The design of HEPS beam diagnostics

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On behalf of HEPS beam diagnostics group

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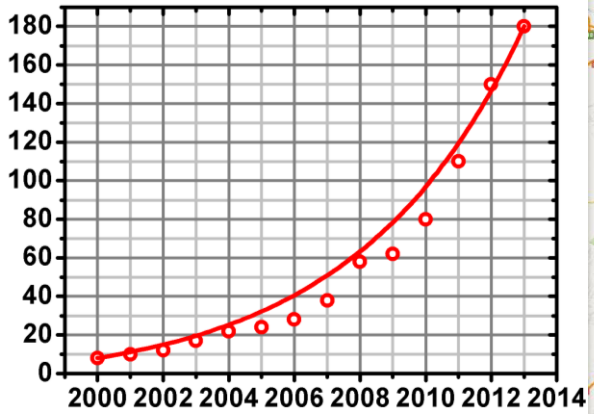
Outline

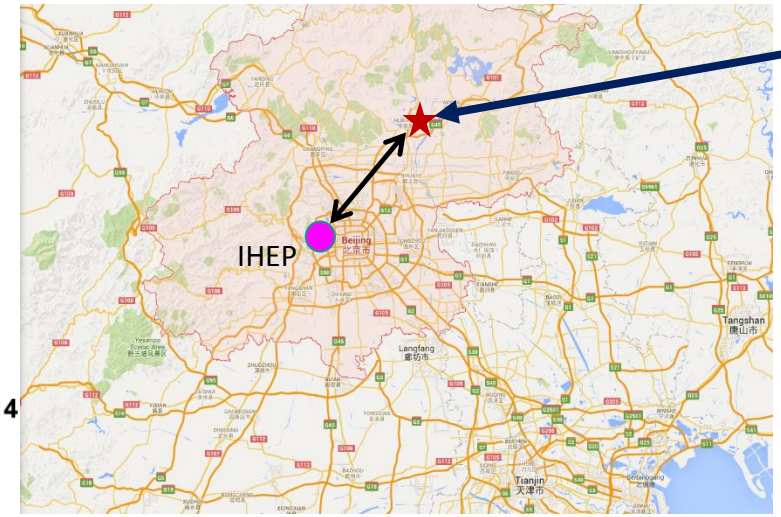
New light source in China — High energy, high brightness

- The number of users and new research fields increased as rapid growing of the Chinese sciences and economy



e.g. Increase of structure biology users in China

A new photon science research center at the northern China

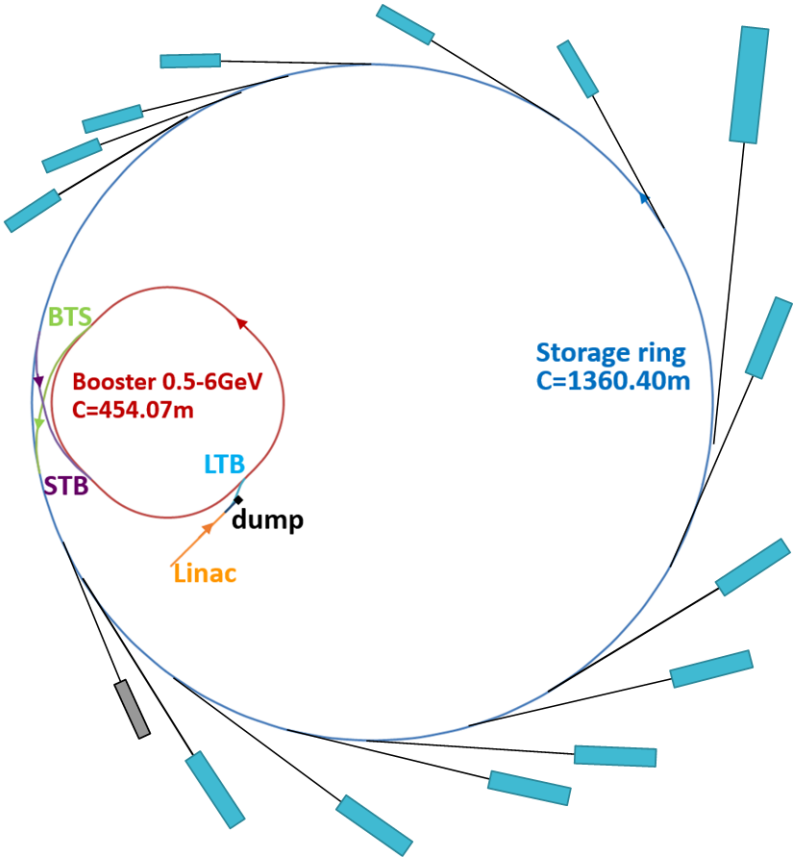


About 80 km from IHEP

Courtesy of Q. Qin

Technical features of the new light source

- 6GeV, 200 mA, swap-out injection
- Circumference 1360 m
- Multi-bend achromat(7 bend) lattice
- High-brightness, ultra-low emittance(ex, ey)
- 41 insertion device straight sections
- Flexible operation: High-brightness and timing modes, round and flat beams



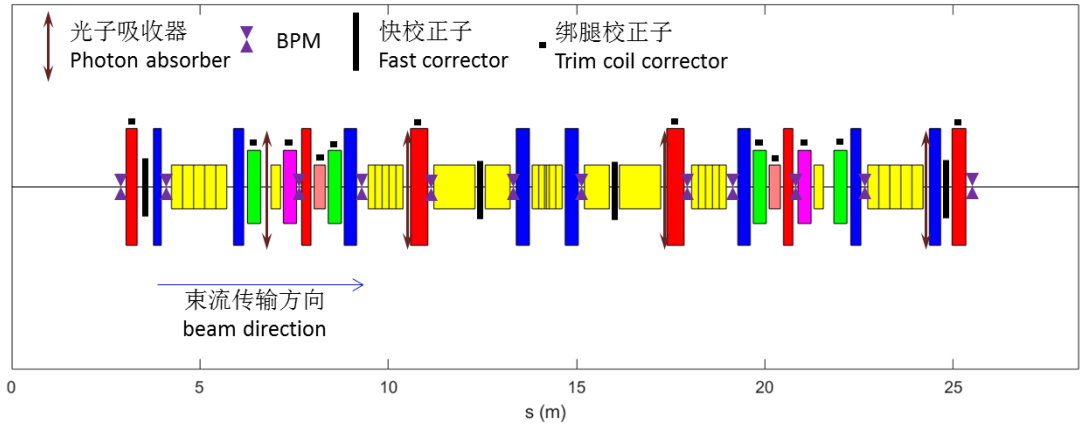
HEPS beam instrumentation

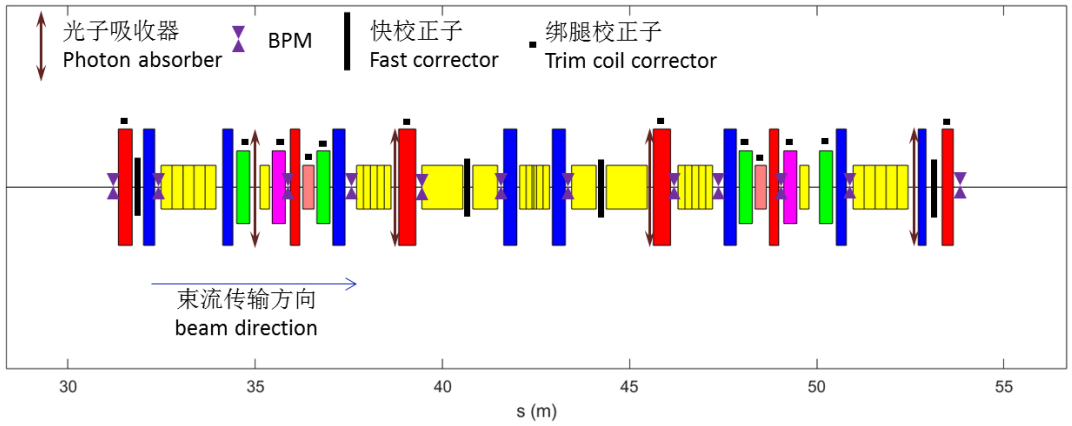
		LINAC	LTB	Booster	BTS	SR	STB
Position	Button BPM	1		80		48*12+3	
	Stripline BPM	6	8		11		11
Current	ICT	7	2		2		2
	DCCT			1		1	
	BCM			1		1	
Profile	OTR/YAG	7	2		2		2
	X-Ray Diagnostics beamline					2	
	VSLM Diagnostics beamline			2		1	
BLM	Pin Diode					10*48	
	Fiber BLM			4			
Other	Pilot Tune			1		1	
	Direct Diode Detection			1		1	
	Bunch length					1	
	Slits	1					
	Emmitance	2					
	Energy analysis	2					
	BxB Feedback (H & V& L)			1		1	

BI Parameters of storage ring

System	Method	Main parameters	Quantity
Bunch Current Monitor	BCM	Resolution:1/1024	1
Average current	DCCT	Range: 0.1mA~500mA ; Linearity: ≤0.1% ;	1
Beam Positon Monitor	Four-buttons BPM	Resolution: ≤ 0.1 μm@200mA	576
Chamber displacement measurement	High resolution displacement monitor	Resolution: ≤ 100nm	8
Beam length	Streak camera	Resolution ≤ 2 ps	1
Beam profile	Double-slit interference & KB mirror	Resolution ≤ 0.2μm	1
Bunch purity measurement and improving	Time-correlated Single photon counting	Resolution $\leq 10^{-6}$	1
Tune measurement	Pilot tune/3D	Resolution $\leq 10^{-5}$	1
Beam loss monitor	PIN diode type	Counts rate: 10 MHz	500
Beam instability curing	Bunch by bunch feedback system	Damping time ≤0.5*rise time	3

Beam position monitor

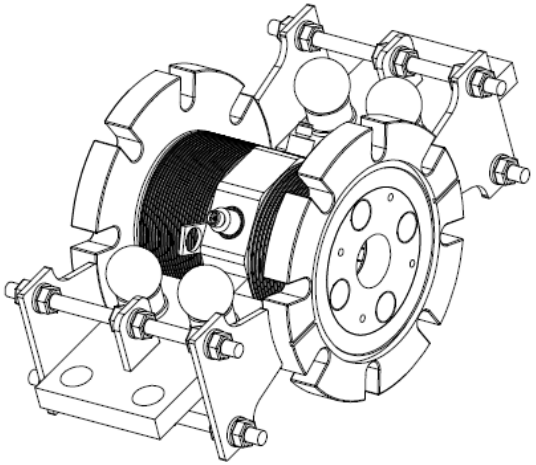




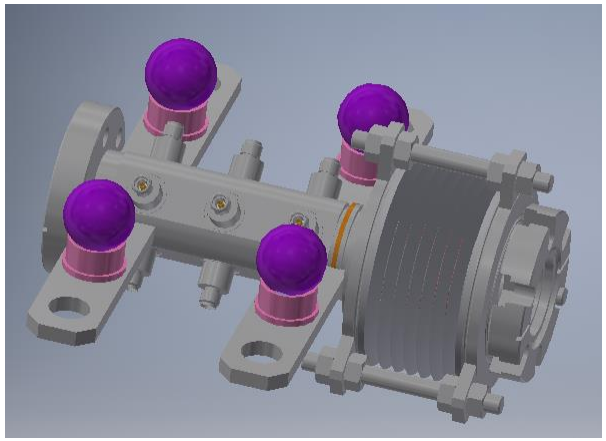
HEPS lattice is 24 cells which have two 7BAs structure, in every 7BA, there are 10 BPMs in arc and 2 BPMs in ID, so totally we have 48*12=576 BPMs.

