SEY and Clearing Studies at KEKB

Y. Suetsugu, KEKB Vac Group

Contents

- Introduction
- Studies
  - Beam duct with Ante-chambers
  - Coatings with Low SEY
  - Clearing Electrodes (plan)
- Summary

Introduction

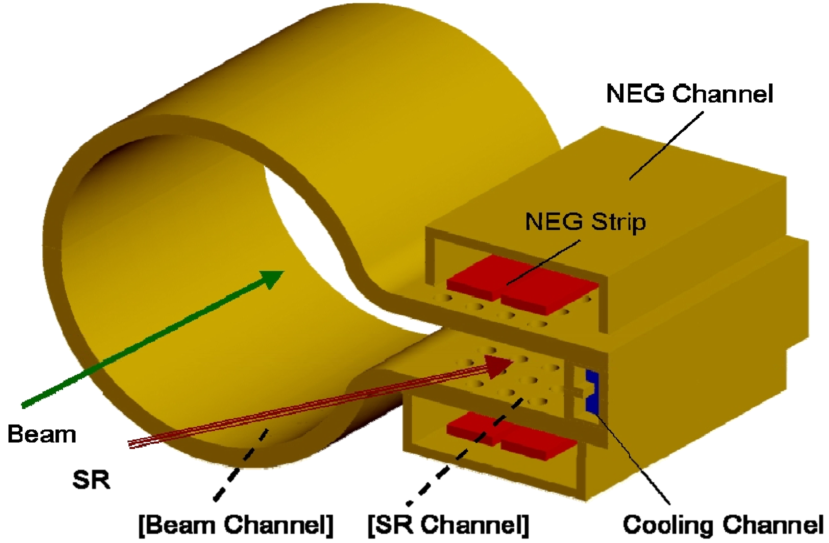
- Studies on ECI at KEK B-factory (KEKB)
  - Using positron ring (LER)
    - E = 3.5 GeV, I = max.1.7 A, 1.2 mA/bunch (1.2×10^{-8} C)
    - Usually ~1400 bunches, 6 ~ 8 ns bunch spaces
    - Beam duct : ϕ94 mm
  - Experiments to suppress electron emission
    - Solenoid field
    - *In situ* SEY measurement
    - Beam duct with ante-chamber
    - Coatings with low SEY
    - Clearing Electrode [Plan]

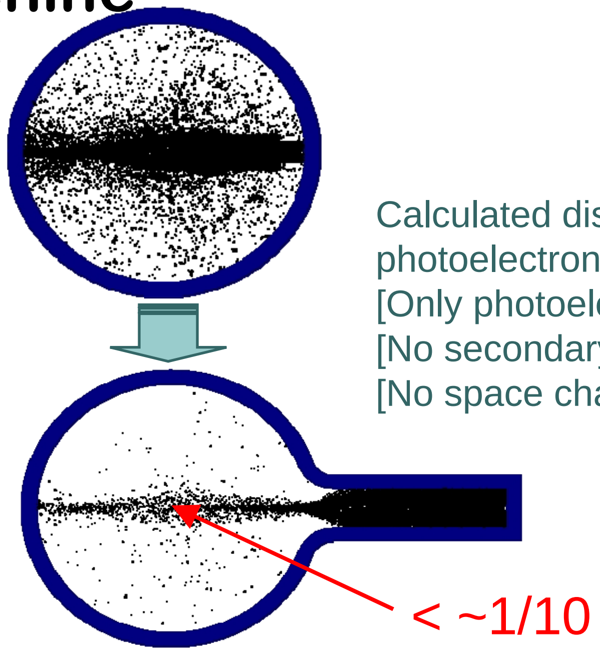
→ Here the results and plans are briefly reviewed.

Beam Duct with Ante-chambers

- **Beam duct with ante-chamber (2003~):**
  - **Effective to reduce photoelectrons in beam channel**
  - **Also effective to dilute power density of SR**
    - **Important for high intensity machines: ex. Super B-factories**
- **Use copper for high current machine**

[Beam duct with antechamber]



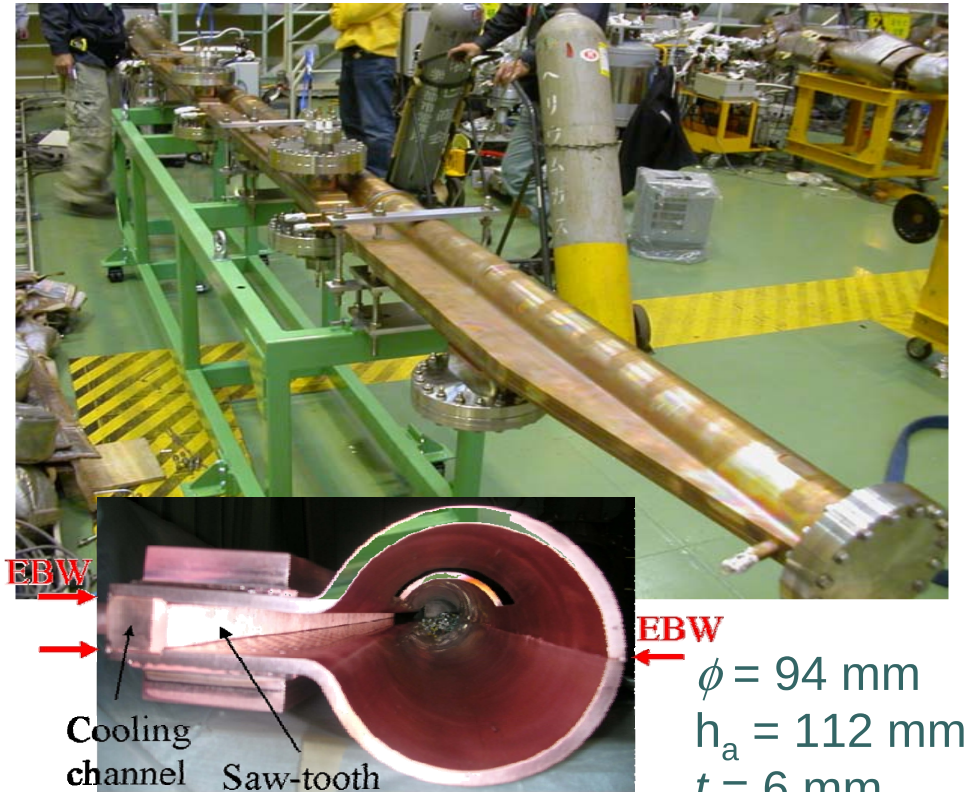


Calculated distribution of photoelectrons
[Only photoelectrons]
[No secondary electrons]
[No space charge]

Beam Duct with Ante-chambers

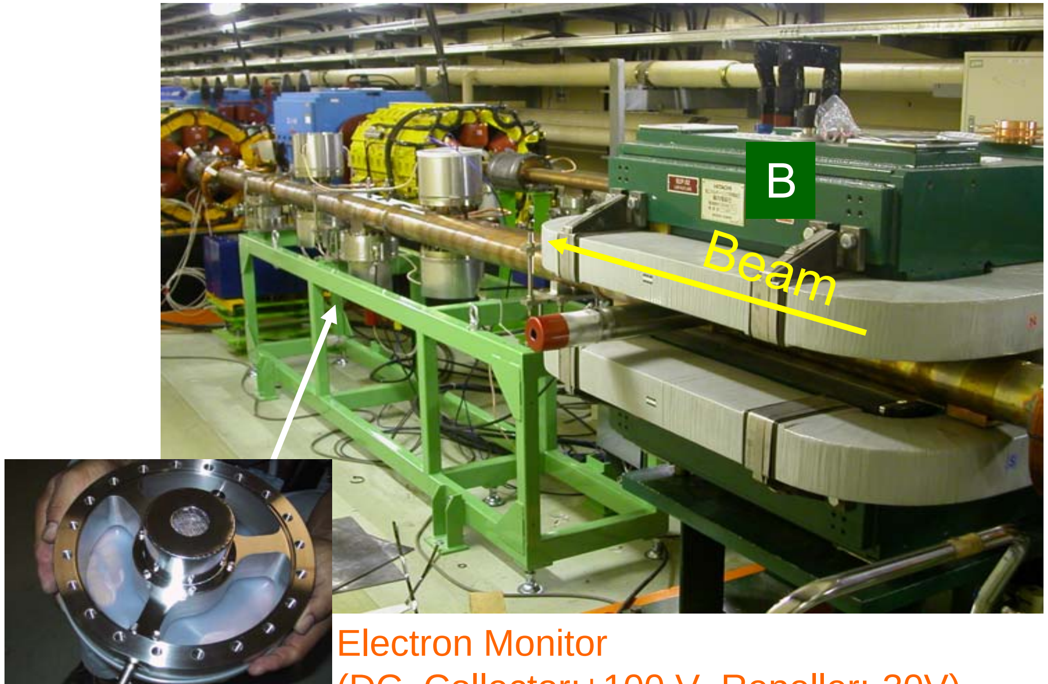
- Copper ducts with an antechamber was manufactured
  - Installed in the KEKB positron ring
  - Electron current was measured using a electron monitor

[Test duct (pressing)]



ϕ = 94 mm
h_a = 112 mm
t = 6 mm

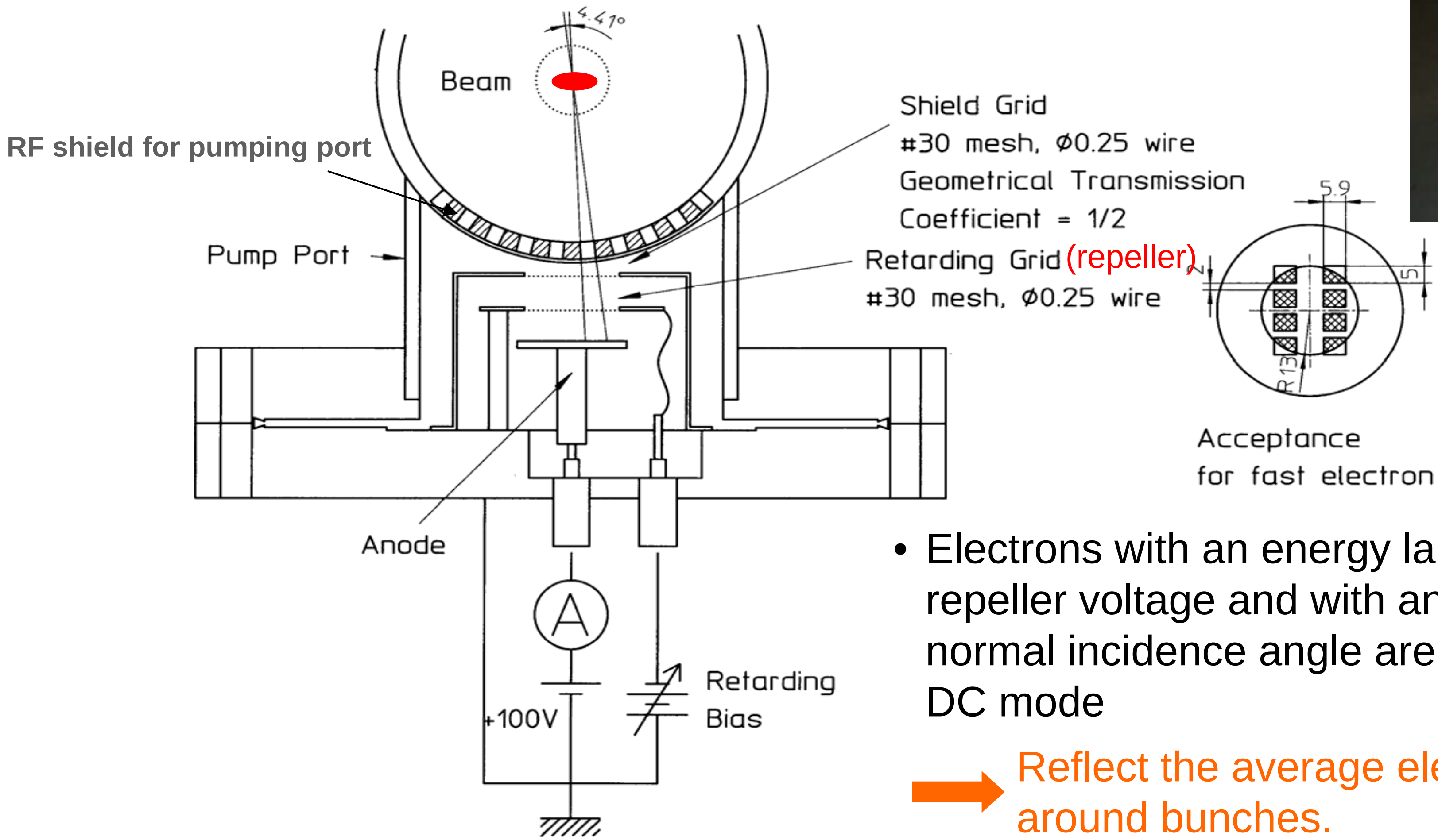
[Installed test duct]

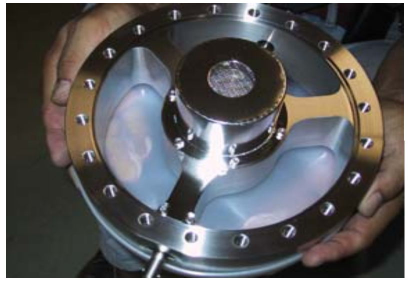


Electron Monitor
(DC, Collector:+100 V, Repeller:-30V)

Beam Duct with Ante-chambers

- **Electron Monitor**
  - **Attached at the bottom of test chamber**





Area of collector : 6x5x5.9/4~40 mm^2

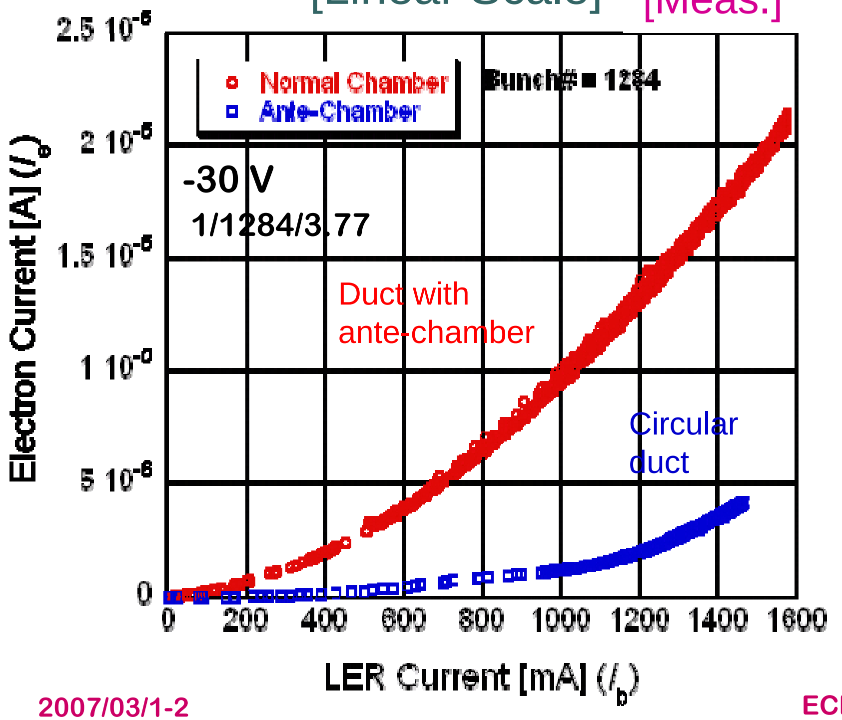
- Electrons with an energy larger than the repeller voltage and with an almost normal incidence angle are measured in DC mode

→ Reflect the average electron density around bunches.

