Instabilities simulation and observation

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21-th KEKB Accelerator Review Committee

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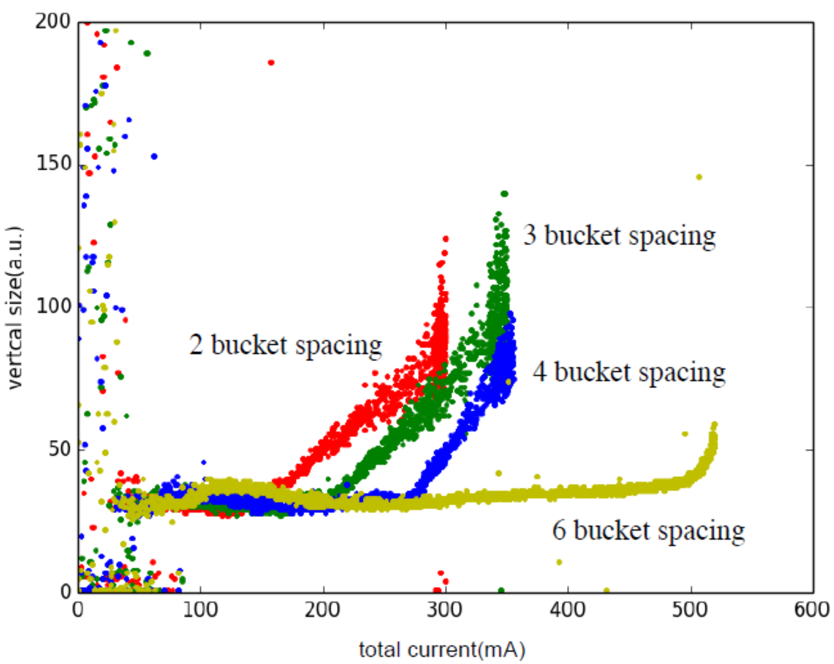
Contents

- Beam size blow-up due to Electron cloud
- Coupled bunch instability due to electron cloud
- Coupled bunch instability in HER
- Tune shift measurement and transverse impedance
- Bunch length measurement

Beam size blow-up in LER

- Beam-size blowup observed in KEKB has been seen in early stage of SuperKEKB commissioning

1. Threshold I~300mA in Apr 19 (Y. Funakoshi)
2. Electron cloud has been monitored at AL chamber w and w/o TiN coating (Y. Suetsugu).
3. Beast study threshold I~600mA, N_{bunch}=1576 in May 17 (Nakayama et al)
4. Systematic study in 1 June (H. Fukuma et al.)
5. Permanent magnets are set at aluminum bellows.(Y. Suetsugu et al.)
6. Systematic studies in 8 July (H. Fukuma et al.)



June 1, 2016

4 train x150 bunches, N_{bunch}=600

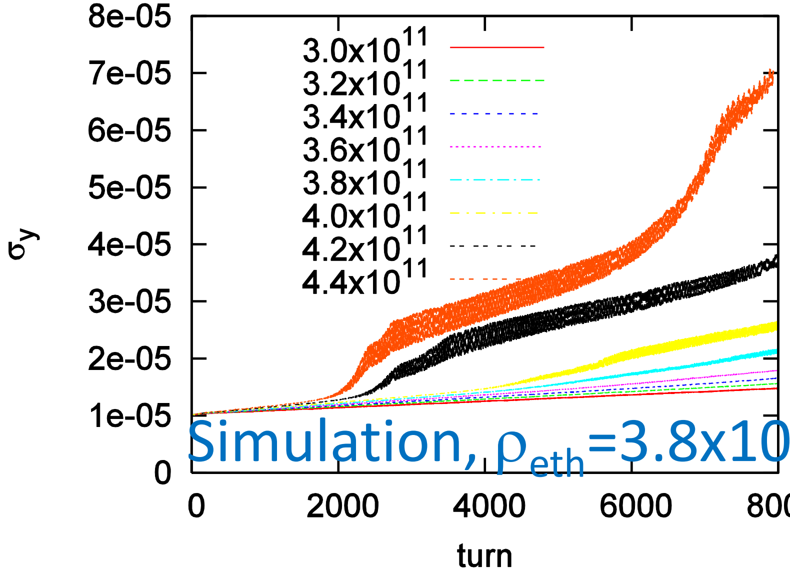
Threshold beam current

160, 200, 260,500 mA for 2, 3, 4, 6 bucket spacing

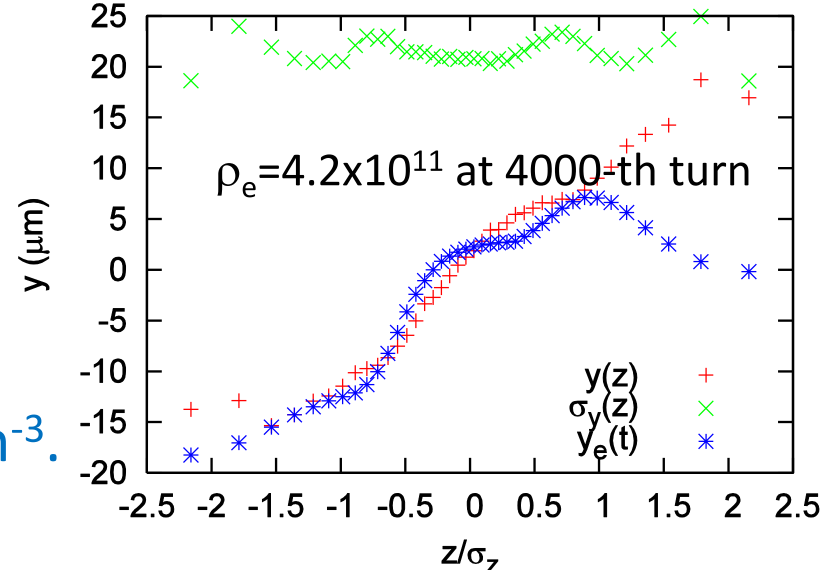
H. Fukuma et al.,

Instability simulation at SuperKEKB design stage

- Using code PEHTS



Simulation, ρ_{eth}=3.8x10^{11} m^{-3}.



$$\rho_{e,th} = \frac{2\gamma\nu_s\omega_e\sigma_z/c}{\sqrt{3}KQr_e\beta_y L} = 2.2\times10^{11}\ \mathrm{m}^{-3},$$

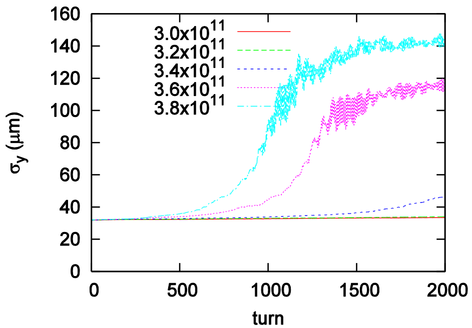
where $K = \omega_e\sigma_z/c = 17$ and $Q = min(\omega_e\sigma_z/c, 10)$

Design target for vacuum system: ρ_e<10^{11} m^{-3} in average of whole ring

Simulation studies using beam study condition

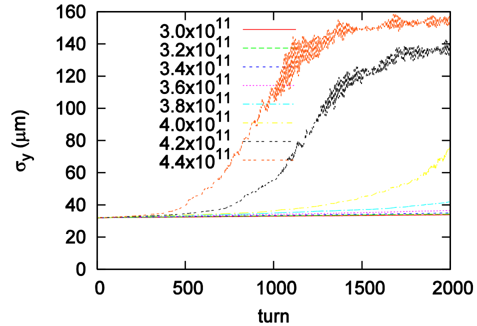
Threshold of the electron density

ε_x=2nm, ε_y=15pm, σ_z=6mm, ν_s=0.019



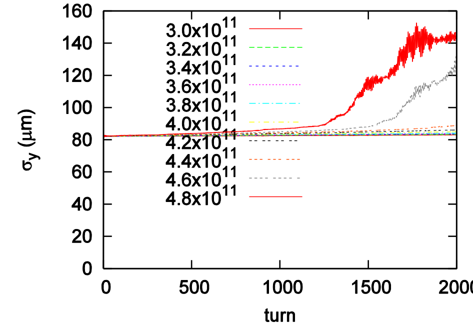
Np=1.6x10^{10}

I_{th}=160mA, 4ns spacing



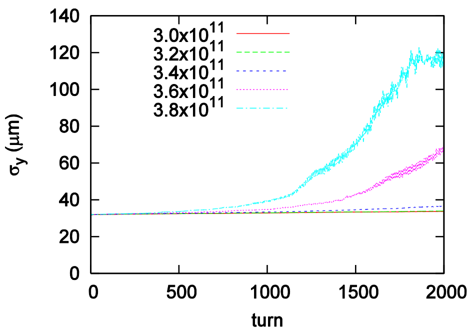
Np=2.7x10^{10}

I_{th}=260mA, 8ns spacing



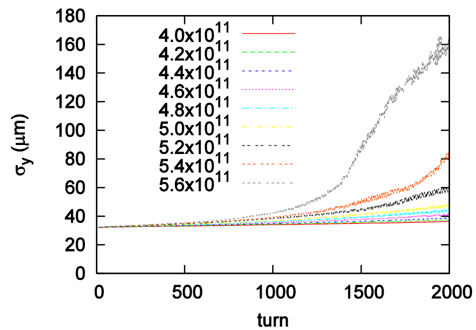
Np=2.1x10^{10},

ε_y=100pm



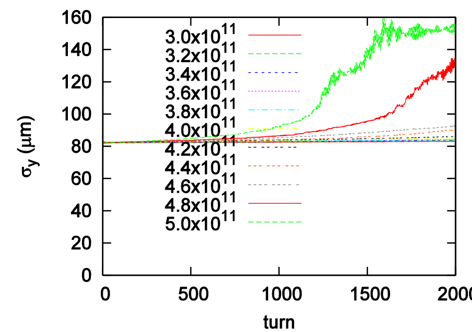
Np=2.1x10^{10}

I_{th}=200mA, 6ns spacing



Np=5.2x10^{10}

I_{th}=500mA, 8ns spacing



Np=2.4x10^{10},

ε_y=100pm

Simulated threshold electron density (condition before solenoid installation)

