Numerical Calculations of the NLC Damping Ring Impedances*

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NLC Damping Rings

- 2 main rings for generating low emittance e^+/e^-
- 1pre-ring for capturing e^+; collective effects less severe
- similar to 3rd generation synchrotron light sources
- main damping ring parameters:

  - circumference ~ 300 m

    250 m, 1.6 cm radius vacuum chamber

    50 m, 0.8 cm radius wiggler chamber
  - bunch length ~ 4 mm
  - energy ~ 2 GeV
  - current ~ 750 mA

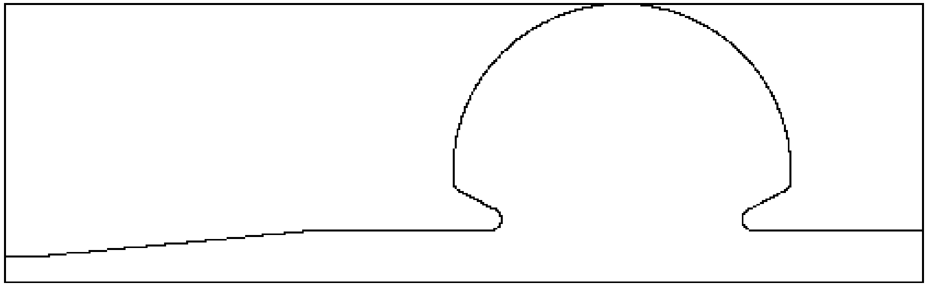
NLC damping ring broadband impedances

- Identify beamline components that generate impedance:
  - RF cavities (3)
  - resistive wall (300 m aluminum beampipe)
  - ante-chamber slots (102)
  - beam position monitors (159)
  - bellows masks (102)
  - injection kickers (2)
  - transverse feedback kickers (2)
- Calculate short-range wakefield at normal bunch length to obtain the impedance budget
- Calculate wakefield at shorter bunch length to obtain Green's function wakefield for beam instability studies (Karl Bane, this workshop)
- Longitudinal and transverse broadband impedances
- MAFIA for 2D and 3D modeling

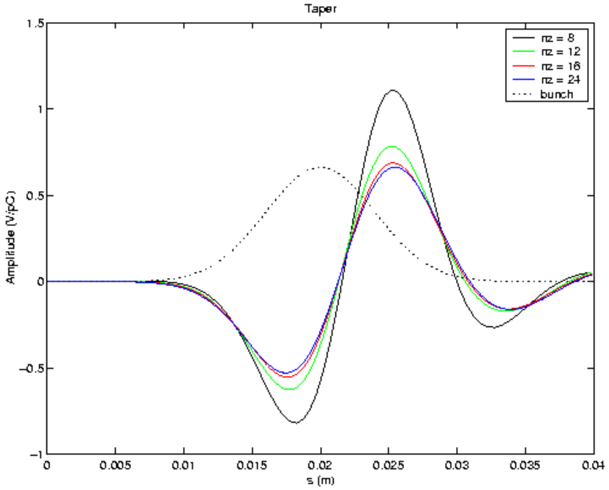
Longitudinal broadband impedance

- calculate short-range wakefield for normal bunch length of 4mm
- determine loss factor and inductance
- obtain broadband impedance budget
- determine the contributions of different beamline components to the impedance budget

RF cavity longitudinal wakefield

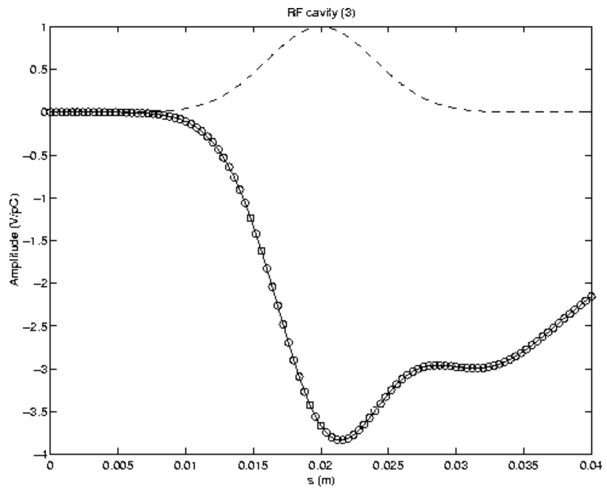


Taper wakefield

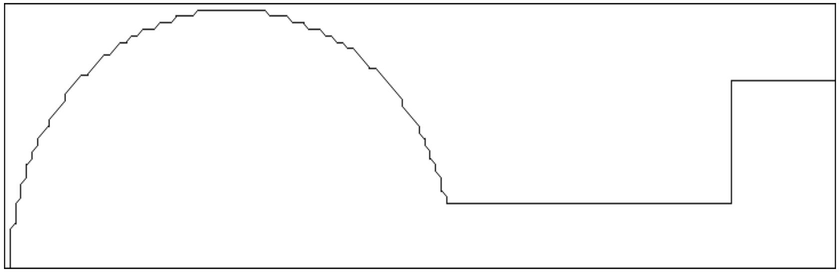


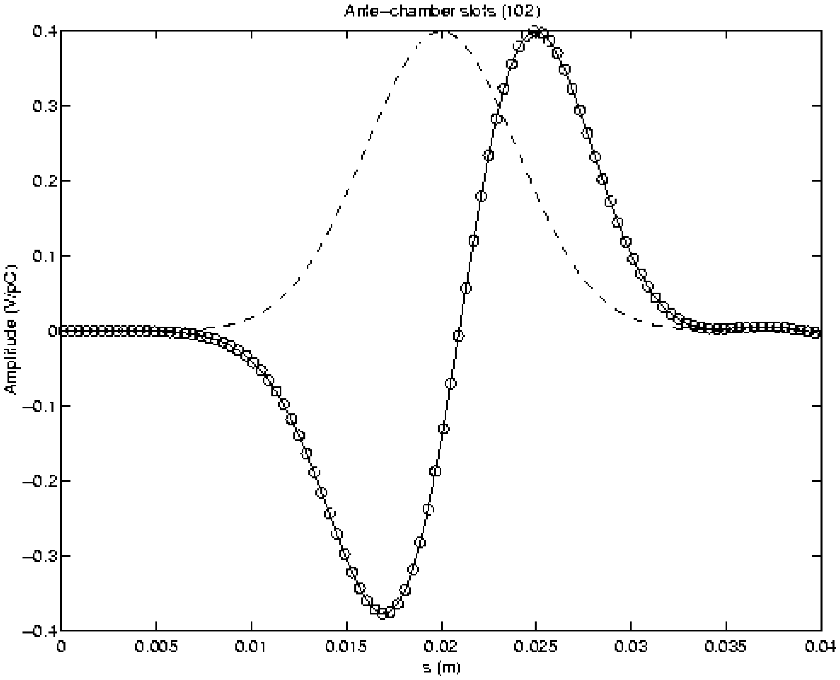
- scaled to 714 MHz from PEP-II
- tapered to beampipes at ends of RF section
- ignore crosstalk between cavity and taper
- taper wakefield sensitive to mesh size
- loss factor:
  - cavity: 0.970 V/pC
  - tapers: 0.067 V/pC
- inductance from tapers = 0.41 nH
- 3 cavities, 2 tapers

