R&D on Vacuum Components for High Current Accelerators

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on behalf of Vacuum Group, KEK B-factory

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  - Beam duct
  - Inner Coating with Low SEY
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Introduction

- Future accelerators, such as Super B-factories, operate with a beam current of several amperes, and a bunch lengths of a few mm, in order to achieve a high luminosity, $>1\times10^{36}$ $cm^{-2}s^{-1}$, for example.
- These beam parameters impose severe challenges to the vacuum system.
  - Beam duct has to manage the synchrotron radiation (SR) power density up to several tens Wmm^{-2}.
  - Vacuum components should have low beam impedance, and stand up against the intense higher order modes (HOM).
  - Suppression of the electron cloud instability (ECI) is a serious problem in a positron ring.
- Development of vacuum components to satisfy the conditions are essential keys to realize the future accelerators.

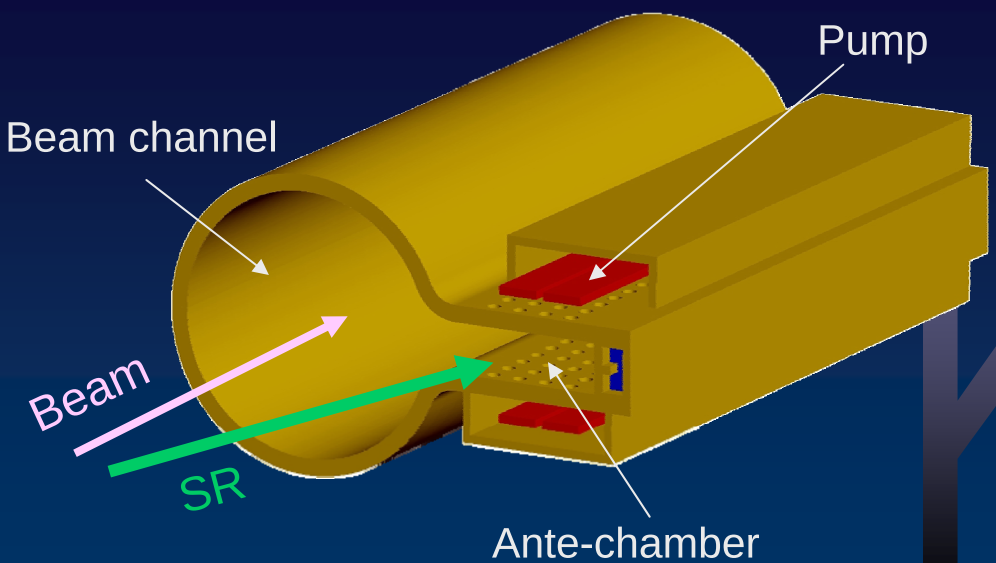
Introduction

- To meet the demands, R&D on vacuum components has been progressing at KEK, using intense beams of the KEK B-factory ring (KEKB).
  - Low Energy Ring (LER): 3.5 GeV, Max.1.8A (1389 bunches)
  - High Energy Ring (HER): 8.0 GeV, Max.1.4 A (1389 bunches)
- Studied Components:
  - Copper beam ducts with one or two ante-chambers.
  - Inner surfaces with a low secondary electron yield (SEY).
  - Bellows chambers and gate valves with high thermal strength and low beam impedance.
  - Special connection flange with no gap at the connection point.
  - Novel movable mask (collimator) with low beam impedance.
- The results of the R&D are reviewed here.

Beam Duct

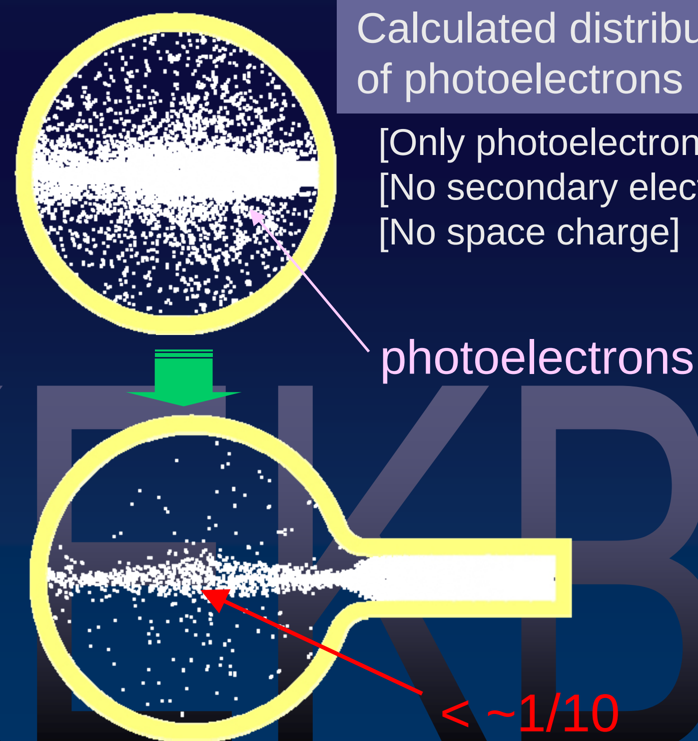
- Beam duct with ante-chamber (2003 ~)
  - Ante-chamber = additional chamber
  - Effective to reduce photoelectrons in the beam channel
  - Also effective to dilute the power density of SR
- Use copper

Beam duct with antechamber



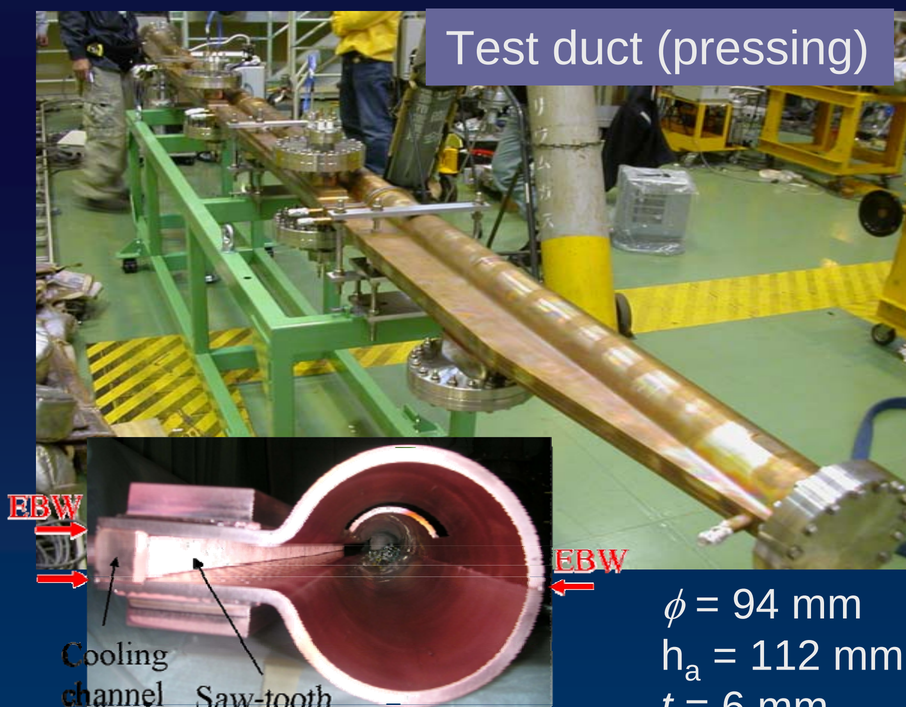
Calculated distribution of photoelectrons

[Only photoelectrons]
[No secondary electrons]
[No space charge]



Beam Duct

- Copper ducts with an antechamber for arc sections
  - Manufacturing properties were investigated. → No problem
  - Installed at an arc section of the KEKB positron ring (2003).
  - Reduction of photoelectrons was confirmed.



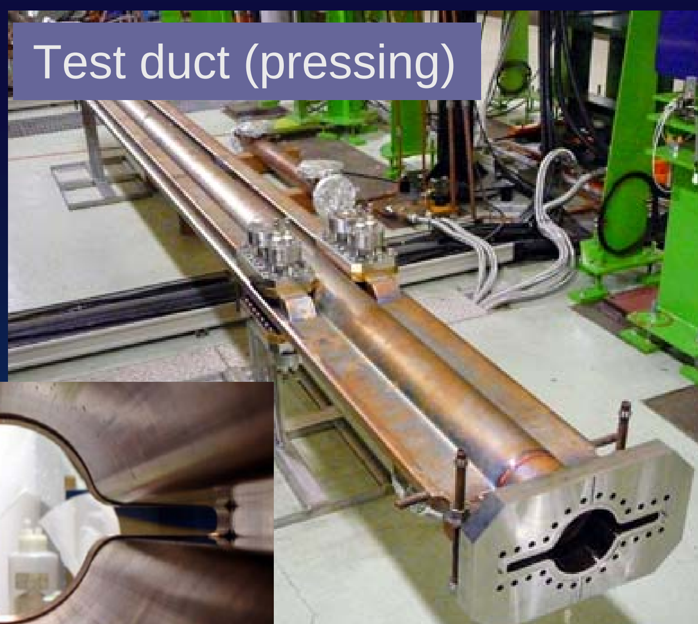
ϕ = 94 mm
h_a = 112 mm
t = 6 mm

Electron Monitor
(DC, Collector:+100 V, Repeller:-30V)

Beam Duct

- Copper duct with two ante-chambers (2005~)
  - Installed into LER wiggler section.
  - Reduction of photoelectrons was confirmed again from the measured electron number.
  - No problem up to 1.7 A.

