INTRA-BUNCH FEEDBACK SYSTEM IN THE J-PARC MAIN RING

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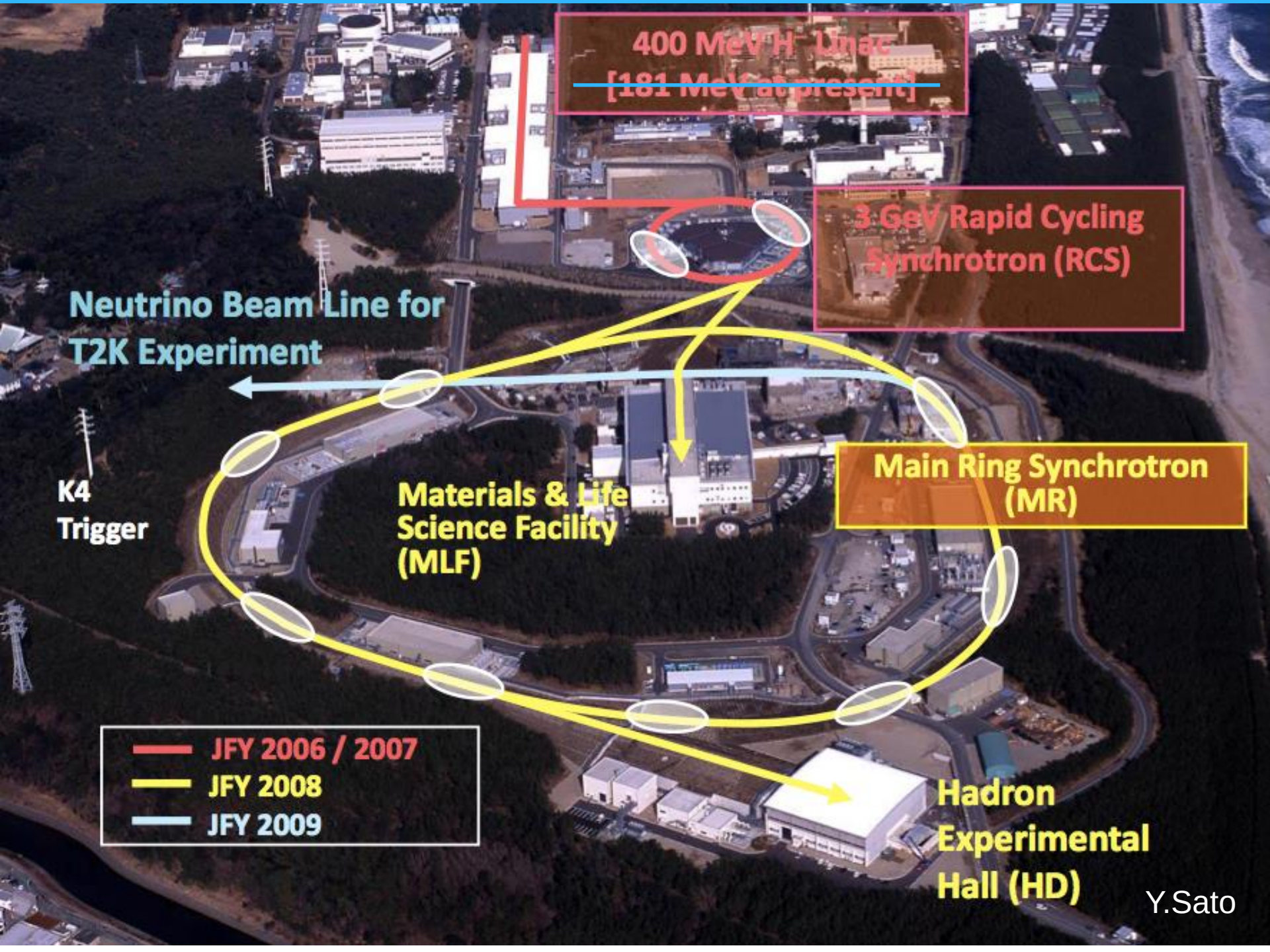
Outline

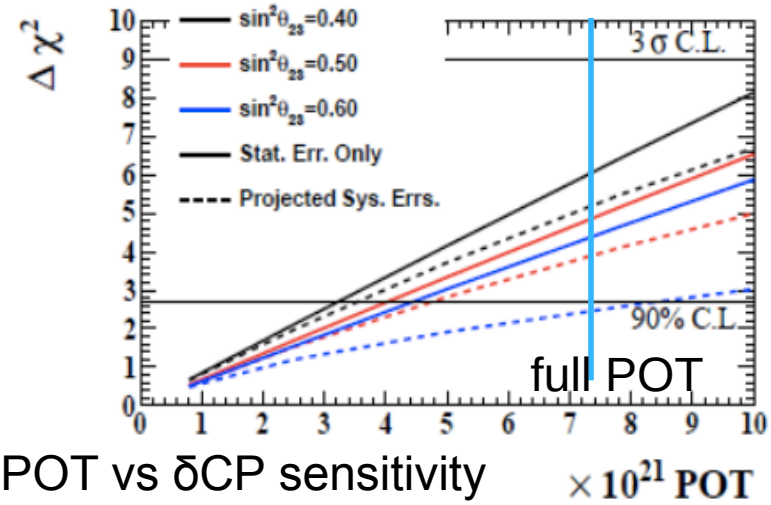
- Introduction
  - J-PARC and T2K
- Feedback system
  - Components
- Tests using the beams
  - Beam Condition
  - Reduction of Oscillation Amplitude
  - Fourier Analysis
- Current Status and Prospects
- Conclusion

INTRODUCTION


400 MeV H⁻ Linac
[181 MeV at present]
3 GeV Rapid Cycling Synchrotron (RCS)
Neutrino Beam Line for T2K Experiment
K4 Trigger
Materials & Life Science Facility (MLF)
Main Ring Synchrotron (MR)
JFY 2006 / 2007
JFY 2008
JFY 2009
Hadron Experimental Hall (HD)
Y.Sato

T2K experiment

- 6.57x10^{20}POT(Proton On Target) are accumuated and discovered ν_e appearance mode.
- Only 8 % of tolal assigned POT.
- Next step is search for CP violation in lepton sector.
- Anti- v run started in 2014.
- Intensity upgade of J-PARC MR is the key to find δ_{CP} in T2K!

