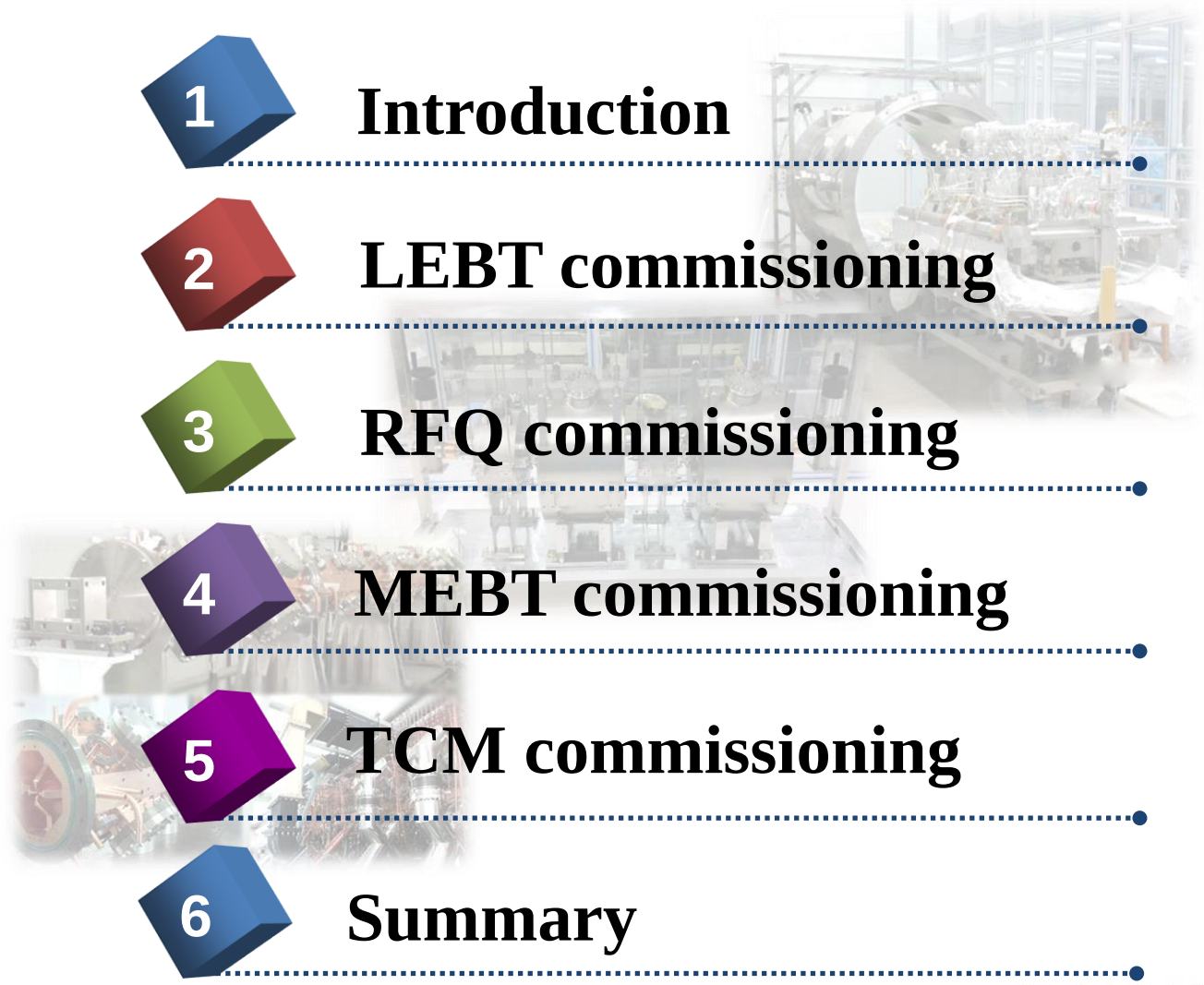
Institute of High Energy Physics

Front end commissioning for China-ADS Injector-I test facility

YAN Fang

On behalf of China-ADS beam commissioning group

Outline



1 Introduction

2 LEBT commissioning

3 RFQ commissioning

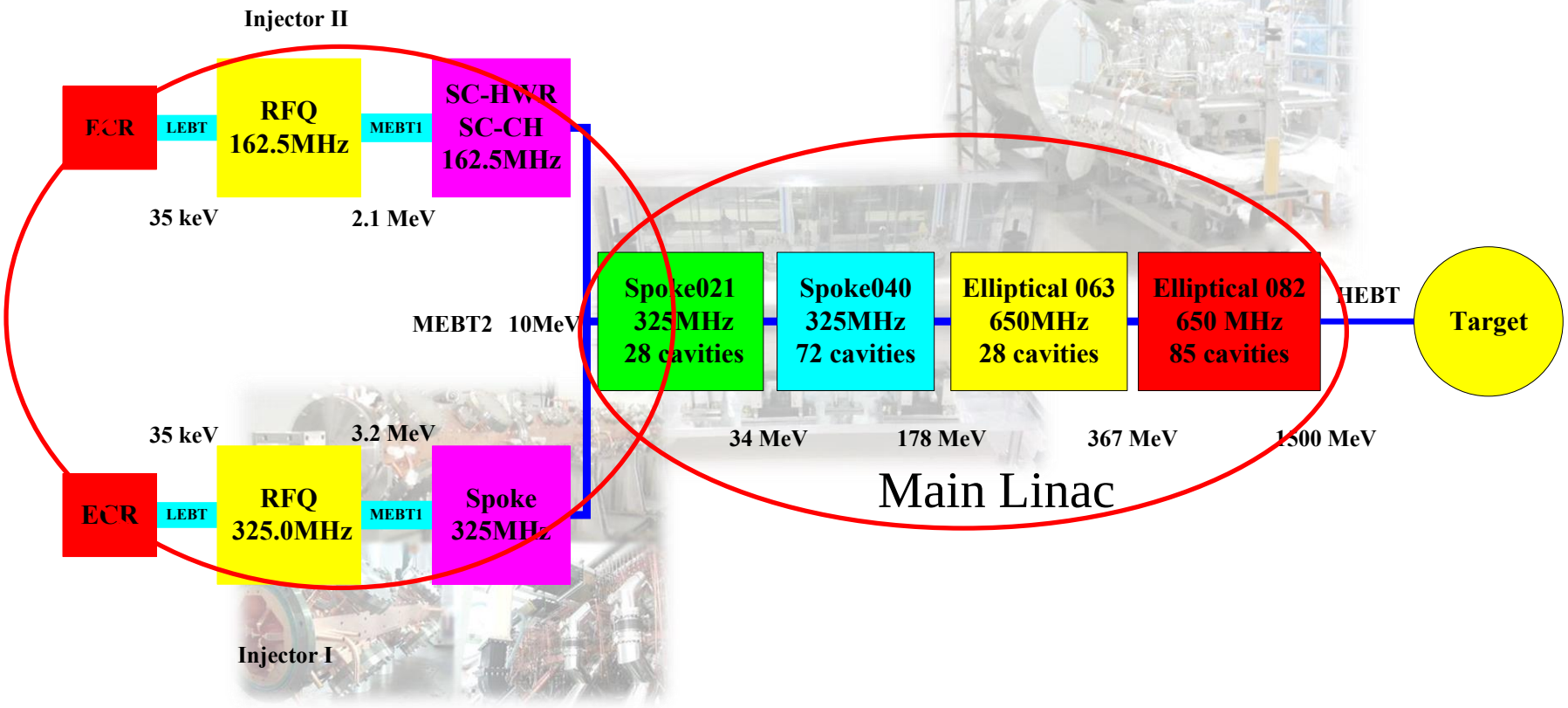
4 MEBT commissioning

5 TCM commissioning

6 Summary

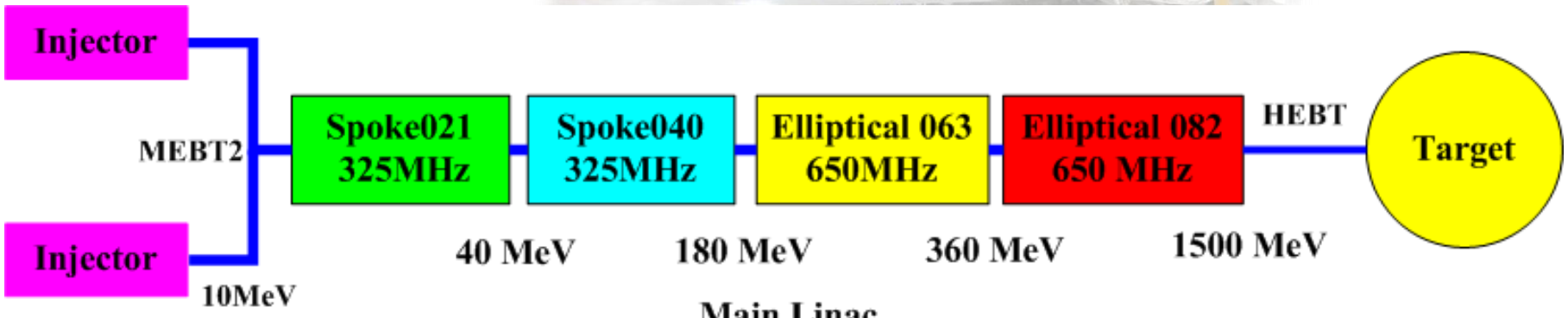
1. Introduction

Schematic figure of ADS driver linac



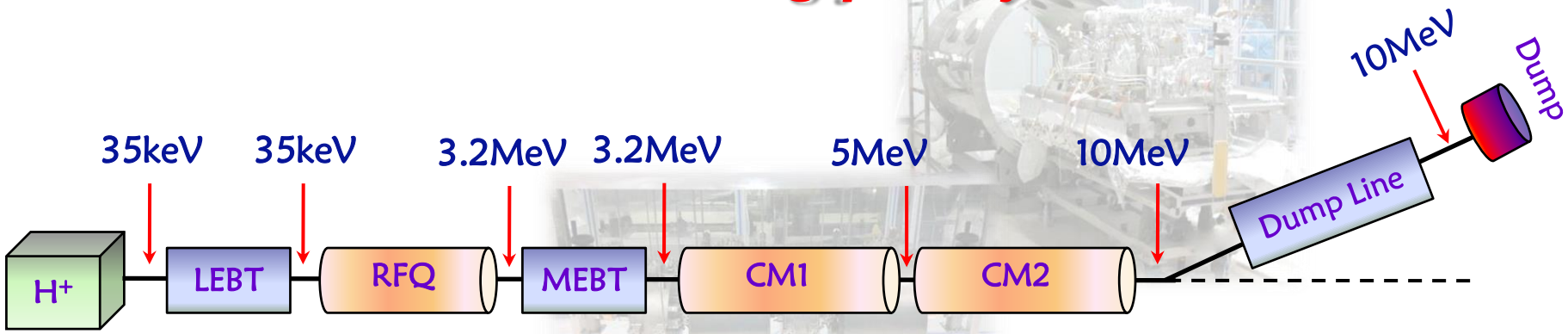
1. Introduction

Schematic figure of ADS driver linac



1. Introduction

Schematic figure of ADS Injector-I testing facility

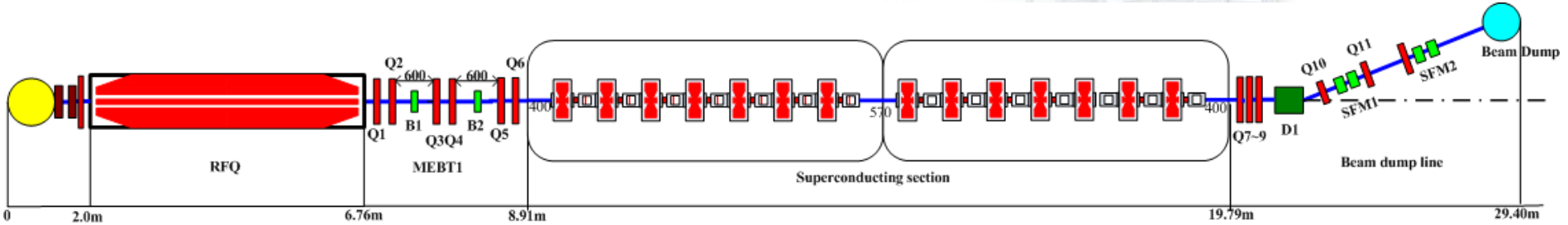


➢ To demonstrate the design scheme. Two different Injector test stand on basis of two different design schemes are fabricated and commissioned independently in IMP & IHEP campus.

➢ The injector-I scheme is based on the frequency of **325MHz** and as shown in the image on top of this slide, it is composed of an ECR source, a LEBT line, a 4-vane type copper structure RFQ, a MEBT and a superconducting linac and a beam dump line.