ϕ = 94 mm
h_a = 224 mm
t = 6 mm

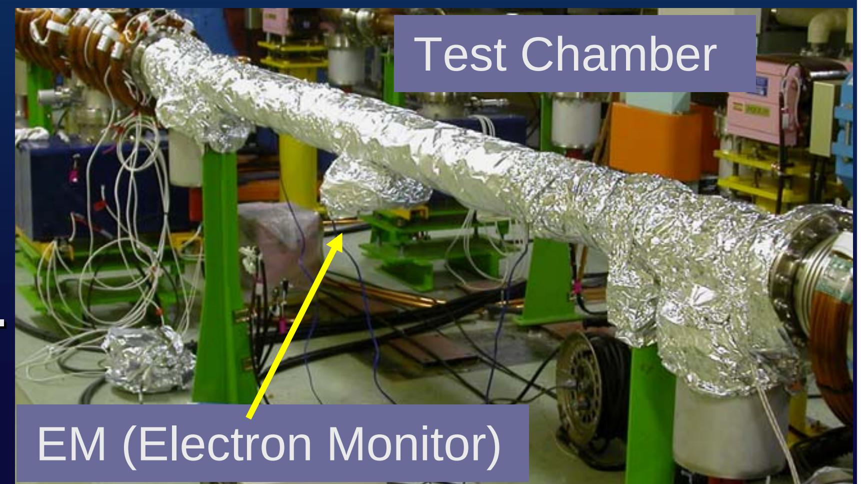


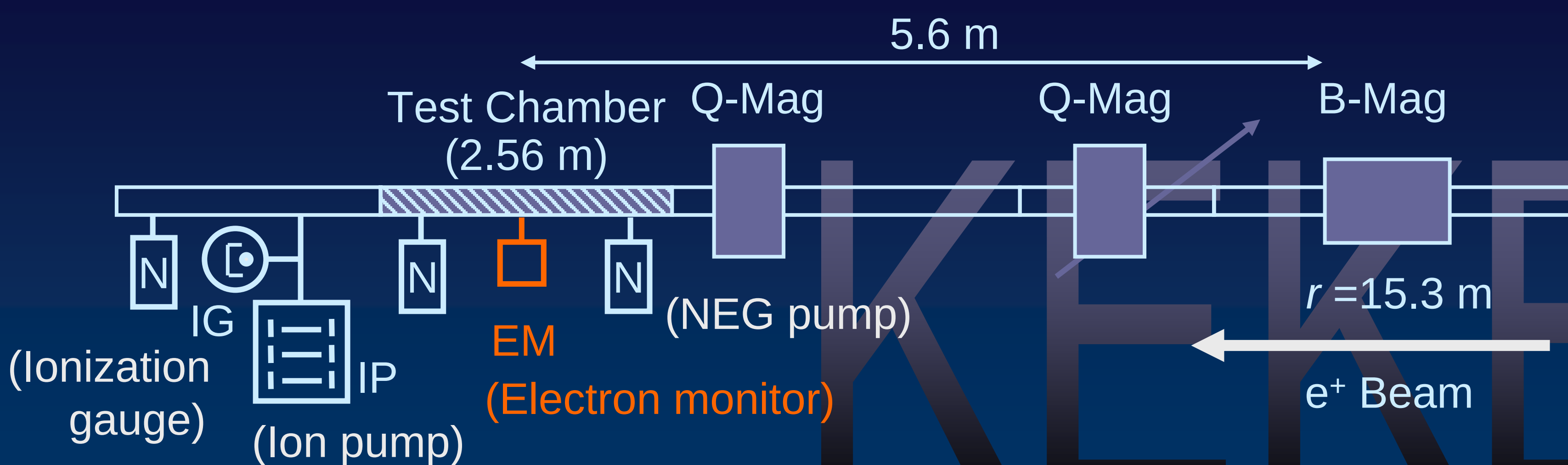
Inner Coating

- Survey of surfaces with a low SEY (2004~)
  - Essential cure against the formation of electron cloud at relatively high current
- Test chambers with NEG and TiN coatings were installed in the KEKB positron ring (ϕ94).
- Electron numbers were measured under the same condition, and compared with each other.
- Photoelectron yield (η_e) and the maximum secondary electron yield (δ_{max}) were estimated using a simulation of the electron current.

Inner Coating

- Experiment at arc section
  - Test chambers were installed at an arc section.
  - Direct SR of 6.4×10^{14} photons/s /m/mA was irradiated at side wall.
    - Realistic condition
  - Incident angle ~8 mrad.

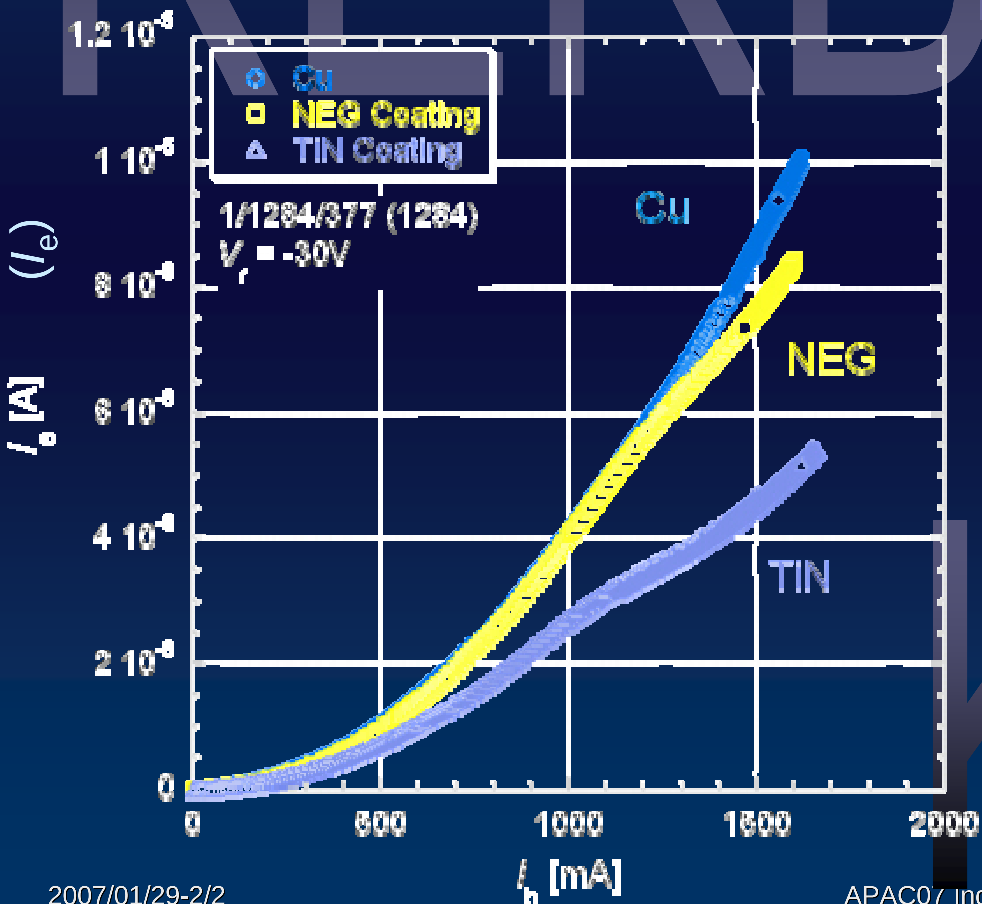




Inner Coating

- Measured electron current (I_e) for Cu, TiN, NEG at the same beam condition

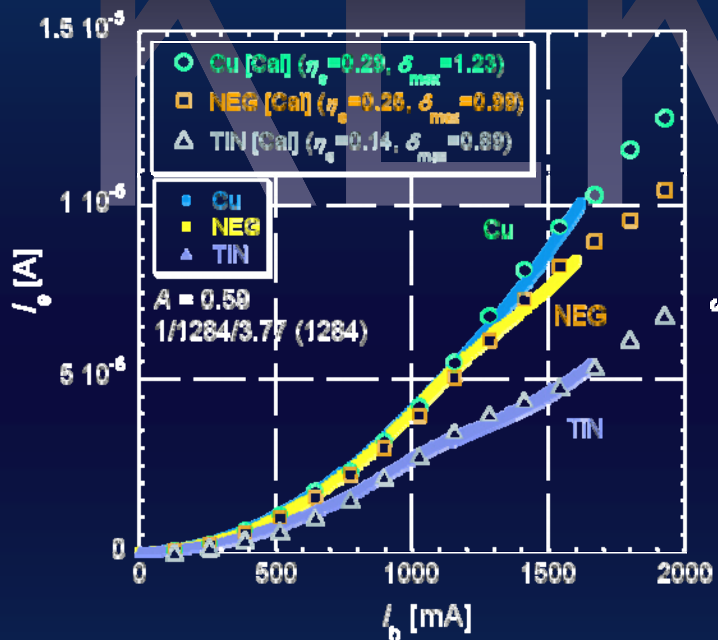
Electron dose >10mC/mm²: After aging

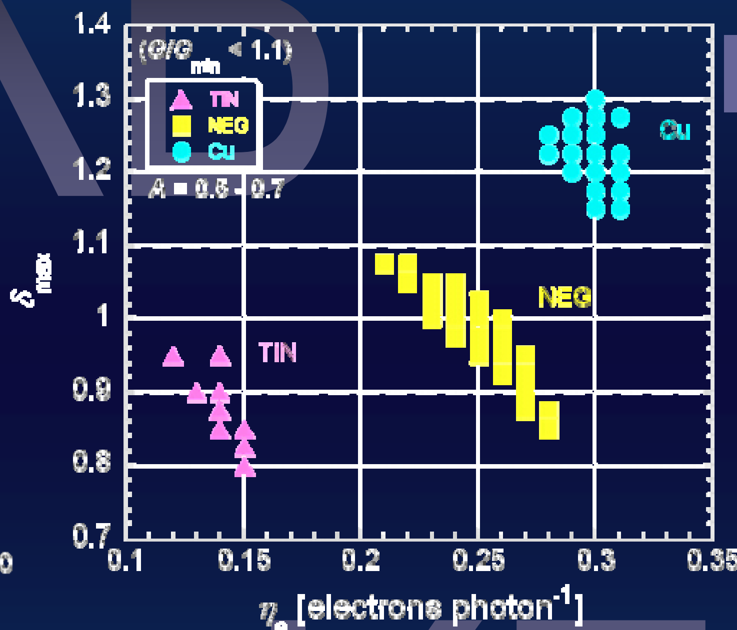


- I_e for NEG coating is almost the same as that of Cu, except for high current.
- I_e for TiN coating is clearly lower than those for Cu and NEG (by a factor of 2).
- TiN seems better from a view point of small electron number in the beam duct.

Inner Coating

- Estimated η_e and δ_{max} (arc section) by simulation





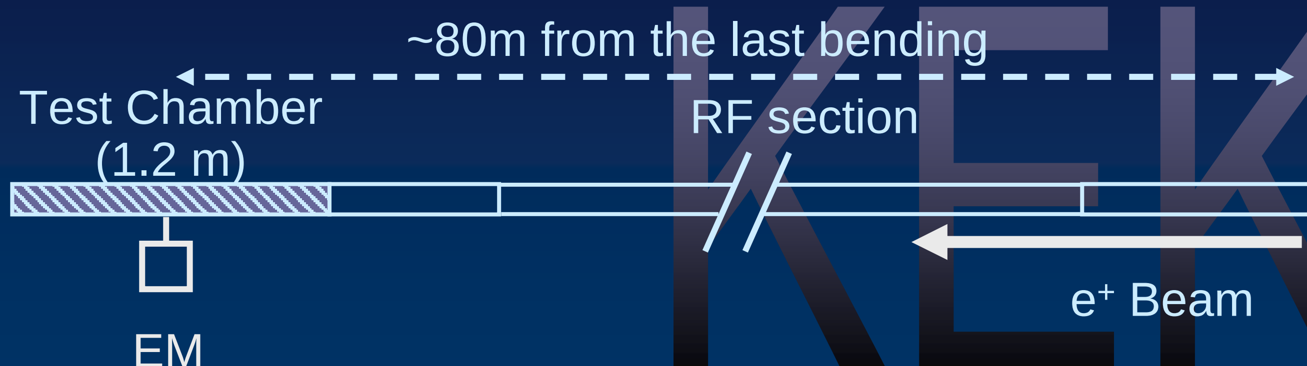
Fitting

	η_e	δ_{max}
Cu	0.28-0.31	1.1-1.3
NEG	0.22-0.27	0.9-1.1
TiN	0.13-0.15	0.8-1.0

- TiN seems better from a view point of low δ_{max} and small η_e.
- δ_{max} of NEG is lower than Cu, but not so clear due to high η_e.
- δ_{max} of Cu, NEG and TiN is near to those measured in laboratory after sufficient electron bombardment (after aging).

