IPAC13 in Shanghai

13, May, 2013

ADS Program and Key Technology R&D in China

Wenlong Zhan CAS & ADS Group(IMP, IHEP, IPP)

OUTLINE

I. Introduction of ADS

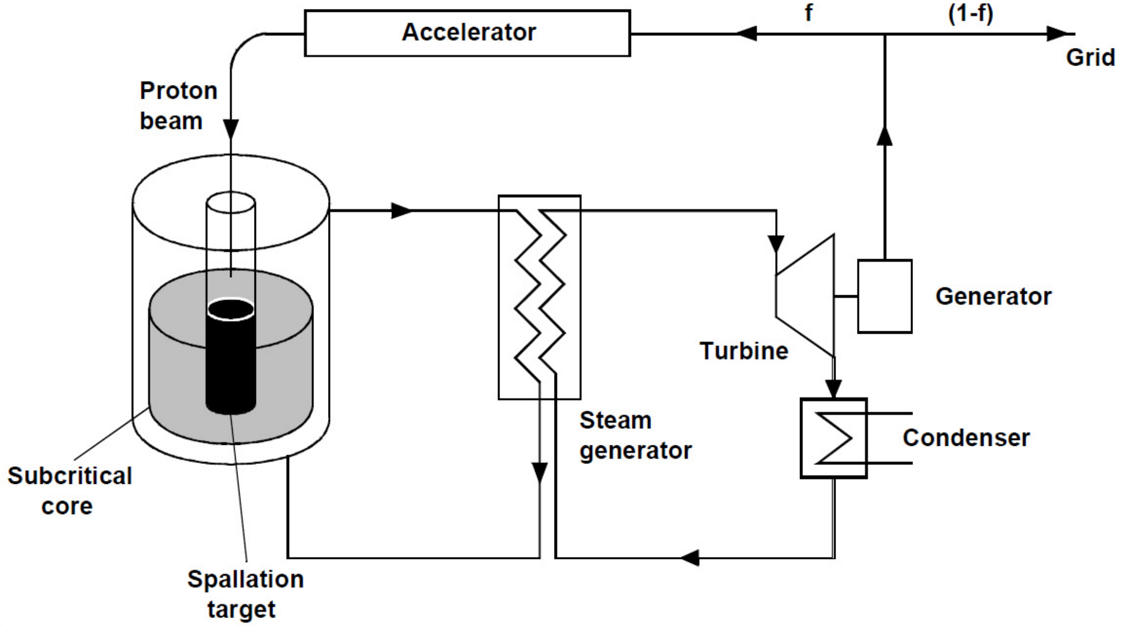
- Motivation
- ADS Roadmap in China

II. Progress of ADS in China

- Overview of C-ADS
- Accelerator System
- Spallation Target
- New Site, New Research Center

Motivation

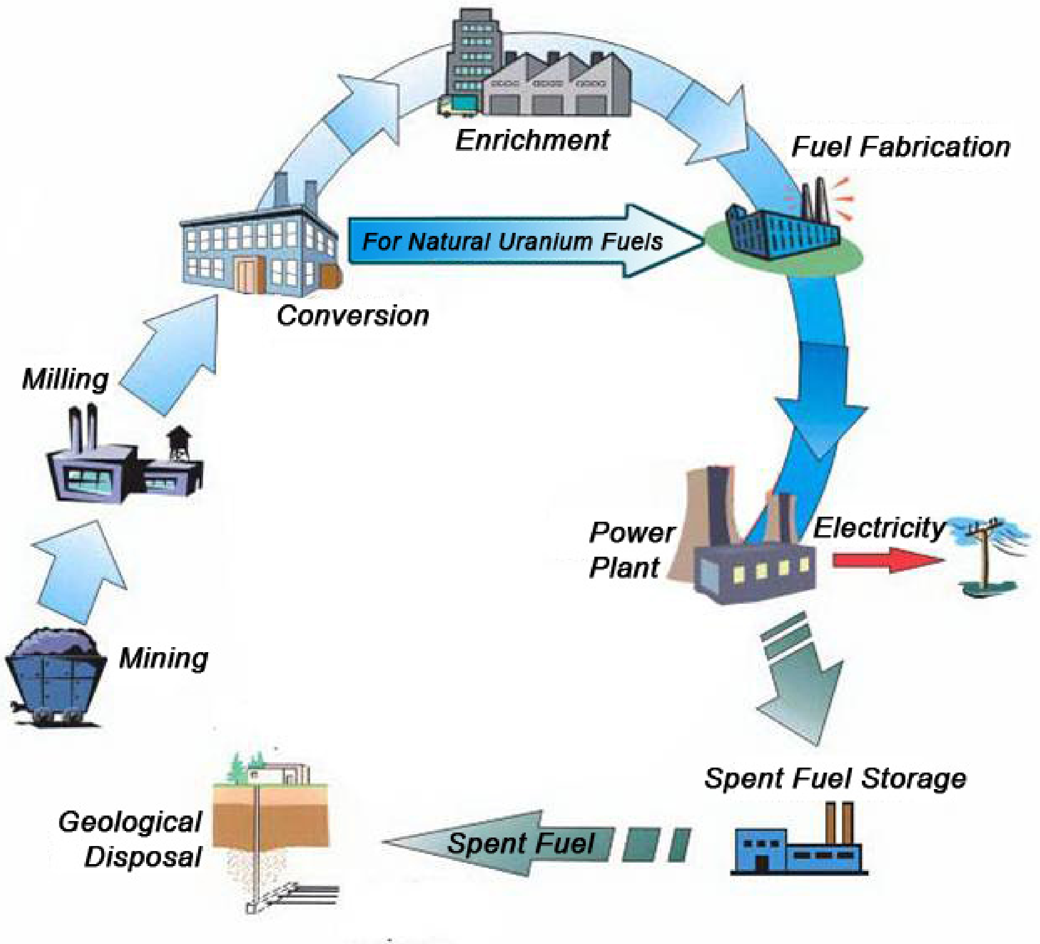
- **Accelerator Driven System was proposed for nuclear waste transmutation, accelerator driven thorium reactor (ADTR)…, since early 1990's**
- **ADS produce hard, intense spallation neutron by accelerating high power proton on target for driving subcritical core**
- **ADS consists of <u>high power proton accelerator & spallation target,</u> subcritical core**



ADS and FR in Advanced Nuclear Fuel Cycles — A Comparative Study, NEA/OECD, 2002

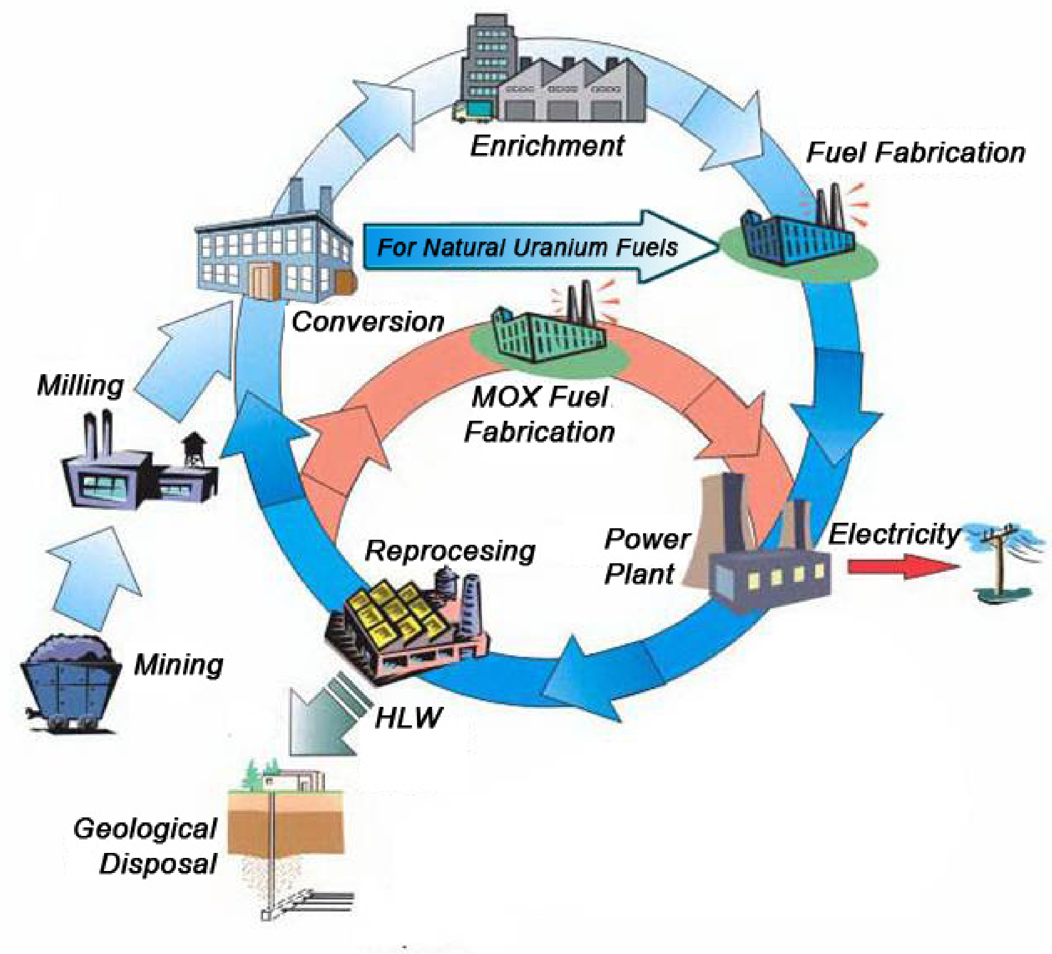
Nuclear Fuel Cycle (IAEA-TECDOC-1613)

Open Cycle



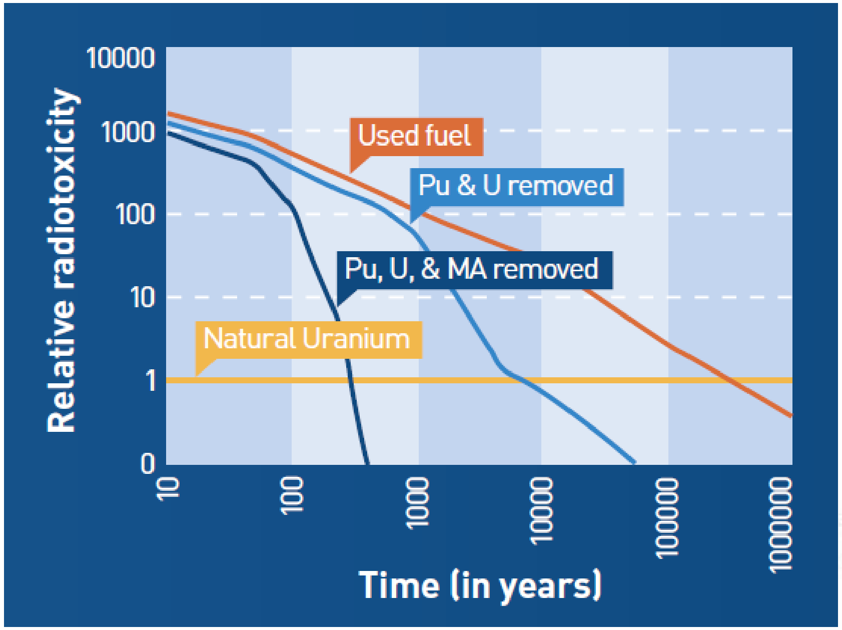
Nuclear Fuel Cycle (IAEA-TECDOC-1613)

Close Cycle



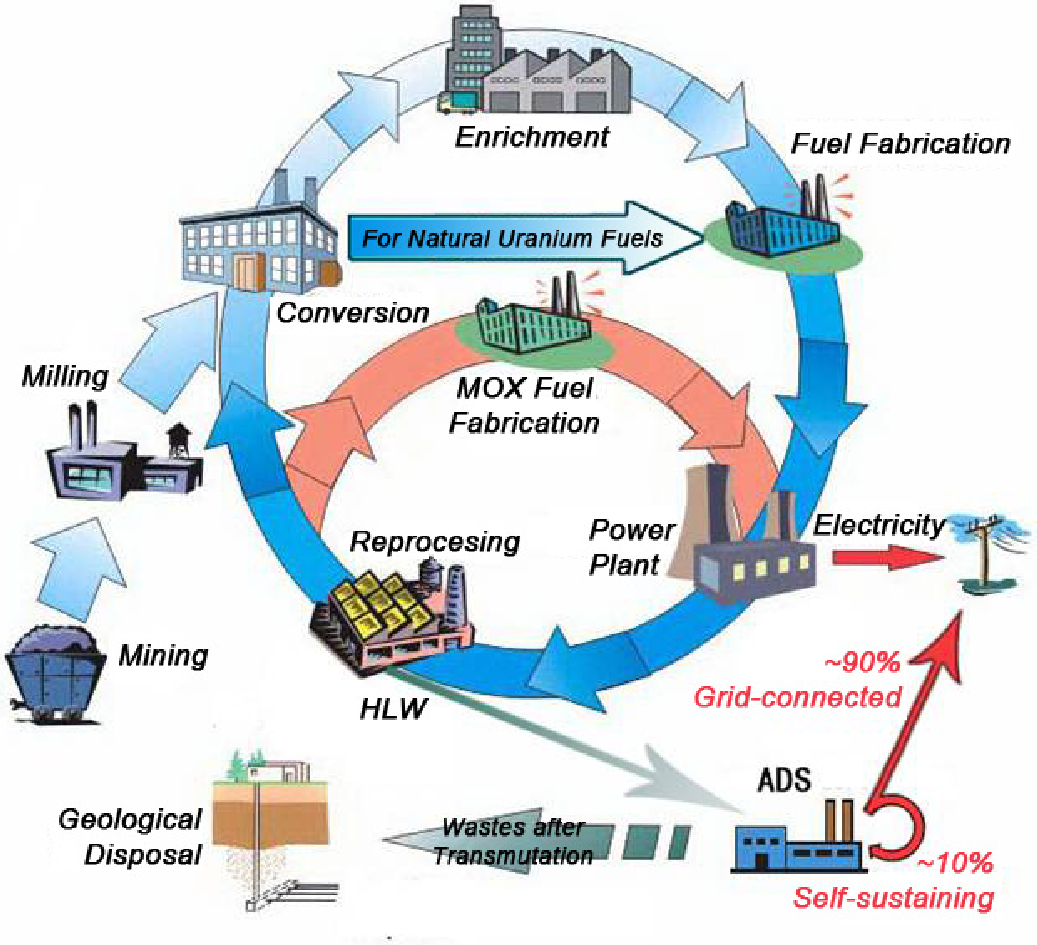
Nuclear Fuel Cycle (IAEA-TECDOC-1613)

ADS+Close Cycle



Total radiotoxicity of spent fuel relative to the radiotoxicity of natural uranium ore.

