Estimation of Impedances & Loss factors of SuperKEKB LER

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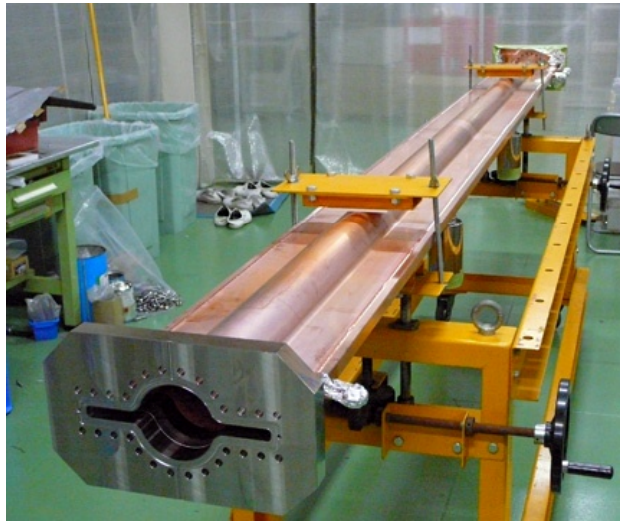
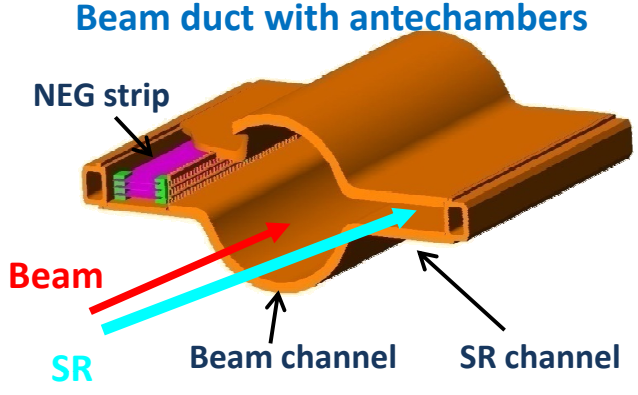
Introduction

- Beam duct of SKEKB is quite different from that of KEKB.
  - Cross-section : Circular duct ⇨ beam duct with antechambers
  - Diameter of beam channel (LER): 94 mm ⇨ 90 mm
  - Material : Cu ⇨ Al or Cu
- Designs of many components were changed and the loss factors and impedances of them have been estimated by using GdfidL. (LER only. HER is not yet.)
  - Bellows chamber
  - SR mask
  - Flange connection
  - Movable mask (Collimator)
  - Pumping port
  - BPM, BxB FB BPM
  - IP chamber
- Bunch (q=1 C) went through the center of the beam channel, and the wake potentials were monitored.
- Loss factor and impedance (longitudinal) were estimated from the wake potential.
  - Bunch length : 3 ~ 10 mm
  - Length of wake potential : 0.1 m (for loss factor calculation)
    5.0 m (for impedance calculation)
  - Mesh size : ~0.2 mm