1. Introduction

Layout of ADS Injector-I testing facility

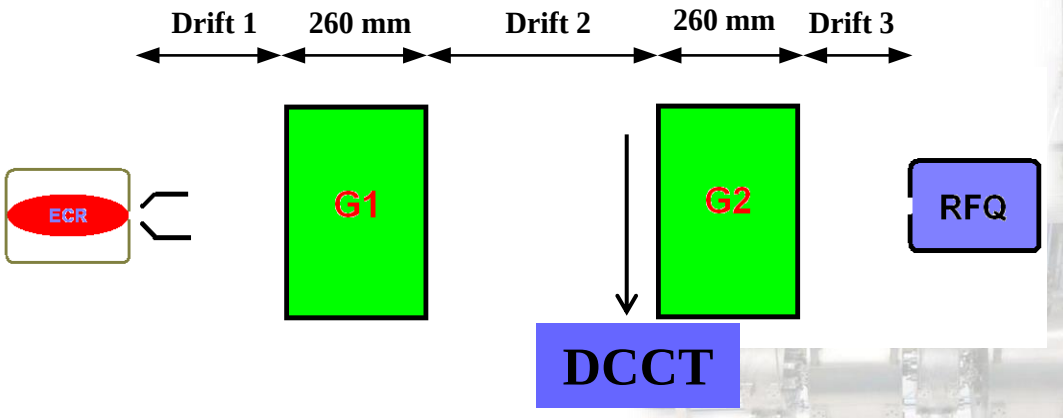


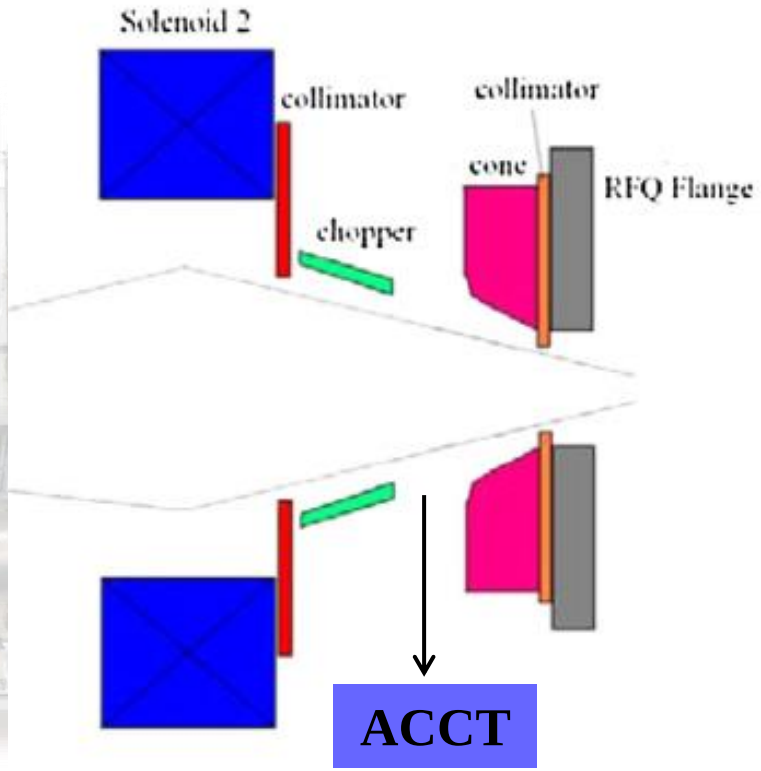
Particle	Proton
Energy (MeV)	10
Current (mA)	10
Beam power (kW)	100
Duty factor (%)	100
RF frequency (MHz)	325

- Injector I testing facility is being commissioned in stages.
- The SOURCE+LEBT+RFQ +TCM have been installed and commissioned.
- The TCM with two β=0.12 Spoke cavities are operated stably at 2K.

2. LEBT commissioning

Total length of the LEBT is 1.67m





Requirement At RFQ entrance

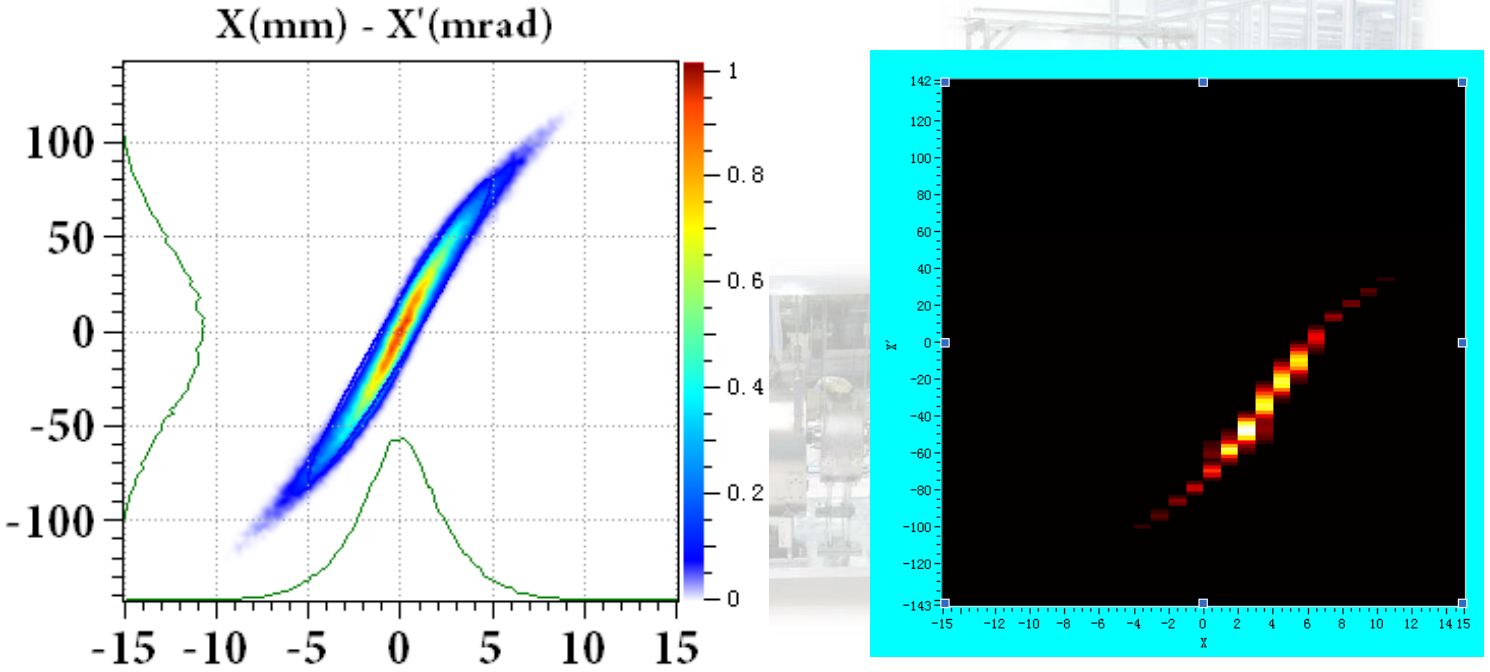
Ion type	proton
Energy	35 keV
Beam current	>10 mA
Operation mode	CW
ΔE/E	<0.1%
Beam current stability	<±1%

LEBTs chopper for accelerator commissioning & fast protection:

- Repetition frequency: 1 Hz~ 50 Hz
- pulse width: 30 μs~ CW
- Rise (down) time: <20 ns

2. LEBT commissioning ➡ emittance measurement

- **Beam phase space at the measured location (8.8cm drift downstream the LEBT exit): left for simulation and right for measurement.**