There are another 3 multi-button BPMs for Tune, BCM and FBs.

Beam position monitor

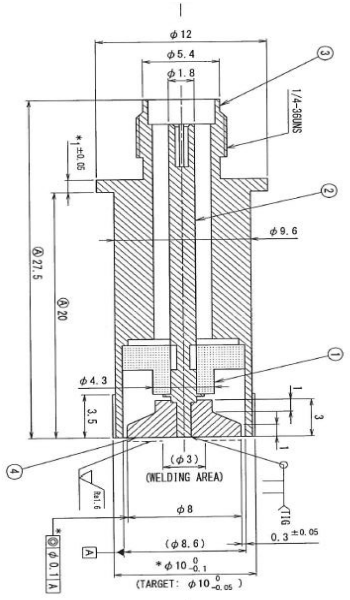


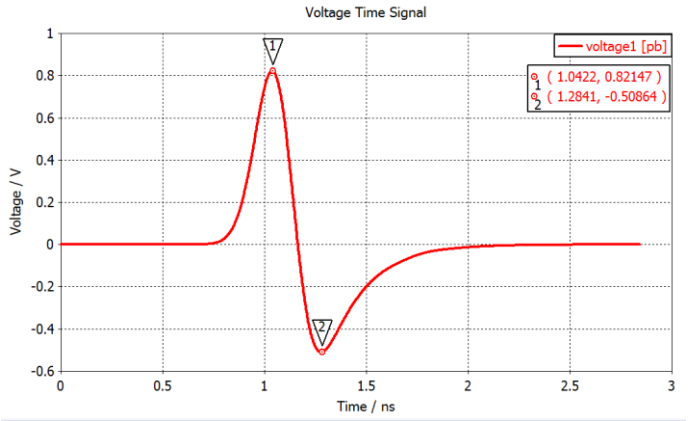
BPM with two bellows

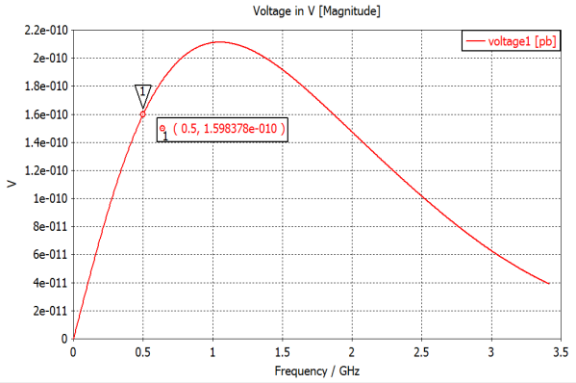


Specific BPM for Tune\BCM\FB

Duct inner diameter	22mm
Button diameter	8mm
The gap	0.3mm
The length	108mm

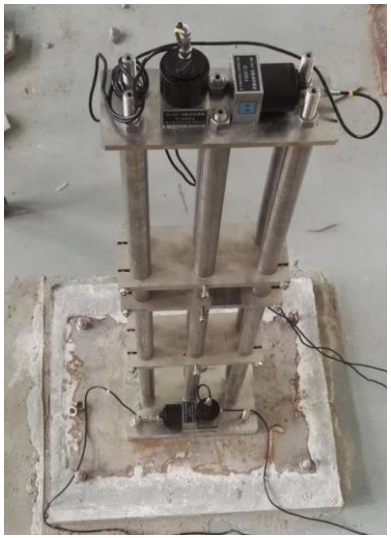






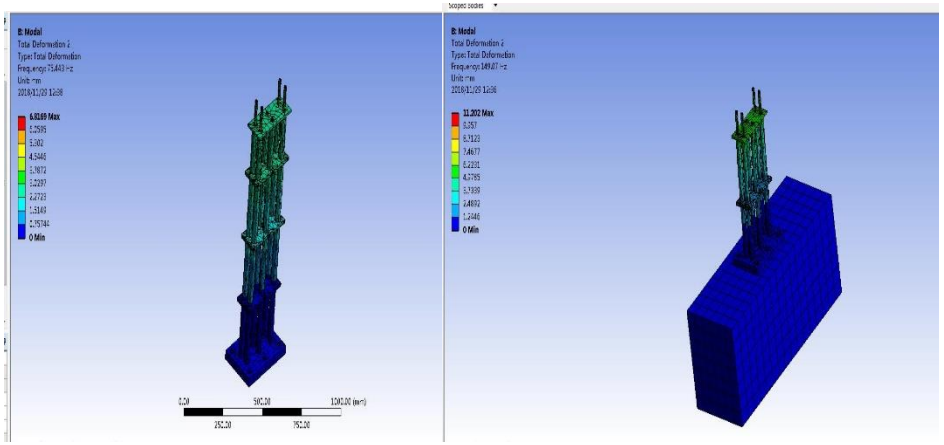
BPM support

Carbon fiber support for BPM in arc.



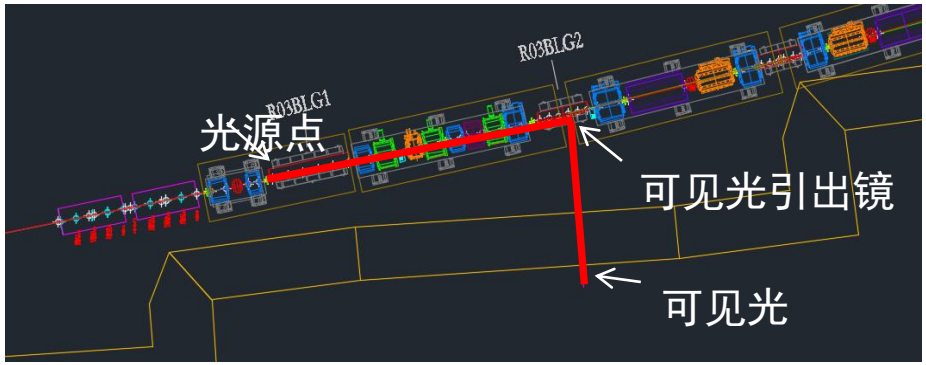
Invar support for BPM in ID.

Invar from ground, the natural frequency is 75.4Hz;
Invar with small mass concrete, the frequency is 149.07Hz;
Invar with big mass concrete, the frequency is 157.39.
Need to balance the thermal expansion effect and improving natural frequency.

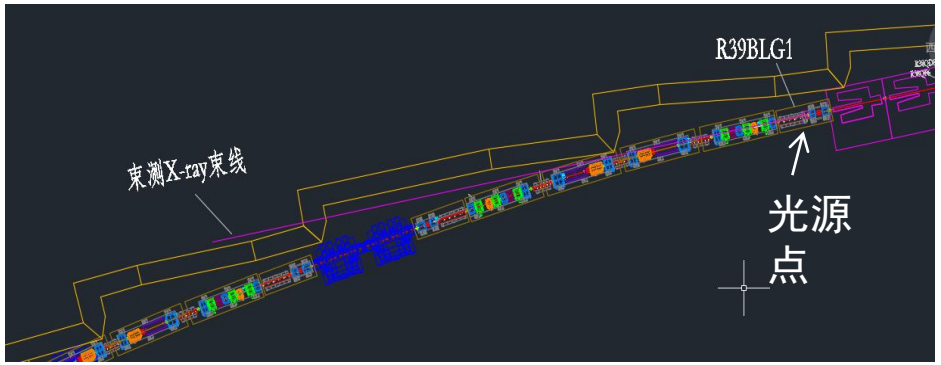


Synchrotron light based beam diagnostics

NO	Type	Source Location	Function
1	Visible Light	Downstream of injection section	Bunch length
2	X-ray	Downstream of SC cavity	Beam profile and bunch purity
3	X-ray	Bending magnet	Energy spread

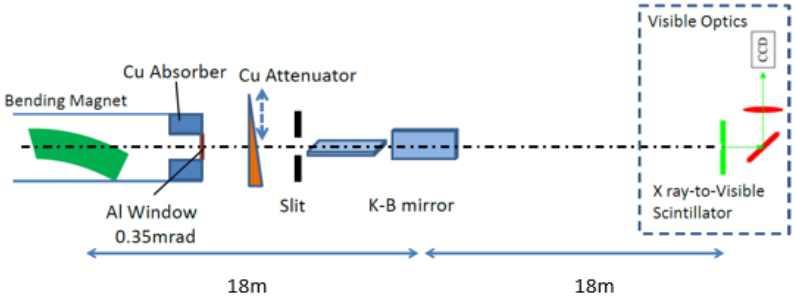


Visible light beam line



X-ray beam line

Synchrotron light based beam diagnostics



Imaging system based on KB mirrors

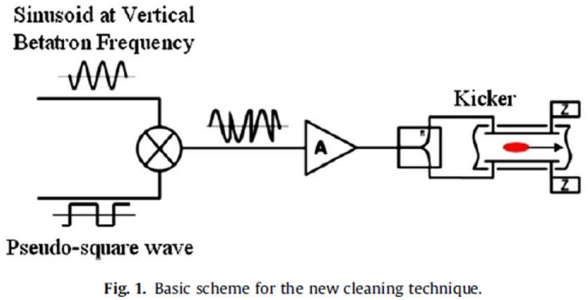
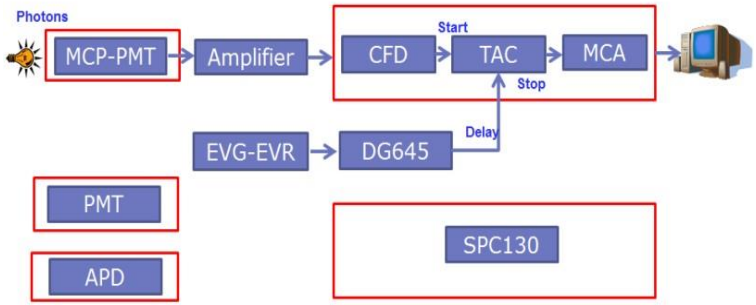


Fig. 1. Basic scheme for the new cleaning technique.