Combined wakefield



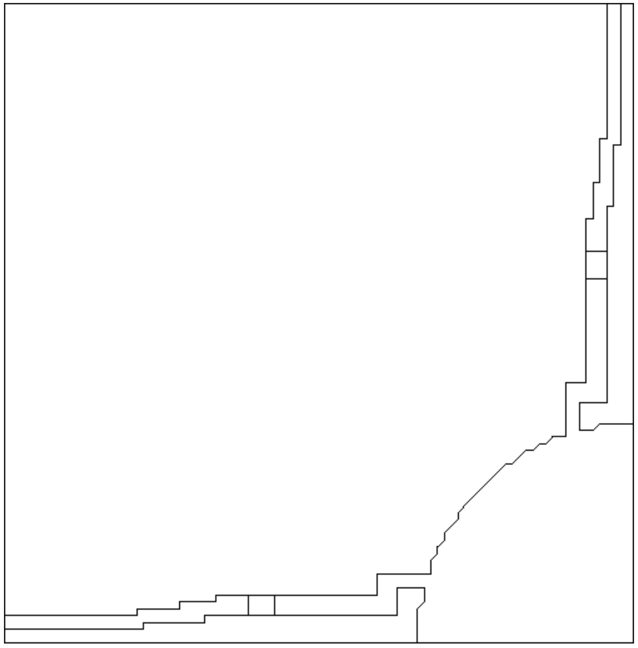
Ante-chamber slot longitudinal wakefield

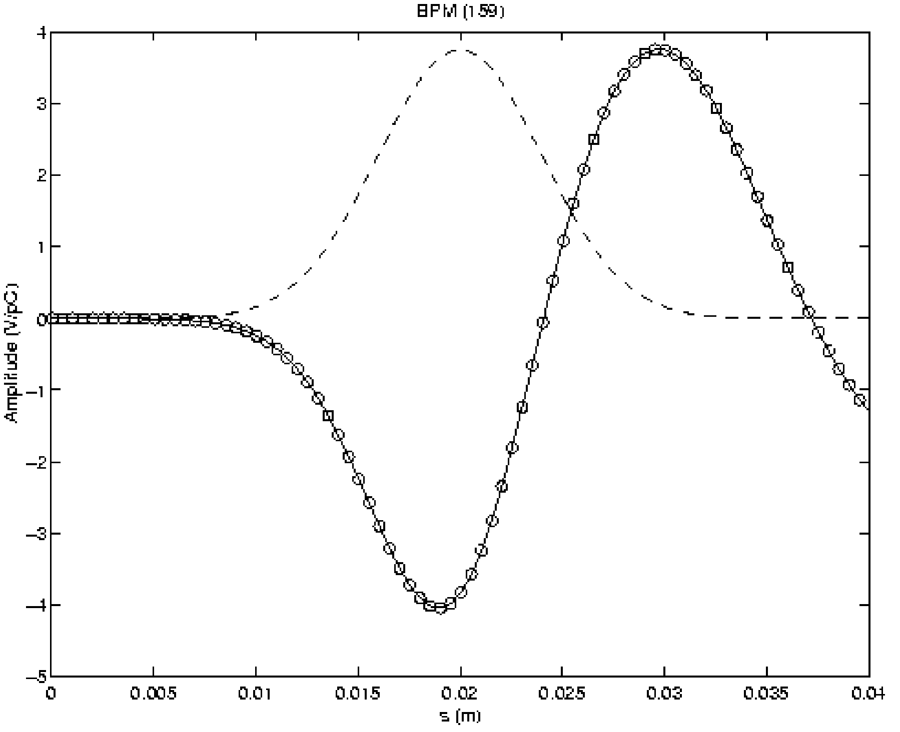




- 8 cm wide
- tapers inside slots at both ends
- loss factor = $6.65\mathrm{x}10^{-4}$ V/pC
- inductance = $2.72\mathrm{x}10^{-3}$ nH
- 102 slots

