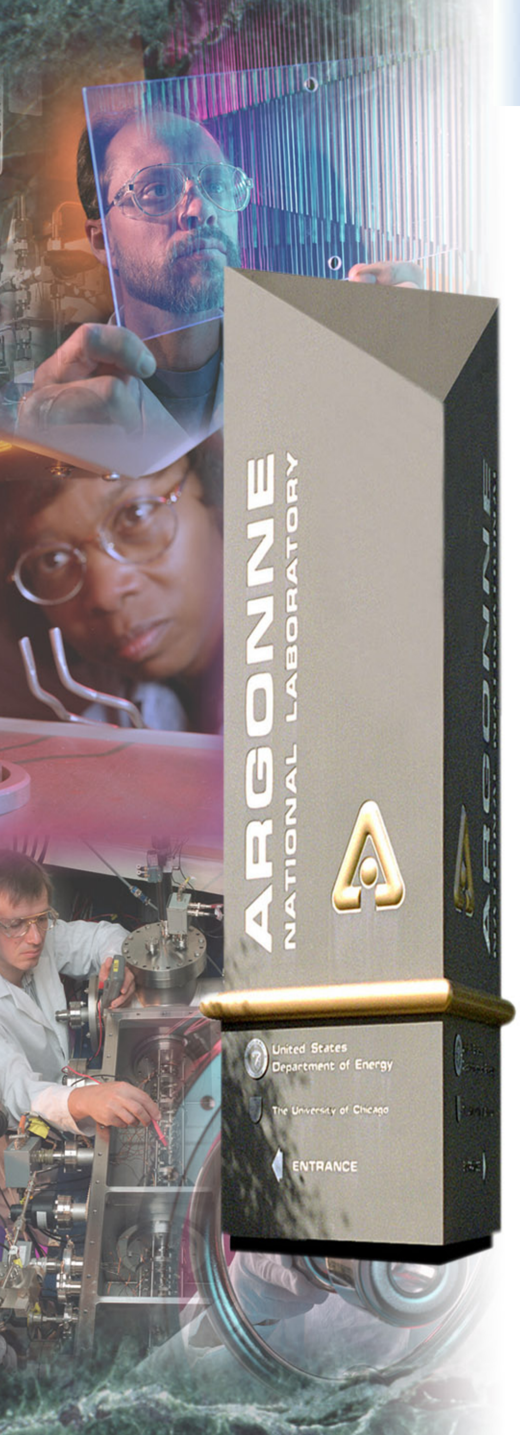

ARGONNE NATIONAL LABORATORY

Effects of Impedance in Short Pulse Generation Using Crab Cavities

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Advanced Photon Source

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Outline

- Motivation & approach
- Single bunch effects
- Multibunch effects
- Discussion
- Summary

Motivation

- Will impedance will spoil the results (~1 ps x-ray pulses)?
  - Vacuum chamber impedance
  - Deflecting cavity impedance
- Minimize impact of deflecting cavities on APS performance; i.e. deliver stable, low-emittance, high photon brightness outside deflecting cavity insertion

Approach

- Preliminary tracking using vacuum chamber impedance
- Specify de-Qing requirements for LOM/HOMs (Y.-C. Chae) for cavity design (G. Waldschmidt)
- Revisit tracking with vacuum chamber impedance including deflecting cavities

APS Operating Modes (100 mA nominal)

Standard

- 24 bunches (h=1296), 4.25 mA/bunch, 150 ns bunch spacing (54 λ_{rf}), top-up

Special operating mode 1

- 324 bunches, 0.3 mA/bunch, 11 ns bunch spacing (4 λ_{rf}), non top-up

Special operating mode 2

- Hybrid mode: 16 mA single bunch $\pm$1.6 μs gaps; 84 mA in closely spaced bunch trains (56 bunches); top-up

Hybrid mode favored for time-resolved science. Preliminary impedance study used 5 mA (below microwave instability threshold).

