Institute of High Energy Physics

Development of the C-ADS SRF Accelerator at IHEP

Fang YAN

Cai MENG

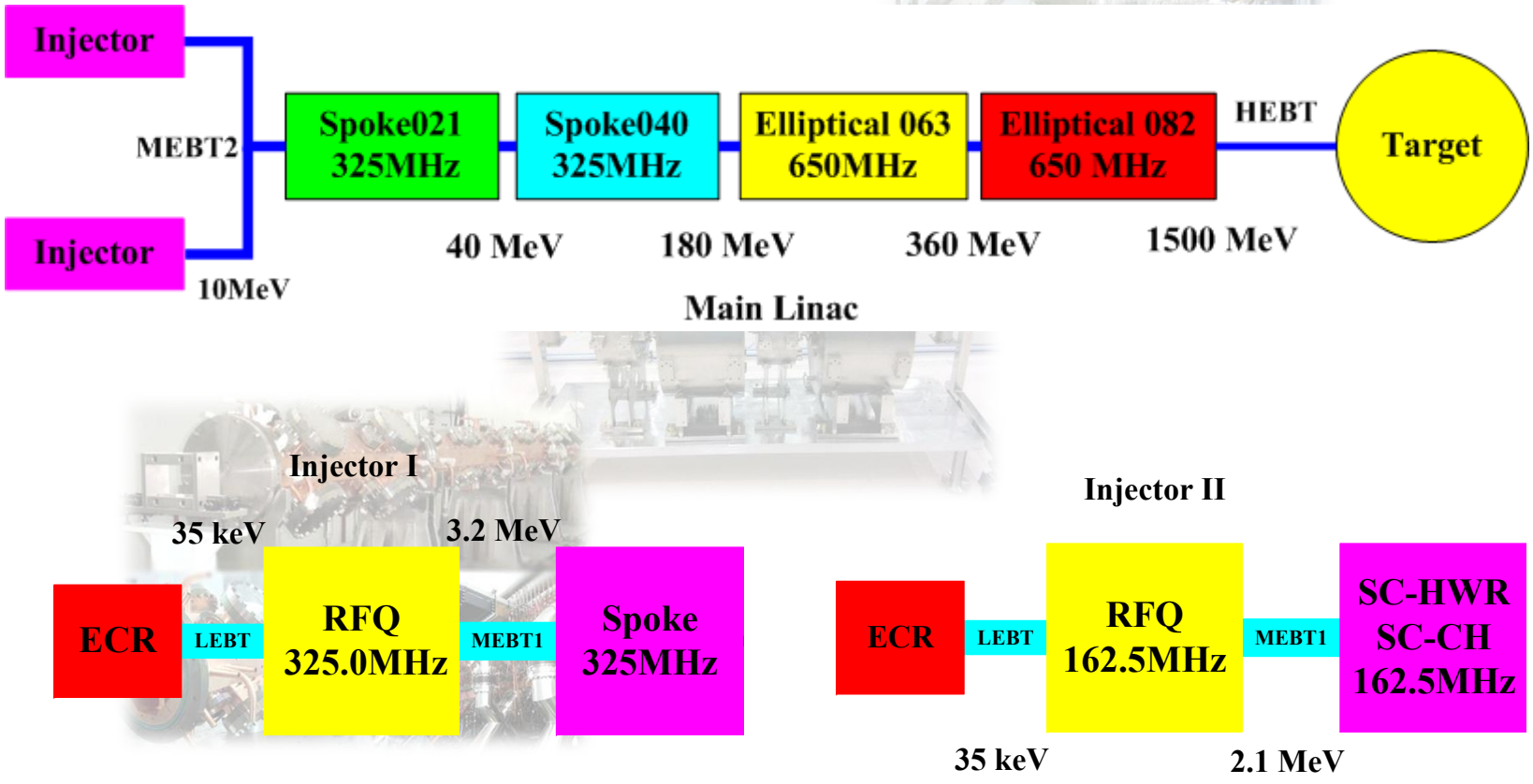
On behalf of the China-ADS commissioning group in IHEP

Lanzhou, China, July 17th, SRF2017

Outline

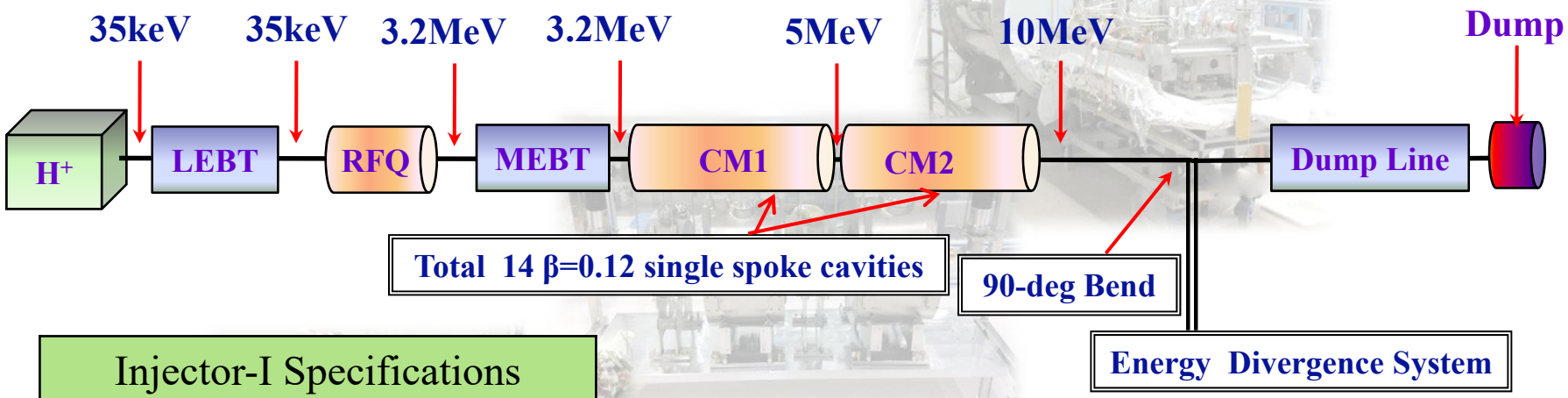
1. Introduction

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

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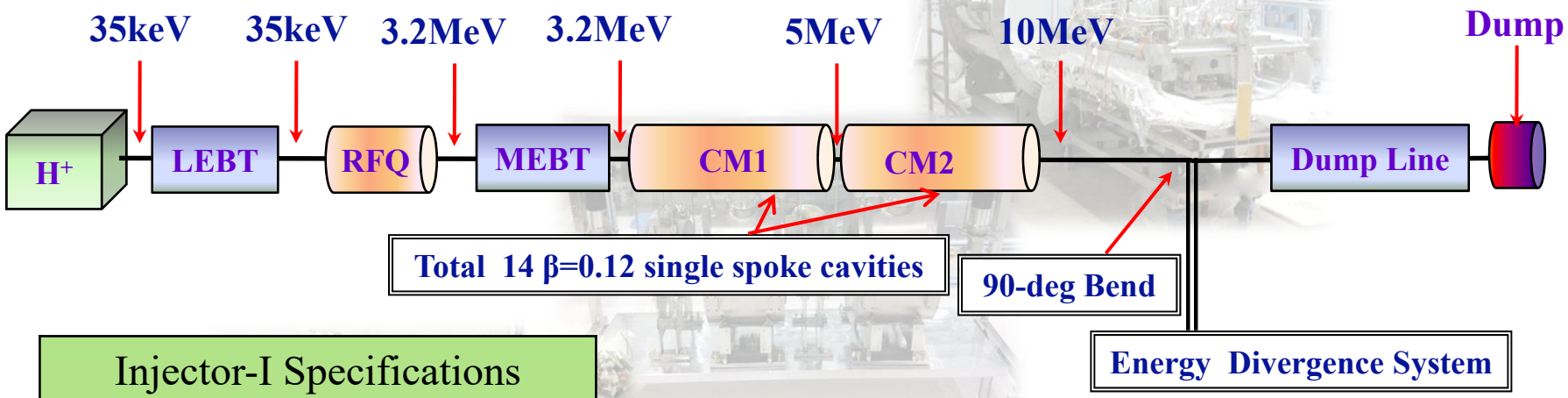

Injector-I Specifications	
Particle	H^+
Output Energy (MeV)	10
Current (mA)	>1
Beam power (kW)	100
Duty factor (%)	100
RF frequency (MHz)	325

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- LEBT: including a chopping system
- 4-vane type copper structure RFQ: 3.2MeV
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2. Design philosophy and considerations

Design philosophy

- **Superconducting cavities as possible**
  - ✓ The main obstacle preventing CW operation of a room temperature (RM) structure is the heat dissipation as high power needed to be feeding in;
  - ✓ Besides, independently phased resonators make local compensation possible;
  - ✓ Modular solid-state amplifiers used increasing the reliability of the linac;
  - ✓ Bigger aperture than RM acceleration structure;
- **Space charge effect**
  - ✓ Tune depression bigger than 0.4, the linac is designed to follow the resonance-free or equipartition condition;
- **Focusing structures**
  - ✓ Max. zero-current phase advance per cell is limited to below 90˚ to avoid parametric resonances & bigger than 30˚ ;
- **Acceptance**
  - ✓ Transverse: beam pipe radius is bigger than 8.5 times of the rms beam size ;
  - ✓ Longitudinally: Sync. Phase bigger than 10 times of the long. RMS size.

