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Lessons of high-power CW beam commissioning of injector II of Chinese ADS

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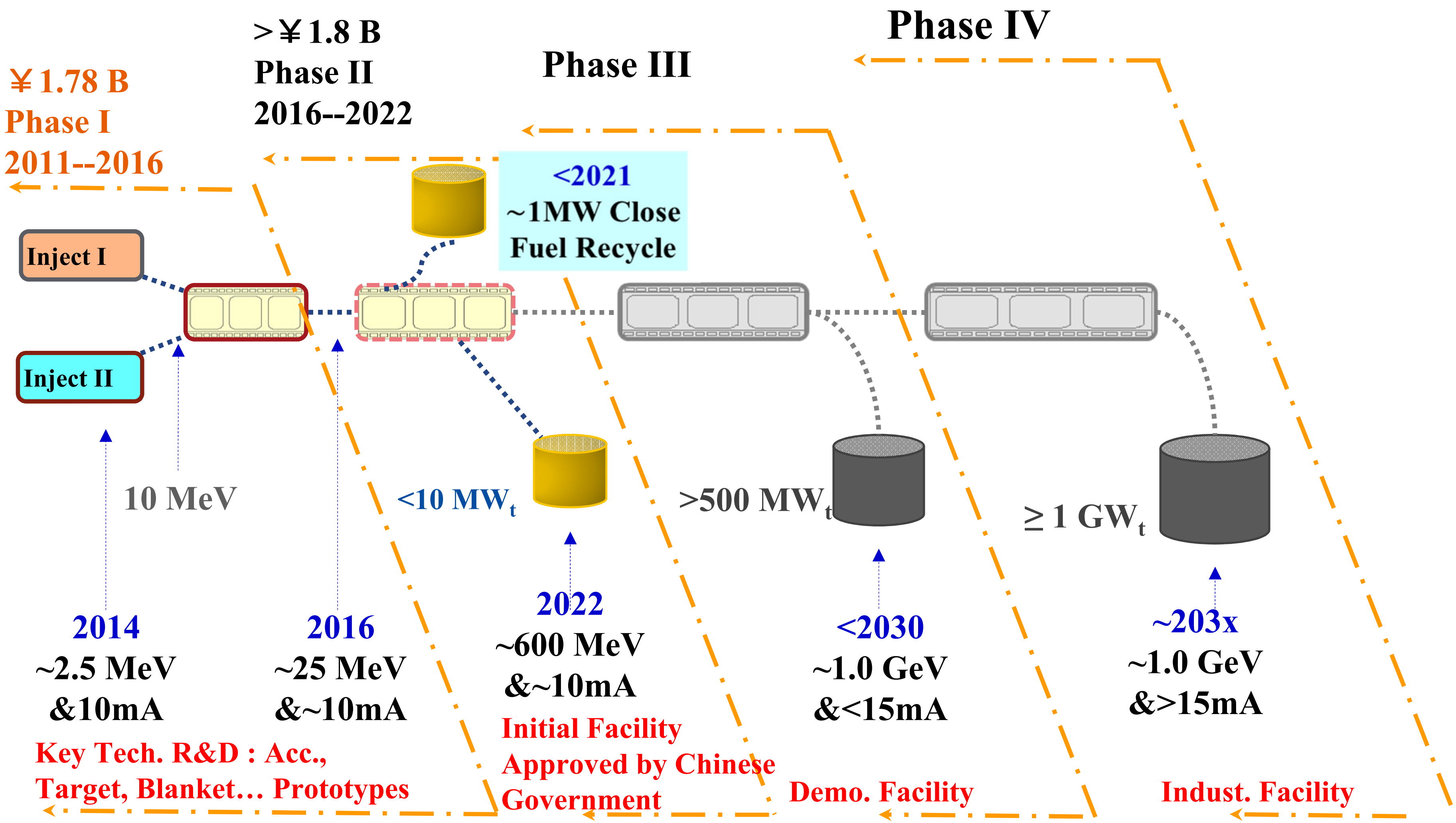
Outlines

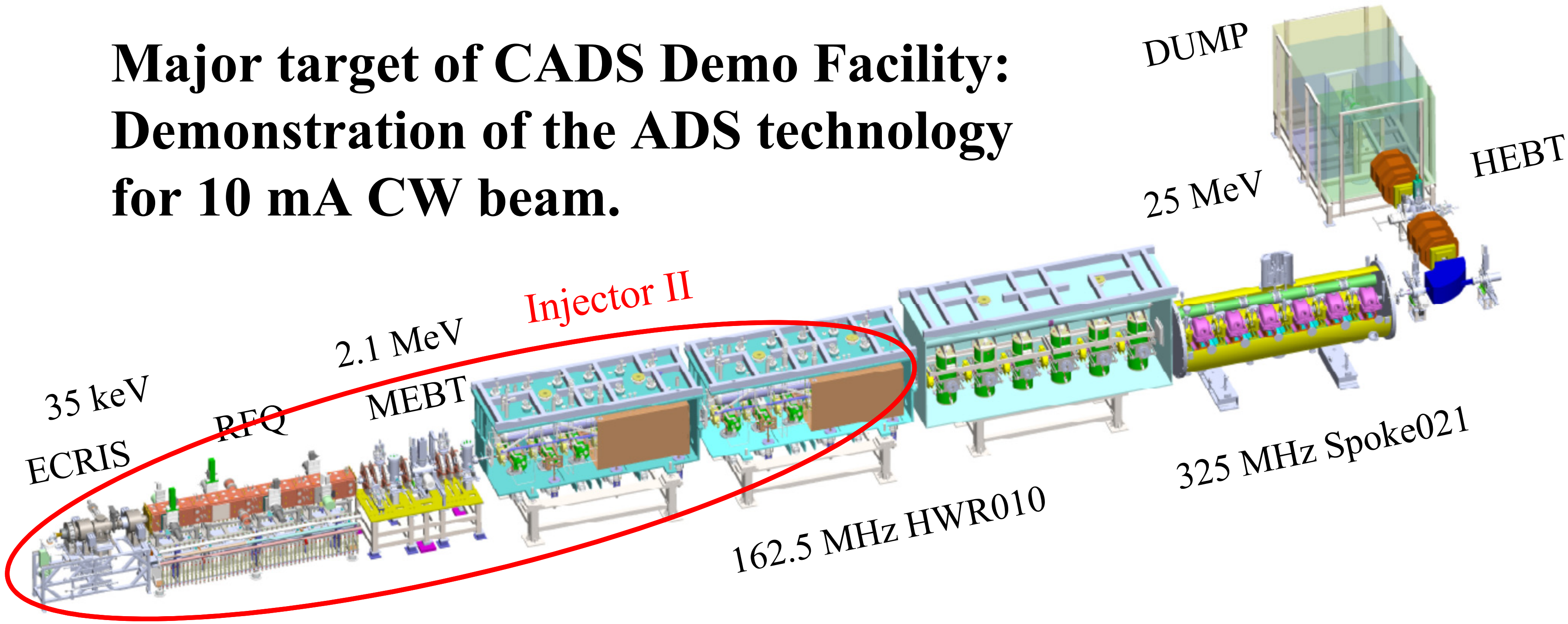
- **Introduction**
- **Experiences and Lessons**
- **Summary**
- **Acknowledgment**