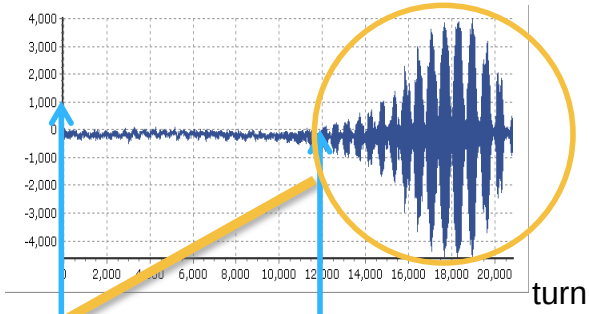


POT vs δCP sensitivity

Instabilities at J-PARC MR

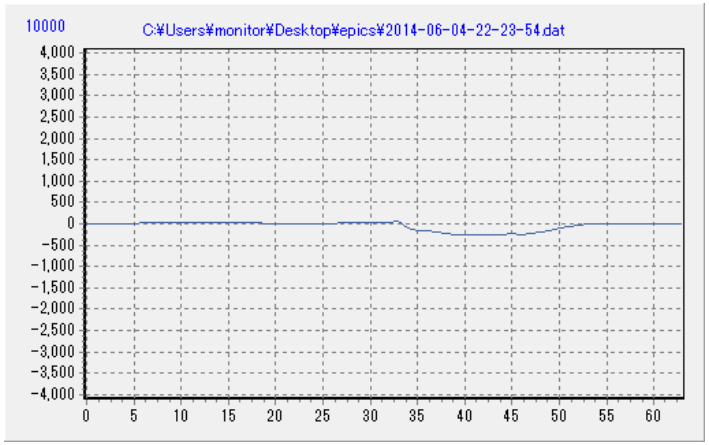
Instabilities has been observed at the beam power 230kW, with chromaticity ξy=*-0.3* .
We avoid this instabilities by tuning chromaticity ξy=*-3.2* .

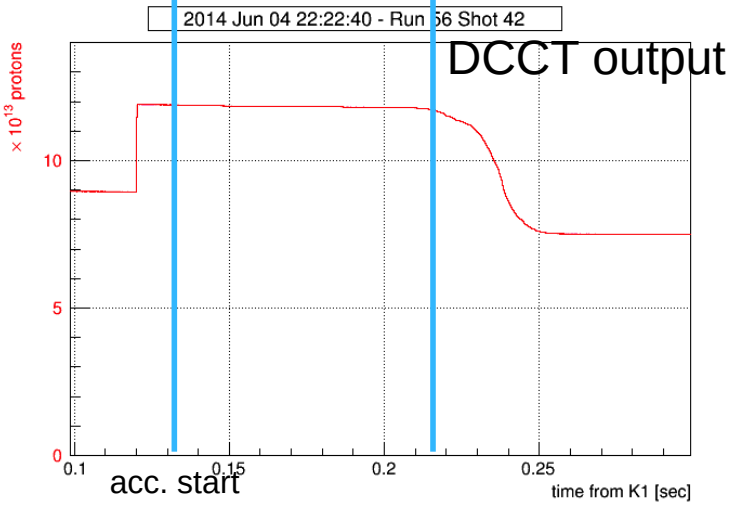
betatron oscillation amplitude



turn

Observed bunch motion (plotted every 4 turns)

