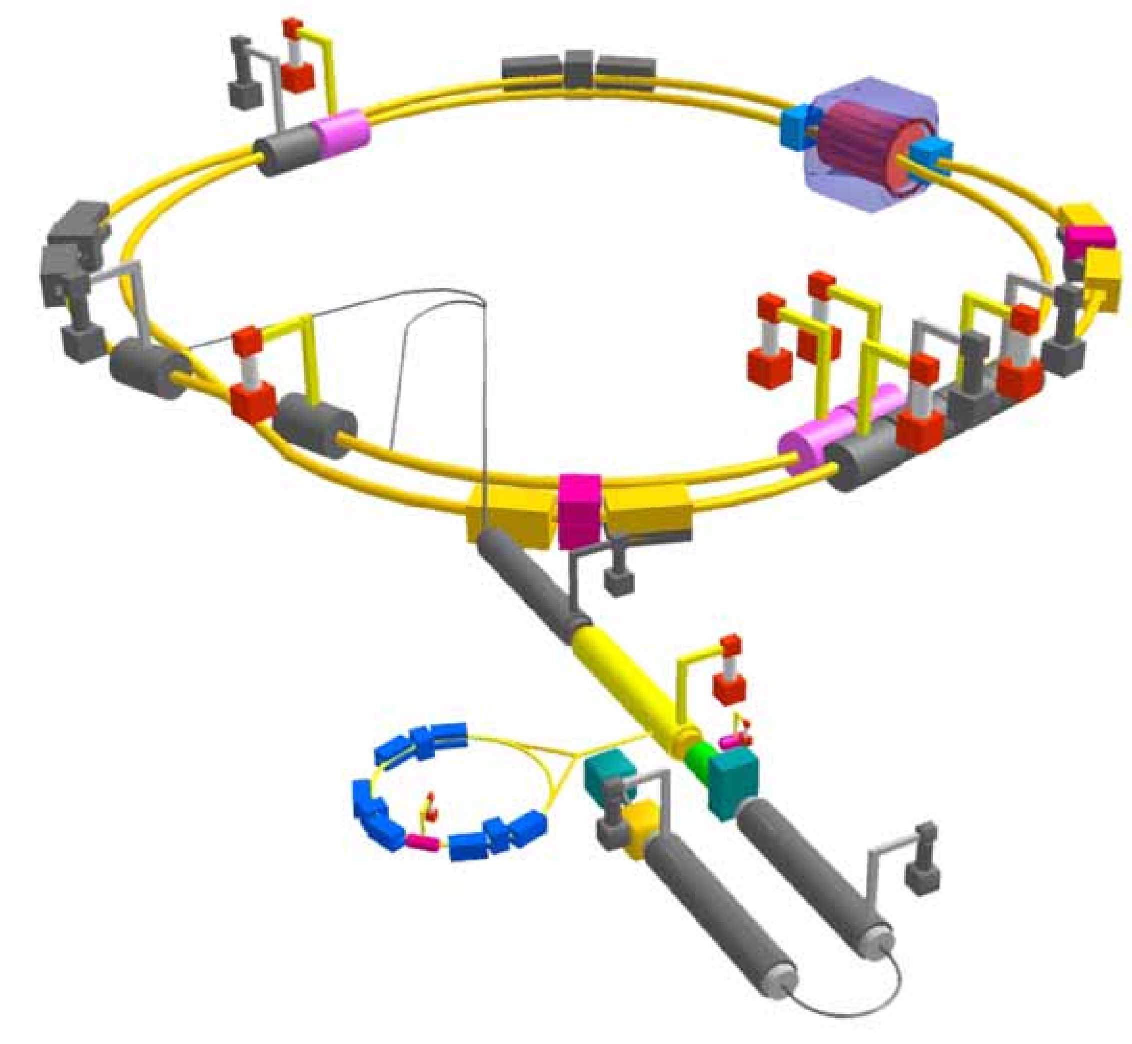
Coupled-bunch instabilities and related effects due to electron cloud in SuperKEKB LER

Makoto Tobiyama

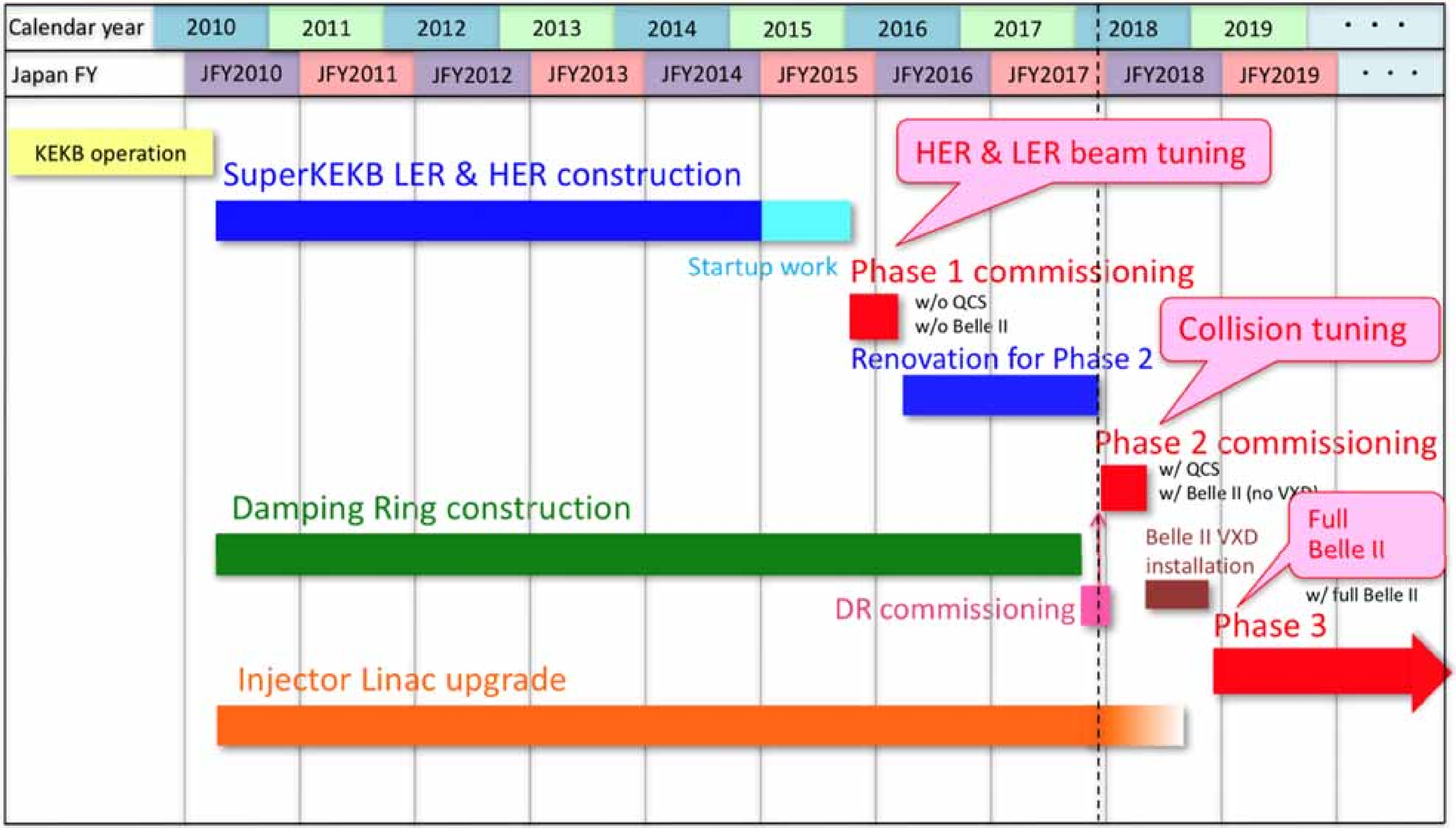
KEK Accelerator Laboratory and SOKENDAI

SuperKEKB accelerators



- Circumference 3km
- LER:e^+ 4GeV 3.6A
- HER:e^- 7GeV 2.6A
- f_{RF}=508.886MHz
- h=5120
- Low emittance 3.2/4.6nm with ~0.28% xy-coupling
- Bunch length 6/5 mm @1mA/bunch
- β^* at IP H/V 32/0.27mm 25/0.3mm
- Luminosity $8x10^{35}$
  - x40 of KEKB

Project History and Near-term Plan



K. Akai et al.

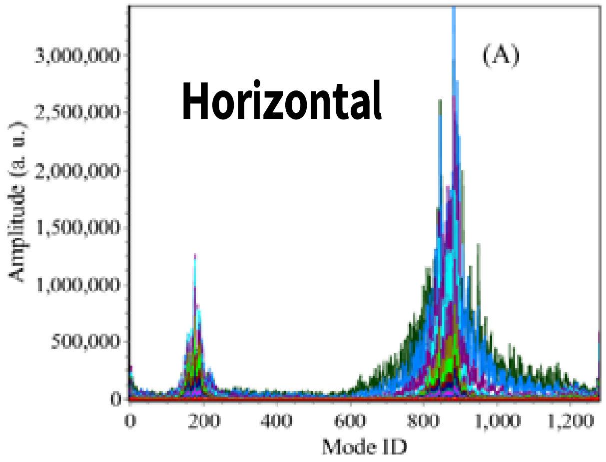
Electron Cloud Effect of KEKB LER

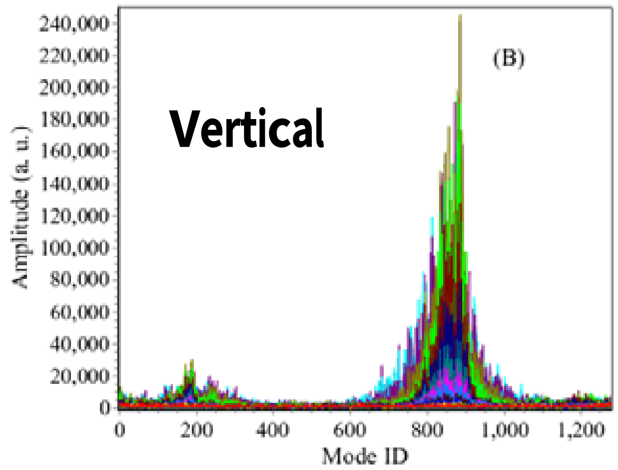
- KEKB LER(3.5 GeV positron ring)
  - Unexpected strong transverse coupled-bunch instabilities and an increase of the vertical beam size with beam current have been observed.
  - To suppress beam blowup and the coupled-bunch instability, we wound weak-solenoid magnets in almost all the straight sections (>95%) with magnetic field~4.5mT.
  - Also using transverse bunch-by-bunch feedback systems to suppress coupled-bunch instabilities.

Coupled-bunch instabilities (CBI) due to ECE

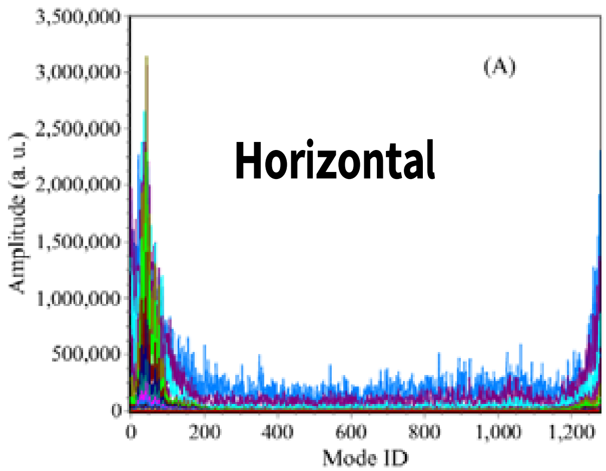
- **Rather broader unstable modes that reflect the cloud distribution**
  - Higher modes : natural electron clouds in the drift space region.
  - Lower modes : electron clouds near the chamber surface due to enough solenoidal field.
- **Growth rate of the unstable modes have relation to the electron cloud situation**
  - Intermediate additional solenoidal filed: worst growth rate
  - No solenoidal field and enough solenoidal field : similar growth rate. Adding external field might suppress the vertical beam size blowup but not suppressing the coupled-bunch instabilities.

