Present Status of R&D on Beam Duct with Ante-chamber, Movable Mask Ver.6, and Clearing Electrode for ECI

KEKB Vacuum Group
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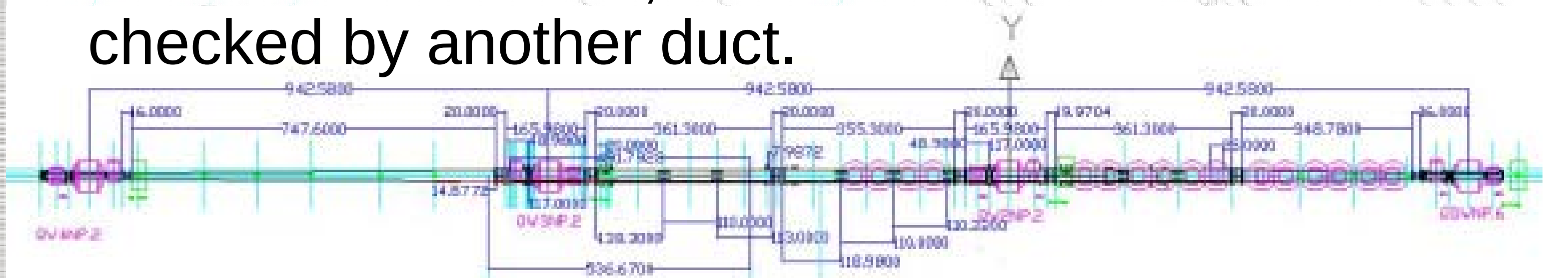
Beam duct with antechamber R&D so far

- We have been developing a copper beam duct with antechambers to reduce;
  - SR power density at side wall.
  - Electrons in a beam channel (for positron ring).
  - Beam Impedance.
- Two ducts for arc section and three ducts for wiggler section have been successfully manufactured by pressing or cold drawing method.
- They were installed into KEKB LER, and tested with beam.
- No serious problem up to 1.7 A (1389 bunches) has been observed for years.

Beam duct with antechamber 2007 summer

- New copper beam ducts were installed into Nikko wiggler section at the most downstream side of wiggler magnets (about 30 m long including tapers.)
- Seven ducts including two ducts with BPM for quadrupole magnets (Q-duct).
- Six bellows with comb-type RF-shield.
- Diameter of beam channel is 90 mm.
- Inside was coated with TiN (except for tapers).
- No electron monitor, and the effect of TiN will be checked by another duct.



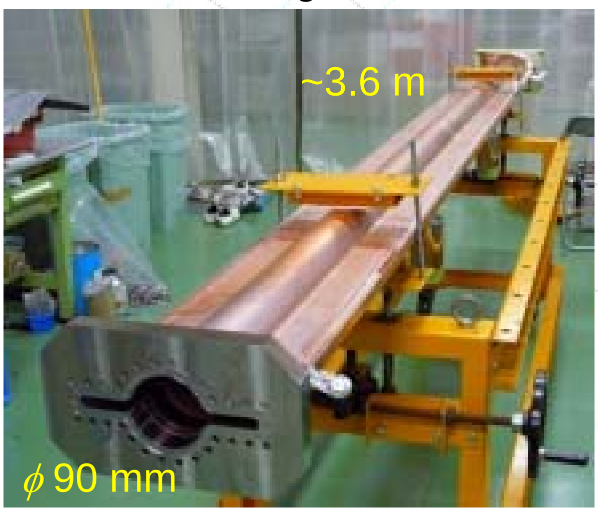
QW4NP.2 QW3NP.2 QW2NP.2 QDWNP.6

Beam duct with antechamber
Manufacturing

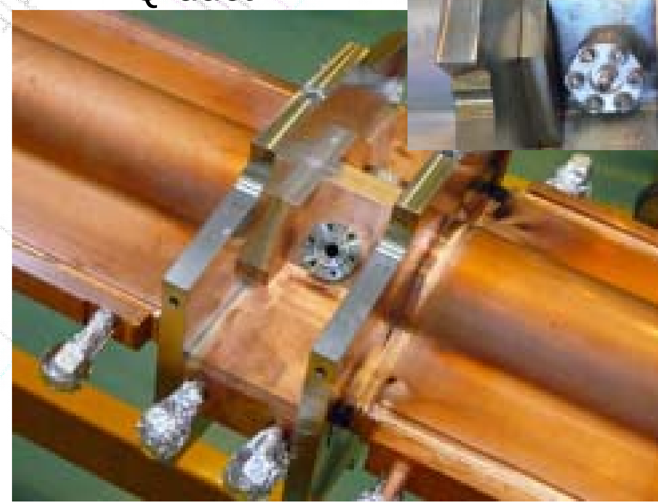
- Cold drawn copper pipe, and welded by EB.
- MO-type flange (stain-less steel).
- BPM electrode was connected by ICF flange.
- No mapping before installation;
  Gain mapping will be done by BBA

BPM

Straight duct

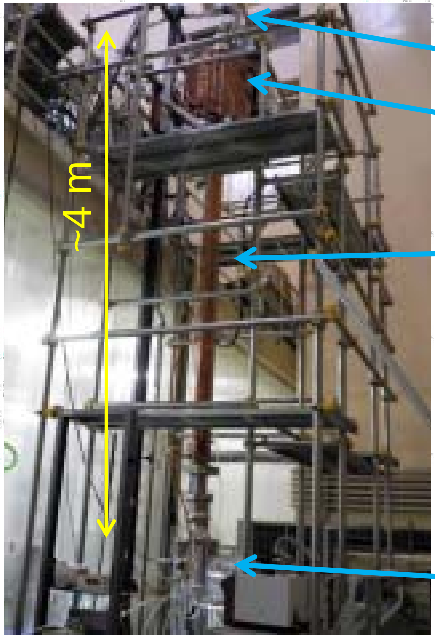


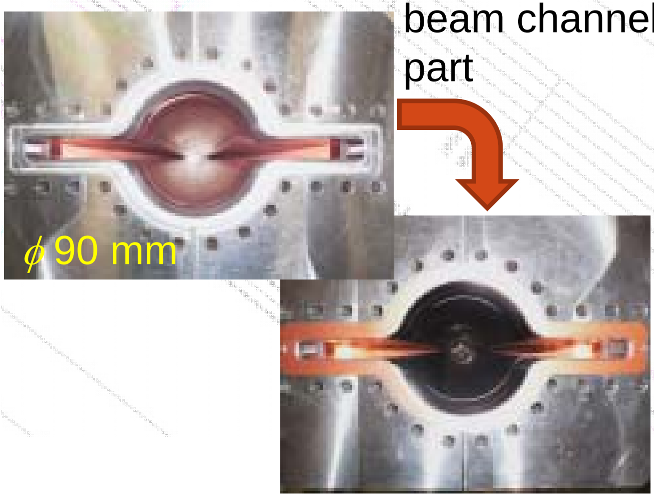
Q-duct



Beam duct with antechamber
TiN coating

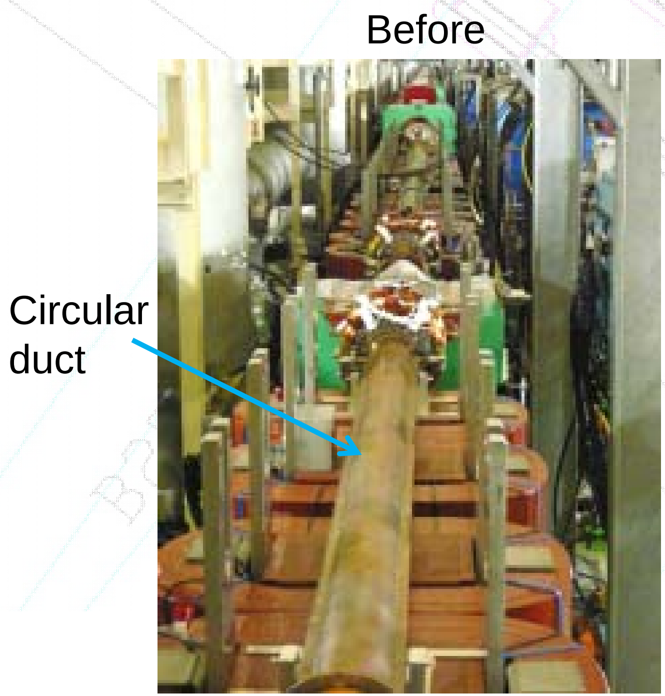
- TiN was coated in KEK (K. Shibata et al.)
- Coating system available for ~4 m pipe was set up.
- Thickness is ~200 nm, which is determined from adhesiveness of film and δ_{max} (~0.84).