3. Status ➡ Injector SC section assembling

The SC section of injector-I include 2 cryomodules (CM1+CM2) : consist of 14 β_g= 0.12 Spoke cavities, 14 SC solenoid and 14 BPM in total. All the assembling of Injector-I has been installed in the tunnel and successfully commissioned.

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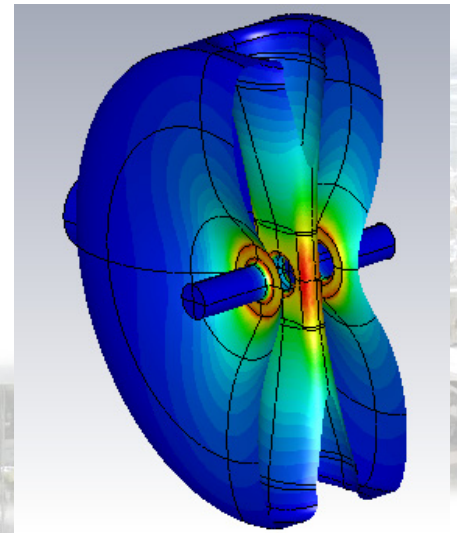
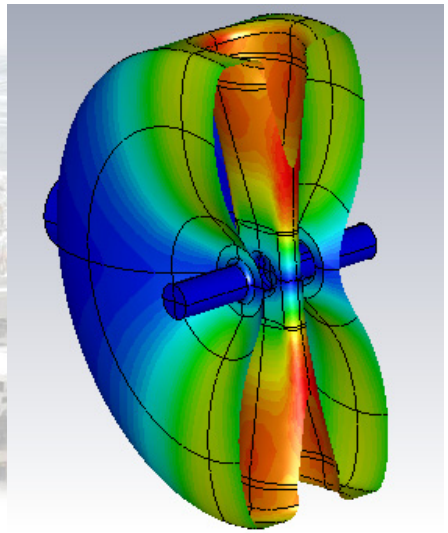
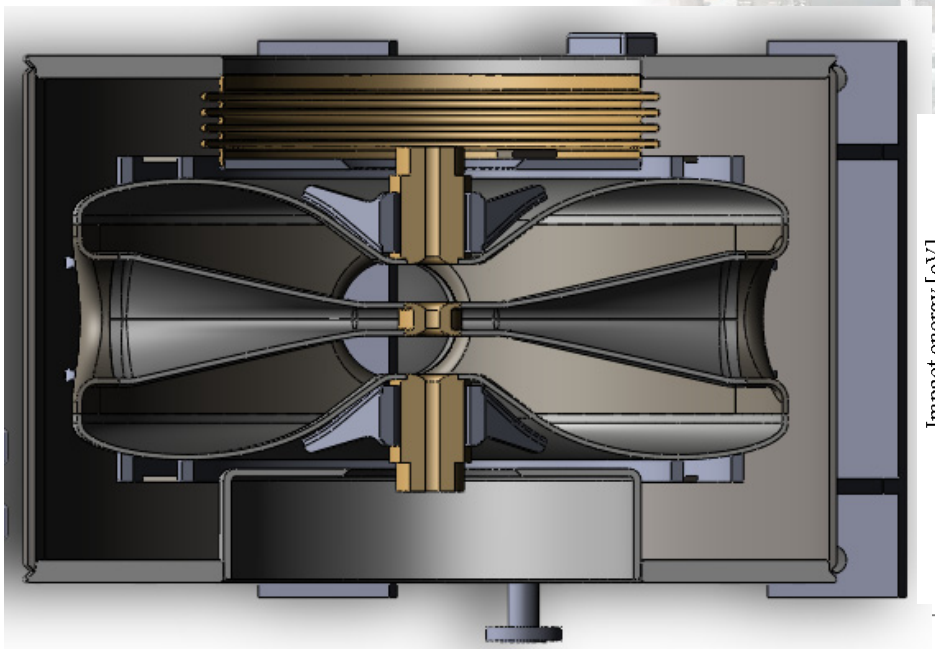
MOPB099: Design of C-ADS Injector-I Cryomodule for 325MHz Cavities

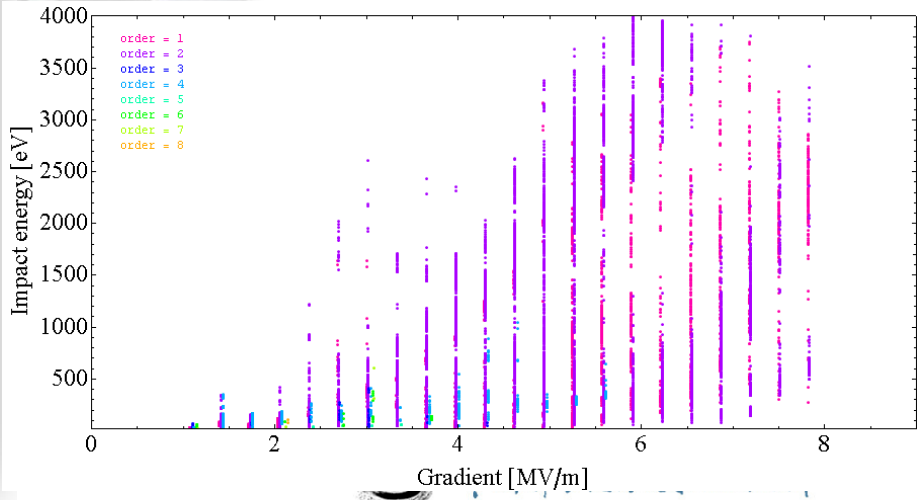
3. Status ➡ Injector SC section assembling

Designed $Vacc_0$	0.80 [MV]
Ep at $Eacc_0$	29.3 [MV/m]
Bp at $Eacc_0$	41.6 [mT]
Dynamic loss [W]	<11.6/1.2 (4K/2K);
df/dp (tuner attached)	40 [Hz/mbar]









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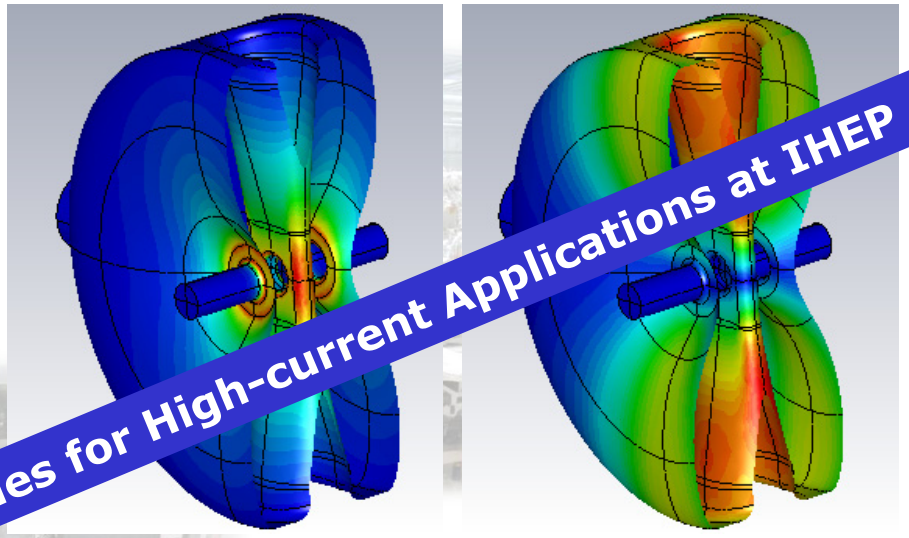

