# PS2 Space Charge Simulations

Ji Qiang, Robert Ryne, LBNL

Uli Wienands, SLAC

Larp CM14 Collaboration Meeting, Apr. 26-28, 2010, Fermilab

# Outline

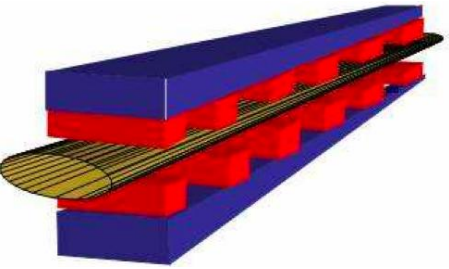
- Computational models
- Space-charge simulation with RF ramping
  - Case 1
  - Case 2
- Summary
- Future Work

# MaryLie/IMPACT (ML/I)

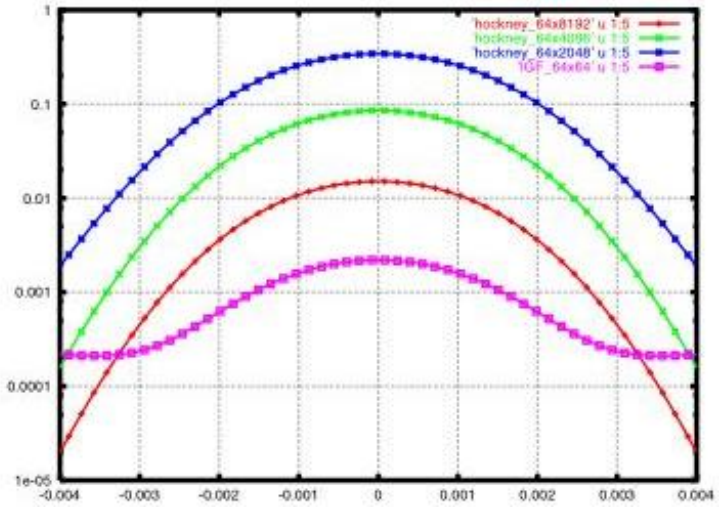
- Combines capabilities of MaryLie code (A. Dragt, U Md) with IMPACT code (J. Qiang, R. Ryne, LBNL) + new features
- Multiple capabilities in a single unified environment:
  - Map generation
  - Map analysis
  - Particle tracking w/ 3D space charge
  - Envelope tracking
  - Fitting and optimization
-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

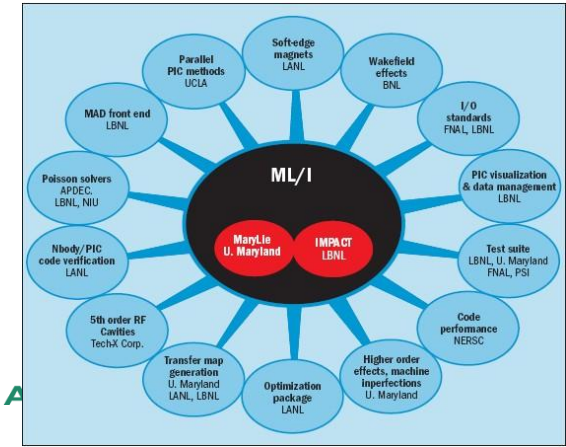


Alex Dragt, U. Md.



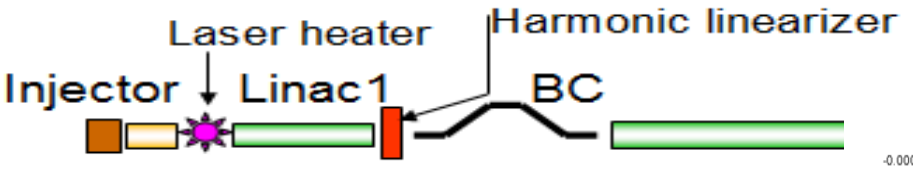

Error in E-field computed w/ different algorithms applied to a 2D Gaussian elliptical distribution w/ 500:1 aspect ratio

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



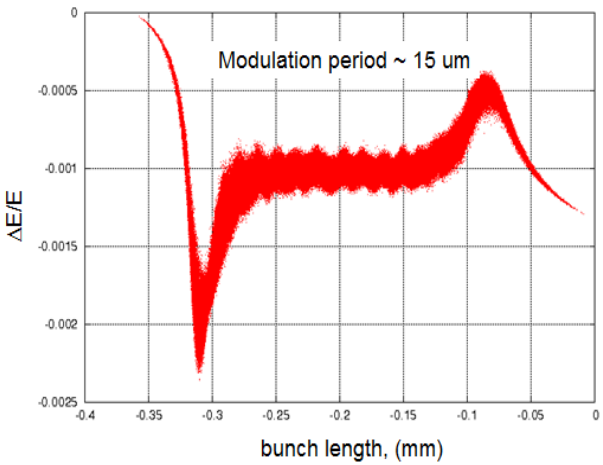
# IMPACT code suite

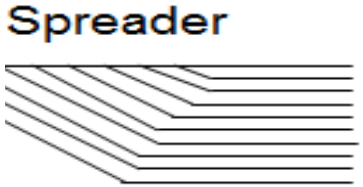
- IMPACT-Z: parallel PIC code (z-code)
- IMPACT-T: parallel PIC code (t-code)
- Envelope code, pre- and post-processors,…
- Optimized for parallel processing
- Applied to many projects: SNS, JPARC, RIA, FRIB, PS2, future light sources, advanced streak cameras,…
- Has been used to study photoinjectors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




One Billion Macroparticle Simulation of an FEL Linac

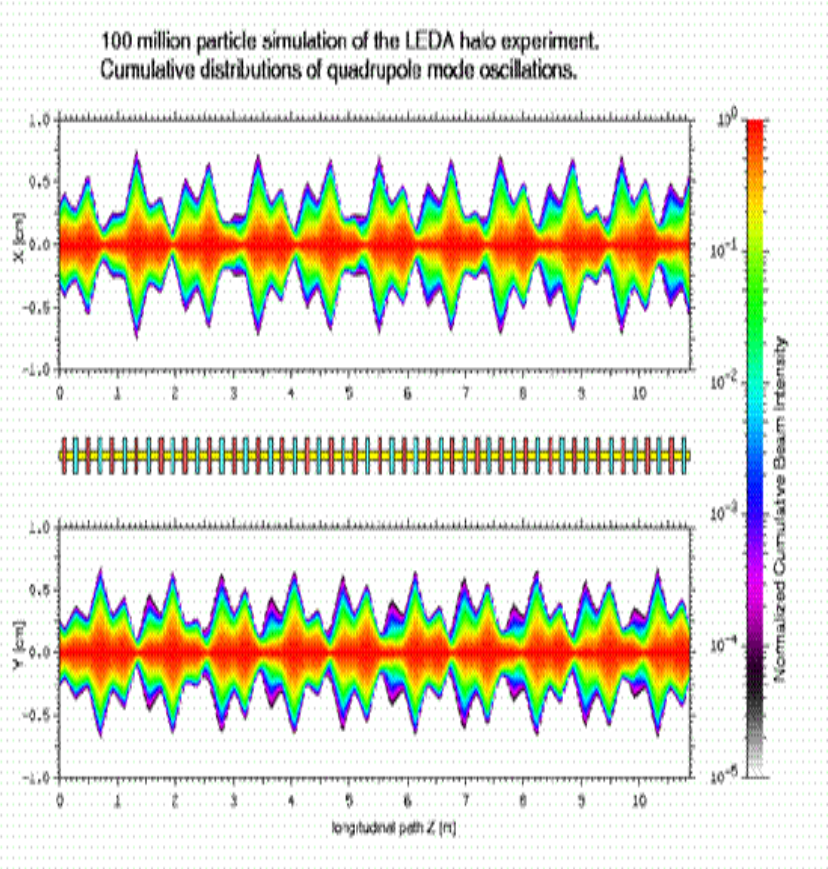
(~2 hrs on 512 processors)



# 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

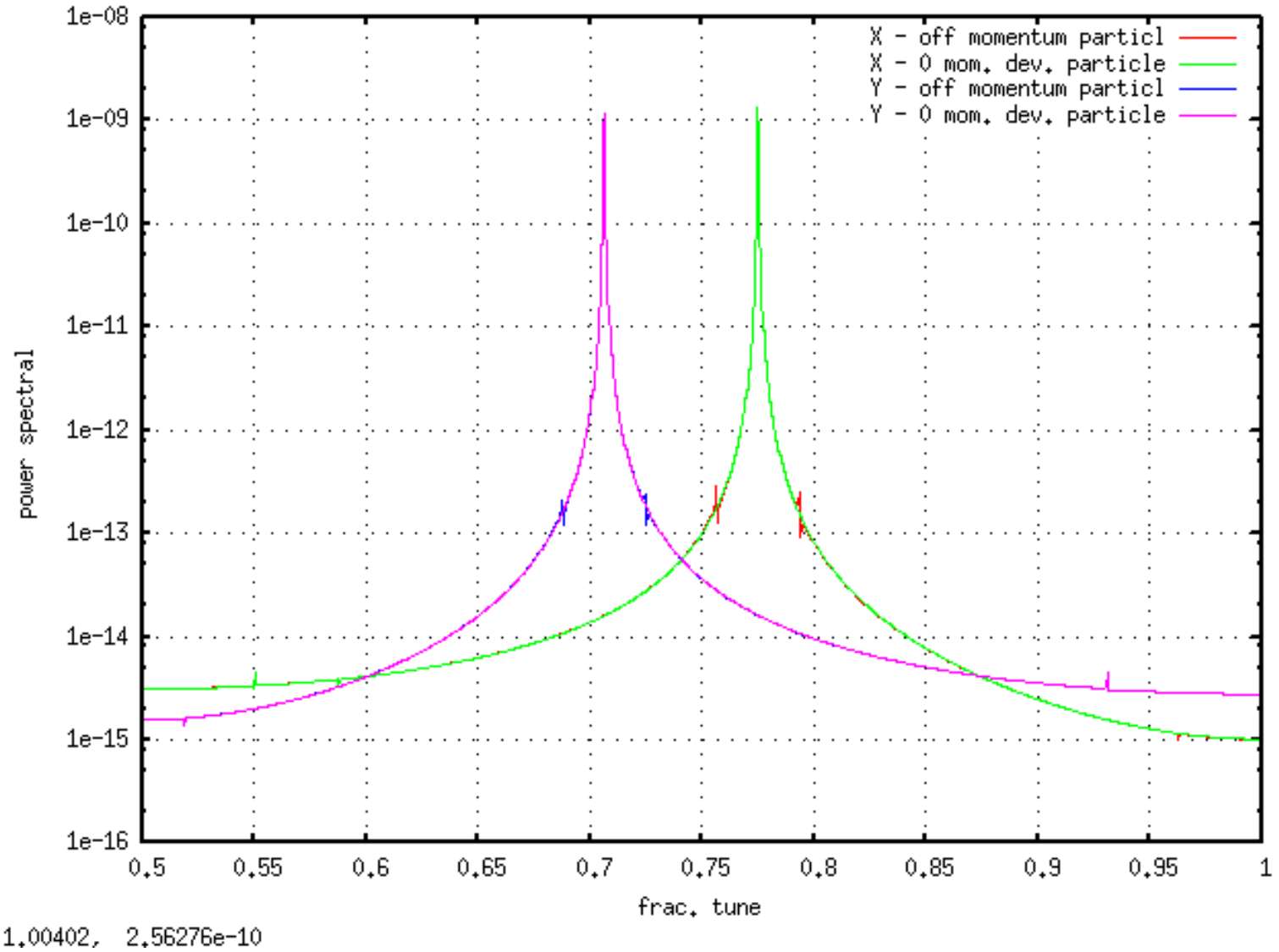


# Physical Parameters for PS2 Simulations

---
---
Vrf = ramping with f = 39.3 MHz
Ek = 4 GeV
Emit_x = Emit_y = 3 mm-mrad
Emit_z = .098 eV-sec