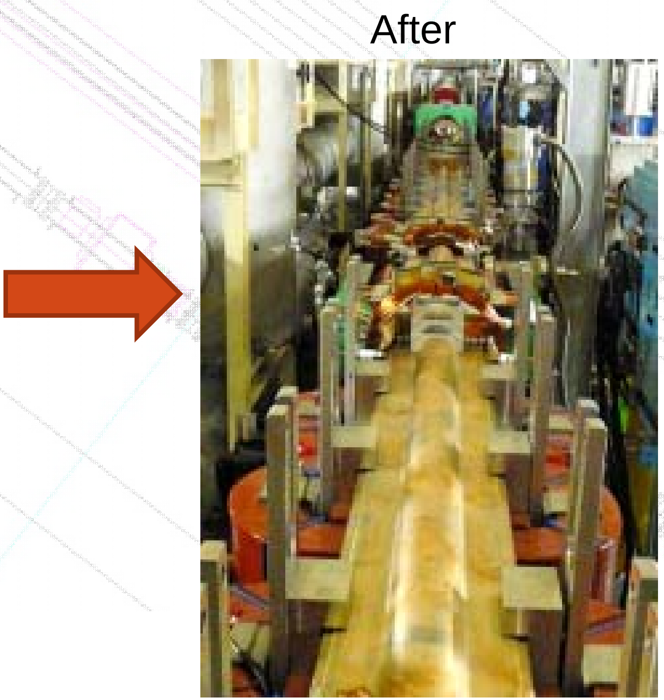




Beam duct with antechamber Installation

- Installation was successful (~1 week).
- With a help of other groups, such as RF, Magnet, Monitor and Cryogenics groups.

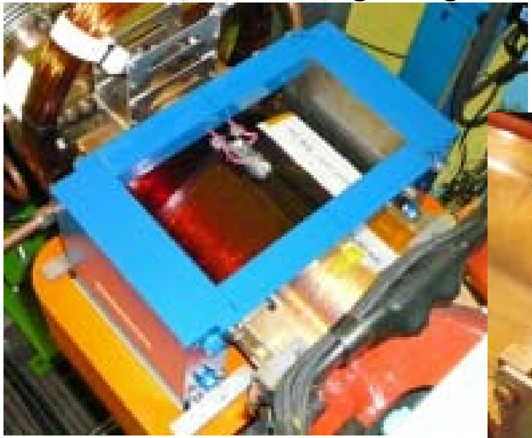




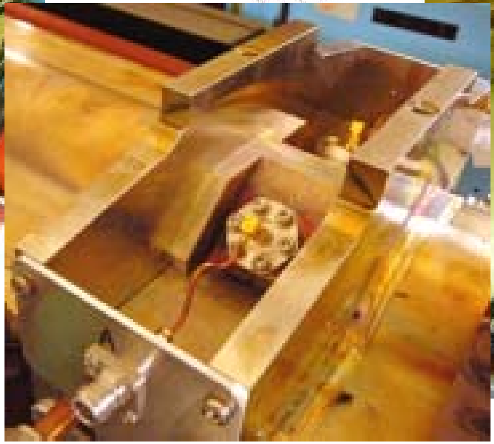
Beam duct with antechamber BPM and magnet

- New wide vertical steering magnets were prepared to fit wide ducts (~280 mm gap).
- BPM system is the same as that of KEKB.
- Solenoids were wound at drift space.

Wide vertical steering magnet



BPM system

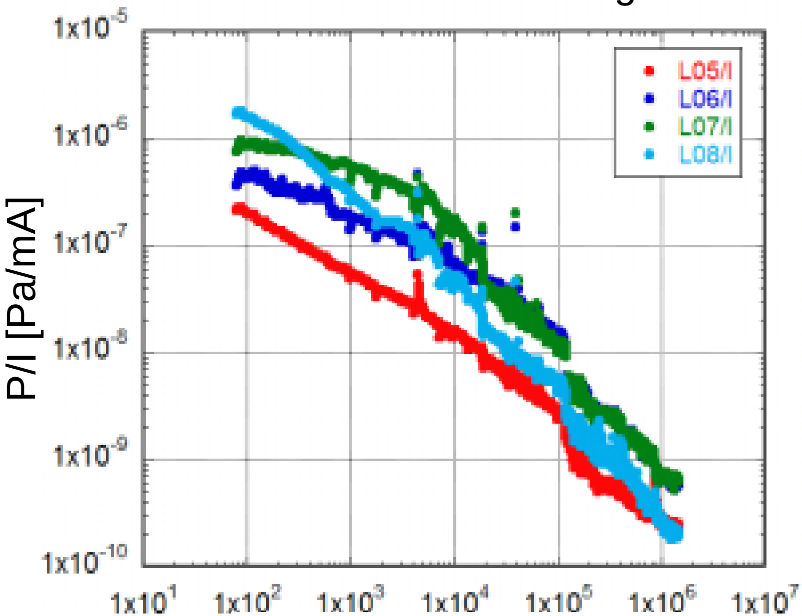


Solenoid at drift space

Beam duct with antechamber
Beam test

- Beam test started in October.
- Vacuum pressure is still a little higher than neighborhood, but the vacuum scrubbing is smoothly proceeding.
  - High SR density
  - Relatively low pumping speed
- No excess heating of bellows chambers.
- A big problem was a vacuum leak at flange.

Vacuum scrubbing



Beam duct with antechamber
Problem

- Just after starting the beam test, a vacuum leak had occurred at a flange connection (~1×10^{-3} Pam^3/s).
- Pressure increased just after a beam abort.
- That flange was extremely heated up.
- Color of copper gasket was found to be changed at the antechamber section due to over heating.
- Local heating of gasket
  → plastic strain by heating
  → contraction after beam abort
  → vacuum leak

Gasket in trouble

Beam duct with antechamber

Cause

- It was found that the height of bellows was lower by 3 - 4 mm from a nominal one.
  →The SR hit the upper part of flange.
  - About 50 W → over 250°C

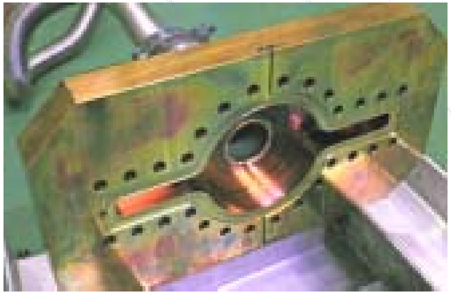
- Careless mistake, but the trouble taught that;
  - A careful alignment is important, especially for a straight section, where SR from far upstream magnet passes through the antechamber.
  - Any cures will be required considering unexpected steering of beam, even for arc sections.
    - Water cooling, Copper alloy flange, SR masks, etc.
  - Careful control of beam orbit is also important.

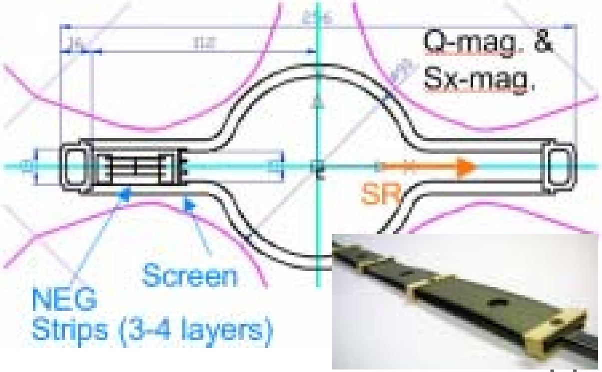
Beam duct with antechamber R&D in progress

- Ducts for a bending magnet (B-duct)
  - Now manufacturing with a curvature of 16 m (for LER) using a cold drawn pipe.
- Development of pump system installed in ante-chamber.
  - Ex., three layers of ST707 strips.
- Copper alloy flange.
  - Ex., Zr-Cr-Cu or Cr-Cu
- Check TiN effect using ante-chamber.

