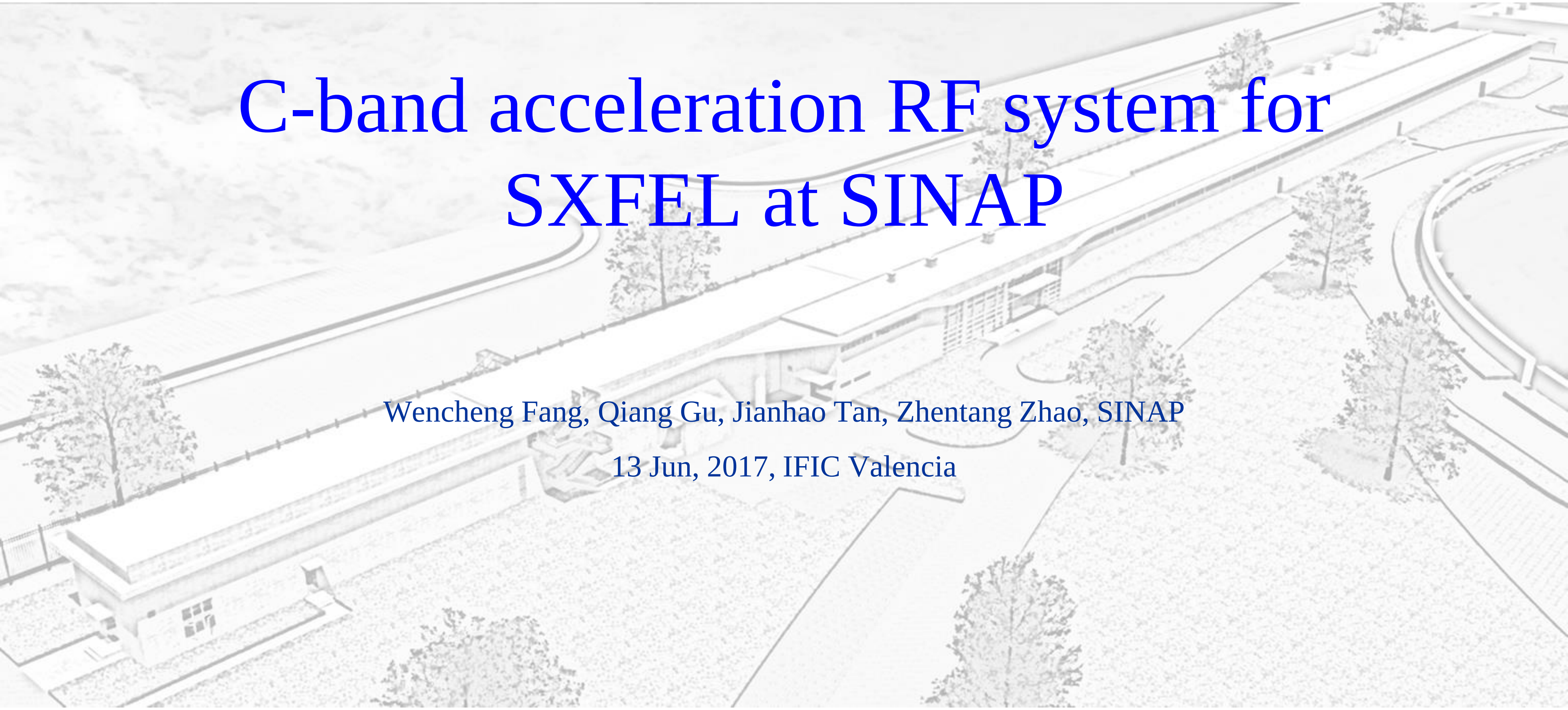


C-band acceleration RF system for SXFEL at SINAP

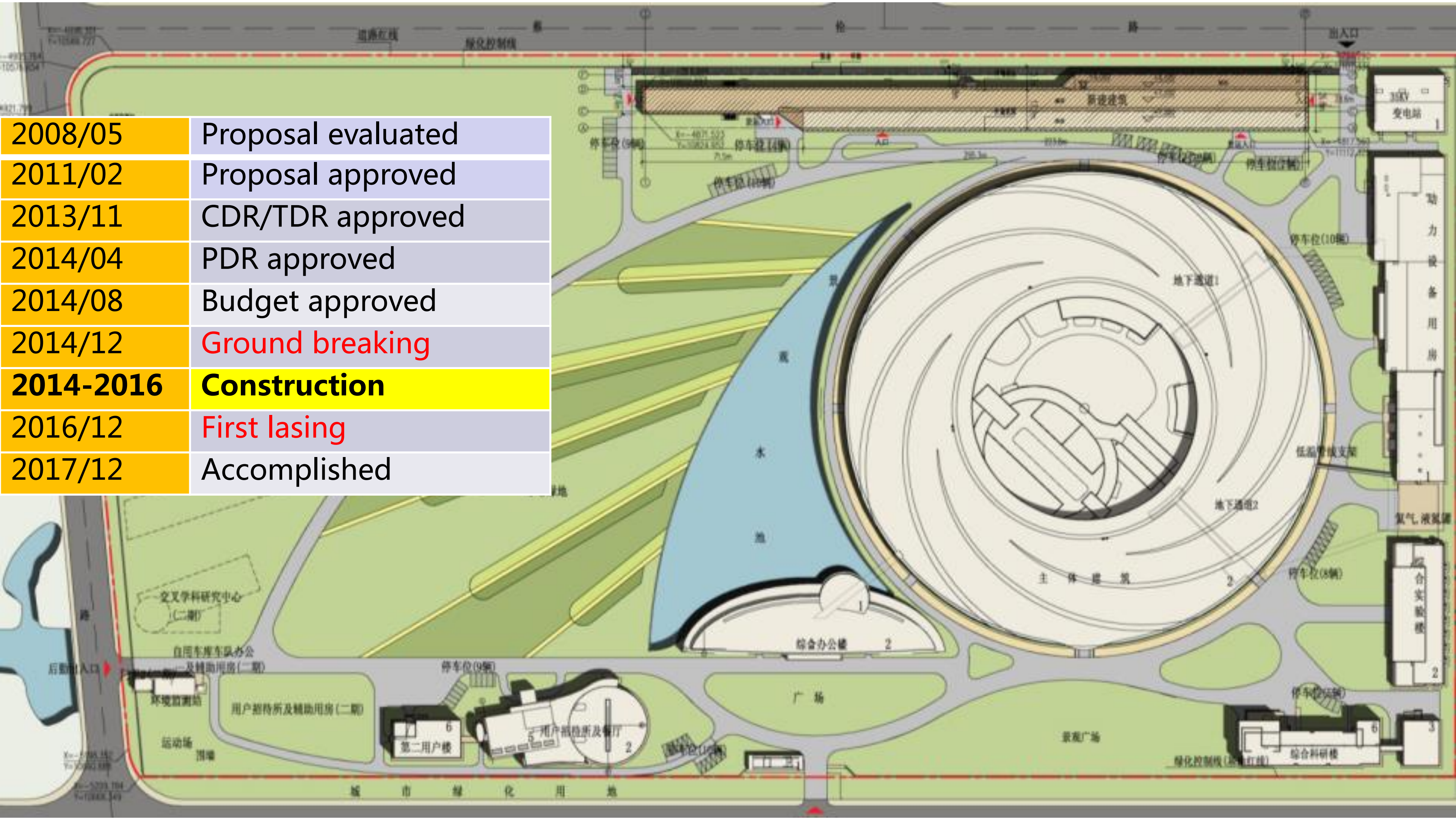
Wencheng Fang, Qiang Gu, Jianhao Tan, Zhentang Zhao, SINAP

13 Jun, 2017, IFIC Valencia

Outline

- Background application in SXFEL
- Prototype test results
- Layout and installation of C-band RF system
- RF conditioning and beam test results.
- Upgrading plan for user facility
- Summary