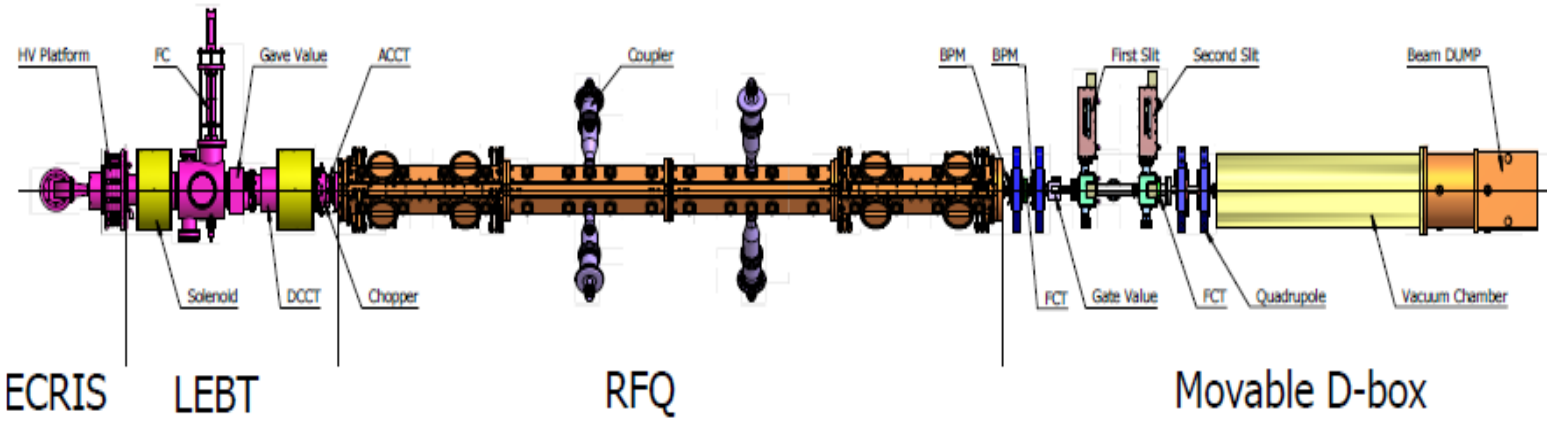


Beam parameters at the LEBT exit and the RFQ entrance

Parameters	I_{beam} (mA)	α	β (mm/mrad)	$E_{n,\,ms}$ (π mm.mrad)
Design goal	10	2.41	0.0771	<0.20
Measurement (backward deduced from the measured location)	11.5	2.18	0.0774	0.14

Alison detector: 5% background assumed

3. RFQ commissioning ➡ RFQ specifications

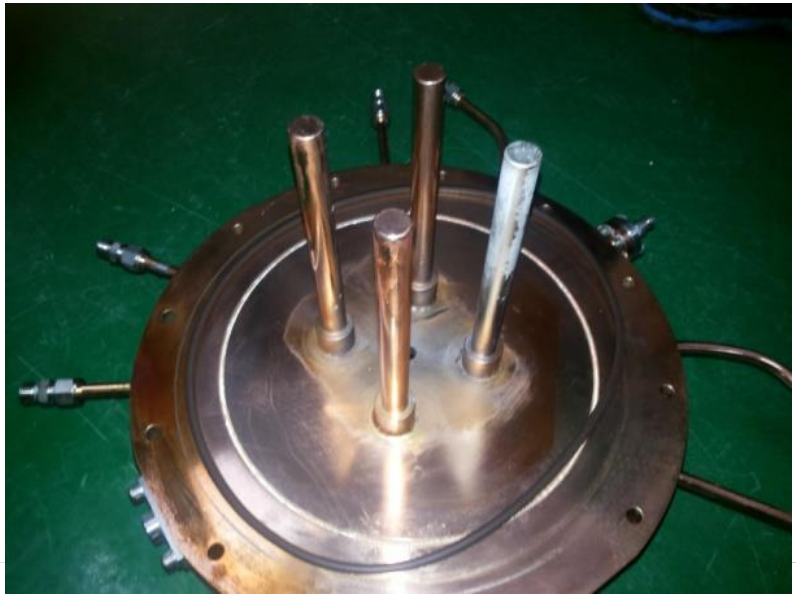


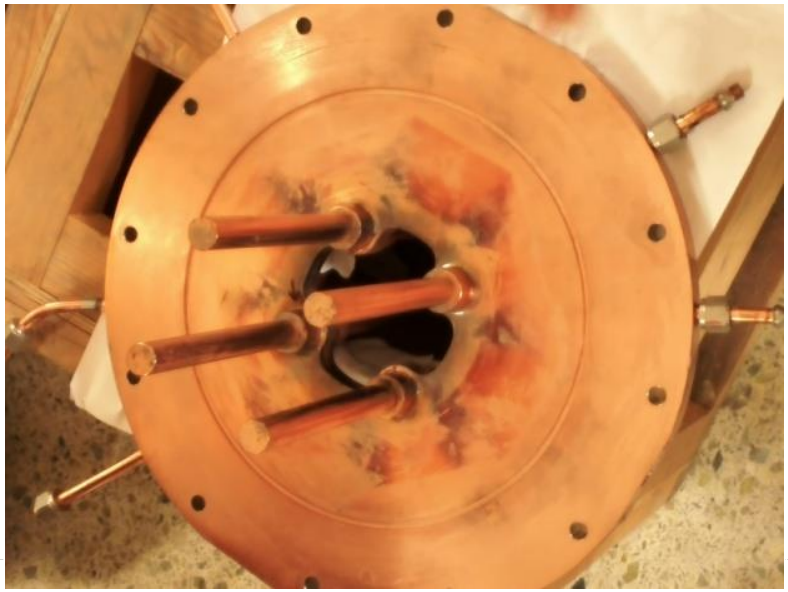
- It is composed of two resonantly coupled physical segments and each segment includes two technical modules connected together with flanges.
- Totally 4 couplers are mounted on the RFQ and two couplers on one physical segment.
- The longitudinal normalized rms emittance is designed to be smaller than transverse emittance for better cavity efficiency.

Parameters	RFQ in IHEP
RF frequency (MHz)	325.0
Pulsed beam current (mA)	15
Injection energy (keV)	35
Output energy (MeV)	3.2
Inter-vane voltage (kV)	55
Minimum aperture (mm)	2
Maximum modulation	2
Accelerator length (cm)	469.95
$\varepsilon_{n.rms.t}$ (π.mm.mrad)	0.2
$\varepsilon_{n.rms.l}$ (π.mm.mrad /π.deg.MeV)	0.16 / 0.058

3. RFQ commissioning ➡ Towards CW

- **The RFQ conditioning began on May 15th , 2014 .**
- **71% RF duty factor was achieved on June 12nd, 0.71 ms /1 kHz, 250 kW power, but stopped by the vacuum leakage of the entrance plate because of the cooling water valve of the plate closed.**
- **Then an aluminum plate was installed instead temporarily .**
- **80% duty factor was achieved, 0.8 ms/1 kHz, 257 kW power in the RFQ on June 20th, 2014, but was interrupted because of the vacuum leakage of the RFQ coupling plate.**

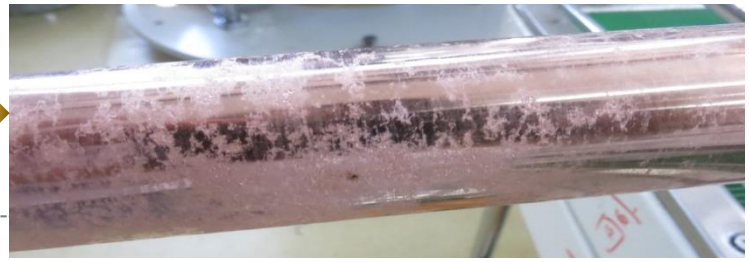




3. RFQ commissioning ➡ Towards CW

- On July 6th , 2014, the new coupling plate was installed.
- On July 12th , in 0.996 ms/1 ms, 99.6% RF duty factor, 240 kW power
- July 17~19th , long pulse, 24 ms/25 ms, 96% duty factor, 229 kW.
- On July 19th , the new RFQ entrance plate installed.
- On July 22nd , total four coupler ceramic windows were cracked because of the head LLRF interlock was shielded artificially for control system commissioning of the LLRF system.
- On July 31st , 4 new couplers installed.
- On Aug 21st , pulse mode, 12.5 ms/79.975 Hz, top record of 99.97% duty factor was achieved, 250 kW, but couldn't keep very long.
- On Aug 22nd , CW mode, 194 kW, keep 30 min, However 2nd coupler vacuum leakage happened during the CW conditioning.

Inner conductor antenna tip: possible serious MP
Image courtesy of the report "ADS 325MHz RFQ FPC problem review", Huang Tongming



3. RFQ commissioning ➡ Towards CW

- On Aug 27th , the 2nd coupler installed.
- To Sep 3rd , pulse mode, 19.7 ms/20 ms, RF duty factor 98.5%, 233 kW /CW mode, 152 kW.
- On Sep. 4th , RF contact spring discharging were found on #4 coupler.

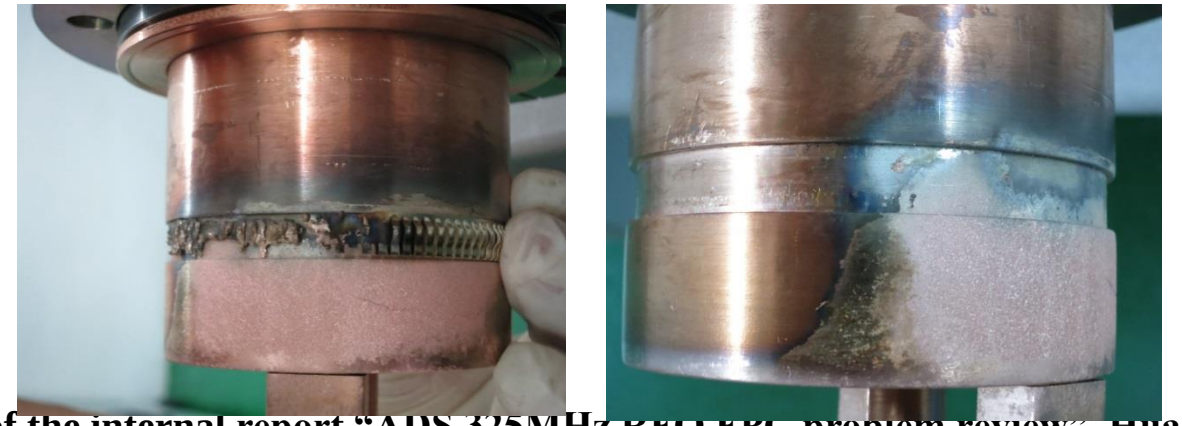


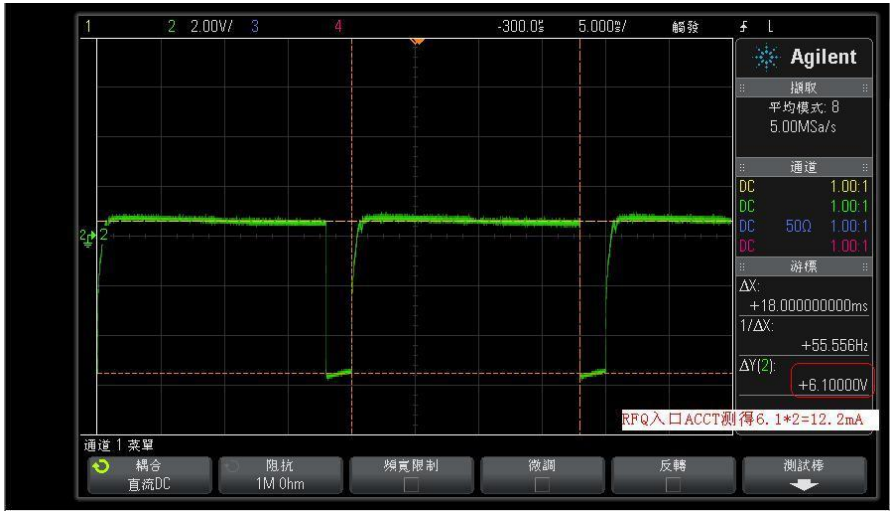
Image courtesy of the internal report "ADS 325MHz RFQ FPC problem review", Huang Tongming

