CEPC Beam Instrumentation R&D

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Accelerator Center, IHEP

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Outline

- Overview of CEPC beam instrumentation systems
- 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：<0.02um 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

BEAM INSTRUMENTATION R&D

R&D Motivation

- To reduce the budget of The 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 feedback system
- Easy to maintain and upgrade

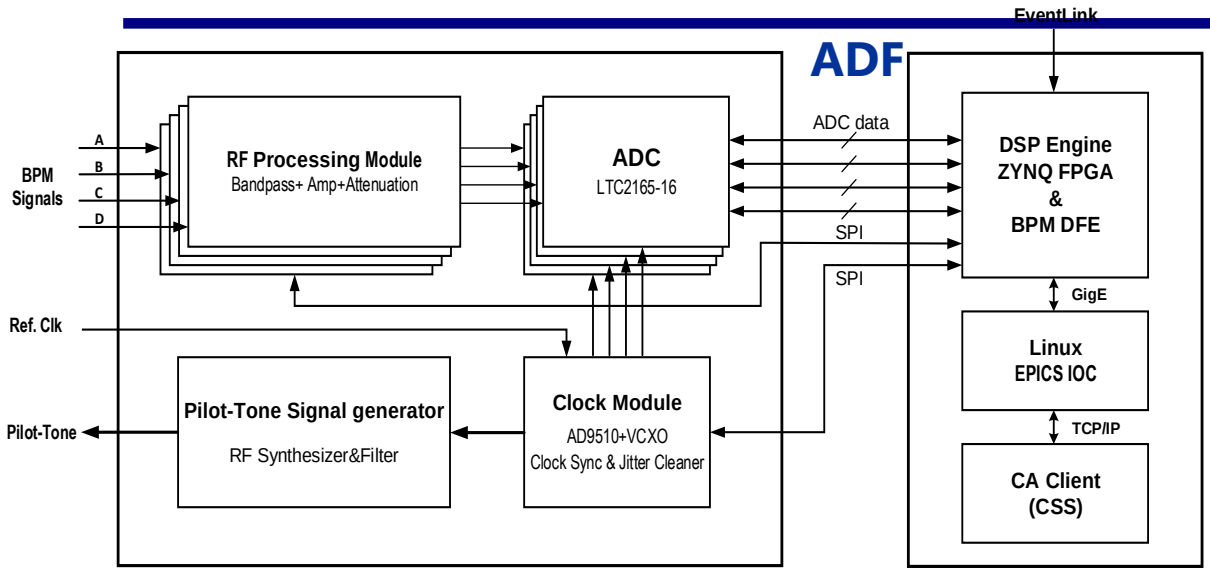
CEPC beam instrumentation R&D

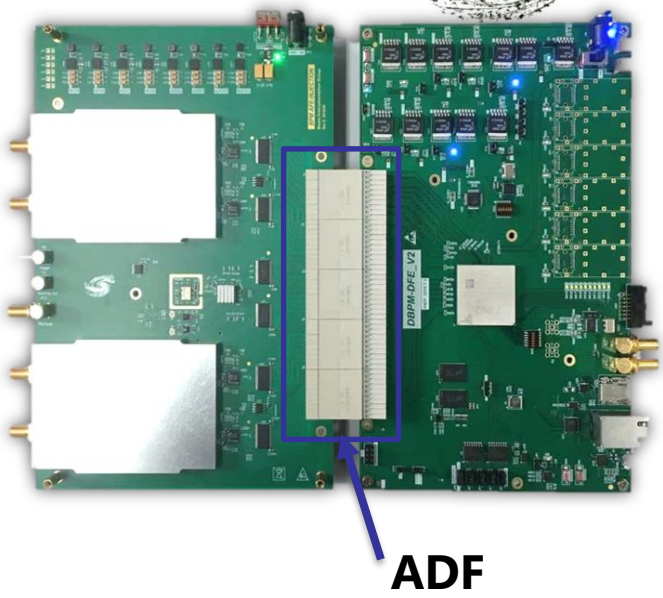
- Beam position monitor system
  - **BPM electronics**
  - **Feed through R&D**
- Feedback systems

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 at the start of 2015
- Finished the first version(V1.0) of the electronics in 2018.
- The second version(V2.0) was finished in the middle of 2019. The 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 upgrading to homemade electronics in 2020.
- 8 versions of BPM electronics have been tested in the past six years.

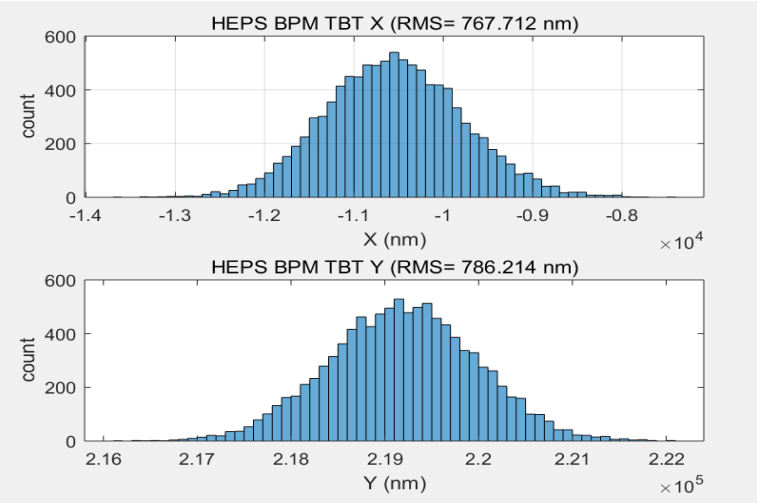
Overview of the BPM electronics



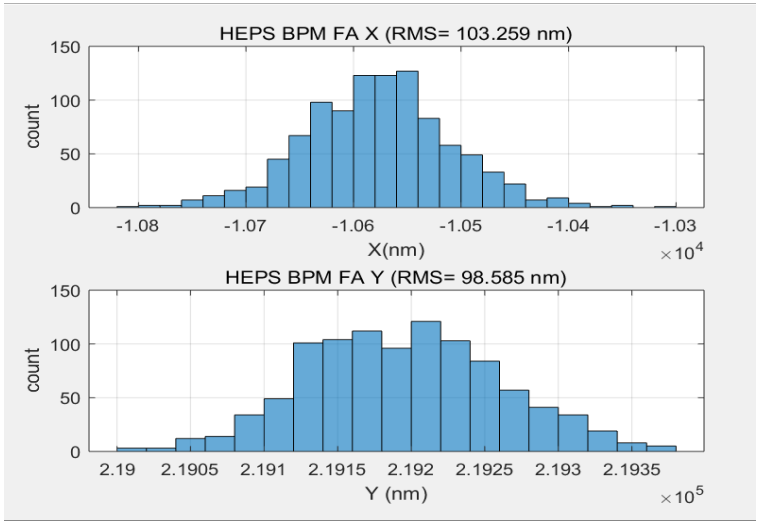


- Since of ADF interface is not suitable for RF signal transmission, so we developed new hardware, ADC&CLK in AFE board.
- AFE board： RF Processing+ ADCs + Clock + Pilot tone;
- DFE board： FPGA(ZYNQ) + DDR3 memory + SFPs + Ethernets;
- EPICS IOC： In ZYNQ FPGA, Increase the convenience of the BPM system;

