TRANSVERSE IMPEDANCE MODEL FOR PARTICLE TRACKING CALCULATIONS

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Necessity of Beam Dynamics Simulations

- SNS ring operating parameters and requirements
  - High beam intensity
    - 1.5E+14 protons at 1 GeV in 165 m bunch
  - Low loss limits
    - 1 W/m uncontrolled loss limit
    - Driven by requirement of high availability
- Must choose design and operating scenarios to minimize losses due to
  - Lattice resonances
  - Space charge resonances
  - Impedance-driven instabilities
- Detailed beam dynamics studies are essential.

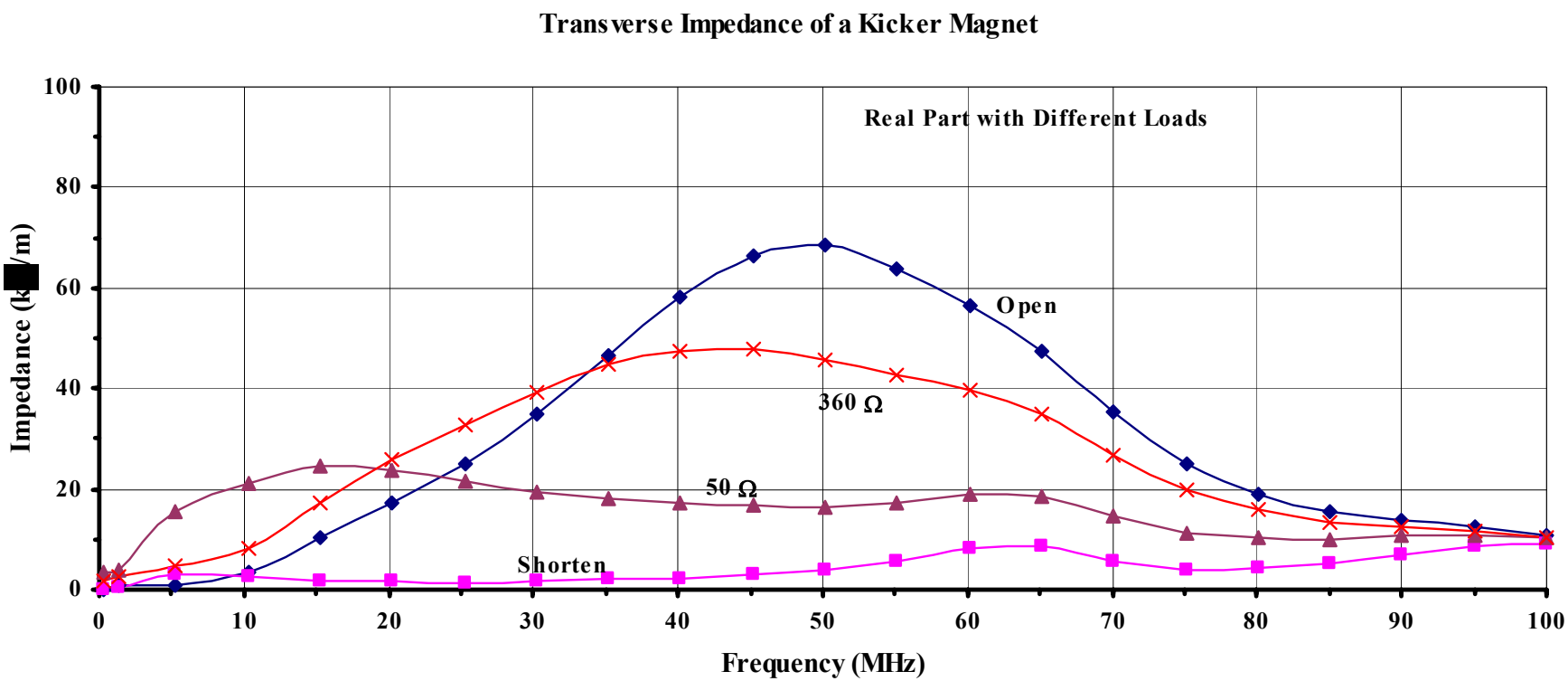
Transverse Impedance Model

- Transverse impedance treated as localized node in ORBIT
  - Element length must be short compared to betatron oscillation wavelength
  - If physical impedance is not short, multiple impedance nodes are required
- Impedance representation
  - Fourier components at betatron sidebands of the ring frequency harmonics
  - Velocities less than light speed included in formulation
- Particle kicks
  - Convolution of beam current dipole moment with impedance
  - Current evaluation assumes dipole moment evolves from previous turn according to simple betatron oscillation

