Recent Studies on Beam Pipes and Electron Cloud Issues

The 14th KEKB Review on 9-11 February 2009 at KEK

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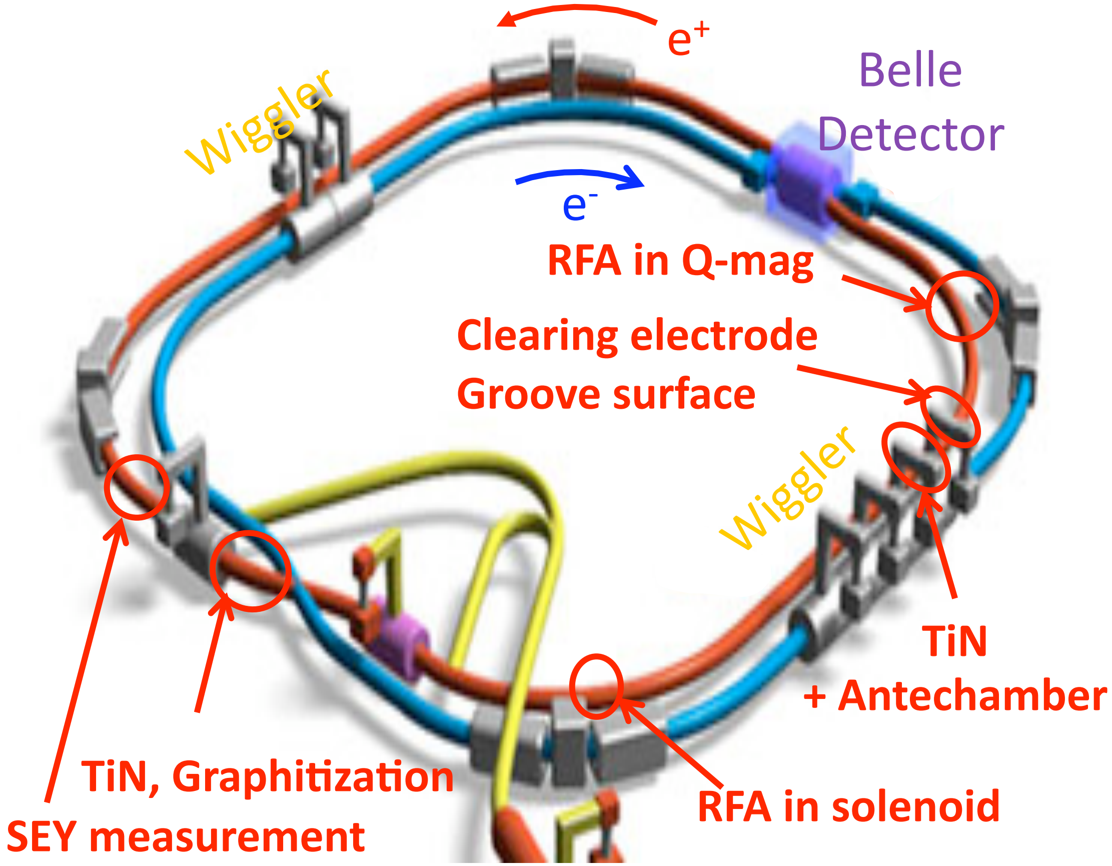
Resent Study Items at LER

- Various studies for SuperKEKB have been performed using an intense beam of KEKB Low Energy Ring (LER).
  - Recent studies are focused on beam pipes and electron-cloud effects.

LER : Positron ring

Energy : 3.5 GeV, Current : ~1600 mA, Bunch space : 2~8 ns, Bunch charge : ~1.0×10^{-8} C



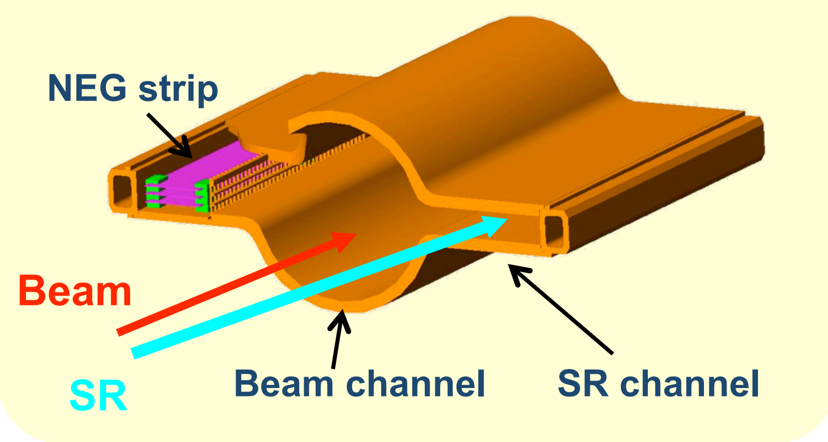
Recent study items at LER

- Beam pipe with antechambers
- Clearing electrode
- Groove surface
- TiN coating
- Graphitization
- RFA-type electron detectors
- SEY measurements

Beam Pipes 1

- Copper beam pipe with antechambers has been developed.
  - Benefits of antechamber scheme are;
    - Reduction of SR power density at side wall.
    - Reduction of photoelectrons in beam channel (positron ring).
    - Reduction of beam impedance.

Beam pipe with antechambers

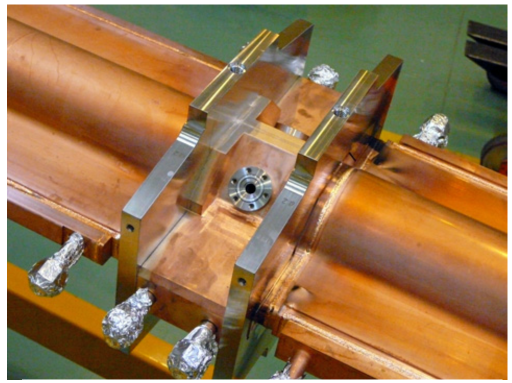


- Several beam pipes with antechambers have been installed into KEKB LER, and tested with beam.
  - No serious problem has been observed until now.
  - Straight pipe is OK. How about bent pipe?

⇩

We started manufacturing test.

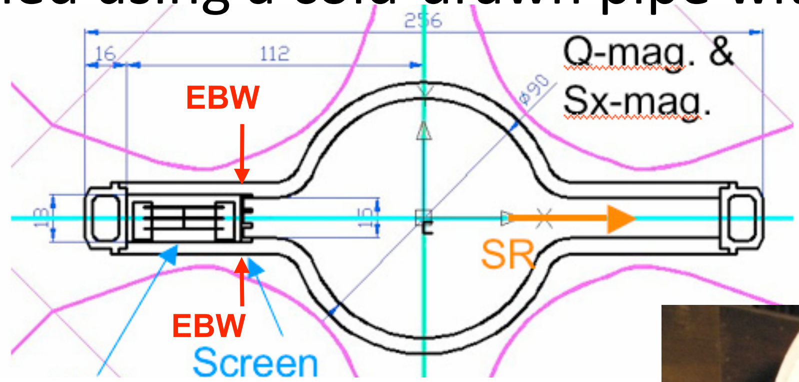
Straight pipe

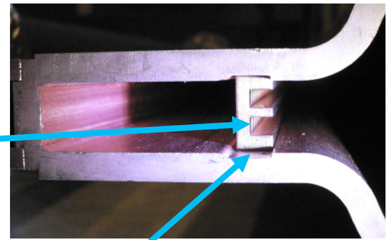


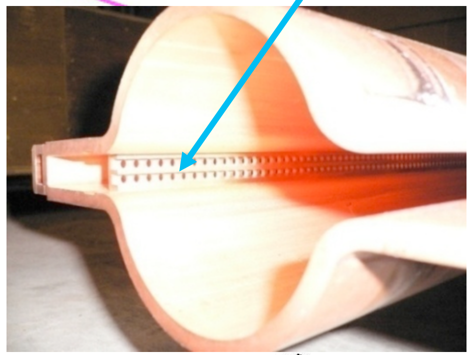
Q-pipe with BPM ports

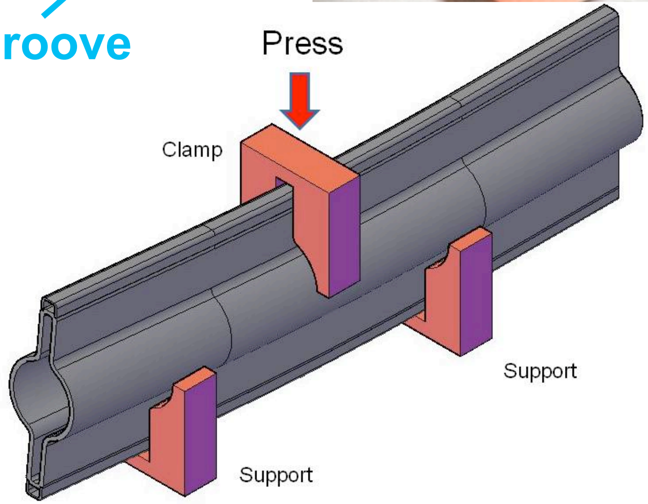
Beam Pipes 2

- Bending test was performed using a cold-drawn pipe with a screen for pumping channel.
  - Specifications;
    - Cold drawn pipe.
    - Two antechambers.
    - Screen to hide pumps.
    - Curvature of 16 m for LER.
  - Fabrication procedure;
    - Widen the aperture elastically in a vertical direction temporally, and insert the screen in the pump channel.
    - Fix the screen positions by EBW from outside.
    - Bend the beam pipe by three-point bending method.







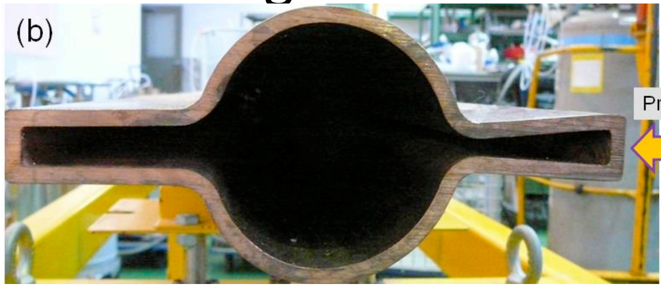


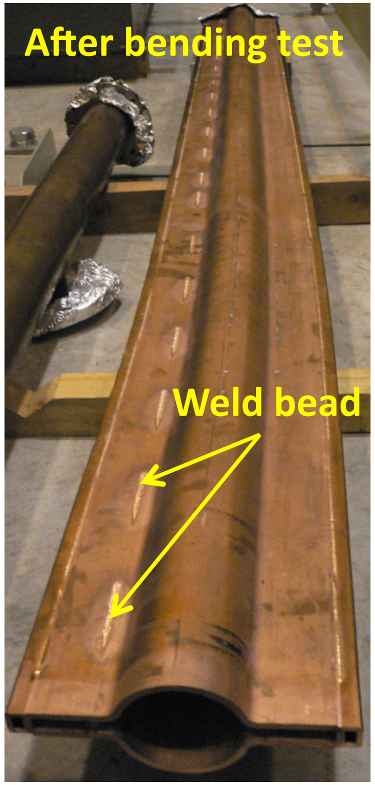
Beam Pipes 3

- We visually checked the test pipe after the bending test.
  - Fabrication accuracy :
    - Deformation of the aperture was observed in the first bending test without screen.

      ⇨ This problem was finally solved by installing a hard plastic block into the antechamber during bending process.

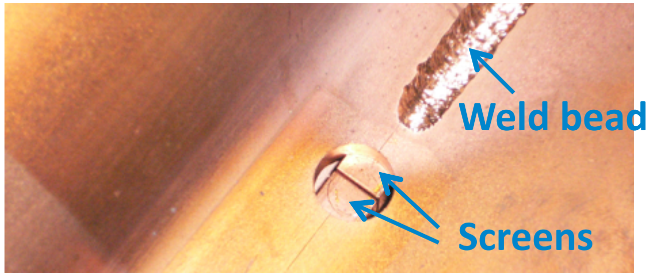
      The screen (below) also helps prevent the deformation.

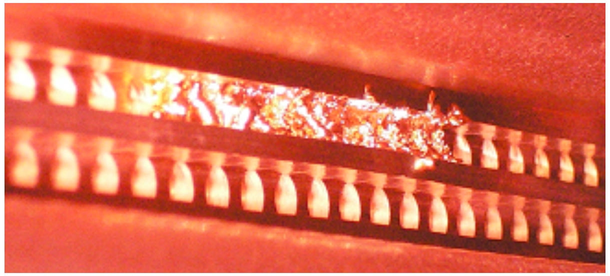




  - Screen :
    - Some holes were made to check the gap between screens.
    - Molten copper leaked into the inside of the beam pipe.
    - It seems that the screens can be held in a stable position even without EBW.

