The Low Level RF control system of CAFe and the conceptual design for CiADS at IMP

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- *The LLRF control system of CAFe*
- *The introduction of CiADS*
- *The conceptual LLRF design for CiADS*

The introduction of CAFe

Chinese ADS Front-end Demo linac (CAFe)

IMP collaboration with IHEP 2011 ~ 2017

Features:

Ions: P，H2+，α

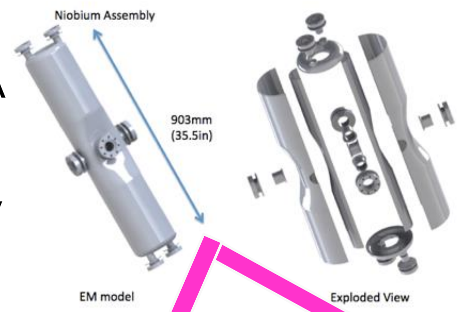
Current: 0.1 mA to 10 mA

E out RFQ: 3.1 MeV

E out CM4: 25/30/40MeV

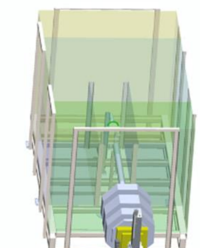
CM Temp.: 4.5 K

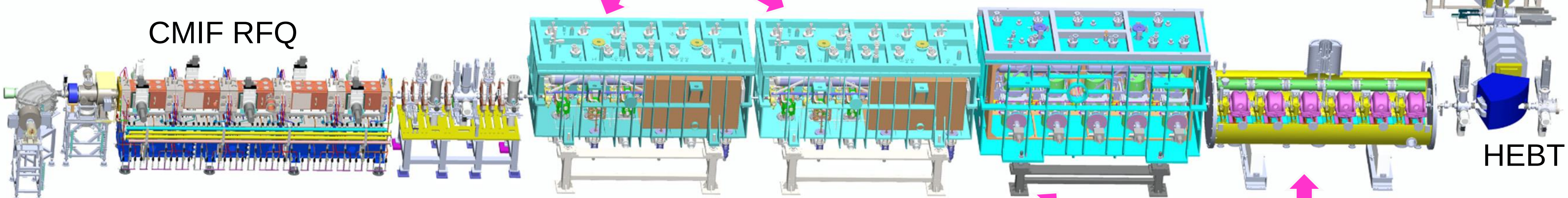
162.5 MHz Half-wave Cavity



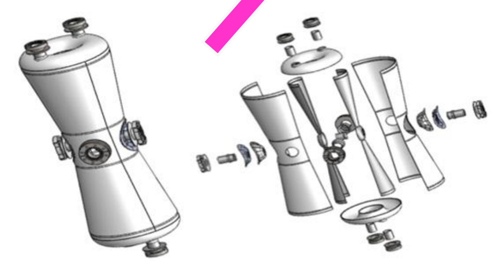
Major goal of CAFe Facility: Demonstration of the SC linac technology for 10 mA CW beam.

DUMP





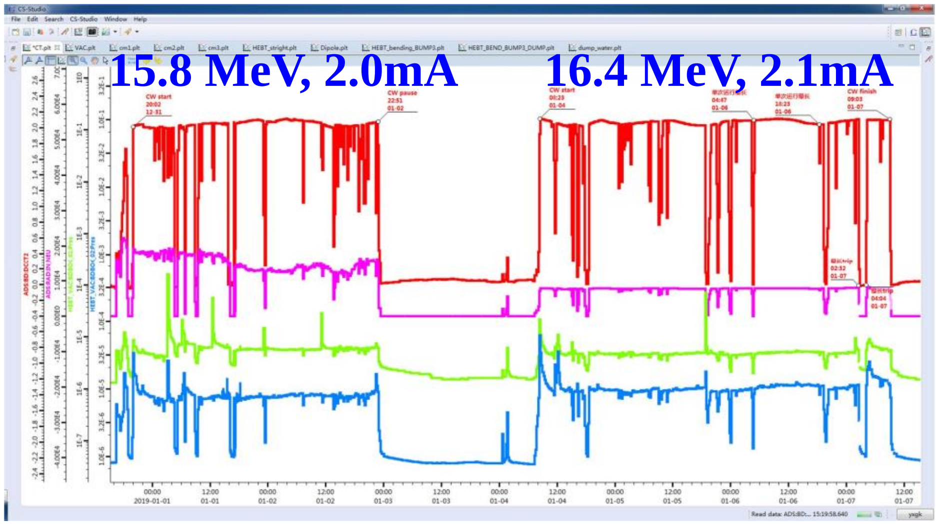
	Freq.	Cavity type	number
RFQ	162.5 MHz	4-vane	1
CM1	162.5 MHz	HWR010	6
CM2	162.5 MHz	HWR010	6
CM3	162.5 MHz	HWR015	5
CM4	325 MHz	Spoke021	6



