IBIC 2021
International Beam Instrumentation Conference

上海同步辐射光源
Shanghai Synchrotron Radiation Facility

BPM system development & applications in commission of SXFEL-SBP

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SSRF BI Group

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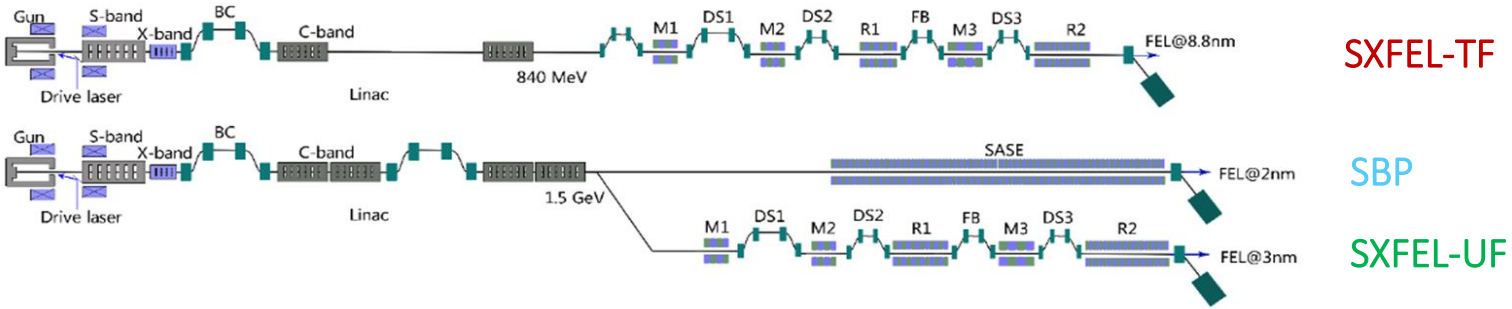
SXFEL introduction

SXFEL


SSRF
SXFEL
532m，1 LINAC，2 undulator beamline，5 experimental stations
1.5 GeV LINAC (S+C+X band)
Water window soft X-ray

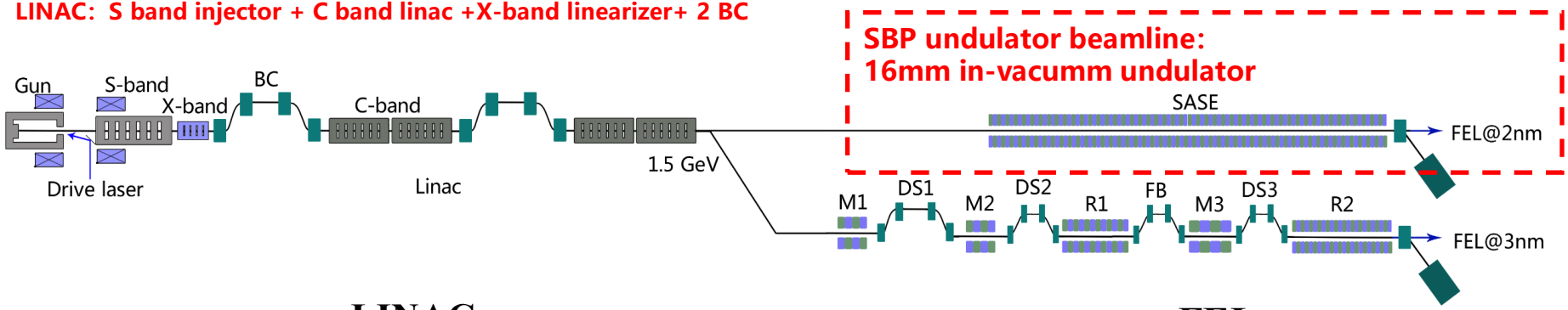
Shanghai soft X-ray Facility （SXFEL)

- SXFEL consists of:
  - SXFEL-TF
  - SXFEL-UF
  - Shanghai-XFEL Beamline Project （SBP）
- SXFEL-TF (0.8Gev) began construction from 2014, completed commissioning and national acceptance in 2020
- SXFEL-UF & SBP (1.5Gev) received funding in 2016 and then started construction



SXFEL layout & Main technical target of SBP

LINAC: S band injector + C band linac +X-band linearizer+ 2 BC



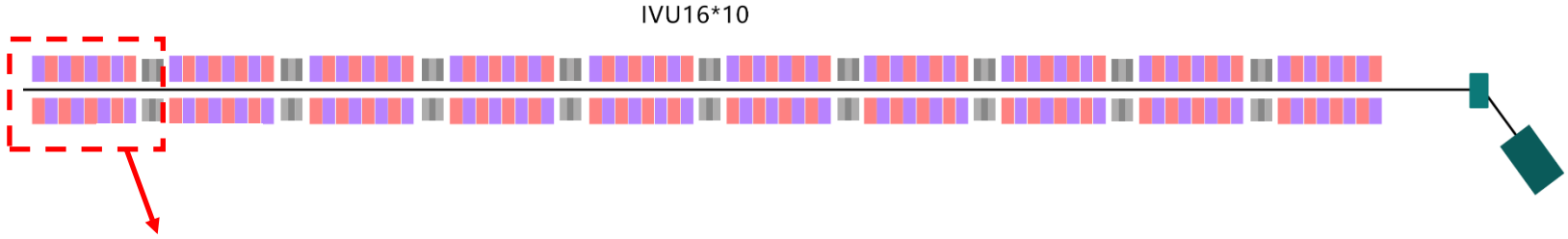
LINAC

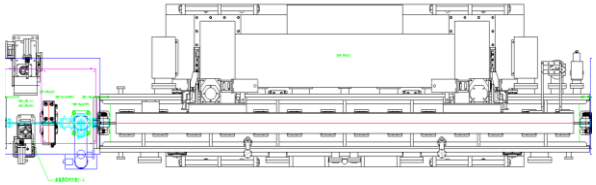
	Target	Actual value
Beam charge (nC)	0.5	0.6
Beam energy (GeV)	1.5	1.357
Emittance (mm.mrad, rms)	≤ 1.5	1.5
Peak current(A)	≥ 700	1000

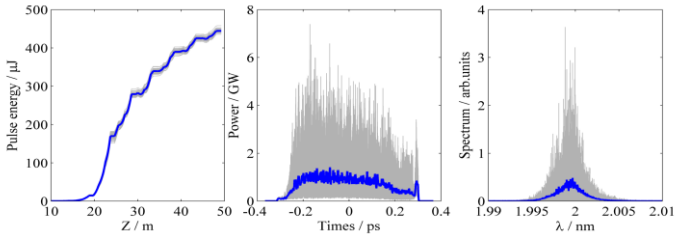
FEL

	Target	Actual value
Wavelength (nm)	2.0	1.98
Length (ps)	~ 0.4	< 0.3
Power (MW)	≥ 100	≥ 400

Layout of SBP undulator beamline



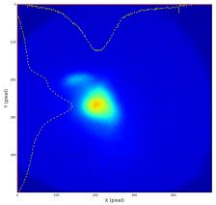




Main parameters	
FEL wavelength	~2 nm
FEL peak power	≥100MW
FEL pulse length	~400 fs (FWHM)
FEL pulse energy stability	~10% (rms)
FEL transverse position stability	~10% (rms)