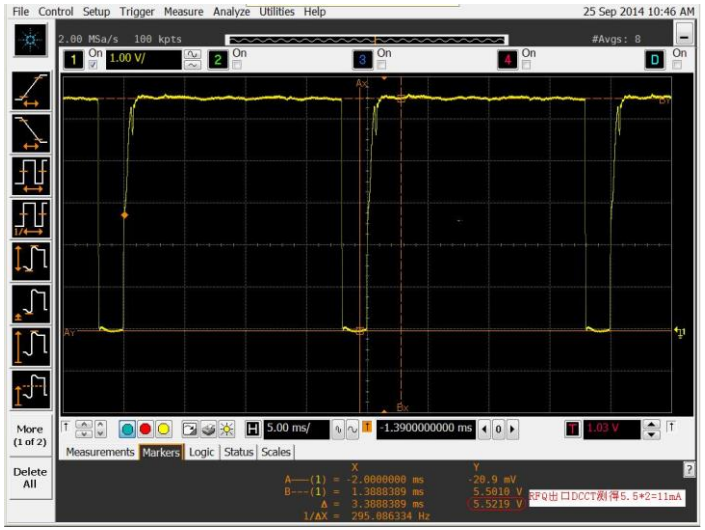
- On Sep 14th , the 3rd coupler ceramic window cracked due to the inner and outer conductor shorten by the condensate water.
- On Sep 19th , the new 3rd coupler installed.
- On Sep 26th , 19.8 ms/20 ms, RF duty factor 99%@256 kW
- The commissioning was stopped for the scheduled MEBT&TCM installation.

3. RFQ commissioning ➡ With beam

Transmission of the beam with duty factor of 90%

Entrance current: 12.2mA (LEBT ACCT) The beam current out of the RFQ: 11mA (DCCT)



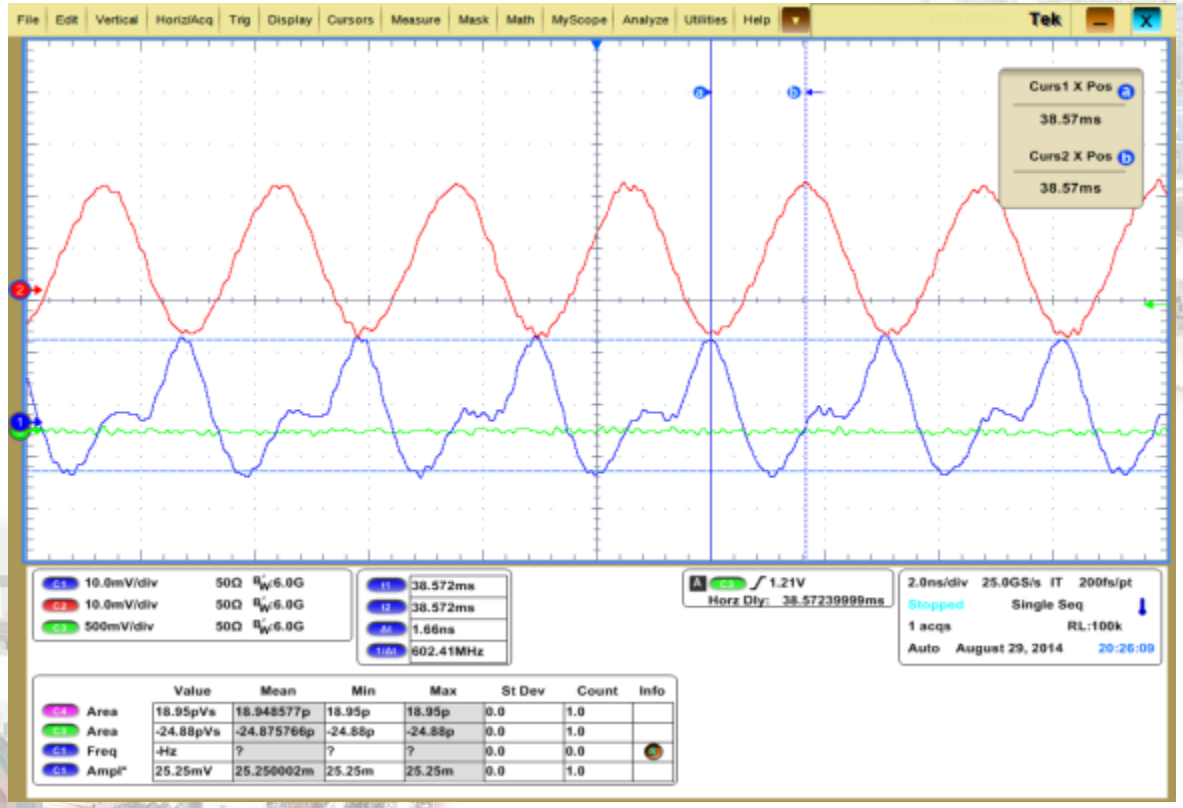


Beam Duty factor	50%	60%	65%	70%	90%
Transmission efficiency	95%	95%	95.6%	95%	90%
RFQ output current	11.1mA	10.9mA	10.9mA	10.6mA	11mA
Last time	8.5min	60min	4.3min	5min*	3min
Pulse width/Rep. Freq.	10ms/50Hz	12ms/50Hz	13ms/50Hz	14ms/50Hz	18ms/50Hz
Power in the cavity	289kW	305kW	314kW		298kW
Experiment Date	20140901	20140901	20140901	20140902	20140925

*Interlocked because of the temperature of the beam dump target area over 60°.

3. RFQ commissioning

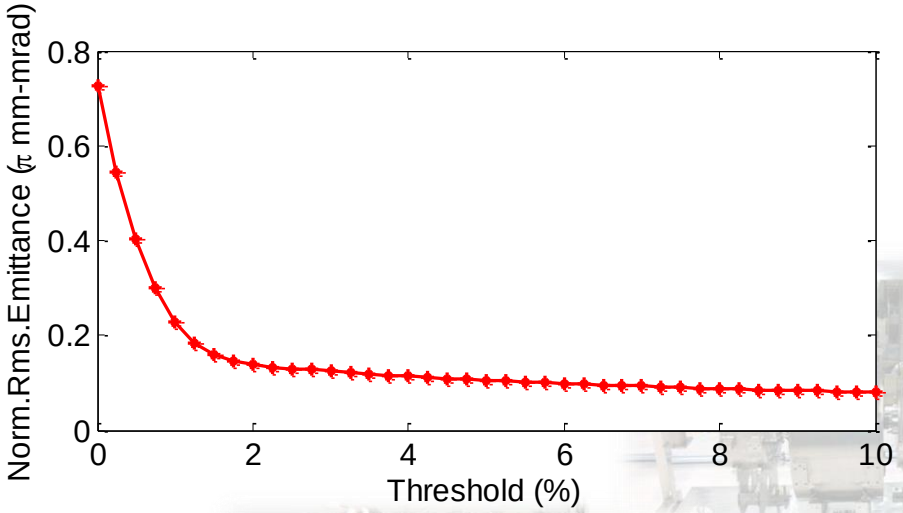
Energy measurement

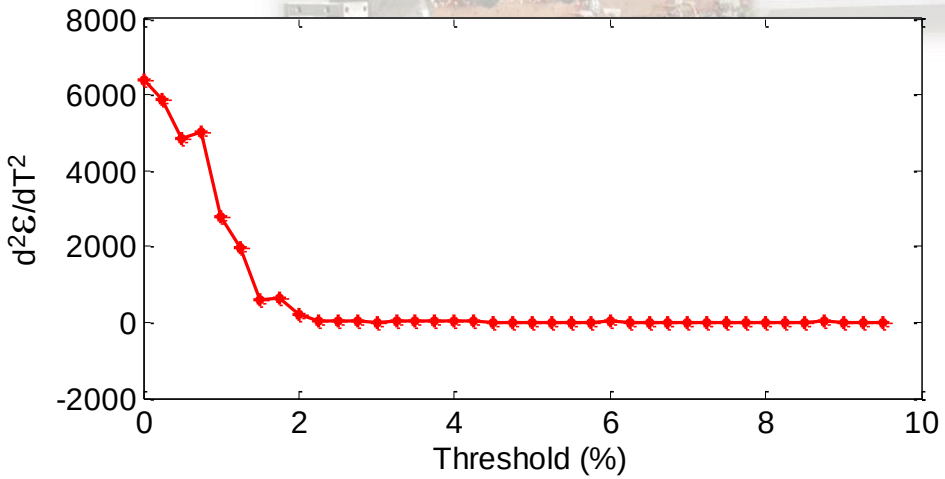


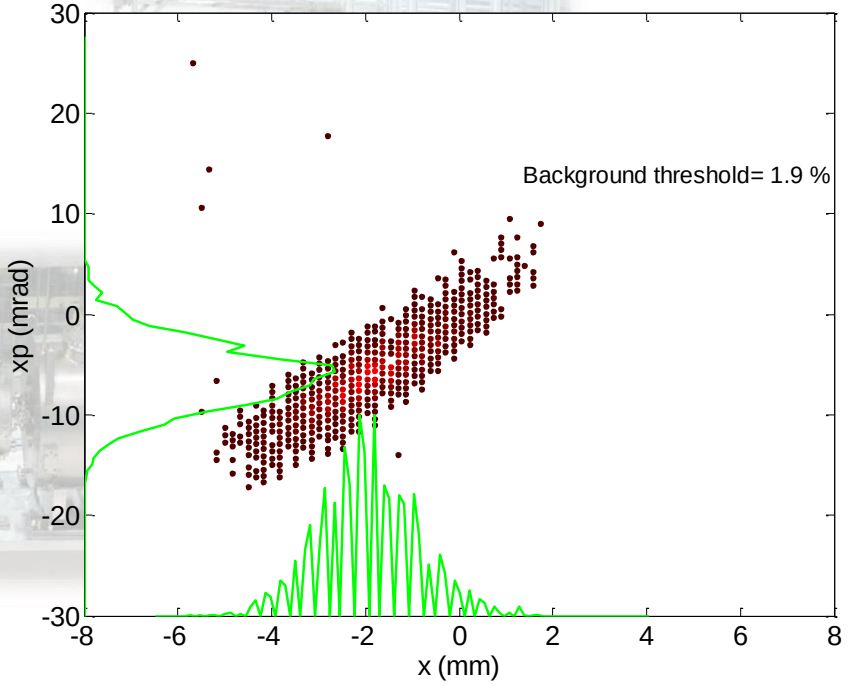
- *The RFQ energy was measured using two FCTs*
- *The upstream FCT signal: blue The downstream FCT: red*
- *RFQ energy: 3.2MeV*