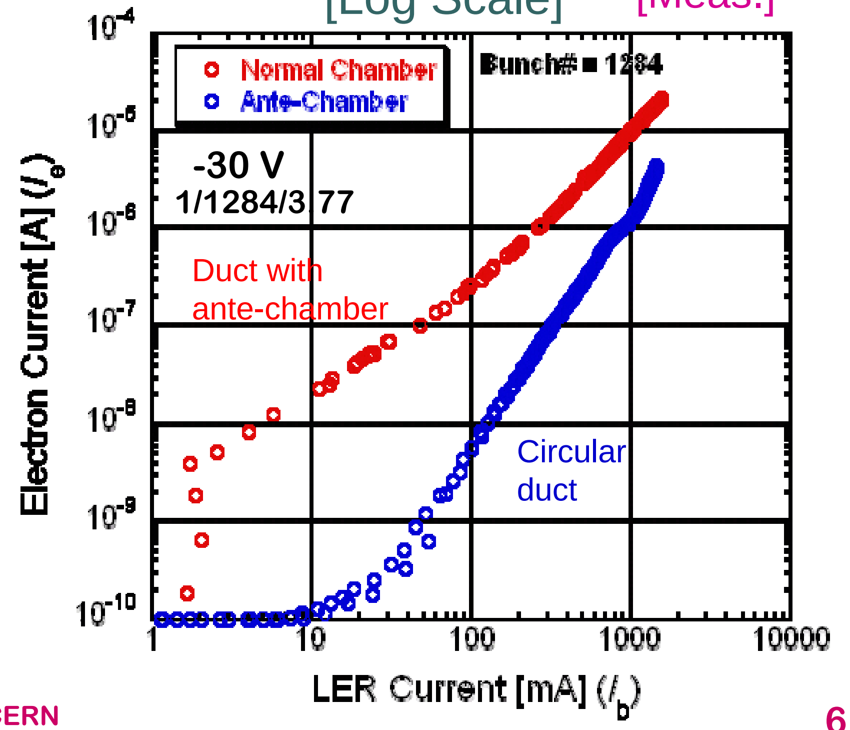
Beam Duct with Ante-chambers

- Comparison with simple circular duct.
  - At low current (<100 mA) : Reduction <1/100
    - Photoelectron is well suppressed.
  - At high current (>1500 mA): Reduction by a factor of 4
    - Secondary electron is important. ⟶ Surfaces with low SEY

[Linear Scale] [Meas.]



[Log Scale] [Meas.]



Low SEY Coatings

- An essential way to suppress ECI at high current region
- Promising candidates:
  - TiN coating
    - Has long history for various apparatus.
  - NEG coating
    - Developed by CERN and SAES Getters.
    - Has pumping effect.
  - Rough surface (groove)
    - Proposed from BINP and SLAC
    - R&D is undergoing
  - DLC (Graphite), or Graphitization
    - Need further R&D

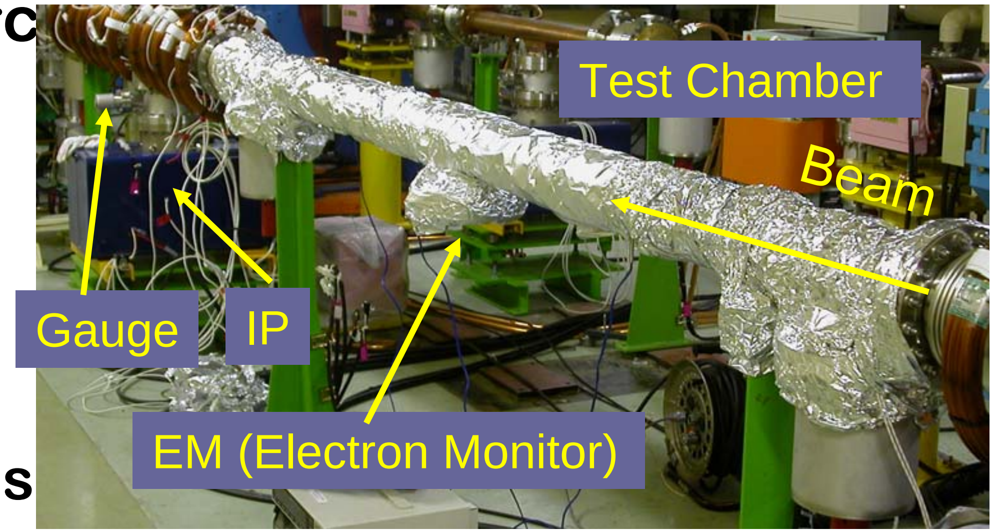
Focused on at KEKB (TiN coating, NEG coating)

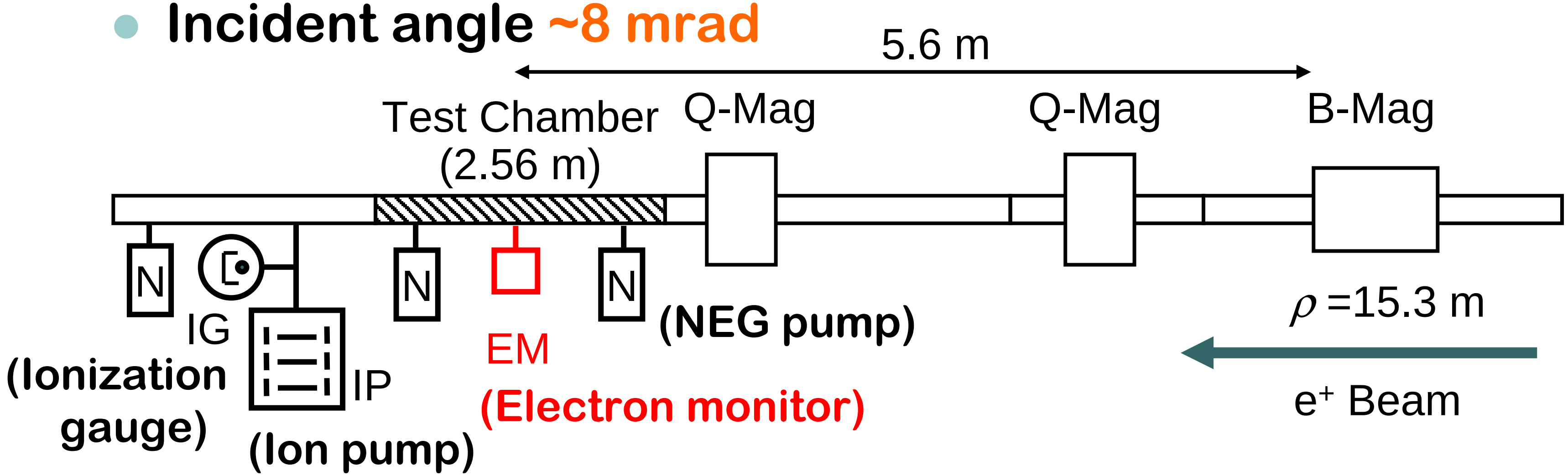
Low SEY Coatings

- Methodology
  - Test chambers (Cu, TiN-coated and NEG-coated) were installed in the KEKB positron ring.
  - Number of electrons near the beam orbit was measured using an electron monitor, and compared each other.
  - Photoelectron yield and secondary electron yield was estimated using a simulation of electron current.

Low SEY Coatings

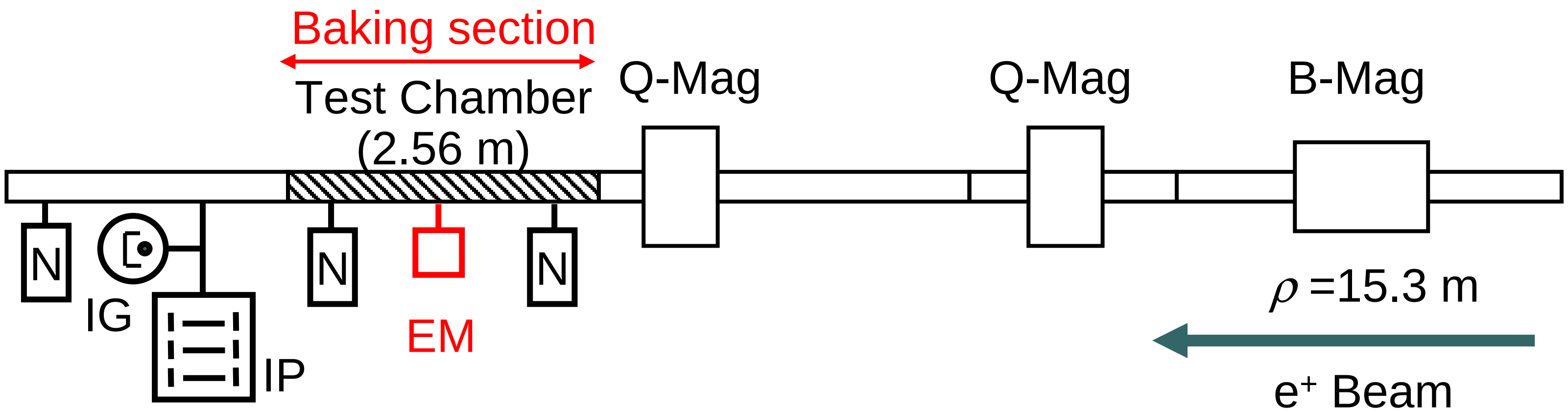
- Ex.1: **Measurement at an arc section (2004~)**
  - Direct SR of 6.4×10^{14} photons/s/m/mA was irradiated at side wall.
    - Realistic condition including photoelectrons
  - Incident angle ~8 mrad





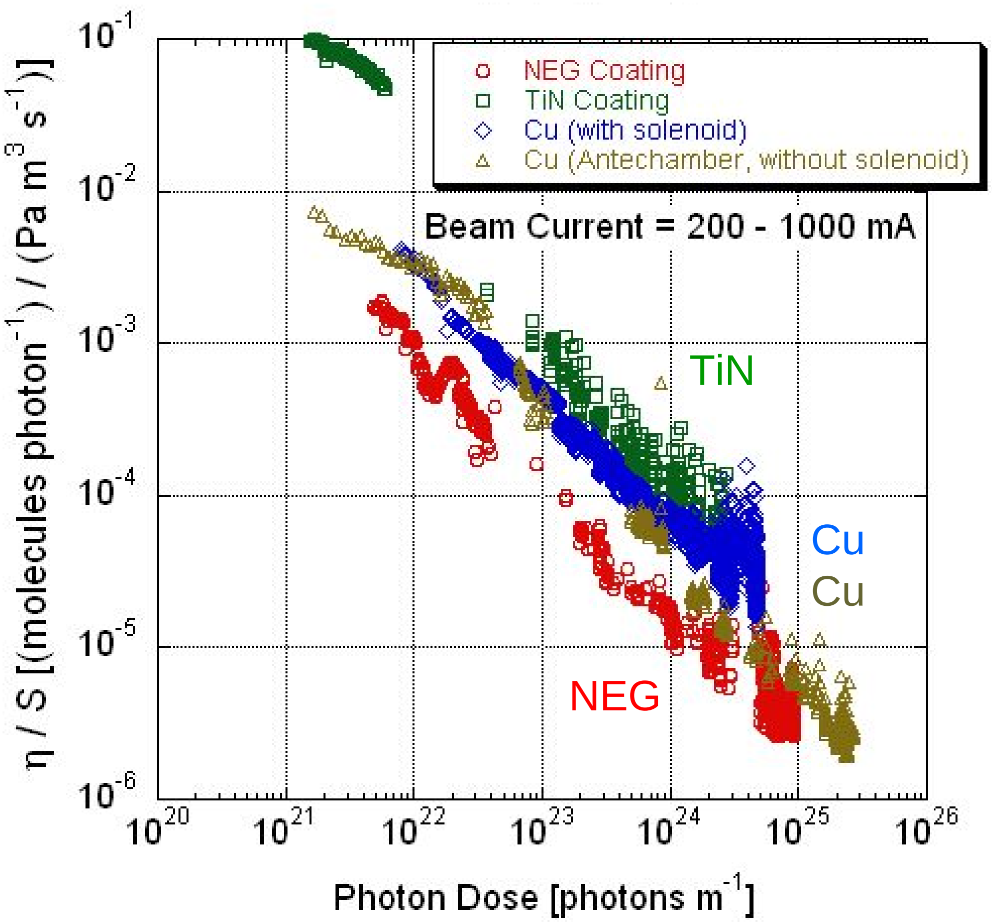
Low SEY Coatings

- Test chambers were baked before the installation at 150°C for 24 hours.
- NEG-coated chamber was baked *in situ* after the installation for at 180°C 6 hours followed by at 200°C for 2 hours.
  - Only test chamber
  - No *in situ* baking for TiN-coated chamber



Low SEY Coatings

- Vacuum scrubbing

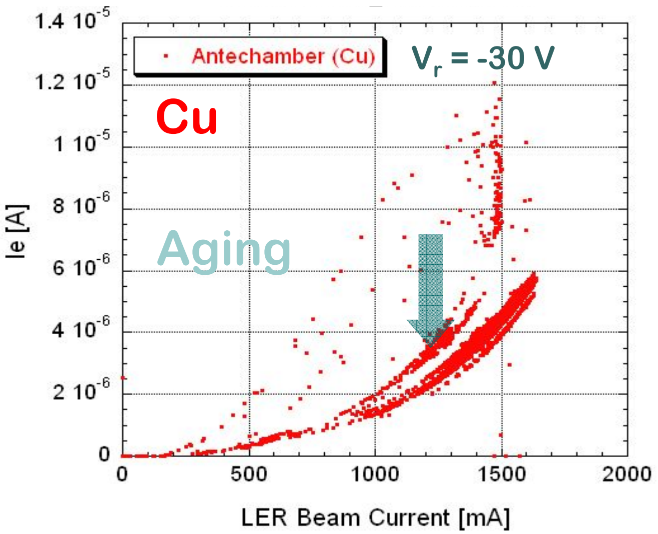


- NEG-coated chamber is the lowest.
  - By a factor of 5 @1E24 ph./m compared to copper.
  - Low gas desorption rate, and pumping in itself.
  - But not so prominent as reported so far.

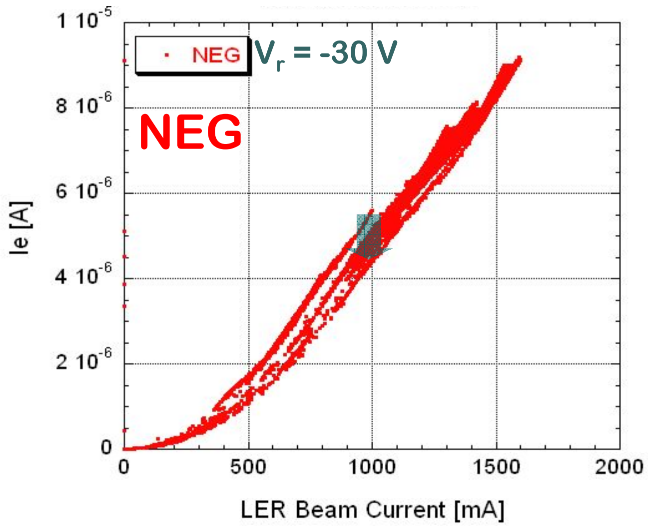
    ← Only one chamber was baked.
- TiN-coated chamber was much higher than copper at first, but by a factor of 2 at1E24 ph./m.

