The Application of Beam Arrival Time Measurement System at SXFEL

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- Introduction
- Beam Arrival Time Measurement Techniques
- Typical RF Based Phase Detection
- Beam Flight Time Detection
- Conclusion & Future Work

SXFEL

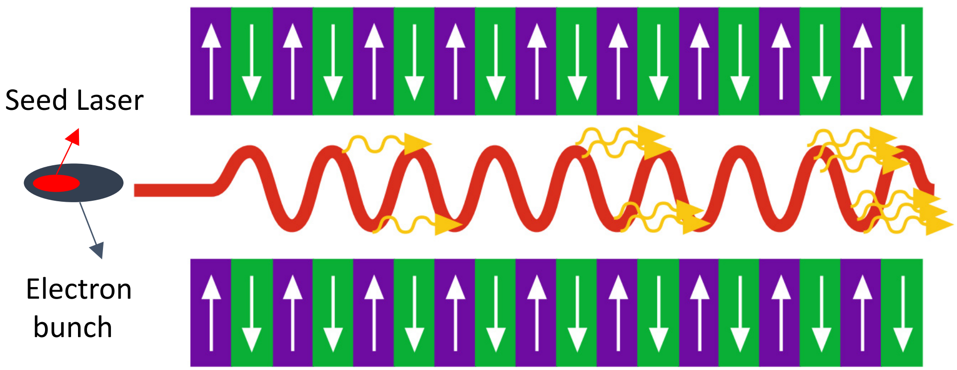
Shanghai Soft X-ray FEL Test Facility

Shanghai Soft X-ray FEL User Facility

Parameters	Test Facility	User FEL-1	User FEL-2	Unit
FEL type	HGHG-EEHG	HGHG-EEHG	SASE Self-seeding	
Output Wavelength	9	2 ~ 10	1.2 ~ 3	nm
Bunch charge	0.5 ~ 1	~ 0.5	~ 0.2	nC
Pulse length (FWHM)	~0.5	0.03 - 1	0.03 - 1	ps
Peak current	~0.5	0.7	0.7	kA
Rep. rate	1 ~ 10	10 ~ 50	10 ~ 50	Hz

Motivation

FEL Facility

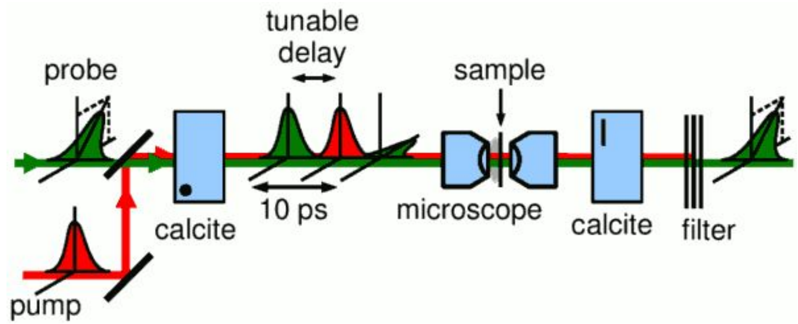


To acquire ultra-short and high-brightness light :

The precise synchronization between the electron bunches and the seed laser pulses in three-dimensional space

measure → **Beam arrival time (Longitudinal)**

Experiment



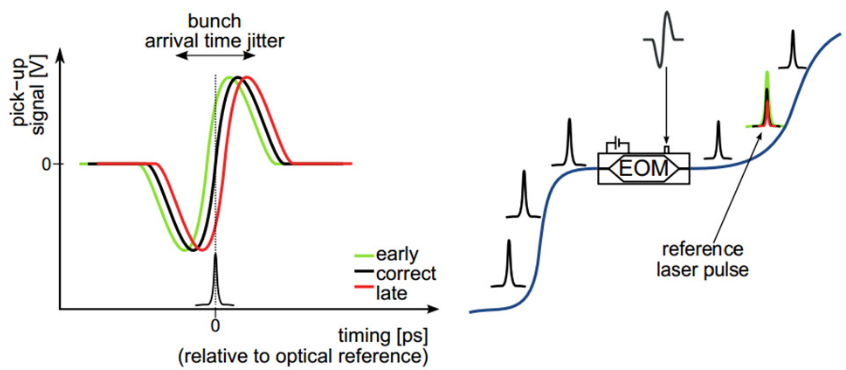
Time-resolved experiments :

- Require high temporal resolution & stability
- Reduce the timing jitter of the electron bunch, correct timing drifts

