



Low Level RF Applications based on MicroTCA.4 at IHEP

Xinpeng Ma

Institute of High Energy Physics, Chinese Academy of Sciences

On behalf of LLRF team

2018-12-06



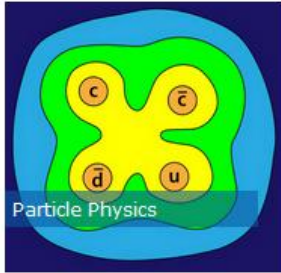
Outline

- History of LLRF at IHEP
- LLRF Applications of IHEP
 - ADS Injector I and Main Linac
 - SHB
- Future Applications
- Summary

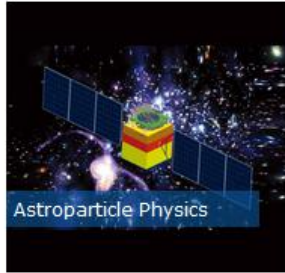
Institute of High Energy Physics



Accelerator Technology and Science



Particle Physics



Astroparticle Physics



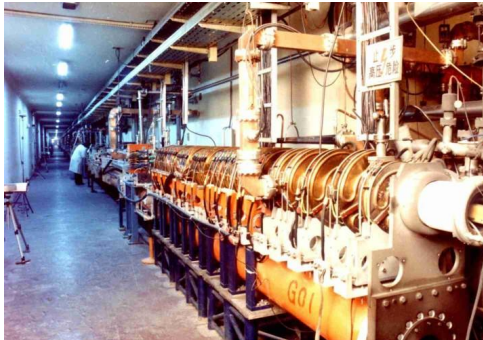
Multi-Disciplinary Research



Computing



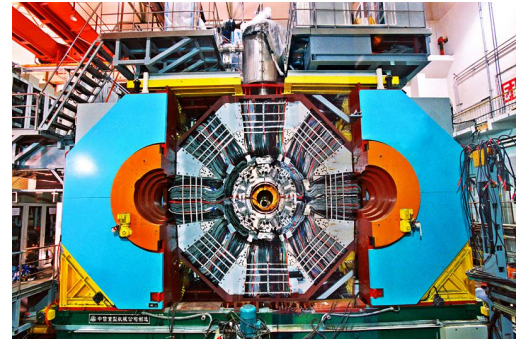
Technology Transfer



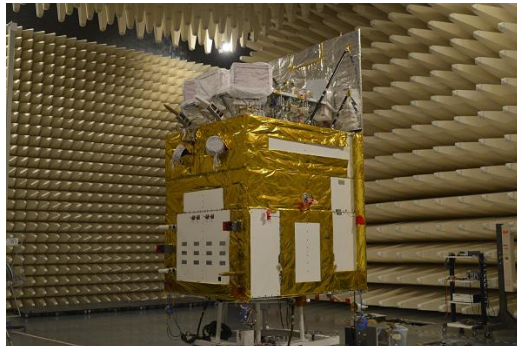
2.5GeV Linac



2.5GeV E-/E+ Collider / SR



particle detector



space telescope

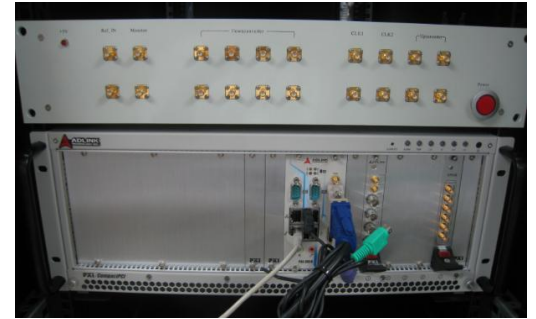
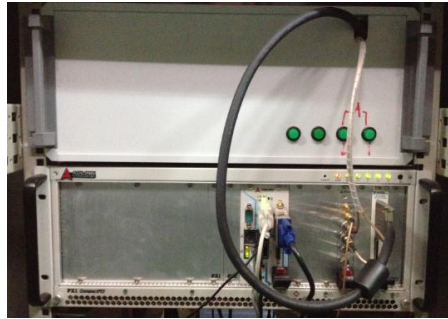
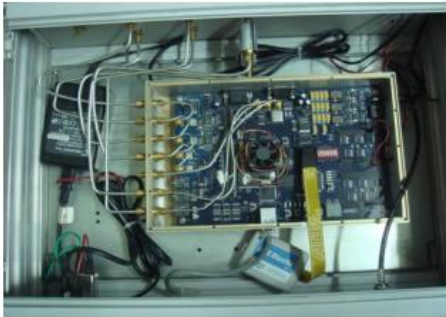