Low SEY Coatings

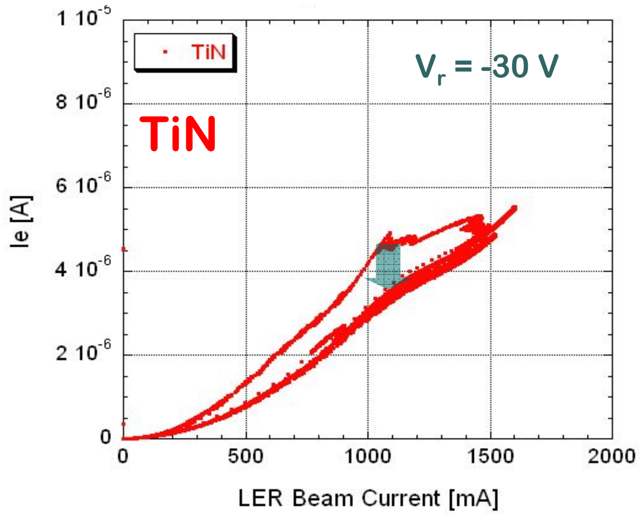
- Electron currents （I_e) were measured against beam current （I_b) in a usual beam operation.
- **Aging of SEY by electron bombardment** was seen at the beginning.



Antechamber (Cu)
A baking at 150°C 24 hours before installation



NEG
A baking at 200°C for 2 hours before operation in the tunnel to activate NEG



TiN
A baking at 150°C 24 hours before installation

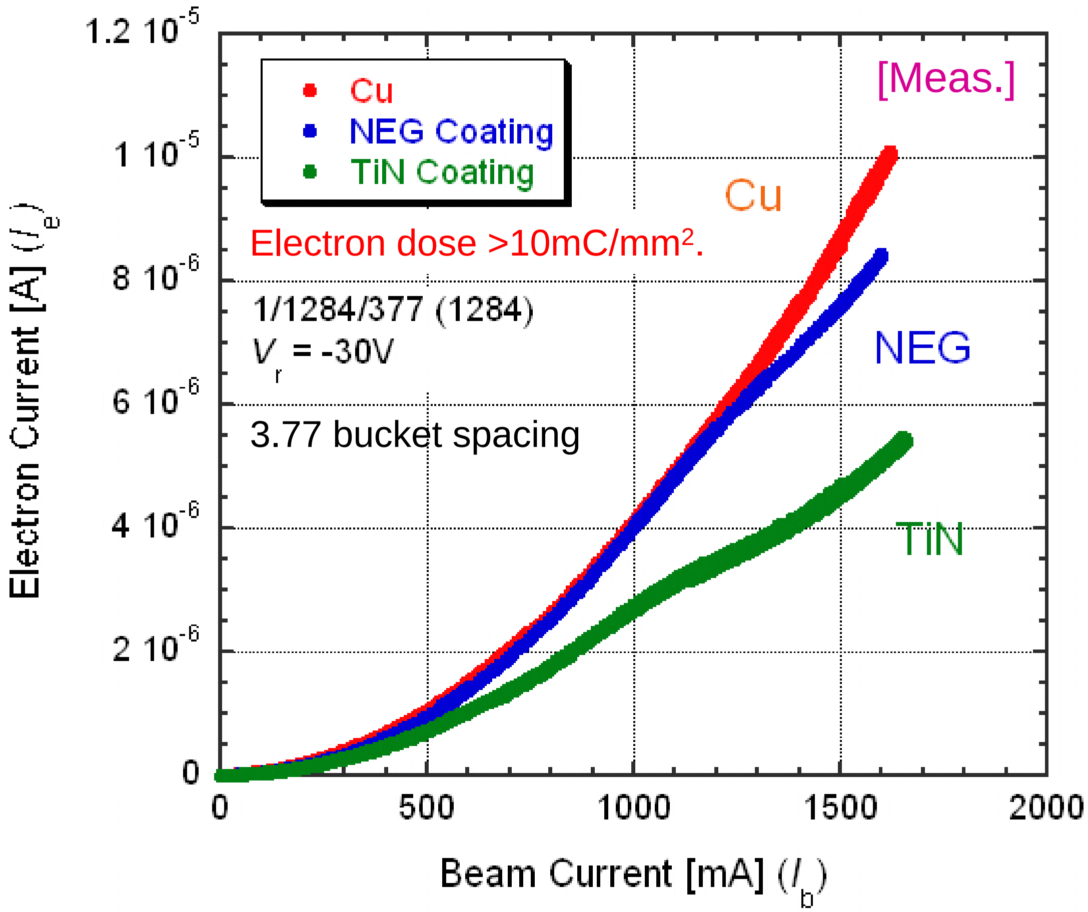
Electron Dose：4×10^{-6}A/1500mA/40mm^2 ~ 7×10^{-11}C/s/mA/mm^2

40 A hours: $7 \times 10^{-11} \times 40000 \times 3600$ ~ 1×10^{-2}C/mm^2 =10 mC/mm^2, ~2 days at KEKB

Low SEY Coatings

- Cu, TiN, NEG for the same beam condition

(After sufficient aging)

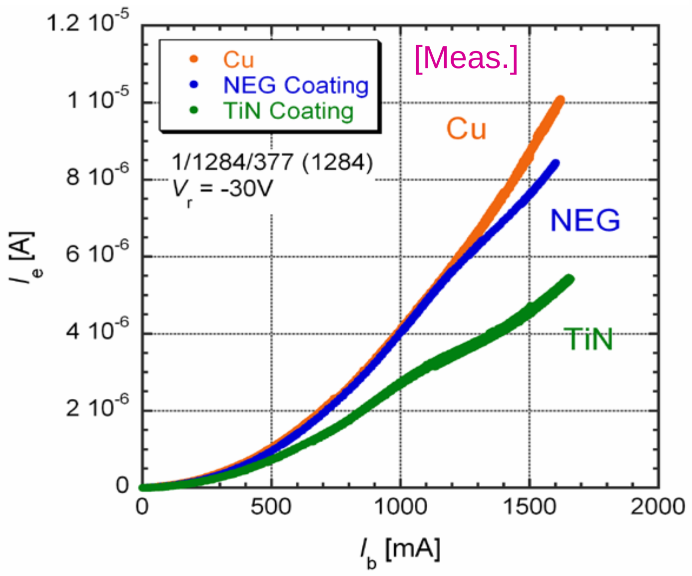


- I_e for NEG coating is almost same as that of Cu, except for high current.
- I_e for TiN coating is clearly lower than those for Cu and NEG (1/2 ~ 1/3).
- TiN seems better from the view point of small electron numbers in the beam duct.
- Little difference even after additional baking of NEG-coated chamber at 220°C for 2 hours.

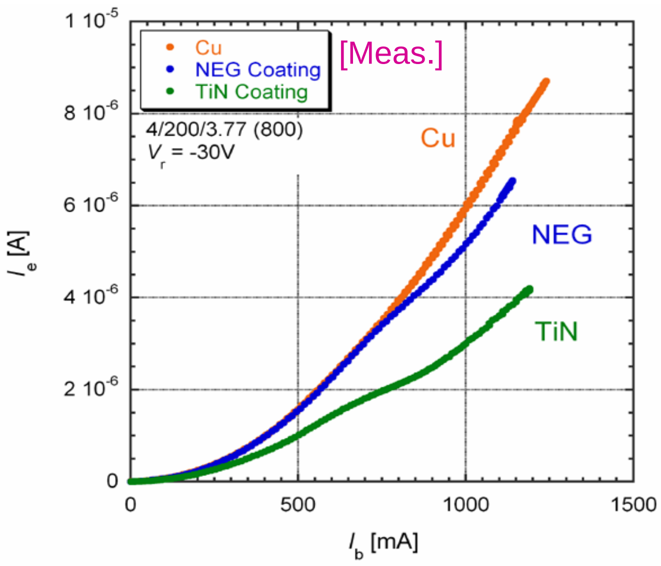
Low SEY Coatings

- **Dependence on bunch filling pattern**
  - **For every case, I_e(Cu) ~ I_e(NEG) > I_e(TiN)**

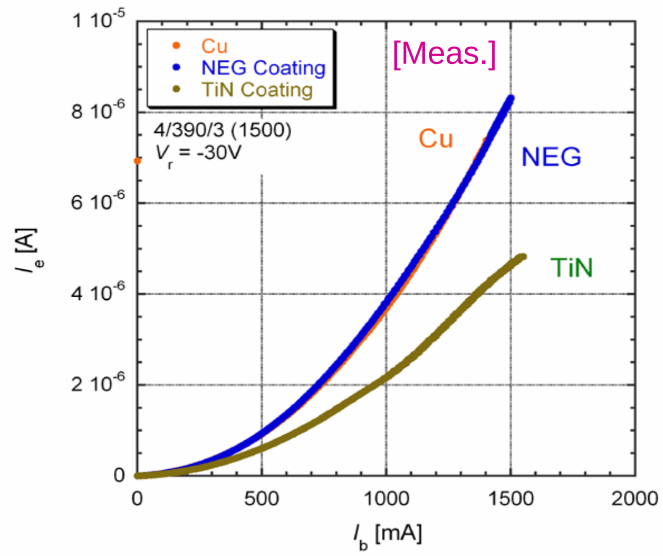
1/1284/3.77 (#1284)



4/200/3.77 (#800)



4/390/3 (#1500)

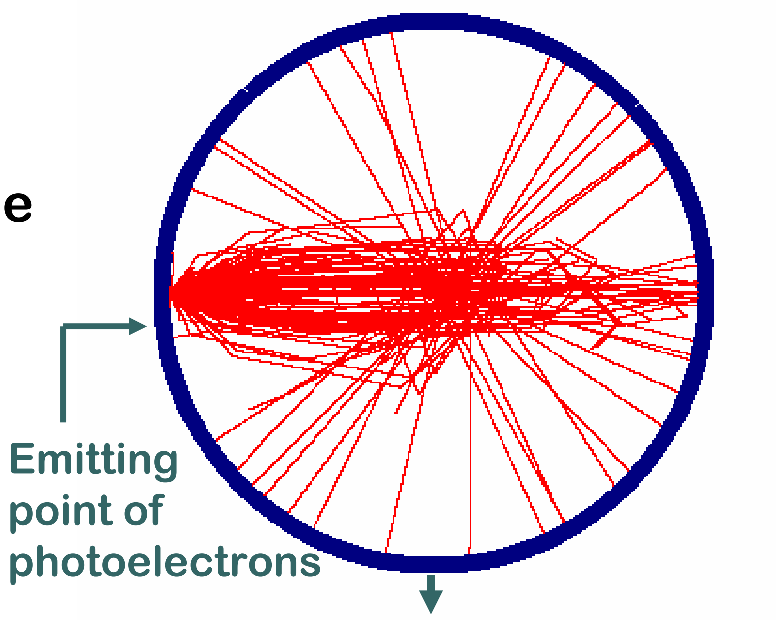


1 RF bucket = 2 ns
1 mA / bunch = 1×10^{-8} C / bunch = 6.2×10^{10} e^- / bunch

Low SEY Coatings

- Simulation
  - Understand the behavior of measured electron currents
  - Estimate the SEY (δ_{max}) and PEY (photoelectron yield, η_e) of Cu, NEG and TiN.
- Method:
  - "Macro" electrons ($\leq 10^4$ electrons) are traced from the emission, and the number of electrons hitting the bottom of duct (position of electron monitor) with an almost normal incidence angle are counted.
  - η_e: Constant
  - SEY: Follows Furman's formula (constant profile with E_{max}=300eV)

$$\delta(E) = 1.11 \times \delta_{max} \times \left(\frac{E}{E_{max}} \right)^{-0.35} \times \left[1 - \exp\left(-2.3 \times \left(\frac{E}{E_{max}} \right)^{1.35} \right) \right]$$

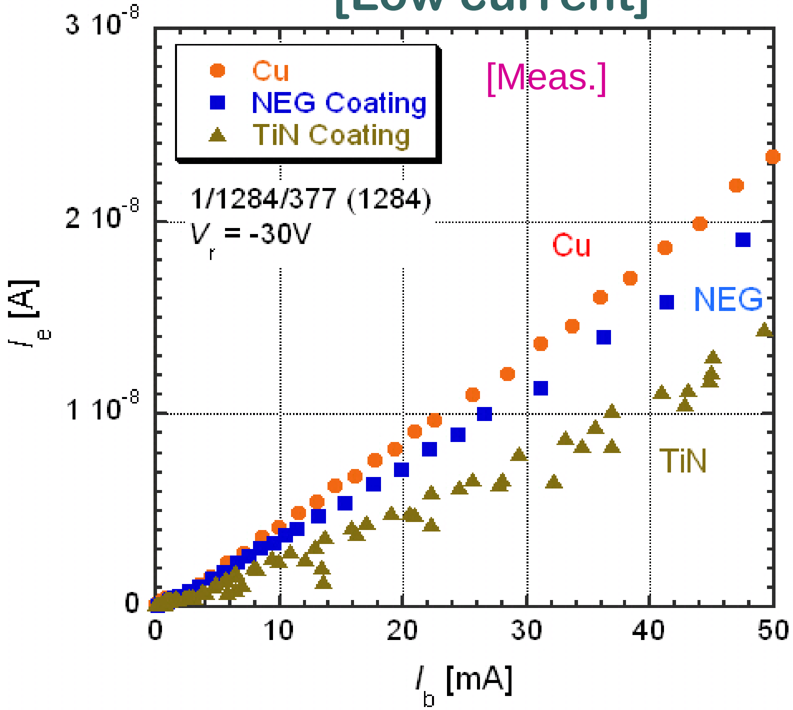


[Example of electron trajectories (Only photoelectrons, No secondary electrons, No space charge)]

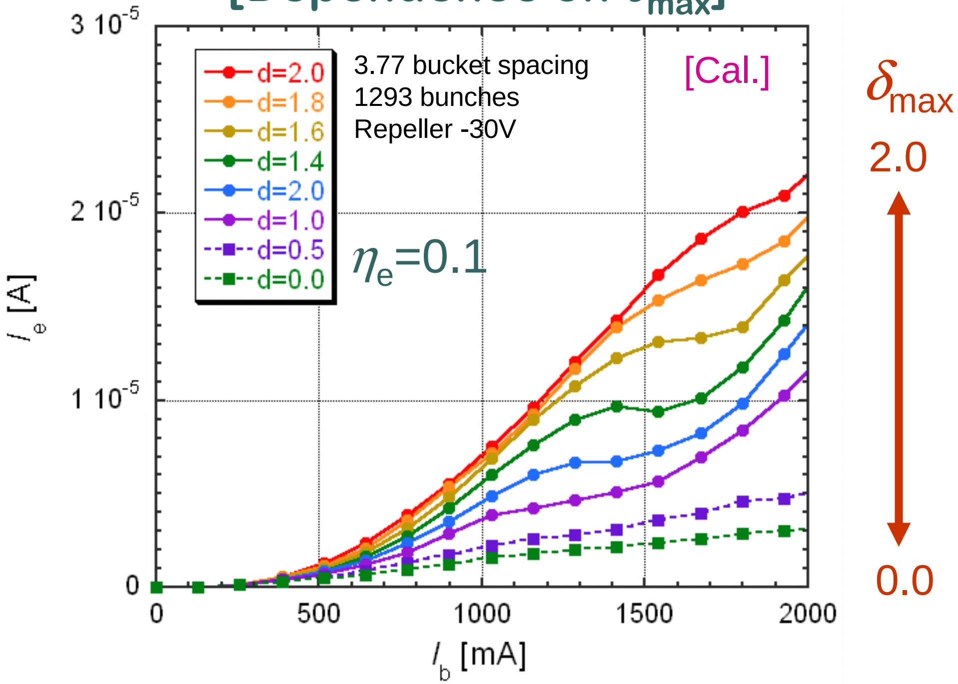
Low SEY Coatings

- I_e curves depend on η_e and δ_{max}.
- Estimation of η_e and δ_{max} by curve fitting:
  - I_e at low I_b → photoelectrons are dominant → η_e
  - I_e at hihg I_b → secondary electrons are dominant → δ_{max}