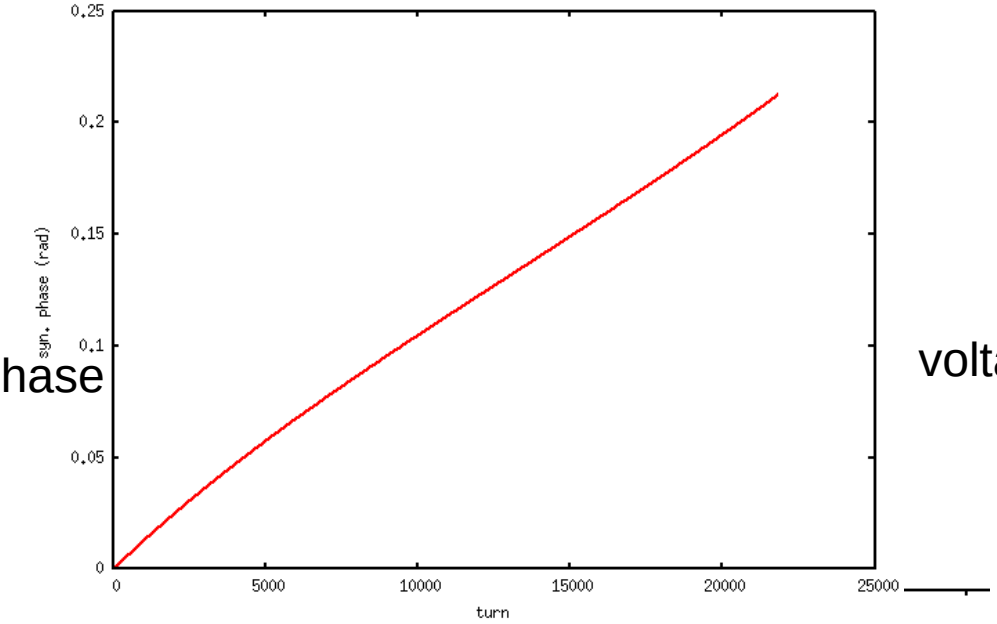
Half Aperture = 5.5cm x 3 cm
I = $4.0 \times 10^{11}$
---
Numerical Parameters:
---
70 SC per tur
65x65x128 grid points
939,000 macroparticles
---

# Power Spectrum of 0 mom. Dev and off mom. Particle trajectories



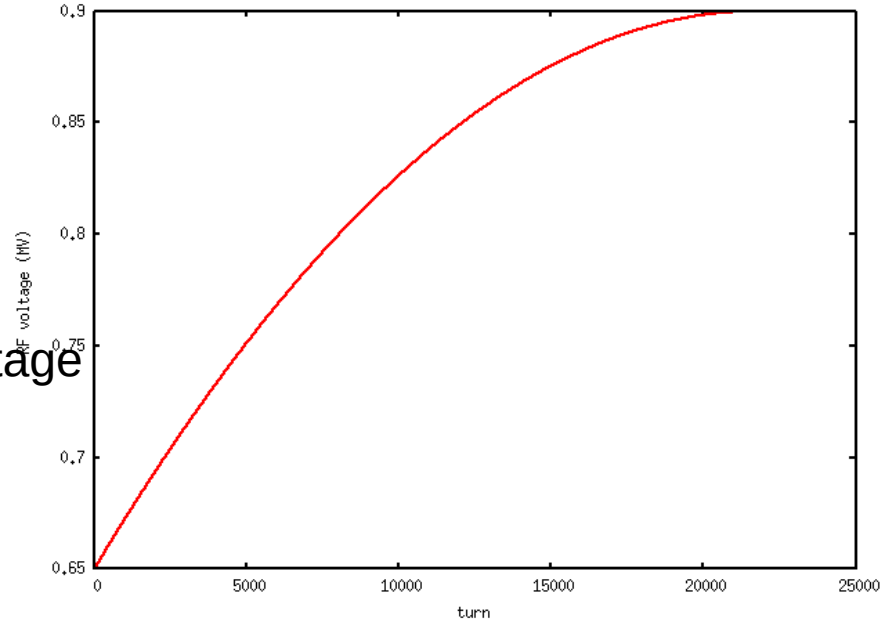
# RF Phase/Voltage Ramping and Beam Kinetic Energy Ramping

