CEPC Beam Instrumentation

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On behalf CEPC Beam Instrumentation Team

1st FCCee Beam Instrumentation Workshop

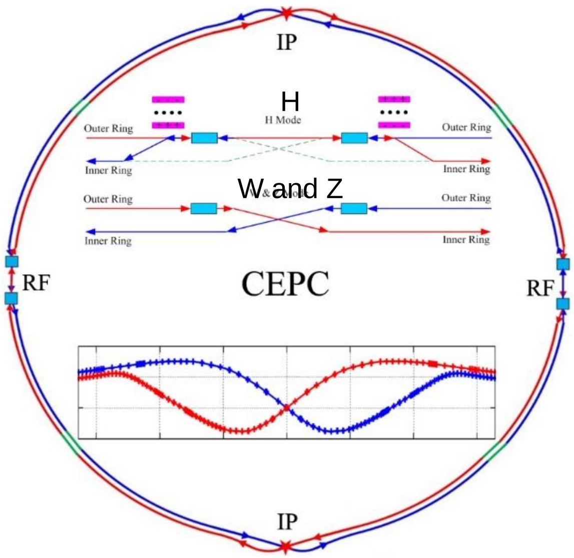
November 21 and 22, 2022 at CERN

Outline

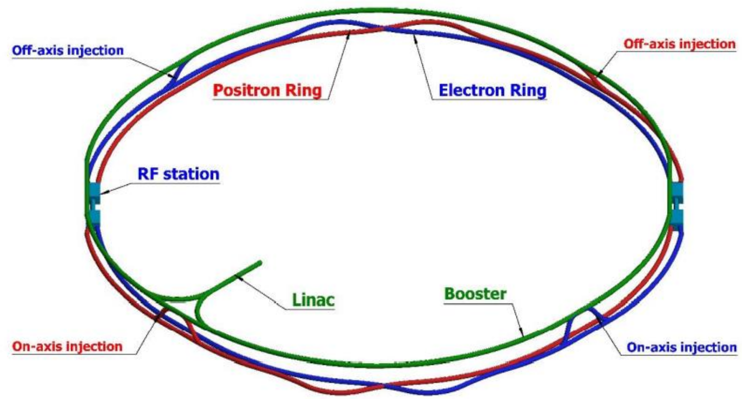
- Introduction of CEPC
- CEPC beam instrumentation requirements
- CEPC beam instrumentation design towards TDR
- Summary

CEPC Storage ring Layout

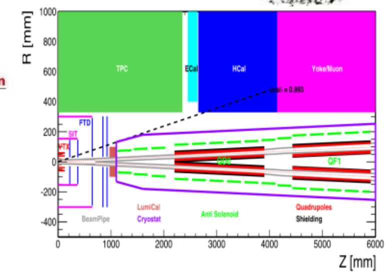
CEPC as a Higgs Factory： ttbar, H, W, Z, followed by a SppC ~100TeV

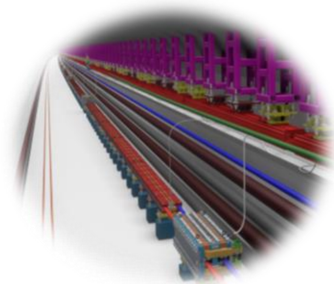


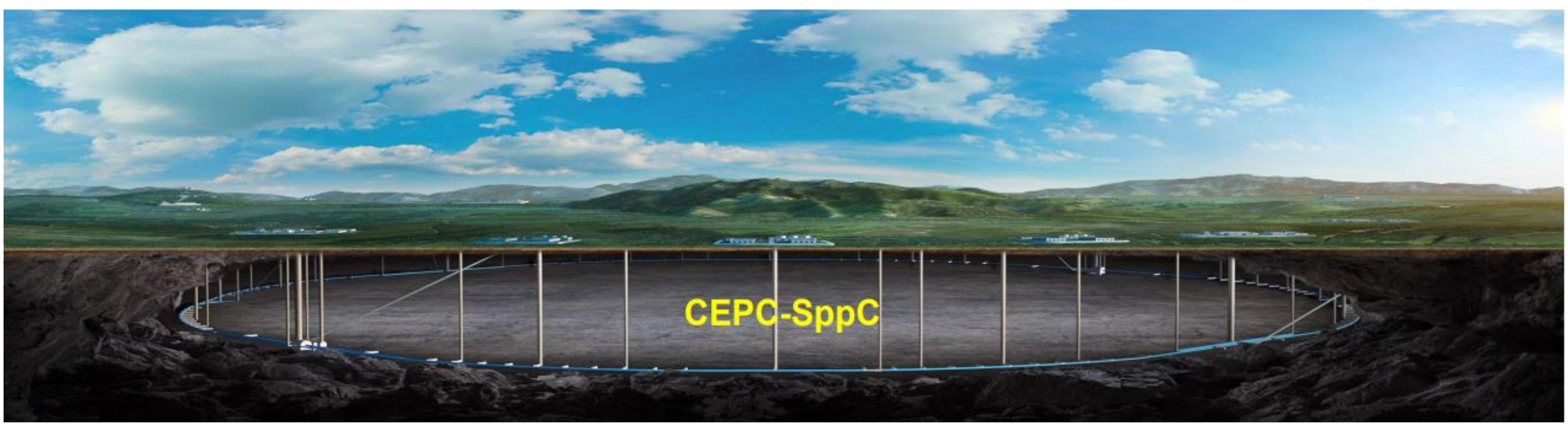
CEPC collider ring (100km)



CEPC booster ring (100km)







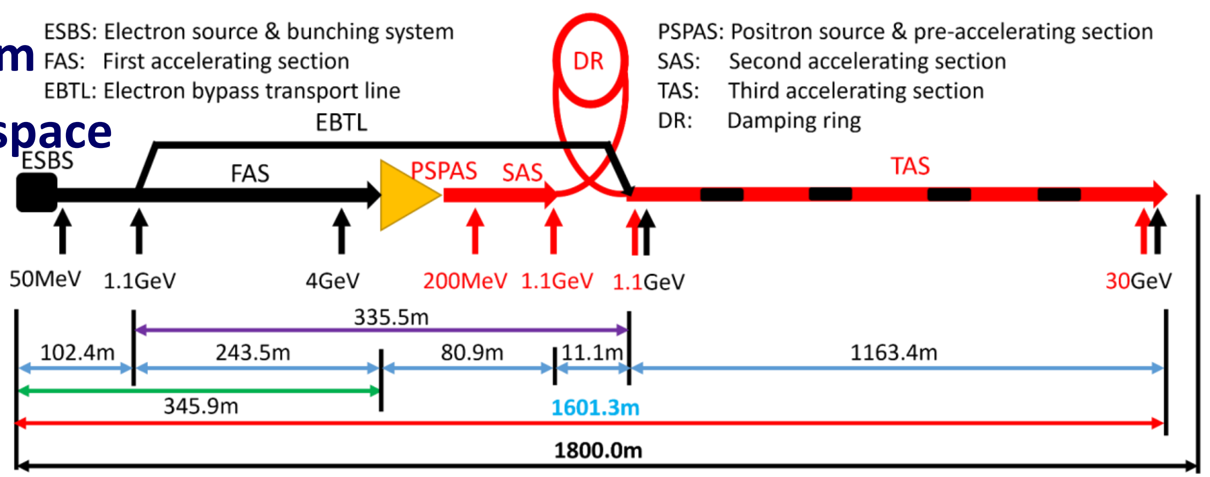
CEPC High Luminosity Parameters

	ttbar	Higgs	W	Z
Number of Ips	2			
Circumference [km]	100.0			
SR power per beam [MW]	30			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
Bunch population [10^10]	20	14	13.5	14
Beam current [mA]	3.3	16.7	84.1	803.5
Momentum compaction [10^-5]	0.71	0.71	1.43	1.43
Beta functions at IP (bx/by) [m/mm]	1.04/2.7	0.33/1	0.21/1	0.13/0.9
Emittance (ex/ey) [nm/pm]	1.4/4.7	0.64/1.3	0.87/1.7	0.27/1.4
Beam size at IP (sigx/sigy) [um/nm]	39/113	15/36	13/42	6/35
Bunch length (SR/total) [mm]	2.2/2.9	2.3/3.9	2.5/4.9	2.5/8.7
Energy spread (SR/total) [%]	0.15/0.20	0.10/0.17	0.07/0.14	0.04/0.13
Energy acceptance (DA/RF) [%]	2.3/2.6	1.6/2.2	1.2/2.5	1.3/1.7
Beam-beam parameters (ksix/ksiy)	0.071/0.1	0.015/0.11	0.012/0.113	0.004/0.127
RF voltage [GV]	10	2.2	0.7	0.12
RF frequency [MHz]	650	650	650	650
HOM power per cavity (5/2/1cell)[kw]	0.4/0.2/0.1	1/0.4/0.2	-/1.8/0.9	-/-/5.8
Qx/Qy/Qs	0.12/0.22/0.078	0.12/0.22/0.049	0.12/0.22/	0.12/0.22/
Beam lifetime (bb/bs)[min]	81/23	39/18	60/717	80/182202
Beam lifetime [min]	18	12.3	55	80
Hour glass Factor	0.89	0.9	0.9	0.97
Luminosity per IP[1e34/cm^2/s]	0.5	5.0	16	115

CEPC Linac Layout

Parameter	Symbol	Unit	Baseline
Energy	E_{e-}/E_{e+}	GeV	**30**
Repetition rate	f_{rep}	Hz	100
Bunch charge		nC	1.5 (3)
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5

- **Latest Baseline scheme (2022.6)**
  - **Energy: →30 GeV**
    - **C-band accelerating structure @TAS**
      - **Higher gradient → Shorter linac tunnel length**
      - **Small aperture & Strong wakefield**
- **Layout**
  - **The tunnel is 1.8km**
    - **Linac is about 1.6 km**
    - **200 m as reserved space**



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	2408
		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