      ⇨ Screen dose not have to be welded.





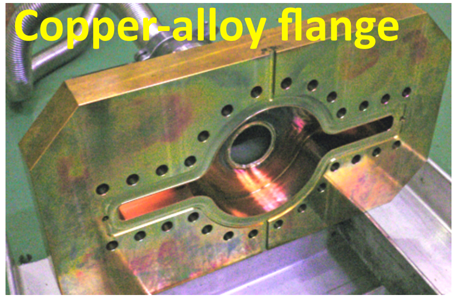
Beam Pipes 4

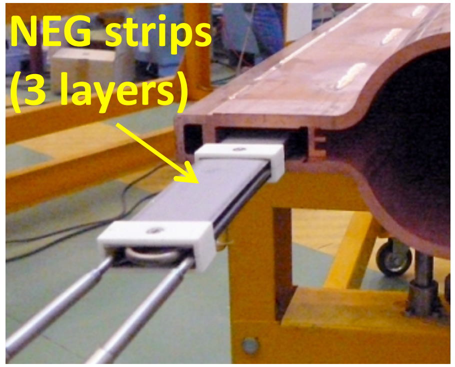
- Manufacturing of two beam pipes (B-chamber & Q-chamber) is now proceeding.
  - Features of beam pipe :
    - Copper-alloy flanges

      We can omit transitions between copper and stainless-steel required in the case of stainless-steel flange. (Simplify the manufacturing procedure and then reduce the cost.)

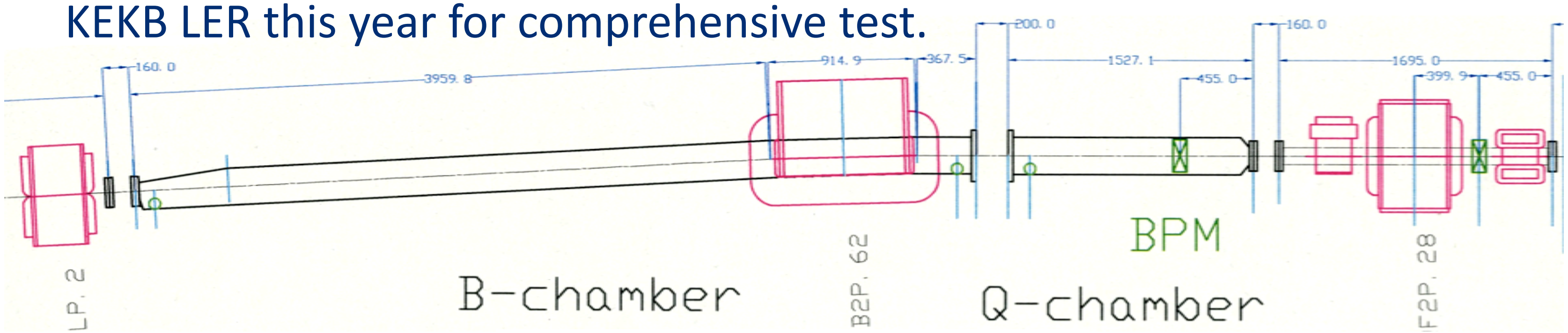
      Cooling efficiency is also improved.
    - New pump system for antechamber

      Three layers of ST707 NEG strips was designed for this pipe. Pumping test has been performed.



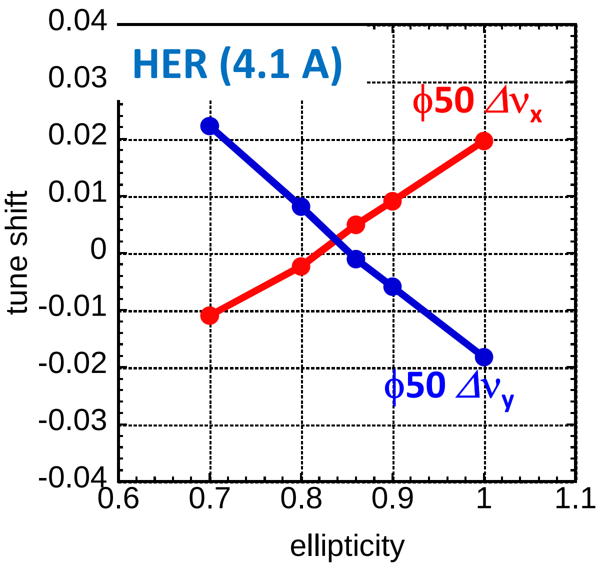


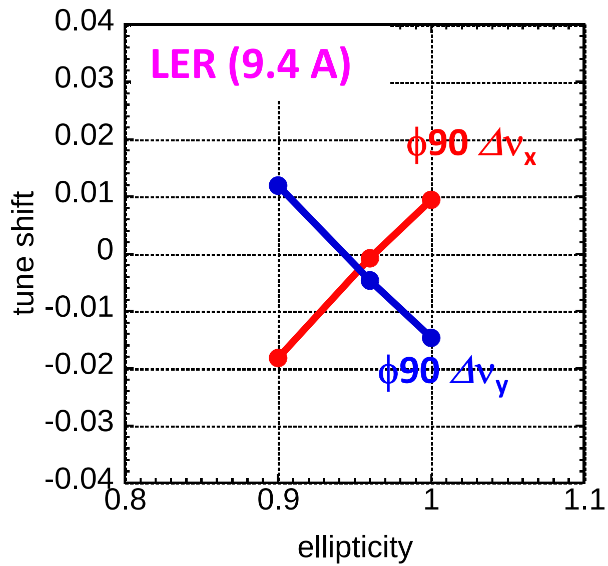
- These pipes will be completed by the end of March, and be installed into KEKB LER this year for comprehensive test.

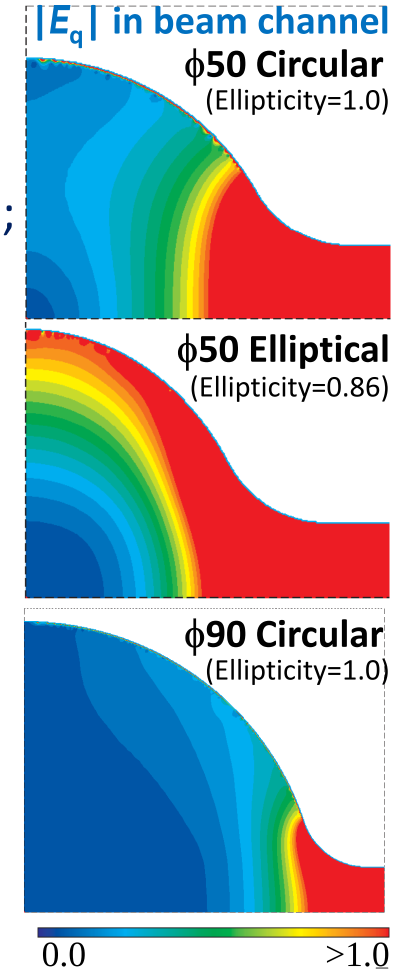


Beam Pipes 5

- Tune shifts due to the quadrupole field (E_q)of resistive-wall wake of beam pipe with antechambers were also checked.
  - Estimation of E_q in beam channel with MAFIA electrostatic solver (2D)
    - In case of ϕ50 beam channel (for HER);
      - Elliptical beam channel is useful to spread the weak area of E_q.
    - In case of ϕ90 beam channel (for LER);
      - E_q in circular beam channel seems to be enough small.
  - Estimated tune shift at maximum beam currents of SuperKEKB;
    - Tune shift $|\Delta\nu|$ is within acceptable limit (0.1) even for circular beam channel in both rings.
      - Elliptical beam channel can reduce the tune shift further.



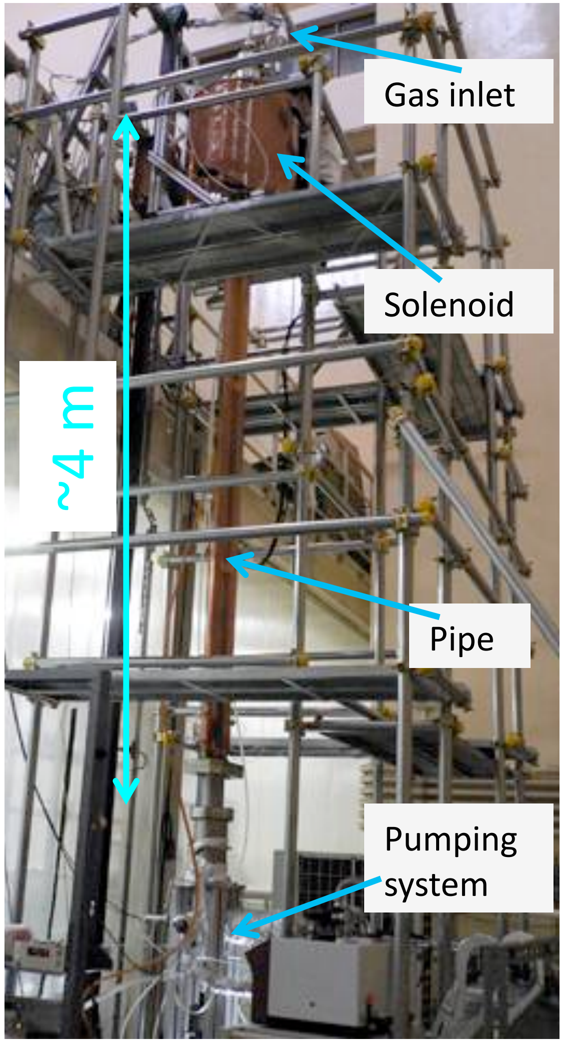




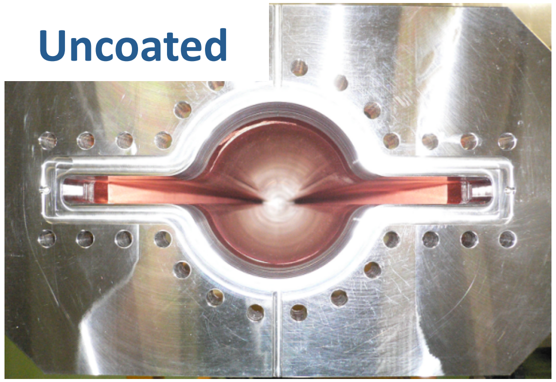
TiN Coating 1

- Mitigation of electron cloud in magnets is a key issue for SuperKEKB.
  - In magnets we can not use the solenoid coil which is a promising measure for drift space (discussed later).
- Reduction of SEY by coating has been studied.
  - TiN coating system for long beam pipes was built at KEK.
    - Coating was done by DC magnetron sputtering of titanium in Ar and N_2.
    - Thickness : 200 nm
    - Maximum SEY of TiN film on sample piece was 0.84 (electron dose : 0.001 C/mm^2)
  - Several beam pipes have been coated with TiN, and installed in KEKB LER.