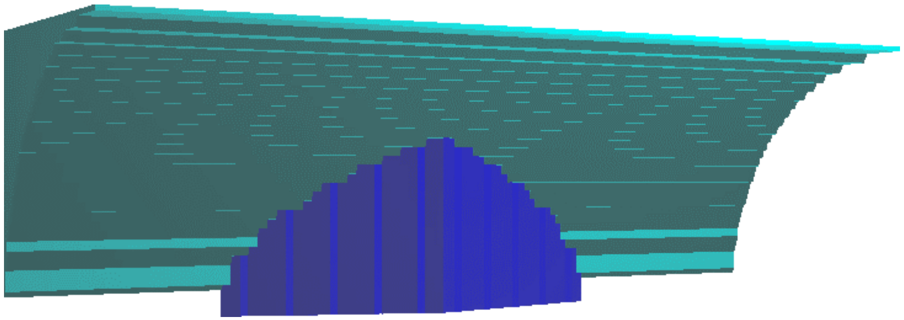
BPM longitudinal wakefield

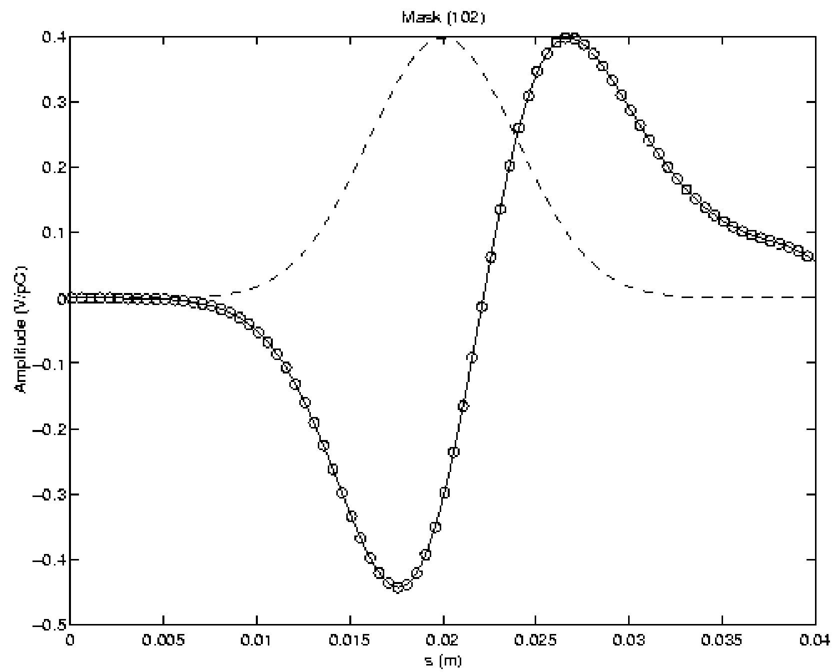




- four 8 mm buttons
- loss factor = 0.014 V/pC
- inductance = 0.019 nH
- 159 BPMs

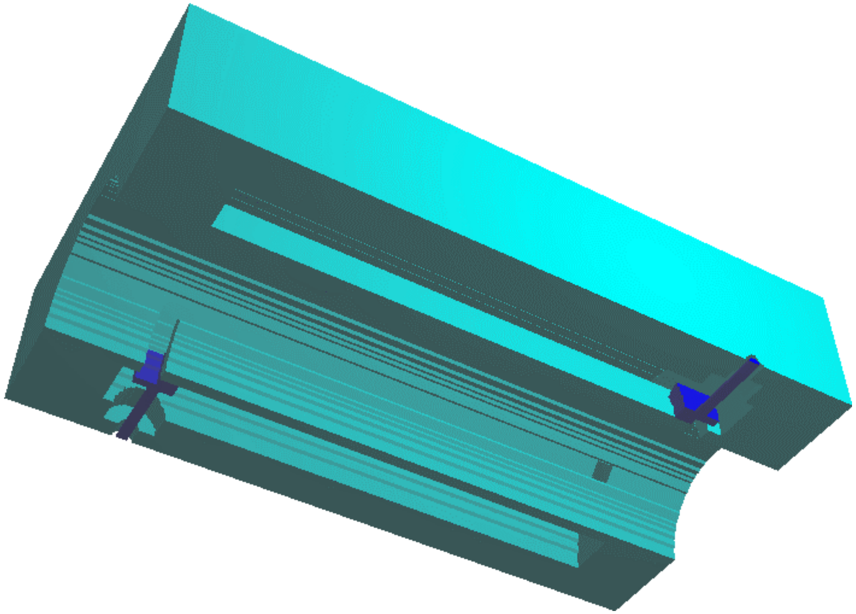
Mask longitudinal wakefield

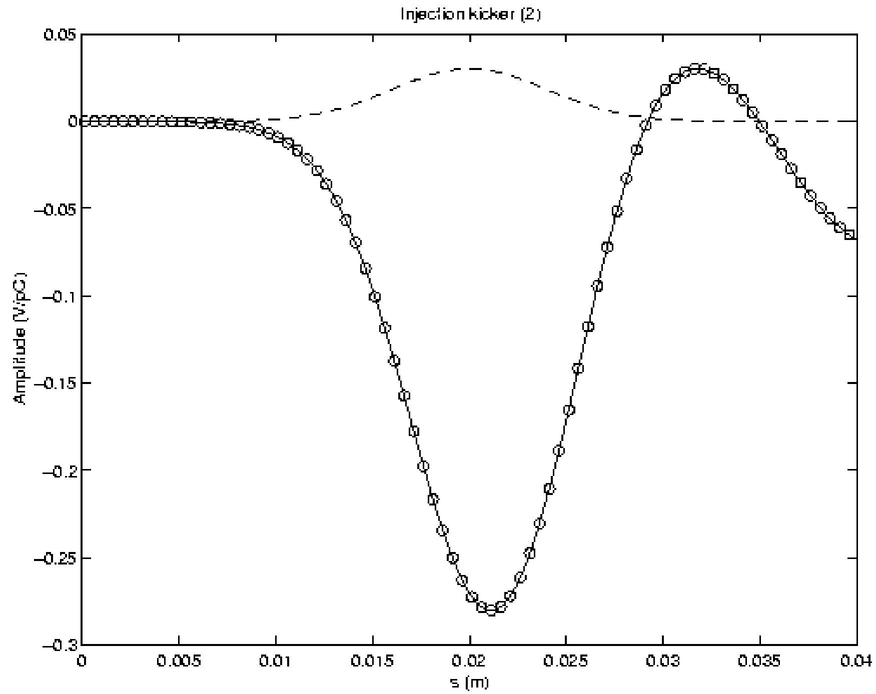




- 2 mm depth, 2.5 cm long
- loss factor = 0.0016 V/pC
- inductance = 0.0039 nH
- 102 bellows masks

