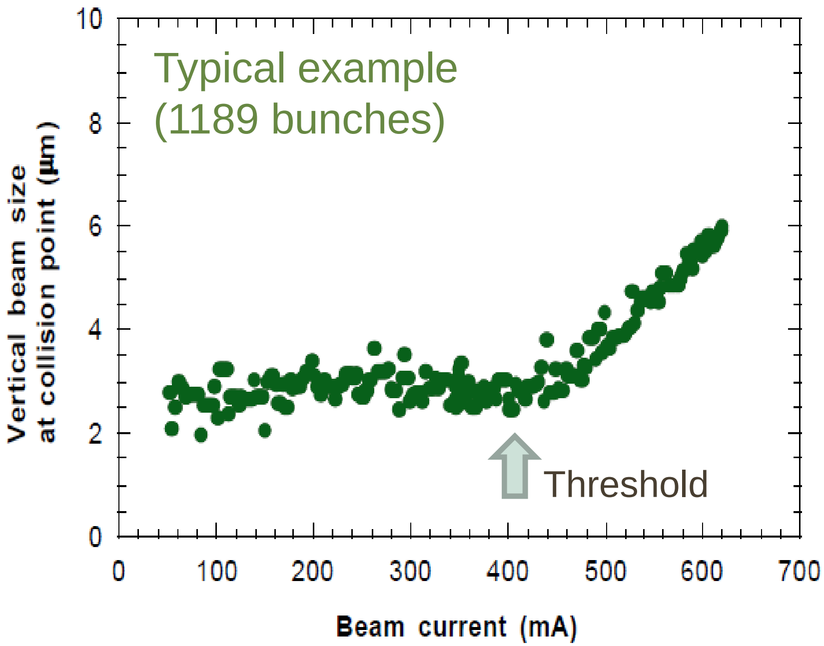
Review of Electron Cloud R&D at KEKB

Y. Suetsugu for KEKB Group

1. **Diagnostics**
   1. Beam Size Blow-up
   2. Beam Instabilities
   3. Electron Density
   4. SEY (Secondary Electron Yield)
2. **Mitigation**
   1. Solenoid
   2. Beam Pipe with Antechambers
   3. Coating to Reduce SEY
   4. Clearing Electrode
3. **Summary**

Diagnostics

- Beam size blow-up: Starting point of our EC R&D
  - The KEKB LER (positron ring) has suffered vertical beam size blow-up due to electron clouds, which deteriorated the luminosity.
  - Single beam and multi-bunch effect of EC.

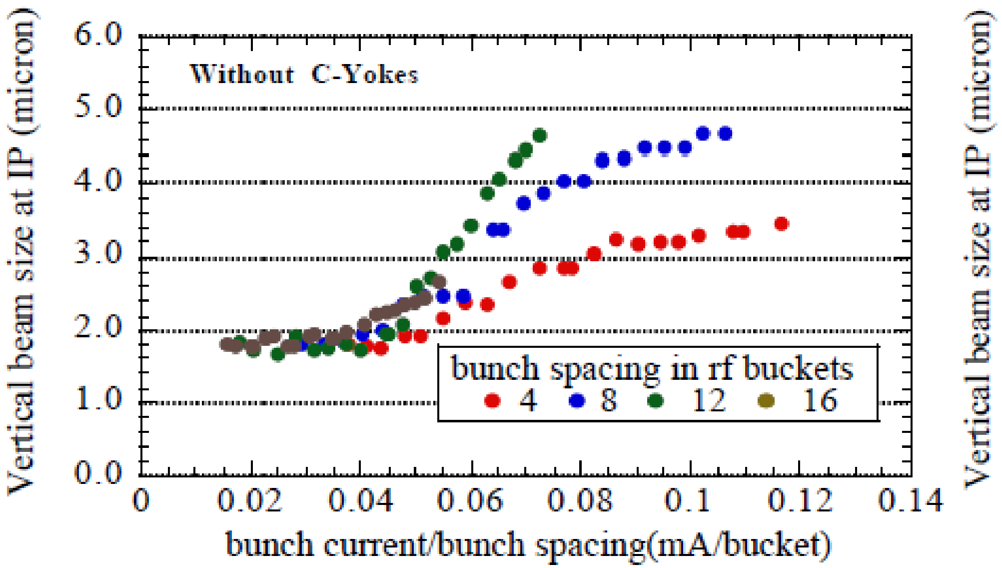


(Measured by interferometer)

Basic parameters of KEKB LER	
Energy	3.5 GeV
Circumference	3016.26 m
Nominal bunch current	1.3 mA
Nominal bunch spacing	2~8 ns
Harmonic number	5120
RMS beam size (x/y)	0.42/0.06 mm
Betatron tune	45.51/43.57
RF voltage	8 MV
Synchrotron tune	0.024
Radiation damping time	40 ms

Diagnostics

- Beam size blow up: Threshold
  - The blowup had a threshold which was determined by the charge density (bunch current/bunch spacing).
    → Support the blowup due to head-tail instability



Model (F. Zimmermann)

BBU: $I_{b,th} \propto \sqrt{L_{sep.}}$

(Beam Beam Breakup)

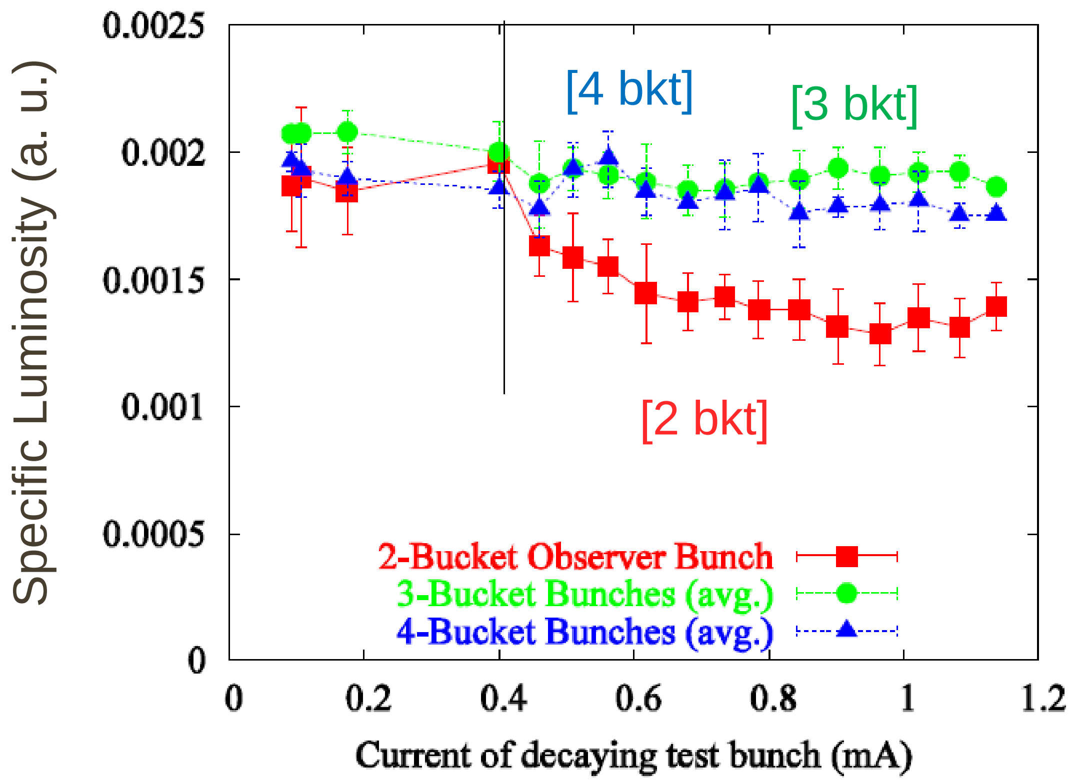
Head-tail, TMCI : $I_{b,th} \propto L_{sep.}$

$I_{b,th}$ (threshold current of blow-up) / L_{sep} ~ const.
This supports that the head-tail instability is a cause of blow-up.