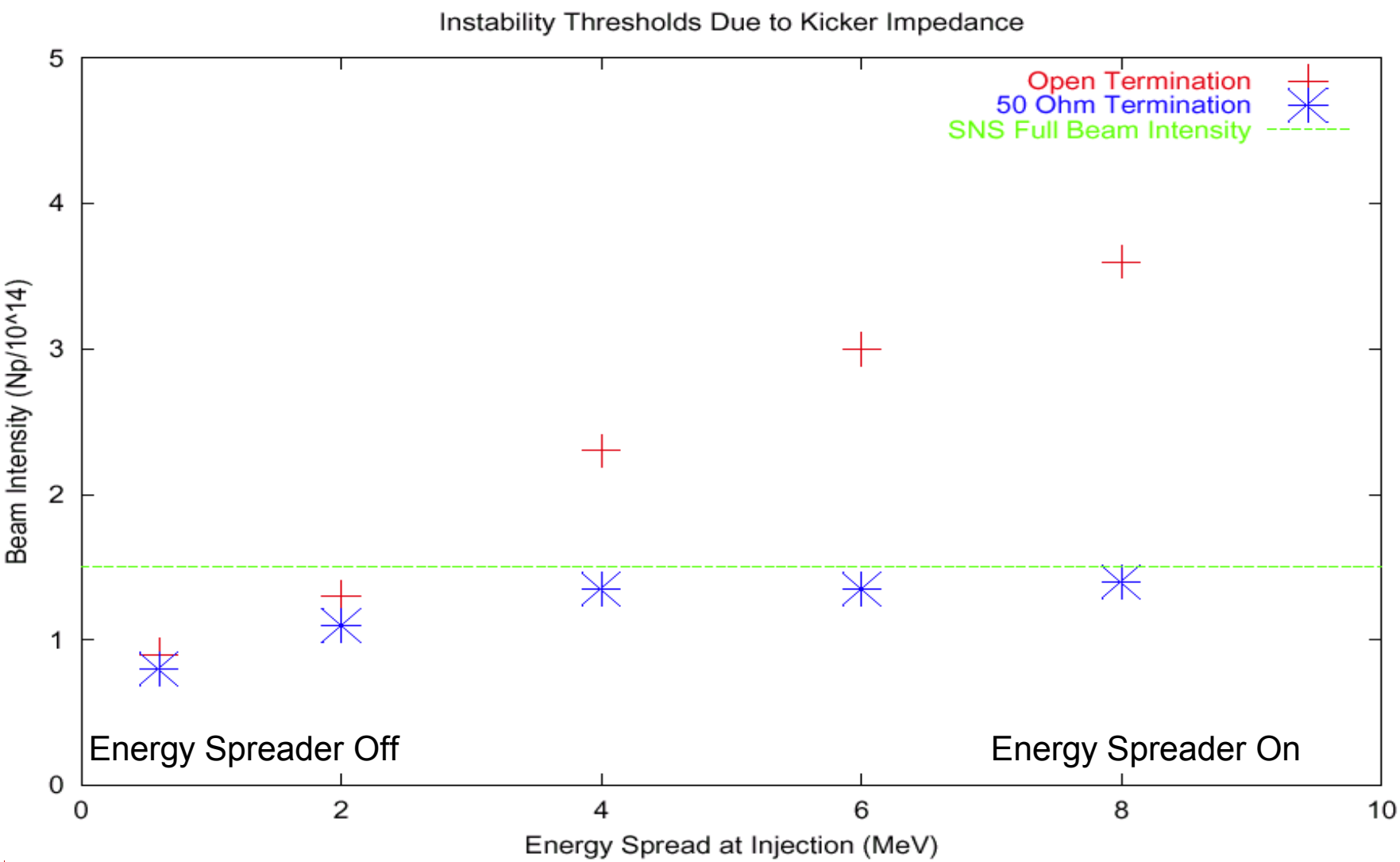
SNS Extraction Kicker: Instability Threshold

- The transverse impedance module was used to simulate instability thresholds due to the extraction kicker for an actual SNS injection scenario.
- The impedance for the extraction kicker was taken from measurements (by J. G. Wang).
- Calculations were carried out for open termination and for 50 Ohm termination.
- 50 Ohm termination yields lower instability thresholds than does open termination.
- Large halos are generated for unstable cases.
- The inclusion of a 3-D space charge model will modify the present results.

