CEPC Beam Instrumentation R&D

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Outline

- Overview of 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

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 and beam loss monitor
- Key technologies of beam diagnostics. Beam instrument at IP and beam feed back system
- Easy to maintain and upgrade

CEPC beam instrumentation R&D

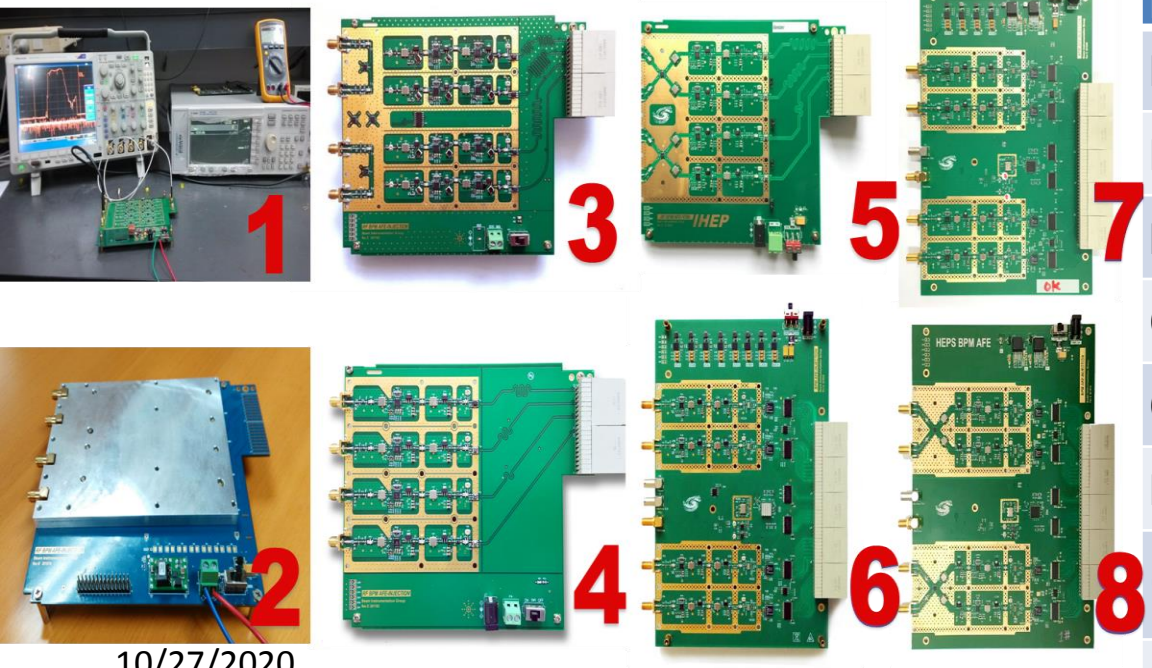
- Beam position monitor system
  - **BPM electronics**
  - **Feed through R&D**
  - **BPM at interaction point（IP）**
- Beam loss monitor
- Feedback systems

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 are upgrade to home-made electronics this year.

The front-end electronics of BPM

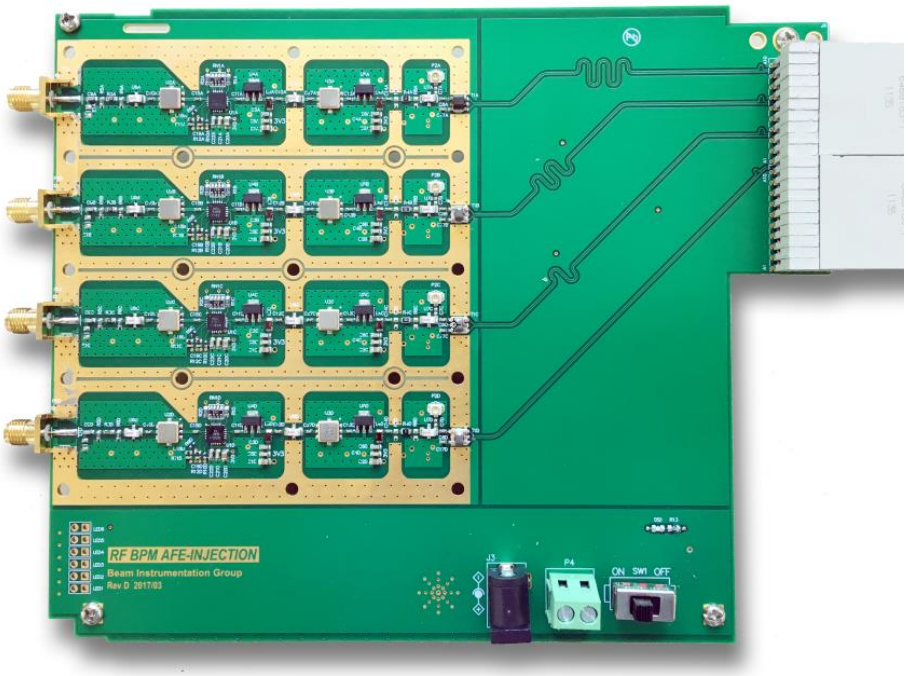
- Eight editions of electronics have been developed to improve the performance in the past four years.
- Finally, the front-end electronics cross talk is better than -70dB and the dynamic range is 60dB

