Simulations of Space Charge Effects at PS2

Ji Qiang and Robert Ryne

Lawrence Berkeley National Laboratory

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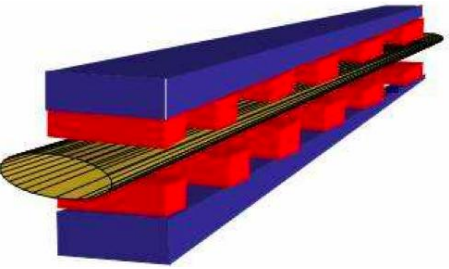
MaryLie/IMPACT (ML/I)

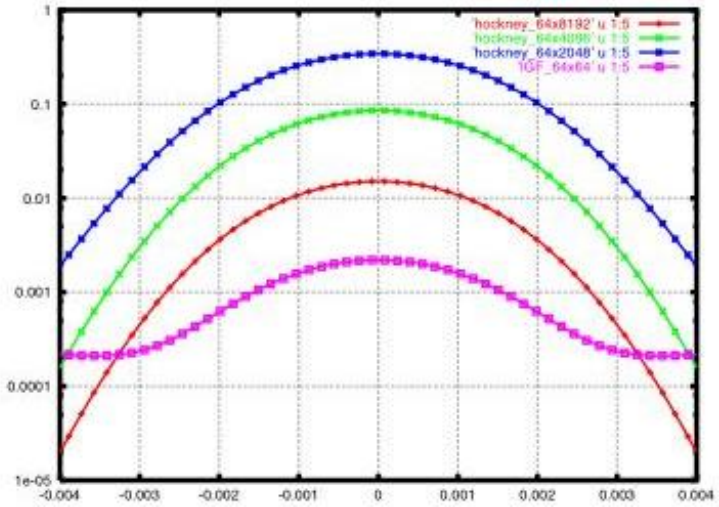
- Combines capabilities of MaryLie code (A. Dragt, U Md) with IMPACT code (J. Qiang, R. Ryne, LBNL) + new features
- Multiple capabilities in a single unified environment:
  - Map generation
  - Map analysis
  - Particle tracking w/ 3D space charge
  - Envelope tracking
  - Fitting and optimization
- Recent applications: ERL for e-cooling @ RHIC; CERN PS2

- Parallel
- 5th order optics
- 3D space charge
- 5th order rf cavity model
- 3D integrated Green func
- Photoinjector modeling
- "Automatic" commands
- MAD-style input
- Test suite
- Contributions from LBNL, UMd, Tech-X, LANL,…

Map computation from surface data

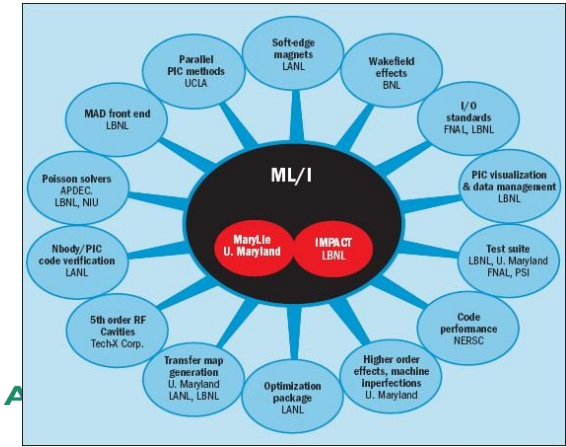


Alex Dragt, U. Md.



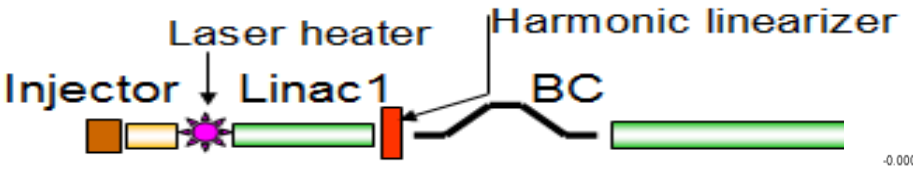
Error in E-field computed w/ different algorithms applied to a 2D Gaussian elliptical distribution w/ 500:1 aspect ratio

Integrated Green Function on 64x64 grid is more accurate than Hockney on 64x2048, 64x4096, 64x8192.



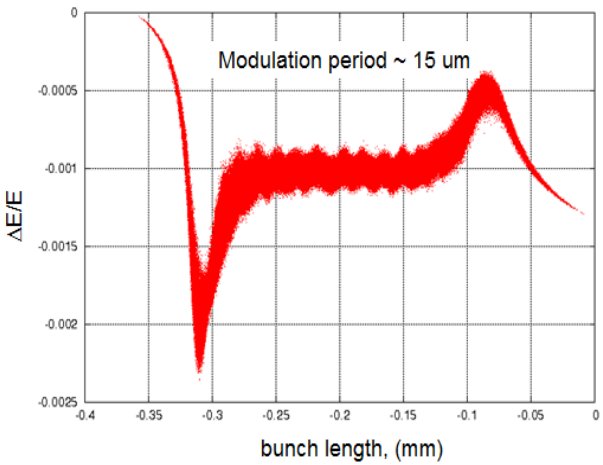
IMPACT code suite

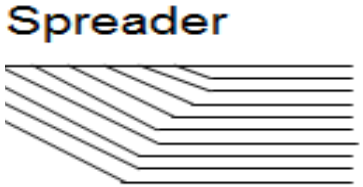
- IMPACT-Z: parallel PIC code (z-code)
- IMPACT-T: parallel PIC code (t-code)
- Envelope code, pre- and post-processors,…
- Optimized for parallel processing
- Applied to many projects: SNS, JPARC, RIA, FRIB, PS2, future light sources, advanced streak cameras,…
- Has been used to study photoinjectors for BNL e-cooling project, Cornell ERL, FNAL/A0, LBNL/APEX, ANL, JLAB, SLAC/LCLS



One Billion Macroparticle Simulation of an FEL Linac

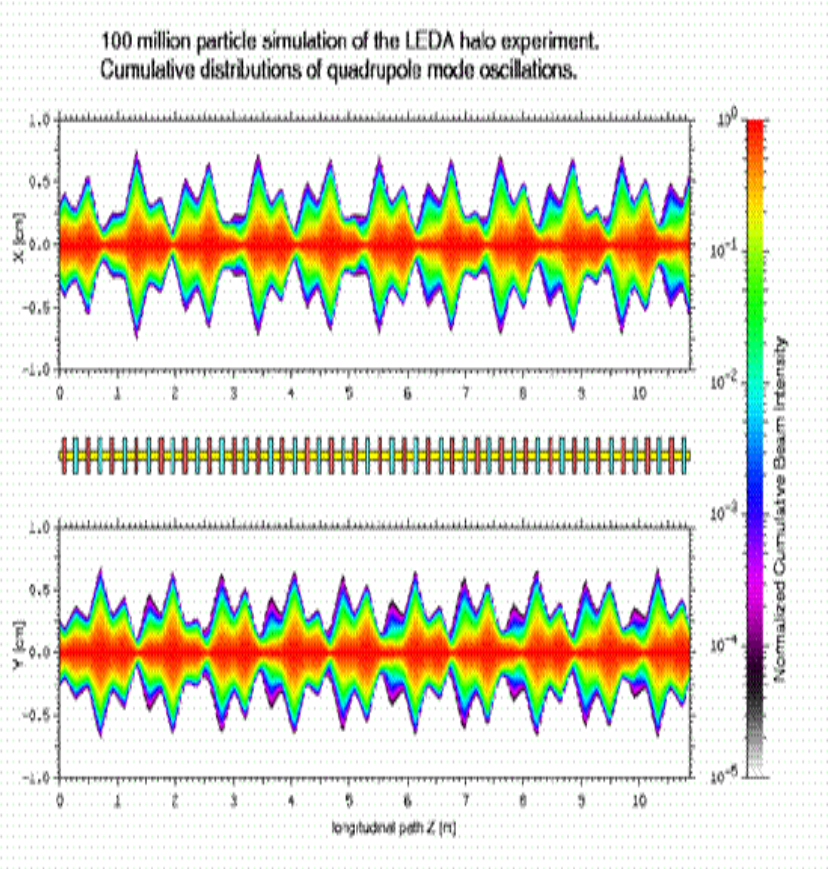
(~2 hrs on 512 processors)





