Effect of Solenoid in Quadrupole Magnet on Electron Cloud Instability

11th KEKB Accelerator Review Committee (2006.03.21)

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1. Introduction

The electron cloud instability(ECI) at KEKB LER is largely mitigated by the solenoid field applied to the vacuum chambers in drift space.

However, the blowup is still observed when the bunch spacing is reduced to 3.27 rf buckets or shorter.

A question is where the remaining electron clouds are.

The electron clouds may be accumulated in a quadrupole field because the magnetic field is zero at the center of the magnet.

To investigate the electron clouds in the quadrupole magnet, a solenoid made of a flat cable was developed and installed in 88 quadrupole magnets which are 25% of the quadrupole magnets in arc sections.

If the remaining electron clouds are mainly in the quadrupole magnet and the solenoid can affect the electron cloud in the quadrupole, the effect of the solenoid on the ECI may be observed.

Expected electron density if the electrons in the quadrupole are the primary cause of the ECI.

A condition where the strong head-tail instability occurs.

(K. Ohmi and F. Zimmermann, Phys. Rev. Lett.,**85**, 3821 (2000))

$$\int \rho \cdot ds > \frac{2\gamma \nu_s}{\pi r_e \beta_y}$$

ρ : the cloud density,
s : the obit length,
ν_s : the synchrotron tune,
β_y : the average vertical beta function.

Total length of quadrupole magnets is 218m which is 7.2% of the circumference.

⇨ Average ρ in the quadrupole $> 7.4\ 10^{12}\ m^{-3}$

2. Flat cable solenoid system

As we do not want to split the quadrupole magnet to wind the solenoid, and a gap between a vacuum chamber and poles of the quadrupole is only about 2mm, a flat cable was used as the solenoid.

The flat cable was attached to connectors so as to make a loop of a wire.

- Flat cable : ECO-OKIFLEX-SN4 (Non-halogen cable)

  Thickness of the cable : 0.98 mm

  Wire pitch : 1.27 mm

  Wire resistance : 222 ohm/km

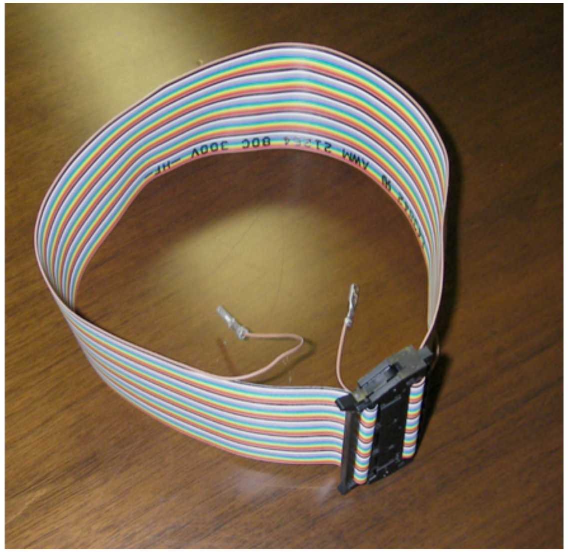
  (5 ohm for a piece with the connector)

  Maximum current : 2.1 A

  Temperature rise (@current 2 A, room temp. 24ºC)

  18 ºC(cable), 33ºC(connector)

- Power supply : KENWOOD 5A, 300V
- Field strength : 17Gauss@2A



A piece of the solenoid

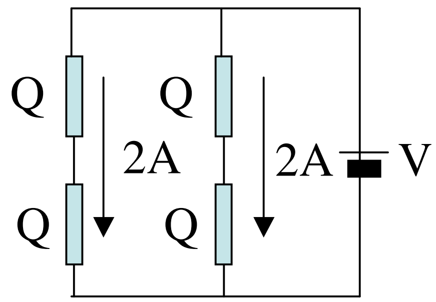
Installation

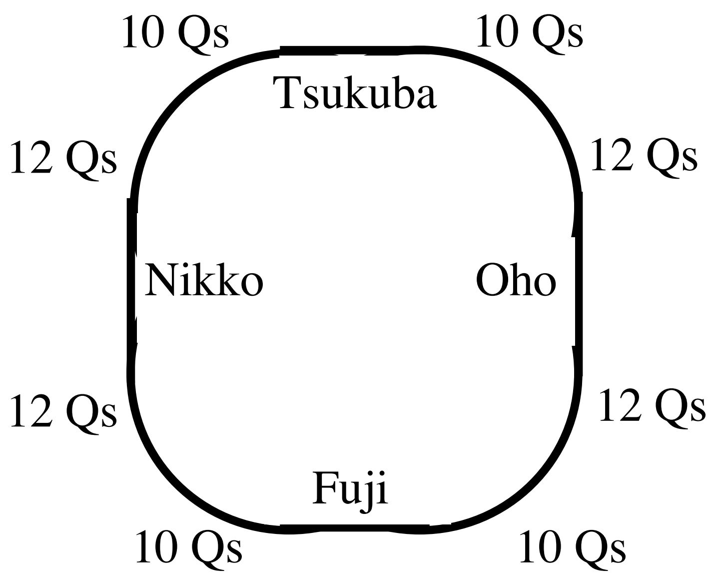
Eight pieces of the solenoid were set in a quadrupole.

The solenoids were installed in 88 quads among 461 quadrupoles.

Location of the solenoids was near the entrance of each arc because of easy wiring work of DC cables.

Circuit





3. Experiment

Procedure :

Measure the sideband of the dipole oscillation and the vertical beam size with turn-on or -off of the solenoids in the quadrupoles.

The appearance of the sideband is related to the ECI.

The blowup of the vertical beam size caused by the ECI is our main concern.

The dipole oscillation was measured by the BOR(Bunch oscillation Recorder).

The vertical beam size was measured by the interferometer.

Fill pattern 8/50/2, 4/80/3

(# of trains/ # of bunches in a train/ bunch spacing in unit of rf bucket)

1) Experimental conditions

Betatron tune : $(\nu_H, \nu_V) = (45.522, 43.623)$

Chromaticity : $(\xi_H, \xi_V) = (2.1, 6.5)$

Vertical feedback gain : -14.6dB

RF voltage : 8 MV ($\nu_s = 0.024$)

Solenoid : turn-on except for the solenoids in the quadrupoles

The beam conditions were chosen so as to avoid the low injection rate, the dipole oscillation and the beam size blowup by the coupling resonance.

(In physics operation,
Betatron tune=(45.506, 43.531), Chromaticity = (2.1, 4.8),
Vertical feedback gain = -18.6dB)

Above conditions were maintained throughout the experiment.

2) Sideband

The Fourier power spectrum of each bunch is calculated individually.

