Experimental Study on Suppression of Electron Cloud Effect at the KEKB Positron Ring

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Contents

Introduction

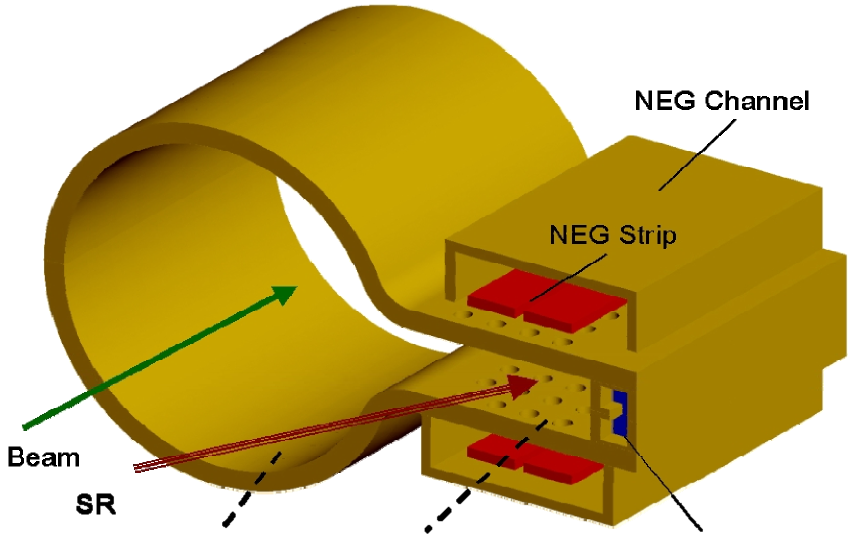
- Studies on ECI at KEK B-factory (KEKB)
  - Using positron ring (LER)
    - E = 3.5 GeV, I = max.1.7 A, 1.2 mA/bunch (1.2×10^{-8} C)
    - Usually ~1400 bunches, 6 ~ 8 ns bunch spaces
    - Beam duct : ϕ94 mm
  - Experiments to suppress electron emission
    - Solenoid field
    - Structure of bema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

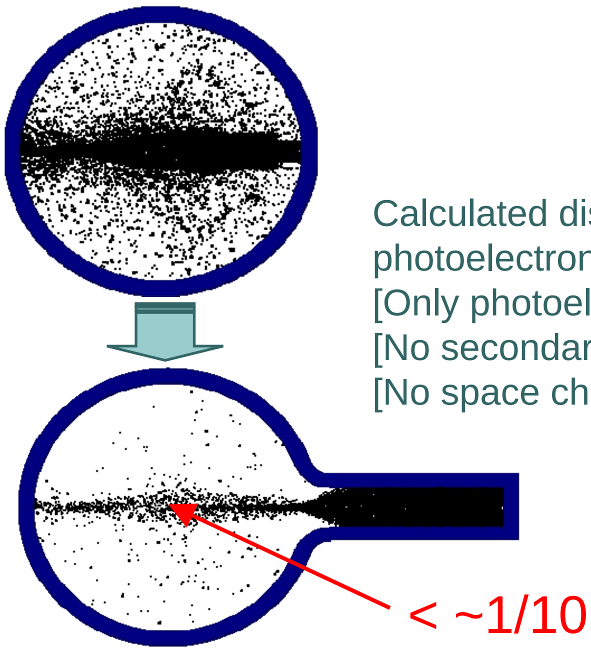
Here the results are briefly reviewed.

Experiment: Beam Duct

- **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**

[Beam duct with antechamber]





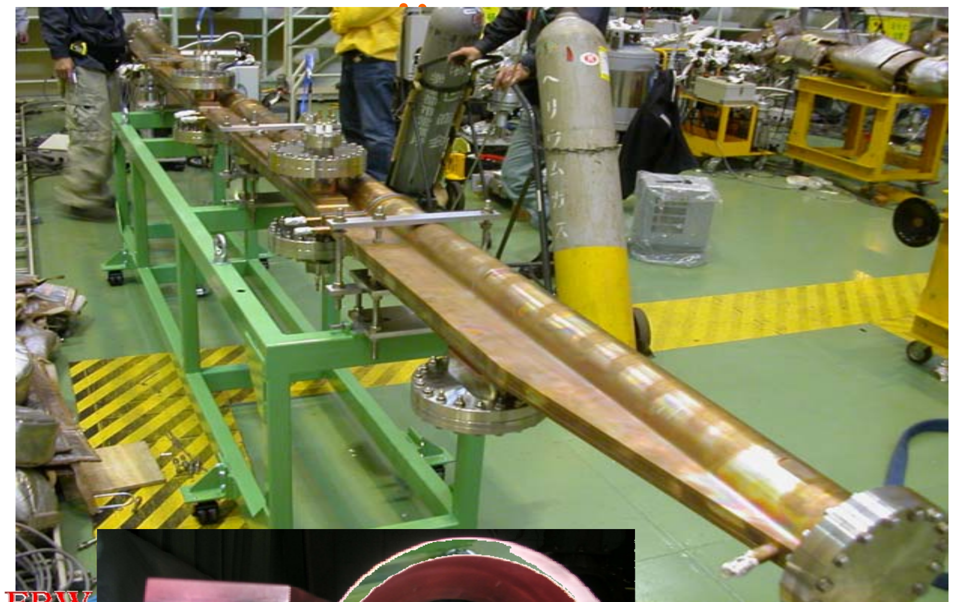
Calculated distribution of photoelectrons
[Only photoelectrons]
[No secondary electrons]
[No space charge]

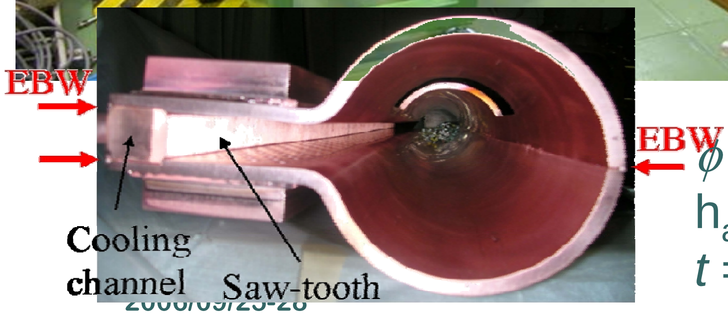
Y.Suetsugu, et al.,NIM-PR-A, 538 (2005) p.206

Experiment: Beam Duct

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

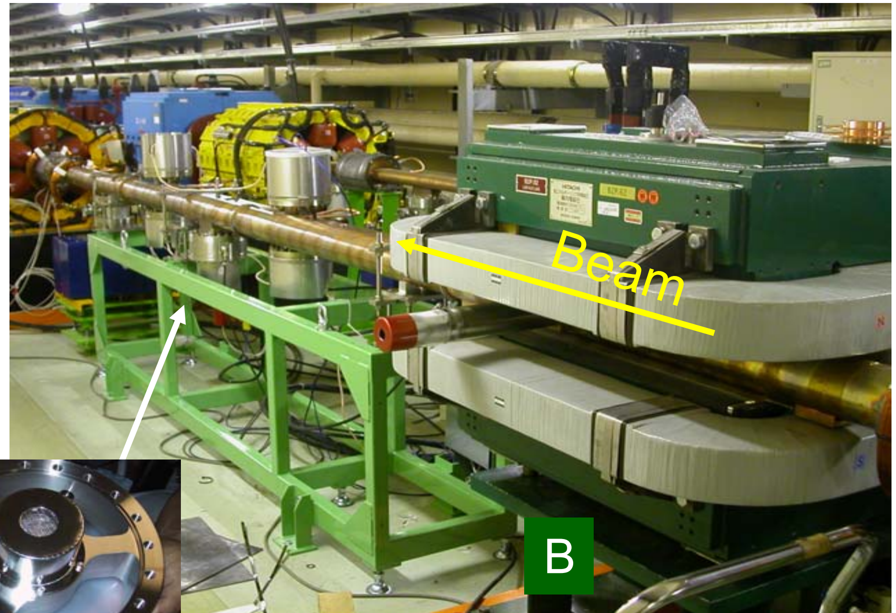
[Test duct (pressing)]





ϕ = 94 mm
h_a = 112 mm
t = 6 mm

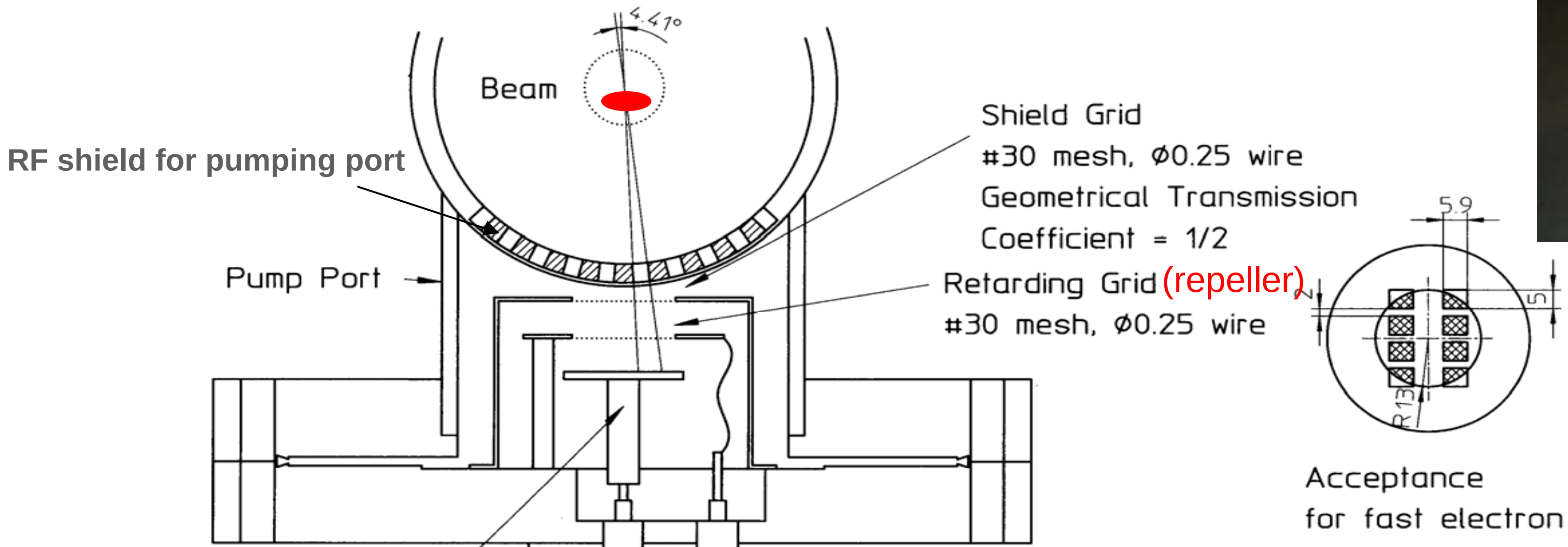
[Installed test duct]

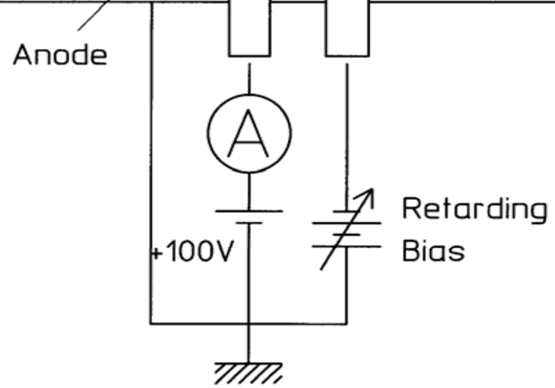


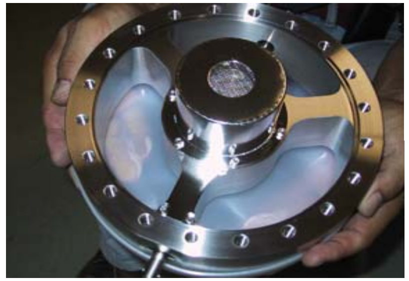
Electron Monitor
(DC, Collector:+100 V, Repeller:-30V)