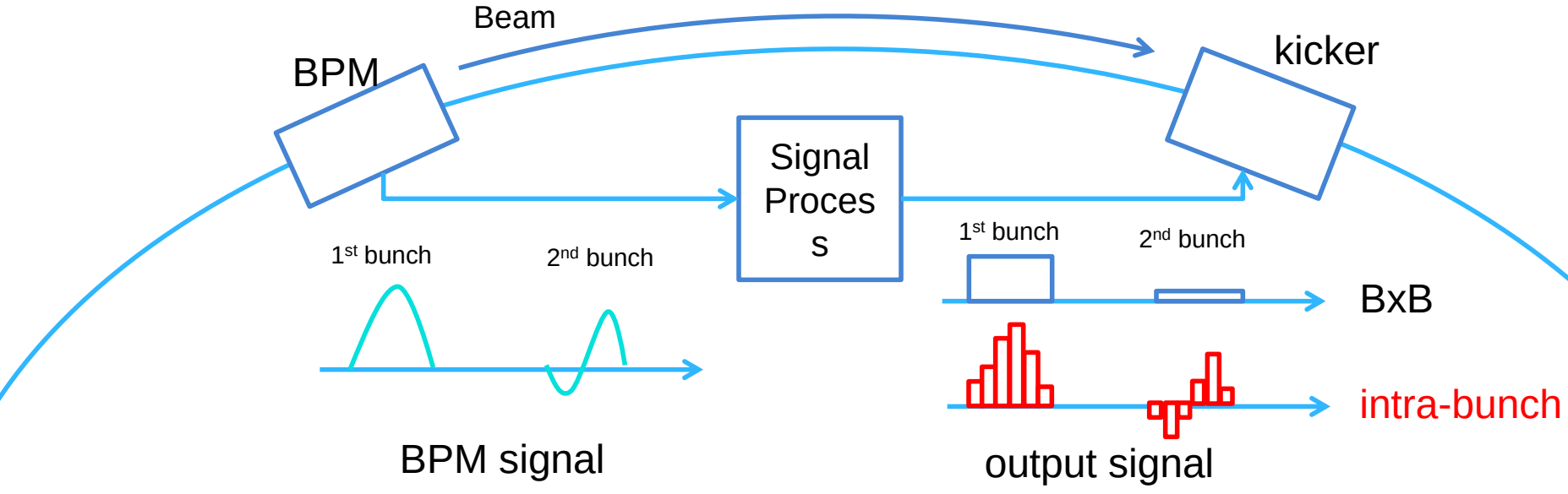




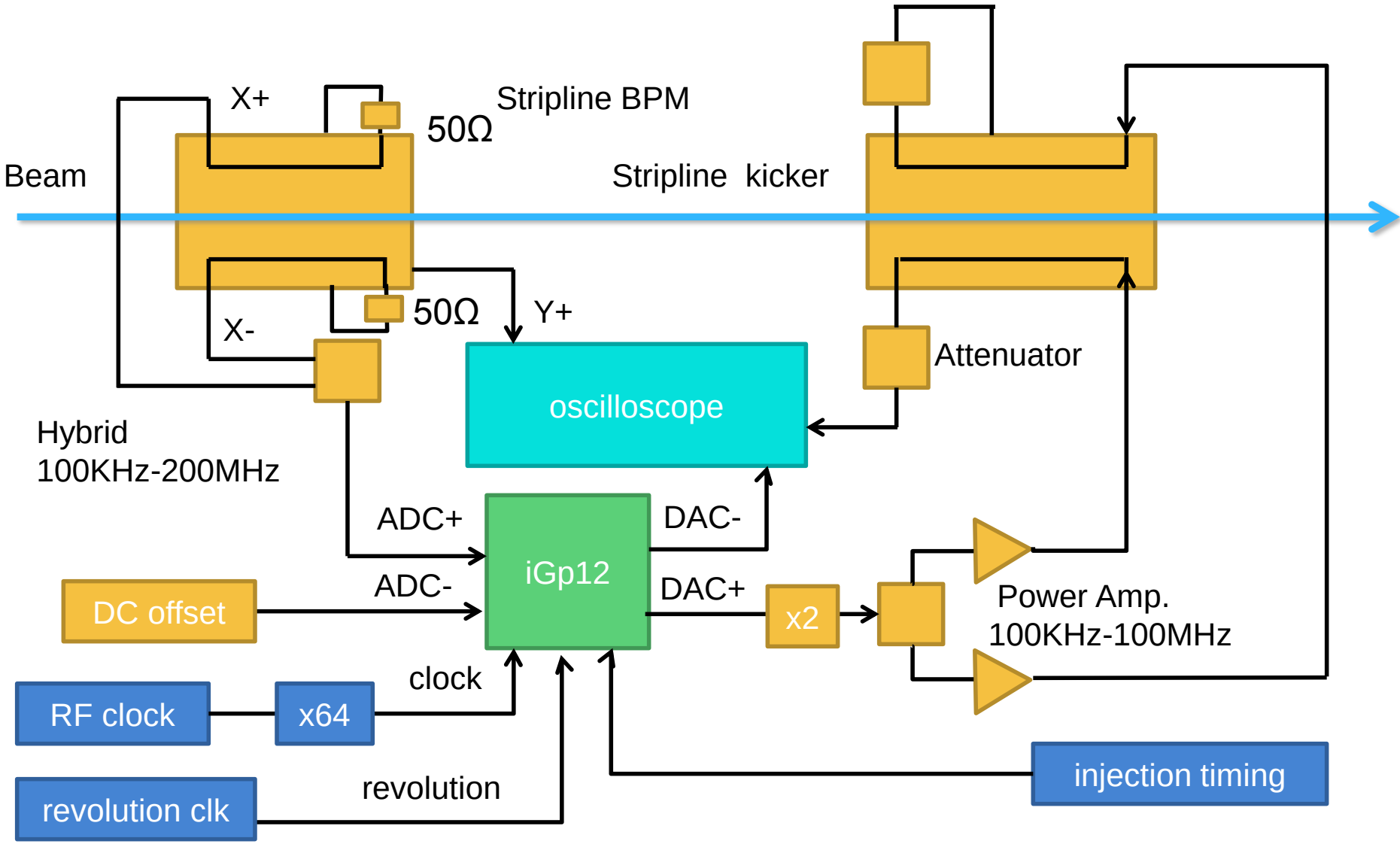
TRANSVERSE FEEDBACK SYSTEMS

Intra-bunch feedback system

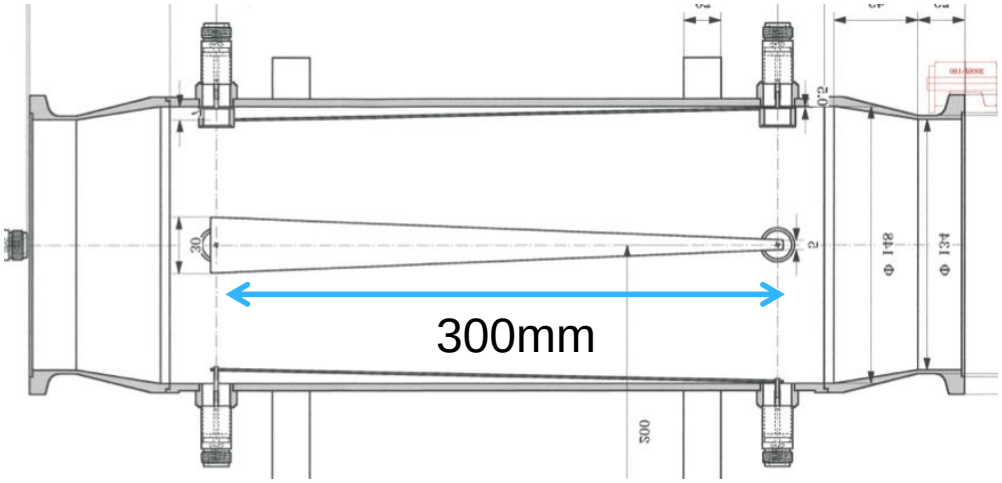
- Bunch by bunch(BxB) feedback system has been developed since 2009.
- used to achieve 230kW beam power.
- Even with the BxB feedback system on, internal bunch oscillations have been still observed-> potentially a source of the beam loss
- A more wideband and precise feedback system –named intra-bunch feedback system- is needed.

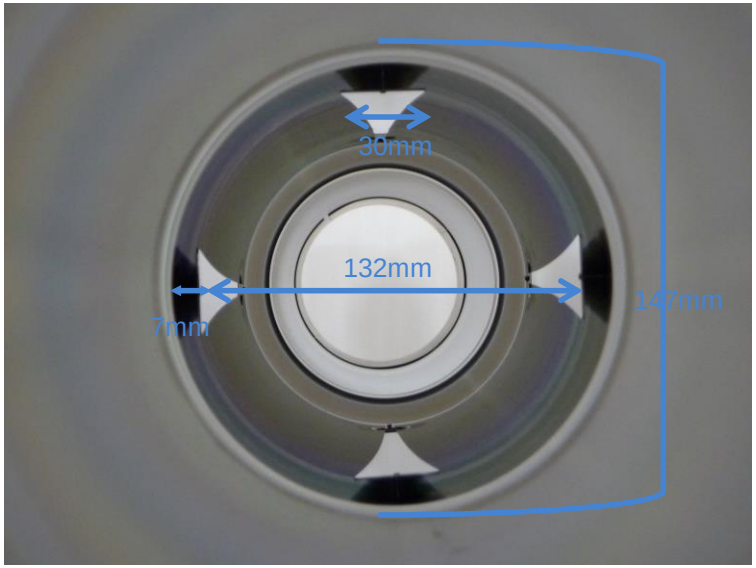


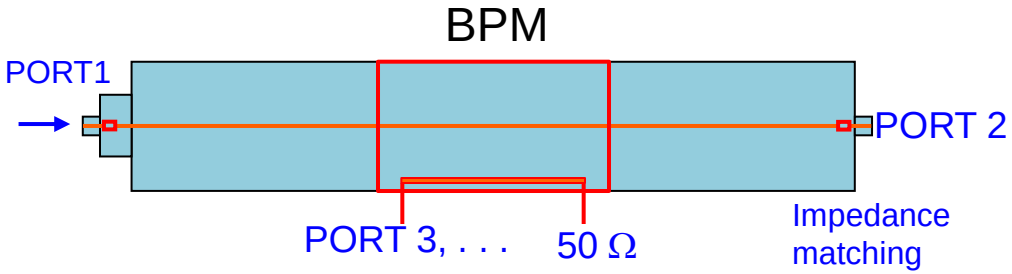
Transverse feedback system –schematic view-