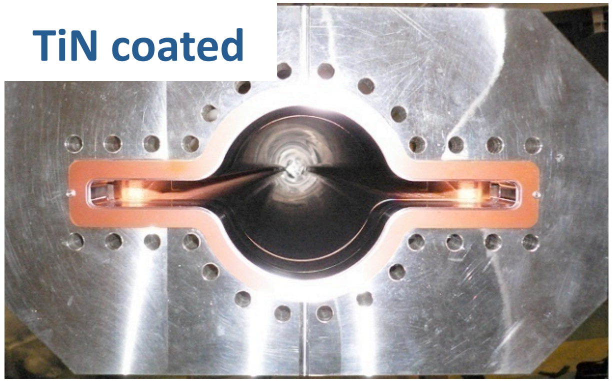
K. Shibata, EPAC2008



Uncoated



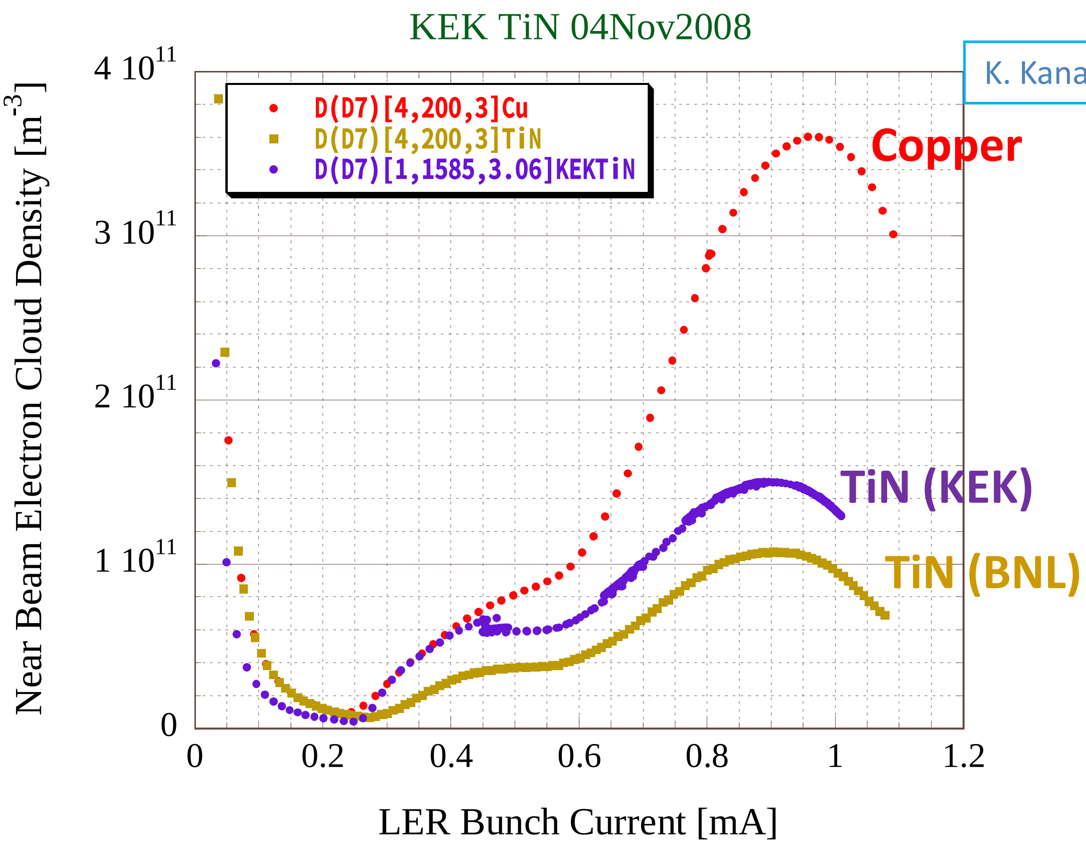
TiN coated



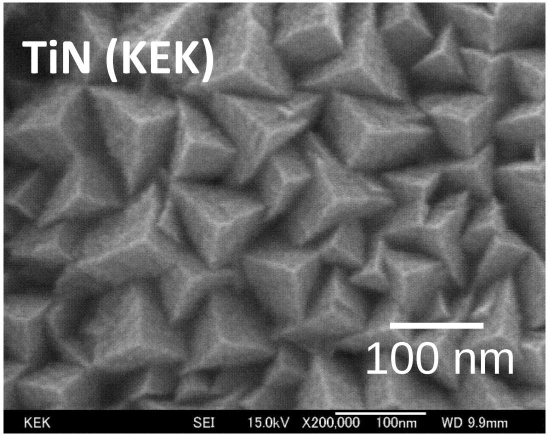
TiN Coating 2

- Measurement of electron density in KEKB LER (no magnet)
  - Electron density in circular beam pipe (ϕ94 mm)
    - TiN (KEK) is as effective as TiN (BNL).
    - Mitigation of electron also comes from its surface structure?

ϕ 94 mm



K. Kanazawa

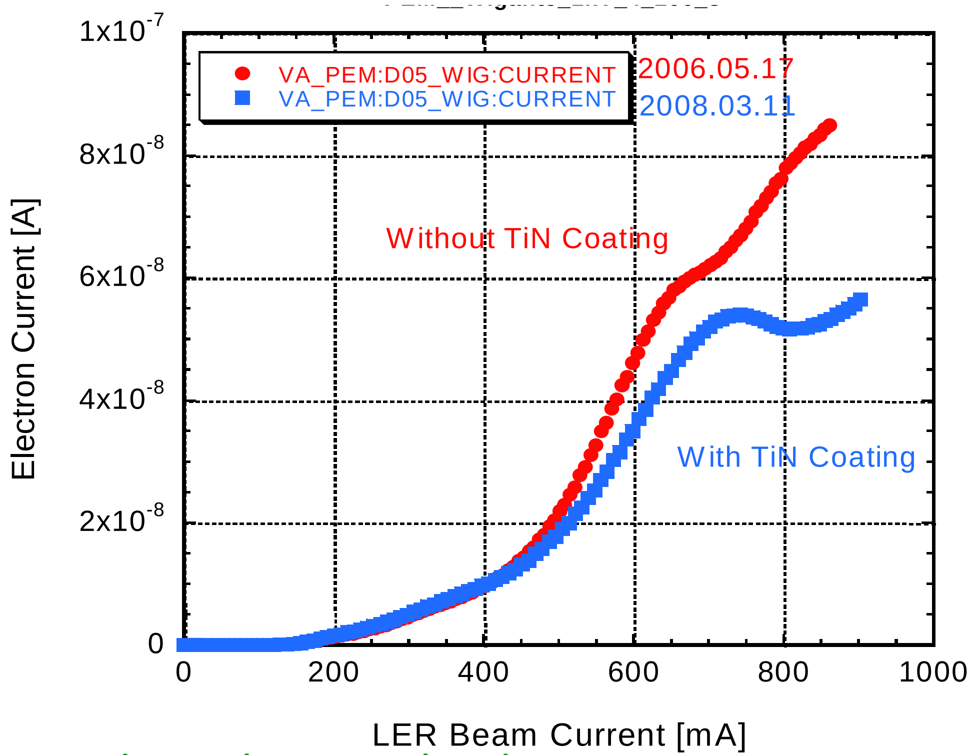


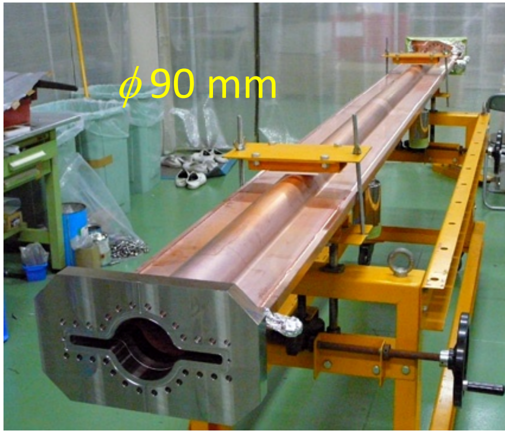
Electron Microscope Image

H. Hisamatsu and M. Nishiwaki

TiN Coating 3

- Measurement of electron density in KEKB LER (no magnet)
  - Electron density in beam pipe with antechambers





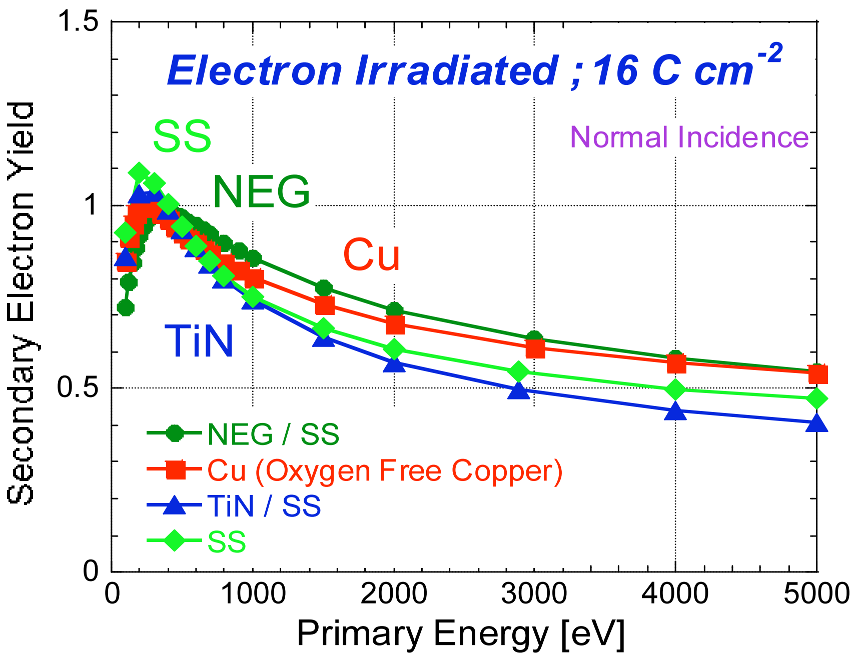
Y. Suetsugu, ILCDR2008

- TiN can reduce electron cloud.
- Combination of beam pipe with antechambers and TiN coating is a promising measure in magnets of SuperKEKB.

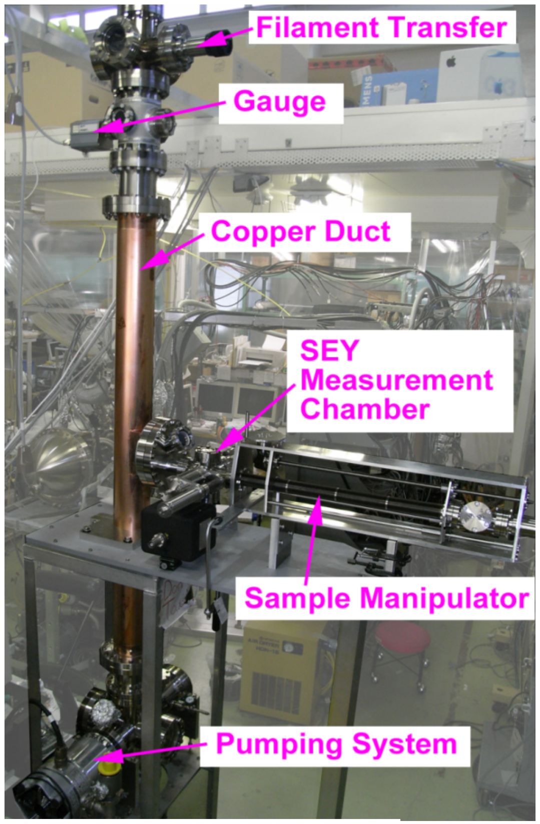
  But more effective countermeasures are preferable to surely suppress the electron cloud effect.

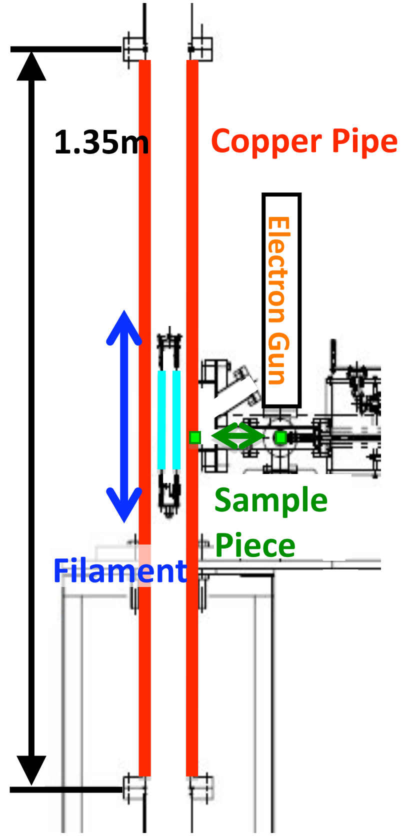
Graphitization 1

- Electron beam induced graphitization is also studied.
  - Graphitized surfaces have shown low SEY in laboratory experiments.
    - Maximum SEY decreased to 1.0-1.1 (electron irradiated : 0.0016 C/mm^2)
  - Setup for graphitization of copper beam pipe was newly developed.
    - 500 eV electrons irradiate to pipe surface.
    - Emission Current Density : 170μA/cm^2



