Advancements in Beam Arrival Time Measurement For SHINE

zhouym@sari.ac.cn

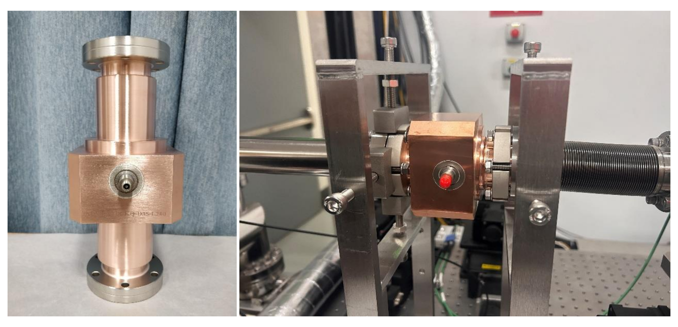
Authors: Y.M. Zhou, S.S. Cao, J. Chen, X.Q Liu, L.W Lai, R.X. Yuan

Shanghai Advanced Research Institute, CAS, Pudong, Shanghai 201210, P.R. China

Abstract

The jitter of the beam arrival time can significantly impact the synchronization between the seed laser and the electron beam, which will constrain the brightness and stability of the FEL. It is one of the important parameters for beam diagnostics. To align with the SHINE's (Shanghai HIgh repetition rate XFEL aNd Extreme light facility) requirements of a 1MHz repetition rate and a dynamic range from 10pC to 300pC, we developed a beam arrival time measurement system utilizing a cavity probe. This system is capable of achieving a specification of 20fs at a charge of 100pC. Our approach included designing measurement schemes based on intermediate and radio frequencies, and establishing a comparative test platform at the SXFEL (Shanghai Soft X-ray Free-Electron Laser Facility). This article will detail the construction of two systems and compare their test results across various charges. It has also been confirmed that the system can accurately measure beam arrival times for charges less than 1pC.

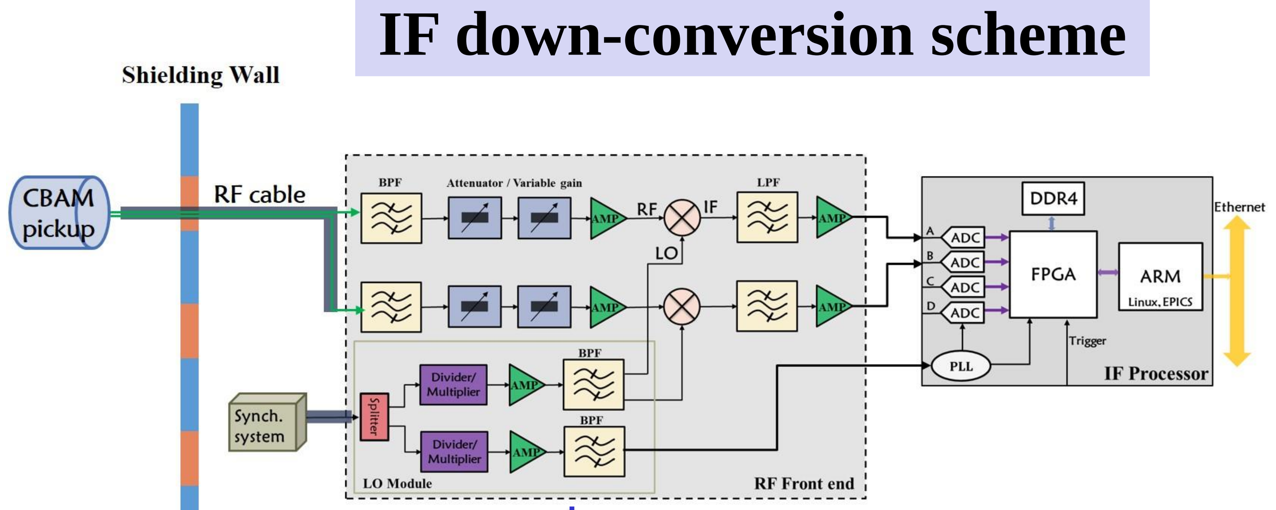
System structure of bunch arrival time measurement system

