Operation Status and Upgrade of CSNS

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CHINESE ACADEMY OF SCIENCES

Outline

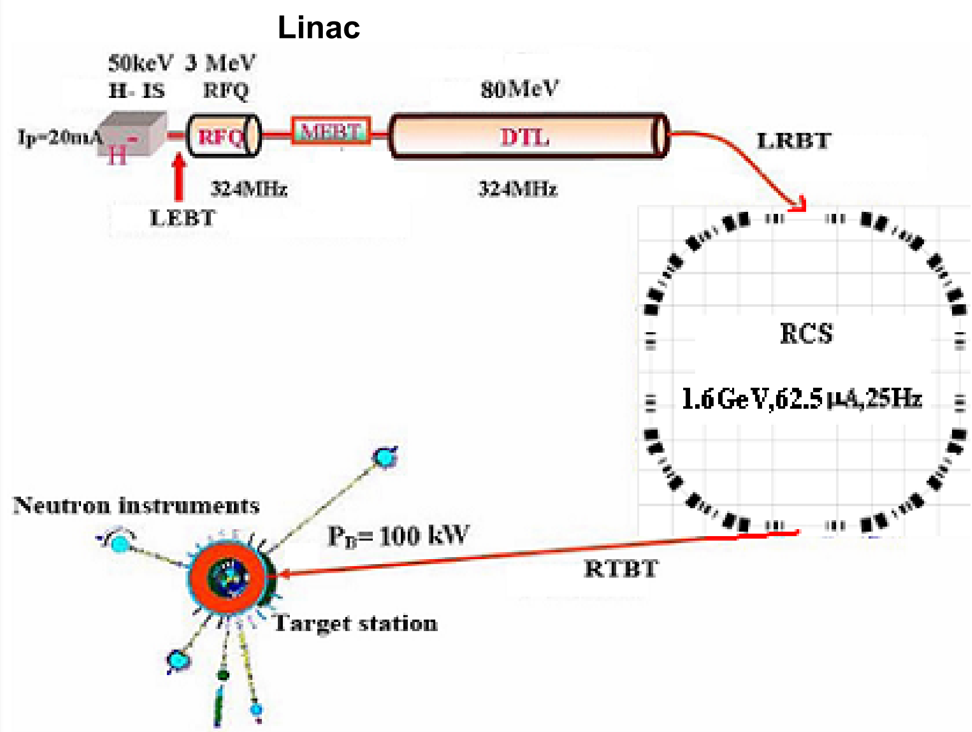
- Project Overview
- Accelerator Commissioning
- User Operation
- Upgrade Plan
- Summary

1, Project Overview

Project Design

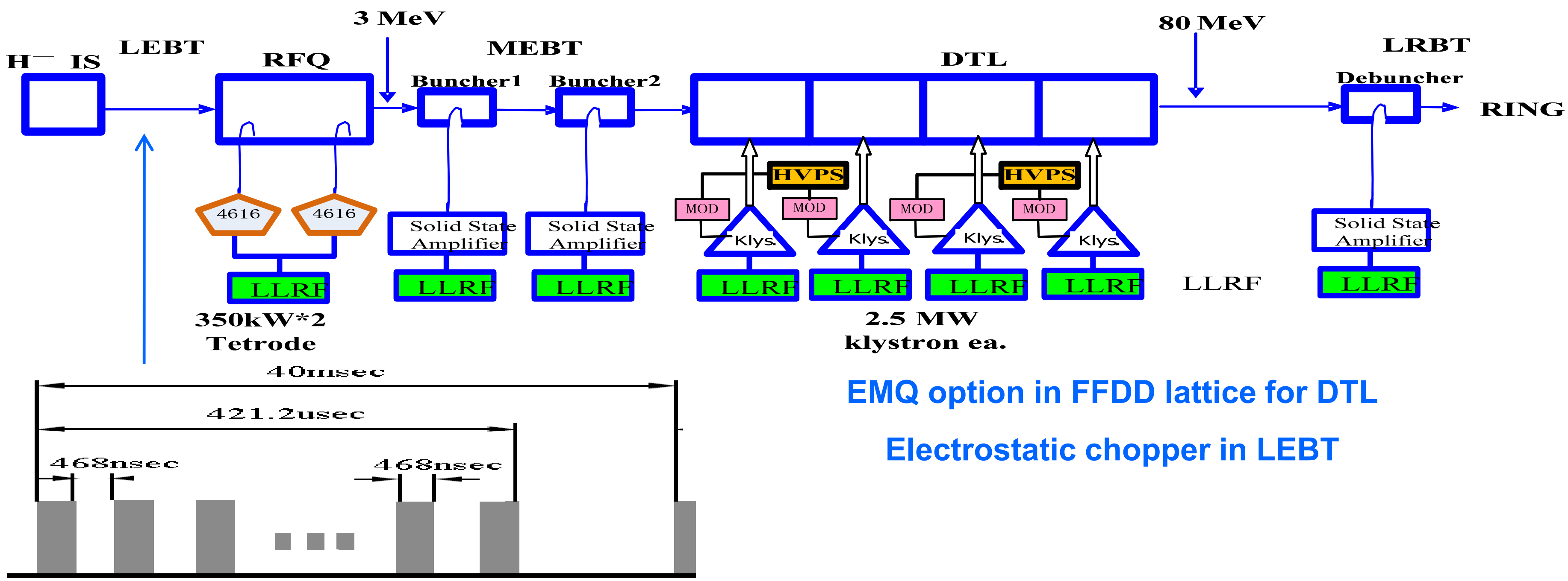
- **The phase-I CSNS facility consists of an 80-MeV H^- linac, a 1.6-GeV rapid cycling synchrotron(RCS), beam transport lines, a target station, and 3 instruments.**

Project Phase	I	II
Beam Power on target [kW]	100	500
Proton energy [GeV]	1.6	1.6
Average beam current [μA]	62.5	312.5
Pulse repetition rate [Hz]	25	25
Linac energy [MeV]	80	300
Linac type	DTL	+SC
Linac RF frequency [MHz]	324	324
Macropulse. ave current [mA]	15	40
Macropulse duty factor	1.0	1.7
RCS circumference [m]	228	228
RCS harmonic number	2	2
RCS Acceptance [πmm-mrad]	540	540
Target	1	1
Spectrometers	3	20



The first high-energy high-intensity proton accelerator in China

H^- Linac Design

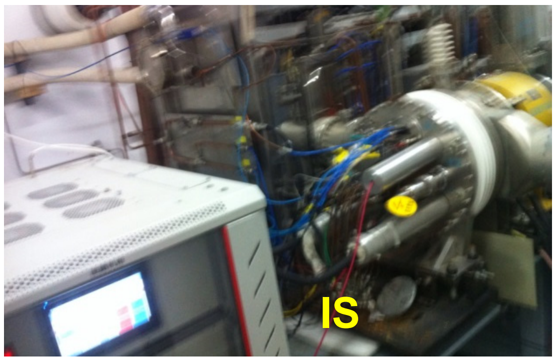


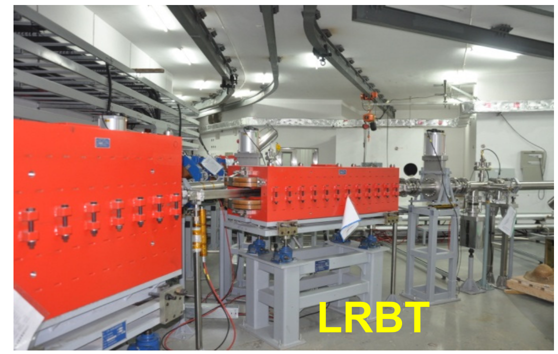
EMQ option in FFDD lattice for DTL

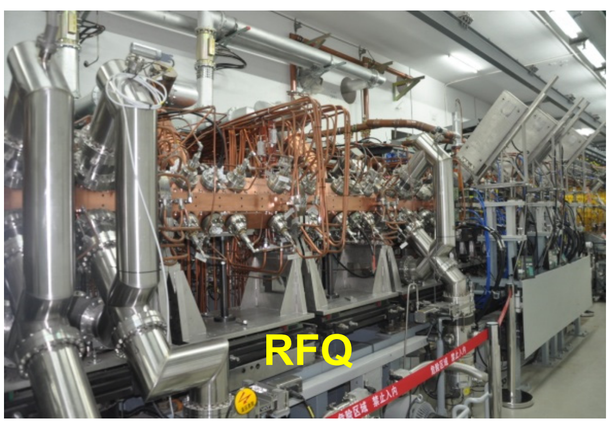
Electrostatic chopper in LEBT

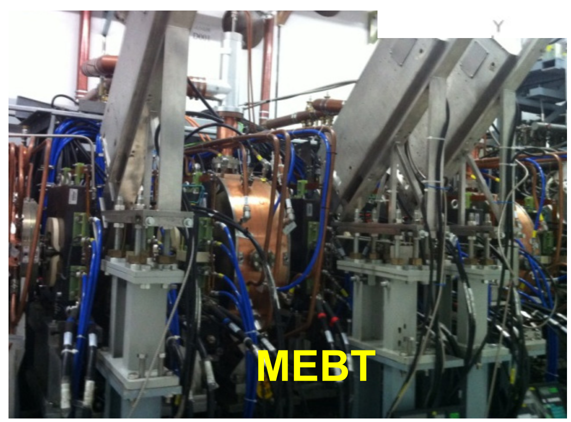
	Ion Source	RFQ	DTL
Input Energy（MeV)		0.05	3.0
Output Energy(MeV)	0.05	3.0	80
Pulse Current (mA)	20/40	15/30	15/30
RF frequency (MHz)		324	324
Chop rate (%)		50	50
Duty factor (%)	1.3	1.05	1.05
Repetition rate (Hz)	25	25	25

Linac installed in the tunnel



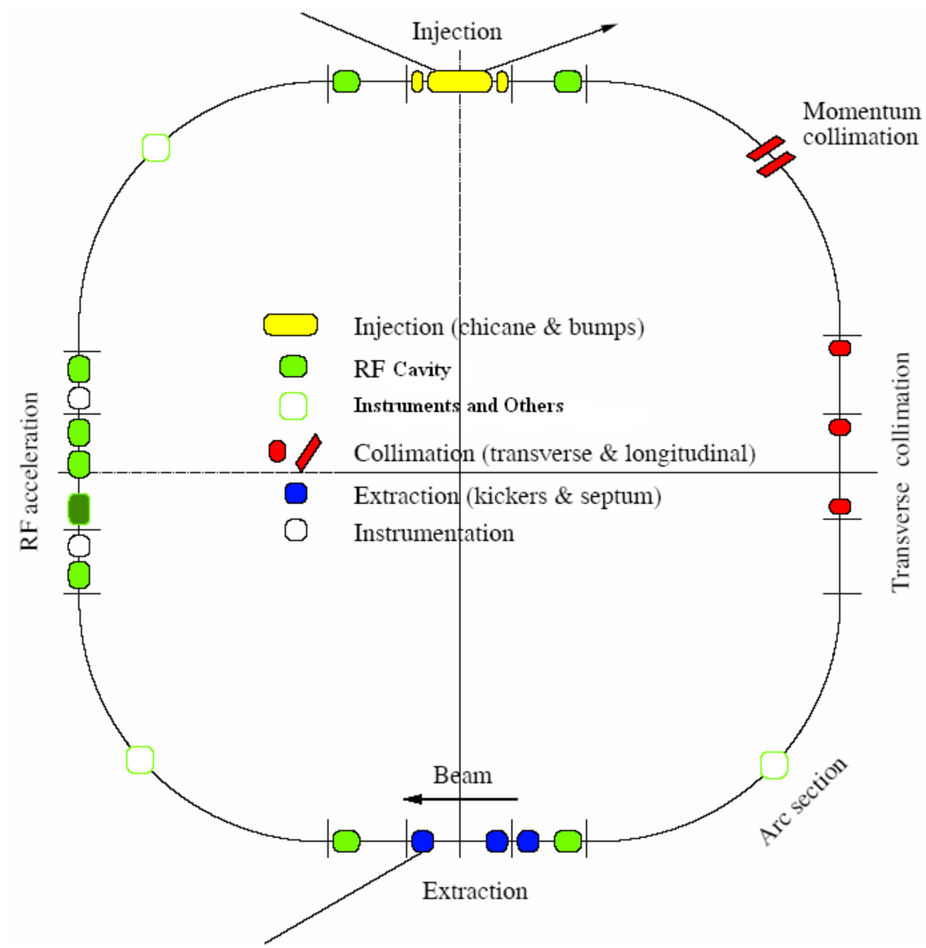






RCS Design

- Lattice of 4-fold symmetry, triplet.
- 227.92m circumference.
- Four long straight sections for injection, acceleration, collimation and extraction.
- 24 main dipoles with one power supply.
- 48 main quadrupoles with 5 power supplies.
- Ceramic vacuum chambers for the AC&pulsed magnets.
- 8 RF ferrite loaded cavities to provide 165 kV.



