Institute of High Energy Physics

Commissioning of the China-ADS Injector-I testing facility

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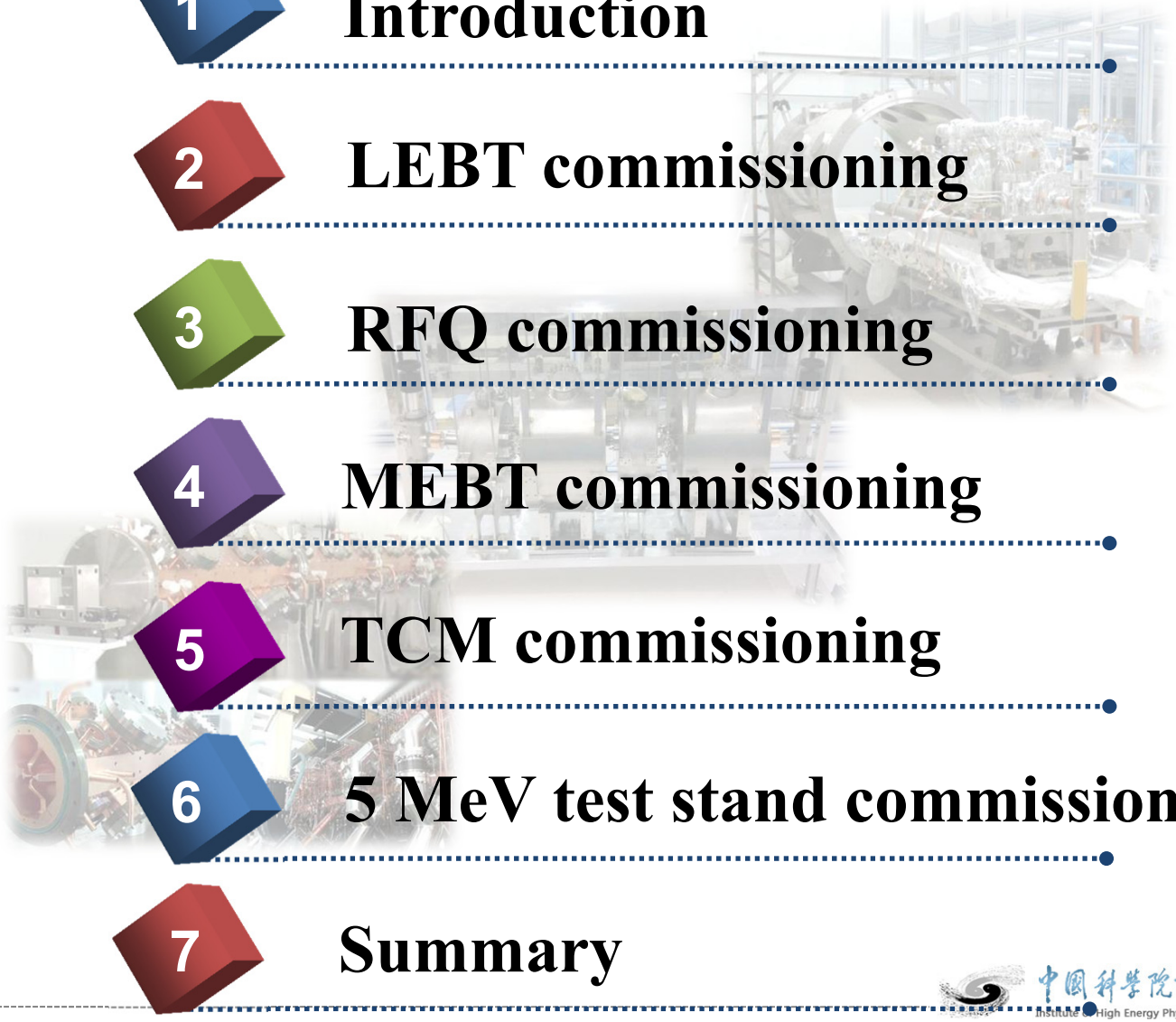
On behalf of the China-ADS Injector-I team in IHEP

