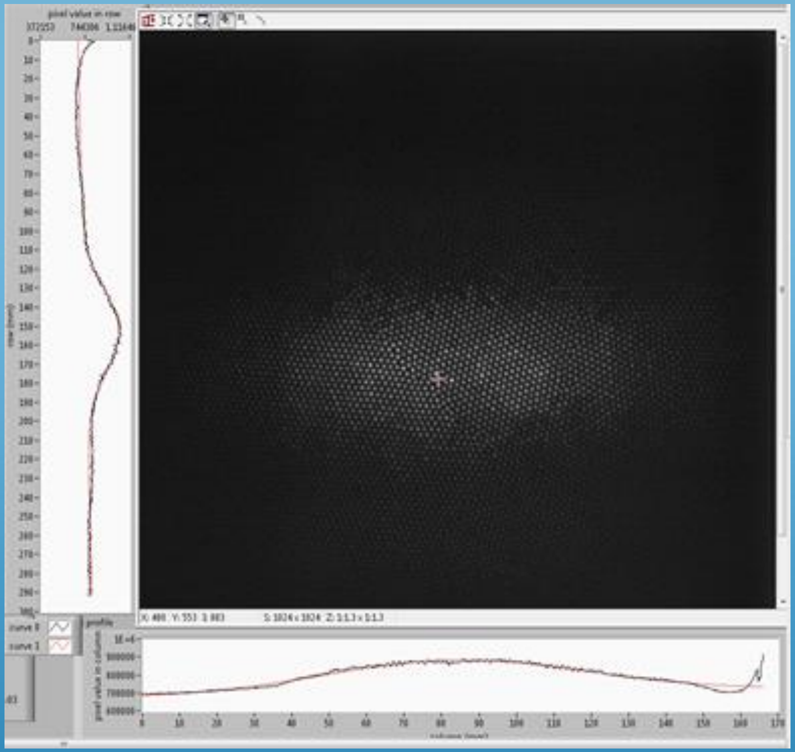
China Spallation Neutron Source Beam Commissioning



CSNS CHINESE ACADEMY OF SCIENCES

John Thomason
& Shinian Fu

ATAC

John Thomason – STFC (chair)
Roland Garoby – ESS
Kazuo Hasegawa – JAEA
Mike Seidel – PSI
Andrei Shishlo – ORNL
Takeshi Toyama – J-PARC
Wu-Tsung W Weng – BNL

NTAC

Andrew Taylor – STFC (chair)
Carla Andreani – University of Rome
Masatoshi Arai – ESS
Masatoshi Futakawa – JAEA
John Haines – ESS
John Galambos – ORNL
Takeshi Kamiyama – KEK
Peter Peterson – ORNL
Rob Robinson – ANSTO

Ninth International CSNS Advisory Committee review meeting December 18 – 20, 2017

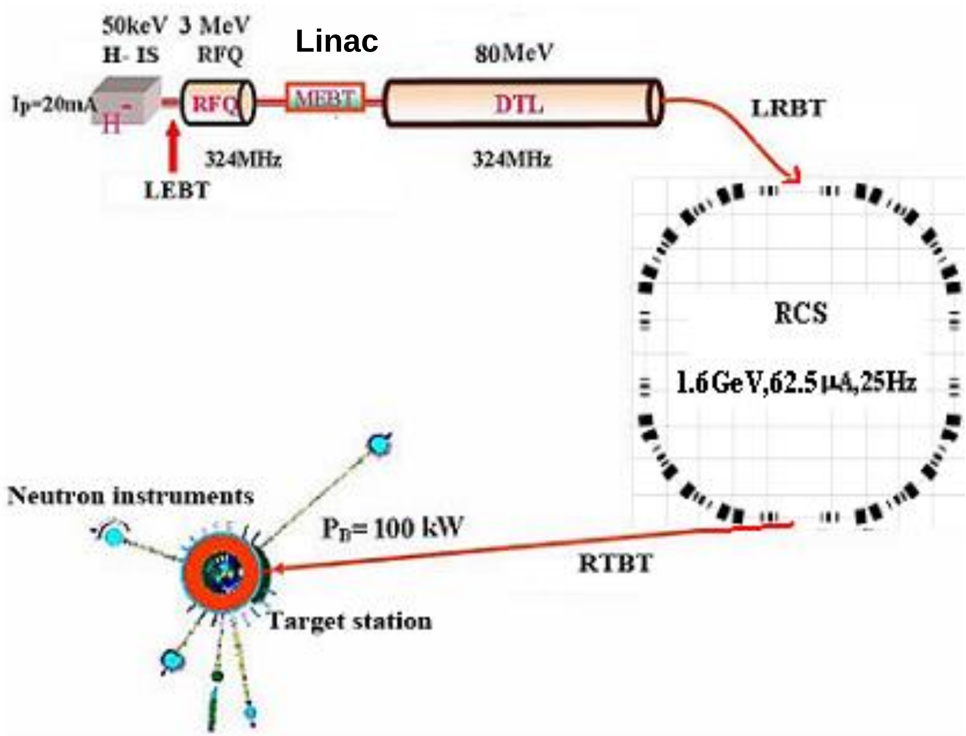
Contents

- Accelerator Overview
- Linac Commissioning
- RCS Commissioning

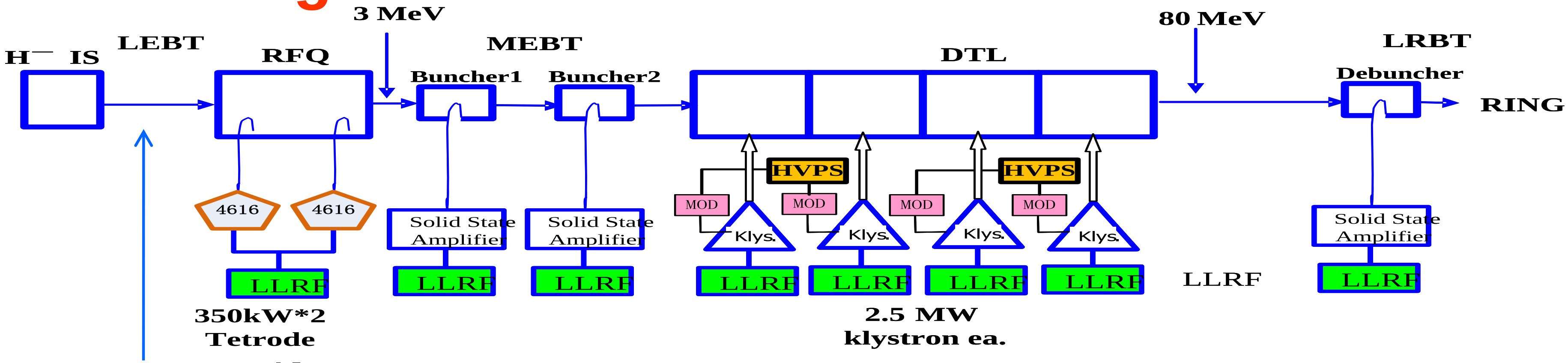
1. Accelerator Overview

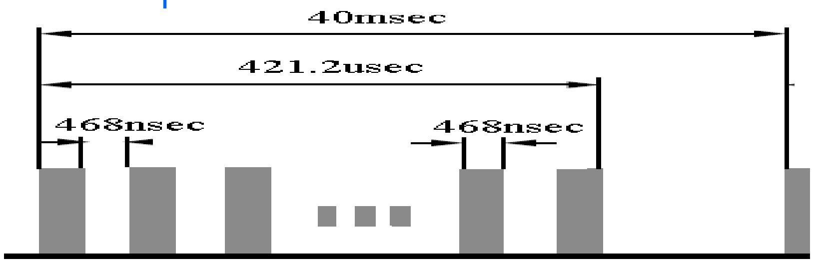
Accelerator major design parameters

Project Phase	I	II
Beam Power on target [kW]	100	500
Proton energy [GeV]	1.6	1.6
Average beam current [μ A]	62.5	312.5
Pulse repetition rate [Hz]	25	25
Linac energy [MeV]	80	250
Linac type	DTL	+Spoke
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