ADS/ADANES Roadmap in China



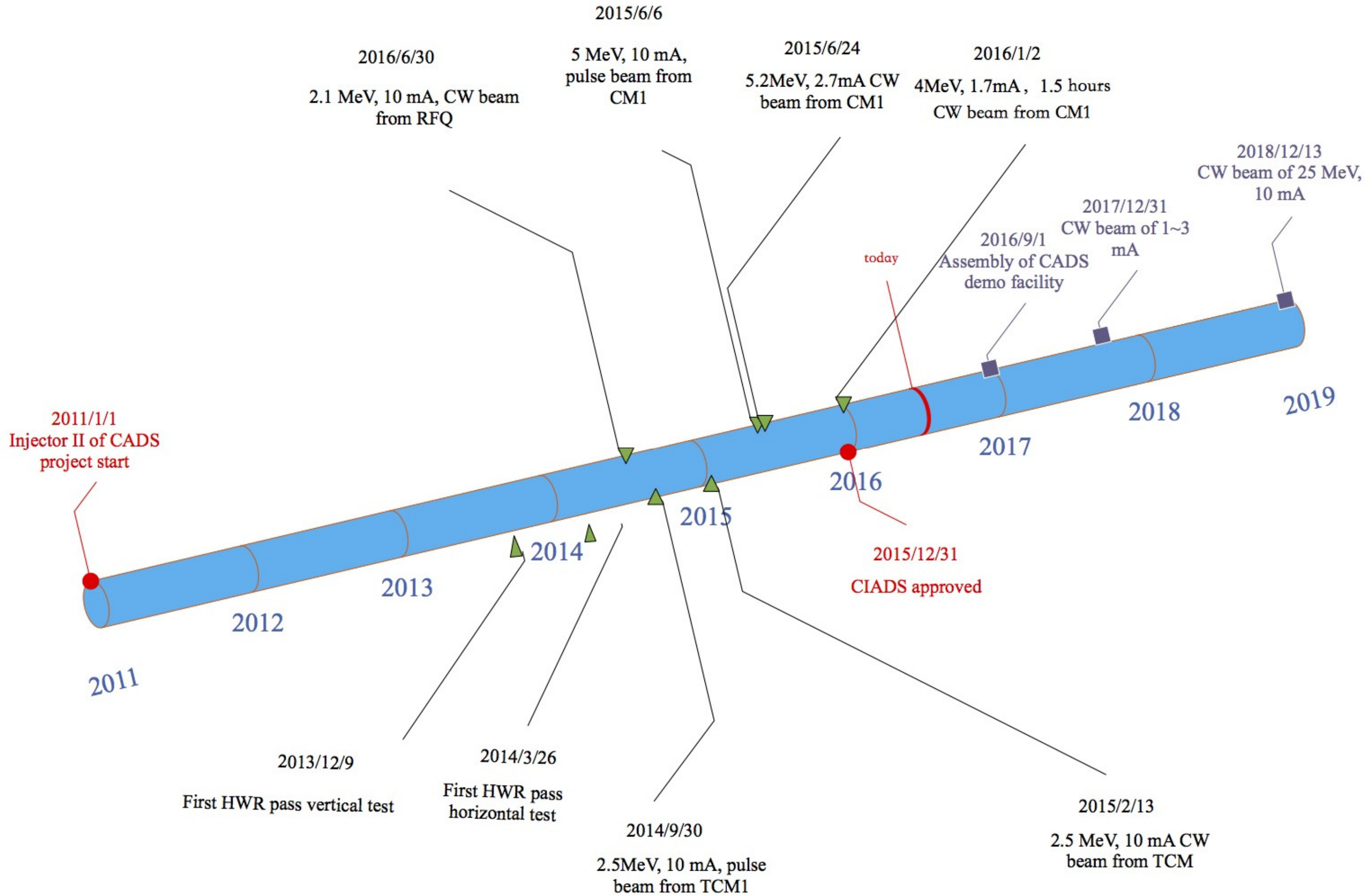
Layout of CADS Demo Facility

Major target of CADS Demo Facility: Demonstration of the ADS technology for 10 mA CW beam.

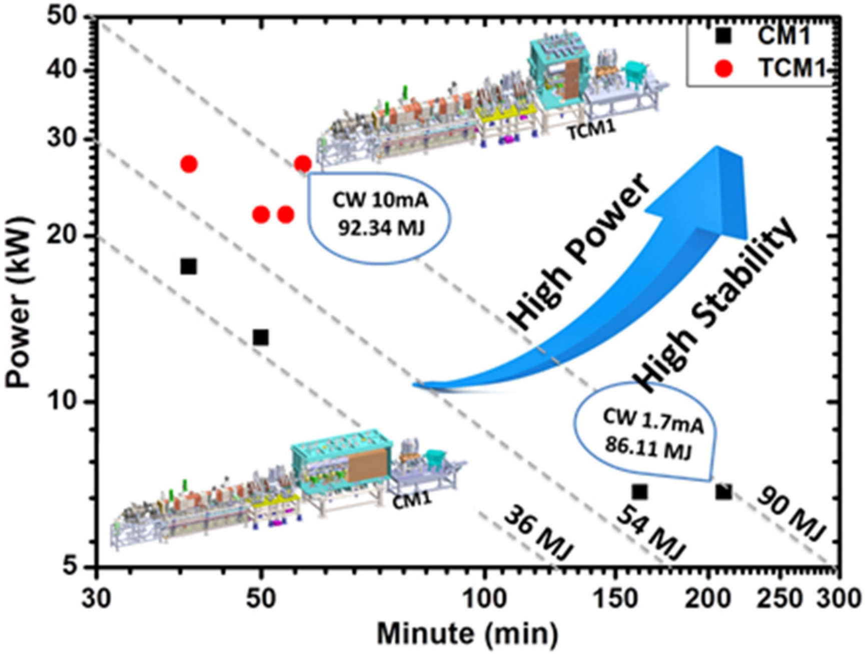


	RFQ	CM1	CM2	CM3	CM4
frequency	*162.5 MHz*	*162.5 MHz*	*162.5 MHz*	*162.5 MHz*	*325 MHz*
output energy	*2.1 MeV*	*5 MeV*	*10 MeV*	*17 MeV*	*25 MeV*
cavity type	*4-vane*	*HWR010*	*HWR010*	*HWR010*	*Spoke021*
cavity numb	*1*	*6*	*6*	*6*	*6*

Milestones of CADS Demo Facility



Summary of beam commissioning



Accelerator	*Beam energy*	*Beam time*	*CW*	*CW @ 10 mA*
RFQ	*2.1 MeV*	*1390 h*	*59 h*	*10 h*
TCM1 (1 HWR)	*2.5 MeV*	*208 h*	*22.5 h*	*2.5 h*
CM1 (6 HWRs)	*5 MeV*	*400 h*	*20 h*	*Imax = 4mA*
CM1+CM2 (12 HWRs)	*10MeV*	*Conditioning trouble with couplers*		

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- **Experiences and Lessons**
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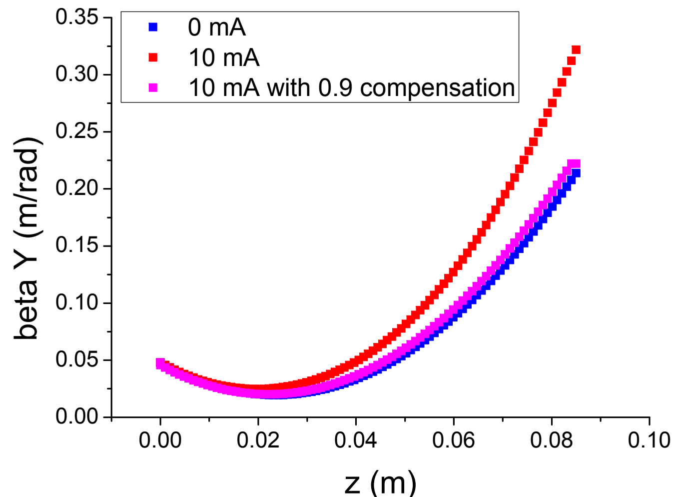
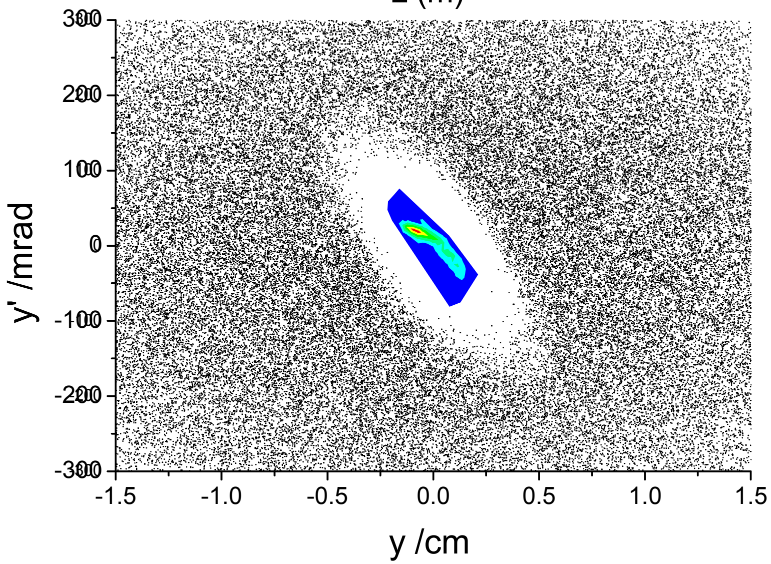
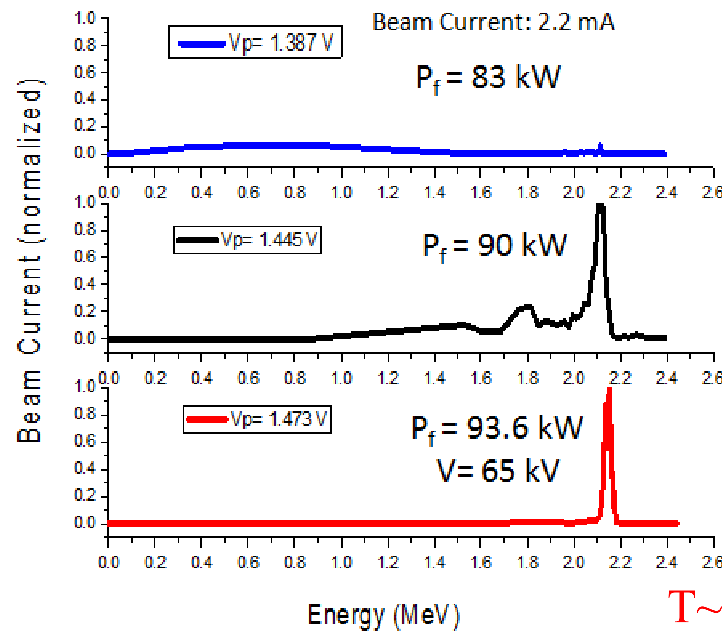
Experiences and Lessons

