Electron cloud mitigation strategy in SuperKEKB

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on behalf of KEKB Vacuum Group

- Super KEKB Project
- Electron cloud issue in positron ring
- Mitigation strategy
  - Drift section (incl. Q magnet sections)
  - Bend section
  - Wiggler section
- Summary

SuperKEKB project_1

- **KEKB (KEKB B-factory) in KEK Tsukuba campus**

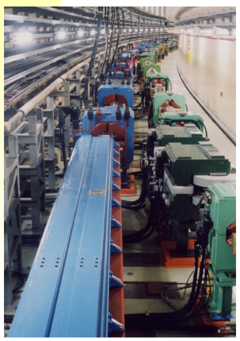
- **Asymmetric two ring collider**
  - Circumference : 3016 m
  - Electron ring (HER) : 8 GeV
  - Positron ring (LER) : 3.5 GeV
- **Operation ended last June**
  - Operation (MR):
    ~12 years since Dec., 1998
  - Typical Beam current:
    1.3 A (e^-) x 1.6 A (e^+)
  - Peak L: 2.1 x 10^{34} cm^{-2} s^{-1}
  - Integrated L:1041 fb^{-1}

The commissioning finished successfully!

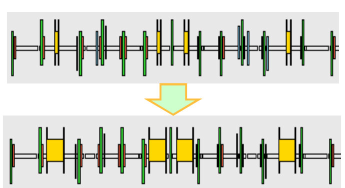
SuperKEKB project_2

- **SuperKEKB: High luminosity e$^-$-e$^+$ collider aiming a luminosity ~ 8x10^{35} cm^{-2}s^{-1}, 40 times higher than KEKB**
  - With nano-beam and double beam currents
  - Explore new physics beyond the Standard Model.

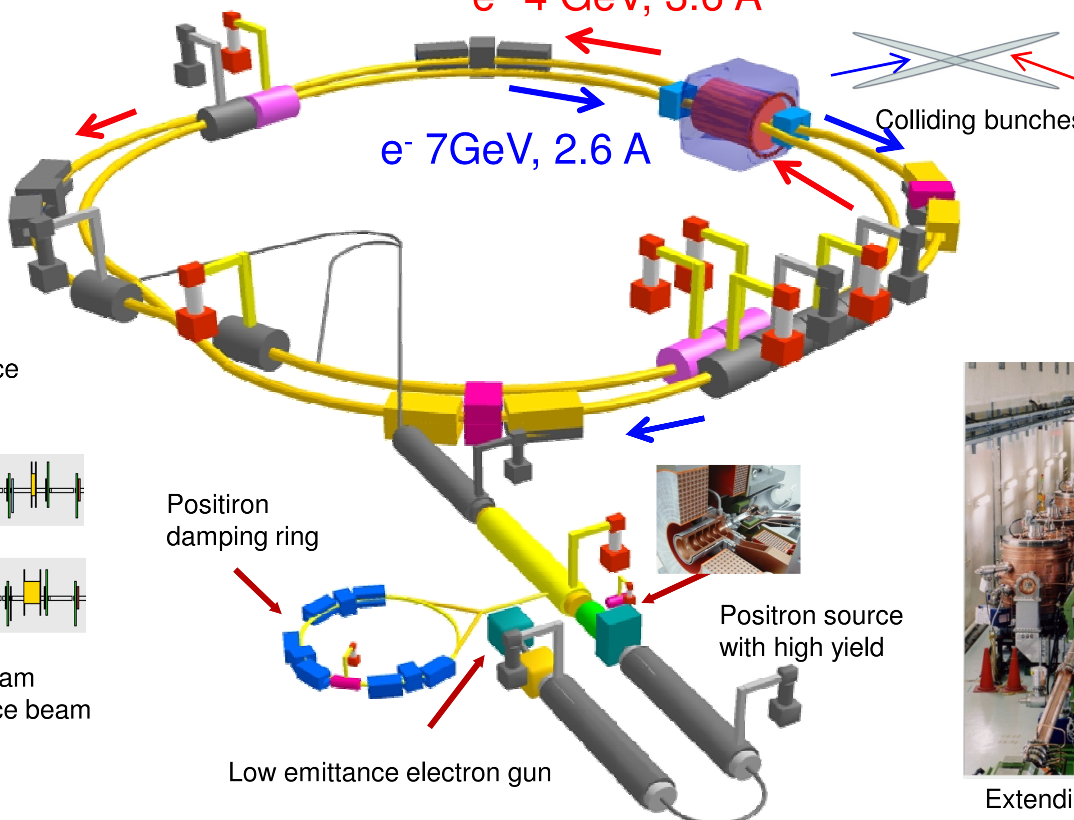
$$L = \frac{\gamma_{\pm}}{2 e r_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

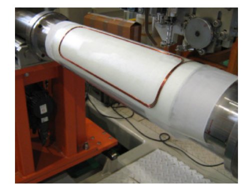


Long dipoles to reduce emittance



Optimization of the beam optics for low emittance beam





Superconducting magnet to shrink colliding beam at IP

Extending of RF system for high beam current

SuperKEKB project_3

- **Machine parameters**

2010/Sept/8	LER	HER	HER	HER	unit
wiggler	Full	None	6/10	Full	
E	4.000	7.007	7.007	7.007	GeV
I	3.6	2.6	2.6	2.6	A
Number of bunches	2,500	2,500	2,500	2,500	
Bunch Current	1.44	1.04	1.04	1.04	mA
Circumference	3,016.3700	3,016.3700	3,016.3704	3,016.3707	m
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/(2.8)	5.3(5.2)/(4.2)	4.6(4.5)/(3.6)	4.3(4.1)/(3.2)	nm/pm
β_x^*/β_y^*	32/0.27	25/0.30	25/0.30	25/0.30	mm
α_p	3.49×10^{-4}	4.55×10^{-4}	4.55×10^{-4}	4.54×10^{-4}	
σ_δ	$8.00(7.66) \times 10^{-4}$	$5.85(5.78) \times 10^{-4}$	$6.35(6.29) \times 10^{-4}$	$6.59(6.54) \times 10^{-4}$	
V_c	9.4	12.4	14.7	15.8	MV
σ_z	6.0(5.0)	5.0(4.9)	5(4.9)	5(4.9)	mm
ν_s	-0.0256	-0.0254	-0.0277	-0.0287	
ν_x/ν_y	44.53/43.57	45.53/43.57	45.53/43.57	45.53/43.57	
U_0	1.87	2.07	2.43	2.67	MeV
$\tau_{x,y}/\tau_s$	43.0/21.5	68.2/34.1	58.0/29.0	52.8/26.4	msec

