Commissioning of C-ADS Injector I

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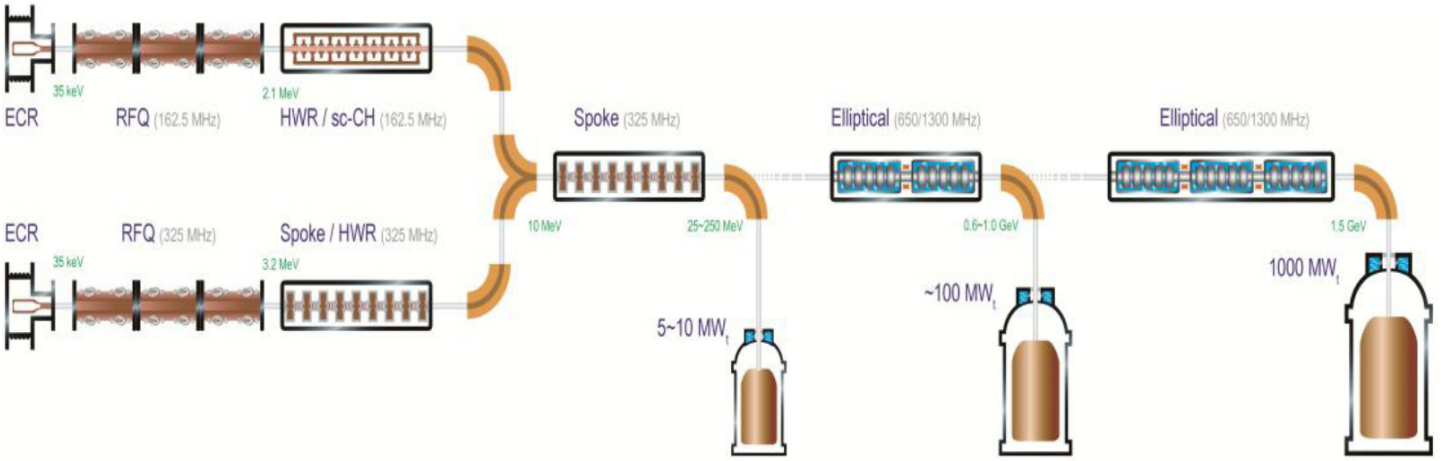
Outline

- **Introduction**
- **LEBT、RFQ、MEBT commissioning**
- **TCM commissioning**
- **CM1 commissioning**
- **CM1 & CM2 commissioning**
- **Summary**

China ADS Roadmap

2011 2016 2023 203x



1st Phase

R&D
supported by CAS

25 MeV@3-10 mA

2nd Phase

CIADS

INITIAL FACILITY

250 MeV@10 mA

3rd Phase

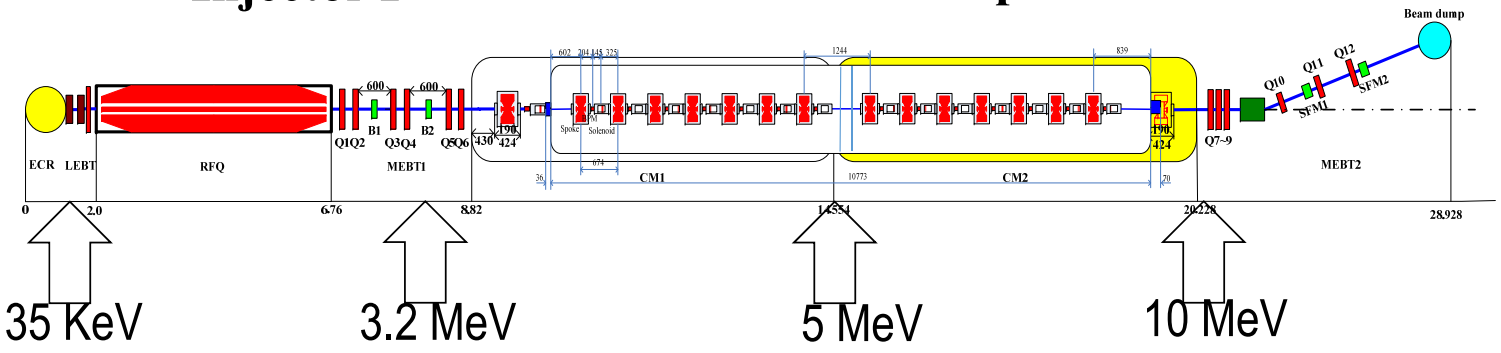
DEMO FACILITY

1.5 GeV@10 mA

10MeV injector – Different technology R&D

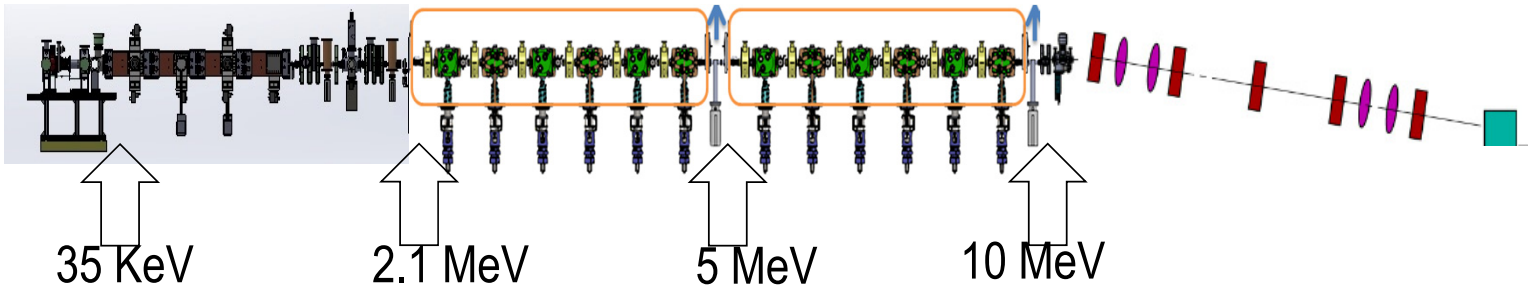
IHEP/Beijing

Injector I **Based on 325 MHz Spoke012**



IMP/Lanzhou

Injector II **Based on 162.5MHz HWR010**



Target of accelerator R&D (Phase I)