RCS Installation

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Instruments Suite

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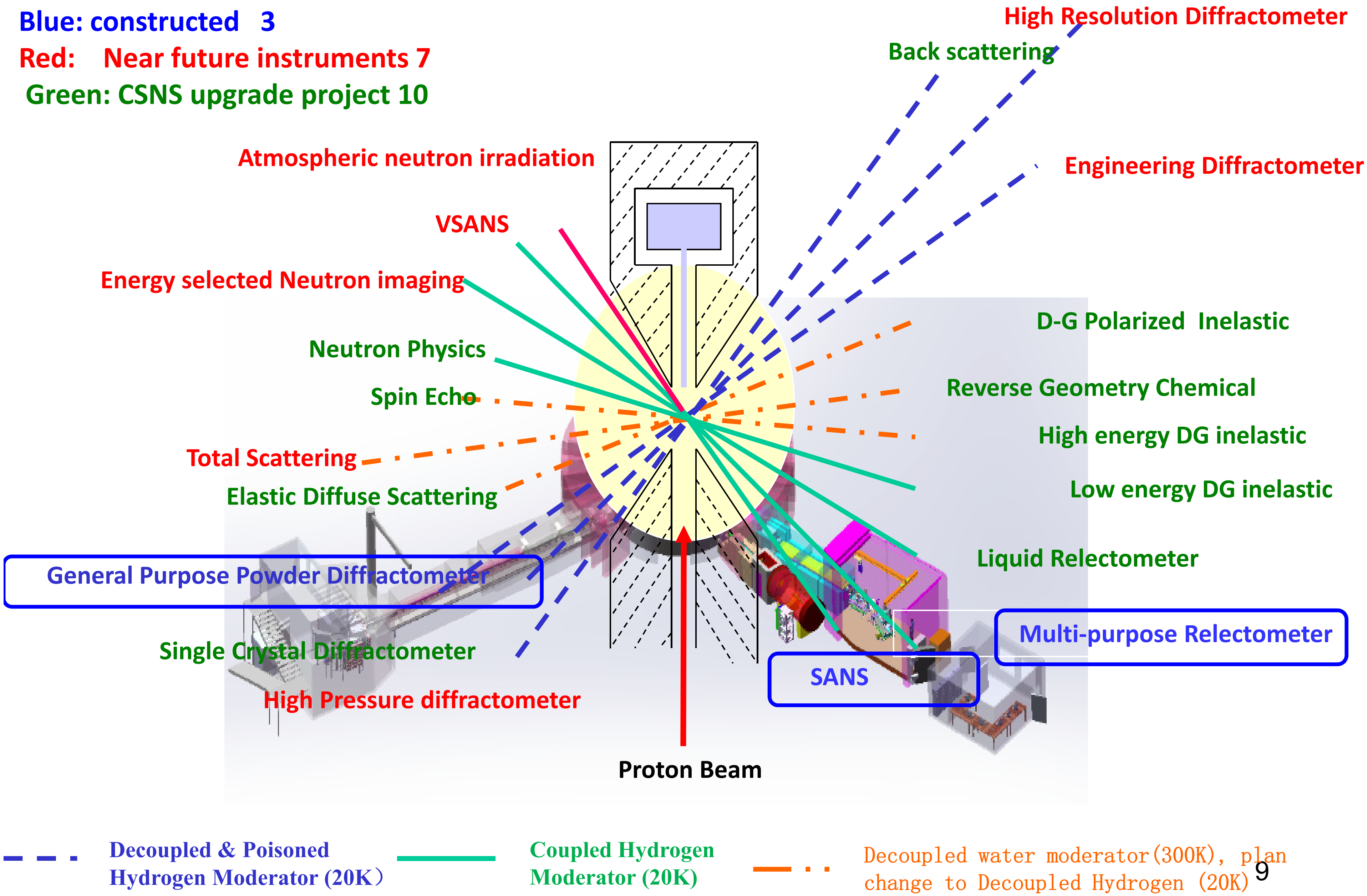
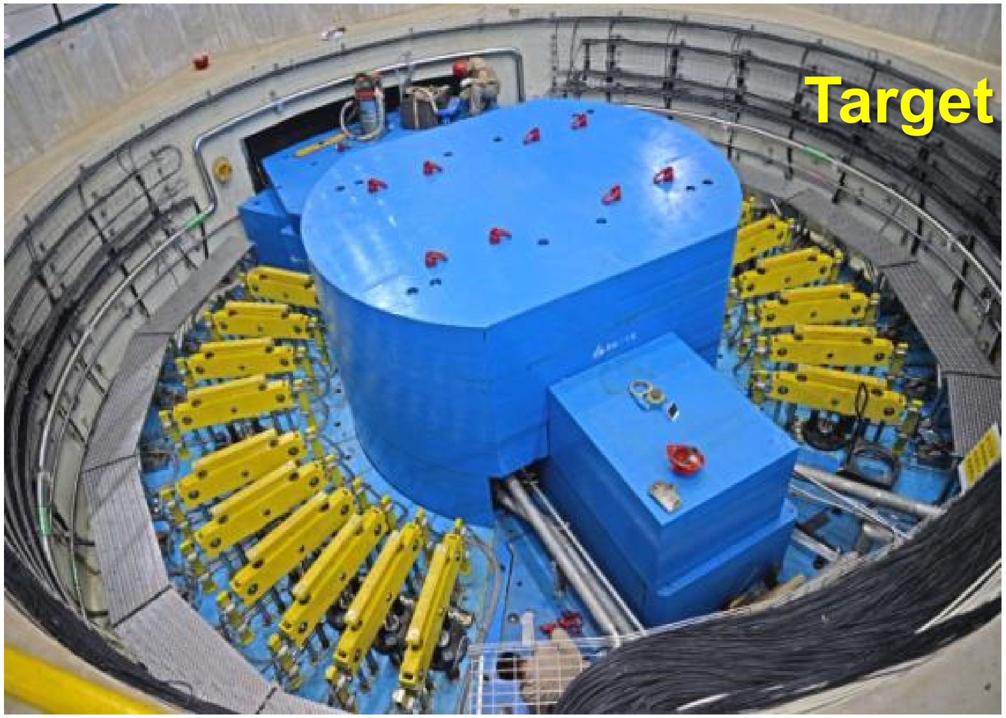
Blue: constructed 3

Red: Near future instruments 7

Green: CSNS upgrade project 10

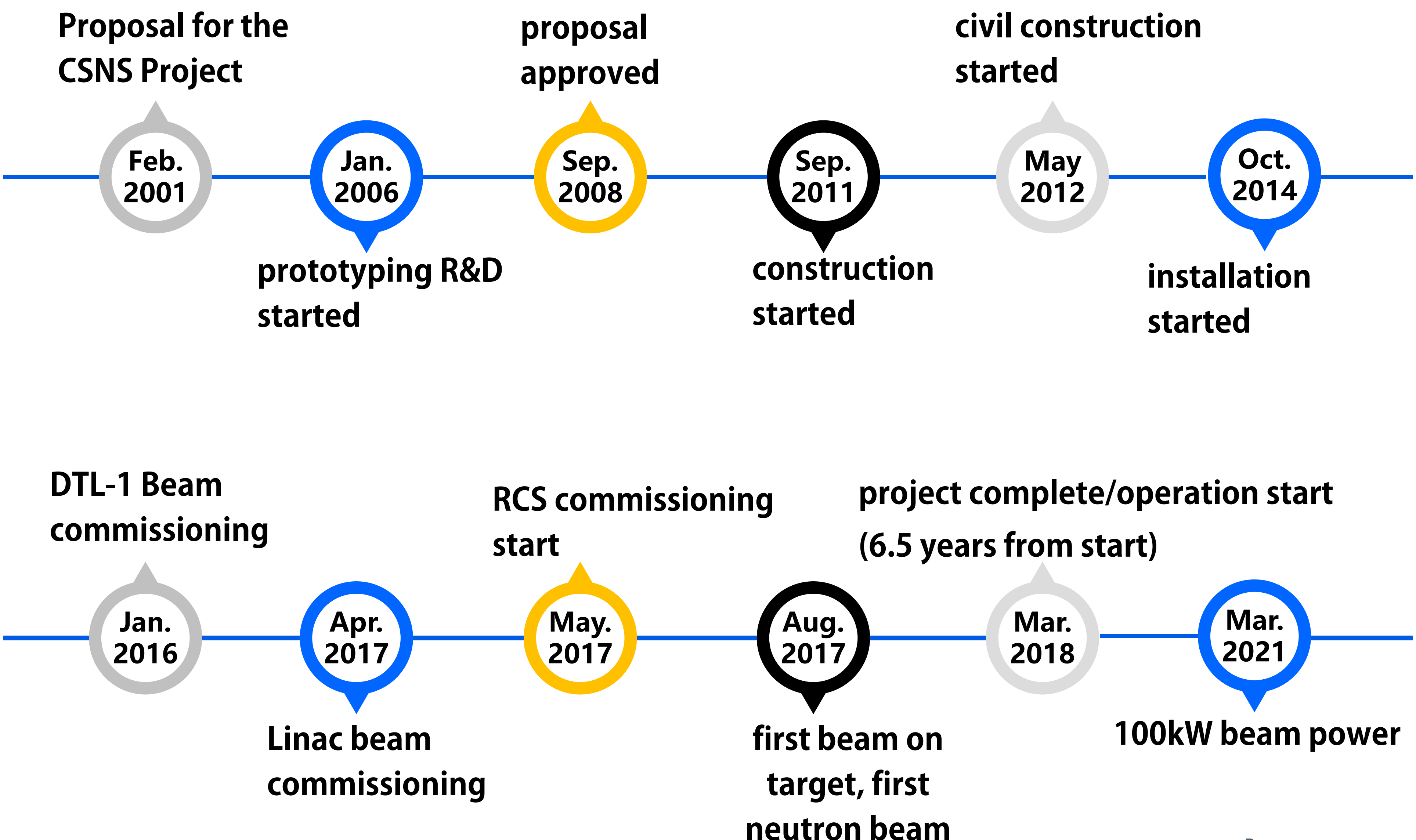


Target Station



Scattering Halls

Key Milestones (on schedule)



Budget and Expenditure (within budget)

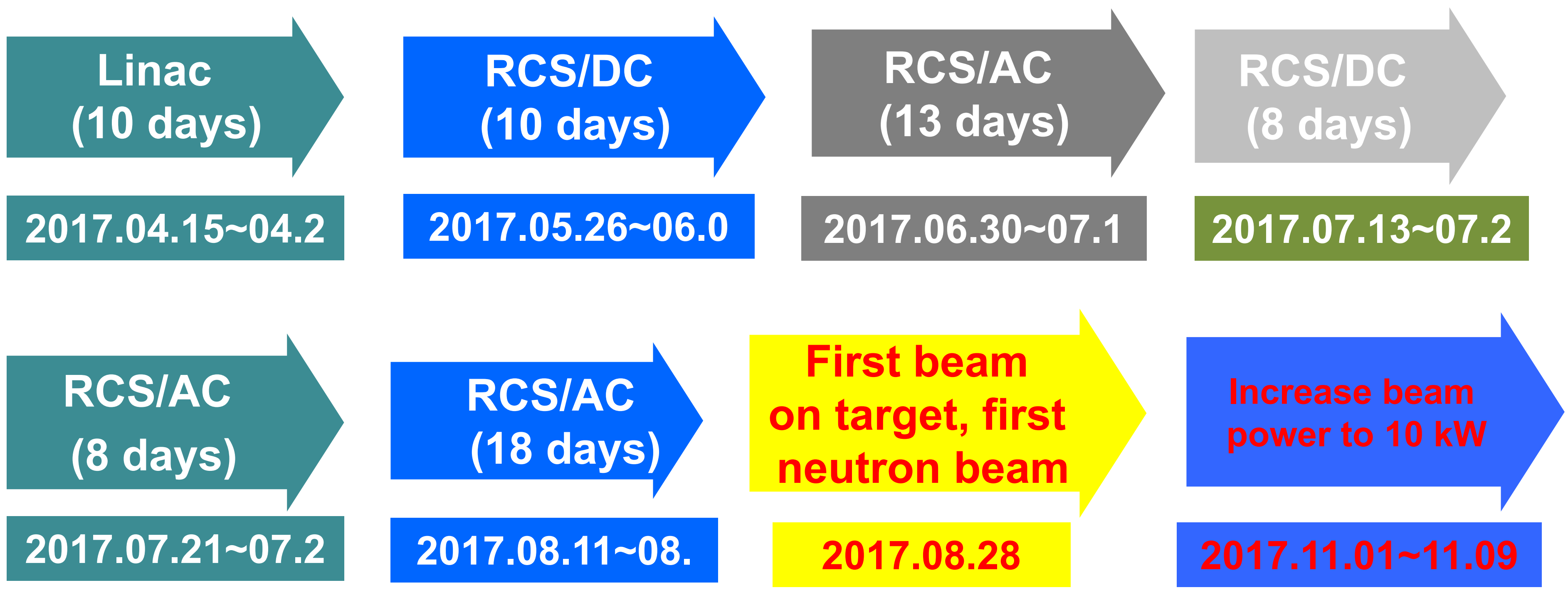
- The total budget approved is 1.86632 B RMB (268M US$)， actual investment is 1.8740665 B RMB (268.7M US$)
- The expenditure of the equipment's is within the budget
- The deficit of the civil construction is paid by the local governments

NO.	Systems	Approved Budget (Million RMB)	Actual Investment (Million RMB)
1	Accelerator	62,664.66	62,362.90
2	Target and Instrument	39,763.04	41,161.86
3	Utilities	21,853.81	24,914.20
4	Others	62,350.49	58,967.69
Total		**186,632**	**187,406.65**

2， Accelerator Commissioning

Beam commissioning in 2017

- 1 of 4 DTL klystrons was not available in 2017.
- RCS was commissioned with 60MeV linac beam from 3 DTL tanks.
- It took 67 days to reach the beam power of 10kW.