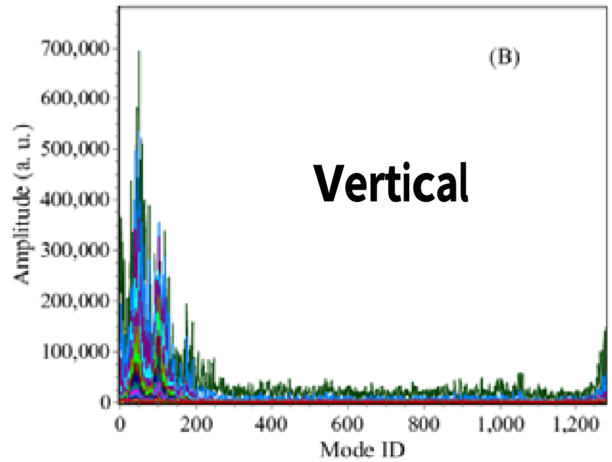
Unstable modes with a full field and without a solenoid field at KEKB LER





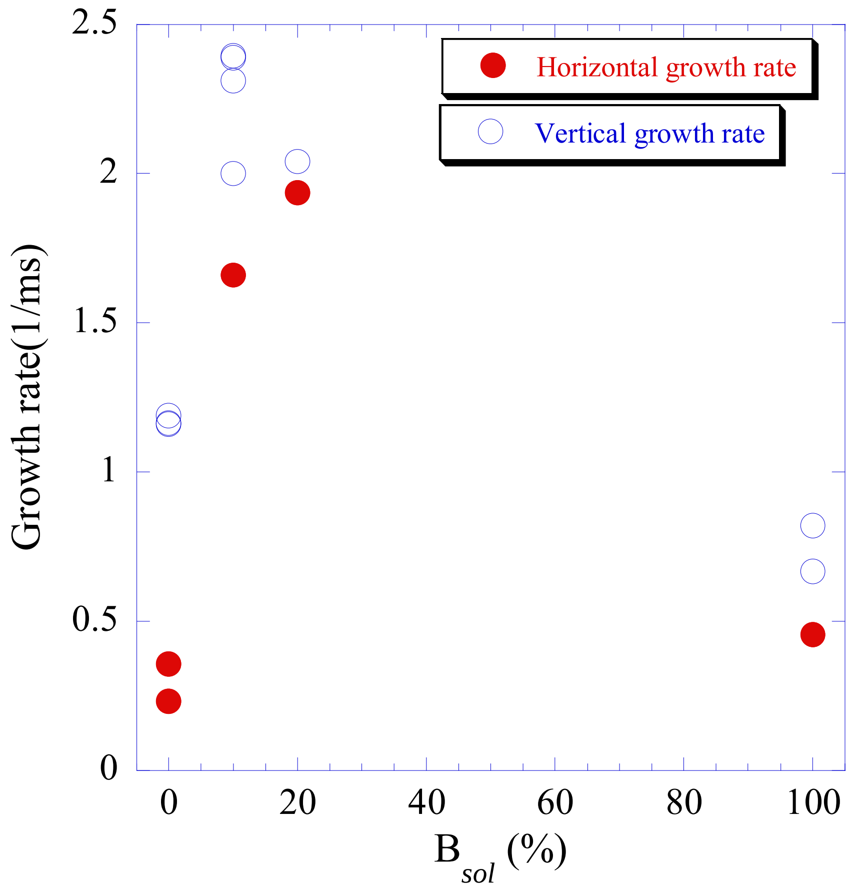
Unstable modes without a solenoid field (Bsol=0% Lsol=0%)





Unstable modes with a full solenoid field (Bsol=100%, Lsol=100%)

Growth rate vs B_{sol}



A large enhancement of the growth rate for both the horizontal and vertical planes are seen at lower solenoid fields.

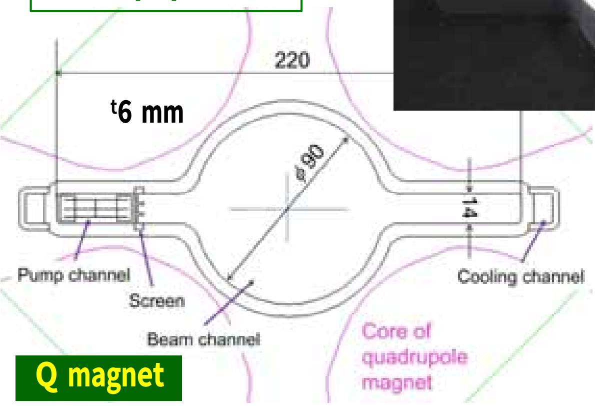
The growth rates with a full solenoid field are almost the same as the zero solenoid field for the horizontal plane, or slightly lower for the vertical plane.

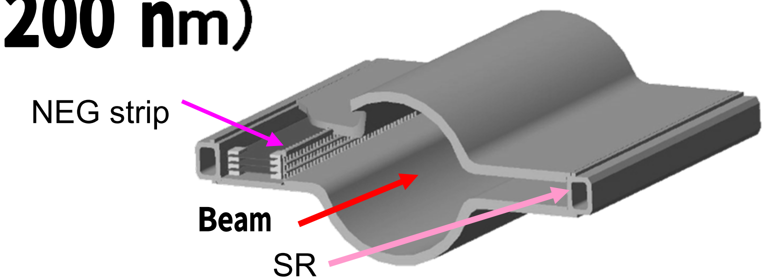
Insufficient solenoid field makes the coupled-bunch situation much worse than no-solenoid case!

Mitigation for SuperKEKB

- **Replace most of the LER vacuum chambers with antechamber made of aluminum alloy with TiN coating (thickness of around 200 nm)**

Conductance:
~ 88 l/s/m



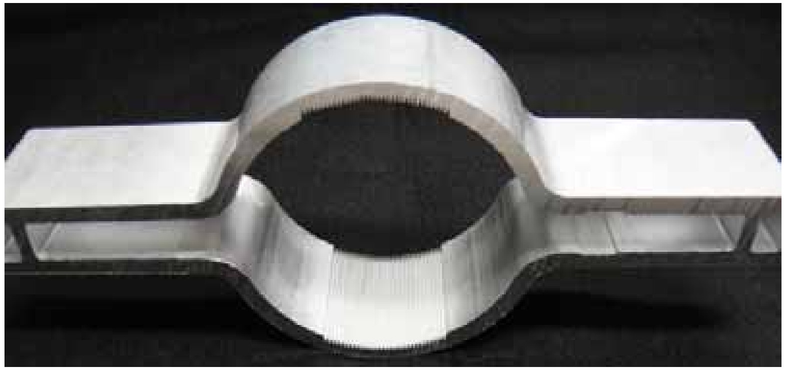


Ref. Y. Suetsugu's talk

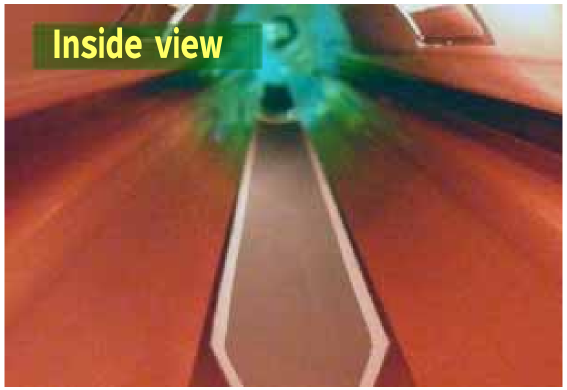
Mitigation for SuperKEKB (cont.)

- **Grooved surface for bending magnet section**

Valley ：R0.1~0.12
Top ：R0.15
Angle：18~18.3 °



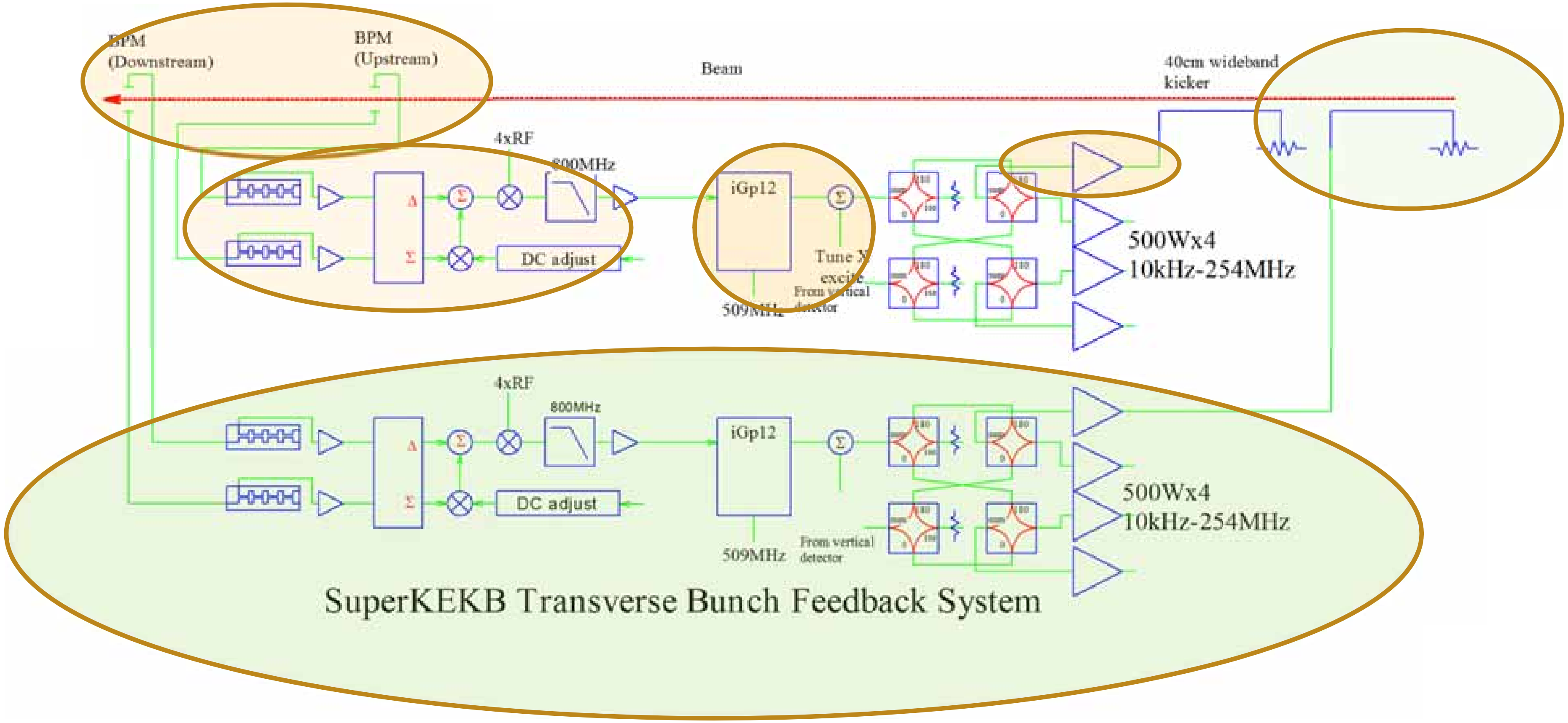
- **Clearing electrodes for wiggler section**



Max 1kV/100mA

Ref. Y. Suetsugu's talk

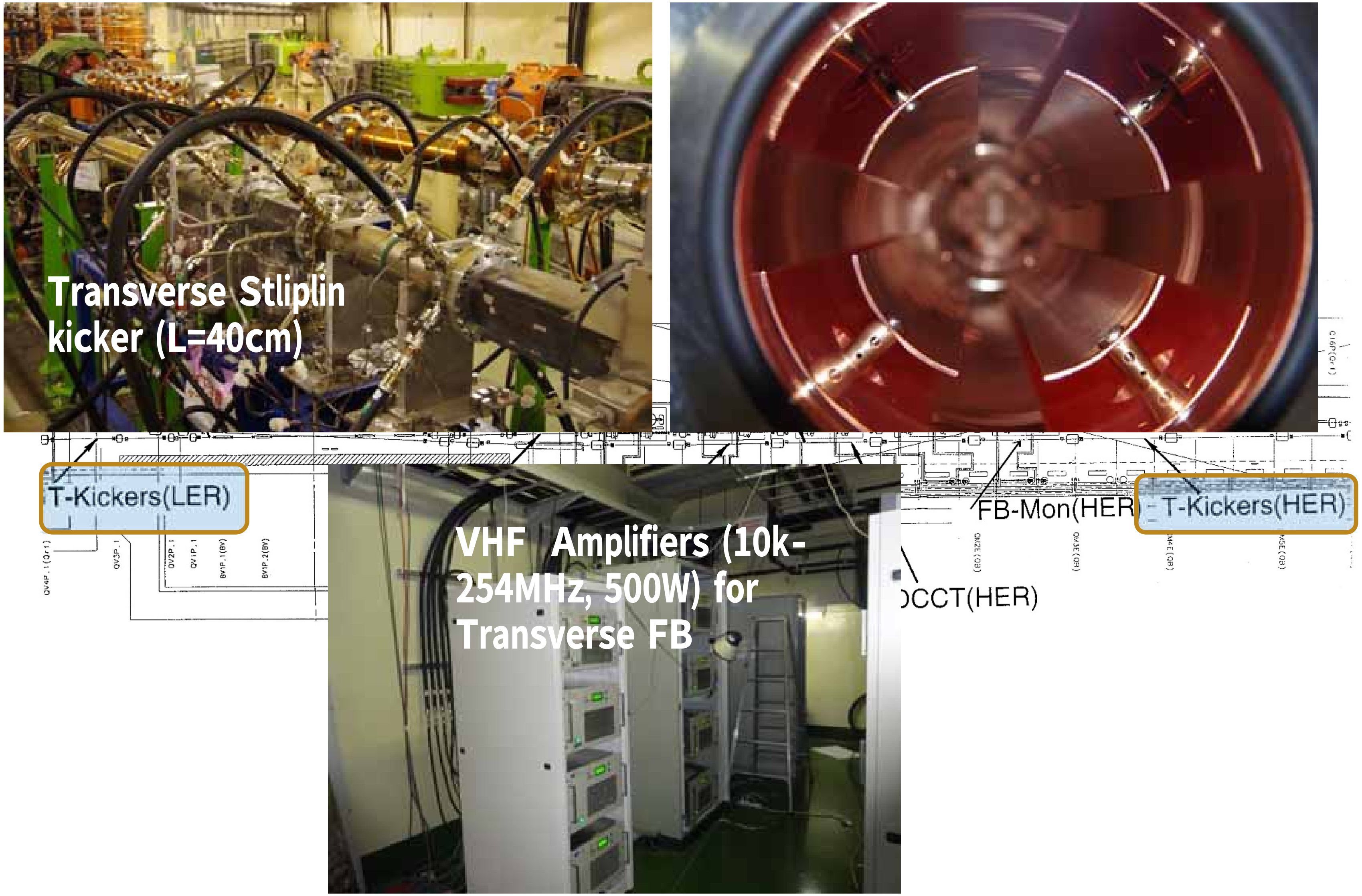
SuperKEKB Transverse FB systems



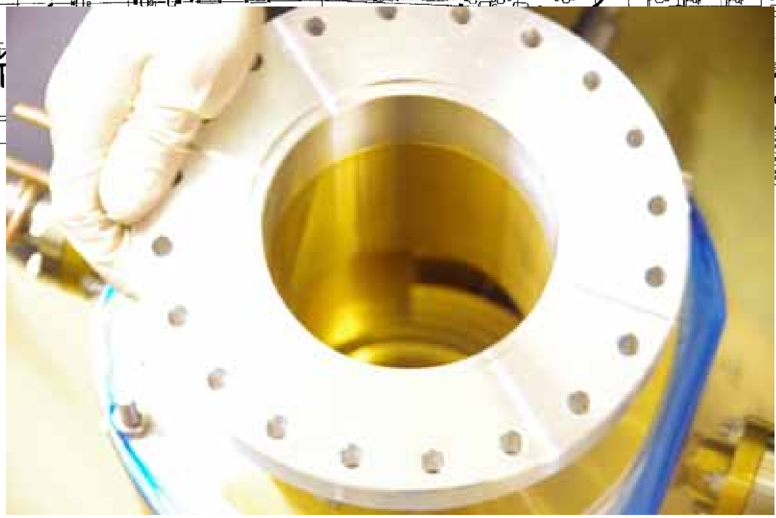
Collaborating SLAC(US-Japan) and INFN-LNF(KEK-LNF)

