CSR in SuperKEKB and SuperB DR

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Thanks to: Y. Cai, S. Guiducci, M. Kikuchi, K. Oide, S. Kramer

2nd SuperB collaboration meeting@INFN-LNF

Dec. 15, 2011

Outline

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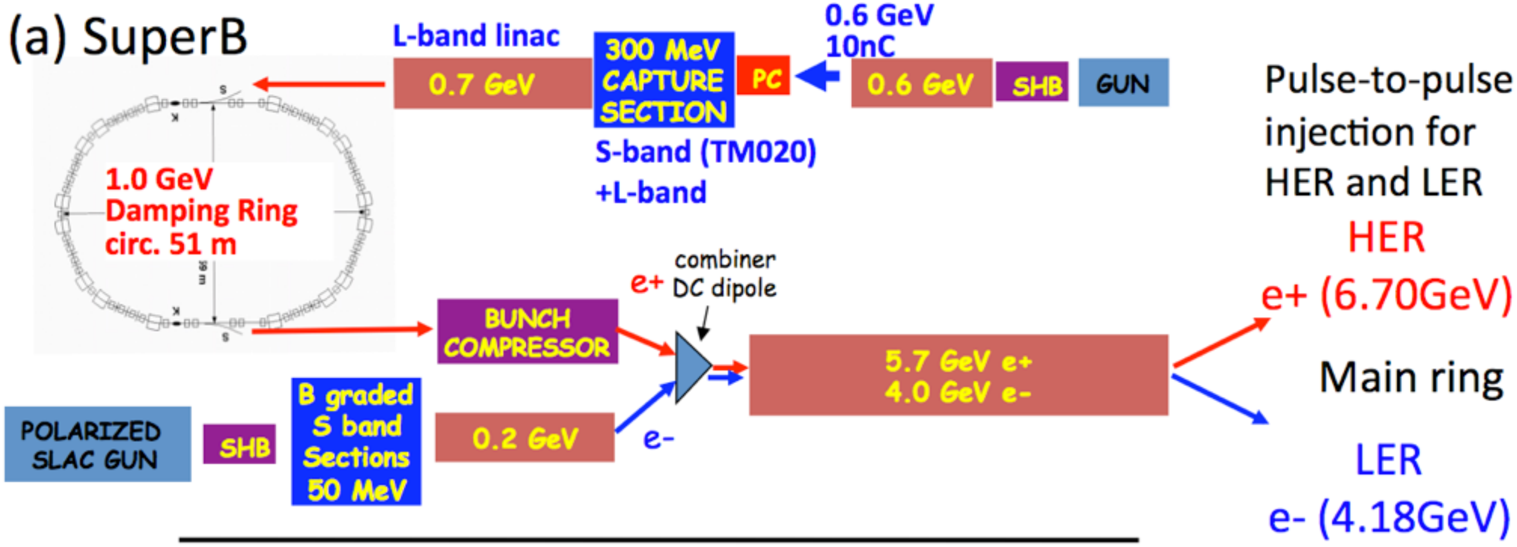
1. Introduction

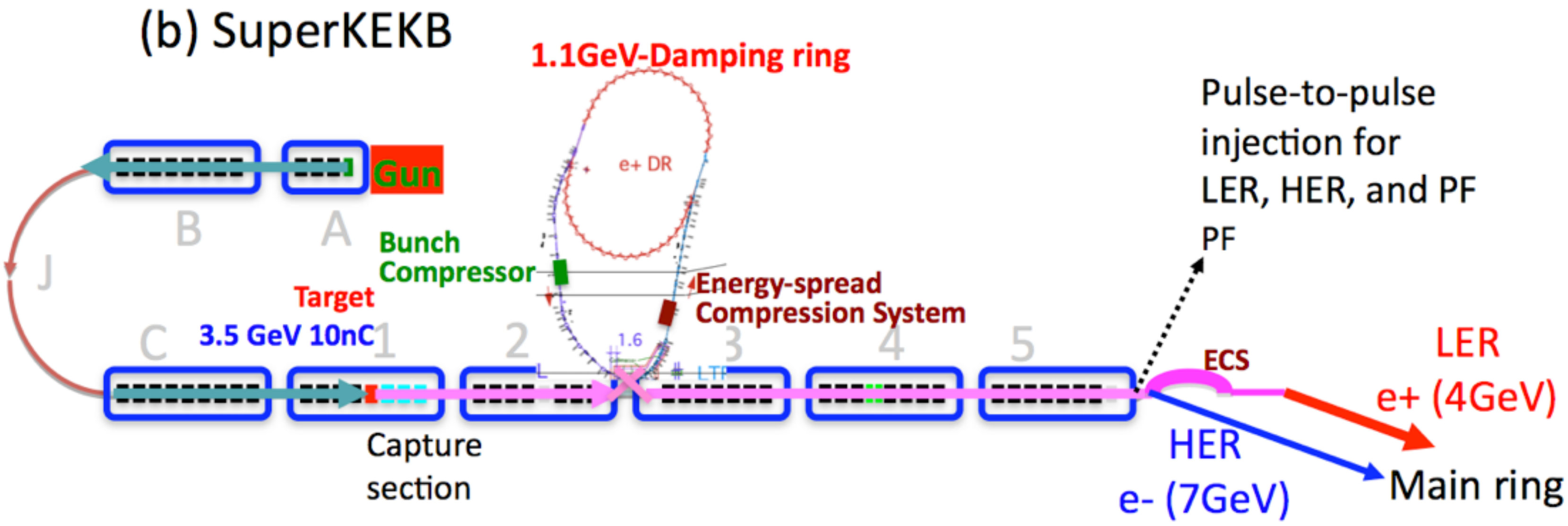
Let me start from two conclusions:

1). At the present designed bunch current, the SuperB and SuperKEKB DRs operate above CSR instability threshold. CSR is not a concern.

2). To achieve high bunch population up to 5×10^{10}, CSR might set challenges.

1. Introduction - Layout





Courtesy of N. Iida

N. Iida, et al., THYA01, IPAC'11 (2011)

1. Introduction - Machine parameters

TABLE I. SuperB and SuperKEKB positron damping rings parameters

	Symbol	SuperB	SuperKEKB
Energy (GeV)	E	1.0	1.1
Circumference (m)	C	51.1	135.5
Number of bunches	N_b	1[a]	2
Particles/bunch	N	4.0×10^9	$1.3^{\mathrm{b}} \times 10^{10}$
Hor./Ver. equilibrium emittance (nm)	ϵ_x/ϵ_y	23/0.2	41.4/2.07
Horizontal damping time (ms)	τ	7.3	10.9
Relative energy spread	σ_δ	6.2×10^{-4}	5.5×10^{-4}
Momentum compaction	α_p	0.0057	0.0141
Bunch length (mm)	σ_z	4.8	6.53
RF frequency (MHz)	f_{RF}	475	509
RF voltage (MV)	V_{RF}	0.5	1.4

1. Introduction - Machine parameters (cont'd)

Vacuum chamber width/height (mm)	w/h	34/24[c]	34/24
Number of dipoles		16	32/38/6/2
Dipole length (m)	L_b	0.75	0.74248/0.28654/0.39208/0.47935
Bending angle/dipole		0.3927	0.27679/0.09687/0.1246/0.15218
Bending radius (m)	R	1.91	2.68/2.96/3.13/3.15
Total bending angle		2π	13.5903[d]

[a] With maximum number of 5, according to Ref. [1].

[b] The maximum charge produced by the positron generator is 5.0 [4].

[c] Assumed to be the same as SuperKEKB DR.

[d] Reverse-bend optics [4].

[1] S. Guiducci, et al., IPAC'11, p. 3738

[4] M. Kikuchi, et al., IPAC'10, p. 1641

2. Simple instability analysis

Y. Cai, FRXAA01, IPAC'11 (2011)

Shielding parameter:

$$\chi = \sigma_z \sqrt{\frac{R}{h^3}}. \tag{1}$$

Alfvén current:

$$I_A = 4\pi\epsilon_0 \frac{m_e c^3}{e}. \tag{2}$$

Threshold with coasting beam + free-space CSR model:

$$N_{th1} = \frac{CI_A}{ce} \frac{\pi^{1/6}\alpha_p \gamma \sigma_\delta^2 \sigma_z}{\sqrt{2}R^{1/3}\lambda^{2/3}}. \tag{3}$$

Threshold with coasting beam + parallel-plates shielding:

$$N_{th2} = \frac{CI_A}{ce} \frac{3\sqrt{2}\alpha_p \gamma \sigma_\delta^2 \sigma_z}{\pi^{3/2}h}. \tag{4}$$

Threshold with bunched beam:

$$N_{th3} = \frac{CI_A}{ce} \frac{\alpha_p \gamma \sigma_\delta^2}{\sigma_z} \frac{\sigma_z^{4/3}}{R^{1/3}} \xi_{th}, \tag{5}$$

where

$$\xi_{th} = 0.5 + 0.34\chi. \tag{6}$$

2. Simple instability analysis (cont'd)

Y. Cai, FRXAA01, IPAC'11 (2011)

The theory reasonably agrees with experiments ...