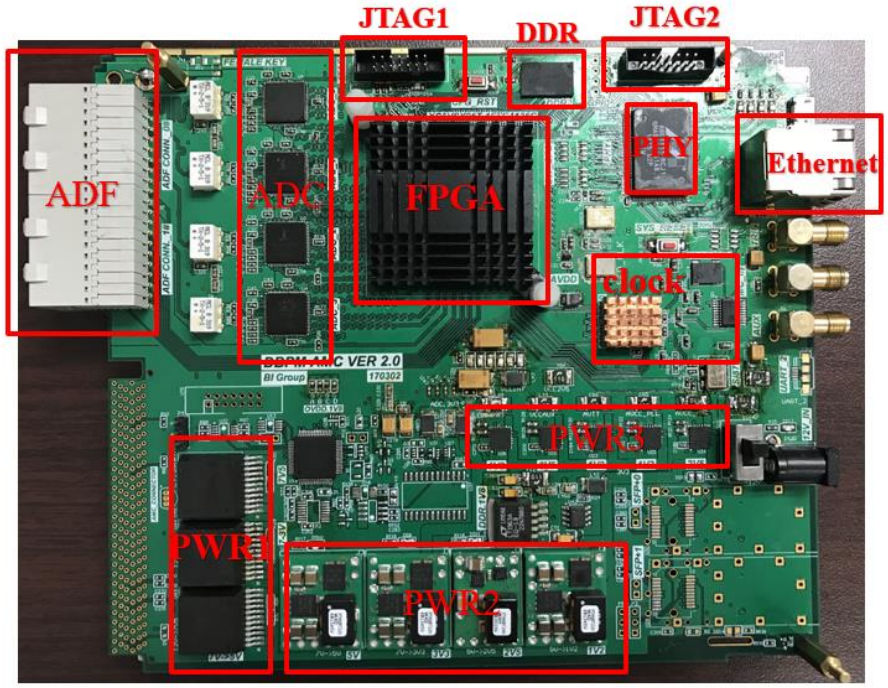


Parameter	Value
Dynamic Range	60dB
Noise Figure	< 10 dB
Input power	-60 to 0 dBm
Central frequency	499.8MHz
Cross talk	< -40 dB
Bandwidth(3dB)	30 MHz
1dB Compression Point	> 20 dBm
Long term stability	< 0.01dB

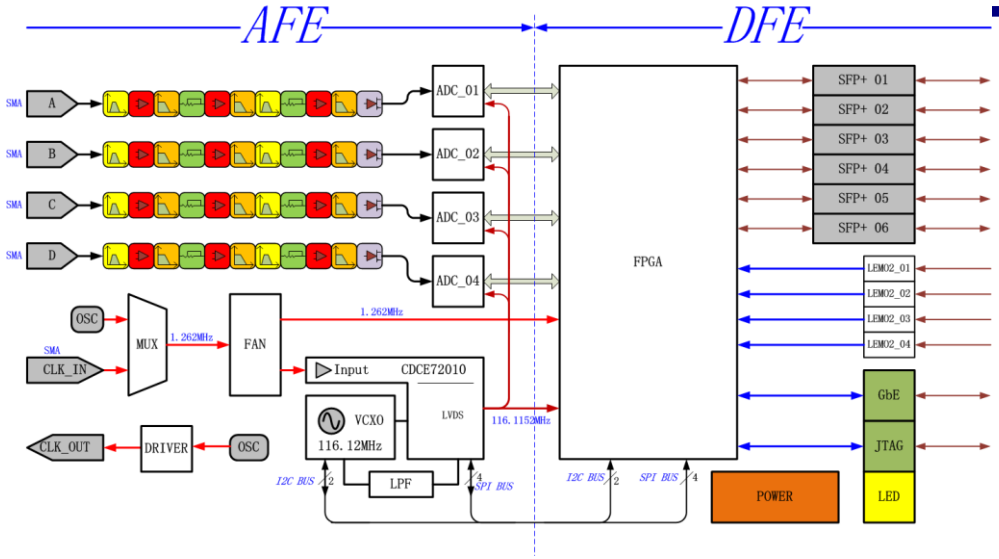
BPM electronics version1.0

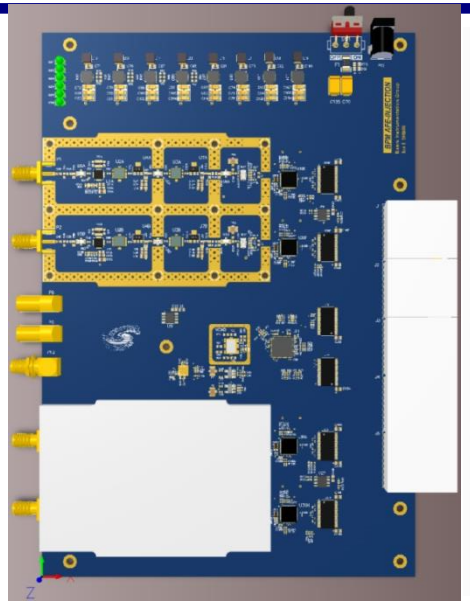
- ADC chips were placed in Back-end module
- The clock logic was located in the Back-end module, same with the ADC logic.
- RF signal transfer from frond-end module to back-end one with the ADF connector.

