CEPC Beam Instrumentation

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Outline

- CEPC beam instrumentation system
- Beam instrumentation R&D
- Summary

The beam instrumentation in CEPC Linac

	Item	Method	Parameter	Amounts
Linac	Beam position	Stripline BPM	Resolution： 30um	140
	Beam current	ICT	2.5%@1nC-10nC	42
	Beam profile	YAG/OTR	Resolution: 30um	80
	Beam emittance	Q+PR	10%	3
	Beam energy & spread	AM+PR	0.1%	3
Damping ring	Average current	DCCT	Resolution :50uA@0.1mA-30mA	1
	Beam position	Button BPM	Resolution : 20um @ 5mA TBT	40
	Tune measurement	Frequency sweeping	Resolution:0.001	1

The beam instrumentation in CEPC booster

	Item		Method	Parameter	Amounts
Booster	Beam position monitor	Turn by turn	Button electrode BPM	Measurement area (x × y) : ±20mm×±10mm Resolution：<0.02mm Measurement time of COD：< 4 s	1808
		Bunch by bunch	Button electrode BPM	Measurement area (x × y) : ±40mm×±20mm Resolution：0.1mm	
	Bunch current		BCM	Measurement range：10mA / per bunch Relatively precision：1/4095	2
	Average current		DCCT	Dynamic measurement range：0.0~1.5A Resolution:50uA@0.6-8mA Linearity：0.1 % Zero drift: <0.05mA	2
	Beam size		Double slit interferometer x ray pin hole	Resolution:0.2 μm	2
	Bunch length		Streak camera Two photon intensity interferometer	Resolution:1 ps	2
	Tune measurement		Frequency sweeping method	Resolution:0.001	2
			DDD	Resolution:0.001	
	Beam loss monitor		optical fiber	Space resolution:0.6m	400
	Feedback system		TFB	Damping time<=3ms	2
	Feedback system		LFB	Damping time<=35ms（50ms）	2

The beam instrumentation in CEPC ring

	Item		Method	Parameter	Amounts
Storage ring	Beam position monitor	Closed orbit	Button electrode BPM	Measurement area (x × y) : ±20mm×±10mm Resolution：<0.6um Measurement time of COD：< 4 s	2900
		Bunch by bunch	Button electrode BPM	Measurement area (x × y) : ±40mm×±20mm Resolution：0.1mm	
	Bunch current		BCM	Measurement range：10mA / per bunch Relatively precision：1/4095	2
	Average current		DCCT	Dynamic measurement range：0.0~1.5A Linearity：0.1 % Zero drift: <0.05mA	2
	Beam size		Double slit interferometer x ray pin hole	Resolution:0.2 μm	4
	Bunch length		Streak camera Two photon intensity interferometer	Resolution:1ps@10ps	2
	Tune measurement		Frequency sweeping method	Resolution:0.001	2
			DDD	Resolution:0.001	
	Beam loss monitor		PIN-diode	Dynamic range:120 dB Maximum counting rates≥10 MHz	5800
	Feedback system		TFB	Damping time<=47ms	2
			LFB	Damping time<=100ms	2

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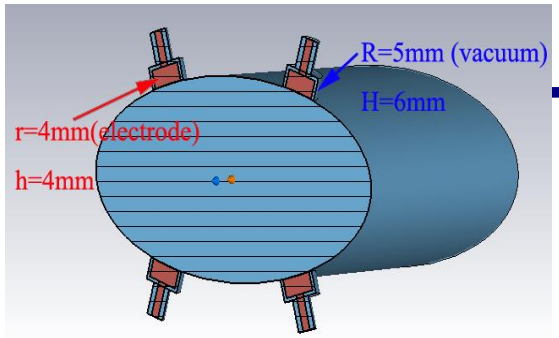
Refine of CDR design

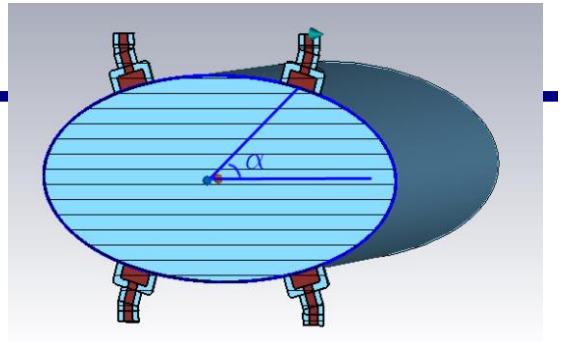
- Beam position monitor
- Beam current monitor
- Tune measurement
- The beam instrumentation of IP

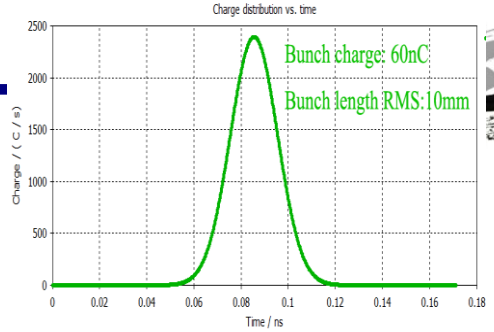
Beam Position monitor

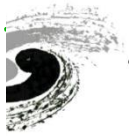
- To provide the beam position and orbit
- To calculate machine parameters related to beam position
- Apart from specific BPMs, there are 4708 BPMs in booster and storage ring.
- Button type electrode with 8mm diameter will be adopted, for its good high frequency response and small beam impedance
- The resolution of BPM will be ~2um

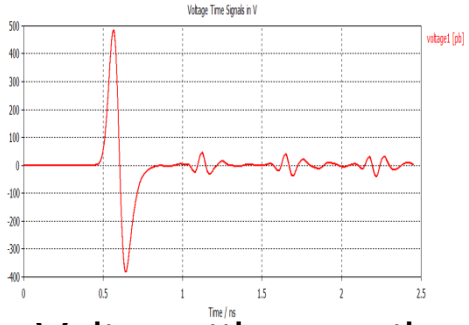
BPM pick-ups simulation

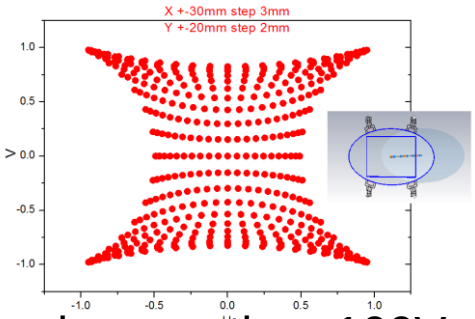


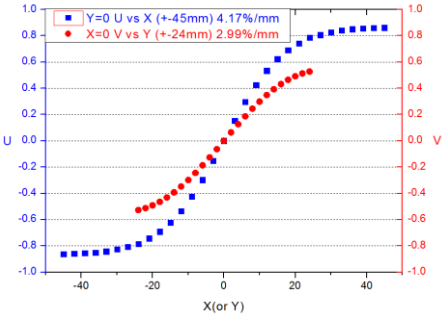




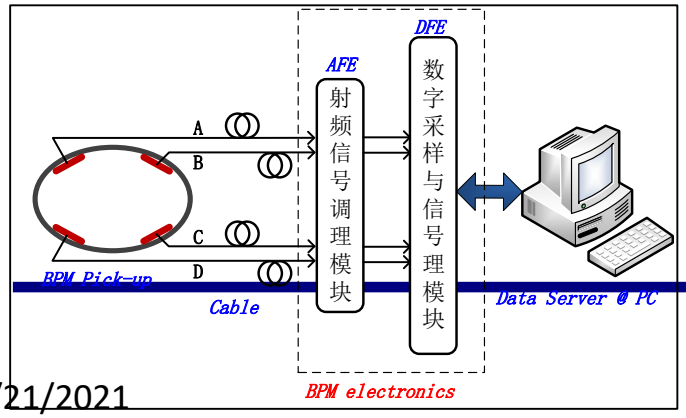








- Volts getting on the pickup is more than 100V when button diameter is 8mm
- Sensitivity be simulated at the different angle