H. Fukuma, ECLOUD02

Diagnostics

- Beam size blow up: Effect on luminosity
  - Measured Using Bunch-by-Bunch Luminosity monitor

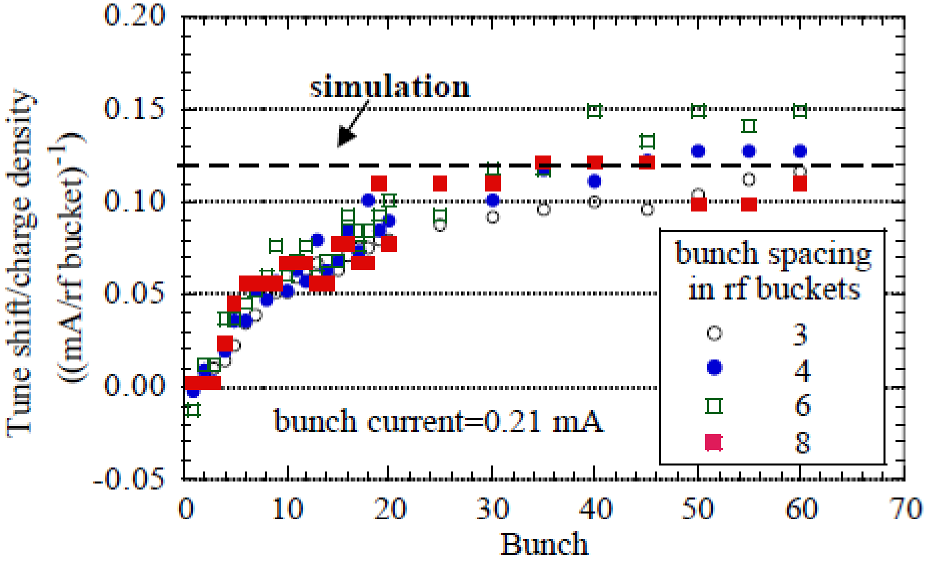


- Specific luminosity of observer bunch is lower than that of regular bunches above 0.4 mA, but is the same below 0.4 mA.
- Consistent with sideband behavior, and explanation that loss of specific luminosity is due to electron cloud instability.

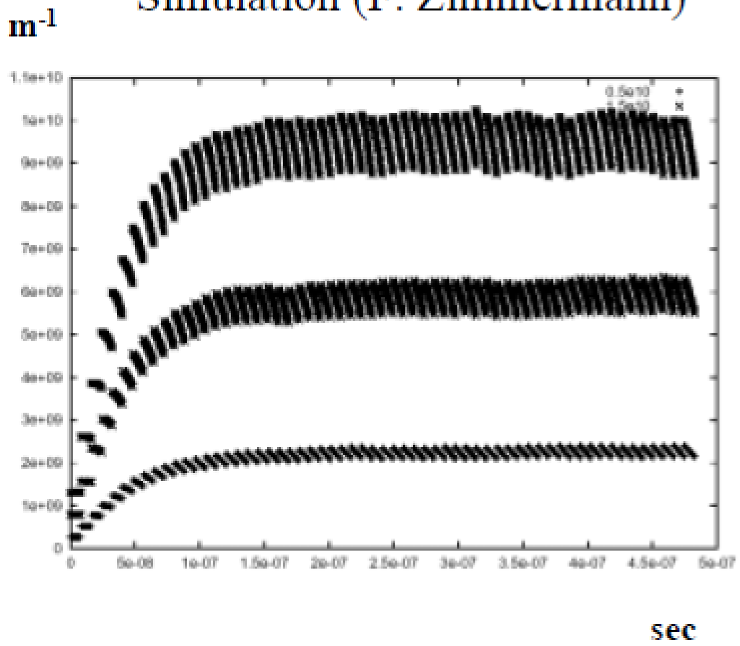
J. Flanagan, ECLOUD02

Diagnostics

- Build up
  - Tune shift is another indication of EC.
  - Vertical betatron tune increased along the train and almost saturated after several ten bunches.



Simulation (F. Zimmermann)

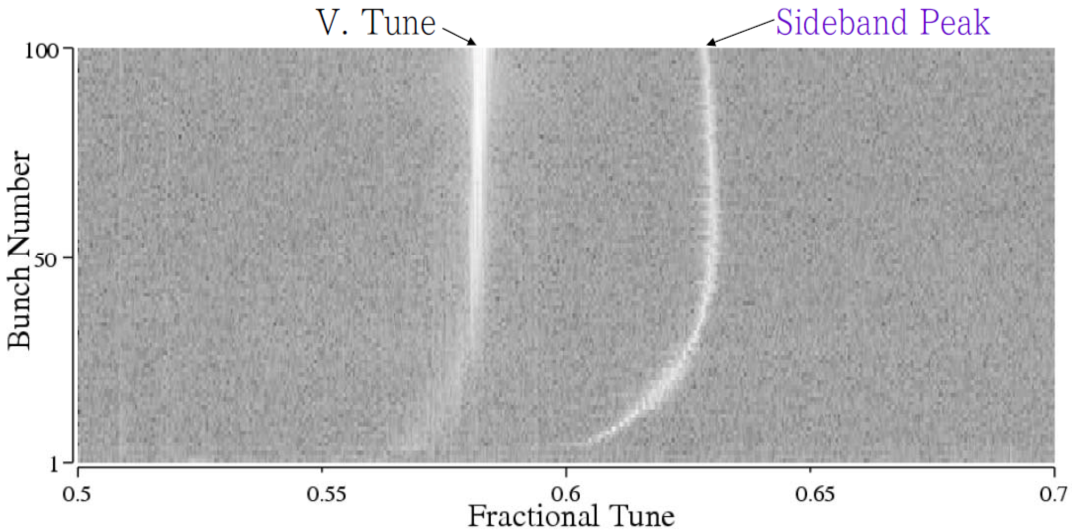


Tune shift and build-up time is consistent with simulation.

H. Fukuma, ECLOUD02

Diagnostics

- Head-tail instability: Synchro-Betatron sidebands
  – Direct evidence of Head-Tail instability due to EC



- LER single beam, 4 trains, 100 bunches per train, 4 rf bucket spacing
- Solenoids off: beam size increased from 60 μm ->283 μm at 400 mA
- Vertical feedback gain lowered
  – This brings out the vertical tune without external excitation

Bunch Oscillation Recorder (BOR)

– Digitizer synched to RF clock, plus 20-MByte memory.
– Can record 4096 turns x 5120 buckets worth of data.
– Calculate Fourier power spectrum of each bunch separately.

- Sideband appears at beam-size blow-up threshold, initially at ~ $\nu_b + \nu_s$, with separation distance from ν_b increasing as cloud density increases.
- Sideband peak moves with betatron peak when betatron tune is changed.
- Sideband separation from ν_b changes with change in ν_s.
- Position of the first bunch exhibiting the side band shifted with ν_s.

J. Flanagan, ECLOUD07

Diagnostics

- Head-tail instability: Synchro-Betatron sidebands
  - The behavior is consistent with simulation

Simulation (PEHTS)

(HEADTAIL gives similar results)

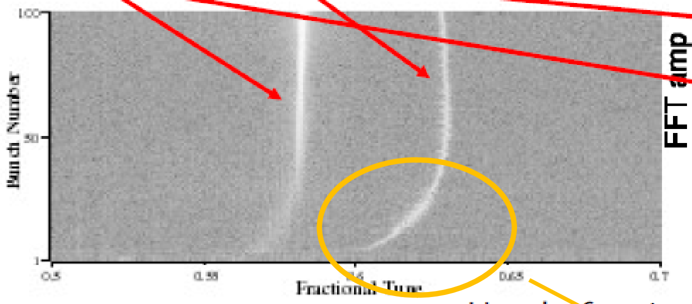
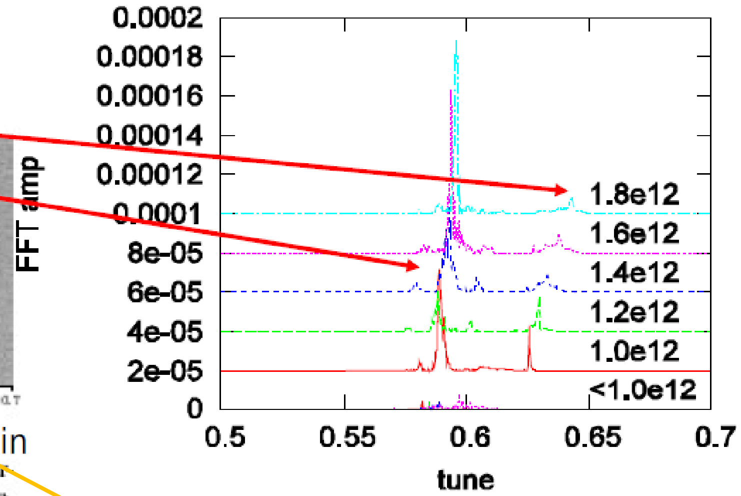
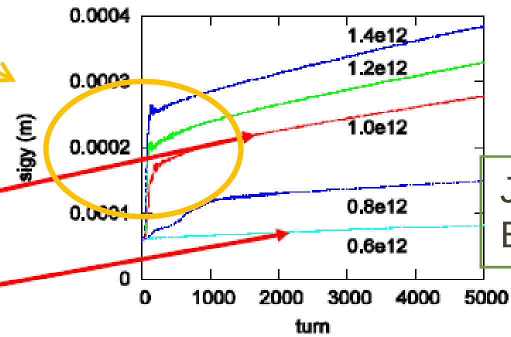


FIG. 1. Two-dimensional plot of vertical bunch spectrum versus bunch number. The horizontal axis is the fractional tune, from 0.5 on the left edge to 0.7 on the right edge. The vertical axis is the bunch number in the train, from 1 on the bottom edge to 100 on the top edge. The bunches in the train are spaced 4-rf buckets (about 8 ns) apart. The bright, curved line on the left is the vertical betatron tune, made visible by reducing the bunch-by-bunch feedback gain by 6 dB from the level usually used for stable operation. The line on the right is the sideband.





