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Successful Beam Commissioning of Chinese ADS Injector II and Front-end Demo Linac

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Outlines



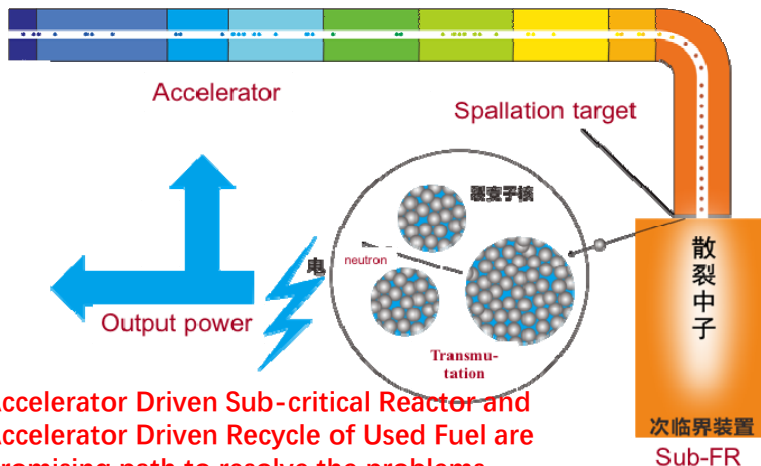
- **Introduction of Chinese ADS project**
- Commissioning of CW SC-Linac
- Summary of Commissioning Progress
- Acknowledgments

● NP development in China

- 37 reactors in operation, 20 reactors under construction, 3.56% share in 2016
- 58 GWe in operation, 30 GWe under construction, 7% share in 2020
- 350 ~ 400 GWe in operation (391GWe in the world in 2017), ~20% share in 2050

● Management and safe disposal of nuclear waste

- ~10000 ton/year now in the world
- Total capacity of Yucca Mountain ~ 70000 ton; Approved by US congress in 2002
- 300~500M\$ budget per year; 833.4M\$ in 2015; 986.2M\$ in 2016

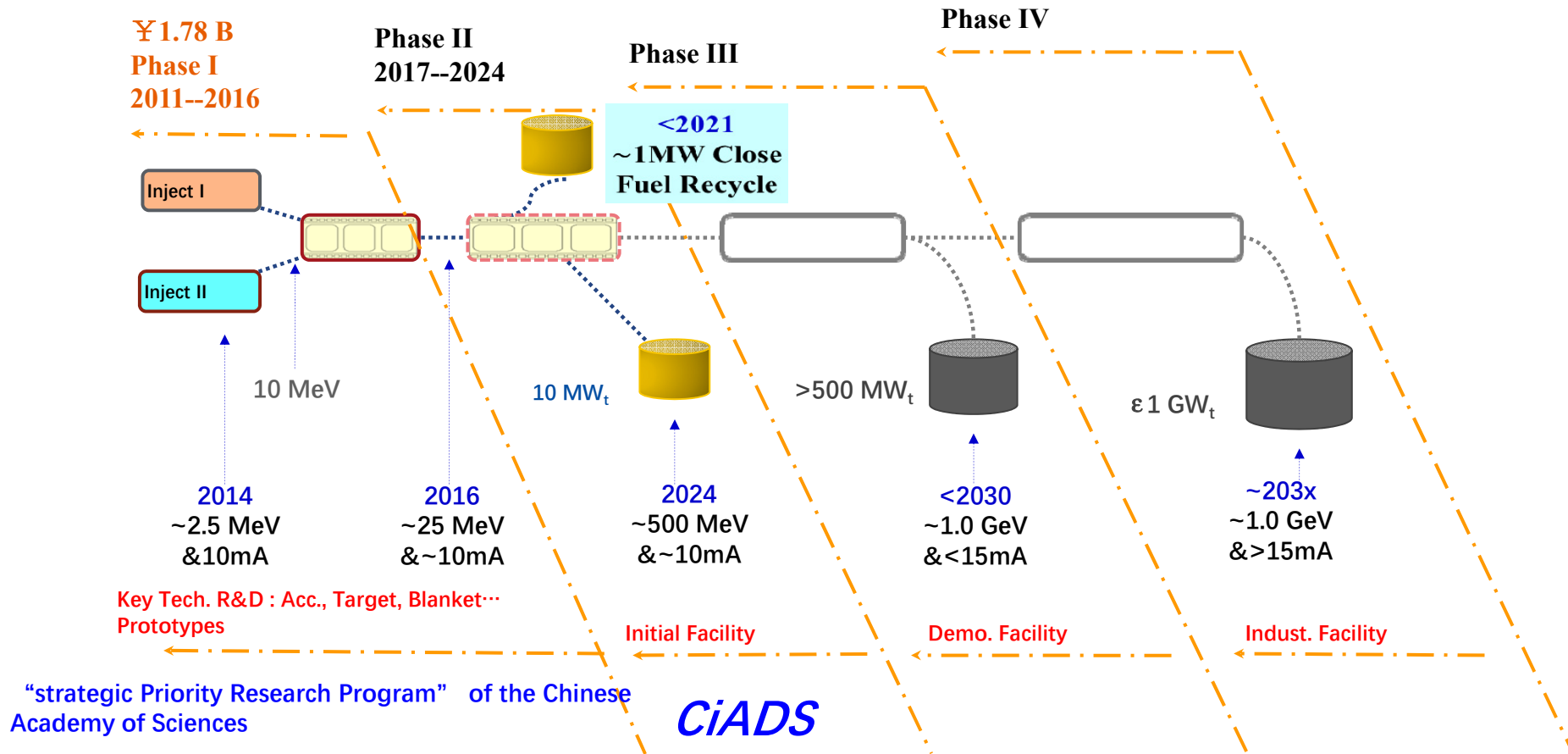


Accelerator Driven Sub-critical Reactor and Accelerator Driven Recycle of Used Fuel are promising path to resolve the problems.





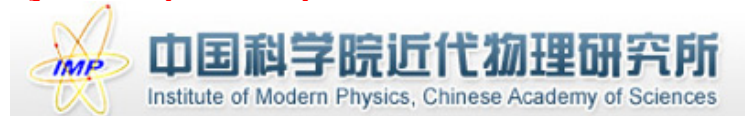
ADS/ADANES Roadmap in China



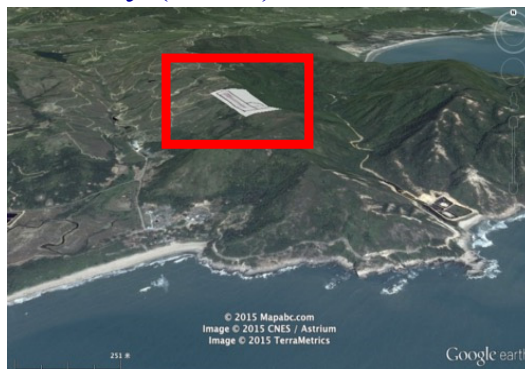
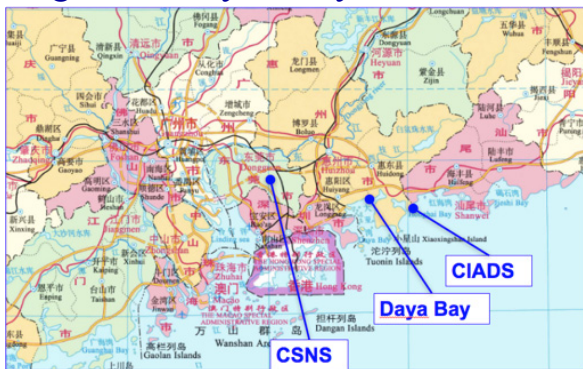
CIADS Project (2017-2024)

China initiative Accelerator Driven System (CiADS)

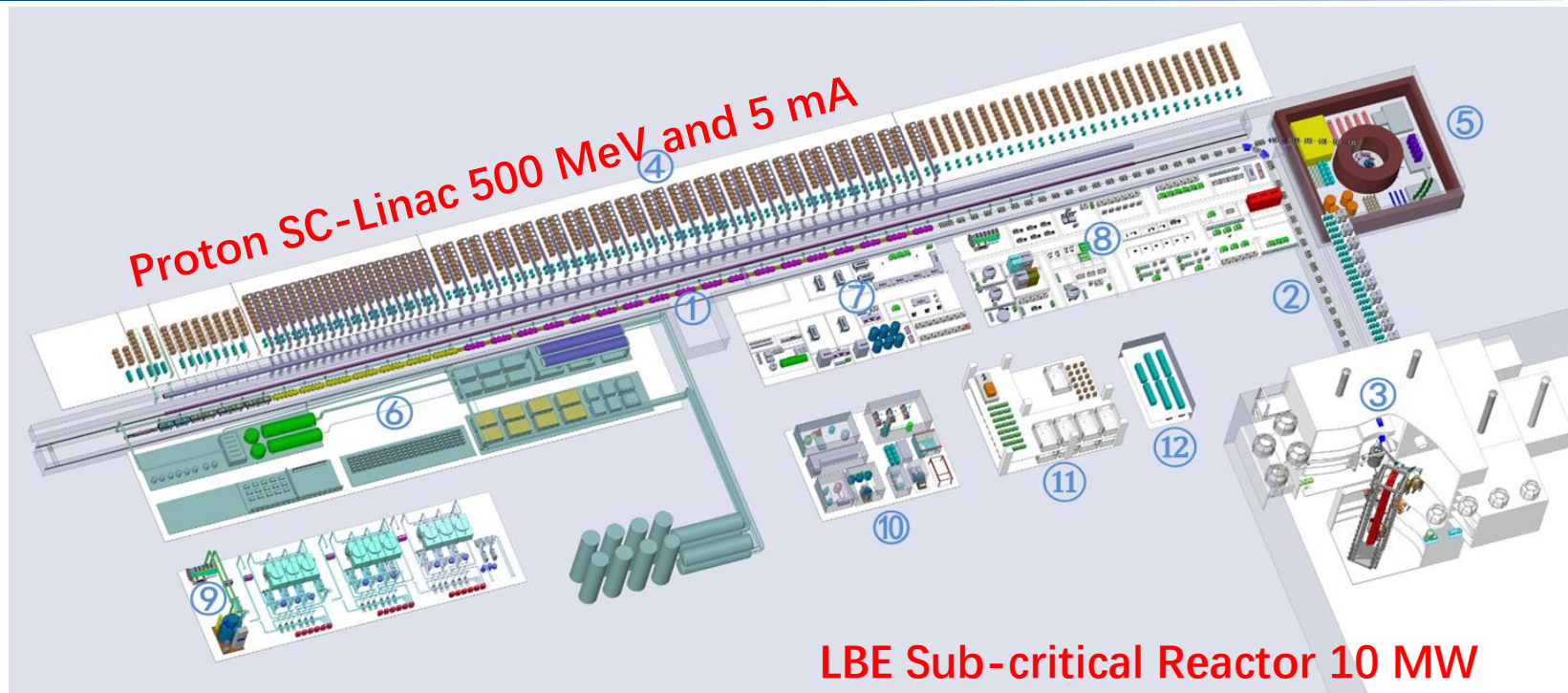
- Approved in Dec. 2015
- Leading institute: IMP
- Budget: >1.8B CNY (Gov. and Corp.)
- Location: Huizhou, Guangdong Prov.
- Contribution Partners: CIAE, CGN, IHEP, CASHIPS.



