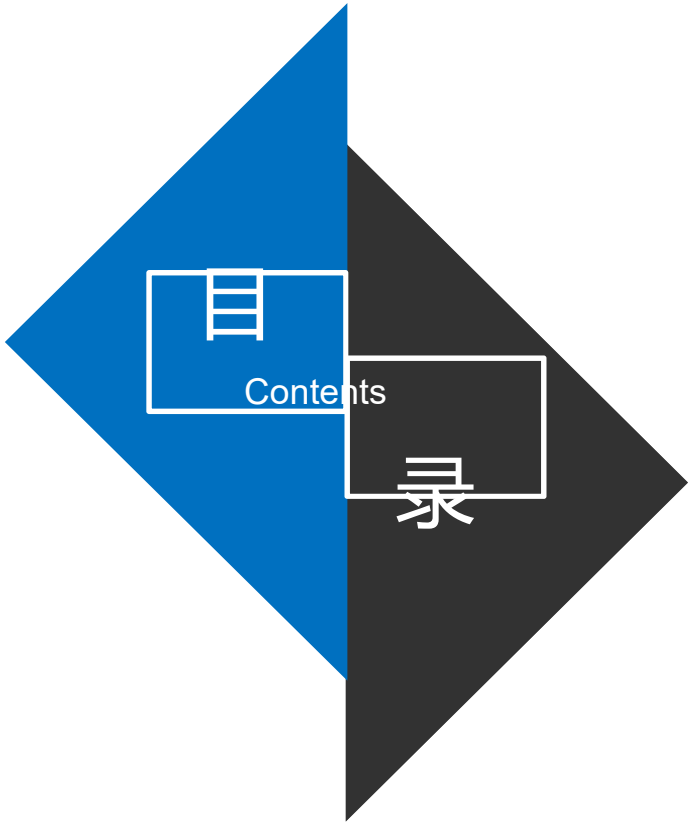
NSRL 中国科学技术大学 国家同步辐射实验室 NATIONAL SYNCHROTRON RADIATION LABORATORY

Beam feedback and IP feedback for STCF

Joint Workshop on Future Charm-tau Factory

Zeran Zhou

NSRL USTC 2019 09 26



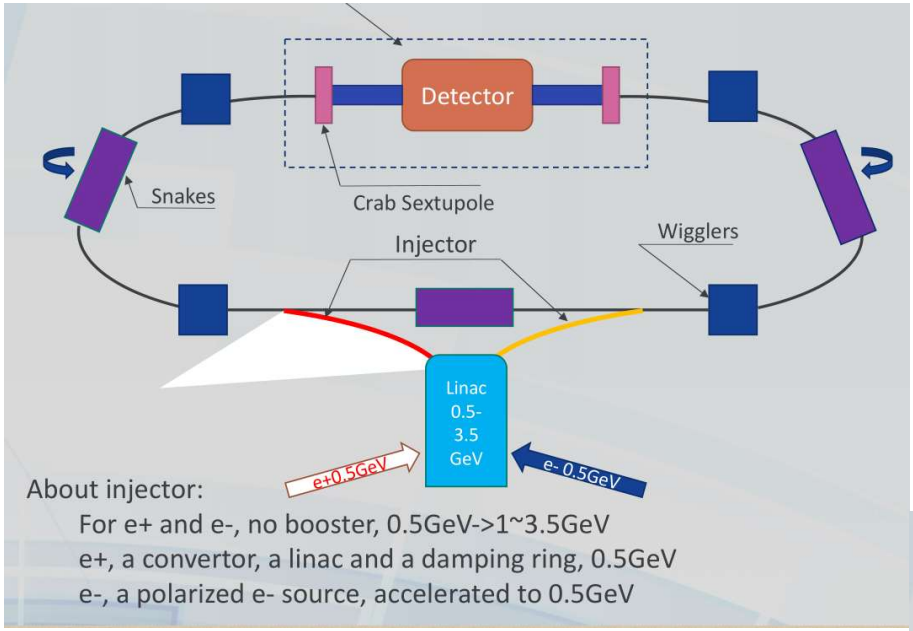
01 Motivation

02 Beam feedback Developing

03 IP feedback study

04 Summary

Motivation



About injector:

For e+ and e-, no booster, 0.5GeV->1~3.5GeV

e+, a convertor, a linac and a damping ring, 0.5GeV

e-, a polarized e- source, accelerated to 0.5GeV

Impedance and Collective Effects

- Characteristics for Super Tau-Charm Factory beam
  - High Current: ~2A; (compared to light sources)
  - Low Energy (compared to B factory, FCC-ee/CEPC…)
  - For Ring only: Like 3rd Generation Light Source
  - For Collider: Beam-beam Effects
  - Single Bunch:
    - Touschek, Microwave instability, Bunch Lengthening, TMCI, IBS, etc.
  - Multi-bunch:
    - Coupled-Bunch Instability, HOM, Electron Cloud, etc.

Multi-bunch collective phenomena are a big limitation to high current operation in storage rings:

--transverse and longitudinal instabilities

--beam quality deterioration

--beam loss

high beam currents have been possible only by using powerful beam feedback systems(electron ring, positron ring, damping ring)

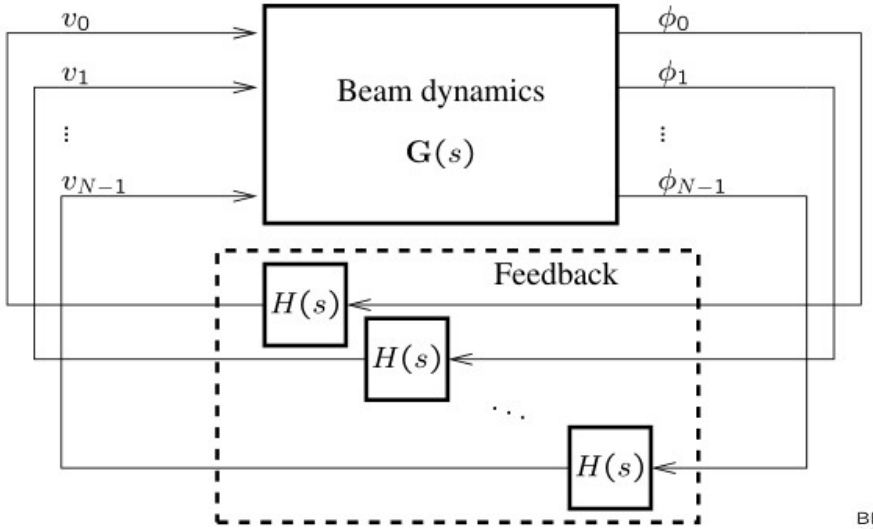
Parameters	Phase1	Phase2
Circumference/m	600~800	600~800
Optimized Beam Energy/GeV	2.0	2.0
Beam Energy Range/GeV	1-3.5	1-3.5
Current/A	1.5	2.0
Emittance $(\varepsilon_x/\varepsilon_y)$/nm·rad	6/0.06	5/0.05
β Function @IP (β_x^*/β_y^*)/mm	60/0.6	50/0.5(estimated)
Full Collision Angle 2θ/mrad	60	60
Tune Shift ξy	0.06	0.08
Hourglass Factor	0.8	0.8
Aperture and Lifetime	15σ, 1000s	15σ, 1000s
Luminosity @Optimized Energy/$\times 10^{35}$cm^{-2}s^{-1}	~0.5	~1.0

Two feedback systems are needed

- Beam Feedback system should handle:
  - horizontal and vertical planes, also longitudinal plane;
  - various unstable modes coming from unknown sources:
    - Resistive wall
    - Photo electron instability
    - Fast ion instability
    - Injection kicker induced oscillation

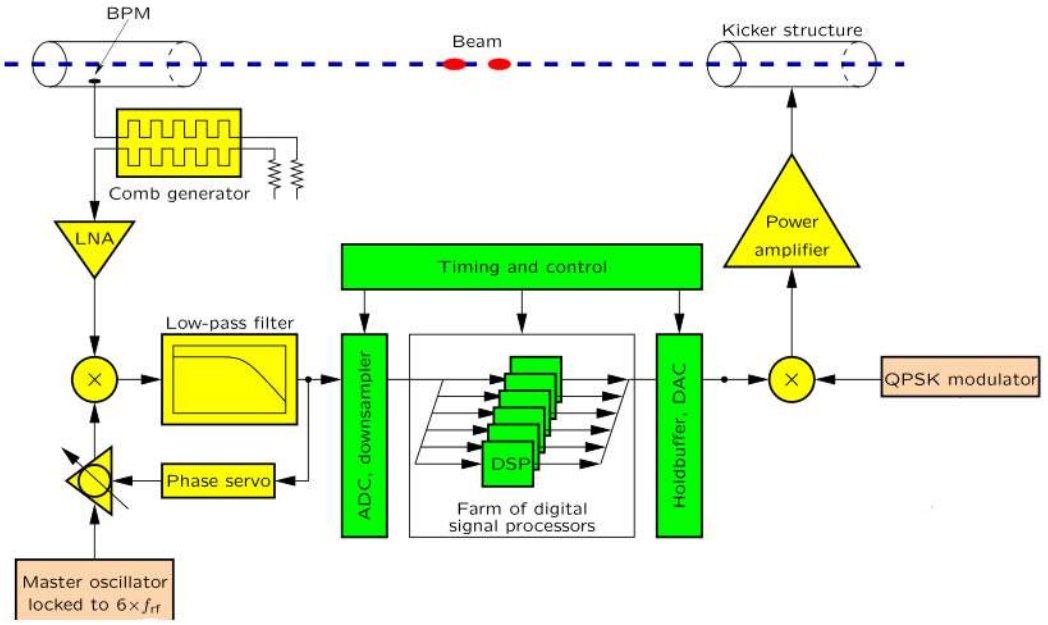
- IP Feedback system to maximize luminosity
  - A luminosity dither system is needed for collision orbit feedback, finding the horizontal offset at the interaction point (IP) that maximizes luminosity.