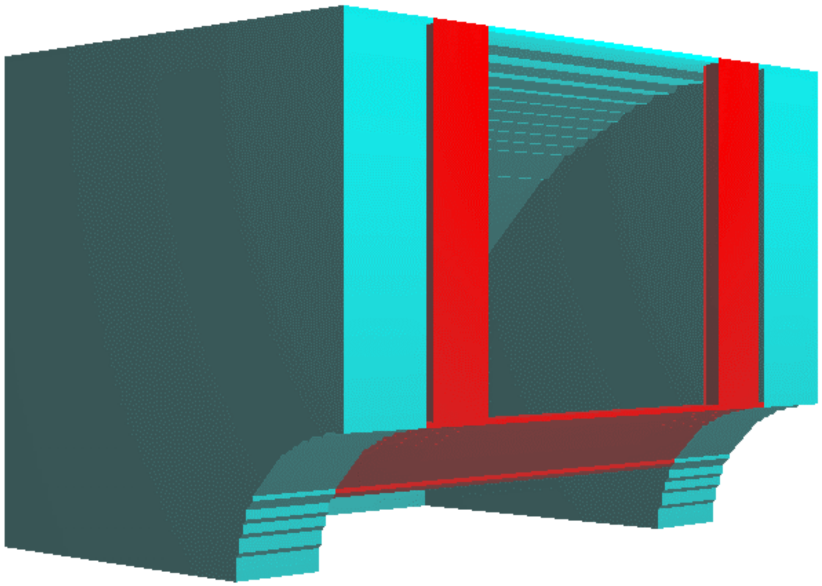
Injection kicker longitudinal wakefield

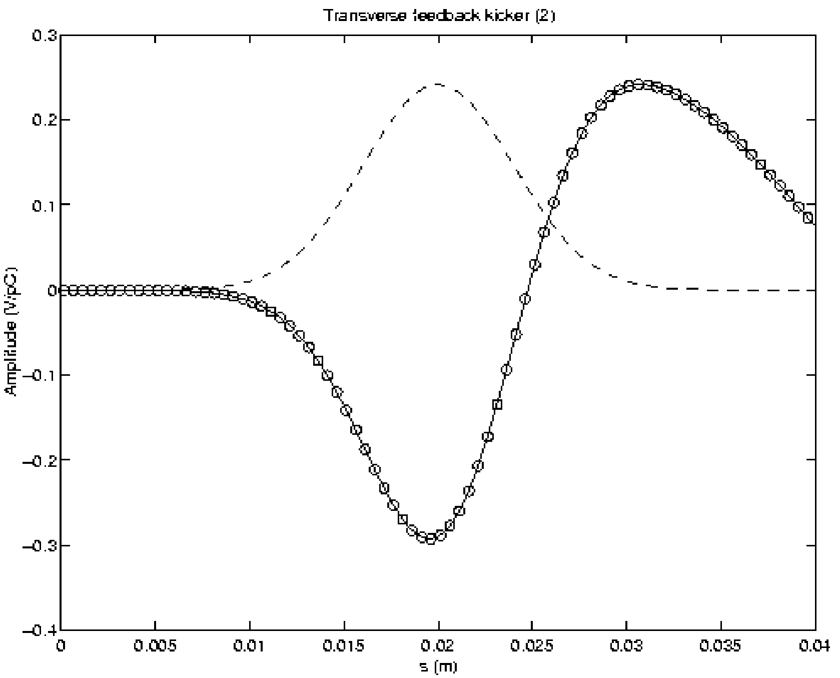




- DELTA-type kicker
- 4 mm wide slots
- loss factor = 0.096 V/pC
- inductance = 0.103 nH
- 2 injection kickers

Transverse feedback kicker longitudinal wakefield





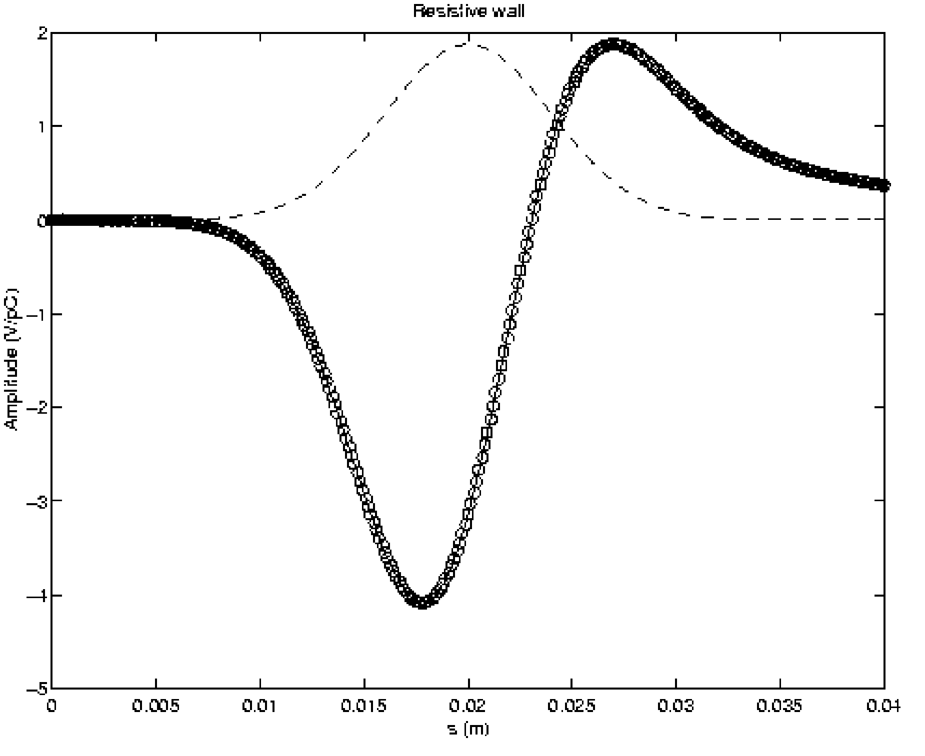
- Two 1.6 cm wide slots
- loss factor = 0.086 V/pC
- inductance = 0.107 nH
- 2 transverse feedback kickers