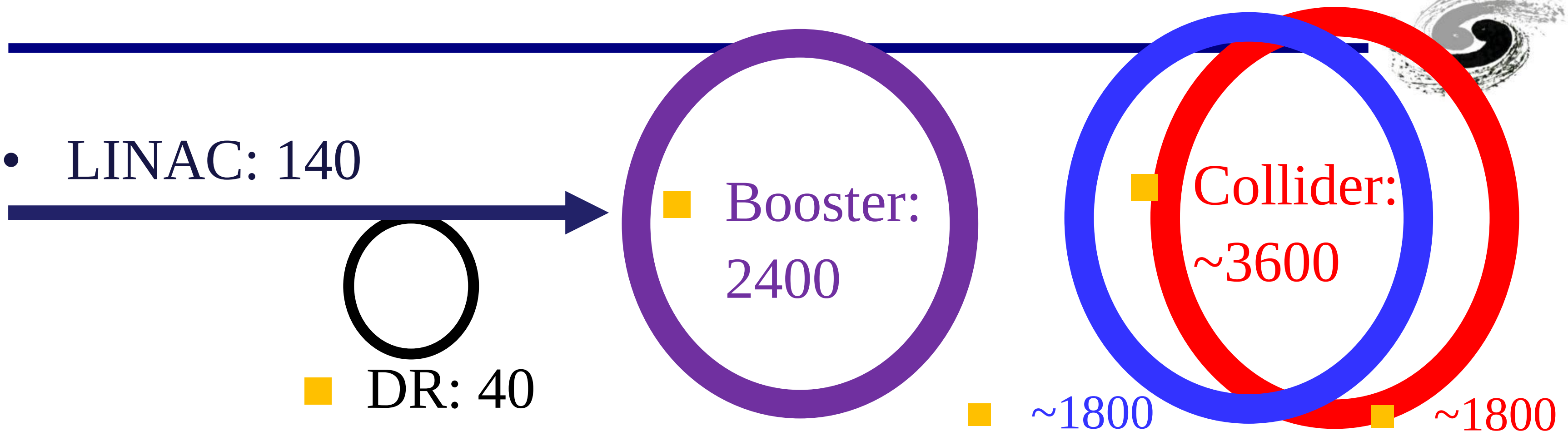
The beam instrumentation in CEPC ring

	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	3544
		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<=1ms	2+1
			LFB	Damping time<=12ms	2

CEPC beam instrumentation towards TDR

- Beam position monitor
- Beam feedback system
- Beam size and bunch length measurement
- Bunch by bunch measurement and its application
- Beam current measurement
- Beam loss monitor
- ……

BPMs number and distribution



Totol length of ESBS+FAS+PSPAS+SAS+TAS: 1800 m

	Numbers of BPM	Machine Size
BEPCII	165(19+15+66 × 2)	240 m
HEPS	~700(40+80+590)	1.4 km
CEPC	~6200	100 km
FCC-ee[1]	~6000	~92 km

Cost：about ¥100,000 / BPM (base on home-made electronic)

BPMs overview

- The total number of the BPMs has been increased compared with CDR because of the changing of lattice.

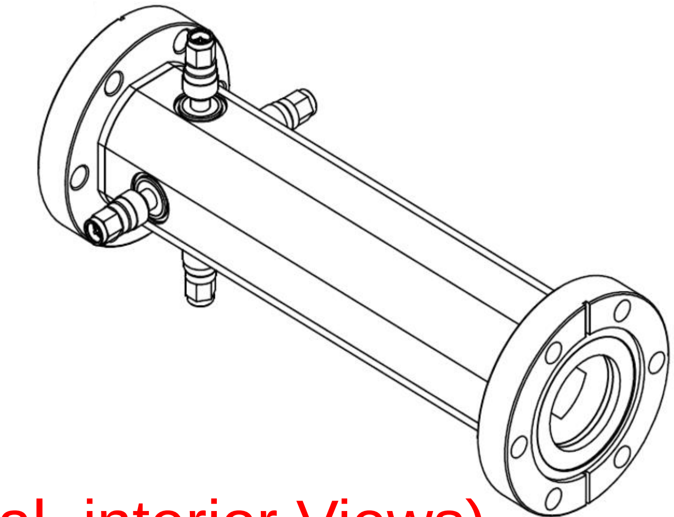
	LINAC	Damping ring	Booster	e+ ring	e- ring	Transfer line	Total
CDR Button	1	40	1808	1450	1450	/	~4889
CDR Strip	140	/	/	/	/	/	
TDR Button	1	40	2408	1772	1772	/	~6133
TDR Strip	140	/	/	/	/	/	

Design principles:

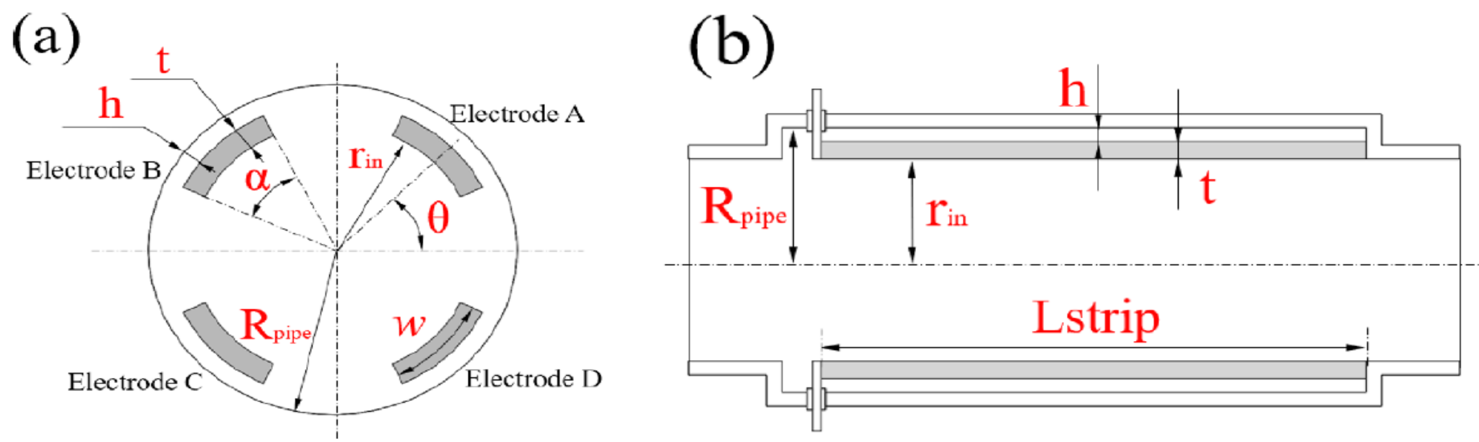
1. LINAC – stripline type , Ring – button-type
2. 4 BPMs /2π phase advanced (363 β oscillation period →445Htt)
3. 1 BPM /10-20 m in LINAC 4. Electronics in the tunnel …

CEPC BPM design: stripline-type





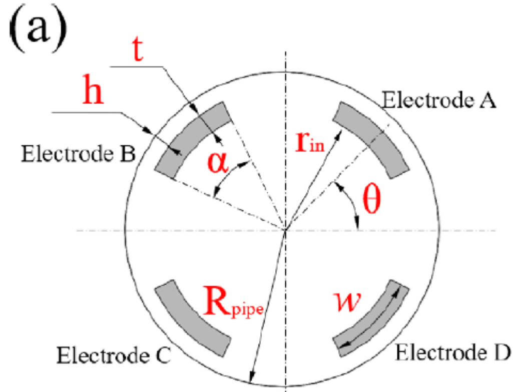
A picture of a stripline BPM(external, interior Views)

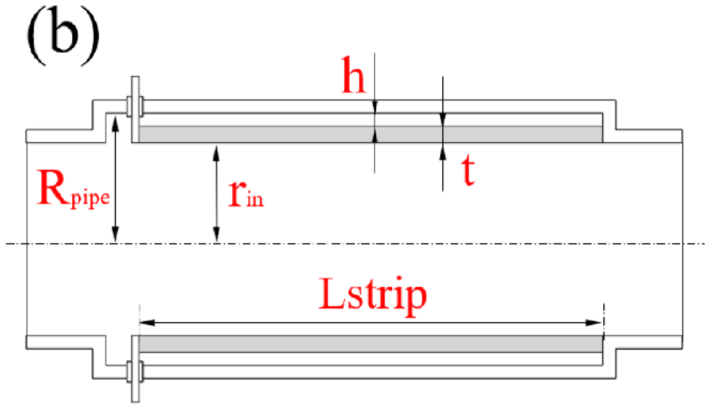


Schematic of stripline BPM: (a) Front view; (b) Side view

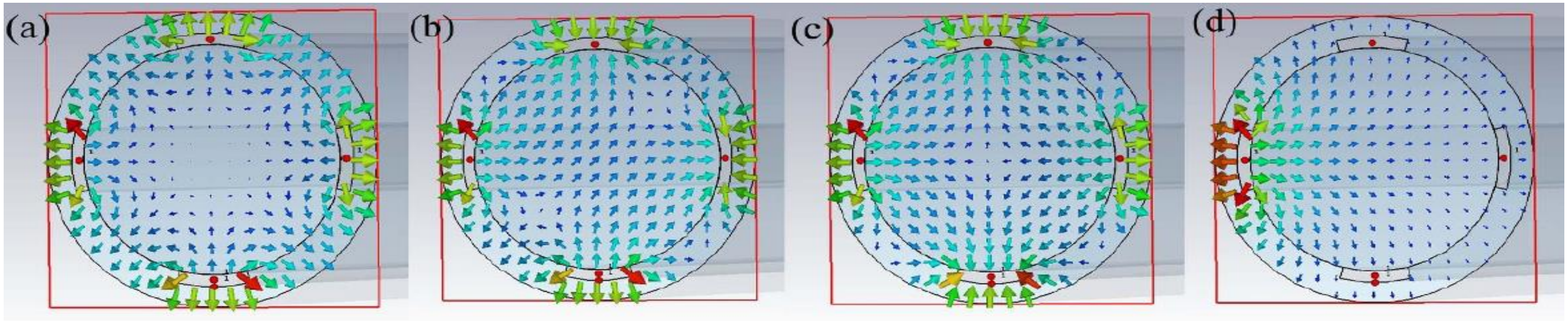
CEPC BPM design: stripline-type

- **Basic Requirements:** The mechanical parameters (α,t,h,r_{in}) of the strip should make the characteristic impedance of the strip Z_0= 50 Ω