measure → **Beam arrival time**

Measurement scheme selection

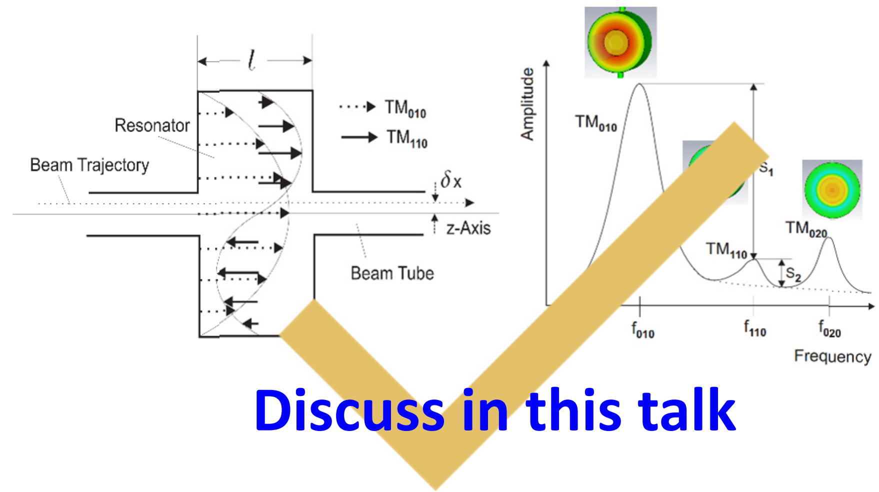
Electro-optical detection scheme



- **Better performance**

- **Great cost**
- **Complexity**

RF based phase detection scheme



Discuss in this talk

- **Simple**
- **Inexpensive**

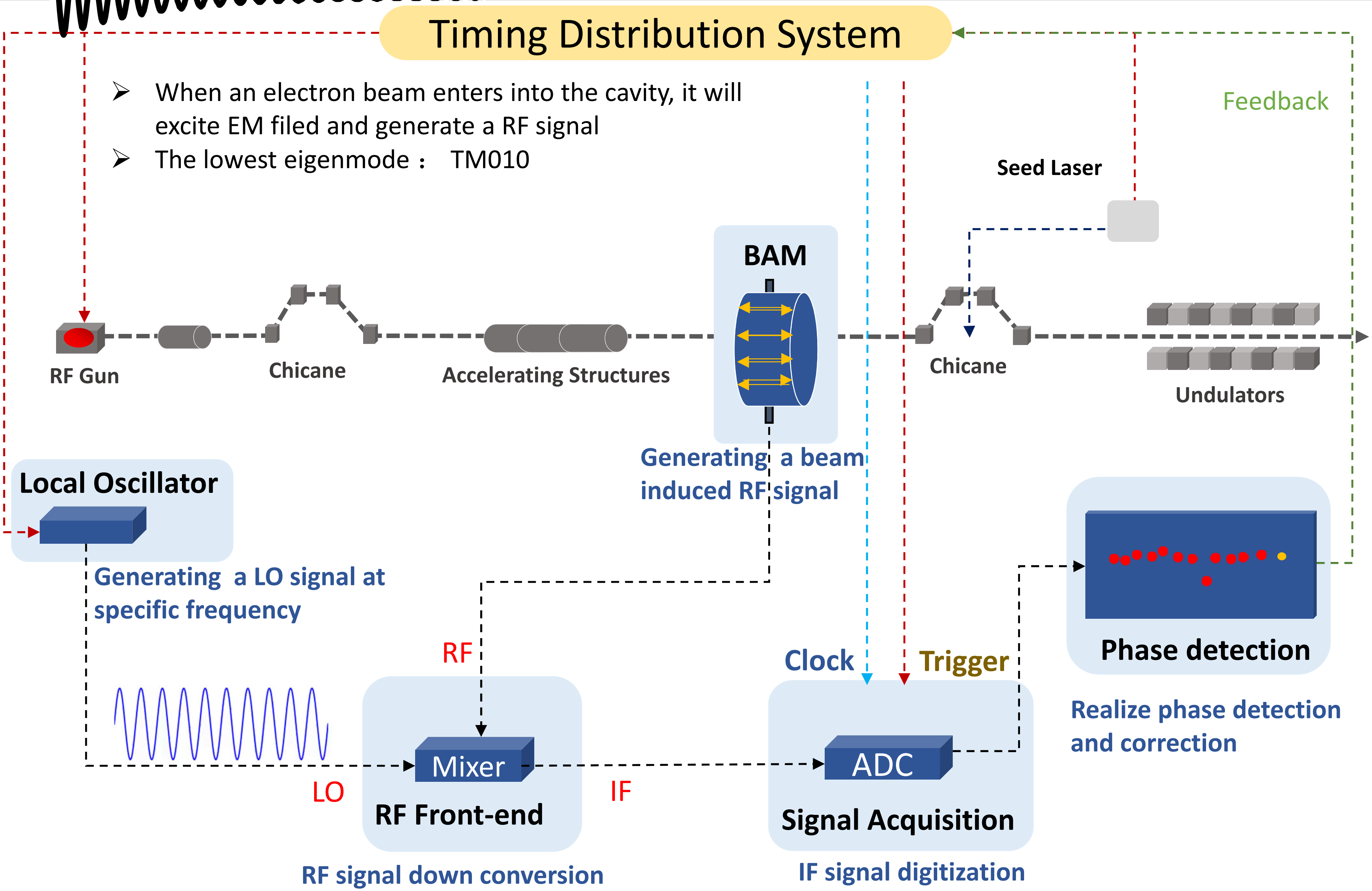
- **Rugged**

Bock M K et al. Recent developments of the bunch arrival time monitor with femtosecond resolution at FLASH[J]. WEOCMH02, IPAC2010, Kyoto, Japan, 2010.

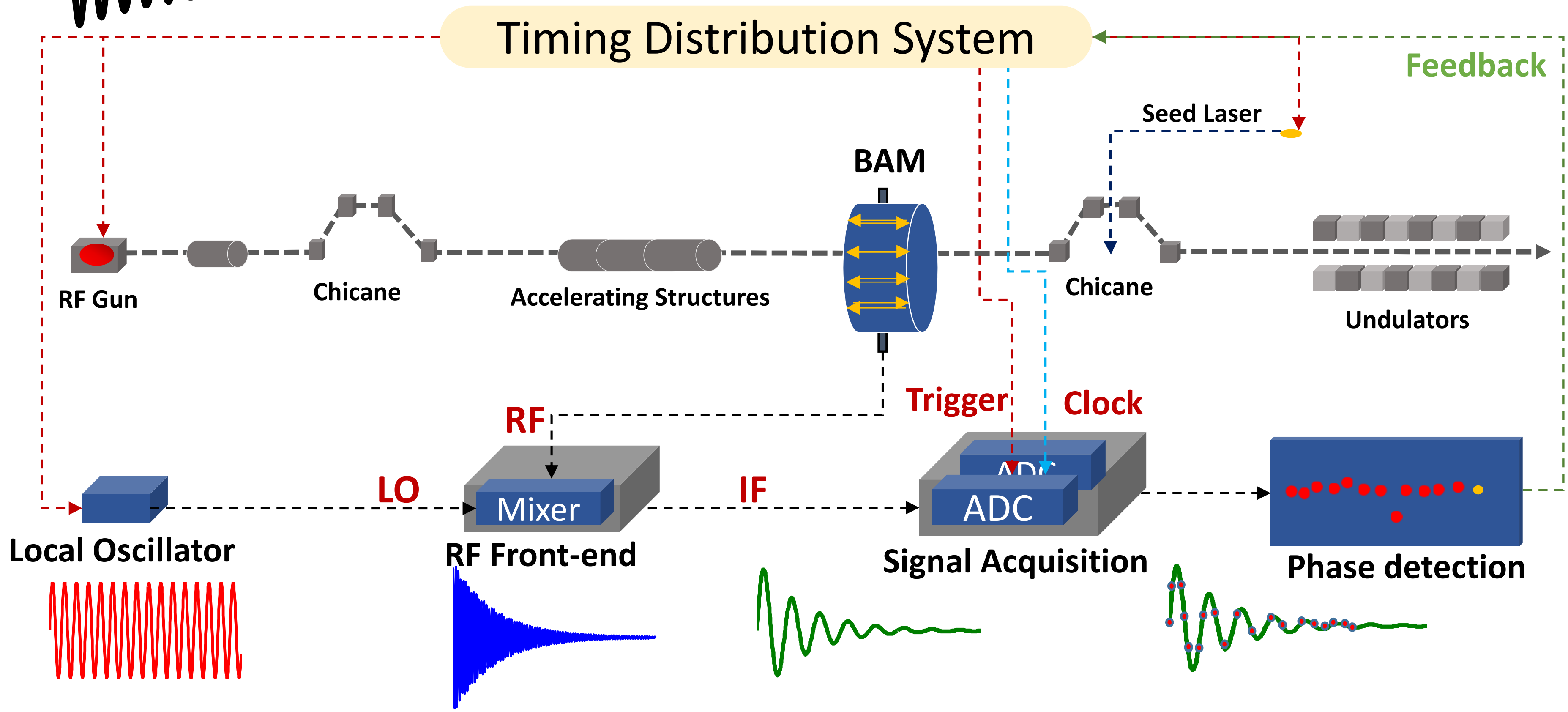
Lorenz R, Sabah S, Waldmann H, et al. Cavity-type beam position monitors for the SASE FEL at the TESLA test facility[R], 2003.

Typical RF BAM System Overview

- When an electron beam enters into the cavity, it will excite EM filed and generate a RF signal
- The lowest eigenmode： TM010



Typical RF BAM System Limitation



Limitation: Require a high stable reference signal

- Long distance
- Temperature
- Humidity
- Physical motion

……

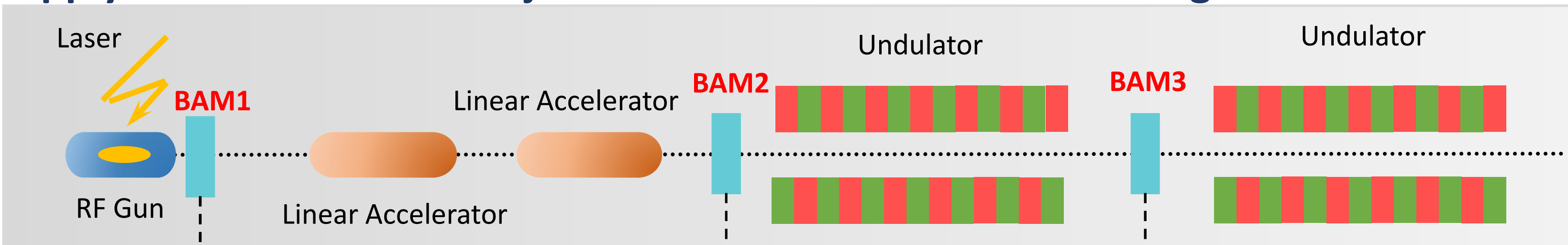
Frisch J. Beam Arrival Time Monitors[C],IBIC2015, Melbourne, Australia, 13-17 September 2015

