Impedance issues in KEKB and SuperKEKB

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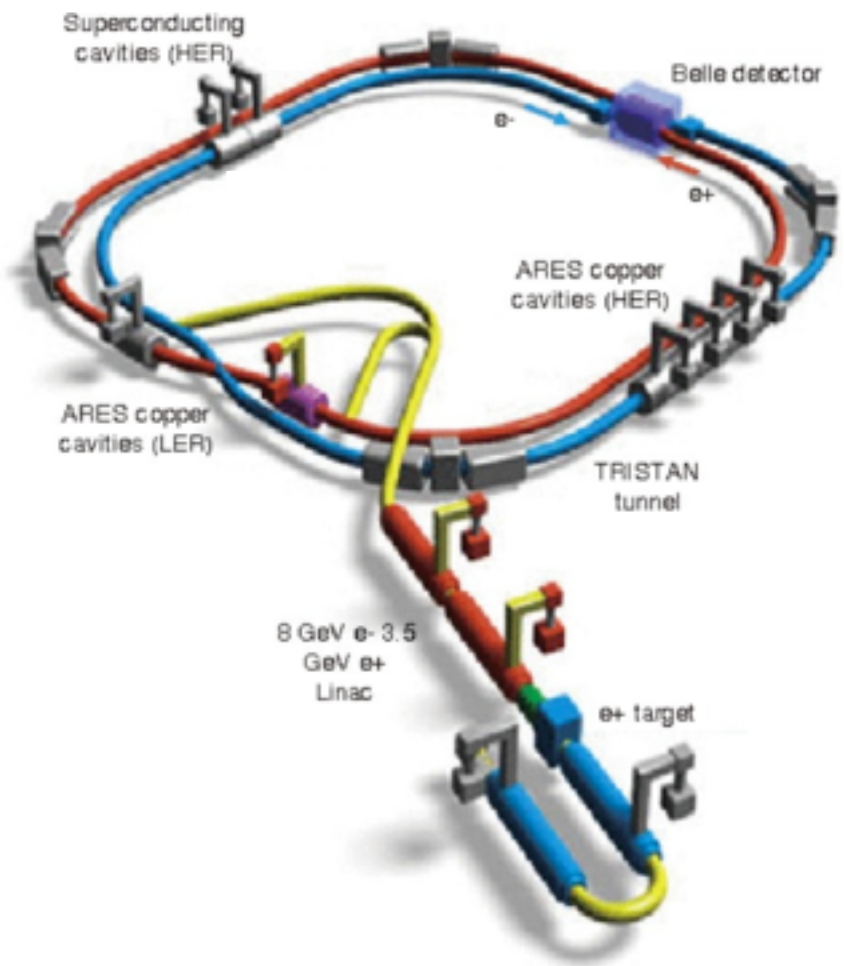
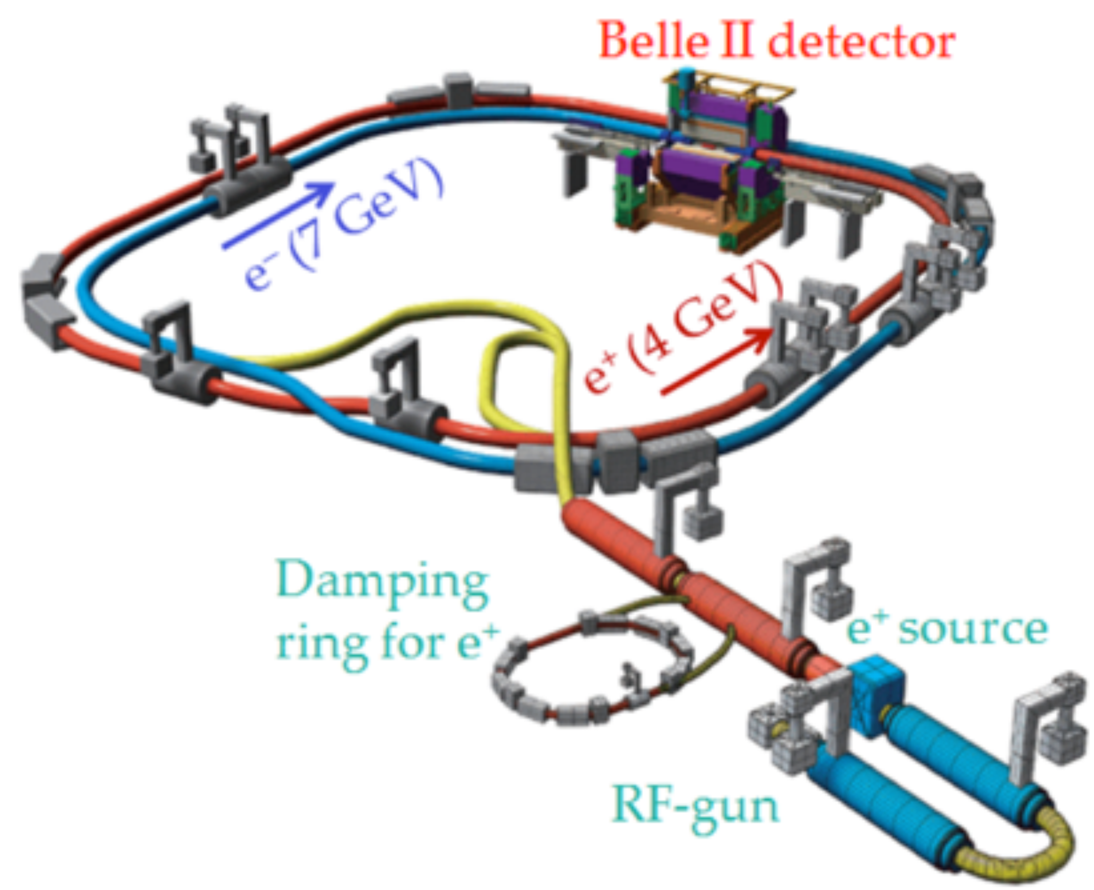
Outline

- ➤ **Introduction**
  - **KEKB and SuperKEKB**
- ➤ **Impedance model and Single-bunch effects**
  - **Impedance calculations, impedance budget, …**
  - **Bunch lengthening, MWI, beam tilt, TMCI, …**
- ➤ **Coherent synchrotron radiation (CSR)**
  - **Its role in KEK's projects**
  - **Code developments and impedance calculations**
  - **CSR driven MWI**
  - **CSR field dynamics**
- ➤ **Summary**

1. Introduction

	LER		HER	
	SKEKB	KEKB*	SKEKB	KEKB*
E (GeV)	4	3.5	7.007	8
I_b (mA)	1.44	1.03	1.04	0.75
ε_x (nm)	3.2	18	4.6	24
ε_y (pm)	8.64	180	12.9	240
α_p (10^{-4})	3.25	3.31	4.55	3.43
σ_δ (10^{-4})	8.08	7.73	6.37	6.3
σ_z (mm)	5	4.6	4.9	5.2

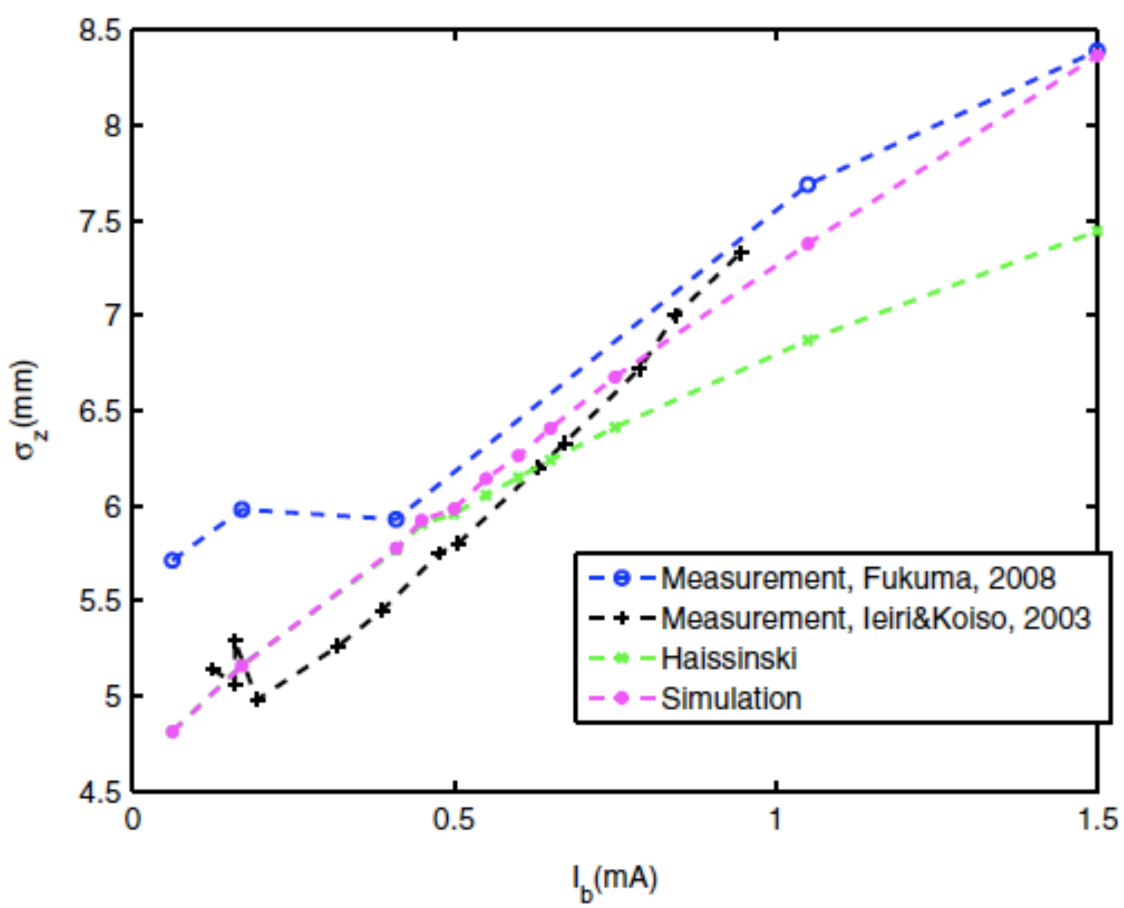


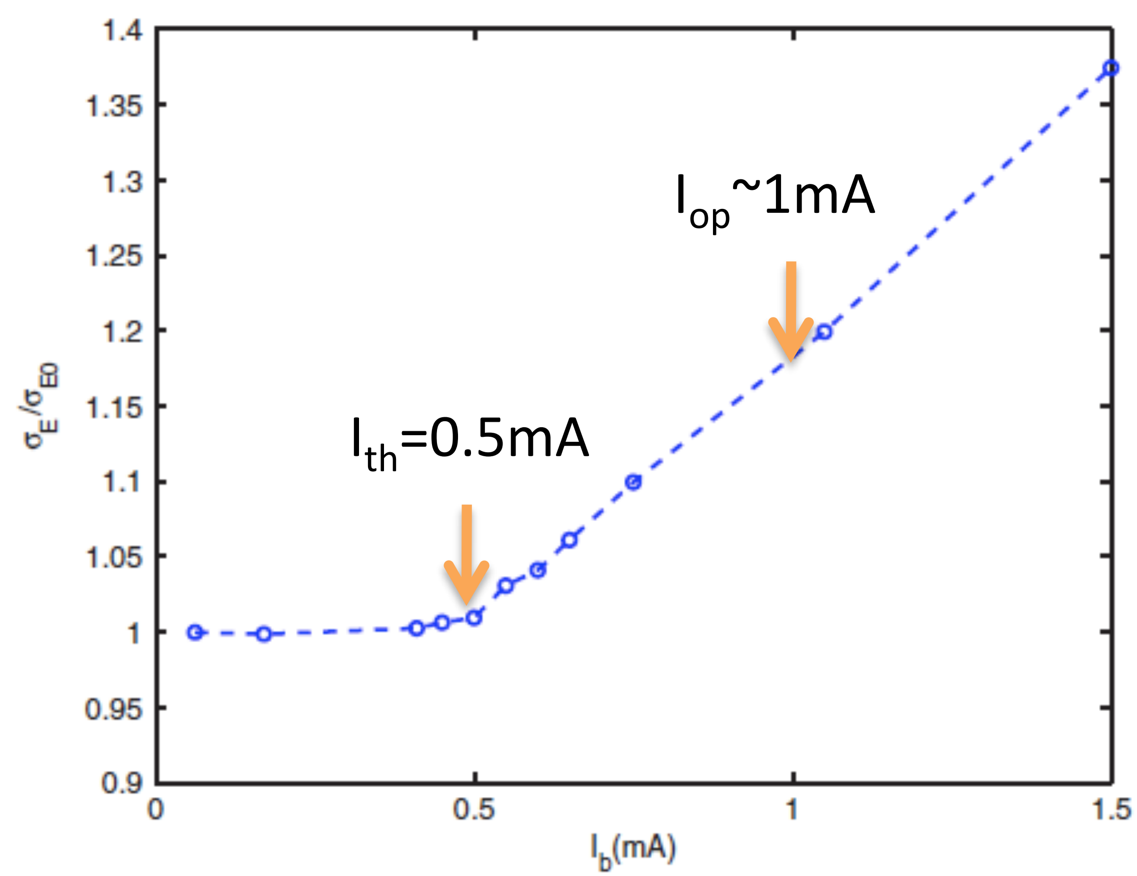


2. Impedance model: KEKB

➤ Y. Cai's model for KEKB

- VFP solver
- 3-parameter broadband resonator model
- Fit the measured bunch lengthening and profile
- Determine the MWI threshold and compare with physics data





Y. Cai et al., PRST-AB 12, 061002 (2009)

Parameter	Description	LER
L (nH)	Inductance	116.7
R (KΩ)	Resistance	22.9
C (fF)	Capacitor	0.22

2. Impedance model: KEKB

➤ Pseudo-Green function wake calculation

- **Geometric wakes, resistive wall, CSR, CWR**

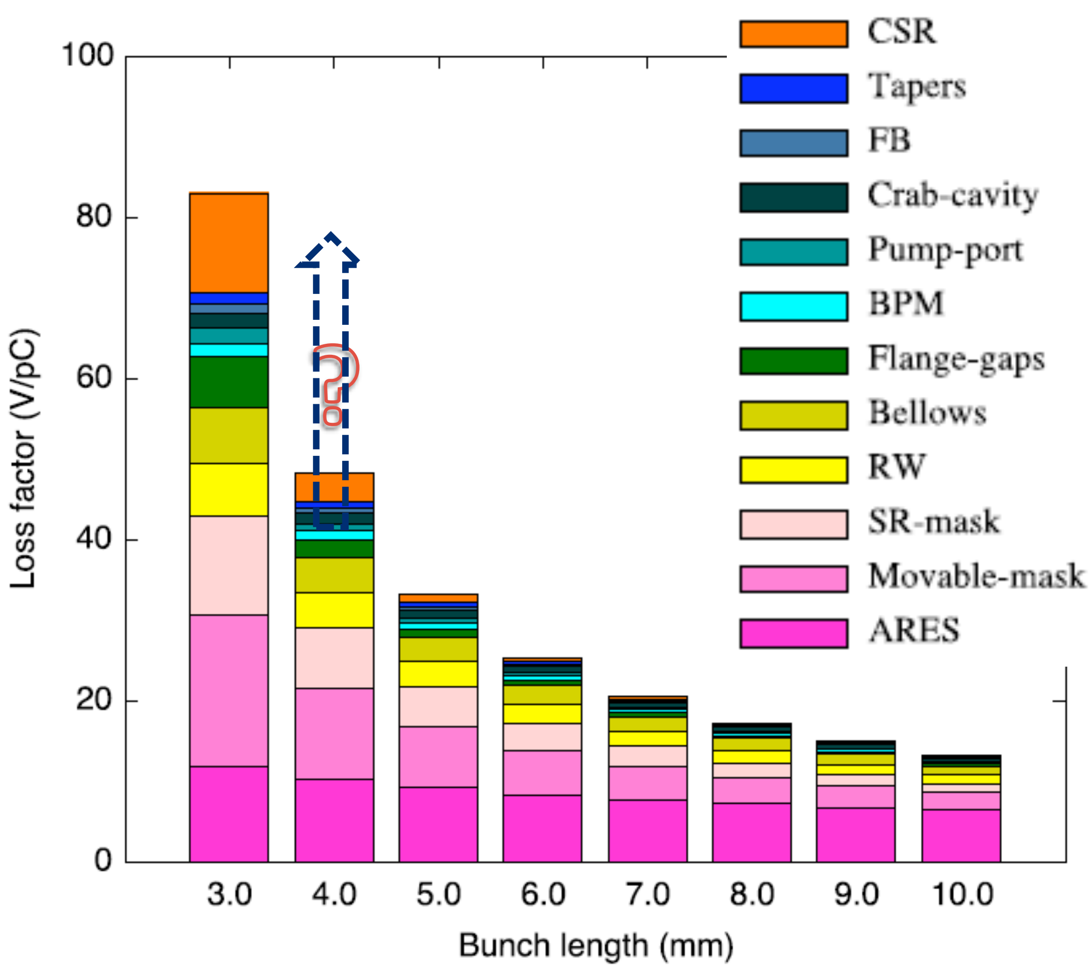
Component	Number	Software
ARES cavity	20	GdfidL
Movable mask	16	GdfidL
SR mask (arc/wiggler)	1000 (905/95)	GdfidL
Bellows	1000	GdfidL
Flange gap	2000	GdfidL
BPM	440	MAFIA
Pumping port	3000	GdfidL
Crab cavity	1	ABCI
FB kicker/BPM	1/40	GdfidL
Tapers ARES/Crab/Abort/Injection IR(IP/QCSL/QCSR)	 4/2/2/2 6(2/2/2)	GdfidL
Gate valves f94/f150/94x150	26/13/2	GdfidL

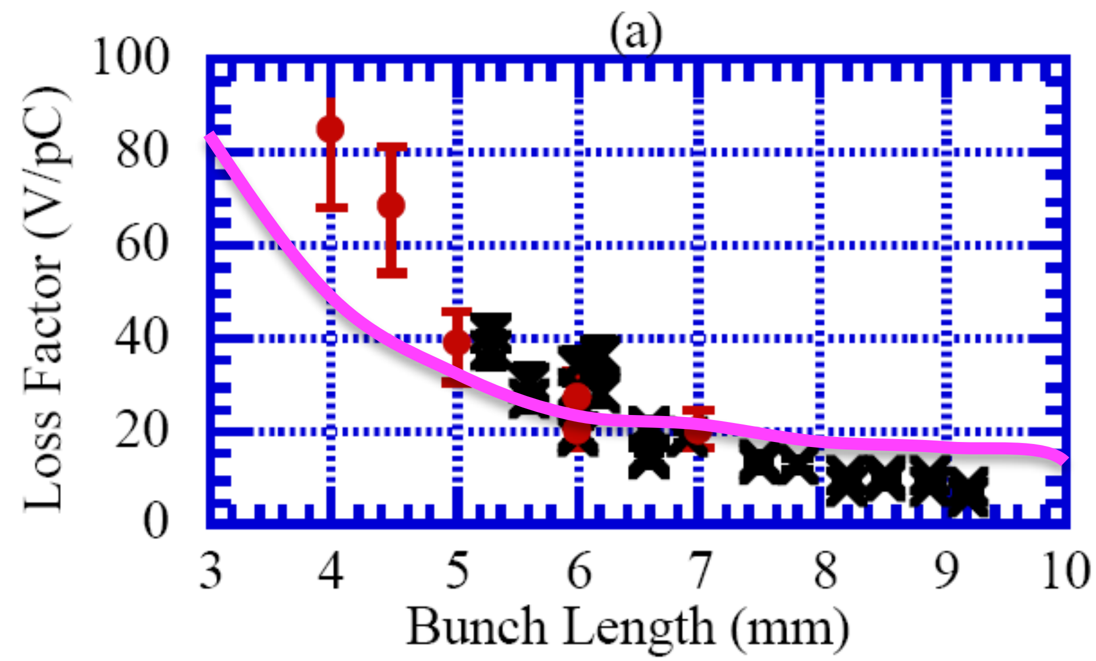
D. Zhou et al., ICAP09, TH2IOpk02

2. Impedance model: KEKB

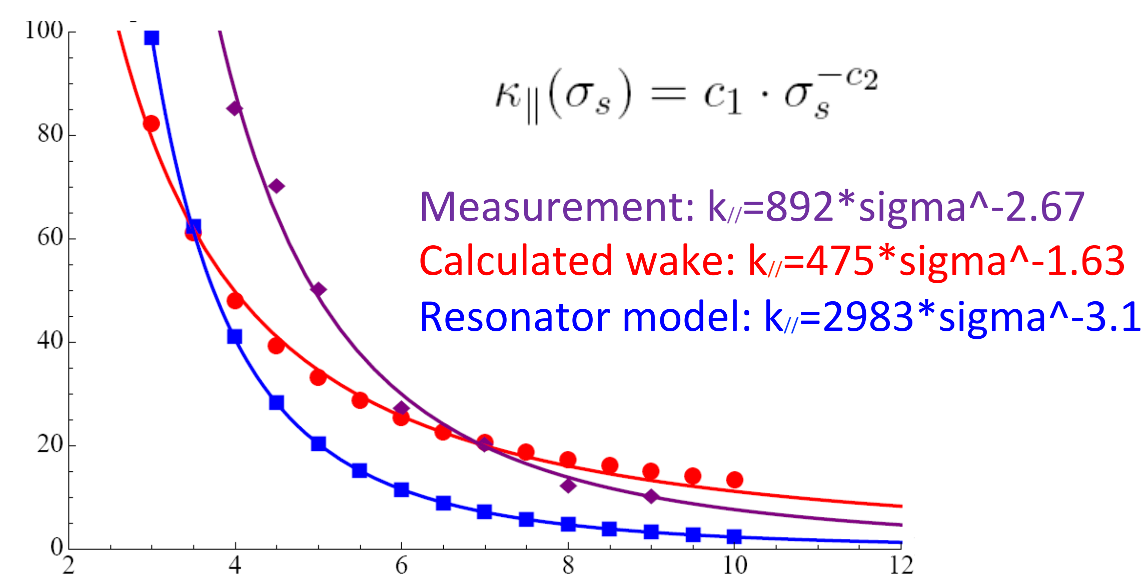
➤ Simulations using Pseudo-Green function wake

- **Estimate loss factors and compare with measurements and prediction of broadband resonator model**





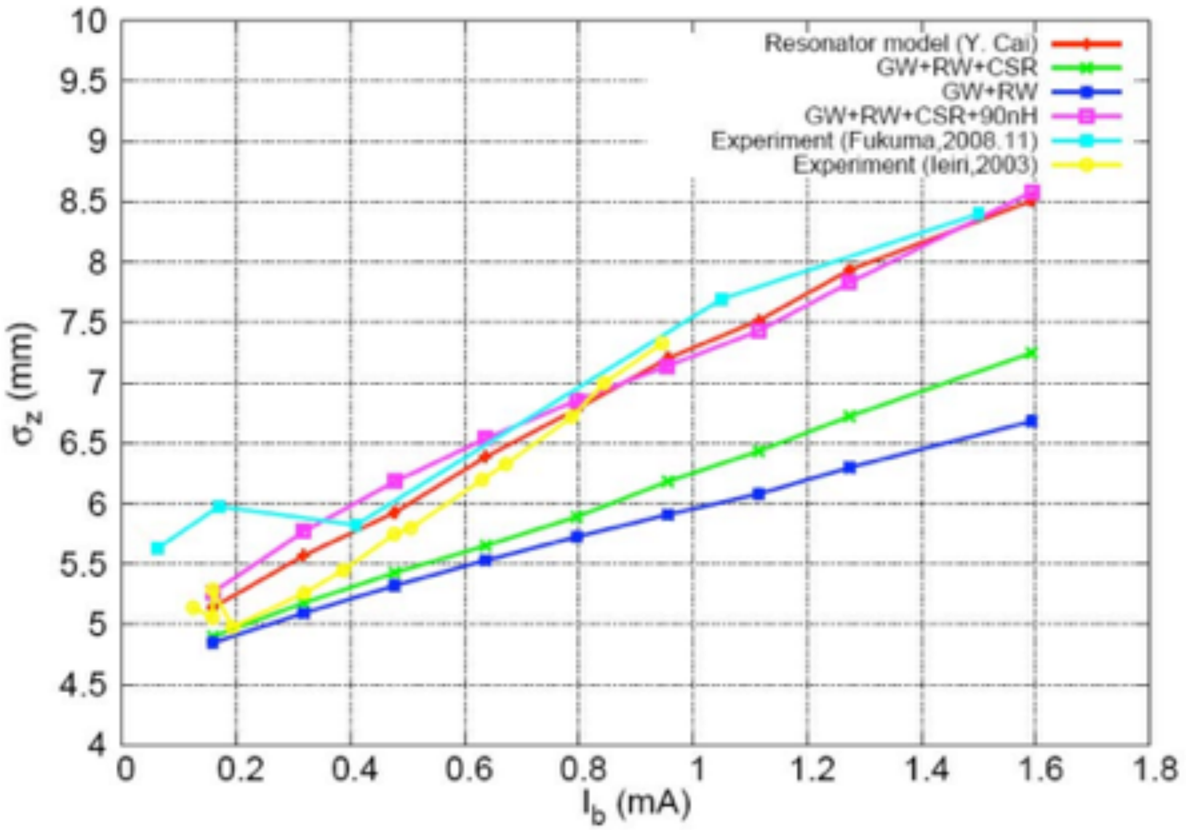
T. Ieiri and H. Koiso, 14th SAST 2003

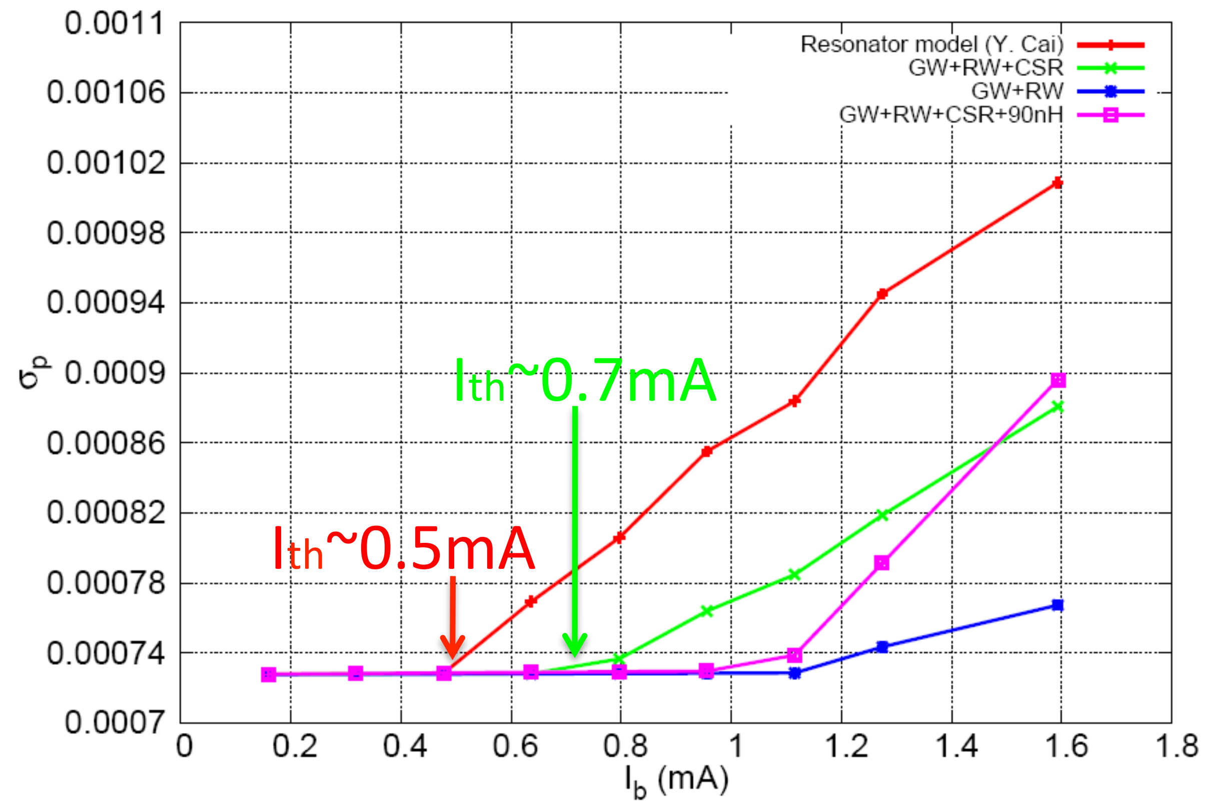


2. Impedance model: KEKB

➤ **Simulations using Pseudo-Green function wake**

- **Use VFP solver to simulate bunch lengthening and MWI**
- **CSR plays a role but seems not serious**
- **Missing impedance sources? CSR/CWR/RW not well modelled in MWI simulations? NOT clear yet**