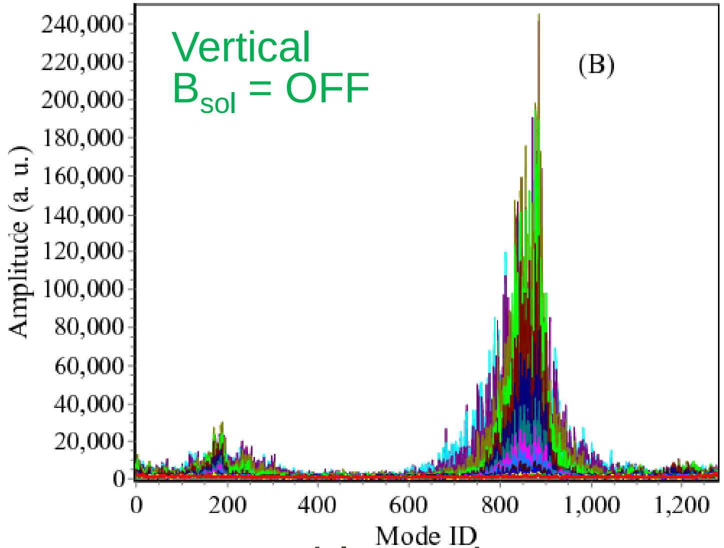
Head-tail regime

Incoherent regime

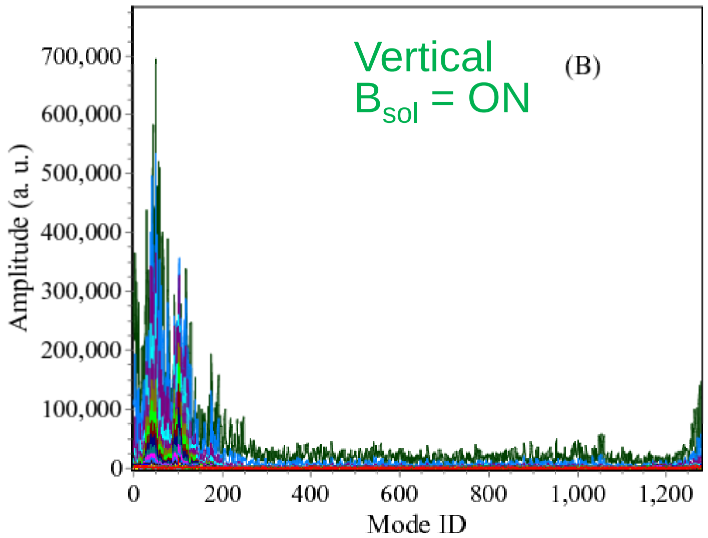
J. Flanagan, ECLOUD07

Diagnostics

- Coupled bunch instability
  - A small betatron oscillation of a bunch is transmitted, amplified to other bunches via the electron cloud.
    →Transverse coupled-bunch instability is excited.
  - Clear evidence of an electron cloud induced coupled-bunch instability.



Unstable modes
without a solenoid field



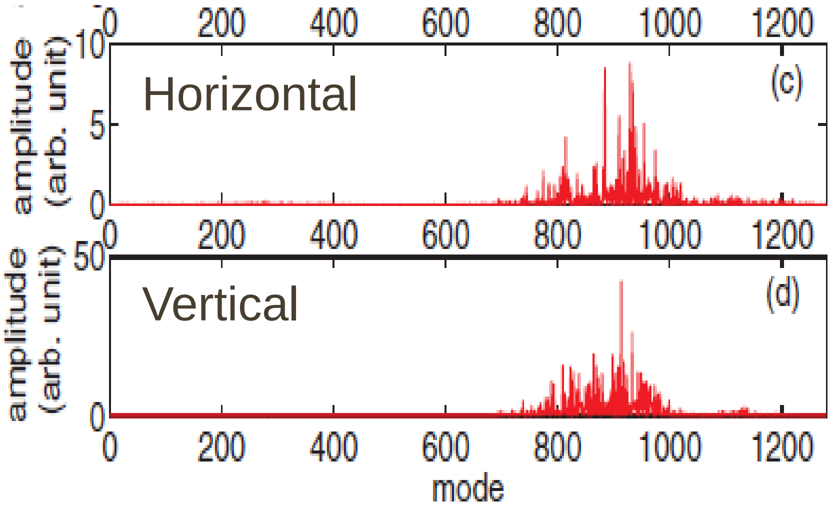
Unstable modes
with a full solenoid field

M. Tobiyama, ECLOUD07

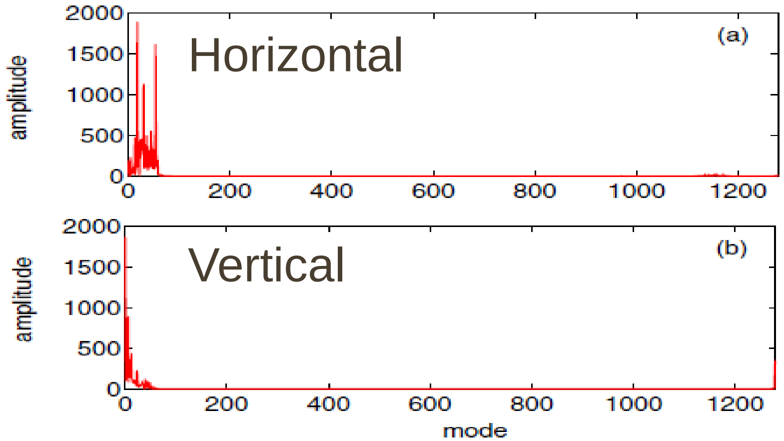
Diagnostics

- Coupled bunch instability
  - The experimental results supported the simulation where the instability is dominated by the electron clouds in the drift space with the lower secondary emission rate δ_{max} = 1.0 rather than 1.5.

No solenoid, δ_{max} = 1.0



Solenoid field = 10 G



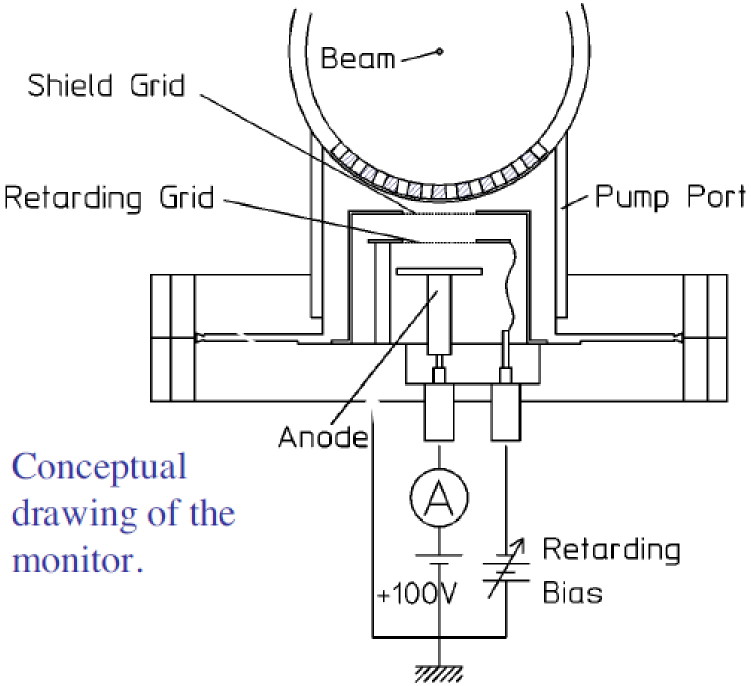
S. S. Win et al, PRST-AB 8, 094401 (2005)

Diagnostics

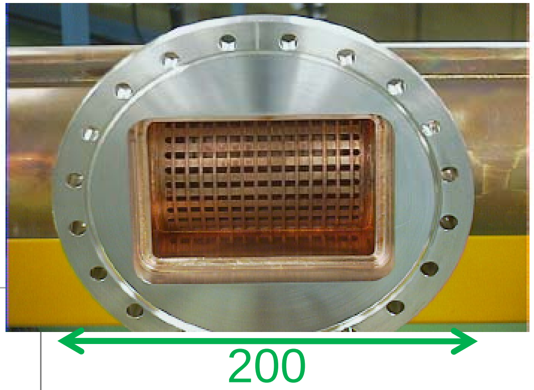
- Electron Density

Electron Monitors

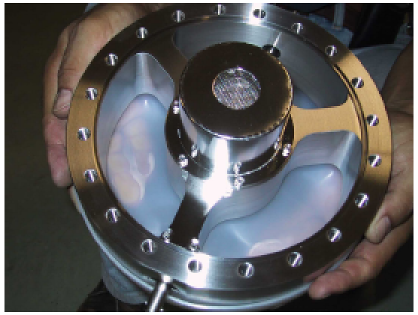
Retarding field analyzer type electron monitors are set at pump ports of KEKB LER.



