Injection Transient Observation via Bunch-by-bunch Beam Size Measurement System

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SSRF BI Group

Outline

- Bunch-by-bunch study background
- System Setup
- Application: Injection transient study
- Next Works
- Summary

Bunch-by-bunch study background

Why bunch-by-bunch study

For Users

- FB and Top-up make users happy usually
- Unstable beam conditions will damage data quality
  - Beam instabilities
  - The injection transient every 5mins (top-up)

Need better knowledge of instability phenomenon for optimization

For BI Engineers

- Only static information can be monitored during daily operation
- Injection transient is a very good window to learn more about machine

Get more information during routine injections

For Physicists

- A bunch is a basic unit for physics study
- Parameters of individual bunch is better than average values for physicists

Need parameters of every bunches

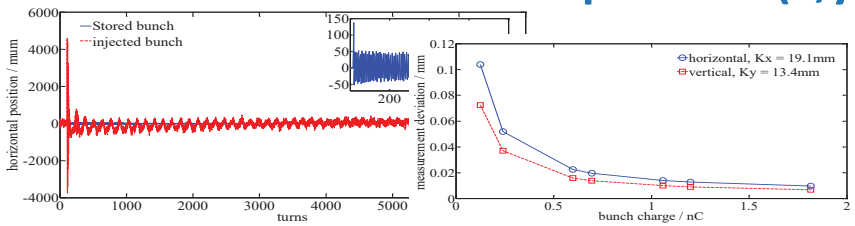
All requires

An eye on every bunches to ***study*** their behaviors

We are building a ***6-dimensional bunch-by-bunch*** diagnostic system

What we are building

Beam position (x,y)

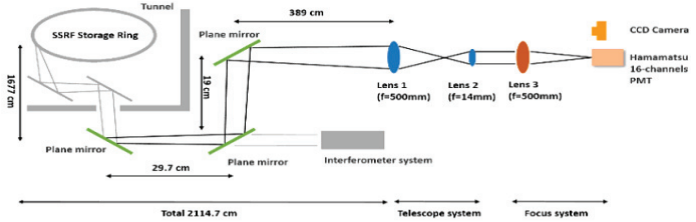


Button pickups + BBB DAQ + Δ&Σ algorithm

Resolution ≤ 10μm

(Y. Yang, IPAC13; Y.B. Leng, IBIC13; Y.B. Leng, IPAC15; Z.C.Chen, PRST,2014)

Beam transverse size(horizontal , vertical)



SR light + PMT array + BBB DAQ

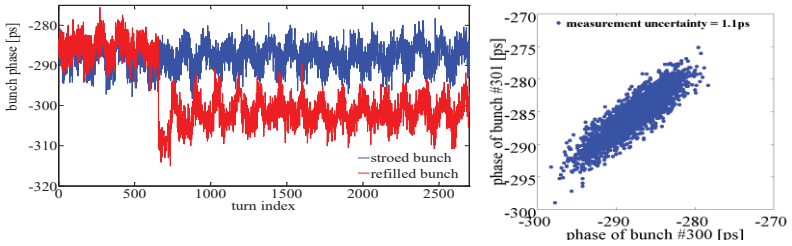
+ Gaussian fitting algorithm

(H. J. Chen, IPAC17)

6-dimensional bunch-by-bunch diagnostic system

✦ discussed in this talk

Beam longitudinal phase (z)



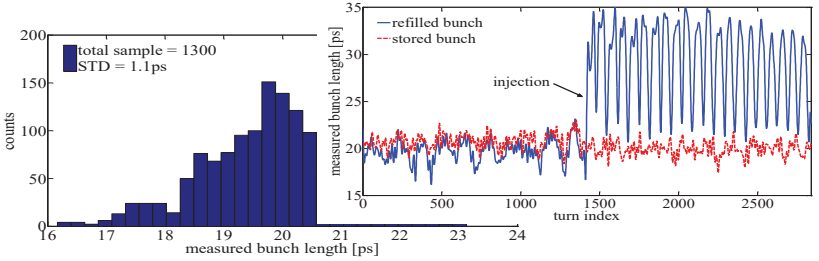
Button pickups + BBB DAQ

+ Rising edge detection

Resolution ≤ 2ps

(Y.M. Zhou, IPAC17; Poster TUPWC02 in IBIC17)

Beam longitudinal length



Button pickups + Two-frequency system

(L.W.Duan,NST, 2017, H. J. Chen, IPAC17)

Fast beam size measure in future light source

- For second-phase upgrade project at SSRF

  More insertion devices → transverse instabilities raise up

- For injection process optimization

  No available method to detect injection process →

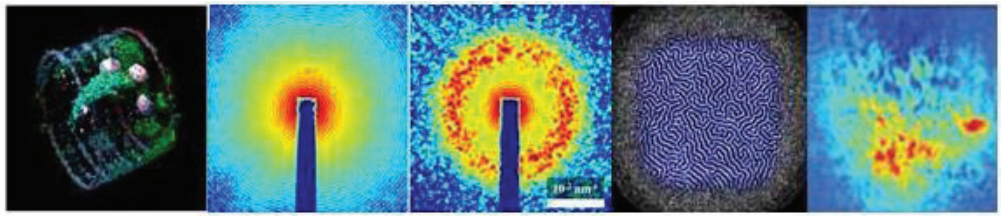
- For diffraction-limited storage ring in the future →

Bunch-by-bunch beam size measure system

→ Study and monitor the instabilities

→ A guild for injection optimization

→ Provide a effective tool for problem research, like impendence mismatch, large interference during injection

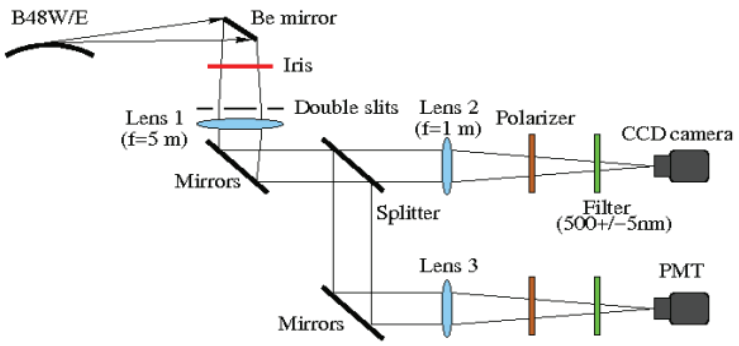


Fast beam size system at CESR

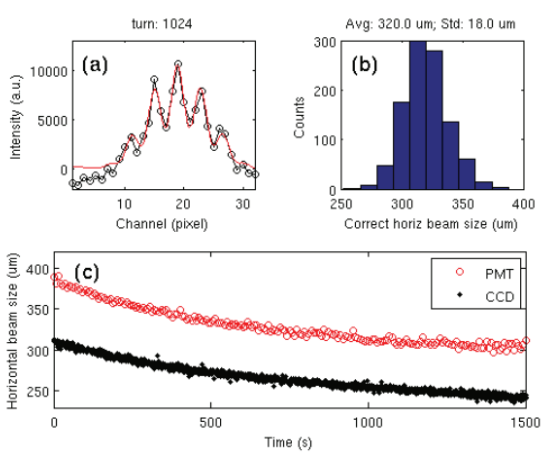
Visible light part

Interferometer (Hor.)
π- polarization (Ver.)

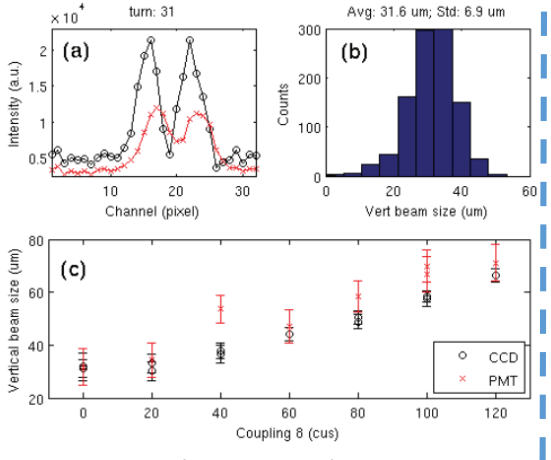
✚ PMT array ✚ Turn-by-turn signal readout @ CESR



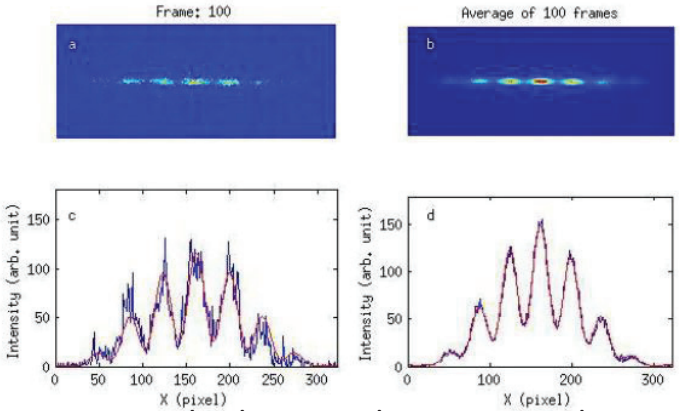
Horizontal size measurement system at CESR