Bunch feedback components

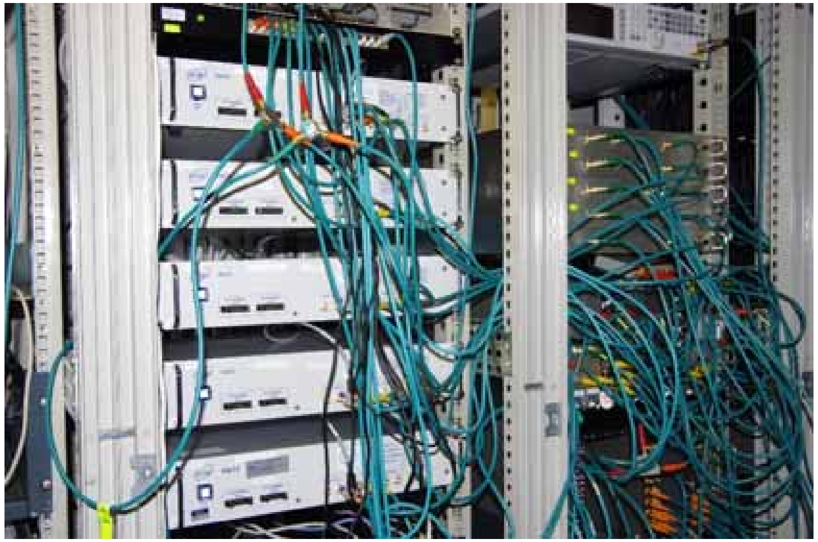
Bunch feedback components

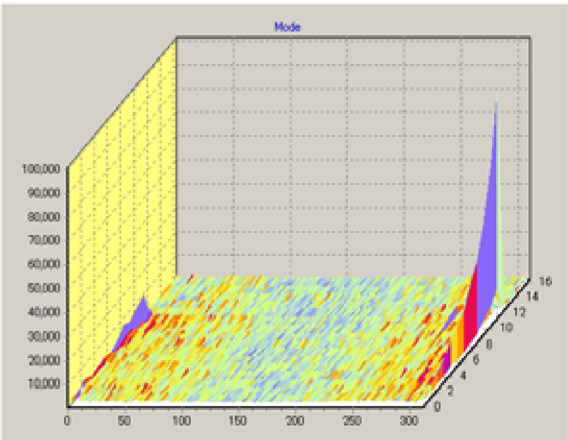


Bunch feedback components



iGp12 digital feedback filter





- **Successor of iGp digital filters developed under US-Japan collaboration with SLAC.**
  - 12bit ADC/DAC
  - 10 – 20 tap FIR filter
  - 12MB memory to analyze instabilities
- **10 iGp12s are used**
  - With larger FPGA (VSX95T)
  - (2 with normal FPGA (VSX50T) for DR)
- **Single bunch excitation using PLL**

Commissioning stages

- Phase-1 (Feb 2016-Jun 2016)
  - Without Belle-II detector (with Beast test detector)
  - Without superconducting final quads
  - Without collision
  - Without positron damping ring
- Phase 2 (Jan 2018 – Jul 2018)
  - With Belle-II detector and superconducting final quads.
    - Without innermost detector (Pixel, SVD)
  - With positron damping ring
  - Target luminosity : $1x10^{34}$
- Phase 3 (Feb 2019---)
  - Full set Belle2 detector
  - Physics run with target luminosity of $8x10^{35}$

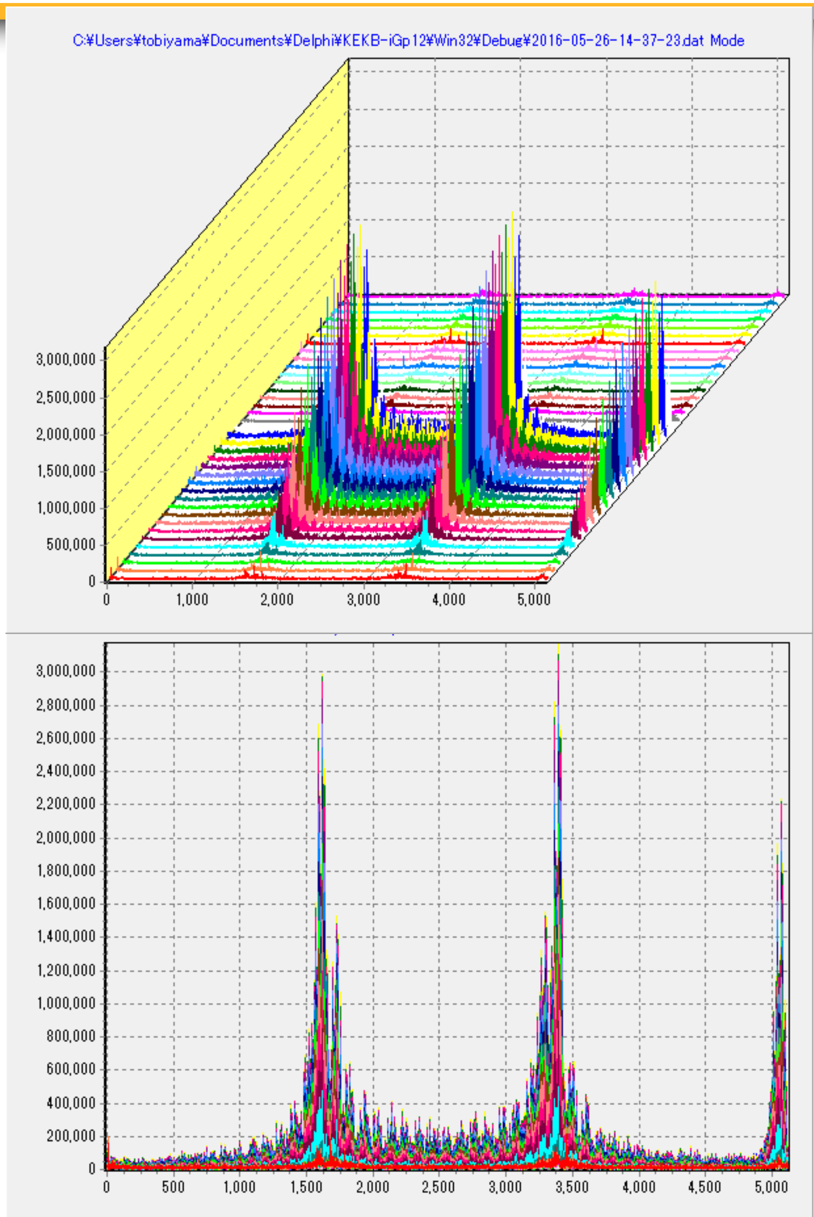
Transient-domain analysis of instabilities

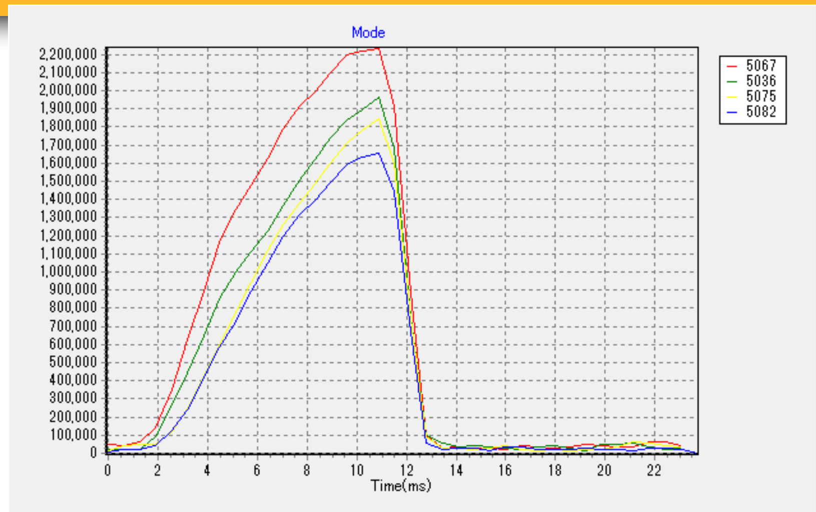
- **Open the transverse (horizontal or vertical) feedback loop (change the feedback gain to zero) and start recording the each bunch position observed in the iGp12 feedback processors.**
  - Maximum recording length (without downsamping) in the iGp12 processor is around 23 ms.
  - Nominal "growth time" is around 4 ms to 10 ms.
- **Close the feedback again before losing beam.**
- **Transfer data (EPICS waveform) to Windows PC to analyze the evolution of unstable modes.**

Mode analysis

- Make FFT of base 5 for the oscillation data of 256 turns (5120 bunches x 256 data points) to obtain the whole spectrum.
- Extract amplitude of the spectrum that corresponds to the betatron frequencies (fb+m x frev), where m represents the mode of the oscillation.
- Align the amplitude by increasing order of the mode-id.
- Repeat the above the procedure while adavancing the starting-point of the data by 128 turns.

G-D example for HER (e- 7GeV)



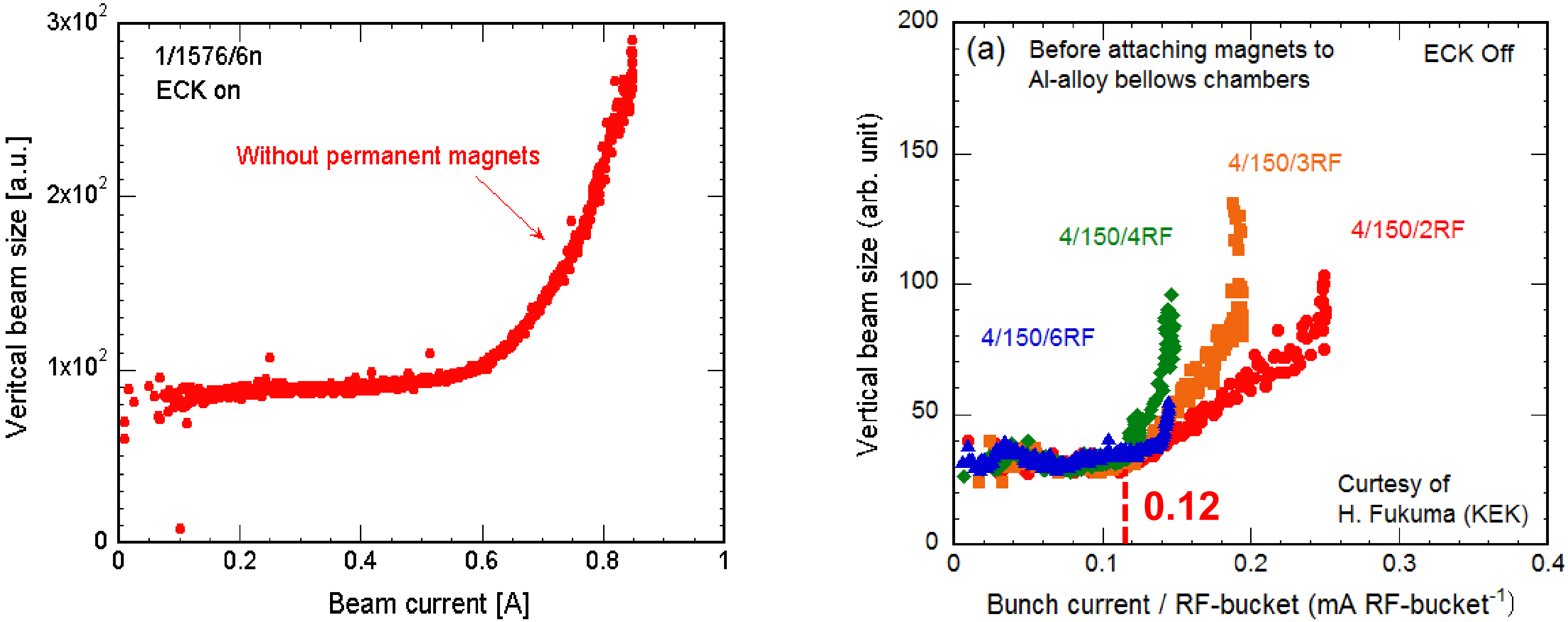


8 Tap FIR filter
732mA, by 3 filling, 0.5mA/bunch
Vertical
Growth~0.9ms
FB damping~0.5ms

During Phase 1 operation

- **Found vertical beam size blowup starting 0.6A with 3.06-RF bucket pattern.**
  - **Starting similar current line density for various filling patterns**