lerfqlc1351 herfqlc5210 herfqlc5214 herfqlc5215

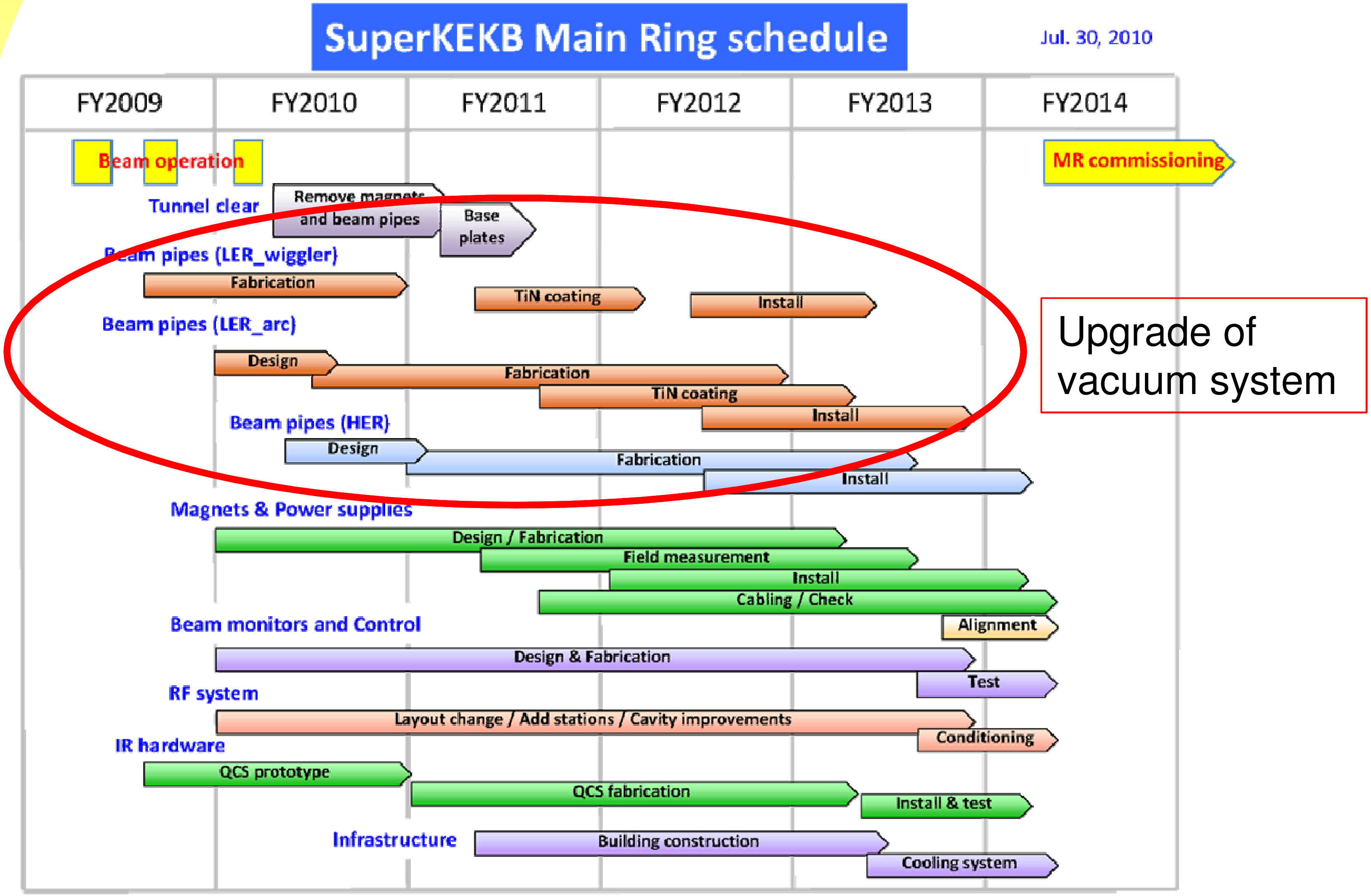
SuperKEKB project_4

- **In July, the MEXT, Ministry of Education, Culture, Sports, Science and Technology, that supervises KEK, has announced that it will appropriate a budget of 100 oku-yen (approx. $117M) over the next three years (JFY2010-2012) for the high performance upgrade program of KEKB.**
- **Council for Science and Technology in MEXT has announced that the SuperKEKB project should be pushed forward with one of the highest priority.**
- **MEXT is requesting construction budget of SuperKEKB to Ministry of Finance for FY2011 (40 oku-yen).**

Upgrade to SuperKEKB has practically started.

SuperKEKB project_5

- **Main upgrade plans (depend on the future funding)**



SuperKEKB project_6

- **Upgrade of vacuum system**
  - Beam pipes are newly manufactured.
    - Magnets are re-aligned.
  - Beam impedances should be decreased further (pump ports, bellows, photon masks, etc.) .
  - Higher stability against high beam currents.
    - New components (Bellows chambers, etc.)
  - LER (positron ring): More powerful countermeasures against the electron cloud are required.

- Now the design of the LER vacuum system is undergoing.
- Electron cloud is a key issue in the vacuum system. The strategy for mitigation are proposed based on various experiments and simulations so far. Fortunately, the diameter of the beam pipe is almost the same to that in KKEB.

Electron cloud issue_1

- The single bunch instability is main concern.
  - Leads to increase in emittance
  - Coupled bunch instabilities will be cured by feed-back system.
- Simulation and calculation by Ohmi, et al.

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

Threshold of density

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

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 = 0.026	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] =1.59E11 ⇨ Target: 1E11

Electron cloud issue_2

- **Estimation of electron densities (KEKB)**
  - From the various experiments at KEKB LER.
  - For circular copper beam pipe (ϕ 94mm, δ_{max}~1.2), 4 ns spacing, ~1 mA/bunch, no solenoid field
  - Around the beam

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 parts

Average density (n_e) should be less than 2 % !

(5E12 → 1E11 [e^-/m^3])

Electron cloud issue_3

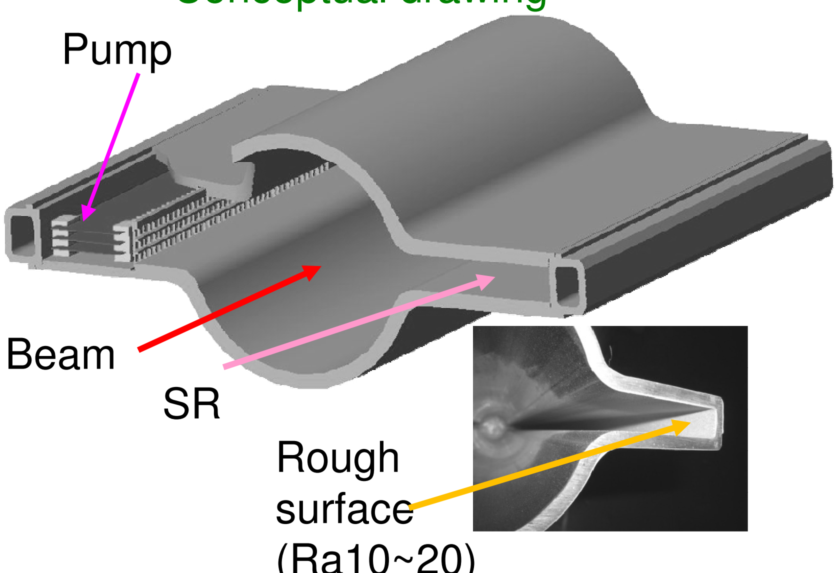
- **Countermeasures for main parts are chosen carefully, by "putting the right person for the right place"**
- **Possible countermeasures;**
  - Beam pipe with antechambers
  - Solenoid field
  - Coatings with low SEY
  - Grooved surface
  - Clearing electrode
- **Countermeasures were evaluated based on**
  - Various experimental and simulation results in KEK and other institute
  - Construction schedule, Cost
  - Past experience
  - Effectiveness, Stability, Influence on beam