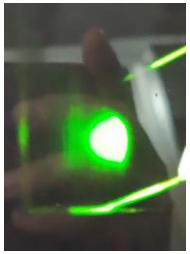
- 10 in-vacumm undulator IVU16, SASE, aim to 2nm wavelength radiation;
- High-accuracy BBA system, cavity BPM, phase shifter, Correction magnet, Quadrupole magnet…

SBP SASE commission time line



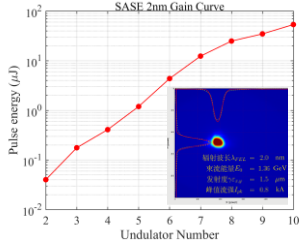
Beam energy 890 Mev
SASE 5.6 nm

24th April



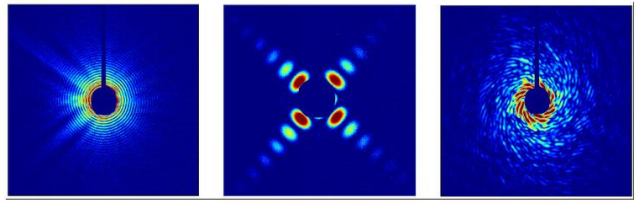
First light to
experimental station

9th May



Beam energy: 1357 Mev
SASE 2.4 nm first light
SASE 2.0 nm first light

13-14th May

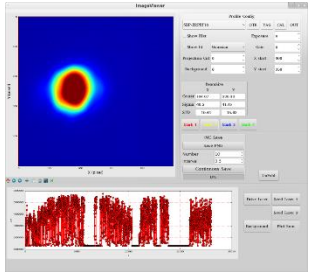


First single-shot CDI experiment
@2.4nm wavelength

24th June

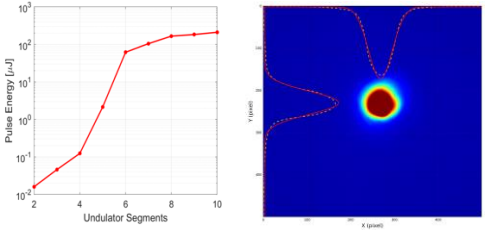
29th April

First light to beamline



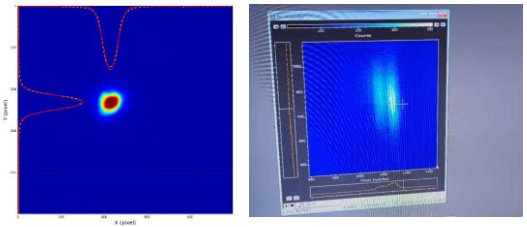
11th May

Beam energy 1130 Mev
SASE 3.5 nm first light
SASE 3.5 nm saturation



19th May

SASE 2.0 nm saturation
Spectrum measured



Motivation of BPM development

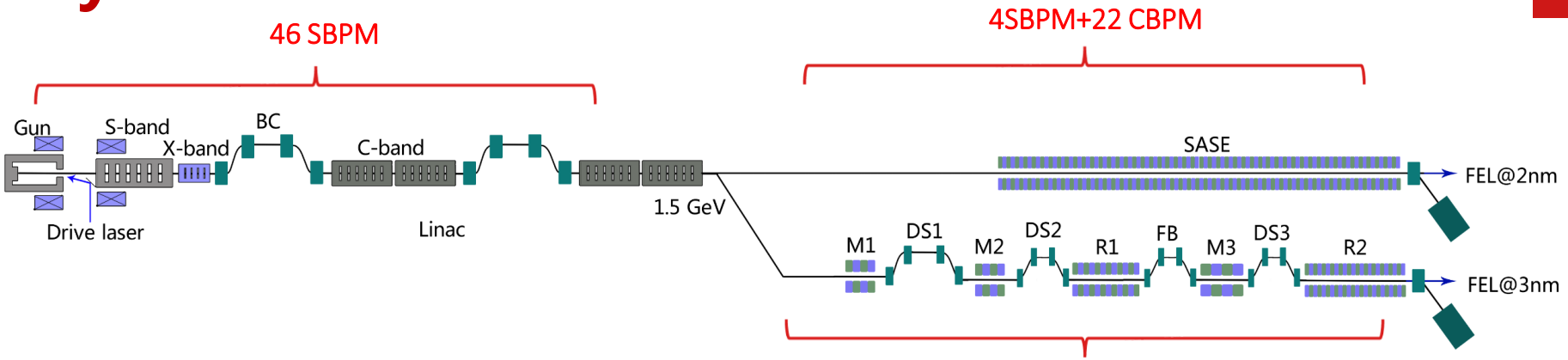
- **From physics requirements：**
  - **LINAC:** High-precision position measurement to ensure the stability of beam orbit, Resolution requirement: 10μm@500pC;
  - **Undulator:** High-precision position measurement to ensure that the electron beam and the seed laser are strictly coincident in three dimensions. Resolution requirement: 1μm@500pC.

- **For accelerator operator:**
  - The basis of the feedback system;
  - To ensure the stability of FEL output power;
  - Non-interceptive measurement
  - Relative measurement of bunch charge

- **For user:**
  - Stable X-ray

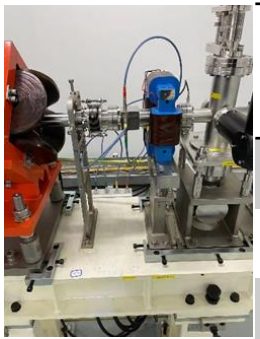
BPM system development

Layout of BPMs for SXFEL



Stripline BPM

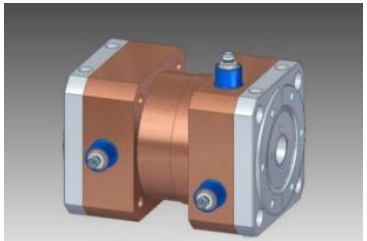
Resolution requirement: 10μm @ 500pC



Beam pipe Diameter (mm)	Length (mm)	Angle (°)	Quantity
25	150	30	27
35	150	20	16
16	150	20	7

Cavity BPM

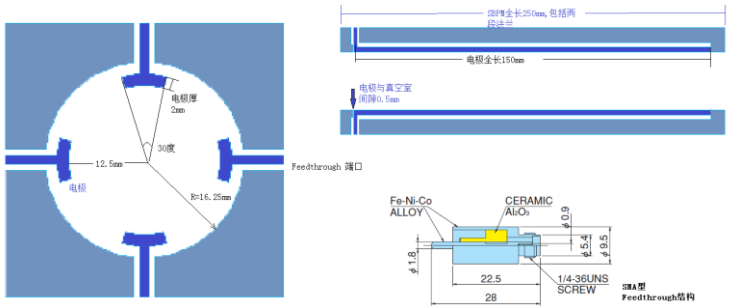
Resolution requirement: 1μm @ 500pC

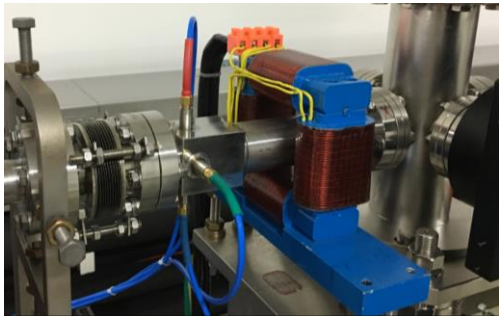


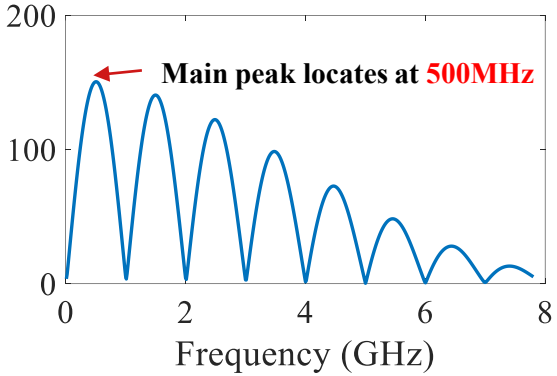
Cavity	Frequency	Q Value
Reference	4693± 3MHz	2250 ±10%
Horizontal	4681 ±3MHz	4500 ±10%
Vertical	4688±3MHz	4500 ±10%