Horizontal size result vs CCD



Vertical size result vs CCD



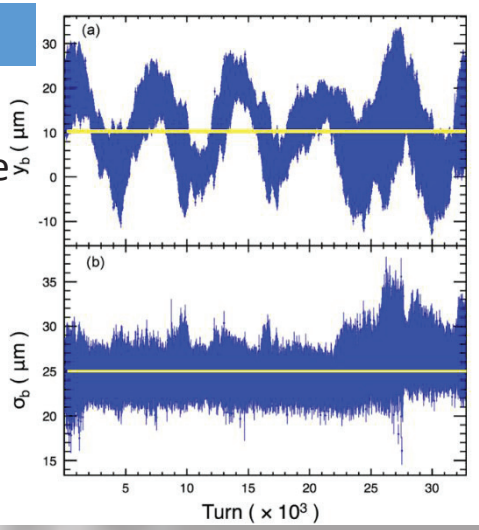
Single shot gated camera result

Fast gated camera method

- 3ns gate time
- Single-shot mode
- Interferometer optical front-end

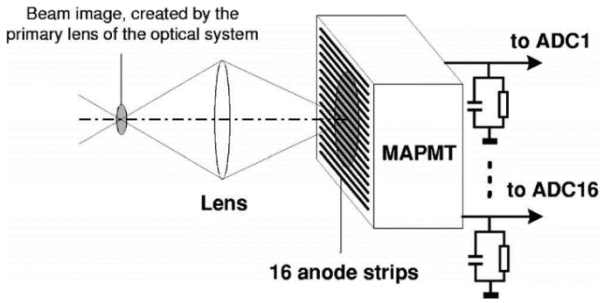
X-ray part

- Single Slit or Coded aperture front-end
- 32 channels linear InGaAs detector
- 4ns time resolution

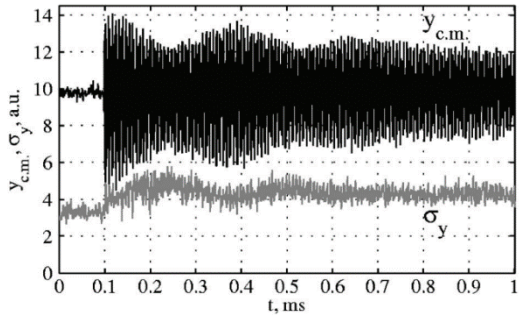


Fast beam size system at BINP

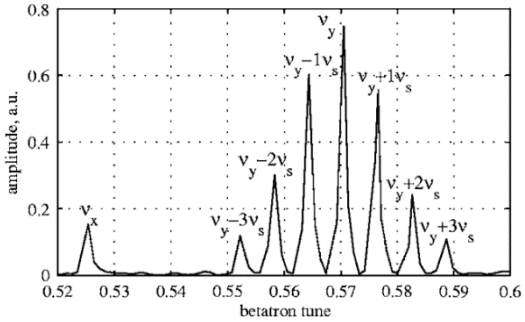
PMT detector



Vertical size measurement based on PMT array at VEPP-4M



Turn-by-turn result of injection



Spectra result near tune

(A.V. Bogomyagkov et al, Rev. Sci. Instrum.78, 2007)

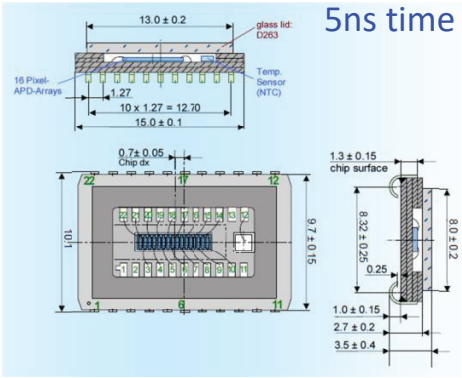
APDA detector

(V. Dorokhov et al., IBIC2016)

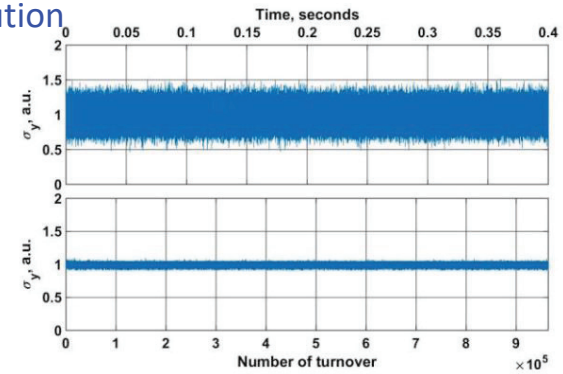
PMT array detector problems

- Has a low value of an average anode current
- can't be used for multi-bunched beam