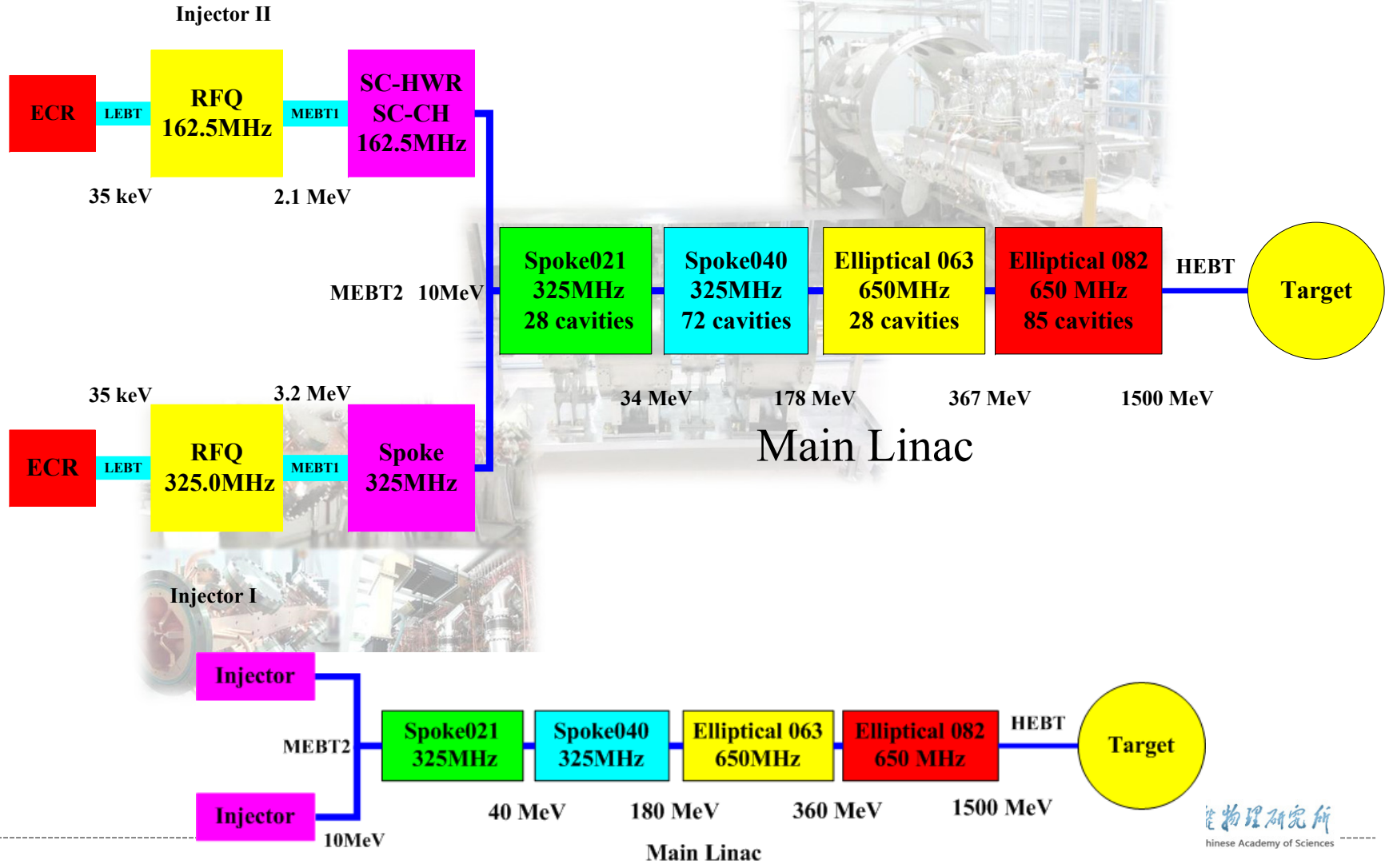
IPAC2016
Busan, Korea, May 8 -13, 2016

Outline



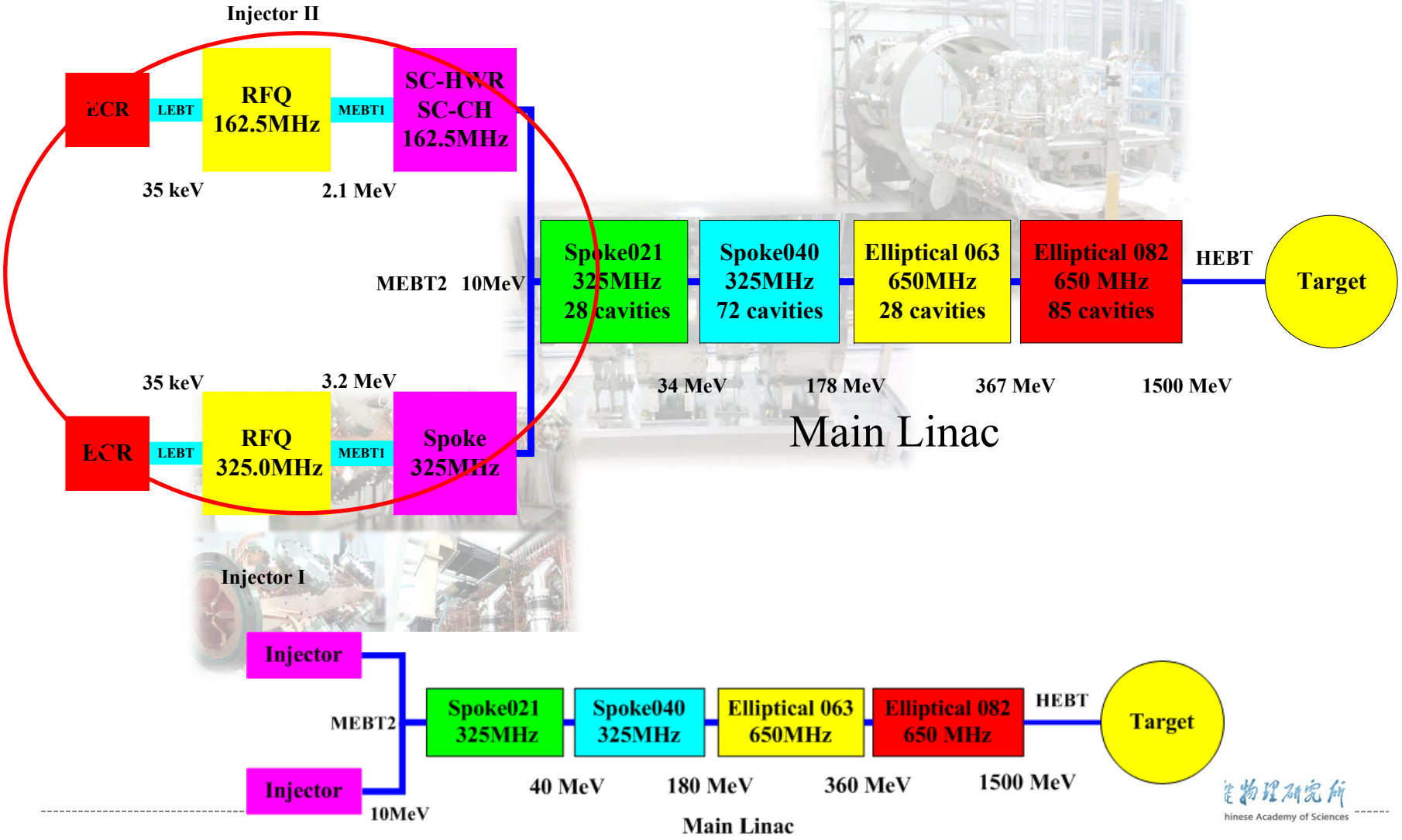
1. Introduction

Schematic figure of ADS driver linac



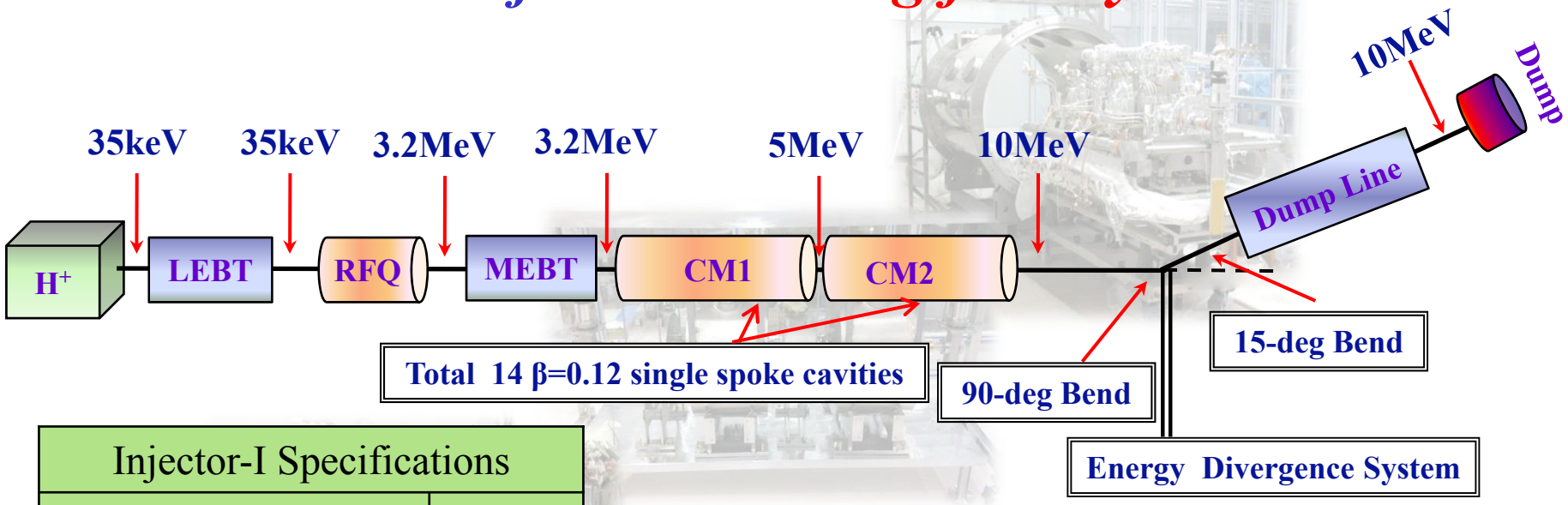
1. Introduction

Schematic figure of ADS driver linac



1. Introduction

The layout and specifications of ADS Injector-I testing facility



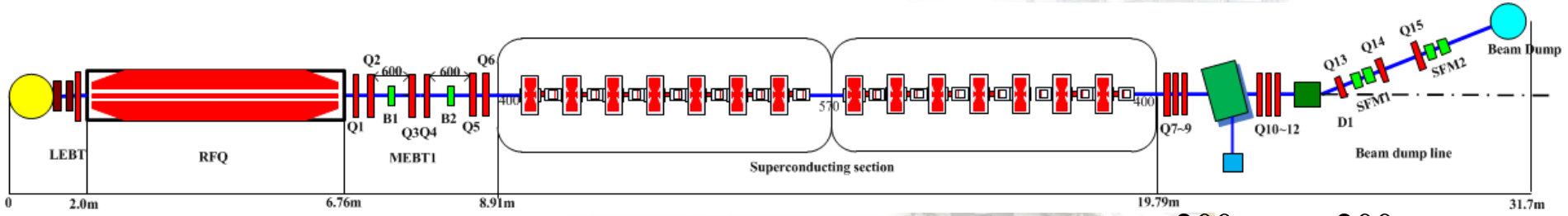
Injector-I Specifications	
Particle	H^+
Output Energy (MeV)	**10**
Current (mA)	**10**
Beam power (kW)	100
Duty factor (%)	**100**
RF frequency (MHz)	**325**

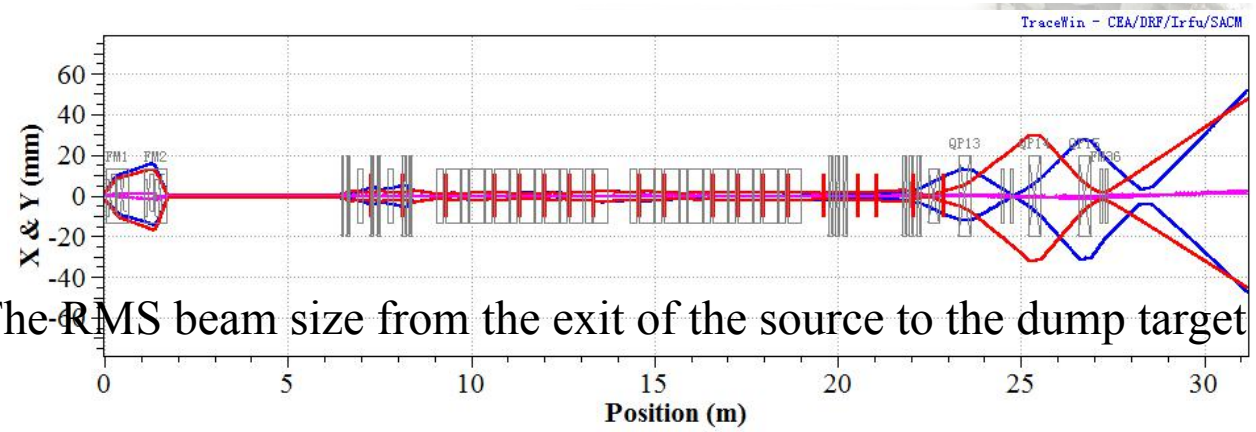
Injector-I consists of:

- ECR source providing with 35keV proton
- LEBT: including a chopping system
- 4-vane type copper structure RFQ: 3.2MeV
- MEBT
- SC section: including two cryomodules → **5**/10MeV
- Energy divergence system & beam dump line

1. Introduction

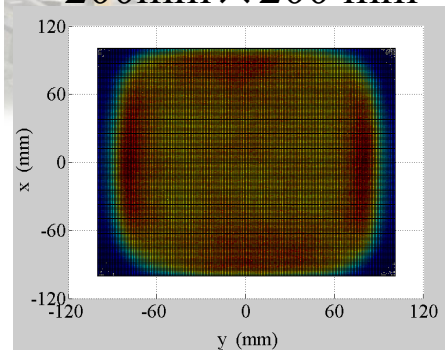
Commissioning status of Injector-I linac





The RMS beam size from the exit of the source to the dump target

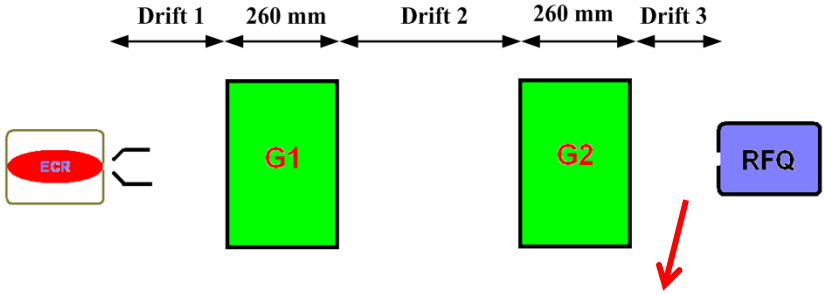
200mm×200 mm

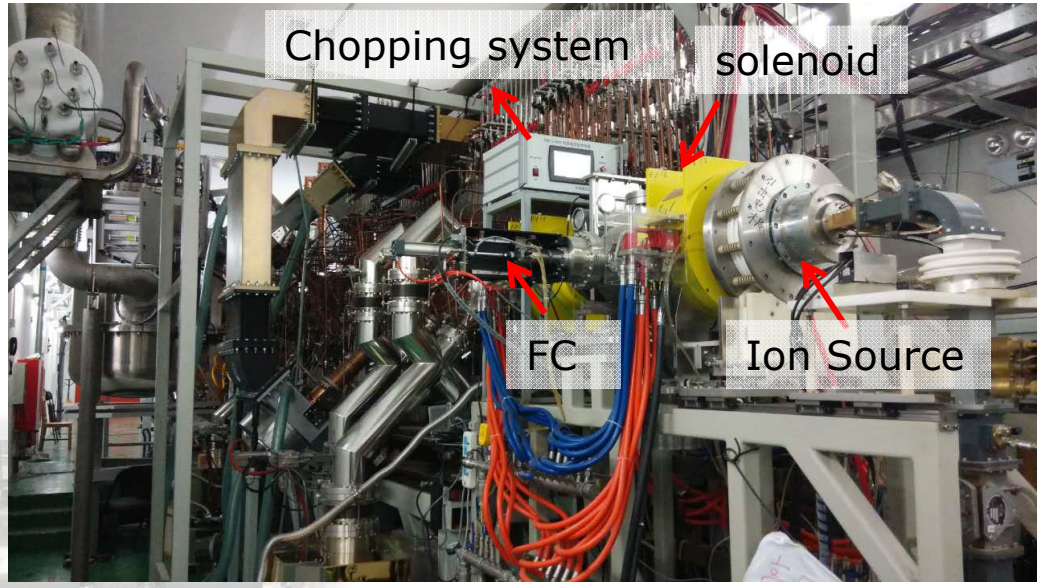


- The Injector I testing facility is being commissioned in stages
- The Source+LEBT+RFQ has been commissioned with maximum 90% duty factor beam
- The TCM /CM1 with 2/7 β=0.12 Spoke cavities have been conditioned after the RFQ
- The CM1 output energy reached 6MeV with pulsed beam @2K
- At present, all the assembling as shown in the top figure, have already installed in the tunnel, ready to be commissioned.