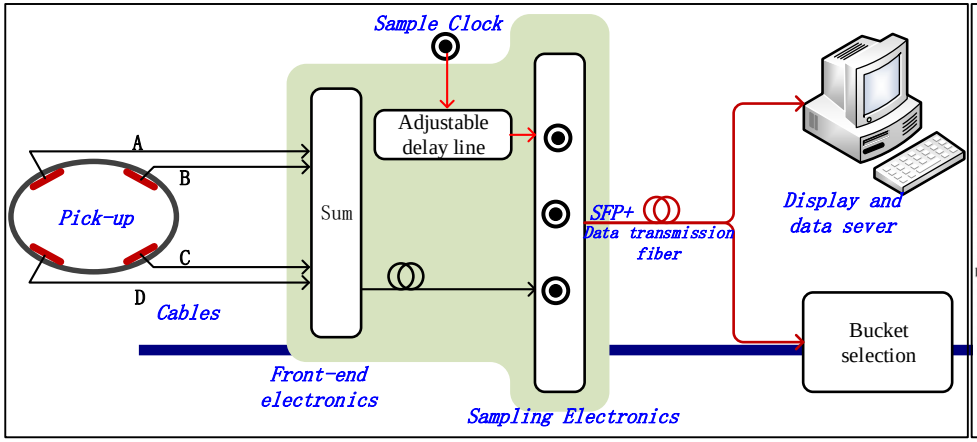
- RF Beam position monitor
- In-house developed BPM electronics
- The BPM pick-ups are designed based CEPC beam parameters

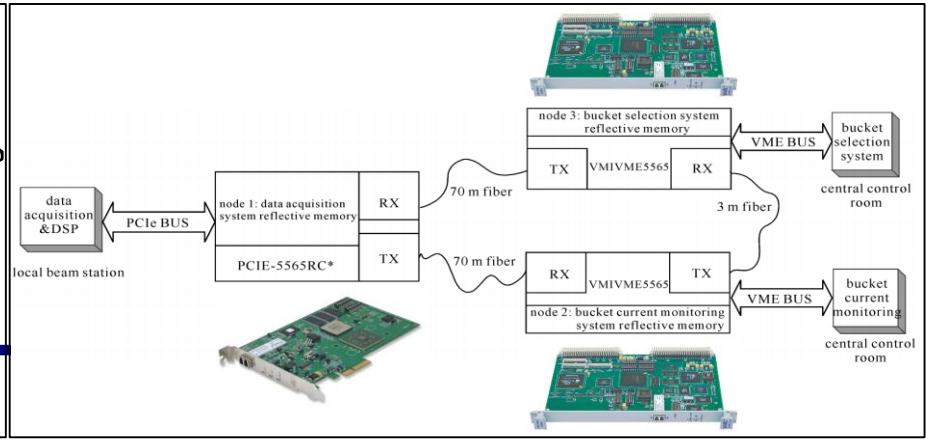
Beam current monitor

- Including DCCT (for average current) and BCM (bunch current monitor)
- Using Bergoz-type DCCT to measure the average current of the beam and to calculate the life time of beam. The resolution will be μA level;

Beam current monitor

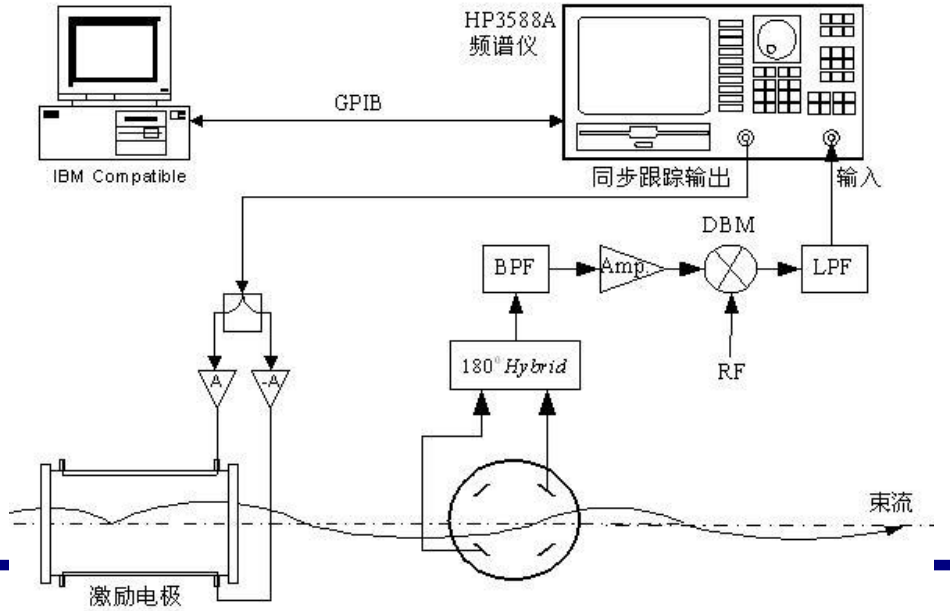
- Bunch current monitor with fast ADC sampling BPM sum signal is used to measure bunch current and share data with injection control system for bucket selection.
- The fast ADC is commercial product. Innovative Integration XG-12. 2 channels 12-bits ADC with 1G sampling rate. 512MBytes DDR2 DRAM and PCI Express x8 sockets for data transmission.





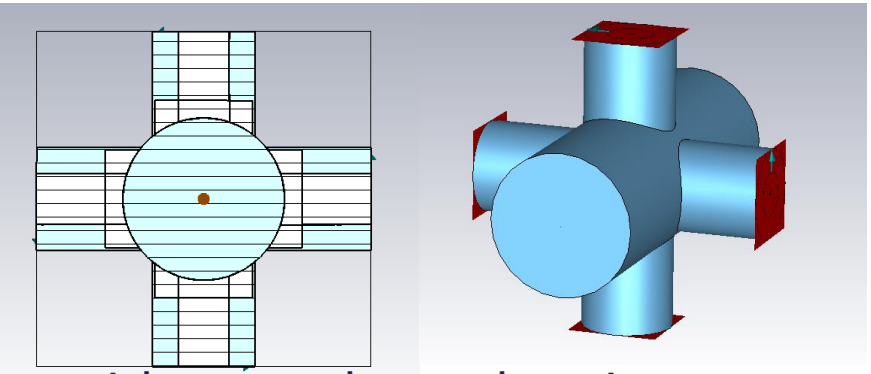
Tune measurement system

- Frequency sweeping method with gated pulse or FFT analyzing to the data from the digital BPM.
- The BPM monitor, signal processing unit and the kicker form the entire system.
- Direct Diode Detection（3D）is another choice for tune monitor