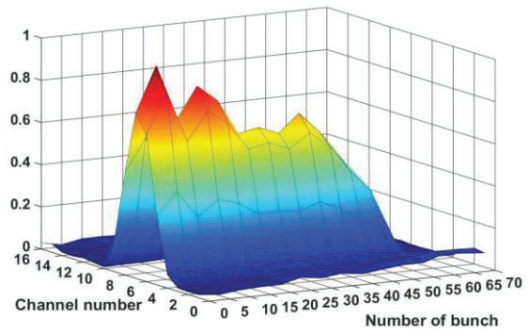
5ns time resolution



Avalanche photodiode array detector

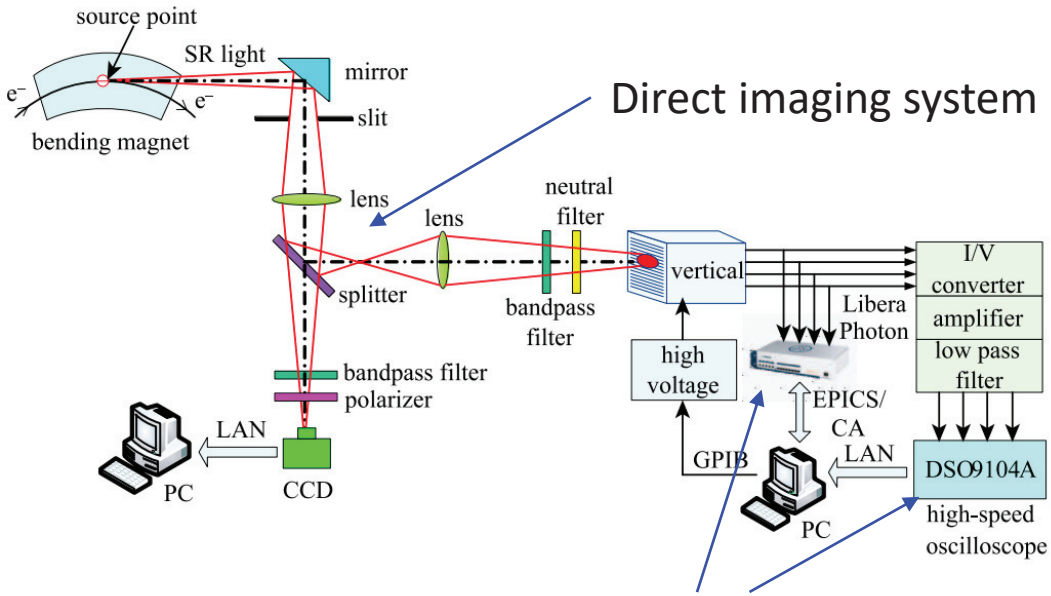


Comparison of PMT and APDA



Result of bunches in one turn

Fast beam size system at HLS

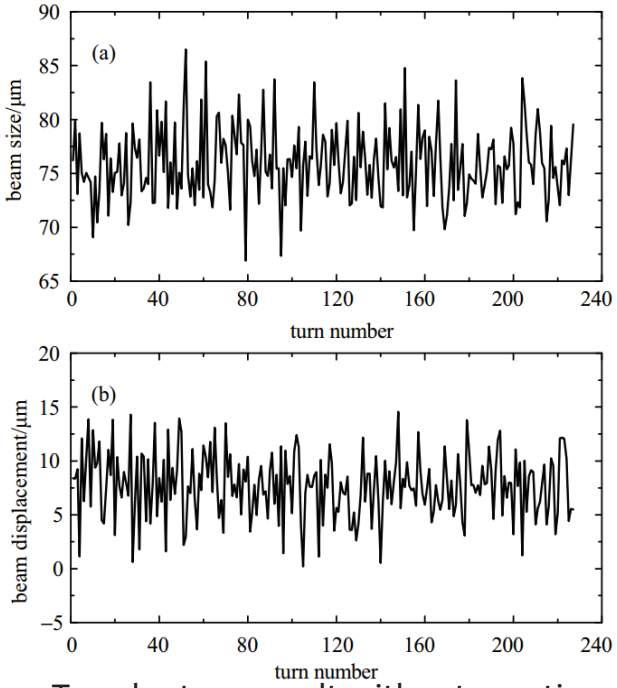


Direct imaging system

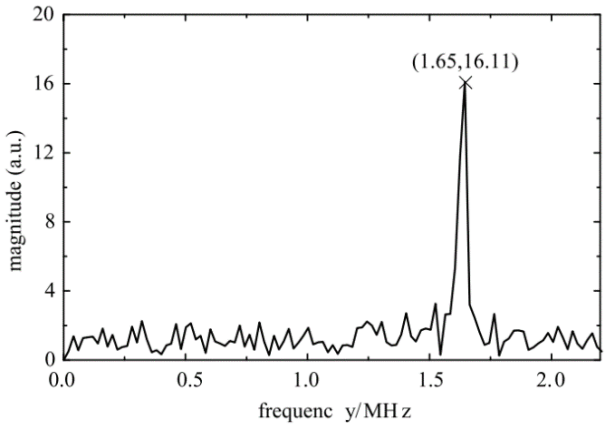
Two acquisition devices:

- Signal digitizer
- High-speed oscilloscope

(C.C.Cheng, et al., Chinese Physics C, vol 40, 2016)



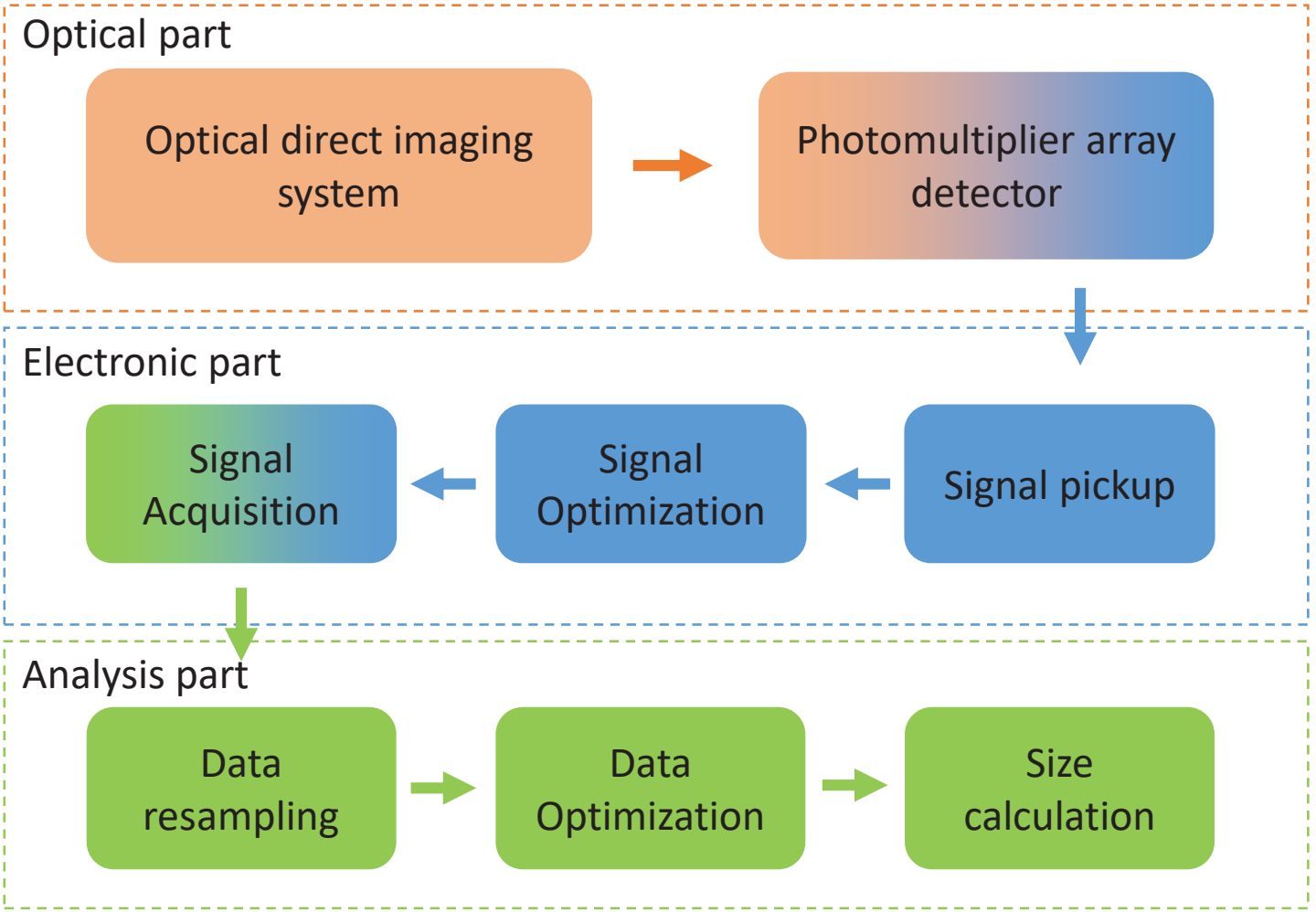
Turn-by-turn result without exaction



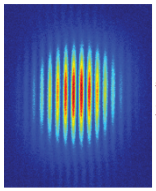
Position spectra with vertical betatron oscillation

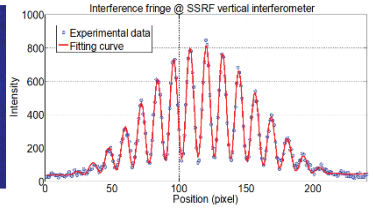
Bunch-by-bunch beam size measurement system

