The Recent LLRF Activities in Chinese Labs - Addition

Contributions from Chinese labs/universities who are absent from this conference

Speaker: Zheng Gao

- Introduction
- LLRF Activities in Chinese Universities

  LLRF R&D in *University of Science and Technology of China* (*USTC*)

  LLRF R&D in Tsinghua University

  LLRF R&D in Chongqing University
- LLRF Activities in Chinese Research Institutes

  LLRF R&D in *Institute of High Energy Physics (IHEP)*

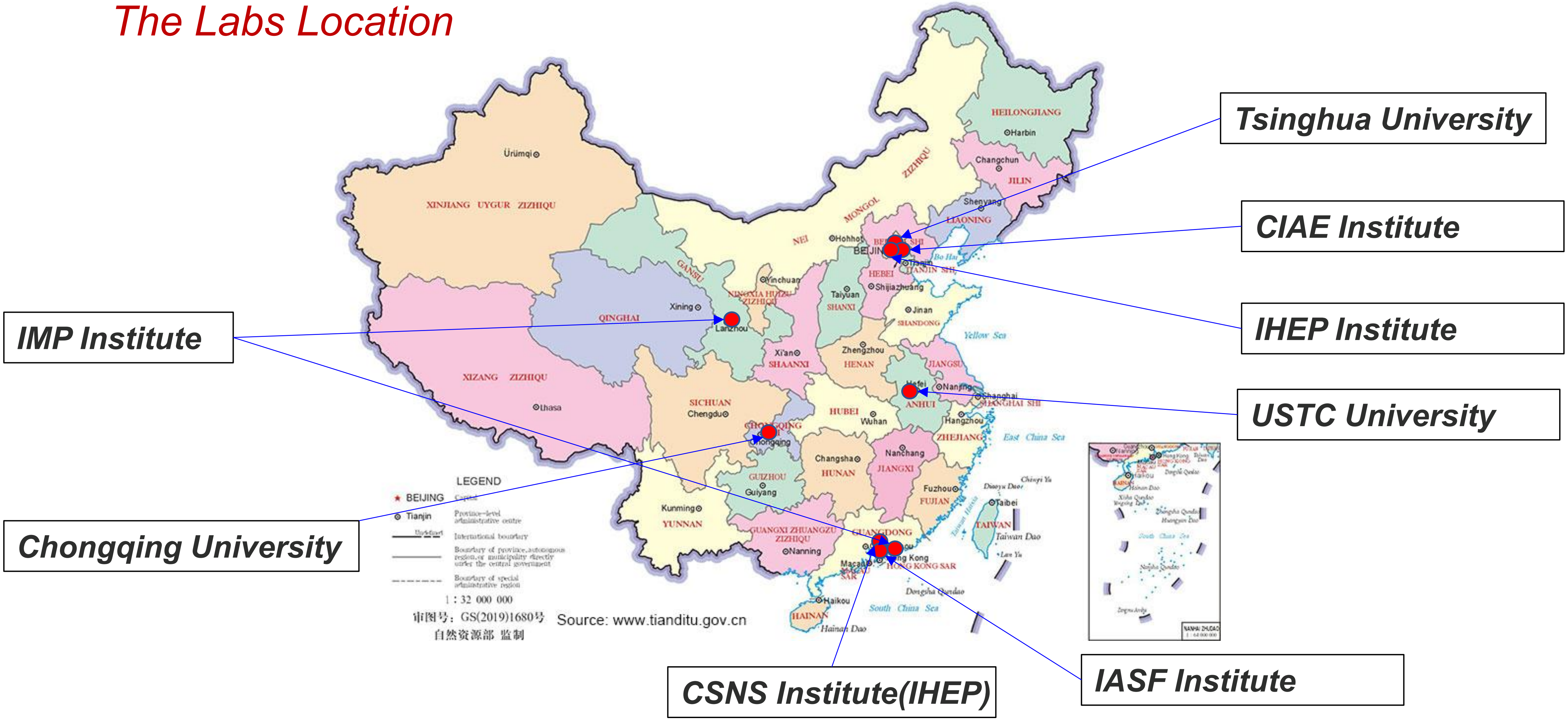
  LLRF R&D in *Institute of Advanced Light Source Facilities* (*IASF*)

  LLRF R&D in *China Institute of Atomic Energy* (*CIAE*)

  LLRF R&D in *Institute of Modern Physics* (*IMP*)
- Summary

Introduction – Contributions from Labs

The Labs Location



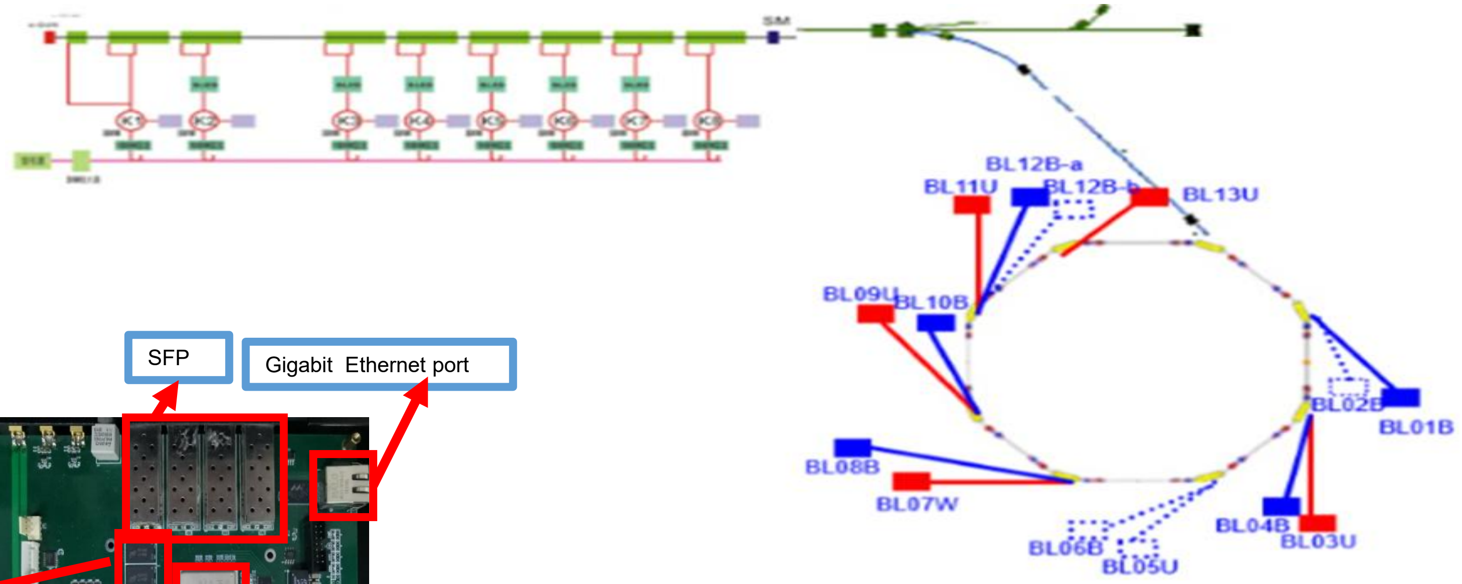
LLRF R&D in *University of Science and Technology of China (USTC)*

Authors:

Zeran Zhou[1], Ziyu Xiong[1], Fangfang Wu[1], Kai Zhang[1], Xiaofang Hu[1], Baiting Du[1], Kunlin Wu[1]

1 University of Science and Technology of China (USTC)

HLS-II LLRF System



Hefei Light Source II (HLSII):

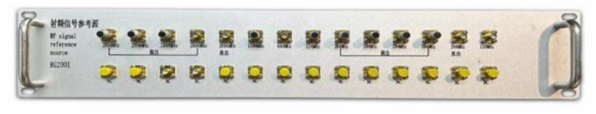
Linac (8 sections)

▪ Electron energy	0.8 GeV
▪ Repetition frequency	1 Hz
▪ Working frequency	2856 MHz

Storage Ring

▪ Perimeter	66.13 m
▪ Frequency	204 MHz
▪ Current	400 mA

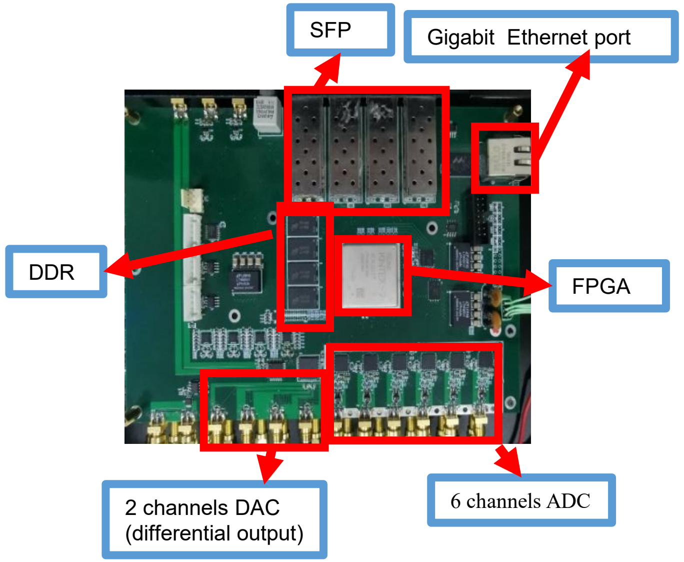
Signal source



Frequency synthesizer

Signal processor

➢ The LLRF system (2856M) operating at HLS II Linac

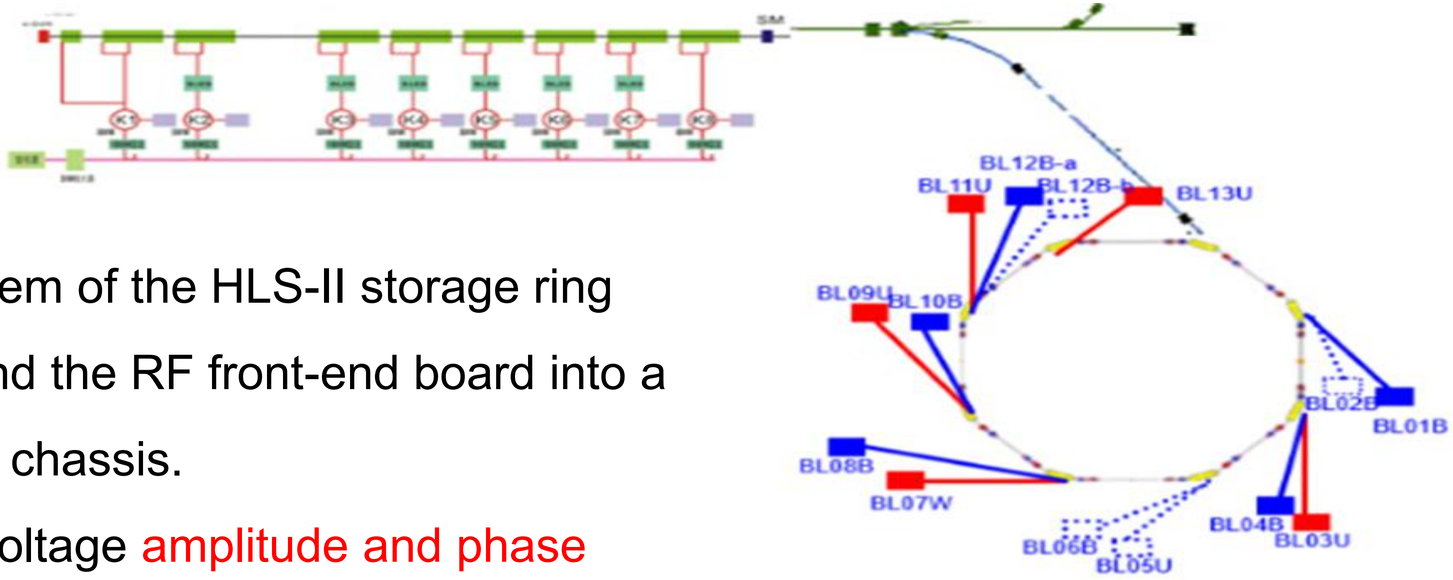


➢ The digital board of Linac LLRF

Since May. 2022, three self-developed LLRF processors have replaced the No. 6,7, 8th MTCA based processors in HLS II. They have been running smoothly and reliably over three years, without any failure. And the long-term amplitude and phase stability of closed loop are respectively 0.1% and 0.10° (RMS),which ensuring the stable operation of HLS II under the top-off injection mode.

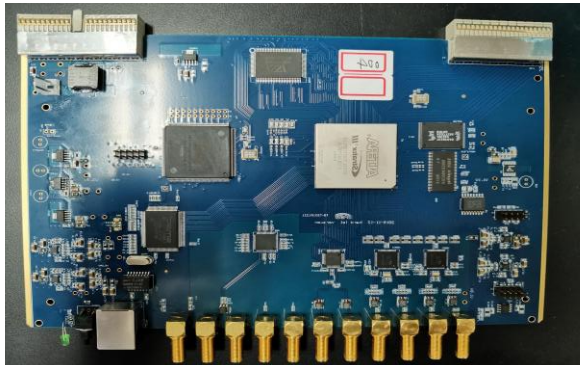
Hefei Light Source (HLS) is a dedicated 2.5-generation synchrotron radiation facility for the vacuum ultraviolet and soft X-ray region. Its main components include an 800 MeV linear accelerator injector and an 800 MeV electron storage ring. The facility is equipped with 10 beamlines and experimental stations, as well as 5 bending-magnet beamlines.

HLS-II LLRF System (cont.)

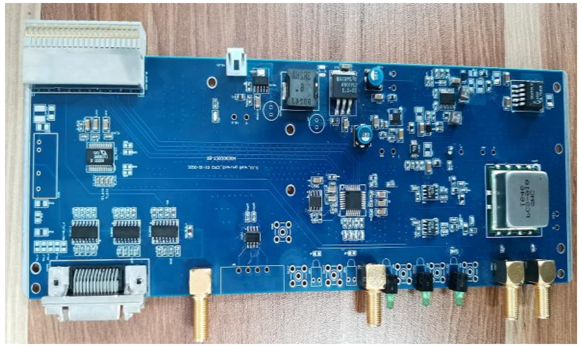


The 204 MHz normal-conducting RF LLRF system of the HLS-II storage ring integrates the digital signal processing board and the RF front-end board into a 6U CPCI form factor, housed within a single 6U chassis.

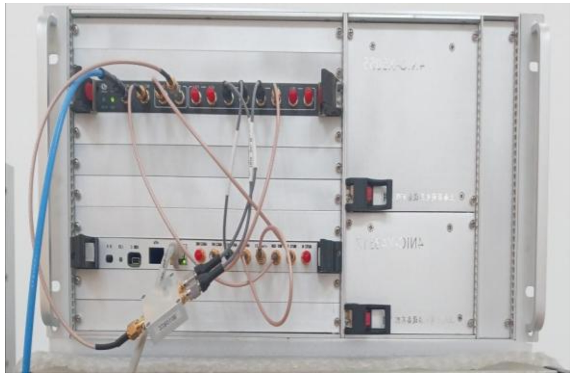
Under closed-loop beam operation, the cavity voltage amplitude and phase stability can reach RMS ≤ 1% and 0.8° @ 150 kV.



- The digital board in Storage ring LLRF

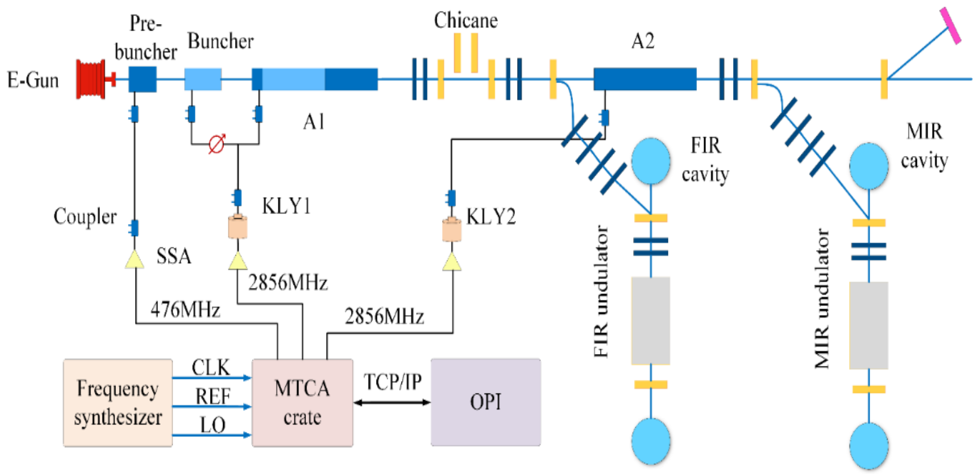


- Tuning Motor Driver Board

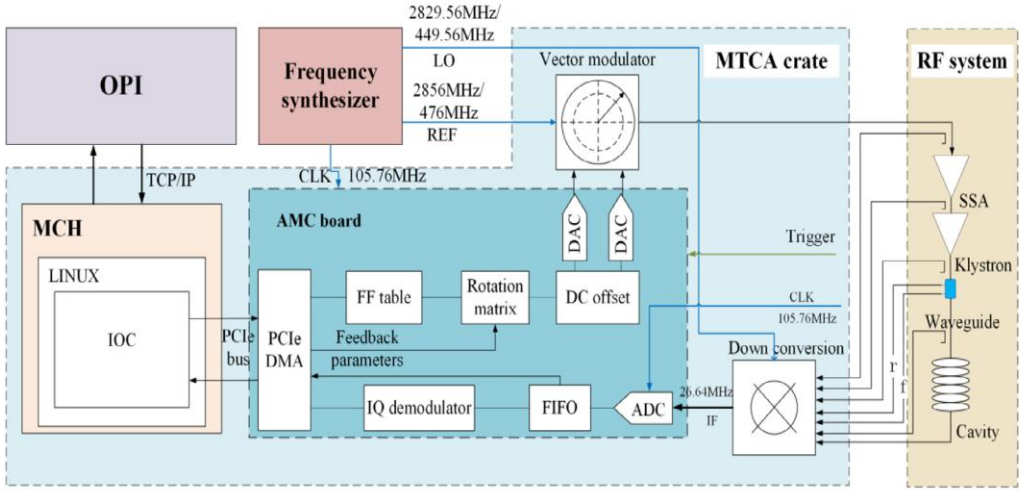


- The LLRF system(204M) operating at HLS II Storage ring

Infrared Free Electron Laser (IR-FEL) LLRF system



➢ The IR-FEL Linac microwave acceleration structure.