- N_b=600, ε_x=2nm, ε_y=15pm, σ_z =6mm, ν_s=0.019

spacing	$I_{p,th}$ (mA)	$N_{p,th}$ (10^{10})	$\omega_e/2\pi$ (GHz)	$\omega_e\sigma_z/c$	ρ_{eth} (Q=10) ($10^{11}m^{-3}$)	ρ_{eth} (Q=6) ($10^{11}m^{-3}$)	ρ_{eth} (Simu) ($10^{11}m^{-3}$)
2 (4ns)	160	1.6	61	7.7	1.91	2.45	3.4
3 (6ns)	200	2.1	71	8.9	1.65	2.45	3.4
4 (8ns)	260	2.7	80	10.1	1.47	2.45	3.8
6 (12ns)	500	5.2	111	14.0	1.47	2.45	5.0
3.06	500	2.0	37	5.5	2.89	2.90	4.4
3.06	600	2.4	41	6.0	2.63	2.65	4.4

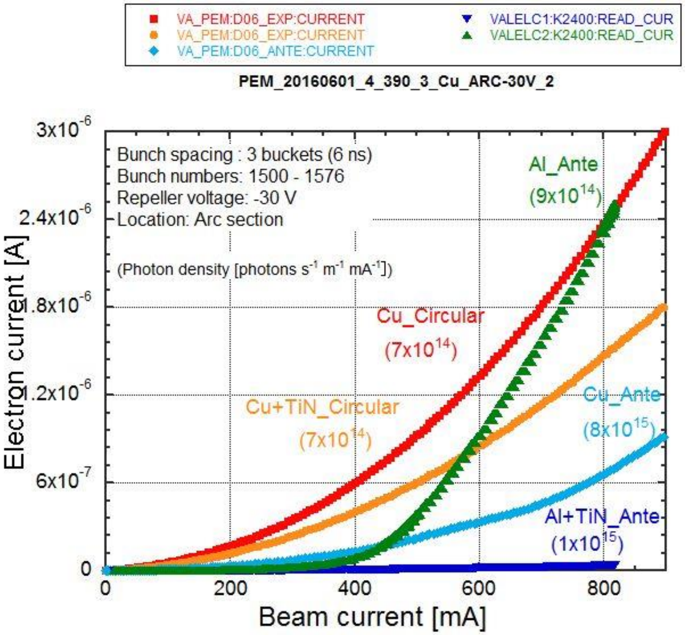
N_b=1576, ε_y=100pm

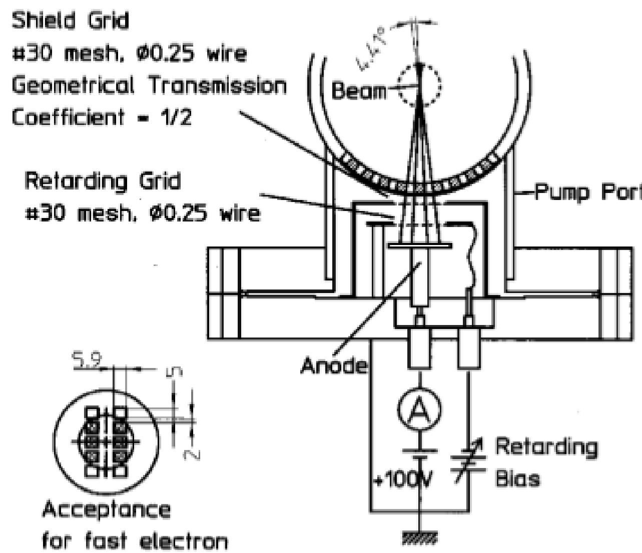
$$\rho_{e,th} = \frac{2\gamma\nu_s\omega_e\sigma_z/c}{\sqrt{3}KQr_0\beta L}$$

$$K = \omega_e\sigma_z/c$$

$$Q = \min(\omega_e\sigma_z/c, 6)$$

Electron cloud measurement

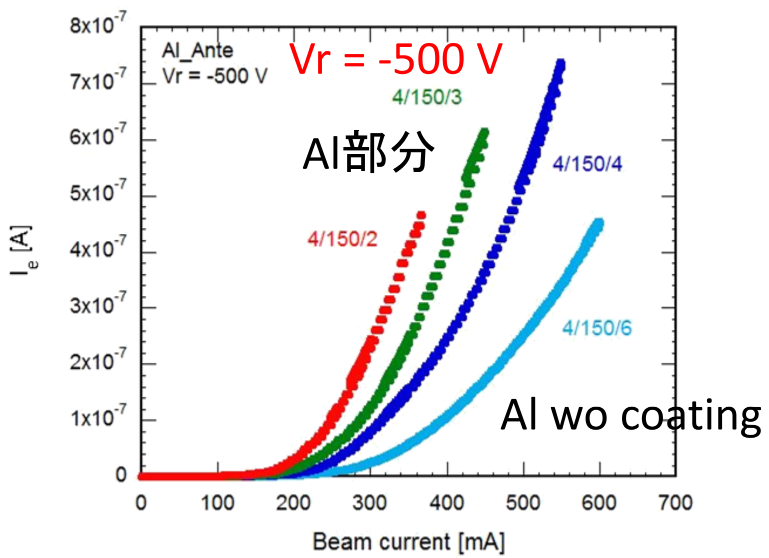


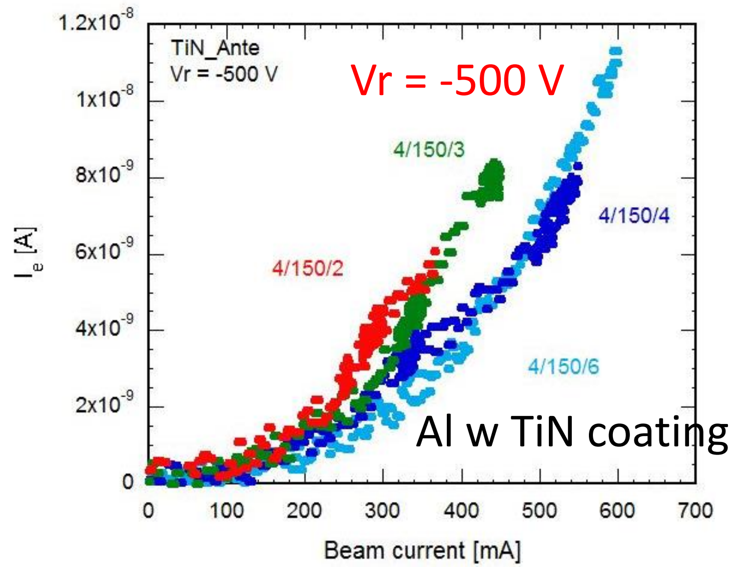


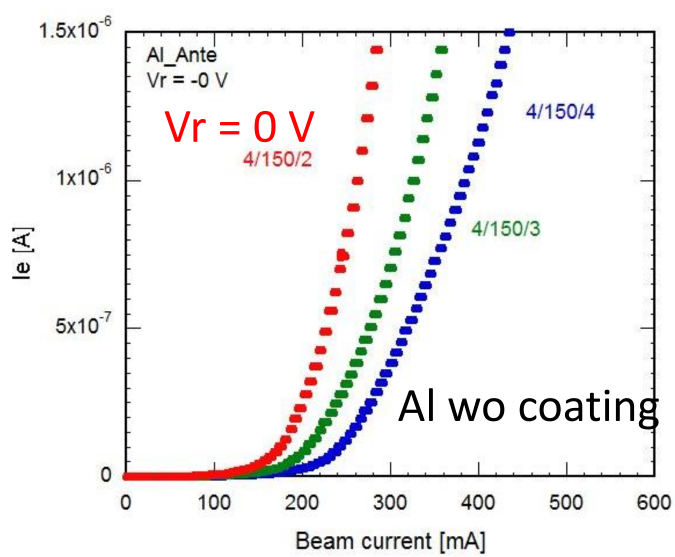
- Retarding bias, V=500V or 0V, select electrons with E>500eV or all, respectively.
- Electron E=500eV, v=1.3x10^{7}m/s. R/v=3.8ns, R=5cm, density can be estimated considering volume with energy gain 500eV from a bunch. 500eV may be critical for 2 (4ns) spacing.
- For V=0V, electron rate production including secondary is detected.