Conceptual drawing of the monitor.



Pump port of KEKB LER

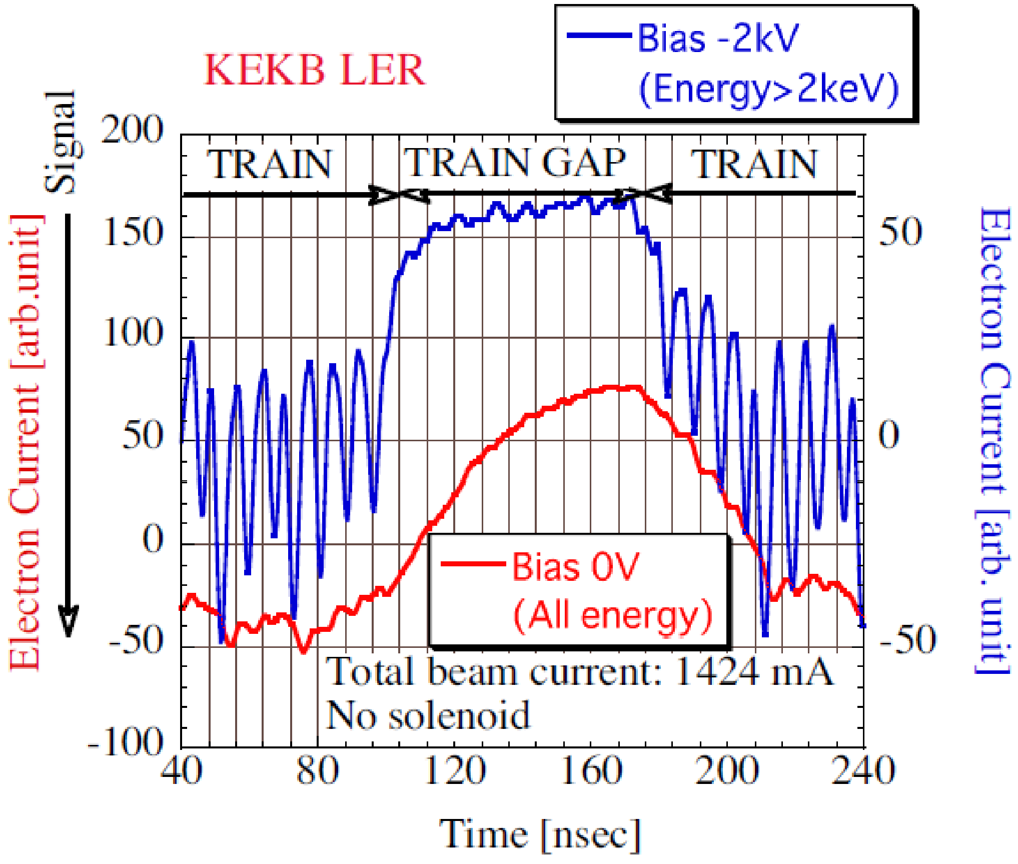


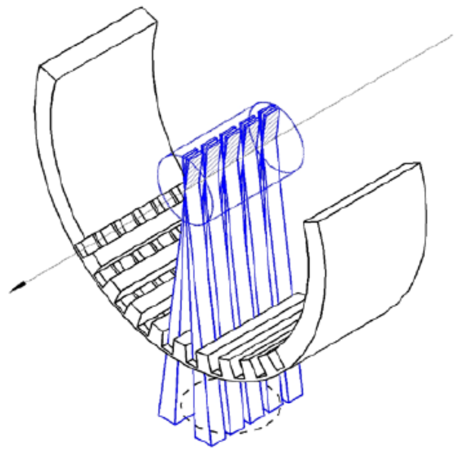
Electron Monitor (Modified Type)

K. Kanazawa, ECLOUD07

Diagnostics

- Electron Density



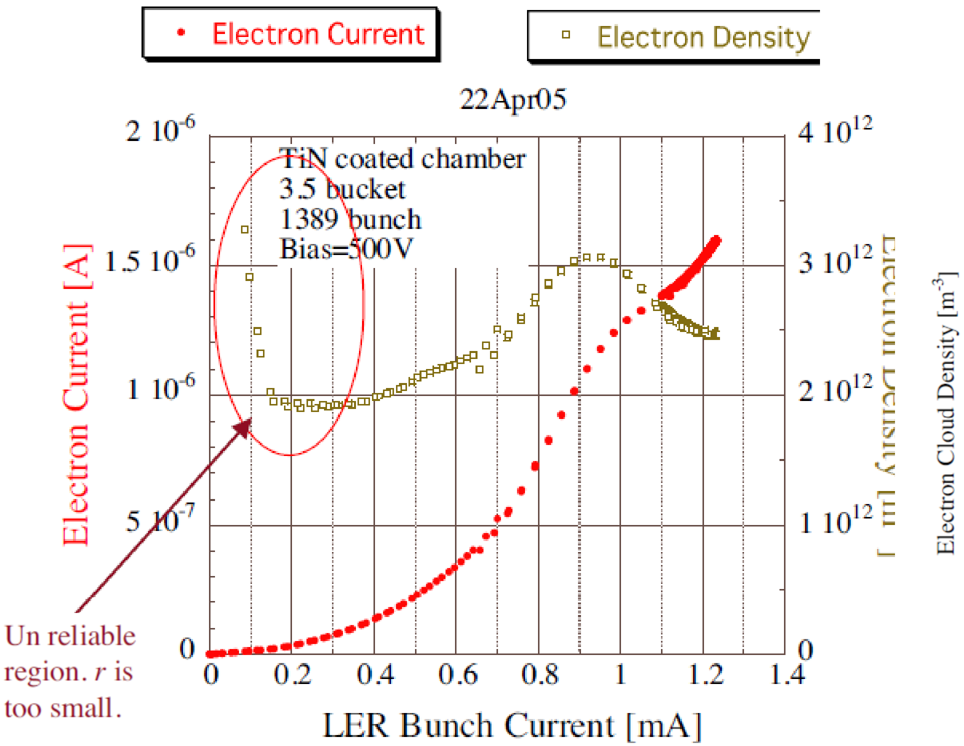


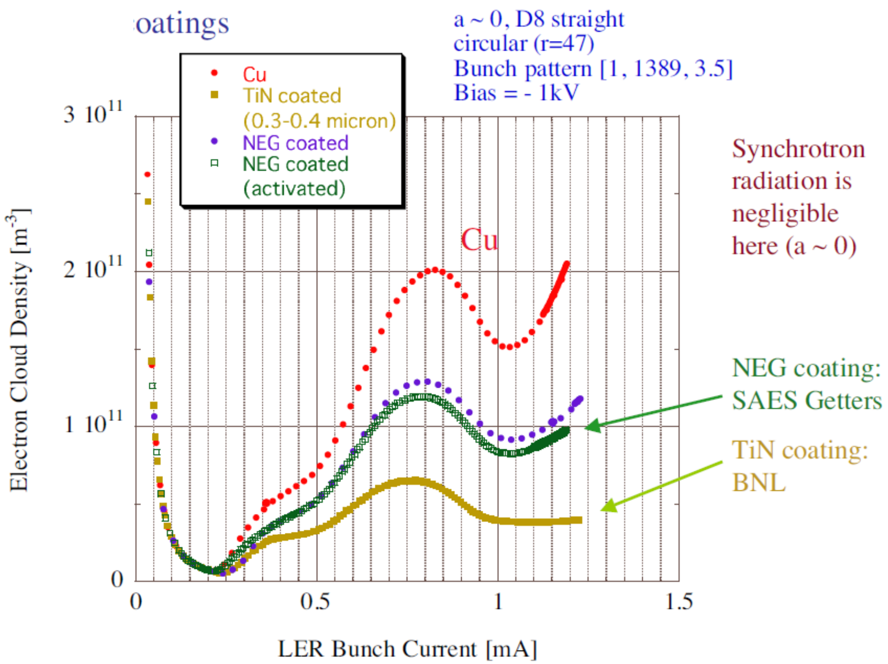
Electron density around the beam can be estimated by measuring electron with a sufficient high energy.
[In field-free region]

K. Kanazawa, ECLOUD07

Diagnostics

- Electron Density
  - Example of measurement
  - Useful to directly estimate the electron density.





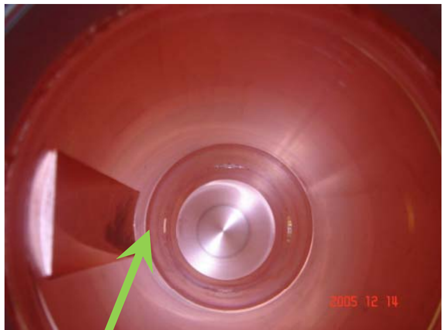
K. Kanazawa, ECLOUD07

Measurements in solenoid and Q-magnet are planned
→ Kanazawa-san's talk.