- ✓ **To verify the feasibility of preliminary design for low energy and make determination for the scheme of low energy section as a whole.**
- ✓ **Specially R&D in key parts:**
  - ➢ **beam dynamics: to accumulate the experience for the design and operation of SC proton Linac on the future**
  - ➢ **sc cavities, high power couplers**
  - ➢ **ion source with high beam**
  - ➢ **cryogenic system**
  - ➢ **RFQ with CW**
  - ➢ **beam diagnostic system**
  - ➢ **digital LLRF**

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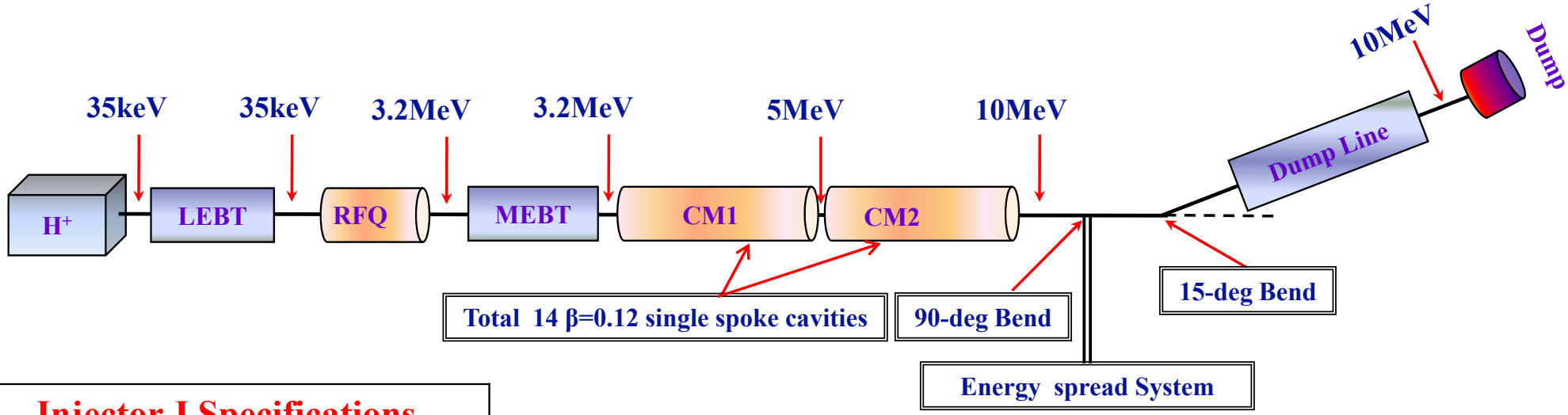
The layout and specifications of ADS Injector-I



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

Injector-I consists of

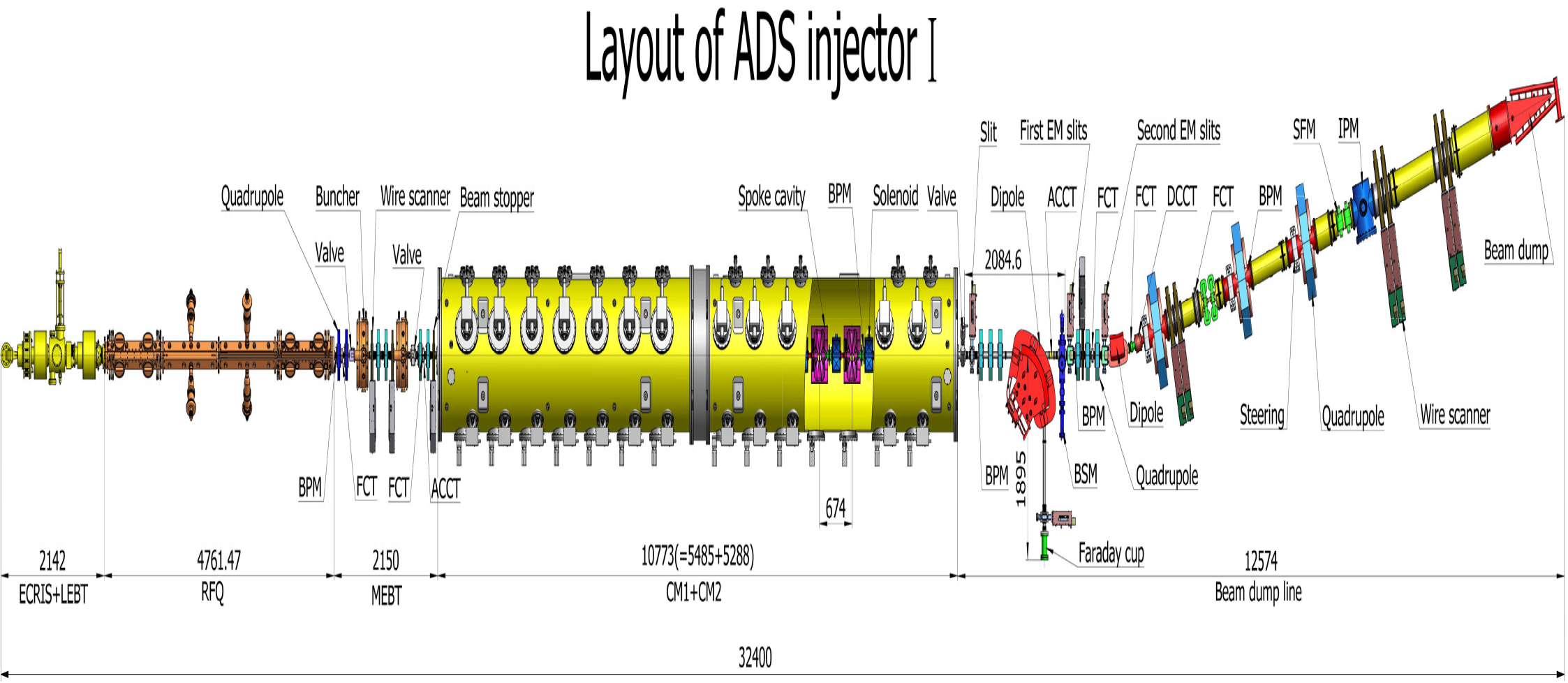
- 35-keV ECR source
- LEBT including a chopping system
- 3.2MeV four vane type copper structure RFQ
- MEBT
- SC section: including two cryomodules 5/10MeV
- Energy analysis system & dump line

Commissioning Phasing of Injector I

For speeding up the project and considering the technical difficulties, the commissioning of injector I is divided into 4 phases:

- **Phase 1, with ECRIS + LEBT + RFQ + MEBT, to get 3.2 MeV beam;**
- **Phase 2, with ECRIS + LEBT + RFQ + MEBT + TCM (two superconducting cavities), to reach 3.6 MeV;**
- **Phase 3, with ECRIS + LEBT + RFQ + MEBT + CM1 (seven superconducting cavities), to reach 5 MeV;**
- **Phase 4, with ECRIS + LEBT + RFQ + MEBT + CM1+ CM2 (same as CM1), to finally achieve the design goal of C-ADS Injector I.**

Commissioning Phasing of Injector I



Commissioning strategy of injector I

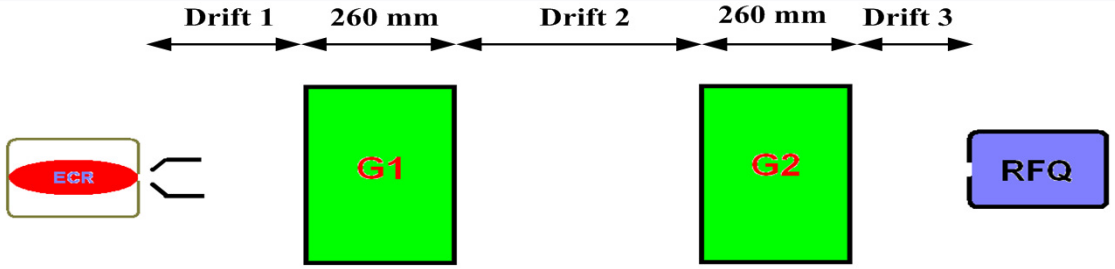
Commissioning Strategy: From easy to difficult, hardware debugging and beam commissioning in parallel.

The typical commissioning beam patterns are as follows:

1. **Narrow-Pulse** √
   - **10mA, 20μs, 2Hz.**
2. **Long-Pulse or CW** ╳
   - **3mA**
   - **10mA**

Commissioning Progress

LEBT commissioning

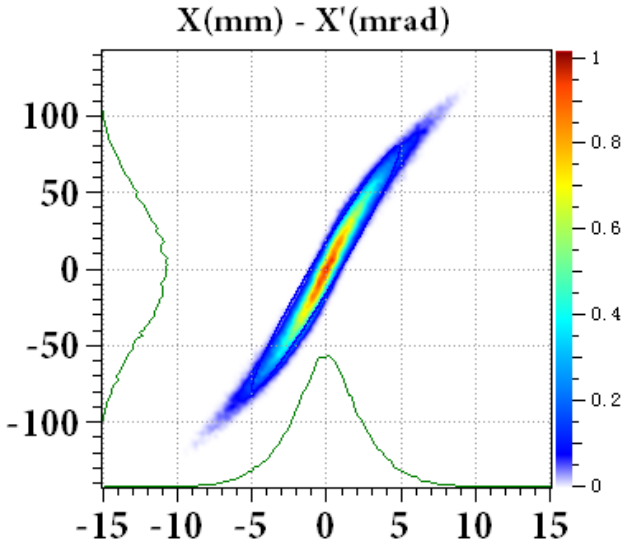


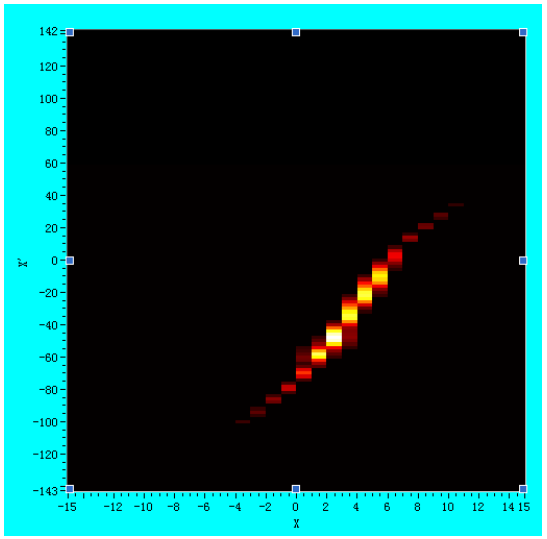
Total length of LEBT is 1.67m

Beam parameters at the LEBT exit

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

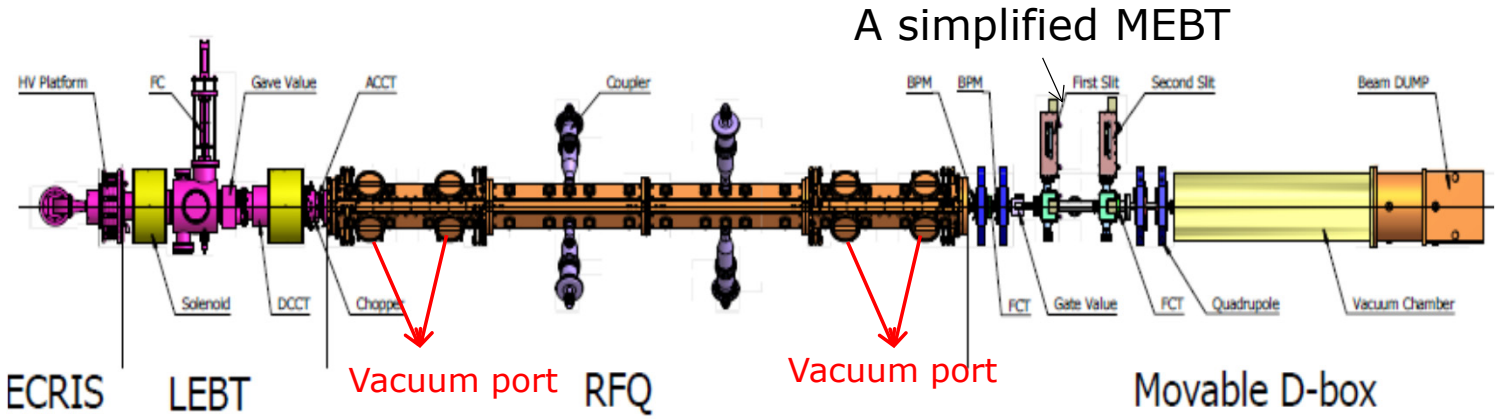
Emittance Simulation





Emittance Measurement

RFQ commissioning



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

RFQ commissioning--*Milestones*

Year of 2014:

- May 15th , conditioning began
- June 12nd, 71% RF duty factor reached, 0.71 ms /1 kHz, 250 kW
- Aug. 21st , *99.97% RF duty factor reached, 12.5 ms/79.975 Hz, 250 kW*
- Aug. 22nd , *CW mode/194 kW*
- Sep. 1st , commissioned with beam, 65% duty factor
- Sep. 2nd , commissioned with beam, 70% duty factor
- Sep. 25th , *commissioned with beam , 90% duty factor*
- Sep. 27th , stopped for installation of MEBT&TCM according to the project scheduled

Year of 2015:

- Mar. 5th, RFQ conditioning restart
- Mar. 16th , 94% RF duty factor reached, 270kW, 0.94ms/1ms
- Mar. 20th ~Apr. 10th , CW conditioning, 158kW maximum

RFQ commissioning

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
Continuously operating 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 area over 60°.