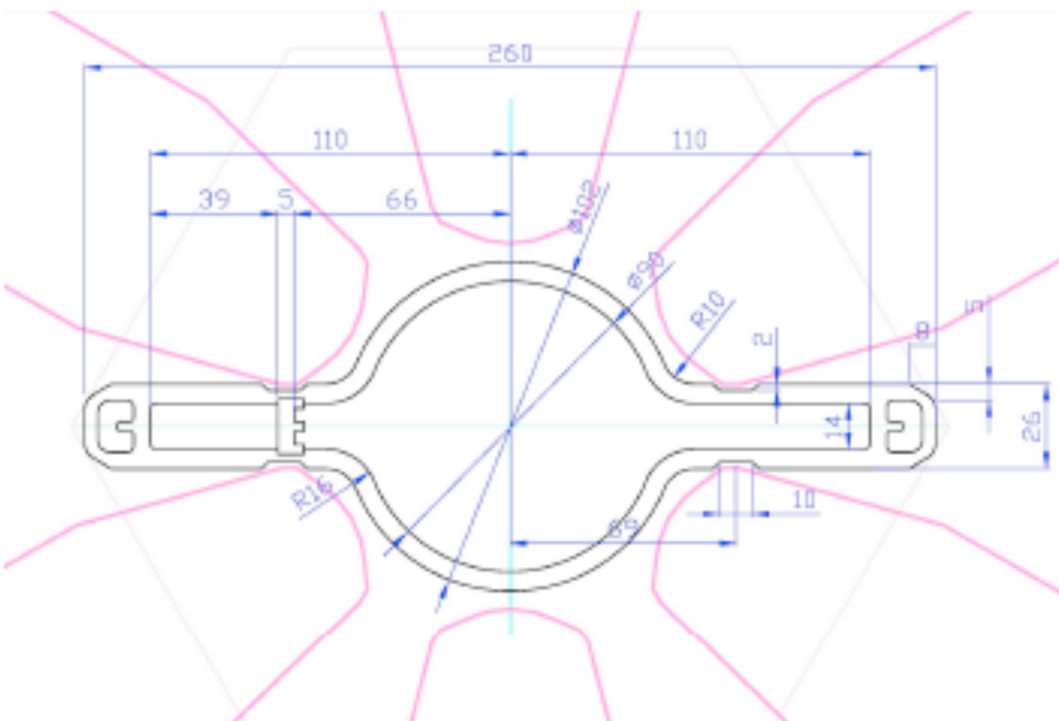


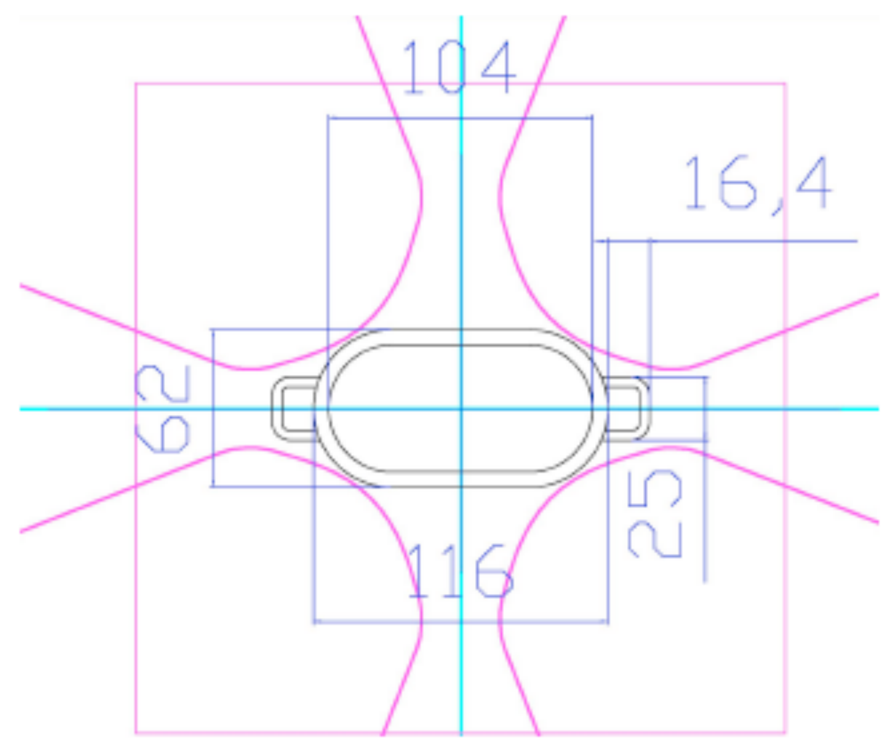


2. Impedance model: SuperKEKB

- **Upgrade LER**
  - ϕ94mm => ϕ90mm w/ antechamber
  - New Ecloud suppression devices
  - Bellows: Finger-type => Comb-type
  - Movable masks => PEP-II type collimators
- **HER almost no changes**

LER typical (~90%)	HER typical (~70%)
Aluminum w/ antechamber	Copper w/o antechamber

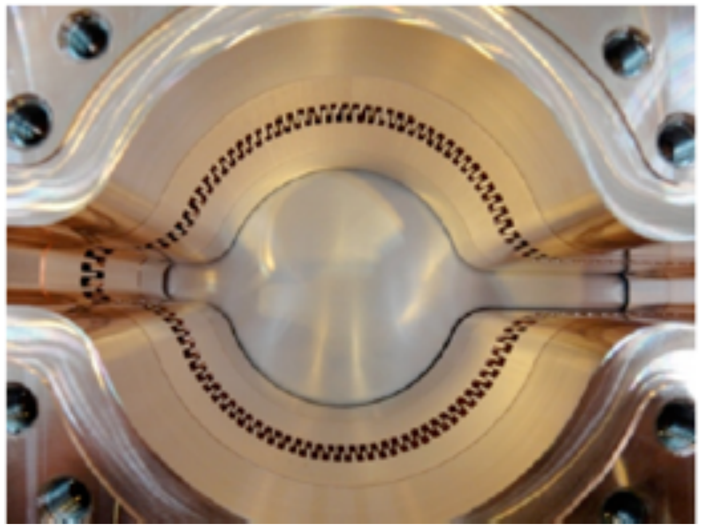


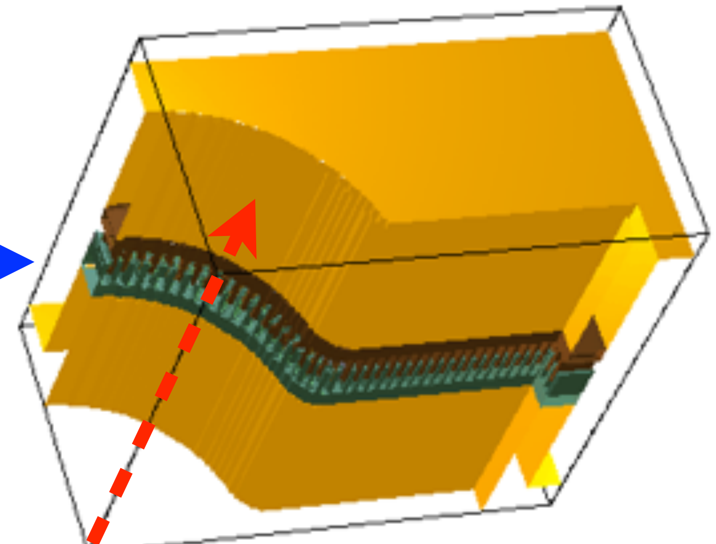


Y. Suetsugu and K. Shibata

2. Impedance model: SuperKEKB: LER

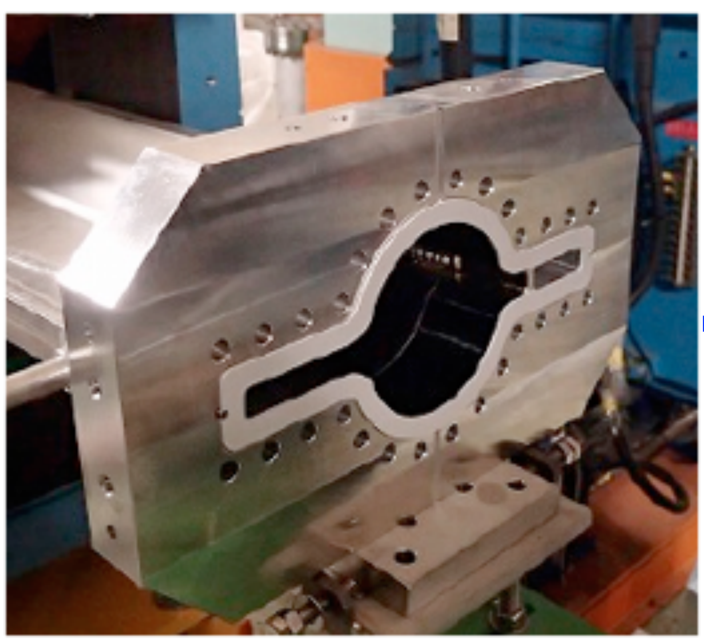
Bellows

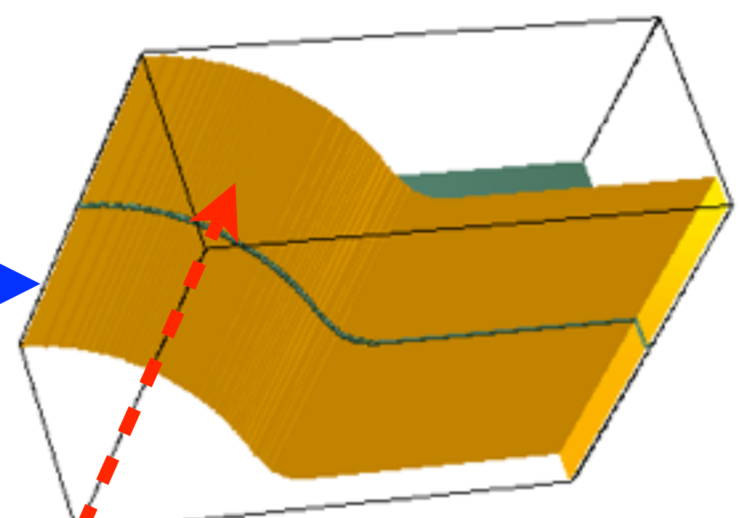




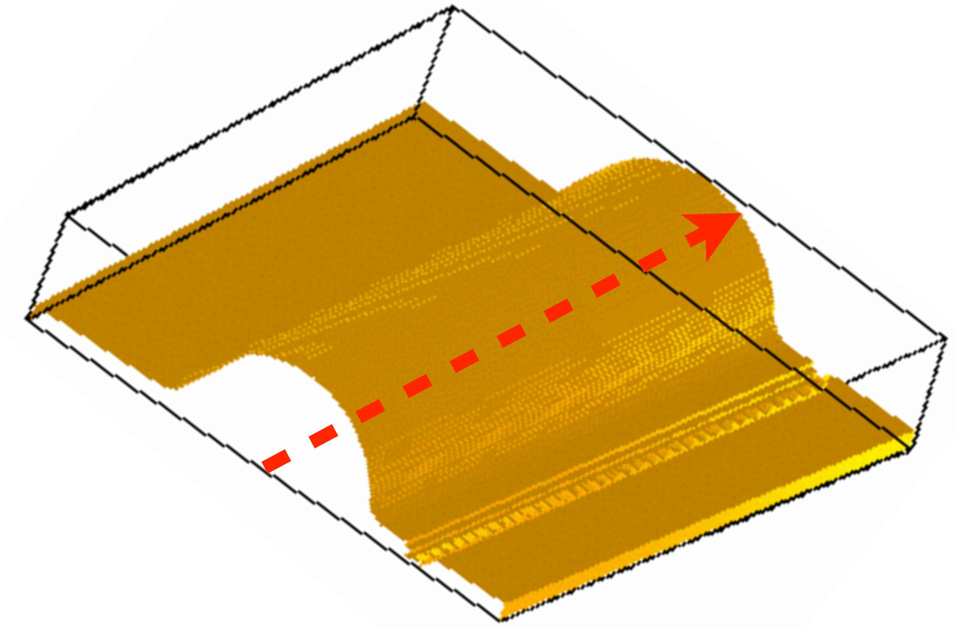
Comb-type: Unique for SuperKEKB

MO-type flange





Pumping port



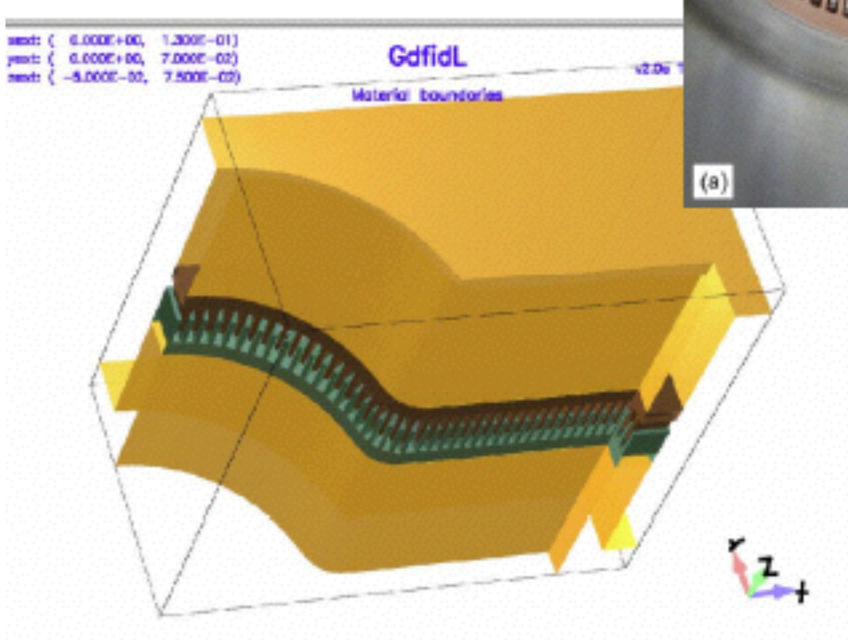
ARES RF cavity

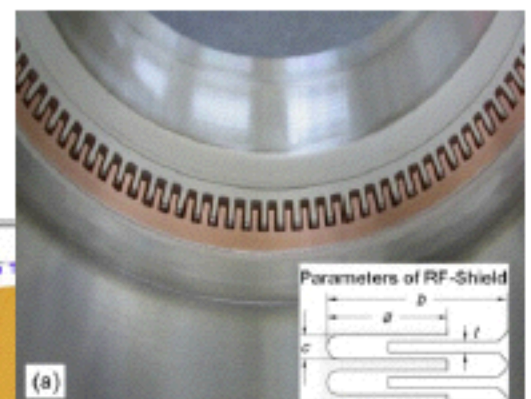
T. Abe and K. Shibata

2. Impedance model: SuperKEKB: LER: Bellows

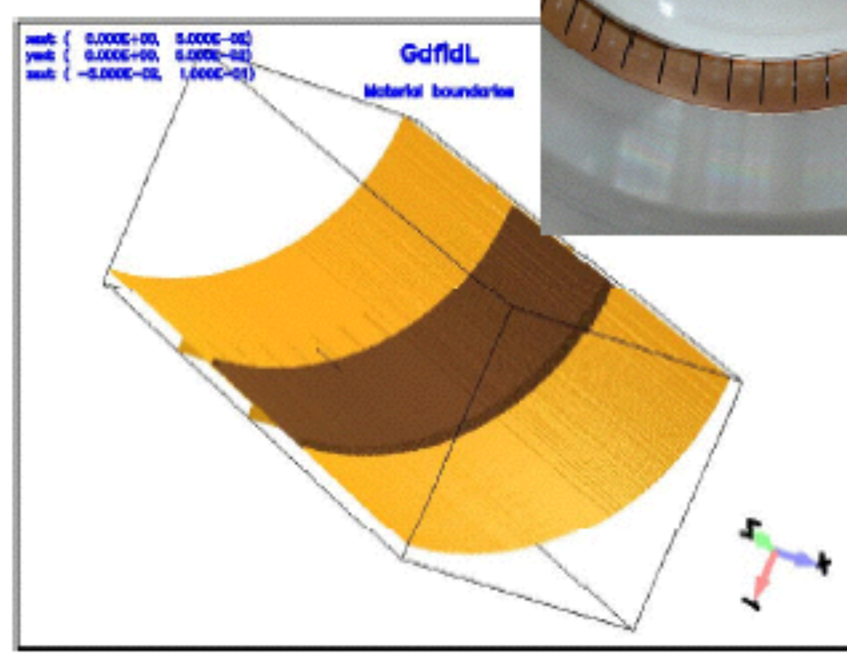
- Bellows chamber with comb-type RF shield will be used in SKEKB.
  - There is no radial step on the inner surface.
    (There is a small step (~1 mm) in a conventional bellows chamber.)
  - RF is shielded by nested comb teeth.
    length : 10 mm
    radial thickness : 10 mm

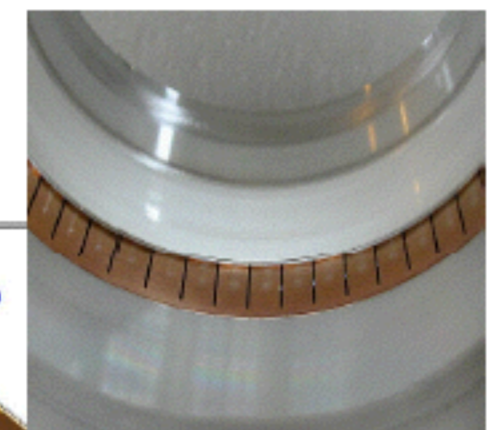
SKEKB





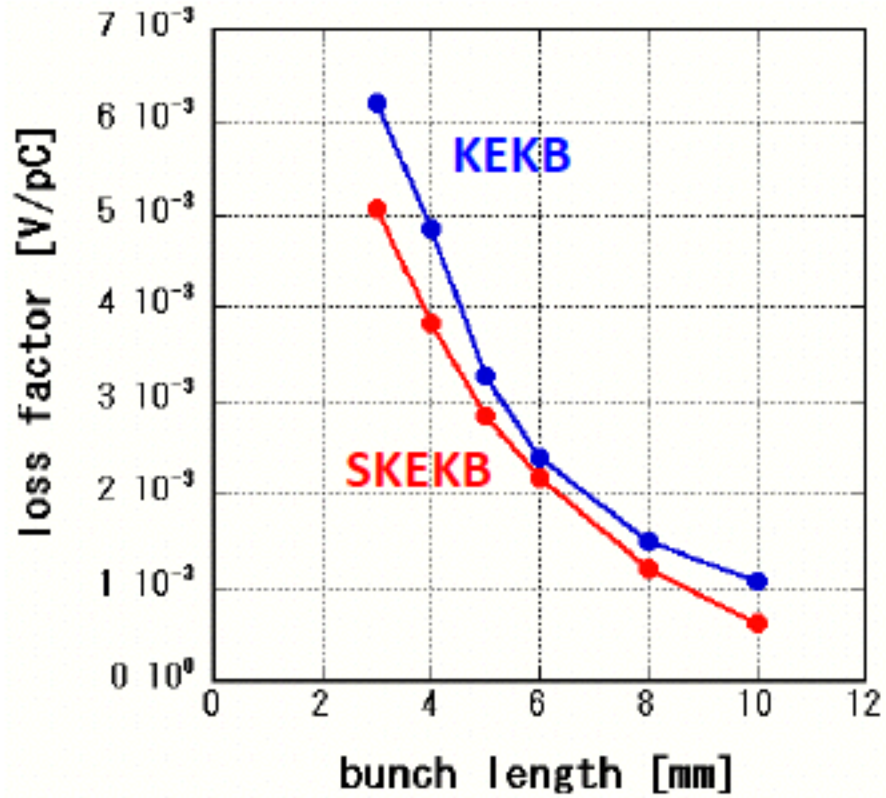
KEKB

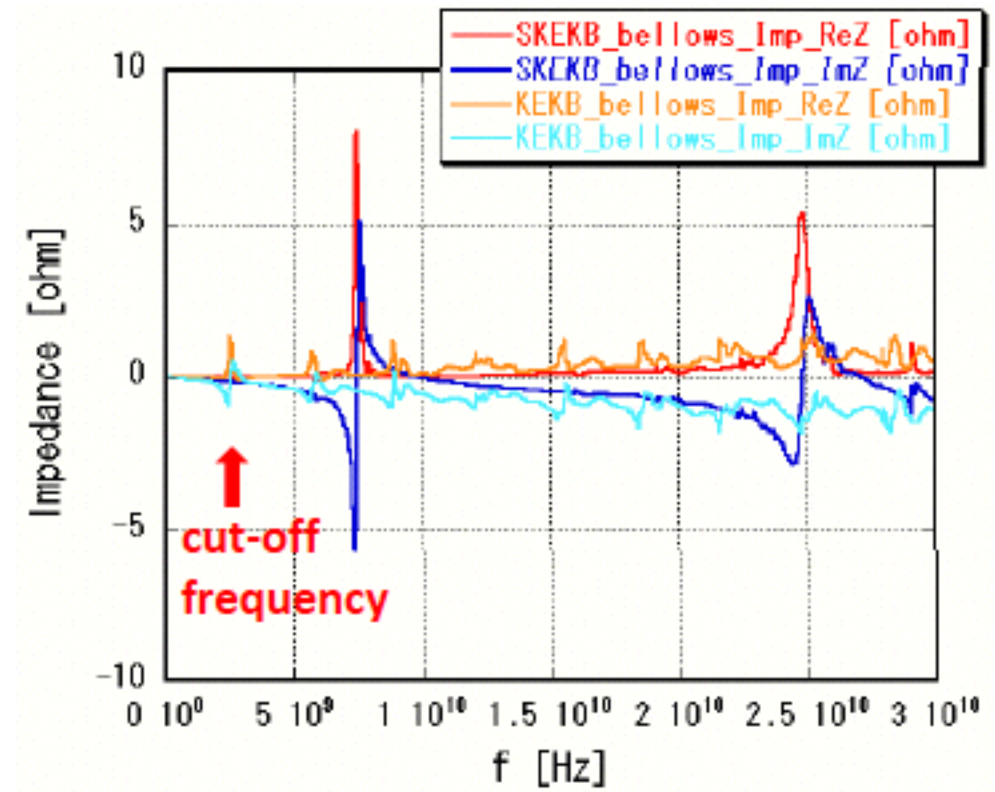




K. Shibata

2. Impedance model: SuperKEKB: LER: Bellows





- Loss factor (σ_z = 6 mm)

  $k = 2.2\times10^{-3}$ V/pC

  ⇩ 1000 pieces in one ring

  ***k*_total = 2.2 V/pC**

- Impedance

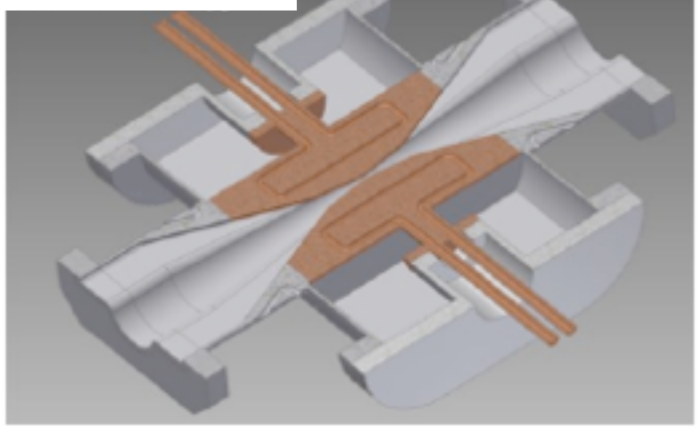
  It was found that there are trapped modes at 7.5 GHz and 25 GHz (over cut-off frequency (2.5GHz)). Effects of these trapped modes on the beams will be investigated.