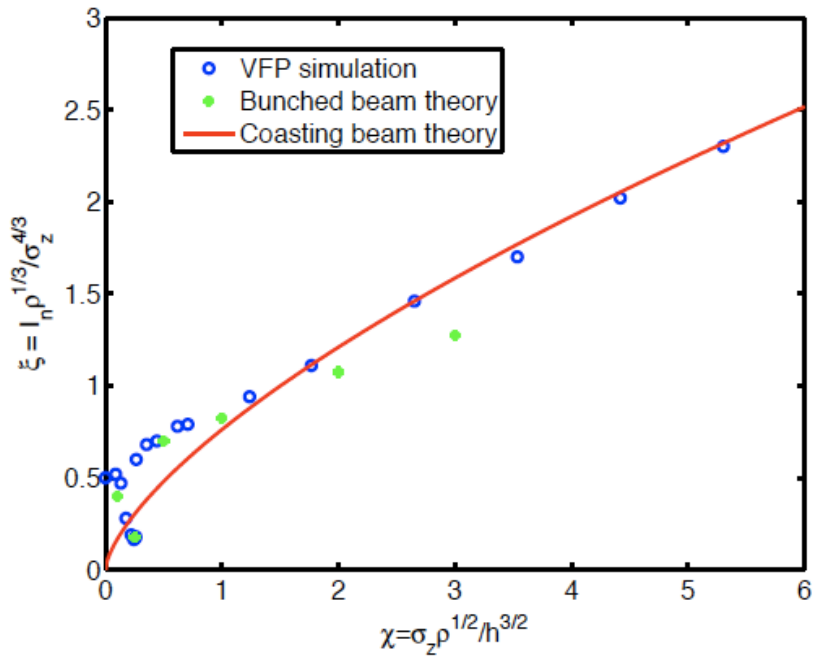


Figure 5: Threshold ξ^{th} as a function of the shielding parameter χ. The circles are the result of the VFP simulation[7].

Table 2: Comparison of Theory with Measurements at Various Synchrotron Light Sources

Machine	F (meas.)	F (theory)	χ
BESSY II	7.46	5.84	0.48
MLS	3.40	5.23	0.29
ANKA	4.36	5.58	0.42
Diamond	2.90	1.48	0.25

$$F = 4\pi\xi^{th}(\chi)/3^{1/3}$$

Courtesy of Y. Cai

2. Simple instability analysis (cont'd)

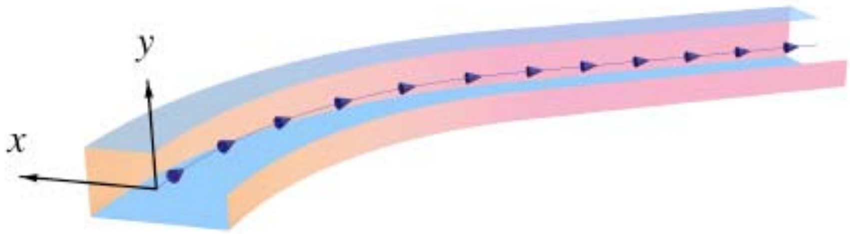
TABLE II. Estimated instability threshold for SuperB and SuperKEKB positron damping rings

	SuperB	SuperKEKB
Design	0.4×10^{10}	1.3×10^{10}
N_{th2}	1.19×10^{10}	4.6×10^{10}
N_{th3}	1.17×10^{10}	4.4×10^{10}

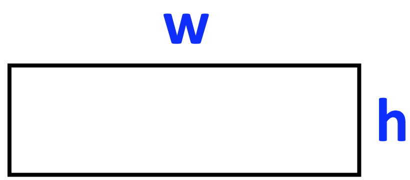
CSR instability thresholds of the DRs of SuperB and SuperKEKB are estimated based on Eqs. (4) and (5). The results are shown in Table II. The values give us an optimistic conclusion: For both DRs, the instability threshold is about 3 times larger than the designed bunch population.

3. Calculation of CSR impedance

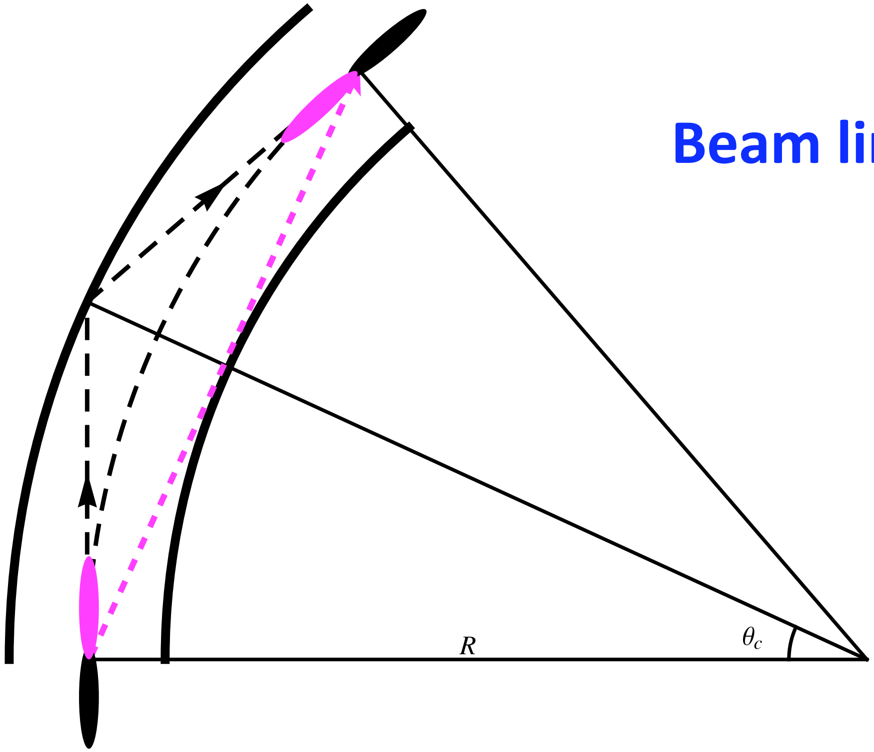
Two codes, Oide's (arbitrary cross-section) and Zhou's (rectangular cross-section), were used in CSR calculations.