Linac design





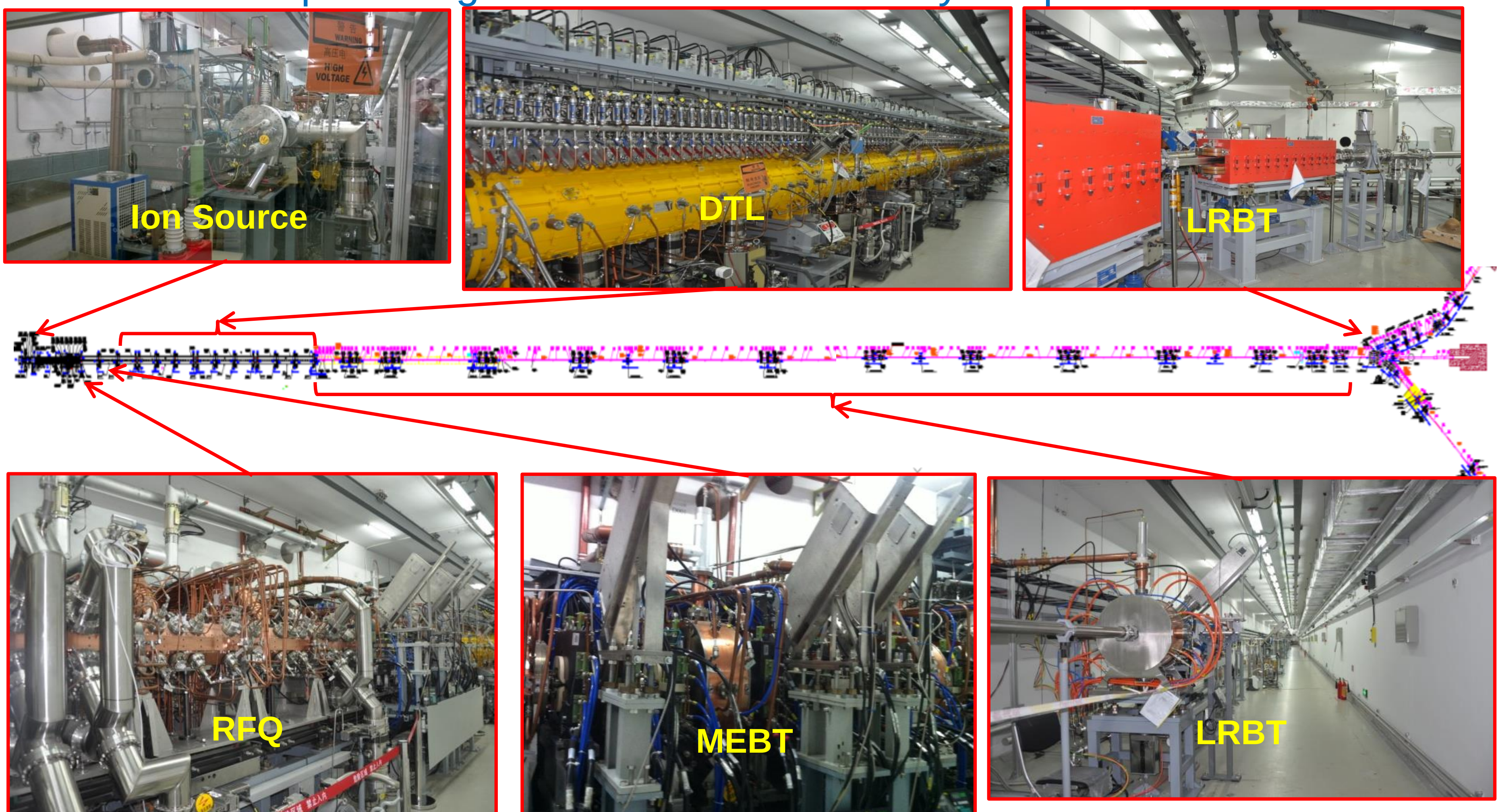
EMQ option in FFDD lattice for DTL

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	20/40	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

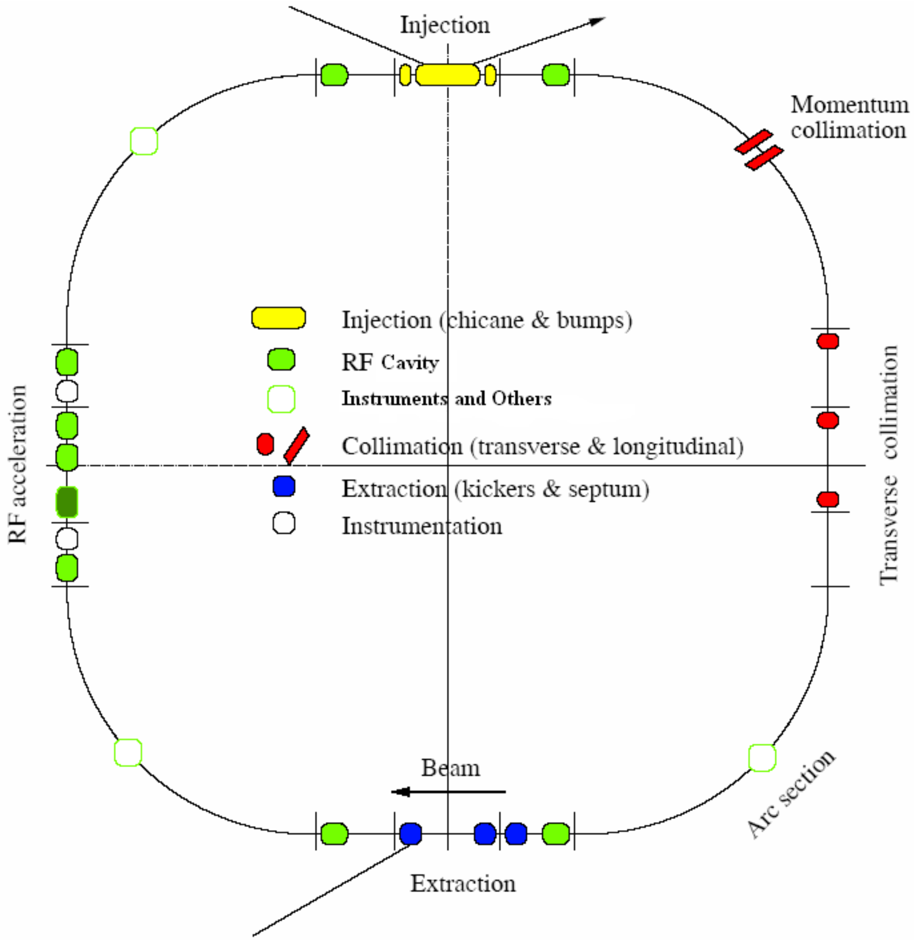
Linac commissioning

- Linac has been commissioned, but unfortunately one CPI klystron has had to be repaired again and thus DTL-4 delayed operation until now.