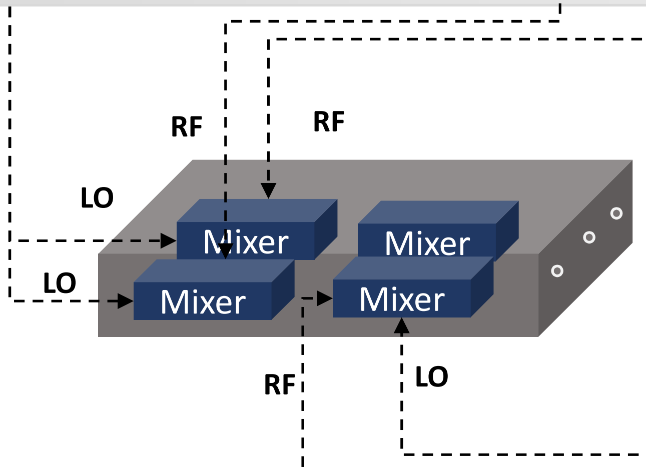
SXFEL environment:

- Temperature and humidity control outside the tunnel: **not good**
- Existing environment noise outside the tunnel, physical motion
- **a lot of thing to do ……**

Proposed scheme Two Cavity Mixing

❶ Apply a BAM next to the injector to instead of the reference signal

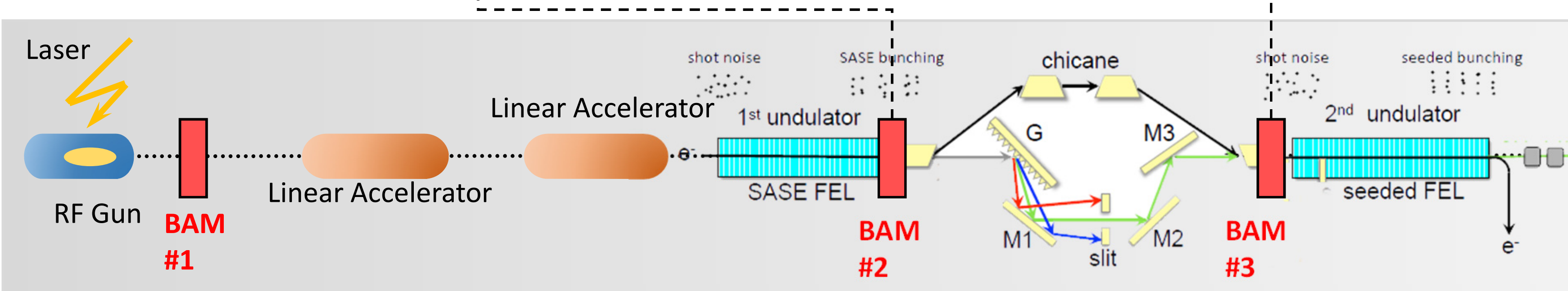




Advantages:

- The two BAMs have similar features, such as temperature sensitivity
- Temperature inside the tunnel is much stable
- Efficient for self-seeding FEL:
  - Focus on the beam flight time
  - Short distance
  - Smaller interference

❷



Self-seeding FEL: Install one BAM at chicane's entrance and exit, respectively

BAM Cavity

- Extract energy out of the cavity to gain the information about the beam arrival time

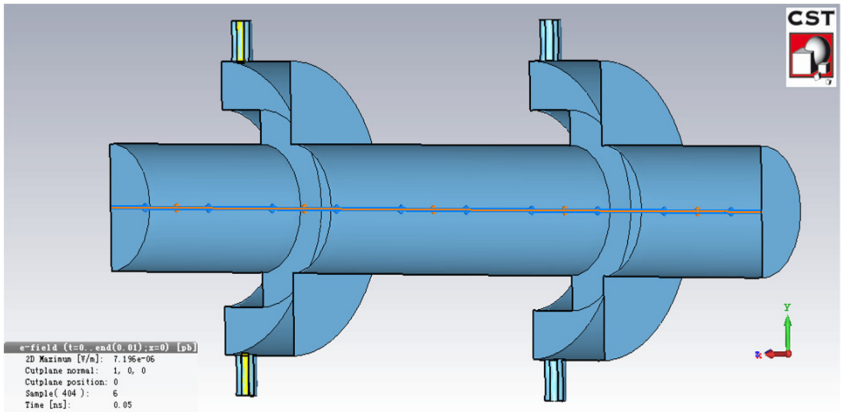


Figure :Model build in simulation software

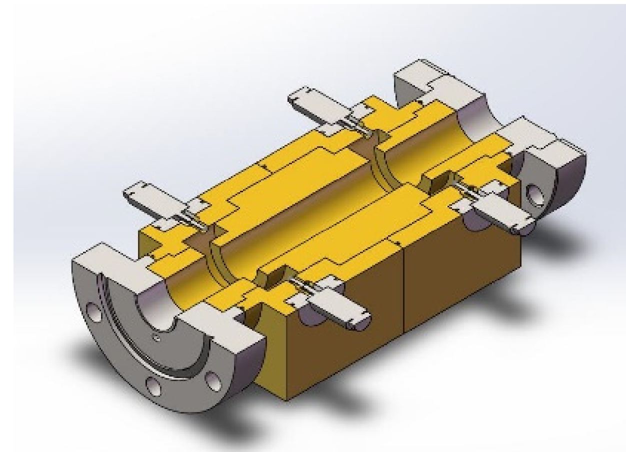


Figure : 3-D mechanical drawing

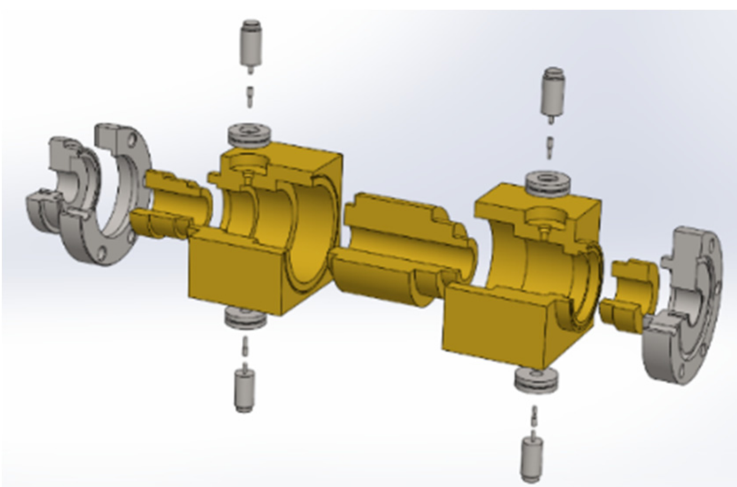
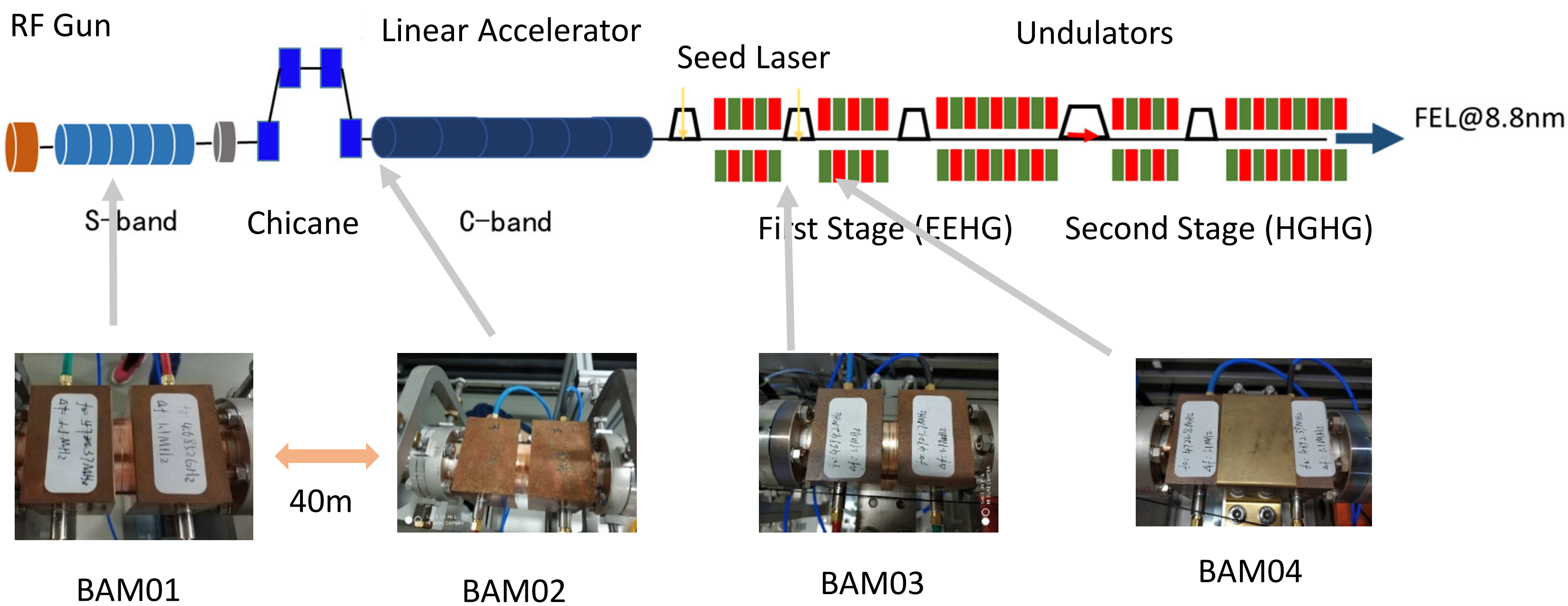