2. LEBT commissioning

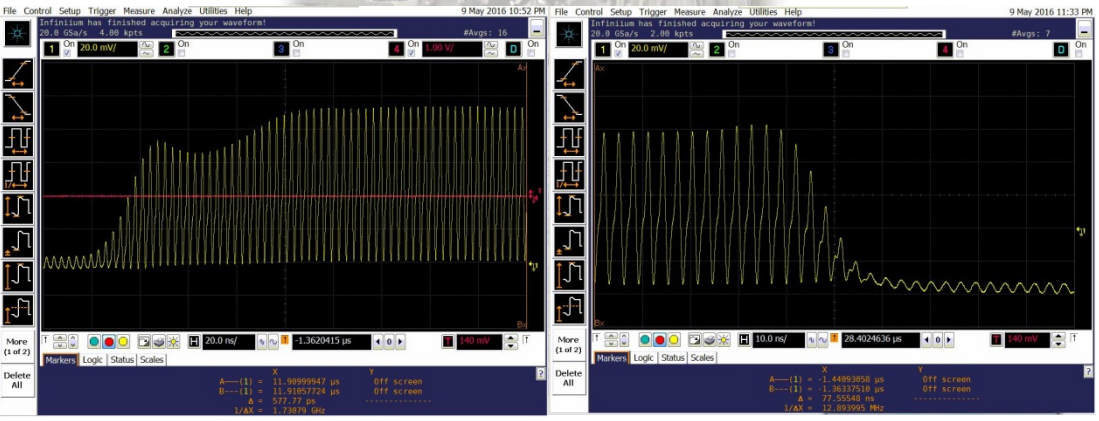
Total length of the LEBT is 1.67m





LEBTs chopper for accelerator commissioning & fast protection:

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



LEBT chopper rise time (left trace) and fall time measured at the FCT of the MEBT

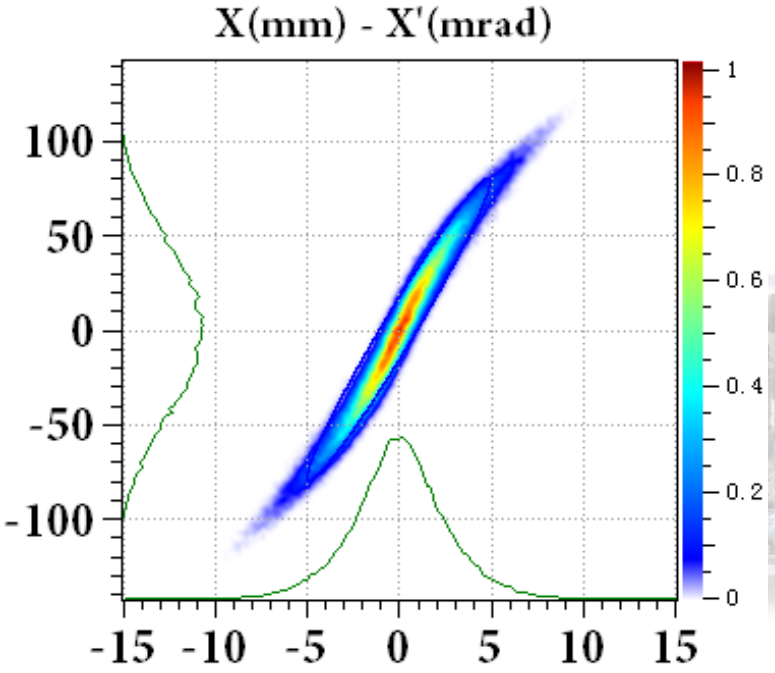
Requirement At RFQ entrance

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

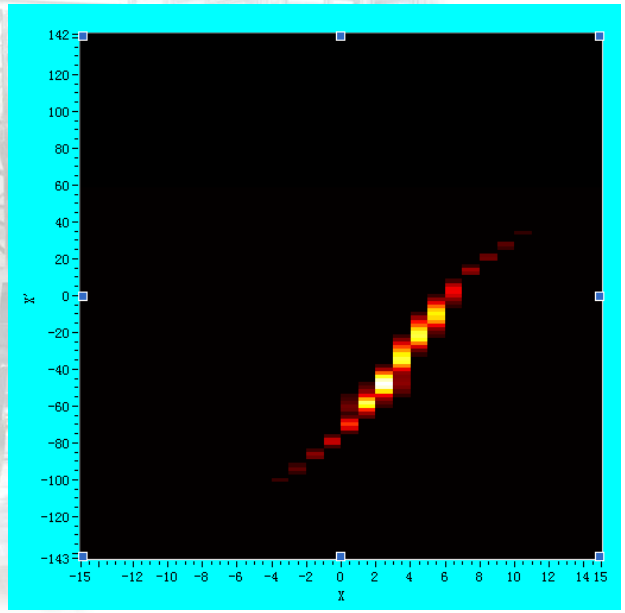
2. LEBT commissioning ➡ emittance measurement

- **Beam phase space at the measured location (8.8cm drift downstream the LEBT exit):**

Simulation



Measurement

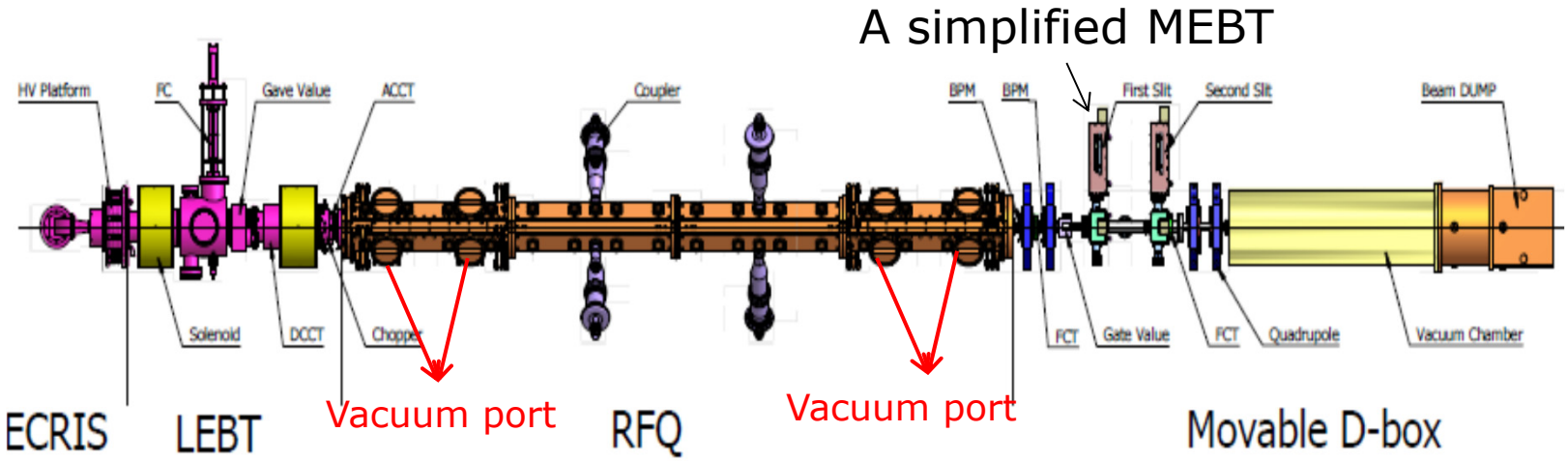


Beam parameters at the LEBT exit and the RFQ entrance

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

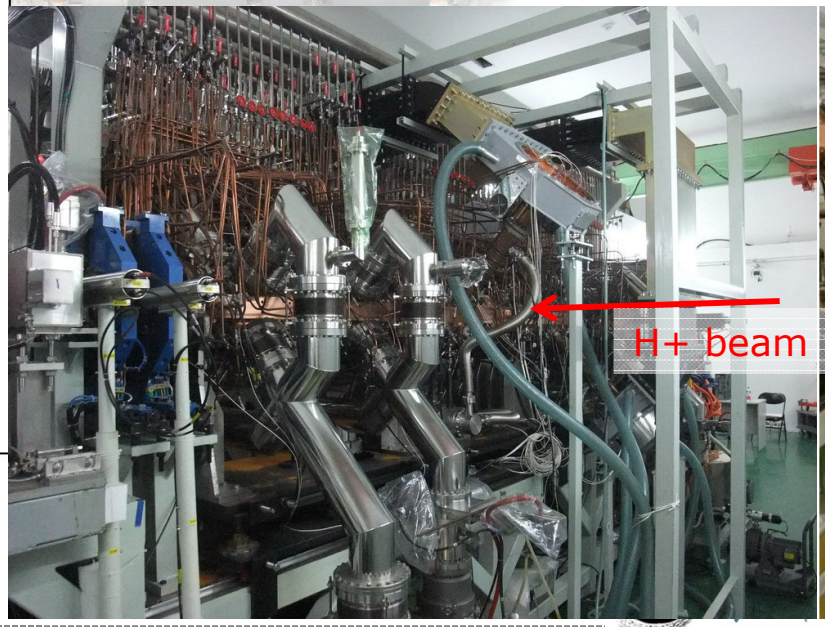
3. RFQ commissioning ➡ RFQ specifications & layout



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

The designed beam transmission out of RFQ is 98.7%

RFQ installed in the tunnel



Power Coupler

RFQ 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 scheduled MEBT&TCM installation

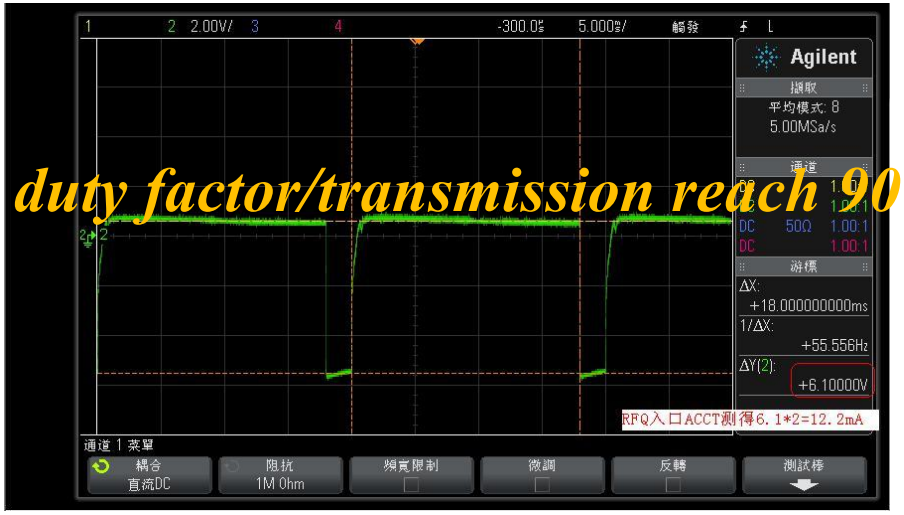
Year of 2015:

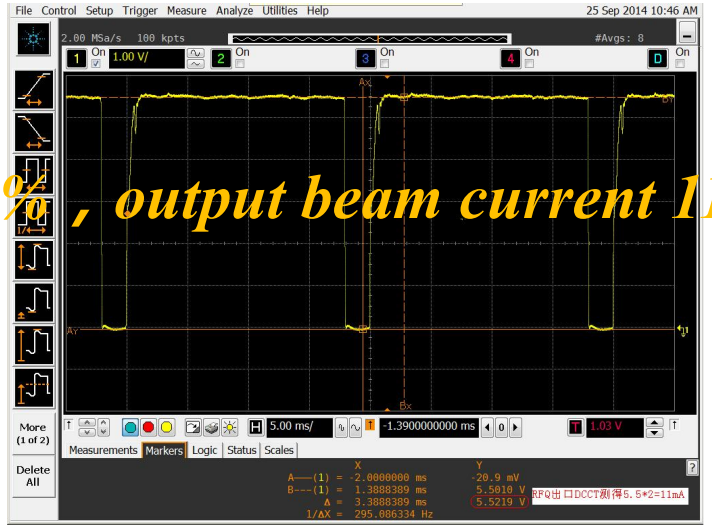
- Mar. 5th, RFQ conditioning resume
- Mar. 16th , 94% RF duty factor reached, 270kW, 0.94ms/1ms
- Mar. 20th ~Apr. 10th , CW conditioning, 158kW maximum
- Apr. 13th, disassemble the 1# coupler

3. RFQ commissioning ➡ With beam

Transmission of the beam with different duty factors

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





90% duty factor/transmission reach 90%, output beam current 11mA

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
Lasting 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 ➡ With beam

RFQ transmission

#1 Coupler position

#3 Coupler position

Picture taken @ 2015.07.28

Picture taken @ 2014.07.26

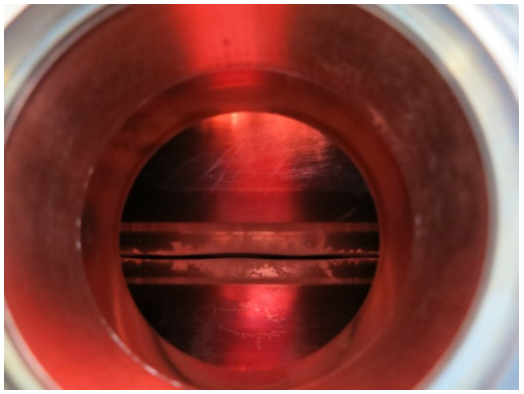
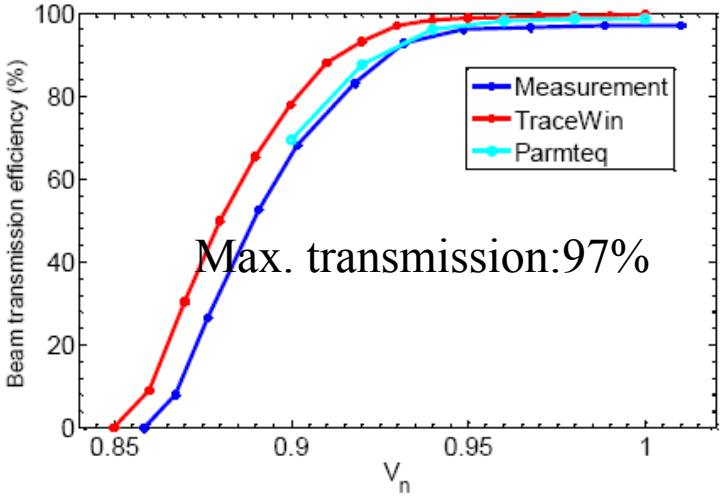


Image courtesy of from T. Huang's report

Verification of tank level with transmission scan

@20150715



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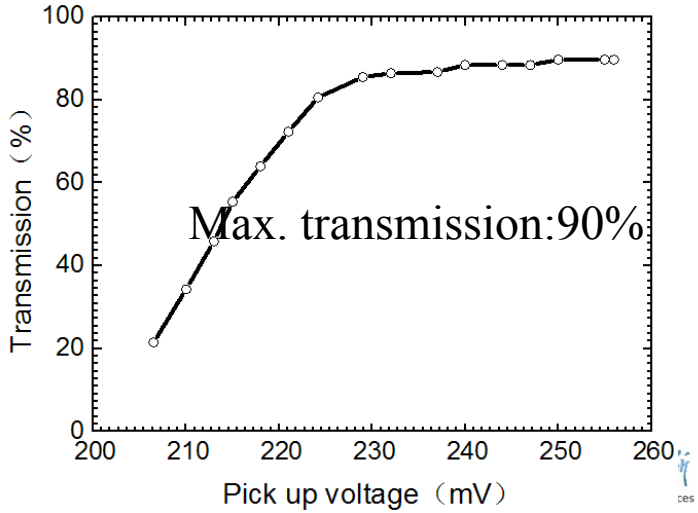
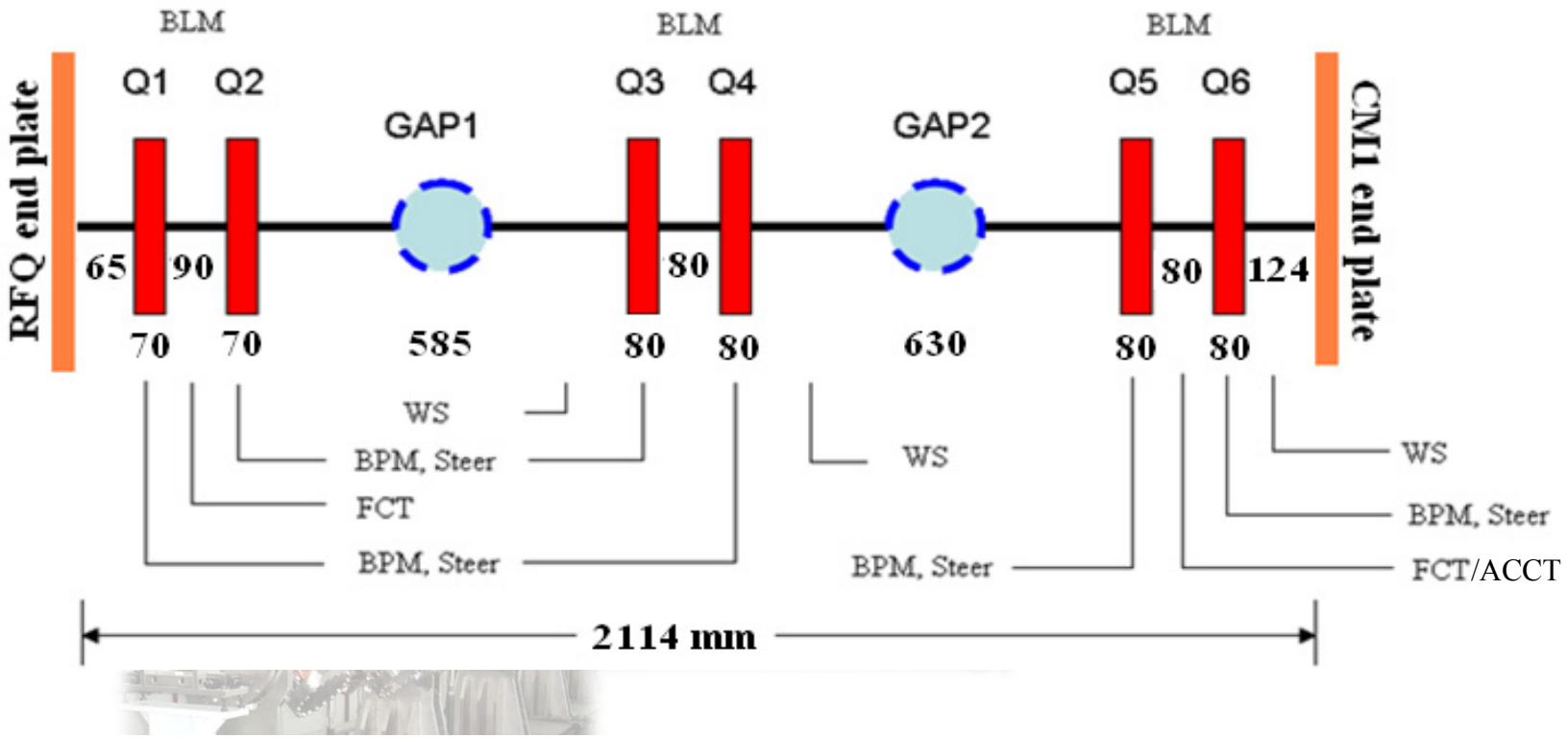


Image courtesy of the paper, "Beam commissioning of C-ADS injector-I RFQ accelerator", Cai Meng et al., IPAC2015.

4. MEBT commissioning ➡ MEBT layout



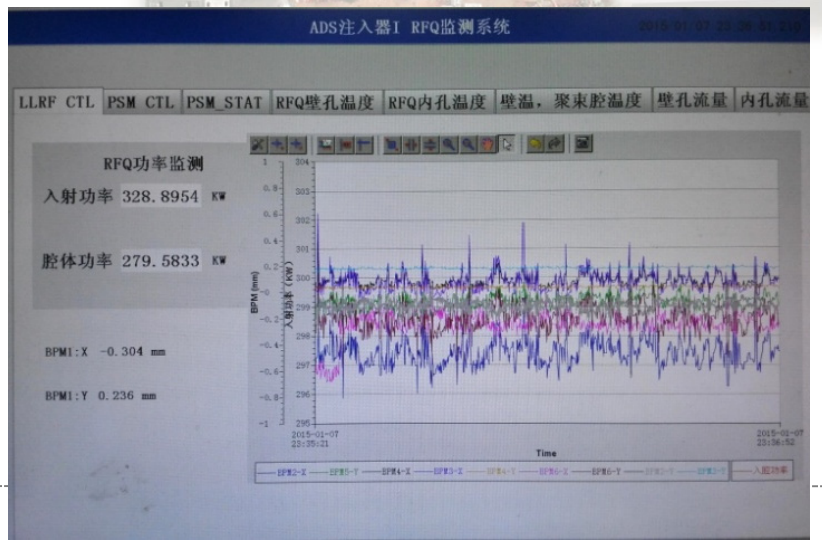
- MEBT is composed of 6 Quadruples, 6 pair of Steering magnets and 2 Bunchers
- Beam diagnostic devices include 6 Beam Position Monitors, 2 Fast Current Transformers , one AC current transformer, 3 Wire Scanners.

