Vacuum System for KEKB Upgrade
- mainly for arc section -

Y. Suetsugu
on behalf of KEKB Vacuum Group

- Design strategy
  - Change to the nano-beam scheme
  - Design of main components
- Electron cloud issues in the positron ring
  - R&D of countermeasures
  - Mitigation strategy
- Summary and Remained issues

Design strategy_1

- **Change to the nano-beam scheme from the high-current scheme;**
  - Energy (LER: 3.5 → **4 GeV**, HER: 8 → **7 GeV**)
  - Emittance (ε_x 24 → **3.3 nm** [LER])
  - Beam current (LER: 9.4 → **3.6 A**, HER :4.1 → **2.6 A**)
  - Bending radius (LER 15.3 → **71 m**)
  - Bunch length (3 → LER: **6 mm**, HER: **5 mm**)
- **Impact on the vacuum system_1**
  - SR power for LER is reduced compared to the case in the previous high-current scheme.
    - Lower current, longer bending radius

  →Aluminum beam pipe is now available for LER.
    - ~3 W/mm^2 (ref: HER ~15 W/mm^2, if ha = 90 mm)
    - Cost reduction (?)
    - Gives more choices for the fabrication methods, and for the countermeasures against electron cloud issues.

Design strategy_2

- **Impact on the vacuum system_2:**
  - Photon density is reduced to one-half.
    - Lower beam current
  - HOM power is also reduced.
    - Longer bunch length, Lower beam current
  - Requirement to avoid beam instabilities is similar.
    - Fast Ion and Electron Cloud are still key issues.
  - Beam current may be increased in the future.
    - Leave room for higher beam currents

- The requirements to the vacuum system was actually relaxed, but still severer than that of KEKB.
- The design strategy fundamentally follows that considered so far for high-current scheme.
- Aluminum-alloy beam duct gives more choices in the design.

Design strategy_3

- **Beam ducts** are newly manufactured.
  - Magnets are re-aligned.
  - Beam impedances should be decreased further（pump ports, bellows, photon masks, etc.）.
  - **LER:** More powerful countermeasures against the electron cloud are required.

- **Main vacuum components** are also newly designed.
  - Bellows chambers, gate valves, movable mask (collimators), stoppers, etc. are designed to fit the beam ducts.
  - Higher strength against higher beam currents are required.

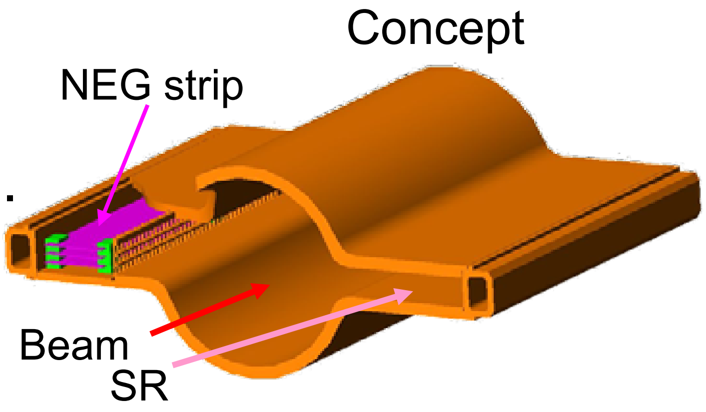
Design strategy_4

- **Main pumps (NEG)** are replaced with new ones.
  - Reset lifetime
- **Auxiliary pumps (ion pumps), rough pumping system, vacuum gauges (CCG), L-angle valves, thermo sensors, etc.** are reused, with some new backups.
  - Ion pumps were found to be fine after 10 years operation.
- **Electric lines, cooling water pipes, control systems** are basically reused as it is, after maintenance.
  - Cooling water pipes should be rearranged.
- **Capacity of water cooling system** should be enhanced.

Design of main components_1

- **Beam ducts** with ante-chambers
  - A countermeasure against the electron cloud.
  - Low beam impedance
    - Pump ports and SR masks locate in an antechamber.
  - Reduction of SR power is not a main purpose now.
  - Fit to the existing (reused) magnets.
  - **LER:** Aluminum alloy is now available. Copper is required for wiggler sections.
  - **HER:** Copper is required.

- **Pump (NEG) is installed into one of the ante-chamber** (inside of the ring)
  - Distributed pump system for effective pumping. *S* ~ 80 l/s/m.
  - Inserted from end flanges.

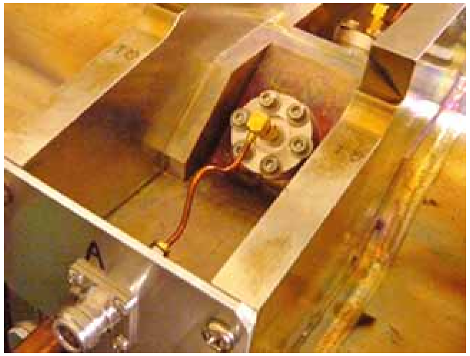


Design of main components_2

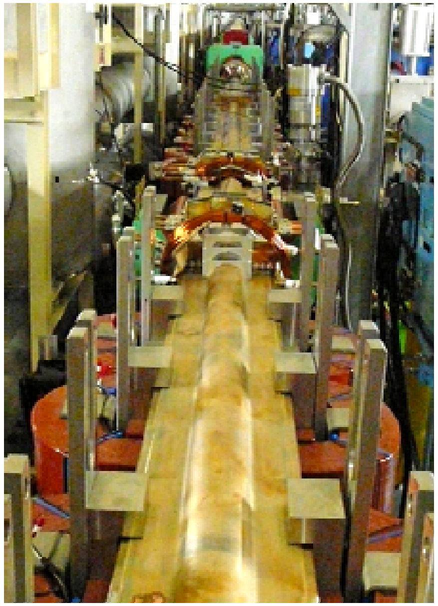
- **R&Ds of beam ducts_1**
  - Copper beam ducts with antechambers have been installed into the LER, and tested with beams.
  - Cold drawing method for copper pipe was established.

Straight duct

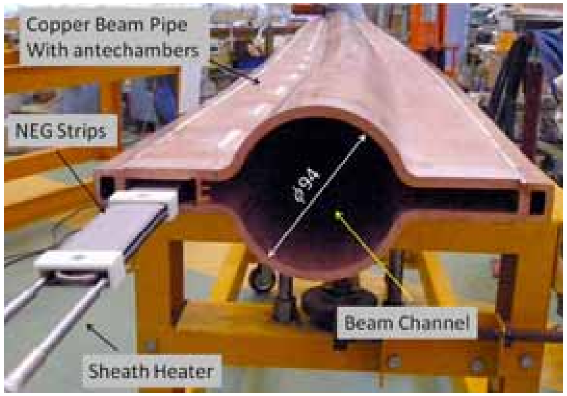
BPM



Wiggler section



Bent duct

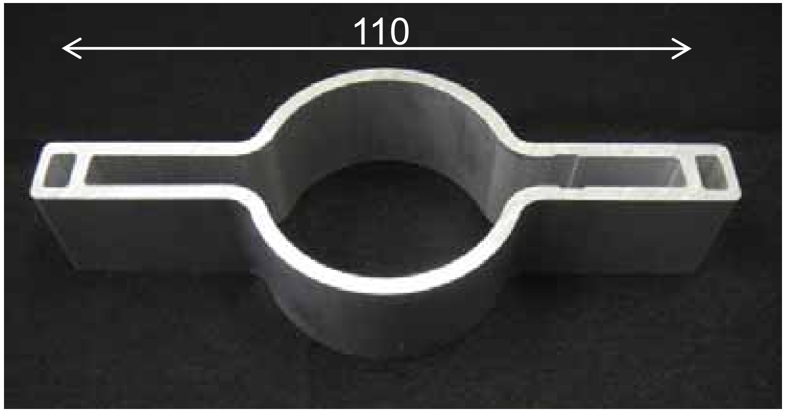


Arc section

Design of main components_3

- **R&Ds of beam ducts_2**
  - Extrusion of aluminum-alloy beam duct is under going for LER.

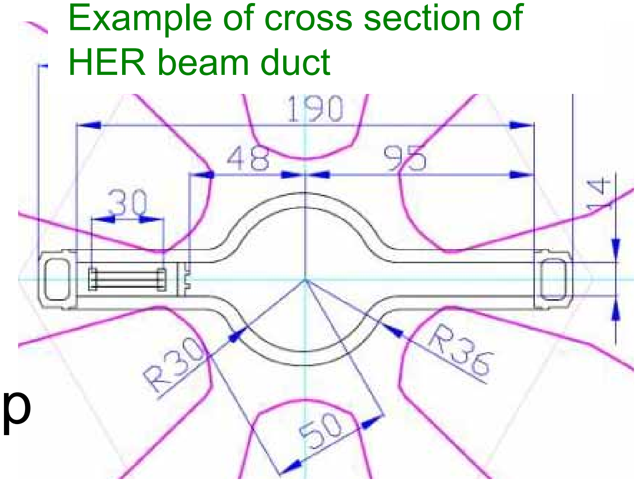
Aluminum-alloy duct



Aluminum-alloy duct

- The design of **HER beam duct** has not yet fixed.
  - Fit to existing magnets.
  - If the half-aperture is ~90 mm the SR power is the same level as the present HER.
    →Negotiation with Mag. group

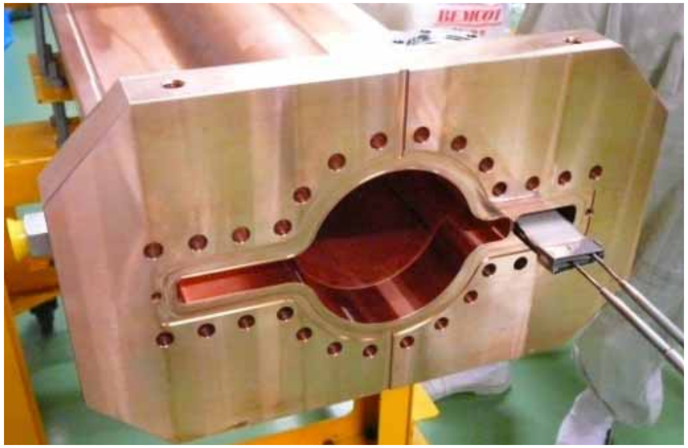
Example of cross section of HER beam duct



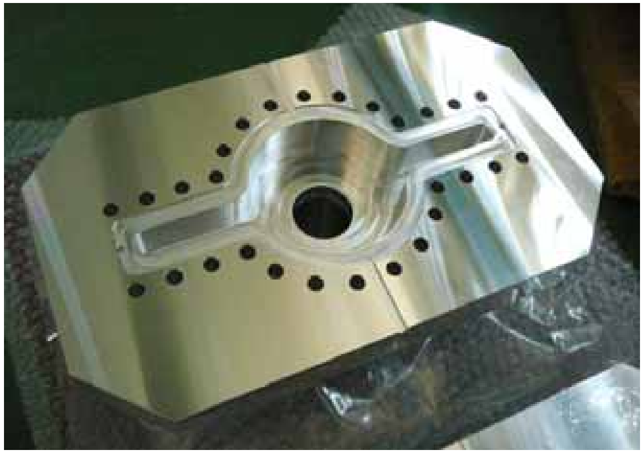
Design of main components_4

- MO-type **Flanges**
  - Thermally strong, sure RF bridge, applicable to ante-chamber scheme, low beam impedance
  - In addition to SS flanges, **copper alloy** and **aluminum-alloy** flanges has been developed.
    - Easy welding to pipes, reduction in heating by joule loss
  - Several flanges have been installed into the ring and tested.

Cu-alloy flange (CrZrCu)



Al-alloy flange (A2219, A2024)

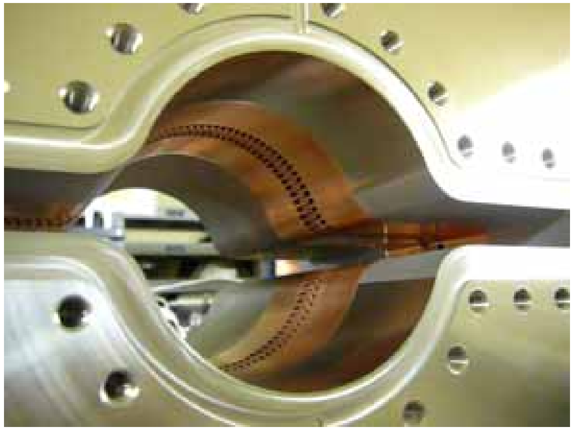


Design of main components_5

- **Bellows and gate valves** with comb-type RF-shield
  - Sure RF shielding, thermally strong
  - applicable to ante-chamber scheme
  - Finger-type for some cases, if flexibility is required.
- Trial models have been installed into the ring and tested.
  - Reduction in the temperature of bellows has been demonstrated.
- Copper RF shield will be used even for aluminum-alloy beam ducts.