Location is in Huizhou city, Guangdong Province, 73 km away from Huizhou and 140 km away from Shenzhen. The site is on the top of hill, latitude is around 150m, facing the South Sea and backing on the mountain. The High Intensity Heavy Ion Accelerator Facility (HIAF) is in the same campus.



Overview of CiADS



① SC LINAC

② Coupling beam line

③ Reactor Hall

④ RF High power station

⑤ Beam dump and target

⑥ Cryogenic station

⑦ Accelerator assembly Hall

⑧ SRF conditioning hall

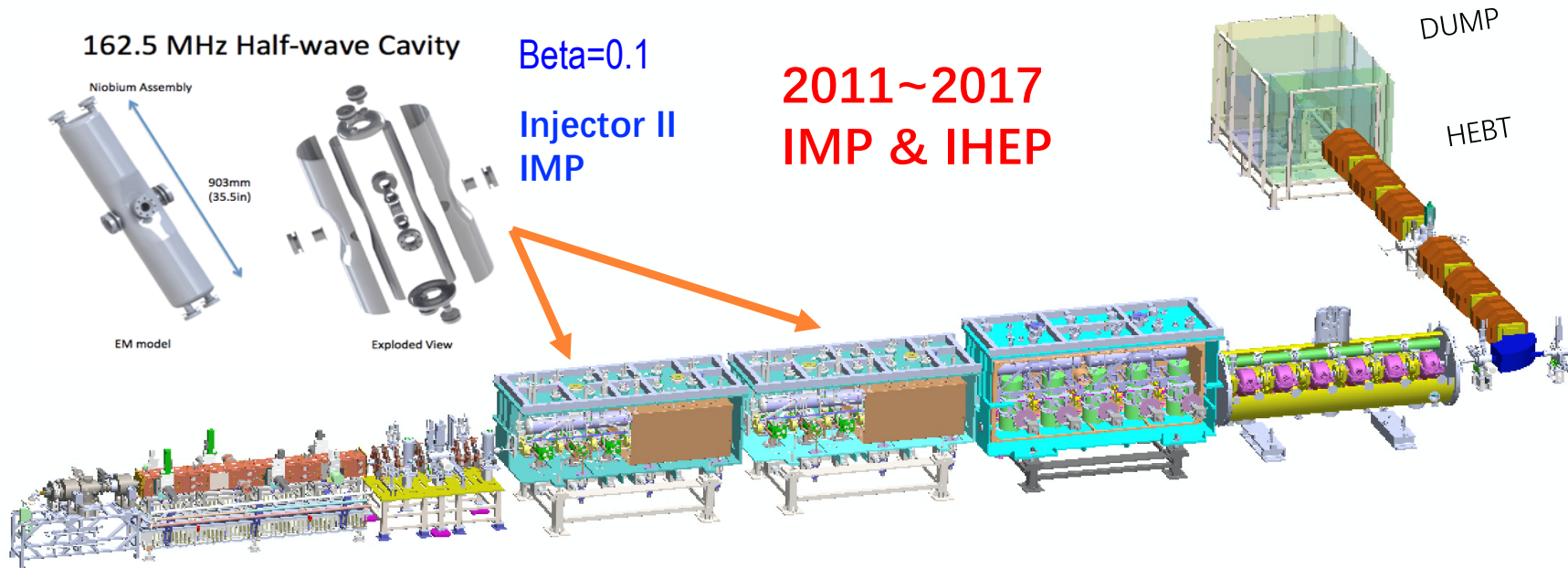
⑨ Cooling water station

⑩ Target assembly hall

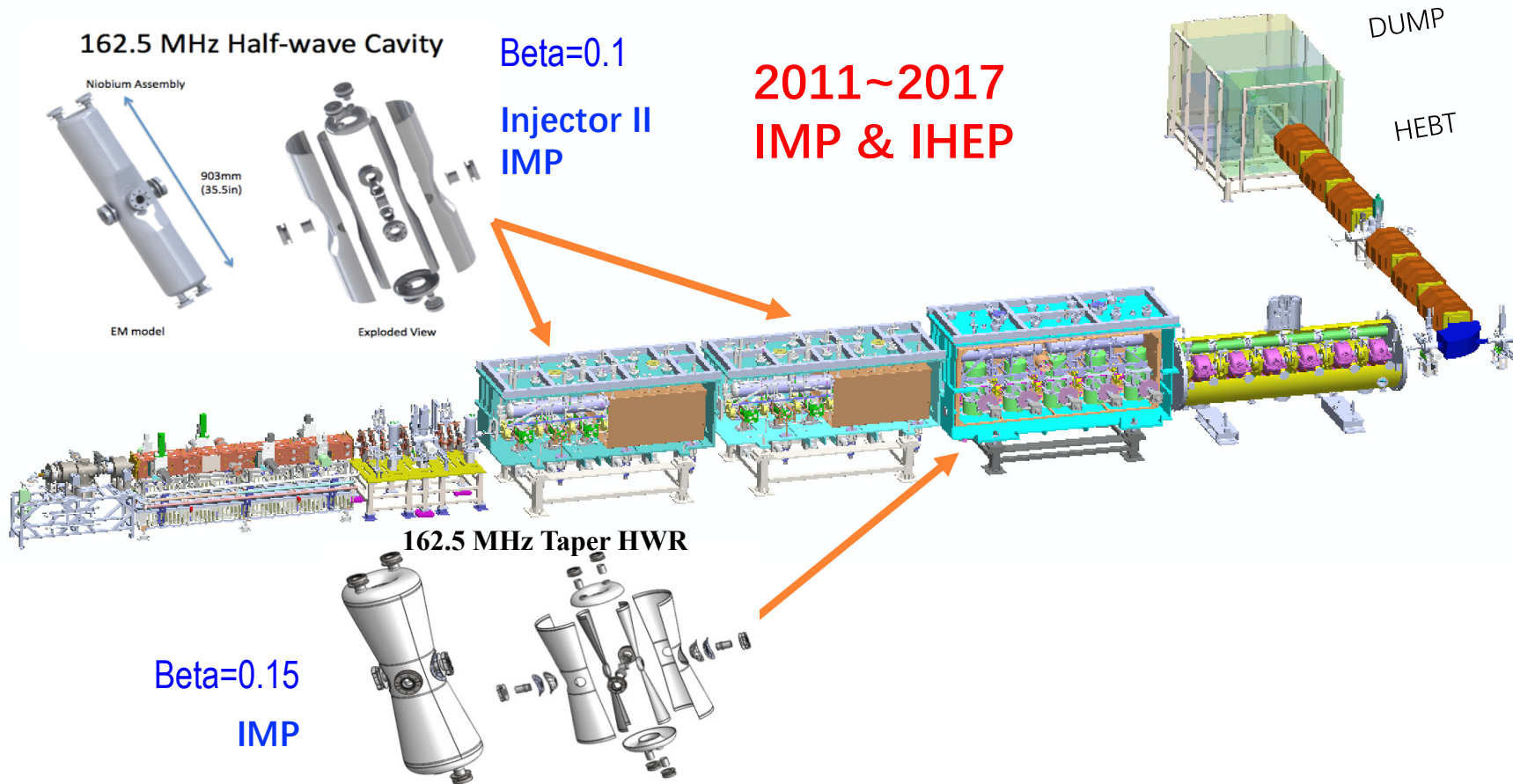
⑪ Hot cell building

⑫ Central Electric station

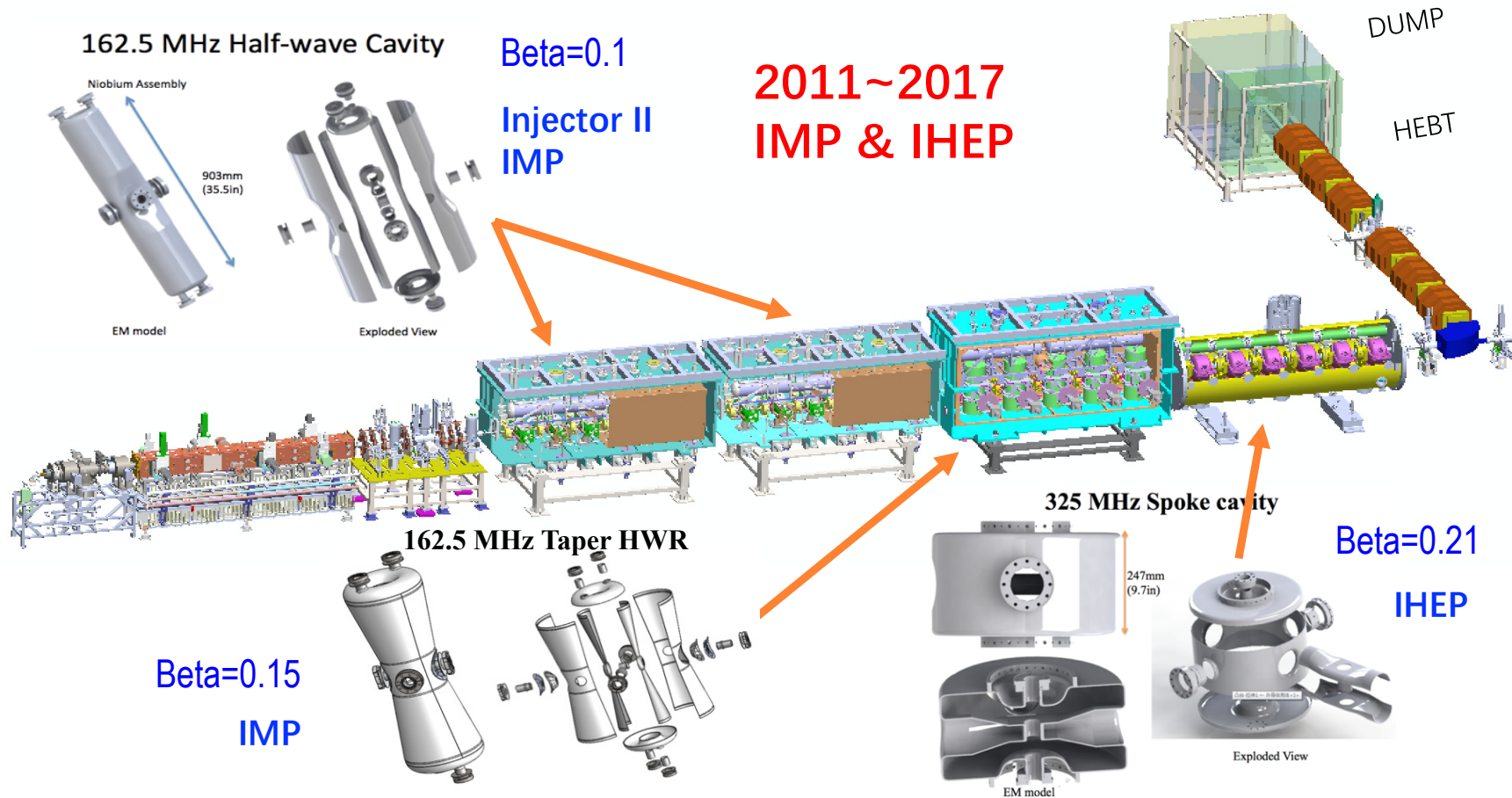
Chinese ADS Front-end Demo Linac



Chinese ADS Front-end Demo Linac



Chinese ADS Front-end Demo Linac





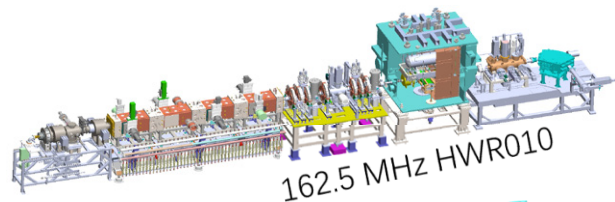
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- **Commissioning of CW SC-Linac**
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Commissioning Stages since 2014