spallation neutron source



Brief History of LLRF at IHEP

- Before 2009, analog LLRF;
- Until 2012, digital LLRF hardware from many vendors: Altera, NI, ADLink, GE ...or customized;
- Communication bus/link: Ethernet, PCI, PXI, ...



- Then ...From **2013**, MicroTCA.4 adopted in LLRF, introduced by DESY



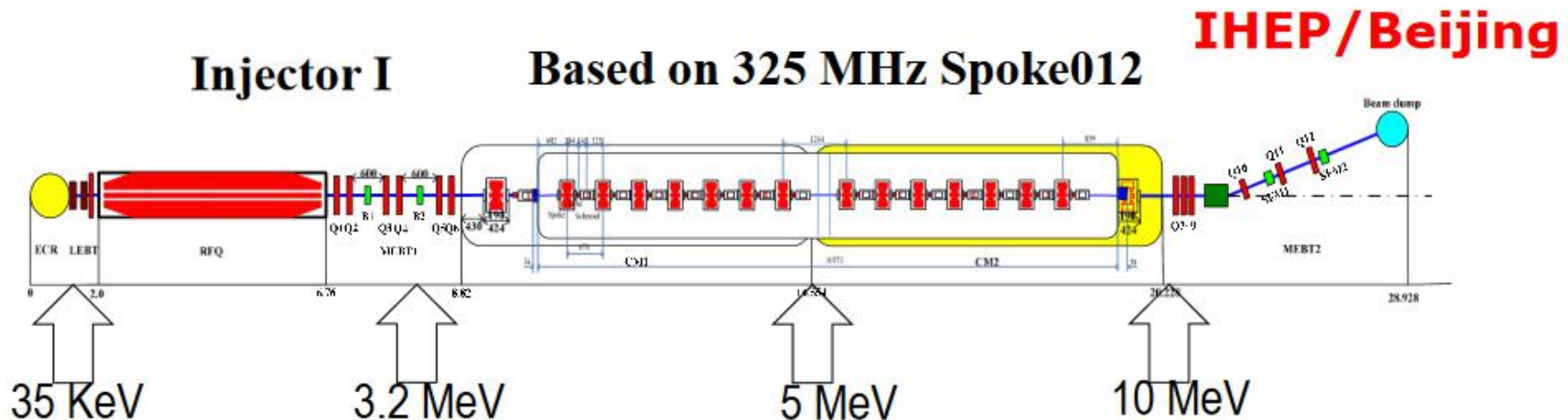
LLRF Application

- ADS Injector I and Main Linac



China Accelerator Driven Sub-critical System(ADS)

- Strategic Project to solve the nuclear waste problem in China;
- **1st Phase:** 10MeV CW proton injector and 25MeV main linac;
- **IHEP** build 325MHz Injector I : 1 RFQ + 2 Bunchers + CM1(7 spoke cavities) + CM2(7 SC cavities); and CM4(6 SC cavities)

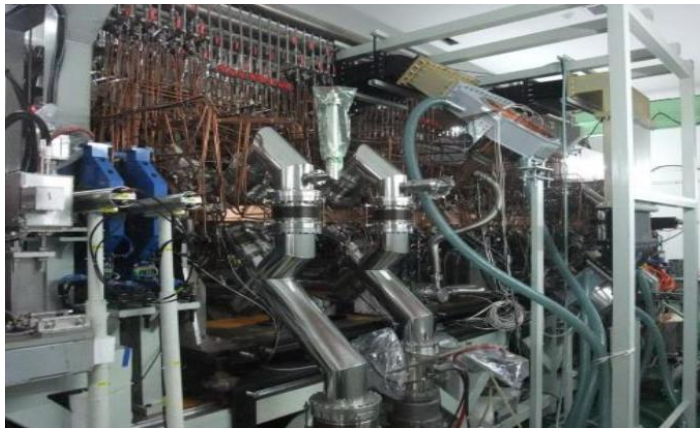


Layout of ADS Injector I built by IHEP



LLRF Application

ADS Injector I and Main Linac:



Parameter	Value
Frequency (MHz)	325
Q_L	~ 7000
Injection energy (keV)	35
Output energy (MeV)	3.2
Beam current (mA)	10
Beam duty factory (%)	100
Total power (kW)	< 250
Beam transmission (%)	98.7

Parameter	Value
Frequency (MHz)	325
Q_L	$\sim 12,000$
Particle energy (MeV)	3.2
Beam current (mA)	10
Beam duty factory (%)	100
Total power (kW)	6.3
Effective voltage (kV)	120
Tuner tuning range (kHz)	740

Parameter	Value
Operation frequency (MHz)	325
β_0	0.14
E_p/E_{acc}	~ 5
Q_{ext}	$\sim 5 \times 10^5$
R/Q	~ 150
df/dp (Hz/mbar)	+40
df/dF (Hz/N)	60

Main Parameters of RFQ, Buncher and Spoke Cavities



LLRF Application

■ ADS Injector I and Main Linac:

- Struck SIS8300/SIS8900, 1xRFQ+2xBUN+CM1(7xSC)+CM2(7xSC);
- First time MicroTCA.4 system used on SC Linac in China;

- Standard LLRF structure;
- LLRF controller is the same for all the cavities;
- Standalone RF front-end including LO&CLK module, up&down-converter;

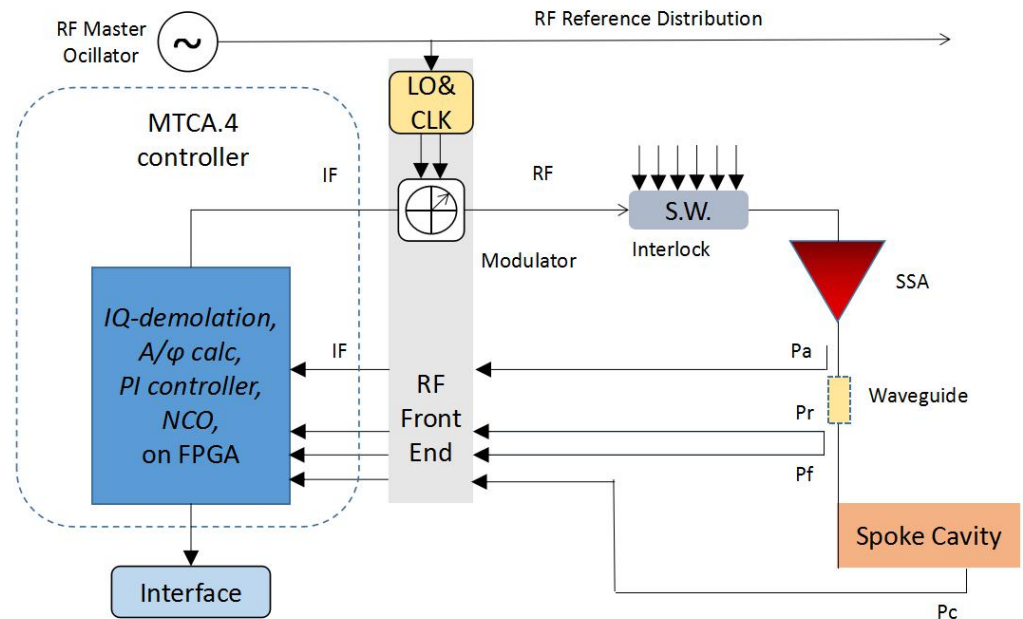


Diagram of LLRF system



LLRF Application

■ ADS Injector I and Main Linac:

Cabinets
of LLRF for
14 SC
cavities



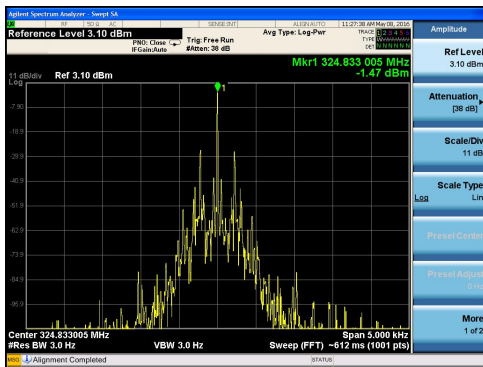
R. Liu, DESIGN AND COMMISSIONING OF LLRF SYSTEM FOR ADS PROJECT IN CHINA, IPAC2016
X. Ma, MICROTCA.4-BASED LLRF SYSTEM FOR SPOKE CAVITIES OF FC-ADS INJECTOR I, IPAC2016



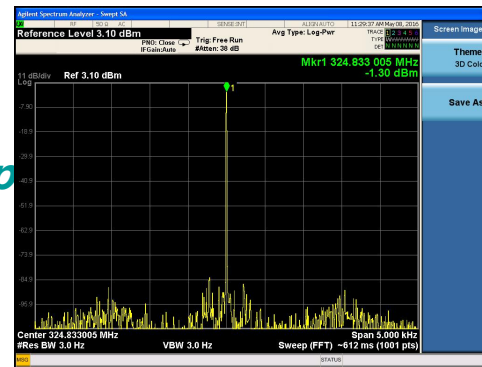
LLRF Application

■ ADS Injector I and Main Linac:

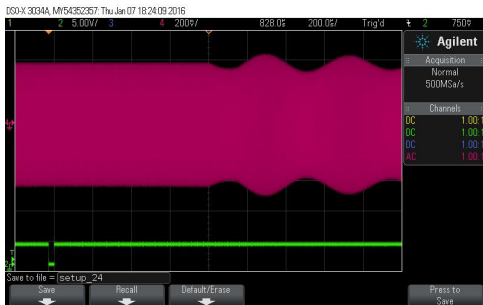
Some performance results:



Open Loop



Close Loop



Feedback

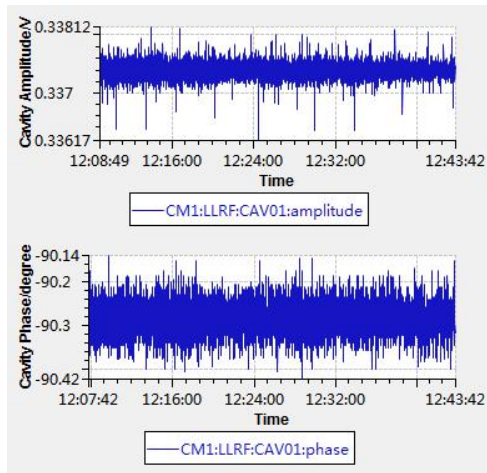


Feedback + Feedforward



LLRF Application

■ ADS Injector I and Main Linac:



p-p stability: $A/\phi: 0.3\%/0.2\text{deg}$

UI for operator

Cav. #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Eacc (MV/m)	3.92	5.44	6.52	5.97	6.96	5.14	5.36	5.68	4.92	6.25	6.14	6.67	6.08	3.59

Acceleration field of SC cavities



LLRF Application

March, 2017, Main Linac - CM4 started: 6 SIS8300L2/SIS8900;



- First application of SIS8300L2
- Firmware is upgraded to V2.0
 - multi-channels sig. monitoring
 - support work in CW or pulsed
 - support feedback and FF
 - support I/Q and A/ ϕ mode
 - support GDR and SEL mode
 - support ramping, automatic phase scanning, automatic conditioning, add white noise, etc.