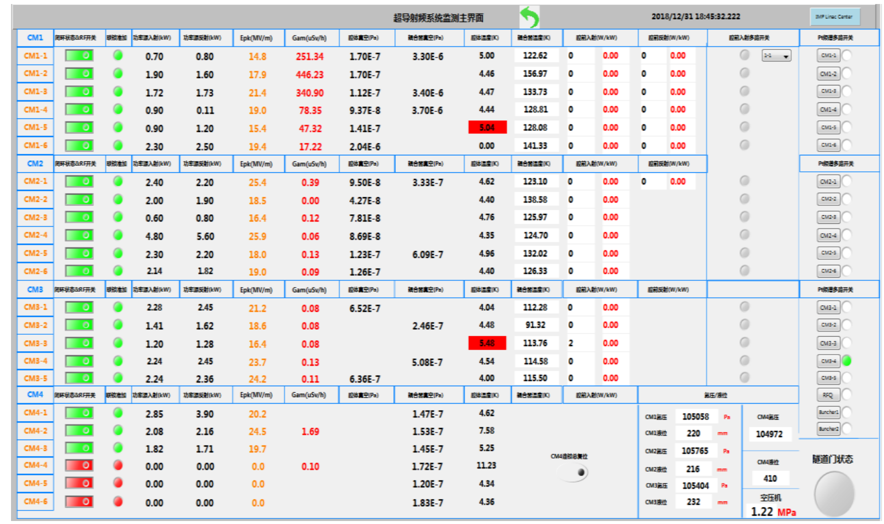
162.5 MHz Taper HWR

The operation status of CAFe

The high power beam operation for Reliability Test in 2019



100 hours high beam power operation test record

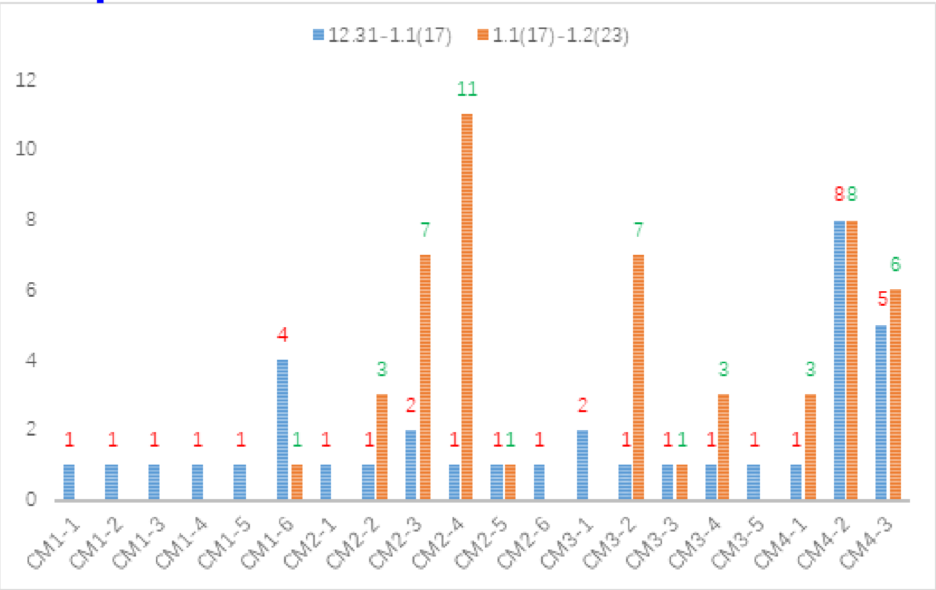


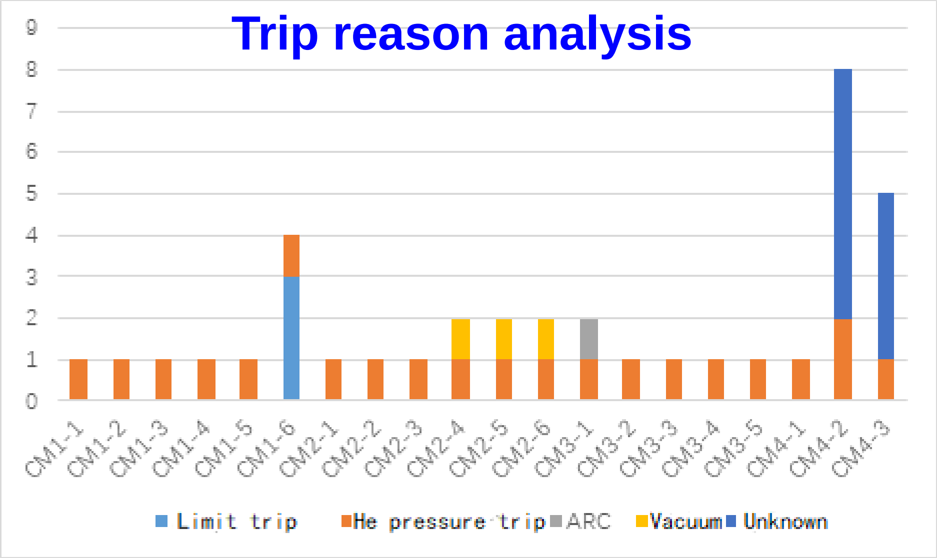
SRF system operation status during CW beam test

	CM1	CM2	CM3	CM4
Epk(MV/m)	14.8, 17.9, 21.4, 19, 15.4, 19.4	25.4, 18.5, 16.4, 25.9, 18, 19	21.2, 18.6, 16.4, 23.7, 24.2	20.2, 24.5, 19.7
Pin(kW)	0.7, 1.9, 1.7, 0.9, 0.9, 2.3	2.4, 2, 0.6, 4.8, 2.3, 2.1	2.3, 1.4, 1.2, 2.2	2.8, 2, 1.8
Helium pressure(Pa)	10500	105700	105400	10500