System Setup



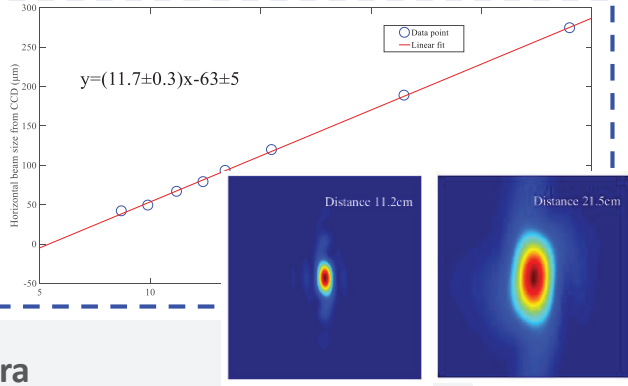
Optical imaging

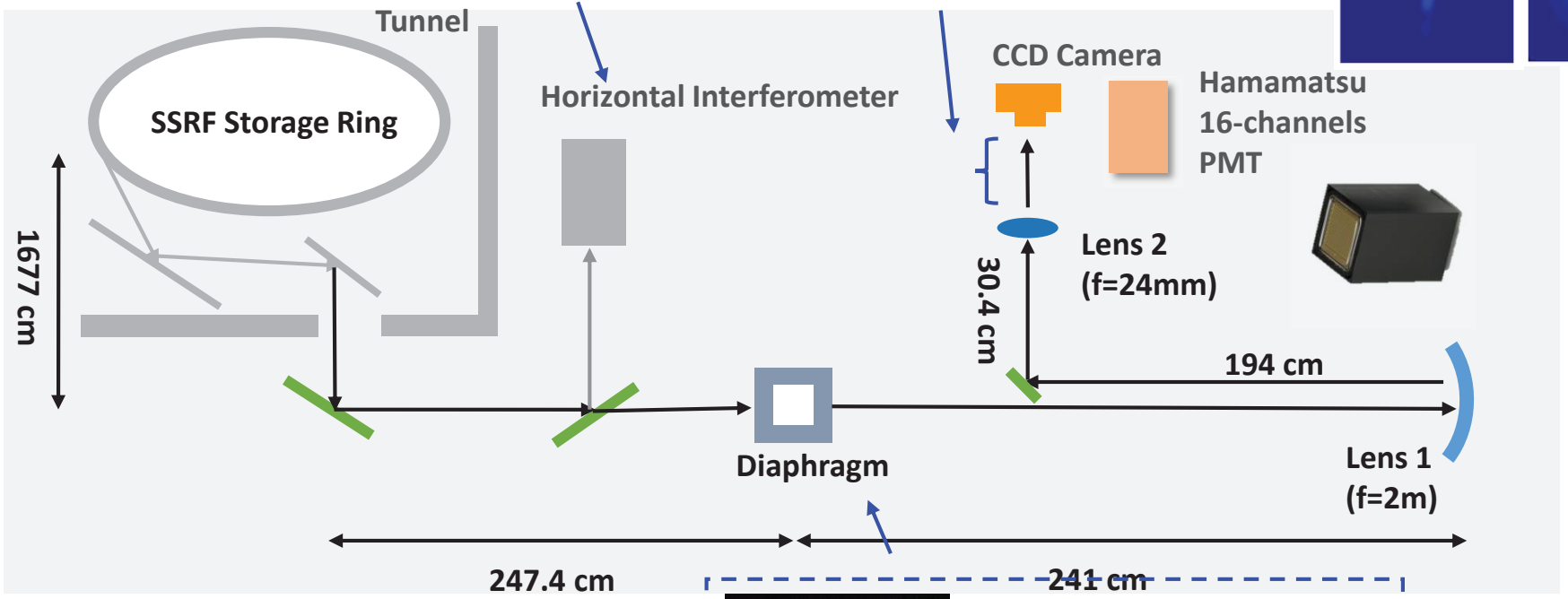


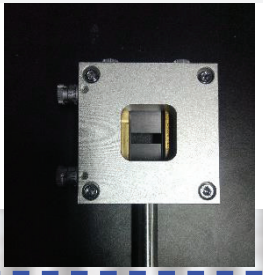


- Average and precision size measure
- About 53 μm
- For system PSF calibration

Detect virtual image after focus point for proper size at PMT



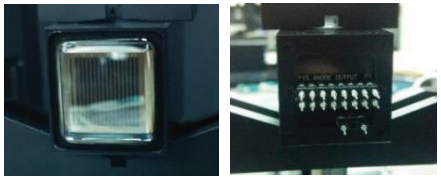


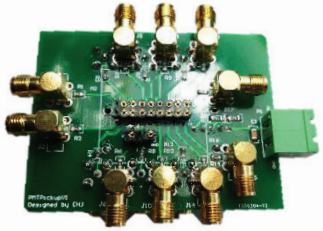


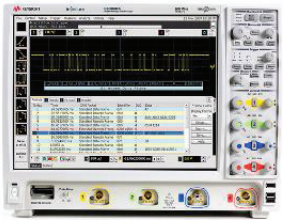
- Choose one part of input light spot
- Defend the effect of Be mirror deformation

Signal conditioning & acquisition

PMT array detector → Signal Front-end Pickup board → Signal Amplifiers → High-speed signal acquisition







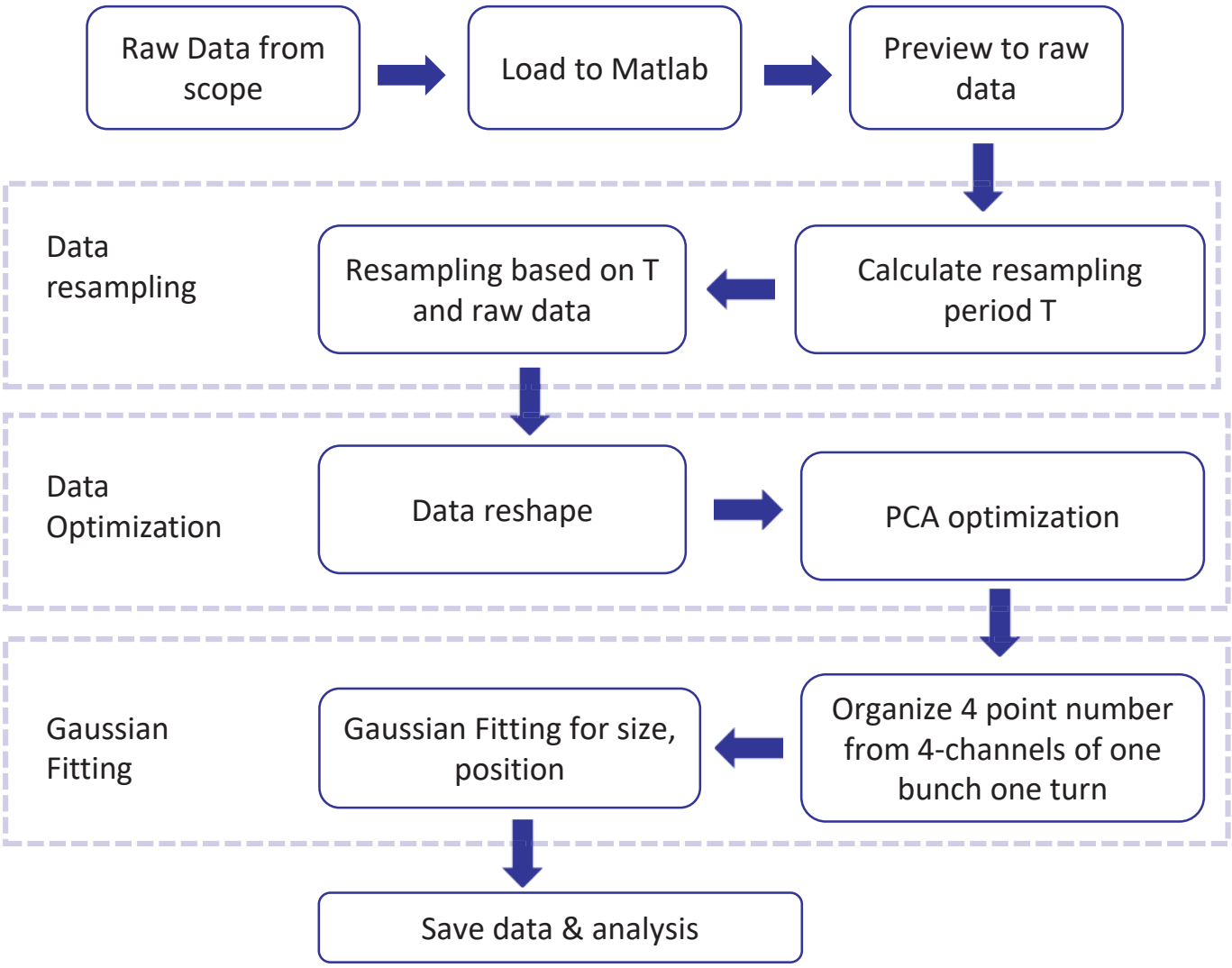
- Hamamatsu H10515B
- 16 channels
- 0.6 ns rise time
- 1mm channel pitch
- Spectral range: 300-800nm

- Pick up signal from plug pins
- Export signal with SMA connector
- Supply -800 V to PMT array

- Hamamatsu C5594 amplifier module
- High bandwidth 50kHz – 1.5GHz
- High gain: 36dB
- Signal level at about 100-200mV

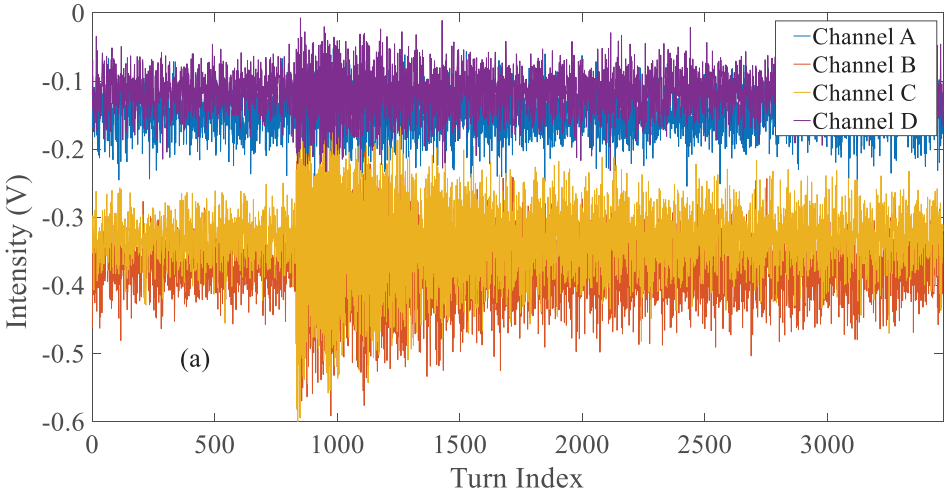
- Agilent DSO9064A oscilloscope
- Analog bandwidth 600MHz
- High sampling rate: 5GS/s