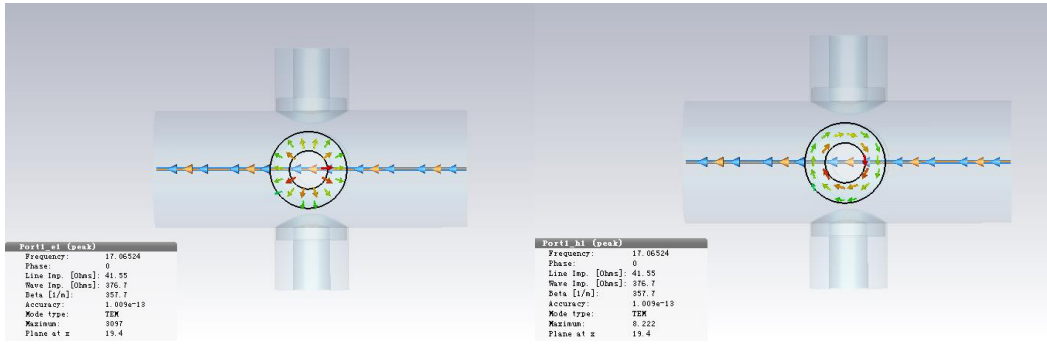


The beam instrumentation of IP

4 button electrodes structure

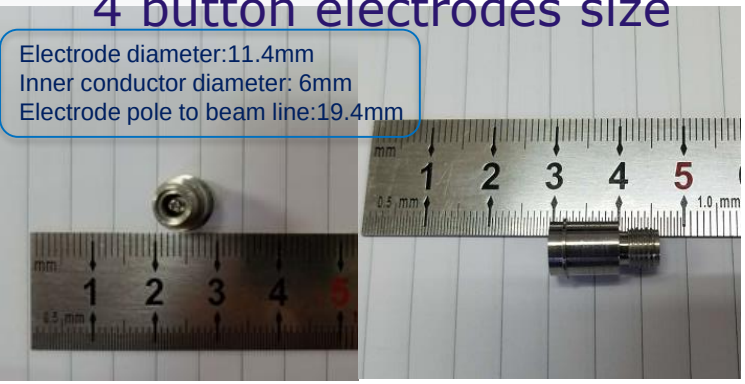


Electromagnetic field at electrodes

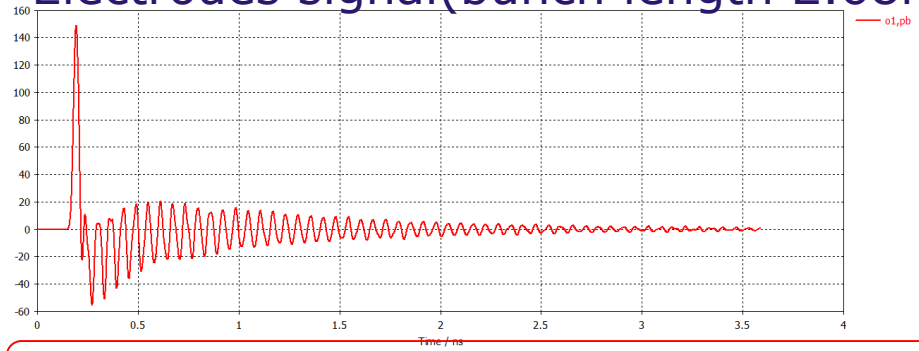


4 button electrodes size

Electrode diameter:11.4mm
Inner conductor diameter: 6mm
Electrode pole to beam line:19.4mm



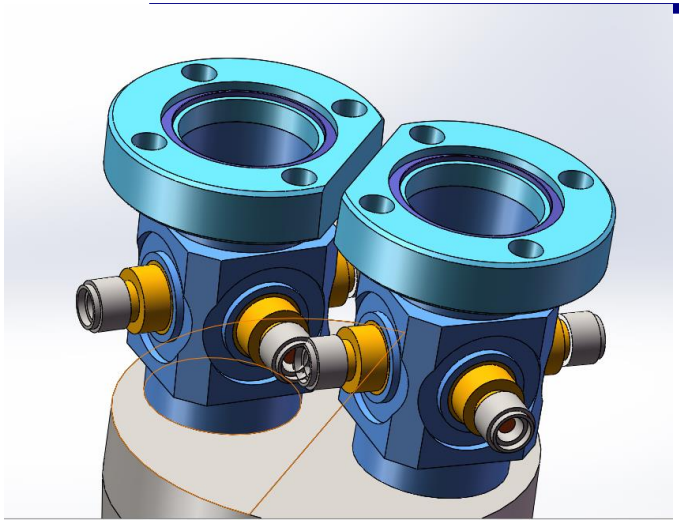
Electrodes signal(bunch length 2.68mm)

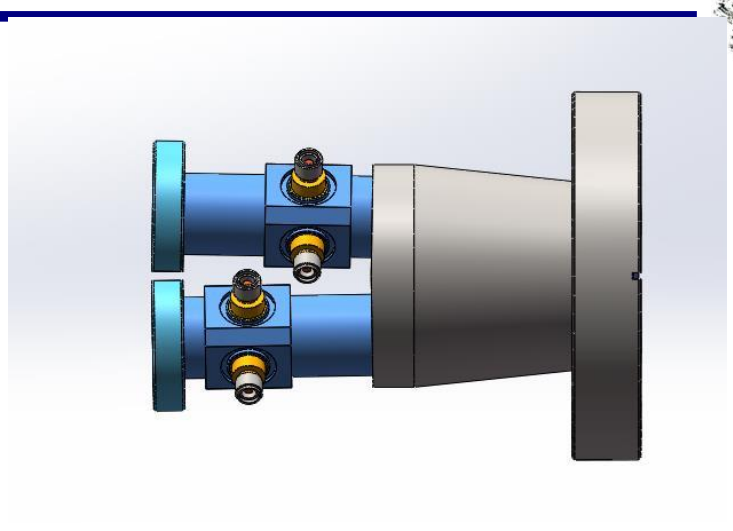


Due to the short bunch length, signal has many resonance hump, signal amplitude proportional to the bunch charge.

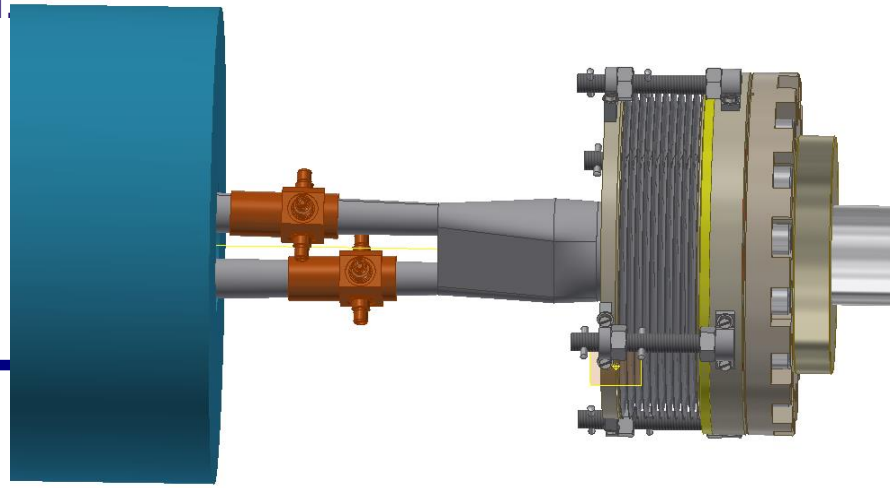
Size and signal intensity can be satisfied by CEPC MDI requirement.

