Vacuum Upgrade for Super KEKB

Y.Suetsugu, KEK

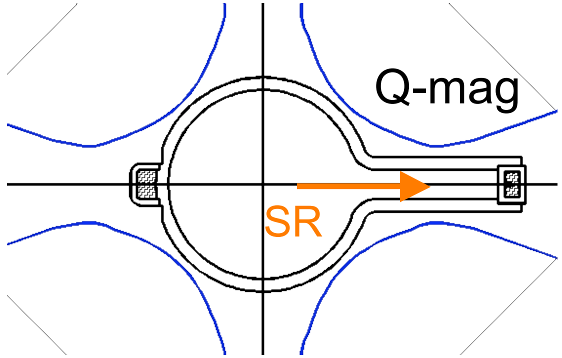
1. Brief Review of Vacuum Design (Arc)
2. Recent R&Ds
    a. Beam Duct with Ante-chamber
    b. Surfaces with low SEY (Beam Test)
    c. Bellows Chamber
    d. Connection Flange
    e. Movable Mask (Collimator)
3. Summary

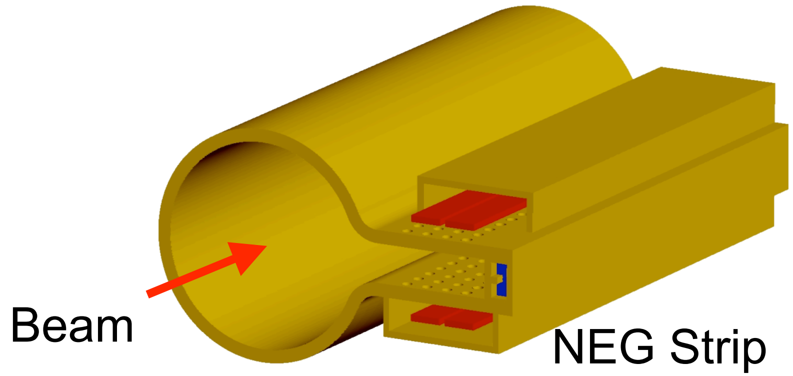
Basic Design of Vacuum System _1

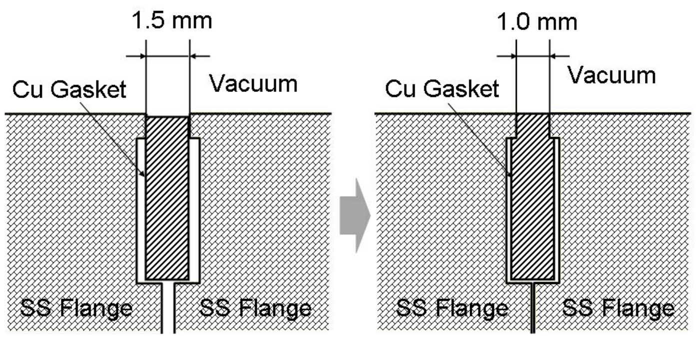
- Main issues of vacuum system come from high currents (LER:9.4 A, HER:4.1 A) and a short bunch (σ_z = 3 mm):
  - Intense SR power
    - Max.28 kW/m even for a beam duct with ante-chamber
    - Max.40 W/mm^{2}, at 51 mrad incidence
  - High gas load
    - Ave.5x10^{-8} Pa m^3/s/m, for η = 1x10^{-6} molecules/photon
    - Pumping speed of ave.0.1 m^3/s/m to get ave.5x10^{-7} Pa
  - Lots of photoelectrons [e$^+$]
    - Photons: ave.~1x10^{19} photons/m/s
  - Intense HOM power
    - 1 V/nC ➔ ~200 W (N_b = 5120, f_c = 100 kHz)
  - High wall current
    - Peak:~250 A (σ_z = 3 mm)

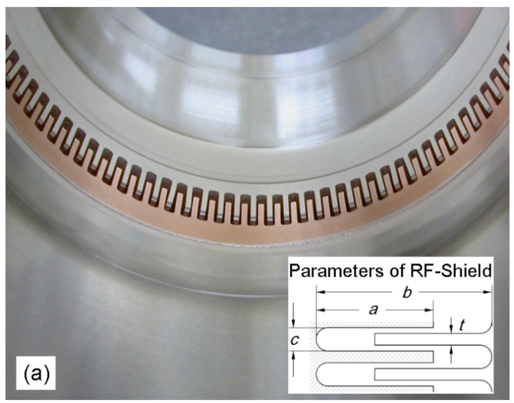
Basic Design of Vacuum System _2

- Proposed basic designs for arc are:
  - Beam duct:
    - Copper beam duct with an ante-chamber
    - Distributed pumping by NEG strips
    - Inner surface with low SEY or/and solenoid [e+]
  - Bellows and gate valves:
    - With comb-type RF shield
  - Connection flange:
    - MO-type flange or conventional RF bridge + vacuum seal
  - Movable mask (collimator)
    - New design with low impedance (no concrete design)
  - . . . . .









Basic Design of Vacuum System _3

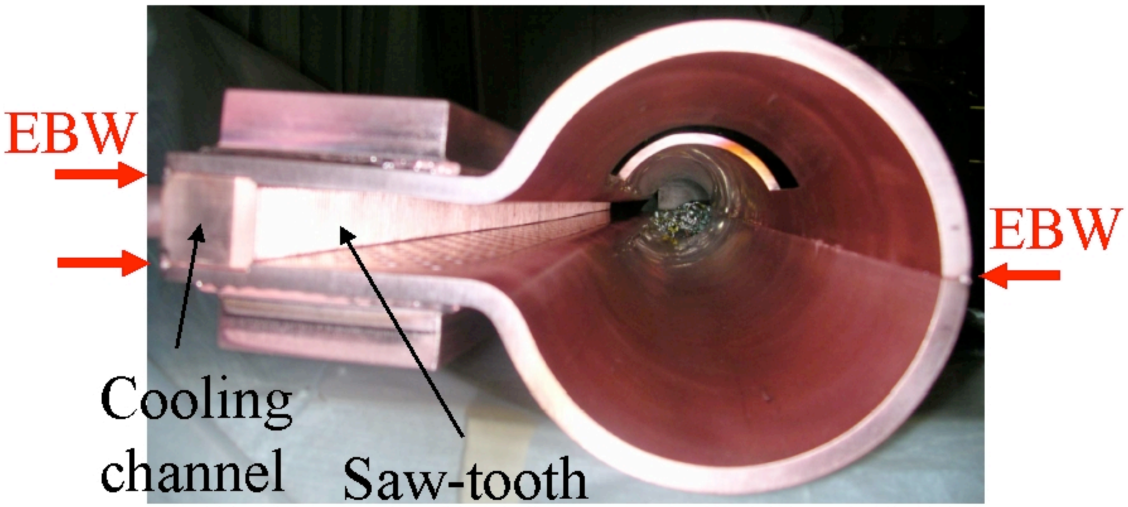
- Recent R&Ds are focused on:
  - Copper beam duct with ante-chamber
    - Beam test of two trial models, Measurement of photoelectrons, Application of NEG strips
  - Surface with low SEY
    - NEG coating and TiN coating
    - Test with beam
  - Bellows chamber with comb-type RF shield
    - Beam test of comb-type RF shield
    - Application to gate valve
  - Connection flange with smooth inner surface
    - Applying MO-type flange to beam duct with antechamber
  - Movable mask
    - Simulation study of a new structure with low impedance

Beam Duct with Ante-chamber _1

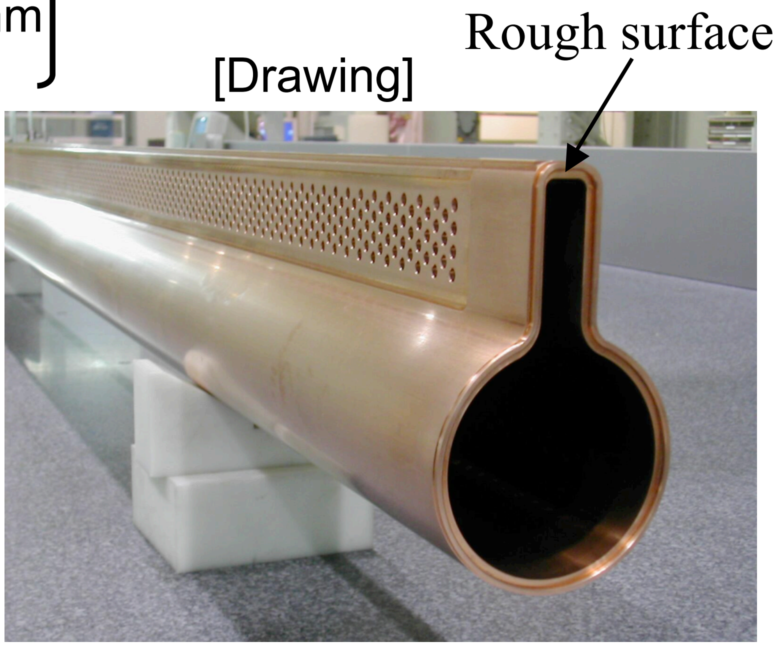
- Two test models of copper beam ducts with ante-chamber were manufactured.
  - Oxygen Free Copper (OFC), Length = 5.2 m.
- Two manufacturing methods were tried:
  - Pressing: Pressing from a Cu plate (assembly of four pieces)
  - Cold drawing: Drawn from a pipe (one piece)

ϕ = 94 mm
h_a = 112 mm
t = 6 mm

[Pressing]