APS Impedance

Single bunch (tracking)

- Broadband impedance from Impedance Database [Y.-C. Chae et al., Proc 2003 PAC, 3008, 3011, 3014, 3017]
- Vertical impedance dominated by undulator vacuum chamber transitions (~85% of total 1.2 M Ω/m)
- Total Z_y (BBR): R_s = 0.5 MΩ/m, Q=0.4, f_{res} = 20 GHz
  - Validation: reproduces measured vertical tune slope $\Delta\nu_y/\Delta I$ and TMCI threshold
- Longitudinal impedance dominated by rf cavities
- Total Z_z (BBR): R_s/n = 0.4 Ω, Q=2, f_{res} = 25 GHz
  - Validation: reproduces microwave instability threshold of 7 mA, and PWD bunch lengthening to within 75%

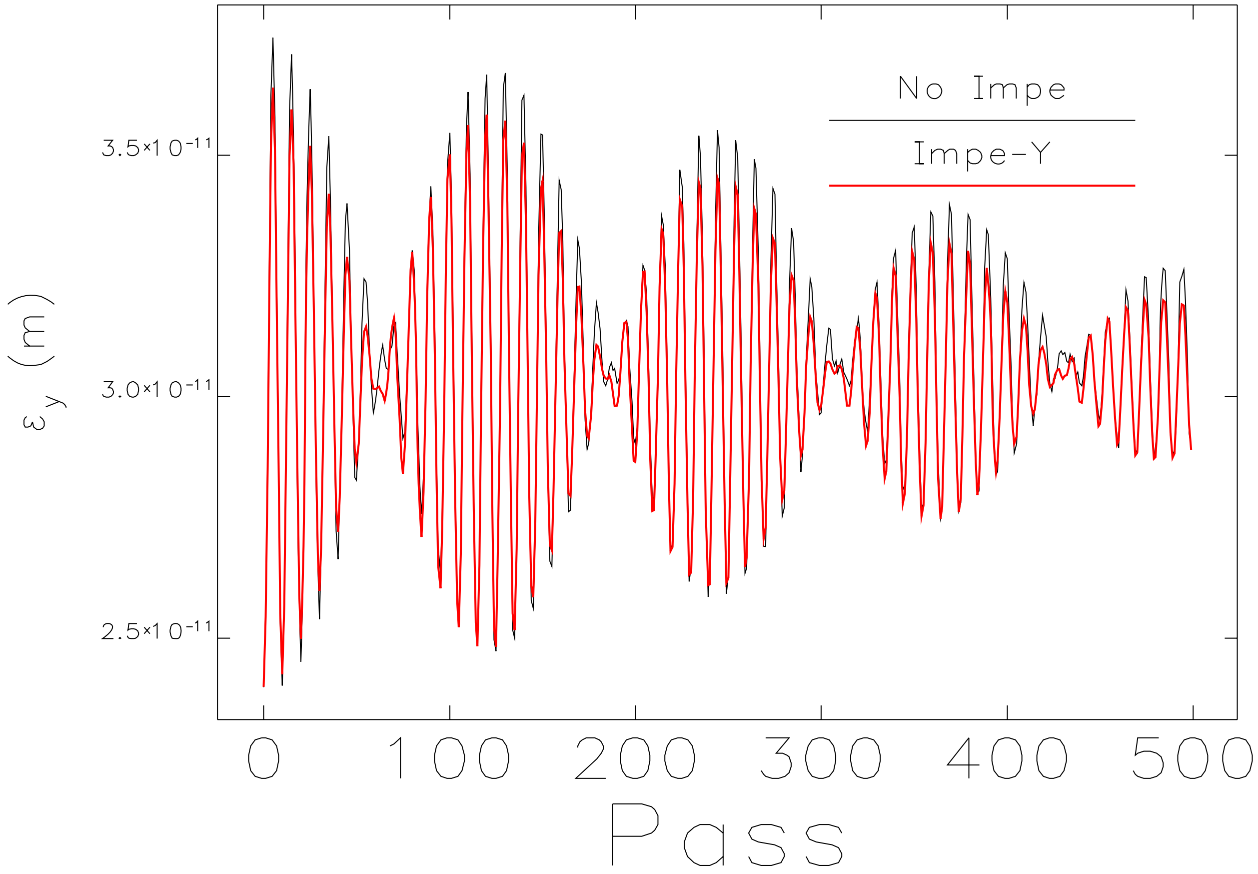
Multibunch (analytical)