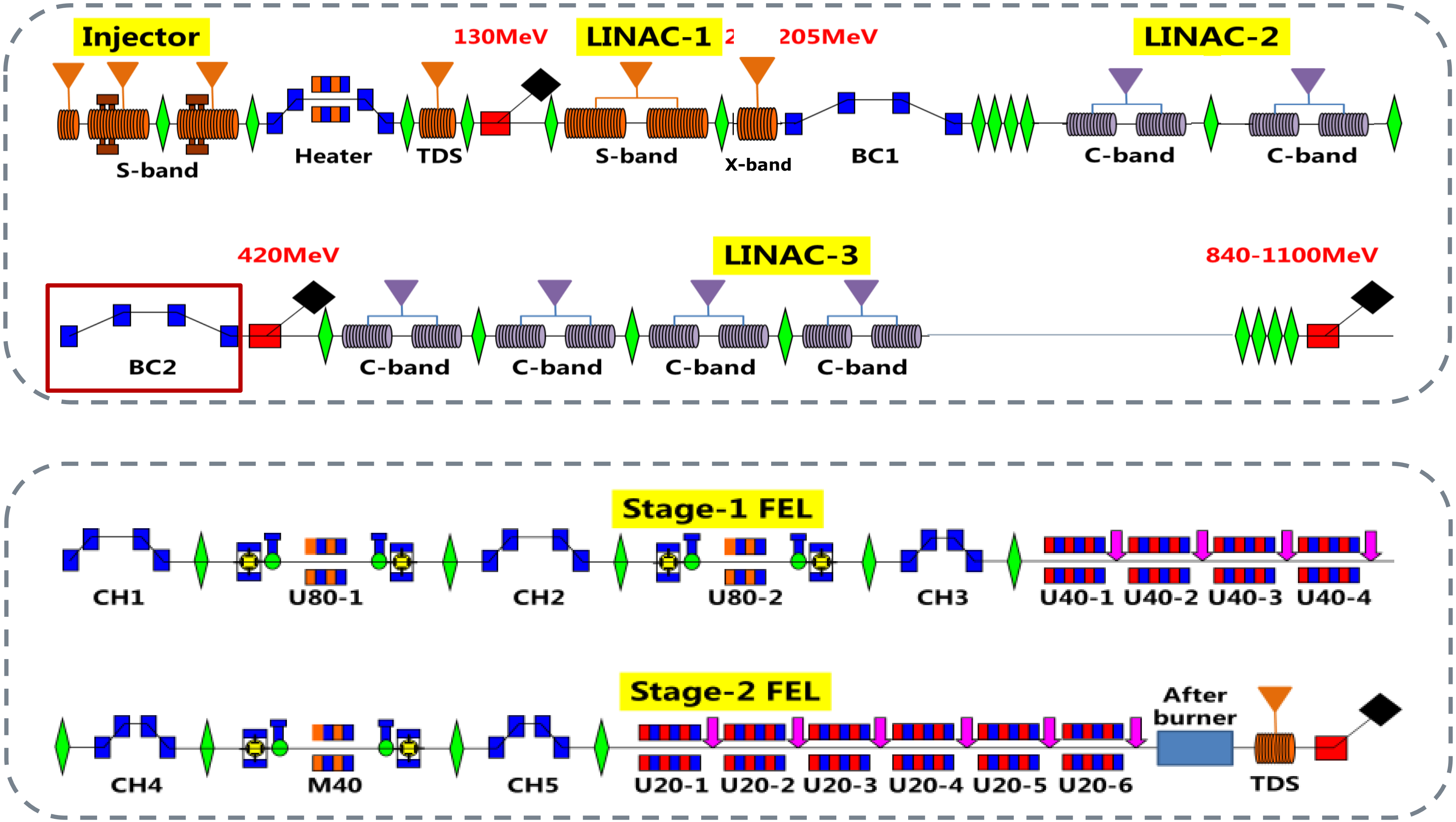
Shanghai Photon Science Center in Zhangjiang campus of SINAP



2008/05	Proposal evaluated
2011/02	Proposal approved
2013/11	CDR/TDR approved
2014/04	PDR approved
2014/08	Budget approved
2014/12	Ground breaking
2014-2016	**Construction**
2016/12	First lasing
2017/12	Accomplished

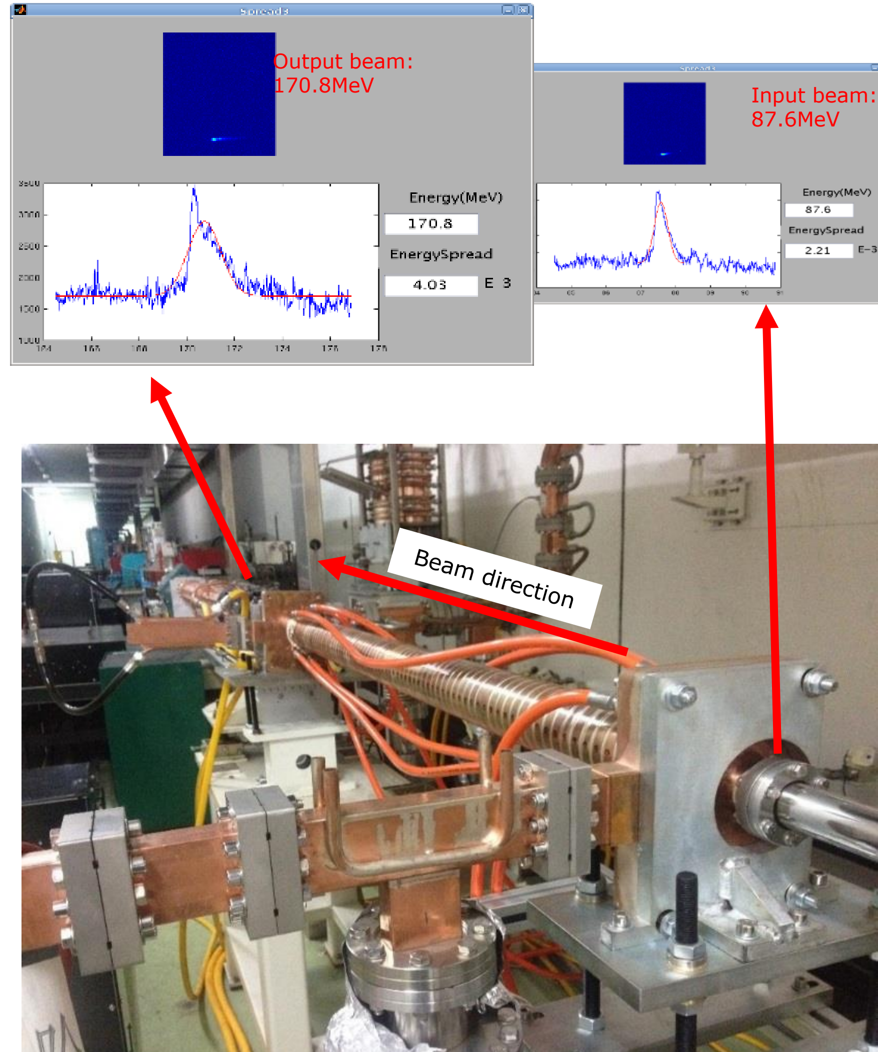
SXFEL layout plan at SINAP

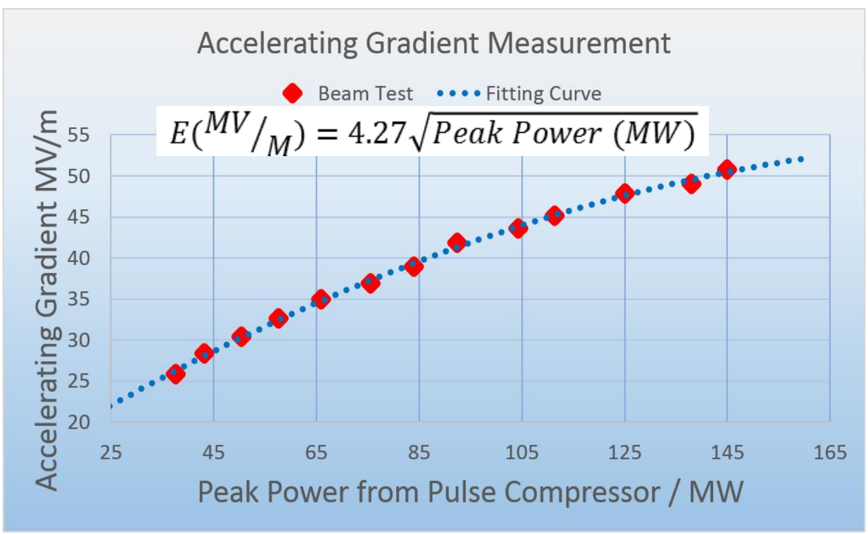
SXFEL test facility linac layout



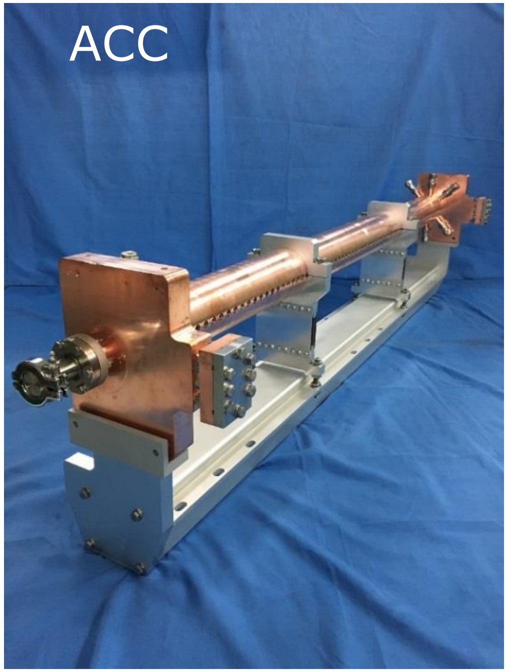
Beam test results of Prototype (50.8MV/m maximum)

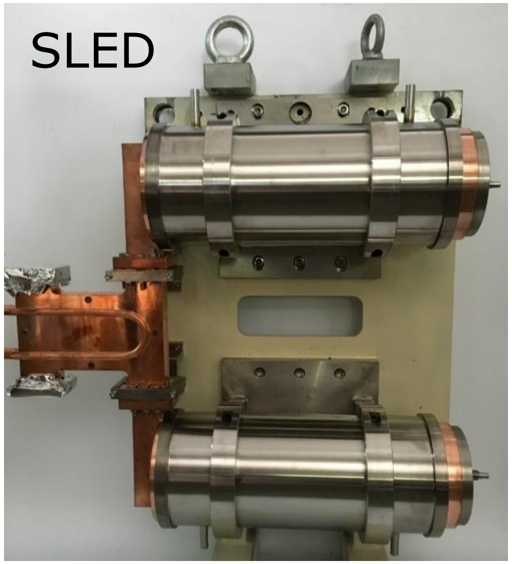
1. About more half month RF conditioning.
2. Beam energy is accelerated to maximum energy of 170.8MeV
3. 50.8MV/m maximum gradient is got, corresponding to effective length of 1.638m.
4. Different gradients are also measured.