Beam commissioning in 2018

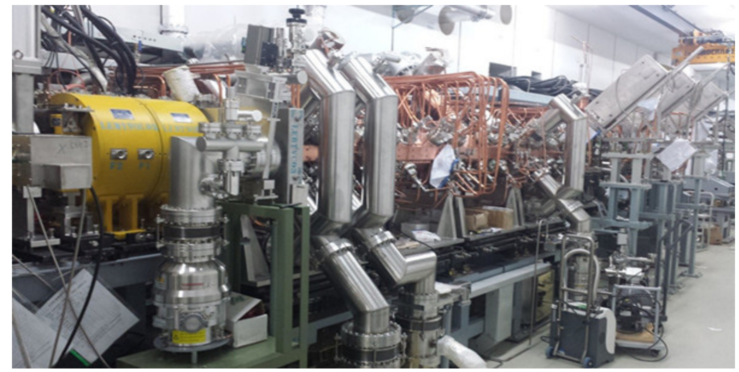
- ✧ In the beginning of 2018, 4 DTL tanks were available and the beam commissioning were resumed.
- ✧ It took 18 days to recover the beam power to 10kW with 80MeV linac beam.
- ✧ From the Jan. 22, the beam was delivered to target for neutron spectrometers commissioning and user operation
- ✧ By mid-March, the beam power is increased to about 25kW.

Time table of commissioning in 2018:

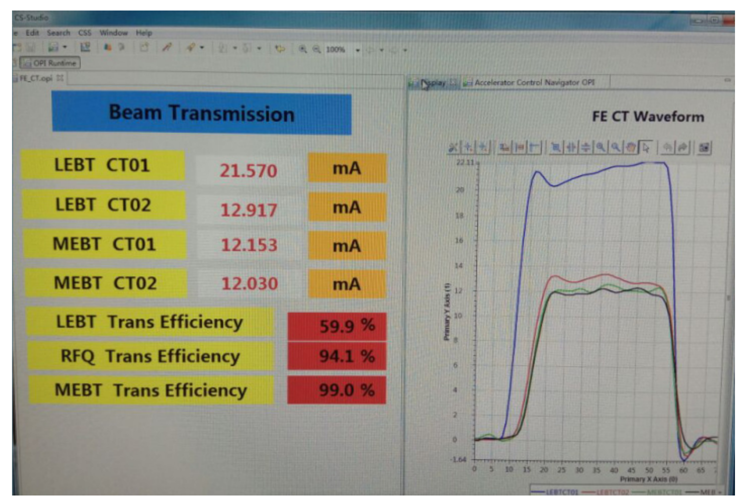
- ✓ Jan. 4~ 13 Linac to 80MeV
- ✓ Jan. 14~ 17 RCS/DC
- ✓ Jan. 18~ 21 RCS/AC
- ✓ Jan. 22~ Commissioning of instruments and user operation
- ✓ March Beam power increased to ~25kW

Frontend beam commissioning

- From low duty to high duty: 50 → 500 μs, 1 → 25 Hz (chop rate: 0 → 50 %)。
- Then, 90 hours continuous operation @25Hz, 500 μs , 50% chop rate。
- Best transmission rate for RFQ: 94% 。



	Design	Measured
Ion source current [mA]	20	31
MEBT Peak current [mA]	15	17
MEBT Beam energy[MeV]	3.0258	3.02±0.015
Chopping rate [%]	50	50
Pulse width [μs]	420	500
Pulse repetition rate [Hz]	25	25
Emittance (π mm mrad)	0.22	0.27



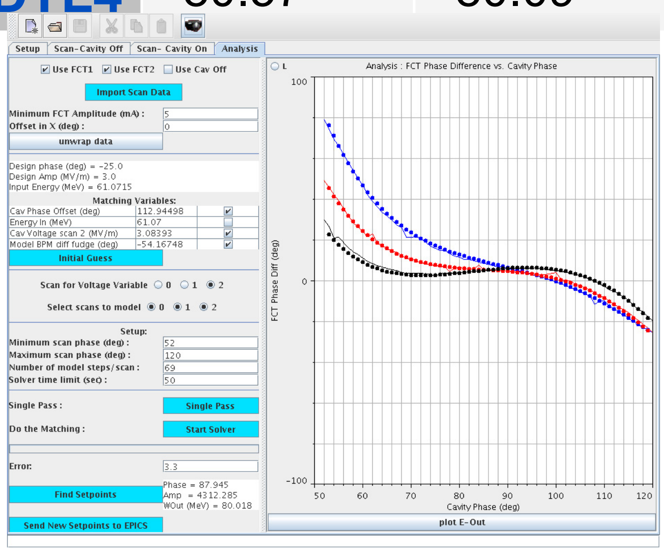
■ DTL tanks

- DTL 1-3： Apr. 2017, Tank-3 output 15mA beam @60MeV.
- DTL 4: Jan. 2018, 80MeV beam.

	Measured （MeV）	Designed （MeV）
DTL1	21.81	21.67
DTL2	41.67	41.41
DTL3	60.80	61.10
DTL4	80.57	80.09

CT Display 2018-02-01 14:10:51

LEBT CT01	27.59	mA	LEBT Trans	70.3	%
LEBT CT02	19.39	mA	MEBT Trans	99.4	%
MEBT CT01	16.19	mA	RFQ Trans	83.5	%
MEBT CT02	16.10	mA	DTL1 Trans	98.3	%
DTL CT01	15.83	mA	DTL2 Trans	99.6	%
DTL CT02	15.77	mA	DTL3 Trans	98.1	%
DTL CT03	15.47	mA	DTL4 Trans	100.3	%
LRBT CT01	15.51	mA	DTL Trans	96.4	%

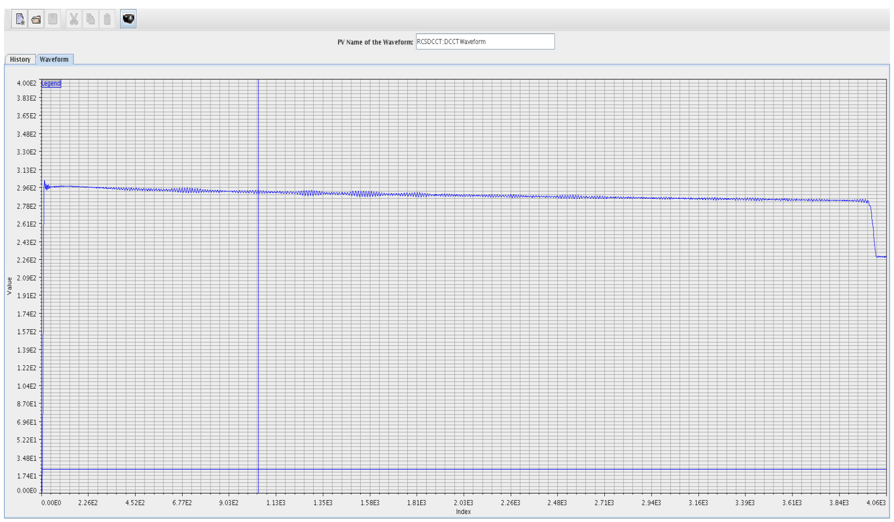


■ RCS——storage mode（DC)

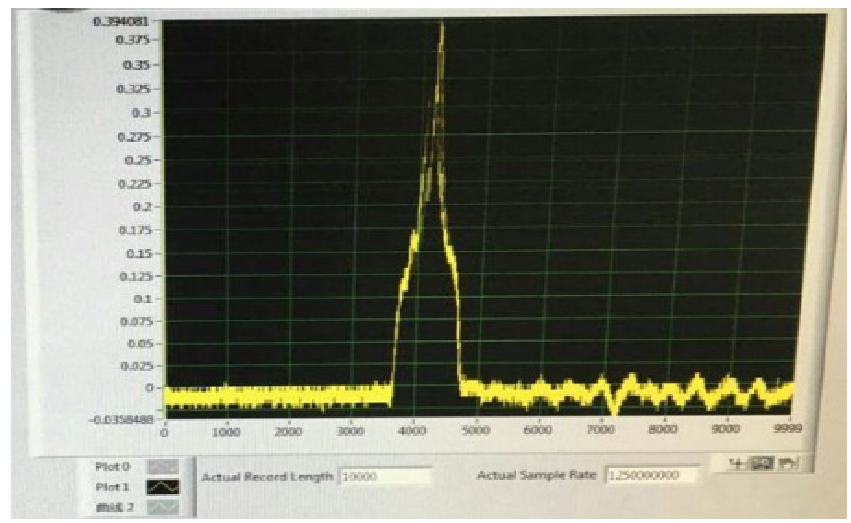
MOPTS068/Shou-Yan Xu

WEPRB040/Xiao Li

- For controlling beam loss, we started RCS operation with storage mode at single shot.
- June 2017, the storage beam was firstly extracted from the ring.

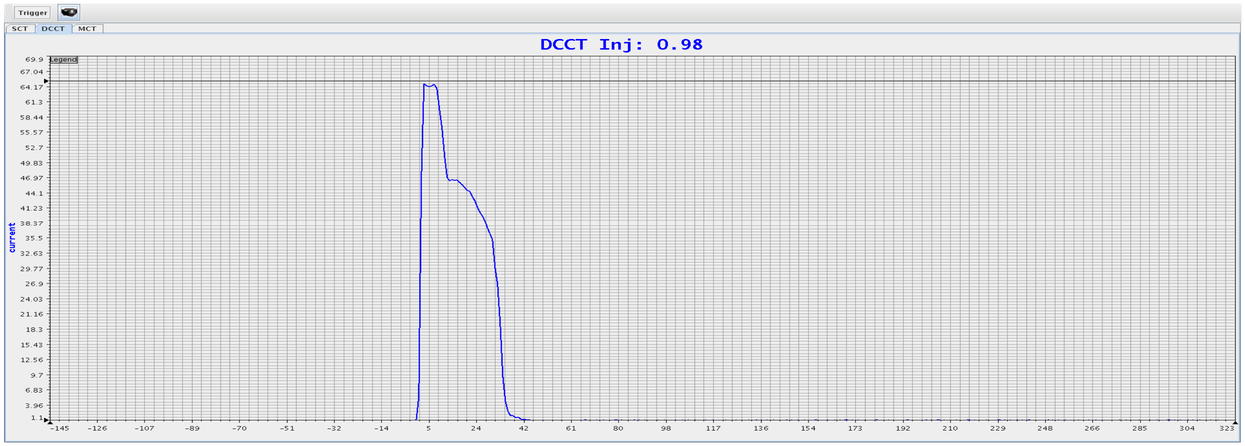


Beam transmission rate higher than 98% through the

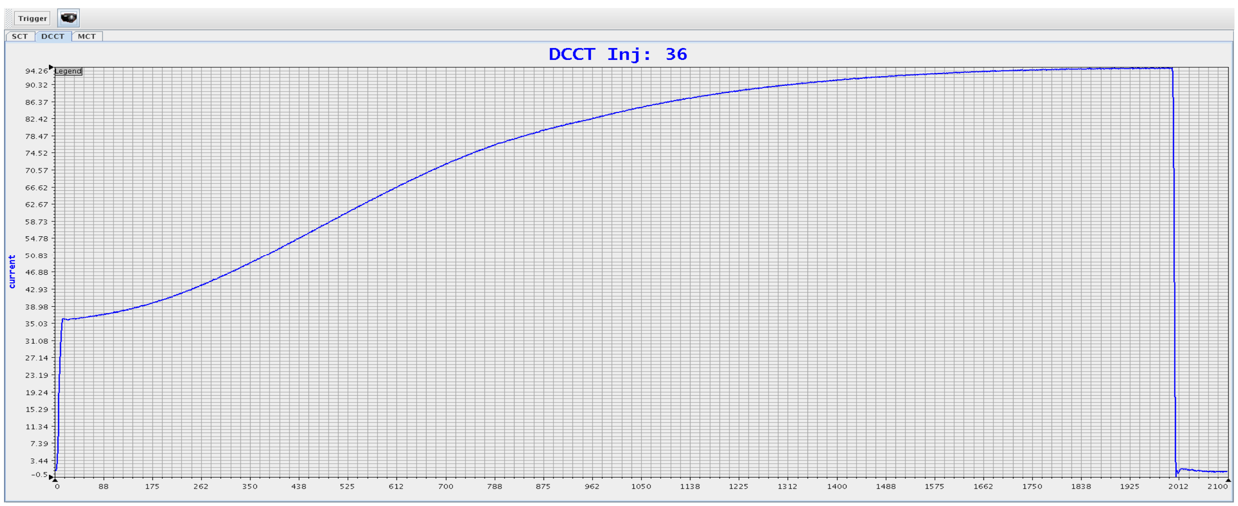


Measured signal of the extracted beam

■ RCS accelerating mode (AC)