The trips analysis of CW high beam power test

Trip statistics

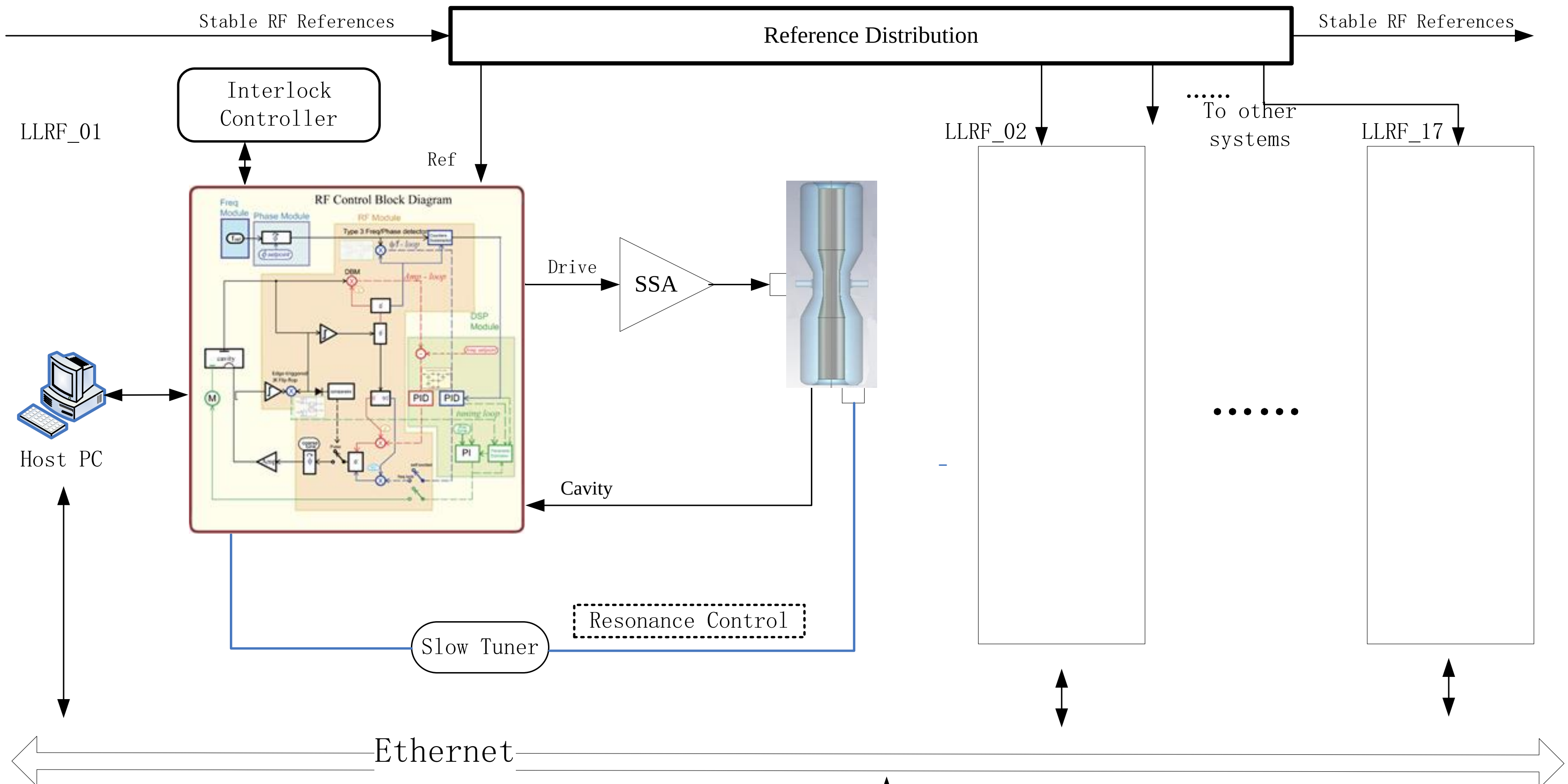


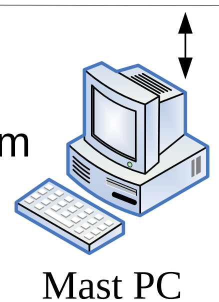


Statistics of trips from SRF system during CW high beam power test, the availability better than 89%.

The most trip sources are helium pressure fluctuation and unknown reasons.

The LLRF control system of CAFe



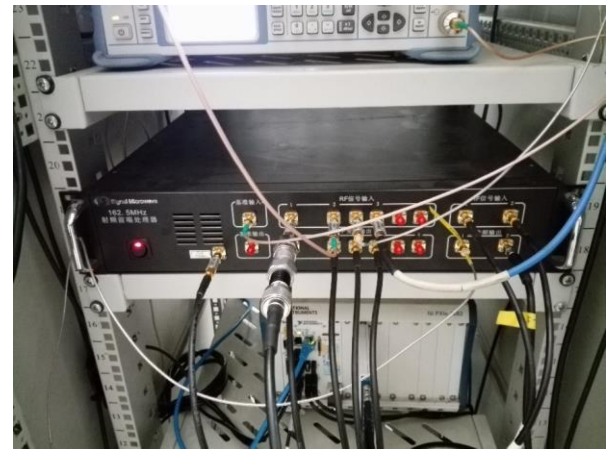


✓ The architecture of HWR SC LLRF system

- 162.5 MHz RF frequency.
- Twenty controllers.
- Solid state amplifier.
- EPICS IOC embedded.