Bunch purity improving system using kicker to kick off (ALS)

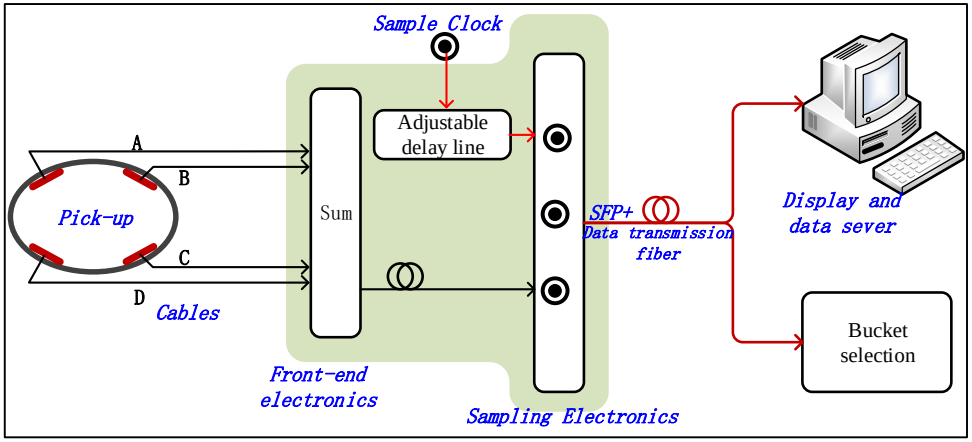
C10910 streak camera from Hamamatsu

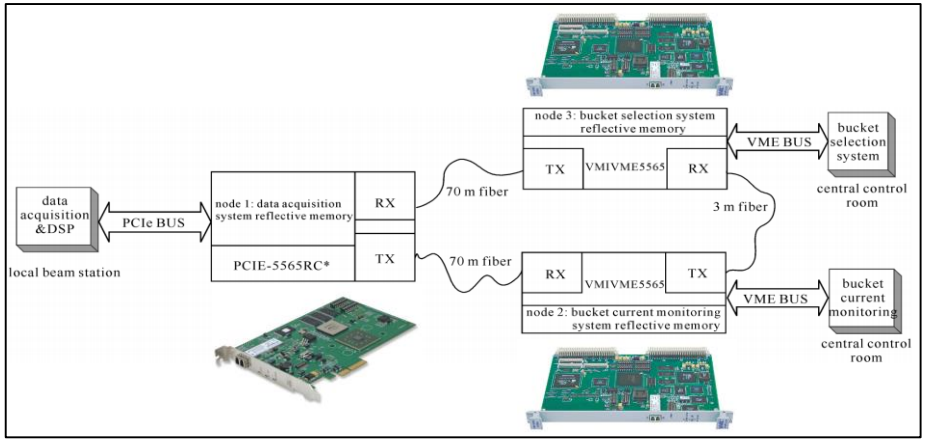


Time-correlated single photon counting for bunch purity measurement

Beam current monitor

- DCCT is employed for the average 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.

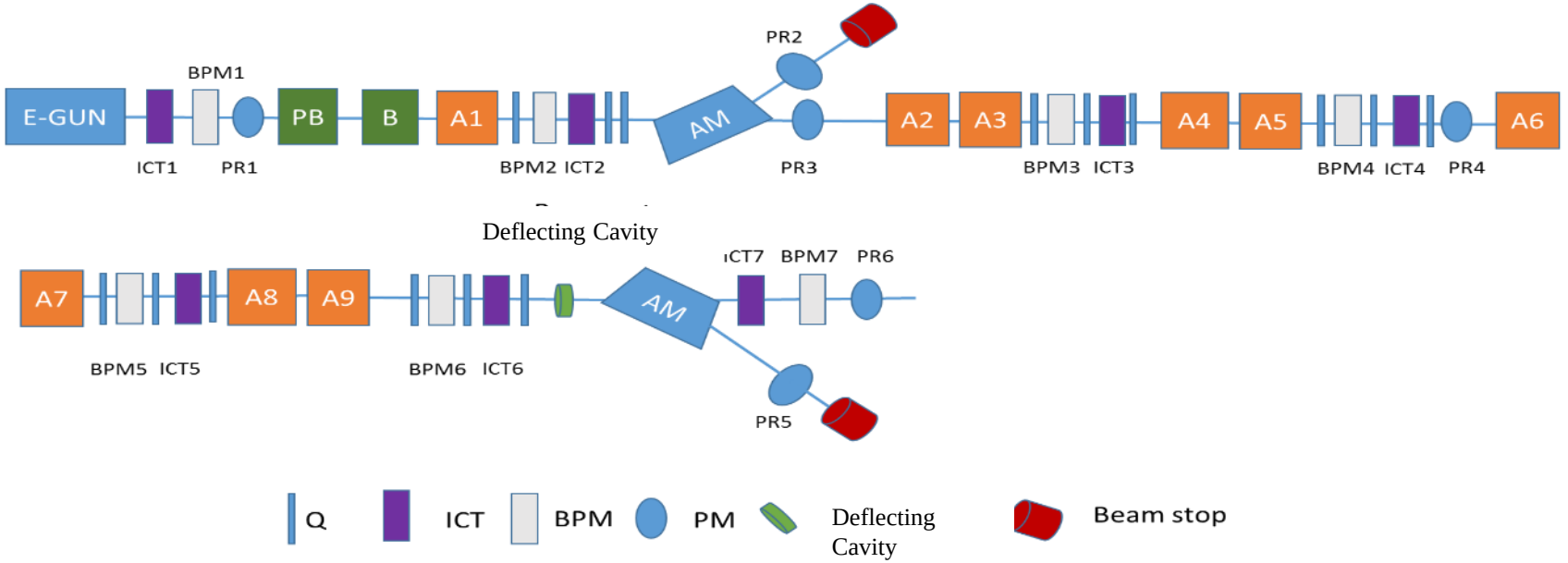




Other system of beam diagnostics

- Beam loss monitor
  - Bergoz's PIN-diode based counting modules
- Feed back system
  - There are 3 feedback systems for transverse and longitudinal directions
  - Bunch by bunch feedback
- Vacuum chamber monitor
  - MICRO-EPSILON capacitive displacement transducer

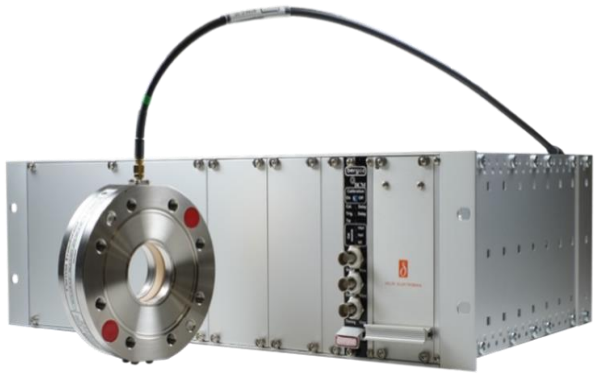
Linac beam instrumentation



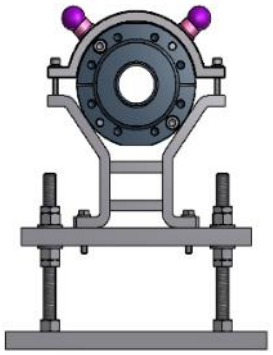
Monitor	NO.	Design Goal
EBPM	1+6	30um@2.5nC
ICT	7	1%@2.5nC
OTR/YAG	6	0.1mm
Slits	1	0.1mm@30mm

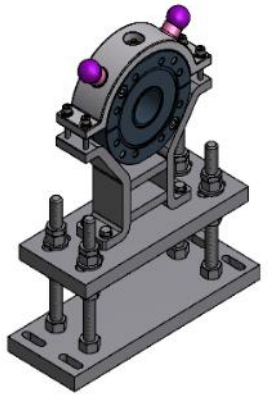
Beam current/charge monitor

- ICT (integrating current transformer), connected to integrate and hold electronics, is adopted to measure bunch charge during normal operation and the efficiency of linac.
- There are 7 ICTs located at gun exit , A1, A3, A5, A7, A9 exit and also the end of linac.



Connector	SMA
Flange	DN63CF
Sensitivity	2.5Vs/C (10:1)
Output Pulse length (6σ)	< 1us
Output Rise time	~30ns
Input Bunch length	>250ps
Droop	10%/us
Linearity error	10%

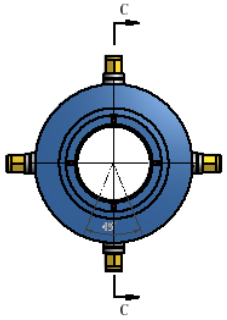


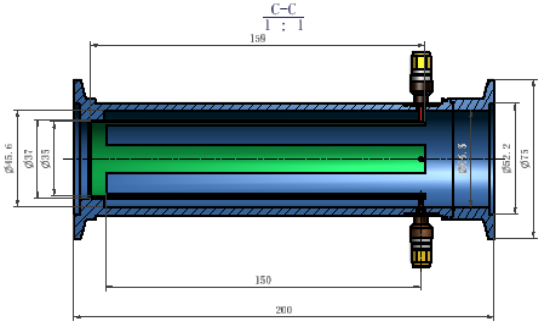


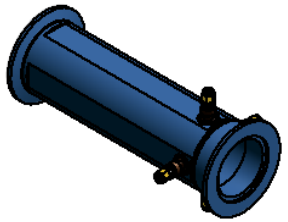
Beam position monitor

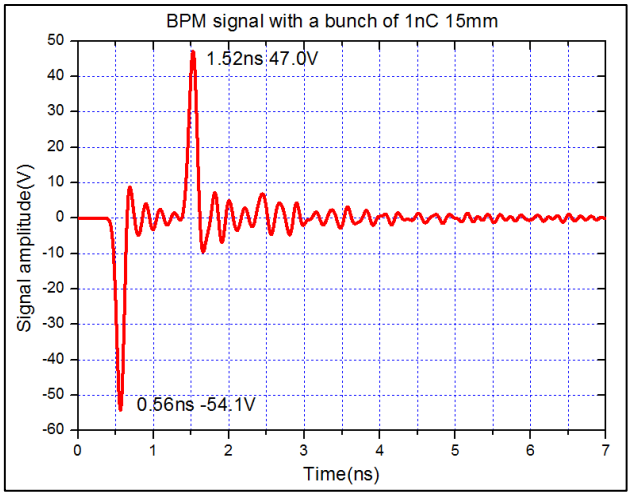
The specification of strip line BPM

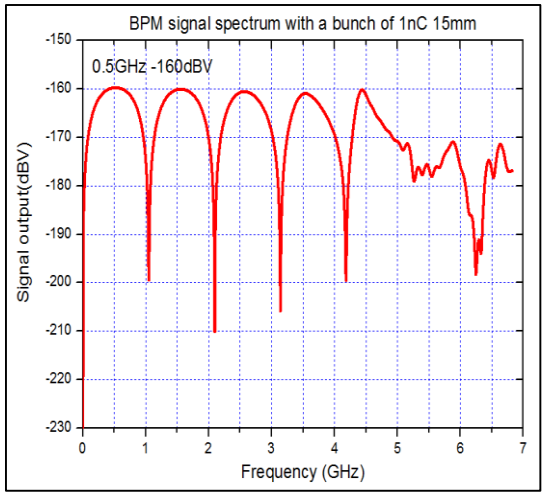
Total length	**200mm**
Duct outer diameter	**52mm**
Duct inner diameter	**45.6mm**
Stripline length	**150mm**
Stripline outer diameter	**37mm**
Stripline thickness	**1mm**
Stripline opening angle	**45 degrees**