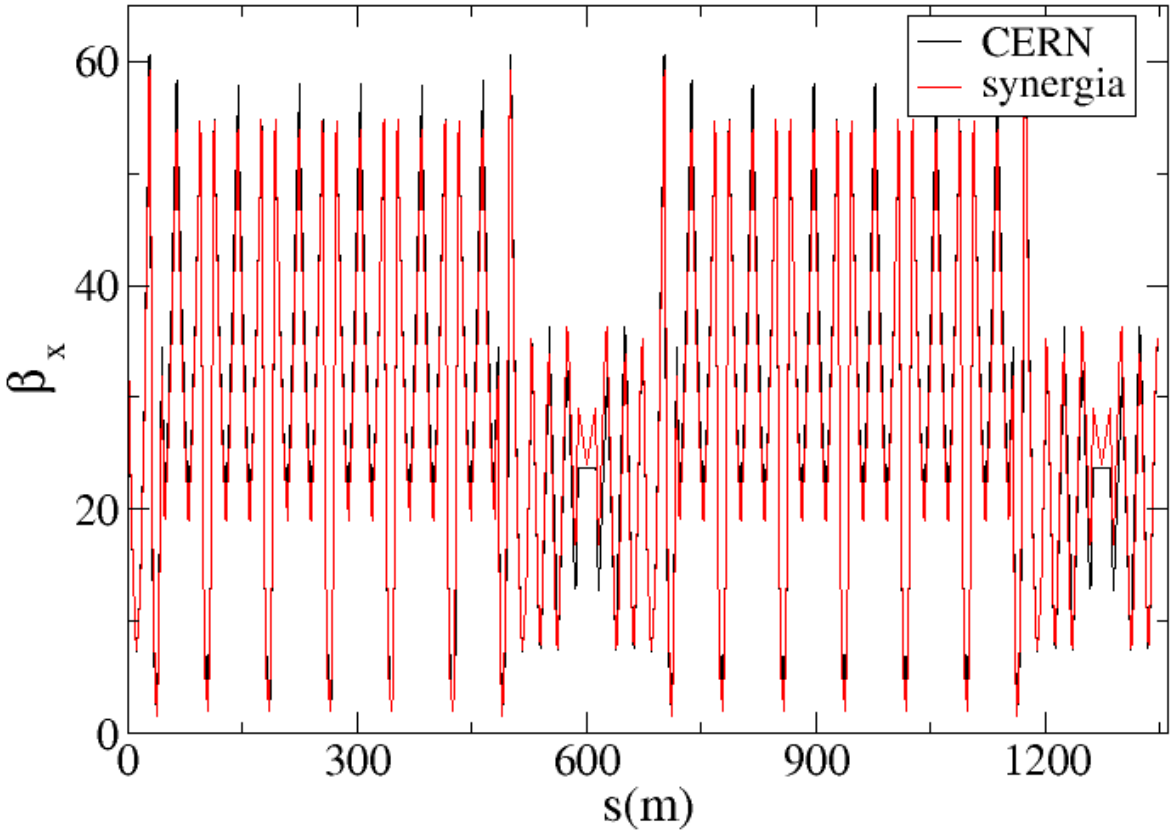
IMPACT-Z

- Parallel PIC code using coordinate "z" as the independent variable
- Key Features
  - Detailed RF accelerating and focusing model
  - Multiple 3D Poisson solvers
    - Variety of boundary conditions
    - 3D Integrated Green Function
  - Multi-charge state
  - Machine error studies and steering
  - Wakes
  - CSR (1D)
  - Run on both serial and multiple processor computers
  - Multiple turn tracking
  - Thin lens kick for nonlinear elements
  - Lumped space-charge calculation

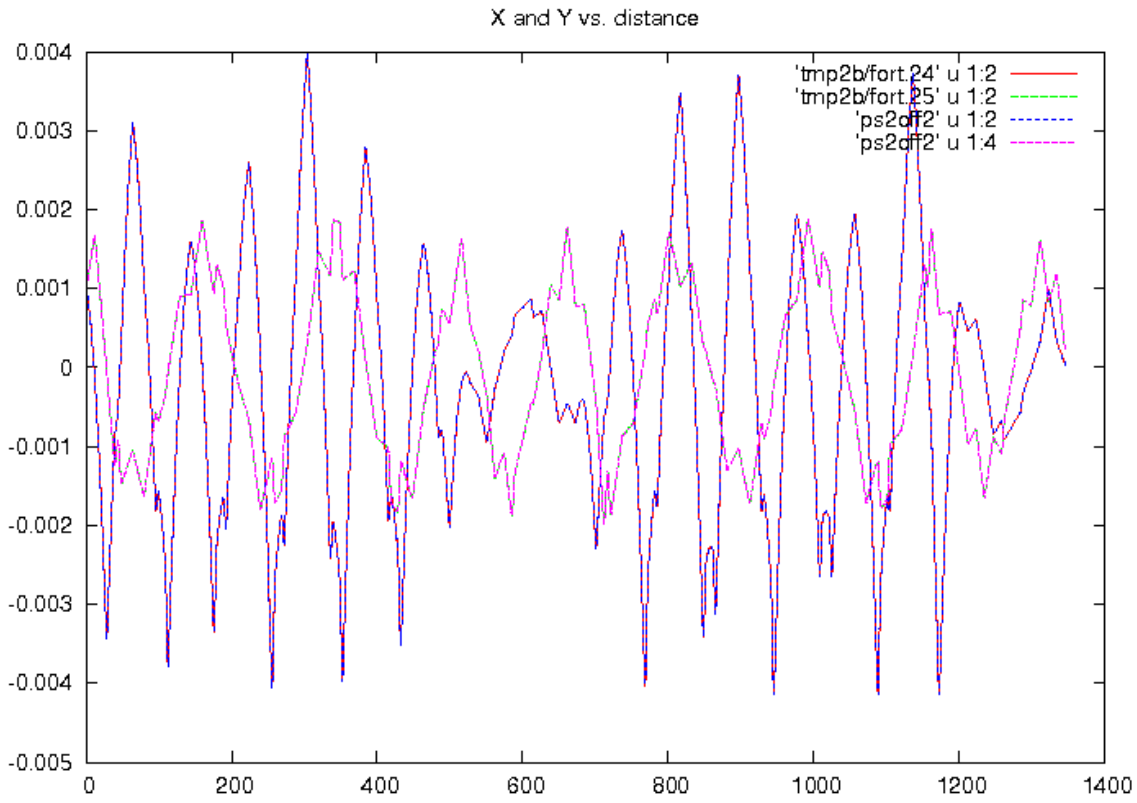


Initial studies

- Able to read MAD description (except for SEQUENCE)
- ML/I and Synergia produced linear lattice functions in agreement w/ previous CERN results



IMPACT and ML/I agreed on single-particle trajectories



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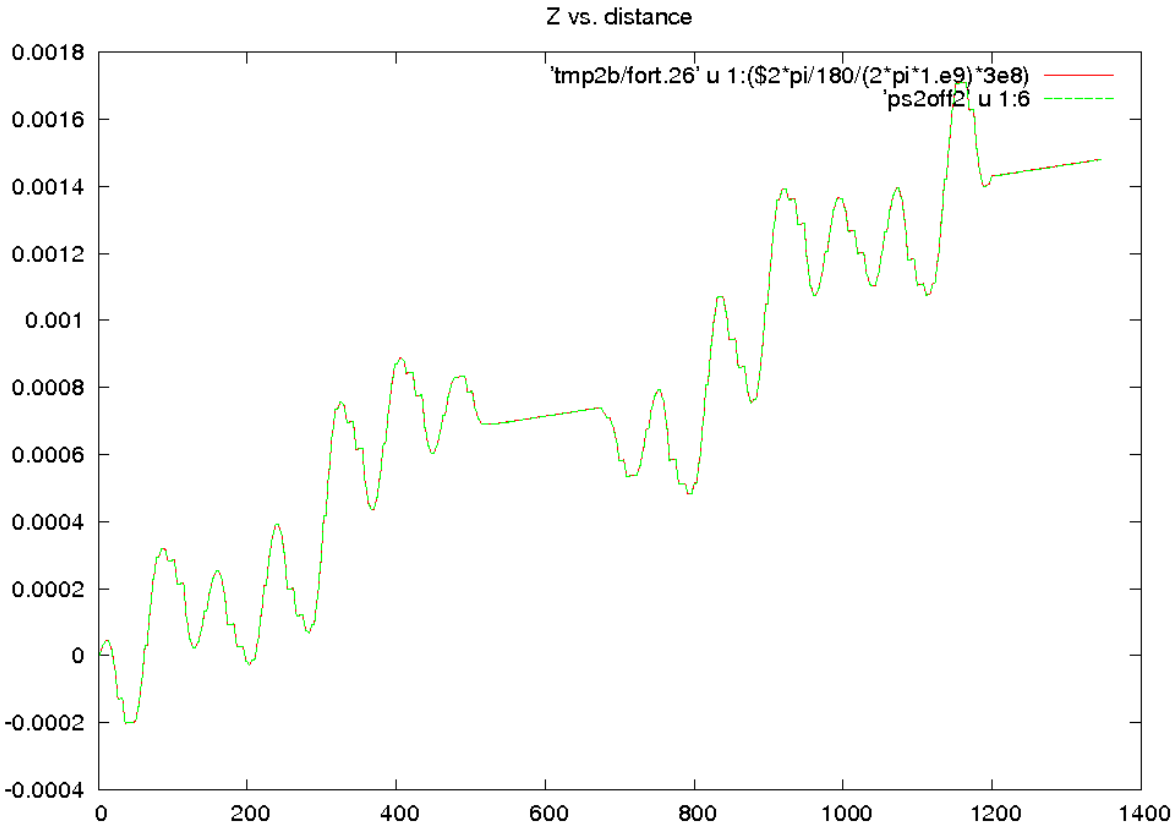