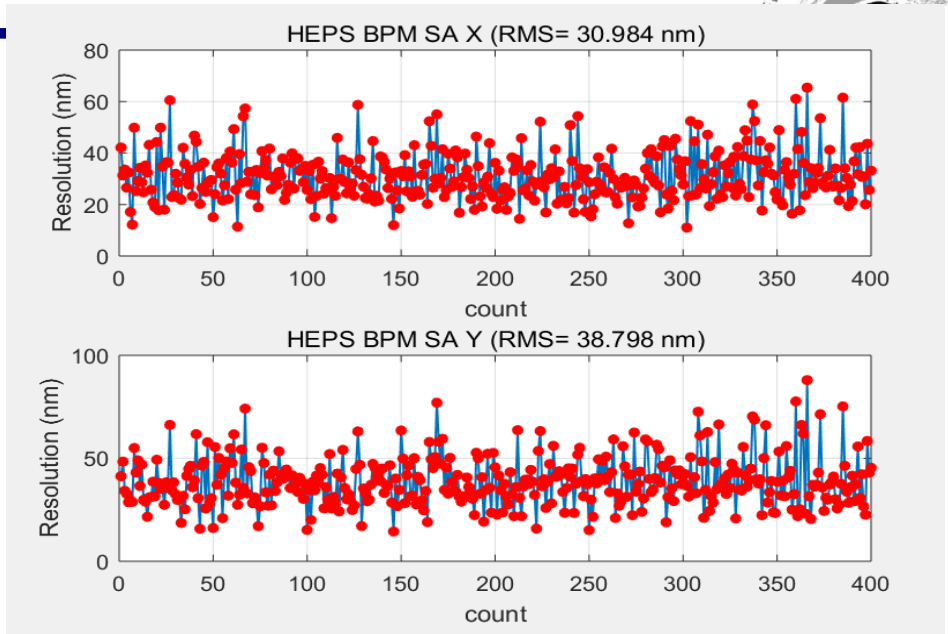
BPM TbT/FA/SA resolution test in lab



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



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



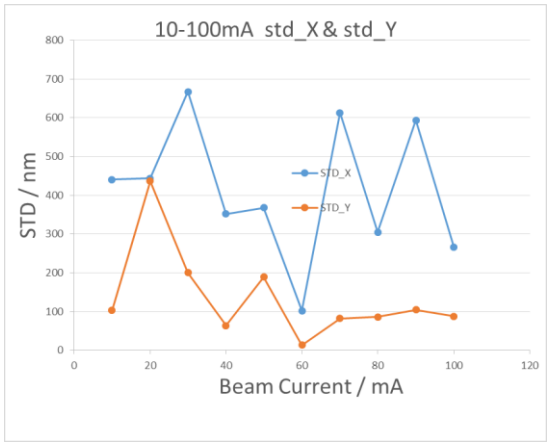
SA RMS(X=30nm,Y=38nm) 10points STD

- We test the performance of DBPM in lab
- 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;