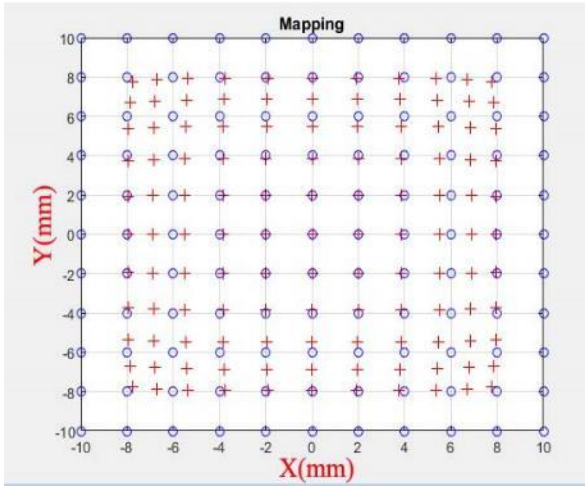




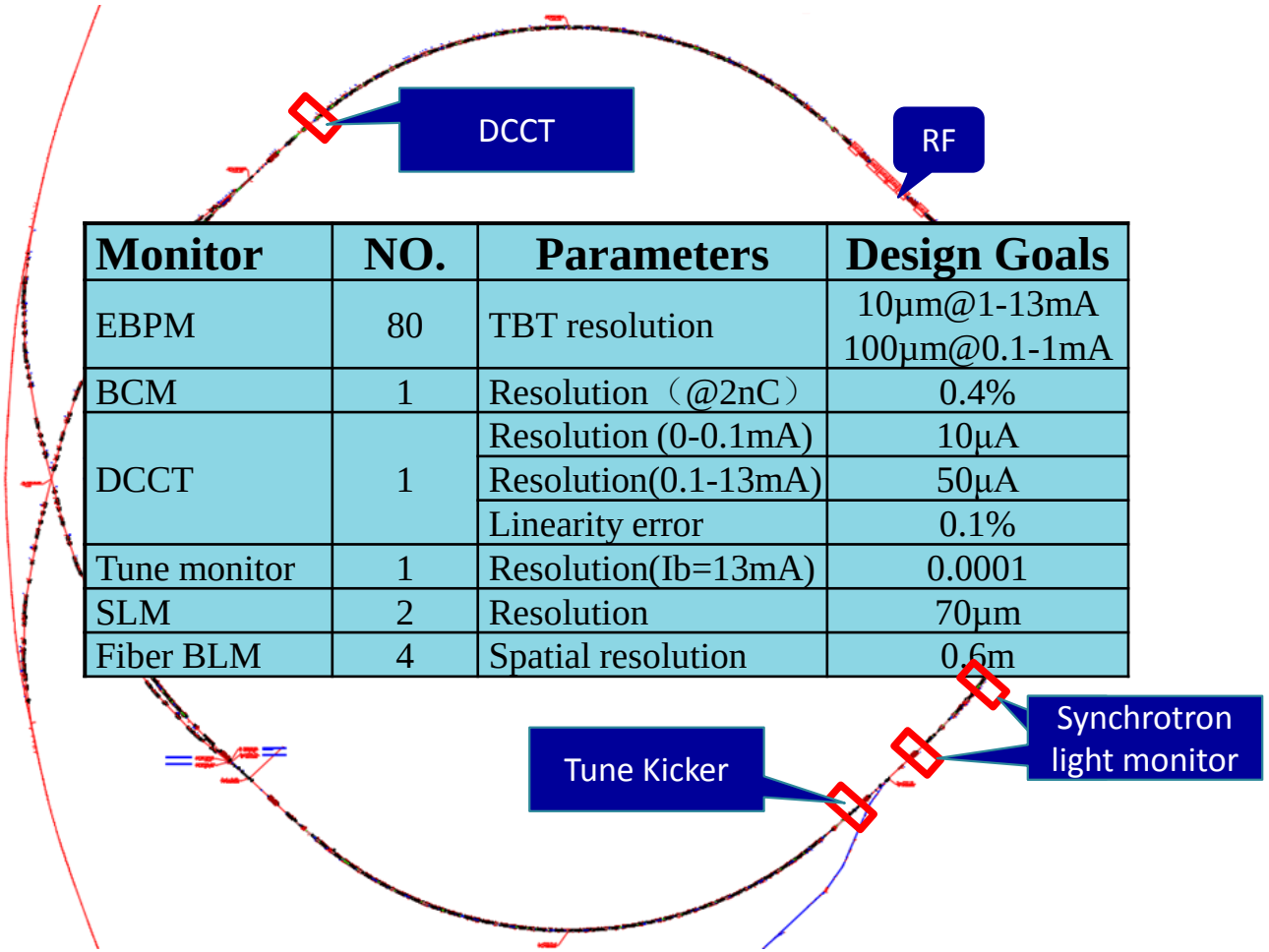








The layout of Booster beam instrumentation



Monitor	NO.	Parameters	Design Goals
EBPM	80	TBT resolution	10μm@1-13mA 100μm@0.1-1mA
BCM	1	Resolution（@2nC）	0.4%
DCCT	1	Resolution (0-0.1mA)	10μA
		Resolution(0.1-13mA)	50μA
		Linearity error	0.1%
Tune monitor	1	Resolution(Ib=13mA)	0.0001
SLM	2	Resolution	70μm
Fiber BLM	4	Spatial resolution	0.6m

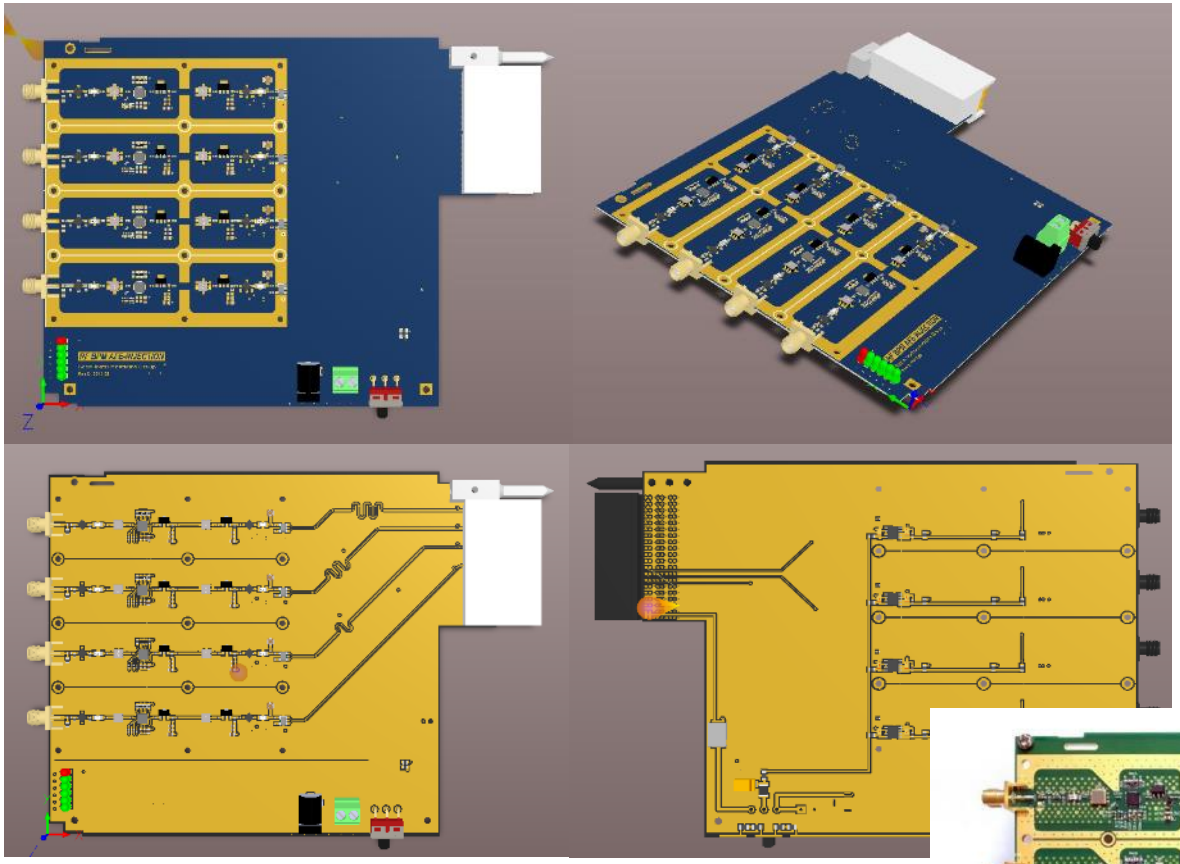
The efforts on beam diagnostics R&D

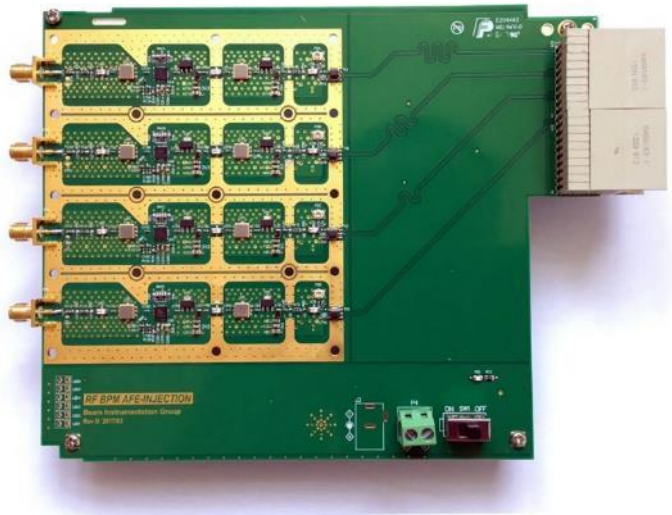
- The home-made BPM electronics
- The KB mirror for beam profile measurement