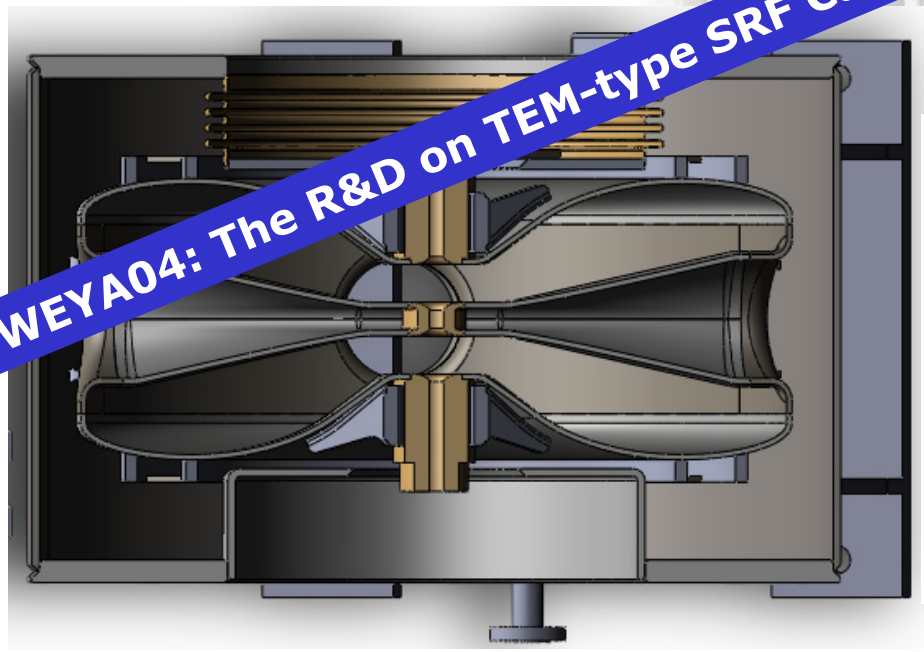

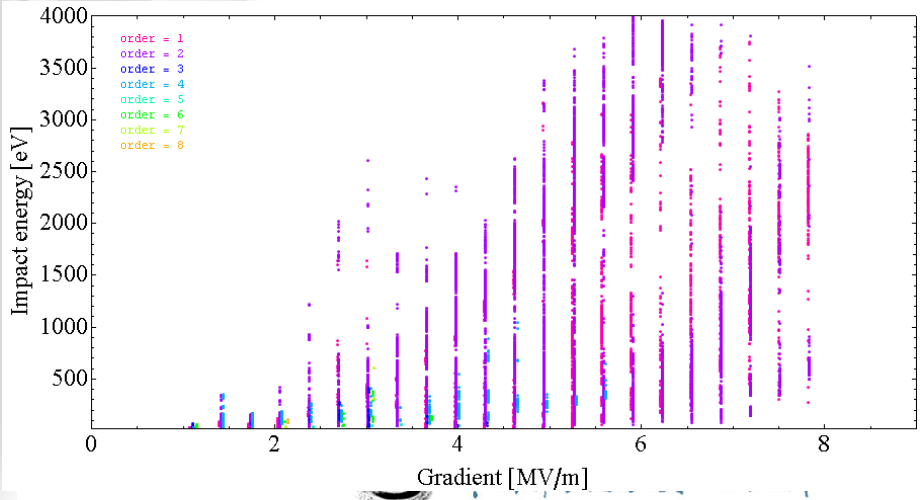

WEYA04: The R&D on TEM-type SRF Cavities for High-current Applications at IHEP

3. Status ➡ Injector SC section assembling

All the couplers used for SC cavities and RT RFQ of Injector-I are developed in IHEP; in the past five years, dozens of power couplers have been developed at IHEP for different cavities of CADS project.

Cavity type	Freq.	Coupler type	Power	Status
Spoke (SCC) β=0.12	325MHz	Coax, fixed, capacitive, single window	Test: CW, 10 kW Oper: CW, 10 kW	Beam Commissioning
Spoke (SCC) B=0.21	325MHz	Coax, fixed, capacitive single window	Test: CW, 20kW (SW) Oper: CW, 6 kW (SW)	Beam commissioning
HWR (SCC) β=0.10	162.5MHz	Coax, fixed, capacitive, single window	Test: CW, 20 kW Oper: CW, 10 kW	Beam commissioning
5-cell (SCC) β=0.82	650MHz	Coax, fixed, capacitive single window	**Test: CW, 150 kW (TW)**	High power test
RFQ-I (NC)	325MHz	Coax, fixed, inductive, single window	Test: CW, 105 kW Oper: CW,100 kW	Beam commissioning
RFQ-II (NC)	162.5MHz	Coax, fixed, inductive, single window	Oper: CW,80 kW	Beam commissioning

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HWR (SCC) β=0.10	162.5MHz	Coax, fixed, capacitive, single window	Test: CW, 20 kW Oper: CW, 10 kW	Beam commissioning
5-cell elliptical	650MHz	Coax, fixed, capacitive single window	**Test: CW, 150 kW (TW)**	High power test
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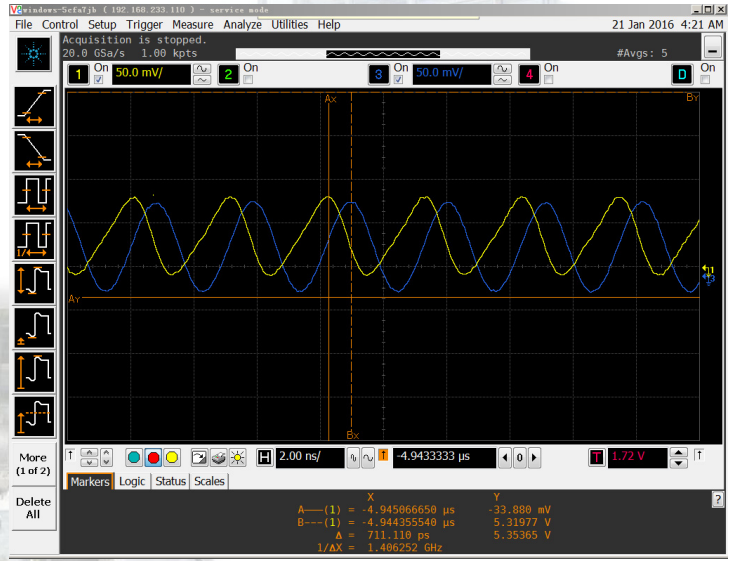
RFQ-II (NC)	162.5MHz	Coax, fixed, inductive, single window	Oper: CW,80 kW	Beam commissioning

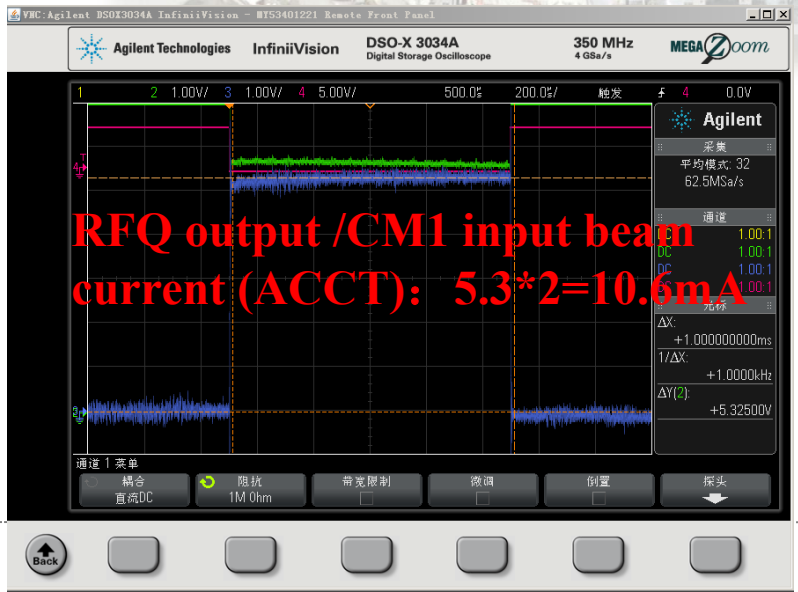
MOPB070: The Improvement of the Power Coupler for C-ADS SC Spoke Cavities