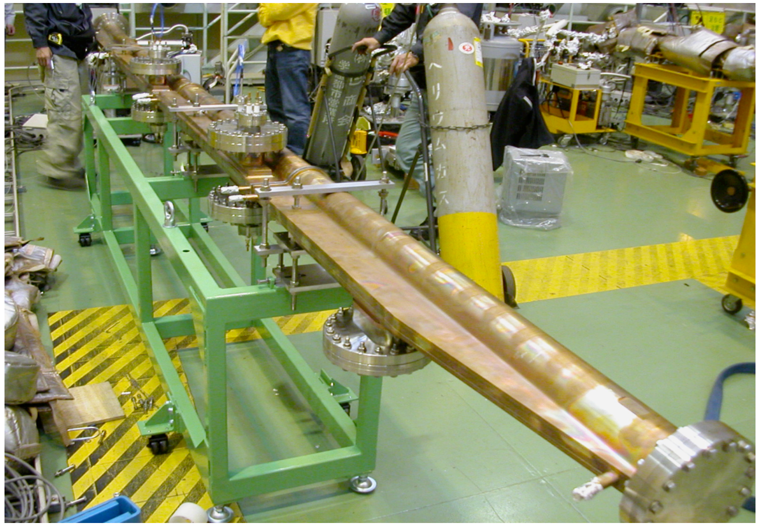


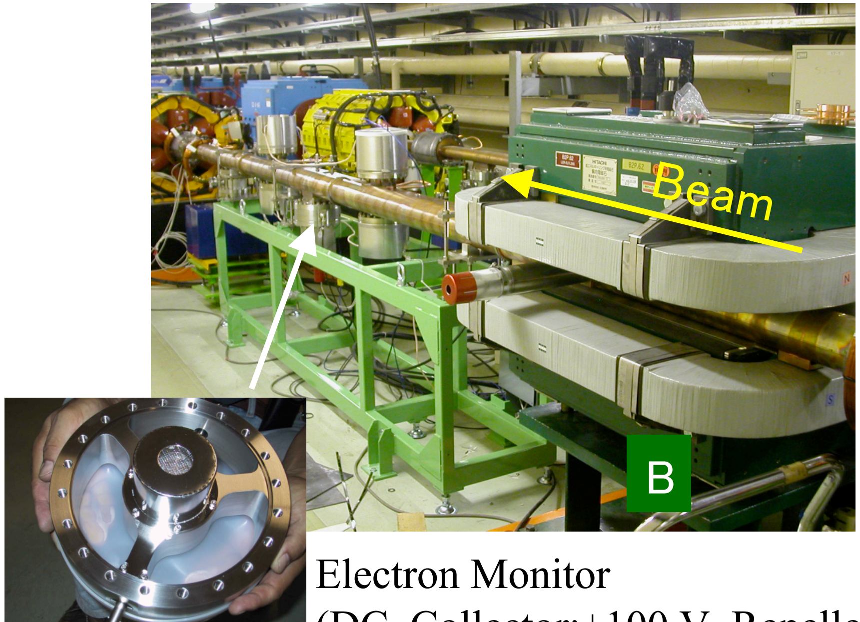
[Drawing]



Beam Duct with Ante-chamber _2

- No essential problem was found for both manufacturing methods.
- Then, these two ducts were installed in LER last year, just downstream side of a bending magnet.
- Electron currents in the beam channel, temperatures and pressures were measured during a usual beam operation.





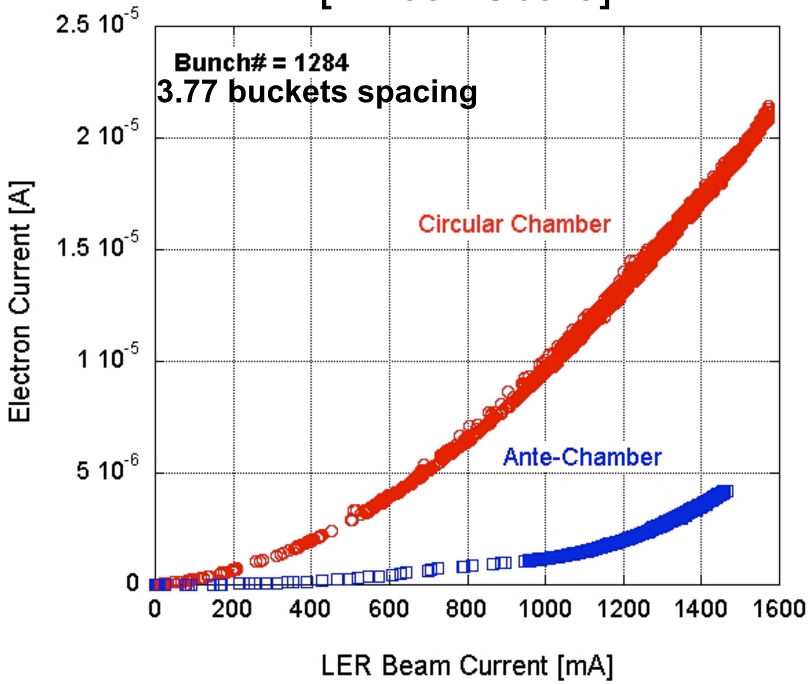
Electron Monitor
(DC, Collector:+100 V, Repeller:-30V)

Beam Duct with Ante-chamber _3

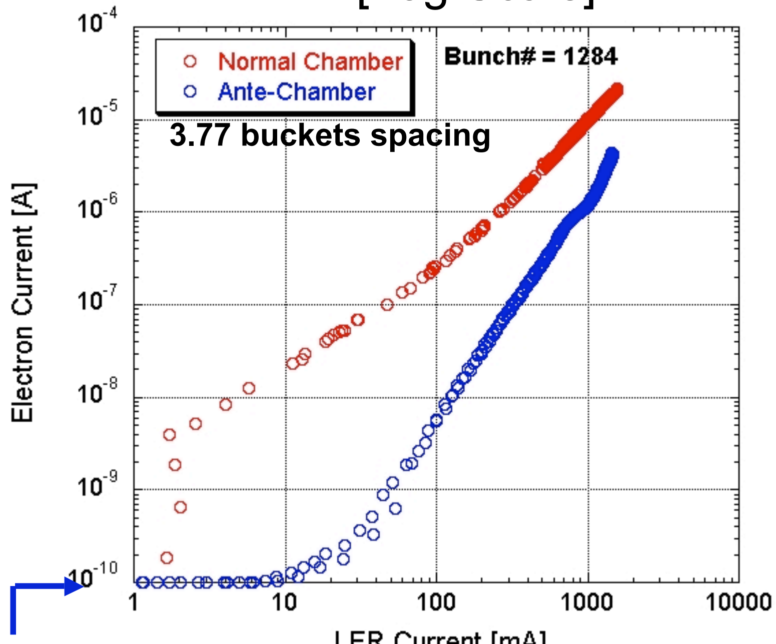
- Electrons in the beam channel
  - Photoelectrons decreased by factors at high current (I_b ≥1 000 mA).
  - The reduction was by orders at low current (I_b ≤ 100mA).
  - Multipactoring seems to become important at higher current.
- Combination with solenoid field, and an inner surface with a low SEY will be required at higher current.

Repeller Voltage = -30 V

[Linear Scale]



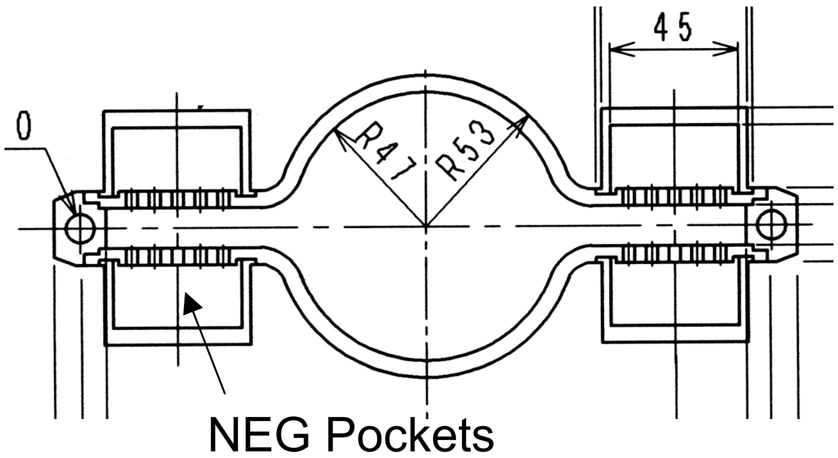
[Log Scale]



Beam Duct with Ante-chamber _4

- Beam duct with ante-chamber works almost as expected and the manufacturing is found to be possible.
- Next Step
  - Manufacturing of a beam duct for wiggler section is undergoing. (SR hit both sides)
    - Pressing, but one piece (4.5 m). Four NEG pockets.
  - The duct will be installed next summer, and tested together with bellows chambers (described later).

[Cross Section]



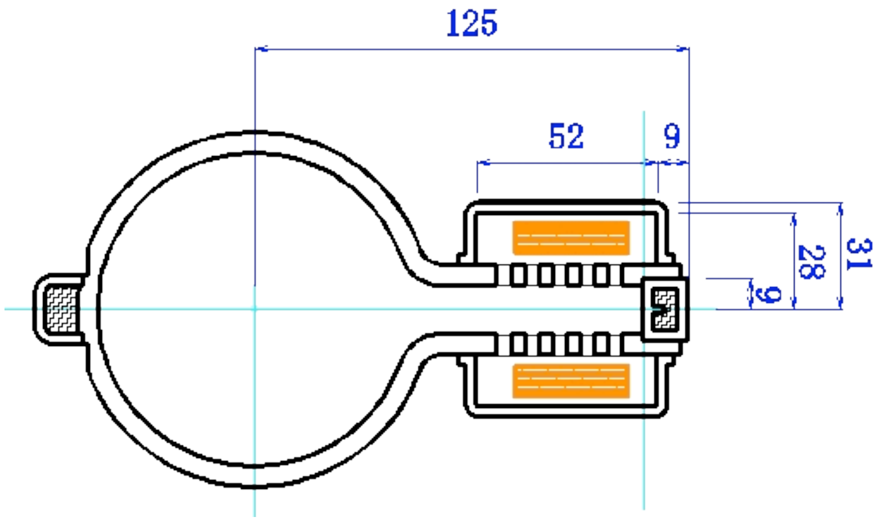
[Pressed Plate (Cu)]