- CBI thresholds calculated to estimate de-Qing requirements

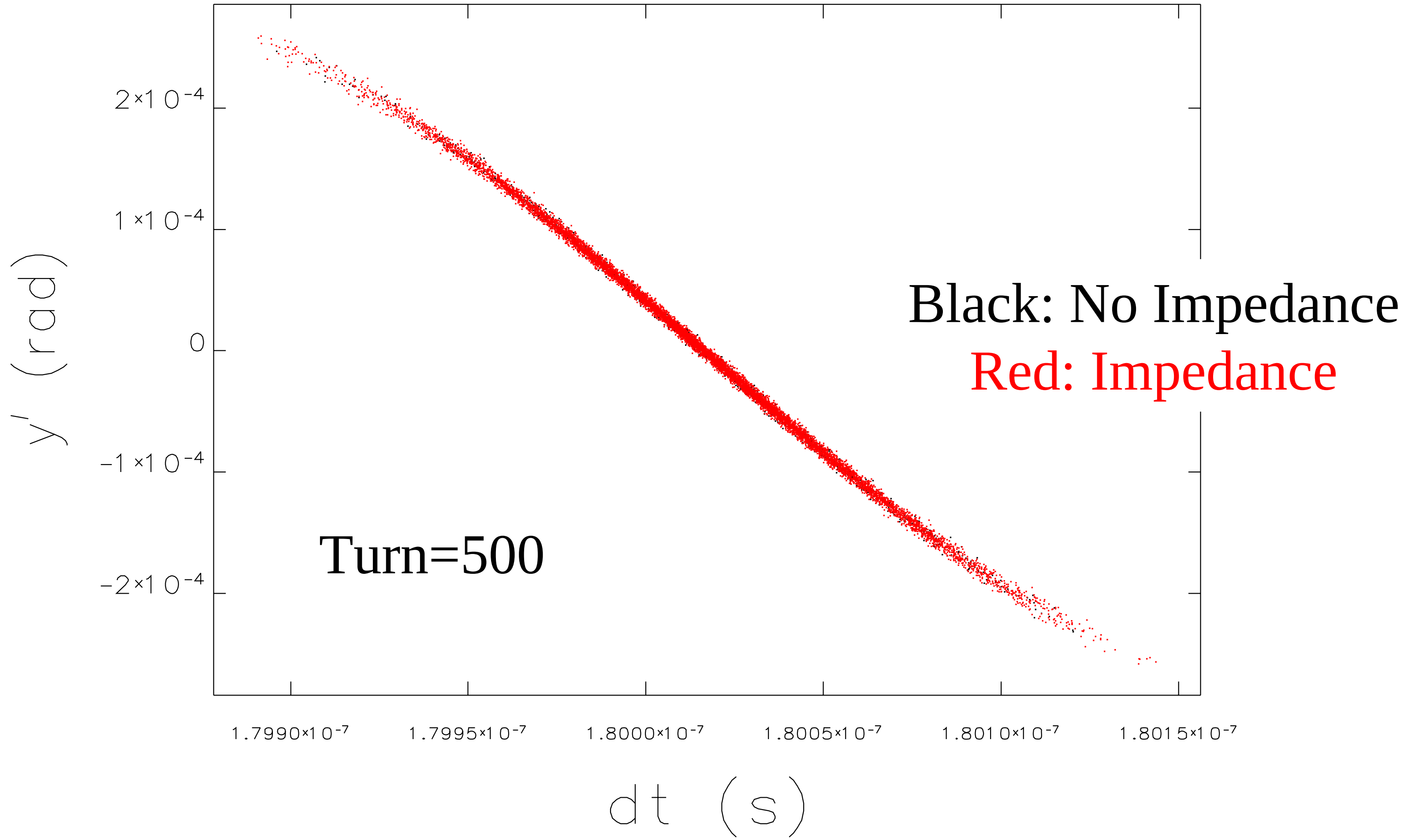
Chae's Simulation Condition (1): Vertical Only