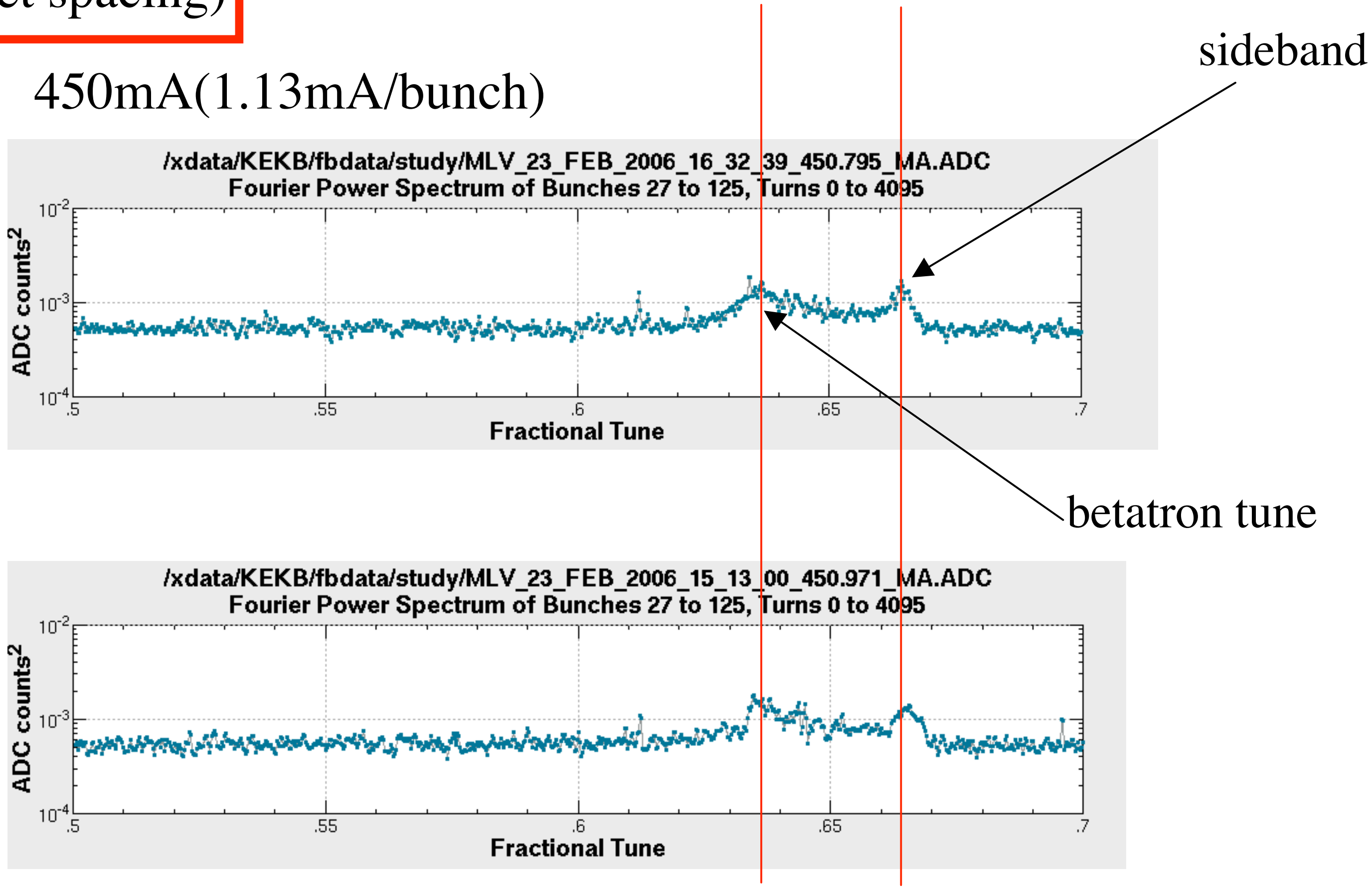
a) Overlapped spectrum of all bunches (averaged over trains)

8/50/2(2 bucket spacing)

450mA(1.13mA/bunch)

Solenoid on

Solenoid off

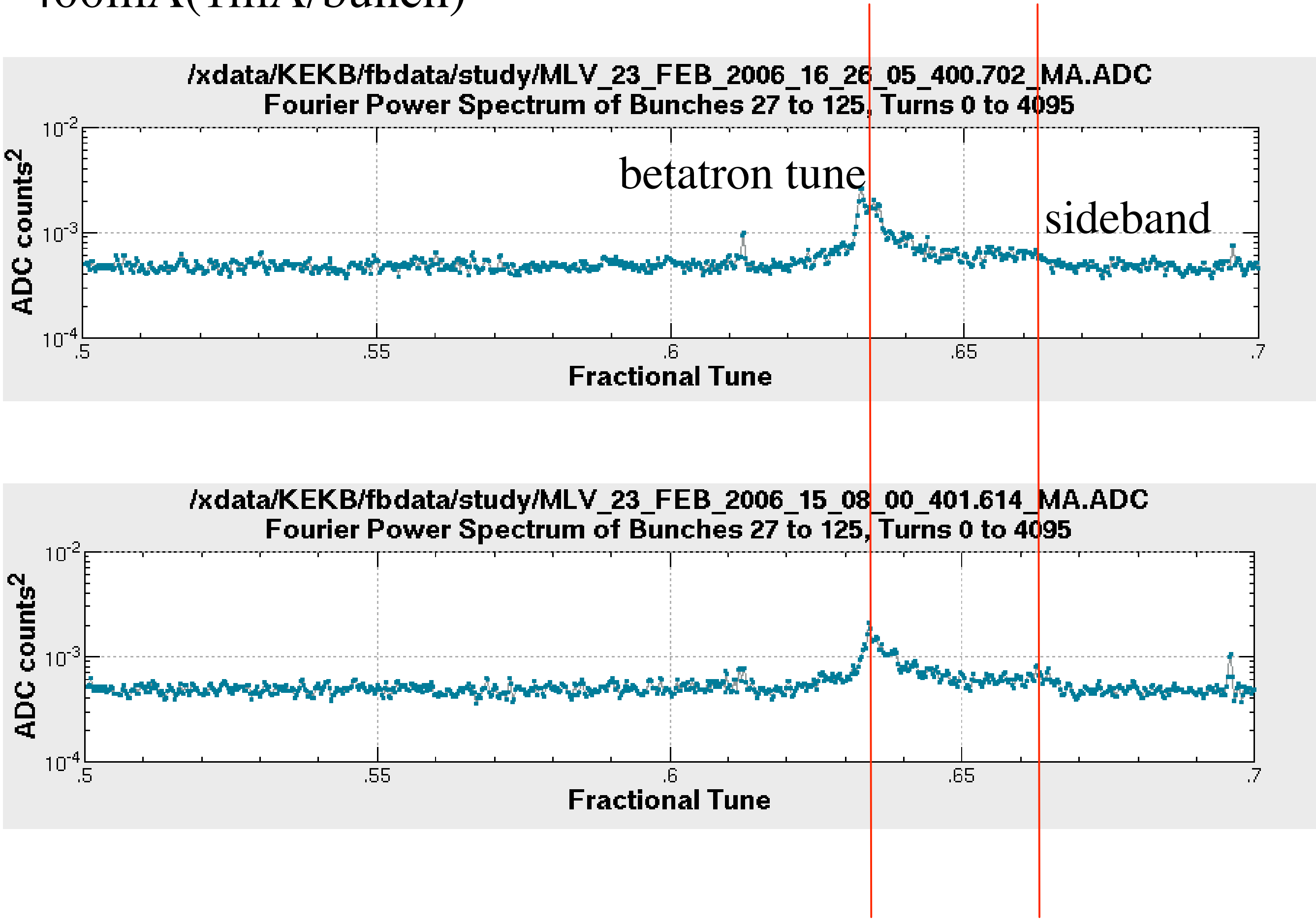


8/50/2(2 bucket spacing)

400mA(1mA/bunch)