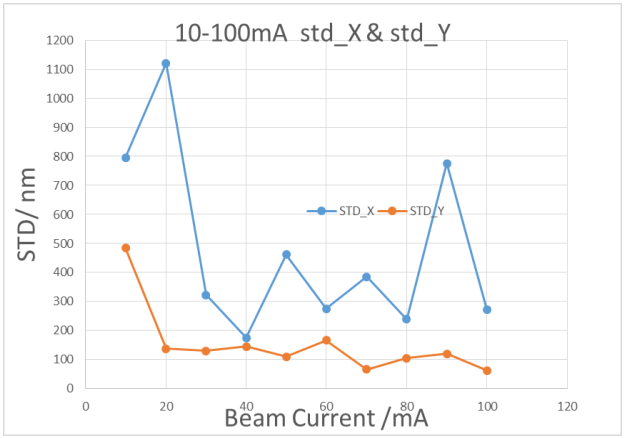
Beam test in BEPCII

- Resolution of BPM electronics （**110 bunches, 1/3**）

BPM3



BPM4

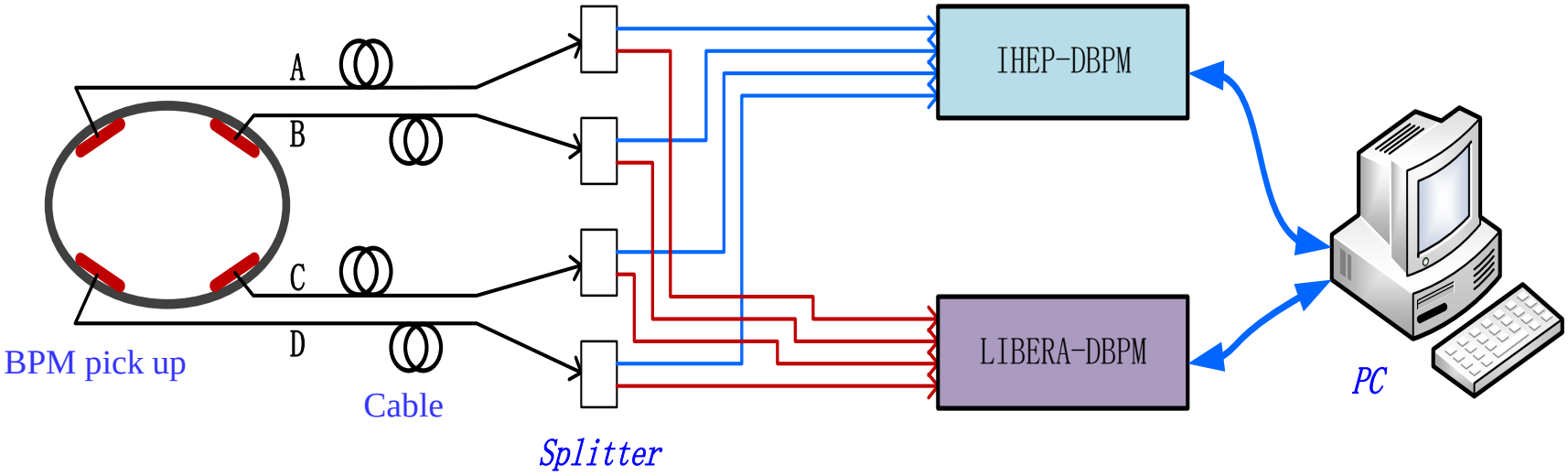


BPM5

BPM electronics NO.	Beam current （10-20mA）		Beam current （20-818mA）	
	ΔX(um)	ΔY(um)	ΔX(um)	ΔY(um)
Commercial product	-	-	6	7
BPM1	-	-	10	17
BPM3	22	11	29	11
BPM4	71	61	11	36
BPM5	5	17	4	31

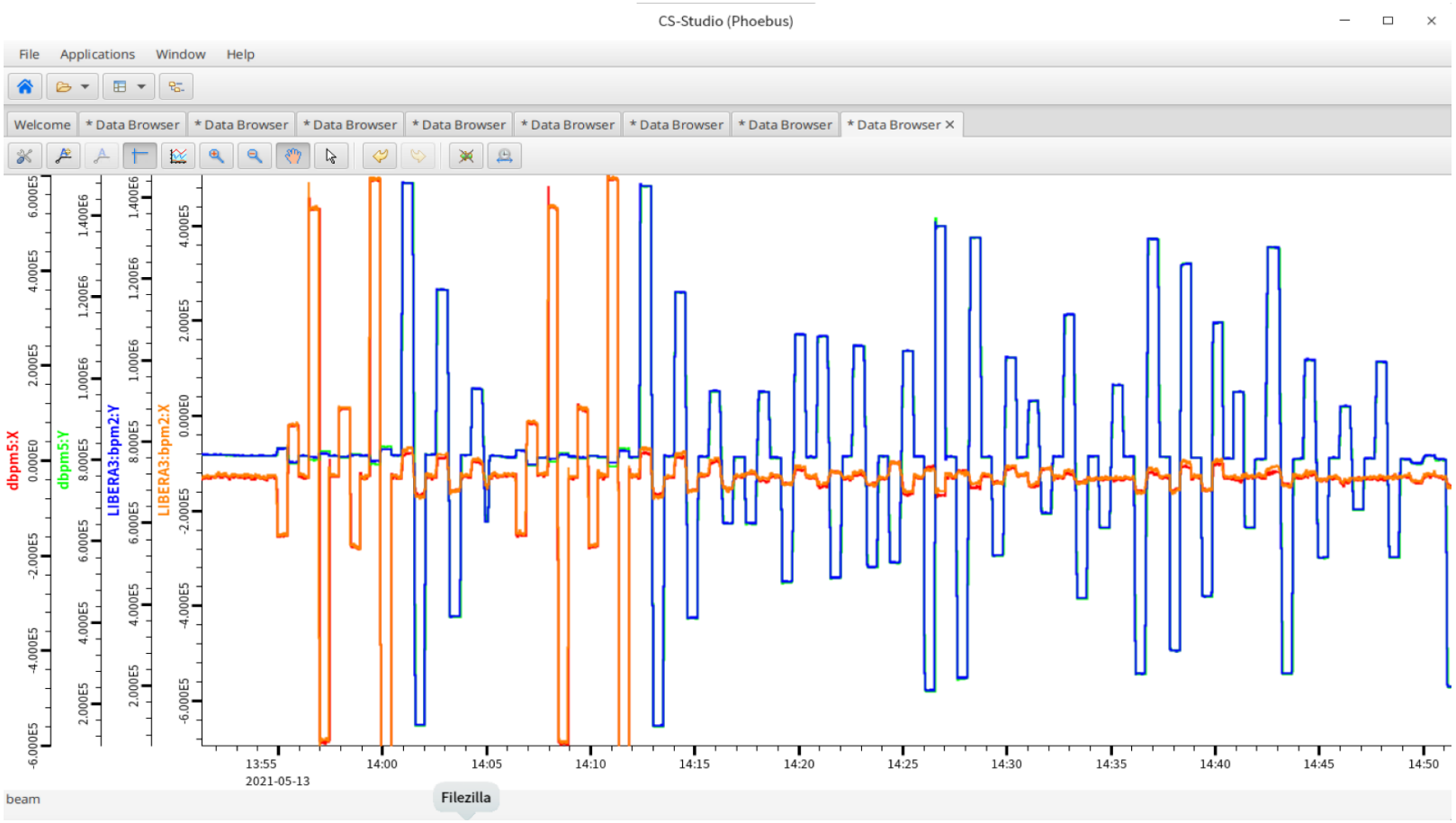
Beam current dependence of BPM electronics