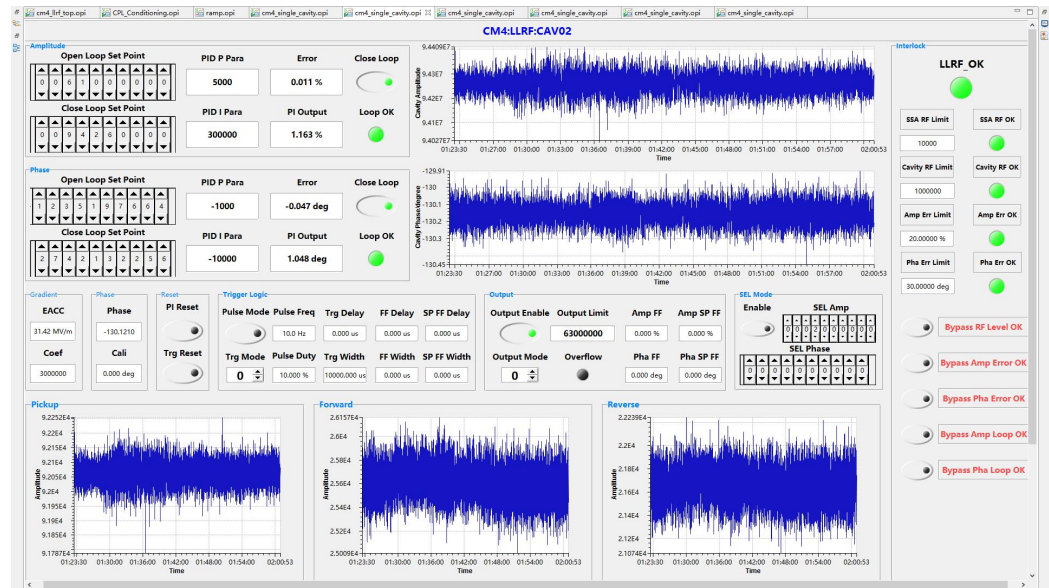


LLRF Application

- ADS Injector I and Main Linac:
- LLRF for CM4 fully delivered to the user;
- LLRF is very robust during >1 year beam operation;



Cryomodule4 @ Main Linac



UI of LLRF for CM4



LLRF Application

■ ADS Injector I and Main Linac: **Beam achievement.**

- Sep. 2014, The ECR Source+LEBT+RFQ has been commissioned with Max. 90% duty factor beam;
- Feb. 2015, MicroTCA hardware LLRF are implemented;
- Oct. 2015, The CM1 output reached **6MeV/10mA/30us** beam @2K;
- Jan. 2016, The CM1 output reached **6MeV/10mA/1ms** beam @2K;
- July 2016, The CM2 output reached **10.1MeV/10.6 mA/20μs/20Hz** beam @2K , transmission efficiency is 100%.
- Jan. 2017, The CM2 output reached **10MeV/2.1mA CW** beam @2K;
- Apr. 2017, LLRF hardware/firmware upgrated and implemented on CM4;
- June 2017, The CM4 output reached **25.0MeV/0.15mA CW** proton beam @4K;



LLRF Application

- BEPCII Sub Harmonic Bunchers

BEPCII SHB NC Bunchers

- Normal conducting pill-box cavities on BEPCII Linac
- 2 SIS8300L2/SIS8900 boards for 2 Sub-Harmonic Bunchers of E-Linac
- Frequency: 142.8MHz and 571.2MHz; PPS:1-50Hz;

Parameter	SHB1	SHB2	Unit
f_0	142.8	571.2	MHz
Q_0	~8175	~13629	/
Power	10	7	kW
Pulse width	60	60	us
Rep. Rate	1-50	1-50	Hz
shunt impedance	1.4	3.0	M Ω