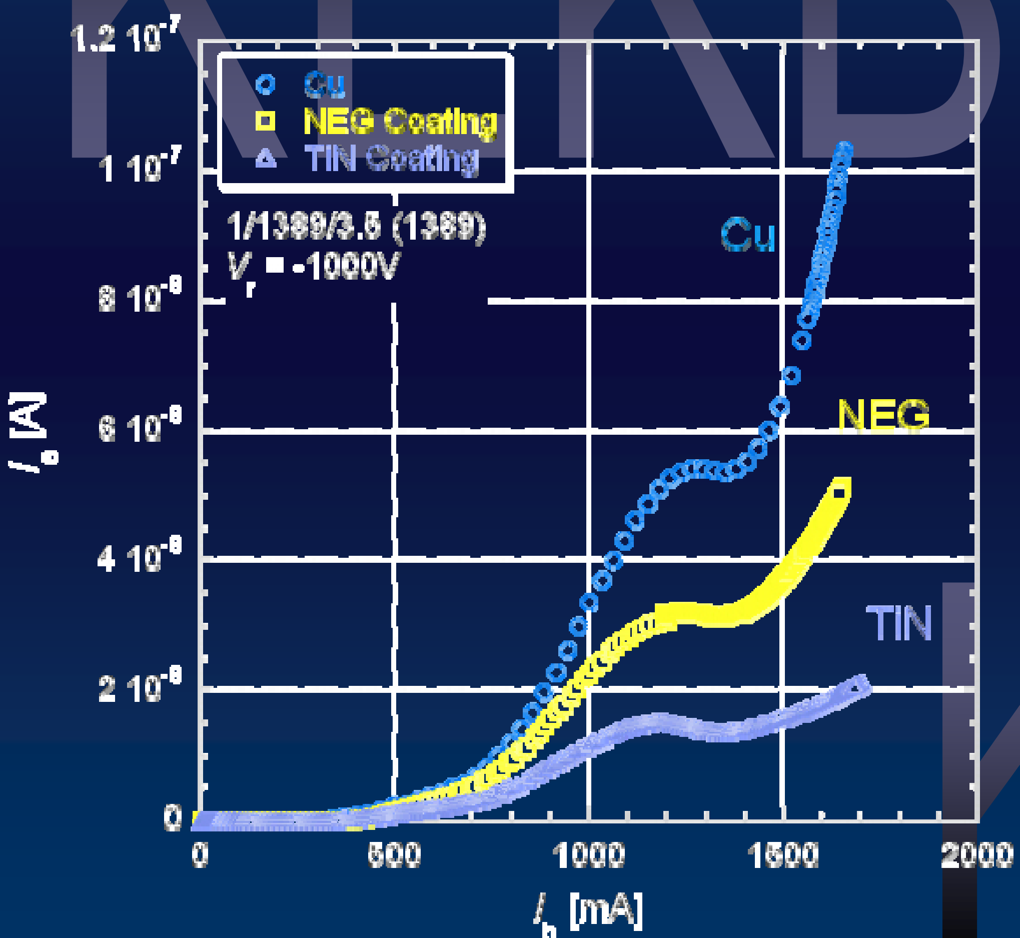
Inner Coating

- Measurement at a straight section (2006~)
  - Low direct SR : 3.3×10^{12} photons/s/m/mA (<1/100 of arc)
  - Eliminate the effect of SR
- Copper, TiN coating and NEG coating
  - Incident angle = 0.6 mrad



Inner Coating

- Measured electron current

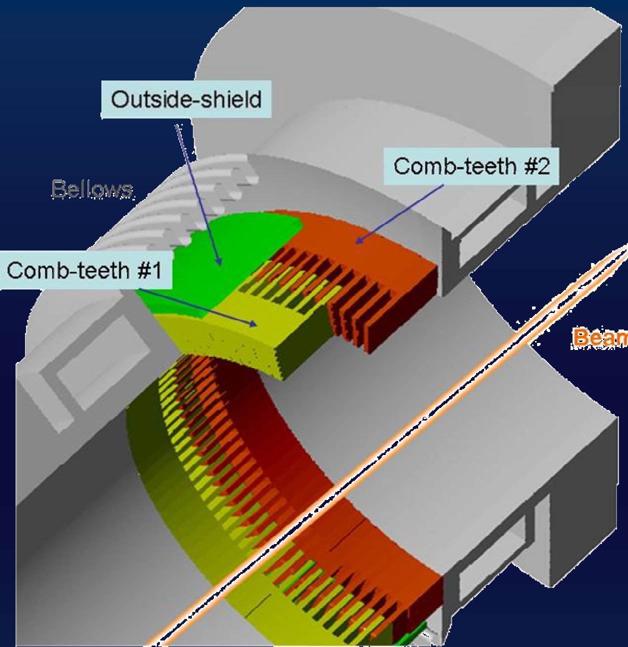


- Electron density for TiN coating is about 1/3 ~ 1/4 of that of copper.
- Electron density for NEG coating is about 2/3~1/2 of that of copper. The difference between Cu and NEG became clear. ←Small effect of SR.
- The curves can be reproduced by similar η_e and δ_{max}.
- TiN is still better from the view point of low SEY.

➥ Combination with ante-chambers

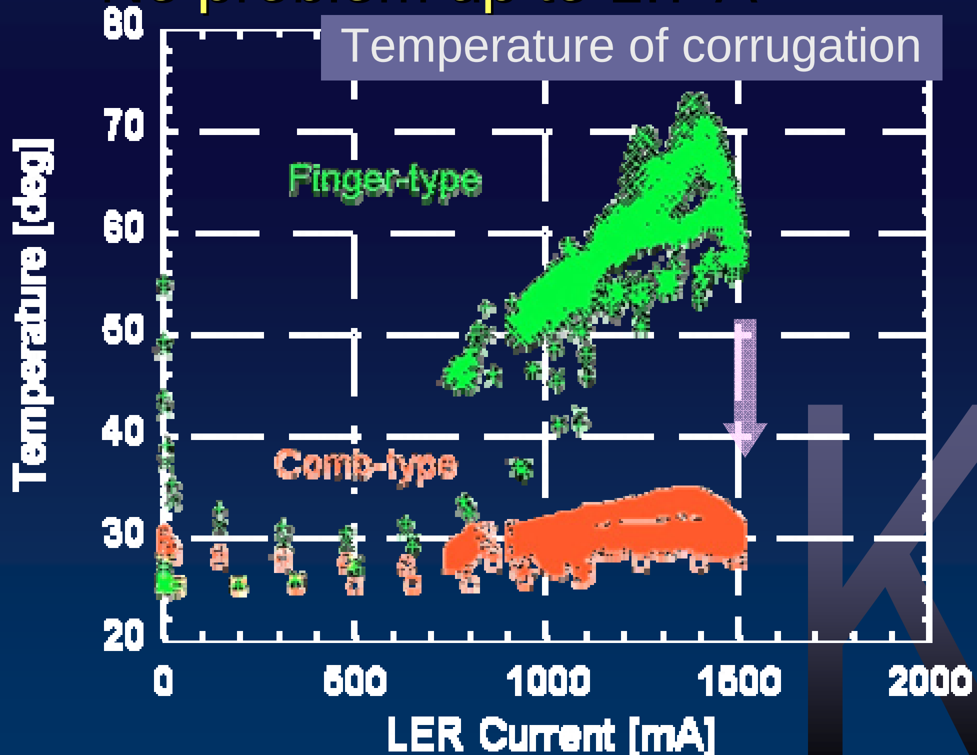
Bellows & Gate Valves

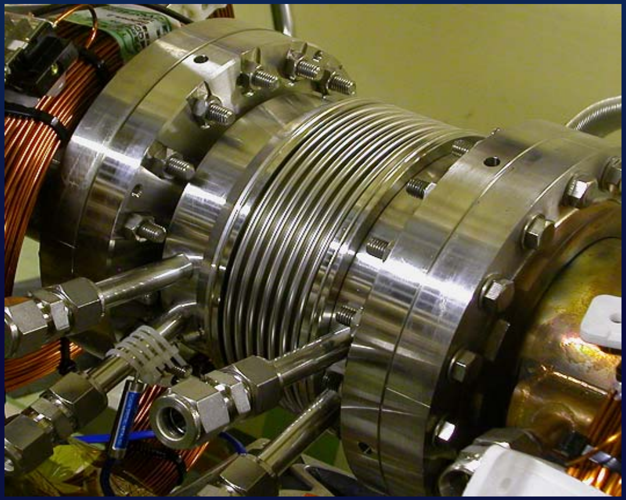
- Comb-type RF-shield (2003~)
  - Proposed at KEK
- Nested teeth instead of fingers
  - High thermal strength
  - Small leakage of HOM (TE-mode)
    - <1/10 of finger type
  - Low beam impedance
    - ~1/2 of finger type
  - Applicable to various apert
  - Limited offset
  - Complicated structure

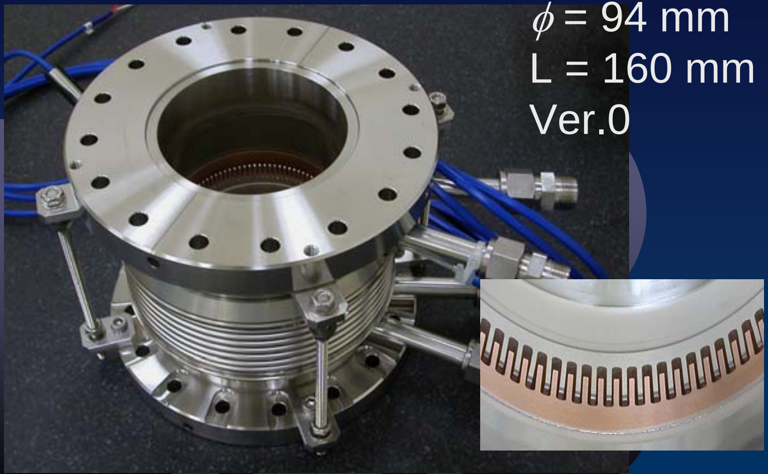


Bellows & Gate Valves

- First application to circular bellows (2003~)
  - ϕ94, L=160 mm
  - Temperature rise decreases to 1/6
  - No problem up to 1.7 A







ϕ = 94 mm
L = 160 mm
Ver.0

Bellows & Gate Valves

- Bellows for a beam duct with ante-chambers (2005~)
  - Easy to apply to a complicated cross section.
  - No problem up to 1.7 A.
  - Inside was checked this winter, and no damage was found.