- LEBT and RFQ settings
- Transverse lattice verification of MEBT
- Orbit of MEBT and CM1
- Beam power ramping procedure
- CW beam and trips
- Beam losses with wrong phase setting
- 1st accident and lessons
- 2nd accident and lessons

LEBT and RFQ settings

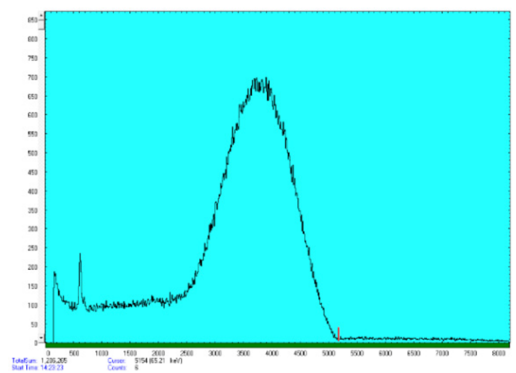






RFQ Voltage calibrated with energy spread, more precise than Transmission.

T~96 % of RFQ

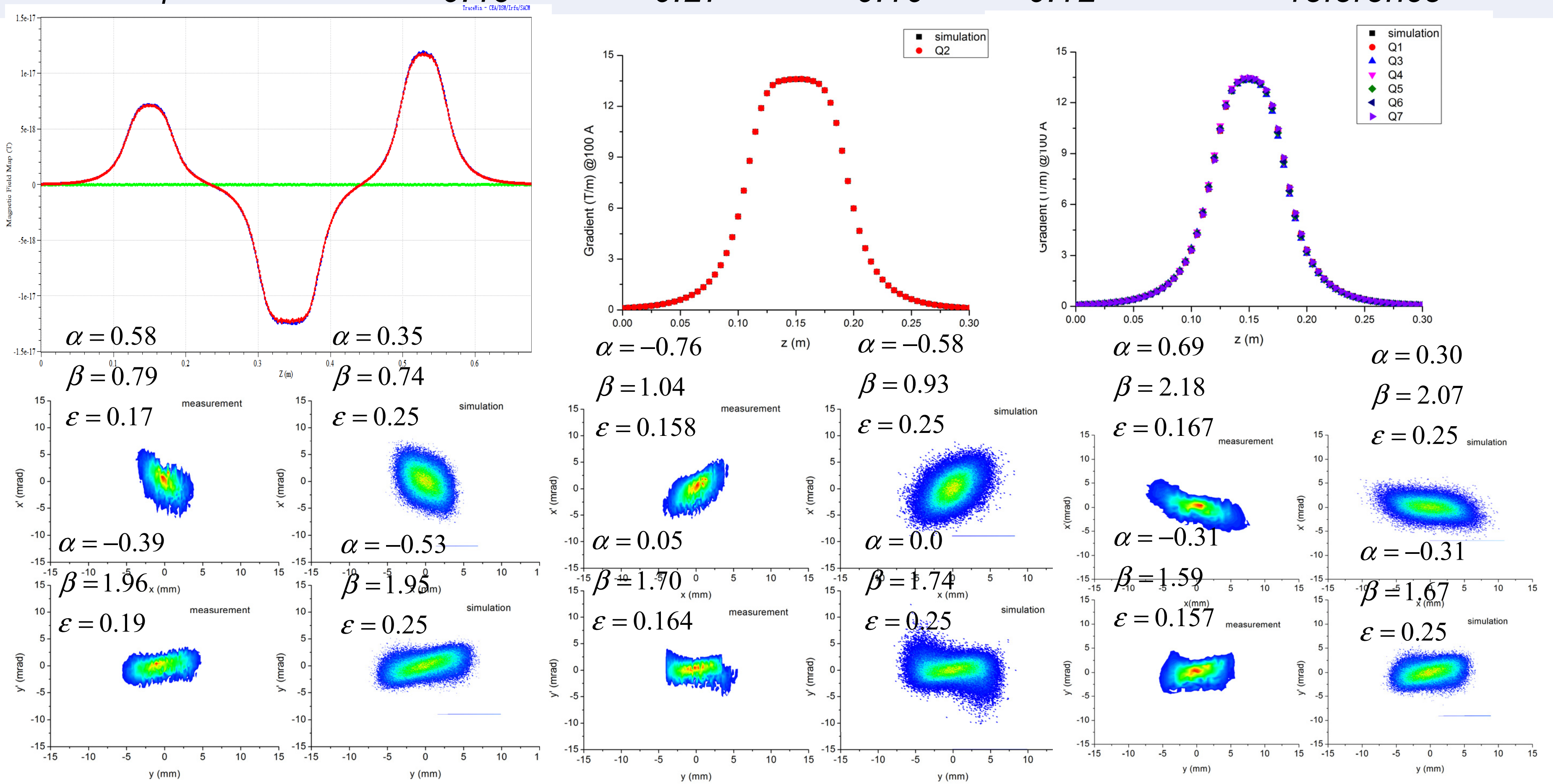


X ray measurement agrees with energy spread calibration.

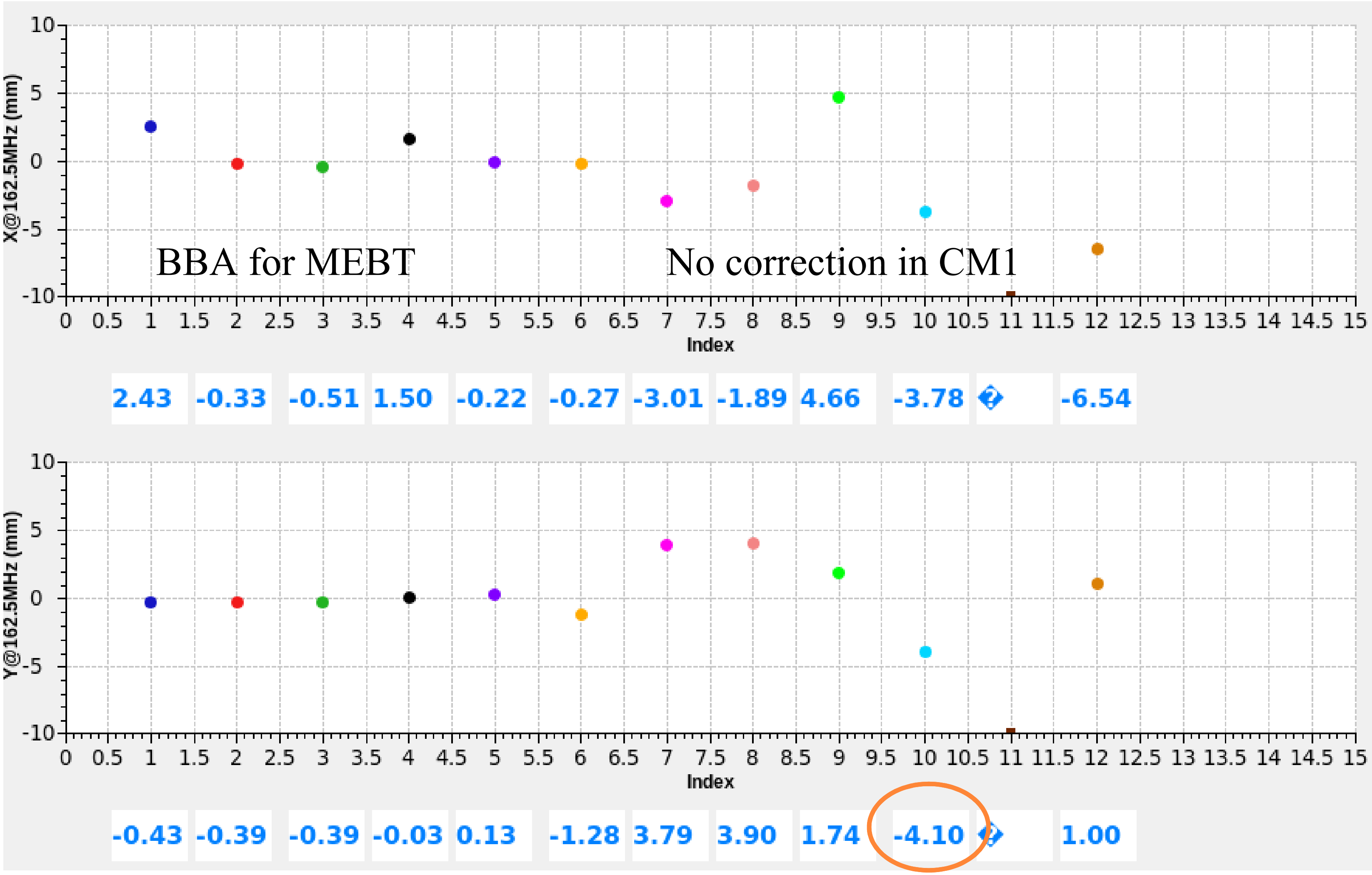
RFQ P_c power set point = 100 kW

Transverse lattice verification of MEBT

	α_x	β_x (m/rad)	α_y	β_y (m/rad)	Mismatch factor H/V
From Q1-3 & emittance	0.3	0.25	-0.11	0.12	0.078/0.005
Parmteq simulation	0.46	0.27	-0.10	0.12	reference