Bellows chamber

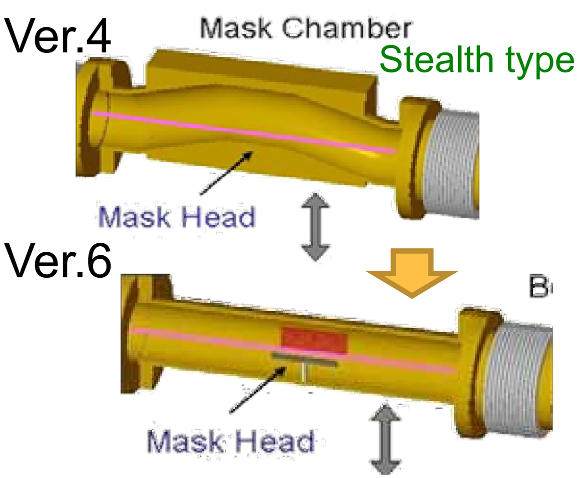
RF-shield (gate valve)



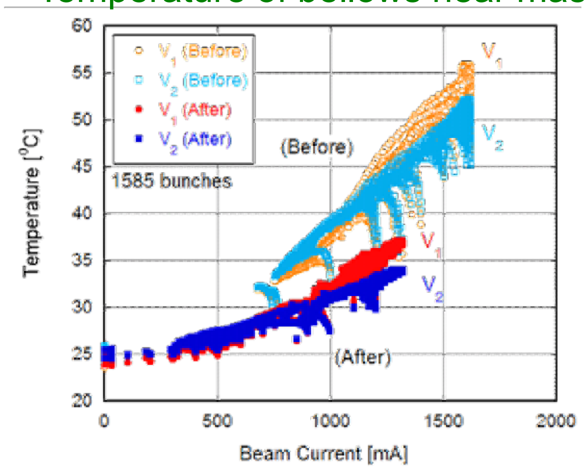
Gate valve

Design of main components_6

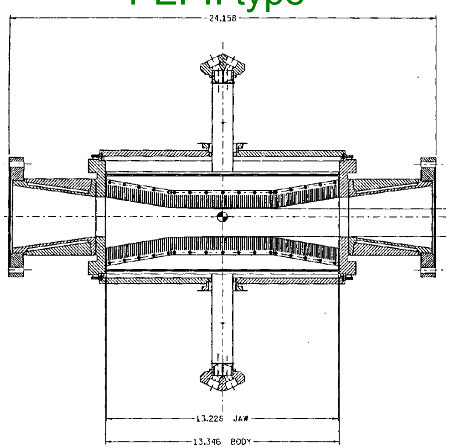
- **Movable mask:** Stealth type has been tested.
- Very sorry to say, but it met an severe obstacle.
  - Even a diamond support could not withstand the intense beam power, although the principle was demonstrated at low beam currents --- suspend the R&D.
- Modified present type (Ver.4) will be used in the commissioning stage at least.
  - Or advanced type of that used in the PEP-II ? (fit to the antechamber scheme?)
  - HOM absorbers will be reinforced.



Temperature of bellows near mask



PEPII type



Electron cloud issues_1

- **Electron cloud instability** can be a serious problem for LER (positron ring).
- The threshold of electron density to excite the single-bunch instability:

K. Ohmi , KEK Preprint 2005-100 (2006)

$$\rho_{e,th} = \frac{2\gamma \nu_s \omega_{e,y} \sigma_z / c}{\sqrt{3} K Q r_e \beta L}.$$

Here,

$$\omega_{e,y} = \sqrt{\frac{\lambda_+ r_e c^2}{\sigma_y(\sigma_x + \sigma_y)}}$$

E [GeV] = 4.0				
γ = 7828	N_b	= 6.25E+10		
ν_s = 0.0185	Q_b[C]	= 1.4E-08	(1.4 mA/bunch)	
	S_b [m]	= 1.2	(4ns)	
σ_z [m] = 6.E-03	λ [C/m]	= 5.2E+12	($Q_b/2/\sigma_z$)	
c [m/s] = 3.E+08	σ_y [m]	= 2.E-05		
K = 11	σ_x [m]	= 2.E-04		
Q = 7				
r_e [m] = 2.80E-15	ω_e	= 5.46E+11	$K = \omega_e \sigma_z / c$	
β_y [m] = 25	$\omega_e \sigma_z / c$	= 10.9	$Q = \mathrm{Min}(Q_{nl}, \omega_e \sigma_z / c)$	
L [m] = 3016			Q_{nl} ~7	

ρ_{th} [e^-/m^3] =1.13E11 → Target: 1E11

Electron cloud issues_2

- **Expected electron density without any cures**
  - Estimated from experiments so far at KEKB.
  - For a circular Cu pipe (ϕ 94mm), 4 ns spacing, 1 mA/bunch, No solenoid.

Sections	**L [m]**	**L [%]**	**n_e [e^-/m^3]**	**n_ex L [%]**
Total	3016	100	Ave.5E12	100
Drift space (arc)	1629 m	54	8E12	78
Steering mag.	316 m	10	8E12	15
Bending mag.	519 m	17	1E12	3.1
Wiggler mag.	154 m	5	4E12	3.6
Q & SX mag.	254 m	9	4E10	0.063
RF section	124 m	4	1E11	0.072
IR section	20 m	0.7	5E11	0.063

Main part (Drift space (arc), Steering mag.)

Any countermeasures are required to reduce n_e down to 2%!

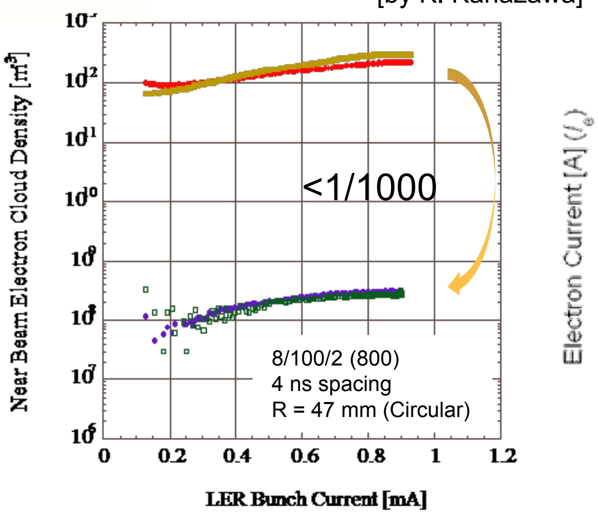
(5E12 → 1E11 [e^-/m^3])

Electron cloud issues_3

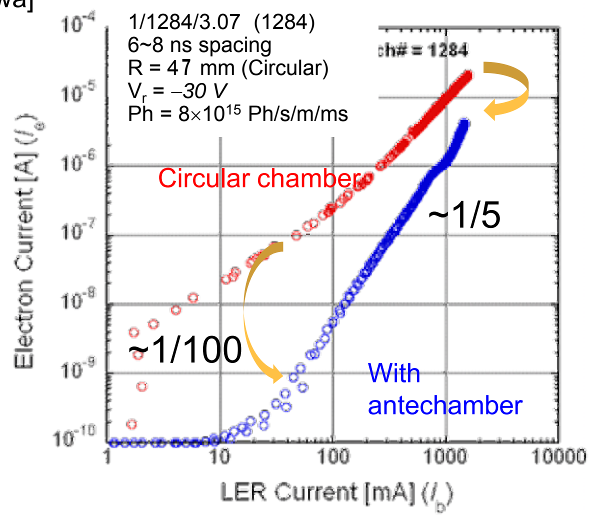
- **Established counter measures**
  - **Solenoid filed** at drift section (~50 G): Effective to both photoelectrons and secondary electrons.
  - **Ante-chamber scheme**：Effective to photoelectrons. Adopted at PEPII LER
  - **TiN coating** (Reduction in SEY)：Effective to secondary electrons. Adopted at PEPII LER

Effect of solenoid

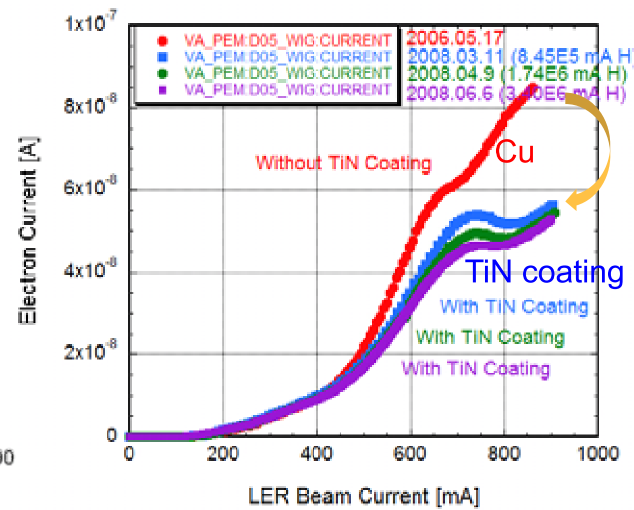
[by K. Kanazawa]



Effect of antechamber



Effect of TiN coating



Electron cloud issues_4

- **Comparison among these countermeasures**
  - Standard = bare copper ducts (circular)

Materials, methods	Relative EC density	Notes
Al	~20	Coatings are indispensable.
Cu (Circular pipe)	1	
Solenoid [Drift space]	~1/50	~50 G, considering gaps (<1/1000 if uniform)
Ante-chamber scheme	~1/5	<1/100 for photoelectrons
Cu (Al)+TiN coating	~3/5	Relatively high gas desorption

- Any coatings (TiN, NEG, DLC, etc.) is effective independent of the underlying materials (Cu or Al). But the effect seems small for its work (time and labor).
- Note that aluminum beam duct requires any coatings to reduce SEY.

Electron cloud issues_5

- **Application of these countermeasures**

Sections	n_e [e^-/m^3]	n_exL [%]
Total (3016 m)	5E12	100
Drift space (1629)	8E12	78
Steering mag. (316)	8E12	15
Bending mag. (519)	1E12	3.1
Wiggler mag. (154)	4E12	3.6
Q & SX mag. (254)	4E10	0.06

Drift space and steering mag. ⇒ Ante-chamber (Cu or Al+coating) ×1/5 + Solenoid ×1/50

Bending, wiggler, Q & SX mag. ⇒ Ante-chamber (Cu or Al+coating) ×1/5

⇓

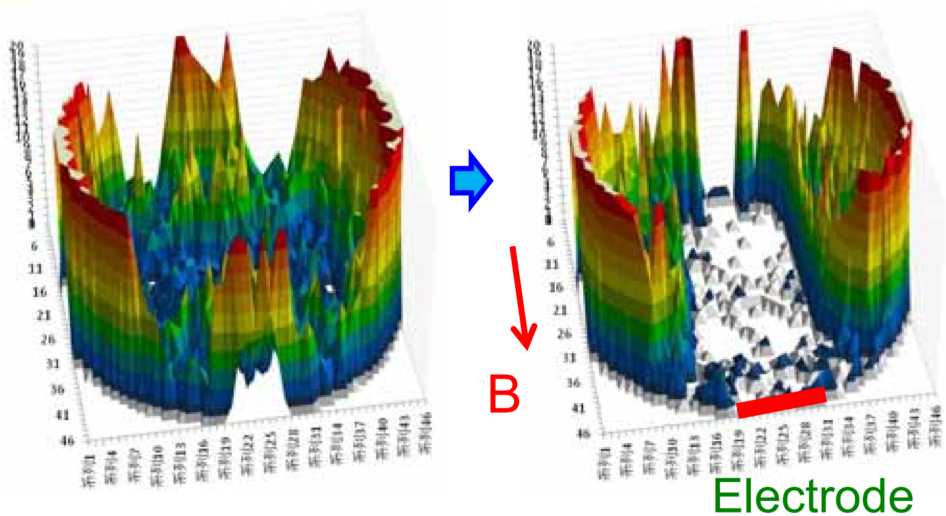
Sections	n_e [e^-/m^3]	n_exL [%]
Total (3016 m)	9E10	100
Drift space (1629)	3E10	18
Steering mag. (316)	3E10	3.4
Bending mag. (519)	2E11	38
Wiggler mag. (154)	7E11	39
Q & SX mag. (254)	8E9	0.81

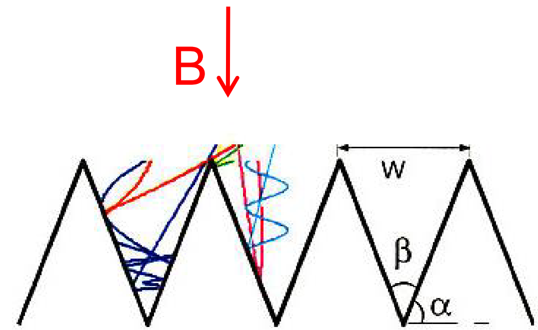
Bending and wiggler mag.: Main

- Average n_e is still borderline region
- If with TiN-coating, n_e ~ 6E10 e^-/m^3
- Further countermeasures in bending and wiggler magnets are desirable.

Electron cloud issues_6

- **Countermeasures in bending and wiggler magnets**
- Candidates:
  - **Clearing electrode**
    - Attract electrons by electro-static field
  - **Grooved surface**
    - Lower effective SEY geometrically
- Experimental R&Ds have been performed using KEKB LER
  - Also as a part of US-Japan collaboration for ILC DR





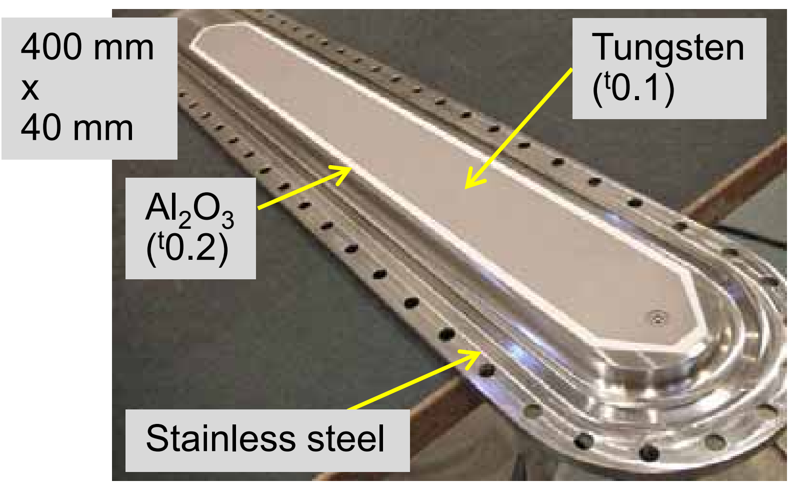
by L. Wang et al.