Basic idea of bunch-by-bunch feedback



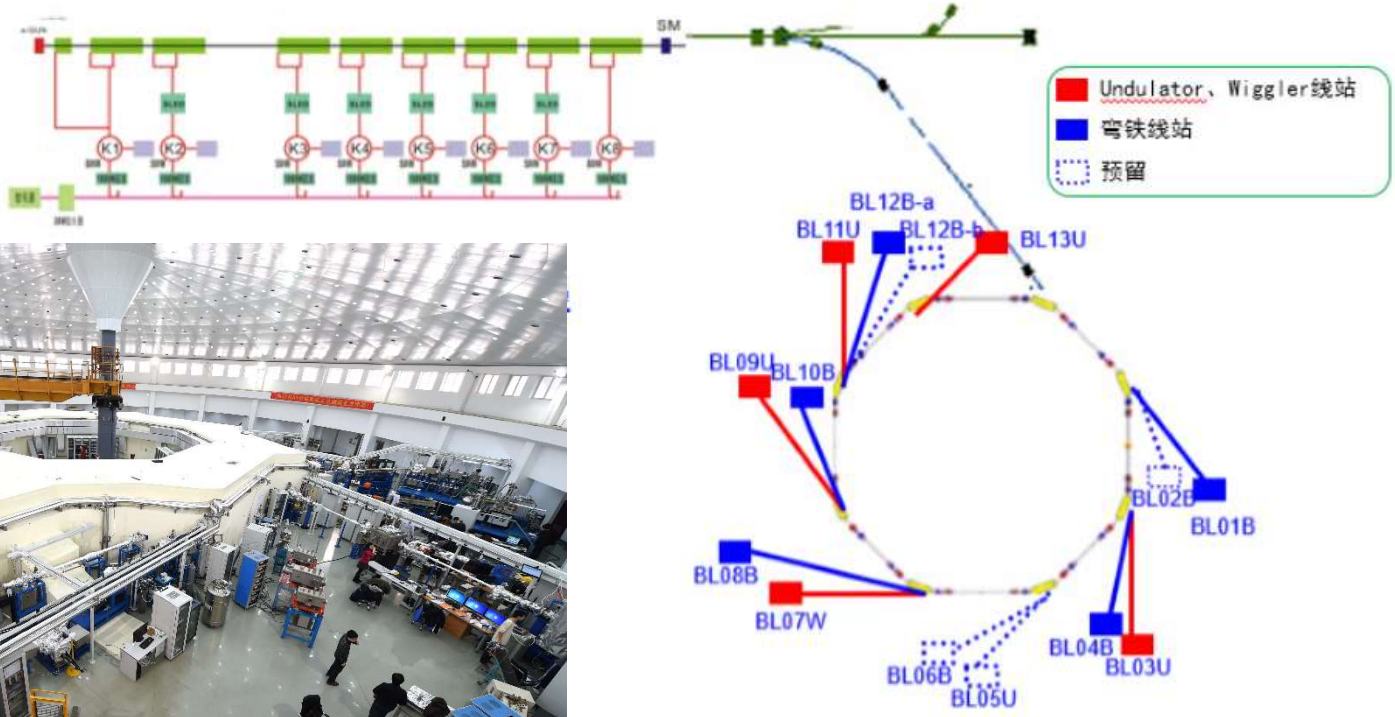
Coulpled-bunch instabilities are detected using BPMs:
1. Multi-input multi-output (MIMO) system of beam;
2. For N bunches, there are N inputs and outputs.
3. Sequential processing, parallel analysis.

A bunch-by-bunch feedback individually steers each bunch by applying electromagnetic kicks every time the bunch passes through the kicker.



Hefei Light Source(HLSII)

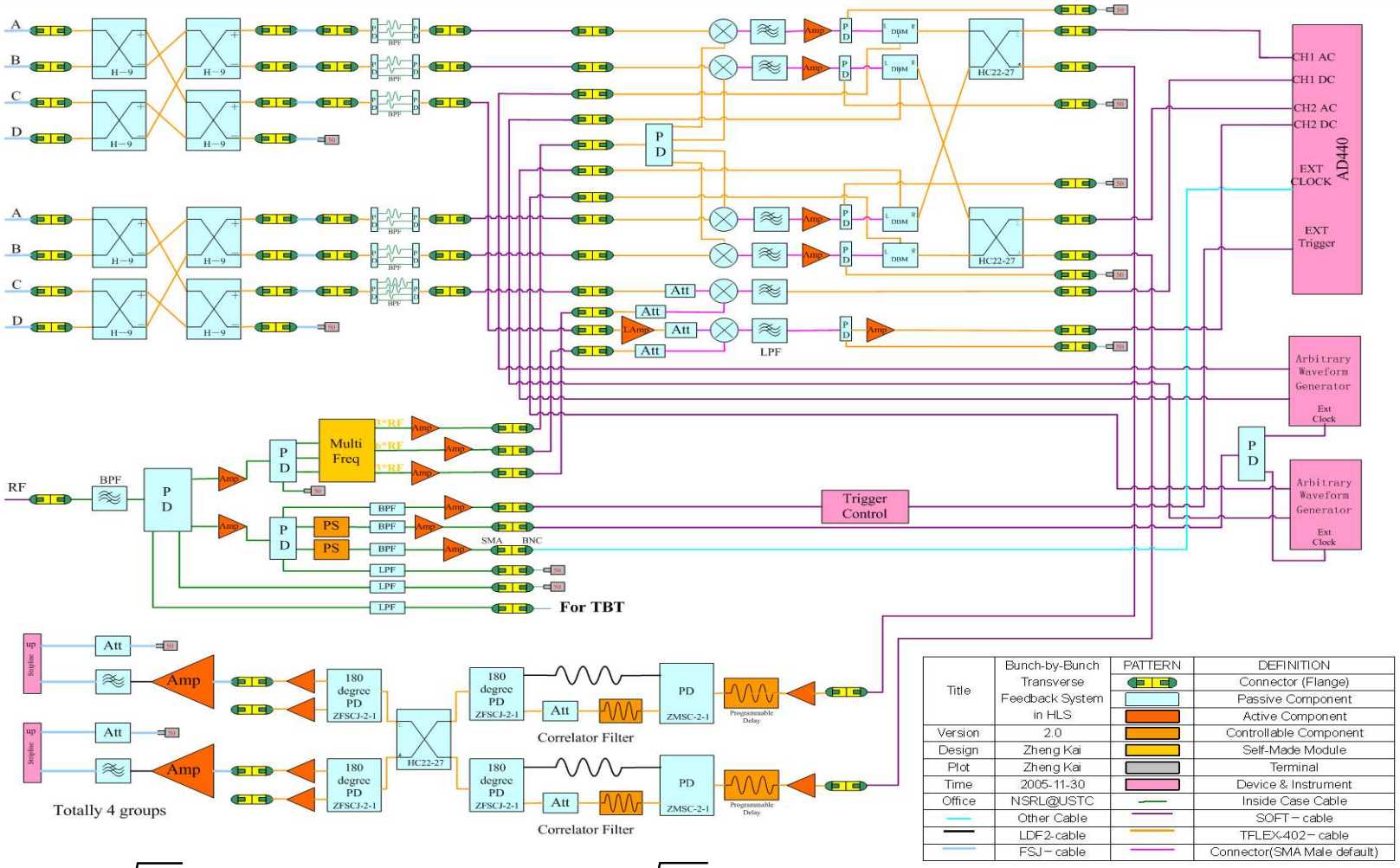
HLSII is 800MeV synchrotron radiation facility with 360mA current, 66m circumference storage ring and an 800 MeV full energy injection linac, which has complete from HLS to HLSII at 2014, top-up operation at 2018.