Orbit corrections

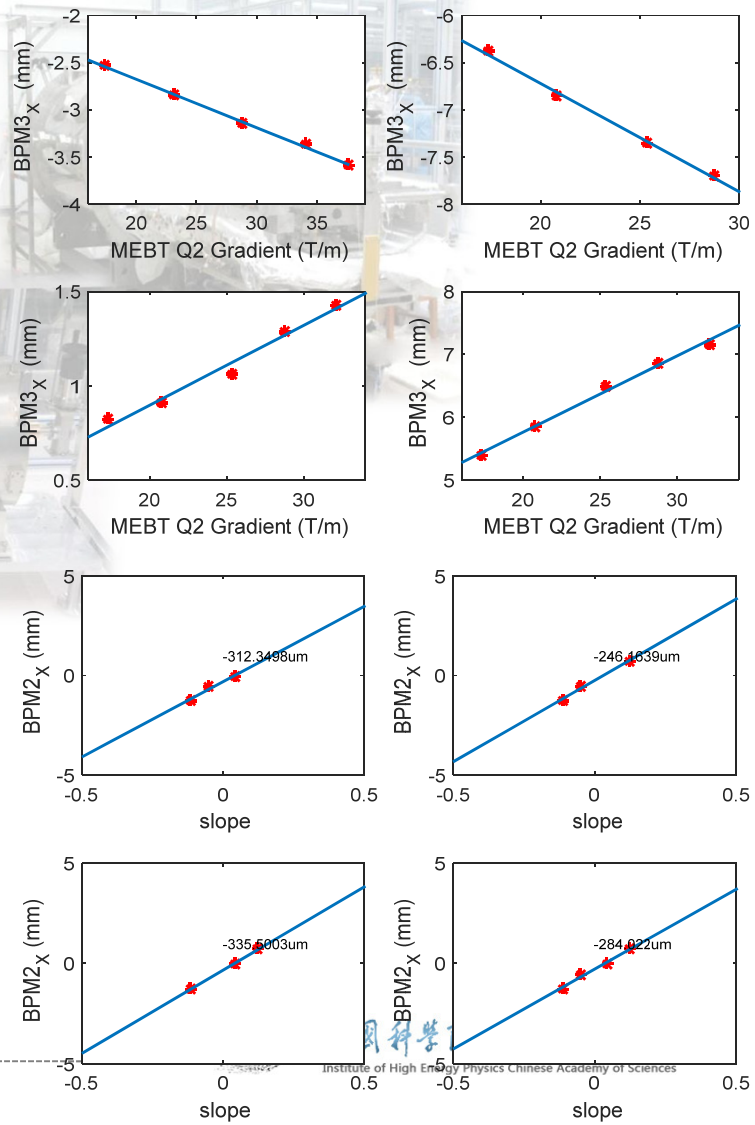
The middle three BPMs offsets according to the beam based BBA

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

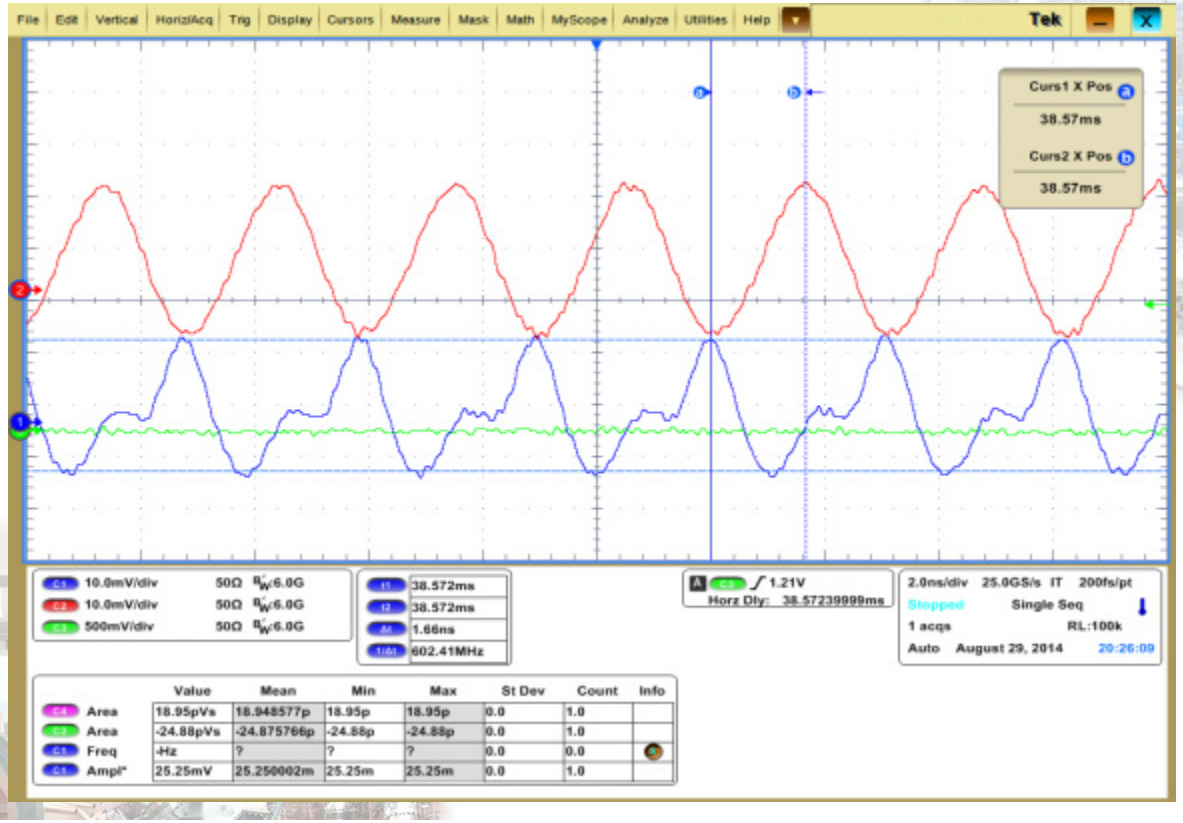


BPM BBA analysis results



4. MEBT commissioning

Energy measurement



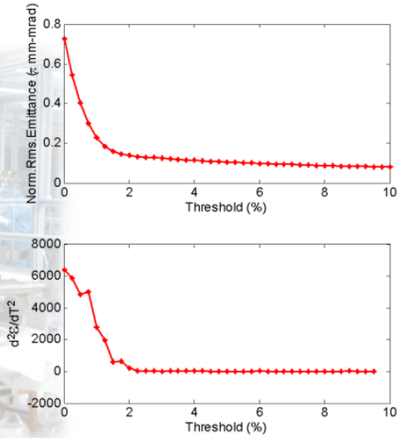
- *The RFQ energy was measured using two FCTs*
- *The upstream FCT signal: blue The downstream FCT: red*
- *RFQ energy: 3.2MeV*

4. MEBT commissioning

Emittance measurement

Three different methods were used for the MEBT section emittance measurements:

– Double slits: the second derivative of the emittance is taken as the function of the threshold, the one goes down to zero

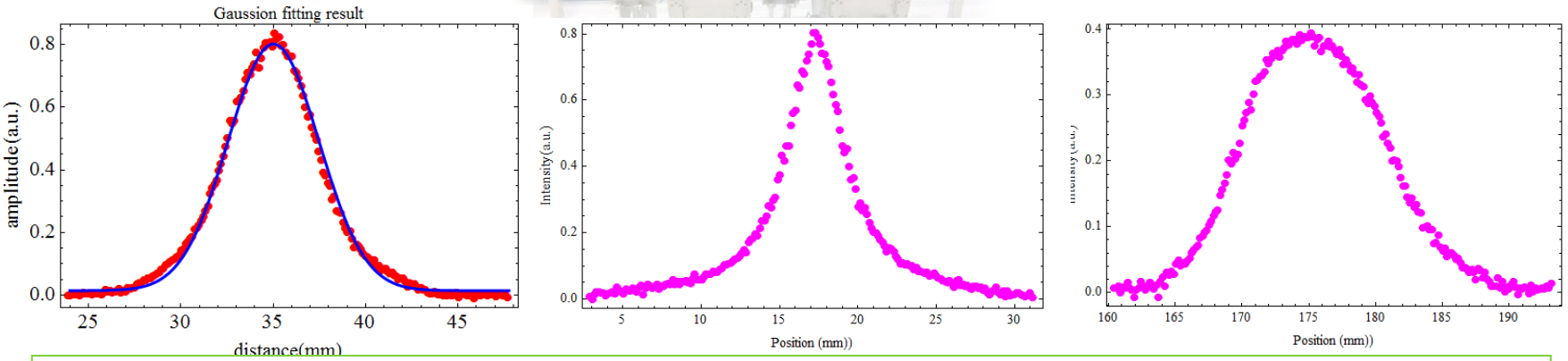


– Wire scan: wires are positioned in 3 different positions

we got no solution from this measurement/more wires are needed

– **Quad. scan: fitting method for RMS beam size/space charge effect**

Wire Scan data



Problems during the data processing for the wire scan data getting from Quad. Scan:

- RMS beam size determination is difficult as the beam size is twisted when we varying the quadruple gradient;
- The traditional method with transfer map doesn't consider the space charge effect.

4. MEBT commissioning

Emittance measurement: conclusion

- Direct Root Mean Square formula was used in our case for the RMS beam size calculation to eliminate the data processing errors caused by the fitting formula;

Details was presented in the poster: H. Geng, # MOPOY027

- Evolutionary algorithm instead of transfer map was used to consider the space charge effect. Initial twiss parameters and emittance were assumed, and the simulation data using TraceWin were compared with the experimental RMS beam size until they are converged.

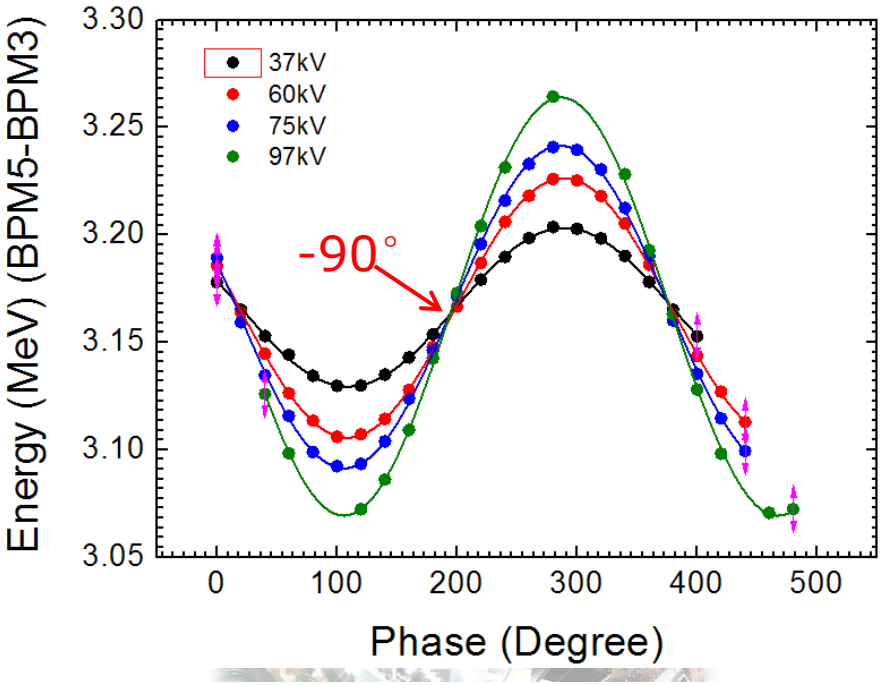
Details is presented in the poster: Y. Zhao, # MOPOY032