3. RFQ commissioning

Emittance measurement using double slits



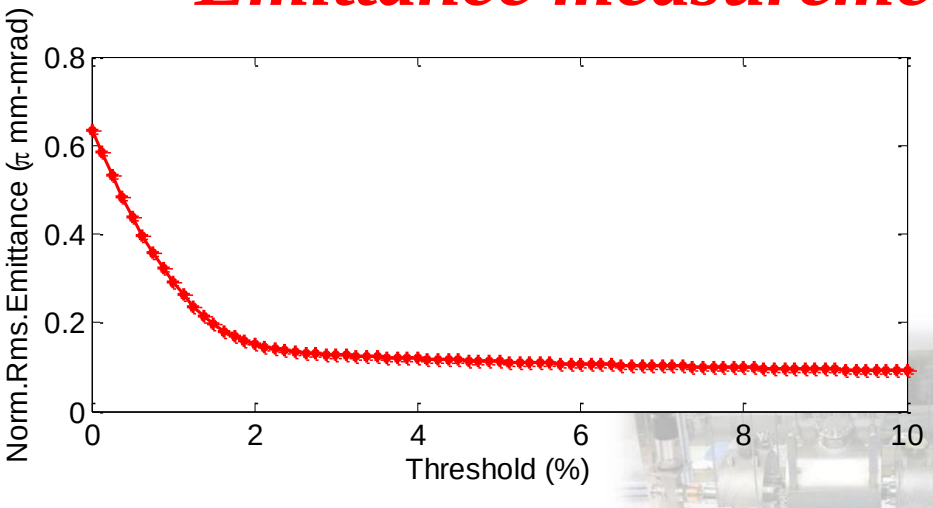


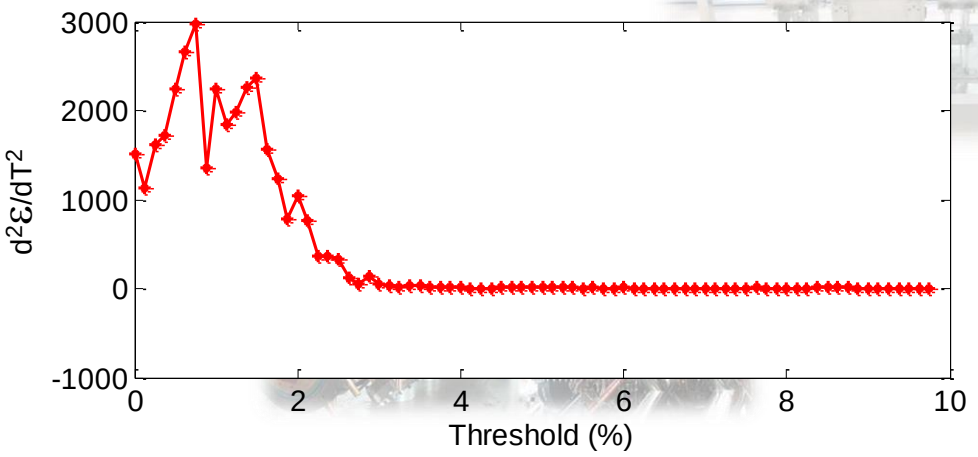


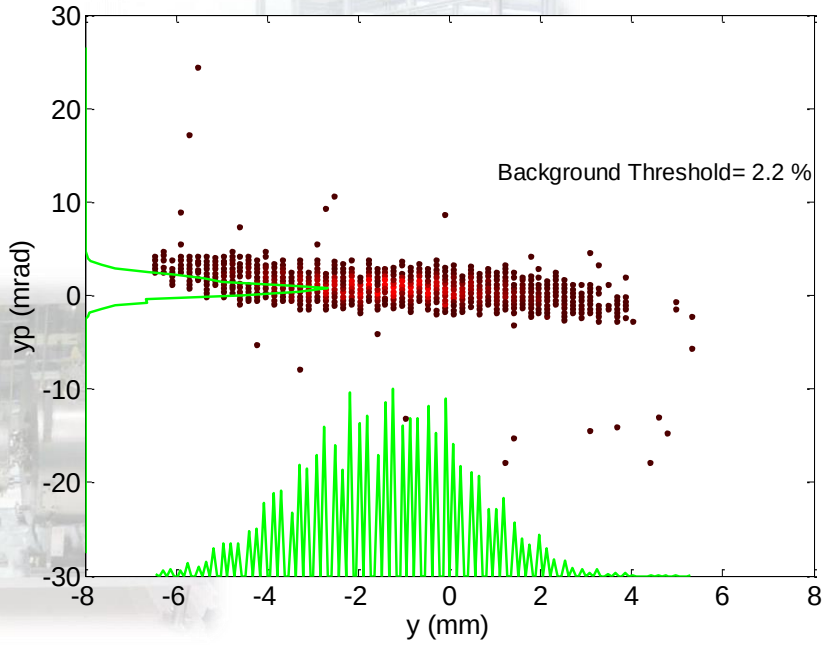
$$\varepsilon_{n,rms} = 0.142\ \pi mm.mard$$
$$\alpha = -1.78, \beta = 0.648\ mm/mard$$

3. RFQ commissioning

Emittance measurement using double slits

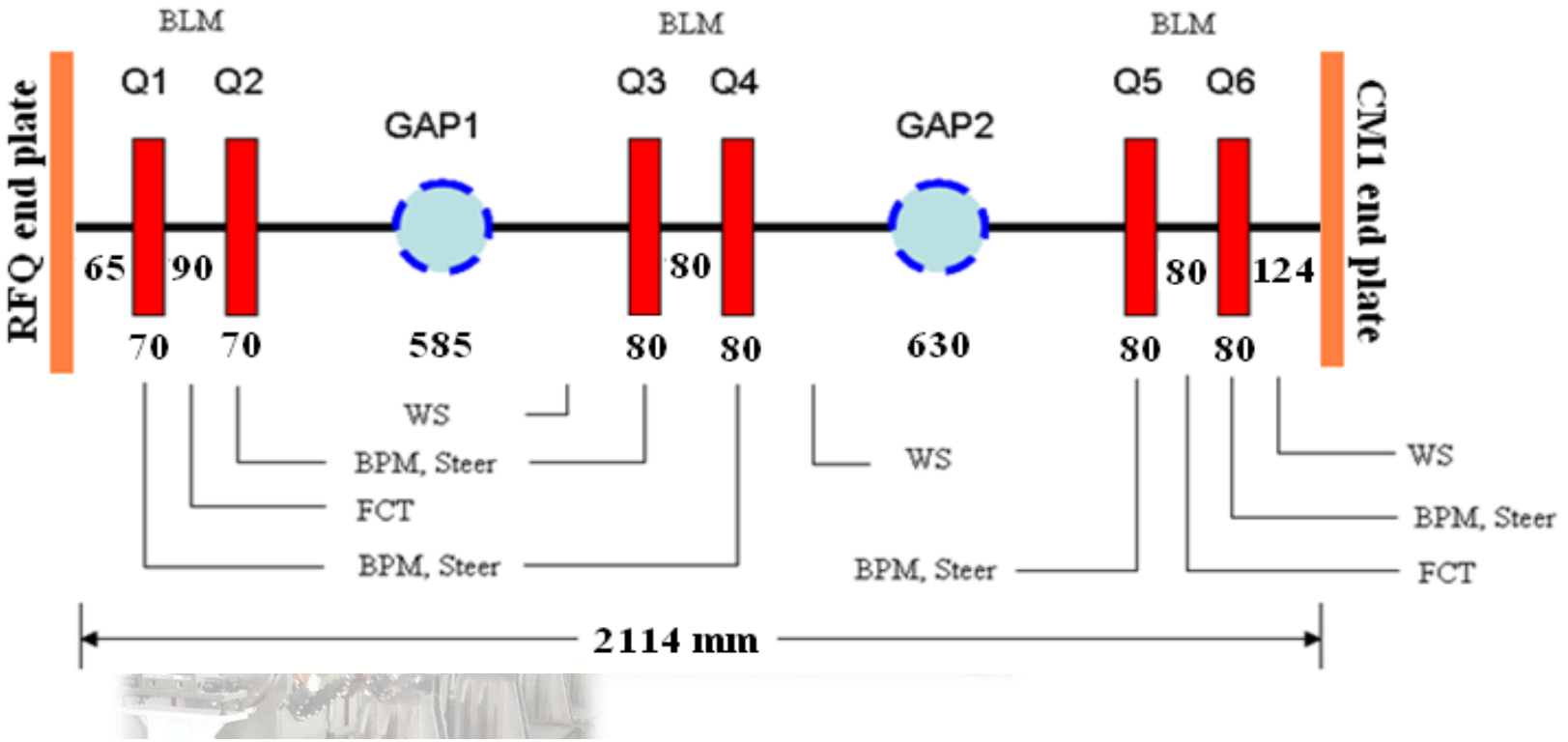






$$\varepsilon_{n,rms} = 0.143\ \pi mm.mard$$
$$\alpha = 0.46, \beta = 1.85\ mm/mard$$

4. MEBT commissioning ➡ MEBT layout



- **MEBT is composed of 6 Quadruples, 6 Steering magnets and 2 Bunchers**
- **Beam diagnostic devices includes 6 Beam Position Monitors, 3 Beam Loss Monitors, 2 Fast Current Transformers and 3 Wire Scanners.**

4. MEBT commissioning

Orbit corrections & the RFQ output energy

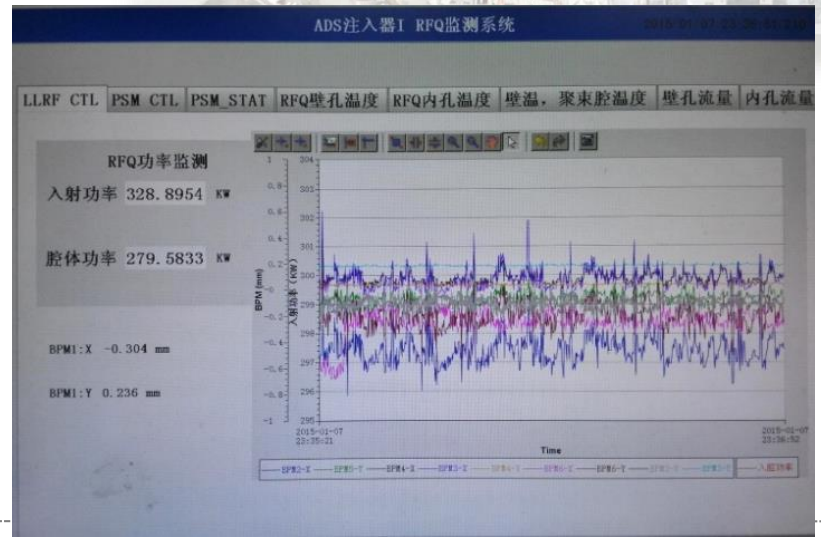
- **Beam conditions:**
  10Hz/300us, 0.3% duty factor,10mA
- **Theoretical cavity power dissipation:**
  272.94 (1.4*$P_{SUPERFISH}$) (kW)