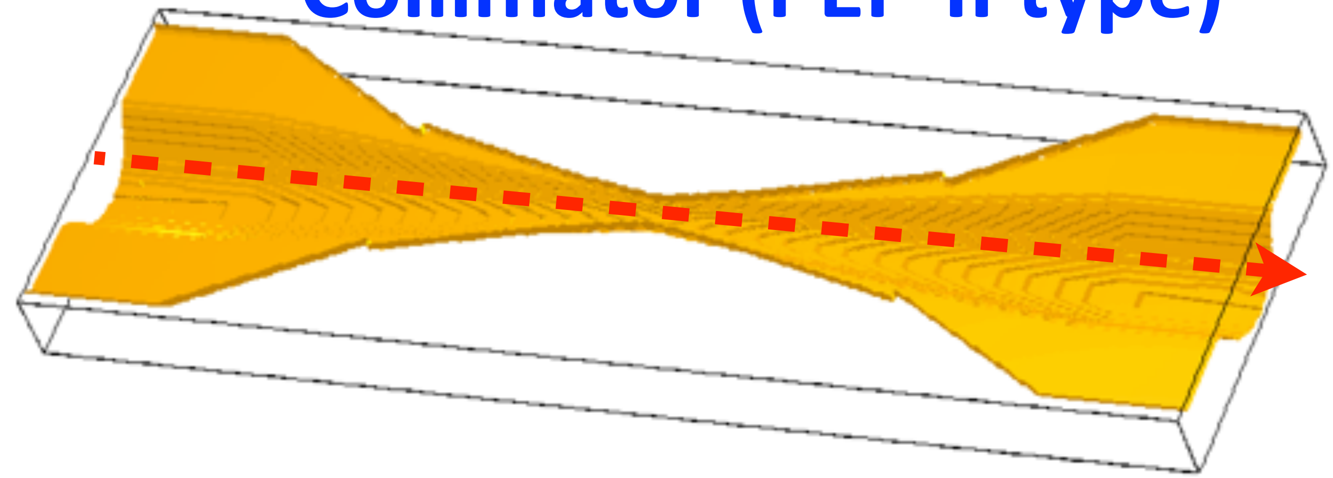
K. Shibata

2. Impedance model: SuperKEKB: LER

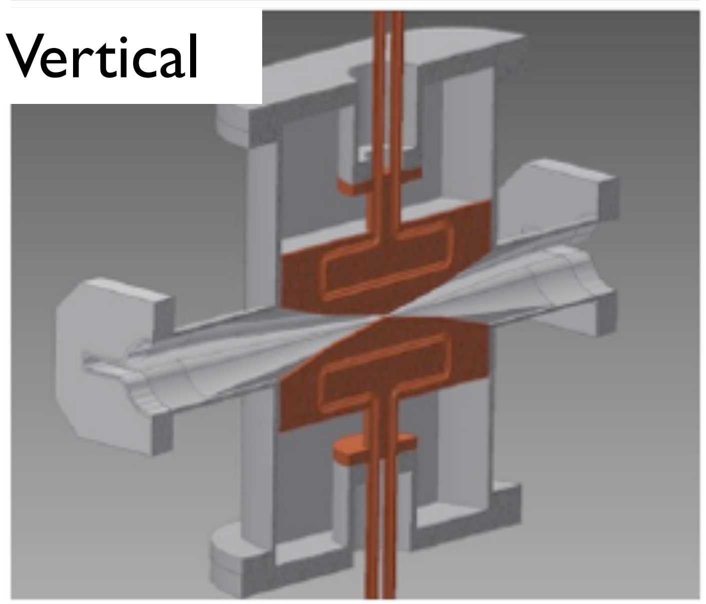
Collimator (PEP-II type)

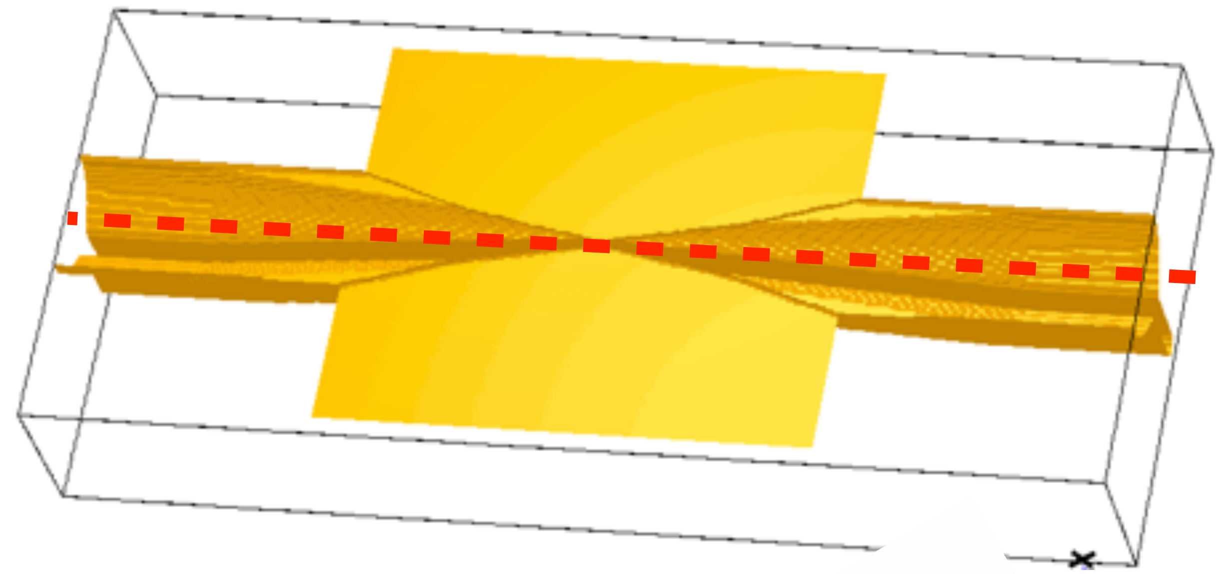
Horizontal



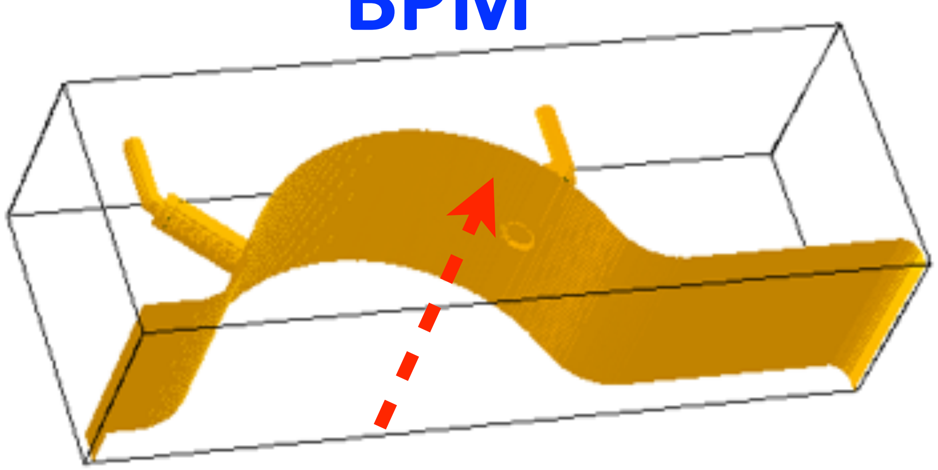


Vertical

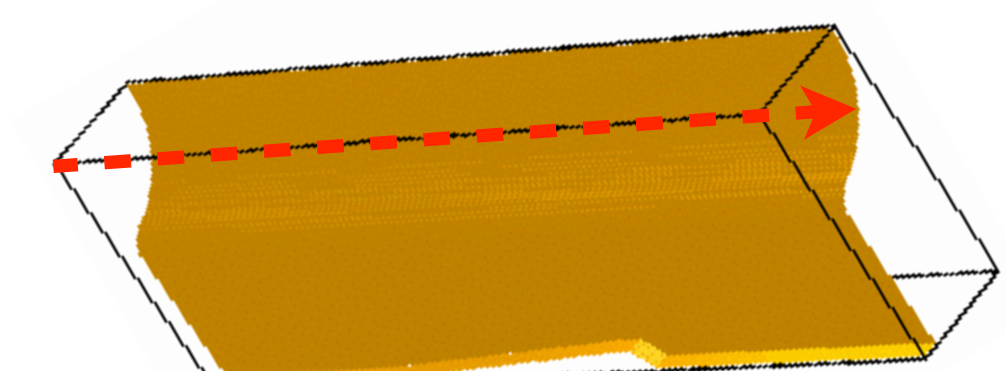




BPM



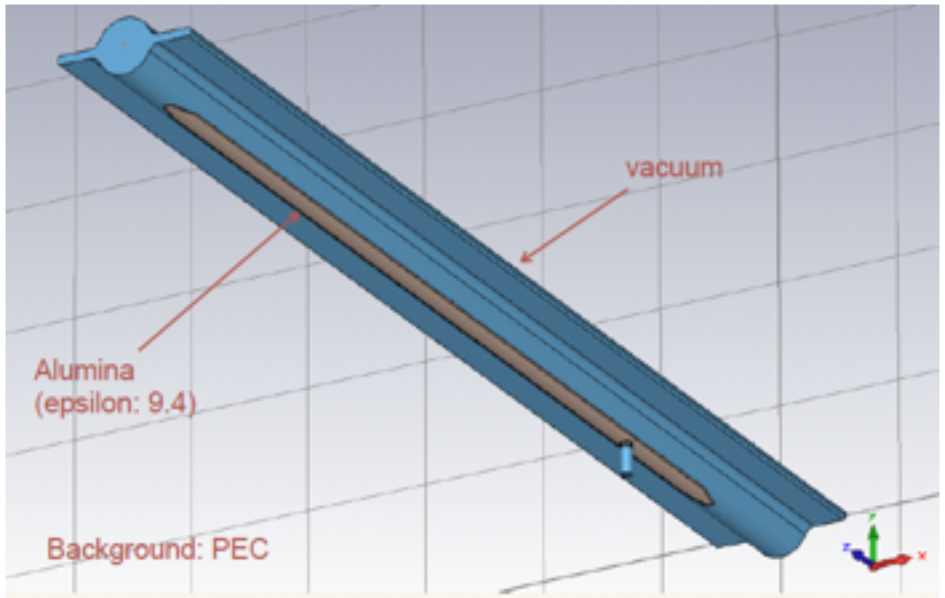
SR mask



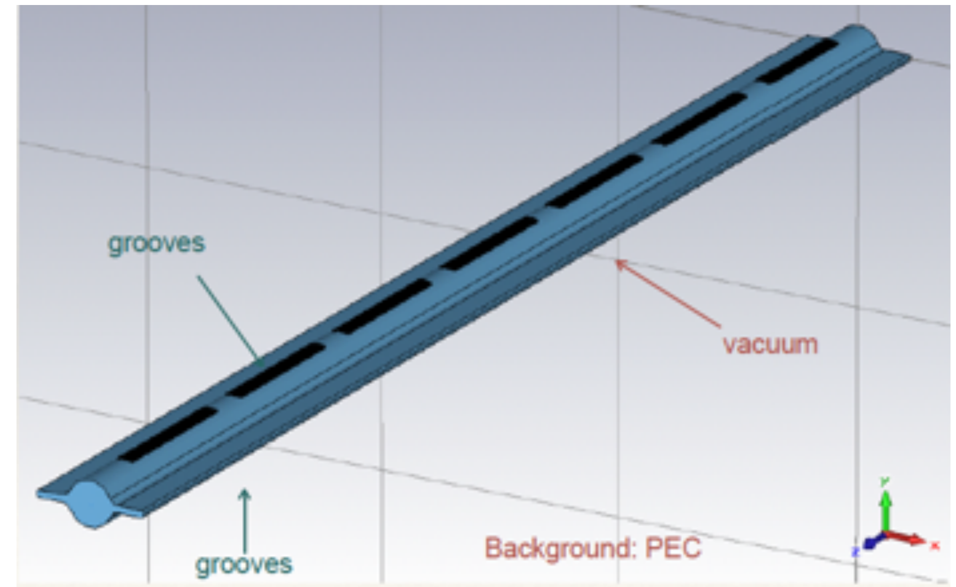
T. Ishibashi, M. Tobiyama, and K. Shibata

2. Impedance model: SuperKEKB: LER

Clearing electrode



Grooved surfaces



From T. Ishibashi

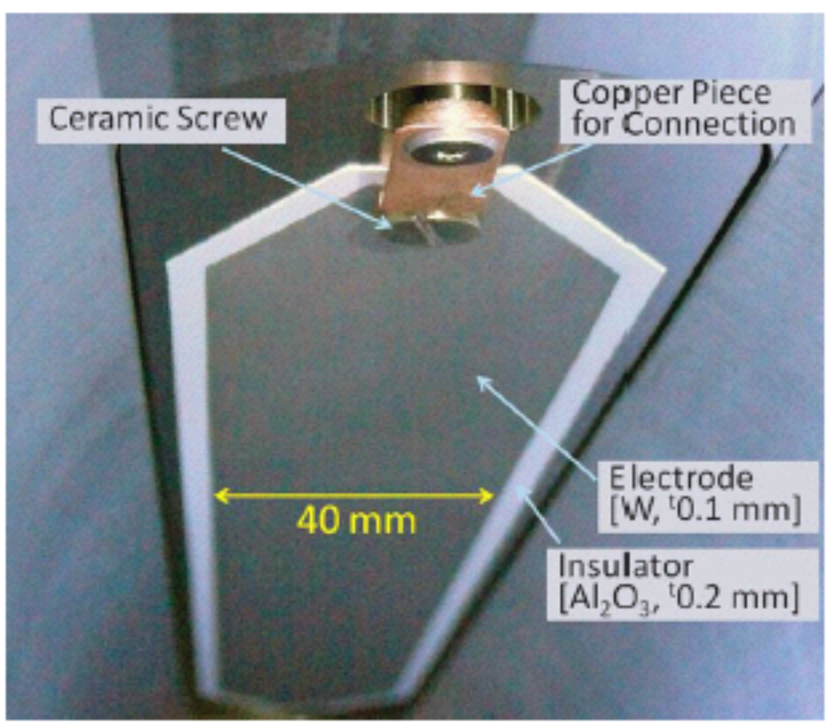


Fig. 2. Clearing electrode installed in test chamber. The electrode and the feed-through are connected by small piece of copper.

Tested in KEKB

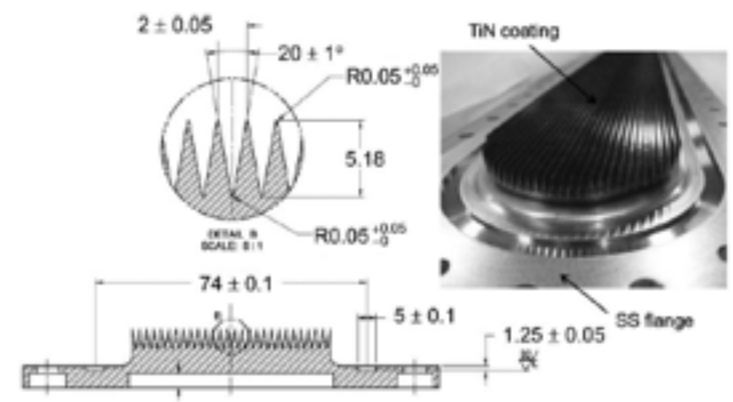


Fig. 1. Insertion with TiN-coated groove surface.

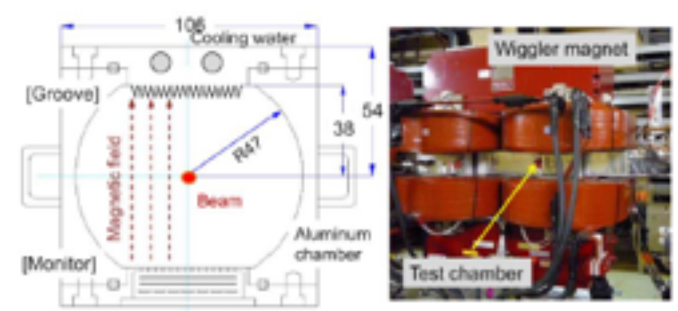


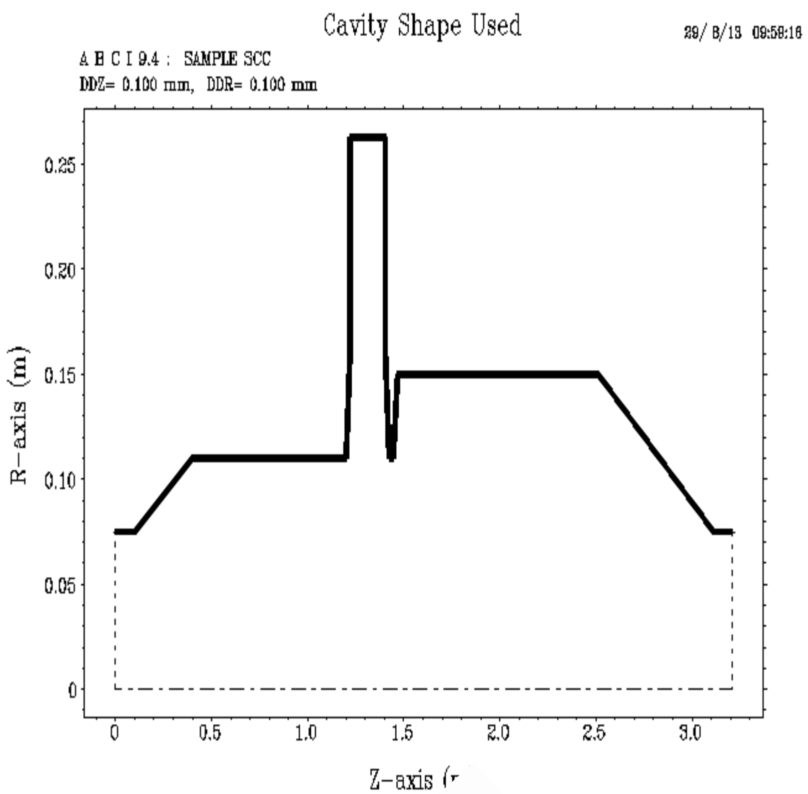
Fig. 2. Cross-section of the test chamber and the experimental setup in a wiggler magnet section in the KEKB positron ring.

Ref. Y. Suetsugu et al., NIMA 598 (2009)

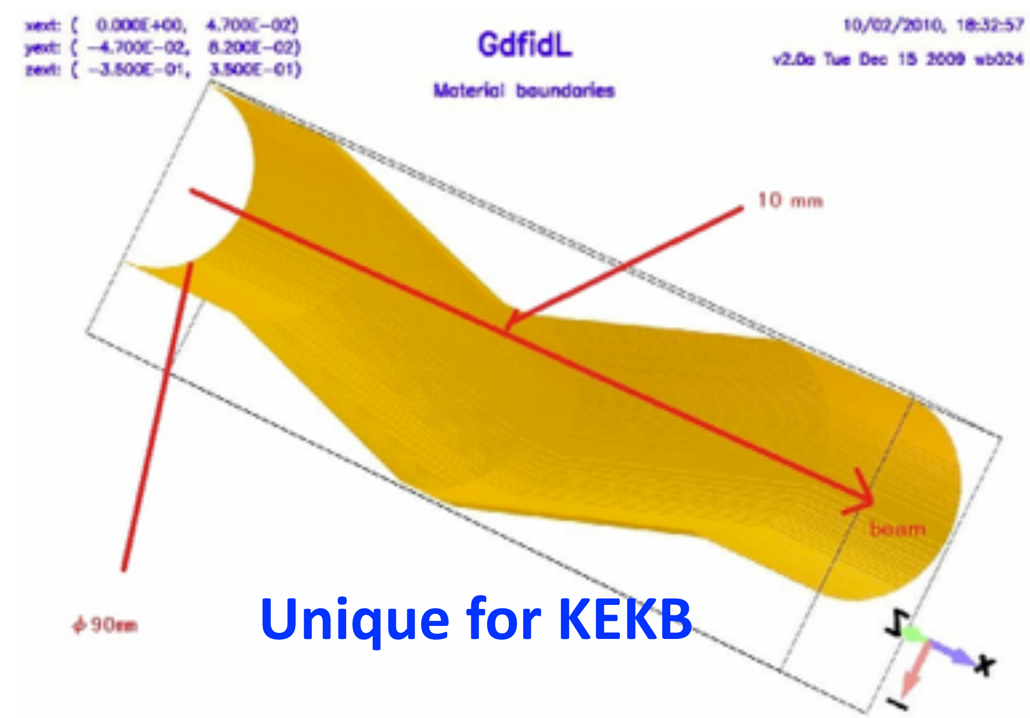
Ref. Y. Suetsugu et al., NIMA 604 (2009)

2. Impedance model: SuperKEKB: HER

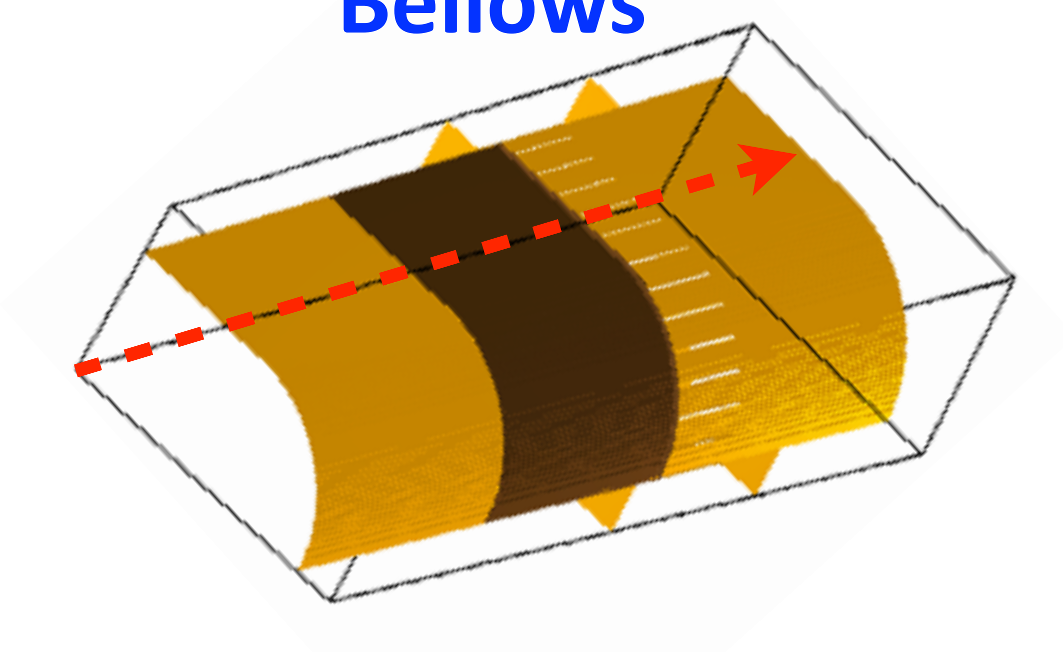
SCC (ABCI)



Movable mask (KEKB type)