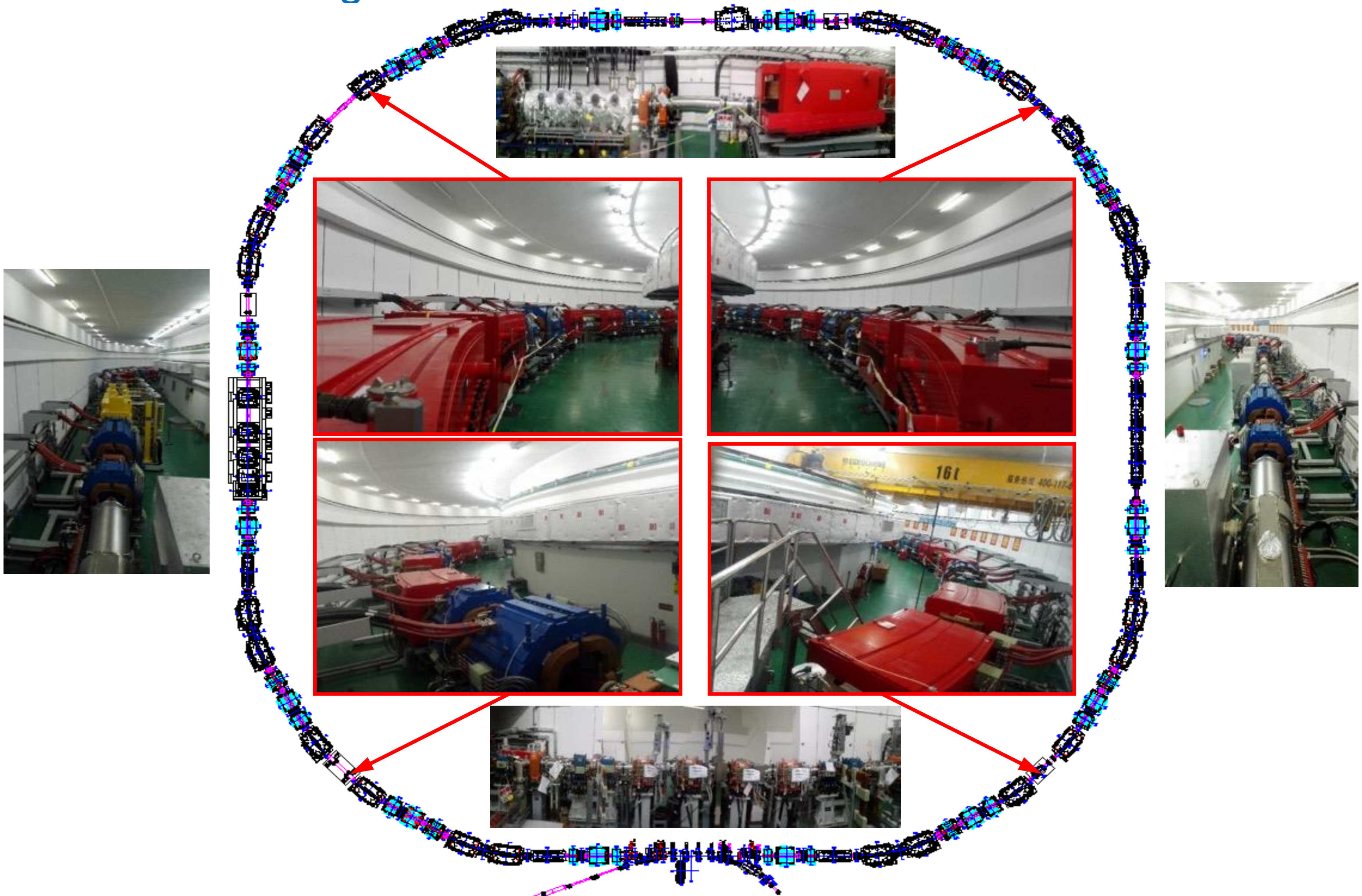
RCS design

- 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 commissioning

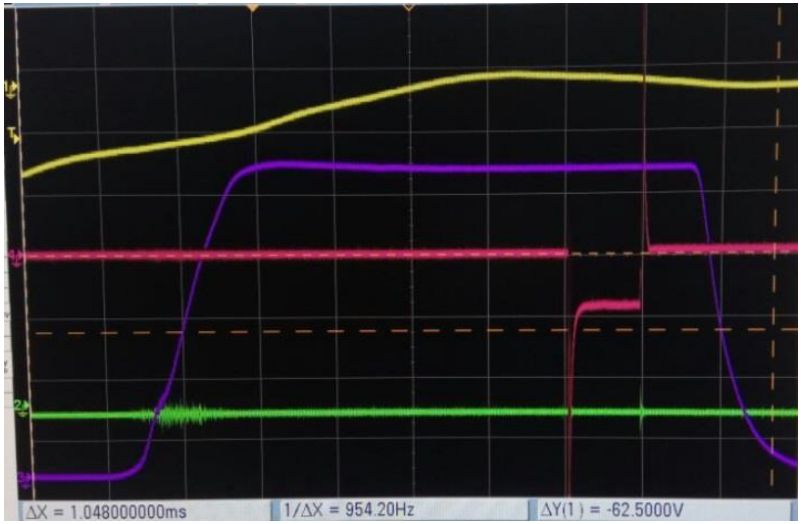
- All RCS facilities including magnets, vacuum, RF, injection & extraction, collimator and diagnostics have been commissioned.



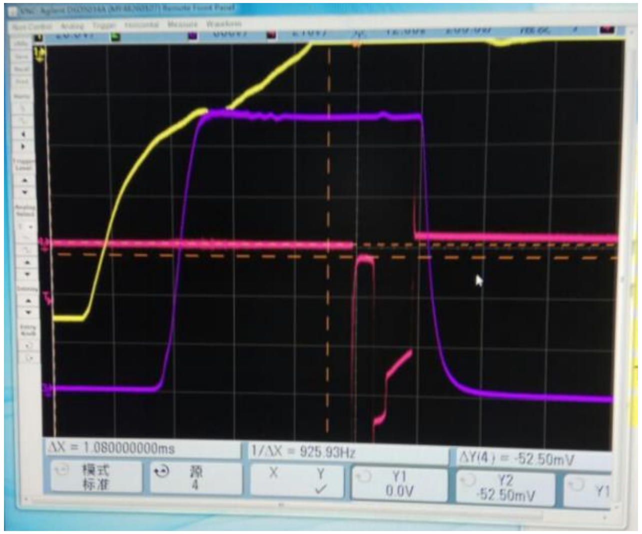
2. Linac Commissioning

Ion source operation

- Have put a large amount of effort into increasing the reliability and availability.
- Ion source works very stably at high duty factor, but becomes unsatisfactory at low duty factor for early stage beam commissioning.
- Life time of source body is around 1 month.