Diagnostics

- SEY (Secondary Electron Yield)
  - SEY is an important parameters in considering EC build up by multipactoring.
  - Measurement of SEY of various materials, such as copper, copper with coatings and graphite, using sample pieced has been performed in laboratories.
  - Measurements of samples exposed to real positron beam were also tried recently.

In situ. Measurement (i.e. without exposure to air) is possible.



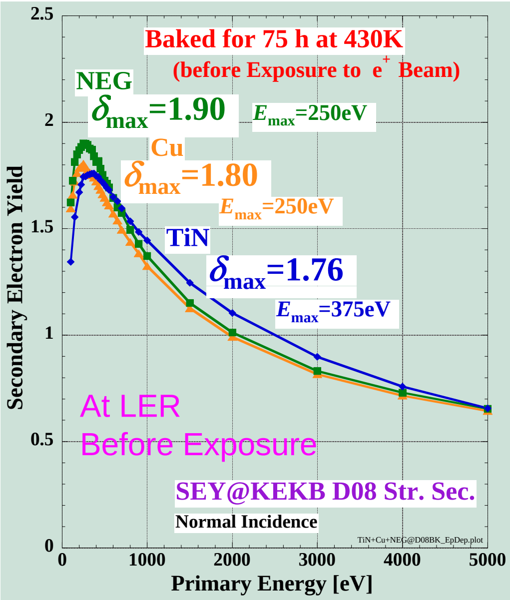
Sample Surface

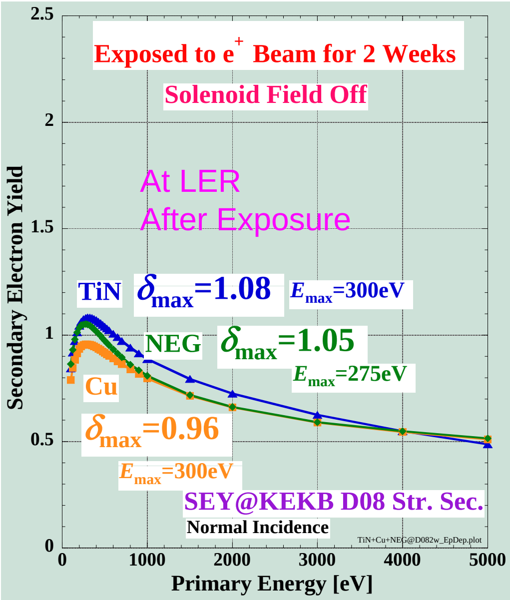
S. Kato, KEK Review 2007

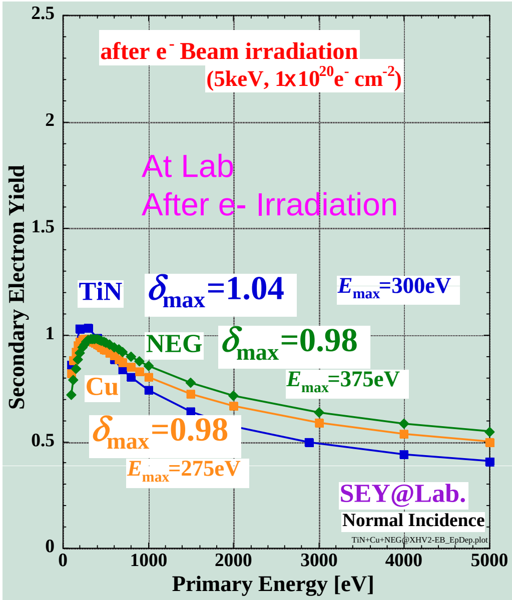
Diagnostics

- SEY
  - Direct measurement using samples

S. Kato, KEK
Review 2007





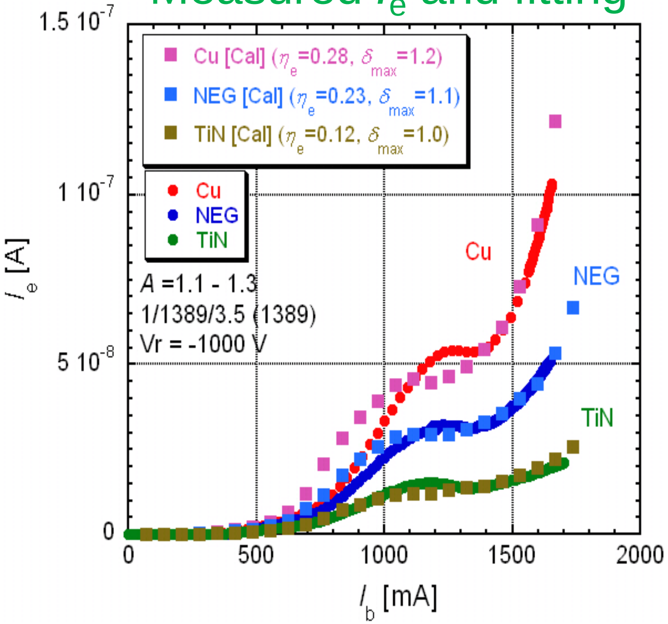


- After Exposure to beam: Drastic decease of δ_{max} for all samples.
- Results are almost consistent with those results obtained at Lab.
- e^- beam induced graphitization was found for copper surface exposed to e^- cloud as found in lab experiment. In lab, the same graphite formation at TiN surface + graphite and carbide formation at NEG surface were found.

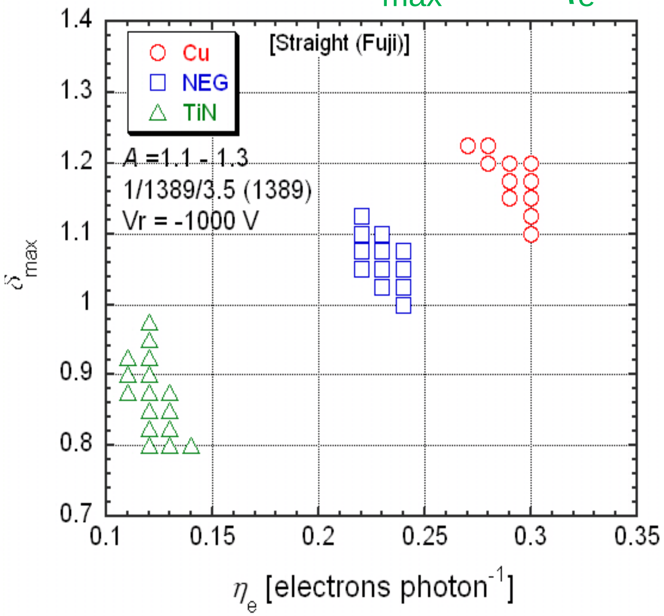
Diagnostics

- SEY
  - Estimation from measured electron current, utilizing a simulation.

Measured I_e and fitting



Estimate δ_{max} and η_e



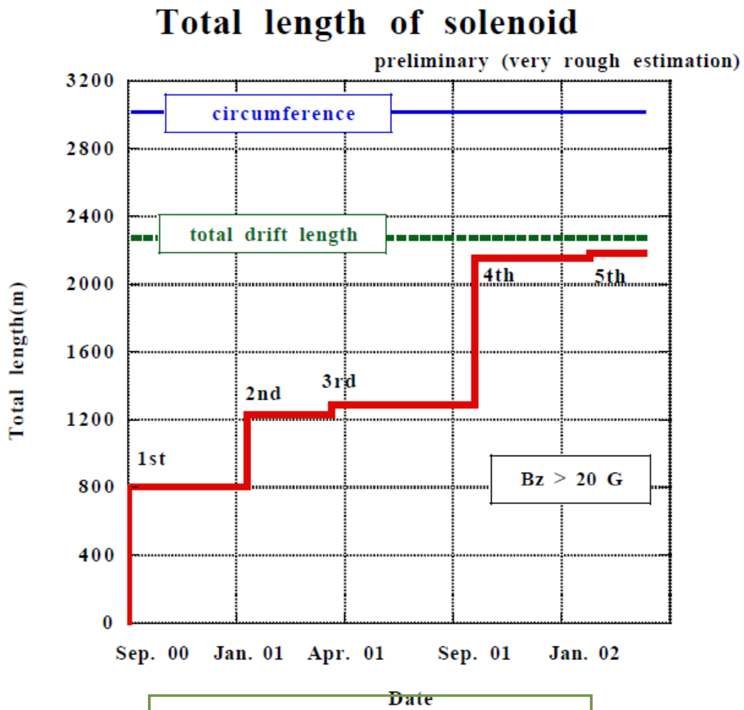
3.5 bucket spacing
1389 bunches
Repeller -1000V

	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 (photoelectron yield), 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.