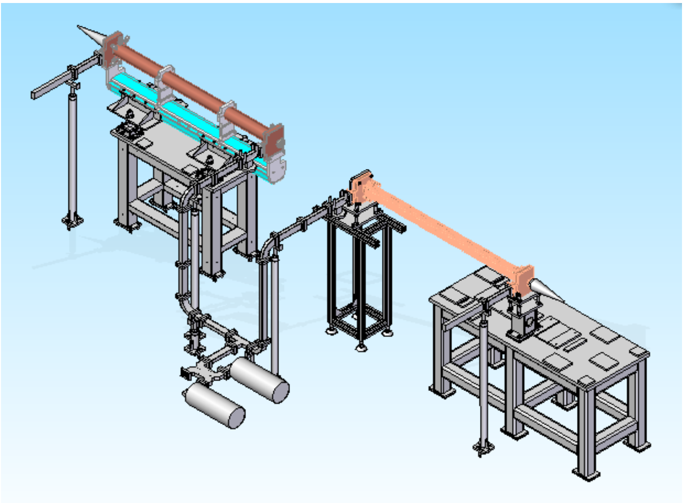


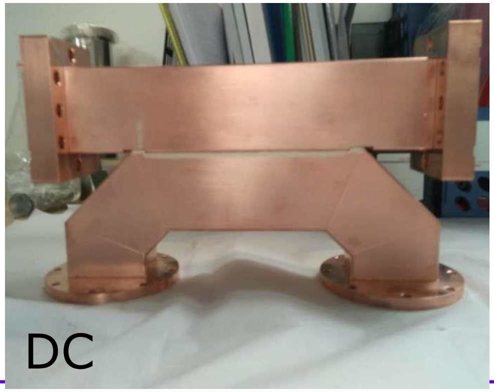


C-band RF unit prototype test results（Sep. 2016）



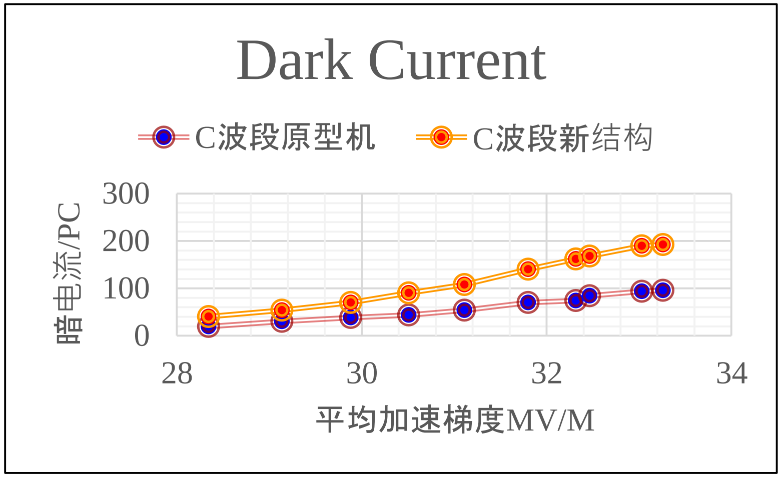


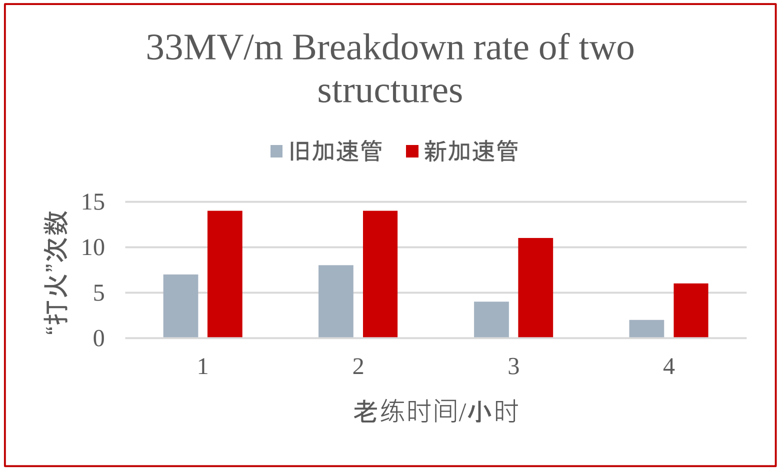




High power test results of RF unit

1. C-band RF unit has been tested for 1 week, and reached 33MV/m accelerating gradient. Which power of klystron is about 30MW.
2. The new acc structure has two times than old structure on dark current and breakdown rate, maybe because time was not enough for RF conditioning of new acc structure.
3. Due to time and power limited, no further RF conditioning was proceeded for higher gradient.



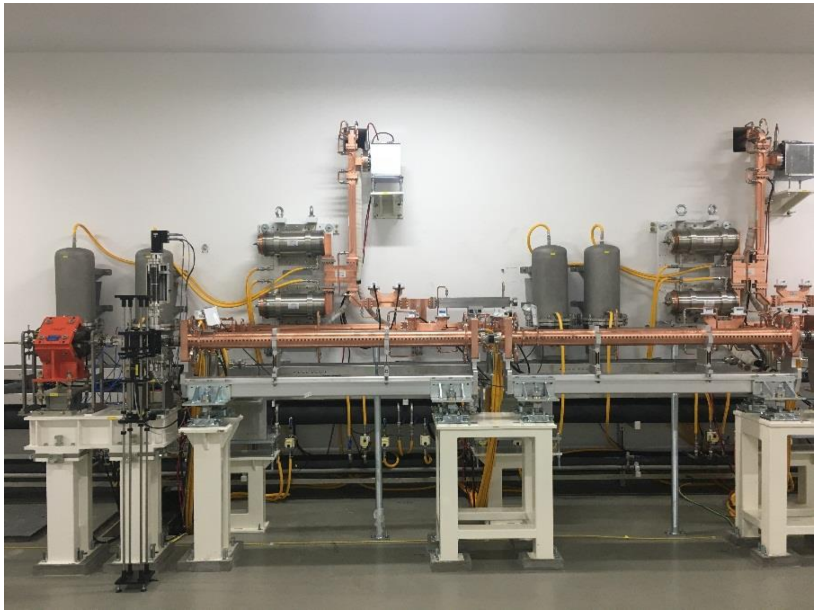


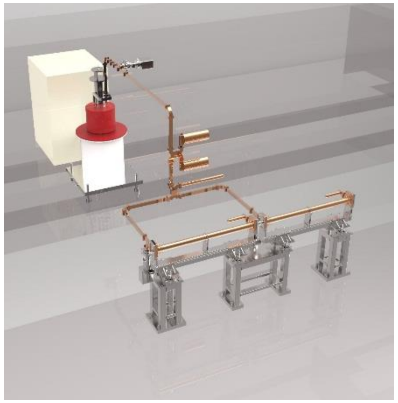
C-band RF system for main linac

1. Totally there are 6 C-band RF units as main linac.
2. 6 klystrons, modulators and amplifiers as power source
3. 12 accelerating structures, 6 pulse compressor, and waveguides.
4. 3 boxes of LLRF based on MTCA 4.0, each box controls two RF units.

Layout of C-band unit

1. 50MW C-band klystron is from Mitsubishi.
2. PFN-thyratron type modulator is developed at SINAP.
3. Acc, PC and waveguide is developed at SINAP
4. C-band load was made by Tsinghua University.
5. Low-level hardware system based on MTCA is from Struck company in Germany, and developed by SINAP.





C-band klystron PV-5050

1. All 7 C-band klystrons are from Mitsubishi.
2. 30MW power is required in the first step for 34MV/m.
3. 42MW power is required in the second step for 40MV/m.

