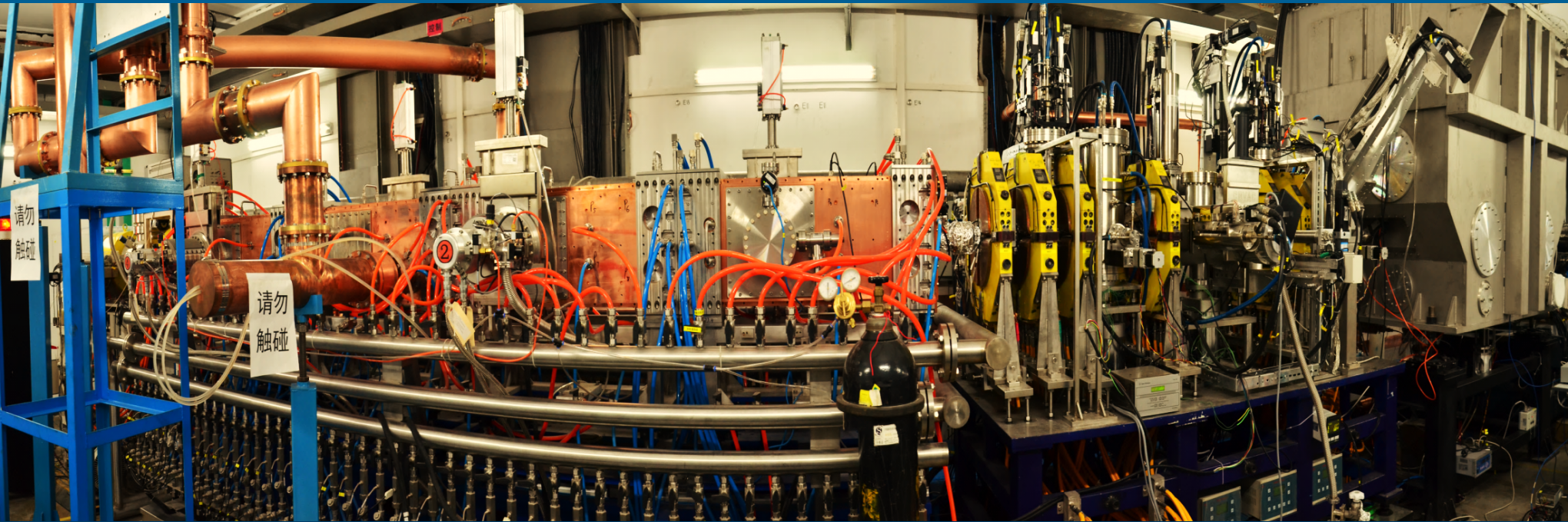


Beam commissioning activities at demo facility of C-ADS Injector II



C-ADS Injector Demo Facility

Zhijun Wang

Institute of Modern Physics, CAS@Lanzhou

6th Open Collaboration Meeting on Superconducting Linacs for High Power Proton Beam
Daresbury, UK, May 23-24, 2016



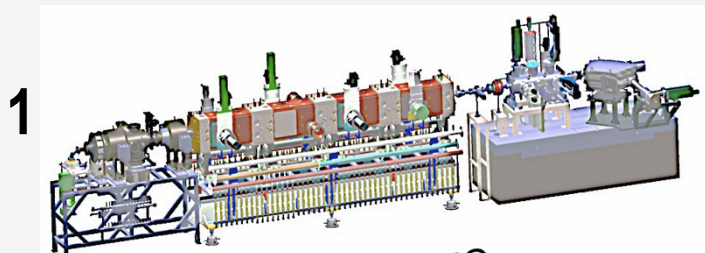
Outline



- Introduction of the beam commissioning progress
- Commissioning Issues for the C-ADS injector
- Summary and outlook
- Acknowledge

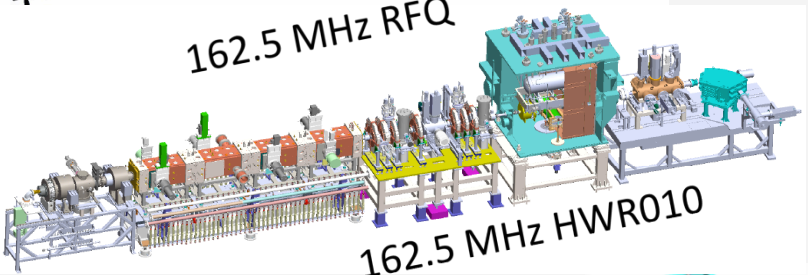


Commissioning Schedule of C-ADS injector



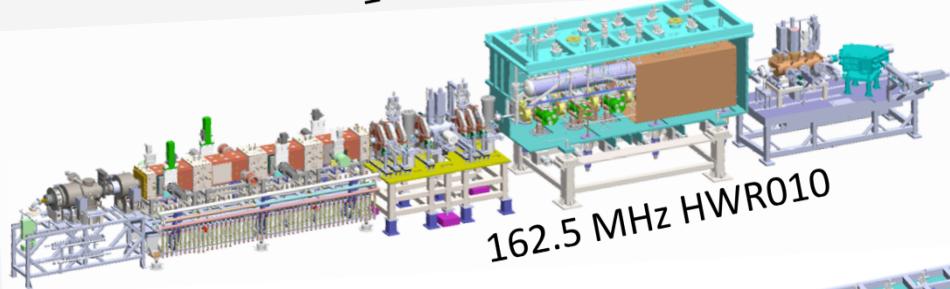
1

- At the beginning of June , RF CW achieved,2014
- June 6th, the first beam, **energy is 2.15 MeV ,2014**
- June 30th, **10 mA, CW beam**, beam power 21.6 kW,2014



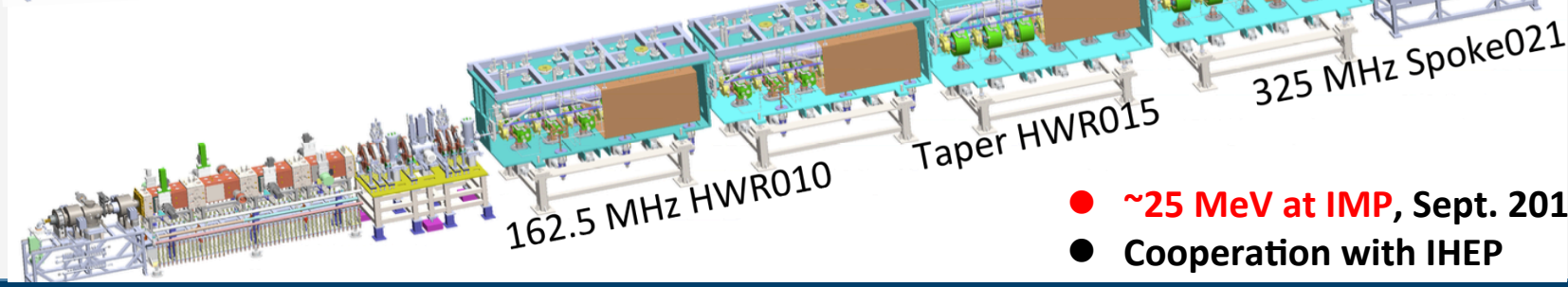
2

- ECRIS + LEBT + RFQ + MEBT + TCM, **2.5 MeV,2015**
- RFQ commissioning, validate CM design.
- CW operation with 10 mA in Feb, 2015 successfully



3

- ECRIS+LEBT+RFQ+MEBT+CM6, **5 MeV**
- 10.2mA,5.3MeV, pulsed beam at 6th Jun:**2.7mA, 5.2 MeV ,CW** at 24th Jun ,2015