Beam Duct with Ante-chamber _5

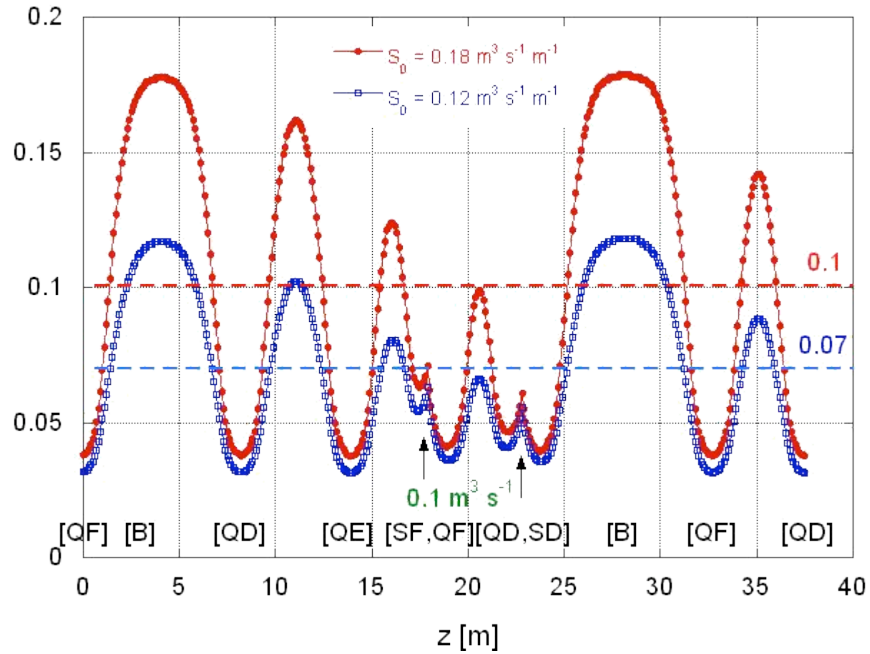
- Manufacturing of beam duct with ante-chamber is possible, but, practically, leaves still room for improvement.
- Main problems in the present design
  - Complex structure
  - Many welding lines
  - No pump in Q or Sx magnets

→ High Cost
Low reliability
Low average pumping speed

[Present design]

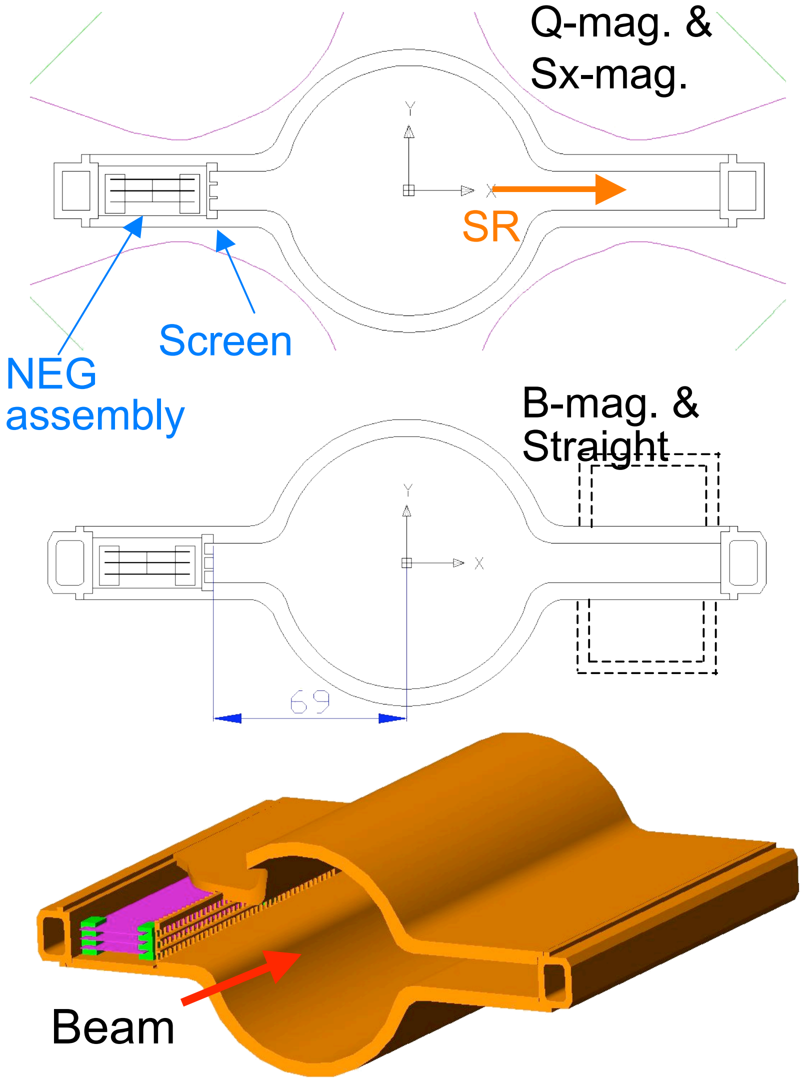


[Effective pumping speed (HER)]



Beam Duct with Ante-chamber _6

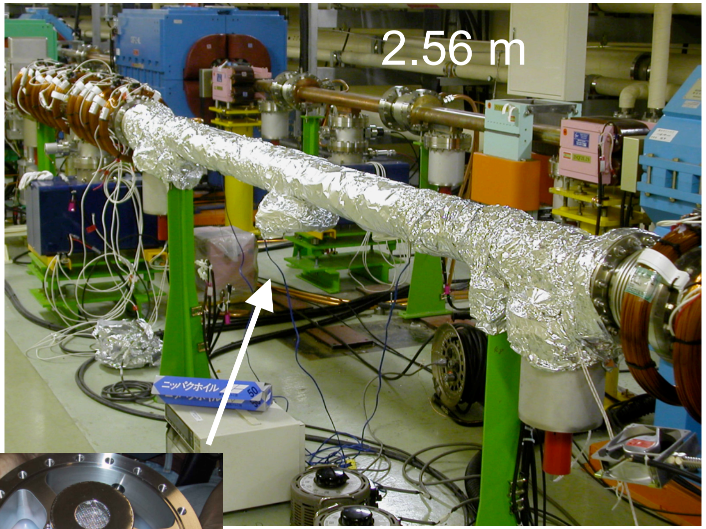
- Recent idea for beam duct design
  - Basically the same as the present design for outer side, but pump is in the antechamber at inner side.
  - A screen in the ante-chamber (~70 mm from beam) hides the NEG assembly (multi-strips, for ex.).
  - The same structure for B and Straight duct, and omit NEG pockets.
- Features
  - Pumps in Q and SX magnet
    ➔ Uniform effective pumping speed
  - Simpler structure and less welding lines ➔ Low cost
  - Easy install of NEG strip from end flange ➔ Multi-strips is possible
  - Impedance of screen is low:
    ~10^4 V/C/m ~a few mW/m
- Further considerations are required.
  - Bending, NEG assembly



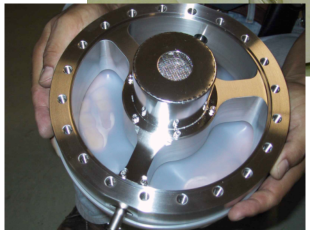
Surface with Low SEY _1

- Surface with a low secondary electron yield
  - Necessary for e+ ring to suppress ECI. (Antechamber is not sufficient)
  - Promising candidates are:
    - NEG (Ti,Zr,V) coating:
      Studied in CERN and applied to LHC
    - TiN coating: Applied to PEPII LER , , ,
    - Groove: Proposed by BINP, SLAC, , ,

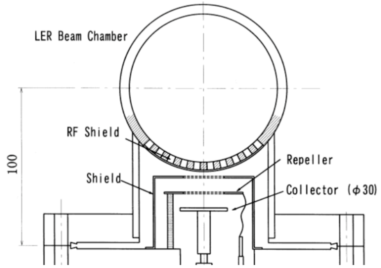
[Test chamber in the tunnel]



- Two test chambers with NEG coating and TiN coating were prepared last year.
- They were installed in LER and electrons in the duct and pressures were measured during a normal operation.
- The first experiment using e+ high current machine
- Photons: 6×10^{14} photons/mA/m



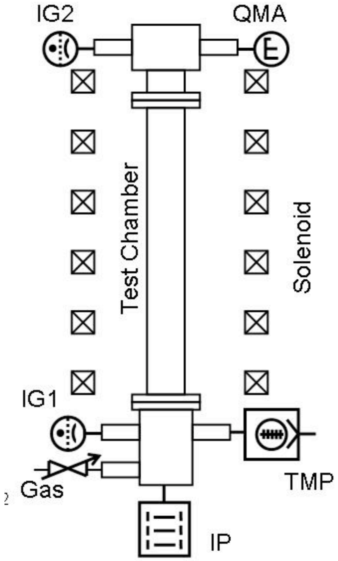
[Electron Monitor]



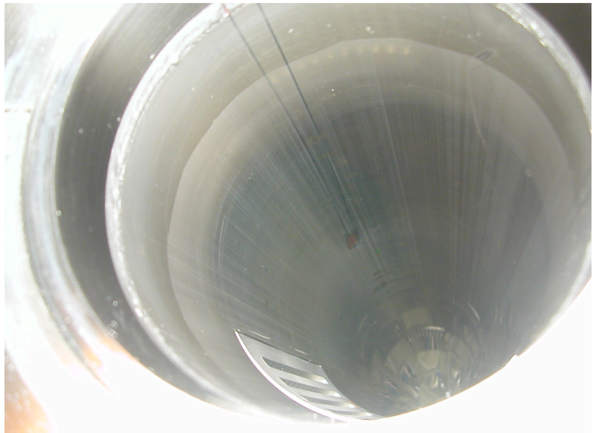
Surface with Low SEY _2

- NEG (Ti,Zr,V) coating:
  - Coated at BINP
  - Magnetron discharge
  - P ~ 0.3 Pa (Kr), B ~105 G
  - I = 150 mA, V = 400 V
  - Temperature is kept at 100°C during coating
  - Thickness1 μm
  - Ti:Zr:V = 30:26:44 (atoms)
  - Activated in situ. at 220 °C for 2 hours
- TiN coating:
  - Coated at BNL
  - Magnetron discharge
  - P ~ 1.3 Pa ($Ar+N_2$)
  - I ~ 1700 mA, V ~ 380 V
  - Temperature is kept at 220°C during coating
  - Thickness 0.3 ~1 μm
  - Ti:N =49 : 51
  - No baking in situ.