Grooved surface

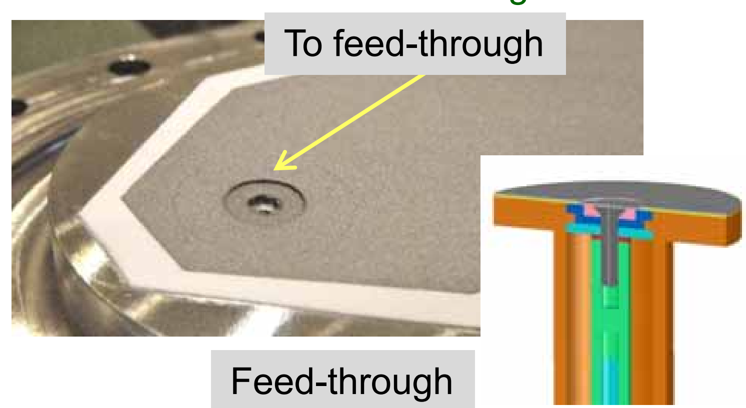
Electron cloud issues_7

- **Clearing electrode** has been said to be very effective to reduce EC in magnetic field.
  - Impedance and heating of electrode have been serious problems for intense e^+ beam.
- Very thin electrode structure was developed.
  - 0.2 mm Al_2O_3 and 0.1 mm tungsten (W) electrode formed by a thermal spray method. ± 1 kV is OK.
  - Good heat transfer and low beam impedance
  - Flat connection between feed-through and electrode

An insertion for test with a thin electrode



Connection to feed through

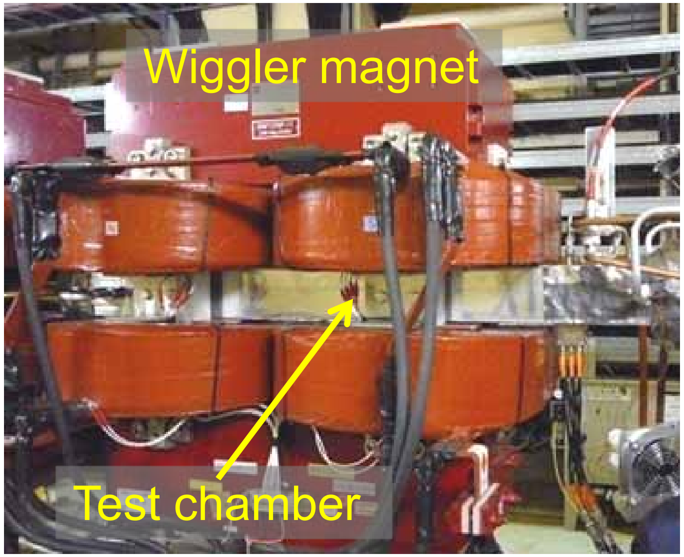


Y. Suetsugu, H. Fukuma, M. Pivi and L. Wang, NIM-PR-A, 598 (2008) 372

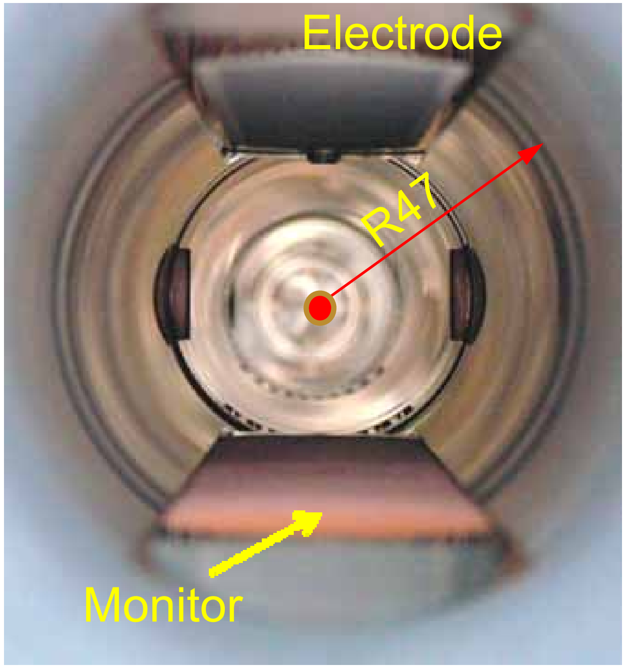
Electron cloud issues_8

- A **test chamber** was installed in a wiggler magnet.
  - Magnetic field: 0.78 T
  - Effective length: 346 mm
  - Aperture (height): 110 mm
  - Photons: 1x10^{14} photons/s/m/mA

Test chamber in a wiggler magnet



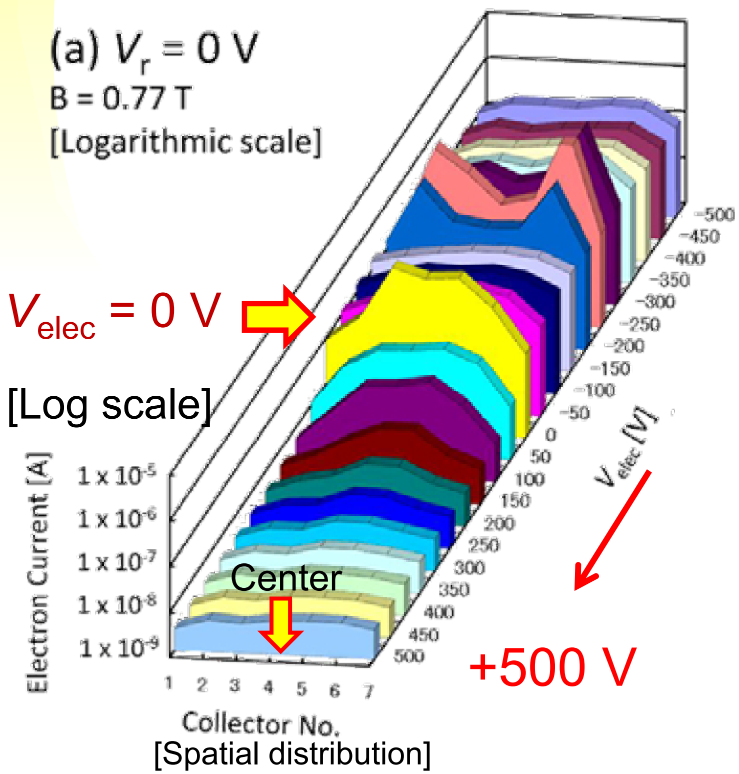
Inside view



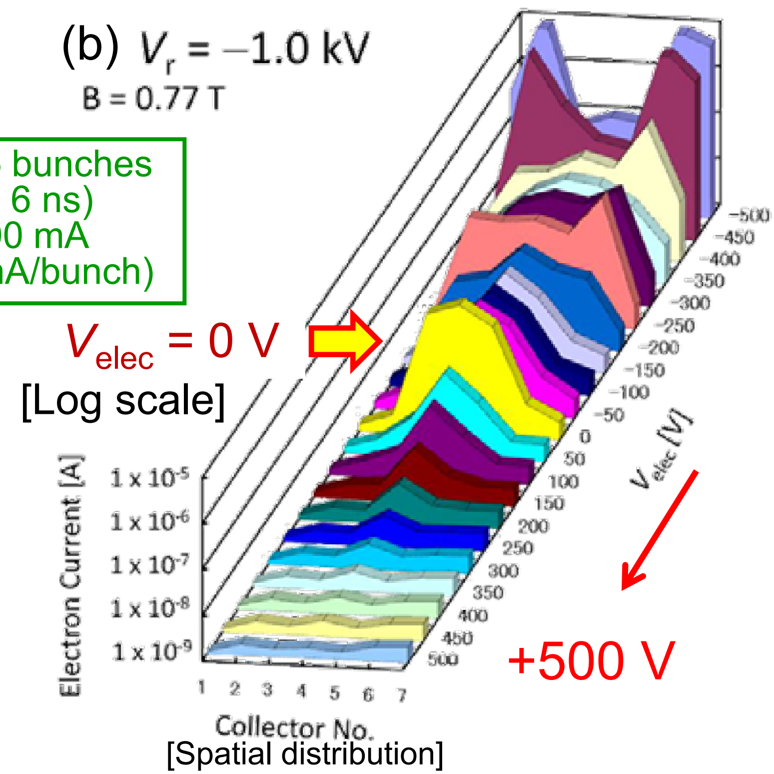
- An electron monitor and an insertion with an electrode are placed at the center of a pole, face to face.
- Electron monitor has an RFA and 7 strips to measure spatial electron distribution (~40 mm width in total).

Electron cloud issues_9

- **Results:** Effect of electrode potential (V_{elec})
  - Drastic decrease in the electron density by applying V_{elec} was observed. (For negative large V_{elec}, electrons flows into the monitor)
  - Similar effect was observed for 2 ~ 16 ns spacings.

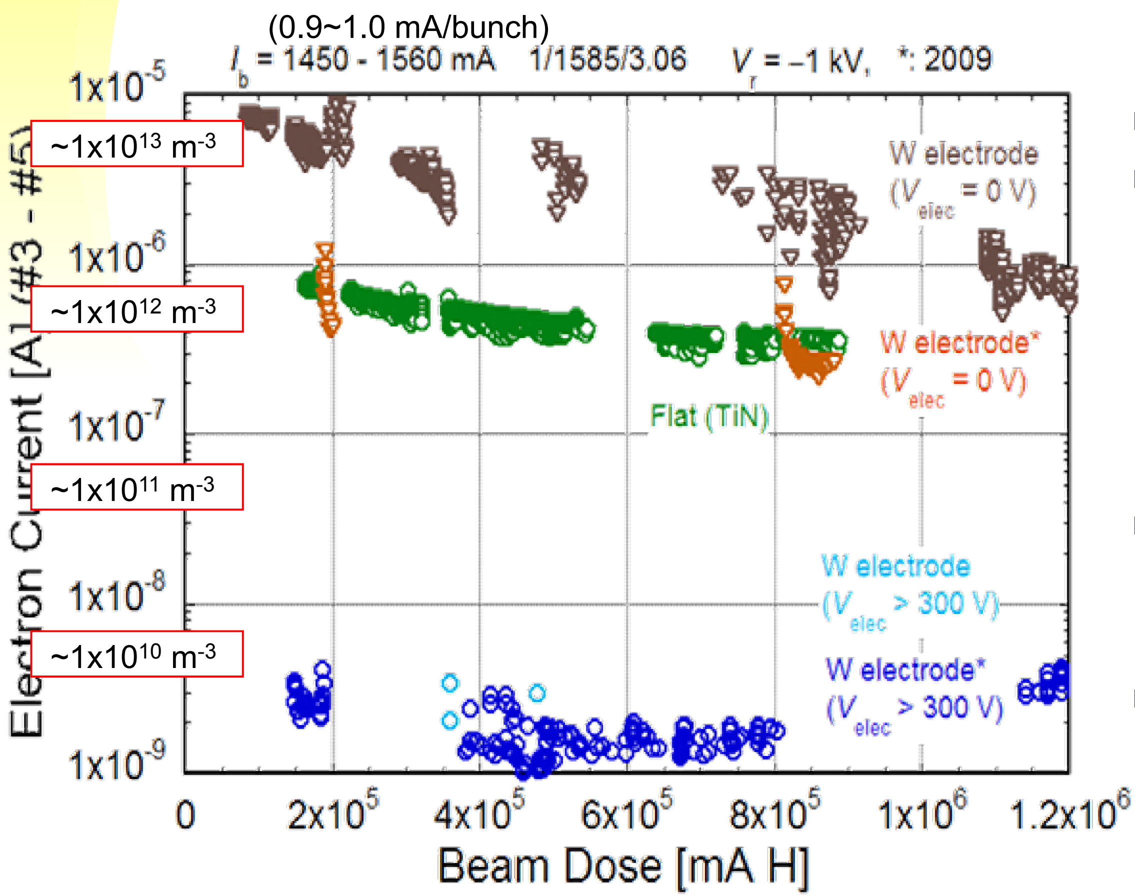


1585 bunches
(B_s ~ 6 ns)
~1600 mA
(~1mA/bunch)



Electron cloud issues_10

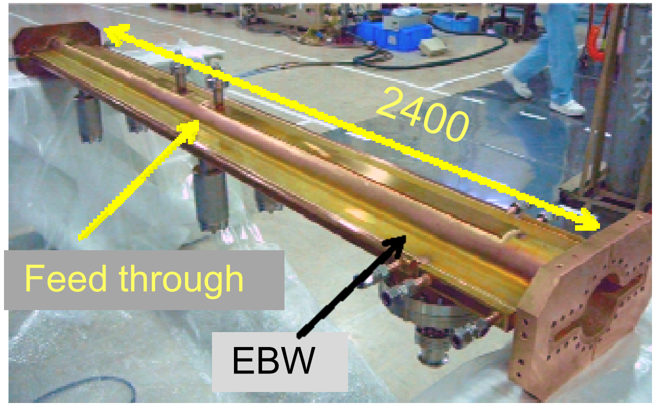
- **Results:** Change with beam dose
  - The electron density decreased to less than ~1/100 at V_{elec} > ~+300 V compared to the values at V_{elec} = 0 V (W) and a TiN-coated flat surface.