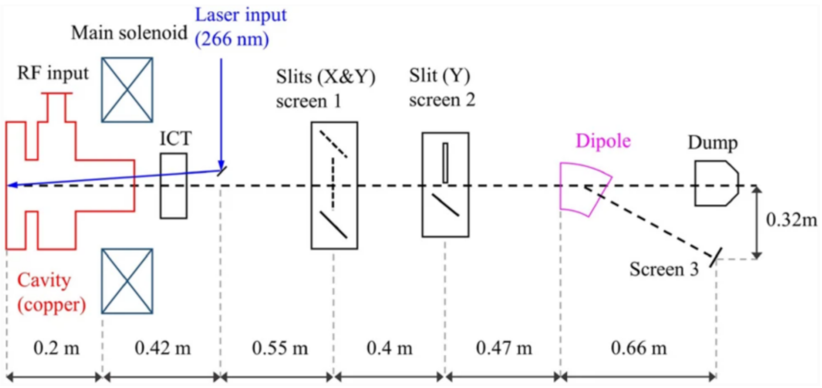


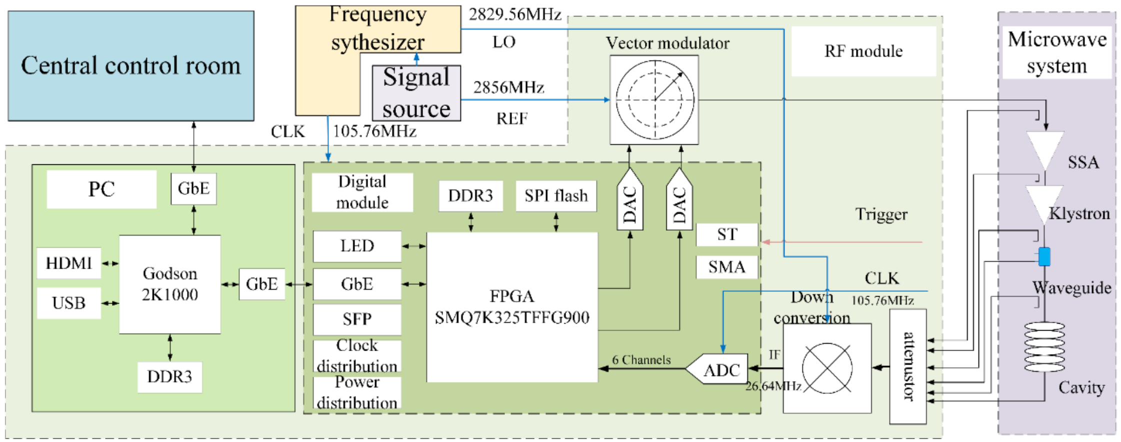
➢ Schematic of DLLRF for IR-FEL.

The infrared free-electron laser facility (IR-FEL) is a new free-electron oscillator user facility in the University of Science and Technology of China (USTC), which has come into user operation in September 2021. The LLRF system consists of three MTCA-based LLRF units: one operating at 476 MHz and two at 2856 MHz, with a repetition rate of ~10 Hz and a pulse width of 6 μs.

➢ The LLRF system operating at IR-FEL

Terahertz Free Electron Laser(NFThz) LLRF system





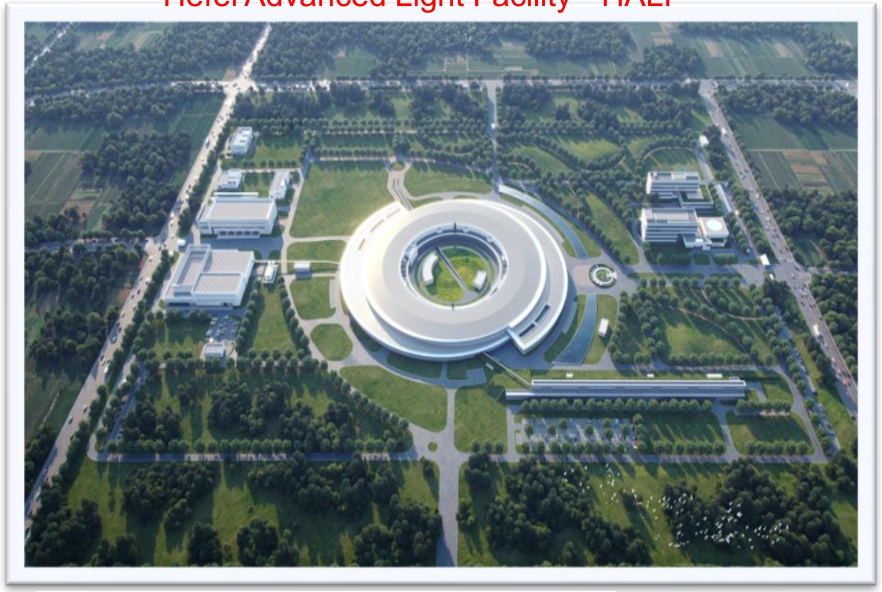
➢ Schematic of DLLRF for Thz.

The terahertz near-field high-throughput material property testing system, led by the USTC, is a national major scientific research instrument that passed acceptance by an expert panel organized by the National Natural Science Foundation of China on July 27, 2024. The device is designed with an electron energy of approximately 15 MeV and employs an S-band klystron which operates at a repetition rate of 2 Hz with an RF frequency of 2856 MHz. The LLRF system adopts a self-developed S-band digital LLRF to ensure stable operation.

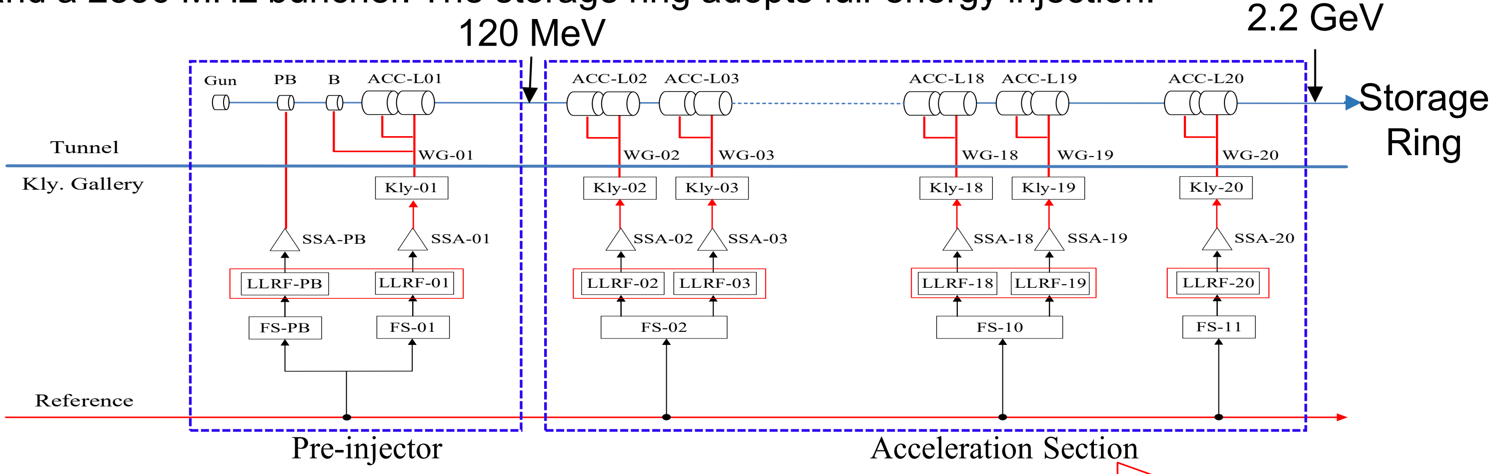
➢ The LLRF system operating at Thz

Hefei Advanced Light Facility (HALF) LLRF system

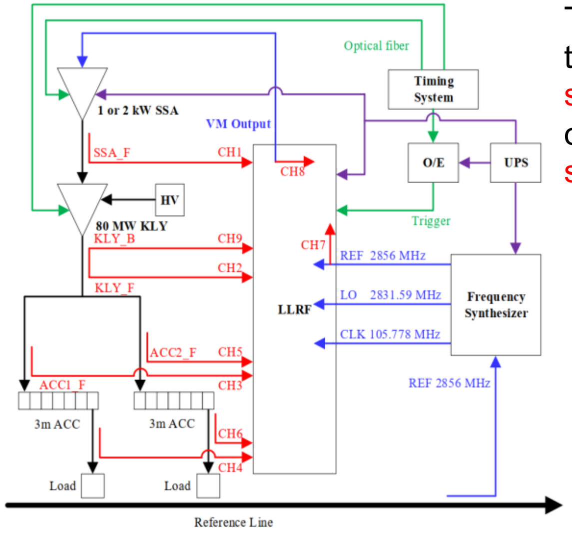
Hefei Advanced Light Facility - HALF



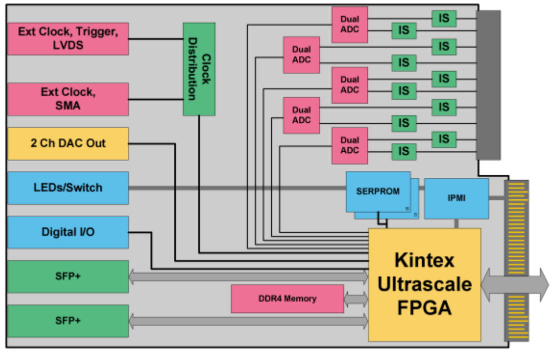
The Hefei Advanced Light Source has a circumference of 480 m and a 2.2 GeV electron accelerator accommodating 35 beamlines. The injector consists of a 476 MHz pre-buncher and a 2856 MHz buncher. The storage ring adopts full-energy injection.



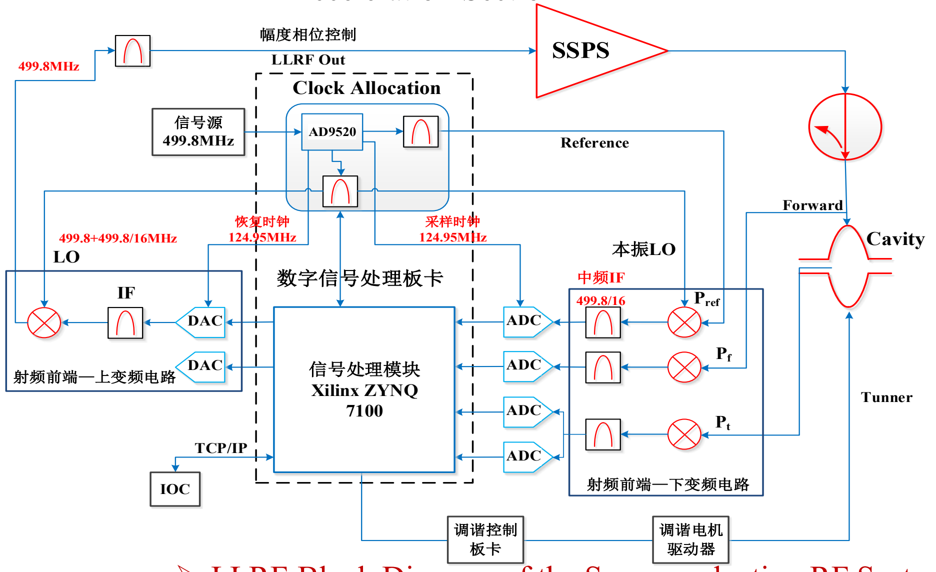
The storage ring LLRF stabilizes the amplitude and phase of the microwave fields in the accelerating structures, with RMS specifications of 0.2% and 0.2°, respectively. Under closed-loop operation with beam, the cavity voltage amplitude and phase stability can reach RMS ≤ 1% and 0.8° at 150 kV.



➤ Linac LLRF Block Diagram



➤ The MTCA.4 digital board of Linac LLRF



➤ LLRF Block Diagram of the Superconducting RF System

LLRF R&D *in Tsinghua University*

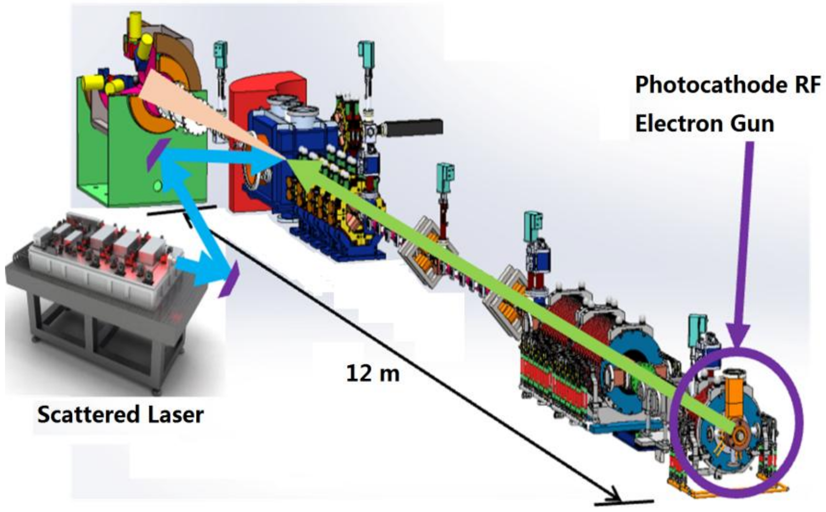
Authors:

Prof. Huang, Prof. Du[1], Dr. Jia[1], Prof. Li[1], Prof. Tang[1], Prof. Chen[1],

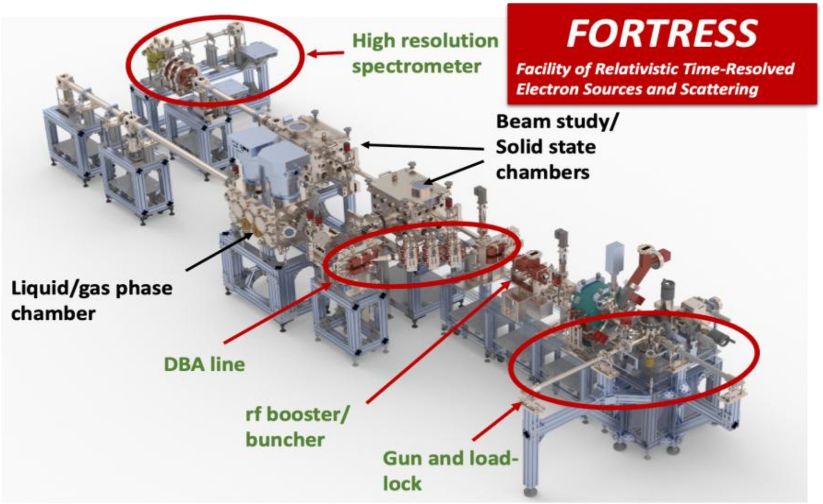
1 Tsinghua University

SYNC&LLRF of THU

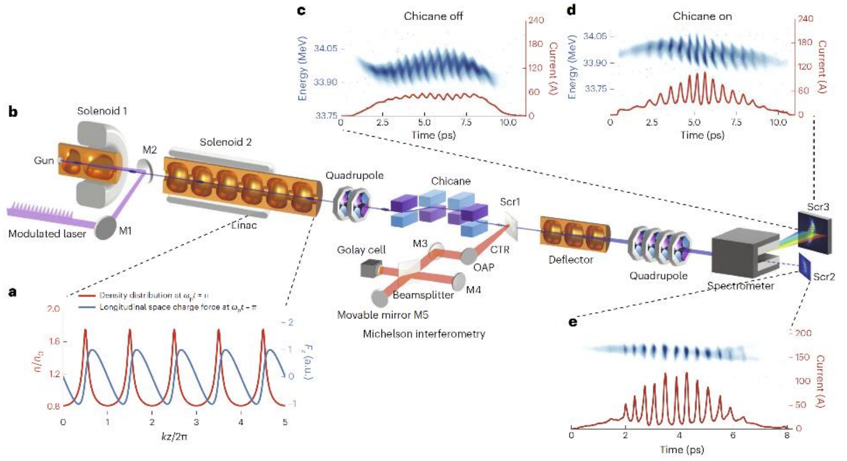
- **Developed for Inverse Compton scattering X-ray source, Ultra-fast electron diffraction/microscopy, THz facility and plasma wake-field acceleration which are based on photoinjector and laser.**
- **Jointly developed with LBNL at early stage，and upgraded and developed independently later.**



The inverse Compton scattering device



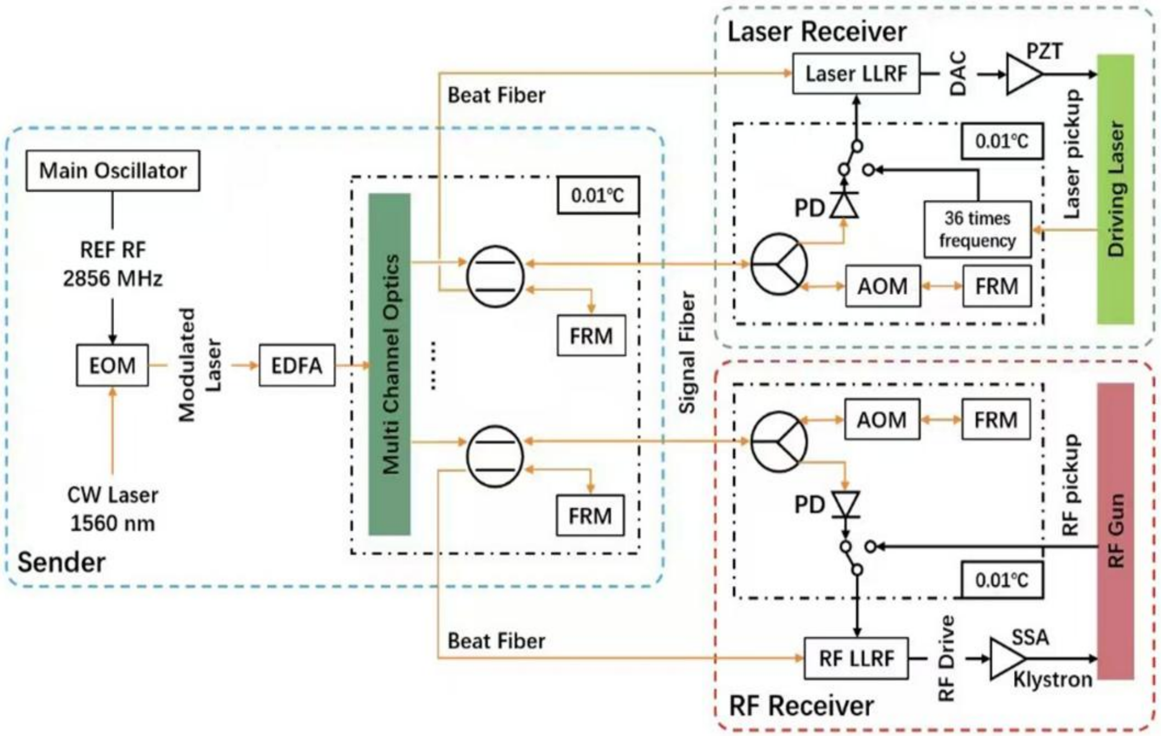
The Facility of time-resolved electron sources and scattering