Solenoid on

Solenoid off

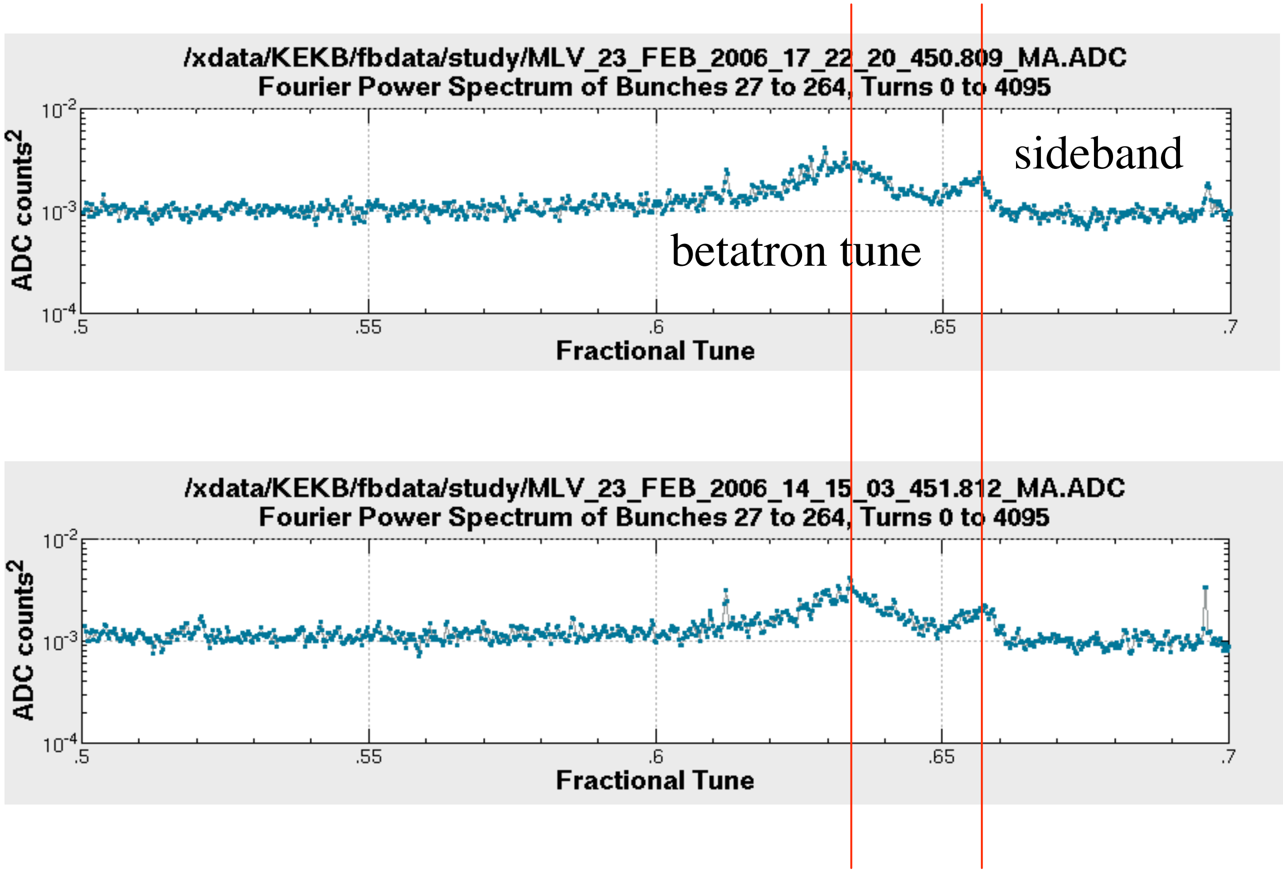


4/80/3(3 bucket spacing)

450mA(1.4mA/bunch)

Solenoid on

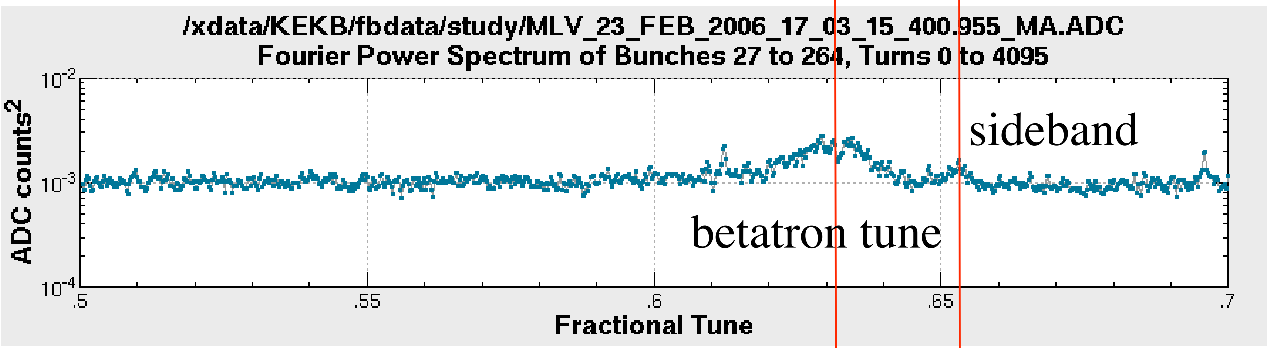
Solenoid off



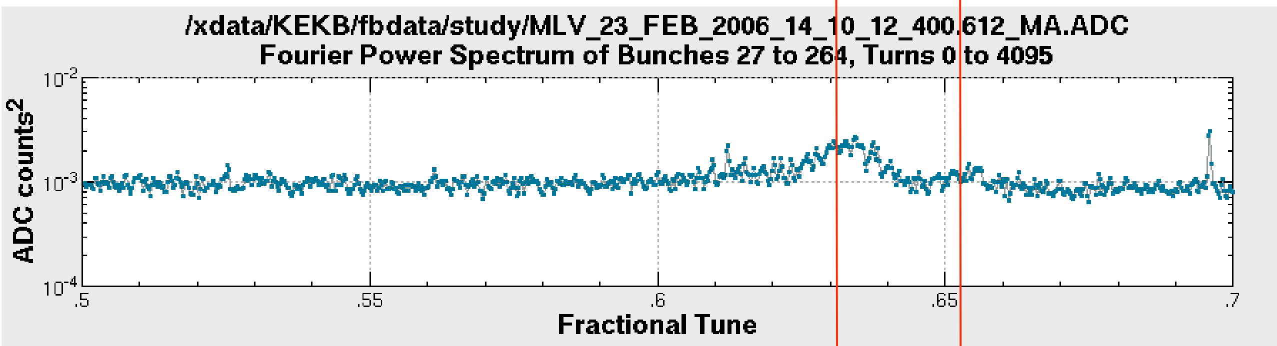
4/80/3(3 bucket spacing)

400mA(1.25mA/bunch)