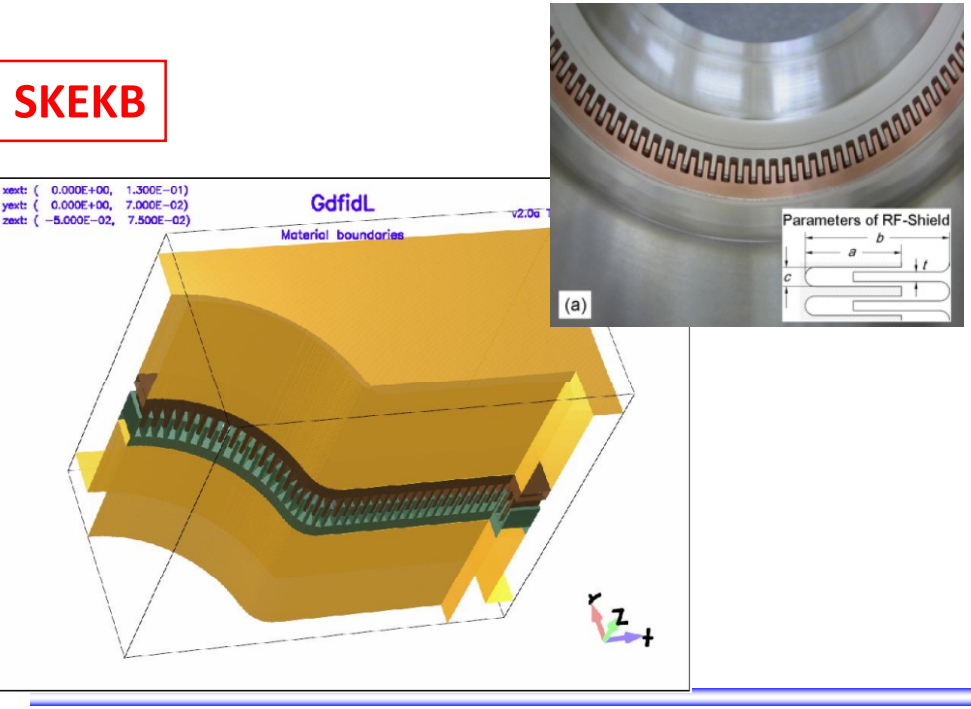




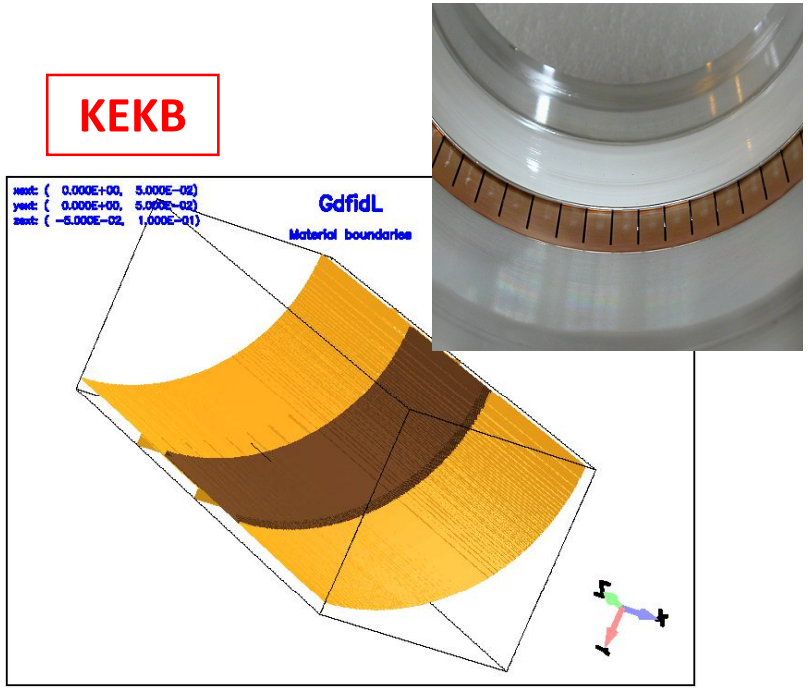
Bellows

- 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

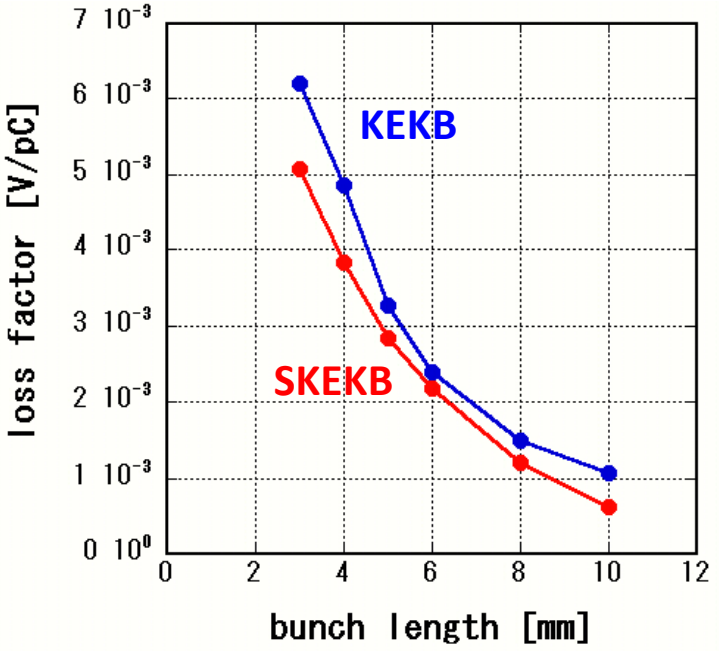
SKEKB

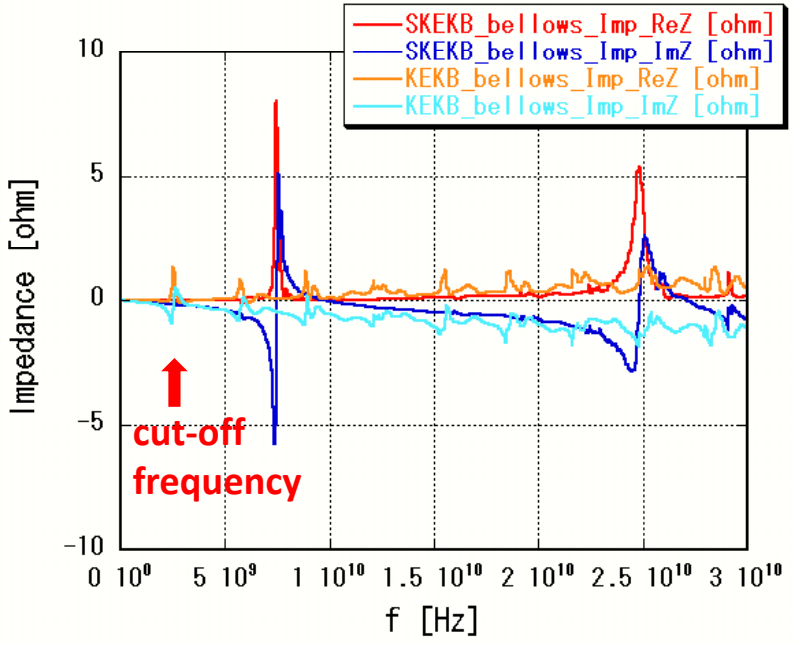


KEKB



Bellows





- Loss factor (σ_z = 6 mm)

  k = 2.2×10^{-3} V/pC

  ⇩ 1000 pieces in one ring

  k_total = 2.2 V/pC

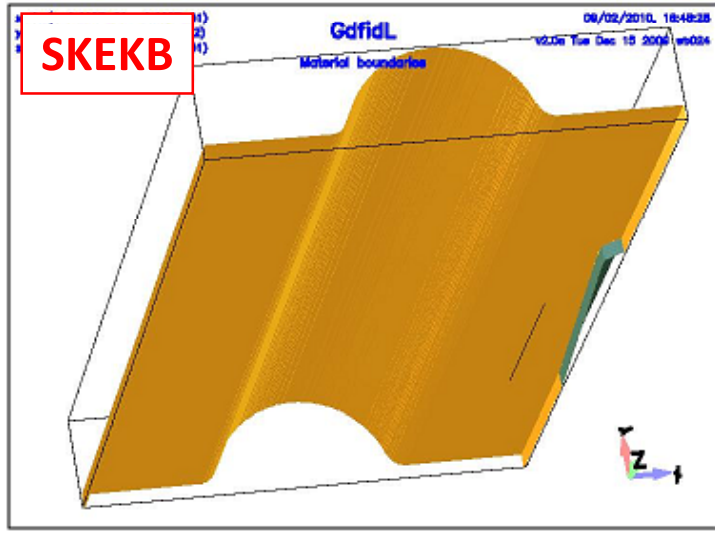
- Impedance

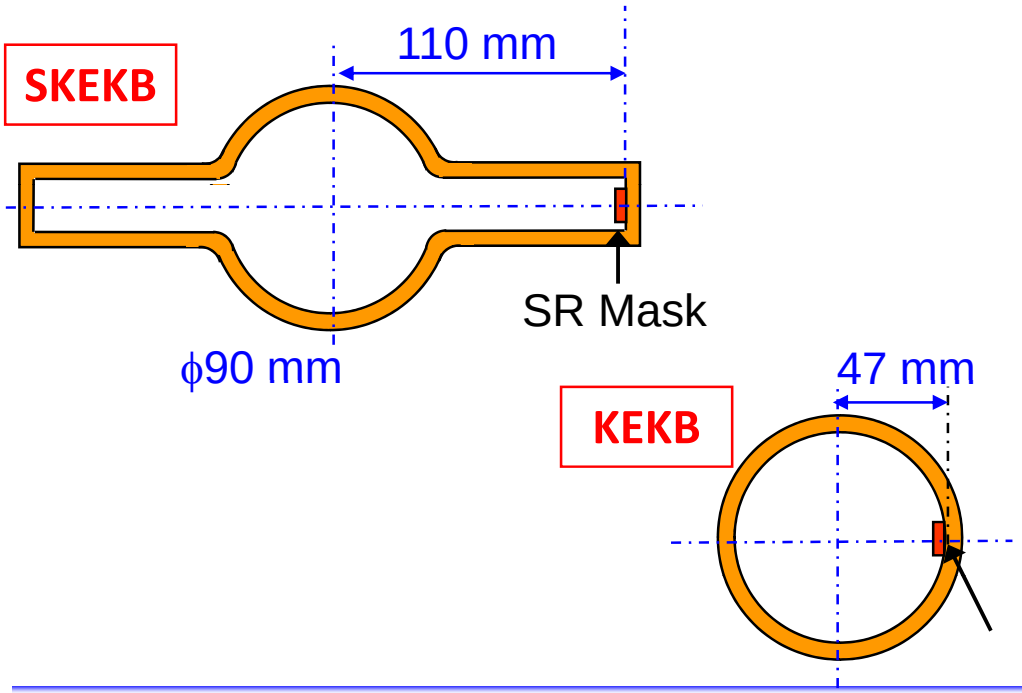
  It was found that there are trapped modes at 7.5 GHz and 25 GHz (over cut-off frequency (2.5GHz)).