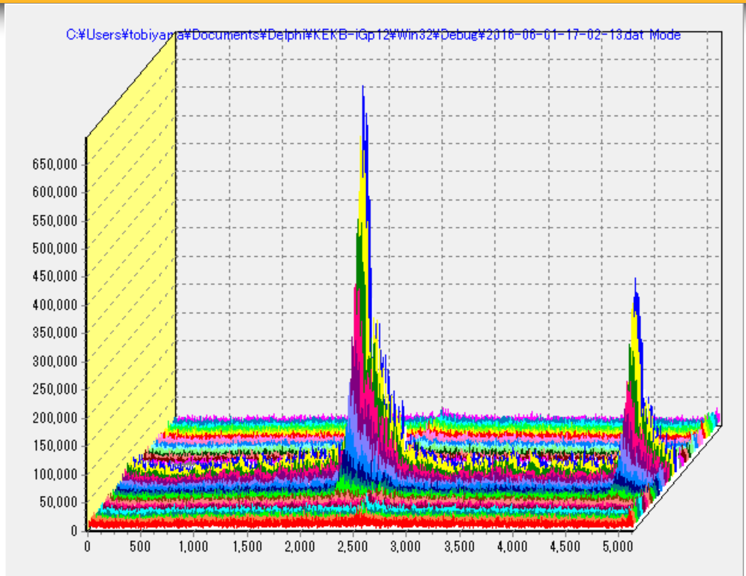
Vertical beam size blowup

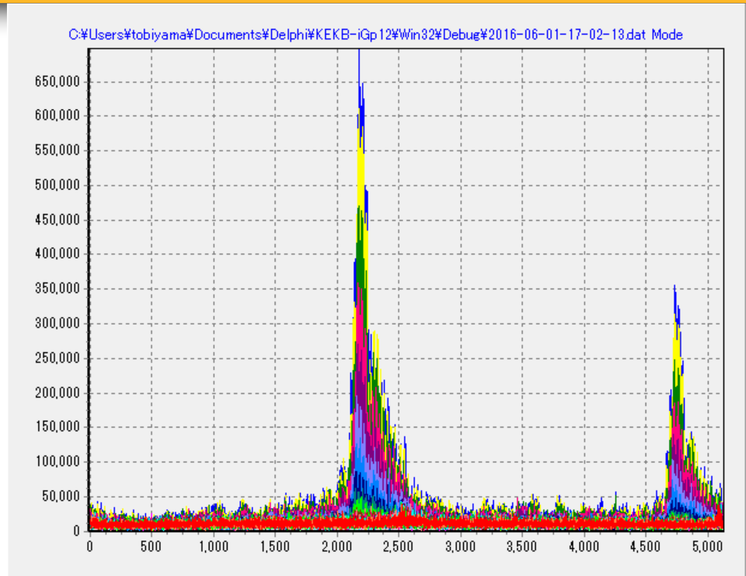


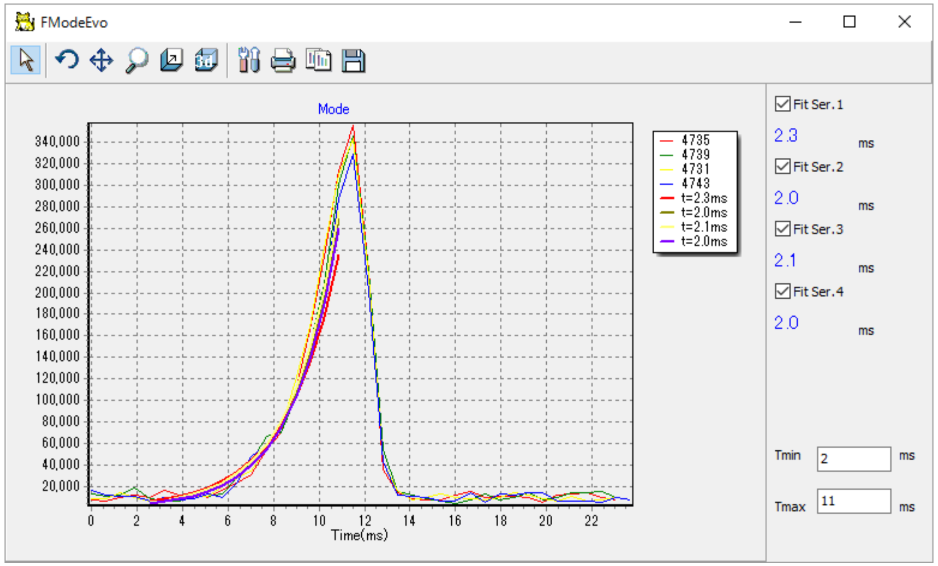
Grow-Damp experiments

- By 2, By 3, By 4, By 6 RF bucket patterns (150 bunches per train), several bunch trains, up to 600 mA.
- Checked G-D behaviors with several beam currents
  - Horizontal and Vertical, upstream and downstream iGp12 processors.
  - For some filling pattern with much faster growth rate, the re-capture of the oscillation was not easy (cause beam abort due to loss at beam collimators), especially for vertical plane.

Example of by 2 vertical (200mA)