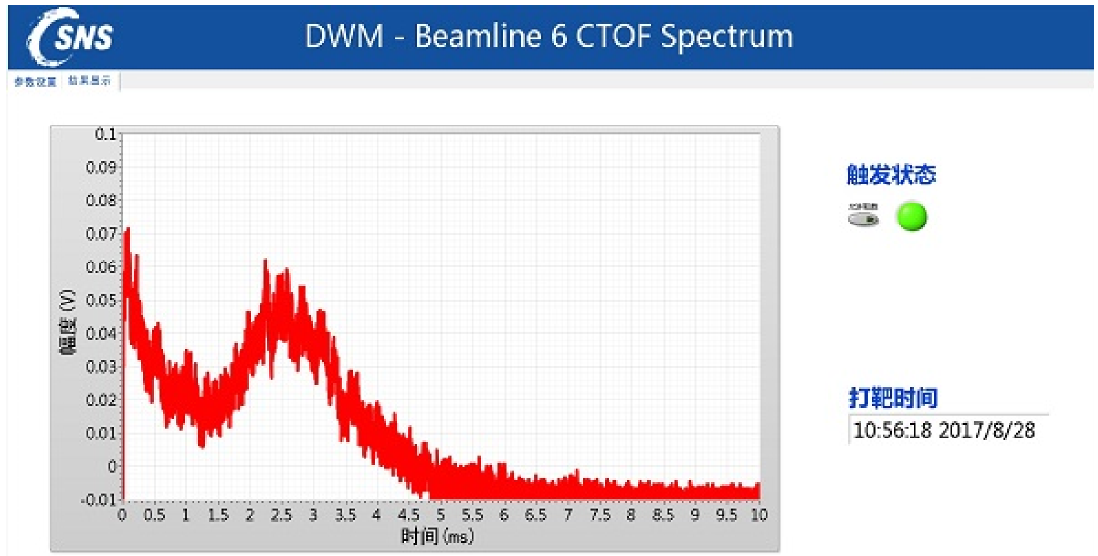
July 2017 RCS started AC mode: the first shot of beam survive only for 4ms， not reaching the final energy.

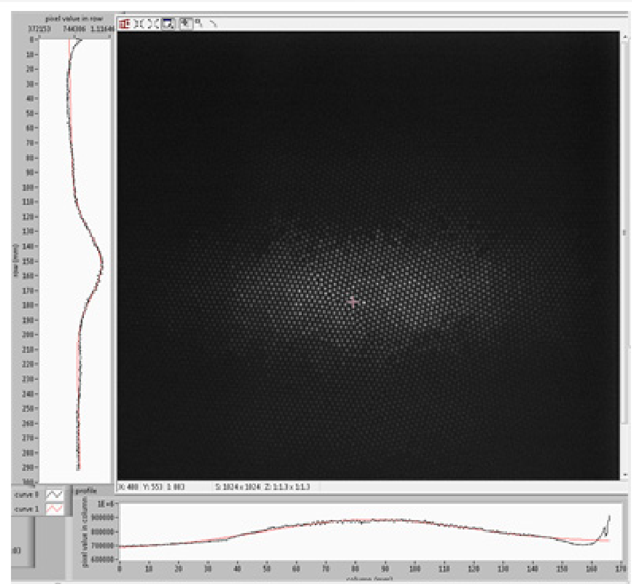


On the same day, beam was accelerated to 1.6GeV design energy. And soon transmission rate reached almost 100%

■ First beam on target on schedule

- **August 2017 the first proton beam hit on the target and produced spallation neutrons. This a important milestone for CSNS project.**
- **Beam commissioning confirms a good performance in design, manufacture and commissioning.**





Design Goal (Sept. 2011)

Beam power	Rep. rate	Ave. Curr.	Beam Energy	Neutron Effi.	Neutron Flux
100 kW	25 Hz	63 μA	1.6 GeV	0.1 (n/p/sr)	$2*10^7$

- Keep the potential of upgrading beam power to 500kW.
- 1/10 beam power is required for acceptance, and the design goal will be met in 3 more years.

Achieved in Acceptance (Aug. 2018)

All achieved or exceeded

Beam power	Rep. rate	Ave. Curr.	Beam Energy	Neutron Eff.	Neutron Flux
10 kW	25Hz	6.3μA	1.6GeV	0.005(n/p/sr)	10^5
23 kW	25Hz	14.5μA	1.6GeV	0.125	$2.5*10^6$

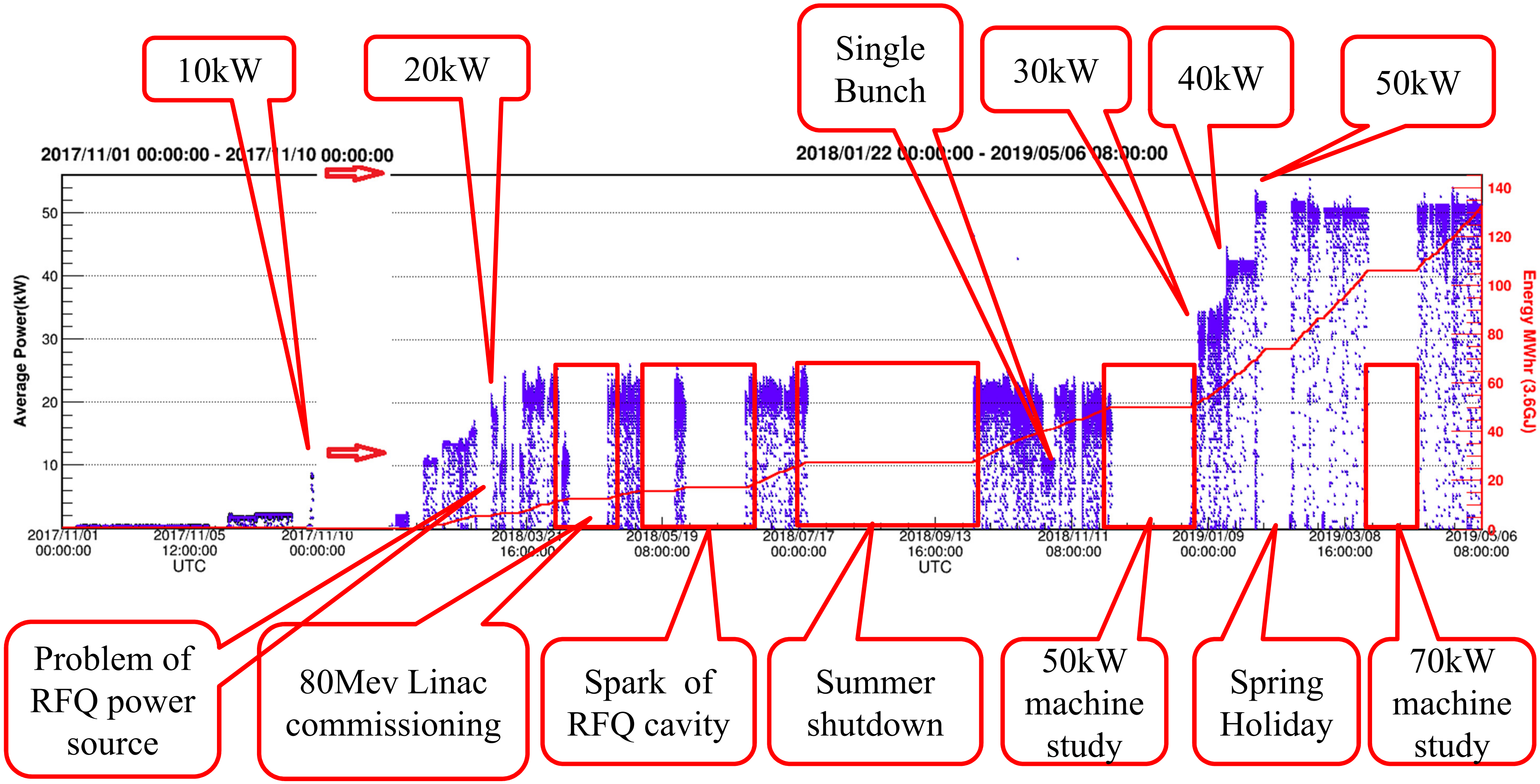
CSNS Passed State Acceptance on Aug. 23 2018

The review committee agreed that the performance of the CSNS has reached or is even better than the planned acceptance goal. The highest neutron efficiency of the target station and the three initial instruments reached the international level.

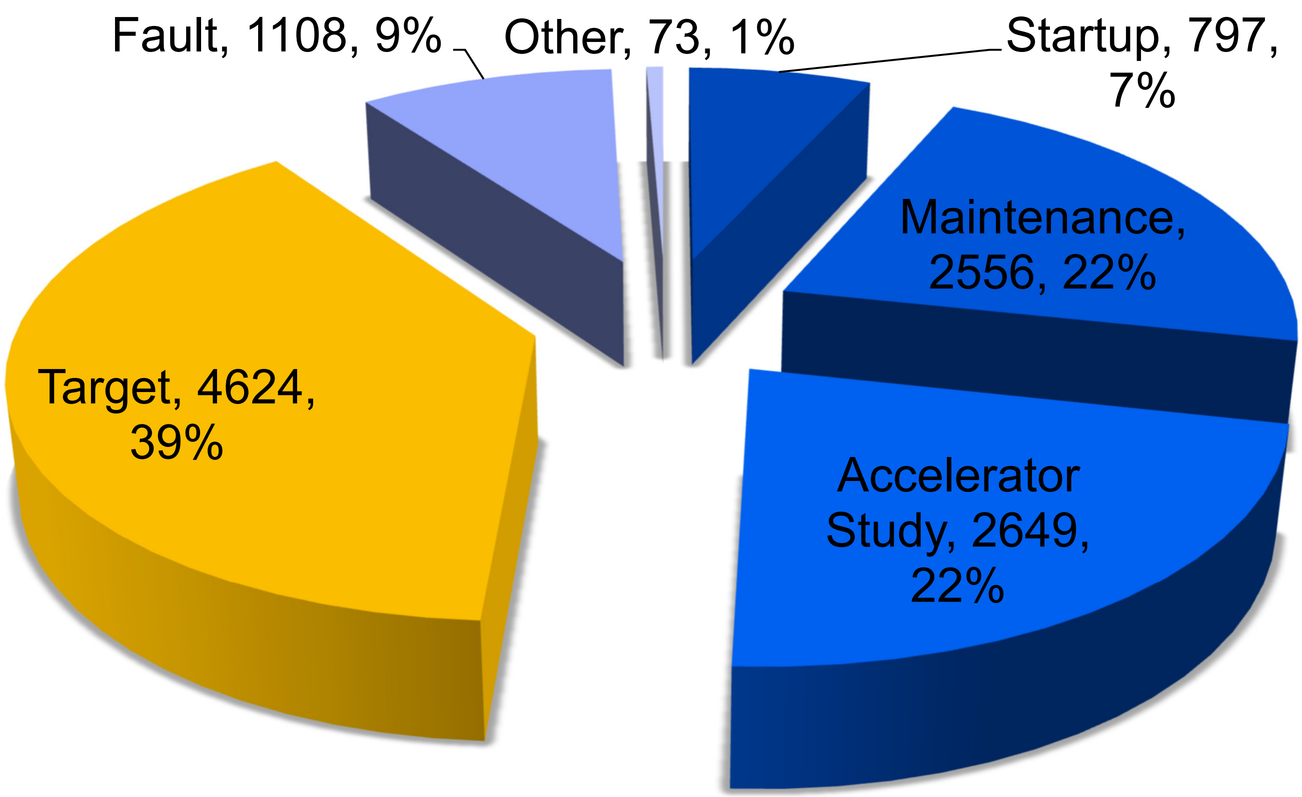
The review committee concluded that some significant innovative technologies in accelerators, target station and instruments were achieved at CSNS.