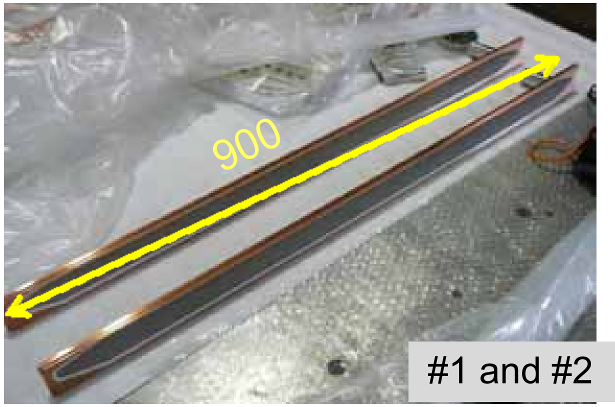


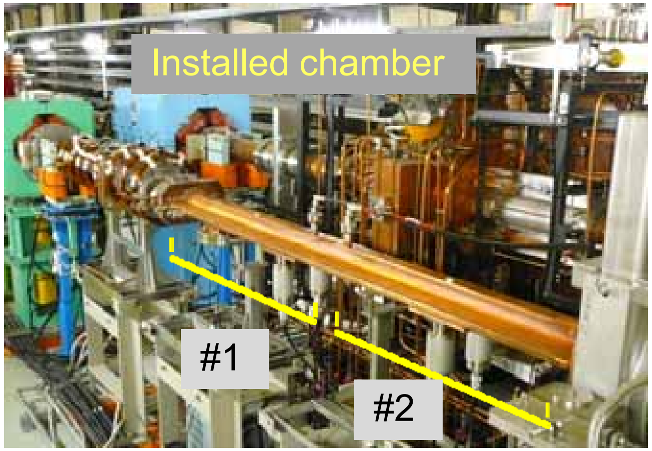
- Two-time experiments.
- Electron currents for the thermal-sprayed tungsten (V_{elec} = 0V) is similar to the case of flat TiN-coated surface. ←Rough surface?
- The second result was lower than the first one. ← Aging of surface?
- No extra heating of electrode and feed-through was observed.

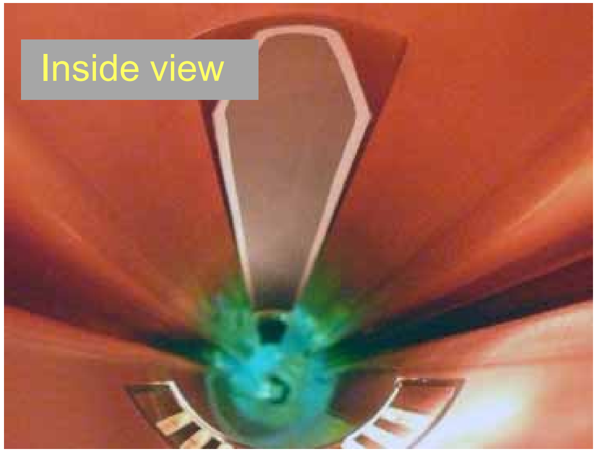
Electron cloud issues_11

- **Application to a real beam pipe** with antechambers.
  - Final check of feed through and heating of electrode.





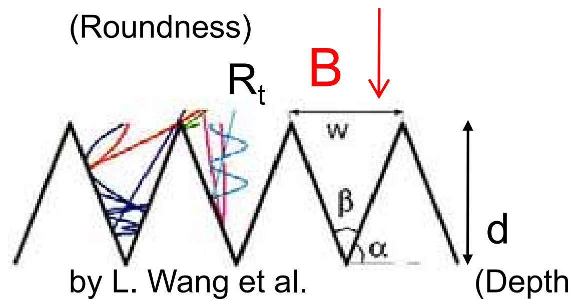


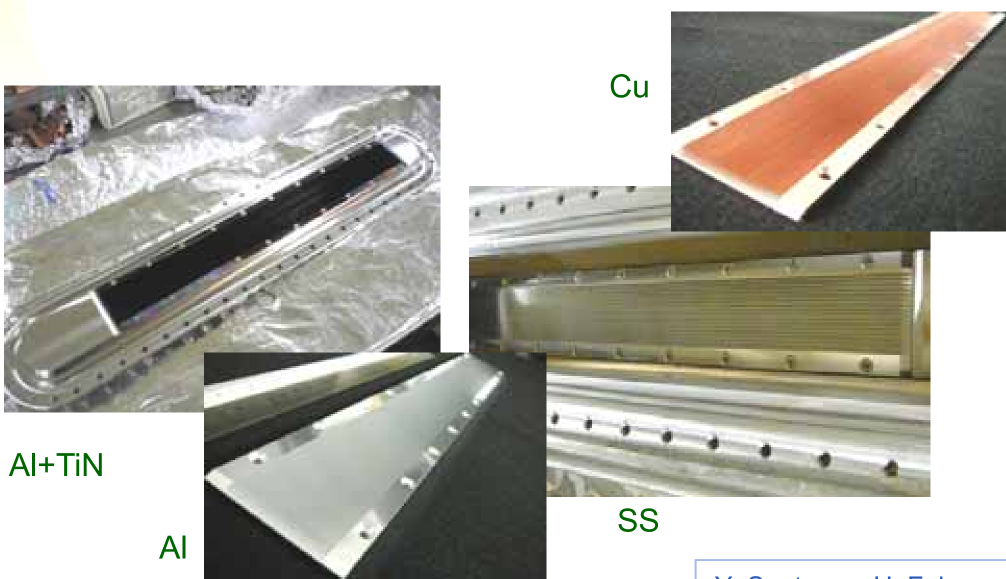


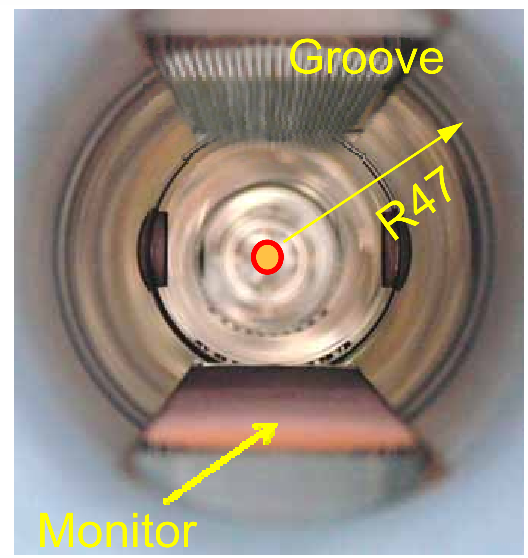
  - No extra-heating, degradation of insulation are found after one-month operation. (the experiment will be continued)

Electron cloud issues_12

- **Grooved surfaces:** geometrically reduce SEY.
  - The properties were studied in a wiggler magnet using the same experimental setup to that of the clearing electrode.
  - B = 0.78 T
- Parameters of grooves
  - Material: Cu, Al-alloy, SS
  - β : 20~30°, R_t:0.1~0.2 mm
  - d: 2.5~5 mm



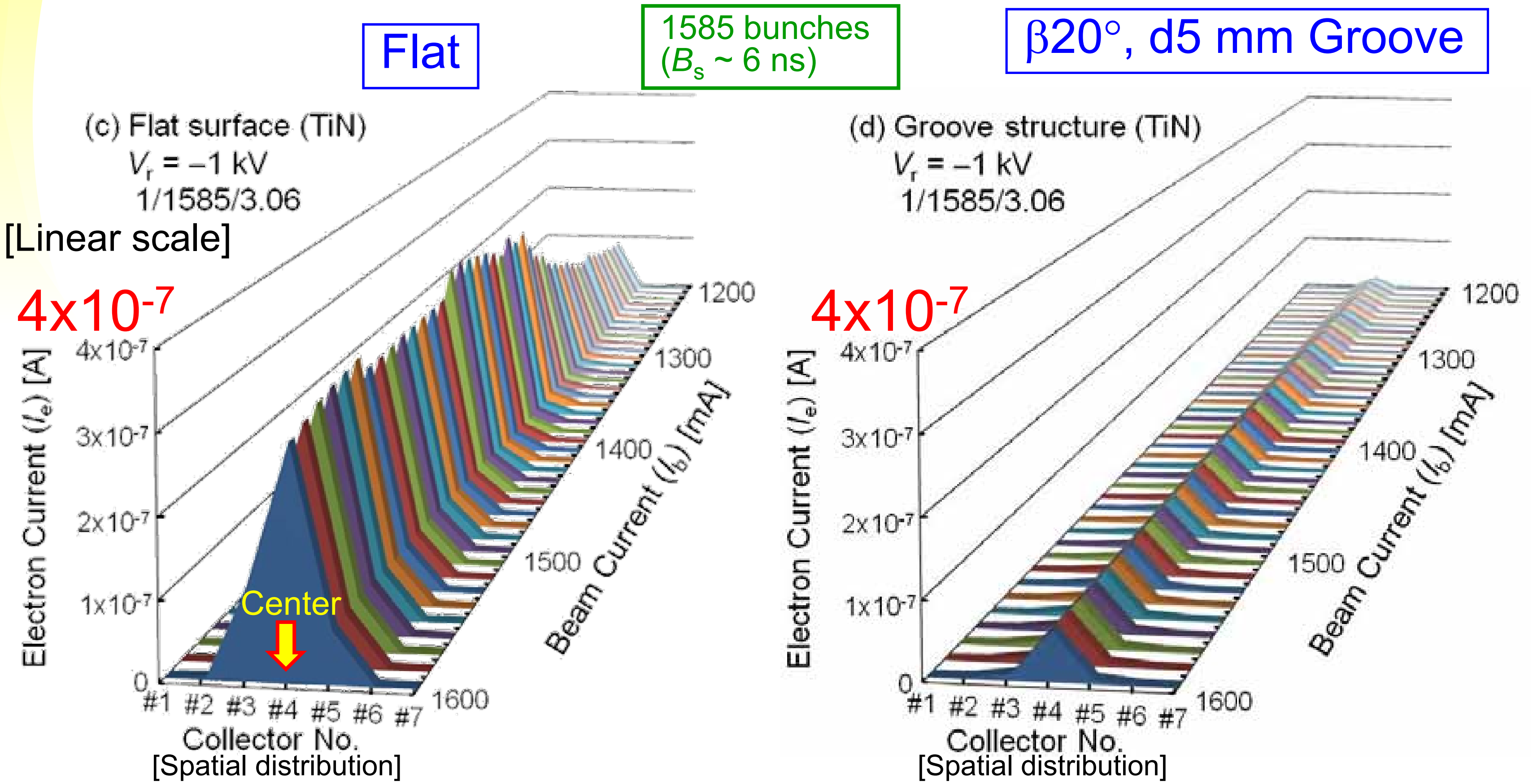




Y. Suetsugu, H. Fukuma, M. Pivi and L. Wang, NIM-PR-A, 604 (2009) 449

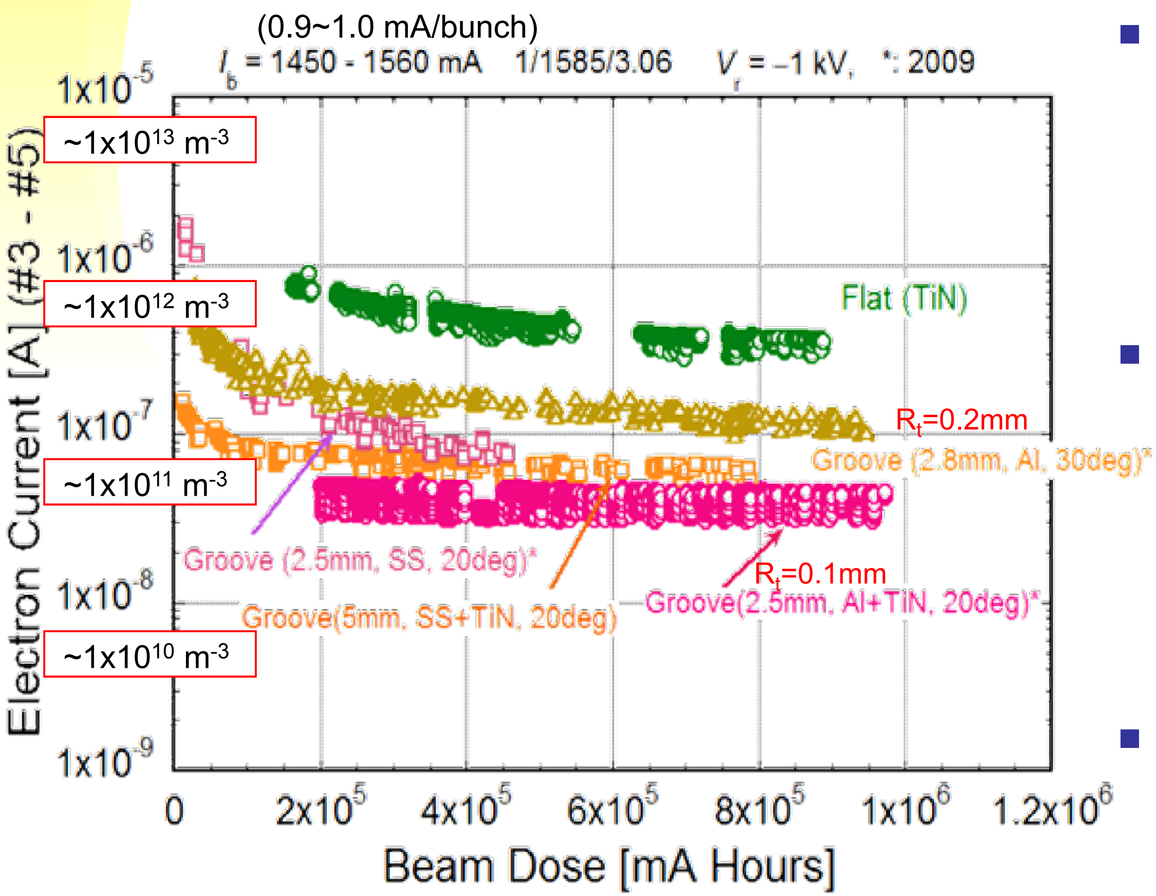
Electron cloud issues_13

- **Results:** EC growth
  - A significant reduction in the electron density was observed by using grooved surfaces.
  - Similar effect was observed for 2 ~ 16 ns spacings.