Comb teeth (Cu)

Inside view

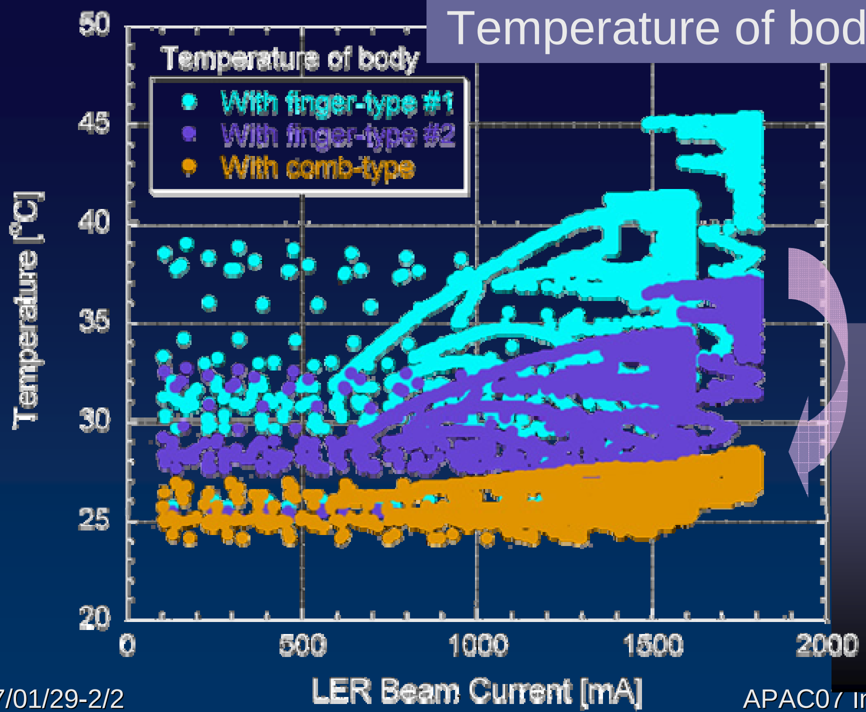
Whole view

ϕ = 94 mm
h_a = 224 mm
L = 200 mm
Ver.2

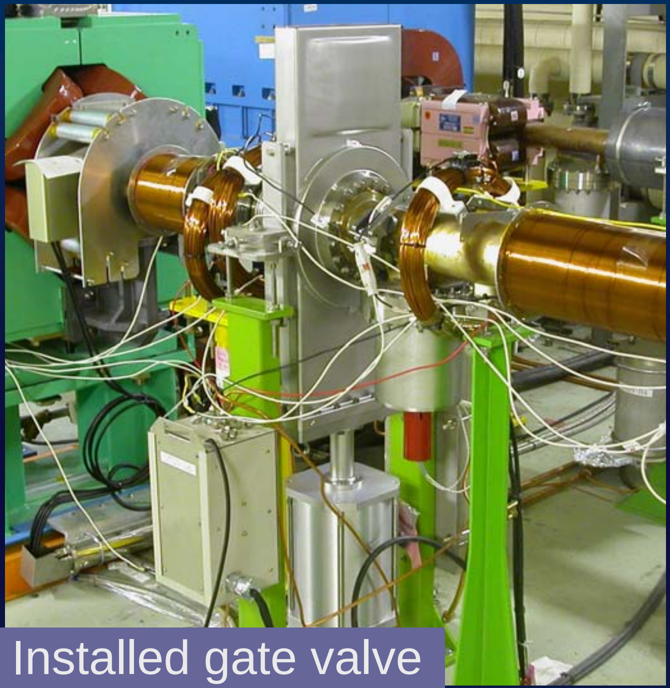
Bellows & Gate Valves

- Circular gate valves (2005~)
  - Simplified structure = No sliding point
  - Collaboration with VAT Vakuumventile AG.
  - Temperature rise of body decreased to 1/3.

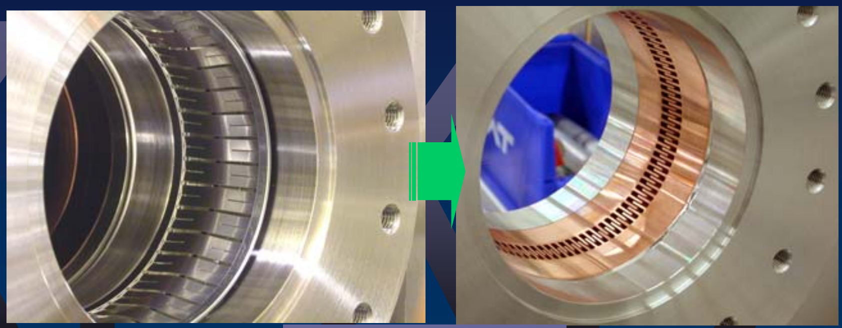
Temperature of body



ϕ = 94 mm
L = 95 mm
Ver.2



Installed gate valve



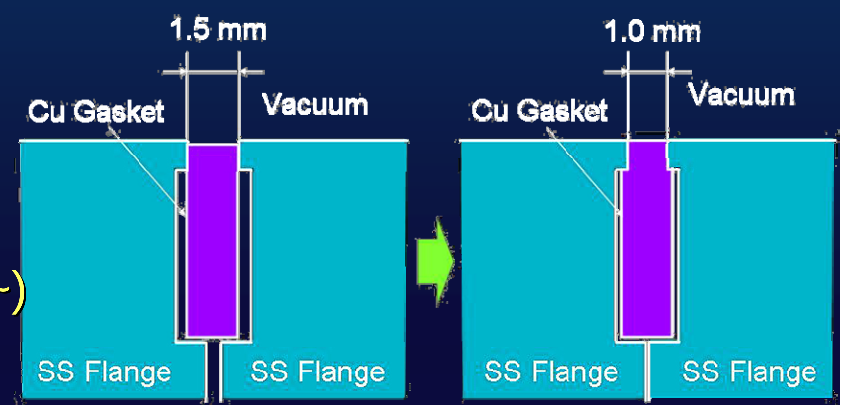
Inside view

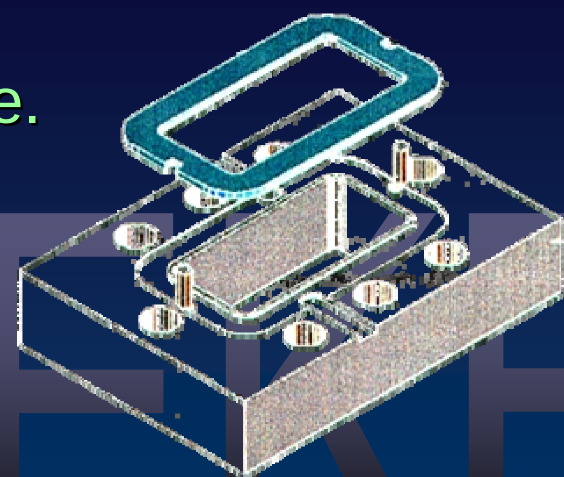
Connection Flange

- Important components
  - Large number → Impedance
  - High current → RF-bridge

- MO (Matsumot-Ohtsuka) Flange (2004~)
  - Seal a vacuum at only the inner surface.
  - Vacuum seal doubles as RF bridge.
  - No gap and step at the inner surface.
  - Can follow the complicated cross section.
  - Bakable

[Vacuum side]





Rectangular model (for waveguide)

Connection Flange

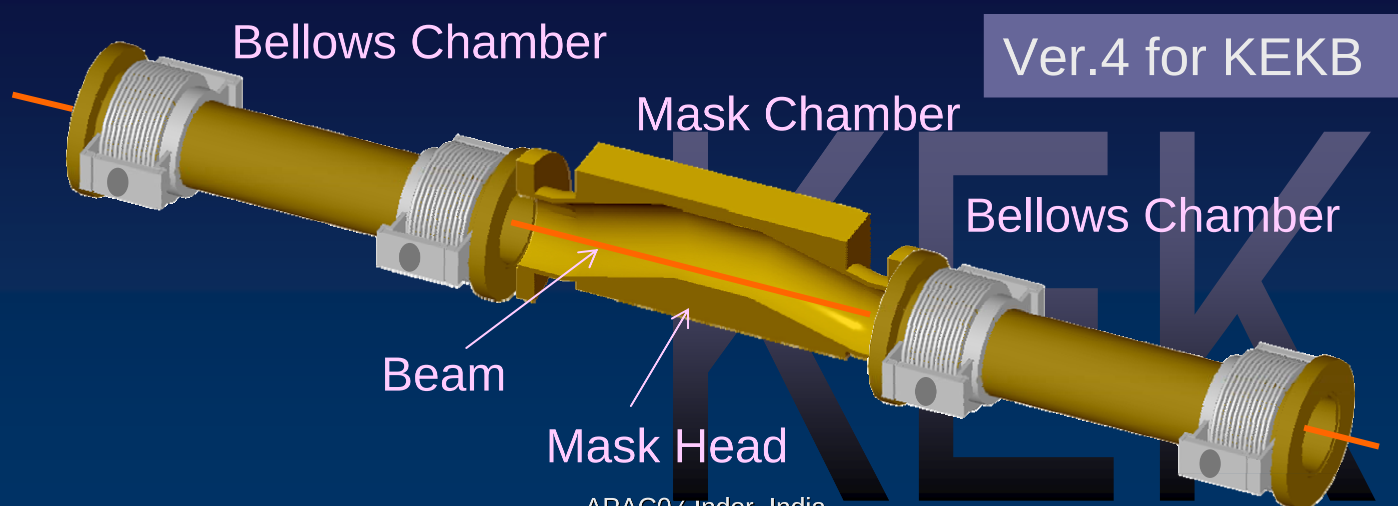
- Application to bellows chambers and beam ducts (2005~)
  - Vacuum was sealed with a fastening torque of <18 Nm.
  - No problem up to 1.7 A (8 flanges)
  - Applied to new test chambers (28 flanges), and will be tested this year.

MO flange for beam duct

MO flange for bellows chamber

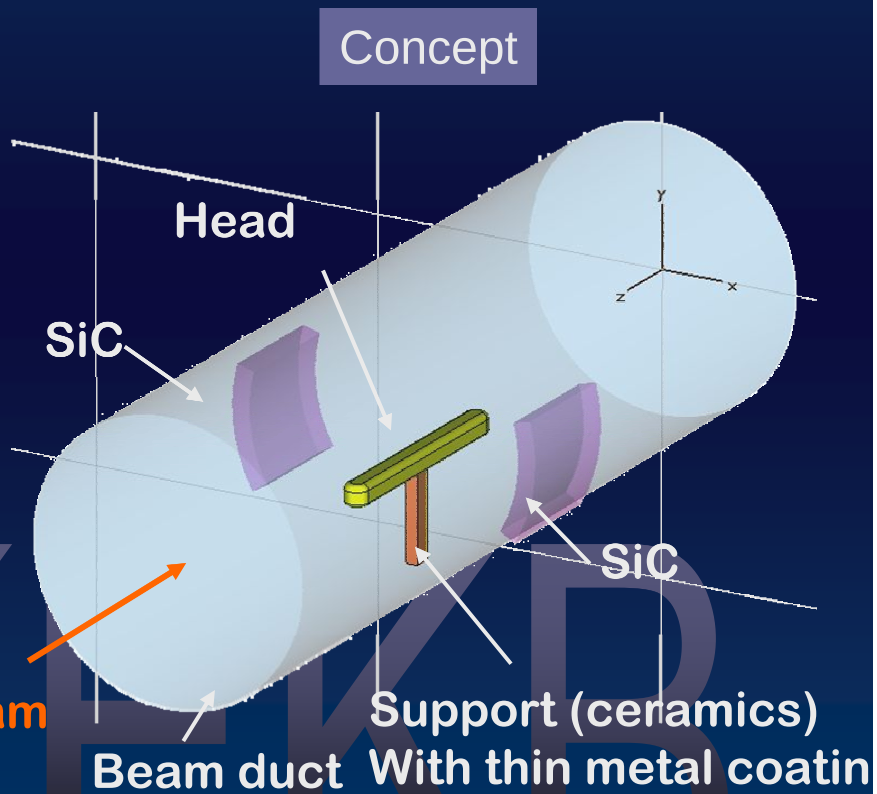
Movable Mask

- Movable mask (collimator) (2003~)
  - Indispensable to reduce background of detector
- Problems for high current operation
  - High Impedance (k = 1 V pC^{-1} @ σ_z = 3 mm)
  - Damage of head due to direct hitting of bunches
- Basically use the same configuration to present type, but the mask chamber should be changed.