The beam instrumentation of IP





- Space conflict for the inside two buttons has been solved by staggering the position ~1cm.
- Monitoring the time when two beams arrive at the collision point, e+ and e- signals can be distinguished.



R&D Motivation

- To reduce the budget of BI system, due to a large number of monitors and the high price of commercial products. Such as BPM
- Key technologies of beam diagnostics.
- Easy to maintain and upgrade

CEPC beam instrumentation R&D

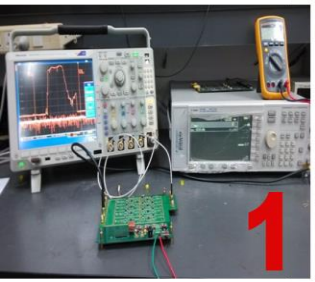
- Beam position monitor system
  - **BPM electronics**
  - **Feed through R&D**
- Feedback systems

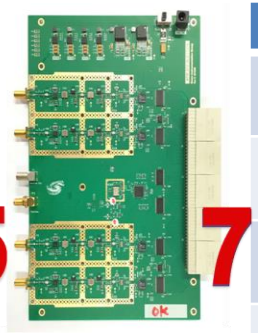
Overview of the BPM electronics R&D

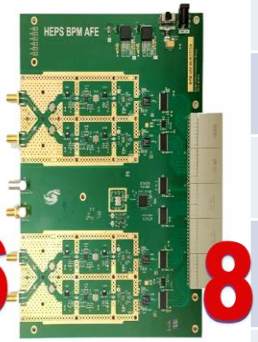
- The R&D of BPM electronics founded by seed money of IHEP and other funding（ HEPS-TF etc. ）
- Kicked off in the start of 2015
- The first version(V1.0) of the electronics was finished in 2018.
- The second version(V2.0) was finished in middle of 2019. modification was done to improve the performance of the electronics.
- The BPM electronics were installed and operating in BEPCII Linac in 2019
- BEPCII SR BPMS were upgrade to home-made electronics last year.

The front-end electronics of BPM

- Eight editions of electronics have been developed to improve the performance in the past four years.
- Finally, the front-end electronics cross talk is better than -70dB and the dynamic range is 60dB



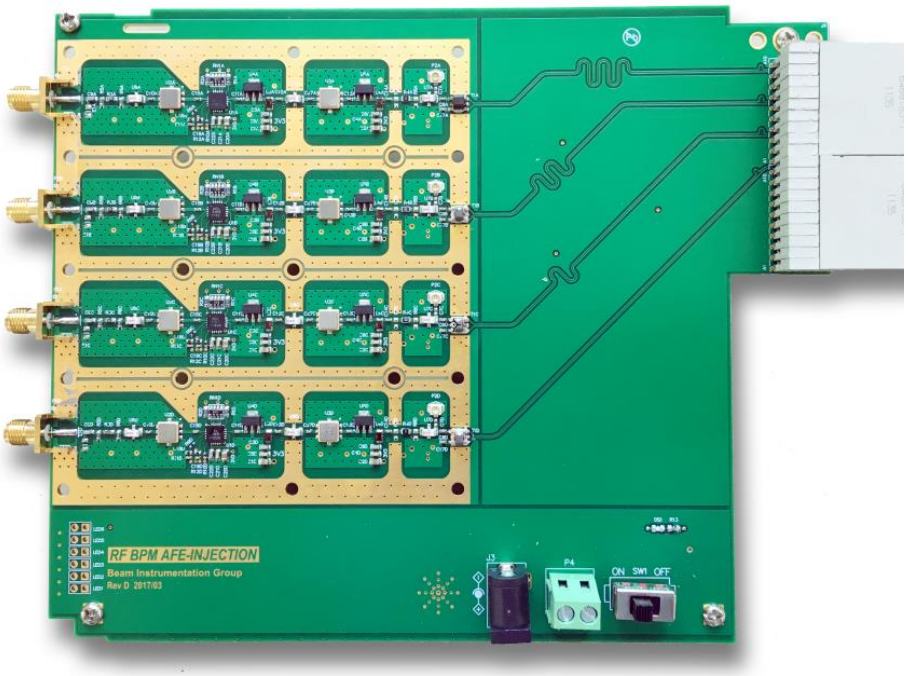


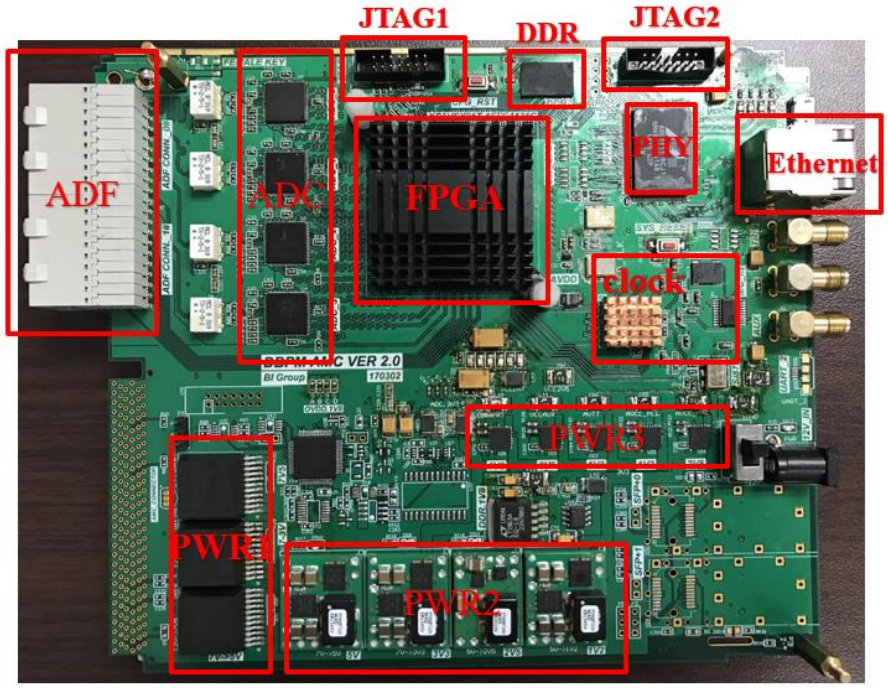


Parameter	Value
Dynamic Range	60dB
Noise Figure	< 10 dB
Input power	-60 to 0 dBm
Central frequency	499.8MHz
Cross talk	< -40 dB
Bandwidth(3dB)	30 MHz
1dB Compression Point	> 20 dBm
Long term stability	< 0.01dB