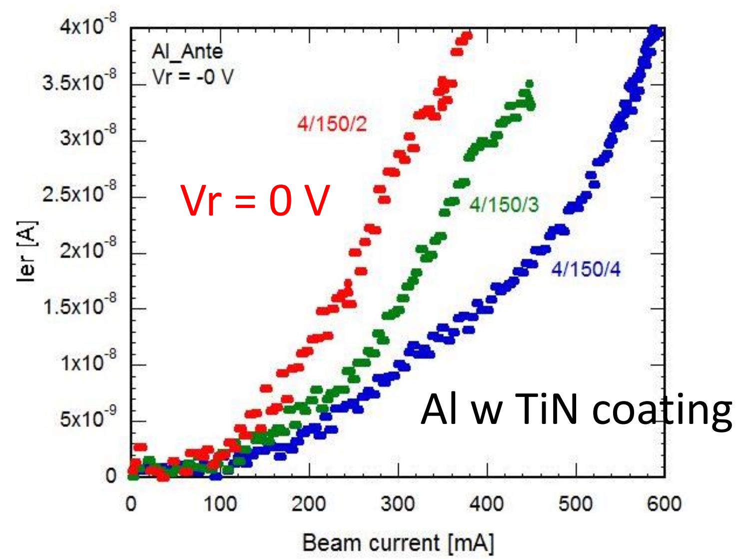
Measured electron current

Y. Suetsugu









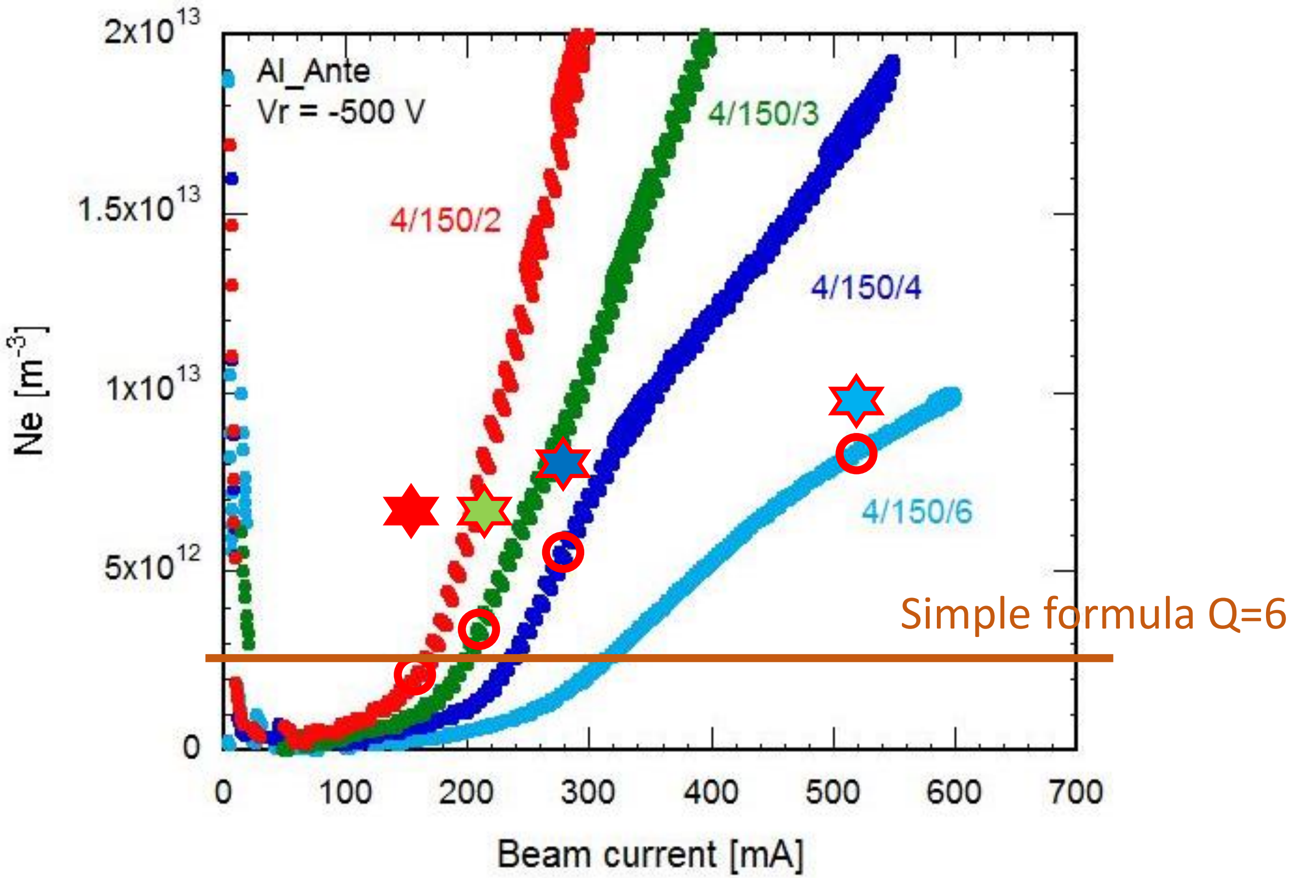
For V=0V, 1μA, electron production rate is 0.3×10^9 m^{-1}/bunch

Electron density at the blow-up threshold

Simulated electron density at the threshold current

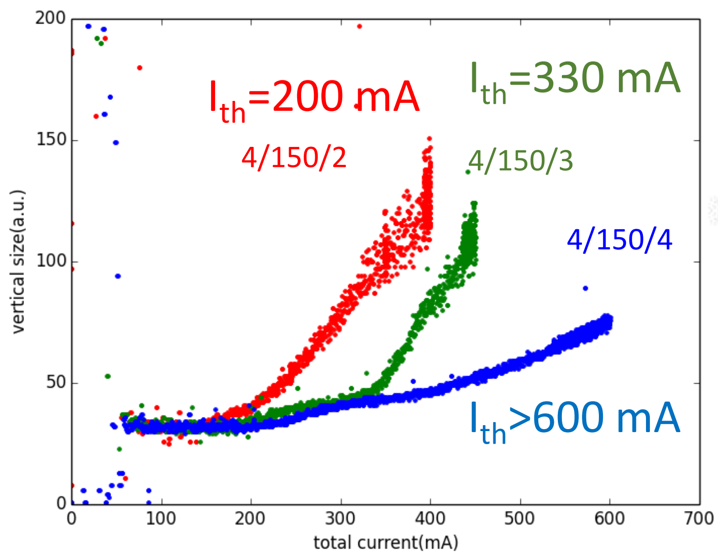
Measured threshold current and density

Only Al part

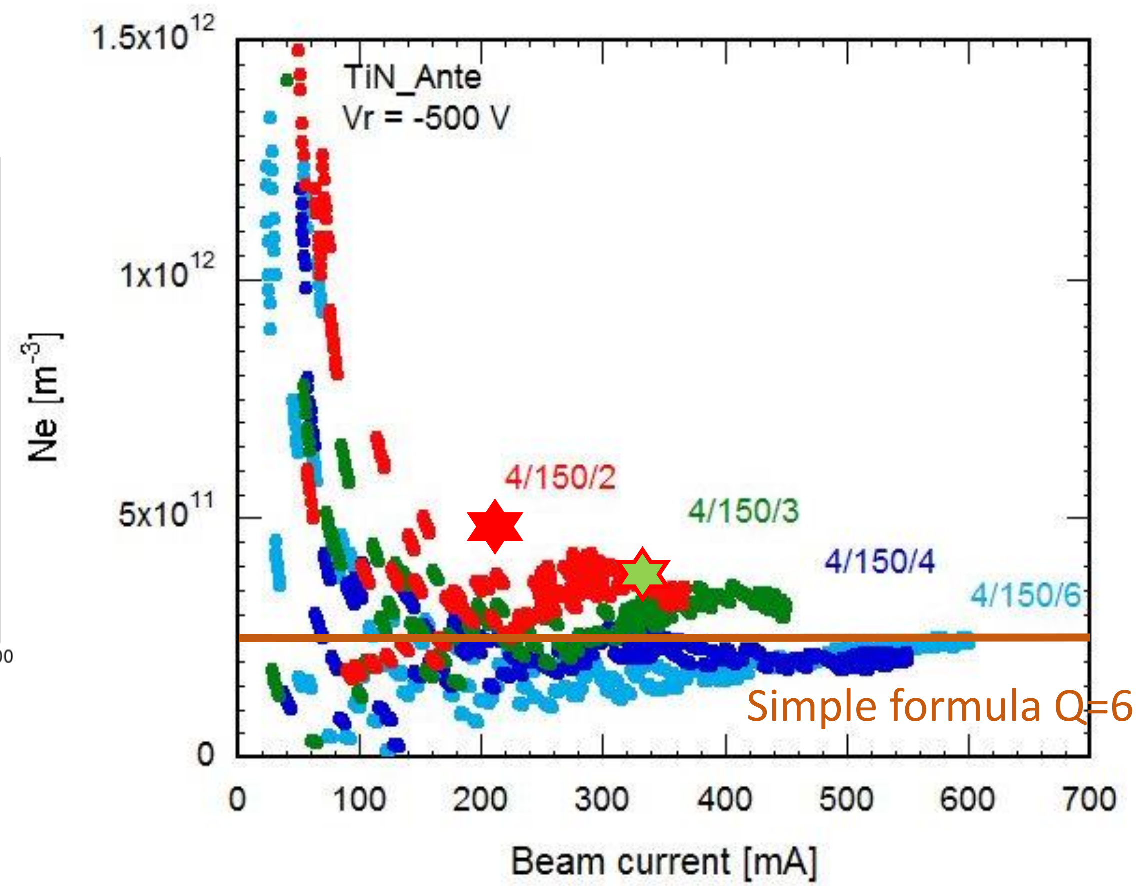


After installation of permanent solenoid at Al bellows

2016/6/8



Simulated electron density at the threshold current

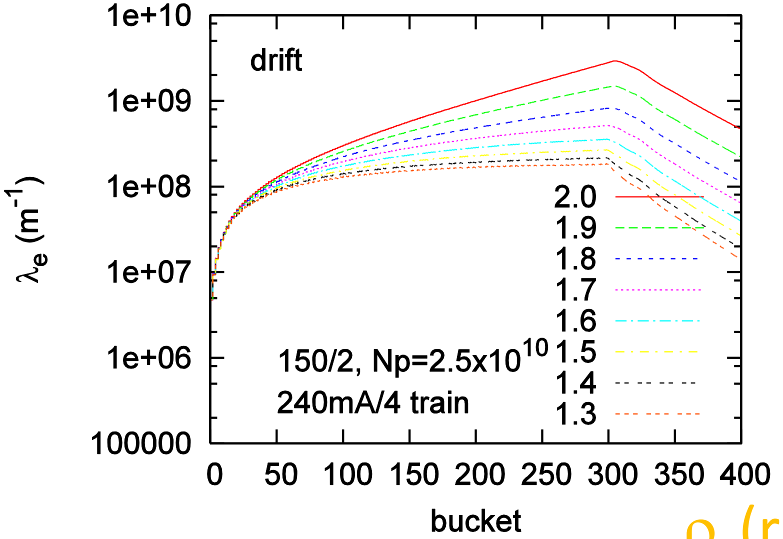


Threshold of electron cloud density after solenoid attach

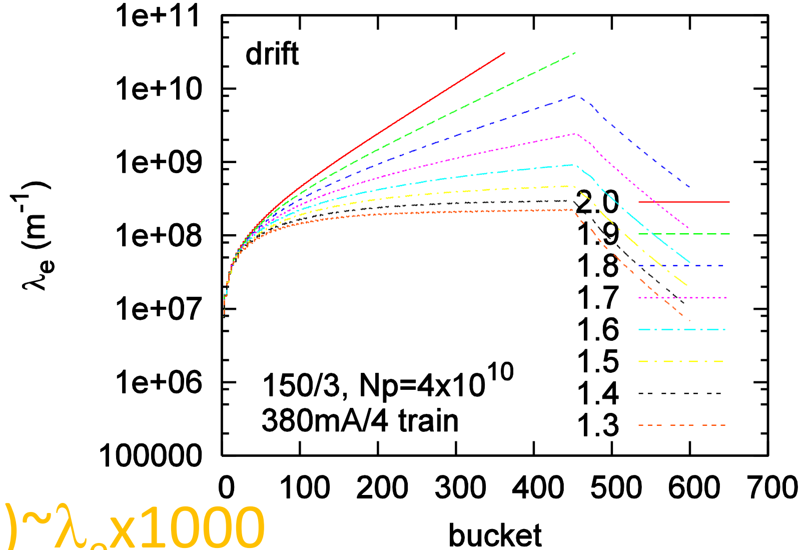
spacing	$I_{p,th}$ (mA)	$N_{p,th}$ (10^{10})	$\omega_e/2\pi$ (GHz)	$\omega_e\sigma_z/c$	ρ_{eth} (Q=10) ($10^{11}m^{-3}$)	ρ_{eth} (Q=6) ($10^{11}m^{-3}$)	ρ_{eth} (Simu) ($10^{11}m^{-3}$)
2 (4ns)	200	2.1	71	8.9	1.65	2.45	3.4
3 (6ns)	330	3.5	91	11.5		2.45	4.8
4 (8ns)	>600	>6.3					
6 (12ns)							
3.06	500	2.0	37	5.5	2.89	2.90	4.4
3.06	600	2.4	41	6.0	2.63	2.65	4.4