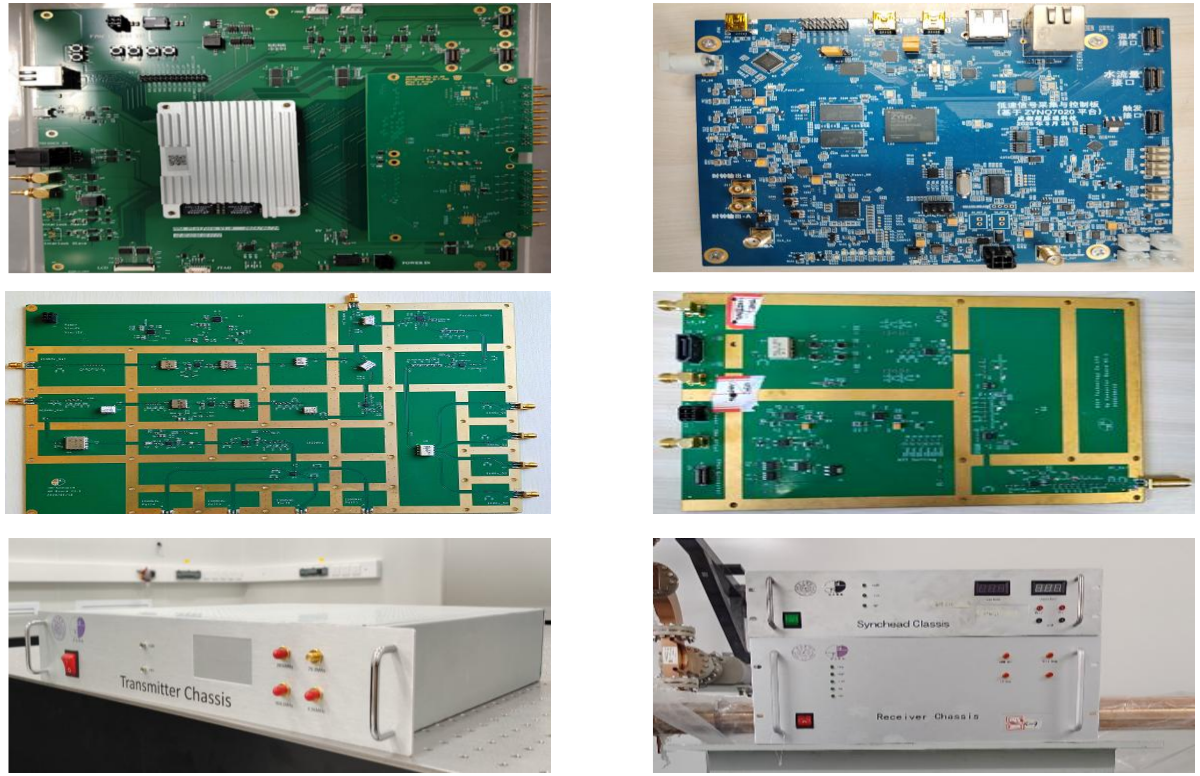
The terahertz electron beams

SYNC&LLRF of THU

- A synchronization and LLRF system based on CW laser has been developed:
  - 2 digital boards + more than 20 RF front boards = more than 10 chassis.
  - 2 bands reference RF(REF): S-band 2856MHz and L-band 1300MHz.
  - 4 bands RF receiver and 1 laser receiver: S-band 2856MHz、X-band 11424MHz、L-band 1300MHz、VHF-band 216.67MHz and Laser 79.3MHz.



Schema of CW laser synchronization system

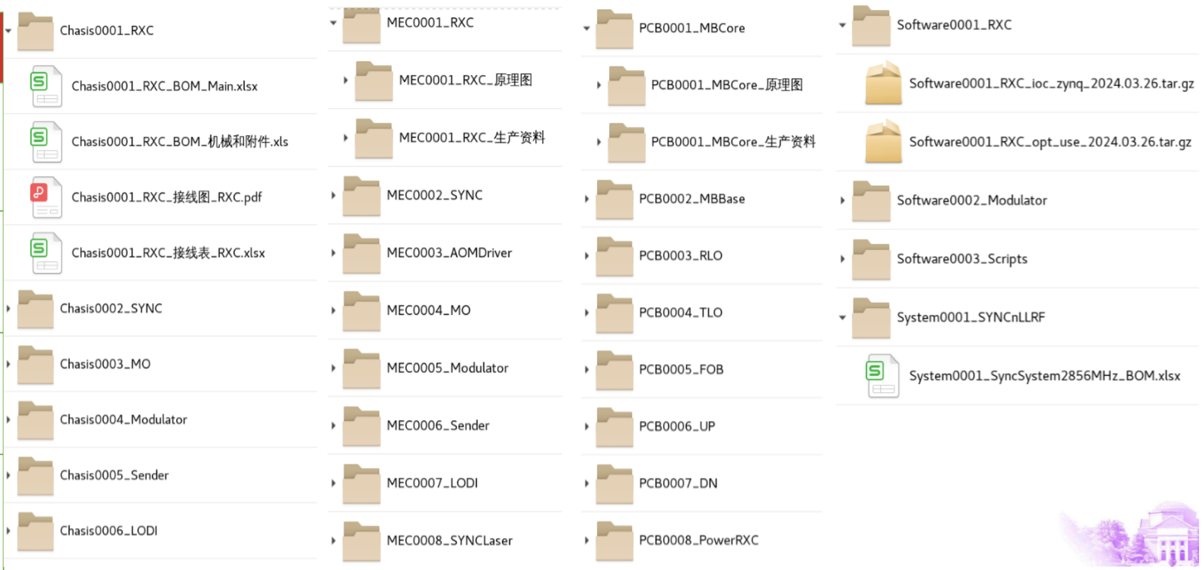


Show of some hardware

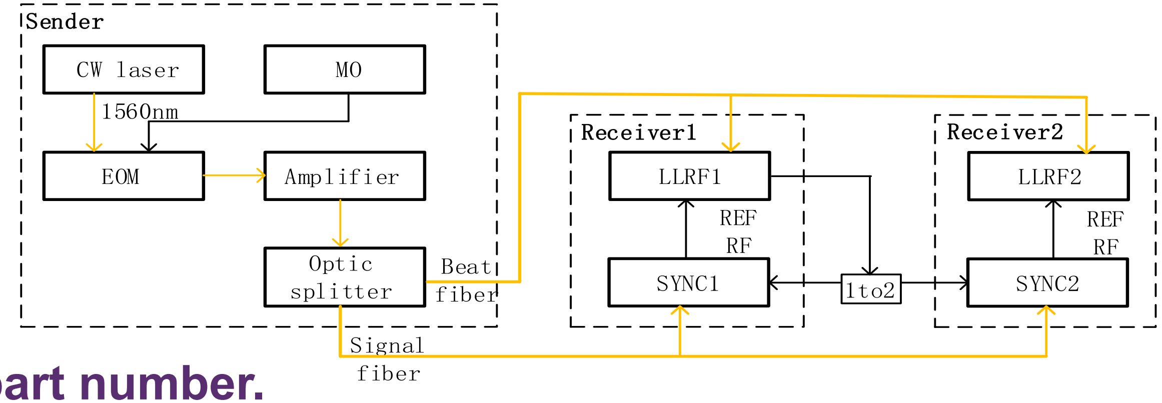
SYNC&LLRF of THU-Achievements

Main parameters

Content	Parameter
REF's slow drift between two RF ends, tested including LLRF	Peak to peak 14fs@24h, S band Peak to peak 35fs@24h, X band
L-band LLRF	Amplitude stability RMS 0.0041% Phase lock accurate RMS 0.01°
S-band LLRF	Amplitude stability RMS 0.0074% Phase lock accurate RMS 0.01°
X-band LLRF	Amplitude stability RMS 0.0097% Phase lock accurate RMS 0.03°
VHF-band LLRF	Amplitude stability RMS 0.0046% Phase lock accurate RMS 0.0023°
Laser LLRF	Phase lock accurate RMS 0.02°



Production management

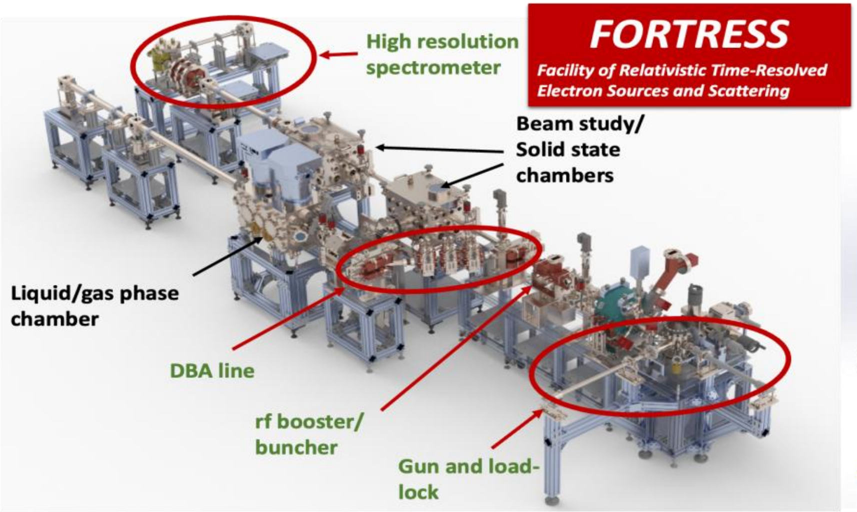


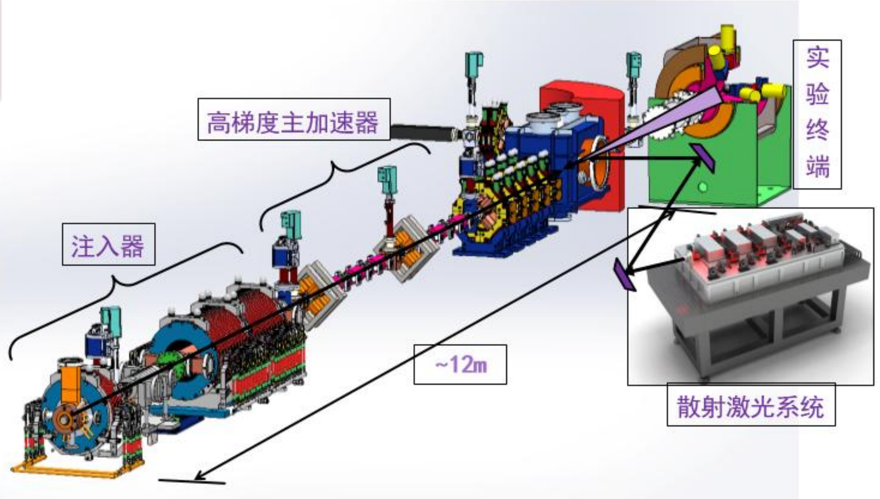
Test method of REF's slow drift between two RF ends

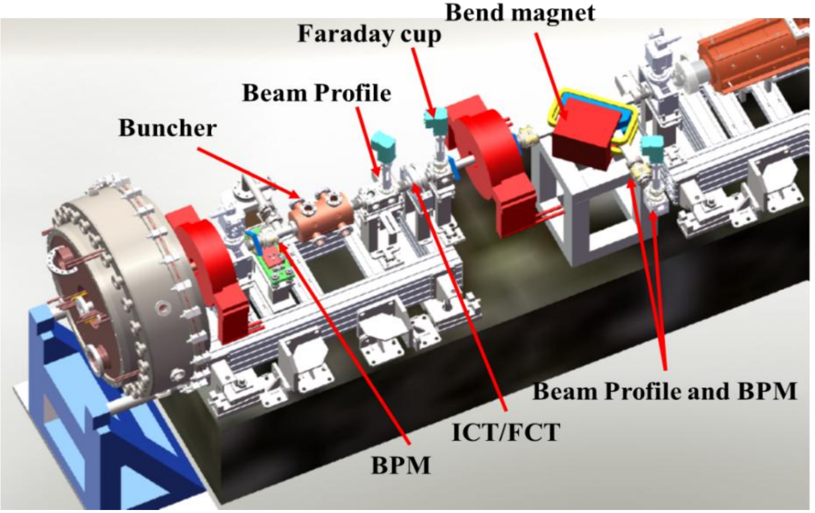
- **The whole system can work at room temperature.**
- **Academic:**
  - **1 technological appraisal.**
  - **2 papers, 5 invention patent.**
- **Production:**
  - **Management with part number.**
  - **Stable mass production.**

SYNC&LLRF of THU-Application

- FORTRESS:
  - An ultra-high spatiotemporal resolution electron microscope.
  - Sub-5-fs RMS bunch duration and synchronization are demonstrated.
  - 2 manuscripts are under review at PRL.
- VIGAS:
  - The first compact gamma-ray source with MeV-level energy of the world.
  - The synchronization and LLRF system has been deployed, currently under beam commissioning.
- VHF gun test platform:
  - A VHF electron gun that operates in CW mode at 216.667 MHz.
  - Cathode gradient 27 MV/m and gun voltage 780 keV.







LLRF R&D in *Laboratory for Ultrafast Transient Facility in Chongqing University (UTEF)*

Authors:
Junqiang Zhang[1], Lei Yang[1], Zhongquan Li[1]

1 Ultrafast Transient Experimental Facility (UTEF)

Linac LLRF @ UTEF

Ultrafast Transient Experimental Facility (UTEF) is composed of a synchrotron radiation light source and an electron microscope.
UTEF is developed in 2 phases, phase I is a pre-research project, including a 500MeV light source and an electron microscope platform; phase II including a 3GeV light source and an electron microscope cluster。

Timeline of UTEF:

2024/04	Facility construction starts
2025/05	Linac starts installation
2026/01	Storage ring starts installation
2026/12	Project completed

Parameters of 500MeV ring

Parameters	Value	Unit
Energy	0.5	GeV
Ring circumference	76.78	m
Beam current	0.5~1	A
Focusing type	QBA	
Natural emittance	8.56	nm rad
Working point（x, y）	6.198, 3.357	-
Length of straight section	8*4	m
Working frequency	499.8	MHz
Energy loss per turn	4.34	keV
Natural energy spread	0.37×10^{-3}	

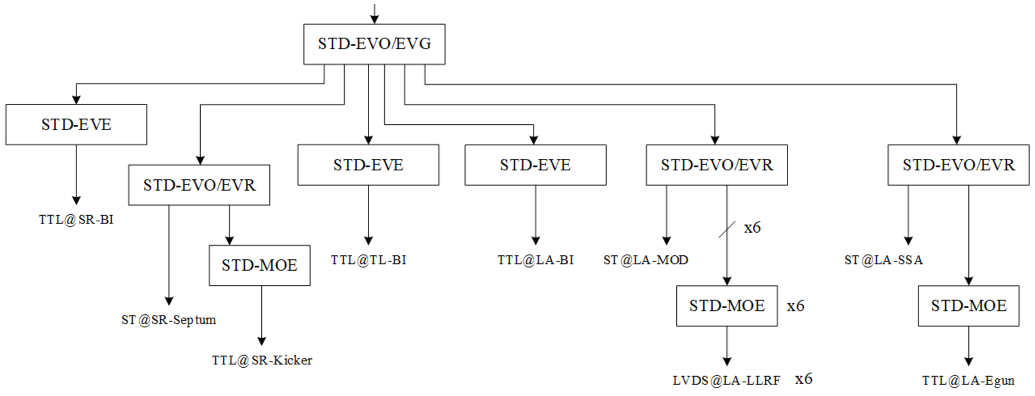
Linac LLRF @ UTEF

NATIVE-R2

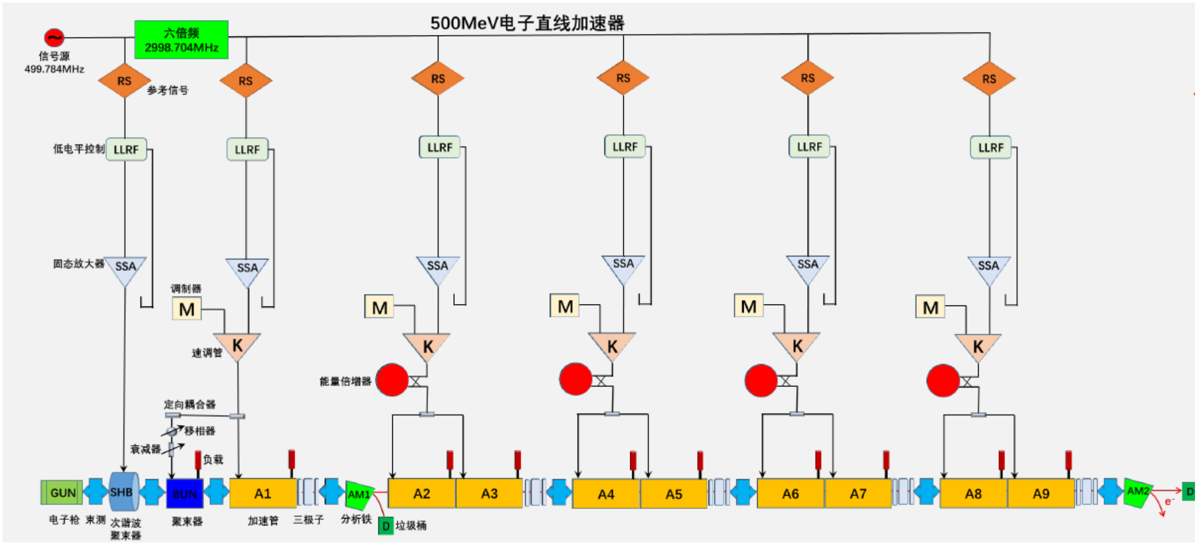
DWC8VM1

SIS8300KU

- MTCA.4 based LLRF system



- Event timing system

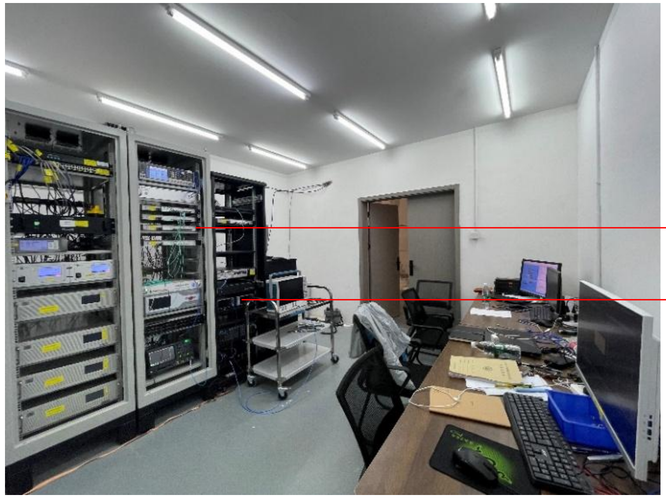


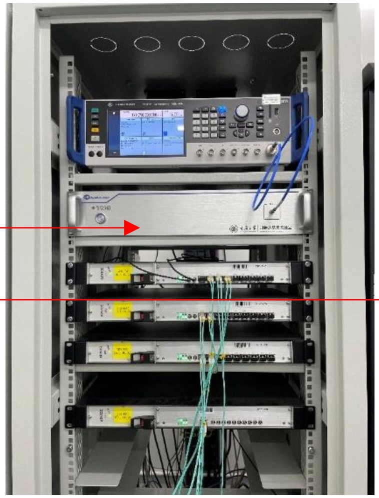
- The layout of the Linac

Parameters of 500MeV Linac

Parameters	value	unit
Beam energy	500	MeV
Beam charge	≥1	nc
Beam length	≤1	ns
Energy spread	≤0.5 (rms)	%
Normalized emittance	≤50 (rms)	mm.mrad
Repetition rate	2	Hz
Working frequency	499.79/2998.74	MHz
Amplitude stability	0.2 (rms)	%
Phase stability	0.1 (rms)	°