Parameters Used in PS2 Simulations

Physical Parameters:

Vrf = 1.5 MV with f = 40 MHz
Ek = 4 GeV
Emit_x = Emit_y = 3 mm-mrad
Emit_z = .098 eV-sec
Xrms = 4.51mm
Yrms = 2.81mm
Trms = 1.11 rad
Aperture = 8 cm
$I = 4.2 \times 10^{11}$

Numerical Parameters:

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60 SC per tur
65x65x128 grid points
1000,000 macroparticles

Zero current matching

- Zero current matched beam found using ML/I normal form capabilities:
  - Normalize 1-turn map: $M=A^{-1}NA$ (A= normalizing map; N=normal form)
  - Let $\zeta=(x,p_x,y,p_y,t,p_t)$ and consider a function g that depends only on $(x^2+p_x^2),(y^2+p_y^2),(t^2+p_t^2)$
  - Then $f(\zeta)=g(A\,\zeta)$ is a matched beam.
  - Proof: The distribution after one turn is given by

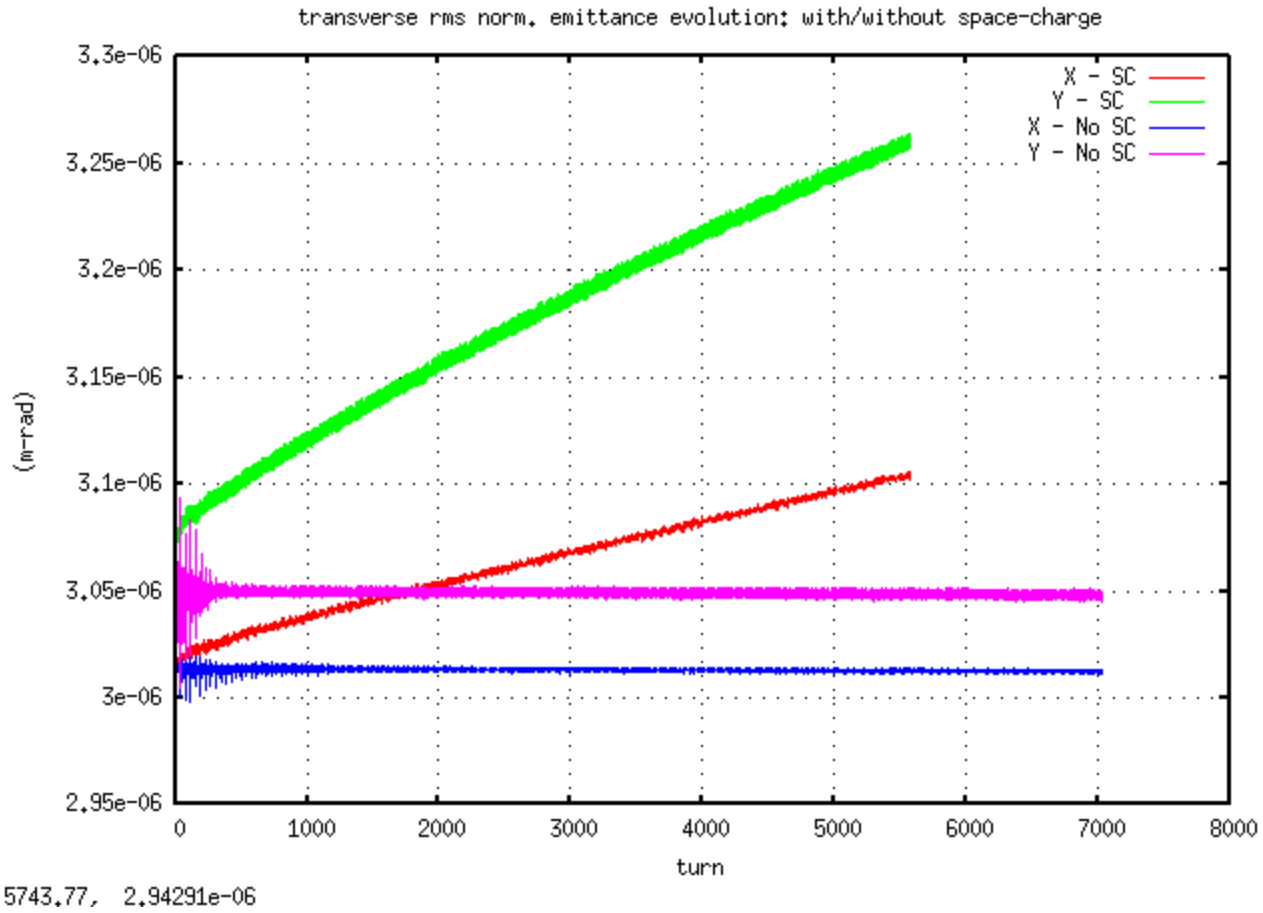
    $f(M^{-1}\zeta)=g(AN\,A^{-1}.\,A\,(x^2+p_x^2),(y^2+p_y^2),(t^2+p_t^2))=$

    $g(AN\,(x^2+p_x^2),(y^2+p_y^2),(t^2+p_t^2))=$

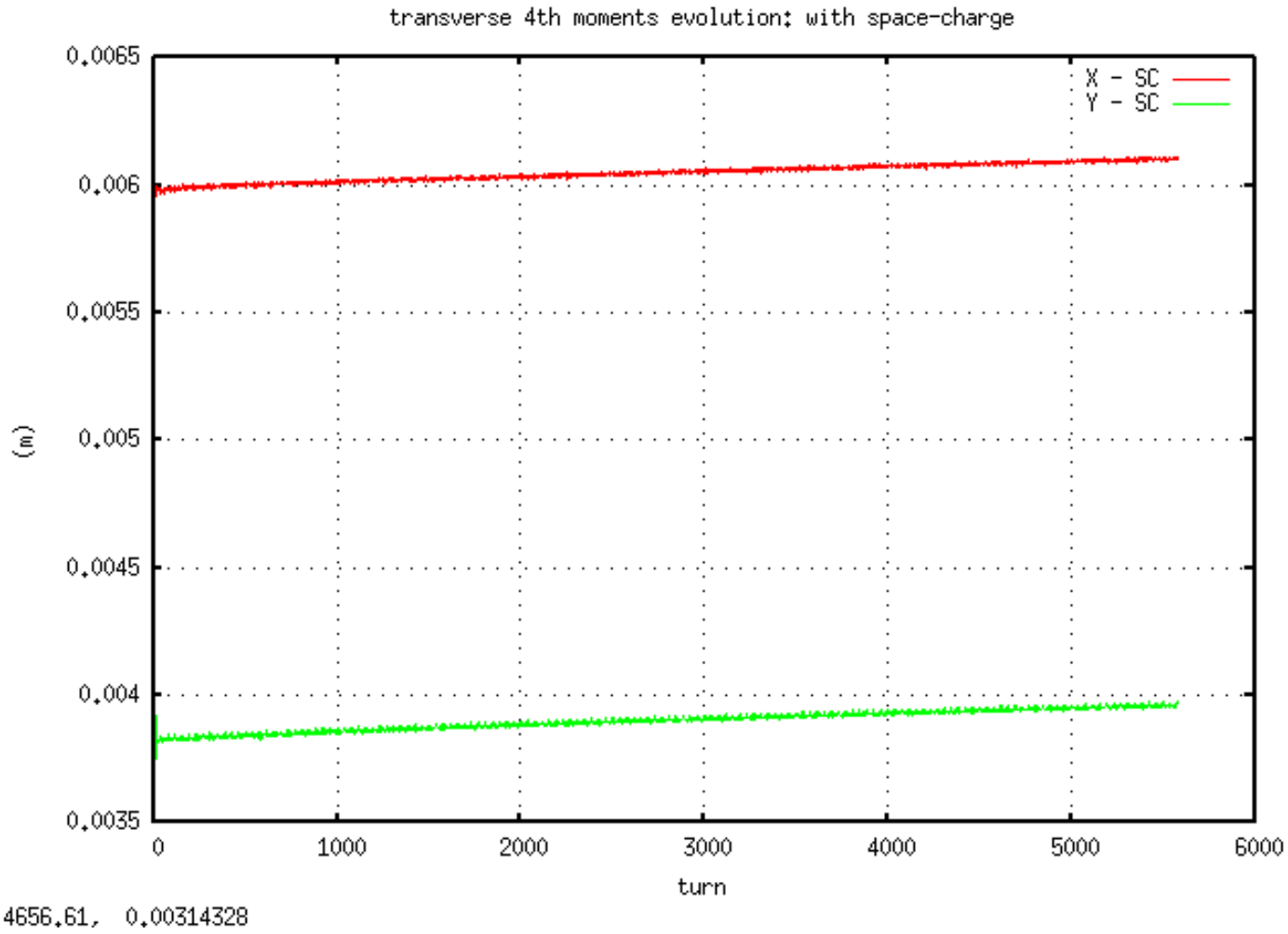
    $g(A\,(x^2+p_x^2),(y^2+p_y^2),(t^2+p_t^2))$