Data processing

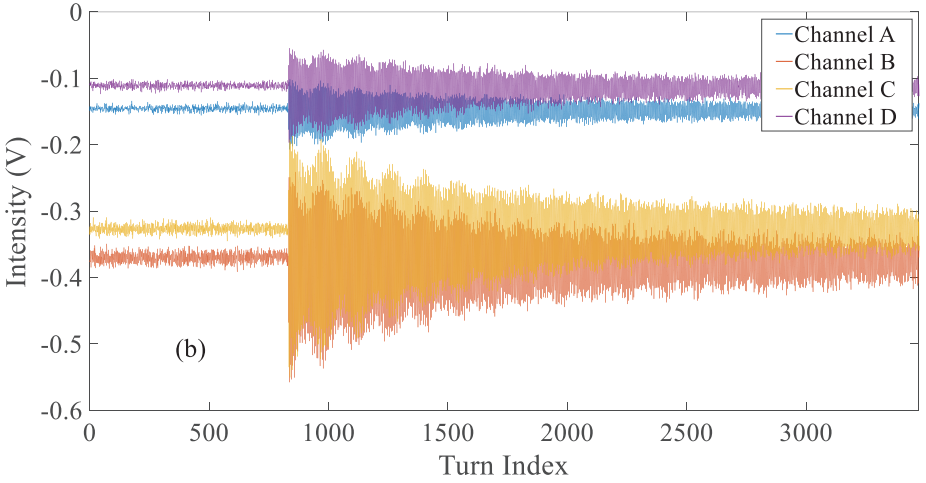


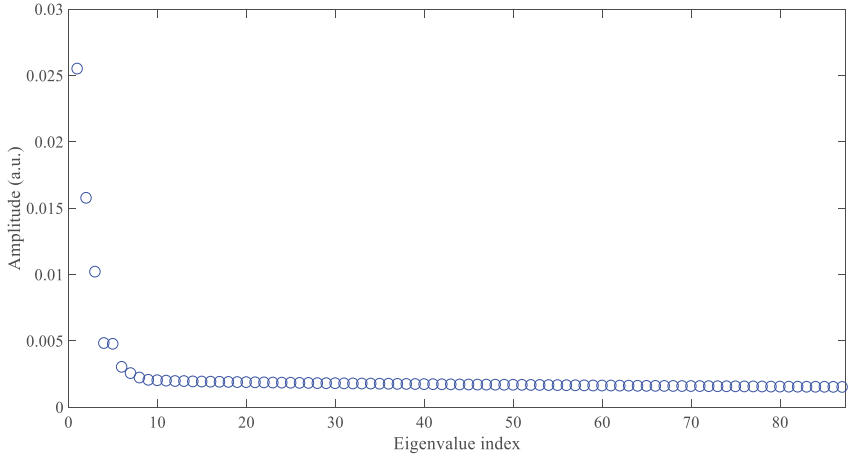
PCA optimization

Original Signal

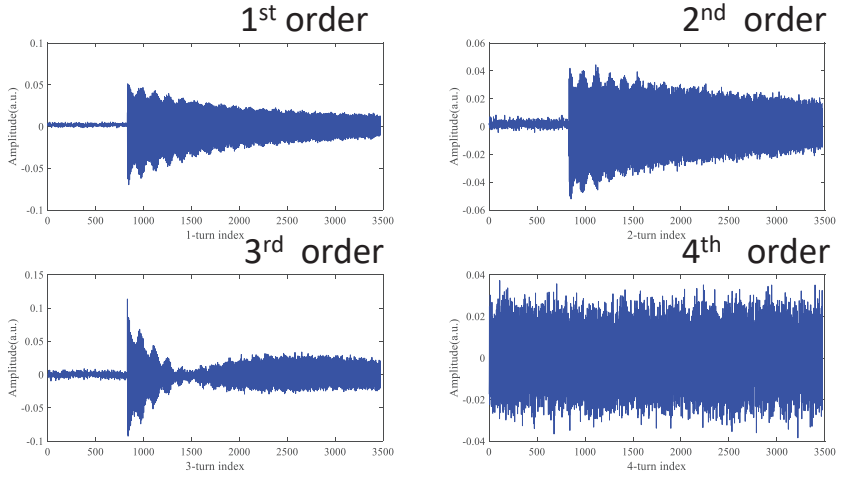


Signal after PCA optimization





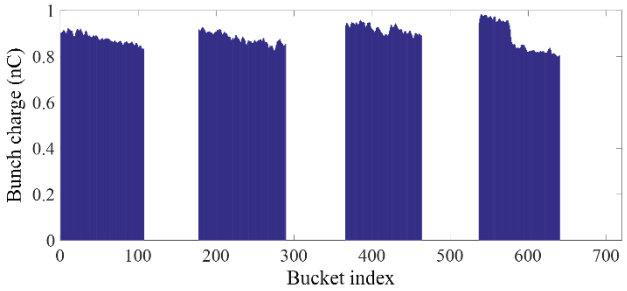
Eigenvalue index of Channel B original signal



Temporal wave of first four orders

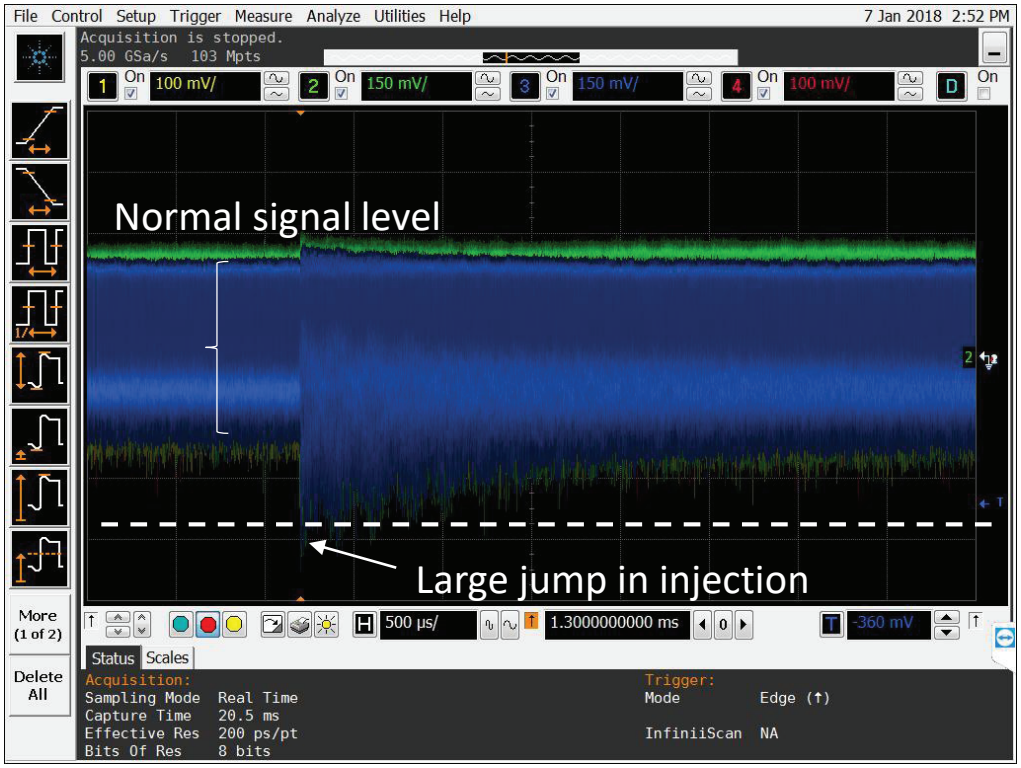
Injection transient study

Injection capture

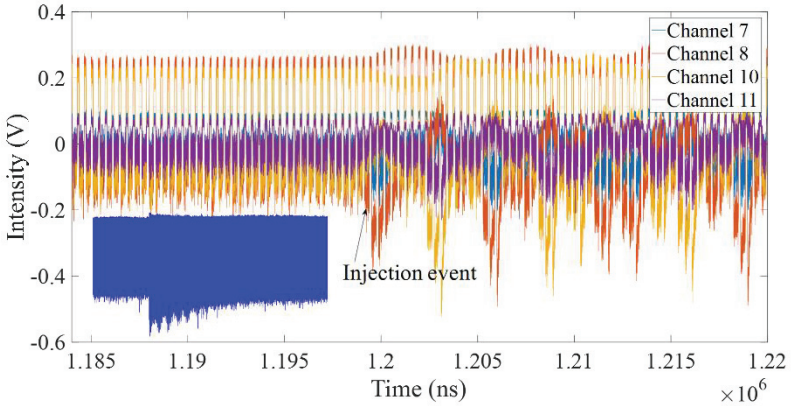


Filling pattern of top-up operating mode at SSRF

- Beam current: about 260mA
- Bunch charge: about 0.78nC
- Four long beam chains,
  each one about 120 filled buckets and 60 blank buckets
- Transverse feedback system OFF