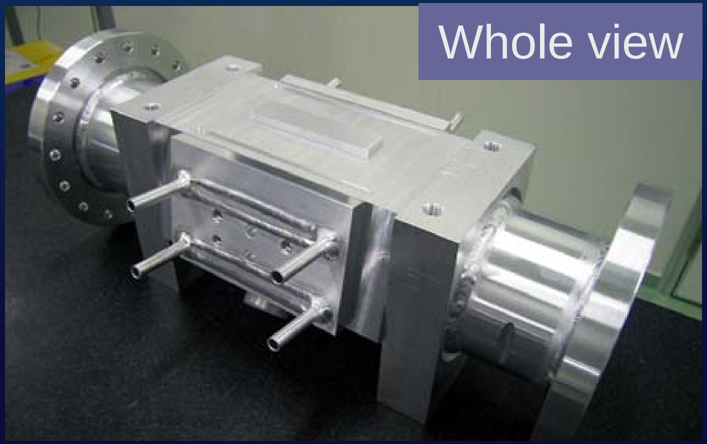
Movable Mask

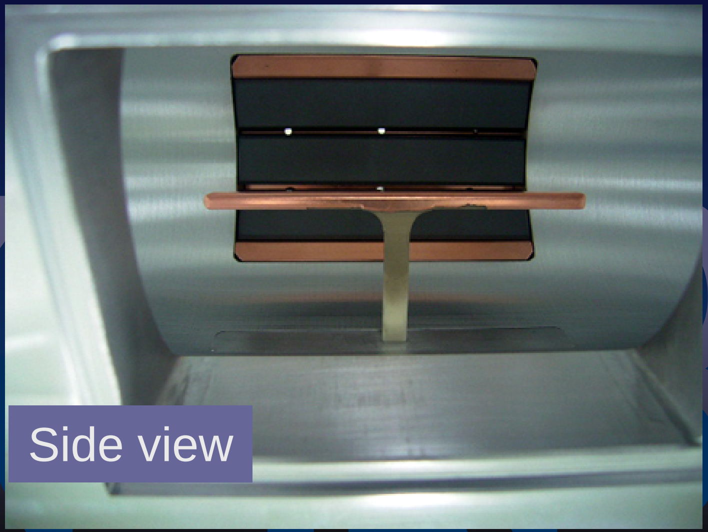
- Proposal of a new mask chamber
  - Ceramic support
    - Little interference with beam
      - *k* decreased to ¼ of Ver.4
      - No problem of CBI
    - With thin metal coating to avoid charge up of head
  - Ceramic head
    - Little damage by beam
  - With HOM absorber (SiC)
    - Absorb trapped modes



Movable Mask

- Trial Model for beam test
  - Vertical mask for LER will be installed this winter.
  - Beam test will start from February.





Summary and Future Plan

- R&D of various vacuum components to adaptable to high current accelerators are proceeding using KEKB.
  - Beam duct with ante-chambers Inner coatings with low SEY, Bellows chambers and gate valves, Connection flanges, and Movable masks
  - R&D is steadily proceeding step by step.
- Next step:
  - Replacement of the present circular beam ducts at a wiggler section (~30m) by that with ante-chambers with TiN coating [this summer].
  - Beam test of a new movable mask.
  - R&D of a clearing electrode for ECI, as an application of the new movable mask (ceramics support).

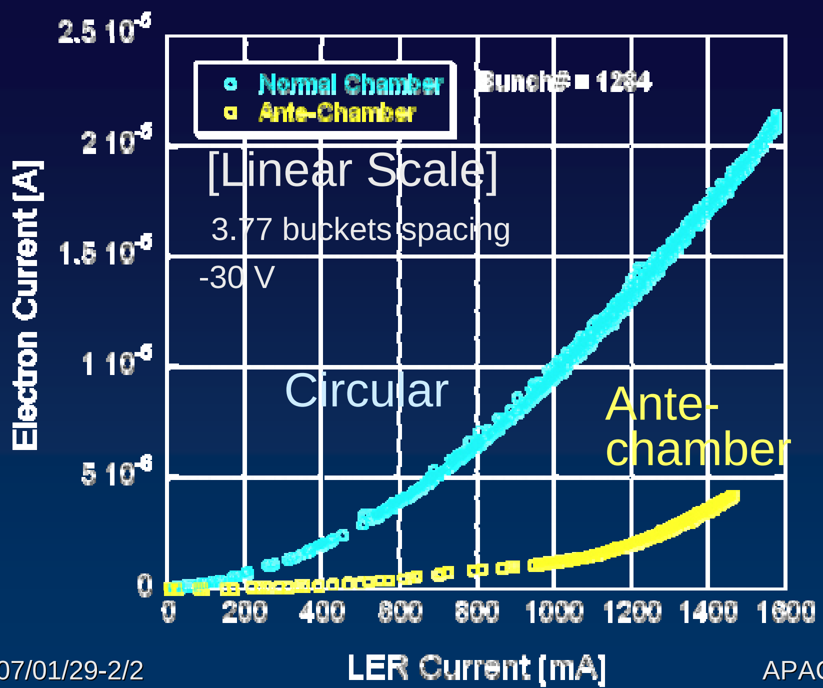
END

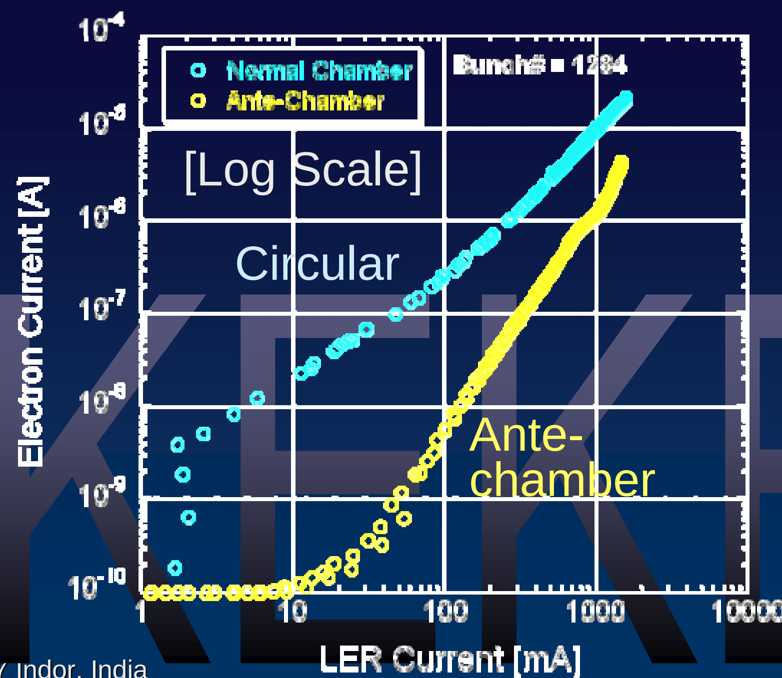
KEKB

KEKB

Beam Duct

- Measurement of electron number
  - Electron current ⇐ Number of electrons around beam orbit
  - Compared with a circular simple duct
  - Reduction <1/100 for low beam currents (<100 mA) :
    - Photoelectron is well suppressed.
  - Reduction by a factor of 4 for high currents (>1500 mA):
    - Secondary electron is important. → Surface with low SEY





Inner Coating

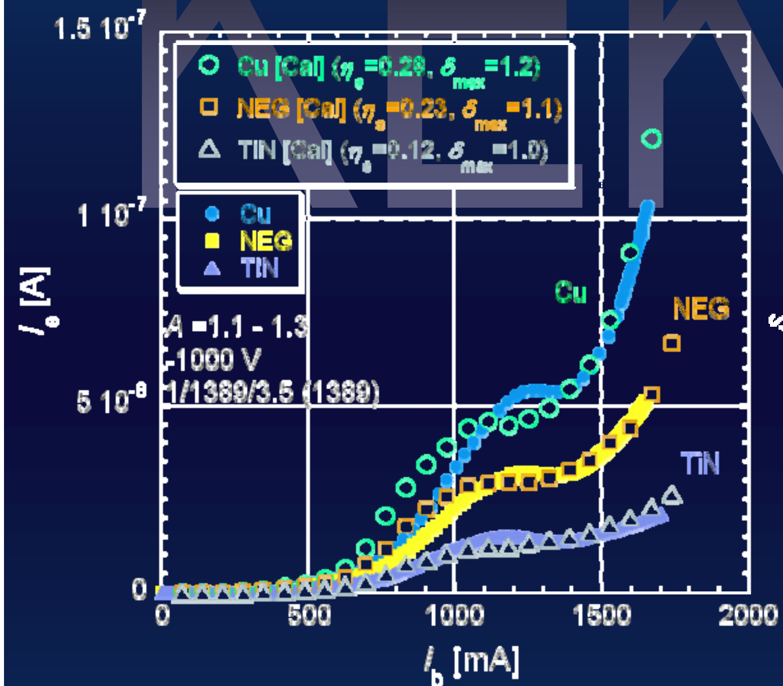
- Estimation of the max. SEY (δ_{max}) and the photoelectron yield (η_e) of Cu, NEG and TiN coating, by a simulation.
  - Make use of the behavior of measured electron currents.

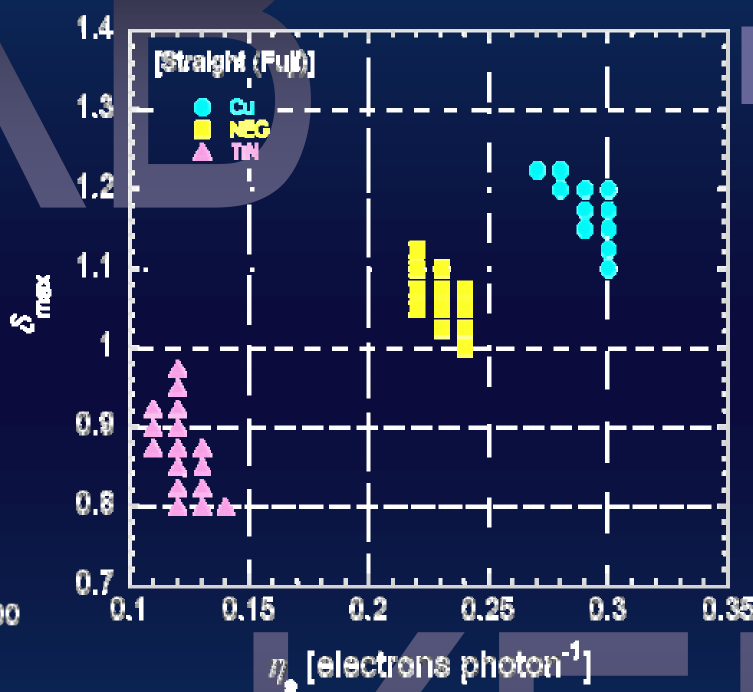
- Simulation Method:
  - "Macro" electrons ($\leq 10^4$ electrons) are traced from the emission, and the number of electrons entering the electron monitor) are counted.
  - Curve fitting to the measured electron current.