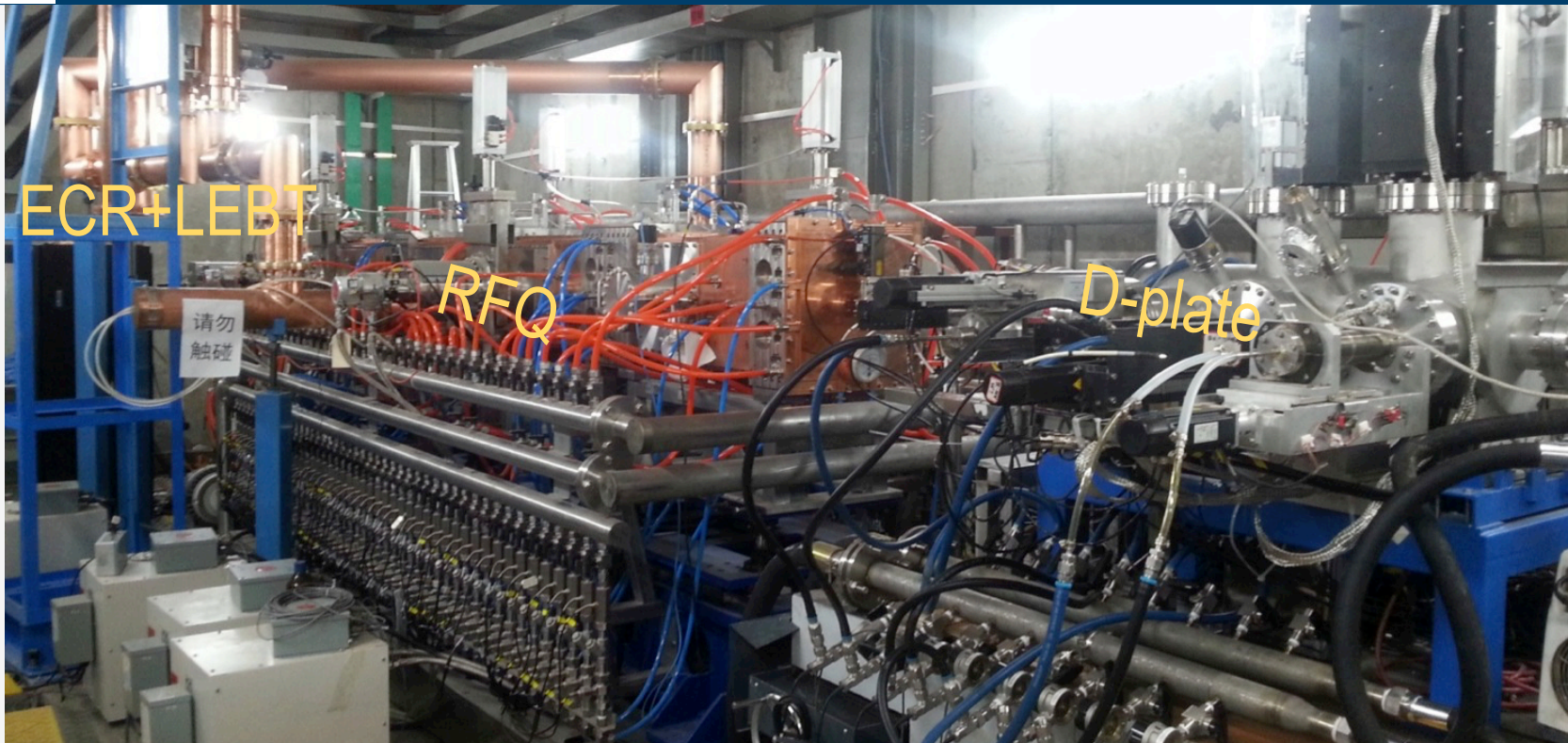


4

- **~25 MeV at IMP**, Sept. 2016 – 2017
- Cooperation with IHEP



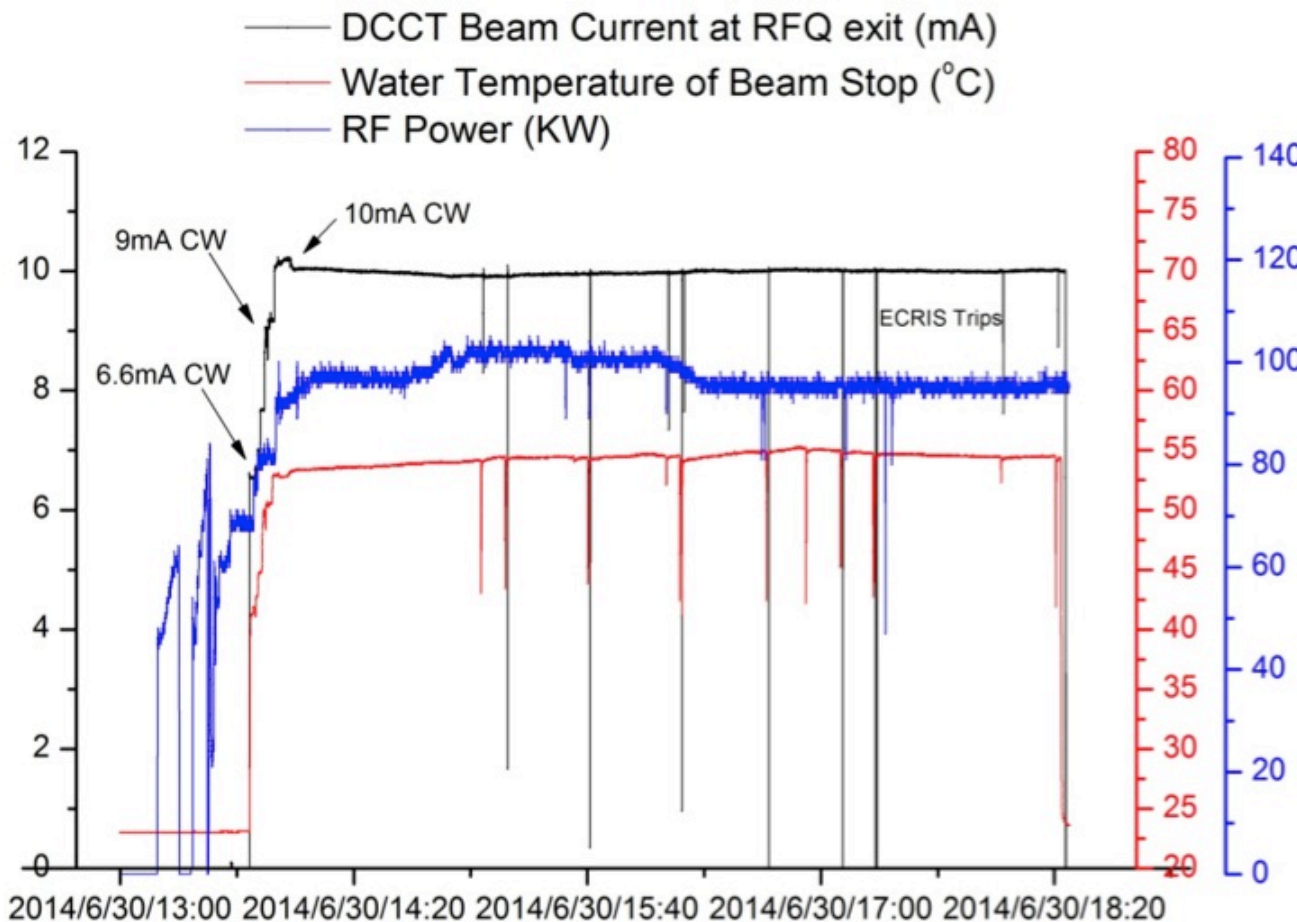
1、 Beam commissioning of 162.5MHz CW RFQADS



- June 6th, 2014, the first beam, energy is 2.15 MeV
- June 30th, 2014, 10 mA, CW beam, 4.5 hours, beam power 21.6 kW
- July 18th-19th, 2014, tested and peer reviewed by CAS
- Total operation time is ~1000 hours including CW@10mA around 10 hours
- Record of non-trip operation is ~220 hours



1. Beam commissioning of 162.5MHz CW RFQADS



June 30th, 2014, Beam is CW. The current jumped from ~5 mA to ~10 mA, kept for 4.5 hours. Ion source arcing is the main trips and caused the AMP shutdown finally.



2、 Beam commissioning of MEBT&TCM1

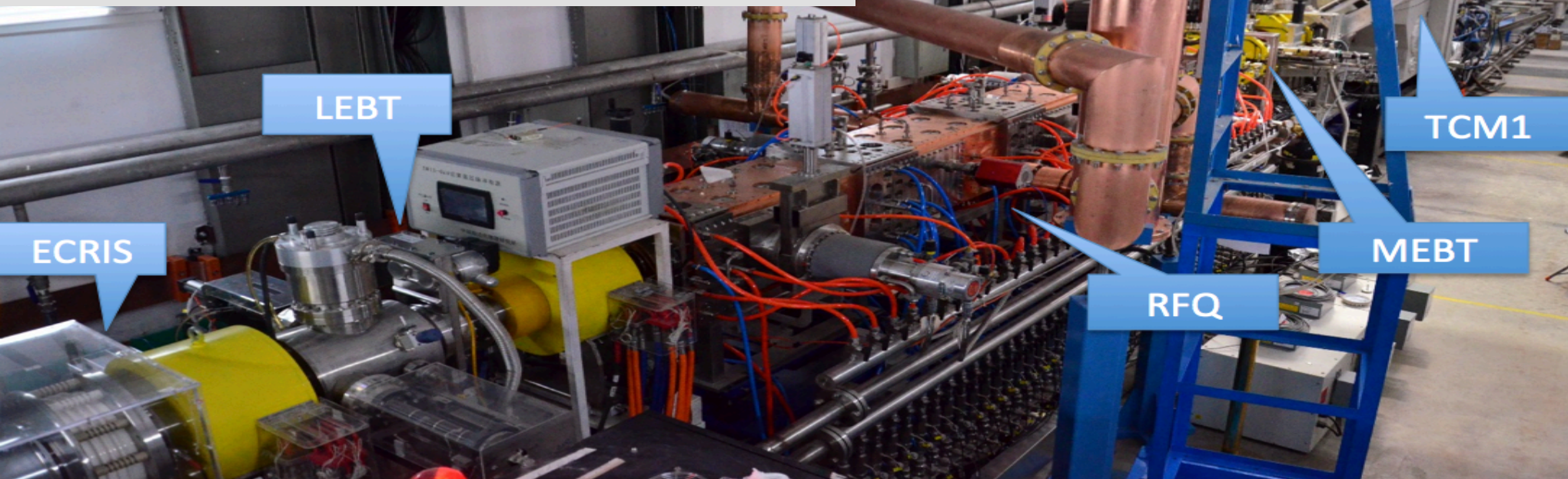
ECRIS+LEBT+RFQ+MEBT+TCM1+D-Plate ~2.5 MeV at 10 mA