[Set up of NEG coating]

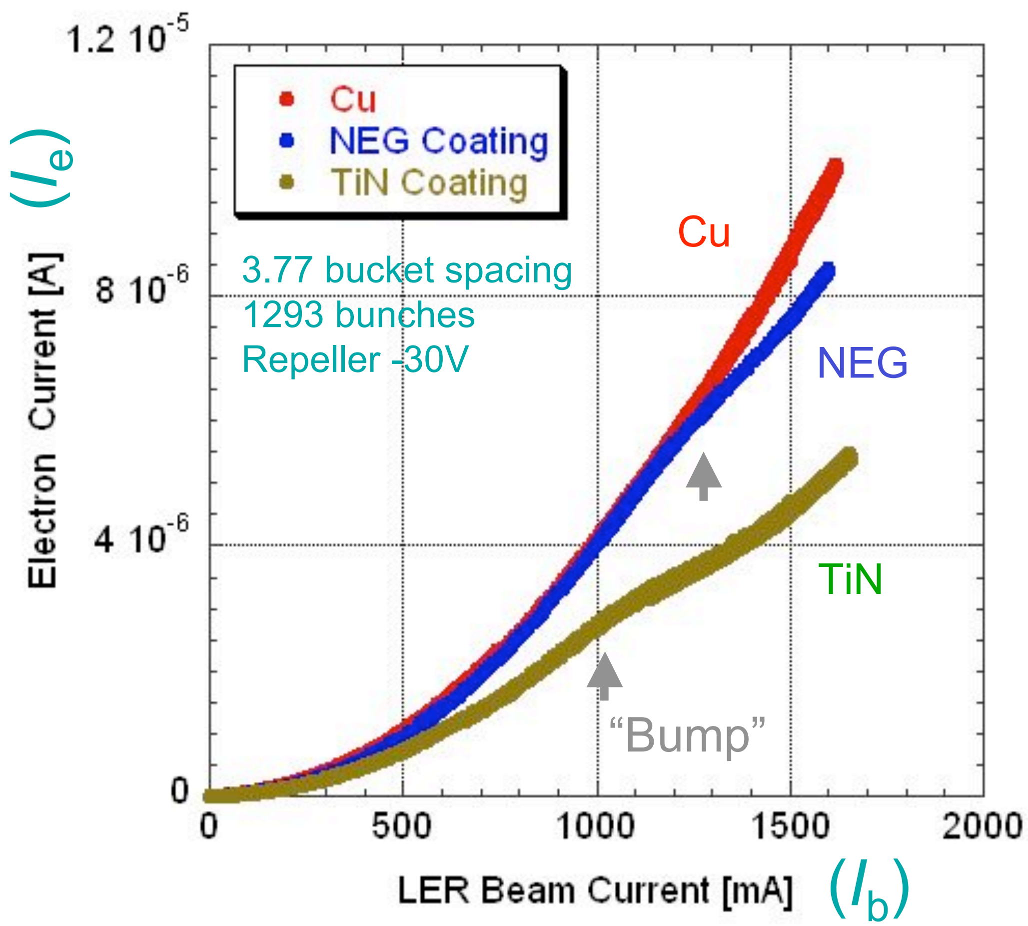


[Inner surface of NEG coated chamber]



Surface with Low SEY _3

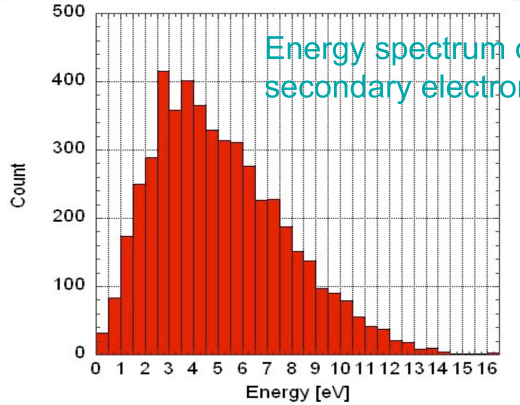
- Measured electron current (I_e) vs. beam current (I_b)

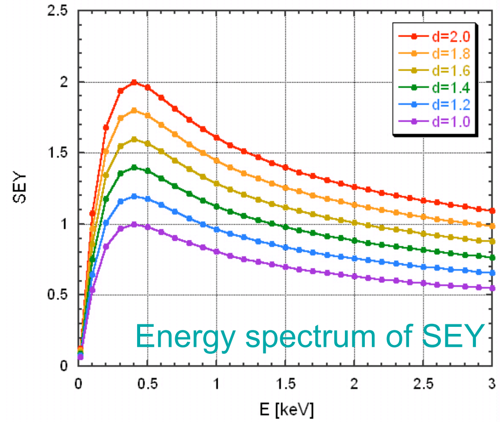


- I_e were measured after electron bombardment of ~1×10^{20} e^-/cm^2 (stable).
- I_e for NEG coating is almost same as that of Cu, except for high current.
- I_e for TiN coating is clearly lower than those of Cu and NEG.
- They cannot be compared simply, because the effect of SR (photoelectron yield) has to be considered.
- A simulation was tried to explain the behavior of curves and to estimate δ_{max} (Max. SEY) for three surfaces, especially paying attentions to "bumps" in the curves.

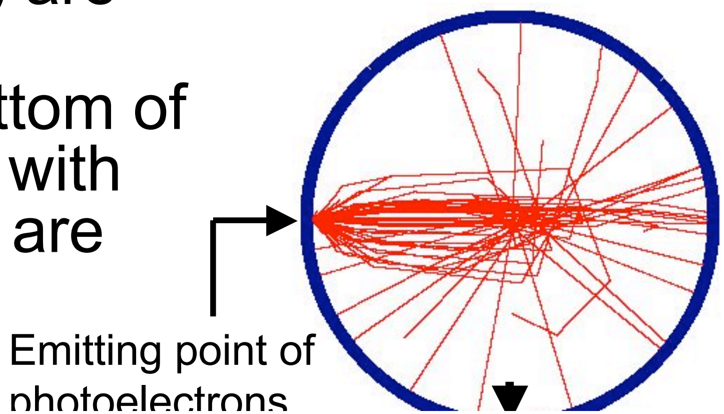
Surface with Low SEY _4

- Assumptions in simulation
  - 2-dimensional
  - Energy spectrum of emitted electrons (same for photoelectrons and secondary electrons)
  - Energy spectrum of SEY (M.A.Furman at al.*)
  - Direct photons:6x10^{14} photons/m/mA
  - Reflected photons:6x10^{14} photons/m/mA
  - Space charge assuming a uniform electron density





- “Macro” electrons (≤10^4 electrons) are traced from the emission and the number of electrons hitting the bottom of duct (position of electron monitor) with an almost normal incidence angle are counted.

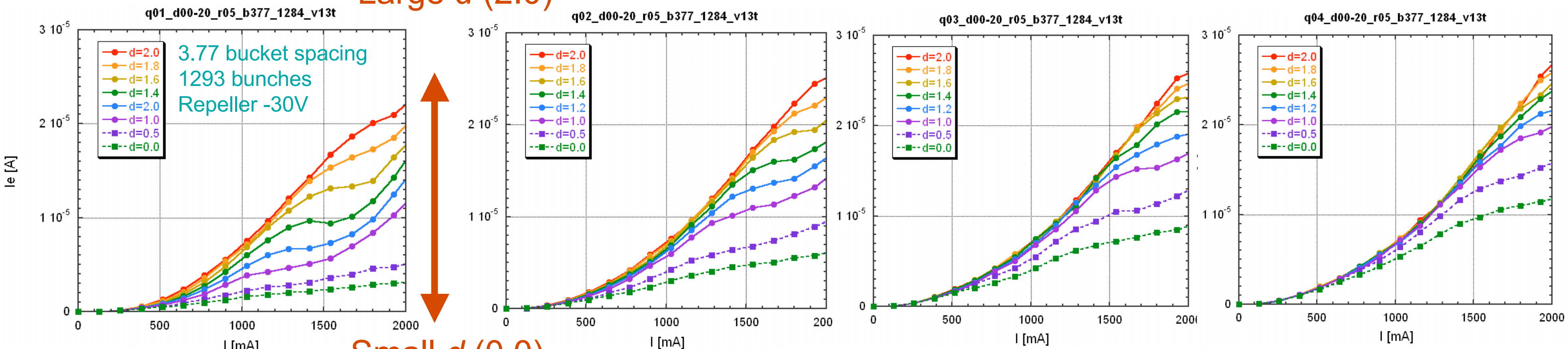


*Proc. MBI97, Tsukuba, 1997

Surface with Low SEY _5

- Simulation: electron current (I_e) vs. beam current (I_b)
  - Main parameters are q (photoelectron yield) and d (δ_{max}).