The LLRF control system of CAFe

RFQ LLRF control system

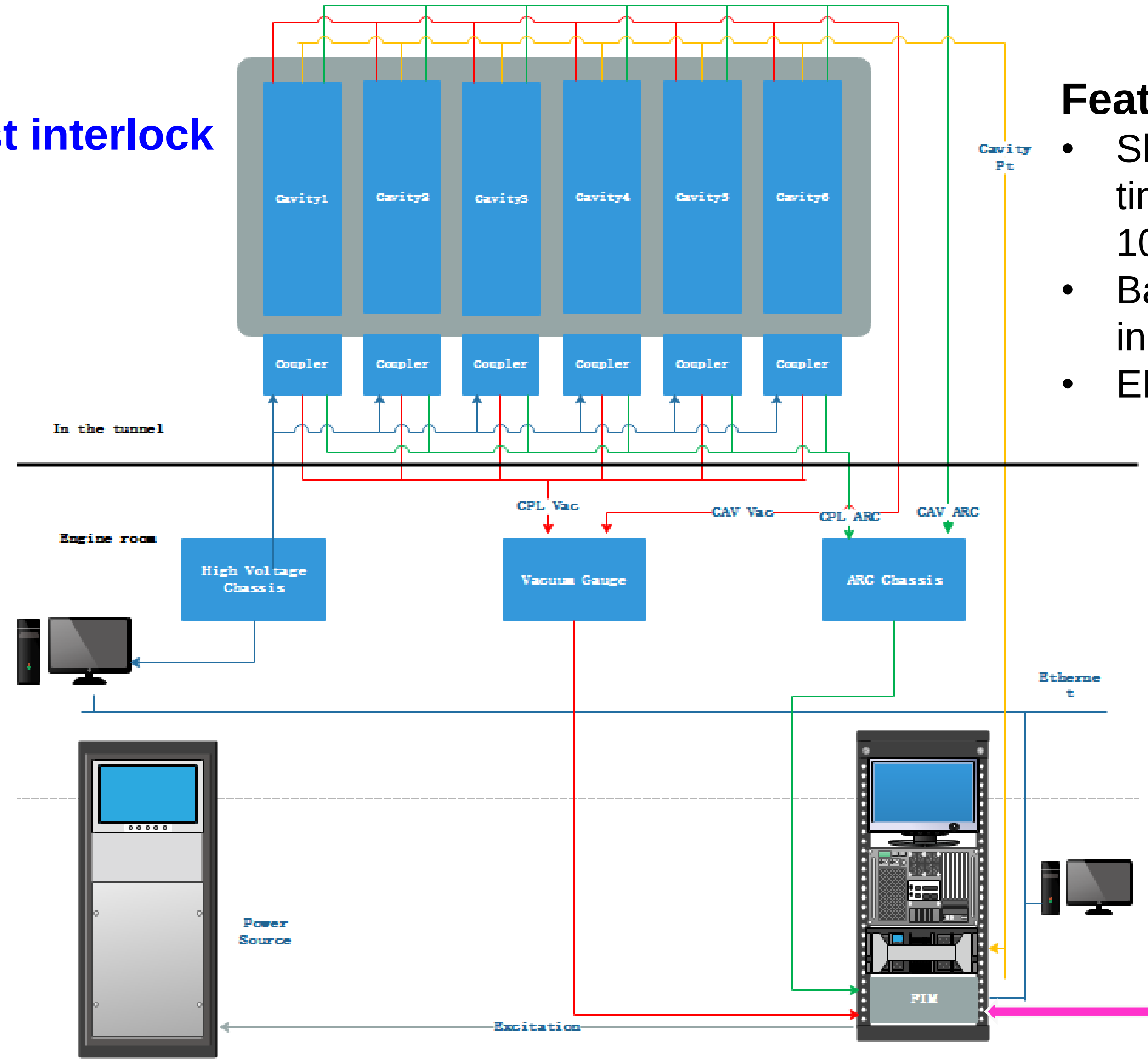


VXI board

Buncher LLRF controller

The LLRF control system of CAFe

The fast interlock system



Features:

- Shutdown RF in the us time scale, less than 10 us.
- Based on the fast logic in FPGA.
- EPICS IOC integrated.

China initiative Accelerator Driven System (CiADS)

Features:

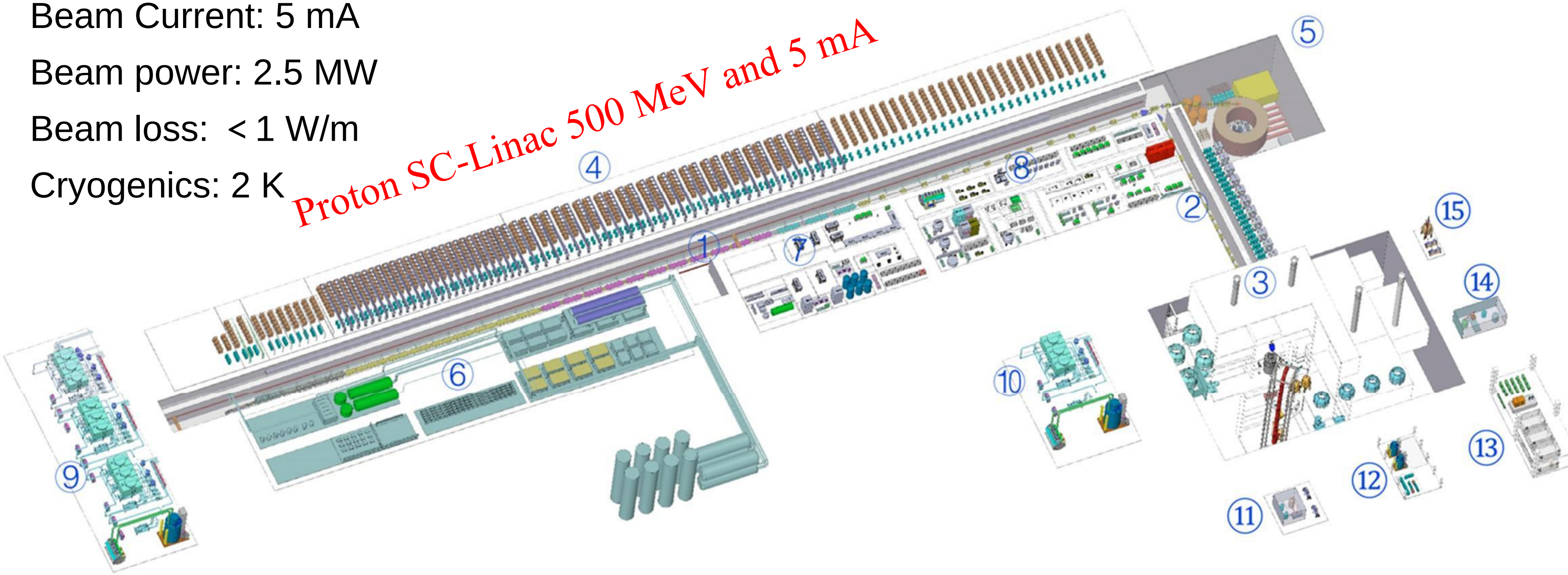
Energy: 500 MeV

Beam Current: 5 mA

Beam power: 2.5 MW

Beam loss: < 1 W/m

Cryogenics: 2 K

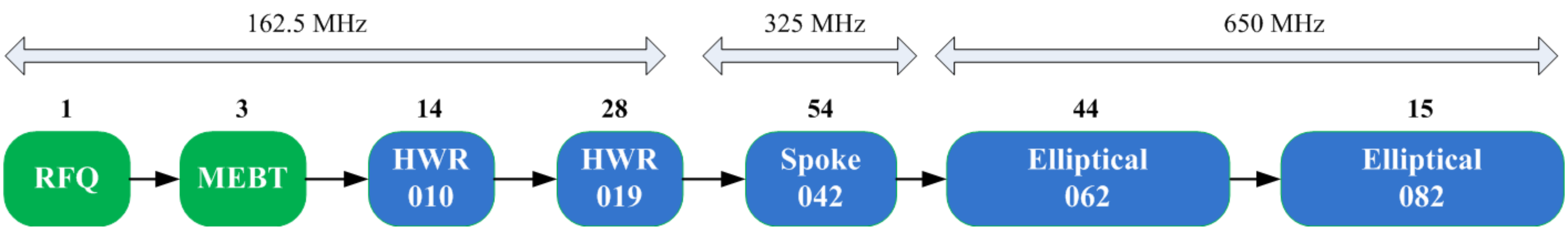


① SC LINAC
② Coupling beam line
③ Reactor Hall
④ Accelerator equ. hall
⑤ Beam dump and target
⑥ Cryogenic station
⑦ SRF hall
⑧ SRF conditioning hall
⑨ Cooling water station

The conceptual LLRF design for CiADS

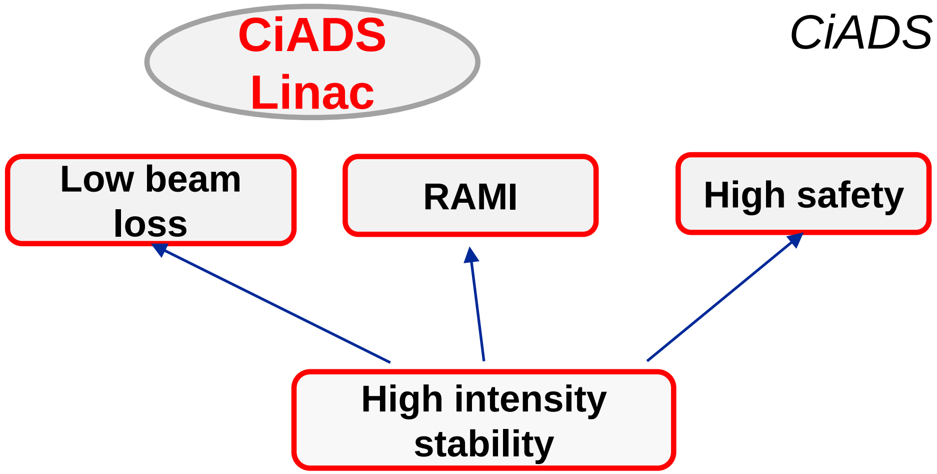
- ***The Linac of CiADS***
- ***The requirements of CiADS Linac***
- ***The conceptual LLRF design***

