

Status of the IMPACT Parallel Beam Dynamics Code

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**DOE Grand Challenge in Computational Accelerator Physics,
Advanced Computing for 21st Century Accelerator Science and Technology
Project, and Los Alamos Accelerator Code Group**
using resources at the
**Advanced Computing Laboratory and the
National Energy Research Scientific Computing Center**

In Collaboration with

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University of California at Los Angeles
- Salman Habib:
Los Alamos National Laboratory
- Robert Ryne:
Lawrence Berkeley National Laboratory
- Panagiotis Spentzouris
Fermi National Accelerator Laboratory
- Others are welcome to contribute!

IMPACT

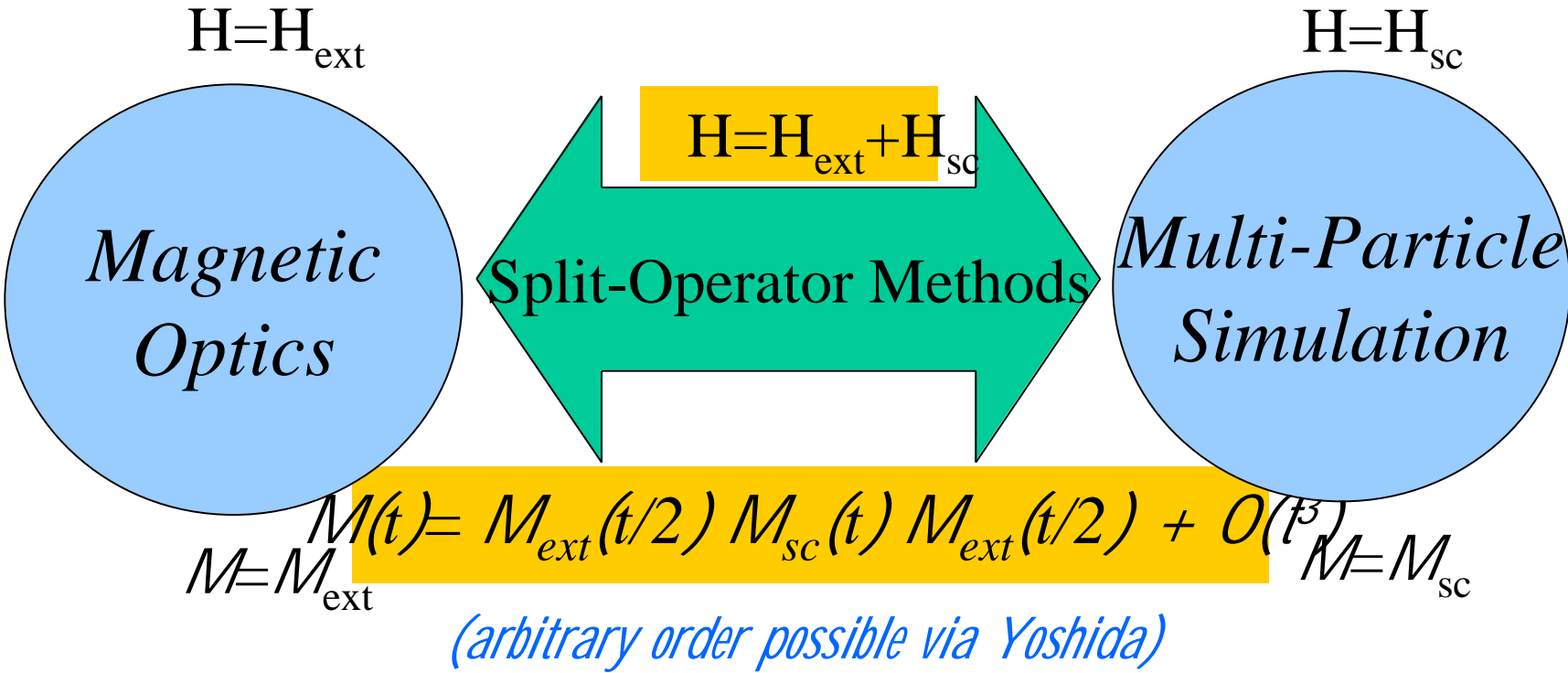
(Integrated Map and Particle Accelerator Tracking)

- Started as
 - 3D parallel PIC code
 - Split-operator based with $H = H_{\text{external}} + H_{\text{space charge}}$
 - 3D space charge w/ 2 types of boundary conditions
 - Linear maps for drifts, quads, rf gaps
 - Maps computed “on the fly” by numerically integrating the equations for the linear transfer map
 - based on well-established methods for computing maps
 - generalization to high order straightforward
 - transformations are symplectic by construction
 - No need for Prome-like corrections for rf gap transformations
 - Reference trajectory equations also computed “on the fly”

Particle-In-Cell Simulation with Split-Operator Method

- Particle-in-cell approach:
 - Charge deposition on a grid
 - Field solution via FFT-based convolution with open boundary conditions
 - Field interpolation from grid to particles
- Split-operator method with $\mathbf{H} = \mathbf{H}_{\text{external}} + \mathbf{H}_{\text{space charge}}$
- Philosophy:
 - Do not** take tiny steps to push ~ 100 million particles.
 - Do** take tiny steps to compute maps, then push w/ maps

Split-Operator Approach



Current Features of IMPACT Code

- Two Particle Advance Algorithms:
 - Linear Map
 - Nonlinear Lorentz Force Integrator
- External Beam Line Elements:
 - Quadrupole, Solenoid + RF gap, 3D constant focusing
 - DTL, CCDTL, CCL, SC
 - Dipole (nonlinear Lorentz integrator only)
- 3D Space Charge with 6 Types of Boundary Conditions
- Ionization Cooling (in progress)
- Error Studies:
 - Field Gradient Errors, Phase Errors, Misalignment Errors, Rotation Errors
- Restart Function and Dynamic Load Balance

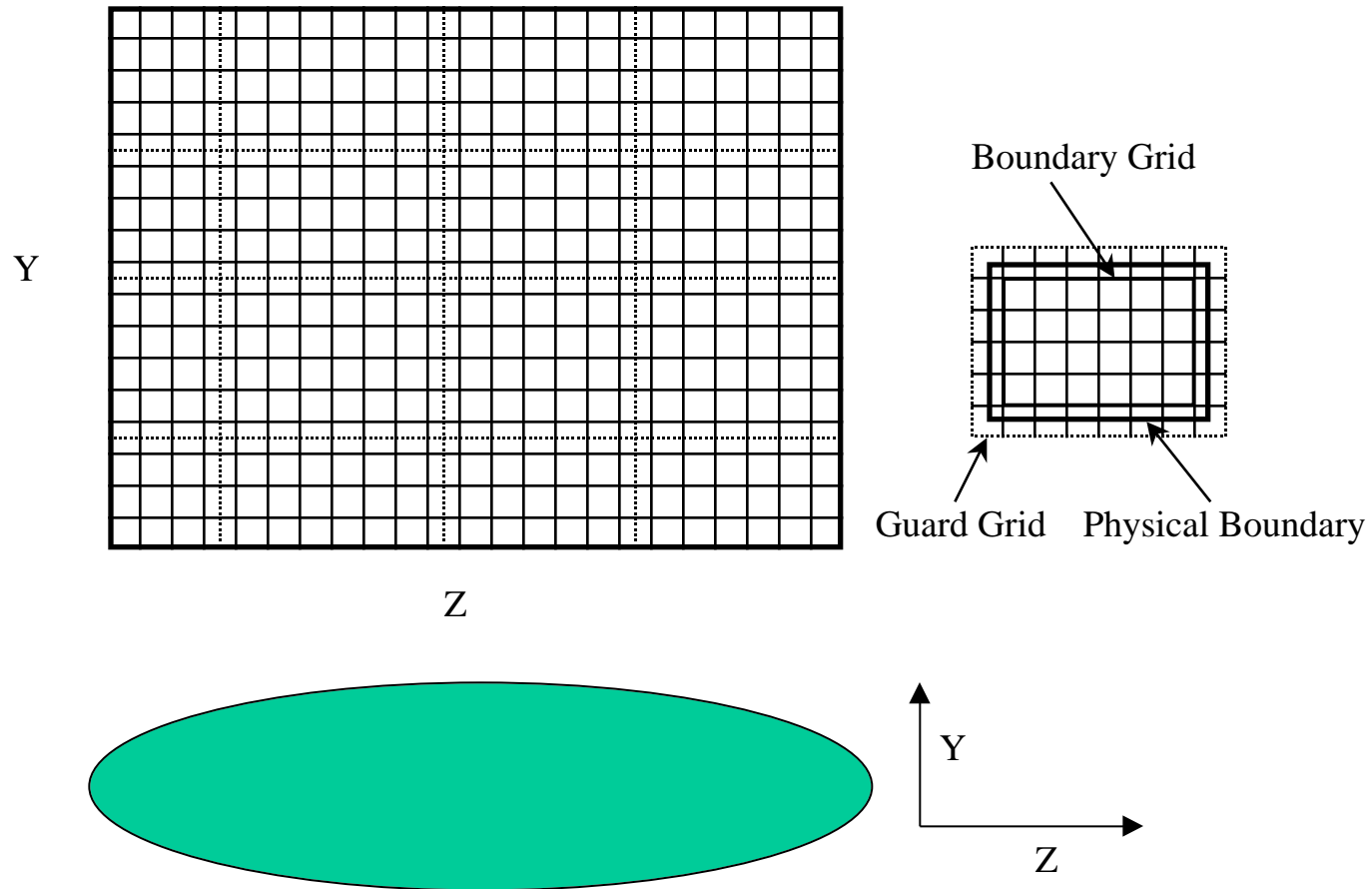
Inputs of IMPACT Code

- Global Numerical Parameters
- Initial Distribution Parameters:
 - 6D Gaussian, 6D Waterbag, SemiGaussian, KV + Uniform in z, 6D Uniform, Read-In
- Global Beam Parameters
- External Beam Line Element Parameters:
 - Geometry parameters and numerical steps
 - Field information: E_r , E_z , H_{θ} on grid; Discrete E_z on the axis, Fourier coefficients of E_z on the axis
- Diagnostic Flags