Bellows

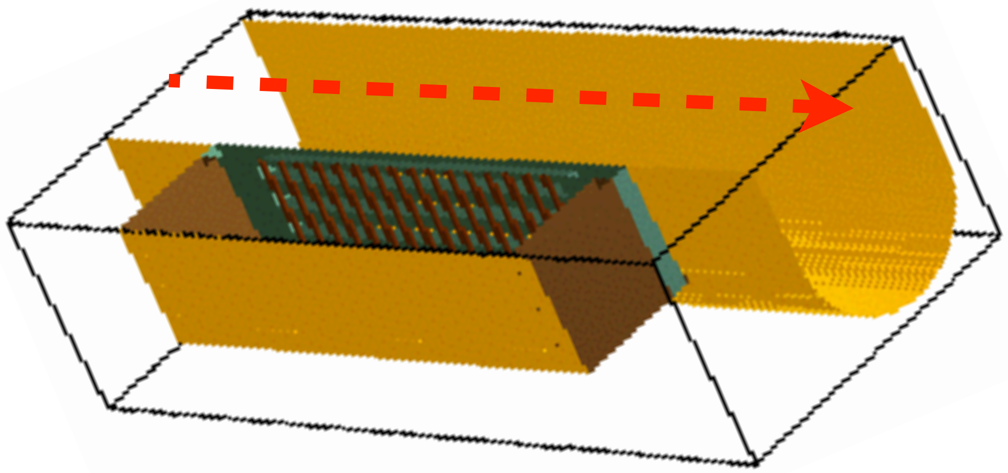


ARES RF cavity

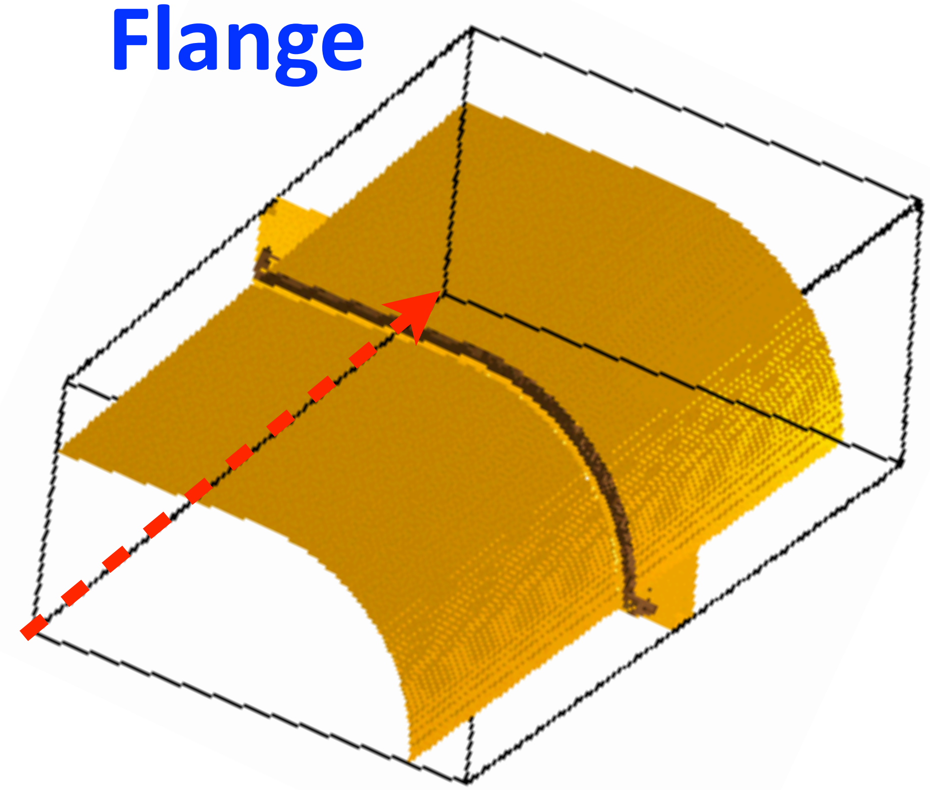
T. Abe, Y. Morita, and K. Shibata

2. Impedance model: SuperKEKB: HER

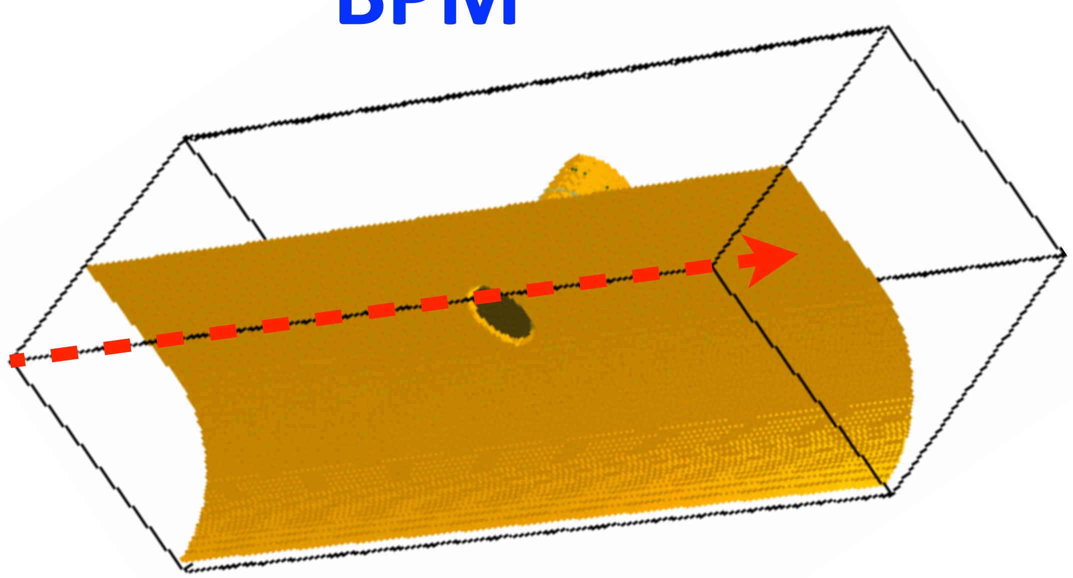
Pumping port



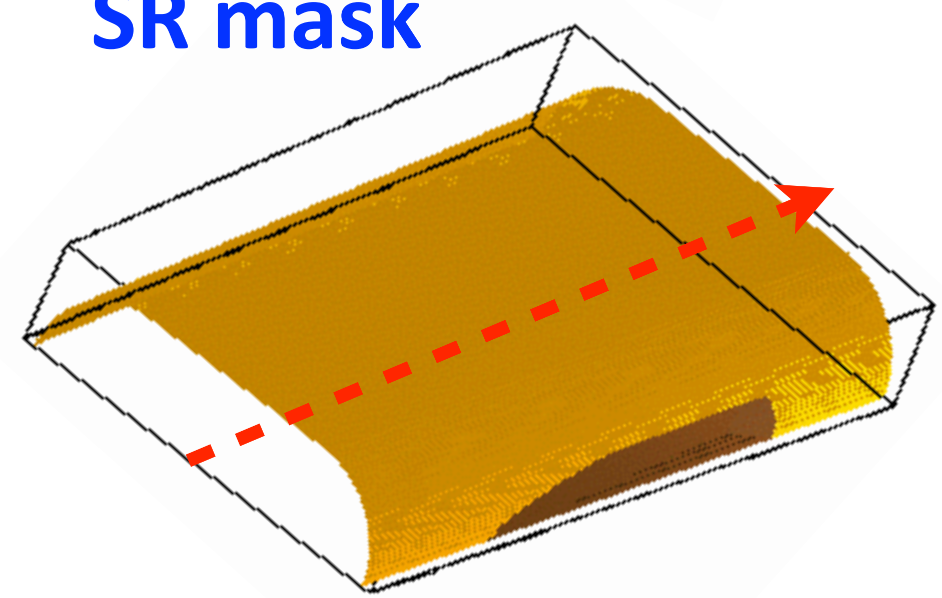
Flange



BPM



SR mask

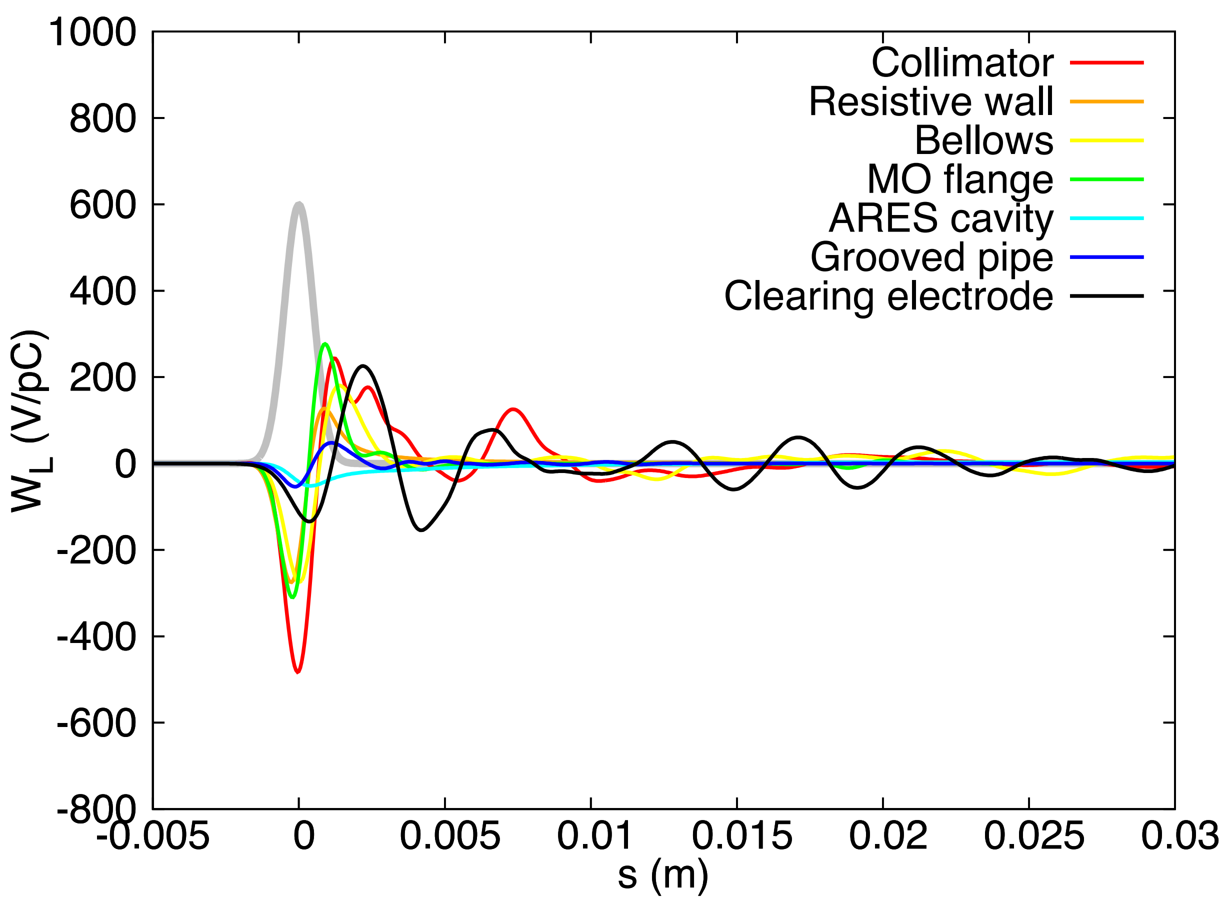


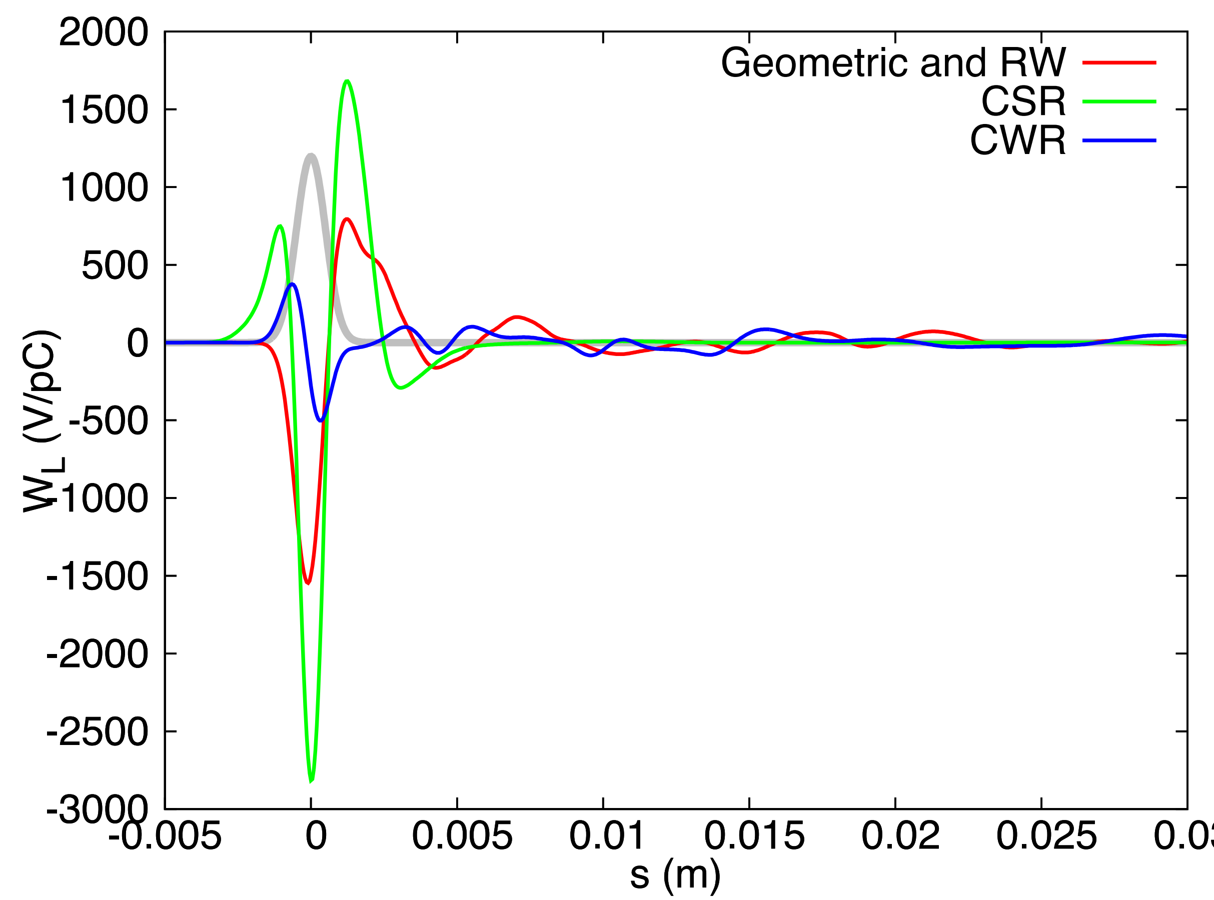
K. Shibata and M. Tobiyama

2. Impedance model: SuperKEKB: LER

➤ Pseudo-Green wake function

- σ_z=0.5mm
- CSR and CWR: CSRZ code with rectangular chamber

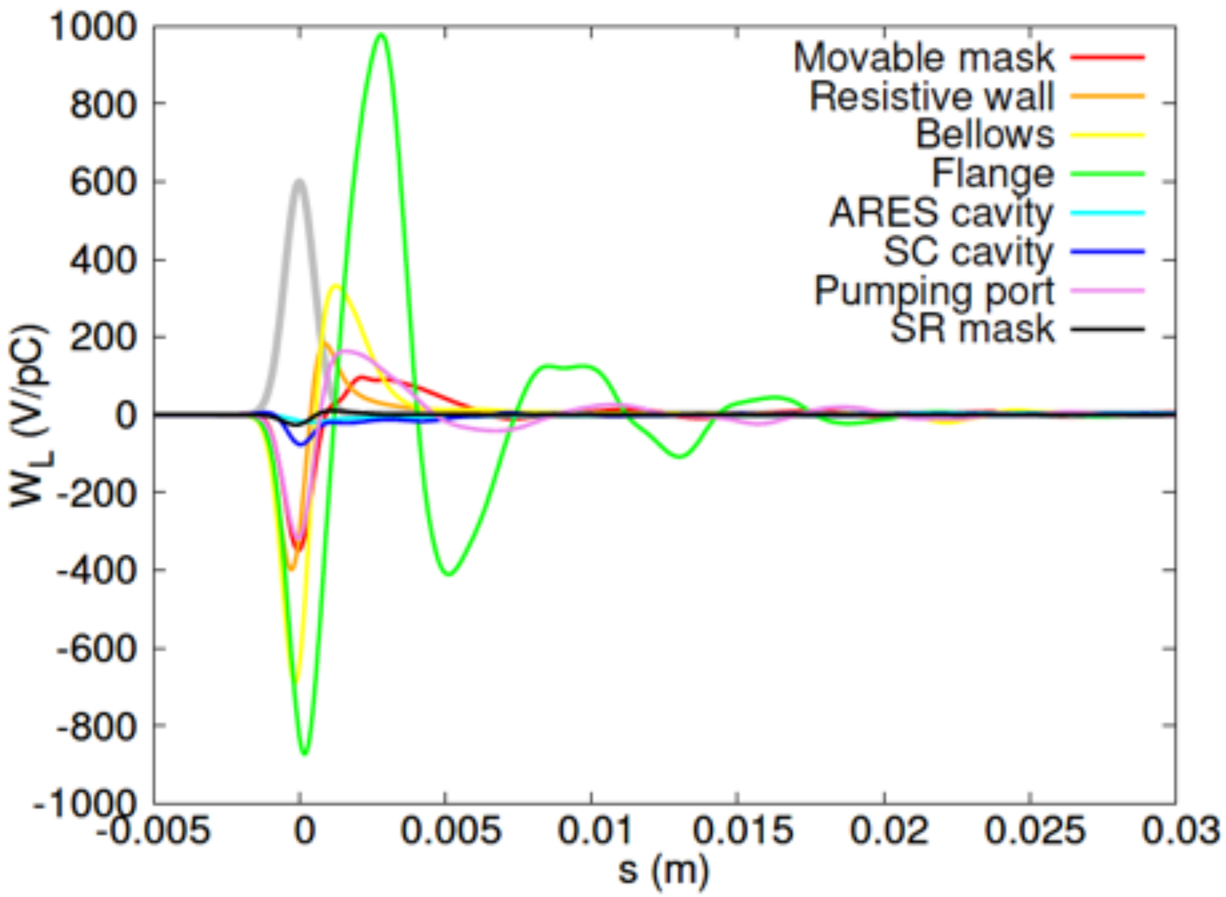


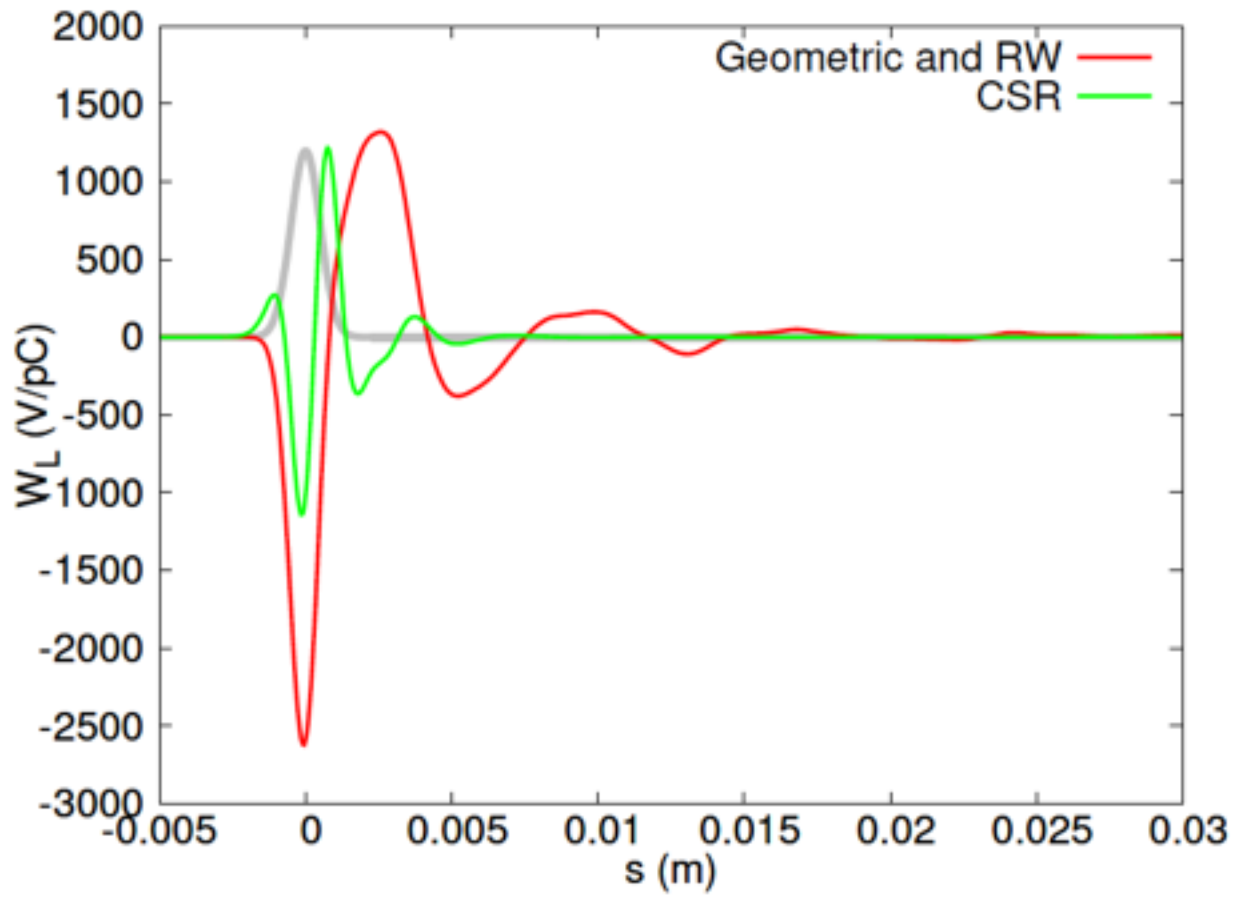


2. Impedance model: SuperKEKB: HER

➤ Pseudo-Green wake function

- σ_z=0.5mm
- CSR: CSRZ code with rectangular chamber
- CWR not considered yet





2. Impedance model: SuperKEKB: Budget

➤ Impedance budget with σ_z=5/4.9mm:

● Loss factors, resistance and inductance are calculated at nominal bunch lengths with input of Pseudo-Green function wakes

Table 2: Key parameters of SuperKEKB main rings for MWI simulations.

Parameter	LER	HER
Circumference (m)	3016.25	3016.25
Beam energy (GeV)	4	7.007
Bunch population (10^{10})	9.04	6.53
Nominal bunch length (mm)	5	4.9
Synchrotron tune	0.0244	0.028
Long. damping time (ms)	21.6	29.0
Energy spread (10^{-4})	8.1	6.37

Component	LER			HER		
	$k_{\|\|}$	R	L	$k_{\|\|}$	R	L
ARES cavity	8.9	524	-	3.3	190	-
SC cavity	-	-	-	7.8	454	-
Collimator	1.1	62.4	13.0	5.3	309	10.8
Res. wall	3.9	231	5.7	5.9	340	8.2
Bellows	2.7	159	5.1	4.6	265	16.0
Flange	0.2	13.7	4.1	0.6	34.1	19.3
Pump. port	0.0	0.0	0.0	0.6	34.1	6.6
SR mask	0.0	0.0	0.0	0.4	21.4	0.7
IR duct	0.0	2.2	0.5	0.0	2.2	0.5
BPM	0.1	8.2	0.6	0.0	0.0	0.0
FB kicker	0.4	26.3	0.0	0.5	26.2	0.0
FB BPM	0.0	1.1	0.0	0.0	1.1	0.0
Long. kicker	1.8	105	1.2	-	-	-
Groove pipe	0.1	5.7	0.9	-	-	-
Electrode	0.0	2.2	2.3	-	-	-
Total	19.2	1141	33.4	29.0	1677	62.1

Ref. D. Zhou et al., IPAC14, TUPRI021

2. Impedance model: Budget

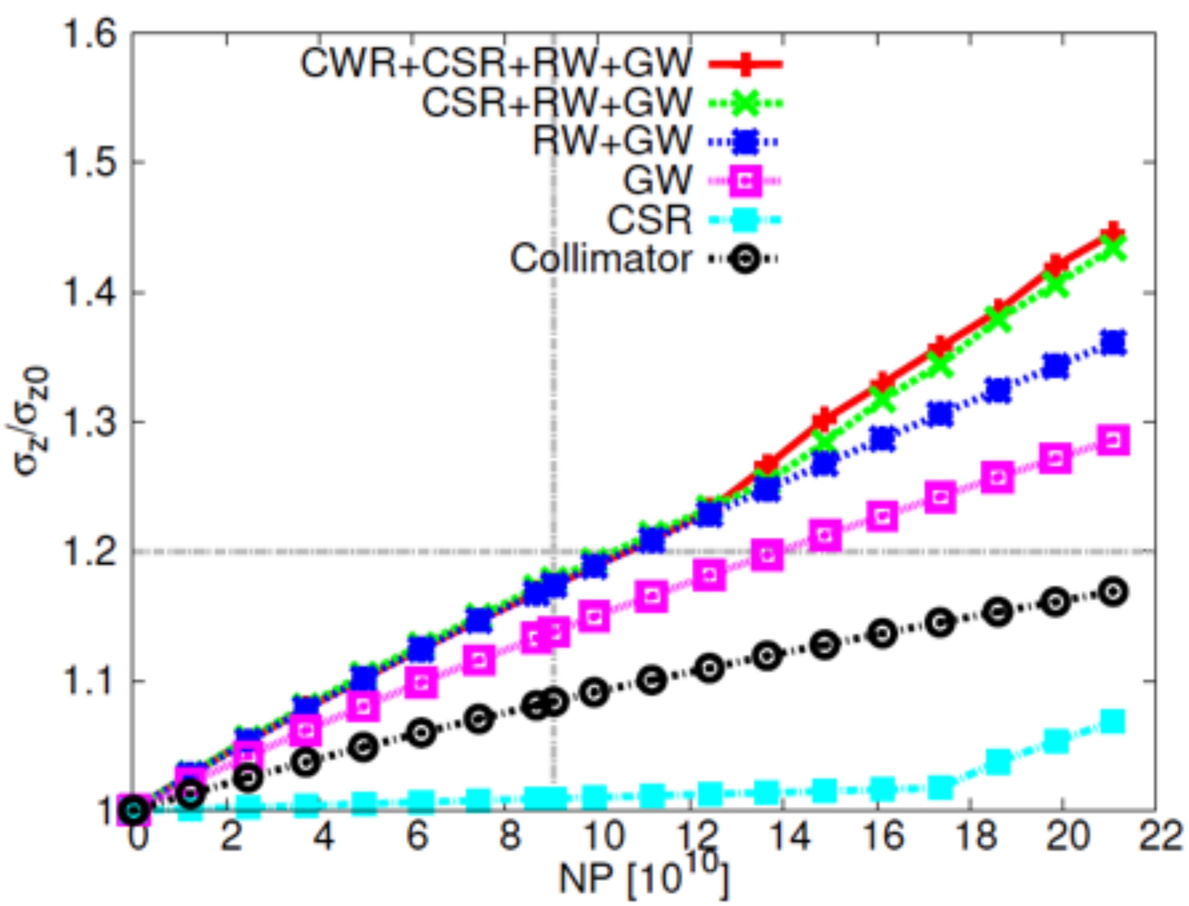
➤ Compare LER of KEKB and SuperKEKB

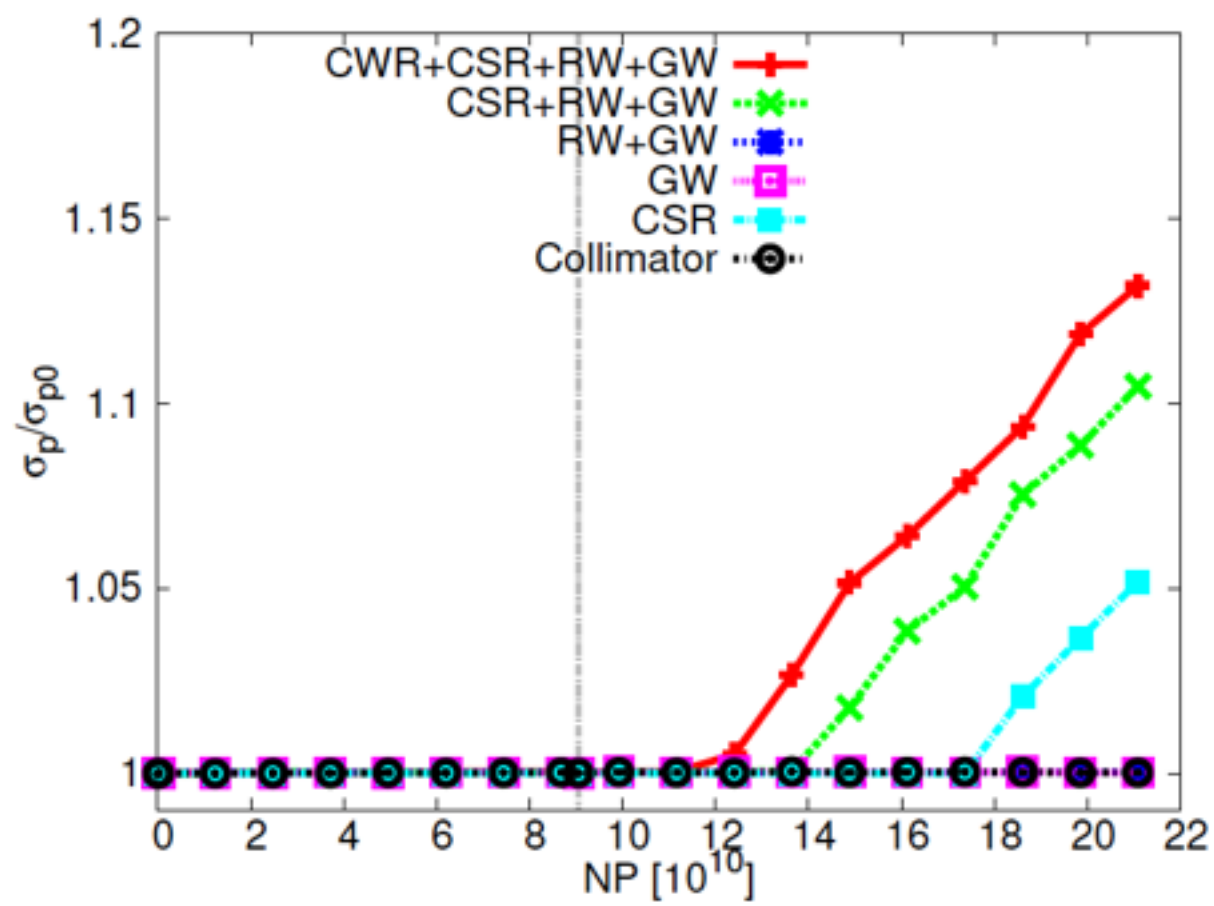
Component	Super-LER			KEKB-LER		
	$k_{\|\|}$	R	L	$k_{\|\|}$	R	L
ARES cavity	8.9	524	-	9.2	545	-
Crab cavity	-	-	-	1.0	60.1	-
Collimator	1.1	62.4	13.0	7.6	447	11.9
Res. wall	3.9	231	5.7	3.7	222	5.5
Bellows	2.7	159	5.1	3.0	178	6.6
Flange	0.2	13.7	4.1	1.1	62.1	18.5
Pump. port	0.0	0.0	0.0	0.5	28.8	5.5
SR mask	0.0	0.0	0.0	5.0	298	8.5
IR duct	0.0	2.2	0.5	0.2	9.9	0.6
BPM	0.1	8.2	0.6	0.8	46.8	0.8
FB kicker	0.4	26.3	0.0	0.2	13.2	0.0
FB BPM	0.0	1.1	0.0	0.2	13.5	0.7
Gate valve	-	-	-	0.1	4.2	0.2
Taper	0.0	0.7	0.1	0.3	16.6	1.3
Long. kicker	1.8	105	1.2	-	-	-
Groove pipe	0.1	5.7	0.9	-	-	-
Electrode	0.0	2.2	2.3	-	-	-
Total	19.2	1142	33.5	32.9	1945	60.1

2. Impedance model: SuperKEKB: LER: MWI

➤ **Simulations with input of Pseudo-Green wake:**

- Use Warnock-Cai's VFP solver
- Collimators are important sources in bunch lengthening
- Simulated $\sigma_z \approx 5.9$mm @Design bunch current
- Simulated MWI threshold is around NP_{th}=1.2E11
- Interplay between CSR and conventional wakes?