Drift section_1

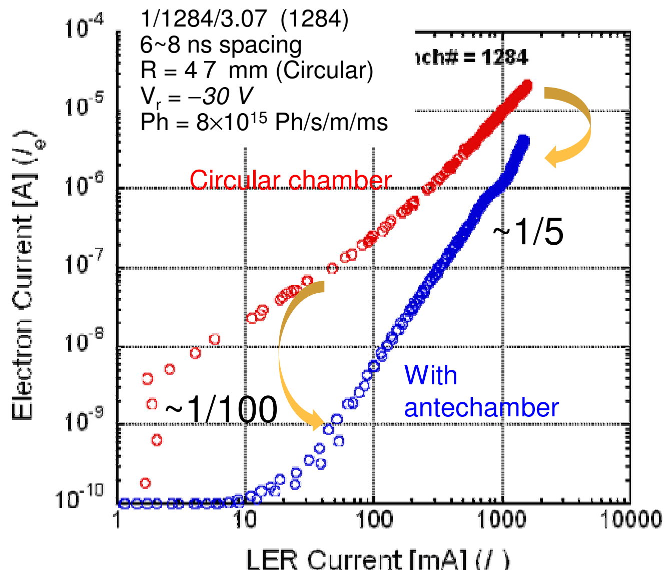
- **Beam pipe with antechambers**
  - Effective to reduce photoelectrons
    - Adopted in PEP-II LER
  - Also effective to reduce photon scattering (with rough surface)
  - Contribute to decrease impedance
  - Reduction rate ~ 1/5 at high current region

Depth: 65 mm
Height:14 mm
Arc

Conceptual drawing



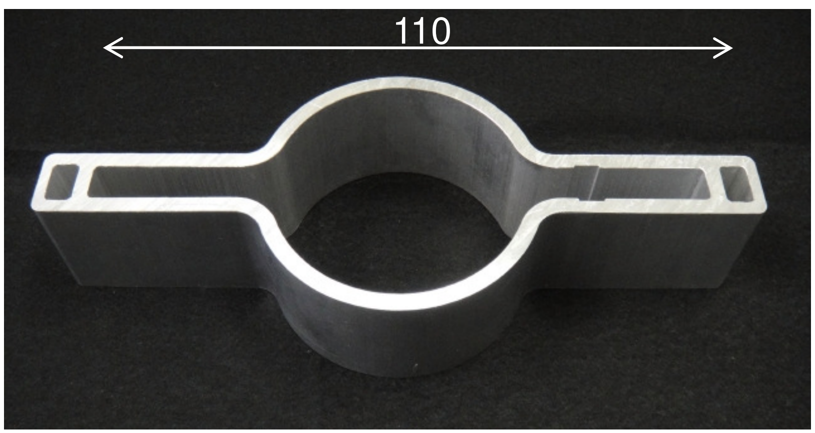
Effect of antechamber



Drift section_2

- **Beam pipe with antechambers**
  - Manufacturing by extrusion is possible for aluminum-alloy beam pipe. Cold drawing is available for copper pipes.
  - Aperture of antechamber: depth=65 mm, height= 14mm
    - Fit to existing magnets (Q, Sx)
  - The same cross section for not only the drift space, but also in other sections.
    - Uniform cross section → reduction in beam impedance

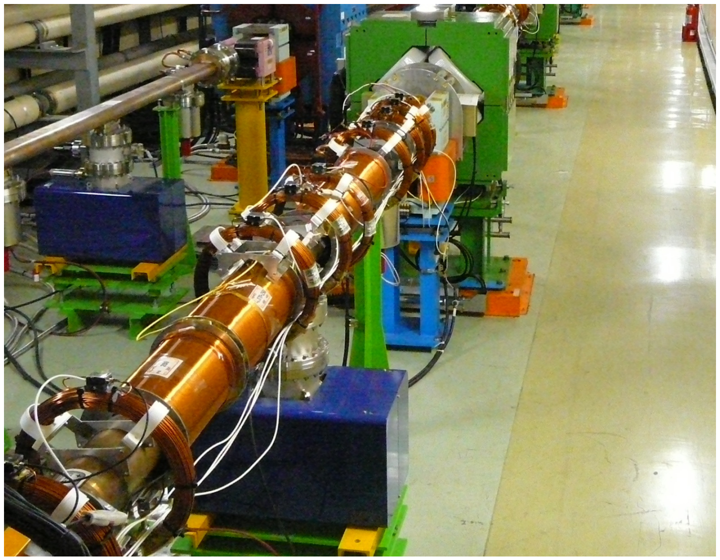
Aluminum-alloy beam pipe formed by extrusion



Drift section_6

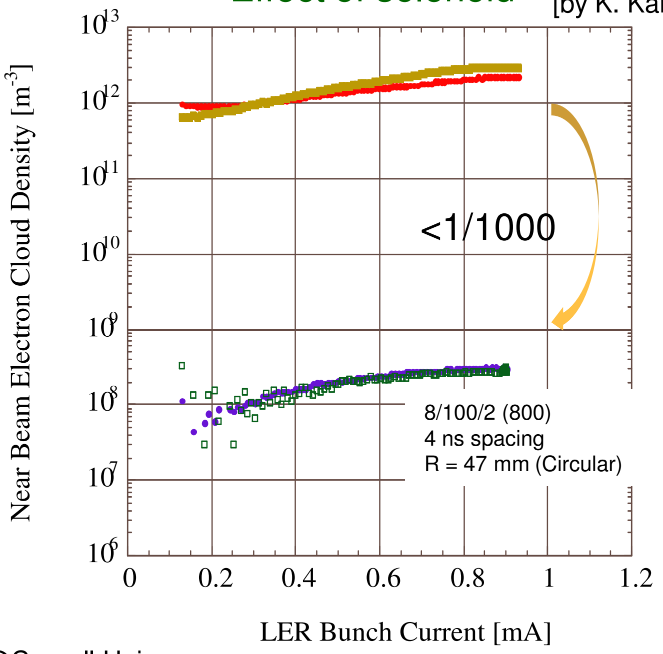
- **Solenoid field**
  - Very effective to effectively suppress both photoelectrons and secondary electrons.
    - Experience in KEKB and PEP-II, be careful about coupling
  - Available only in drift space (and in correctors)
  - Reduction rate: <1/1000 if uniform (Cu). Practically ~1/50 (i.e., 98% of the section is covered by solenoid field)

Solenoid in KEKB (~50 G)



Effect of solenoid

[by K. Kanazawa]



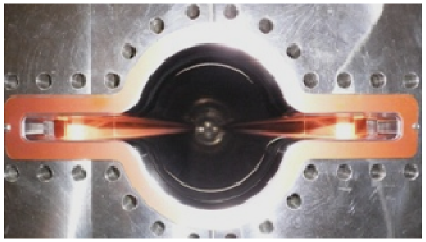
Drift section_4

- **TiN coating**
  - Aluminum-alloy beam pipe is used in SuperKEKB LER
    - Low SR power in the present ring design
    - Low cost (manufacturing), short construction period, easy handling

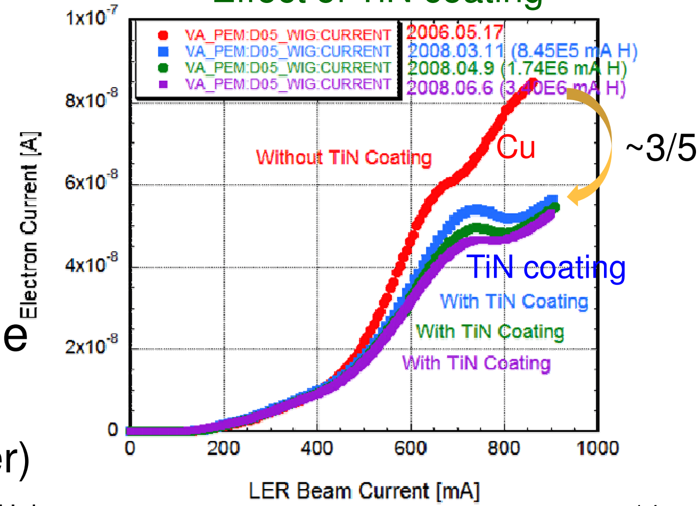
  → Any coating to reduce SEY is indispensable