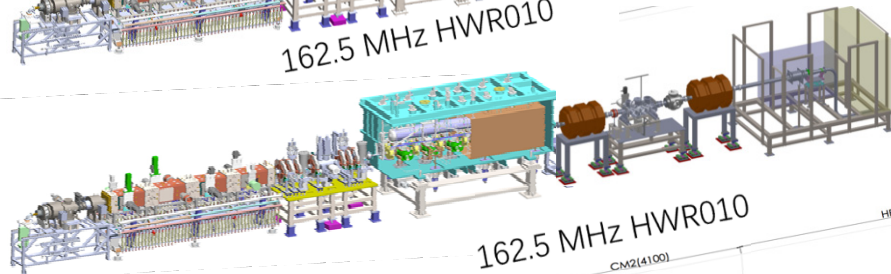
1



162.5 MHz HWR010

- ECRIS + RFQ + MEBT + TCM1 (single HWR)
- Energy is ~ 2.5 MeV
- First beam **October 1st, 2014**

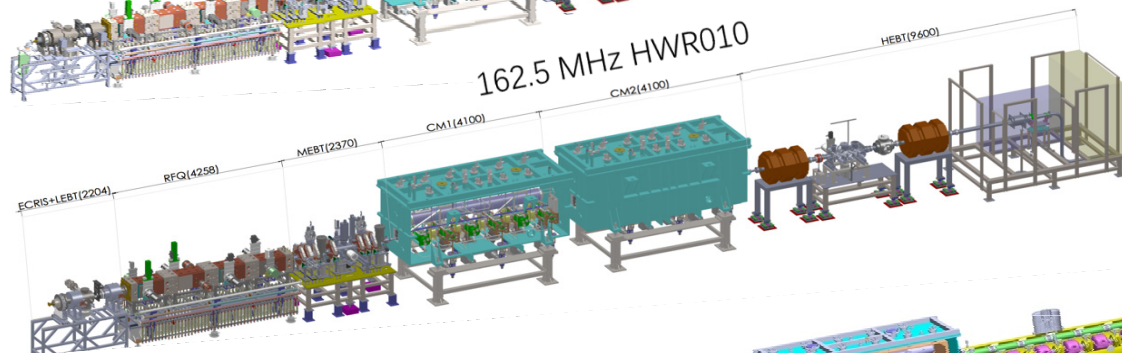
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162.5 MHz HWR010

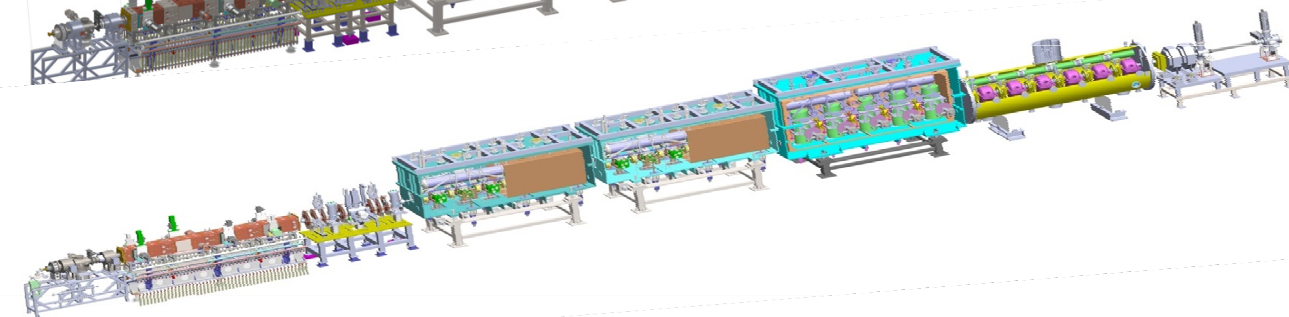
- ECRIS + RFQ + TCM6
- Energy is ~ 5 MeV
- First beam **June 6th, 2015**

3



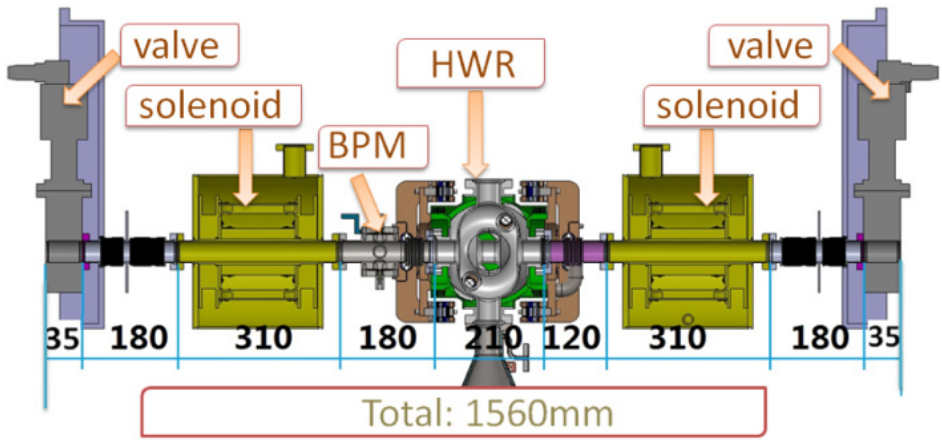
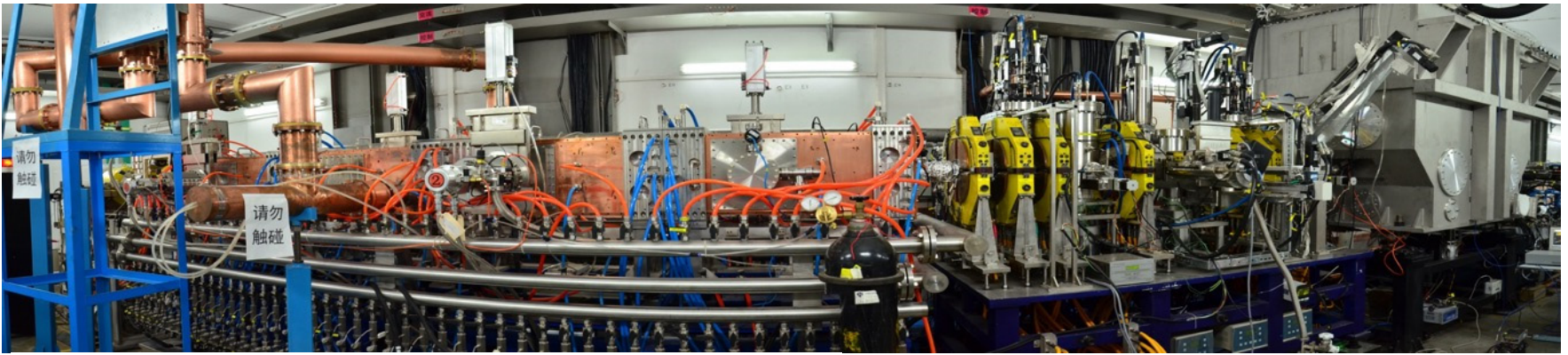
- ECRIS + RFQ + CM1 + CM2
- Energy is ~ 10 MeV
- First beam **September 15th, 2016**

4



- ECRIS + RFQ + CM1 + CM2 + CM3 + CM4
- Energy is ~ 25 MeV
- First beam **June 5th, 2017**

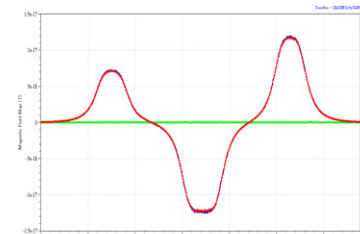
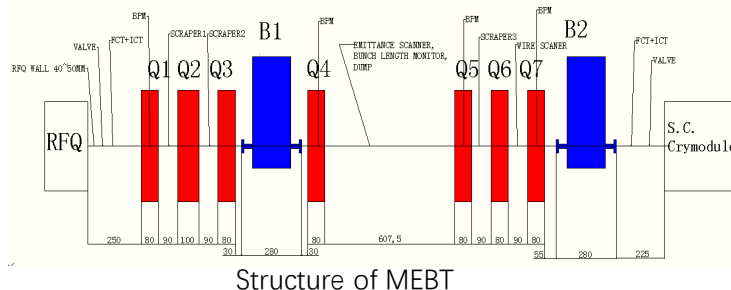
TCM1 of 2.5 MeV



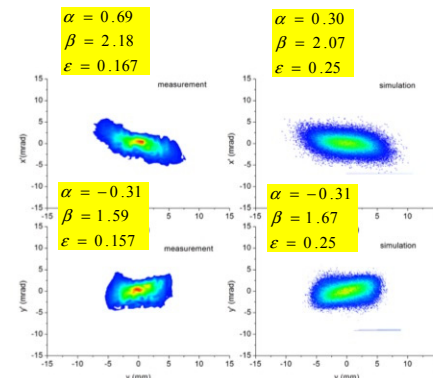
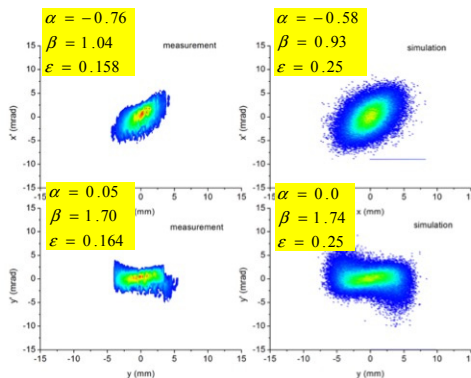
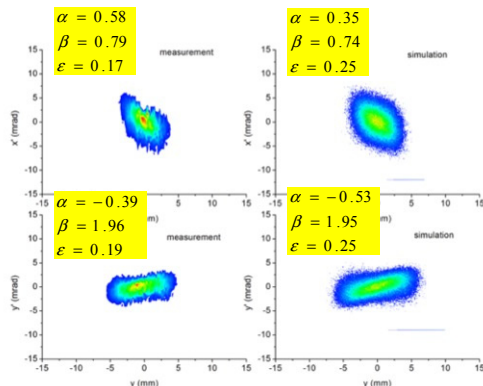
One cavity and two solenoids as prototype for assembly and tuning

Initial Beam Re-built at MEBT

- Scan Q1-3 for several measurements
- Trace back to get the exit twiss parameter of RFQ which agrees with the design of ParmteqM