The home-made BPM electronics

- For the HEPS will have been built several years later, so we develop the DPBM prototype with BEPCII parameters, and DBPM system will tested in BEPCII.
- HW design
  - RTM Design
  - AMC Design
- FW design
- SW design
- Test of the DBPM

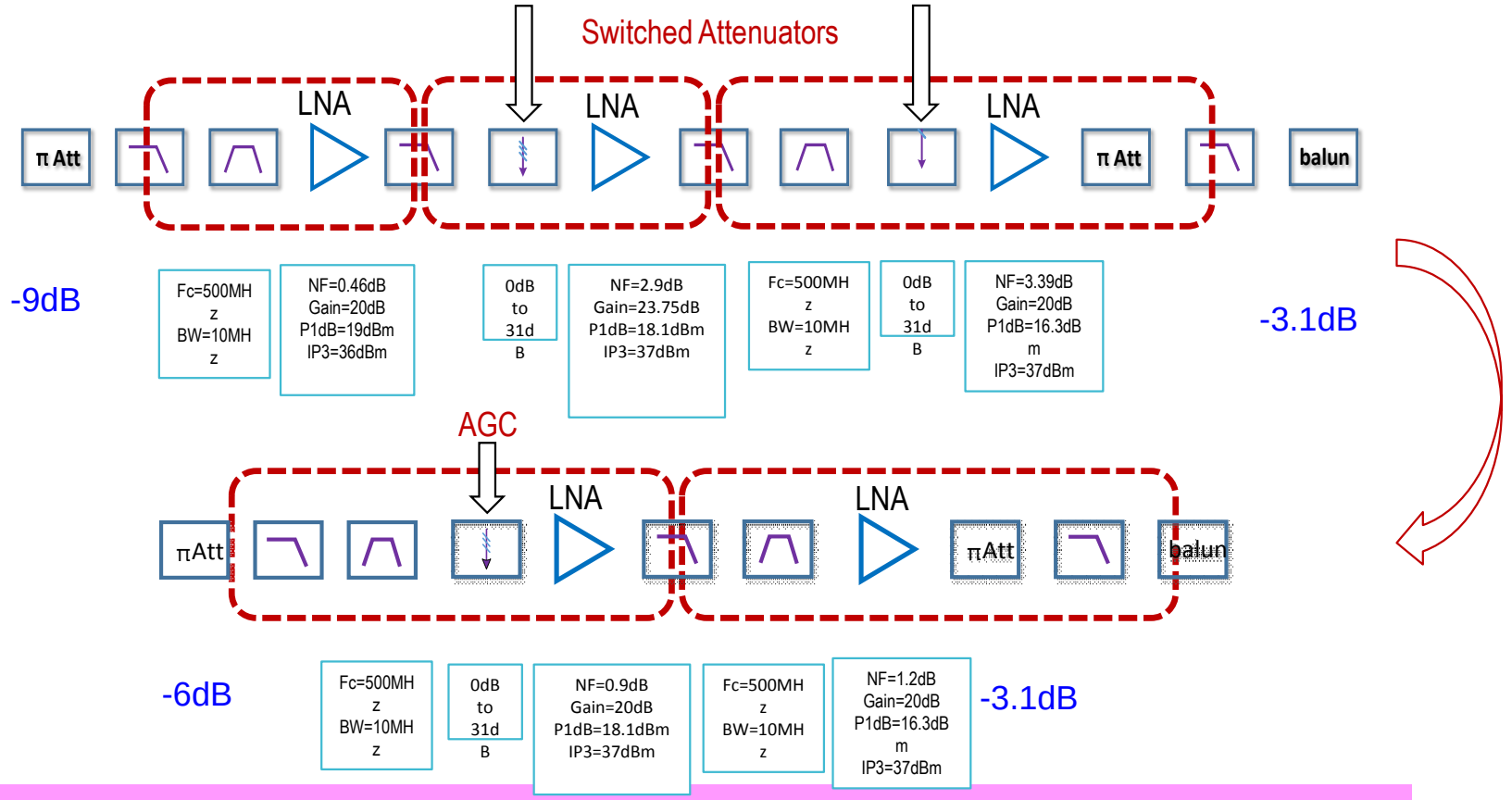
RTM Module design





- ✓ No cross-calibration
- ✓ Low Noise design
- ✓ Low power consumption

DBPM_RTM function block



1、Two LNAs are enough
2、The place of Attenuator is designed carefully
3、Attention to the Impedance matching & Noise

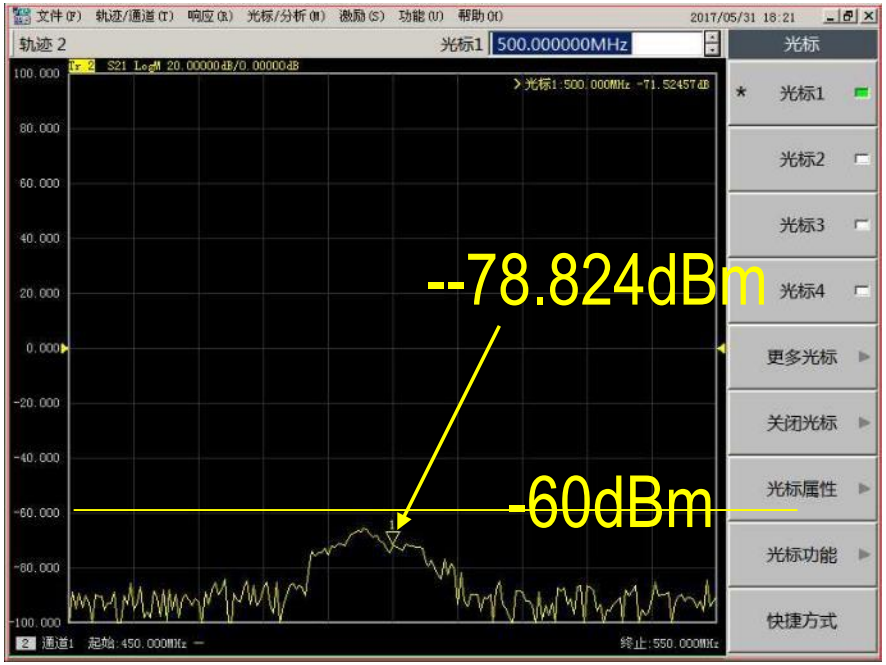
S-Parameter Characterization

Receiver S-Parameter Characterization

S21-Parameter Characterization

The performance of band pass filter is good!