Experiment: Beam Duct

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







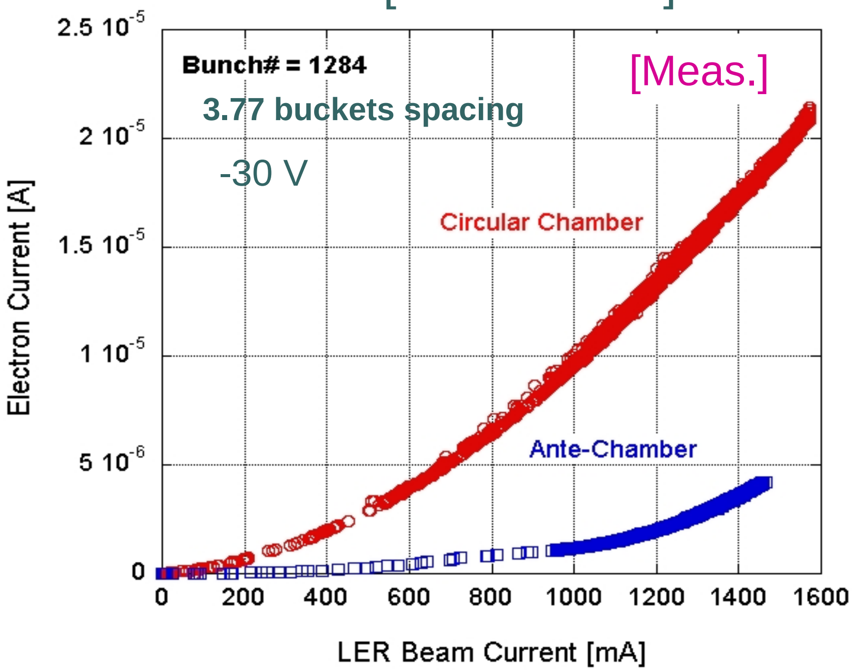
Area of collector : 6x5x5.9/4~40 mm^2

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

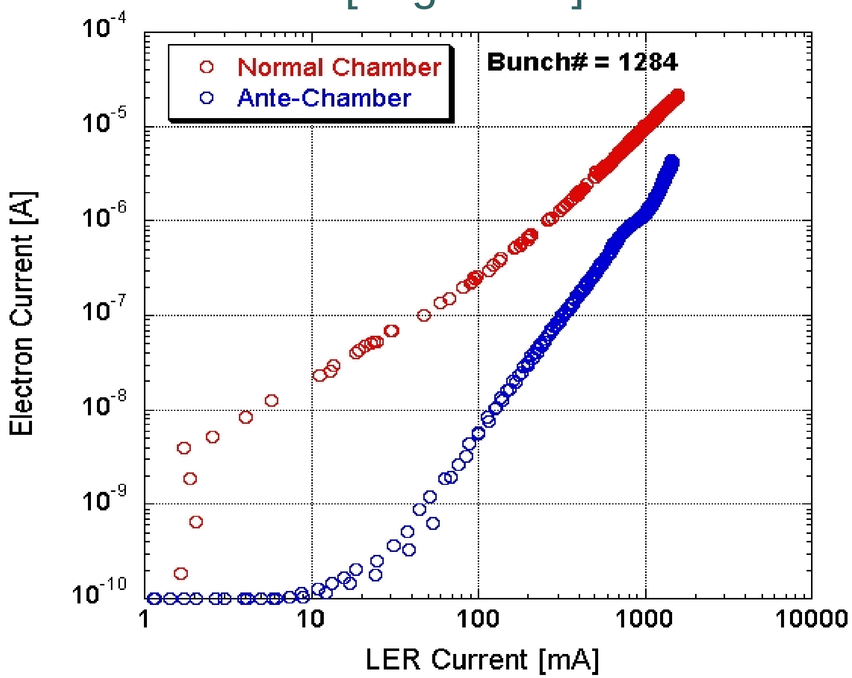
Experiment: Beam Duct

- 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. ➡ Surface with low SEY

[Linear Scale]

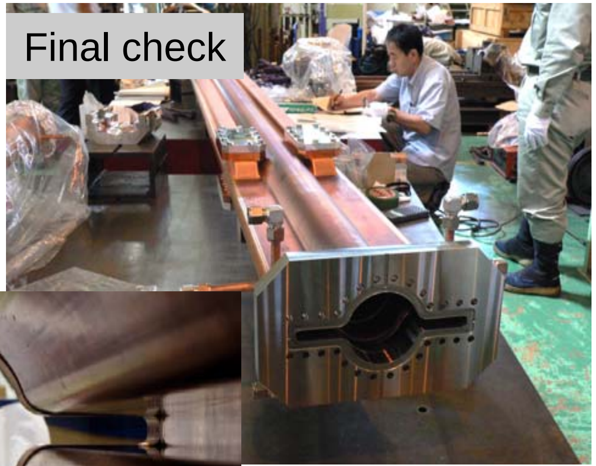


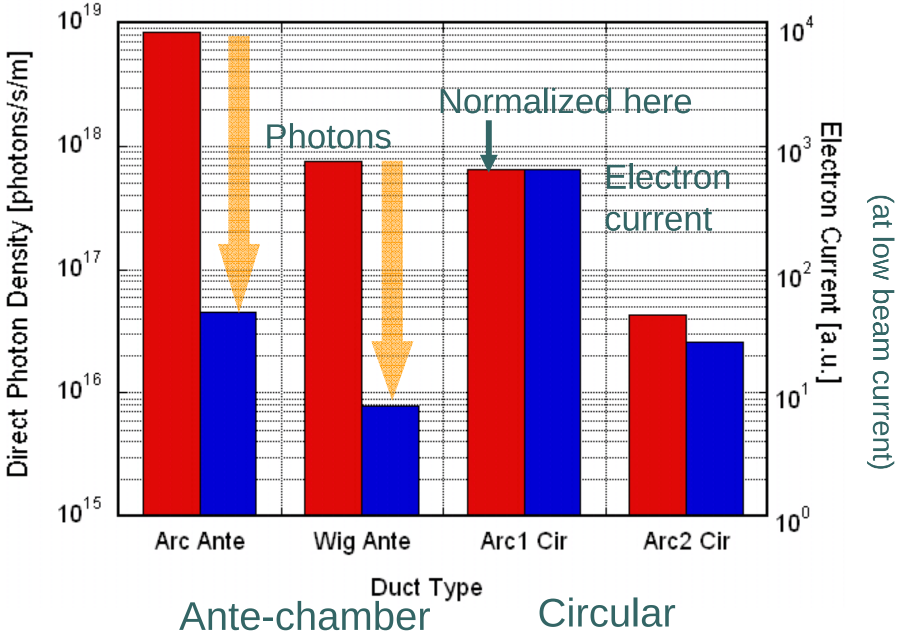
[Log Scale]



Experiment: Beam Duct

- **Beam duct at wiggler section (2005~)**
  - **A test duct was installed into LER wiggler section.**
  - **Reduction of photoelectrons were confirmed again.**





Experiment: Low SEY Surface

- Essential cure at relatively high current
  - Surface with a low SEY
- 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
    - Intensive R&D is undergoing at SLAC
  - DLC (Graphite)
    - Need further R&D

Focused on at KEKB

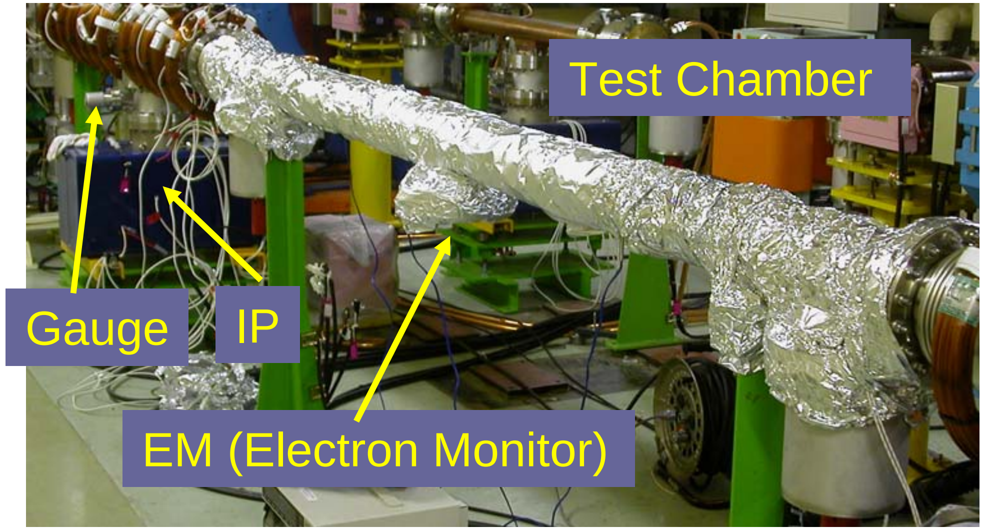
Y.Suetsugu, et al.,NIM-PR-A, 554 (2005) p.92
Y. Suetsugu,et al;,NIM-PR-A, 556 (2006) p.399

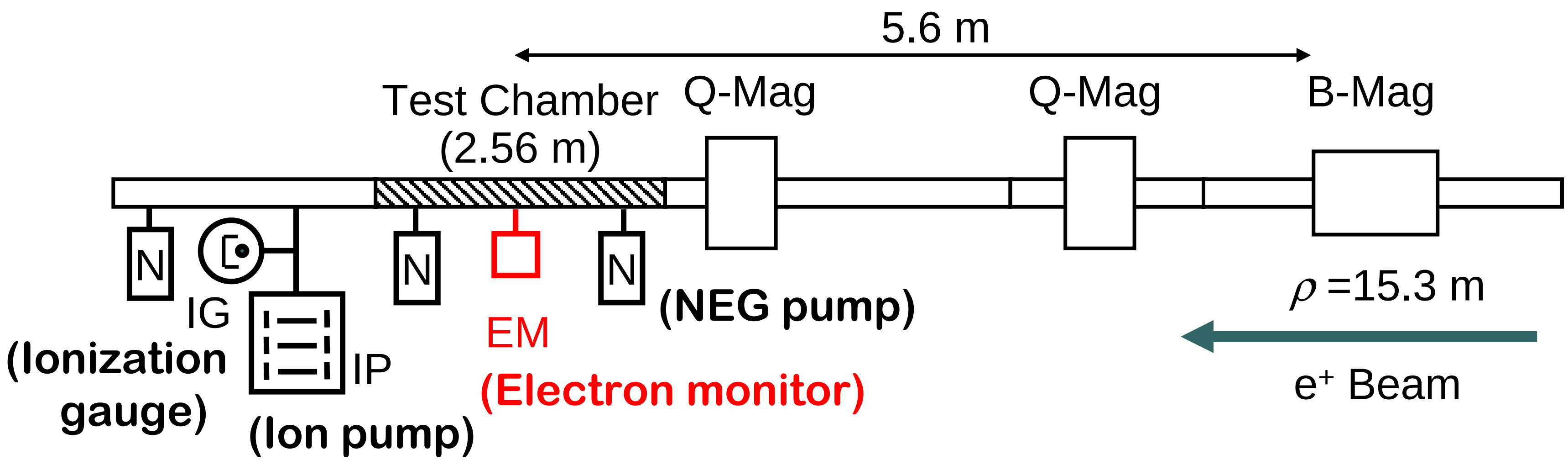
Experiment: Low SEY Surface

- Our experiment (2004~):
  - Effects of TiN and NEG coatings were examined using the KEKB
- 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.