  - Choice of coating material: TiN
    - Long experience in PEP-II LER (high-current positron ring)
    - Many applications in various places, and well studied coating technique
    - NEG: difficulty in activation in our ring, high gas load in the high current machine
    - Graphite: Still in the R&D phase (coating technique, gas desorption, resistivity, stability,,), too early for large-scale application. Comparable to TiN.
  - Reduction rate: ~3/5 (Cu, antechamber)

TiN coating in a beam pipe

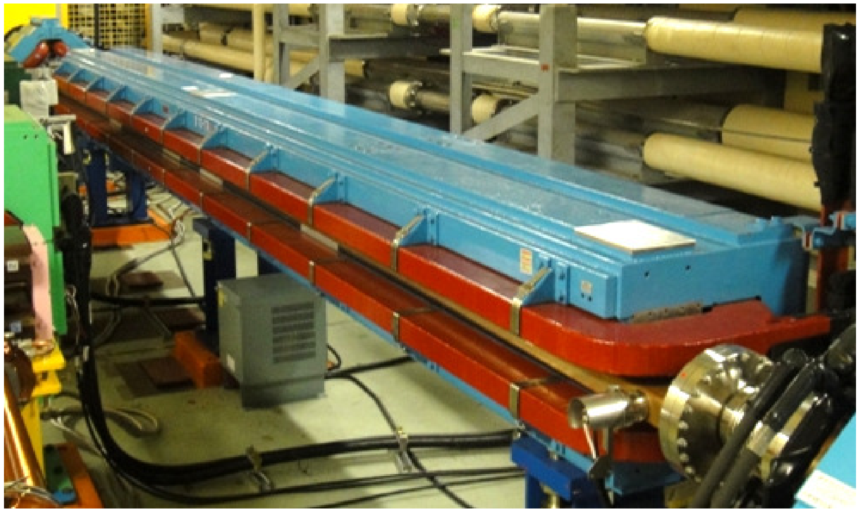


Effect of TiN coating



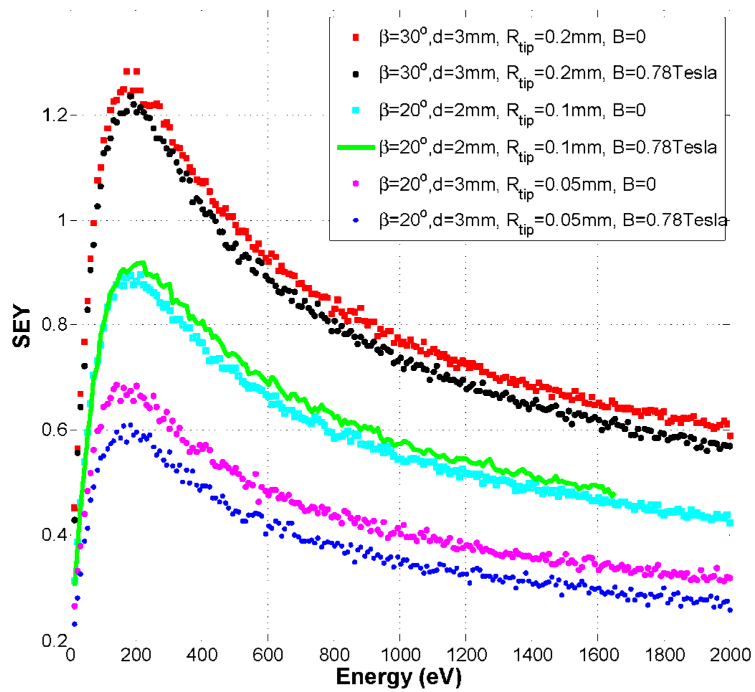
Bend section_1

- **Beam pipe with antechamber**
  - The same cross section to that in the drift section
  - Material: Aluminum alloy
  - Magnet: L = 4 m, B = 0.18 T, ρ = 74 m
- TiN coating
  - As in the case of drift section
- But, solenoid is unavailable.

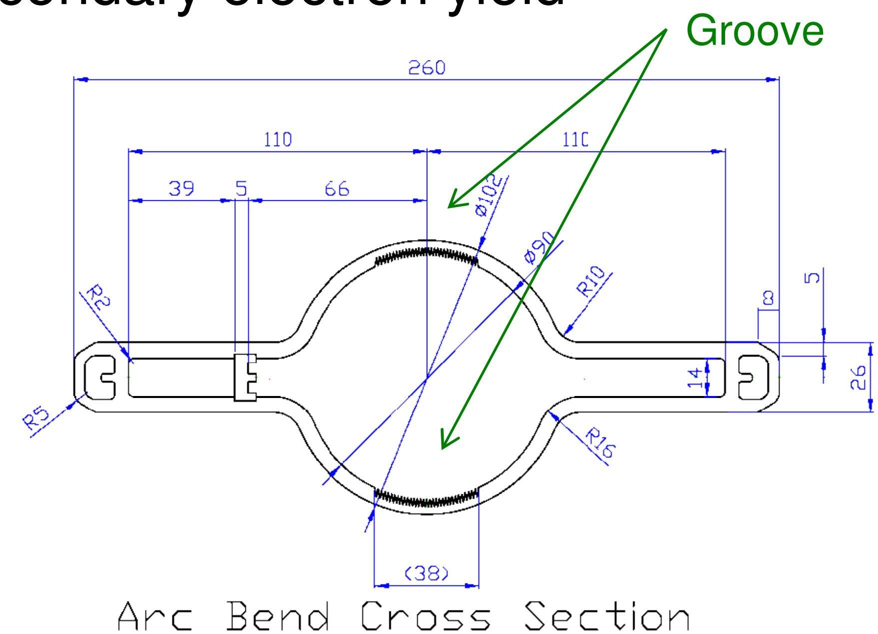


Bend section_2

- **Grooves at top and bottom**
  – Effective in reducing secondary electron yield
  – With TiN coating



[by L. Wang]

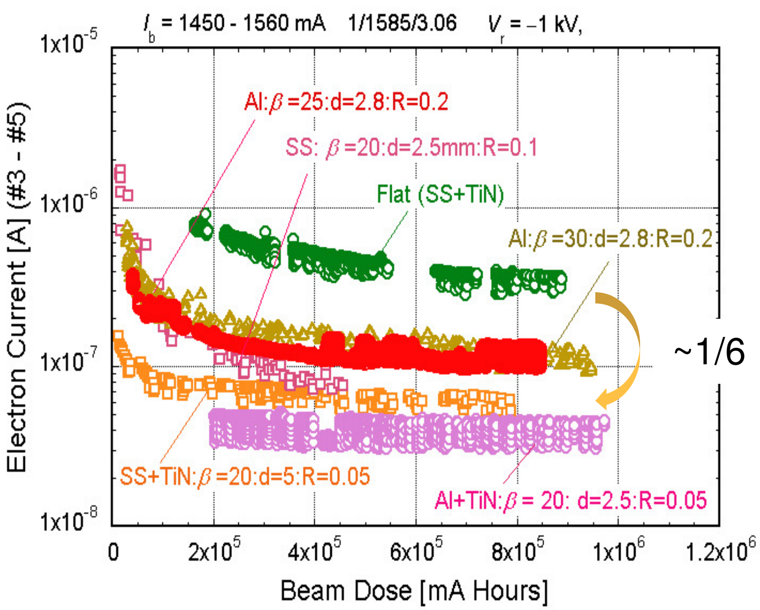


- Sharper edges and smaller angles give lower SEY
- Shallower groove has smaller impedance.