Timeline of BxB system at HLS

- 2005~2008 Analog transverse bxb feedback system
- 2007~2010 Digital transverse bxb feedback system
- 2014~now Digital transverse and longitudinal feedback

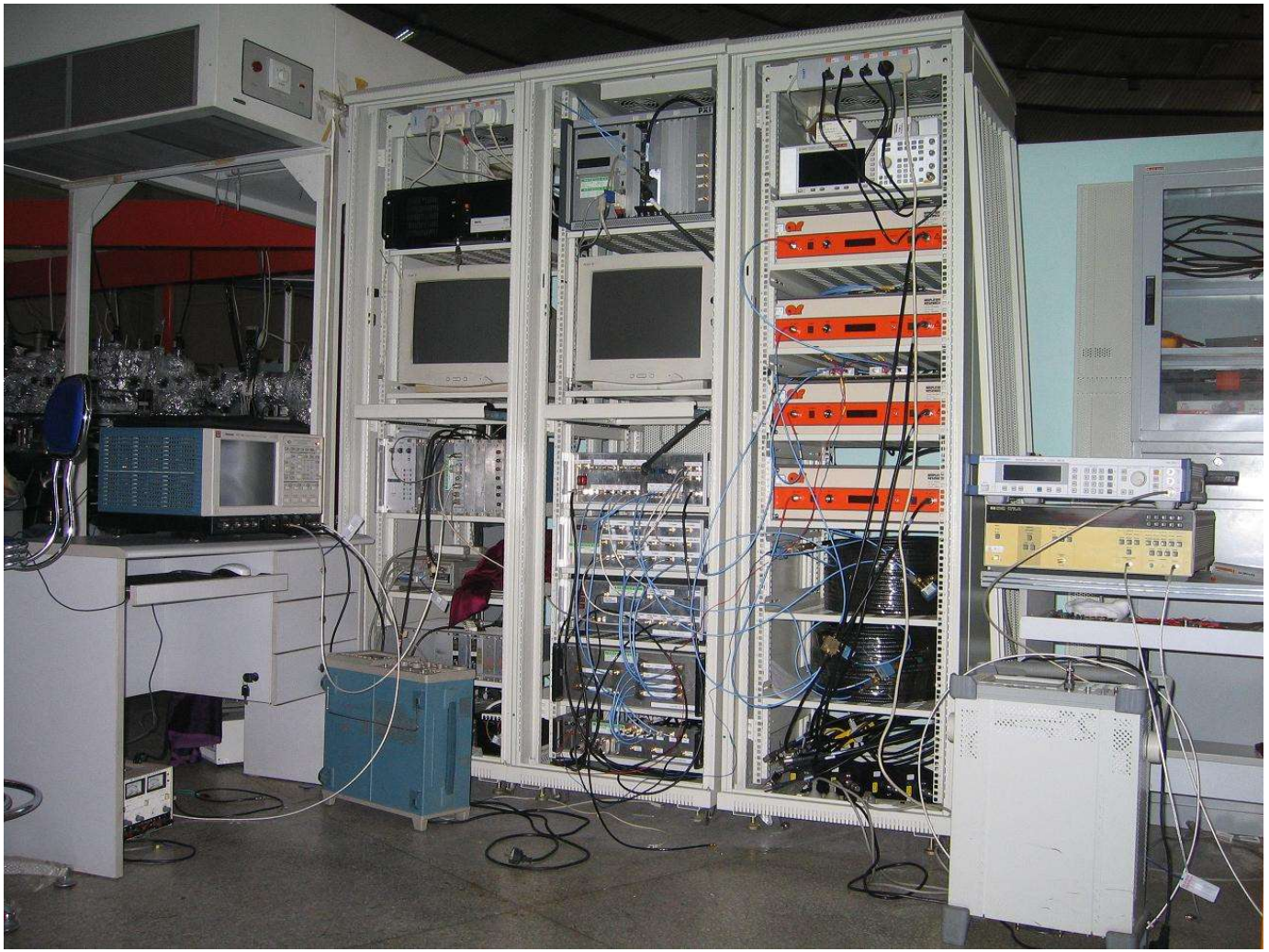
2005~2008 Analog transverse bxb feedback system



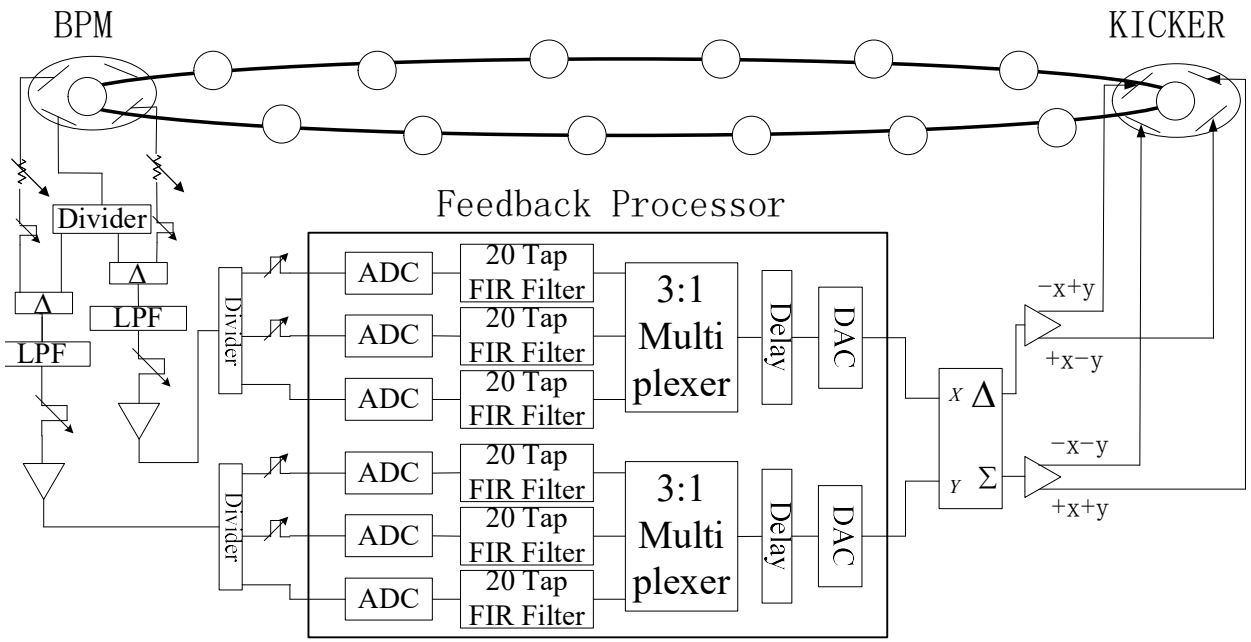
$$x_1 = a_1\sqrt{\beta_1}\sin(\varphi_1(s)) \qquad x_2 = a_2\sqrt{\beta_2}\sin(\varphi_1(s)+\varphi_0)$$

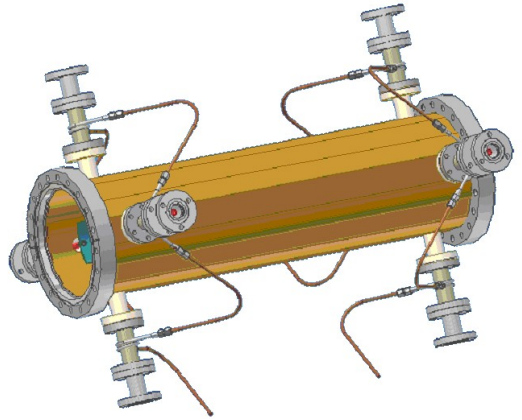
$$\Delta\varphi = \tan^{-1}[a_2\sqrt{\beta_2}\sin\varphi_0/(a_1\sqrt{\beta_1}+a_2\sqrt{\beta_2}\cos\varphi_0)]$$

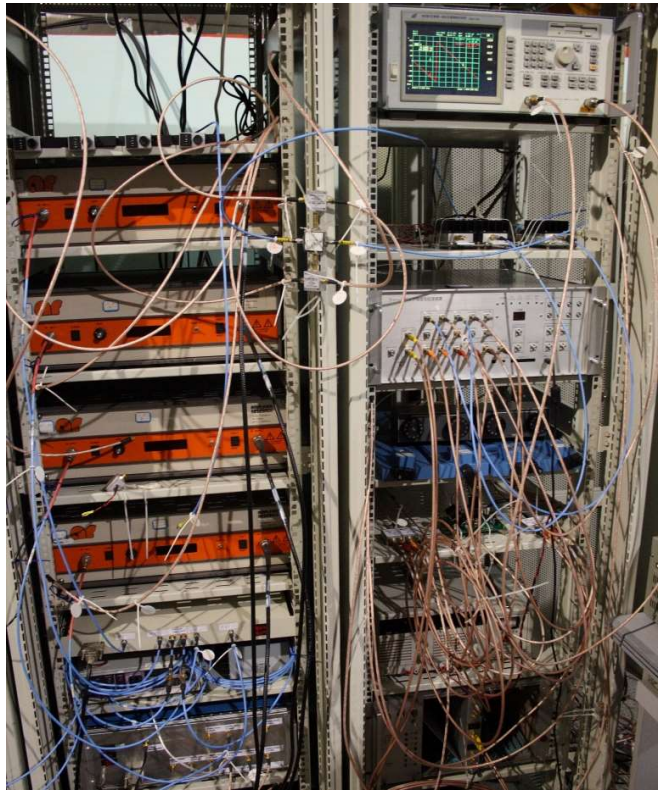
Analog feedback system (photo taken at 2006)

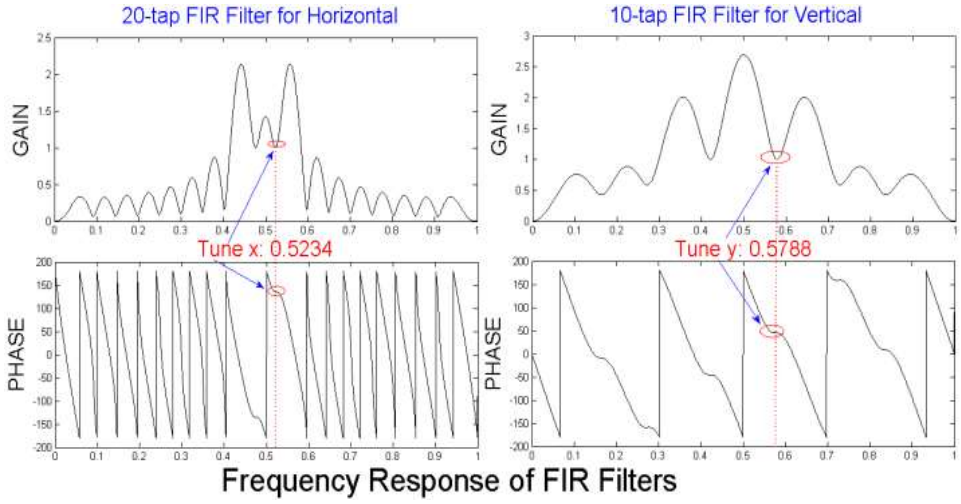


Digital transverse bxb feedback system of HLS(photo taken at 2008)