Experiment: Low SEY Surface

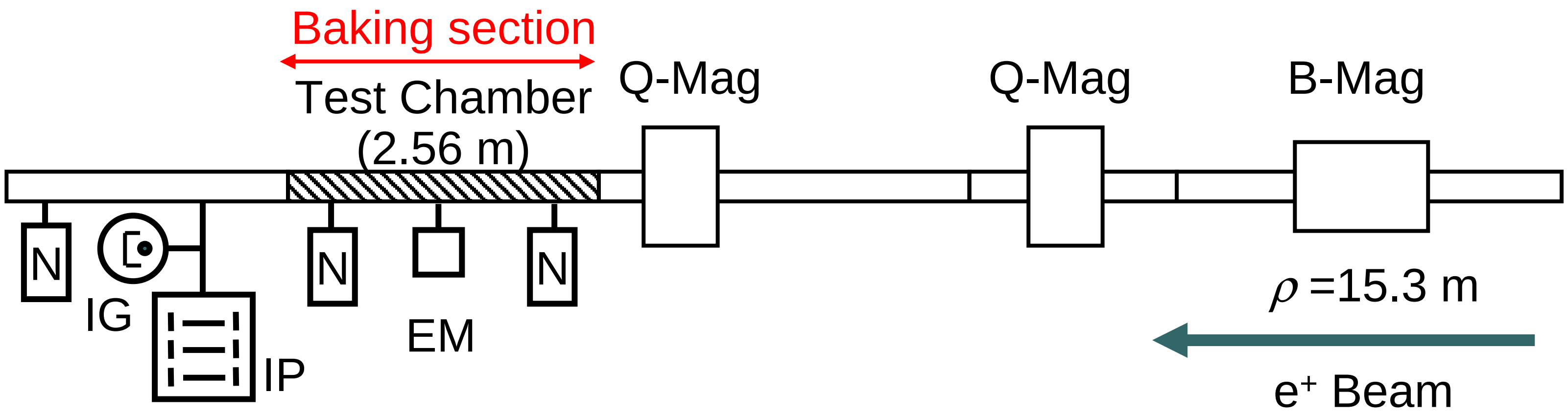
- Test chambers were installed in arc section.
  - Direct SR of 1×10^{16} photons/s/m/mA was irradiated at side wall.
  - Incident angle ~8 mrad.





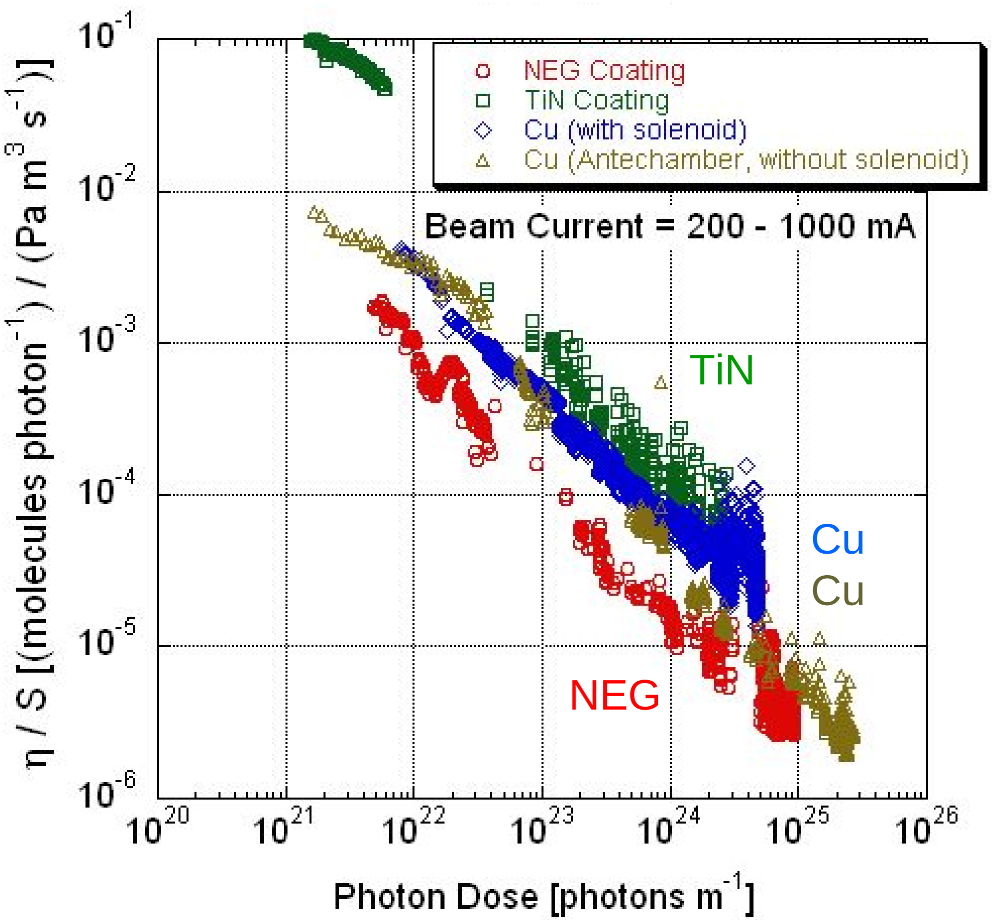
Experiment: Low SEY Surface

- Test chambers were baked before the installation at 150°C for 24 hours.
  - Residual gas components, base pressures were checked.
- **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



Experiment: Low SEY Surface

- Vacuum scrubbing

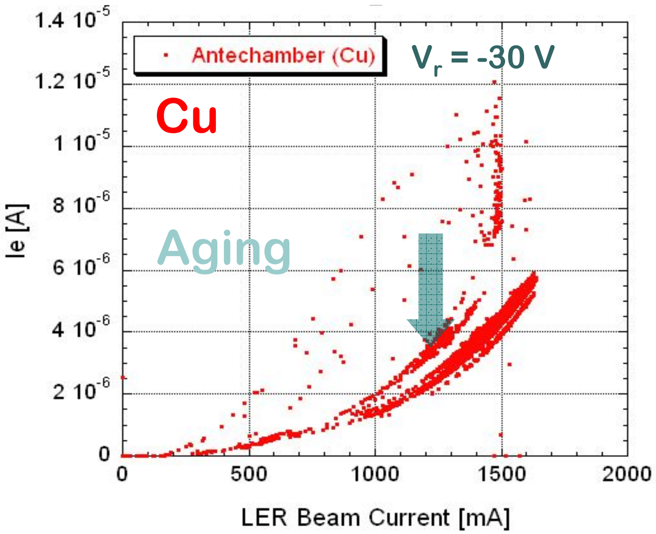


- NEG-coated duct is the lowest among the three surfaces.
  - By a factor of 5 @1E24 compared to copper.
  - Low gas desorption rate, and pumping in itself.
  - But not so prominent as reported so far.

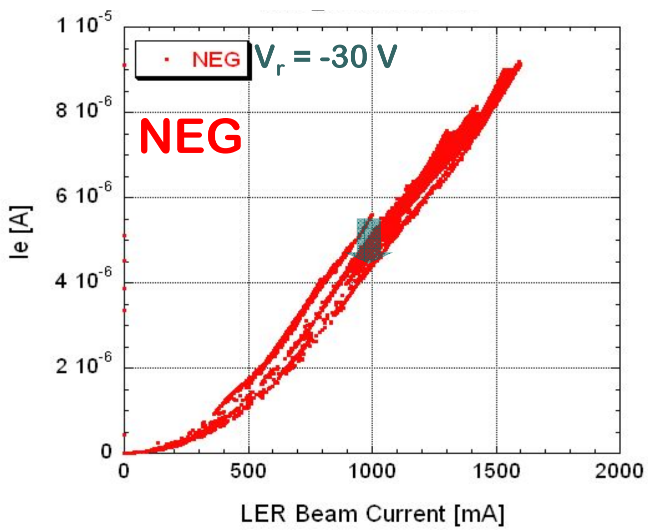
    ← Only one chamber was baked.
- TiN-coated duct was much higher than copper at first, but by a factor of 2 @1E24.

Experiment: Low SEY Surface

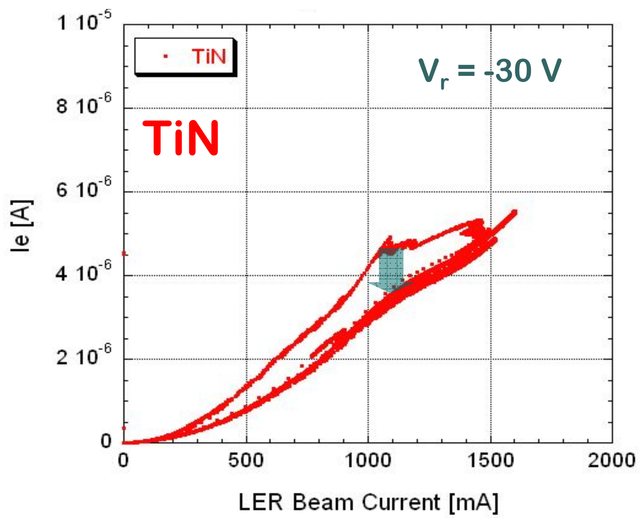
- Electron currents were measured against beam current in a usual beam operation.
- Aging of SEY by electron bombardment was seen.



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

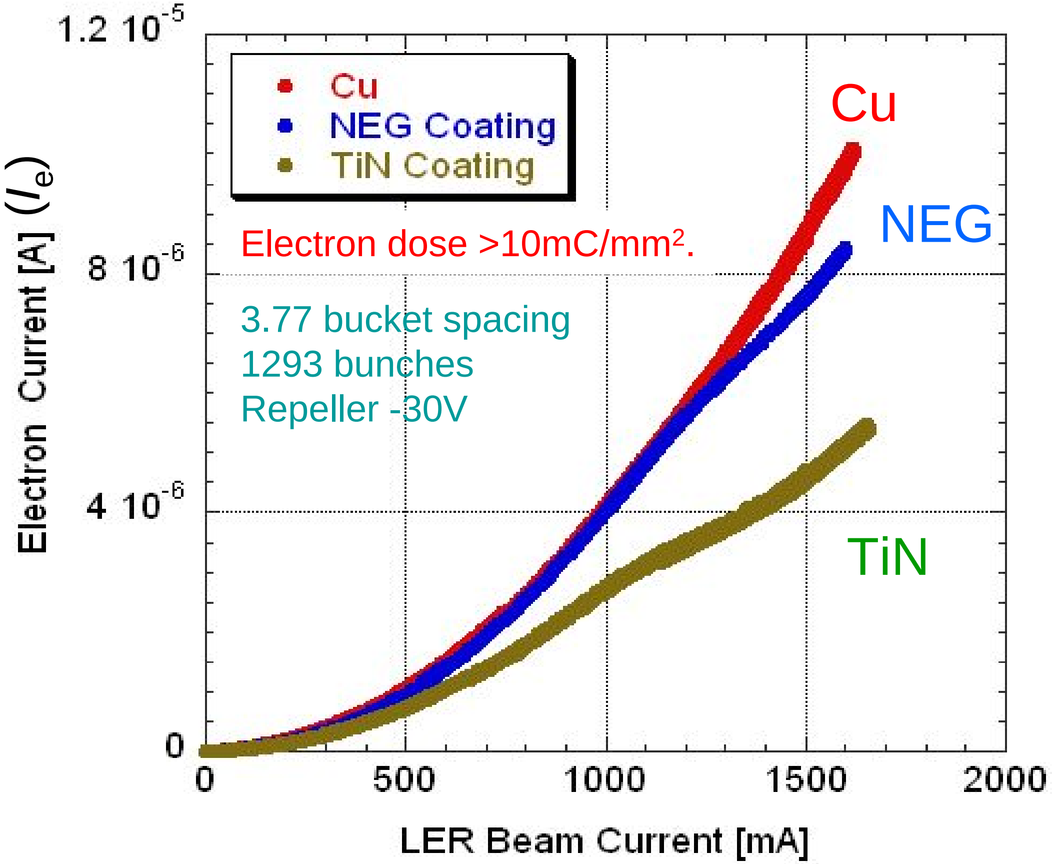
Electron Dose : 4×10^{-6}A/1500mA/40mm^2 ~ 7×10^{-11}C/s/mA/mm^2

@40 A hours: $7\times10^{-11}\times40000\times3600$ ~ 1×10^{-2}C/mm^2 =10 mC/mm^2