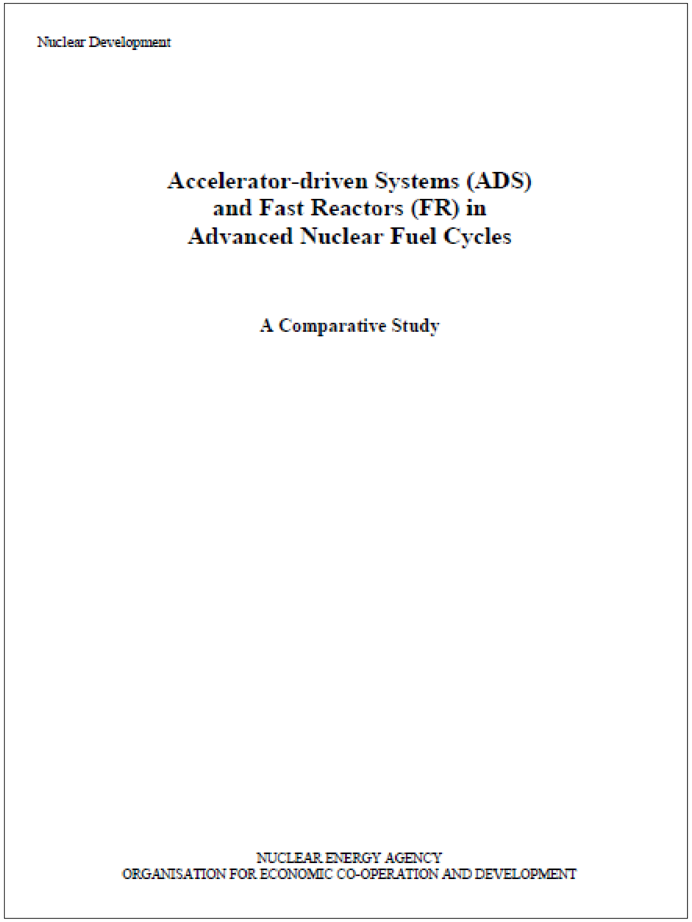
- Used fuel → Open Cycle (~300,000y)
- Pu & U removed →Close Cycle (~5000y)
- Pu, U, & MA removed → ADS + Close Cycle (~300y)



Advanced Nuclear Fuel Cycles

- ***ADS and FR in Advanced Nuclear Fuel Cycles — A Comparative Study***, NEA/OECD, 2002

  - **ADS is better at burning waste than Fast Reactors**
  - **ADS employs a fast neutron spectrum and solid, fertile-free fuel with the primary mission of transmuting transuranics or MA**
  - **ADS could support more PWR waste transmutation**
  - **……**


Nuclear Development

Accelerator-driven Systems (ADS)
and Fast Reactors (FR) in
Advanced Nuclear Fuel Cycles

A Comparative Study

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

ADS Activities (except US & CN)

项目		加速器功率 (MW)	K_{eff}	堆功率 (MW)	谱通量 ($n/cm^2/s$)	靶	燃料
日本2004 JAERI-ADS		27 (1.5GeV/18mA)	0.97	800	快	铅铋	MA/Pu/ZrN
韩国 HYPER		15 (1GeV/10~16mA)	0.98	1000	快	铅铋	MA/Pu
欧盟	意/法 XT-ADS-A/B	3.6 (600MeV/3~6mA)	0.95~0.97	80	快 10^{15}	铅铋/钢	U/Pu/MOX
	比利时 XT-ADS-C	1.75 (350MeV/5mA)	0.95	50	快 3×10^{15}	铅铋（无窗）	U/Pu/MOX
	EFIT	16 (800MeV/20mA)	~0.97	数百	快 $\sim10^{15}$	铅（无窗）	MA
俄罗斯	INR	0.15 (500MeV/10mA)	0.95~0.97	5	快	钨	MA/MOX
	NWB	3 (380MeV/10mA)	0.95~0.98	100	快 $10^{14\sim15}$	铅铋	UO_2/UN U/MA/Zr
	CSMSR	10 (1GeV/10mA)	0.95	800 级联方案	中间 5×10^{15}	铅铋	Np/Pu/MA 熔盐

- **ADS demo projects require: ~1GeV&10mA accelerator, and 10's MW Spallation Target**

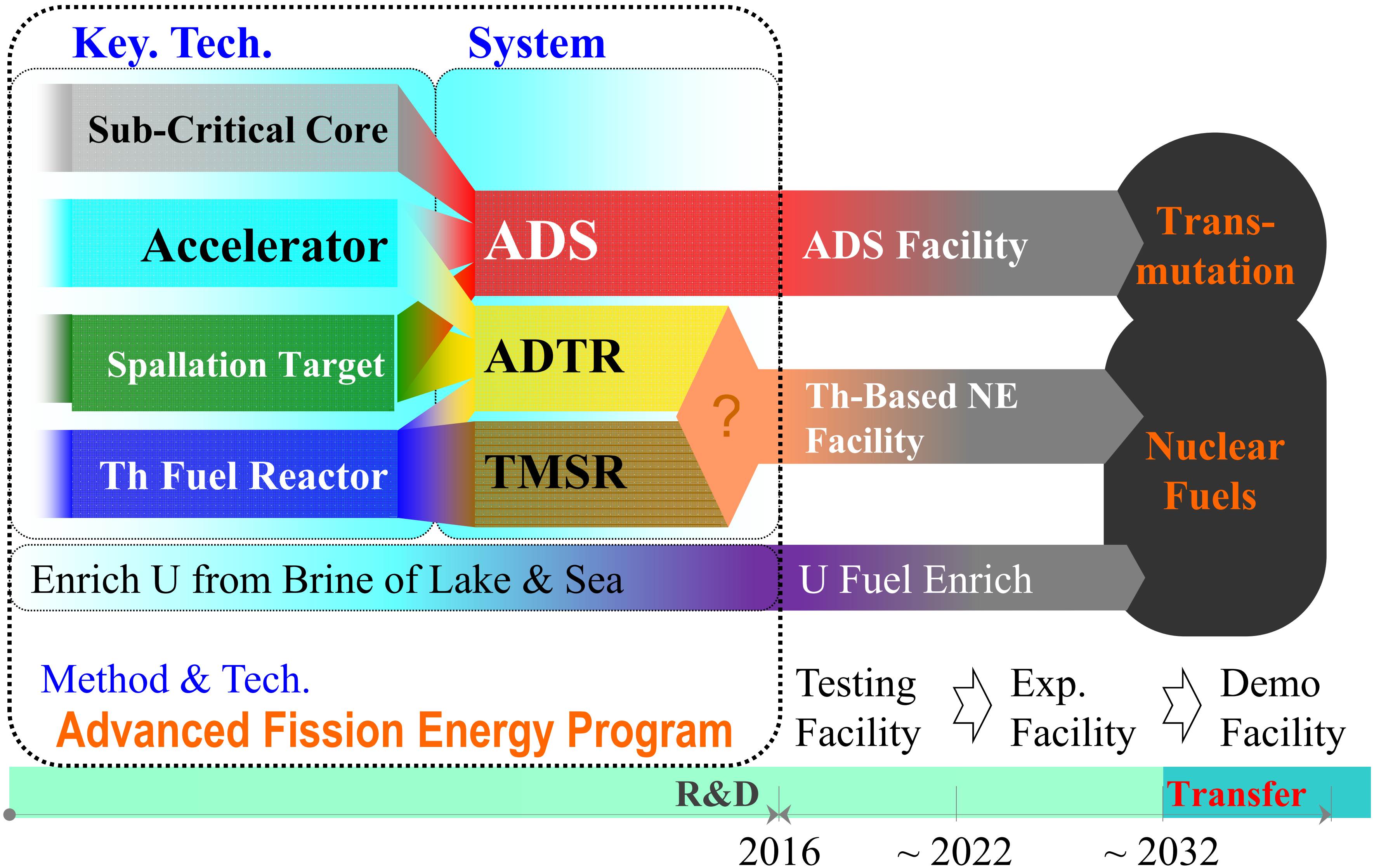
ADS Technology Readiness (ADS White Paper, DOE, 09/2010)

		Transmutation Demonstration	Industrial-Scale Transmutation	Power Generation
Front-End System	Performance			
	Reliability			
Accelerating System	RF Structure Development and Performance			
	Linac Cost Optimization			
	Reliability			
RF Plant	Performance			
	Cost Optimization			
	Reliability			
Beam Delivery	Performance			
Target Systems	Performance			
	Reliability			
Instrumentation and Control	Performance			
Beam Dynamics	Emittance/halo growth/beamloss			
	Lattice design			
Reliability	Rapid SCL Fault Recovery			
	System Reliability Engineering Analysis			

Nuclear Power Development in China

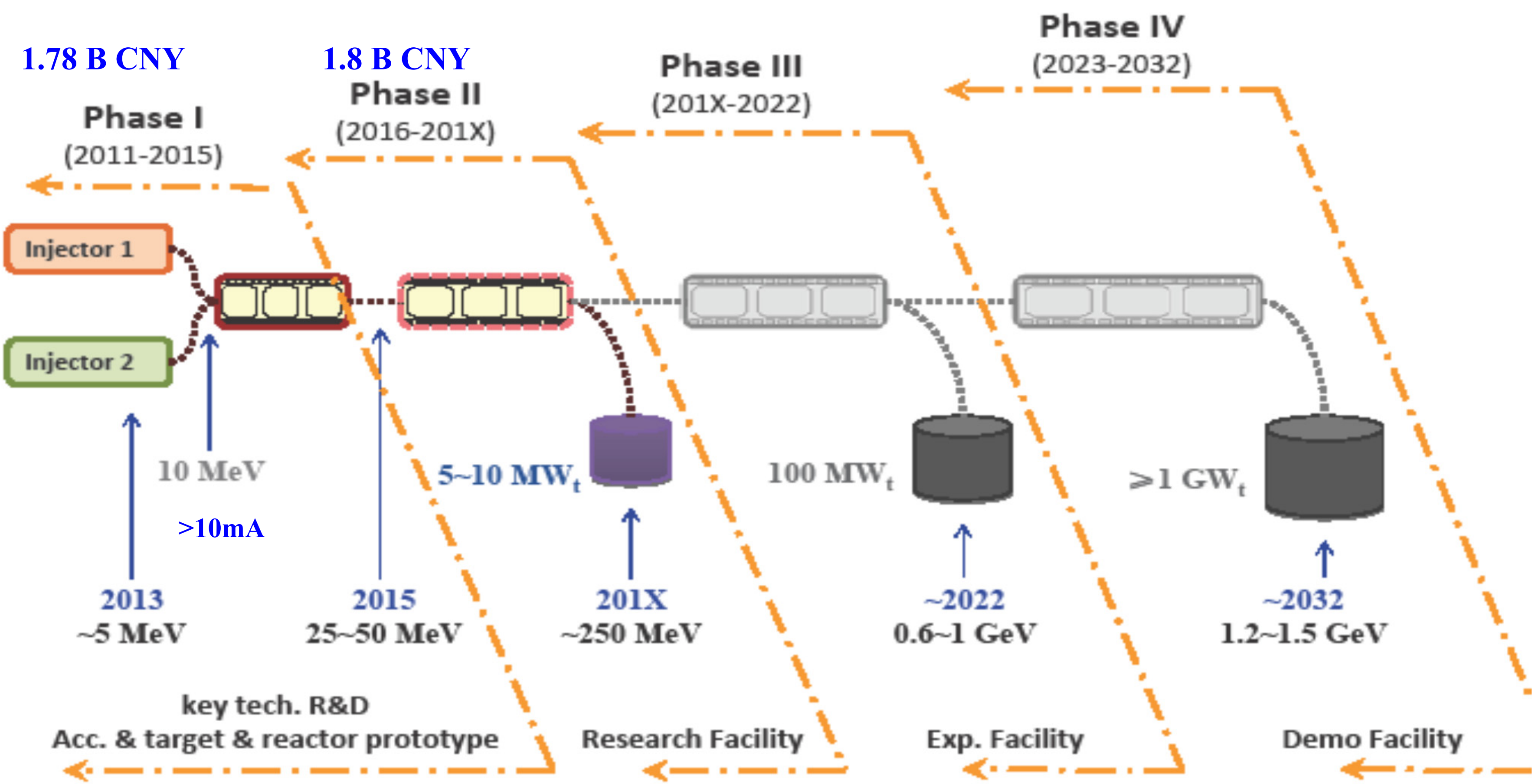
- **To May 2013 (www.world-nuclear.org/info/...)**
  - Operating 17set reactors, 13.955GW$_{e;}$ (6th in world)
  - Constructing 28 set reactors, 30.550GW$_e$; (1st in world)
  - Planned 49 set reactors, 56.020 GW$_e$; (1st in world)
- **According to some information: (slower after 2011.3)**
  - **2020**: ~70 GW$_e$ NPP in operation and 30GW$_e$ NPP under construction; >5% of NP to total installed power capacity
  - **2030**: ~10% of NP to total installed power capacity
  - **2050**: >400 GW$_e$ NPP → **almost same as the scale of the total in the world todays!**

Special Program of NE in CAS (Fund 9/2011)