Channel to Channel Isolation



A→B

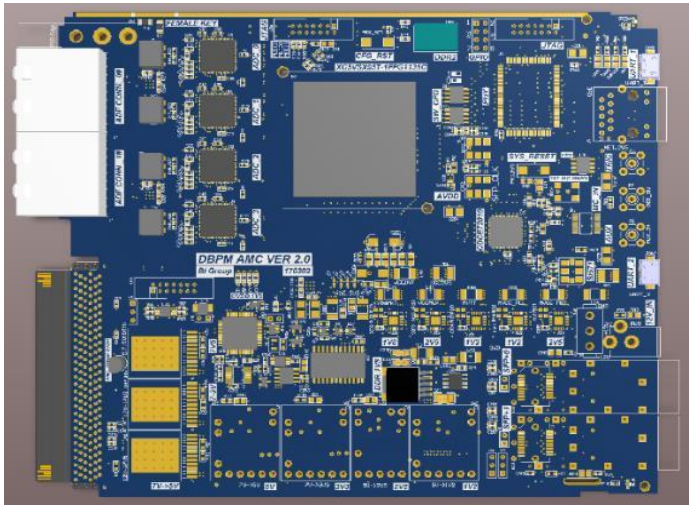
6.5dBm→-78.8dBm

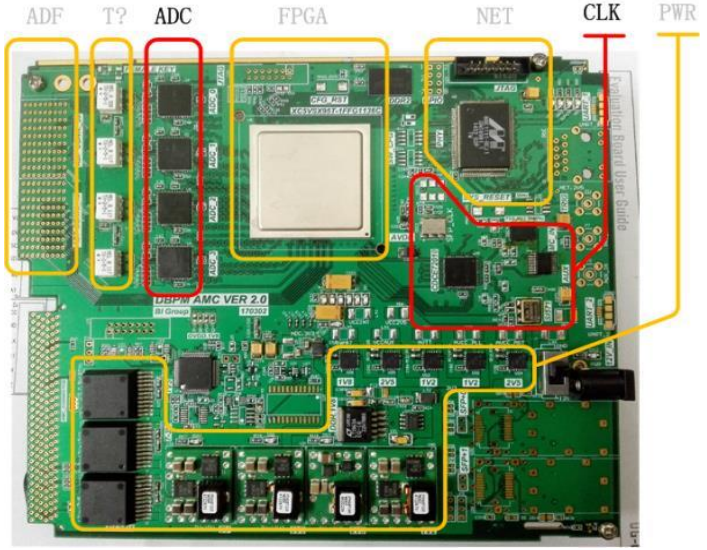
B→A

6.5dBm→-77.47dBm

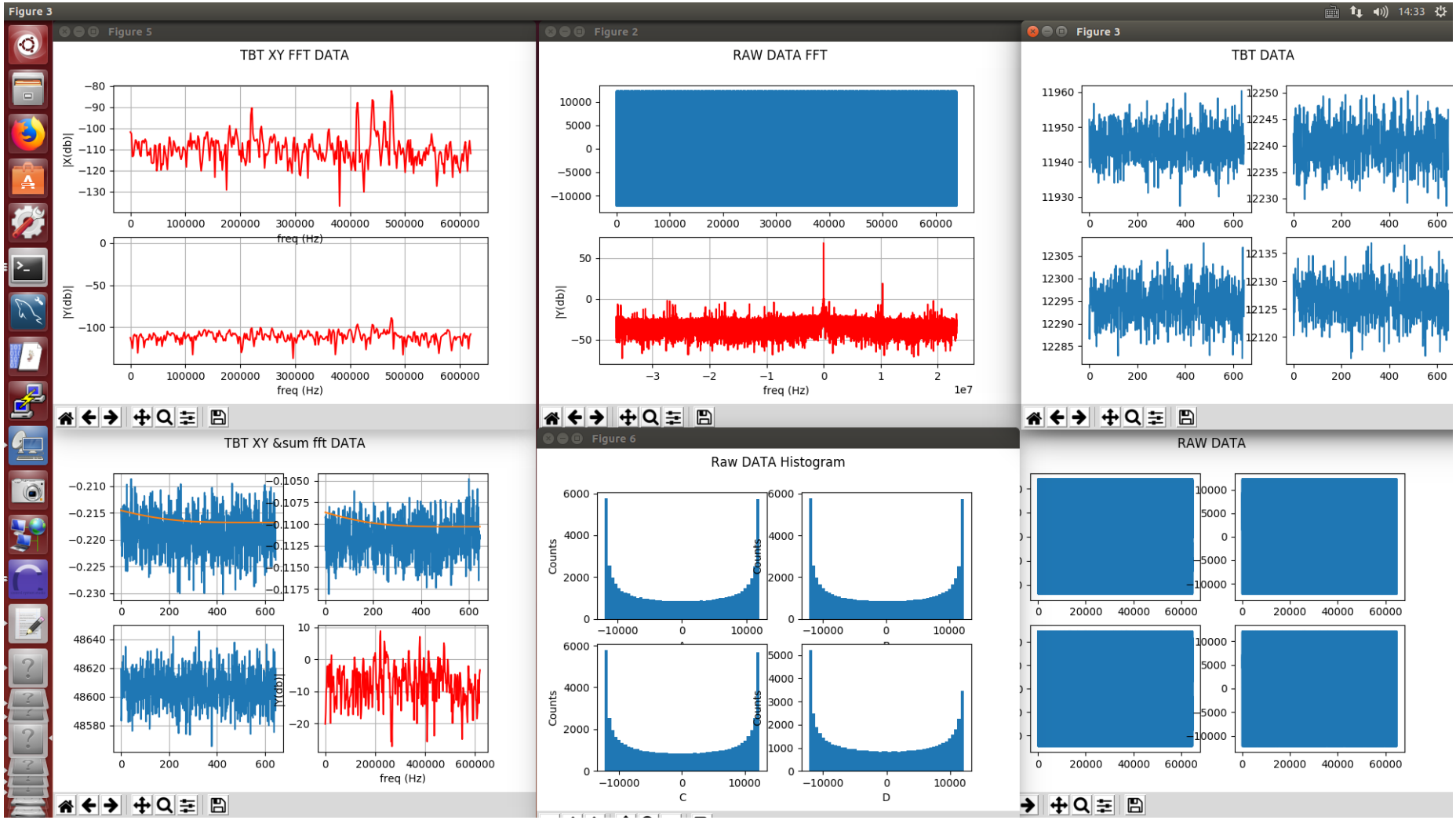
Function module

- Power Logic
- **Clock Logic**
- FPGA Logic
- **ADC Logic**
- NET Logic
- Other Logic…





RAW ADC data and analysis



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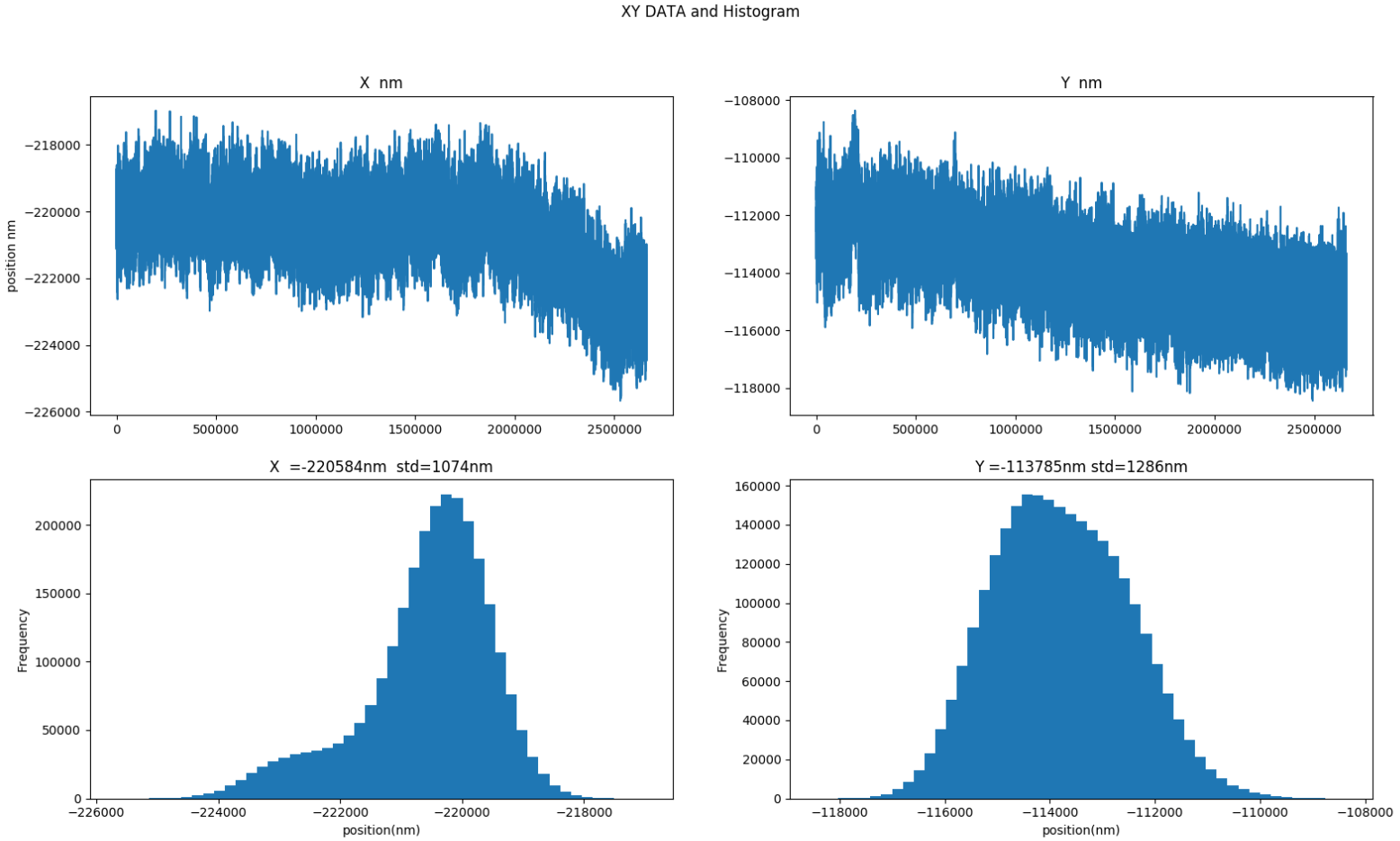
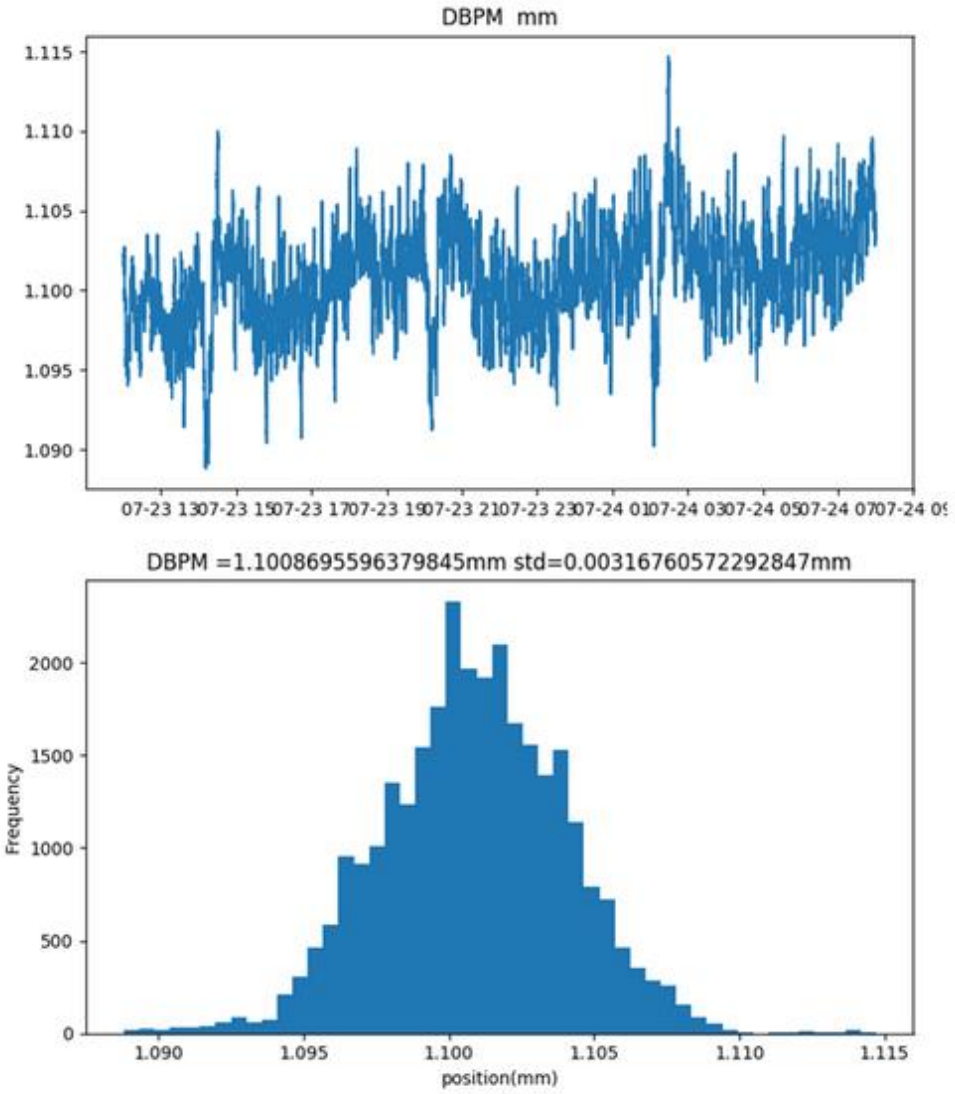