Solenoid on

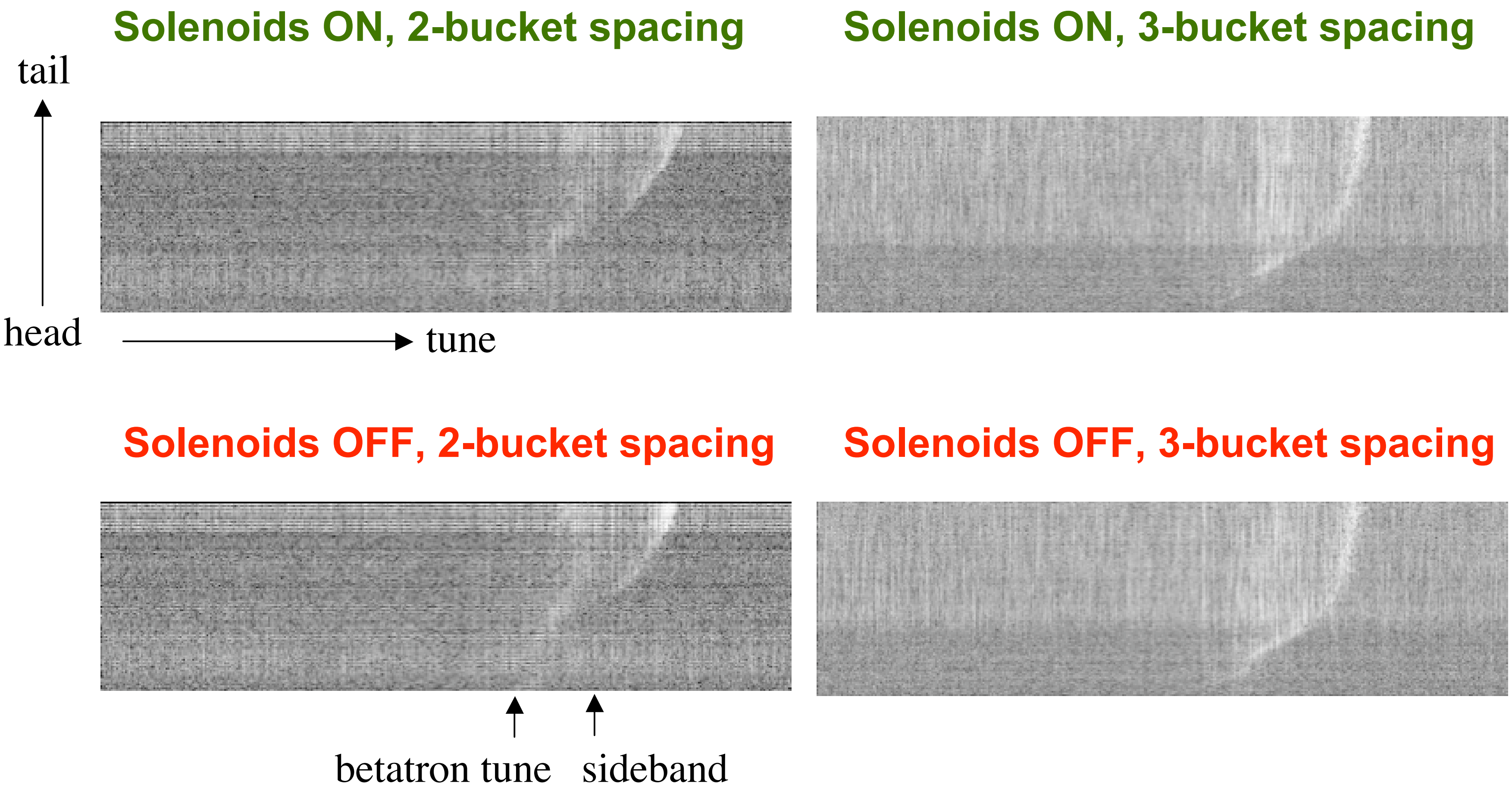


Solenoid off

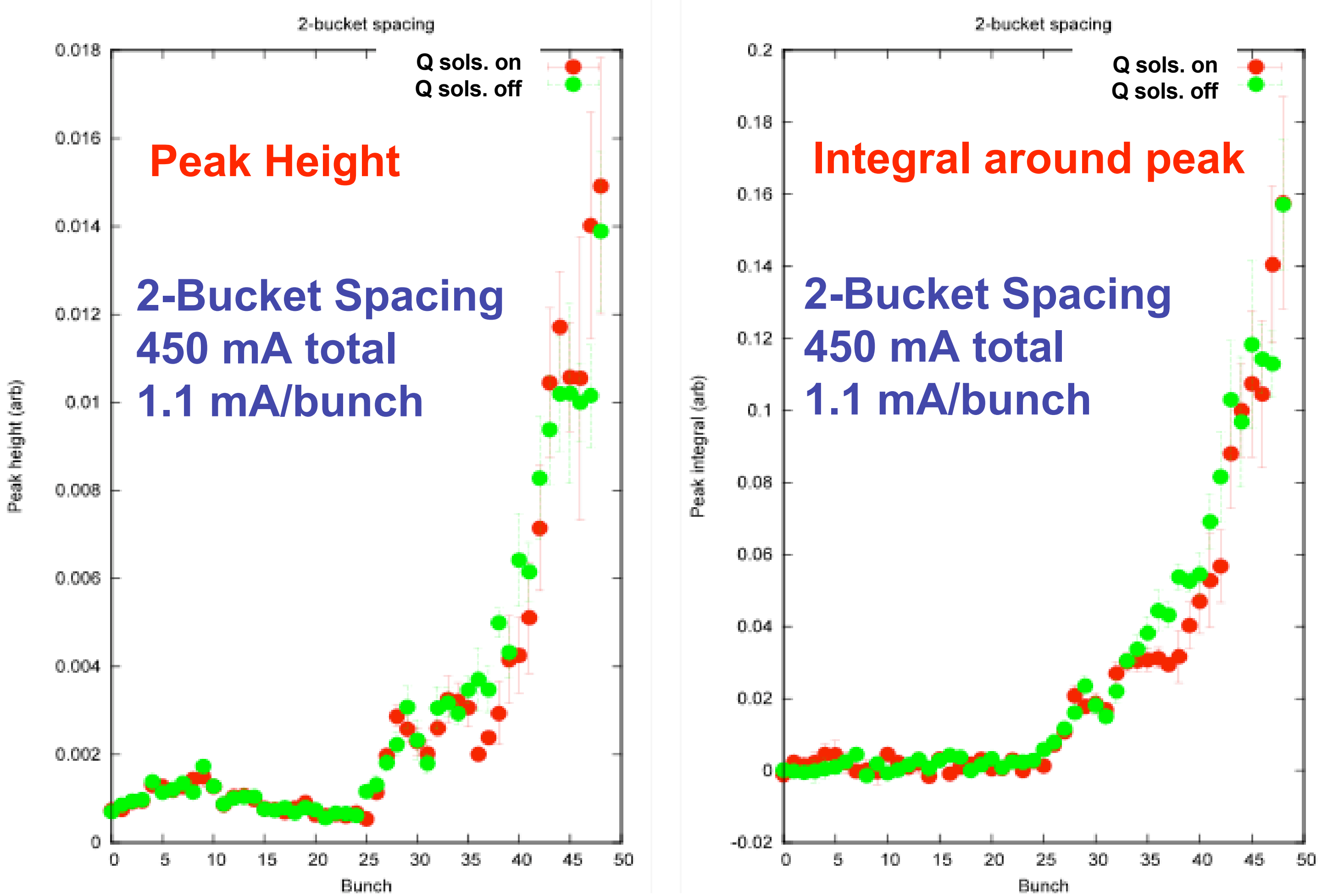


There is no clear difference in the peak position and the height of the sideband with or without the solenoid field in the quadrupoles.

b) Sideband along the train (J.W. Flanagan)



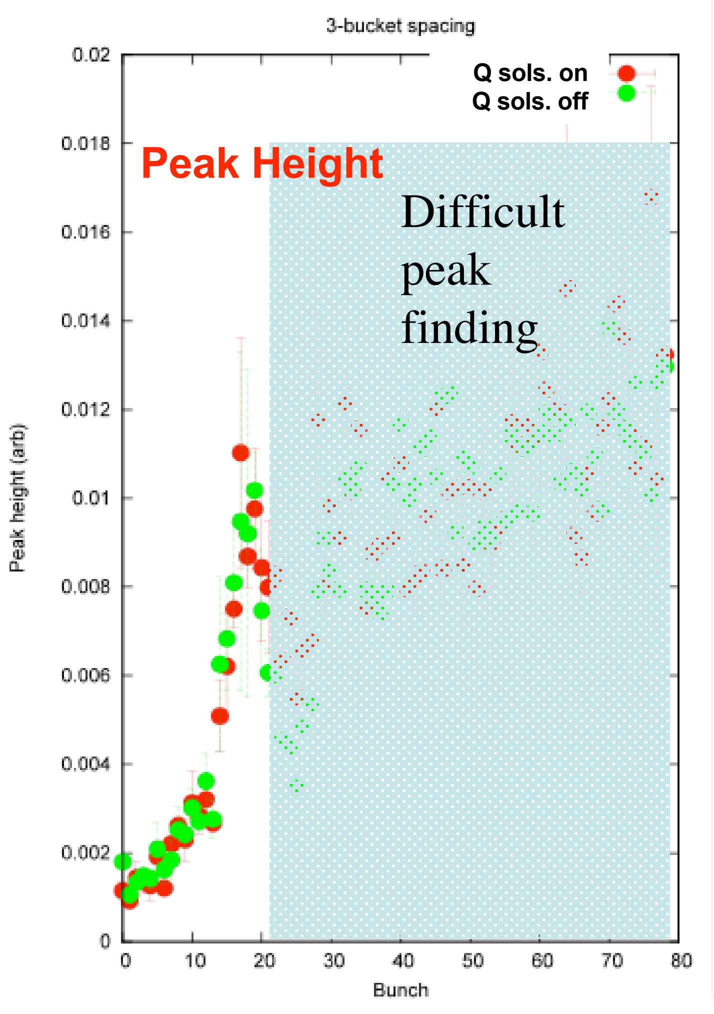
Sideband peak size (2 bucket spacing)

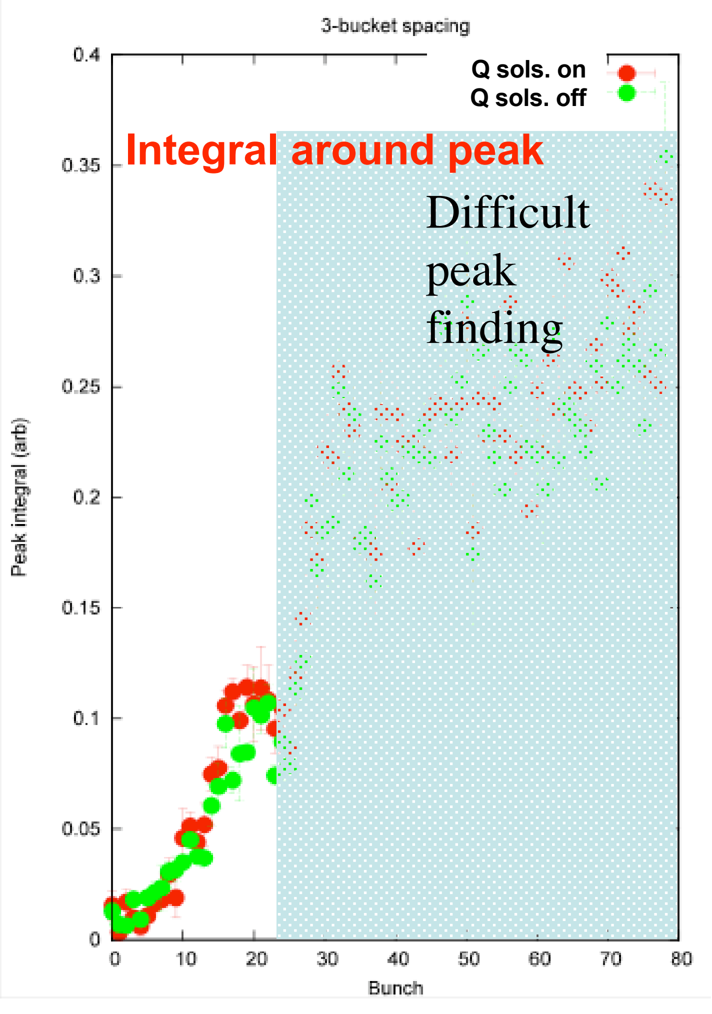


There is no clear difference in the data with or without the solenoid field in the quadrupoles.