Simulated electron cloud build up in Drift

Np=2.5x10^{10}, I=240 mA for N_b=150x4=600

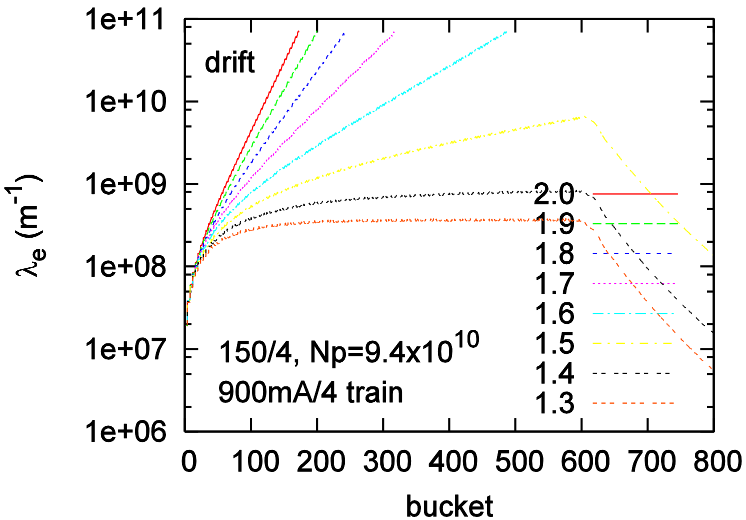


Np=4x10^{10}, I=380 mA for N_b=600

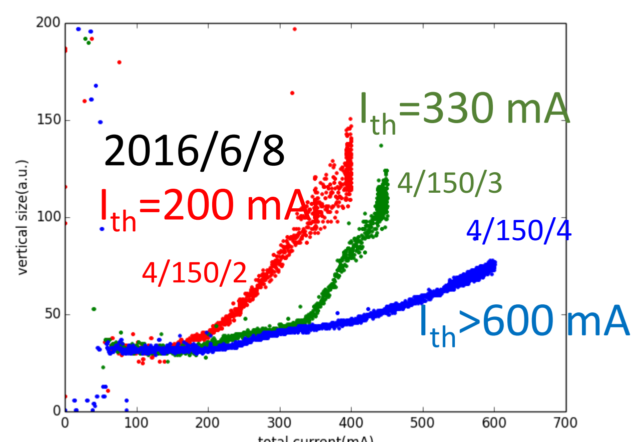


$\rho_e(r=0) \sim \lambda_e x1000$

Np=9.4x10^{10}, I=900 mA for N_b=600



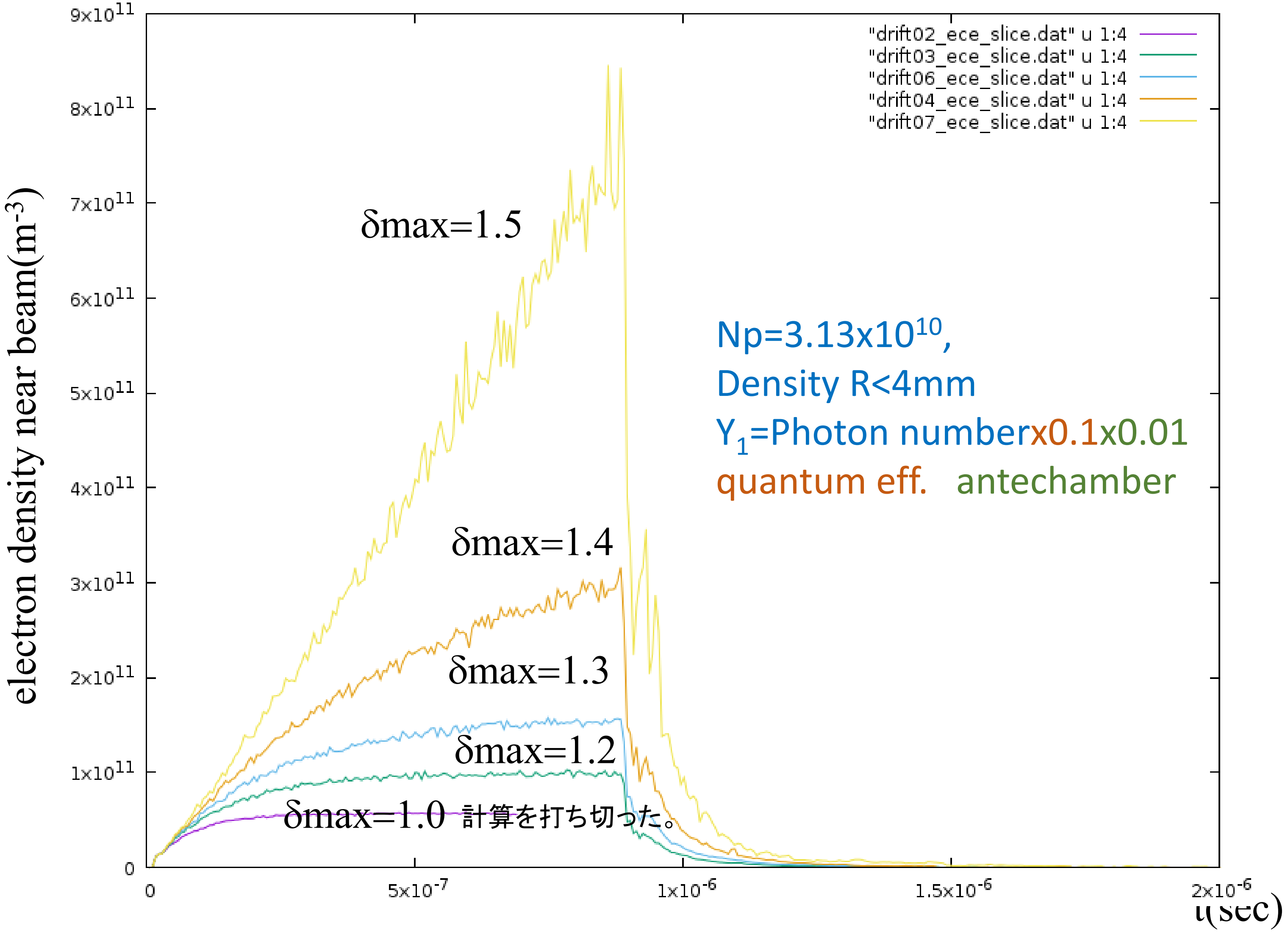
Beam current: Slightly higher than measured threshold



Y_1=Photon numberx0.1x0.01

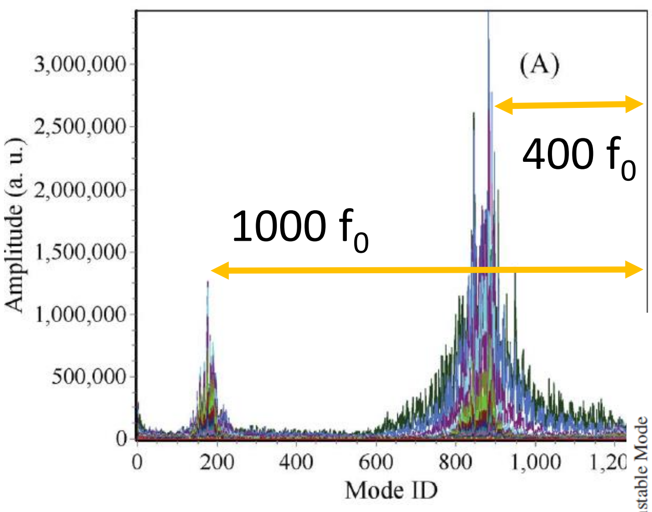
E cloud buildup

CLOUDLAND, Fukuma

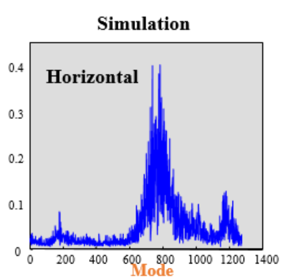


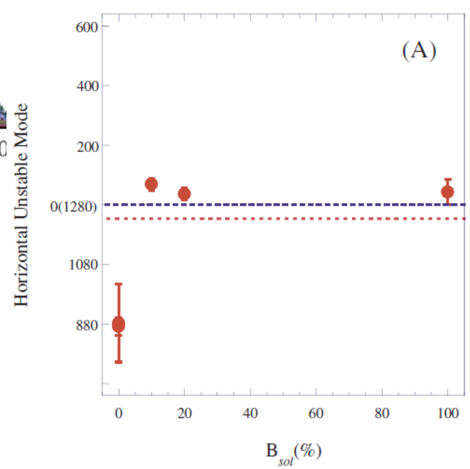
Coupled bunch instability caused by electron cloud

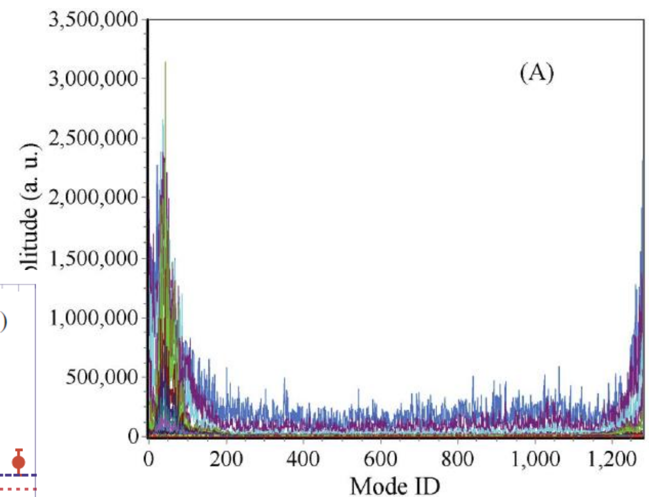
- Electron cloud motion reflects coupled bunch instability mode.
- Electrons in drift, short range wake ~10ns
- Electrons in solenoid, slow rotation around chamber surface.