Electron cloud issues_14

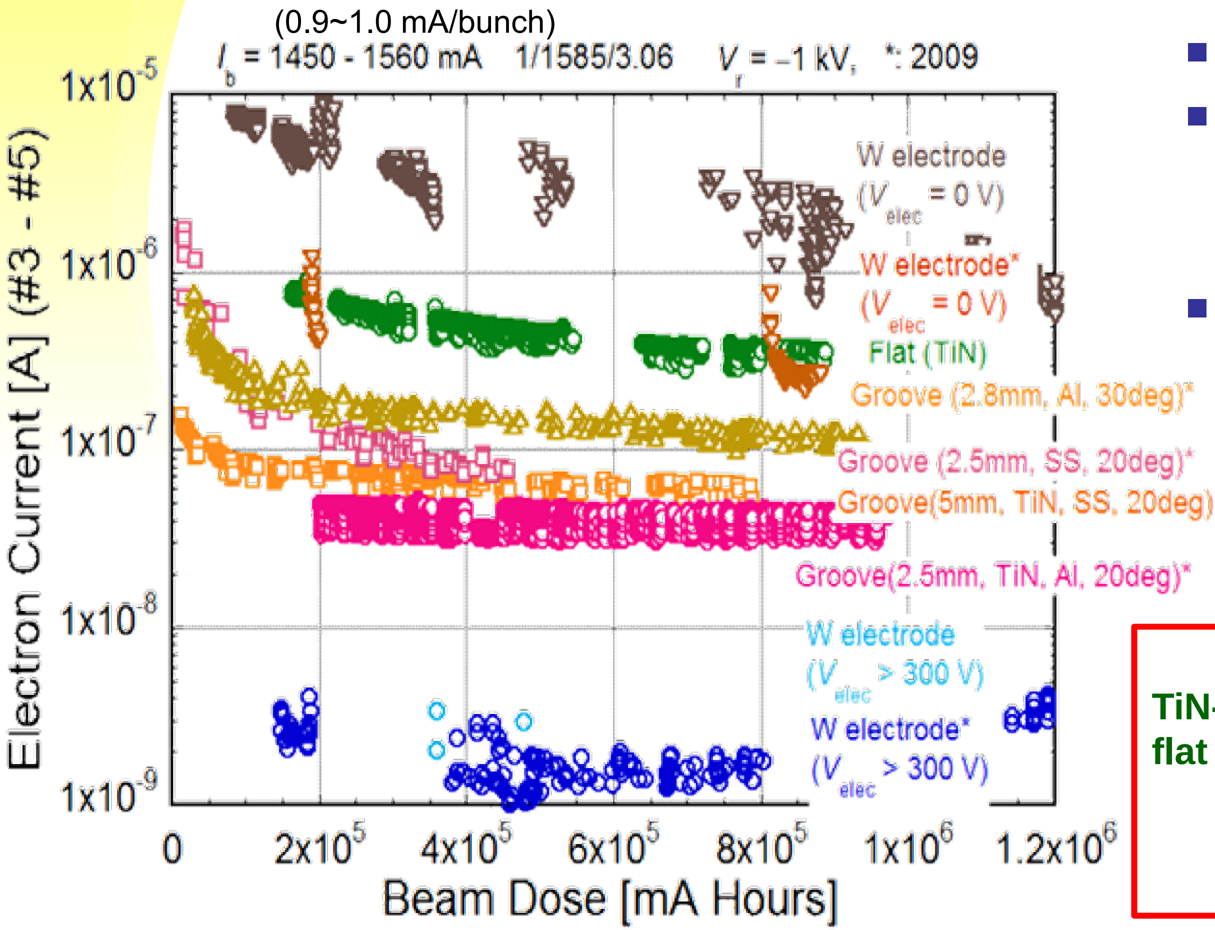
- **Results:** Change with beam dose
  - The electron density decreased to 1/6~1/10 compared to the case of a flat TiN-coated surface (β = 20). That is, less than ~1/10 compared to flat copper.



- Electron densities for grooves surfaces in these parameters were lower than the case of a flat TiN-coated surface.
- Smaller electrons even if no-coating: TiN coating improves the effect, but the groove structure seems much effective to reduce SEY.
- Less density for smaller β and R_t.

Electron cloud issues_15

- **Comparison between clearing electrode and groove**
  - All data so far are plotted in one figure



- B = 0.78 T
- Measured with the same monitor at the same location.
- Clearing electrode is much effective in reducing electron density compared to other methods.

TiN-coated flat surface 〉〉 **Grooved surface (β~20°)** 〉〉 **Clearing electrode**

1/6~1/10 ~1/10

Electron cloud issues_16

- **Updated comparison among mitigation techniques**
  - Based on the experiments so far. Standard = Cu (circular pipe)

Materials, methods	Relative effect	Notes
Al	~20	Coatings are indispensable.
Cu (Circular pipe)	1	
Solenoid [Drift space]	~1/50	~50 G, considering gaps (<1/1000 if uniform)
Antechamber	~1/5	<1/100 for photoelectrons
Cu (Al) +TiN coating	~3/5	Relatively high gas desorption
Groove (β~20°) [in B]	~1/10	Top and bottom
Electrode [in B]	~1/100	Most effective against EC. Expensive?

- Clearing electrodes and grooved surfaces can be strong countermeasures in dipole fields, more effective than any coatings.

Electron cloud issues_17

- **Application of further countermeasures**

Sections	n_e [e^-/m^3]	n_exL [%]
Total (3016 m)	9E10	100
Drift space (1629)	3E10	18
Steering mag. (316)	3E10	3.4
Bending mag. (519)	2E11	38
Wiggler mag. (154)	7E11	39
Q & SX mag. (254)	8E9	0.81

×1/10
+ Groove?
⇨ Ante-chamber (Cu or Al+coating)
⇨ Ante-chamber (Cu) + Electrode
×1/100

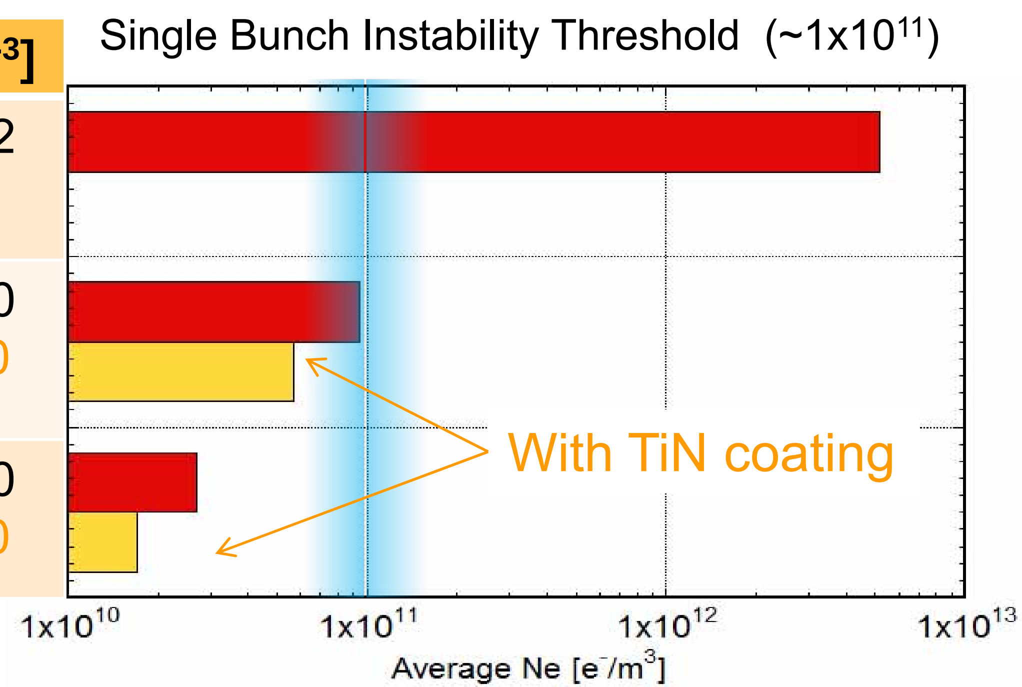
Sections	n_e [e^-/m^3]	n_exL [%]
Total (3016 m)	3E10	100
Drift space (1629)	3E10	68
Steering mag. (316)	3E10	13
Bending mag. (519)	2E10	14
Wiggler mag. (154)	4E9	1.5
Q & SX mag. (254)	8E9	2.8

- Further low average n_e.
- If with TiN-coating, n_e ~ 2E10 e^-/m^3
- This is the result with the maximum possible cures at present.

Electron cloud issues_18

- **Expected reduction in the electron density**
  - Major electron cloud will be reduced by antechamber scheme and solenoid field at arc section.
  - Electrodes in wiggler and grooves in bending magnets will decrease EC further and increase the safety margin.

Condition	ne [m^{-3}]
Circular Cu chamber [KEKB beam pipe]	5.2E12
Solenoid at Drift (1/50) +Cu Antechamber (1/4)	9.4E10 5.7e10
+Electrode in Wiggler (1/100) +Groove in B (1/10)	2.7E10 1.7e10



Electron cloud issues_19

- **Impact on the beam impedance**
  - The evaluation has just started (→back up slides).
  - Compared to the resistive wall (ϕ90 mm, Cu)
  - **Clearing electrode**, assuming;
    - One electrode, proportional to the length.
    - Resistive wall of W is included (over estimate).

Further investigation is required.

	1 m	Total (~80 m / 3000 m) [in wiggler magnets]
Loss factor	~x 2.1	~x 1.03
Wake potential (height)	~x 6 (5+1)	~x 1.11

  - **Grooved surface**, assuming;
    - Grooves at top and bottom, proportional to the length (over estimate).
    - Increase in resistive wall of 50 % by grooved surface is included.

	1 m	Total (~520 m / 3000 m) [in Dipole magnets]
Loss factor	~x 1.3	~x 1.05
Wake potential (height)	~x 2 (1+1)	~x 1.17

Summary & Remained issues_1

- **Super KEKB is challenging for the vacuum system.**
- **The design will fundamentally follows that considered in the high-current scheme.**
  - Basic R&D on components has almost finished.
  - Optimization of design should be required considering the cost.
  - Aluminum beam ducts can be used for LER now.
    - Radiation survey is undergoing using KEKB.
- **For countermeasures against electron cloud in a dipole field, clearing electrodes and grooved surface are found to be very effective.**
  - Ante-chamber and solenoid reduce main part of electrons.
  - By using clearing electrodes and grooved surface in dipole field, the average electron density further decrease.
    - Grooves were also effective in drift space (experiment of SLAC).
  - The affect on the beam impedance should be considered carefully.

Summary & Remained issues_2

- **Choice of material for LER beam ducts**
  - Should be considered together with countermeasures against EC, constructing scenario (schedule), cost, etc..
  - Present plan: The Right Material in the Right Place

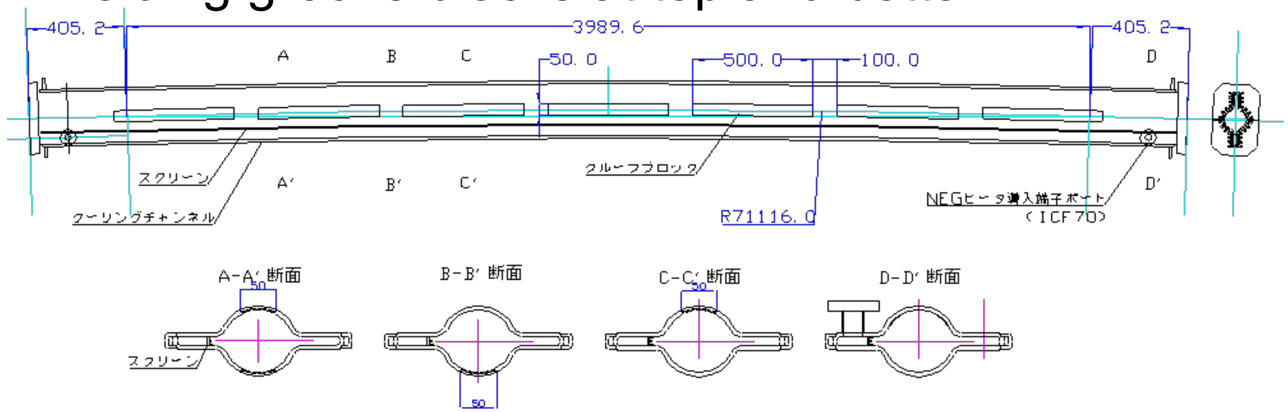
Drift space	Cu or Al+Coating (or Groove)
Q and Sx mag.	Cu or Al+Coating (or Groove)
B mag.	Al+Groove (with coating?) or Cu+Groove
Wiggler mag.	Cu+Electrode

Notes:

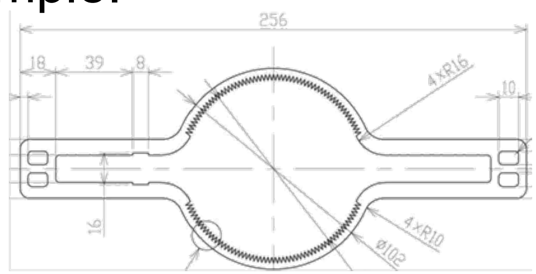
- Copper is a good material, i.e., low SEY (after scrubbing), good radiation shielding, low gas desorption, experiences in KEKB.
- (TiN) coatings have relatively high gas desorption. Wait scrubbing? They are effective, but the effect seems small for its labor. Coating can be done after the commissioning (?)
- Depends on the beam test in the next run.