Bending test

Copper alloy flange test



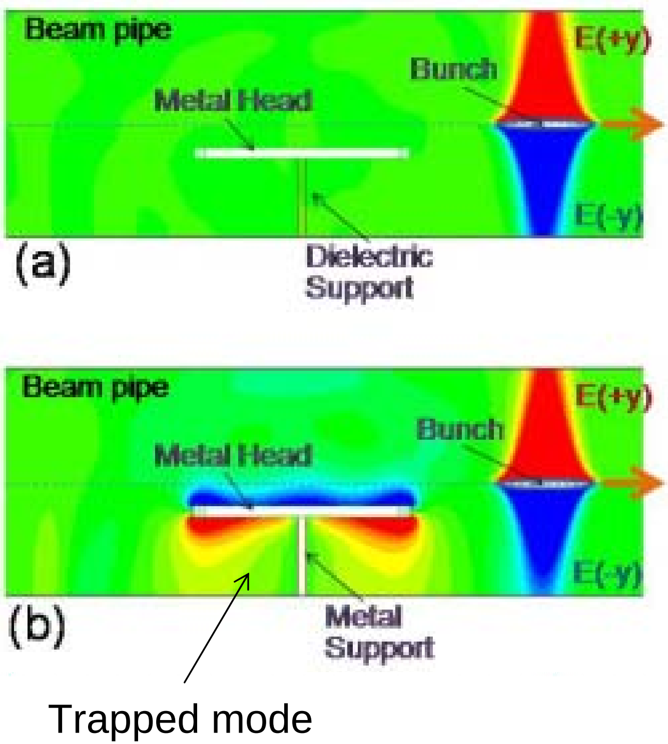


Beam duct with antechamber
Summary

- R&D for key components for the vacuum system with ante-chamber scheme has almost completed.
- Remained important issues for the concrete design of Super KEKB;
  - Optimization of beam duct shape.
    - CSR effect, Resistive wall effect, Conductance, Impedance, ….
  - Deformation of beam duct by heating.
    - Displacement gauge for BPM, Rigid duct support?, ….
  - ECI cure in magnet
    - Drift space :TiN coating + Solenoid will be OK.
    - In magnet ? TiN coating + ??? [See the last topic]
  - Design of special components
    - septum, abort window, …
  - Design of vacuum system at IR.
    - How to deal intens SR power,…

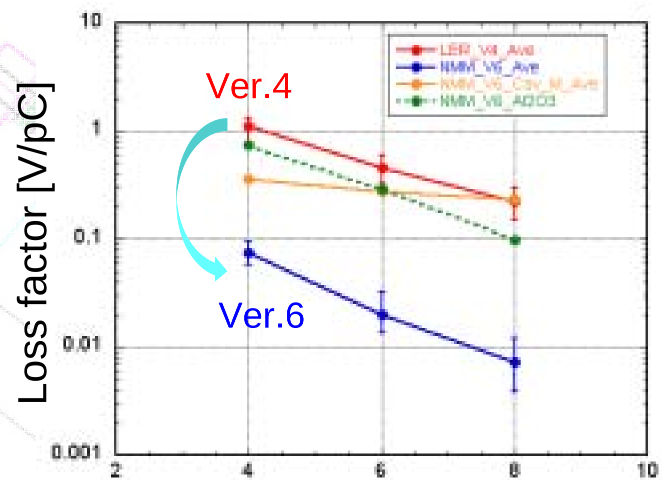
Movable Mask Ver.6 Concept

- Proposal :Metal head supported by dielectric material



  - Little interference with beam
  - Small impedance

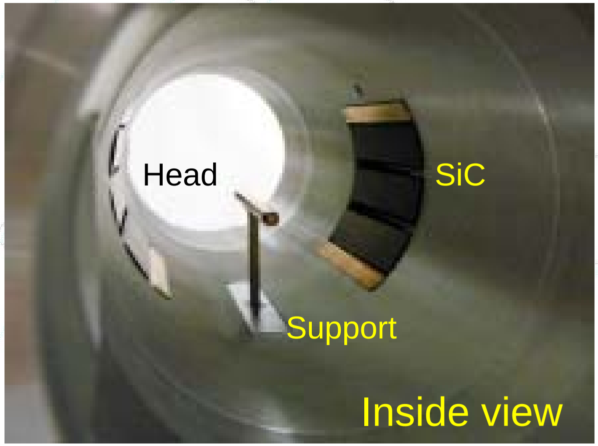
Loss factor



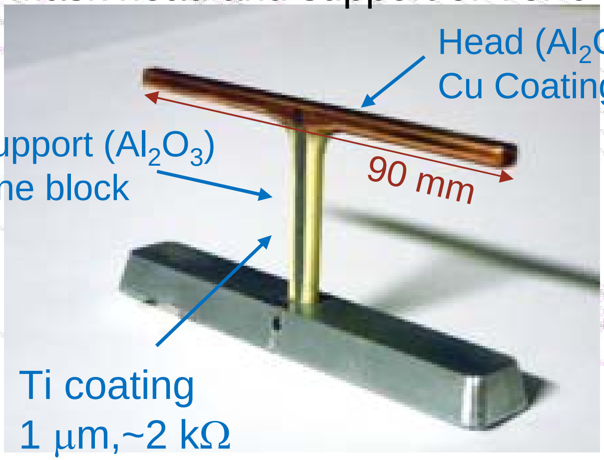
Movable Mask Ver.6
The first test model (Ver. 6.0)

- In 2006, Ver.6.0 was manufactured.
- Head: Al_2O_3 Coated with copper
- Support: Al_2O_3 (Ti coating at one side)
  - Head and support was shaped as a unit.
- HOM absorber: SiC (Inside of chamber)
- Installed into LER for proof of concept.

Inside view of mask chamber

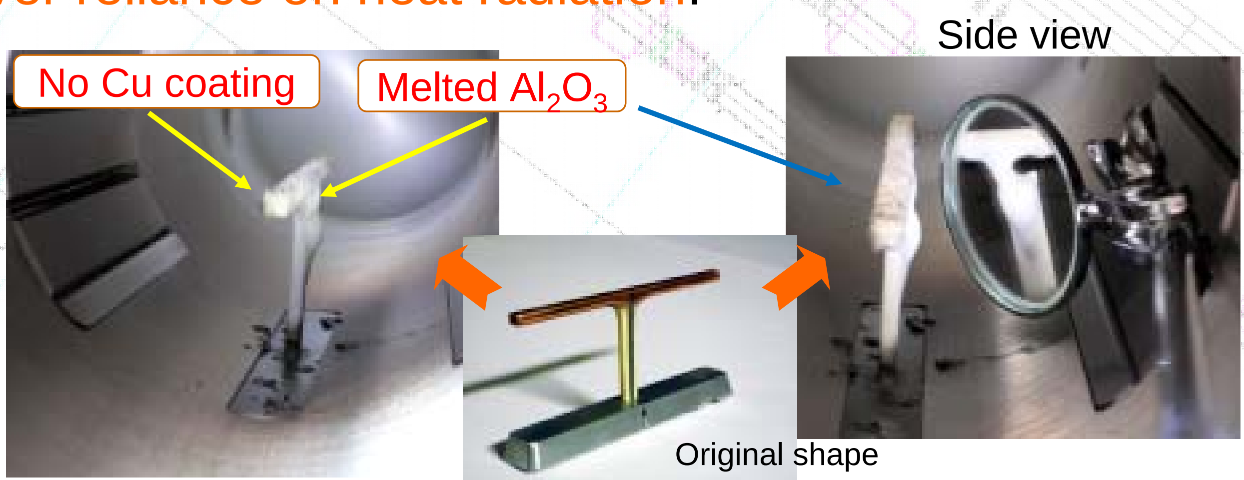


Mask head and support of Ver.6.0



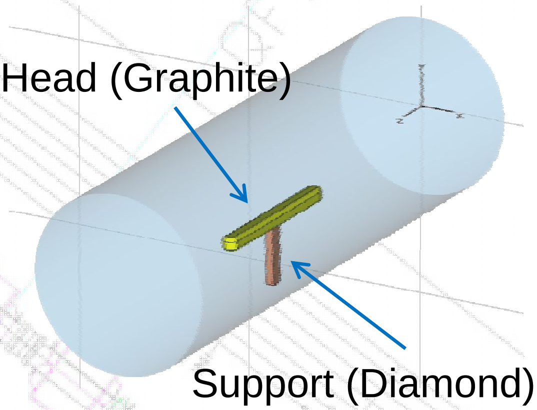
Movable Mask Ver.6
Problem

- Excess heating was observed from the beginning.
- At 700 mA (1389 bunches), copper coating had evaporated, and Al_2O_3 had melted! (spring, 2007).
- Cause：
  - The head with Cu coating shaped a cavity.
  - Underestimate of tanδ; temperature dependence of tanδ was not considered.
  - Over reliance on heat radiation.