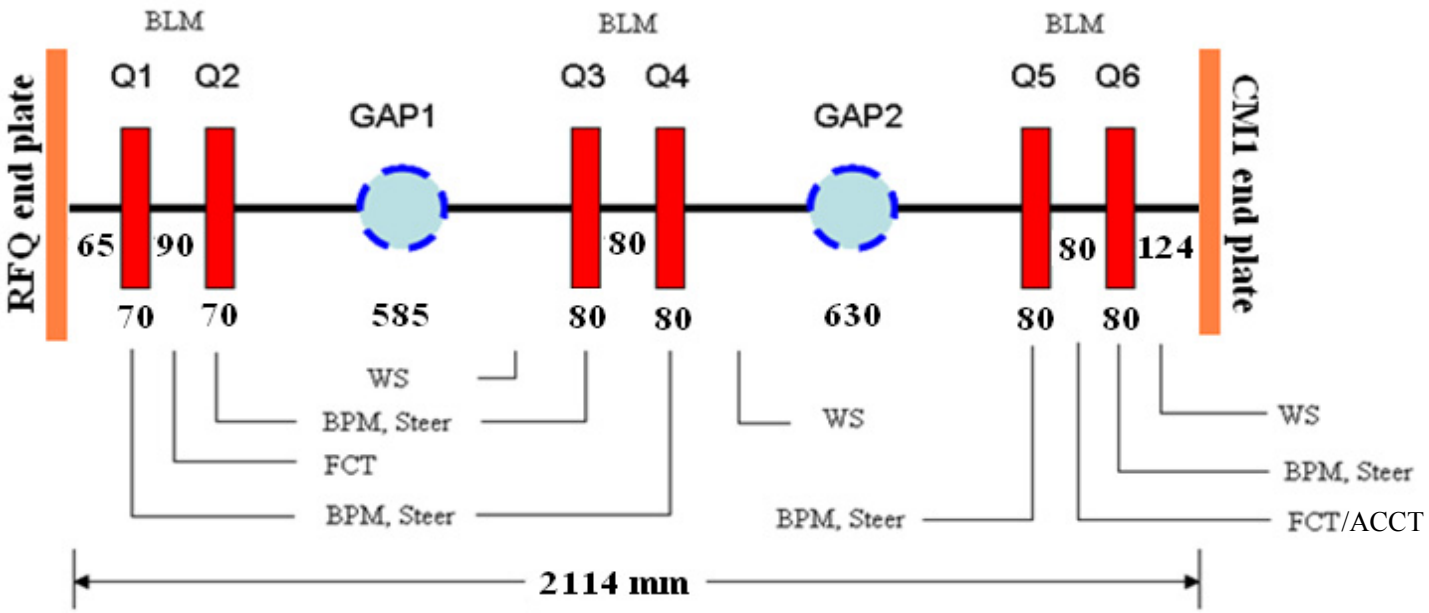
Beam: 11mA/3.2MeV, Duty cycle >90%,
Transmission efficiency > 95%
Average beam power>31kW
RF power >300kW

Issues of RFQ commissioning

Though the beam duty factor is very close to CW, but it is really that the CW have not been reached. The reasons are as follows:

- **Early problems is lack of experience, such as the master oscillator can't be switched from pulse mode to CW mode directly; conditioning mode (with pulse generator and switch gradually from pulsed to "CW"); coupler damaged.**
- **Later, the problems is that we have to catch up the project schedule. Once the CM2 commissioning with narrow pulse beam is completed, we will restart the RFQ conditioning and commissioning by CW mode and 3 mA beam.**

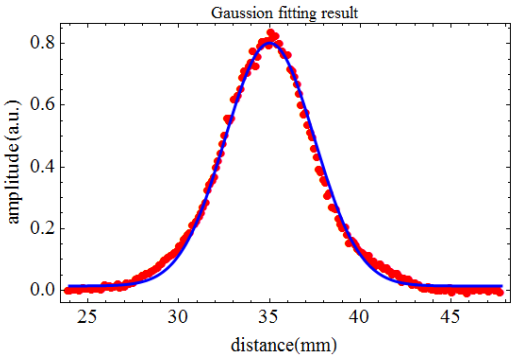
MEBT commissioning



- MEBT is composed of 6 Quadruples, 6 pair of Steering magnets and 2 Bunchers
- Beam diagnostic devices include 6 Beam Position Monitors, 2 Fast Current Transformers , one AC current transformer, 3 Wire Scanners.

MEBT commissioning

- **BBA**
- **Orbit corrections**
- ***Energy measurement: RFQ energy: 3.2MeV***
- ***Emittance measurement***
  - ***Double slits***
  - ***Wire scan---Quad. Scan method***