Chamber model



Chamber cross-section



Beam line: =(Bend)
=(Bend1, Bend2, ...)
=(Bend, Drift)
=(Bend1, Drift1, Bend2, Drift2, ...)

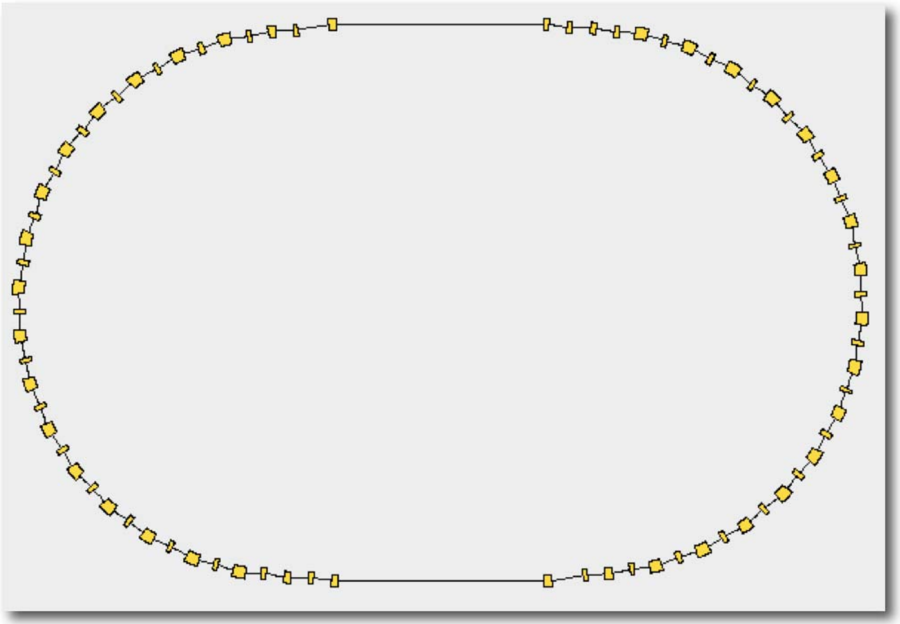
Transient, chamber shielding, interference effects are in numerical calculations.

3. Calculation of CSR impedance (cont'd)

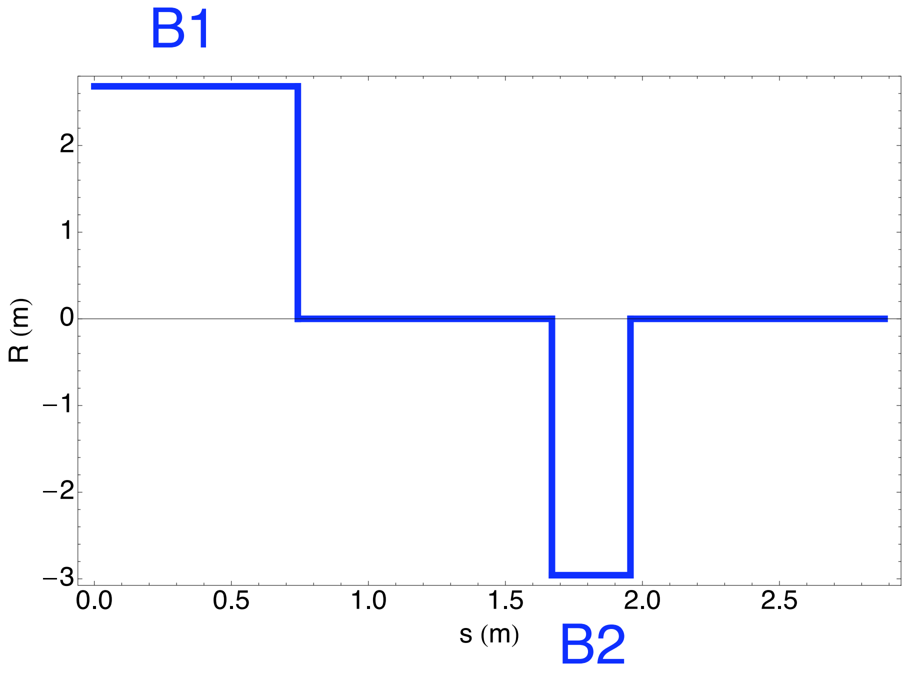
SuperKEKB damping ring: multi-bend interference

w/h=34/24 mm, L_{bend}=0.74/0.29 m, R=2.7/-3 m (reverse bends)
L_{drift}=0.9 m, N_{cell}=32

Vacuum chamber is assume to be smooth along the ring, but this is not the truth and is a pessimistic assumption.