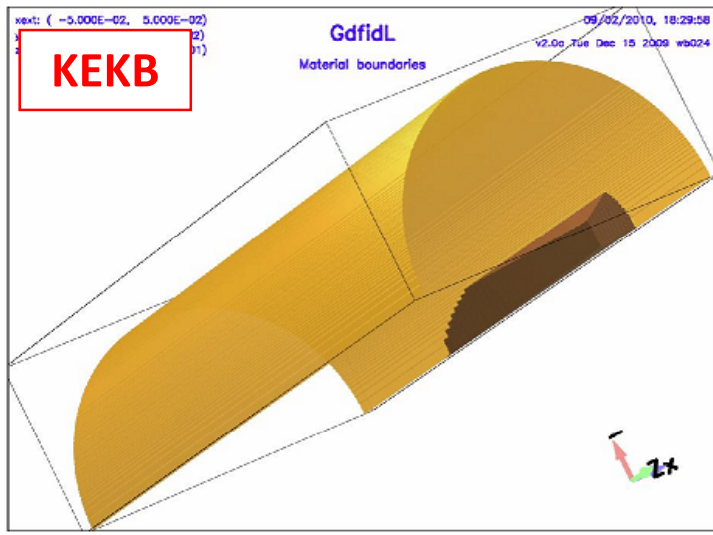
  Effects of these trapped modes on the beams will be investigated.

SR mask

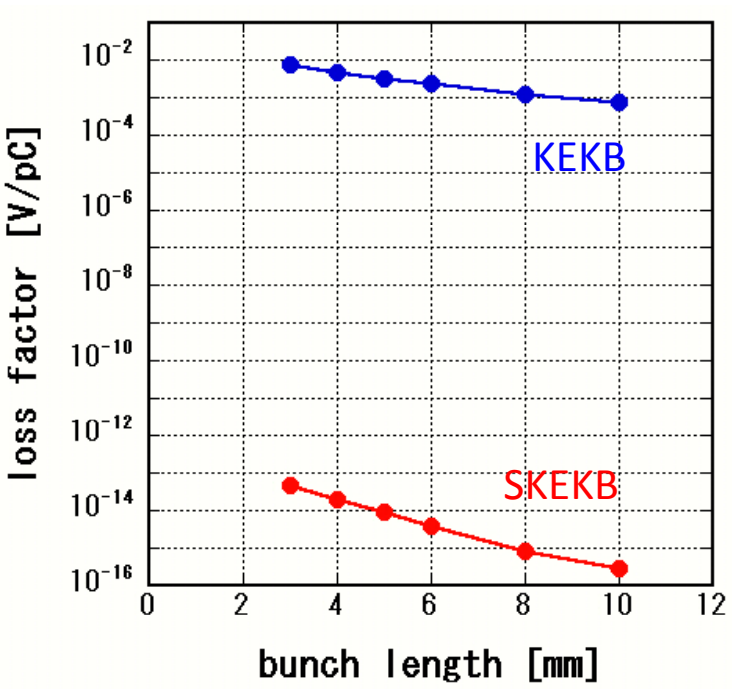
- SR mask is located at the side wall of the SR channel (antechamber).
  - The height of the SR mask is ~8 mm
  - Compared to KEKB, the effect of the SR mask on the beam will be very small.

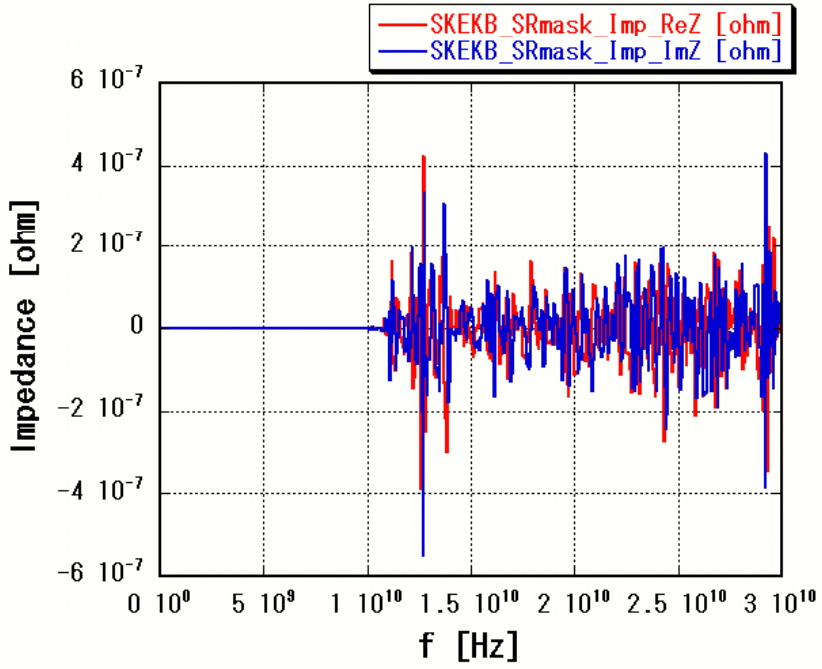






SR mask





- Loss factor (σ_z = 6 mm)

  k = 1.8×10^{-15} V/pC (much smaller than KEKB)

  ⇩ 1000 pieces in one ring

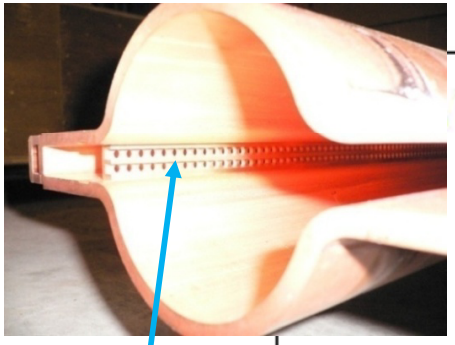
  k_total = 1.8×10^{-12} V/pC (much smaller than other components)

- Impedance

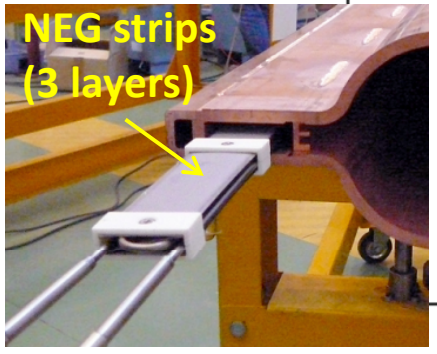
  Negligible small.