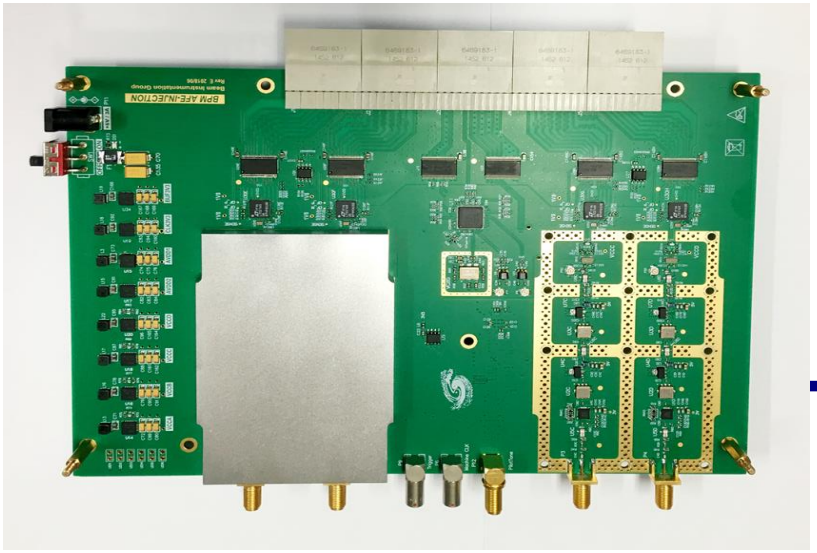




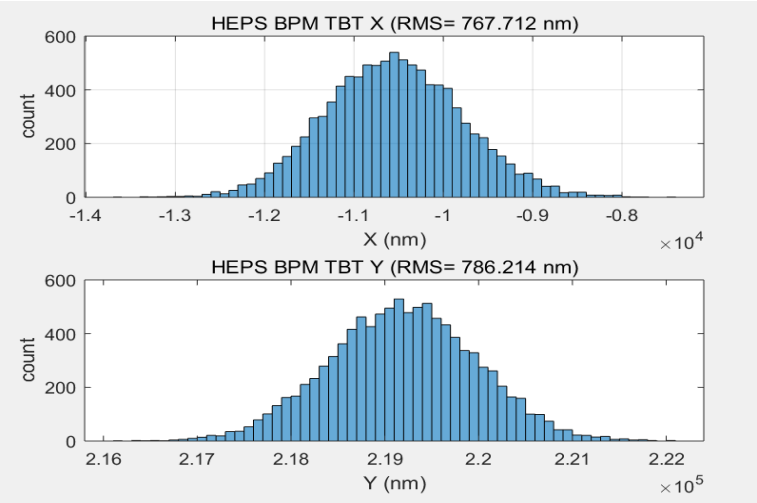
BPM electronics version 2.0



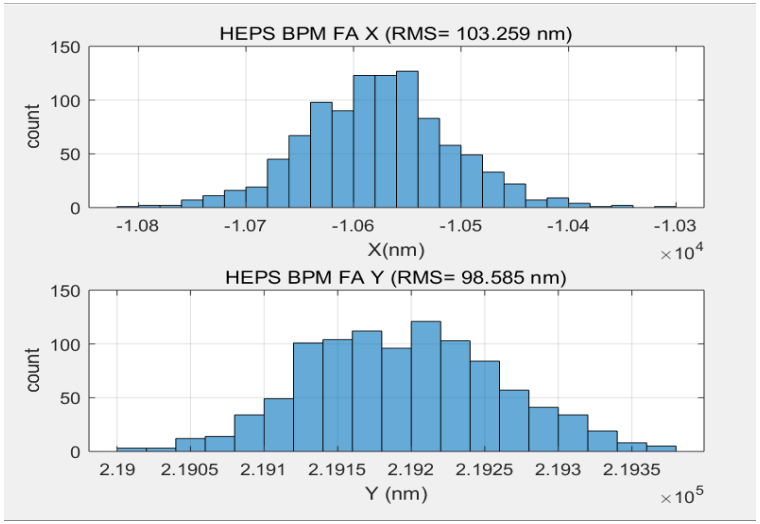




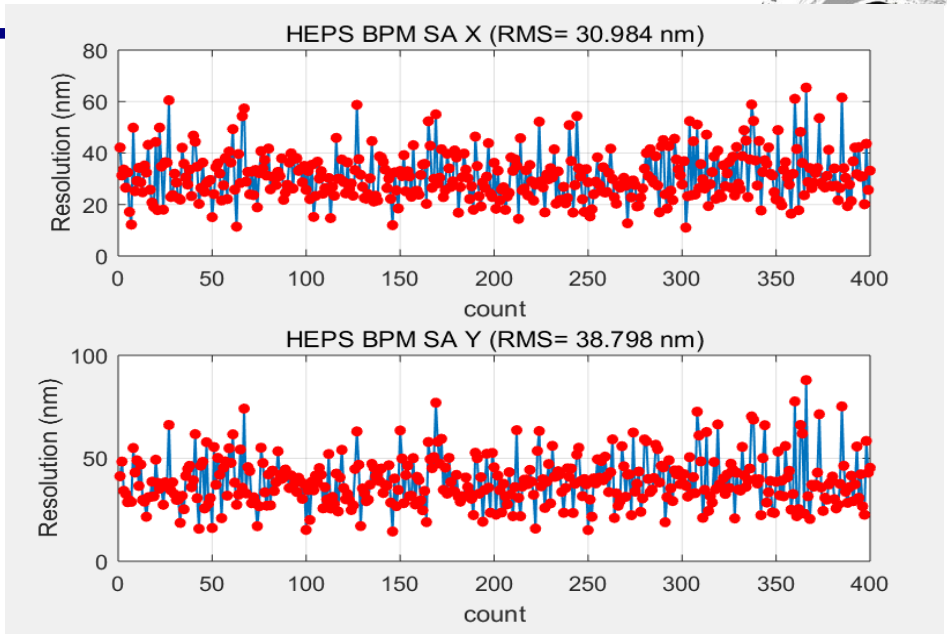
BPM TbT/FA/SA Resolution Test in Lab



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;

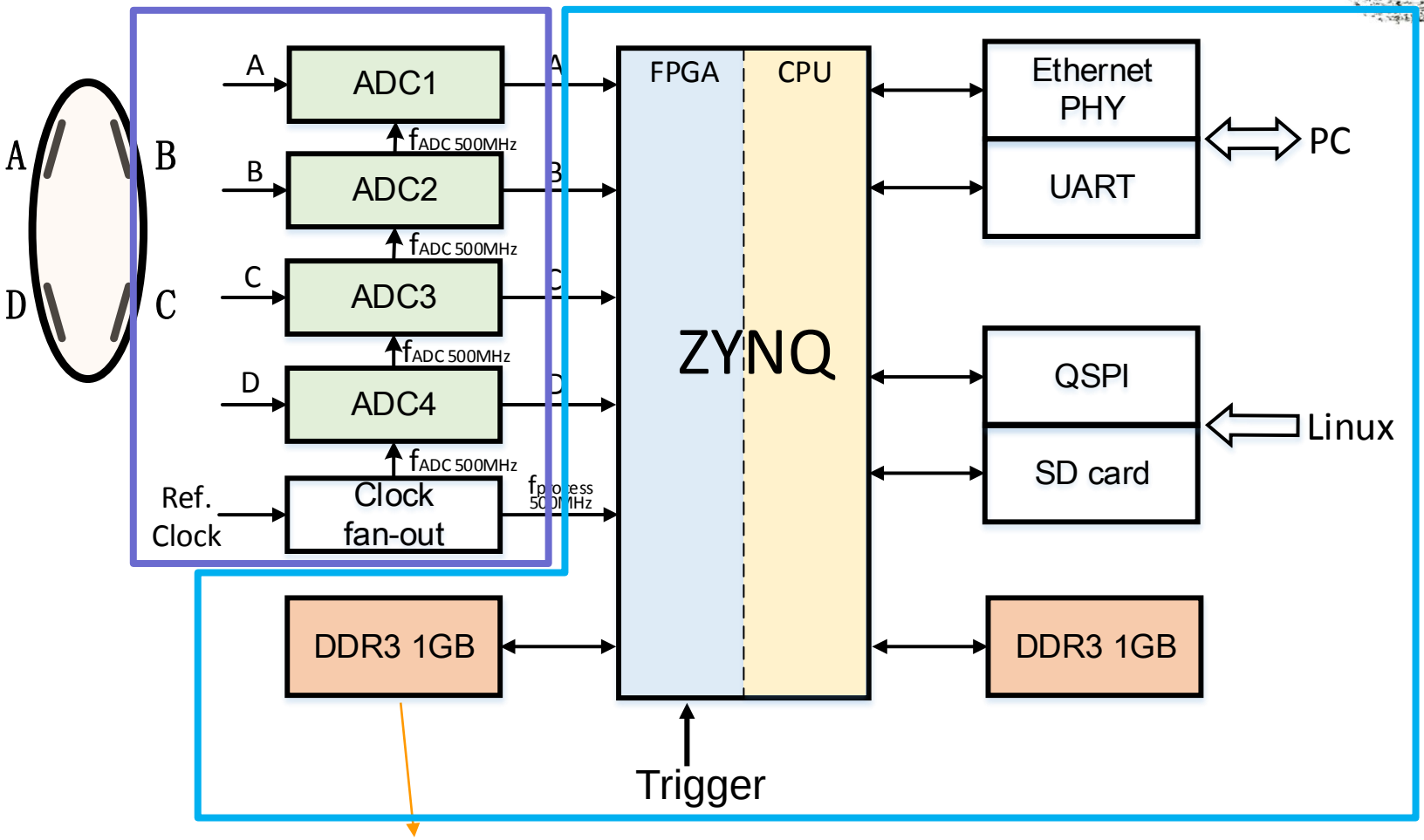
Application of BPM electronics in BEPCII