Large *d* (2.0)



Small *d* (0.0)

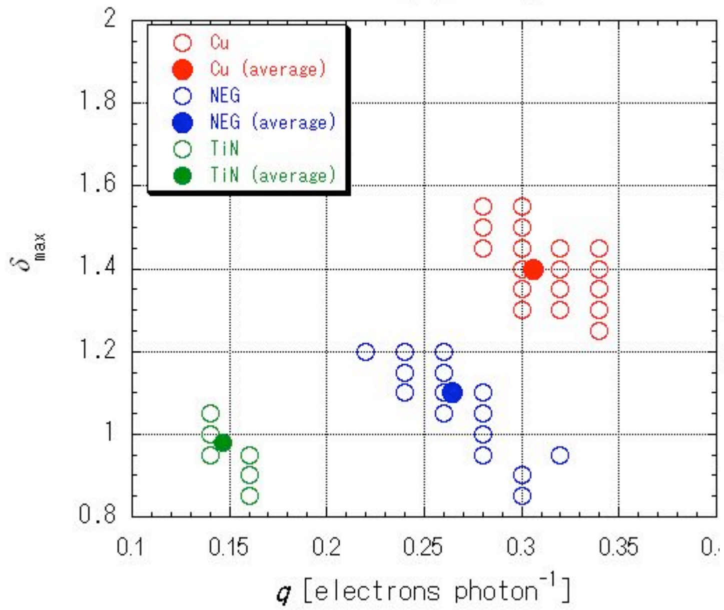
Low *q* (0.1) ↔ High *q* (0.4)

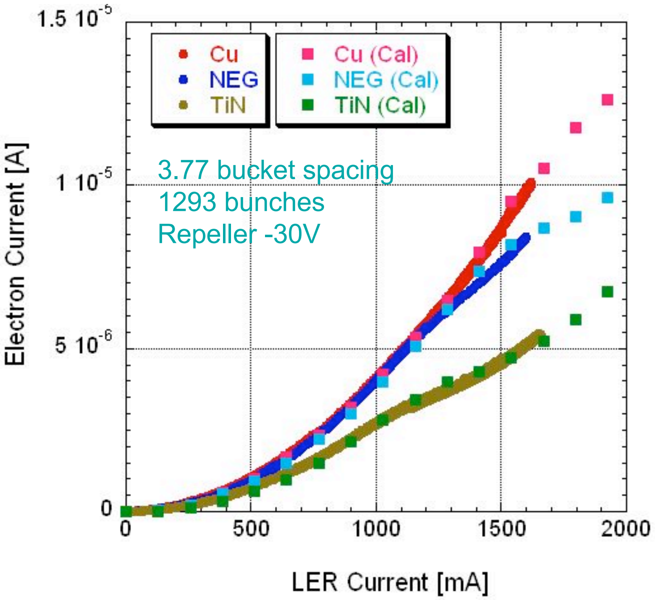
- I_e strongly depends on *d* for low *q*.
- I_e is independent of *d* for high *q*, especially for low I_b.
- I_e is almost constant for high *d*, which is limited by space charge.
- I_e mainly determined by *q* for very low I_b ($\leq$ 30 mA)
- The "bumps" are clear for low *q* or low *d*, and the shape and the position depend on *q* and *d*.

➔ Estimations of *q* and *d* are possible by curve fittings.

Surface with Low SEY _6

- Curve fitting
  - Curve fitting by scanning q ($0.1 \leq q \leq 0.4$) and d ($0.8 \leq d \leq 2.0$).
  - Constraints : q [Cu]=0.3~0.4, q [Cu] : q [NEG] : q [TiN]=1:~0.8:~0.55
    (from exp. at PF) (from data at I_b = 30 mA)





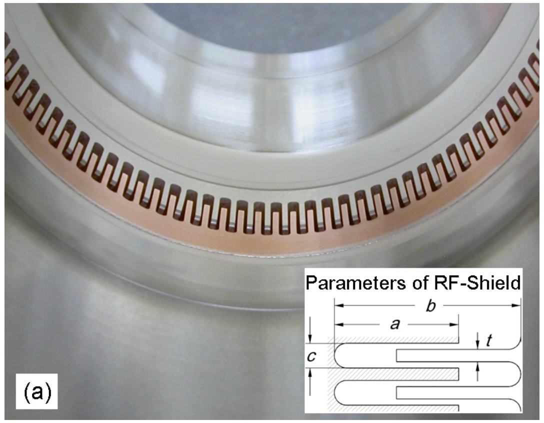
	q	δ_{max}
Cu	0.28-0.34	1.3-1.55
NEG	0.23-0.3	0.95-1.2
TiN	0.14-0.16	0.85-1.05

- High photons in e^+ machine makes the effect of low SEY unclear.
- TiN coating seems better from view points of low SEY and small q.
- The pressure, however, was low for NEG coating.
- Further investigations, such as tests at little photon region, at straight section or beam duct with ante-chamber, will be continued.

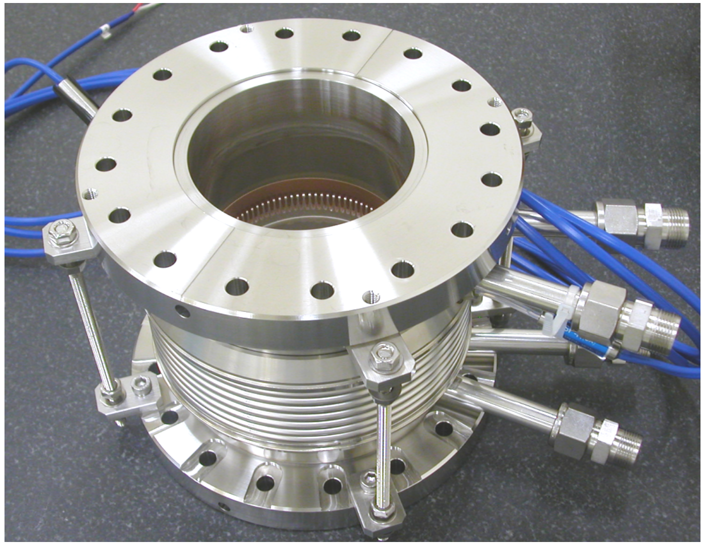
Bellows Chamber _1

- The comb-type RF shield has been developed in KEK.
- Two circular bellows chamber was installed in LER two years ago.
  - Good results were obtained.
    - Temperature decreased to <1/6
    - Temperature of comb ~ 50 °C at 1.6 A
    - No damage after 1.5 year operation

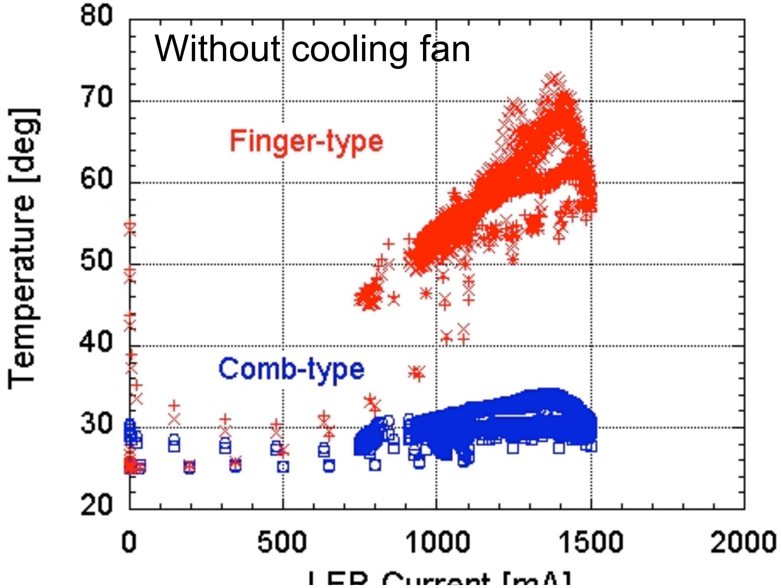
[Comb-type RF shield]



[Circular Type Bellows]



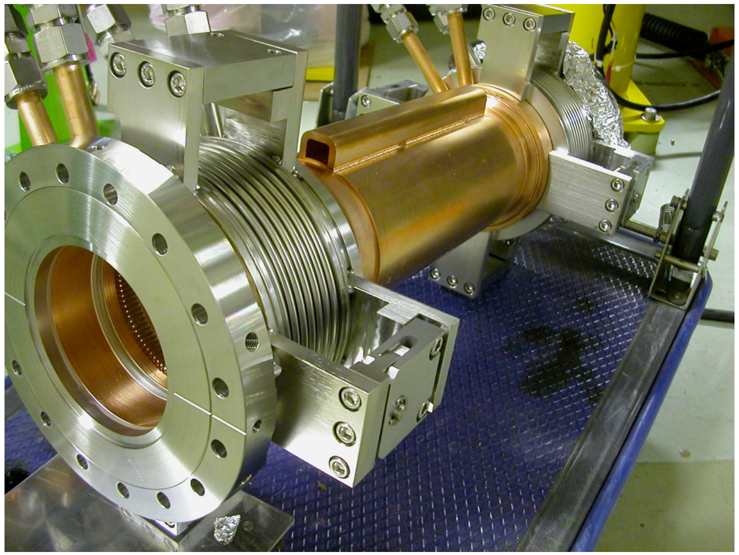
[Temp. of corrugation]



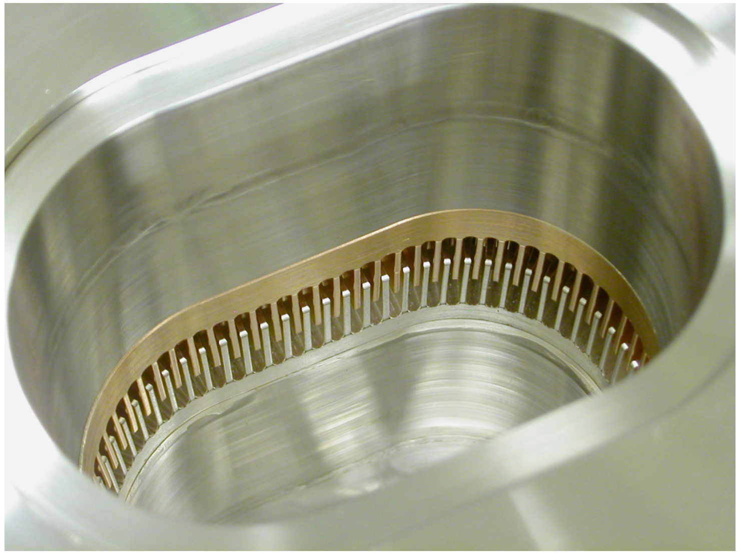
Bellows Chamber _2

- Last summer, four more circular bellows chambers were installed just near movable masks, where a bending (max.~30 mrad) is required. The intense heating was cured.
- A Race-track (48 x 64) bellows chamber was also installed.
  The most severe section in the ring.
- No problem was found so far.