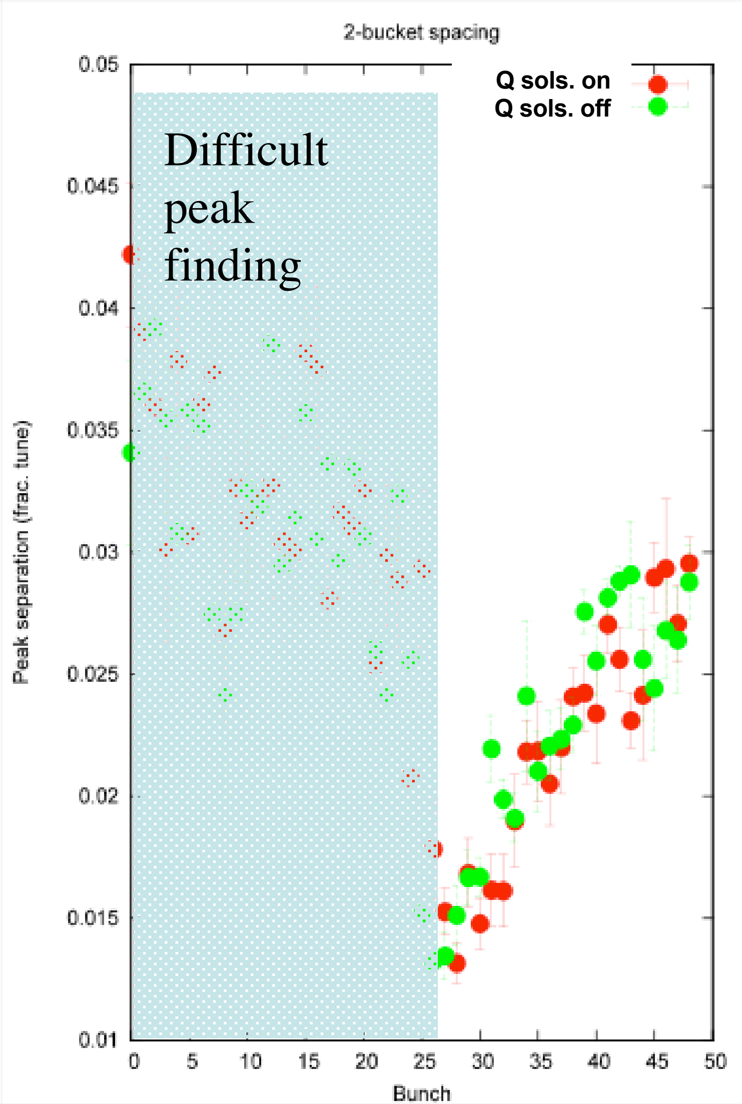
Sideband peak size (3 bucket spacing)

3-Bucket Spacing, 450 mA total, 1.4 mA/bunch



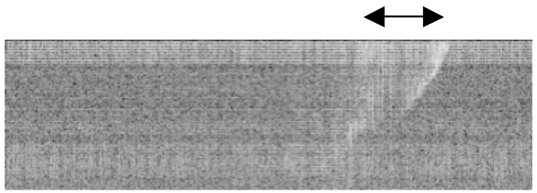


Sideband-betatron peak separation (2 bucket spacing)