[Low current]

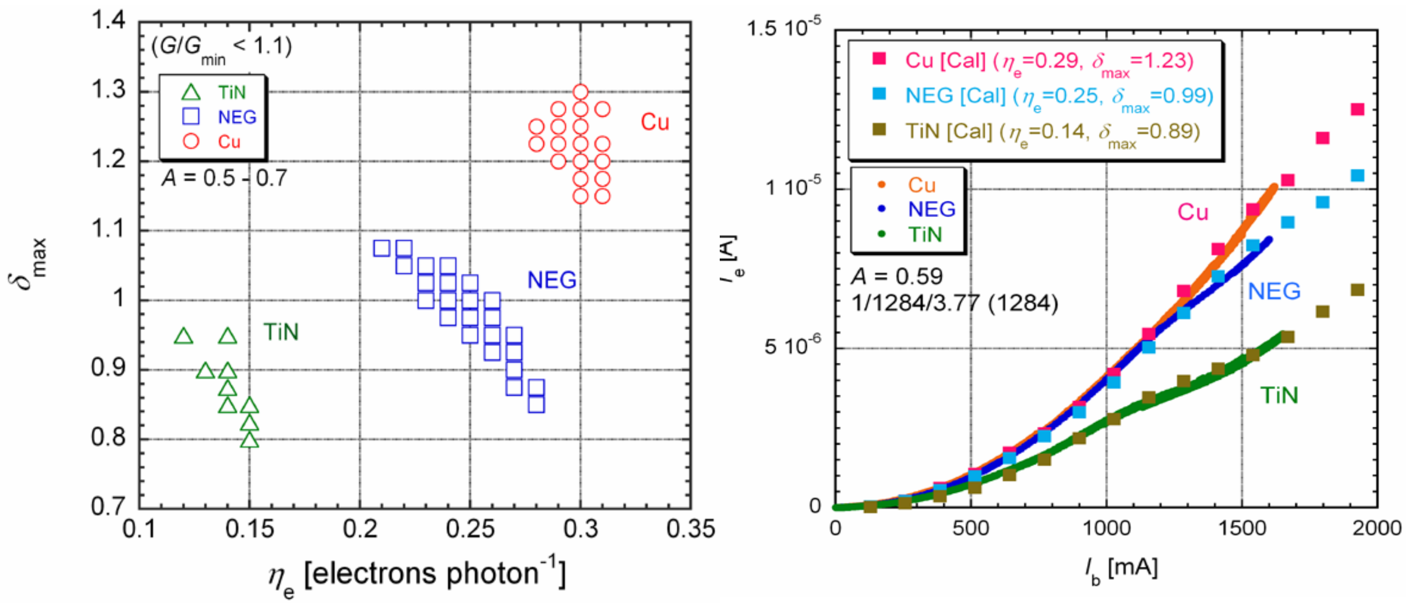


[Dependence on δ_{max}]



Low SEY Coatings

- Curve fitting by scanning photoelectron yield η_e ($0.1 \leq \eta_e \leq 0.4$) and Max. SEY δ_{max} ($0.8 \leq \delta_{max} \leq 2.0$).



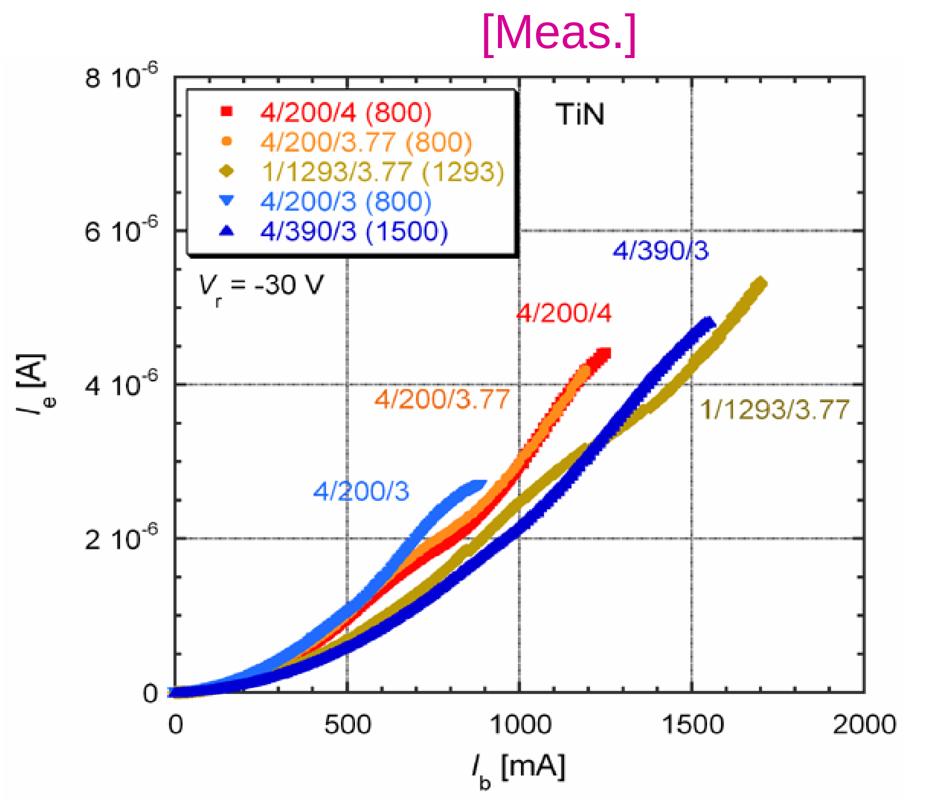
3.77 bucket spacing
1293 bunches
Repeller -30V

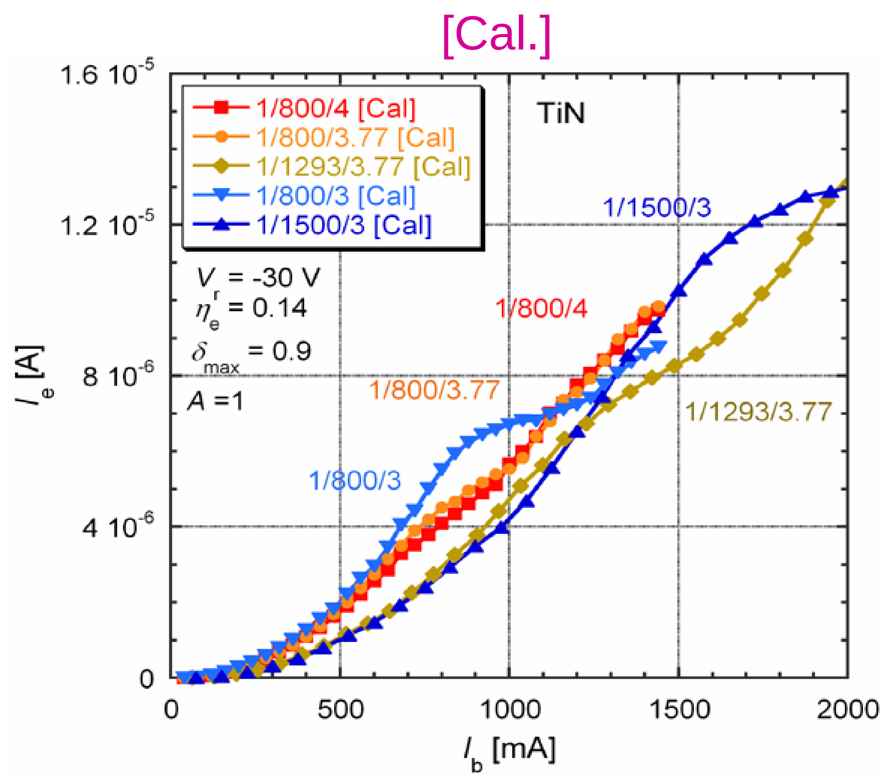
	η_e	δ_{max}
Cu	0.28-0.31	1.1-1.3
NEG	0.22-0.27	0.9-1.1
TiN	0.13-0.15	0.8-1.0

- TiN coating seems better from view points of low δ_{max} and also low η_e.
- δ_{max} of NEG is lower than Cu, but not so clear due to the high η_e.
- The δ_{max} of Cu, NEG and TiN is near to those measured in laboratory after sufficient electron bombardment.

Low SEY Coatings

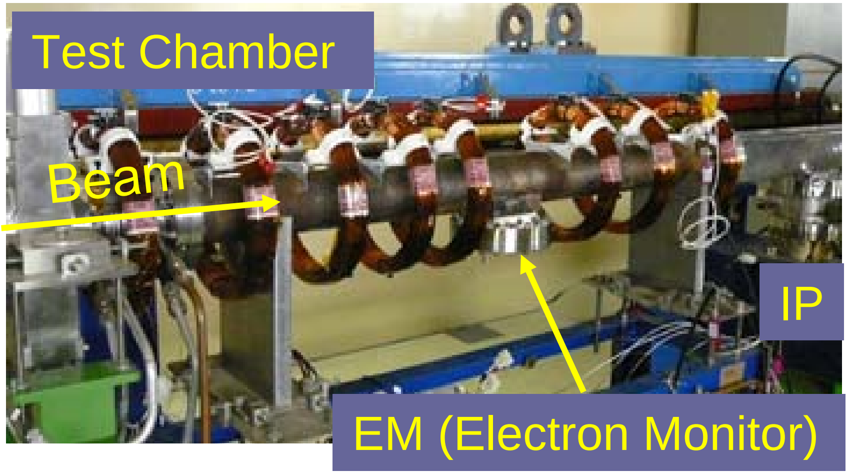
- **Ref: Simulation well explained the dependence on bunch fill pattern.**

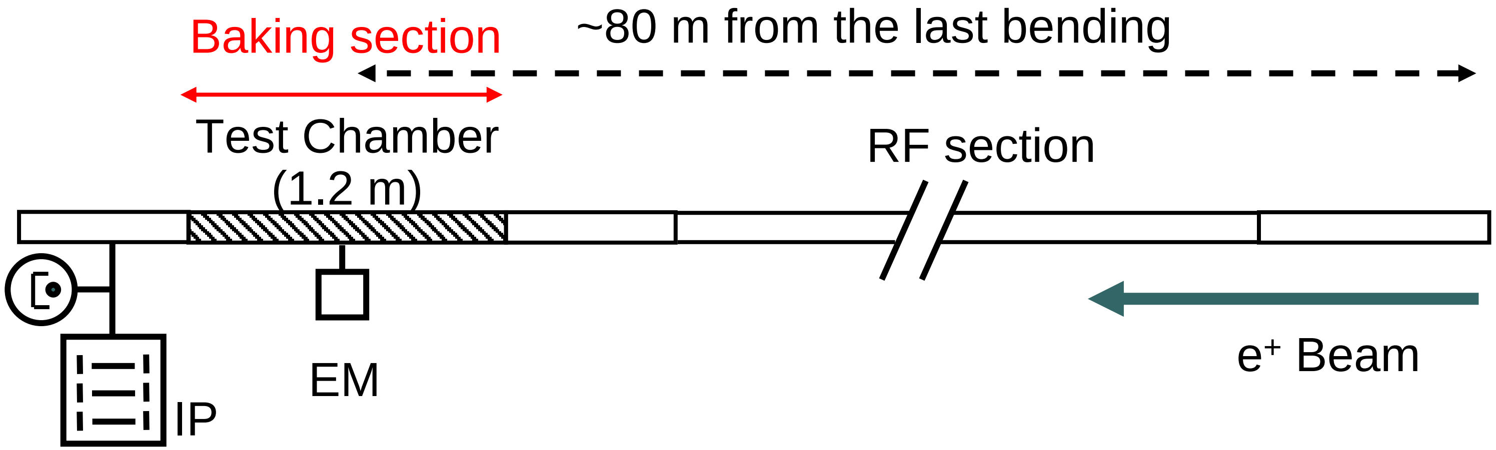




Low SEY Coatings

- Ex.2: Measurement at a straight section (2006~)
  - Low direct SR : 3.3x10^{12} photons/s/m/mA (<1/100 of arc)
  - Eliminate the effect of SR
- Copper, TiN coating and NEG coating
  - The same procedure to the experiment at arc section

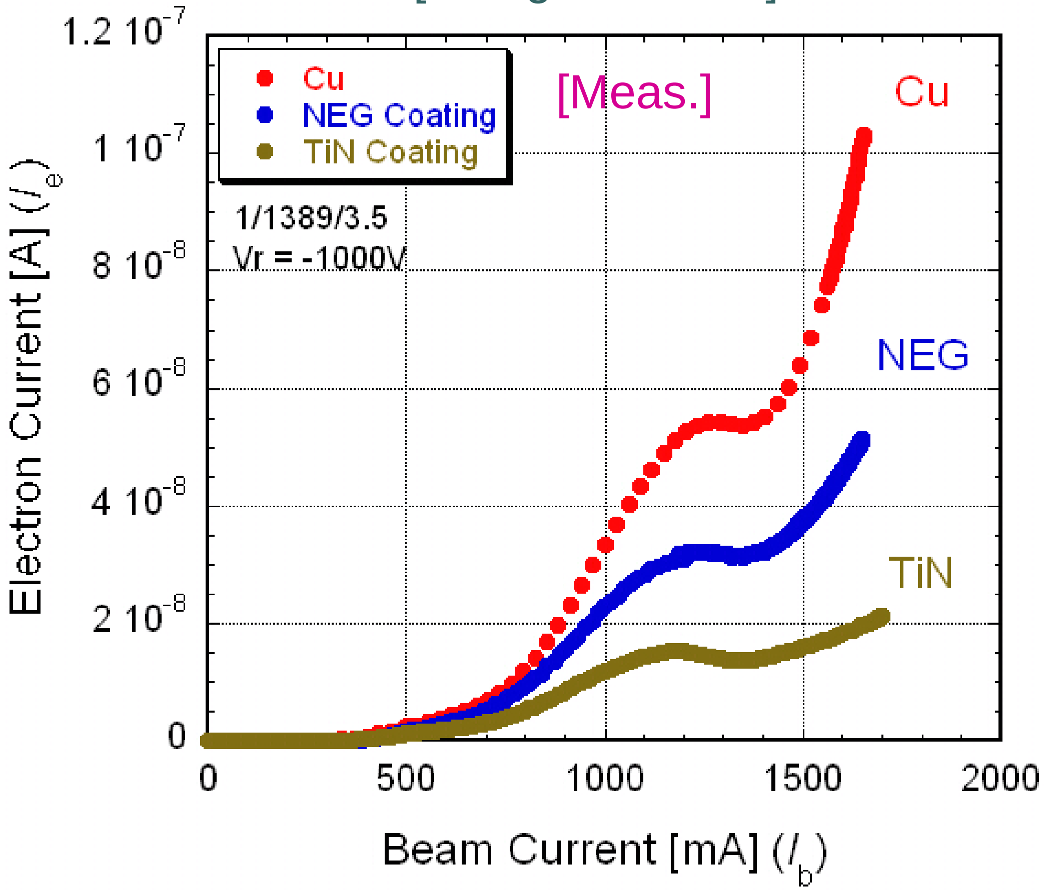




Low SEY Coatings

- Measured electron currents (I_e) for Cu, NEG-coating and TiN-coating at the same condition

[Straight Section]

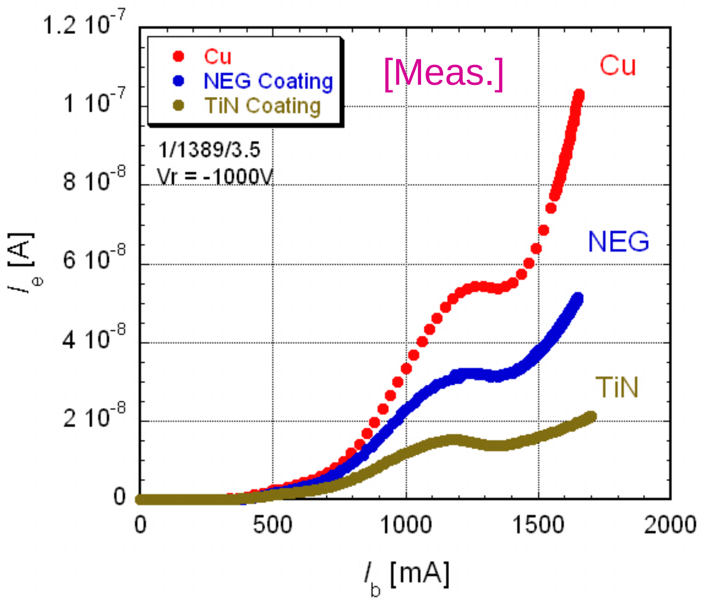


- I_e for NEG coating is 2/3 - 1/2 of that for Cu.
- I_e for TiN coating is 1/3 - 1/4 of that for Cu.
- NEG is clearly lower than Cu.
- TiN again seems better from the view point of small electron numbers in the beam duct.
- Little difference even after additional baking of NEG-coated chamber at 200°C for 2 hours.