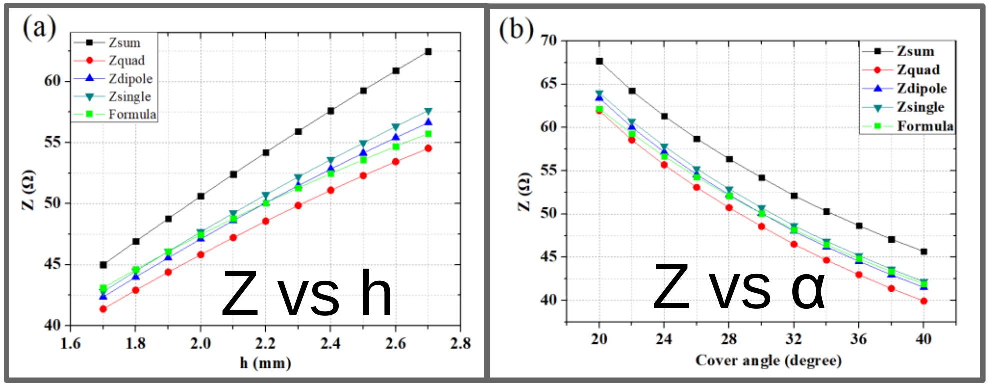
Higher requirements

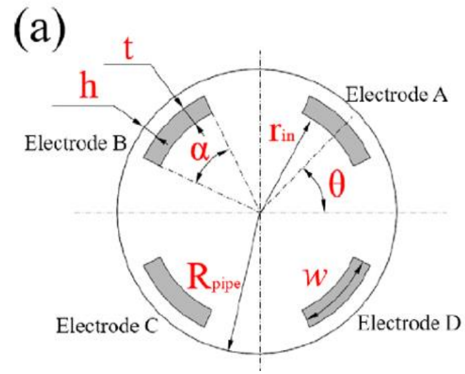


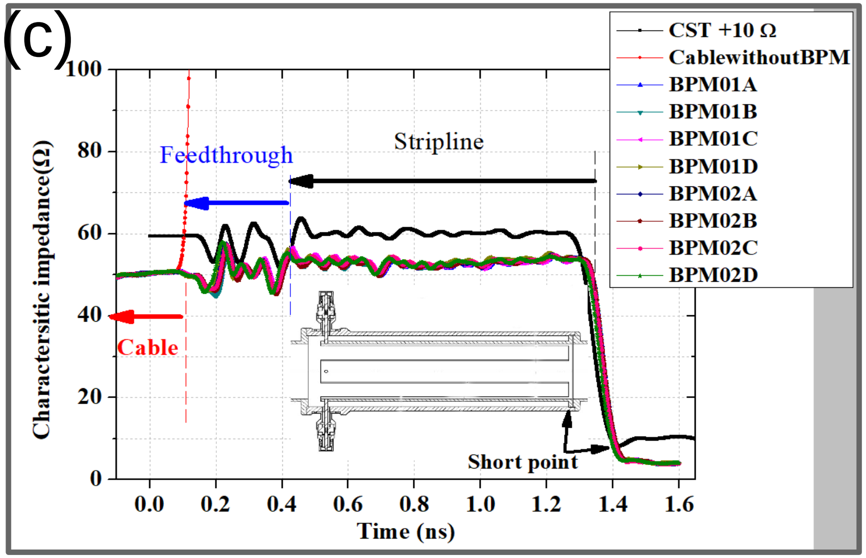
E-field of a stripline in different eigenmodes, (a) Sum (b) Quadrupole(c) Dipole (d) Single electrode $\sqrt{Z_{sum}Z_{quad}} \approx Z_{dipole} \approx Z_{single} \approx 50\ \Omega$

Strip impedance design

CST simulation and a time-domain reflectometer (TDR) results*







*J. He, Y. F. Sui et,al. Measurement Science and Technology **33** (2022) 115106, https://doi.org/10.1088/1361-6501/ac8277

(a–b) impedance for different modes vs. *h* and *α* by CST; (c) measured by TDR(Tektronix DSA8200). Experimental results are in a good agreement with simulations (below 3%).

Stripline design considering

- $r_{in} \geq r_{beam}$, $t \geq 1.2$ mm, $r_{in} + t + h \leq A_1$, $t + h \leq A_2$ $L_{strip} = \frac{2N-1}{4}\frac{c}{f_0}$, N=0, 1, 2
- r_{beam} is the radius of the beam stay-clear area, 1.2 mm is the minimum thickness of the strip when the longitudinal length is greater than 100 mm (enough mechanical strength), A_1 and A_2 are the mechanical size limits for the flange and the commercial feedthroughs, respectively.

After considering all the associated factors mentioned above, the parameters are determined.

Mechanical parameters of the CEPC stripline BPM

Location	r_{in}	t	h	α	θ	Z_{single}	L_{strip}	Z_{CST}
Unit	mm	mm	mm	degree	degree	Ω	mm	Ω
LINAC(FAS+SAS)	15	1.5	2.2	30	0	50.8	150	50.3 ± 0.5
LINAC(TAS)	10	1.2	0.6	30	0	49.9	150	50.4 ± 0.5

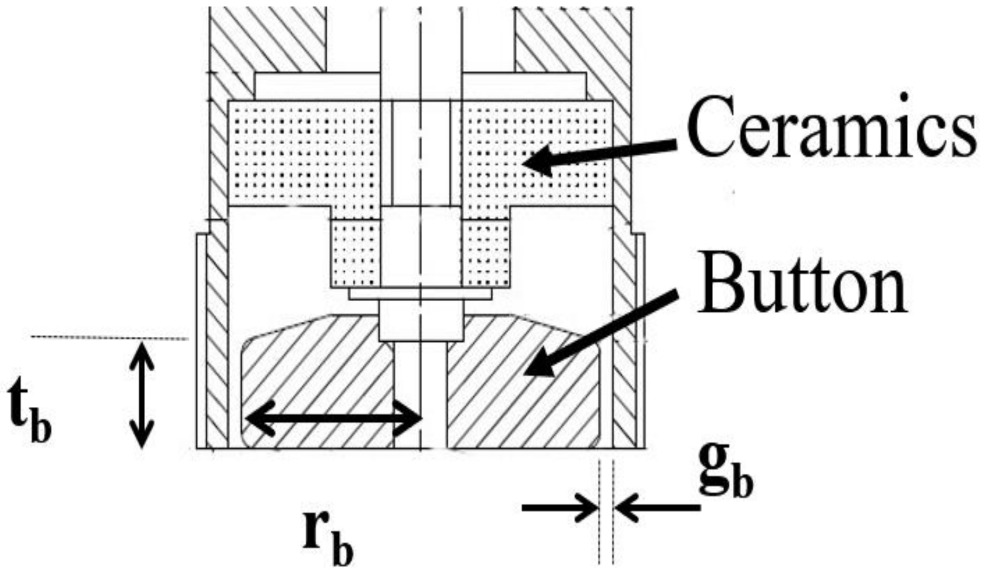
A button-type also could be used for LINAC, structure is simpler but signals are smaller than strip.

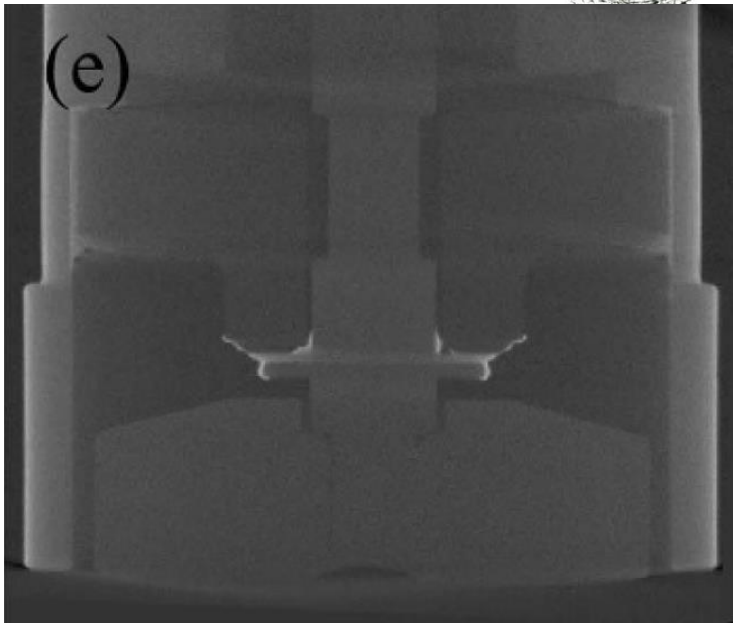
CEPC BPM design: Button-type

$$U = Z_t \times I_{bean} = \frac{r_b^{\,2}}{2bcC_b} \times \frac{j\omega RC_b}{1 + j\omega RC_b} \times I_{beam}$$

- The BPM design always is in a dilemma: the bigger transfer impedance (Zt) means a better resolution but also a more serious beam instability
- Several tips to depress the wakefield without decrease signal too much:
- 1. Impedance optimization (to reduce the reflection)
- 2. Smaller gap (avoiding short)
- 3. To hide the sealed dielectric, Bell- shape (SIRIUS) or bigger t_b
- 4. A design without skirt
- 5. A design of asymmetric structure
- 6. Dielectric with a smaller ε_r (To replace ceramics by glass)

Button BPM design : R_b, t_b, g_b





Mechanical drawing and X-ray tomography of a button pickup

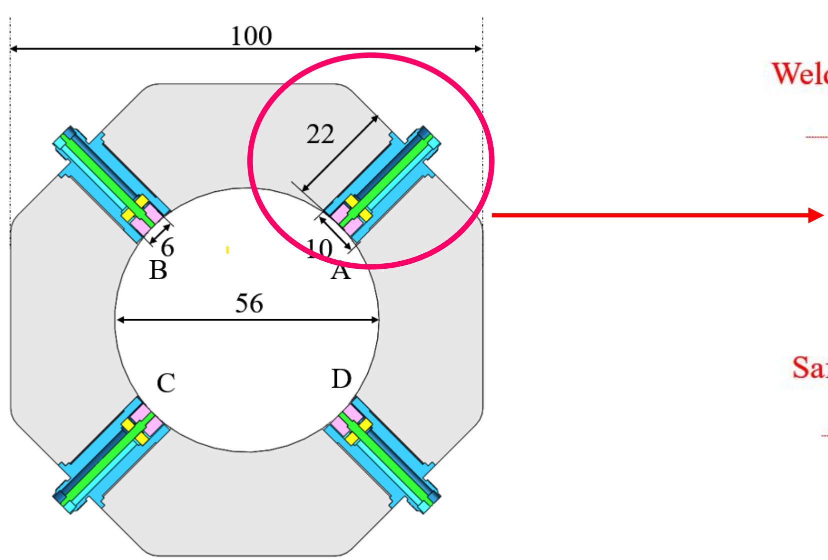
Three important parameters for button-type BPMs: radius r_b, height t_b and gap g_b.

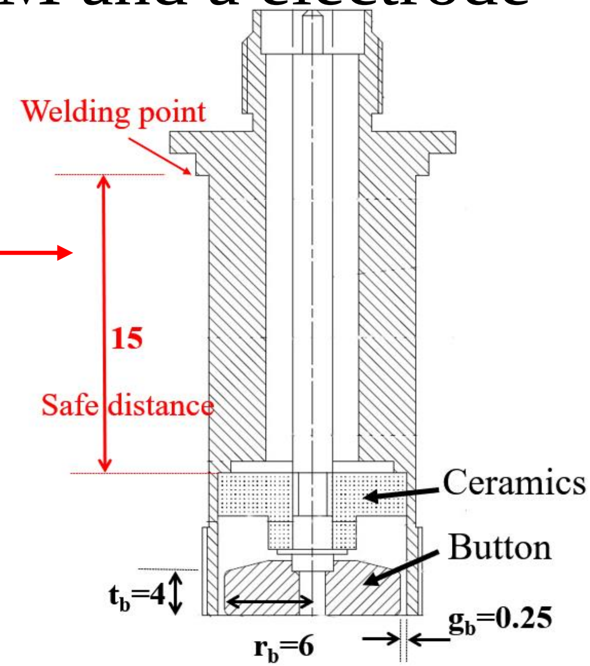
CEPC BPM design: Button-type

- Design goal: To increase the signal and decrease the wakefield.