M. Nishiwaki and S. Kato, Vasscaa4 2008

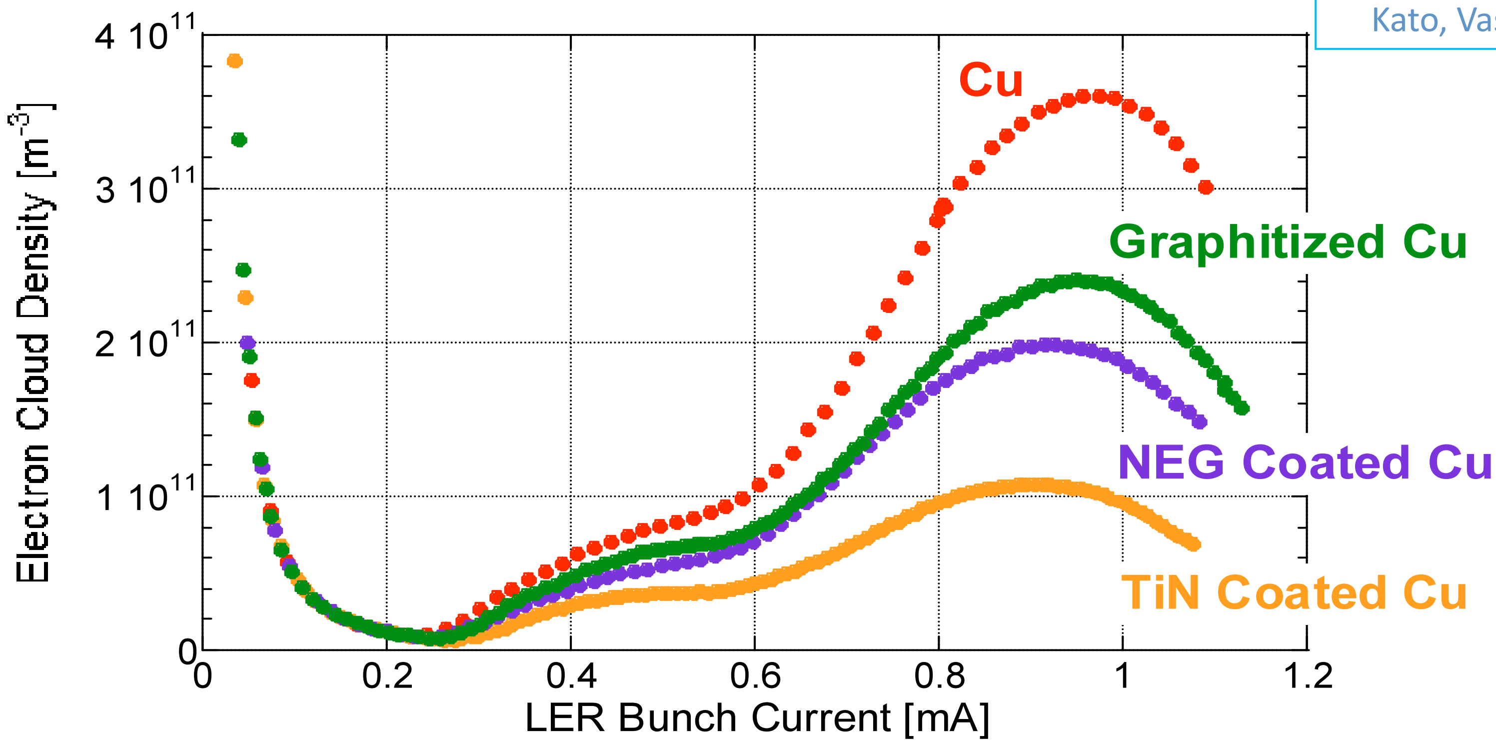




Graphitization 2

- Measurement of electron density in KEKB LER (no magnet)
  - Graphitization was effective to reduce electron cloud density.
  - The effect was less than TiN and NEG, however.

M. Nishiwaki and S. Kato, Vasscaa4 2008



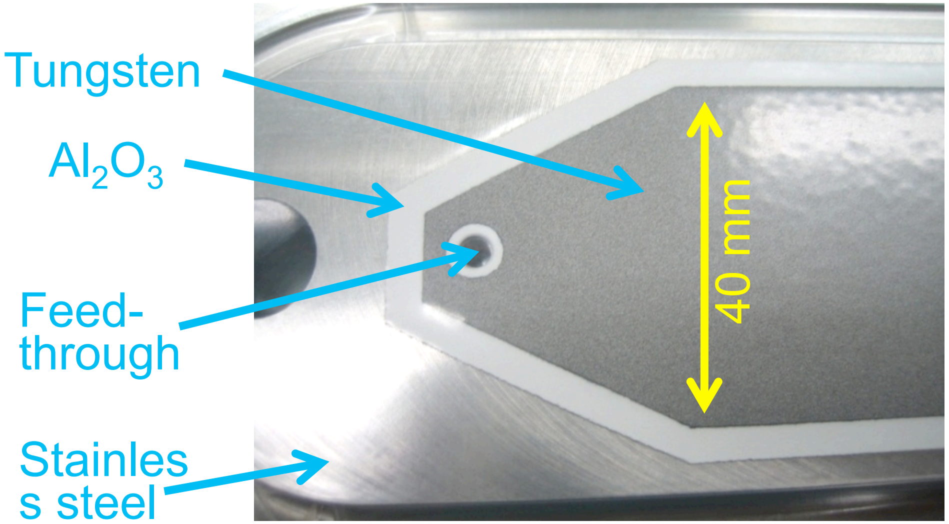
  - Graphite layer was too thin (FWHM ~10 nm) ?
  - Thicker graphite coating on copper pipe is in preparation.

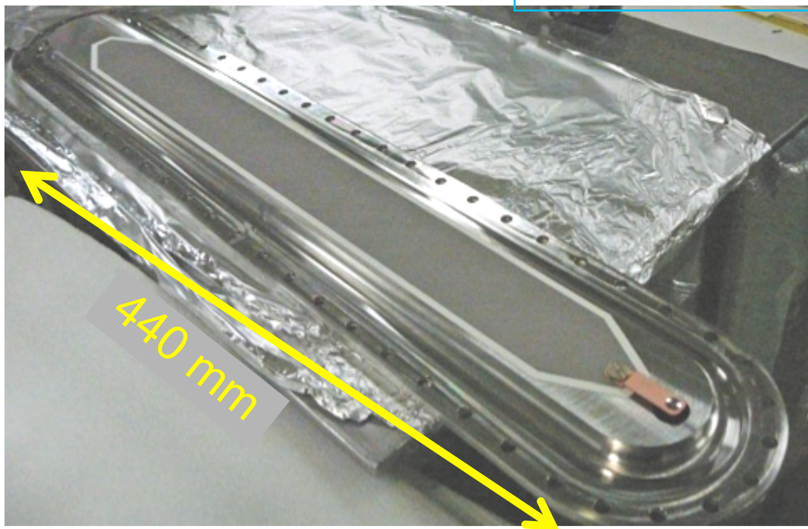
    New test chamber will be installed this winter.

Clearing Electrode 1

- Study on clearing electrode also started for mitigation of electron cloud in magnets.
  - Very thin electrode (0.1 mm, Tungsten) and insulator (0.2 mm, Al_2O_3) were developed. (Thermal Spray)
  - Clearing electrode and electron detector were installed in wiggler magnet of LER. (placed at the center of pole)
    - To demonstrate the effect of electrode, the electron density was measured by the electron detector with 7 strips.
    - 7 strips can measure the horizontal spatial distribution of the electron cloud.
  - Sustainability for high beam current was also tested.

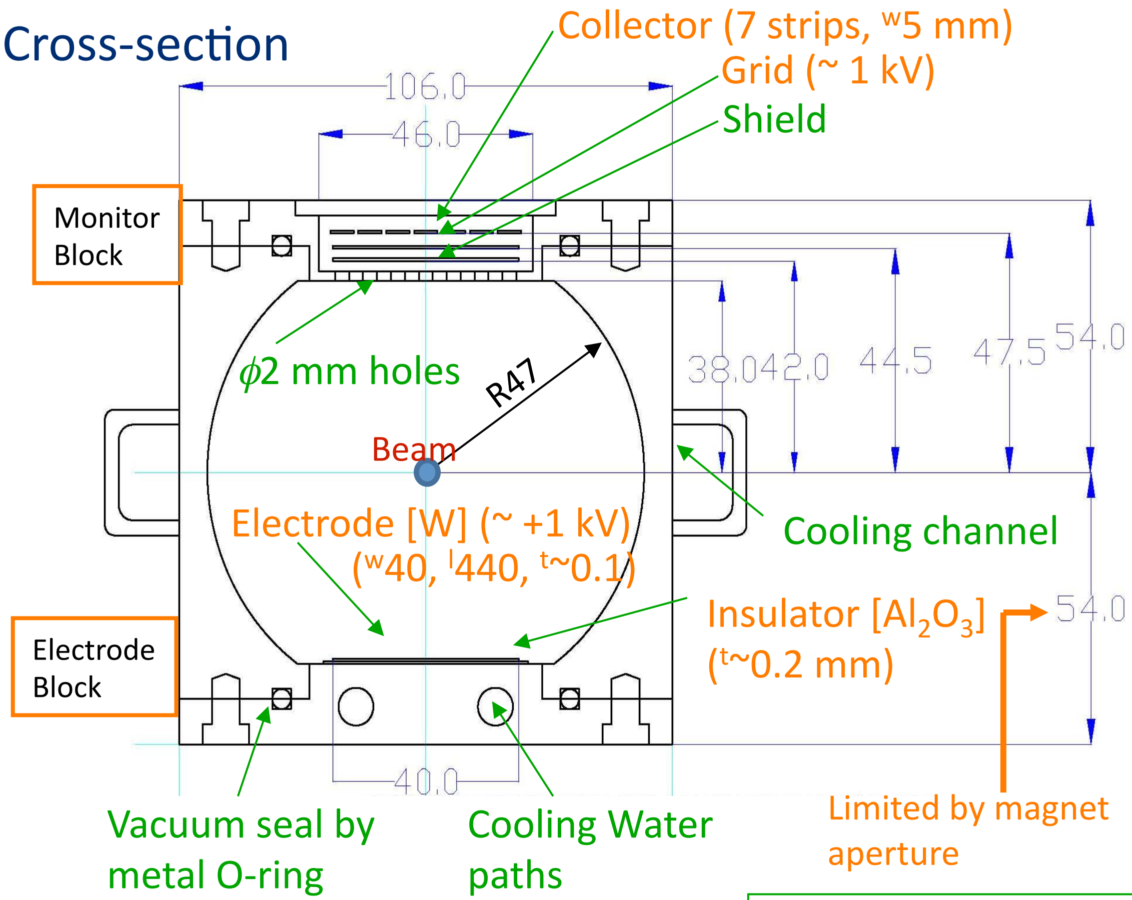
Y. Suetsugu et al., NIM-PR-A, 598 (2008) 372

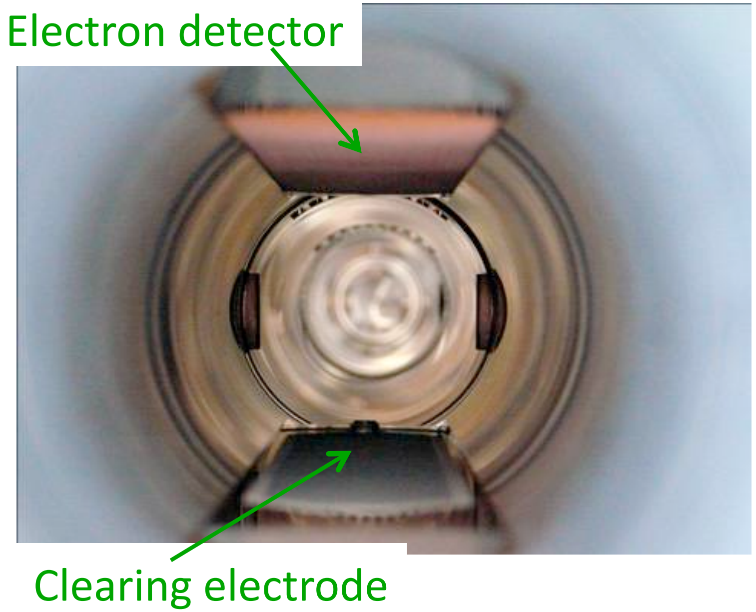


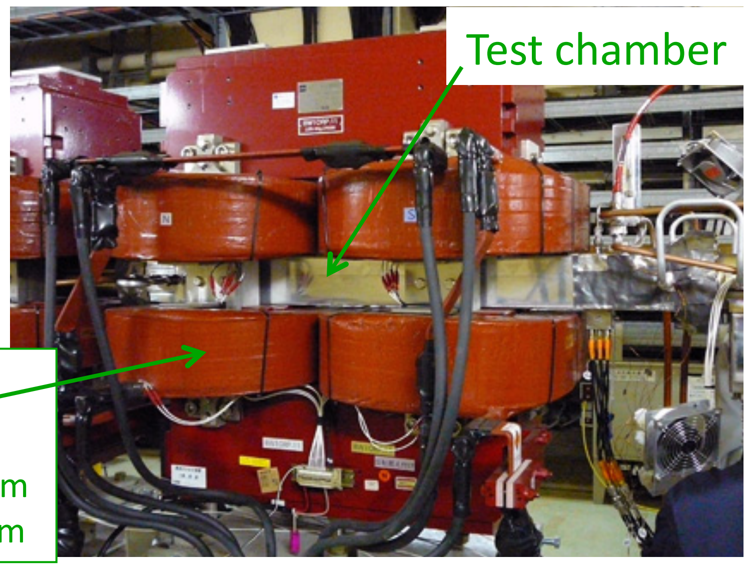


Clearing Electrode 2

Cross-section







Wiggler magnet
Magnetic filed : 0.77 T
Effective length : 346 mm
Aperture (height) : 110 mm