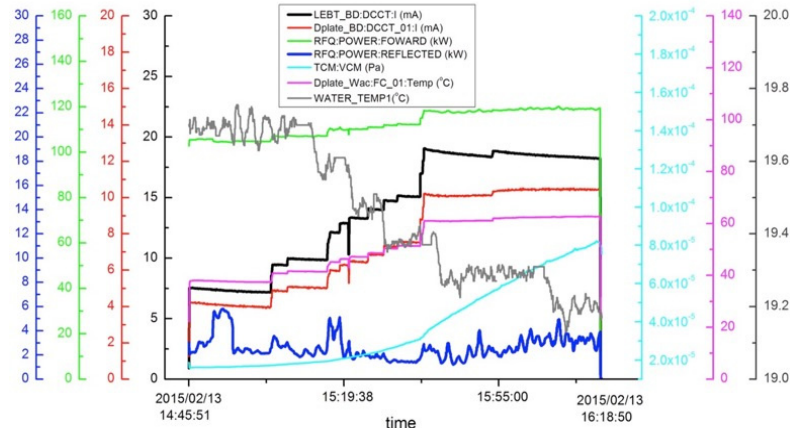
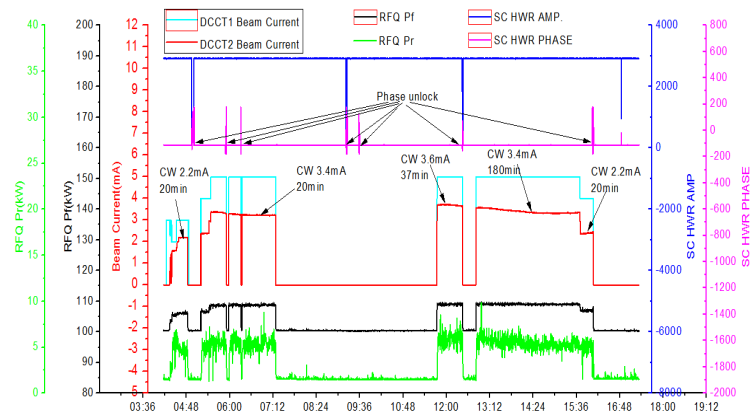


	α_x	β_x (m/rad)	α_y	β_y (m/rad)	Mismatch factor H/V
Rebuilt by Measurement	0.3	0.25	-0.11	0.12	0.078/0.005
Parmteq simul (design)	0.46	0.27	-0.10	0.12	reference

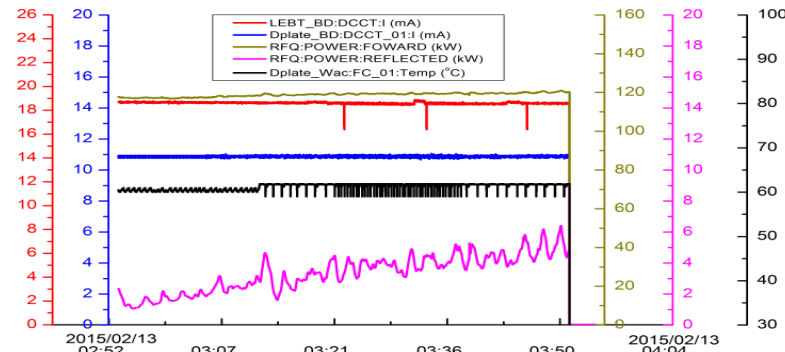




CW Beam Commission to 10 mA



● Feb. 4th, 2015, 4.2~10.83 mA, 2.5MeV, CW



● Feb. 23rd, 2015, achieved 2.5MeV/~11mA/28kW, stable for 1 hour

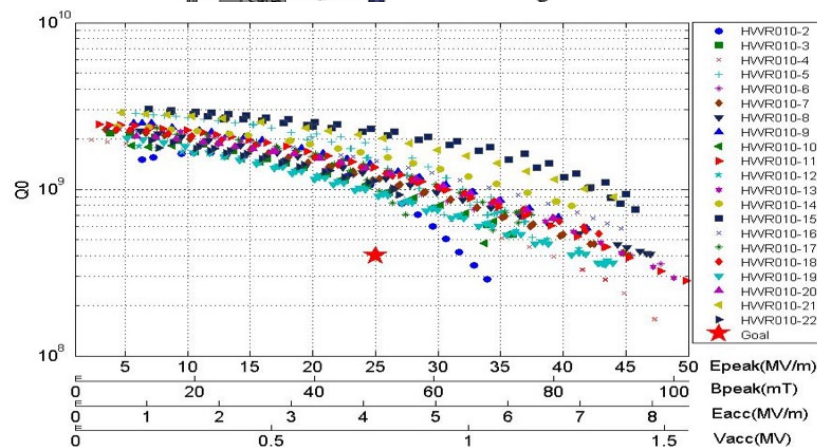
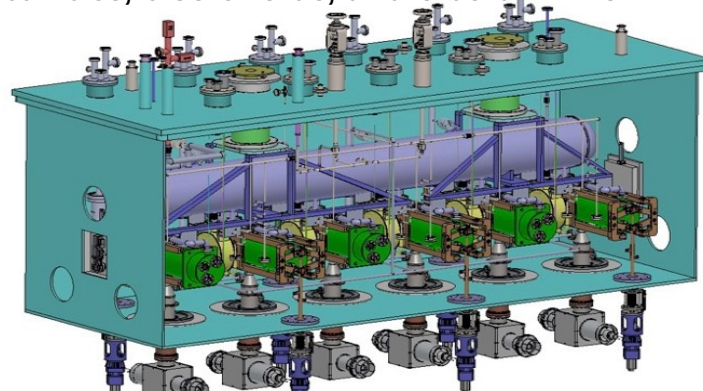
● Nov.25th, 2014, first CW, 3.4 mA, ~6 hours.

- RFQ works with two bunches and one HWR, RF frequency can not change any more like working alone.
- Due to detuning of 3 mA beam-loading, Pr is 5 kW, but it is still stable.
- 10 mA beam will cause ~8 kHz detuning of RFQ, Pr is large enough to shut down AMP.
- Frequency tuned by temp. of 0.5 C to keep Pr stable.

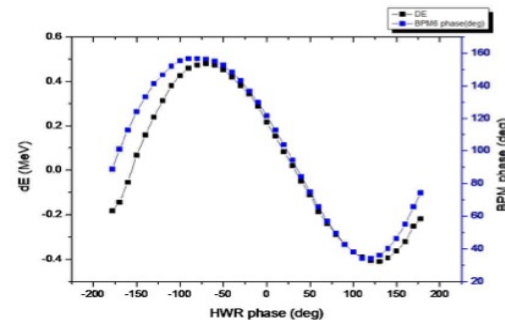
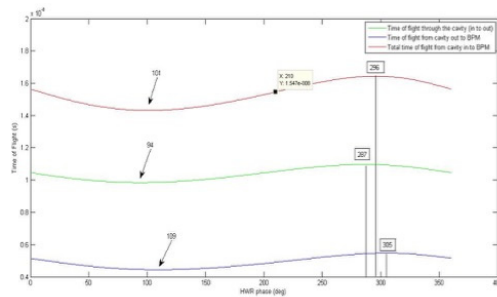
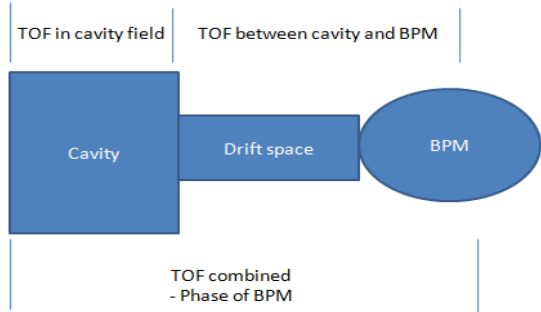
TCM6 with 5 MeV



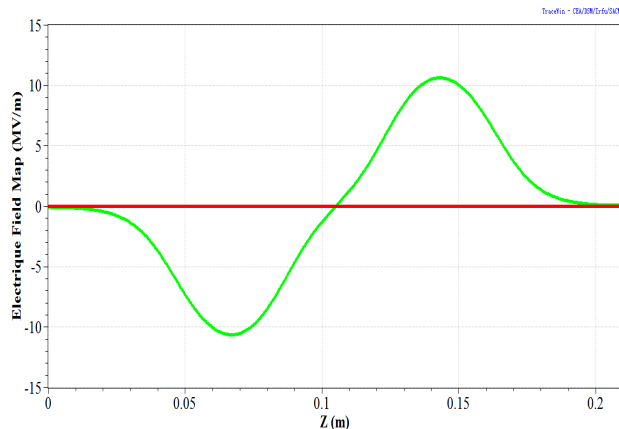
6 cavities, 6 solenoids, and 5 cold-BPMs



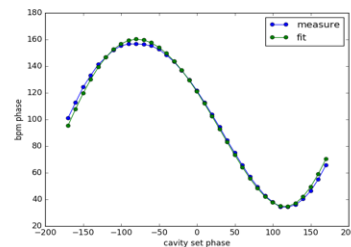
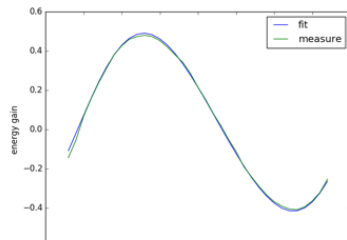
Phase Scanning of Low-beta Cavity



The fitting curve VS measured data curve using Gap model

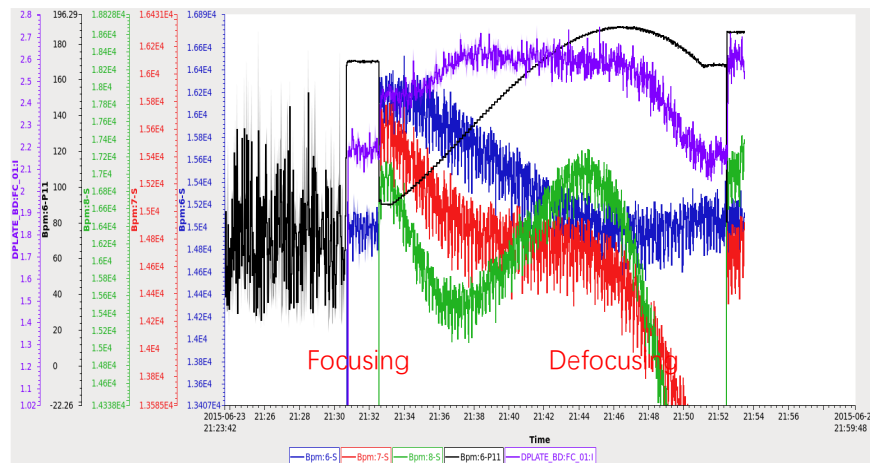
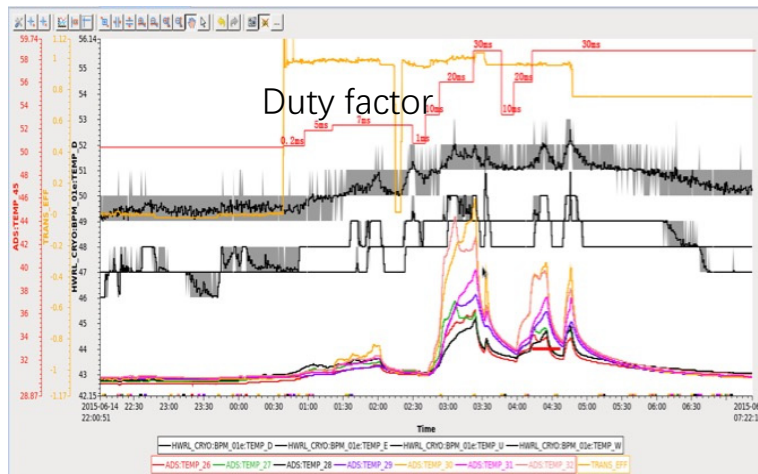