KEKB



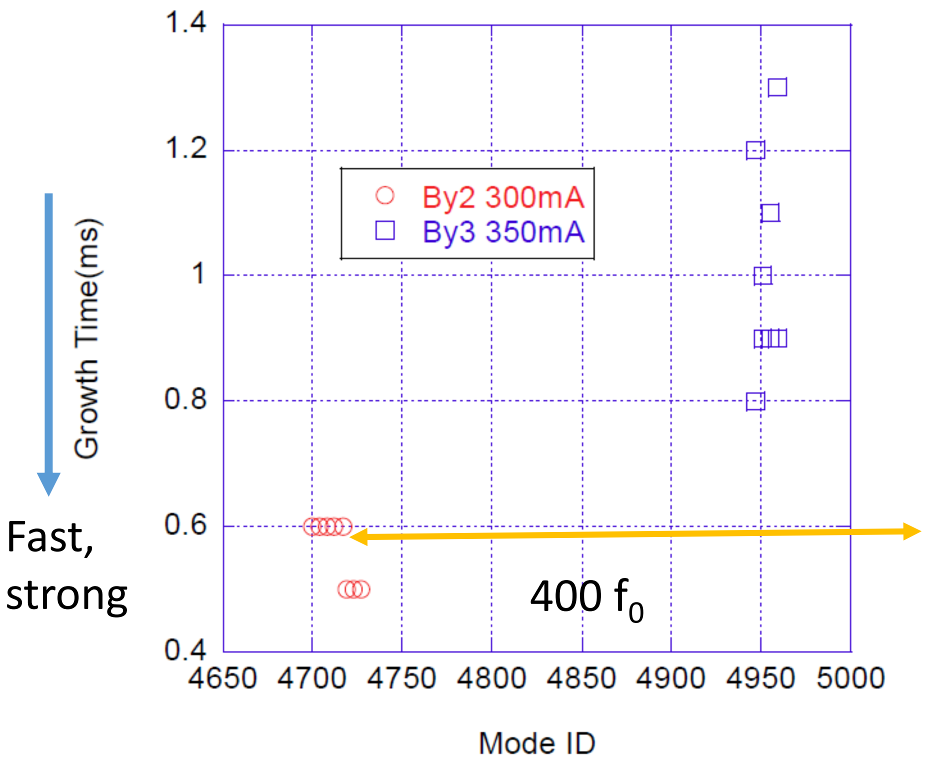


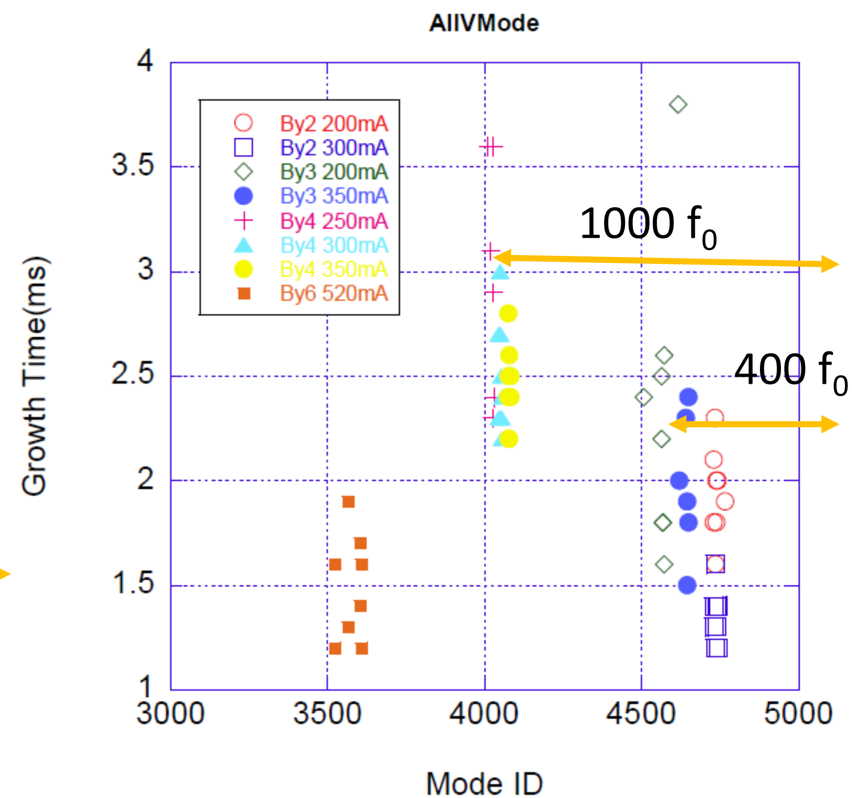


Unstable mode (before solenoid installation)

M. Tobiyama

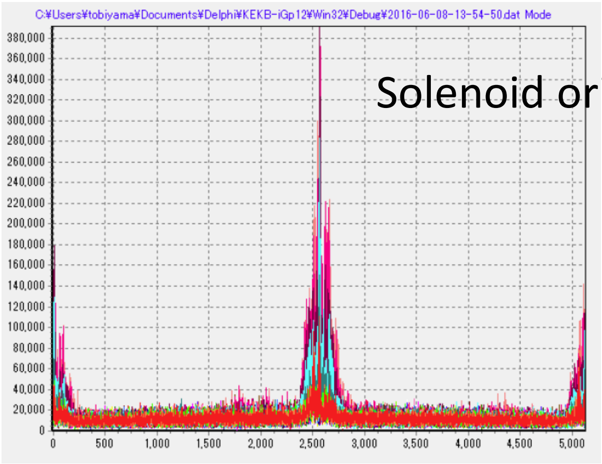
- Typical signal of coupled bunch instability caused by drift electrons

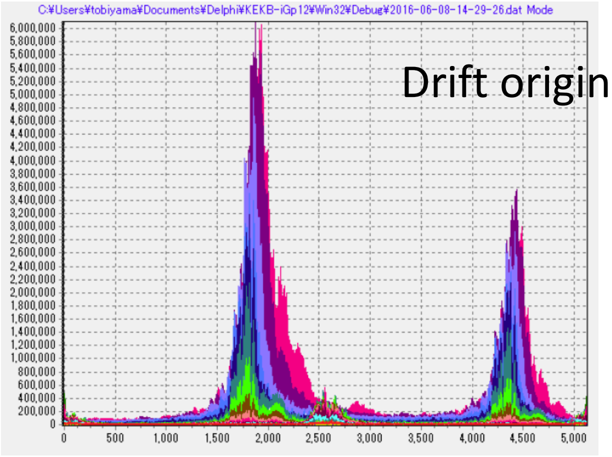




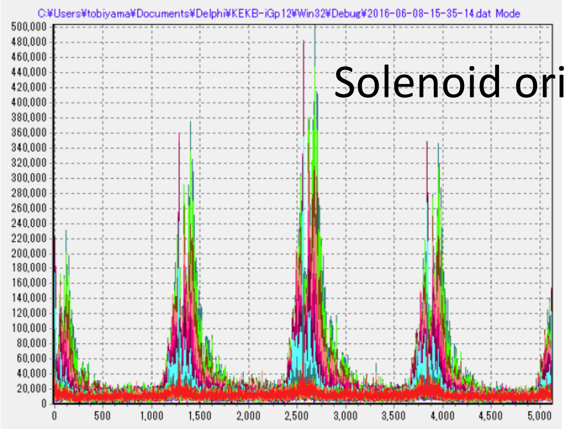
Mode spectrum

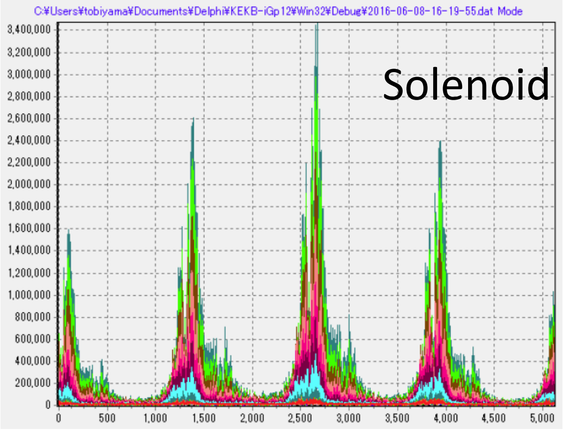
By 2 ver   300mA   400mA





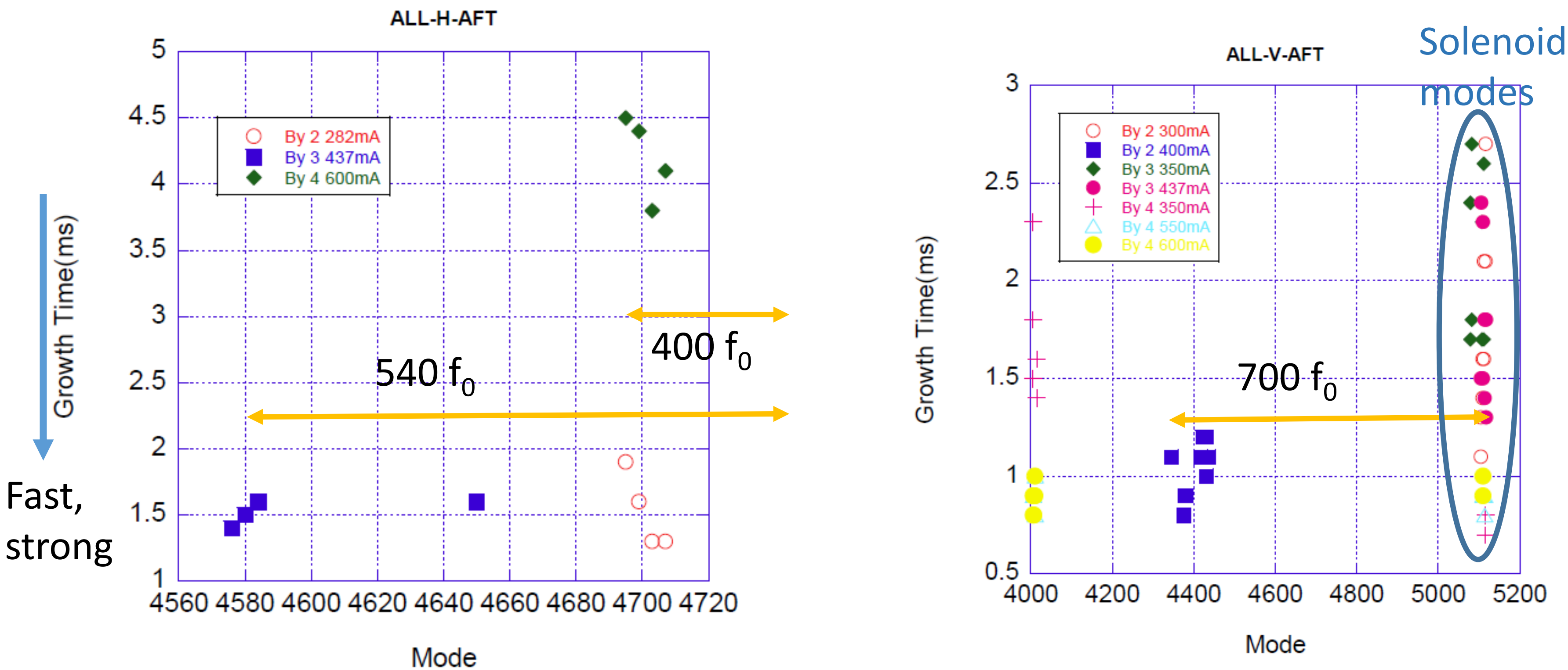
By 4 ver 350mA   600mA





Unstable mode (after solenoid installation)