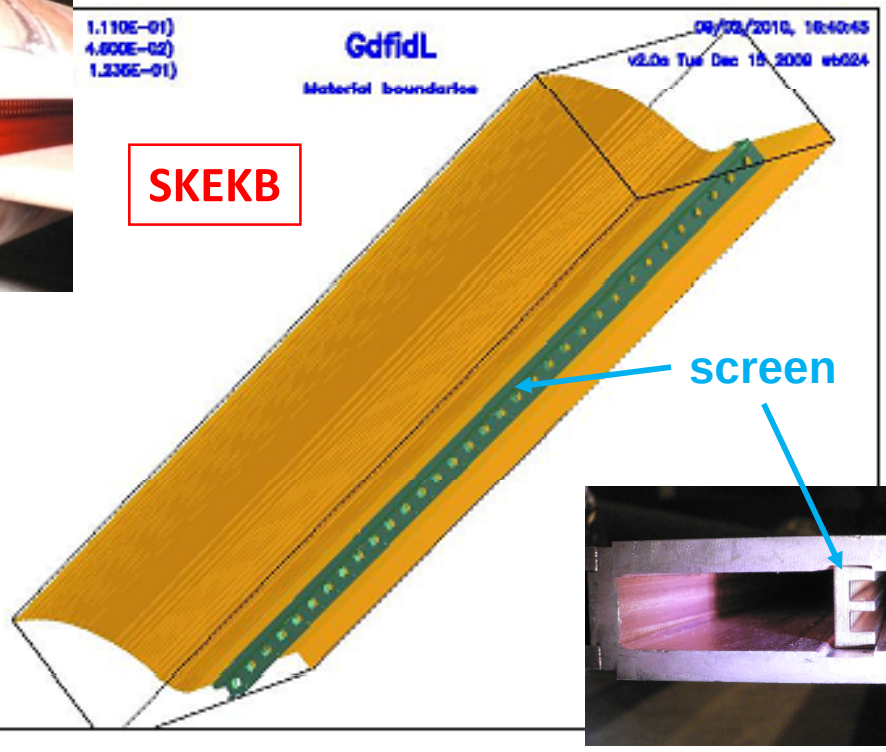
Pumping port

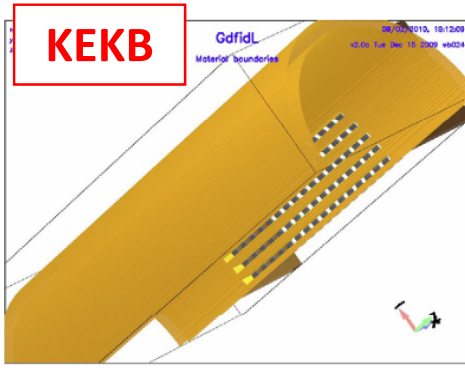
- NEG strips are installed into the antechamber.
  - The antechamber for pump is isolated by using a screen with small holes (ϕ4mm).
  - GdfidL model with a length of 0.247 m was made for calculation.



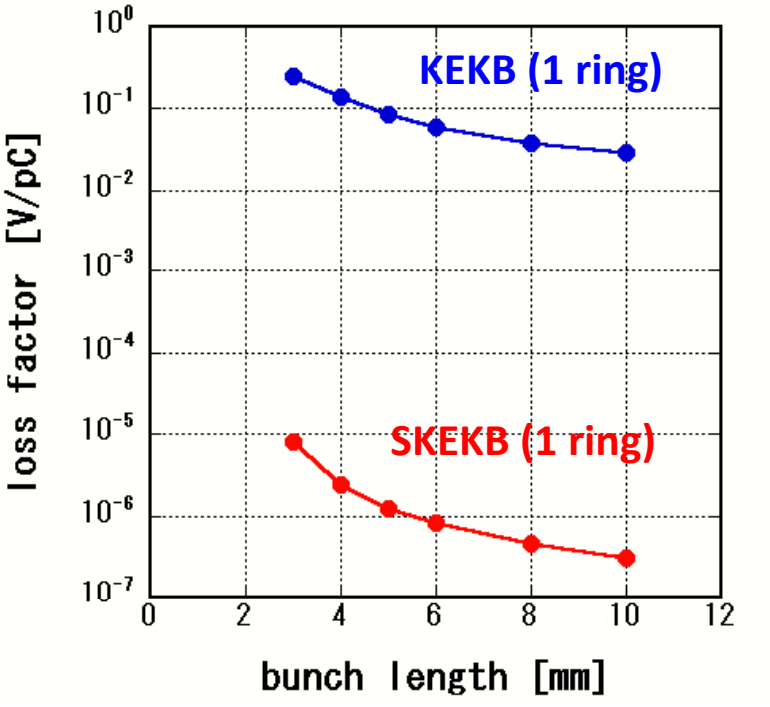
screen

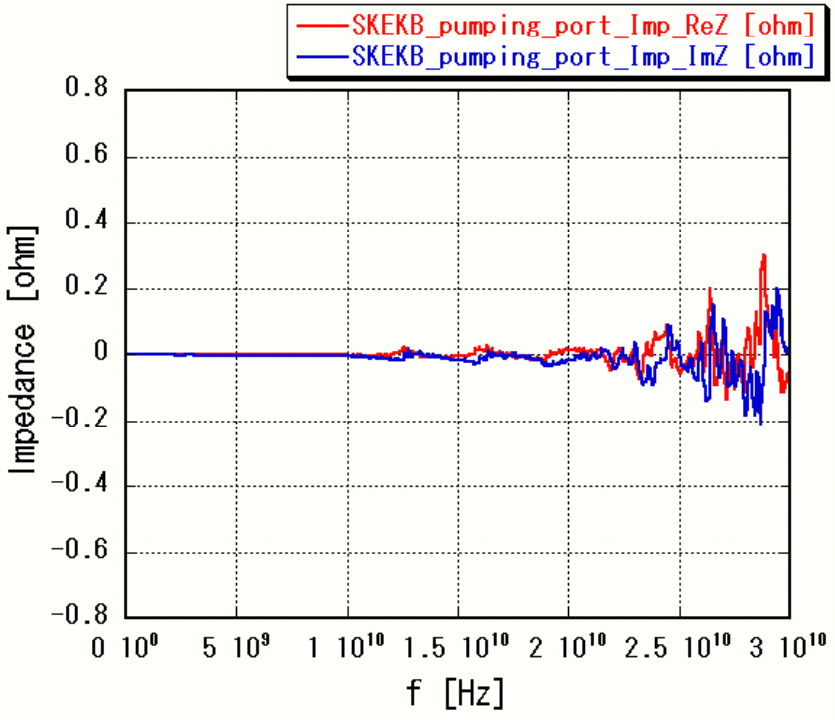






Pumping port





- Loss factor (σ_z = 6 mm)

  k_0.247 m = 90.2 V/C

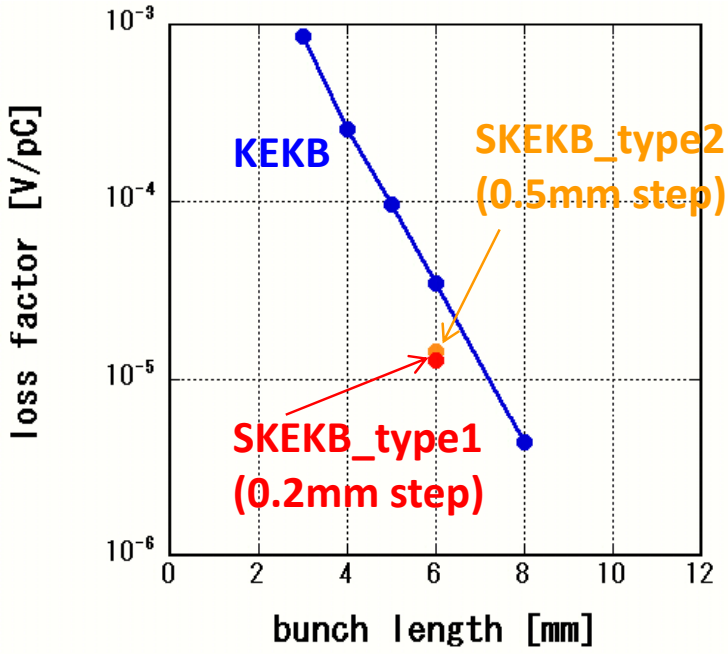
  ⇩ 2200 m for 1 ring

  k_total = 4.5×10^{-7} V/pC (much smaller than the conventional pumping port)

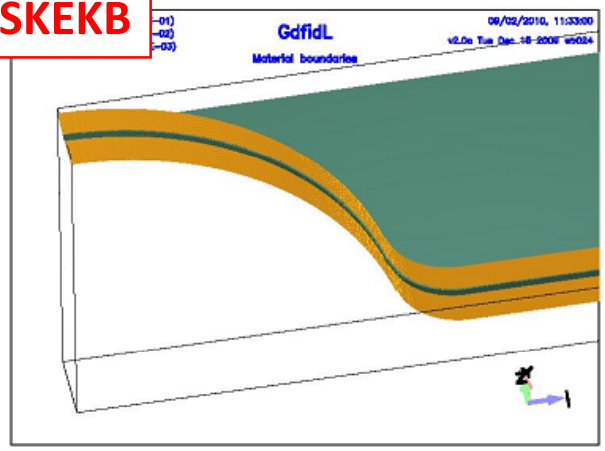
- Impedance
  - No trapped mode is found.