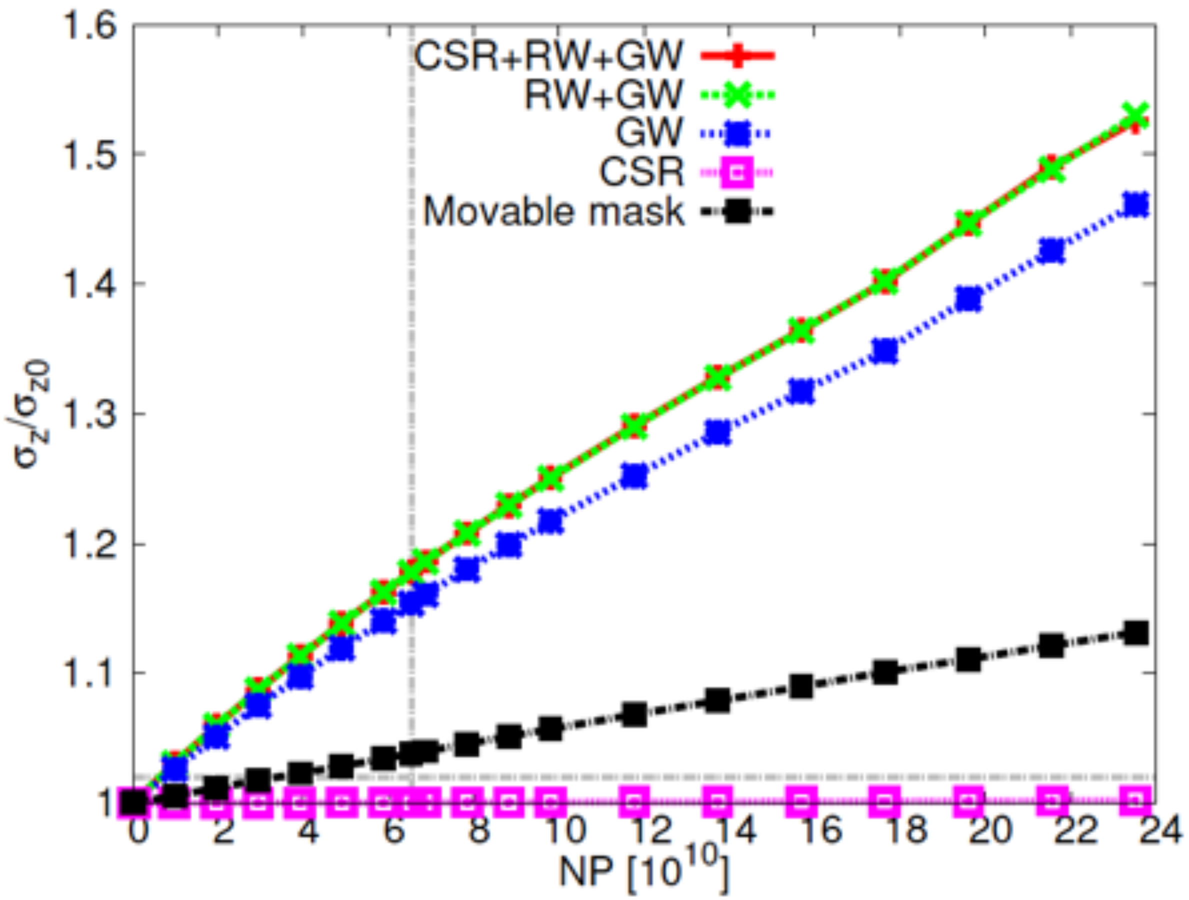


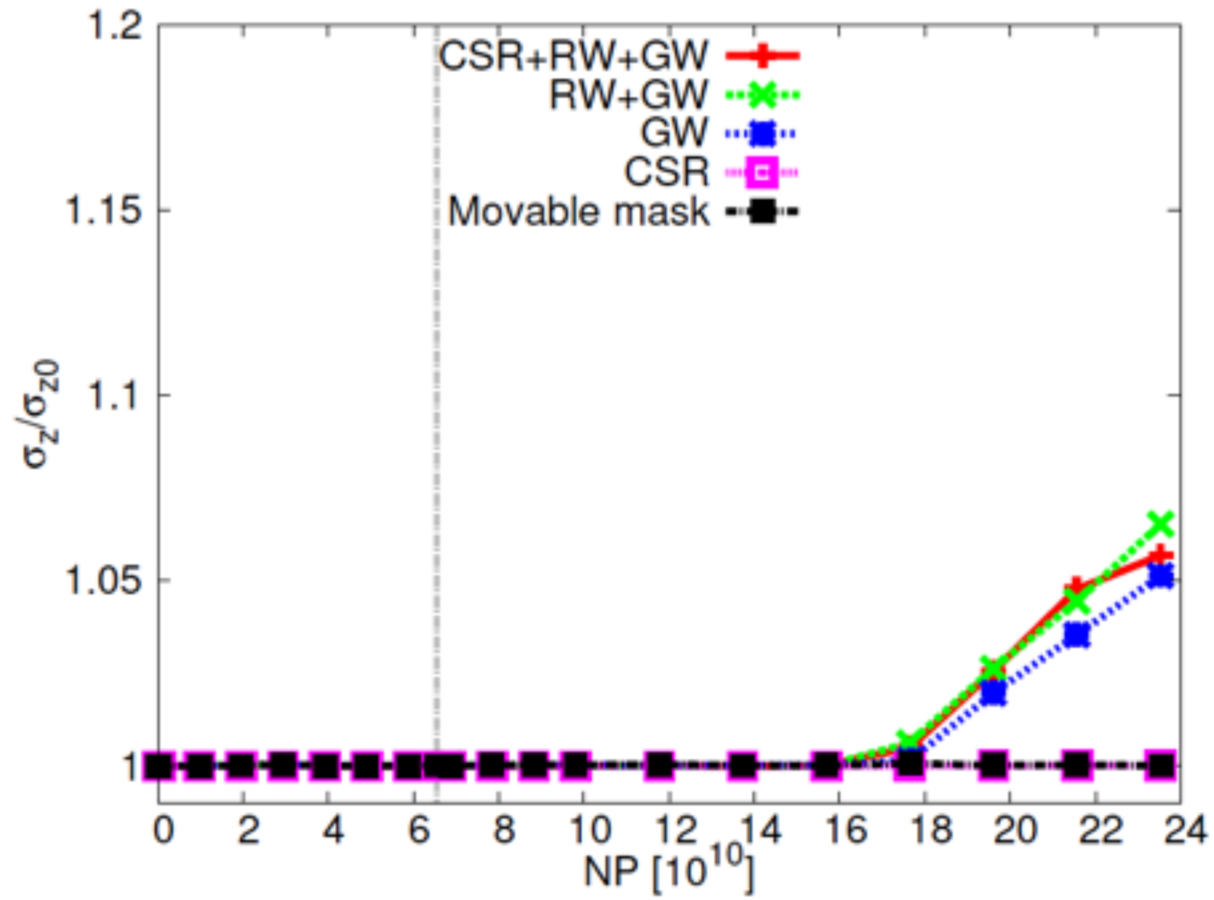


2. Impedance model: SuperKEKB: HER: MWI

➤ **Simulations with input of Pseudo-Green wake:**

- Use Warnock-Cai's VFP solver
- Simulated $\sigma_z \approx 5.8$mm @Design bunch current
- Simulated MWI threshold is around NP_{th}=1.7E11
- CSR and CWR are likely to be not important.





2. Impedance model: Transverse: Beam tilt

➤ Transverse beam tilt:

- **To be a concern in low emittance rings**
- **Asymmetric protrusion (if exists)**

$$\Delta\epsilon_y = \frac{1}{4\sin^2(\pi\nu_y)}\beta_y\theta_{\rm rms}^2$$

$$\theta_{\rm rms} = \frac{Ne^2}{\gamma m_0 c^2}\sqrt{\langle (W_y - \langle W_y\rangle)^2\rangle}$$

$$\langle W_y\rangle = \int_{-\infty}^{\infty} W_y(s)\lambda(s)ds$$

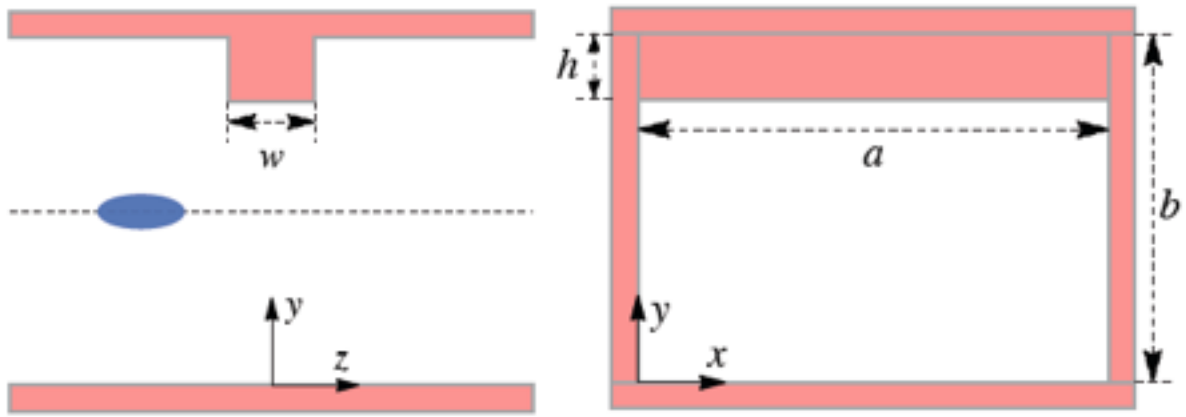
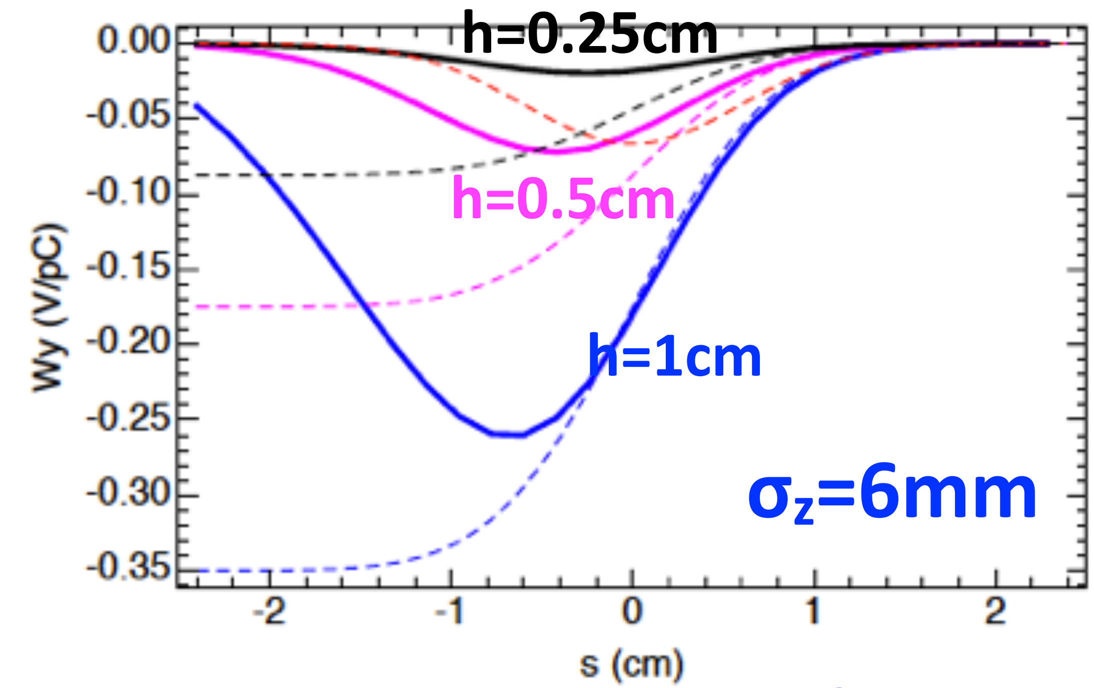


TABLE II. Emittance increase in LER of SUPERKEKB

Corrugation depth h (cm)	1	0.5	0.25
$\theta_{\rm rms}$ (nrad)	290	77	20
$\Delta\epsilon$ (pm)	0.45	0.03	0.002



G. Stupakov and D. Zhou, NIMA 764 (2014) 378–382

G. Stupakov

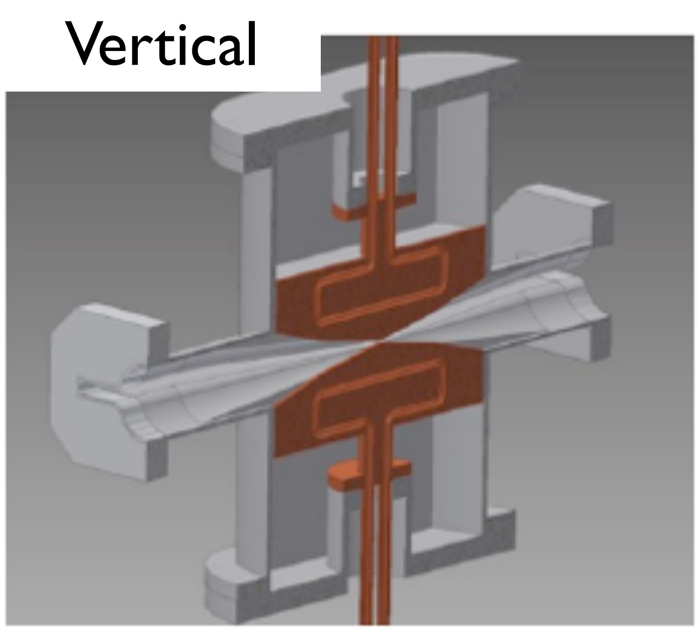
2. Impedance model: Transverse: Beam tilt

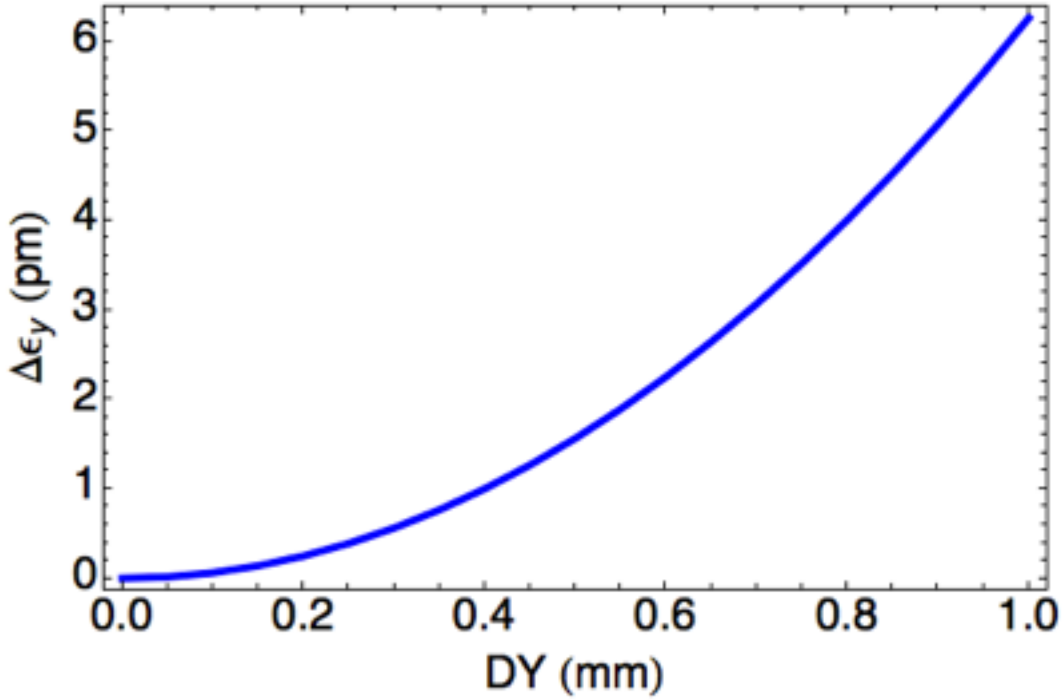
➤ Transverse beam tilt:

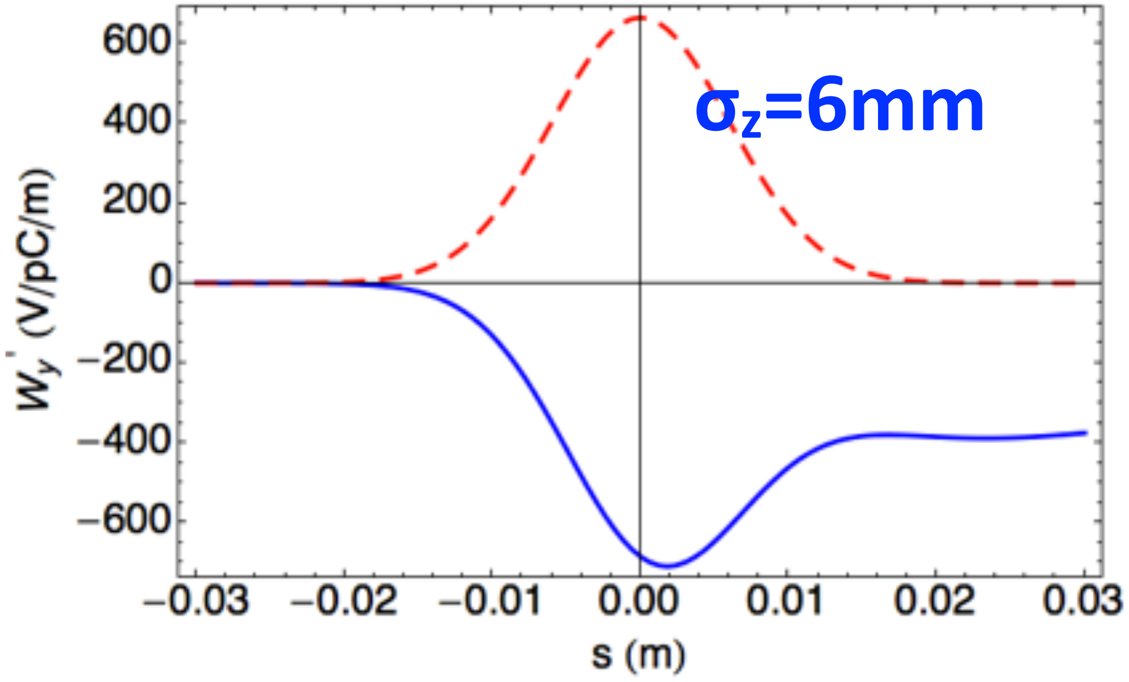
- Symmetric 3D structure (like collimator) with orbit offset
- D02V1 in LER as an example: d=-2/2mm, βy=104.6m
- COD DY < 0.2 mm required

$$\Delta\epsilon_y = \frac{1}{4\sin^2(\pi\nu_y)}\beta_y\theta^2_{\rm rms}$$

$$\theta_{\rm rms} = \frac{Ne^2\Delta y}{\gamma m_0 c^2}\sqrt{\langle(W'_y - \langle W'_y\rangle)^2\rangle}$$







2. Impedance model: Transverse: TMCI: LER

- TMCI in LER
  - We estimated the threshold of the Transverse Mode Coupling Instability using actual β value at location of each collimator with $\sigma_z = 6$ mm.
  - D02V1 is the main impedance source because it would be used with the narrow aperture ($d = \pm 2$ mm).
  - The threshold is about 1.71 mA/bunch (Design value: 1.44 mA/bunch) in the latest collimator design.

TMC threshold (mA/bunch)

	All Closed	Actual apertures		Bunch current (design)
Horizontal	1.41	13.15	>	1.44 mA/bunch
Vertical	1.32	1.71		

$$I_{thresh} = \frac{C_1 f_s E/e}{\sum_i \beta_i \kappa_{\perp i}(\sigma_z)}$$

C_1 : constant ≈8
f_s : synchrotron frequency
E : beam energy
β : beta function
$k_\perp$: kick factor

Collimator Aperture List (mm)

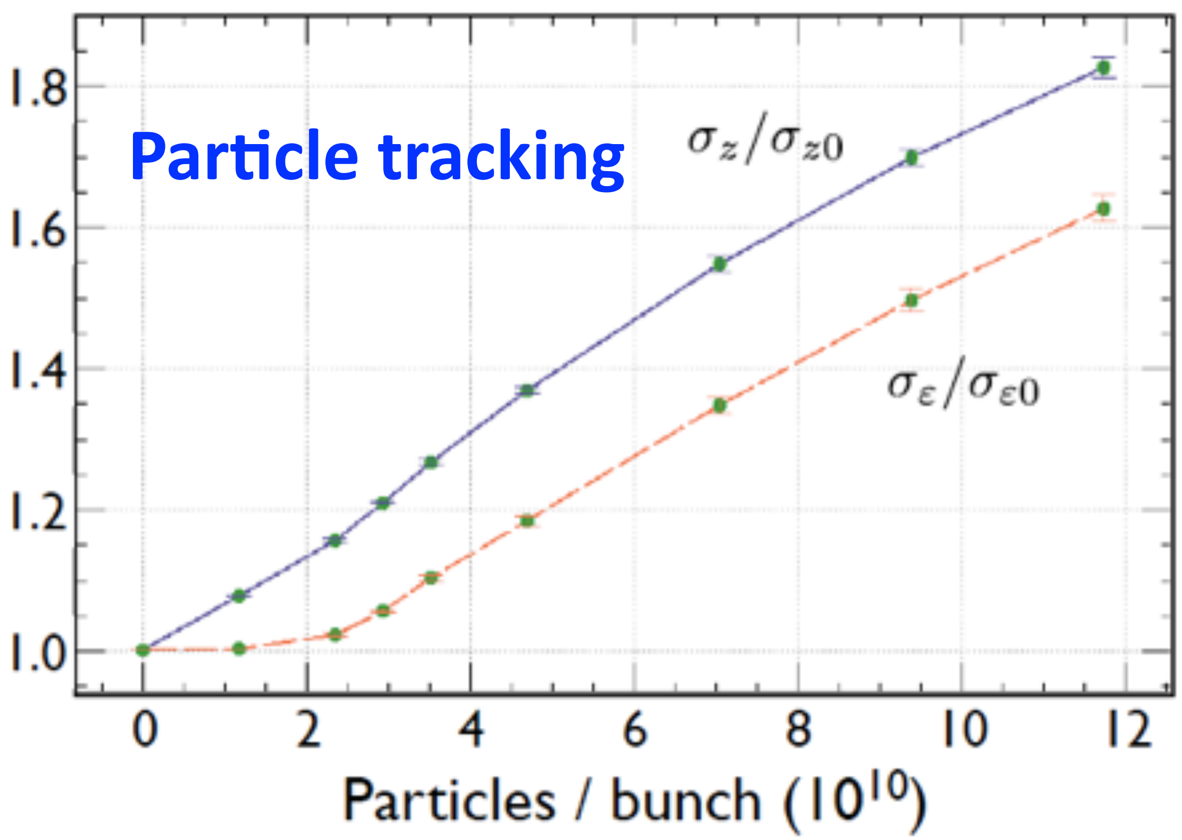
D06H1	-16.0/+17.0	D03H1	-21.0/+20.0	D02H1	-10.6/+12.0
D06H2	-16.0/+16.0	D03H2	-18.0/+20.0	D02H2	-16.0/+20.0
D06H3	-16.0/+15.0	D03V1	-9.0/+9.0	D02H3	-18.0/+21.0
D06H4	-13.0/+13.0	D03V2	-9.0/+9.0	D02H4	-13.0/+9.0
				D02V1	-2.0/+2.0

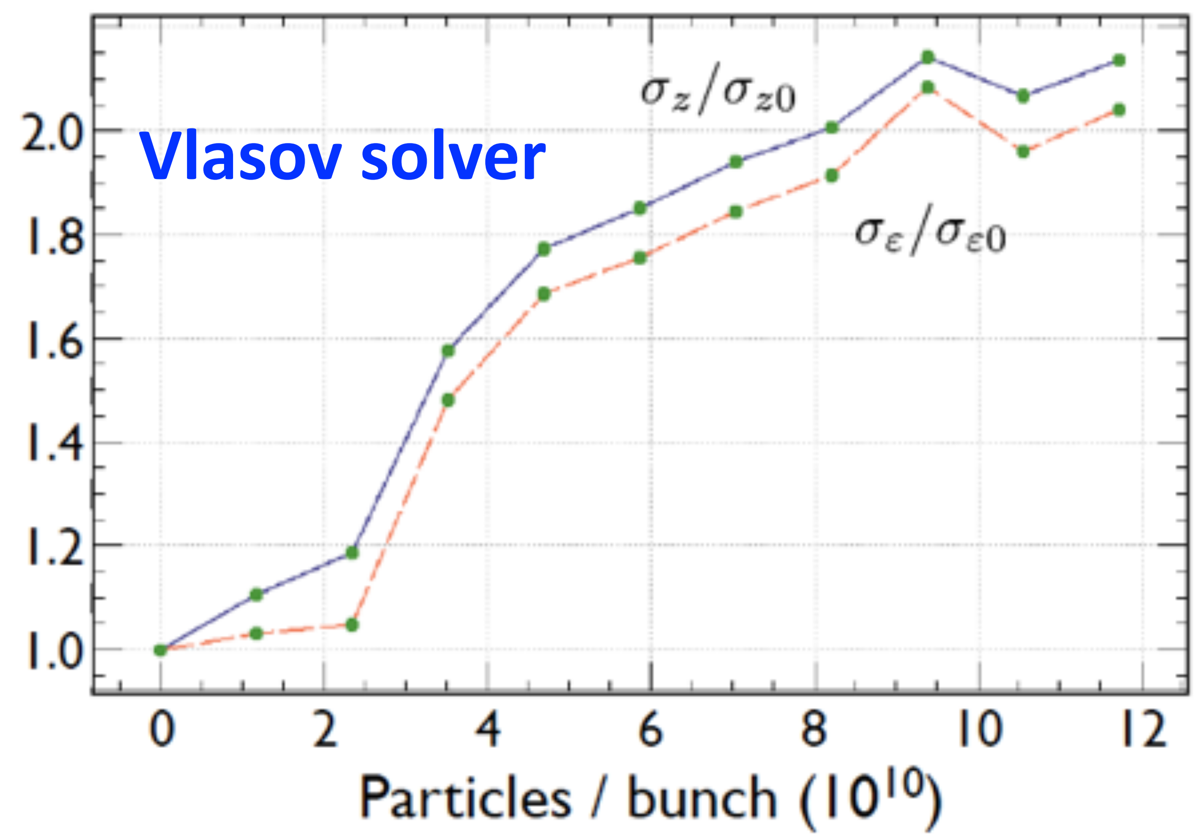
T. Ishibashi

3. CSR: SuperKEKB design

➤ High-current scheme

- **CSR driven MWI in LER was very serious**





N (design)	11.7	10^{10}
σ_{z0}	3	mm
$\sigma_{\varepsilon 0}$	7.1	10^{-4}
ν_z	-0.022	

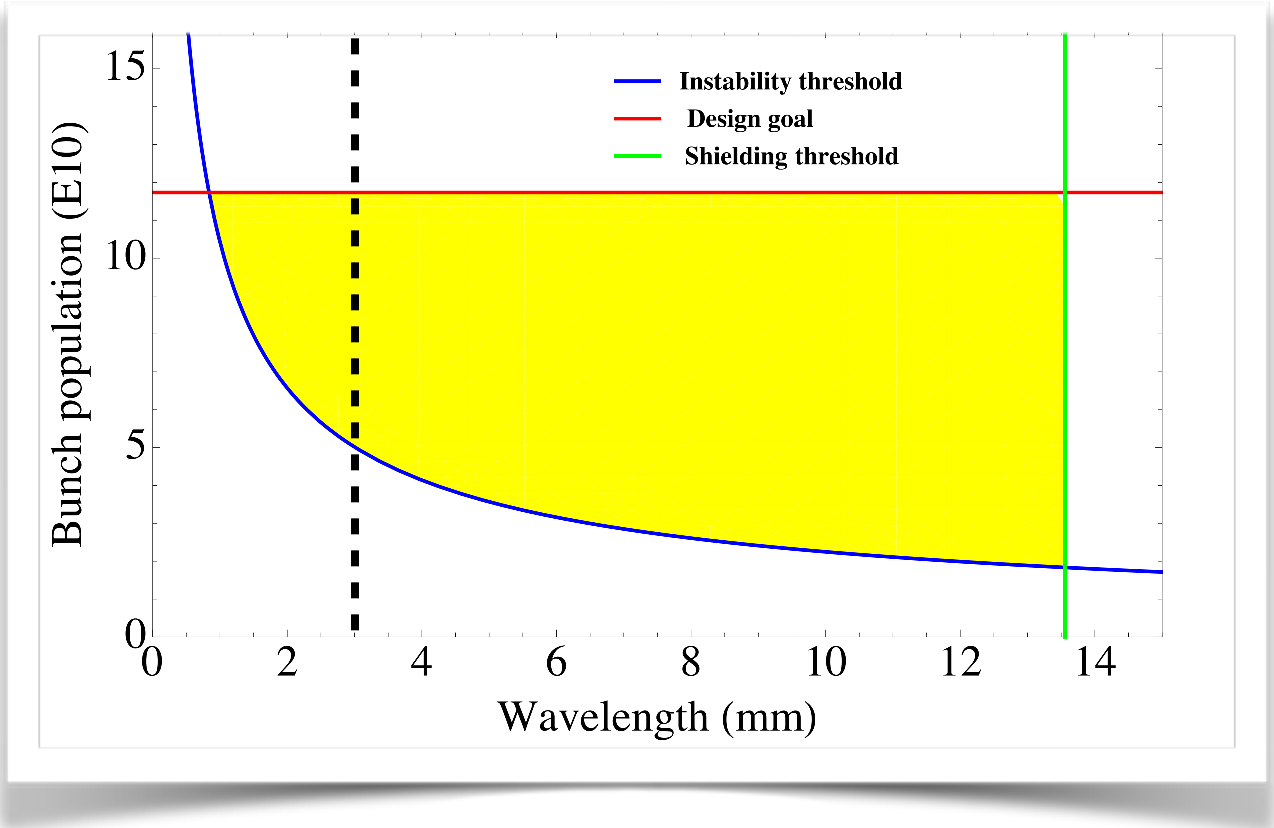
K. Oide, et al., MO3RAI01, PAC'09 (2009)
T. Agoh, PhD thesis (2004)