[Near Movable Mask]



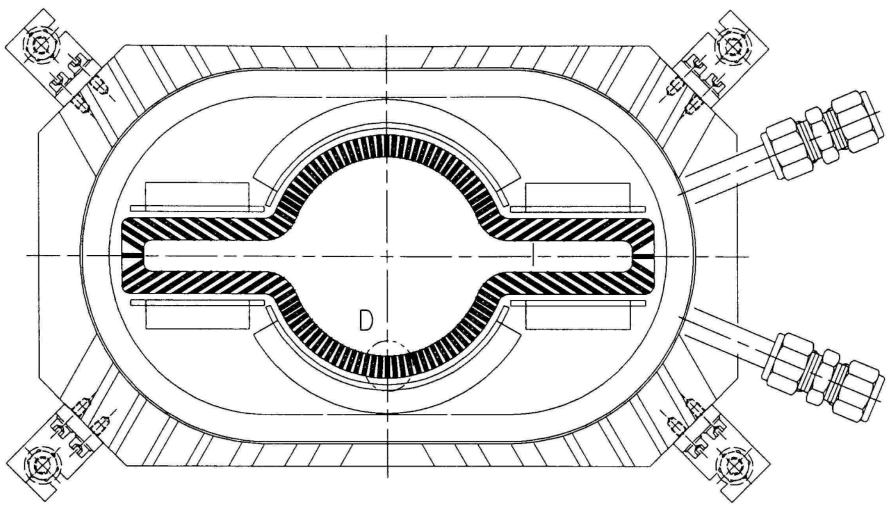
[48x64 Race-track]

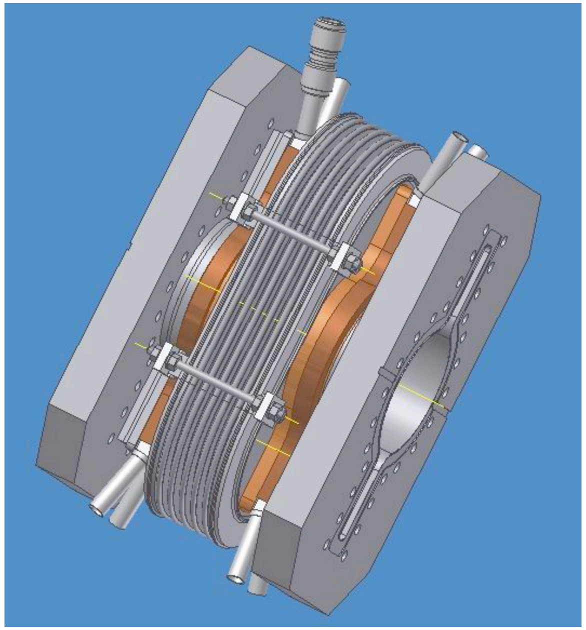


Bellows Chamber _3

- Next Step
  - Beam test of a bellows chamber for wiggler section.
  - Manufacturing is undergoing.
  - Install next summer?

[Conceptual Design]

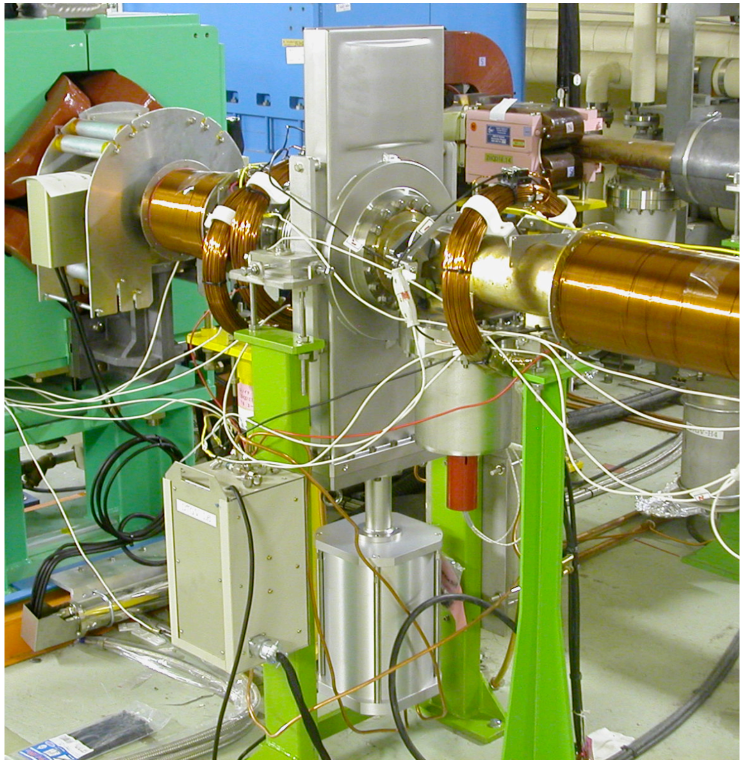


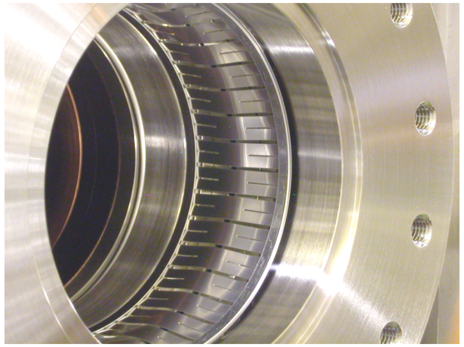


- Option
  - We do not eliminate a possibility to use a finger-type RF shielding with SiC inside the bellows.
  - But, the comb-type RF shielding seems more basic remedy for heating problem, if things go well.

Gate Valve _1

- Gate valve has the same problem to bellows chamber.
- Heating problem has been observed already in KEKB.
- Application of comb-type RF-shield to gate valve is studied.
  - A test model (circular type) is manufactured and installed in LER this winter.





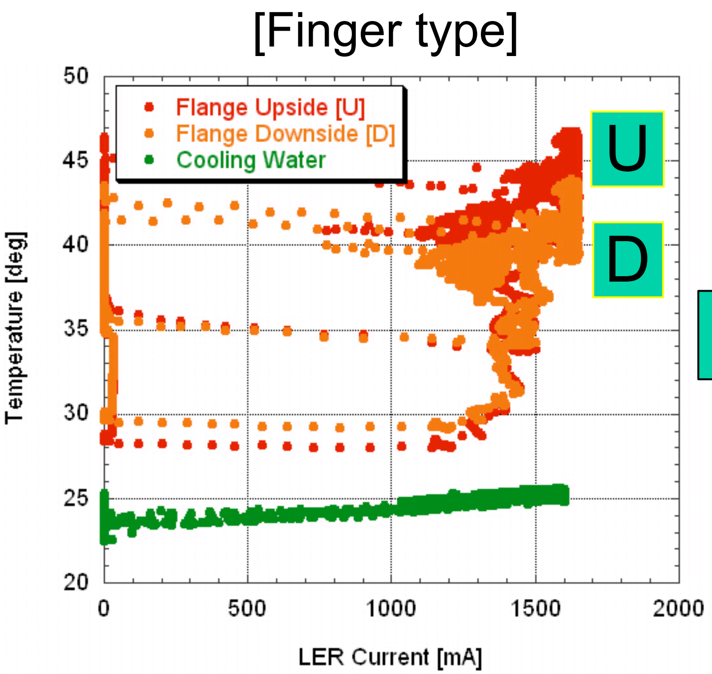
Fingers:
Ag plated SS

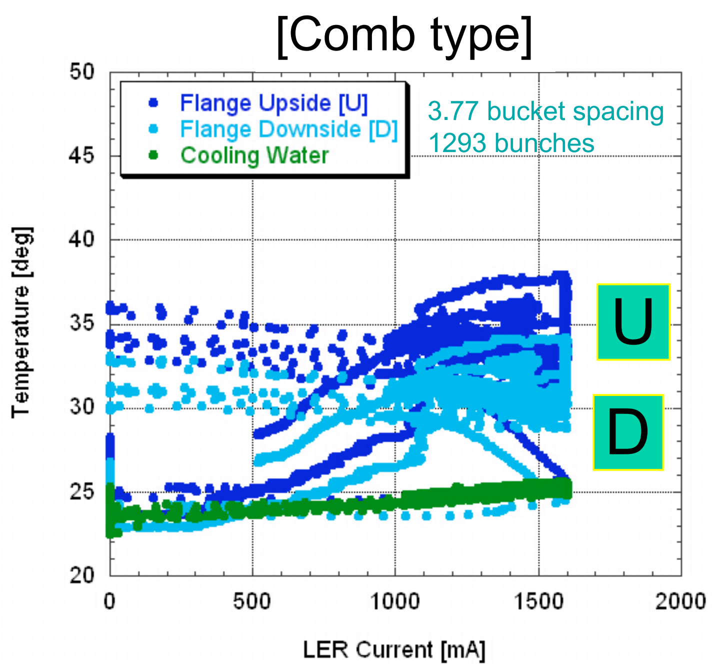
Teeth:
Cu

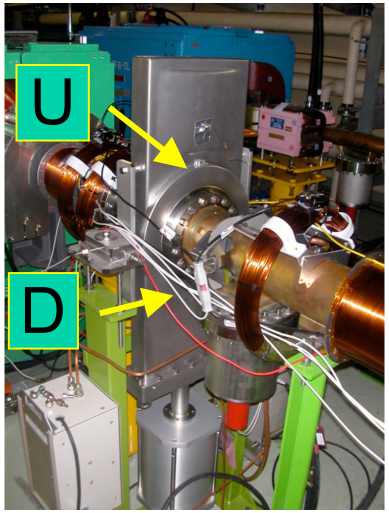
[Collaboration with VAT Co.]

Gate Valve _2

- Temperatures at several points on the body were measured
  - Temperature rise at up and down side of flange decreased to 60% of conventional one.
  - Temperature rise of body was 2~3 °C, decreased to 30 %.
- Comb-type RF shield is also available to gate valve, may be suitable compared to bellows chamber.