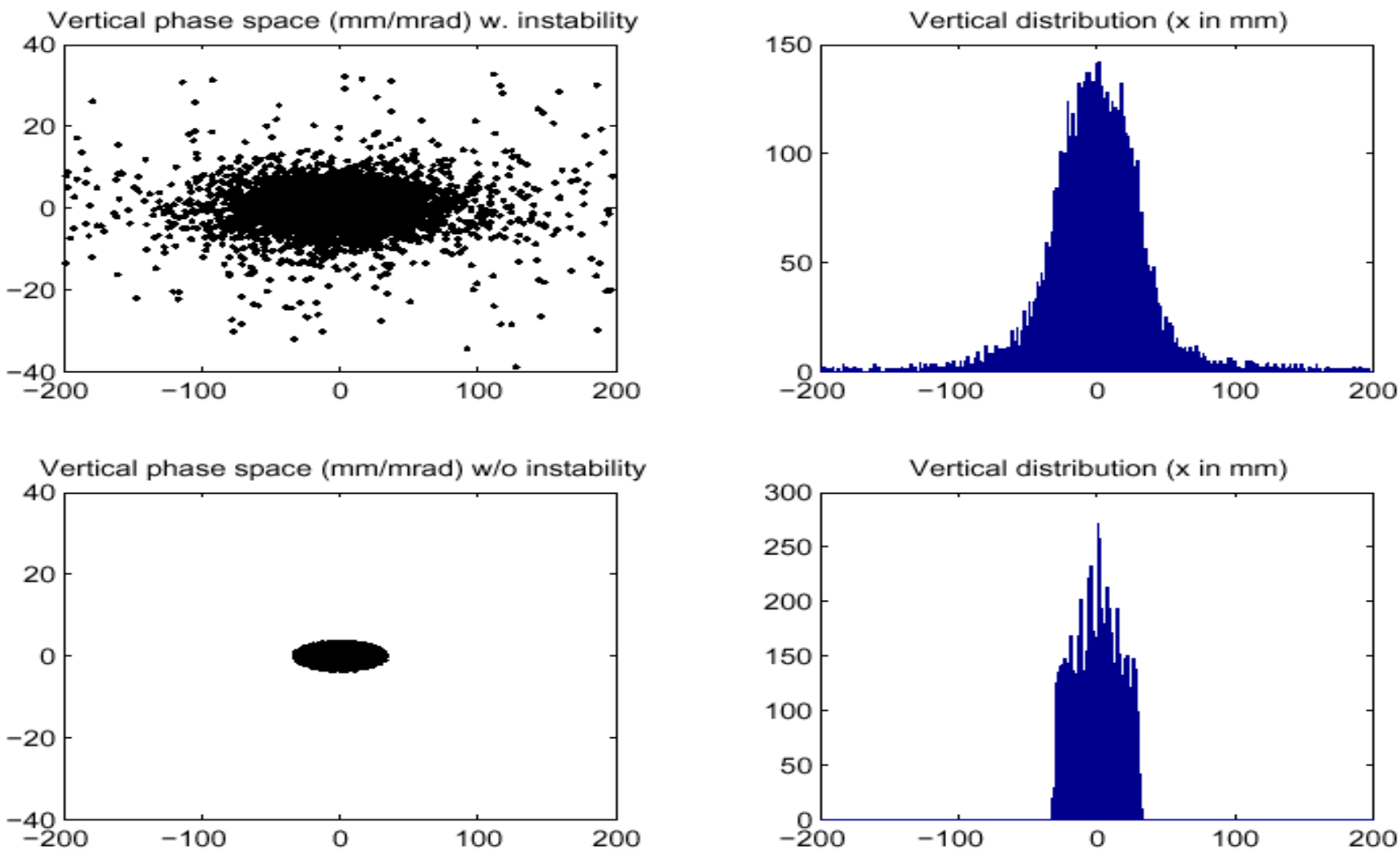
SNS Extraction Kicker: Transverse Impedance Measurement