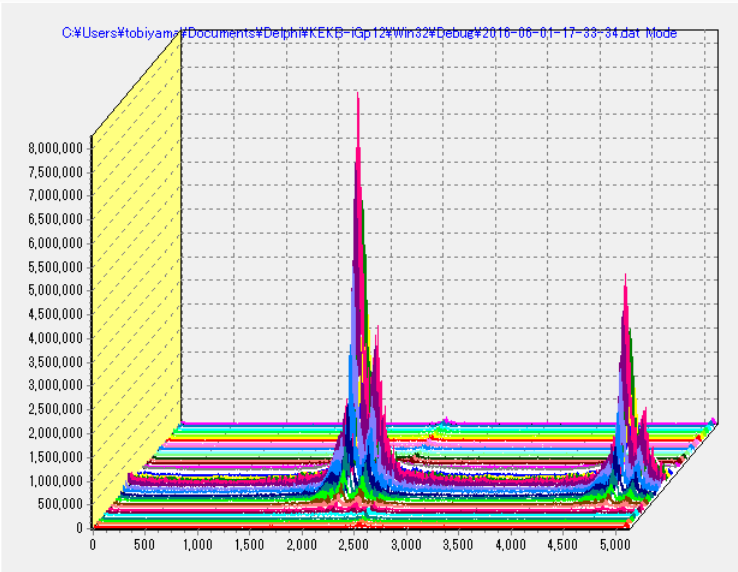


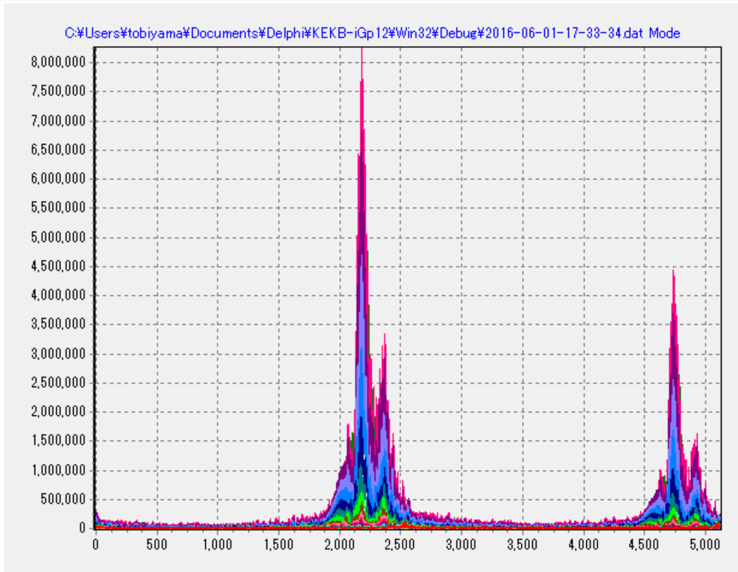


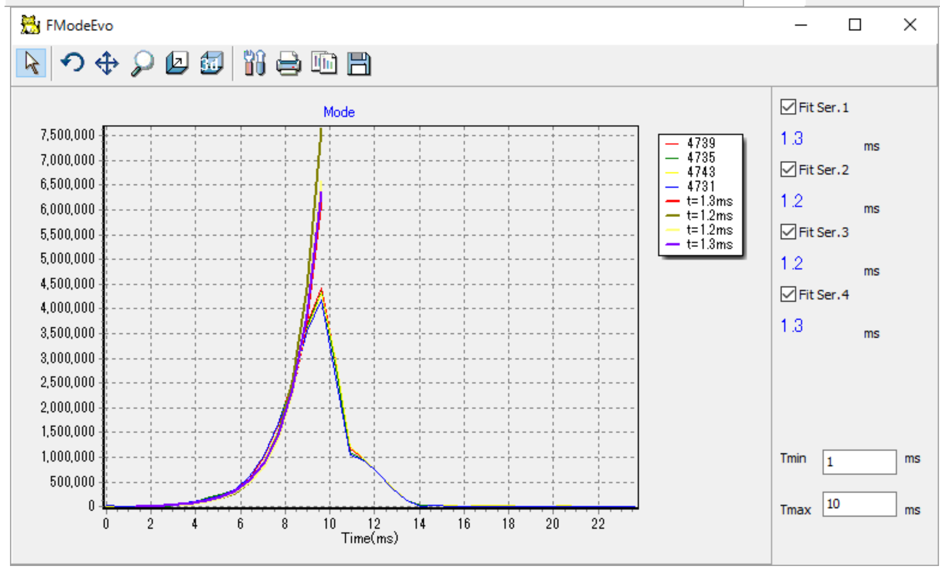


By2 200mA Vertical
Growth time~ 2.0ms
Damp < 0.5ms

By 2 (300mA) vertical

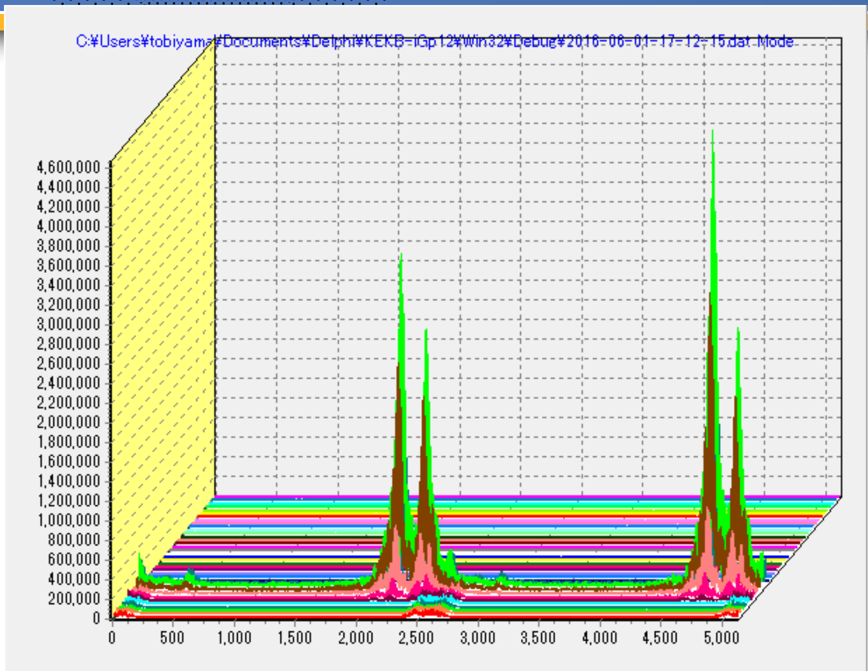


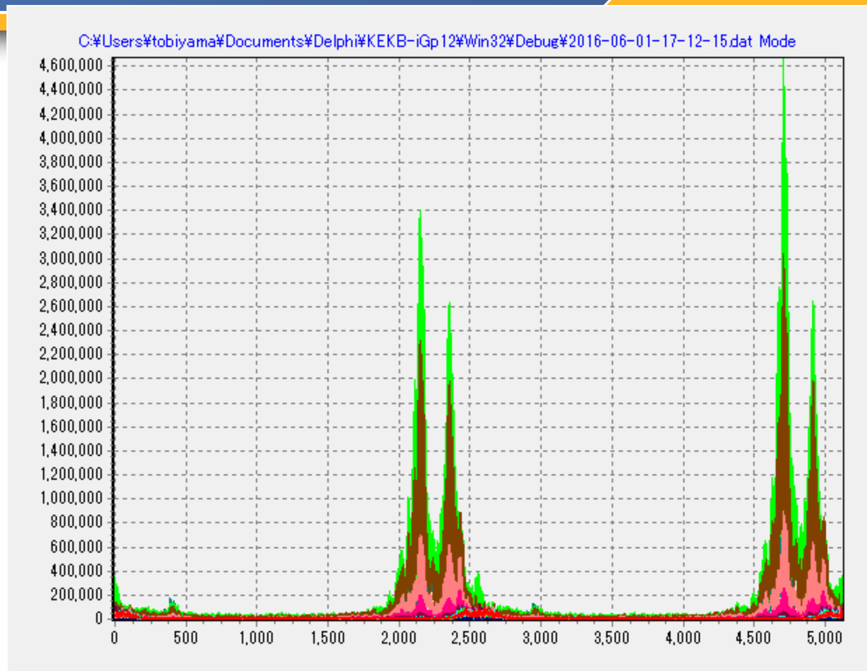


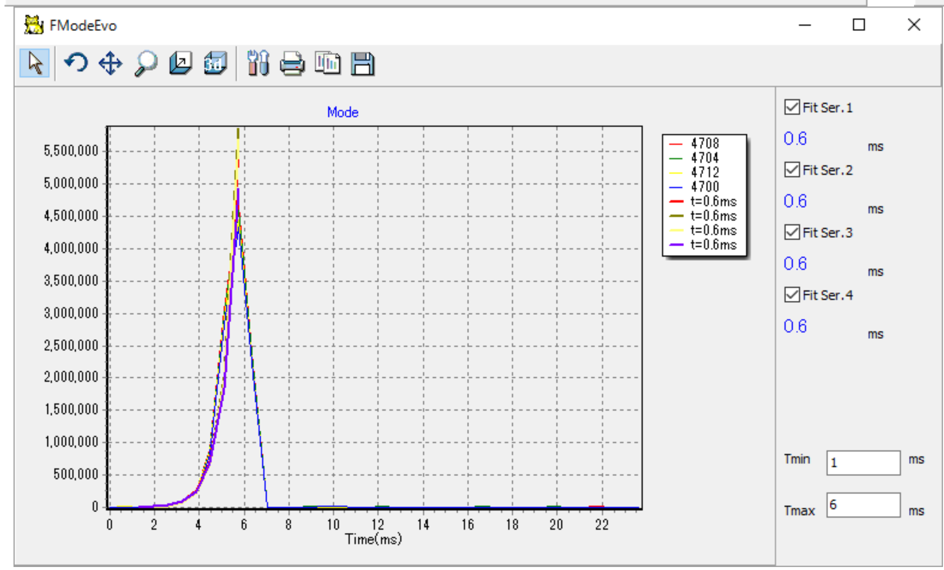


Growth ~ 1.2ms
Damp : unable to recapture

By 2 (300mA) Horizontal

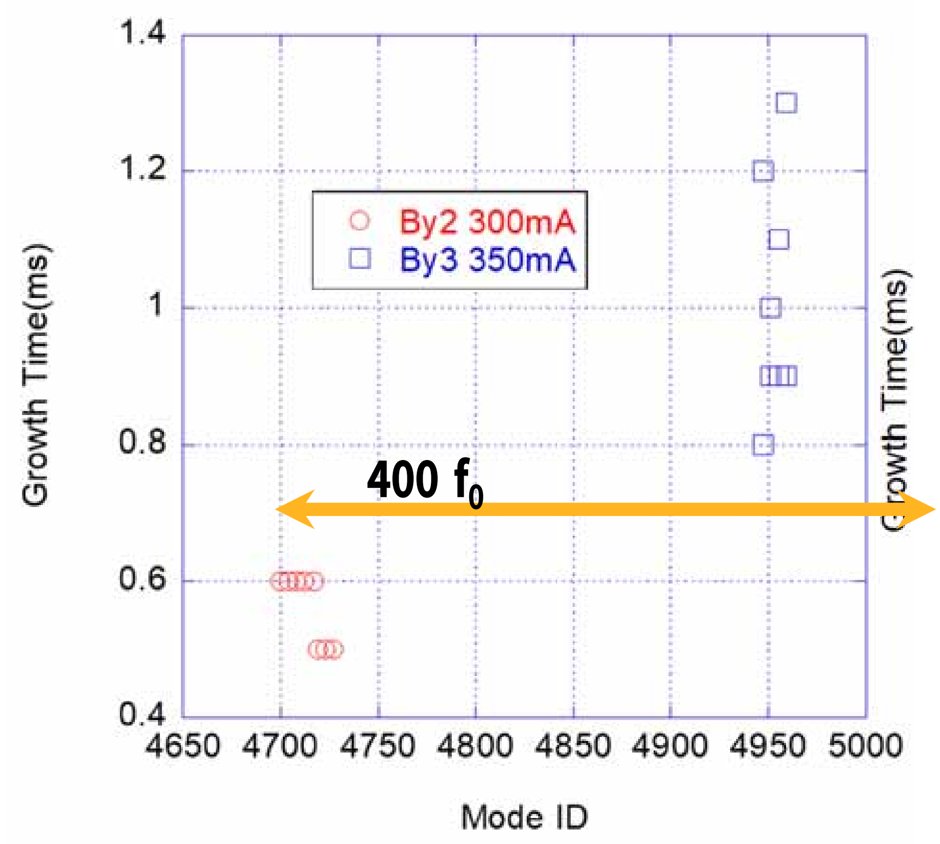


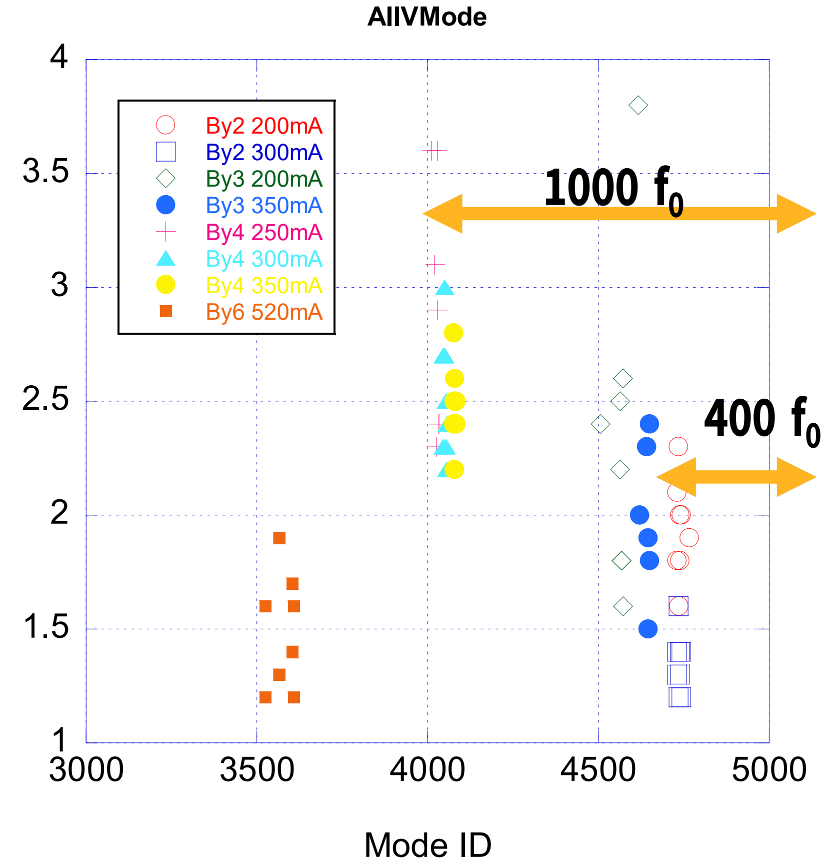




By 2 Horizontal mode
Growth ~ 0.6ms
Damp < 0.5ms

Unstable modes

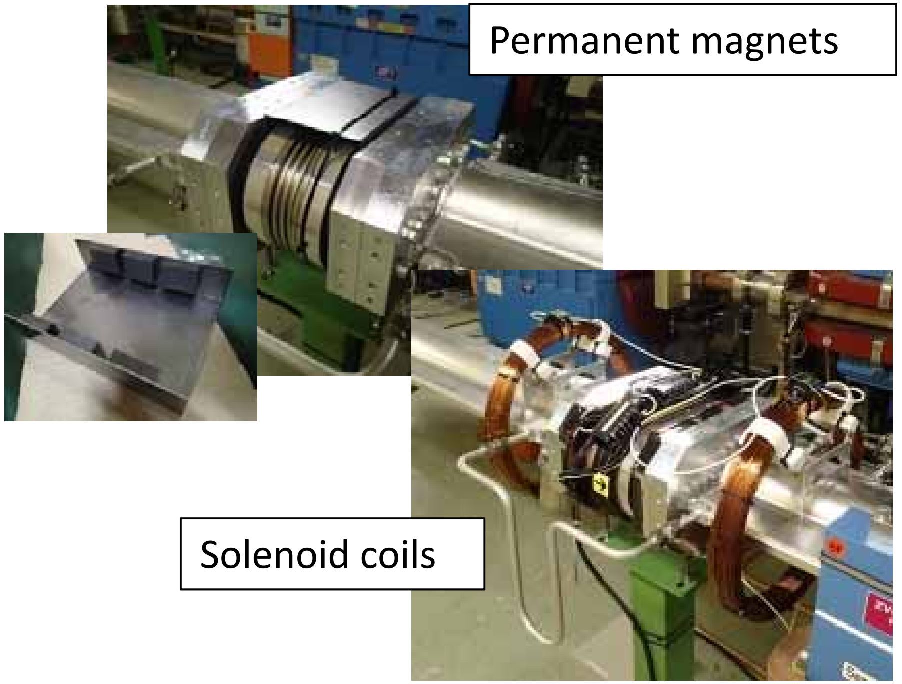


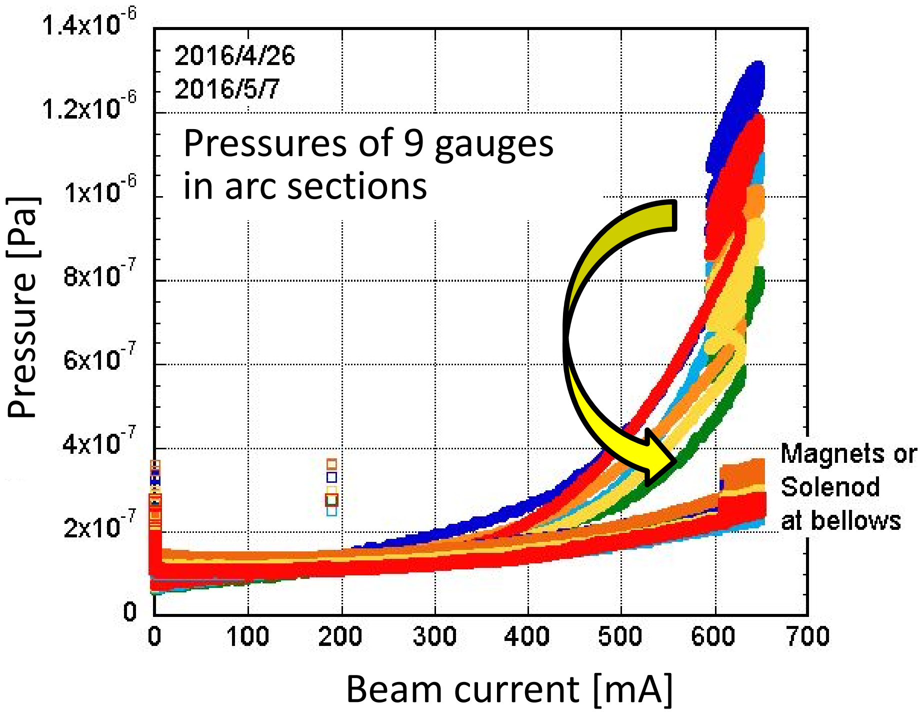


- **Typical signal of coupled bunch instability caused by drift electrons.**

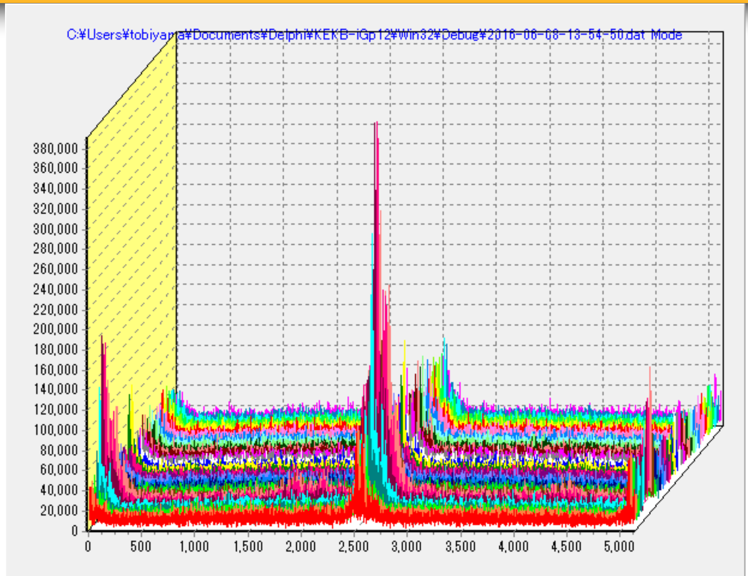
Problems - 1

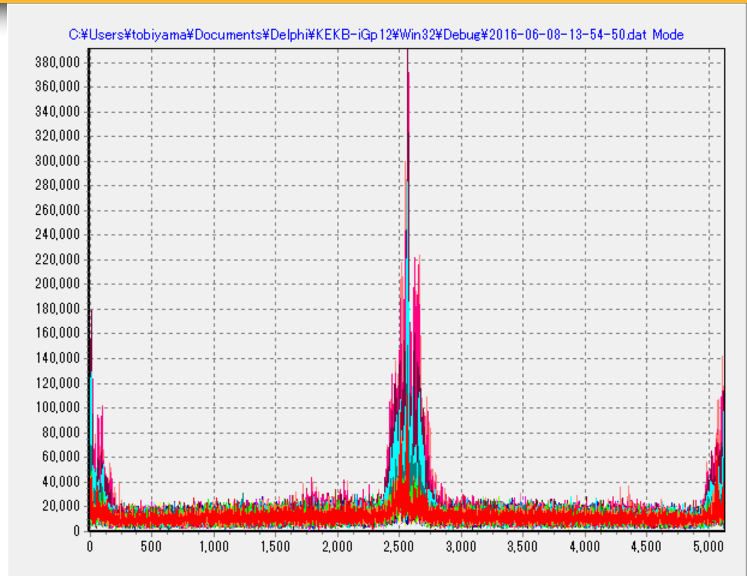
- Non-linear pressure rise against the beam current in LER - 4
- As a test, we applied a magnetic field of axial direction by solenoids or permanent magnets at nine aluminum bellows chambers (~30 m section). The strength is 40 ~ 100 G near the inner wall at the center of bellows.
- As a result, the rate of pressure rise at this section relaxed!