BPM ~exponential directional coupler~



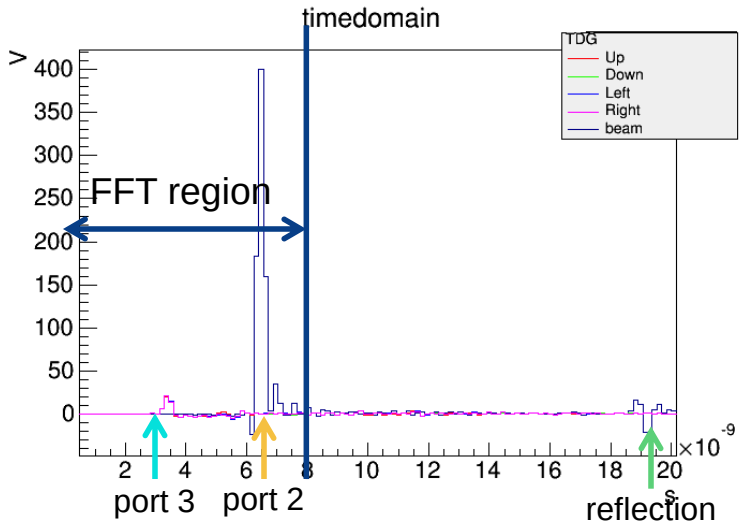


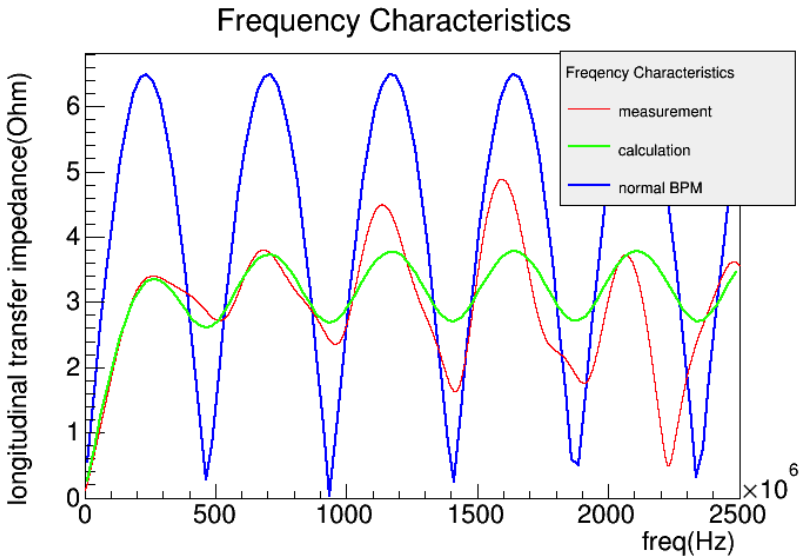


- Linnecar's design in SPS.
- Wideband frequency compared to normal stripline BPM.

- Calibrated with network analyzer by the stretched wire method.

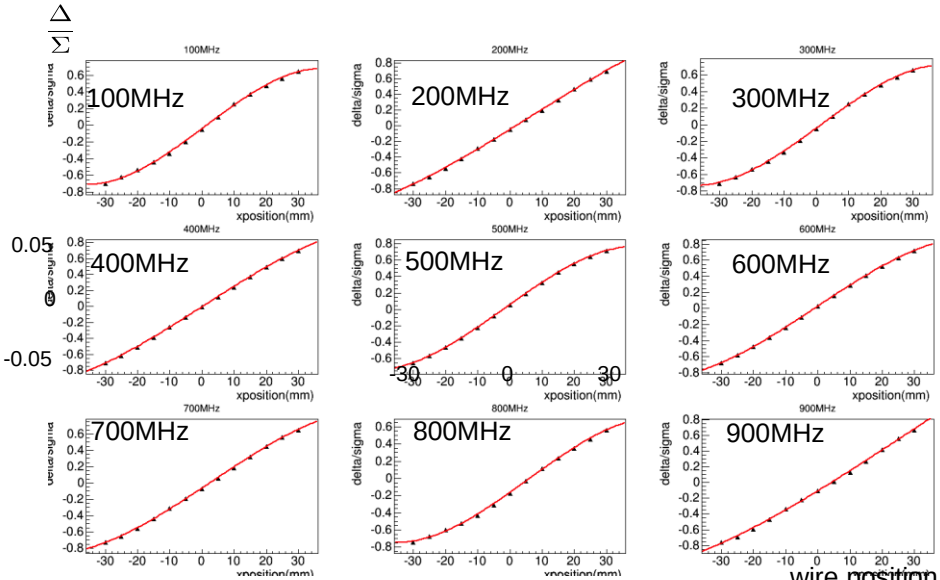
T. Linnecar, "THE HIGH FREQUENCY LONGITUDINAL AND TRANSVERSE PICK-UPS USED IN THE SPS", CERN-SPS/ARF/78-17 (1978)





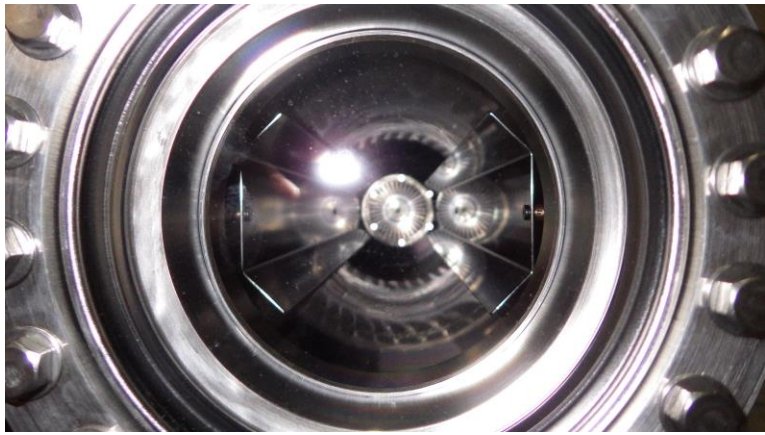
- Using time domain gate (TDG) method to cut
  the effect of reflections.
- achieved sensitivity around 1GHz.posotion sensitivity constant κ=0.027±0.002 (/m) at the range 1MHz-1GHz

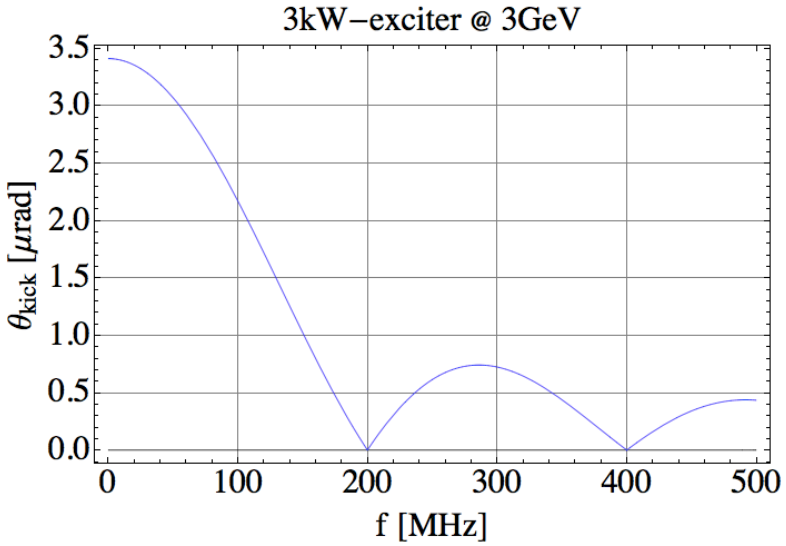
$$\frac{X_+ - X_-}{X_+ + X_-} = \kappa x$$

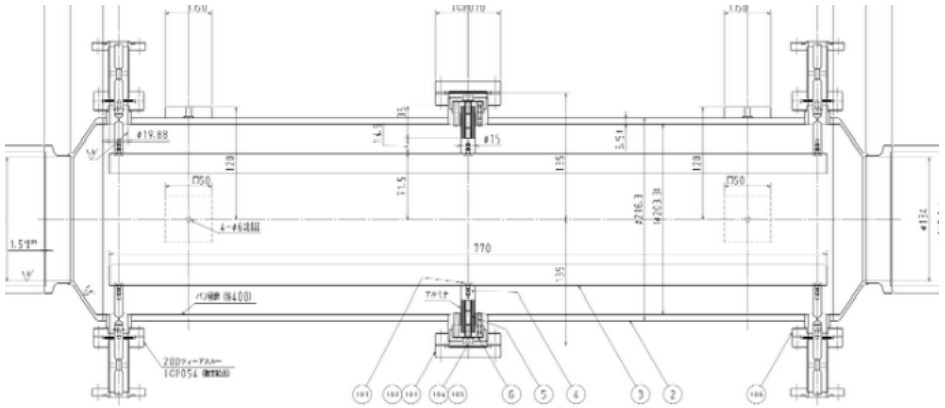


kickers and power amplifiers

- Stripline kicker is used.
- Diamond-like Carbon coating for reduction to multipactoring when used for slow extraction.
- Kick angle is 3.5 μrad at 3GeV,DC with two 3kW power amps.
- The bandwidth of whole system is limitted by power amp(100kHz-100MHz)