Ex. of simulation

Inner Coating

- Estimated η_e and δ_{max} (straight section)





Fitting at high current

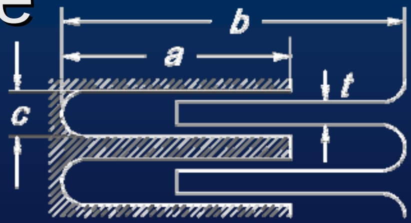
Assuming the same η_e with that of arc section

	η_e	δ_{max}
Cu	0.2 7 -0.30	1.1-1.25
NEG	0.22-0.24	1.0-1.15
TiN	0.1 1 -0.14	0.8-1.0

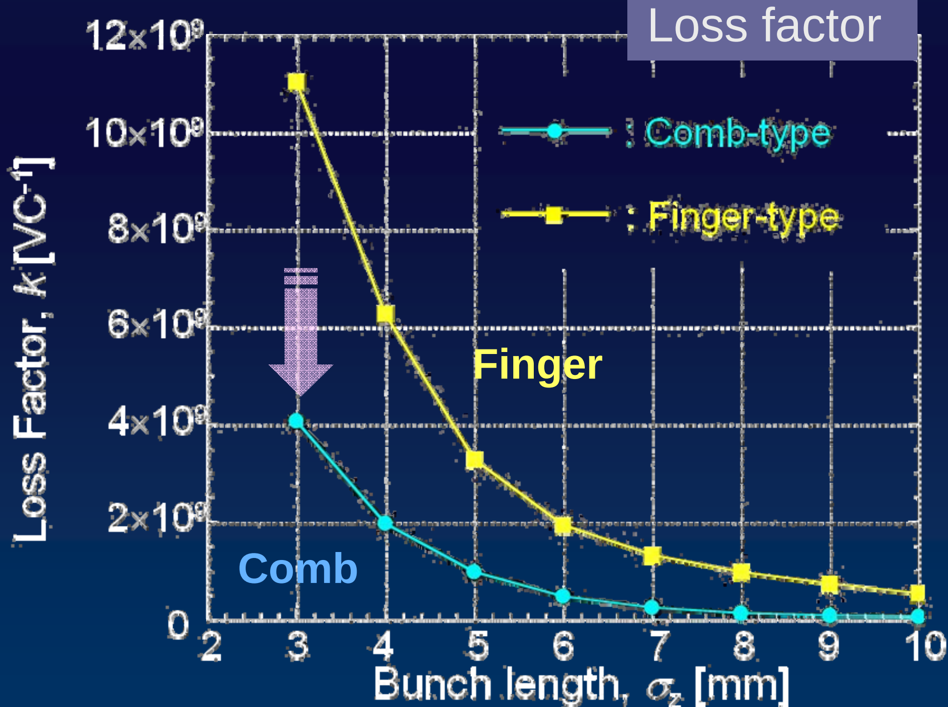
- Consistent with the measurement at arc section.
- However, SR photons should be higher by a factor of 3 to obtain the measured current.
  - Small incident angle, Scattered photons

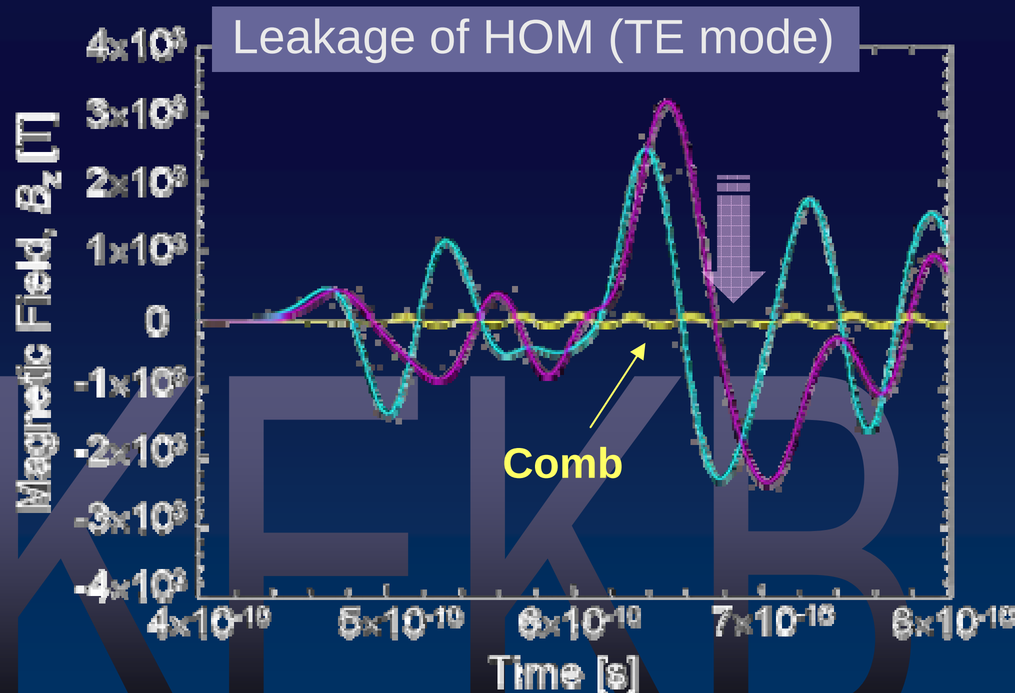
Bellows & Gate Valves

- Calculation of loss factor and HOM leakage
  - Loss factor is about 1/2.
  - HOM leakage is about 1/20.



a=10 mm, b=15 mm
c=2 mm,   d=1 mm

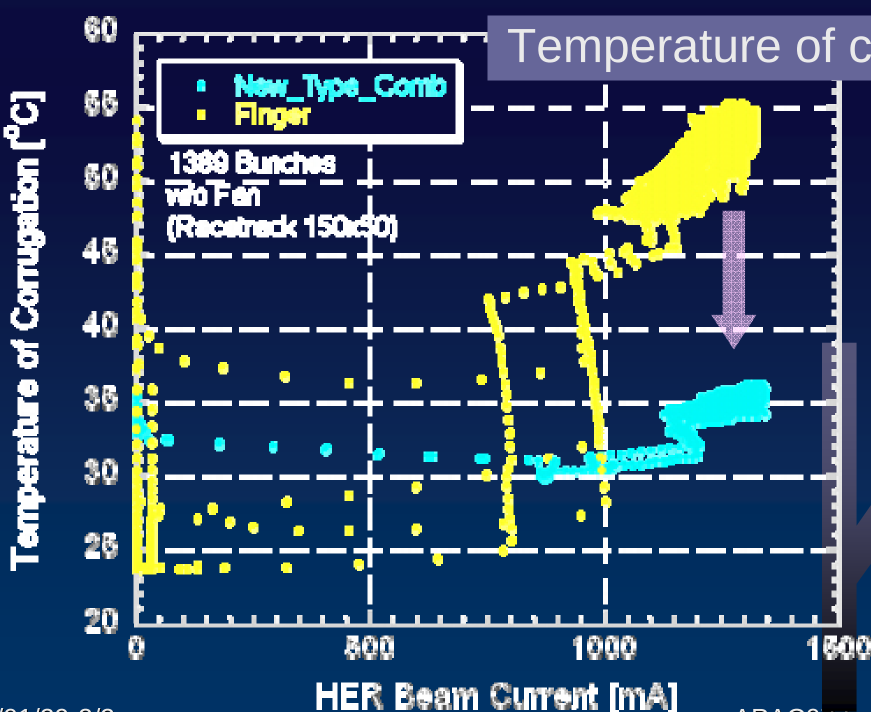


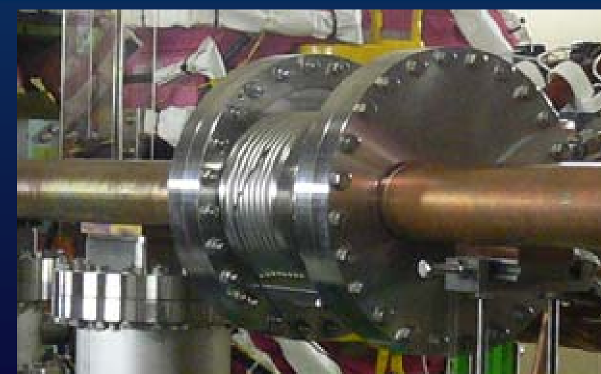


Bellows & Gate Valves

- Racetrack Bellows (2005~)
  - 150 x 50 mm racetrack
  - No problem up to 1.4 A
  - Temperature rise decreased to 1/3 of that of the conventional bellows.

Temperature of corrugation



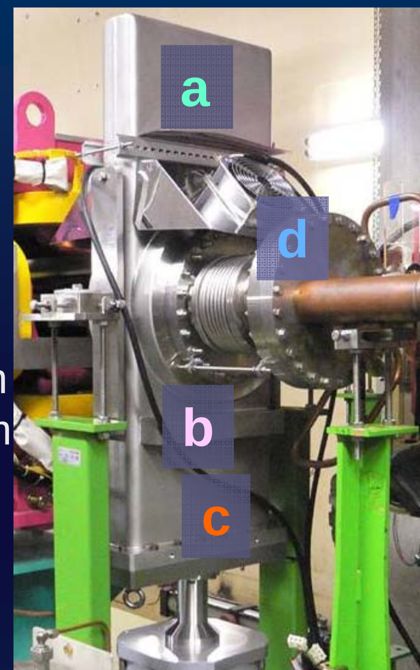


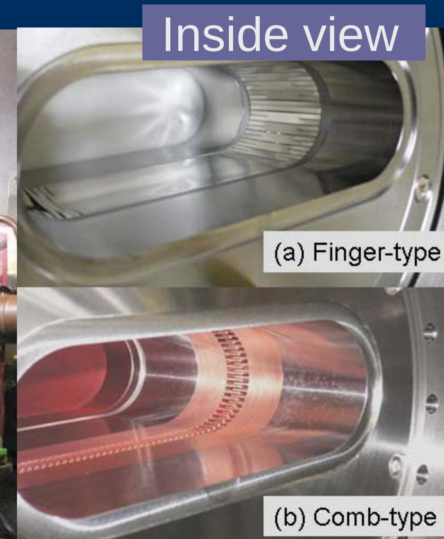
150x50 mm
L = 200 mm
Ver.2

Bellows & Gate Valves

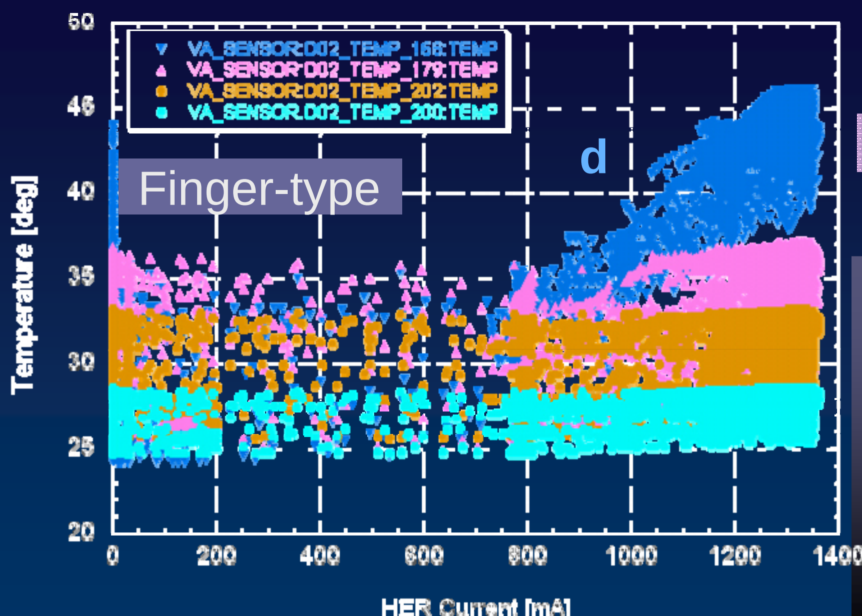
- Racetrack gate valves (2006~)
  - 150x50 racetrack
  - No problem up to 1.4 A
  - Temperature of adjacent bellows also decreased.