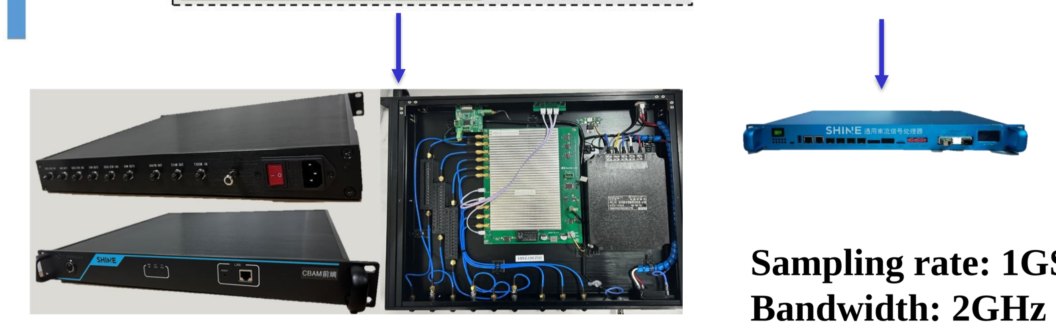


CBAM Probe

Parameters	Values
Frequency	3.520 GHz
Cavity length L	4.5 mm
Cavity diameter a	65 mm
Quality factor Q_L	2212
Decay time constant τ	200 ns
Cavity bandwidth	1.6 MHz