Energy measurement : BPM1-DP, BPM3-DP, Time of flight

Energy measurement: Slit2, deflection dipole, FC4

Beam current measurement: DCCT-DP, ACCT2

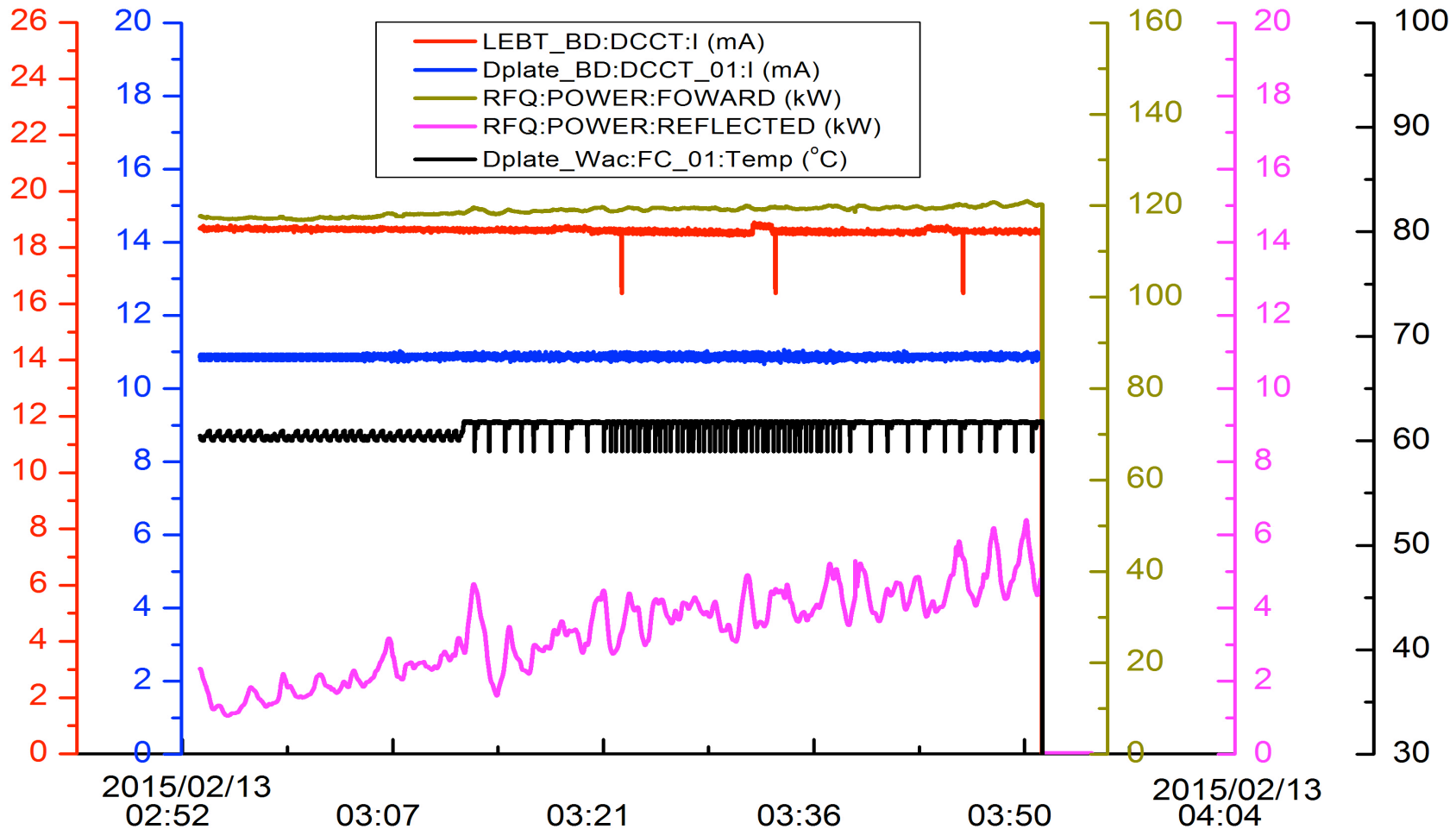
Transmission efficiency measurement: DCCT-DP, ACCT2



- Oct. 1st, 2014, first beam from TCM1, 2.6 MeV, 2.3 mA, Transmission ~100%
- Nov.25th, MEBT and TCM (HWR010) operated at 2.67MeV@CW mode around 6 hours. The max current was 3.6 mA and beam power >9.6 kW.
- Feb. 5th, 2015, 2.51MeV/4.2-10.83mA/72m, Feb. 13rd, 2.55MeV/~11mA/60m。
- Hours on Nov. 27th. Total operation time was ~ 200 hours.



2、 Beam commissioning of MEBT&TCM1



Feb. 13th, 2015, ~11mA, 2.55 MeV, CW, 60min; beam power 28kW.
Beam stop due to ion source trip.

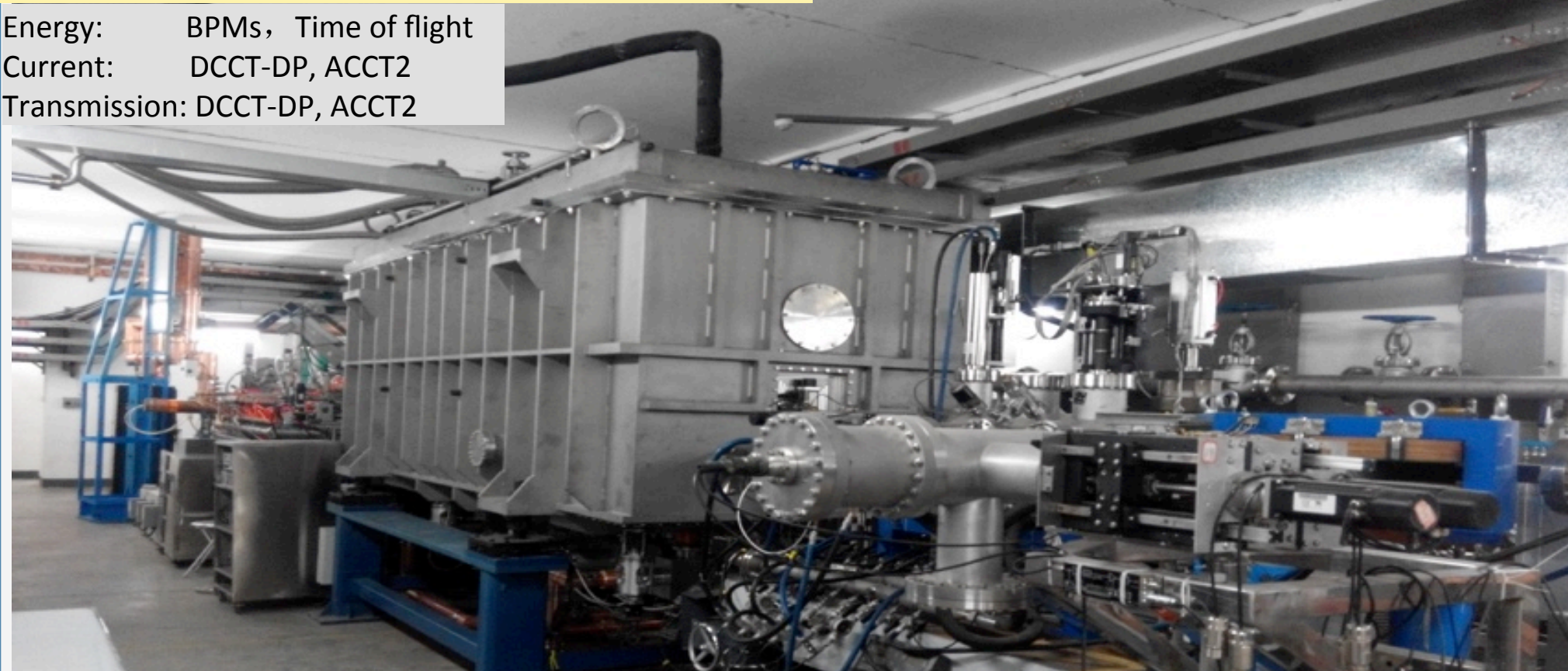


3、 Beam commissioning of TCM6



ECRIS+LEBT+RFQ+MEBT+HCM6-1+D-Plate ~5 MeV at 10 mA

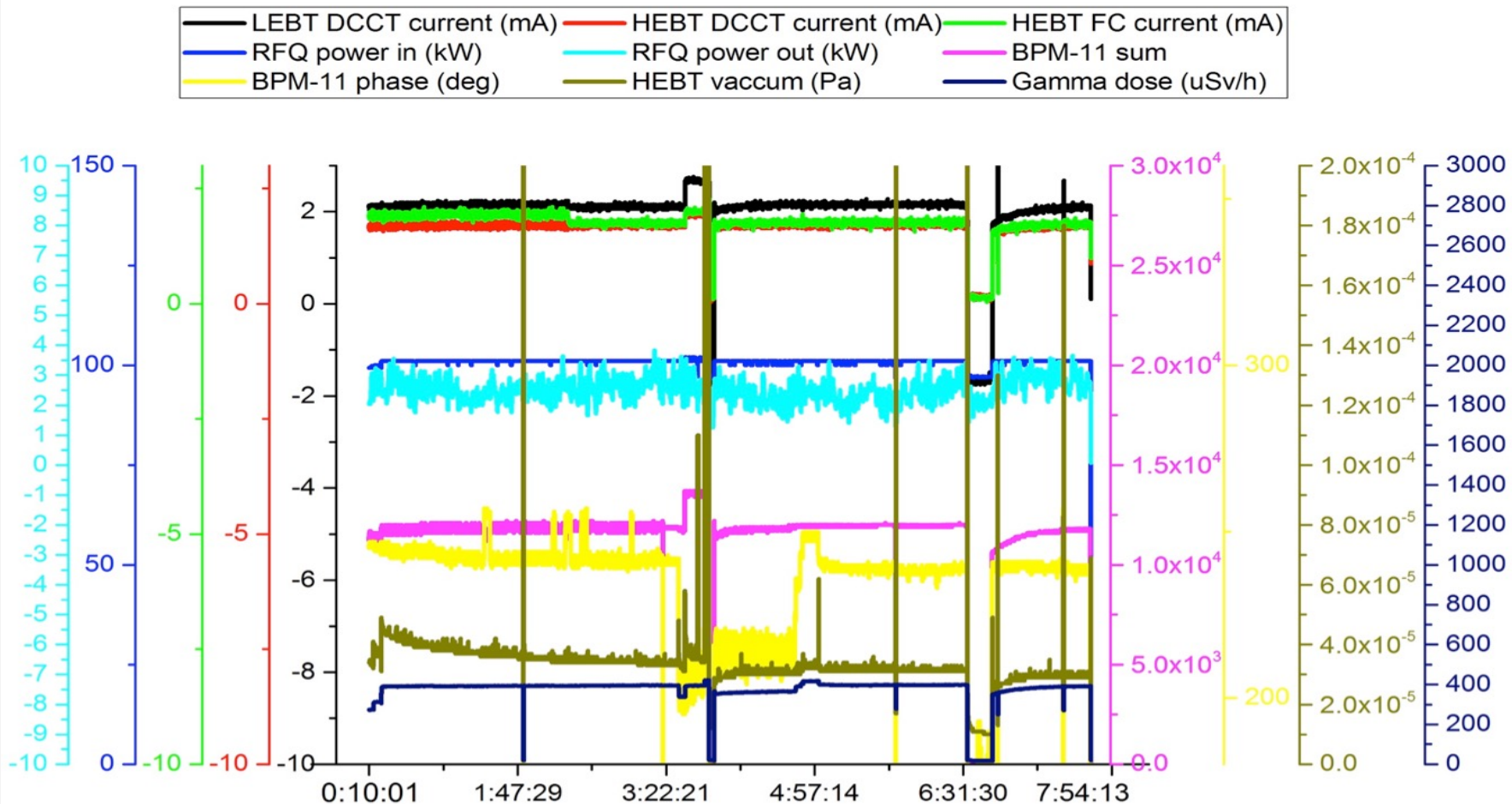
Energy: BPMs, Time of flight
Current: DCCT-DP, ACCT2
Transmission: DCCT-DP, ACCT2