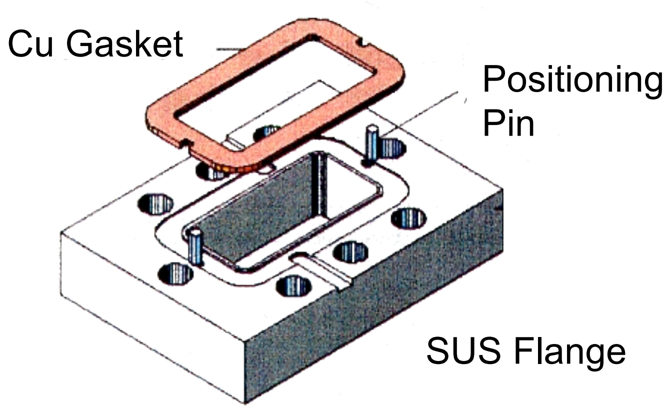


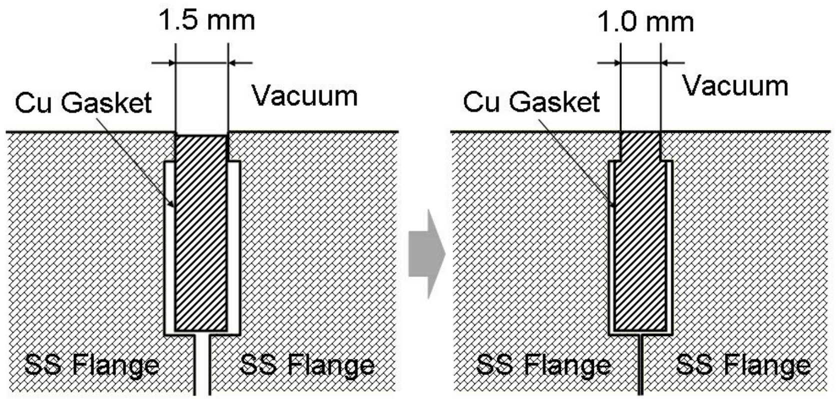




Connection Flange _1

- Gap between connection flanges becomes a big problem for high current and short bunch.
  - Conventional RF-fingers or metal O-rings are insufficient.
  - Heating has been observed in KEKB
- MO-type Flange
  - Developed for C-band wave guide in Japan (circular and rectangular)
  - Features
    - Smooth inner surface (Less than 0.2 mm step)
    - High thermal strength (1.5 mm copper gasket)
    - Reliable electrical contact (Vacuum seal = RF bridge)
    - Simple structure (Uni-sex structure)
- Application to a beam duct with ante-chamber is studied.



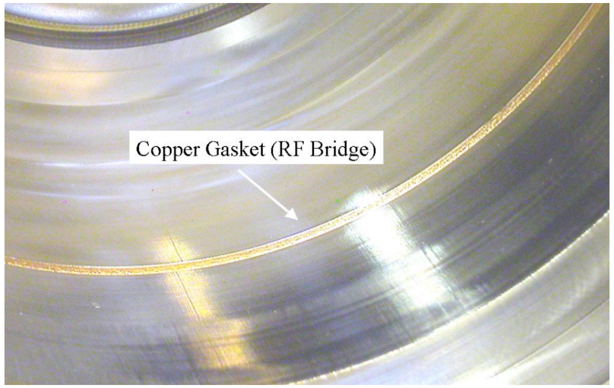


[Concept of MO-type flange]

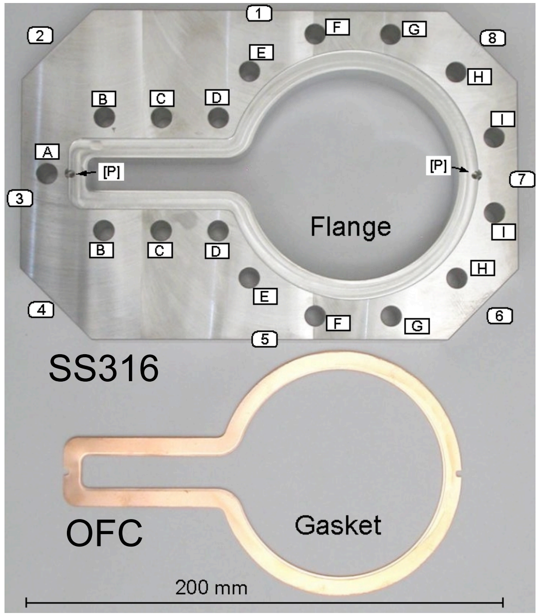
Connection Flange _2

- Experiment using a test flange
  - Only flange (without duct)
- Promising results were obtained.
  - Vacuum sealing was possible with a reasonable fastening force.
  - Baking up to 250°C, twist up to 5 mrad were OK.

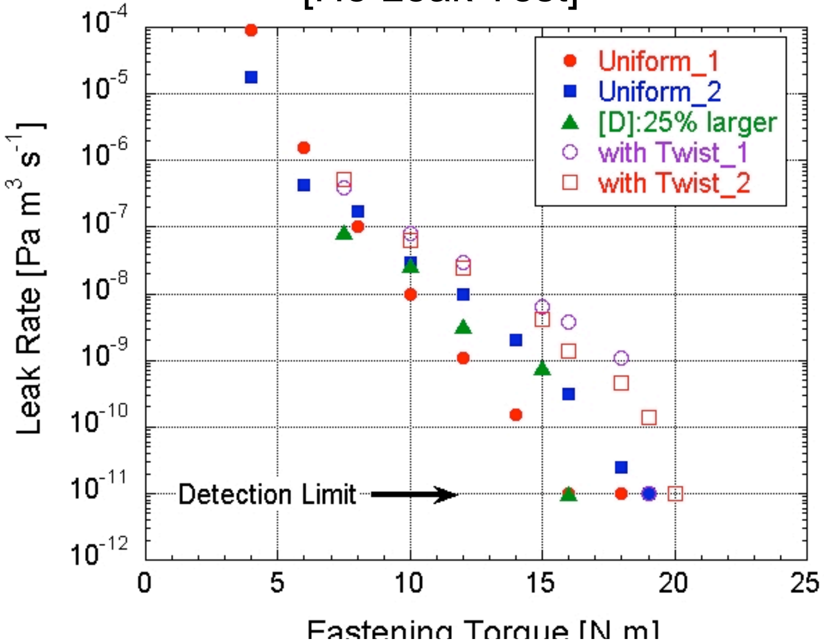
[Inside view of MO-type flange]



[Test Flange]



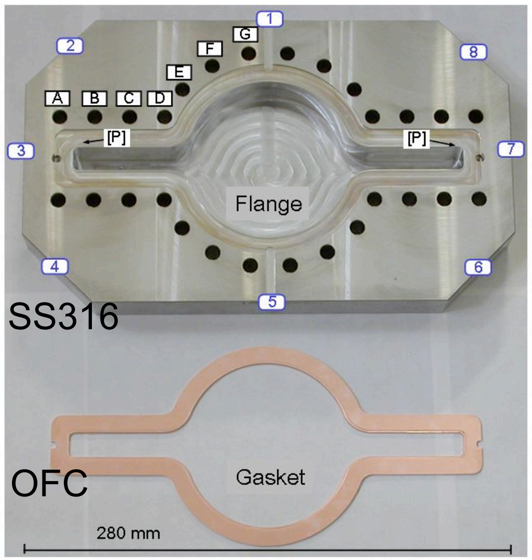
[He Leak Test]



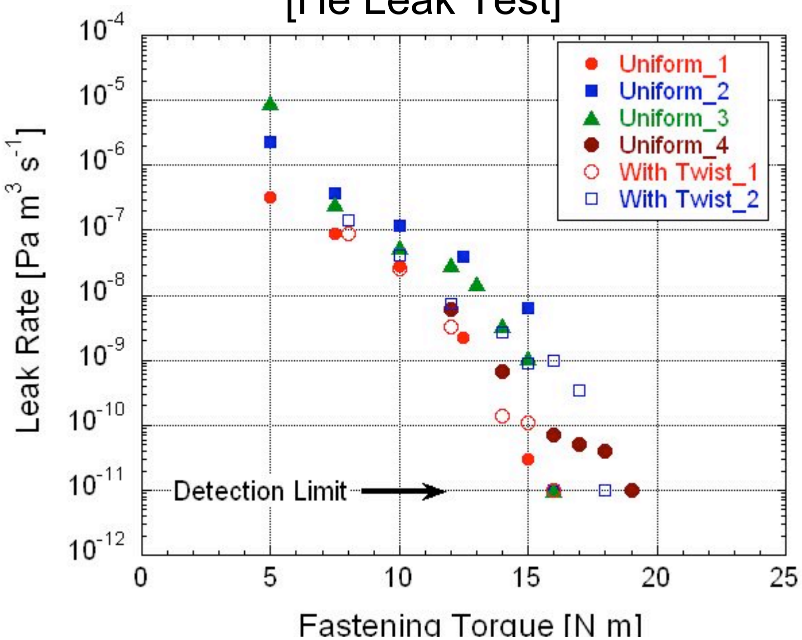
Connection Flange _3

- MO-type flange for a wiggler duct was also tested.
  - Baking at 150°C was OK. Twist (5 mrad) was OK.
  - No problem was found.
- Next steps
  - Application to test chambers and test with beam
    - Test together with beam duct next summer?
  - Copper-alloy flange ➔ Easy to weld (in future)

[MO-type flange for wiggler duct]