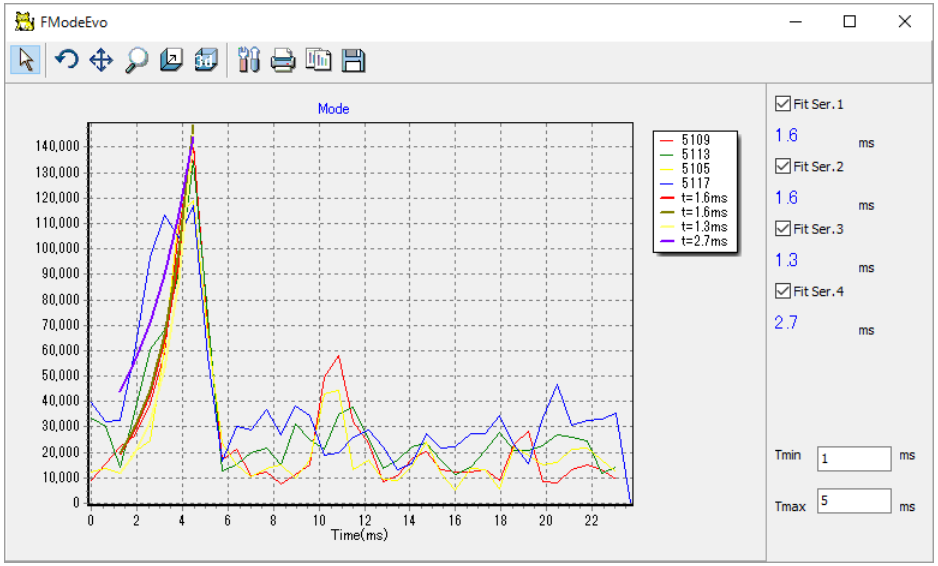




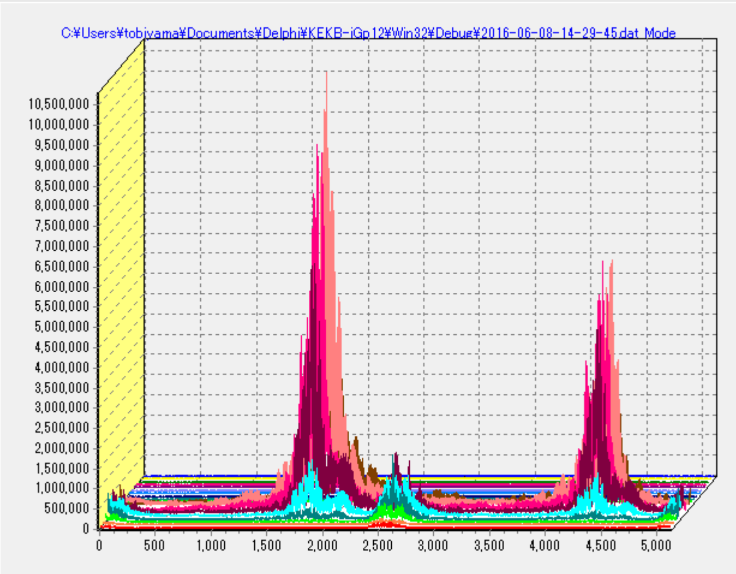
After installing permanent magnets at Bellows sections

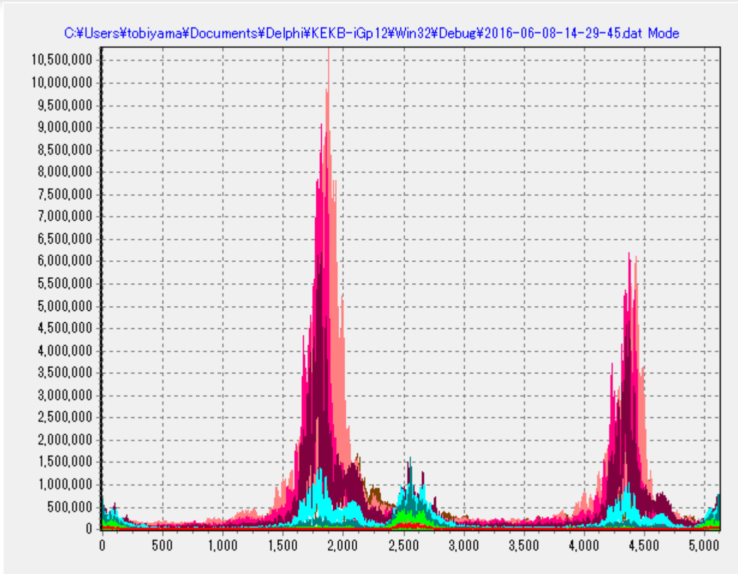


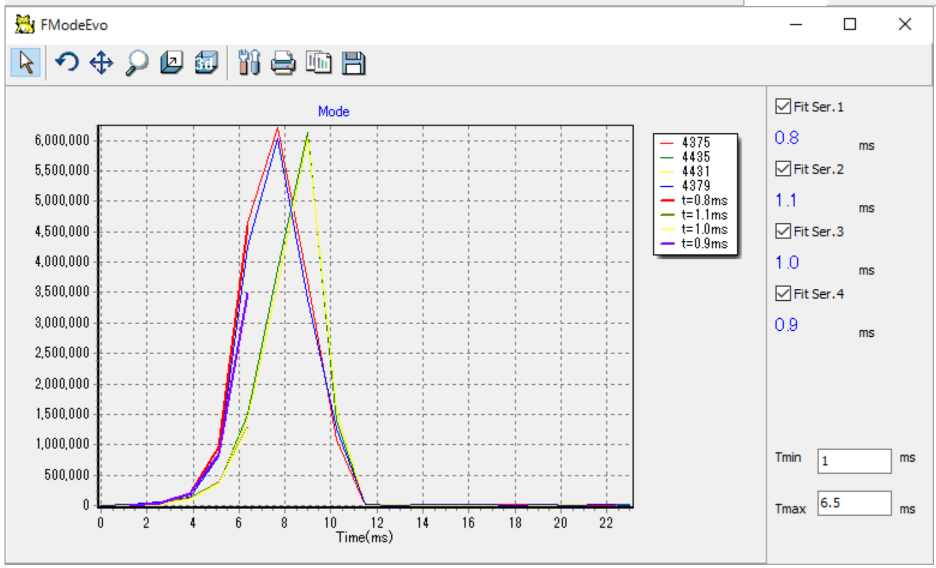




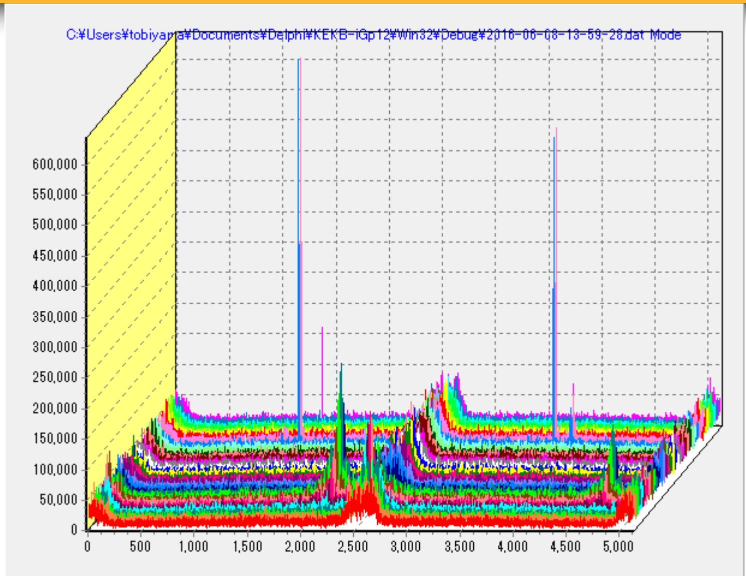
By 2 Vertical 300mA
Growth ~ 1.6ms
Damp <0.5ms