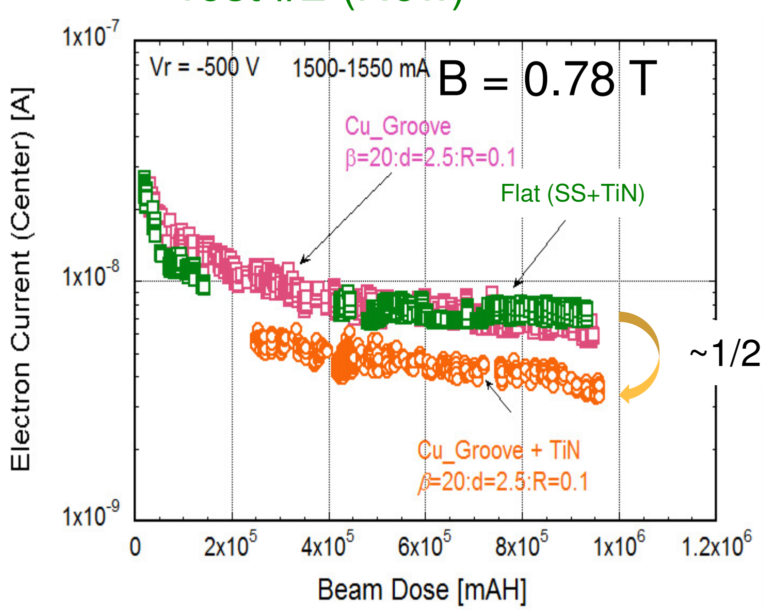
Bend section_3

- **Grooves at top and bottom**
  - Have been tested in KEKB wiggler using two setup.
  - Reduction rate for the groove with R0.1, β 20°, TiN coating:
    Test#1: ~1/6
    Test#2: ~1/2 (still in aging process?) : Similar value to that in the experiment at CESR-TA (beam condition is different)
  - Reduction rate: ~1/4 (two grooves at top and bottom)

Test #1



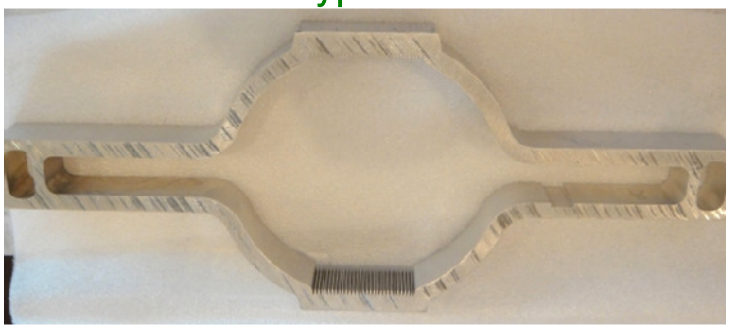
Test #2 (New)

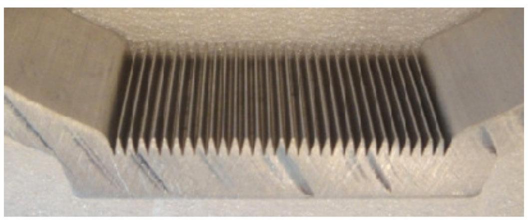


Bend section_4

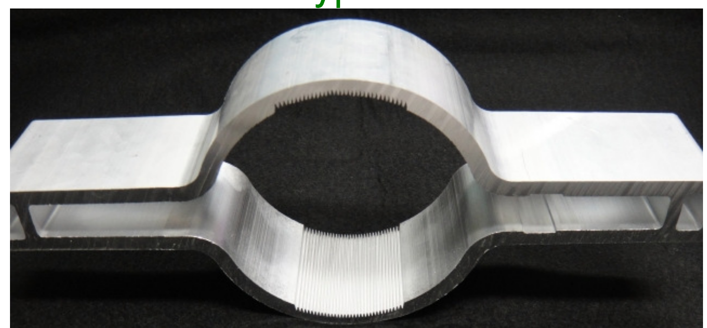
- **R&D on forming of grooves by extrusion (aluminum)**
  - Two test beam pipes with groove were manufactured
  - Different manufacturer

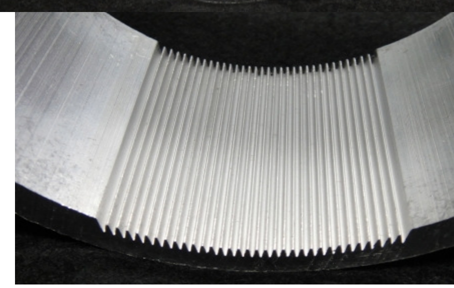
Type 1

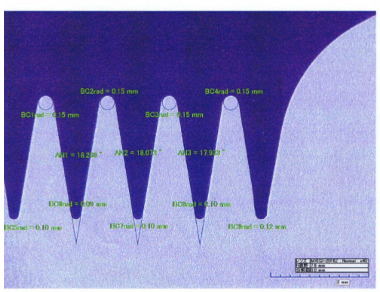




Type 2







Valley :
R0.10~0.12
Top : R0.15
Angle : 18°~18.3 °

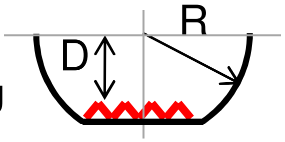
Valley : R0.11~0.13
Top : R0.14~0.16
Angle : 21.5 ° ~22.5 °

A little more improvement is required.

Bend section_5

- **Impedance of grooves**
  - Grooves are top and bottom
  - Incl. 50 % increase of resistive wall impedance (over estimation?)
  - 520 m out of 3016 m (17%)
  - Length:1m/groove, tilt angle:10 mrad
    proportional to the length (overestimation?)

D=40
R=45
d = 3
20 deg



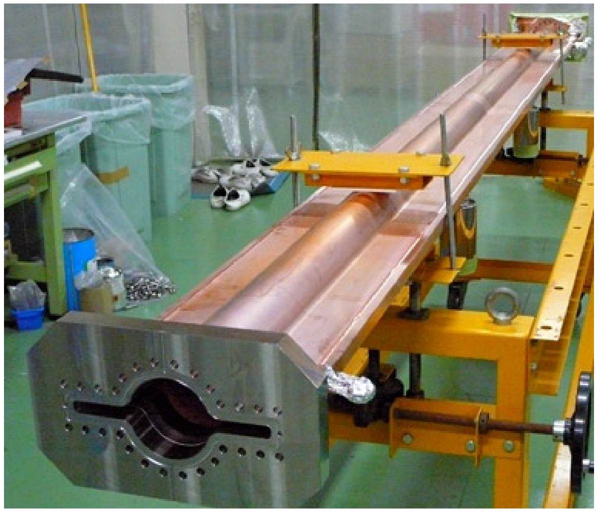
Total loss factor	O	8×10[11] V/C << 1.8×10[13] V/C in total
Microwave instability	O	By simulation (using wake potential)
Transverse single bunch instability		Estimation has just begun.
Transverse mode coupling instability	O	Total kick factor ~ 5×10[12] V/C/m. Threshold bunch current ~ 1400 mA/bunch.