Electrical specifications

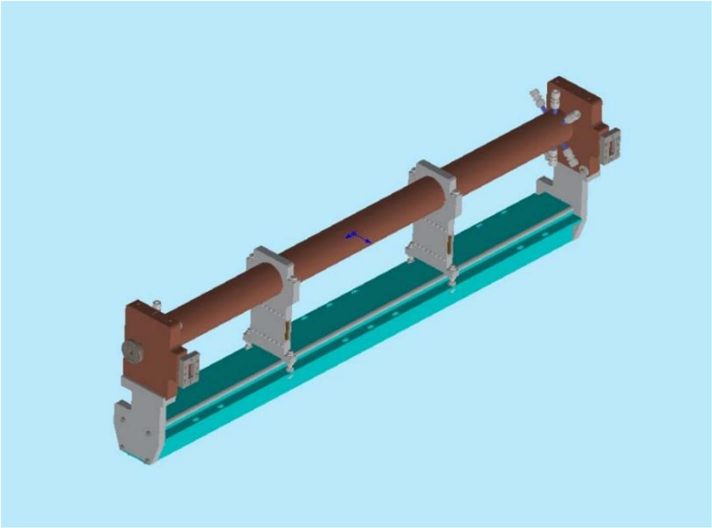
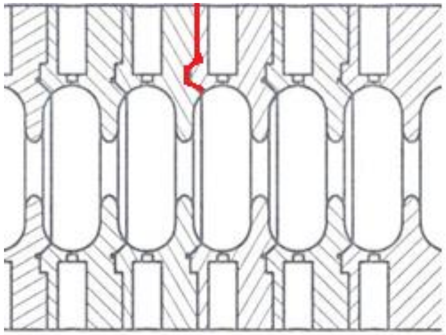
	Parameter	Rated value
1	Frequency	5712 MHz
2	RF peak output power	50 MW
3	Voltage pulse width	6.2μs
4	RF pulse width	2.5μs
5	Peak beam voltage	350kV
6	Peak beam current	320A
7	Peak driver power	130W (200W max)
8	Pulse repetition frequency	50Hz
9	No spark time at nominal ratings	2hours min
10	Efficiency	43%min
11	Gain	54dB min
12	Heater voltage	120V max
13	Heater current	4.5A max
14	Heater power	500W max
15	Preheating time	1hour
16	Ion pump voltage	3.0-5.0kV
17	Ion pump current	5μA max

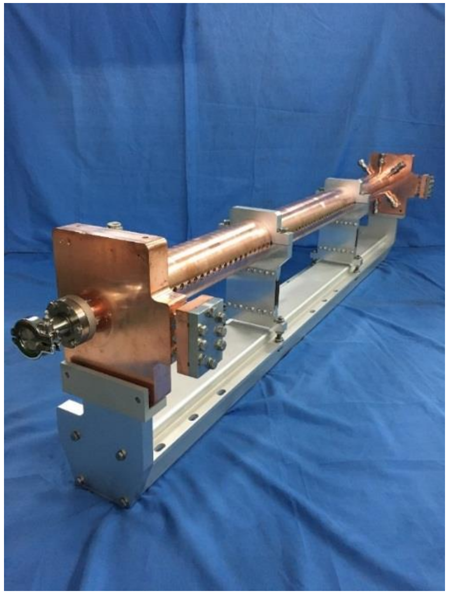
Modulator (PFN + Tharatron)

Item	Value	Unit
Pulse voltage	350	kV
Pulse current	320	A
Pulse power	112	MW
Pulse width (flat-top)	3	µs
FWHm	5.5	µs
Repetition rate	10	Hz
Average power	7	kW
Transformer ratio	1:16	
PFN voltage	45	kV
Switch current	5200	A
PFN type	20 cells	
PFN impedance	4.33	Ω
PFN capacity	0.635	µF
Charging voltage	50	kV
Charging current	480	mA
Flatness	<±0.25	%
Amplitude stability（rms）	< 0.02	%
Rise edge jitter（rms）	< 10	ns

Accelerating structures

1. This structure is constant gradient, phase advance is 4pi/5, target is 40MV/m at least.
2. Rounded cell for higher impedance, and tuner is remained.
3. Compact coupler with single port, inner water cooling.
4. Four support points, in which one is fixed, two are flexible, and one is free.

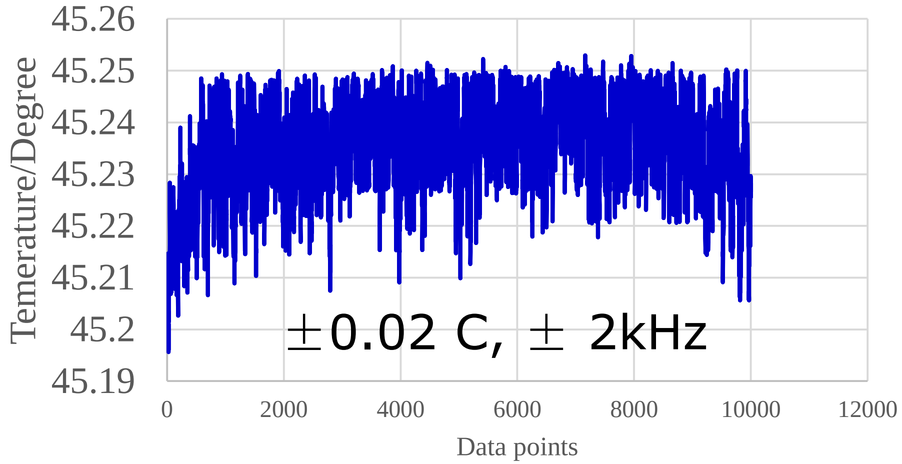


Pulse compressor

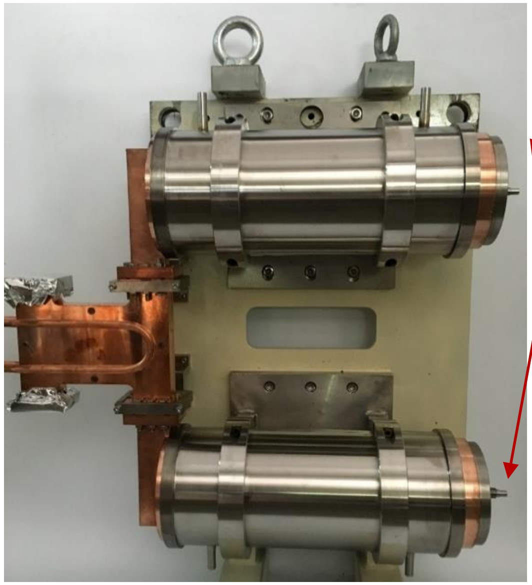
1. Pulse compressor was first tuned by mechanical tuner.
2. During operation, advanced Chiller are used to make temperature stable, and also to tune PD slightly.