Home made products VS commercial products

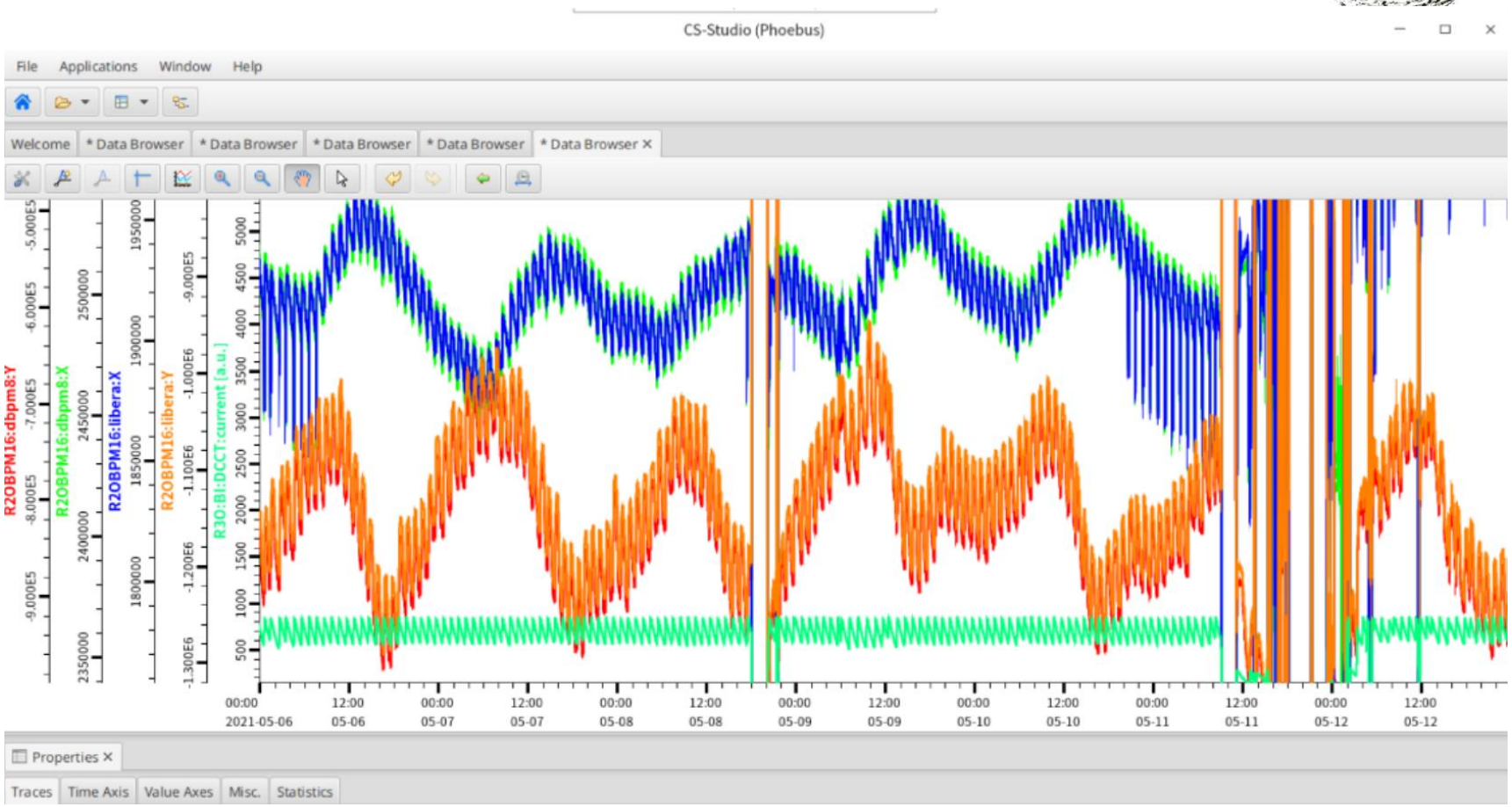


Comparative test of self-developed product and commercial product

Long time stability (1 hour)



Long time stability (7 days)



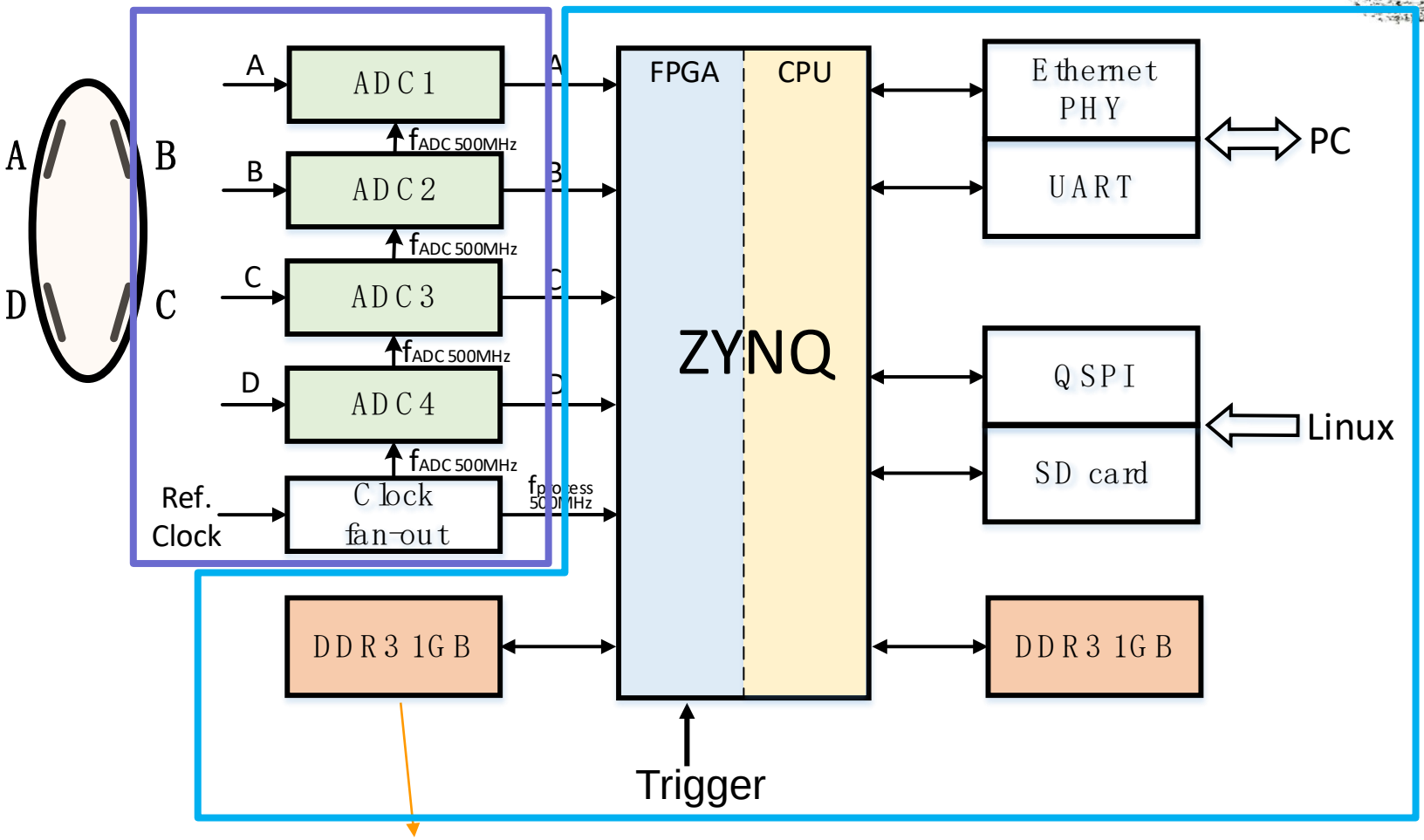
Application of BPM electronics in BEPCII

- After finishing the prototype test, small batch production and application has been made in BEPCII
- 20 sets of single-pass mode BPM electronics were developed for the linac and put in operation in the middle of 2019.
- Totally, 60 sets including SR mode and Collider mode BPM electronics were upgraded in the BEPCII storage ring.