June 6th, 2015, pulse beam 99us@1Hz, 5.2MeV, 10.2mA
June 24th, 2015, 5.3MeV/2.7mA/CW/14kW
Dec 27th, 2015, 4.6MeV/4mA/CW/40min; 4.6MeV/3mA/CW/50min
Jan 2th, 2016, 4MeV/1.7mA/CW/6.8kW, CW 7.5 h



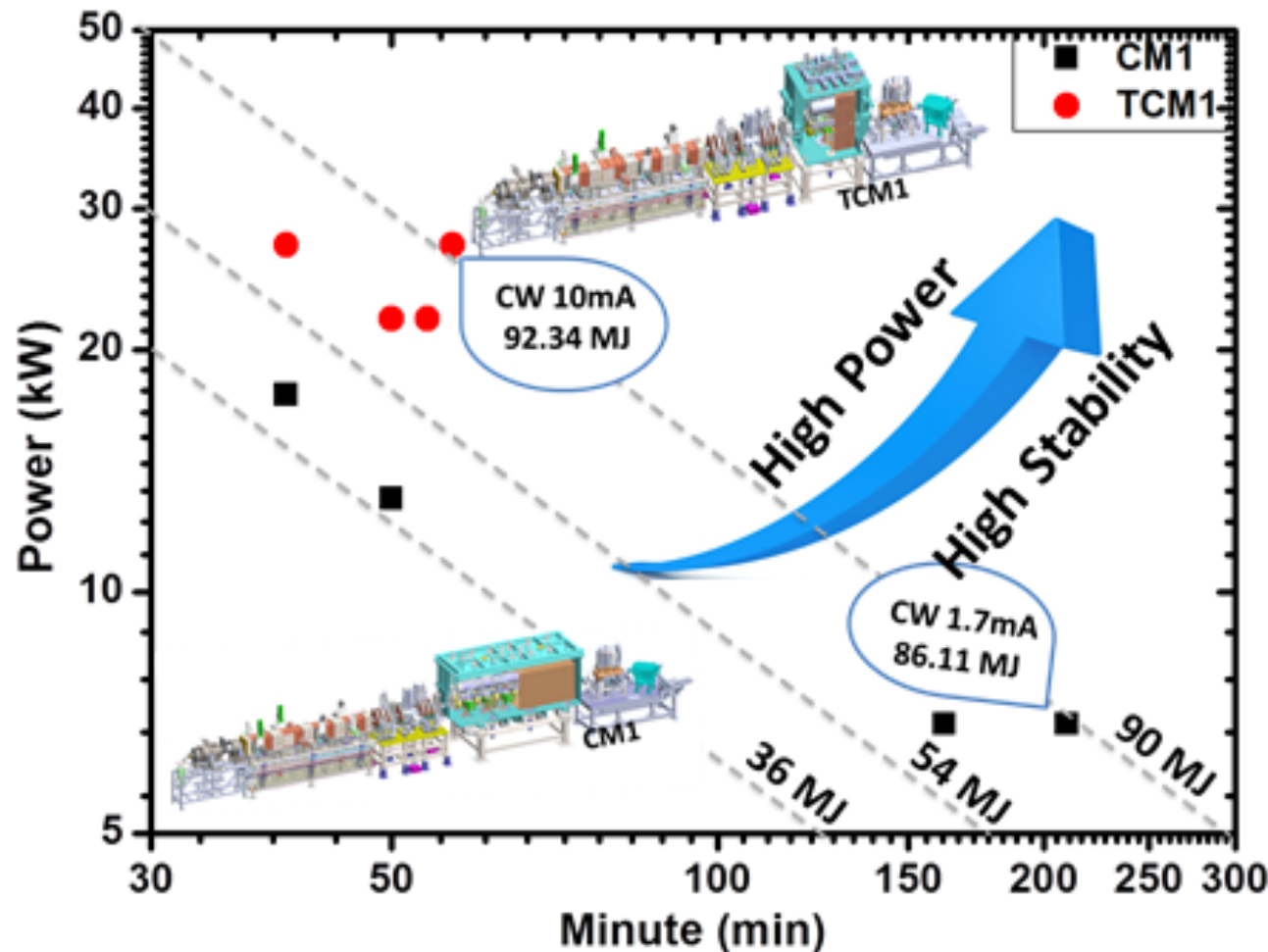
3、 Beam commissioning of TCM6



Jun. 2th, 2016, ~2mA, 4 MeV, CW, 7 hours; Beam stop due to RFQ system shunt down.



Summary of Beam commissioning



- Beam loss control
- Beam loading effect for RFQ
- Beam loss detection
- Beam parameters measurement
- Machine accident for MPS failed and HCE

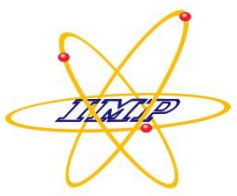
.....



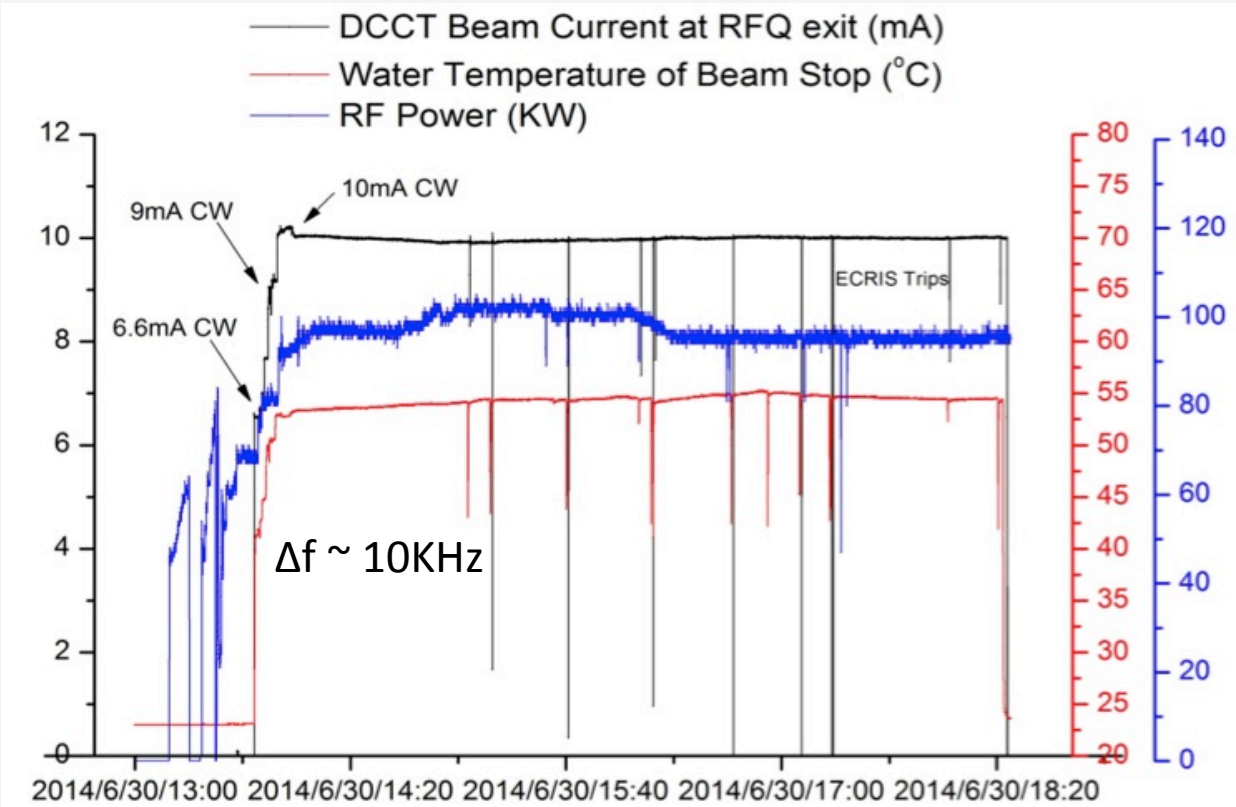
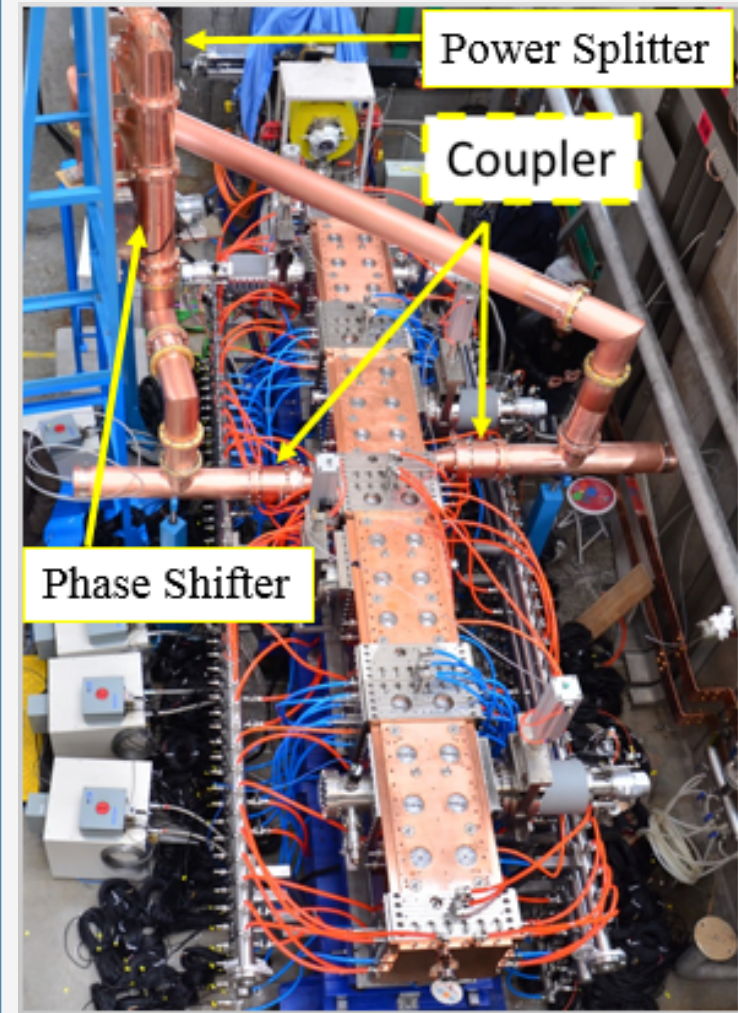
Beam commissioning Issues for the Prototype of C-ADS injector