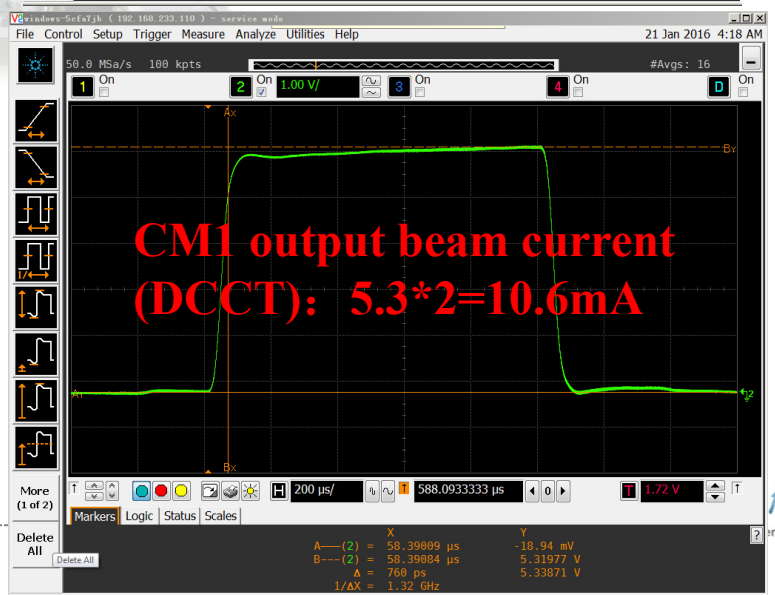
4. Pulsed mode commissioning ➡ 5MeV test stand

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**



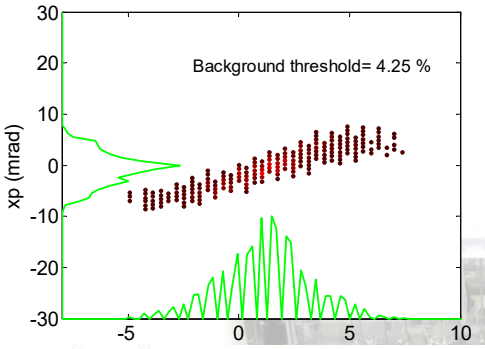


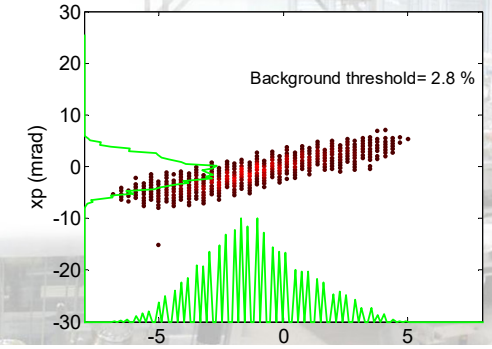


4. Pulsed mode commissioning ➡ 5MeV test stand

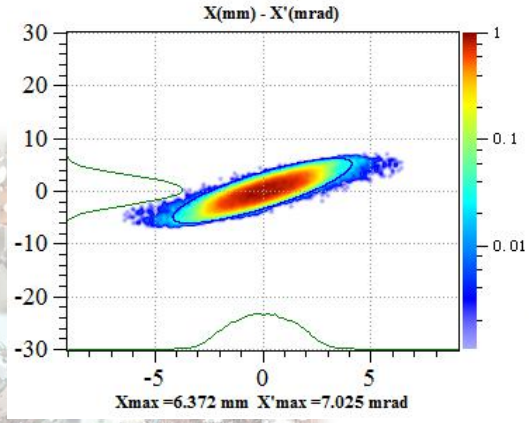
Emittance measurement results V.S simulation at the exit of CM1 with nominal design