ADS Roadmap in China

ADS Roadmap in CAS



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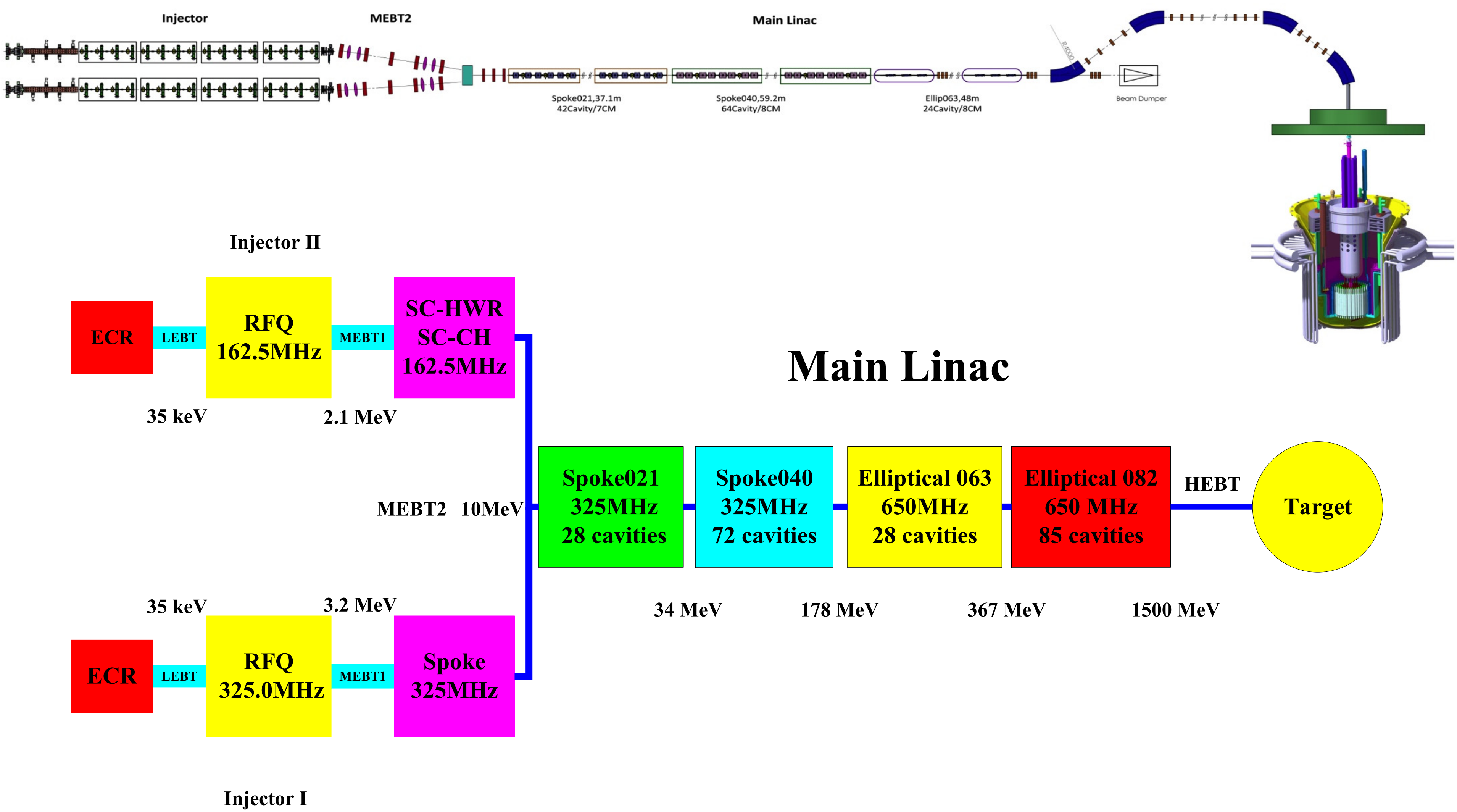
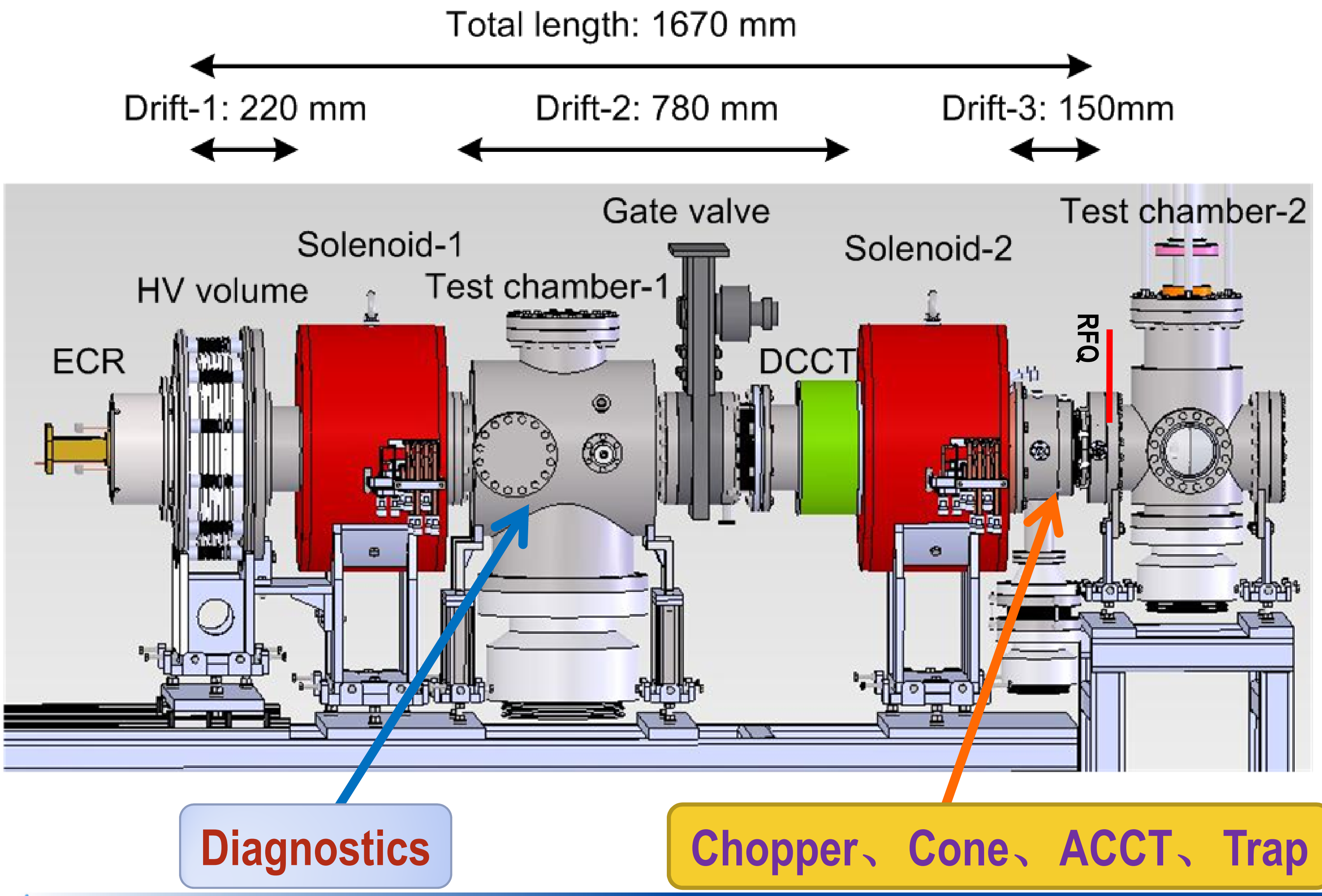
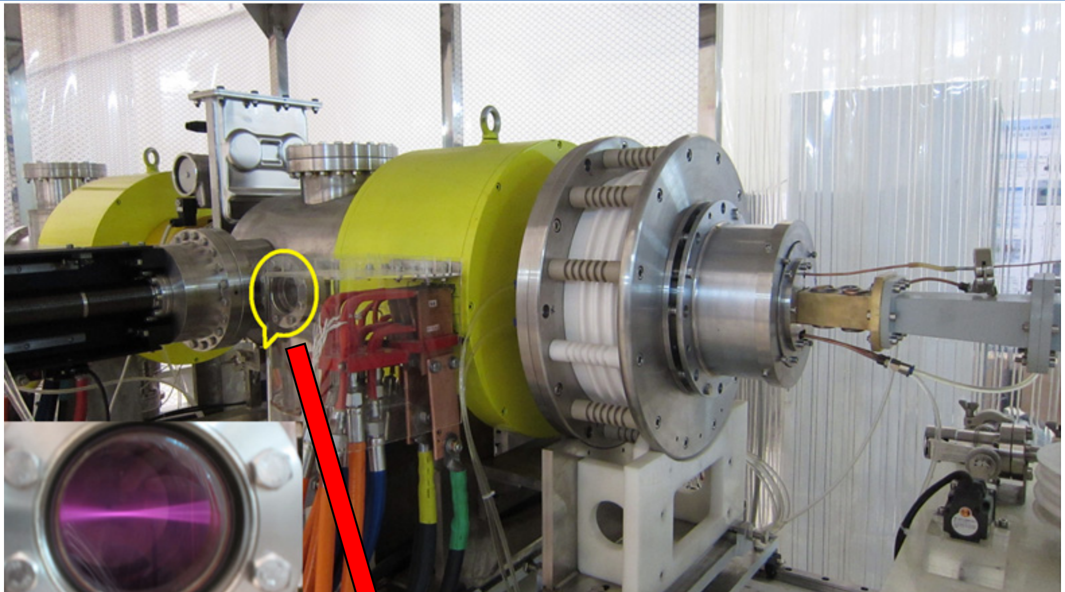
Configuration of C-ADS



Accelerator System: ECRIS + LEBT

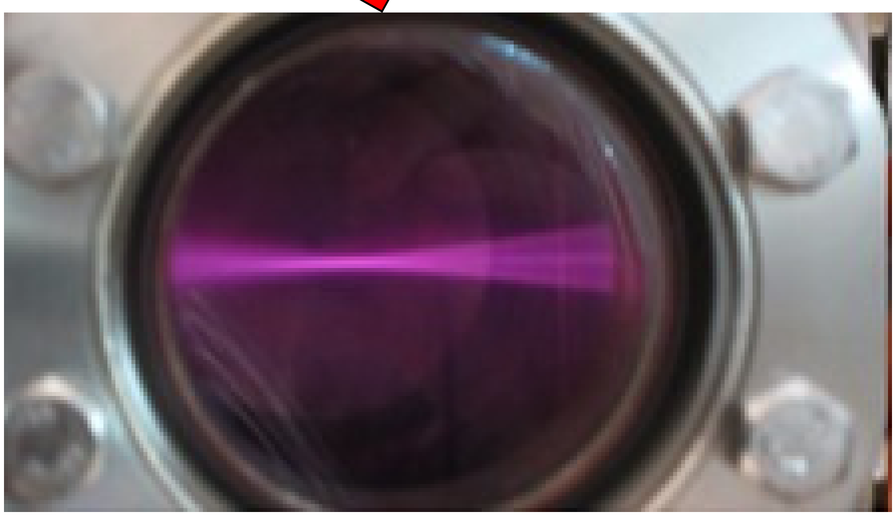


ECRIS+LEBT is commissioning at IMP

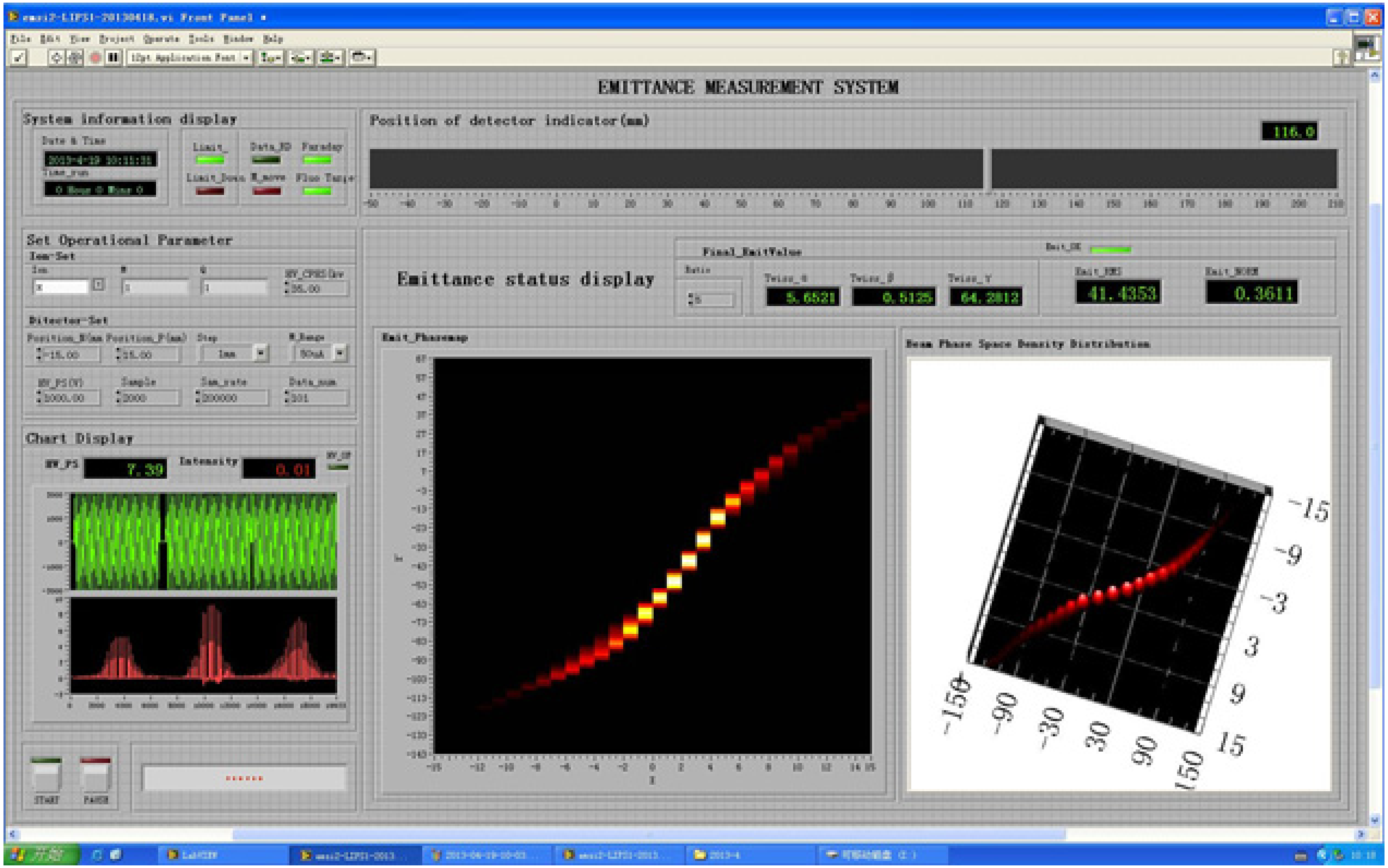


The first ECR Proton Ion Source is commissioning at IMP. 25 mA Proton with 35 keV has been extracted.

Stability still need to be improved in long time.



Measurements at the end of LEBT

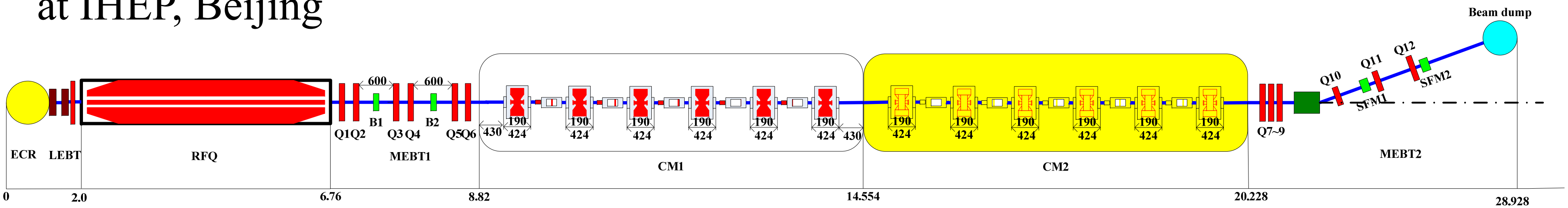


Vb=-2kv，G1=230A，G2=261A，S1=S2=S3=S4=0 ,FC02=3 mA，HV=35kv@6mA

Accelerator System: Two options of 10-MeV Injectors

Injector I
at IHEP, Beijing

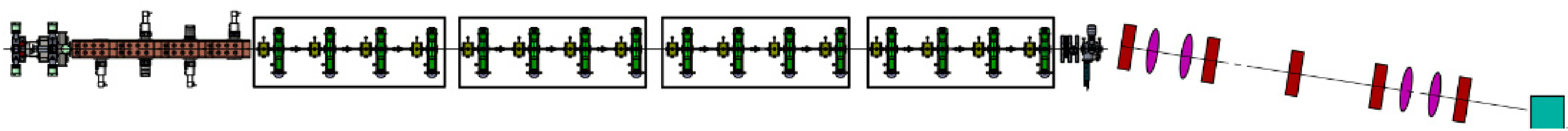
Base on 325 MHz and Superconducting Spoke cavity