Frequency	5712MHz
Quality factor	About 180000
Coupling coefficient	About 7.5

12 hours Temperature measurement

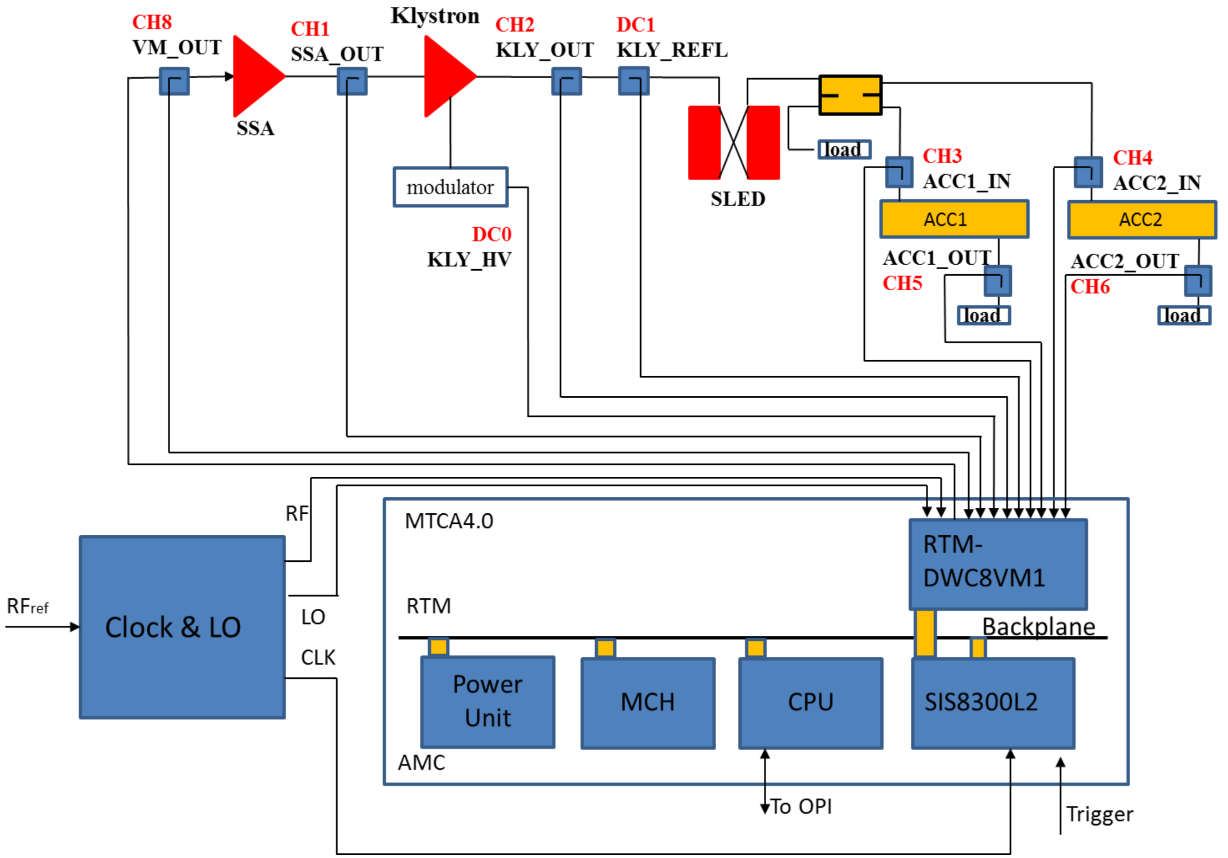


Tuner

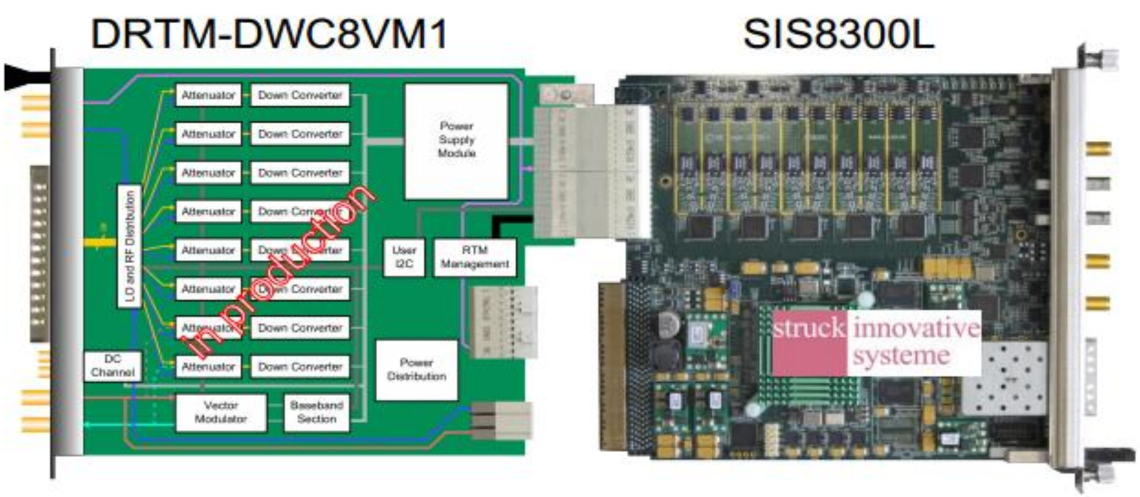


LLRF based on MTCA 4.0

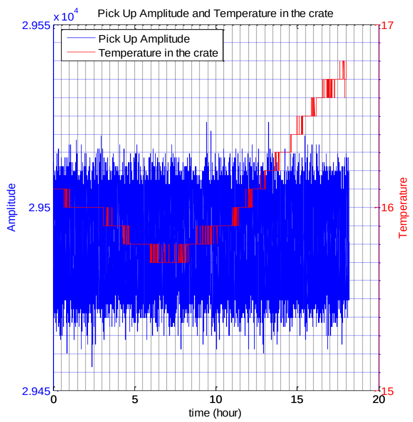
1. LLRF system is based on MTCA 4.0 hardware and software driver, and was developed to carry out many functions, including amplitude and phase feedback and modulation, data acquisition and reflection protection.
2. 8 RF signals and 2 DC signals channels.
3. Each crate controls two C-band RF units.

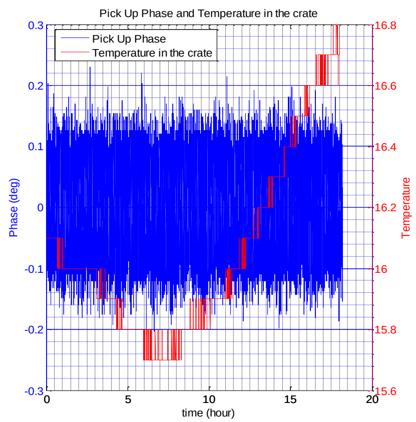


MicroTCA core: DRTM-DWC8VM1 and SIS8300L board



- **Struck SIS8300L Board**
  - RF signals acquisition.
  - FPGA feedback control
  - IQ signals output
  - 10 channels 125 MHz 16-bit ADC
  - 2 channels 250MHz 16-bit DACs
  - Virtex 6 FPGA

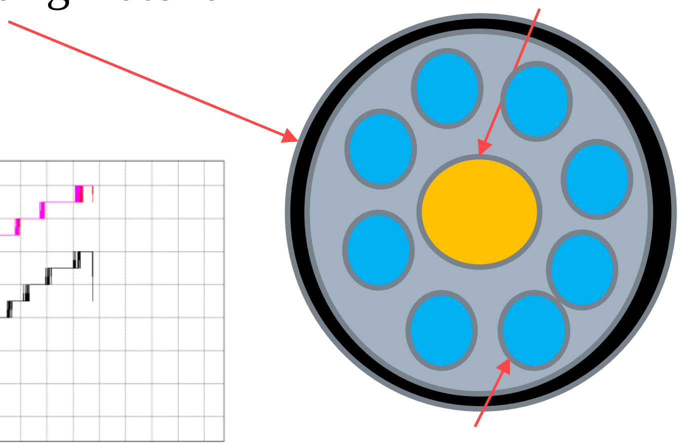


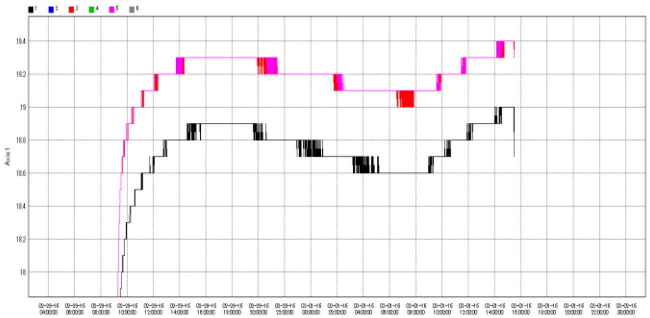


Amplitude and phase stability with local master and Amplifier: 0.17% and 0.4 degree (peak-to-peak) for S-band

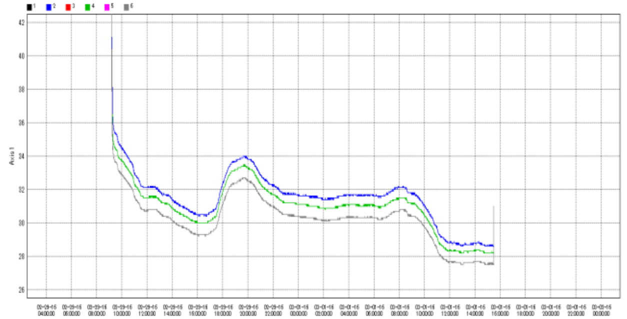
- **DRTM-DWC8VM1 Board**
  - 8 channels down-converter（700MHz-7GHz）
  - Stability: amplitude<0.005%
  - phase<10fs(rms)[10Hz,1MHz]
  - 2 DC channels for coupling（DC-400MHz）
  - One channel for up-converter（50MHz-4GHz)
  - Tunable attenuator for RF input

Temperature control of cabinet and cable for LLRF

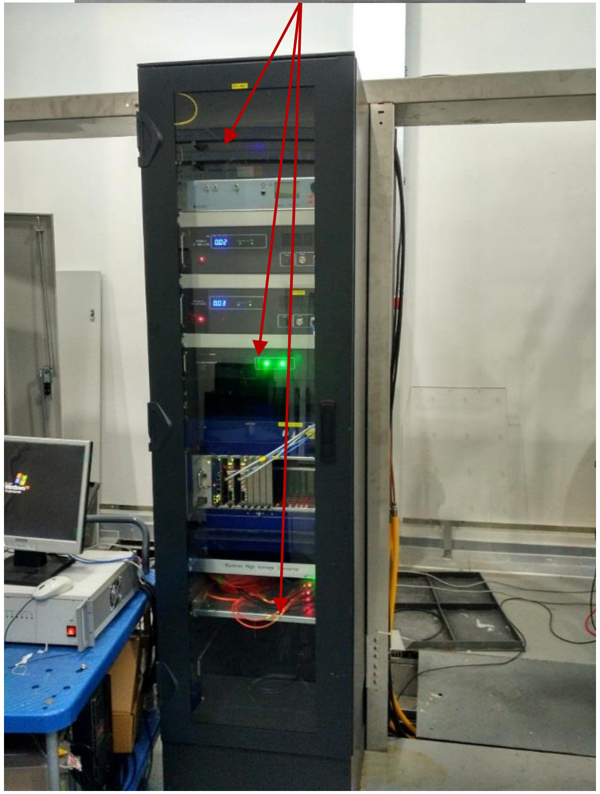




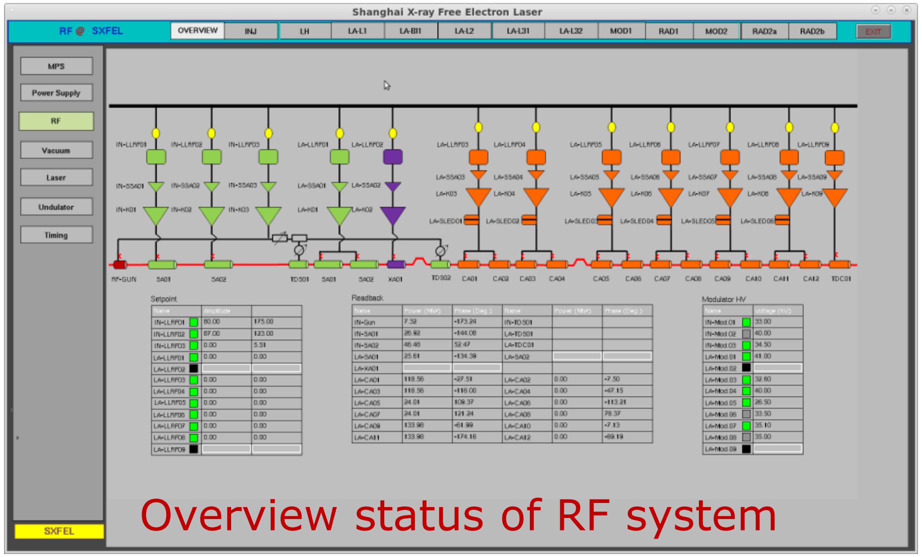
Three locations for temperature measurement
±0.1°C stability during 29 hours