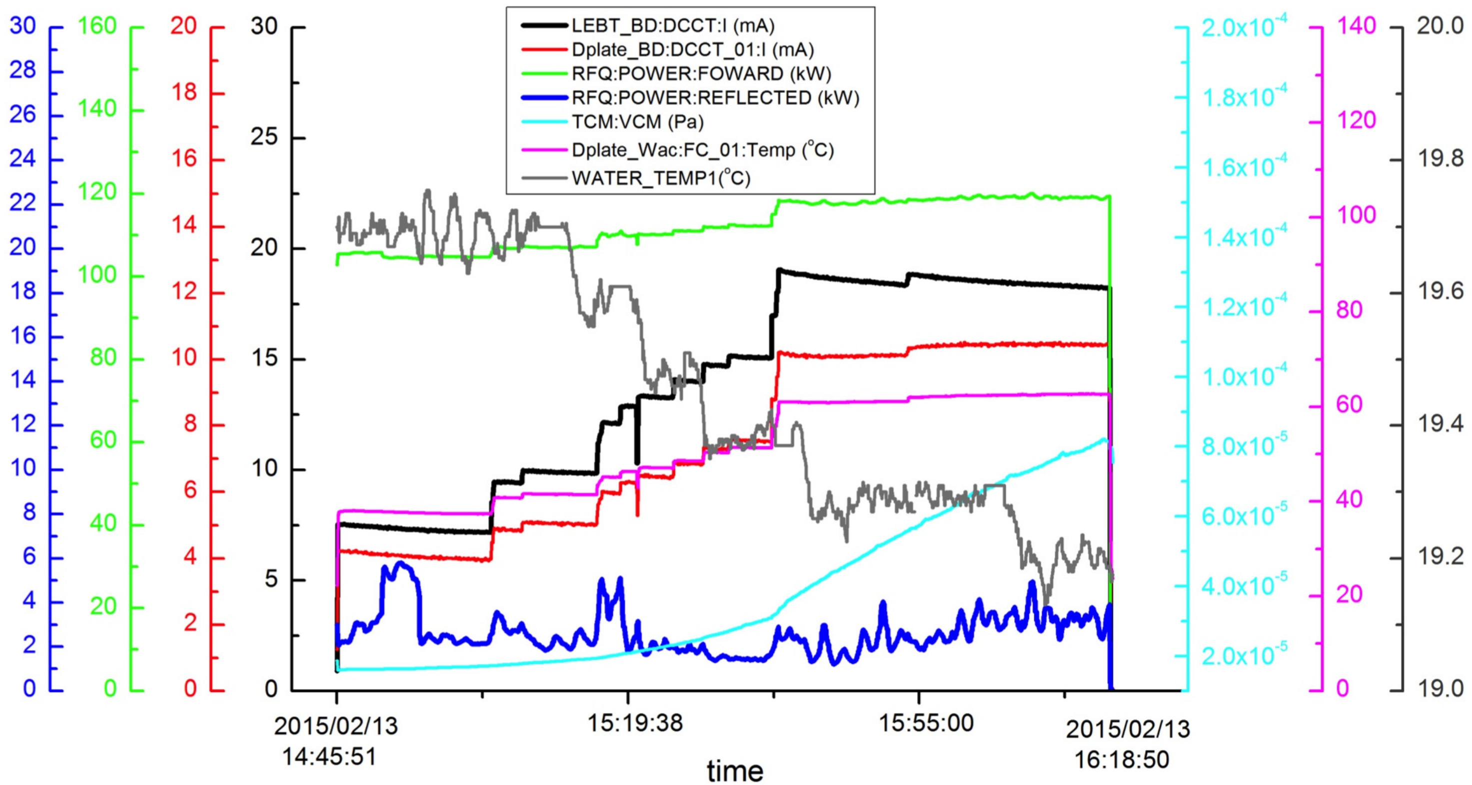


Orbit from MEBT to CM1



Beam power ramping procedure

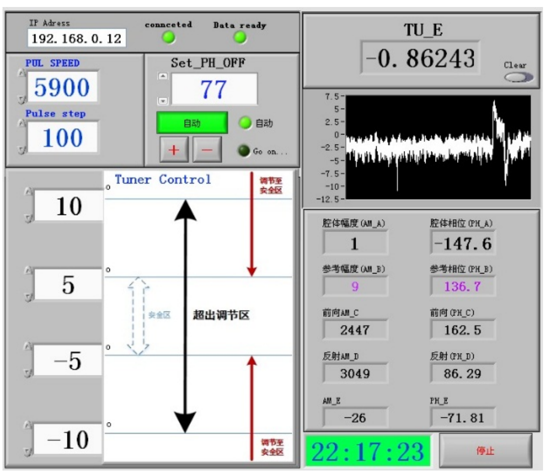
1. 10 mA, 20 us/1 Hz beam, hardware calibration.
2. 10 mA, 20 us/1 Hz beam, lattice verification.
3. 1~2 mA, 20 us/1 Hz to CW, by steps.
4. 2 mA to 10 mA, by steps.



Beam power ramping procedure

No circulator for RFQ, to minimize P_r, RFQ vane water temperature is tuned down by 0.5 ^oC, i.e. ~10 kHz for CW beam loading from 2 mA to 10 mA. Explanation, see THPM2Y01, Huang Ran, on July 7th afternoon.

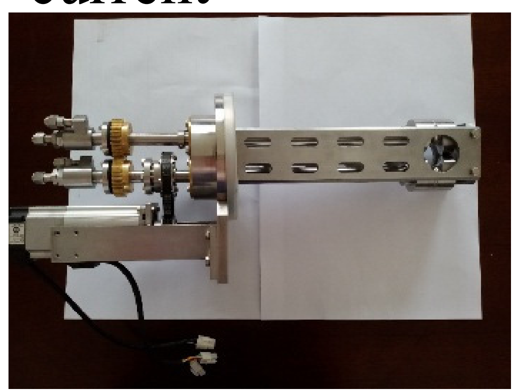
LLRF controlled Water Mixer for RFQ stability

