMS Emittance with 1, 2, and 4 Slices



Correlated RMS Energy Spread with 1, 2, and 4 Slices



A Schematic Plot of LCLS Injector Layout

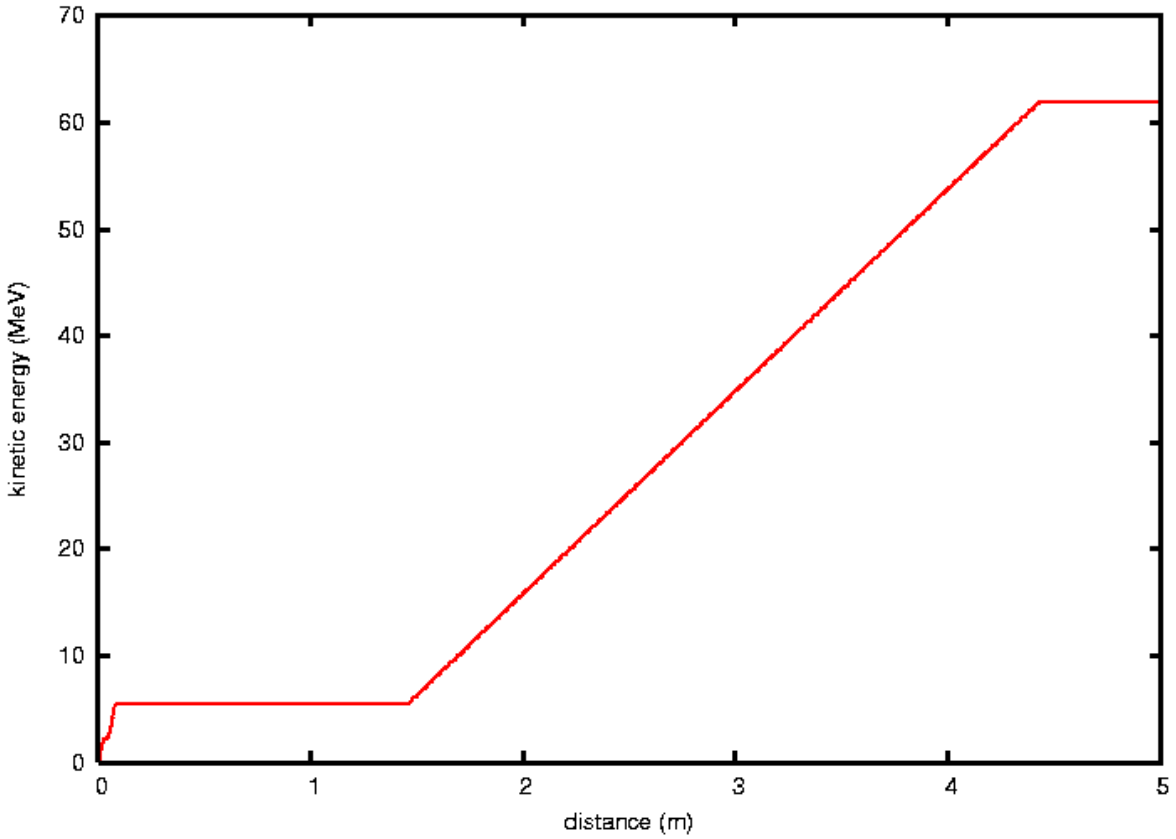


UV Laser 200 μJ,