BPM system 1: Stripline BPM introduction

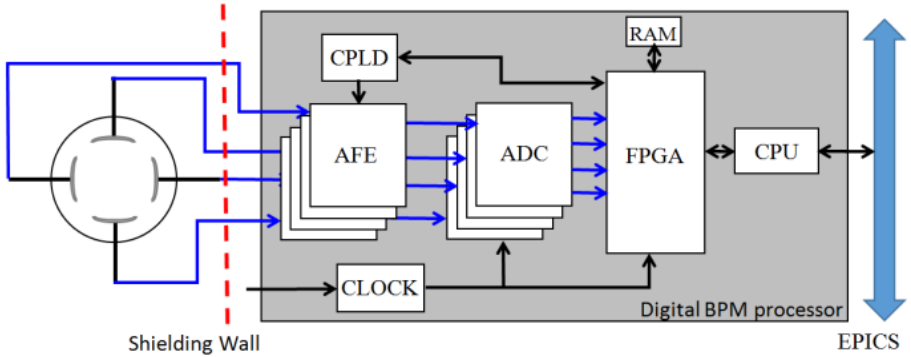
Stripline BPM pickup







System structure diagram

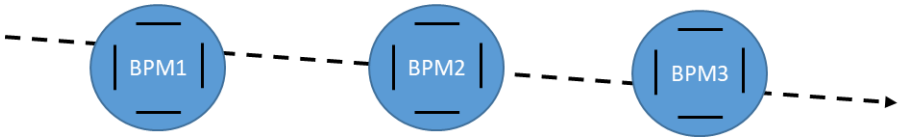


Homemade Digital BPM processor

Parameters	value
Channels	4
Central Frequency	500MHz
Bandwidth	~20MHz
Dynamic range	31dB
ADC bits	16
Max ADC rate	125MSPS
FPGA	Xilinx xc5vsx50t
Clock	Ext./Int.
Trigger	Ext./Self/Period
Software	Arm-Linux/EPICS

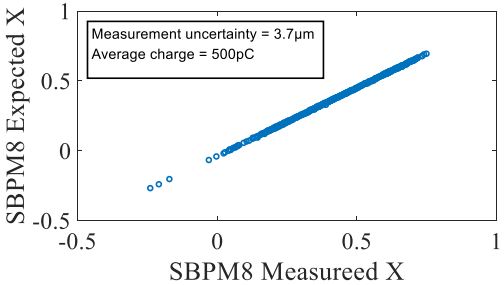
BPM system 2: SBPM performance evaluation

"Three BPM" method

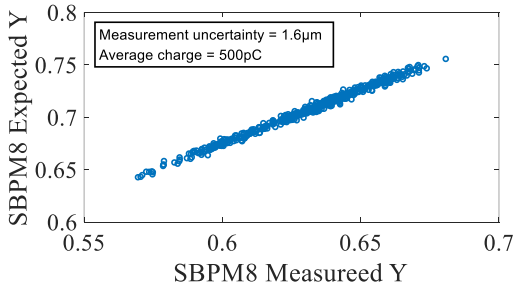


$$POS2_{pre} = (POS1_m + POS3_m) / 2;$$
$$Resolution = std(POS2_m - POS2_{pre})/\sqrt{2}$$

Horizontal: 3.7μm@500pC

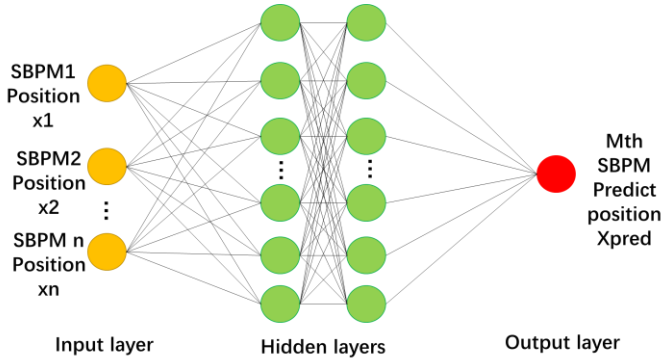


Vertical: 1.6μm@500pC

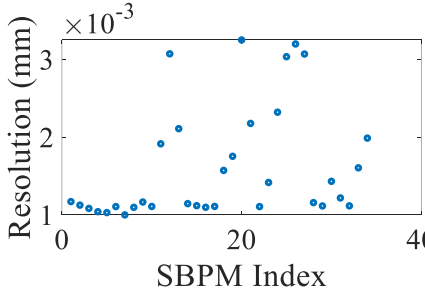


"Neural network" method

Used for global evaluation



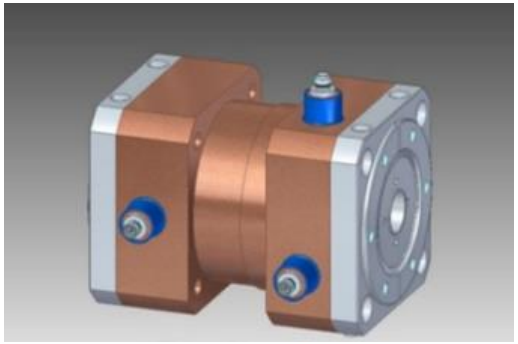
$$\sigma_{res} = \sqrt{\frac{1}{p}\left(\sum_{i=1}^{p}\left(x_i - x_{pred,i}\right)^2\right)}$$

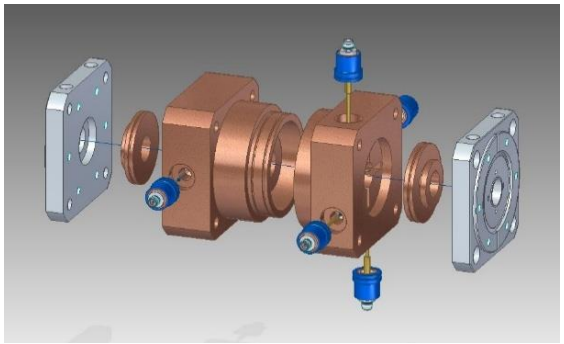


A new method based on neural network has been employed to evaluate all SBPMs at SXFEL-UF;

(MOPAB281, IPAC2021)