35 KeV 3.2 MeV 5 MeV 10 MeV

Injector II
at IMP, Lanzhou

Base on 162.5 MHz and Superconducting HWR cavity

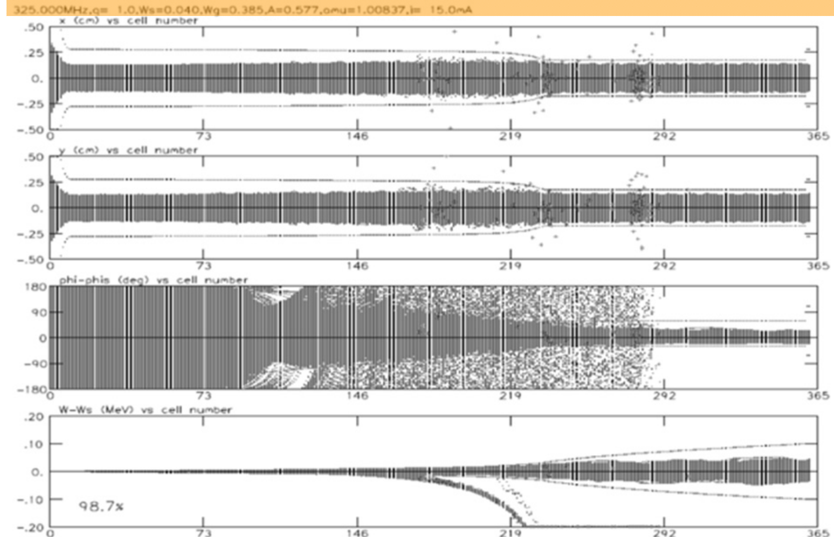


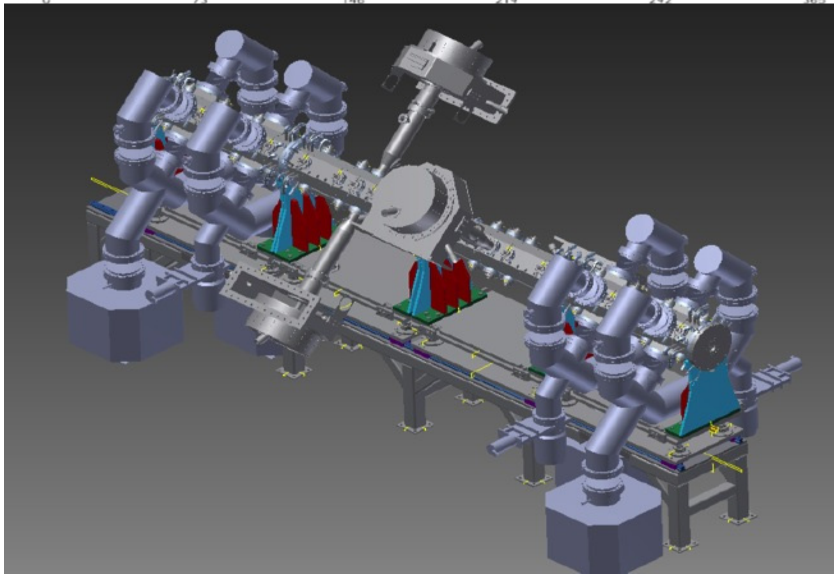
35 KeV 2.1 MeV 5 MeV 10 MeV

Accelerator System: RFQ for Injector I

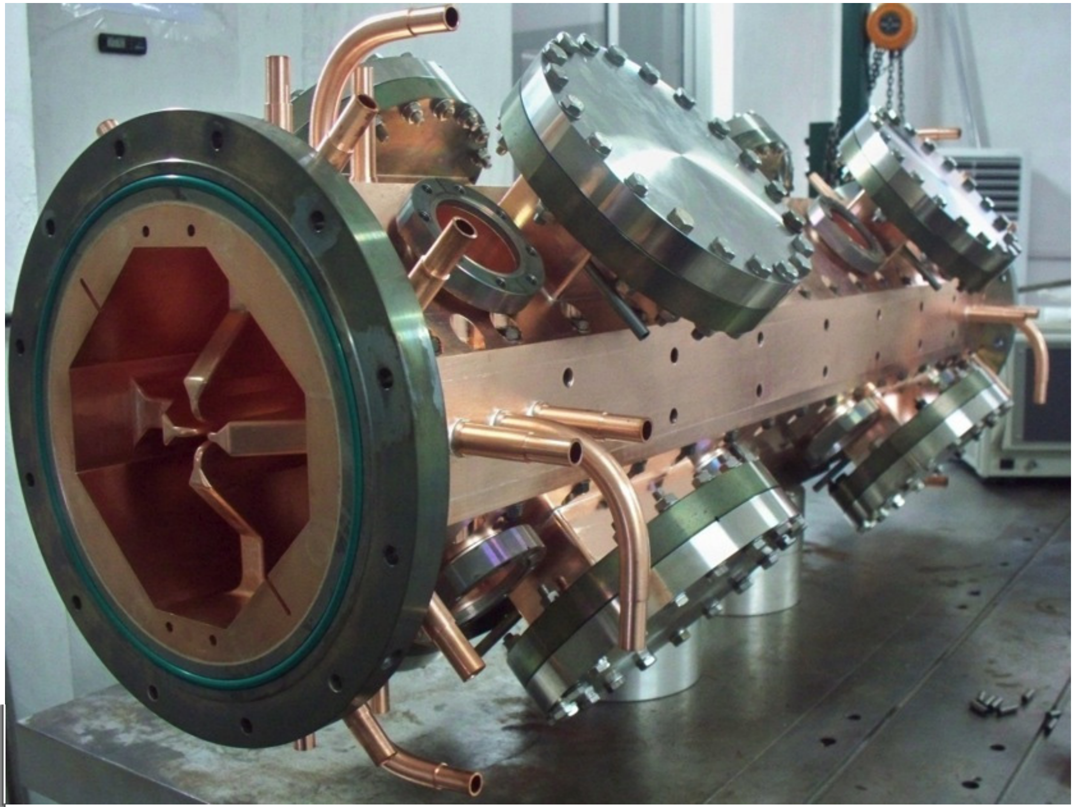
Parameters	Value
Frequency (MHz)	325
Injection energy (keV)	35
Output energy (MeV)	3.2128
Pulsed beam current (mA)	15
Beam duty factor	100%
Inter-vane voltage V (kV)	55
Beam transmission	98.7%
Average bore radius r_0 (mm)	2.775
Vane tip curvature (mm)	2.775
Maximum surface field (MV/m)	28.88 (1.62Kilp.)
Cavity power dissipation (kW)	272.94
Max. copper power/Area (W/cm^2)	3.77
In norm. rms e (x,y,z) (πmm.mrad)	0.2/0.2/0
Out norm. rms e (x/y/z) (πmm.mrad/MeV-deg)	0.2/0.2/0.0612
Vane length (cm)	467.75
Accelerator length (cm)	469.95

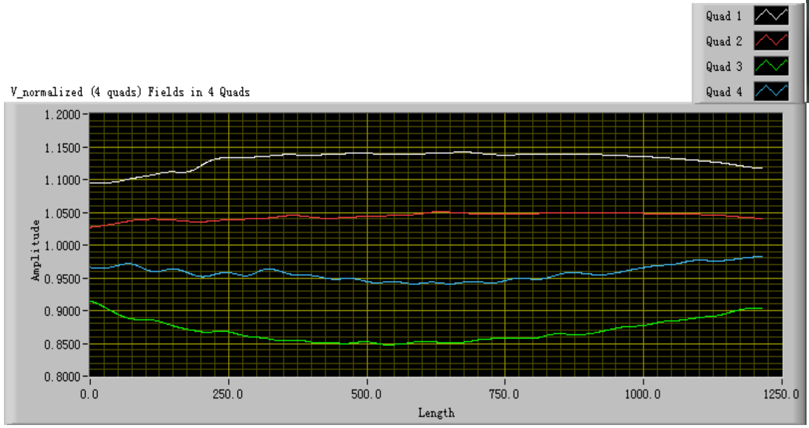
The beam transmission is about 98.7%





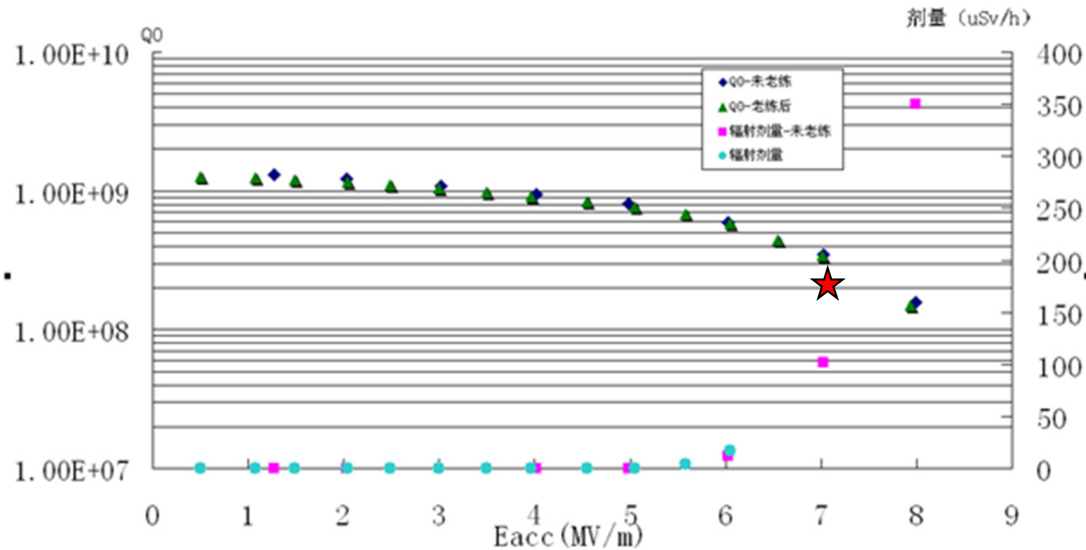
Progress of RFQ for Injector I (325MHz)





Cold test of all modules has been done. Commissioning is expected on Fall.

Spoke012 for Injector I

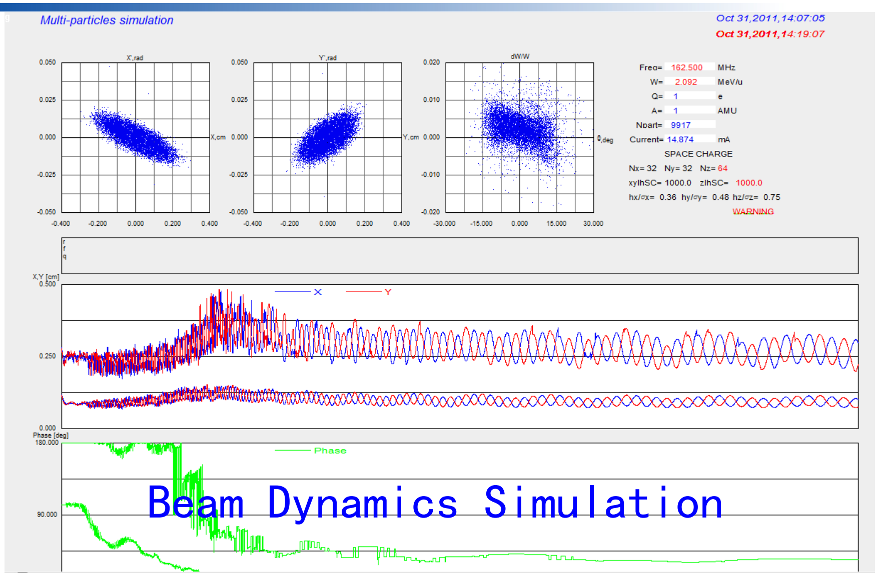


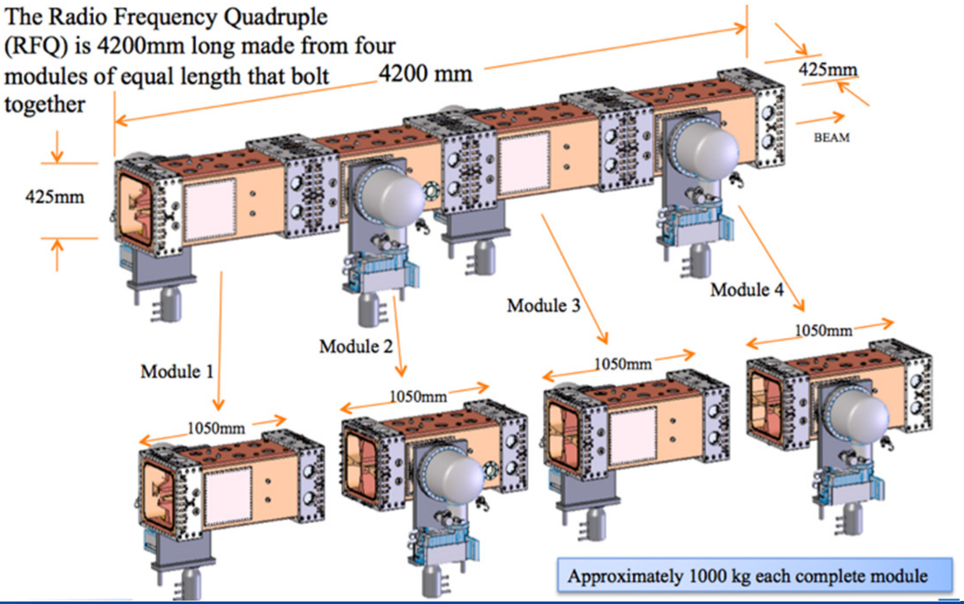
Parameters	Unit	
Freq.	MHz	**325**
Beta		**0.12**
Epeak/Eacc		4.3
Bpeak/Eacc	mT/(MV/m)	6.5
Uacc=0.78MV	MV/m	30.1
R/Q	Ω	161

E_{acc} **8.1MV/m@$Q_0$1.5×10^8**

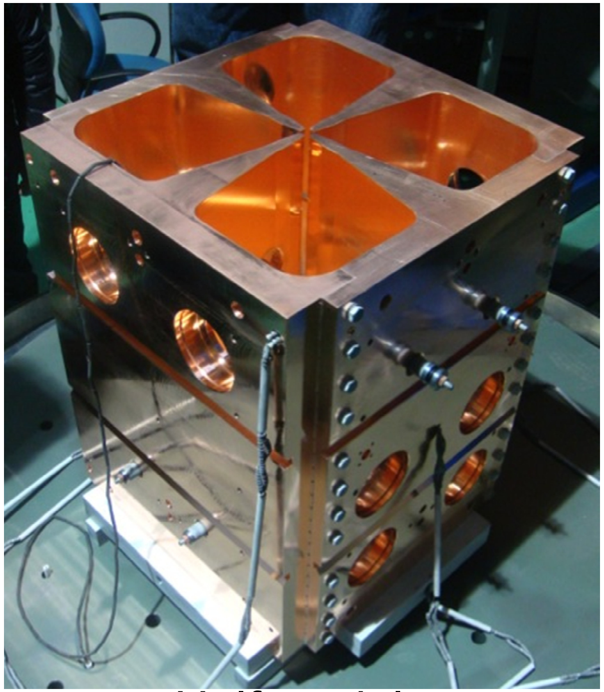
Accelerator System: RFQ for Injector II

Parameter	Value
Ion species	Proton
frequency [MHz]	162.5
Inter-vane voltage *V* (kV)	65
Average bore radius r_0 (cm)	0.5731
Vane tip curvature (cm)	0.4298
ρ / r_0	0.75
Vane length / Total length (cm)	419.2 / 420.8
m_{max}	2.38
Number of cells	192 (including 2 T cell)
Maximum surface field (MV/m)	15.7791
Synchronous phase	From -90° to -22.7°
a_{min} (cm)	0.3158
Transverse acceptance (RMS, x/y, πmm.mrad)	0.3/0.3
Input norm. RMS emittance (x/y, πmm.mrad)	0.3/0.3
Output norm. RMS emittance (x/y/z, πmm.mrad, keV.ns)	0.31/0.31/0.92
Overall beam transmission @ 0 /15 mA	99.7% / 99.6%