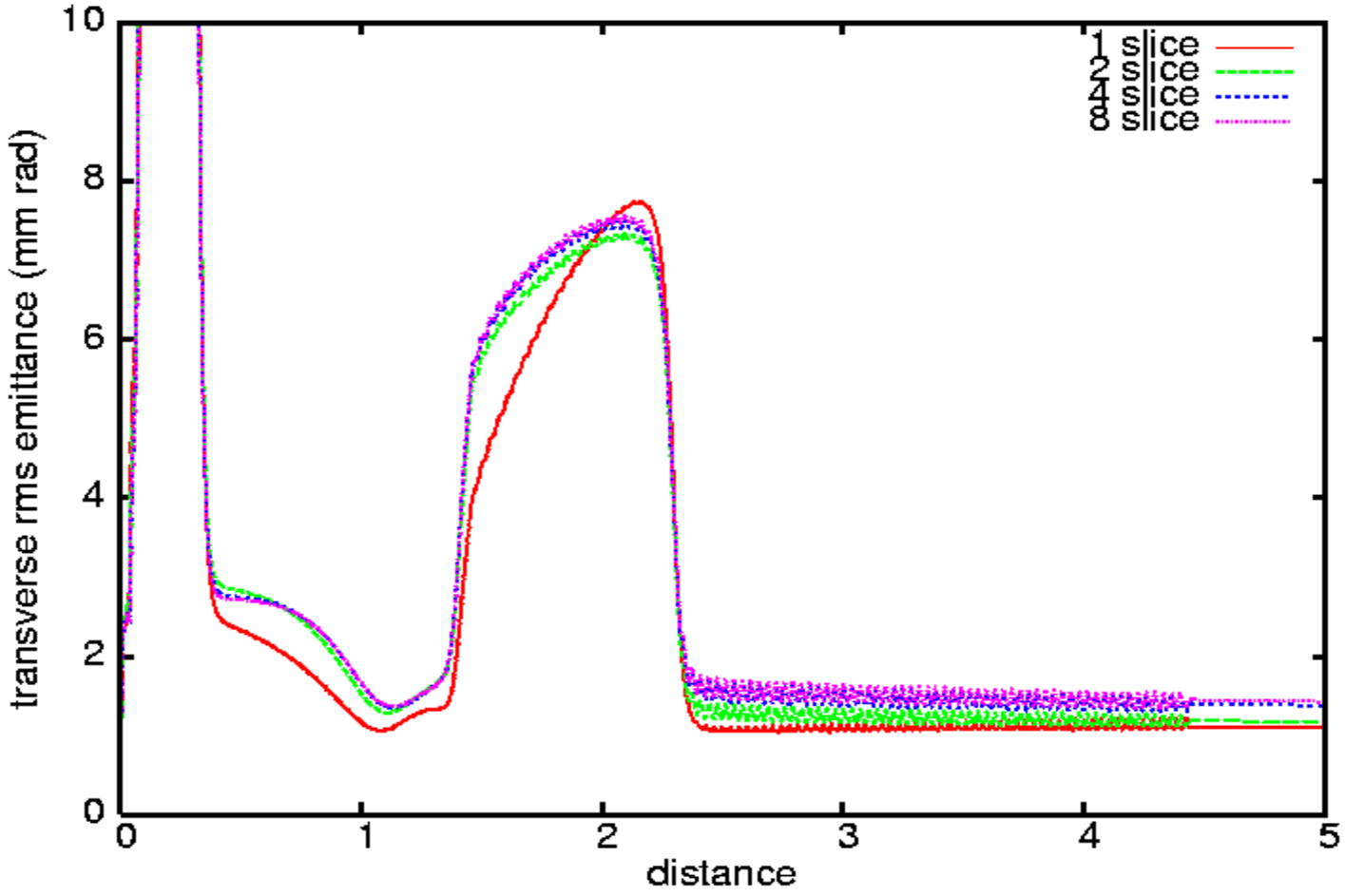
λ = 255 nm, 10ps, r = 1.2 mm

Peak Current	100 A
Charge	1 nC
$\varepsilon_{projected}, \varepsilon_{slice}$	≤ 1.2,1 μm.rad
Repetition rate	120 Hz