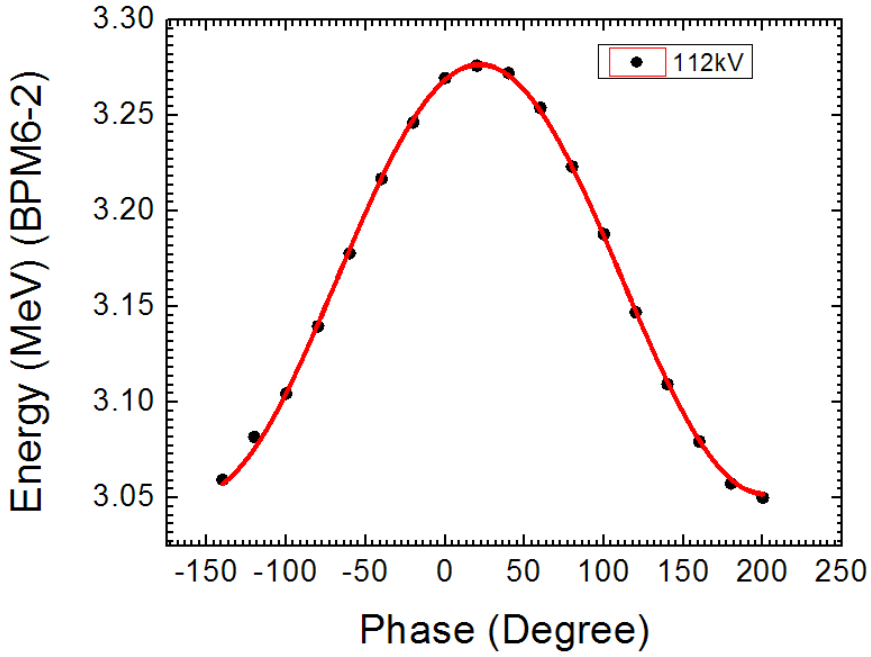
Beam performance at the MEBT entrance

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 (backward deduced from the measured location)	**Quad. scan**	**-1.8/0.72**	**0.17/0.09**	**0.16/0.21**
	Multi-wires	**-**	**-**	**-**
	Double slits	**-1.78/0.65**	**0.46/1.85**	**0.14/0.14**

4. MEBT commissioning

Beam tuning results of two bunchers

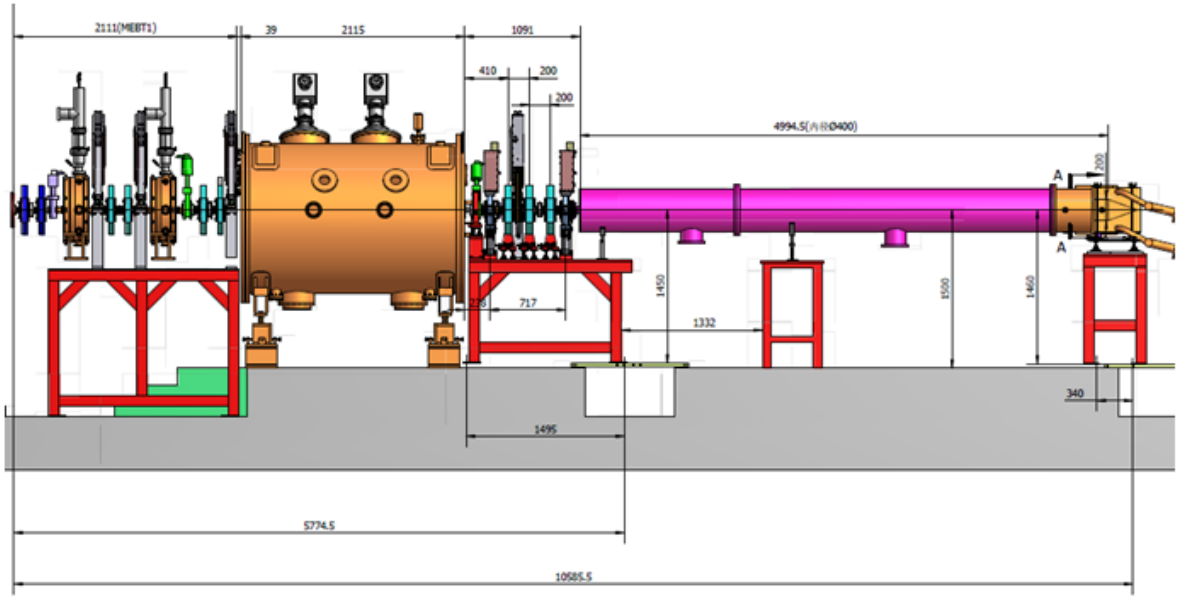


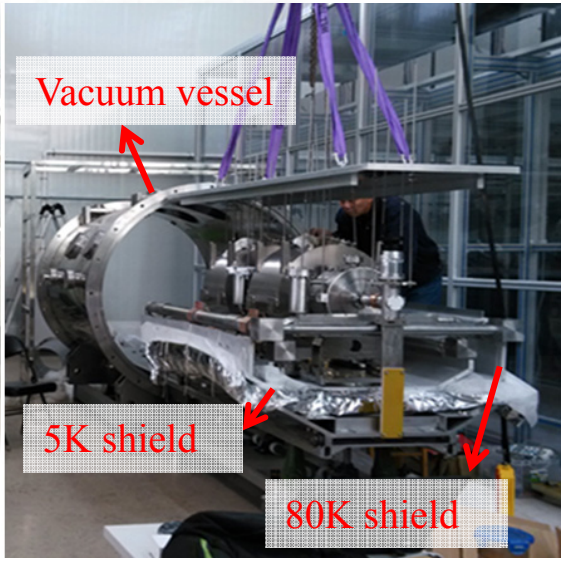


The first buncher：
Designed effective voltage: 54kV
Sync. phase：-90°

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

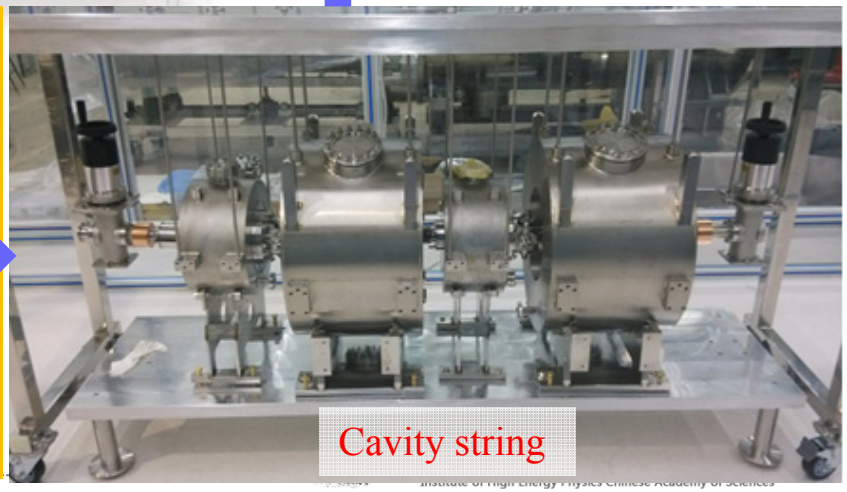
5. TCM commissioning ➡ TCM layout





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

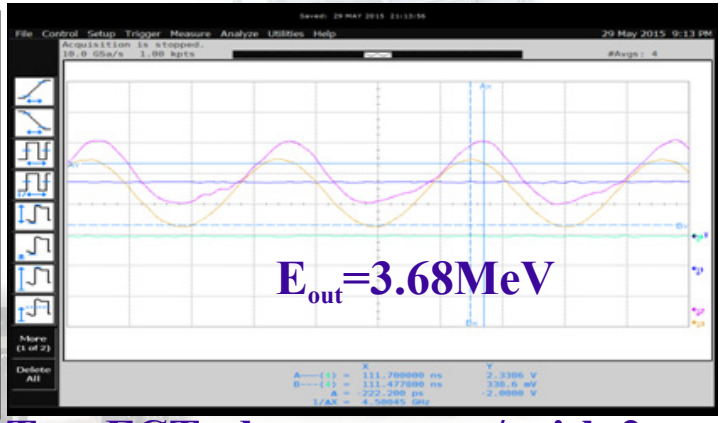
- Two β=0.12 spoke cavity
- Two solenoid
- Two cold BPMs



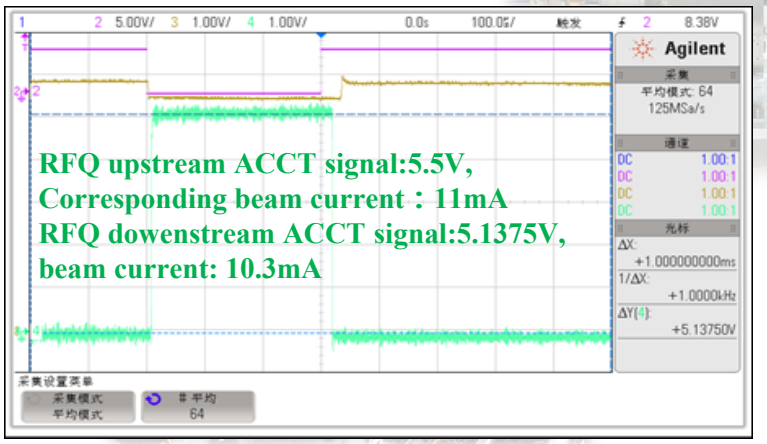
5. TCM commissioning

Beam tuning results of the TCM

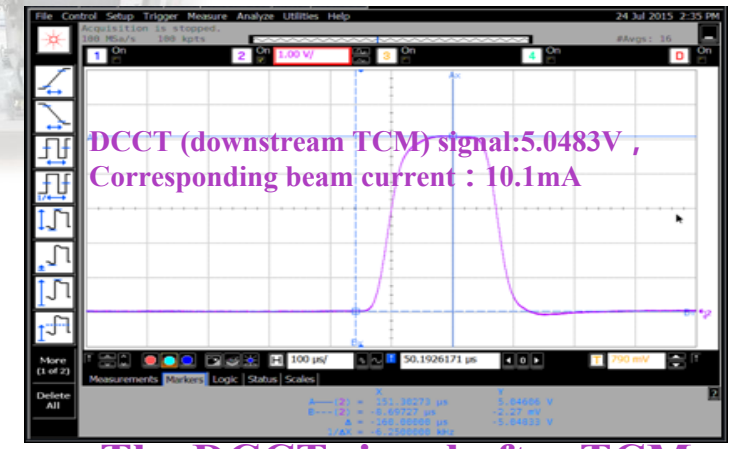
- **Beam duty factor: 1.5 ‰**
- **TCM 2 cavities achieved Max.: E_{acc}=3.1MV/m (E_p=14MV/m)**
- **TCM transmission：98%**
- **RFQ+TCM transmission：92% output current: 10.1mA**



Two FCTs downstream / with 2 cavities on



Two ACCT signals before & after RFQ



The DCCT signal after TCM

Lesson learned: the accelerating gradient was preventing by serious field emission caused by cavity contamination, we did some improvement accordingly for the CM1/2 cavities and the accelerating gradient goes higher!