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

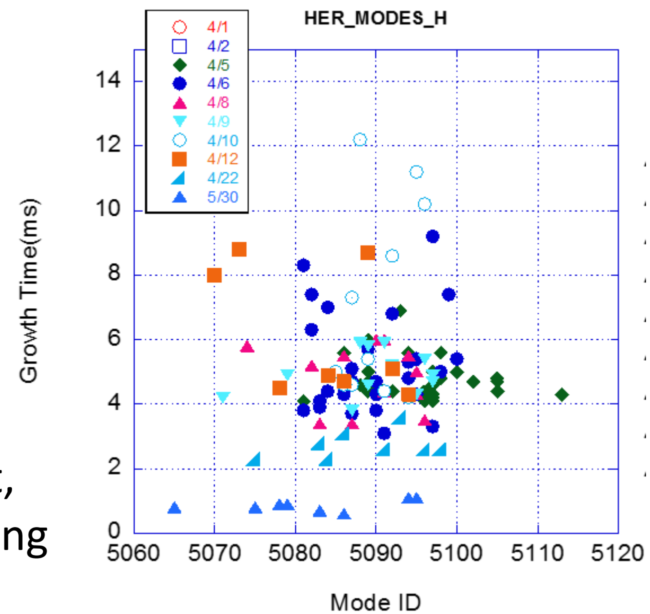


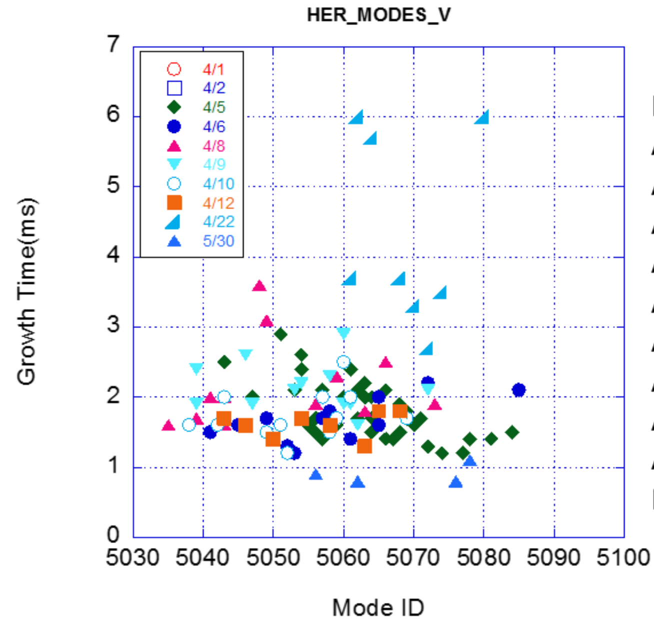
Coupled bunch instability in electron ring (HER)

M. Tobiyama

- Ion?

Fast, strong

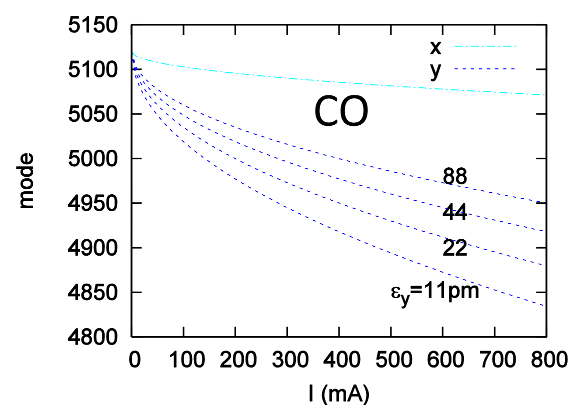




	Beam current	Nb
Apr.1	174mA	1163
Apr.2	174	1163
Apr.5	225	953
Apr.6	240	953
Apr.8	280	953
Apr.9	280	1163
Apr.10	280	1163
Apr.12	340	1163
Apr.22	520	1394
May.30	738	1576

$$\omega_{i,x}^2 = \frac{2\lambda_e r_A c^2}{A_i \Sigma_x(\Sigma_x + \Sigma_y)} \qquad \omega_{i,y}^2 = \frac{2\lambda_e r_A c^2}{A_i \Sigma_y(\Sigma_x + \Sigma_y)} \qquad \Sigma_{x(y)} = \sqrt{\sigma_{e,x(y)}^2 + \sigma_{i,x(y)}^2}$$

$$Mode = 5120 - \frac{\omega_{i,xy}}{\omega_0}$$

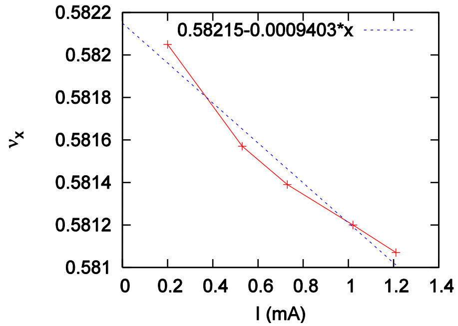


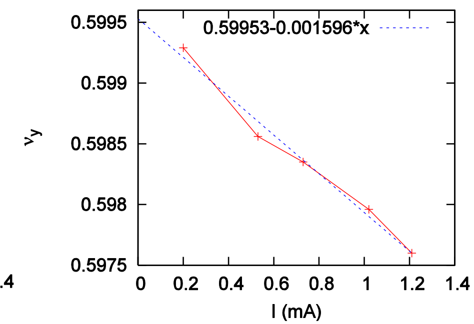
Resistive wall
5120-1=5119

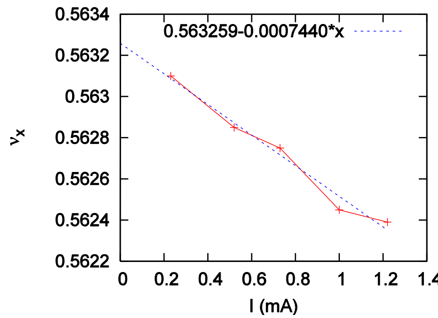
Impedance estimation- transverse

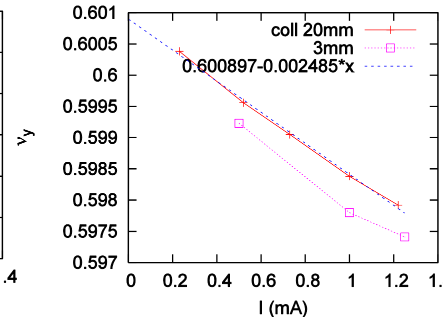
- Tune shift as function of bunch current

$$\Delta\nu_x = \frac{1}{4\pi^{3/2}}\frac{Nr_e}{\gamma}\frac{L}{\nu_x\sigma_z}\frac{iZ_{eff}}{Z_0} \qquad iZ_{eff}(k\Omega) = 33.3\frac{\Delta\nu_x}{I(mA)} \text{ LER} \qquad = 58.2\frac{\Delta\nu_x}{I(mA)} \text{ HER}$$

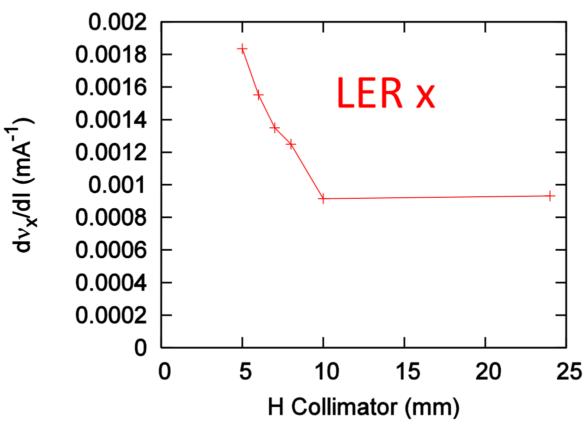


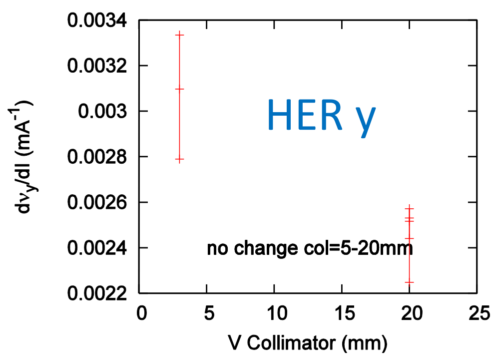






$iZ_{eff} = 31\ (x) \quad 53\ (y)\ k\Omega/m$ $\qquad$ $iZ_{eff} = 43\ (x) \quad 145\ (y)\ k\Omega/m$