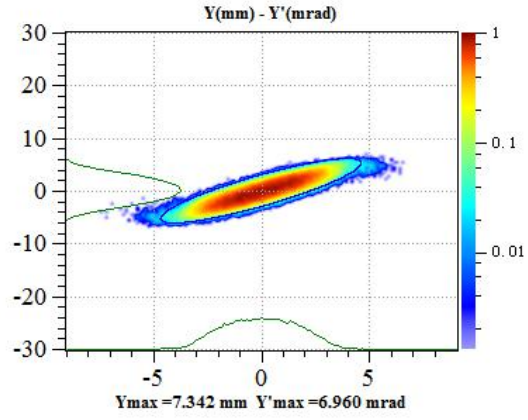
Measured





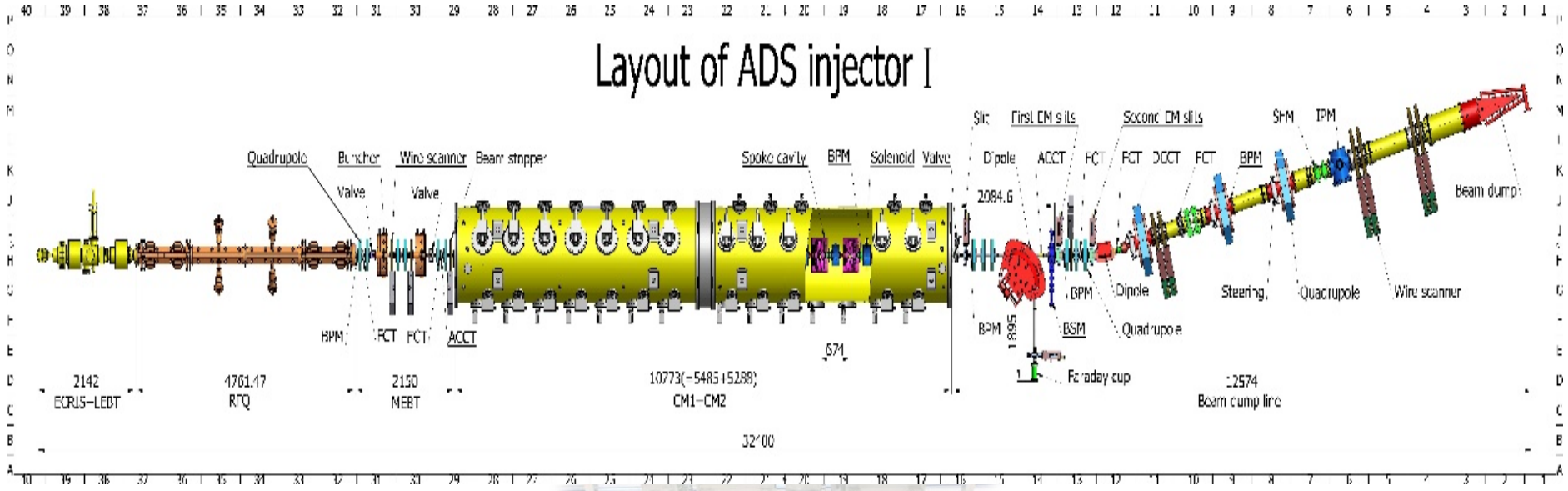
Simulated

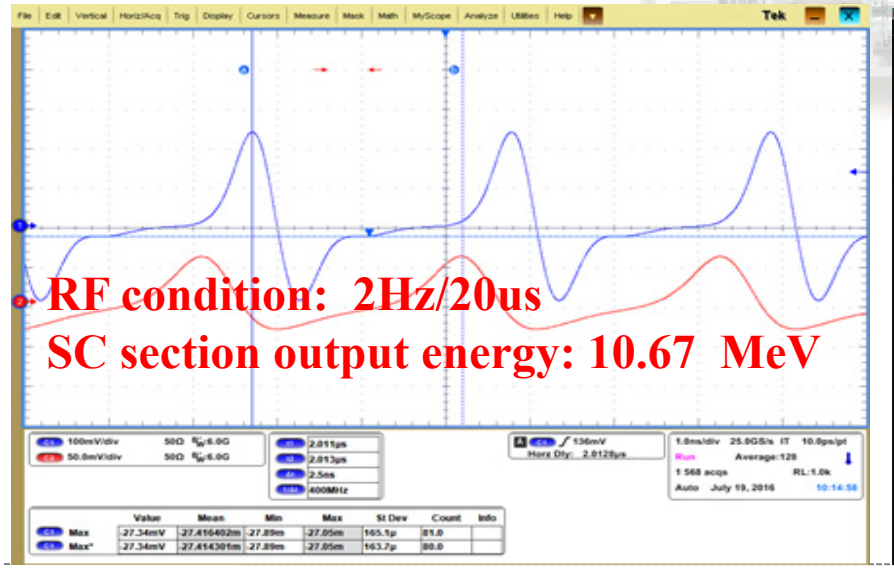


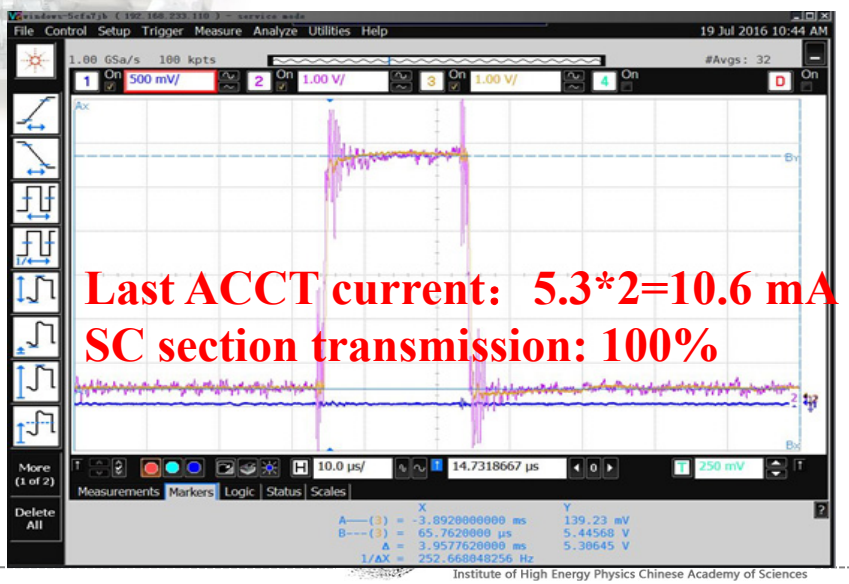


Parameters	αx/αy	βx/ βy (mm/mrad)	$E_{n,rms,x/y}$ (π mm.mrad)
Simulation results according to emit. measurement results by Quad. Scan with 30% long. mismatch at RFQ exit	-1.44/-1.75	1.18/1.53	0.22/0.21
Measurement (Double slits)	-2.12/-1.97	1.56/1.81	0.29/0.27

4. Pulsed mode commissioning ➡ Injector-I (10MeV) test stand







4. Pulsed mode commissioning ➡ Injector-I (10MeV) test stand

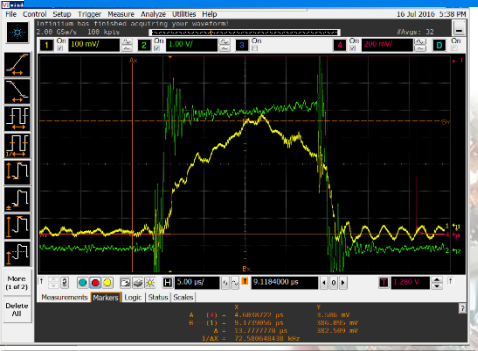
The operating gradient of the 14 SC cavities @ 10.67MeV/10.6mA

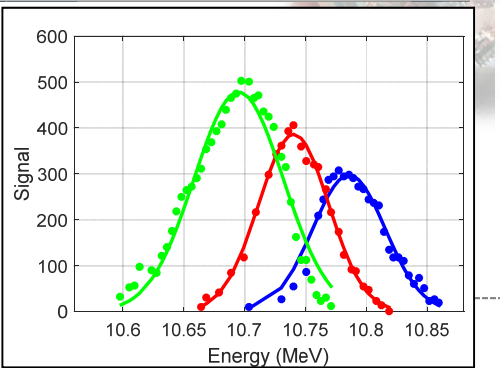
Cav. #	1	2	3	4	5	6	7
E_p(MV/m)	17.1	24.4	29.1	26.4	30.6	33.7	26.3
Cav. #	8	9	10	11	12	13	14
E_p(MV/m)	26.0	26.0	28.6	27.8	31.0	30.7	19.2

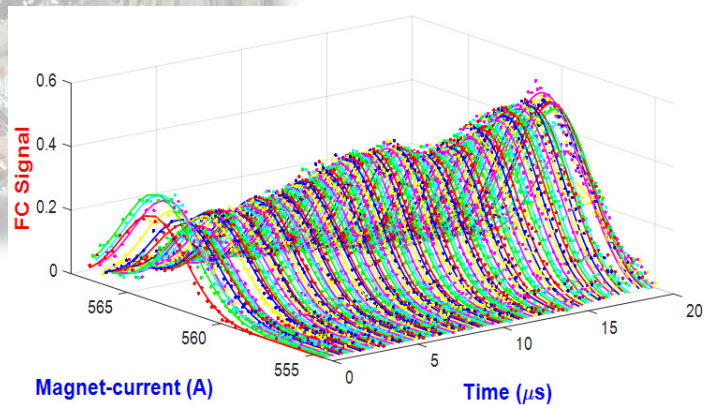
Energy divergence results @10.67MeV/10.6mA