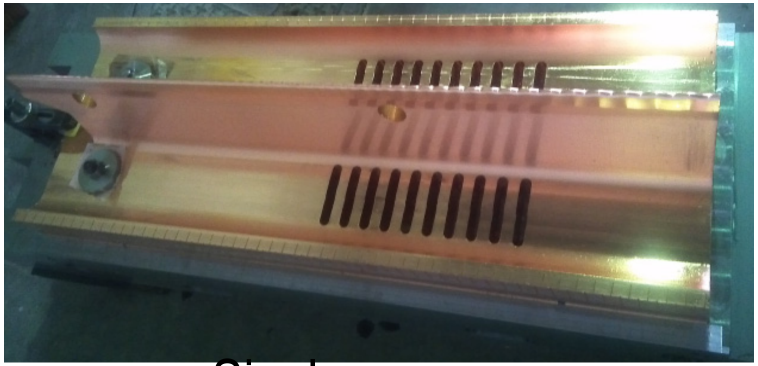




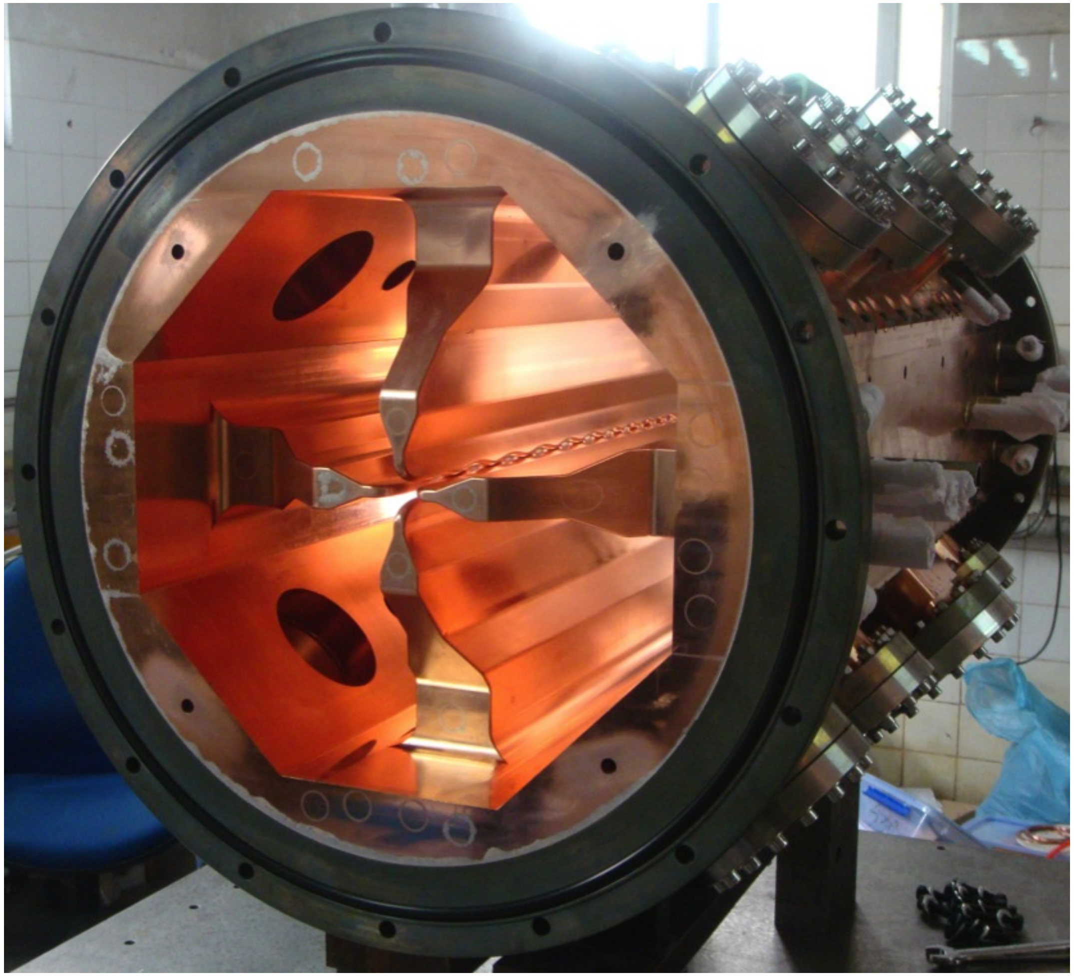
Progress of RFQ for Injector II (162.5MHz)



Half module

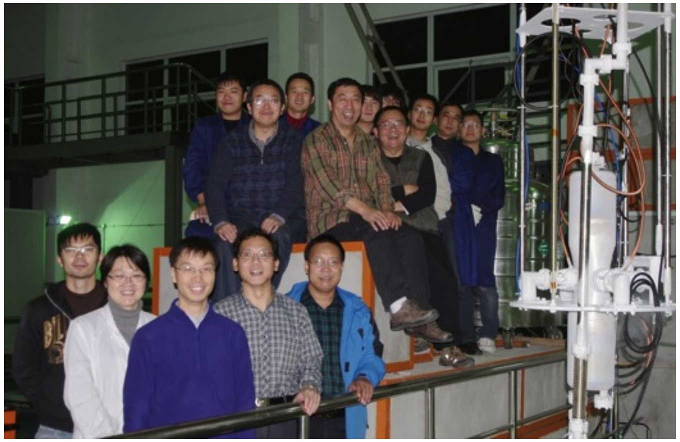


Single wane

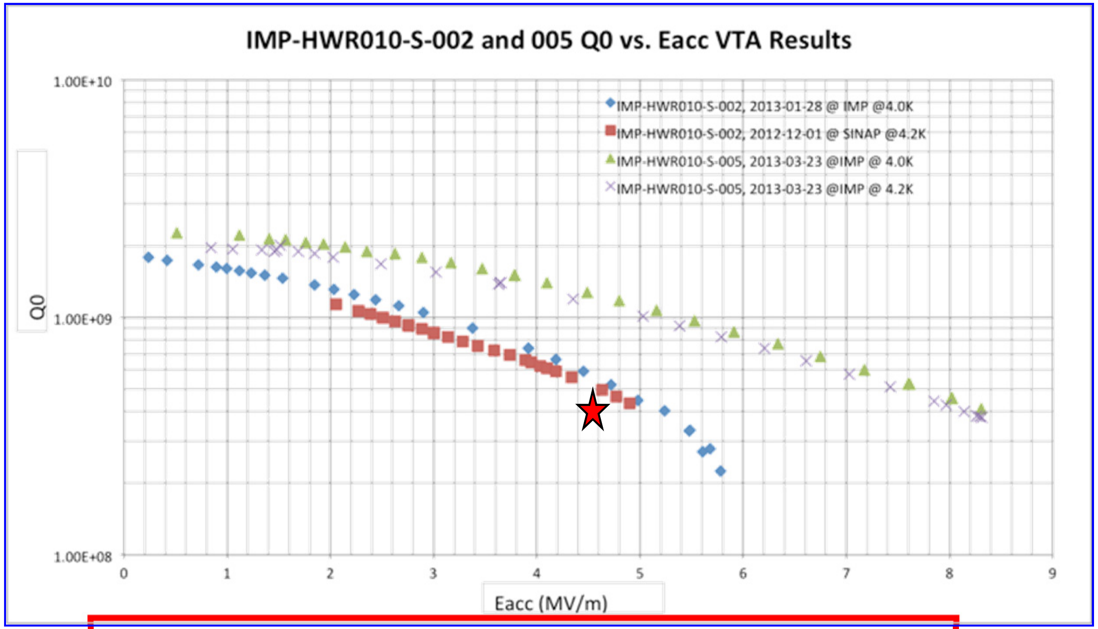


Test module is ready for high power testing

HWR010 for Injector II

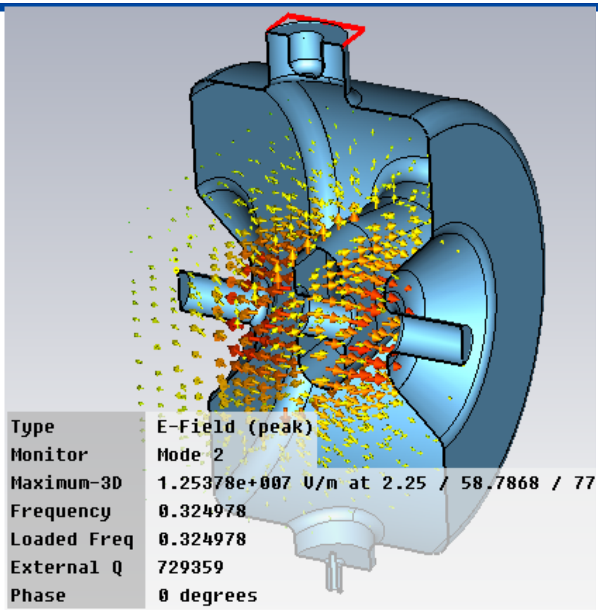


Freq. (MHz)	162.5
βopt	0.10
Epk/Eacc	5.34
Bpk/Eacc	10.92
Q0 (@4.5K)	4.1E8
Uacc (MV)	0.78
Pdiss (W)	10

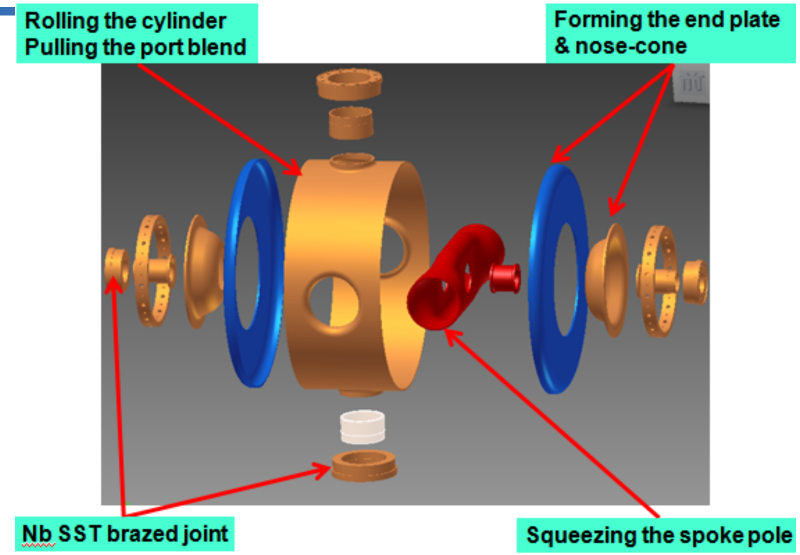


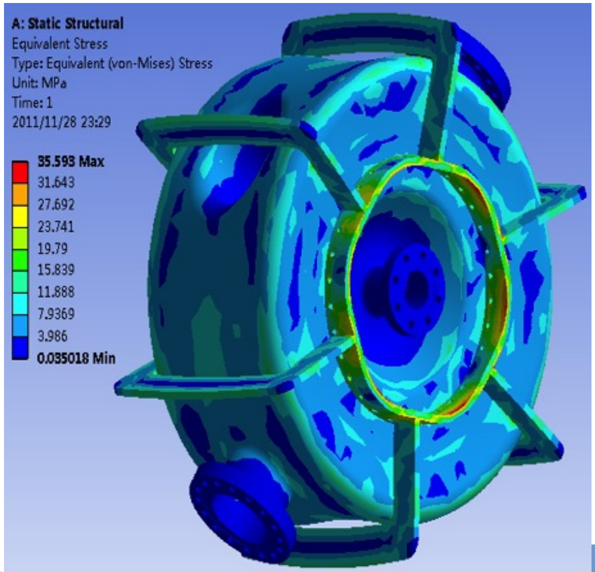
E_{acc} 8.3MV/m@$Q_0 4.1\times10^8$

Progress of Spoke021 for Main Linac

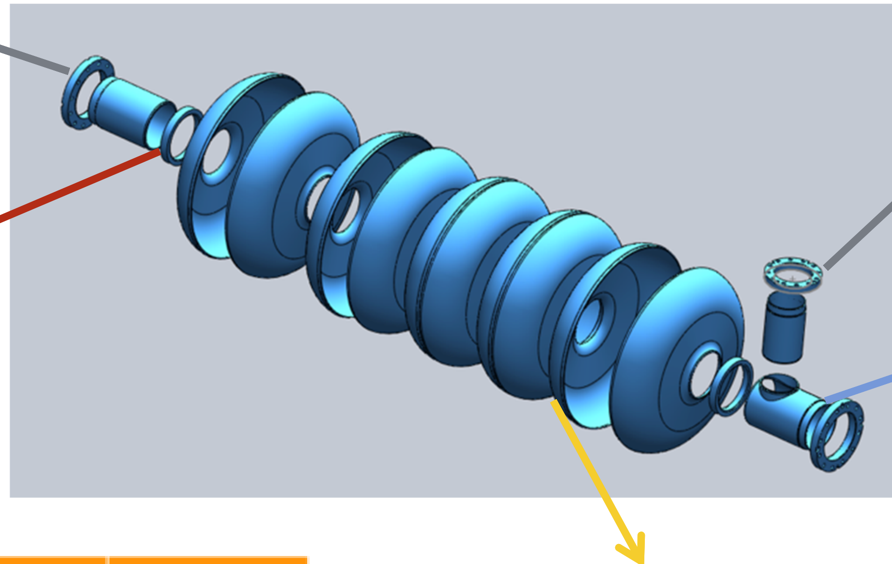


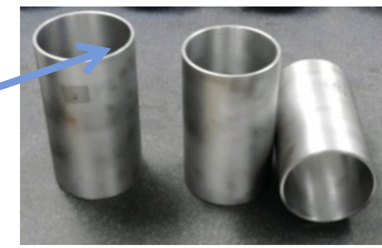
Para.	
E_p/E_{acc} /(void)	3.88
H_p/E_{acc} /mT/(MV/m)	8.13
β_{opt}	0.246
r/Q /Ω	206
G /Ω	87
R_{BCS} /nΩ	0.68
Q0@Rres=5nΩ	1.38E10
$Q_{e,opt}$	7.28E5





Progress of Cavity for Main Linac





	Center cell	End cell
L (cm)	9.461	9.461
E_p/E_{acc}	2.12	
H_p/E_{acc} mT/(MV/m)	4.05	
r/Q [Ω]	514.6	
G [Ω]	235.5	
k [%]	0.9%	
Field flatness [%]	>98	

Beta=0.85 Freq.=650 MHz

RF Couplers Development

325MHz, Spoke
CW, 10kW
Tested

325 MHz, RFQ
CW, 100 kW
Tested

162.5MHz, HWR
CW, 20kW
Tested

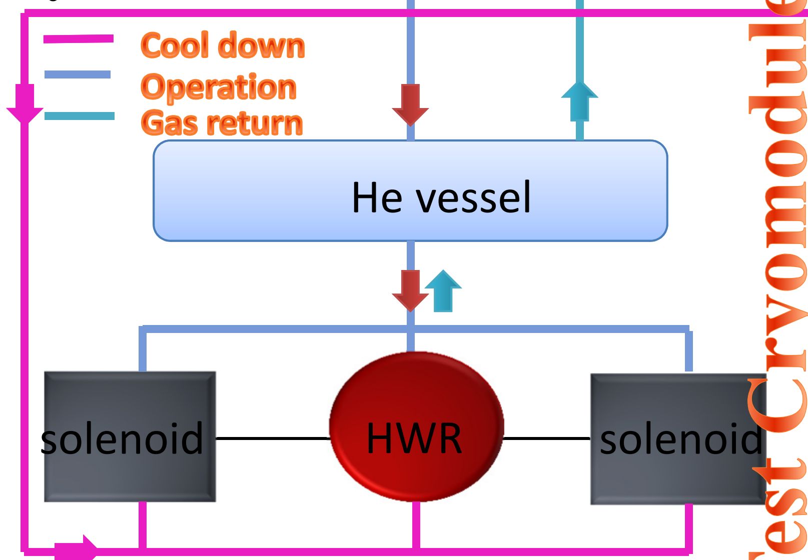
Solid State Amplifiers

Testing Item	Requirements
frequency	162.5 MHz ± 2 MHz
Freq. stability	< ±1×10-8/day
RF standard	0dBm～10dBm continuous tuning
Output Power	≥20kW（CW，Pulse）full reflection
Duty factor	1%～100% tuning
Harmonic	≤-30dBc
Harmonic of PS	≤-50dBc
Random Harmonic	≤-60dBc
Amplitude stability	≤±1×10^{-2}/24 hours
Phase stability	≤±5°/24hours, open loop
Output interface	50Ω coaxial, 4-1/2

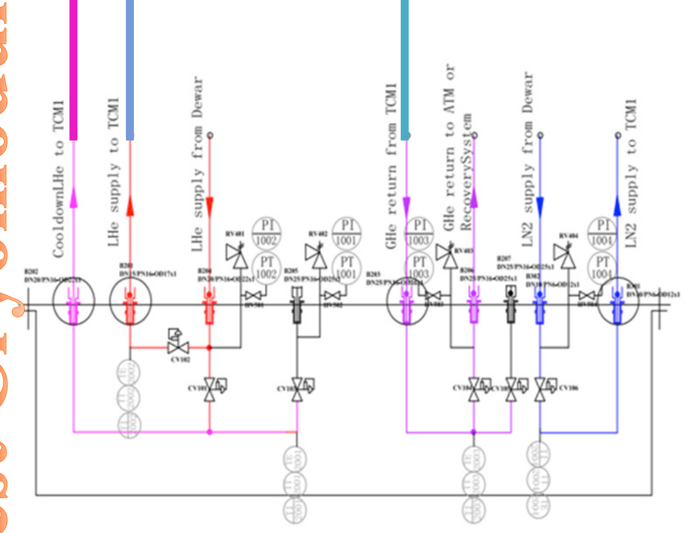
The solid state amplifiers of 162.5 MHz at 20 kW and 325 MHz at 10 kW were tested. All specifications are reached.