- Use M. Borland's early lattice file (pre 2005 PRST-AB paper)
- Two deflecting cavities, 2-sector insertion
  - Frequency = 4*352 MHz
  - Voltage = 2 MV
- MB's Trick: Reduce total rf accelerating voltage to 2 MV to obtain 40 ps bunch length for 5 mA without including synchrotron radiation and Z-impedance effects
- Impedance Elements
  - BBR impedance in the Y-plane
  - 40-BBR elements at 40 sectors, each with strength Total $Z_y/40$
  - No impedance in Z plane
  - No synchrotron radiation effects
  - 10k macroparticles tracked for 500 turns

Comparison: Y Impedance vs. No Impedance



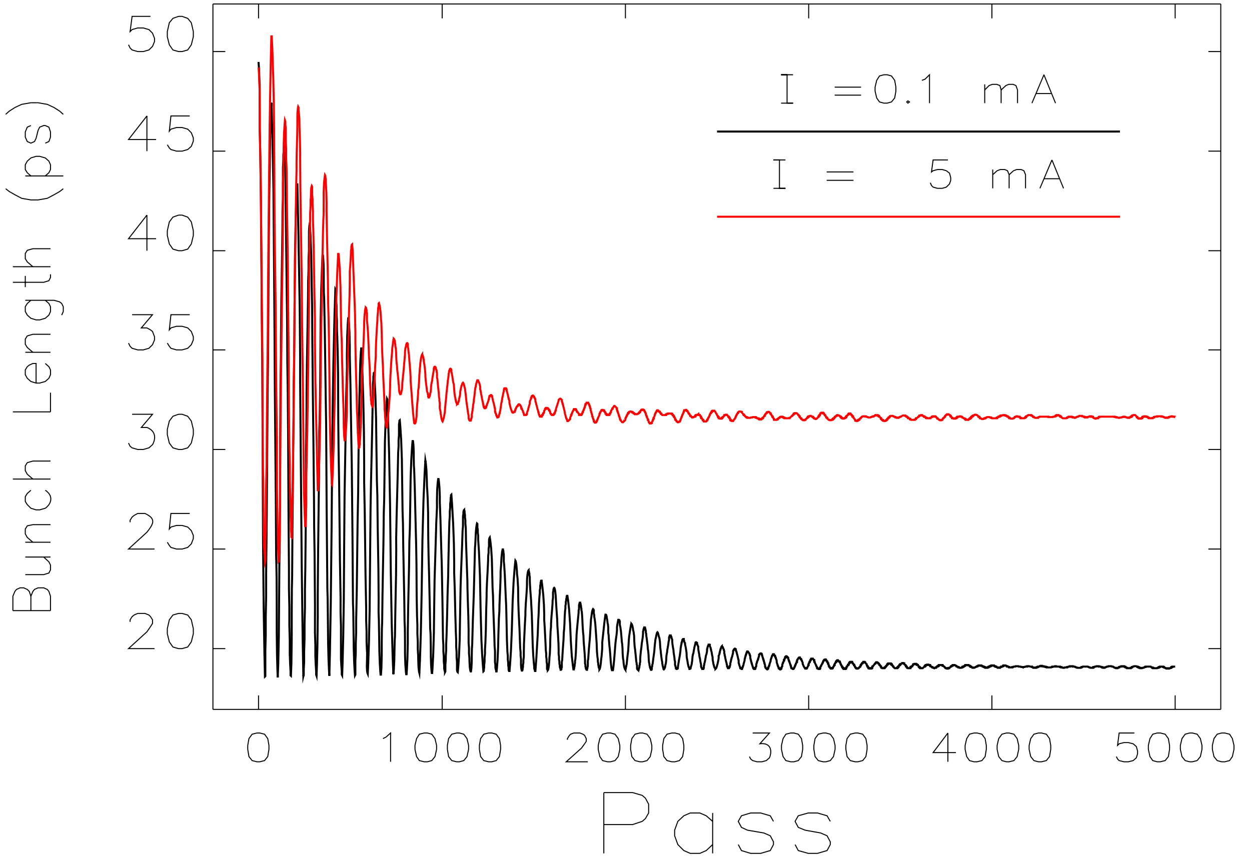
Comparison: Y Impedance vs. No Impedance