The fitting curve VS measured data curve using field-map model



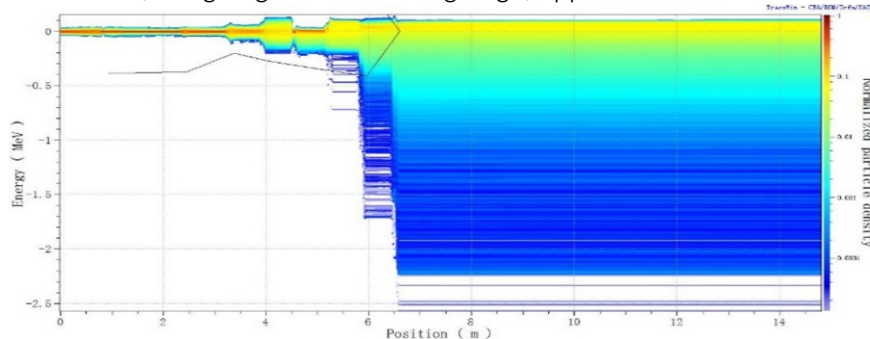
HWR cavity	ΔE (MeV, Meas)	ΔE (MeV, App)
CM1-2	0.16	0.15
CM1-4	0.203	0.206
CM2-2	0.117	0.12
CM2-3	0.095	0.105
CM2-4	0.325	0.312

Beam-loss with Wrong Phase Setting



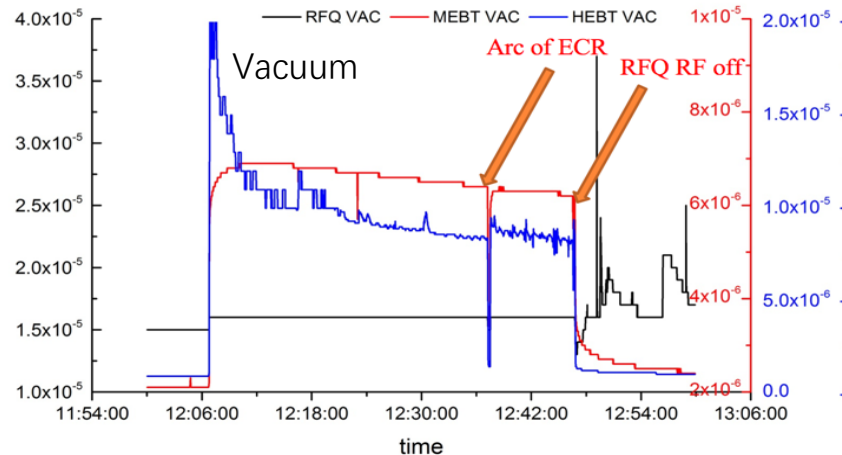
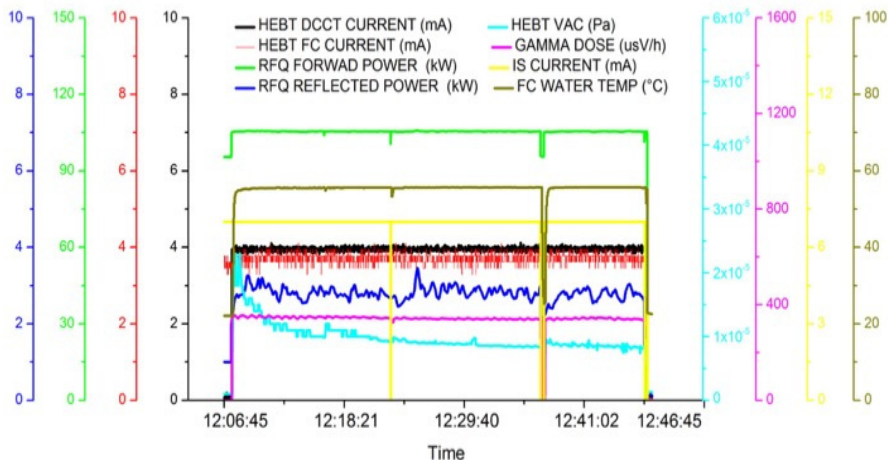
- All HWRs phase are set to -20 deg. But HWR2 and HWR5 are actually 20 deg due to the wrong phase sign of LLRF. This causes beam loss, measured by the temperature sensors on the tube at the end of CM and in HEBT during beam power ramping by increasing duty factor.

HWR2, rising edge is the focusing edge, opposite to other cavities.

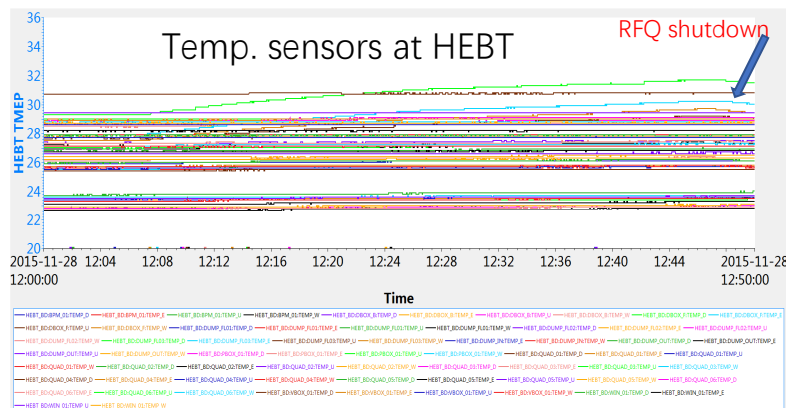


Simulation shows beam energy spread is -2 MeV at the exit of CM

High current beam commission

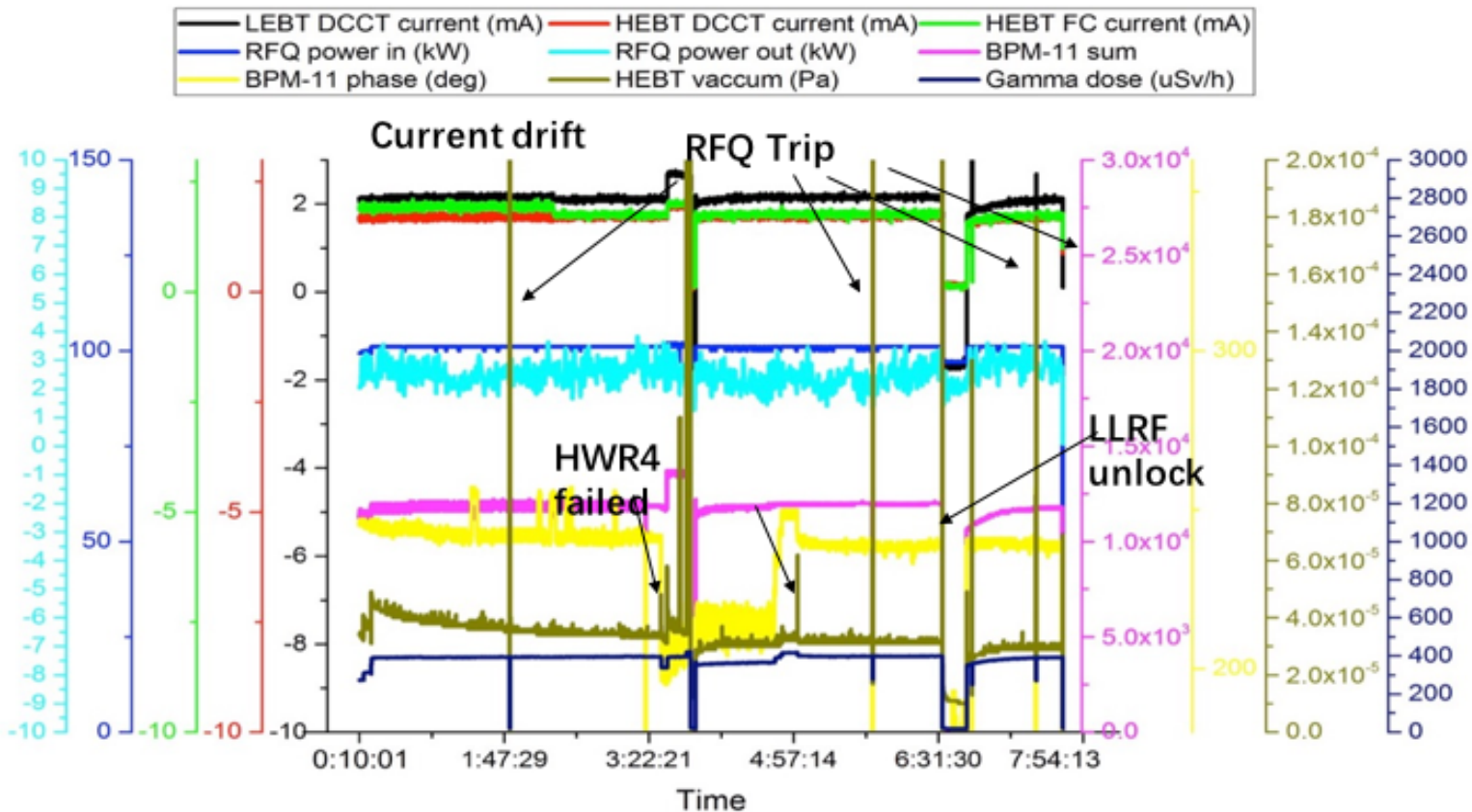


- June 6th, 2015, 5.2 MeV, 10.2 mA; June 24th, 5.3 MeV, 2.7 mA, first CW beam; Nov. 28th, 4.6 MeV, 4 mA, 40 min.
- Vacuum in RFQ and HEFT got worse due to beam-loss in RFQ and beam-stopper in HEFT.
- Almost no temp. rising of sensors at HEFT.