Increase	Feature	Advantage	Disadvantage
r_b	Larger area and Cb	Higher signal level	Lower resolution
t_b	Larger volume	Lower wake impedance	Lower resolution
g_b	More trapped modes	Higher resolution	Higher wake impedance

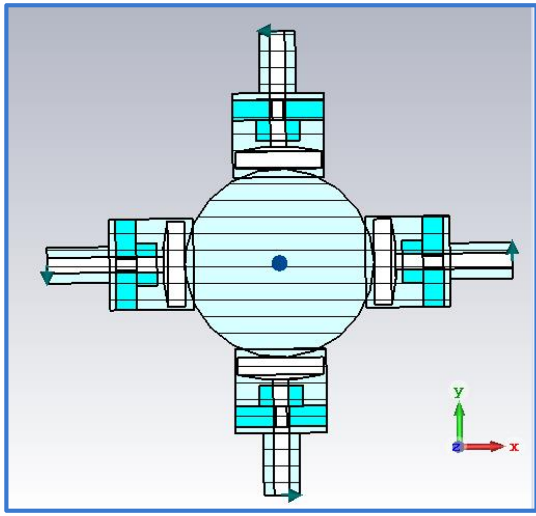
Mechanical structure of a BPM and a electrode



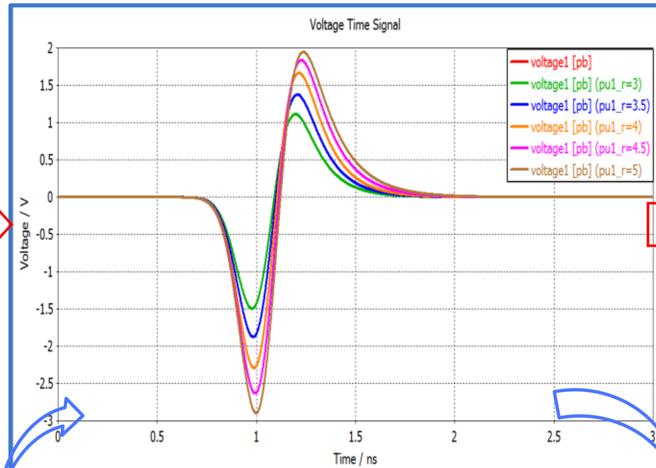


Button BPM design flow

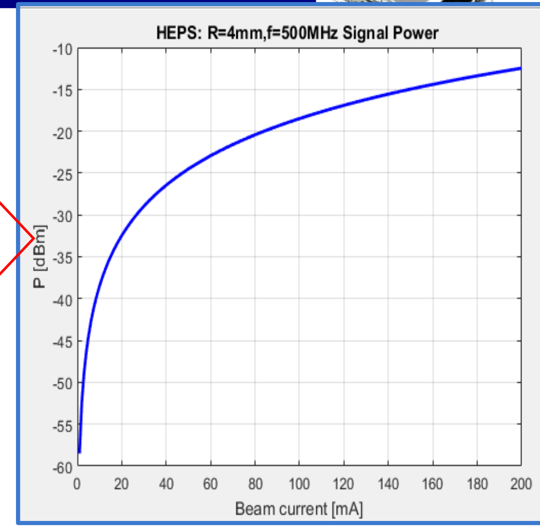
Mechanical parameters



Responding

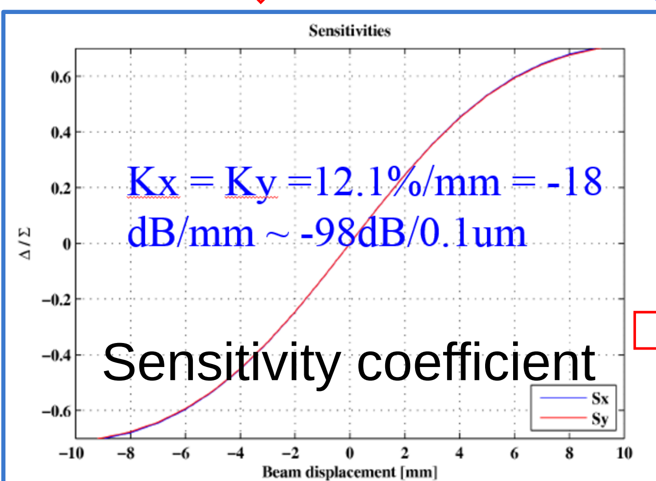


Different beam paramete



Changing beam position

$$U_{eff} = \sqrt{4k_B T \cdot R \cdot \Delta f}$$



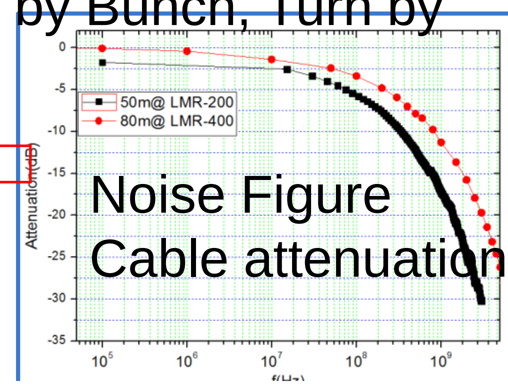
Kx = Ky =12.1%/mm = -18 dB/mm ~ -98dB/0.1um

Sensitivity coefficient

Different Bandwidth： Bunch by Bunch, Turn by Turn…

Resolution

Signal-to-noise ratio



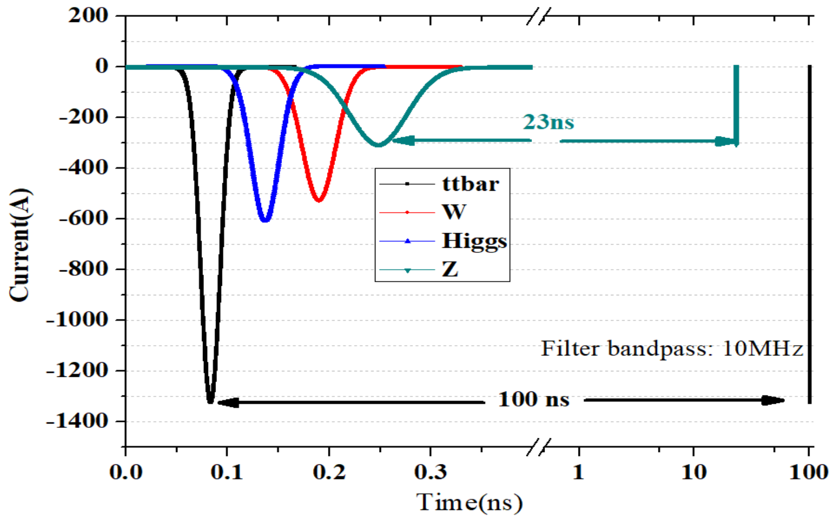
Noise Figure

Cable attenuation

$$H_{coax}(f) = -0.0328L\left(0.12229\sqrt{f} + 0.00026f\right)\text{dB}$$

CEPC BPM design: Button-type

The time structure of a bunch in different mode



Preliminary design parameters

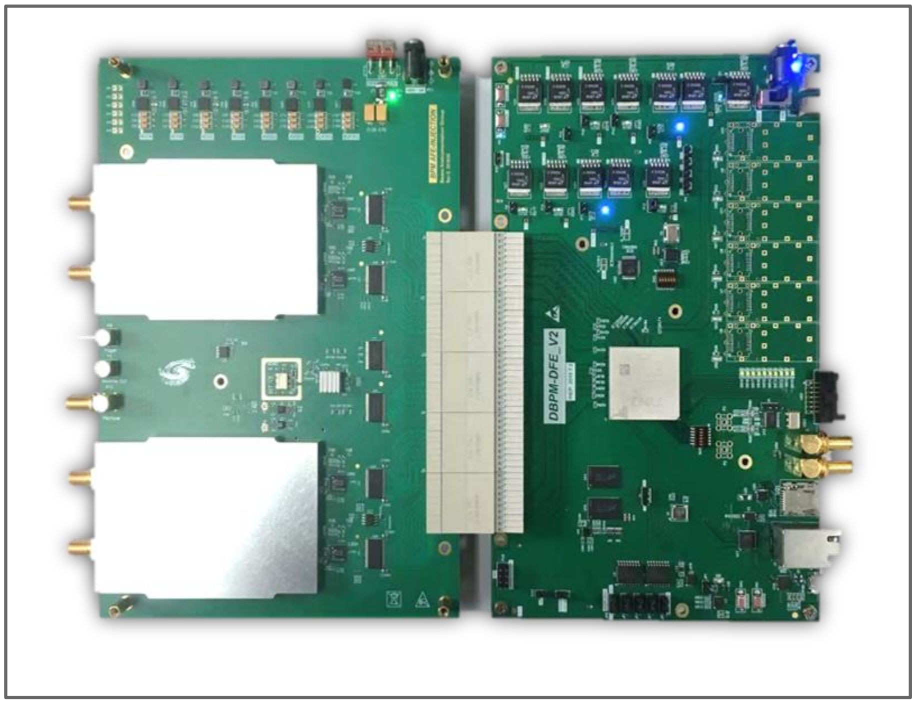
	Value
R_b	3 mm
t_b	4 mm
g_b	0.25 mm
C_b	2.8 pF

Parameters of the CEPC button-type BPM for different mode

	Charge	Bunch length	Current peak	DC Current	650MHz
	nC	mm	A	A	dBm
Higgs	20.8	4.1	607	0.208	-24.4
Z	22.4	8.7	308	0.974	-10.9
W	21.6	4.9	527	0.216	-23.7
ttbar	32.0	2.9	1315	0.320	-20.2