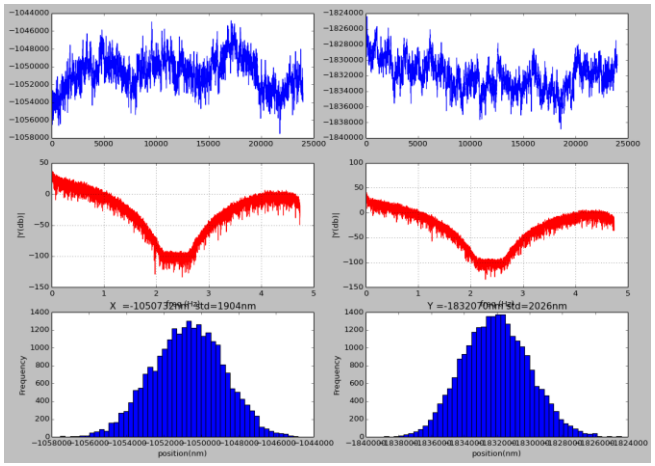
Beam test in BEPCII

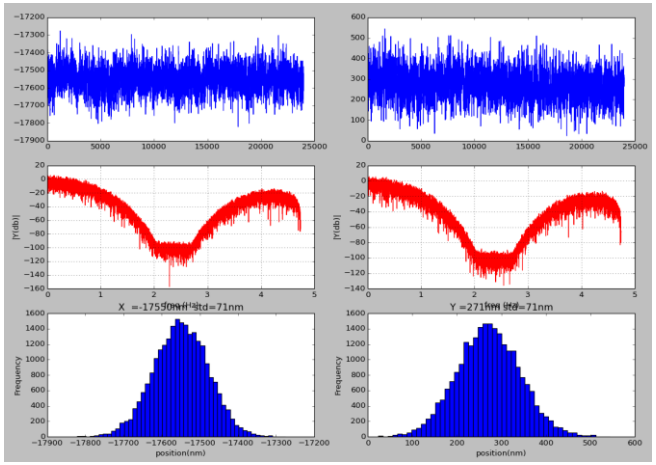


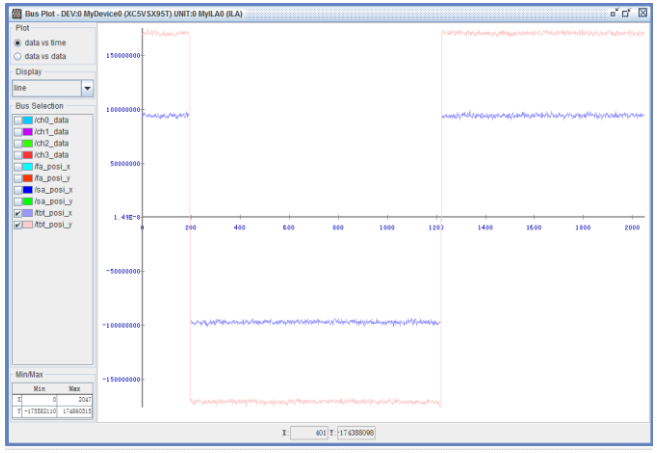
The beam position resolution results for the IHEP-developed DBPM (Image by IHEP)

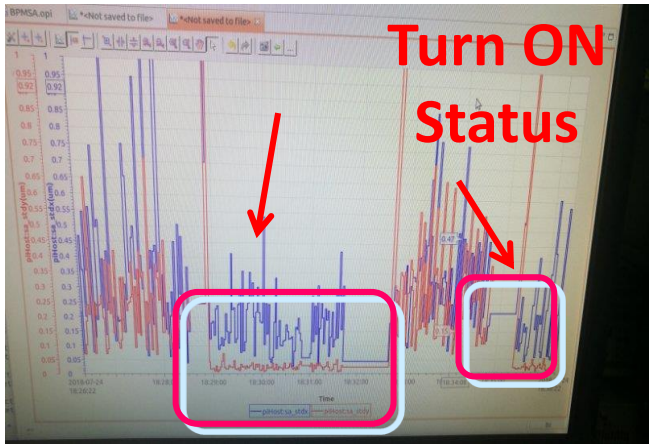
Temperature influence

- Thermostatic control Cabinet
- Cross-bar
- Pilot-Tone







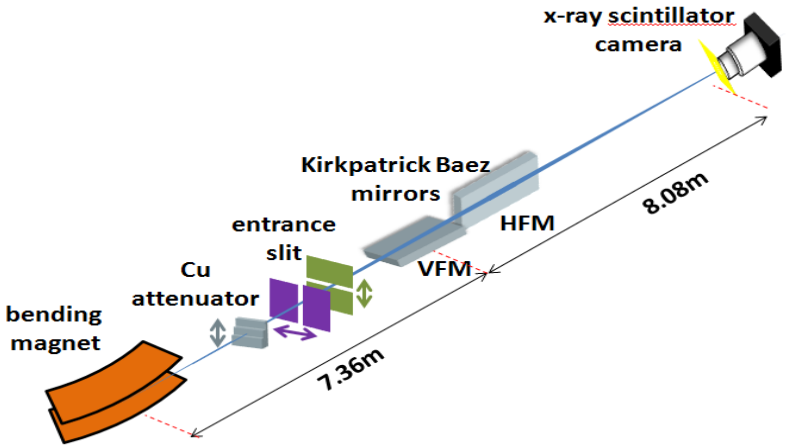


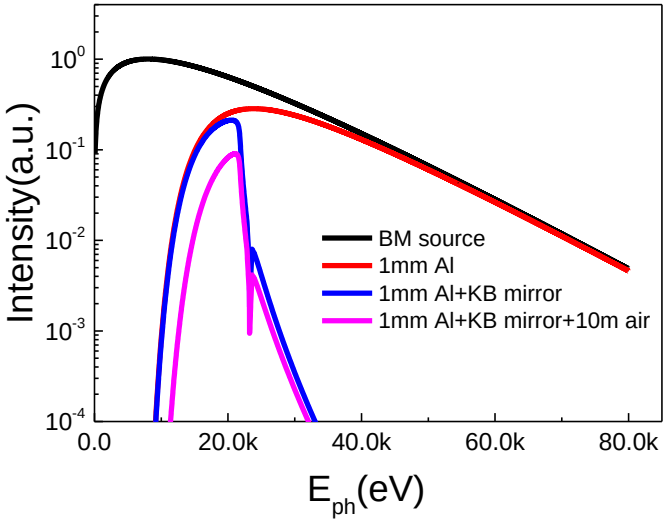
Motivation of KB mirrors R&D

- High energy photon source (HEPS) is expected to achieve 60 pm·rad ultralow-emittance with MBA (Multiple-Bend Achromat) lattices design
- Both horizontal and vertical beam sizes of HEPS storage ring are below ten microns. It's a challenge for measuring such small beam size in both directions.
- Kirkpatrick Baez (KB) mirror imaging system was evaluated to measure it

Kirkpatrick Baez mirror design

	VFM	HFM
shape	cylindrical	cylindrical
radius of curvature	2.57 km	2.57 km
grazing angle	3 mrad	3 mrad
substrate	silicon	silicon
coating	Rh	Rh
acceptance angle	122 μrad	117 μrad
size L ×W× H	320 mm×40 mm×40 mm	320 mm×40 mm×40 mm
clear aperture L×W	300 mm×10 mm	300 mm×10 mm
RMS roughness	<0.2 nm	<0.2 nm
RMS slope error	<0.3 μrad	<0.3 μrad
distance to source	7.36 m	7.72 m
distance to image	8.08 m	7.72 m
magnification	1.1	1
heat load	hitting 1.083W absorbed 0.832W	hitting 0.251W absorbed 0.058W

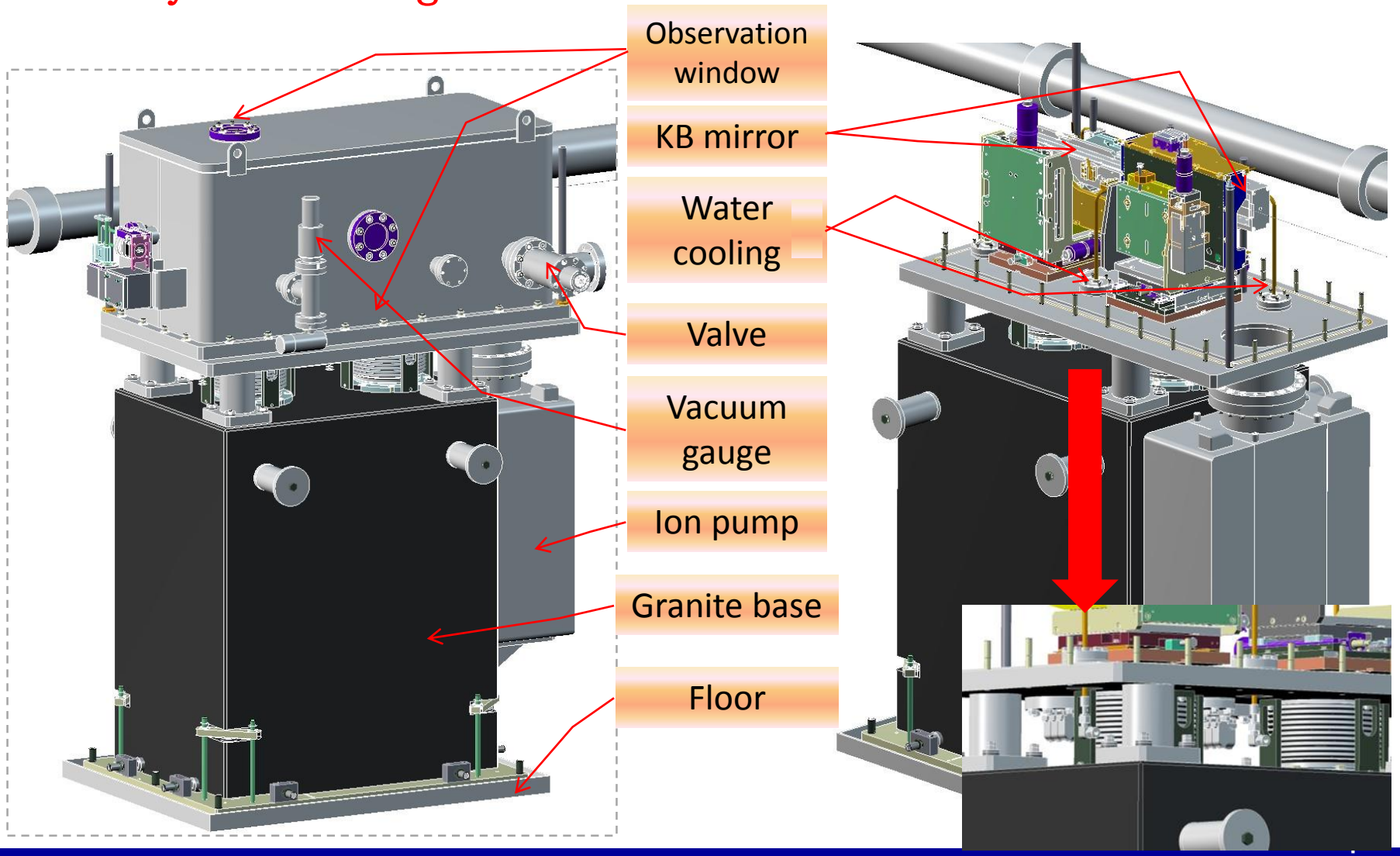




(Color) Spectrum of the synchrotron radiation from bending magnet source, and filtered by Al window, KB mirror, and 10m air

