中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences
中国科学院
CHINESE ACADEMY OF SCIENCES

LINAC 2016, MSU, East Lansing, USA, September 26th ~30th, 2016

Commissioning of the ADS Front-end at IMP in Lanzhou

Yuan He

Linear Accelerator Center

Institute of Modern Physics, CAS

Outlines

- **Introduction of Chinese ADS Front-end Demo Lianc in Lanzhou (CAFE)**
- **Commissioning of CW RFQ**
- **Commissioning of CW SC-Linac**
- **Summary of Commissioning Progress**
- **Acknowledgments**

Project CIADS (2018-2024)

China Initiative Accelerator Driven System (CIADS)

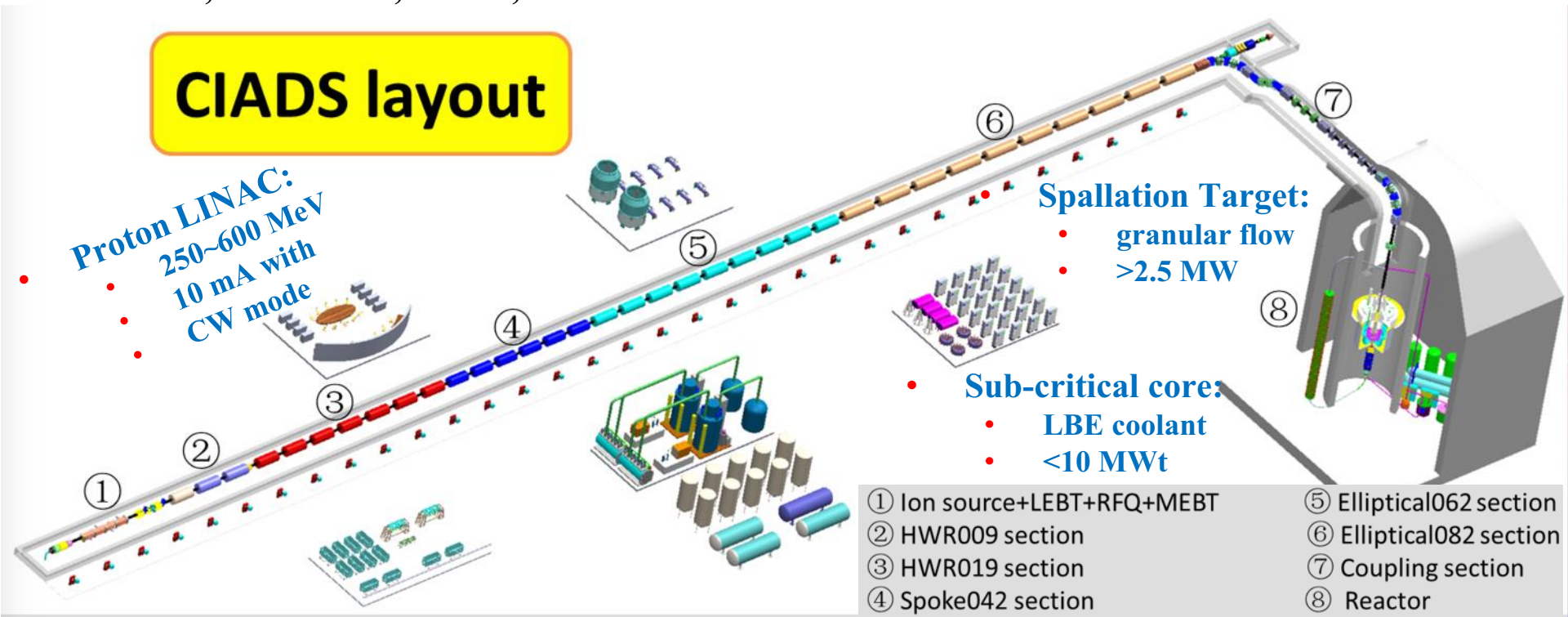
- Approved by central Gov. in Dec. 2015
- Leading institute: IMP
- Budget: >1.8B CNY (Gov. and Corp.)
- Location: Huizhou, Guangdong Prov.
- Cooperation Partners:
  IHEP, CASHIPS, CIAE, CGN

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

中广核 CGN

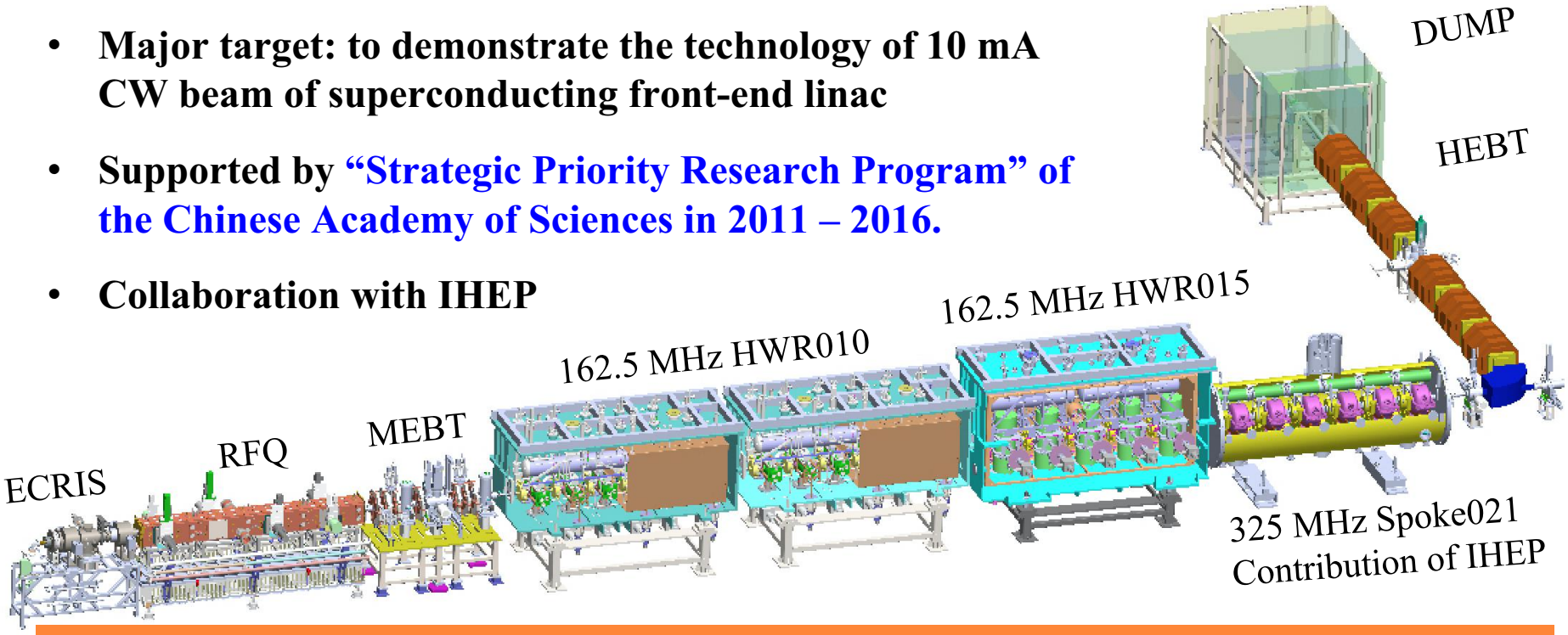
Hefei Institutes of Physical Science
Chinese Academy of Sciences

CIADS layout



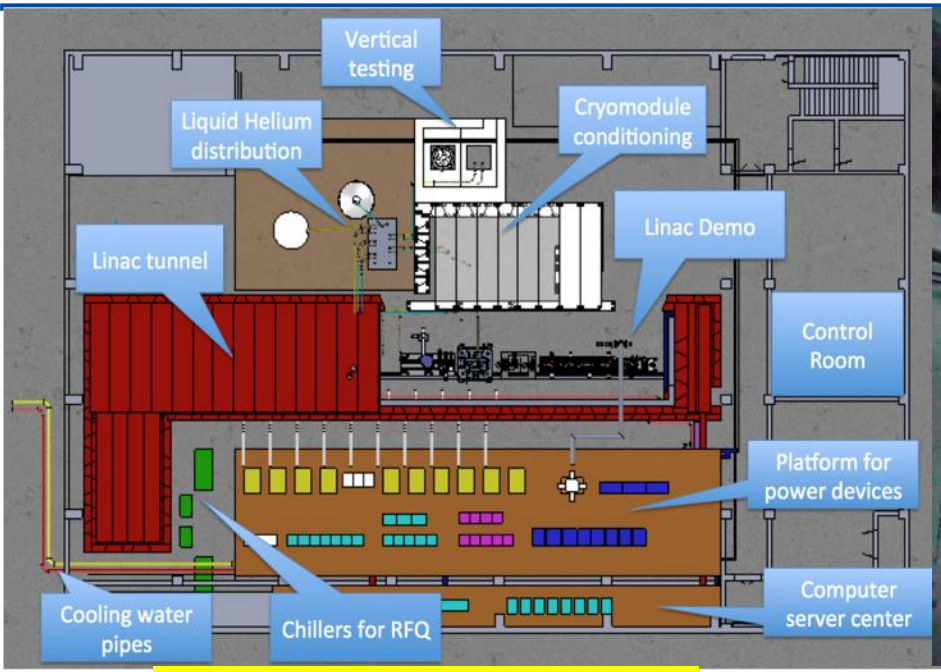
Chinese ADS Front-end Demo Linac

- **Major target: to demonstrate the technology of 10 mA CW beam of superconducting front-end linac**
- **Supported by "Strategic Priority Research Program" of the Chinese Academy of Sciences in 2011 – 2016.**
- **Collaboration with IHEP**



	RFQ/IMP	CM1/IMP	CM2/IMP	CM3/IMP	CM4/IHEP
frequency	*162.5 MHz*	*162.5 MHz*	*162.5 MHz*	*162.5 MHz*	*325 MHz*
output energy	*2.1 MeV*	*5 MeV*	*9 MeV*	*17 MeV*	*25 MeV*
cavity type	*4-vane*	*HWR010*	*HWR010*	*HWR015*	*Spoke021*
cavity number	*1*	*6*	*6*	*5*	*6*