- After finishing prototype test, small batch production and application has been done in BEPCII
- From this year, all of BEPCII SR BPM electronics will upgrade to home-made one.
- 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.

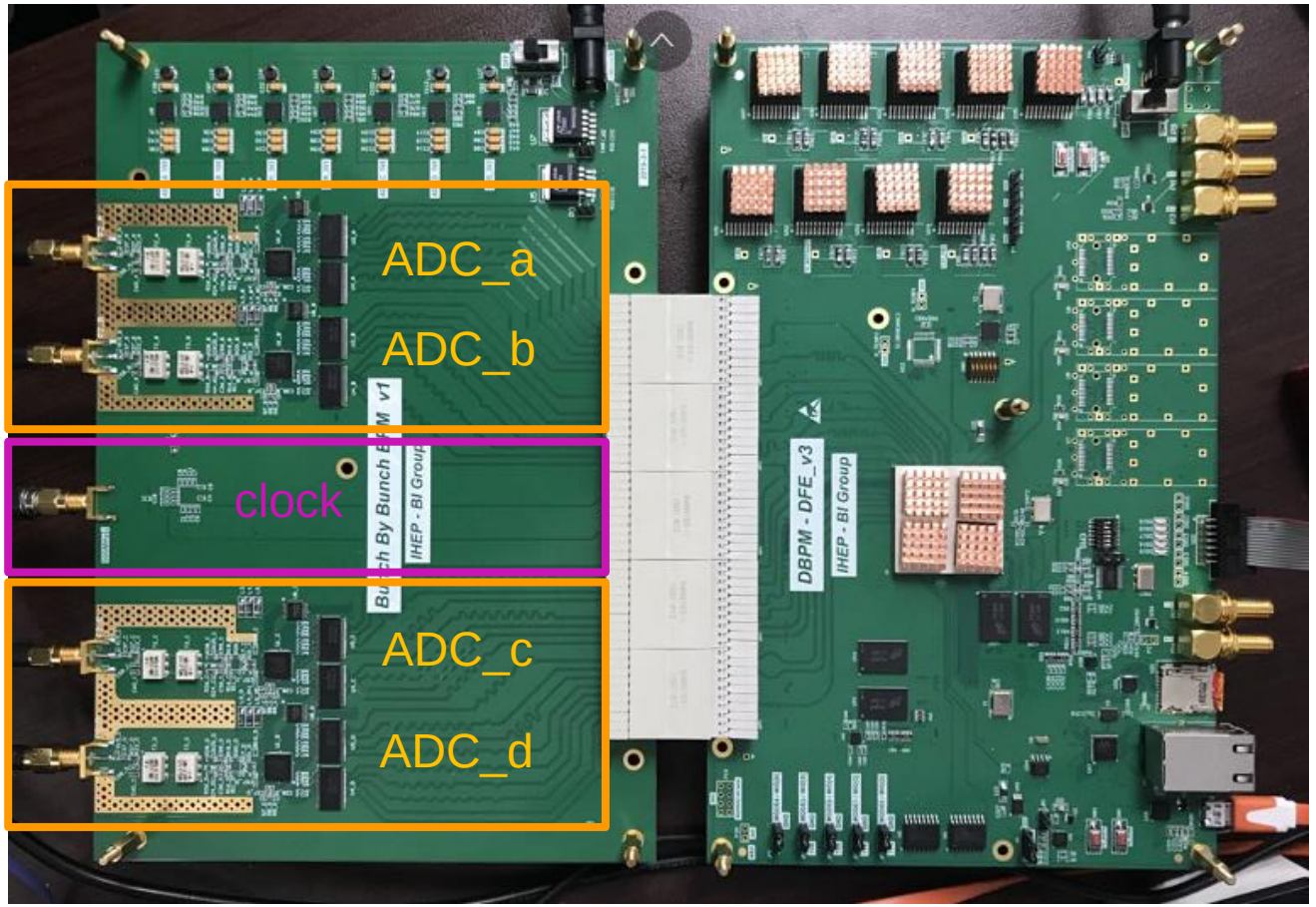
Bunch by bunch BPM electronics



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