Figure : 3-D mechanical drawing

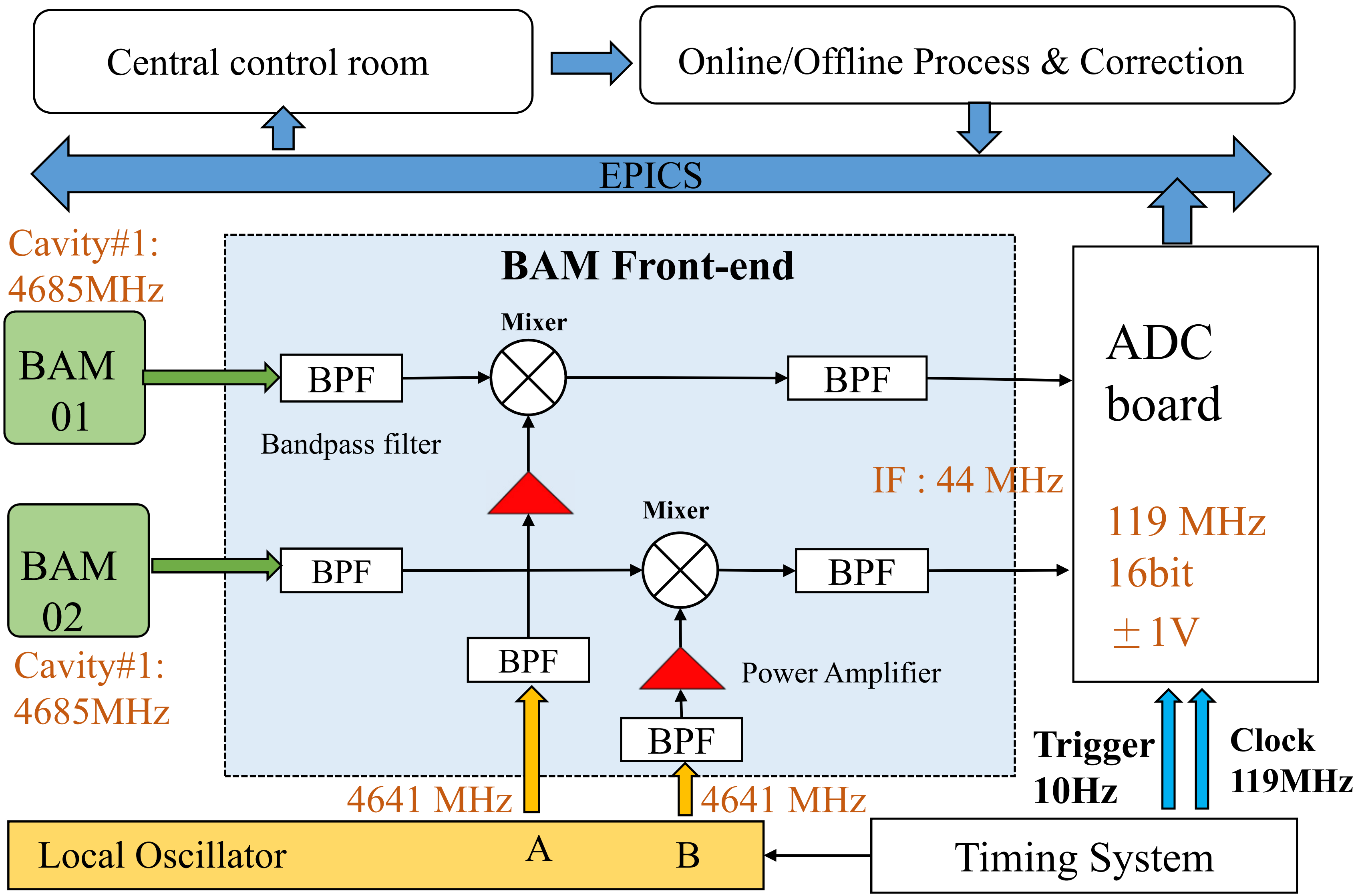
Parameters	Cavity #1	Cavity #2
Frequency / GHz	4.685	4.72
Q_0	4796	4835
Q_e	1.8e5	1.9e5
Q_L	4671	4716
R over Q/Ohm	107.2	107.9
Bandwidth /MHz	1.002	1.025
τ /ns	318	318