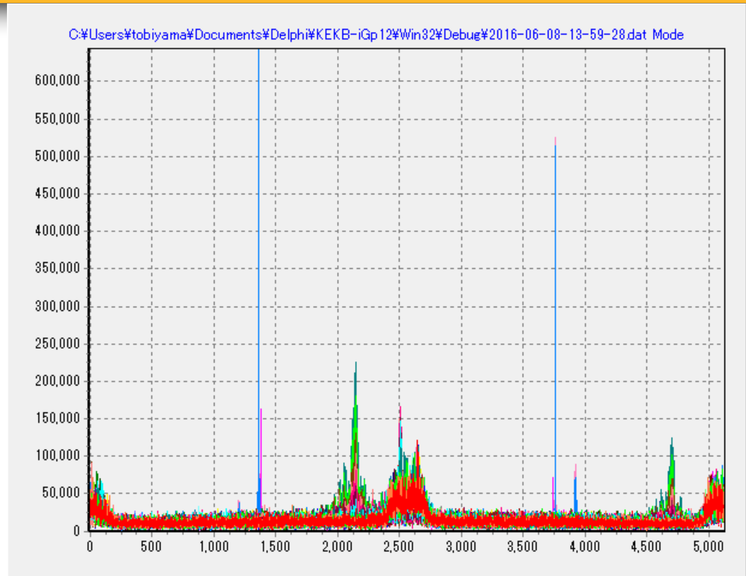


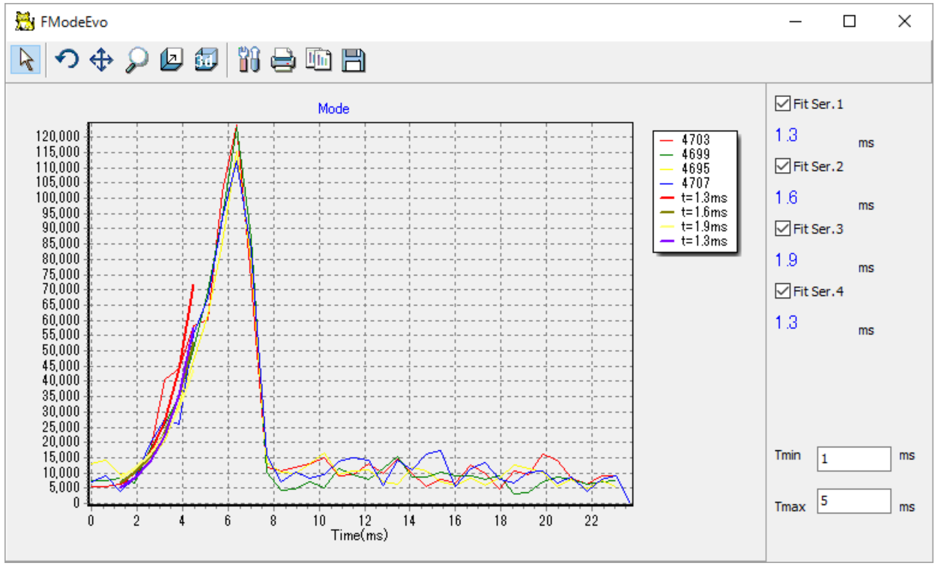




By 2 Vertical 400mA
Grwoth ~ 0.8ms
Damp unable to re-capture

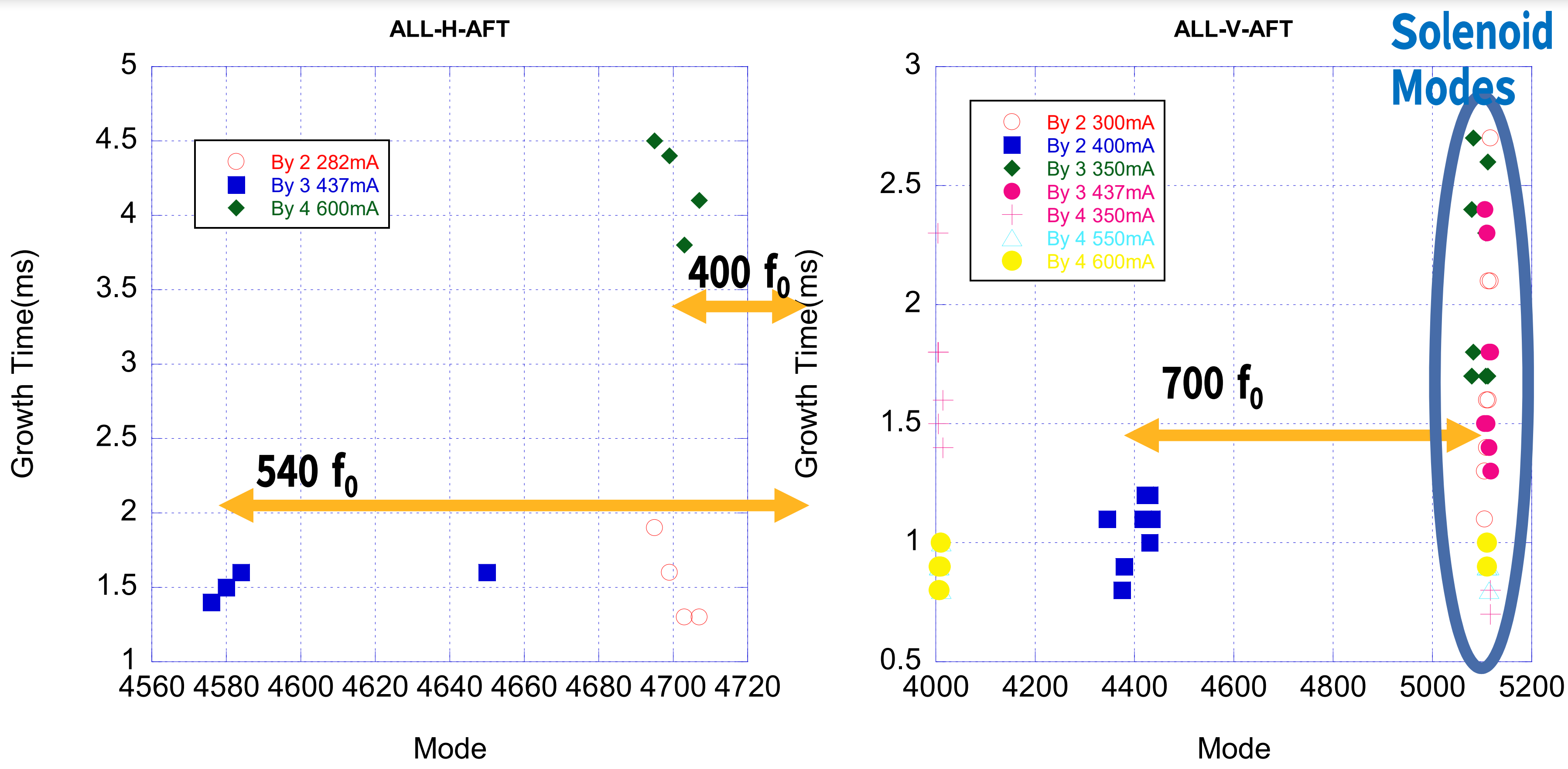






By 2 Horizontal 282mA
Growth ~ 1.3ms
Damp <1ms

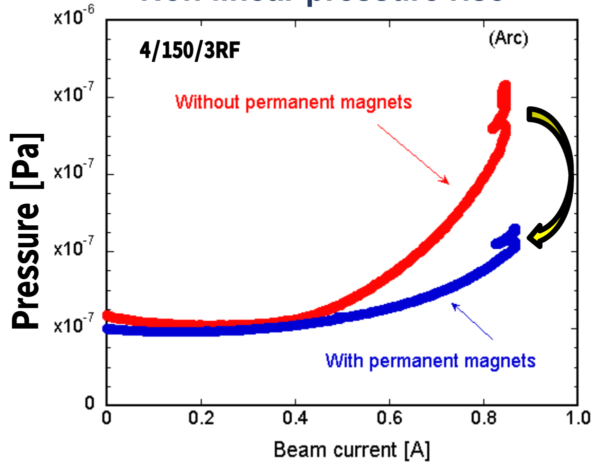
Unstable modes



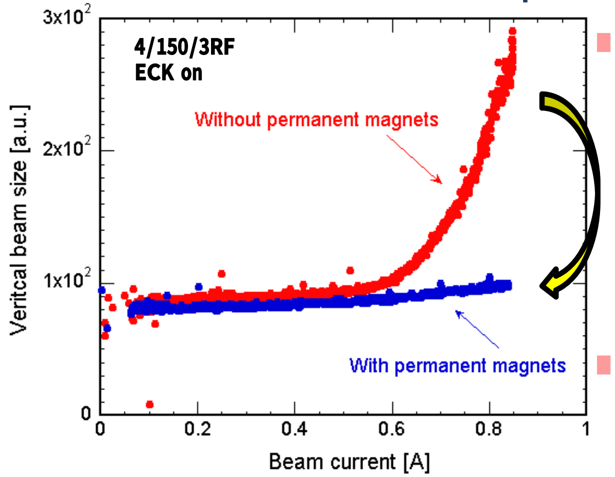
- **Typical modes caused by electrons in solenoid is seen.**
- **Mode seems to change to those of drift origin at higher current.**

Pressure/V-beamsize before/after

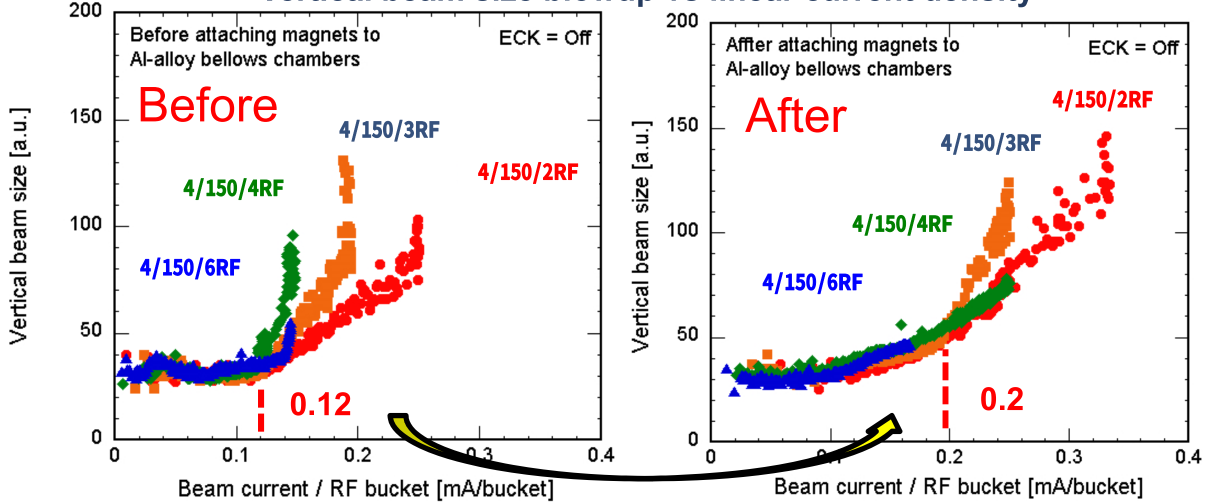
Non linear pressure rise



Vertical beam size blowup



Vertical beam size blowup vs linear current density



- **Nonlinear increase of vacuum pressure has been suppressed.**
- **Vertical blowup of beam size has also been mitigated.**
  - **Threshold line density of blowup has increased up to 1.5 times higher than before.**

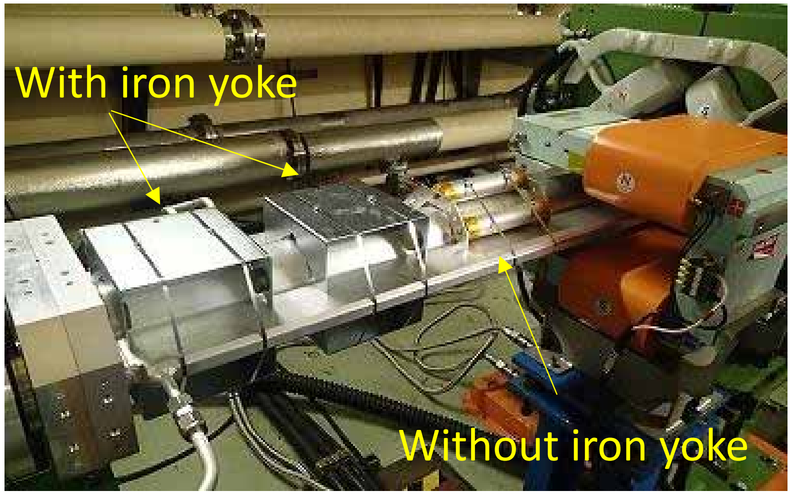
Electron cloud

- As a countermeasure against the EC problem of SEKEB, the units of permanent magnets have been attached to the drift space of the ring.
  - Units with iron yokes (plates) for the space far from electro-magnets (> 250 mm).
  - Units with non-magnetic materials (without iron yokes) for the space near electro-magnets (< 250 mm).

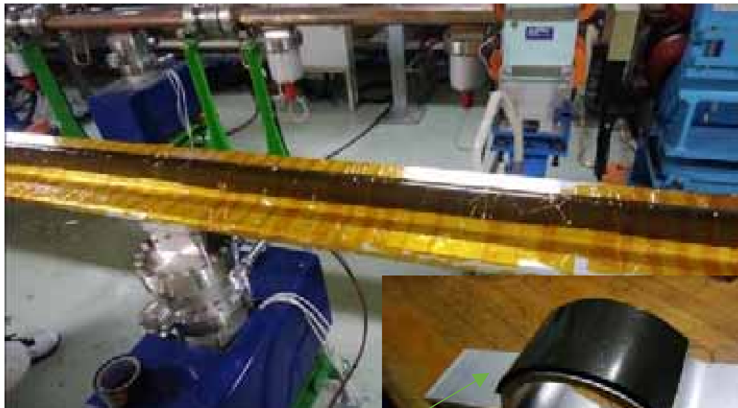
Y. Suetsugu
K. Shibata
T. Ishibashi
S. Terui
M. Shirai

- New permanent-magnet system using neodymium-magnet sheets was developed for narrow spaces. The performance will be checked in Phase-2 commissioning.

Units of permanent magnets at drift space



Neodymium-magnet sheets for test



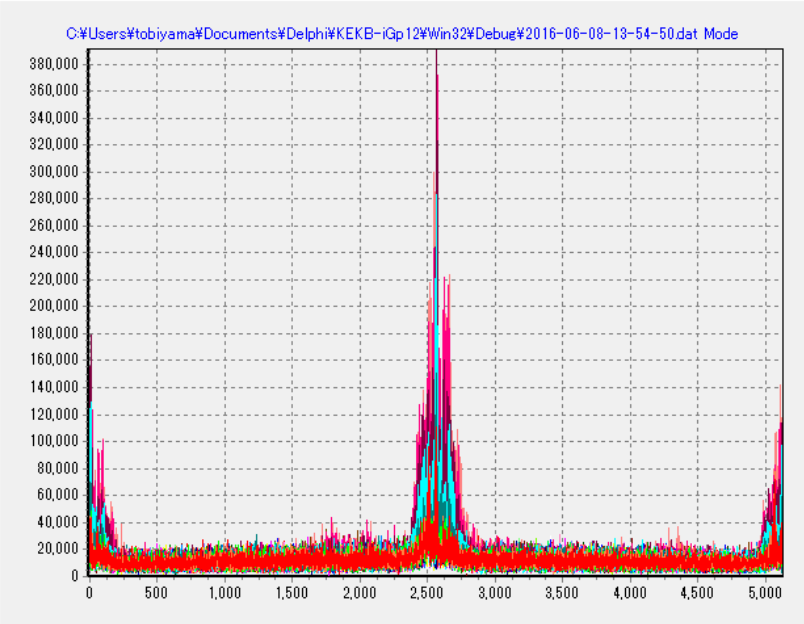
Neodymium-magnet sheets

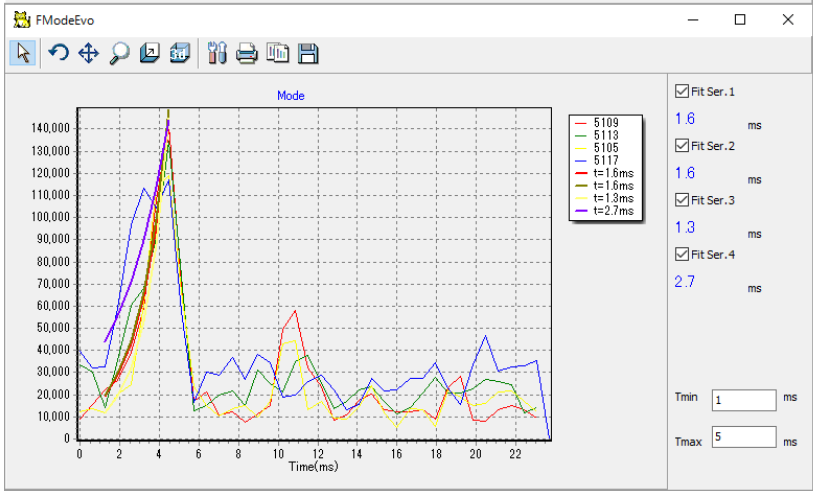
Ref.: Y. Suetsugu et al., Proceedings in IPAC17, Copenhagen, Denmark (2017) p.2925.