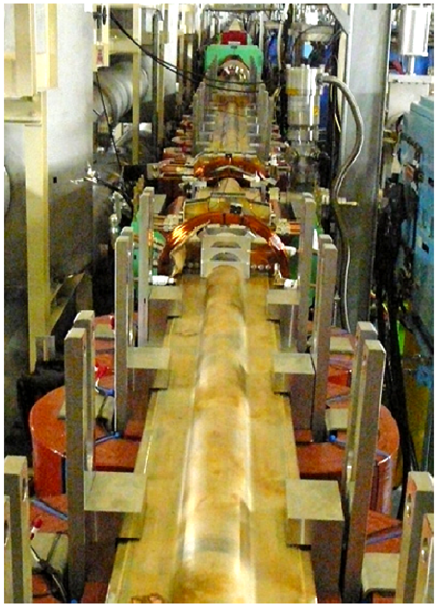
- The loss factor and kick factor changes 3~4 times for the tilt angles of 0 ~ 10 mrad.
- No groove for the drift section and Q and Sx section.
  ← small merit compared to the increase in impedance

Wiggler section_1

- **Beam pipe with antechambers**
  - Material: copper ← High SR power
- **Solenoid:** Gaps between magnets (small part)
- **TiN coating:** Quadrupole magnets section (small part)

Wiggler section

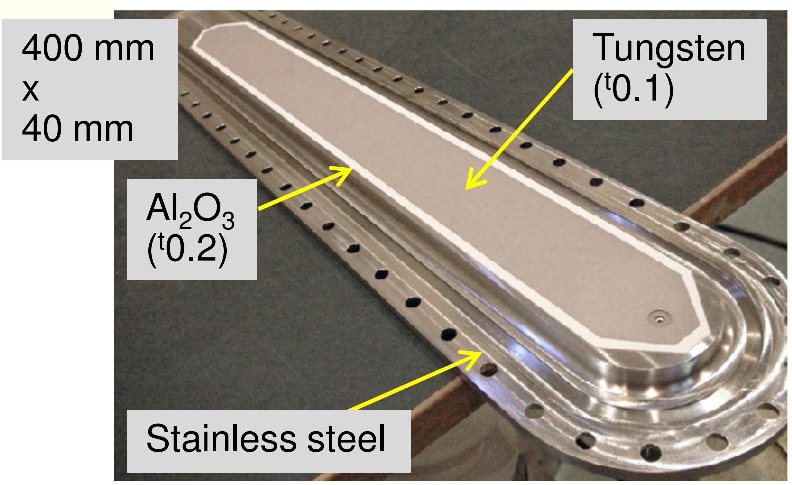


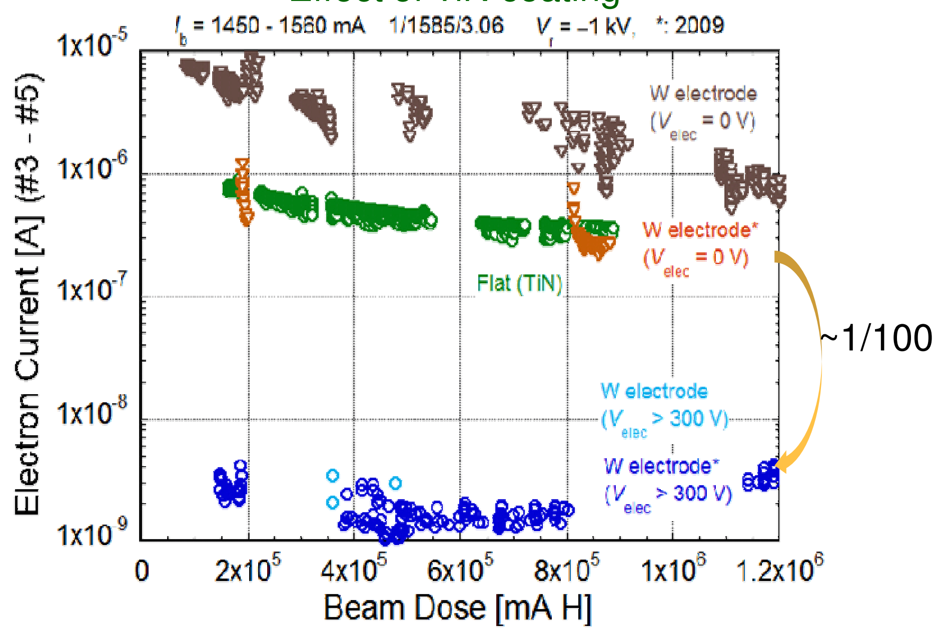


Wiggler section_2

- **Clearing electrode**
- Very thin electrode
  - 0.2 mm Al_2O_3 and 0.1 mm tungsten
  - Small impedance and high thermal transfer
- Reduction rate: ~1/100
  - Very effective in KEKB wigglers
  - Demonstrated also in CESR-TA, CERN (proton)

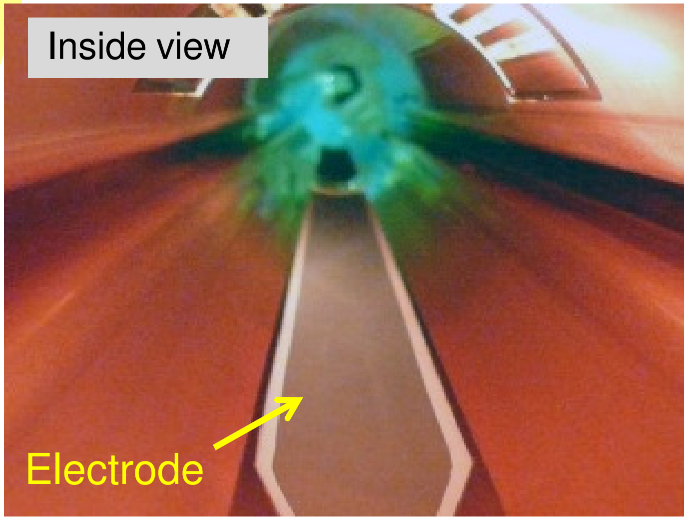
An insertion for test with a thin electrode