Layout



Reverse bends (1 cell)

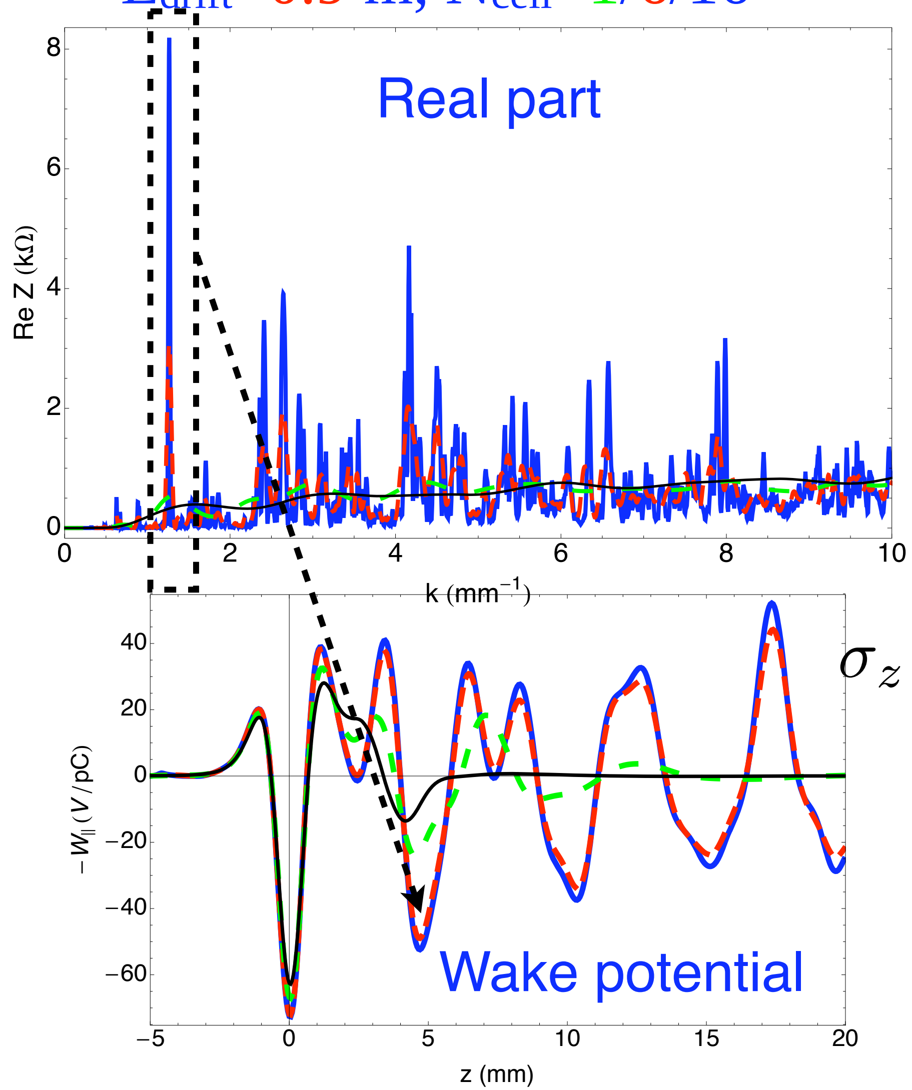
M. Kikuchi, et al., IPAC'10, p. 1641 (2010)

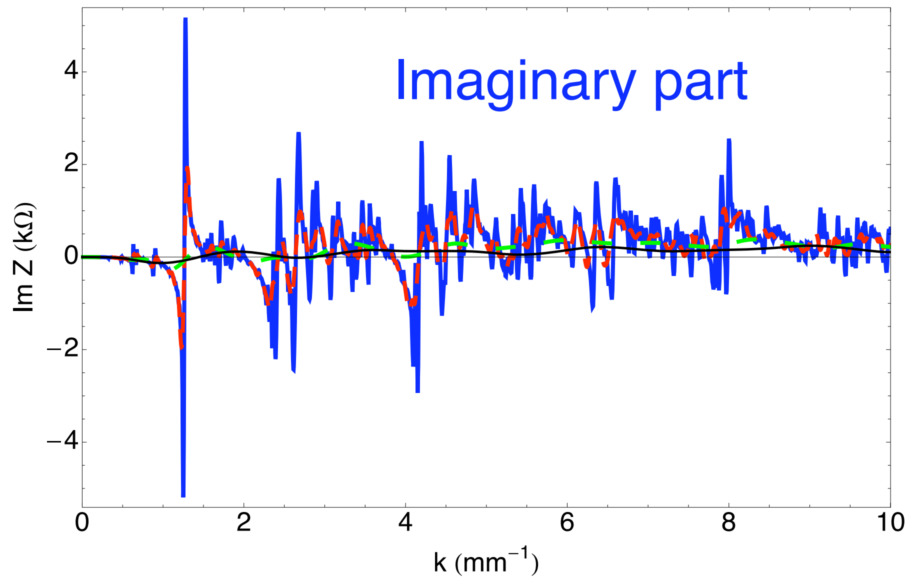
3. Calculation of CSR impedance (cont'd)