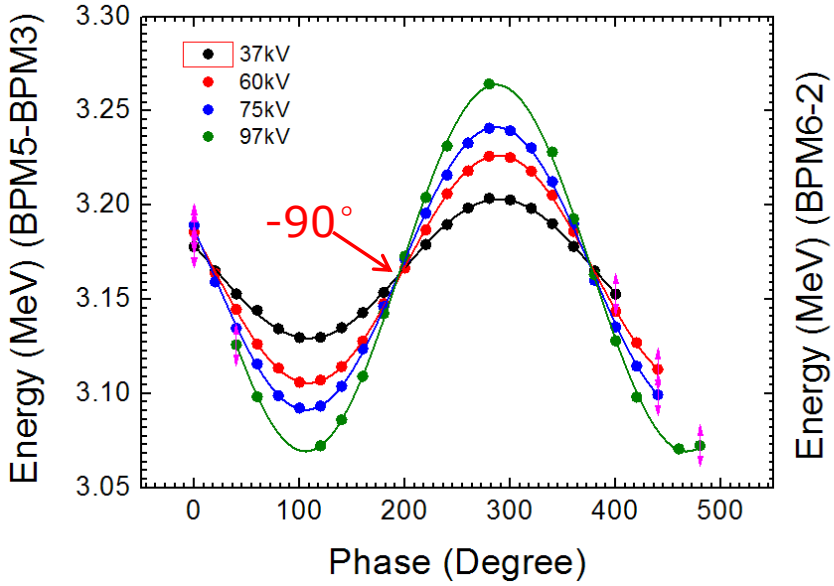
Wire Scan data

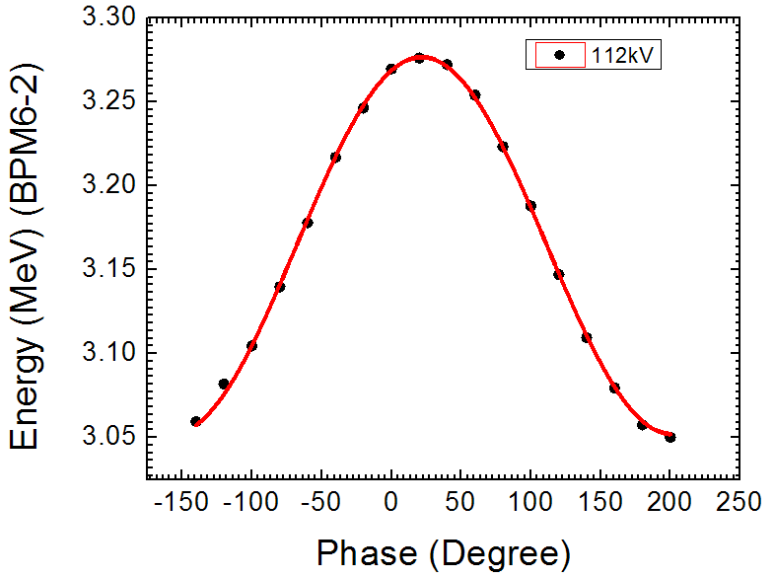
Beam performance at the MEBT entrance

Parameters		α_x/α_y	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	Quad. scan	-1.8/0.72	0.17/0.09	0.16/0.21
	Double slits	-1.78/0.65	0.46/1.85	0.14/0.14

MEBT commissioning—two bunchers

Beam tuning results of two bunchers

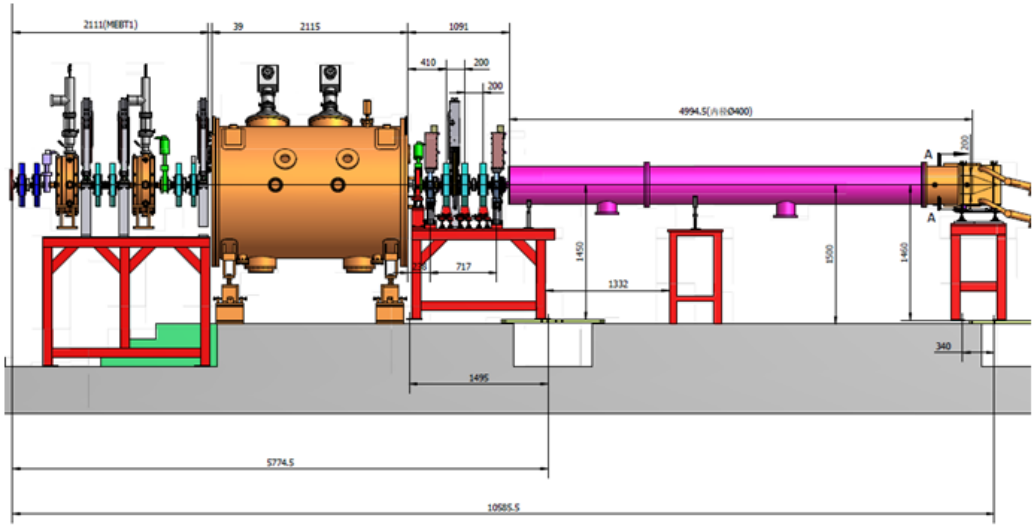




The first buncher：
Designed effective voltage: 54kV
Sync. phase：-90°

The second buncher：
Designed effective voltage: 104kV
Sync. phase：-90°

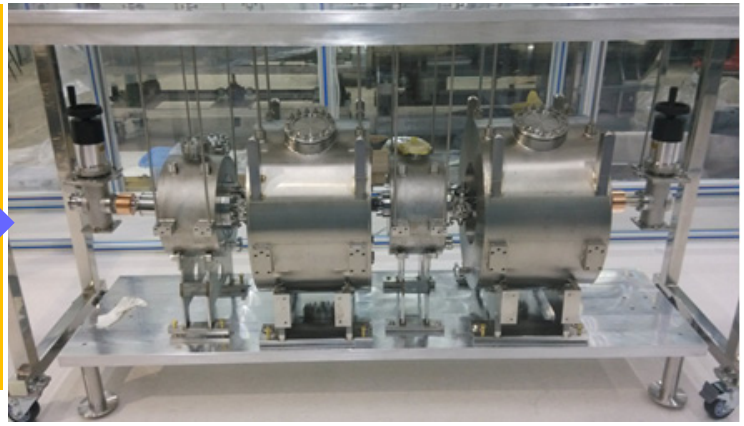
TCM commissioning



- Duty cycle : 1.5 ‰
- TCM energy : 3.39 MeV(1st)/3.68 MeV(2nd)
- Transmission efficiency : 98%
- RFQ+TCM transmission efficiency : 93.4%
- beam: 10.1mA

The Testing Cryomodule (TCM) is mainly consist of:

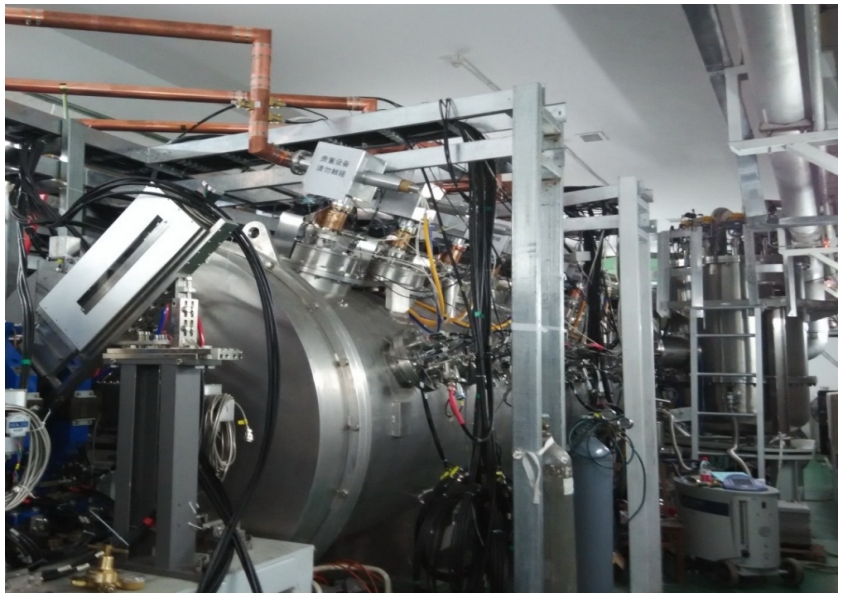
- Two β=0.12 spoke cavity
- Two solenoid
- Two cold BPMs