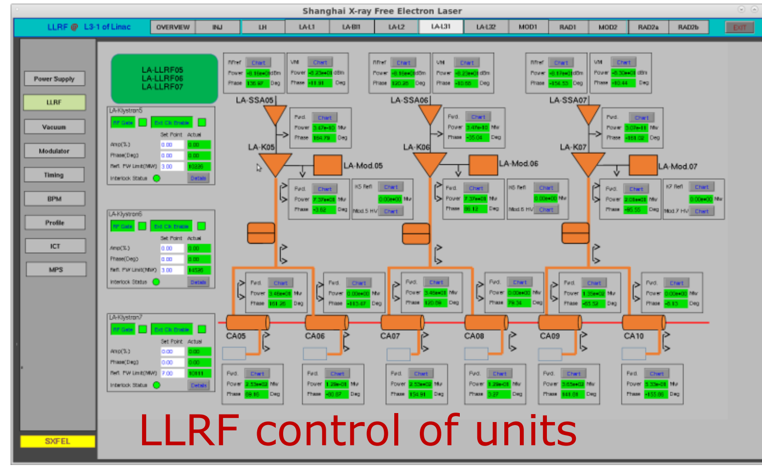


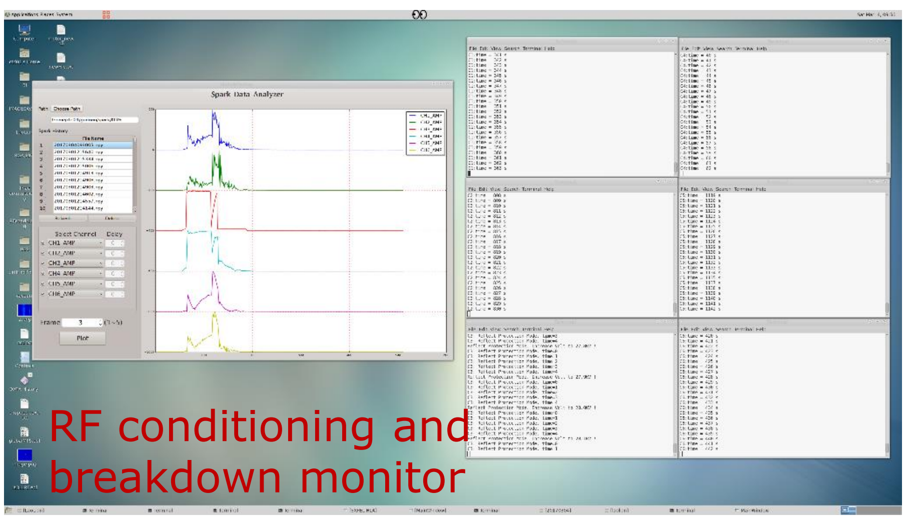
Three locations for humidity measurement
±2.8% stability during 29 hours