3. CSR: SuperKEKB design

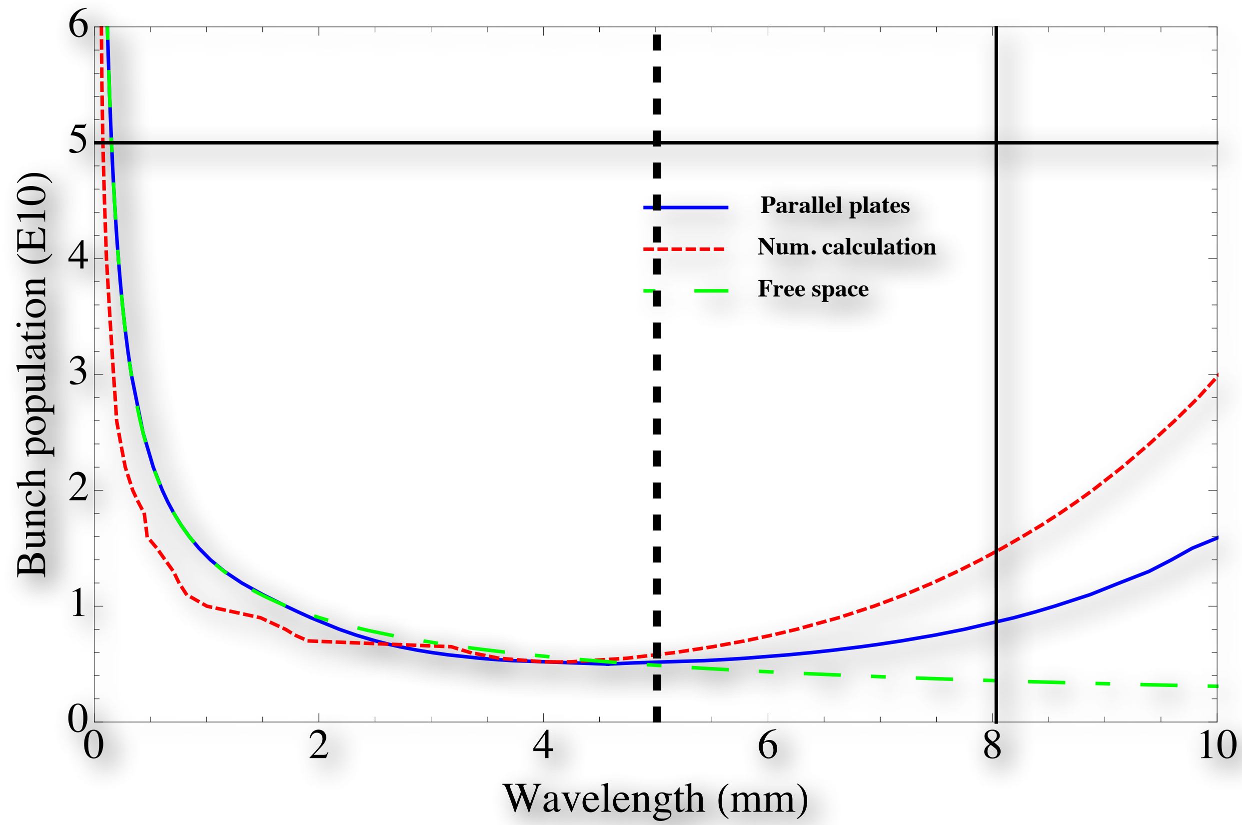
Simple estimation of CSR instability threshold [Stupakov and Heifets (2002)] **...**

$$I_b > \frac{\pi^{1/6}}{\sqrt{2}} \frac{ec}{r_0} \frac{\gamma}{\rho^{1/3}} \alpha_p \delta_0^2 \sigma_z \frac{1}{\lambda^{2/3}}$$

SuperKEKB LER (High-current scheme)



SuperKEKB DR (Version 1.140)



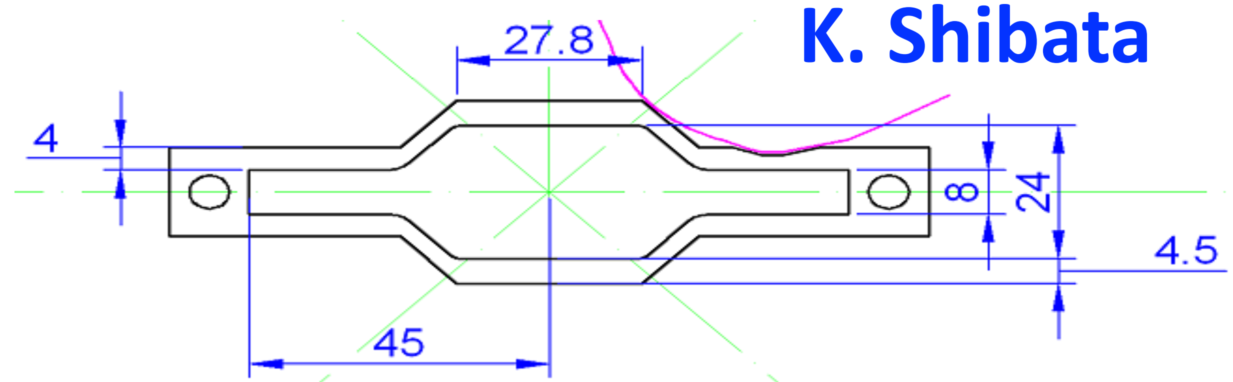
Shielding threshold:

$$\lambda_c = 2\sqrt{b^3/R}$$

G. Stupakov and S. Heifets, PRST-AB 5, 054402 (2002)
J. Byrd, et al., PRL 89, 22, Nov. 2002
D. Zhou, et al., IPAC'10, p. 1554 (2010)

3. CSR: SuperKEKB

- DR design
  - Optics: CSR-optimized
  - Vacuum chamber and RF system



K. Shibata

- Collaboration
  - KEK: T. Agoh, H. Ikeda, M. Kikuchi, K. Ohmi, K. Oide, K. Shibata, K. Yokoya, D. Zhou
  - SLAC: Y. Cai, G. Stupakov, L. Wang et al.
  - CERN: F. Zimmermann
- Intensive CSR impedance calculations
  - Benchmark: 5 codes (Agoh, Oide, Zhou, Stupakov, L. Wang)
  - Single-bend and multi-bend
  - Rectangular and arbitrary cross-section of chamber
- Intensive simulations of MWI
  - Macro-particle tracking: SAD
  - Vlasov solver: SAD, Warnock-Cai's code

3. CSR: SuperKEKB

- **Y. Cai's theory on CSR effects in rectangular chamber**
  - **Steady-state CSR model**
  - **Square chamber lowers MWI threshold [Surprise!]**
  - **Chamber aspect ratio >2 preferred**

$$N_{th} = \frac{C I_A}{ce} \frac{\alpha_p \gamma \sigma_\delta^2}{\sigma_z} \frac{\sigma_z^{4/3}}{R^{1/3}} \xi_{th}$$

$$I_A = 4\pi\epsilon_0 \frac{m_e c^3}{e} \qquad \chi = \sigma_z \sqrt{\frac{R}{b^3}}$$

Parallel plates:

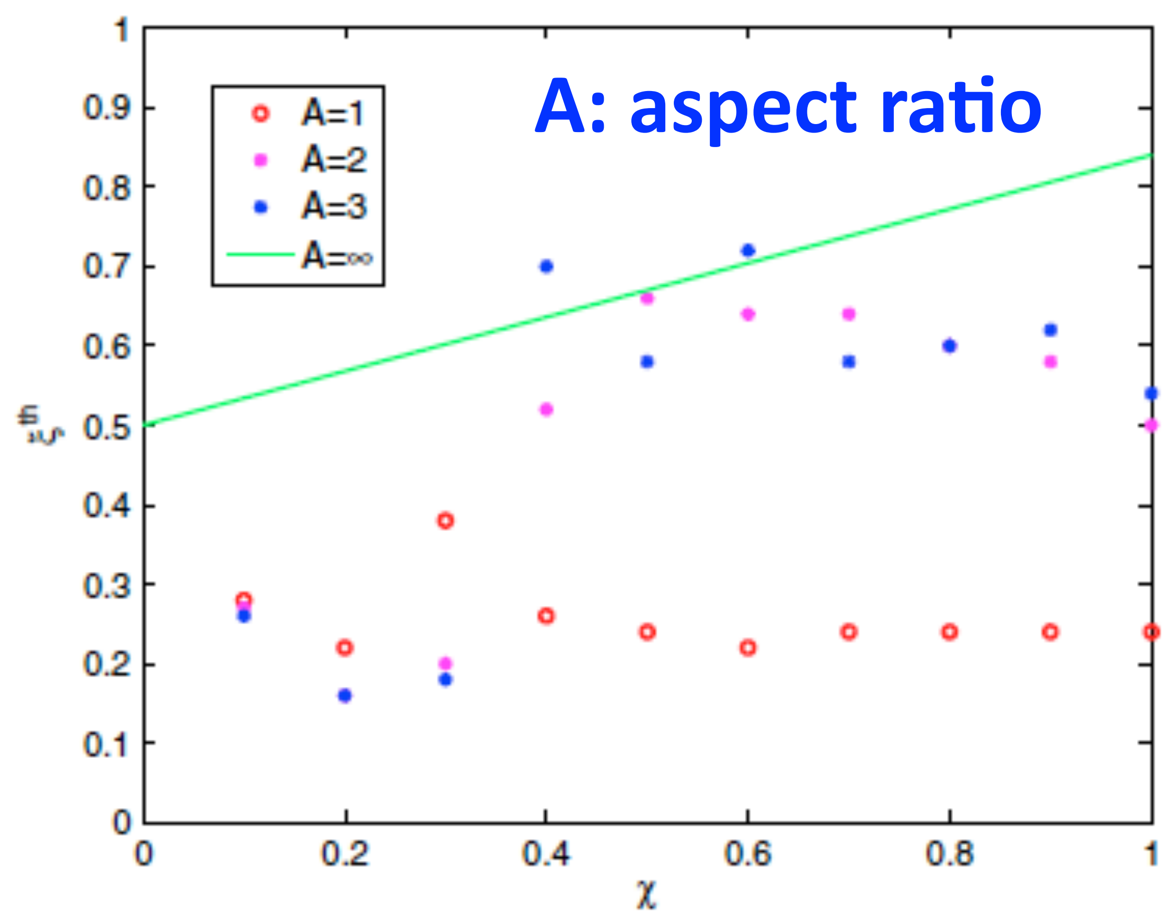
$$\xi_{th} = 0.5 + 0.34\chi$$

Rectangular chamber:

$$\xi = \xi_{th}(\chi, A = \frac{a}{b}, \frac{1}{\omega_s \tau_d})$$

Scaling law of coherent synchrotron radiation in a rectangular chamber

Yunhai Cai
SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA
(Received 21 October 2013; published 12 February 2014)



Ref. Y. Cai, PRST-AB 17, 020702 (2014)

3. CSR: SuperKEKB

➤ Y. Cai's theory on CSR effects in rectangular chamber

	DR			LER	HER
E(GeV)	1.1			4	7.007
NP(10^{10})	5			9.04	6.53
b(mm)	24			90	50
a(mm)	34			90	104
R(m)	2.7/3			74.7	106
χ	1.49	1.67	2.16	1.15	1.98
$\alpha_p(10^{-4})$	141			3.25	4.55
$\sigma_\delta(10^{-4})$	5.5			8.08	6.37
σ_z(mm)	6.6	7.8	11	6	5
ξ_{th}^{old}	1.49	1.67	2.16	1.15	2.1
$N_{th}^{old}(10^{10})$	4.4	5.2	7.6	8.8	20.2
ξ_{th}^{new}	0.5	0.5	0.5	0.25	0.5
$N_{th}^{new}(10^{10})$	1.5	1.6	1.8	1.9	4.9

Ref. Y. Cai, PRST-AB 17, 020702 (2014)

3. CSR: Field dynamics

Parabolic equation (PE) in Frenet-Serret coordinate system:

$$\frac{\partial \vec{E}_\perp}{\partial s} = \frac{i}{2k}\left[\nabla_\perp^2 \vec{E}_\perp - \frac{1}{\epsilon_0}\nabla_\perp \rho_0 + 2k^2\left(\frac{x}{\underline{R(s)}} - \frac{1}{\underline{2\gamma^2}}\right)\vec{E}_\perp\right]$$

T. Agoh, PRST-AB 7, 054403 (2004).

Longitudinal field and impedance:

$$E_s = \frac{i}{k}\left(\nabla_\perp \cdot \vec{E}_\perp - \mu_0 c J_s\right) \qquad Z(k) = -\frac{1}{q}\int_0^\infty E_s(x_c, y_c)ds$$

Contributors:

- G. Stupakov and I.A. Kotelnikov (Mode expansion, PRST-AB 2003, 2009)
- T. Agoh & K. Yokoya (Mesh and Eigenfunction expansion, PRST-AB 2004, 2009)
- D.R. Gillingham and T.M. Antonsen (Time-domain PE, PRST-AB 2007)
- K. Oide (Mesh + Eigen solver, PAC 2009)
- D. Zhou (Mesh + Finite difference, JJAP 2012)
- L. Wang (Mesh + Finite element, 2012)
- D.A. Bizzozero (Mesh + Discontinuous Galerkin method, PRL 2015)
- R. Warnock

3. CSR: Field dynamics

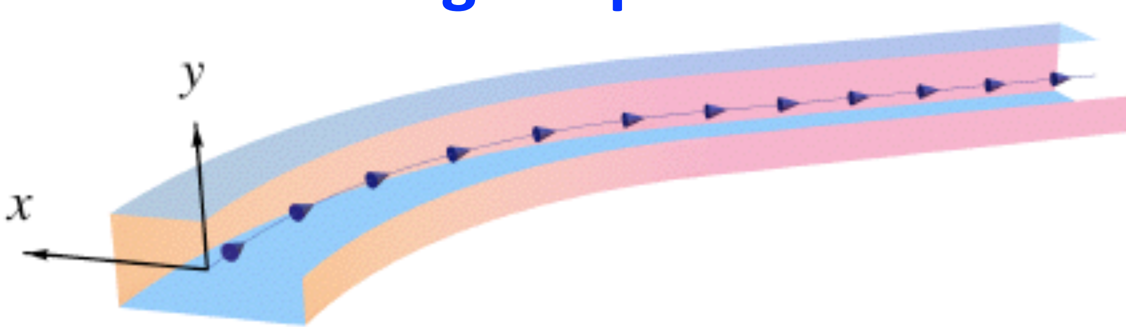
CSRZ code: Uniform rectangular cross-section

Field separation:

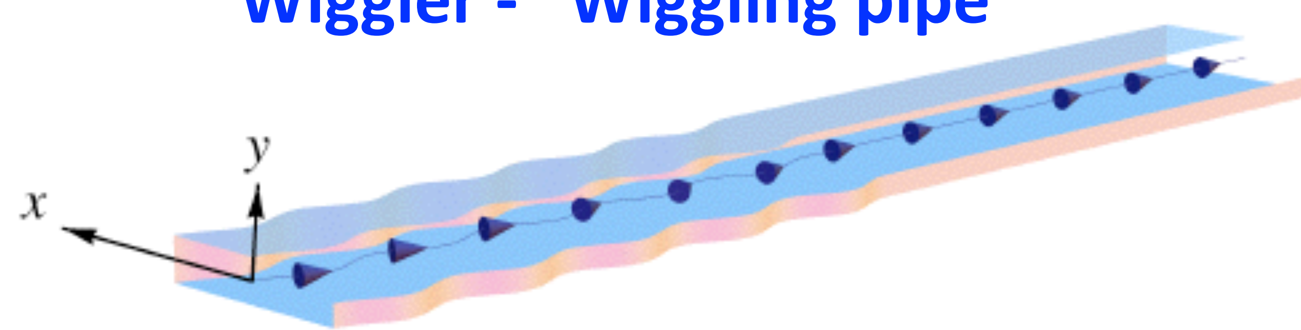
$$\vec{E}_\perp = \vec{E}^r_\perp + \vec{E}^b_\perp \quad \rightarrow \quad \frac{\partial \vec{E}^r_\perp}{\partial s} = \frac{i}{2k}\left[\nabla^2_\perp \vec{E}^r_\perp + 2k^2\left(\frac{x}{R(s)} - \frac{1}{2\gamma^2}\right)\left(\vec{E}^r_\perp + \vec{E}^b_\perp\right)\right]$$

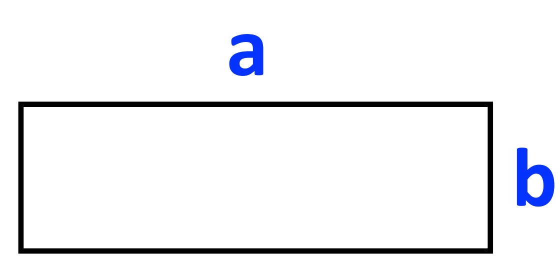
The curvature is variable (Single dipole, soft fringe, a series of dipoles, wiggler, etc.):

Single dipole



Wiggler - "Wiggling pipe"

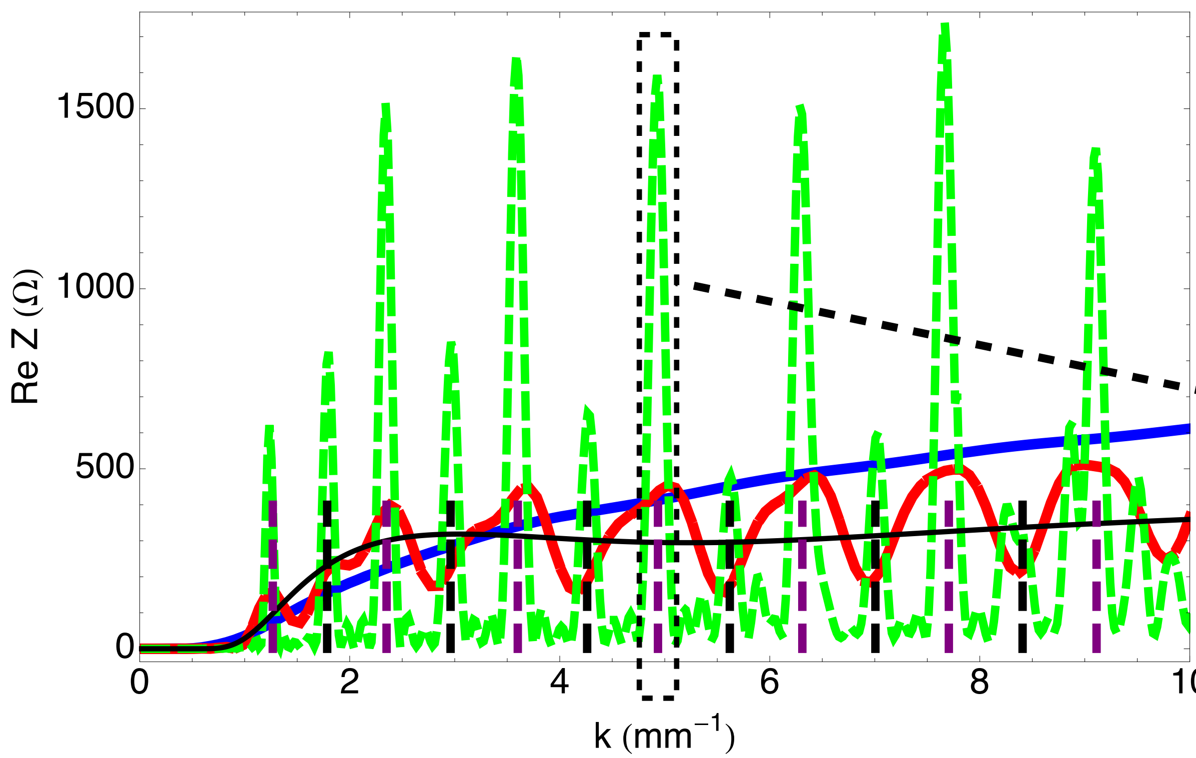




3. CSR: Field dynamics: Eigenmodes

Resonance poles = Eigen modes

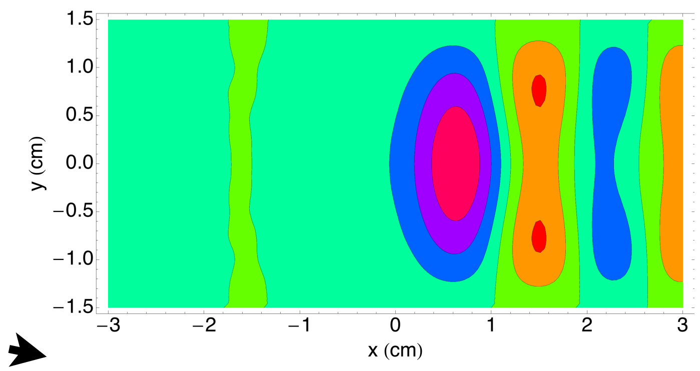
a/b=60/30 mm, L_{bend}=8 m, R=5 m



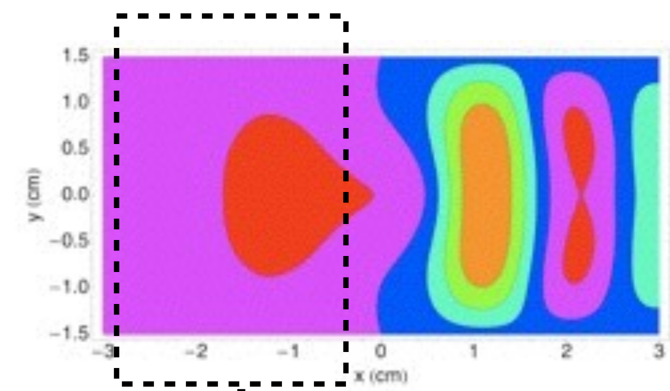
Freq. & index

$$k = 4930\ \mathrm{m}^{-1}$$
$$(m, p) = (3, 1)$$

Im. E_x^r:

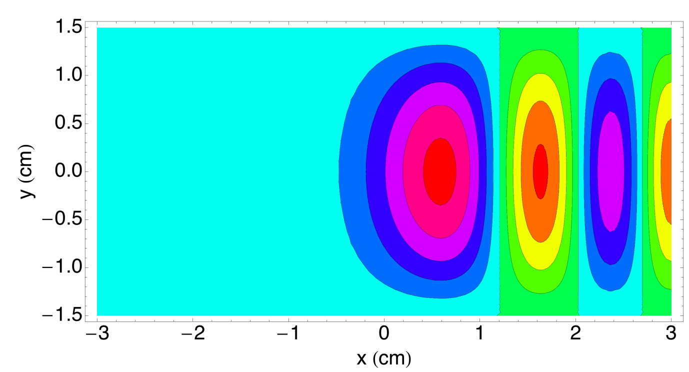


Re. E_x^r:



Overtaking fields

Mode pattern:

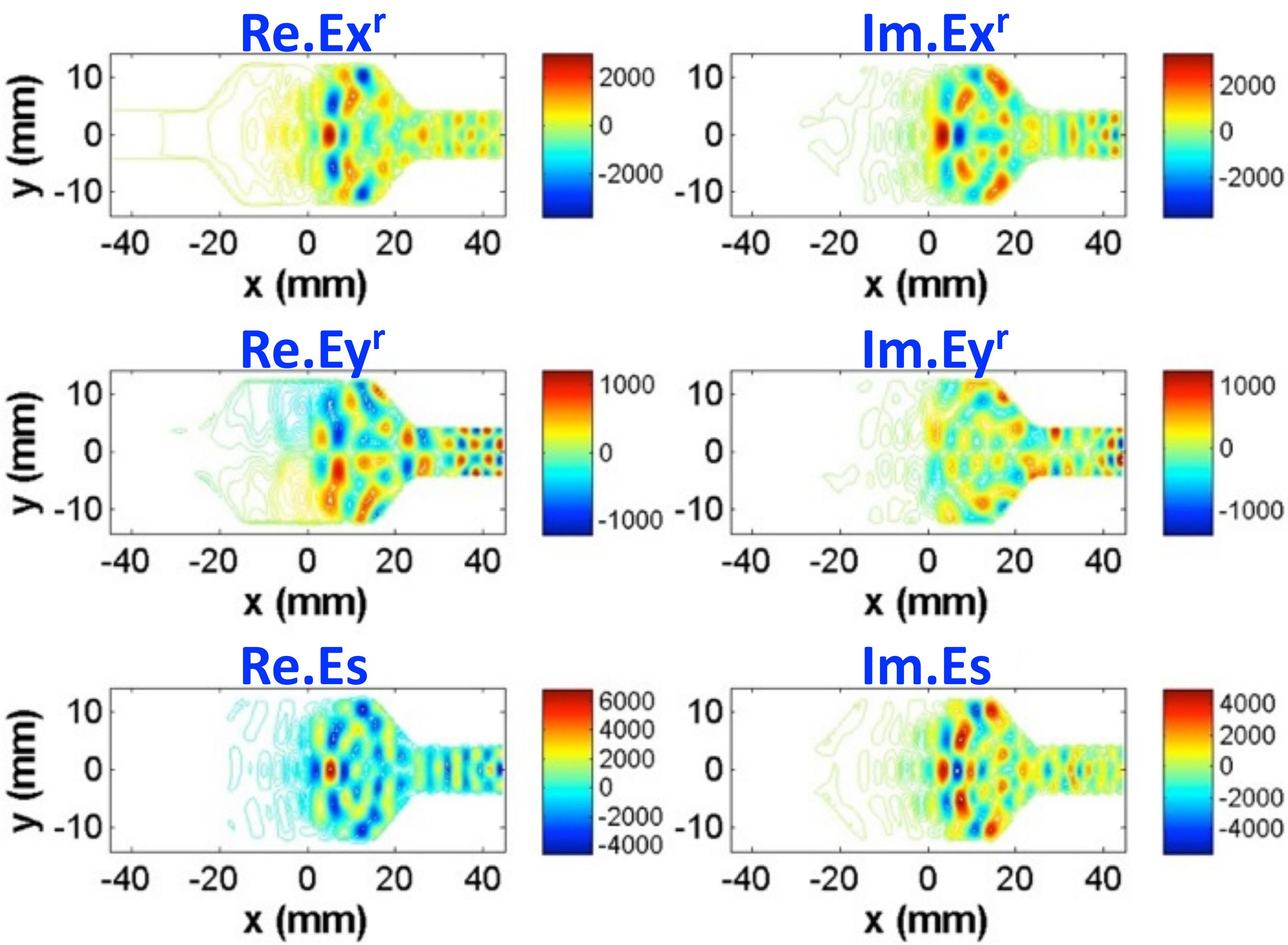


E_x mode: $E_x(x,y) = E_{x0}\mathrm{Ai}\left(k_y^2\kappa^2 - x/\kappa\right)\sin\left[k_y(y+b/2)\right]$