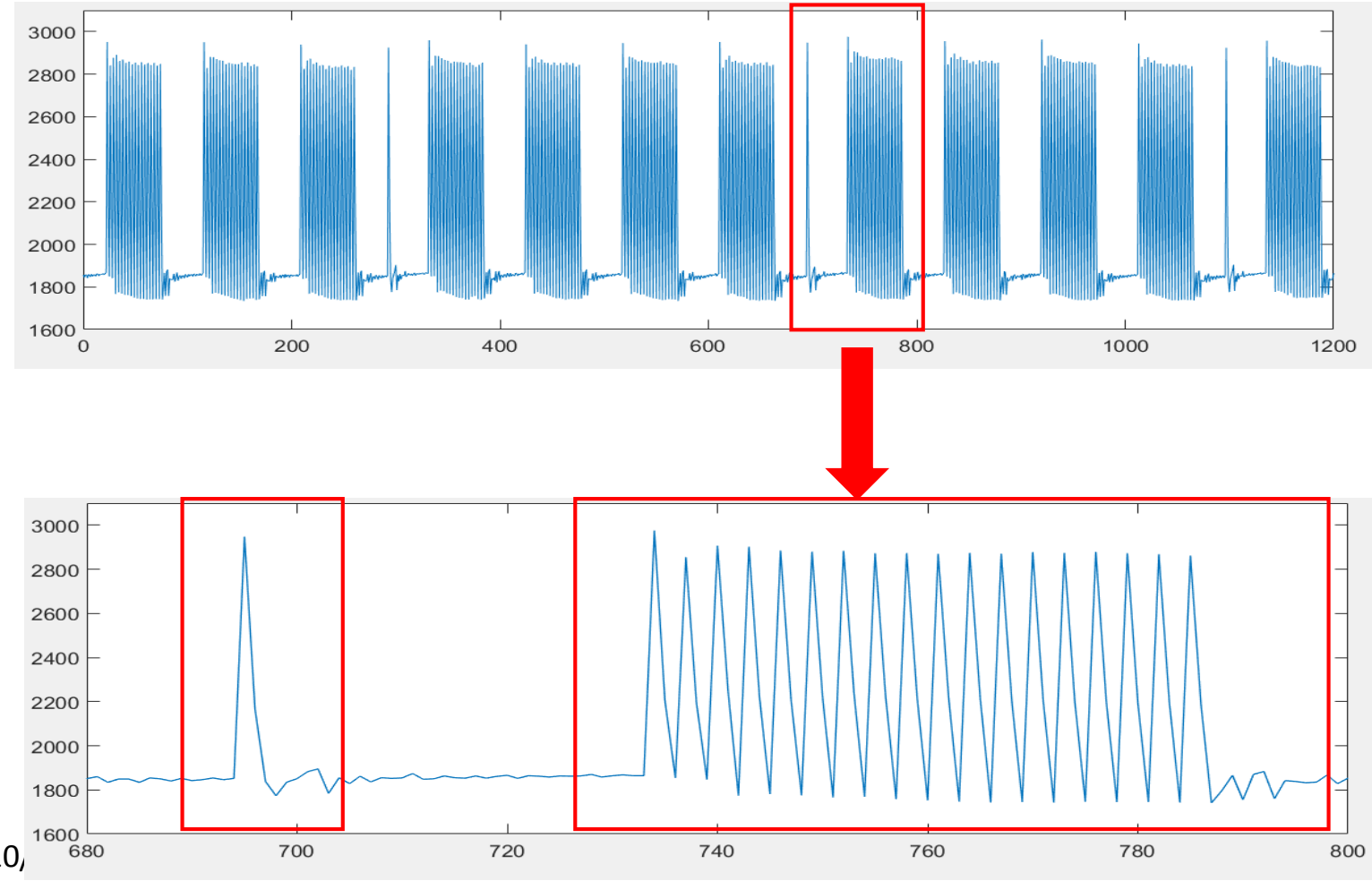


AFE

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.

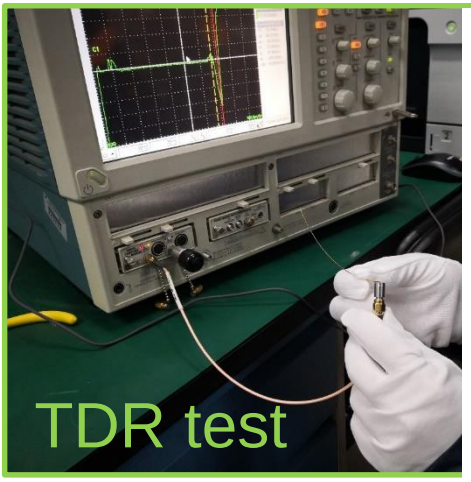
BPM feed-through V1.0

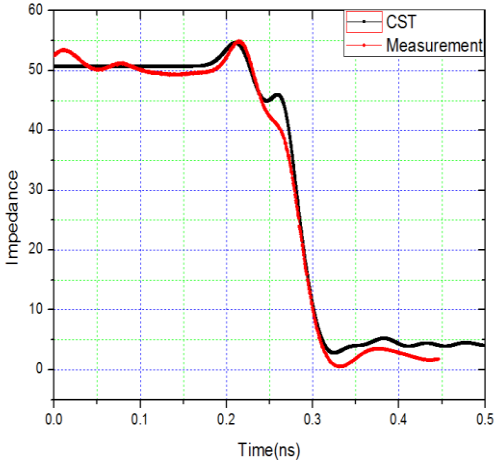
BPM feed-through V2.0

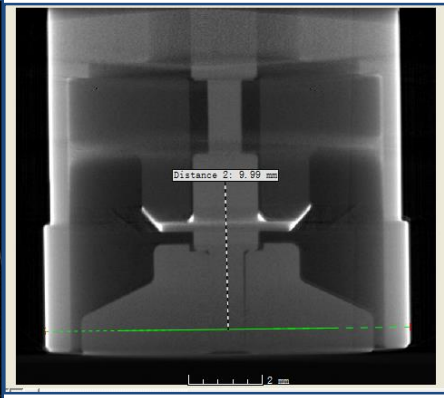
Kicker feed-through

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.