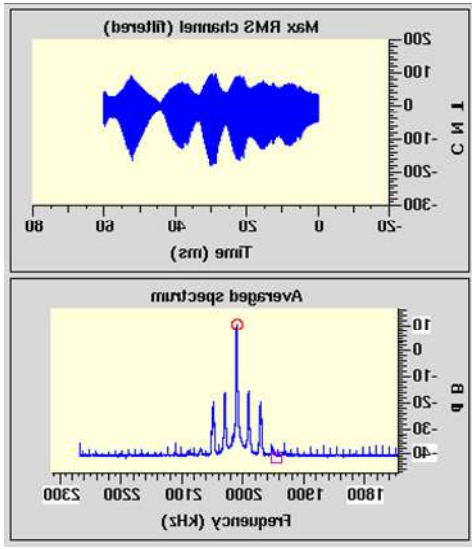


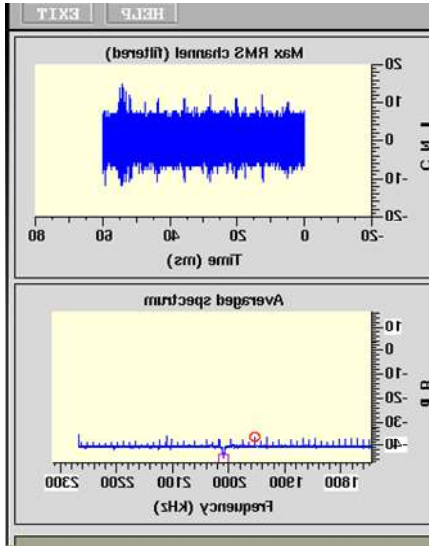


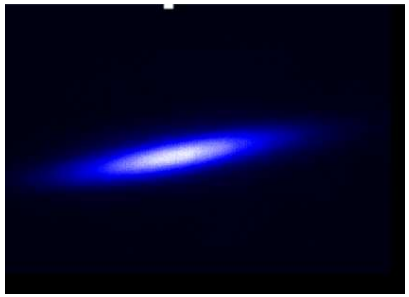


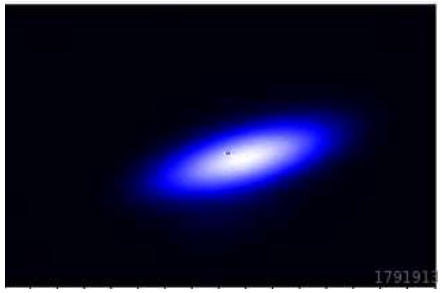
2014~now Digital transverse and longitudinal feedback

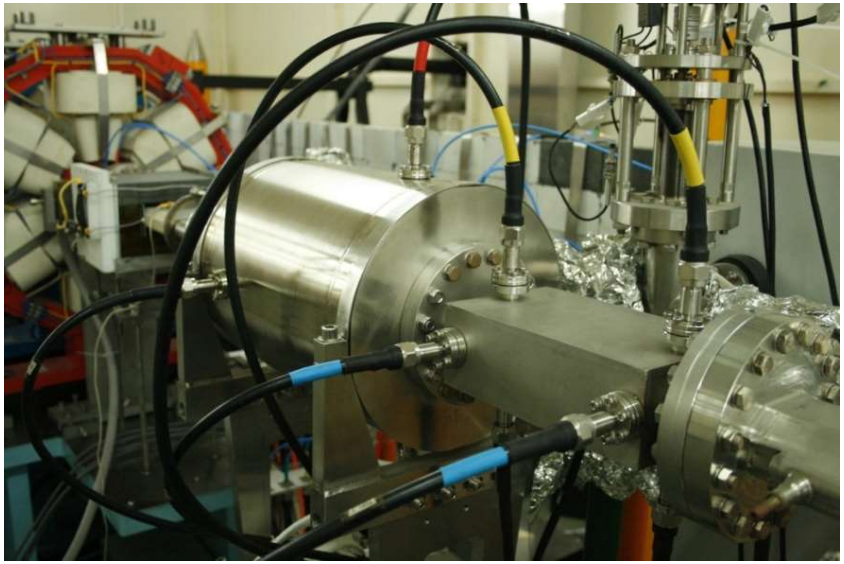
The feedback system was upgraded with digital transverse and longitudinal feedback system by 2014, along with HLSII upgrade project.