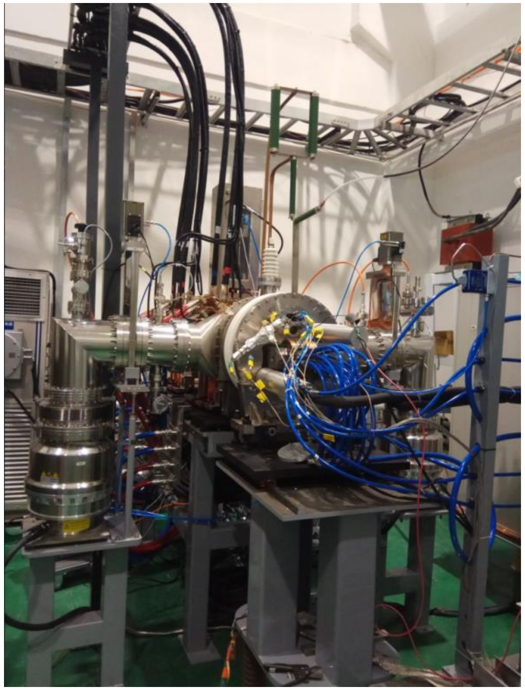


Stable arc current (pink) at high duty

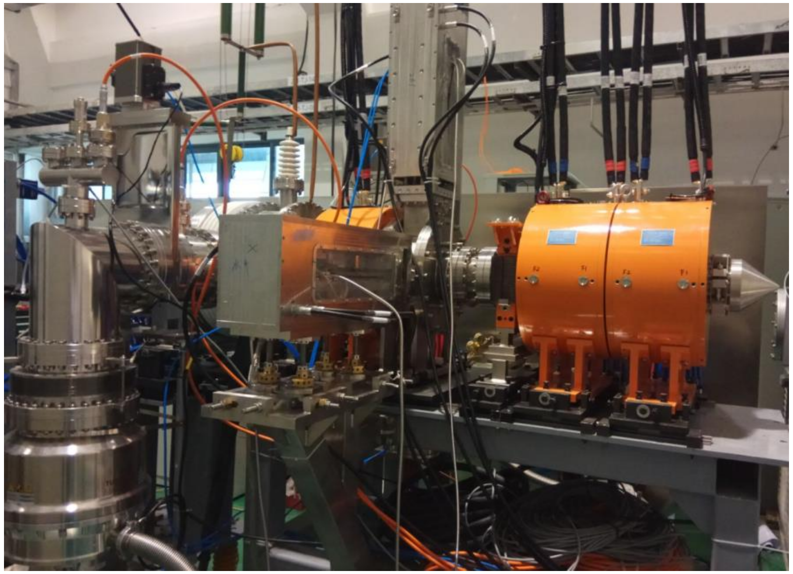


Unstable arc current (pink) at low duty

Ion source hot stand-by and test stand



Hot stand-by ion source



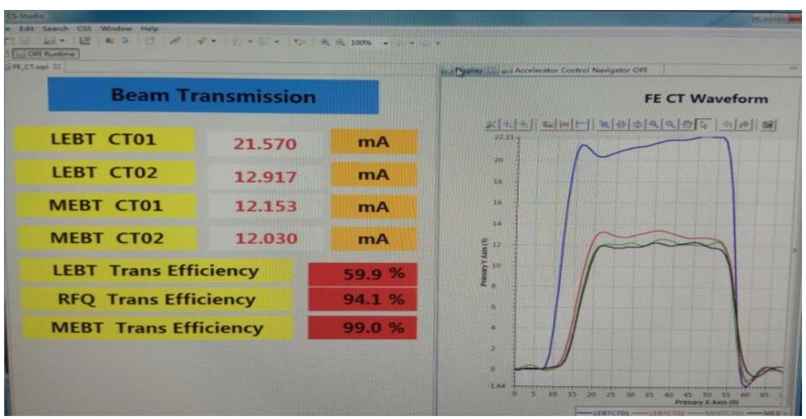
LEBT: solenoids, emittance scanner, guide magnets

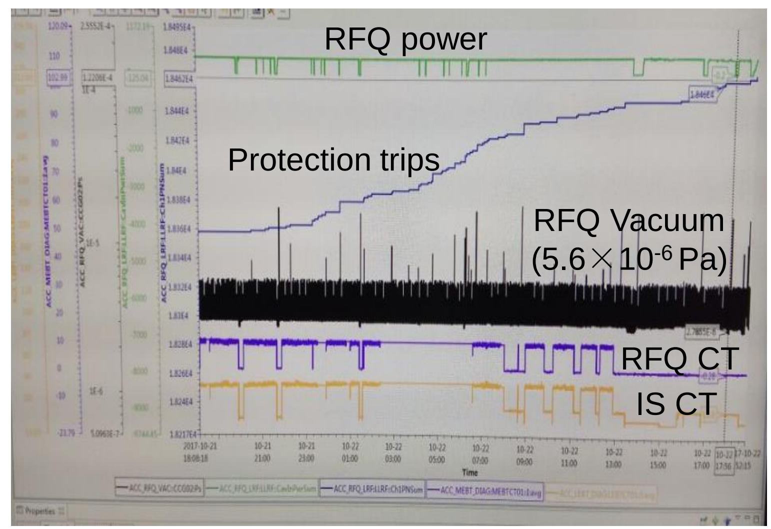
Power supply and control racks

- Ion source hot stand-by for rapid commissioning of a new ion source body so as to improve the availability of beam.
- Test stand for improvement of ion source for future upgrade.

RFQ operation

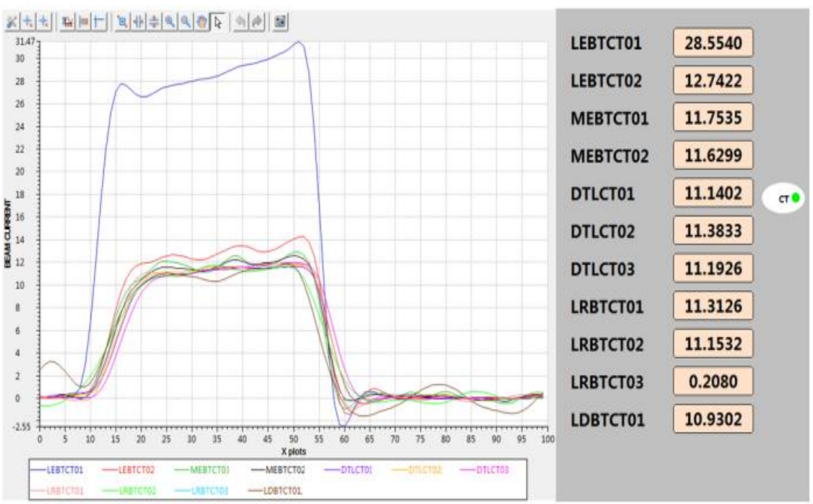
- Aiming at high transmission rate and low spark rate.
- The highest transmission rate reached is 97%, but in normal operation it is around 94% depending on the beam emittance of the ion source.
- All linac trip rate has dropped from around 100/day in August to around 20/day in recent high power conditioning.



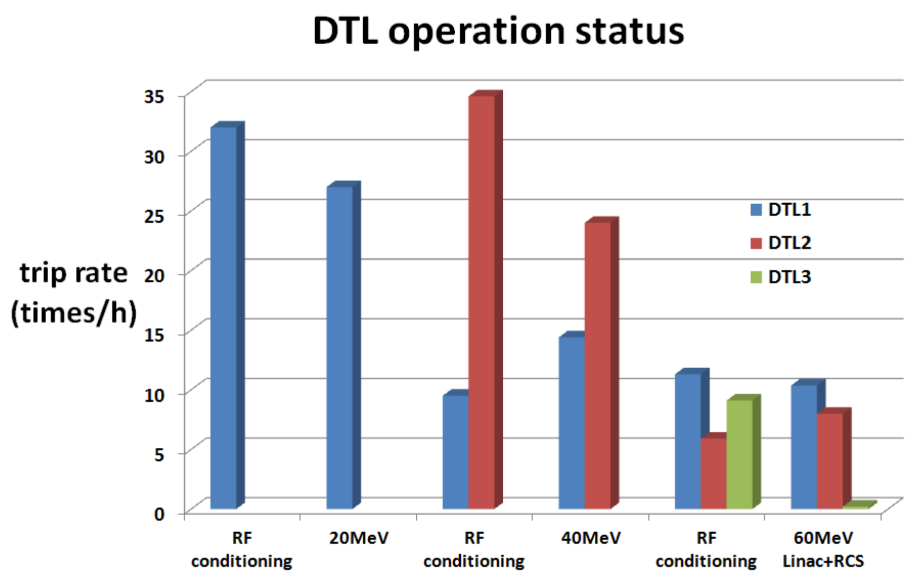


DTL commissioning

- Following successful beam commissioning of DTL1, DTL2 & DTL3 started beam commissioning in April 2017 and reached 60 MeV output beam energy with pulsed peak current of 15mA. The DTL beam transmission rate is 97%.
- Initial high power conditioning for the tanks seems have been insufficient so a second conditioning run was conducted at higher power.