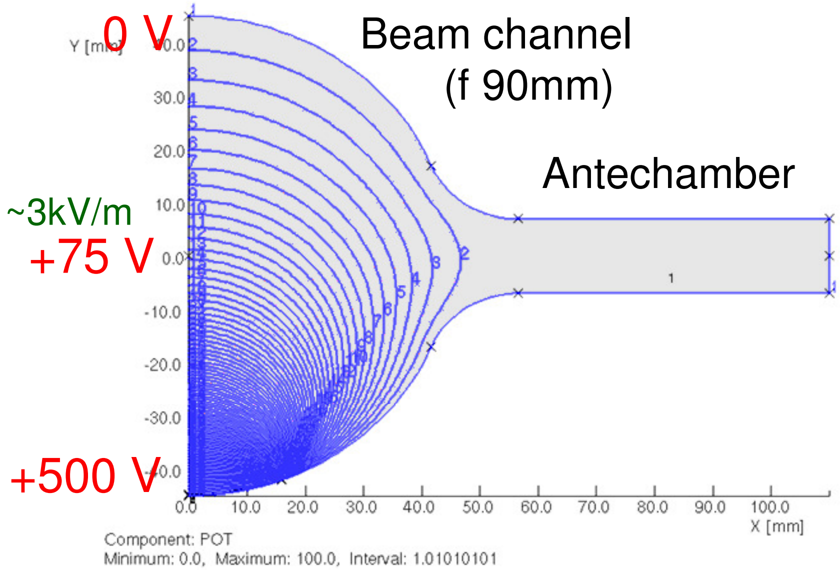


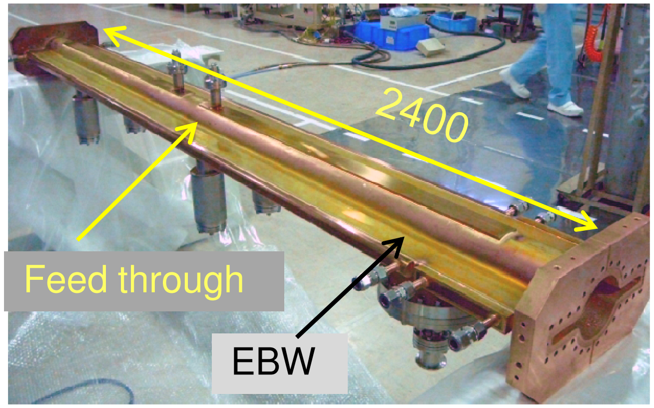


Wiggler section_2

- **R&D using a real beam pipe with antechambers**



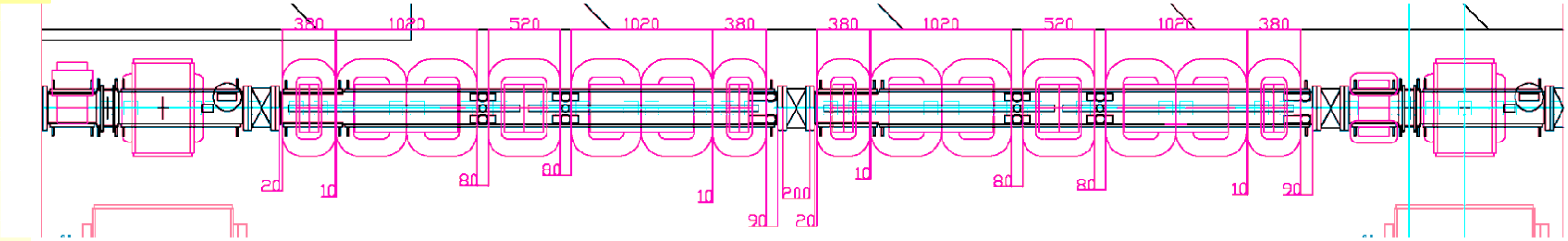




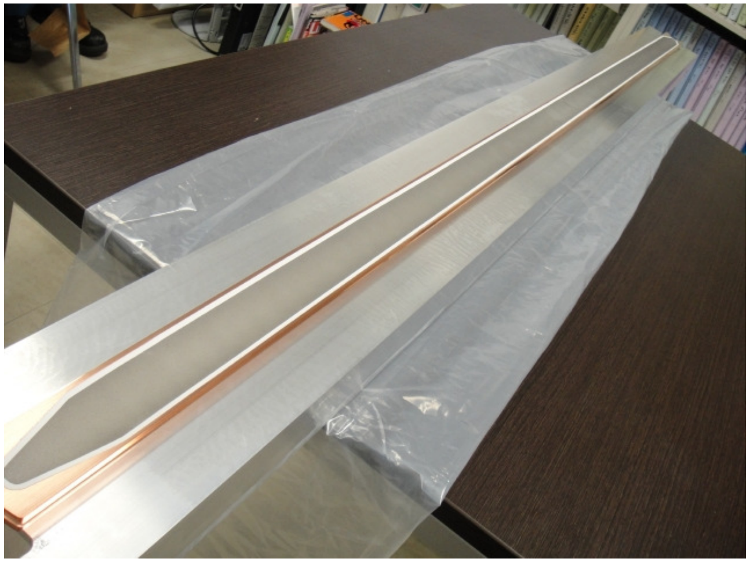
- No reduction in the insulation resistance after approximately 4 months beam operation.
- Long stability is not yet proved. But the effect is attractive.

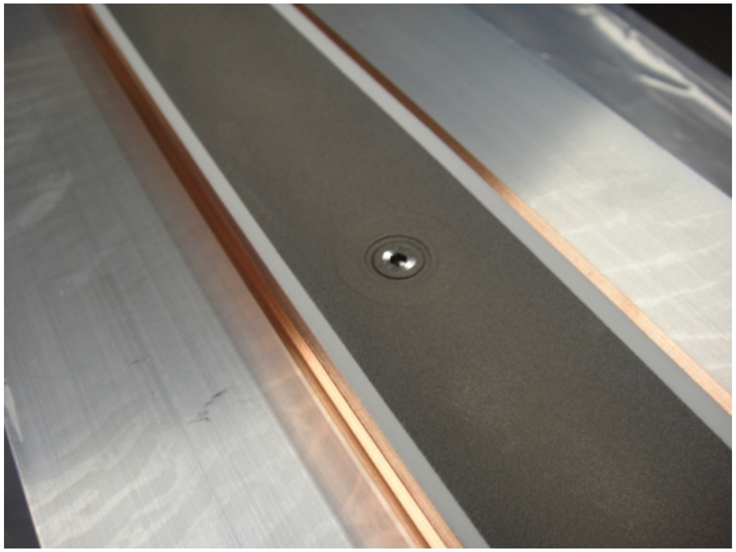
Wiggler section_4

- **Beam pipes for the wiggler section has already started.**
  - 1.6 m electrodes are under manufacturing.



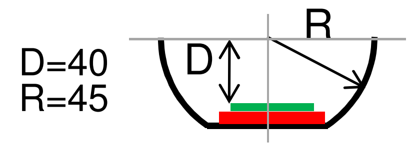
1.6 m clearing electrode block





Wiggler section_5

- **Impedance of electrode**
  - One electrode at top
  - Total length of the electrodes is approximately 160 m (100 electrodes) out of 3016 m circumference (5%).
  - Including the resistive wall of tungsten
  - Length: 1m/electrode, width:40 mm
  - proportional to the length (overestimation?)

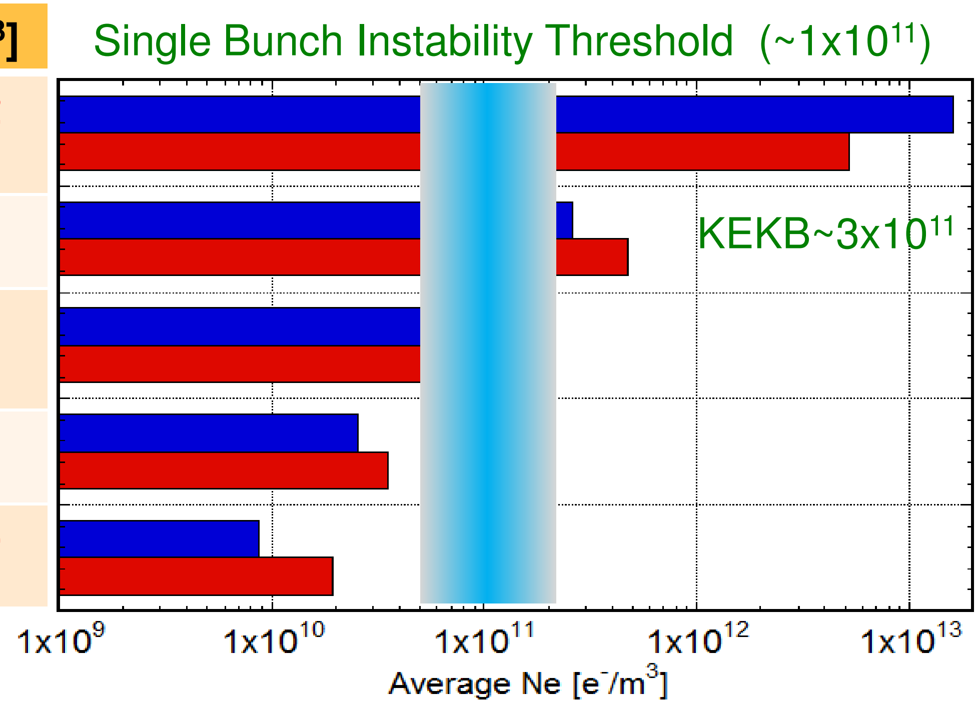


Total loss factor	O	1.7×10^{11} V/C << 1.8×10^{13} V/C in total for one ring
Microwave instability	O	By simulation (using wake potential)
Longitudinal coupled bunch instability	O	Total $R_s \leq 100\ \Omega$, $R_s/Q = 0.1\sim1$ Growth rate ~1 1/s < 30 1/s
Transverse single bunch instability		Estimation has just begun.
Transverse mode coupling instability	O	Total kick factor ~ 1.7×10^{13} V/C/m. Threshold bunch current ~ 400 mA/bunch.