Longitudinal resistive wall wakefield

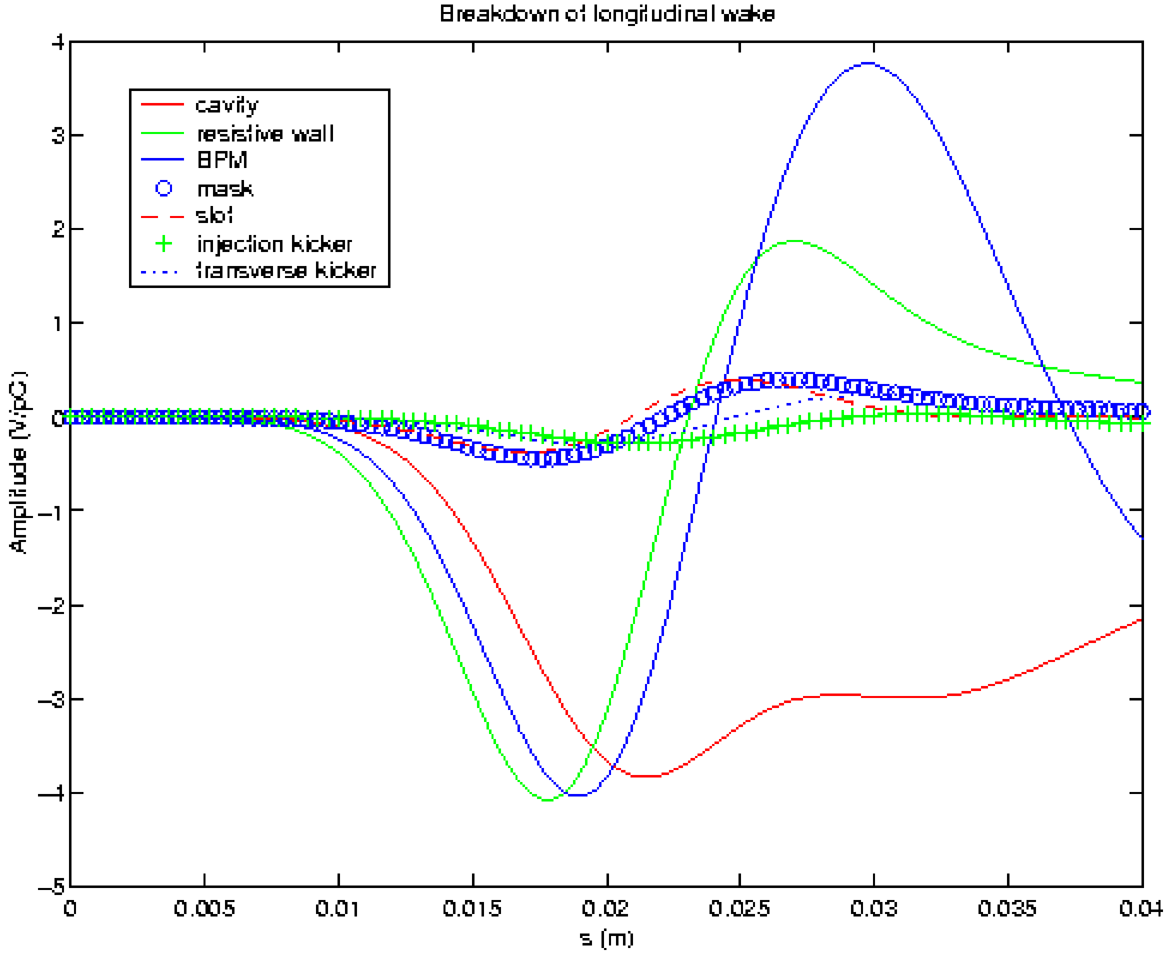
$$W_0(s) = \frac{L}{b\sigma_z^{3/2}} \frac{c}{8\pi} \sqrt{\frac{Z_0}{2\sigma_c}} f\left(\frac{s}{\sigma_z}\right)$$

$$f(u) = |u|^{3/2} e^{-u^2/4} \left(I_{1/4} - I_{-3/4} \mp I_{-1/4} \pm I_{3/4}\right)\Big|_{u^2/4}$$

- aluminum chambers
- 250 m vacuum chamber; 1.6 cm radius
- 50 m wiggler chamber; 0.8 cm radius
- loss factor = 1.867 V/pC



Breakdown of longitudinal wakefield

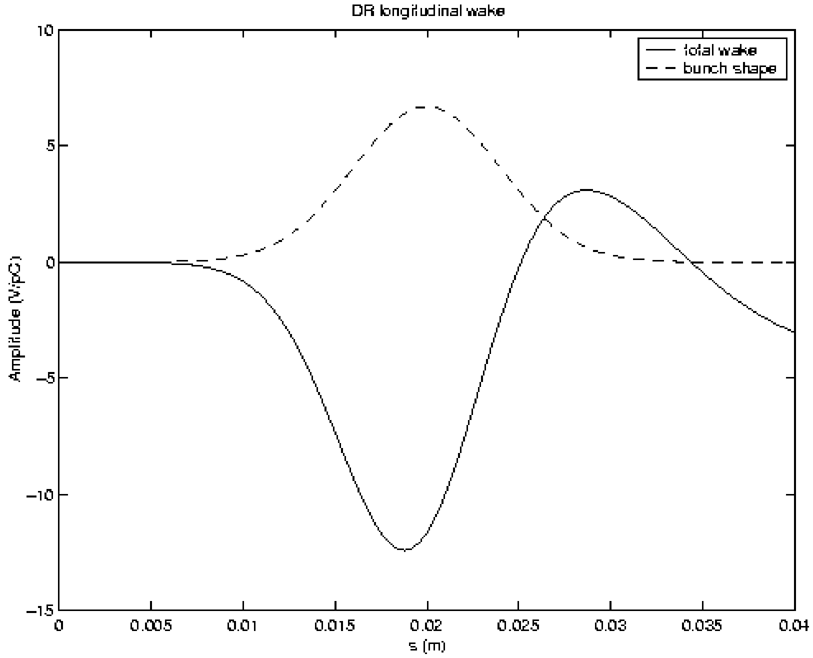


Longitudinal broadband impedance budget

Impedance budget

Component	Quantity	Loss factor (V/pC)	Inductance (nH)
RF Cavity	3	2.976	0.41
BPM	159	2.226	2.97
Slot	102	0.068	0.28
Mask	102	0.168	0.33
Inj. kicker	2	0.192	0.21
Trans. kicker	2	0.171	0.21
Resist. wall		1.867	
Total		7.67	4.40

- $|Z/n| \sim 0.028\ \Omega$
- PEP-II HER ring:
  Loss factor = 2.5 V/pC
  Inductance = 48 nH