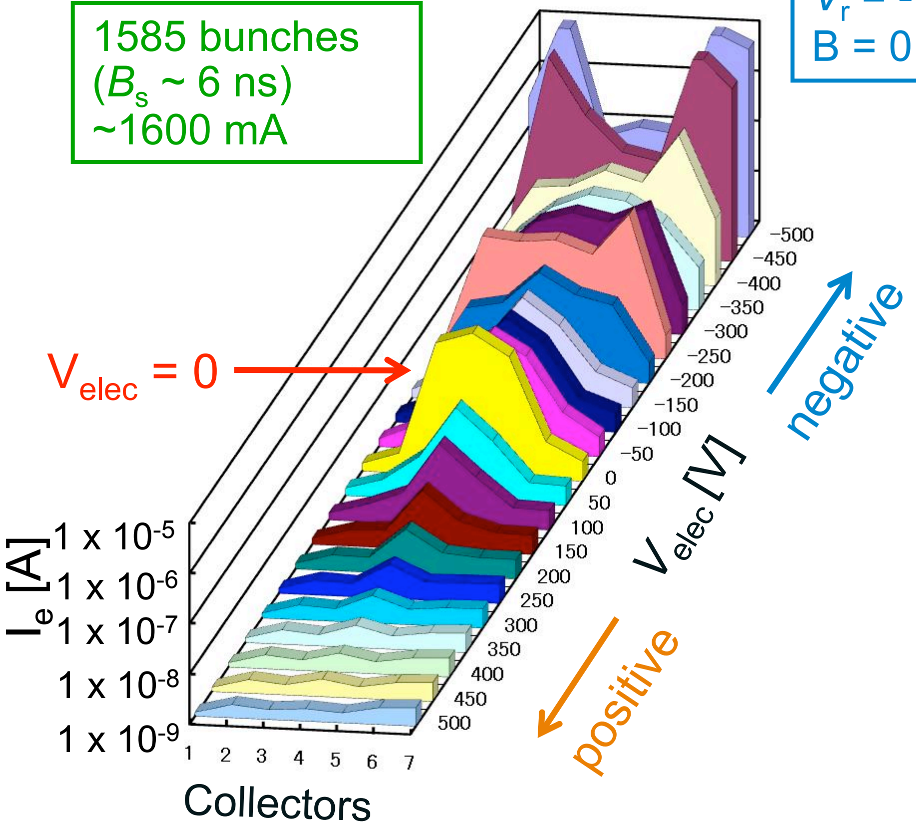
Y. Suetsugu et al., NIM-PR-A, 598 (2008) 372

Clearing Electrode 3

- Drastic decrease in electron density was demonstrated by applying positive voltage.
  - Number of electrons was reduced to 1/10 ~ 1/100 if applied voltage of clearing electrode was more than 300 V for any bunch spacing.

1585 bunches
(B_s ~ 6 ns)
~1600 mA

V_r = -1.0 kV
B = 0.77 T



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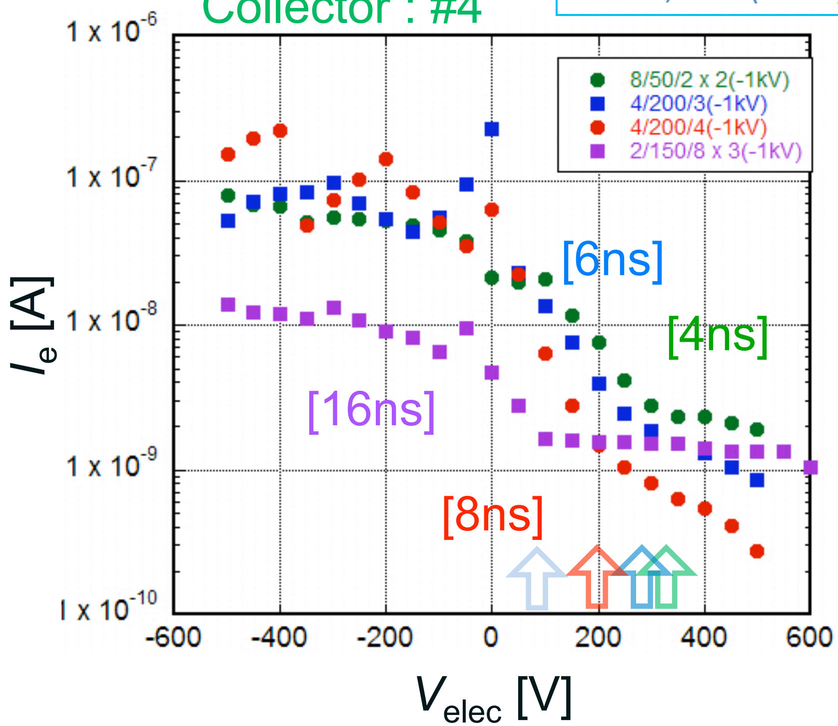
Collector : #4



Clearing Electrode 5

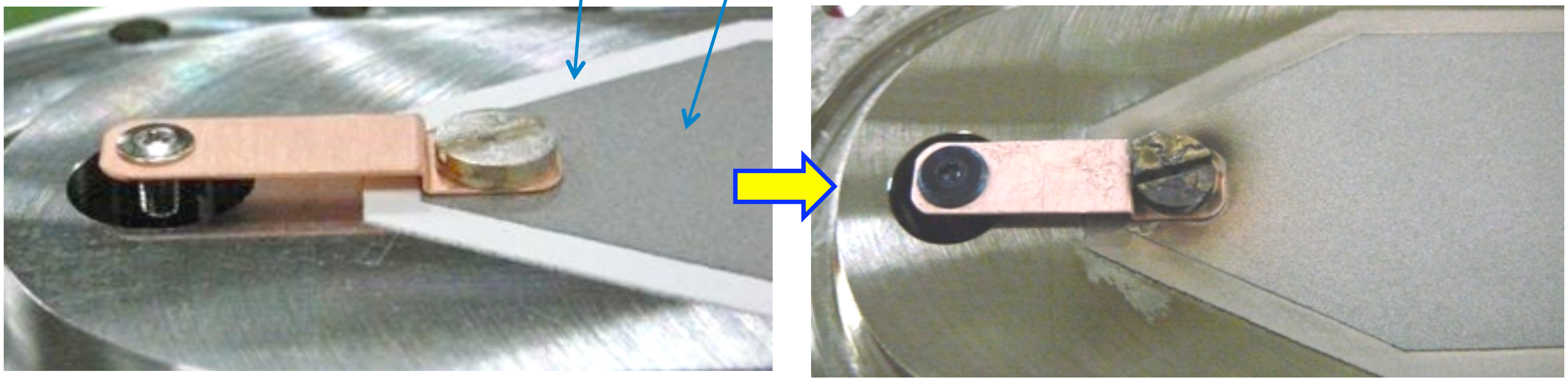
- Electrode was very effective, but modification of the feed-through connection part is required for high beam current.
  - Insulation resistivity decreased from 2 MΩ to several 10 kΩ during the trial period due to discharge at feed-through connection part.

⇨ Improved clearing electrode will be installed this winter.

insulator

electrode

Y. Suetsugu

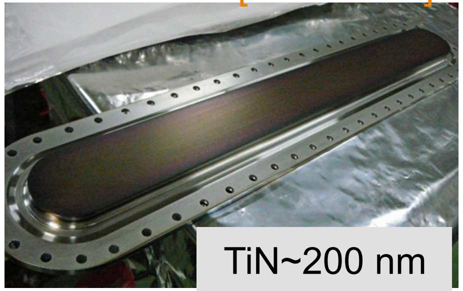


Connection part

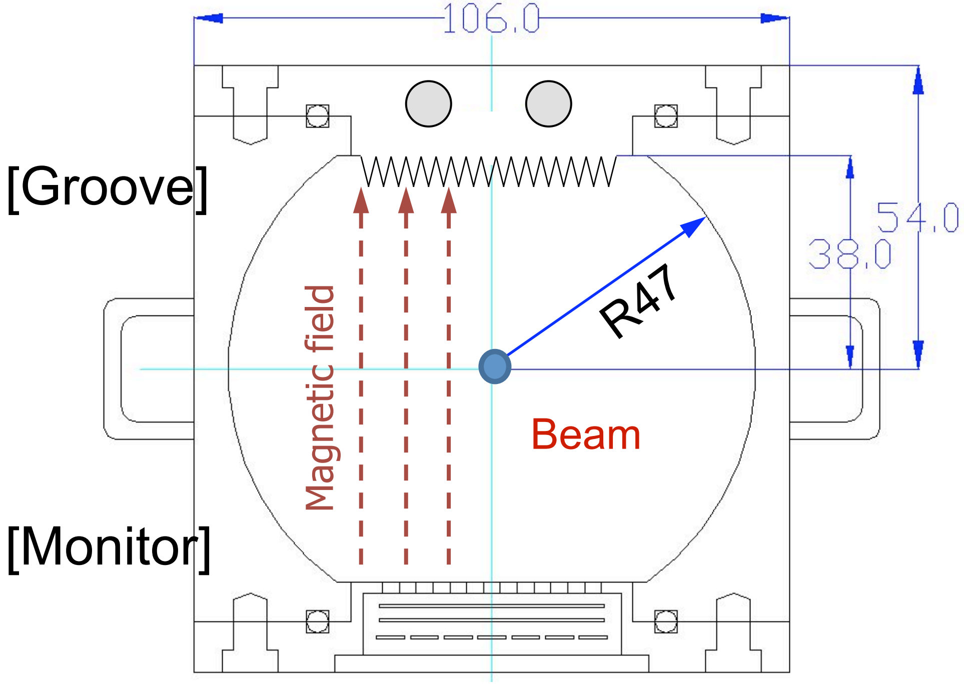
Groove Surface 1

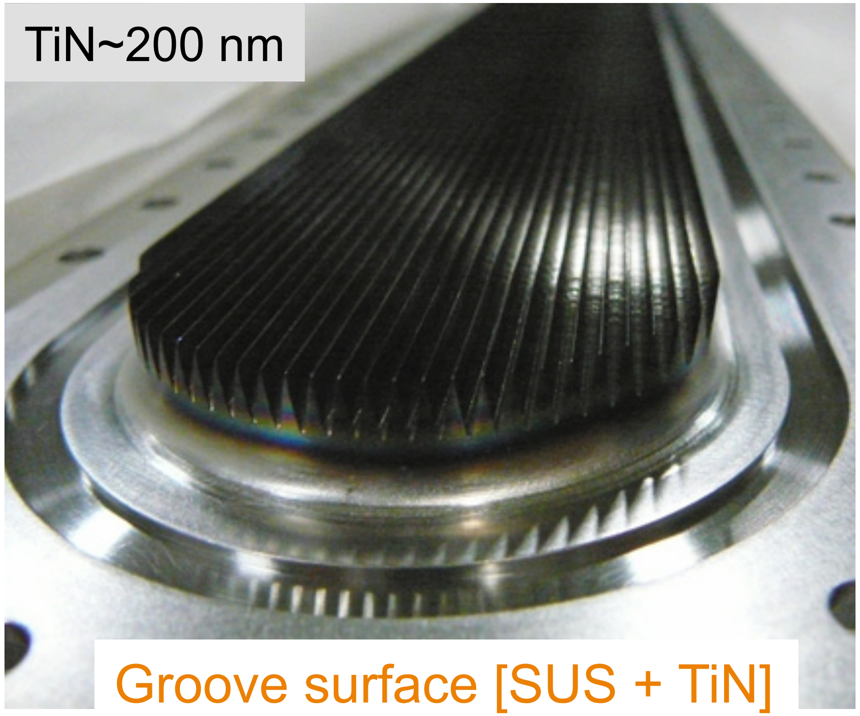
- Effect of groove surface was also studied last autumn.
  (collaboration with SLAC)
  - Electrode was replaced by groove surface.
  - Same setup for clearing electrode was utilized.
  - Groove structure was designed and manufactured in SLAC.
  - Flat surface with TiN coating was also tested for reference.