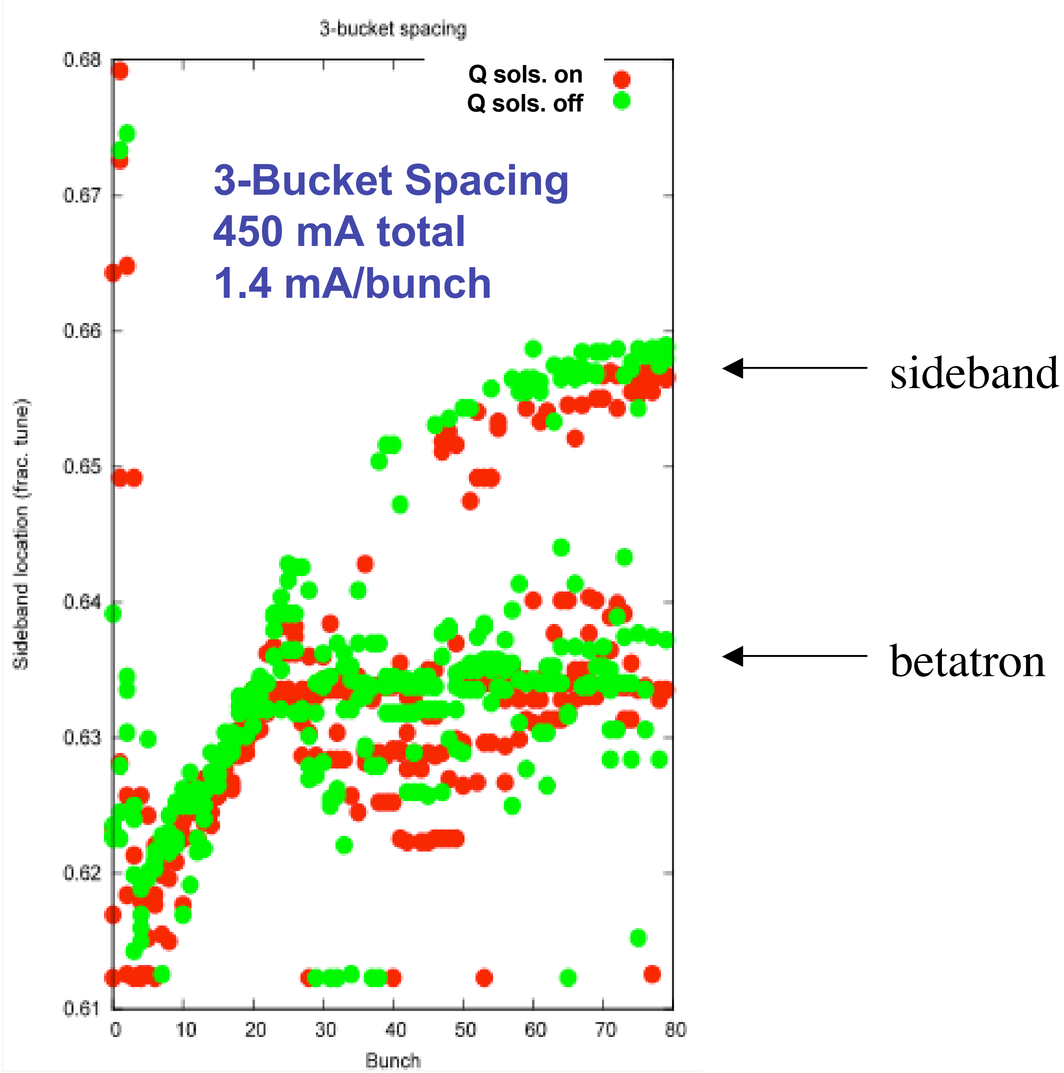


2-Bucket Spacing
450 mA total
1.1 mA/bunch

peak separation



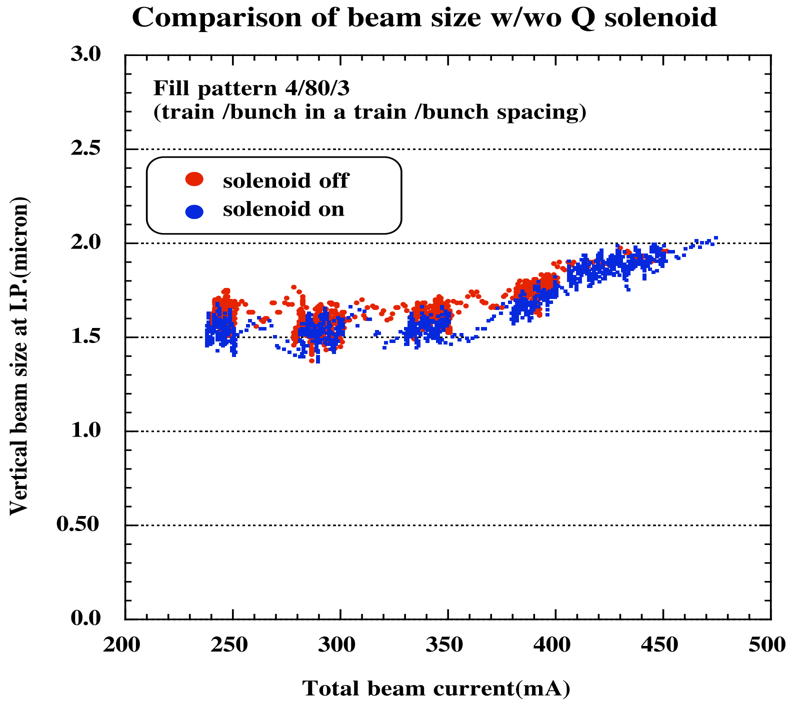
Peak location (3 bucket spacing)

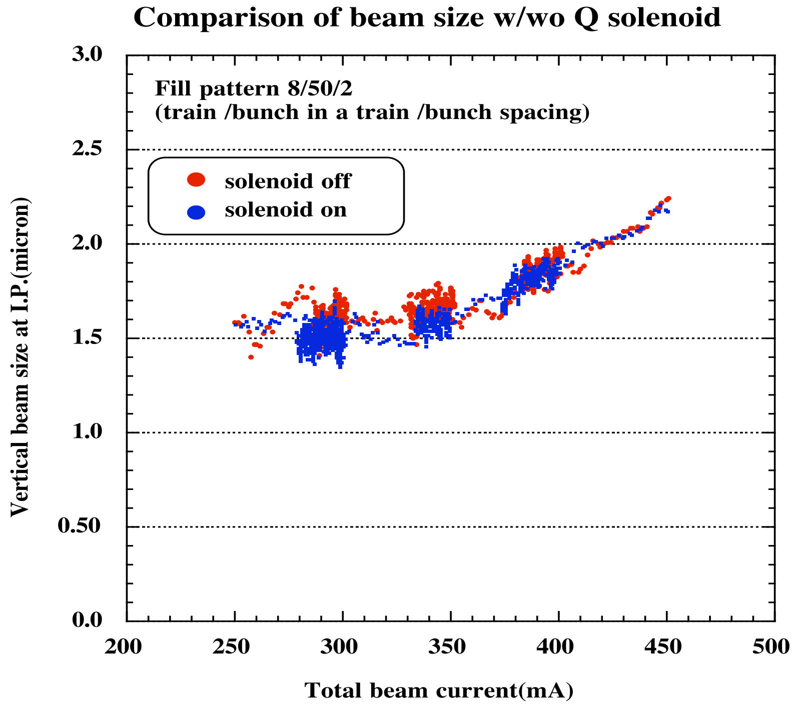


There is no clear difference in the data with or without the solenoid field in the quadrupoles.

3) Vertical beam size measured by the interferometer

The size at the synchrotron radiation source point is translated into that at I.P.

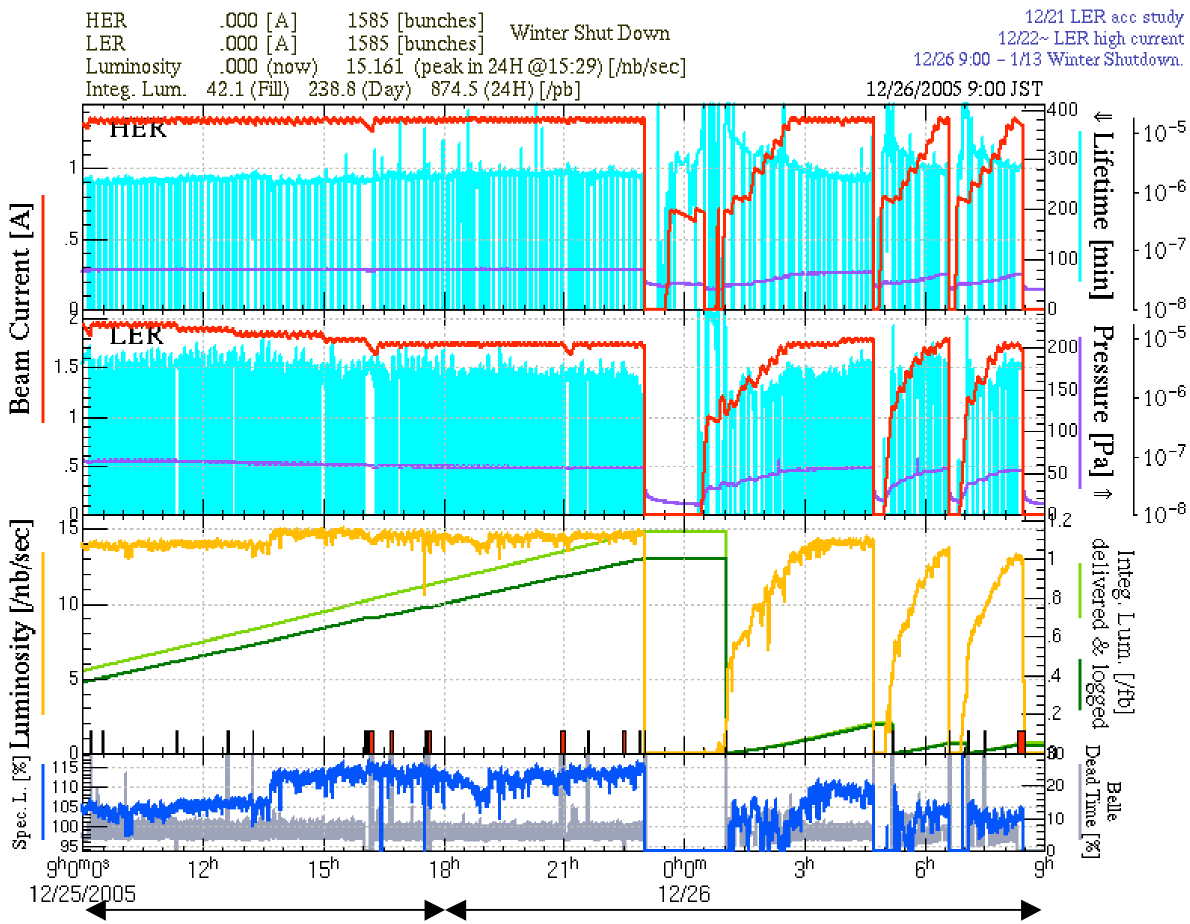




Behavior of the beam size is almost same with or without the solenoid field in the quadrupoles.

4. Effect on luminosity

The effect of the solenoids in the quadrupoles on the luminosity was investigated during physics run.