G. Stupakov and I. Kotelnikov, PRST-AB 6, 034401 (2003).

3. CSR: Field dynamics: Eigenmodes

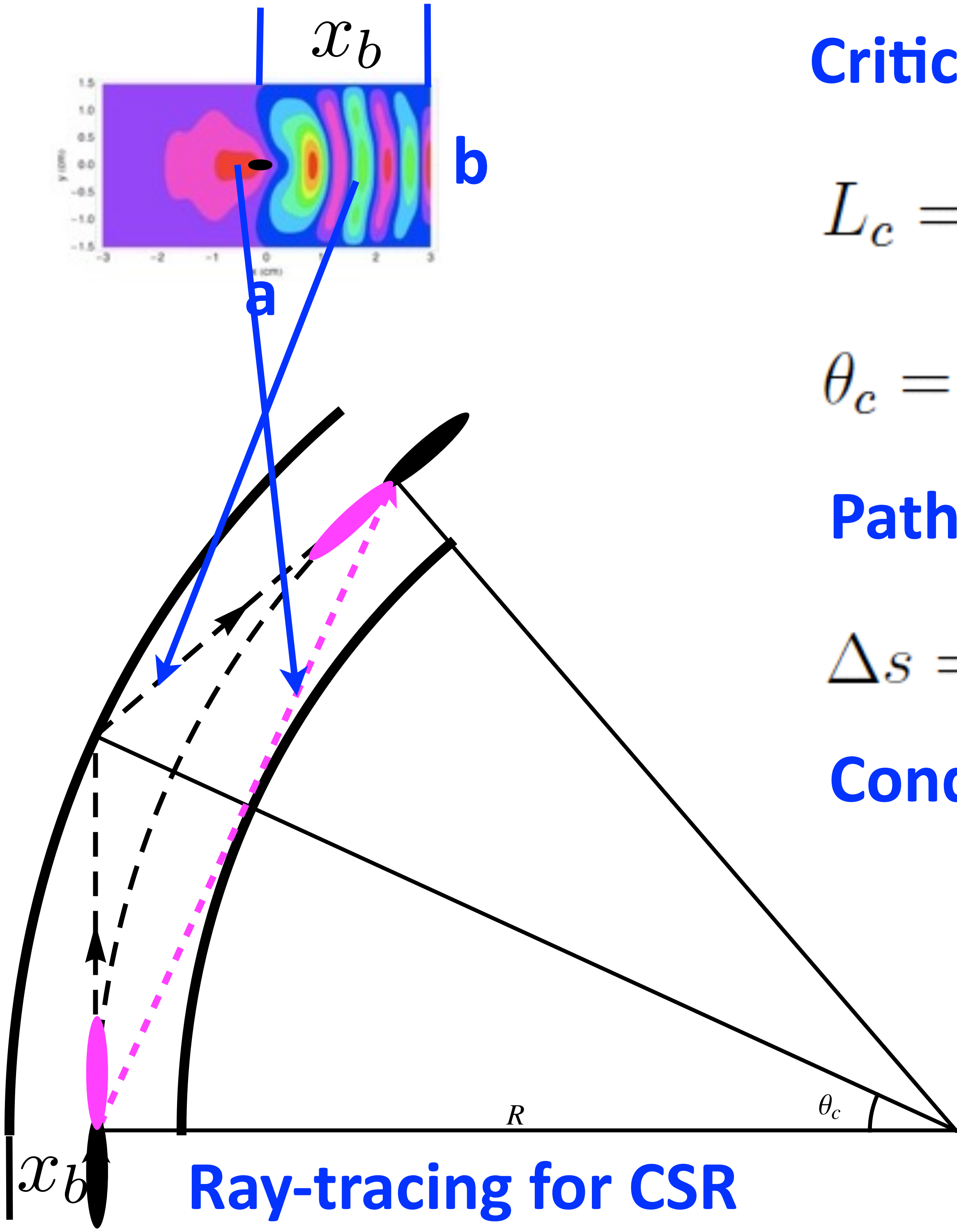
Arbitrary cross-section: Finite element technique + parabolic equation (L. Wang)



Courtesy of L. Wang

3. CSR: Field dynamics: Optical model

Outer-wall reflection can be well approximated by optical model [Derbenev (1995), Carr (2001), Sagan (2009), Oide (2010)]



Ray-tracing for CSR

Critical length (Catch-up distance):

$$L_c = 2R\theta_c \approx 2\sqrt{2Rx_b} \qquad x_b \ll R$$

$$\theta_c = \mathrm{ArcCos}\left(R/(R+x_b)\right) \approx \sqrt{2x_b/R}$$

Path difference:

$$\Delta s = 2R(\mathrm{Tan}(\theta_c) - \theta_c) \approx \frac{4}{3}\sqrt{\frac{2x_b^3}{R}}$$

Condition of neglecting outer wall:

$$\Delta s \gg \sigma_z$$

Y. S. Derbenev et al., TESLA FEL-Report 1995-05 (1995).
G. L. Carr et al., PAC'01, p. 377 (2001).
D. Sagan et al., PRST-AB 12, 040703 (2009).
K. Oide, Talk at CSR mini-workshop, Nov. 08, 2010.
D. Zhou et al., Jpn. J. Appl. Phys. 51 (2012) 016401.

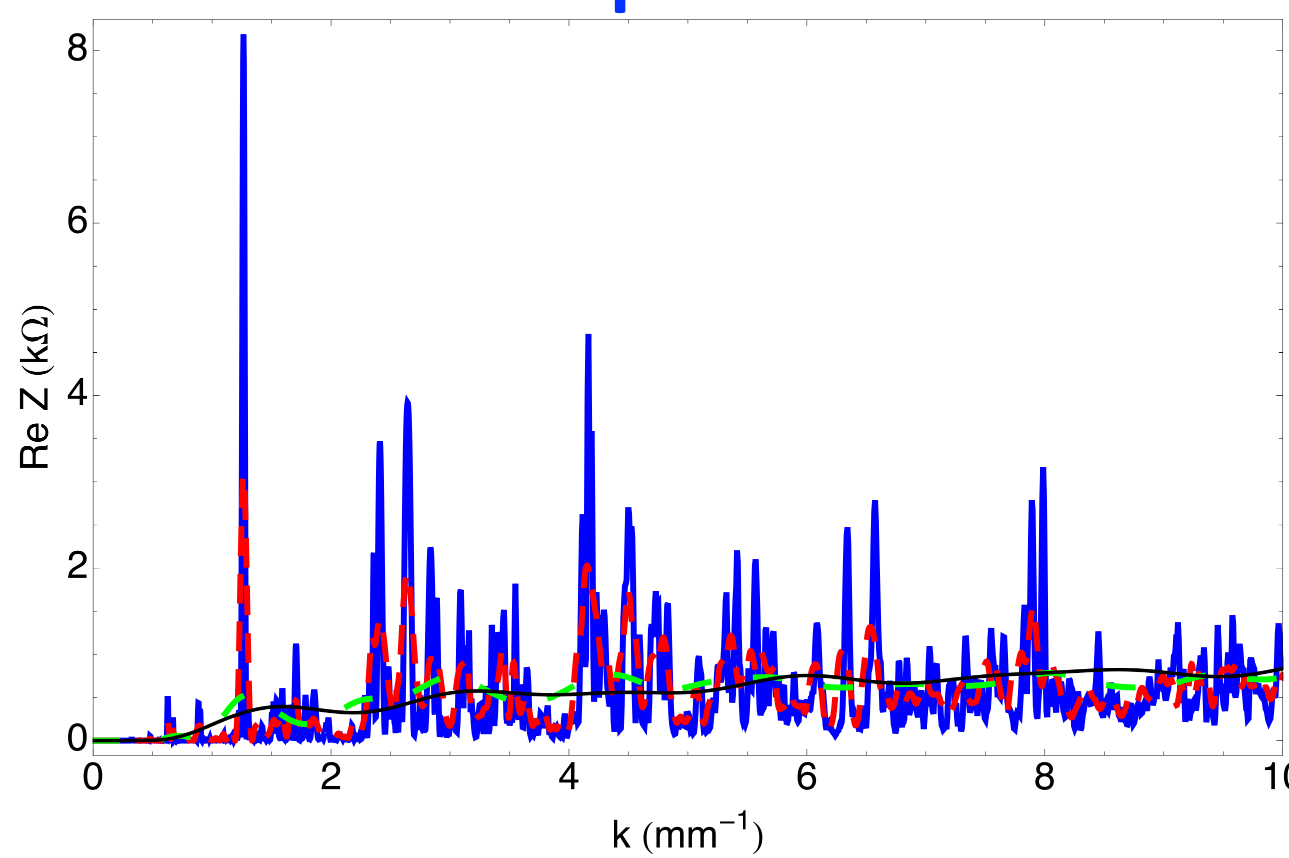
3. CSR: Field dynamics: Multi-bend interference

➤ SuperKEKB DR

- **CSR impedance: Forest of “narrow-band” spikes**
- **Multi-bend interference: Modify the measured power spectrum in CSR**

DR layout

Impedance



3. CSR: Field dynamics: Waveguide modes

R. Warnock's idea: Similarity of steady-state CSR and whispering gallery modes

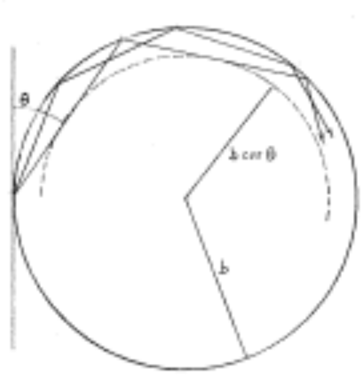
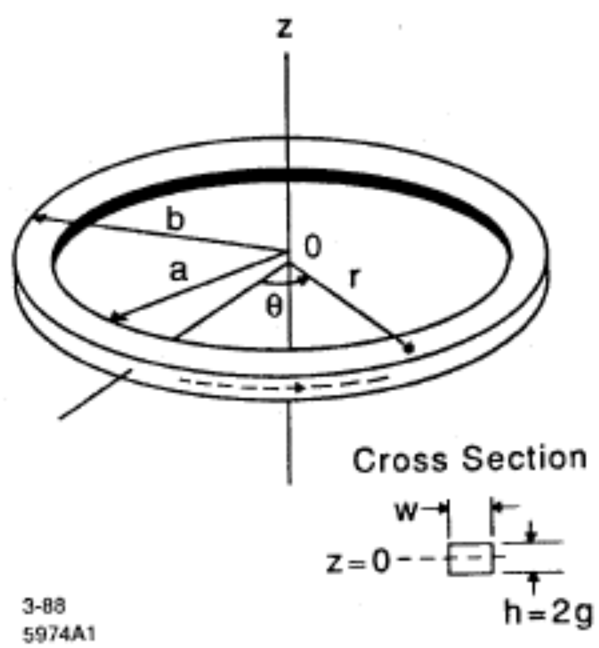


Figure 3: Rayleigh's ray picture



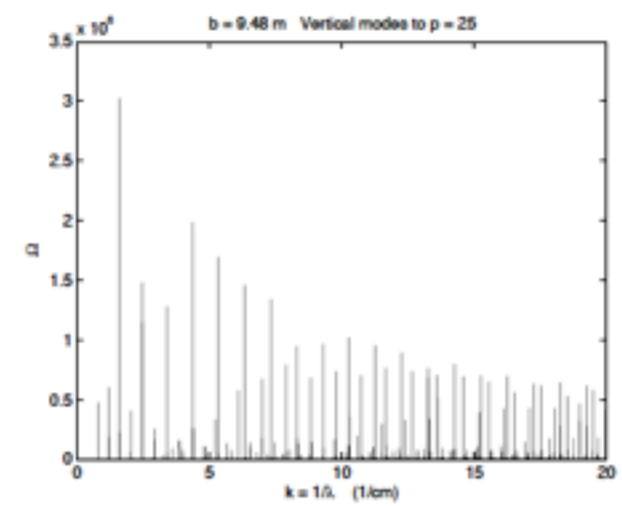


Figure 7: Re $Z(n, n\omega_0)$ for parameters of VUV light source, vs. wave number $1/\lambda$ in units of cm^{-1}.

Ref. R. Warnock, in ICFA beam dynamics Newsletter 63 (2014)

3. CSR: Field dynamics: Measurements

CSR measurements at NSLS VUV ring

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 463 (2001) 387–392

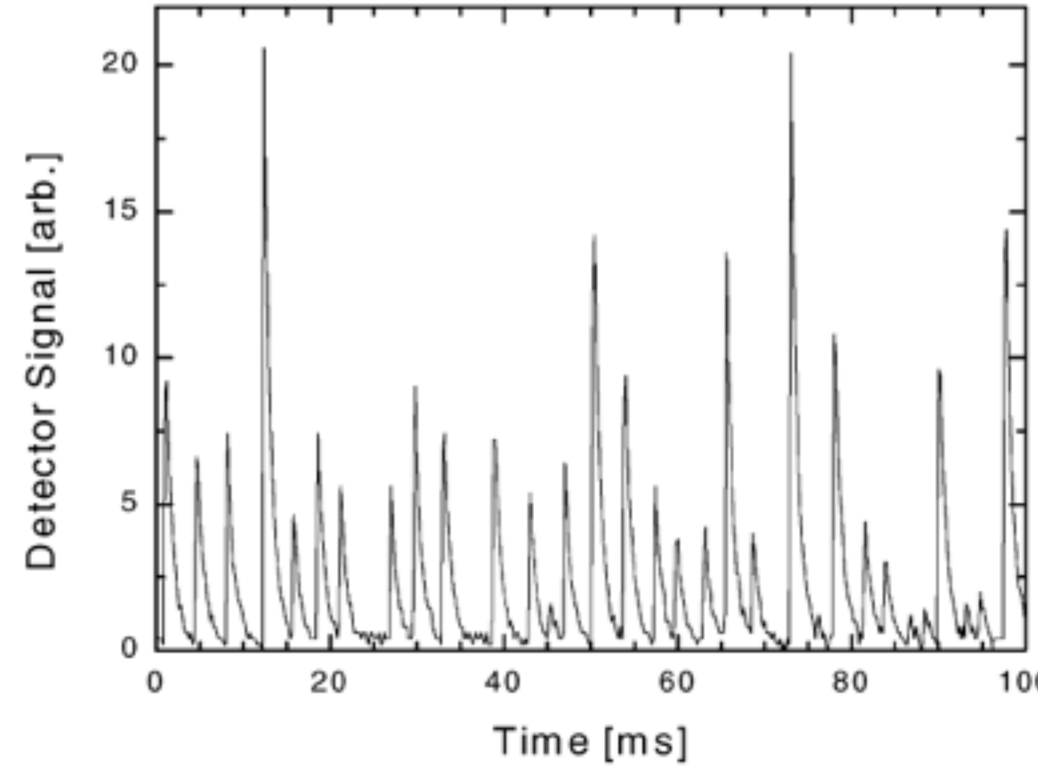
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.nl/locate/nima

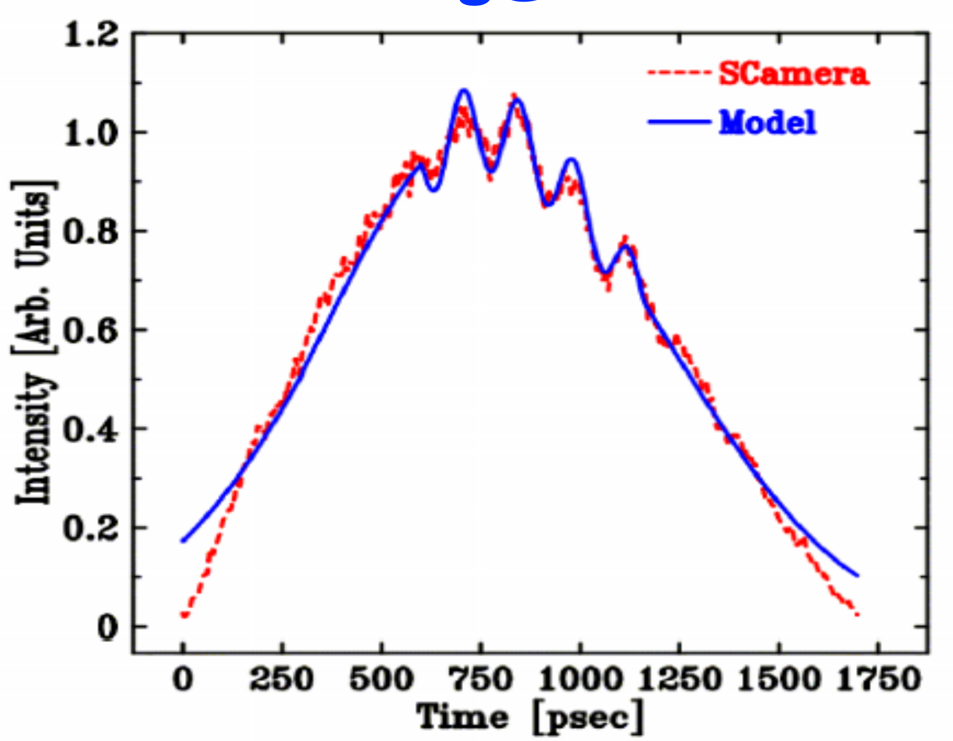
Observation of coherent synchrotron radiation from the NSLS VUV ring

G.L. Carr[a],*, S.L. Kramer[a], J.B. Murphy[a], R.P.S.M. Lobo[b], D.B. Tanner[b]

FIR signal

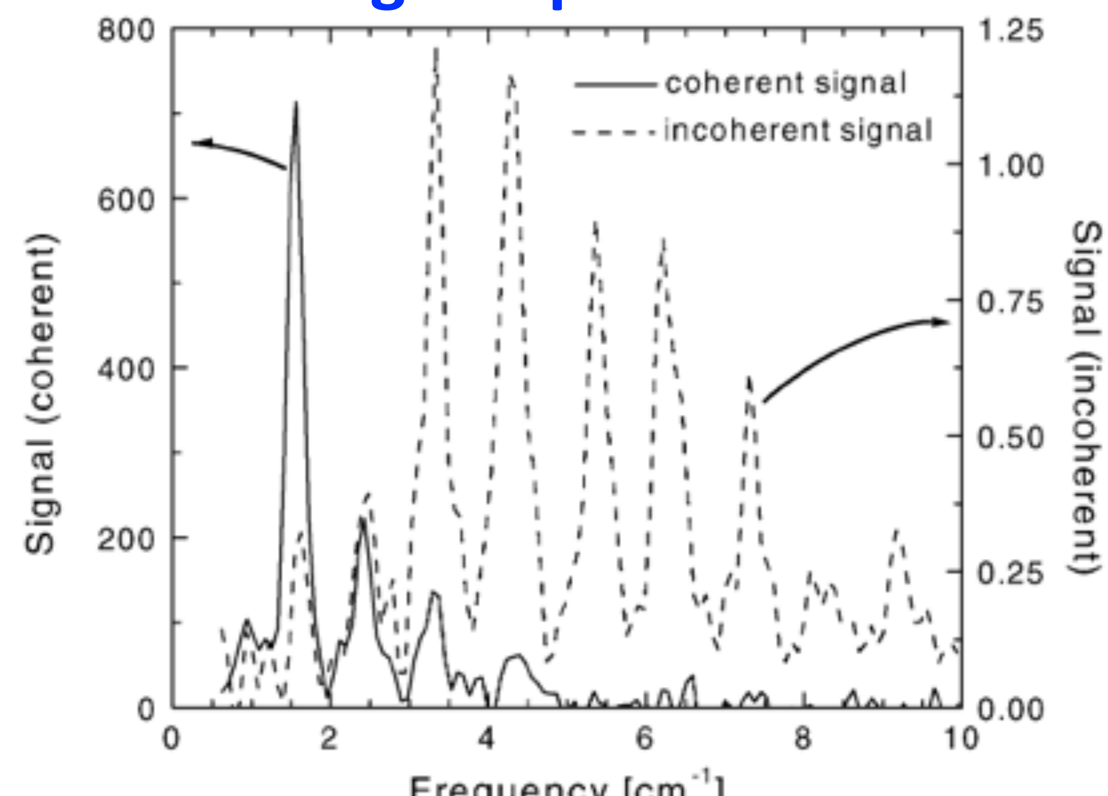


Microbunching@Streak Camera



S. Kramer, EPAC 2002

Signal spectrum

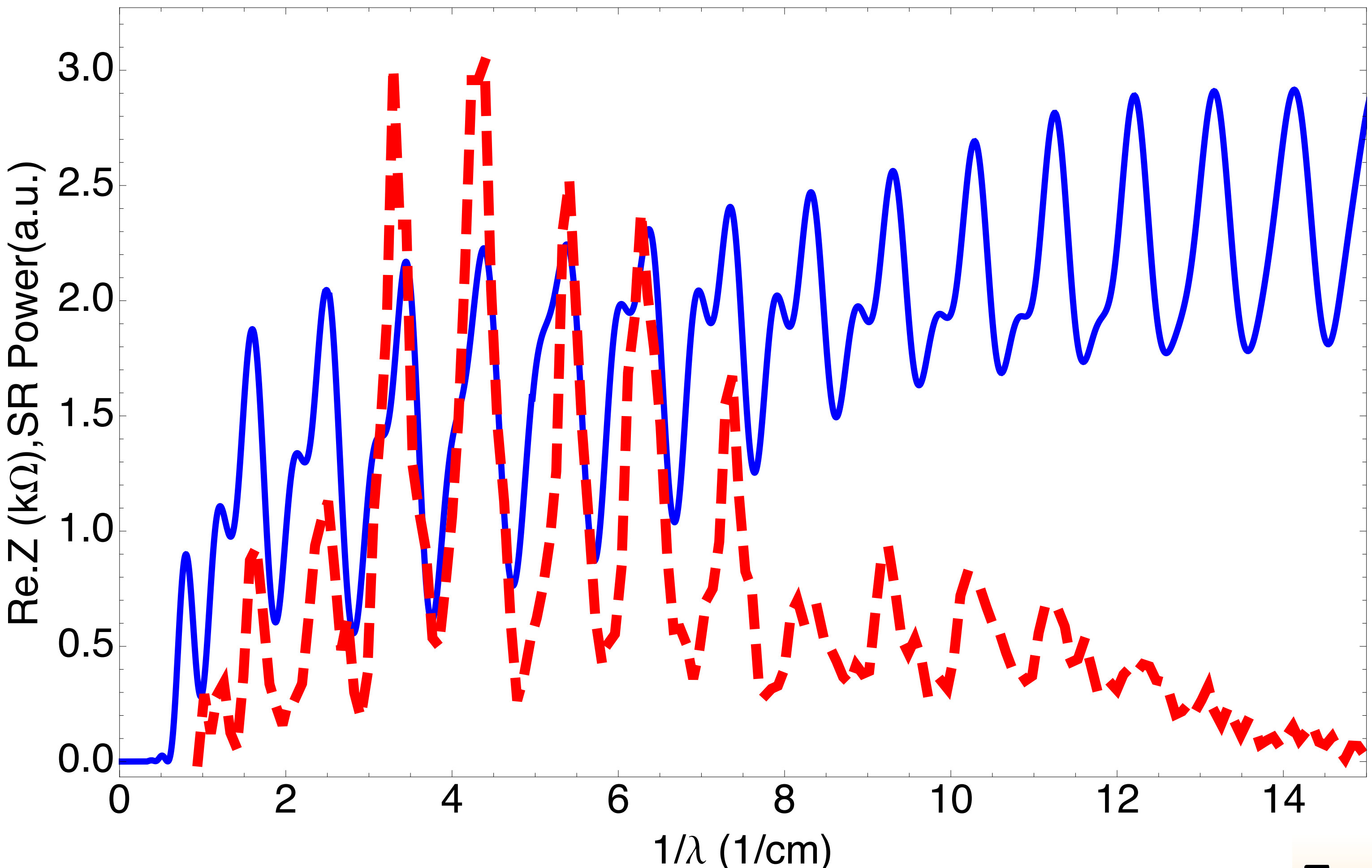


3. CSR: Field dynamics: Measurements

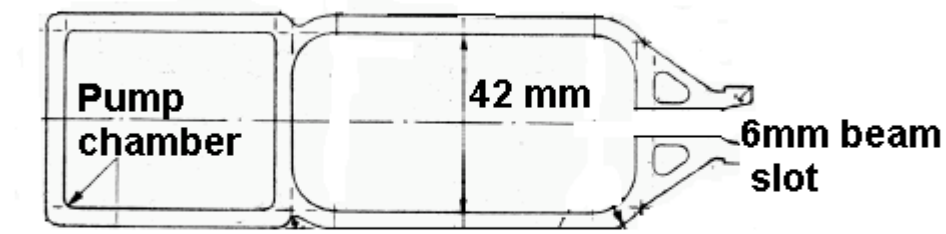
CSR measurements at NSLS VUV ring

$a/b=80/42$ mm, $L_{bend}=1.5$ m, $R=1.91$ m

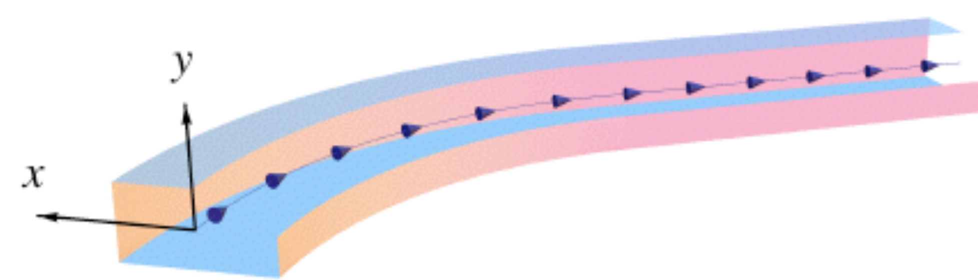
$L_{bend} > L_c=0.8$ m



Chamber cross section



Model for calculation



Blue solid: SR impedance
Red dashed: Measured ISR spectrum
(Data provided by S.L. Kramer)

Excellent agreements in peak positions and widths.
The discrepancy in amplitude at low- and high-frequency parts is attributed to the transfer function of the detection system.

3. CSR: Field dynamics: Measurements

➤ High-resolution CSR measurements at CLS

PRL 114, 204801 (2015) PHYSICAL REVIEW LETTERS week ending 22 MAY 2015

Observation of Wakefields and Resonances in Coherent Synchrotron Radiation

B. E. Billinghurst,* J. C. Bergstrom, C. Baribeau, T. Batten, L. Dallin,
T. E. May, J. M. Vogt, and W. A. Wurtz
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Brookhaven National Laboratory, Upton, New York 11973, USA
(Received 19 January 2015; published 20 May 2015)

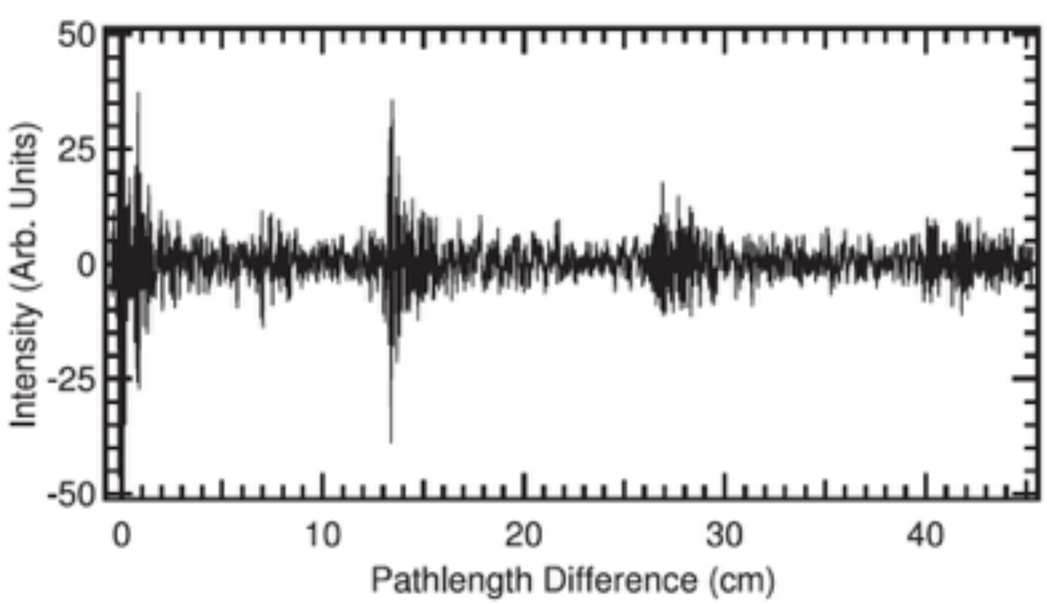


FIG. 1. Interferogram as a function of path length difference.