Experiment: Low SEY Surface

- Cu, TiN, NEG for the same beam condition

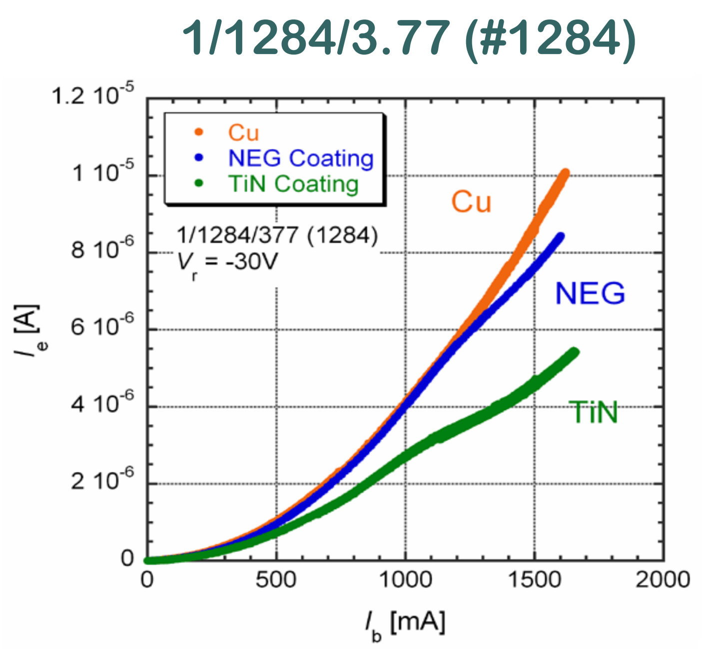
(After aging)

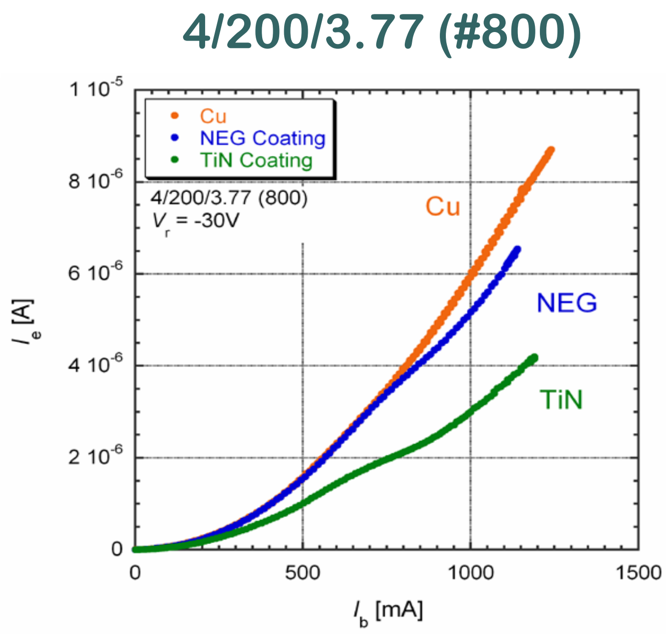


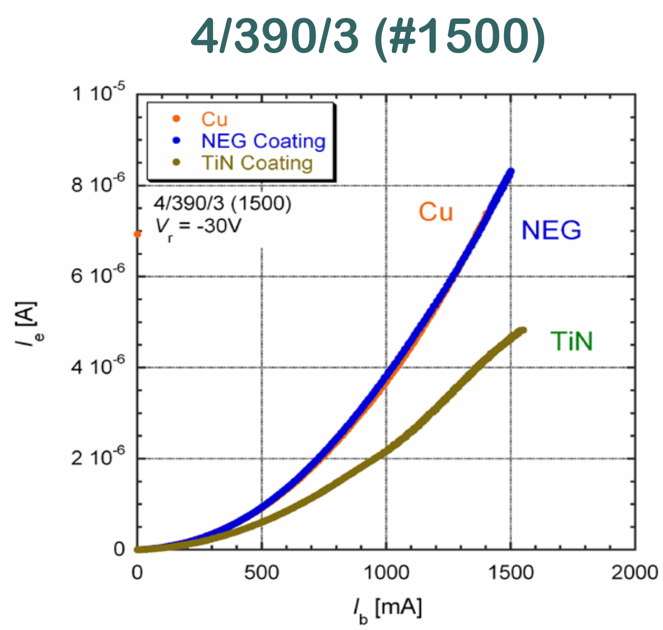
- I_e for NEG coating is almost same as that of Cu, except for high current.
- I_e for TiN coating is clearly lower than those for Cu and NEG (by factor of 2).
- TiN seems better from the view point of small electron numbers in the beam duct.
- Little difference even after additional baking of NEG-coated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

Experiment: Low SEY Surface

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







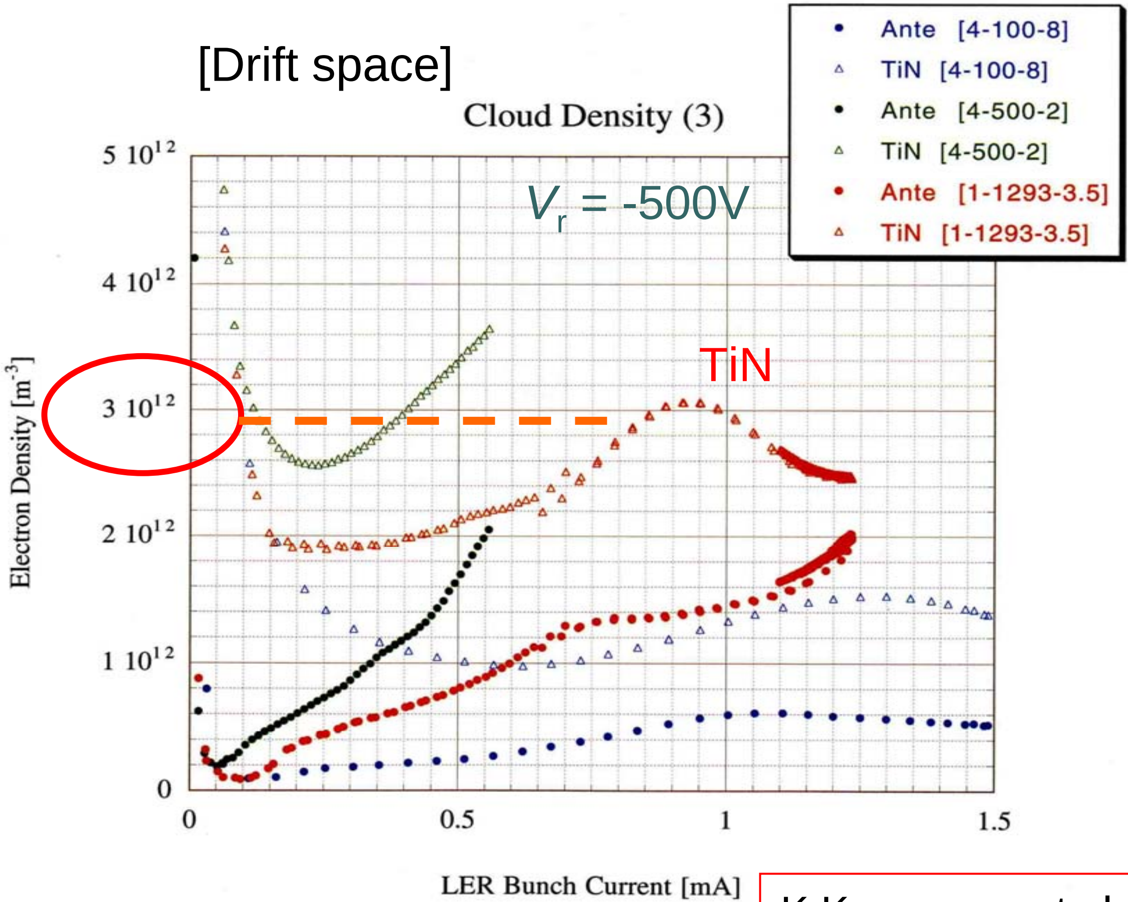
1 RF bucket = 2 ns

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

Experiment: Low SEY Surface

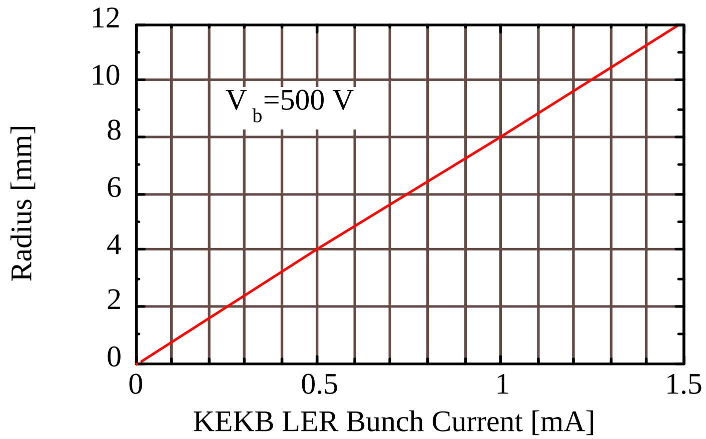
- Electron density can be estimated by the electron current at a high repeller voltage. (by K.Kanazawa, KEK)

[Drift space]



- Repeller voltage = -500V.
- Volume where electrons can obtain the energy was taking into account.
- Accuracy: in a factor of 3

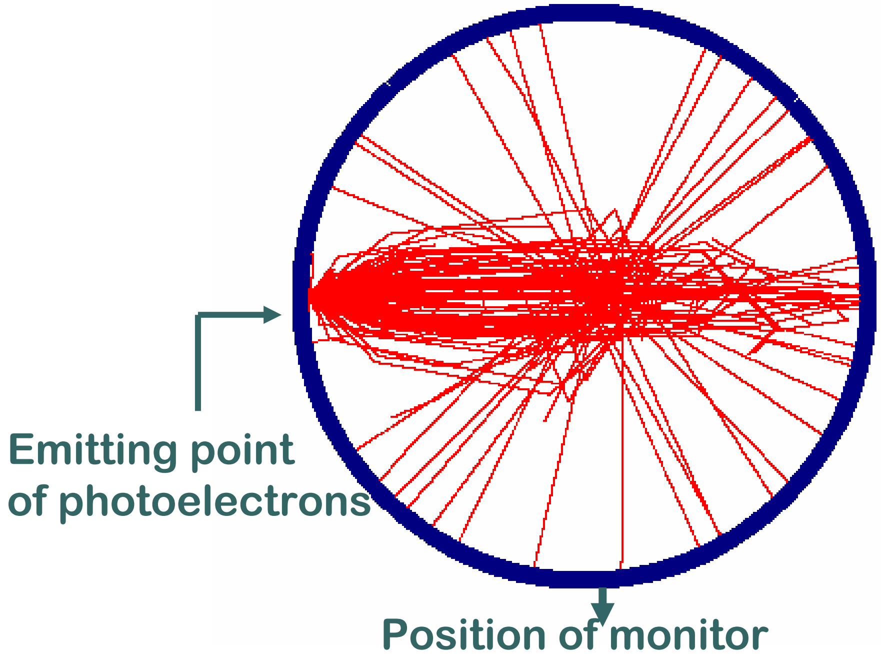
[Region of acceleration]



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

Experiment: Low SEY Surface

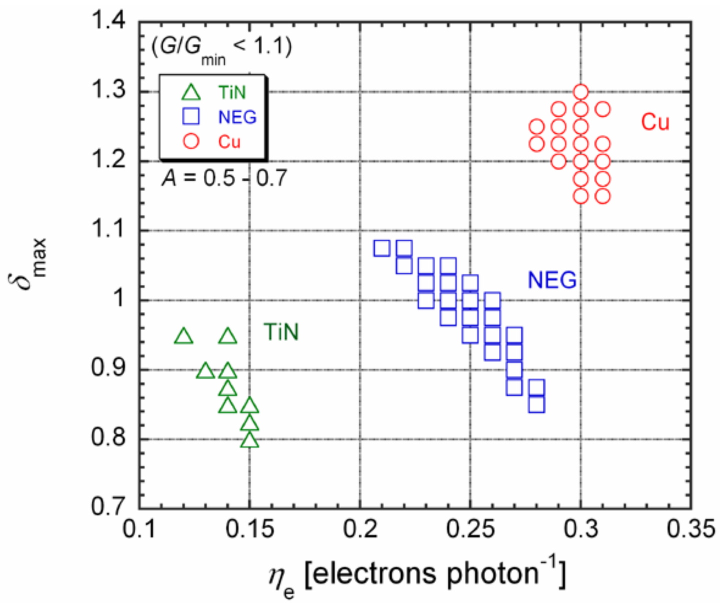
- Simulation
- Purpose
  - Understand the behavior of measured electron currents
  - Estimate the SEY (δ_{max}) and PEY (photoelectron yield) of Cu, NEG and TiN.
- Method:
  - "Macro" electrons ($\leq 10^4$ electrons) are traced from the emission, and the number of electrons hitting the bottom of duct (position of electron monitor) with an almost normal incidence angle are counted.