The Linac of CiADS



System name	RF frequency (MHz)	Close loop stability		Number	Beam Current (mA)	Cavity Bandwidth (HBW)
		Amp(3σ)	Phase(3σ)			
RFQ	162.5	0.1%	0.1°	1	5	≈10 kHz
Buncher	162.5	0.1%	0.1°	3	5	≈10 kHz
HWR010	162.5	0.1%	0.1°	14	5	150 Hz
HWR019	162.5	0.1%	0.1°	28	5	70 Hz
Spoke042	325	0.1%	0.1°	54	5	60 Hz
Elliptical062	650	0.1%	0.1°	44	5	120 Hz
Elliptical082	650	0.1%	0.1°	15	5	100 Hz

The requirements of CiADS Linac



CiADS demo facility (CAFe) CW beam test result

Operation time	7553 min
Beam time	6816 min
Down time	737 min
Availability	0.89

Particle type	***Proton***	
Energy	500	MeV
Beam current	5	mA
Beam power	2.5	MW
Operation mode	CW & Pulse	
Beam loss	< 1	W/m
Number of beam trip / year	~	t<10s
	< 2500/year	10s<t<5m
	< 300/year	t>5m

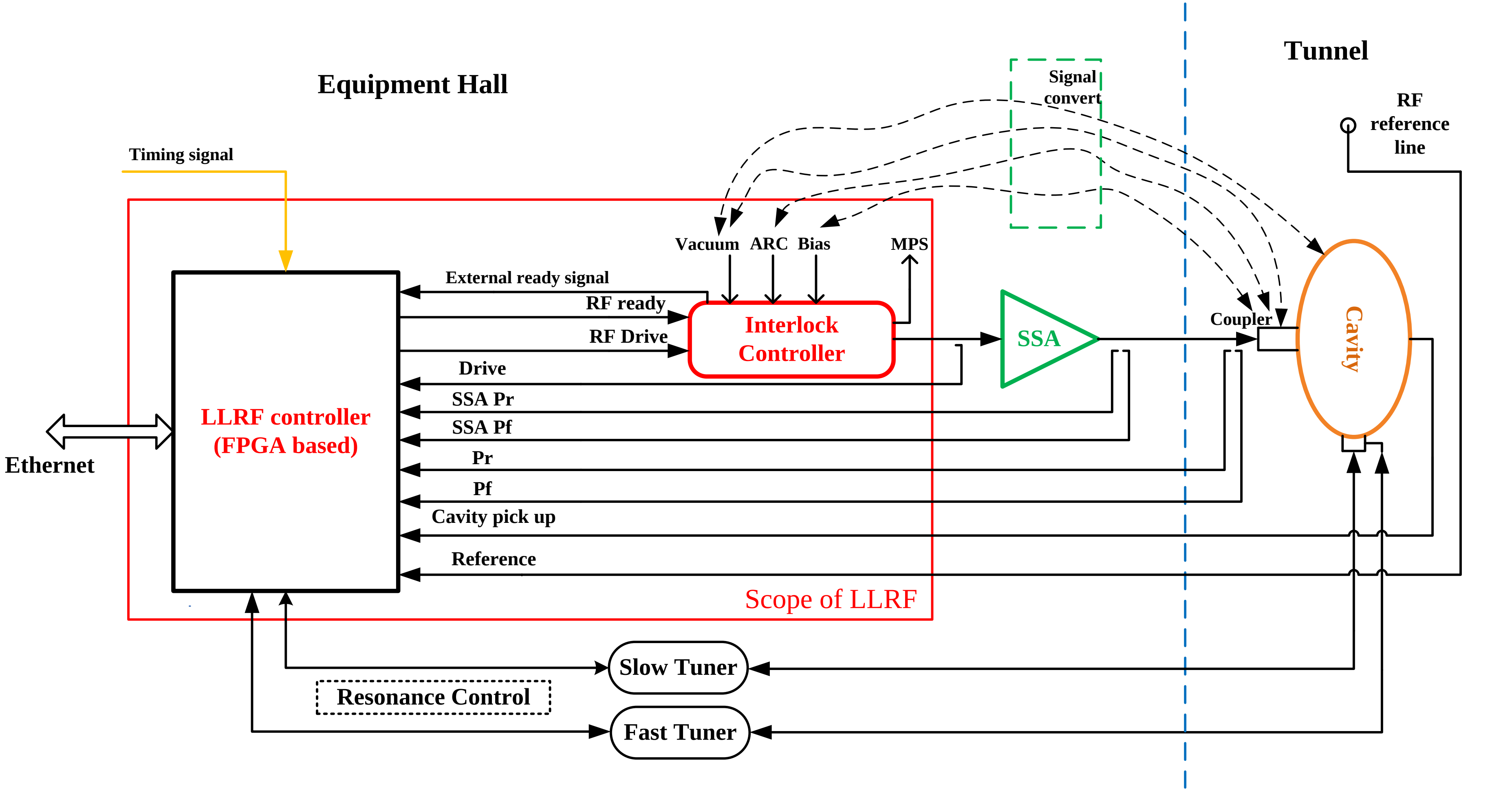
Availability of CiADS linac: Better than 90%

Preliminary analysis of CiADS linac characteristics

Main challenges:

- High availability.
- Fast recovery from trip.
- CW&PULSE operation.