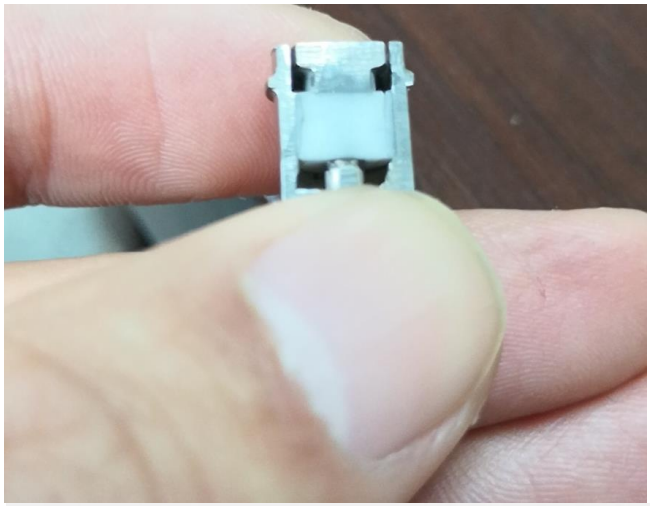


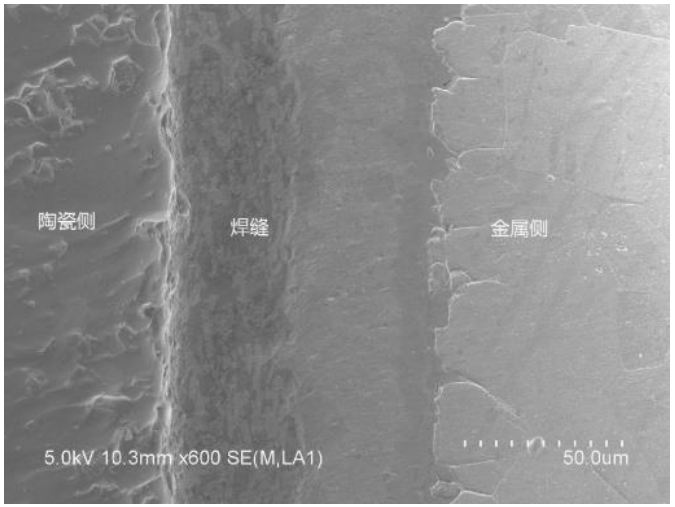


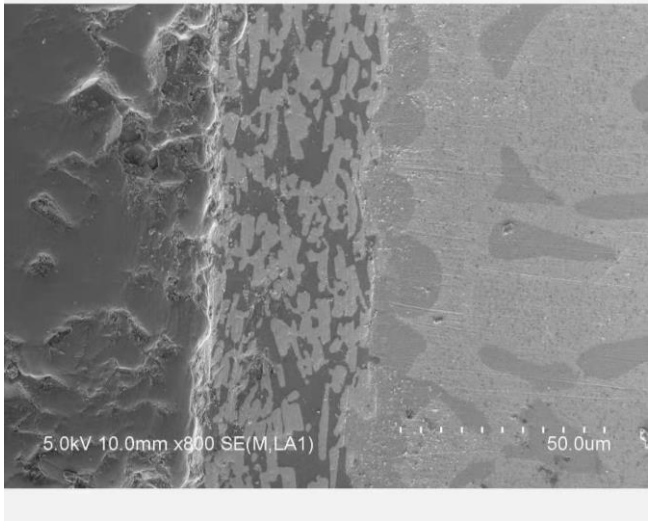


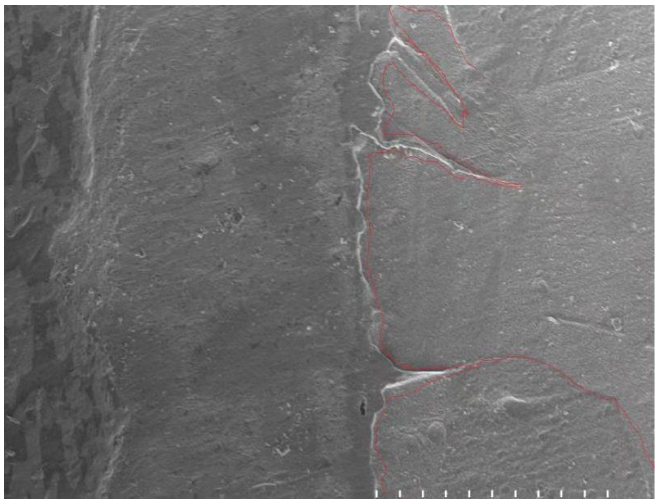
Feed-through R&D

- Morphology of solid surface by SEM



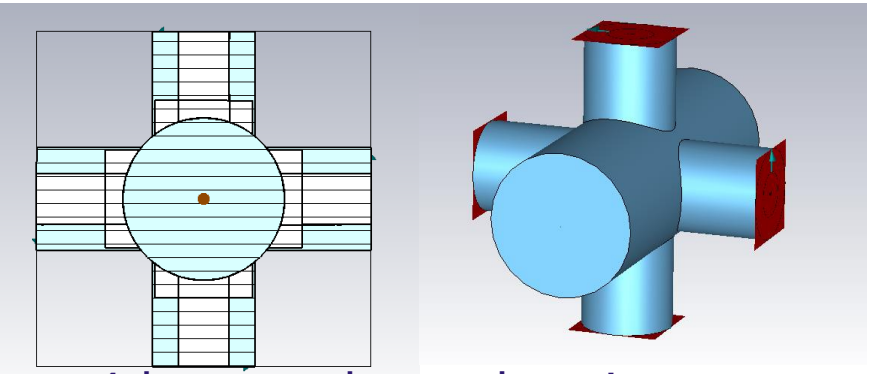




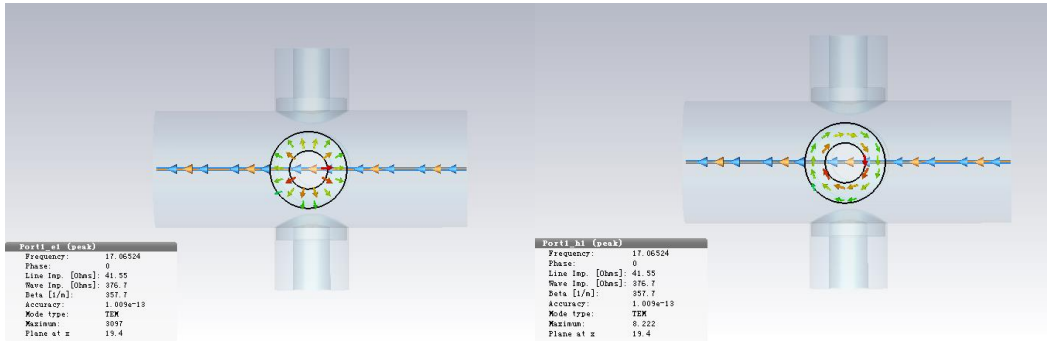


The beam instrumentation of IP

4 button electrodes structure

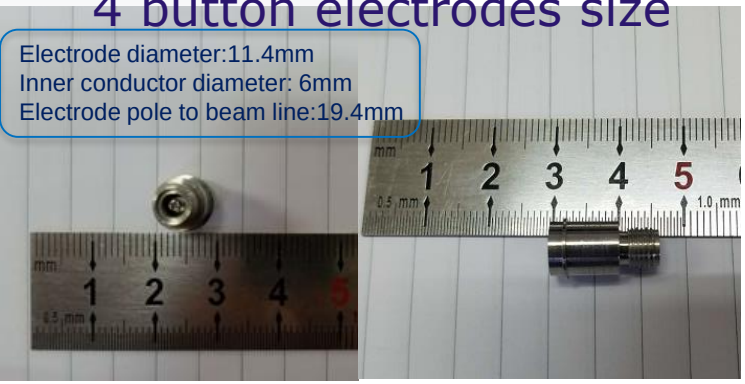