3, User Operation

CSNS commissioning and operation overview

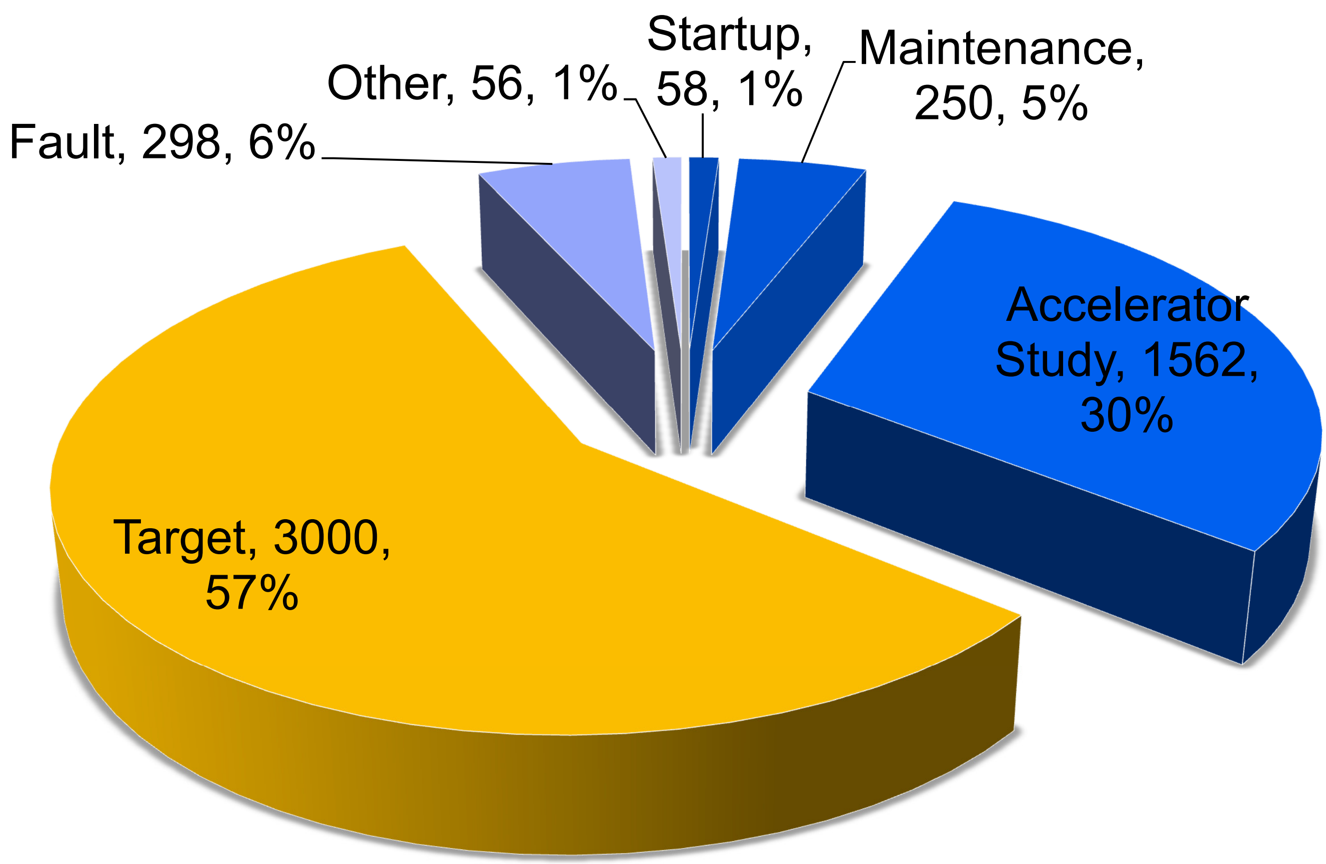


Operation statistics (until now)



Availability is 80%

Operation statistics (from last summ. maint. to now)



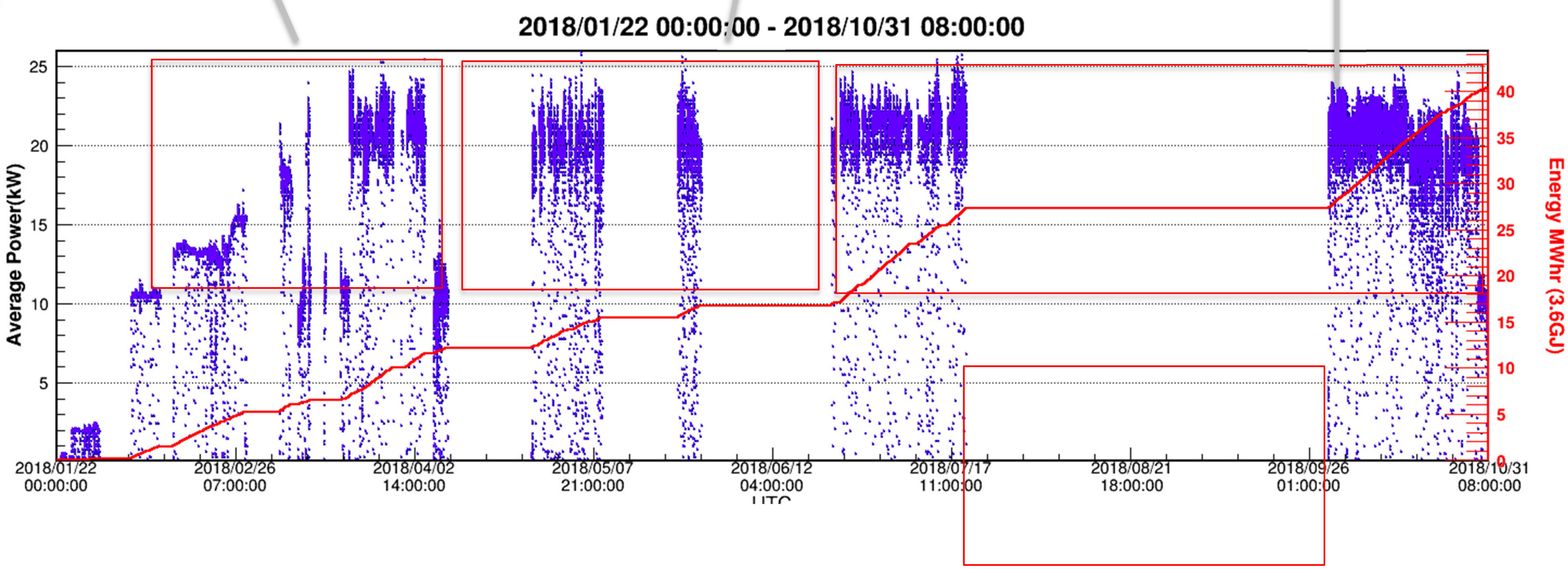
Availability is 91%

Operation in 2018 (2800 Hours for user)

Fault of RFQ RF source (4616 tetrode)