Flat surface [SUS + TiN]



Y. Suetsugu, ILCDR2008



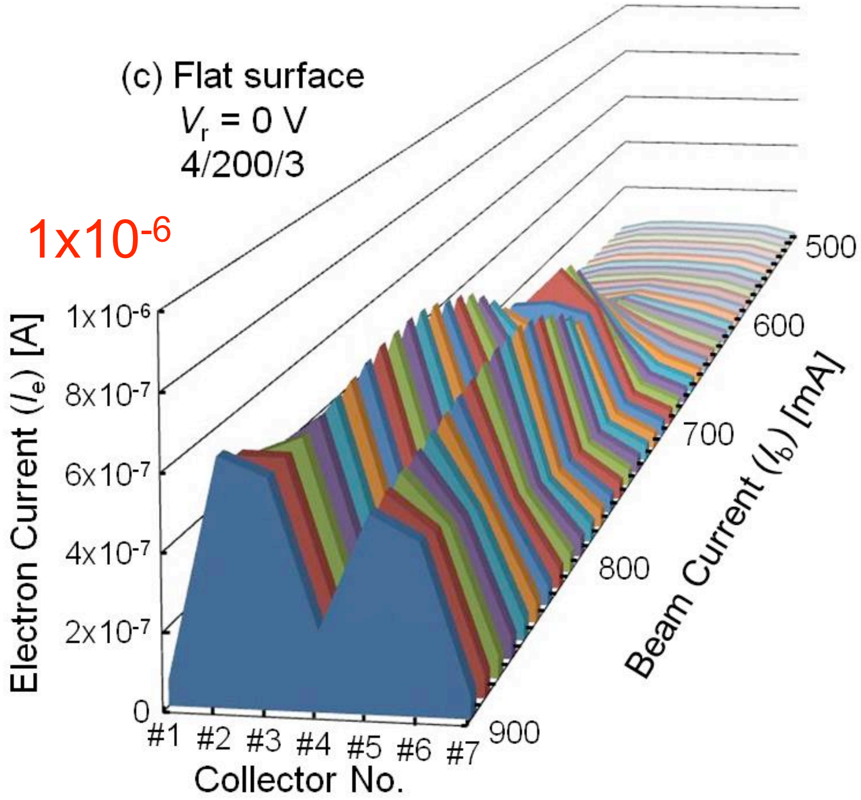


Groove surface [SUS + TiN]

Groove Surface 2

- Electrons for groove surface was reduced to 1/5 ~1/10 the number for flat surface (3 buckets spacing).
  - Further R&D will be carried out toward the practical use of groove surface.

Flat surface



Groove surface

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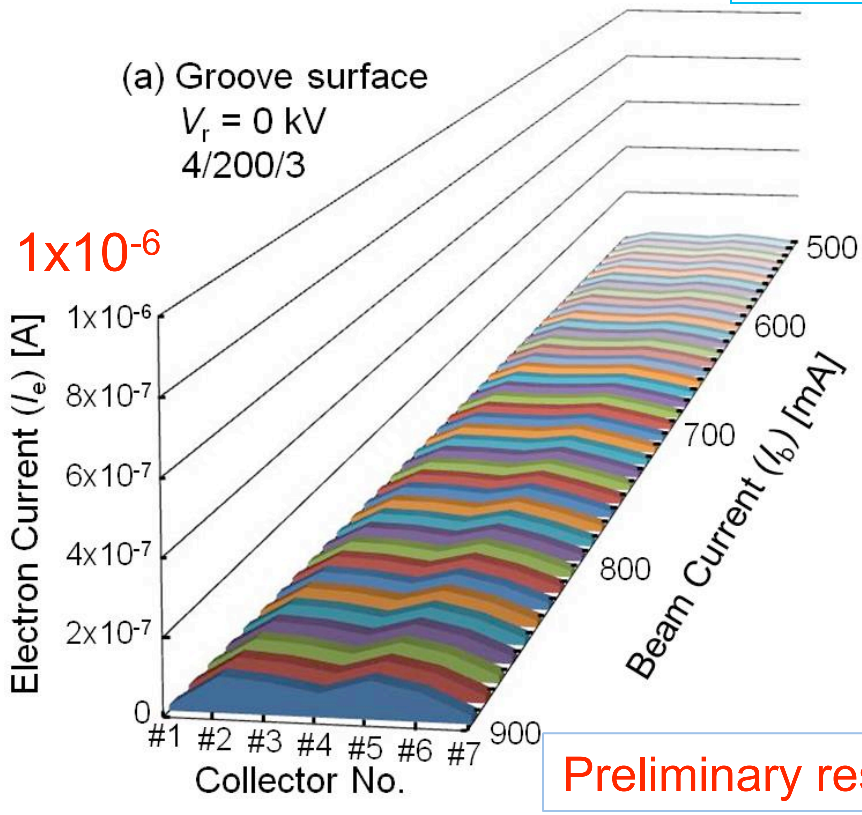
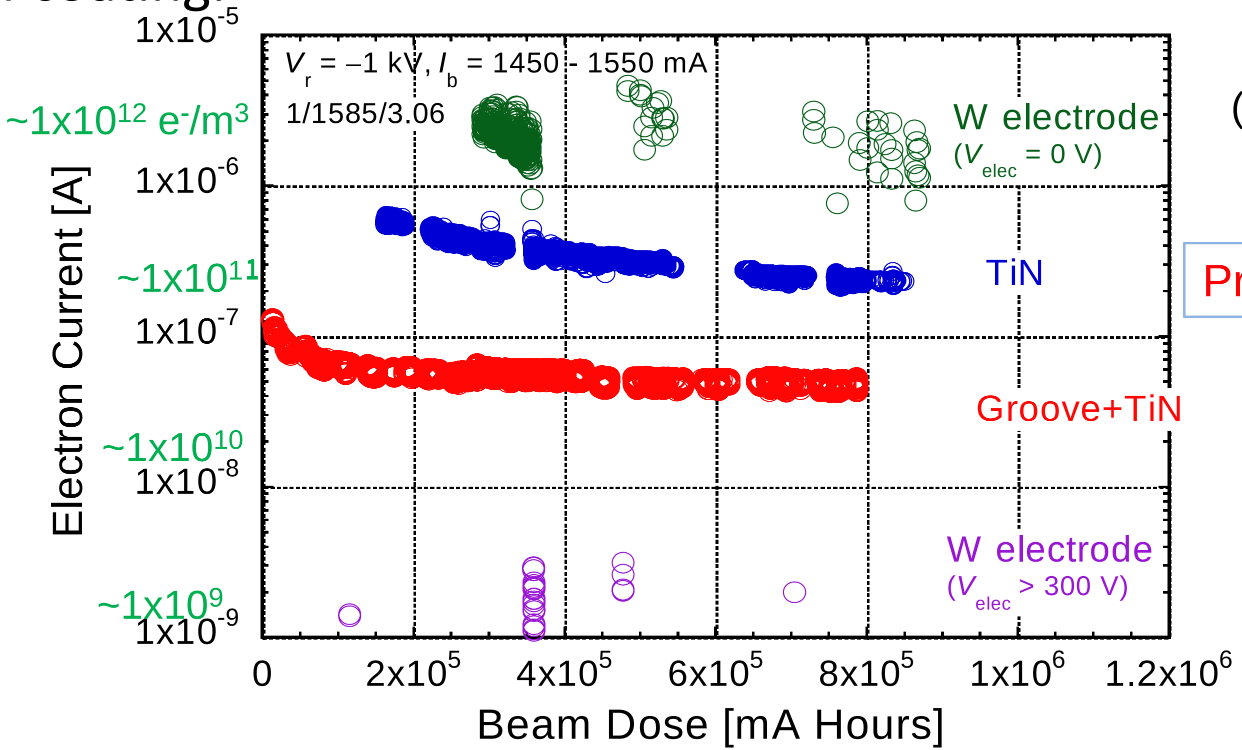


Preliminary result

Mitigation Performance Comparison

- Clearing electrode is much more effective than groove surface and TiN coating.



V_r = -1 kV

(1/1585/3.06)

Preliminary result

- Ranking of estimated performance in magnet is ;

Electrode >> TiN+Groove >> TiN(Flat) > Cu(Flat)

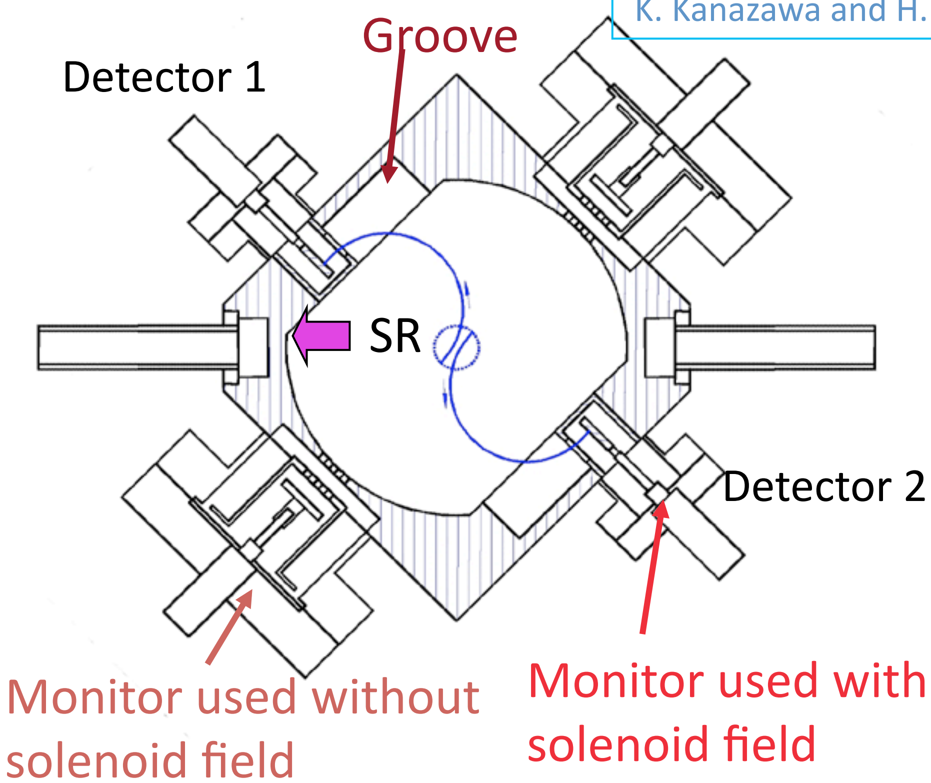
×10 ×5~10 ×2~3

Electrode and groove surface are very promising, but more studies are required to achieve the practical use of them.

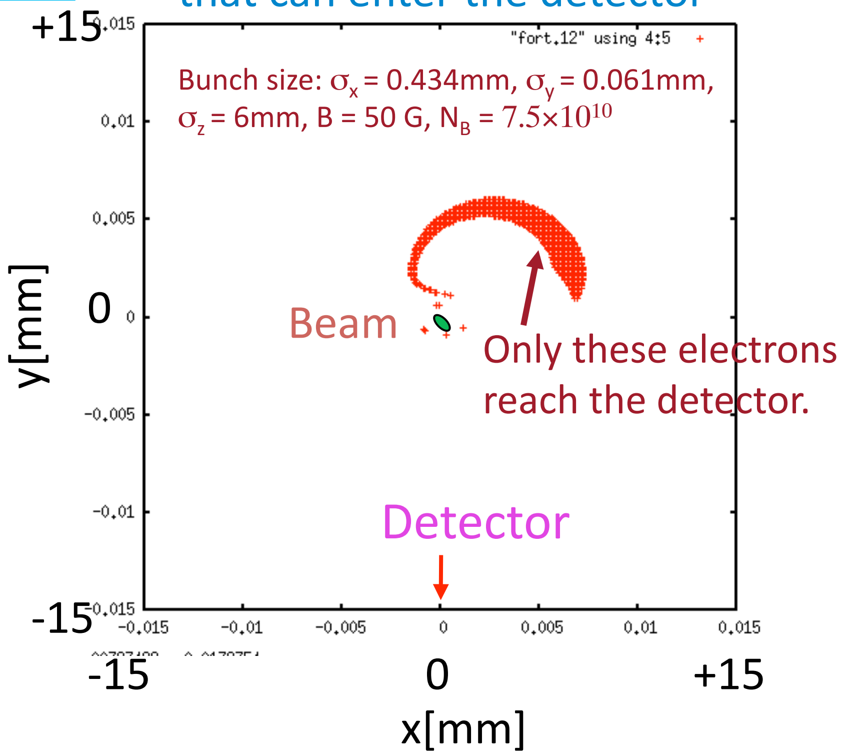
Near Beam Electron Cloud Density Measurement in Magnetic Field with RFA-type Electron Detector 1

- New RFA-type electron detector was installed into KEKB LER to measure electron density in a solenoid coil
  - Only high energy electrons produced near the bunch can enter the groove and reach the detector behind it.
  - With a help of simulation, the detector current is converted into the density near the beam.