BPM system 2: CBPM introduction





Cavity	Frequency	Q Value
Reference	4693± 3MHz	2250 ±10%
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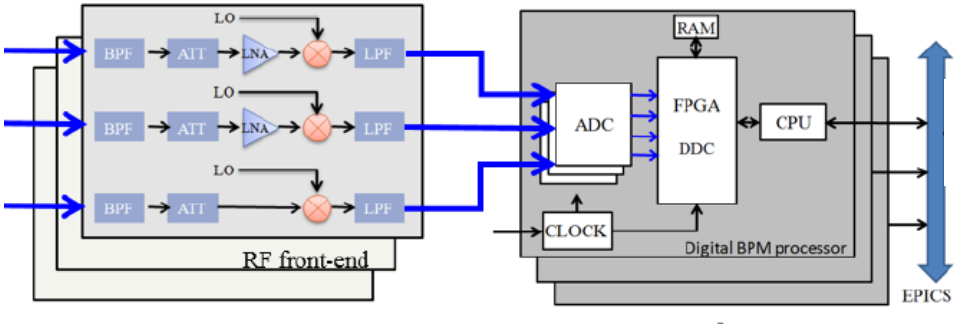
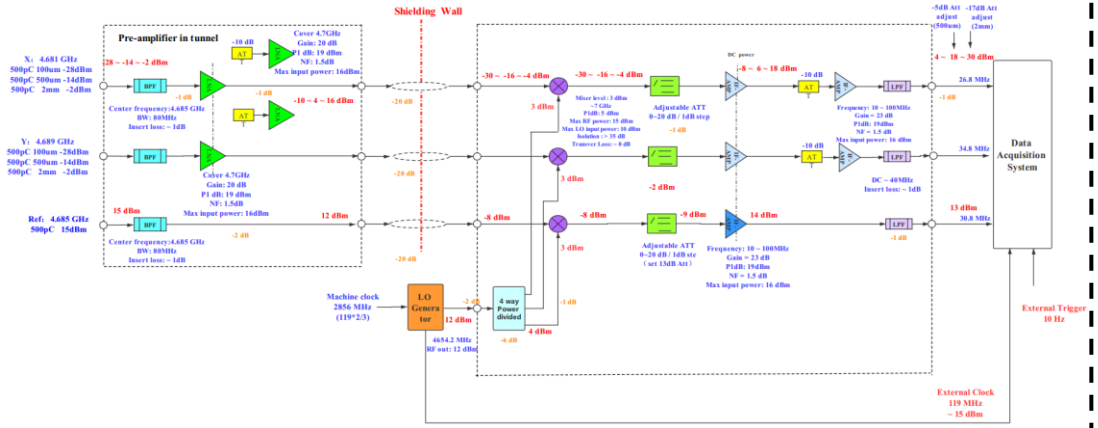


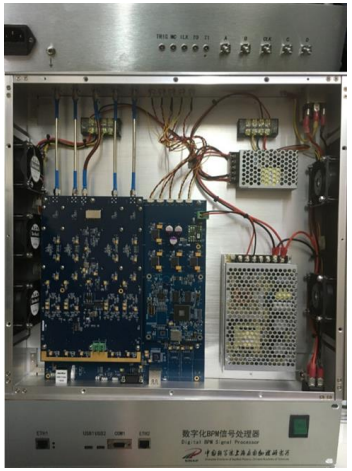
- **High Precision Beam Position Measurements**
  Resolution: 1 nm @500pC
- **Relative measurement of bunch charge**
  Resolution 0.1%
- **System measurement linear range**
  ≥±2mm@500pC

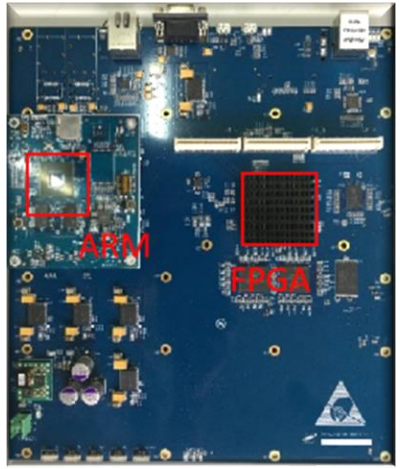
BPM system 2: CBPM RFFE + electronics

RFFE



Homemade DBPM

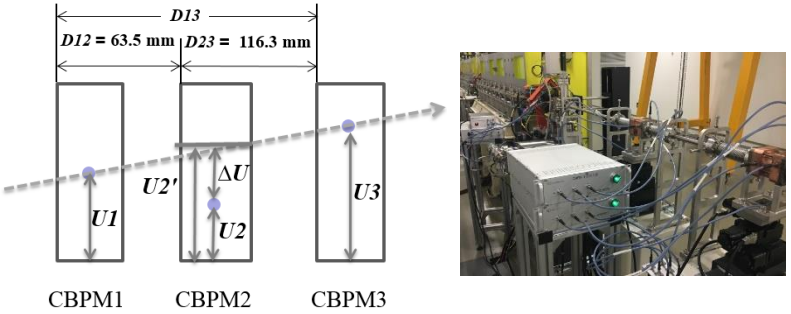




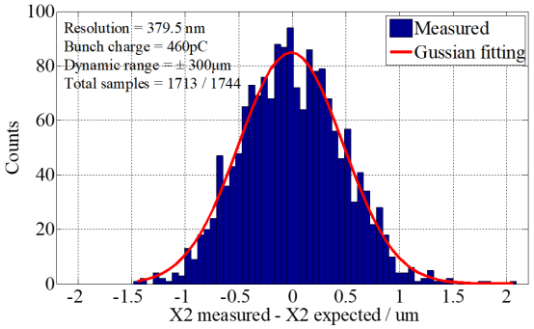
Parameters	value
Channels	4
Bandwidth	~600MHz
ADC bits	16
Max ADC rate	125MSPS
FPGA	Xilinx xc5vsx50t
Clock	Ext./Int.
Trigger	Ext./Self/Period
Software	Arm-Linux/EPICS

BPM system 2: CBPM performance evaluation

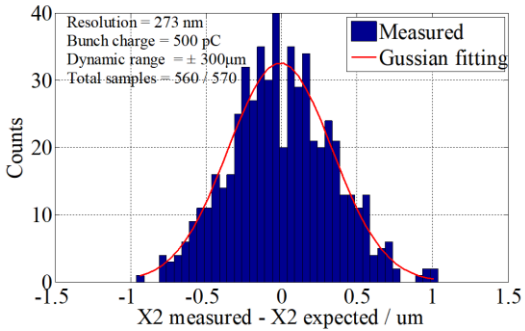
"Three BPM" method



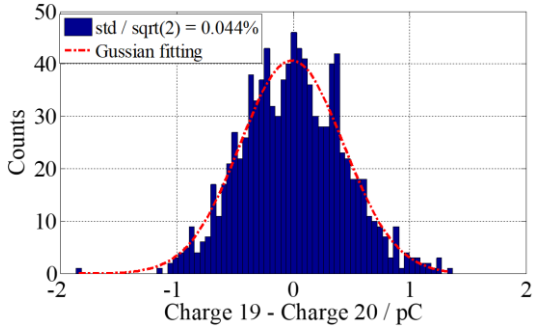
Horizontal: 379.5 nm



Vertical: 273 nm



- BPM2 Expt.: $U_2^{'} = \dfrac{D_{12} \cdot U_3 + D_{23} \cdot U_1}{D_{13}}$
- Residual: $\delta_{CBPM} = GF \cdot std_{\Delta d}$
- GF: $GF = \dfrac{1}{\sqrt{(\frac{D_{23}}{D_{13}})^2 + (\frac{D_{12}}{D_{13}})^2 + 1}}$