Study on home-made electronics

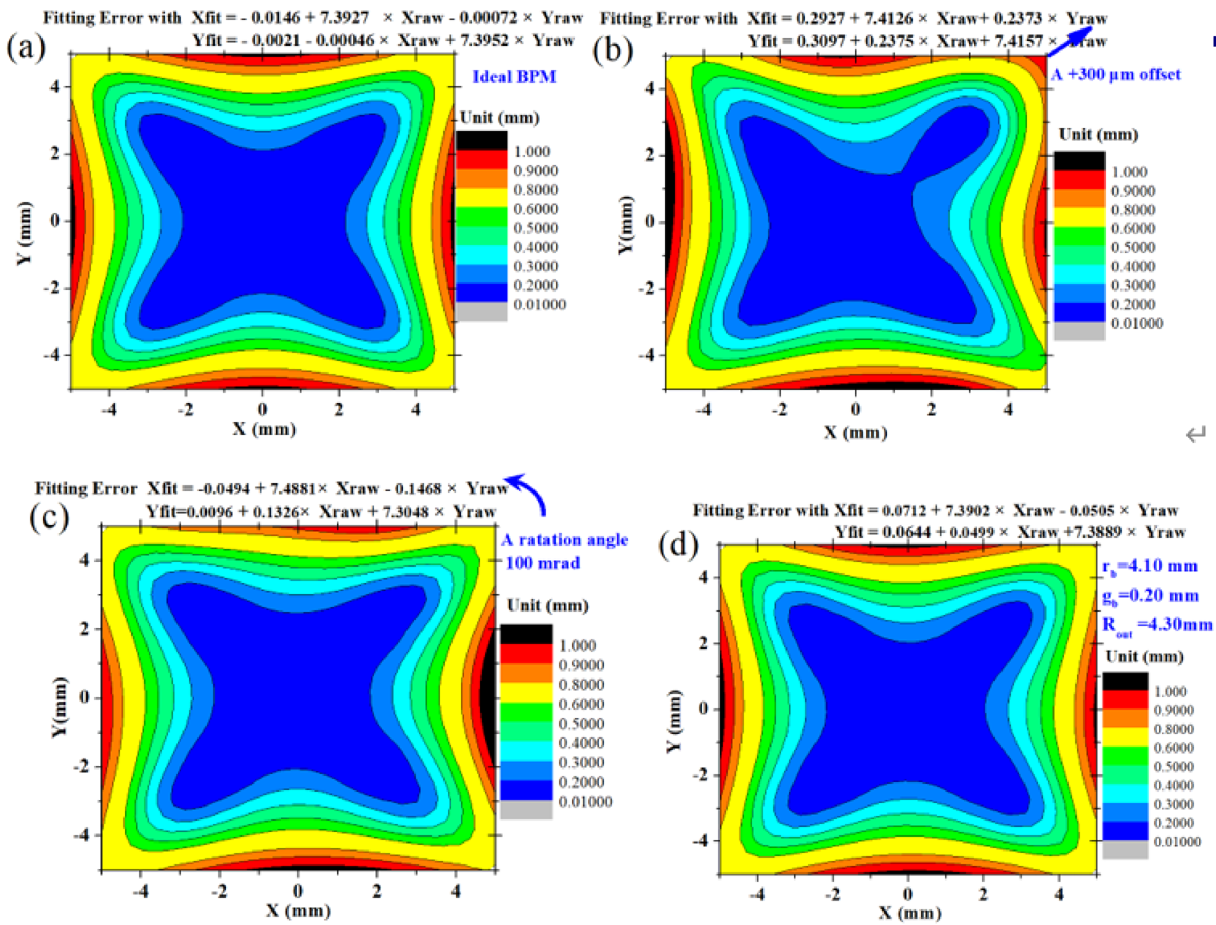
- The home-made BPM readout electronics are about the half cost and the same performance (resolution <0.1 μm) compared with the commercial products.



The picture of electronics made by BI group

~90 sets of electronics running online now(BEPCII)
~700 sets will be used in the HEPS

Study on mechanical tolerance



The effect of button positioning accuracy and BPM pipe mechanical tolerance have been studied[5].

Transverse resistive wall instability - wang na

$$\tau^{-1} = \frac{I_0 c_0}{4\pi(E_k/e)\nu_\beta} \sum_{\mu=0}^{M-1} \sum_{p=-\infty}^{\infty} Z_1\left((\mu + PM)\omega_0 + \omega_\beta\right)$$

- The worst case lowest energy and highest current, so Z mode is the most dangerous.

	ttbar	Higgs	W	Z
Number of Ips	2			
Circumference [km]	100.0			
SR power per beam [MW]	30			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
Bunch population [10^10]	20	14	13.5	14
Beam current [mA]	3.3	16.7	84.1	803.5

CEPC beam parameters of storage ring

	30 MW
Instability growth time [ms]	1.9 (~6 turns)
Radiation damping [ms]	850
Bunch by bunch feedback [ms]	1.0 (~3 turns)

Growth of the most dangerous mode vs. damping factors

The power of transverse feedback

$$\frac{1}{\tau_{FB}} = \frac{f_{rf}\sqrt{\beta_m \beta_k}}{2 \cdot h \cdot E / e} \cdot G$$

$$P = \frac{1}{2} \cdot \frac{\Delta V_{FB}^2}{R_K}$$

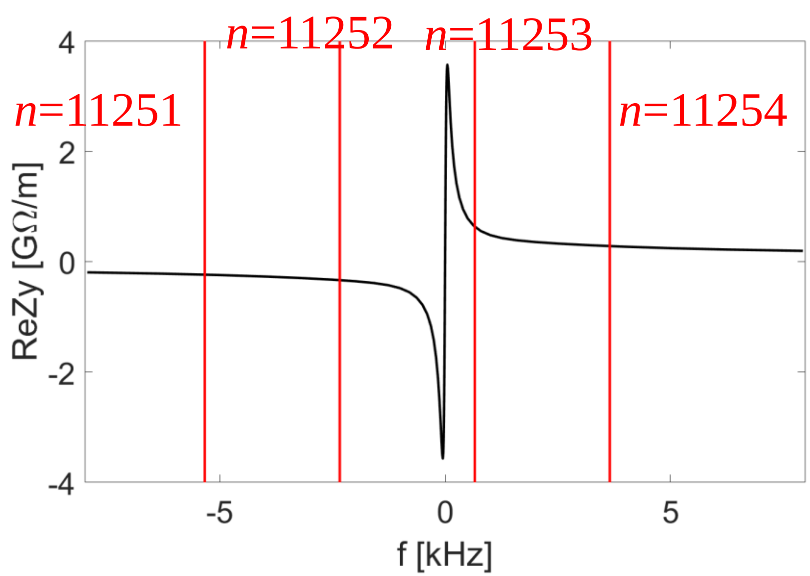
TFB CEPC ring（CDR）	
Parameter	Value
E	4.55E+10
R	1.55E+05
Beta-k	2.25E+02
Beta-m	2.25E+02
A	2.00E-04
T	3.30E-04
tao	1.60E-03
P	8.98E+02

TFB CEPC Ring （30MW）	
Parameter	Value
E	4.55E+10
R	1.55E+05
Beta-k	2.25E+02
Beta-m	2.25E+02
A	2.00E-04
T	3.30E-04
tao	1.00E-03
P	2.30E+03

Conceptual solutions of TFB feedback

- Narrow-band feedback + bunch by bunch feedback
- Consider narrow-band feedback, in addition to bunch-by-bunch ones, for specific instabilities such as resistive wall coupled bunch. Mode No. 19650 & 19651

Mode frequency [kHz]	Mode number	Growth time [ms]
-2.338	19650	1.1 (3 turns)
-5.335	19651	1.6 (5 turns)
-8.332	19650	2.0 (6 turns)
-11.330	19649	2.3 (7 turns)



Conceptual solutions

- Multi-feedback systems for one direction. The double feedback technique was implemented successfully at BEPCII. The result shows that the damping times almost equal to the two feedback systems add up.

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BEPCII 逐束团双反馈系统运行试验研究

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摘要 逐束团反馈控制是抑制束流不稳定性最好的方法，未来的环形正负电子对撞机(Circular Electron Positron Collider，CEPC)等超大型装置的环周长为100 km，束流不稳定增长时间为毫秒量级，这要求束流振荡能在十几圈甚至几圈内被抑制，意味着反馈系统提供的阻尼时间要很短，传统的数字反馈系统显然难以实现。一些缩短阻尼时间的方法相继被提出，其中之一是在储存环中采用若干套束流反馈系统作用于同一束流上，通过阻尼效果的叠加以减少总系统阻尼时间。本文工作主要利用北京正负电子对撞机二期(Beijing Electron Positron Collider II，BEPCII)同步模式外环上两个条带kicker的有利条件，开展双反馈系统带束实验研究，一套是自行研制的逐束团数字横向反馈系统，另一套是Dimtel公司生产的商用逐束团数字反馈系统，分别测量各系统以及双系统的阻尼时间。实验测得商用系统的阻尼时间是0.93 ms，自研反馈系统的阻尼时间为2.98 ms，双反馈系统的阻尼时间为0.70 ms，验证双反馈系统能够有效缩短阻尼时间。

关键词 双反馈系统，阻尼时间，束流振荡，线性拟合
中图分类号 TL506
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Research of the double feedback system operating in BEPCII

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Abstract **[Background]** Digital bunch-by-bunch feedback control is the best way to control bunch instability. It will be applied to the super collider to suppress the beam oscillation within a dozen or even several cycles. The damping time of circular electron positron collider (CEPC) and FCC-ee (Future Circle Collider e^-e^+) is very short, but it is impossible to realize through using traditional digital feedback system. **[Purpose]** This study aims to cure the coupled-bunch instability by using a dual-feedback control system to reduce the damping time for BEPCII (Beijing

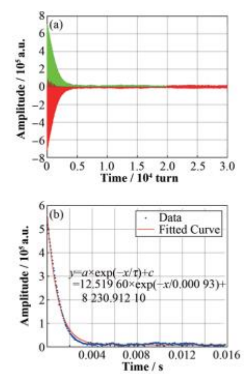
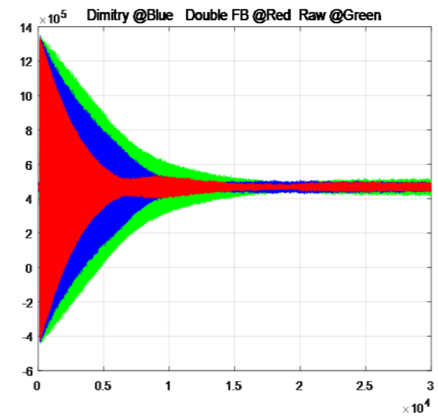


图7 商用反馈系统阻尼时间
(a) 振荡衰减逐圈信息，(b) 数据拟合曲线
Fig.7 The damping time measurement of commercial feedback system
(a) Turn-by-turn information of beam oscillation, (b) Fitting curve of data

根据以上数据计算：

$$\frac{1}{\tau_1}+\frac{1}{\tau_2}=1.26\ \mathrm{ms}^{-1}\approx\frac{1}{\tau_3}=1.33\ \mathrm{ms}^{-1}$$

最后算得双反馈系统阻尼率1.33 ms^{-1}基本是两套反馈系统(仅水平方向)同时运行的阻尼率的叠加1.26 ms^{-1}。图9是根据本次实验获取的各系统作用