- We generated a distribution of 1M particles using this approach, performed element-by-element tracking with ML/I, verified match.
- Then performed space-charge simulations w/ IMPACT-Z

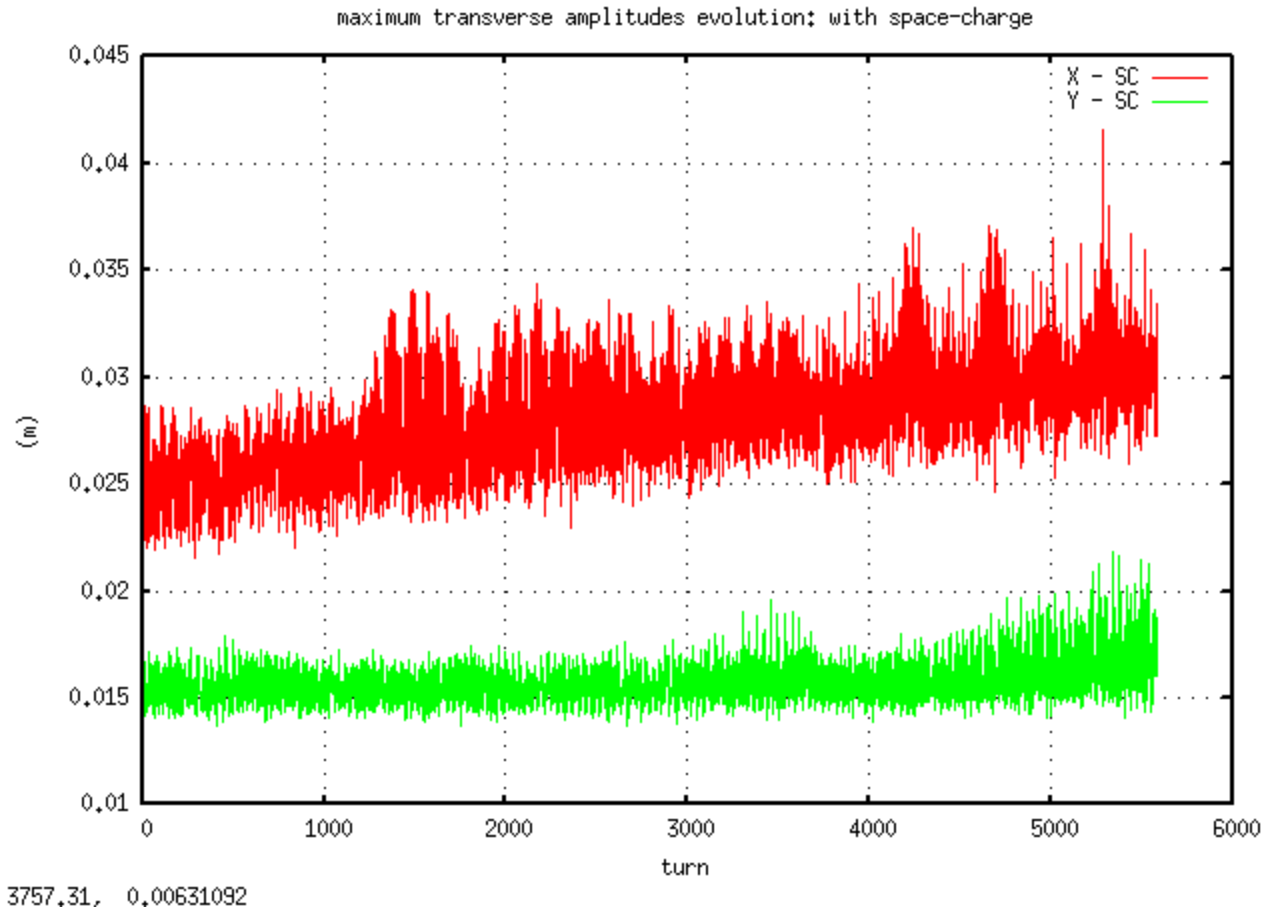
Transverse Emittance Evolution w/o Space Charge Effects