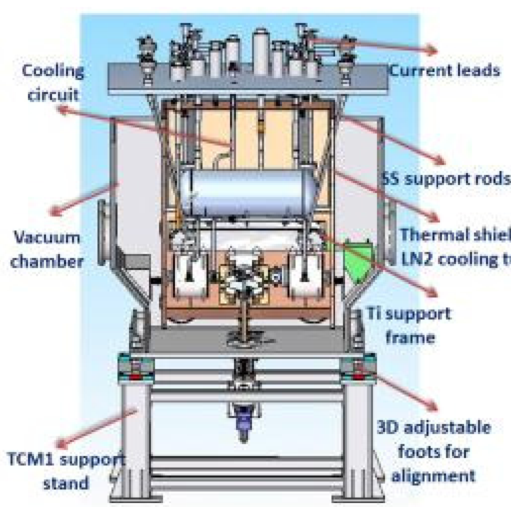
est Cryomodule for In

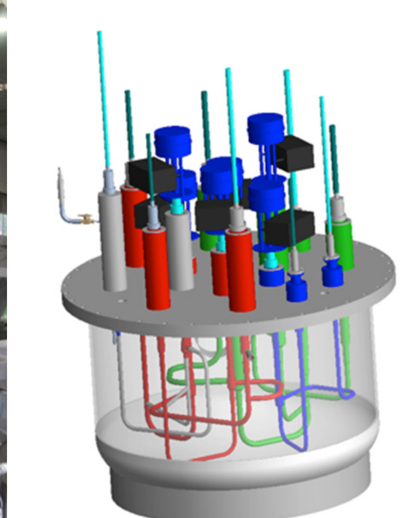
Cryomodule



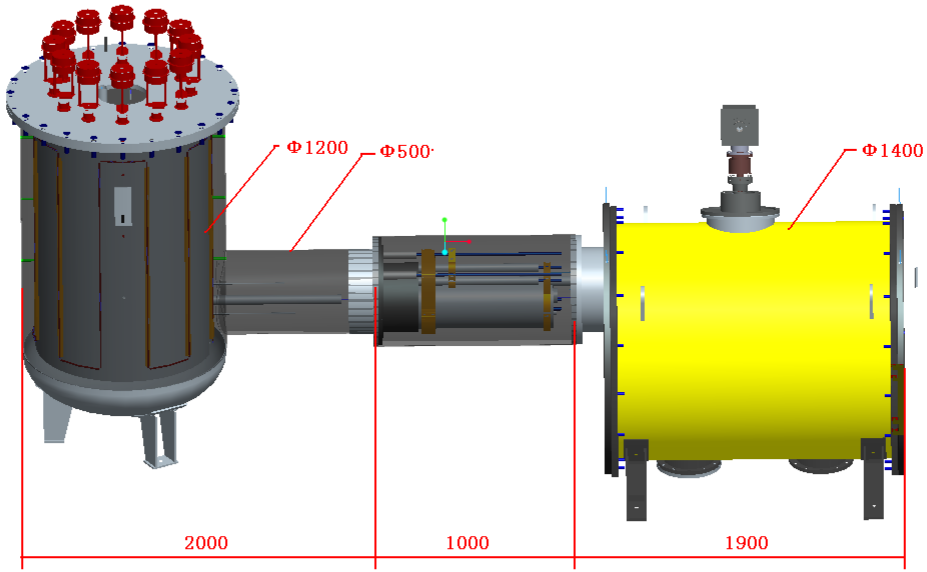
Valve Box



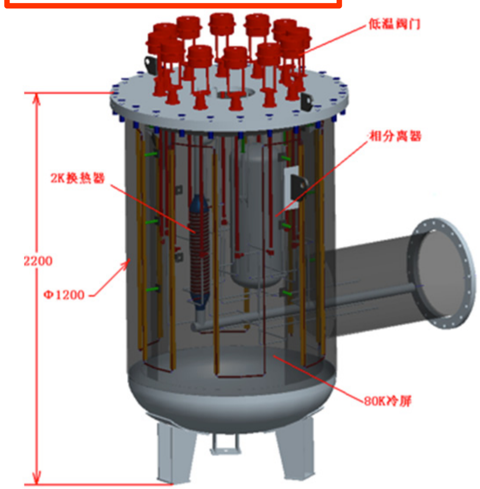




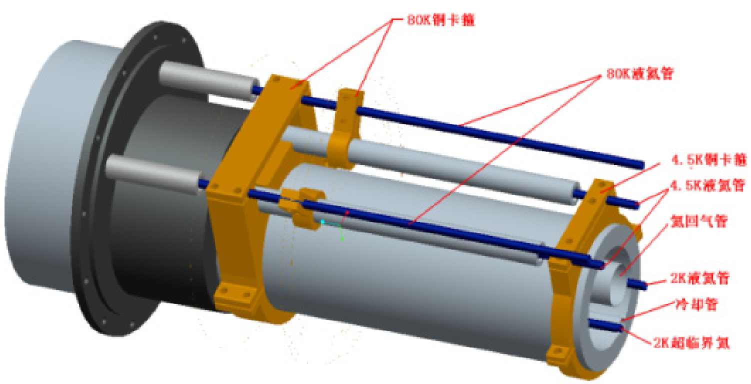
Horizontal Test Stand for Spoke



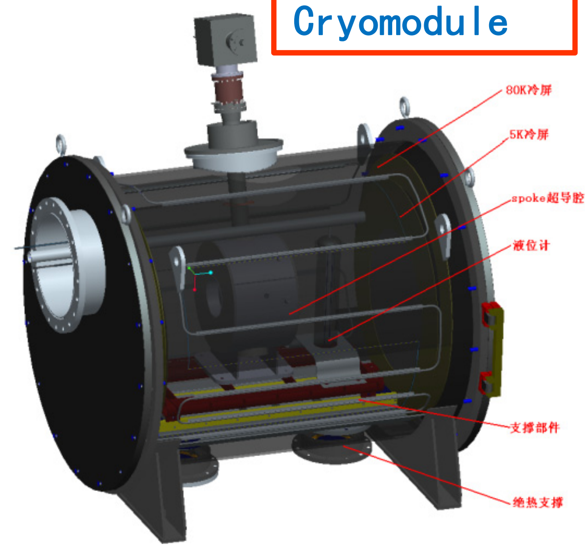
2K valve box



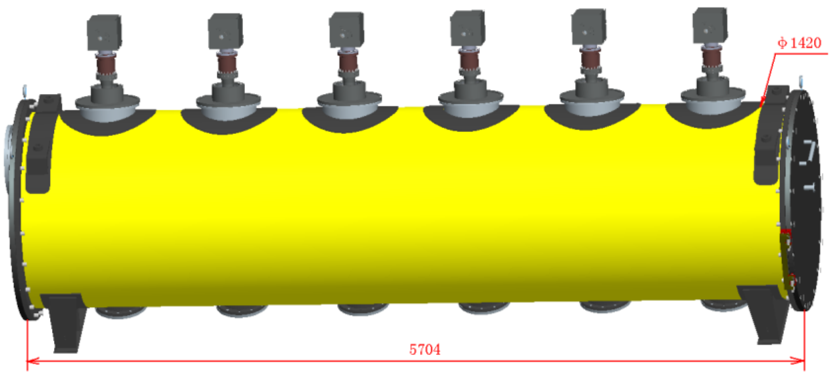
2K shielding

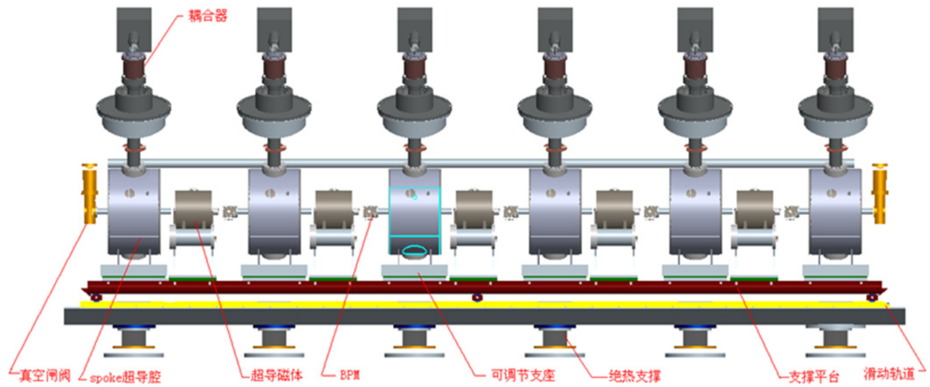


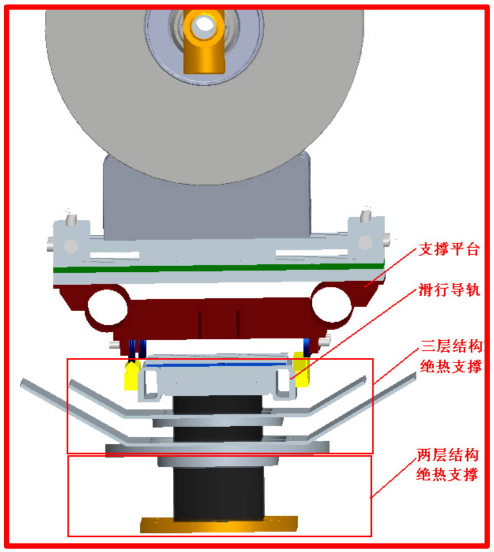
Cryomodule

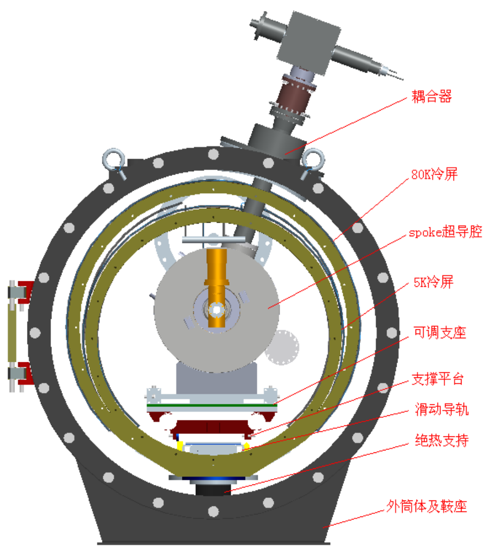


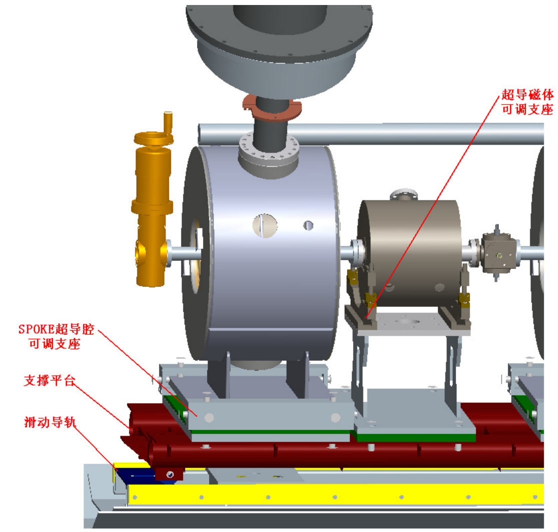
Cryomodule for Spoke012







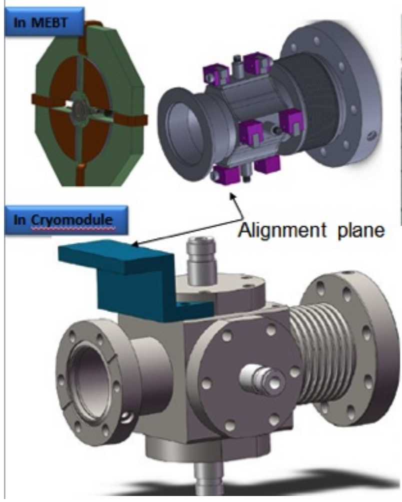


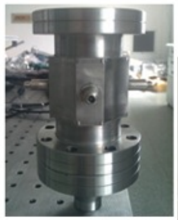


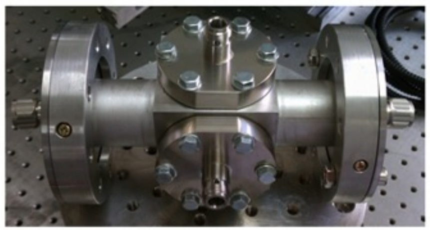
5704 mm, 6 spokes, 6 couplers, 5 solenoids, 5 BPMs, 2 valves inside

Progress of BPM Diagnostics

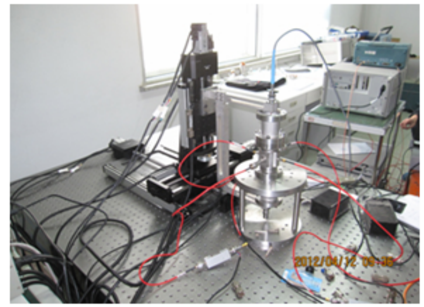
BPM Manufacturing

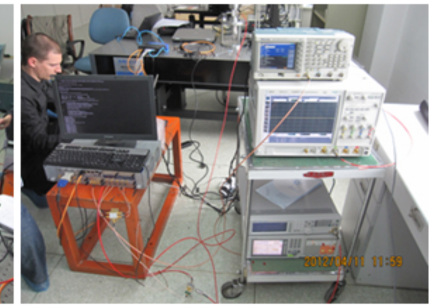


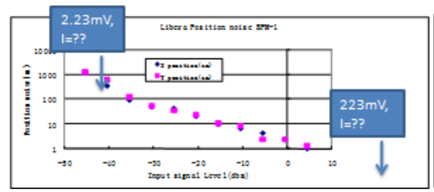


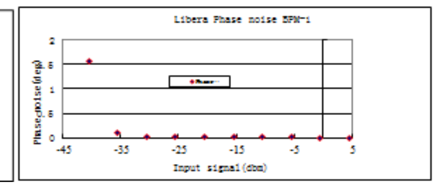


BPM electronics measurement

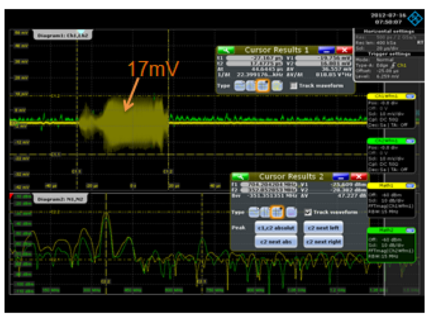


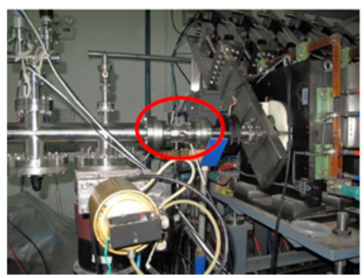






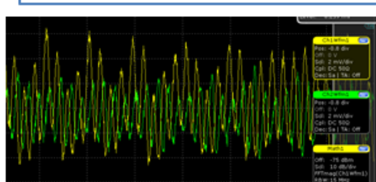
BPM beam measurement in IHEP



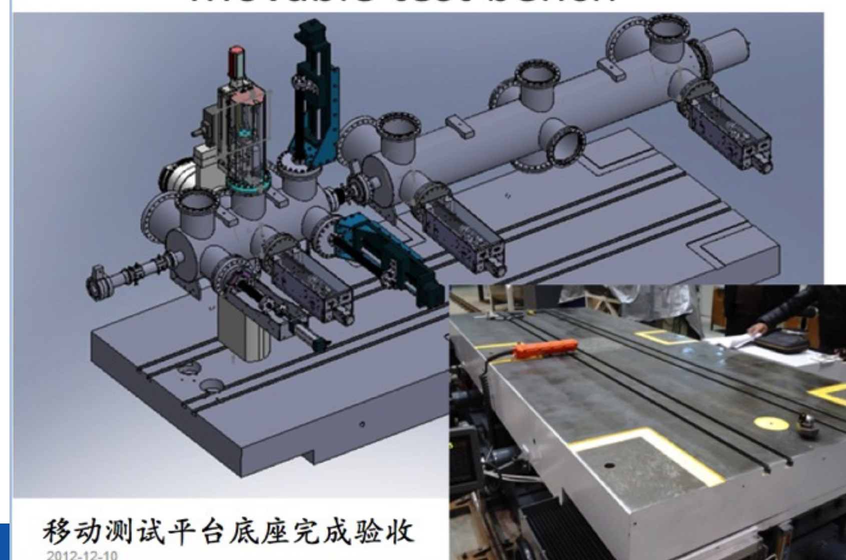


BPM's installation in MEBT of Proton LINAC in the IHEP.