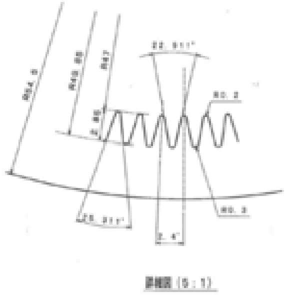
Summary & Remained issues_3

- **R&D for aluminum beam duct with grooves is undergoing**
  – Welding groove blocks at top and bottom.



  – Extrusion: if possible, the manufacturing process becomes very simple.





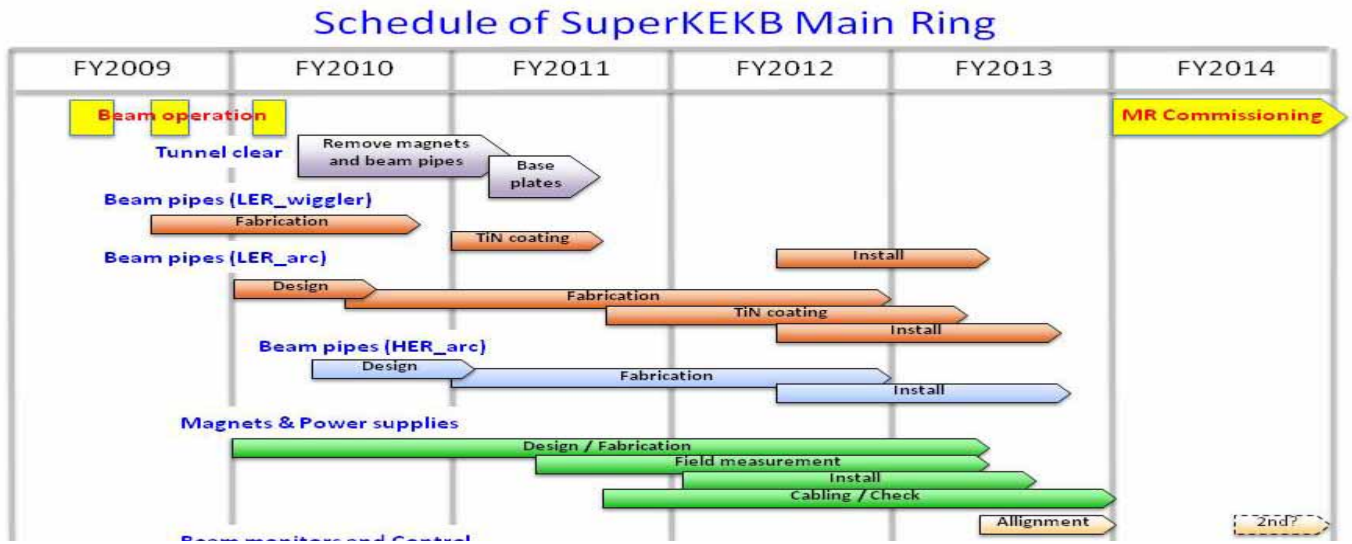
  – Beam test at a straight section (drift space) in the next run.
    → Grooves at whole surface

Summary & Remained issues_4

- **Design of HER beam ducts**
  - Fix the cross section.
  - Components will be the same with those in LER.
- **Design of special component**
  - Movable mask, Septum, Abort window, HOM absorber, etc.

Summary & Remained issues_5

- **Scheduling of manufacturing**
  – Manufacture ~2000 beam ducts (2 ~ 6 m) and install them in 3 years?!
    - Make 4 ducts per day! (200 days per year)
    - Install 8 ducts per day!
  – Discover and nurture new vendors.
  – Establish detailed procedures of preparation (baking, any coating, solenoid winding,,,).
  – Make consistent schedule with magnet installation,,,.

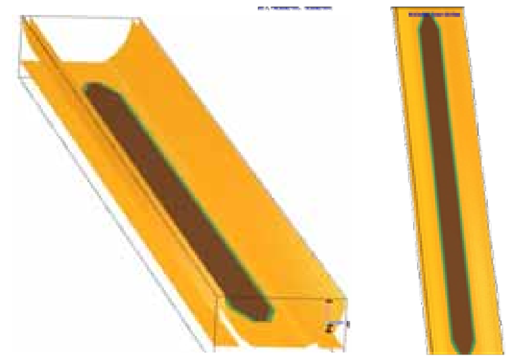


END

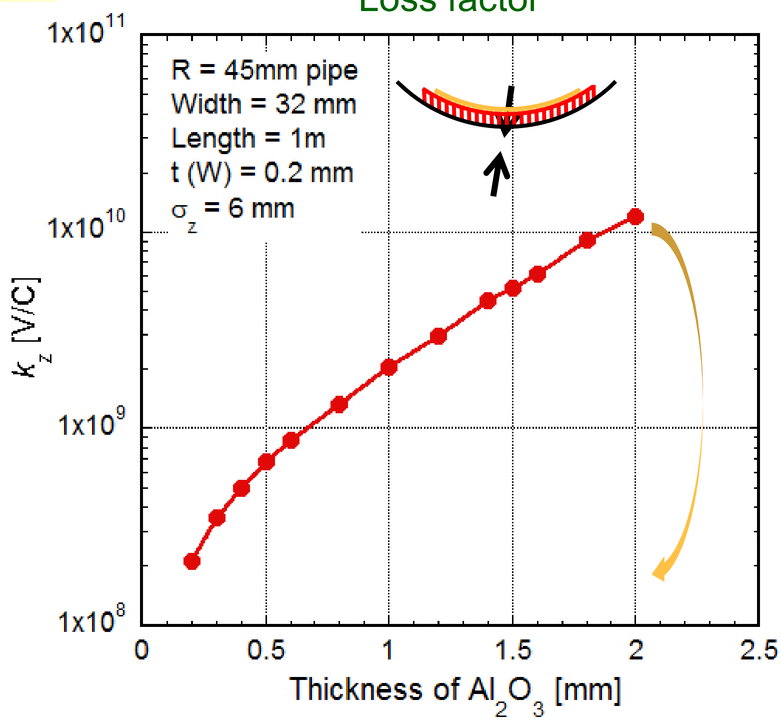
Back up

Impedance of electrode_1

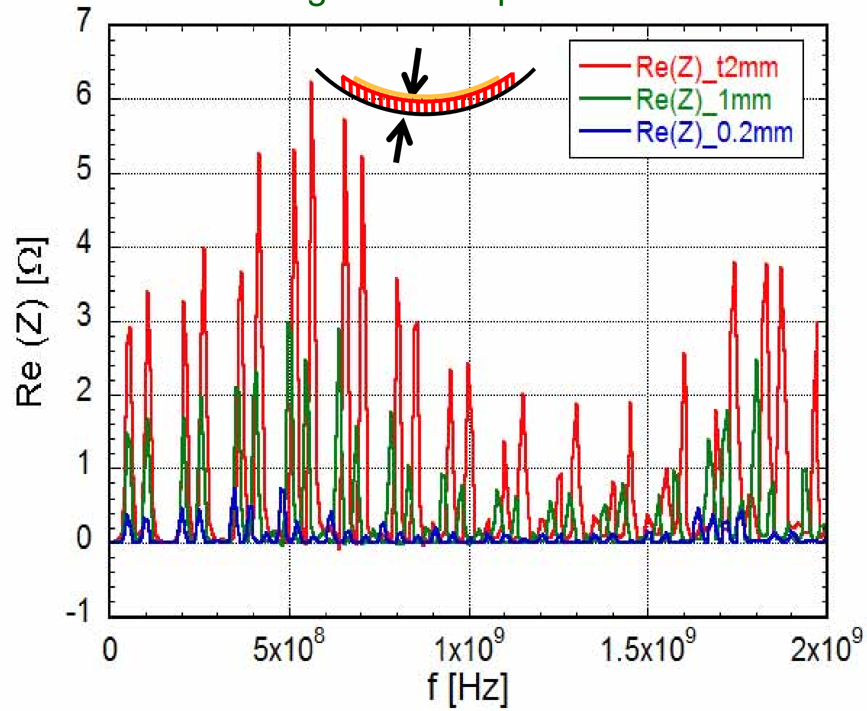
- Dependence of loss factor and wake potential on the thickness of Al_2O_3 insulator
  - Calculated by using GdfidL (1m model, half chamber)
  - t0.2 mm ~ 2.0 mm



Loss factor

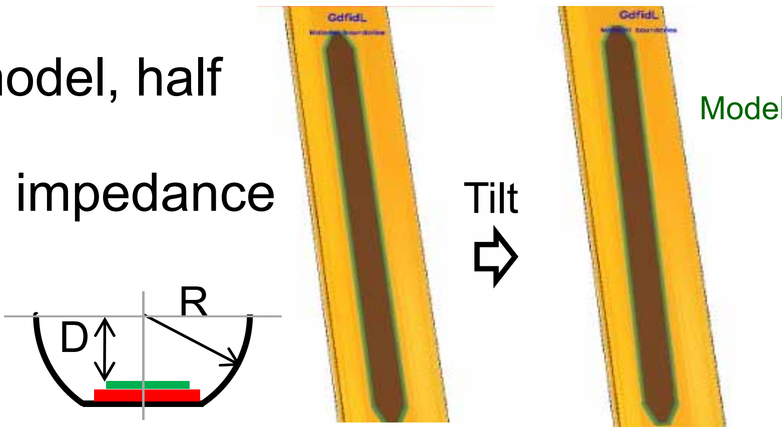


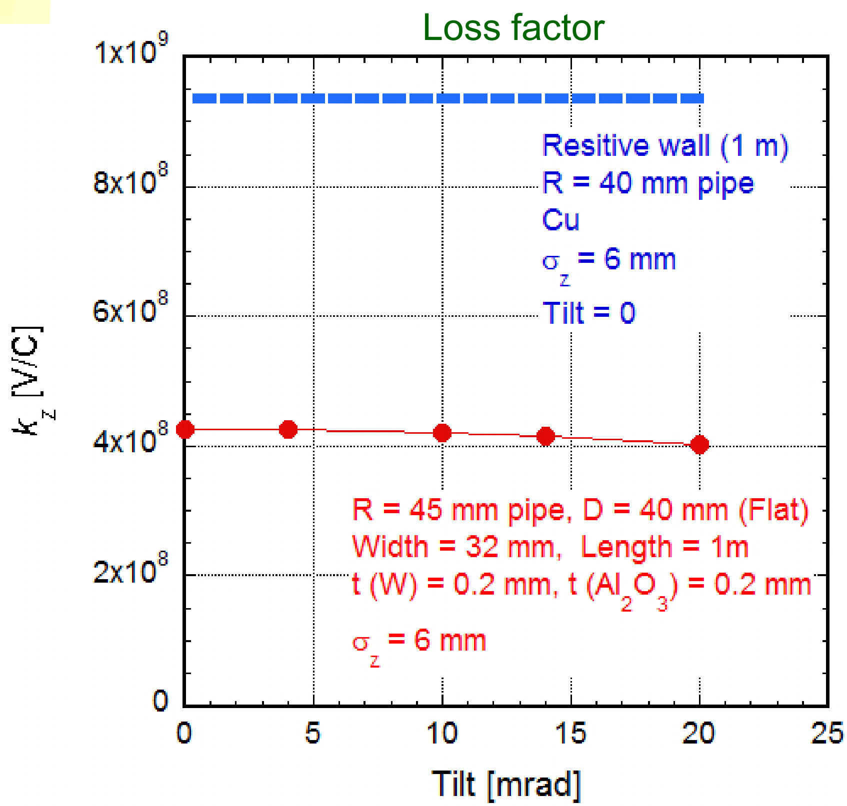
Longitudinal Impedance



Impedance of electrode_2

- Effect of tilt on loss factor
  - Calculated by GdfidL (0.5 m model, half chamber)
  - Comparison with resistive wall impedance
  - Up to 20 mrad