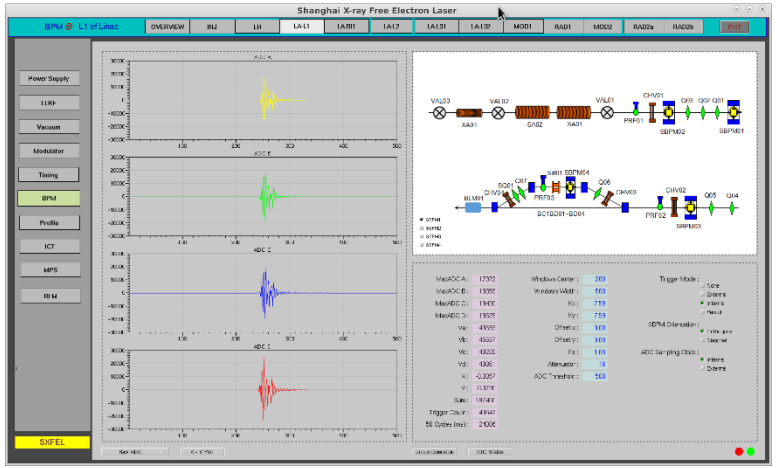


Beam position measurement:

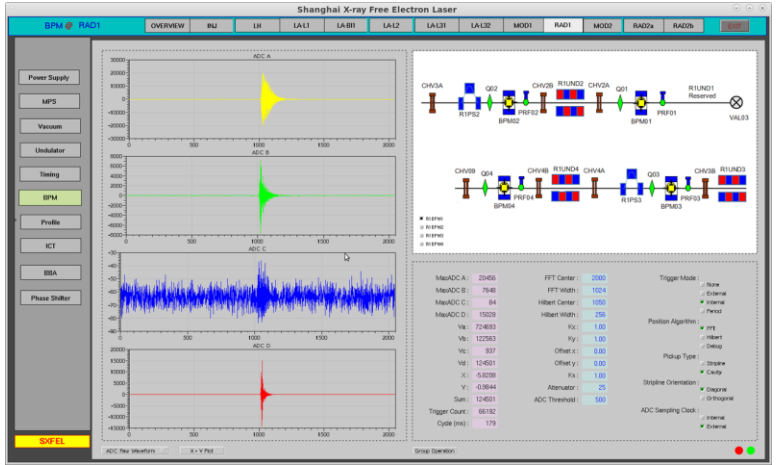
- Horizontal: 379.5nm @500pC ± 300μm
- Vertical: 273 nm @500pC ± 300μm

BPM system OPI

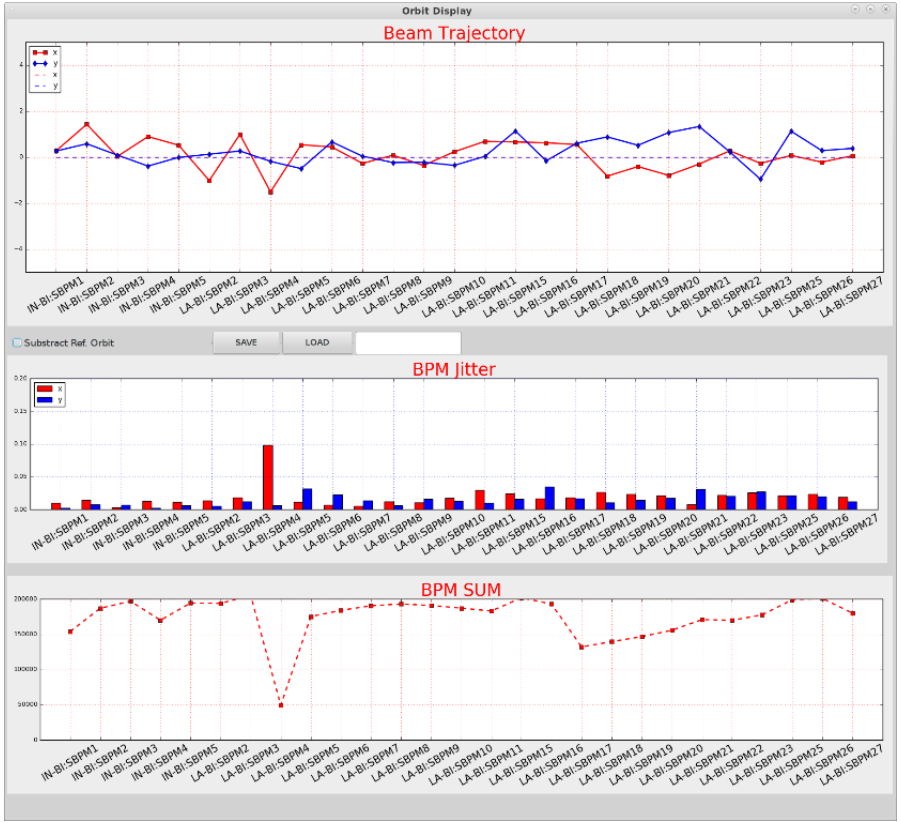
SBPM



CBPM



Orbit display used for commission



Applications in SXFEL commission

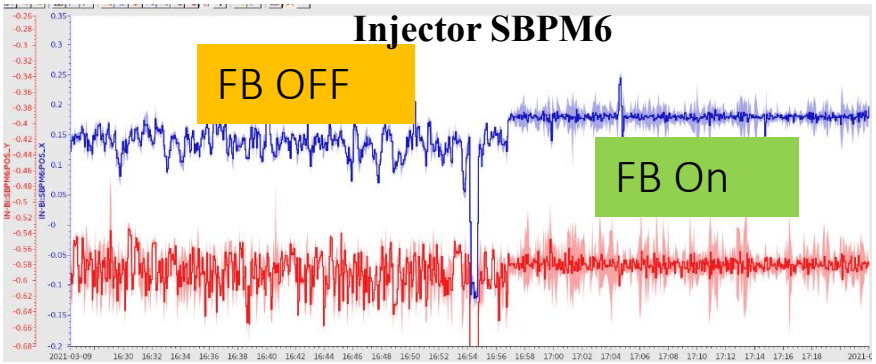
By Gu,Duan

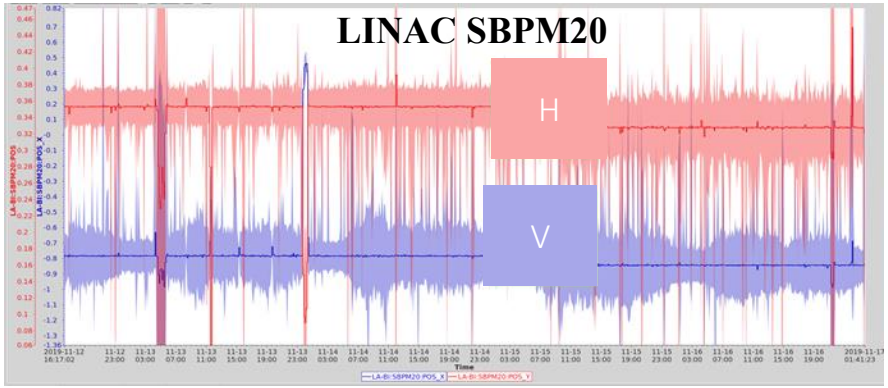
Applications in commission： Orbit feedback system