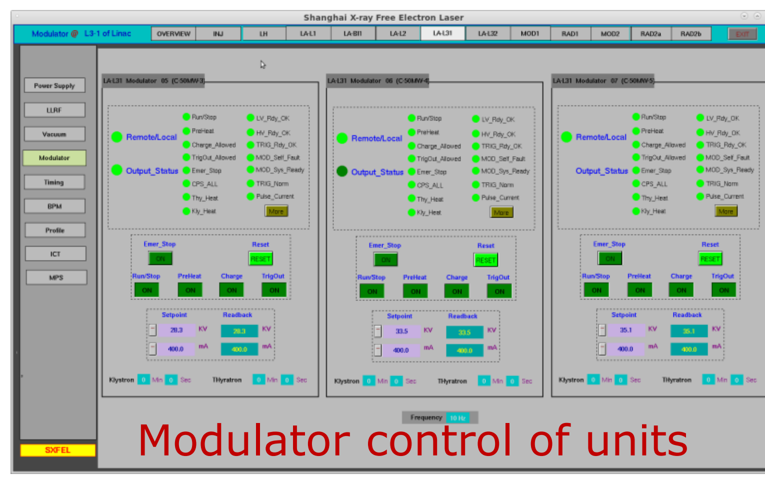


Control windows of RF system

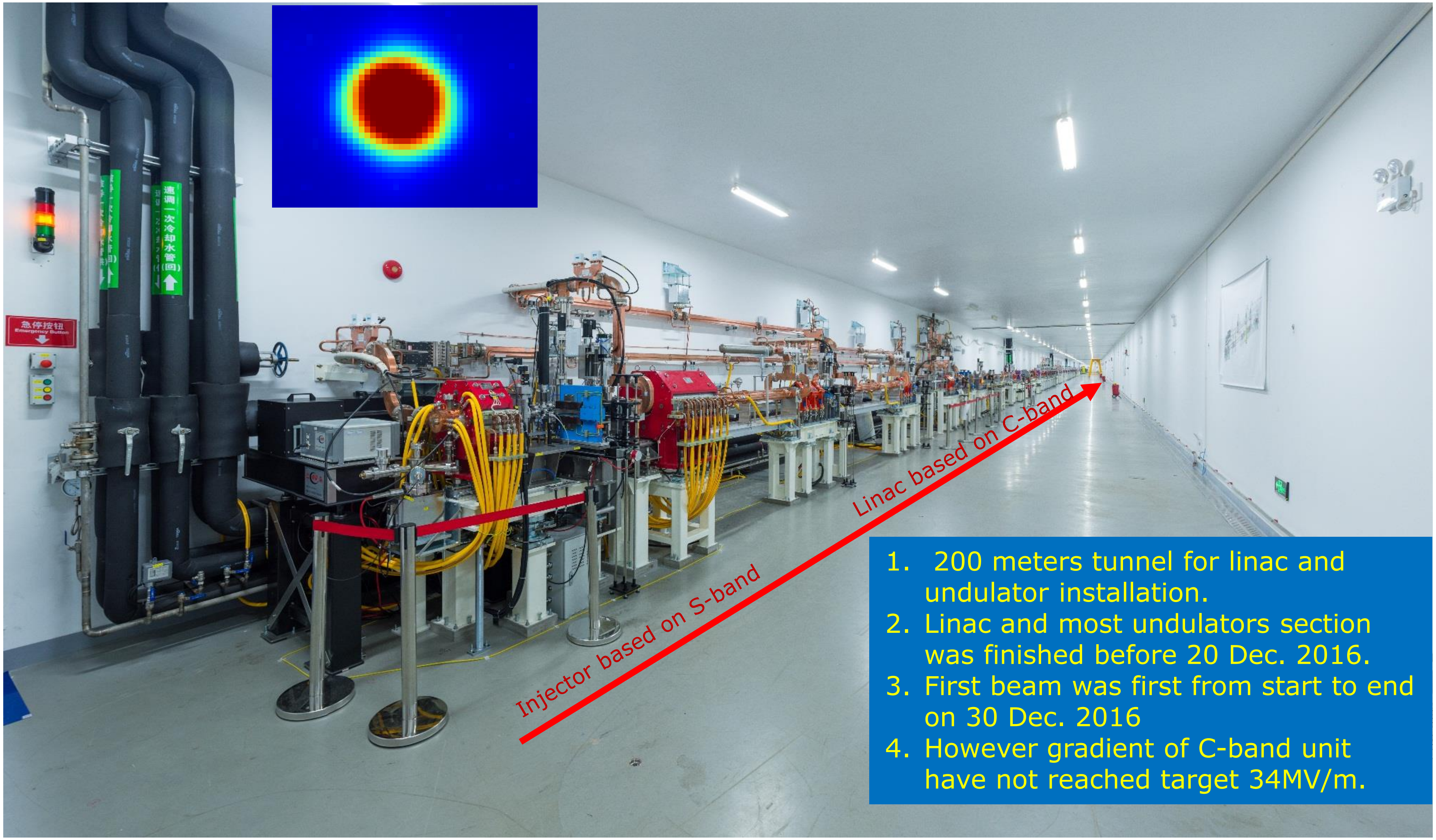

Overview status of RF system


LLRF control of units


RF conditioning and breakdown monitor

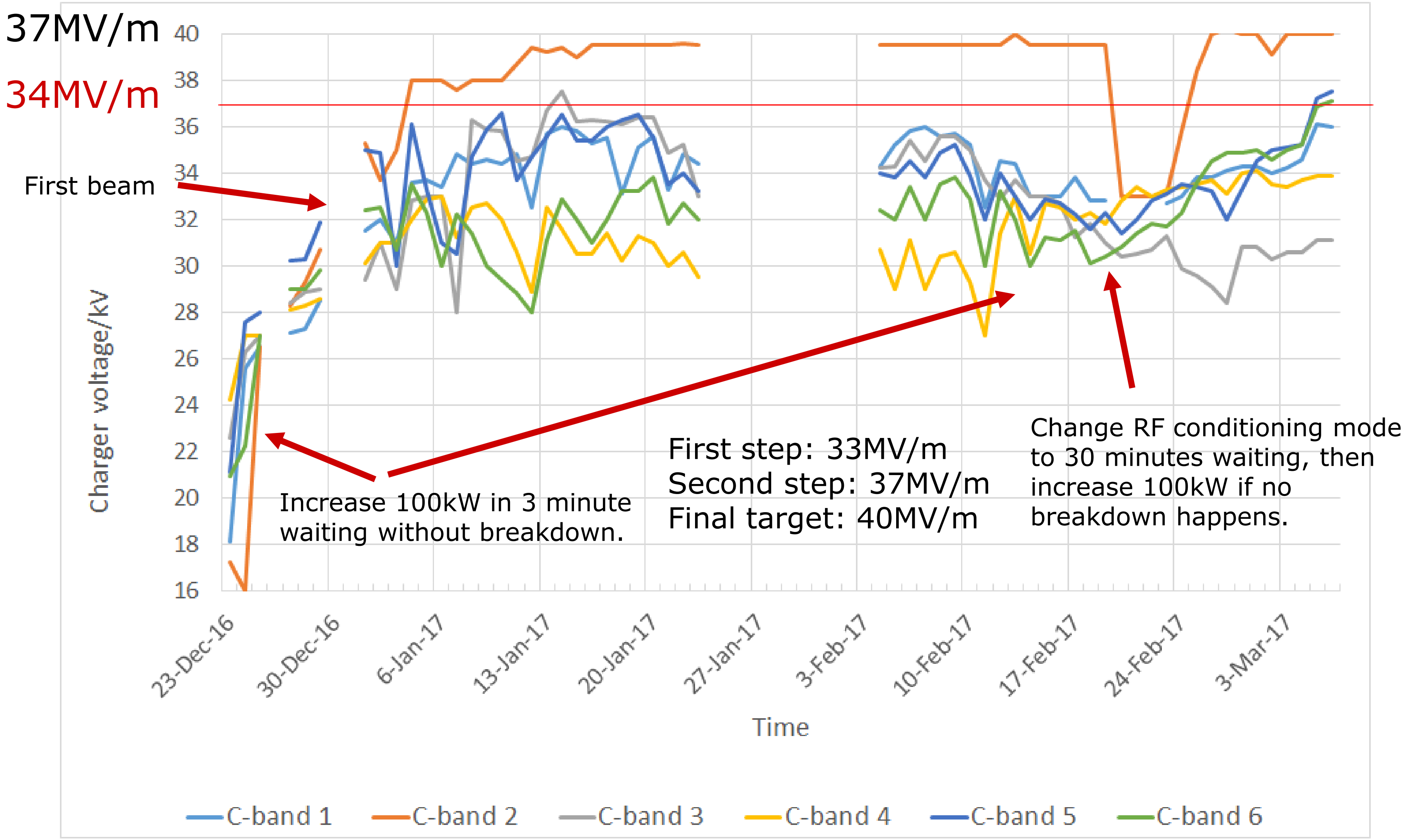

Modulator control of units

Present Status of SXFEL



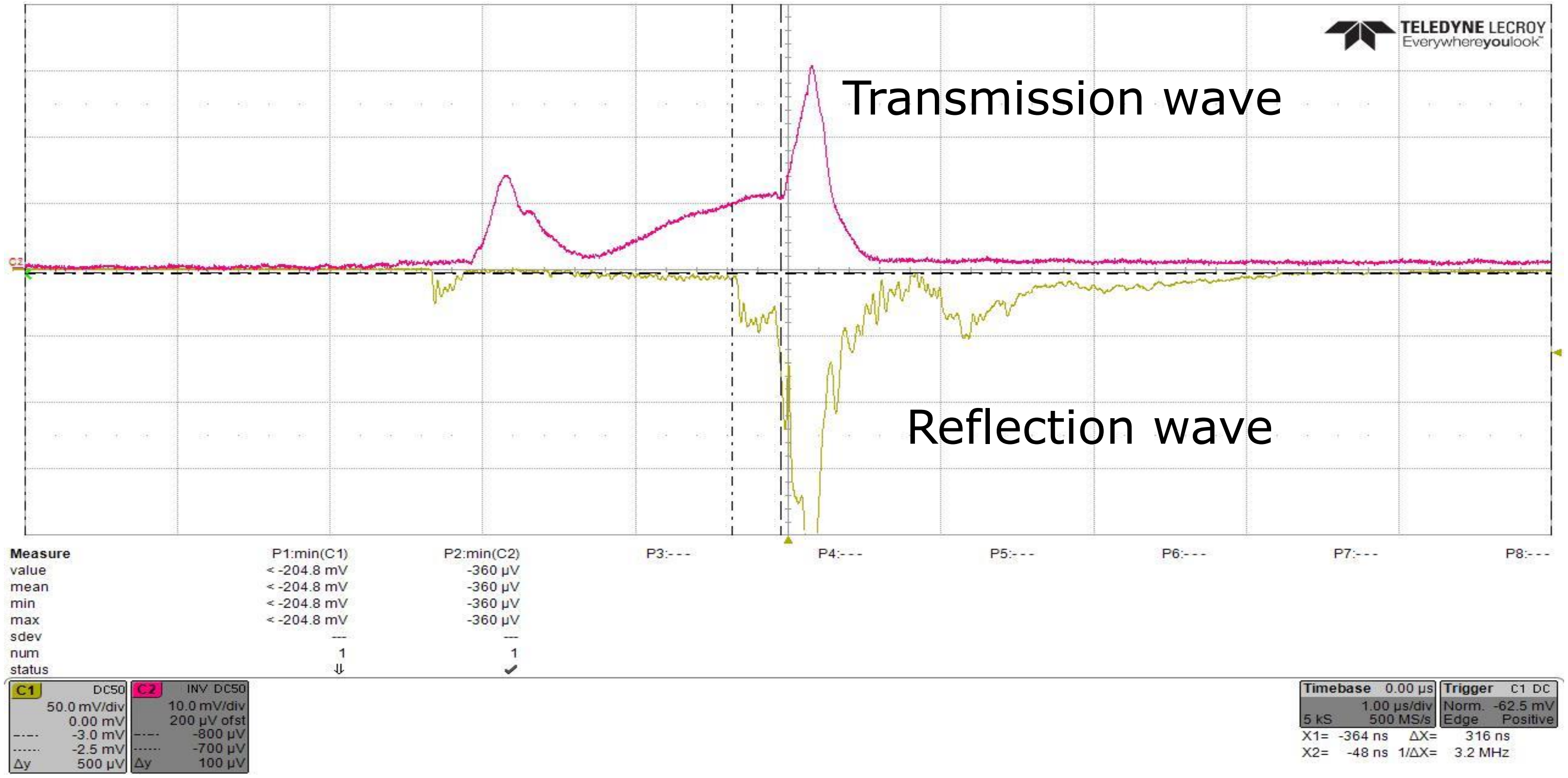
1. 200 meters tunnel for linac and undulator installation.
2. Linac and most undulators section was finished before 20 Dec. 2016.
3. First beam was first from start to end on 30 Dec. 2016
4. However gradient of C-band unit have not reached target 34MV/m.

Problems on RF conditioning of C-band RF units



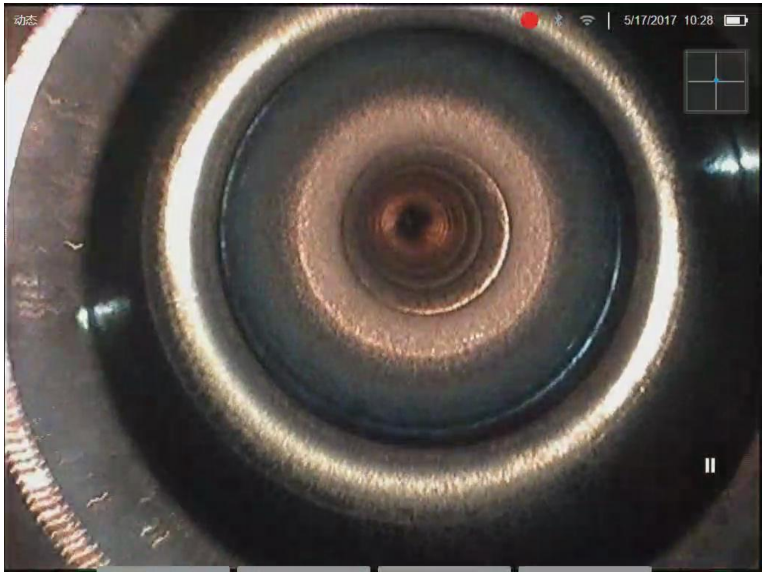
Limitation on accelerating gradient

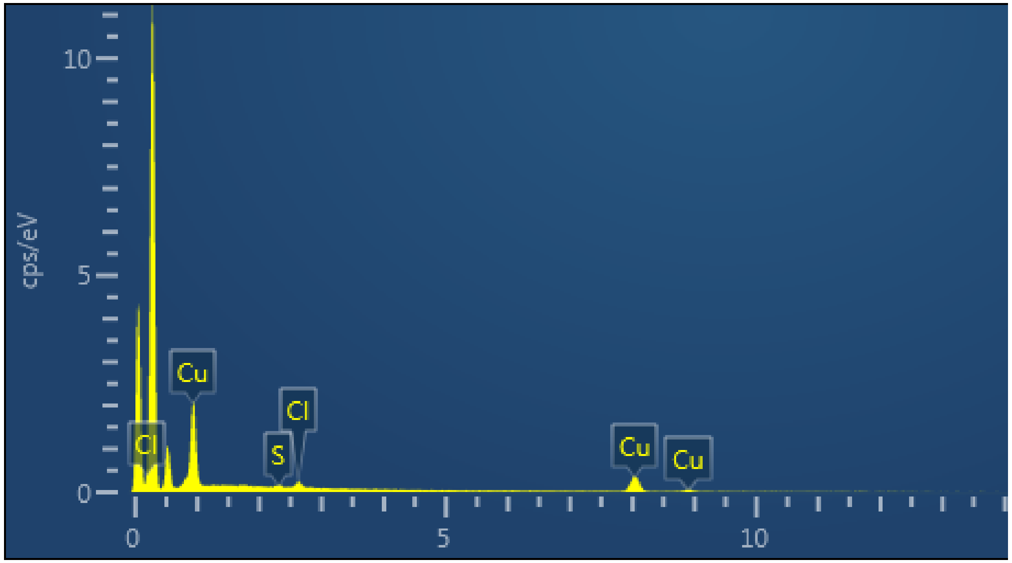
1. No breakdown location monitor system in this facility, so we use on oscillator oscilloscope to capture reflection wave and transmission wave.
2. All breakdowns happens in the upstream accelerating structure, in particular in the beginning end of this structure, because delay time between reflection rise and transmission is about 330ns, which is same as filling time.