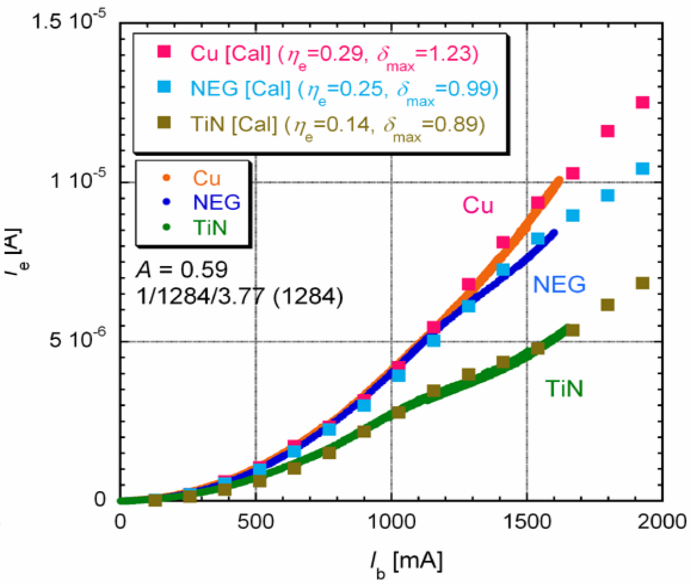


[Example of electron trajectories (Only photoelectrons, No secondary electrons, No space charge)]

Experiment: Low SEY Surface

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





Low Current → PEY
High Current → SEY

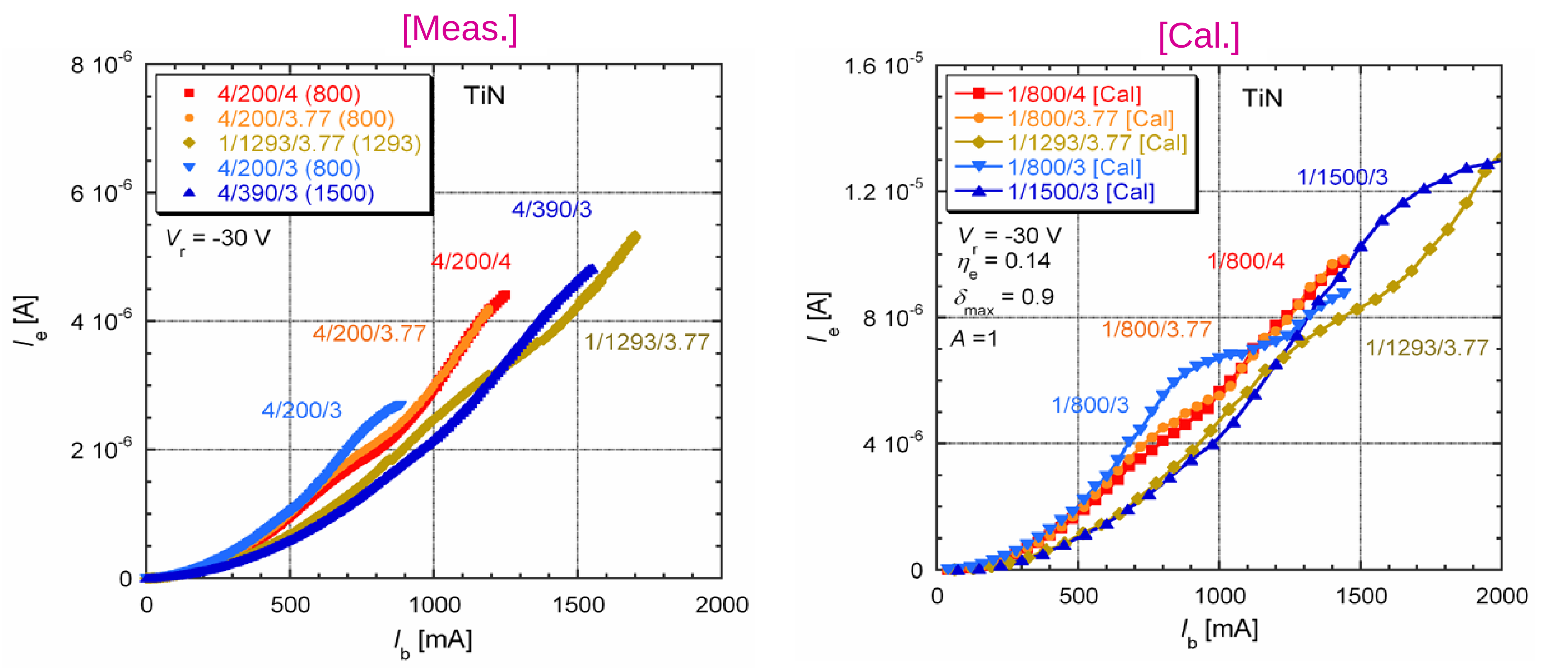
	η_e	δ_{max}
Cu	0.28-0.31	1.1-1.3
NEG	0.22-0.27	0.9-1.1
TiN	0.13-0.15	0.8-1.0

3.77 bucket spacing
1293 bunches
Repeller -30V

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

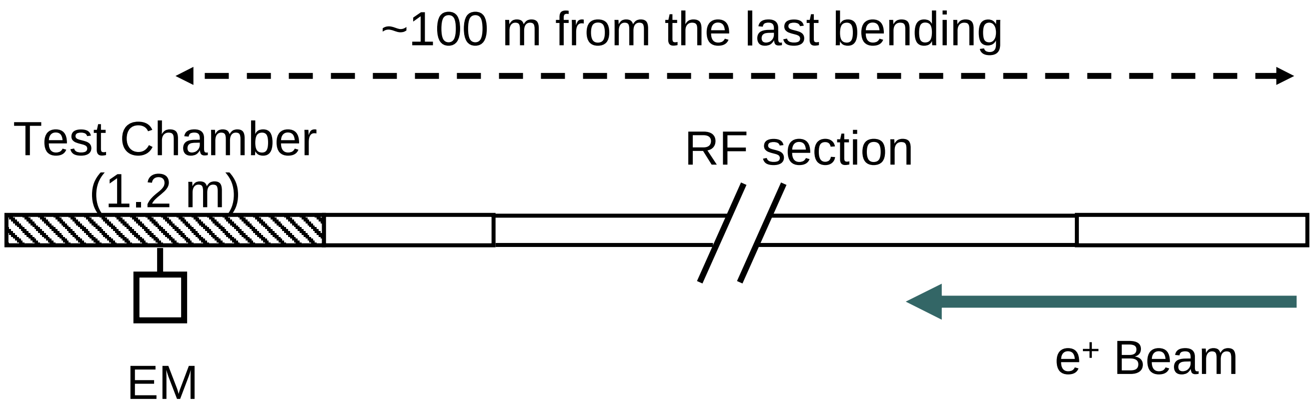
Experiment: Low SEY Surface

- For reference, simulation well explained the dependence on bunch fill pattern.



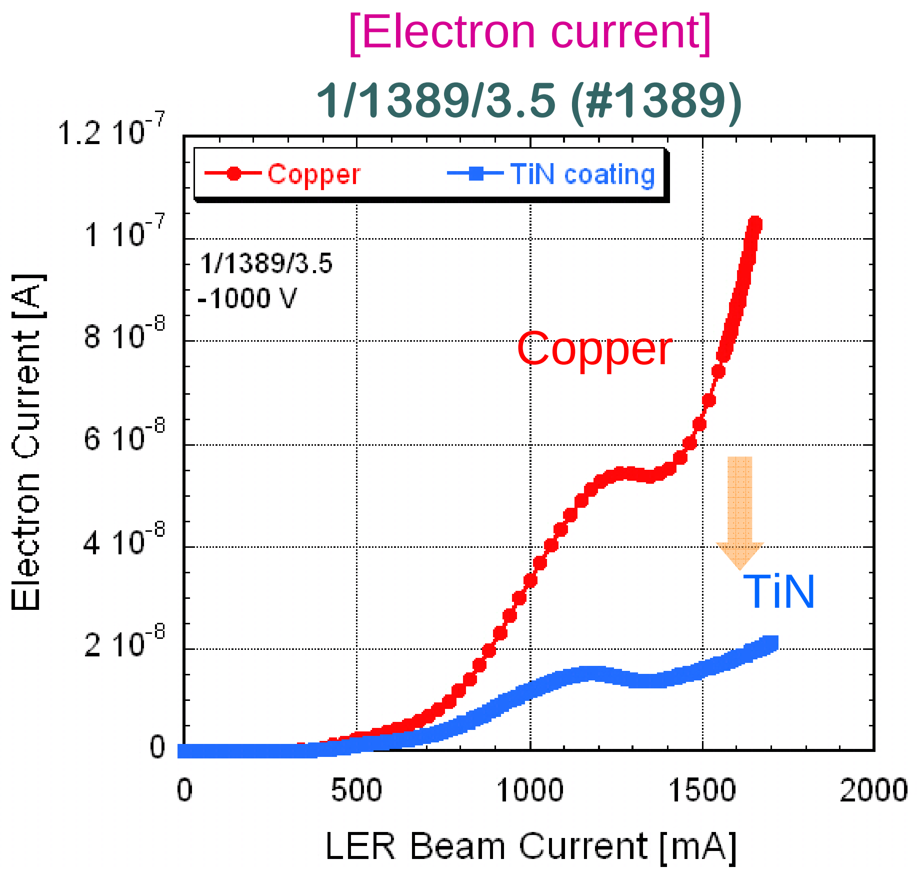
Experiment: Low SEY Surface

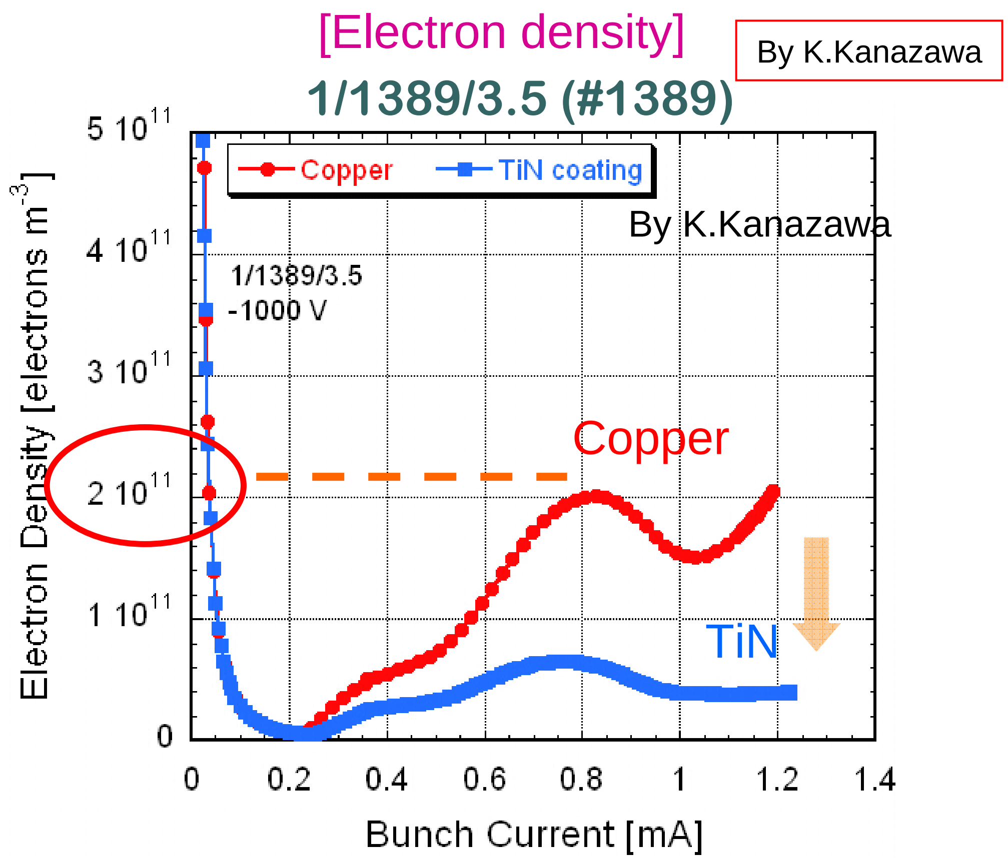
- Measurement at a straight section (2006~)
  - Very low photons: 1×10^{14} photons/s/m/mA (1/100 of arc)
  - SR mask shadows the chamber
  - Eliminate the effect of SR
- Copper, TiN coating and NEG coating (not yet)