BPM is the basic measurement element of the orbit feedback system

Purpose:

- **Transport the electron beam** from the gun to the main beam dump
- Restore reference trajectory
- **Tune manually the trajectory to**
- Keep the trajectory during user beamtime



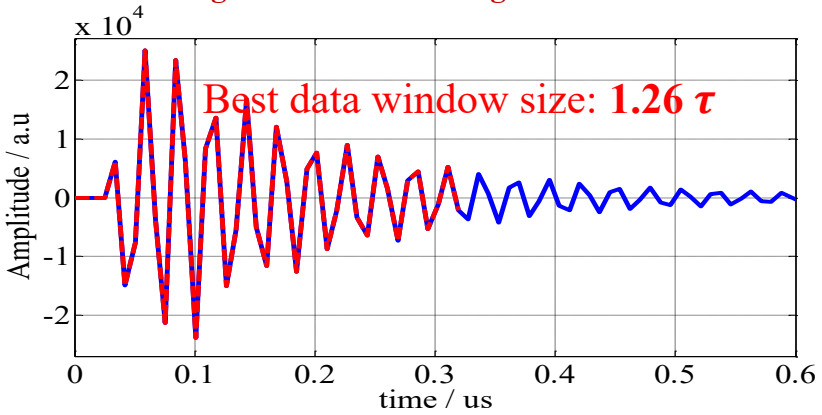


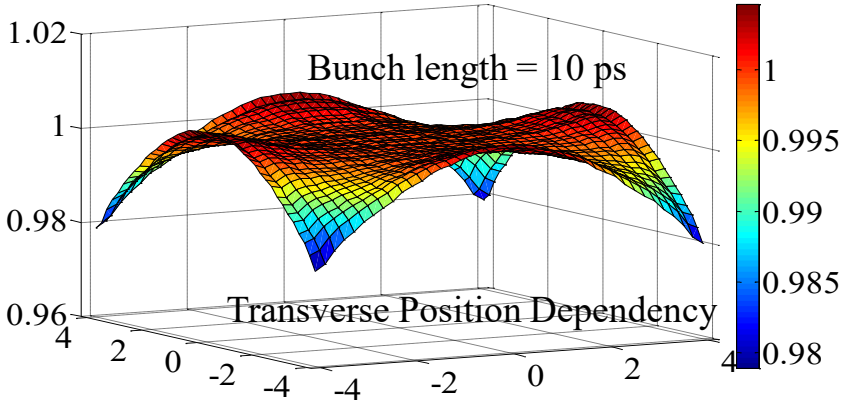
Multi-point orbit feedback based on the response matrix SVD+PID

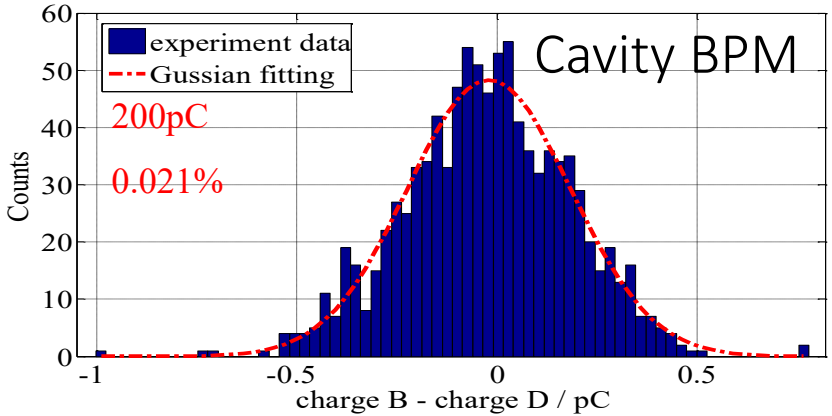
- The slow drift of the beam orbit at the exit of the accelerator is improved from 200μm/day to <5μm/day (rms)
- Long-term stable operation (<10μm/week)

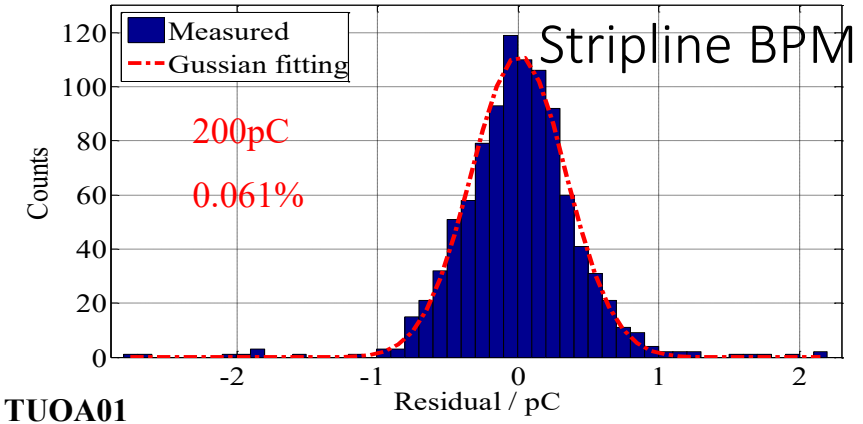
Applications in commission: charge measurement

SUM signal of SBPM and signal from reference cavity can be used to do the beam charge relative measurement









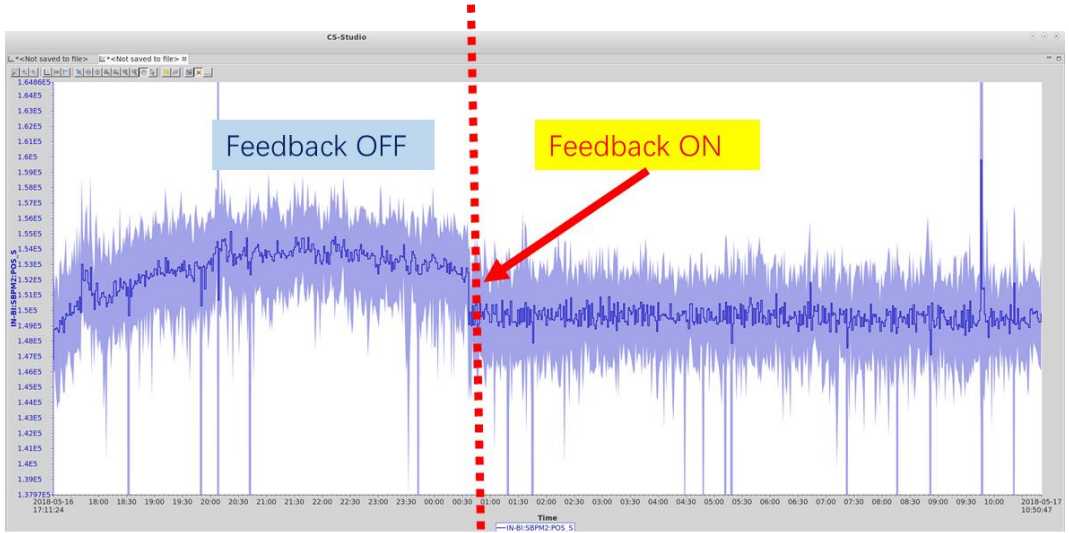
Jian Chen, NIMA 1012 (2021) 165627.