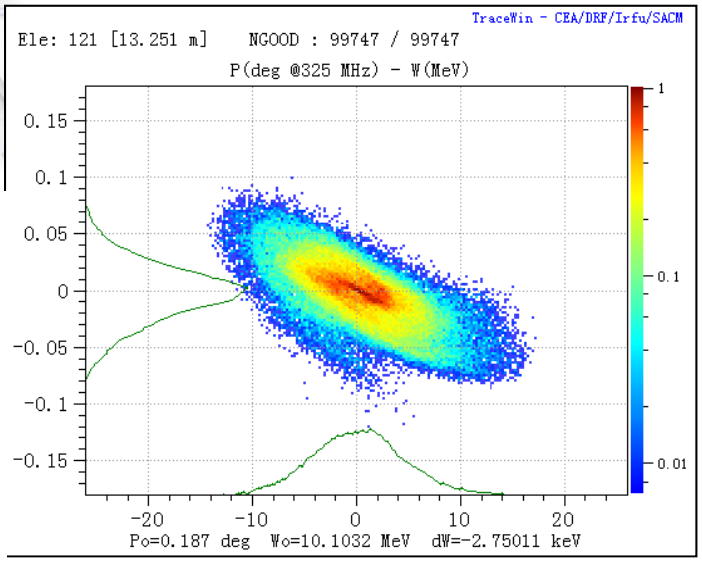
Measurement results：0.32%

Beam dynamics results：0.28%





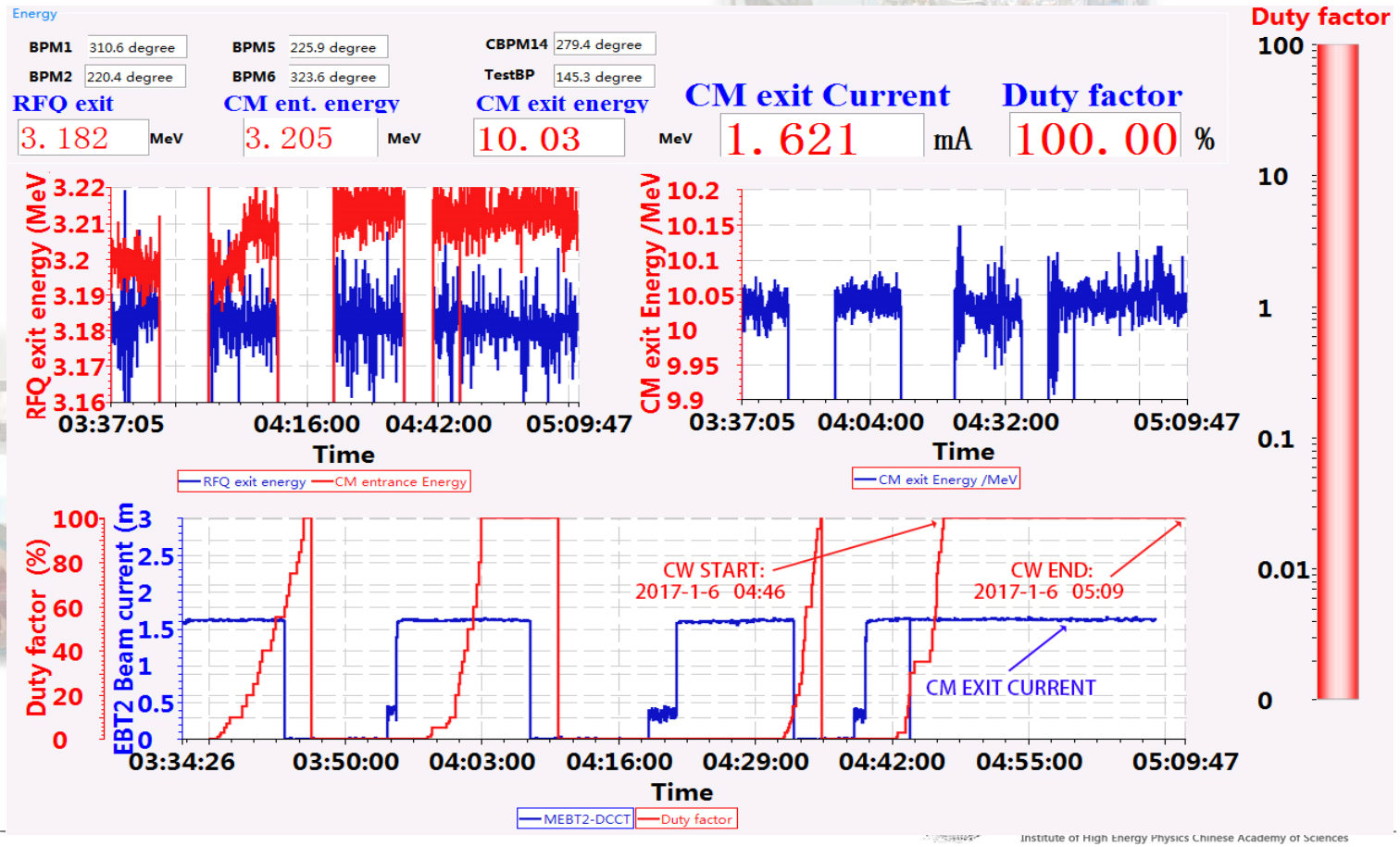




5. CW mode commissioning

CW commissioning of Injector-I @ 1.6 ~2.1mA

Obtained CW beam @10MeV with average beam current of 1.6~2.1mA
The max. stable operating time without trip: 23 min (10.03MeV/1.62mA) @1.6mA



5. CW mode commissioning

CW commissioning of Injector-I @ 1.6 ~2.1mA

14 SC cavity operating gradient @10.08MeV

腔	#1	#2	#3	#4	#5	#6	#7
Ep(MV/m)	16.5	23.9	25.0	26.5	29.1	24.3	20.3
腔	#8	#9	#10	#11	#12	#13	#14
Ep(MV/m)	24.5	18.1	29.6	24.7	27.6	26.1	21.8

14 SC cavity operating gradient @9.1MeV

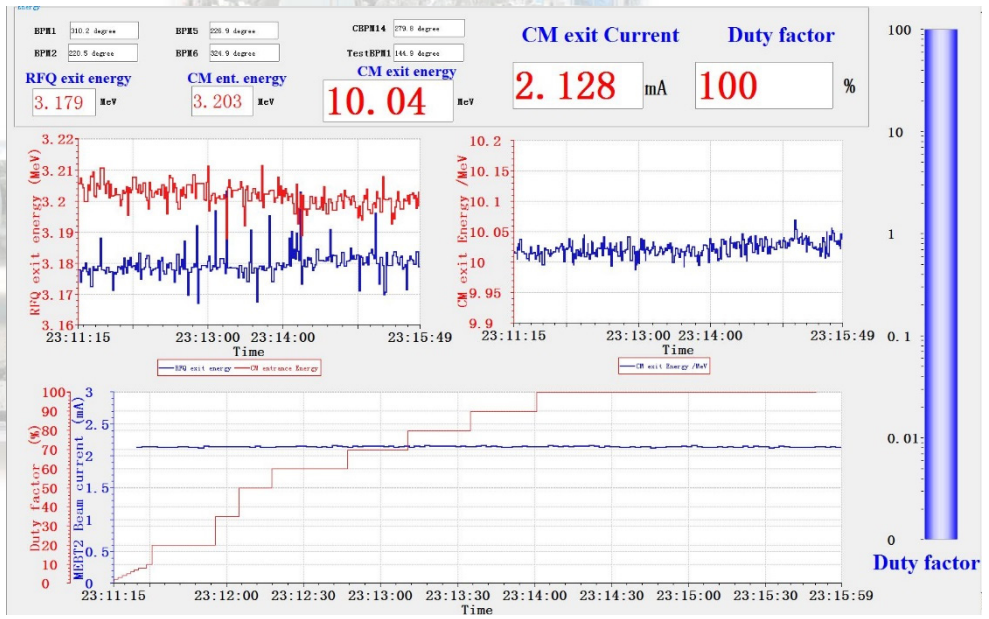
腔	#1	#2	#3	#4	#5	#6	#7
Ep(MV/m)	17.1	19.7	22.2	24.7	24.7	16.7	21.1
腔	#8	#9	#10	#11	#12	#13	#14
Ep(MV/m)	19.3	16.3	24.7	24.7	24.7	24.7	24.7

5. CW mode commissioning

Beam transmission from LEBT to the exit of SC section

LEBT DCCT signal

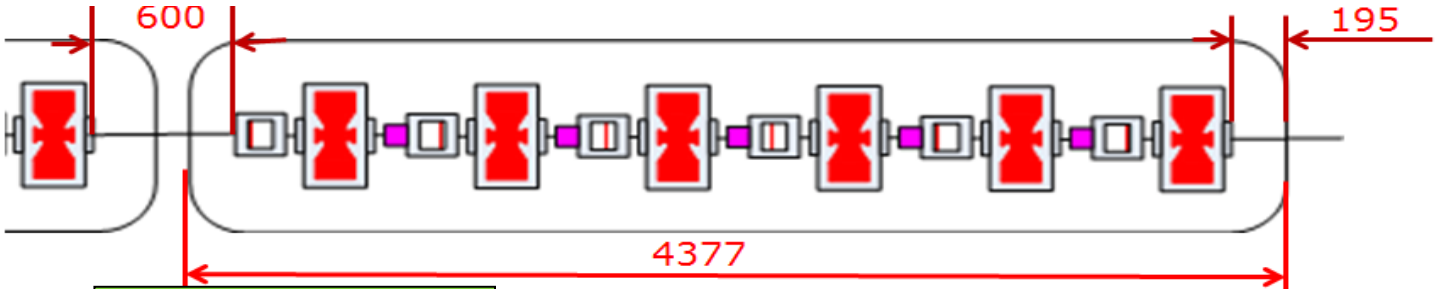
DCCT at the exit



Transmission on CW operation @10MeV：

- **DCCT signal on LEBT DCCT：1.206*2=2.412 mA**
- **DCCT at the exit of SC section：2.128 mA**
- **Beam transmission from LEBT to the end of the linac: 2.128 / 2.412= 88.2%**