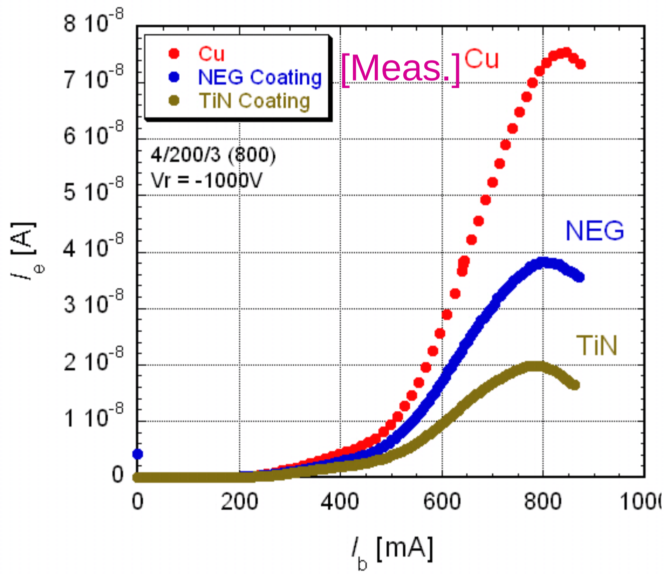
Low SEY Coatings

- **Dependence on bunch filling patterns**
  - **For every case, I_e(Cu) > I_e(NEG) > I_e(TiN)**
    - **Small direct SR made the effect of δ_{max} clearer.**

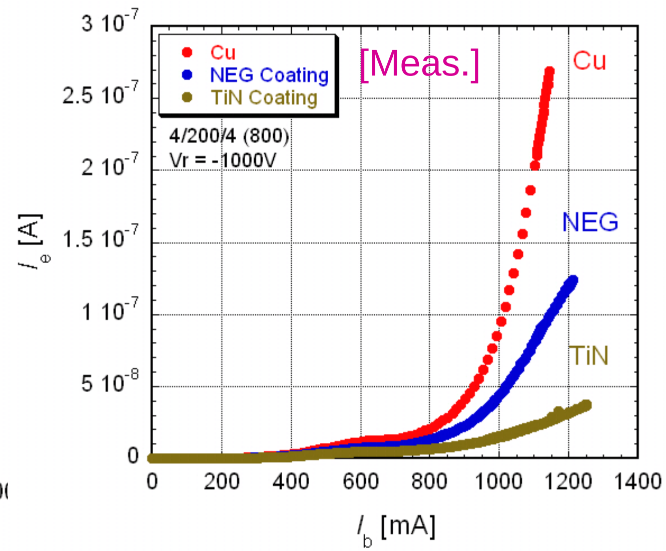
1/1389/3.5 (#1284)



4/200/3 (#800)



4/200/4 (#800)

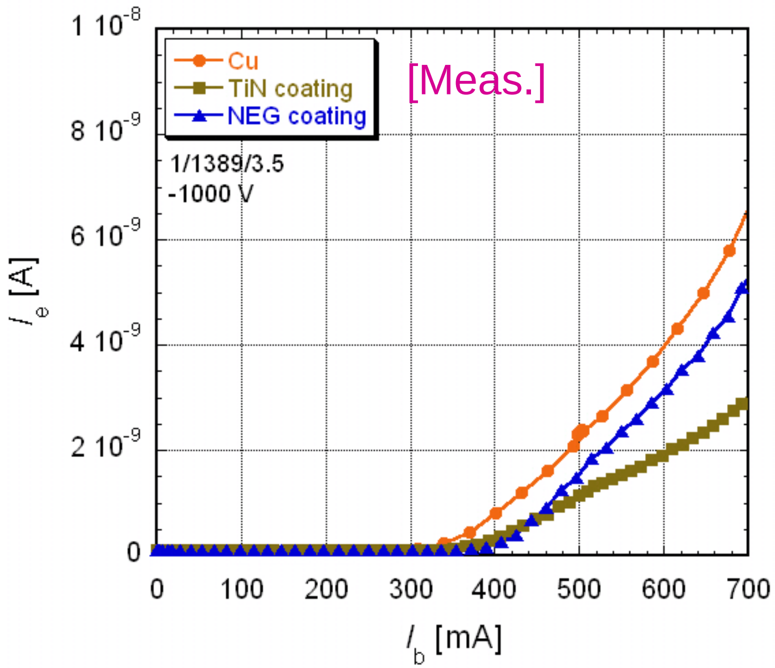


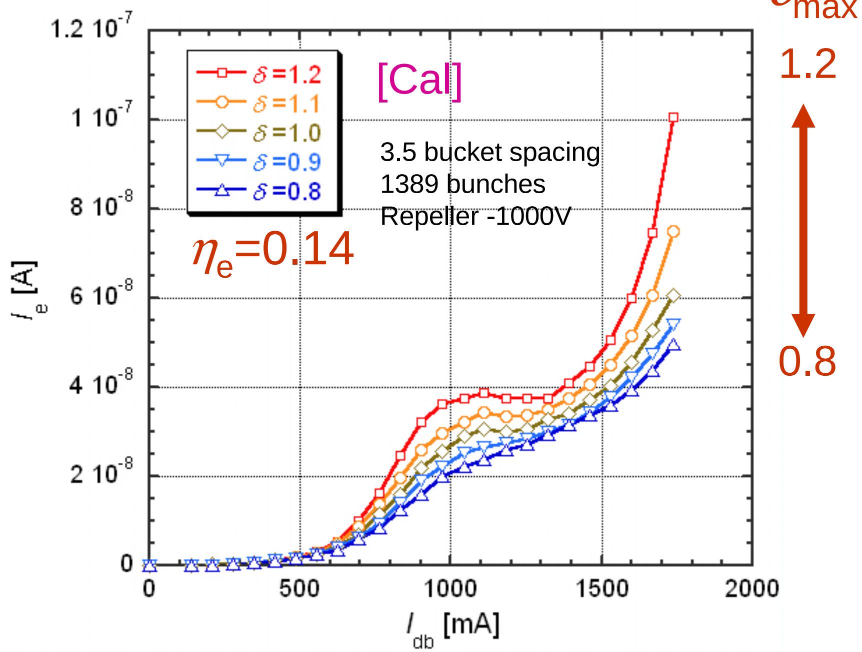
1 RF bucket = 2 ns

1 mA / bunch = 1×10^{-8} C / bunch = 6.2×10^{10} e^- / bunch

Low SEY Coatings

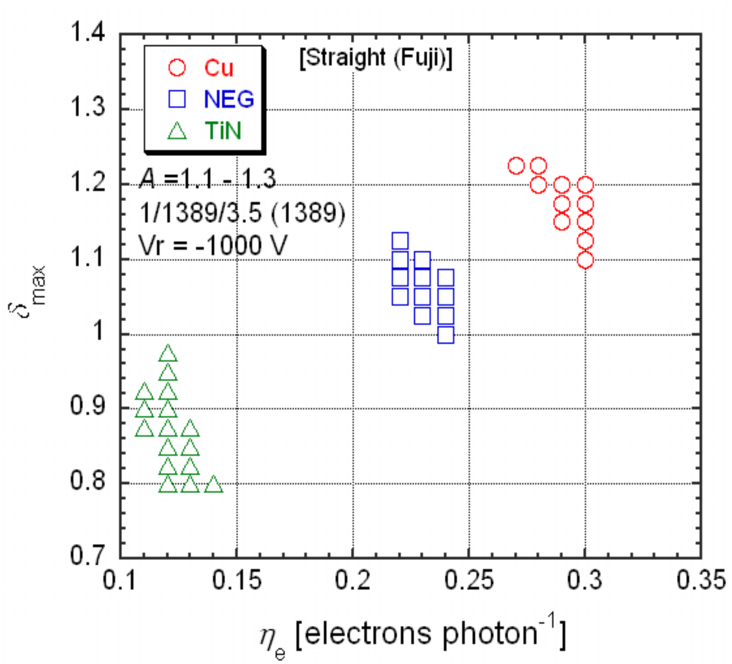
- I_e curves depend on η_e and δ_{max} → curve fitting
- Estimation of η_e and δ_{max} :
  - I_e at low I_b → too low current , and cannot measure I_e
    At I_b = 400 ~600 mA, I_e(Cu) > I_e(NEG) > I_e(TiN)
    → assume the same η_e as before.
  - I_e at high I_b (>1500mA) → δ_{max}

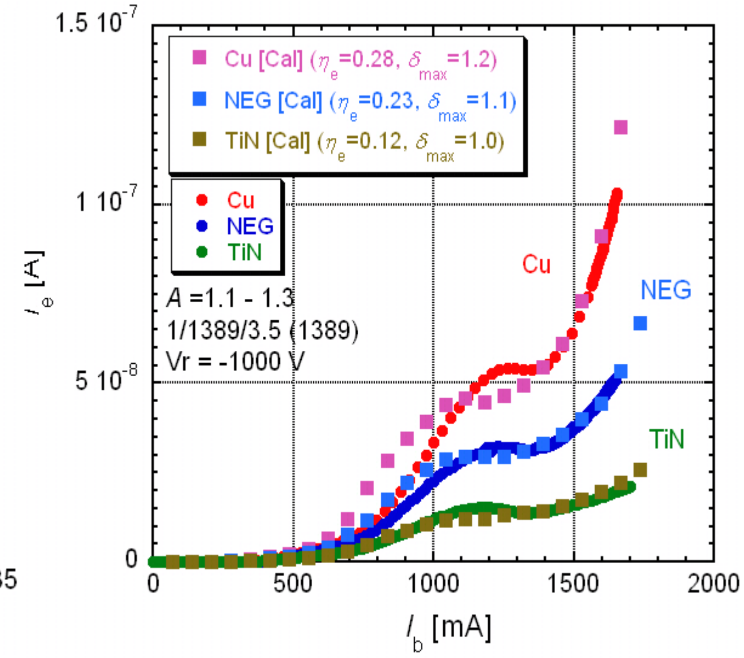




Low SEY Coatings

- Curve fitting by scanning photoelectron yield η_e and Max. SEY δ_{max} .





3.5 bucket spacing
1389 bunches
Repeller -1000V

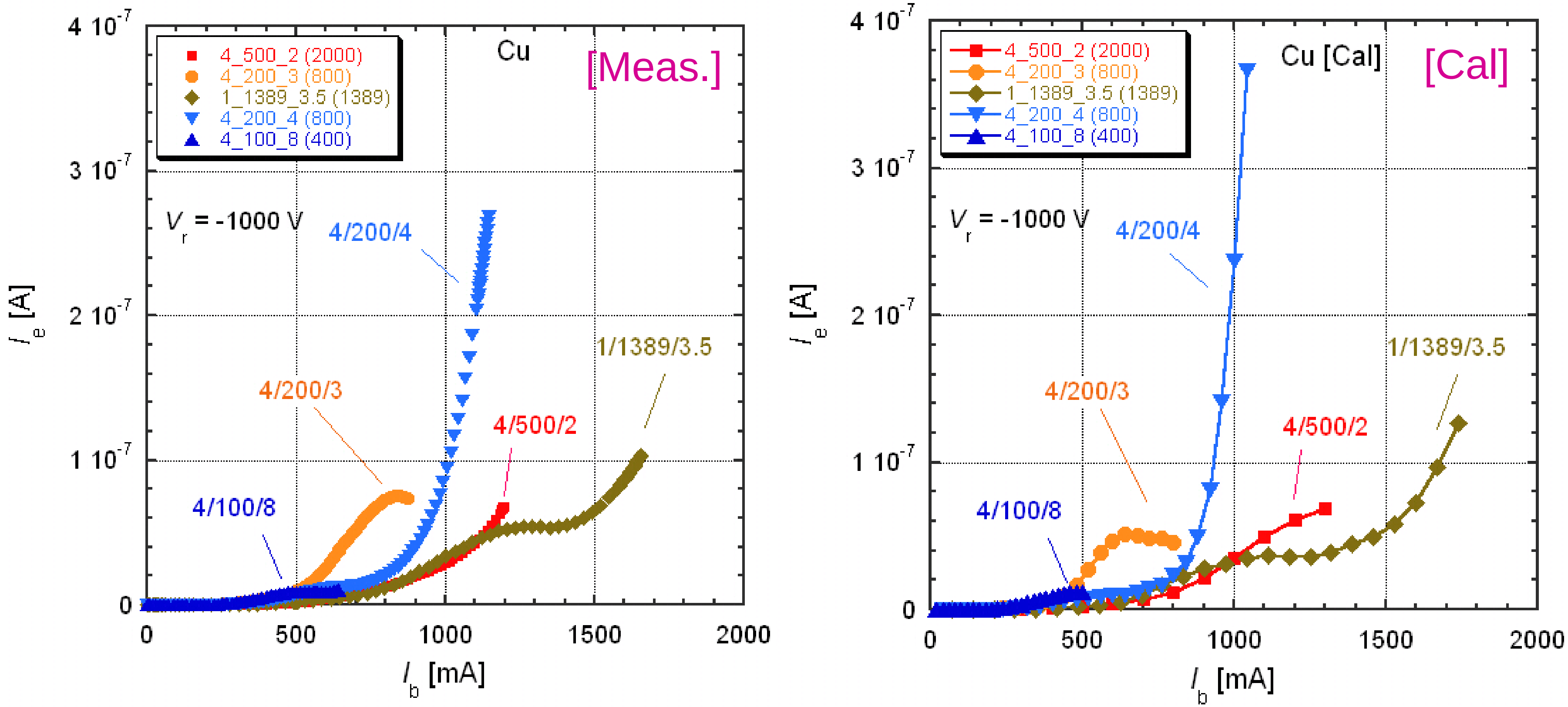
The same η_e were assumed.