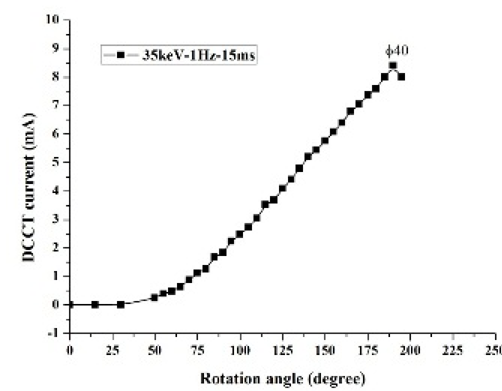


Δf: 1.6 kHz→0.5 kHz

Adjustable Aperture in LEBT smoothly changed the beam current

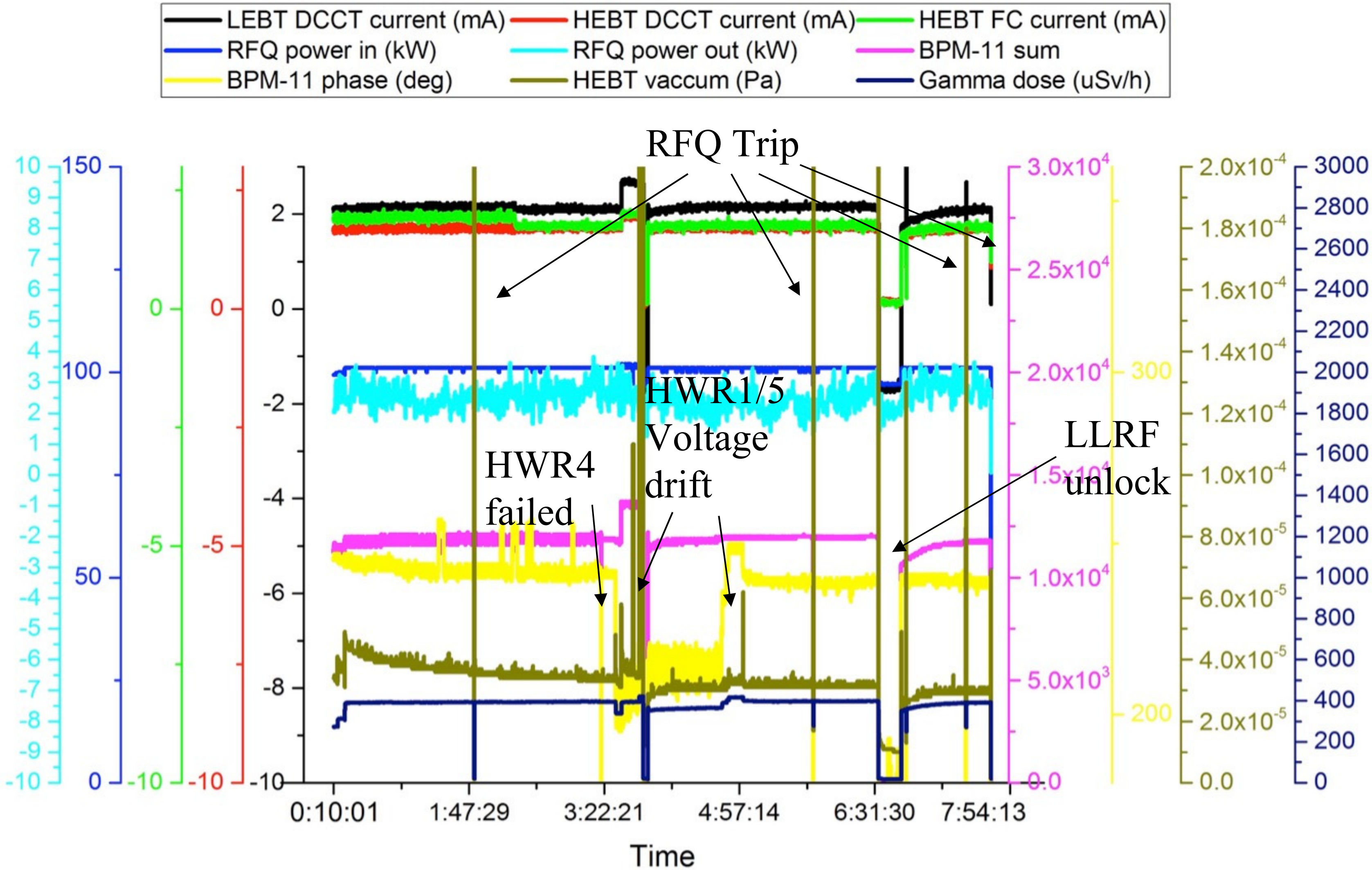
SARAF Annual report 2012





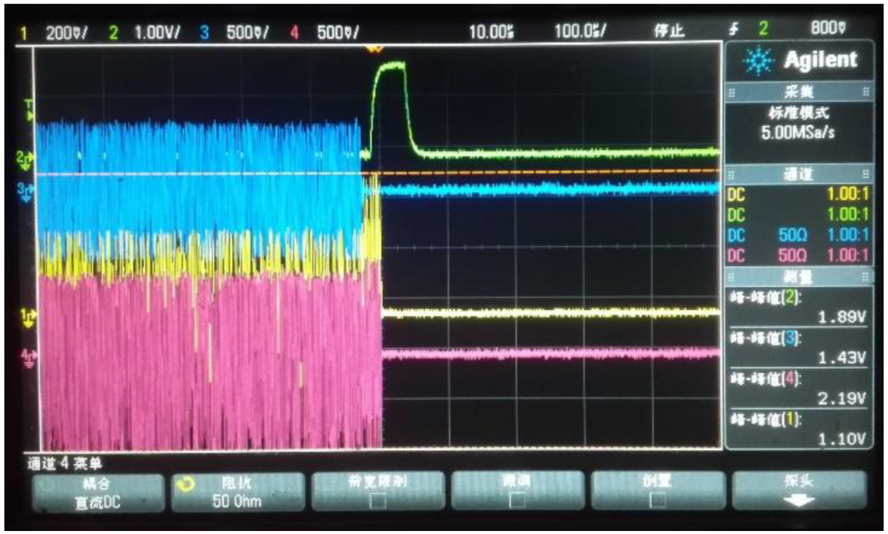
dI: 2 mA →0.1 mA

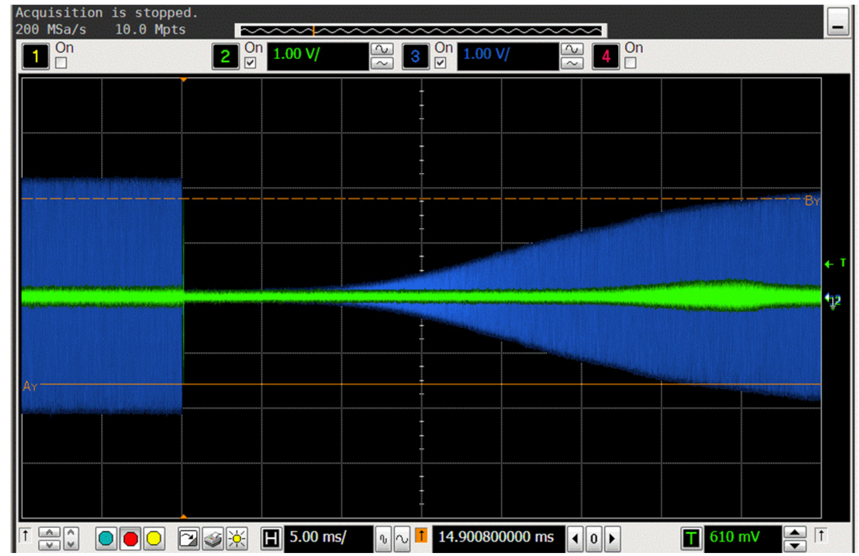
CW beam and trips



Jan. 2th, 2016, ～2mA, 4.0 MeV, CW, 7.5 hours

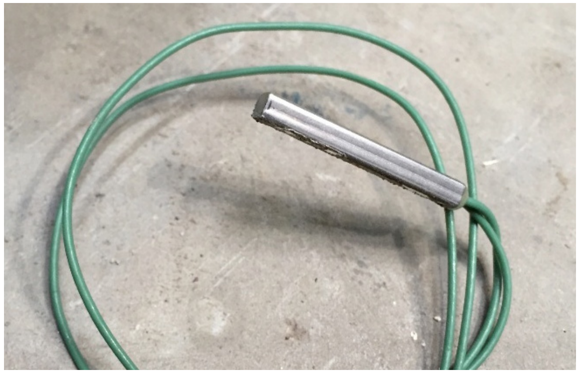
CW beam and trips



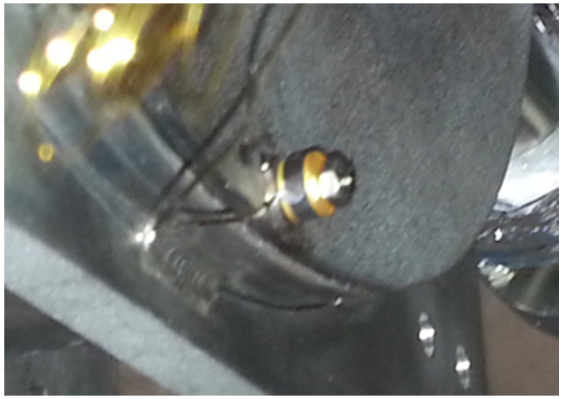


1. P_r overshoot, (from Arc in RF system), interlock LLRF, turn off RF.
2. Wait 50 us, RF recovered to full RF power smoothly in 30 ms.