SNS Extraction Kicker: Transverse Impedance Simulations, Instability Threshold



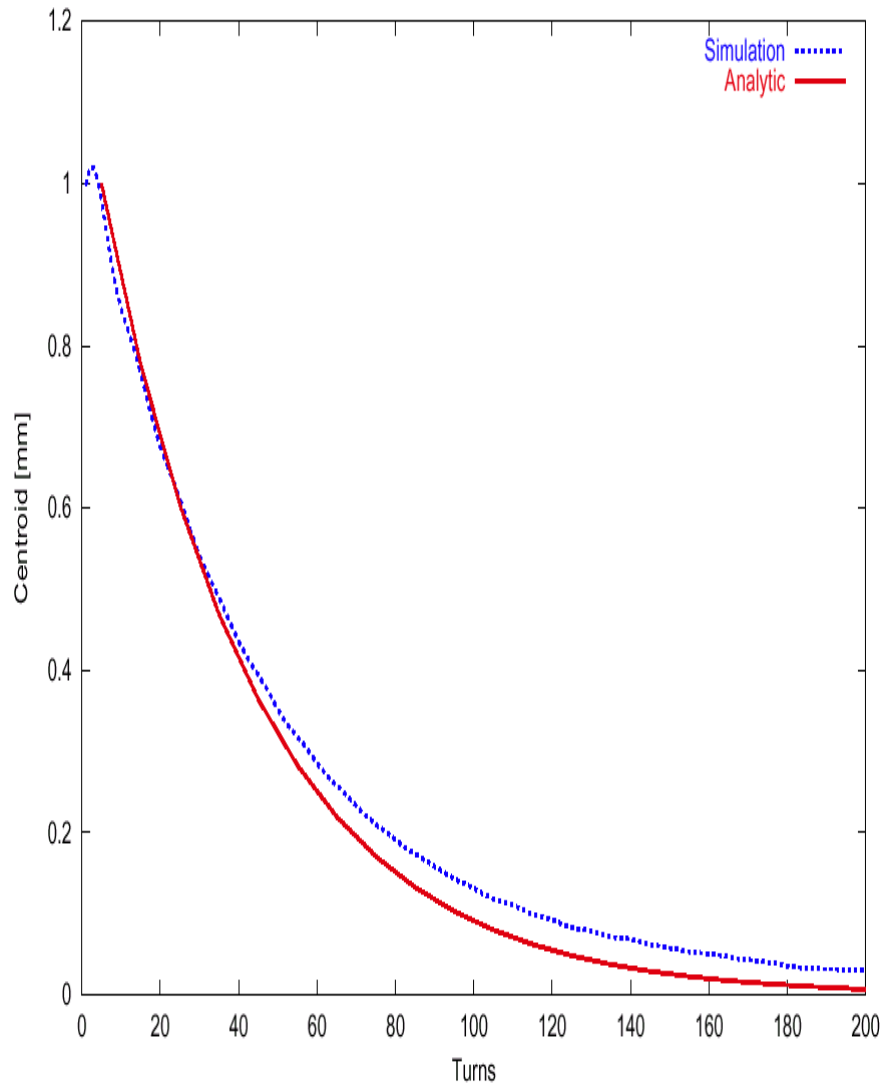
Impedance-Driven Instabilities Lead to Significant Halo