- Beam loading effect of RFQ with 10mA proton beam
- Beam tuning of RFQ for high beam power linac
- Benchmark between simulation and experiential results
- BBA experiments
- Beam loss control and detection
- 6D-emittance measurements with no-interceptive BPMs



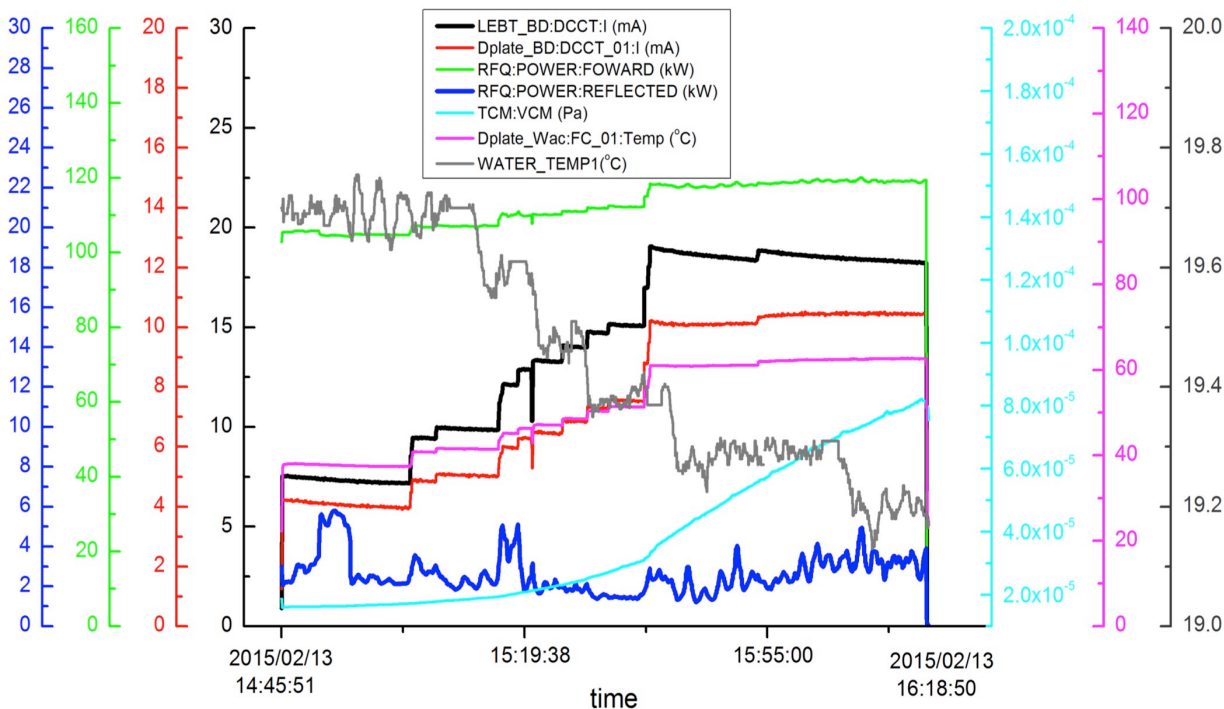
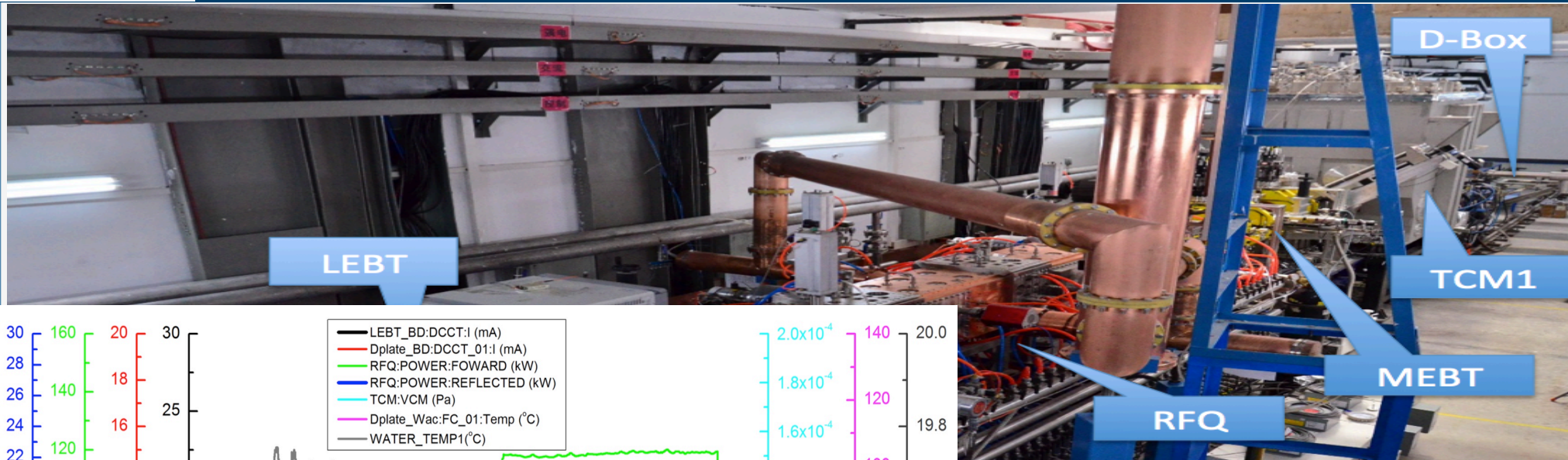
Beam loading effect of RFQ cavity



The RF power amplifier is tuned to compensate the beam loading effect.



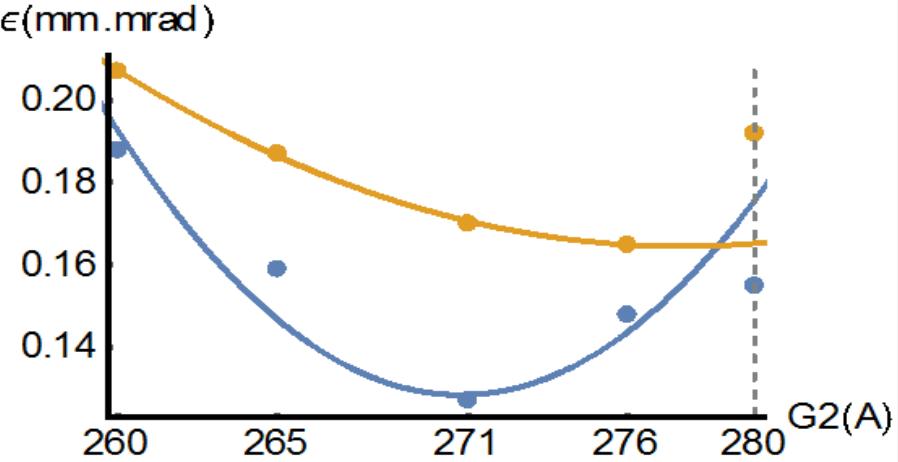
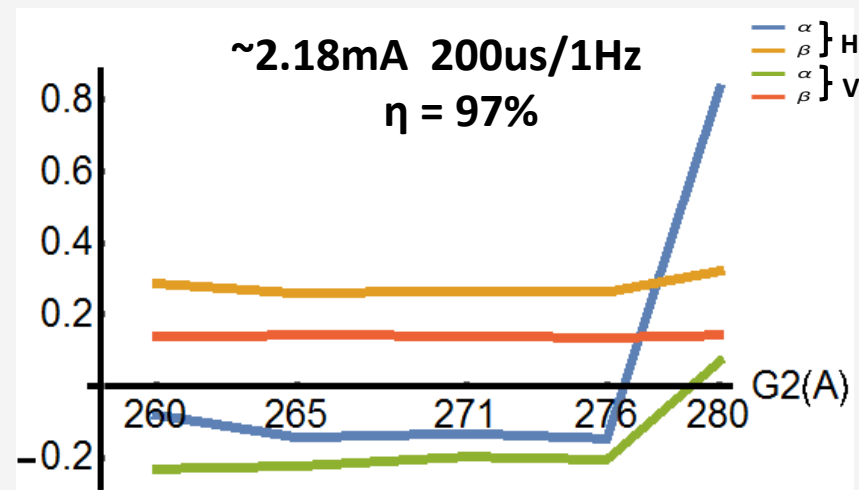
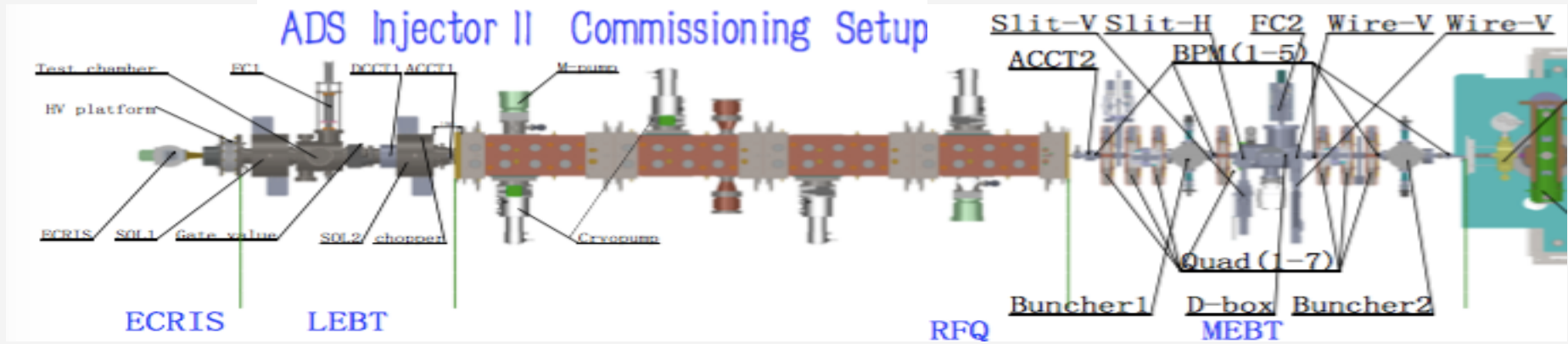
Beam loading effect of RFQ cavity