phase



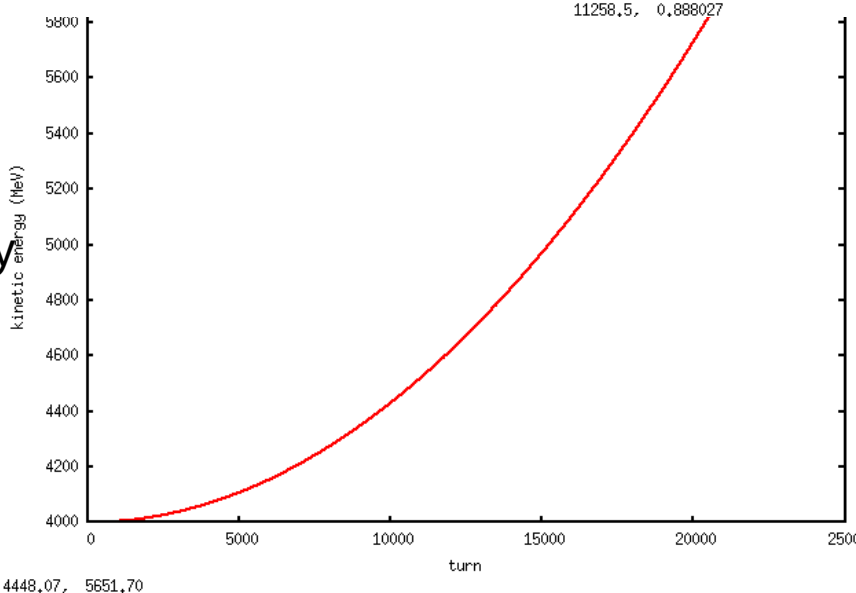

-3085.98, 0.0881633

voltage



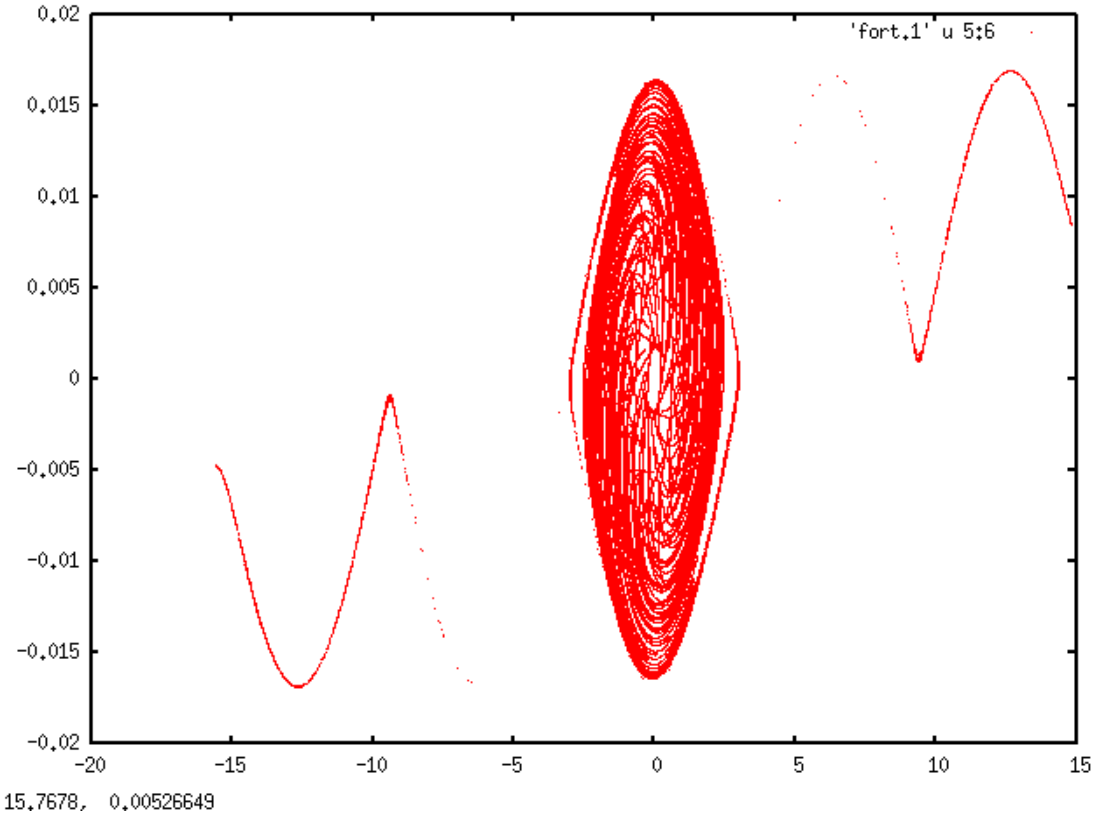

11258.5, 0.888027

energy

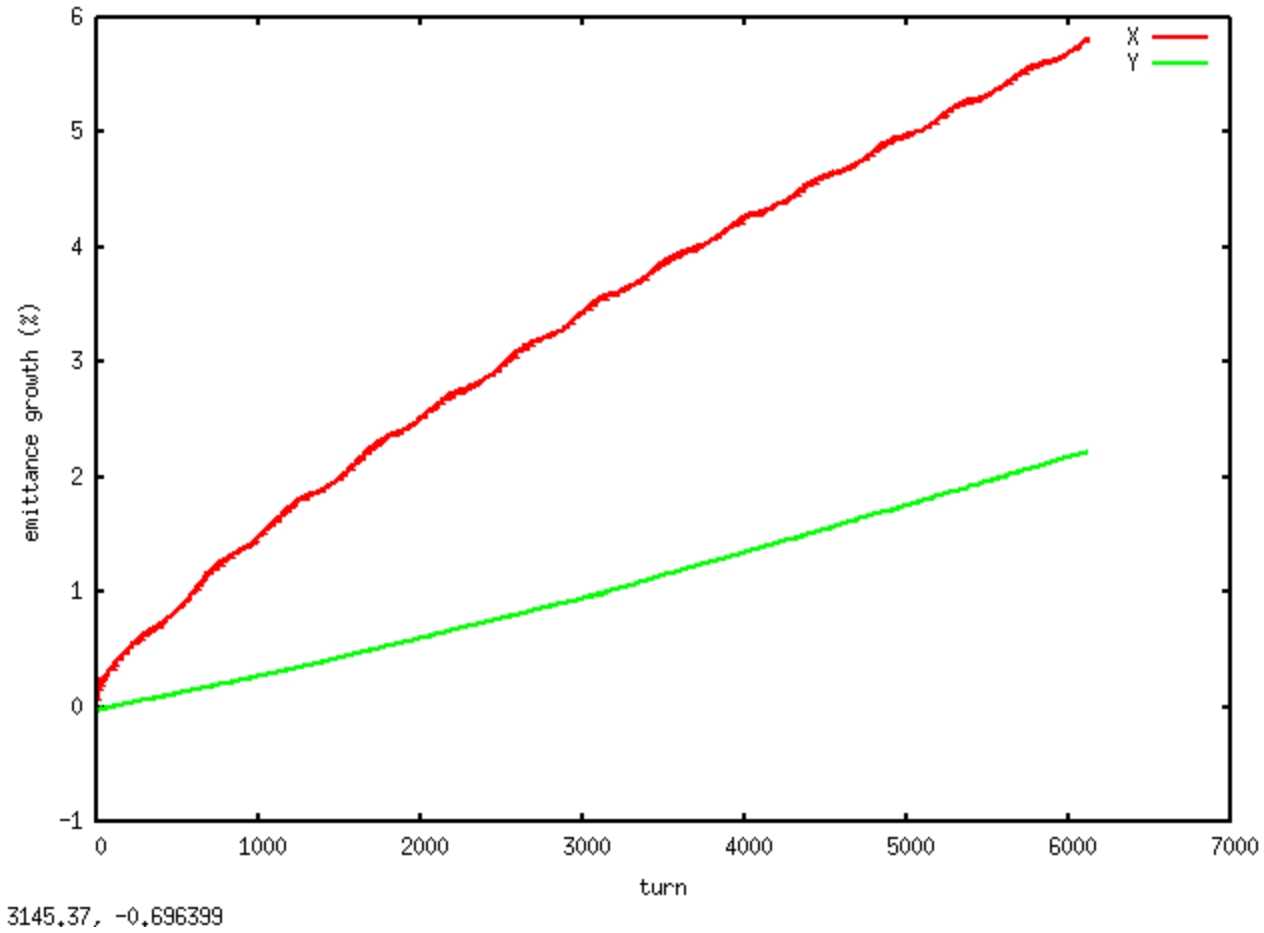



4448.07, 5651.70

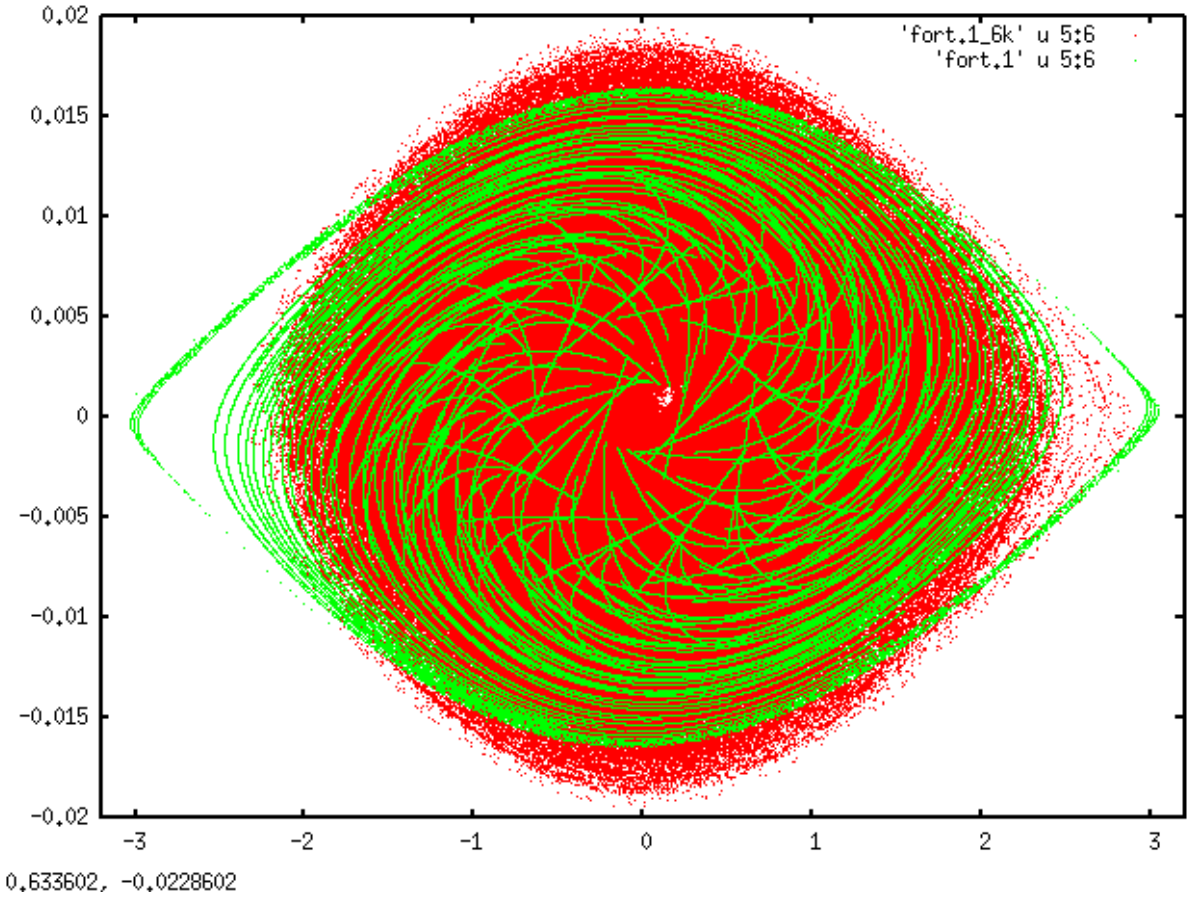
# Initial Longitudinal Distribution after Painting: Case 1