The installation of BAMs at SXFEL



Typical RF based phase detection

Typical RF based Phase Detection Schematic



Typical RF based Phase Detection Results

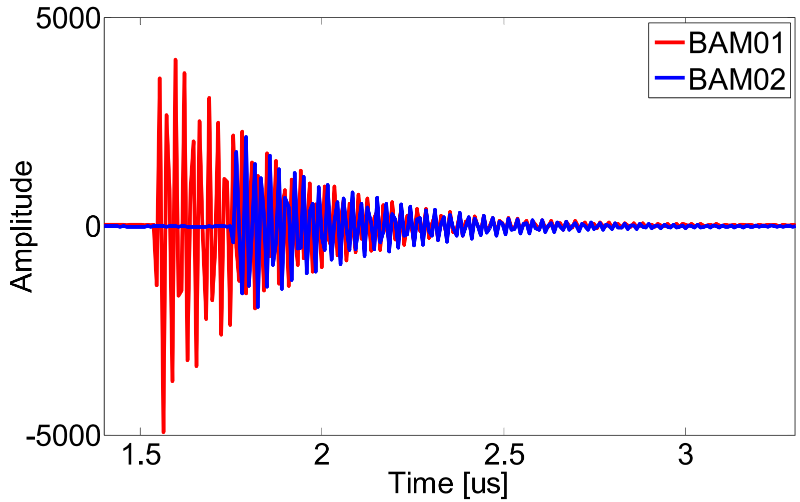


Figure 1: The IF raw signal

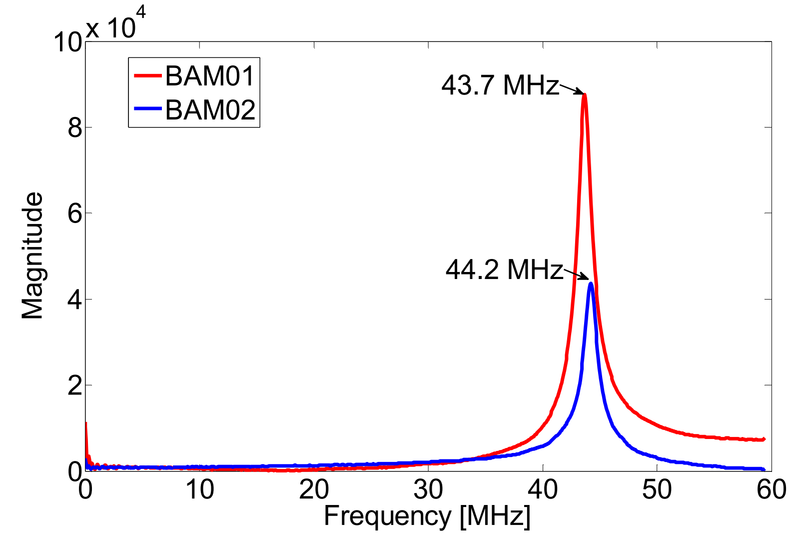


Figure 2: The IF signal frequency spectrum

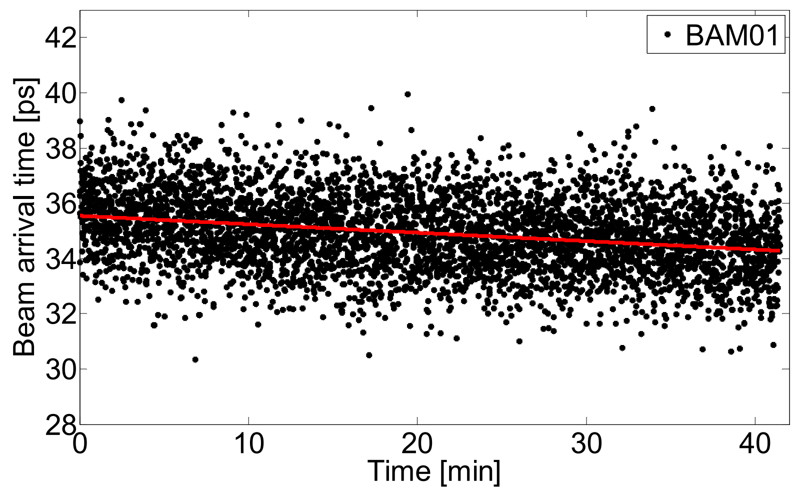


Figure 3: The arrival time of BAM-01

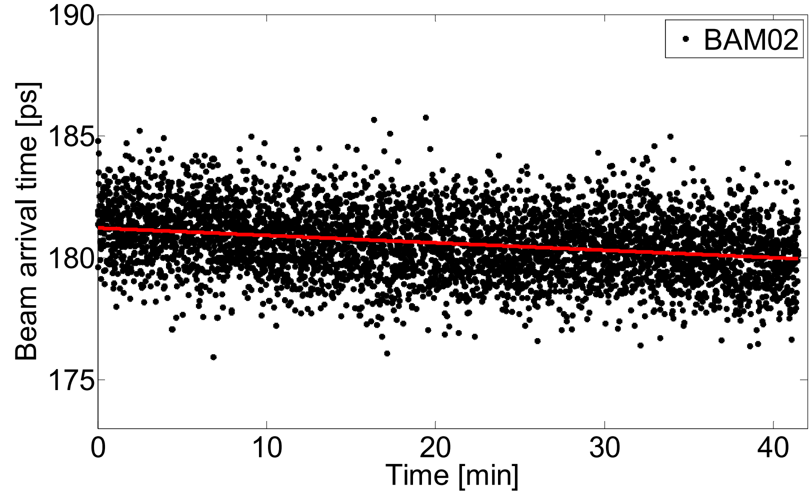


Figure 4: The arrival time of BAM-02

Typical RF based Phase Detection Results

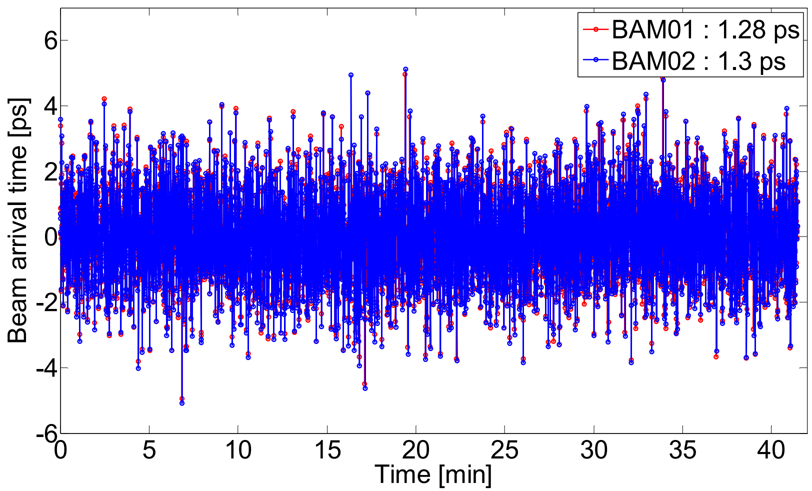


Figure 5: The beam arrival time deviation

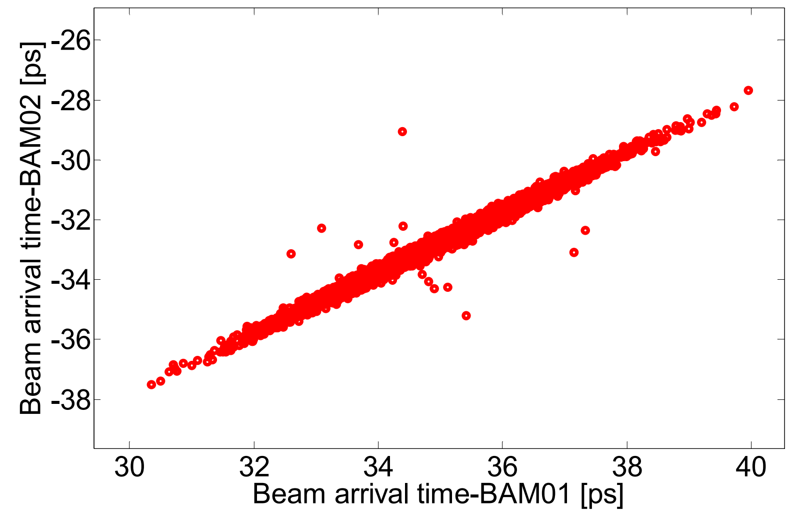


Figure 6: The correlation between the two arrival time

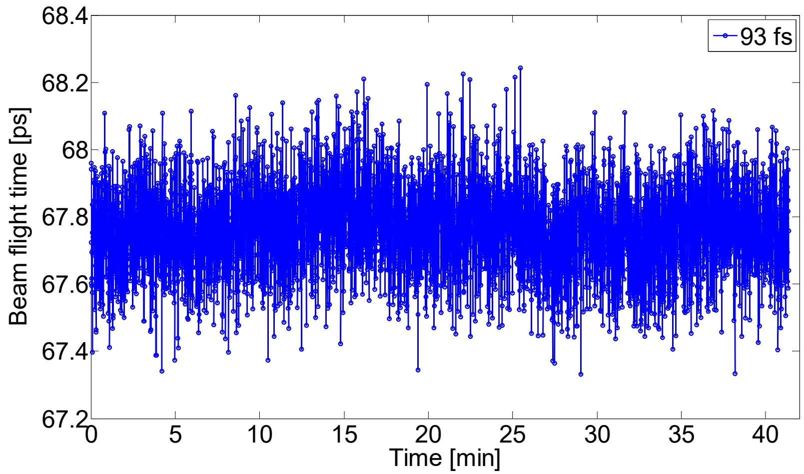