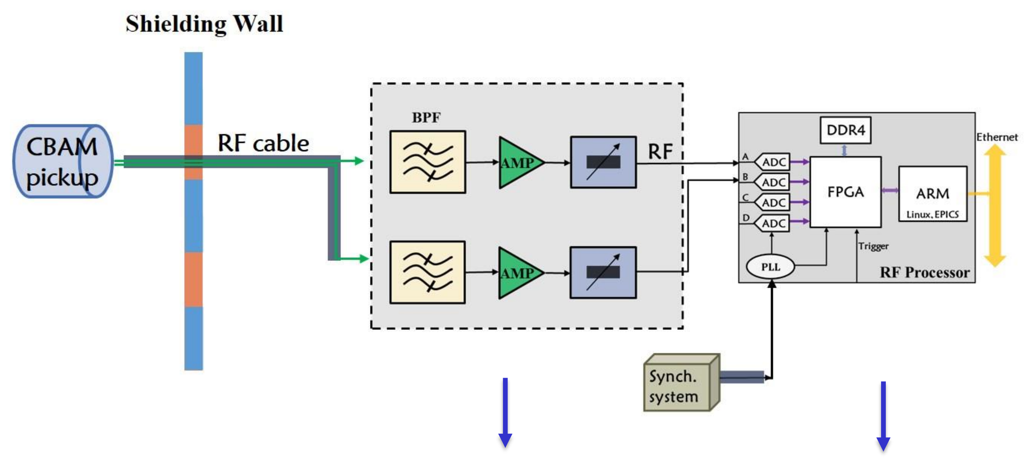
IF down-conversion scheme

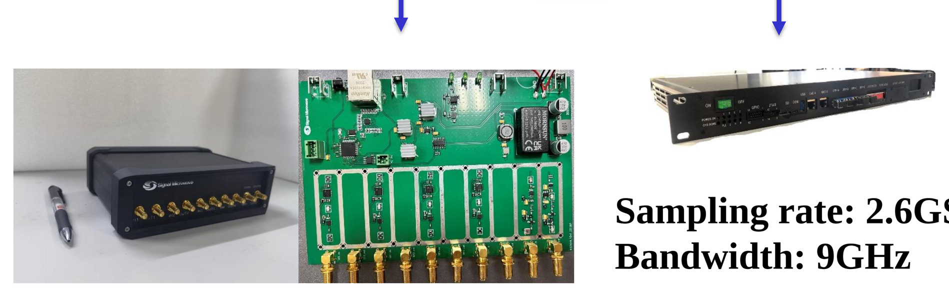




Sampling rate: 1GSPS
Bandwidth: 2GHz

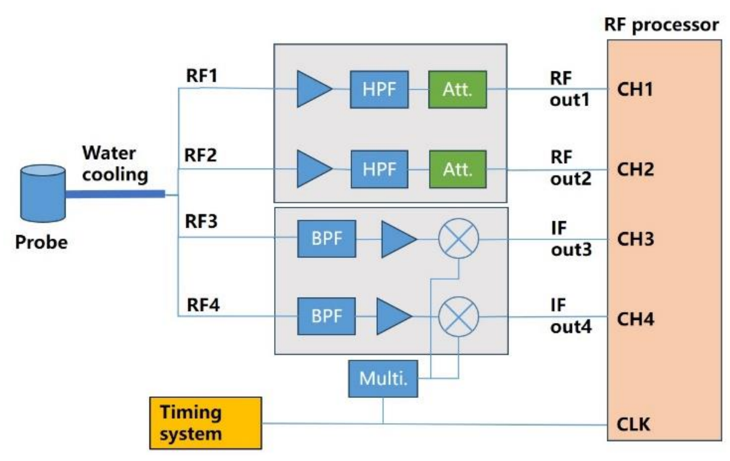
RF direct-sampling scheme



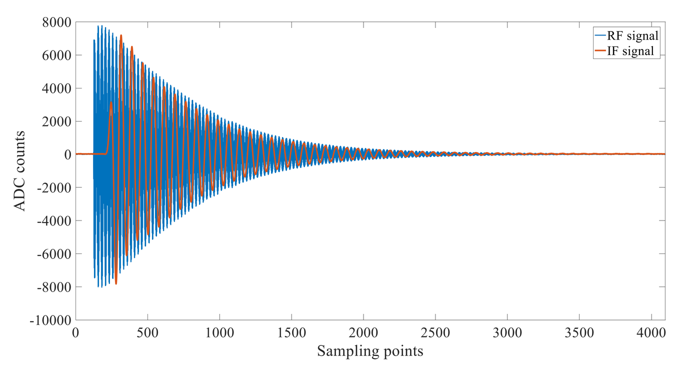


Sampling rate: 2.6GSPS
Bandwidth: 9GHz

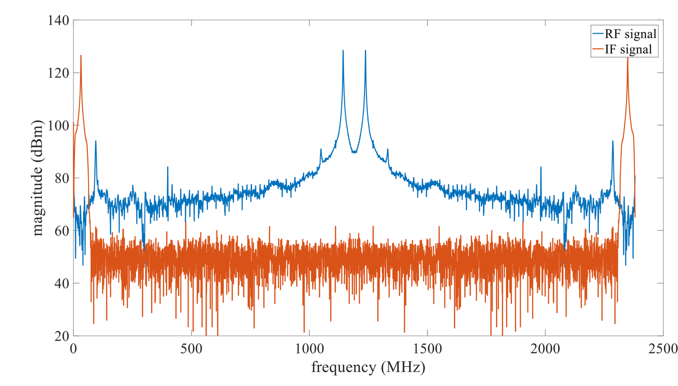
Experimental algorithms and tests



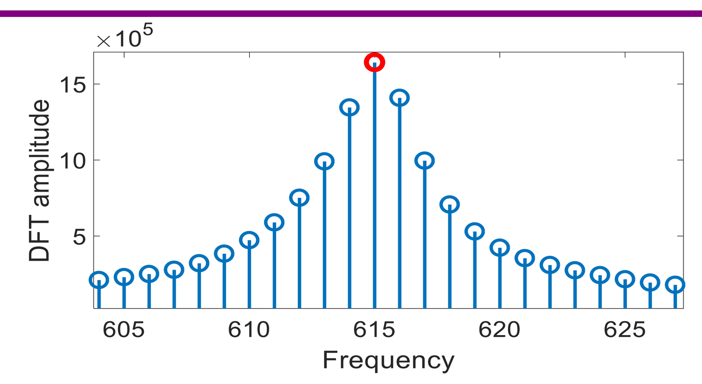
- **RF direct-sampling front-end vs. IF down-conversion front-end**
- **DFT algorithm: calculate amplitude and phase information**
- **Best window: get the best processing performance**