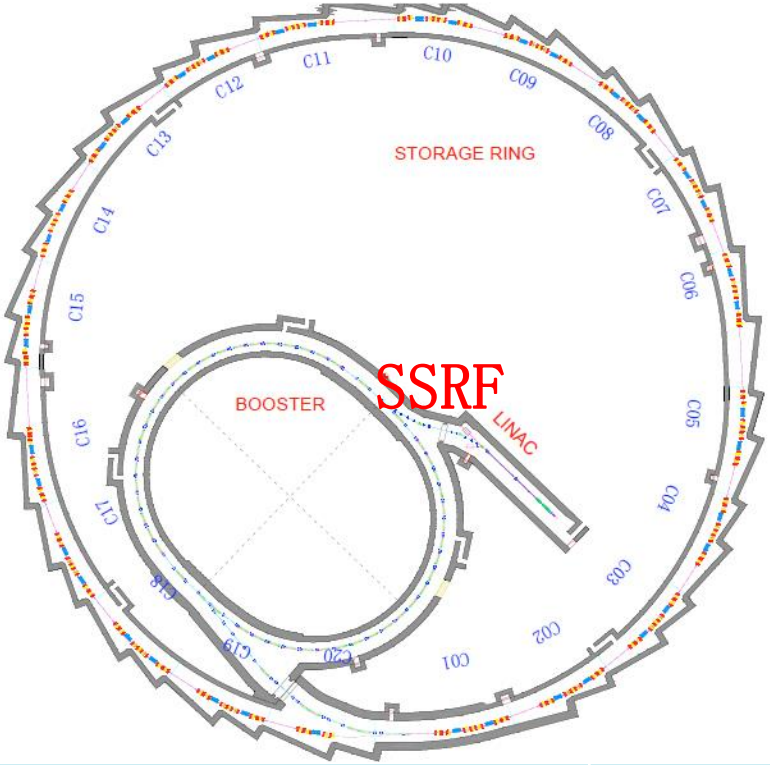
Kirkpatrick Baez mirror

System design and manufacture



Kirkpatrick Baez mirror

Installation site

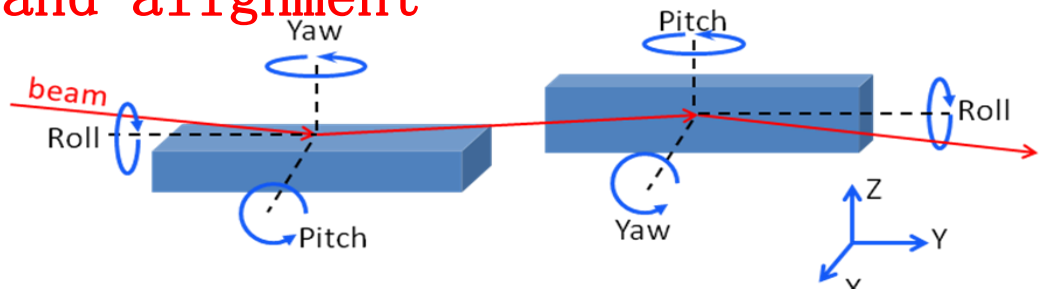


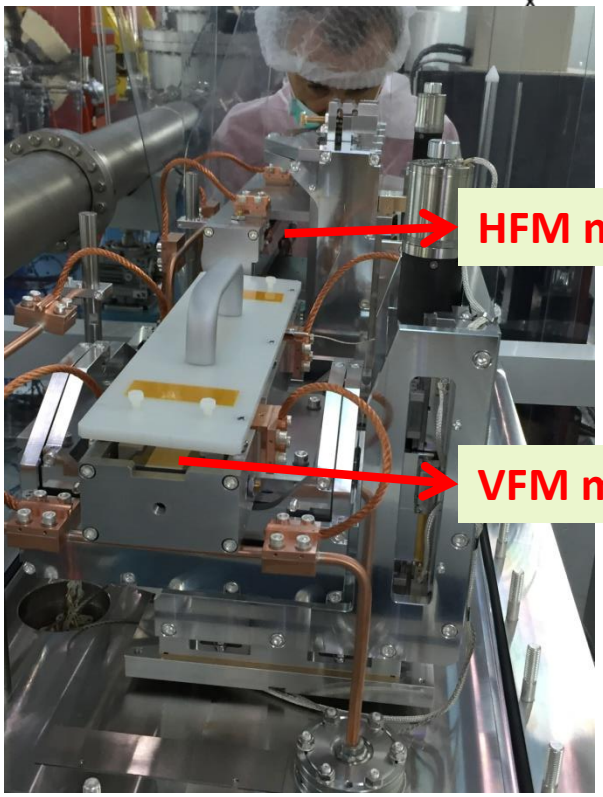
Parameters	Value
Beam energy (GeV)	3.5
Beam current (mA)	200-300
Circumference (m)	432
RF frequency (MHz)	499.654
Natural emittance (nm·rad)	3.9
Magnetic field of dipole (T)	1.2726
Critical photon energy (keV)	10.4
Horizontal RMS beam size (μm)	78
Vertical RMS beam size(μm)	20

Kirkpatrick Baez mirror

KB mirror installation and alignment

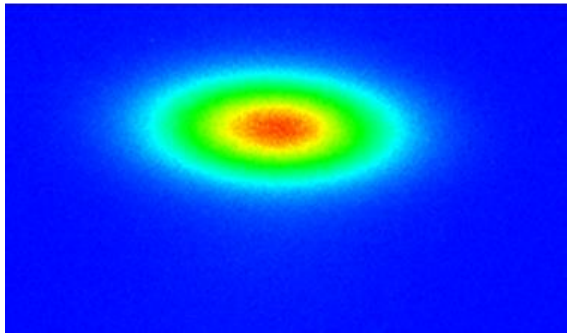
Alignment and fix the ROLL and Yaw of the two mirrors



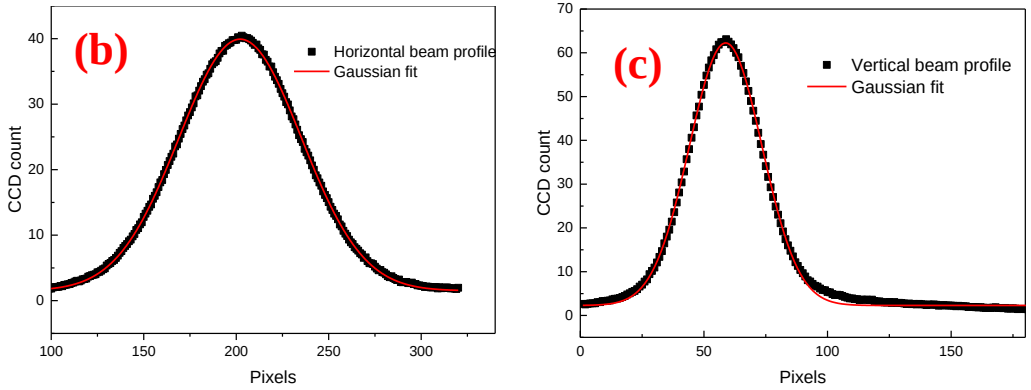


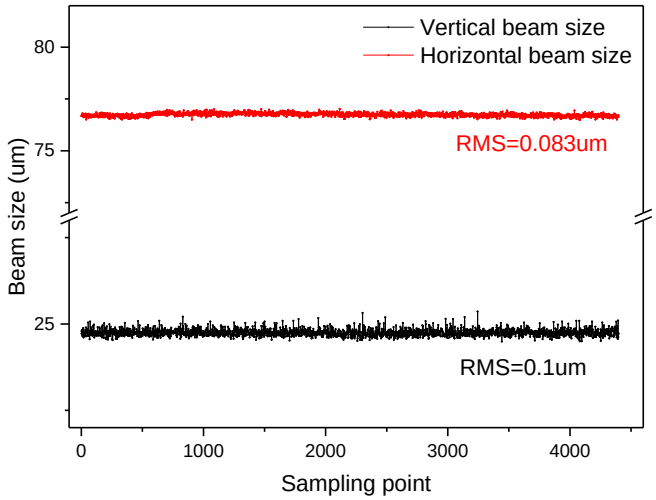
Kirkpatrick Baez mirror

Beam test result



Much thanks to SSRF for the KB mirror beam test !



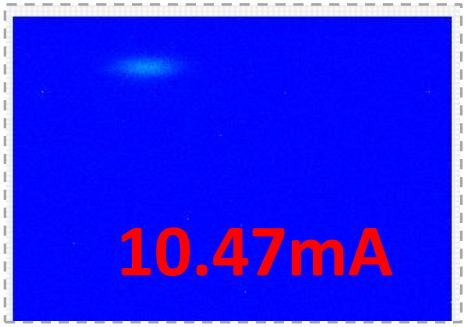


2017-6-7, finshed KB mirror system commissioning,
Get σ_x=74.7 um, σ_y=25.1 um

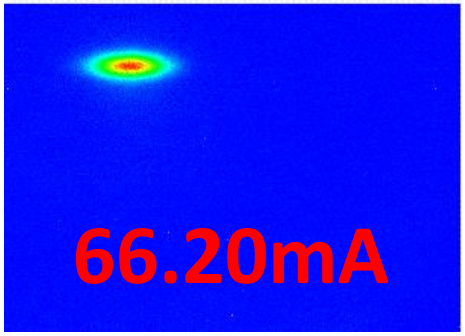
Beam size long-tem measurement data

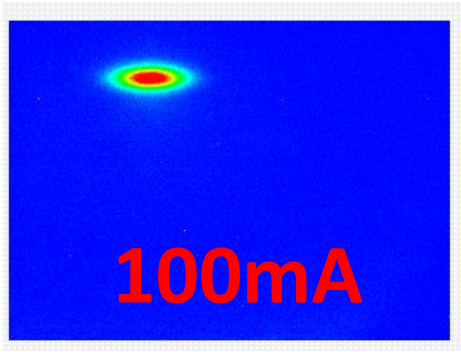
Kirkpatrick Baez mirror

The result of different beam current

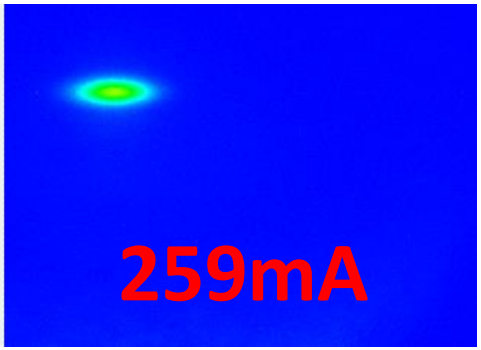


Spot is clearly visible





Spot center saturation



After attenuation

Summary

- The preliminary design of beam diagnostics is finished.
- The prototypes of BPM electronics KB mirror are in hand during HEPS-TF.
- The key technologies are developed will be helpful in construction of HEPS.
- There are still a lot of work to do towards the detail design of beam diagnostics.

Thanks for your attention