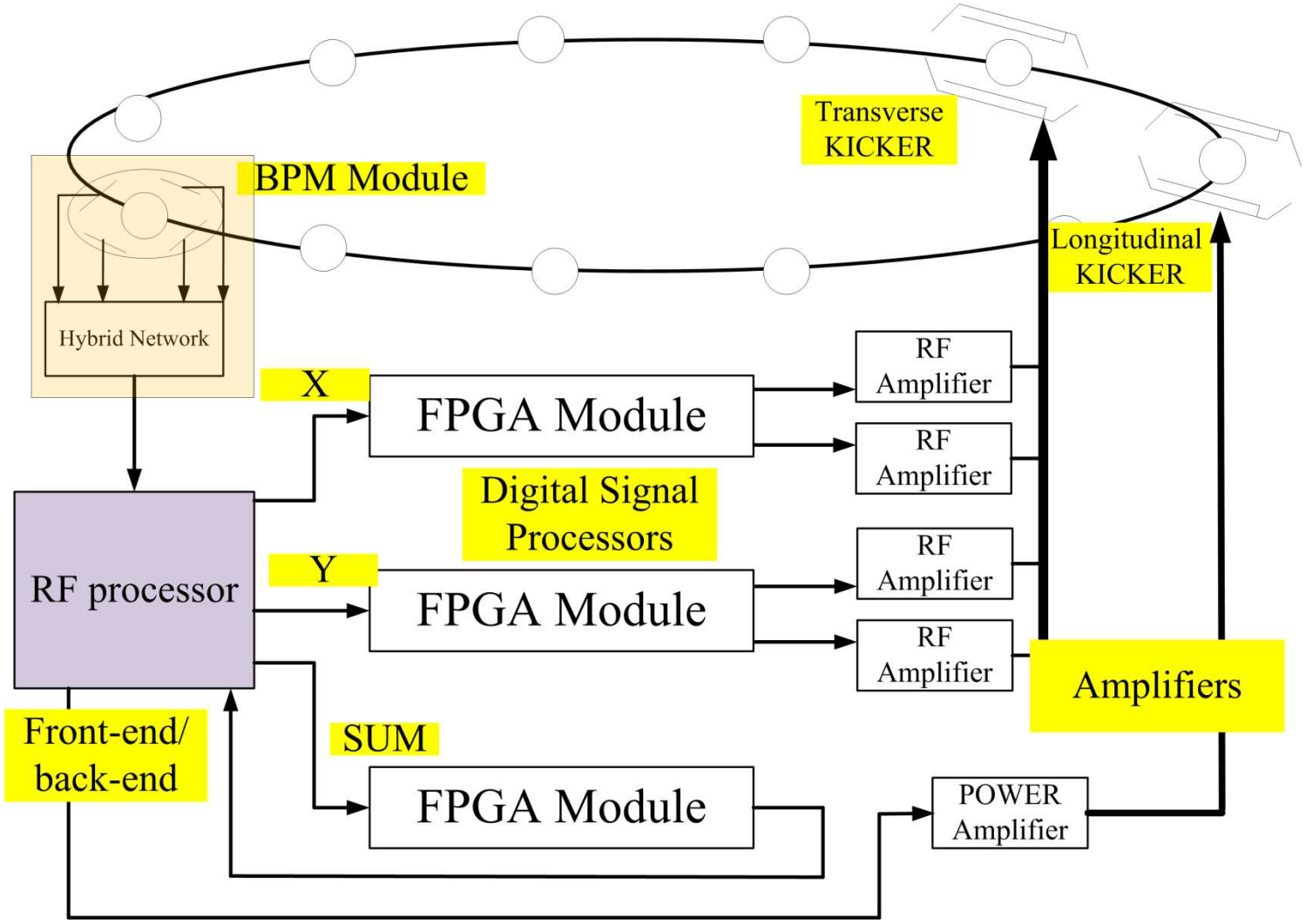




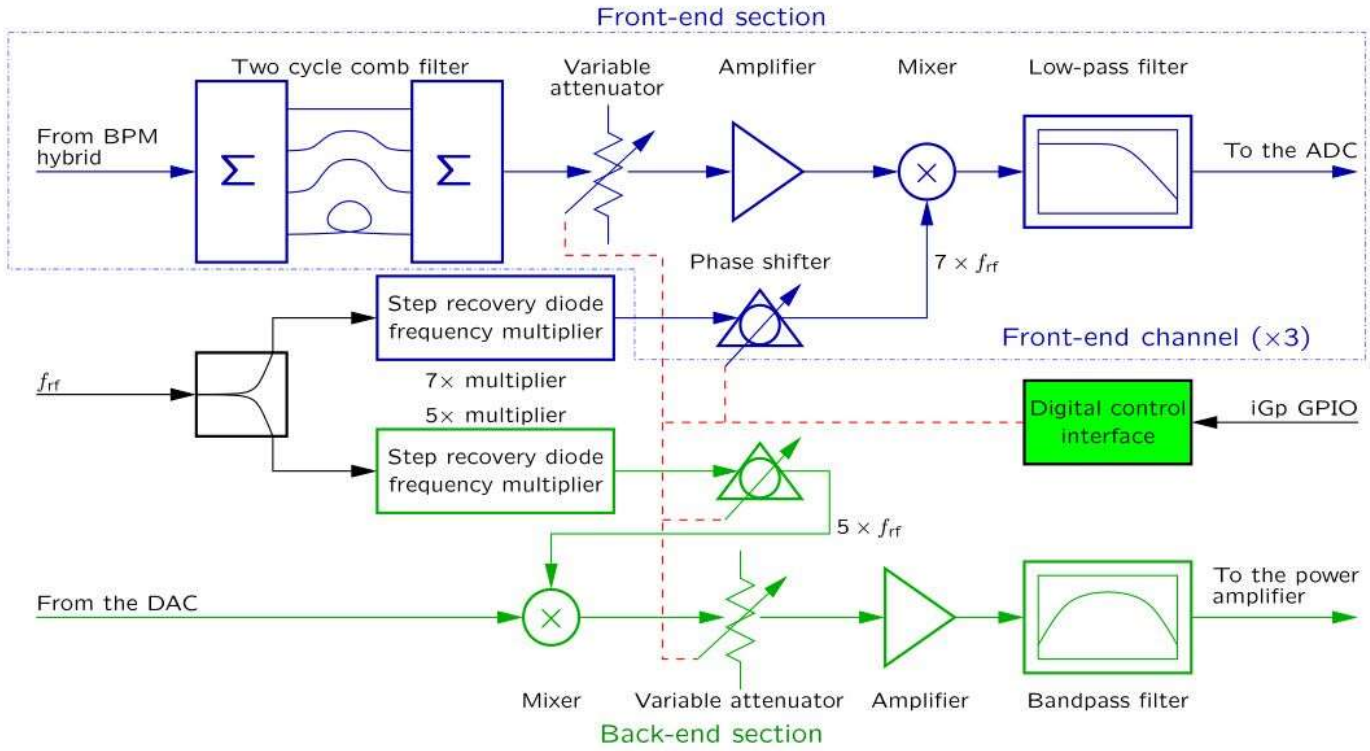




Beam feedback for STCF



RF Processor

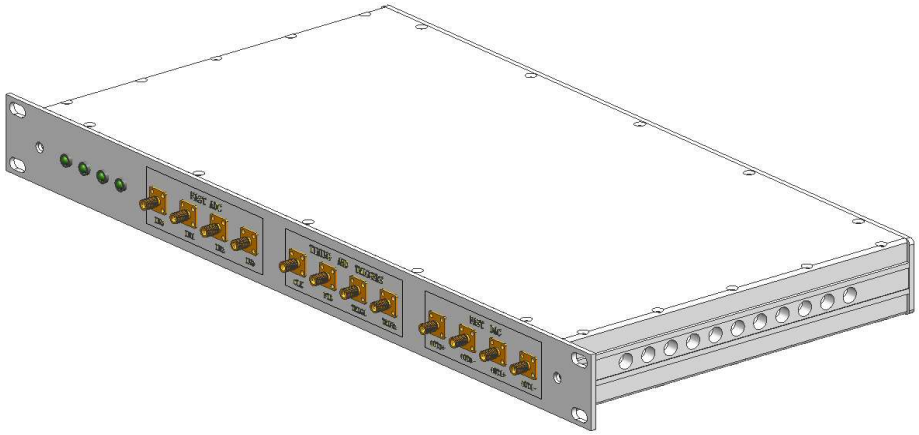


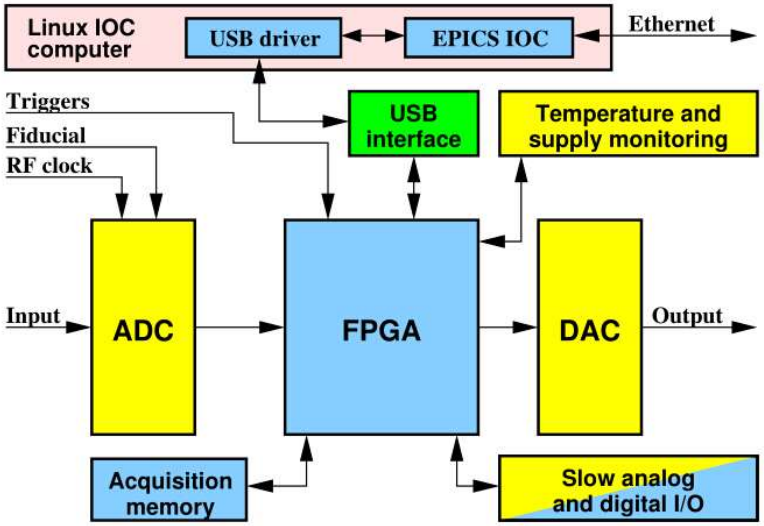
Optimized for 500MHz RF frequency of storage ring (204MHz for HLS)

1. Low amplitude and phase noise;
2. High isolation between neighboring bunches.

Feedback Processor

Designed for 500MHz RF frequency of storage ring





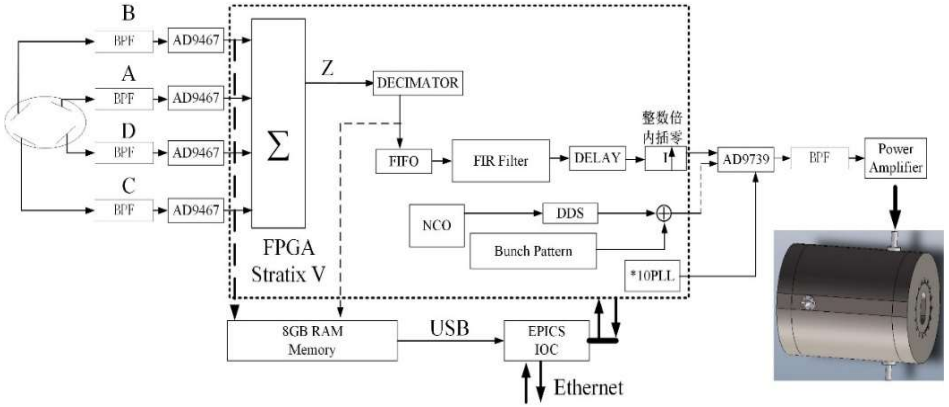
Similar with iGp structure

Digital board + IOC board

Digital board: 500MHz ADCs 2500MHz DACs, Intel Arria V FPGA, PCIe bus

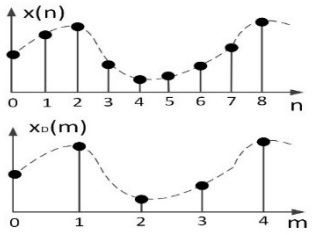
IOC board：X86 system running linux with EPICS

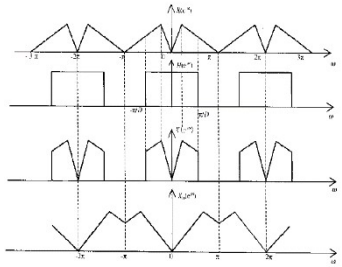
Some techniques for longitudinal feedback processing



ADC Downsampling

$$x_D(m) = x(mD)$$



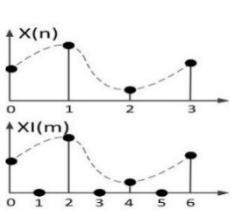


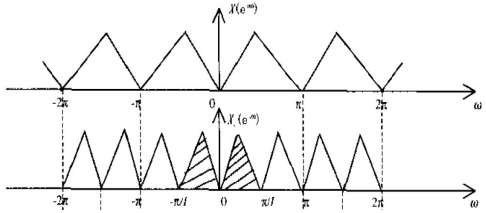
Revolution frequency is much higher(over 100 times in HLSII) than the synchrotron frequency, downsampling technique makes filter design much easier. After downsampled factor D, the spectrum of target tune expands D times.

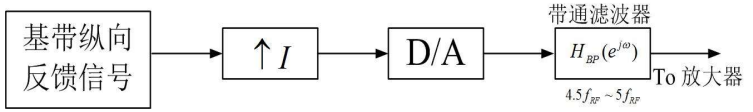
For bunch-by-bunch feedback, the feedback kick of N-th bunch using [N，N-D,N-2D，...]turns BPM data, and the feedback signal repeats D turns for individual bunch.

DAC Interpolation with zero（Upconvert）

$$x_I(m) = \begin{cases} x(\frac{m}{I}), (m = 0, \pm I, \pm 2I, ...) \\ 0，其他 \end{cases}$$







Longitudinal kicker works at RF frequency(~1 GHz), and normally it needs back-end RF components to upconvert base band signal to wide band longitudinal kick signal.