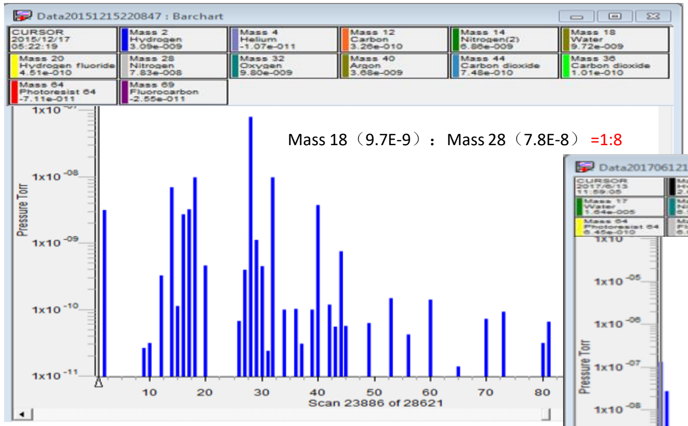
CT measured pulse current along the linac

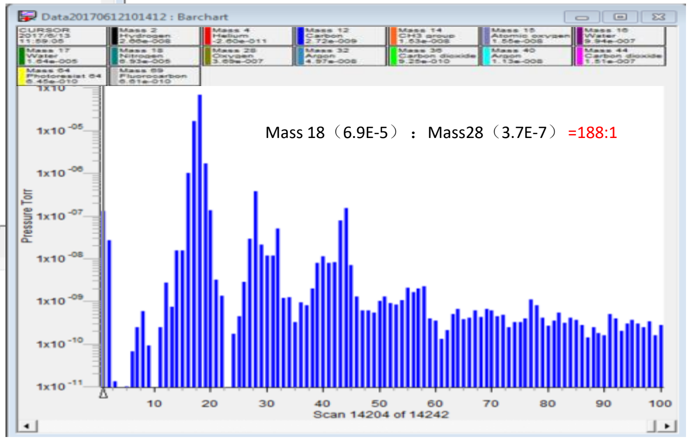


DTL1 Q-13 water leak

- After installation, vacuum leaks were found in a number of drift tubes. Vacuum sealant was used to block the leak points.

- Subsequently a further leak developed in DTL1 and was found to be a water leak from Q-13.





- Prior use of vacuum sealant precludes usual water leak repair *in situ.*

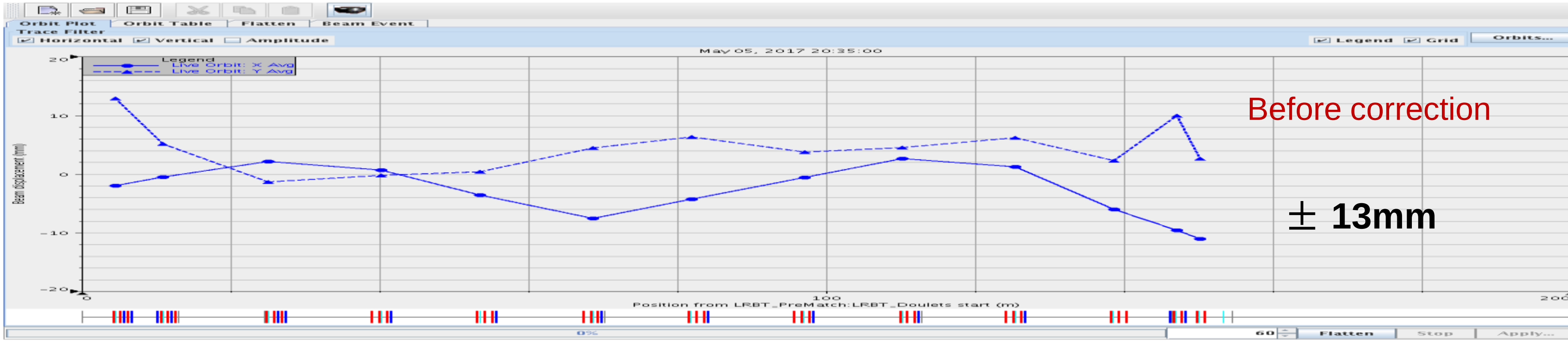
- Cooling to Q-13 has been turned off, along with the corresponding power supply, and the focusing lattice has been modified.

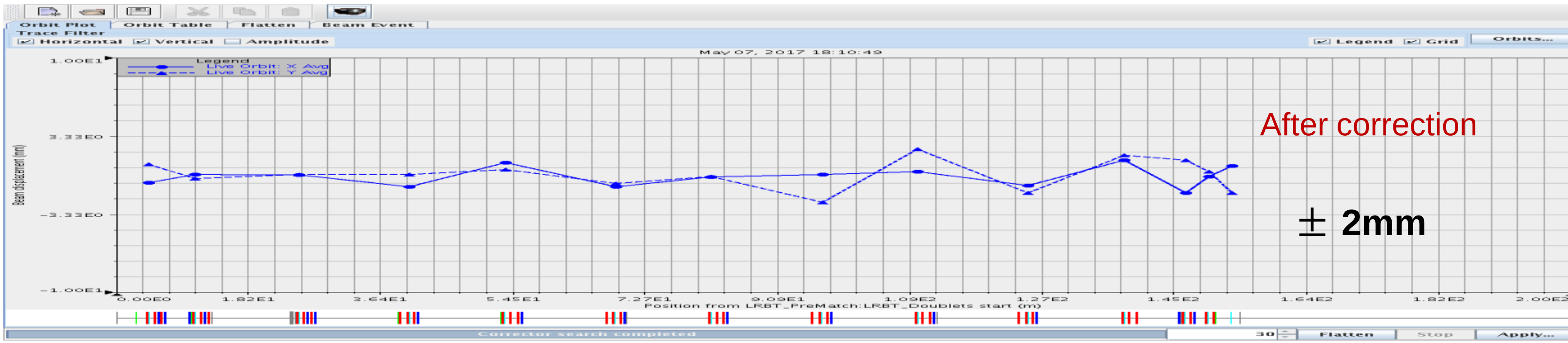
Development of new DT processing technology

- Great effort has been made in finding a new fabrication process to fix the drift tube vacuum problem.
- The major change of the new process is that the weld seam will no longer be processed after electron beam welding to ensure that the the joint is not damaged by post-treatment.
- A spare drift tube for DTL1 Q-13 has been fabricated, and no leakage has been detected. DTL Q-13 will be replaced as it is accessible via a nearby vacuum port.

- Further drift tube failures are probably inevitable and may not be easily accessible for replacement, or be able to be mitigated by a modified focusing lattice.

LRBT commissioning





- Orbit correction is effective in the LRBT beam line, but some sparks were observed in the debuncher cavity – beam loss induced?

LRBT commissioning

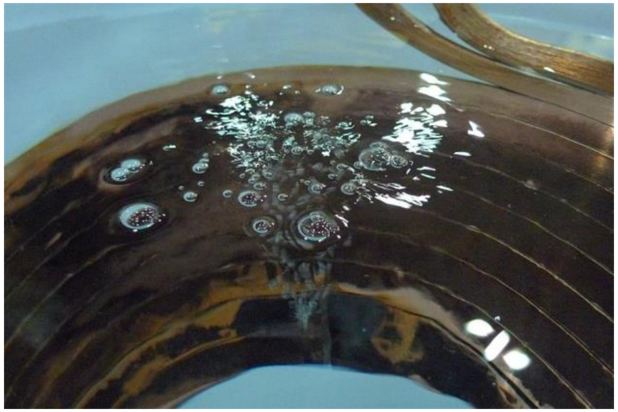
- Hot spot detected in line to LRBT beam dump when sending beam to the RCS