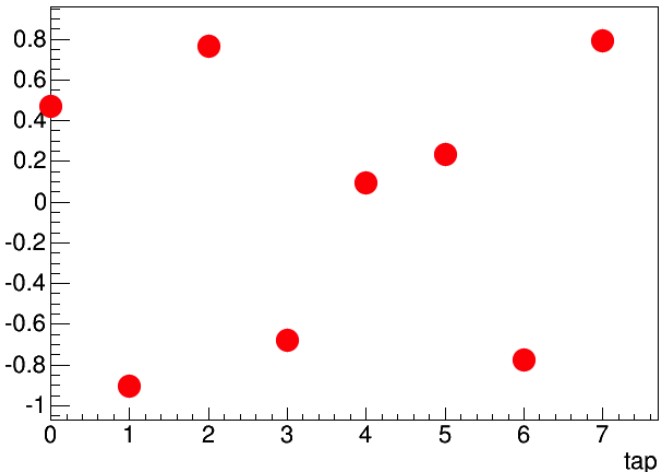
Signal processing - iGp12 -

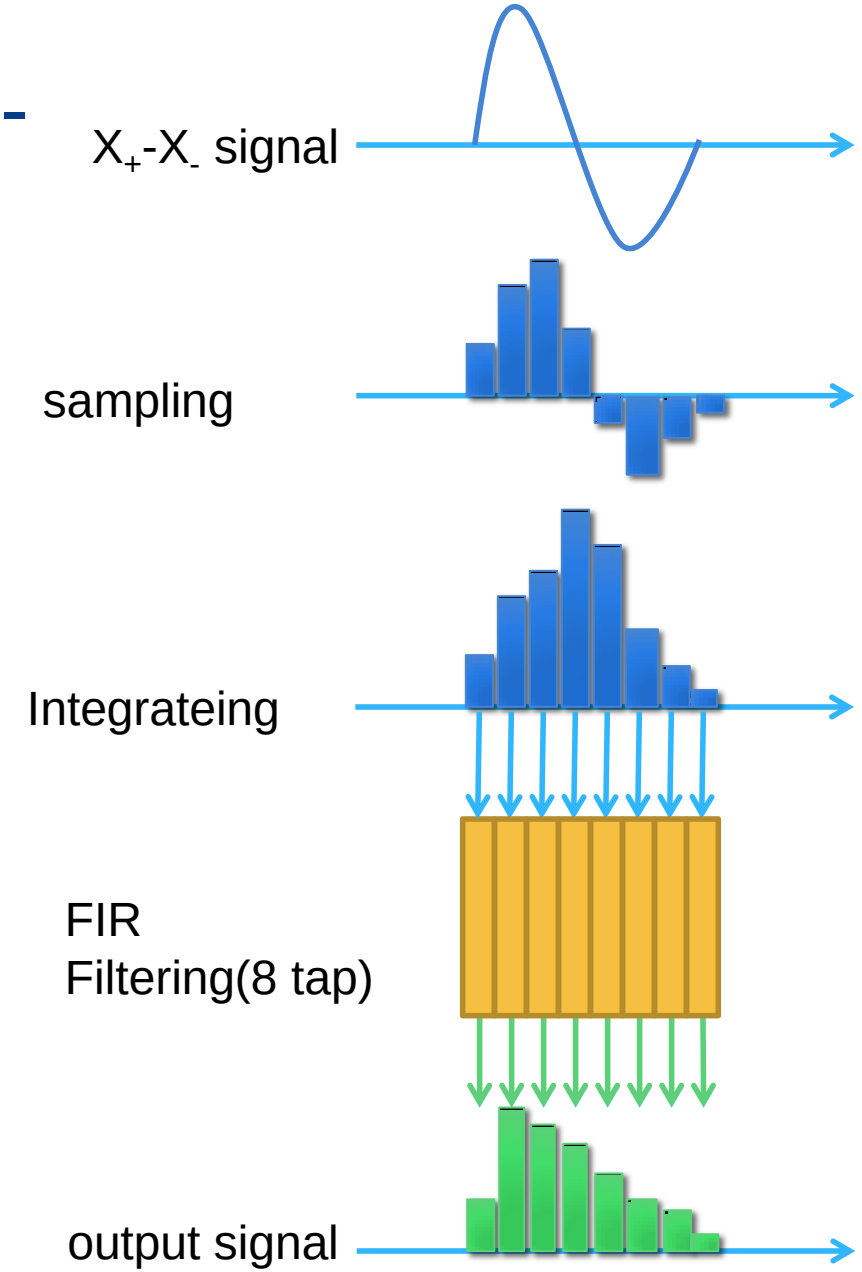
- Clock frequency is 108MHz (f_{RF}x64).
- Before filtering, The BPM singals are integrated to reconstruct beam position.
  - The frequency characteristics of the BPM is approximately linear in the low frequency region (up to 200MHz)

Filter coefficients

$$b[n] = \sin((n-1)\omega T_s + \Delta\phi) - \Delta$$

$$\Delta = \frac{1}{N_{tap}} \sum_{n=0}^{N_{tap}-1} \sin(n\omega T_s + \Delta\phi)$$