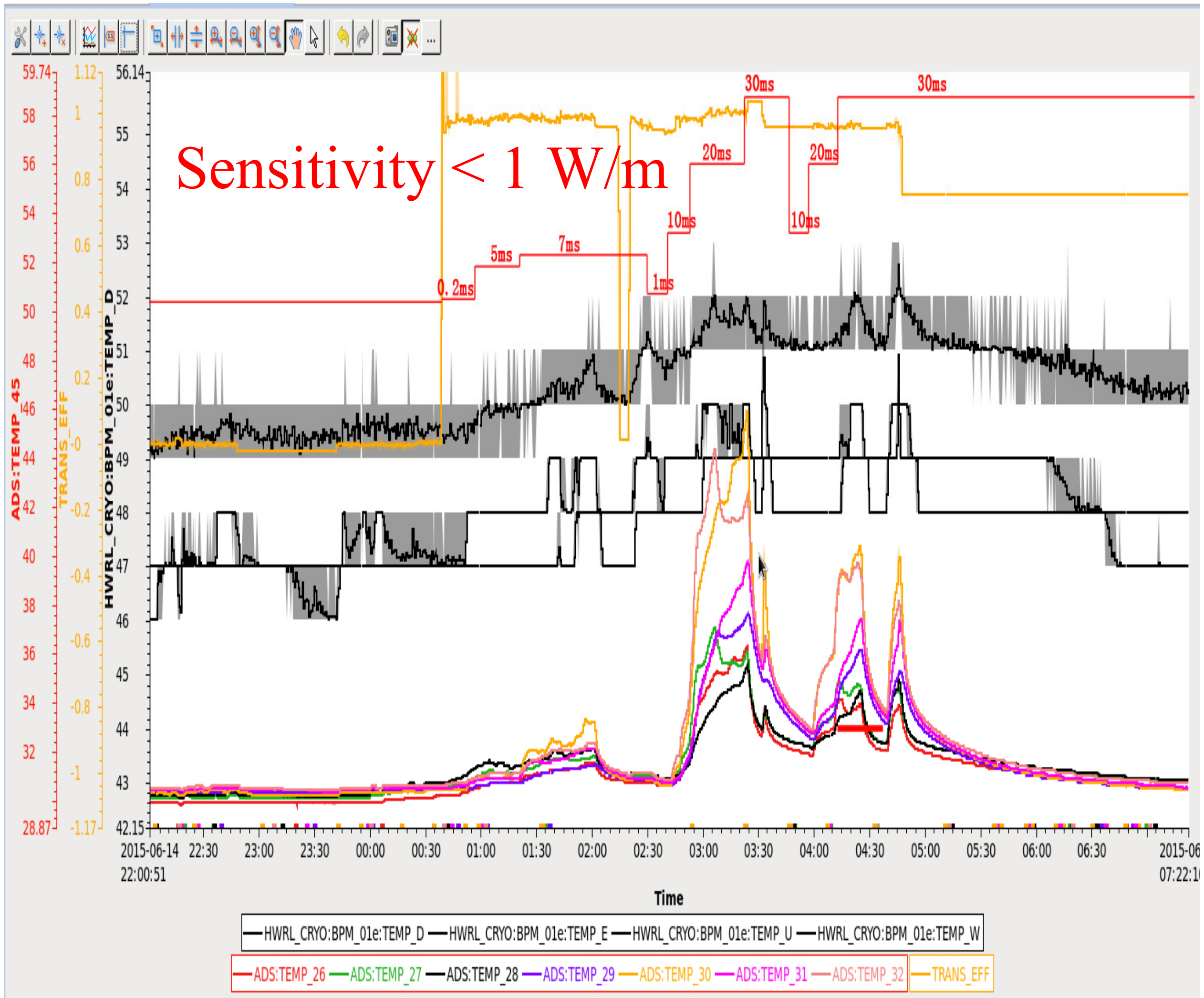
Beam losses with wrong phase setting



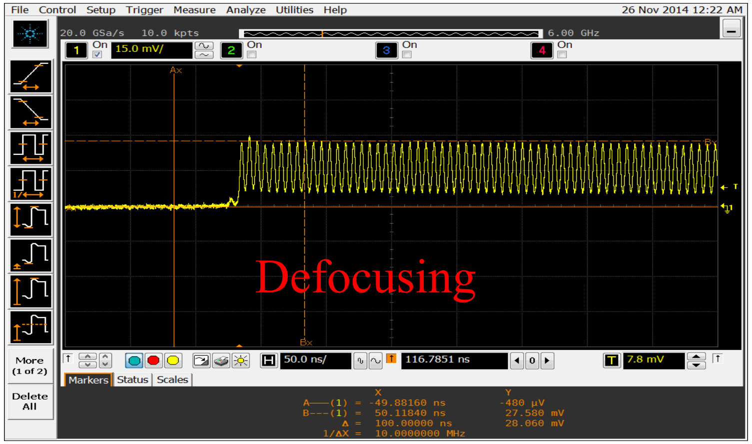
Type: PT100
Normal temperature

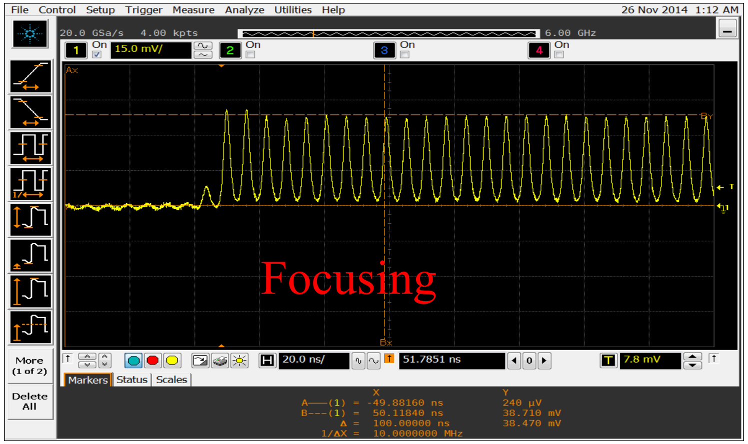


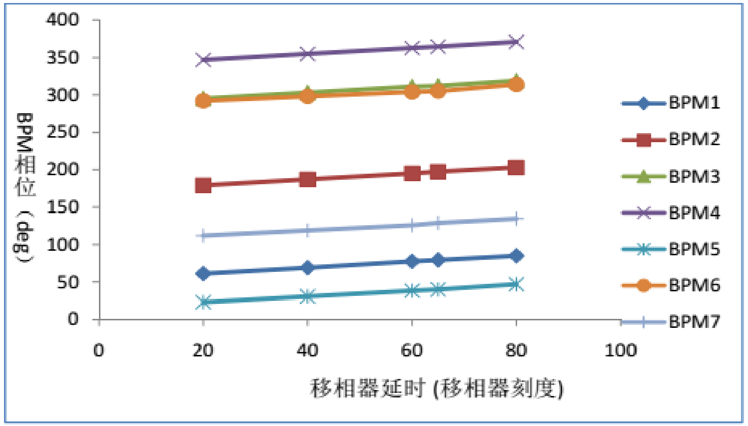
LAKE SHORE:DT-670B
2K-305K(±0.5K)

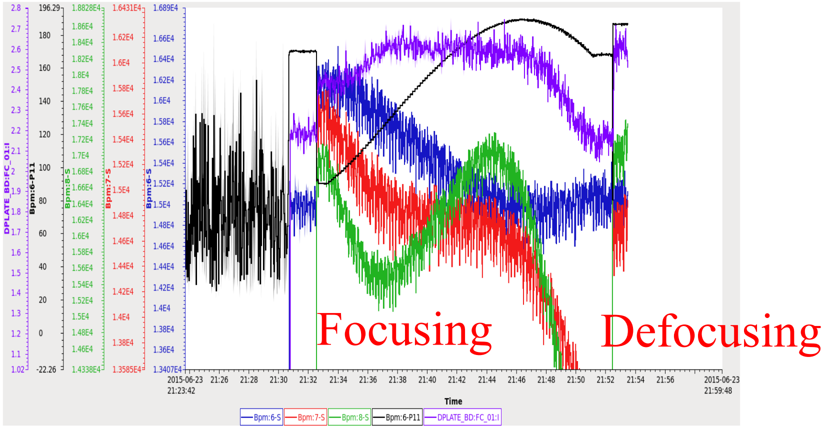


Phase setting determination







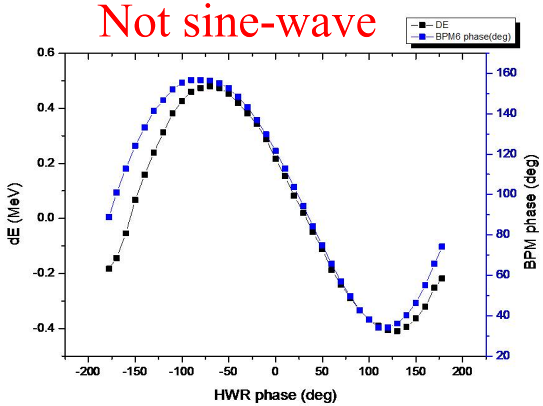


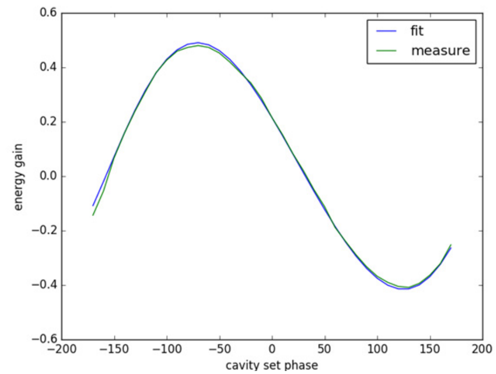
All BPM phases have same signs

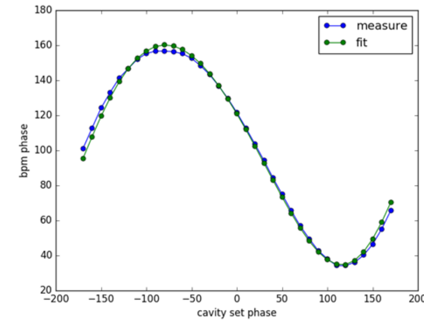
HWR #2 #5 phase signs are opposite to other cavities.