Mitigation

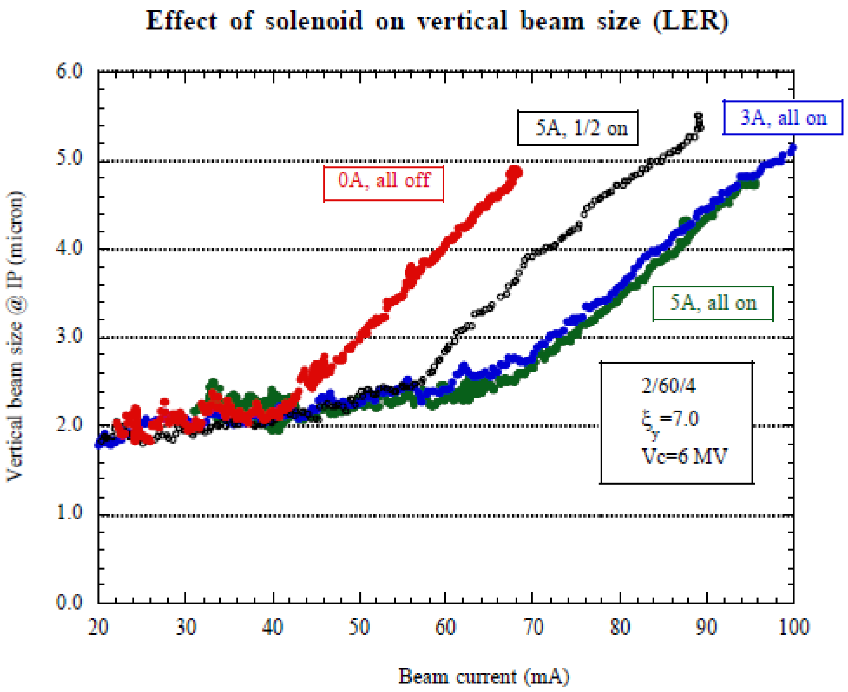
- Solenoid
  - Very effective method for field-free region.
  - Solenoid has been wound since 2000, and now over 95 % of drift region was covered.
  - Blow up is now almost suppressed up to 1.7 A (3.06 RF bucket spacing).

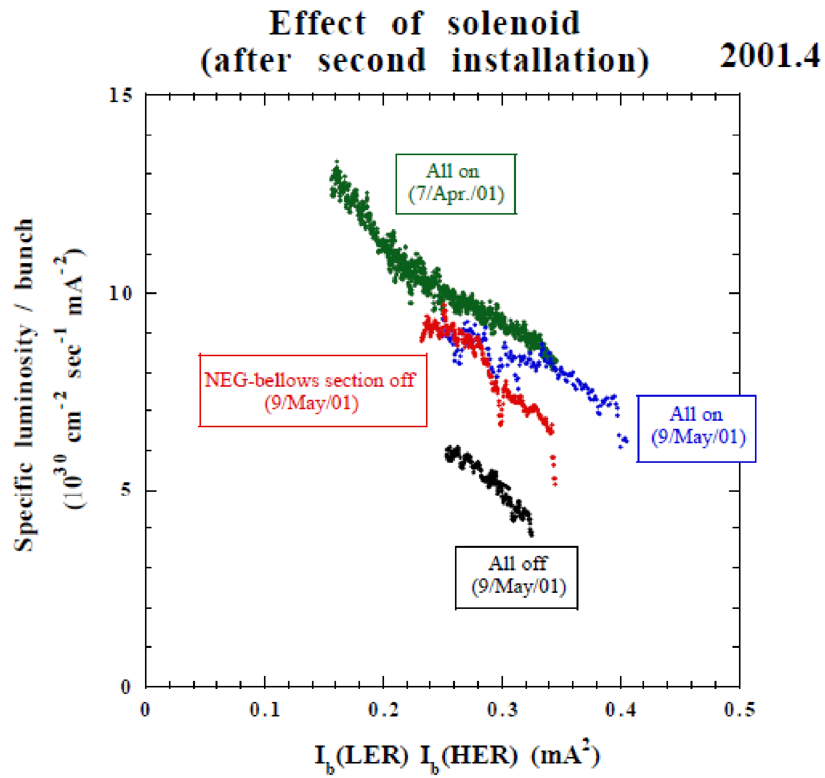


H. Fukuma, ECLOUD02

Mitigation

- Solenoid



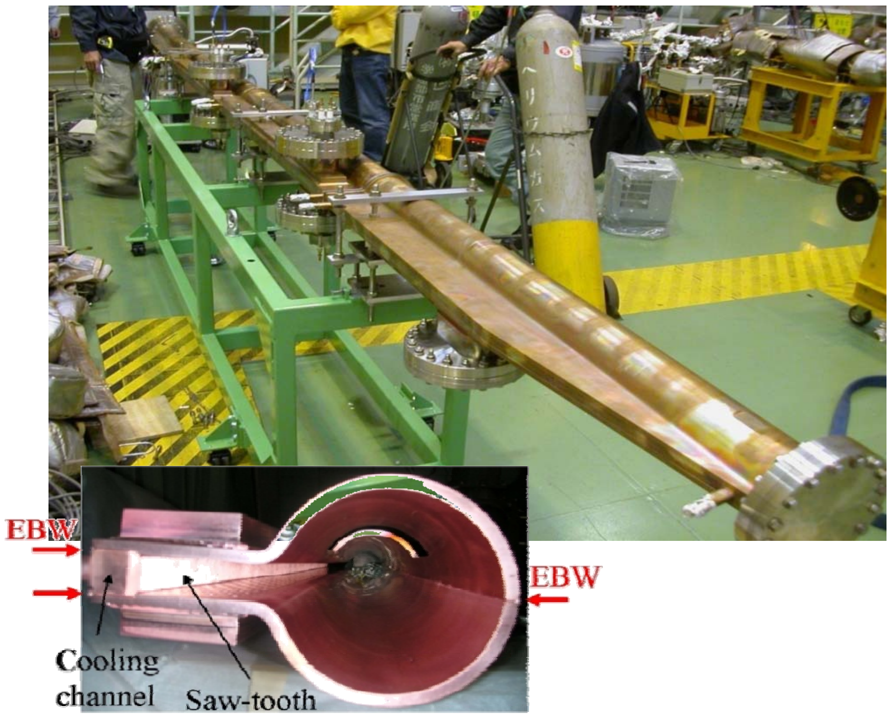


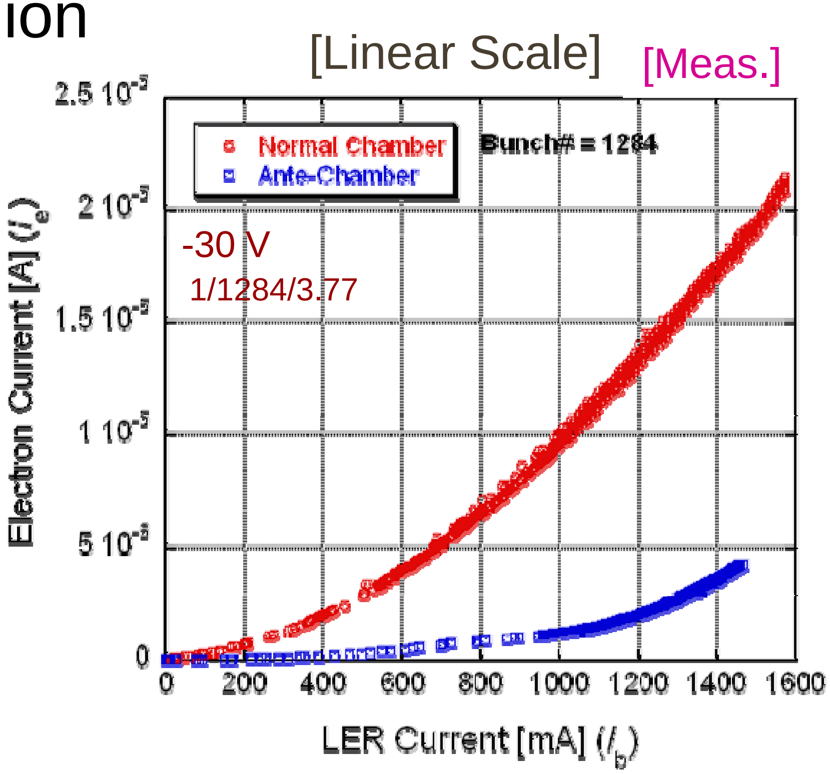
- Solenoid is also useful to determine the location of EC.