Interpolation with zero of DAC introduces mirror spectrum at higher frequency. With interpolation factor *I*, the spectrum of DAC output increases *I* times with mirror spectrums of base band signal. Using band-pass filter to get the desired RF kicks for longitudinal feedback. (Digital upconversion scheme, 2.5GHz DAC is used.)

Mode Analysis

- Each multi-bunch mode is characterized by a bunch-to-bunch phase shift:

$$\Delta\Phi_n = n\frac{2\pi}{M},$$

where n is the coupled bunch mode number (n=0,1,…,M-1), M is harmonic number of storage ring.

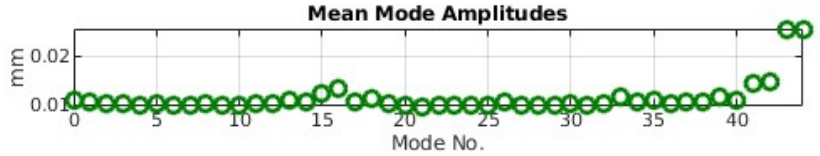
The phase shift for multi-bunch mode could be seen from the bunch-by-bunch data, for sideband frequencies are located at

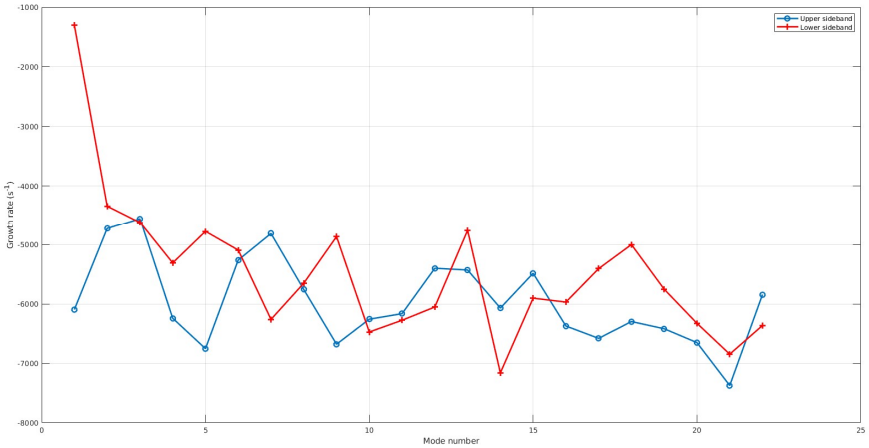
$$f_{p,n,m} = \left| p \cdot M + n + m \cdot \nu_s \right| \cdot f_0 \quad , \quad -\infty < p < \infty,$$

Where p is an integer, vs is the tune, f0 is the revolution frequency, m is the bunch oscillation mode number.

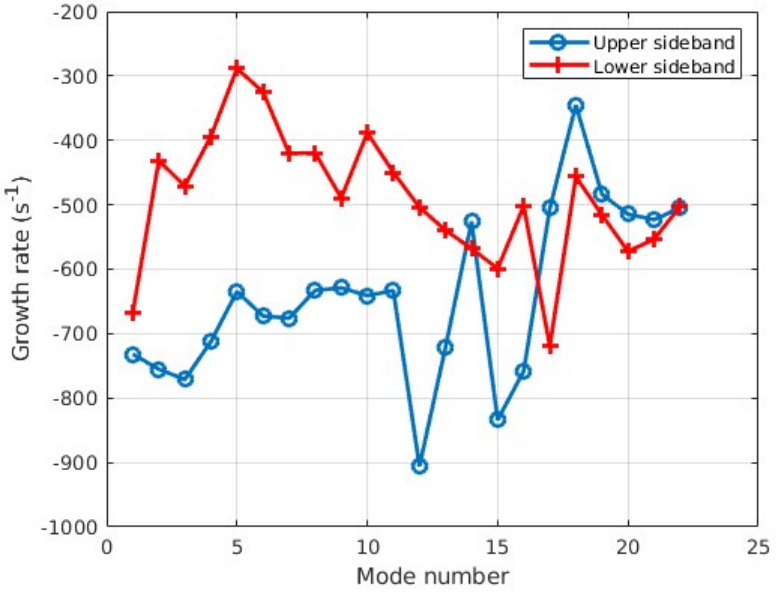
Transverse Mode Analysis of HLSII

Horizontal：
#44 is the dominated mode, resistive wall

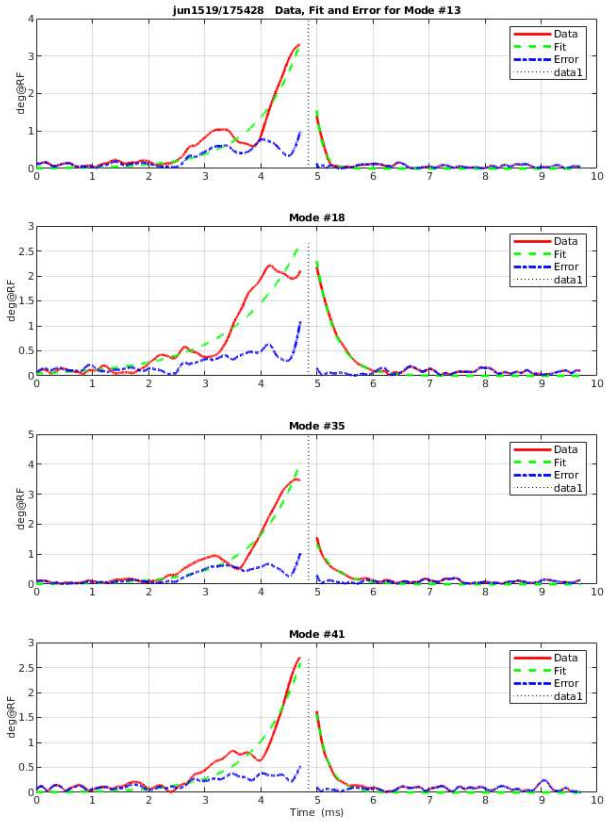


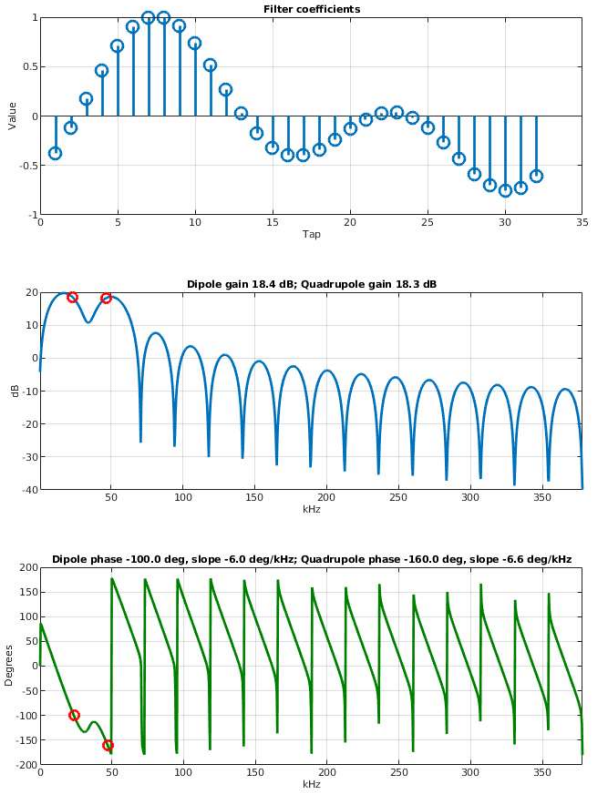


Vertical：
No dominated mode



Longitudinal Mode of HLSII

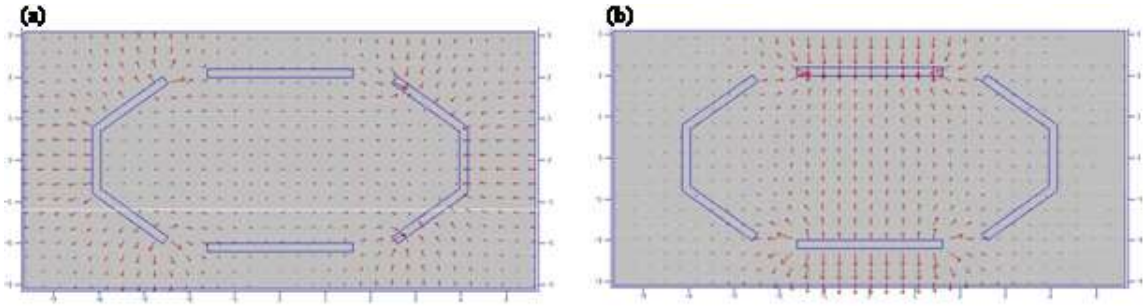


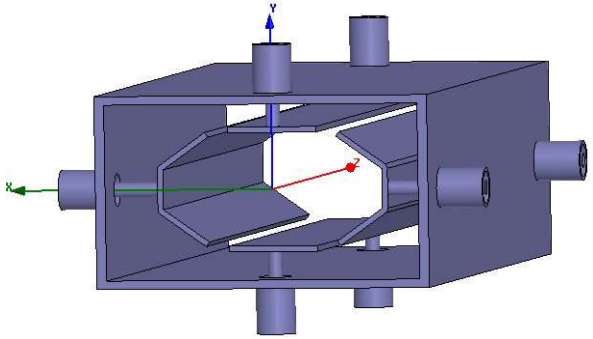


Dominated modes for longitudinal:

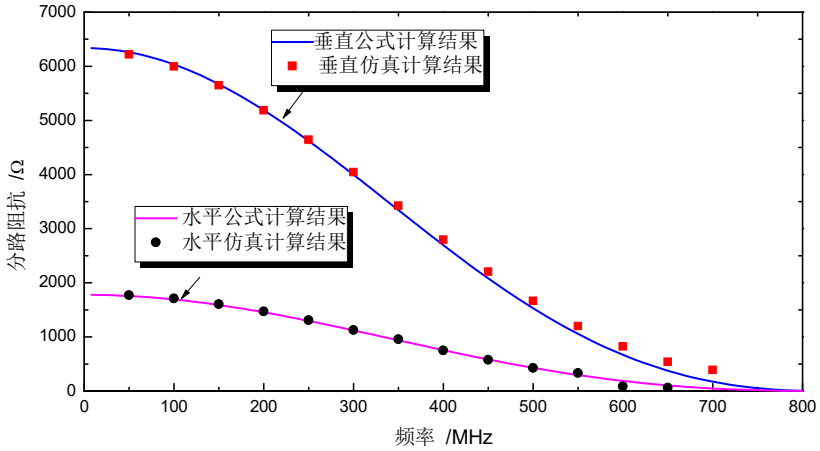
1. mode 13(dipole) and mode 18(quadrupole)
2. The digital filter should suppress the dipole and quadrupole oscillations simultaneously

Stripline type transverse kicker





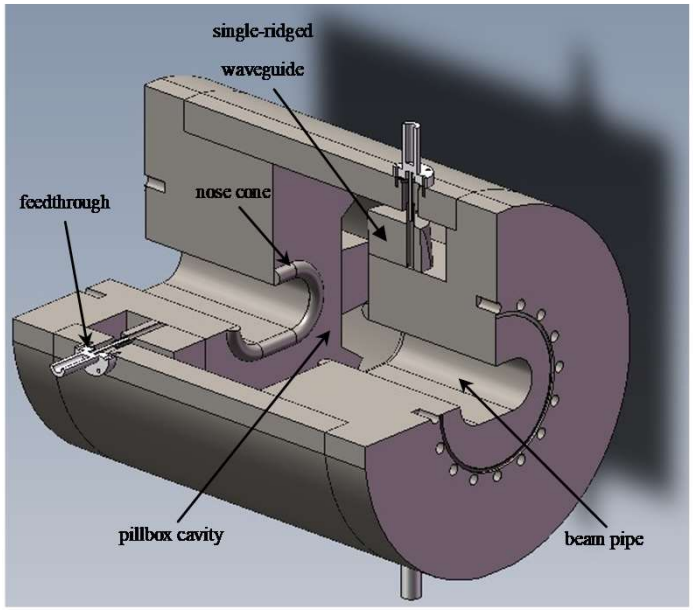
Simulation of 2D electric field distribution by Poisson

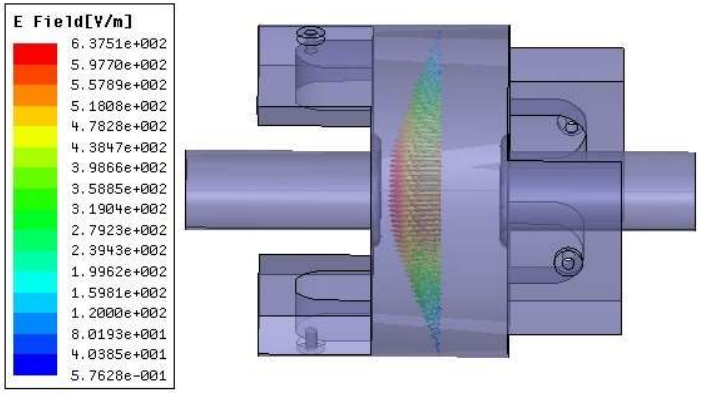


Simulation of shunt impedance

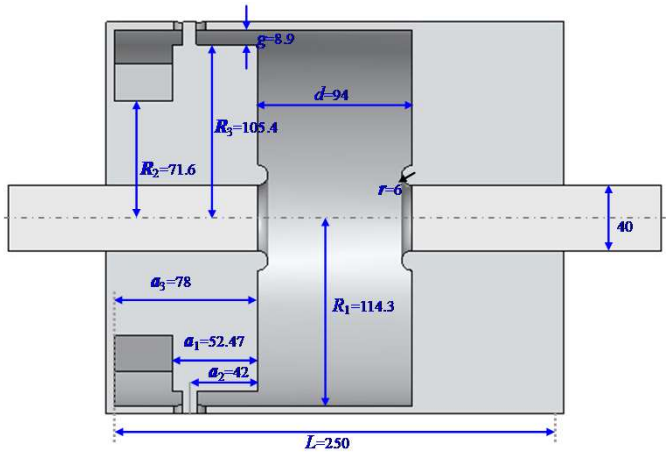
Parameter	Value
bandwidth	102MHz
length of electrodes	183mm
overall length	300mm
electrode thickness	2mm
electrode separation (x,y)	79mm, 40mm
coverage factor (x,y)	0.91,0.87
shunt impedance at 102MHz(x,y)	1.7kΩ,6kΩ
kick voltage at 102MHz(x,y)	272V, 543V

Pill-box type longitudinal kicker

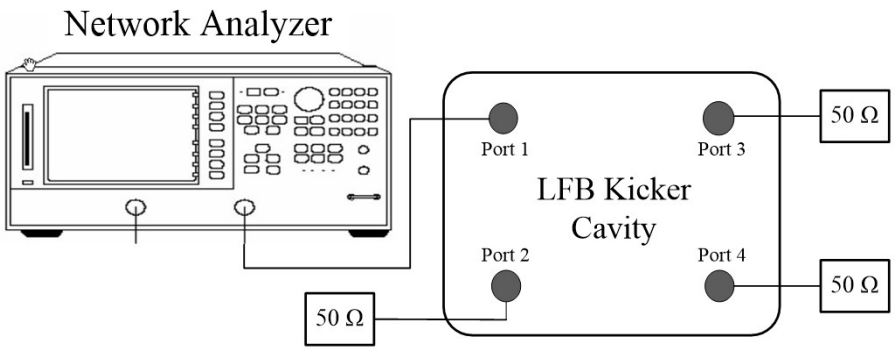


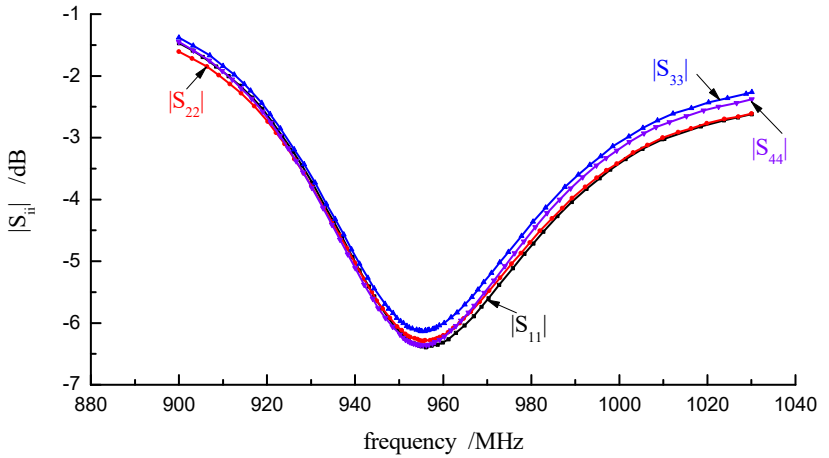


Simulation model using HFSS

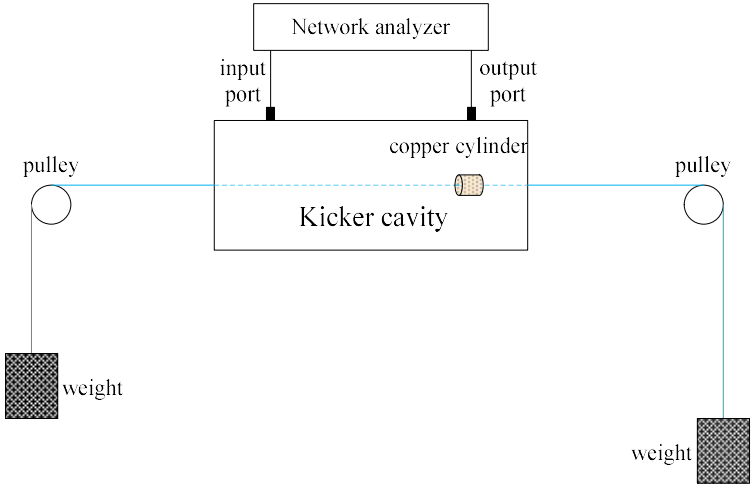


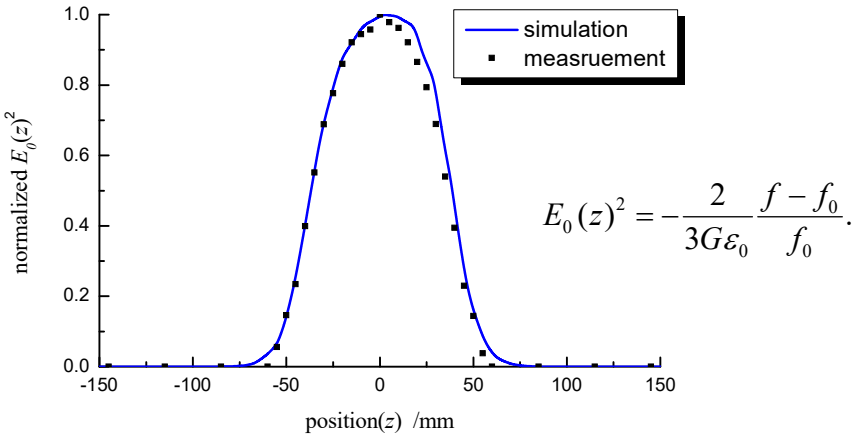
parameter	design	simulated	measured
f_{cent} (MHz)	969.0	968.6	954.4
BW (MHz)	102.0	105.0	100.0
Q_L	9.5	9.22	9.64
R_s (Ω)	1400	1860	N/A