Transverse Tail (4th moments) evolution with space-charge effects

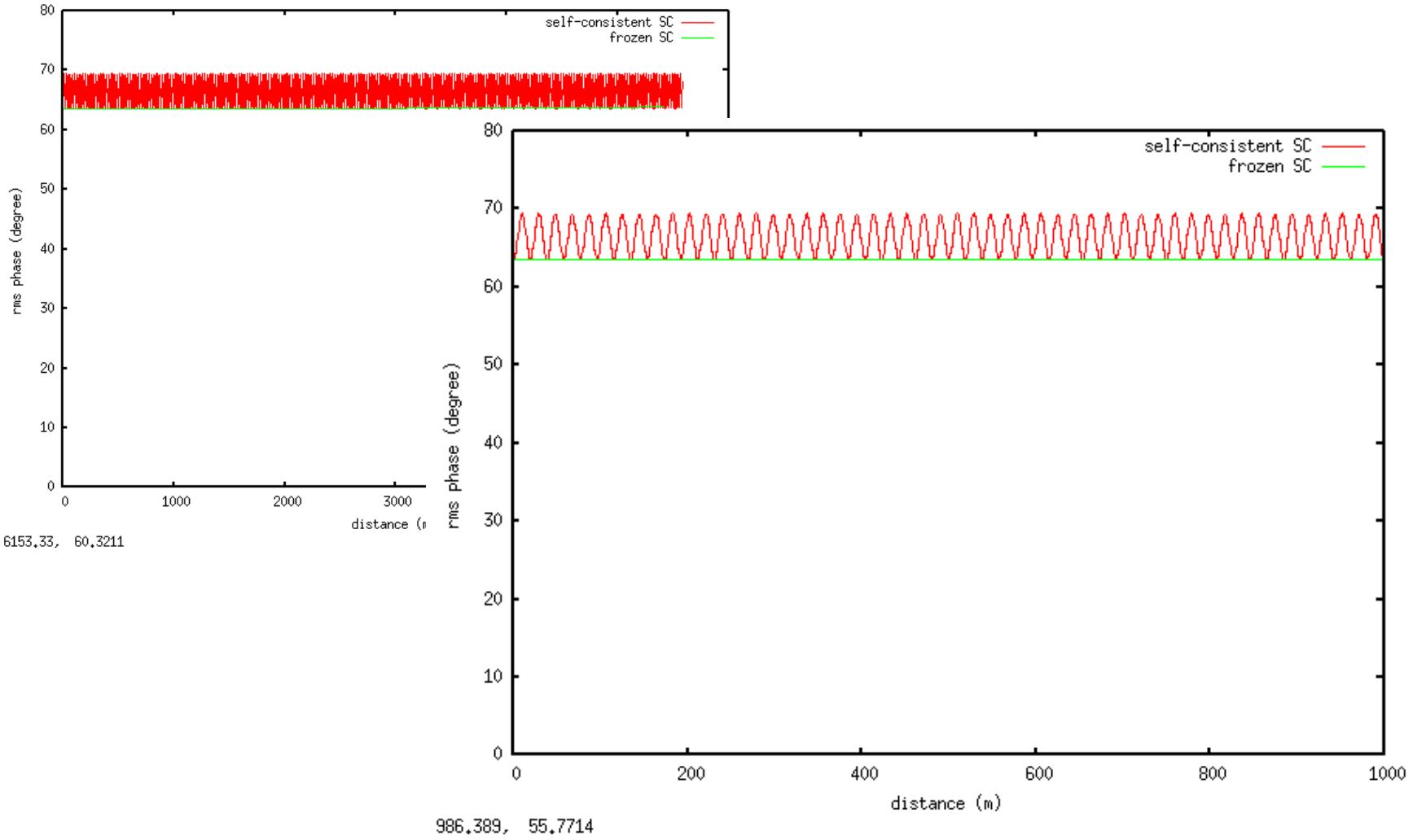


Transverse maximum amp. evolution with space-charge effects

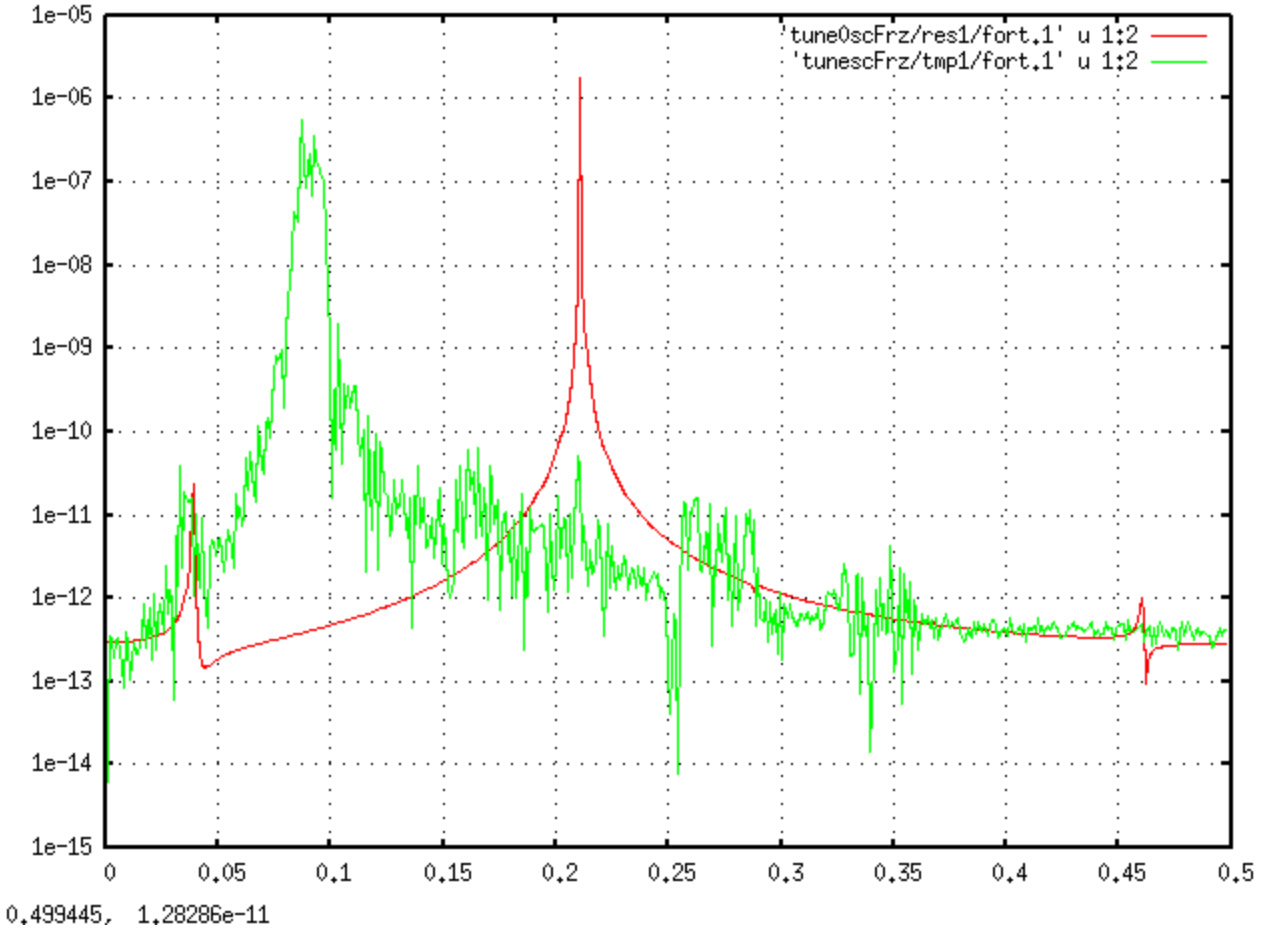


Longitudinal Bunch Length Evolution w/o synchrotron motion

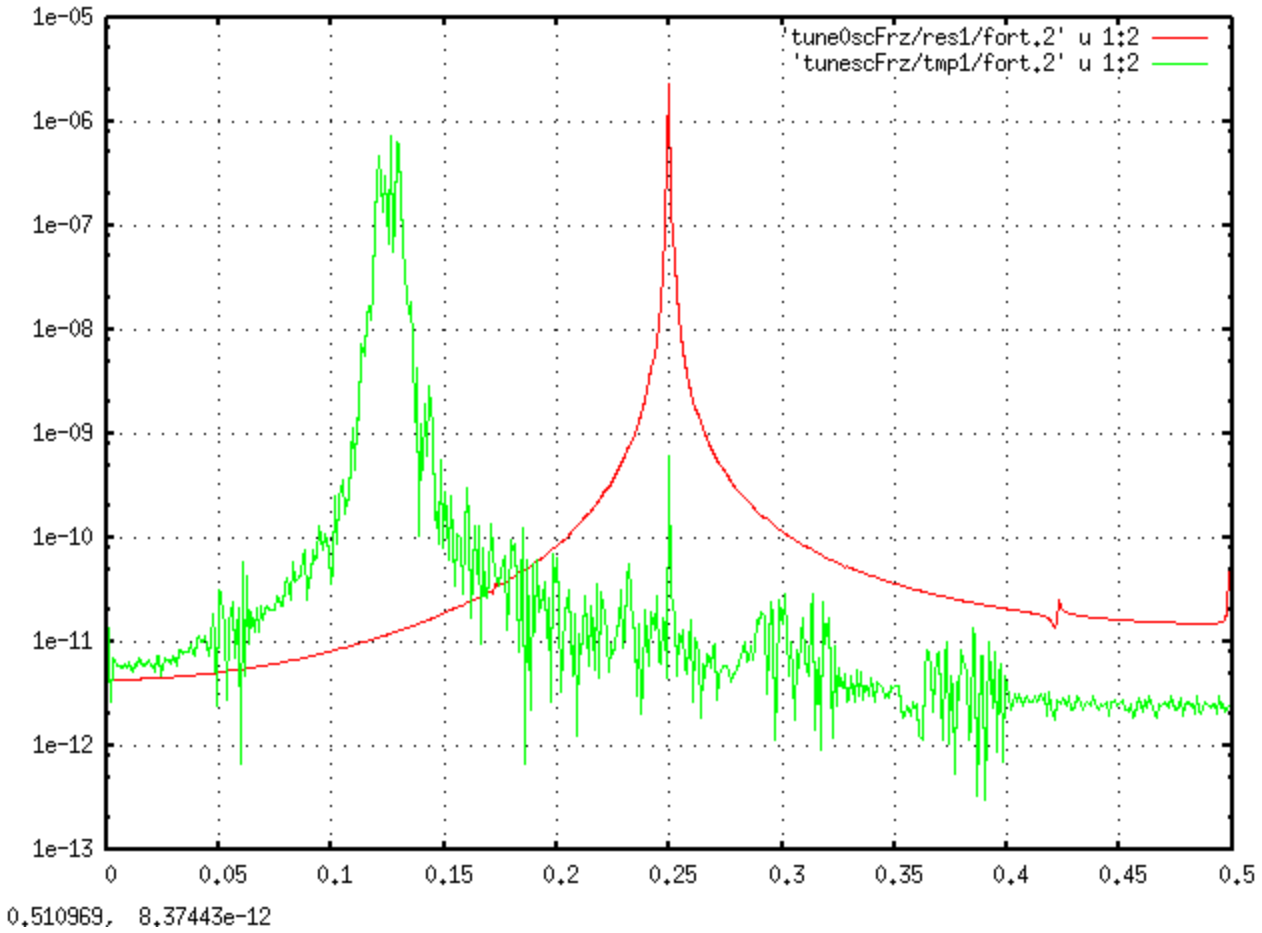
Frozen SC: means no synchrotron oscillation, no energy spread.