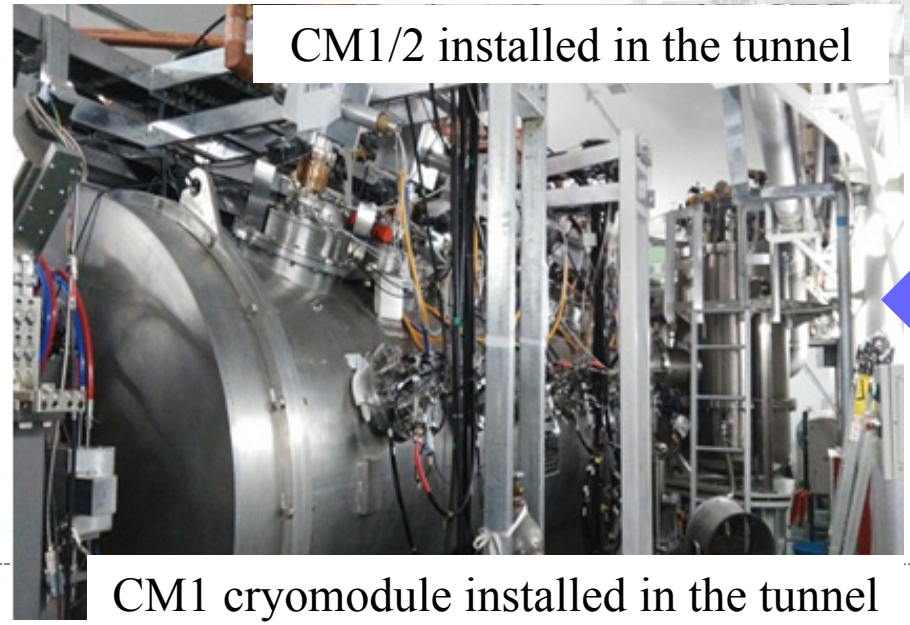
6. 5MeV test stand commissioning ➡ Injector SC section assembling

CM1 cavity string

CM2 cavity string

Ready to be installed in the vacuum vessel

CM1/2 installed in the tunnel



CM1 cryomodule installed in the tunnel

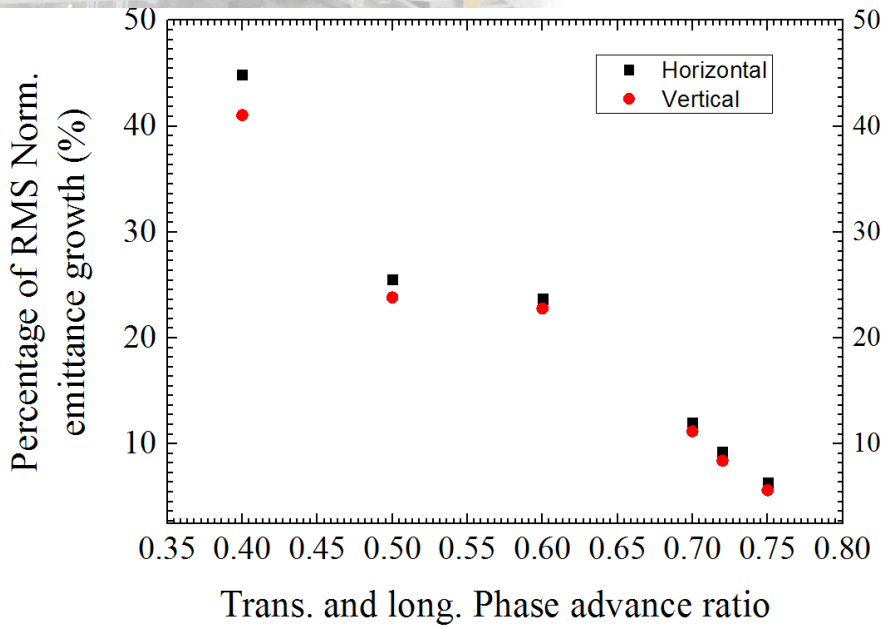
CM1 cryomodule

Emittance growth with different transverse over longitudinal phase advance ratios

During the design of the SC section, different transverse and longitudinal phase advance ratios started from 0.4 up to 0.75 were studied for totally 14 periods without breaking:

- More than 20% RMS normalized emittance growth were observed for the phase advance ratio of 0.4~0.6 with ideal input Gaussian distribution with no errors included.
- Beam losses observed for phase advance ratio of 0.4 because of weak transverse focusing with zero current periodical phase advance smaller than 30 degree.
- A moderate phase advance ratio of 0.75 was chosen to avoid the envelope resonance and emittance growths.

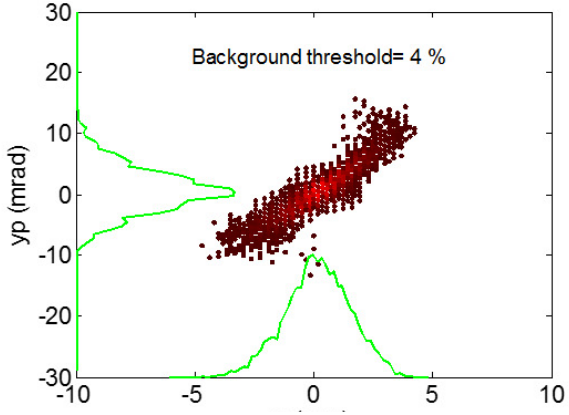
Maximum emittance growth versus different phase advance ratios



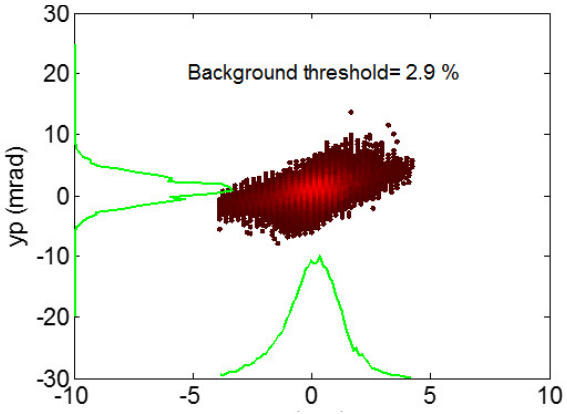
6. 5MeV test stand commissioning

Emittance measurement results

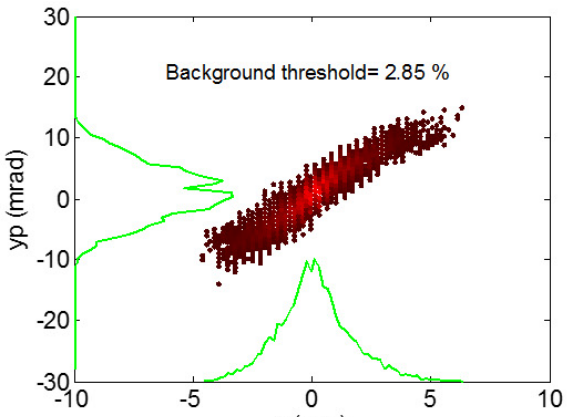
Phase advance ratio of 0.4



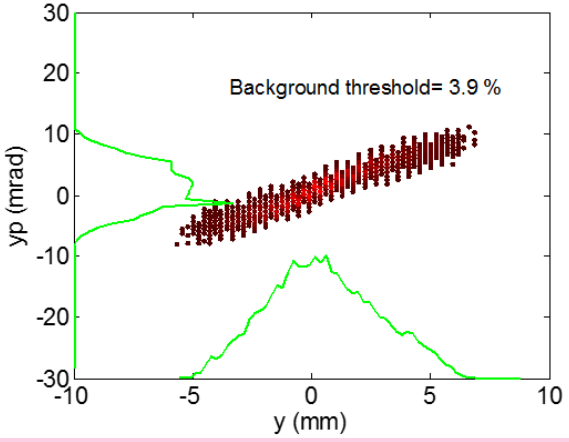
Phase advance ratio of 0.5



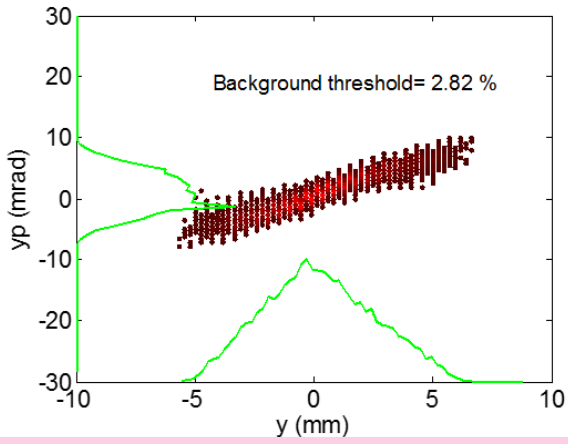
Phase advance ratio of 0.6



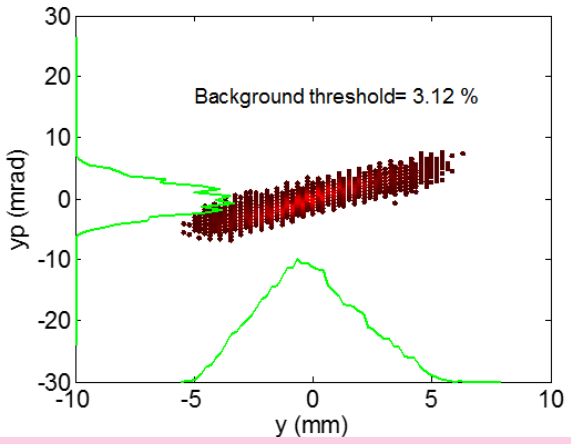
Phase advance ratio of 0.7



Phase advance ratio of 0.72



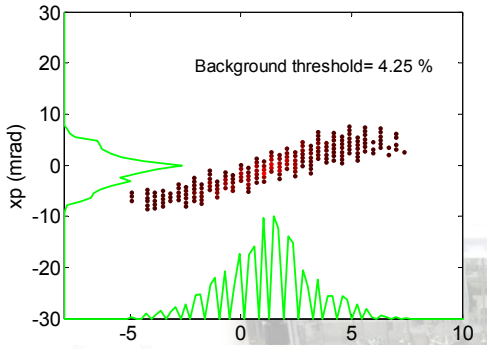
Phase advance ratio of 0.75

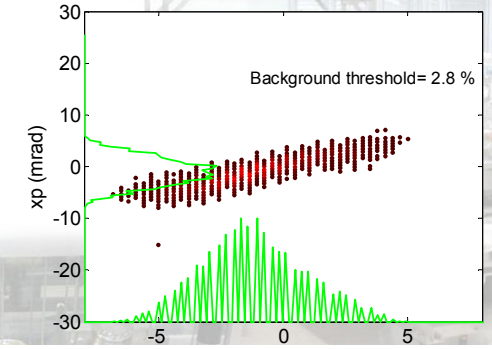


The detail measurement results were presented in the poster, C. Meng, # MOPOY031

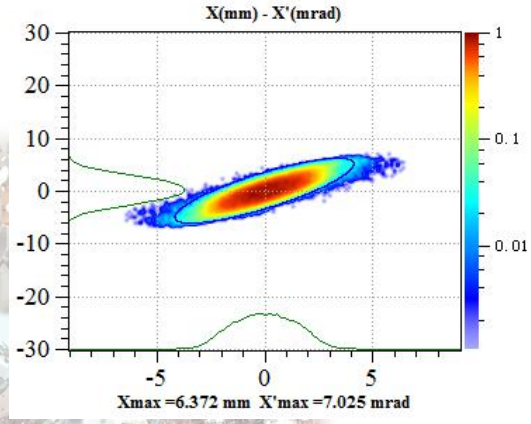
Emittance measurement results V.S simulation at the exit of CM1 with nominal design