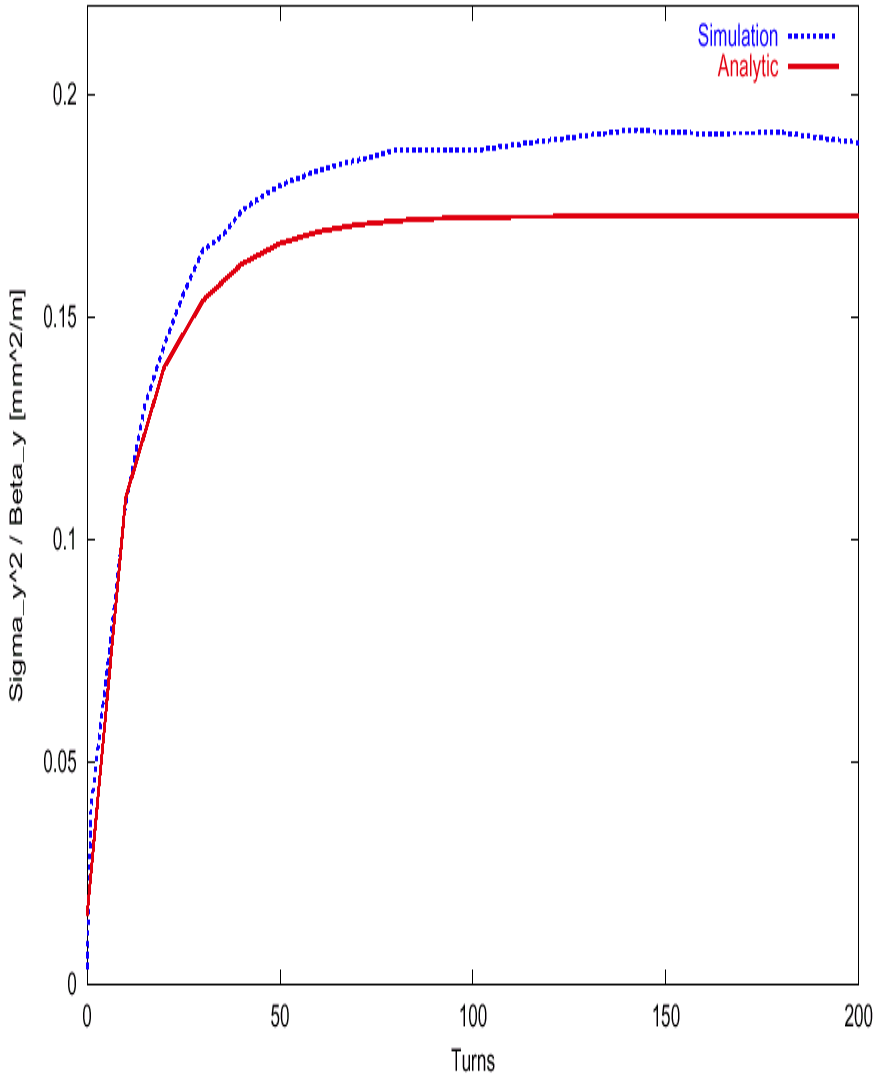
Transverse Impedance Studies: Benchmark

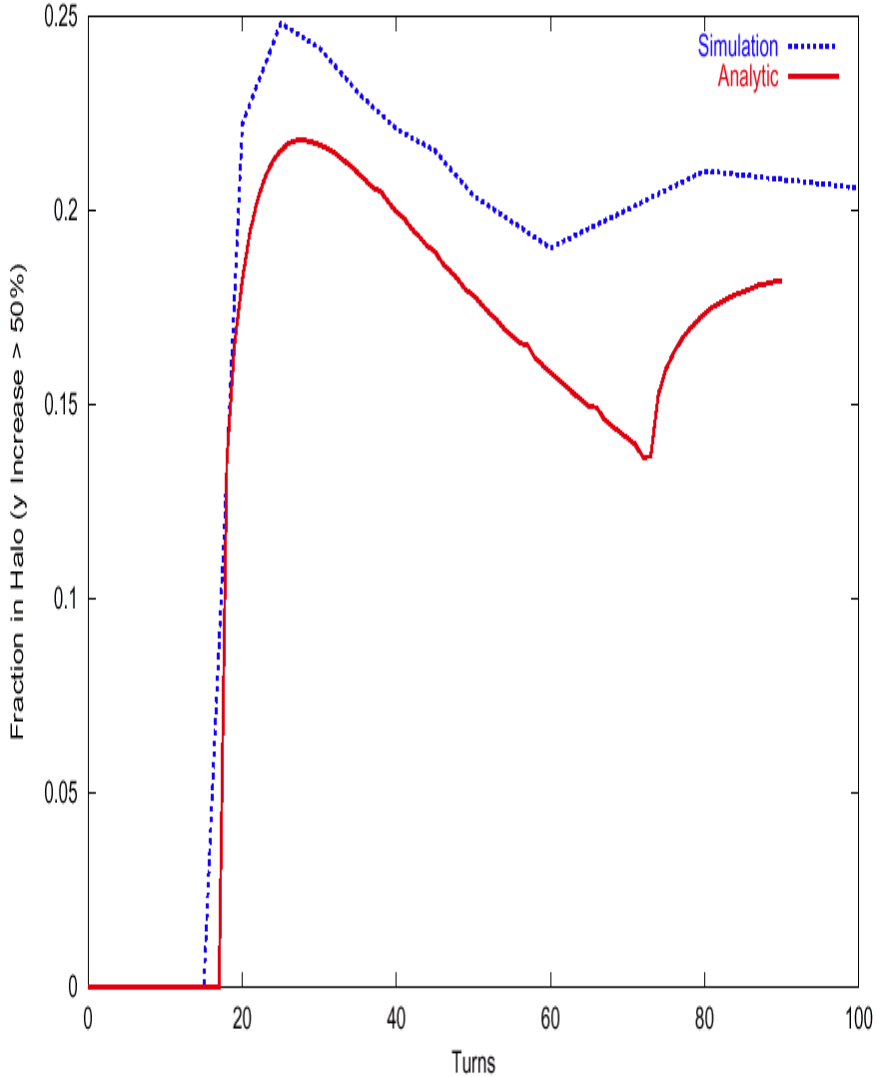
- Benchmark ORBIT with analytic calculation:
  - Straight uniform focusing lattice
  - Periodic length 248 m, tunes (6.4,6.3).
  - Longitudinally localized vertical impedance (b/a = 2, first harmonic, Z = 10^6 Ohm in detailed results shown below)
  - Coasting “pencil” beam with
    - 1 mm displacement in y (0 harmonic);
    - Lorentz energy distribution (1 GeV, RMS width 1%, cutoff at 10%);
    - 10^14 particles.
    - Use 2*10^5 macroparticles.
- Analytic calculation with Vlasov equation and Landau damping.