E-gun commissioning

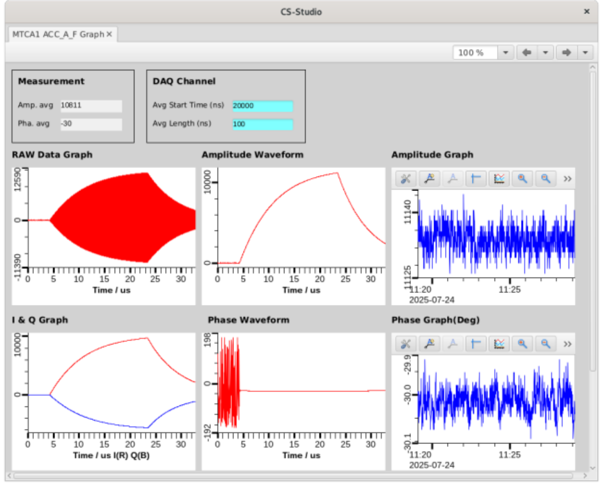




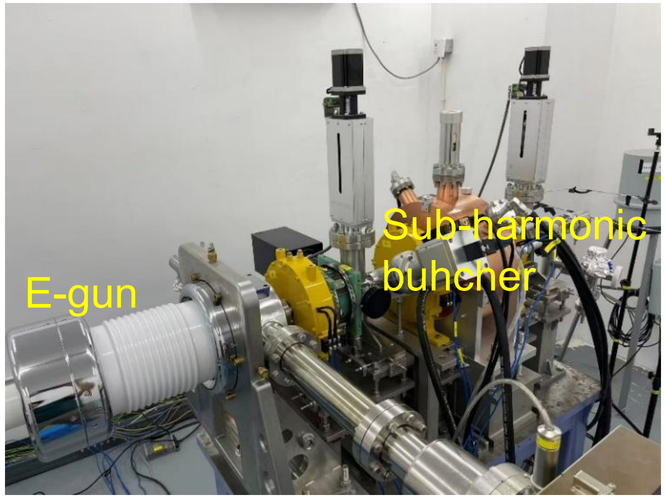
Timing system

LLRF

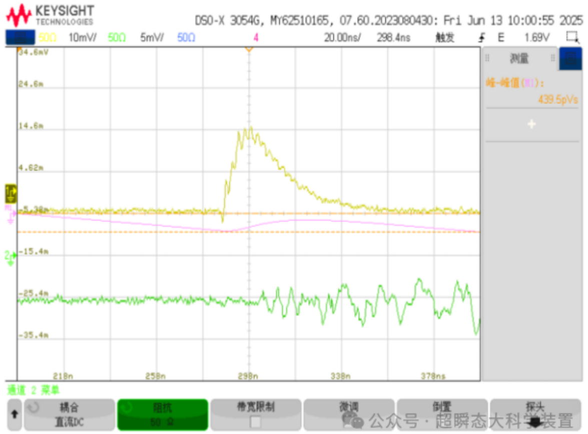
Amplitude stability: 0.02% (rms)
Phase stability: 0.03° (rms)

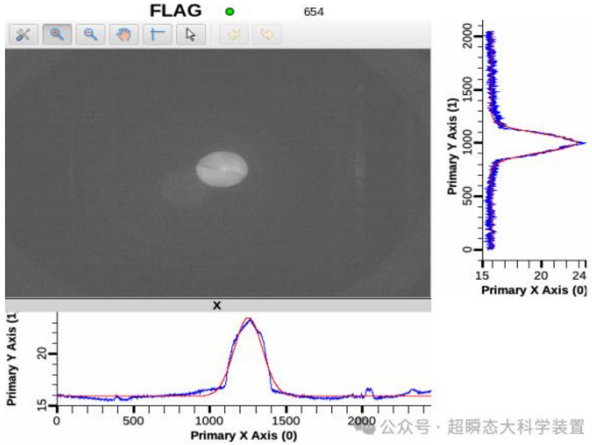


Pickup waveform



E-gun control room and tunnel





Beam @ ICT & profile

LLRF R&D in *Institute of High Energy Physics* (*IHEP*)

Authors:

Xinpeng Ma[1], Nan Gan[1], Yajie Mu[1], Yongyi Peng[1], Wenbin Gao(Ph.D) [1]

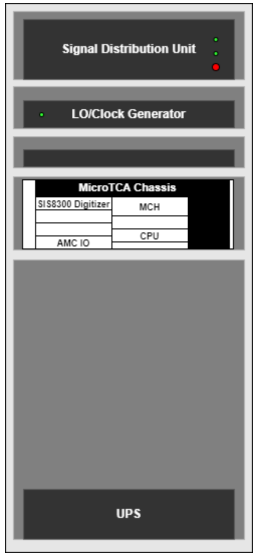
1 Institute of High Energy Physics, Chinese Academy of Sciences

LINAC LLRF at IHEP

➢ HEPS 500MeV LINAC

Talk: X. Ma, Wednesday

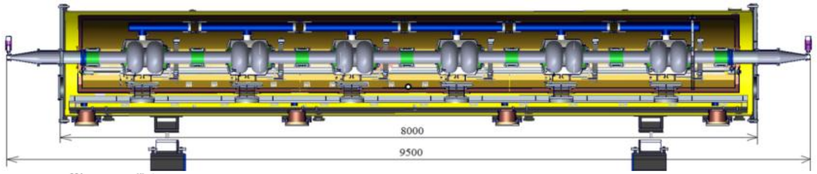
➢ BEPCII 2.5GeV LINAC

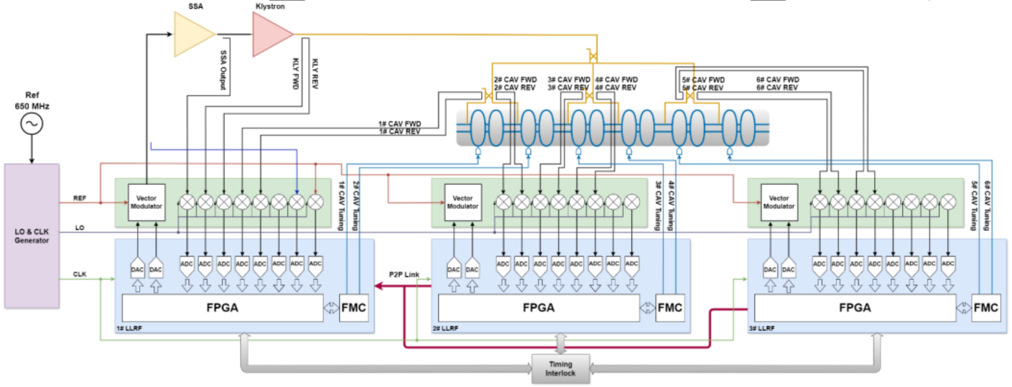


➢ LINAC LLRF Cabinet

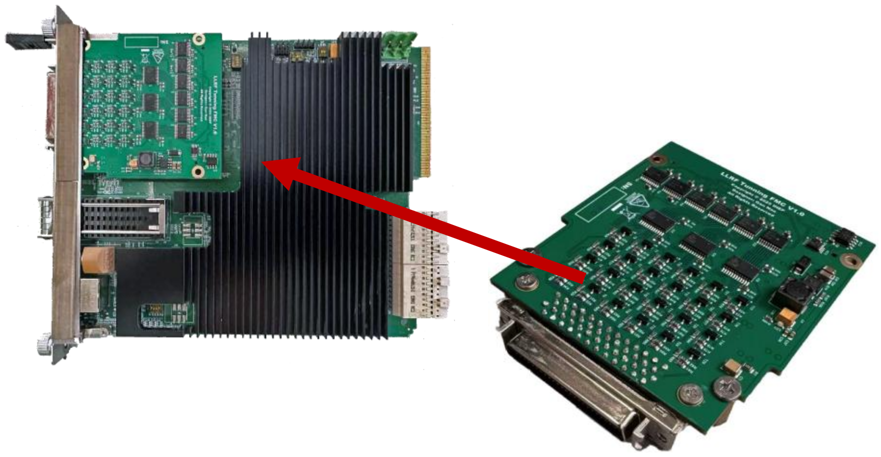
- **Mature Down-Conversion Architecture**
  - Proven design with widespread deployment in HEPS and BEPCII Linac
- **System Deployment**
  - HEPS: 5 sets @ 2998.8 MHz
  - BEPCII: 22 sets @ 2856 MHz
- **Hardware Configuration**
  - Chassis: 3U / 9U
  - Control: 1 CPU / PS / MCH
  - Digitizer: 1 × SIS8300L2
  - Custom RTMs: wideband (650 MHz – 6 GHz)
  - 1 × Trigger Distribution AMC Board
  - 1 × SSA

LLRF system for CEPC EDR Full-scale 650 MHz cryomodule





- ■ Cryomodule Design:
- • Six 2-cell superconducting cavities
- • Operating gradient: 25 MV/m
- • Quality factor $Q_0=3\times10^{10}$
- • 1 klystron RF system powers all 6 cavities
- ■ Vector-Sum LLRF Control System
- • Multi-FPGA architecture for cavity signal acquisition and processing
- • Low-latency point-to-point links transmit probe, forward, and reflected signals to the master controller



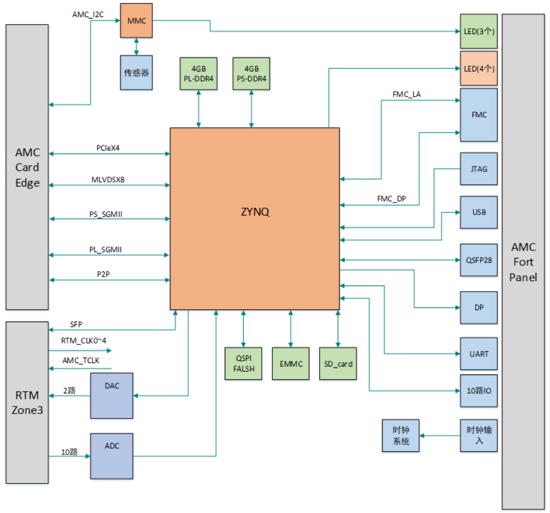
Tuning FMC

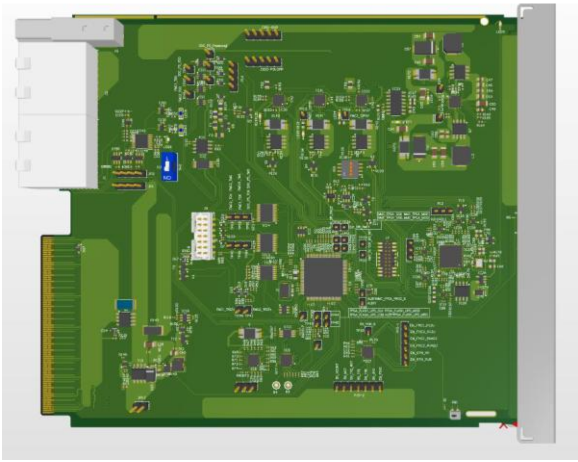
In-house developed MicroTCA hardware platform at IHEP

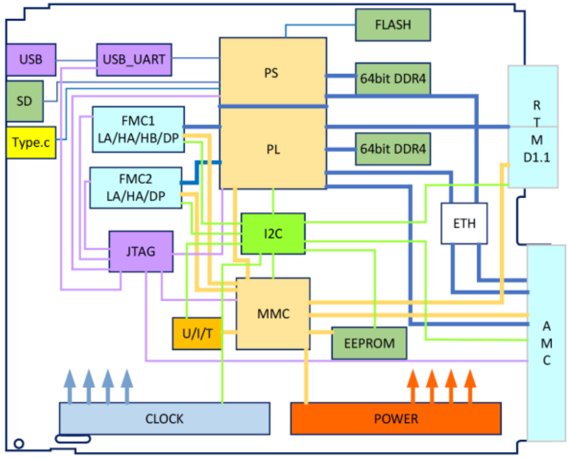
Zynq ultrascale based digitizer:
•Onboard 1 ZYNQ chip;
•8-ch 16bit ADCs, 2-ch 16bit DACs
•The PS side of ZYNQ carries 1 set of DDR chips, with a capacity of 4 GB;
•The PL side of ZYNQ carries 1 set of DDR chips, with a capacity of 4 GB;
•The ZYNQ supports four boot modes: JTAG, SPI-Flash, eMMC, and SD card;
•The board includes 1 FMC connector;
•ZYNQ outputs one QSFP28 optical port to the front panel;
•ZYNQ outputs one DP interface to the front panel;
•The board edge connector (golden finger) supports PCIe x4;
•The board edge connector supports 2 Gigabit Ethernet interface;
•The board edge connector supports one P2P interface, with a data rate of 10 Gbps;

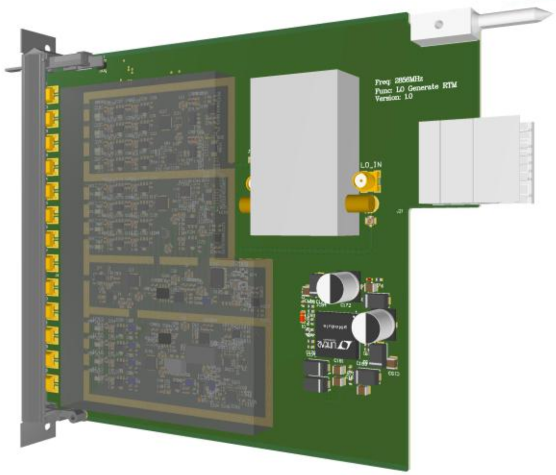
Zynq ultrascale based dual-fmc carrier:
•Main chip: Xilinx Zynq Ultrascale
•FMC interfaces:
•FMC1: All LA HA , HB and DP pins connected (68,48,44;10)
•FMC2: LA, HA, and DP pins connected(68,48;10)
•PCIe support: PCIe Gen.3 x4 (expandable to Gen.3x8 if conditions permit)
•Gigabit Ethernet ports:
•Port 0: Connected to the Processing System (PS) of ZYNQ
•Port 1: Connected to the Programmable Logic (PL) of ZYNQ
•DDR4 memory:
•4 GB DDR4 (2400 MT/s) connected to PS
•4 GB DDR4 (2400 MT/s) connected to PL
•RTM connectivity: Compliant with DESY RTM Class D1.1 (42 LVDS I/O signals, 2 high-speed links)
•Additional interfaces: SD-Card slot, White Rabbit (high-precision time synchronization) support

LO/CLK RTM Board – Key Specifications
- Compatible with MicroTCA.4 RTM, supported by MMC protocol with AMC
- 1 × RF reference input
- Generates 3 frequency types, each distributed to 4 output channels (supports up to 4 DWC applications)
- Reference RF frequency: 2856 MHz (prototype version)
- LO frequency: 2879.8 MHz
- CLK frequency: 95.2 MHz
- IF frequency: 23.8 – 26.775 MHz (typical 25 MHz, IF/CLK = 1/4)
- Input signal level: –10 to +10 dBm
- Output signal level: > 13 dBm
- Provides signal power and board status monitoring via I²C bus
- Includes LNA, power divider, IF band-pass filter (23.8 MHz LC), frequency divider
- LNA jitter performance example @499.8 MHz: 21.4 fs (10 Hz–10 MHz)
- PCB in production (Sep. 2025); Version 2 with temperature control and optimization planned for Q4 2025 – Q2 2026









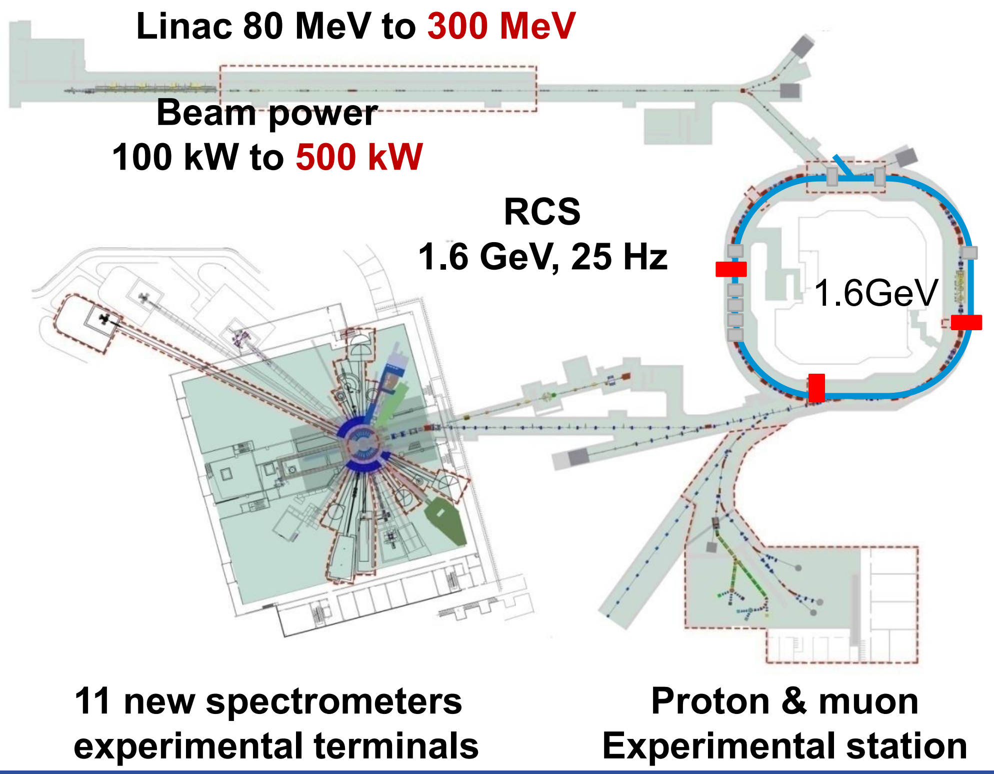
LLRF R&D in *China Spallation Neutron Source* (*IHEP*)

Authors:
Wei Long[1,2], Zhexin Xie[1,2], Jian Wu[1,2], Yang Liu[1,2], Xiang Li[1,2], Xiao Li[1,2]

1 China Spallation Neutron Source (CSNS)
2 Institute of High Energy Physics, Chinese Academy of Sciences

CSNS-II RCS RF system upgrade

- 3 additional 2nd harmonic (MA) cavities
  - To enhance the bunching factor
- Upgrade of CSNS-II RCS LLRF system
  - CPCI bridge chips have been discontinued and are no longer available. Can't back up the hardware!