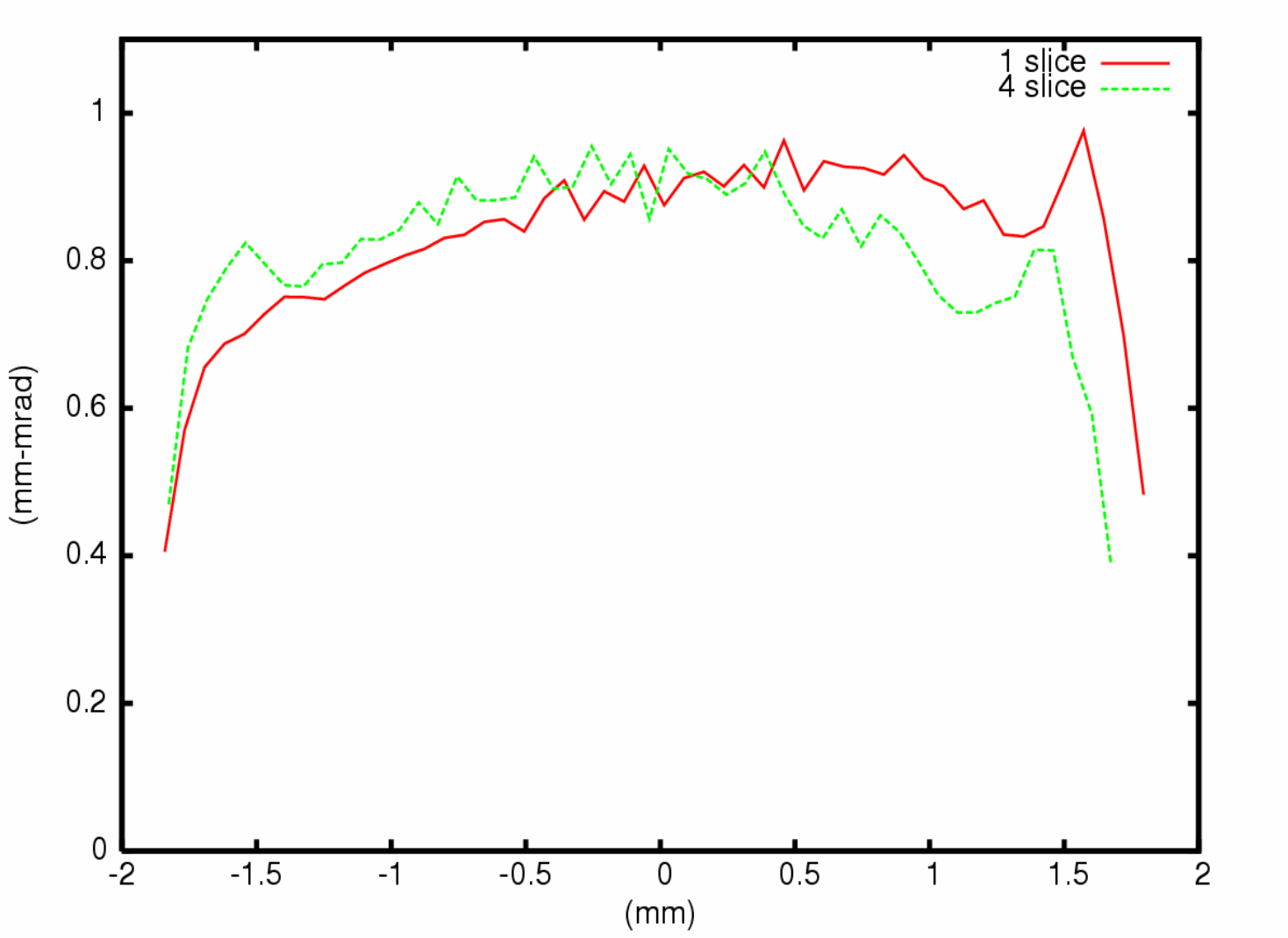
Kinetic Energy vs. Distance at LCLS Injector