	η_e	δ_{max}
Cu	0.28	1.1-1.25
NEG	0.23	1.0-1.15
TiN	0.12	0.8-1.0

- Measured I_e can be reproduced with estimated δ_{max} and η_e, which are consistent with those obtained at arc section.
- TiN still seems better from a view point of low δ_{max} and also low η_e.

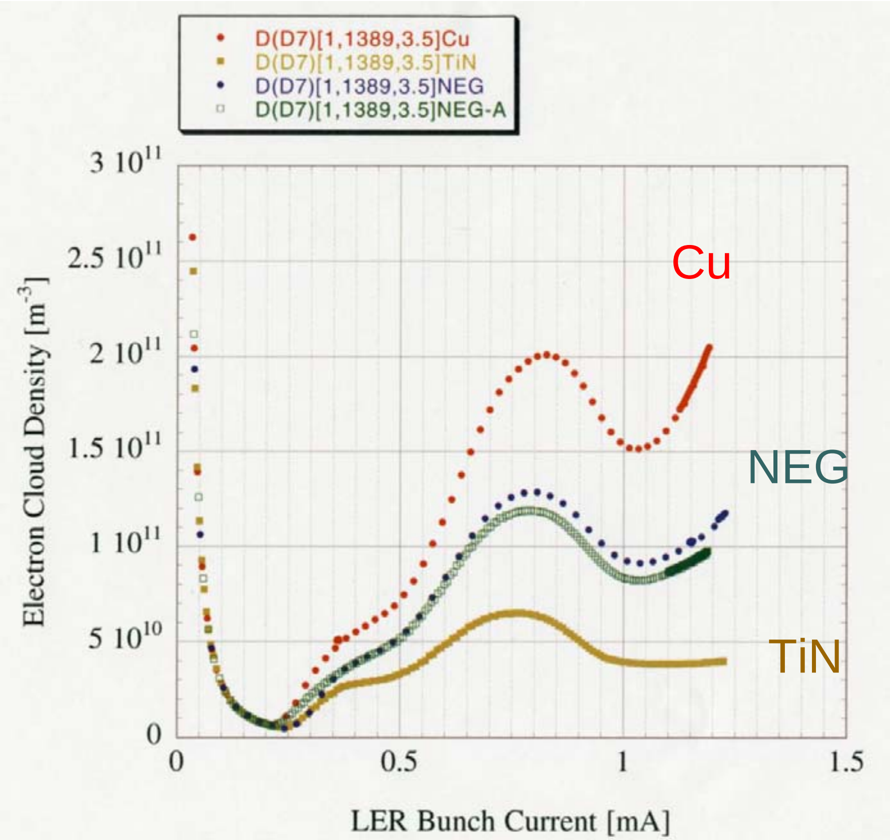
Low SEY Coatings

- Ref: The simulation well explained the dependence on bunch fill pattern.



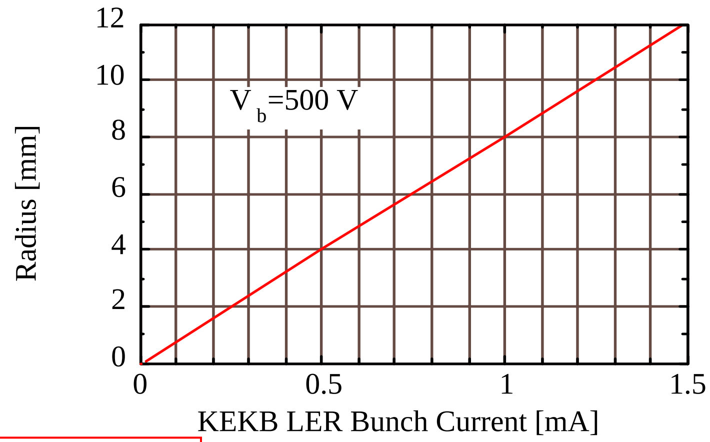
Low SEY Coatings

- Ref: Electron density can be estimated by the electron current at a high repeller voltage. (by K.Kanazawa, KEK)



- Repeller voltage = -1000V.
- Volume where electrons can obtain the energy was taking into account.
- Accuracy: in a factor of 3

[Region of acceleration]

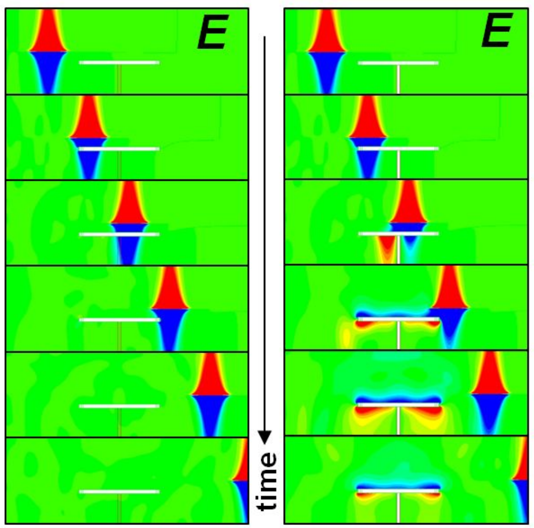


K.Kanazawa et al., PAC2005, p.1054

Clearing Electrode

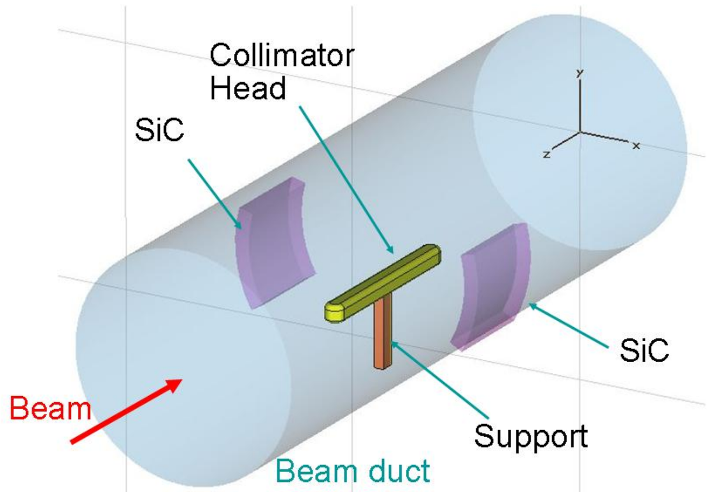
- Effective in magnetic field
- Proposed here is a rod type supported by a ceramics with thin metal coating (high resistivity)
  - Little interference with beams
  - Idea was proposed by F. Caspers as "invisible electrode" ('87)
  - Already adopted at DAΦNE as ion clearing electrodes
  - Similar structure had been proposed as a collimator for KEKB

Interference with beam (MAFIA)



Ceramics (ε_r=4) Metal (Cu)

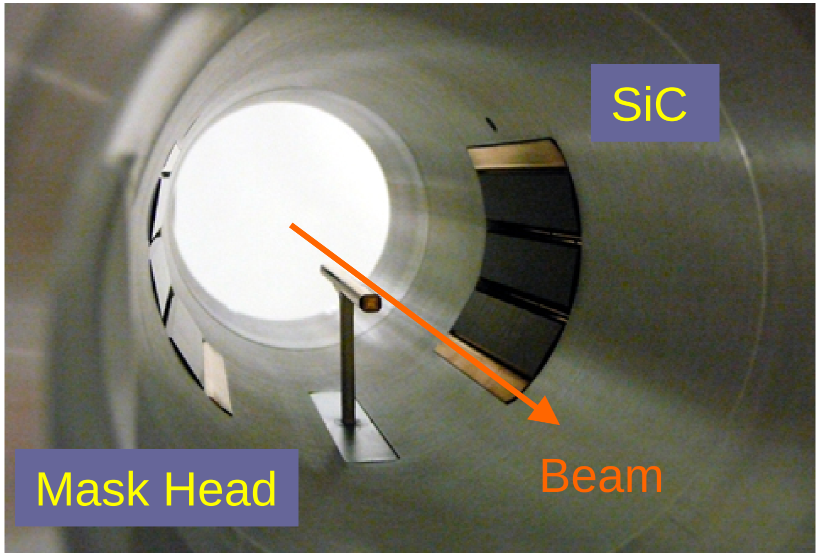
Concept of new collimator



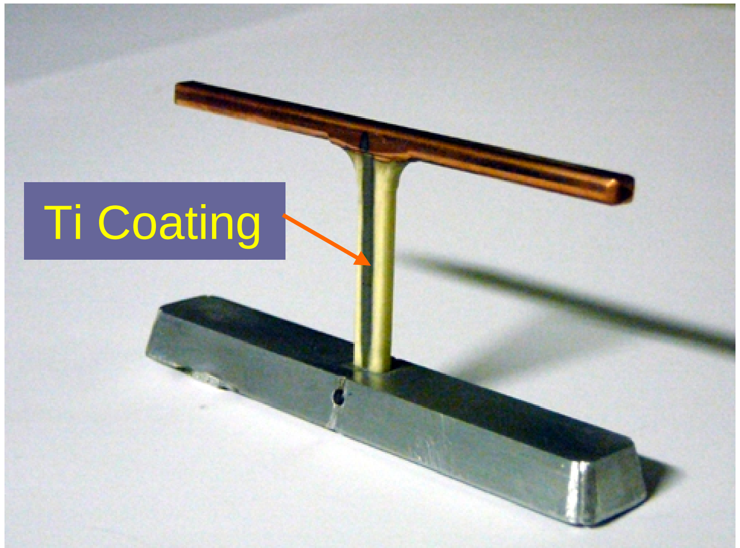
Clearing Electrode

- Ref: Collimator for test
  - Head: 90mm x 5 mm x 4 mm (Cu-coated Al_2O_3)
  - Support: 6mm x 4 mm x 30 mm (Al_2O_3, Ti coating ~ 1μm)
    - Resistivity = 2.4 kΩ
    - δ / t ~ 125 @1.3 GHz (t: thickness of coating)
  - Beam test is now proceeding.

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$$: Skin depth



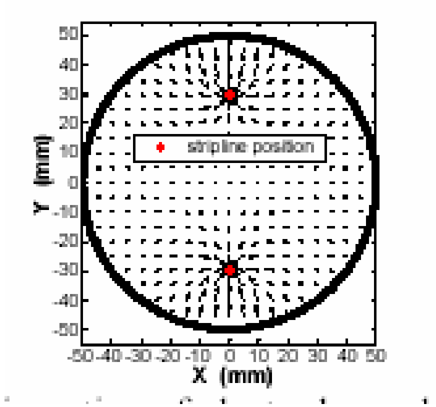
[Inside View]



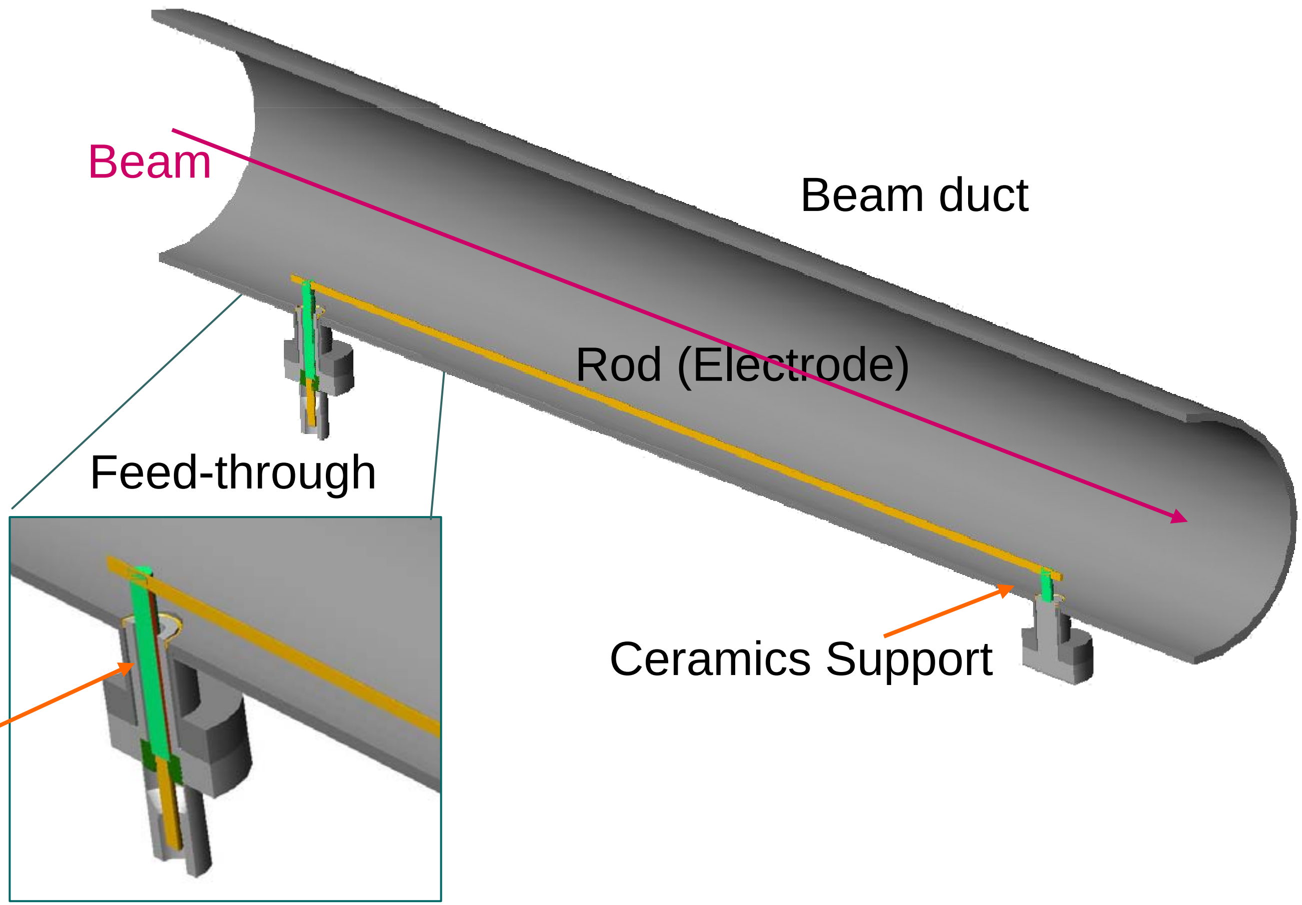
[Mask Head]