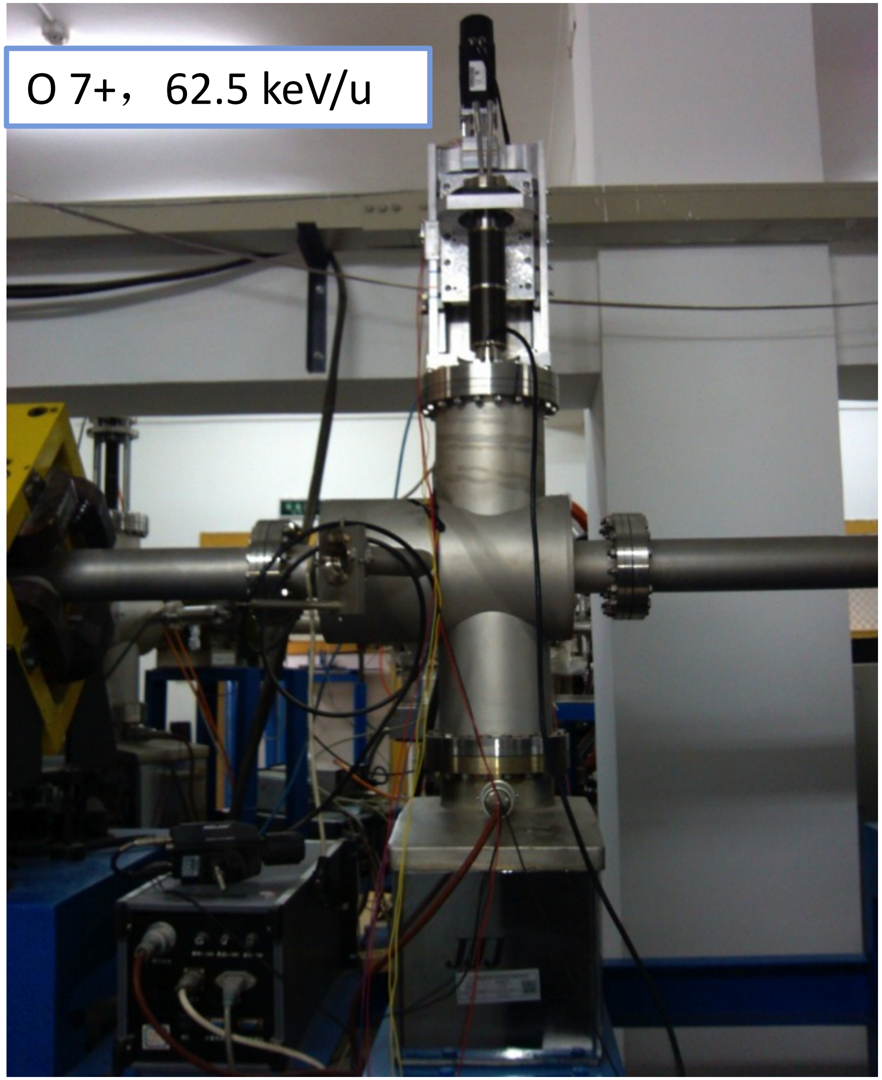
Beam energy	3.5MeV
β	0.086
Bunch frequency	352.2 MHz
Average current	18 mA

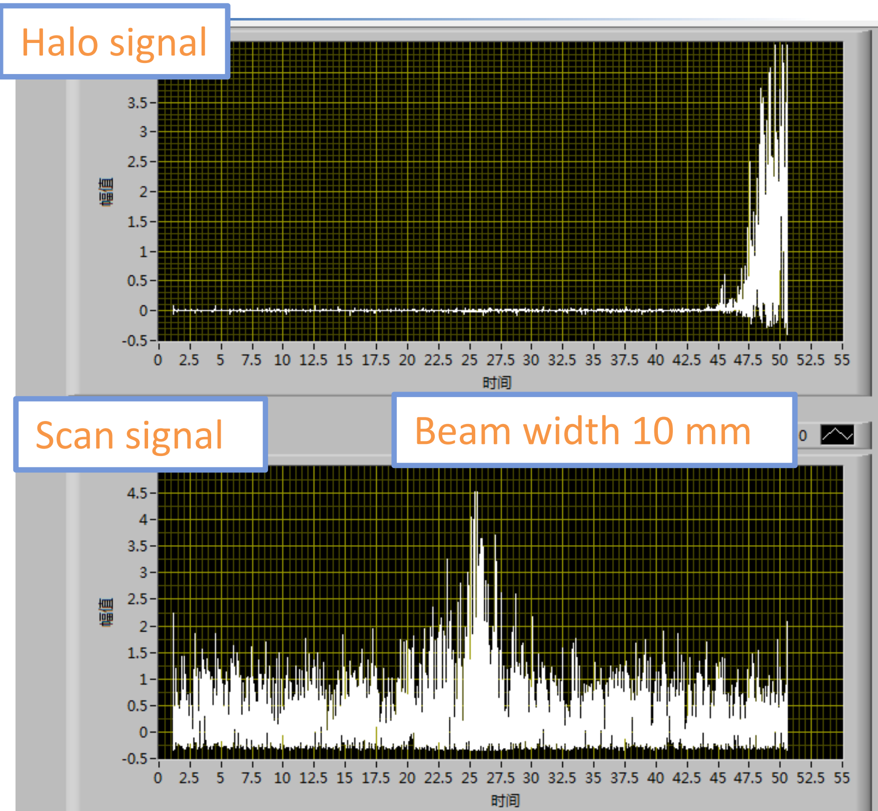


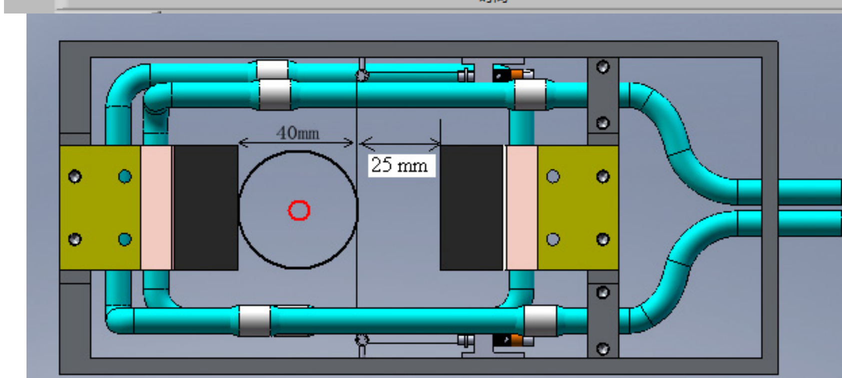
Movable test bench



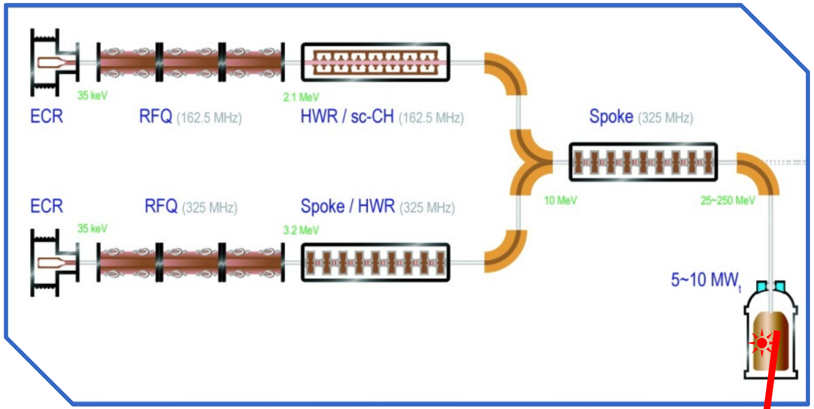
Test of Single Wire Scanner







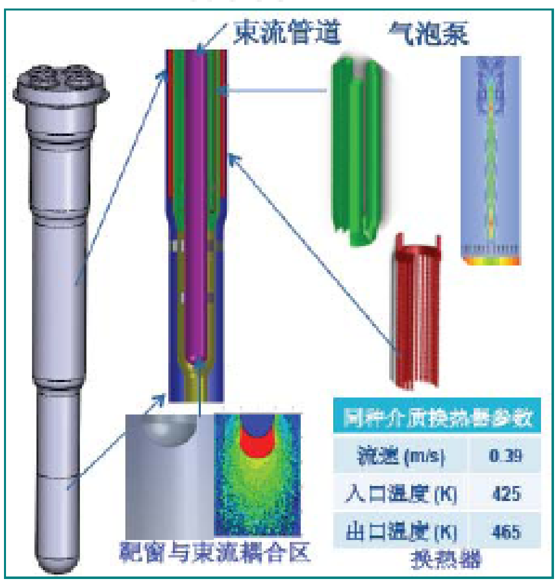
• Spallation Targets



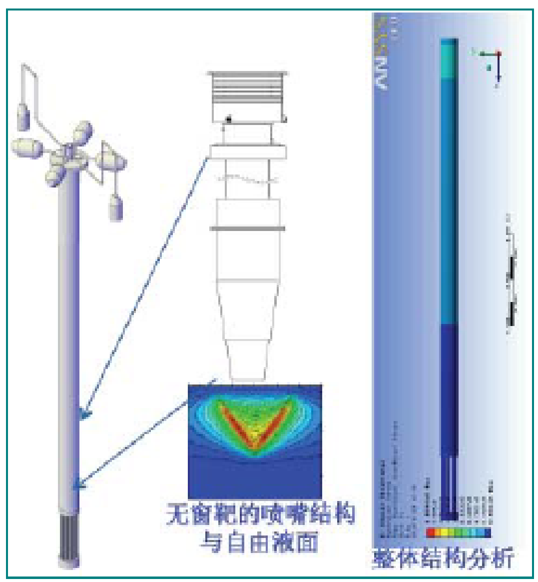
Spallation Target ——

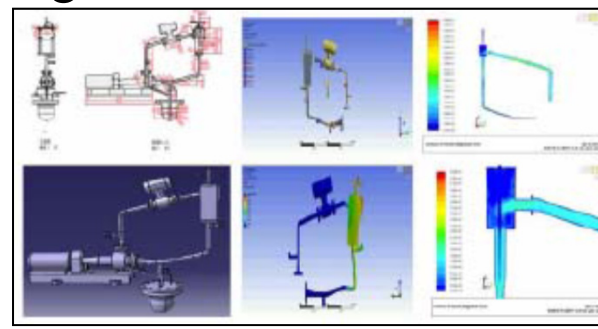
- ➢ Two physical designs of LBE targets under testing
- ➢ New type solid target under designing

LBE target with window



Windowless LBE target



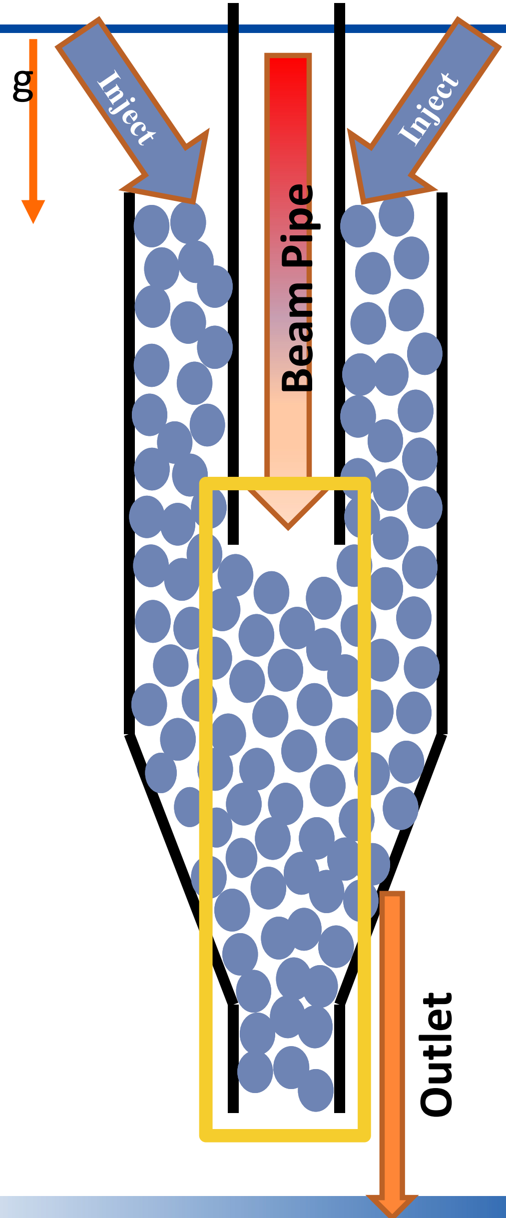


Forced flow liquid LBE loop

Design and simulation (up) and test set-ups (down)

Principle of Granular Flow Spallation Target

Granular Flow by Gravity

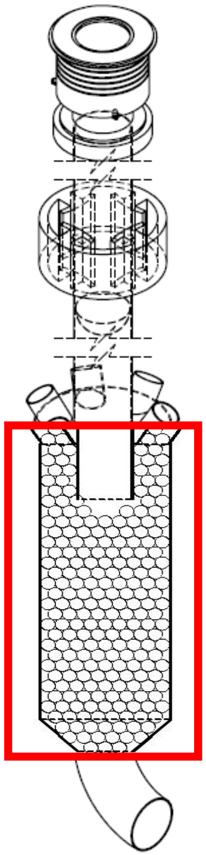


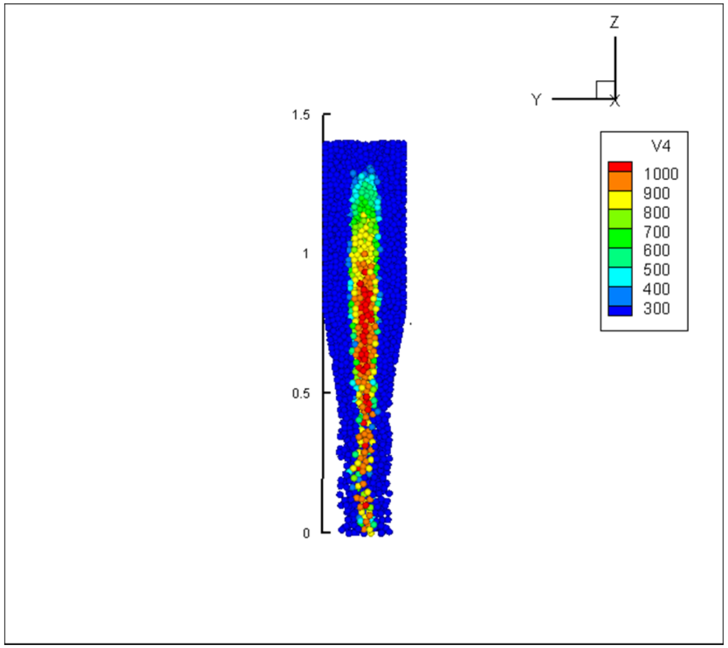
- **Granular flow operates similar as sand clock and Heat is treated off line**