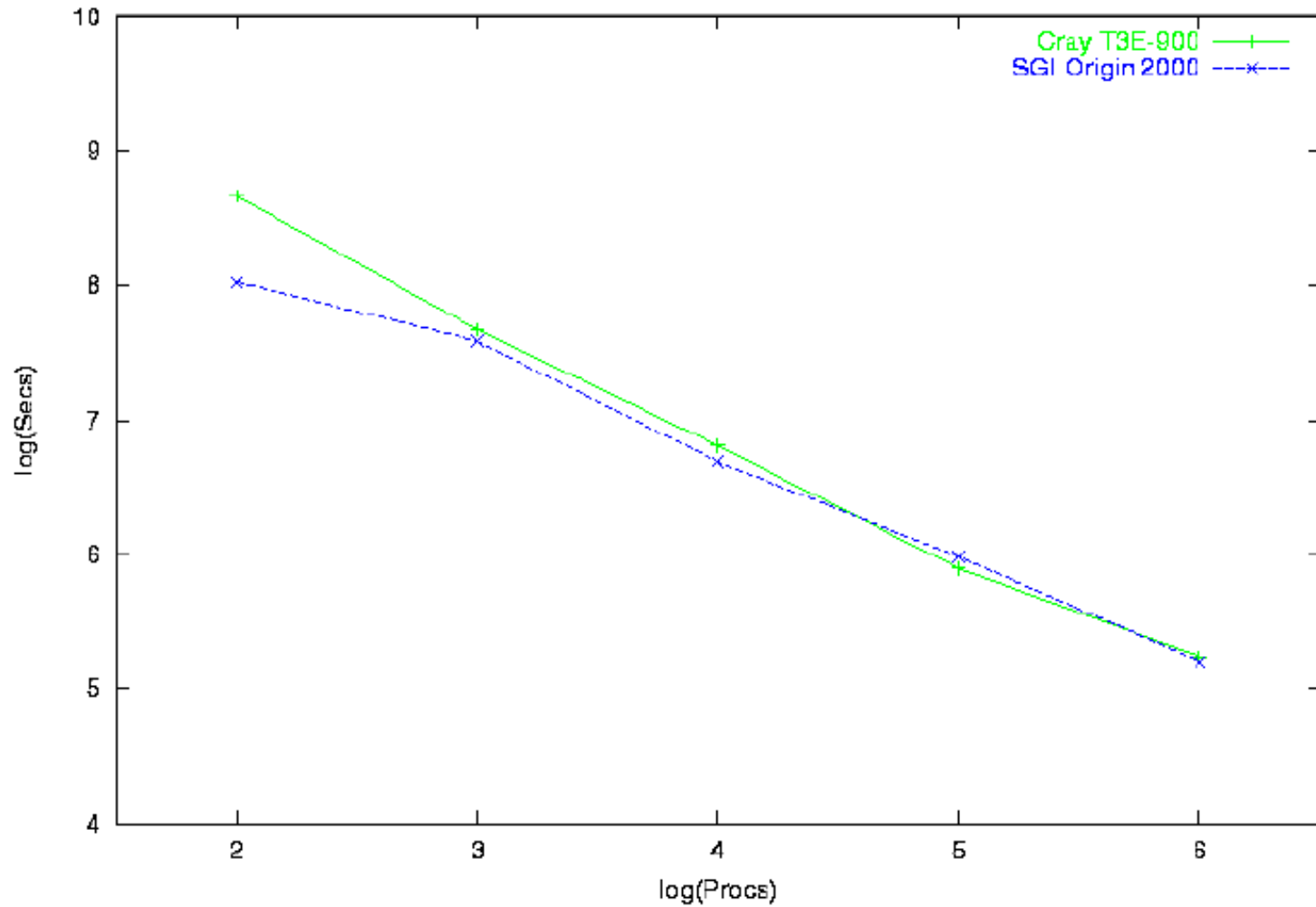
Outputs of IMPACT Code

- Position Dependent Quantities:
 - Kinetic Energy, Maximum Radius, Particle Losses
 - 1st, 2nd, 3rd, 4th moments of X, P_x, Y, P_y, Phase, and Energy deviation
 - Alpha and Normalized RMS Emittances
 - 90%, 95% and 99% Radius and Emittances
- Snap Shots:
 - 6D phase space particle output
 - 3D charge density grid output
 - X-P_x, X-Y, X-Z, Y-P_y, Z-P_z, Y-Z projections
 - X, Y, R accumulated density profiles