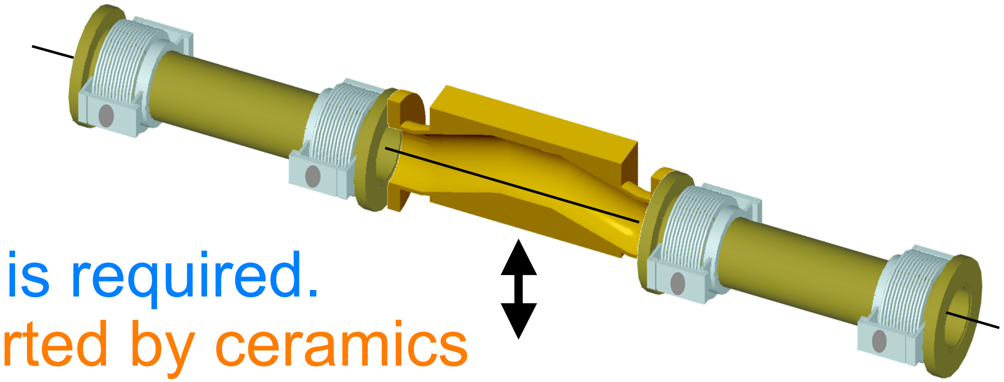


[He Leak Test]

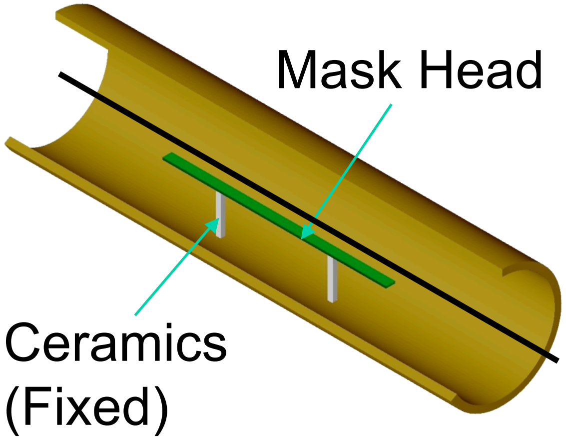


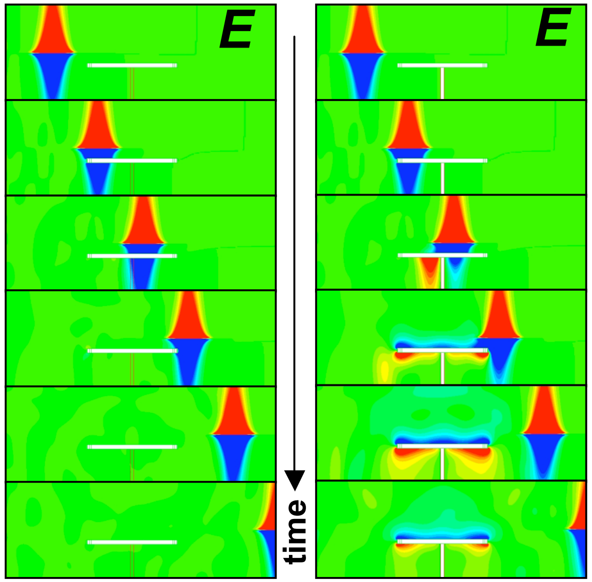
Movable Mask _1

- Design Base: Ver.4 Type in KEKB
- Problem
  - High loss factor
    (~1V/pC ➔ ~200 kW)
  - Damage of head



- Any drastic improvement is required.
- An idea ➔ A head supported by ceramics
  = Reduce interaction of head with beam field





Ceramics (e_r=4) Metal (Cu)

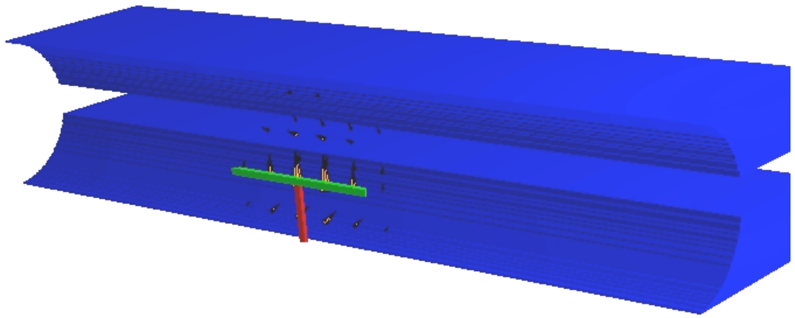
Easily imagined problems:

- Trapped mode
- Heating
- Charge up

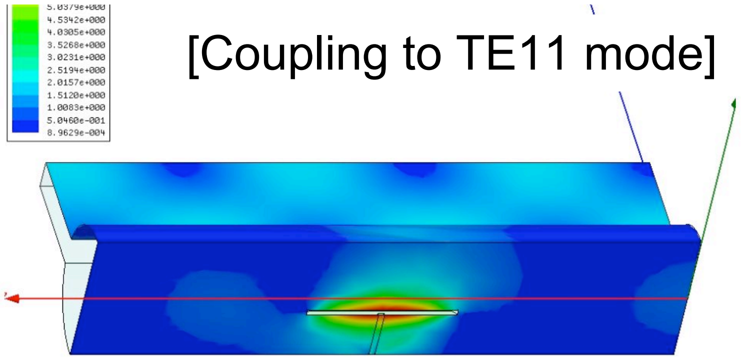
Movable Mask _2

- Trapped Mode
  - Grooved duct to couple with TE11 mode (head is off center)
  - Use HOM damper, but still Q~2000
- Heating
  - Heat conduction is mainly by radiation
  - Estimated input :200W ➔1000 °C (emissivity = 0.5)
  - Apply blackened surface (ex. CuO, as in the case of PEPII)
- Charge up
  - Thin coating of low conductivity material on ceramics support, such as TiN

[Trapped mode]

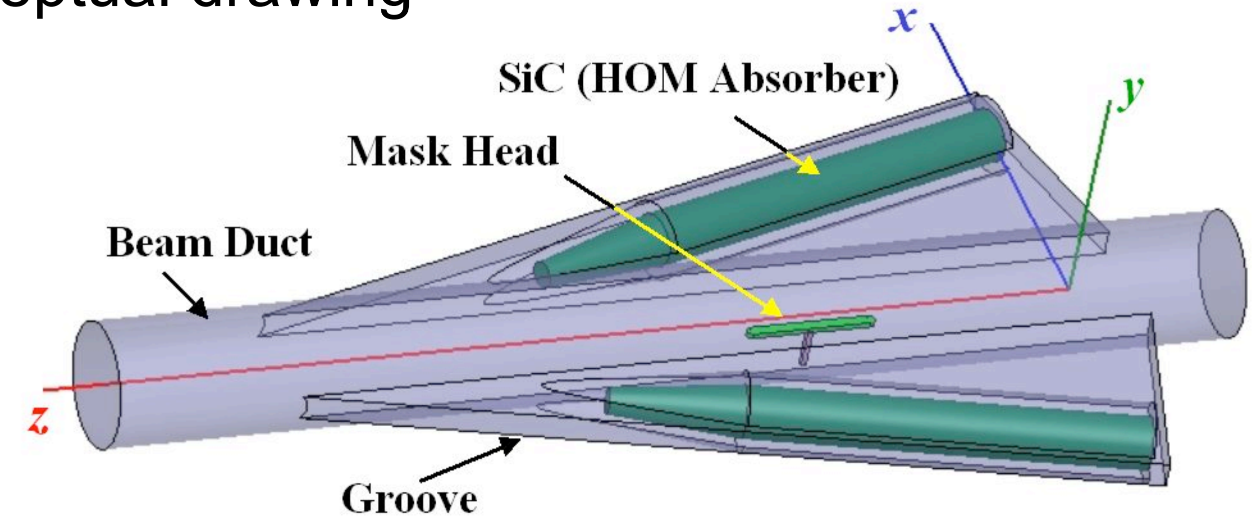


[Coupling to TE11 mode]



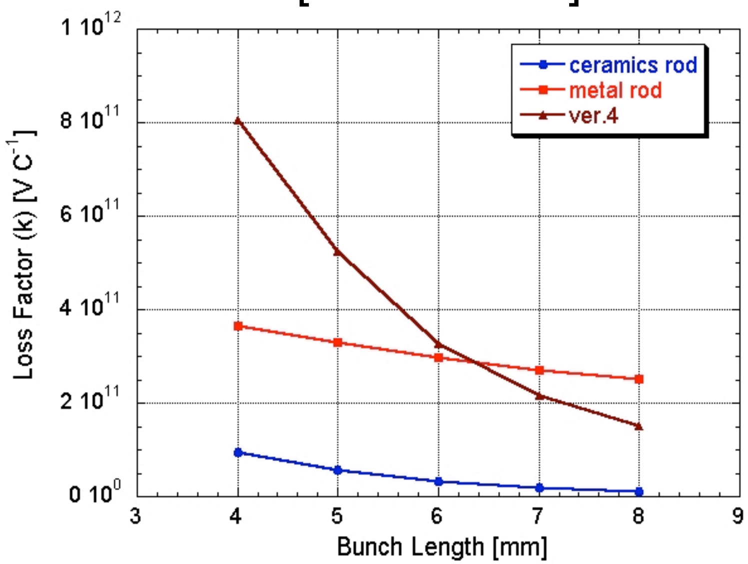
Movable Mask _3

- Conceptual drawing



  - Mask head = Carbon (graphite)
    - Coated by copper?
    - L=80 mm (~0.4 R.L.)
  - Support ceramics = BN (low e_r)
  - Loss factor ~0.1 V/pC (1/10, but still high)

[Loss factors]



- Need further consideration and test.
- Any ideas are welcome!

Summary

- R&Ds for the vacuum system are proceeding steadily.
- Copper Beam Duct with ante-chamber:
  - Both pressing and drawing were well available for manufacturing.
  - Reduction of photoelectrons were confirmed, but other method to suppress the multiplication of secondary electrons are necessary for high currents.
  - Improvement of structure is considered.
- Surface with low SEY
  - NEG coating and TiN coating were studied in the positron ring.
  - Photoelectrons weaken the effect of low SEY.
  - TiN seems better but further investigations are required.
- Connection flange
  - Application of MO-type flange is studied.
  - Bench test showed good results and the beam test is planned.
- Bellows chamber
  - Comb-type RF-shield has been studied and no essential problem was found so far.
- Movable masks
  - Conceptual study has just begun.