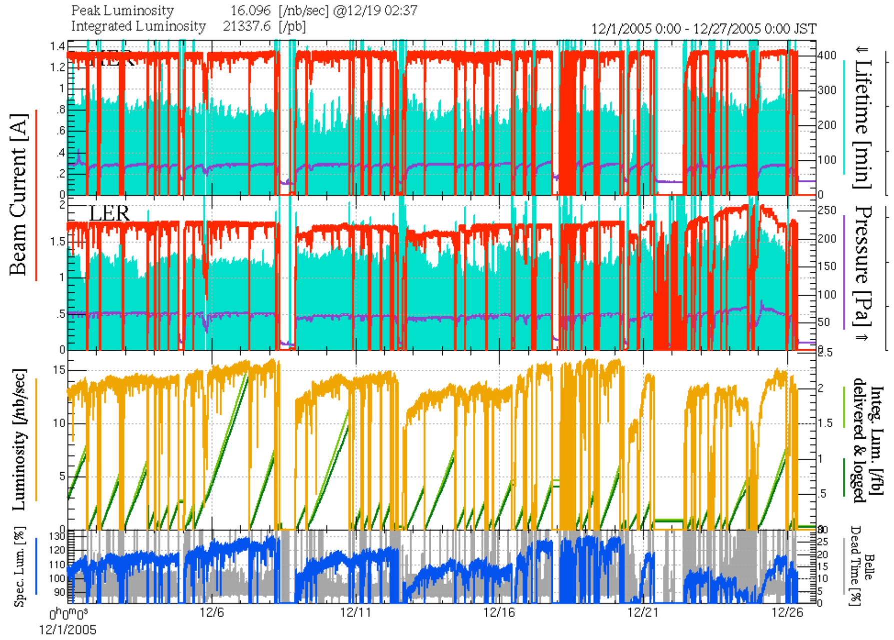


solenoid off

solenoid on

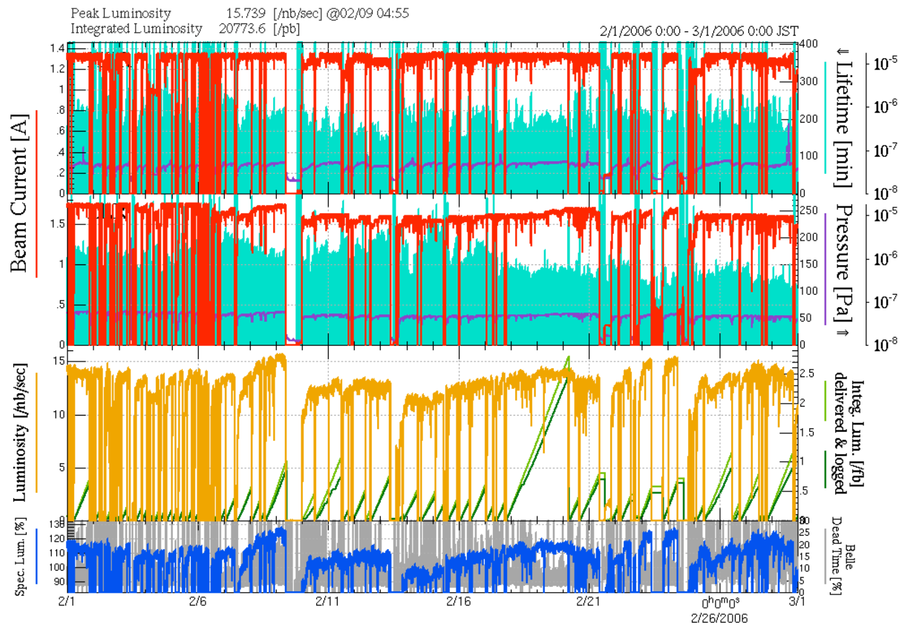
KEKB was operated with turn-on the solenoids in the quadrupoles from this January.

2005.12.01 - 12.26



solenoid off

2006.02.01 - 02.28



solenoid on

No improvement of the specific luminosity was found with turn-on the solenoids in the quadrupoles.

5. Simulations

The results of the experiment were compared with simulation by ECLOUD and CLOUDLAND.

a) Simulation by ECLOUD (F. Zimmermann)

Table 1: Parameters for KEKB electron-cloud simulations.

parameter	symbol	value	
particles per bunch	N_b	8×10^{10}	1.3mA/bunch
rms horizontal beam size	σ_x	600 μm	
rms vertical beam size	σ_y	60 μm	
rms bunch length	σ_z	4 mm	
bunch spacing	$L_{\rm sep}$	1.2, 2.4 m	
quadrupole gradient	B'	5 T/m	
quadrupole length	$l_{\rm quad}$	46 cm	
arc chamber half apertures	$h_{x,y}$	47 mm (round)	
photon reflectivity	R_γ	20% (uniform)	
photoelectrons per beam particle per meter	$d\lambda_{\rm pe}/ds$	0.15 $\rm m^{-1}$	
maximum secondary emission yield	$\delta_{\rm max}$	1.5	
primary energy for max. sec. em. yield	$\epsilon_{\rm max}$	200 eV	
electron reflectivity at 0 energy	R	$\approx 51\%$	
distribution of reflected photons		$\cos\phi$	

Electron cloud in quadrupole field of 5 T/m

(Three different integration routines were tried for the electron motions.)

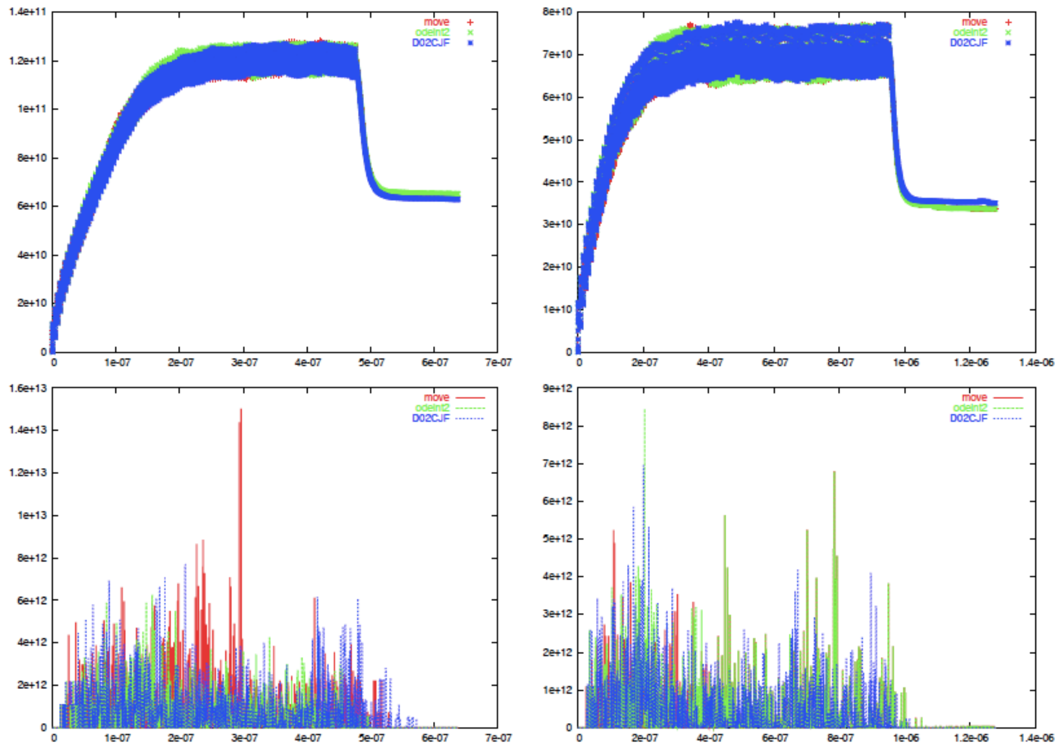
2 spacing 4 spacing

m^{-1}

Electron line density

m^{-3}

Electron central density



sec

The electron central density is less than 10^{12} m^{-3}.

The density will not be enough to cause the ECI according to the rough estimation of the threshold cloud density of the ECI.