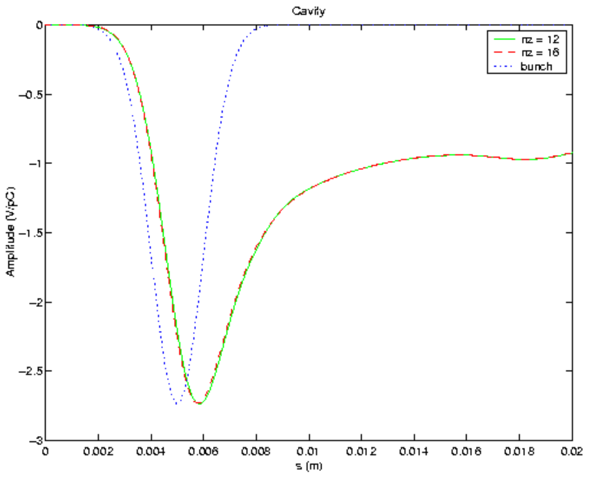
Damping ring longitudinal wakefield

Longitudinal Green’s function wakefield

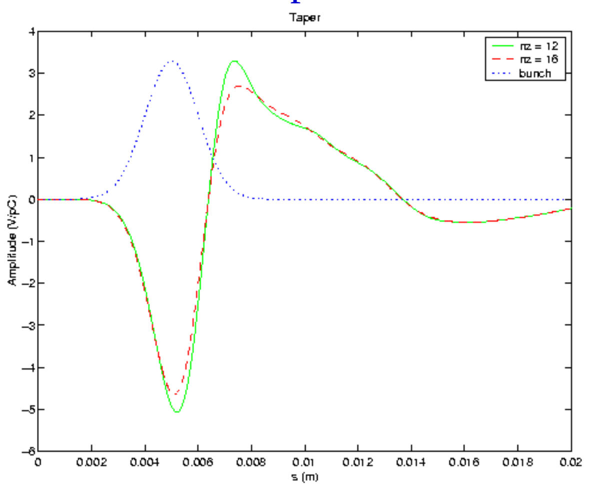
- used as input for studies of single bunch instability
- repeat wakefield calculations for each beamline component at a shorter bunch length
- bunch length ~ 1 mm

RF cavity Green's function wakefield

Cavity

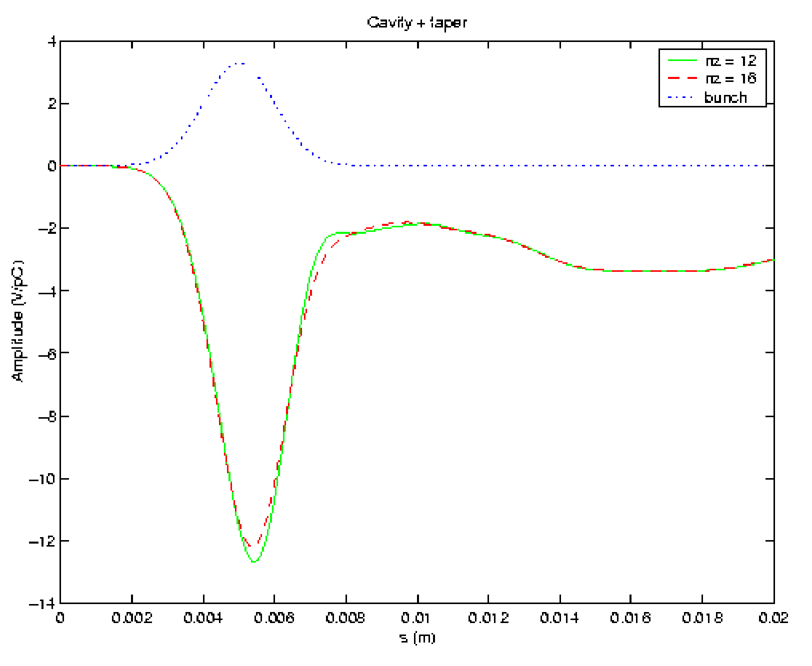


Taper



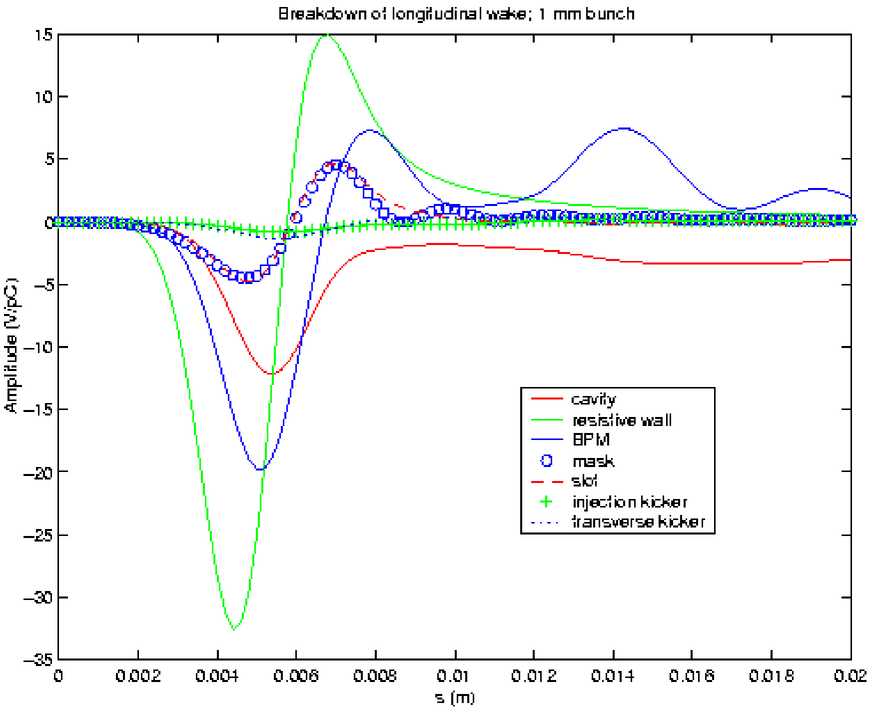
- breakdown into cavity and taper
- cavity as diffraction model
- taper highly resistive
- overall wakefield sensitive to mesh size due to taper