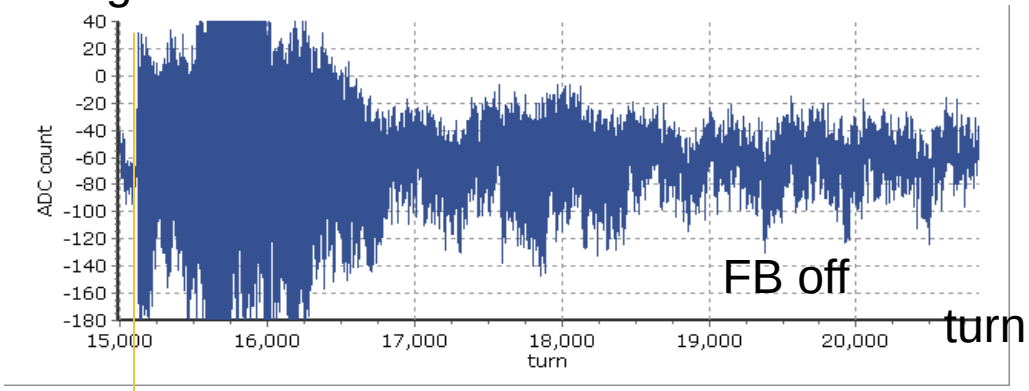
TESTS USING THE BEAM AT THE ENERGY 3GEV

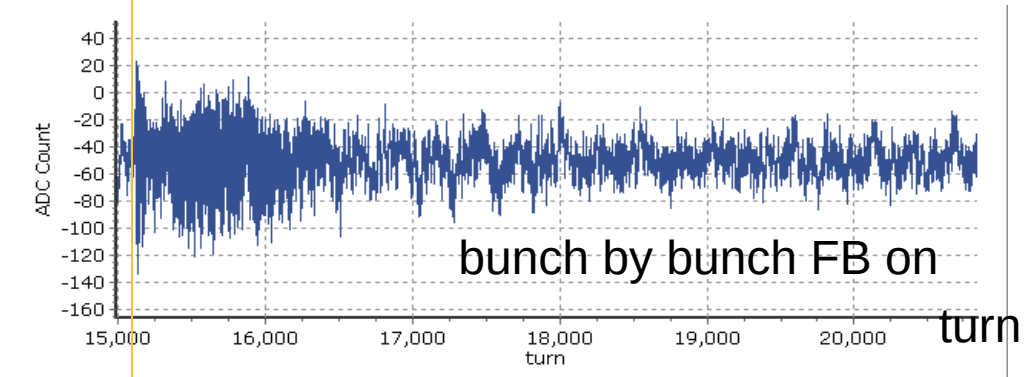
Beam Parameters

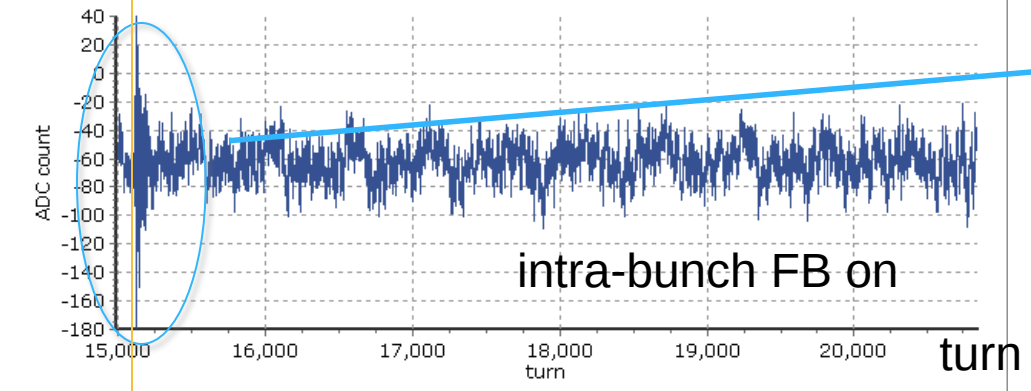
	Beam test	Operation
Circumference	1568m	
Energy	3GeV	3–30GeV
Repetition Period	2.48s	
Beam Power	0.5 kW (3 GeV)	230kW (30GeV)
RF Frequency	1.67 MHz	1.67–1.72MHz
Number of bunches	1	8
Synchrotron tune	0.0017	0.002–0.0001
Betatron tune (hor./ver.)	22.41/20.75	
Intensity (/pulse)	2.7×10^{12}	1.3×10^{14}
Bunch length	150–200 ns	50–200 ns
Chromaticity (hor./ver.)	+0.5/+1.2	−4 – −1
Horizontal feedback	off/BxB FB/intra-bunch FB	
Vertical feedback	BxB FB on	

Reduction of Oscillation Amplitude

single kick



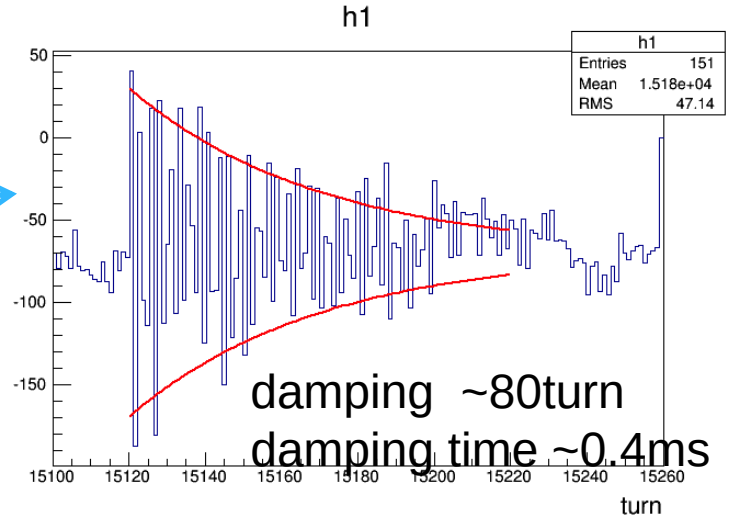




-We test the supression of single kick by injection kicker.
-Sugimoto-san presented about this single kick in the poster MOPME069

-Feedback systems suppress betatron amplitude well.

-Compare with BxB FB and intra-bunch FB, intra-bunch FB suppress better than BxB FB.



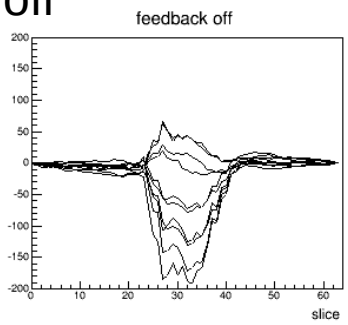
Delta signal motion

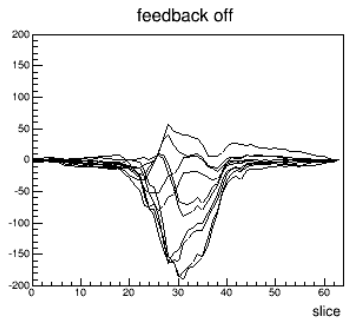
Signals are superimposed
10 times every 5turns