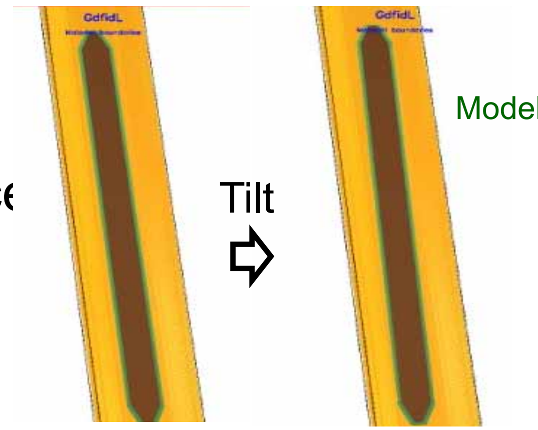


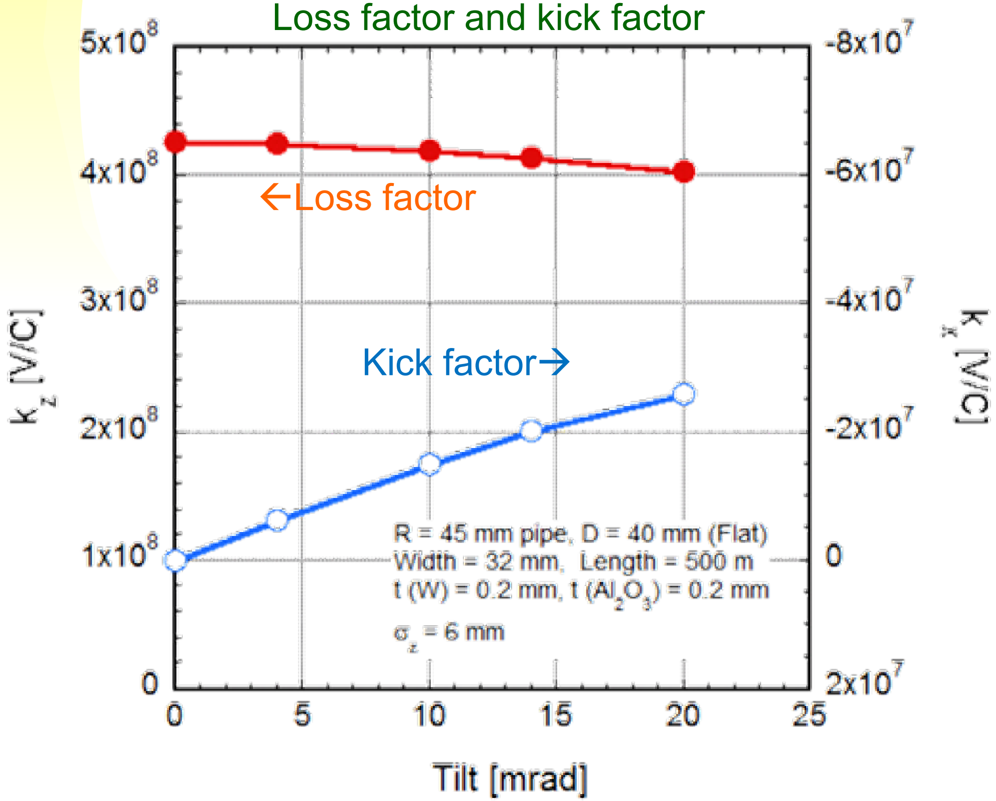


- Loss factor is smaller (~1/2) compared to that of the resistive wall (for 1 m).
- Loss factor is almost constant against the tilt angle.

Impedance of electrode_3

- Effect of tilt on loss factor
  - Calculated by GdfidL (0.5 m model, half chamber)
  - Comparison with resistive wall impedance
  - Up to 20 mrad

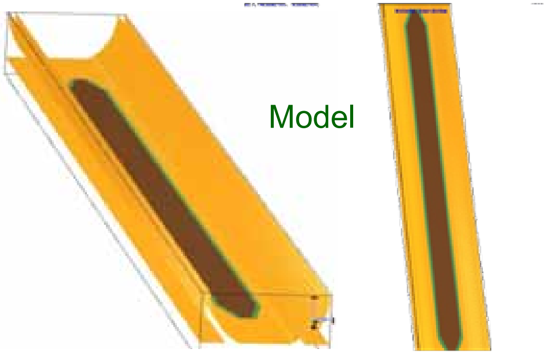


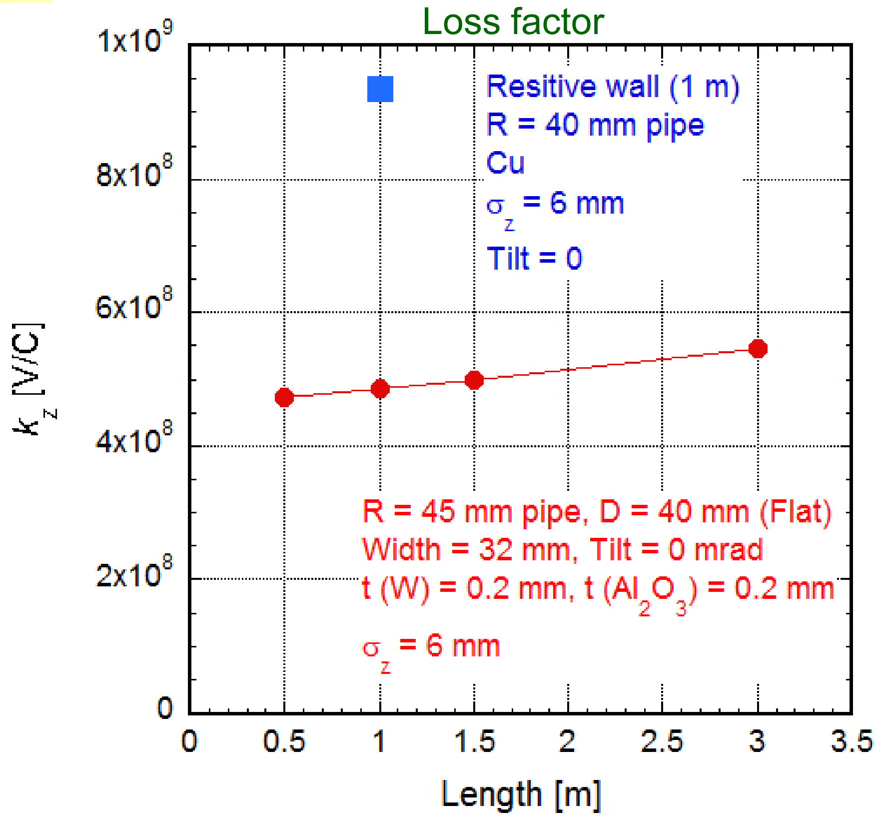


- Loss factor is almost constant against the tilt angle.
- Kick factor increases with the tilt angle.

Impedance of electrode_4

- Effect of length on loss factor
  - Calculated by GdfidL (half chamber)
  - Comparison with resistive wall impedance
  - Up to 3m.

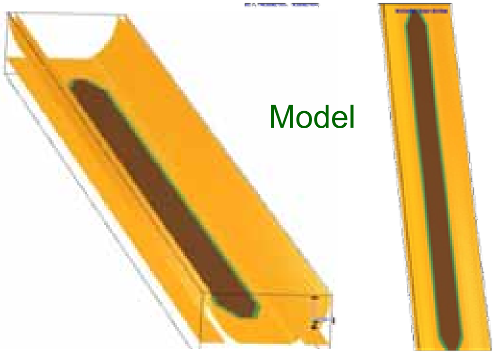


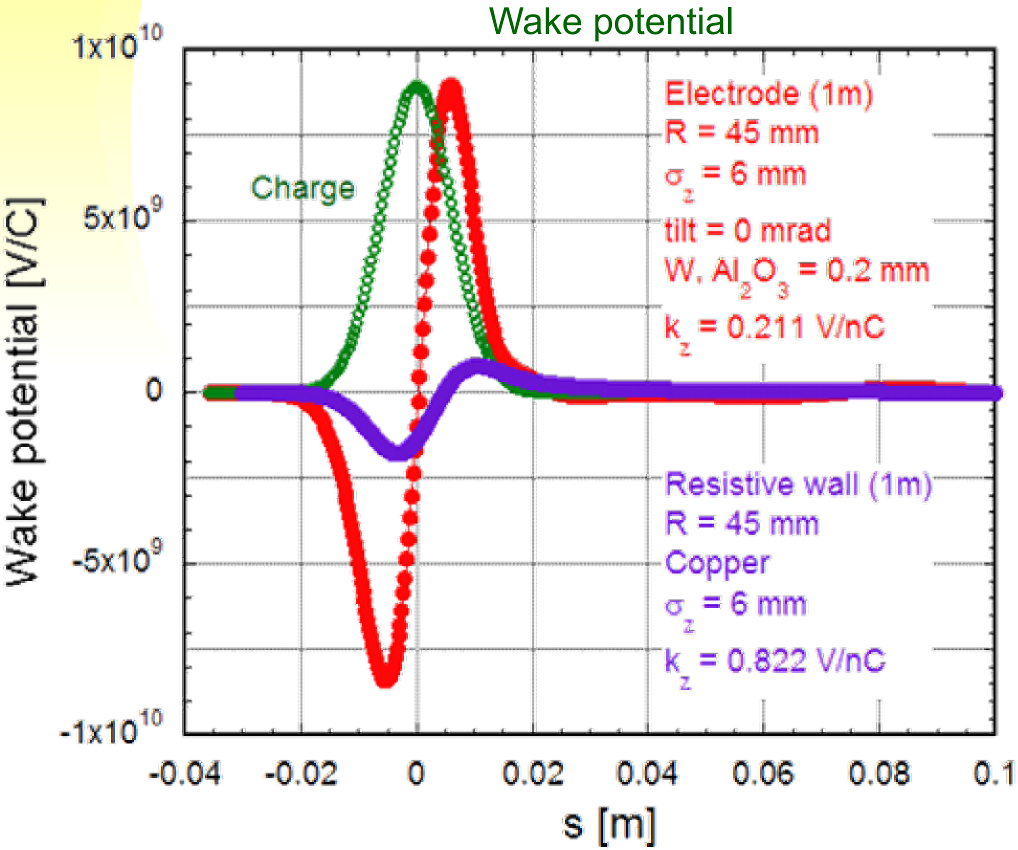


- Loss factor is almost constant against the length.

Impedance of electrode_5

- Wake potential
  – Calculated by GdfidL (0.5 m model, half chamber)
  – Comparison with resistive wall



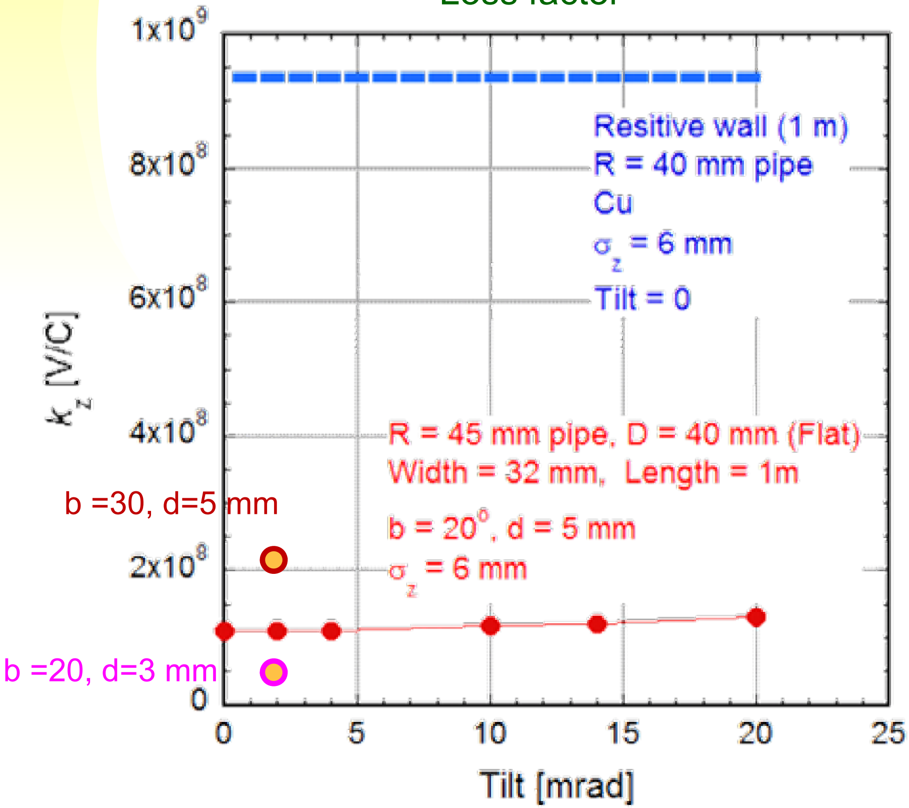


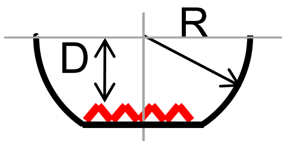
- The wake potential is inductive.
- The peak value of the wake potential is higher by a factor of 5~10, though the loss factor is small.
- Should be carful in using the electrode for long section, in relation to single bunch instability

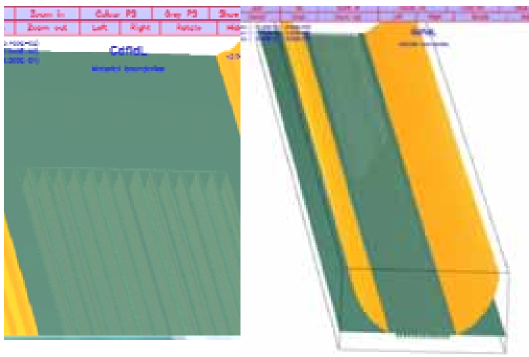
Impedance of groove_1

- Effect of tilt on loss factor
  - Calculated by GdfidL
    (0.5 m model, half chamber)
  - Comparison with resistive wall impedance
  - Up to 20 mrad

Loss factor





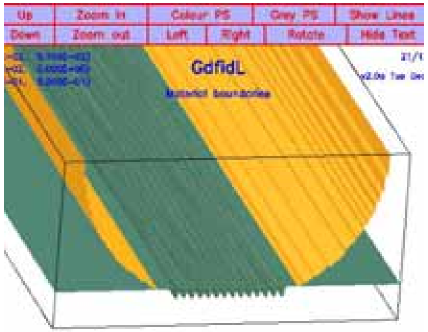


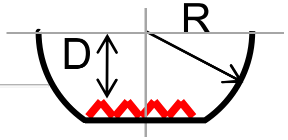
Kick factor

- The grooves are located at both up and bottom.
- The loss factor is very small for tilt angle = 0 ~ 20mrad. (~10 % of resistive wall)
- The loss factor is almost constant against tilt (a little bit increases).