Commissioning Hall and Tunnel



Commission Hall

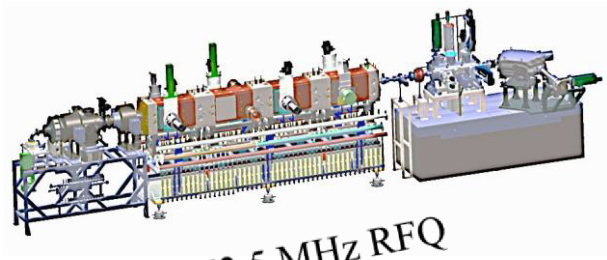
10 MeV Linac

Power Supply Array

SS AMP Array

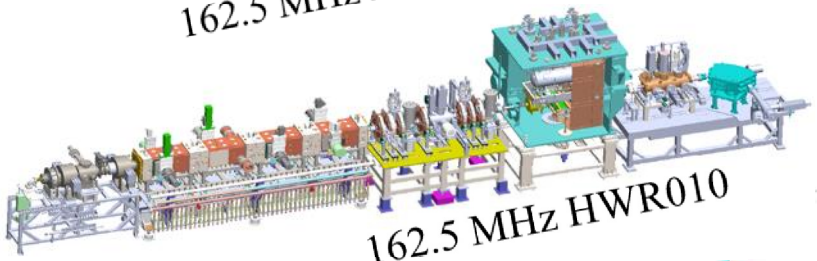
Commissioning Stages since 2014

1



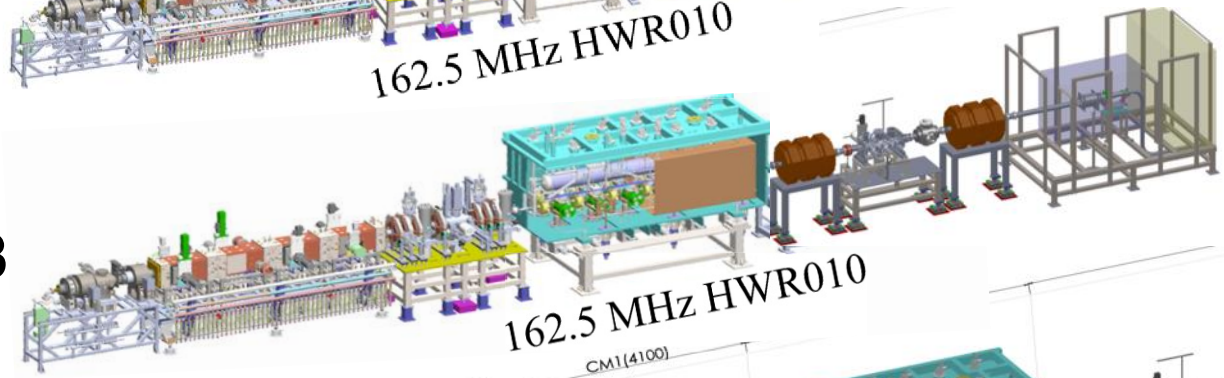
- ECR + RFQ
- Energy is 2.15 MeV
- First beam June 6th, 2014

2



- ECRIS + RFQ + MEBT + TCM (single HWR)
- Energy is 2.5 MeV
- First beam October 1st, 2014

3



- ECRIS + RFQ + CM1
- Energy is 5 MeV
- First beam June 6th, 2015

4

- ECRIS + RFQ + CM1 + CM2
- Energy is ~10 MeV
- First beam September 15th, 2016

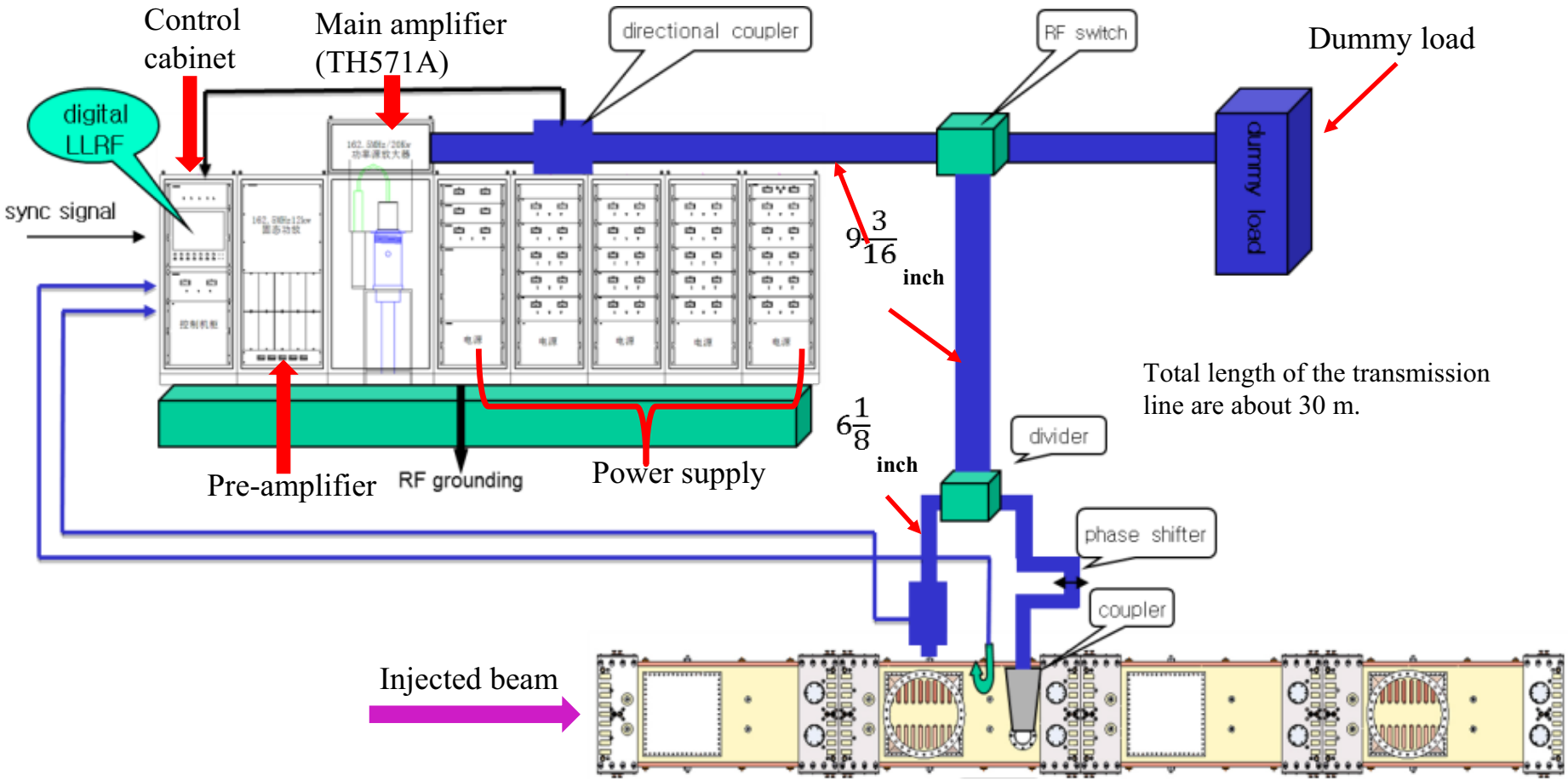
Challenge of the Front-end Linac for ADS

- **First of world to demonstrate the 10 mA, CW beam, at the low-energy superconducting Linac**
  - Highest CW beam power of 6 MW, 10mA/CW@600MeV for CIADS
  - Only SARAF demonstrated 2.1 mA, 2 MeV proton beam before
- **Challenge of commissioning of CW RFQ**
  - RFQ matching for upstream and downstream
  - Detuning due to beam loading
  - Coupler, AMP, and Circulator trouble due to CW RF power
- **Challenge of commissioning of CW superconducting Linac**
  - Twiss parameters re-built at MEBT to initializing beam
  - Orbit alignment and phase calibration
  - Machine protection under high beam power
  - PFC trouble for superconducting cavity

Outlines

- Introduction of Chinese ADS Front-end Demo Lianc in Lanzhou (CAFE)
- **Commissioning of CW RFQ**
- Commissioning of CW SC-Linac
- Summary of Commissioning Progress
- Acknowledgments

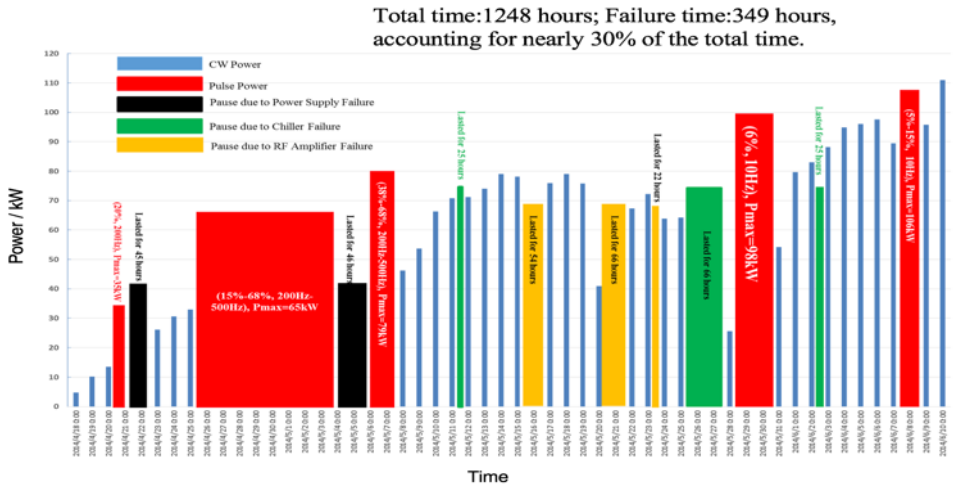
RF system of RFQ



- ✓ Two FPC are used in the RFQ cavity, maximum power is 120 kW;
- ✓ A power divider is used to divide the forward power into two couplers;
- ✓ A phase shifter is installed to balance the phase between the two couplers;

RF Operation Status of RFQ

- Conditioning from April 16 to June 10, 2014, to reach 100 kW, CW RF power
- After 15 months operation, one of FPC was broken, then input cavity, socket, and output cavity were burned in series.
- A 200 kW, CW circulator of AFT was destroyed by arc between cooper pipe and cover plate, conditioned up to 50 kW only.
- Two SSAMP of 80 kW resisting full power reflection instead of the tube AMP finally.