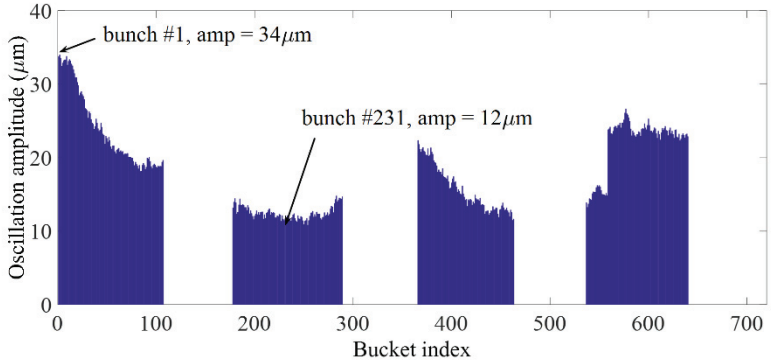
Screen snapshot of captured injection event



Detailed plot of injection event

- Injection occurs about every 5 minutes
- Set a larger trigger level than normal value
- Set 'single' trigger mode in the oscilloscope

Turn-by-turn oscillation



Initial position oscillation amplitude of every buckets

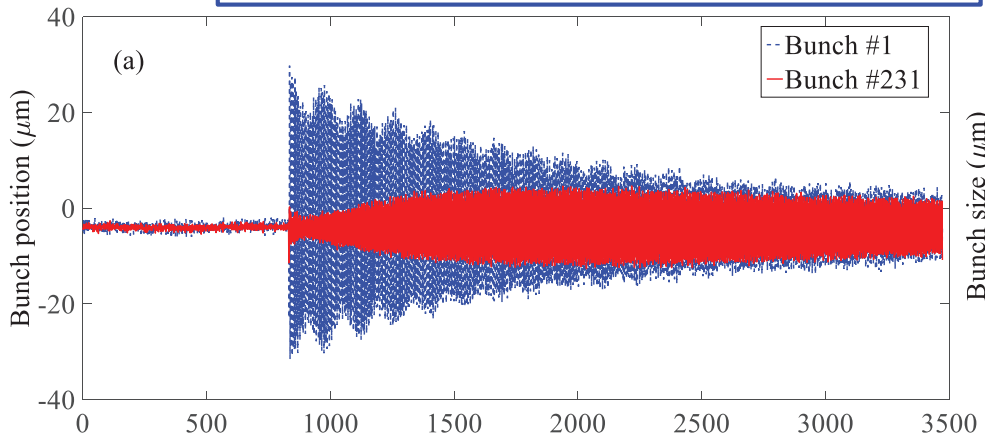
Betatron oscillation introduced by
- mismatch of injection kicker field
- wakefield effects of previous bunches

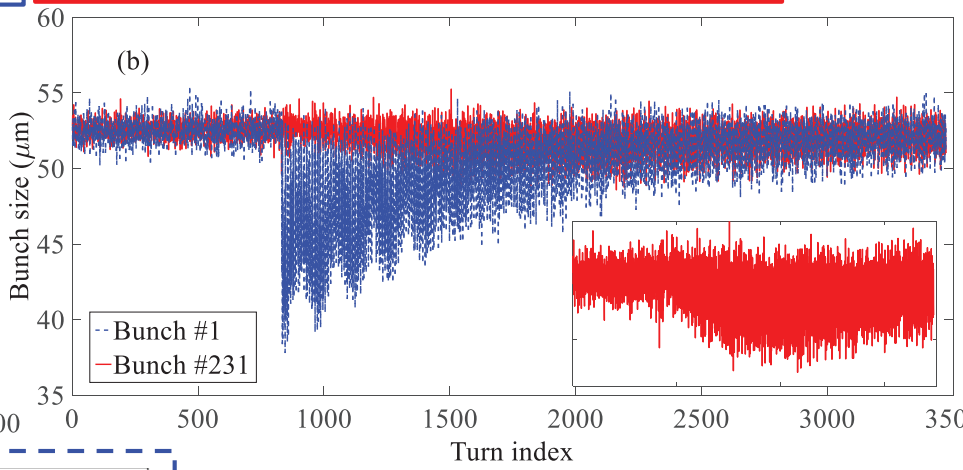
Different bunch showed different oscillation amplitude
- Largest amplitude bunch #1
- Smallest amplitude bunch #231

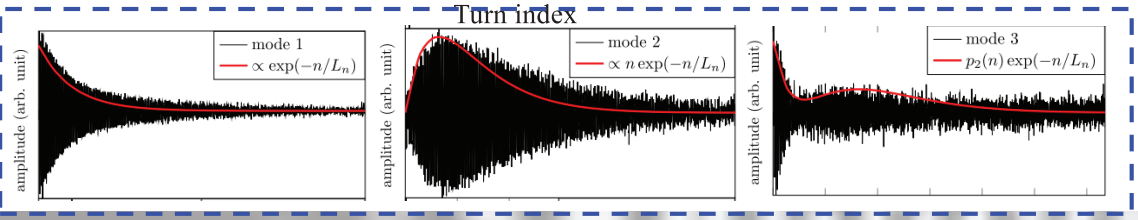
as two bunches for further study

Bunch #1 contributed by kicker mismatch
- typical dumping oscillation

Bunch #231 contributed by wakefield
- enlarge oscillation after transmission

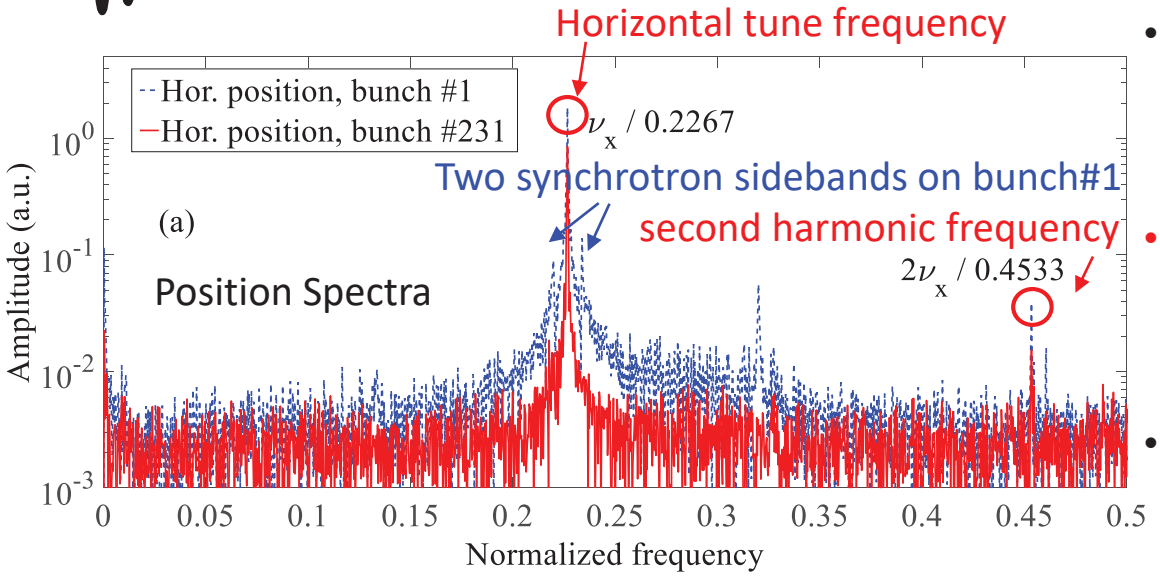




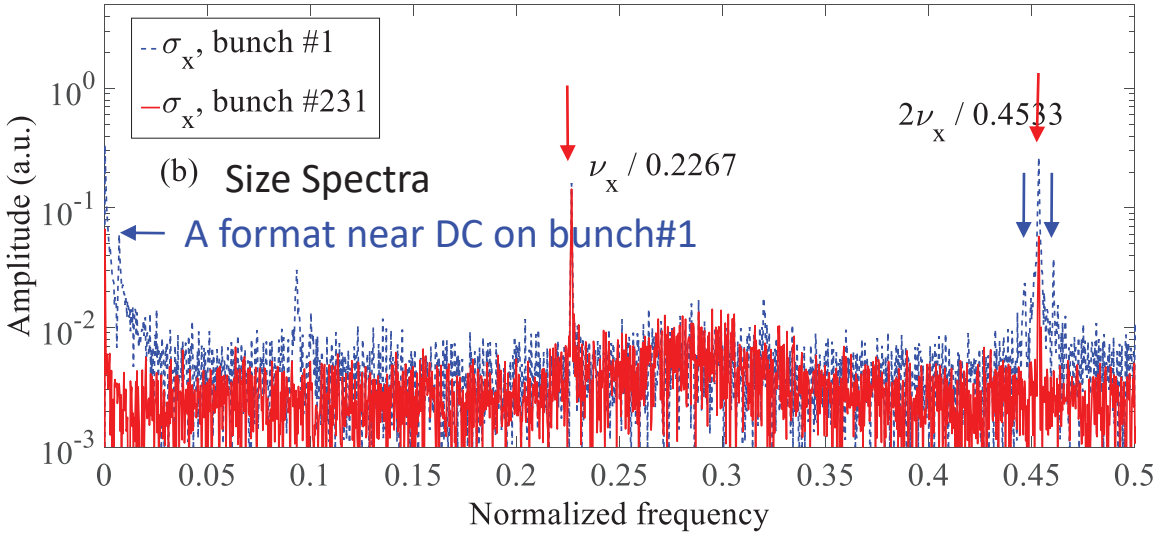


Similar results of position oscillation from BPM system, published in *Zhizhu Chen et al.* ***PRST****2014*