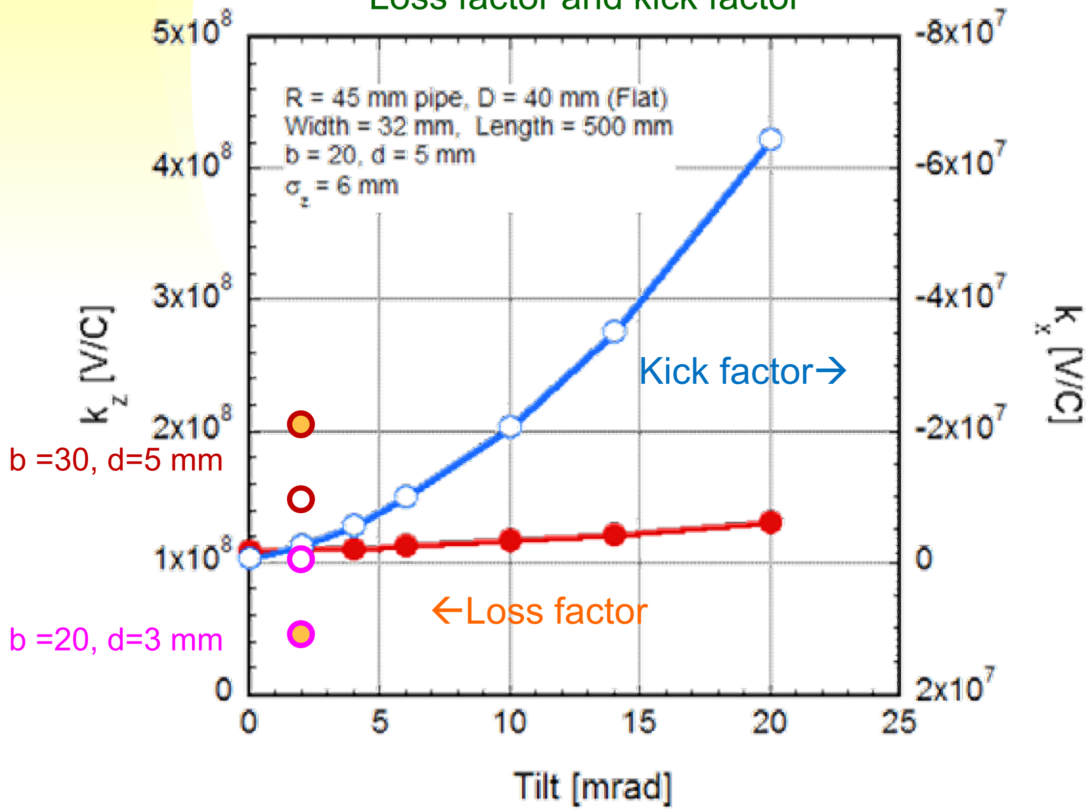
Impedance of groove_2

- Effect of tilt on loss factor
  - Calculated by GdfidL
    (0.5 m model, half chamber)
  - Comparison with resistive wall impedance
  - Up to 20 mrad





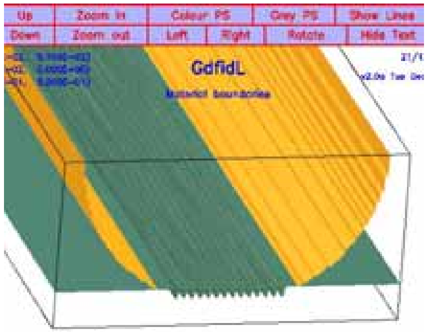
Loss factor and kick factor

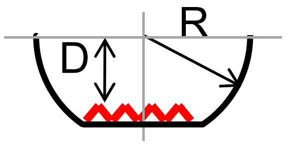


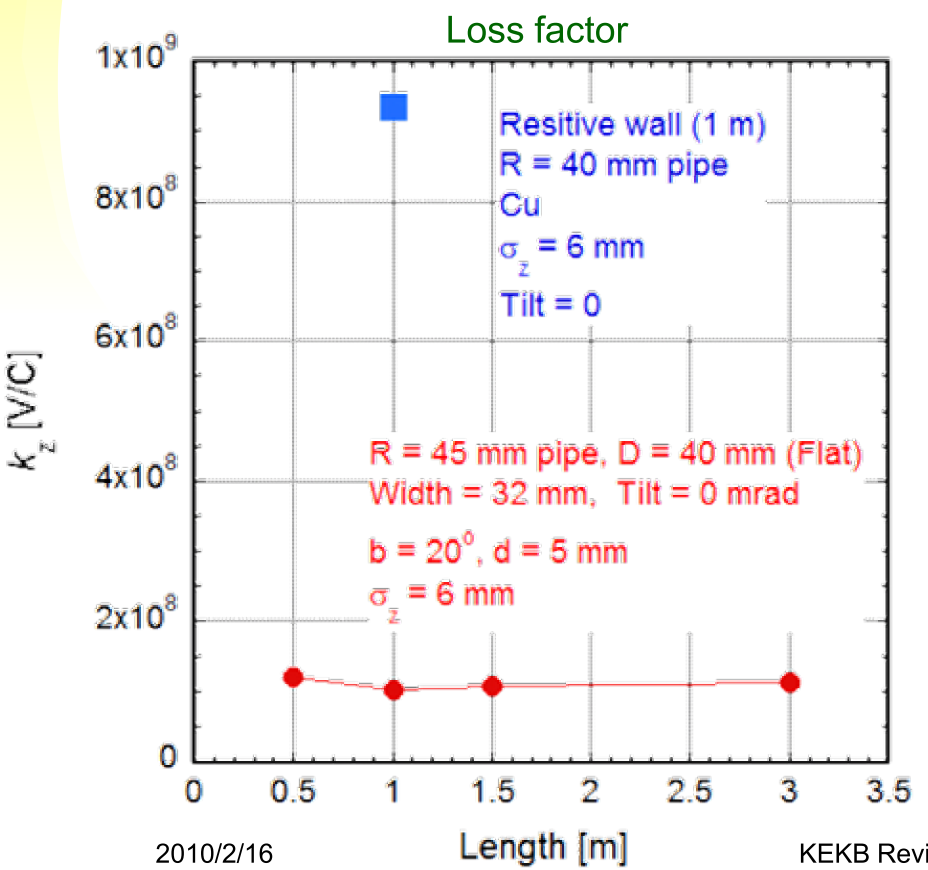
- Loss factor is almost constant against the tilt angle.
- Kick factor increases with the tilt angle. Larger than that in the case of electrode.

Impedance of groove_3

- Effect of length on loss factor
  - Calculated by GdfidL (half chamber)
  - Comparison with resistive wall impedance
  - Up to 3 m.



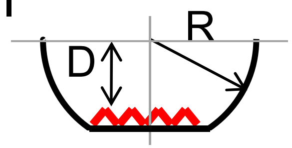


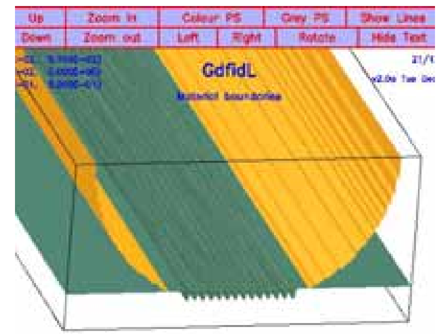


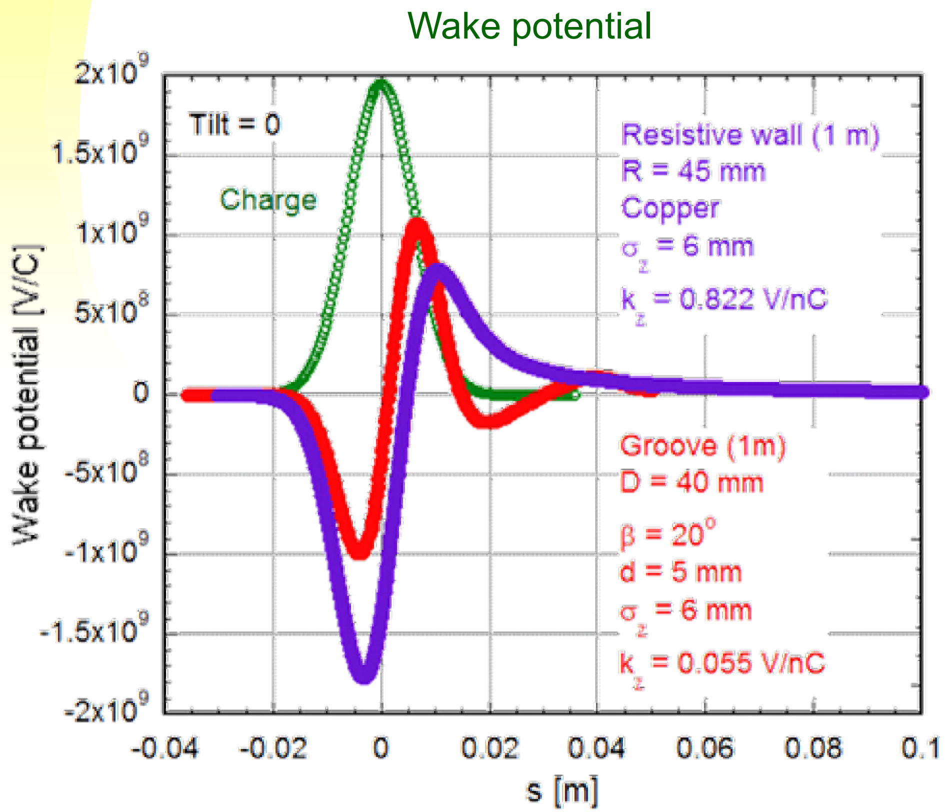
- Loss factor is almost constant against the length.

Impedance of groove_4

- Wake potential
  - Calculated by GdfidL (0.5 m model, half chamber)
  - Comparison with resistive wall



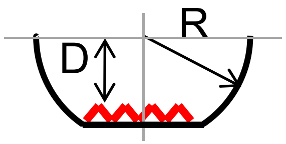


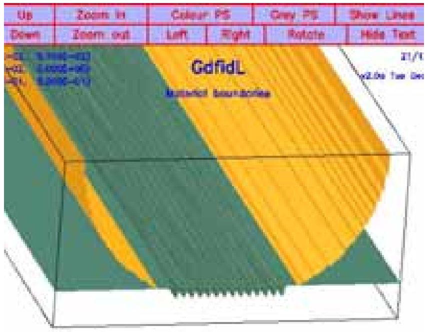


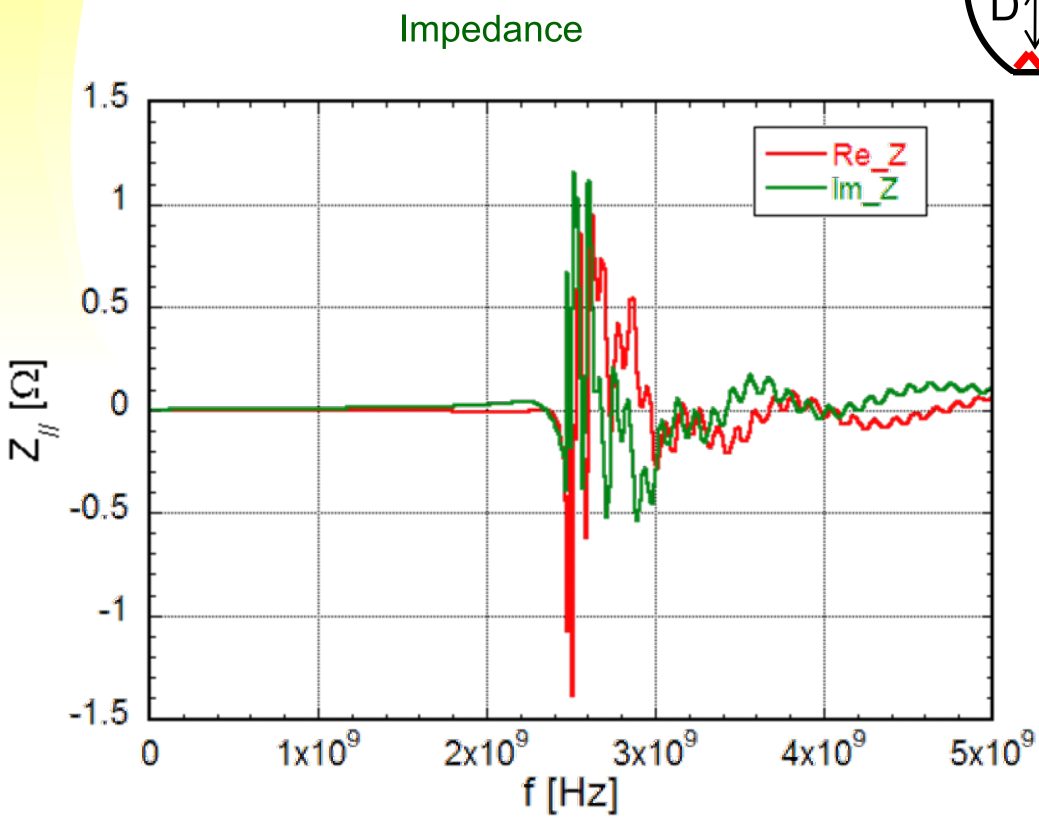
- Wake potential is inductive, and almost the same to that for resistive wall.
- Should be carful in using the electrode for long section, in relation to single bunch instability.

Impedance of groove_5

- Longitudinal impedance
  - Calculated by using GdfidL (1m model, half chamber)
  - σ_z = 20 mm, s = 20 m







- Little trapped mode