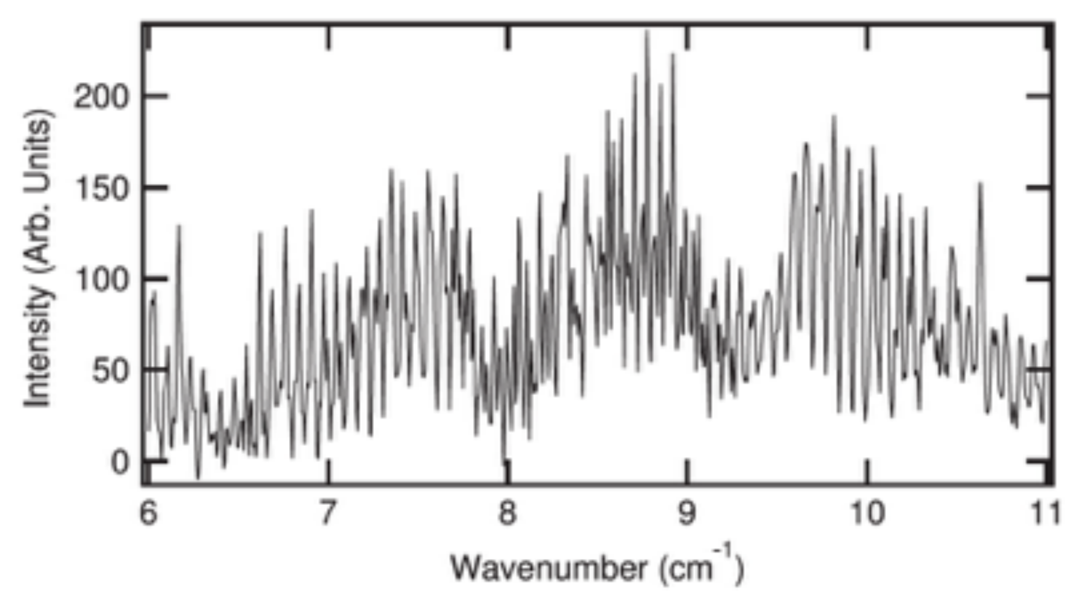
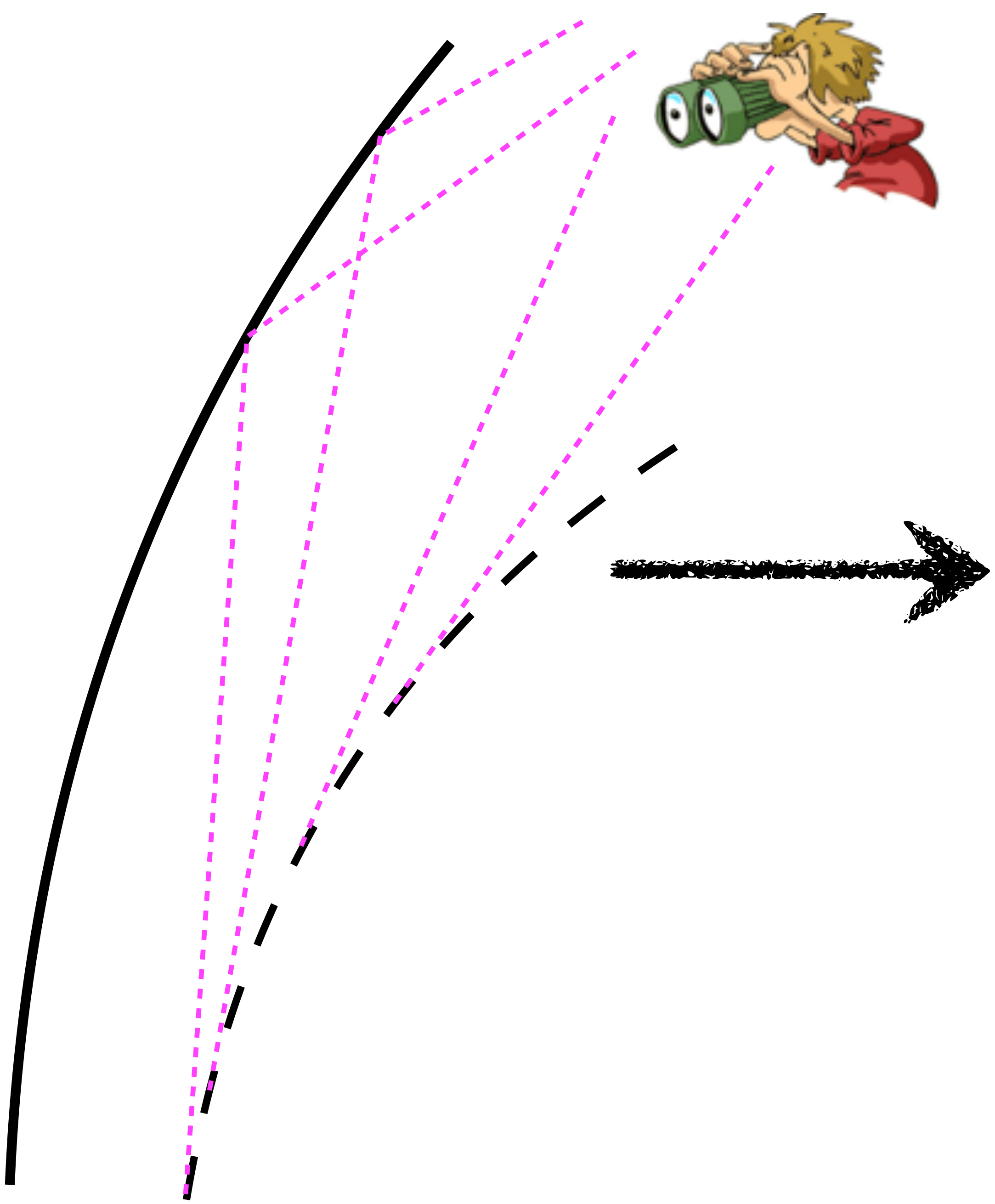


FIG. 2. Fourier transform of the interferogram.

3. CSR: Field dynamics: Measurements

Since the interesting wavelength of CSR is much smaller than the chamber geometry ($\lambda \ll b$), we can safely do ray-tracing for even complicated geometry.



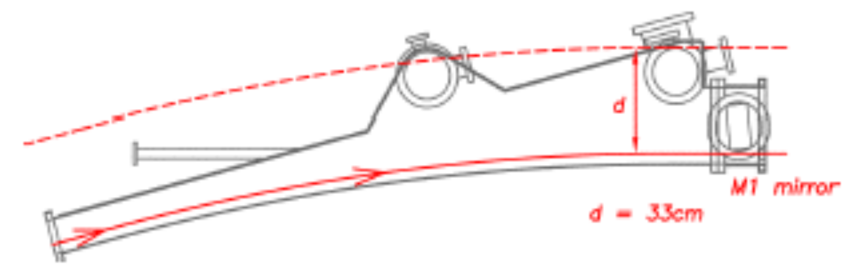


Figure 10: Vacuum chamber of CLS at dipole where IR is extracted

R. Warnock

3. CSR: Field dynamics: Measurements

➤ High-resolution CSR measurements at CLS

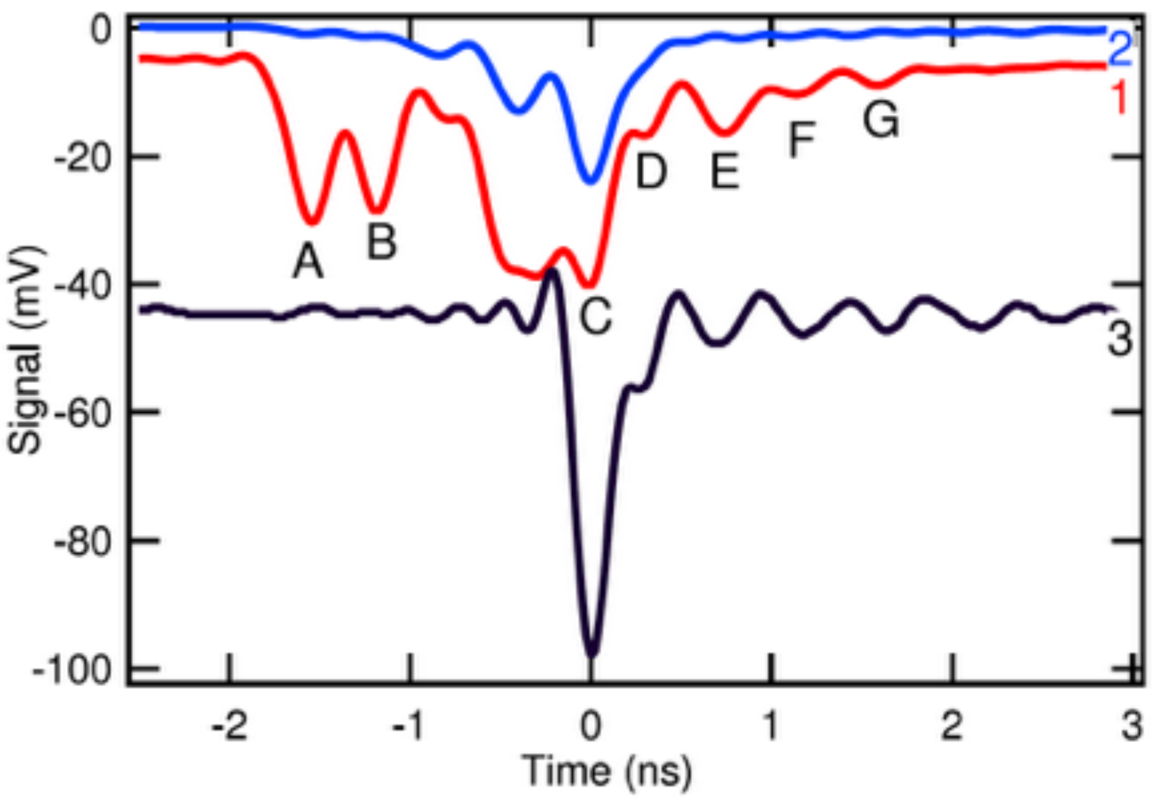


FIG. 4 (color online). rf diode measurements in the time domain (oscilloscope traces) with a 50–75 GHz detector. Diode mounting and polarization: 1—backward horizontal; 2—backward vertical; 3—forward horizontal (with adjustment of time base). For clarity the curves have been separated vertically.

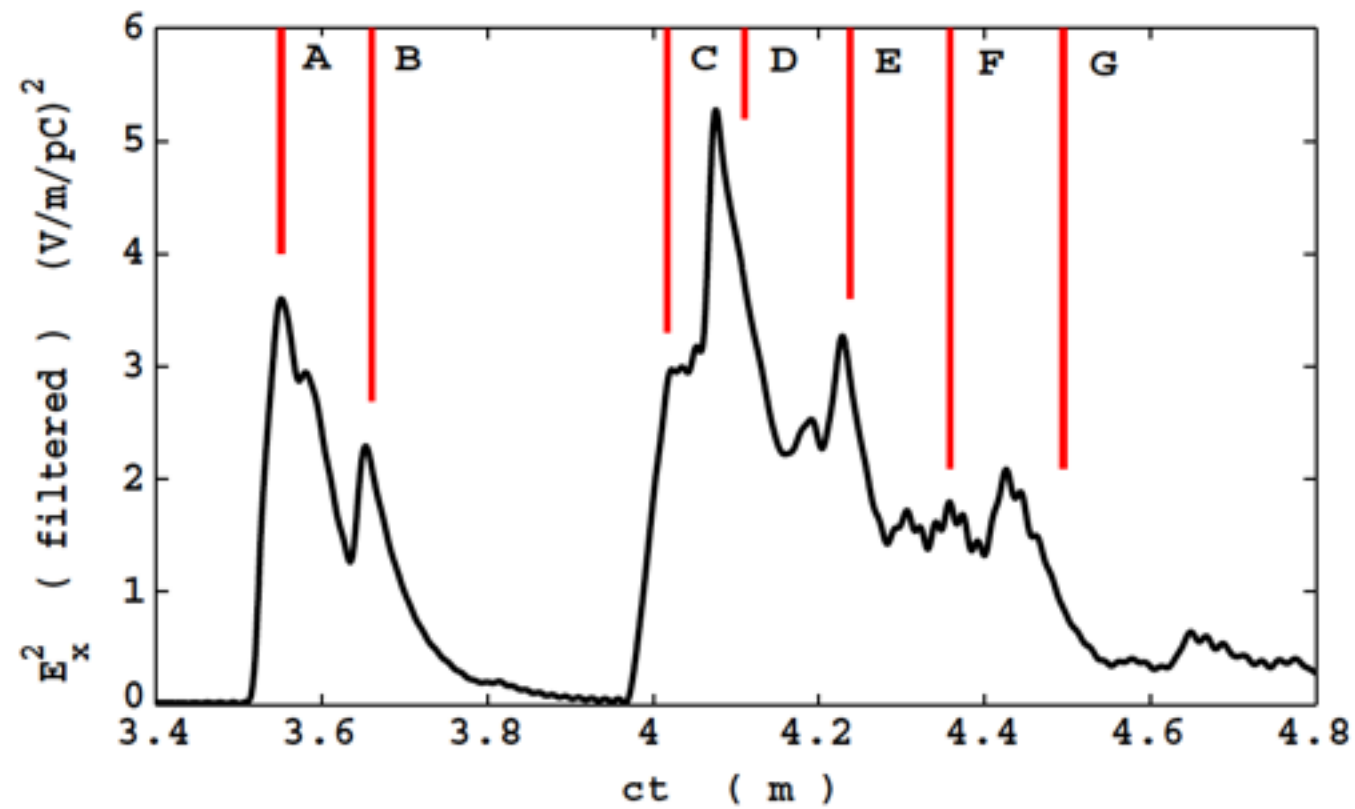


FIG. 5 (color online). Simulated E_x^2 at backward port vs ct, after a low pass filter to account for detector response. The origin of time t is when the bunch is 5 cm before the entrance to the bend. Only the lowest mode in y is included.

B.E. Billinghurst et al., PRL 114, 204801 (2015)

4. Summary

➤ **Impedance model and single-bunch effects**

- **Pseudo-Green function wakes obtained for KEKB and SuperKEKB rings**
- **Sources of bunch lengthening and MWI in KEKB are not well understood yet**
- **Beam tilt and TMCI are potentially important in SuperKEKB**

➤ **CSR**

- **CSR effect is still a concern in SuperKEKB**
- **CSR calculations based on parabolic equations well investigated**
- **CSR fields calculation/measurement with 3D chamber is a very interesting subject to be investigated**

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➤ **SuperKEKB started beam commissioning on Feb. 1st**

- Beam measurements to be delivered
- Welcome to follow the experiences of SuperKEKB

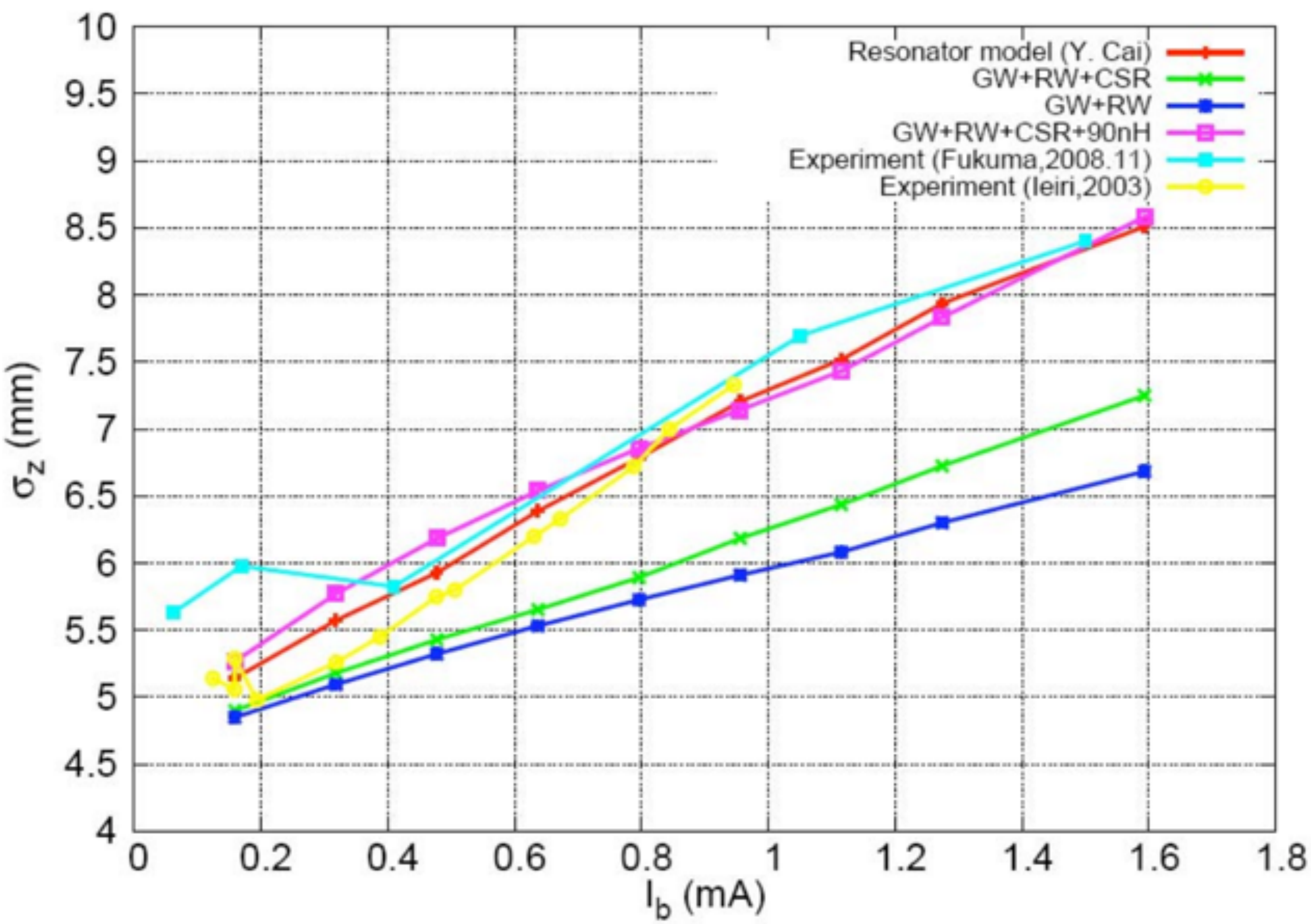
Thanks for your attention!

2. Impedance model: KEKB: LER

➤ **Use Zotter's equation**

$$\left(\frac{\sigma_z}{\sigma_{z0}}\right)^3 - \frac{\sigma_z}{\sigma_{z0}} - \frac{\alpha I_b \mathrm{Im}\left\{Z_\parallel/n\right\}_{eff}}{\sqrt{2\pi}(E/e)\nu_{s0}^2}\left(\frac{R}{\sigma_{z0}}\right)^3 = 0$$

Ref. J. Corbett, TUPP028, EPAC08

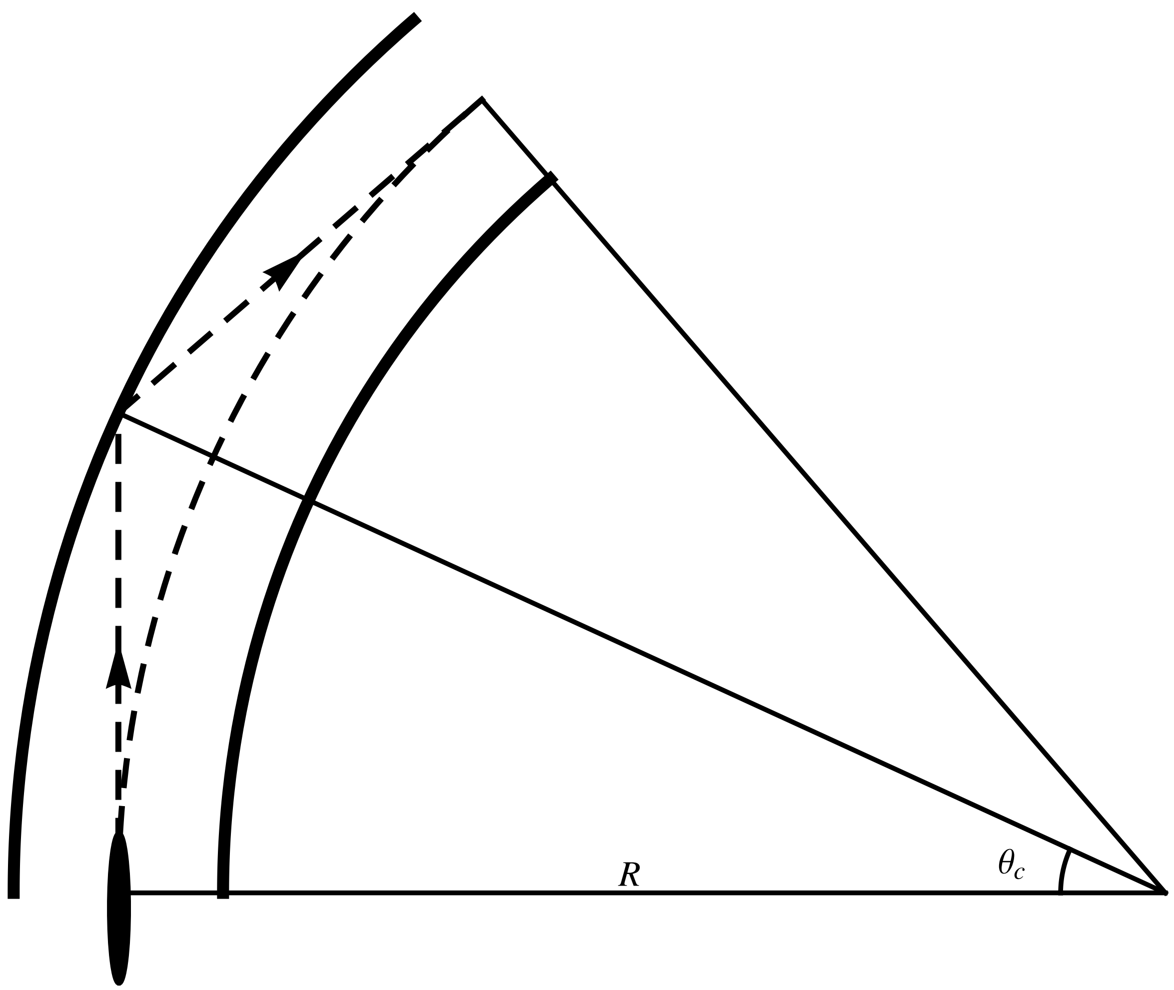


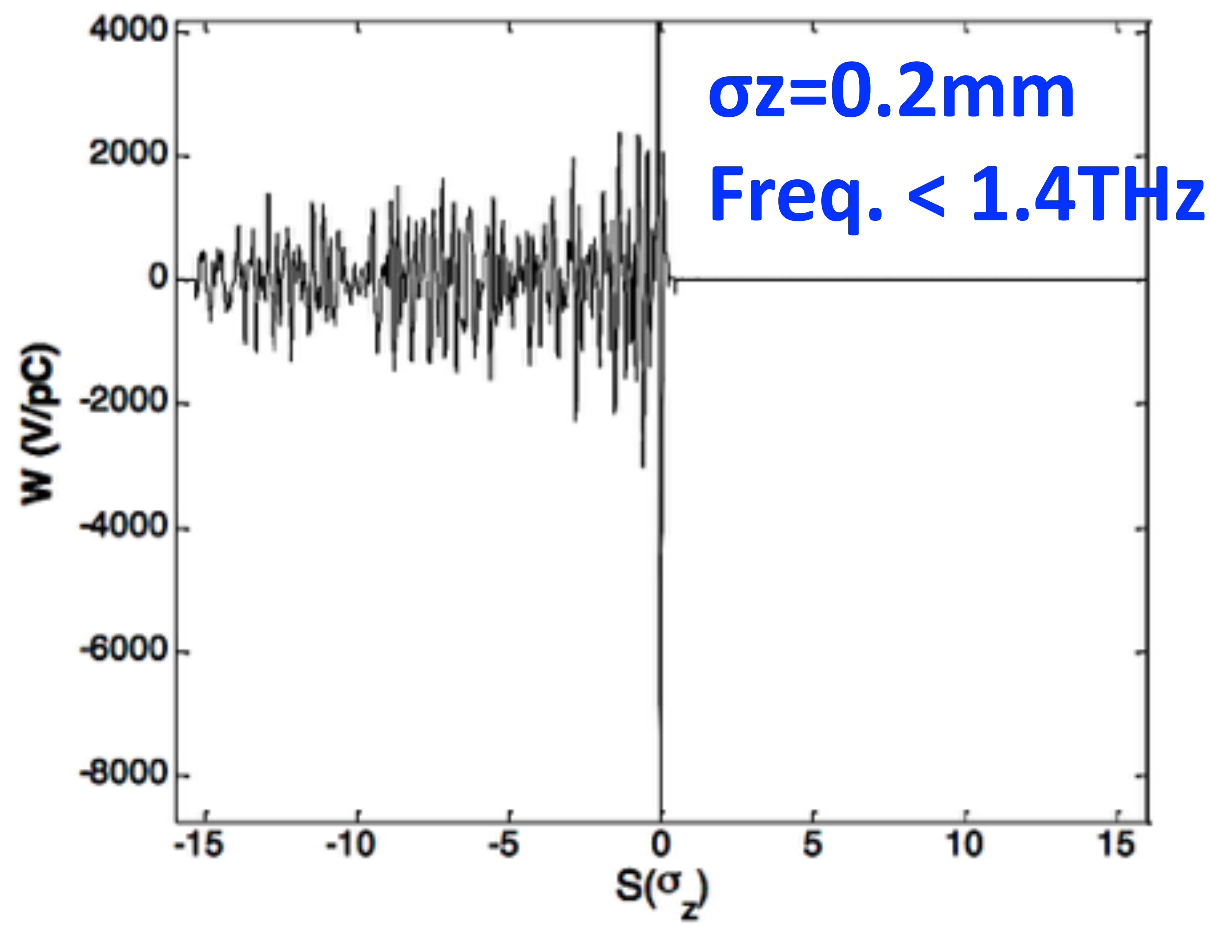
$$L_{\parallel\mathrm{eff}} \approx 34\mathrm{nH}$$

3. CSR: SuperKEKB: Damping ring

➤ Findings: Multi-bunch instability

- Long-range CSR wake extend to distance of ~0.1 m
- Not considered in CSR impedance calculation: Resistive wall and chamber discontinuities
- Likely no multi-bunch CSR instability





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