Expected electron density

- n_e **after applying measures described so far (Red)**
- **n_e of approx. 1/5 of the threshold one is expected.**
- Compared with results of CLOUDLAND (Blue)
  - δ_{max}=1.2, Solenoid field=50G (→n_e=0), Antechamber; photoelectron yield =0.01 (1/10)

Condition	ne [m^{-3}]
Circular Cu chamber [KEKB beam pipe]	5.2E12
+Solenoid at Drift (1/50)	4.7E11
+Antechamber (1/5)+TiN (3/5)	5.7e10
+Electrode in Wiggler (1/100)	3.5e10
+Groove in Bend (1/4)	2.0E10



Low density in the simulation ← ne=0 by solenoid. Careful solenoid winding is important.

Summary_1

- Upgrade of KEKB to SuperKEKB has practically started.
- Change of the vacuum system is a main item in the project, and the electron cloud is a key issue.
- Countermeasures for main part are carefully chosen based on the various studies so far: Conservative ones for major parts, and new ones for small but key parts.

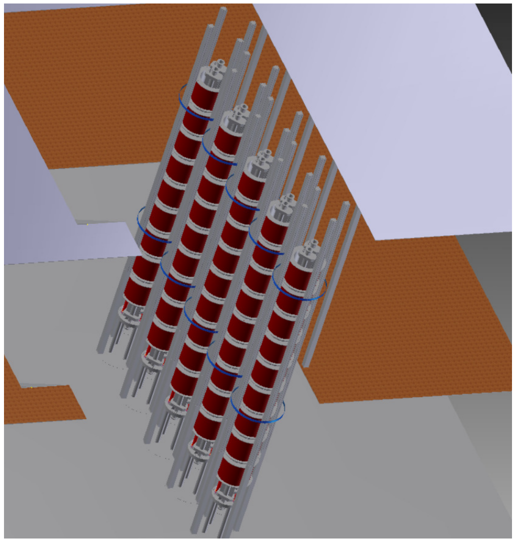
Main parts

Drift section	Antechamber +Solenoid +TiN Coating
Q and Sx mag.	Antechamber +Solenoid +TiN Coating
Bend section	Antechamber +Groove+ TiN Coating
Wiggler section	Antechamber +Electrode (Cu)

- n_e of approx. 1/5 of the threshold one is finally expected.
- The validity of these choices will be verified in several years.

Summary_2

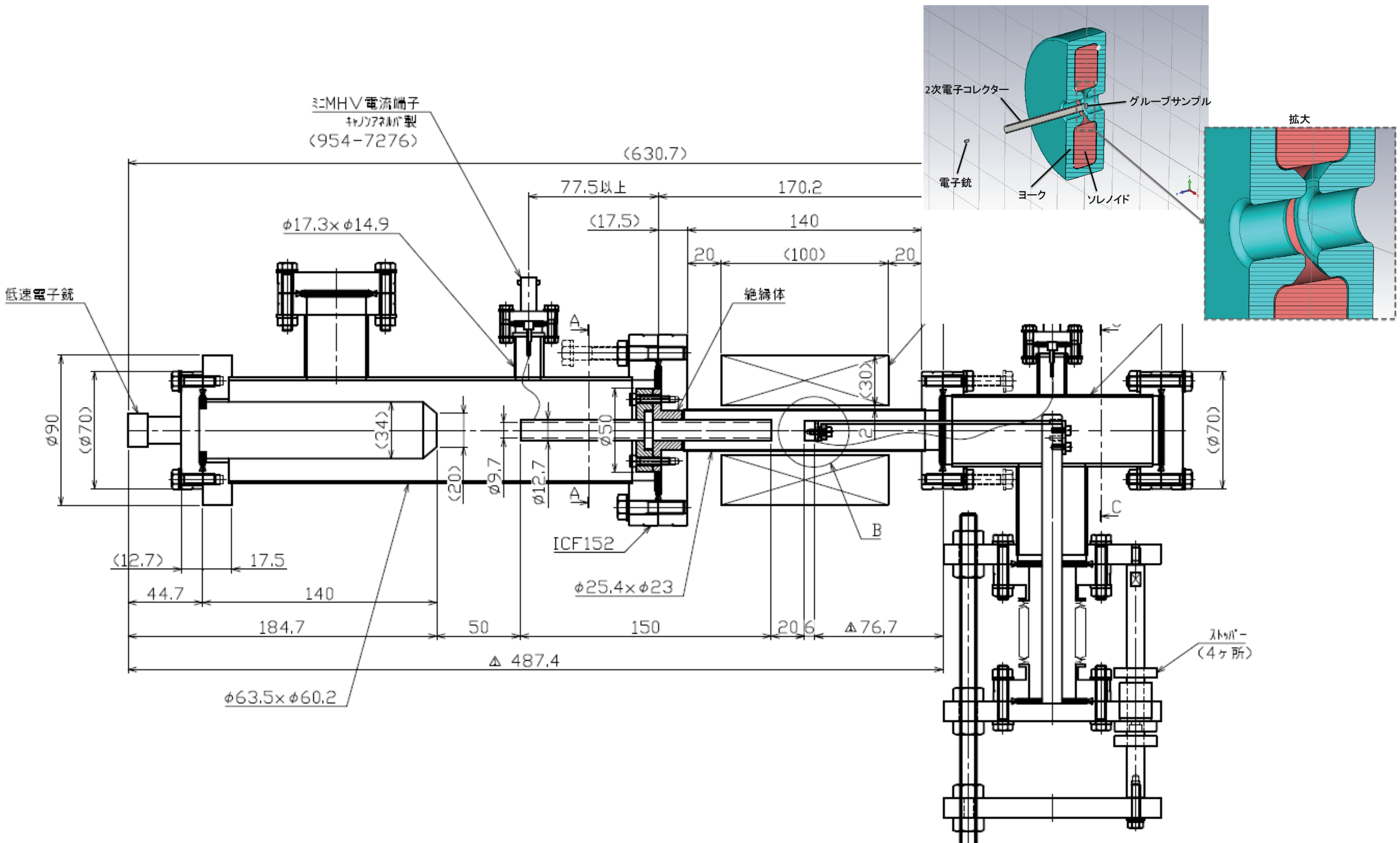
- A set up for the TiN coating is under consideration. The apparatus will be assembled next summer in KEK site.
- The coating will take ~ 1.5 years with 7 coating stations.



- Beam pipes for the wiggler section are in the process of production (delivered in this fiscal year)
- Beam pipes for arc section will be sent out for bids soon.
- Other special section will follow it.

R&D plans

- **Measurement of SEY in a vertical magnetic field**
  - In laboratory
  - The design of apparatus is undergoing



Acknowledgment

- I would like to thank my colleagues in KEKB accelerator division (Oide-san, Akai-san, Koiso-san,,), in SLAC (Pivi-san, Lanfa-san) and in CESR-TA (Palmer-san, Li-san, Billing-san,,,,,) and many other people in various institute for their cooperation, lots of suggestions and encouragement.

Thank you for your attention !