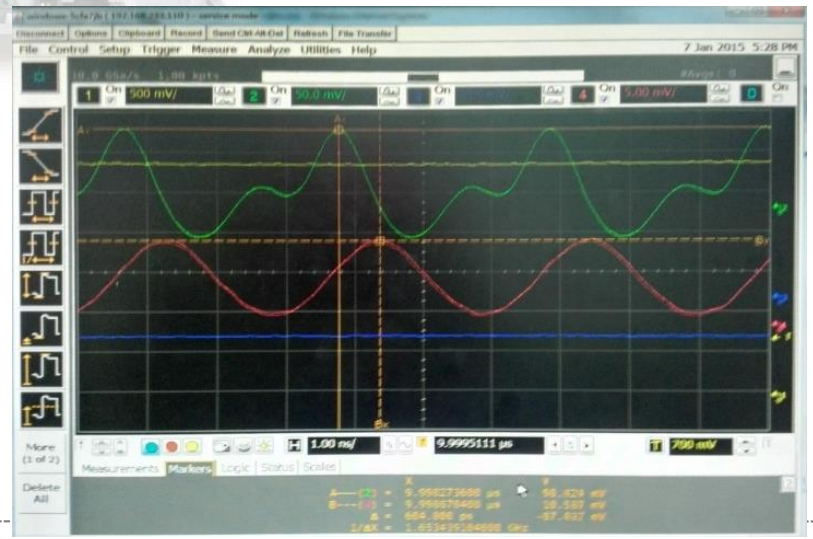
The middle three BPMs offsets according to the beam based BBA

OFFSET	X(mm)	Y(mm)
BPM2	-0.28	0.05
BPM3	0.3	0.08
BPM4	0.055	-0.5

The beam center vibrating measured on all the BPMs are under the range of ±0.15mm

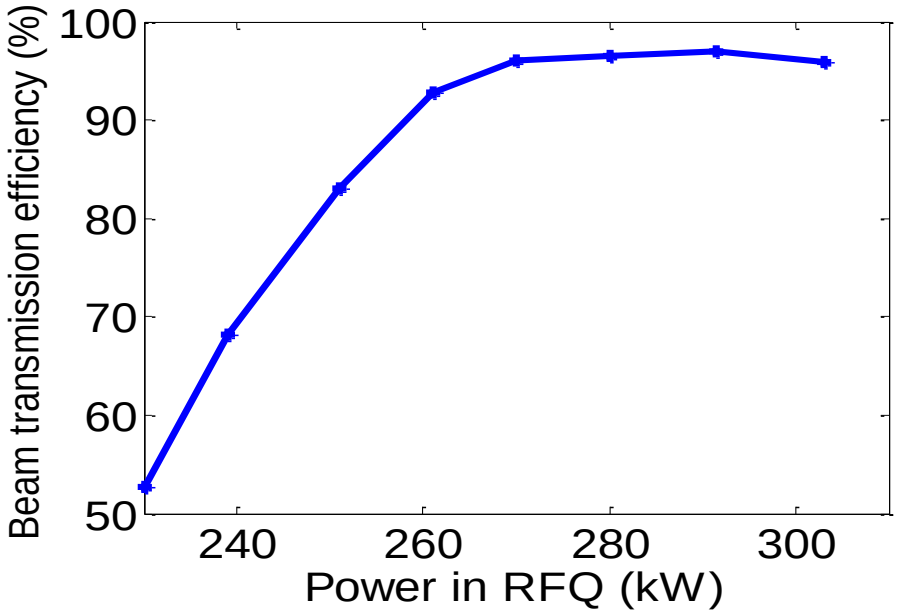
The RFQ out put energy is 3.19MeV (@302kW) measured by 2 FCTs on the MEBT





RFQ transmission

- **Measurement conditions:**
  300μs/50Hz, beam duty factor: 1.5%
- **Conclusion:**
  Power in RFQ: 270-303 kW, transmission:96%-97%
  Fit well with the Parmteq simulations.



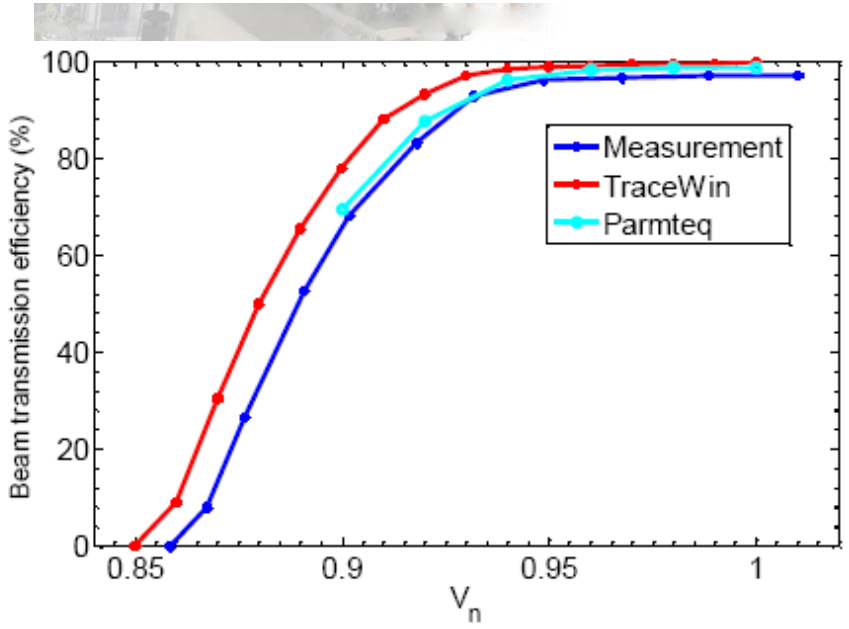
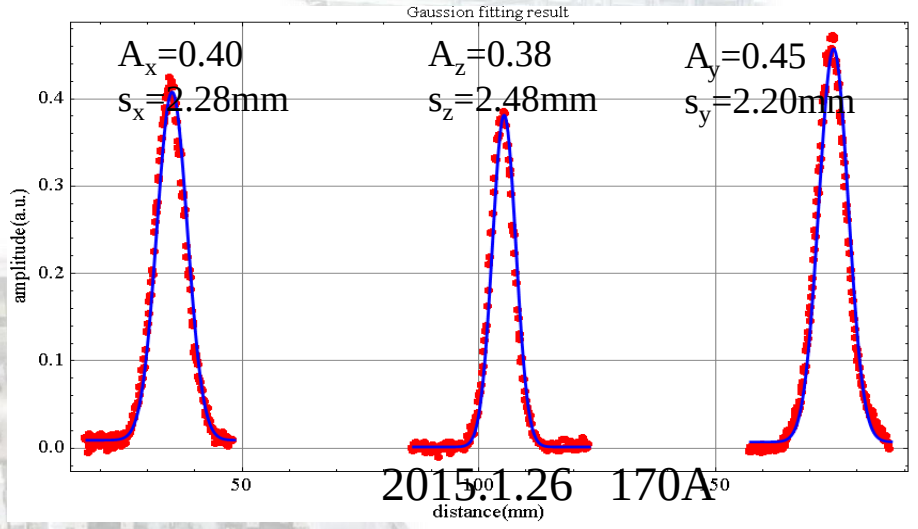


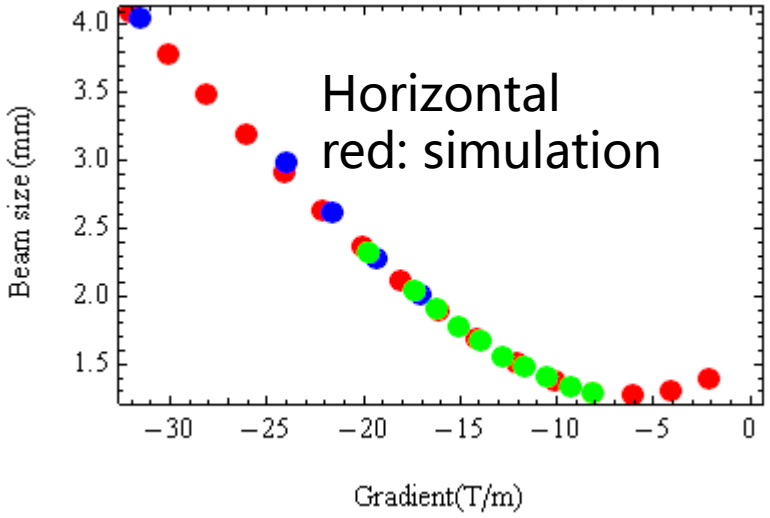
Image courtesy of the paper, "Beam commissioning of C-ADS injector-I RFQ accelerator", Cai Meng et al., IPAC2015.