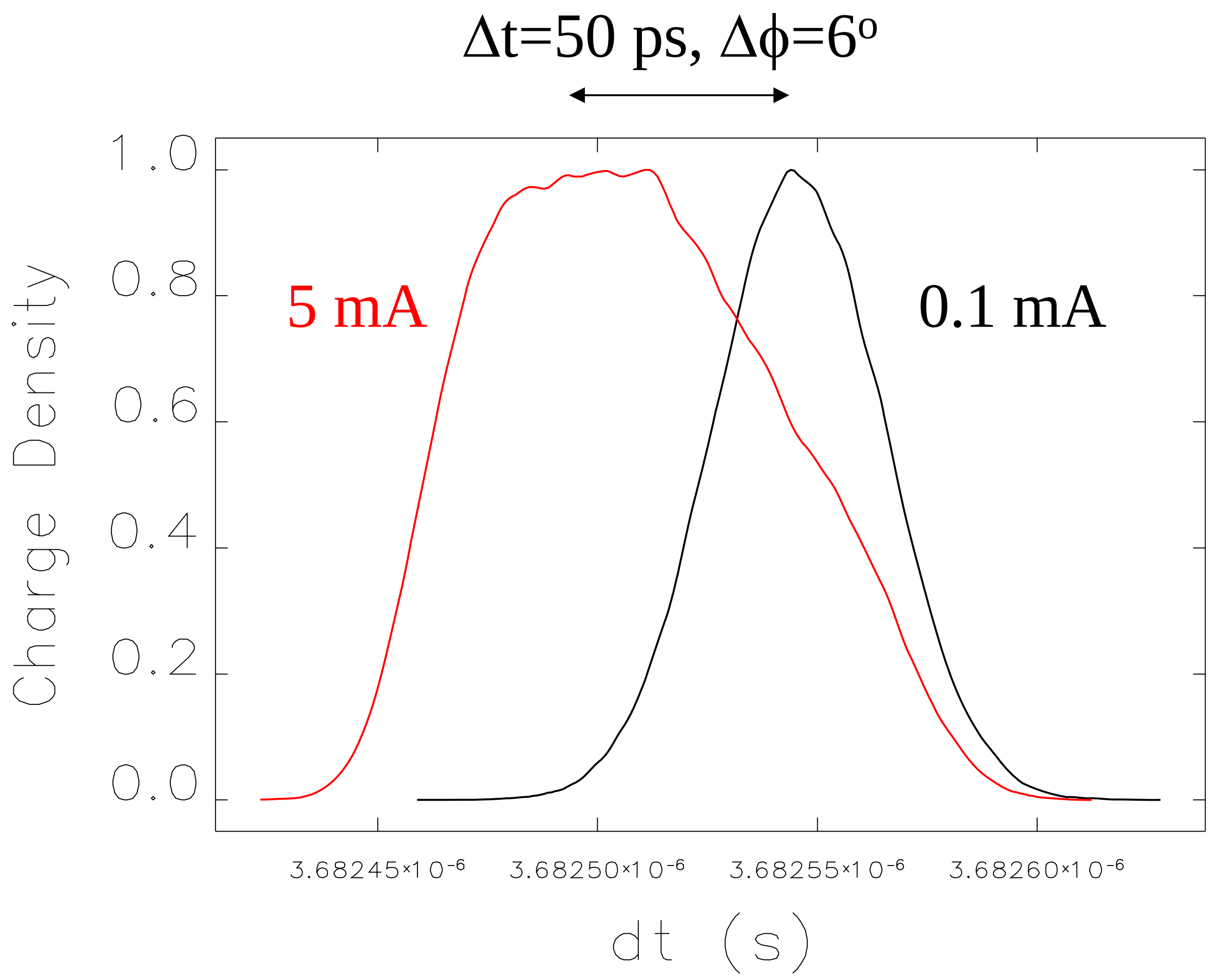
Chae's Simulation Condition (2): Longitudinal + Vertical