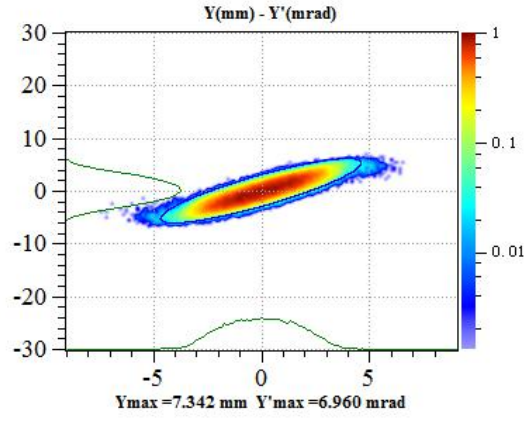
Measured





Simulated



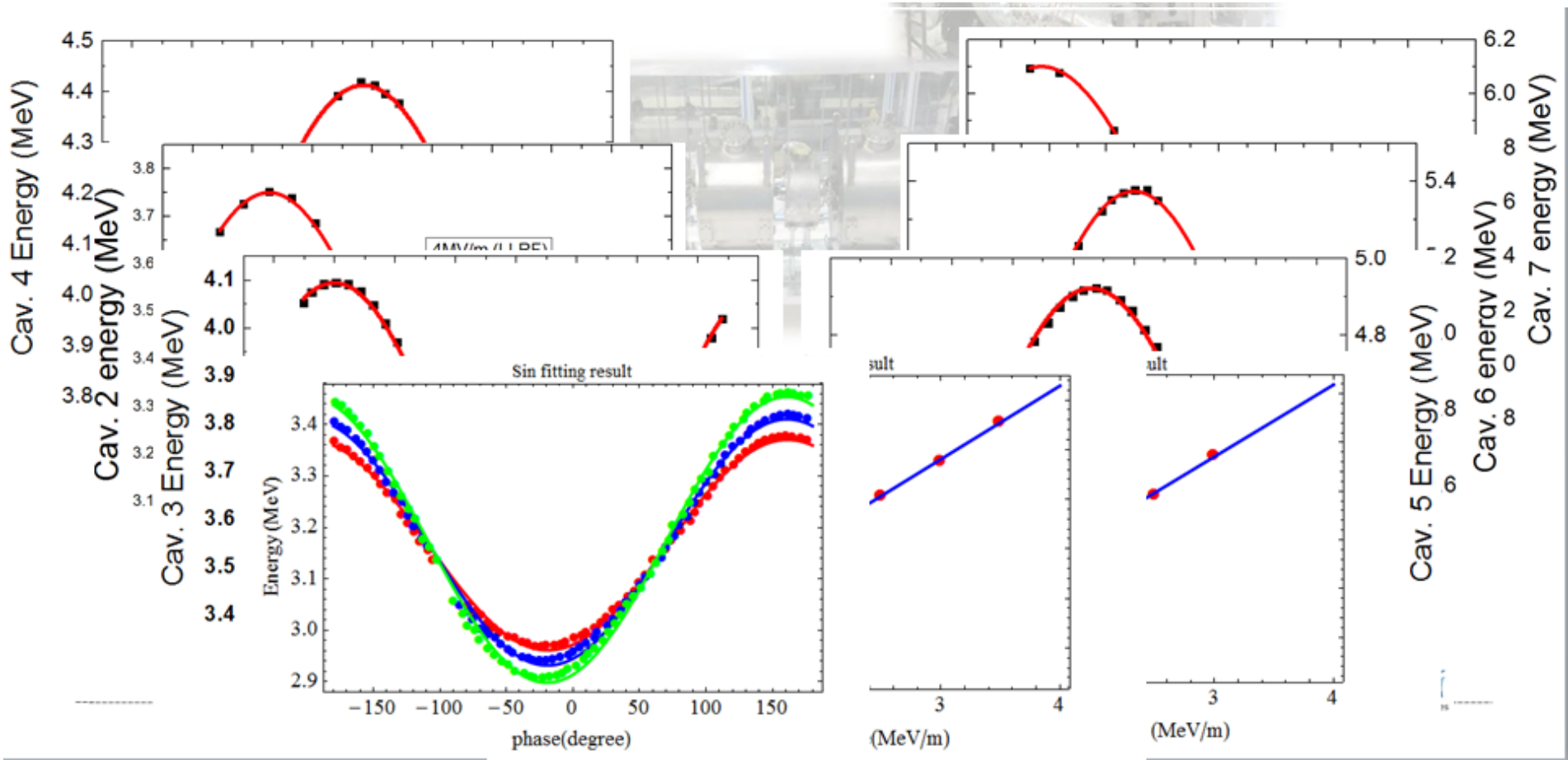


Parameters	αx/αy	βx/ βy (mm/mrad)	$E_{n,rms,x/y}$ (π mm.mrad)
Simulation results according to emit. measurement results by Quad. Scan with 30% long. mismatch at RFQ exit	-1.44/-1.75	1.18/1.53	0.22/0.21
Measurement (Double slits)	-2.12/-1.97	1.56/1.81	0.29/0.27

6. 5MeV test stand commissioning

Commissioning results

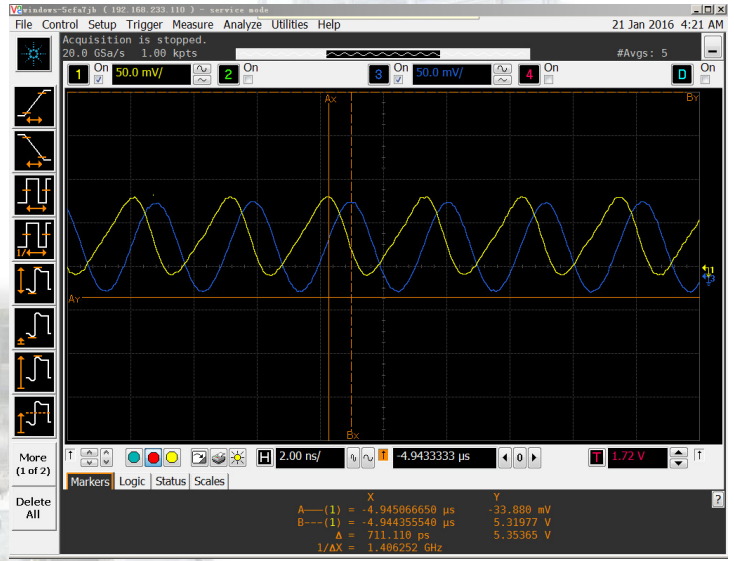
Cav. Number	Bun.1	Bun.2	1	2	3	4	5	6	7
Eacc(MV/m)	69.7kV	91.5kV	4.97	4.97	5.09	5.28	5.42	4.69	4.36

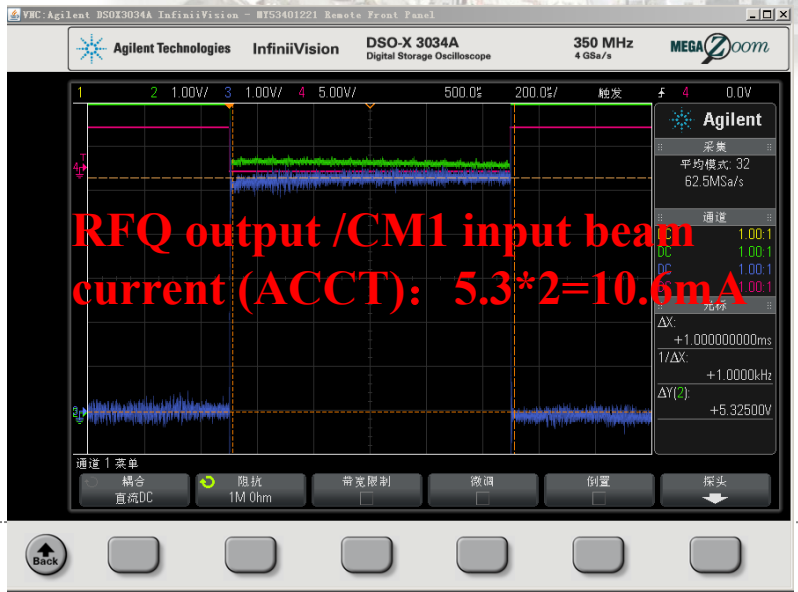


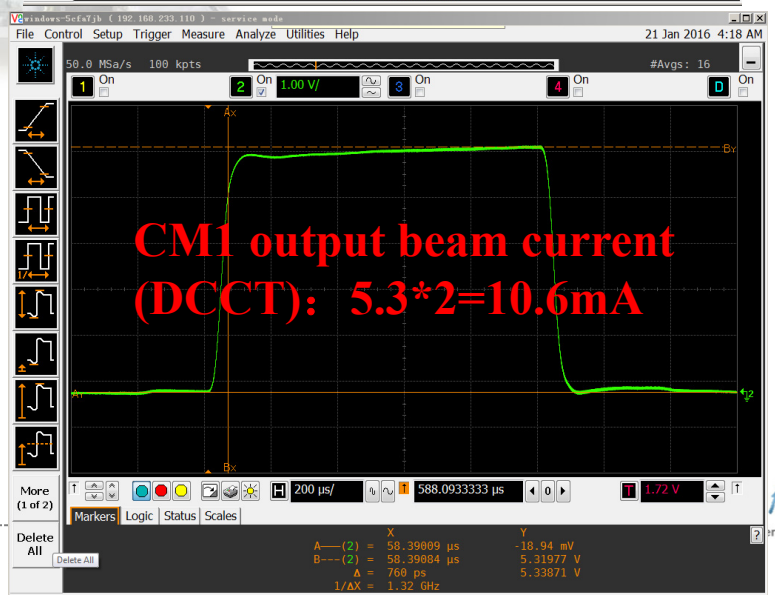
6. 5MeV test stand commissioning

Commissioning results

- **Beam duty factor: 2‰ (2Hz/1ms)**
- **CM 1 output energy with 7 cavities : Eout=6MeV**
- **CM1 transmission ：100%**
- **RFQ+CM1 transmission ： 88.4%**
- **Output current: 10.6mA**







7. Summary

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

Acknowledgement

Sincere acknowledgement to the China ADS Injector-I commissioning group for the great efforts made during the commissioning.

Thanks for your attentions!!