CM1 commissioning

Preliminary commissioning results: *10mA/6.05MeV*

Cav. Number	Bun.1	Bun.2	1	2	3	4	5	6	7
Eacc(MV/m)	69.7kV	91.5kV	4.42	4.96	4.97	5.03	5.33	5.44	7.75



CM1（7spoke012+7 Solenoid +7BPM）

CM1 commissioning

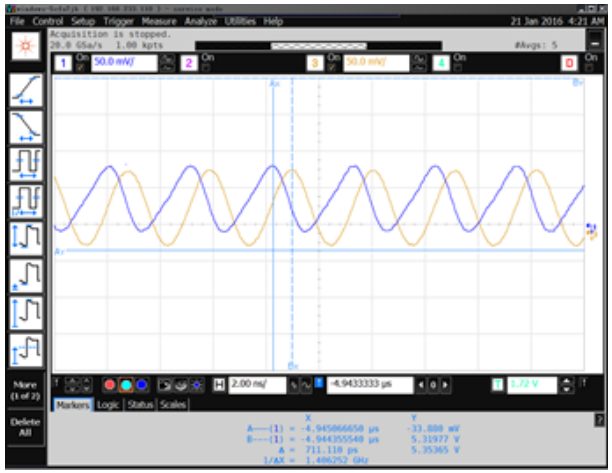
Pulse 1

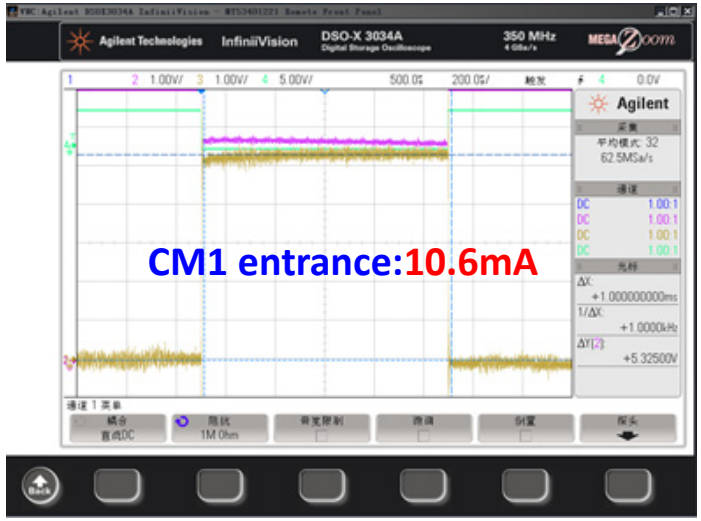
- Duty cycle : 0.15 ‰ (5Hz/30us)
- Energy：6.05MeV
- Beam: 10.4mA
- Transmission efficiency of CM1：100%
- Transmission efficiency for RFQ+CM1 ：88.4%

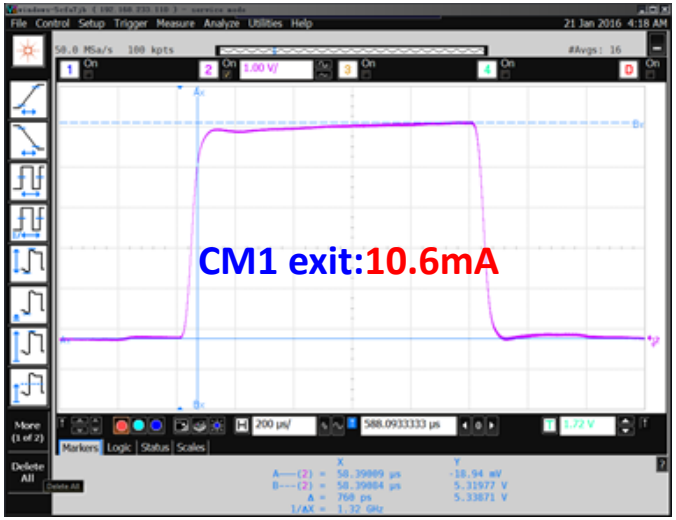
Pulse 2

- Duty cycle : 2 ‰ (2Hz/1ms)
- Energy：5.97MeV
- Beam: 10.6mA
- Transmission efficiency of CM1：100%
- Transmission efficiency for RFQ+CM1 ：88.4%

CM1 energy (FCT3&4 measured)