- Use M. Borland's early lattice file (pre 2005 PRST-AB paper)
- Two deflecting cavities, 2-sector insertion
- Impedance Elements
  - BBR impedance in the Y-plane
  - 40-BBR elements at 40 sectors, each with strength Total Z_y/40
  - 10k macroparticles
  - **Numerical impedance in the Z-plane (rather than BBR model)**
  - **Z-impedance element in one location**
  - **Synchrotron radiation effects included**
  - **Total rf-gap voltage = 9.4 MV**
  - **Number of turns increased from 500 to 5000**

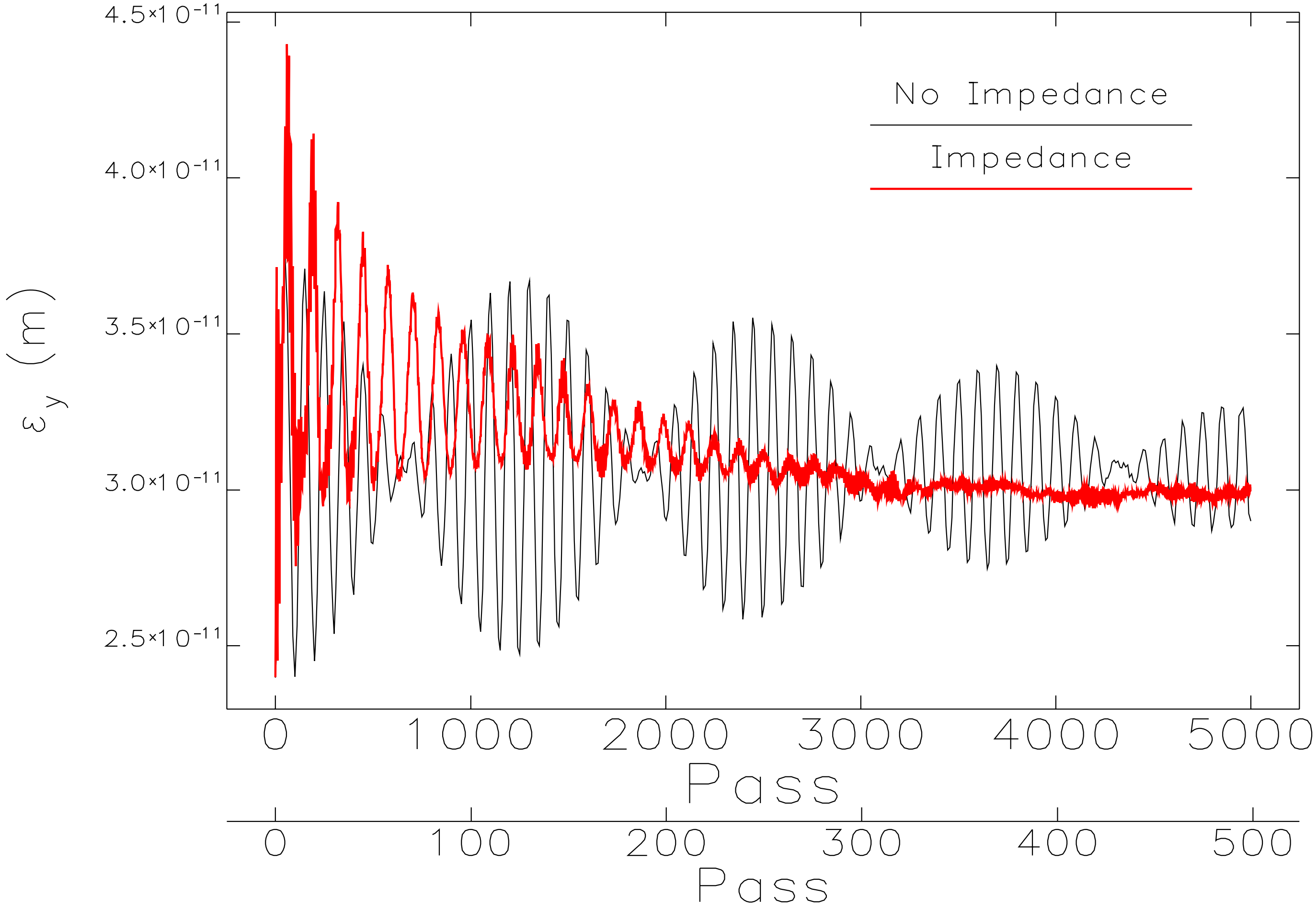
Z-Impedance: Bunch Lengthening



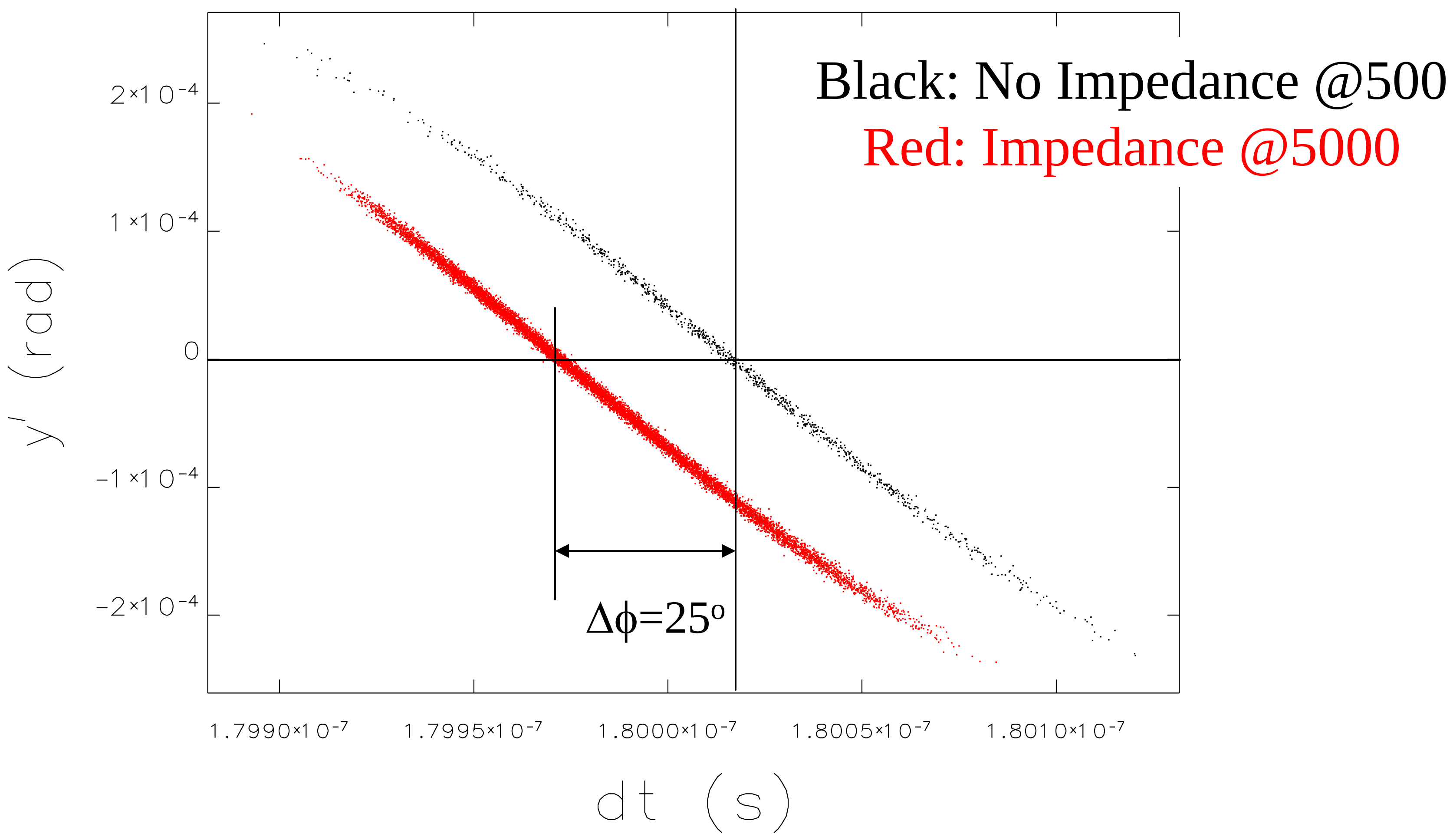
Z-Impedance: Bunch Profile



Comparison: Z Impedance vs. No Impedance



Comparison: Z Impedance vs. No Impedance



Multibunch instab. thresholds from parasitic mode excitation
(per Y-C. Chae)