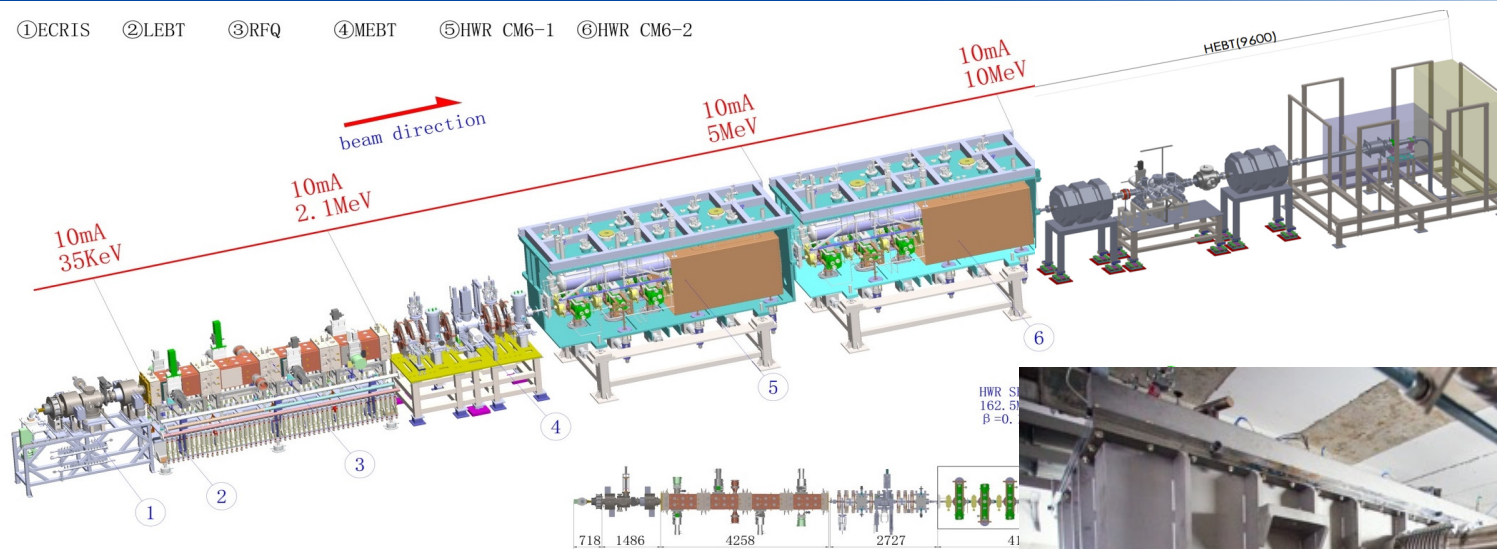
Long-time CW Beam Demonstration



Jan. 2nd, 2016, ~2mA, 4.0 MeV, CW, 7.5 hours; some trips were recovered automatically.

Injector II (CM1 + CM2) of 10 MeV

①ECRIS ②LEBT ③RFQ ④MEBT ⑤HWR CM6-1 ⑥HWR CM6-2

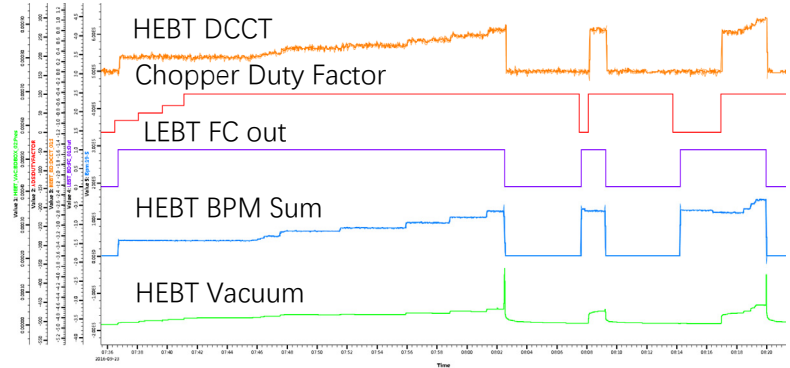
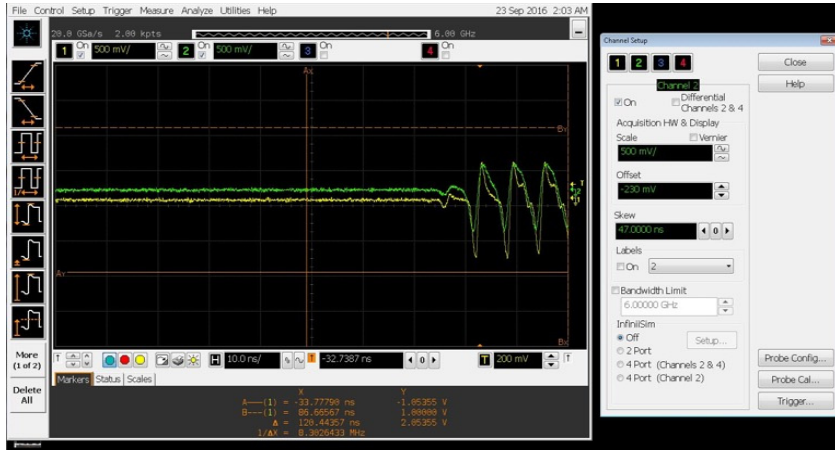


- First cooling down and conditioning of coupler on May 3rd, 2016
- 4 couplers (single-window) were broken in May, and then they were replaced by double-window in tunnel.
- He processing in situ, first beam was achieved on Sept. 15th, 2016.



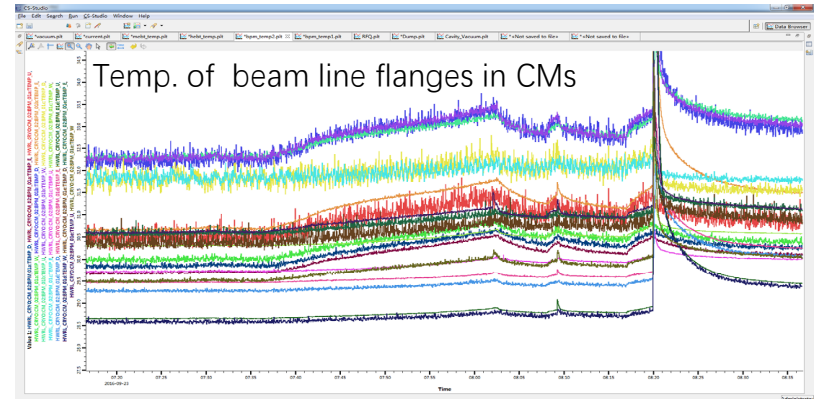
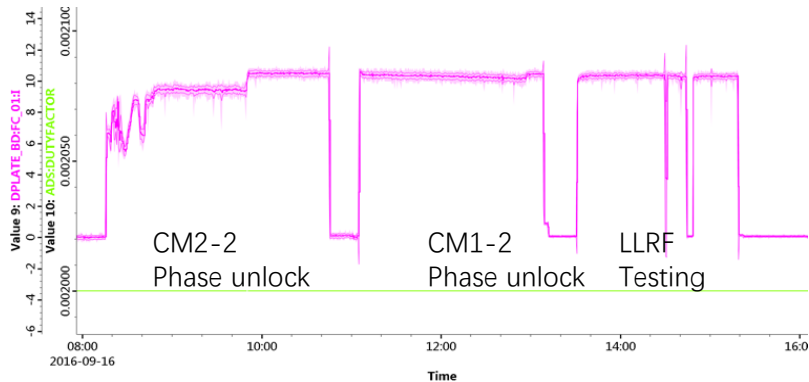


First Commissioning of 7 MeV



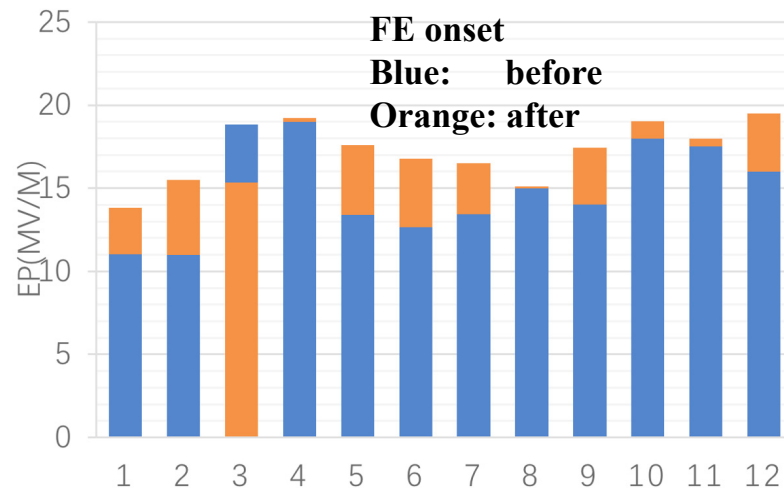
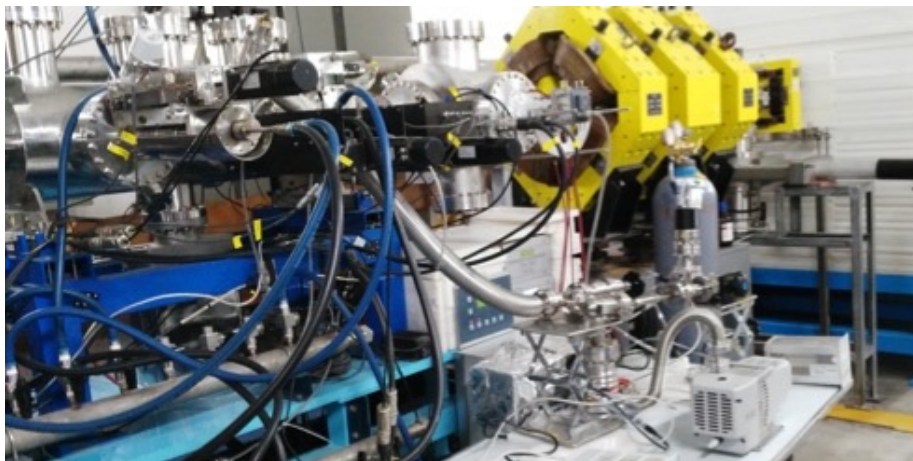
Sept. 24, Achieved CW beam 1 mA & 6.65MeV

Sept. 16, 7 MeV, 10 mA, 20 us, ~7 hours



Phase unlock causes beam loss and triggers MPS

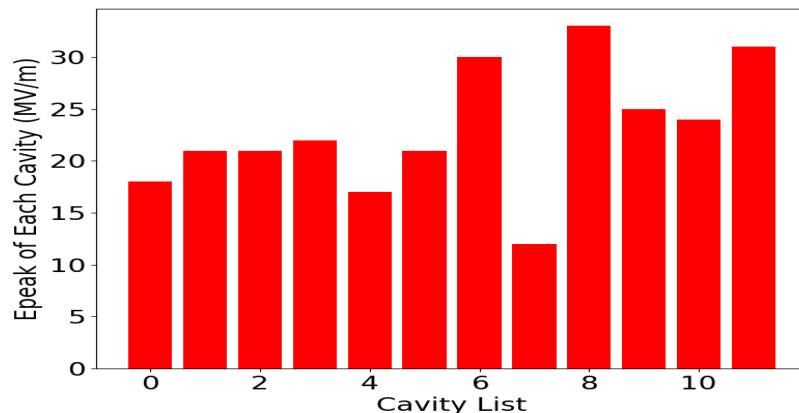
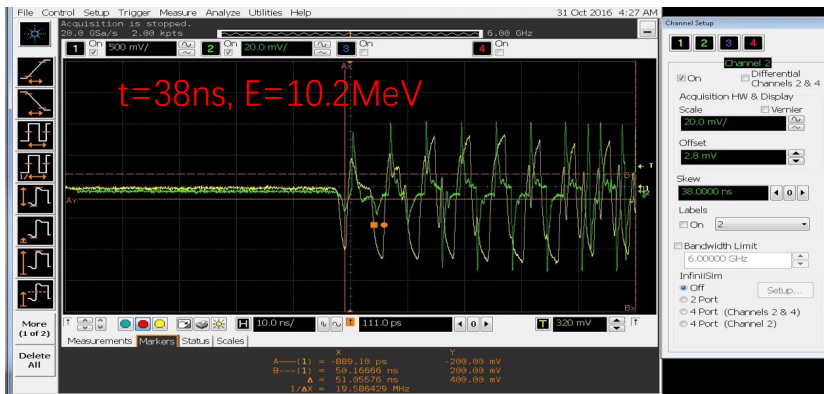
Helium Processing in situ