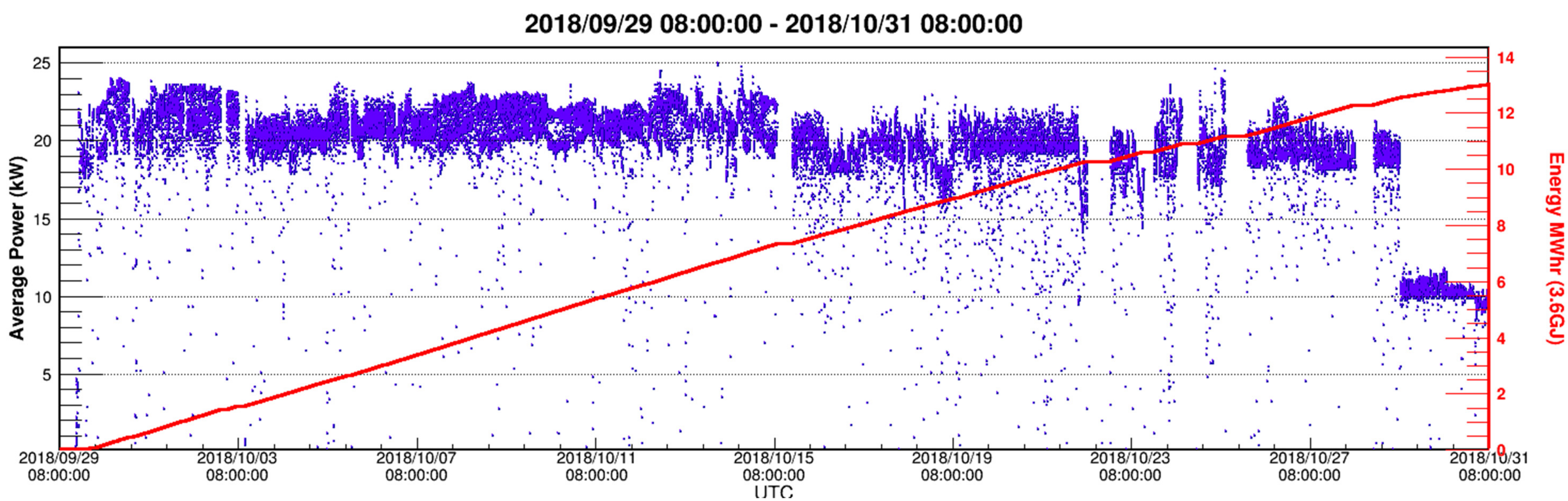
Spark of RFQ cavity & DTL RF source

Operation with high availability



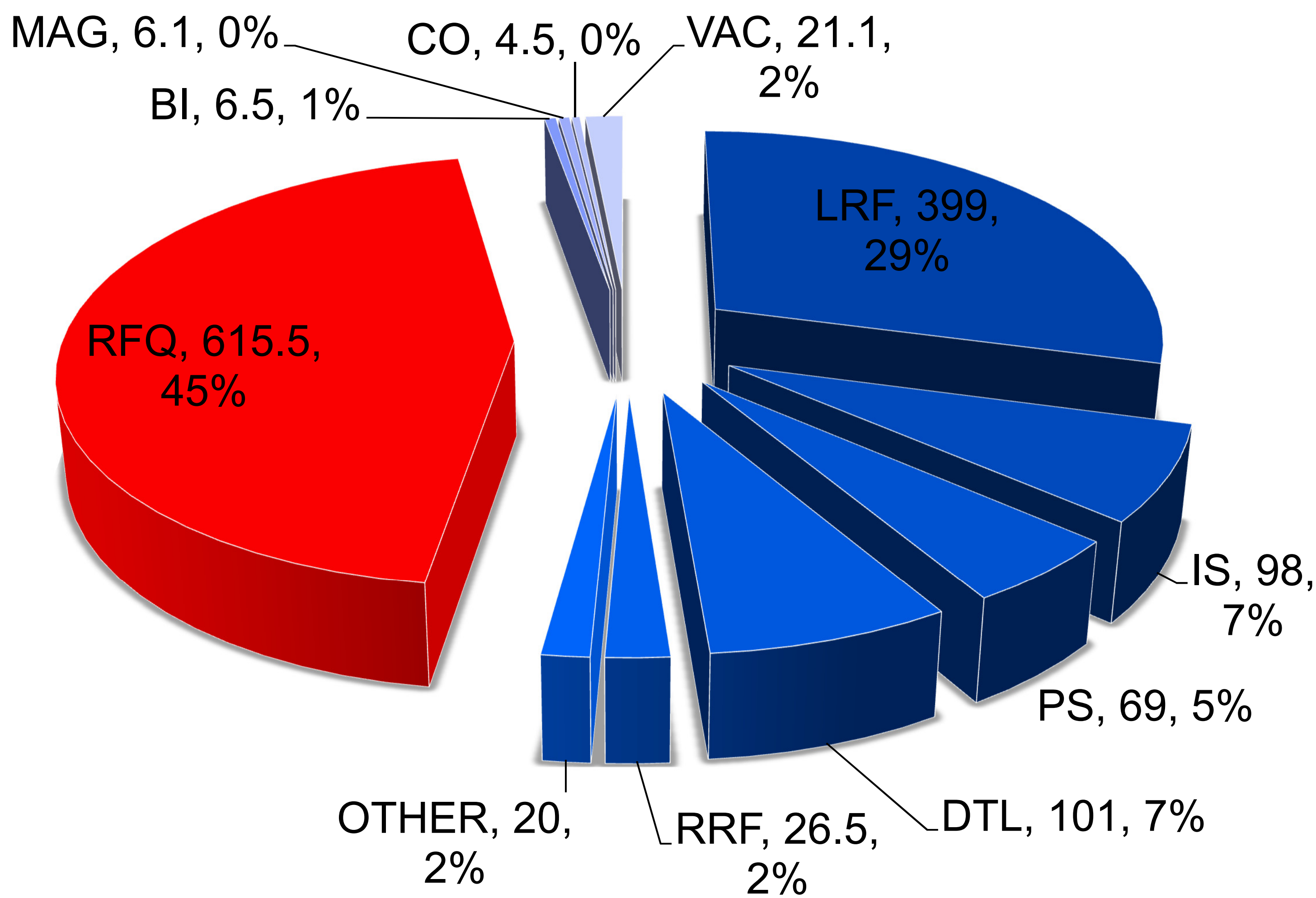
Summer maintenance

High availability after summer maintenance

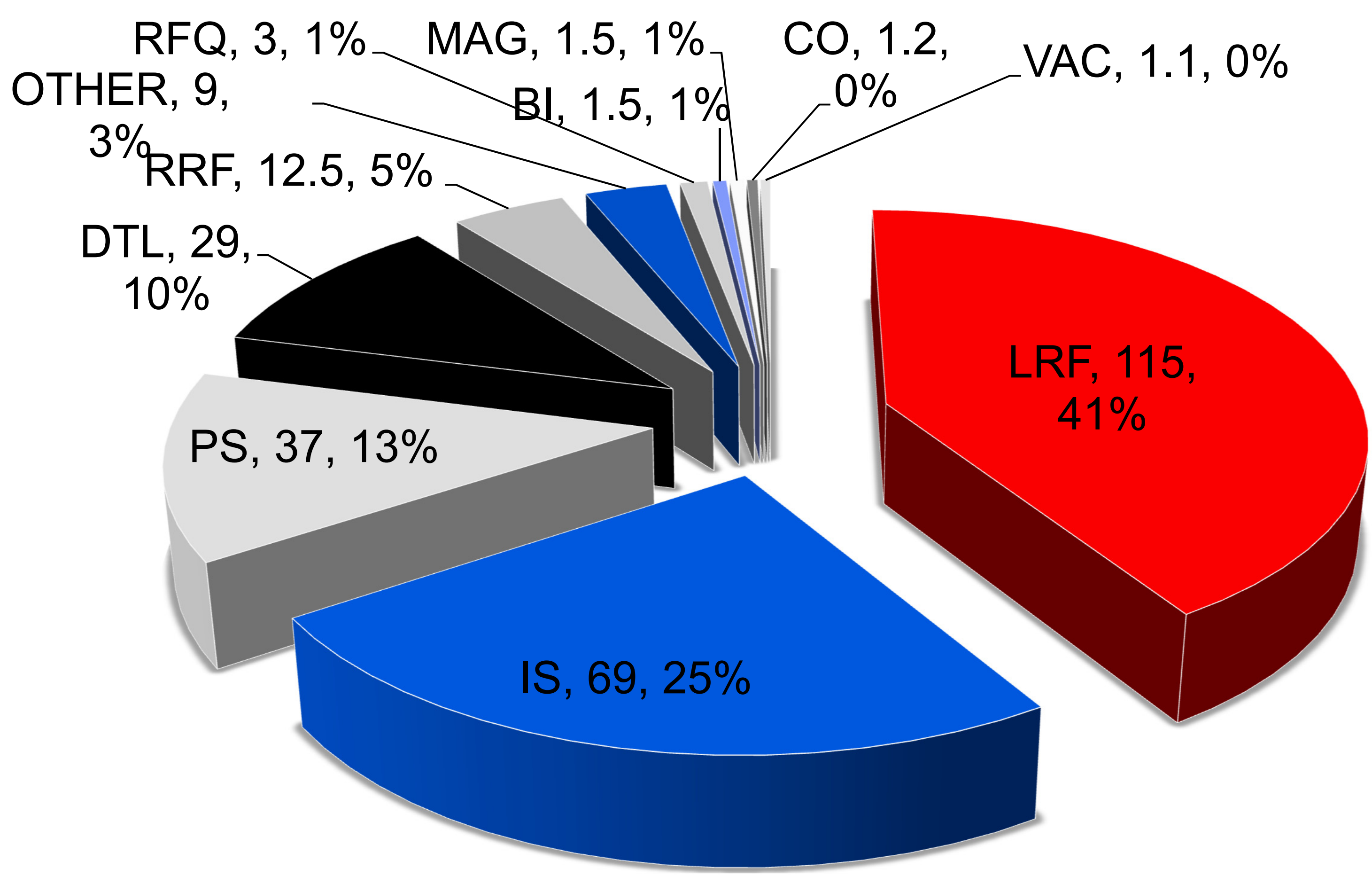


With accumulation of the operation experience, the availability of accelerator was quickly increased. After the summer maintenance, the availability is above 94%.

Downtime statistics (up to now)



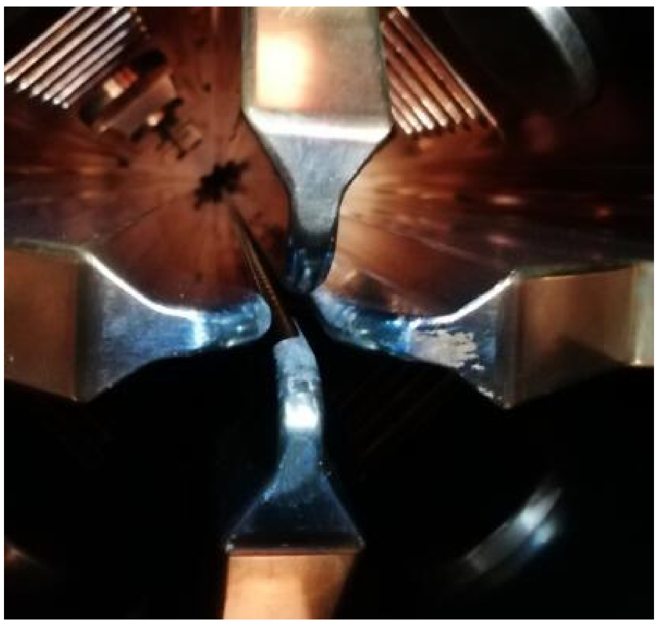
Downtime statistics (from last summ. Maint. to now)



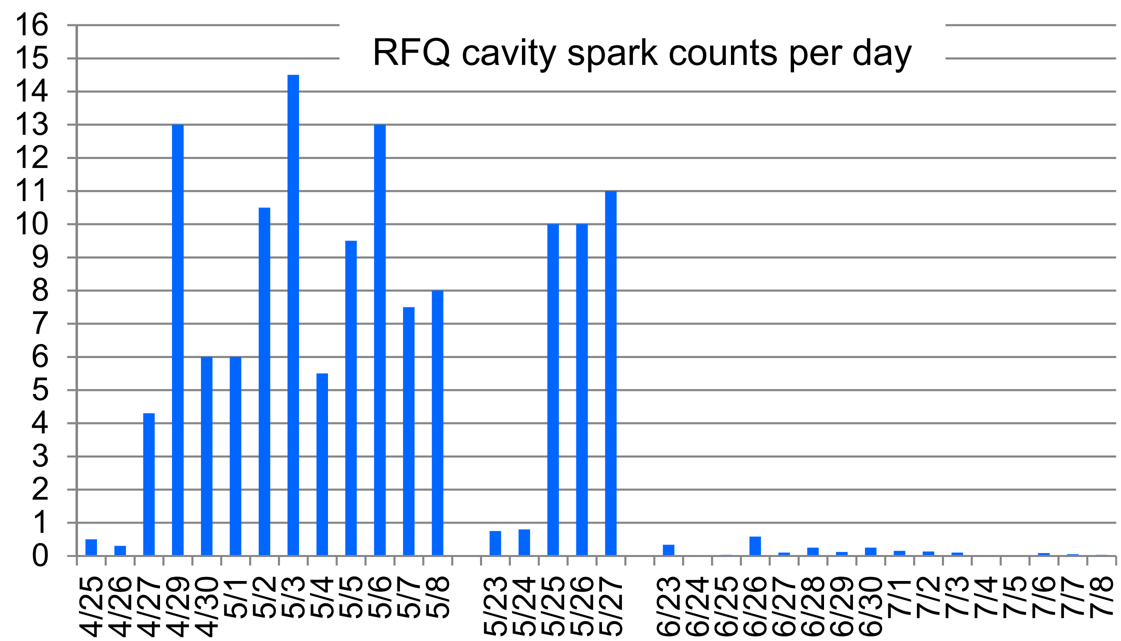
Problem of RFQ spark

TUPTS038/H.F.OUYANG

- The chopped beam lost in the vane of RFQ, is confirmed to be the reason of RFQ spark
- By rotating the chopper 45 degrees, most of the chopped beam passed through the slit between to adjacent vanes.

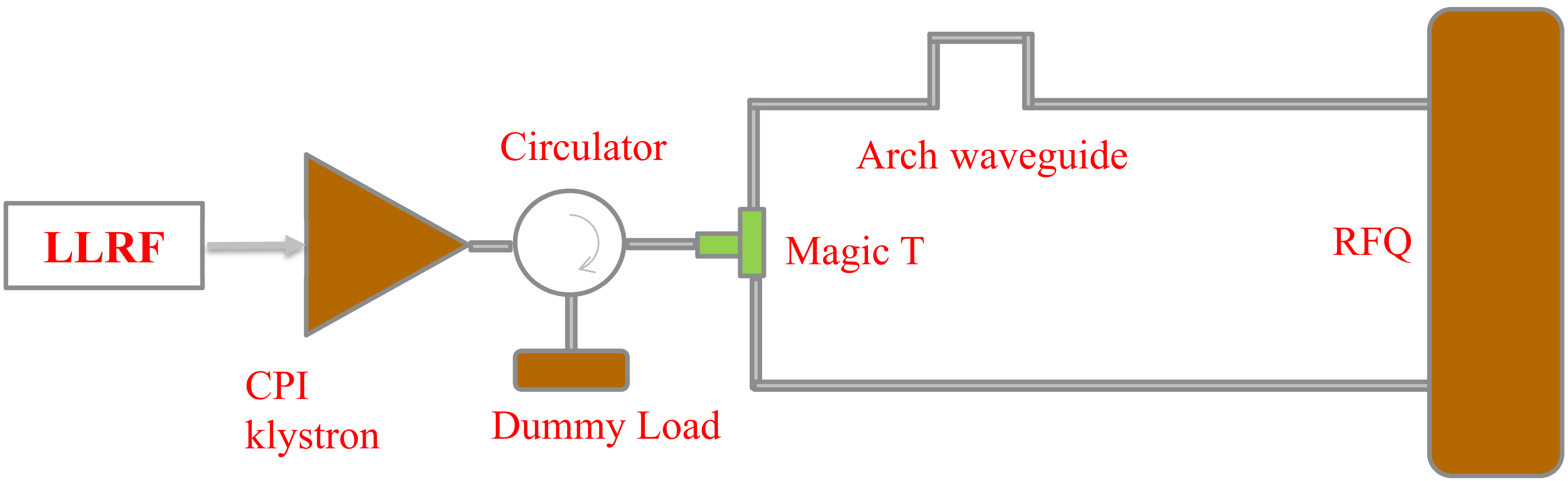


RFQ vane at entrance



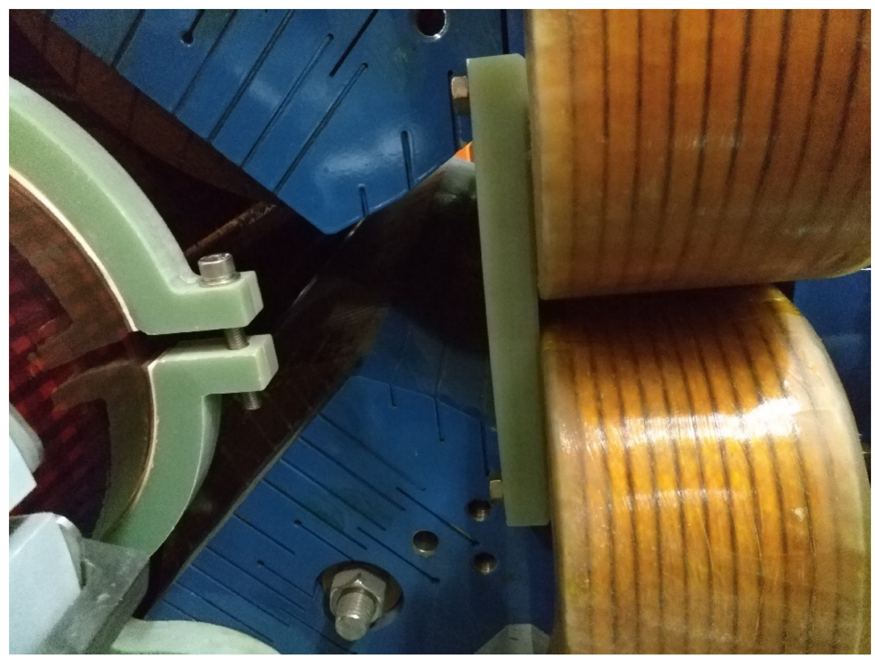
Upgrade the RF source of RFQ

- The stability of the RFQ 4616 tetrode is one of the main cause of fault.
- The short lifetime and price of 4616 tetrode.
- The retired klystron from DTL, can be used for RFQ, zero cost.