Figure 7: The beam flight time deviation

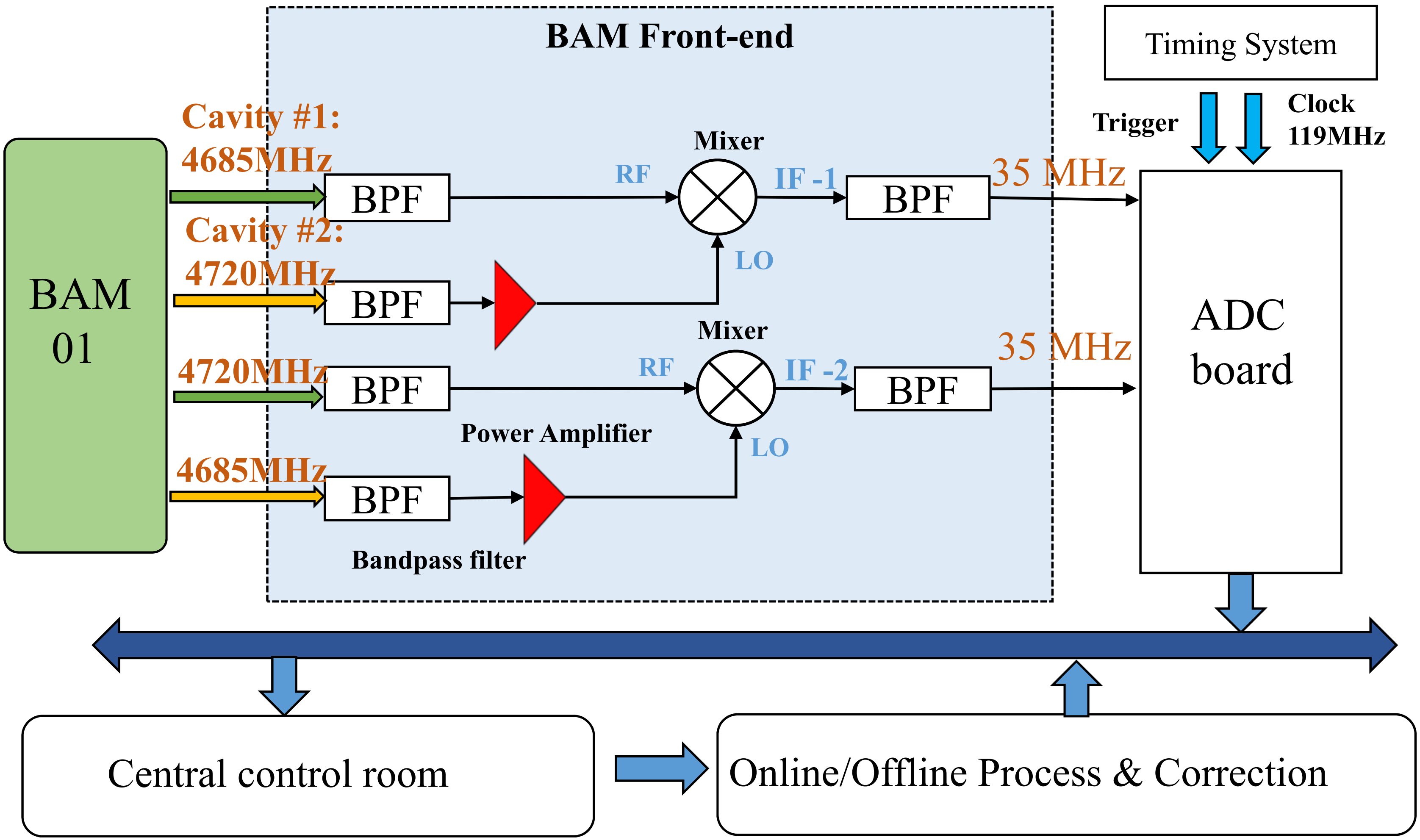
- Bunch arrival time deviation :
  BAM01: **1.28 ps** BAM02: **1.3 ps**
- Beam flight time deviation : **93 fs**
- **Possible jitter source:**
  - **Disturbed reference signal**
  - **Non-optimized electronics**
  - **Environment: temperature…**
  - **long RF cables**
  - ……

Beam Flight Time Detection

two-cavities mixing

- BAM01
- BAM01 & BAM02

Dual-cavities Phase Detection Schematic - *BAM01*



Dual-cavities Phase Detection Results -*BAM01*

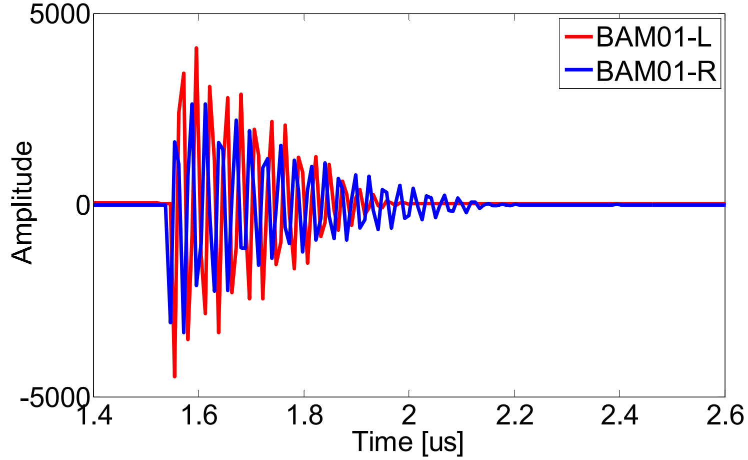


Figure 1： The two IF raw signal

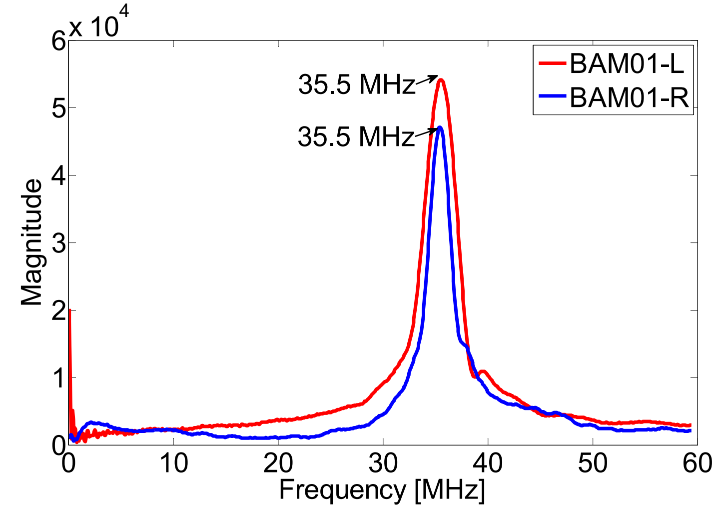


Figure 2： The two IF signal frequency spectrum

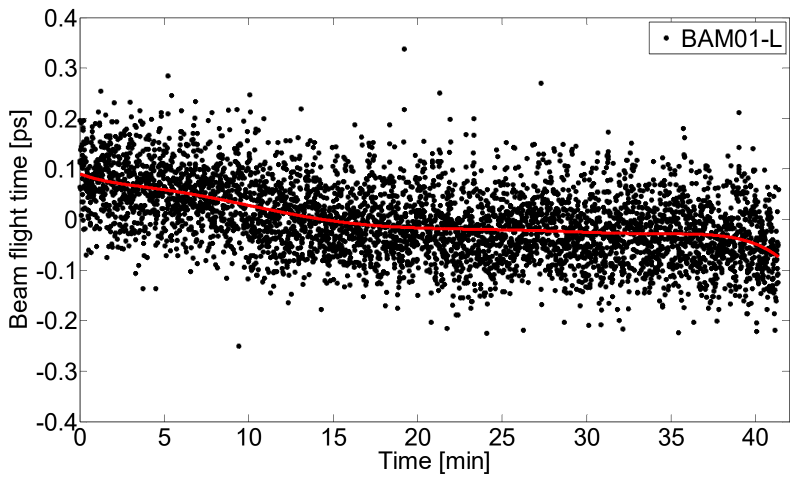


Figure 3： The flight time (IF1)