Spectra analysis

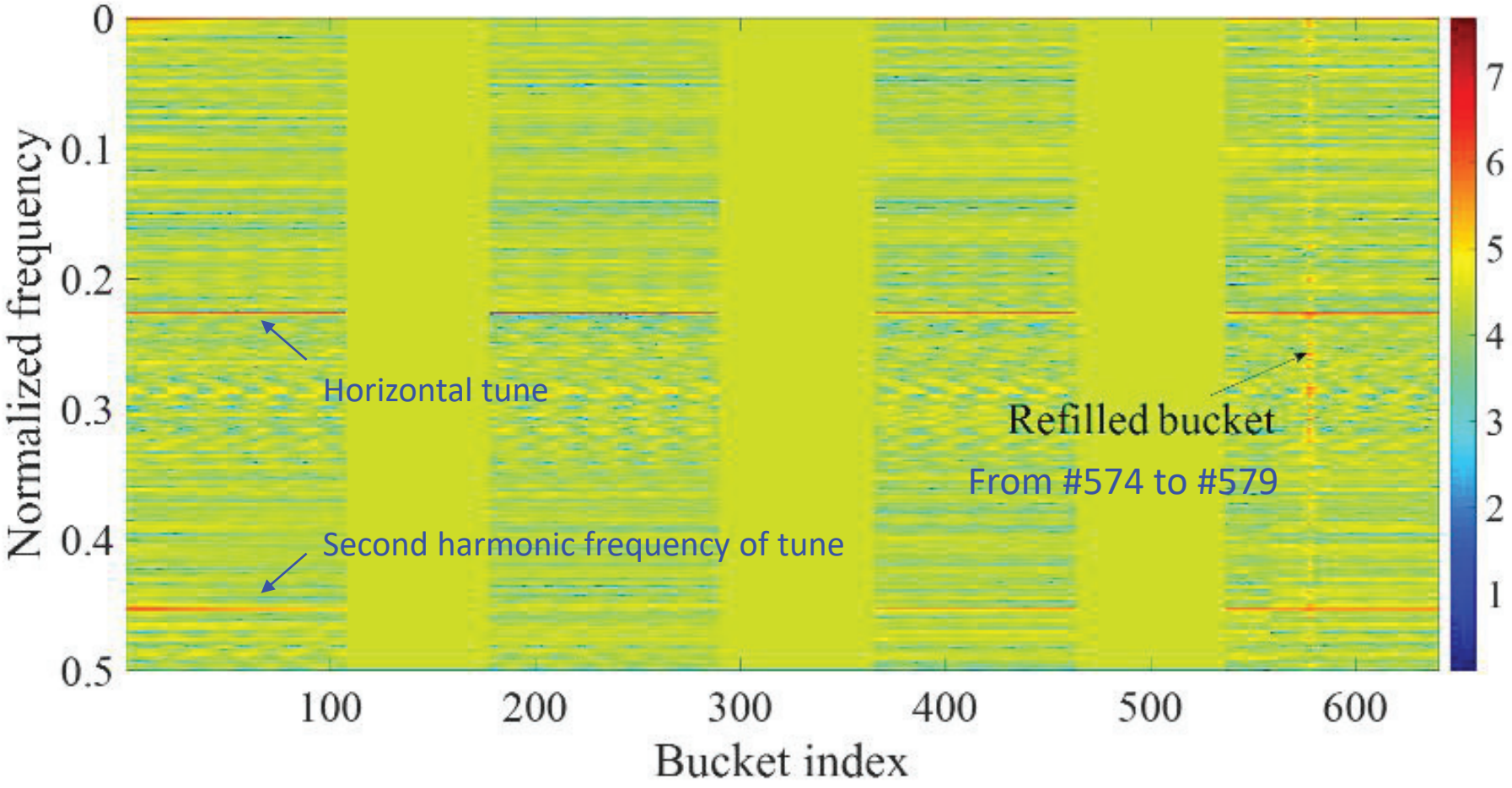


- Clearly peak on tune and its second harmonic frequency as theoretical combining process of stored bunch and refilled bunch
- Two synchrotron sidebands near tune appeared on bunch #1 as its main wide-band contribution of kicker-mismatch
- Similar results as injection spectra from BPM system



- Same tune and its second harmonic
- For bunch #1, main peak on second harmonic frequency of tune with two synchrotron sidebands
- For bunch #231, similar amplitude of tune and second harmonic without synchrotron sideband
- A format near DC appeared on bunch #1, no idea about it.

Size spectra waterfall



Next works

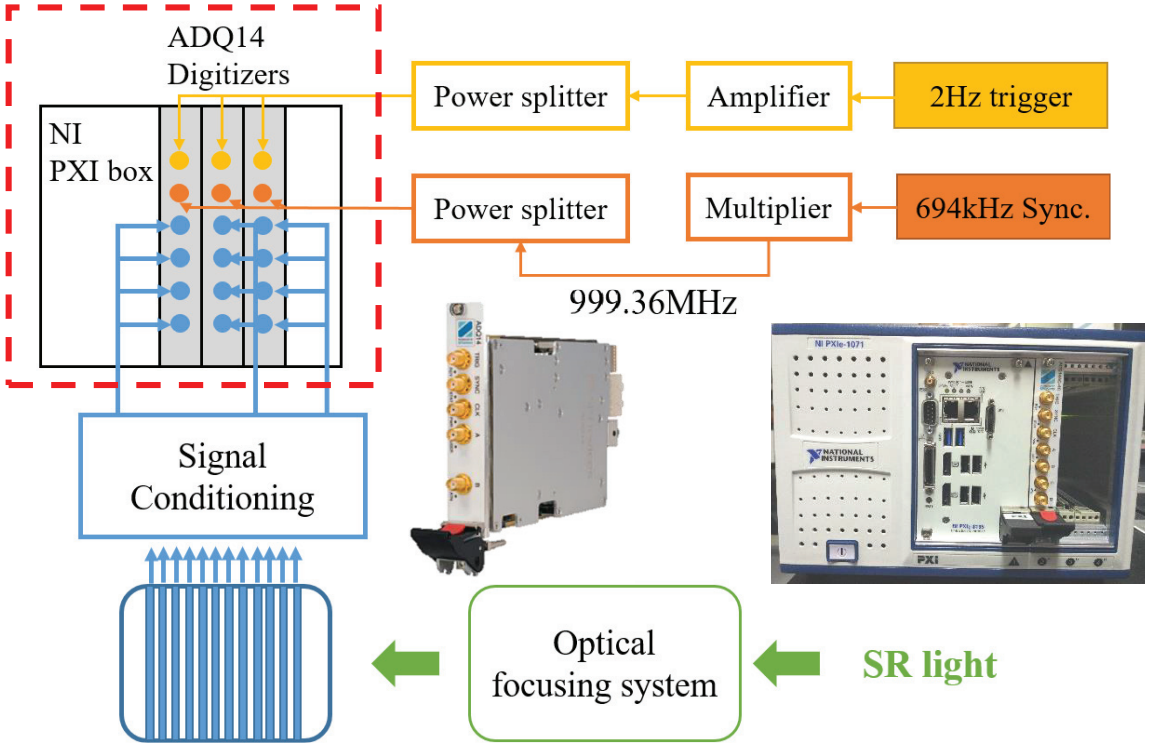
8-16 channels upgrade and synchronized sampling

System error in data calculation

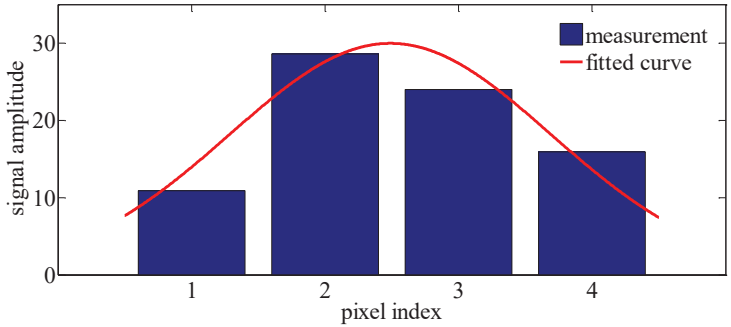
- Gaussian fitting → More channels: 8-16
- Data resampling → Synchronized sampling