Two-Dimensional Domain Decomposition



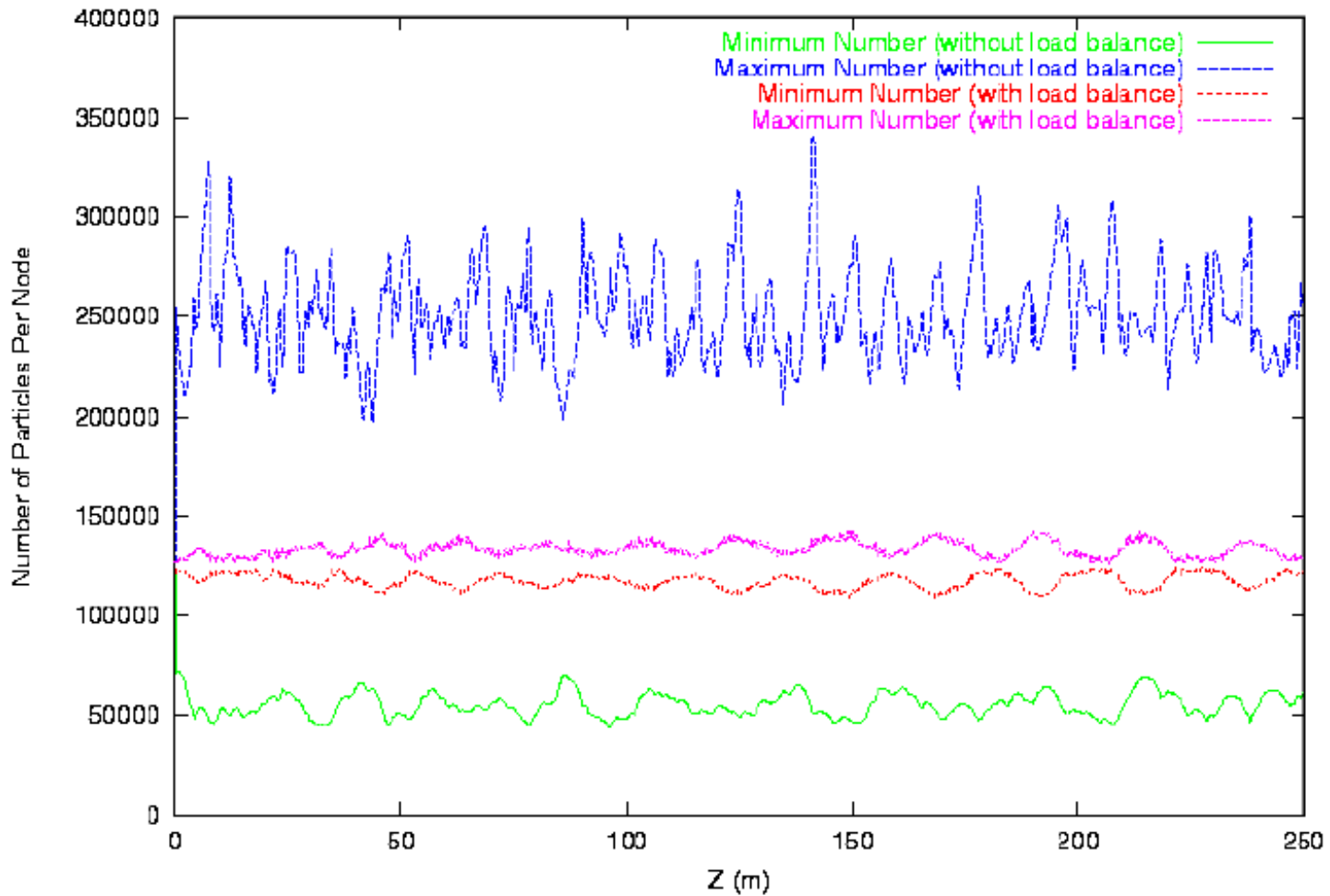
IMPACT Scaling with # of Processors



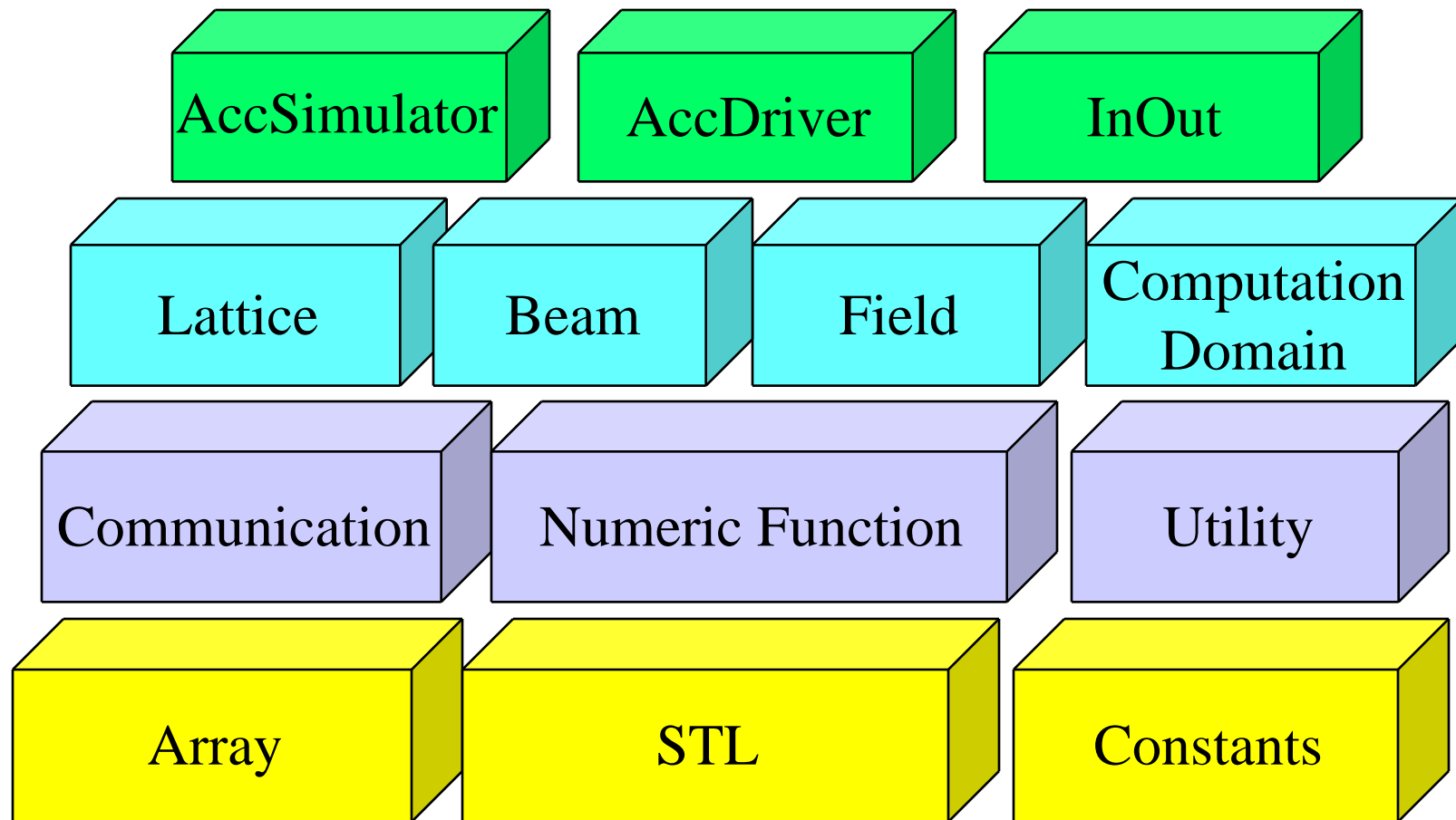
Dynamic Load Balance

- Define a 2-D density distribution function
- Assume that it is separable in y and z
- Load balance in the y direction
- Load balance in the z direction

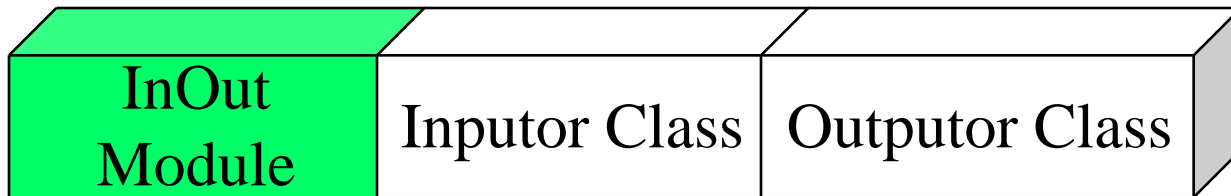
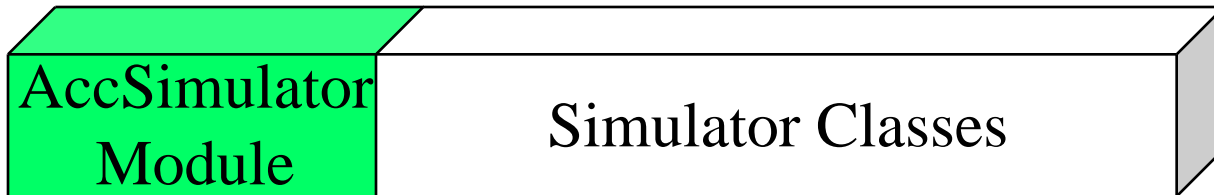
IMPACT: Success of Dynamic Load Balancing