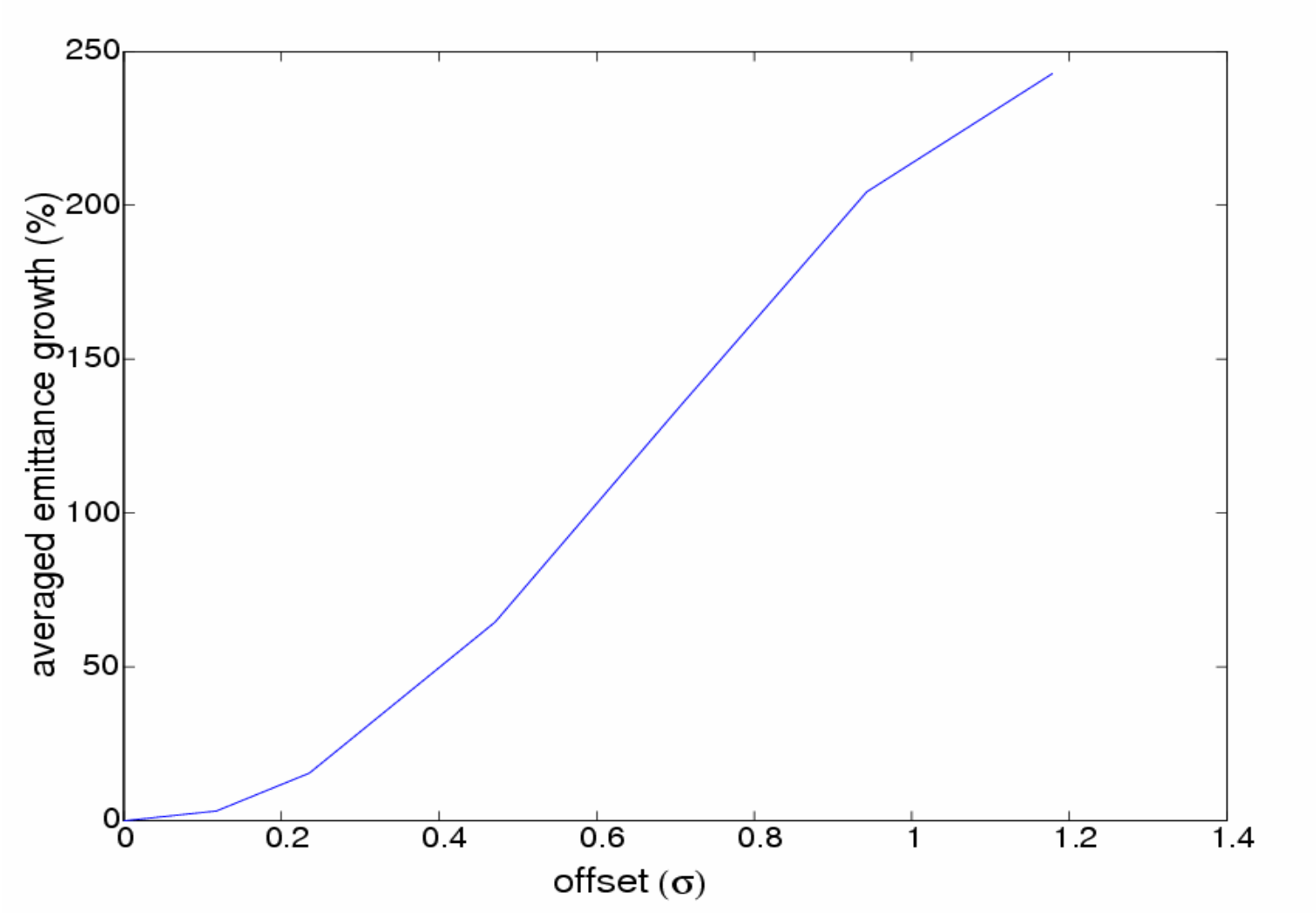
Transverse Projected RMS Emittance vs. Distance with Different Longitudinal Slices



Transverse Sliced Emittance after the L0-1 with Different Longitudinal Slices



Emittance Growth after L0-1 vs. Initial Offset



Acknowledgements

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