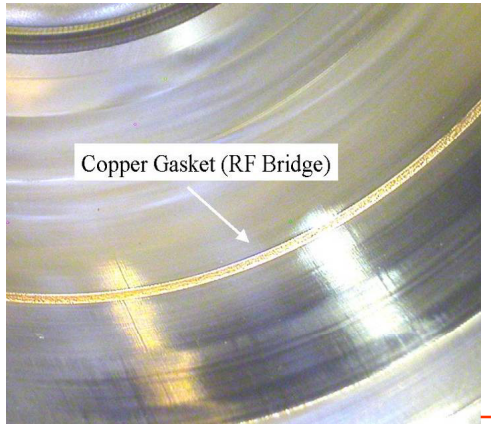
Flange connection

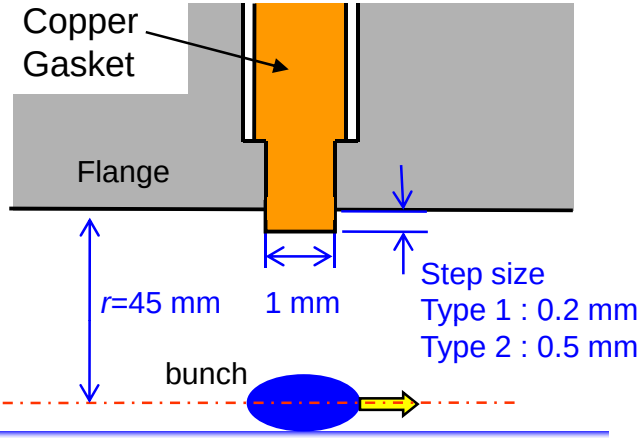
- MO-type flange will be used instead of the conventional one (Helicoflex gasket).
  - Inner surface is much smoother than the conventional one.
- Loss factor (σ_z = 6 mm, type1)
  - $k = 1.28\times10^{-5}$ V/pC $\overset{\times2000}{\Rightarrow}$ **k_total =0.03 V/pC**
  - Calculations for other bunch length are now in progress.
- Impedance
  - Calculations are now in progress.



SKEKB

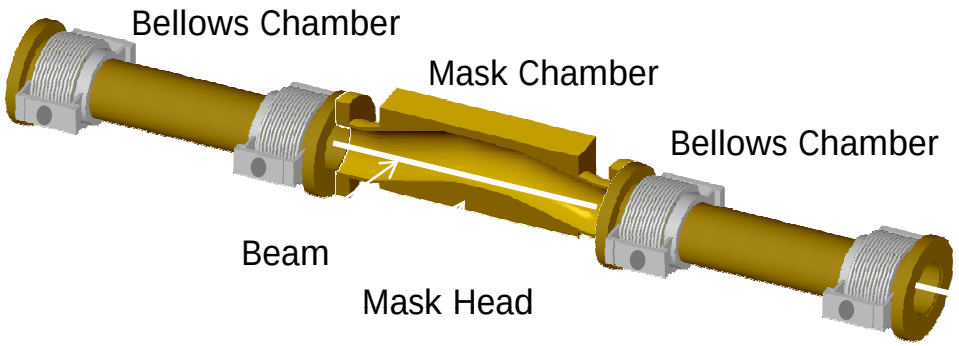


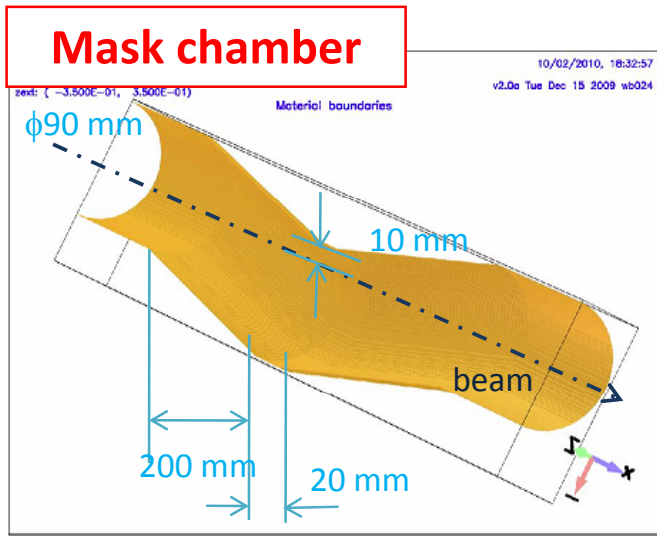


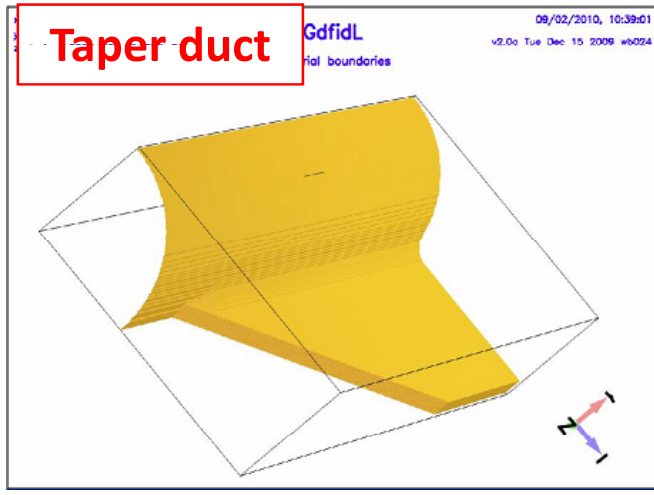


Movable mask & Taper

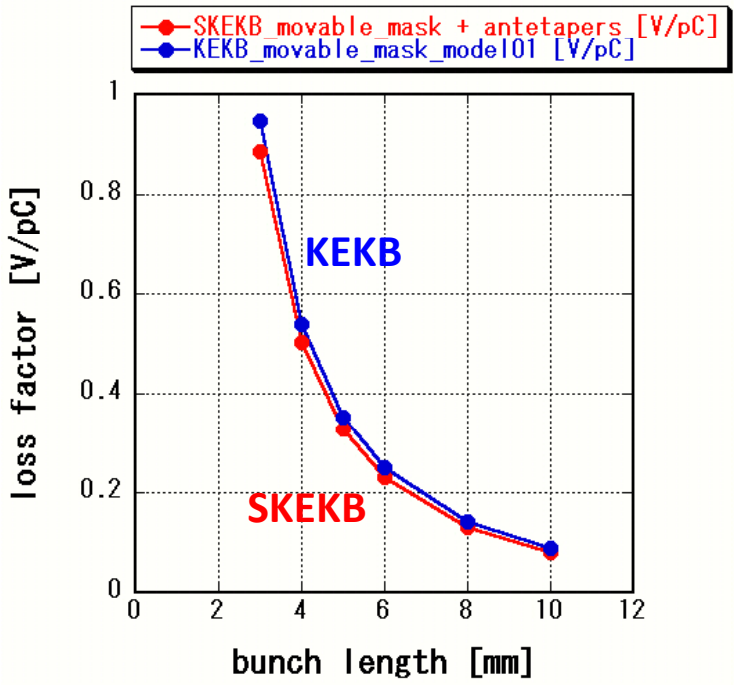
- Basic design of the movable mask will be as same as the conventional one in the commissioning stage.
  - Cross-section of the mask chamber is circular with a diameter of 90 mm.
    (no antechambers)
  - The lengths of a ramp and a mask head are 200 mm and 20 mm, respectively.
  - The distance between a beam and the mask head is 10 mm.
  - The transition ducts (taper ducts) between the movable mask and the duct with antechambers are necessary at the both side of the movable mask.