Movable Mask Ver.6
Next model (Ver. 6.1)

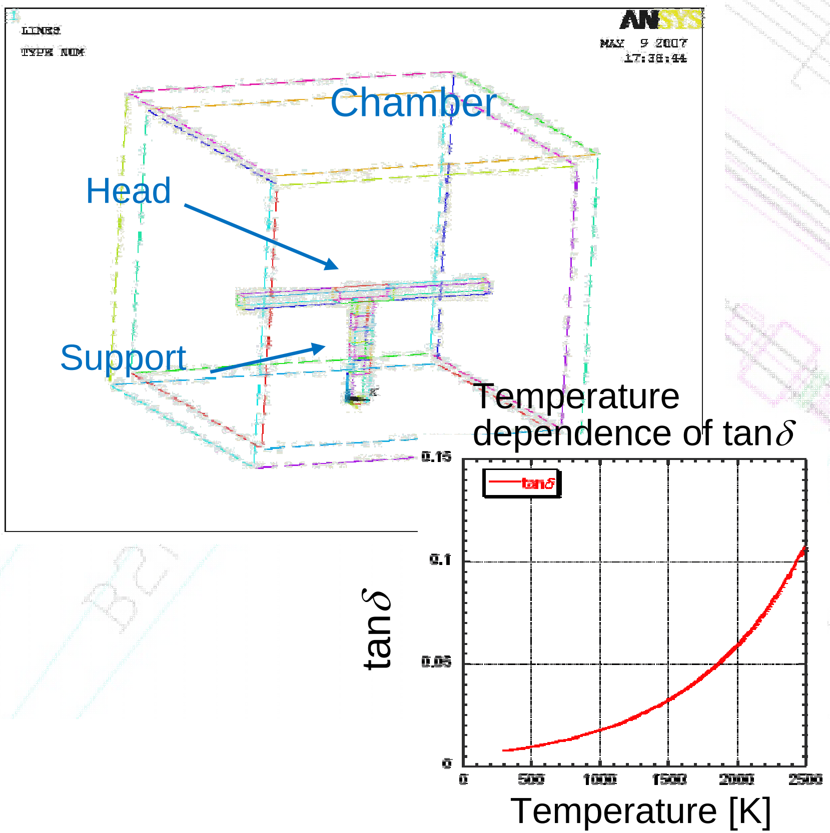
- Ver. 6.1 was designed based on the trouble of Ver. 6.0.
  - Return to original structure.
  - Improvement of thermal strength.



- Head: Graphite
  - $\sigma_c = 2 \times 10^5$ 1/Ω/m (electric conductivity)
  - k = 0.1 W/mm/K (thermal conductivity)
  - Available temperature > 3000°C
- Support: Artificial diamond (mechanical grade)
  - ε_r = 6.0 (relative dielectric constant)
  - k > 1 W/mm/K (cf. copper: k ~ 0.4 W/mm/K)
    →Heat transfer via support can be expected.
  - Available temperature ~ 1500 °C (before carbonization)

Movable Mask Ver.6 Estimation of temperature

- Analysis by ANSYS



- Input power
  - Head: Joule loss and trapped modes.
  - Support: Dielectric loss
- Including exponential dependence of tanδ on temperature.
- Radiation

Movable Mask Ver.6
Temperature for some materials

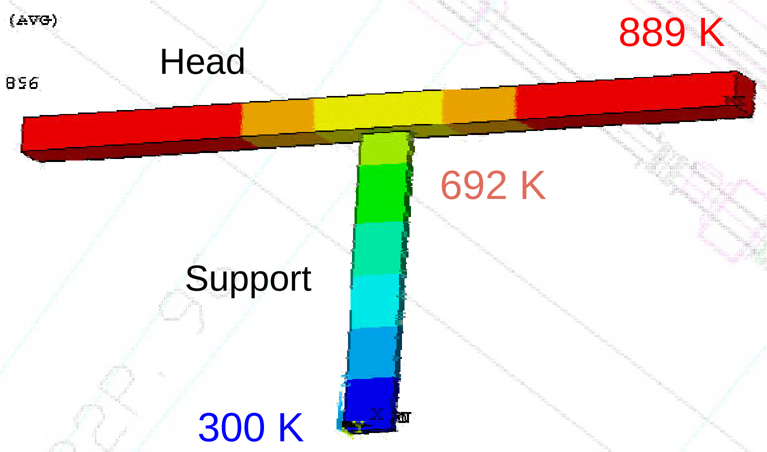
- Max. temperature of support

Preset KEKB

Head material	Support material	Max. T (K) (I^2/N=353)	Max. T(K) (I^2/N=2000)	
Cu (Coating)	Al_2O_3	(980 @42mA,#51)		Ver.6.0 (Initial)
Al_2O_3	Al_2O_3	2607		Ver.6.0 (No Cu coating)
Graphite	Al_2O_3	800	N/A (Thermal run away)	Reproduce the trouble
Graphite	Quarts (SiO_2)	706	N/A (Thermal run away)	
Graphite	AlN	~480	1220	
Graphite	BN	~580	1078	
Graphite	DIamond	~410	~700	Ver.6.1

Movable Mask Ver.6 Estimation of temperature

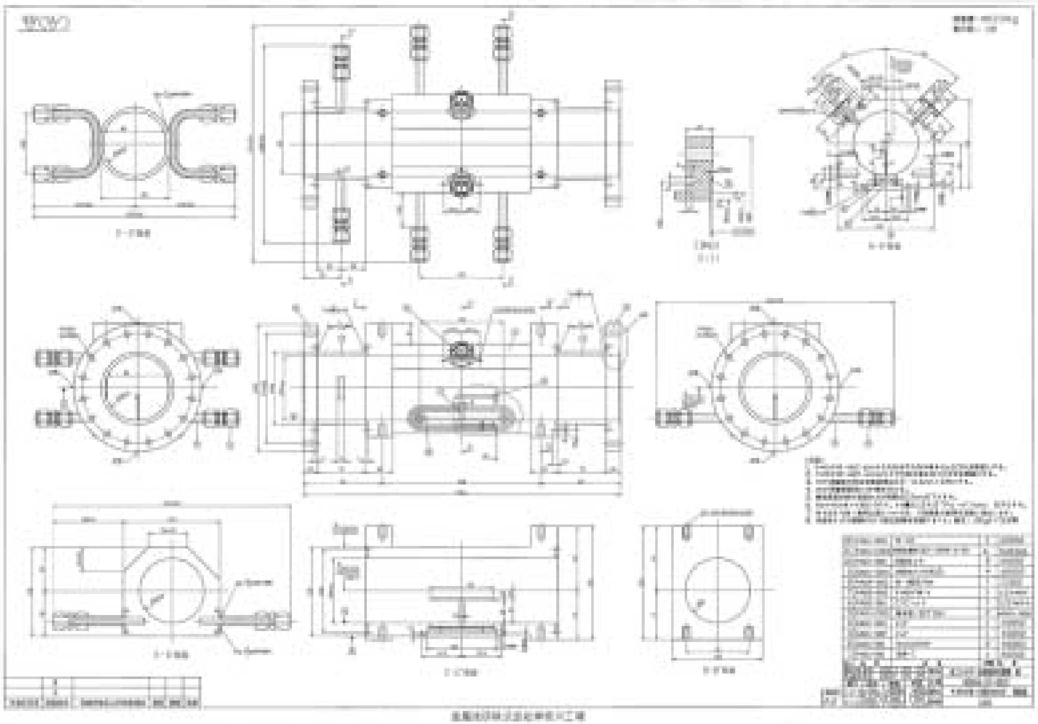
- Analysis by ANSYS



- At 1.7A (1389 bunches).
- Input power
  - Head: 67.5 W
  - Support: 7.7 W
- Max. T：616°C @Head and 430°C @support
- tanδ = 0.0128 (@~700K)

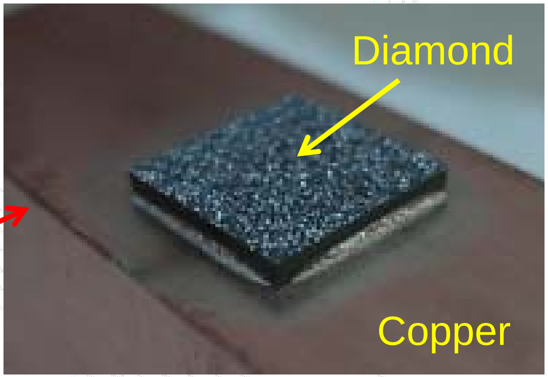
Movable Mask Ver. 6
Ver. 6.1

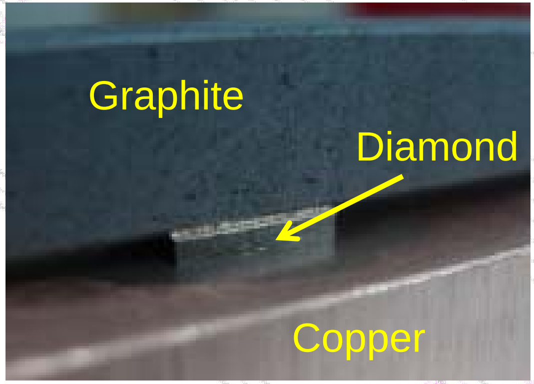
- Now chamber was under manufacturing.
  - The chamber has the same structure with that of Ver.4.
  - The chamber will be installed this winter (January).