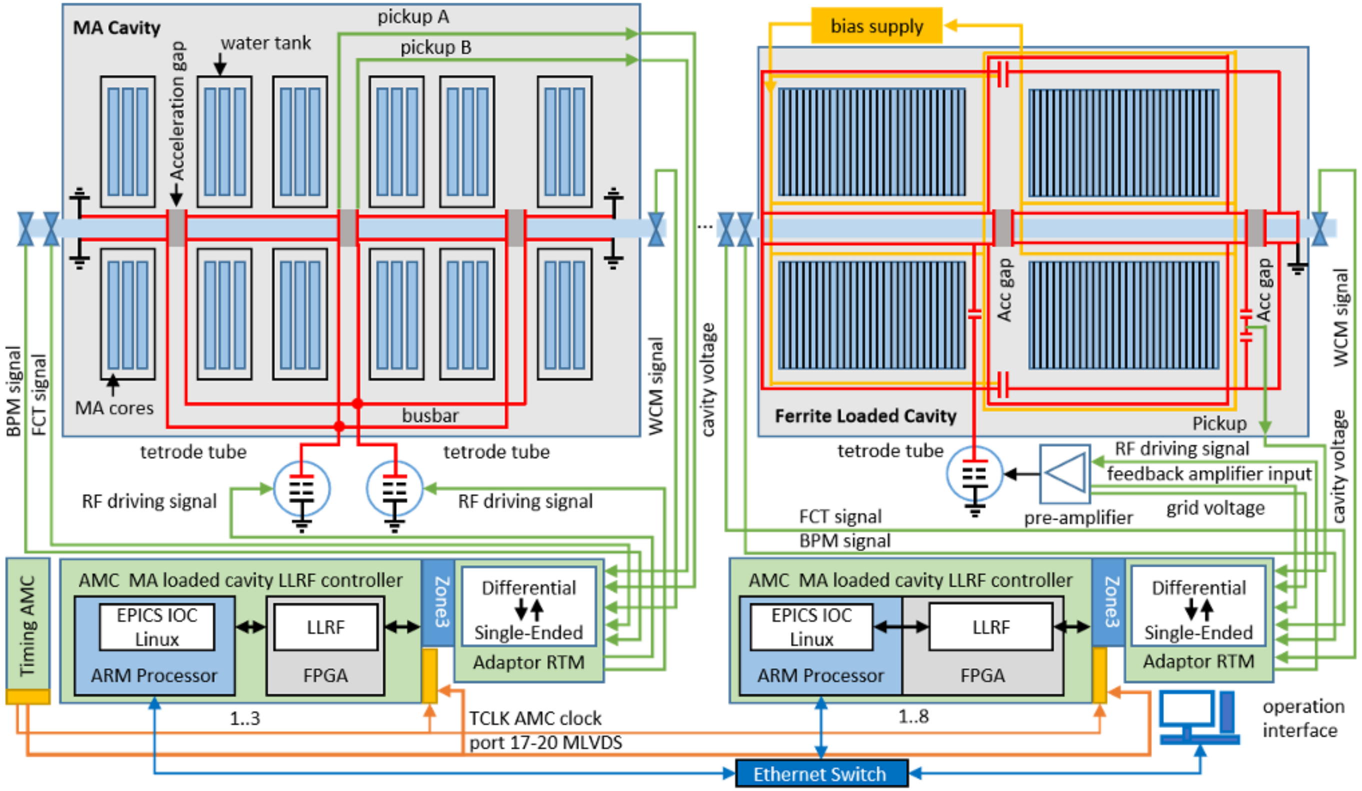


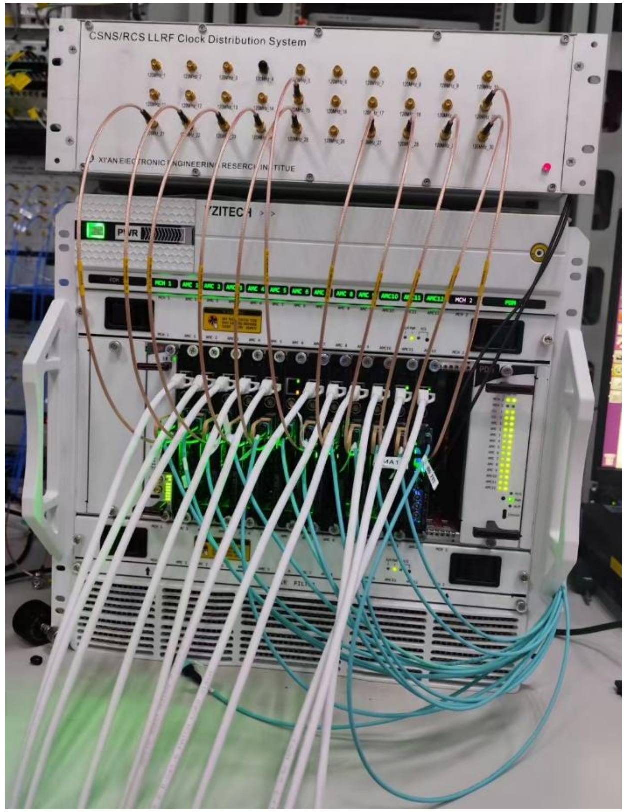
CSNS II upgrade

Phase	CSNS I	CSNS II
Beam power on target	100 kW	500 kW
Linac energy	80MeV	300MeV
Extraction beam energy	1.6GeV	1.6GeV
Average Beam current	62.5μA	312.5μA
Repetition	25Hz	25Hz
Protons per pulse	1.56E13	7.8E13

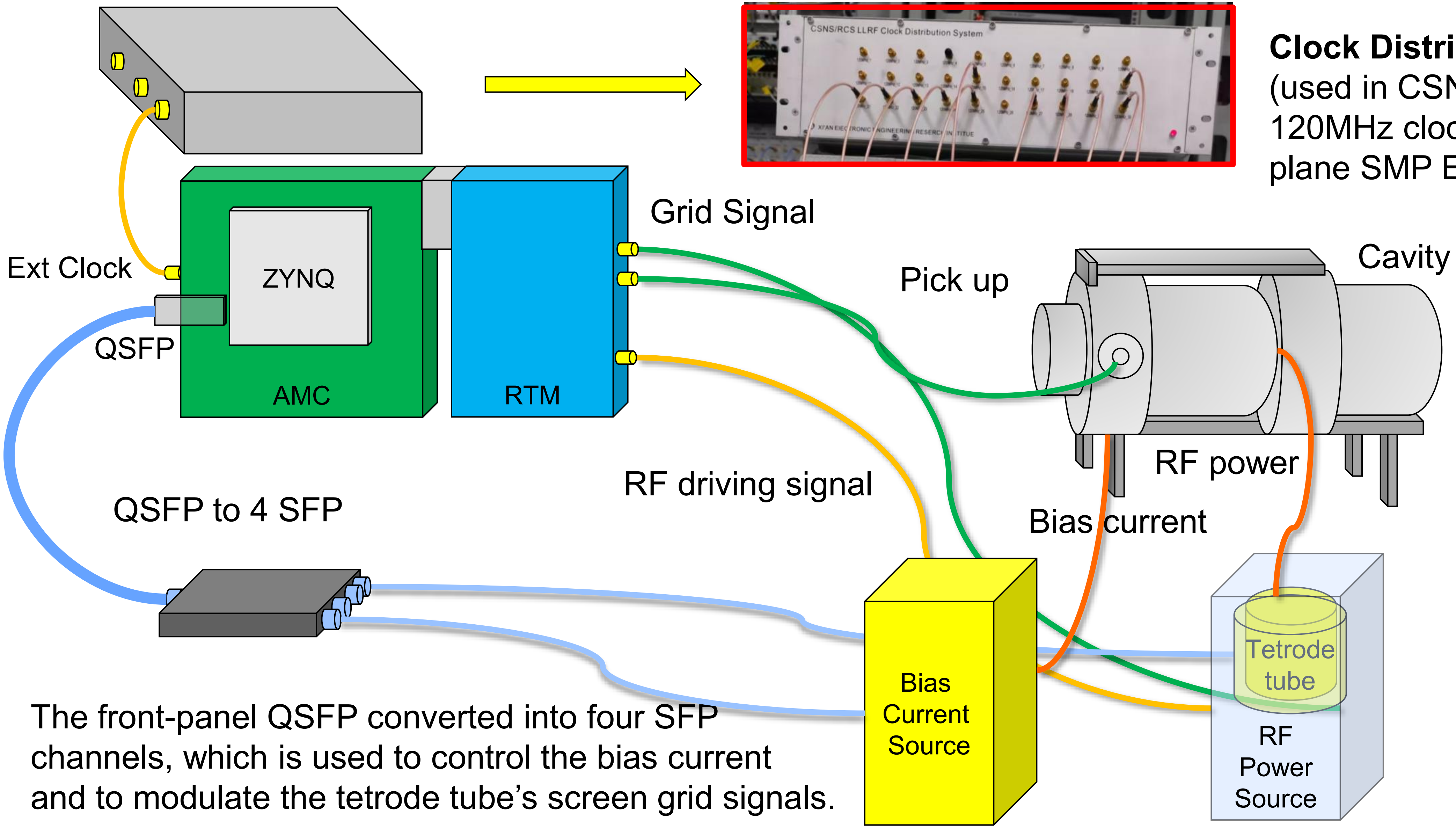
CSNS-II RCS LLRF system

- Upgrade the CSNS-II RCS LLRF system based on MTCA.4
  - Instead of the CSNS-I RCS LLRF hardware platform based on CPCI bus
- Develop domestical MTCA.4 hardware platform
  - Meeting the needs of multiple accelerator systems: RF, control, and beam diagnostics.





CSNS-II RCS LLRF system



Clock Distribution System (used in CSNS-I RCS LLRF) → 120MHz clock → AMC front plane SMP Ext clock input

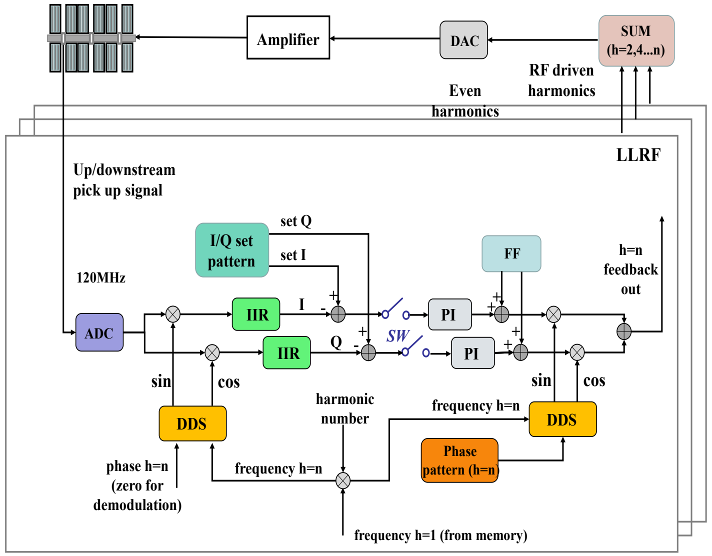
System topology

The front-panel QSFP converted into four SFP channels, which is used to control the bias current and to modulate the tetrode tube's screen grid signals.

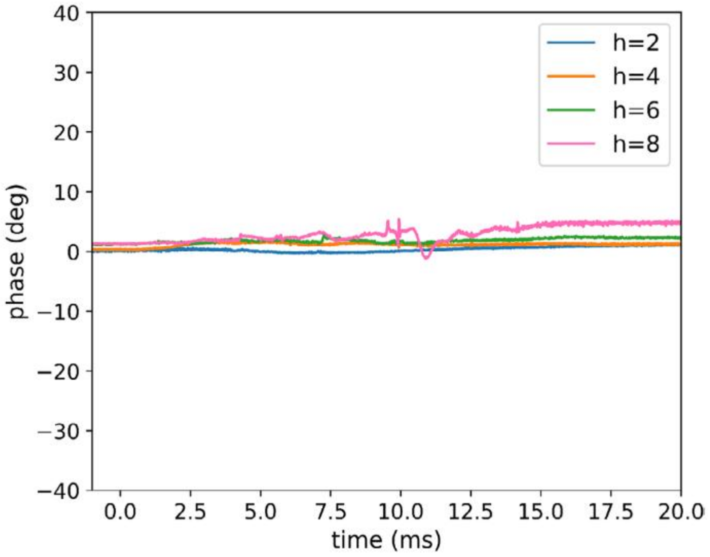
Multi-harmonic feedback control ensures stable beam operation

- J. Wu, et al. Nuclear Science and Techniques, 36 (4), 62

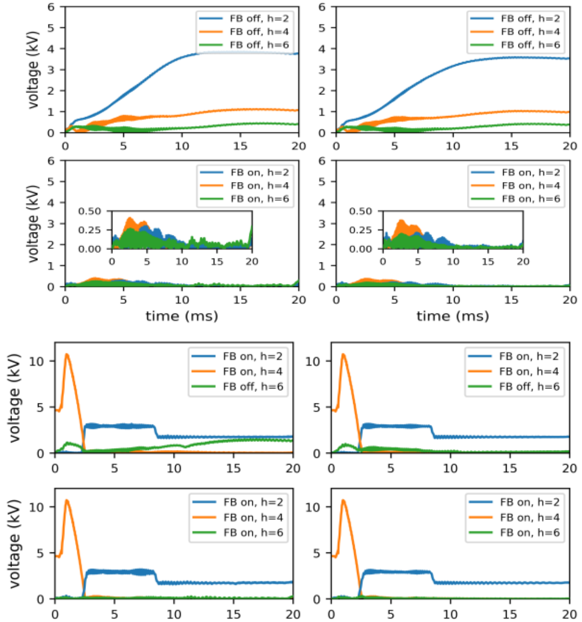
- **Algorithm studied; control framework and loop structure defined by theory**
  - **The CSNS-II RCS Magnetic Alloy Loaded Cavity (MA cavity) features broadband operation, low Q factor, and high accelerating gradient, but harmonic control remains its main challenge.**
  - **Harmonic compensation: low setpoints → A/φ loop instability & increased phase noise**
- **I/Q method: continuous at zero → suitable for low setpoints; but loop delay introduces phase shift → I/Q coupling**
  - **Developed frequency-sweep phase correction → achieves I/Q decoupling & stable feedback**
- **Effective beam loading compensation achieved in 1–7 MHz range**