Burned 200 kW circulator of AFT

Coupler

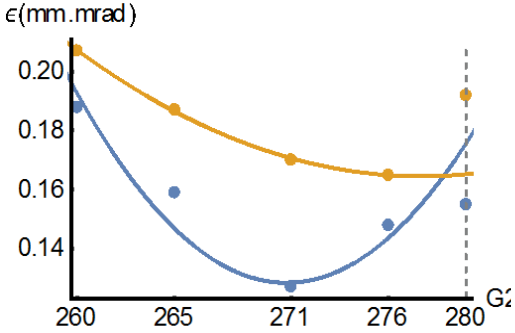
Input cavity

Socket of tube

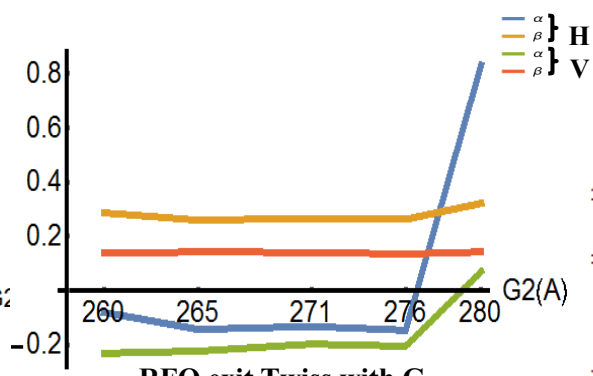
Output cavity

Matching between LEBT and RFQ

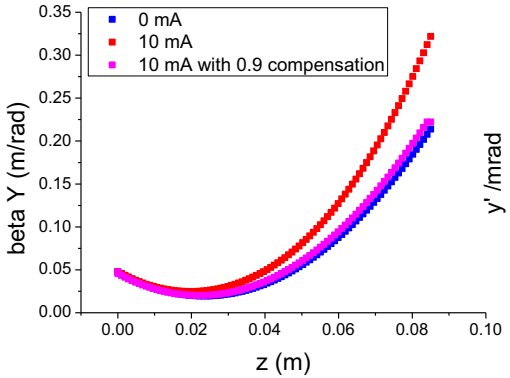
Pf 100 kW, ~2.18mA, 200us/1Hz η = 97%



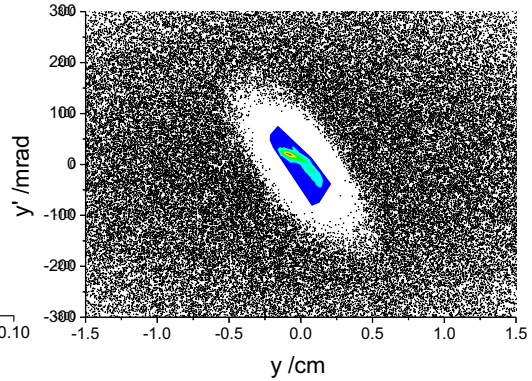
RFQ exit Emittance with G_2



RFQ exit Twiss with G_2

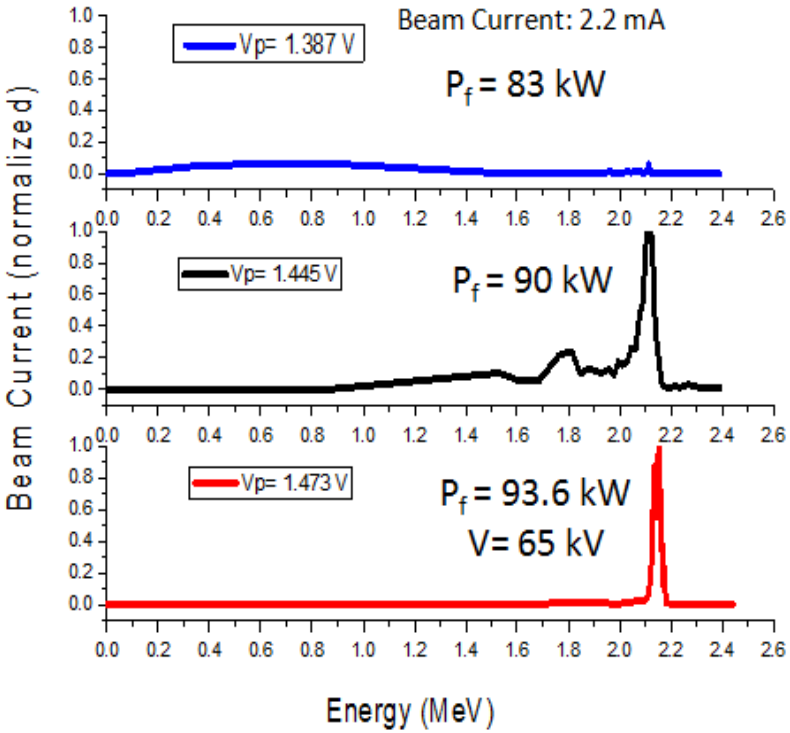


Space Charge Compensation



Match point, with acceptance

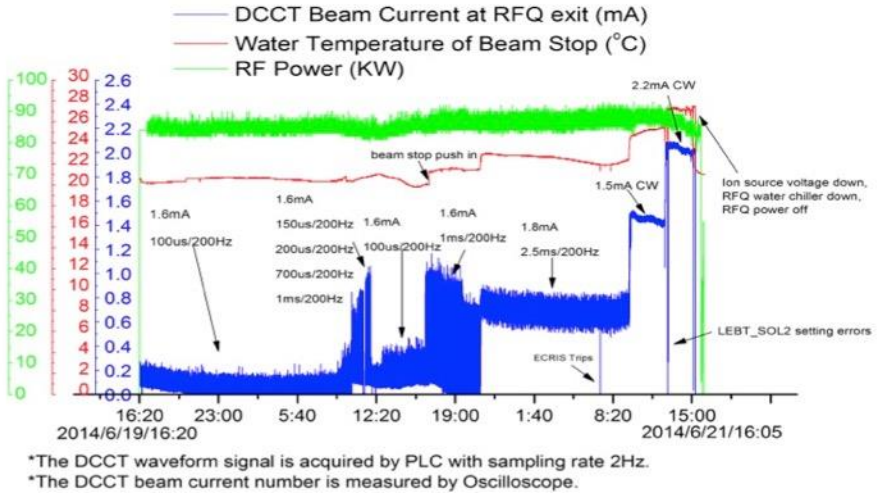
RFQ Voltage calibrated with energy spread, more precise than Transmission.



Solenoids (A)		LEBT exit	EMS measurement			RFQ entrance (Parmteq)	
G1	G2	I (mA)	α	β mm/mrad	ε	α_0	β_0 mm/mrad
210	270	10.0	-2.97	0.18	0.14	1.62	0.070

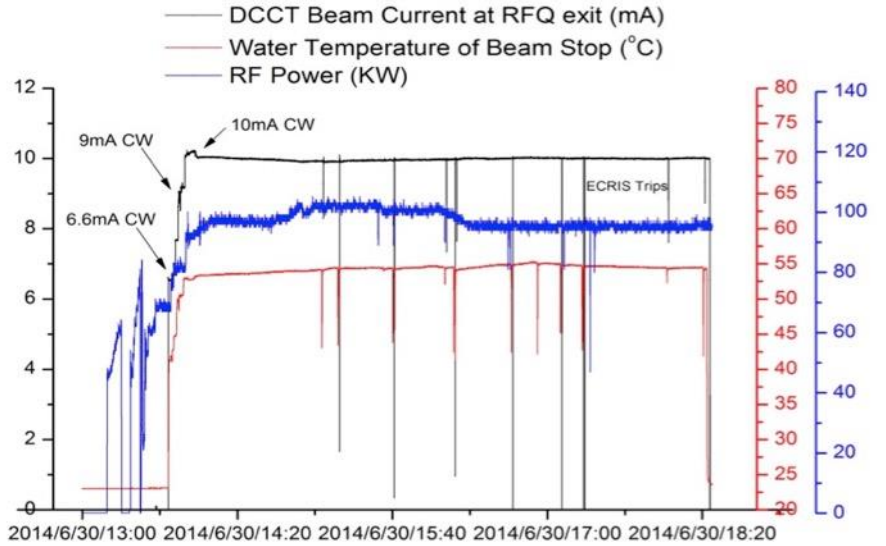
Commissioning of RFQ alone

- The frequency of four-wane is tuned by wane temperature. There is not circulator.
- The beam loading will cause frequency shift while average current rising.
- The frequency of signal moves to reduce the reflection power while the RFQ commissioned alone.
- It took 48 hours to reach the first CW beam through pulse step by step. Conditioning started from100 us, and repetition rate was 200 Hz. The Duty factor was extended from 2% to 50%, then 100%.
- CW beam directly jumped from 5 to 10 mA by several steps.



*The DCCT waveform signal is acquired by PLC with sampling rate 2Hz.
*The DCCT beam current number is measured by Oscilloscope.

First attempt to CW beam



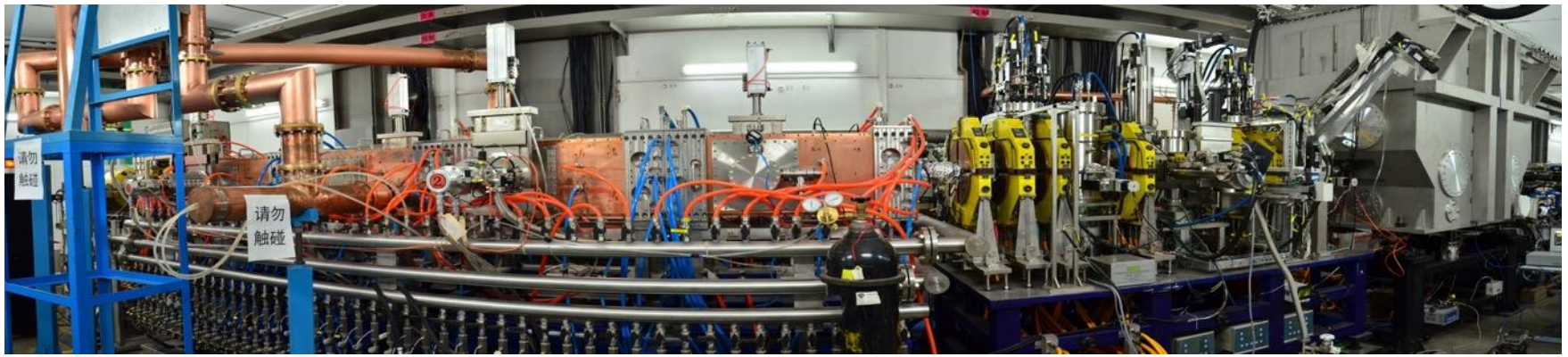
Record of 10 mA CW beam

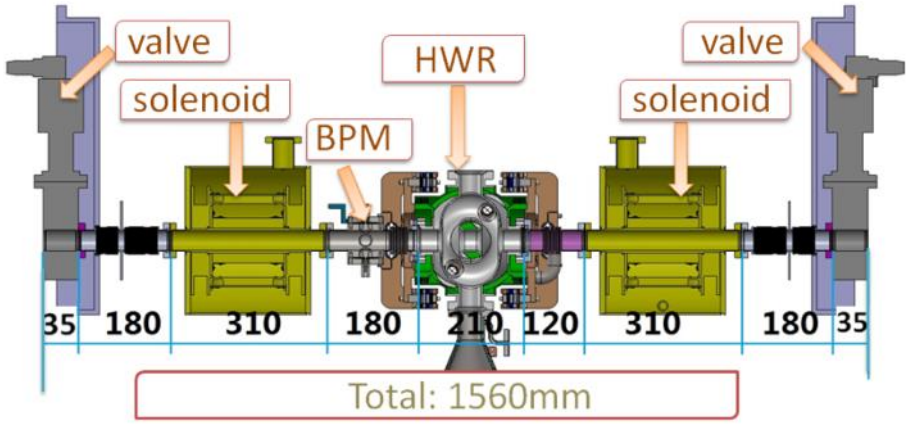
- **June 6th, 2014, the first beam, 2.16 MeV**
- **June 30th, 10 mA, CW, 21 kW, 4.5 hrs**
- **July 18th-19th, tested and reviewed by CAS**
- **Operation beam ~1900 hours by now**

Outlines

- Introduction of Chinese ADS Front-end Demo Lianc in Lanzhou (CAFE)
- Commissioning of CW RFQ
- **Commissioning of CW SC-Linac**
- Summary of Commissioning Progress
- Acknowledgments

Commissioning of TCM of 2.5 MeV

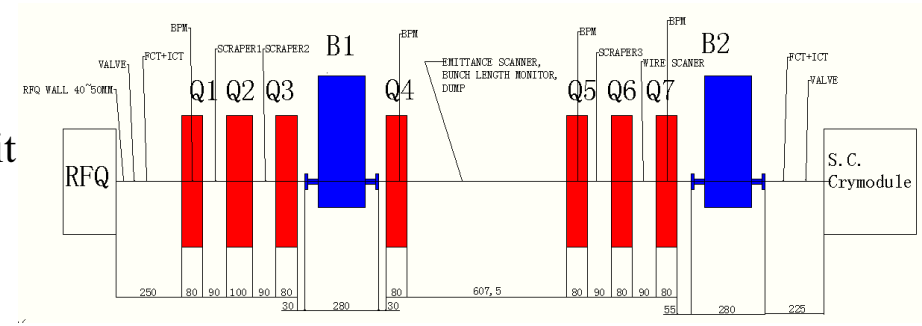




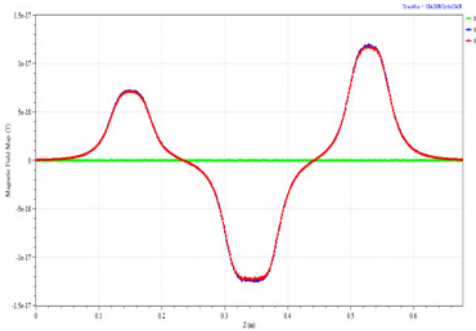
One cavity and two solenoids as prototype for assembly and tuning