Combined wakefield

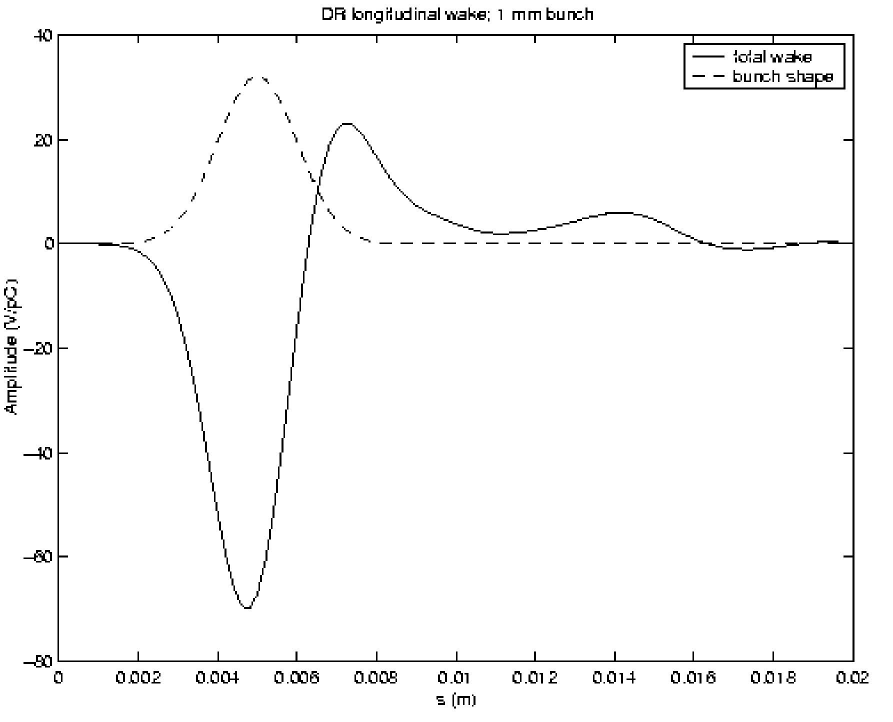


Damping ring longitudinal Green's function wakefield

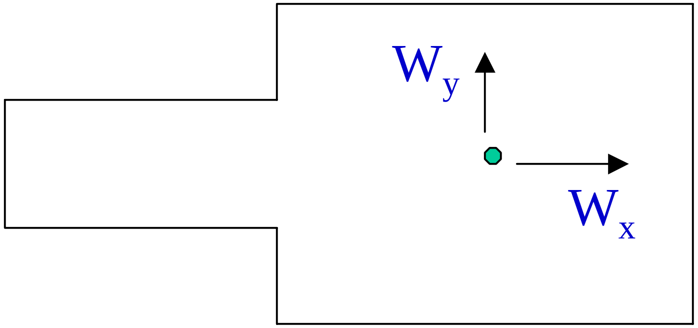
Breakdown



Total



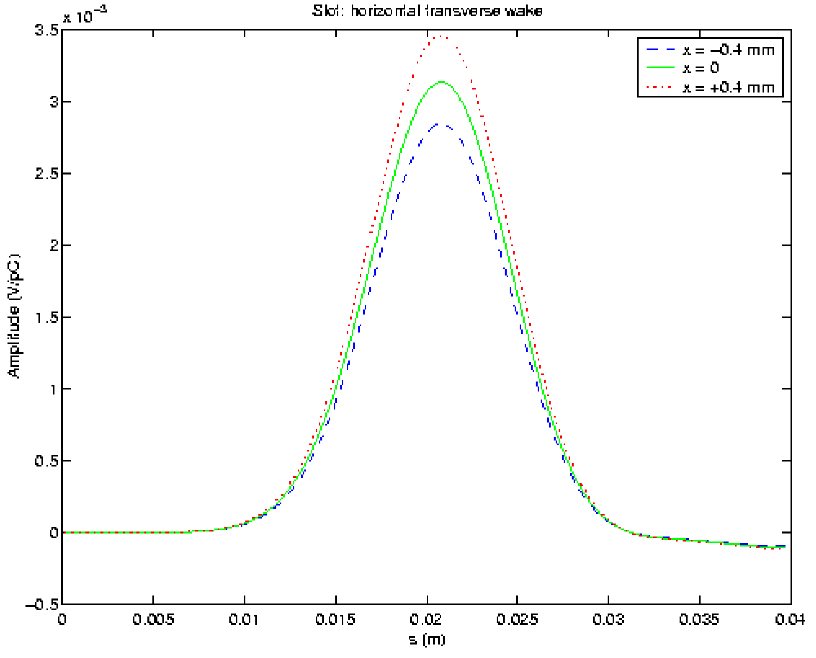
Transverse broadband impedance



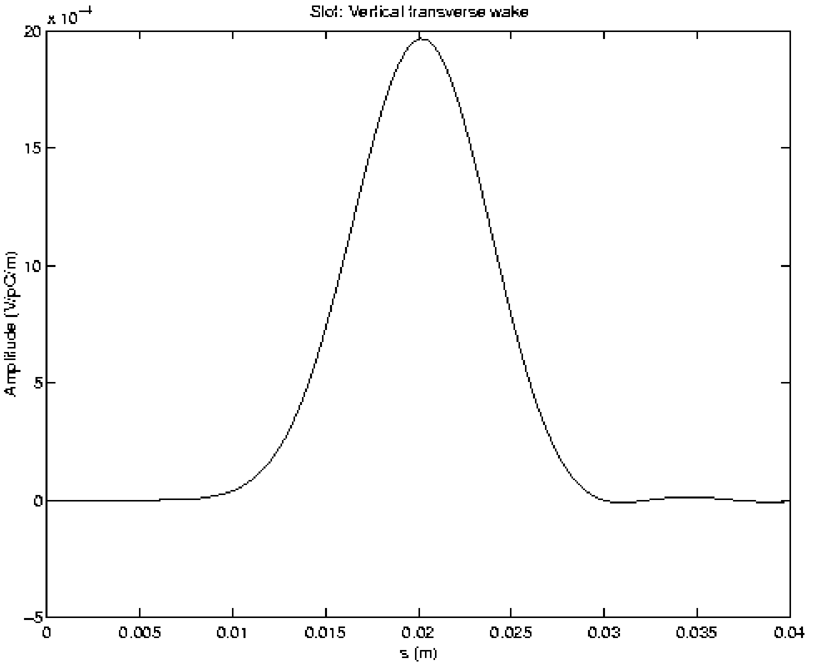
- Cylindrically symmetric structures: $W_x = W_y$
- Non-cylindrically structures:
  - different horizontal and vertical components
  - non-vanishing kick on beam axis
  - transverse wakefield determined by subtracting the dc component
  - wakefield component normally larger in the direction of asymmetry