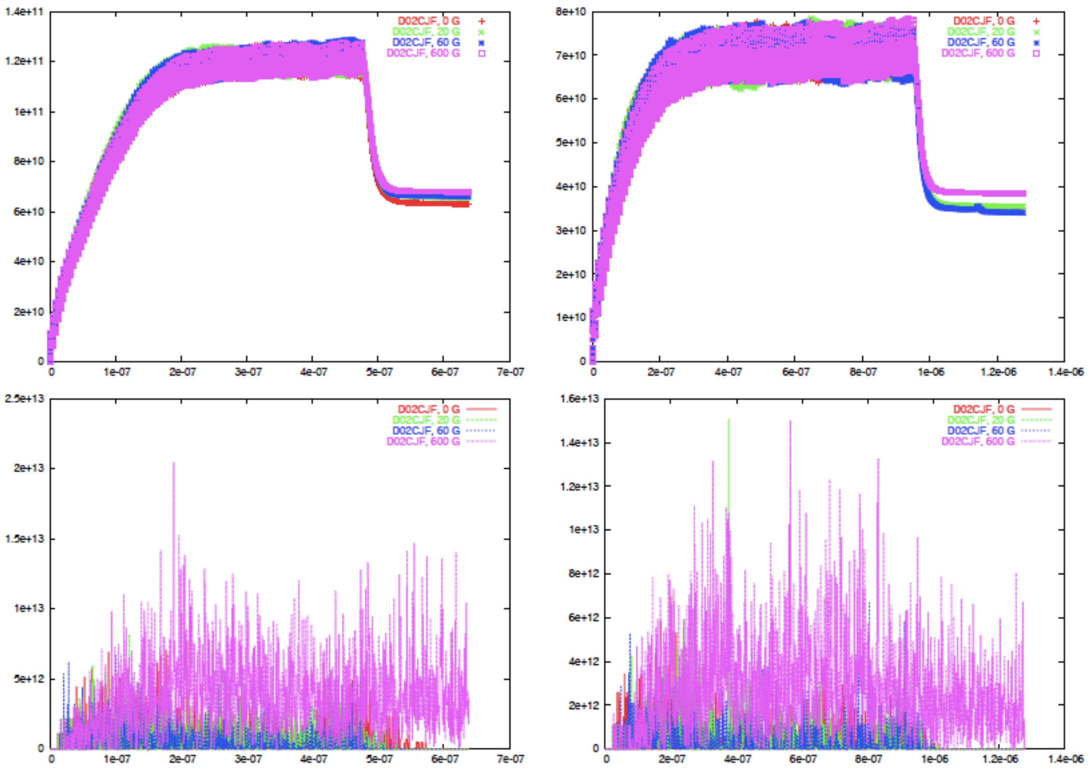
Electron cloud in quadrupole field of 5 T/m with weak solenoid

Solenoid field : 0, 20, 60, 600G

2 spacing | 4 spacing

m^{-1} Electron line density

m^{-3} Electron central density



sec

There is no effect of the weak solenoid on the electron density.

Weaker quadrupole field of 0.1T/m with solenoid field

Solenoid field : 0, 20, 60, 600G

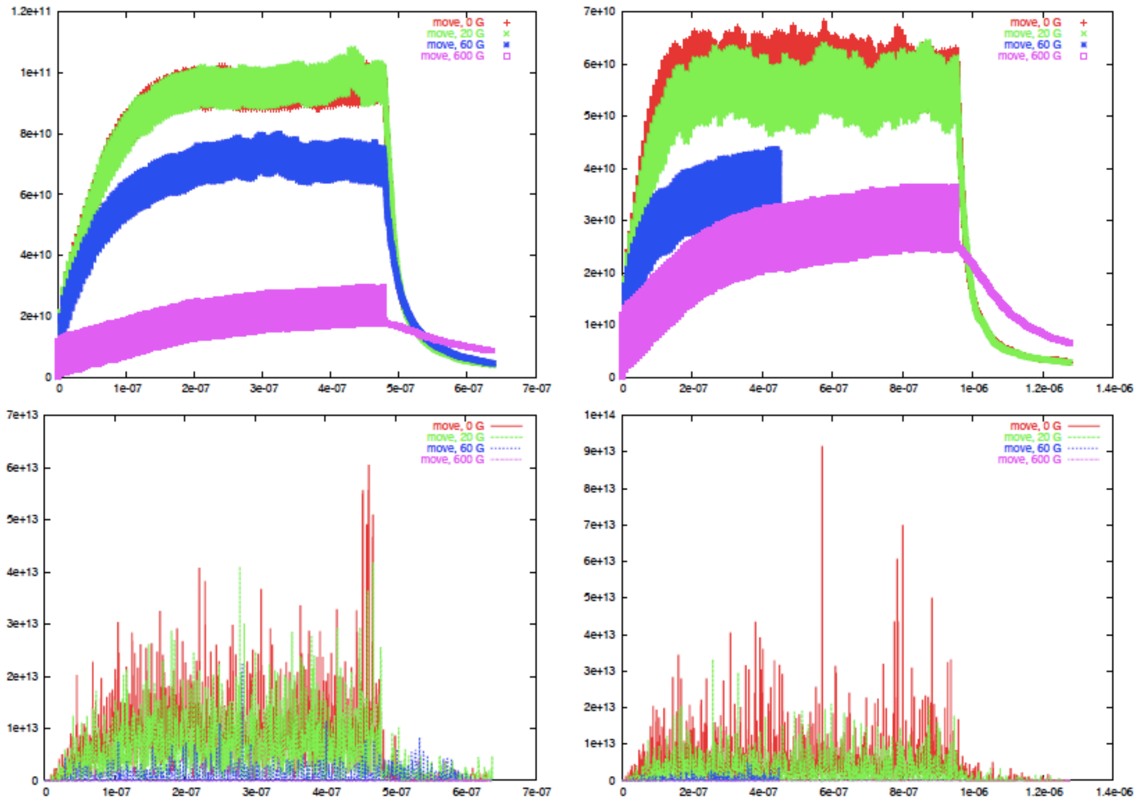
2 spacing | 4 spacing

m^{-1}

Electron line density

m^{-3}

Electron central density



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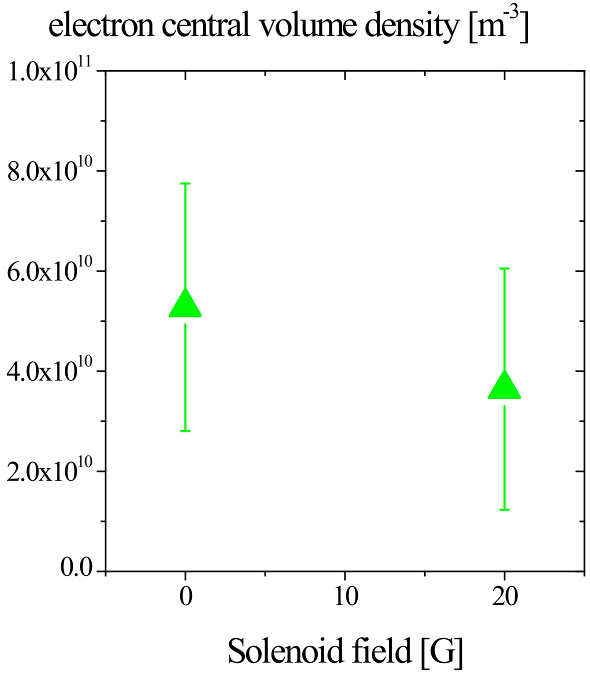
A solenoid of 60 or 600G is effective in reducing the electron density.

b) Simulation by CLOUDLAND (T. Morimoto)

Effect of the solenoid on the electron density

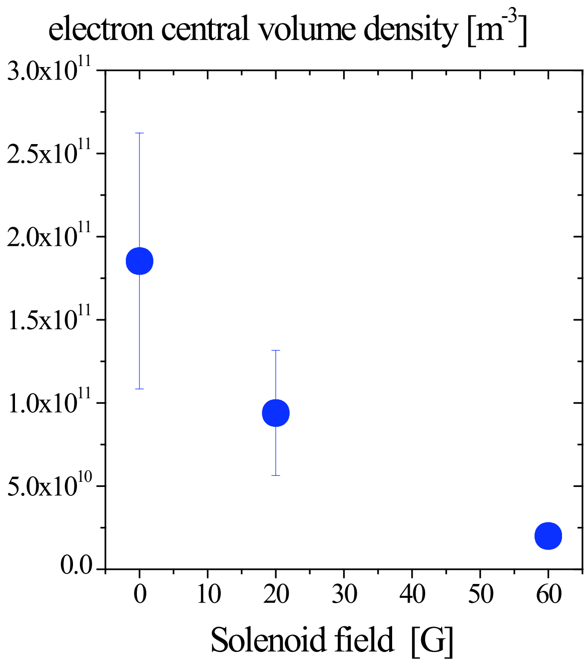
(4 bucket spacing, 2mA/bunch, photoelectron yield 0.1)

Quadrupole field 5 T/m



No effect of the solenoid.

Quadrupole field 0.1 T/m



The solenoid is effective.

The results are qualitatively consistent with those of the ECLOUD.

6. Summary

A flat cable solenoid was developed and installed in quadrupoles to investigate the electron clouds in the quadrupole field.

No clear effect of the solenoids in the quadrupole magnets was found on the sideband, the vertical beam size and the luminosity.

The result of the experiment is consistent with the simulations.

The direct measurement of the electrons by the electron monitor may give a clearer answer on the information of the electron clouds in the quadrupole field (K. Oide).