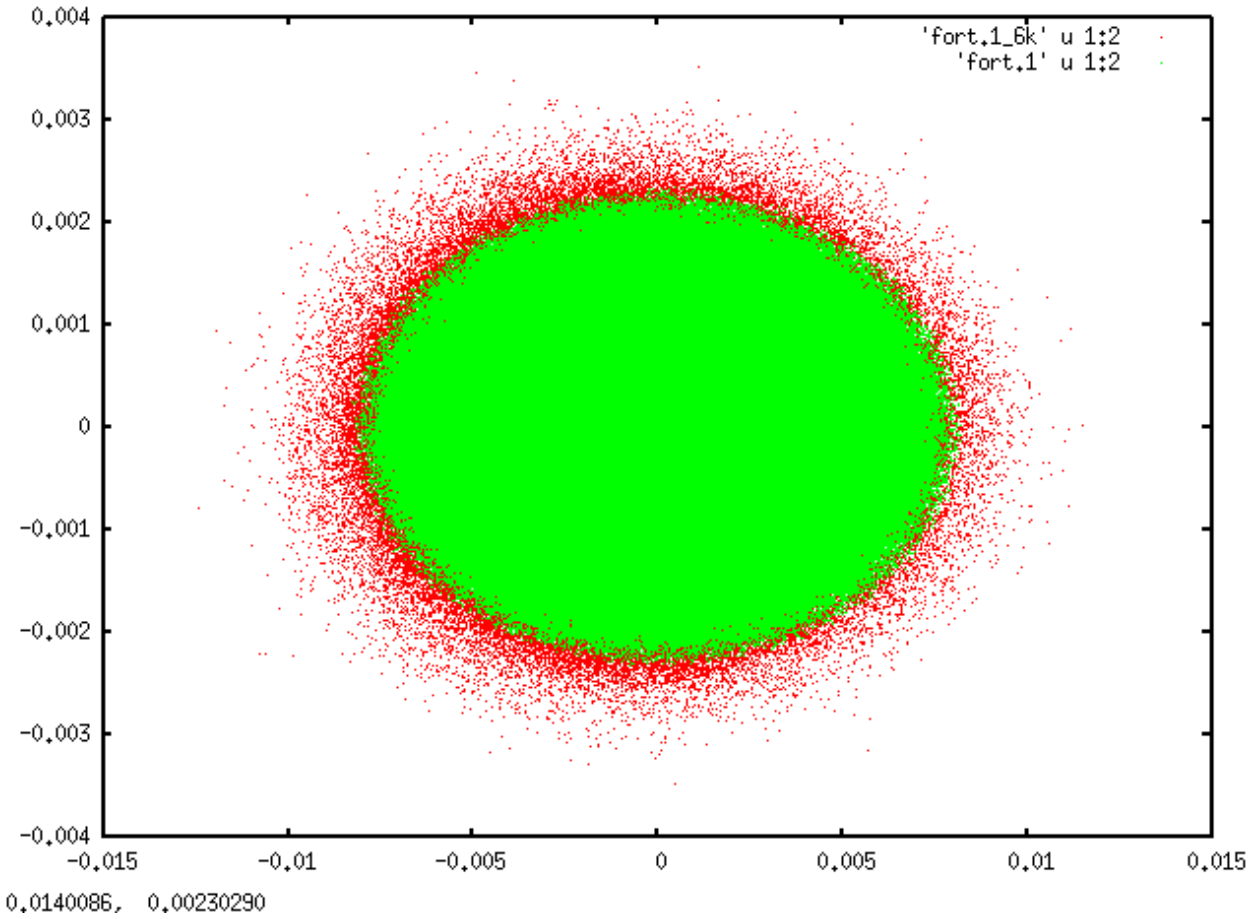
# Transverse Emittances vs. Turns



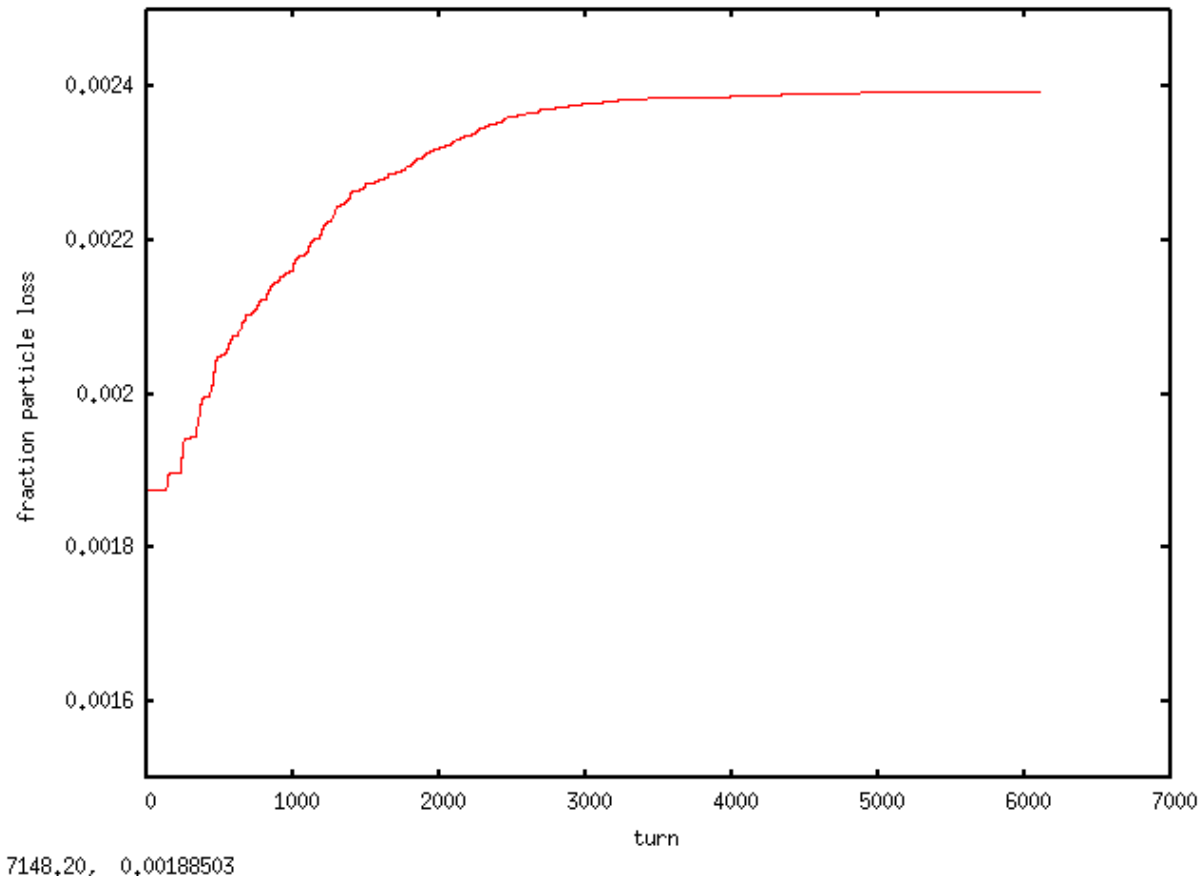
# Initial and Longitudinal Phase Space  after 6000 turns



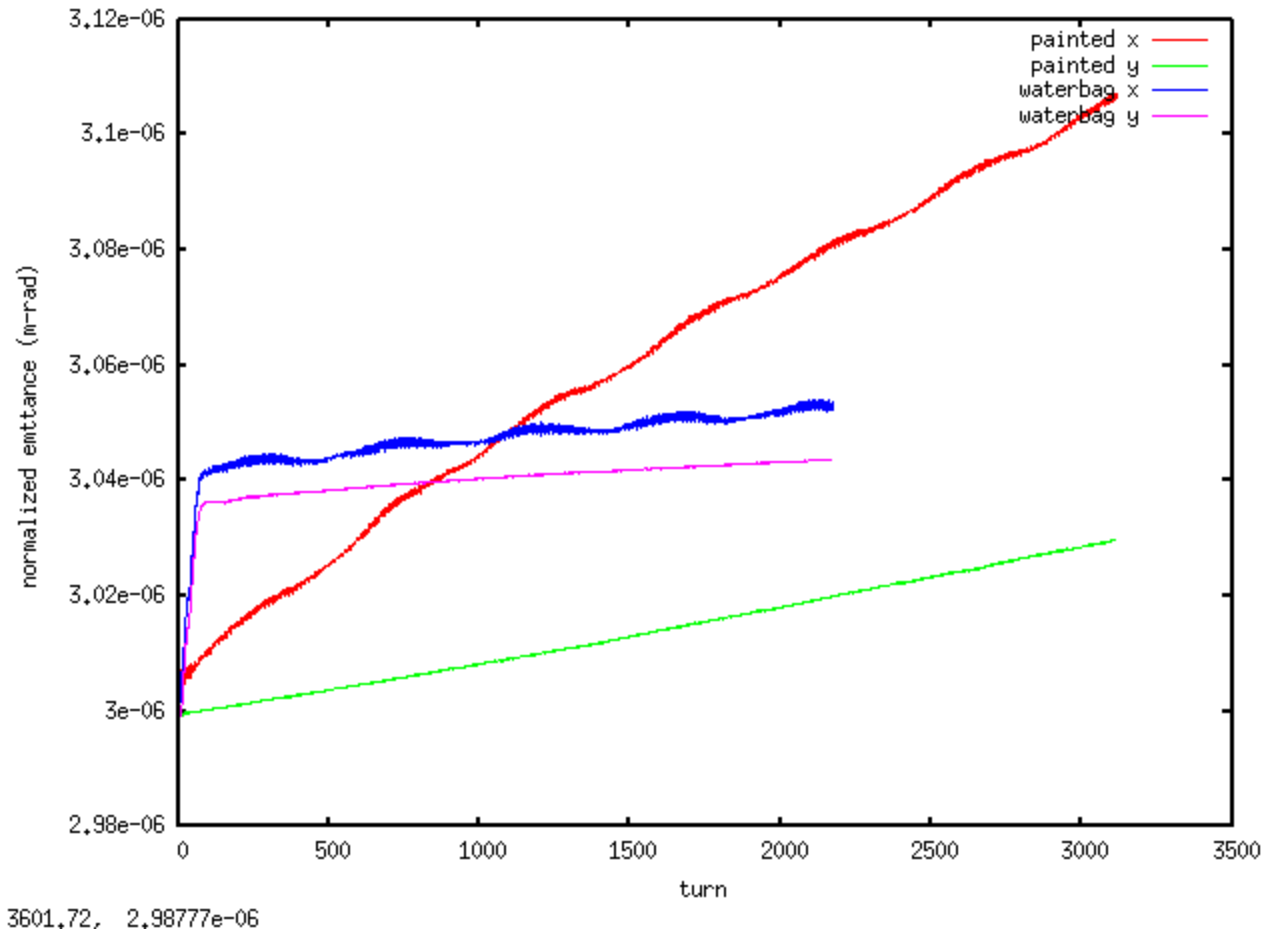
# Initial and Transverse Phase Space after 6000 turns