The temperature of RFQ cavity cooling water is tuned manually to decrease the reflection RF power caused by beam loading!

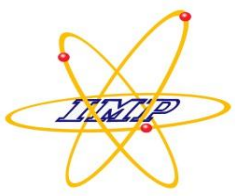


Beam tuning of RFQ for high beam power linac



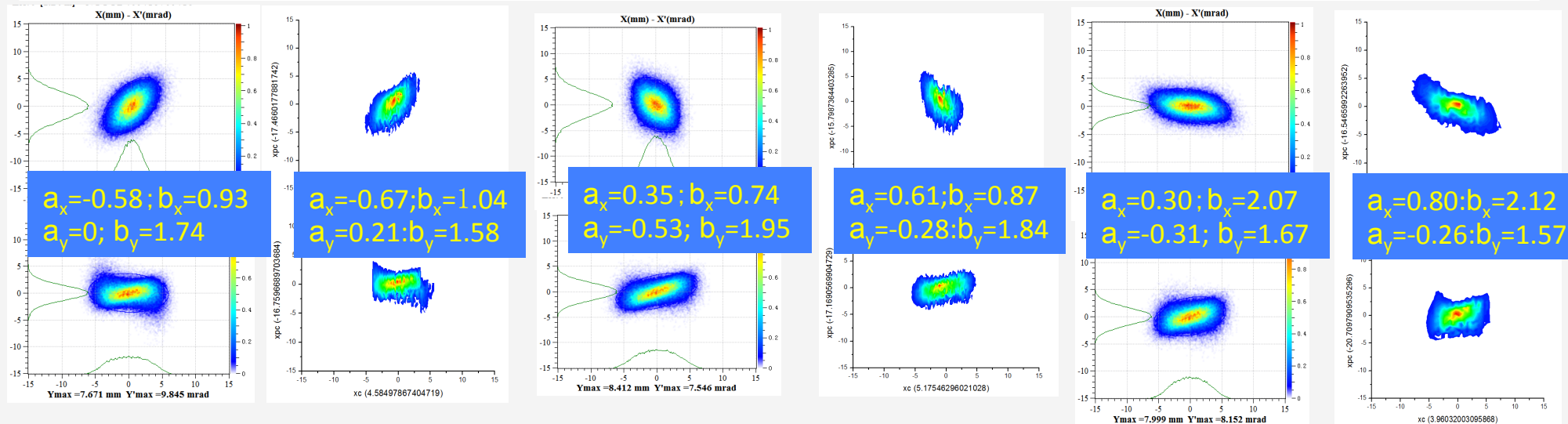
Emittance with different G_2

Maximum transmission is not enough, matching tuning should be considered for the high beam power linac!



Benchmark between simulation and experiential results

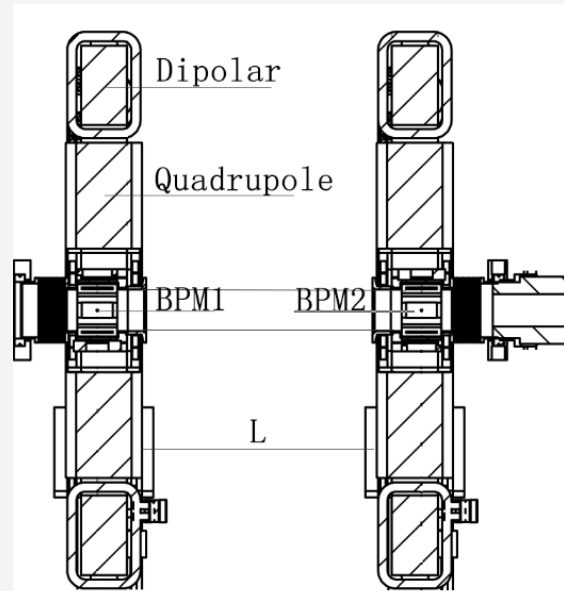
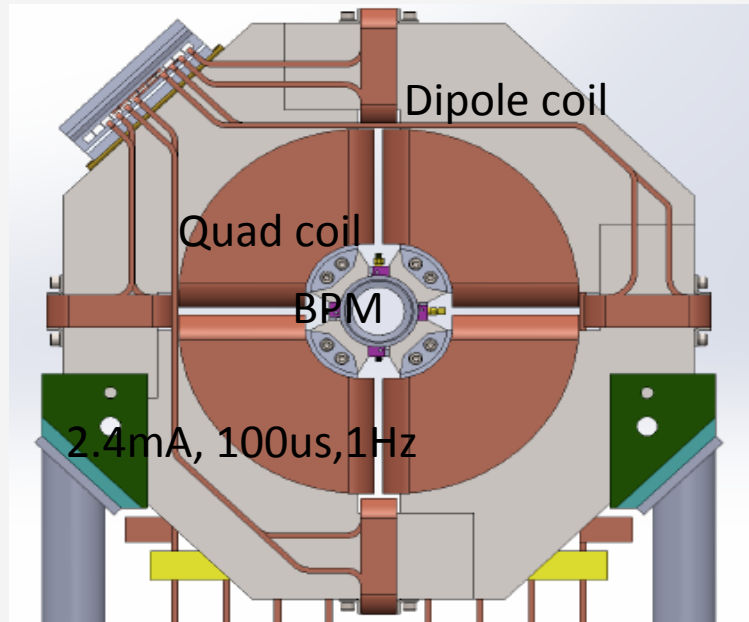
	Alpha_x	Beta_x (m/rad)	Alpha_y	Beta_y (m/rad)
Exp	0.3	0.22	-0.11	0.12
Parmteq	0.46	0.27	-0.10	0.12
Totoutis	0.20	0.22	-0.18	0.11
Track	0.22	0.23	-0.31	0.11



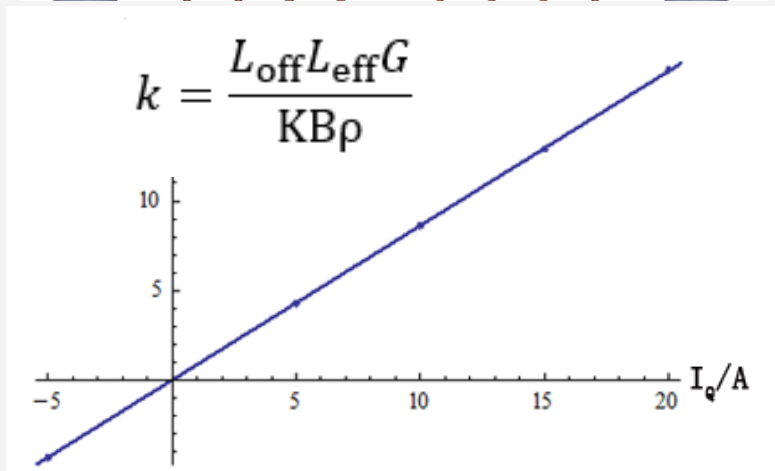
The accurate beam parameters from RFQ cavity by multi measurements!