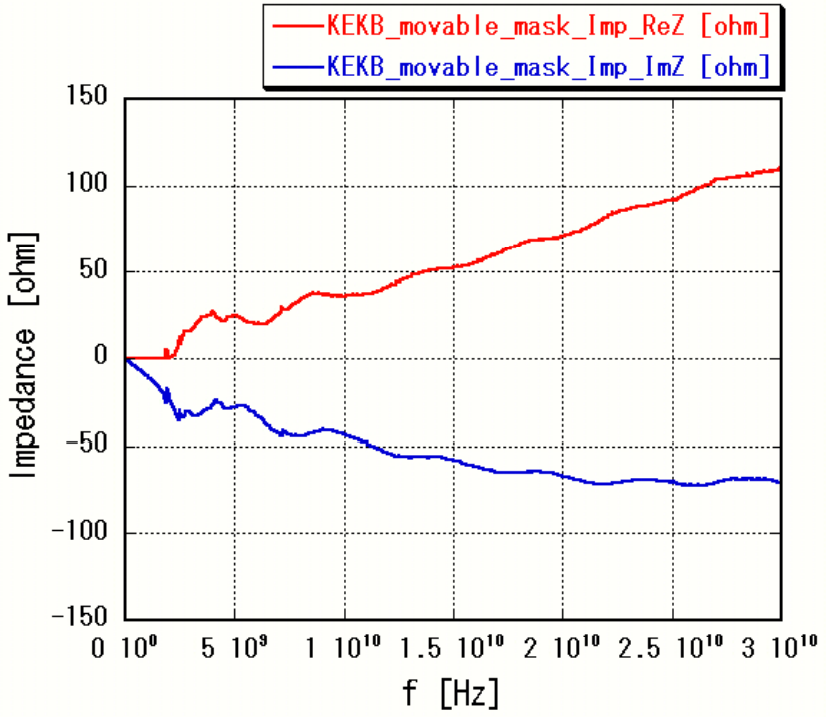






Movable mask & Taper





- Loss factor (σ_z = 6 mm)

  k = 2.31×10^{-1} V/pC (movable mask : 2.31 ×10^{-1}, taper duct : 3.83 ×10^{-4})

  ⇩ 16 pieces in one ring

  k_total = 3.7 V/pC (larger than other vacuum components)

- Impedance

  Effect on the beam will be studied.

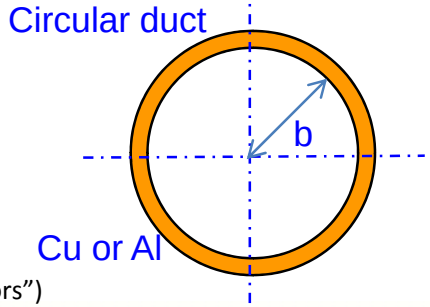
Resistive wall

- Wake fields were calculated from the following formulas.

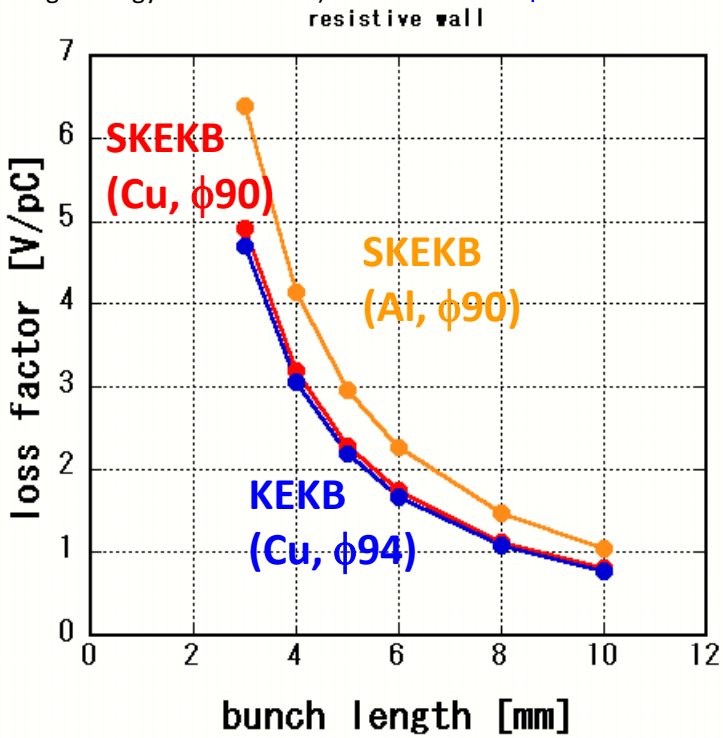
Impedance : $$\frac{Z_m^{//}}{L} = \frac{\omega}{c}\frac{Z_m^{\perp}}{L} = \frac{4/b^{2m}}{(1+\delta_{m0})bc\sqrt{\frac{2\pi\sigma}{|\omega|}}[1+\mathrm{sgn}(\omega)i] - \frac{ib^2}{m+1}\omega + \frac{imc^2}{\omega}}$$

Wake function : $$W_m'(z<0) = \frac{2}{\pi}\int_0^{\infty} d\omega \,\mathrm{Re}\, Z_m^{//}(\omega)\cos\frac{\omega z}{c}$$

(A. Chao, "Physics of Collective Beam Instabilities in High Energy Accelerators")



- The beam duct does not have antechambers. (circular duct)
- The diameter of the duct is 90 mm. (b = 4.5 cm)
- The beam duct is made of Cu or Al. (Conductivity [s^{-1}]: Cu=5.4×10^{17}, Al= Cu=3.2×10^{17})
- The total duct length is 2200 m.