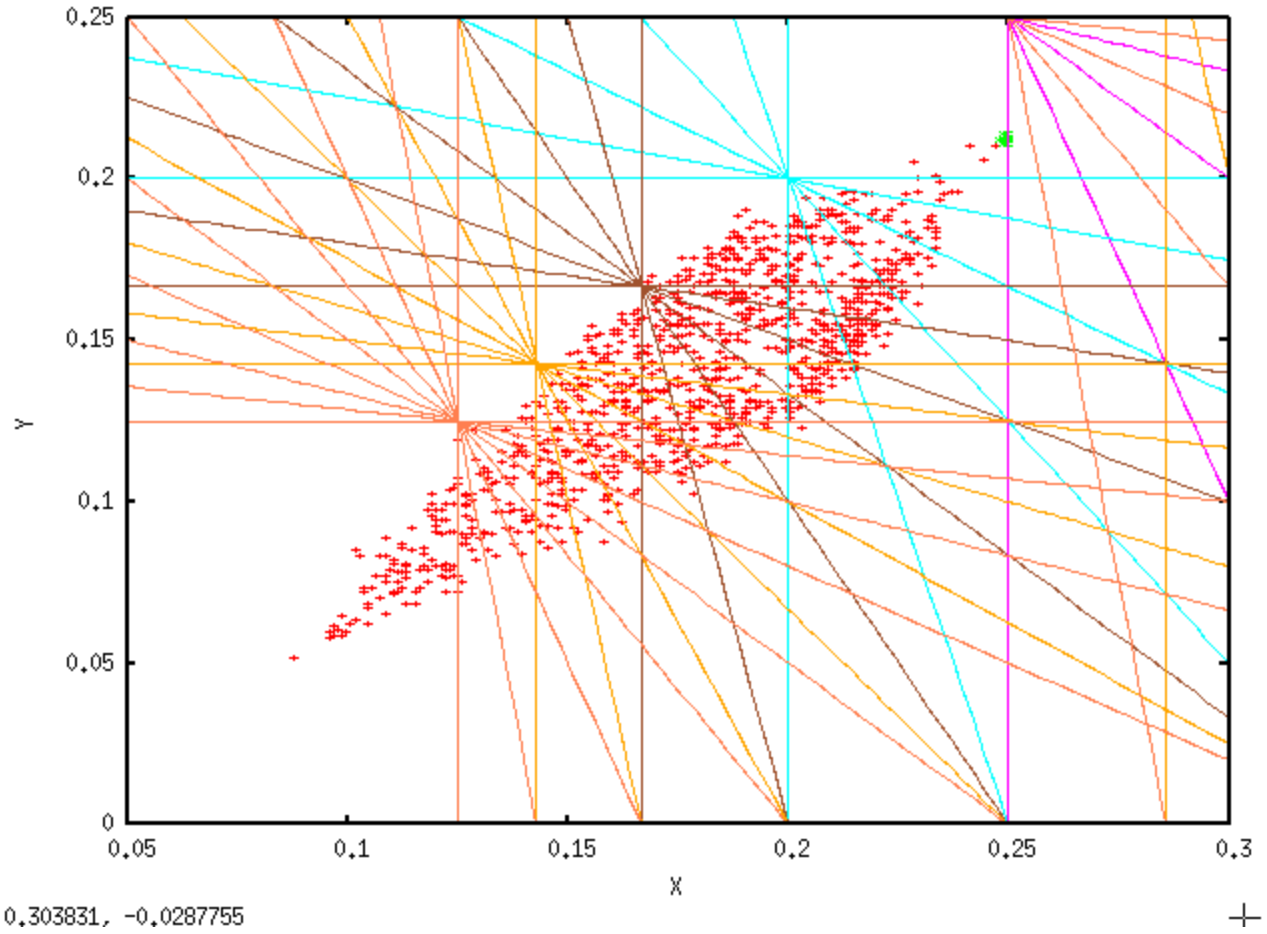
A Single Particle Spectra in Vertical Direction with 0 and with Frozen SC



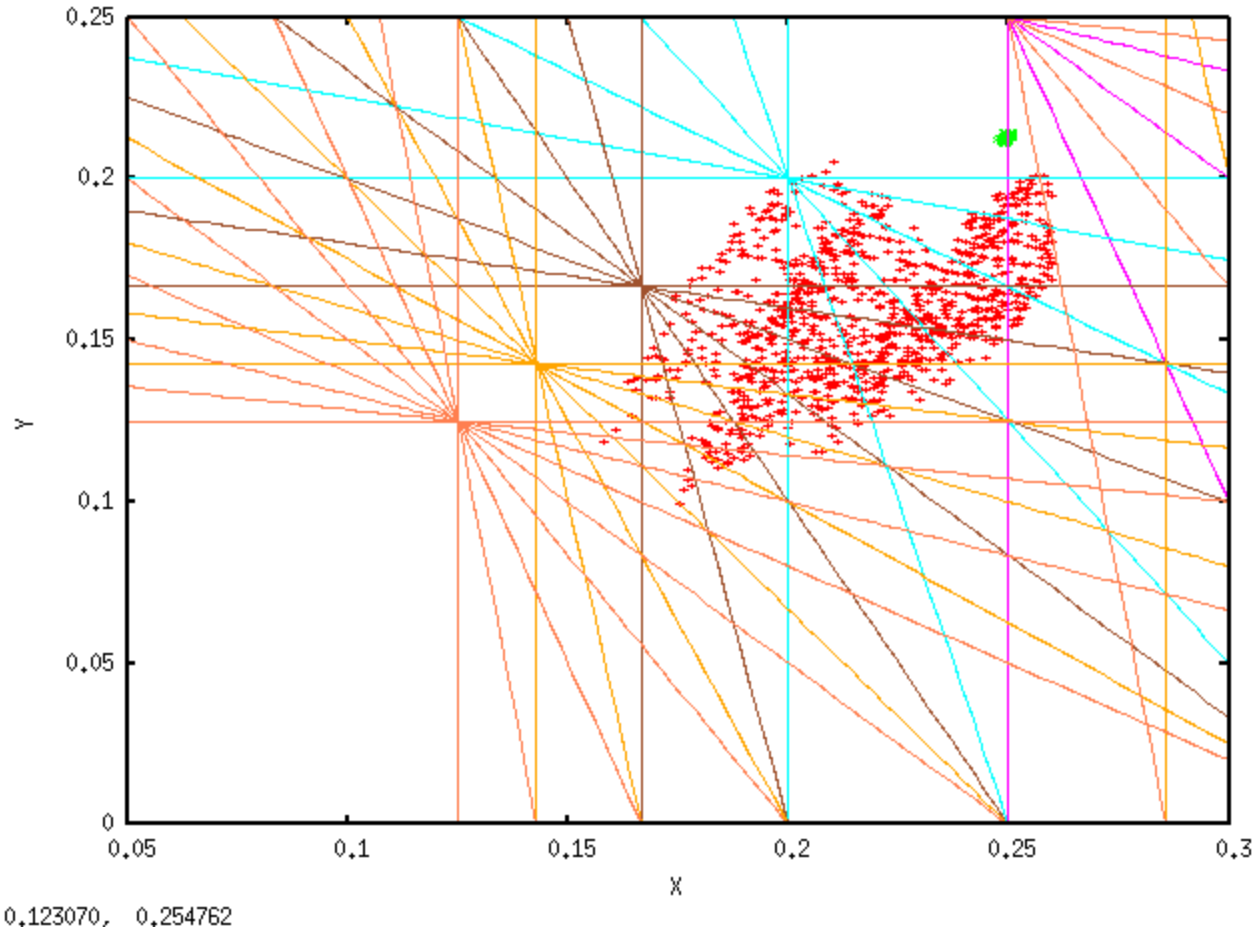
A Single Particle Spectra in Horizontal Direction with 0 and with Frozen SC



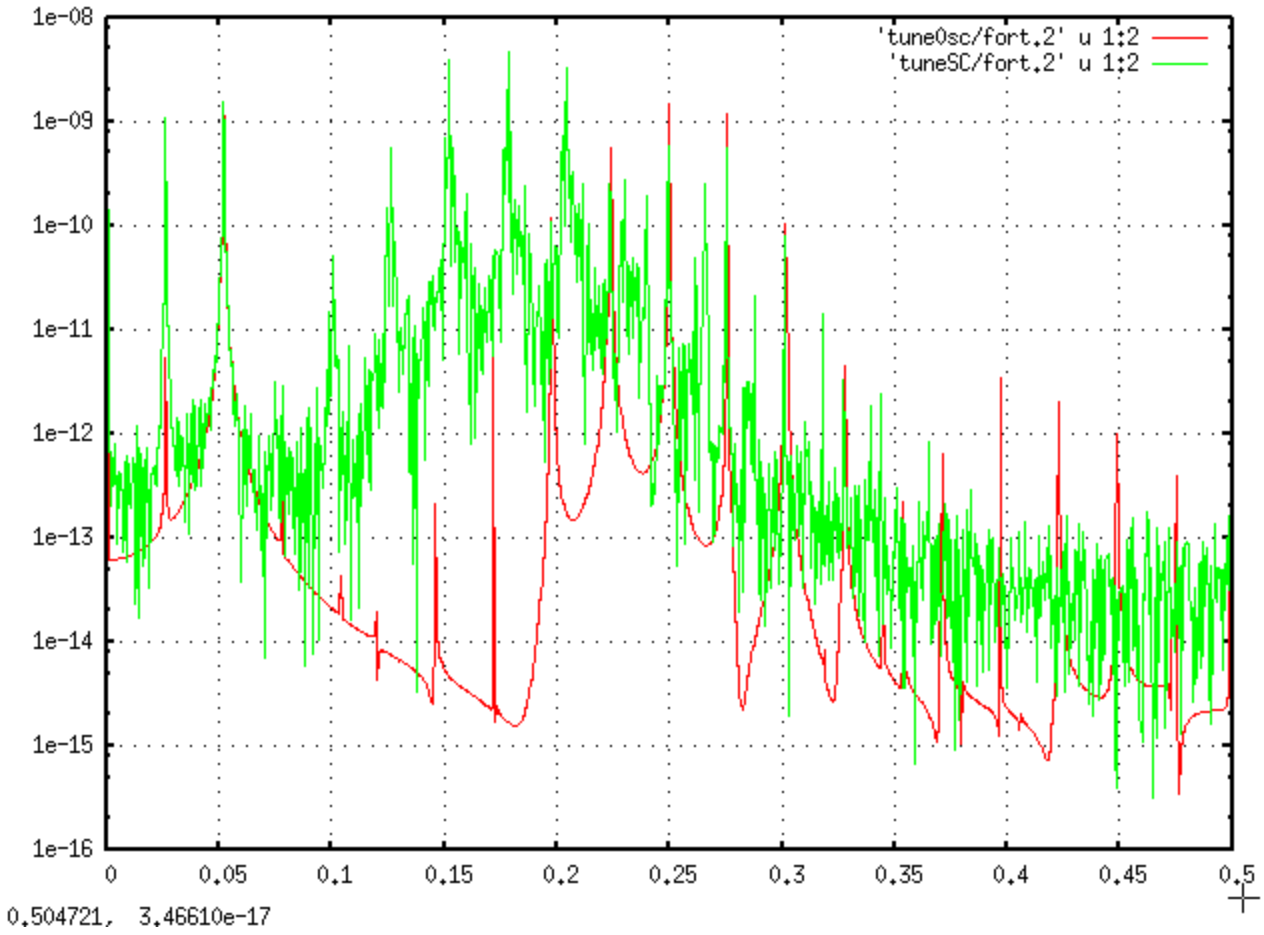
Betatron Tune Foot Print with 0 Current and with Frozen SC