Clearing Electrode

- Concept of a clearing electrode
  - Model: Wire (Rod) type

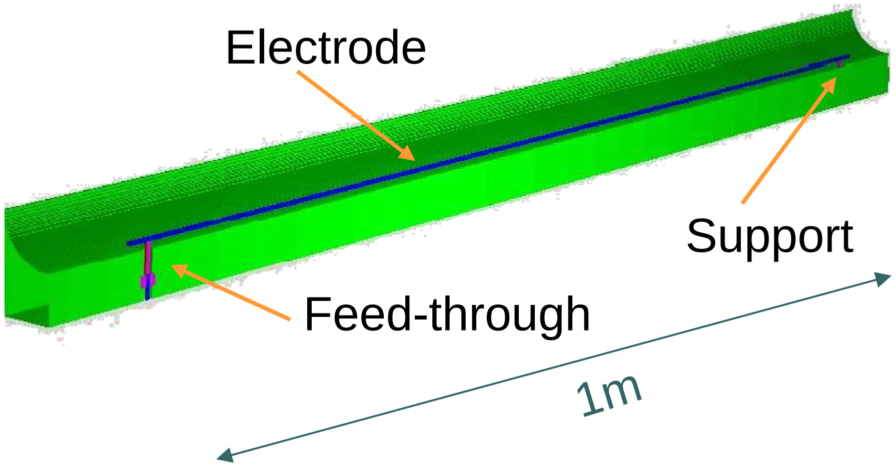


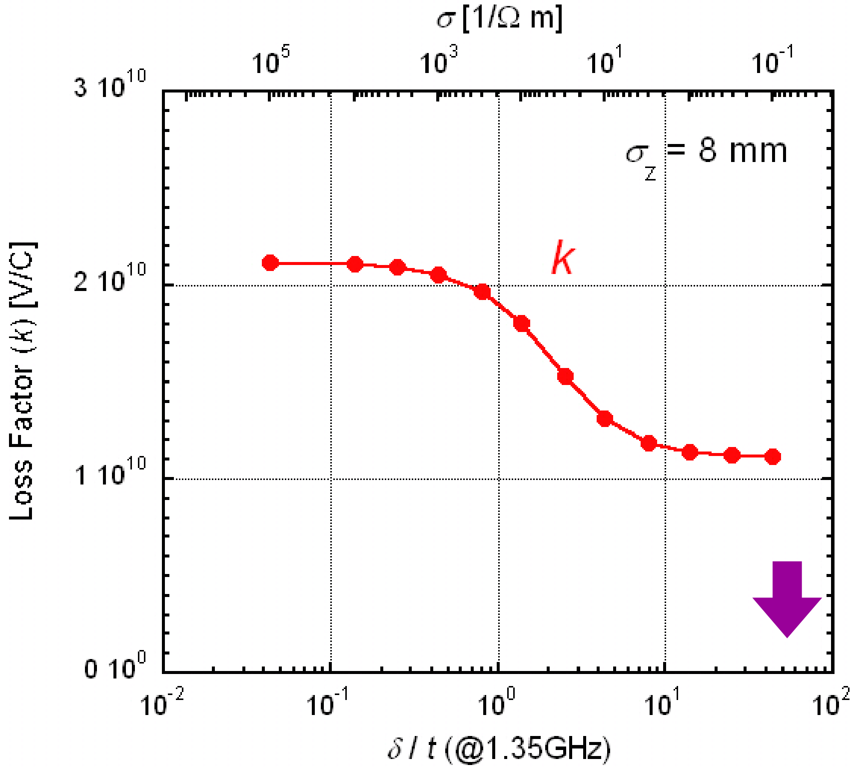
L.Wang et al., EPAC2006



Clearing Electrode

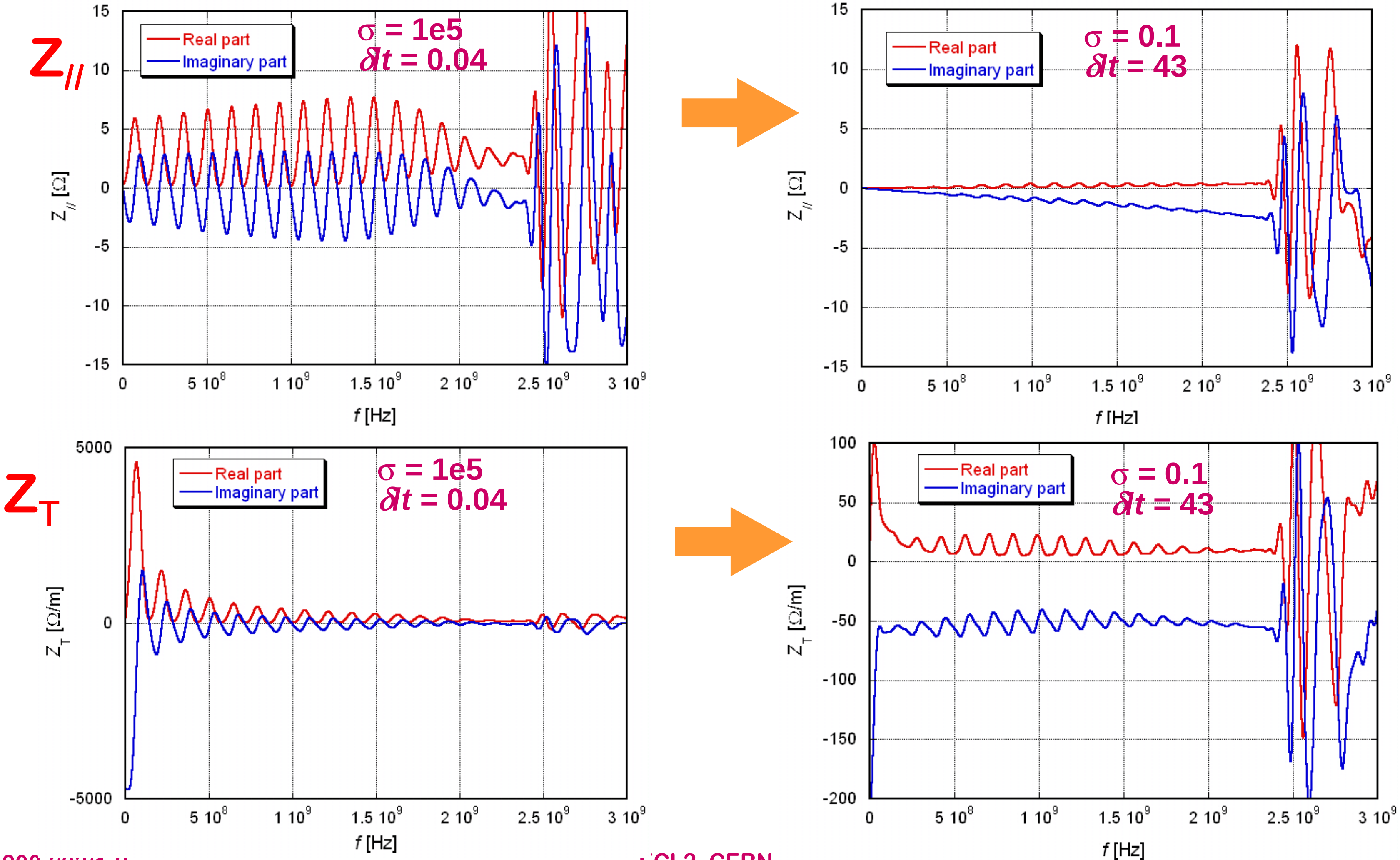
- **Calculated Loss factor by MAFIA**
  - Electrode (Rod): 8 mm from wall, ${}^{W}3$mm, ${}^{H}4$mm, ${}^{L}1$m
  - Support: ϕ4.8 mm (Al_2O_3, ε_r=9.0)
  - Metal coating: 0.8 mm thickness, ${}^{W}2$mm, ${}^{L}28$mm
  - Duct: ϕ94mm, 2.4m
  - Feed-through: ${}^{L}40$mm
  - 1/4 model (2 electrodes)
  - Cal:6m too short?→ GdfidL?





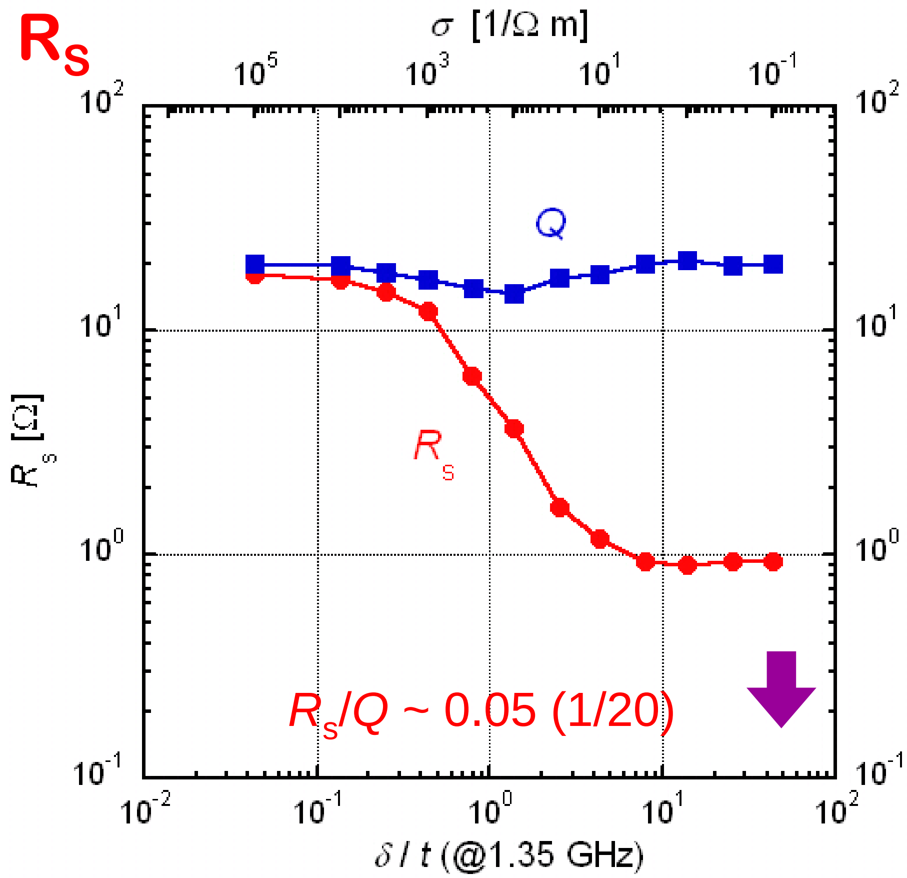
Clearing Electrode

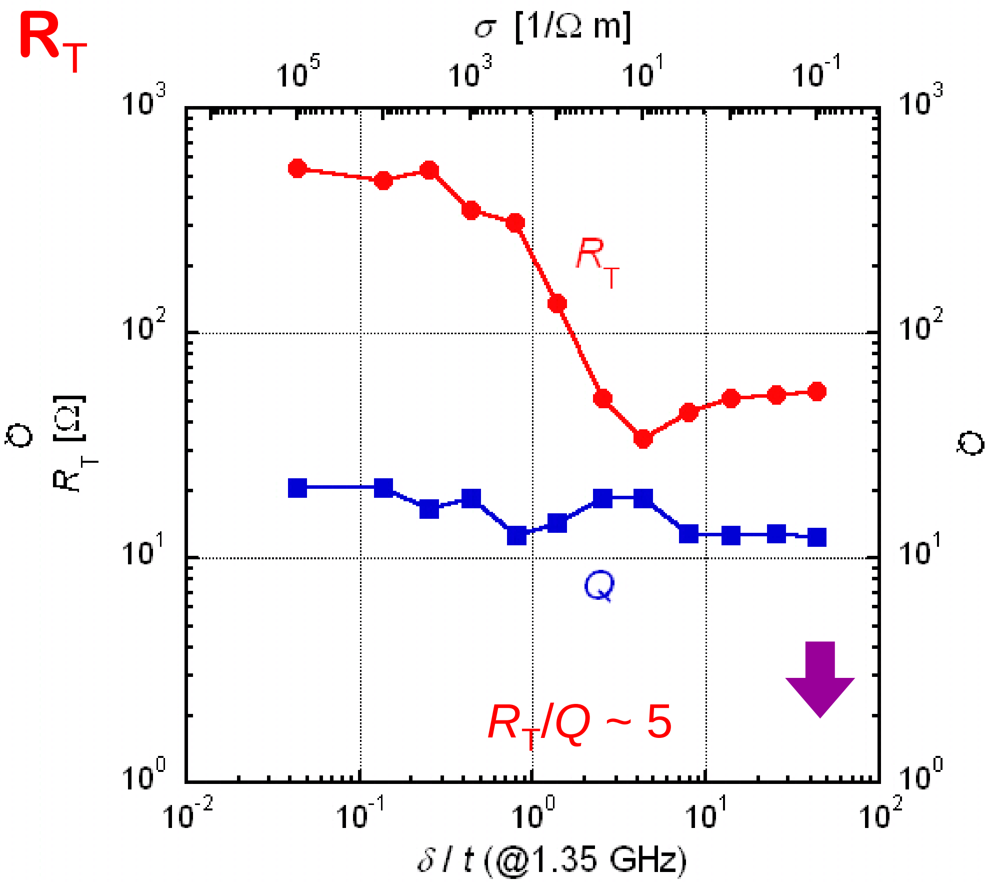
- Calculated Impedance



Clearing Electrode

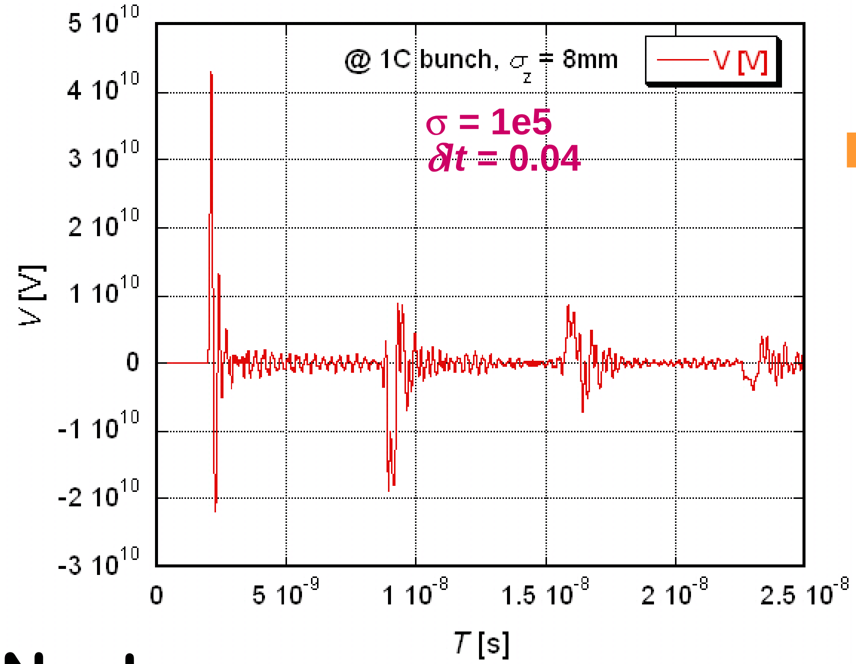
- **Calculated shunt impedance at 1.35 GHz**