Phase curve analysis

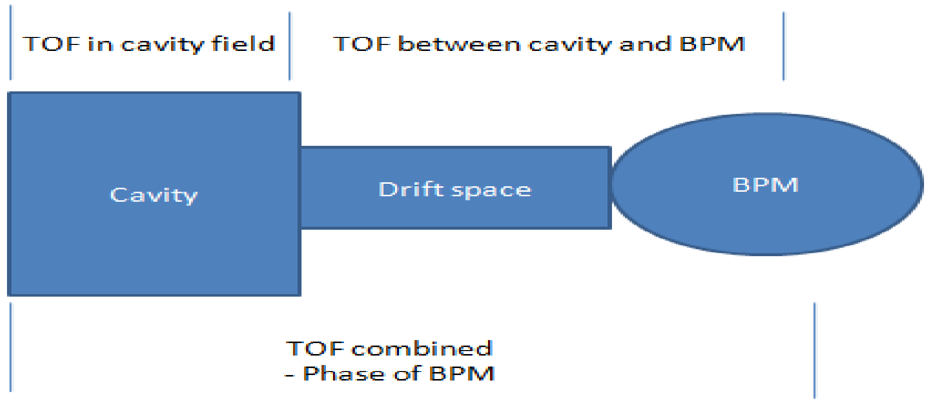
Not sine-wave

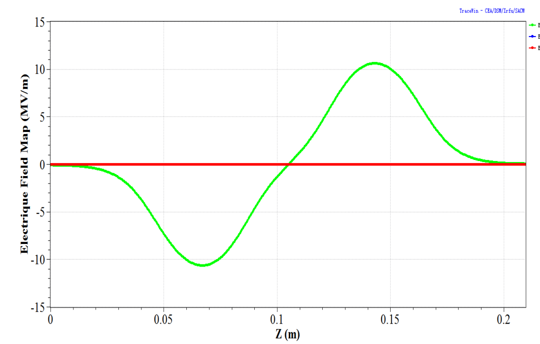


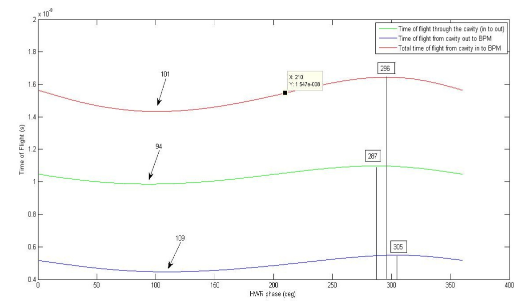




dW/W 0.2 for SC cav and 0.05 for buncher



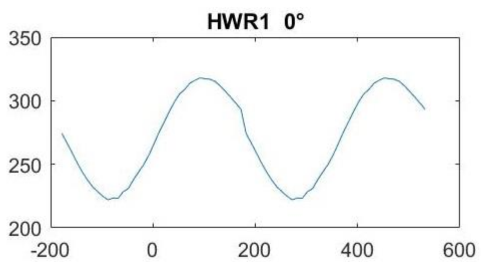


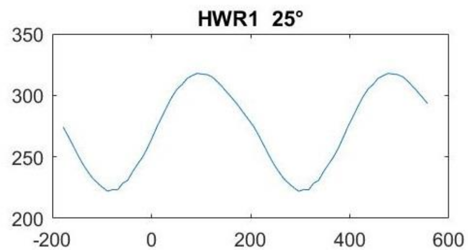


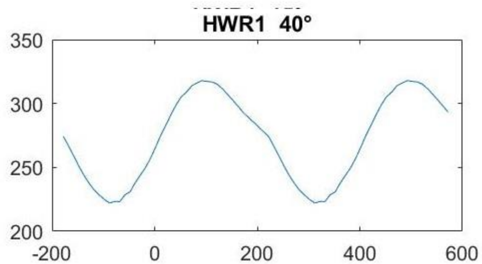
Cavity Field map model predict TOF in cavity and fit the phase curve.

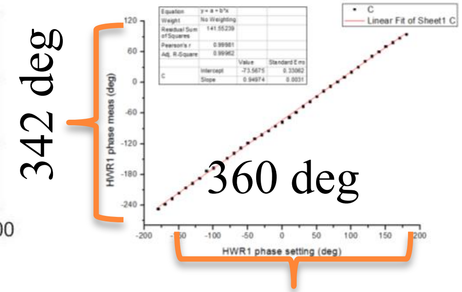
Calibrate input phase and amplitude.

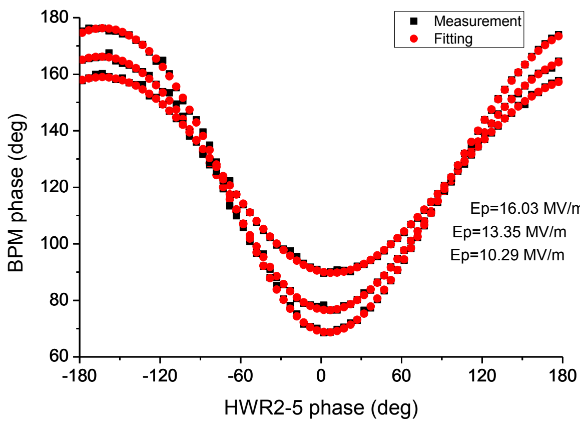
A New phase scan App











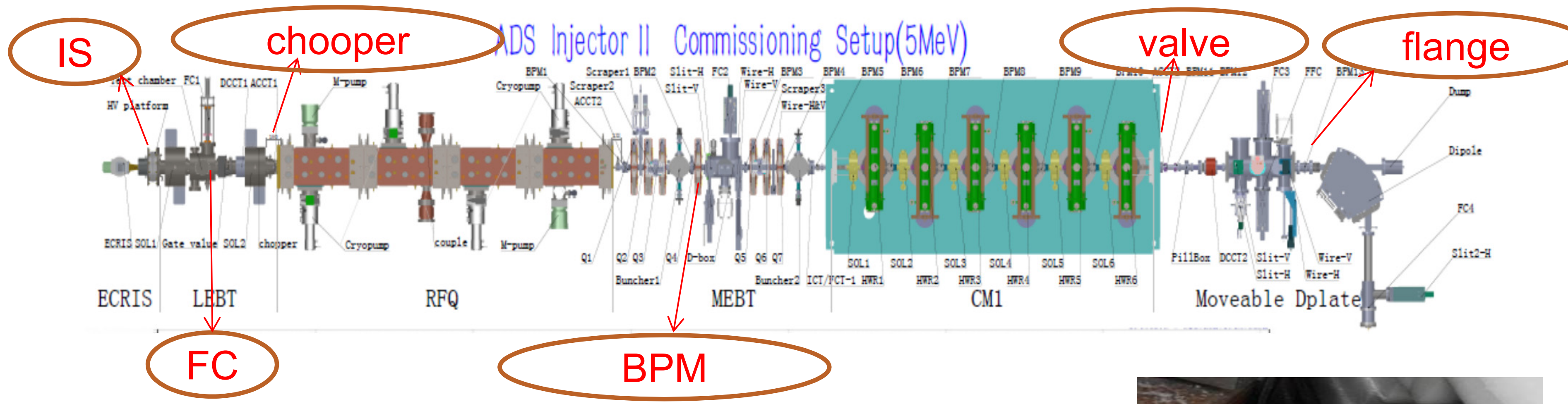
Fixed E_{in}
Fitting Amplitude and input phase

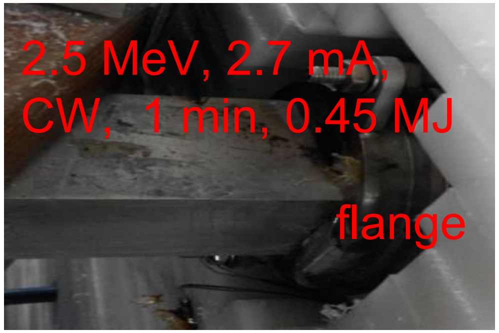
$$\phi_s = \arctan\left[\frac{\int_{S_0}^{S_0+L} qE_z(s)\cdot\sin[\phi(s)]\cdot ds}{\int_{S_0}^{S_0+L} qE_z(s)\cdot\cos[\phi(s)]\cdot ds}\right]$$

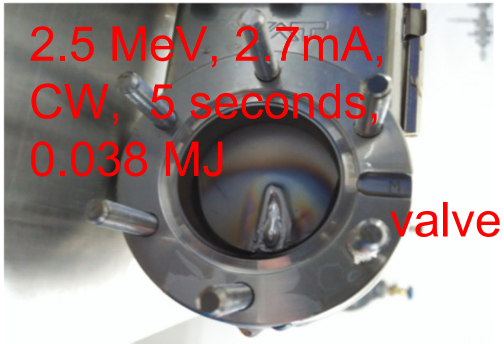
A new phase scan App has been developed, and is successfully used in SC cavity phase settings.