Initial Beam Re-built at MEBT

- Scan Q1-3 for several measurements
- Trace back to get the exit twiss parameter of RFQ which agrees with the design of Parmteq

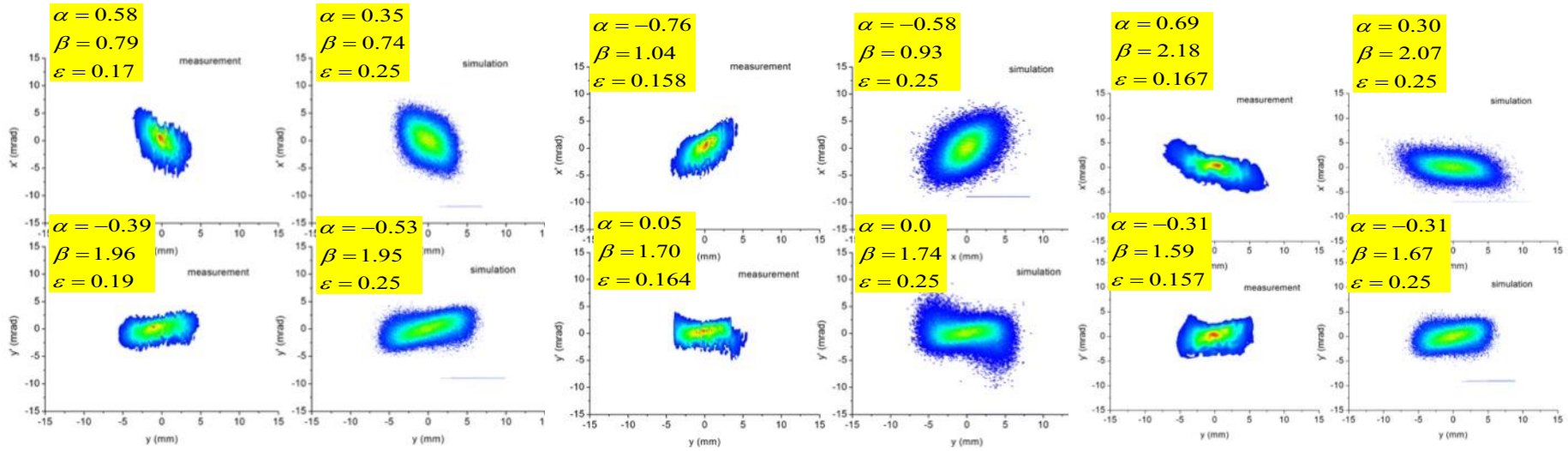


Structure of MEBT

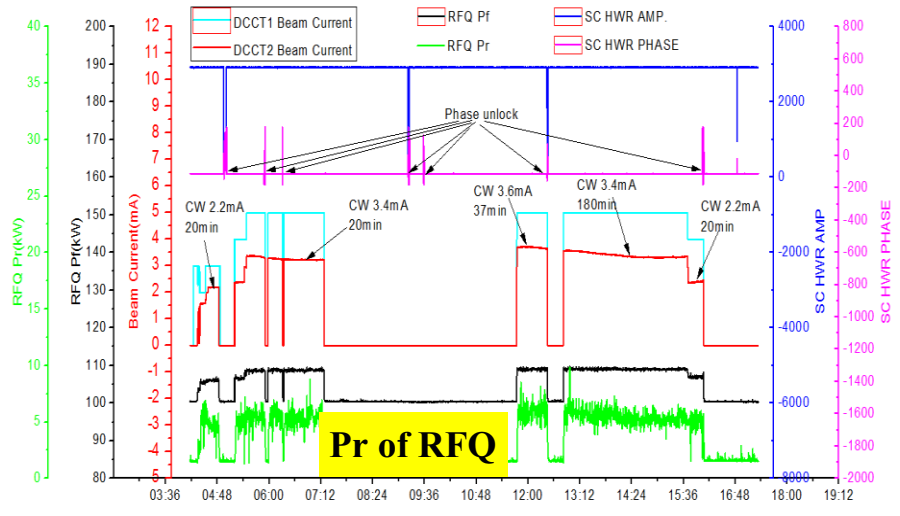


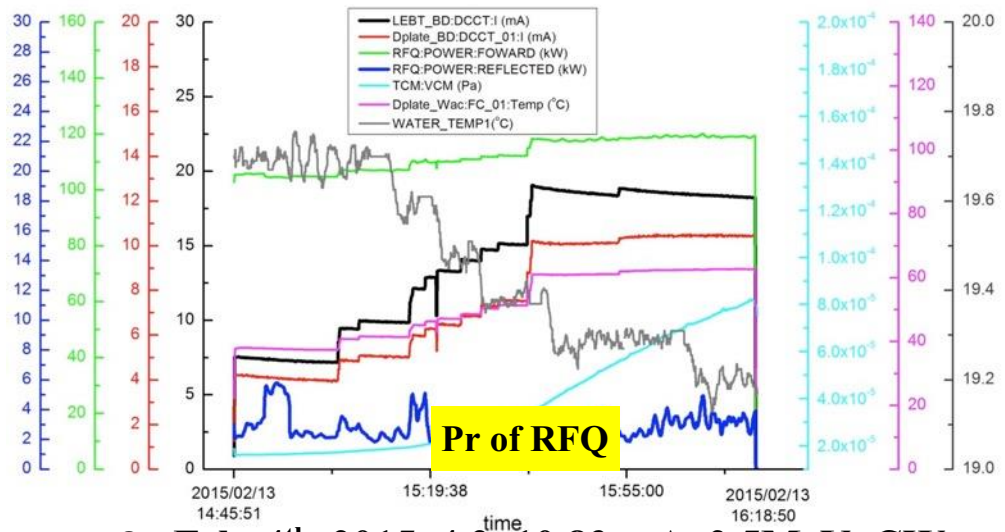
Overlap model of Q1-3

	α_x	β_x (m/rad)	α_y	β_y (m/rad)	Mismatch factor H/V
Rebuilt by Measurement	0.3	0.25	-0.11	0.12	0.078/0.005
Parmteq simul (design)	0.46	0.27	-0.10	0.12	reference



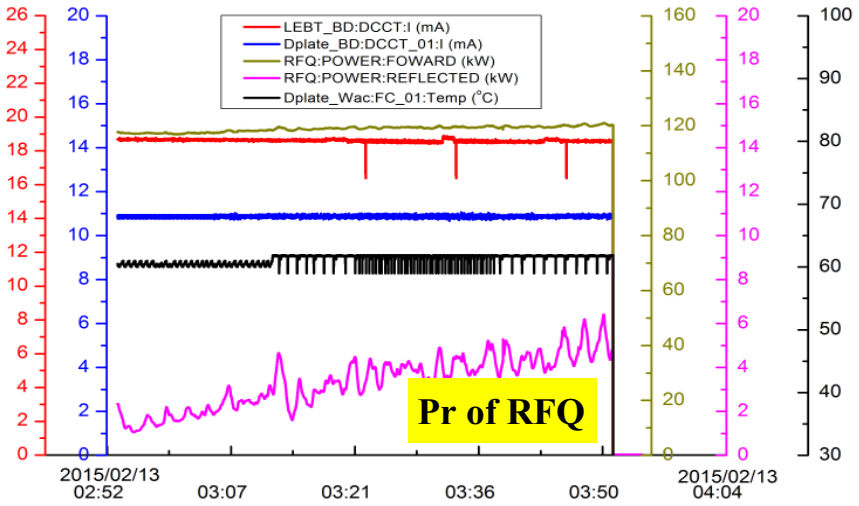
Efforts to 10 mA, CW Beam





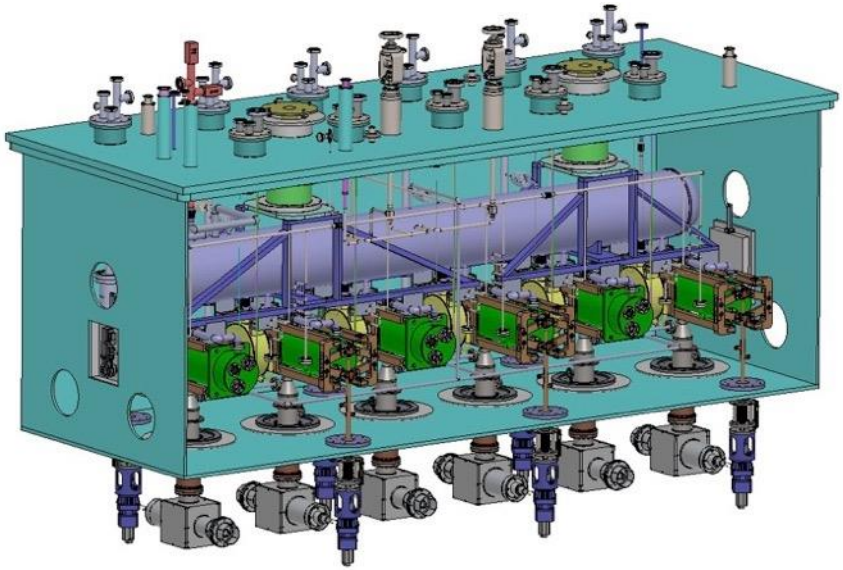
- **Nov.25th, 2014, first CW, 3.4 mA, ~6 hours.**
  - RFQ works with two bunches and one HWR, RF frequency can not change any more like working alone.
  - Due to detuning of 3 mA beam-loading, Pr is 5 kW, but it is still stable.
  - 10 mA beam will cause ~8 kHz detuning of RFQ, Pr is large to shut down AMP.
  - Frequency tuned by temp. of 0.5 C to keep Pr stable.