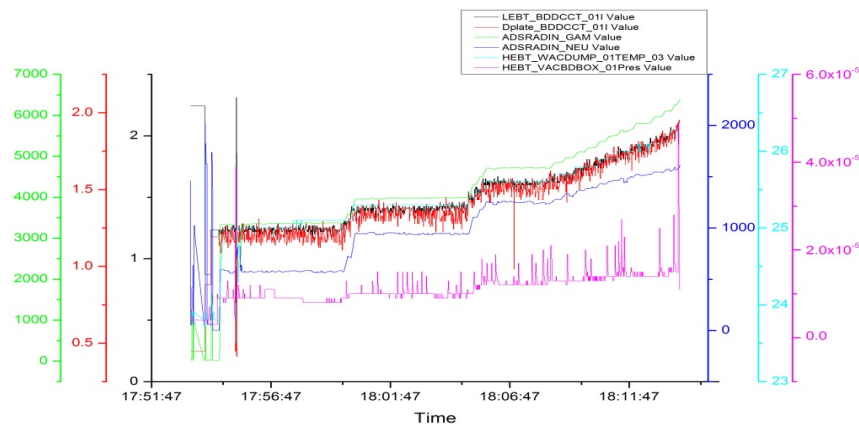
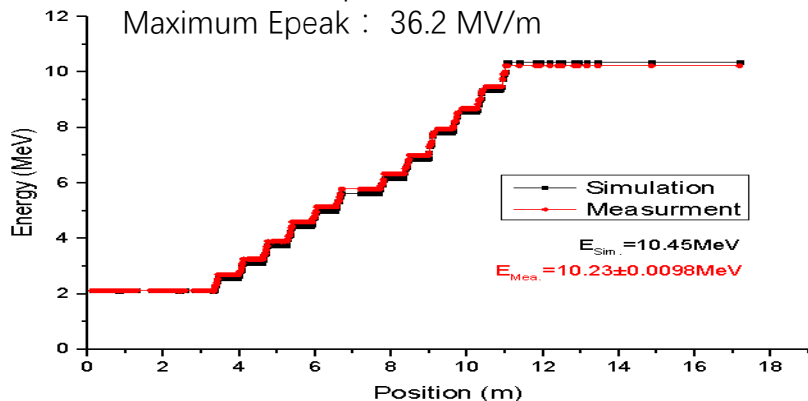
		CM1-1	CM1-2	CM1-3	CM1-4	CM1-5	CM1-6	avg
before	Ep(MV/m)	13.6	12.1	16.2	15.4	11.0	12.1	13.4
after	Ep(MV/m)	19	20.7	22.2	23.6	18.3	21.2	20.8

		CM2-1	CM2-2	CM2-3	CM2-4	CM2-5	CM2-6	avg
before	Ep(MV/m)	15.9	15.8	21.3	15.6	18.3	18.3	17.5
after	Ep(MV/m)	18.8	22.7	32.2	24.9	27.9	36.1	27.1

Commissioning of CM1 + CM2 to 10 MeV



Mean value of Epeak : 23.8 MV/m
Maximum Epeak : 36.2 MV/m

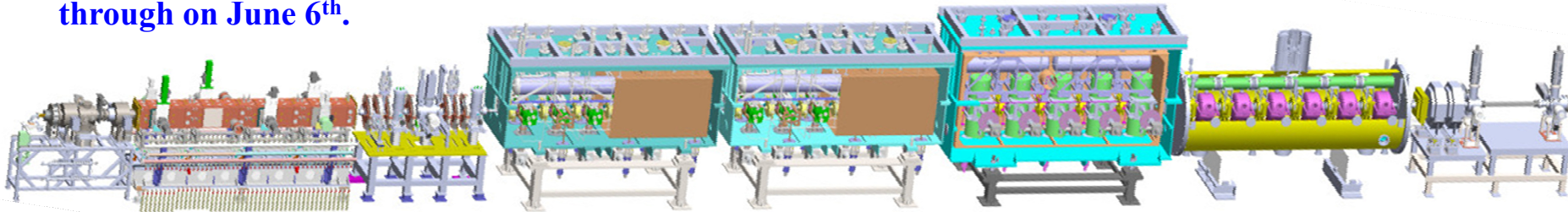


NOV 27th-28th, CW beam operation at 1.2 - 2.7 mA without uncontrolled beam loss

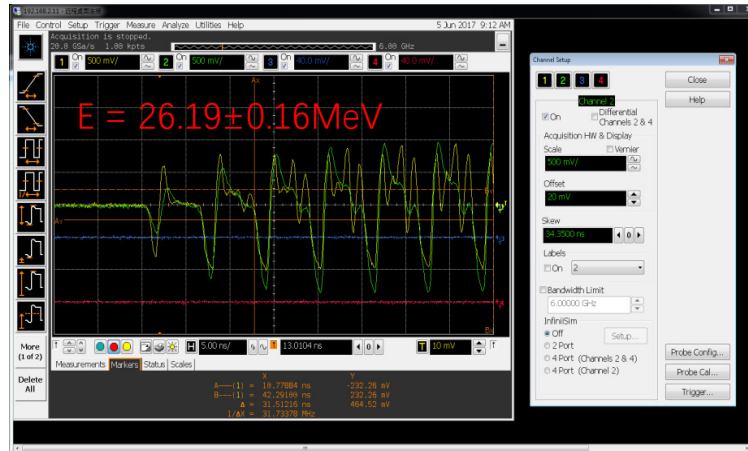
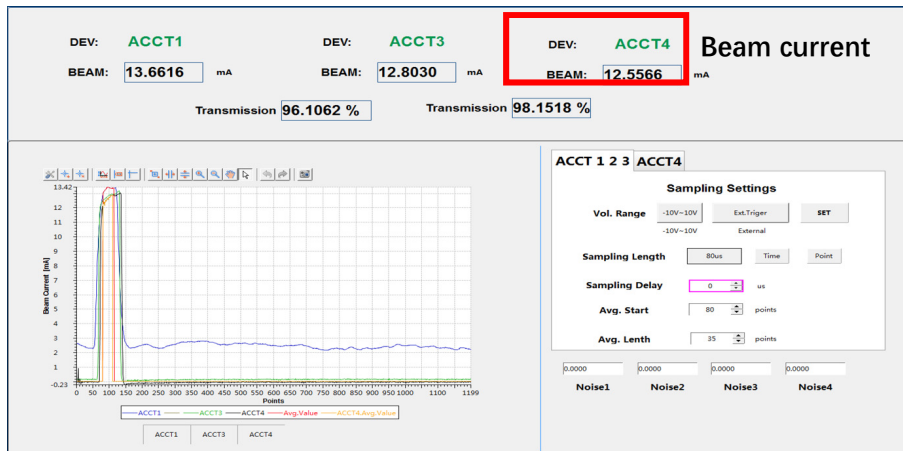
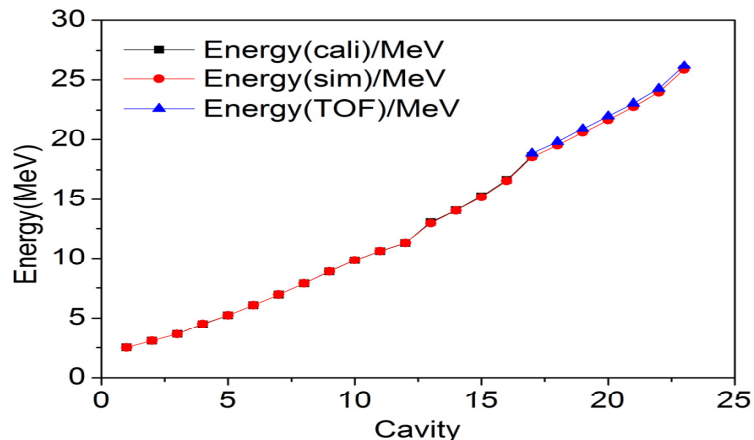
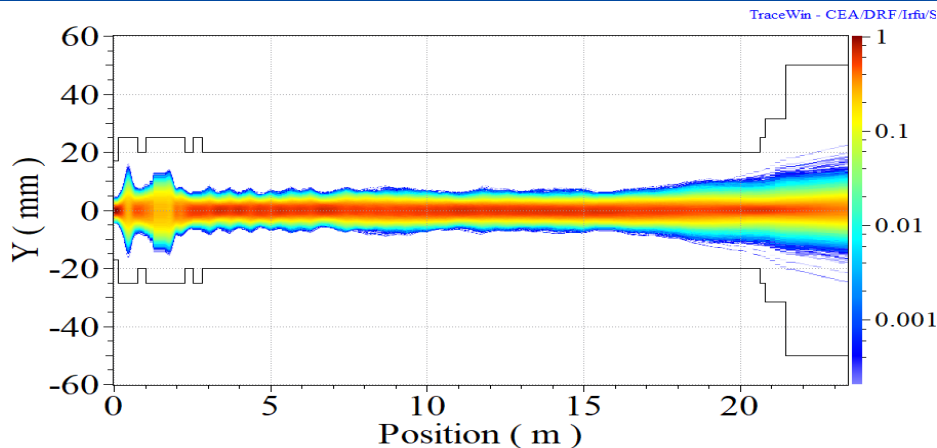
Front end demo (CM1...CM4) of 25 MeV

- CM1,CM2 (injector II) were re-installed in Feb 2017.
- CM3 and CM4 were on line on April. 6th;
- First beam was achieved on May. 27th;
- The energy is up to 26.2 MeV on June. 5th;
- CW beam with energy 25MeV went through on June 6th.