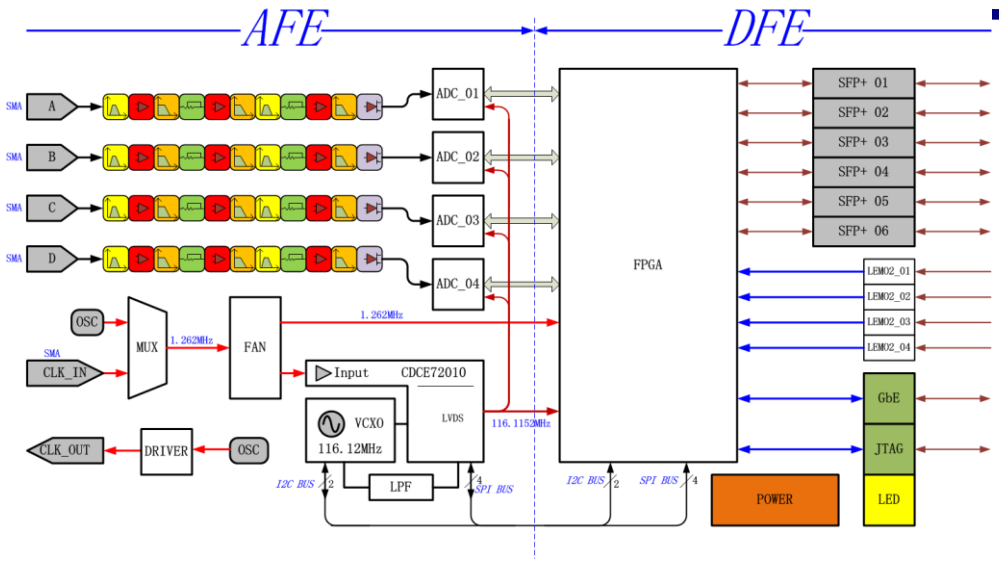
BPM electronics version1.0

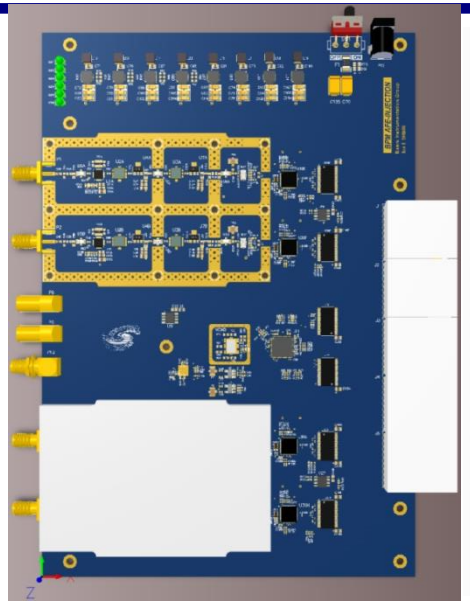
- ADC chips were placed in Back-end module
- The clock logic was located in the Back-end module, same with the ADC logic.
- RF signal transfer from frond-end module to back-end one with the ADF connector.