SuperKEKB damping ring (one arc section) (Perfect conducting wall)

w/h=34/34 mm, L_{bend}=0.74/0.29 m, R=2.7/-3 m (reverse bends)

L_{drift}=0.9 m, N_{cell}=1/6/16





$$\sigma_z = 0.5 \text{ mm}$$

Blue solid lines: 16 cells

Red dashed lines: 6 cells

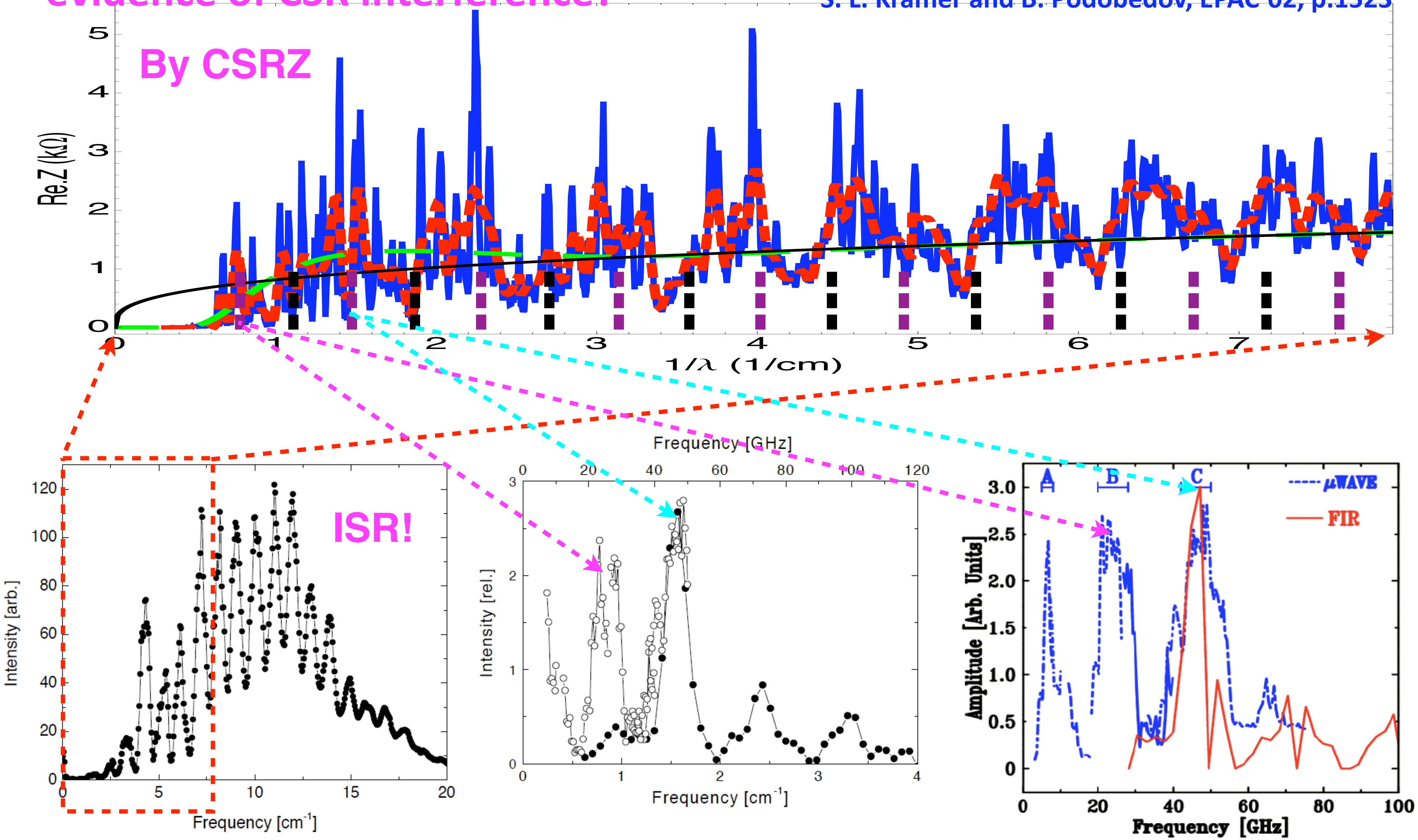
Green dotted lines: 1 cell

Black solid lines: single-bend

3. Calculation of CSR impedance (cont'd)