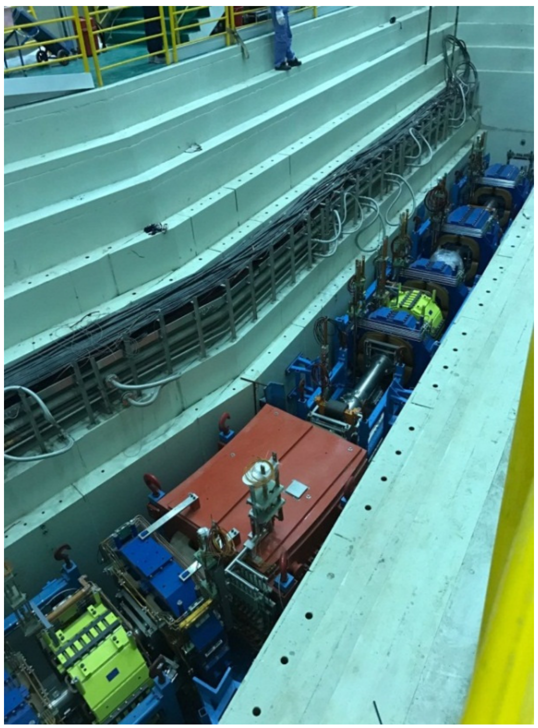
Broken of the Quadrupole coil

- High voltage discharges had caused insulation failures of one RCS-272Q quadrupole magnet due to short distance between the magnet coil and its U-type fixture.
- To avoid the similar failure, all the U-type fixtures of the quadrupole magnets were replaced by the new ones with increased insulation distance.

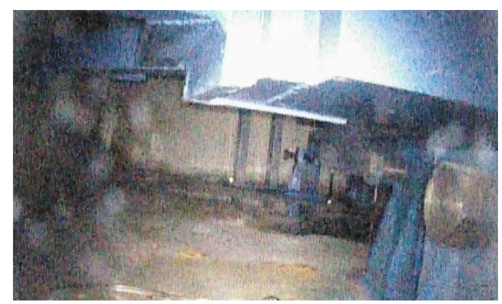


Water leakage in RTBT tunnel

Water Leakage alarm appeared in the RTBT interface during the operation. By using the endoscope, it was found that a ceramic water pipe of the quadrupole was broken, and was replaced.



Leakage position

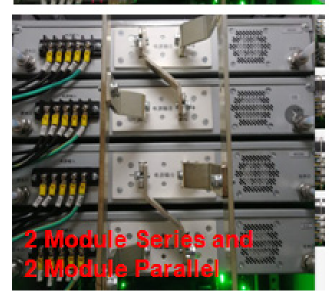


Leakage detection

Problem of RTBT DC Power Supply

TUPMP023/Jun Li

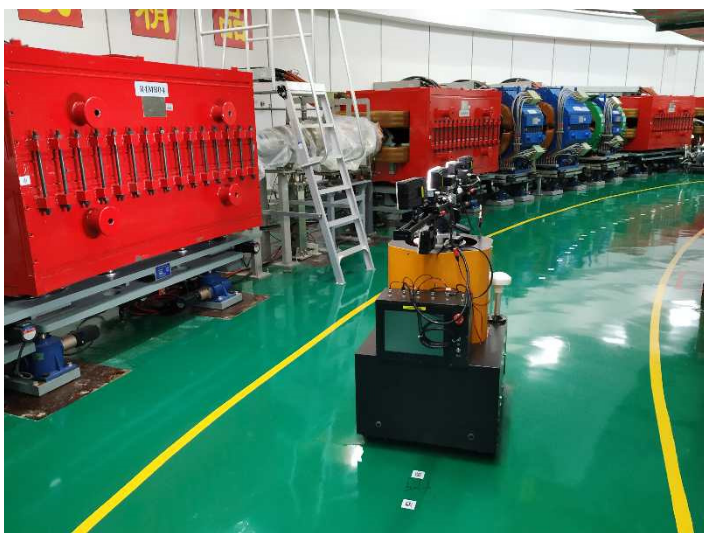
- For these PS, we use the same power module constructed through serial or parallel connection. The single module outputs is 400A/35V (14KW).
- There are total 140 modules, 37 sets .
- Because of high power density and strict processing technology, power supply has found some problems in mass production. It took lots of time to resolve these problems.

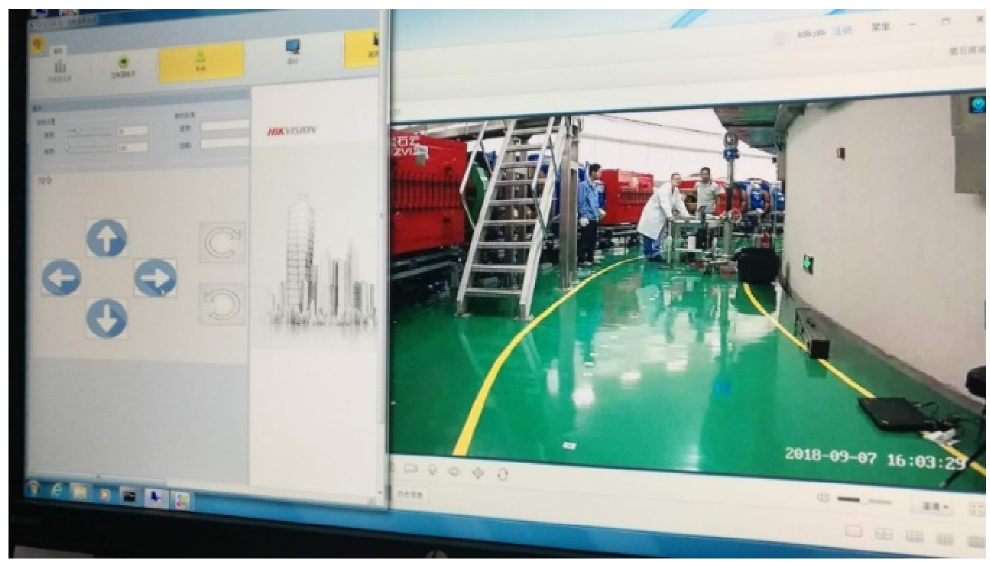


Tunnel robot

WEPGW046/Ling Kang

- A “tunnel robot” was developed as a platform for auxiliary maintenance and measuring. It can move by recognizing the QR codes in the floor, and can carry the manipulator and alignment instrument works in the tunnel.
- It conducted the vibration measurement of the magnets and vacuum pipes





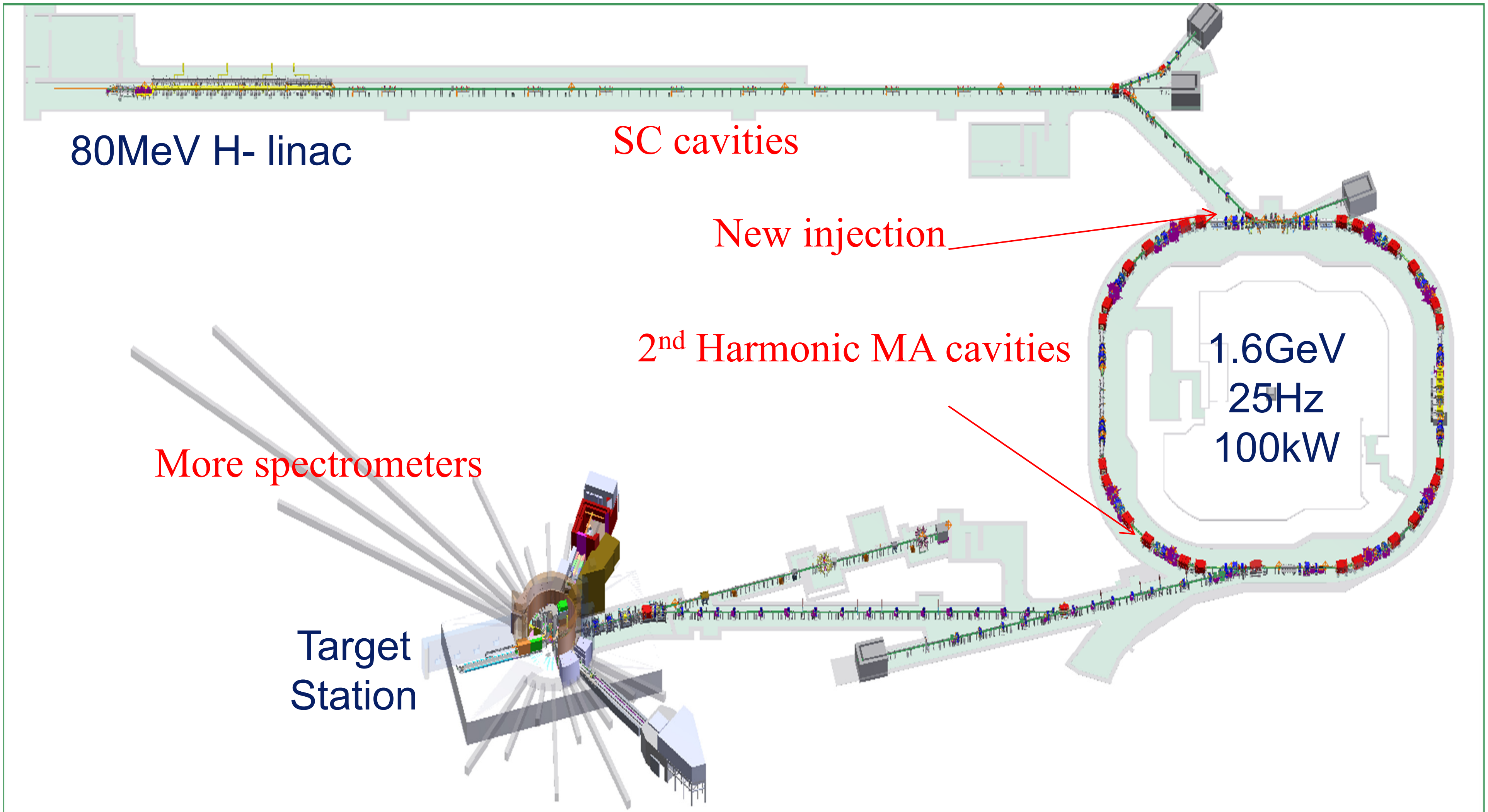
Plan for operation schedule for the first half of 2019
>3600 hours for user in all year

Jan				Feb				Mar				Apr				May				Jun			
TUE	1	T	T	FRI	1	T	T	FRI	1	T	T	MON	1	A	A	WED	1	T	T	SAT	1	T	T
WED	2	T	T	SAT	2	T	T	SAT	2	T	T	TUE	2	A	A	THU	2	T	T	SUN	2	T	T
THU	3	T	T	SUN	3	D	D	SUN	3	T	T	WED	3	A	A	FRI	3	T	T	MON	3	M	M
FRI	4	T	T	MON	4	D	D	MON	4	M	M	THU	4	A	A	SAT	4	T	T	TUE	4	T	T
SAT	5	T	T	TUE	5	D	D	TUE	5	T	T	FRI	5	A	A	SUN	5	T	T	WED	5	T	T
SUN	6	T	T	WED	6	D	D	WED	6	T	T	SAT	6	A	A	MON	6	M	M	THU	6	T	T
MON	7	M	M	THU	7	D	D	THU	7	T	T	SUN	7	A	A	TUE	7	T	T	FRI	7	T	T
TUE	8	T	T	FRI	8	D	D	FRI	8	T	T	MON	8	T	T	WED	8	T	T	SAT	8	T	T
WED	9	T	T	SAT	9	D	D	SAT	9	T	T	TUE	9	T	T	THU	9	T	T	SUN	9	T	T
THU	10	T	T	SUN	10	W	W	SUN	10	T	T	WED	10	T	T	FRI	10	T	T	MON	10	M	M
FRI	11	T	T	MON	11	W	W	MON	11	M	M	THU	11	T	T	SAT	11	T	T	TUE	11	T	T
SAT	12	T	T	TUE	12	T	T	TUE	12	T	T	FRI	12	T	T	SUN	12	T	T	WED	12	T	T
SUN	13	T	T	WED	13	T	T	WED	13	T	T	SAT	13	T	T	MON	13	M	M	THU	13	T	T
MON	14	M	M	THU	14	T	T	THU	14	T	T	SUN	14	T	T	TUE	14	T	T	FRI	14	T	T
TUE	15	T	T	FRI	15	T	T	FRI	15	T	T	MON	15	M	M	WED	15	T	T	SAT	15	T	T
WED	16	T	T	SAT	16	T	T	SAT	16	T	T	TUE	16	T	T	THU	16	T	T	SUN	16	T	T
THU	17	T	T	SUN	17	T	T	SUN	17	T	T	WED	17	T	T	FRI	17	T	T	MON	17	M	M
FRI	18	T	T	MON	18	M	M	MON	18	A	A	THU	18	T	T	SAT	18	T	T	TUE	18	T	T
SAT	19	T	T	TUE	19	T	T	TUE	19	A	A	FRI	19	T	T	SUN	19	T	T	WED	19	T	T
SUN	20	T	T	WED	20	T	T	WED	20	A	A	SAT	20	T	T	MON	20	M	M	THU	20	T	T
MON	21	M	M	THU	21	T	T	THU	21	A	A	SUN	21	T	T	TUE	21	T	T	FRI	21	T	T
TUE	22	T	T	FRI	22	T	T	FRI	22	A	A	MON	22	M	M	WED	22	T	T	SAT	22	T	T
WED	23	T	T	SAT	23	T	T	SAT	23	A	A	TUE	23	T	T	THU	23	T	T	SUN	23	T	T
THU	24	T	T	SUN	24	T	T	SUN	24	A	A	WED	24	T	T	FRI	24	T	T	MON	24	M	M
FRI	25	T	T	MON	25	M	M	MON	25	A	A	THU	25	T	T	SAT	25	T	T	TUE	25	M	M
SAT	26	T	T	TUE	26	M	M	TUE	26	A	A	FRI	26	T	T	SUN	26	T	T	WED	26	M	M
SUN	27	T	T	WED	27	M	M	WED	27	A	A	SAT	27	T	T	MON	27	M	M	THU	27	T	T
MON	28	M	M	THU	28	T	T	THU	28	A	A	SUN	28	T	T	TUE	28	M	M	FRI	28	T	T
TUE	29	T	T					FRI	29	A	A	MON	29	M	M	WED	29	M	M	SAT	29	T	T
WED	30	T	T					SAT	30	A	A	TUE	30	M	M	THU	30	T	T	SUN	30	T	T
THU	31	T	T					SUN	31	A	A					FRI	31	T	T				
Jan				Feb				Mar				Apr				May				Jun			