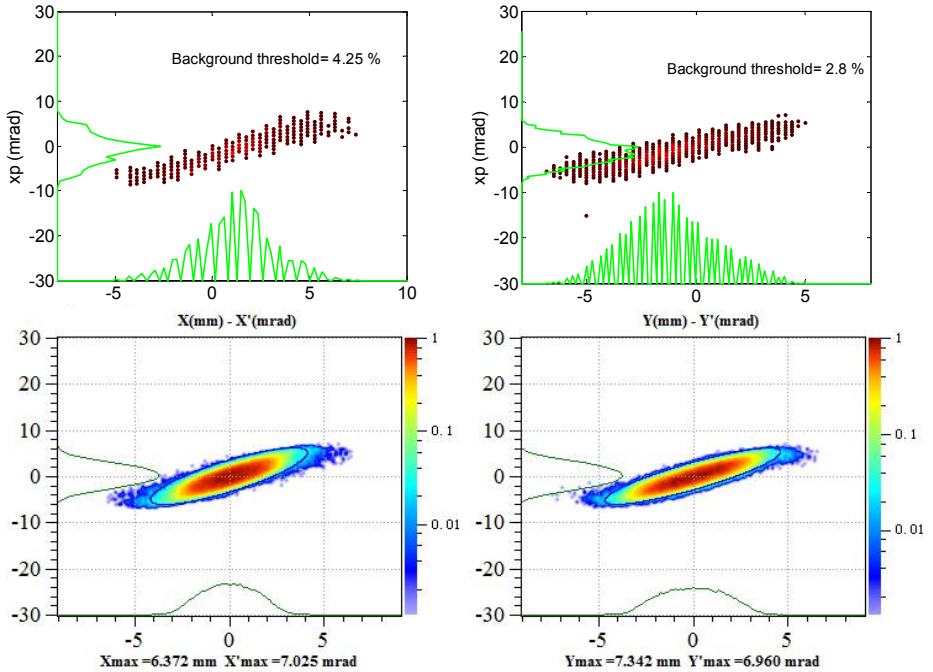


CM1 commissioning

Emittance measurement at the exit of CM1

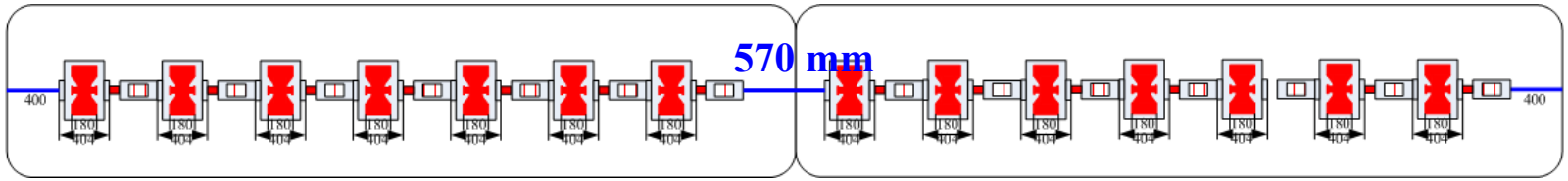
Measured

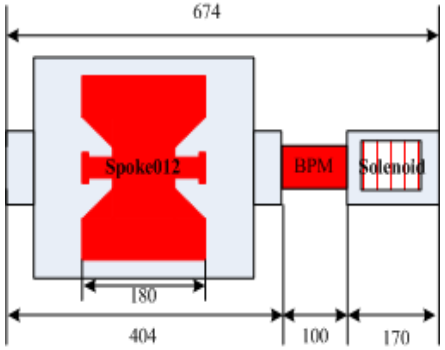
Simulated



Parameters	αx/αy	βx/ βy (mm/mrad)	$E_{n,rms,x/y}$ (π mm.mrad)
Simulation	-1.44/-1.75	1.18/1.53	0.22/0.21
Measurement (Double slits)	-2.12/-1.97	1.56/1.81	0.29/0.27

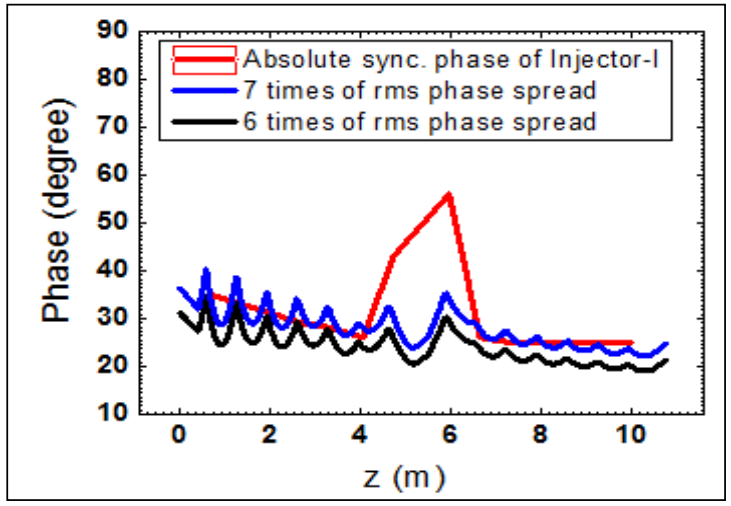
CM1 & CM2 commissioning





One period

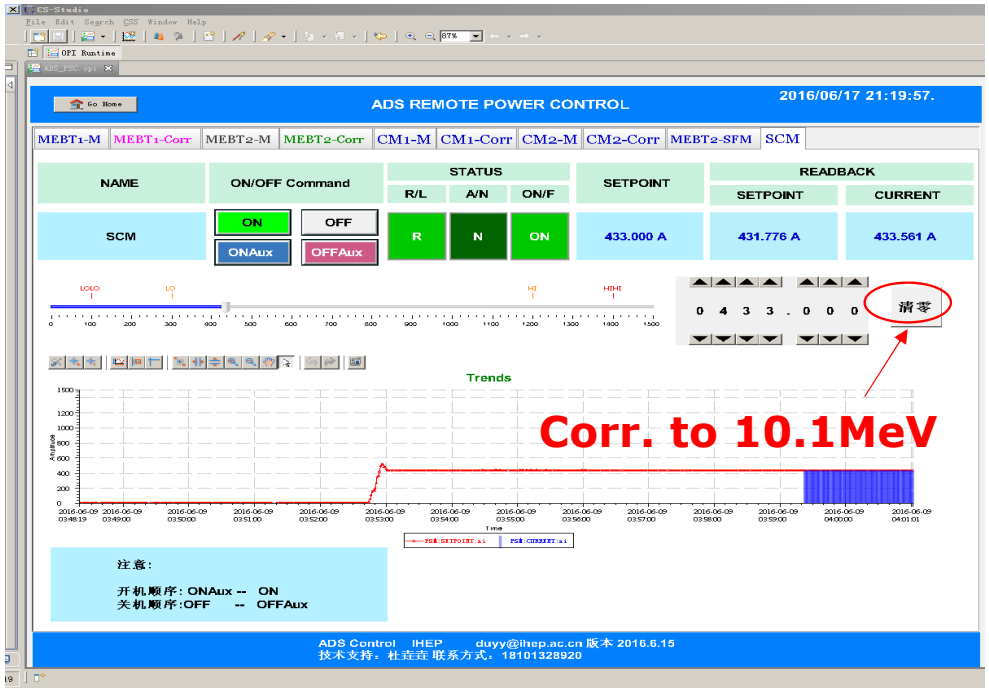
- 1 β=0.12 spoke cavity
- 1 SC solenoid
- 1 cold BPM