The damping time of two TFBs

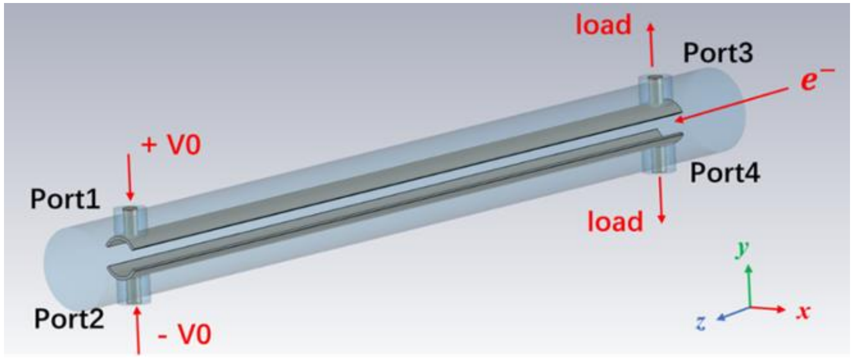
Conceptual solutions

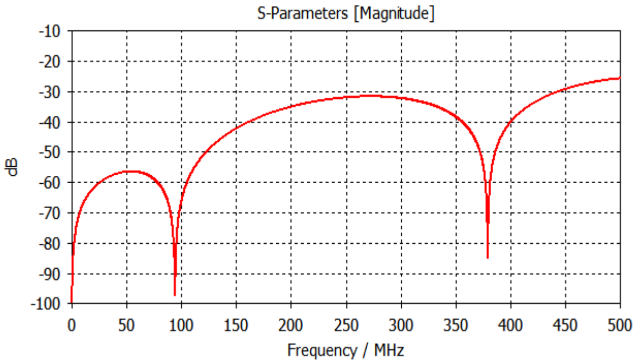
- Multi-feedback systems were also tested at DAFNE. The damping times of the two feedback systems add up about linearly within the measurement error (10-20%)

- **<u>DAFNE, year 2008</u>**
- **<u>New e+ Transverse Horizontal Feedback</u>**
- The damping times of the two feedback's add up linearly
- Damping time measured:
- ~100 ms-1 (1 FBKs) → fb damps in 30 revolution periods (~10 us)
- ~200 ms-1 (2 FBKs) → fb damps in 15 revolution periods (~ 5 us)
- The power of the H FBK has been doubled

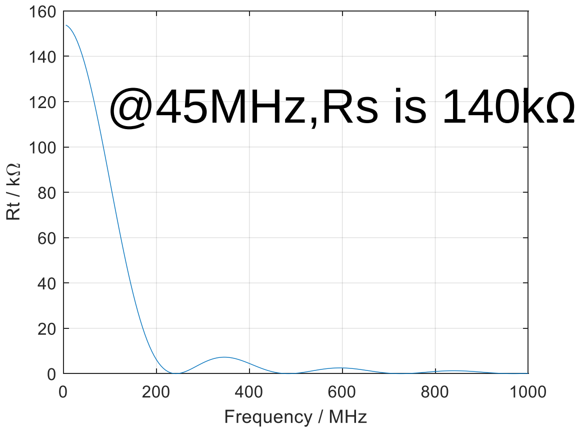
TFB Kicker design（main ring）

The stripline type kickers are used for transverse feedback.





Parameter	Value
Length	600mm
Electrode radius	17mm
Thickness	2mm
Pipe radius	28mm
Open angle	90°



The power of longitudinal feedback

$$\frac{1}{\tau_{FB}} = \frac{f_{rf}\alpha}{2\nu_s E/e} \cdot G \qquad P = \frac{1}{2} \cdot \frac{\Delta V_{FB}^2}{R_K}$$

CEPC LFB（CDR）	
Parameters	Value
f	6.50E+08
alpha	1.11E-05
mus	2.80E-02
deltaphi	1.70E-03
Tao(s)	2.00E-01
E	4.55E+10
Rk(Ω)	2600
V(V)	3.00E+03
P(W)	1.73E+03

CEPC LFB（30MW-12ms）	
Parameters	Value
f	6.50E+08
alpha	1.48E-05
mus	3.50E-02
deltaphi	1.70E-03
Tao(s)	1.20E-02
E	4.55E+10
Rk(Ω)	2600
V(V)	4.69E+04
P(W)	4.23E+05

CEPC TDR Collider Ring Cavity HOM CBI –Zhai Jiyuan

30 MW SR per beam. Consider only SR damping for HOM Q_L requirement. Cavity HOM spread not included.	ttbar		Higgs	W	Z
	new 5-cell common cavity	**old 2-cell common cavity**	**common cavity**	**separate cavity**	**by-pass separate cavity**
Cell number / cavity	**5**	**2**	**2**	**2**	**1**
Beam energy [GeV]	180.0	180.0	120.0	80.0	45.5
Beam current per beam [mA]	3.4	3.4	16.7	84.0	802.6
Revolution time [μs]	333.6	333.6	333.6	333.6	333.6
Momentum compaction	7.1E-06	7.1E-06	7.1E-06	1.4E-05	1.4E-05
Synchrotron tune	0.08	0.08	0.05	0.06	0.04
S [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
L [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cavity number on line per beam	240	240	240	120	30
Average beta-x/y in RF region [m]	30	30	30	30	30
Longitudinal impedance threshold per cavity [ohm*MHz]	3.58E+11	3.58E+11	9.62E+09	9.05E+08	2.27E+07
Transverse impedance threshold per cavity [ohm/m]	1.88E+08	1.88E+08	7.48E+06	1.18E+06	5.12E+04
Cavity higher order mode	**Required Q_L**				
TM011	7.2E+06	9.4E+06	2.5E+05	2.4E+04	**1.5E+03**
TM020	9.3E+06	4.0E+08	1.1E+07	1.0E+06	**4.2E+04**
TE111	4.5E+05	1.3E+06	5.3E+04	8.4E+03	**6.5E+02**
TM110	5.5E+05	9.0E+05	3.6E+04	5.6E+03	**3.5E+02**

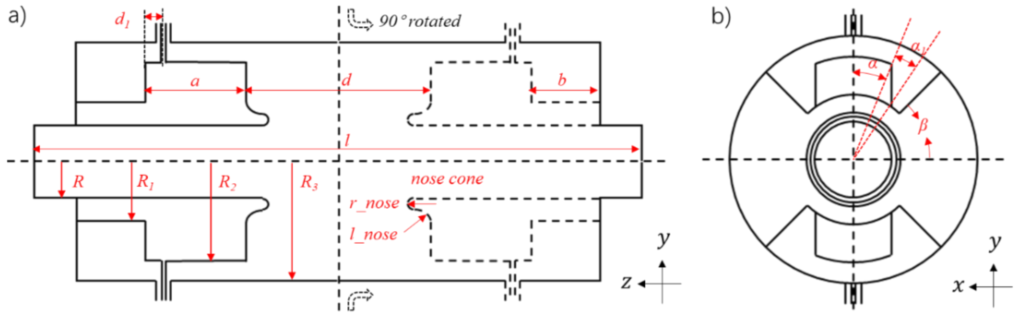
- No beam feedback is needed even for 50 MW.

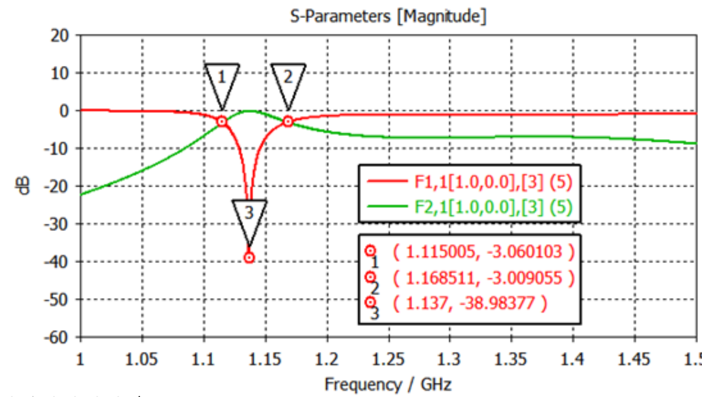
2-cell	**f (GHz)**	**R/Q (Ω)**
TM011	1.17	65.20
TM020	1.38	1.29
TE111	0.84	279.82
TM110	0.91	420.05
5-cell	**f (GHz)**	**R/Q (Ω)**
TM011	1.17	84.80
TM020	1.43	54.15
TE111	0.82	832.23
TM110	0.93	681.15
1-cell	**f (GHz)**	**R/Q (Ω)**
TM011	1.09	28.17
TM020	1.32	0.82
TE111	0.79	157.00
TM110	0.90	291.07

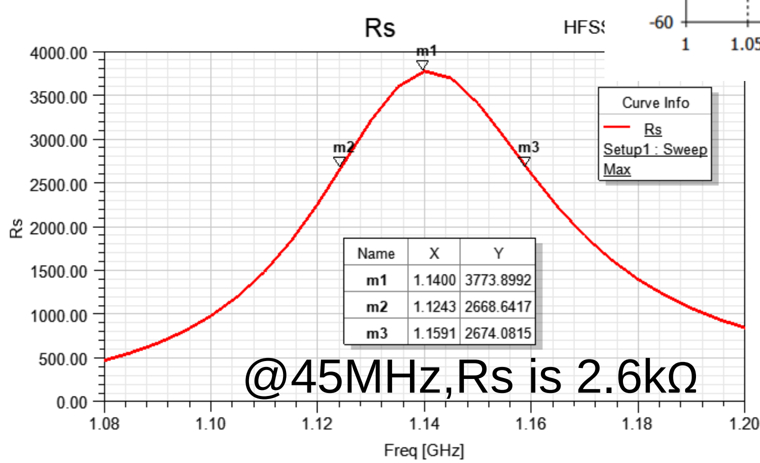
- ...signed 650 MHz 2-cell cavity HOM coupler Q_L can meet Higgs and W damping requirement.
- 1-cell cavity similar to BEPCII can meet 30/50 MW Z HOM damping requirement. No beam feedback is needed even for 50 MW.
- Low lumi Z with 2-cell cavities may need beam feedback depending on the operation beam current.

LFB Kicker design(main ring)

The waveguide loaded pillbox cavities are for the longitudinal direction.







Name	X	Y
m1	1.1400	3773.8992
m2	1.1243	2668.6417
m3	1.1591	2674.0815

@45MHz,Rs is 2.6kΩ

Beam size measurement

- X-ray interferometer

CONCEPTUAL DESIGN FOR SR MONITOR IN THE FCC BEAM EMITTANCE (SIZE) DIAGNOSTIC

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F. Zimmermann, CERN, Geneva, Switzerland

X-RAY INTERFEROMETRY

A simple configuration for Young type double slit interferometer for beam size measurement in FCC-ee is shown in Fig. 5.