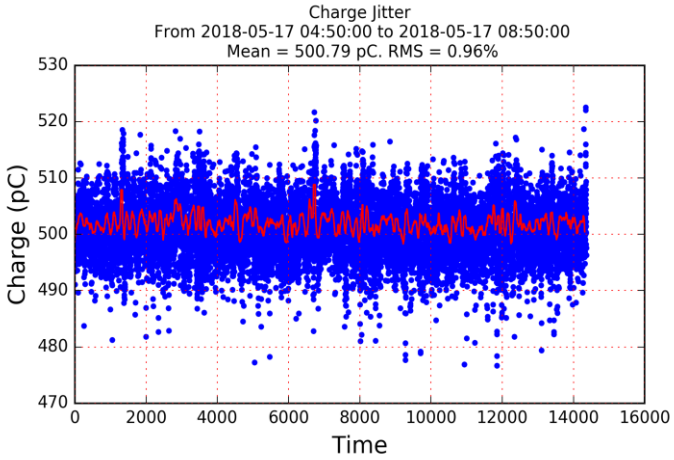
By Gu,Duan

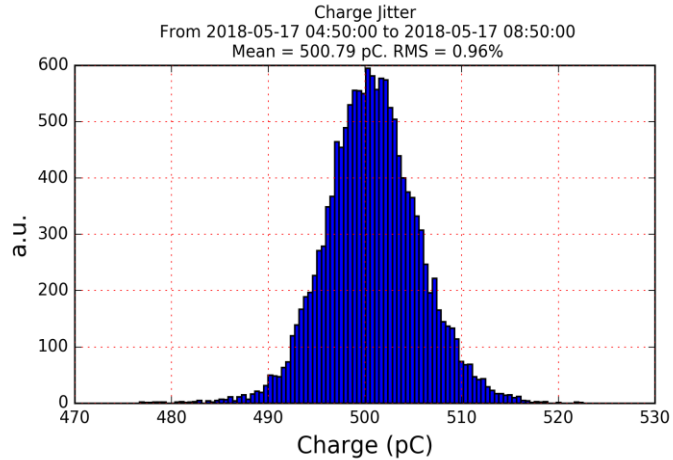
Applications in commission： Charge feedback system

SBPM SUM signal is used for the charge feedback

- **SBPM based relative charge measurement resolution:0.06%;**
- **Charge jitter 0.96%**





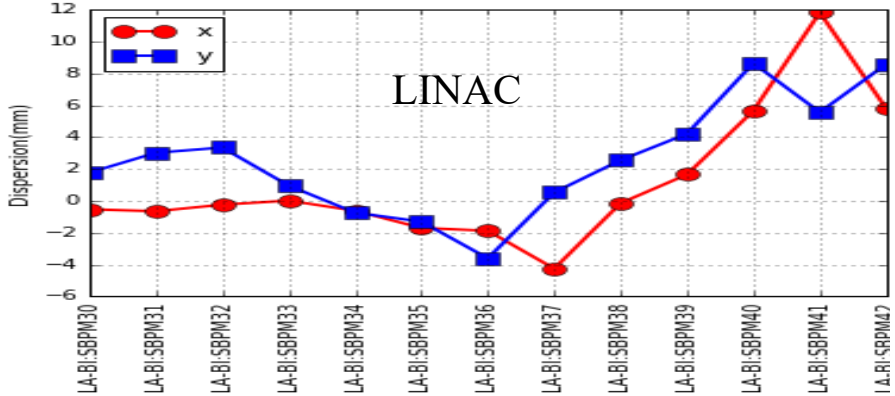


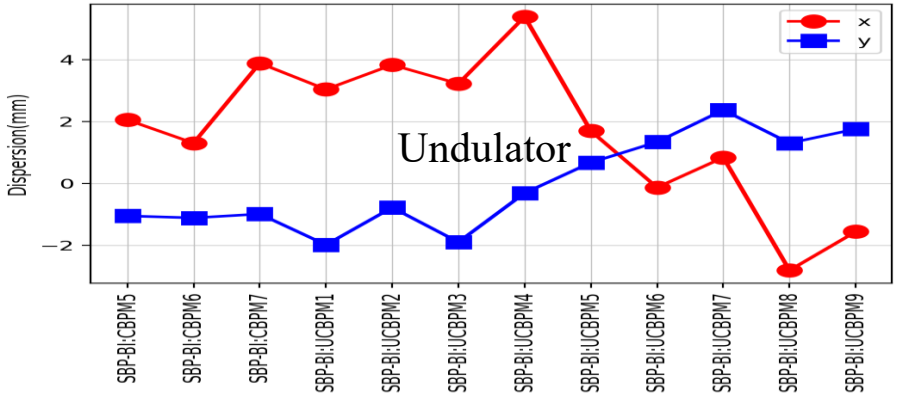
By Feng,Chao

Applications in commission： De-dispersion

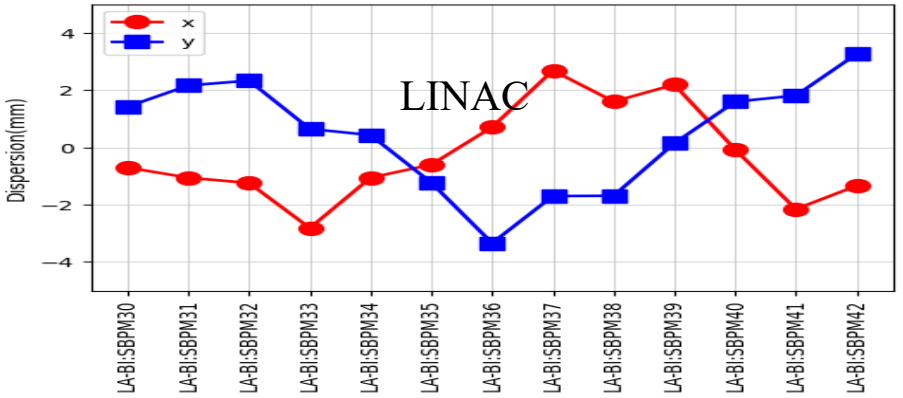
De-dispersion, maintain the emittance of the electron beam