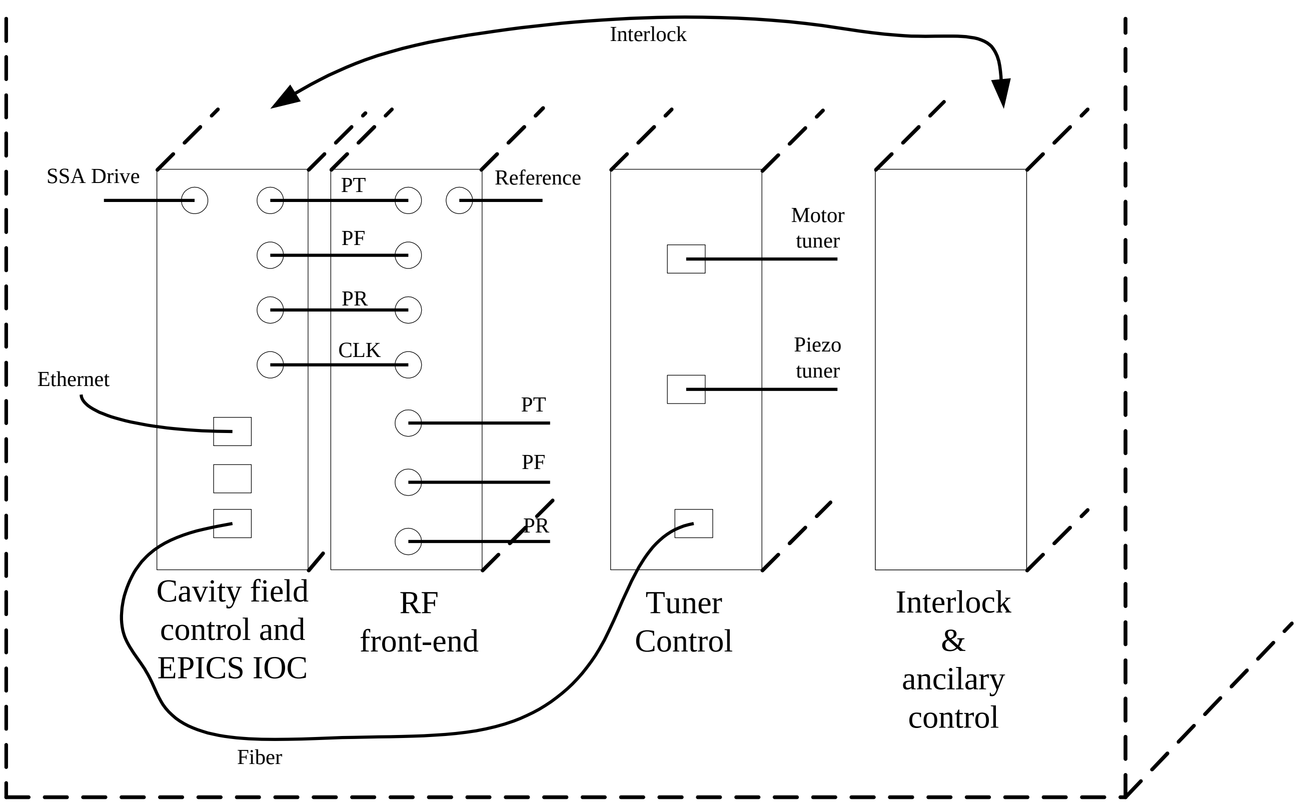
The conceptual LLRF system



LLRF control system includes FPGA based cavity field amplitude and phase control, cavity frequency tuning part, high-power RF interlock protection, and global data communications.

The conceptual LLRF system

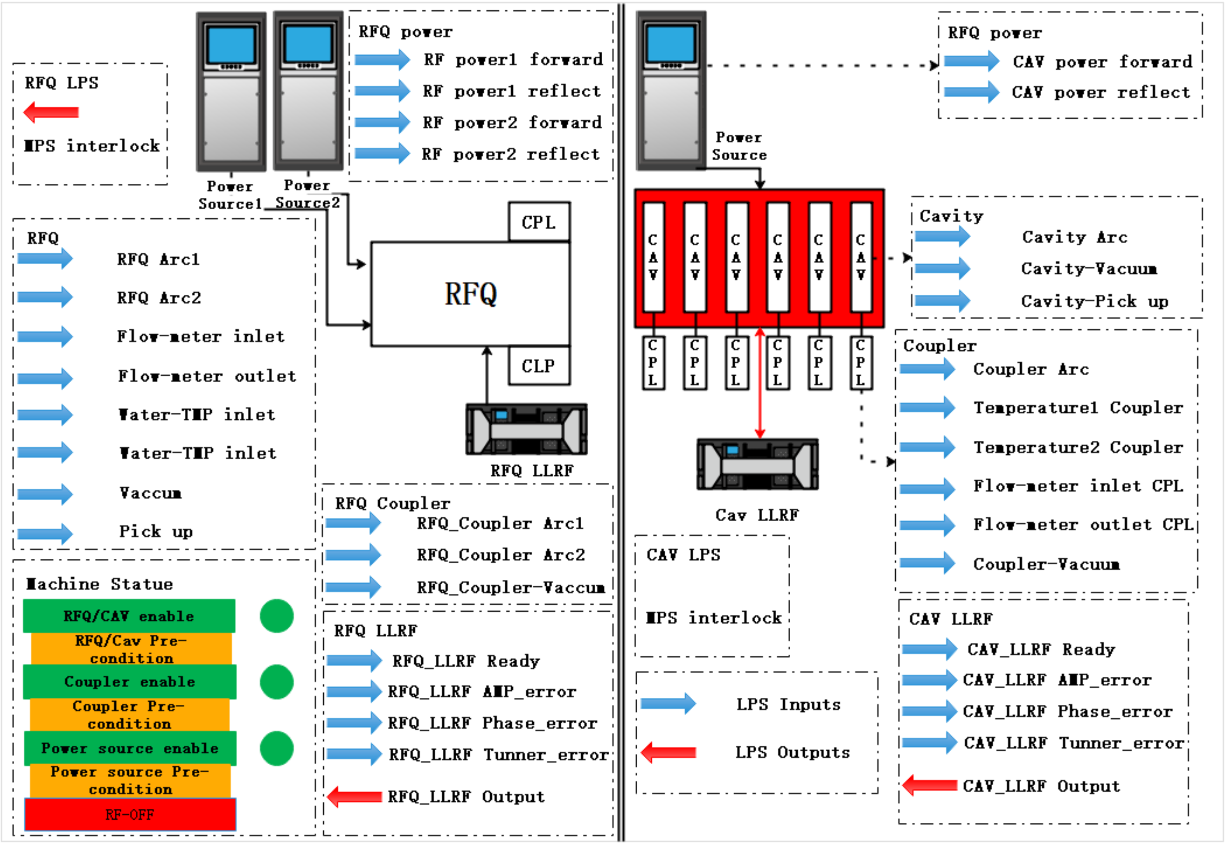
The backplane just provide power supply and mechanical support.
The data communication is provided by fiber link.