Design Granular Flow Spallation target

Parameters	
Granular material	Tungsten/Tungsten alloy
Structure material	TZM/SiC
Granular size	10±5mm
Inlet temperature of granular	250 C
Proton beam	1GeV@10mA=10MW
Intensity of beam	>100 μ A/cm^2
Diameter of beam spot	10cm

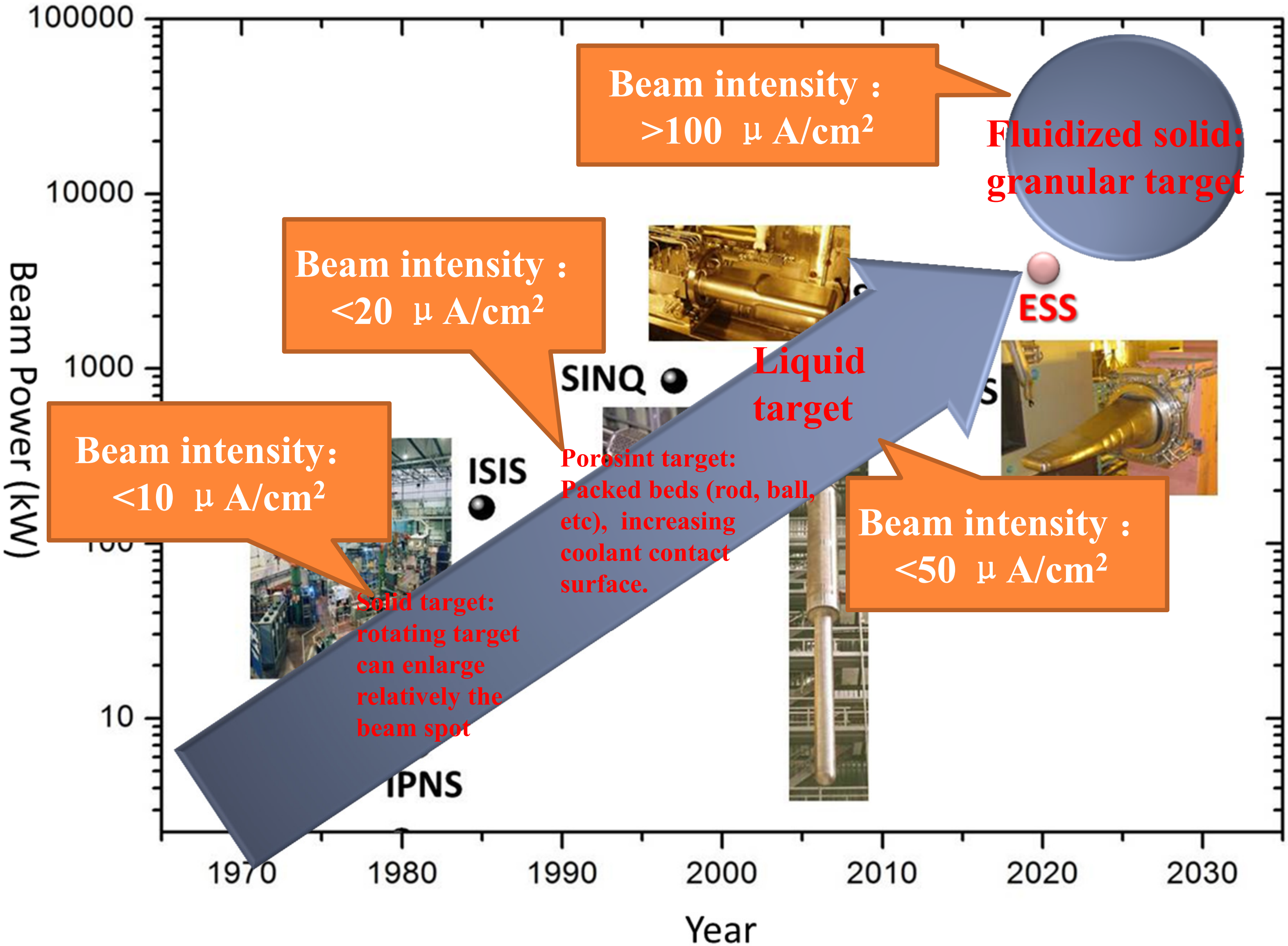
Average temperature increase	Average velocity
400	~0.8m/s
500	~0.5m/s
600	~0.35m/s
800	~0.25m/s





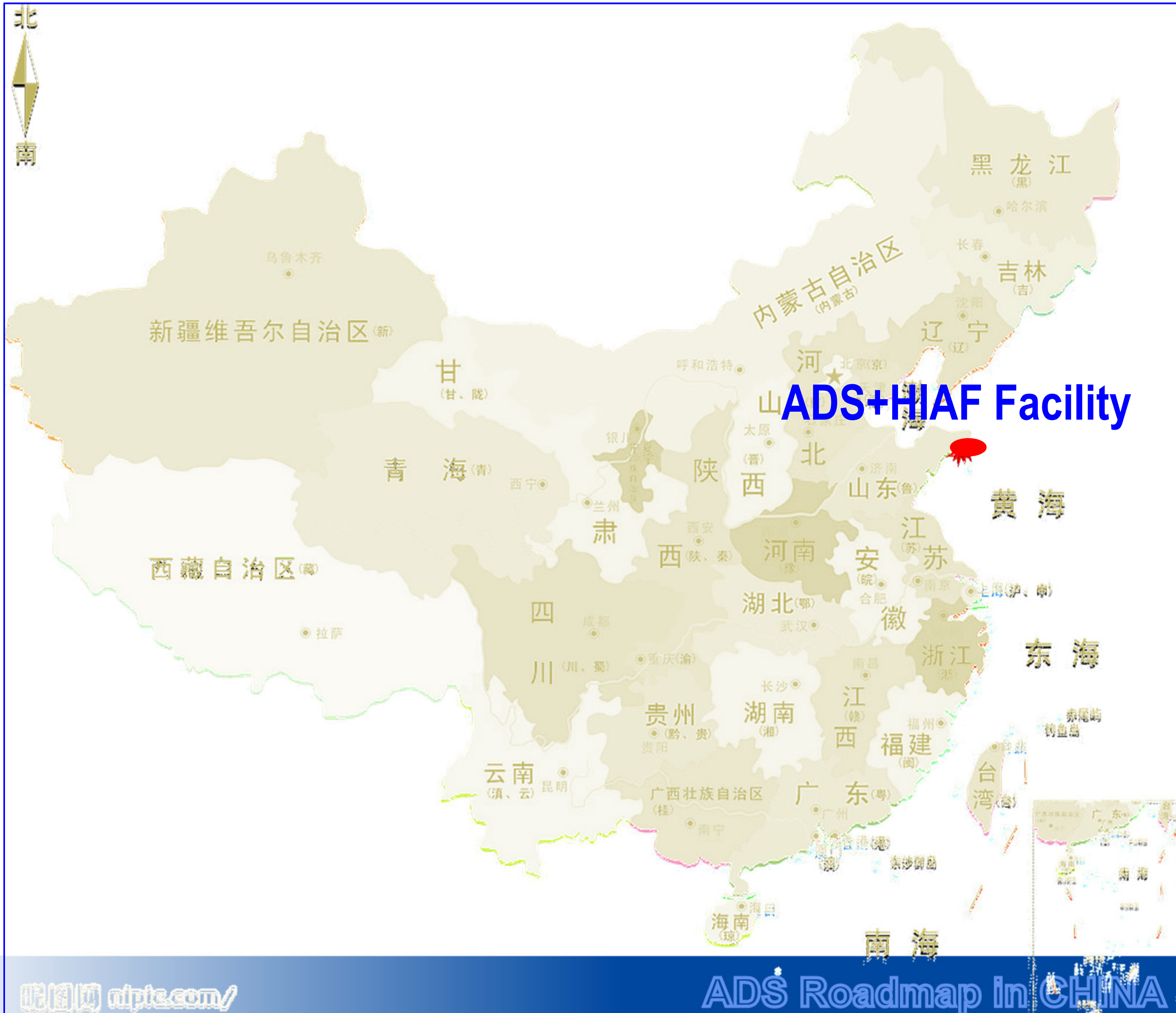
Mass parallel Simulation:
Contact mechanism + MD + MC transport
K20GPU 2500ALU * 32
Number of Ball: 0.5 M

Granular Flow Spallation target: 10's MW



New Site, New Research Center

New Site, New Research Center

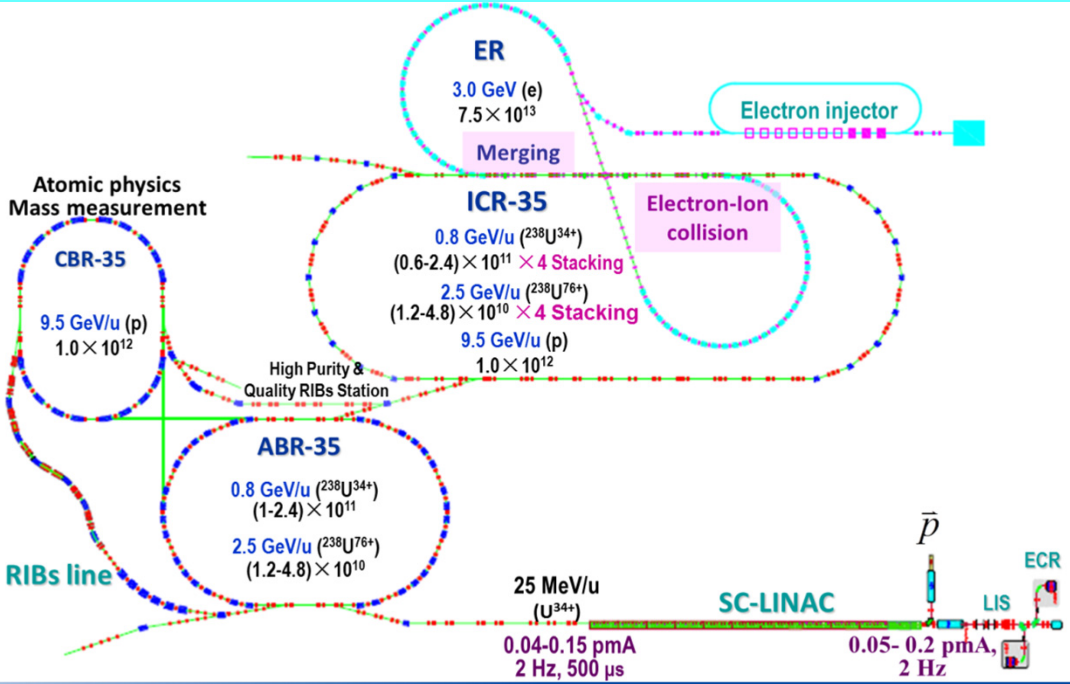


New Site, New Research Center

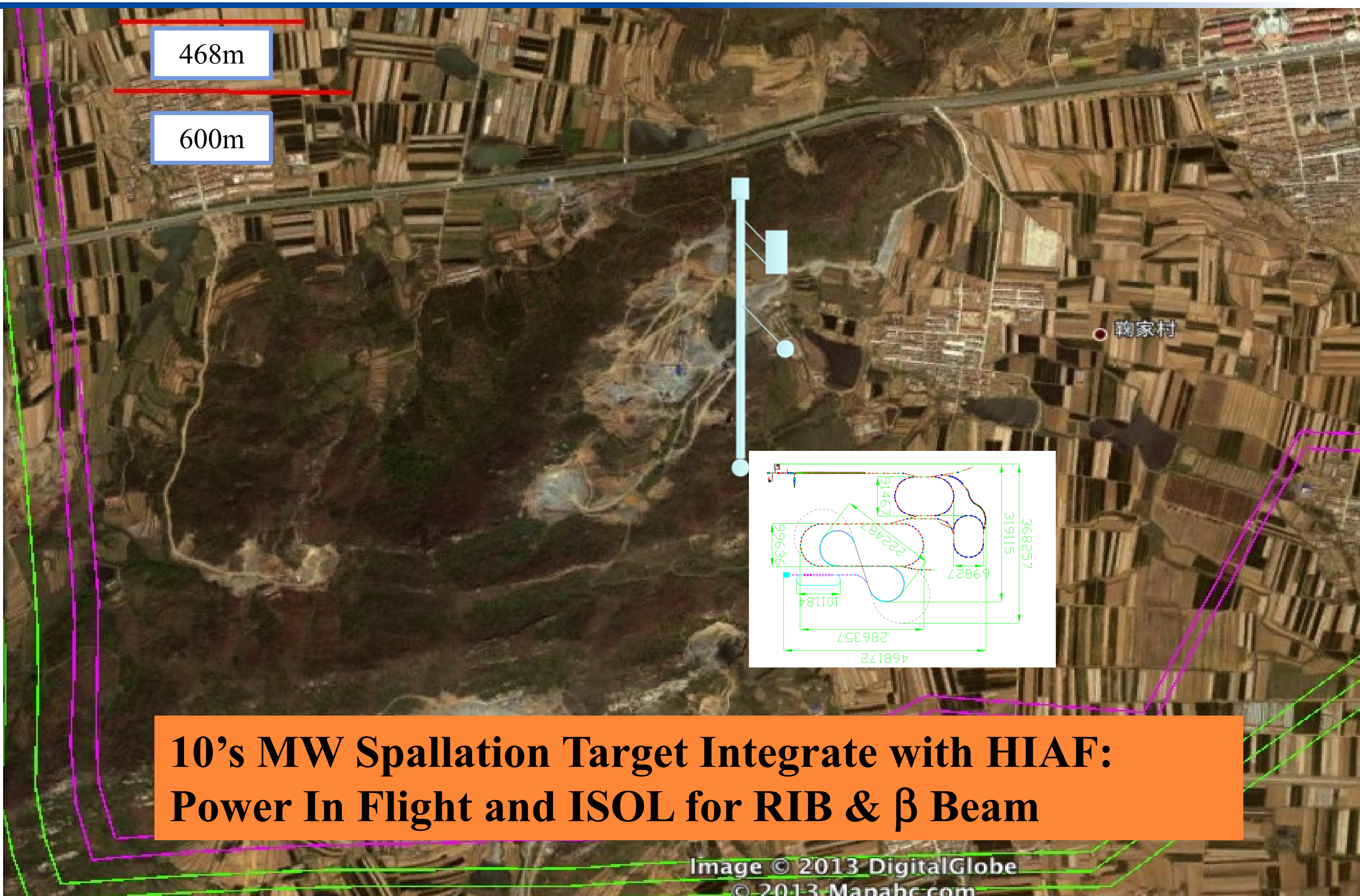
Heavy Ion Accelerator Facility (HIAF)

- (ABR+CBR+ICR): high quality & intensity pulsed RIBs, β & neutron beam → high accuracy RIA, astrophysics, application…
- (ABR+CBR+ICR): high power compressed U beam → HED…
- (ABR+CBR+ICR+ER): polarized e & p beams → EIC;

  U+U, RIB+RIB… → Merging Experiments…



Future Integrate Development



10's MW Spallation Target Integrate with HIAF: Power In Flight and ISOL for RIB & β Beam

Summary

- **ADS physical, most of technical design and prototype fabrication progress in schedule**
- **Accelerator System (two options in low energy)**
  - 2.45 MHz ECRIS under testing, 14 MHz ECRIS is optimizing
  - 162.5 MHz RFQ, HWR & 325 MHz RFQ, Spoke in low energy injectors are fabricating & Testing
- **Spallation Target (two options)**
  - LBE target designed and constructing
  - New type of granular flow target was designed and is starting demo construction
- **New site, New institute are fixing soon (slower than schedule)**

Welcome to Collaboration !

THANKS FOR ATTENTION