H. Fukuma, ECLOUD02

Mitigation

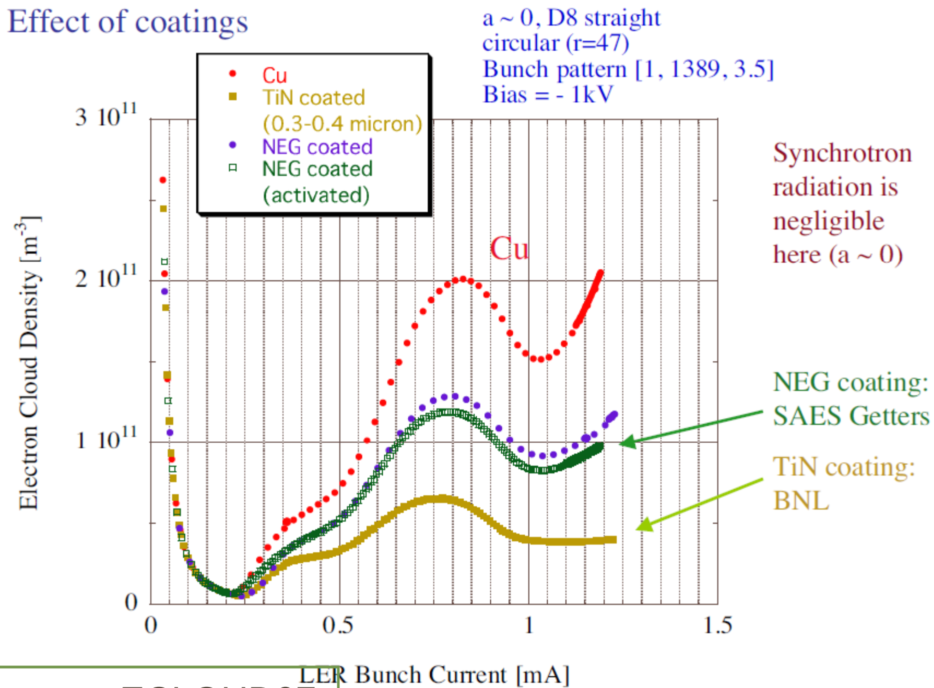
- Beam pipe with antechamber
  - Effective to reduce photoelectron effect
    - Photoelectron: Seed of EC
  - Important in field-free region





Mitigation

- Coating to reduce SEY
  - TiN or NEG coating has been said to be effective to reduce SEY. Important in magnet.
  - Test chambers with coatings were installed into the ring, and the electron densities were measured and compared each other.

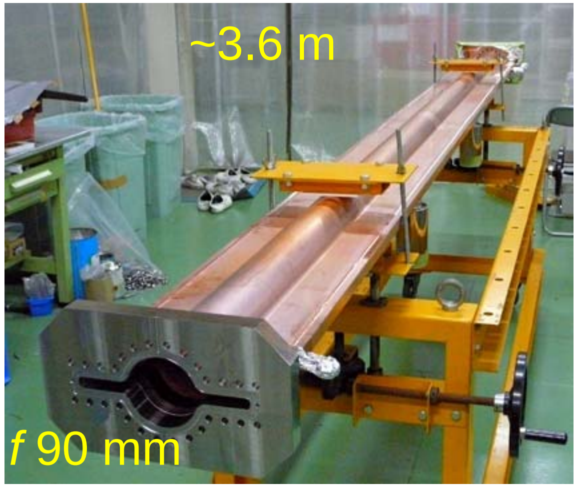


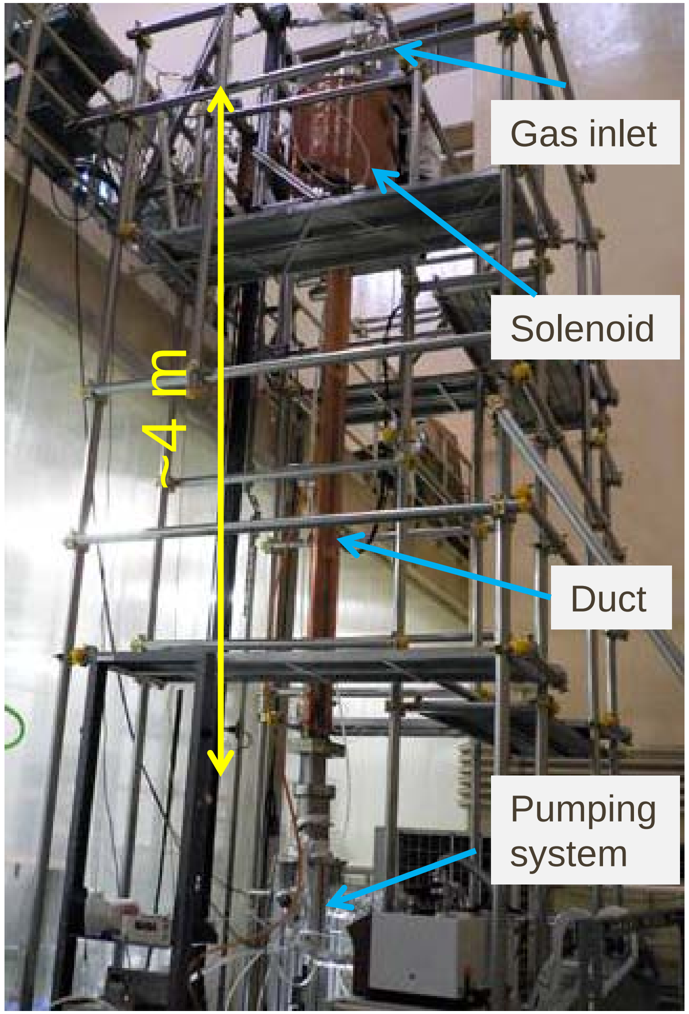
K.Kanazawa, ECLOUD07

- TiN coating is the most promising coating at present
- h_e (photoelectron yield) is also low

Mitigation

- Coating to reduce SEY
  - Recently, combination of beam pipe with antechambers and TiN coating was studied.
  - 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).



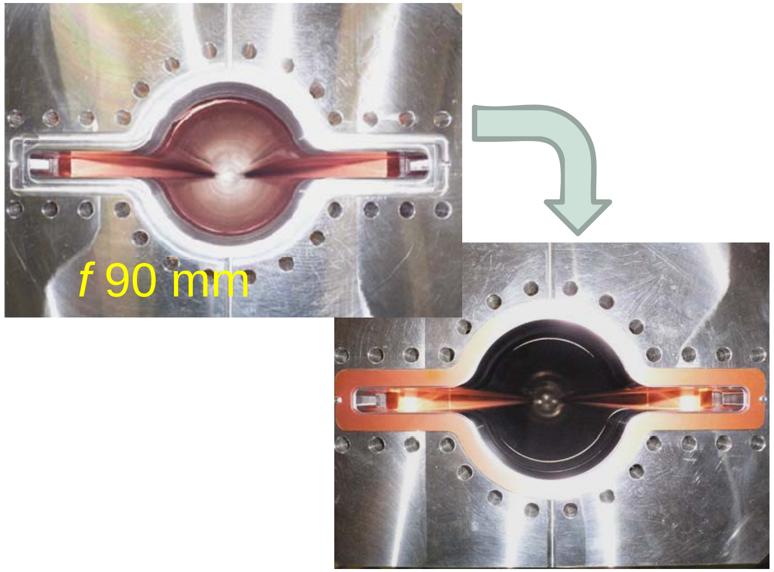


K. Shibata, EPAC2008

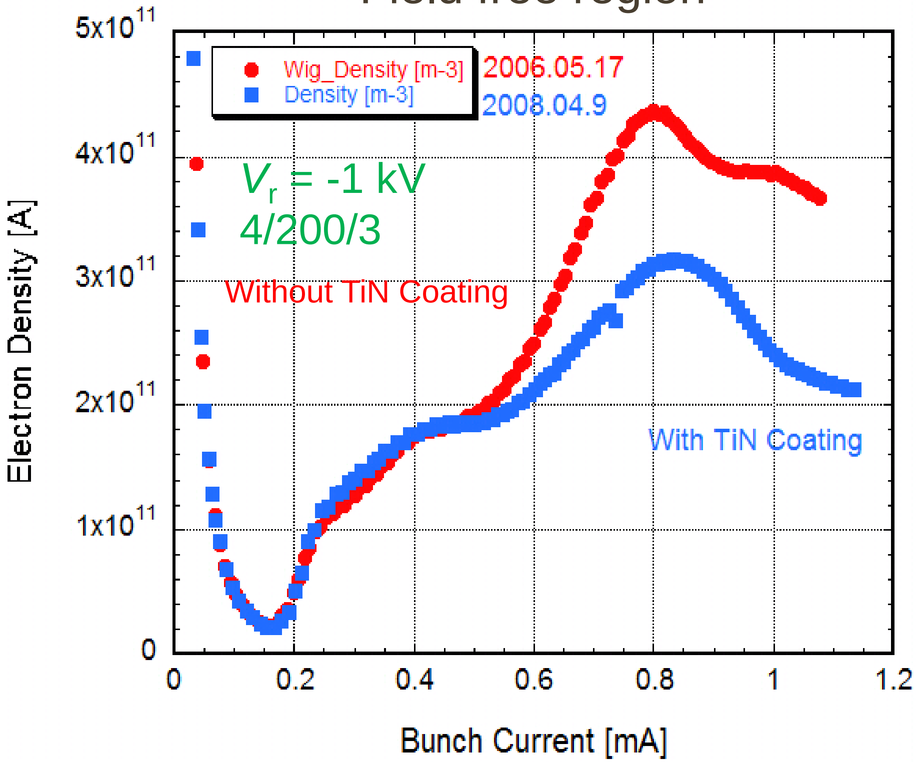
Mitigation

- Coating to reduce SEY
  – Beam pipe with antechambers with TiN coating was installed into the ring.