- Probably due to stripping of H^- to H^+ by residual gas in the RFQ

3. RCS Commissioning

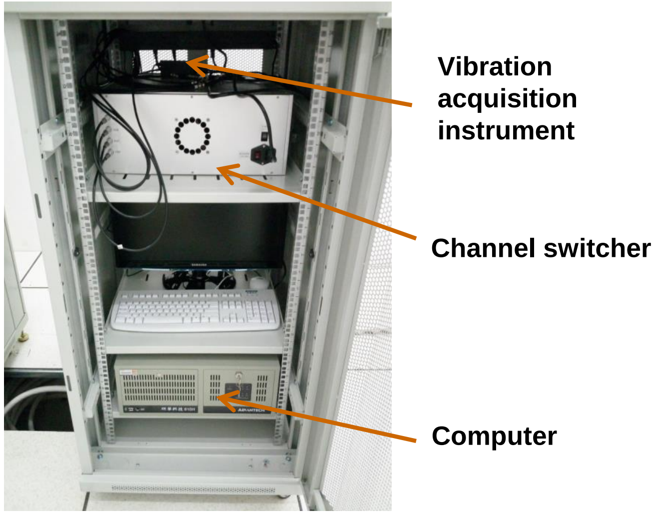
RCS dry running

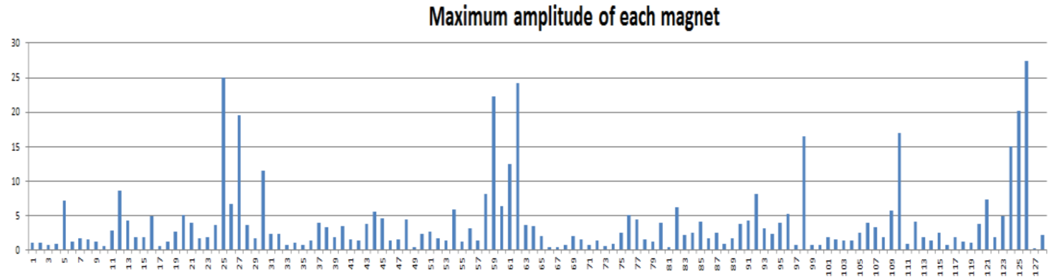
- RCS run with no beam at full power for two periods of one week.
- Problems found:
  - Water leakage was found in one cavity
  - Cooling tubes of two AC magnets were burned through
  - Insulation failures of three quadrupole magnets
  - 17 chokes had strong vibration and had been returned to the manufacture to repair
  - Ceramic vacuum chamber broken
  - Extraction kicker arcing

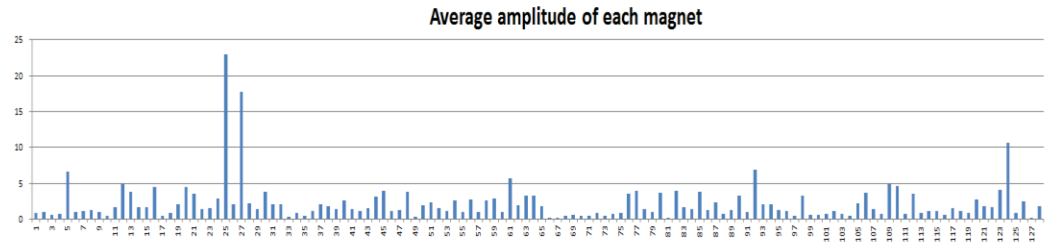


Online vibration monitoring

- A great of attention has been given to the vibration of the AC magnets because it caused a crack of a ceramic chamber of the quadrupole magnet.
- An online vibration monitoring system has been developed and put into operation.

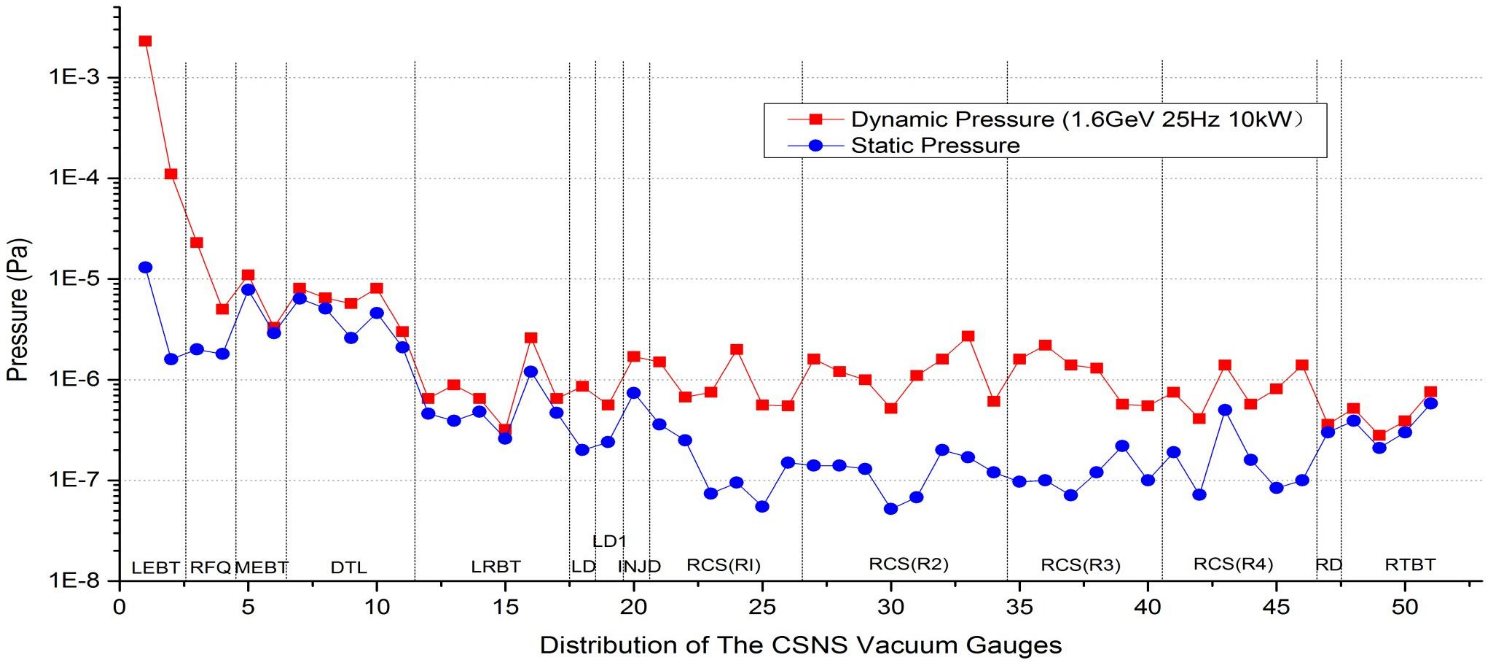






Vacuum operation

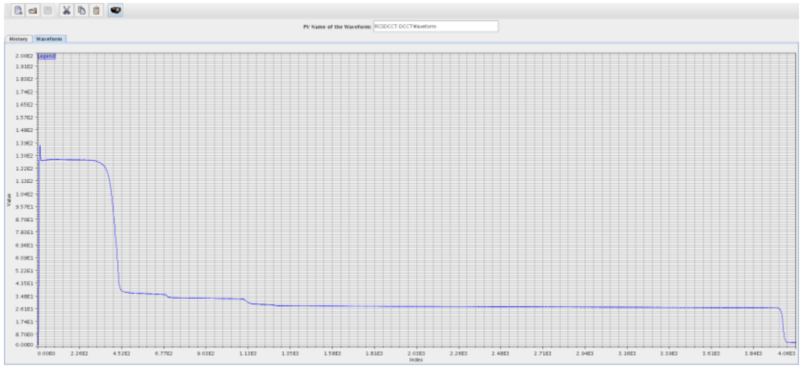
- The vacuum system has been running smoothly.
- The dynamic pressure meets the design specifications.