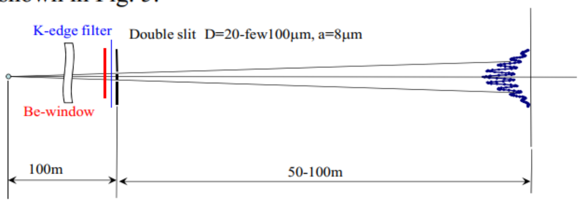
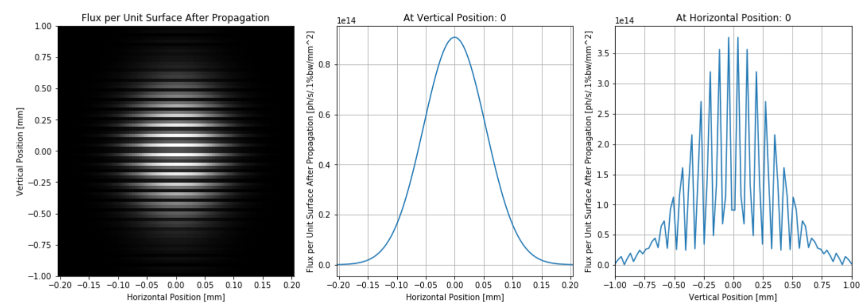
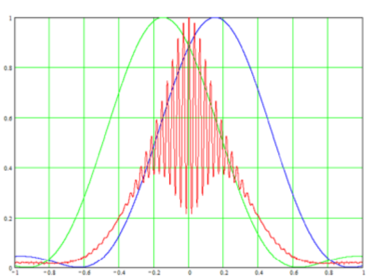
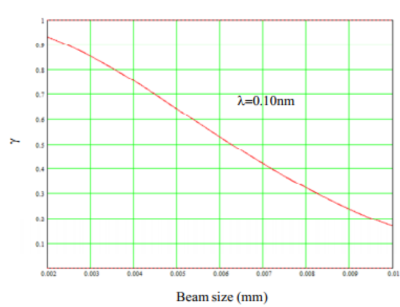


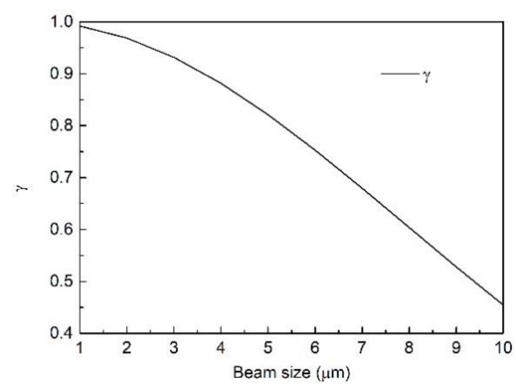
Figure 5: Young type double slit X-ray interferometer.

X ray energy：12keV
Light spot size：x 40e-6m y 5e-6m
Slits：Distance: d=200μm Width: a=8μm
Distance from source to slit: R=100m
Distance between observation point to slit 75m



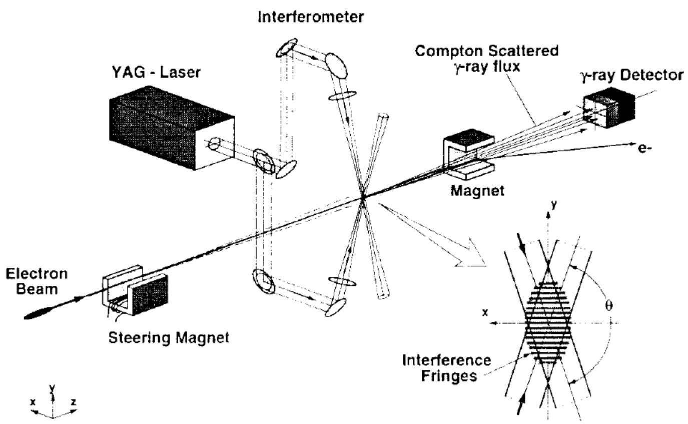


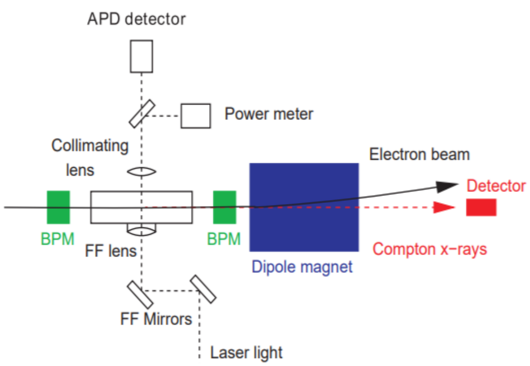




Beam size measurement

- Other alternatives
  - **Laser wire scanner**
    - Based on Compton scattering using high power lasers
    - Based high power fiber laser to measure small beam size





Bunch length measurement

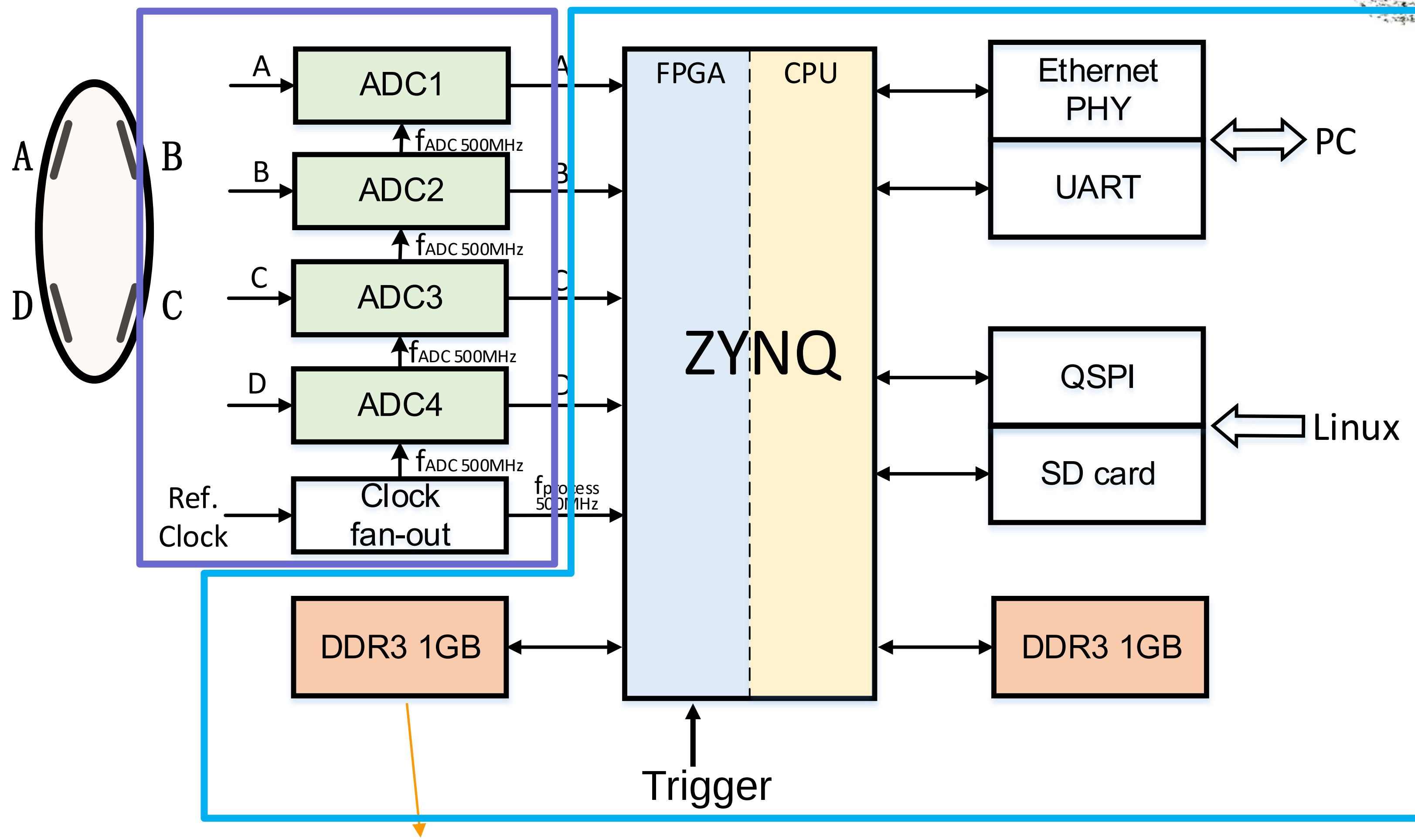
	ttbar	Higgs	W	Z
Energy [GeV]	180	120	80	45.5
Bunch length (SR/total) [mm]	2.2/2.9	2.3/3.9	2.5/4.9	2.5/8.7

- Bunch by bunch measurement system to monitor the bunch length and its lengthening.
- Resolution about 1ps(10% of bunch length）, streak camera based on visible light will be used.
- Visible SR beam line should be necessary.
- Heat deposit onto the SR extraction mirror is not so larger than existing SR machine, so we can use mirror design in SR facilities.(from **T. Mitsuhashi**)

Bunch by bunch measurement

- Bunch by bunch electronics are used to bunch current monitor, bunch by bunch BPM, beam trip monitor, bunch by bunch feedback and so on.
- The accelerator system involves many subsystems, and various conditions are mixed together, so, it is difficult to get to the real cause for beam trip. It is necessary for CEPC to develop bunch by bunch electronics for studying the beam trip.
- To optimize the beam-beam tune shift and to control the stability of individual bunches. This requirement makes it necessary to measure the beam current bunch-by-bunch.