Combined with the advantages of crate and stand-alone chasis, the hybrid LLRF control chassis is proposed, easy to expand and maintain.

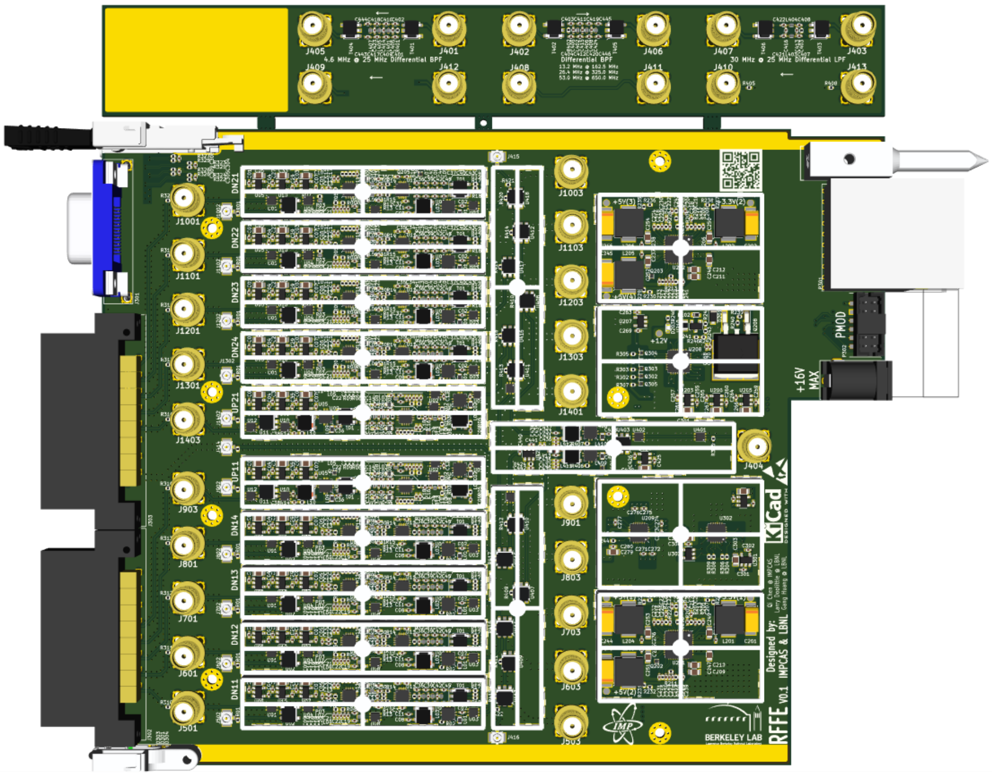
The conceptual LLRF system

The RF interlock system is under design and the prototype of some component will be produced and tested.



Beside the LLRF main controller will monitor RF power and protect RF power source, the Arc and vacuum of coupler will be monitored for fast interlock, the interlock signal will be transmitted with optic fiber.

The RF front-end board design based on mTCA RTM standard



Prototype

Features:

8 downconvert channels, 2 upconvert channels, hardware protection and auxiliary function was developed, include temperature, voltage and current monitor.

Summary

1. *The CiADS demo linac (CAFe) successfully accelerated 25 MeV pulse beam and CW beam in 2017, and then great progress for beam commissioning of CAFe has achieved during last two years.*
2. *The beam commissioning results demonstrated that the LLRF control system can maintain stable operation, but more optimization needed to improve the reliability.*
3. *With the arrival of the new CiADS project, the initial design stage of LLRF system is starting.*
4. *The mTCA platform is one candidate, but the trade-off of system engineering need to be evaluated.*
5. *The next generation FPGA chip (Zynq) is under investigated.*

Thanks!
谢谢！