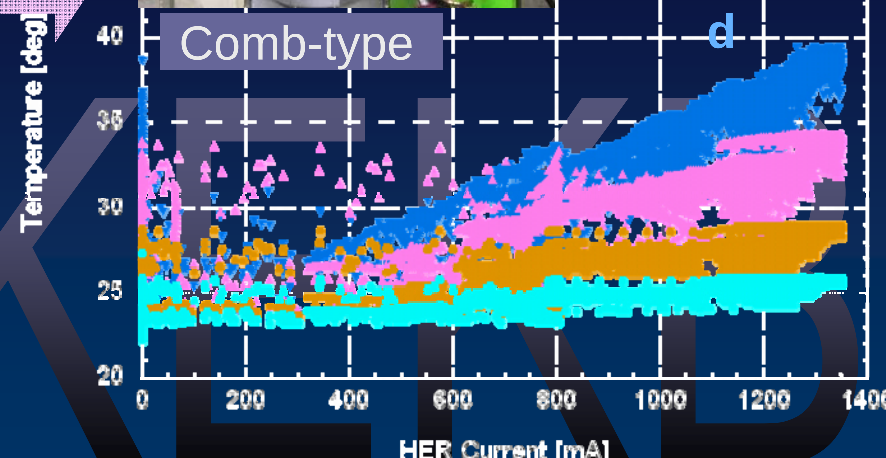
160x50 mm
L = 145 mm
Ver.2





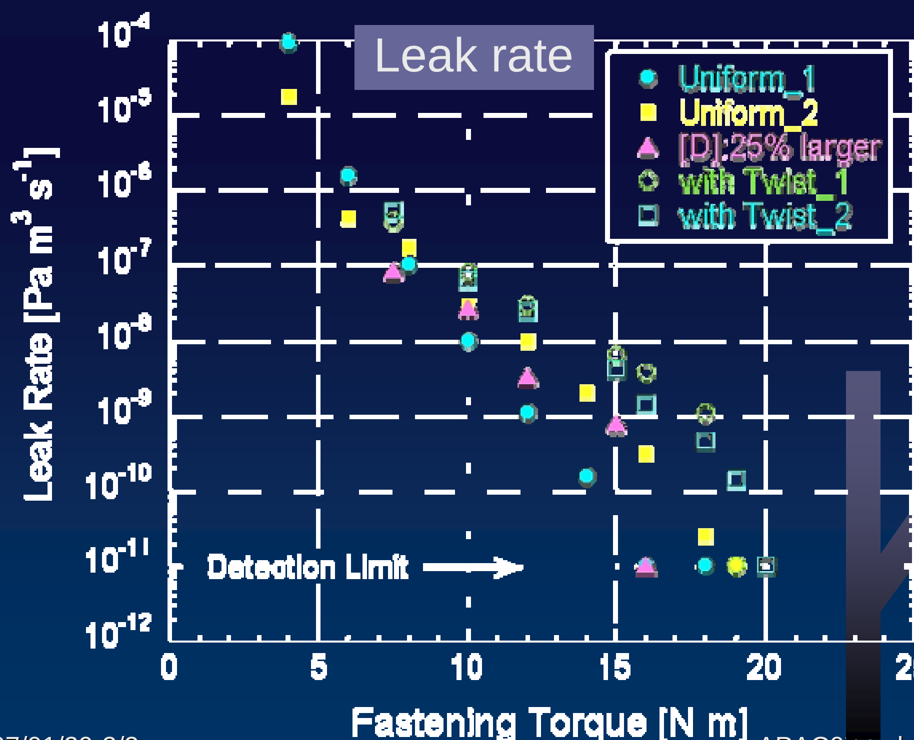
d: Bellows

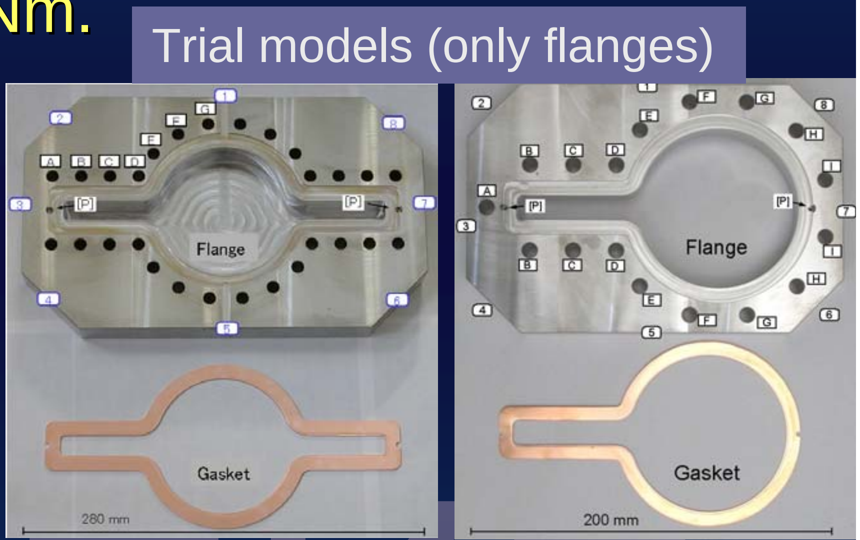


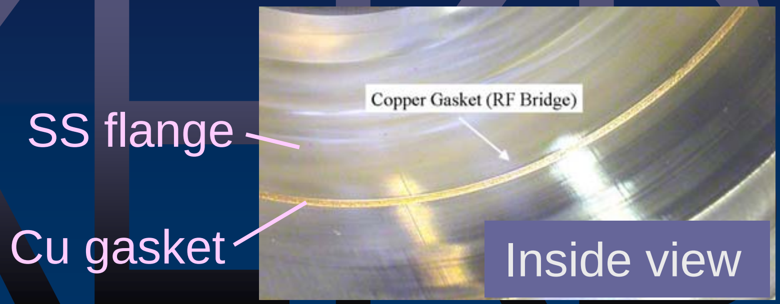


Connection Flange

- Bench test (2004~)
  - Stainless-steel flange and copper gasket (annealed)
  - 180x340 for ϕ94 antechamber, 28 M8-bolts along aperture.
  - Vacuum seal at a torque of ≤ 18Nm.
  - No problem after baking (200°C)