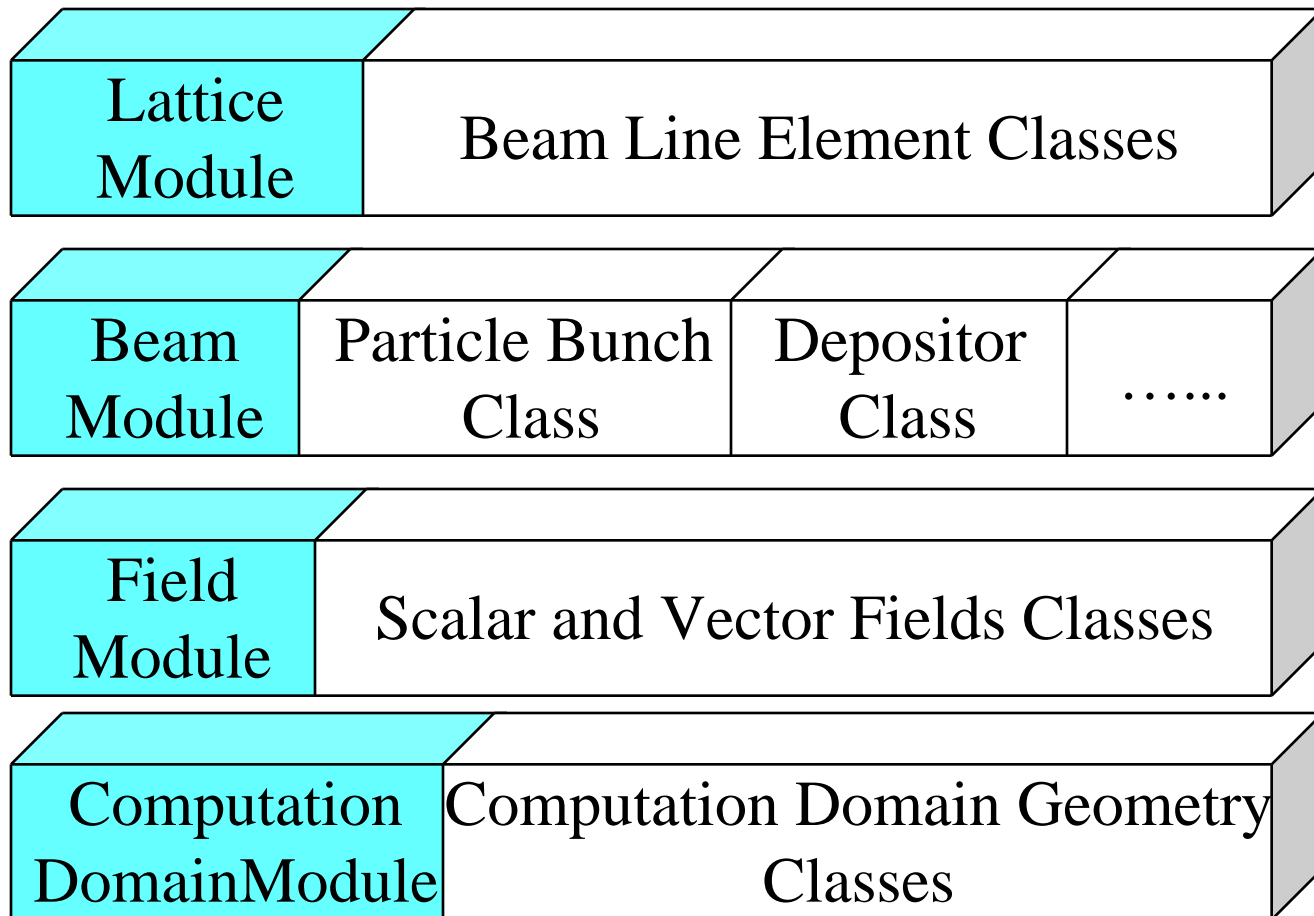
Object-Oriented Multi-Layer Structure



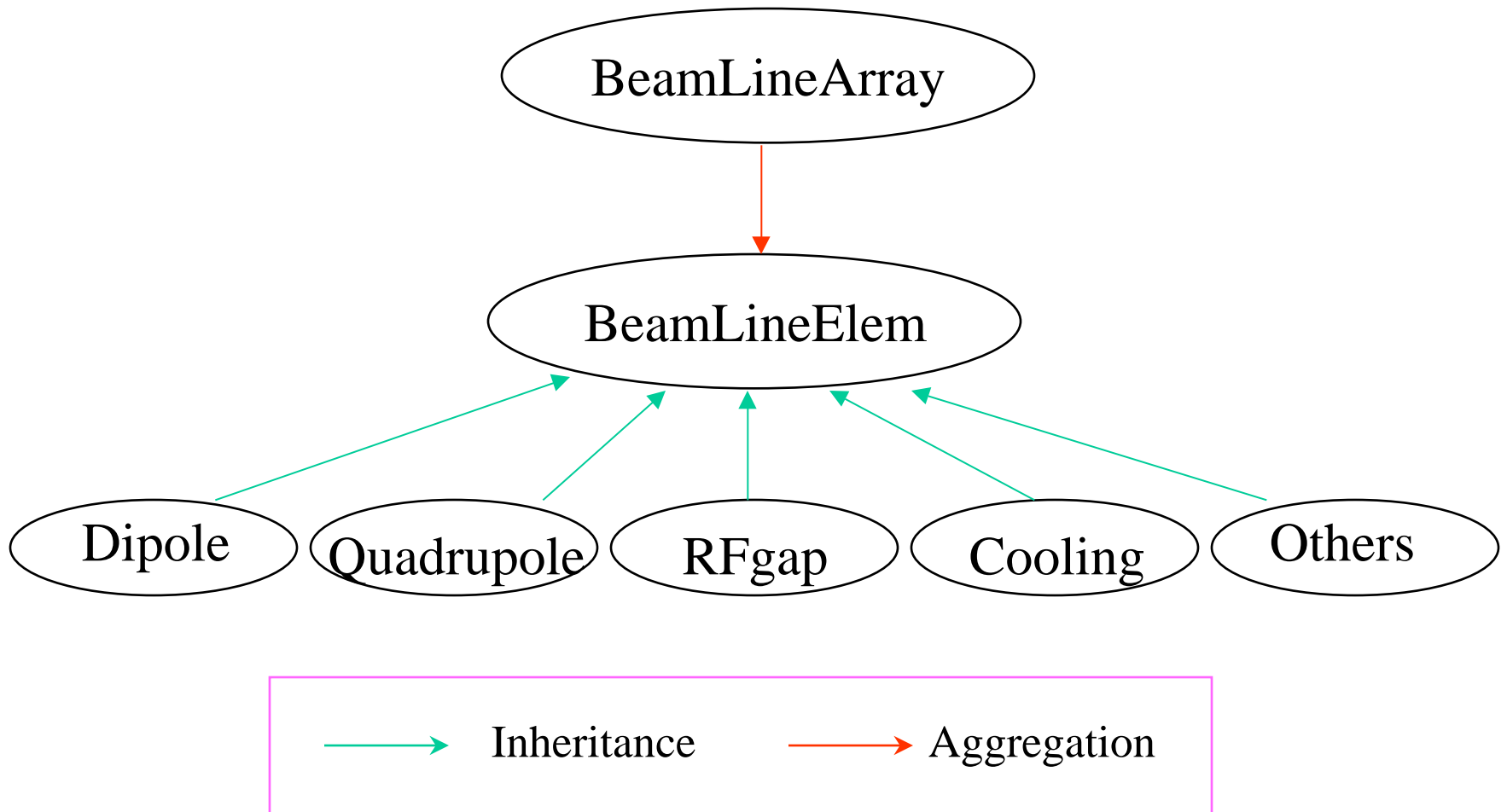
Control Layer



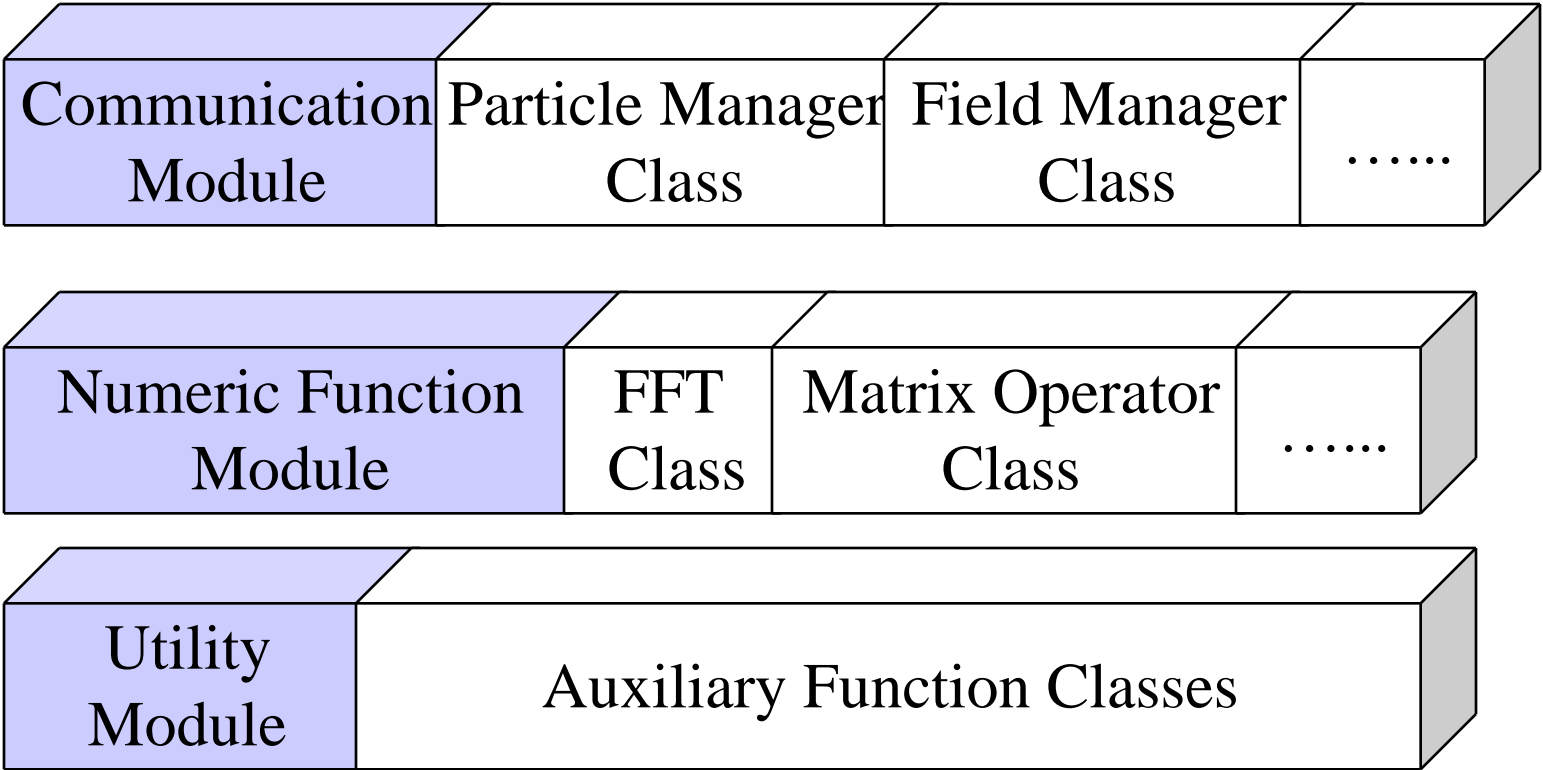
Application Layer



Class Diagram in the Lattice Module



Function Layer



Data Structure Layer

Array
Module

Array Classes

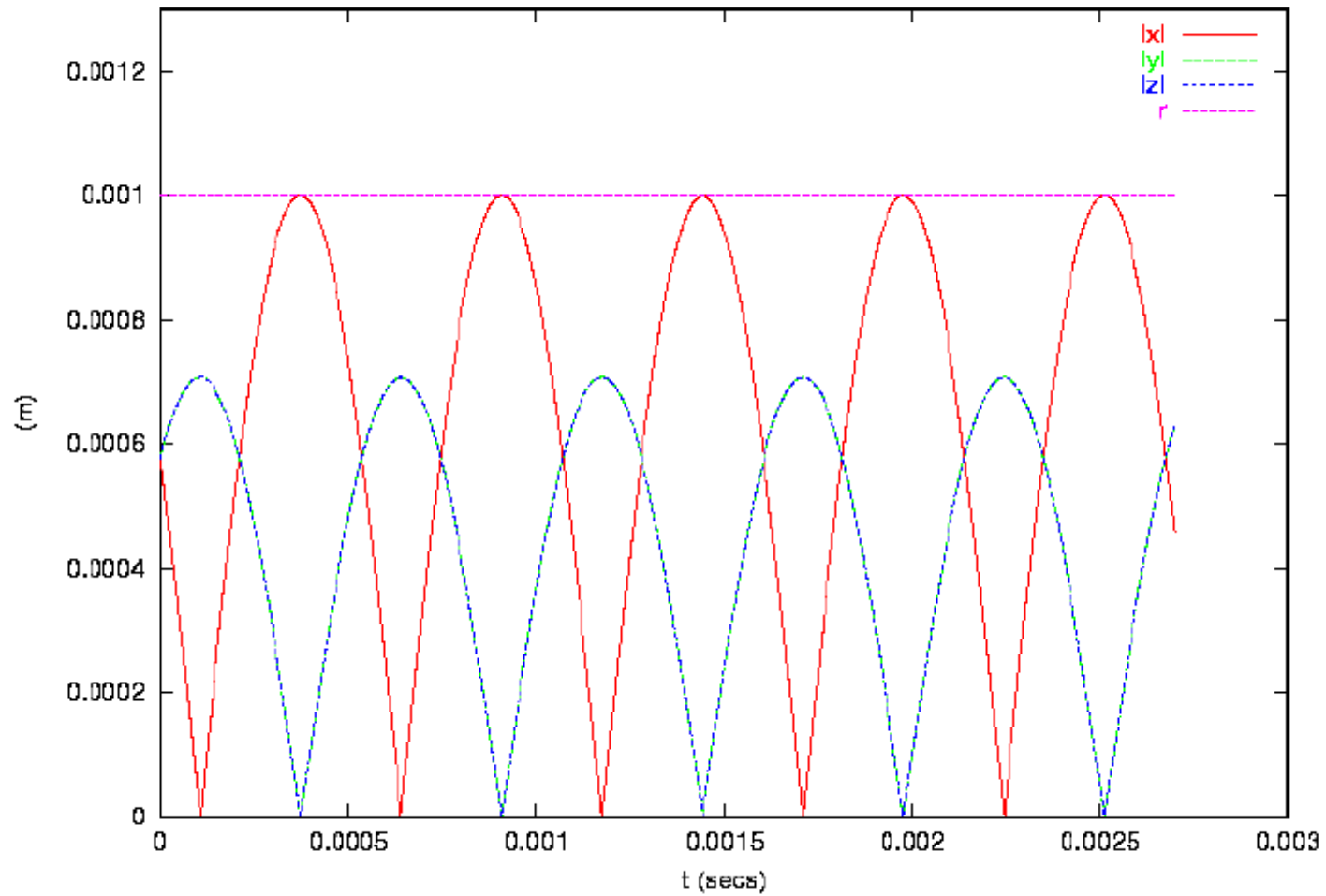
STL
Module

Standard Template Library

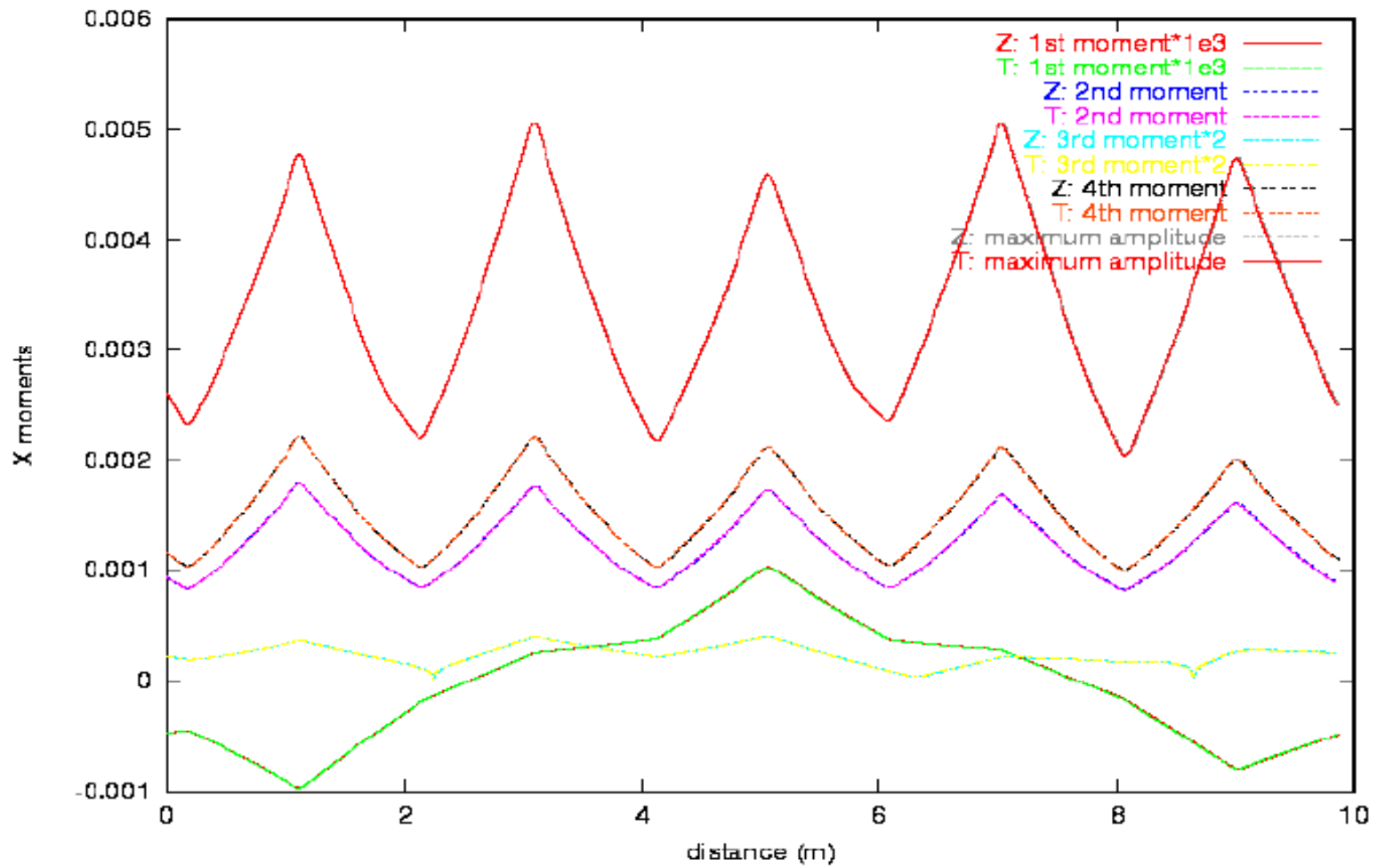
Constants
Module

Numerical and Physical Constants
Classes

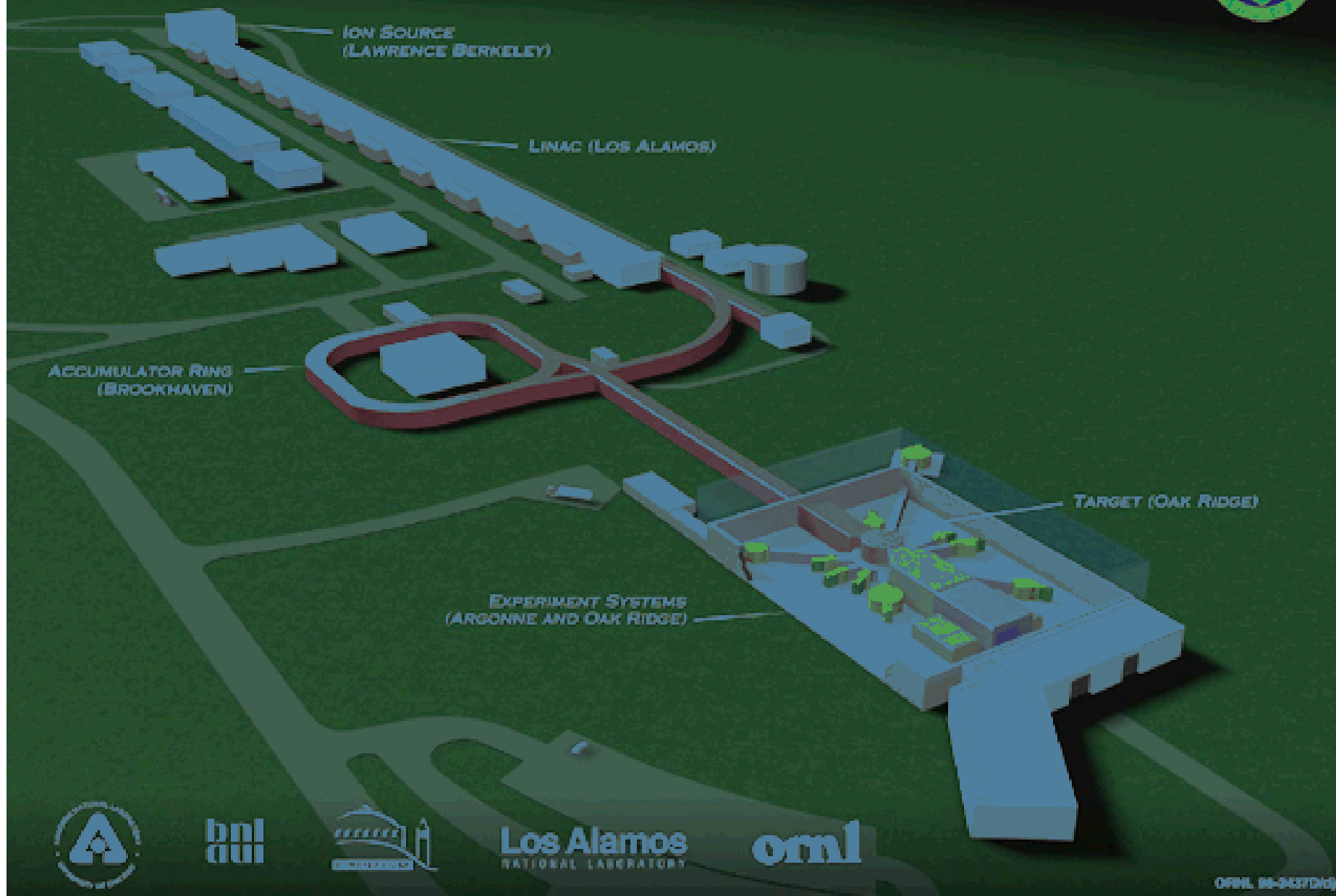
Two Particle Motion In Time Domain Code With Only Space Charge (64x64x64)



Comparison Between Z Code (Impact) and T Code For a FODO Channel (1M and 64x64x64)



SPALLATION NEUTRON SOURCE



Design Energy & Accelerating Gradient vs. Distance

Title:
en0.eps
Creator:
gnuplot 3.5 (pre 3.6) patchlevel beta 340
Preview:
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with a preview included in it.
Comment:
This EPS picture will print to a