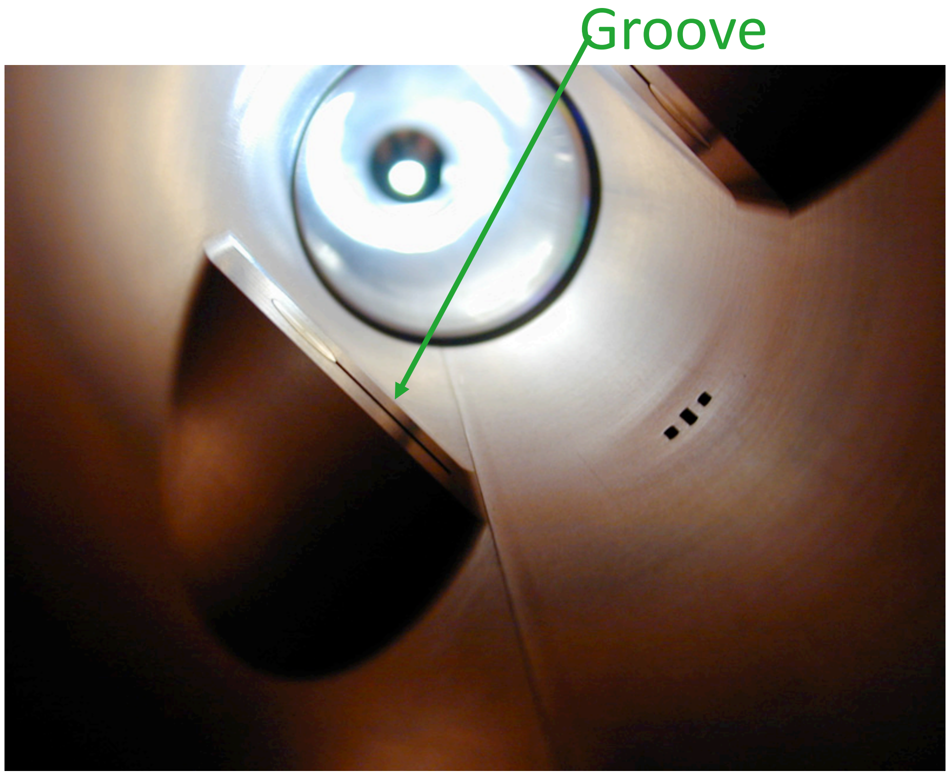
K. Kanazawa and H. Fukuma

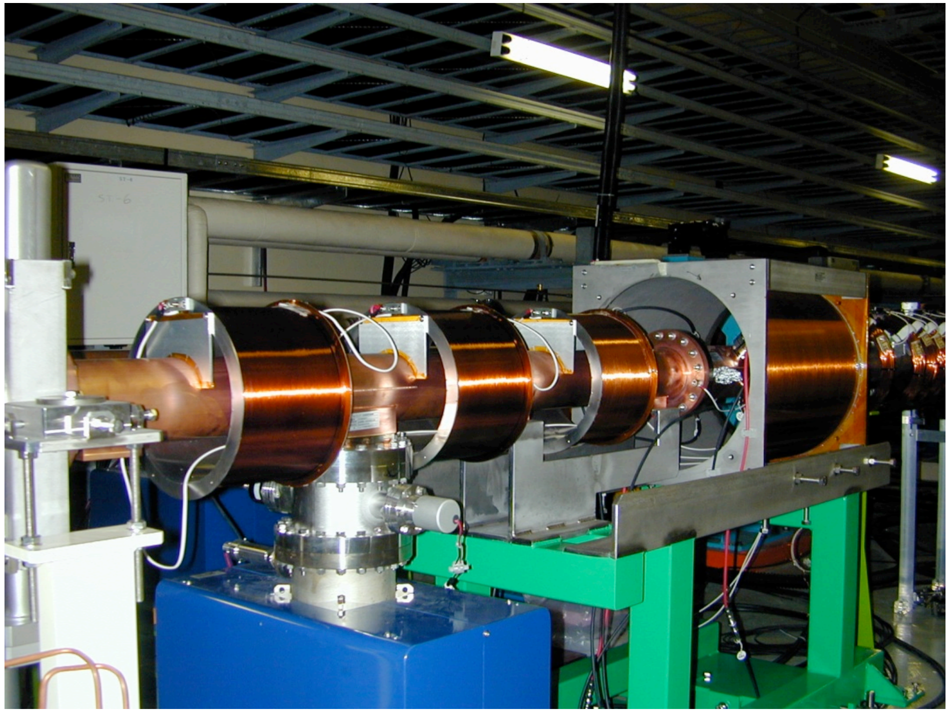


Starting points of electrons that can enter the detector



Near Beam Electron Cloud Density Measurement in Magnetic Field with RFA-type Electron Detector 2

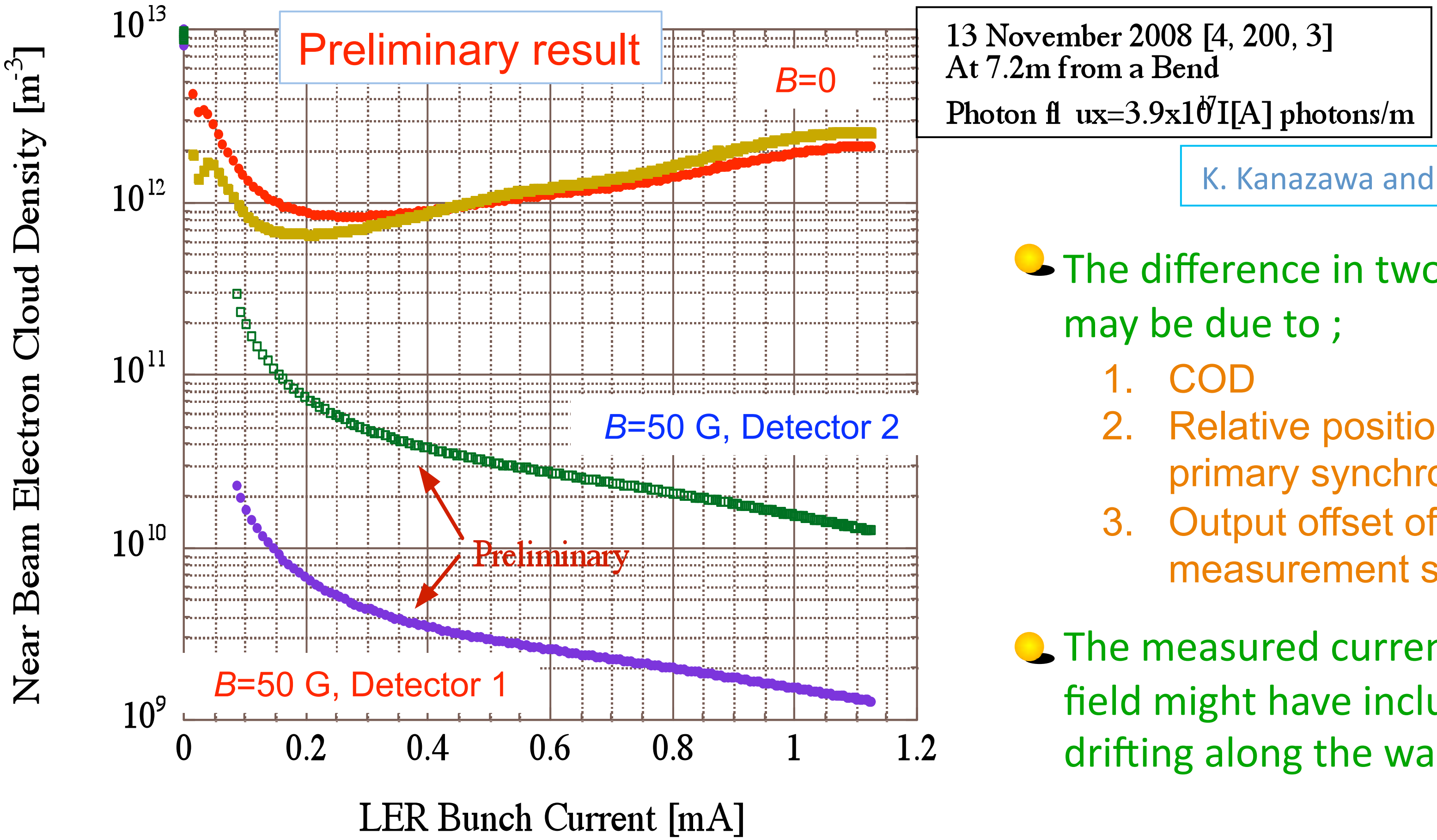




Inside of the chamber

Near Beam Electron Cloud Density Measurement in Magnetic Field with RFA-type Electron Detector 3

- Electron cloud density with solenoid field (B = 50 G) (0.005 T)
  - It was confirmed that the electron cloud density decreased by more than 1/100 in solenoid field.
  - Solenoid coil is a very promising measure for drift space of SuperKEKB.