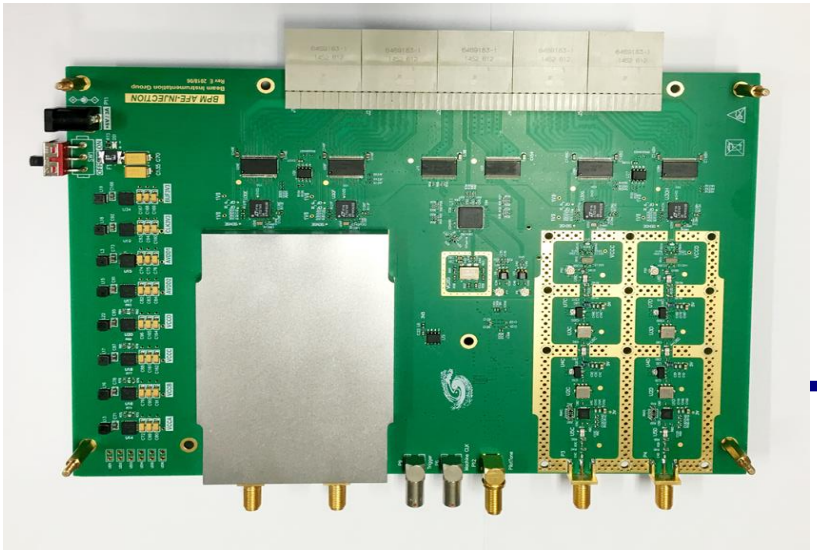




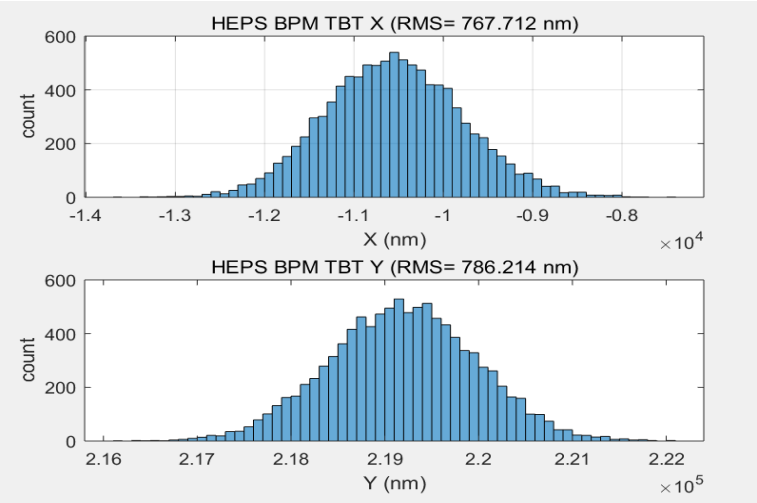
BPM electronics version 2.0



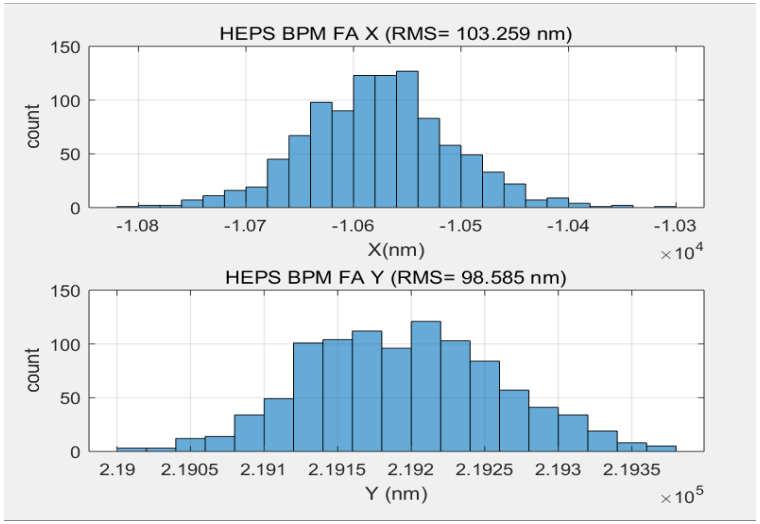




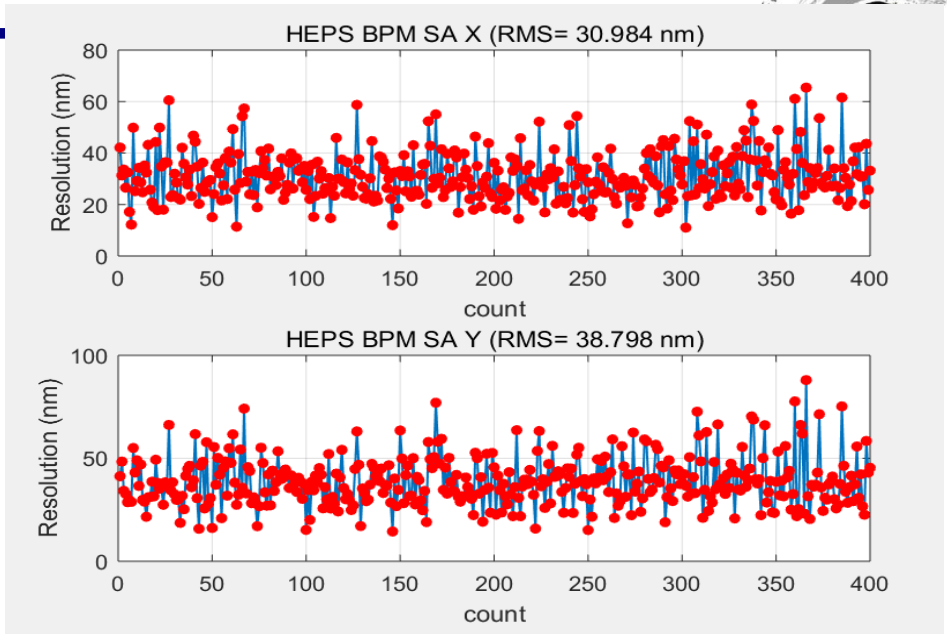
BPM TbT/FA/SA Resolution Test in Lab



TBT RMS (X=767nm,y=786nm)



FA RMS (X=103nm,y=98nm)



SA RMS(X=30nm,Y=38nm) 10points STD

- We test the performance of DBPM in house
- RF frequency is 499.8MHz(-15dBm) from R&S SMA100
- TBT data rms xpos ≈767nm, ypos ≈786nm;
- FA data rms xpos ≈103nm, ypos ≈98nm;
- SA data rms xpos ≈30nm, ypos ≈38nm;
- Kx=Ky=8.26mm;

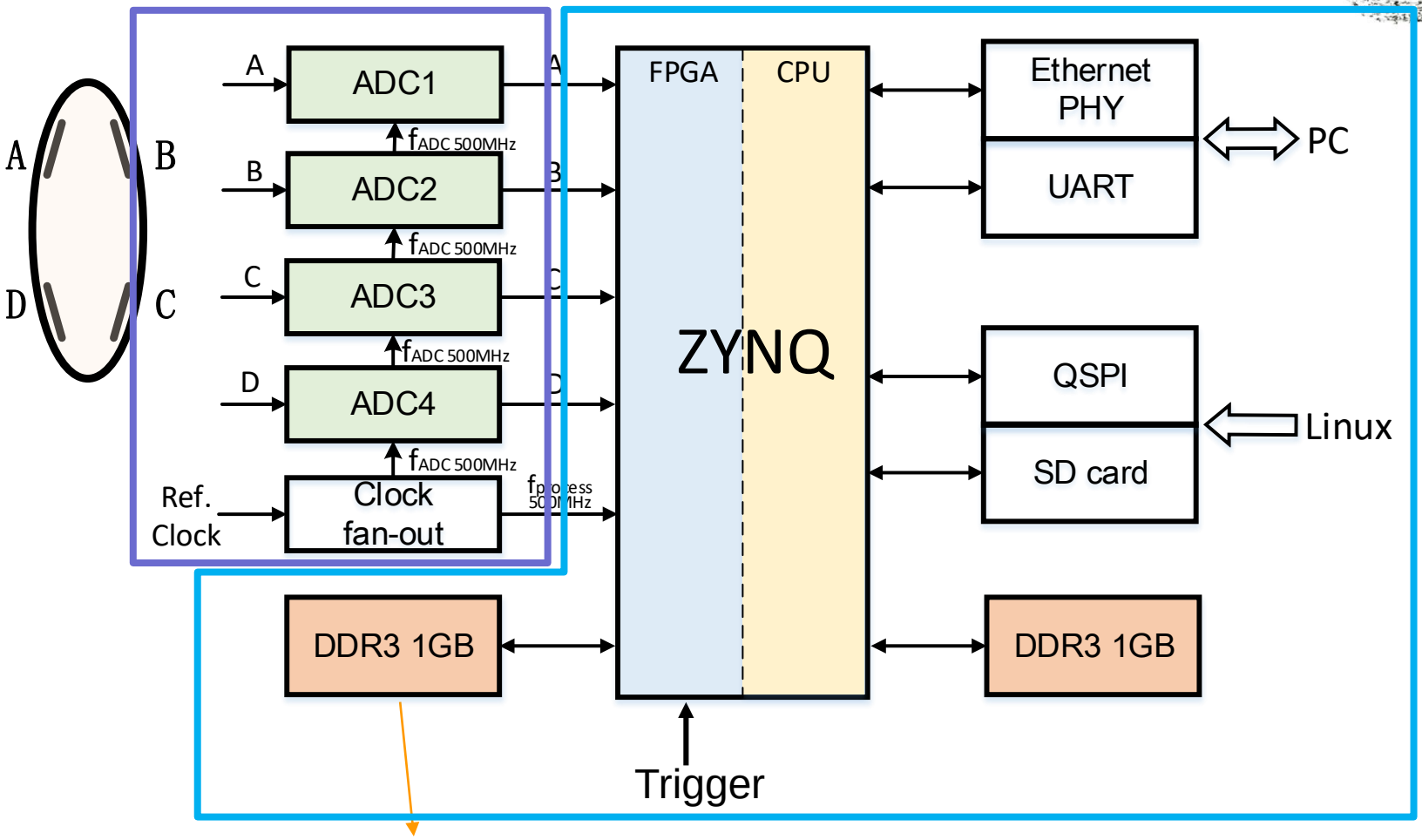
Application of BPM electronics in BEPCII

- After finishing prototype test, small batch production and application has been done in BEPCII
- Last year, a part of BEPCII SR BPM electronics were upgraded to home-made style. The rest will be done this year ，
- The single-pass mode BPM electronics is developed for the linac and put in operation in the middle of 2019.

Bunch by bunch BPM electronics R&D

- The beam trip is an important problem for accelerator operation. Because the accelerator system is very complicated, involves many subsystems, and various conditions are mixed together, so, it is difficult to get to the real cause for beam trip.
- At present, many accelerators all over the world have established a powerful beam trip diagnostic system.
- Beam trip seriously affects the efficiency of the machine, also may cause damage to the hardware system. So, it is necessary for CEPC to develop bunch by bunch BPM for studying the beam trip.