PostScript printer, but not to
other types of printers.

Title:
energy1.eps
Creator:
gnuplot 3.5 (pre 3.6) patchlevel beta 340
Preview:
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with a preview included in it.
Comment:
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PostScript printer, but not to
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Title:
energy2.eps
Creator:
gnuplot 3.5 (pre 3.6) patchlevel beta 340
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Title:
energy4.eps
Creator:
gnuplot 3.5 (pre 3.6) patchlevel beta 340
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Title:
gradient1.eps
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gnuplot 3.5 (pre 3.6) patchlevel beta 340
Preview:
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gradient2.eps
Creator:
gnuplot 3.5 (pre 3.6) patchlevel beta 340
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Title:
gradient4.eps
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gnuplot 3.5 (pre 3.6) patchlevel beta 340
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other types of printers.

Transverse Beam Size as a Function of Energy Using 100 Million Particle Simulation

Title:

sns100trnew.eps

Creator:

gnuplot 3.5 (pre 3.6) patchlevel beta 340

Preview:

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with a preview included in it.

Comment:

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PostScript printer, but not to
other types of printers.

Plots of “Integrated Density” from a 500 Million Particle SNS Simulation

Title:

Creator:
XYBASE Graphics
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PostScript printer, but not to
other types of printers.

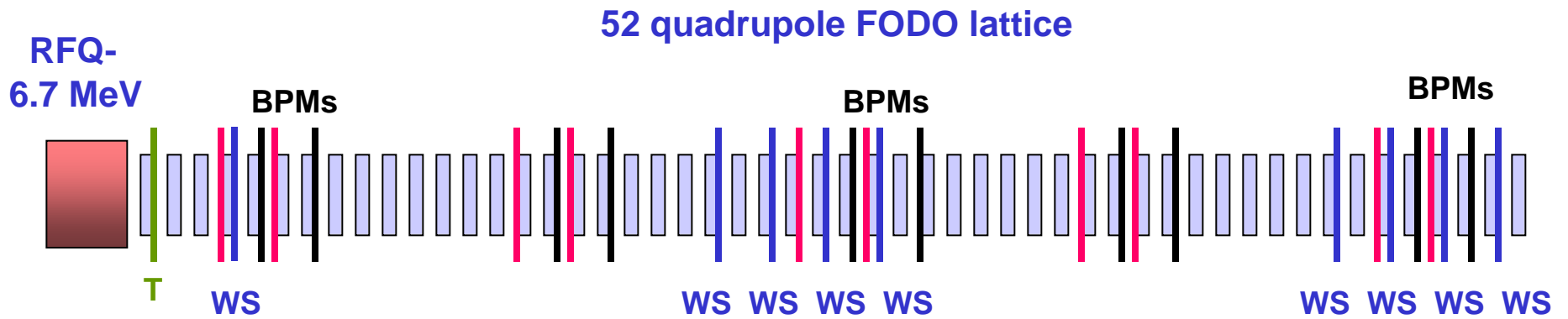
X-P_X Plot

Title:

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XYBASE Graphics
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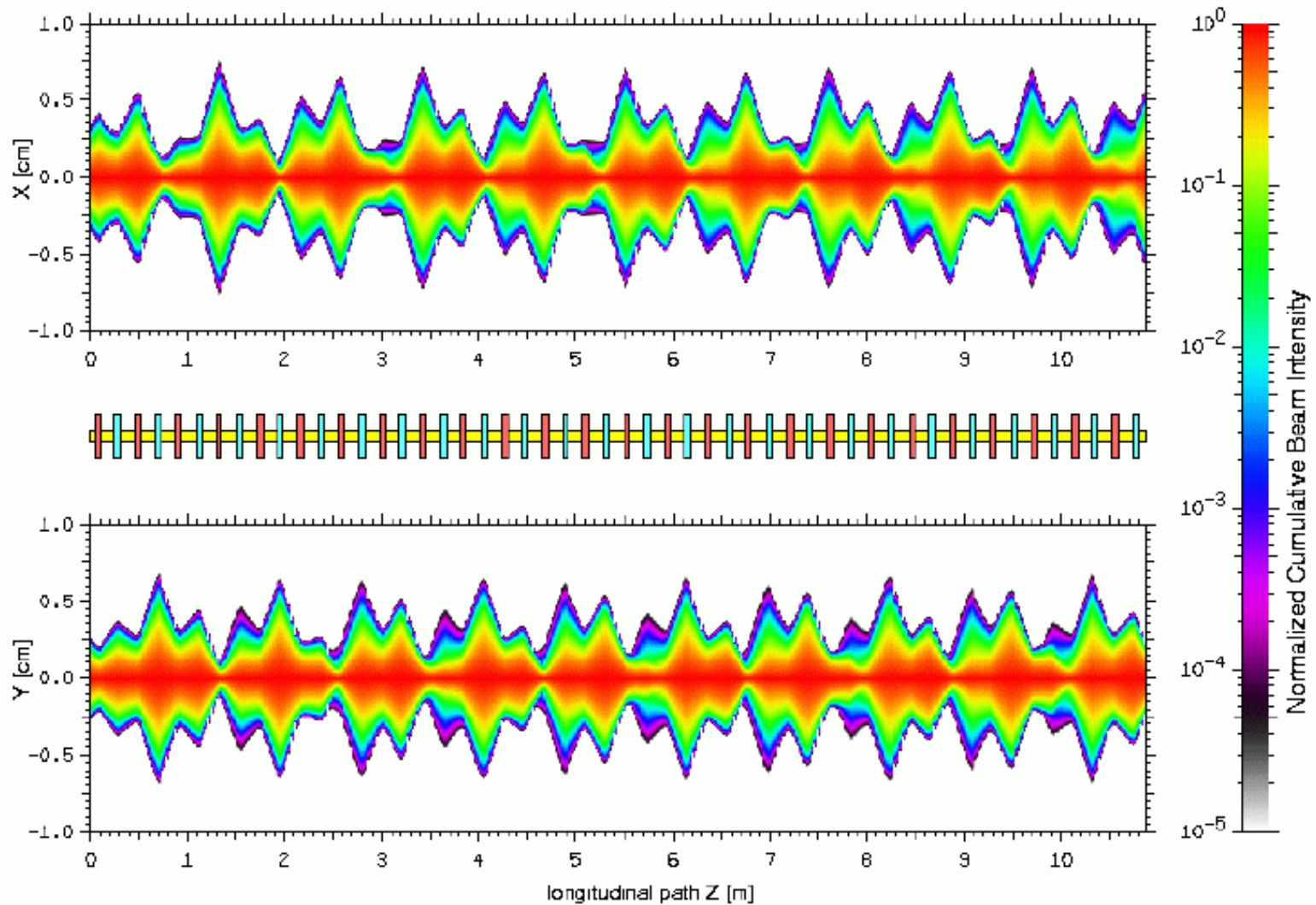
X-Y Plot