BBA experiments- Quads



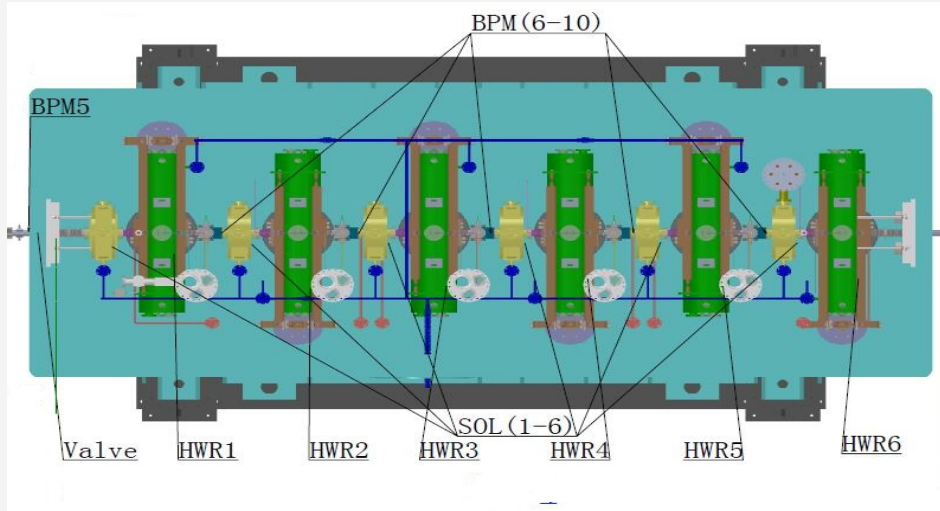
“null comparison method” is proposed to measure the BPM offset.



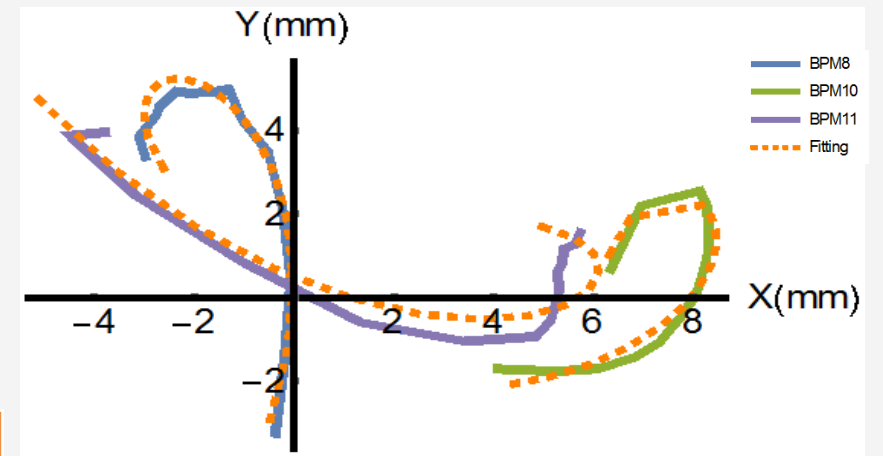
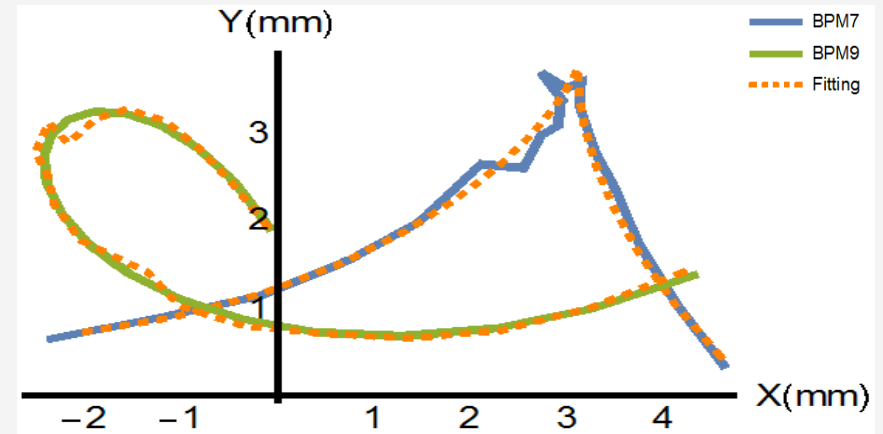
BPM	X (mm)	Y (mm)
BPM1	0.449	0.559
BPM2	-0.026	0.432
BPM3	0.063	-0.325
BPM4	0.434	0.158



BBA experiments- SC solenoids



$$\begin{pmatrix} X_0 \\ X'_0 \\ Y_0 \\ Y'_0 \end{pmatrix} = M^{-1} \cdot \begin{pmatrix} X_1^{(1)} \\ X_1^{(2)} \\ \dots \\ Y_1^{(1)} \\ Y_1^{(2)} \\ \dots \end{pmatrix}$$



	BPM 7	BPM 8	BPM 9	BPM 10	BPM 11
X	-0.04	5.58	-0.03	3.14	13.23
Y	-0.49	1.61	-0.25	-0.38	1.05

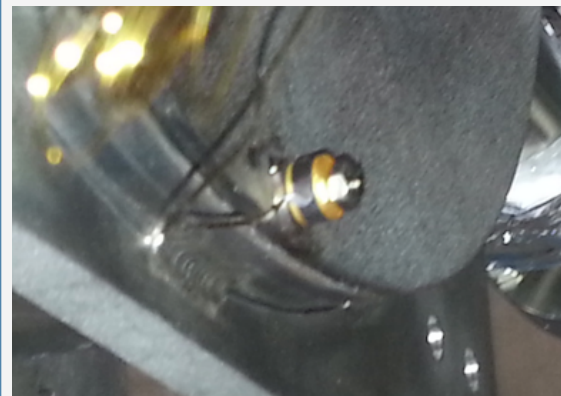
BBA experiment for SC solenoids are carried out, which is very helpful for SC tuning!



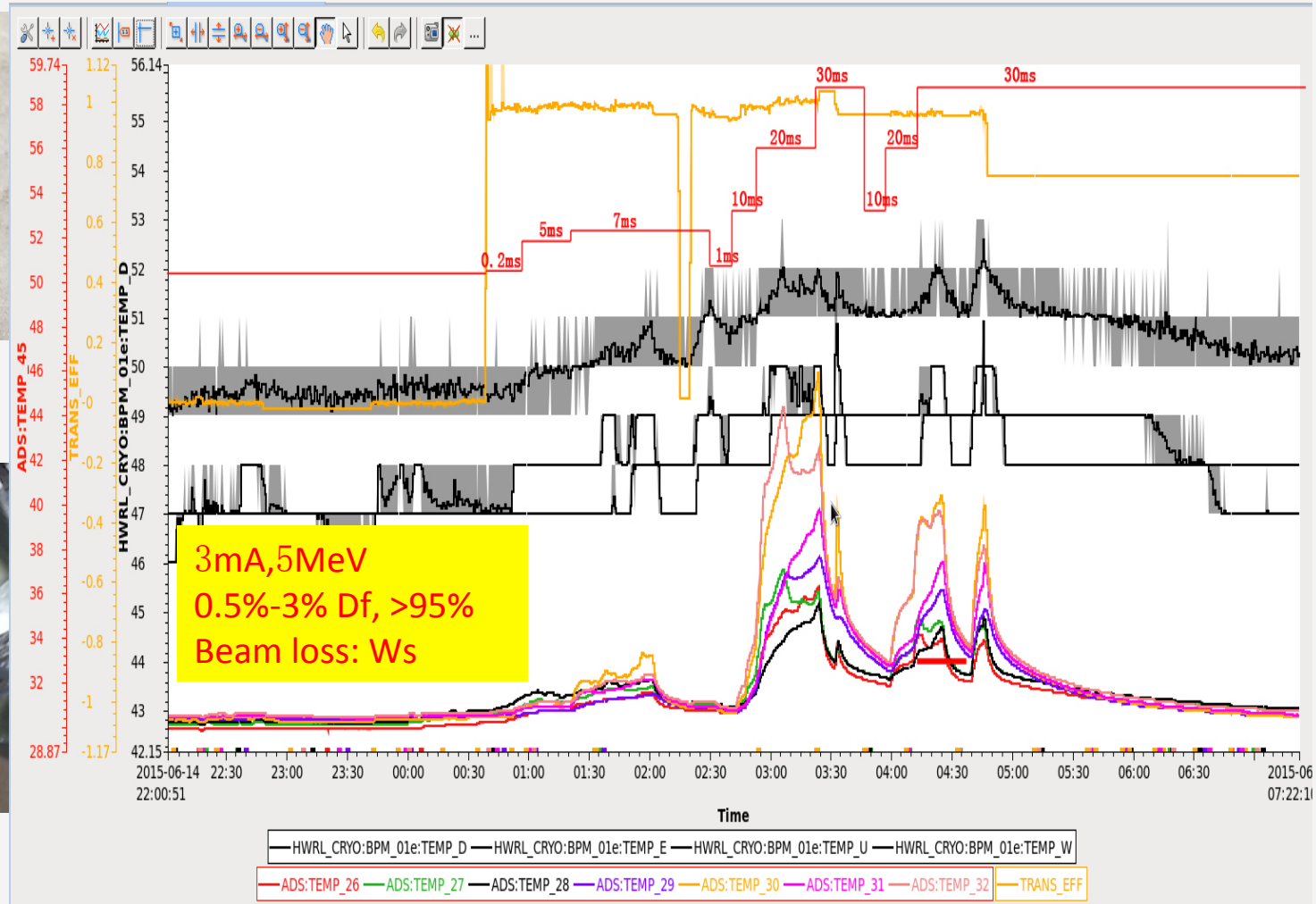
Beam loss detection by the temperature sensor



Type: PT100
Normal temperature



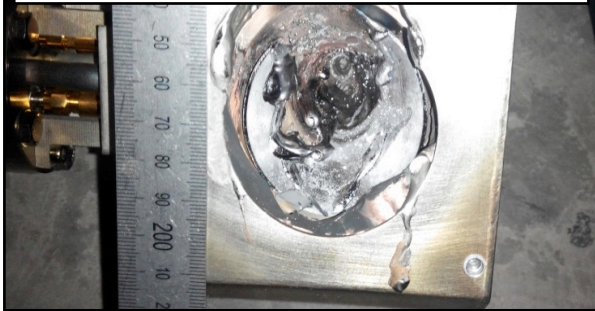
LAKE SHORE: DT-670B
2K-305K ($\pm 0.5K$)