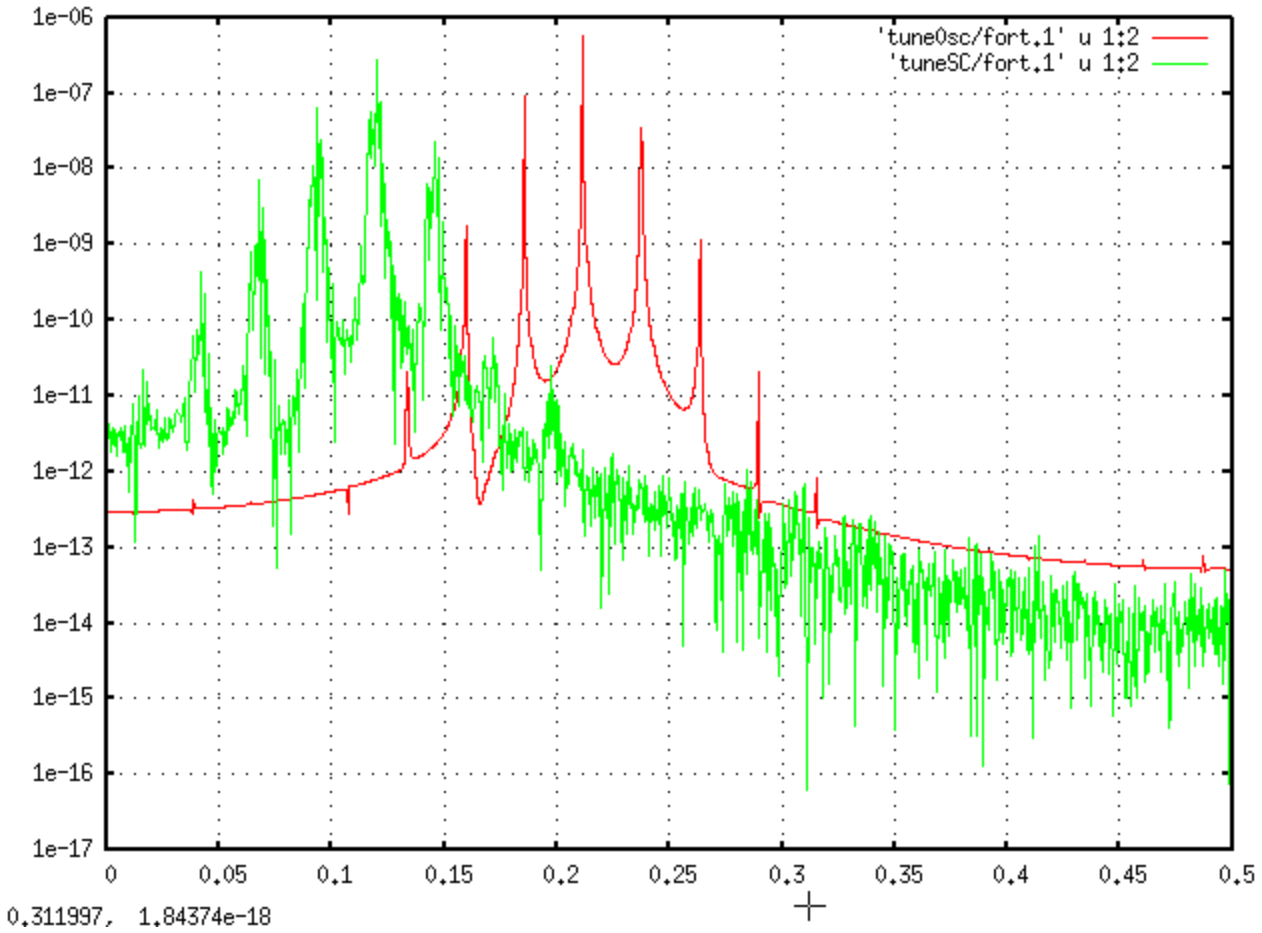
Betatron Tune Foot Print with 0 Current and with Self-Consistent SC



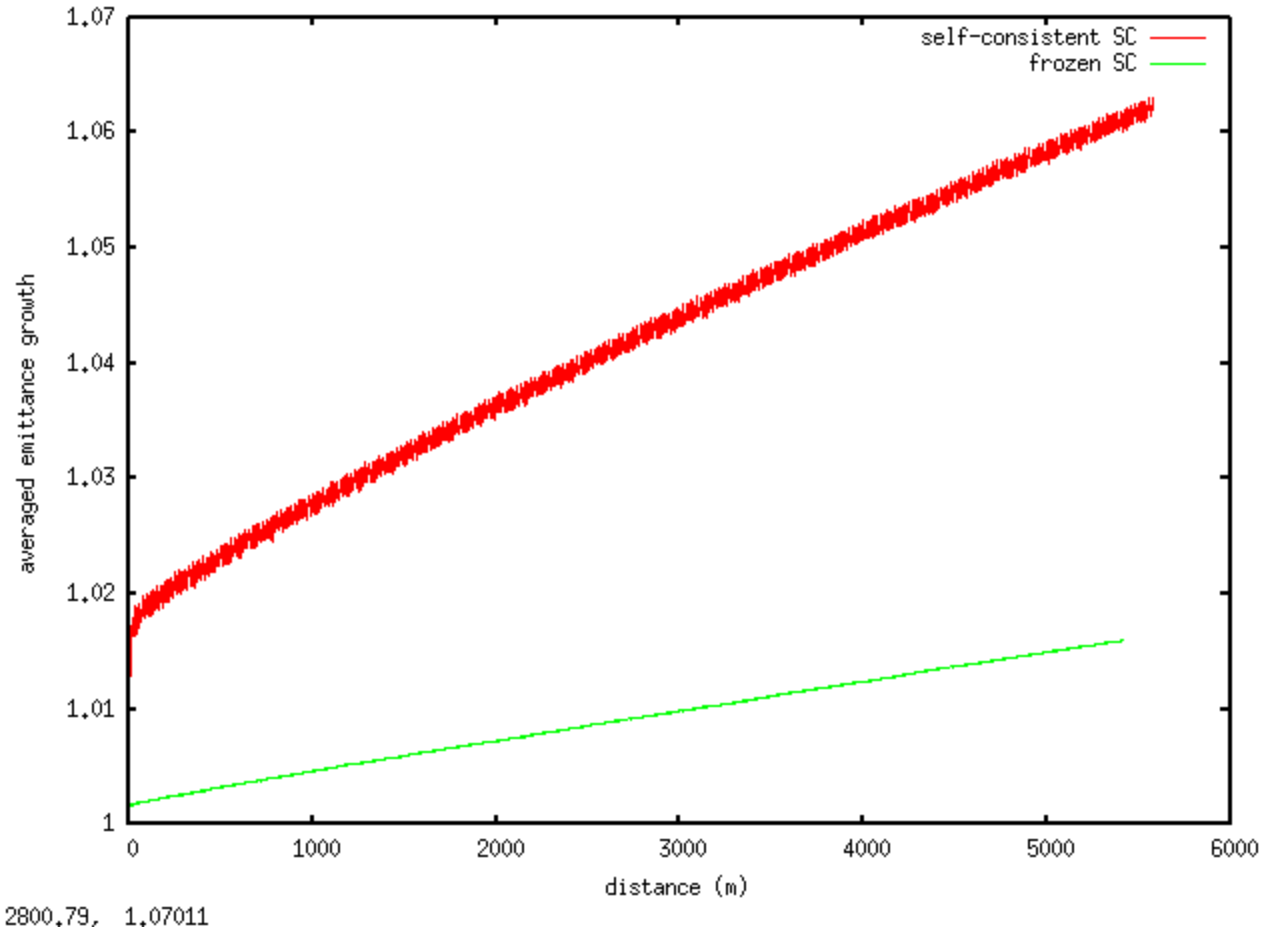
A Single Particle Spectra in Horizontal Direction with 0 and with Self-Consistent SC