- Framework of the Multi-harmonic Control Algorithm



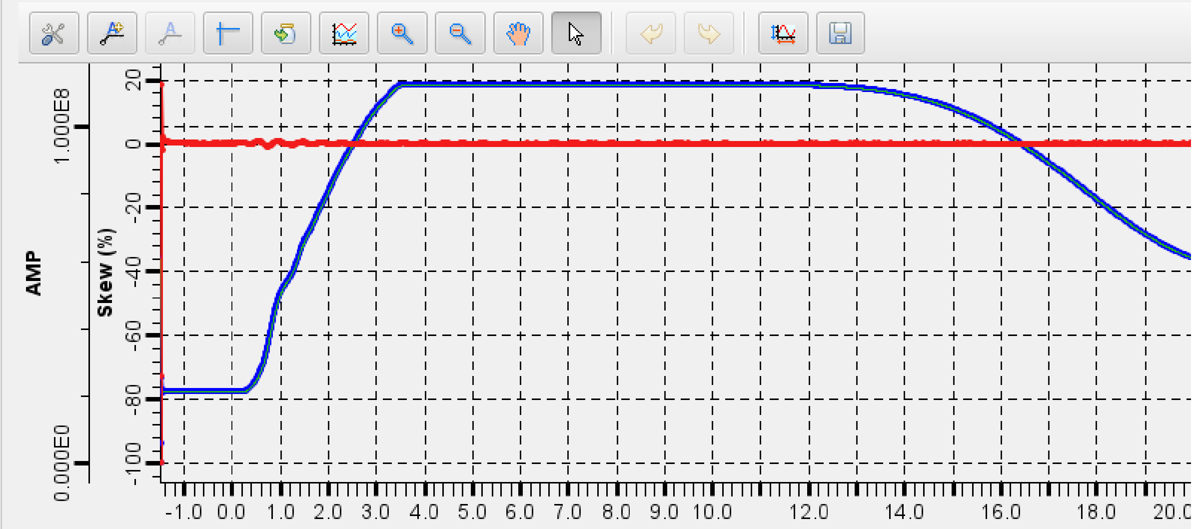
- Loop Phase Correction

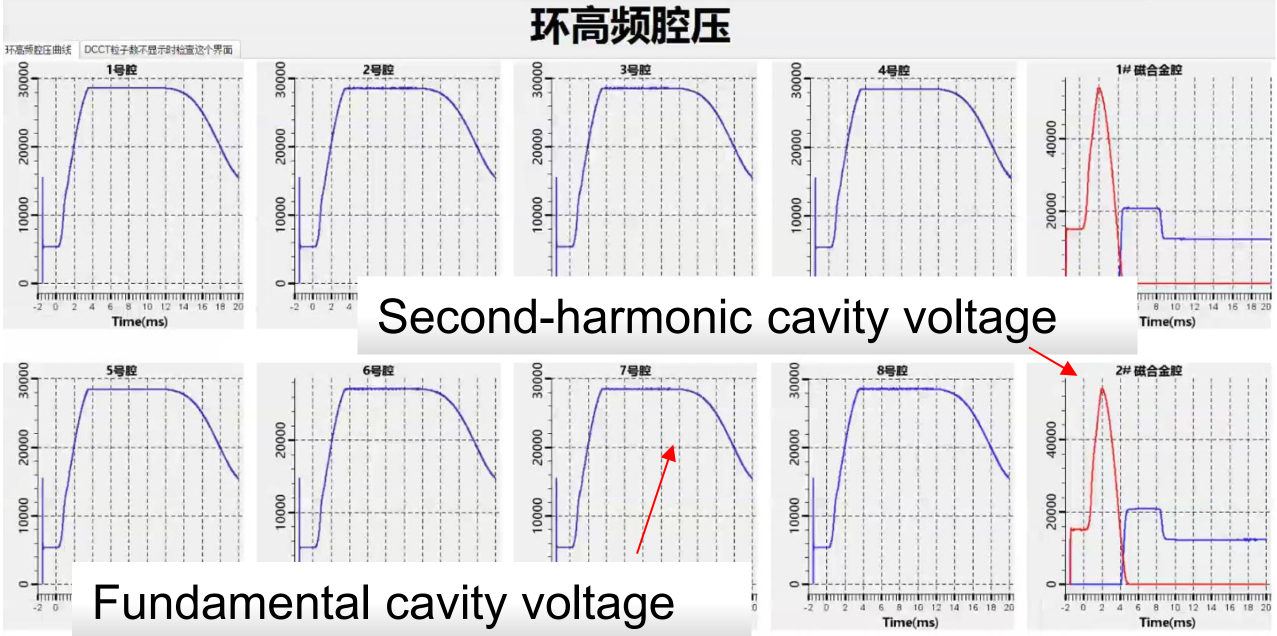


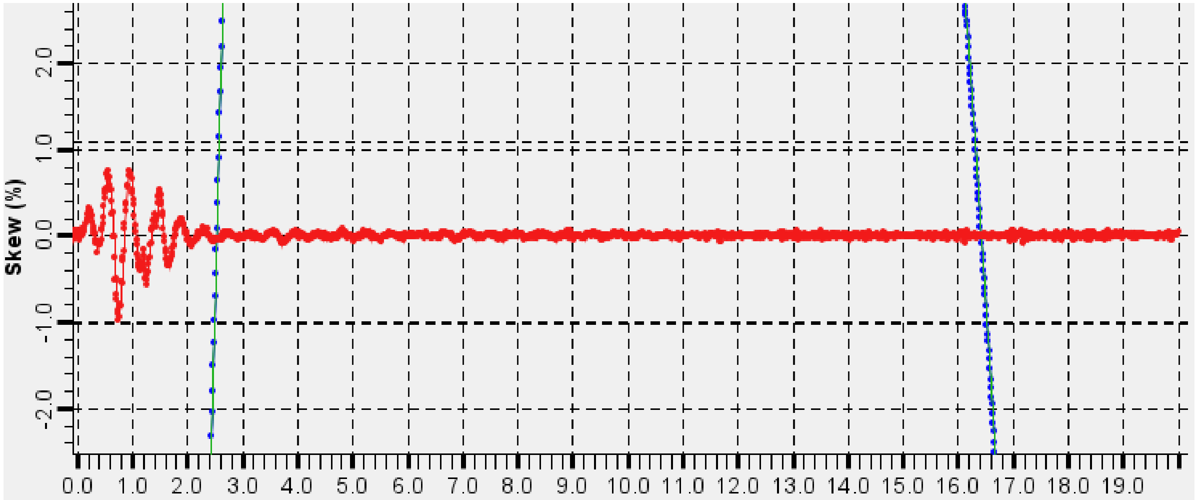
Beam loading < 0.5 kV/gap

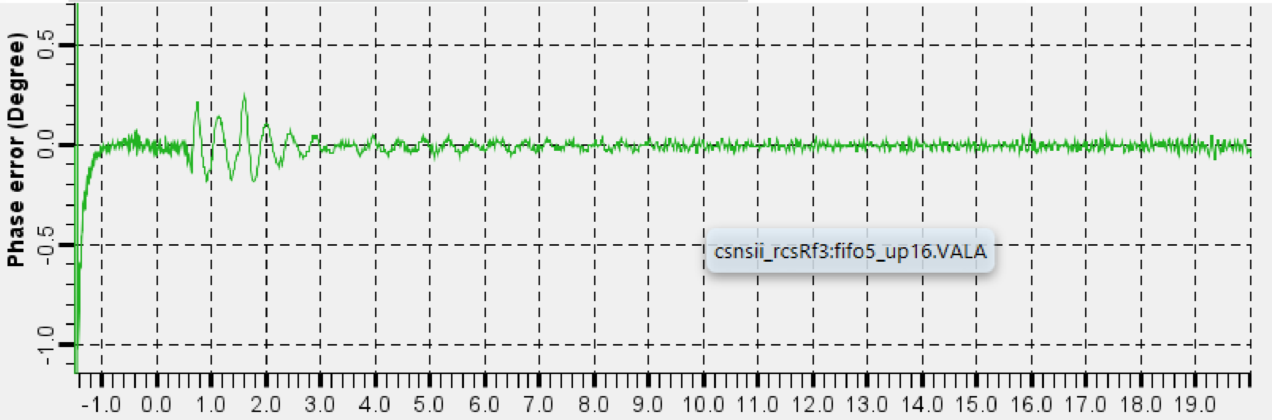
RF field amplitude and phase error

Maintaining the amplitude error and phase error well below 1% (required) and 1° (required)





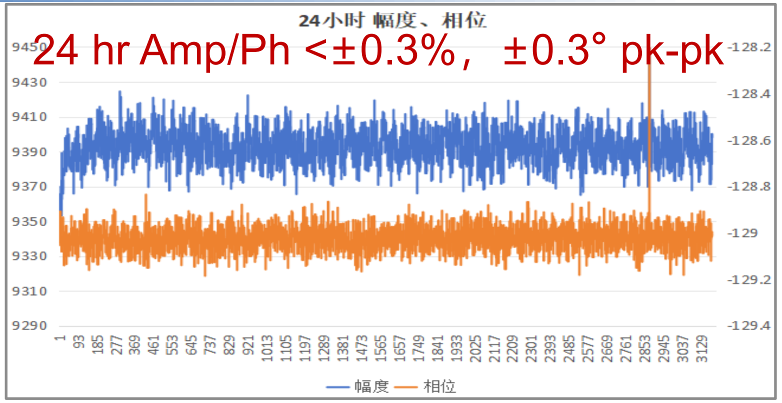


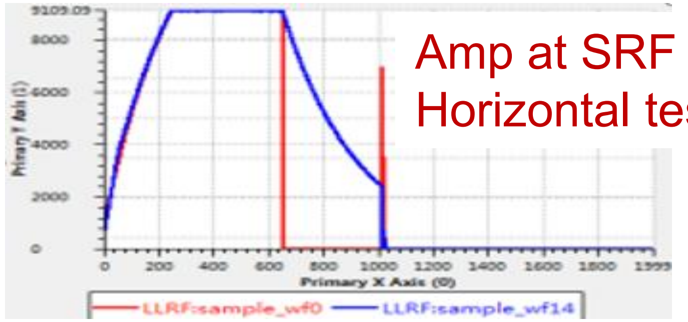


RFSoC-Based LLRF for CSNS-II LINAC

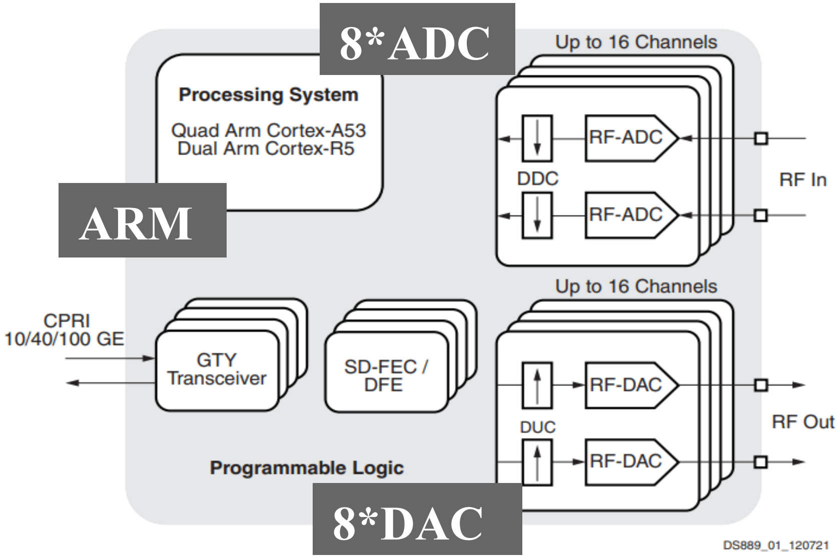
Talk: Z. Xie, Thursday

- **RFSoC-based LLRF for CSNS-II linear accelerator superconducting RF (SRF) prototype.**
  - Miniaturization, low latency, component simplification, and wide bandwidth (10MHz~6GHz)
  - Both digital self excitation and amplitude phase feedback have been achieved
  - A new algorithm to eliminate pulse Lorentz force detuning
- **RFSoC is also applied to the 5.712GHz Southern Light Source testing platform**

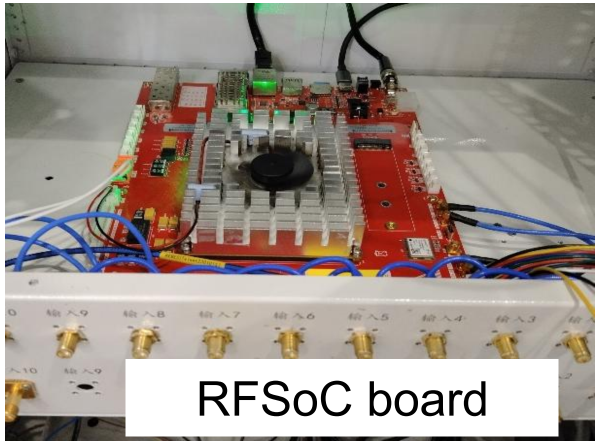




Amp at SRF Horizontal test



RFSoC used at 5.712GHz



RFSoC board

LLRF R&D *in Institute of Advanced Light Source Facilities (IASF)*

Authors:

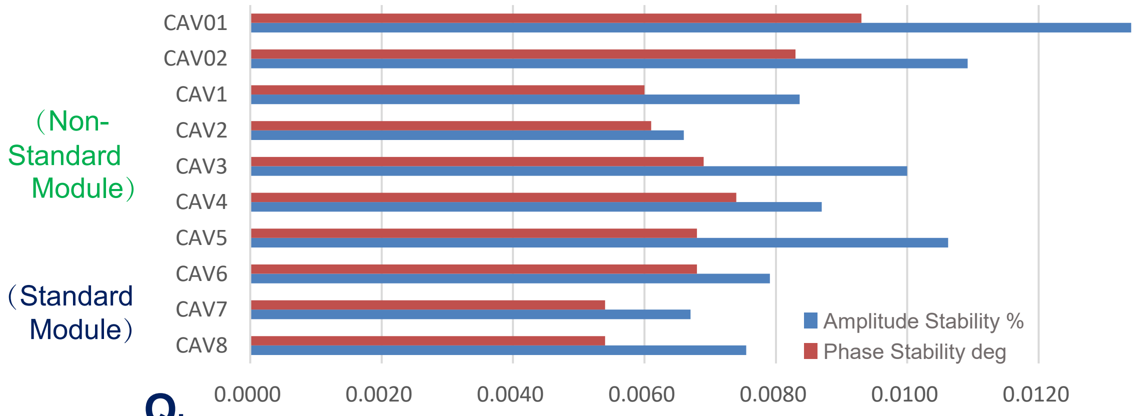
Hongli Ding[1,2], Jinfu Zhu[1], Wei Li[1], Jiawei Han[1], Qiaoye Ran[1], Weixin Qiu[1], Zhiyuan Zhang[1], Xiwen Dai[1], Haokui Li[1], Jiayue Yang[1,2], Weiqing Zhang[1,2]

1: Institute of Advanced Science Facilities, Shenzhen, China
2: Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian, China

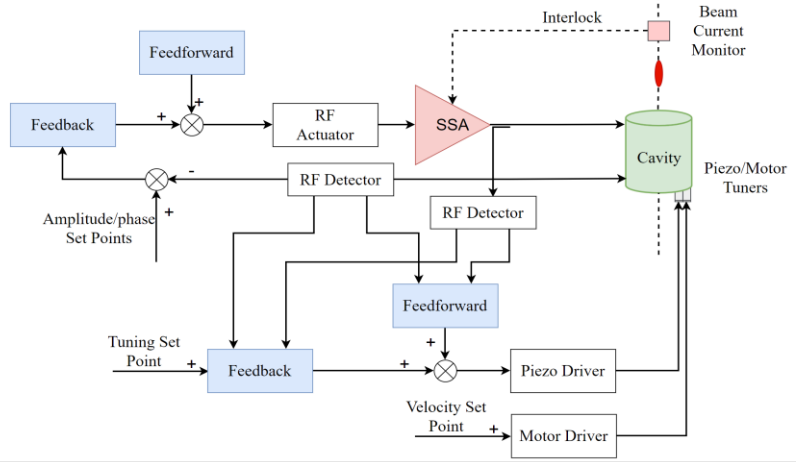
Low-Level RF system (R&D) in IASF

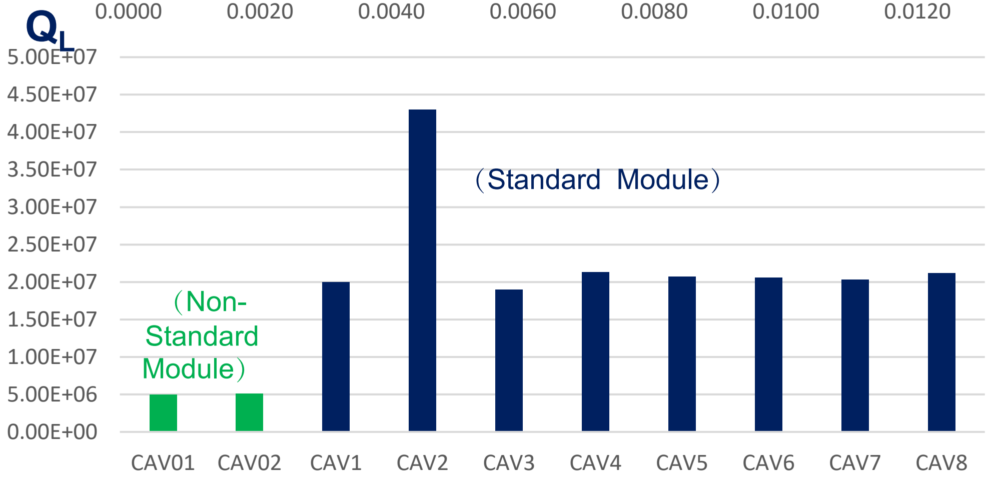
- LLRF control technology has been developed to achieve stable control of 10 superconducting cavities.
- Each cavity achieves a closed-loop amplitude/phase stability of better than 0.02%/0.02 degrees.
- Q_L is approximately 5e6 for the Non-Standard Module module and 2e7 for the Standard module.
- Stable operation has been achieved at a total cavity voltage of 110 MV.

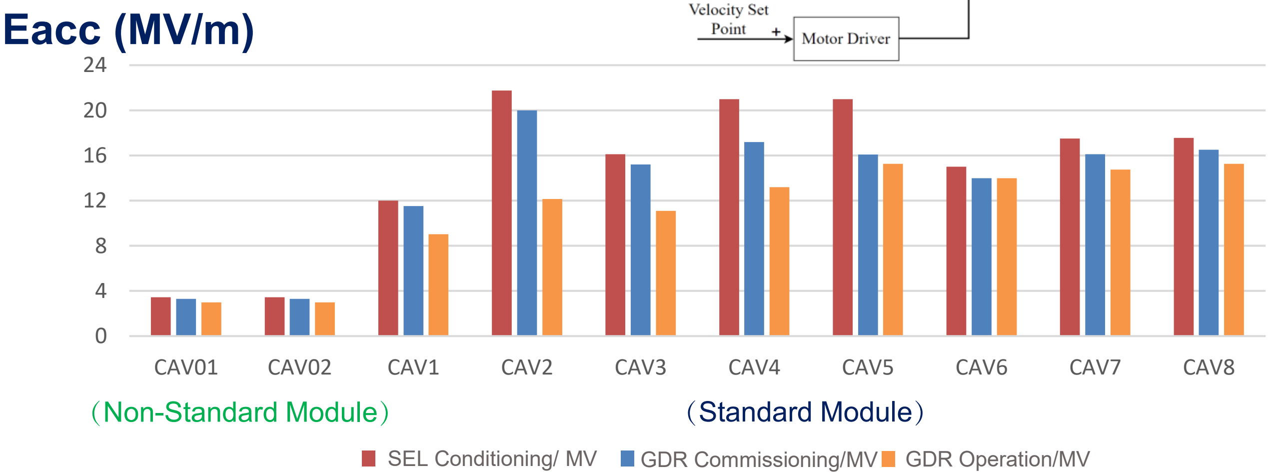
GDR Amplitude and Phase Stability



RF & Tuning Control







Dalian Advanced Light Source Injector

- Jointly developed by Dalian Institute of Chemical Physics and Shenzhen Advanced Light Source Institute.
- First to achieve >100 MeV, 1 MHz repetition rate, 0.1 mA beam delivery