Bunch by bunch BPM electronics

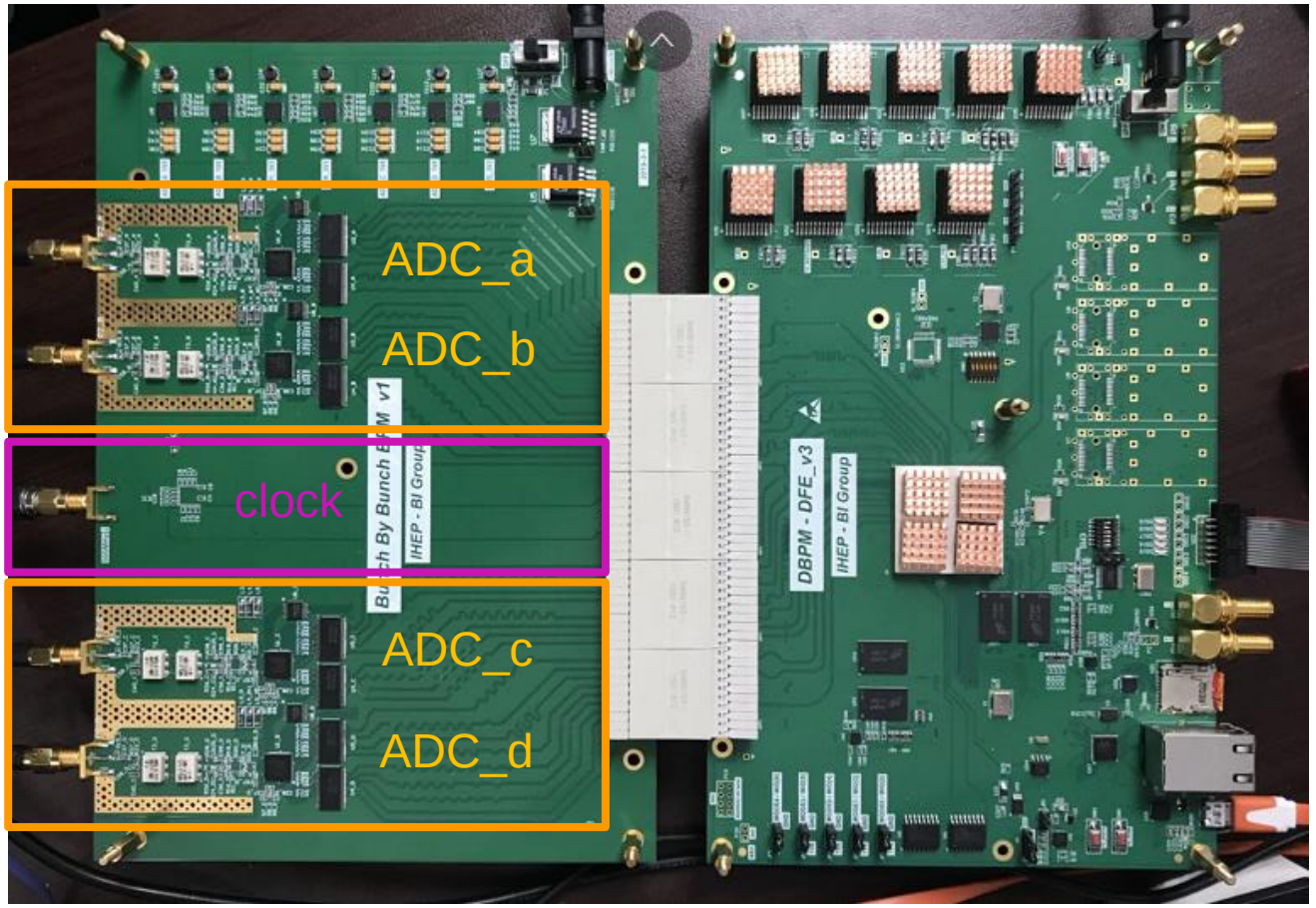


Buffer of bunch by bunch raw ADC data

Bunch by bunch BPM electronics

Sampling clock: 500MHz,free running clock or externally clock locked with beam signal

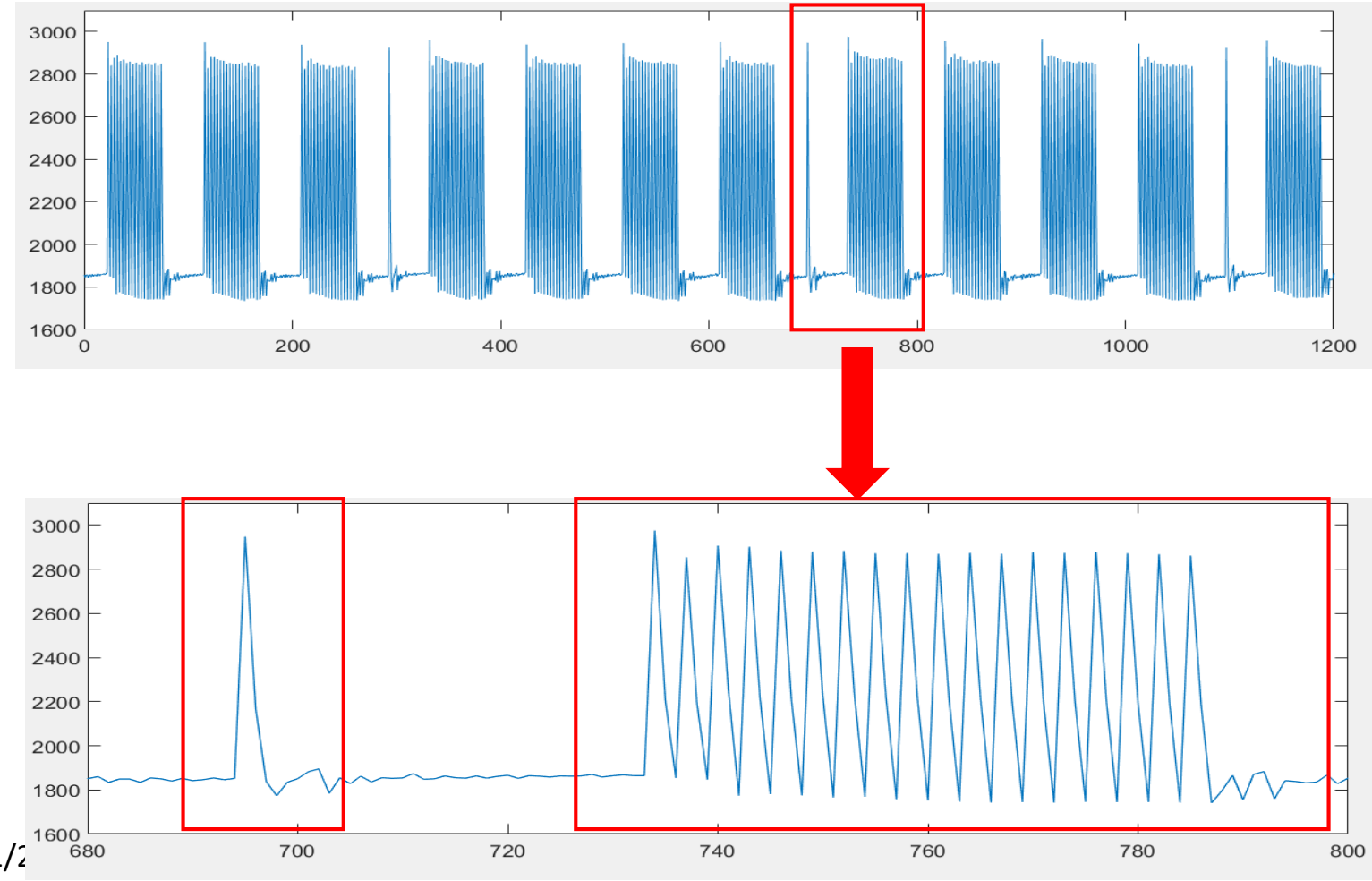
AFE



DFE

Bunch by bunch BPM electronics

Input: simulation pattern of BEPCII , repetition period 6ns



Feed-through R&D

- Finished the study of feed-through in beam instrumentation.
- Independent research and development of feed-through was kicked off
- Two versions of feed-through have been made with the help of CIPC Member Company in the last year.