	CM1/IMP	CM2/IMP	CM3/IMP	CM4/IHEP
Frequency	162.5 MHz	162.5 MHz	162.5 MHz	325 MHz
Energy	6 MeV	11 MeV	18.6 MeV	26.2 MeV
Type	HWR010	HWR010	HWR015	Spoke021
Number	6	6	5	6

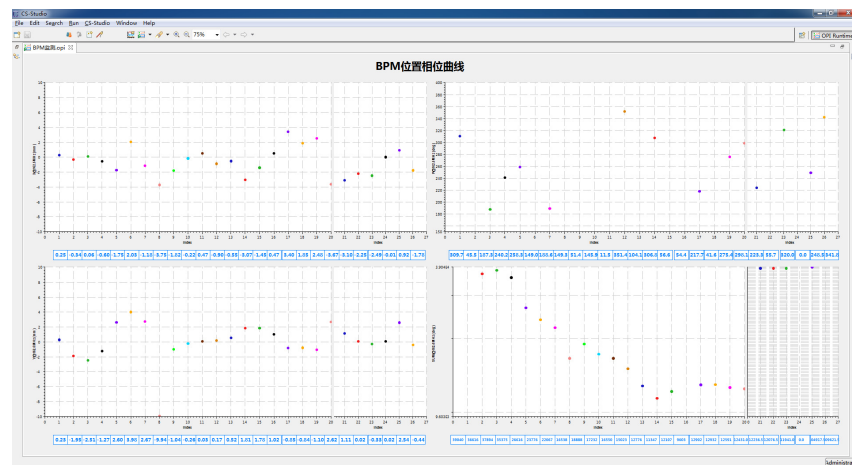
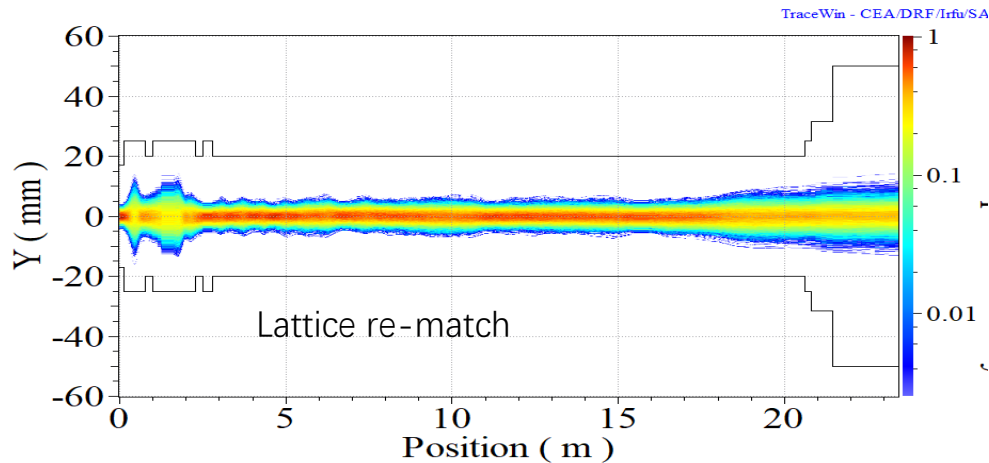


Pulse Beam Commissioning of 25 MeV

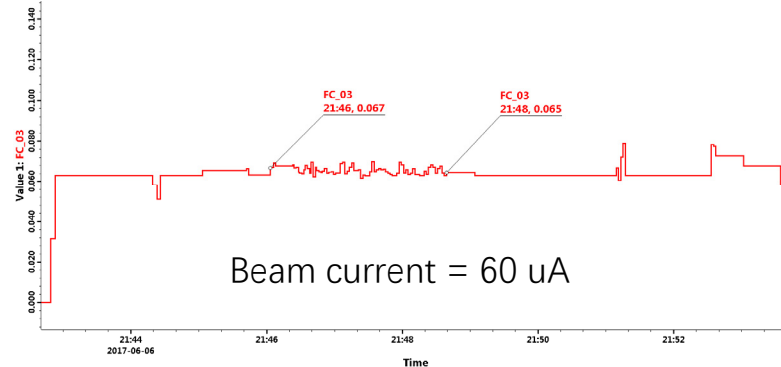
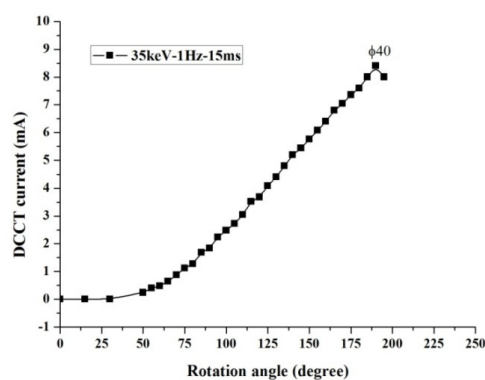
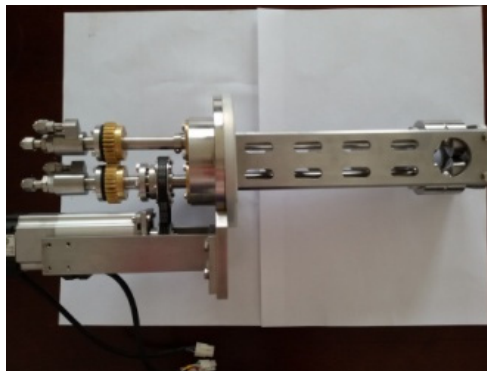




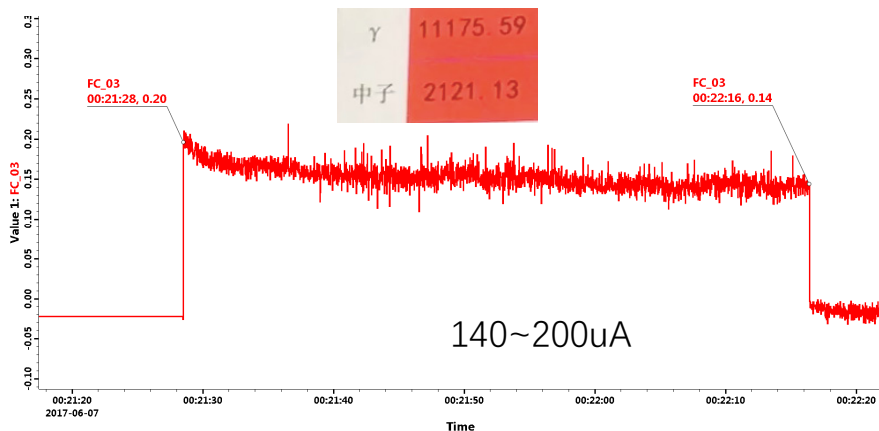
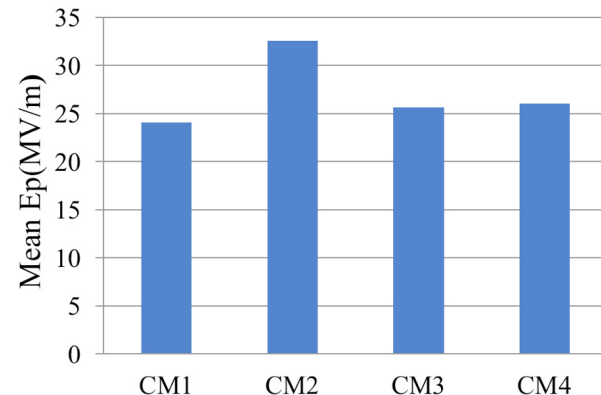
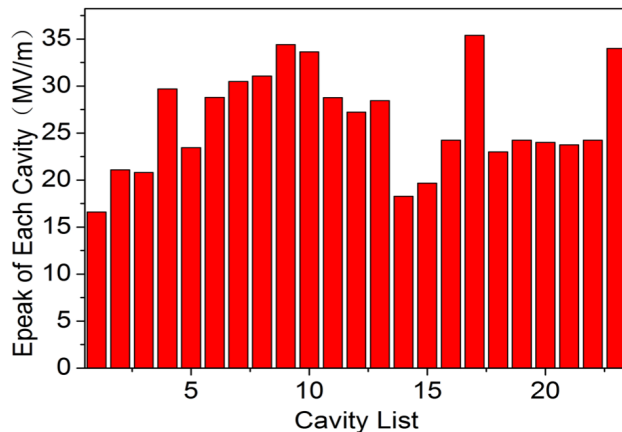
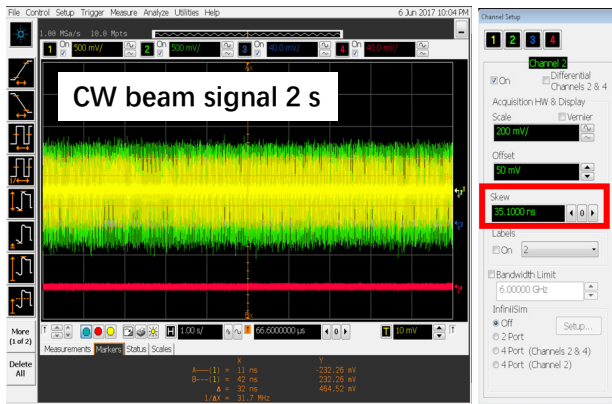
CW Beam Tuning of 25 MeV



Orbit deviation $< \pm 4$ mm



CW Beam Commissioning of 25 MeV



- Beam dump and radiation shielding are the limit to higher beam power and long time operation.
- The next commissioning will be in September. The goal is 2 mA CW proton beam by the end of the year.



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- Commissioning of CW SC-Linac
- **Summary and Acknowledgments**

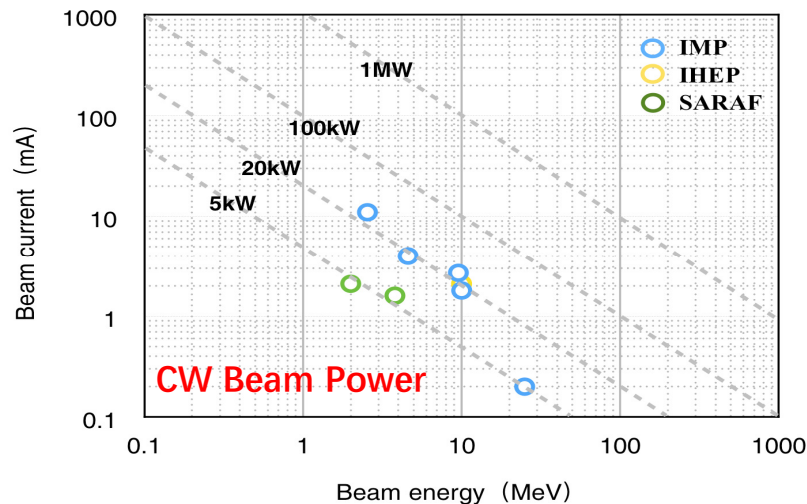


Summary of CW beam Commissioning



Summary of Commissioning from Sept. 24, 2014 ~ Jun. 7, 2017

Commission Stage	First CW beam	E Max (MeV)	Beam time (hours)	CW beam time Total (hours)	CW Current Max (mA)	CW Power Max (kW)
TCM1 (1 HWR)	Nov. 24, 2014	2.55	208	22.5	11	28
TCM6 (6 HWRs)	Jun. 24, 2015	5.3	400	20	4	21
Injector II (CM1+CM2)	Sept. 24, 2016	10.2	317	11	2.7	26
Demo front-end CM1+..CM4	May.27, 2017	26.2	0.5	0.14	0.2	5



- **World first demonstration of the 10 mA, CW beam, at the low-energy superconducting Linac. Only SARAF demonstrated 2.1 mA, 2 MeV proton beam before**
- **Challenges of high power CW superconducting Linac at low energy parts**
 - Twiss parameters re-built at MEFT to initializing beam
 - Orbit alignment and phase calibration
 - Machine protection under high beam power, base on the effective beam loss detection at low energy section



Thanks for the helps

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Thanks for your attention

Please notice more talks and posters on Chinese ADS project

The talks:

On Monday, MOXA07; On Tuesday, FRYA01 keynote; On Wednesday, WEYA04; On Thursday, THXA01, THYA04

The Posters:

MOPB007, MOPB029, MOPB030, MOPB072, MOPB074, MOPB075

TUPB005, TUPB039, TUPB040, TUPB041, TUPB042, TUPB043, TUPB044, TUPB045, TUPB086, TUPB087, TUPB088, TUPB089, TUPB113

THPB022, THPB023, THPB024, THPB057, THPB060, THPB067