Bunch by bunch electronics

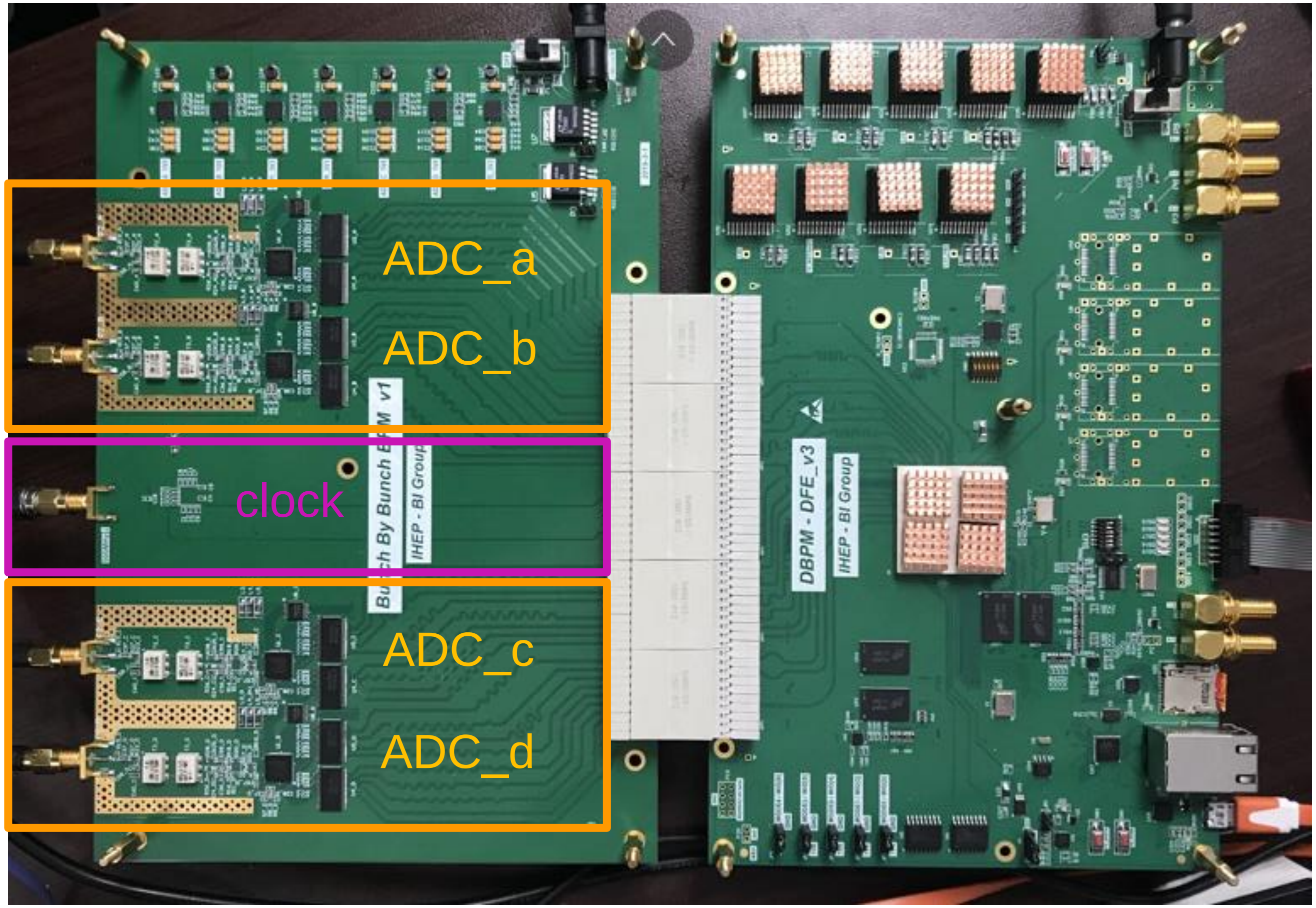


Buffer of bunch by bunch raw ADC data

Bunch by bunch electronics

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

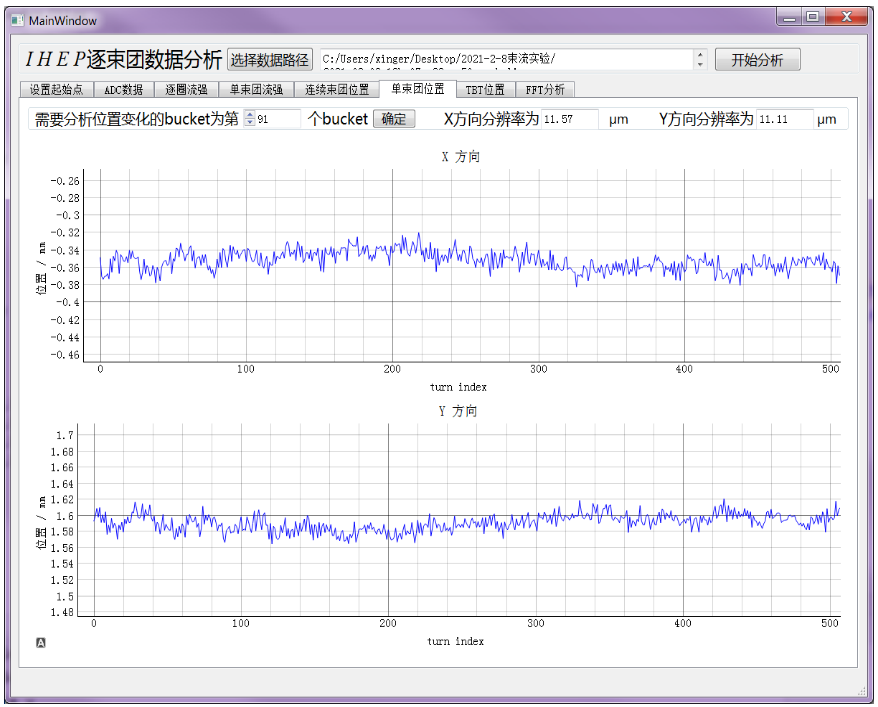
AFE



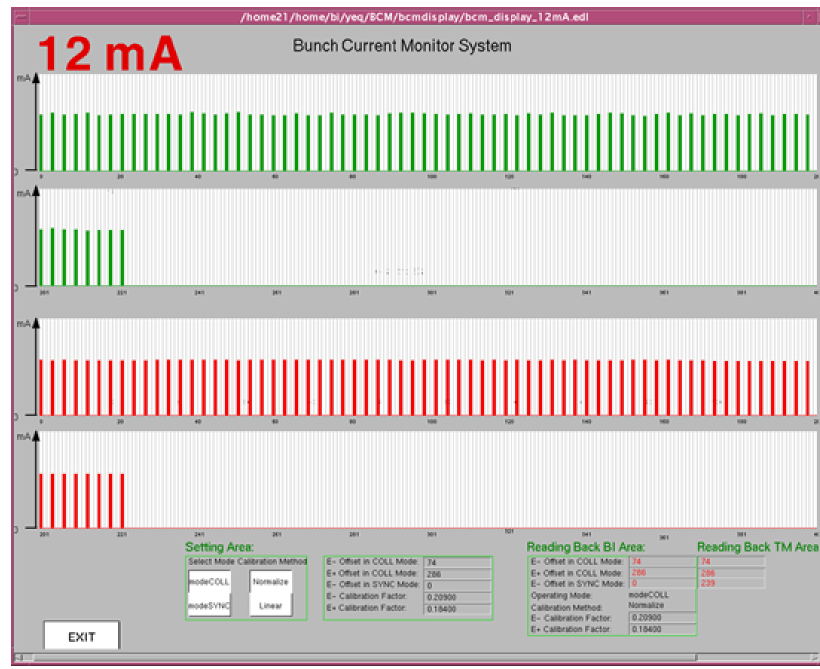
DFE

Bunch by bunch electronics

- The bunch by bunch electronics was test in BEPCII.
- The bunch current and bunch position were measured by BBB electronics



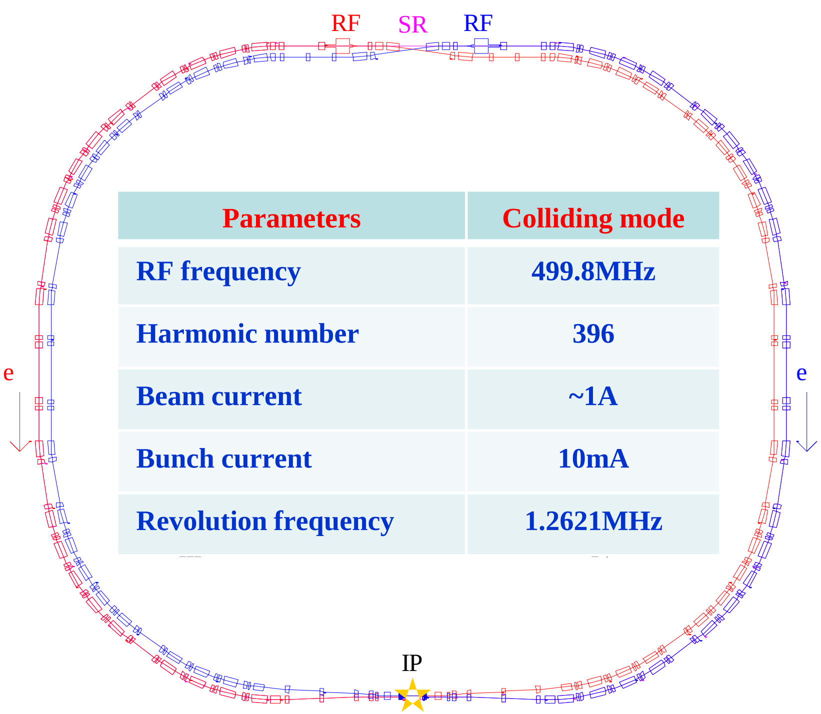
The 91st bunch position were traced in 500 turns



The bunch current were measured by electronics

Beam trip diagnosis

- High beam current can cause the beam instability and make devices unstable, thus easily lead to the beam trip. Beam trip seriously affects the efficiency of the machine, also may cause damage to the hardware system.
- Many accelerator all over the world has established a powerful beam trip diagnostic system, such as LHC, PEP-II, RHIC, TLS and so on.



Parameters	Colliding mode
RF frequency	499.8MHz
Harmonic number	396
Beam current	~1A
Bunch current	10mA
Revolution frequency	1.2621MHz

BEPCII double rings layout

Cause of beam trip

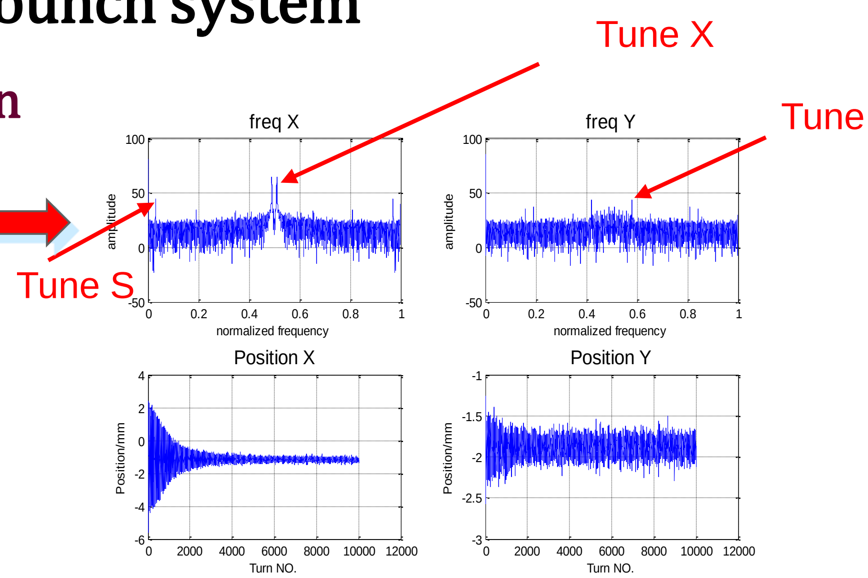
- **Subsystem failure**
- **RF (trip, LLRF)**
- **Beam instabilities**
- **…**

Result of beam trip

- Degrade the operating efficiency
- Troubleshoot time cost
- Others subsystem trip
- …

Beam trip research in BEPCII

- → Beam trip events
  - → more than 300 beam trip events had been collected and analysis
  - → Many contrast experiment
- → Beam trip analysis by bunch-by-bunch system
  - → Time domain and frequency domain
  - → Bunch-by-bunch and turn-by-tune
  - → Tune in three dimensions
- → Some trip events become clear
  - → RF trip
  - → Magnet power instabilities
  - → Beam instabilities
  - → ...



Summary

- CEPC beam instrumentation are facing many technical challenges.
- Lessons learned from HEPS construction and BEPCII operations will be helpful for CEPC beam instrumentation design. Benefits are from key technologies R&D and CIPC members collaborations.
- More efforts should be paid to the system detail design in the future.

Thanks for your attention !