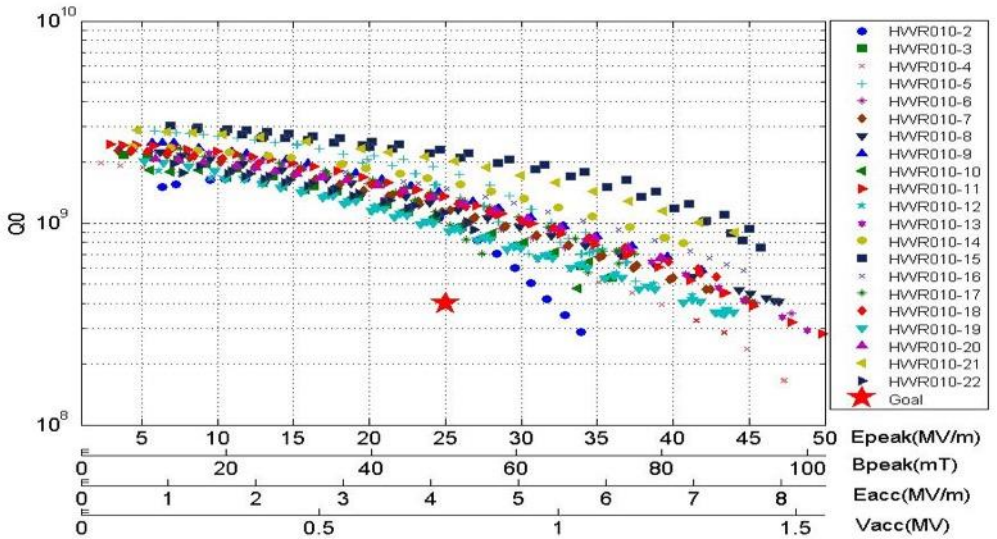
- **Feb. 4th, 2015, 4.2~10.83 mA, 2.5MeV, CW**



- **Feb. 23rd, 2015, achieved 2.5MeV/~11mA/28kW, stable for 1 hour**

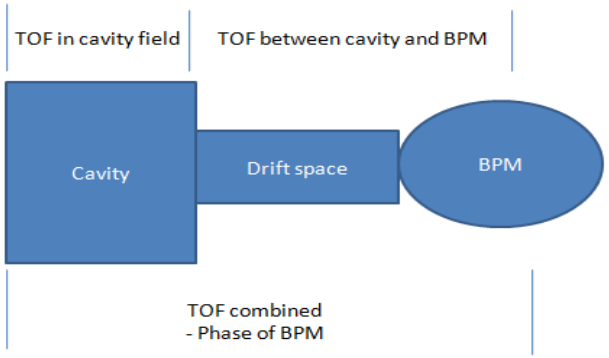
Commissioning of CM1

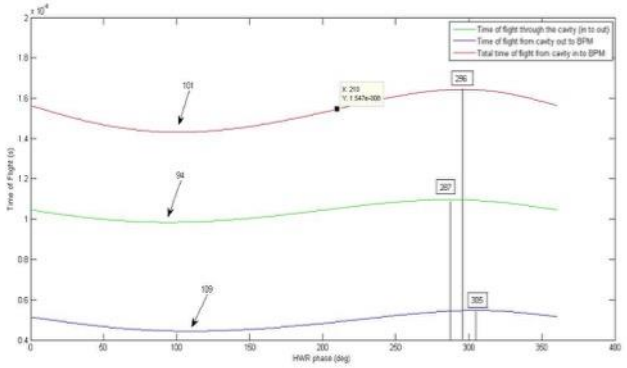


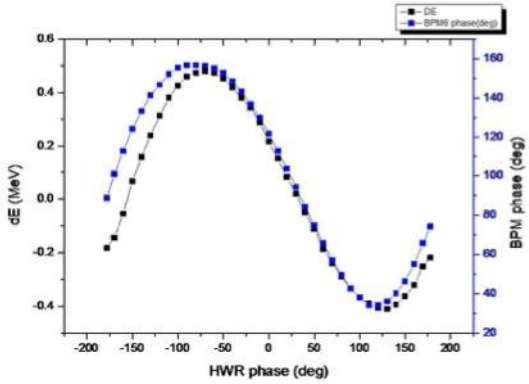


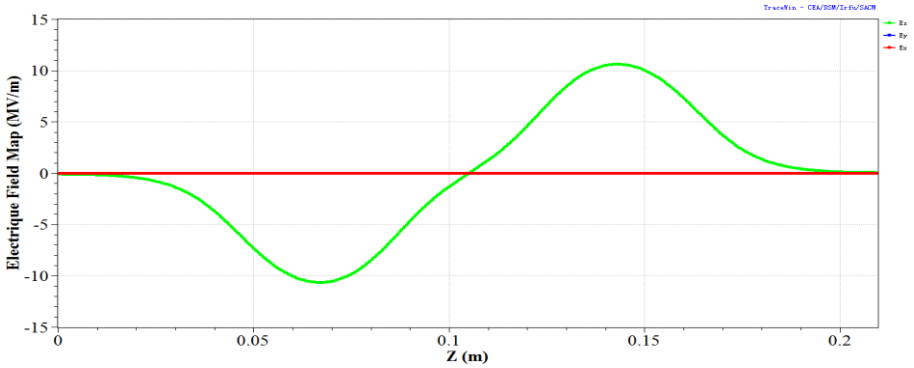
6 cavities, 6 solenoids, and 5 cold BPMs

Phase Calibration of Low-beta Cavity

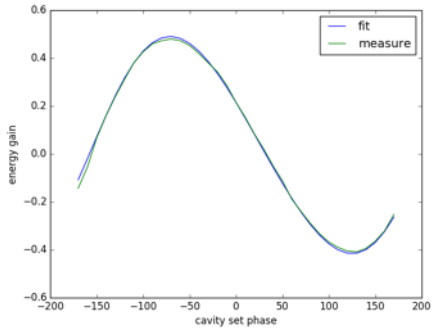


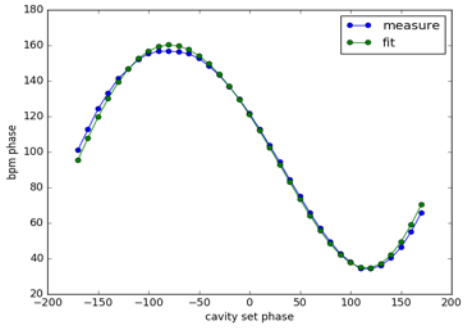




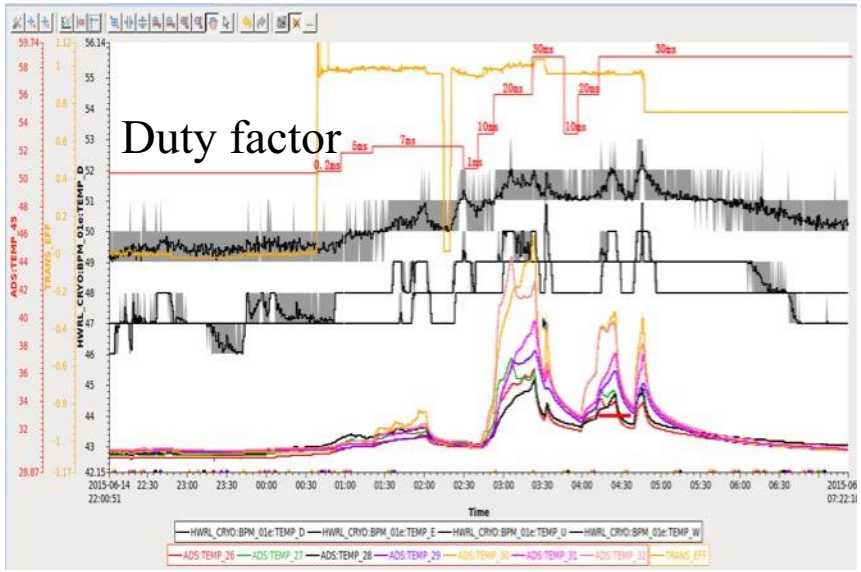


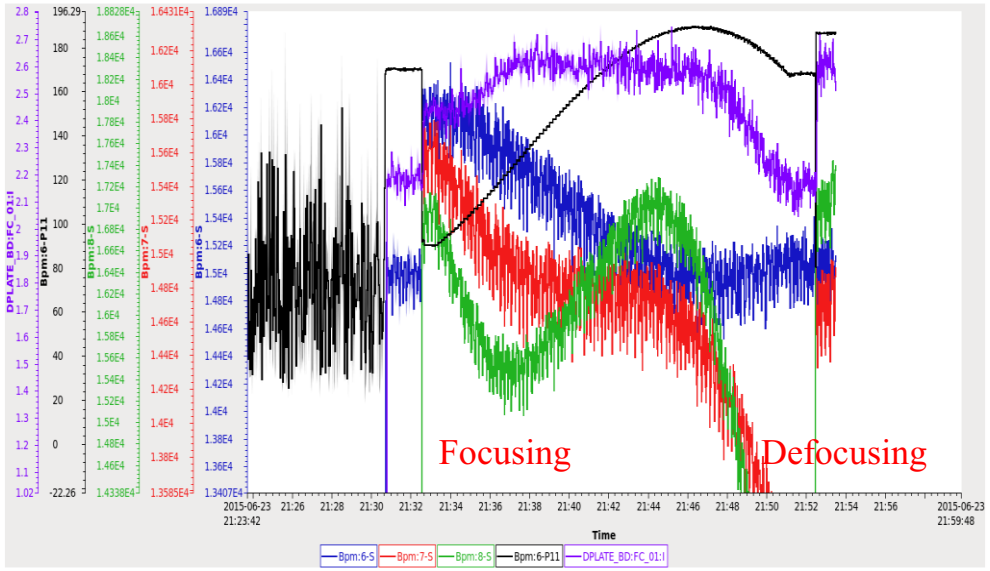
HWR cavity	ΔE (MeV,Meas)	ΔE (MeV,App)
CM1-2	0.16	0.15
CM1-4	0.203	0.206
CM2-2	0.117	0.12
CM2-3	0.095	0.105
CM2-4	0.325	0.312





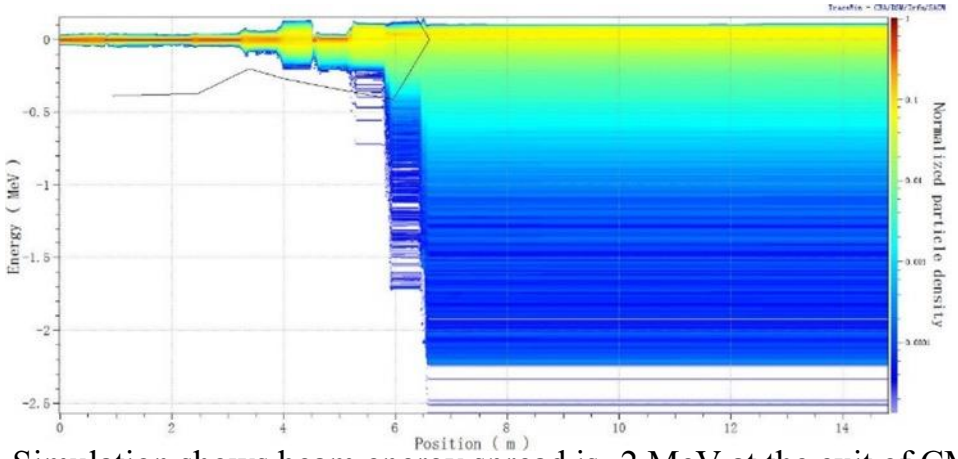
Beam-loss with Wrong Phase Setting





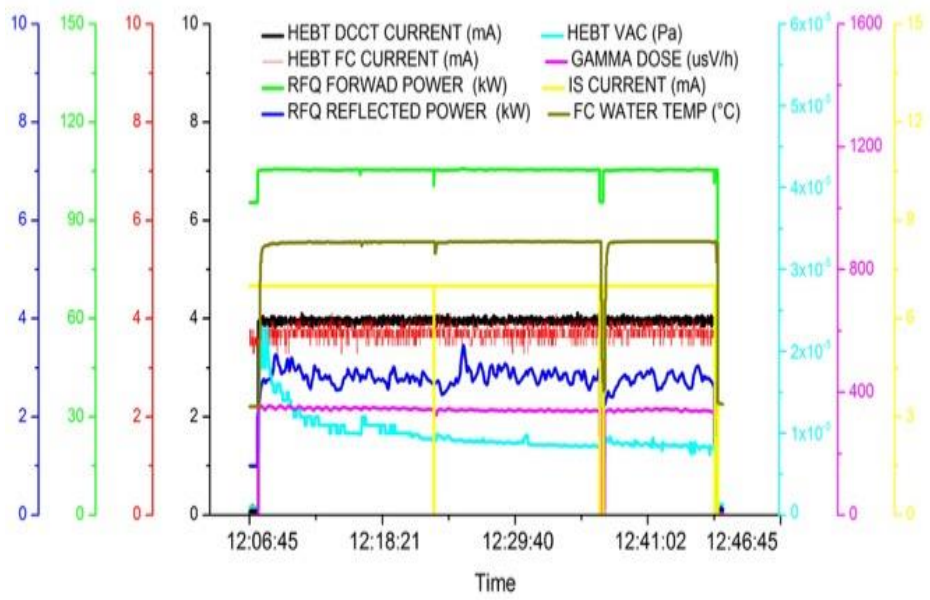
HWR2, rising edge is the focusing edge, opposite to other cavities.