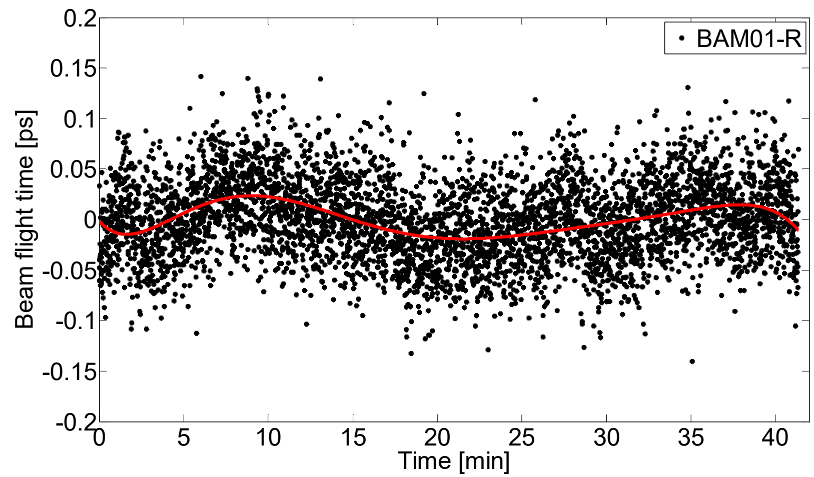
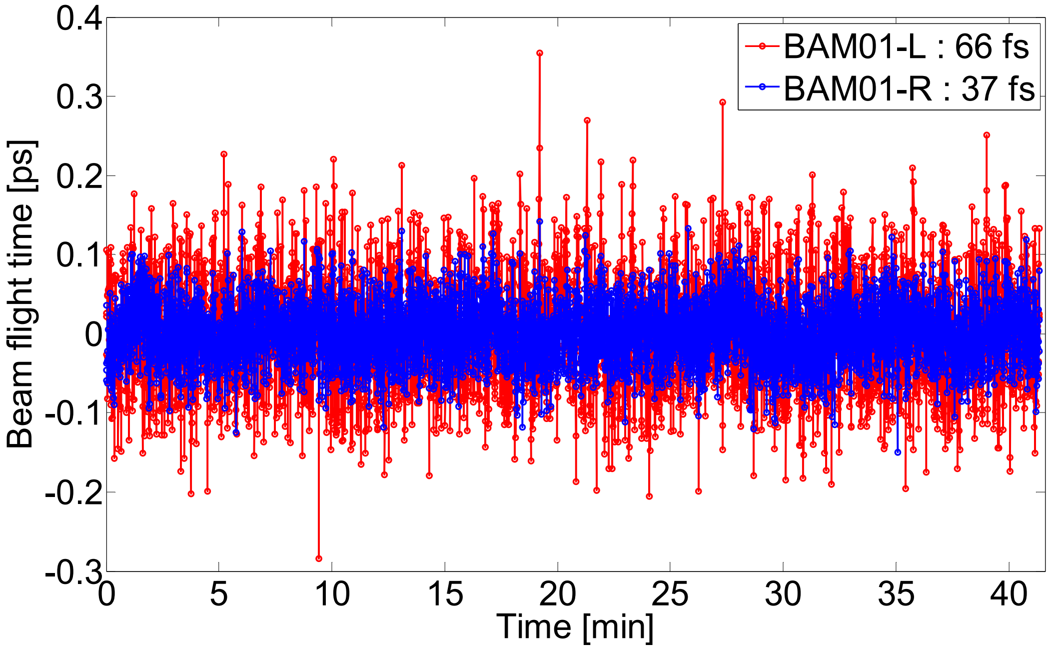


Figure 4： The flight time (IF2)

Dual-cavities Phase Detection Results-*BAM01*



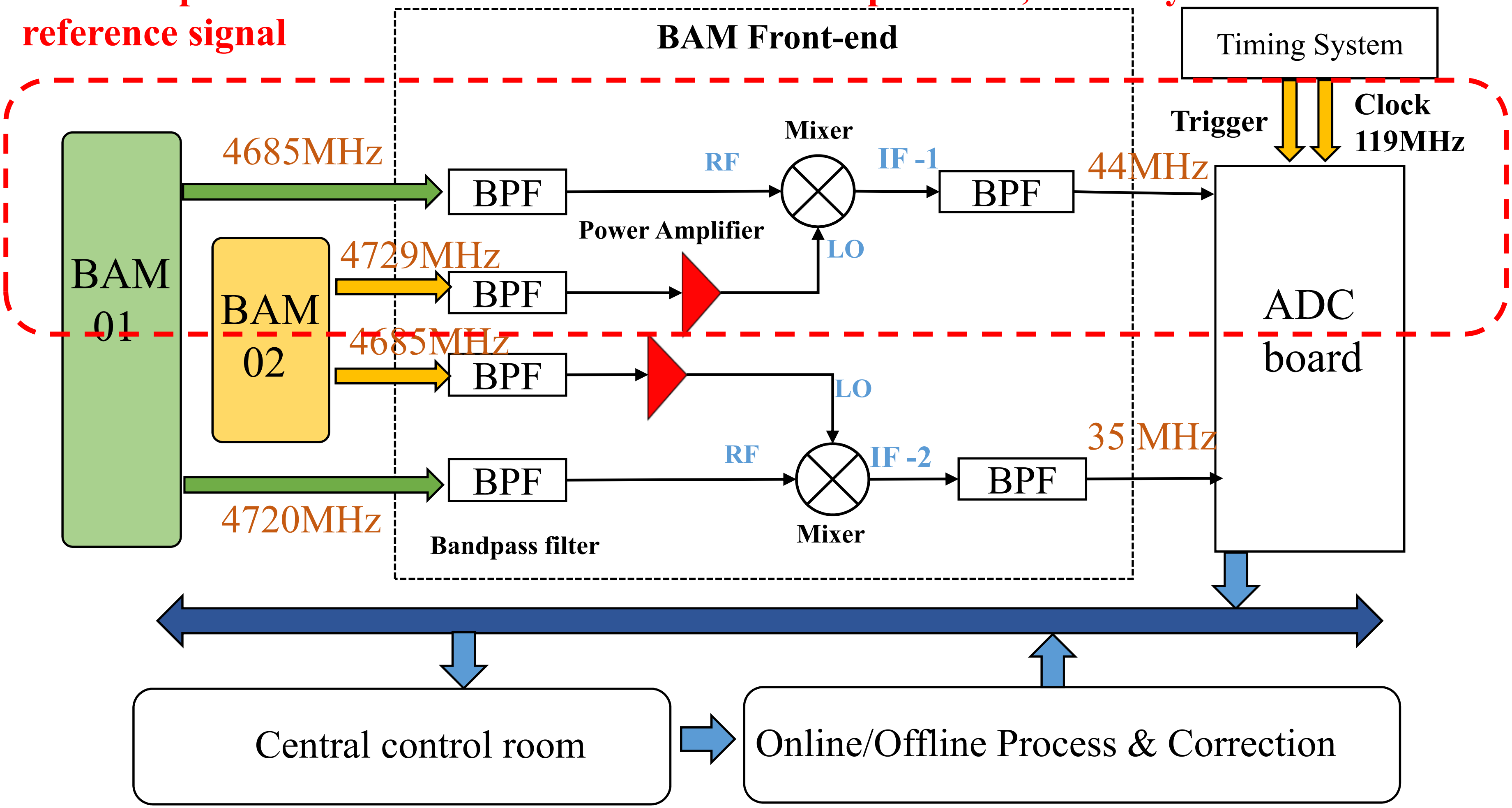
- Beam flight time deviation :
  IF-01: **66 fs** IF-02: **37 fs**

- **Limitation:**
  - Electronics
  - Larger environment noise：near injector, outside tunnel
  - Cavity port & transmission difference

  ……

Dual-cavities Phase Detection Schematic - *BAM01 & BAM02*

This setup is similar to the beam arrival time experiment, the only difference is the reference signal