Movable Mask Ver.6
Test for manufacturing

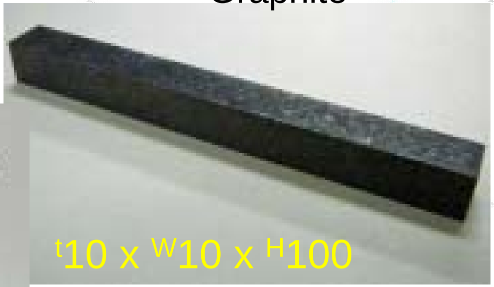
- Blazing test
  - Wetness between diamond and blazing filler metal.
  - Brazing between copper and diamond.
  - Blazing between diamond and graphite. (+mechanical fix)
- Forming of graphite and diamond





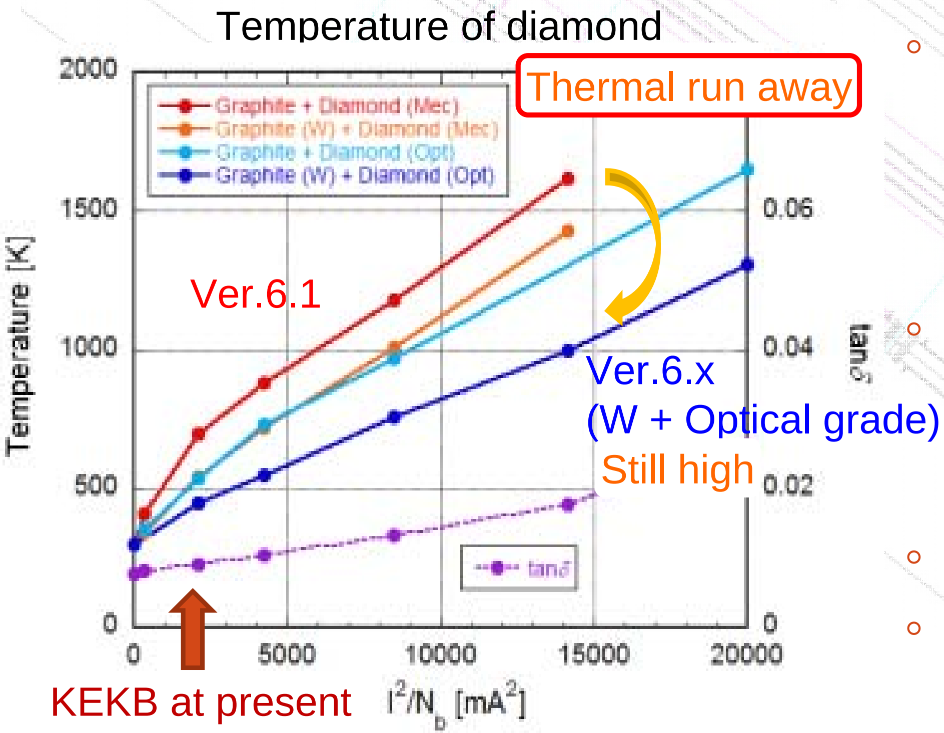
Diamond

Graphite



Movable Mask Ver.6
Issue of Ver. 6.1

- Ver.6.1 will be not available for 10A @5000 bunches, if nothing is done.



- Ver.6.x
  - Head：Graphite + Tungsten coating
    - Thermal spray：Used for fusion reactor.
    - Higher electric conductivity.
  - Support：Optical-grade artificial diamond
    - Higher thermal conductivity, but expensive.
  - Structural change.
  - Further investigation is required.

Movable Mask Ver.6
Summary

- Ver.6.1 are under manufacturing based on the experiences of Ver.6.0.
- Ver.6.1 will be tested using LER next February.
  - Proof of concept (revenge of Ver.6.0)
  - Data taking for the case of further high current
- Ver.6.x should be considered for Super KEKB (10 A at 5000 bunches).

Clearing Electrode Background

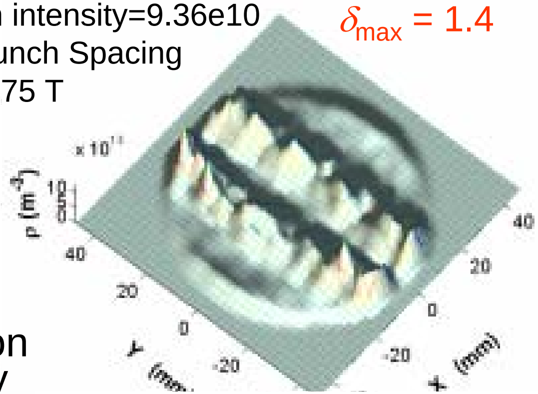
- A solution to suppress electron cloud in magnets.
- Experimental study on a clearing electrode using KEKB positron ring is planed.
- The experiment is also a chain of ILC DR R&D study.
  - With H. Fukuma (KEK), M. Pivi and L. Wang (SLAC)
- Goal
  - Establish the technique of clearing electrode for ECI, which is available for high current machine and with a low beam impedance.
  - Demonstrate the effect on electron cloud formation.

Clearing Electrode
Effect of electrode

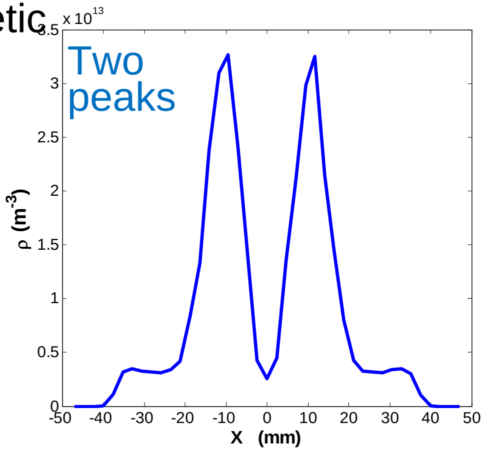
- Simulation (by L. Wang)

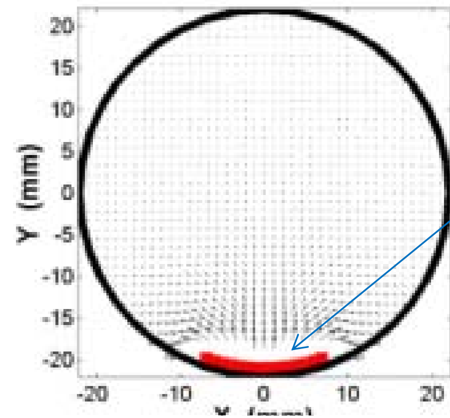
R-pipe=38mm
bunch intensity=9.36e10
3.5 Bunch Spacing
B = 0.75 T

$\delta_{max} = 1.4$

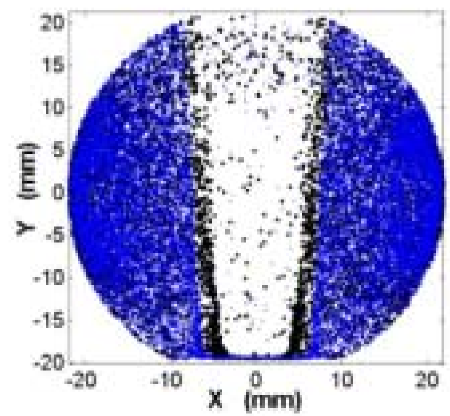


Electron density in magnetic field





Electrode (+)