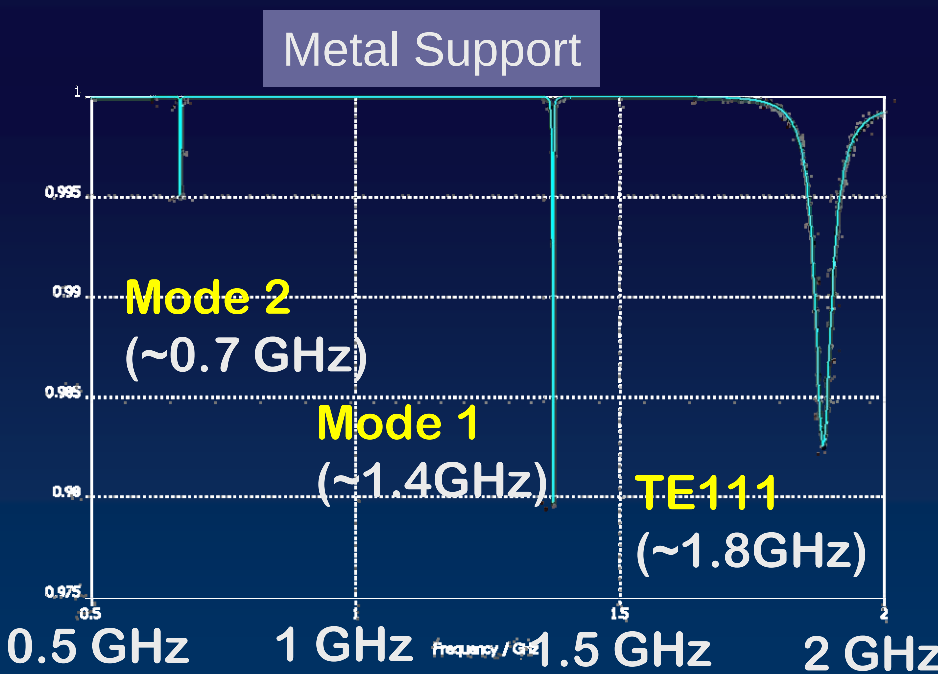


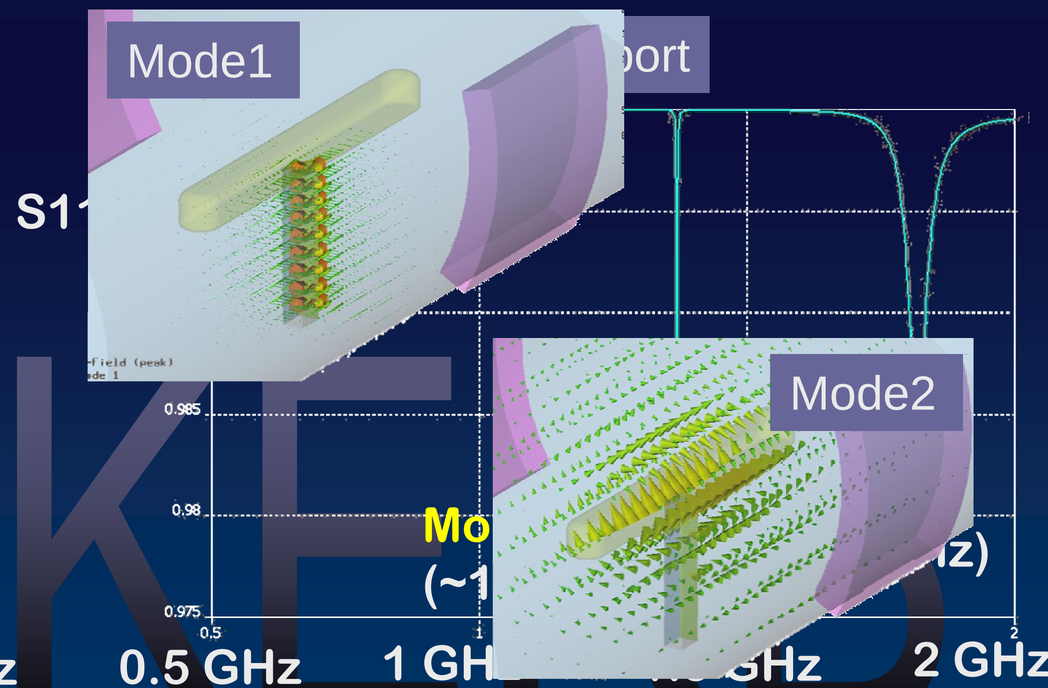




Movable Mask

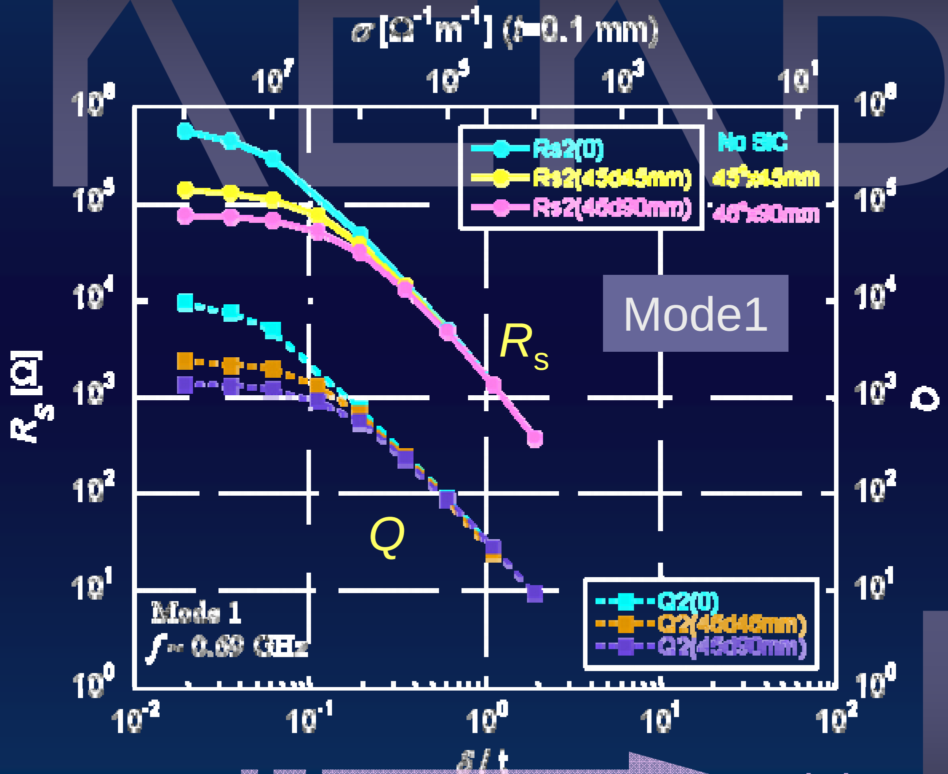
- Calculation of trapped modes
  - Two trapped modes (Mode1 and Mode2) were found.
  - Mode 1 (=0.7GHz) disappeared for ceramics support.

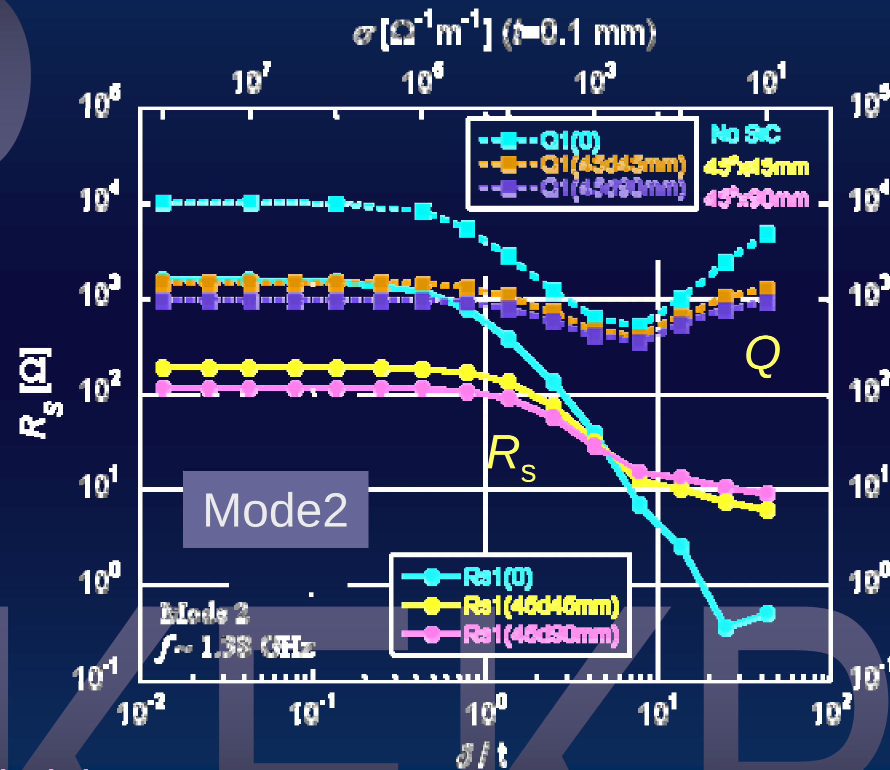




Movable Mask

- Calculation of longitudinal Impedances (R_s) and Q



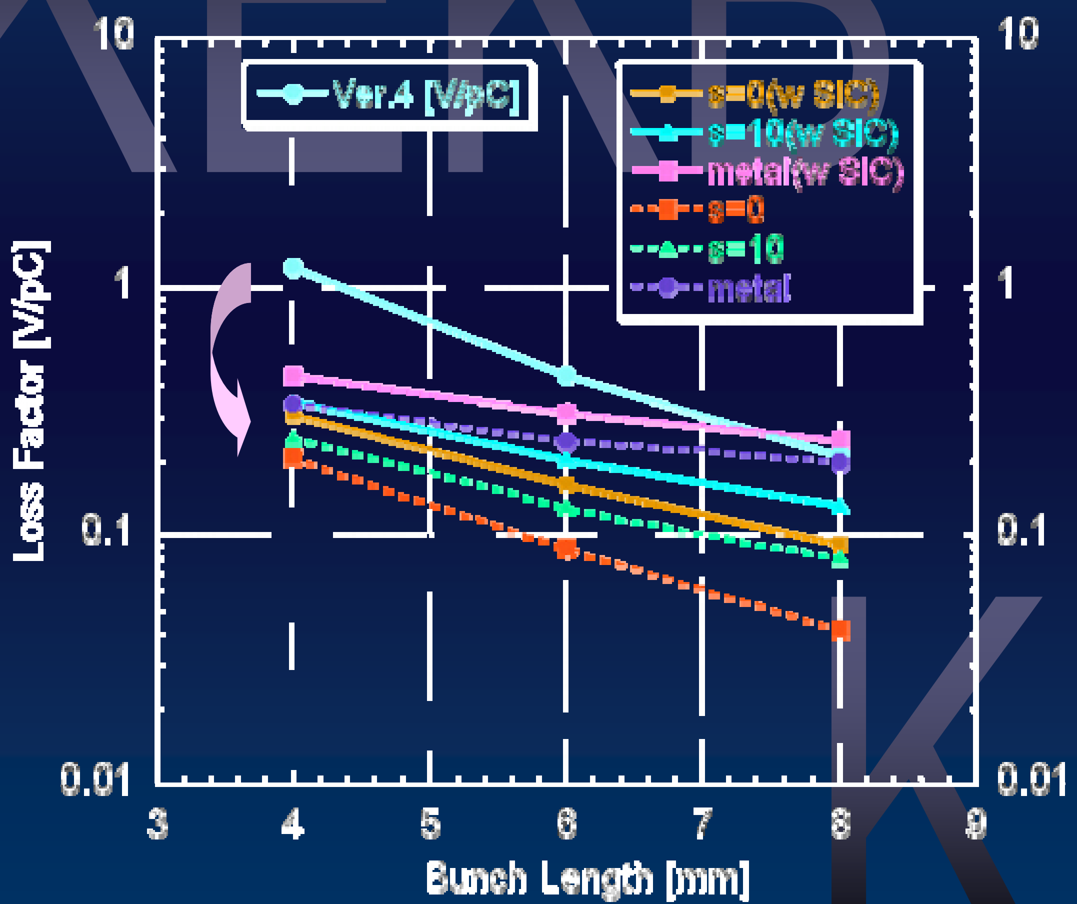


High resistivity

- R_s decreases as increasing the resistivity of coating on support.
- No CBI problem for KEKB at full current operation.

Movable Mask

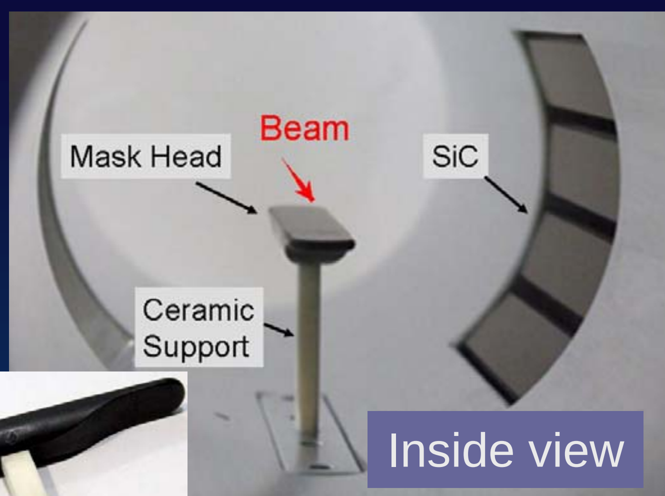
- Calculation of Loss factor



- Loss factor decreases as increasing the resistivity of coating on support.
- Loss factor is about 1/4 of the present Ver.4 mask at σ_z = 4mm, when the coating is 1μm titanium, for example.

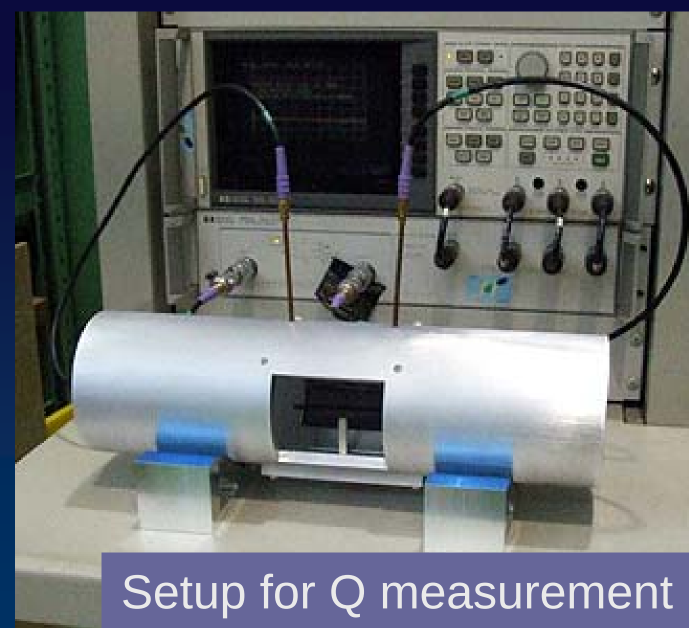
Movable Mask

- Bench test using a test model
  - An atmosphere version was manufactured to check the calculation, and to see the manufacturing property.
  - Measured behavior of trapped modes were well consistent with the calculated one.



Inside view

Mask head and support



Setup for Q measurement