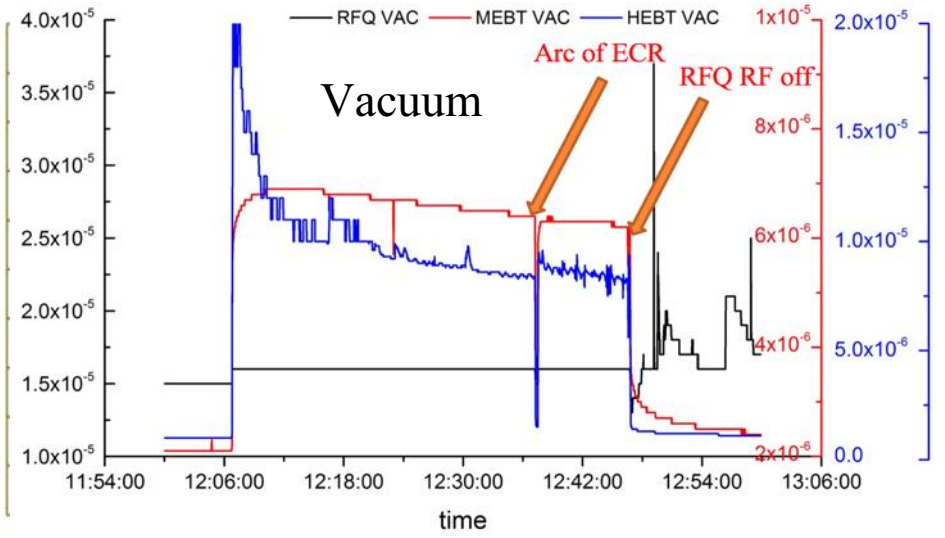
- All HWRs phase are set to -20 deg. But HWR2 and HWR5 are actually 20 deg due to the wrong phase sign of LLRF. This causes beam loss, measured by the temperature sensors on the tube at the end of CM and in HEBT during beam power ramping by increasing duty factor.



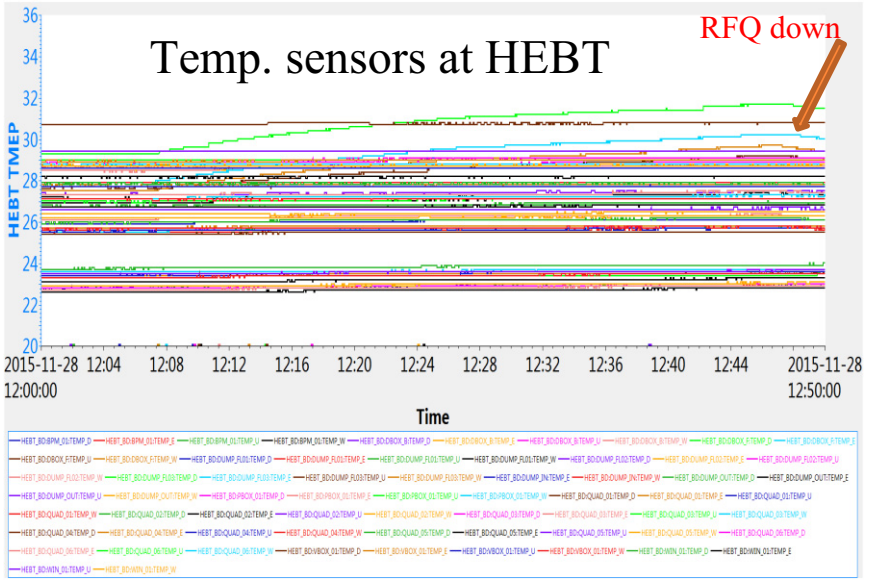
Simulation shows beam energy spread is -2 MeV at the exit of CM

High Current CW Beam Demonstration

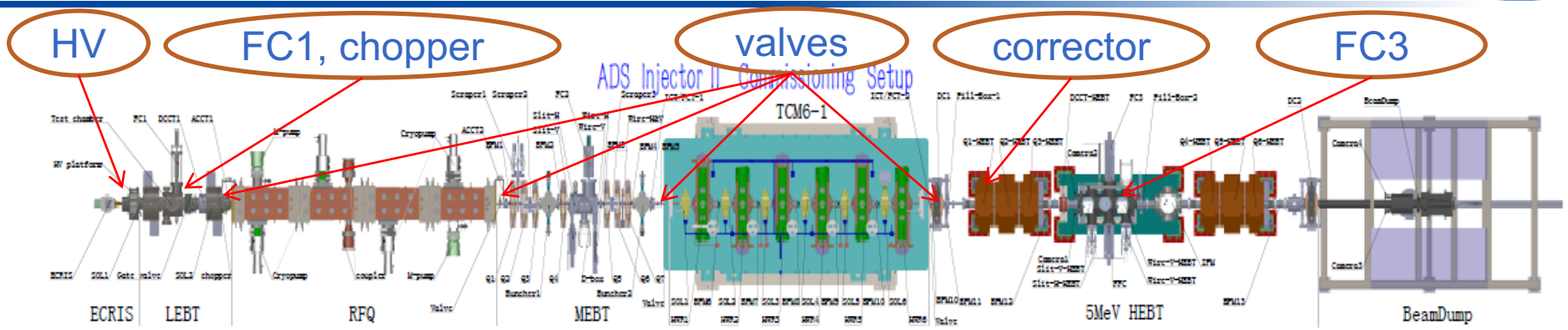




- **June 6th, 2015, 5.2 MeV, 10.2 mA; June 24th, 5.3 MeV, 2.7 mA, first CW beam; Nov. 28th, 4.6 MeV, 4 mA, 40 min.**
- **Vacuum in RFQ and HEBT got worse due to beam-loss in RFQ and beam-stopper in HEBT.**
- **Almost no temp. rising of sensors at HEBT.**

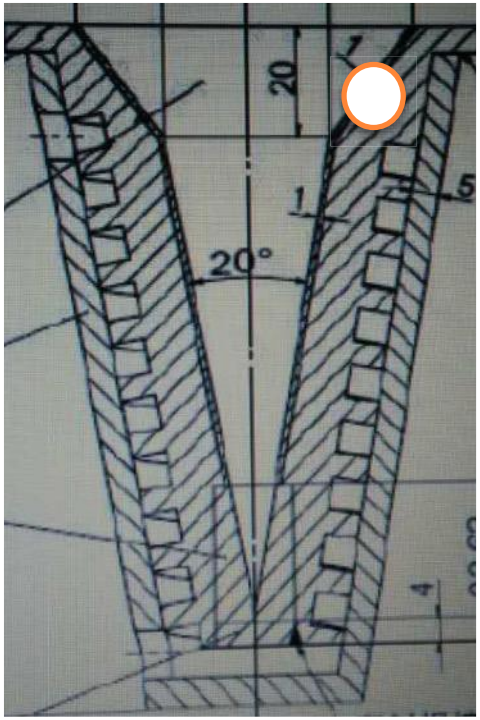


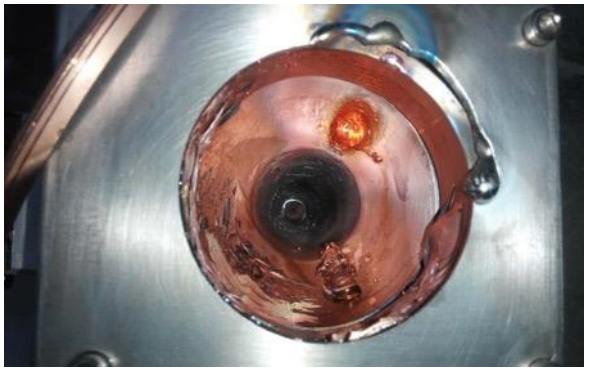
Beam Drilled a Hole in Faraday Cup



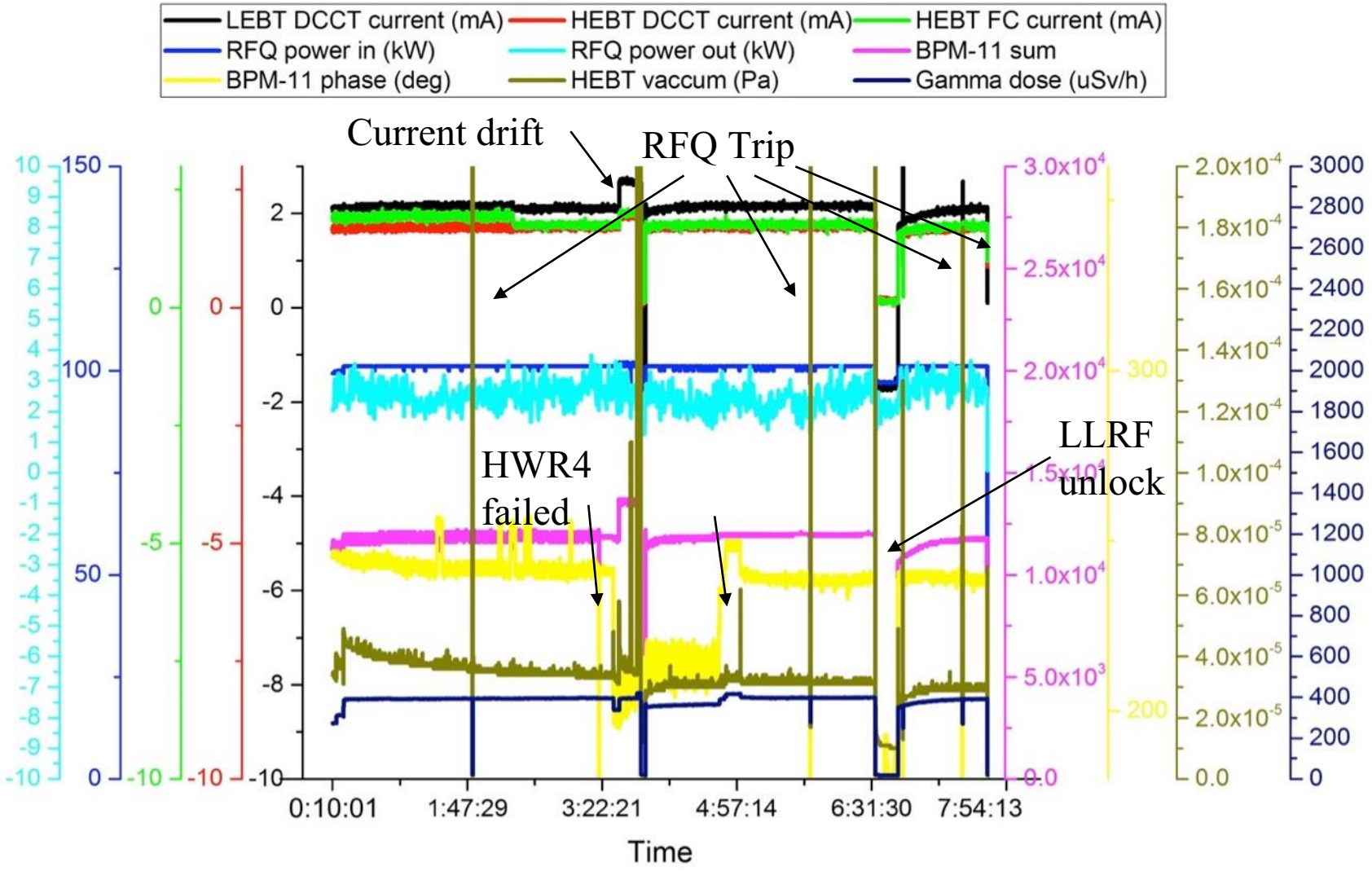
Dec. 4th 2015, 4.6 MeV, 3.9 mA, 18 kW, CW beam, 90s

- FC3 was a stopper, because 30 kW beam from RFQ was stopped before.
- The current of FC3 became unstable, but was ignored.
- Beam was off-centered by ~20 mm. It drilled a hole in FC3. MPS was triggered.
- CM1 was degraded. It was removed from tunnel to refurbish.