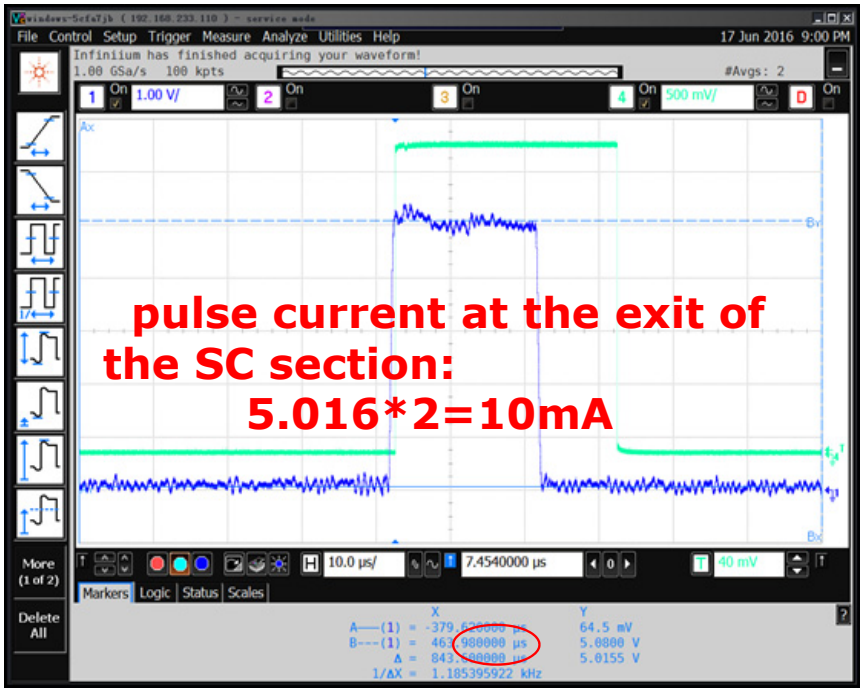


Cav Number	Eacc (MV/m)	Sol (A)
1	4.97	170.4
2	4.97	170.4
3	5.09	170.4
4	5.28	170.4
5	5.42	170.4
6	4.36	132.3
7	4.69	184.2
8	4.14	186.5
9	3.94	132.3
10	6.61	170.4
11	6.83	170.4
12	6.96	168.8
13	7.07	167.0
14	7.19	164.7

CM1 & CM2 commissioning

Cav. #	2	3	4	5	6	7	8	9	10	11	12	13	14
Beam calibrated Eacc (MV/m)	4.90	6.94	5.15	7.03	6.99	5.30	4.73	5.64	5.81	5.69	5.97	5.25	5.53





CM1 & CM2 commissioning

The latest commissioning results of C-ADS injector I:

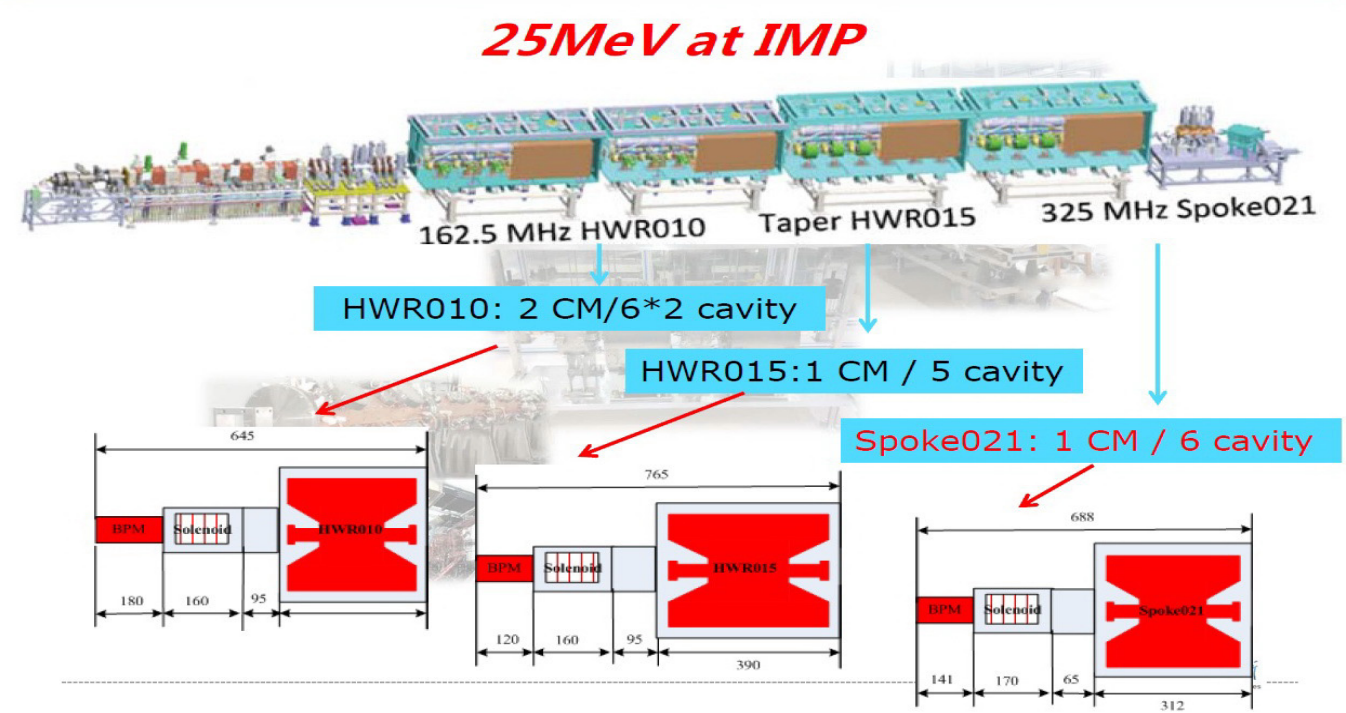
- **Beam energy > 10 MeV**
- **Transmission efficiency : 100%**
- **Beam current > 10mA**

Issues of CM1&CM2 commissioning

- **Have to warmup the SC two times for adjusting the SC frequency.**
- **Electromechanical coupling on SC.**
- **Hard to keep runing stablely for a long time with multiple SC and cavities with high ACC simultaneously**

The goal of 2016 for Us

1. Complete the beam commissioning of CM1 & CM2, and obtain 10MeV/10mA beam.---------have reached on June 17.
2. To complete CM4 assembly and beam commissioning based on injector II , achieve 20-25MeV/10mA. This will be done together with IMP.



Summary

- **The source+LEBT+RFQ+MEBT+CM1+CM2 were successfully commissioned with pulsed beam;**
- **The RFQ is still on the way to CW operation, new conditioning method will be tried later;**
- **More experiments is needed to be done to further understanding the beam performance;**
- **Investigation of the machine reliability and stability will be done in the future.**

Thank you
for your attention !