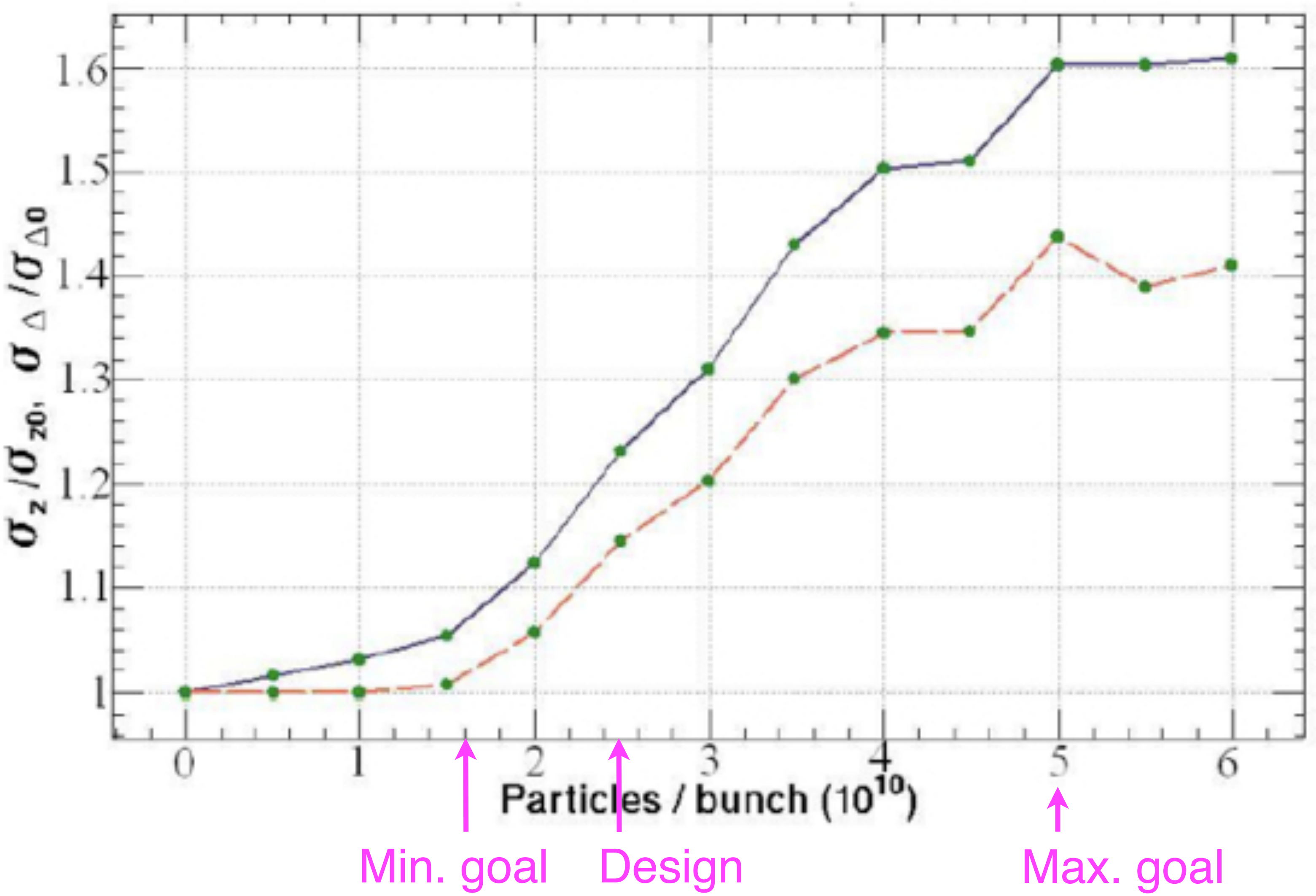
SR power spectrum at NSLS VUV ring: evidence of CSR interference?

G. L. Carr, S. L. Kramer, N. Jisrawi, L. Mihaly and D. Talbayev, PAC'01, p.377
S. L. Kramer and B. Podobedov, EPAC'02, p.1523



4. Numerical simulations

SuperKEKB DR: simulations using Vlasov solver (geometric wakes included) [Ikeda (2011)]**:**