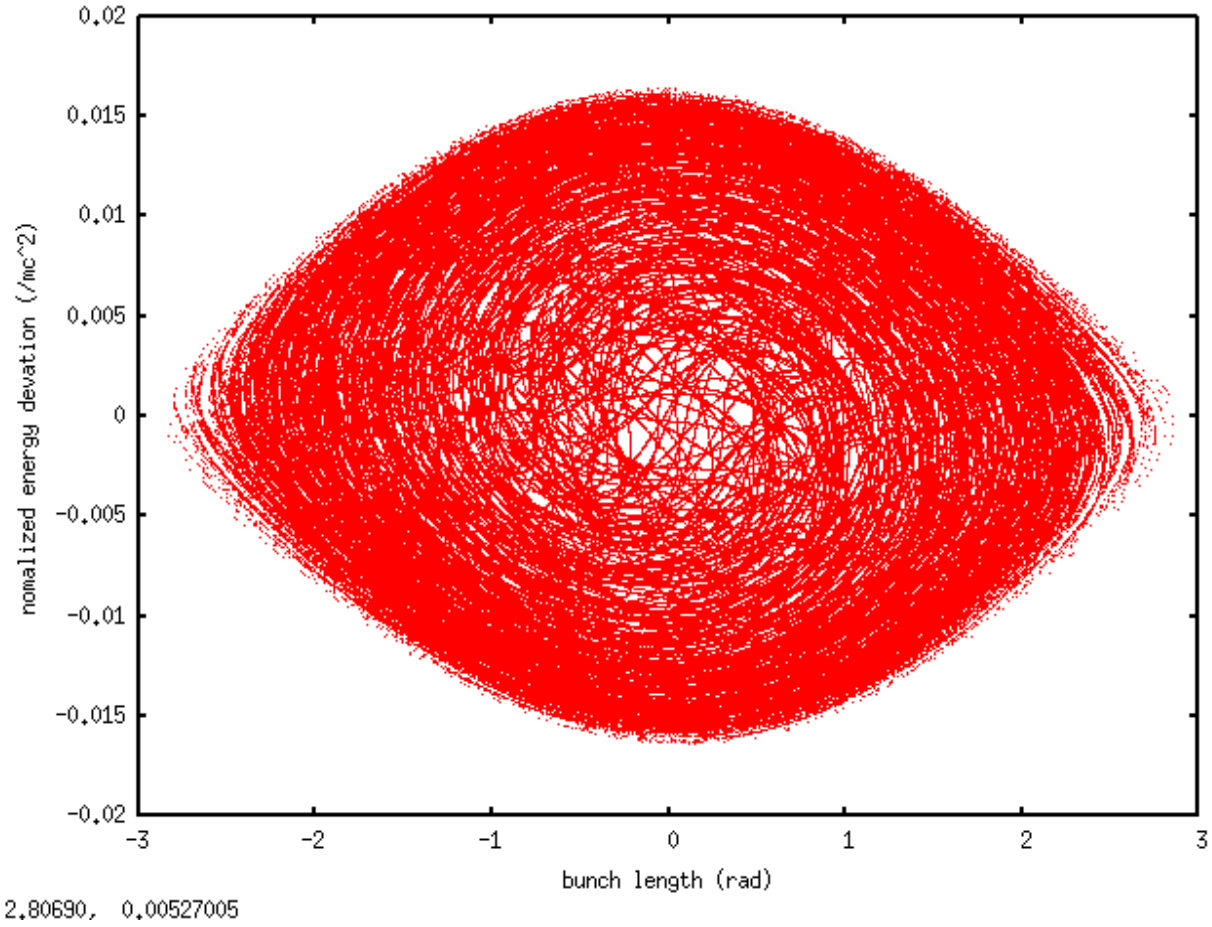
# Fraction of Particle Loss vs. Turns



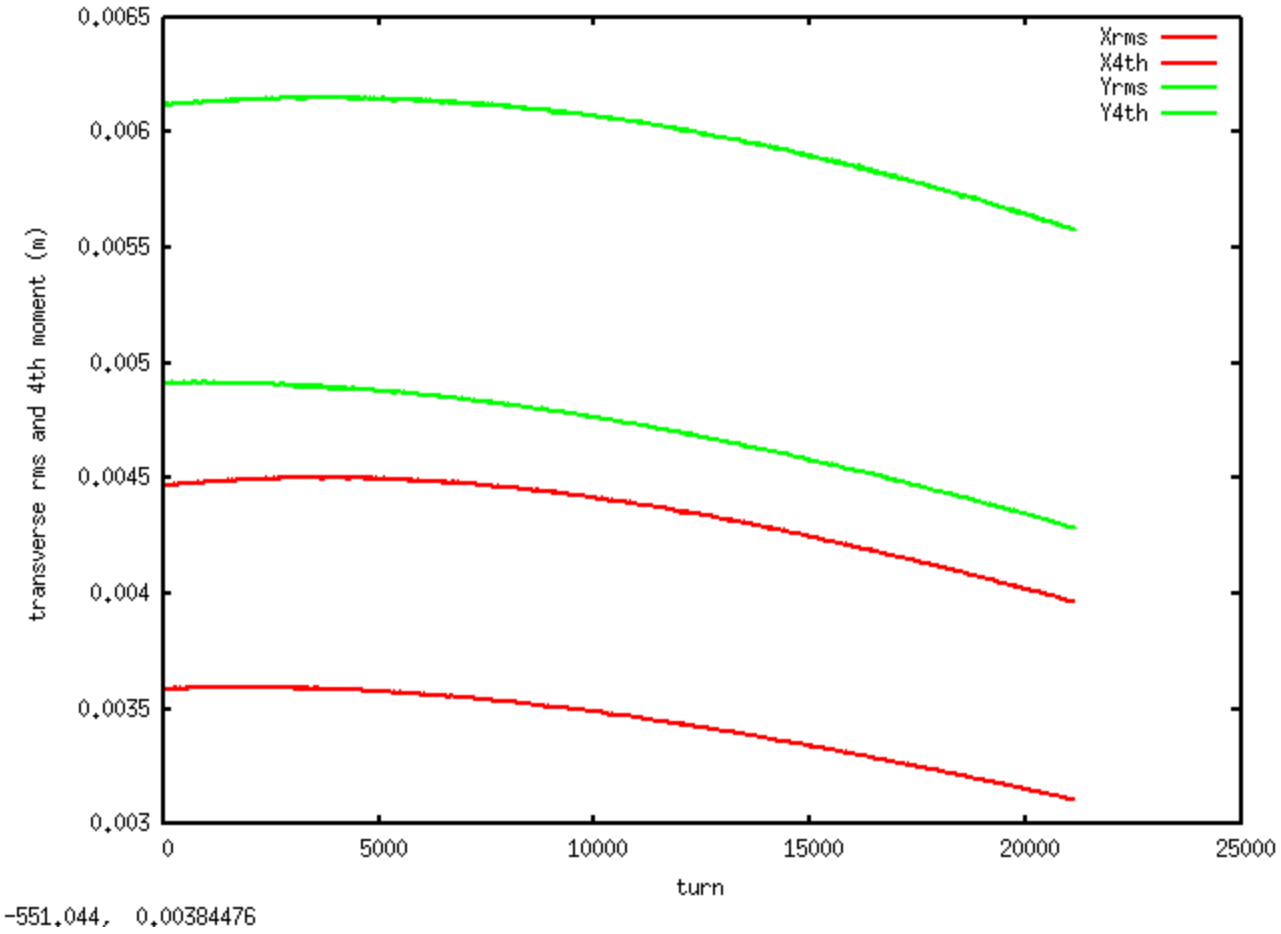
# Emittance Evolution for the 3D Waterbag Distribution and the Painted Distribution



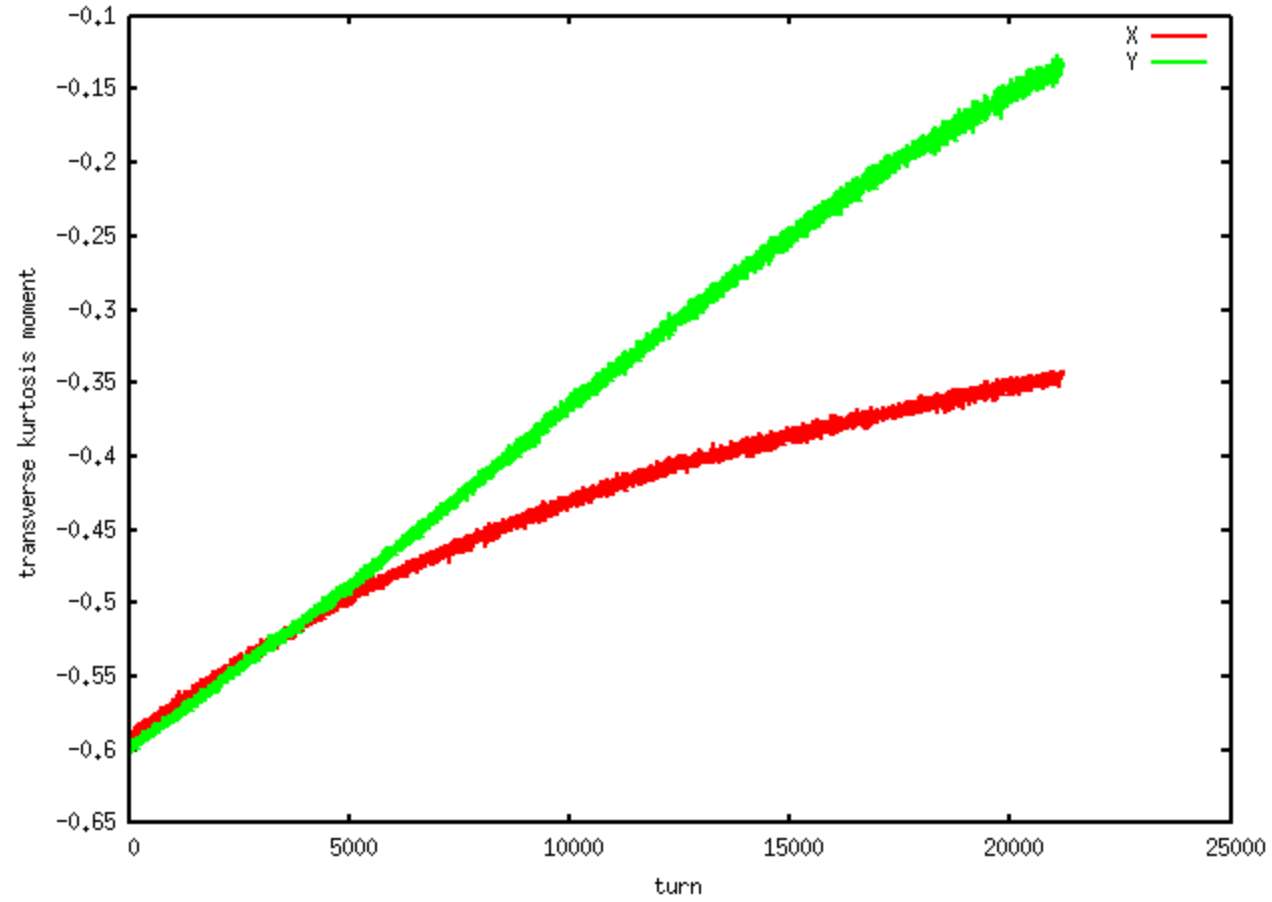
# Initial Longitudinal Distribution after Improved Painting: Case 2



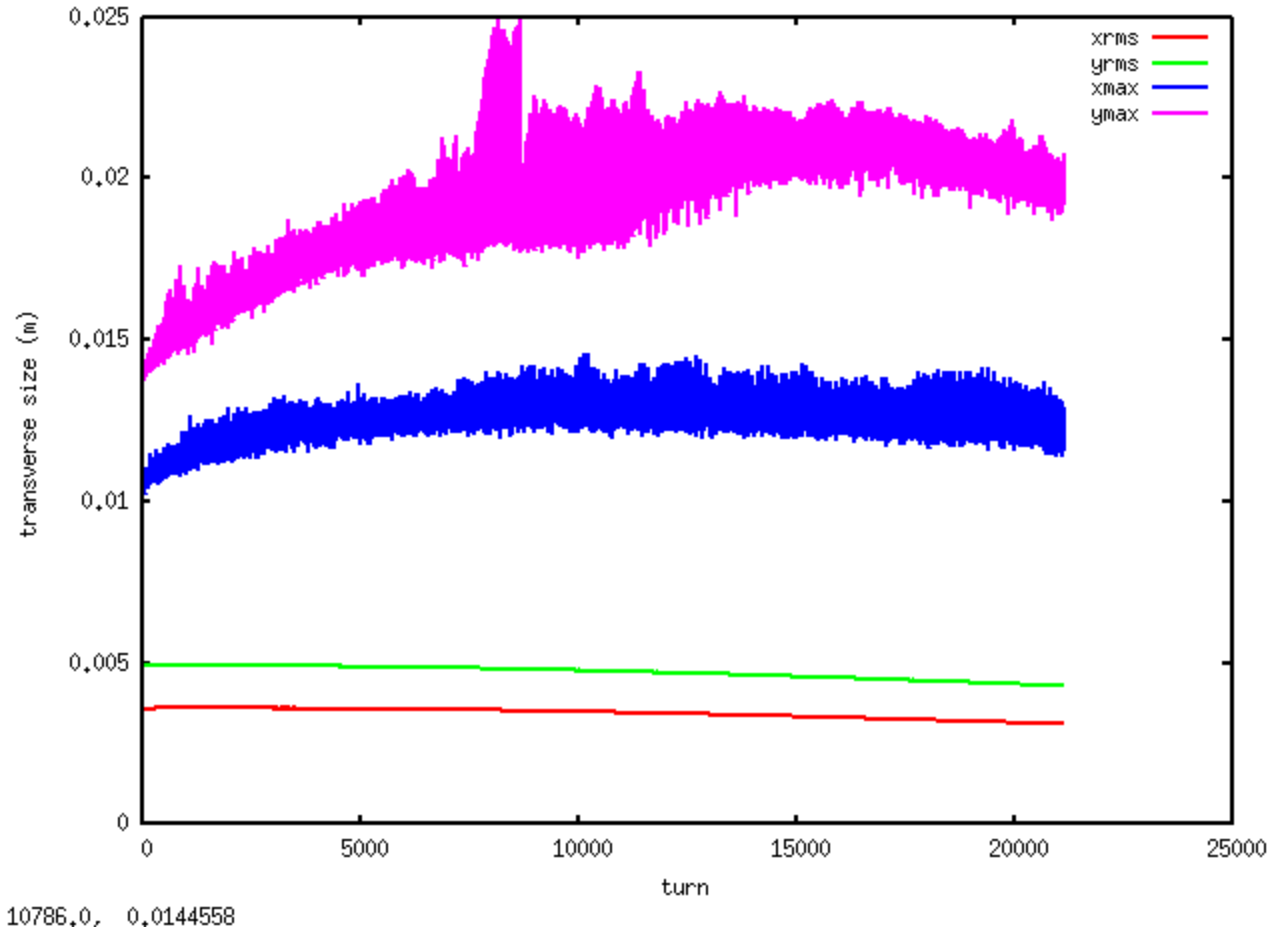
# Evolution of Transverse Rms Sizes and 4th Moments