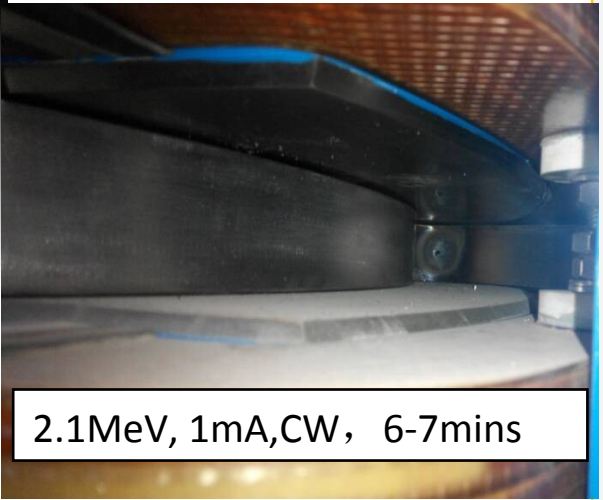


No-interceptive diagnostics-BPMs

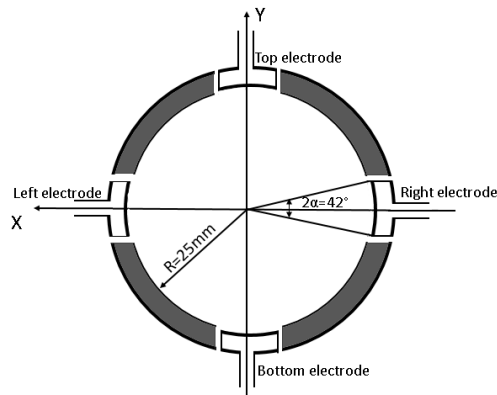
128 hours beam including
2.1MeV, 4.5h, 10mA, and 6h
6mA CW beam.



2.1MeV, 10mA, 100us, 1Hz



2.1MeV, 1mA, CW, 6-7mins



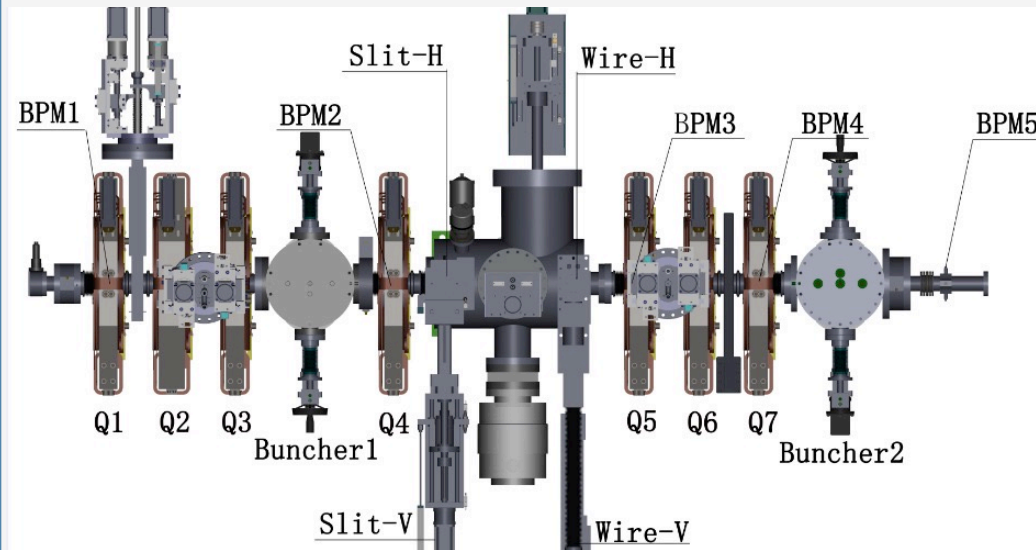
Transverse:
$$\langle x^2 \rangle - \langle y^2 \rangle + \bar{x}^2 - \bar{y}^2 = a^2 \frac{\alpha}{\sin 2\alpha} \frac{A_R + A_L - A_T - A_B}{A_R + A_L + A_T + A_B}$$

Longitudinal:
$$Z_\varphi = \left(-\frac{360^{\circ 4}}{2\pi^2} \left(\frac{f_{RF}}{f_{BPM}} \right)^2 \text{Ln} \left(AMP_{bpm} \cdot I_{BPM}^{sum} \right) \right)^{-1/2}$$

The 6-D Twiss parameters can be calculated by scanning technology.



No-interceptive diagnostics-BPMs



- ❑ Multi-Q scanning
- ❑ Small beam size inside the BPM
- ❑ Benchmarked with slit + wire scanner method
- ❑ The longitudinal emittance is under study

$$\begin{pmatrix} \langle x_i^2 \rangle \\ \langle x_i x_i' \rangle \\ \langle x_i'^2 \rangle \\ \langle y_i^2 \rangle \\ \langle y_i y_i' \rangle \\ \langle y_i'^2 \rangle \end{pmatrix} = (A^T A)^{-1} A^T \begin{pmatrix} (\langle x_f^2 \rangle - \langle y_f^2 \rangle)^{(1)} \\ (\langle x_f^2 \rangle - \langle y_f^2 \rangle)^{(2)} \\ \dots \\ (\langle x_f^2 \rangle - \langle y_f^2 \rangle)^{(m)} \end{pmatrix}$$

	BPM	Wires	$\Delta(\%)$
α_x	0.146	0.302	52
$\beta_x(m)$	0.212	0.22	3.6
$E_x(mmmrad)$	0.294	0.286	2.8
α_y	-0.397	-0.102	289
$\beta_y(m)$	0.141	0.121	5.0
$E_y(mmmrad)$	0.306	0.297	3.0

Noninterceptive transverse emittance measurements using BPM for Chinese ADS R&D project (NIMA)



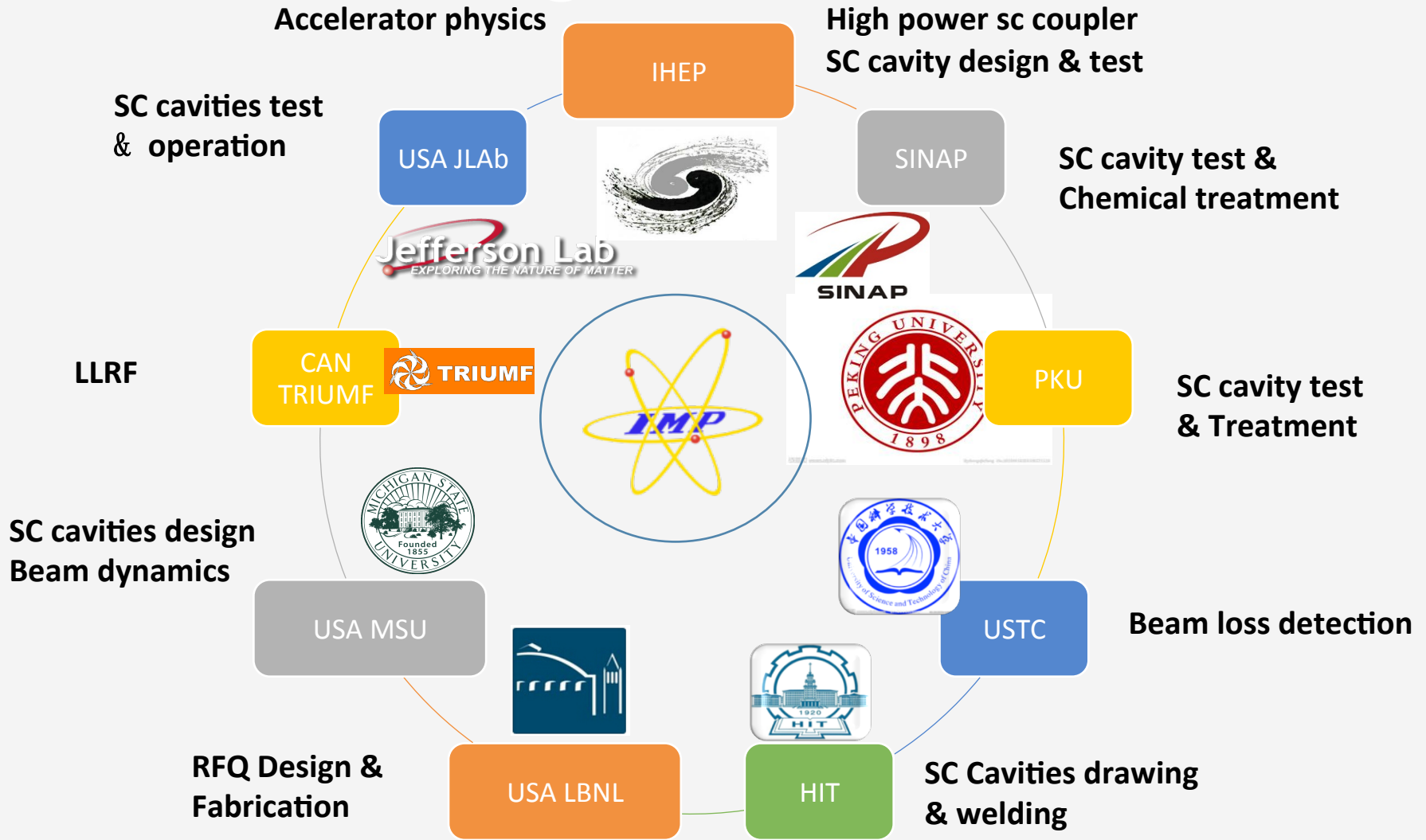
Summary and outlooks



- RFQ with CW 10mA, stability still on the way.
- Transverse emittance has been studied carefully to avoid beam loss from mismatch, longitudinal is the point next step.
- BBA experiments has been carried out to avoid beam loss from beam displacement.
- The temperature sensor has been applied to detect the beam loss for SC linac.
- 6D-emittance measurements with no-interceptive BPM is proposed and the transverse implemented



Acknowledge





THANKS *for your attention!*