Electromagnetic field at electrodes

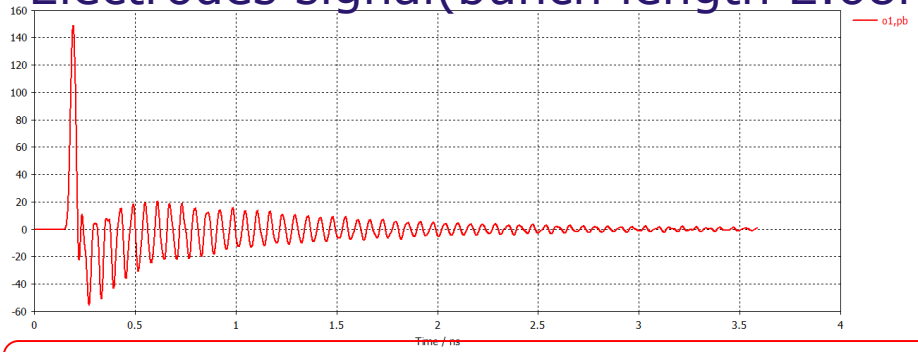


4 button electrodes size

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



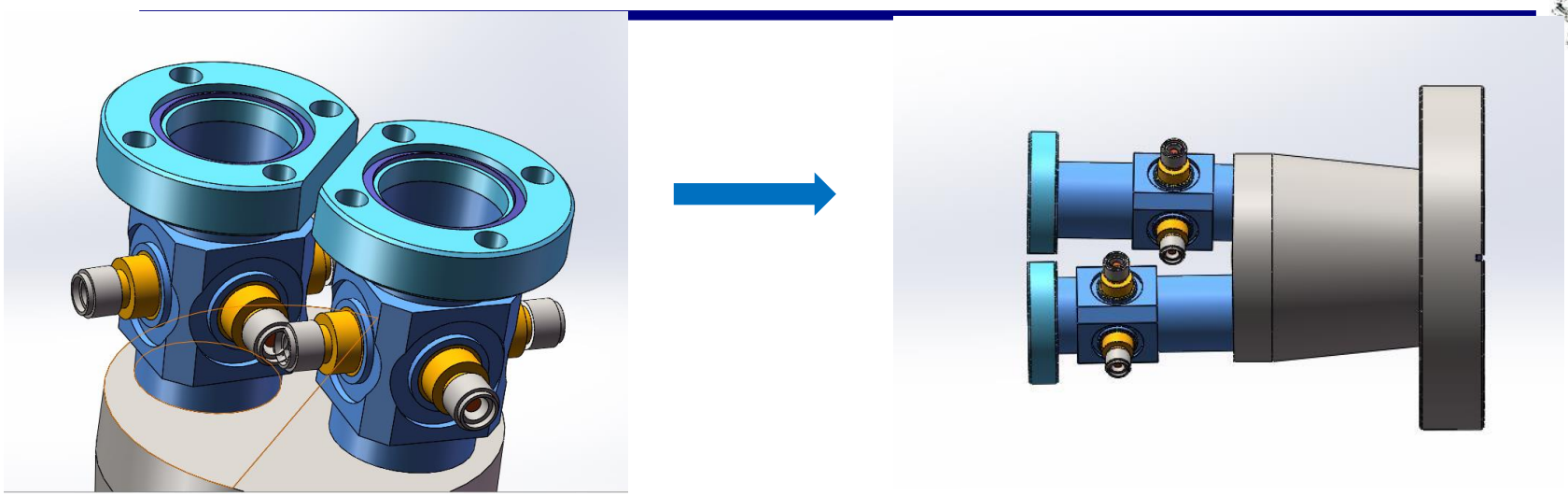
Electrodes signal(bunch length 2.68mm)



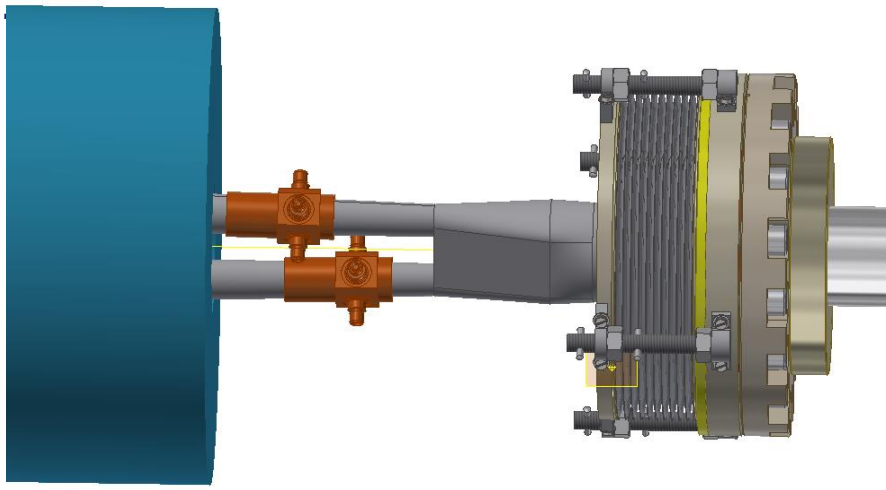
Due to the short bunch length, signal has many resonance hump, signal amplitude proportional to the bunch charge.