Time-domain signals

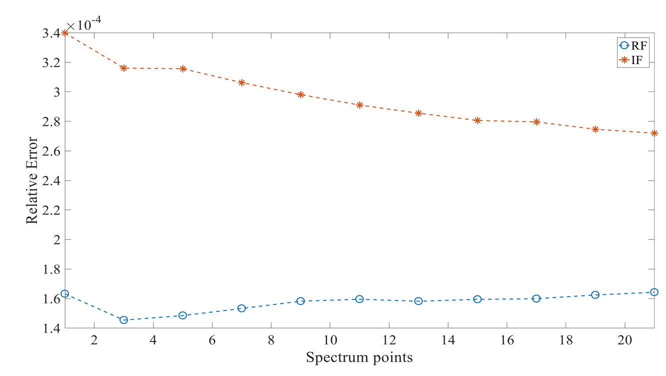


Frequency-domain signals

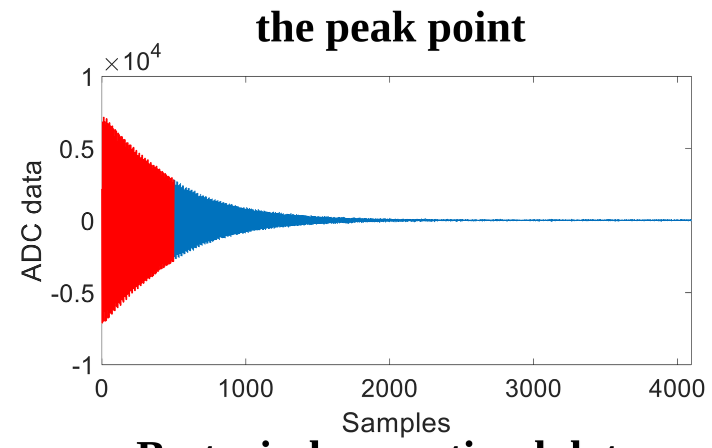


DFT algorithm: sum points around the peak point

main affect

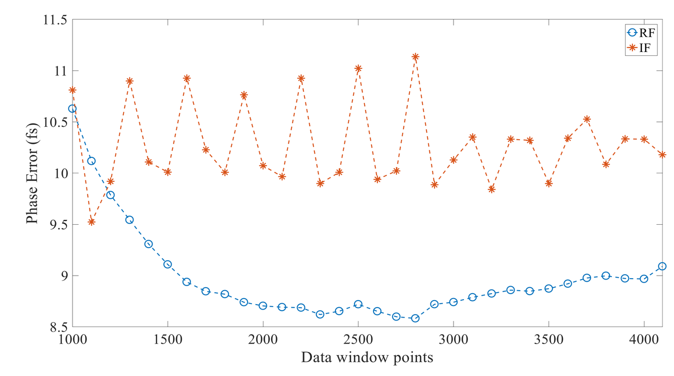


Amplitude relative errors



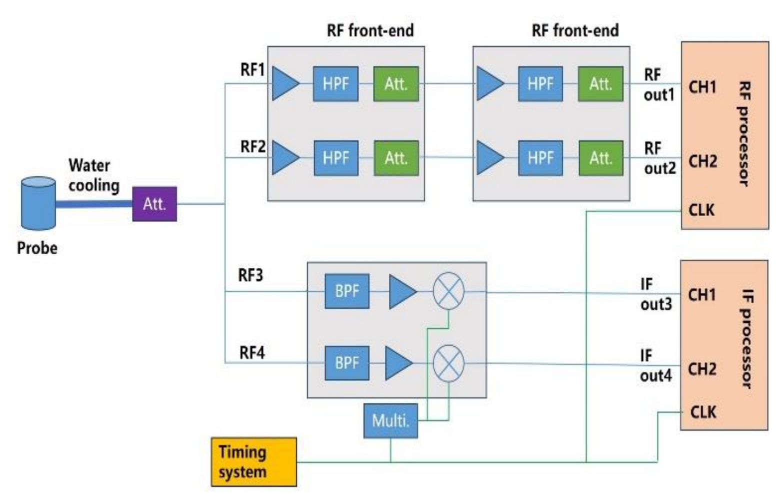
Best window: optimal data processing length