L. Wang et al, EPAC2006, p.1489

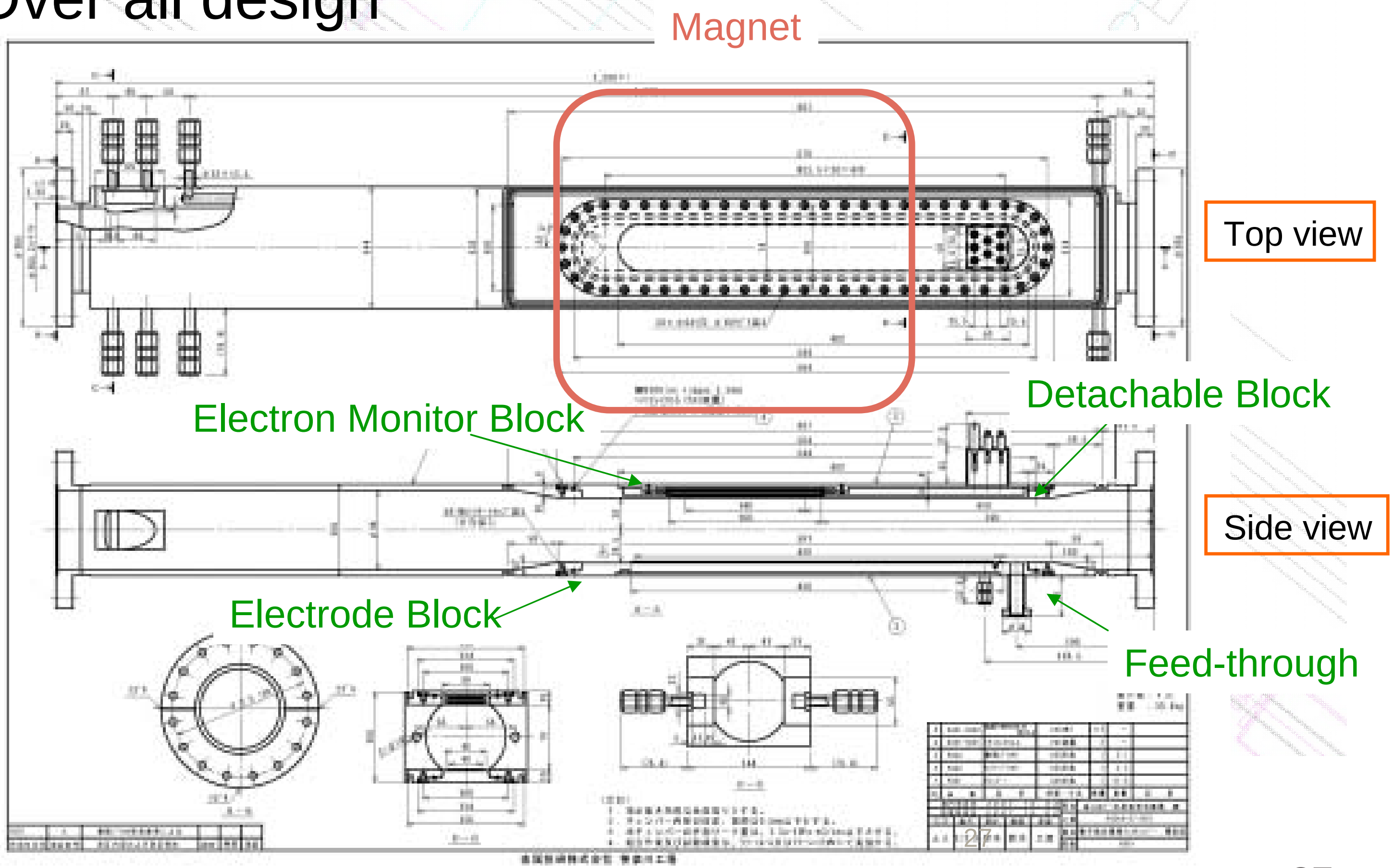
Clearing Electrode
Test plan

- Install a test chamber with a electron monitor (bottom) and a clearing electrode (top) into a wiggler magnet of LER.
  - At the most upstream side of wigglers
    - Very weak SR
  - Magnetic field: 0.75 T
  - Effective length: 346 mm
  - Aperture (height): 110 mm