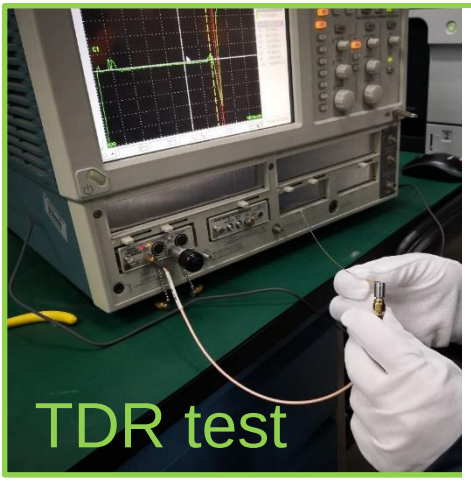
BPM feed-through V1.0

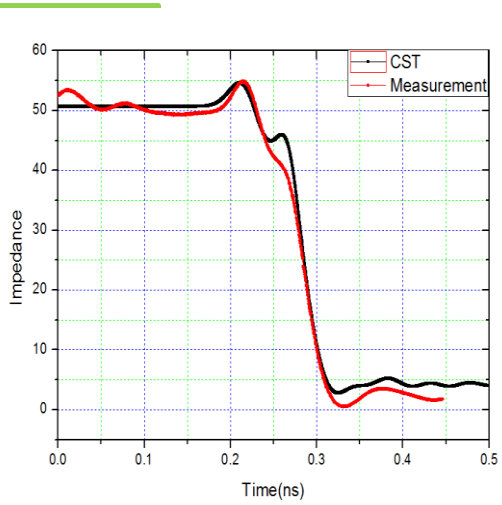
BPM feed-through V2.0

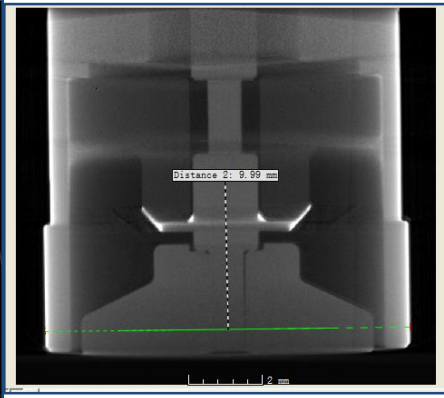
Kicker feed-through

Feed-through R&D

- The test result of the feedthroughs shows that the mechanical properties, high-frequency characteristics and vacuum performance can meet the demands of the CEPC BPM totally.
- TDR for impedance test and X-ray tomography for inner structure check.

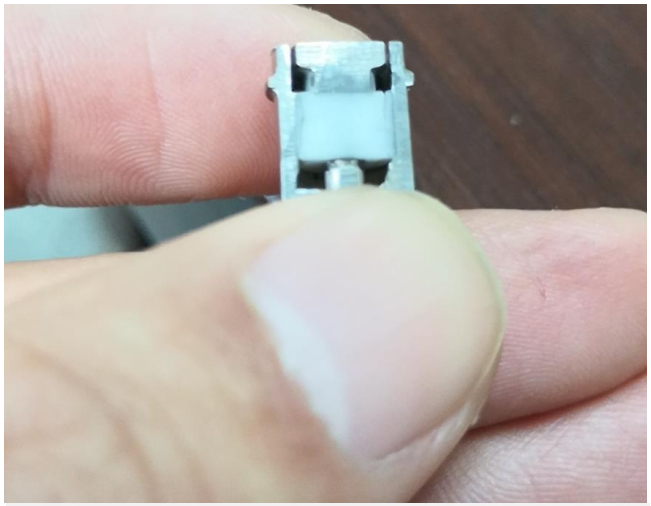


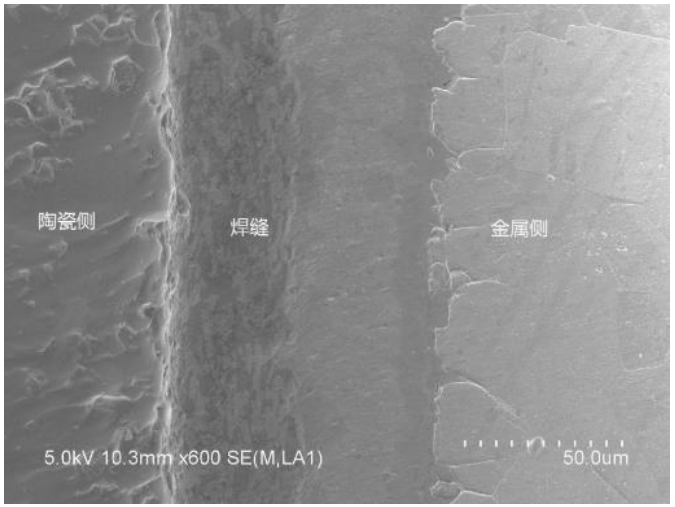


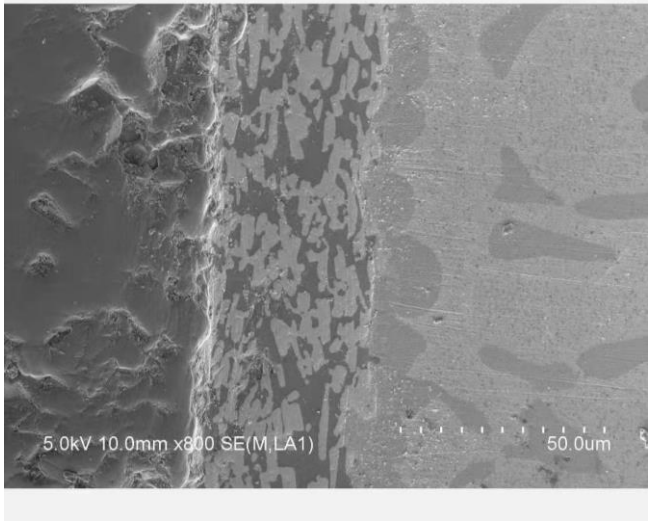


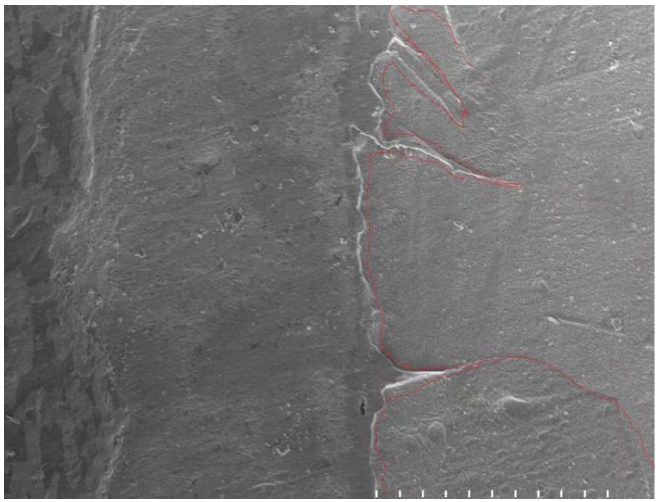
Feed-through R&D

- Morphology of solid surface by SEM









Summary

- Based on the CDR, subsystems such as beam position monitor, beam current monitor and feedback are refined.
- The beam position monitor and other key technologies R&D has been carried out.
- Many modifications have been made in BPM electronics to improves the performance. Small batch production have been used online in BEPCII linac and storage ring.
- The bunch by bunch system was developed for CEPC beam diagnostics. More test will be done with real beam in BEPCII.
- More attention will be paid in the beam feedback and beam instrumentation in interaction point(IP).

Thanks for your attention !