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

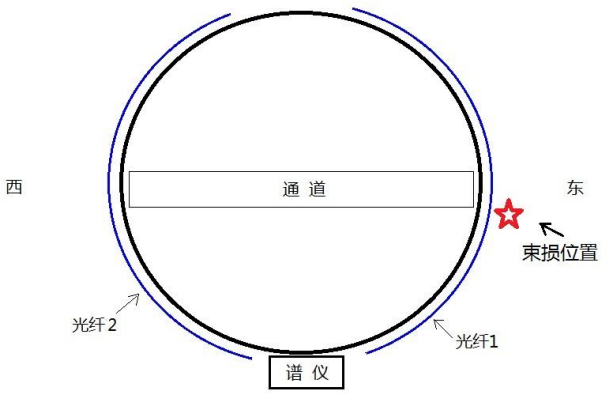
The beam instrumentation of IP

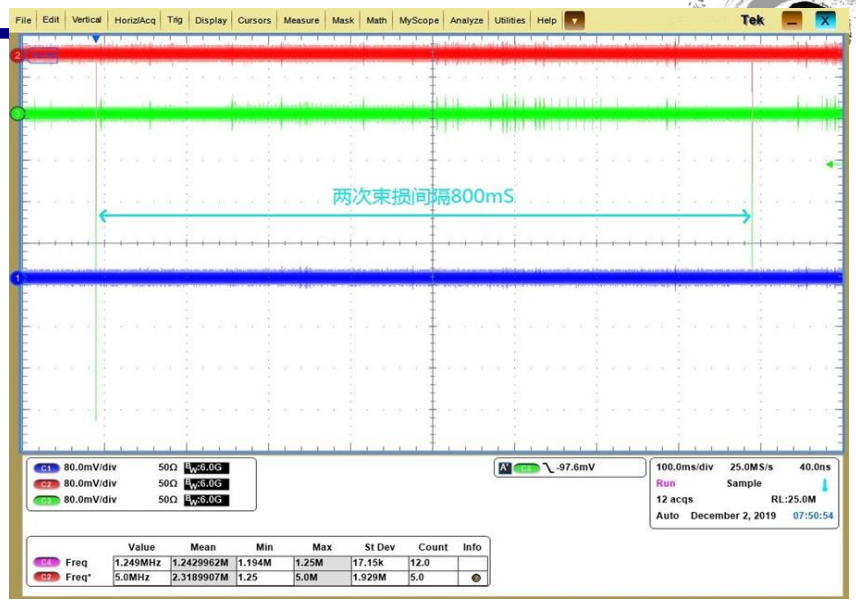


- Space conflict for the inside two buttons has been solved by staggering the position ~1cm.
- Monitoring the time when two beams arrive at the collision point, e+ and e- signals can be distinguished.

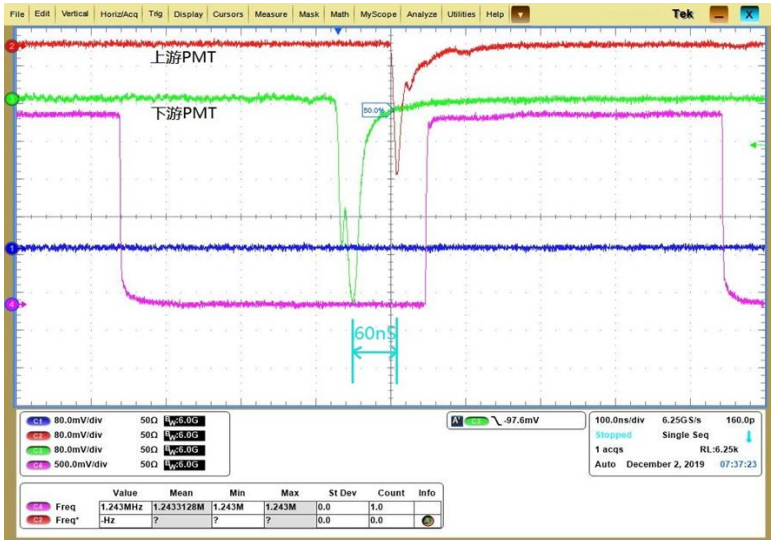


Optical fiber based BLM test in BEPCII



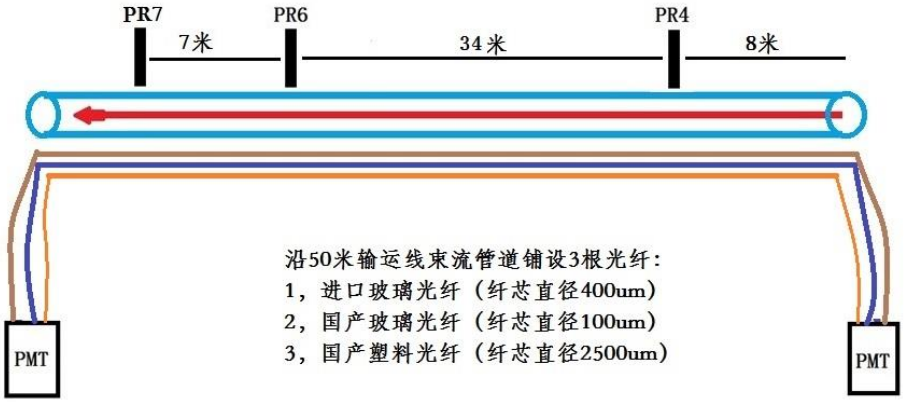


The layout BII SR optical fiber based BLM



The beam loss in during beam injection period

The single bunch mode



Summary

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

Thanks for your attention !