Experiment: Low SEY Surface

- **Measured electron current and density**

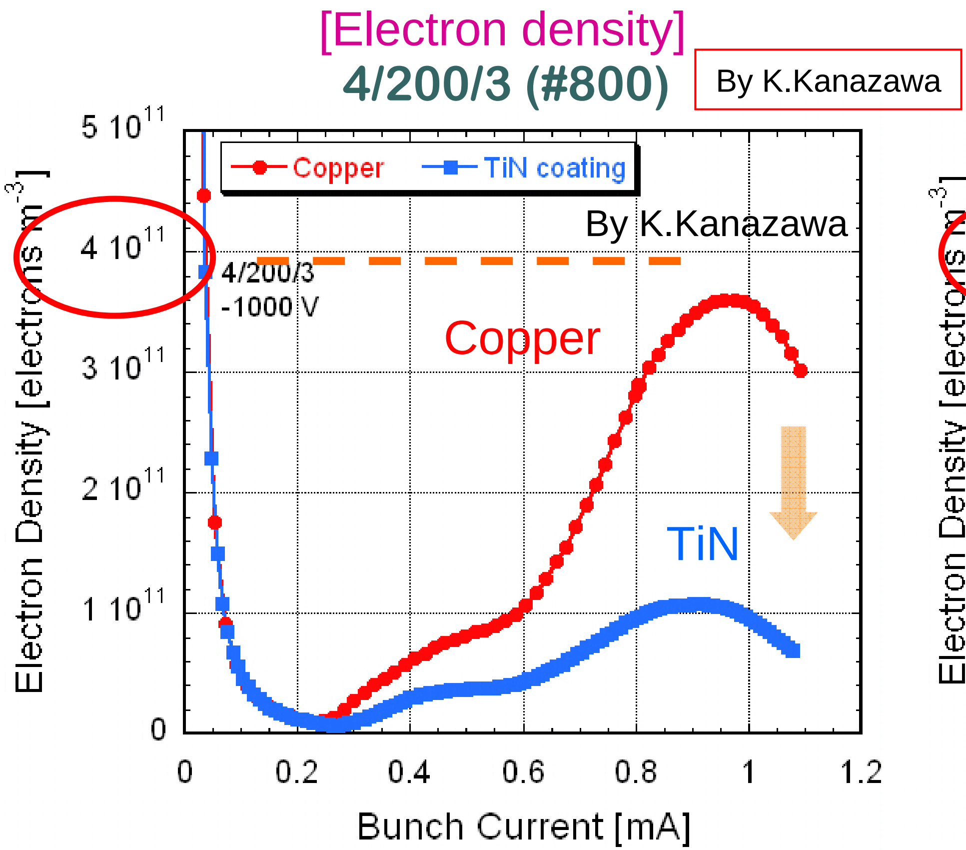


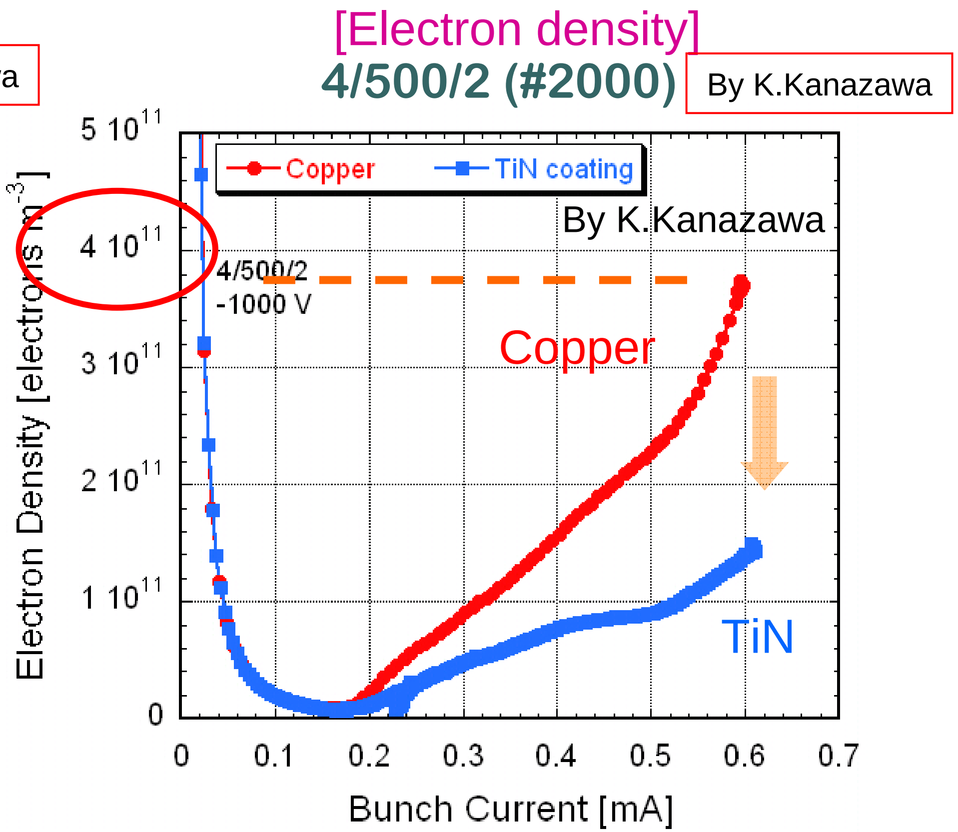


- **Electron density forTiN coated duct is about 1/3 ~ 1/4 of that of copper.**

Experiment: Low SEY Surface

- Measured electron density

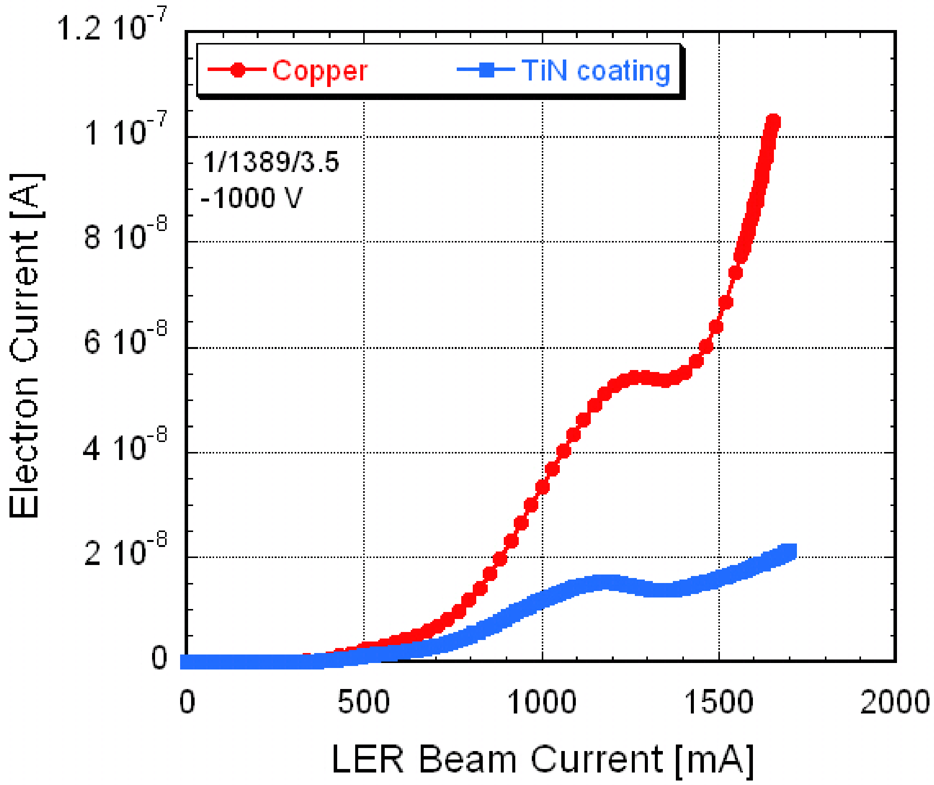


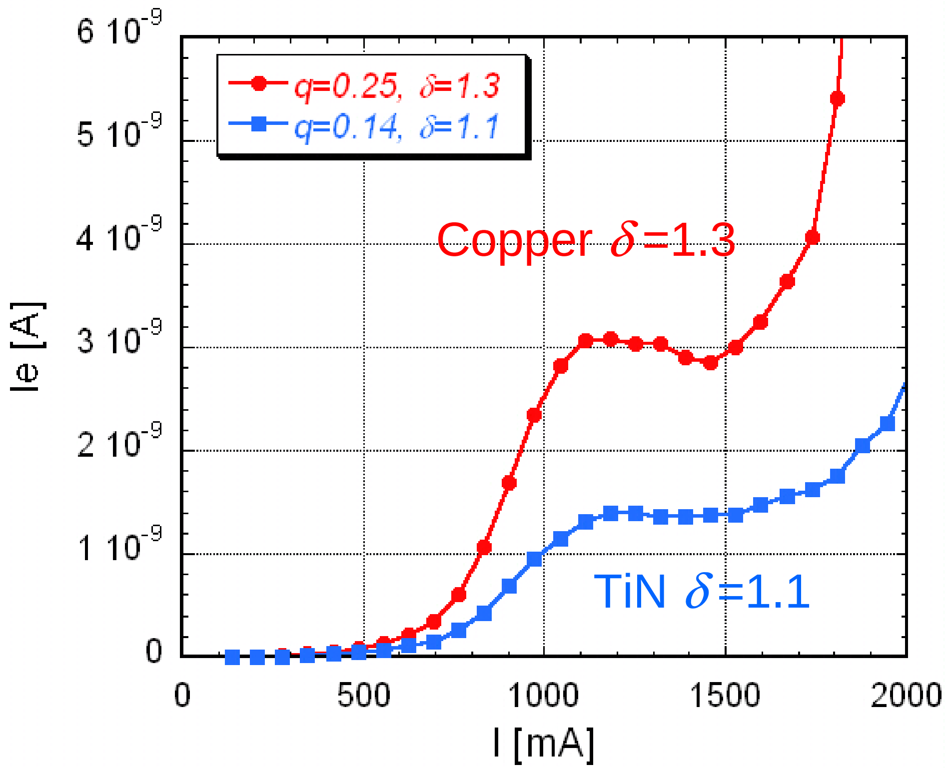


- Electron density forTiN coated duct is about 1/3 ~ 1/4 of that of copper.