Dalian Advanced Light Source Injector

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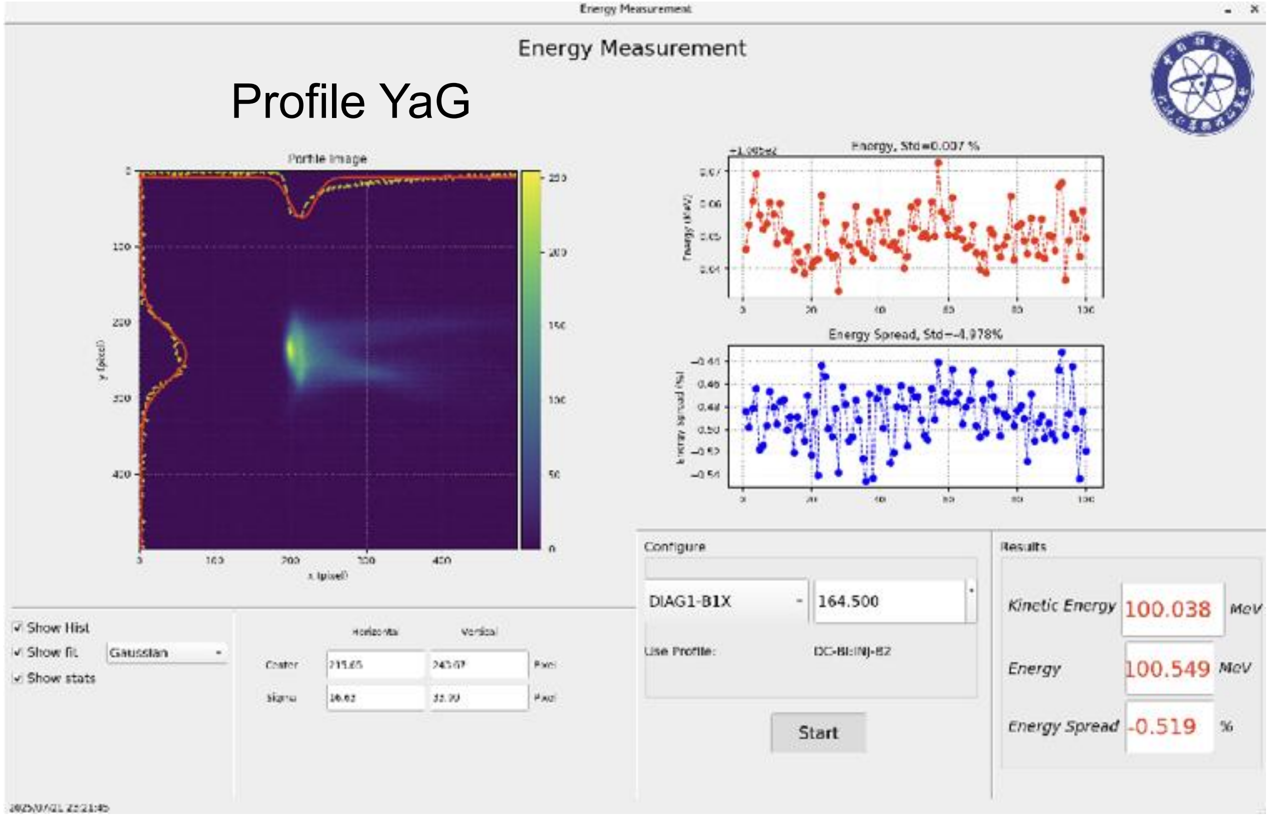
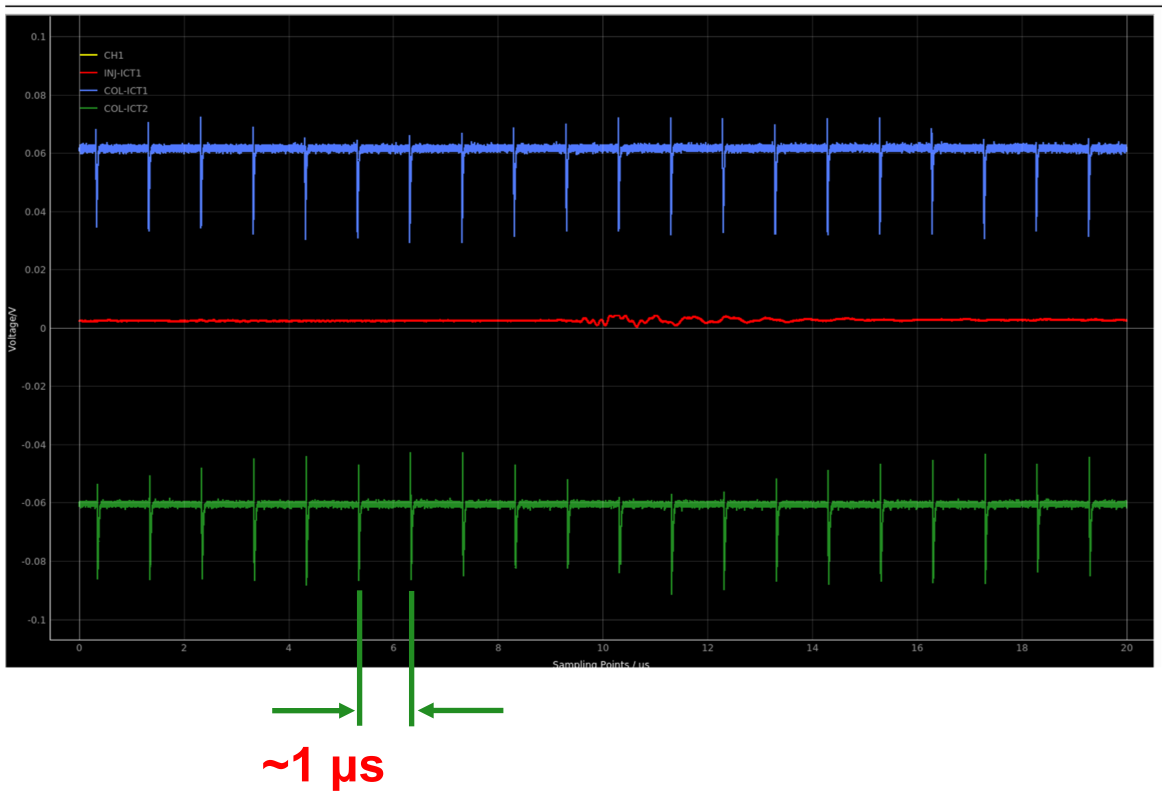




Beam energy measurement (energy jitter (RMS) < 0.007%)

BPM signals (1 MHz repetition rate)

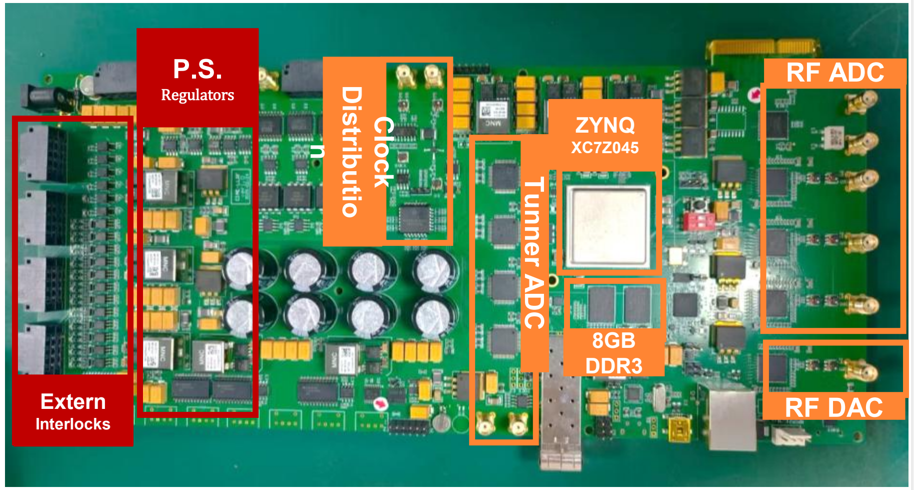
LLRF R&D in *China Institute of Atomic Energy (CIAE)*

Authors:
Zhiguo Yin[1], Tianyi Jiang[1], Xiaoliang Fu[1], Xueer Mu[1], Xiaoxue Xia[1]

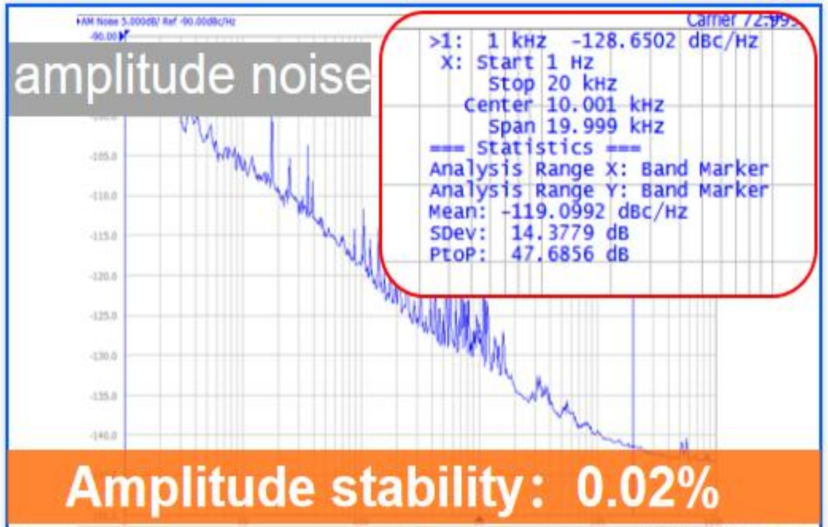
1 China Institute of Atomic Energy (CIAE)

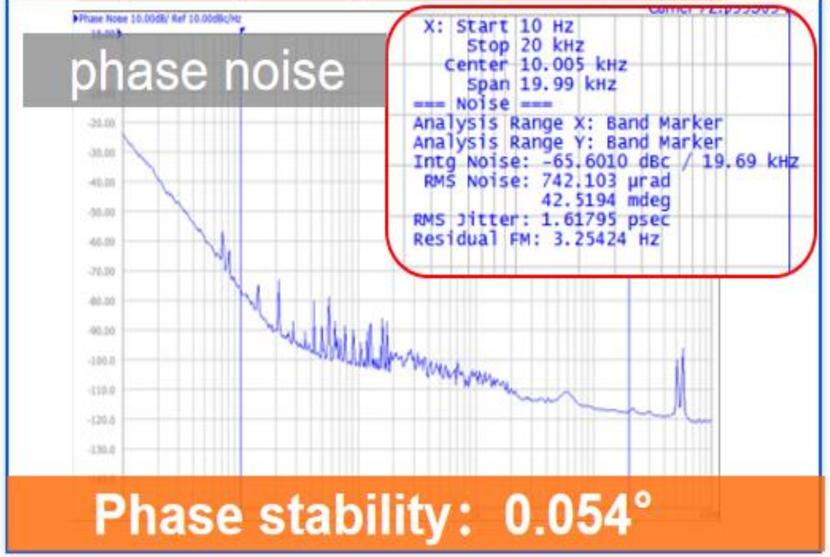
Digital LLRF System: Alpha particle Cyclotron RF

Digital LLRF PCB board



- An upgraded **FPGA-based external excitation digital LLRF system**. The LLRF system controls the amplitudes/phases of the cavities and buncher system.





Features: General digital LLRF system; High density PCB board

[1]Fu X, Yin Z, Fong K, et al. LLRF Controller for High Current Cyclotron-Based BNCT System[J]. IEEE Transactions on Nuclear Science, 2021, 68(10): 2452-2458.

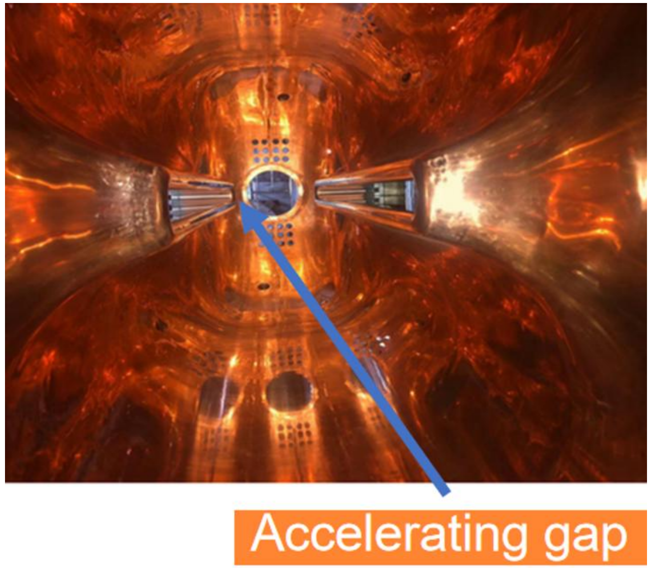
[2] 付晓亮，CIAE和TRIUMF的加速器低电平系统数字化研究，中国原子能科学研究院博士学位论文，2021

[3] 夏小雪，超轻型高温超导回旋加速器的高频低电平控制系统的研究与验证，中国原子能科学研究院硕士学位论文，2025

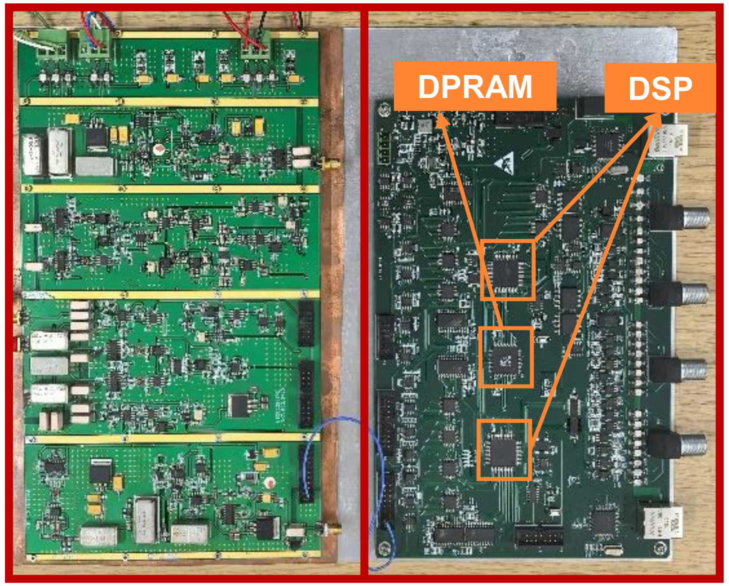
Hybrid SEL LLRF Control: 2 GeV CW FFA Scaled Cavity

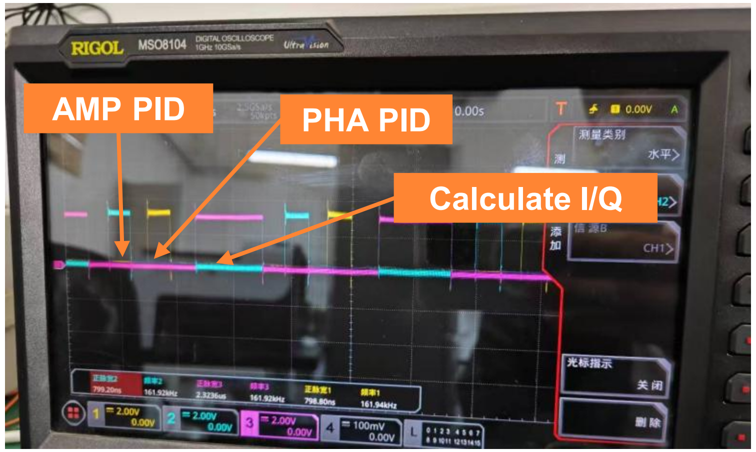
1:4 scale validating cavity

Q=42,000



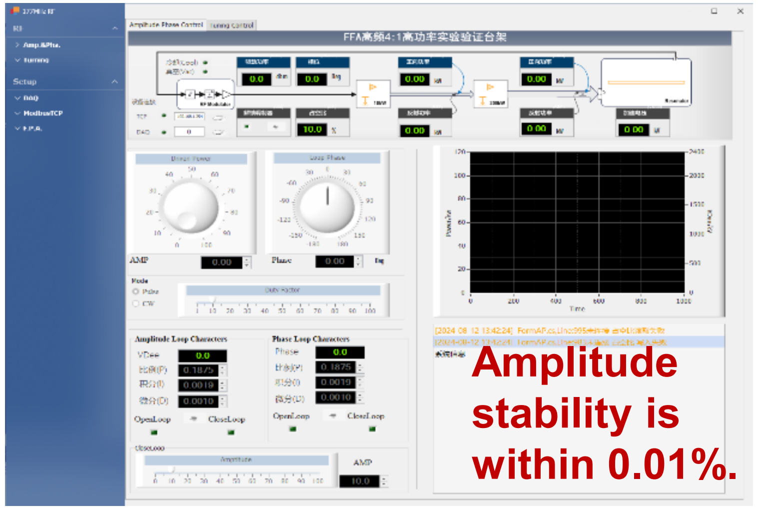
177MHz LLRF hardware





With the Harvard structure, PID single-iteration time < 800 ns.

Digital self-excited/Phase lock mode is good during potential Lorentz detuning, improving the usability of the Q＞10^5 cavity



SEL RF Control Software User Interface

[1] S. Pei, Z. Yin, T. Zhang and G. Yang, Design on High Quality Factor and High Shunt Impedance Waveguide-type RF Cavity for 2 GeV FFAG Proton Accelerator, Atomic Energy Science and Technology, VOL. 54, No. 8, pp 1519-1524, 2020

[2] 殷治国，100MeV强流回旋加速器数字射频低电平系统的设计和实验验证，中国原子能科学研究院博士学位论文，2008

LLRF R&D in *Institute of Modern Physics (IMP)* *for NC Linac and Storage ring*

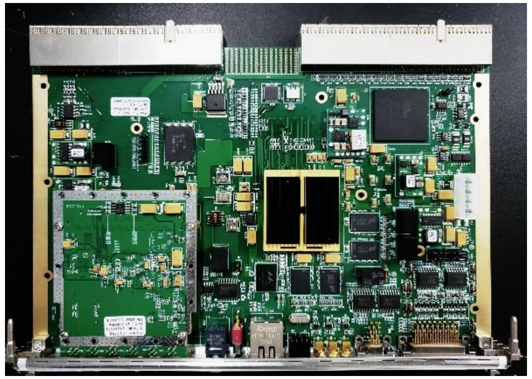
Authors:
Yan Cong[1], Ruifeng Zhang[1], Shilong Li[1], Xiaodong Han[1], Ruihuai Zhou[1]

1 Institute of Modern Physics, Chinese Academy of Sciences

LLRF Controller R&D for NC Linac and Storage Ring

- **The LLRF controller employs a modular design, comprising: a high-performance FPGA board and a commercial 6U cPCI crate.**

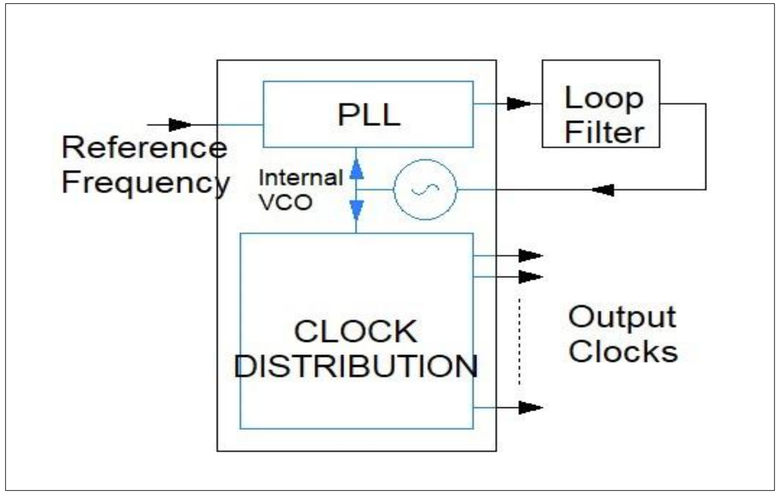
- **FPGA: Xilinx V5;**
- **ADC: 2 CH, 14-Bit, 250MSPS / 16-Bit, 125MSPS ;**
- **DAC: 2 CH, 16-Bit, 250 MSPS / 1.2 GSPS;**
- **Applicable to both IF architecture and direct RF sampling**