Slot transverse wakefield

Horizontal



Vertical

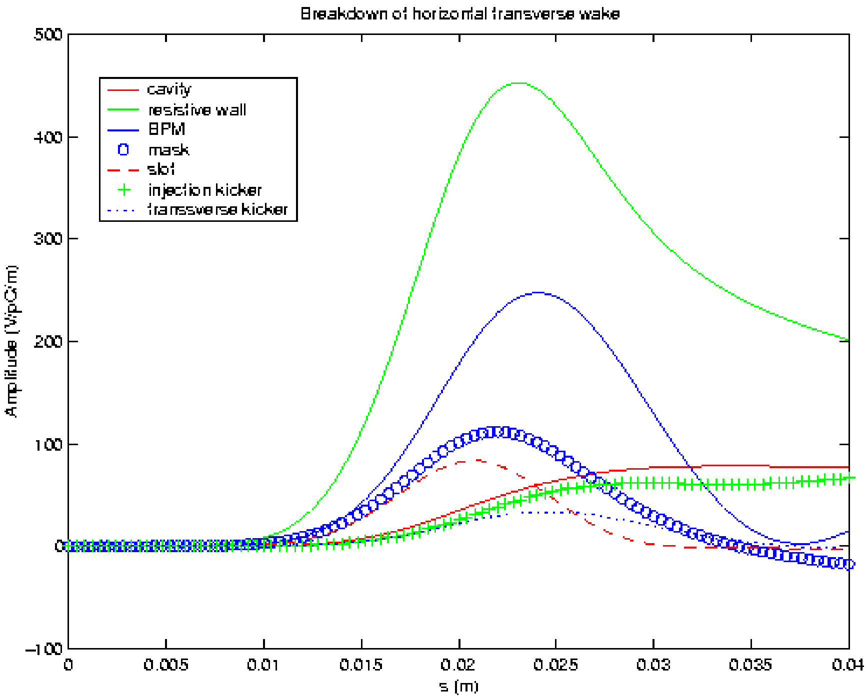


- Kick factor = 0.55 V/pC/m

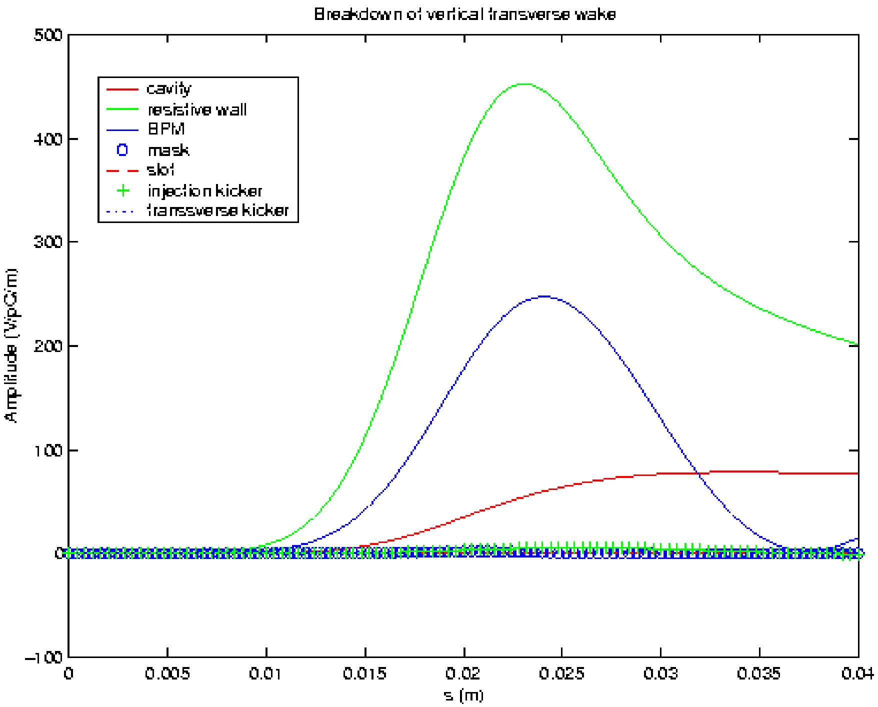
- Kick factor = 1.32x10^{-3} V/pC/m

Breakdown of transverse wakefields

Horizontal



Vertical



Transverse broadband impedance budget

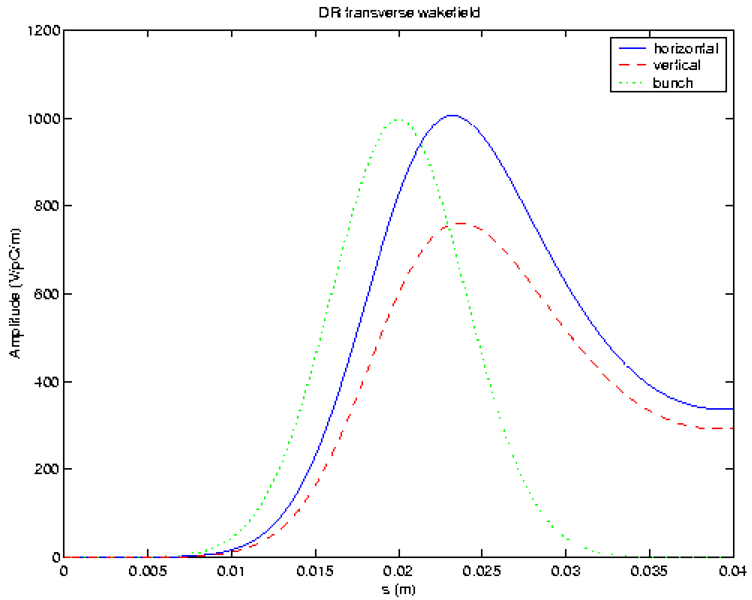
Impedance budget

Component	Quantity	Horizontal kick factor (V/pC/m)	Vertical kick factor(V/pC/m)
RF Cavity	3	36.08	36.08
BPM	159	146.76	146.76
Slot	102	56.34	0.13
Mask	102	77.01	1.22
Inj. kicker	2	25.40	2.86
Trans. kicker	2	19.05	0.40
Resist. wall		320.64	320.64
Total		681.28	508.10

- dominated by resistive wall ~ $1/b^3$:

$$W_1(s) = \frac{L}{b^3 {\sigma_z}^{1/2}} \frac{c}{2\pi} \sqrt{\frac{Z_0}{2\sigma_c}} f\left(\frac{s}{\sigma_z}\right)$$

$$f(u) = |u|^{1/2} e^{-u^2/4} (I_{-1/4} \pm I_{1/4})|_{u^2/4}$$



Damping ring transverse wakefields

Conclusions

- evaluated the broadband longitudinal and transverse impedance budgets of the NLC damping rings
- longitudinal impedance budget contributed mainly by RF cavities, BPMs and resistive wall
- transverse impedance budget dominated by resistive wall
- evaluated the longitudinal Green's function wakefield for beam instability studies