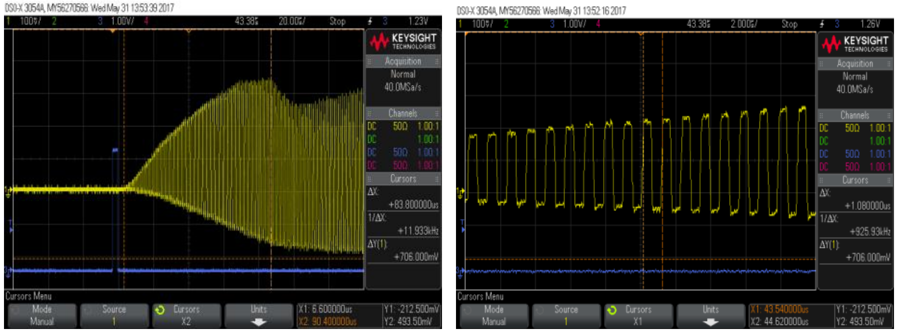
RCS beam commissioning – DC mode

- To control beam loss during beam commissioning single shot beam mode was adopted. For the first step beam commissioning was started in DC mode without acceleration.
- On May 31st first beam was injected into the RCS, and successfully accumulated. The maximum accumulated particle number was about one third of the design goal.

- Beam accumulation:

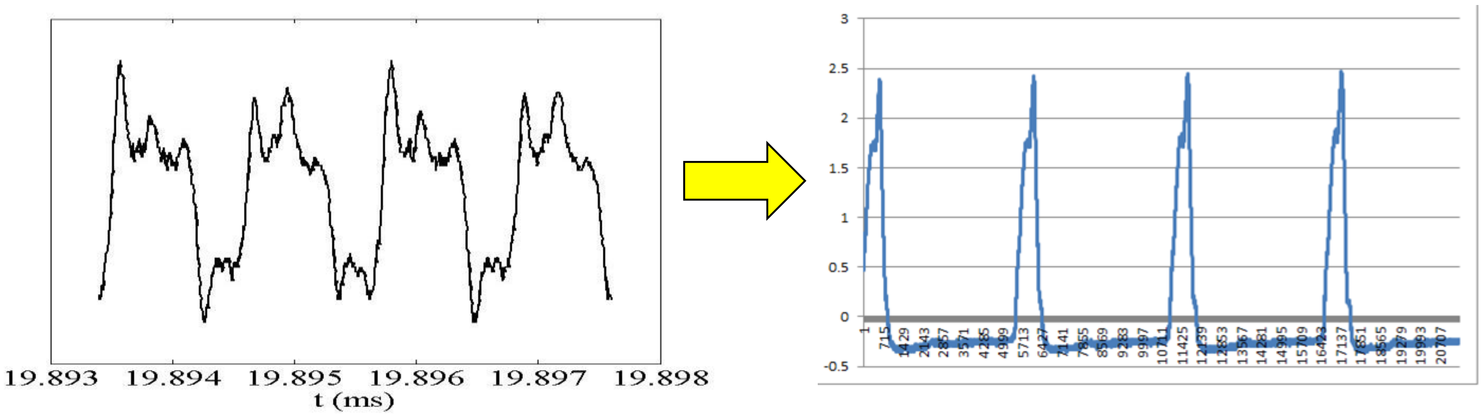


20 mA beam was accumulated in the first shot

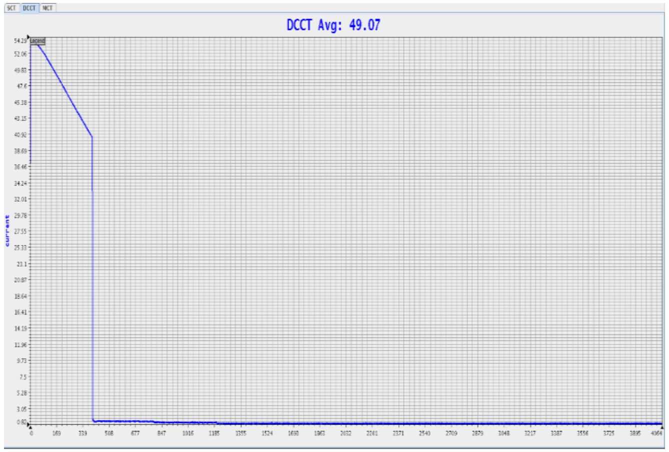


Wall Current Monitor recorded the accumulation process

- On June 5th first DC mode beam was extracted to the RCS beam dump.



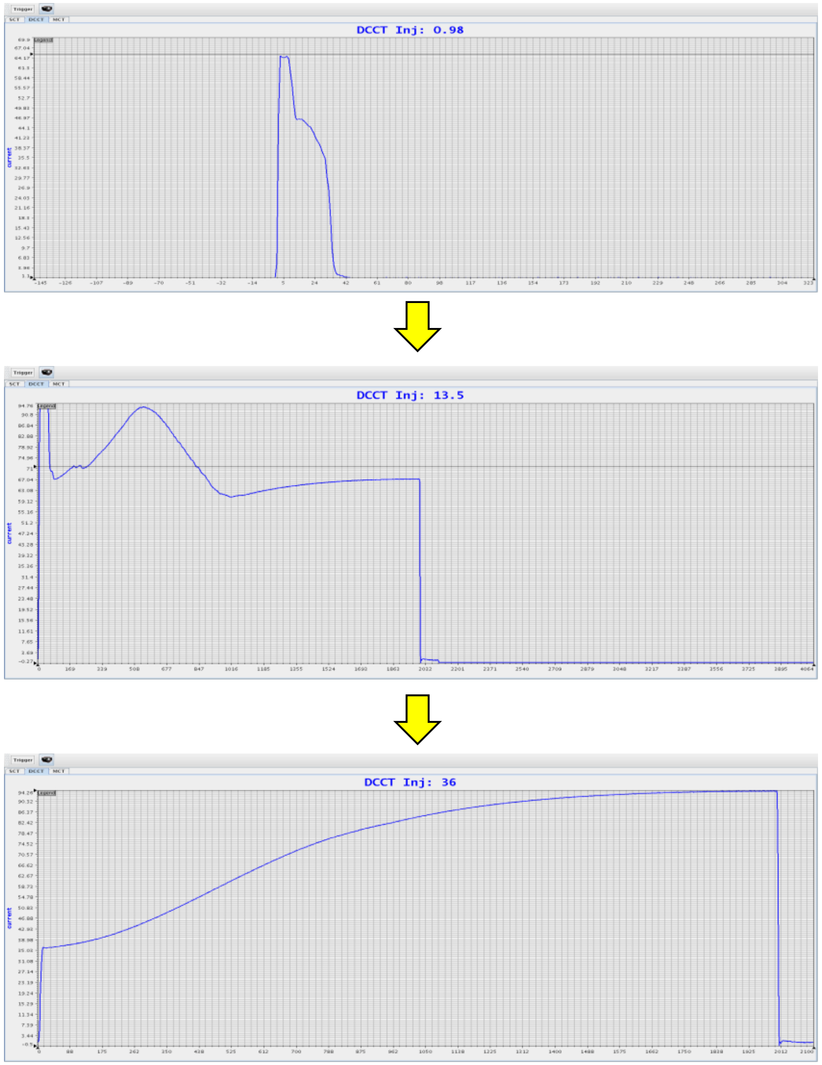
Bunching phase reached – bunched beam can be extracted out of the RCS