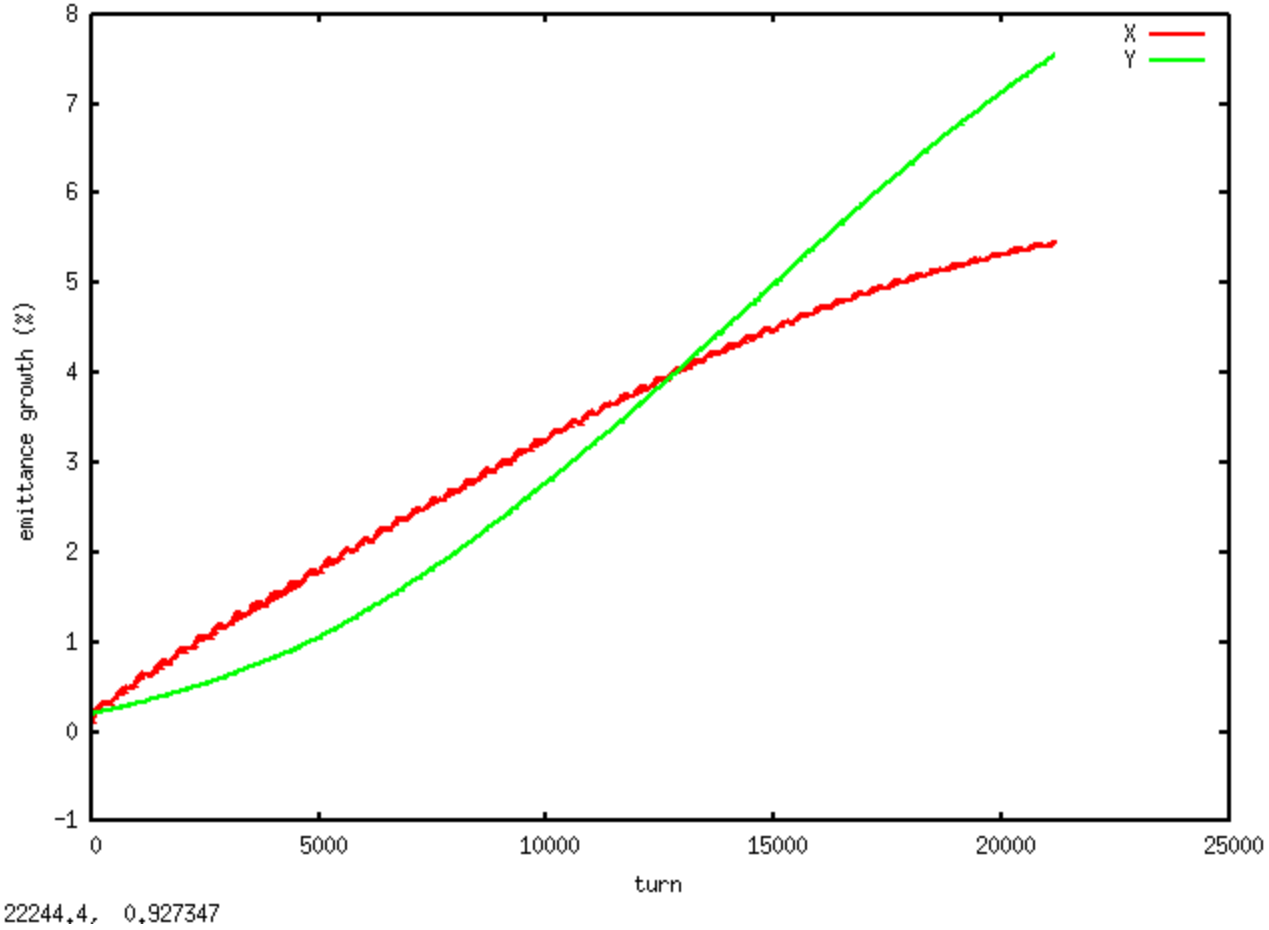
# Evolution of Transverse Kurtosis



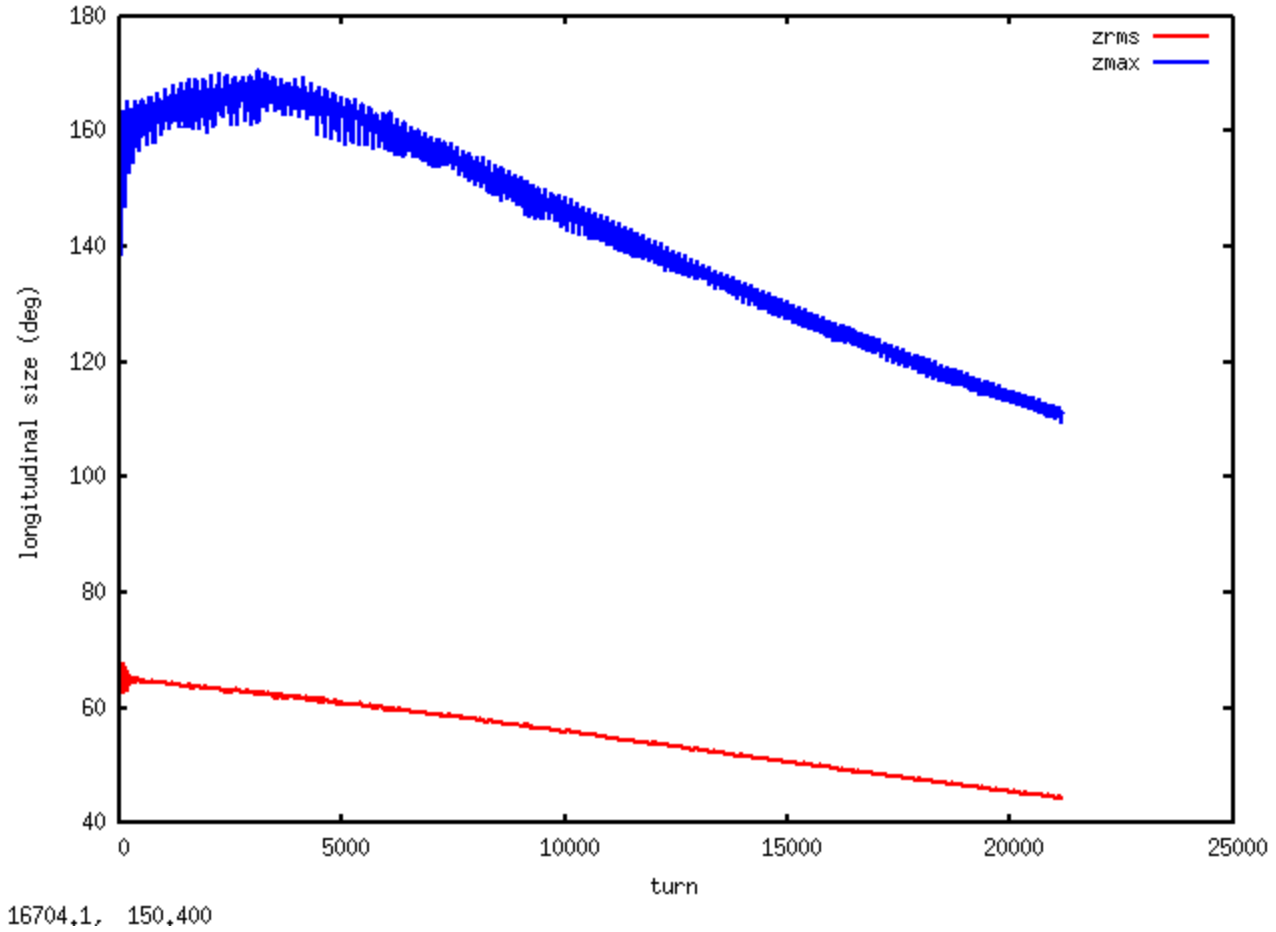
# Evolution of Transverse Rms Sizes and Maximum Aplitudes



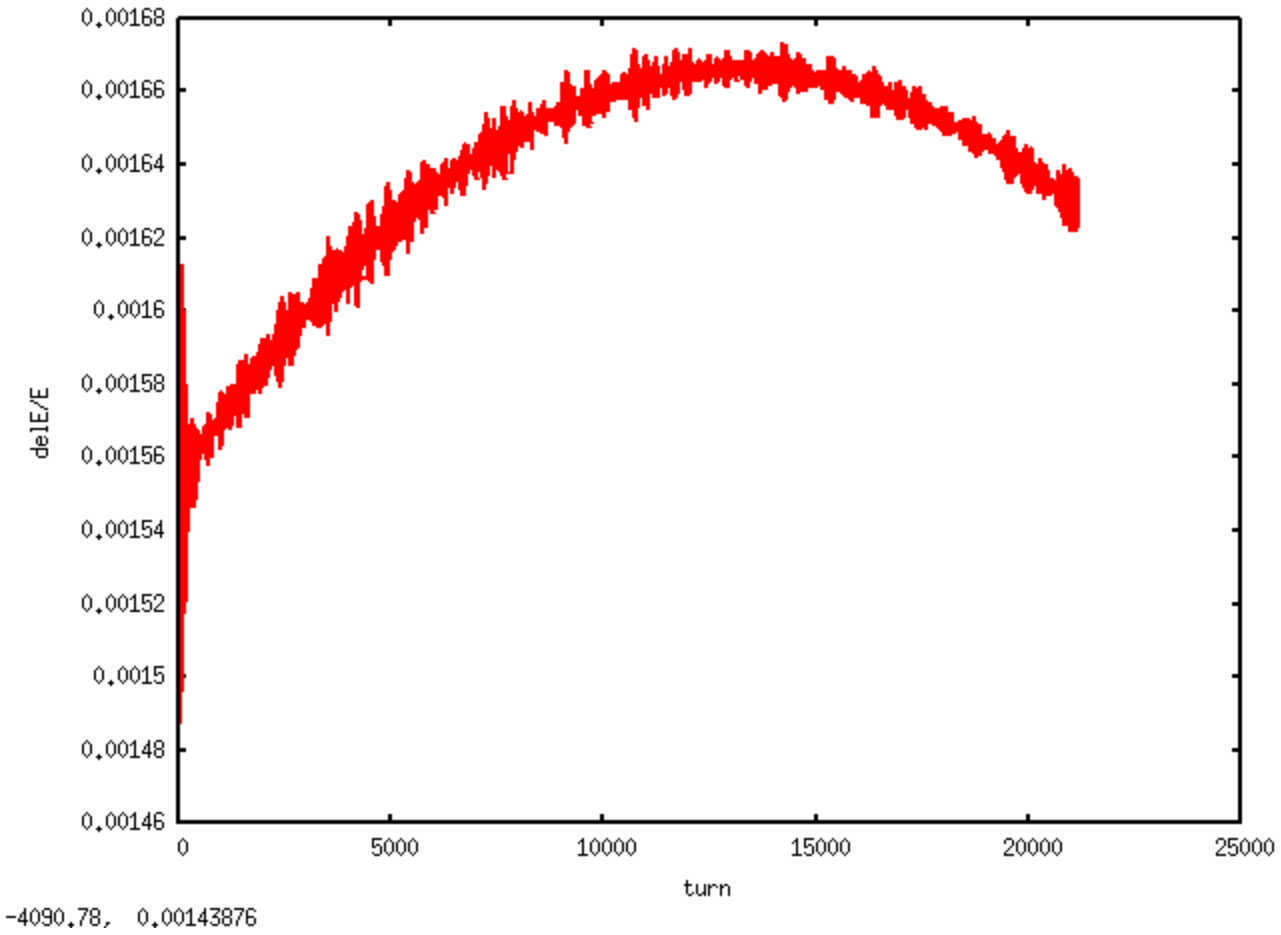
# Evolution of Transverse Rms Emittances