Situation of phase 2

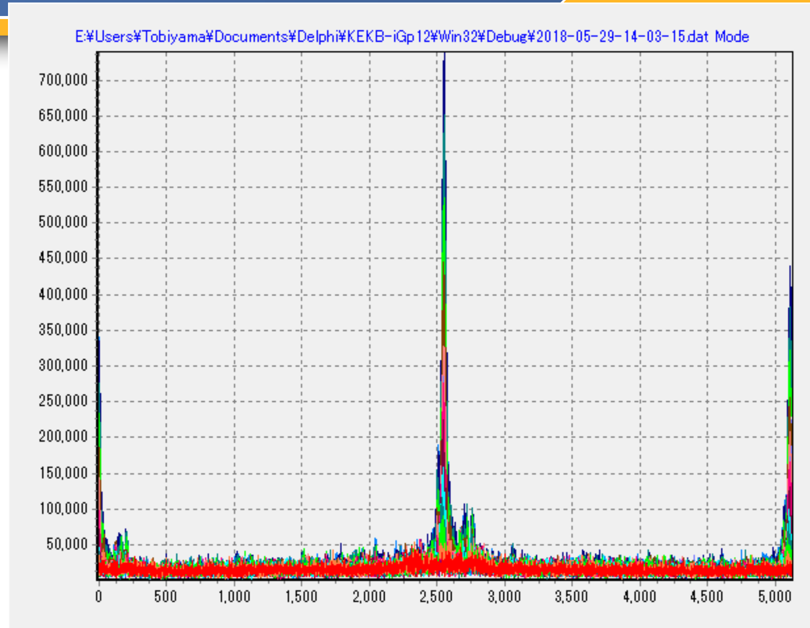
- Preliminary ECE experiment with by 2, by 3, by 4 filling pattern shows
  - Slower growth rate, higher threshold of CBI compared to Phase 1 operation.

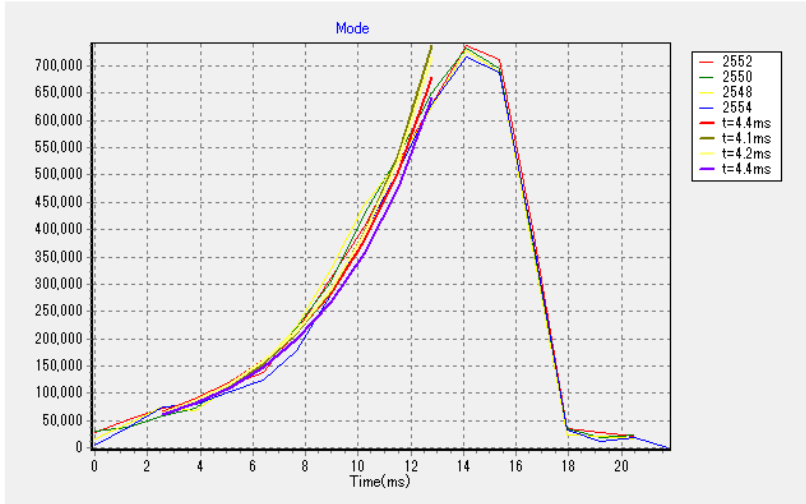
By 2 Vertical plane





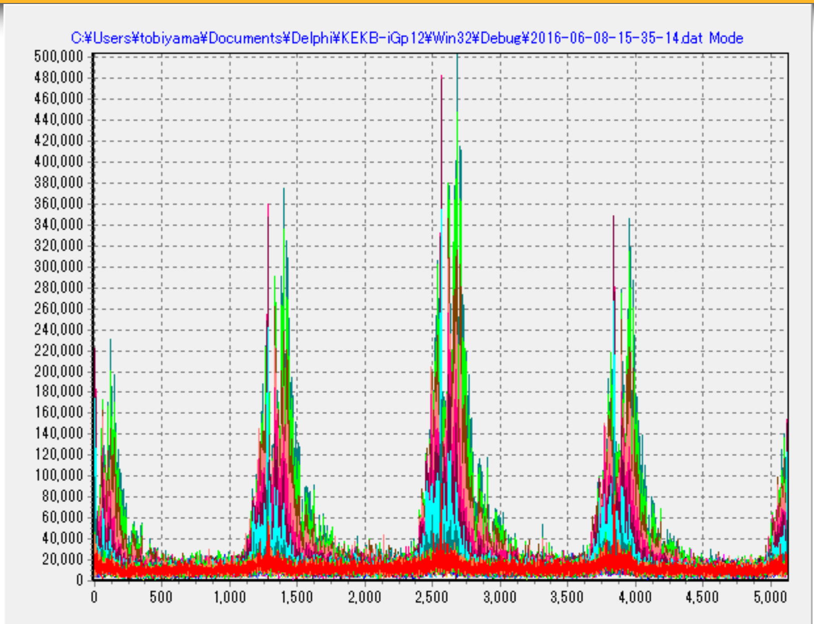
Phase 1 300mA (600 bunches)

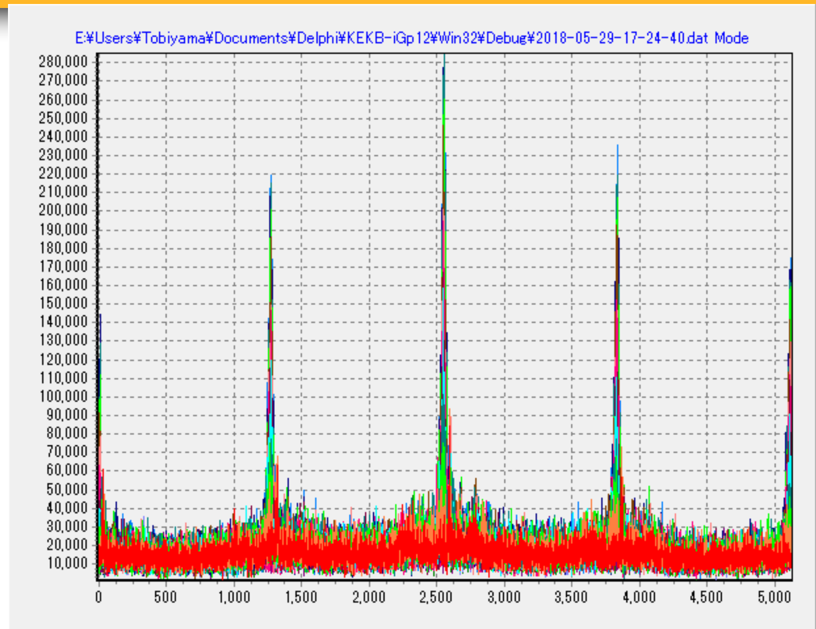


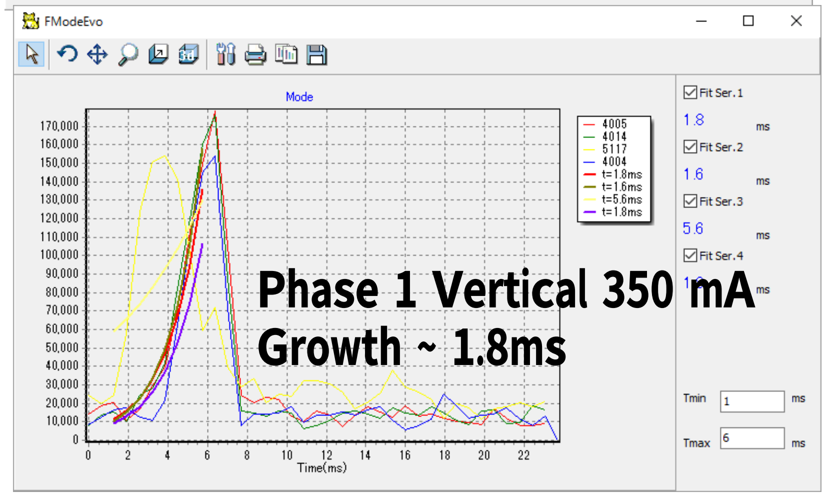


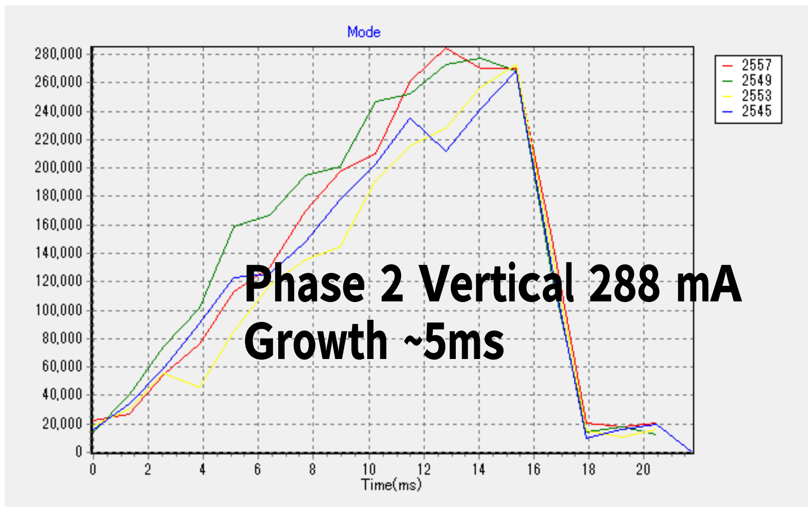
Phase 2 150mA (300 bunches)

By 4 vertical









Summary

- Coupled bunch instability caused by electron cloud effect has been observed in SuperKEKB phase 1 operation, which mainly caused by the Al bellows without TiN coating.
- Mode analysis of transient-domain measurement shows the typical behavior of drift electrons.
- Adding weak solenoid field at bellows section worked well, to suppress increase of vacuum pressure and vertical beam size blowup.
  - Unstable modes has changed to those from solenoid field electrons.
  - For higher beam current, drift electron pattern seems to appear which suggest mitigation at normal drift space might be needed.

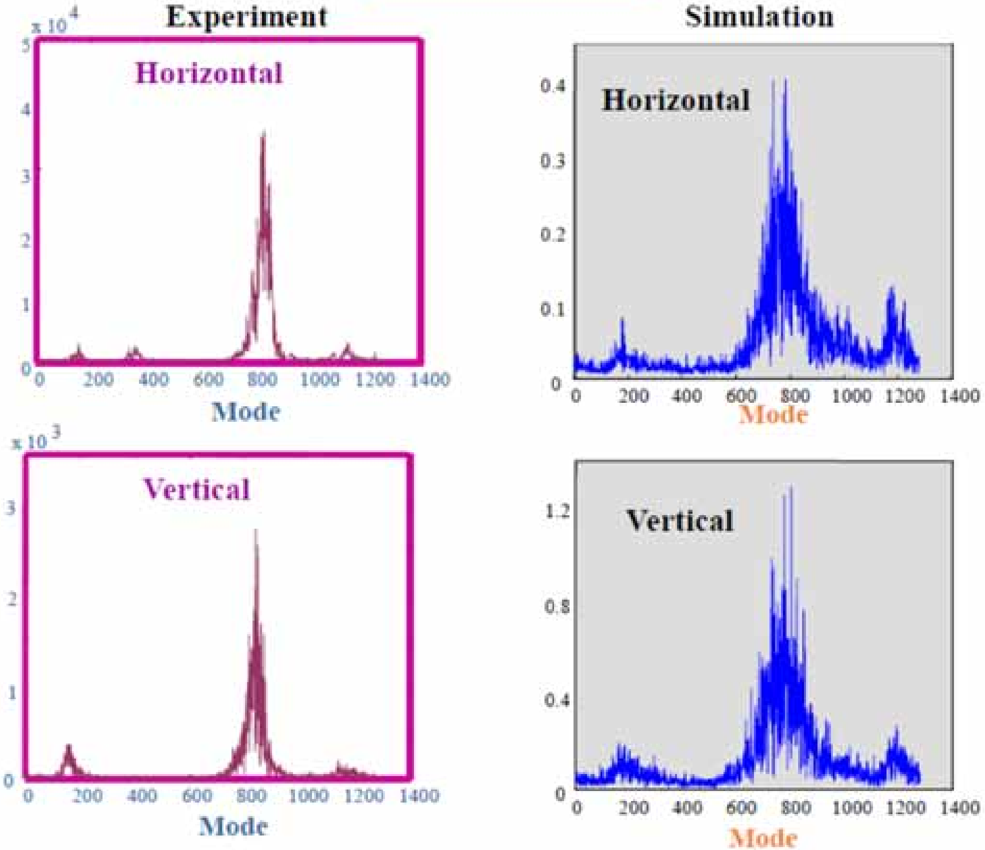
Summary (cont.)

- **From (very) preliminary experiment in Phase 2 operation after adding solenoidal field most of the drift space**
  - Unstable mode pattern has changed
  - Slower growth rate
- **Further experiment with larger beam current (and bunch current)**

backup

KEKB

Solenoid-Off



Su Su Win et al,(EC2002)