Coated at only beam channel part



Field free region

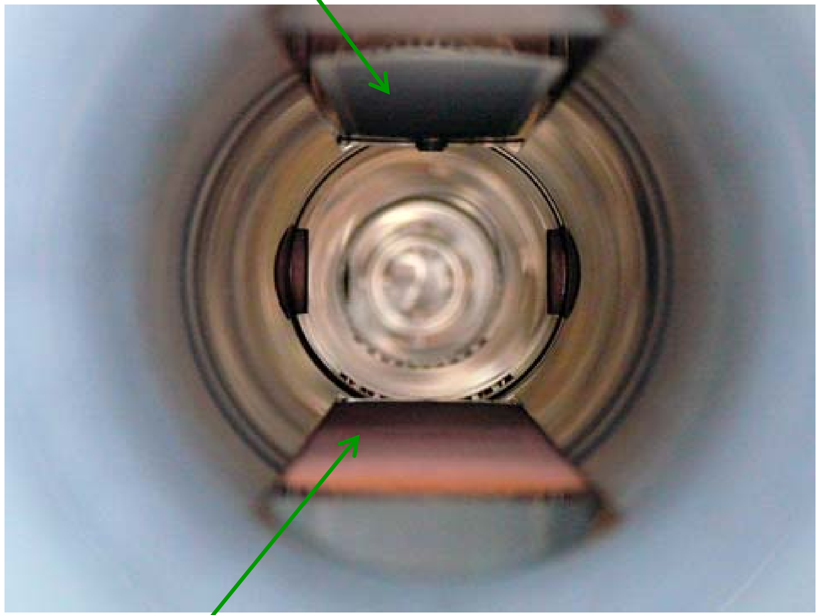


Mitigation

- Clearing Electrode
  - One of the effective cure method in magnet.
  - Recently, an experiment in KEKB LER has just started.

Test chamber

Electrode

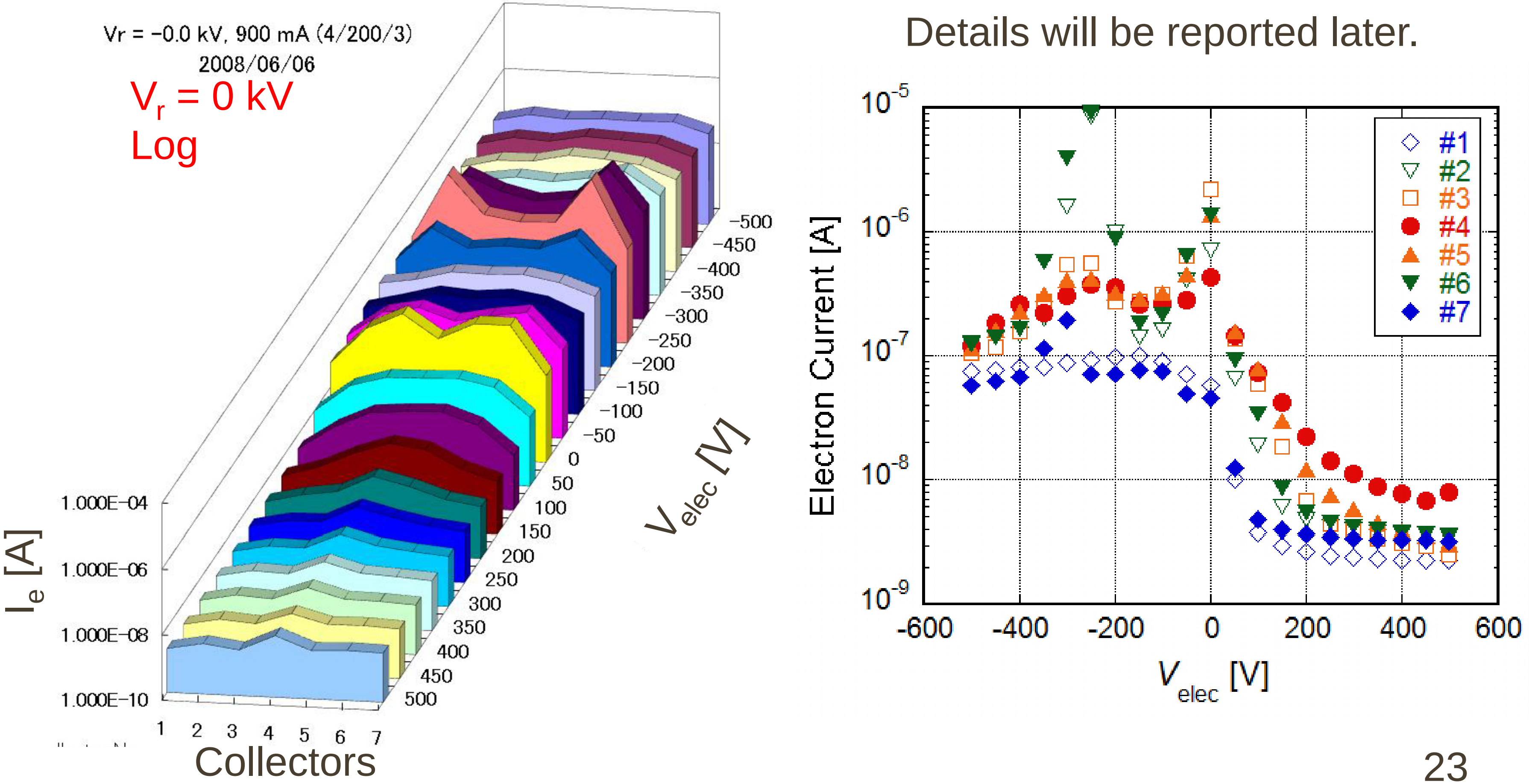


Monitor

Mitigation

- Clearing Electrode
  - Drastic decrease in electron density was demonstrated by applying positive voltage.

Details will be reported later.



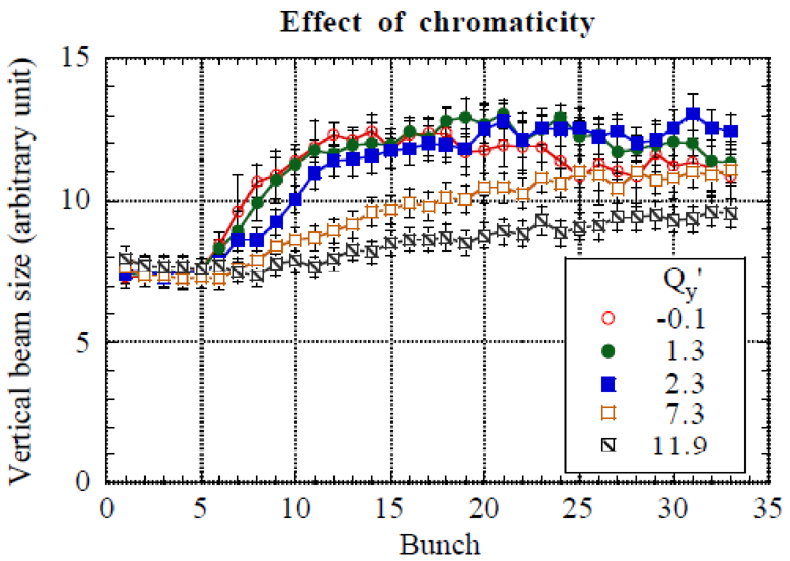
Summary

- Various measurements, simulations to understand EC properties, and experiments for its mitigation have been performed at KEKB positron ring.
- Simulation explained the observations well, but questions still remains.
- Mitigation methods, such as solenoid, coating, duct structure and clearing electrode gave reasonable effect. The solenoid showed a marvelous effect. The cure in magnets is a still remained problem.
- KEKB will stop next year. We have to utilize it as efficiently as possible.

Backup slide

Diagnostics

- Beam size blow up: Effect of chromaticity
  – Blow-up was not observed when the chromaticity was enough high.



H. Fukuma, ECLOUD02

Cloud density at transverse mode coupling instabity (TMCI) threshold ρ_{th}

Vertical: $2.2\times10^{12} + 5.8\times10^{9}$ Q'y
Even if DQ'y = 10, size change ~ 3 % ⇨ Inconsistent?