Benchmark: Dipole Moment Decays at Z = 10^6 Ohms

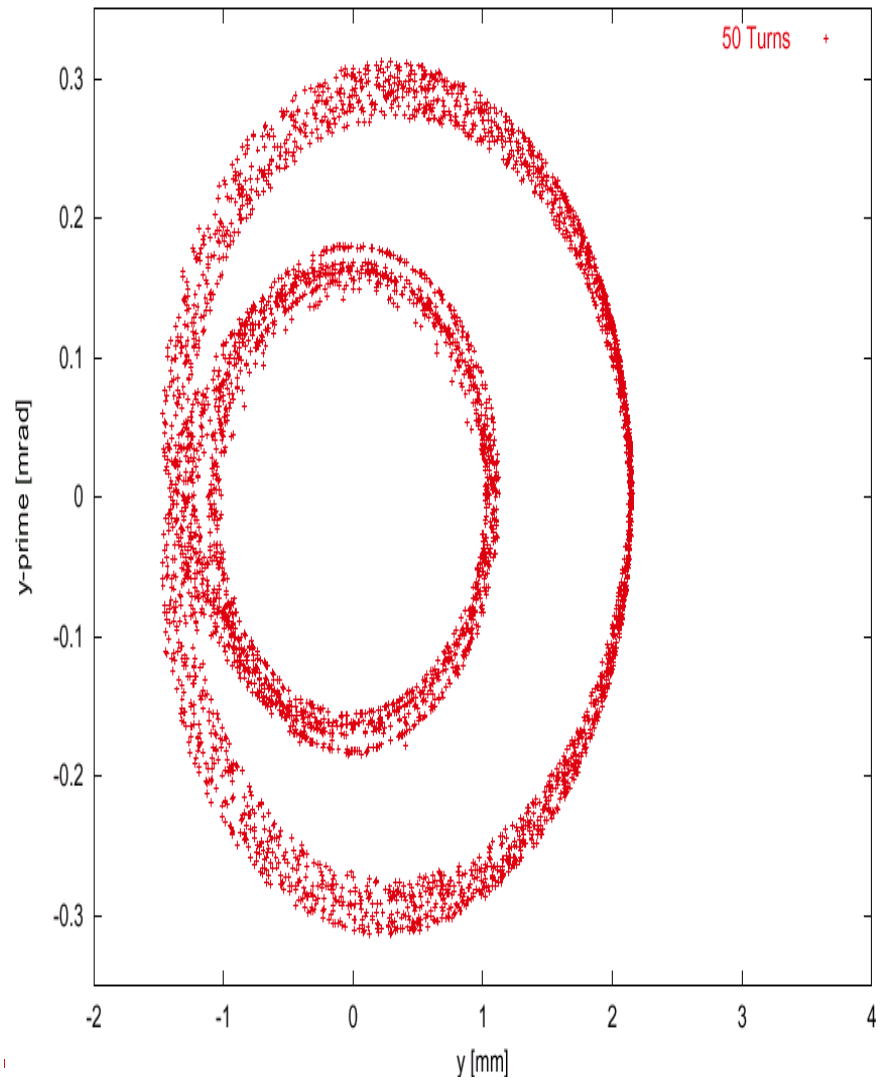


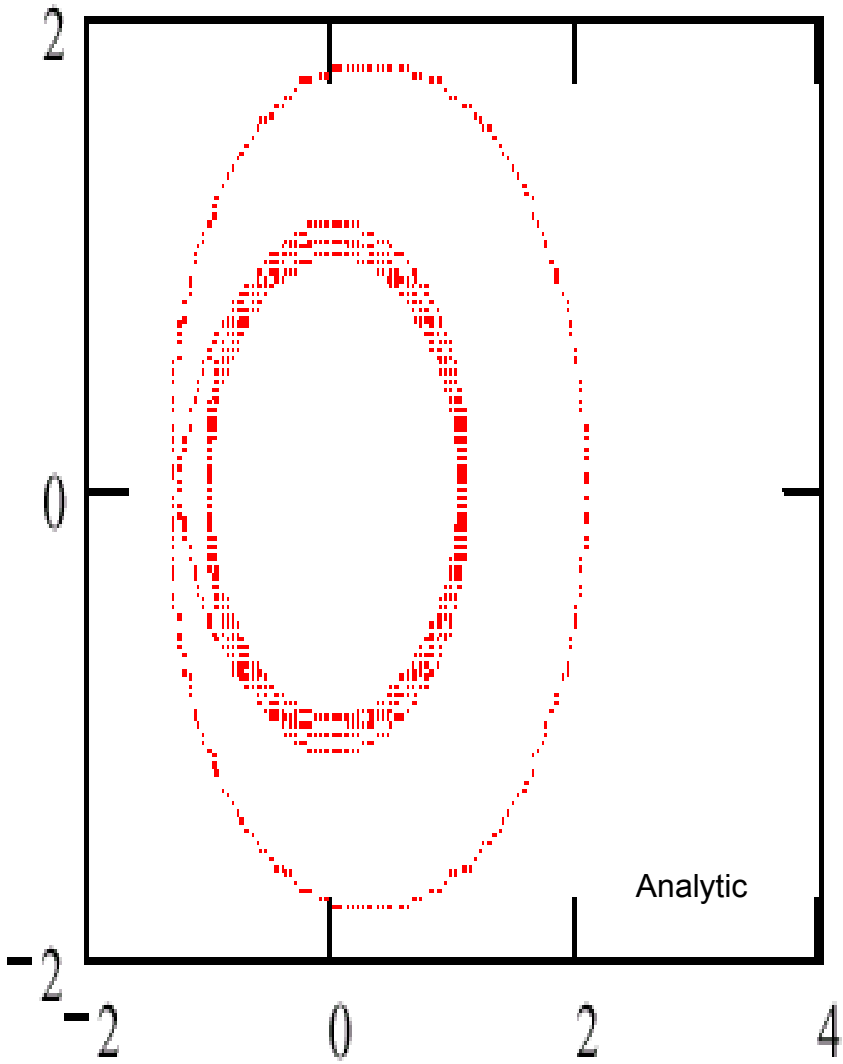
Benchmark: In Spite of Stability, the Beam Grows and Halo Forms