main affect



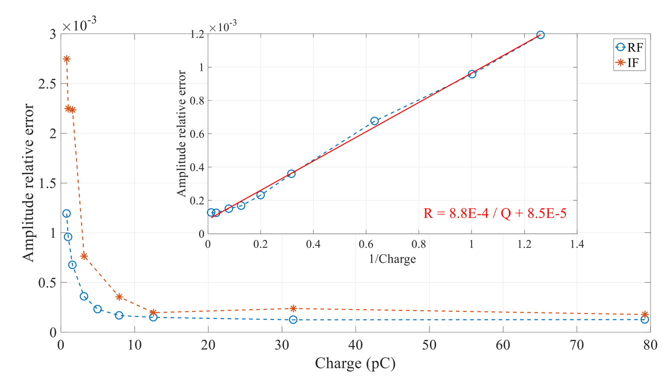
Phase relative errors

Experimental measurement results

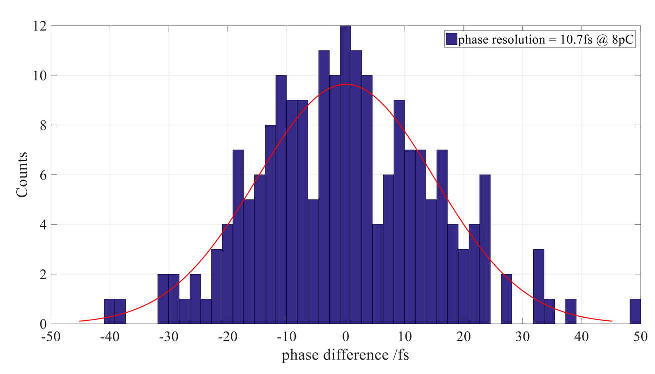


- **RF direct-sampling scheme (adequate gain) vs. IF down-conversion scheme (limited gain)**
- **Charge dynamic range: 0.8pC-80pC**

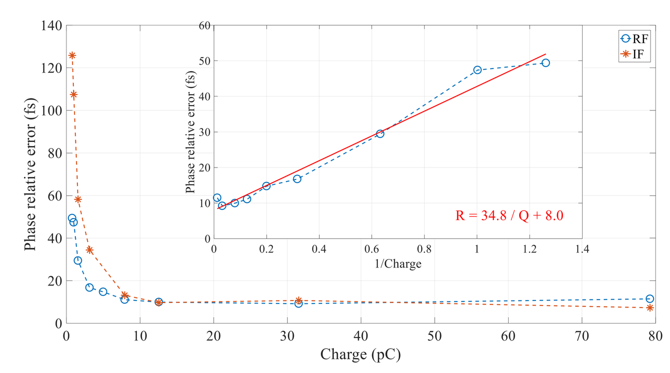
External attenuator	Beam charge	RF Phase errors	IF Phase errors
0dB	80pC	11.5fs	7.3fs
8dB	32pC	9.2fs	10.8fs
16dB	13pC	10.0fs	9.7fs
20dB	8pC	11.1fs	13.2fs
24dB	5pC	14.7fs	*
28dB	3pC	16.7fs	34.4fs
34dB	1.6pC	29.4fs	58.2fs
38dB	1pC	47.4fs	107.4fs
40dB	0.8pC	49.4fs	125.9fs



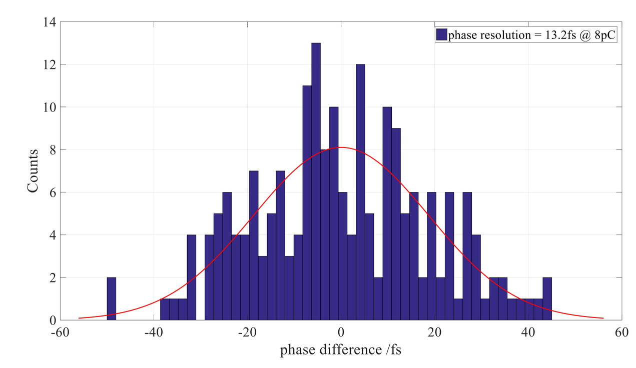
Amplitude errors vs. Charges



Phase error for RF processor: 10.7fs@ 8pC



Phase errors vs. Charges



Phase error for IF processor: 13.2fs@ 8pC

Conclusion

- **Successful construction of beam experimental test setup for SHINE CBAM probe at SXFEL.**
- **Comparison of IF down-conversion scheme and RF direct-sampling scheme tested in the CBAM system.**
- **Discrete Fourier Transform (DFT) and Data Window algorithms are used to obtain the best performance of CBAM amplitude and phase.**
- **Evaluating the performance of two sets of electronics at different charges (0.8pC-80pC).**
- **Amplitude performance: RF direct-sampling electronics are slightly better than IF down-conversion electronics, mainly due to the simple analogue front-end which has a better noise figure.**
- **Phase performance: The two sets of electronic properties are similar for charges greater than 8pC.**

SHINE

中国科学院上海高等研究院
SHANGHAI ADVANCED RESEARCH INSTITUTE, CHINESE ACADEMY OF SCIENCES