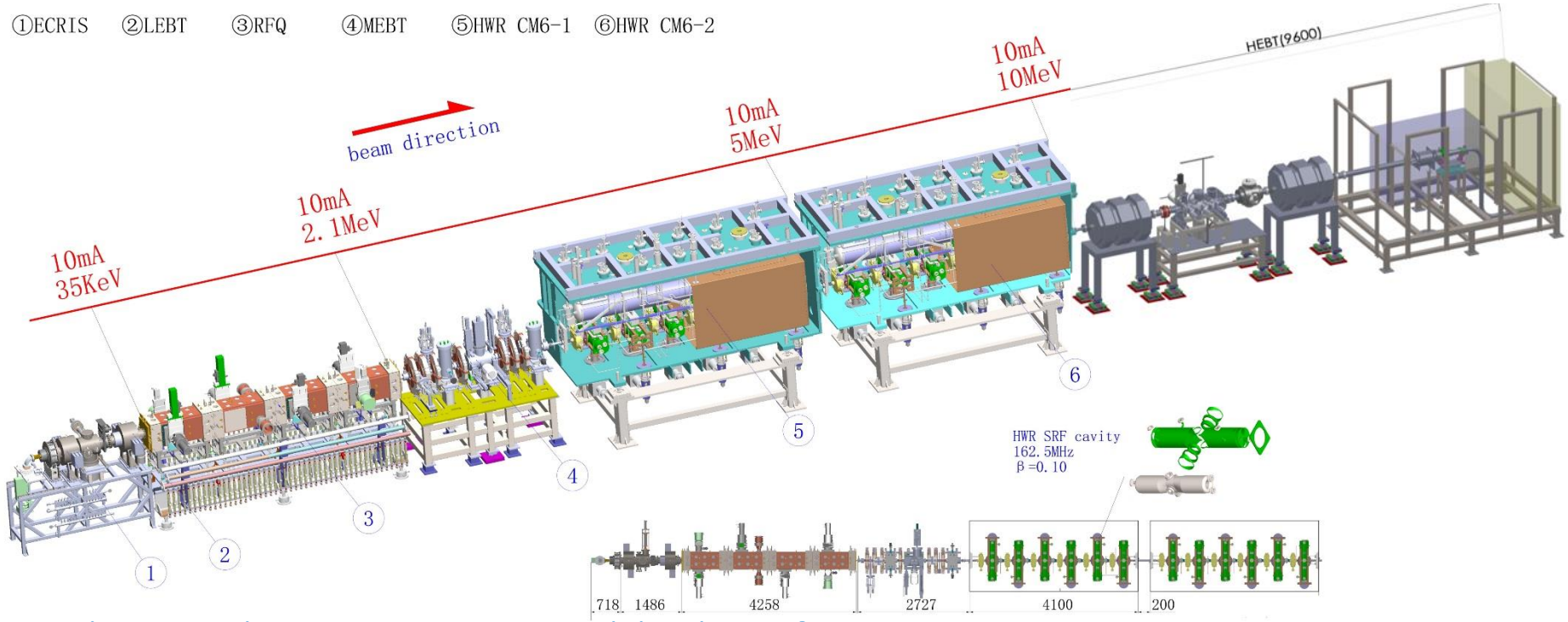


Long-time CW Beam Demonstration



Jan. 2nd, 2016, ~2mA, 4.0 MeV, CW, 7.5 hours; some trips were recovered automatically.

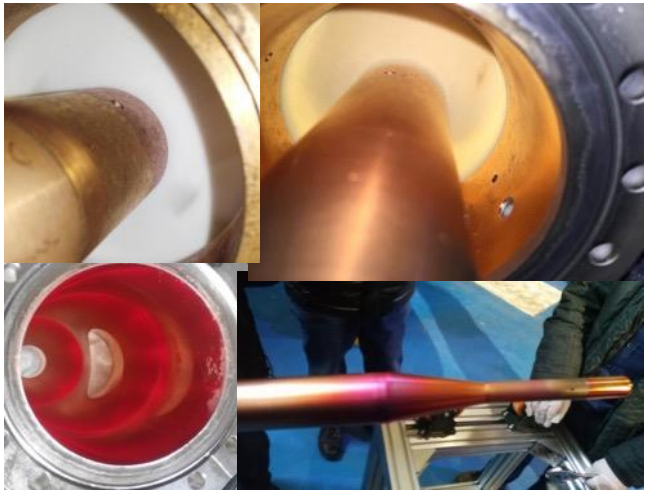
Commissioning of CM1 + CM2



- First cooling down and conditioning of coupler on May 3rd, 2016
- 4 couplers (single-window) were broken in May
- Four broken couplers were replaced by double-window in tunnel in one week.
- Second cooling down in August. First beam was achieved on Sept. 15th, 2016.

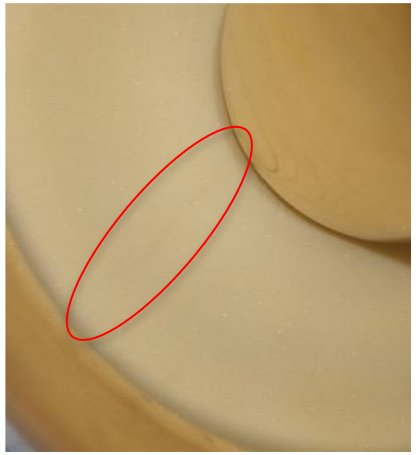
Window Broken of Couplers

Broken windows in 2015



Operated for 6 months after broken

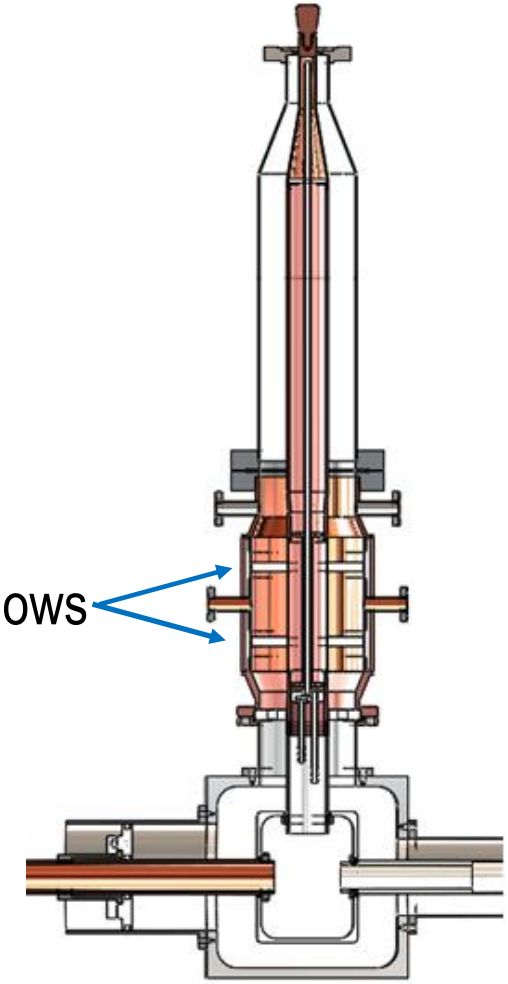
Broken windows in 2016

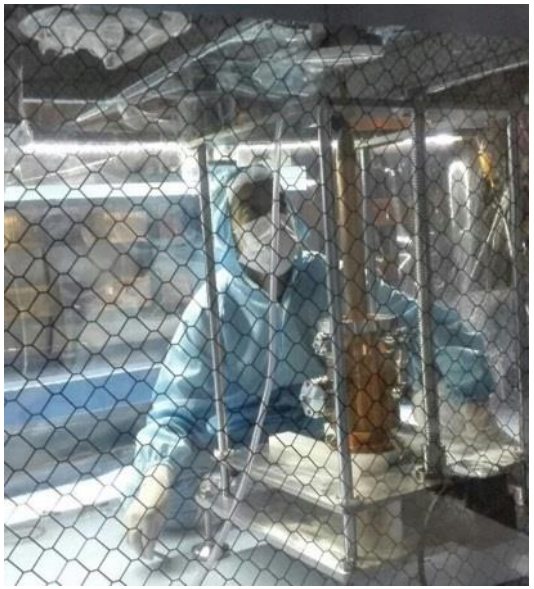


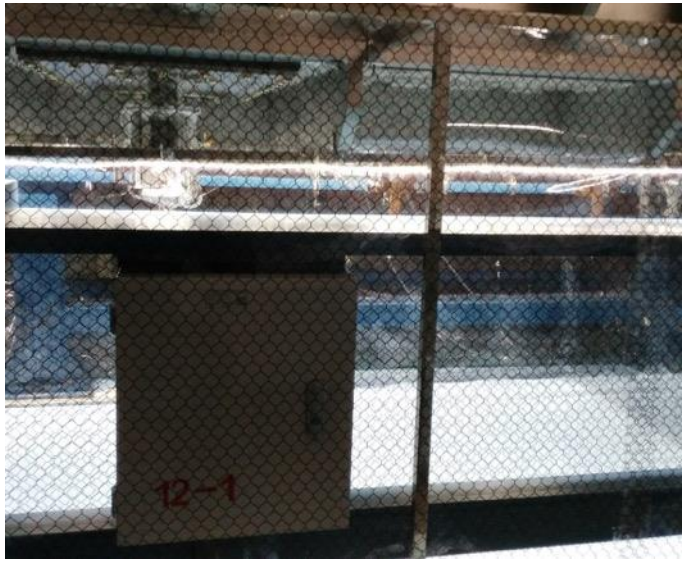
The reasons of windows broken are still discussed and investigated.