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, it is difficult to get to the real cause for beam trip.
- At present, many accelerators worldwide have established a powerful beam trip diagnostic system.
- The other reason is preparing instrumentation for bunch by bunch current and beam position measurement

Bunch by bunch BPM electronics

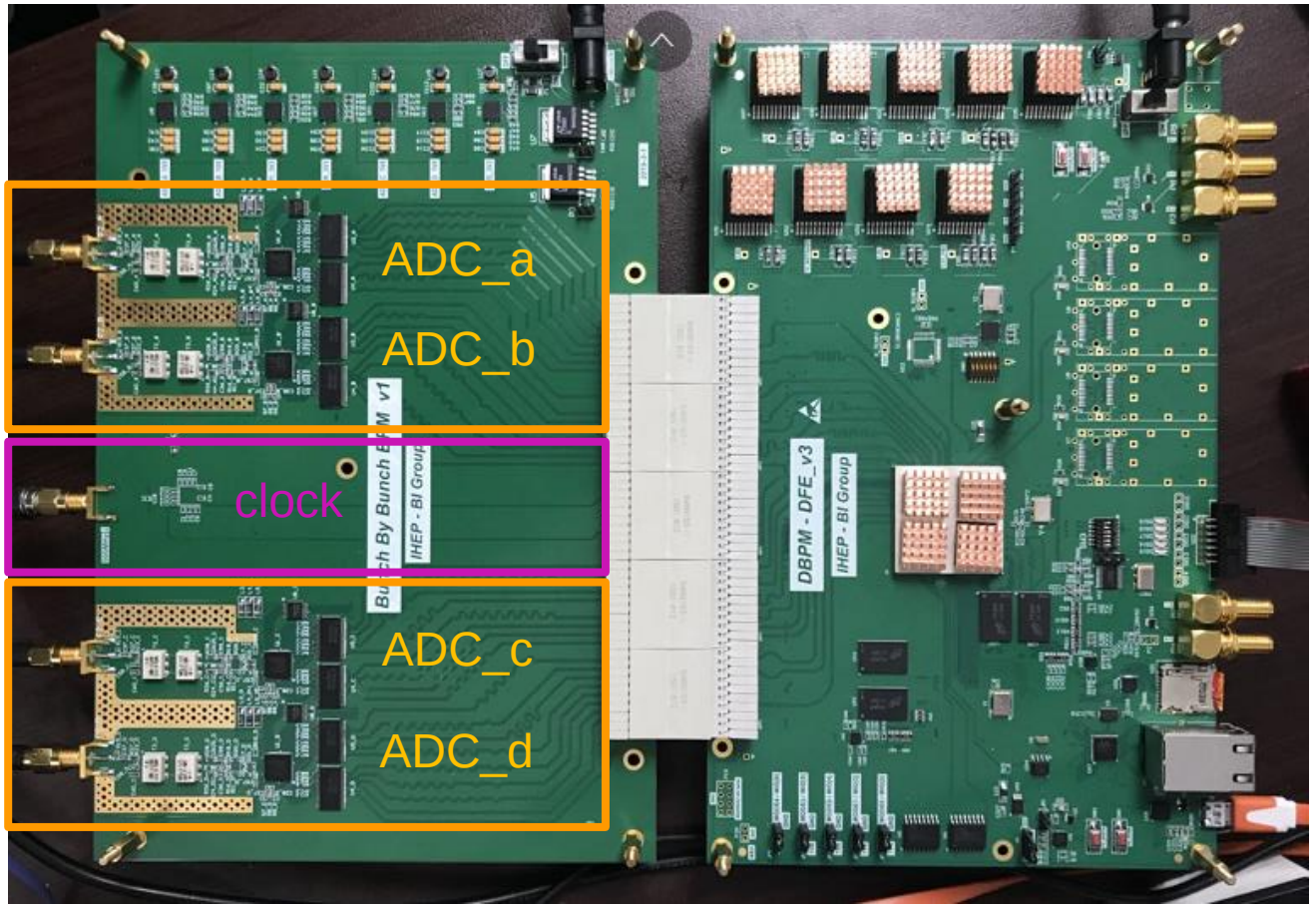


Buffer of bunch by bunch raw ADC data

Bunch by bunch BPM electronics

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

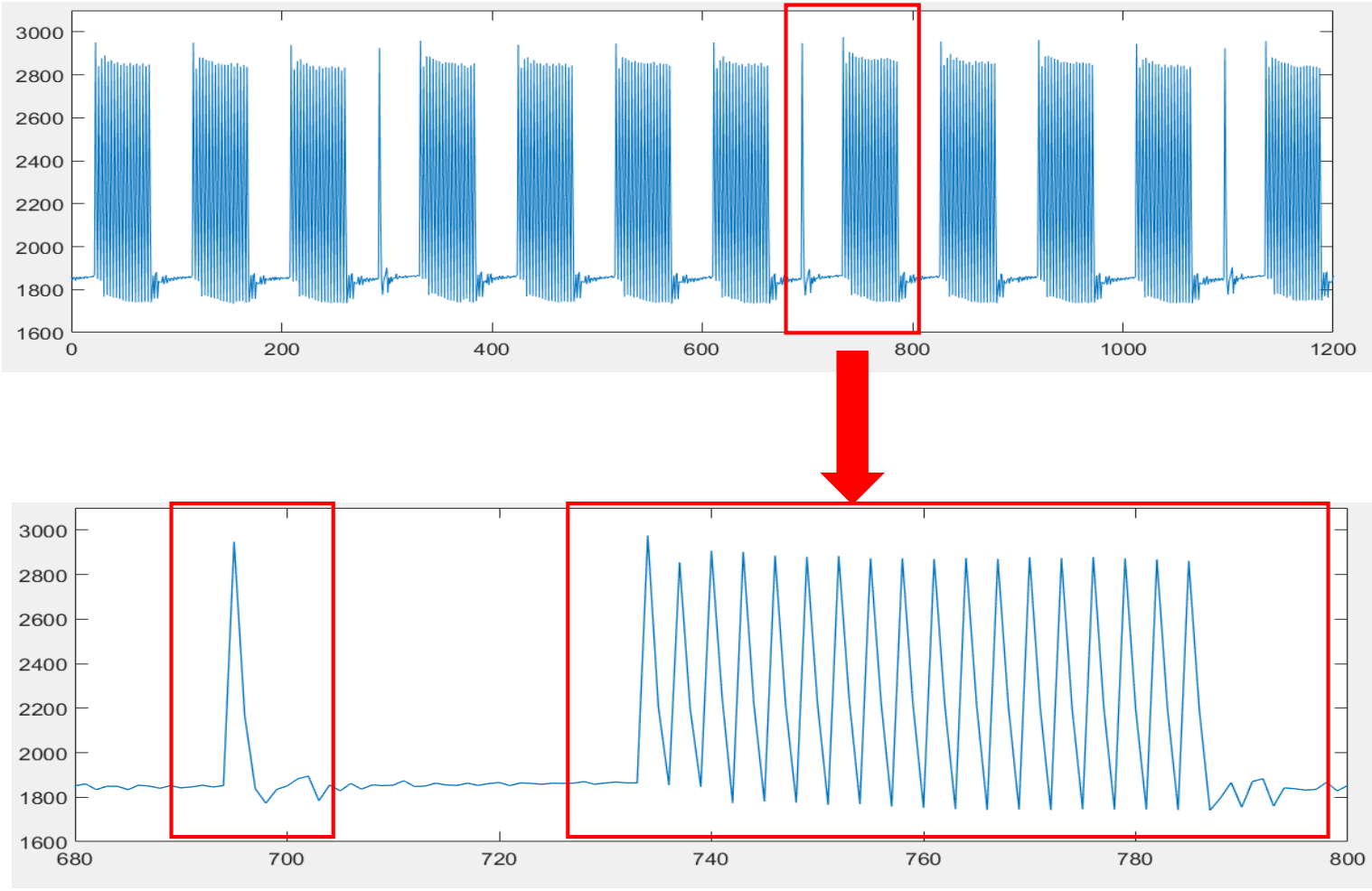