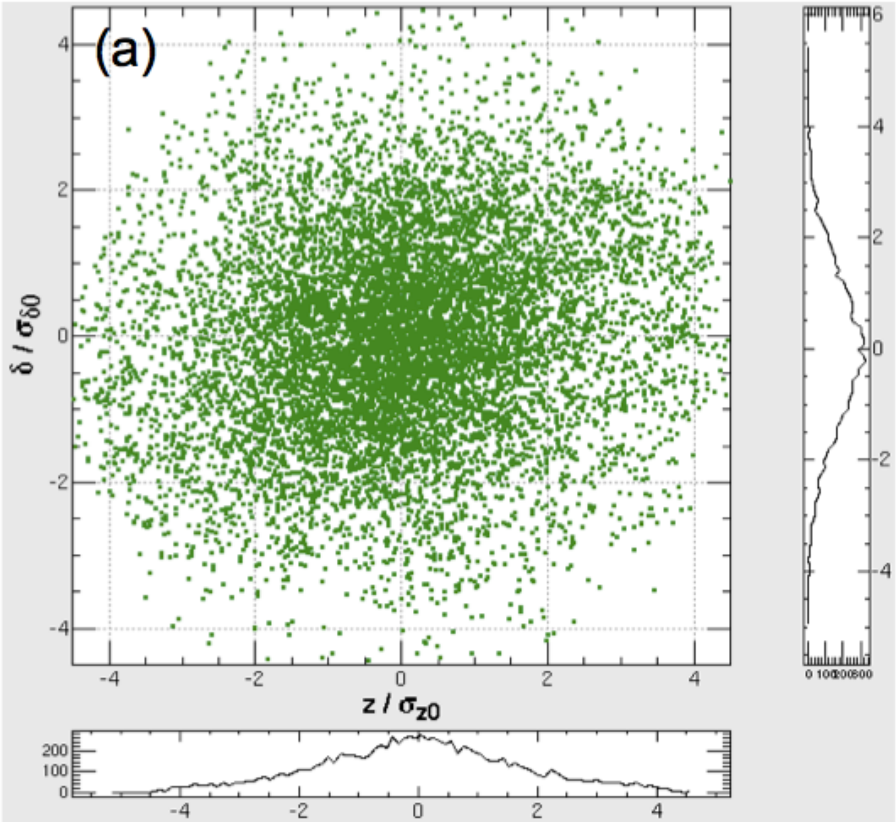
H. Ikeda, et al., THPZ021, IPAC'11 (2011)

4. Numerical simulations (cont'd)

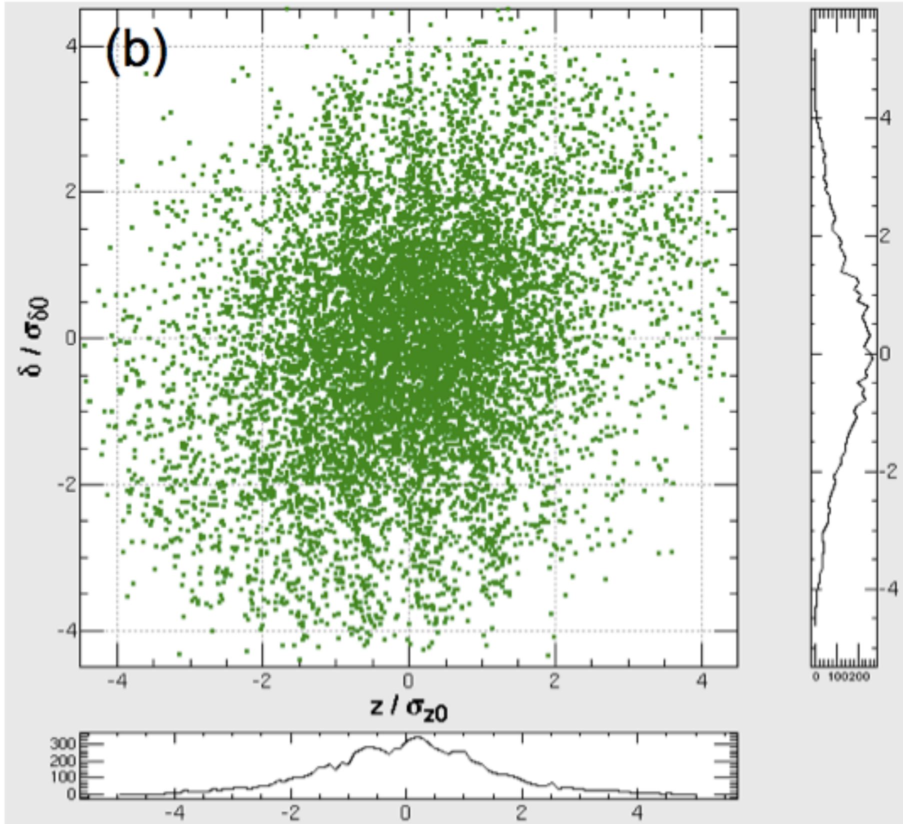
SuperKEKB DR: high-freq. modulation was observed in simulations

[Iida (2011)]

$$N = 5 \times 10^{10}$$



Weak modulation



Strong modulation

N. Iida, et al., THYA01, IPAC'11 (2011)

5. Summary

1). CSR is not a concern in the present design (Minimum bunch current injected to the DR) of SuperB and SuperKEKB DR.

2). The theory with steady-state impedance model is very good for checking CSR instability in the design stage.

3). Transient effect, toroidal chamber shielding and multi-bend interference may play roles in CSR instability in SuperB and SuperKEKB DR (small bending radius and short drifts). For a pessimistic estimate, they might reduce the instability threshold by a factor of 2. Even so there are enough margins.

4). To achieve high bunch population up to 5×10^{10}, CSR might set challenges.