- Loss factor (σ_z = 6 mm)

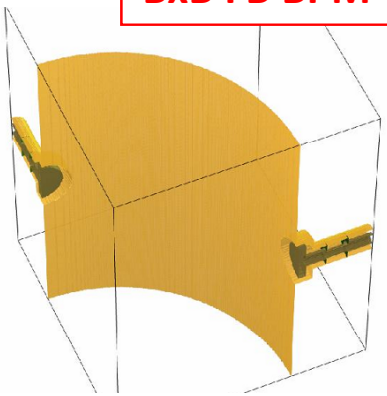
***k*_2200m = 1.7 V/pC (Cu)**

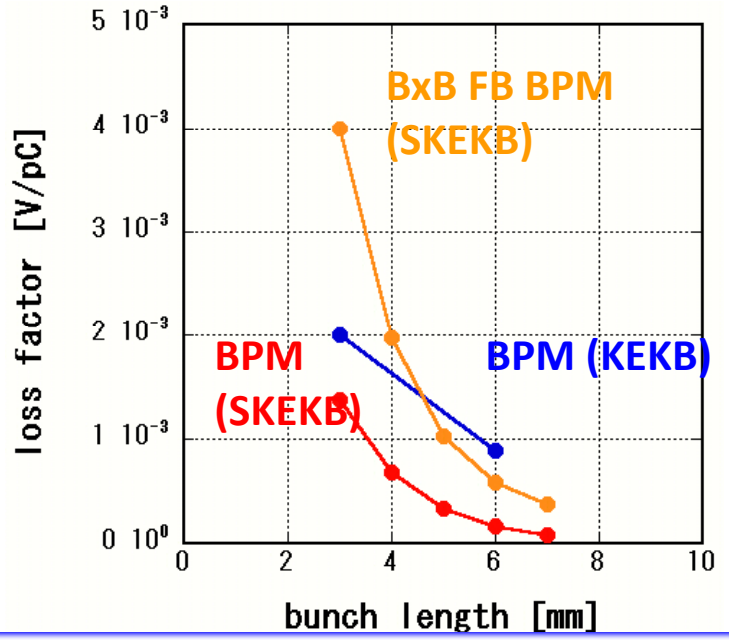
2.3 V/pC (Al)

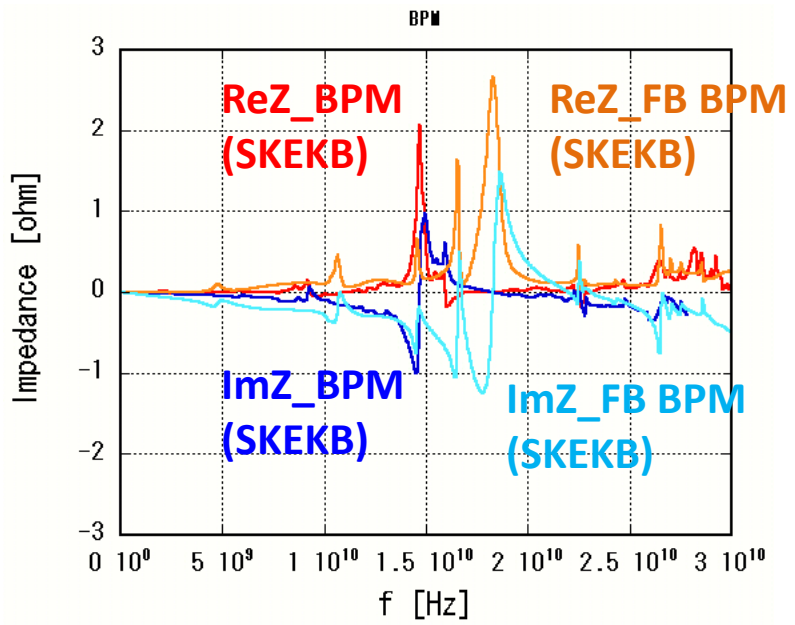
BPM & BxB FB BPM (M. Tobiyama)

- BPMs for high beam current were developed for SKEKB.
  - Reduction of the button electrode size (BPM), duct radius (BxB FB BPM), etc.
- Loss factor (σ_z = 6 mm)
  - BMP : k = 1.6×10^{-4} V/pC ×440 ⇨ $k\_total = 7.2 \times 10^{-2}$ V/pC
  - FB BMP : k = 5.9×10^{-4} V/pC ×10 ⇨ $k\_total = 5.9 \times 10^{-3}$ V/pC
- Impedance
  - Growth rate of coupled bunch instability was estimated from this result, and it was confirmed that it is negligible small.

BxB FB BPM





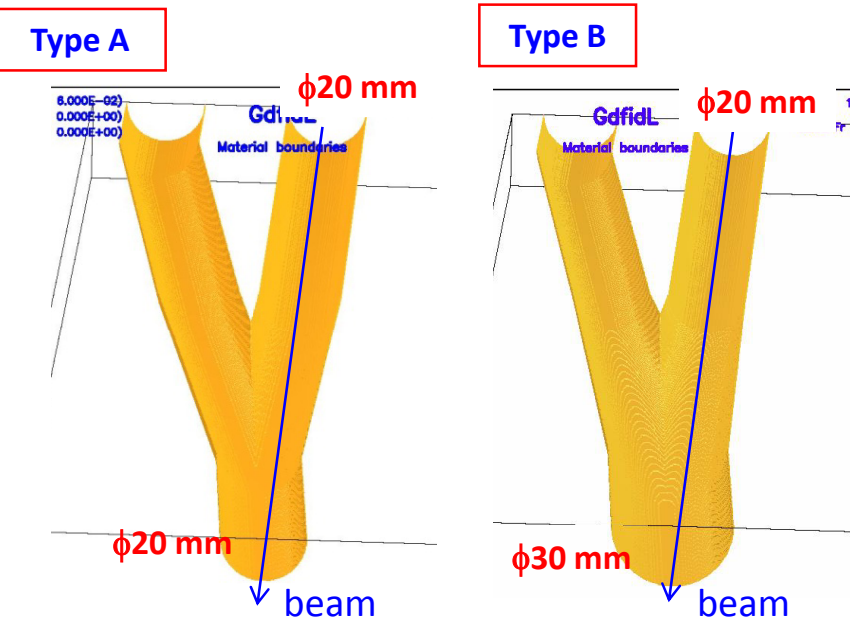


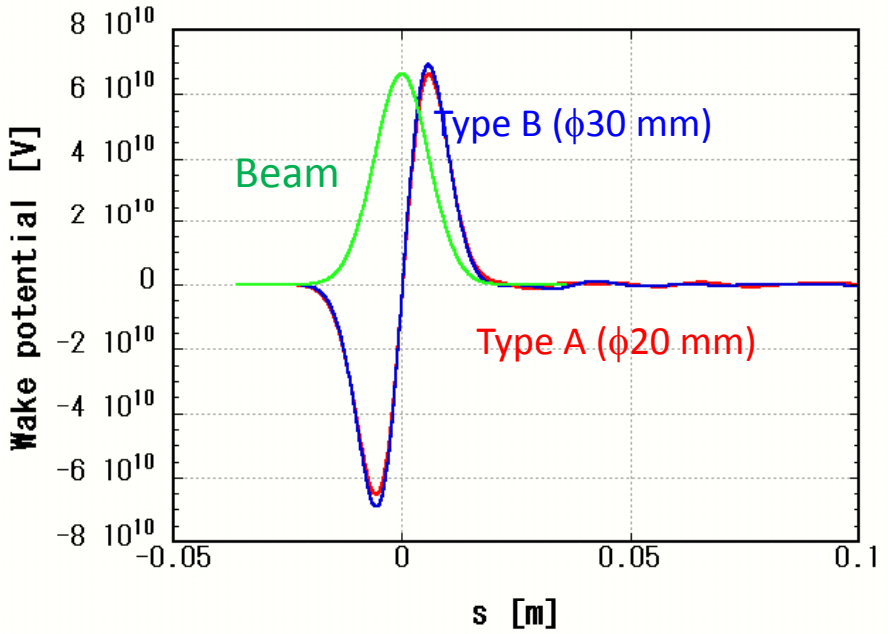
IP chamber

- Two types of IP chambers were designed for SKEKB.
  - Both chambers are same in design except for the diameter of IP duct.
  - IP duct is connected to beam ducts for QCS-magnets (ϕ20 mm) via crotch duct. (crossing angle is 83 mrad)
- Loss factor (σ_z = 6 mm)