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

1st accident and lessons







Date： June 29th 2015

Beam state：2.5 MeV，2.7mA，CW，1 min

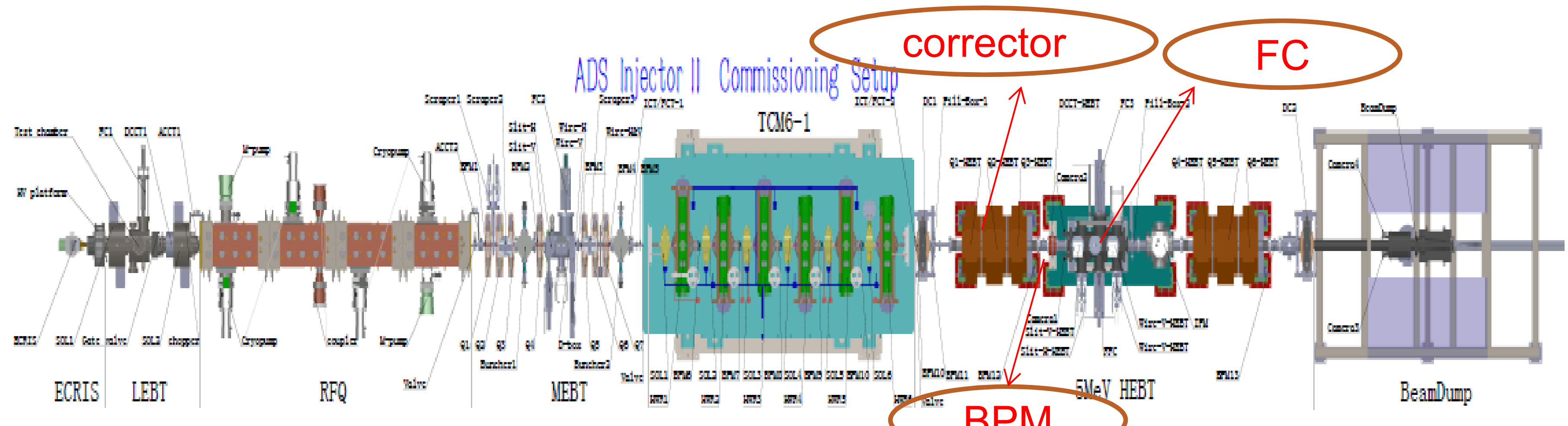
Procedure:

1. Two paths are defined to do beam interlock, chopper and HV-IS.
2. Interlock threshold value of BPM was 1.0 volts, relatively lower. The relay to shutdown HV-IS was disabled by triggers due to noise.
3. Chopper can be recover automatically after 13 s.
4. CW beam recovered after 13 s, and damaged the bellow the bending magnet. Vacuum interlock triggered valves and FC at LEBT. They are the actions of MPS.
5. Valve was inserted, but 1 s later than FC was inserted.
6. Secondary accident is the valve damage and the CM leak.

1st accident and lessons

1. Self-check function of MPS may be important. To make sure every action is in order in advance.
2. All trigger levels should be defined carefully, and be free of noise.
3. Beam loss is detected by temperature sensors attached to the beam pipe, and give signal to MPS system.
4. Interlock of Chopper should not recover beam until be reset manually.
5. Action sequences of inserting devices after vacuum leak should be clearly defined to minimize the damage of machine.

2nd accident and lessons

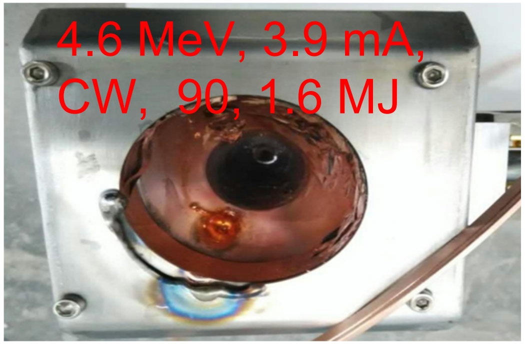


Date： December 4th 2015

Beam state：4.6 MeV，3.9 mA，CW， 90s

1. The BPM upstream of FC was out of order.
2. The current value measured by FC became unstable but was neglected.
3. Beam hit the FC off-centered by ~20 mm. It drilled a hole to the water pipe of FC, then water jetted into the vacuum pipe.

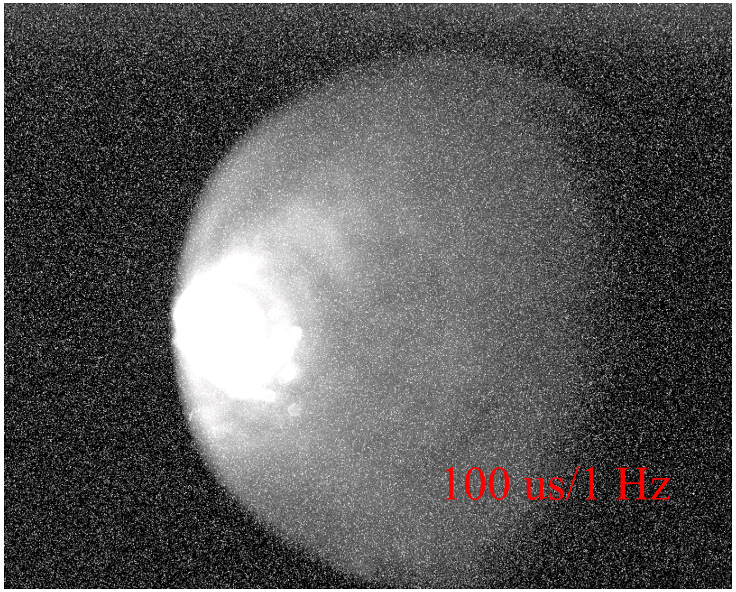
Water leakage of FC

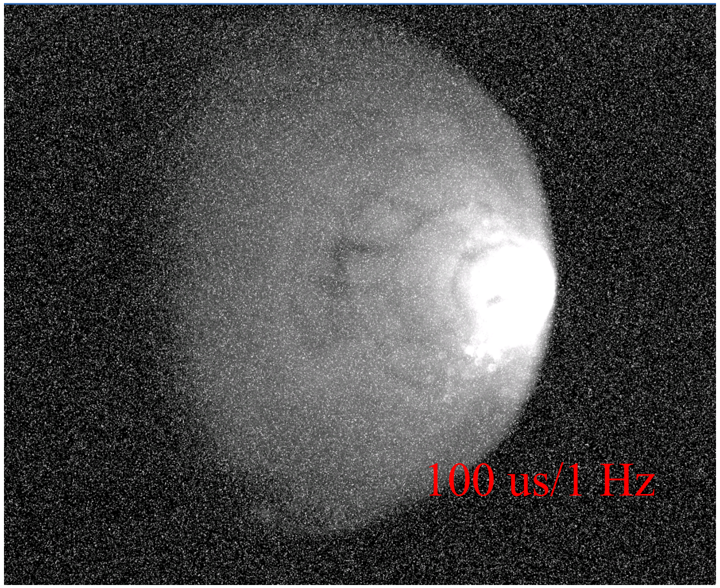


Pump with water

2nd accident and lessons

1. Observe beam position on the FC/DUMP/target is important. We developed an optical camera system.
2. Automatically check lattice during beam power ramping up.
3. Do not bypass any MPS signal until it is well understood or you have the other hand to do it.
4. Stop high power beam to analyze any abnormal or strange phenomena.





Summary

1. Great progress for beam commissioning of CIADS injector II has achieved during last two years.
2. Transverse lattice is confirmed with field overlap model.
3. Beam structure of 4.95 ms/5 ms with 50 us gap to utilize the DBCM system.
4. Circulator is important for stable operation of cavities.
5. A new phase scan app is developed to understand beam information, which is critical for linac commissioning.
6. MPS system is a “safe critical” system for high power Superconducting linac.
7. 20~25 MeV, 10 mA, pulse beam commissioning before the end of 2016, collaboration with IHEP.

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HIT, PKU, SINAP,……

Welcome Collaboration!