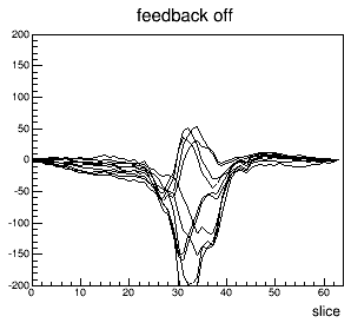
FB off

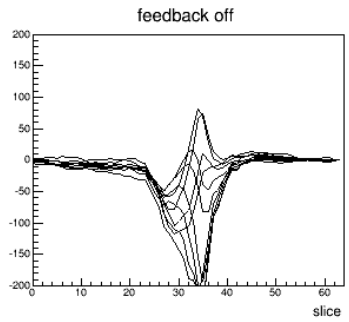
bunch by bunch FB on

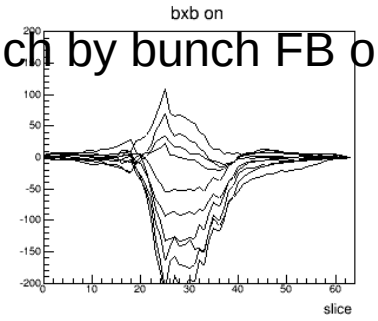
intra-bunch on

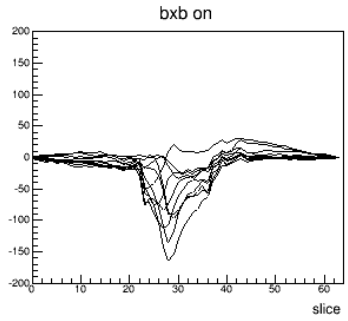


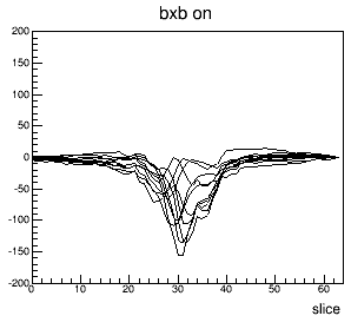


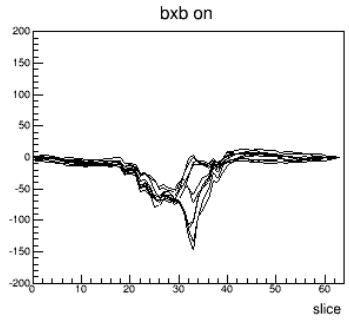


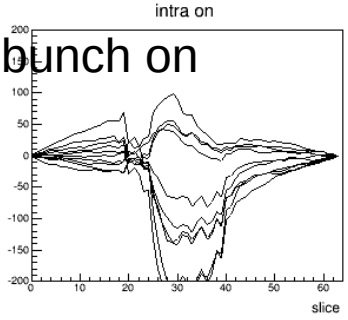


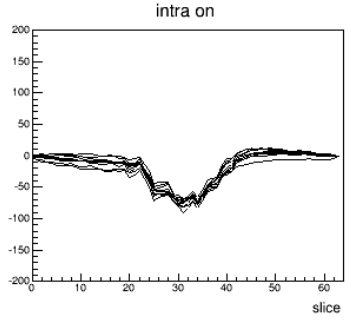


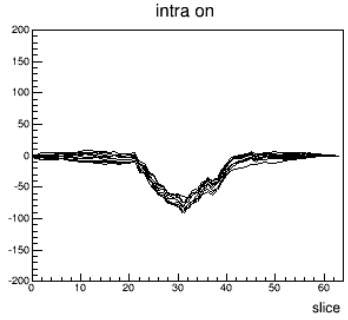


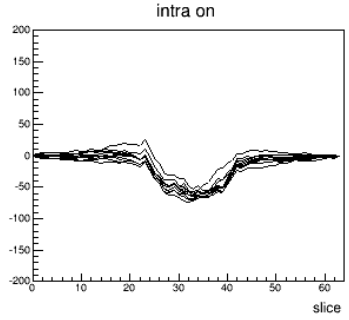












15200th turn

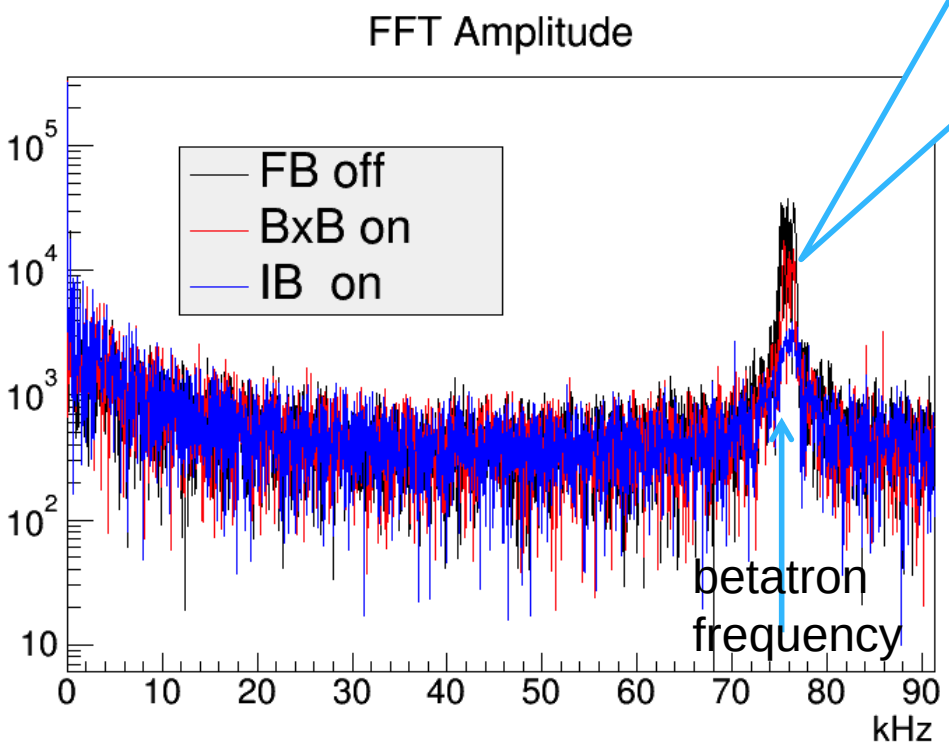
15400th turn

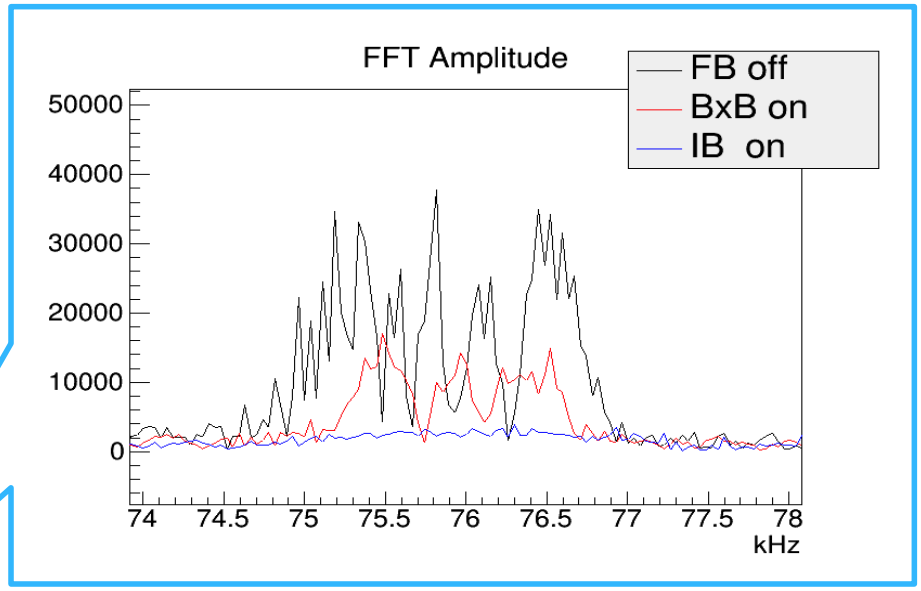
15600th turn

15800th turn

Fourier Analysis

Betatron amplitudes at the range from 15000th to 21830th turn FFT applied.