Experiment: Low SEY Surface

- Estimation of δ_{max} by simulation (preliminary)

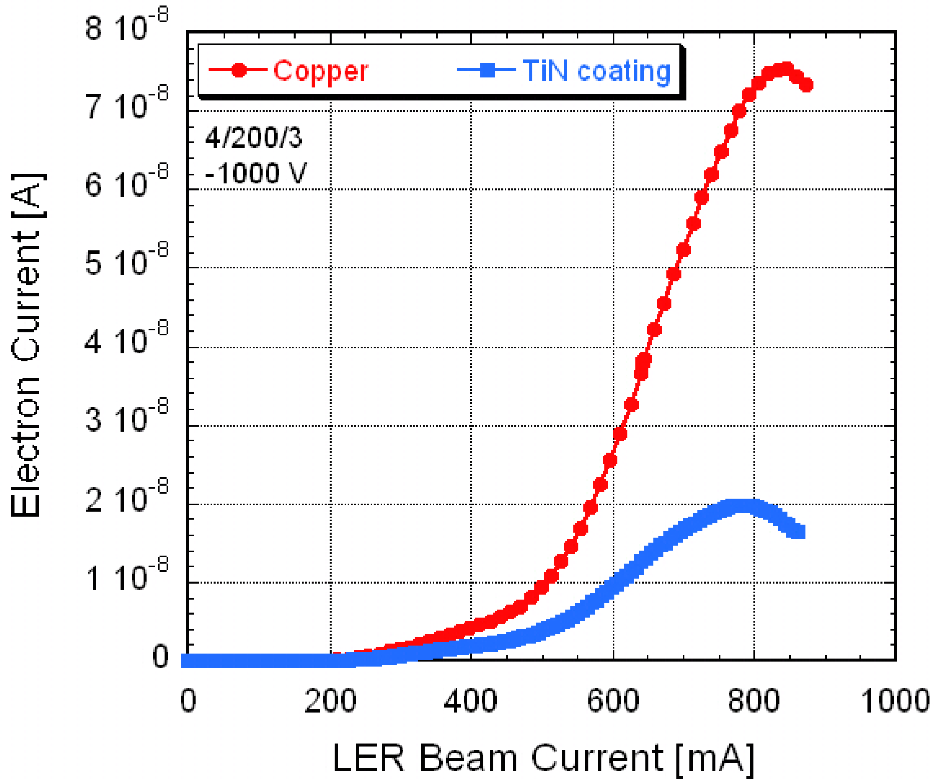


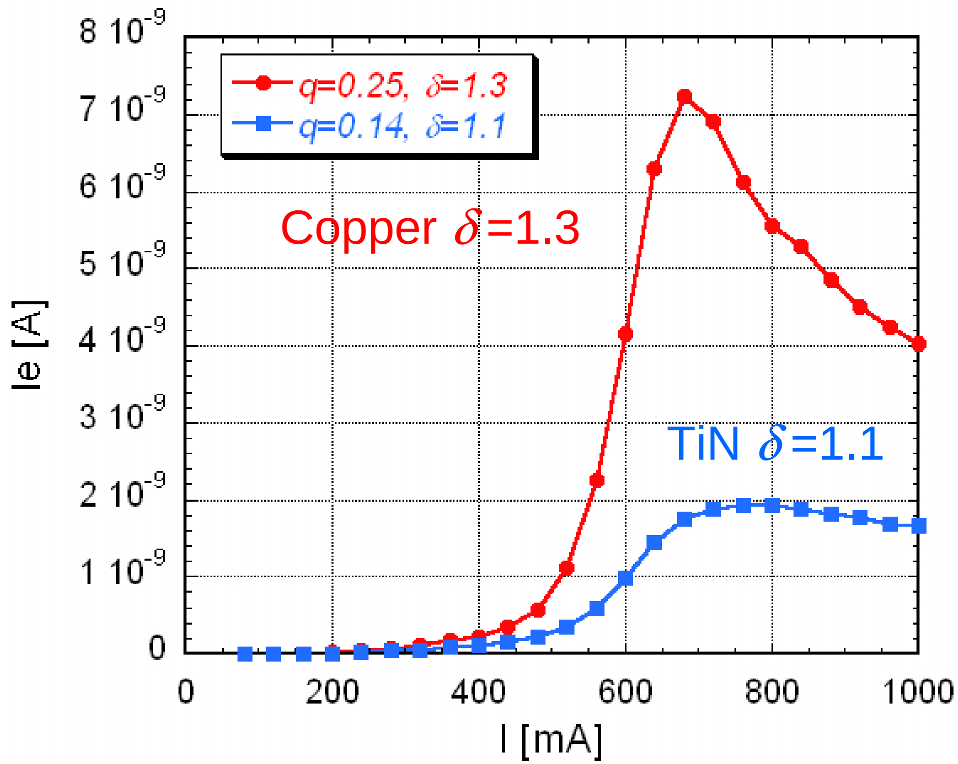


- Behavior of measured electron current qualitatively corresponds to the simulation curve calucated with δ_{max} obtained before.

Experiment: Low SEY Surface

- Estimation of δ_{max} by simulation (preliminary)





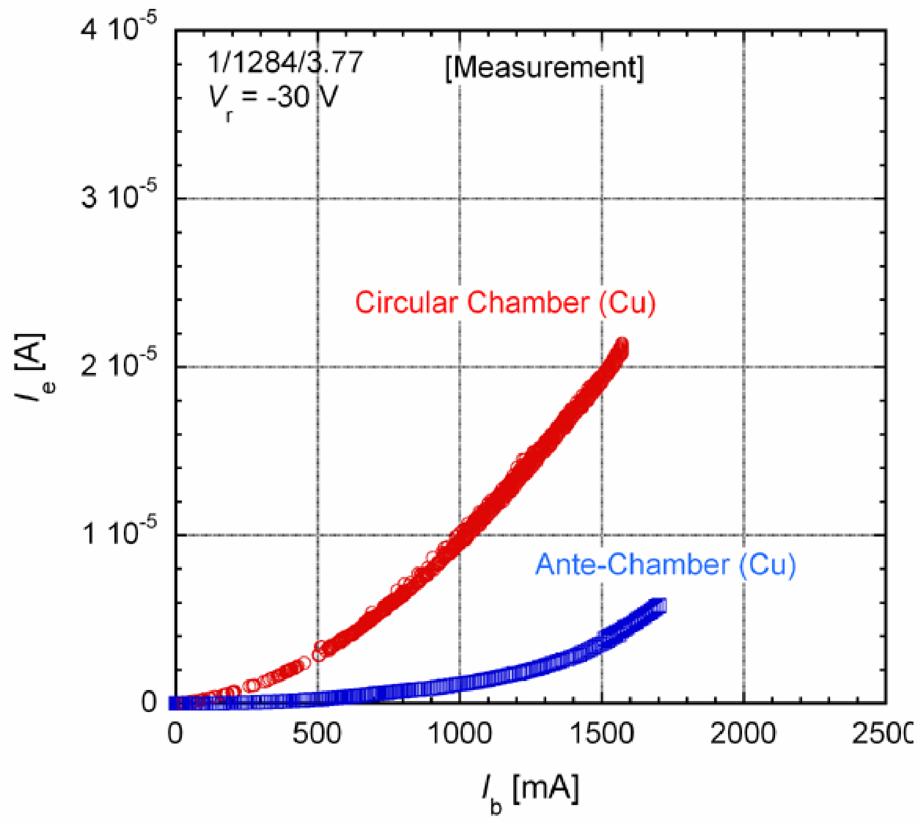
- Further simulation is required.

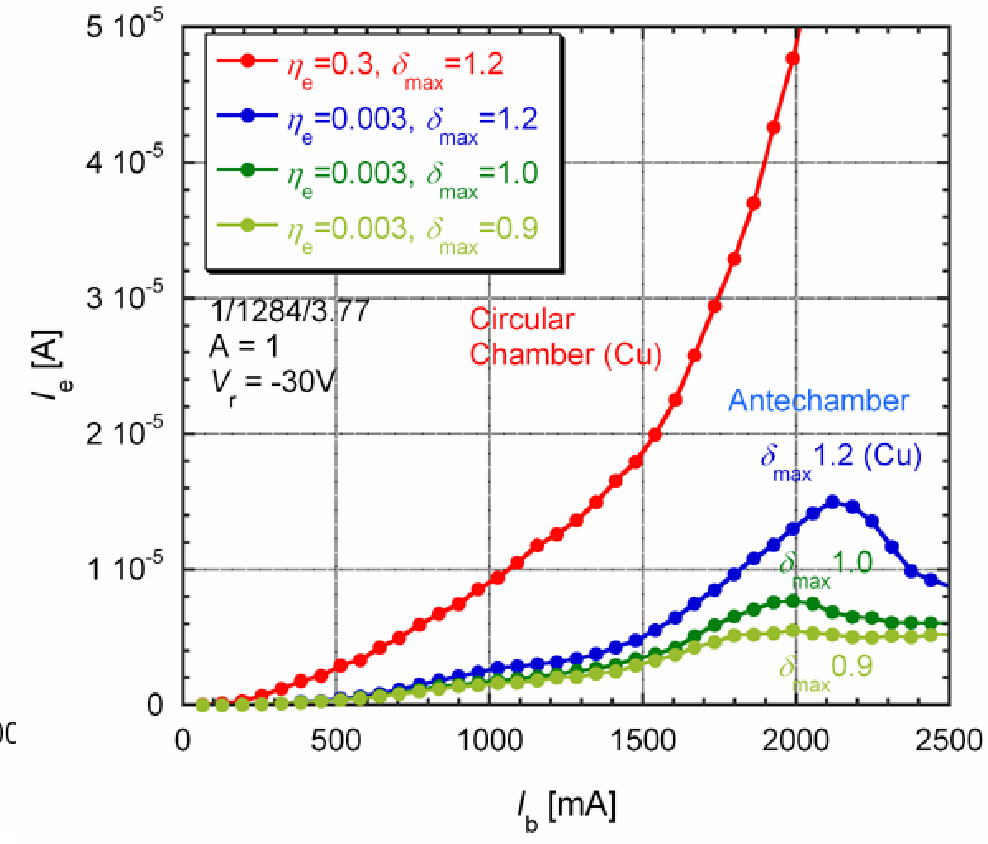
Summary

- R&D to suppress ECI effect has been performed using KEKB positron ring
  - Beam duct with ante-chambers was found to be very effective to reduce photoelectrons, by several orders.
  - TiN coating reduce the electron density even at high current, by factors
  - TiN coating seems the most promising one at present
  - Test of NEG coating duct at straight section is undergoing.
- Next step:
  - Combination of TiN (or NEG) coating and a beam duct with antechamber.
  - Measurement of electron density in B and Q magnets, and Wiggler.
  - Experiment of rough surfaces, and clearing electrode?