APS parameters assumed: I = 100 mA, E = 7 GeV,
α=2.8e-4, $\omega_s/2\pi$=2 kHz, ν_s=0.0073, β_x = 20 m

	Longitudinal	Transverse
Growth Rate, τ_g^{-1} (s^{-1})[1]	$\tau_g^{-1} = \frac{\alpha I_{tot}}{4\pi(E/e)\nu_s} \sum_p \omega_p \operatorname{Re} Z_z(\omega_p)$ $< \frac{\alpha I_{tot}}{2(E/e)\nu_s} \left(R_s \times f_p\right)$	$\tau_g^{-1} = \frac{\omega_0 I_{tot}}{4\pi(E/e)} \beta_\perp \sum_p \operatorname{Re} Z_t(\omega_p)$ $< \frac{\omega_0 I_{tot}}{4\pi(E/e)} \beta_\perp R_t$
Impedance[2] (Ω; Ω /m)	$Z_z(\omega) = \frac{R_s}{1 + jQ(\omega/\omega_r - \omega_r/\omega)}$	$Z_t(\omega) = \left(\frac{\omega_r}{\omega}\right) \frac{R_t}{1 + jQ(\omega/\omega_r - \omega_r/\omega)}$
Damping Rate, τ_d^{-1} (s^{-1})	212	106
Shunt Impedance[2]	$R_s = V^2/2P$	$R_t = (c/\omega_r) R_s / b^2$
Stability Condition: $\tau_g > \tau_d$	$R_s \times f_p < 0.8 M\Omega - GHz$	$R_t < 2.5 M\Omega/m$

[1] A. Mosnier, Proc 1999 PAC.

[2] L. Palumbo, V.G. Vaccaro, M. Zobov, LNF-94/041 (P) (1994; also CERN 95-06, 331 (1995).

Preliminary mode list for single-cell SC cavity (G. Waldschmidt)

Monopole				
Frequency (GHz)	Q (unloaded)	Rs (MΩ)	Rs/Q	De-Q factor
2.28	4.95e9	2.69e5	54.5	7.7e5
3.78	4.47e9	2.65e4	5.9	1.2e5
4.66	2.15e9	1.75e4	8.1	1e5
Dipole				
Frequency (GHz)	Q (unloaded)	Rt (MΩ/m)	Rt/Q	De-Q factor
2.82	4.92e9	2.49e5	50.6	Crabbing mode
3.73	3.00e9	6.00e4	19.9	2.4e4
4.25	3.30e9	1.43e-3	4.3e-7	-
4.43	3.10e9	6.50e3	2.1	2.6e3

Preliminary estimate of BBR contribution

$$\left(\frac{Z}{n}\right)_{cav}^{BB} = \sum_j \frac{R_s^j \omega_0}{Q^j \omega_{res}^j} = 0.0074\ \Omega$$

$\omega_0 = 2\pi$ (271.55 kHz) = revolution frequency

6 MV per sector, 7 single-cell cavities each

Z/n (BB) = 0.1 Ω

Compare with 0.4 Ω total longitudinal BBR

Discussion

- **Chamber impedance not expected to be a show-stopper**
  - Main effect is shift of bunch centroid (rf phase)
  - Implement transverse feedback to control y-centroid
- **Increase the level of sophistication in simulations**
  - Include HOM of deflecting cavities
  - Compare BBR-Model vs. Numerical-Impedance elements
  - Request modifications of elegant if necessary
- **Simulation with impedance is expensive**
  - Single-part. tracking: Np=1k, Nturn=500 ➔ 1 hr
  - Impedance: Np=10k, Nturn=5000 (2-damping times) ➔ **120 hr !**
  - Wait for parallelization of elegant to be completed
  - Refine SC rf cavity design, use final rf & lattice used for single-particle tracking, then include the impedance as final check