Wiggler magnets

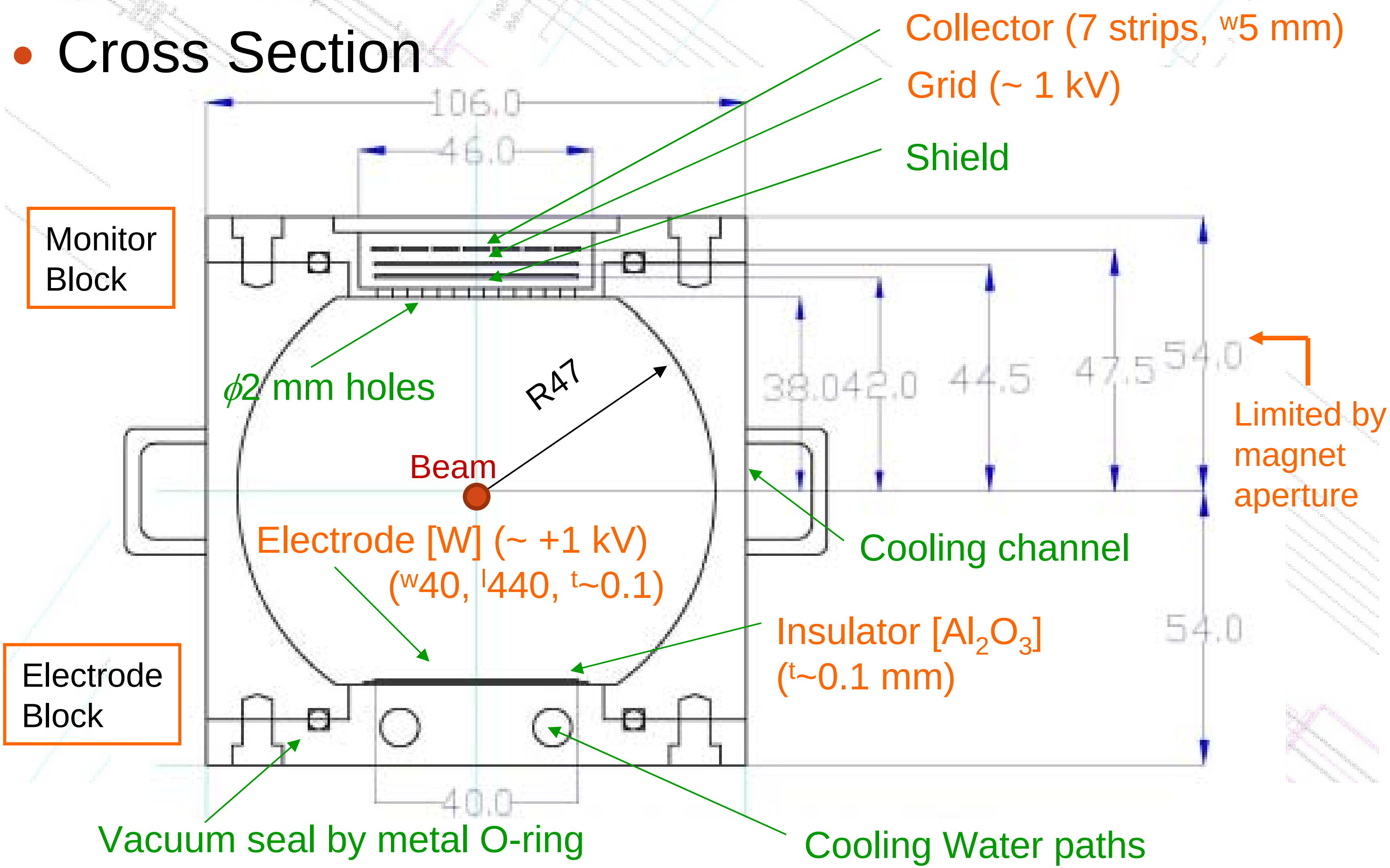
Clearing Electrode Test Chamber

- Over all design



Clearing Electrode
Monitor and electrode

- Cross Section

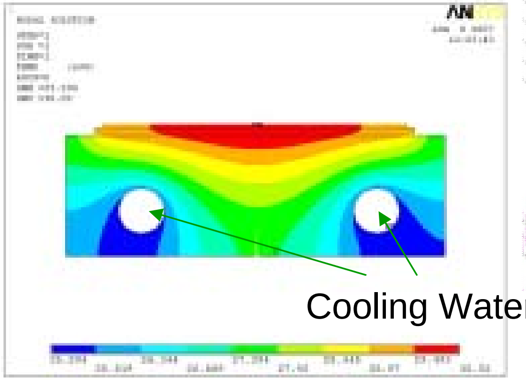


Clearing Electrode

Features of test chamber

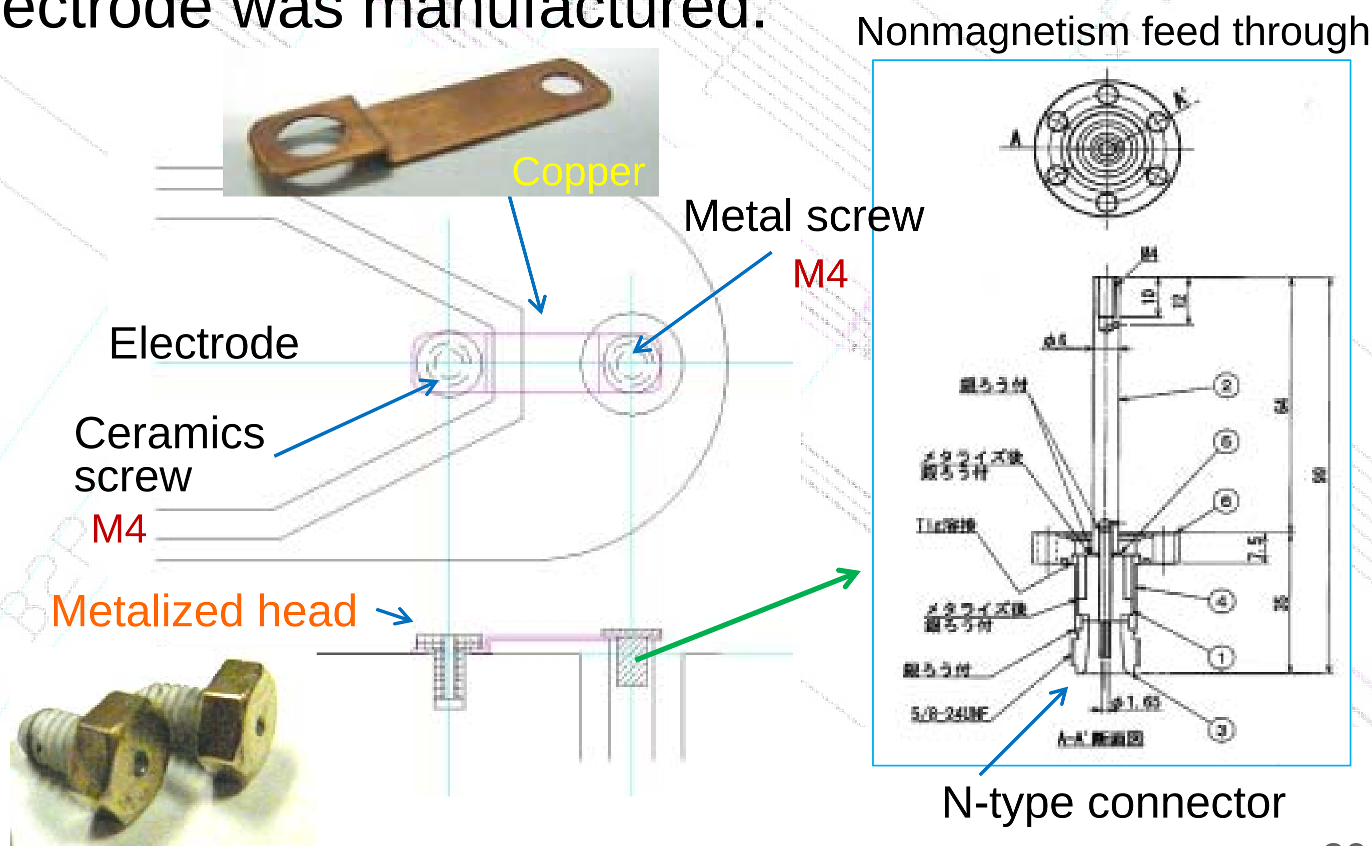
- Strip type electrode.
- Monitor and electrode are exchangeable.
- Electron collectors are seven strips to measure the spacial distribution.
- Very thin electrode and insulator.
  - Electrode: ~0.1 mm, Tungsten, by thermal spray.
  - Insulator: ~0.1 mm, Al_2O_3, by thermal spray.

  →Small beam impedance.
- Water cooling beneath the electrode.
  - Absorb dissipated power in electrode and insulator.



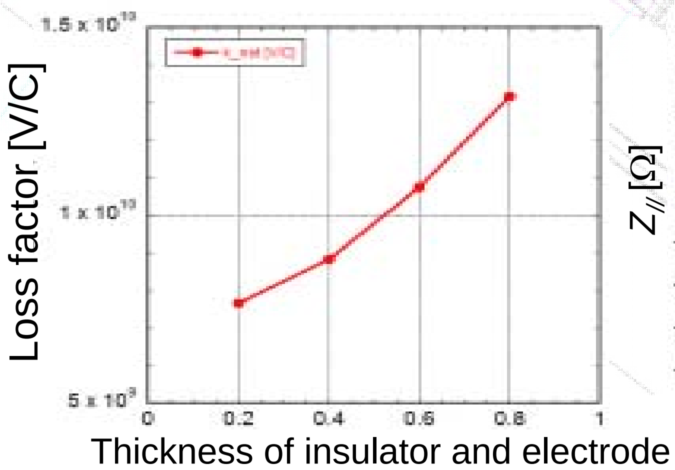
Clearing Electrode
Feed through

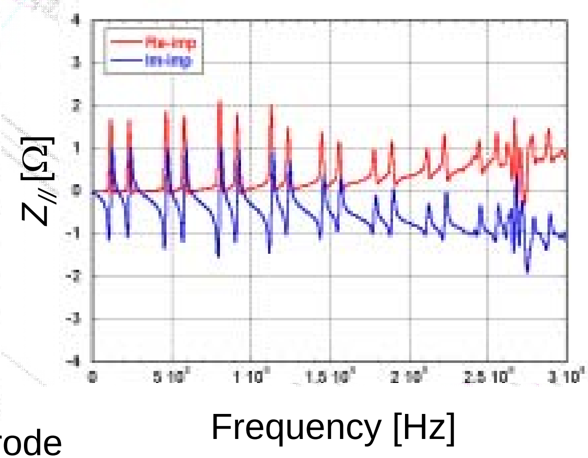
- Copper bridge to connect feed-through and electrode was manufactured.



Clearing Electrode
RF calculation

- Loss factor
  - *k* = 7✕10⁹ V/C, and Input power is ~ 150 W (1.7 A @1389 b).
  - Most of input power into electrode will be dissipated by electrode and chamber.
- Longitudinal impedance
  - Length is 440 mm to avoid resonance with RF frequency.
  - a few Ω

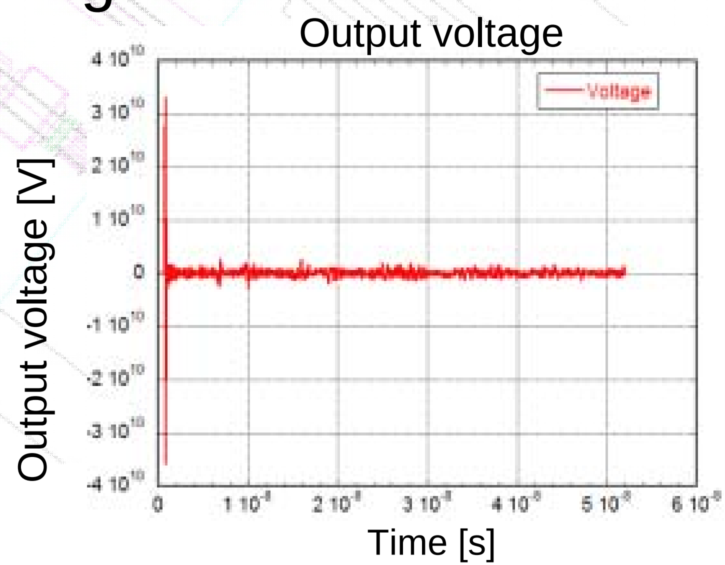




Clearing Electrode
RF calculation (cont'd)

- Values are estimated at 1.7 A (1389 bunches) and assuming no resonance.
- Voltage between electrode and chamber
  - ~ 12 V
- Output voltage of feed-through
  - ~ 600 V (Peak)
- Output power from feed-through
  - ~ 60 W,

    if R=50Ω and no loss.