  k_type1 = 8.72×10^{-4} V/pC

  k_type2 = 7.98×10^{-4} V/pC

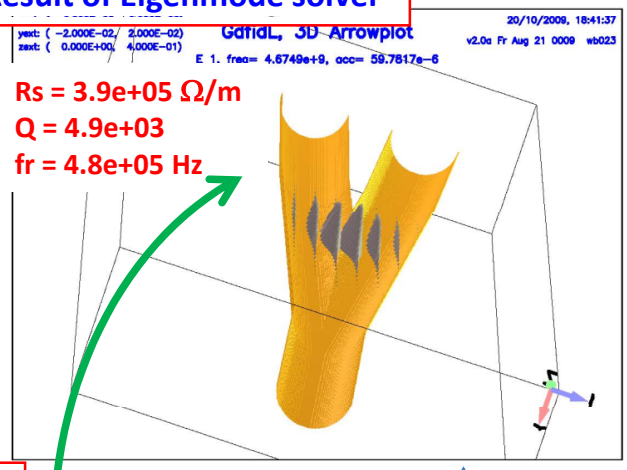




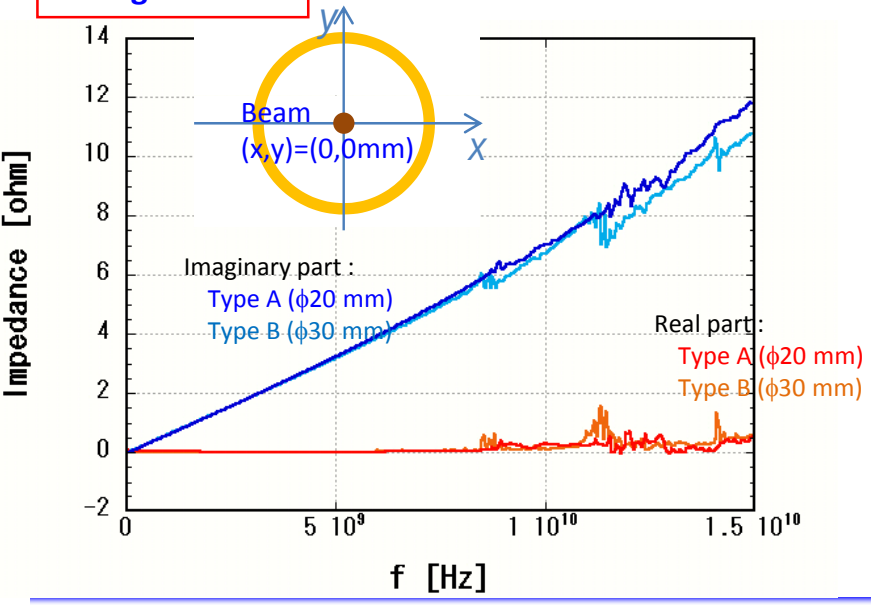
IP chamber

- Impedance
  - No longitudinally trapped mode is found.
  - Vertical deviation of beam from the center of IP duct excites many TE modes which are trapped in the crotch.
  - Effect of these trapped modes on the beam and IP duct will be investigated.

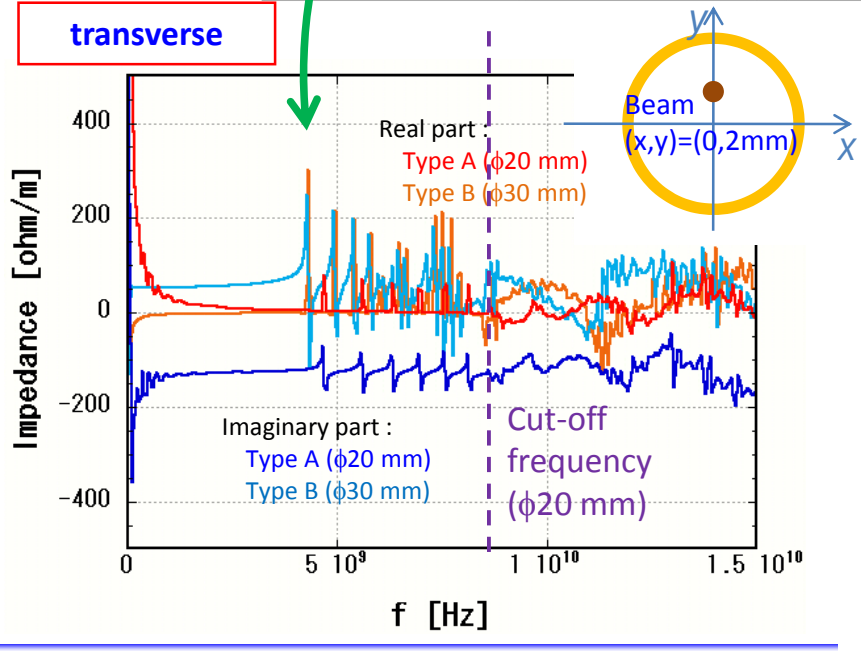
Result of Eigenmode solver



longitudinal



transverse



Total loss factor & Power loss (LER)

Component		Loss factor [V/C]	Number of items	Loss factor (total) [V/pC]
Resistive wall	Al	1.03E+09	2200 [m]	2.26
	Cu	7.89E+08	2200 [m]	1.74
Pumping port		3.65E+02	2200 [m]	8.04E-07
Flange connection		1.28E+07	2000	0.03
Bellows		3.00E+09	1000	3.00
Gate valve		3.00E+09	30	0.09
SR mask		1.82E-03	1000	1.82E-12
Movable mask		2.31E+11	16	3.70
Taper		3.83E+08	16	6.13E-03
BPM		1.63E+08	440	0.07
BxB FB BPM		5.90E+08	10	5.90E-03
FB kicker		5.01E+11	1	0.50
IP chamber		8.00E+08	1	8.00E-04
Cavity (ARES)		4.35E+11	18	7.83
Total k	Al			17.5+α
	Cu			17.0+α

- Power Loss : P_{HOM}
  - Beam current I: 3.6 A
  - Number of bunch : 2503
  - Circumference : 3016.26 m
  - Bunch spacing T_b: 4 ns

$$P_{HOM} = I^2 k T_b = 910 + \alpha \text{ kW (Al duct)}$$
$$883 + \alpha \text{ kW (Cu duct)}$$

Summary

- Loss factors and impedances of the components of SKEKB LER were calculated by GdfidL.
  - Pumping port
  - Flange connection
  - Bellows (Gate Valve)
  - SR mask
  - Movable mask
  - Taper
  - BPMs
  - IP duct
- Total loss factor is ~18 V/pC, and the corresponding power loss is ~ 900 kW.

- Next step:
  - Estimation of other components such as injection section, interaction region, etc.
  - Investigation of the effects of the high-impedance components at high frequency on the beam. (bellows, movable mask, etc)
  - Calculation of loss factors and impedances of the components of HER.