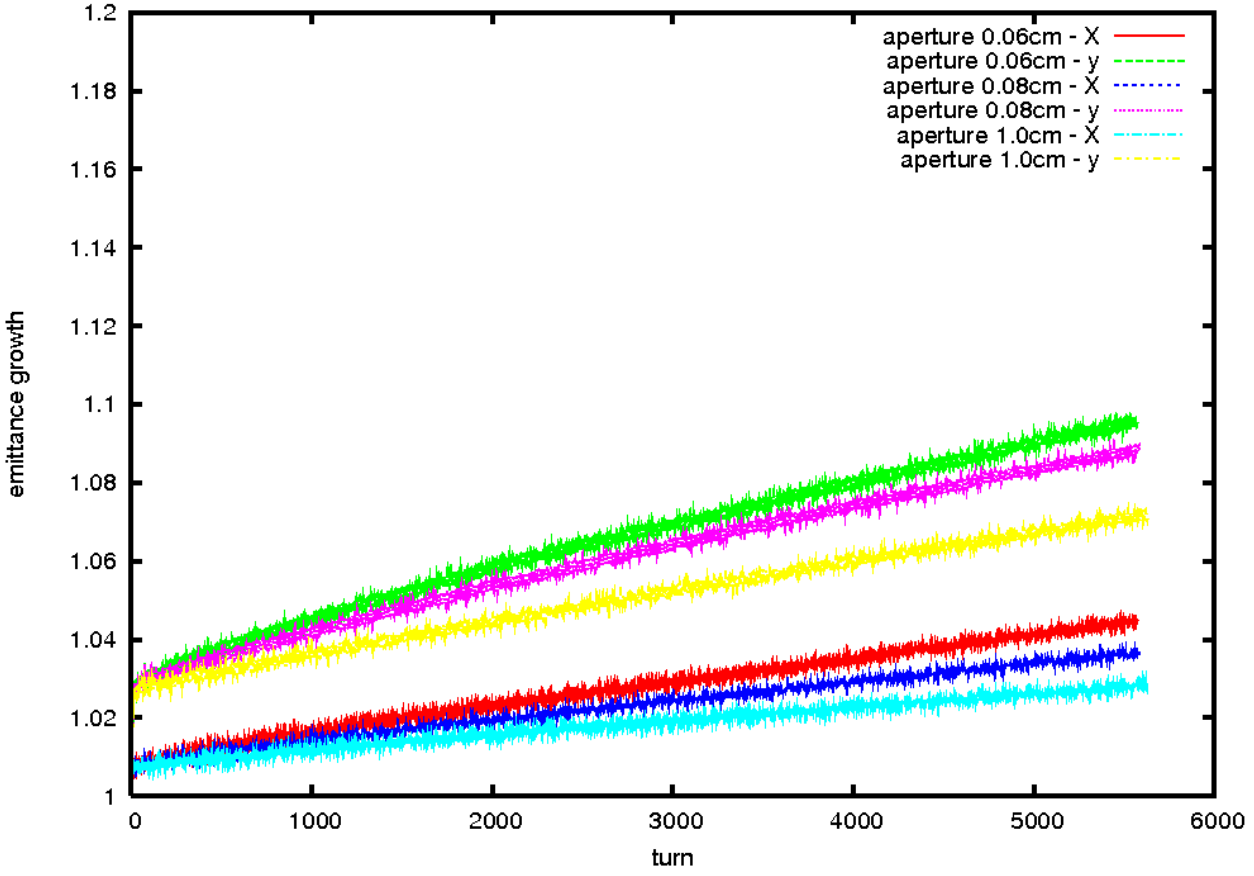
A Single Particle Spectra in Vertical Direction with 0 and with Self-Consistent SC



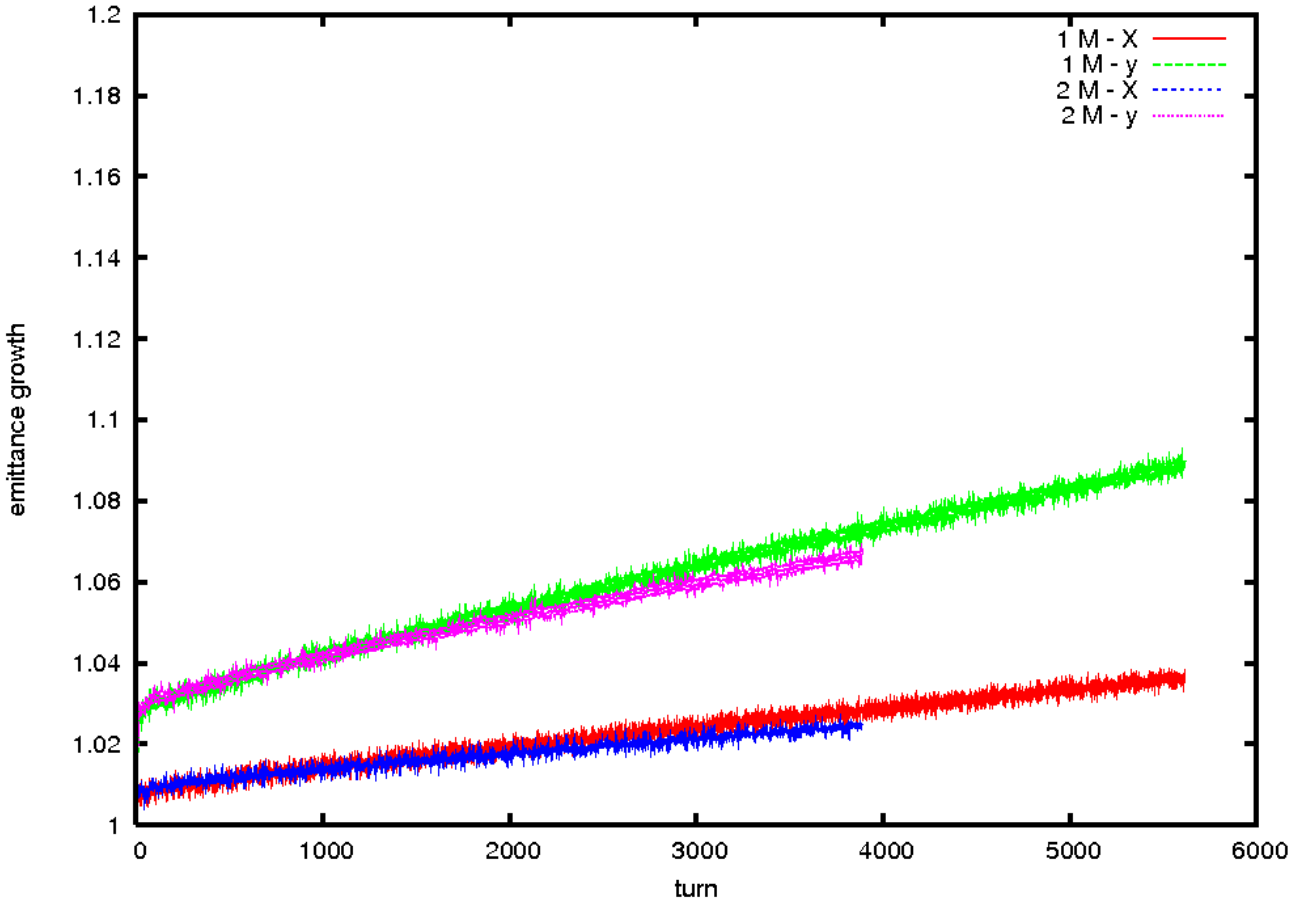
Averaged transverse emittance growth with self-consistent and frozen SC



Transverse emittance growth with self-consistent SC and different aperture sizes



Transverse emittance growth with self-consistent SC using 1M and 2 M macropts.



Summary and Future Plans

- Synchrotron oscillation enhances transverse emittance growth
- Space-charge effects at the injection energy could cause emittance growth for the initial PS2 lattice design
- Evaluate the space-charge effects for the new PS2 design lattice
- Add the energy ramping
- Help the lattice design optimization including the space-charge effects
- Begin studying potential mitigation measure