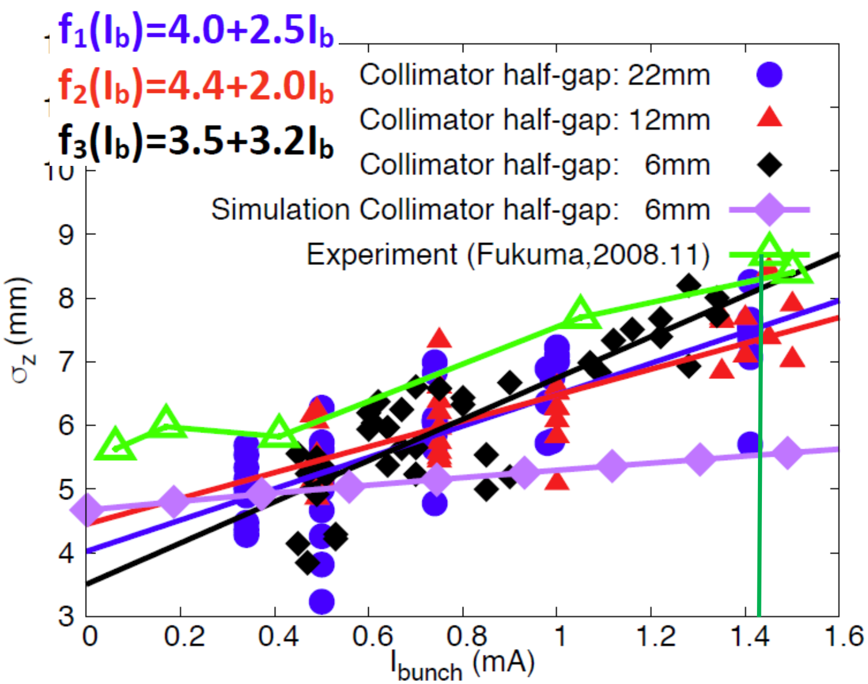


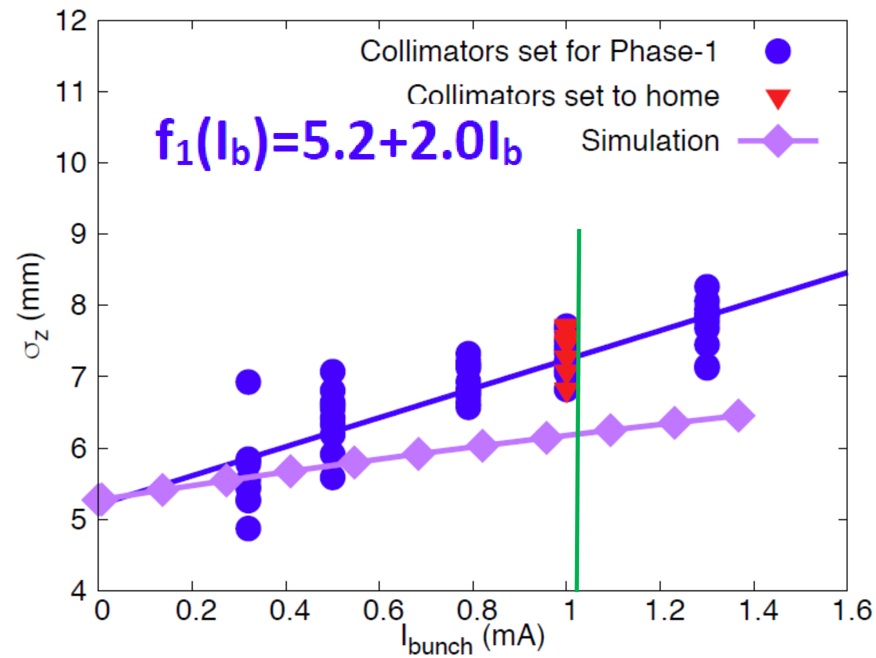


Collimator dependence

KEKB-LER: -0.0034mA^{-1}, 81kΩ/m
coll. open 33-46 kΩ/m T. Ieiri, EPAC00

Longitudinal impedance issue- Bunch length measurement





Measured by a Streak camera

The behaviors are similar as KEKB for both of LER and HER.
Bunch lengthening is stronger than that of simulation.

Summary

- Beam size blow-up has been observed since early stage of SuperKEKB commissioning.
- Electron density at Al bellows part (5% of circumf.) is high ($\rho_e > 10^{12} m^{-3}$). Simulations show the electrons can cause fast head-tail instability.
- Coupled bunch instability caused by electron cloud has also been observed as is predicted.
- Installation of Permanent solenoid reduced the blow up. It is possible to operate with 1A, 4 bucket spacing at present condition.
- Tune shift as function of bunch current was measured to estimate transverse impedance. It was 30-50kΩ/m, similar as KEKB.
- Bunch length was measured by a streak camera. Bunch lengthening, which was similar as KEKB, was observed, 7-8 mm at the design current, while no bunch lengthening in prediction.

Thank you for your attention

Rough estimation of Electron density

- Electron current, I_e=1μA.
- Acceptance of the electron detector, S_{mon}=1 cm^2.
- Number of electron absorbed (=produced) at chamber wall, d=10cm.

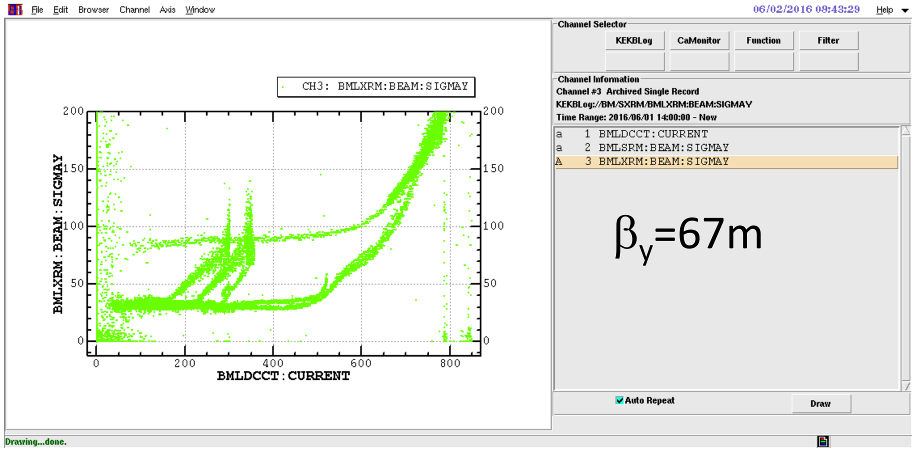
$$n_e = \frac{10^{-6} \times 0.1\pi}{1.6 \times 10^{-19} \times 10^{-4}} = 2 \times 10^{16}\ m^{-1}s^{-1}$$

- Electron stay time in the chamber, τ_e=100ns. Electron density

$$\rho_e = \frac{2 \times 10^{16} \times 10^{-7}}{0.05^2\pi} = 2.5 \times 10^{11}\ m^{-3}$$

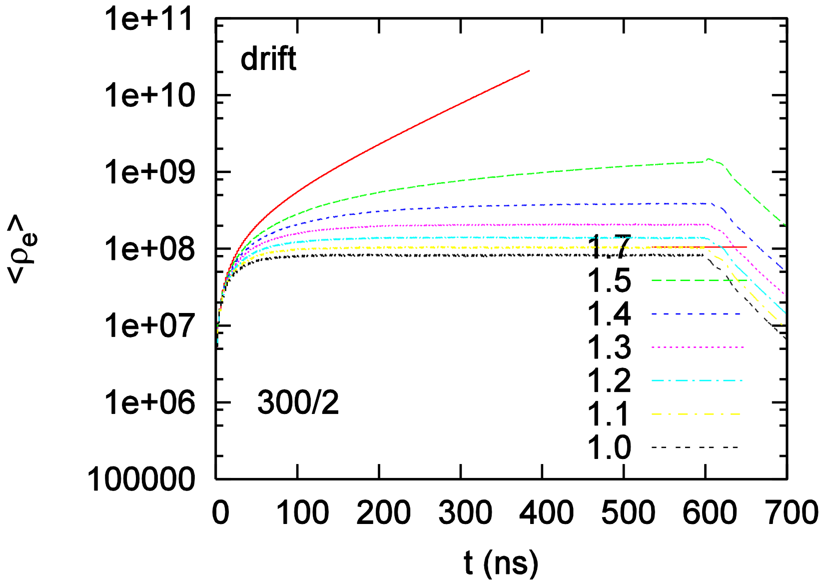
Emittance dependence

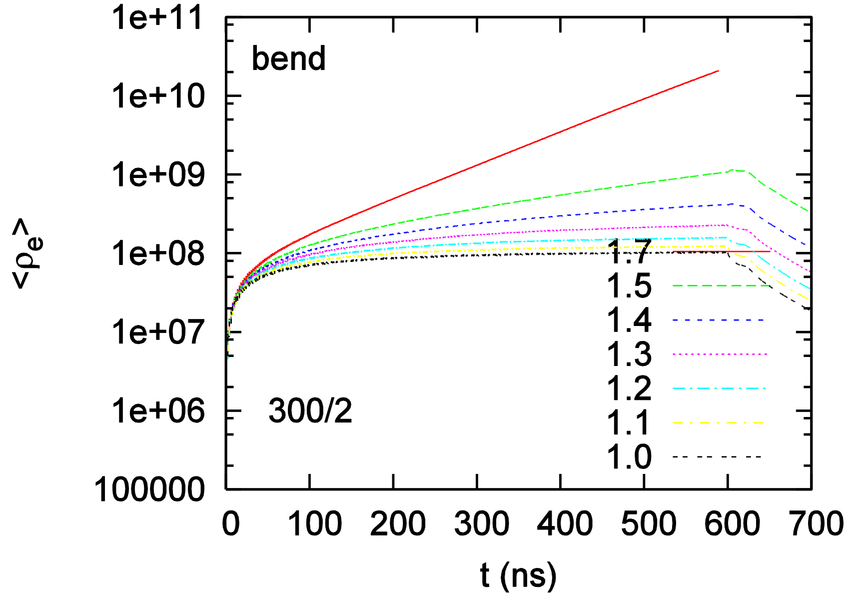
- Vertical emittance knob



Design current & spacing

Np=9.4x10^{10}, I=3600 mA





金澤氏の式を使った電子密度の算出*

＊PAC2005, p.1054

$$D = \frac{\mu(V_b)}{V_{obs}(V_b)} \qquad \mu(V_b) = \frac{I_{obs}(V_b)}{e n_b f_{rev}}$$

$$V_{obs}(V_b) = A\pi r^2 = 2\pi A r_e^2 N_b^2 \frac{m_e c^2}{eV_b}$$

e = 1.602E-19 [C]
f_{rev} = 1E5 [s^{-1}]
r_e = 2.818E-15 [m]
m_e = 9.109E-31 [kg]
c = 3.0E8 [ms^{-1}]

n_b = バンチ数
πA = 通過確率 = 0.0003x1/4 = 7.5E-5
V_b = グリッド電圧 [V]
N_b = バンチ内のe^+の数

$$N_b = \frac{I}{n_b f_{rev} e}$$

I = ビーム電流 [A]