Replacement of Broken Couplers

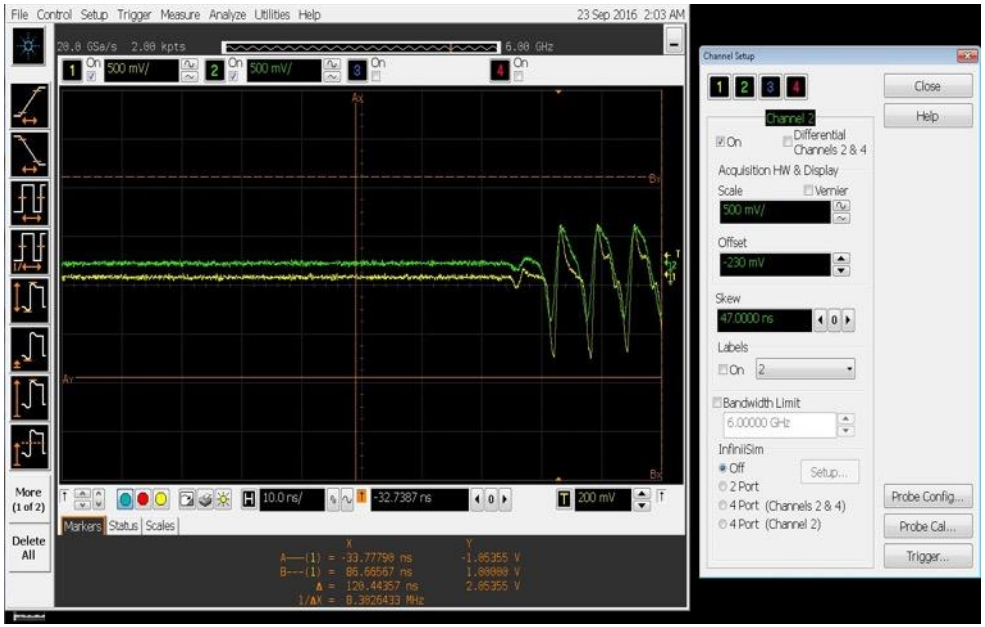
Replacing double-window couplers in tunnel

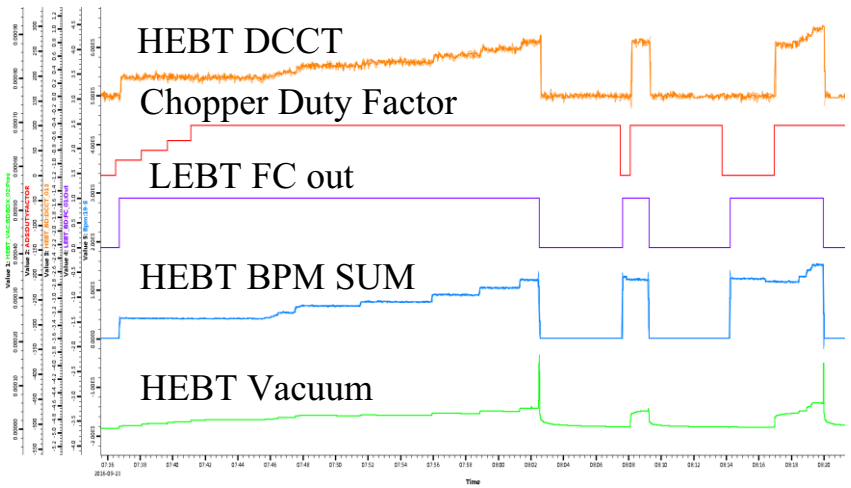




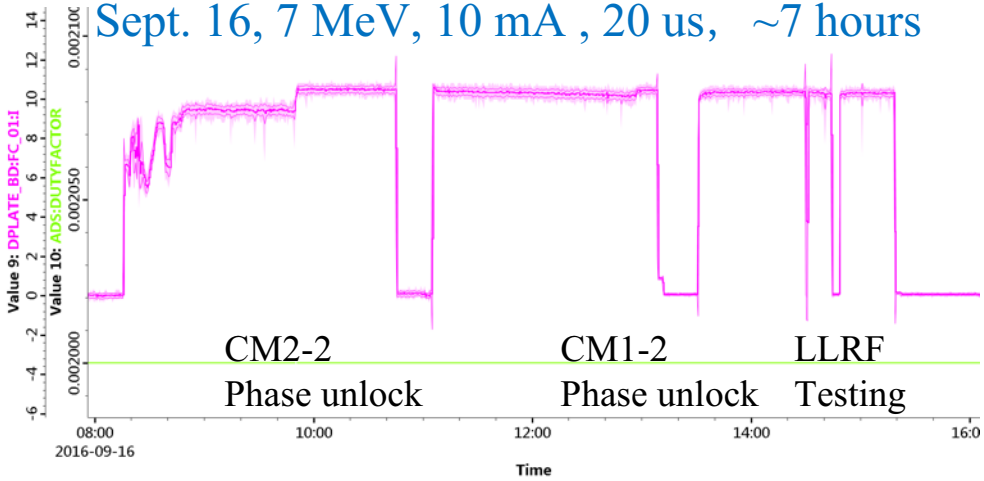


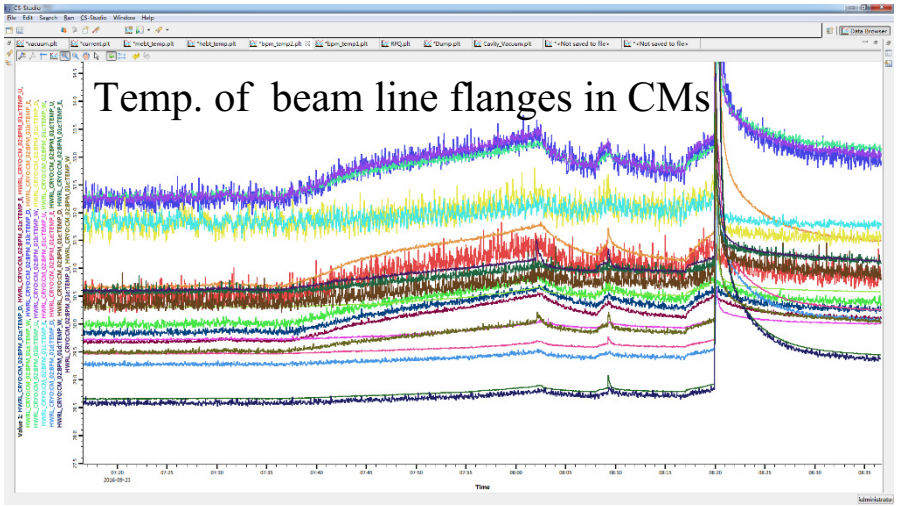
Commissioning of CM1+CM2





Sept. 24, Achieved CW beam 1 mA





Phase unlock causes beam loss and triggers MPS

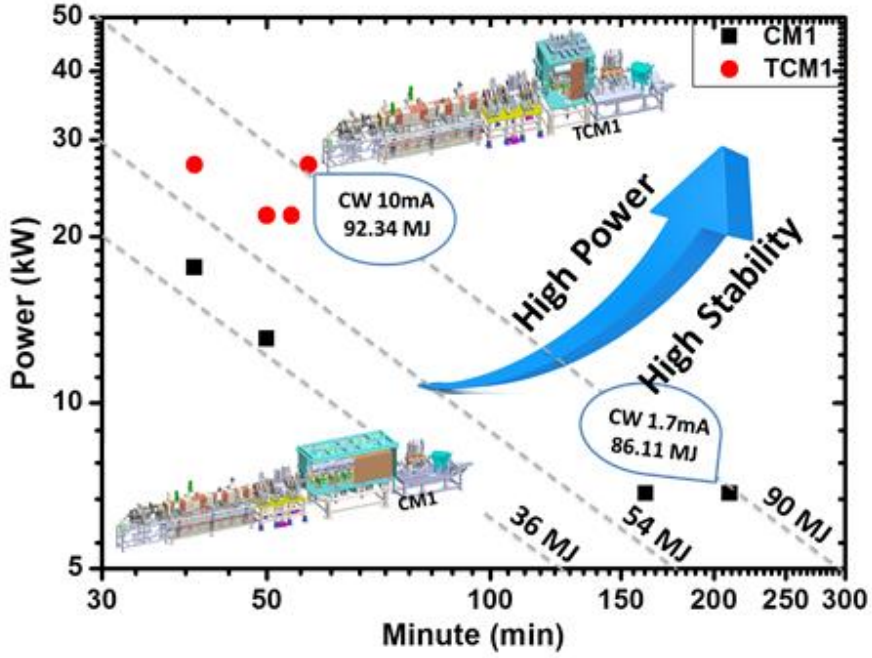
Outlines

- Introduction of Chinese ADS Front-end Demo Lianc in Lanzhou (CAFE)
- Commissioning of CW RFQ
- Commissioning of CW SC-Linac
- **Summary of Commissioning Progress**
- Acknowledgments

Summary of CW Commissioning

Summary of Commissioning from Jun. 6, 2014 ~ Sept. 24, 2016

Accelerator segments	First CW beam	Maximum (MeV)	Beam time (hours)	CW beam time Total (hours)	CW Current Max (mA)	CW Power Max (kW)
RFQ	Jun. 21, 2014	2.15	1819	68	11	23
TCM1 (1 HWR)	Nov. 24, 2014	2.55	208	22.5	11	28
CM1 (6 HWRs)	Jun. 24, 2015	5.3	400	20	4	21
CM1+CM2 (6 + 6 HWRs)	Sept. 24, 2016	7	177	0.6	1	6.65



- Tens of kilowatt CW beam achieved in superconducting front-end of Chinese ADS.
- The tuning procedures of high power CW beam has been demonstrated successfully.
- The dumper is a limit for tuning higher power beam.
- The front-end demo Linac will be finished in 2016.
- Higher power and higher stability will be demonstrated in the future.

Acknowledgements

Thanks for the helps

LBNL: Derun Li's RFQ team

J-Lab: Tom Powers, Bob Rimmer, Haipeng Wang ……

TRIUMF: Bob Laxdual, Ken Feng, Qiwen Zheng ……

ANL: Peter Ostroumov, Brahim Mustapha ……

FNAL: Sergei Nagaitsev, ……

MSU/FRIB: Xiaoyu Wu, Jie Wei, Qiang Zhao, ……

ORNL: Michael Plum, John Mammosser, John Galambos ……

SINAP: Zhengtang Zhao, Jianfei Liu, Li Wang ……

IHEP, HIT, PKU, THU, RIKEN, CEA/Saclay, IPN/Orsay, IAP ……

Thanks for your attention

Welcome to SRF2017 in Lanzhou

http://srf2017.csp.escience.cn

18th International Conference on RF Superconductivity

Lanzhou China

July 17-21, 2017

Home | Overview | Program | Tutorial | Registration | For Authors | Committees | Sponsors & Exhibitors | Travel info | Contacts

Welcome

The SRF2017 will be held on July 17-21, 2017, at the International Conference Center of Lanzhou University, Lanzhou, China. The scientific programs will consist of invited talks, poster sessions and 'hot-topic' discussion sessions. The complete list of technical categories can be found at http://srf2017.csp.escience.cn/dct/page/70006.

The registration and abstract submission system will be open shortly. Please check back later.

July is usually the best time for Lanzhou. We are expecting a mild summer with briiliant thoughts and hot discussions. We are looking forward to seeing you on SRF2017!

For questions regarding the conference or local affairs, please contanct: srf2017@impcas.ac.cn.

Important Dates

- **16-Nov-16** — First announcement/web launch
- **27-Dec-16** — Final Program
- **19-Feb-16** — On-site Registration
- **19-Feb-16** — On-site Registration

Submission | Registration | Payment | Hotel Reservation