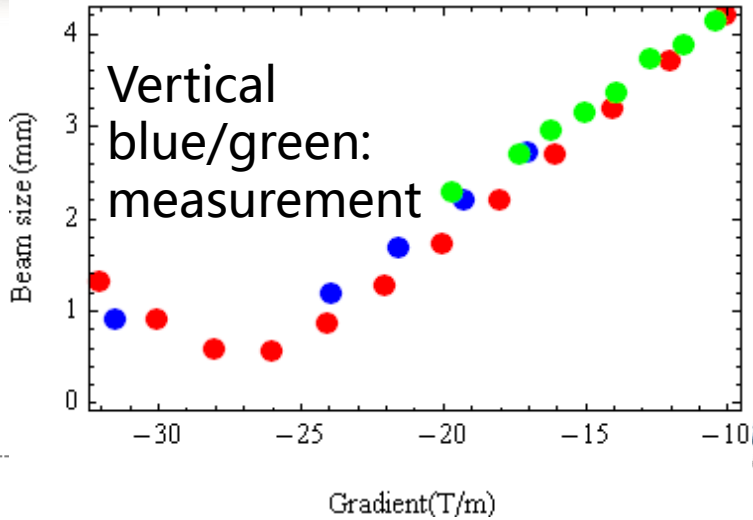
4. MEBT commissioning ➡ Emittance measurement

Quadrupole scan

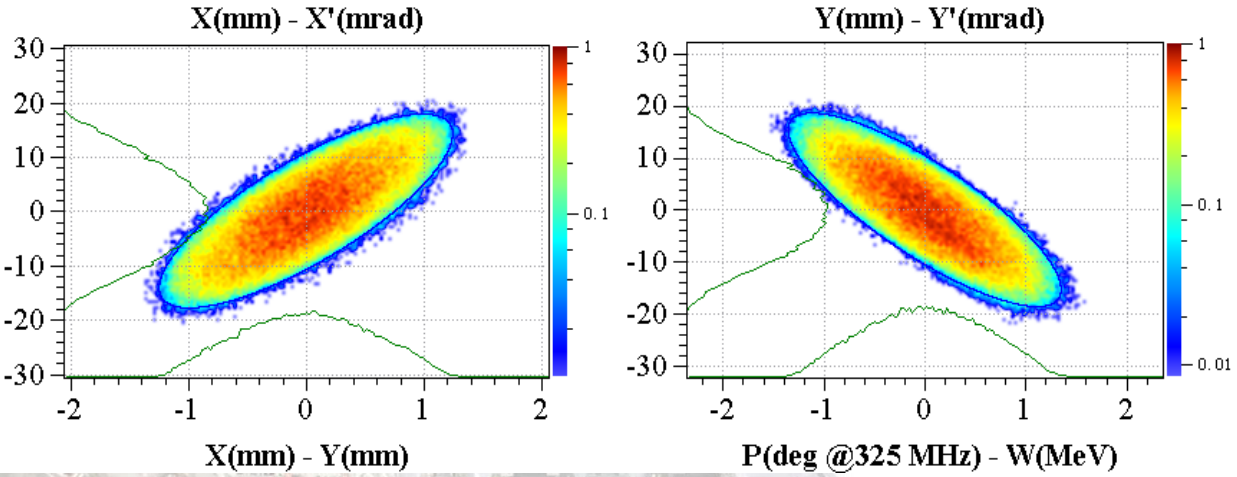
Beam profile monitor







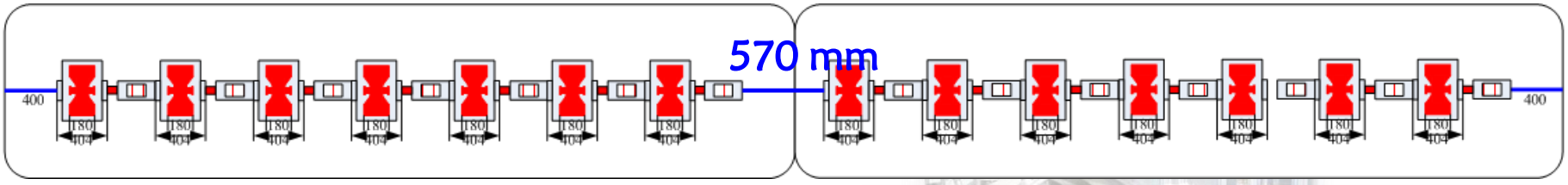
Quadrupole scan ---RFQ exit

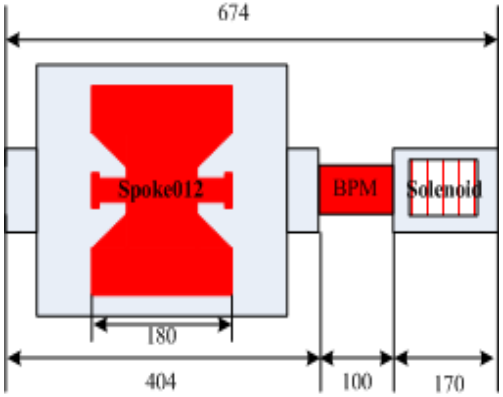


Beam performance at the MEBT entrance

Parameters	α_x/α_x	β_x/β_y (mm/mrad)	$E_{n,rms,x/y}$ (π mm.mrad)
Simulation results	-1.3/1.46	0.12/0.13	0.21/0.20
RFQ exit (backward deduced from the measured location)	-1.77/2.63	0.14/0.30	0.18/0.15

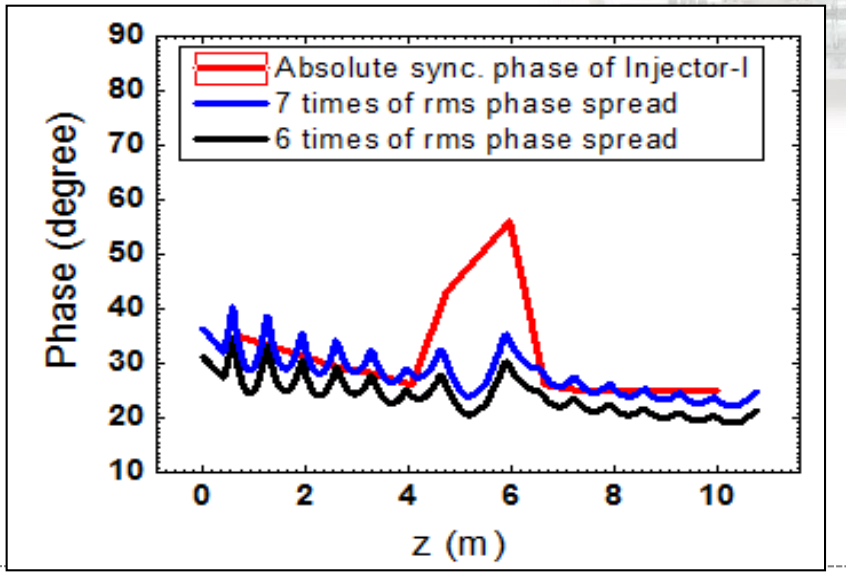
5. TCM commissioning ➡ Injector SC section layout





One period

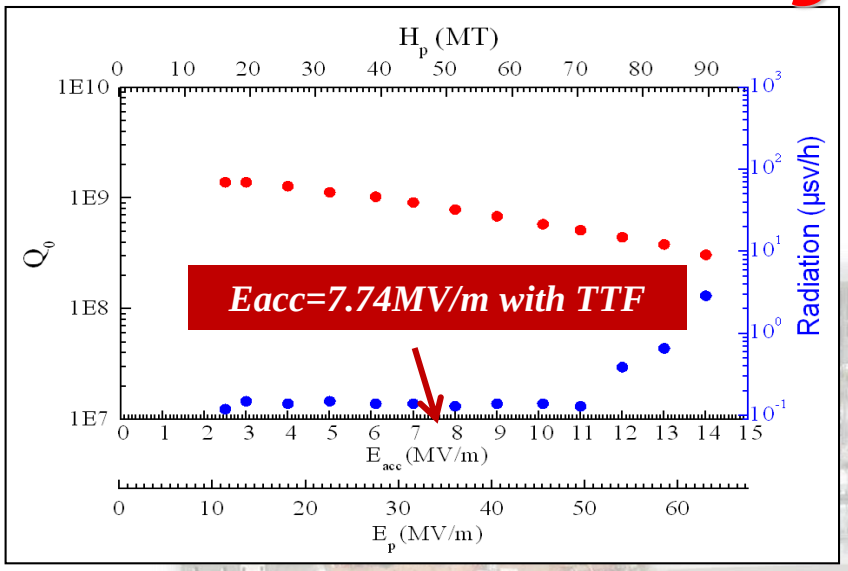
- 1 β=0.12 spoke cavity
- 1 SC solenoid
- 1 cold BPM

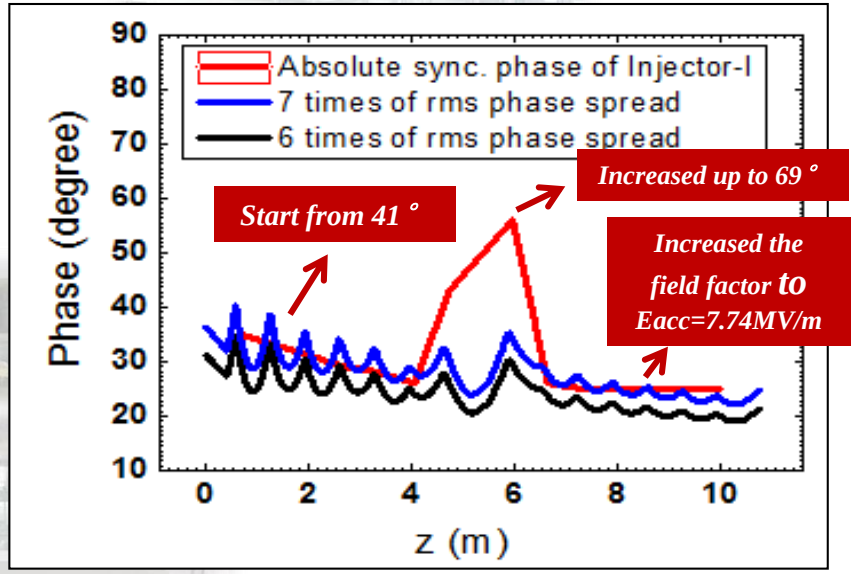


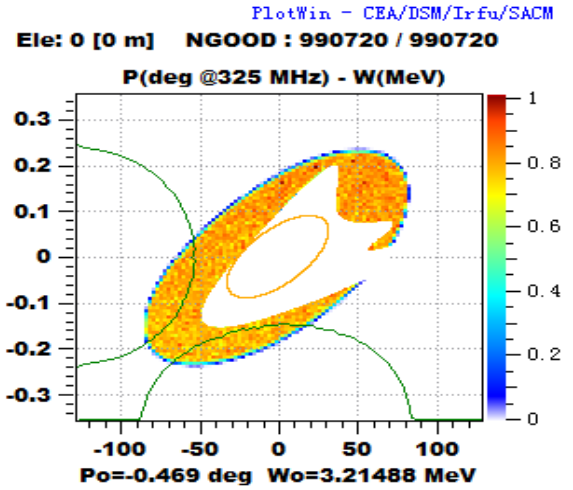
Cav Number	Synchronous phase (deg)	Eacc (MV/m)
1	-35	6.08
2	-33	6.08
3	-31	6.08
4	-29	6.08
5	-28	6.08
6	-26	4.94
7	-43	4.60
8	-56	3.71
9	-26	3.34
10	-25	6.08
11	-25	6.08
12	-25	6.08
13	-25	6.08
14	-25	6.08

5. TCM commissioning ➡ Injector SC section layout

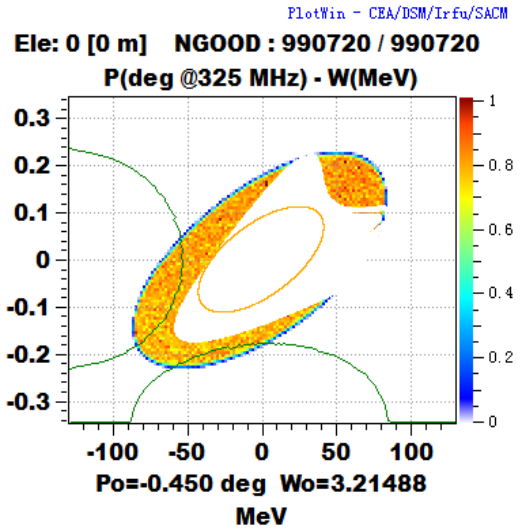
The acceptance is improved on basis of the new cavity testing results