Plan T	Plan M	Plan A	Plan D	Plan W
3000hrs	624hrs	504hrs	168hrs	48hrs

T	Target
M	Maintenance
A	Machine Study
D	Shut Down
W	Warm Up

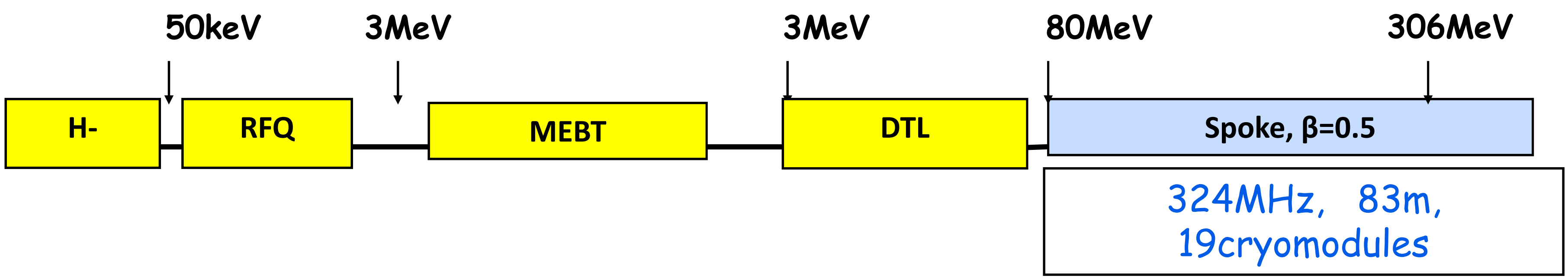
4, Upgrade Plan



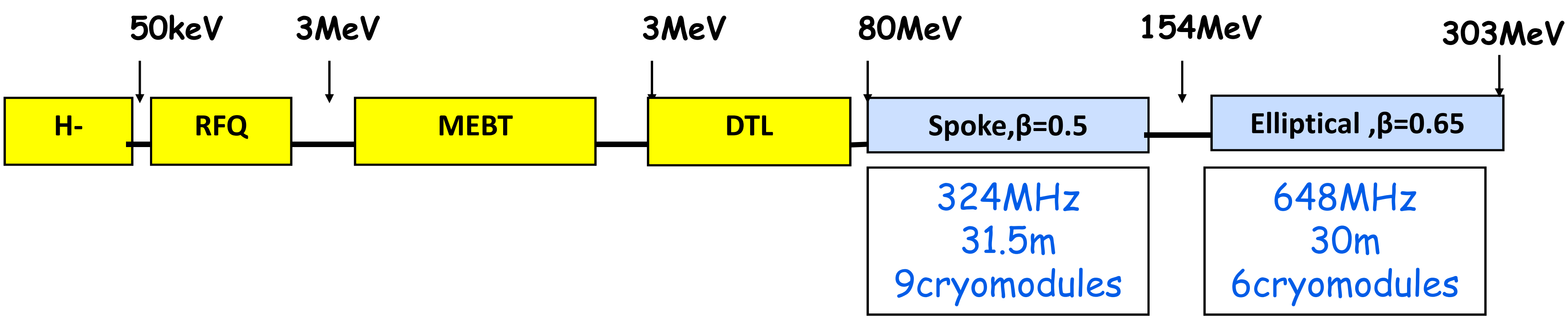
Phase-I status and phase-II upgrade

Layout of the CSNS Linac in Phase-II

Option1:

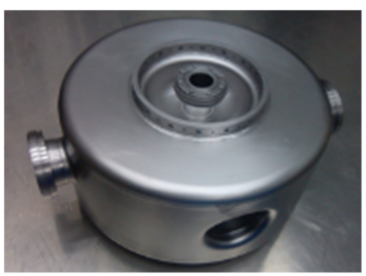


Option2:



Similar SC Cavities Developed at IHEP for ADS

	Cavity type	Freq. (MHz)	β_g	Energy (MeV)	Max. $V_{acc.}$ (MV)
Injector I	Spoke012	325	0.12	3.2-10	0.82
Main Linac	Spoke021	325	0.21	10-34	1.32
	Spoke040	325	0.40	34-178	2.79
	Elliptical063	650	0.63	178-367	7.68
	Elliptical082	650	0.82	367-1500	15.47

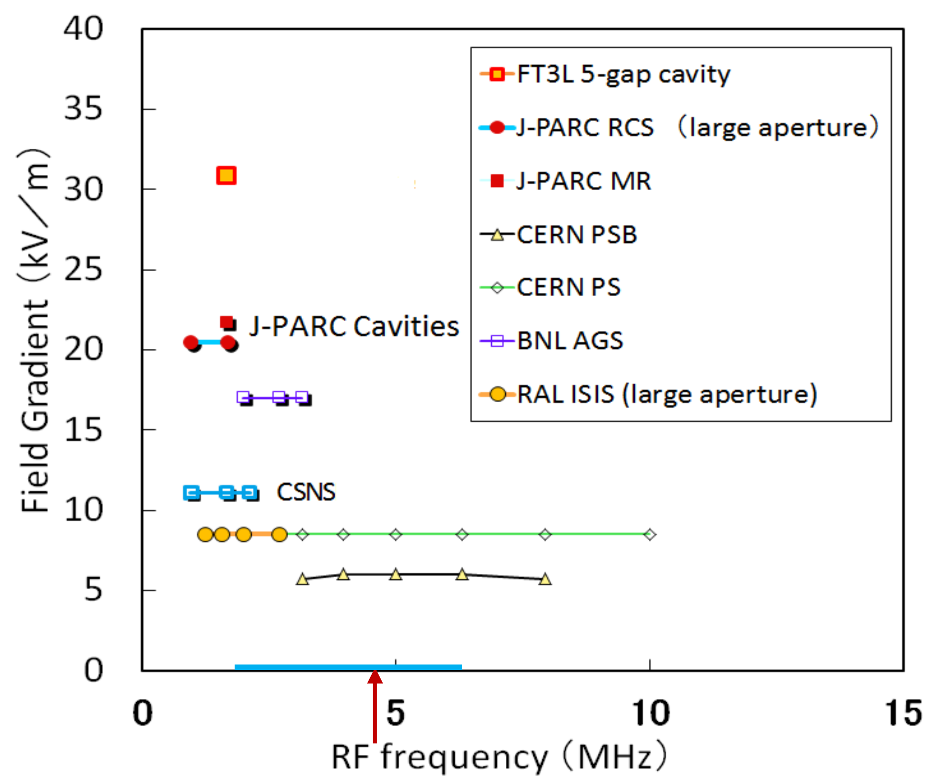




RCS upgrade tasks

- ✧ Secondary harmonic MA loaded cavities
- ✧ New injection system
- ✧ Upgrade of part of AC power supply
- ✧ Some new beam instruments, upon the experiences of present beam commissioning
- ✧ Magnetic field measurement for AC mode with different injection energy: 250,300,350,400MeV
- ✧ Beam dynamics studies, upon present commissioning

MA Loaded Cavity for RCS as 2^{nd} -harmonic buncher

- **Present ferrite loaded cavity**
  - Length: 2.7m
  - RF voltage: 27kV
- **New Secondary MA cavity**
  - Length:1.8m
  - RF voltage: 36kV

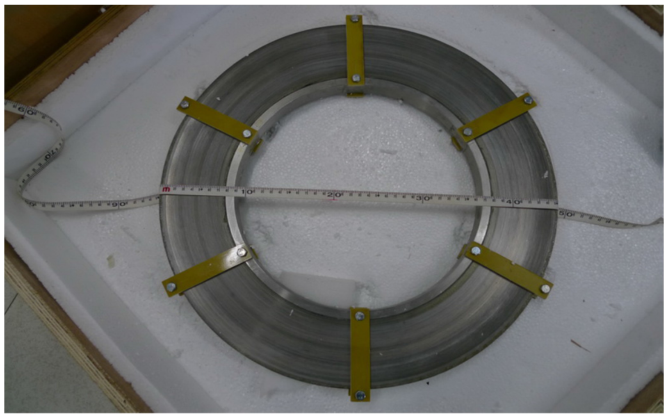


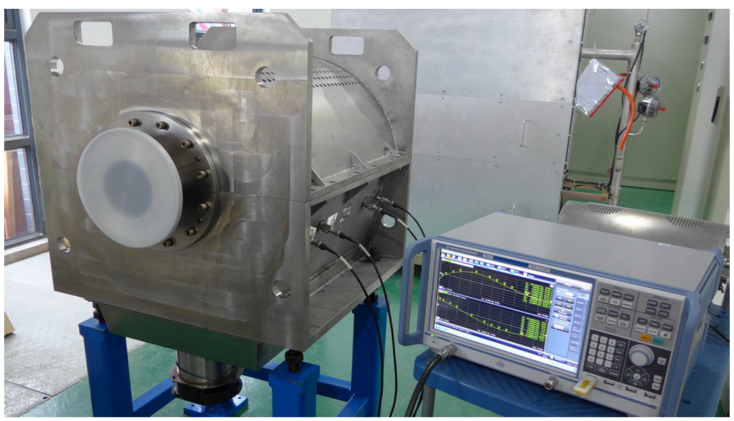
CSNS Second Harmonic RF System

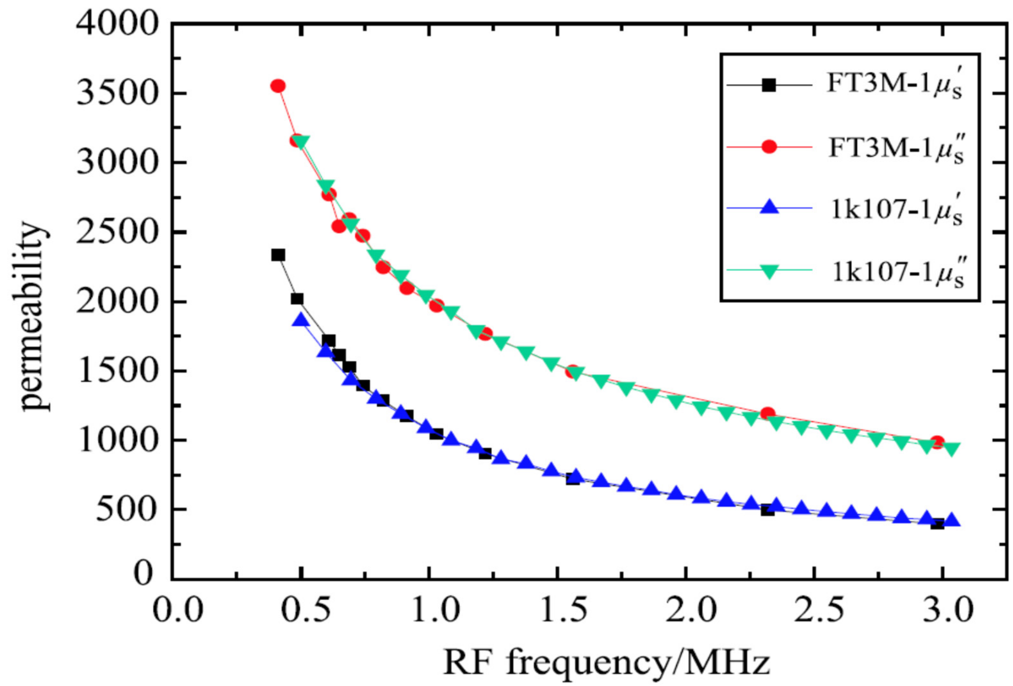
We are lack of experiences of development of high power MA loaded cavity in China.

Domestic MA strips development

WEPRB051/Wu Bin







Prototype measurement results indicate the domestic products are comparable with Japanese products.

Summary

- CSNS construction finished successfully within budget and on time.
- Accelerator beam commissioning has been completed with a good results.
- We reached 50kW beam power on target for user operation with availability higher than 90%.
- CSNS started user operation and meanwhile will gradually raise beam power to 100kW.
- 500kW upgrade is under planning, and the upgrade project is foreseen to be launched as long as we realize 100kW.

THANK YOU!