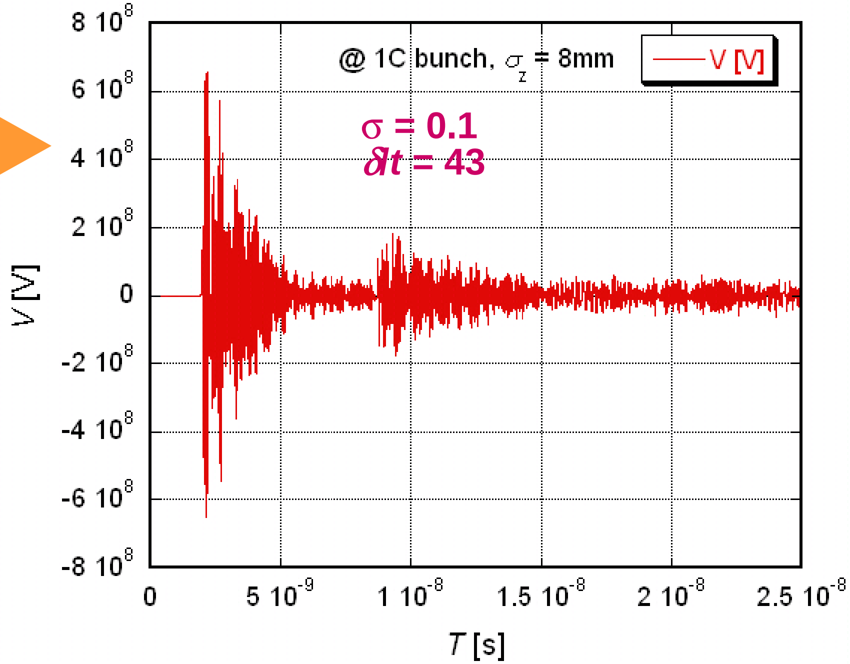




Clearing Electrode

- Output Voltage

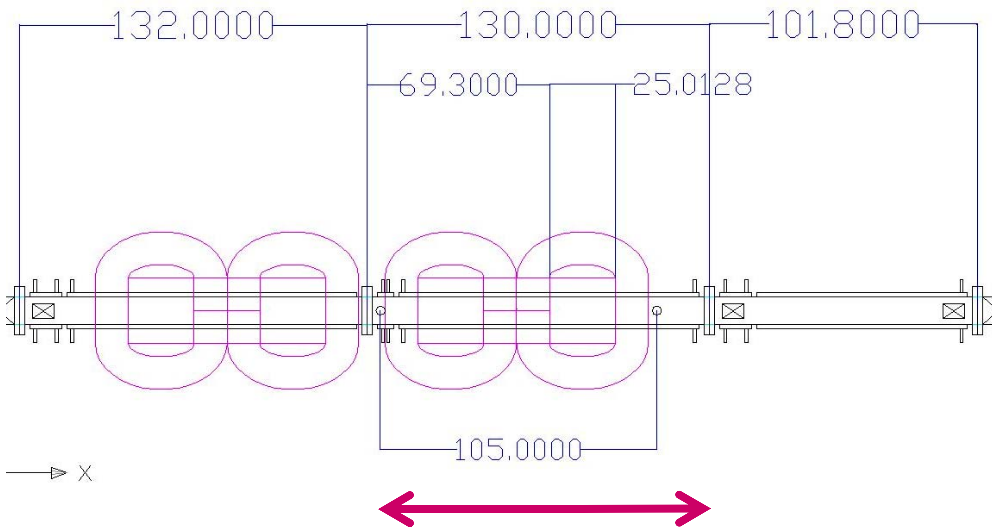




- Next
  - Reduce loss (thinner electrode??)
  - Heating of electrode?
  - Evaluation for CBI, Microwave Instability?
  - Bending?, Other type??, etc.

Clearing Electrode

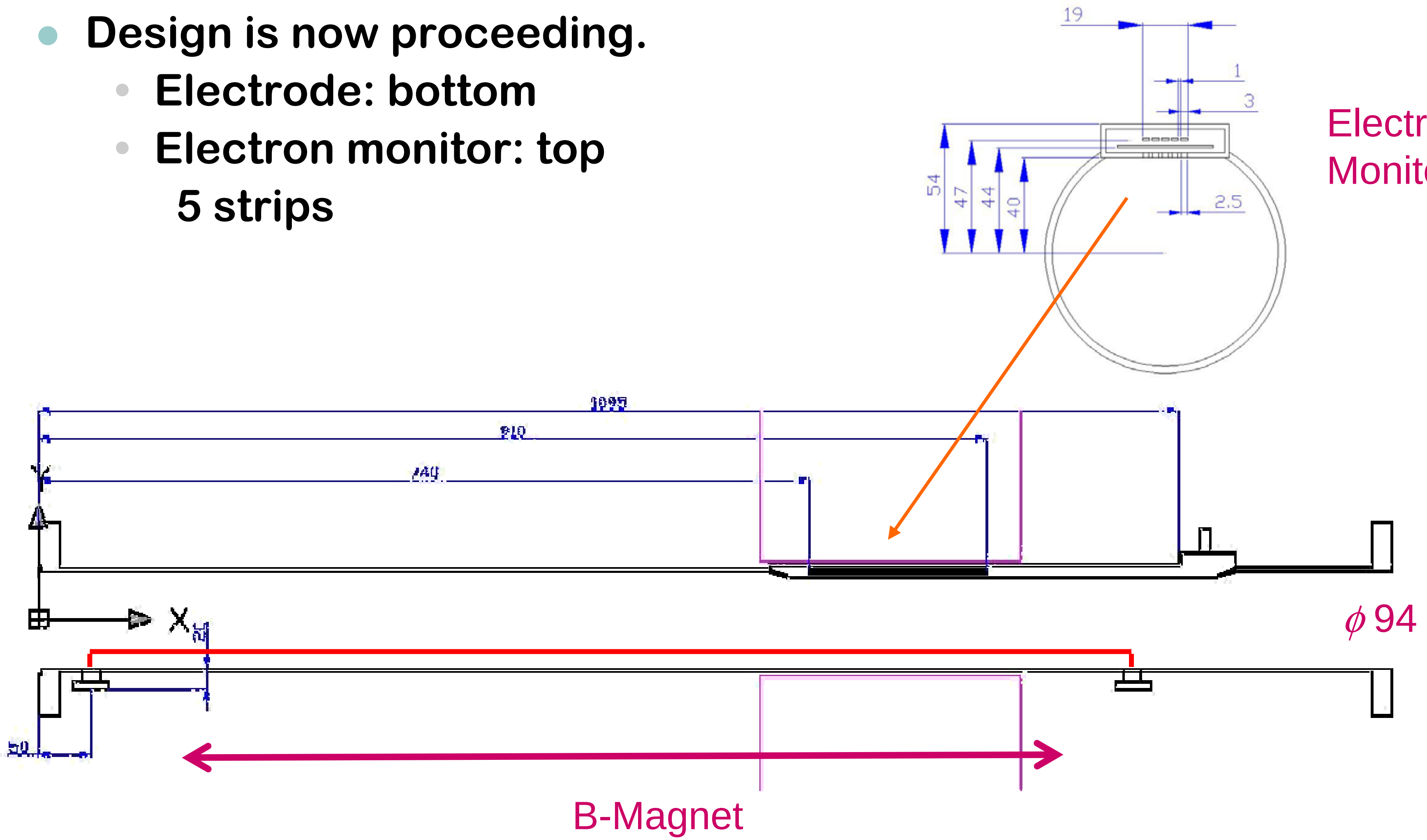
- **Beam test at a wiggler section**
  - **Length of one magnet: 250 mm**
  - **By = 0.75T**
  - **Beam Duct: ϕ94 mm**



Test chamber

Clearing Electrode

- Test Chamber
  - Design is now proceeding.
    - Electrode: bottom
    - Electron monitor: top
      5 strips



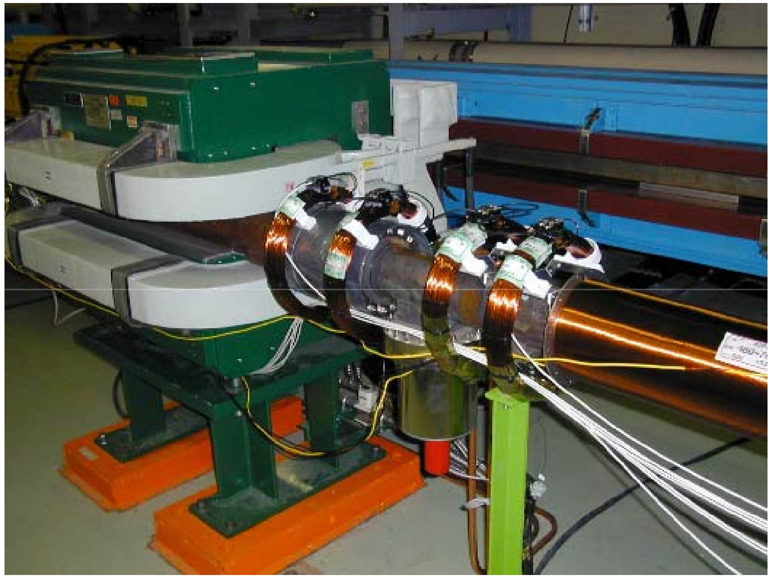
Summary

- R&D to suppress ECI effect has been proceeding at KEK using KEKB positron ring
- Beam duct with ante-chambers was found to be very effective to reduce photoelectrons, by several orders.
- TiN and NEG coatings reduce the electron density even at high current, by factors.
  - TiN coating seems the most promising one at present considering both PEY and SEY.
  - Experiments for a beam ducts with ante-chambers with TiN coating is planned.
- A rod type clearing electrode is now under consideration.
  - Calculation of RF properties are undergoing.
  - Beam test at a wiggle section is planed, where other types of clearing electrode, and surfaces, can be tested.

Beam Duct with Ante-chambers

- **Solenoid field (2002~, mainly by H.Fukuma)**
  - Suppression of vertical beam-size blow-up

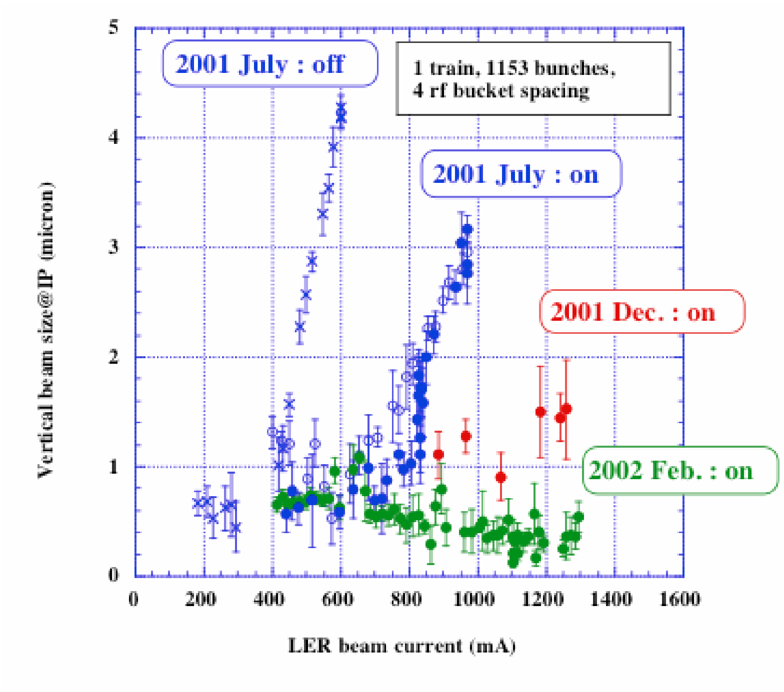
Type	Length (mm)	Diameter (mm)	Turns	Bz (center) @ 5A (Gauss)
Bobbin	150 - 650	148	250(typ.)	45
Bobbinless	40	220	190, 200	48
Bobbinless	40	250	200	43
Bobbinless	40	300	200	37



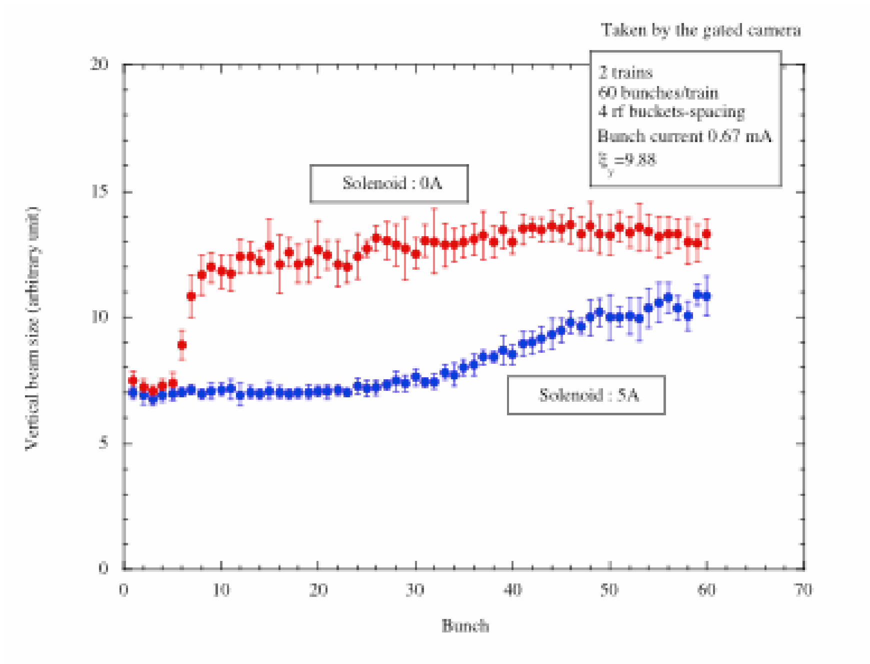
Beam Duct with Ante-chambers

- Solenoid field (2002~, mainly by H.Fukuma)
  - Suppression of vertical beam-size blow-up

Long train for physics run (4 rf buckets spacing)



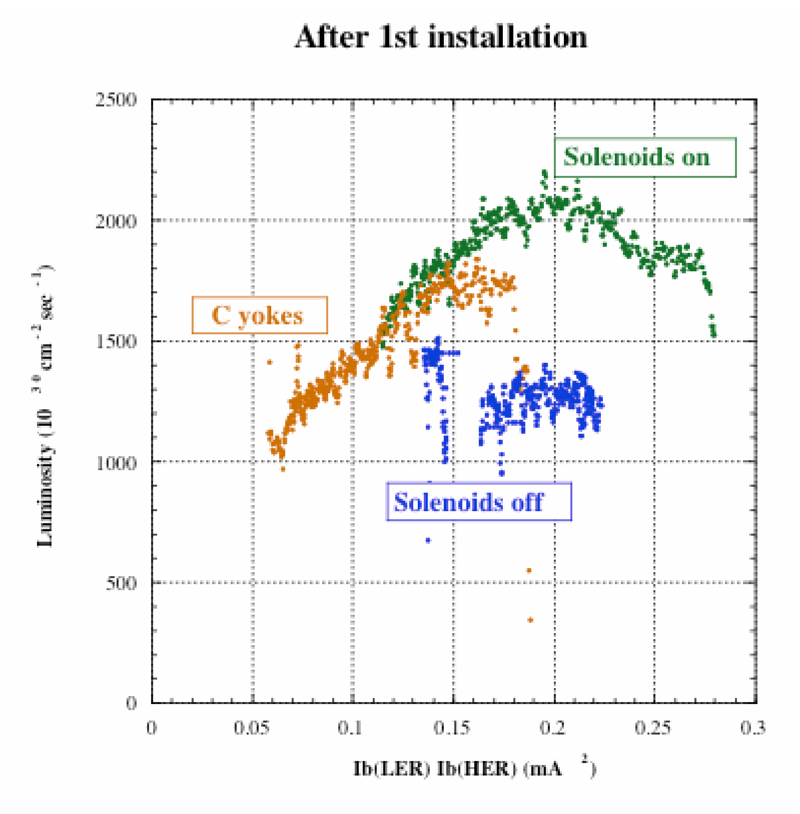
Vertical beam size along train



Beam Duct with Ante-chambers

- Solenoid field (2002~, mainly by H.Fukuma)
  - Suppression of vertical beam-size blow-up

Luminosity



Specific luminosity