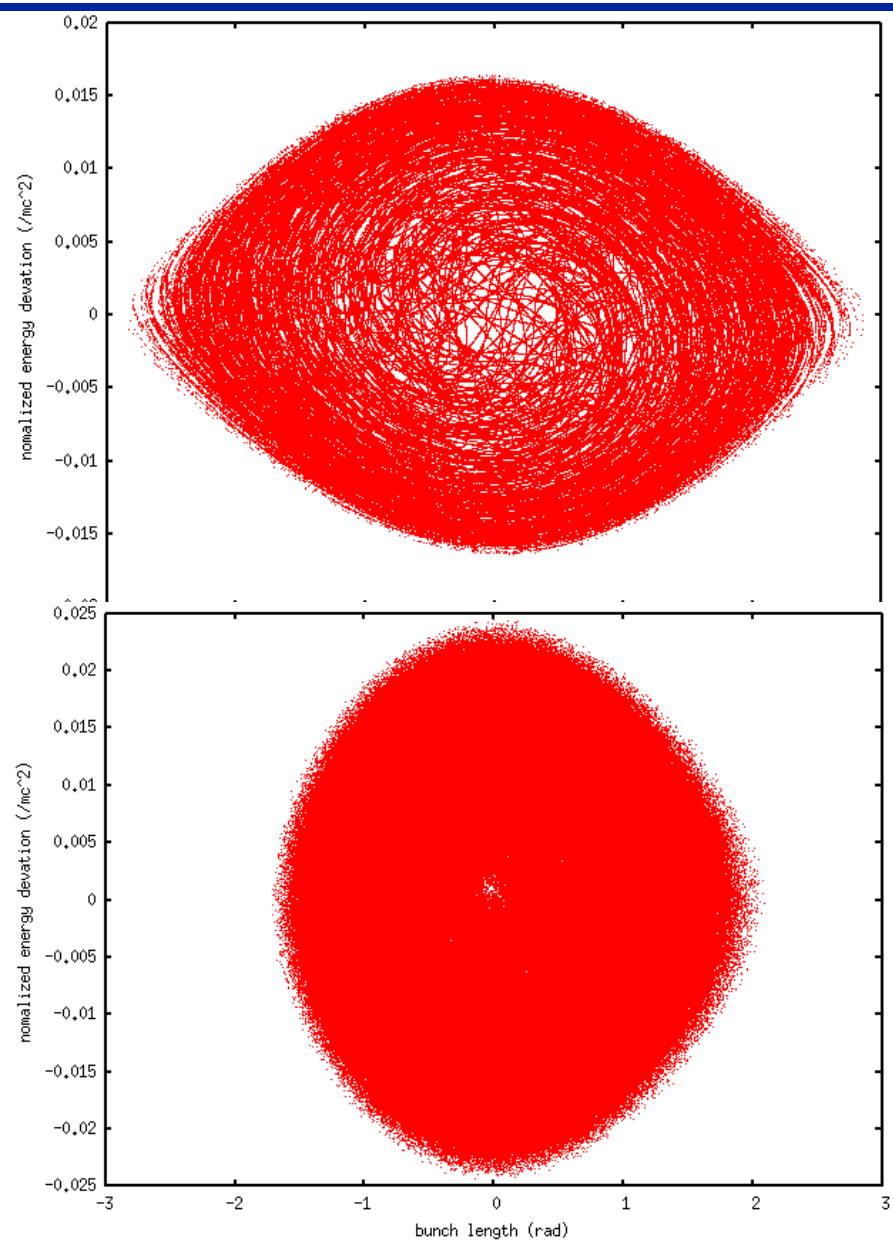
# Evolution of Longitudinal Rms Size and Maximum Amplitude