S11 parameter measurement for each port of longitudinal kicker

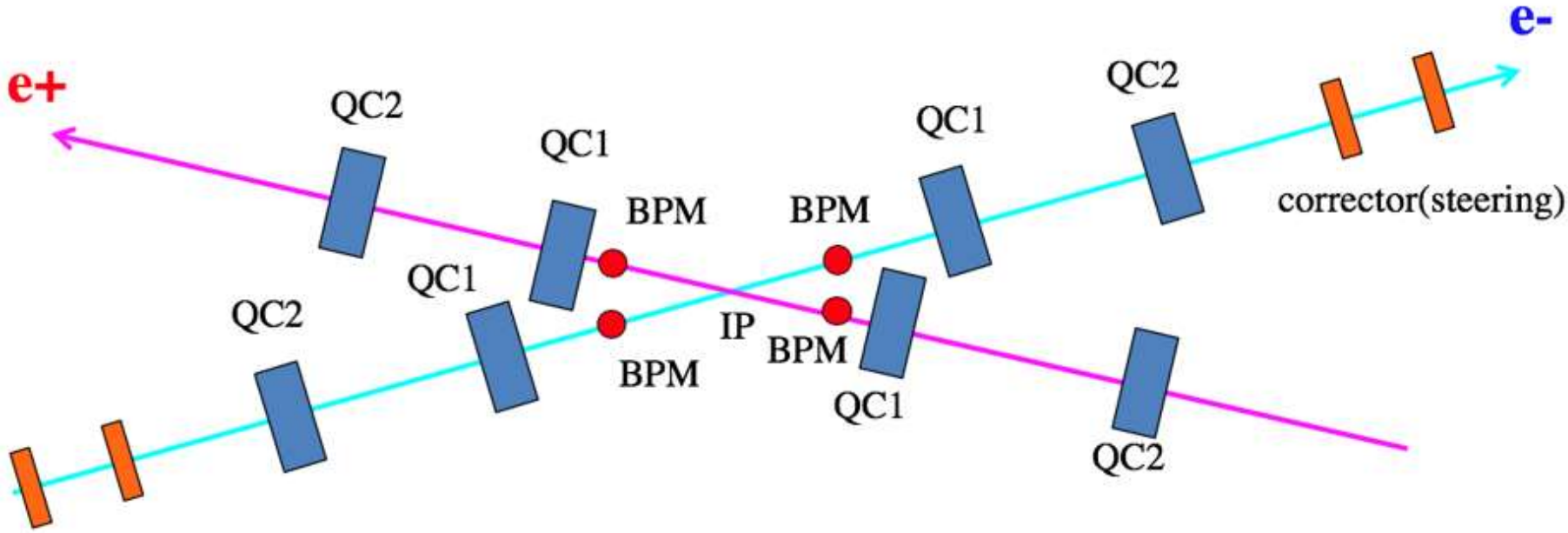




Measured and simulated distribution of the square of the electric field along the central z-axis.

Basic idea of IP feedback system

Maintaining the beams of a two-ring collider in head-on collision requires an active feedback that moves one beam relative to the other to seek maximum luminosity.

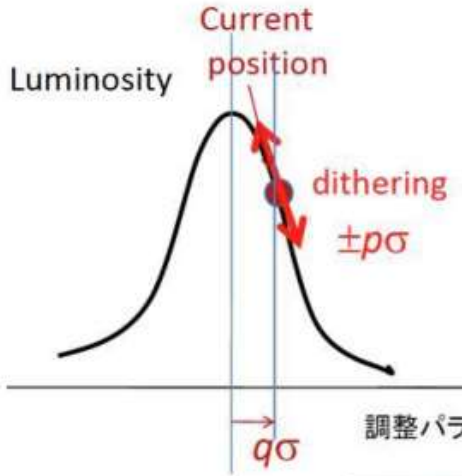


To maximize luminosity, a feedback system adjusts the relative transverse (x, y) position and vertical angle (y') (y' is sensitive due to the small aspect ratio (y/x) of the beams at the IP) at the interaction point (IP) to find the horizontal offset that maximizes luminosity.

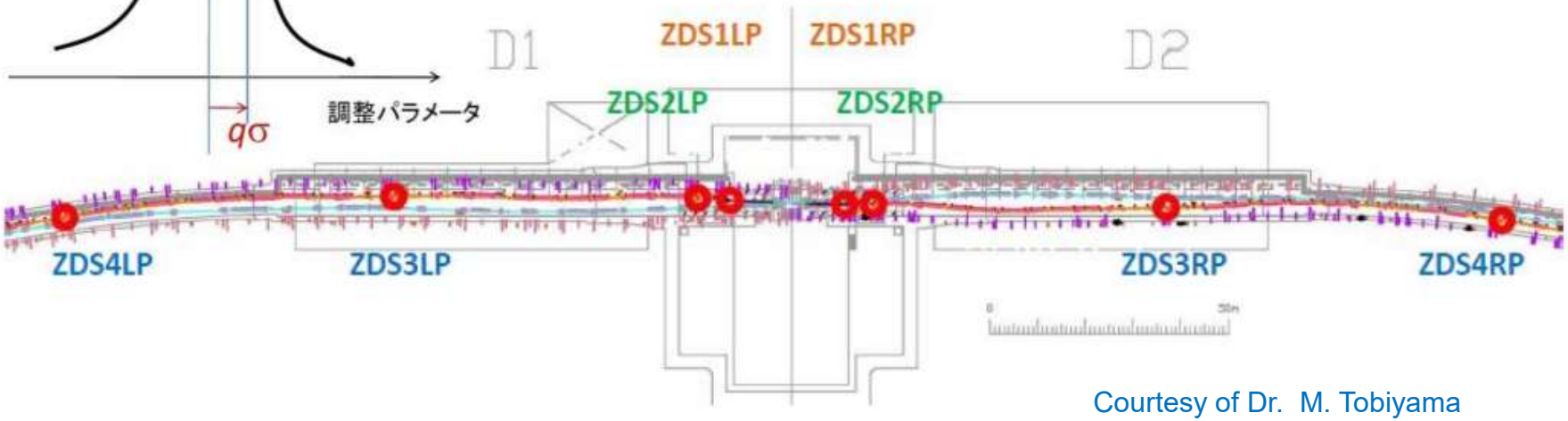
Some priliminary commissioning result of SuperKEKB

When the beam is dithered around the "center," where luminosity peaks, luminosity drops on either side of the peak, giving a modulation at 2wx . When dithered off center, there is additional modulation at the fundamental.

Modulate IP positions and angles with a sinusoidal signal (~60Hz) and detect the frequency and phase response of luminosity monitor using lock-in amplifiers. In the dithering feedback loop, the offset at the IP is adjusted at each feedback cycle to minimize the amplitude of the fundamental harmonics in the luminosity signal.



$$L(x) = L_0\left(1 - \frac{x_0\tilde{x}}{\Sigma_x^2}\cos\omega_x t - \frac{\tilde{x}^2}{2\Sigma_x^2}\cos^2\omega_x t\right)\exp\left(-\frac{x_0^2}{2\Sigma_x^2}\right)$$

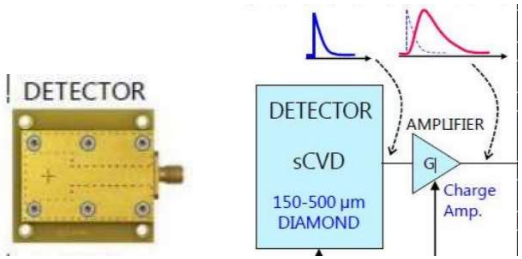


Courtesy of Dr. M. Tobiyama

Essential study for IP feedback

1.Fast luminosity monitor

-- Radiative Bhabha scattering in the very forward direction



2. Dithering system

--A lock-in amplifier determines the luminosity component at the drive frequency. Beam offsets in all three coordinates can be measured simultaneously by using three frequencies, one per coordinate, and three lock-ins.

--Horizontal and vertical pairs of air-core coils are added at four locations surrounding the IP, on vacuum chambers for rapid field penetration. These coils do not maintain the beam position, but only drive the oscillation.

Summary

- Bunch by bunch feedback systems are quite essential for STCF to suppress the coupled-bunch instabilities and they are under developing.
  - RF processor
  - Digital feedback processor
  - Kickers

- IP feedback is important to maximize luminosity for STCF, and it will be studied and it needs collaboration with other labs.