まとめると、

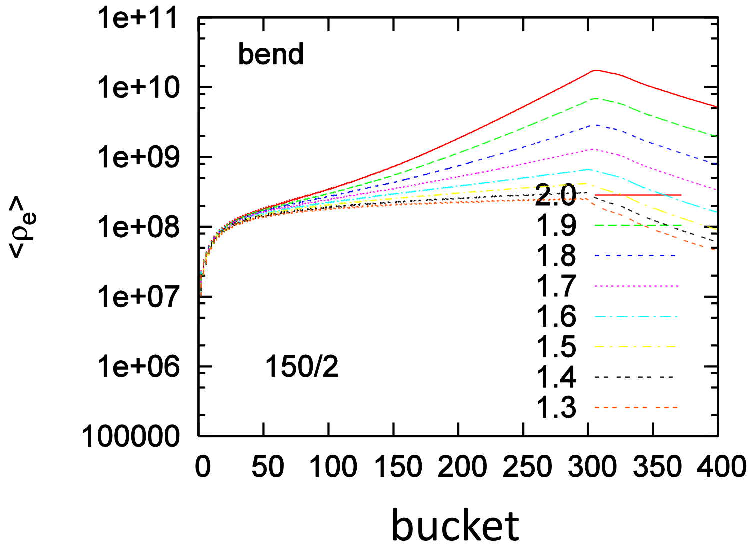
$$D = 2.630\text{E}13 \text{ x } \frac{I_{obs} n_b V_b}{I^2}$$

例えば、2/150/3 V_r = -30 V, I = 200 mA, I_{obs} = 1E-7 A の場合 (平均で)

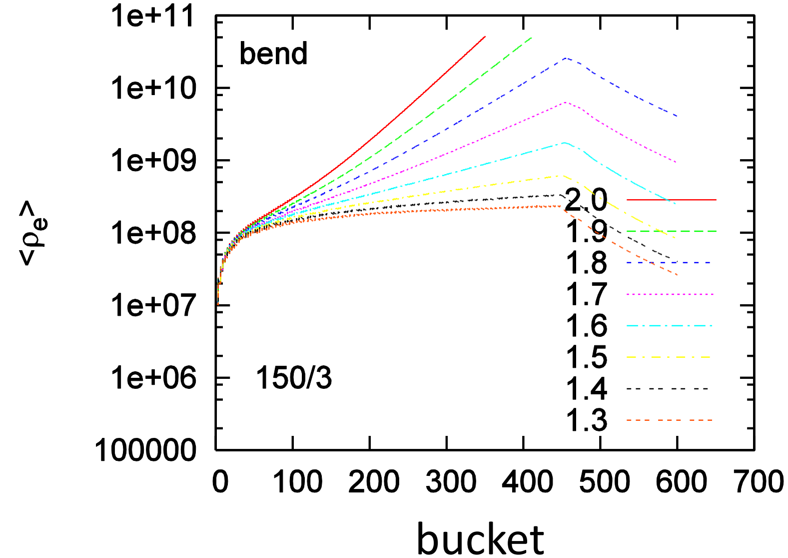
n_b = 600, V_b = 30　　D = 1.18E12 [e$^-$ m^{-3}]

Simulated electron cloud build up in Bend

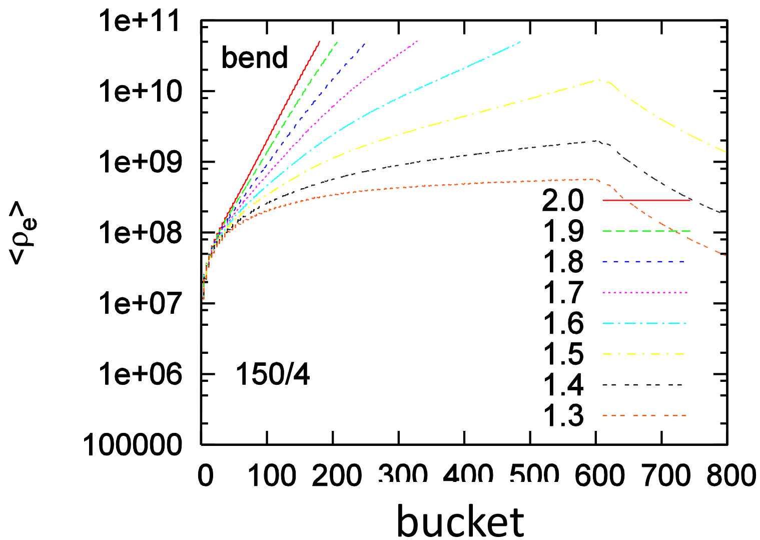
$Np=2.5\times10^{10}$, $I=240$ mA for $N_b=600$

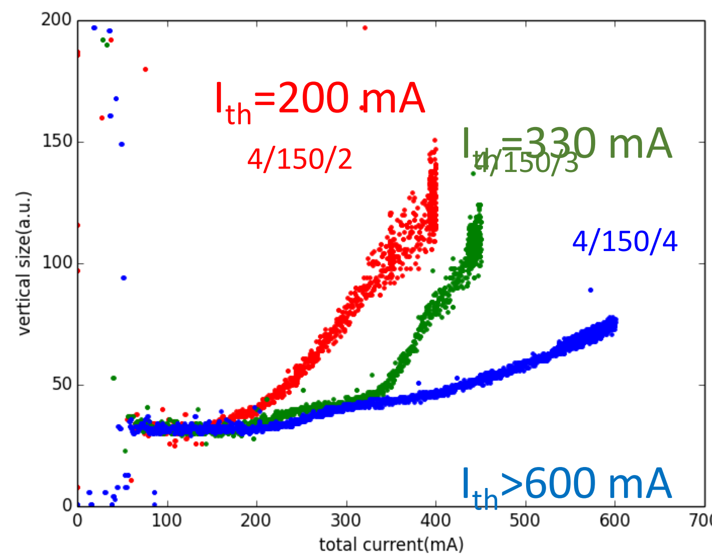


$Np=4\times10^{10}$, $I=380$ mA



$Np=9.4\times10^{10}$, $I=900$ mA

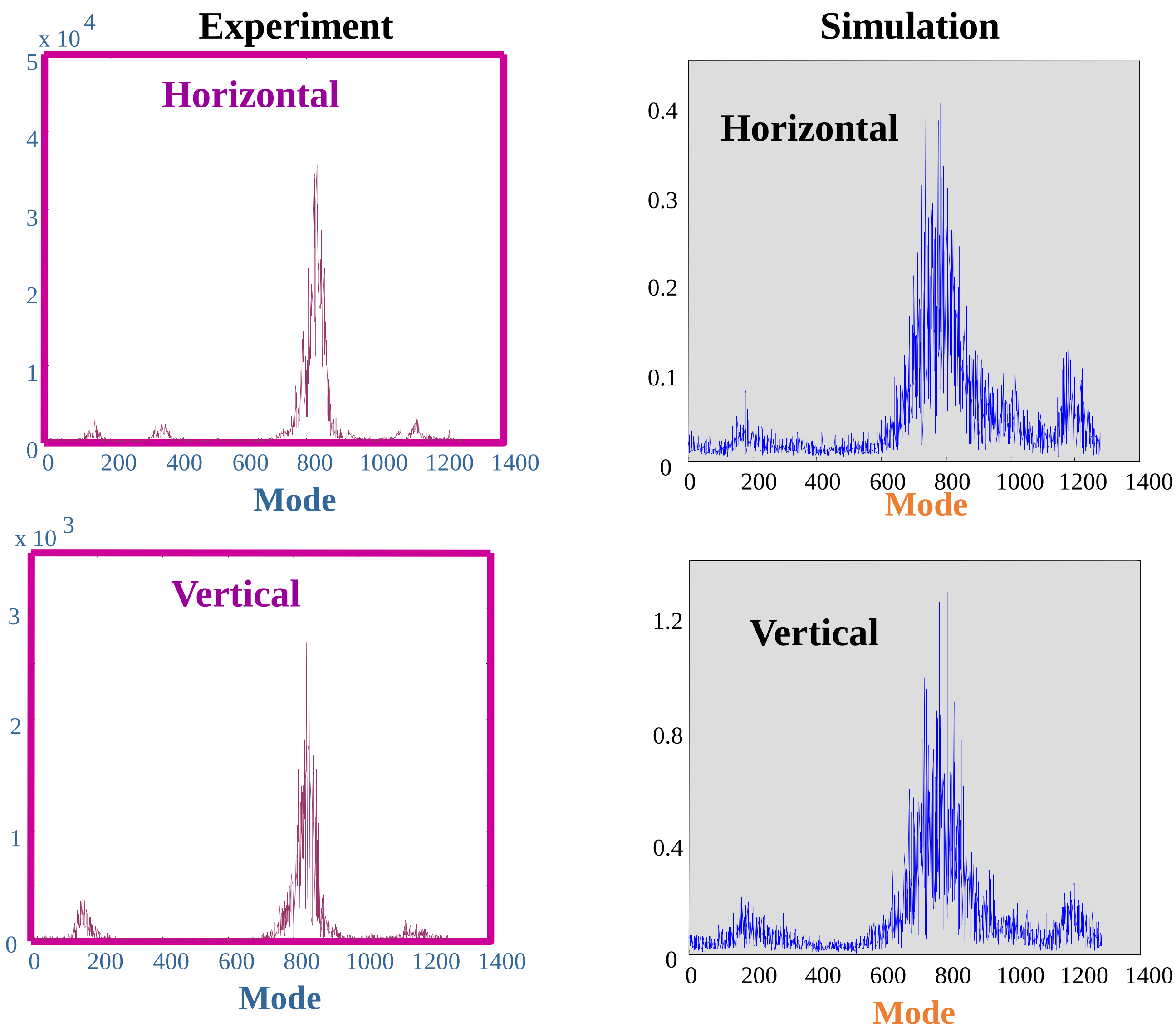




Multipactoring arises Y_{2max}>=1.5 at the threshold beam currents.

KEKB

Solenoid-Off



Su Su Win et al,(EC2002)