Pollution from vacuum system

1. Five structures were removed from beam line, and checked by endoscope, and element analysis.
2. All beginning end of five structures looks black, and main element is Carbon (C), and moreover there exists Chlorine (Cl) and Sulfur (S). All these elements are proved from vacuum system finally.
3. Pollution expanded from vacuum system, and enter first structure of five units, inspires RF breakdown and leaves C, Cl and S on the surface of cells, which are easy to make RF breakdown in high gradient field.



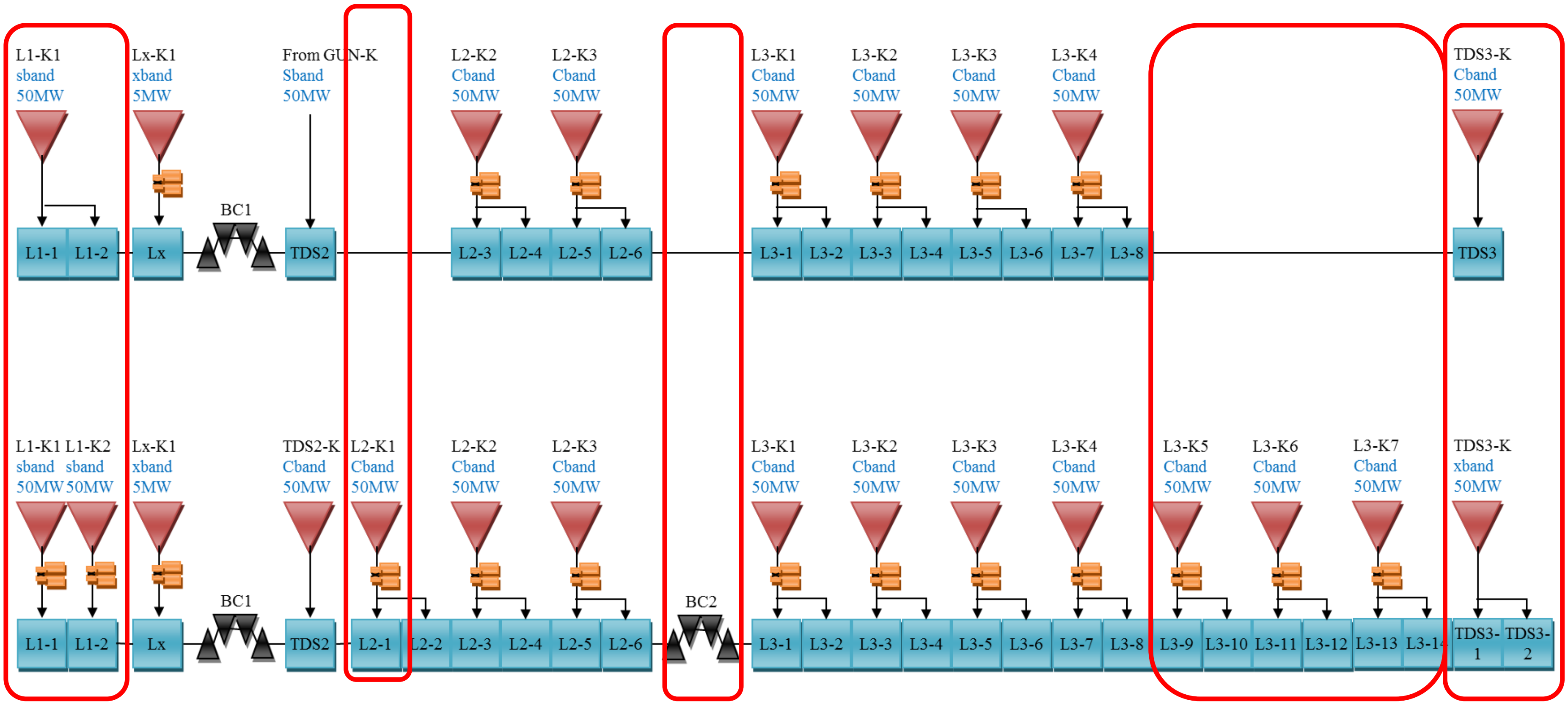


How to solve this serious problem?

1. Re-clean vacuum system, including tubes, valves and profiles, in particular near C-band system.
2. Removing five polluted structures, and finding feasible methods to clean pollution on the cell surface. If it's impossible, we should make new five structures to replace them.
3. The rest of 7 structures are reassembled for three new RF units, and accelerate beam energy to low energy of 500MeV for FEL experiment first, and will boost to 840MeV after new structures arrival.
4. So far three new units have been re-conditioned, and reached 35MV/m at least, and will used for beam acceleration soon.

C-band RF system for SXFEL upgrading

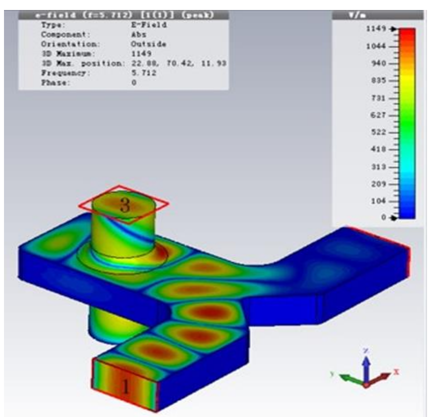
1. Beam energy up to 1.5GeV from 0.84GeV
2. 4 new C-band RF unit will be added to the present facility.
3. Accelerating gradient of C-band RF unit will be up to 40MV/m from 32.5MV/m, klystron output power is up to power of 45MW.

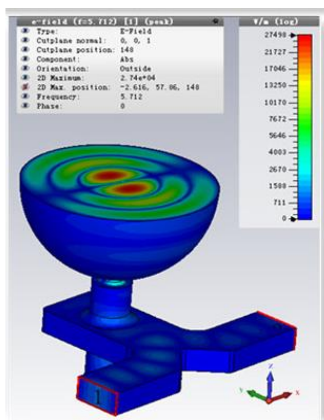


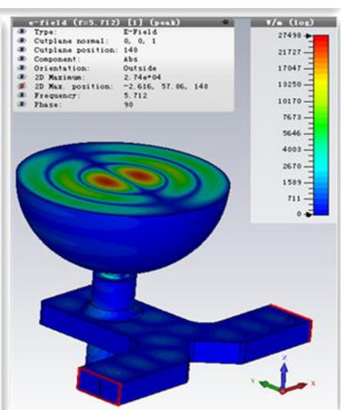
One spare scheme of spherical pulse compressor for user facility

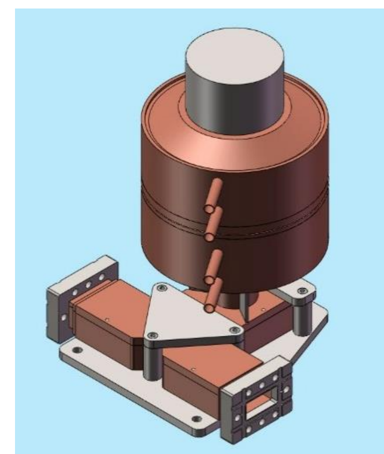
1. Hybrid 3dB coupler, and spherical cavity for two polarized mode.
2. TE013 mode is used for compact sized relatively.
3. Mechanical design is finished and fixed, and is in the process of fabrication.
4. This structure is possible to replace SLED for user facility.

Parameter	Value
Frequency/f	5.712GHz
Working Modes	Two TE_{113} modes
Radius/a	91.02mm
Coupling Coefficient/β	4.9
Quality Factor/Q_0	1.0×10^5
Energy Gain	1.85









Summary

- All C-band RF units have been installed in SXFEL, however RF conditioning of C-band met with serious problems, and five structure were polluted by vacuum system, which limits the accelerating gradient.
- Five polluted structures were removed, and rest seven structures are re-assemble together to form new three C-band RF unit. So far 35MV/m gradient at least was carried out in this three new units, and will provide 500MeV beam for preliminary FEL experiments. In the future five new structures will replace old ones, and boost energy to 840MeV as soon as possible.
- Upgrading of SXFEL test facility has been started, and four new C-band RF units will be installed, and finally accelerating gradient is targeted on 37MV/m for 1.5 GeV or higher energy. New spherical pulse compressor will be one spare scheme for user facility.

Thank you!!!
Welcome to Shanghai!!!