AFE



DFE

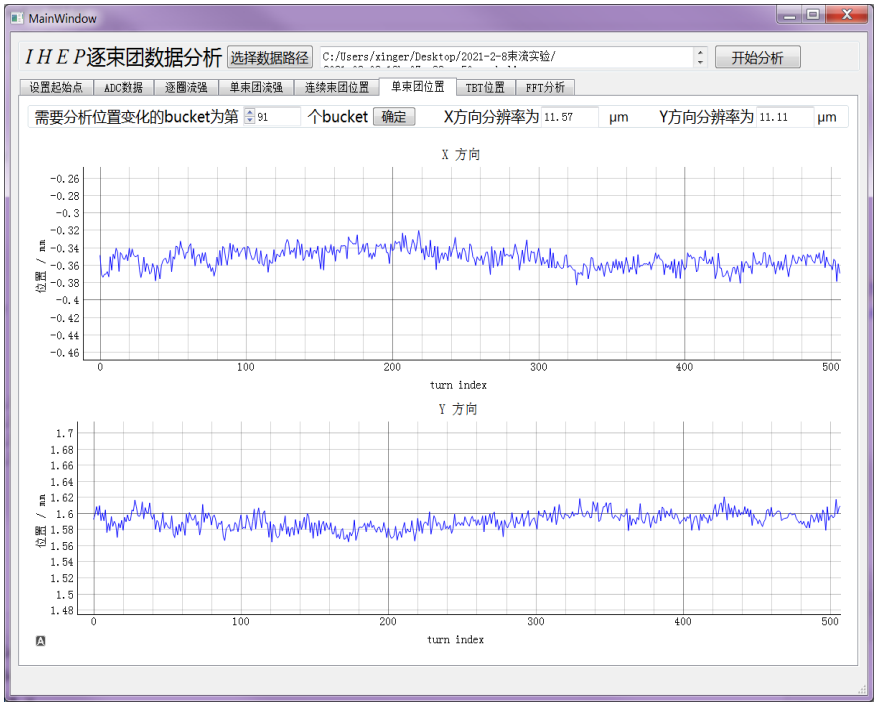
Bunch by bunch BPM electronics

Input: simulation pattern of BEPCII , repetition period 6ns

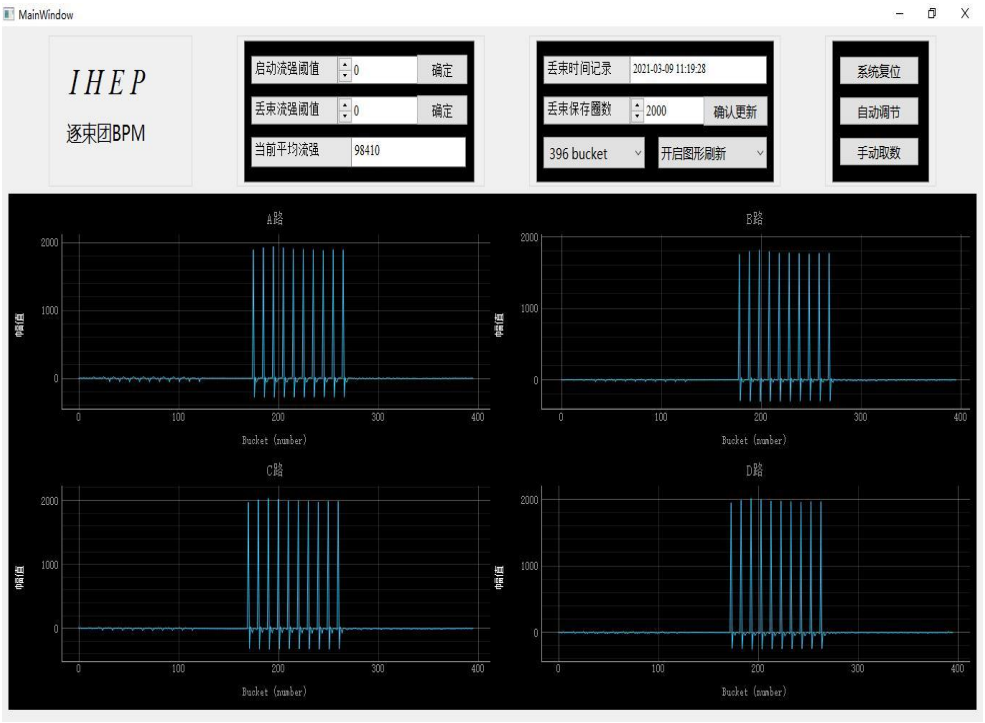


Bunch by bunch BPM electronics

- The bunch by bunch BPM electronics was test in BEPCII.
- The bunch by bunch BPM electronics measured the bunch current and bunch position



The 91st bunch position were traced in 500 turns



The bunch current were measured by electronics

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 the CIPC Member Company.