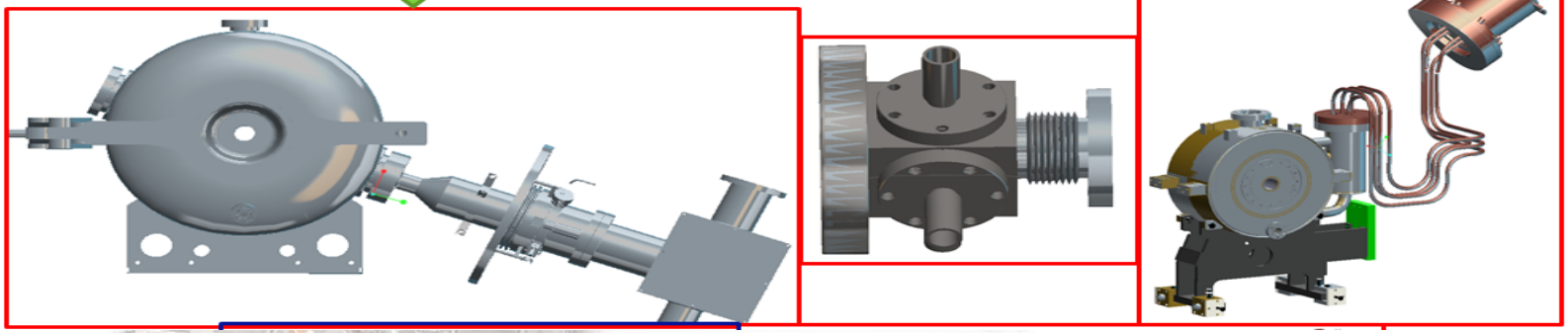
6. The CM4 of 25MeV test stand



SPOKE-021 SC cavity + coupler + tuner

Cold BPM

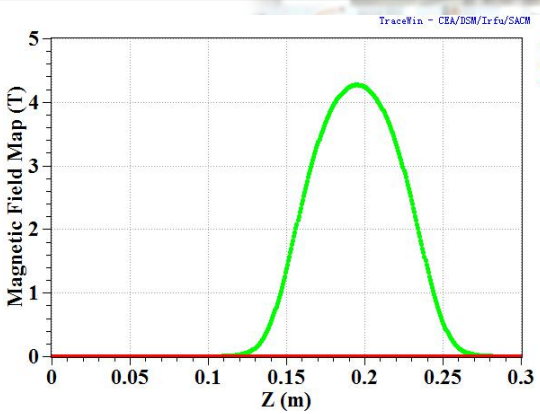
SC solenoid + current leads

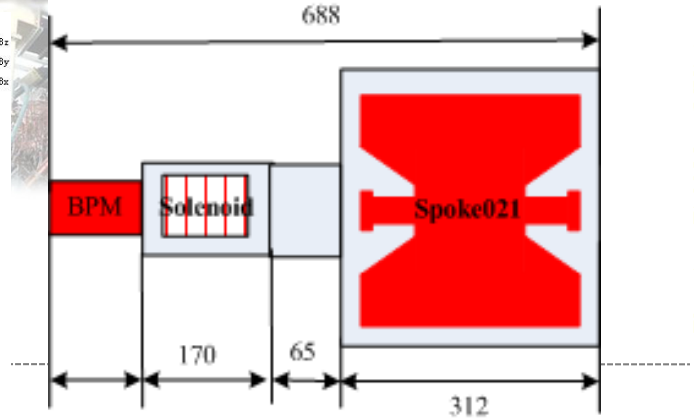


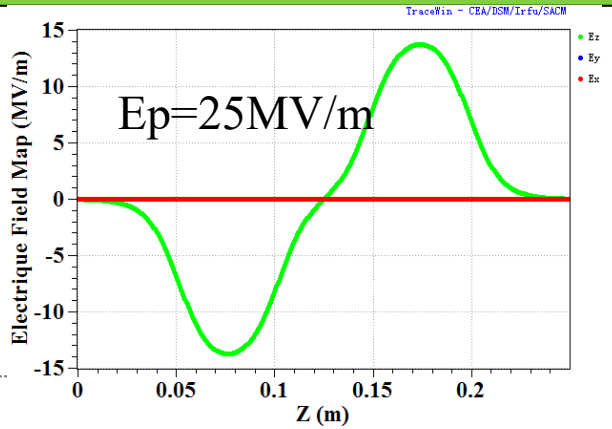
Sol: aperture 40mm

One cell

Spoke021 cavity：Ep=30MV/m, aperture40mm







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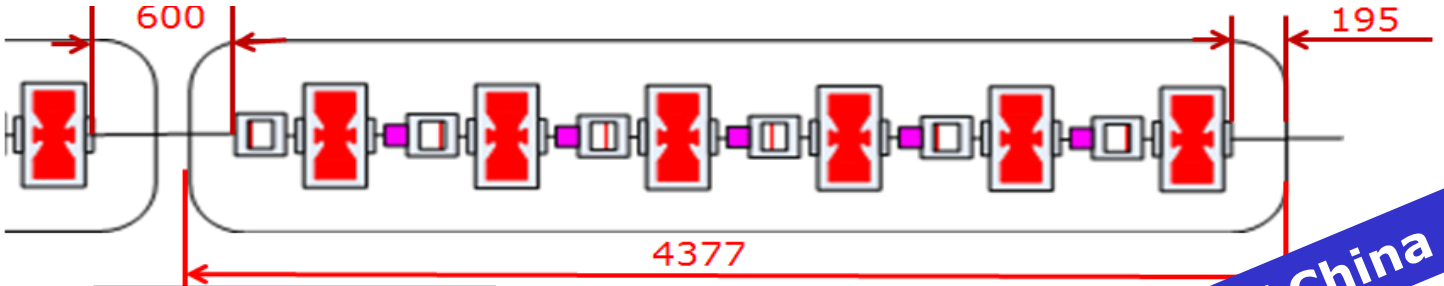
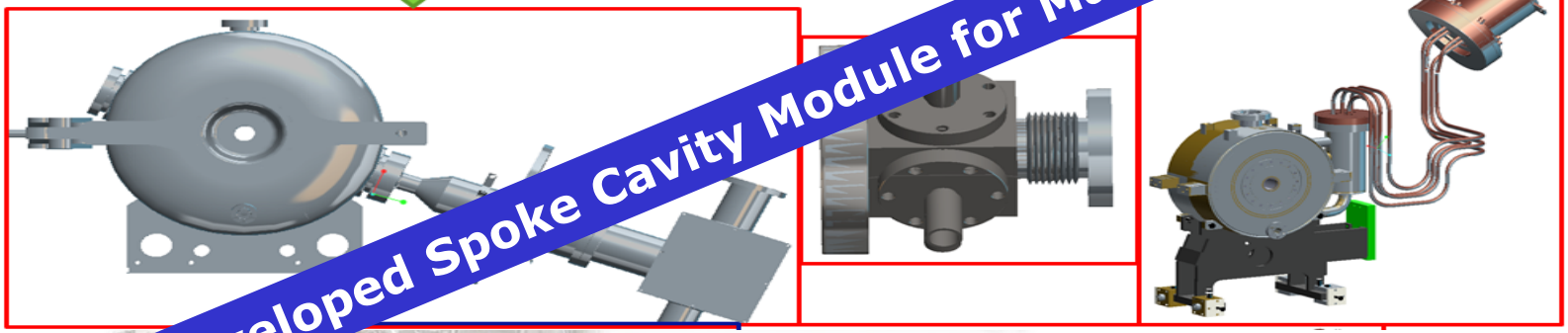


SPOKE-021 SC cavity + coupler + tuner

Cold BPM

SC current leads

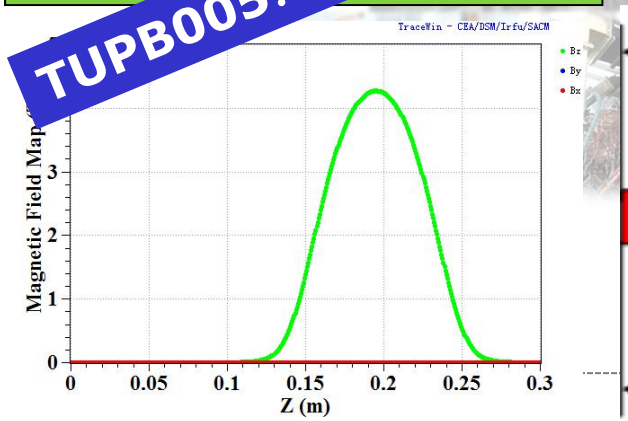


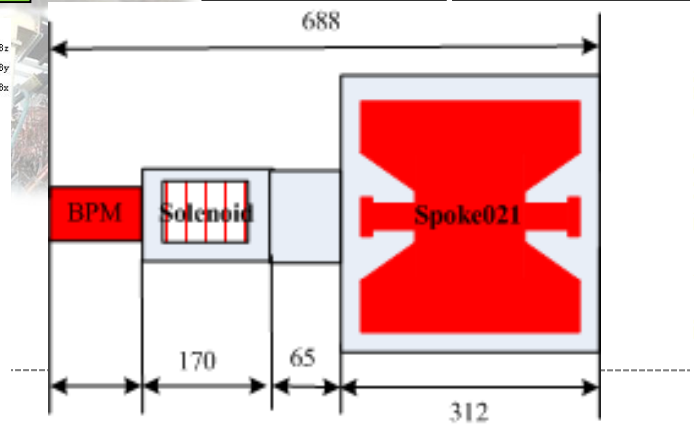
TUPB005：Developed Spoke Cavity Module for Main Linac of China ADS