New acquisition device – ADQ14 digitizer from SP device

Parameter	Value
Channels	4
Sampling rate/channel	1GS/s
ADC bit	14bit
Data memory	2GByte
Coupling	AC
Input range	1.9Vpp
Bandwidth -3dB	1200MHz
External clock reference input frequency	1GHz
External trigger frequency	>1MHz
External trigger signal level	-0.5~3.3V
Application	MATLAB，C/C++，.NET, Python，LABVIEW



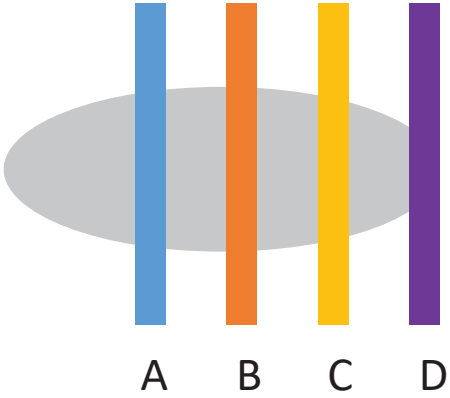
New calculation algorithm & FPGA development



The challenges of Gaussian fitting online processing

- Fitting calculation takes too much time in Matlab
- Fitting algorithm is hard to achieve in FPGA
- Gaussian model is not precision in injection process

New calculation algorithm

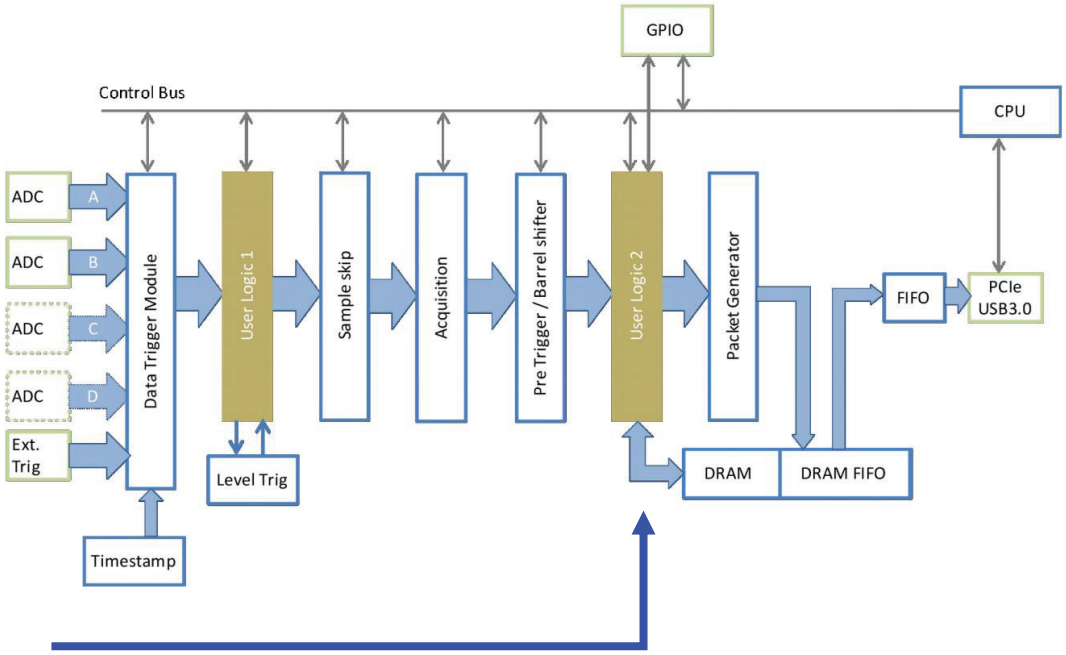


Centroid = (A+B) – (C+D)

Size = (B+C) – (A+D)

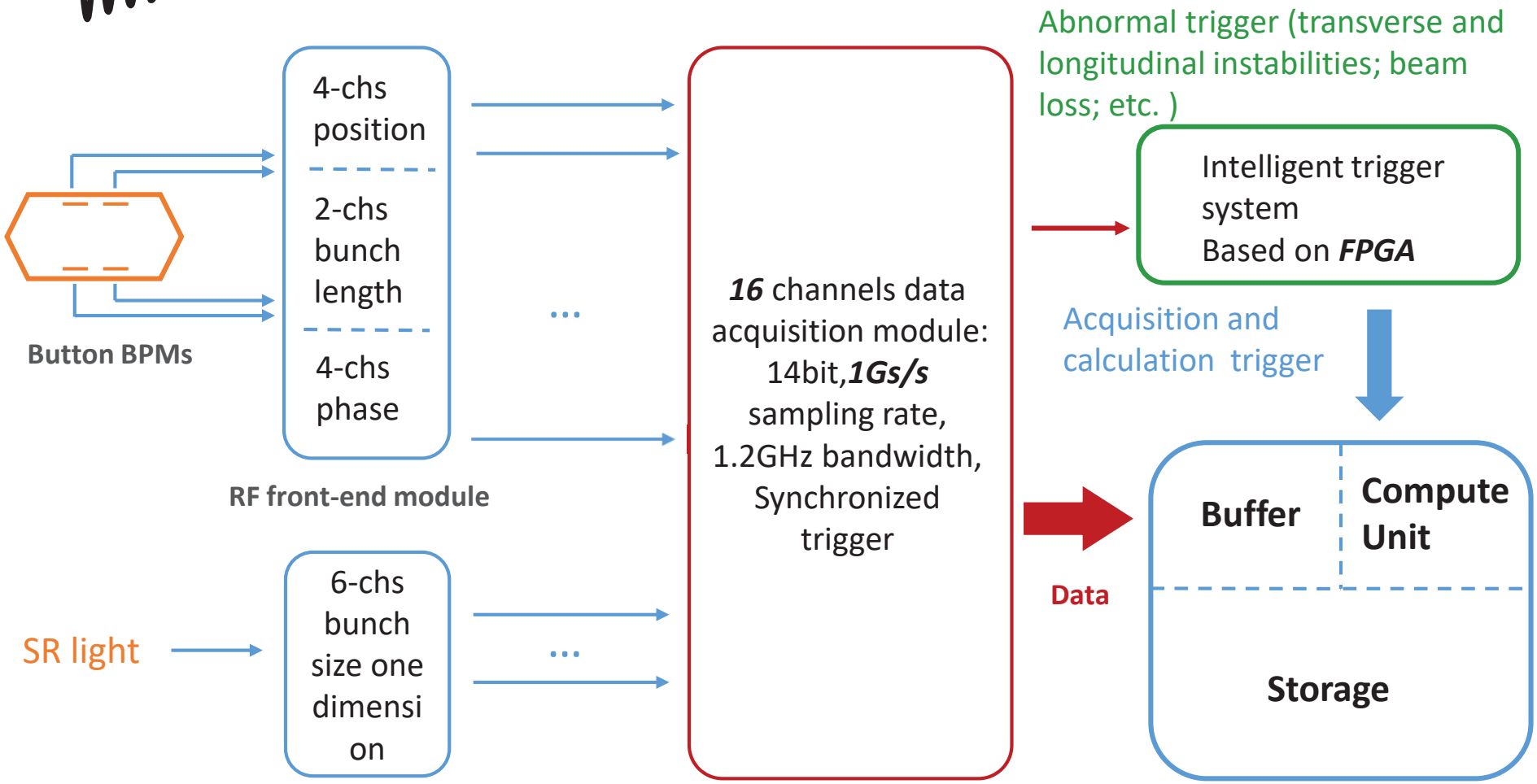
A good upgrade direction & need verification next step

Data workflow of Xilinx FPGA in ADQ14 digitizer



Design FPGA algorithm in User logic 2 module

6D Bunch-by-Bunch System integration



6-dimentional bunch-by-bunch diagnostic system architecture

Abnormal status ***capturing and analysis***
(Beam instabilities events, beam loss, etc.)

Summary

- Four channels bunch-by-bunch beam size measurement system were designed, built and implemented at SSRF
- Injection transient had been successfully captured with a high sampling-rate oscilloscope.
- The betatron oscillation characteristics introduced by kicker field mismatching and wakefield effects were analyzed from position and size results
- 8-16 channels setup, synchronized sampling, new calculation algorithm, online FPGA process and 6D bunch-by-bunch will be upgraded next step for high system resolution, instability process capturing and global parameters analysis.

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Thanks for your attention

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