325MHz Injector-I: Old design: Long. Accept. 6.3 times



325MHz Injector-I: New design Long. Accept: 10 times

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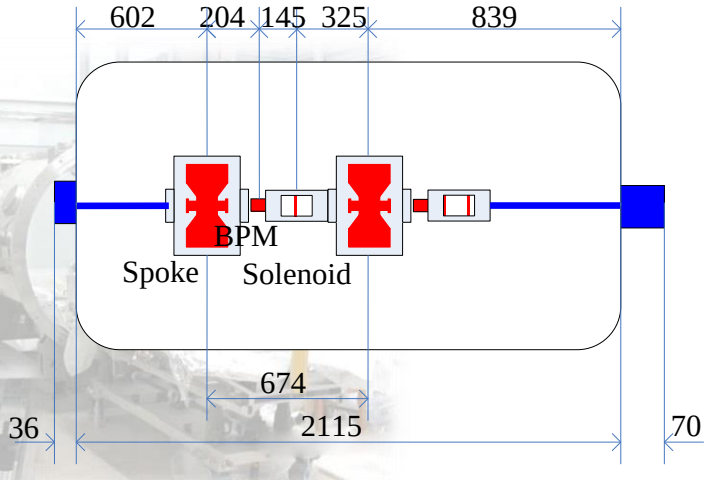
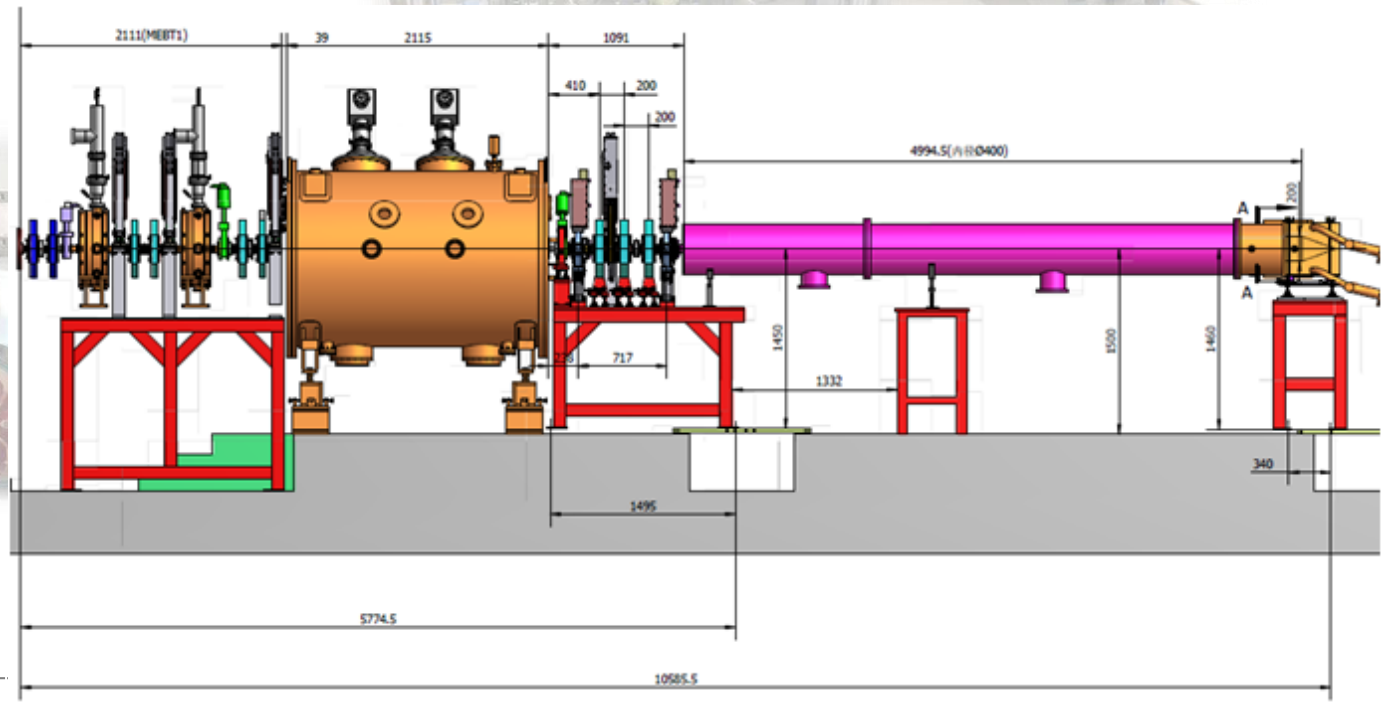
5. TCM commissioning ➡ TCM layout

The Testing Cryomodule (TCM) houses two periods of the Injector SC section, include:

- Two β=0.12 spoke cavity
- Two solenoid
- Two cold BPMs

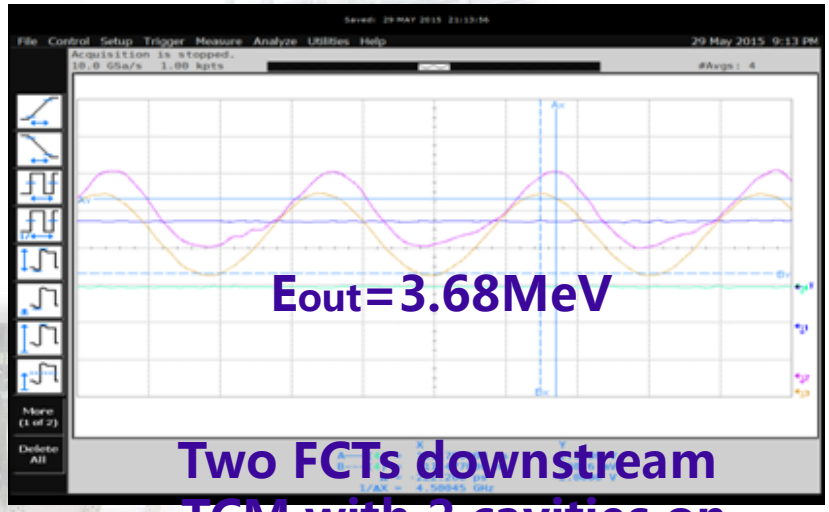




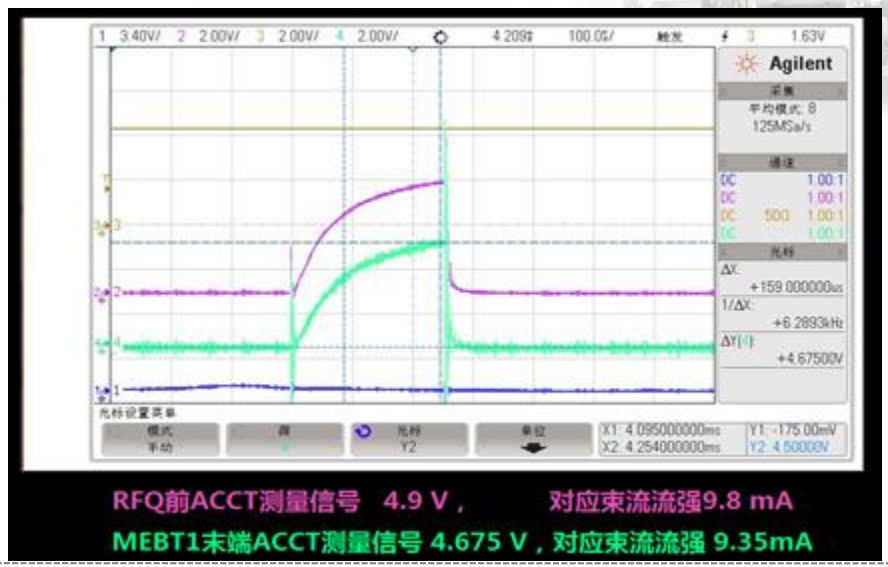
5. TCM commissioning

Preliminary results

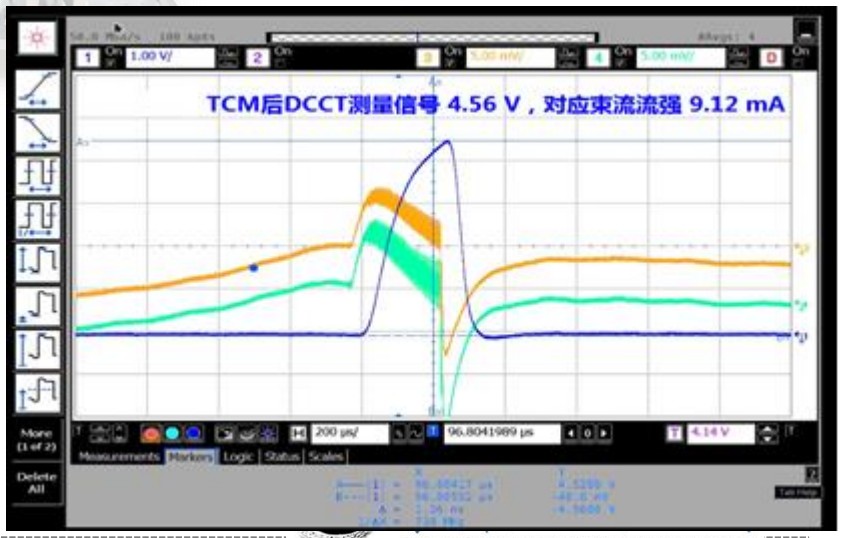
- **Beam duty factor: 1.5 ‰**
- **TCM 2 cavities output energy: 3.38 MeV(1st)/3.68 MeV(2nd)**
- **TCM transmission : 98%**
- **RFQ+TCM transmission : 93%,current: 9.12mA**



Two FCTs downstream TCM with 2 cavities on



Two ACCT signals before & after RFQ



The DCCT signal after RFQ (blue)

6. Summary

- **The source+LEBT+RFQ+MEBT were successfully commissioned with pulsed beam;**
- **The RFQ is still on the way to CW operation;**
- **The maximum RF duty factor achieved during the RFQ commissioning is 99.97% RF duty factor, 12.5 ms/79.975 Hz, 250 kW in cavity;**
- **The highest in cavity power with CW mode is 194kW;**
- **The maximum beam duty factor achieved during the commissioning is 90%, 18ms/50Hz, 298kW in cavity, with beam transmission of 90%;**
- **The TCM commissioning is still on going, the maximum energy achieved is 3.68MeVwith transmission of 93% between the entrance of RFQ and the TCM exit.**

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Thanks for your attentions!!