Clearing Electrode
Test schedule

- First step (from February, 2008)
  - Install outside of magnet (upstream side)
  - Check the heating of electrode
  - If possible, with electron monitor and Measurement without magnet.
- Second step
  - Install into the wiggler magnet with electron monitor
- Third step
  - Groove surface, and other promising surfaces

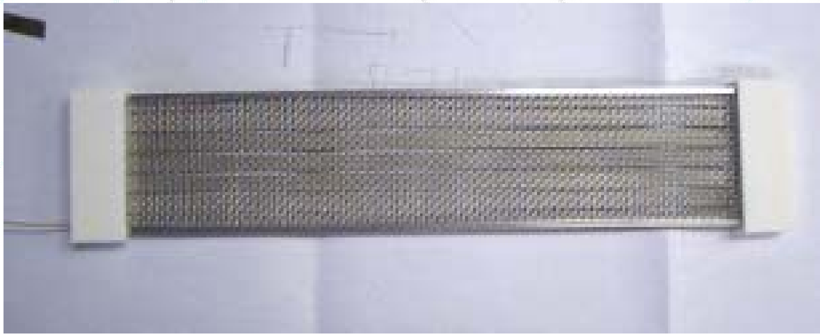
Clearing Electrode Manufacturing

- Machining and assembling are undergoing.

Flange

Machining of chamber

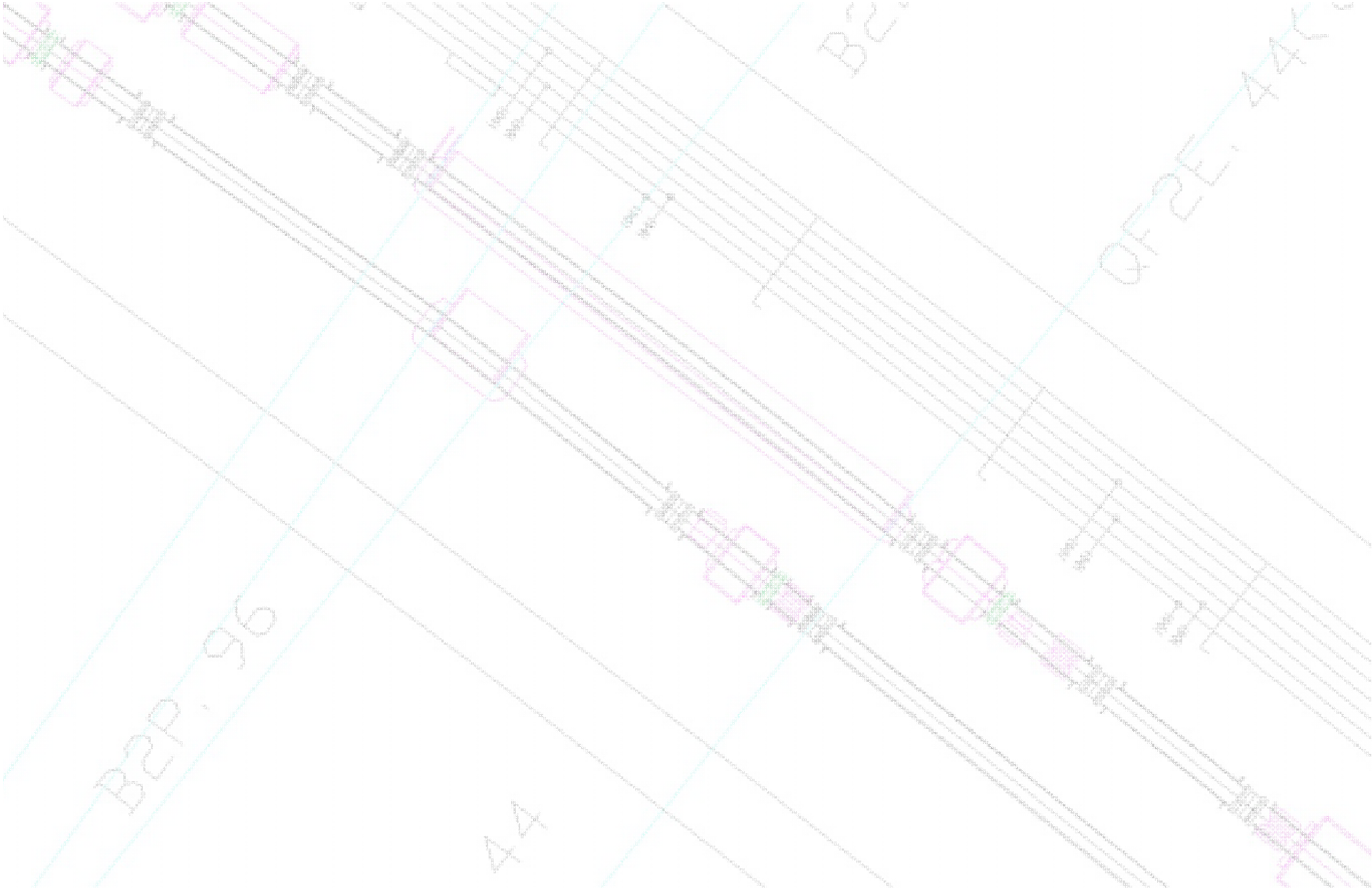
Grid



Collectors

Clearing Electrode
Summary

- Clearing electrode has been studied for a cure of EC in magnets.
- Manufacturing of test chamber is undergoing.
- Thin electrode and insulator contribute to decrease the impedance.
- Beam test will start from next February.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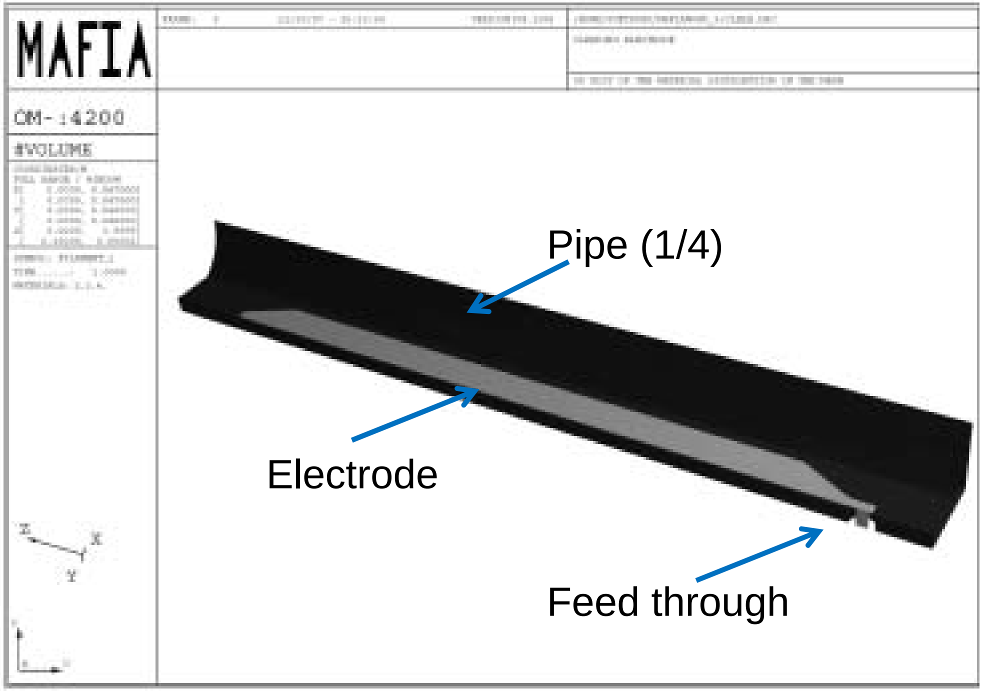
Clearing Electrode
RF calculation

- Calculation By MAFIA

- Model length = 2 m
- 1/4 model
- Electrode position = 195-625 mm (430mm)
- Width = 40 mm
- Mesh sizes = 0.5 x 0.1 x 0.4 mm
- Bunch length = 8 mm
- Electrode thickness = 0.2mm
- Alumina thickness =0.2 mm
- Alumina e_r =9.9
- Port = 14 mm (o), 6 mm (i) (50W)



Embedded + Taper + Feed through