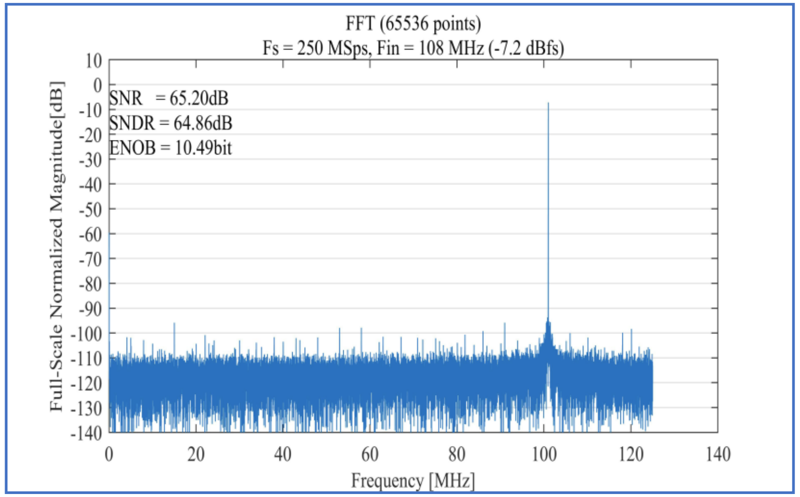


① **FPGA Board**

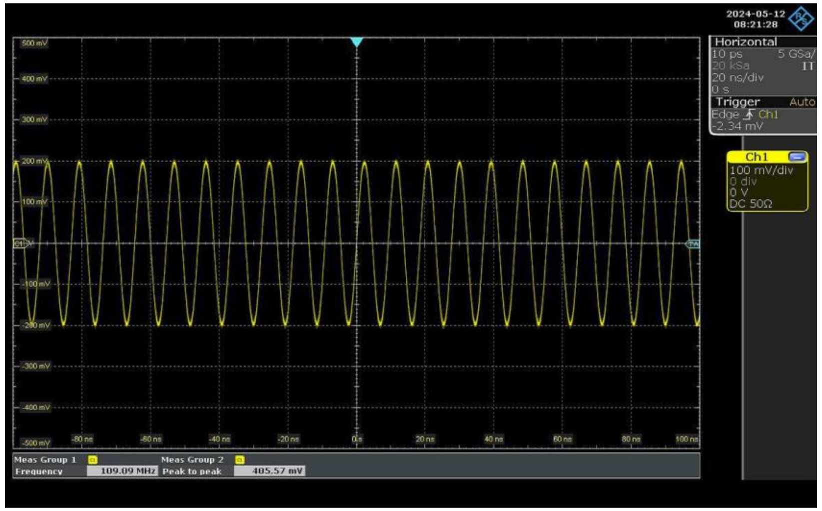
② **cPCI Crate**

- **Configurable PLL generating clocks for ADC, FPGA and DAC**





250 MSPS ADC Sampling Test

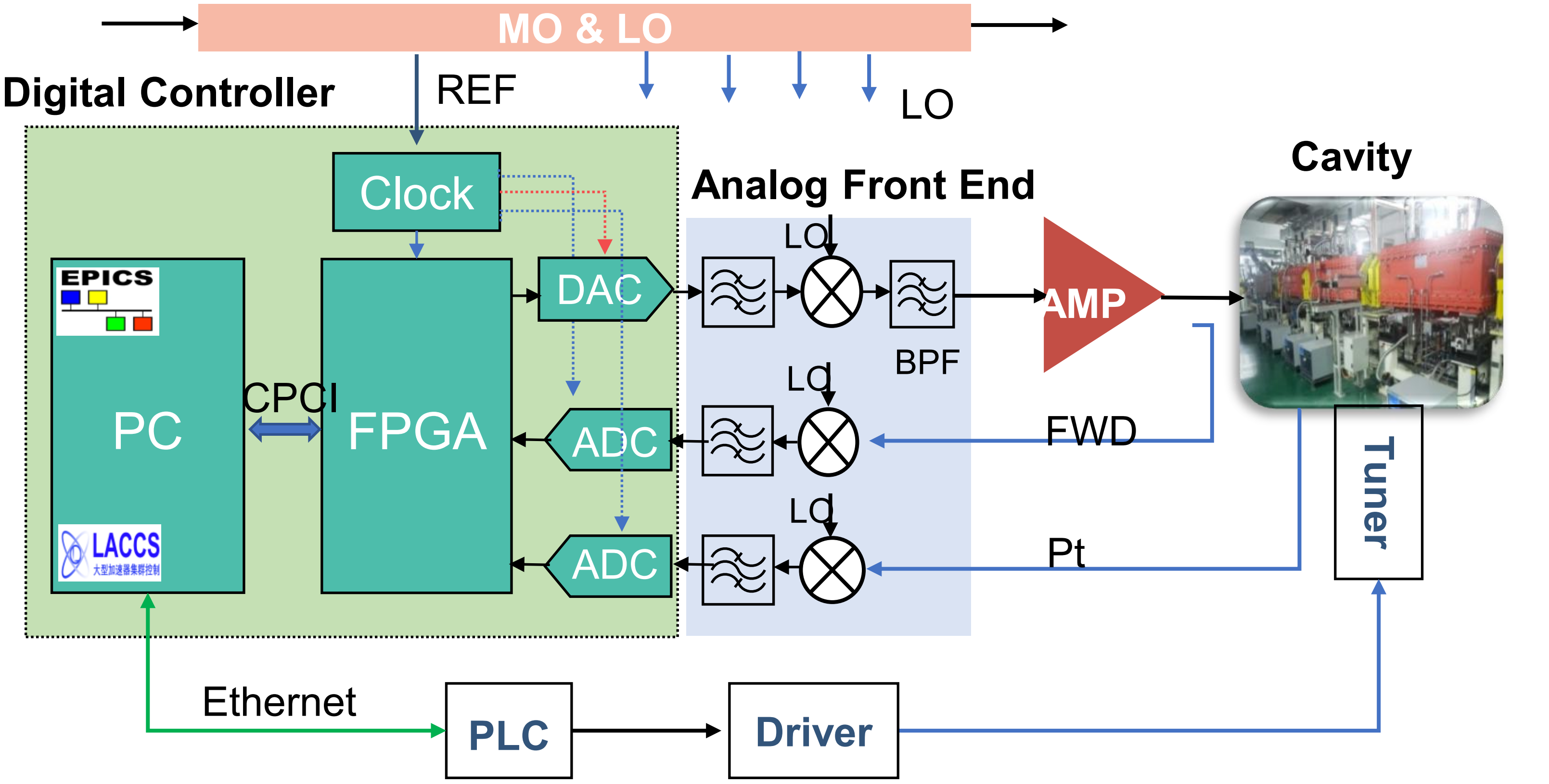


500 MSPS DAC Output Test

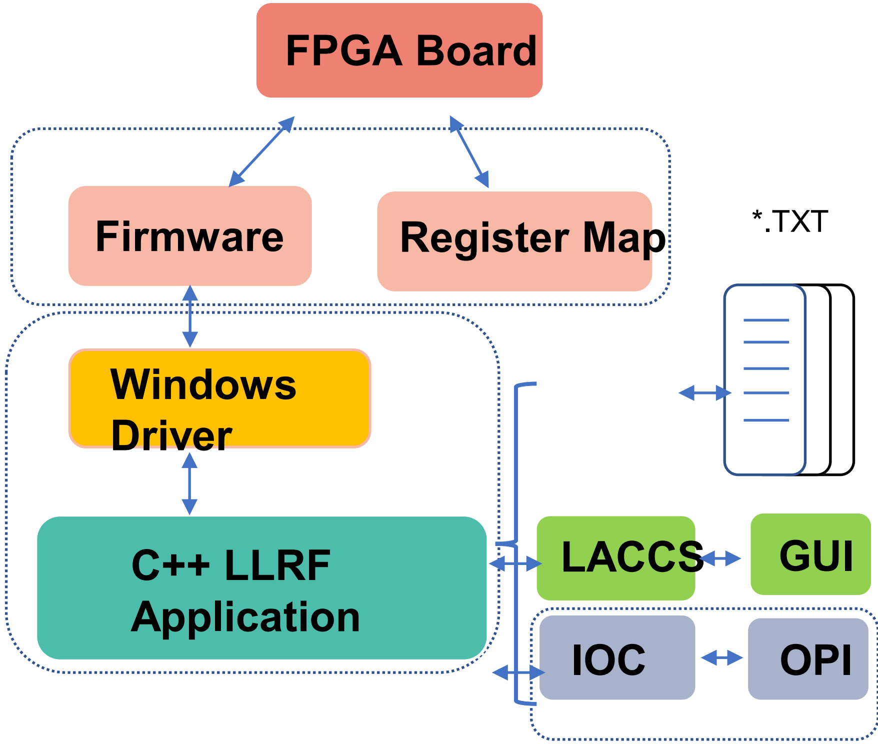
LLRF2025 LLRF Controller R&D for NC Linac and Storage Ring (cont.)

➢ **LLRF Architecture**

- **Hardware architecture**



- **Software architecture**



Control scheme:
- **GDR、PLL**
- **IQ、phase-amplitude**

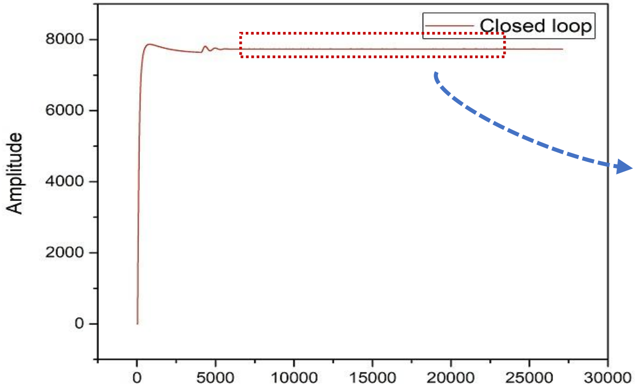
Algorithm:
- **IQ、non-IQ**
- **PI Feedback**
- **Feedforward**

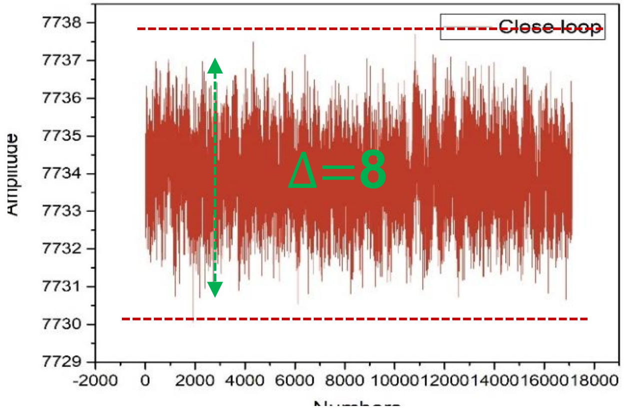
Tuner:
- **Stepper motor**
- **Servo motor**

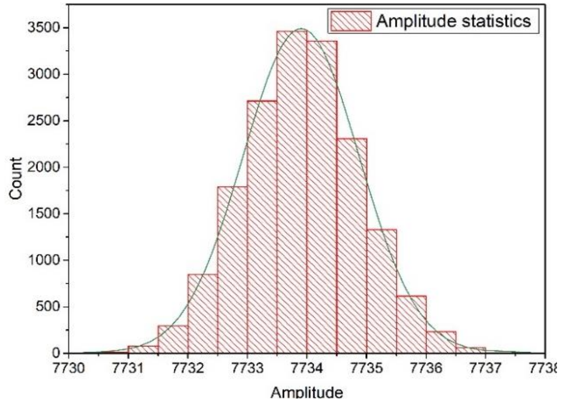
Software:
- **Windows 10 OS**
- **EPICS**
- **LACCS**

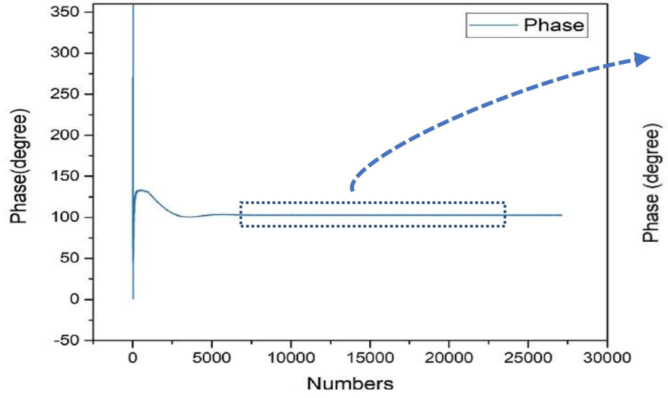
LLRF of NC Linac at SESRI
(Space Environment Simulation and Research Infrastructure)

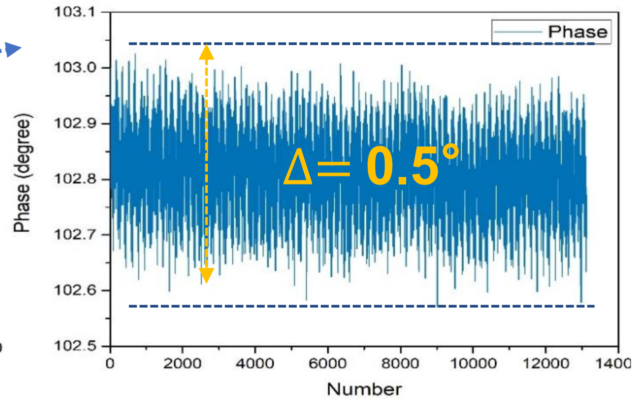
- p， 100~300MeV；Heavy ions， 7~80MeV/u
- Used for studying the interaction of high energy space particle radiation with material, device, module and biological entity
- In early 2021，began equipment installation; In Jan 2023，completed beam commission

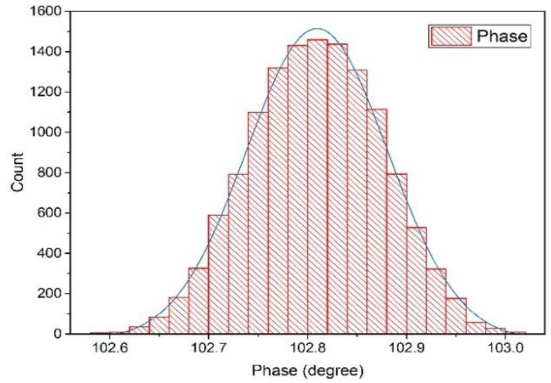










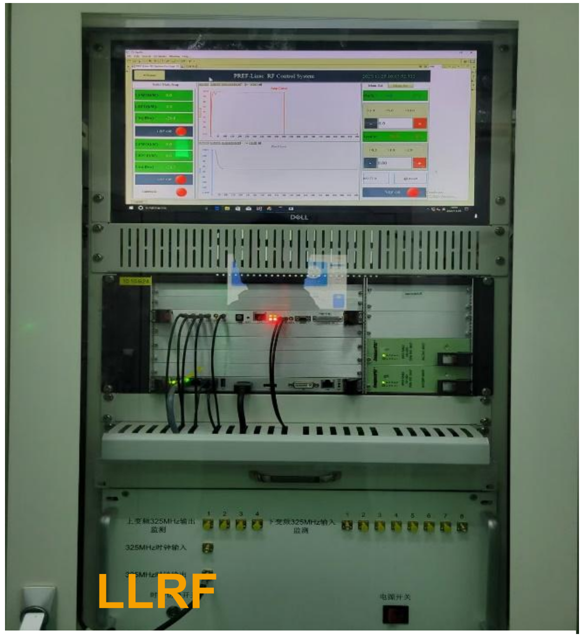


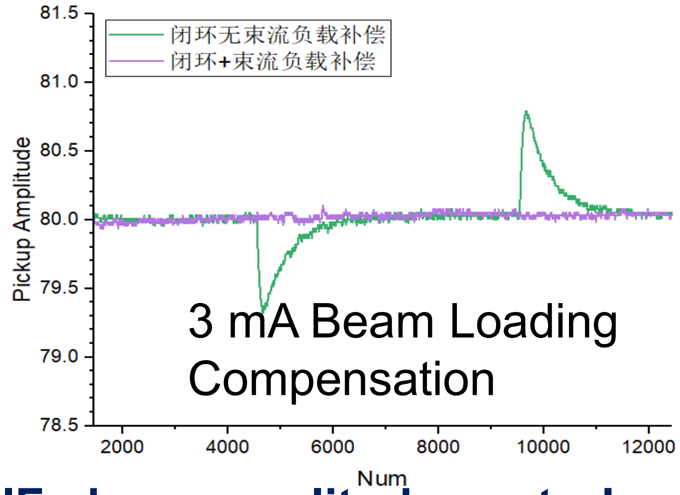
IF IQ control scheme, Pulse-internal closed-loop amplitude and phase stability ≤±0.3%和±0.5°

LLRF of NC Linac at PREF (Proton Radiation Effects Facility)

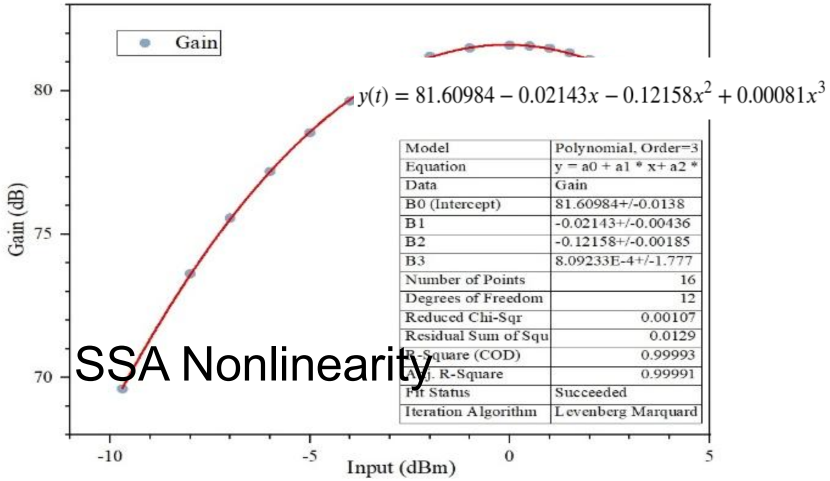
- p，energy adjustable from 10 to 60 MeV
- Used for experimental research on the displacement damage effect
- In early 2023，began equipment installation
- In September 2023，completed beam commission

RF：325MHz
LO：300MHz
IF：25MHz
Rate: 1Hz
Duty：1‰

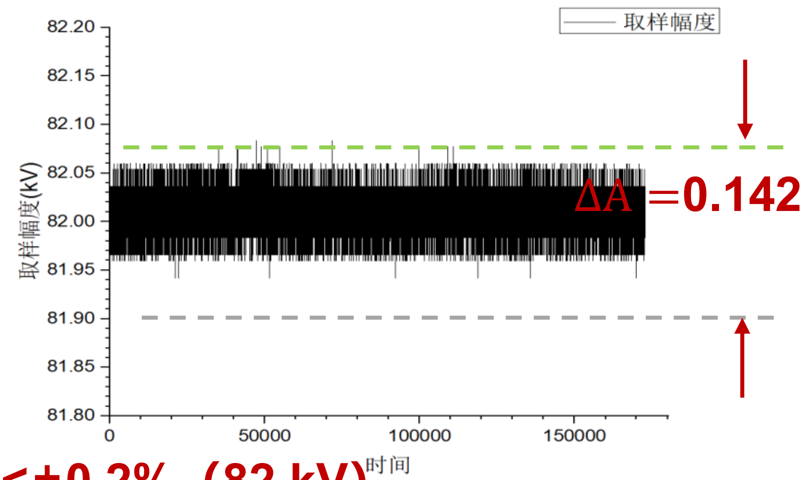




3 mA Beam Loading Compensation



SSA Nonlinearity



IF phase-amplitude control scheme，48-hour long-term stability test: <±0.2%（82 kV）

Summary

- Chinese labs are still very active in LLRF R&D
- The On-going projects are under construction and commissioning phase with the verified LLRF performance
- LLRF hardware solutions and control algorithms are still evolving rapidly
- Universities are making more progress
- More collaborations among Chinese labs and with worldwide LLRF community are still the direction of making efforts