Experiment: Low SEY Surface

- Combination with beam duct with ante-chamber

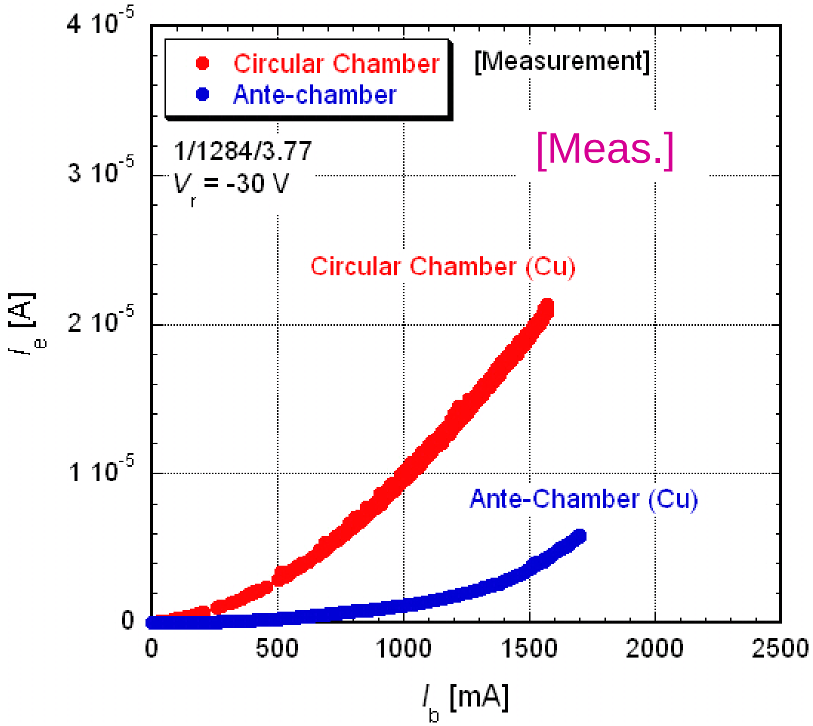


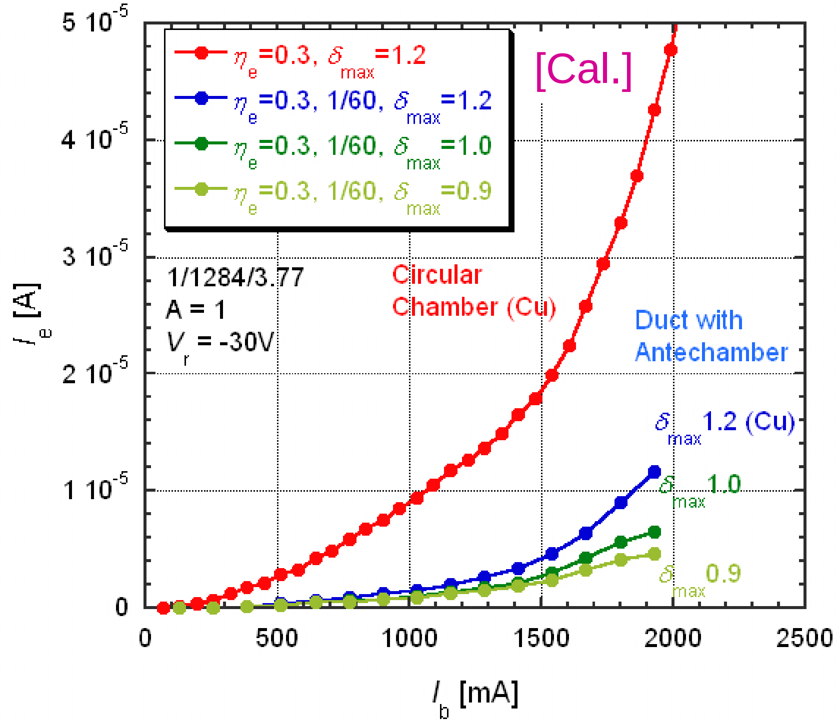


Reference

Calculated Electron Current

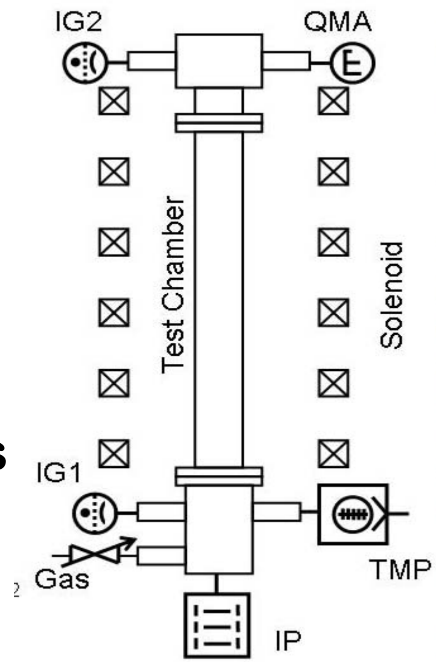
- The reduction of photoelectrons : 1/60
- Well reproduced the measurement.
- For δ_{max}=1.0-0.9, the electron density in the beam channel should further decrease to 1/2, totally 1/6 – 1/8 compared to simple circular one.





NEG coating

- **Conditions:**
  - **Following CERN method.**
  - **Coated at BINP**
  - **Magnetron discharge**
    - **P ~ 0.3 Pa (Kr), B ~105 G**
    - **I = 150 mA, V = 400 V**
  - **Deposition rate = ~1μm/12 hours**
  - **Pre-baking: 24 hours at 250°C**
  - **Temperature is kept at 100°C during coating**



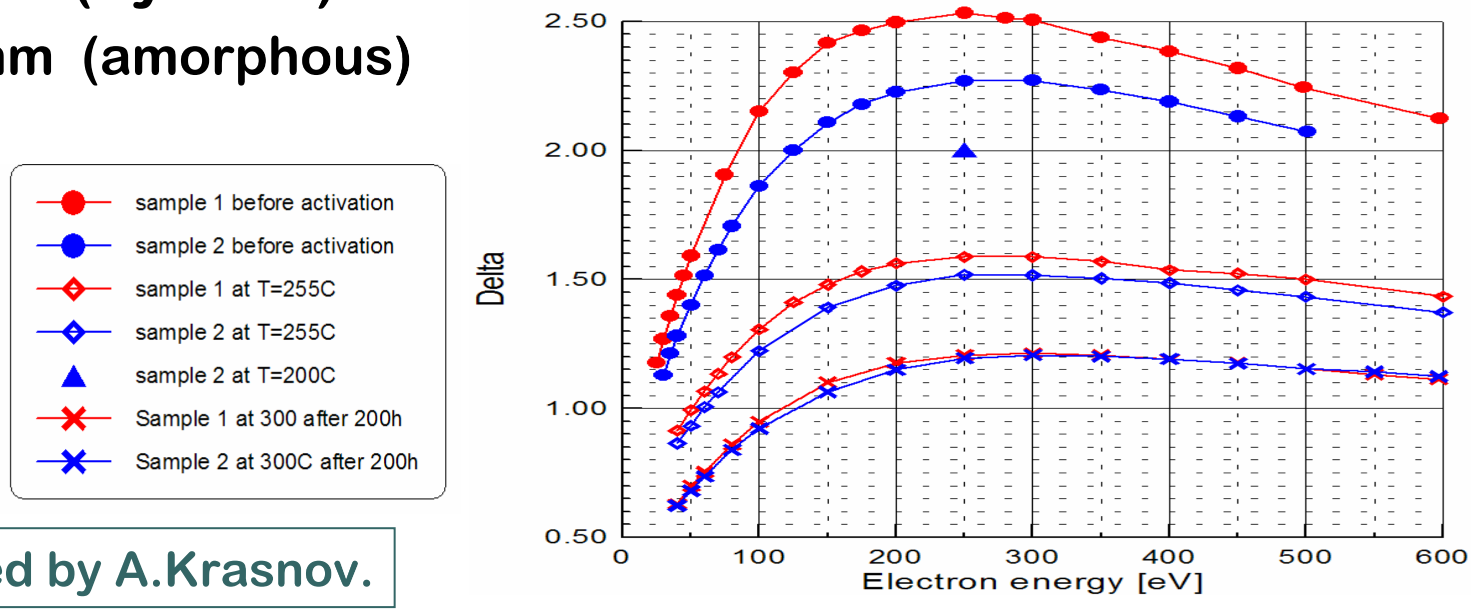
Courtesy of A.Krasnov

A chain of collaboration research with BINP

NEG coating - Properties

- Sticking coefficient just after coating for H_2
  - 1.4 %   (S ~ 0.6 l/s/cm^2)
- Composition (by XRF)
- Thickness (by XRF)
  - 0.7 - 0.9 μm
- Particle size (by XRD)
  - 1.0 - 1.5 nm (amorphous)
- SEY

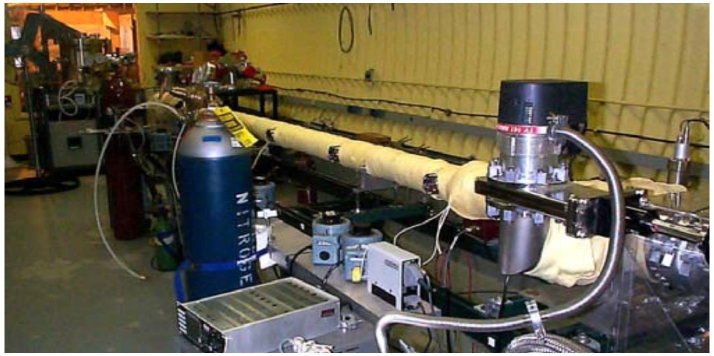
	Atomic fraction %	Weight fraction %
Ti	30	24
V	44	37
Zr	26	39

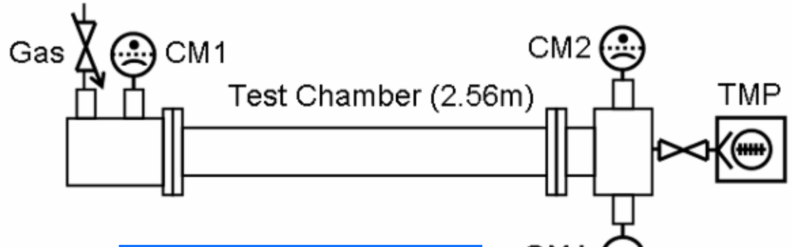


All measured by A.Krasnov.

TiN coating

- **Conditions:**
  - **Following method for SNS**
  - **Coated at BNL**
  - **Magnetron discharge**
    - **P ~ 0.6 Pa (Ar+N_2)**
    - **I ~ 1700 mA, V ~ 380 V**
  - **Deposition rate: ~1μm/1 hour**
  - **Pre-baking: 72 hours at 220°C.**
  - **GDC before coating**
  - **Ti underlayer**
  - **Temperature is kept at 220°C during coating**



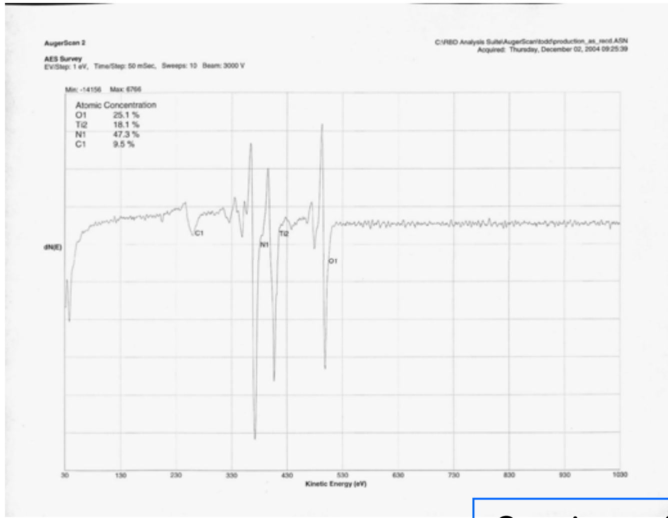


Courtesy of H.Hseuh

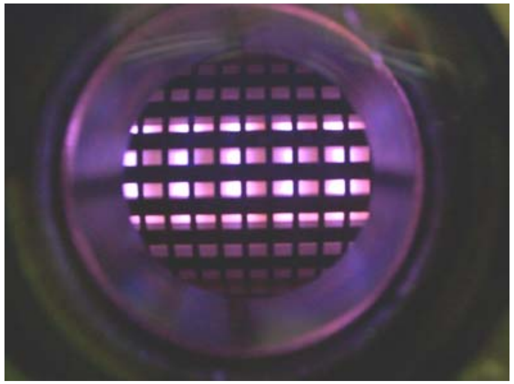
A chain of US-Japan collaboration research

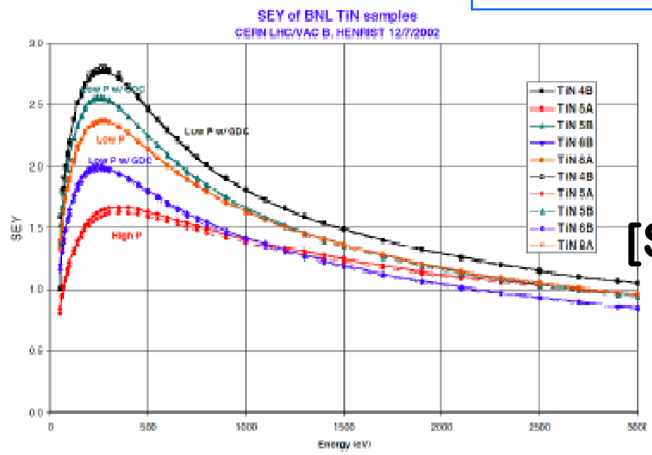
TiN coating - Properties

- Thickness (by stylus profiler)
  - 0.3 ~1 μm
- Composition (by AES)
  - Ti:N =49 : 51
- SEY (from data of SNS chamber)
  - δ_{max}=1.6 – 1.8



Courtesy of H.Hseuh





[SNS]

Fig. 6 The SEY value vs. primary electron energy of coated samples at 1.5 mTorr (Low P) and 5 mTorr (high P).

H. Hseuh, ECLOUD'04