LEDA Halo Experiment Channel

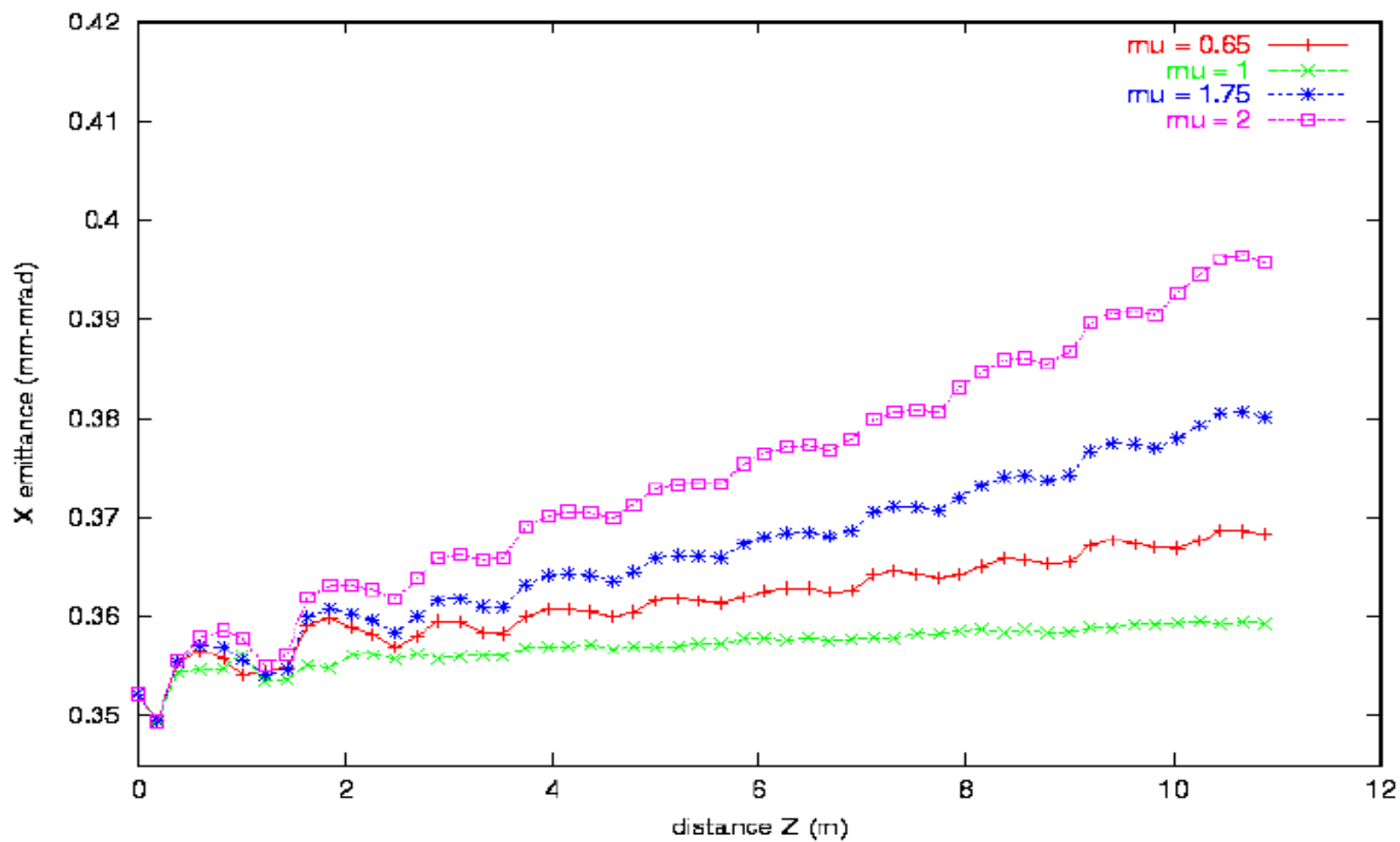


52 Quadrupoles
10 Steering Magnets
9 Wire Scanners
1 Toroid
10 Beam Position Monitors

100 million particle simulation of the LEDA halo experiment.
Cumulative distributions of quadrupole mode oscillations.