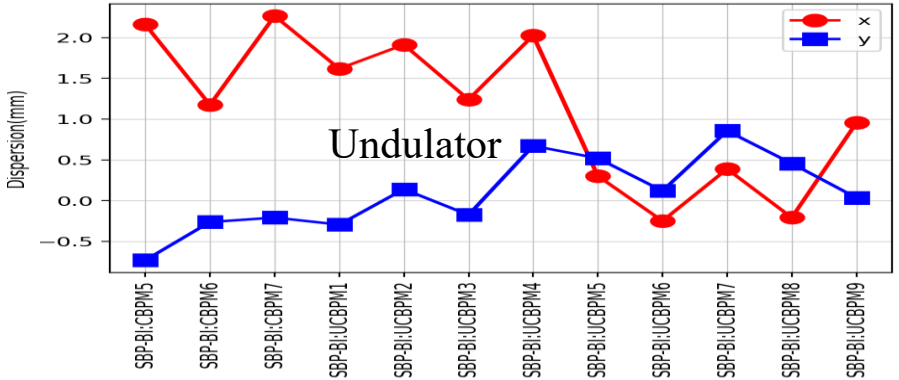
Before





After



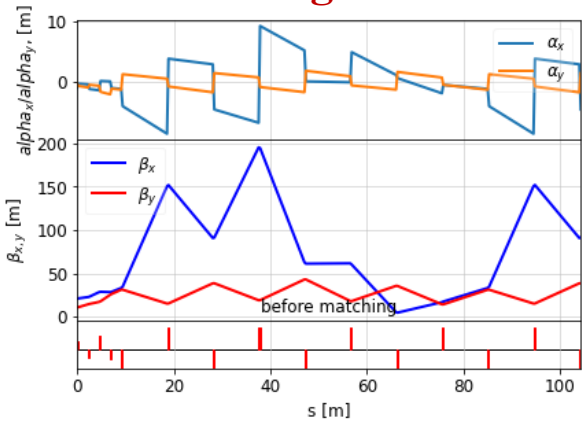


By Feng, Chao

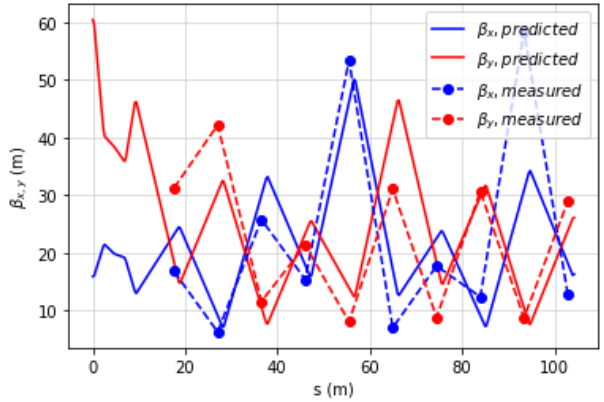
Applications: Transverse matching

Transverse matching to control the beam size to meet the conditions for generating FEL

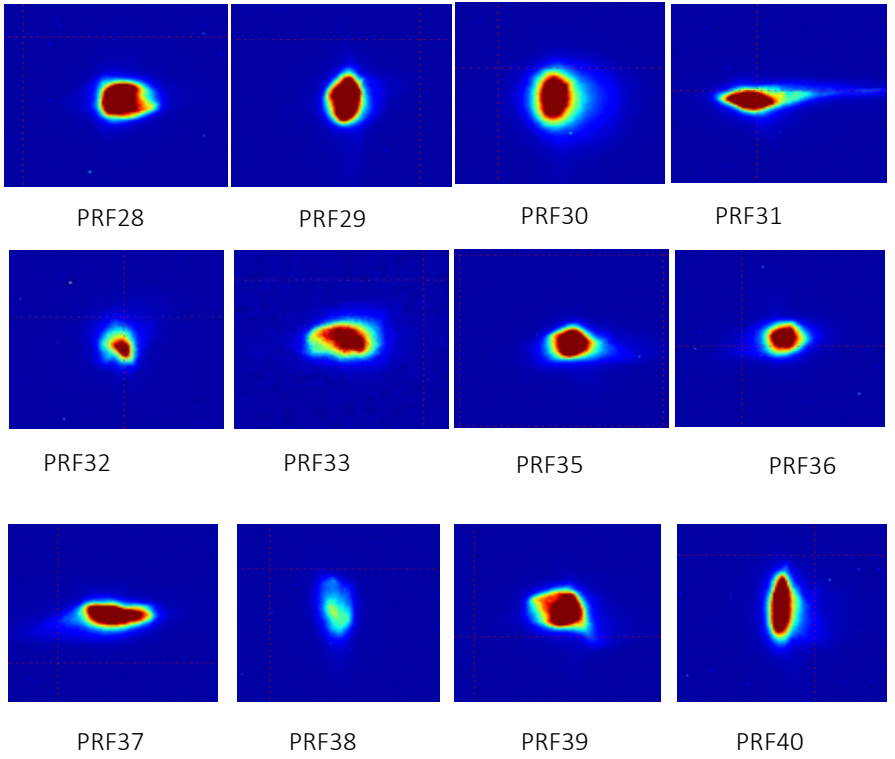
Before



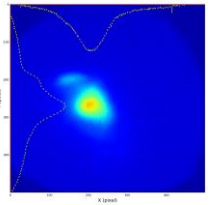
After



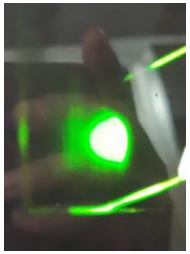
After matching, the beam size is well controlled



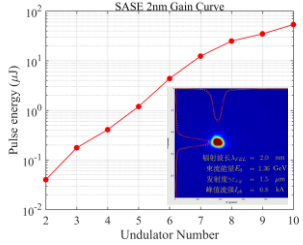
SASE commission time line



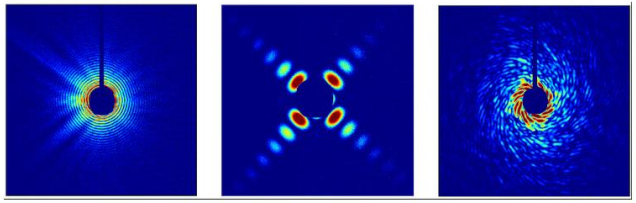
Beam energy 890 Mev
SASE 5.6 nm



First light to
experimental stati



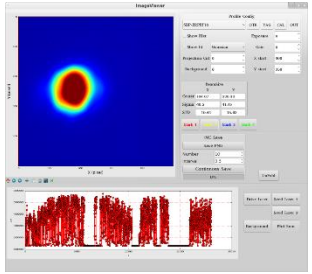
Beam energy: 1357 Mev
SASE 2.4 nm first light
SASE 2.0 nm fi



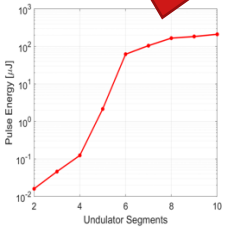
First single-shot CDI experiment
@2.4nm wavelength

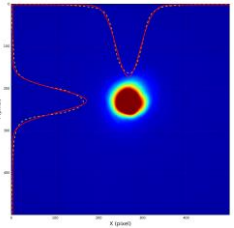
It only took 25 days to finish the commission, and wavelength at 2.0nm

First light to be

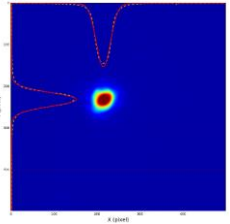


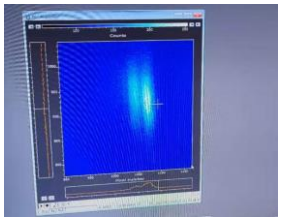
SASE
first light
SASE nm saturation





SASE 2.0 nm saturation
Spectrum measured





Summary

Summary

- **BPM R&D：**
  - **50 SBPMs+ 22 CBPMs have been developed and used in SXFEL-SBP;**
  - **SBPM:** Resolution of beam position measurement: 1.6 μm @500pC, relative charge measurement: 0.061%@200pC;
  - **CBPM:** Resolution of beam position measurement: 273nm@500pC, relative charge measurement: 0.02%@200pC;
  - Homemade DBPM，narrow-band for SBPM, base-band for CBPM.

- **Applications in the commission of SXFEL-SBP:**
  - The basis of the feedback system, beam orbit slow drift< 5μm/day , < 10μm/week ;
  - BPM based de-dispersion to ensure FEL;
  - Transverse matching to control the beam size.


Thanks !