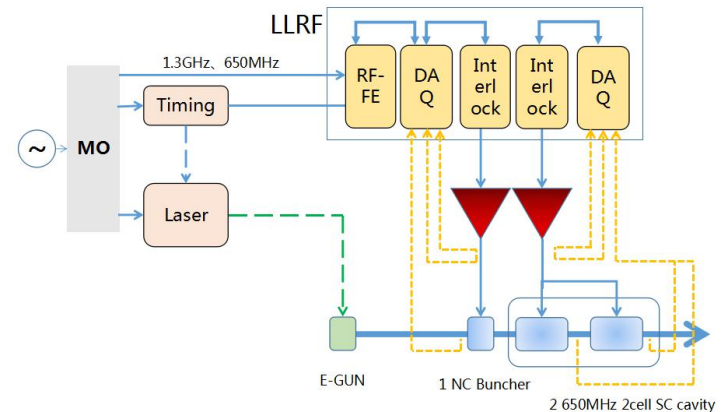
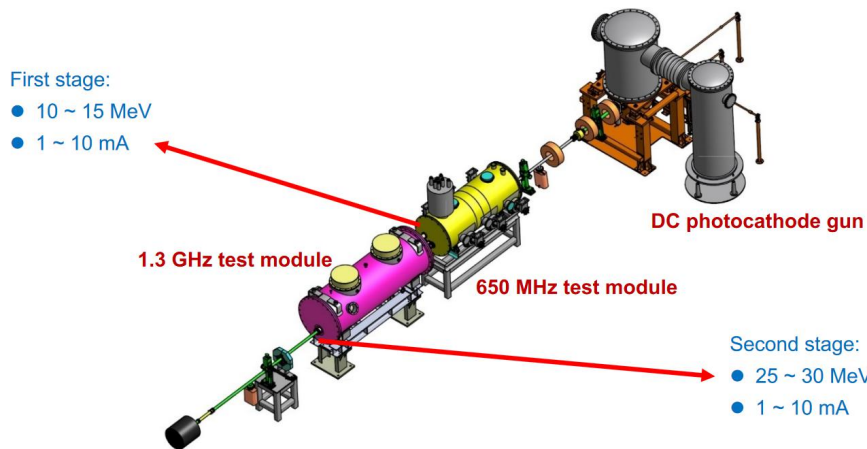
Future applications



PAPS

Platform of Advanced Photon Source Technology R&D

- Test facility for future Photon Source, XFEL/XERL;
- 1.3GHz buncher, two 650MHz 2-cell SC cavities in one CM;
- High requirement: amplitude 0.01%rms, phase 0.01°rms;
- One MicroTCA.4 based LLRF Crate is needed;



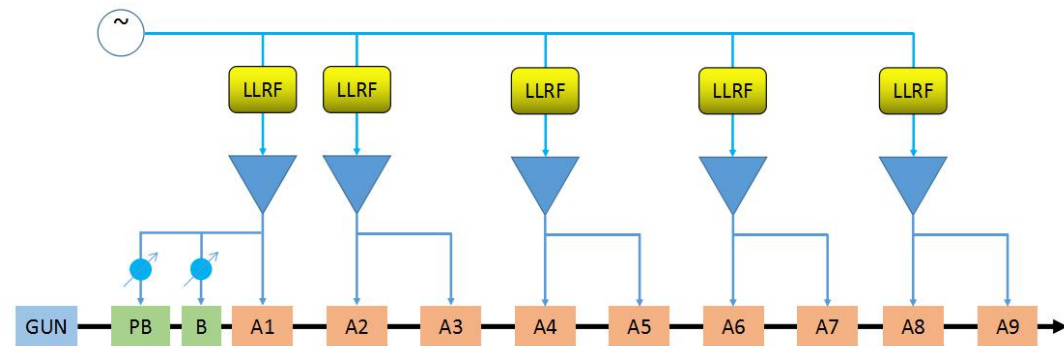
courtesy of X. Li



HEPS

High Energy Photon Source

- 6GeV photon source;
- LLRF for the 500MeV e-linac injector use MicroTCA.4 platform;
- 5 sets of LLRF controller for 5 S-band klystrons and acc tubes;
- Project starts this month;





Summary

- MicroTCA.4 standard hardware platform has been successfully used in the LLRF system for ADS Injector I and main linac, also used on SHB cavities of the BEPCII E-Linac;
- MicroTCA.4-based LLRF will be used in the PAPS, HEPS Project at IHEP in the next future;



Thank you for your attention!