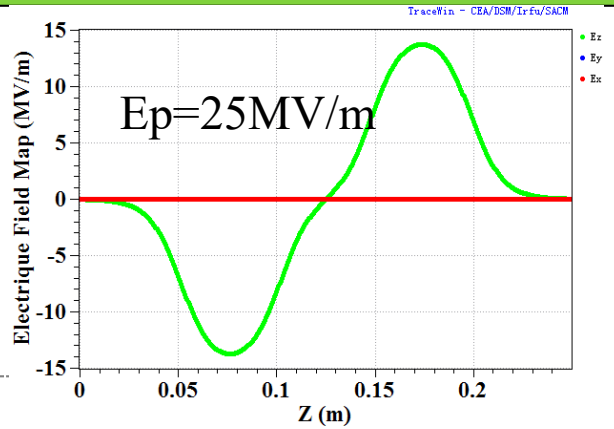
Sol: apertu

One cell

Spoke021 cavity：Ep=30MV/m, aperture40mm





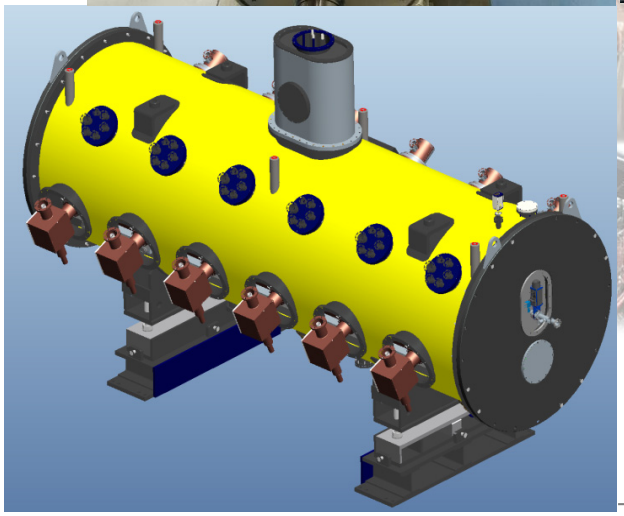


6. The CM4 of 25MeV test stand

4th Cryomodule Assembling of 25MeV test stand





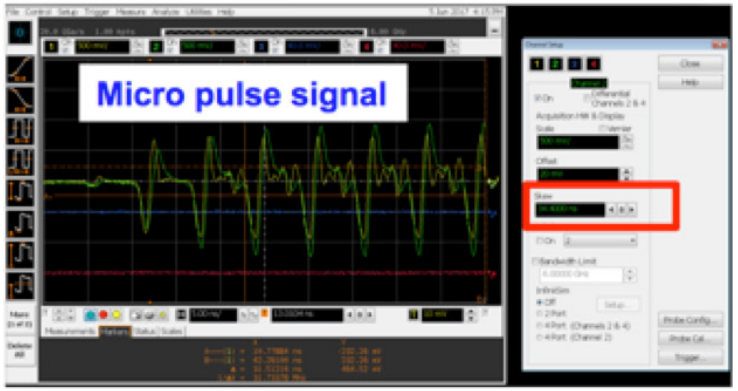


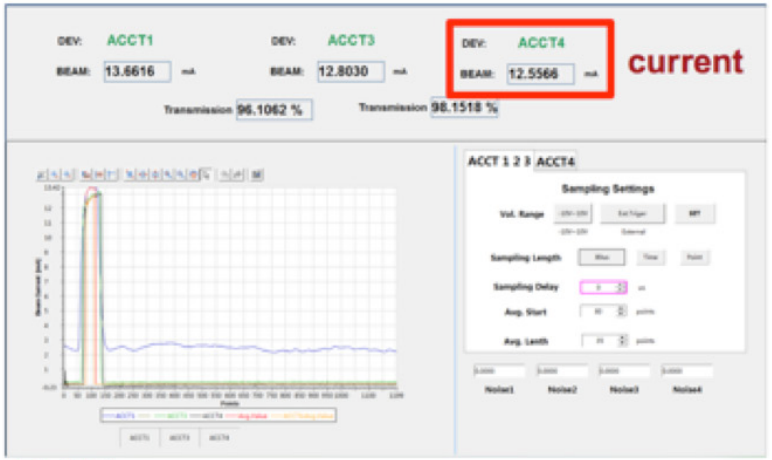

General	
Overall length(flange to flange, m)	4.377
Diameter of Vacuum vessel ,m	1.4
Beamline height from floor, m	1.5
Overall weight, t	12
Cryo-system working temperature, K	4
Number of cavities	6
Number of solenoids	6
Number of BPMs	6

6. The CM4 of 25MeV test stand

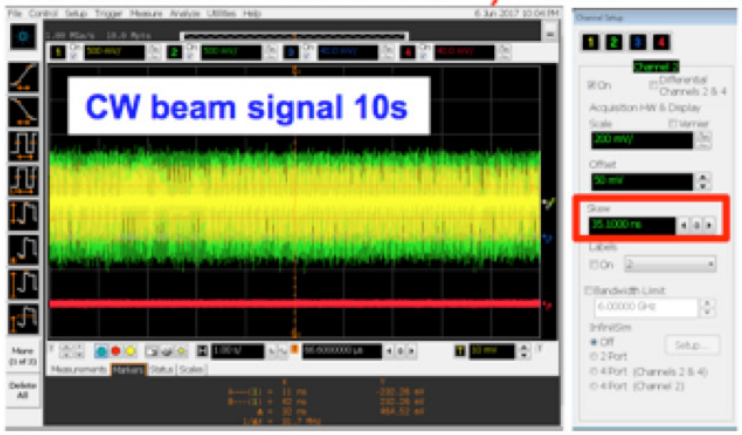
Commissioning results

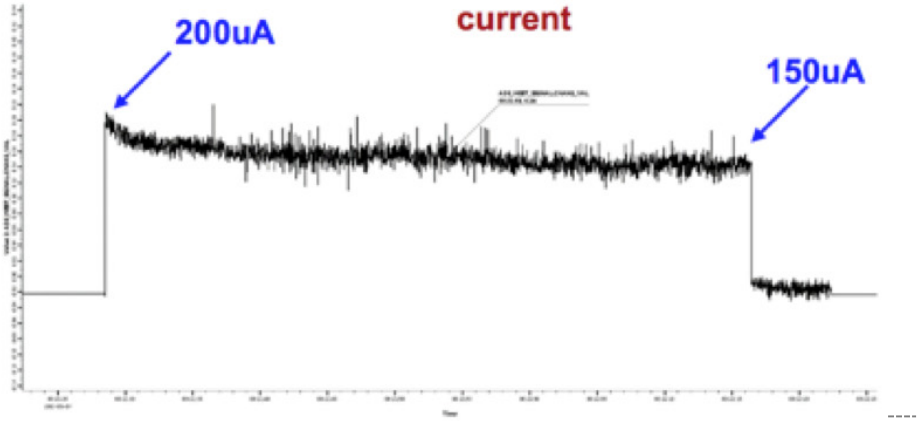
Pulse beam：26.1MeV，12.6mA，5us，1Hz





CW beam：25.0MeV，150~200uA，5kW





7. Summary

The China ADS injector-I testing facility has been commissioned successfully using pulsed and CW beam:

- The maximum energy achieved at the exit of the Injector is 10.67 MeV with beam current of 10.6 mA on pulsed mode.
- CW proton beam with energy of 10 MeV and average beam current of 1.6~2.1 mA have been obtained at the exit of the linac.
- The CW beam with average beam current of 1.62 mA lasted for 23 minutes stably without trip of any devices.
- Preliminary experiment results that have been obtained are encouraging but further work is still needed to do for better understanding of the phenomena that occur in high duty cycle operation of the linac.

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Thanks for your attentions!!