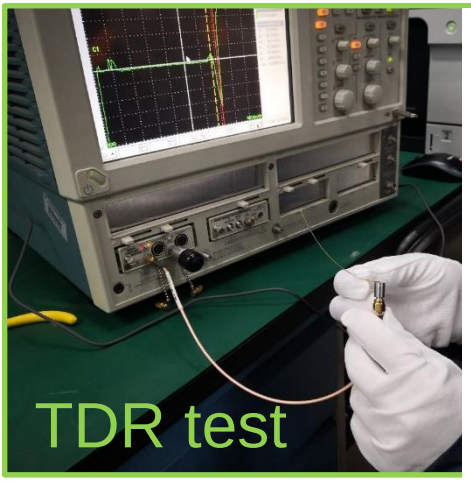
BPM feed-through V1.0

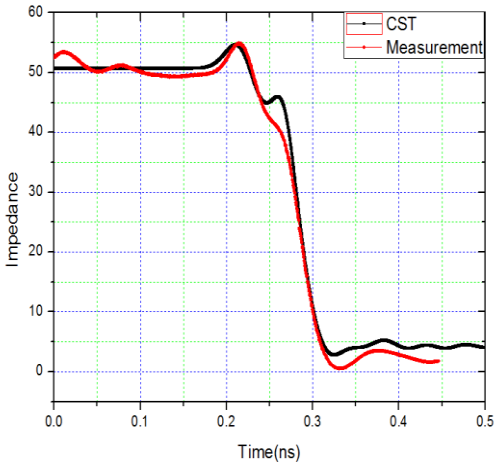
BPM feed-through V2.0

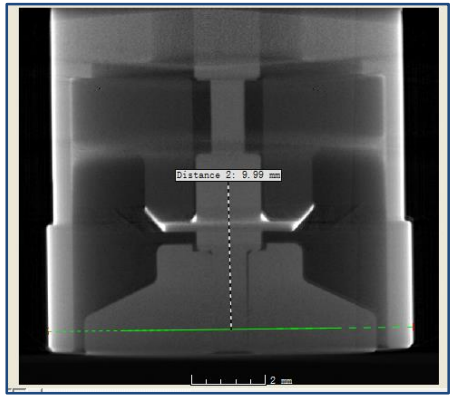
Kicker feed-through

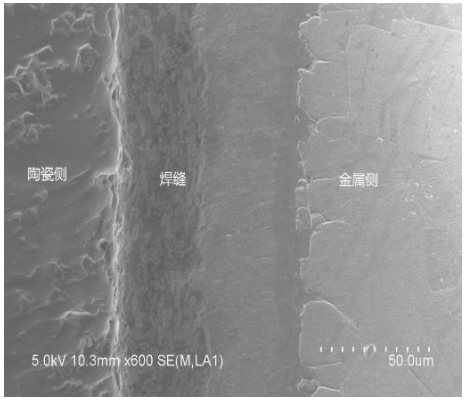
Feed-through R&D

- 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.
- TDR for impedance test and X-ray tomography for inner structure check.
- Morphology of solid surface by SEM.





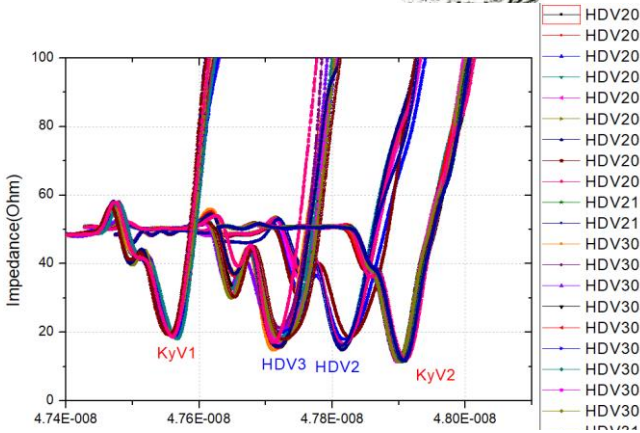


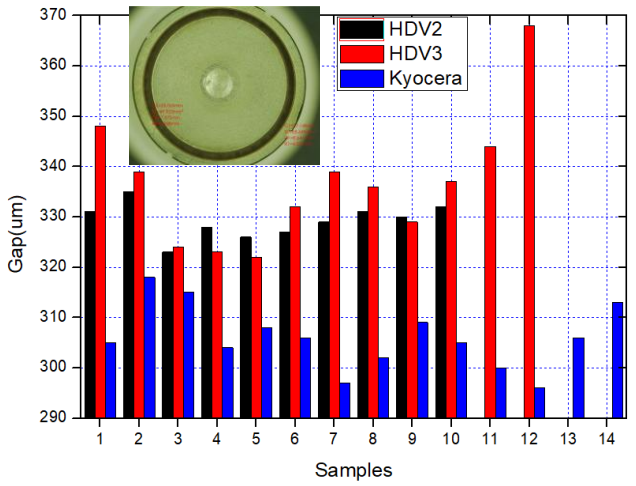


Feed-through R&D

60	ANDESEN	1.8±0.02	6.00	11.00 -0.05	1.00	μr1	μr2	μr3
61	1	1.79	5.95	11.00	1.04	1.332	> 2	1.417
62	2	1.81	5.97	11.02	1.05	1.371	> 2	1.382
63	3	1.79	5.96	11.03	1.03	1.372	> 2	1.380
64	4	1.78	5.96	11.03	1.01	1.394	> 2	1.316
65	5	1.82	5.96	11.02	1.04	1.452	> 2	1.369
66	6	1.80	5.96	11.02	1.04	1.373	> 2	1.385
67	7	1.79	5.95	11.02	1.02	1.448	> 2	1.345
68	8	1.77	5.95	11.02	1.04	1.389	> 2	1.318
69	9	1.79	5.96	11.03	1.02	1.366	> 2	1.344
70	10	1.79	5.96	11.01	1.02	1.356	> 2	1.386
71	11	1.79	5.96	11.02	1.04	1.333	> 2	1.444
72	12	1.79	5.97	11.02	1.02	1.365	> 2	1.438
73	13	1.78	5.96	11.05	1.06	1.471	> 2	1.336
74	14	1.79	5.95	11.03	1.04	1.412	> 2	1.384
75	15	1.80	5.96	11.02	1.03	1.386	> 2	1.337
76	16	1.80	5.96	11.02	1.04	1.394	> 2	1.384
77	17	1.81	5.95	11.02	1.04	1.358	> 2	1.301
78	18	1.79	5.97	11.03	1.02	1.392	> 2	1.390
79	19	1.82	5.96	11.03	1.04	1.426	> 2	1.335
80	20	1.81	5.96	11.04	1.07	1.520	> 2	1.443
81	MAX	1.82	5.97	11.05	1.07	1.520		1.444
82	MIN	1.77	5.95	11.00	1.01	1.33		1.30
83	R	0.05	0.02	0.05	0.06	0.19		0.14
84	Sigma	0.01	0.01	0.01	0.01	0.047		0.042