Dual-cavities Phase Detection Schematic -*BAM01 & BAM02*

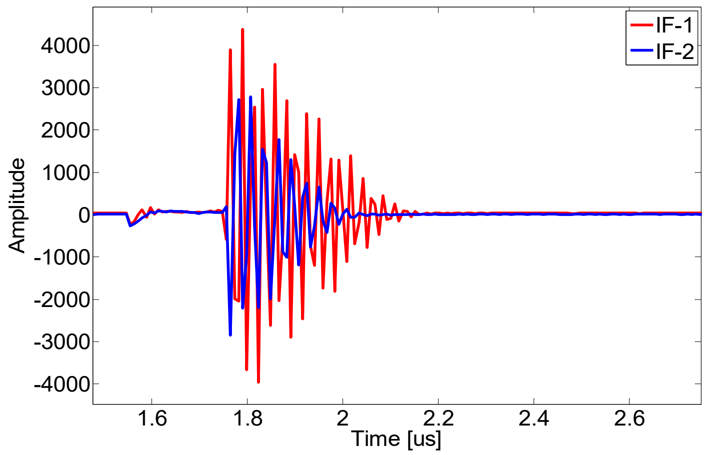


Figure 1： The two IF raw signal

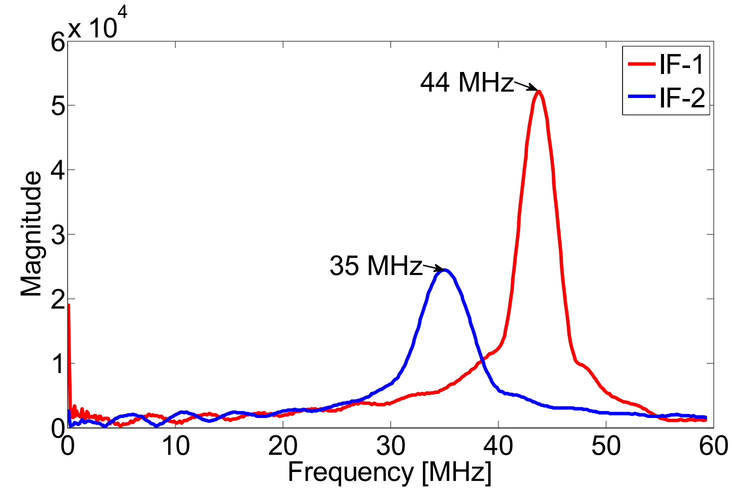


Figure 2： The two IF signal frequency spectrum

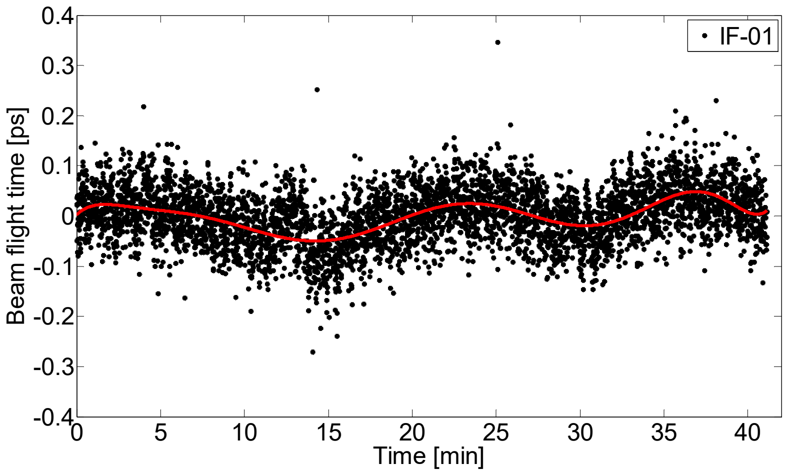


Figure 3： The flight time (IF1)

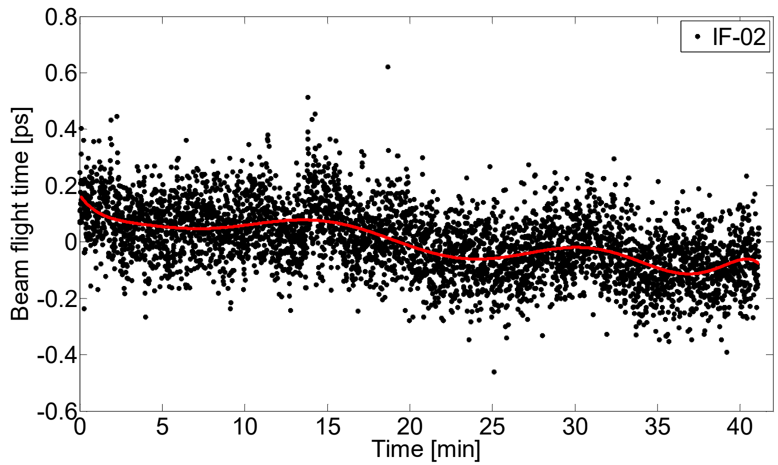


Figure 4： The flight time (IF2)

Dual-cavities Phase Detection Schematic

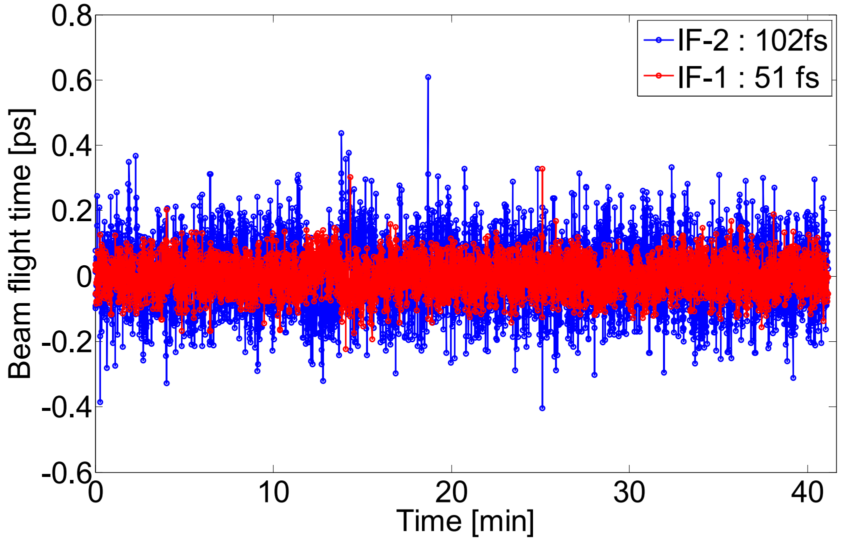


Figure 1： The two beam flight time deviation

- Beam flight time deviation :
  IF-01: **51 fs** IF-02: **102 fs**
- **Possible jitter source:**
  - **Beam jitter**
  - **Electronics**
  - **Transmission, cavity difference**

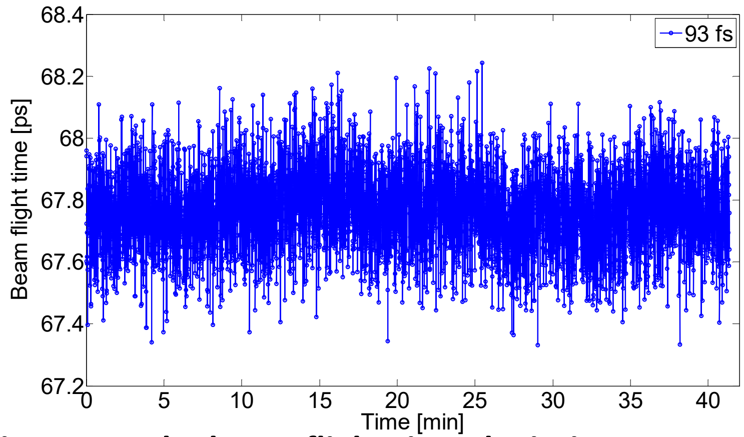


Figure 2： The beam flight time deviation measured by the typical RF based phase detection scheme

Typical scheme vs. Two cavity mixing scheme:

- Reference signal : not stable (transmission)
- Two cavity mixing scheme can get better performance
  (beam flight time measurement)

Conclusion & Future Work

Conclusion

- ✓ Four dual-cavity BAM has been designed, fabricated and installed at SXFEL
- ✓ A two cavity signals mixing scheme to measure the beam flight time/beam arrival time has been proposed & useful for SASE Self-seeding FEL
- ✓ Measured beam flight time via Typical vs. New Proposed scheme: measured best results: 37 fs

Future Work

- Place the RF front-end & ADC inside the tunnel
  - → shorten the RF signal transmission length
  - → stable environment, such temperature, vibration, noise
- Optimize the RF cables
- Optimize BAM RF front-end electronics
- Optimize phase algorithm

Acknowledge

- Appreciated for the support from National Natural Science Foundation of China (No. 11375255 and No. 11375254)

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- Appreciated for the help from beam operation group of SXFEL in beam experiment

Thanks for your attention

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