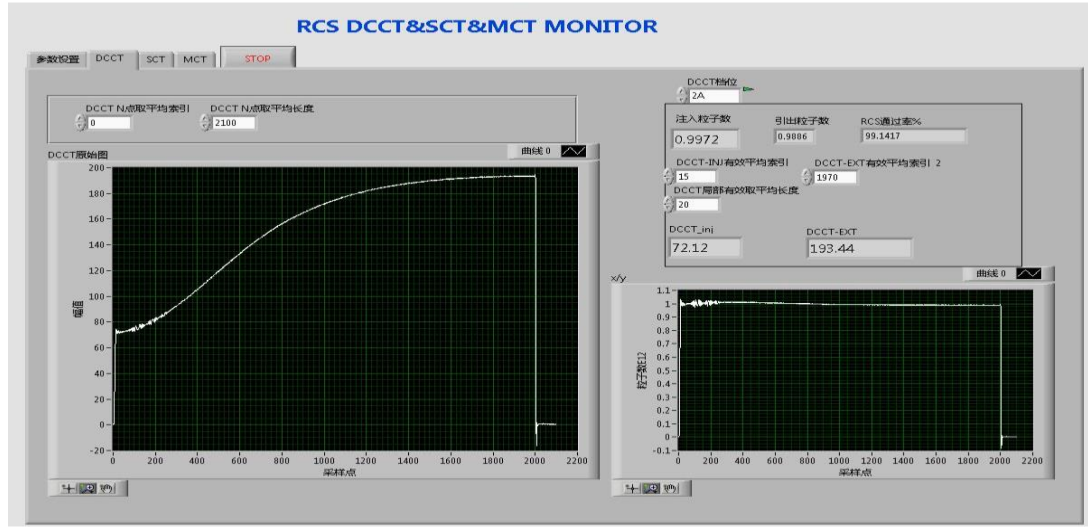
Extraction timing tuned – then beam extracted to RCS beam dump

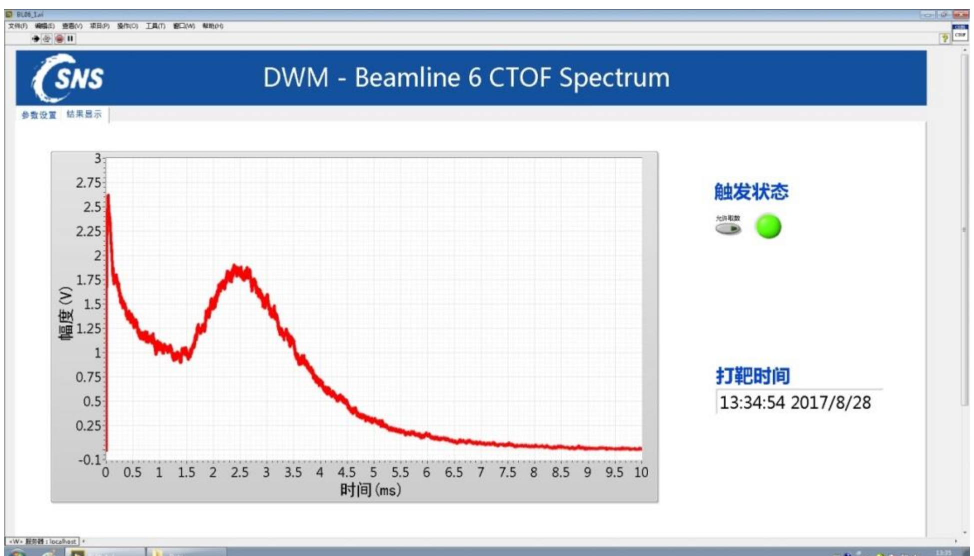
RCS beam commissioning – AC mode

- AC mode commissioning began on July 7th.
- Beam lifetime was 4 ms for the first shot.
- Shifting timing between the RF and B field allowed acceleration and extraction of >70% of the beam at 1.6 GeV.
- Tuning RF phase and amplitude finally gave nearly 99% transmission.



- Beam transmission in the RCS reached >99% after only 4 days' AC beam commissioning.

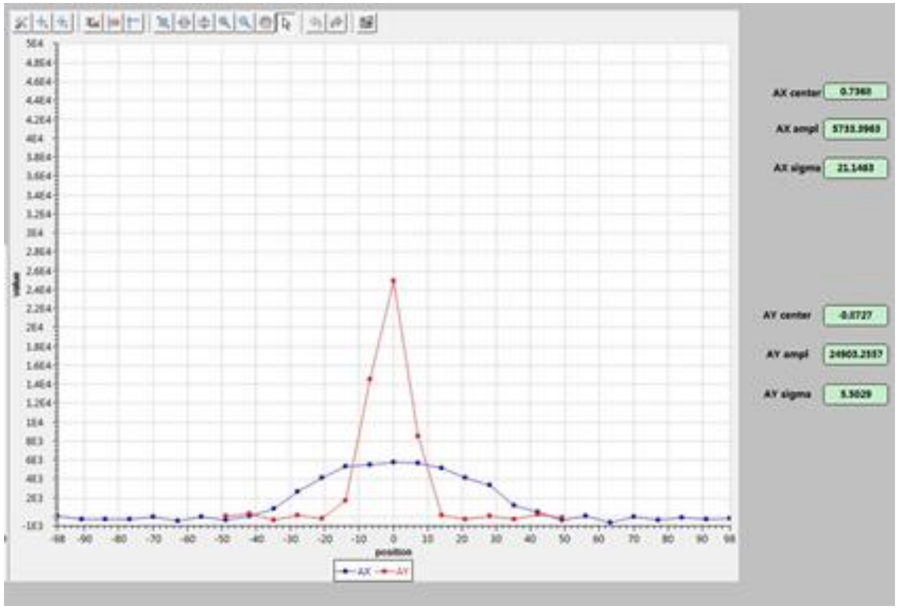




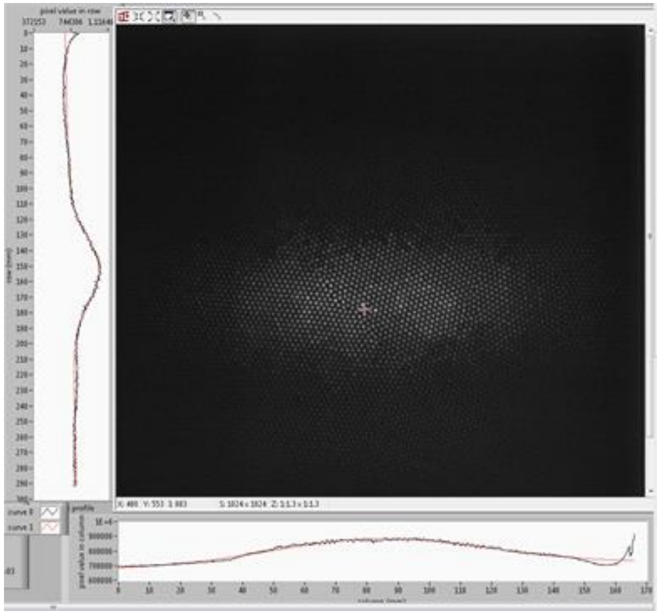
- First neutron spectrum produced on August 28th.

10 kW beam commissioning

- On November 1st began to raise beam repetition rate. 5Hz was reached on November 6th and on November 9th 25Hz beam hit the target. The average beam power reached 10kW, meeting the acceptance requirement.



Beam profile in front of the target



Beam image on the target surface

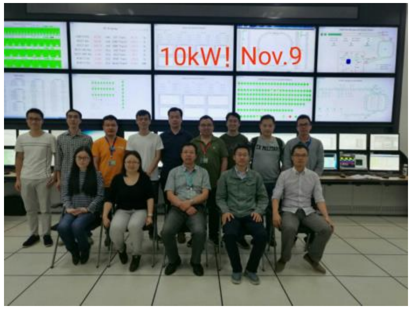
Summary of milestones

2016

Nov.1, 2016	The eighth International Review on CSNS Held
Dec.30, 2016	Accelerator Installation completed

2017

Apr.24, 2017	Linac 60 MeV Beam
Jun.7, 2017	The Proton Beam was Successfully Accelerated to 1.6GeV in CSNS RCS
Aug.25, 2017	Target Station and Instruments Installation completed
Aug.28, 2017	First Neutron Beam Obtained
Nov.1, 2017	A Joint Beam Commissioning Performed
Nov.9, 2017	CSNS Average Beam Power Reached to 10 kW with a repetition rate of 25 Hz for the proton beam pulses
Dec.18, 2017	The ninth international Review on CSNS Held



THANK YOU FOR YOUR ATTENTION!