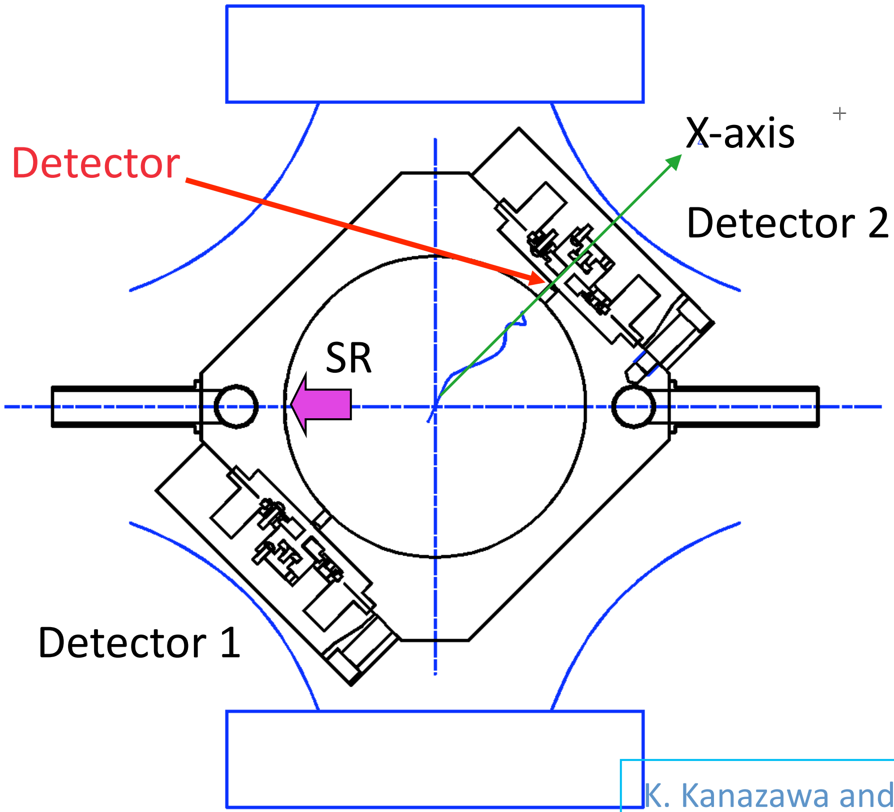


K. Kanazawa and H. Fukuma

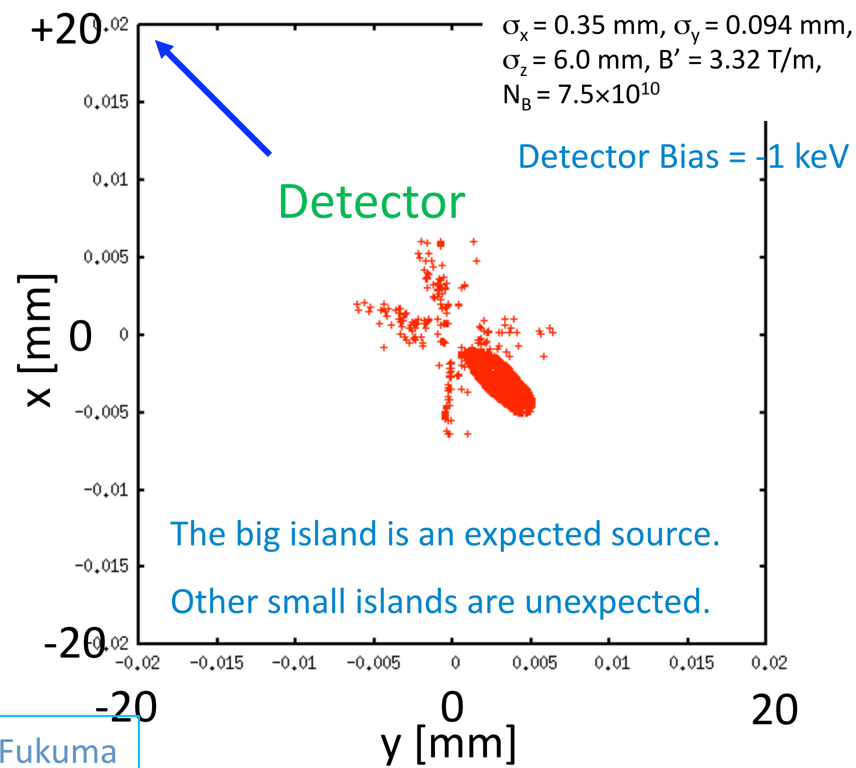
- The difference in two detectors may be due to ;
  1. COD
  2. Relative position to the primary synchrotron radiation
  3. Output offset of amplifier in measurement system
- The measured current in a solenoid field might have included electrons drifting along the wall.

Near Beam Electron Cloud Density Measurement in Magnetic Field with RFA-type Electron Detector 4

- Electron density in a Q-magnet was also measured.
  - Electrons accelerated by bunch with sufficient energy and with a direction close to X-axis can reach the detector.
  - With a help of simulation, the detector current is converted into the density near the beam.



Starting points of electrons that can enter the detector



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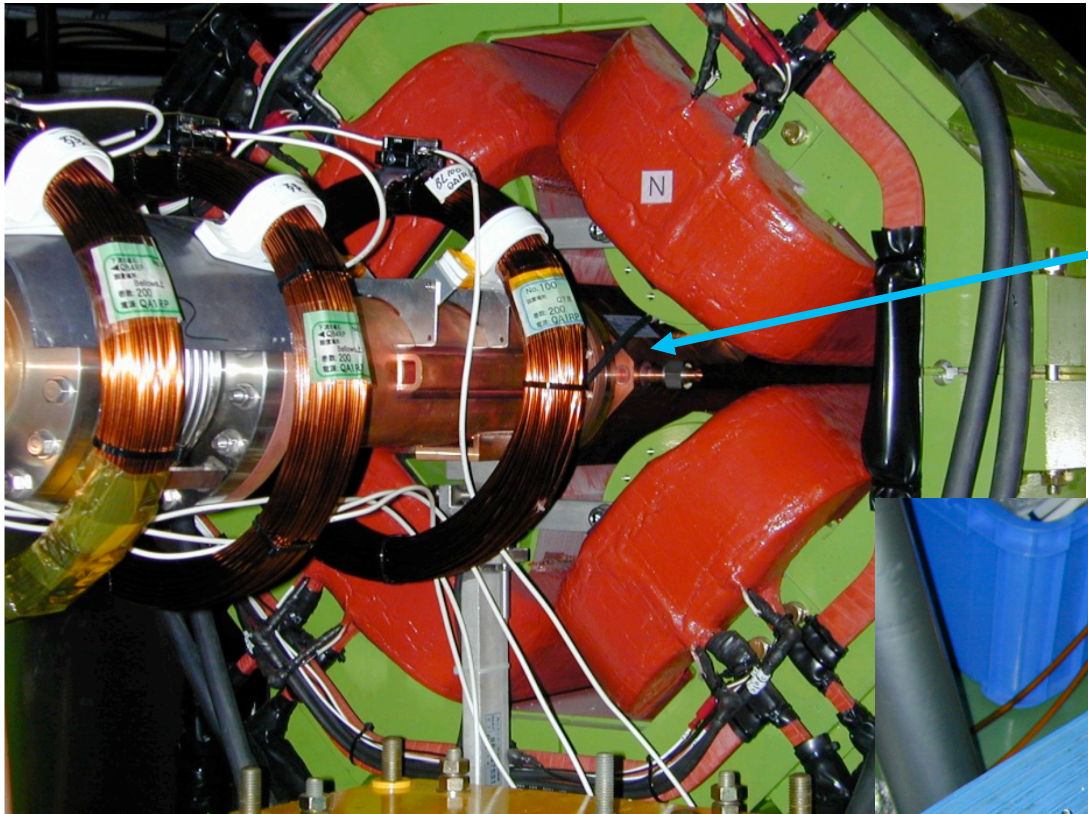
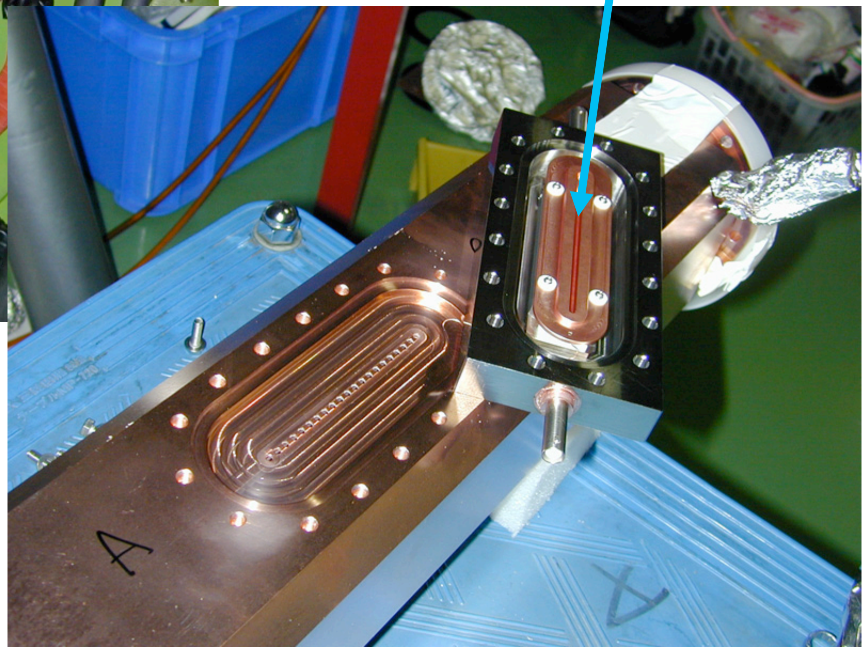
Near Beam Electron Cloud Density Measurement in Magnetic Field with RFA-type Electron Detector 5





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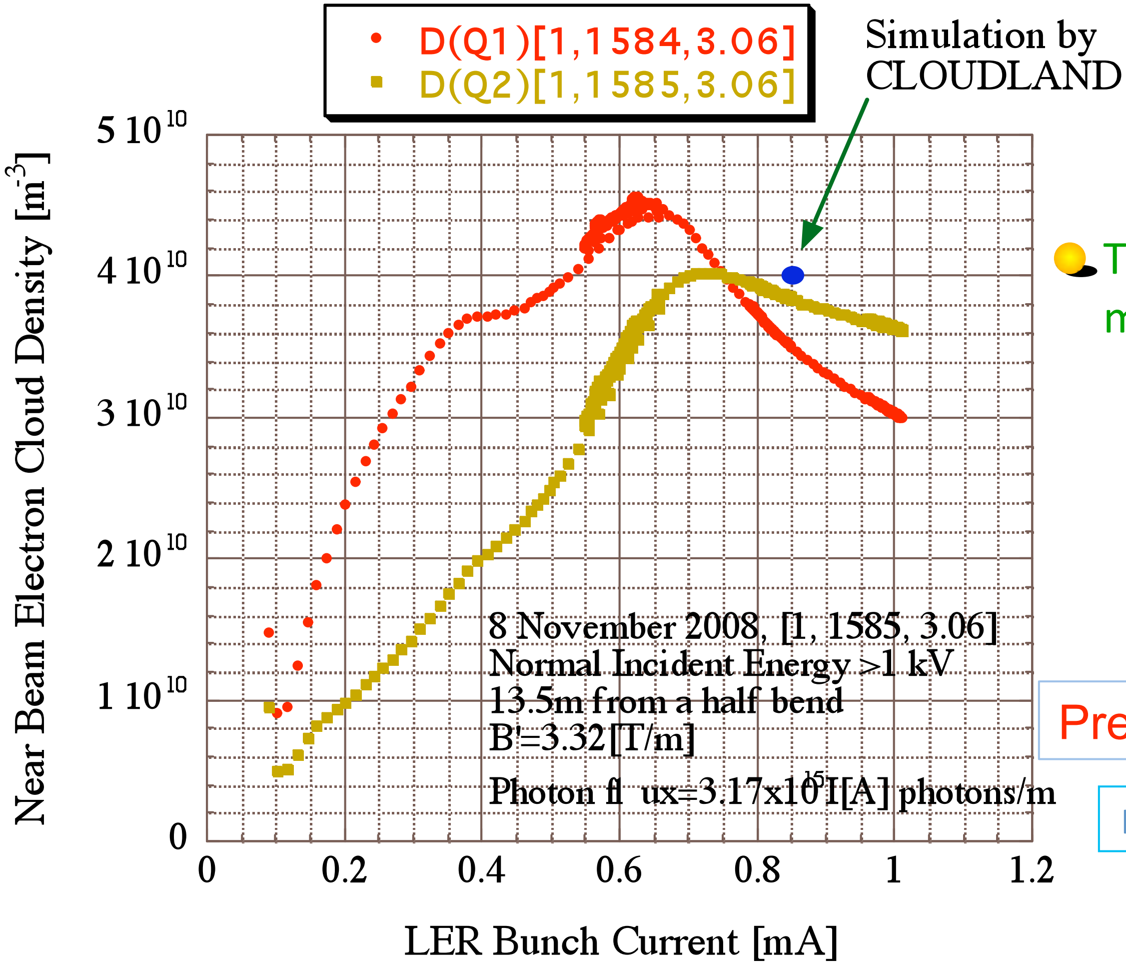
- Electron cloud density in quadrupole field (B' = 3.32 T/m)
  - The observed value in the Q-Magnet was close to the estimation by simulation



Parameters ;
Bunch current : 0.85 mA, 3 bucket spacing, 200 bunches in a train, Photoelectron yield : 0.1, Reflectivity : 0.3, δ : 1.2, E at δmax : 250 eV, Pipe radius : 46 mm, Q field : 3.32 T/m

- The difference in two detectors may be due to ;
  1. COD
  2. Relative position to the primary synchrotron radiation
  3. Output offset of amplifier in measurement system

Preliminary result

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Summary

- Bending test of beam pipe with antechambers was performed, and an actual B-chamber is under fabrication based on the results of the test.
- Various studies on the electron cloud mitigation have been done at KEKB positron ring.
  - Clearing electrode, Groove surface, TiN coating, Graphitization, Beam pipe with antechambers
  - The effects of low SEY coating such as TiN and graphitization were confirmed.
  - Mitigation effect of clearing electrode and groove surface in magnetic field were also experimentally-verified and found to be more effective than other methods.
- New RFA-type electron detectors were developed and installed in KEKB LER to measure the electron cloud density in solenoid coil and quadrupole magnet.
  - It was confirmed that the electron cloud density decreased by more than 1/100 in the solenoid field.
  - The measured electron cloud density in Q-Mag was consistent with the simulation.
- For SuperKEKB :
  - Drift space : antechamber + solenoid
  - In magnets : antechamber + TiN coating + groove surface?
    + groove surface?
    + clearing electrode?

More studies are required.