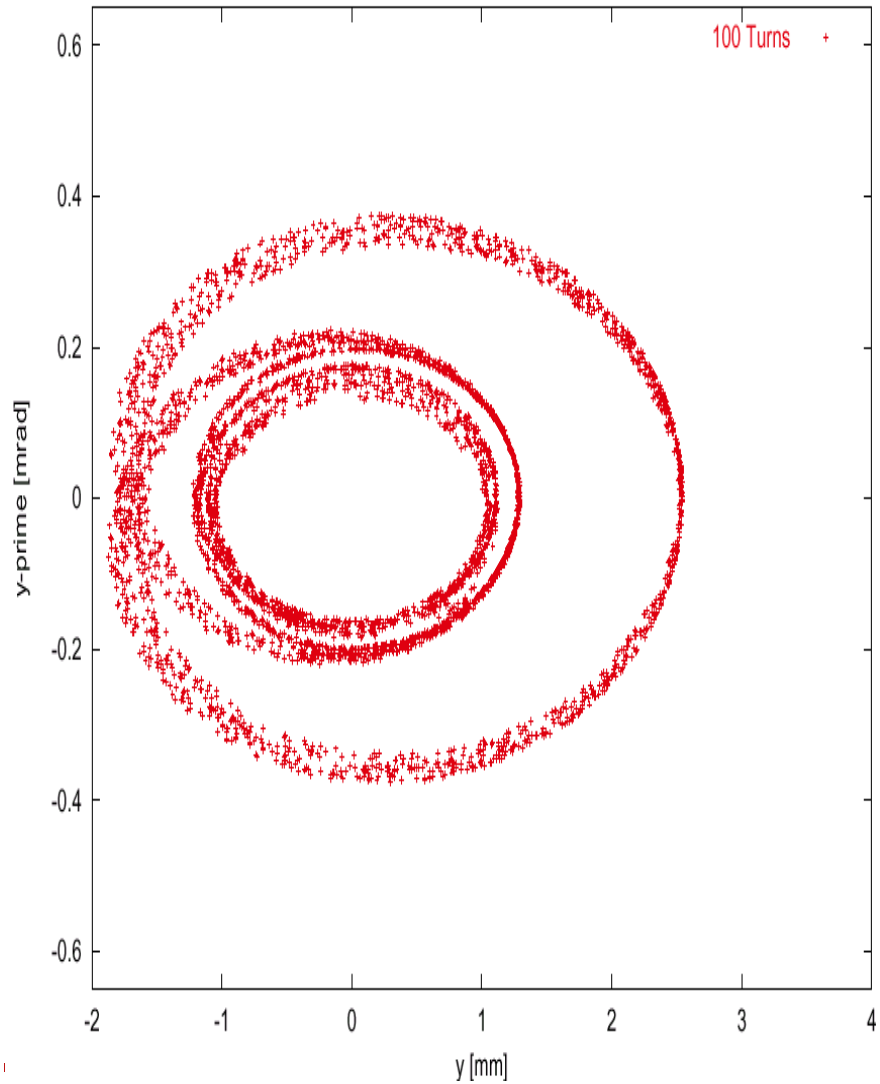


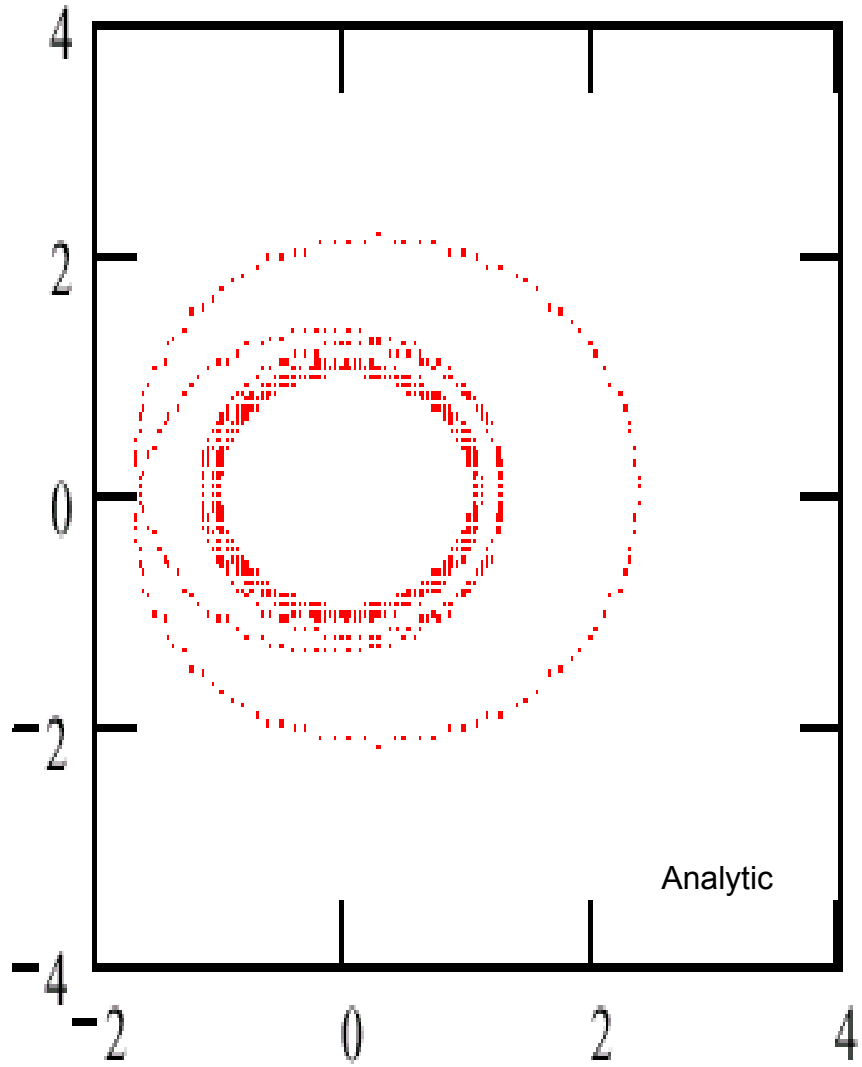
Benchmark: Transverse Phase Space, 50 Turns





Benchmark: Transverse Phase Space, 100 Turns





Transverse Impedance Studies: Benchmark Results, Summary

- Instability threshold at 1.6 Mohm, within 5% agreement.
- Halo can grow even for “stable” cases. This is found both analytically and computationally, and the results of the two approaches are in good agreement.
- These results neglect direct space charge forces.

- Next steps:
  - Develop 3-D space charge solver in ORBIT.
  - Collaborate with BNL to implement impedance and space charge models in UAL.
  - Apply verified models to SNS