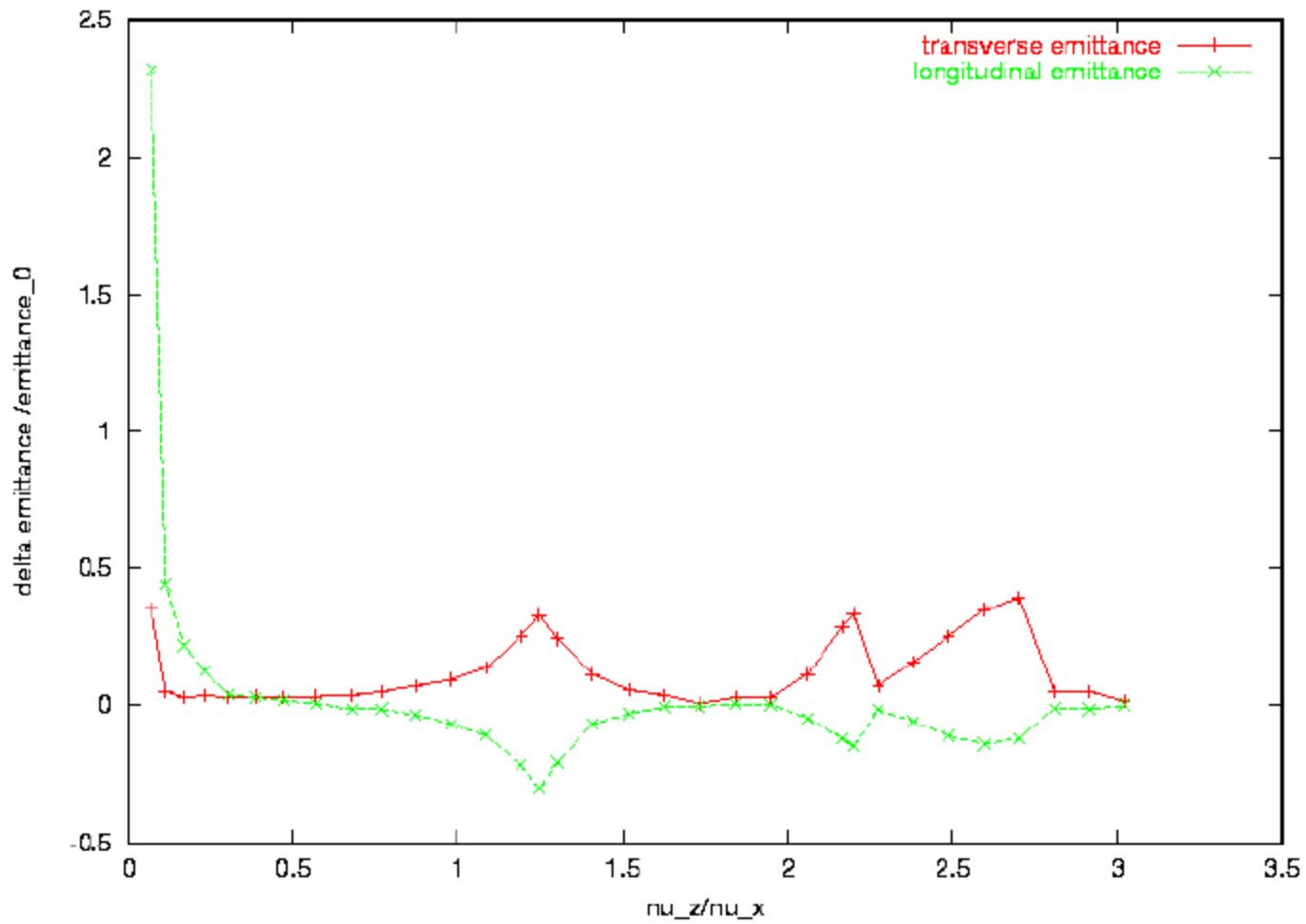


X emittance as a function of distance using 10M particles IMPACT simulation



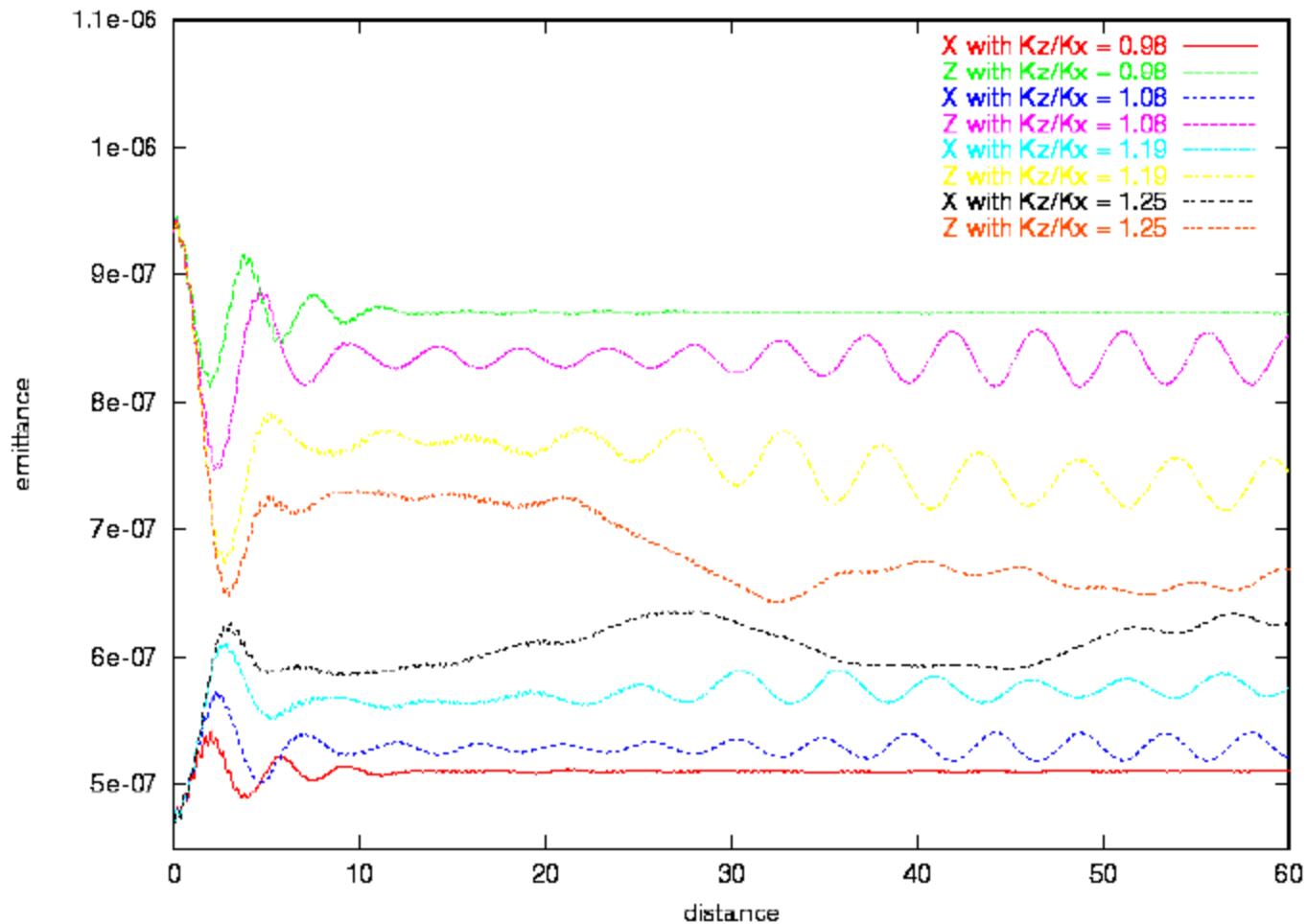
Emittance Growth as a Function of Tune Ratio (TR)

(ER = 2.0, $K_x = 0.5$)

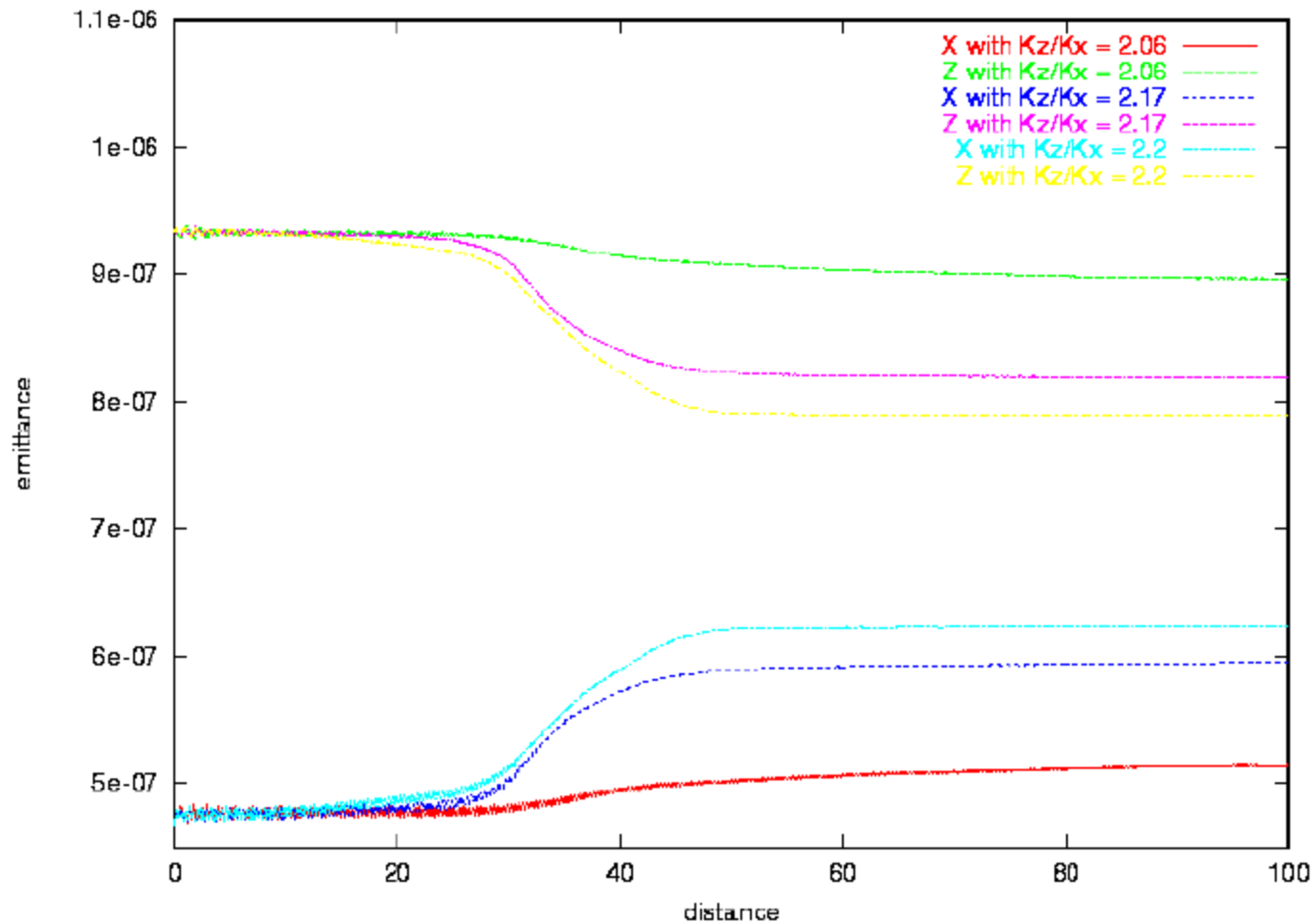


Emittance Exchange as a Function of Distance

(around stopband 1, $ER = 2$, $K_X = 0.5$)



Emittance Exchange as a Function of Distance (around stopband 2, $ER = 2$, $K_x = 0.5$)



Future Work

- Include multiple reference particles
- Include nonlinear maps for external field
- Improve performance by using sub-step
- Extend to modeling the beam dynamics in the ring
- Develop parallel RFQ modeling capability
- Include new 3D Poisson solver from SciDAC software infrastructure centers
- Include multiple species