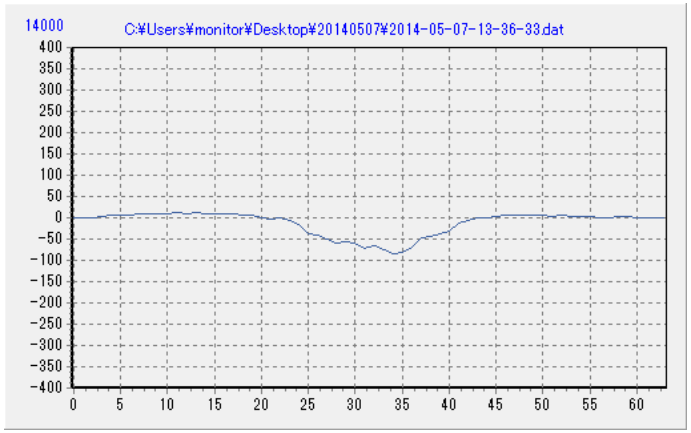




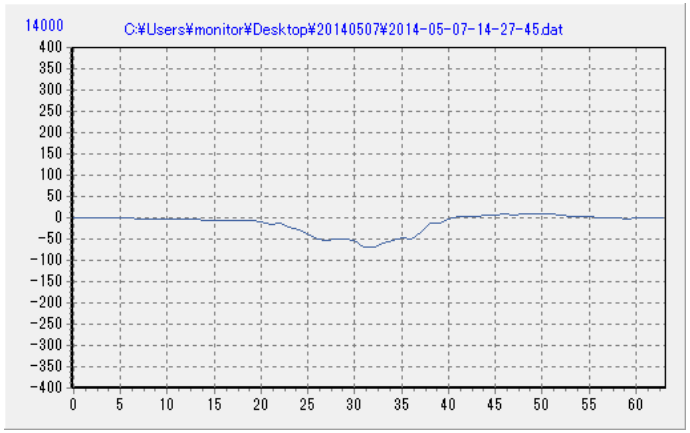
-Reduction betatron frequency amplitude
-Sideband frequencies are disappeared.

Internal bunch motions

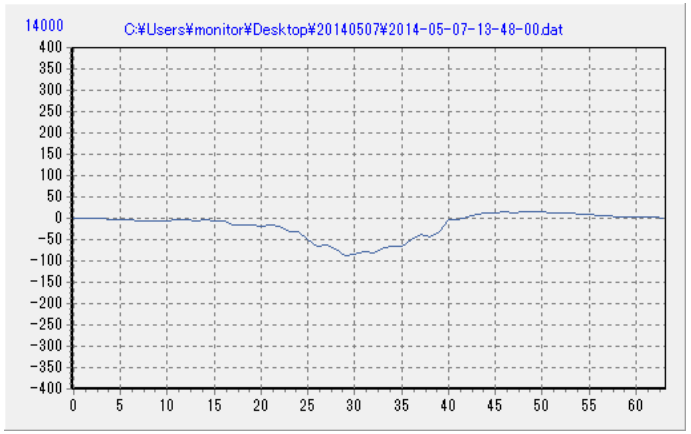
FB off



BxB FB on



intra-bunch on



Current status

- Horizontal intra-bunch FB is used in routine operation to suppress the beam loss caused by single kick at injection (only at 3GeV).
- Reduced beam loss at injection 350 W -> 170 W
- damping time is ~100 turn
- Vertical intra-bunch FB is also developed and used at 3 GeV.

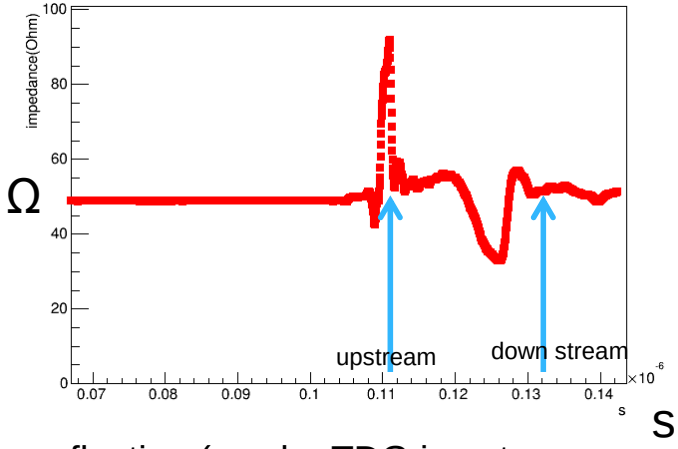
Prospects

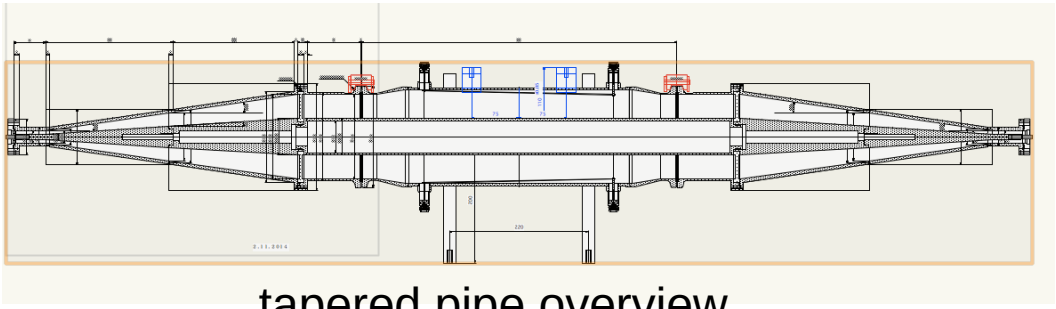
- Feedback in vertical direction during acceleration
  needed for operation with full chromaticity correction.

- BPM improvement
  - We plan to make a refinements.
    Keep impedance constant more precisely.

- BPM calibration
  - The stretched wire method has difficulties in estimating the reflection.(maybe TDG is not sufficient.)
  - We made special tapered pipe for calibration.
  - (reflection is less than 1% in simulation.)

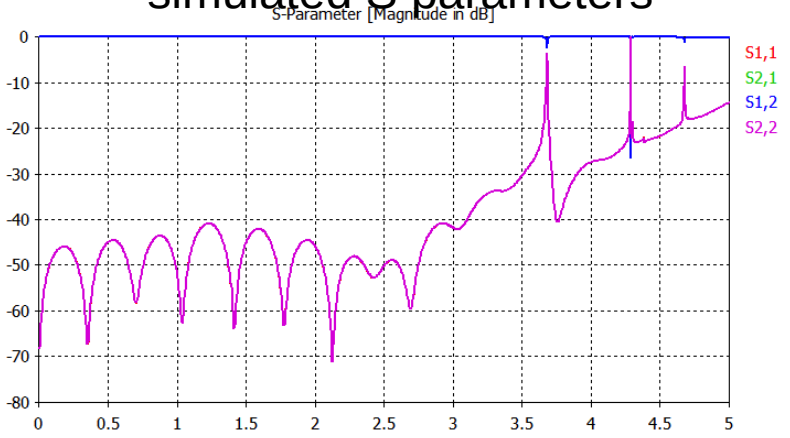
characteristic impedance of the electode measured by TDR.





tapered pipe overview

simulated S parameters



Conclusion

- Intra-bunch feedback system has been developed.
- We succeeded to suppress the intra-bunch motion with this system.
- We used this system to suppress the beam loss by injection kicker at routine operation (beam power ~230kW).
- Reduced the beam loss 350W->170W
- Damping time of this sytem is ~100 turns=~0.5ms
- We plan to make a new BPM and improve the BPM calibration.
- We have to tune this system for acceleration to operate with full chromaticity correction.