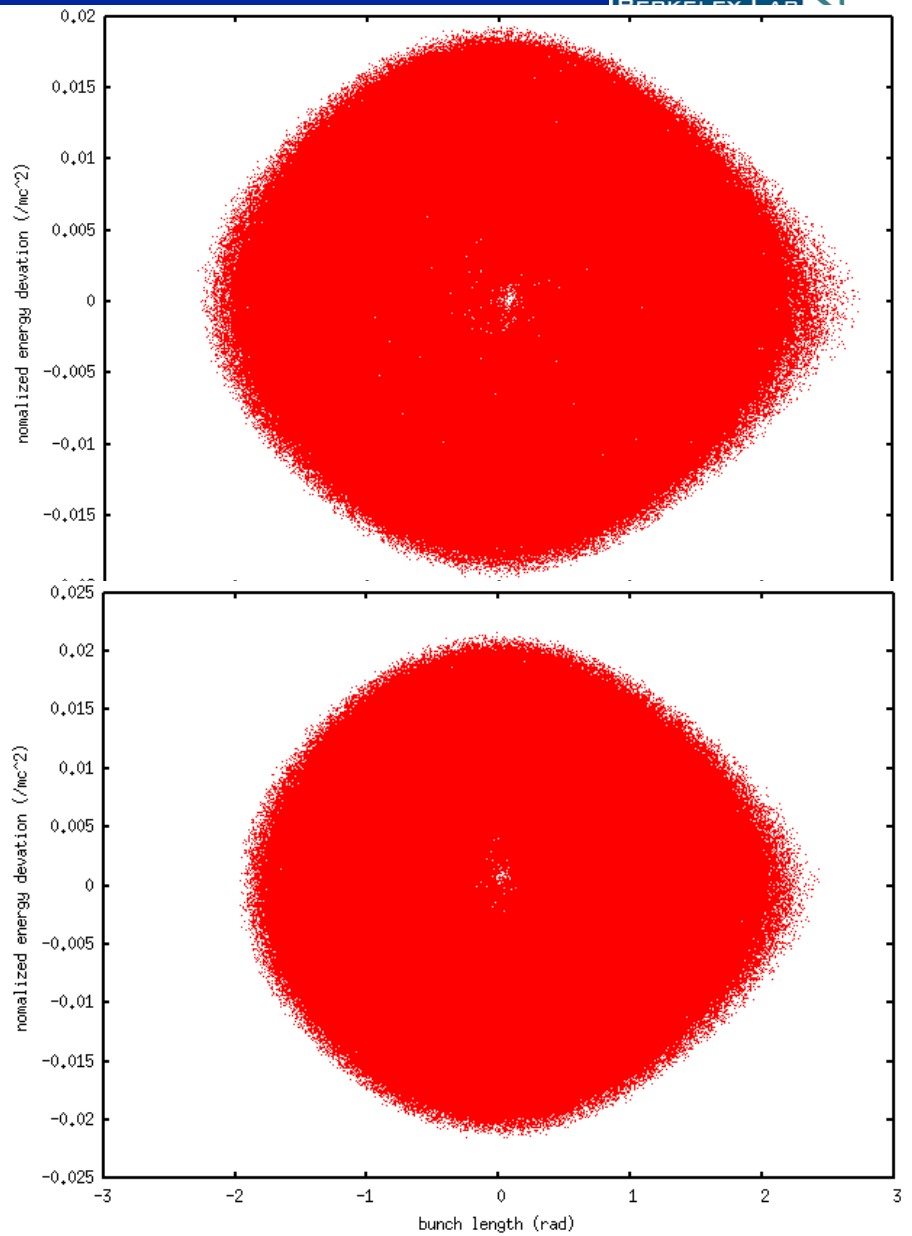


# Evolution of Longitudinal Relative Rms Energy Spread

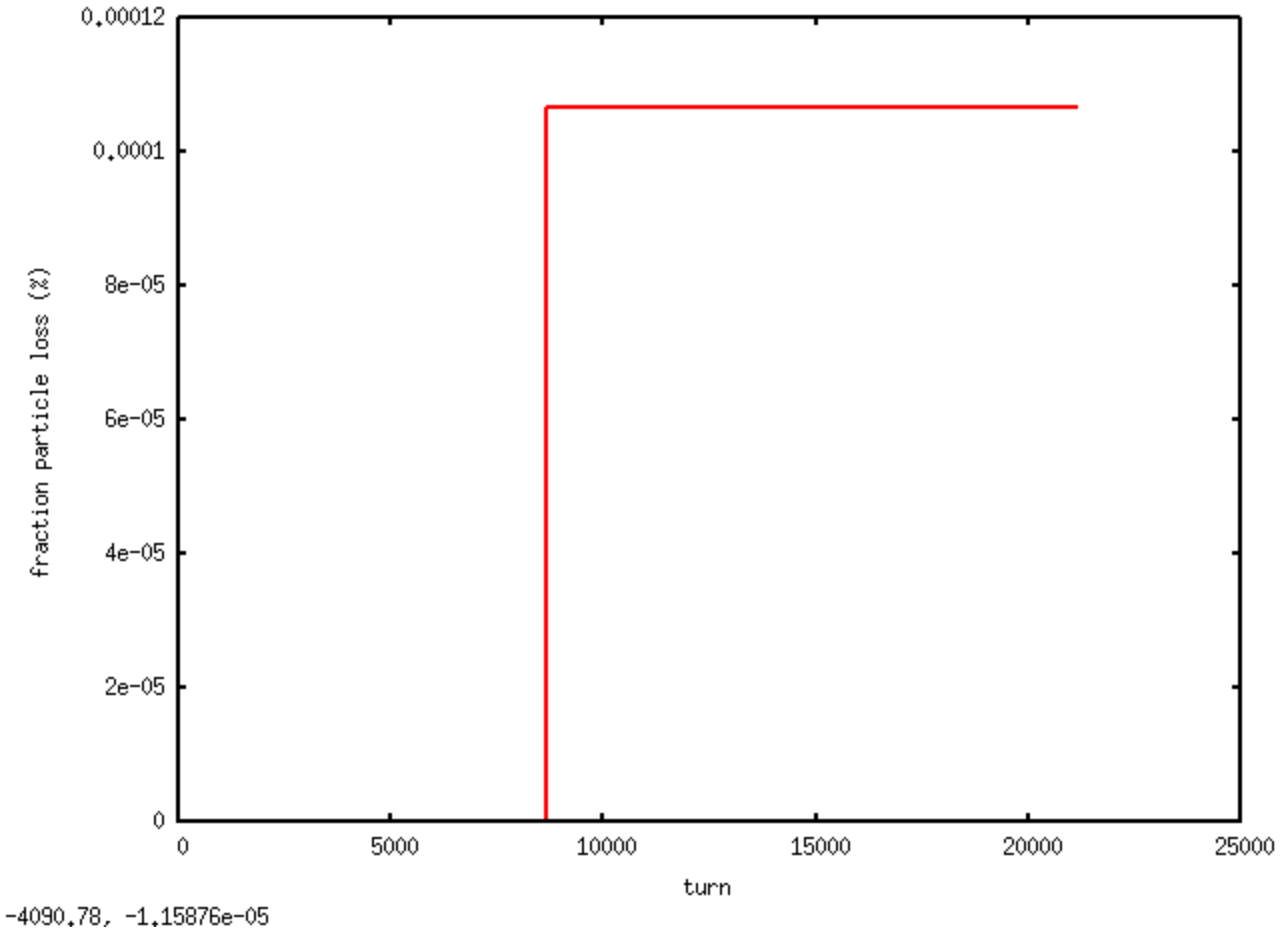


# Evolution of the Longitudinal Phase Space (0, 6k,12k,18k turns)

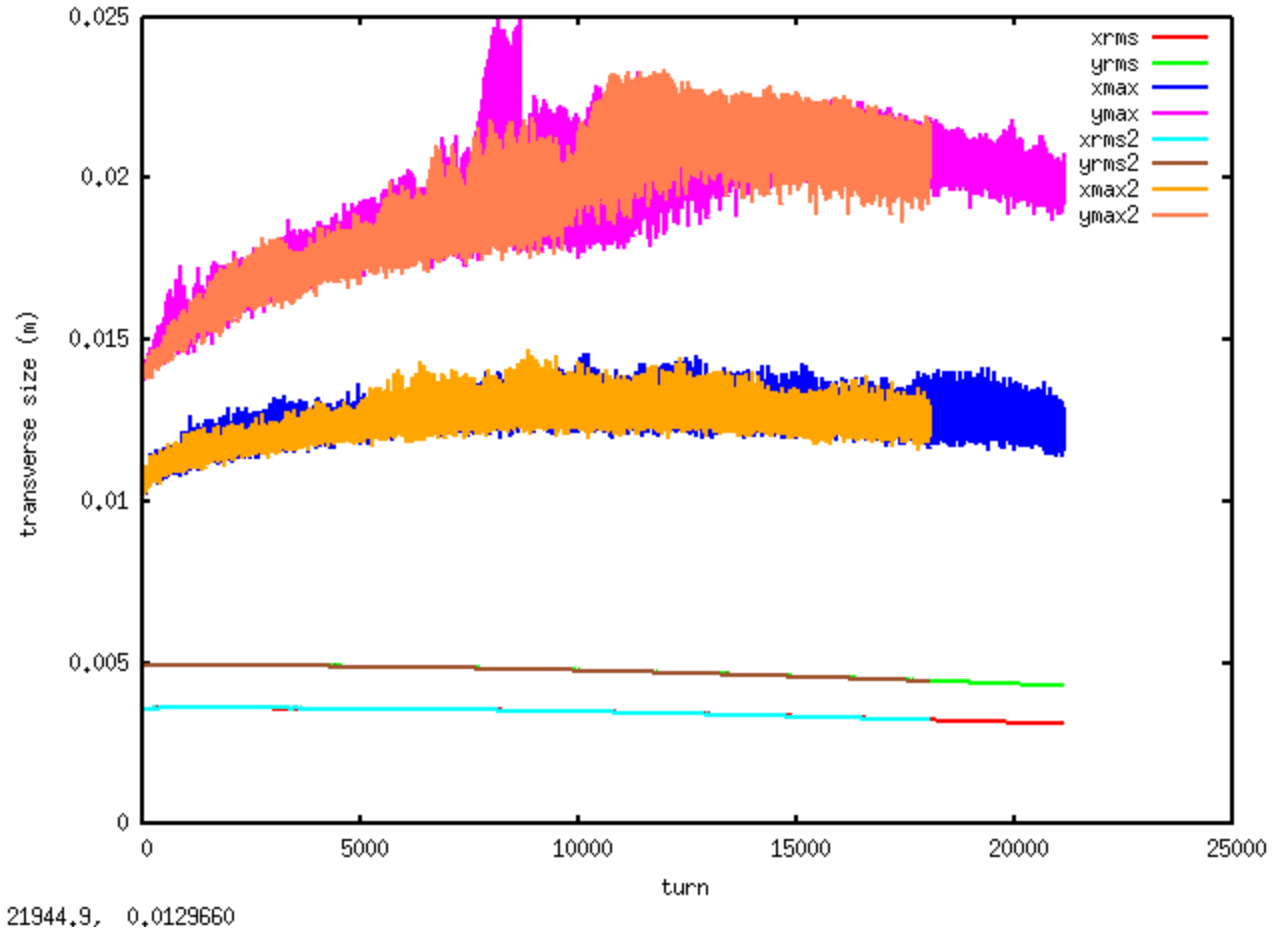


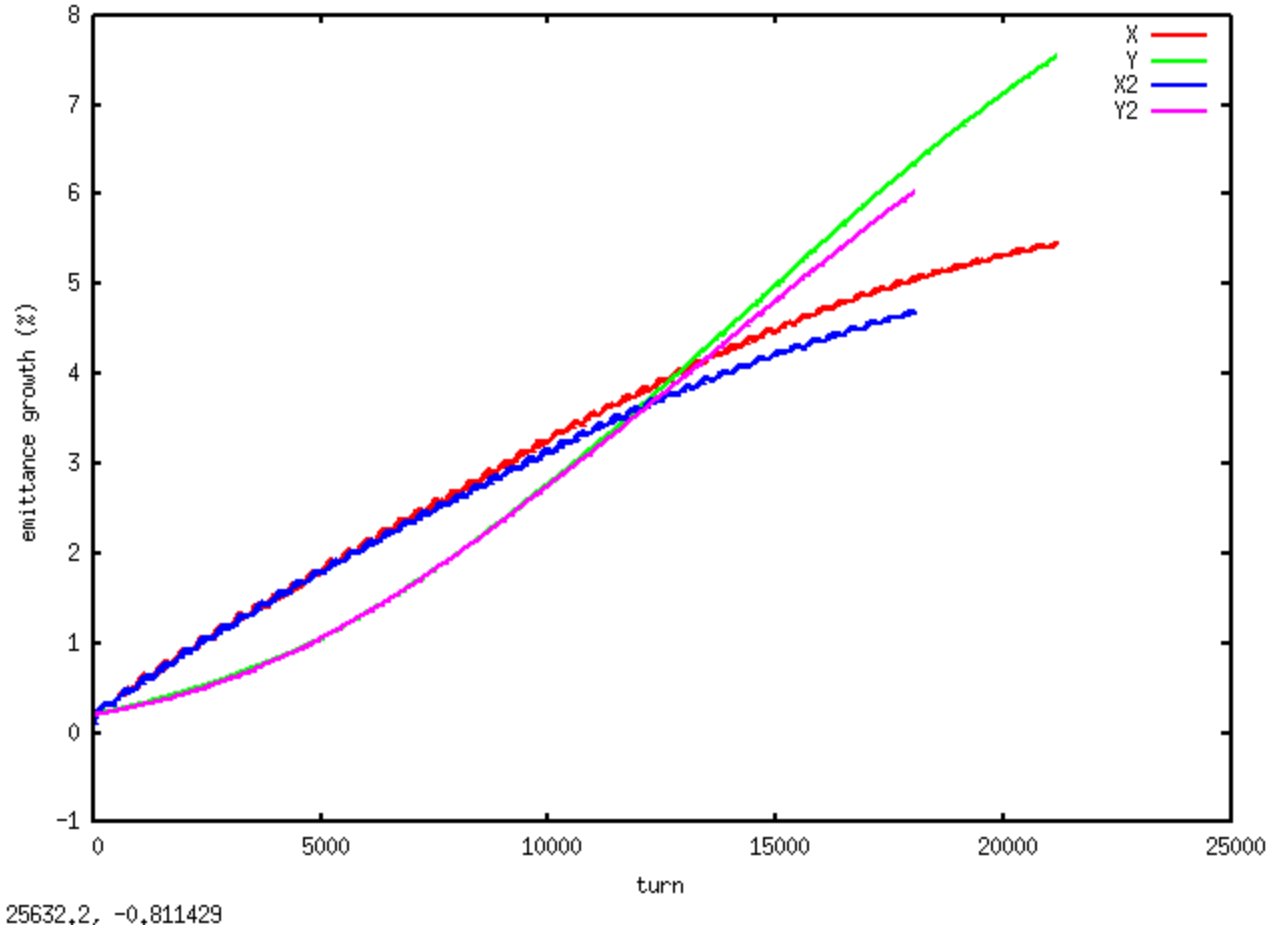
# Evolution of Fractional Particle Loss



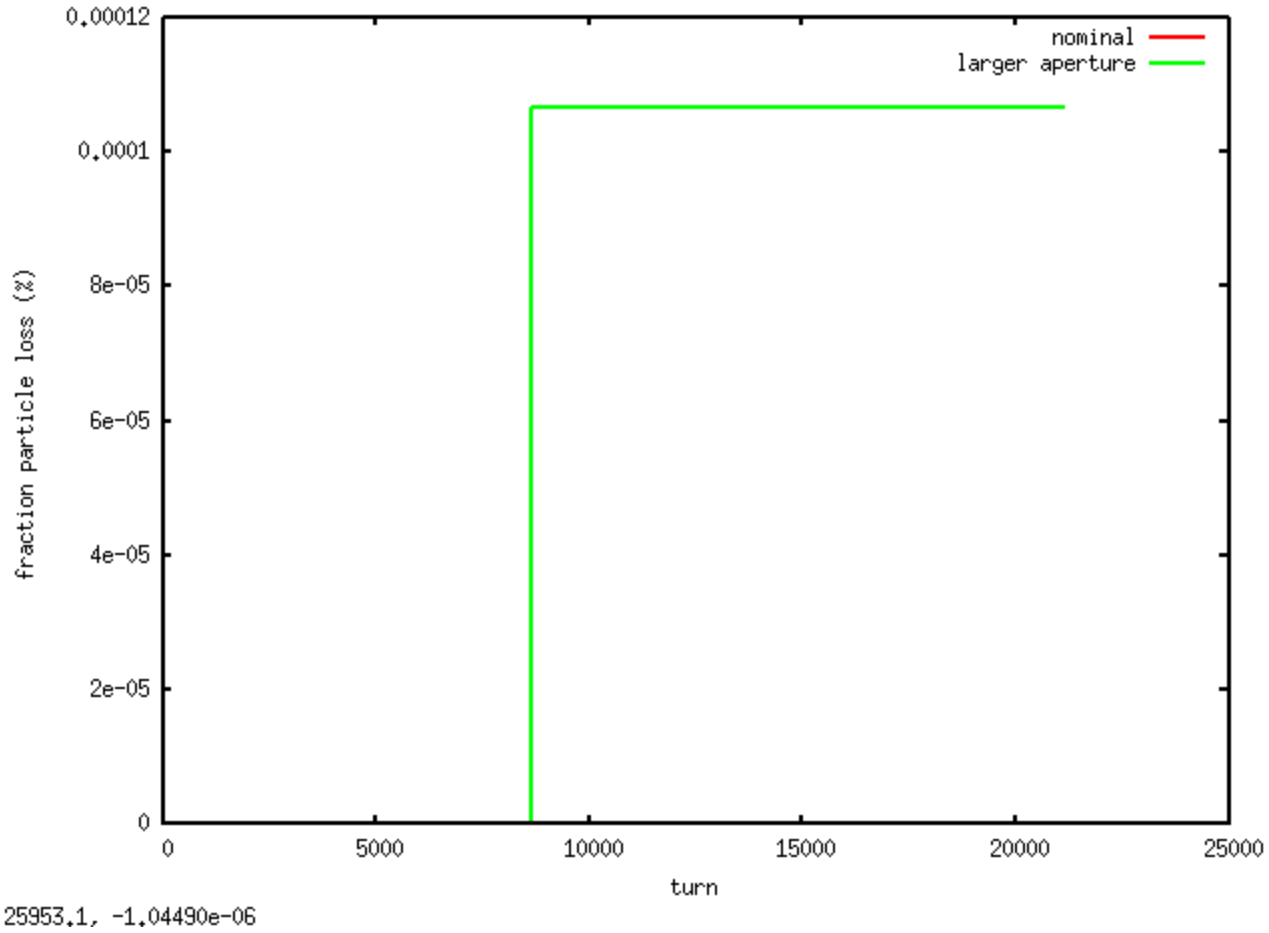
# Transverse Sizes without/with 2 cm Larger Aperture



# Transverse Emittances without/with 2 cm Larger Aperture



# Fractional Particle Loss without/with 2 cm Larger Aperture



# Summary and Future Work

- Space-charge effects causes emittance growth at PS2
- Better painted longitudinal distribution help reduce emittance growth and particle losses
- Current lattice design and ramping scheme seem to be sufficient to keep the particle loss on the level of $10^{-6}$
- Increase of aperture size by 2 cm does not show significant improvement of emittance or particle loss
- Longer time simulation is needed to check the saturation of emittance growth
- Machine lattice, painting scheme and RF ramping optimization include the space-charge effects
- Write the PS2 design report