	μr	10	10.6	9.4	1	22
1	1.123	9.98	10.60	9.40	1.02	22.04
2	1.175	9.99	10.60	9.42	1.05	21.98
3	1.129	9.98	10.59	9.41	1.09	22.04
4	1.117	9.96	10.59	9.41	1.03	22.12
5	1.151	9.98	10.59	9.40	1.05	21.94
6	1.144	9.96	10.62	9.42	1.05	22.14
7	1.106	9.97	10.59	9.40	1.05	22.04
8	1.130	9.98	10.59	9.41	1.04	22.12
9	1.099	9.97	10.58	9.40	1.06	22.15
10	1.129	9.98	10.60	9.38	1.06	21.93
11	1.098	9.97	10.61	9.41	1.07	22.08
12	1.138	9.97	10.59	9.41	1.04	22.03
13	1.108	9.97	10.59	9.43	1.05	22.16
14	1.098	9.96	10.58	9.40	1.06	22.10
15	1.105	9.97	10.59	9.42	1.04	22.10
16	1.099	9.98	10.59	9.40	1.02	22.11
17	1.135	9.98	10.61	9.41	1.04	22.04
18	1.107	9.98	10.60	9.39	1.06	22.06
19	1.150	9.99	10.60	9.41	1.05	21.98
20	1.112	9.98	10.59	9.41	1.08	22.17
21	1.121	9.98	10.60	9.41	1.08	21.98
22	1.096	9.99	10.60	9.41	1.08	21.96
23	1.140	9.99	10.60	9.40	1.07	22.00
24	1.097	9.98	10.59	9.41	1.05	22.07
25	1.105	9.97	10.60	9.42	1.07	22.05
26	1.128	9.97	10.59	9.40	1.08	22.00
27	1.133	9.99	10.59	9.40	1.07	21.89
28	1.105	9.99	10.59	9.40	1.07	22.04
29	1.102	9.97	10.59	9.39	1.03	21.97
30	1.150	9.99	10.59	9.40	1.05	22.01
HdV3-12	1.007	9.97	10.59	9.63	1.06	22.10

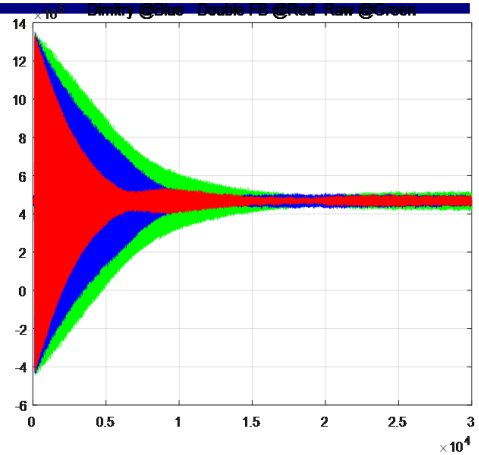




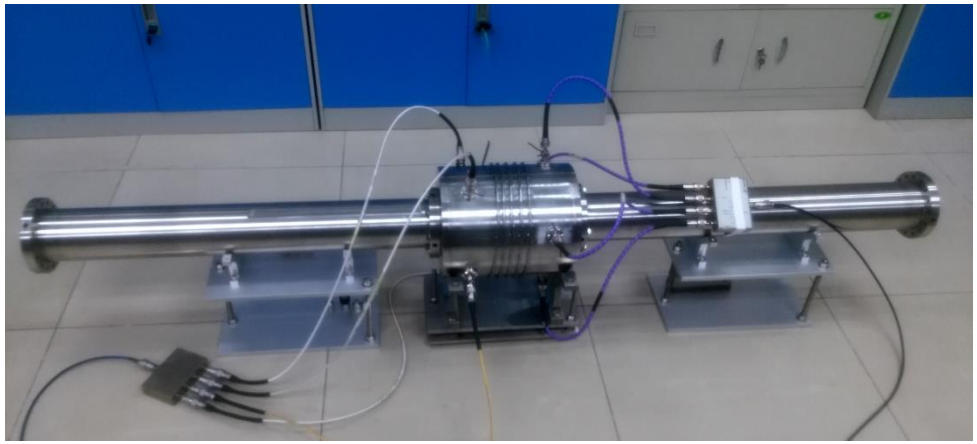
3 Candidate manufacturers, the same design , batch products consistency test

Feedback system R&D

FB electronics R&D based commercial product



The damping time of two TFBs



The kicker design and test in the lab

Status of CEPC beam instrumentation R&D

System	R&D Work supported by			Work to be done
	BEPCII	HEPS/HEPS TF	Funding	
BPM electronics	√	√	√	Radiation hardness Industrialization
Beam position monitor fabrication		√	√	Feed through product and detection; BPM pick-up design,
Longitudinal feedback system	√	√		Electronics development
Transverse feedback system	√	√		Electronics development Longer kicker design
Synchrotron radiation monitor				Cooling of SR extraction mirror; X-ray interferometer; Gas jet scanner
BI at the interaction point			√	Special beam monitor design at IP
Bunch current monitor		√		BBB electronics R&D based home-developed and company
Beam loss monitor			√	beam loss detector R&D Industrialization

Summary

- The beam position monitor, feedback system, and other key technologies R&D has been carried out.
- In-house developed BPMs were tested in the lab and with actual beam in BEPCII. Small batch production has been used online in BEPCII linac and storage ring.
- After three months of trouble-free operation in BEPCII storage ring and linac, more units will be commissioned soon.
- The feedthrough R&D was carried out as planned, and more studies will be done on the consistency of batch products.

Thanks for your attention !