Proton Accelerator Development in China

Shinian Fu

Institute of High Energy Physics, CAS

Beijing, China

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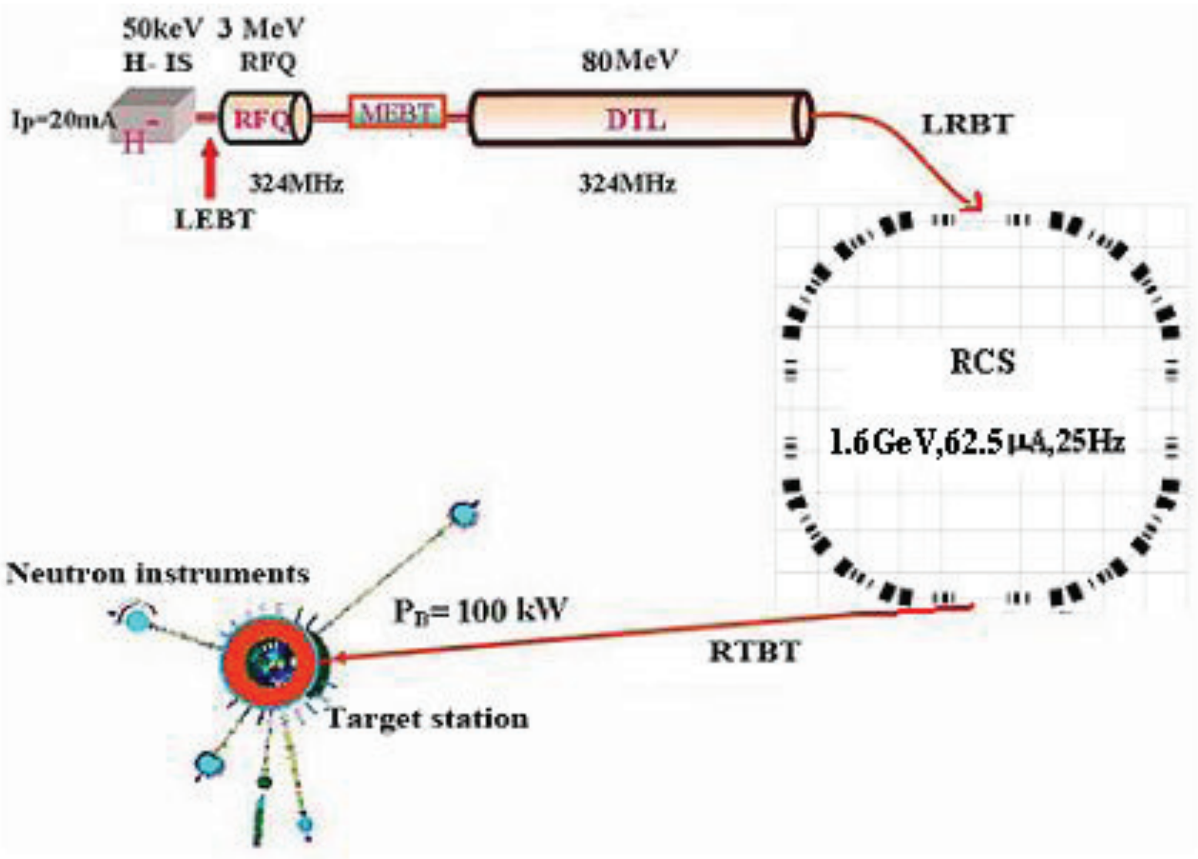
Contents

1, PROTON ACCELERATOR FOR NEUTRON SOURCE---*CSNS*

CSNS Overview

- The phase-I CSNS facility consists of an 80-MeV H^- linac, a 1.6-GeV RCS, 2 beam transport lines, a target station, and 3 instruments.
- Upgradable to 500kW at 25Hz and 20 instruments



	CSNS-I	CSNS-II
Beam power (kW)	100	500
Repetition rate (Hz)	25	25
Target number	1	1
Average current (μA)	62.5	312
Proton energy (GeV)	1.6	1.6
Linac energy (MeV)	80	250

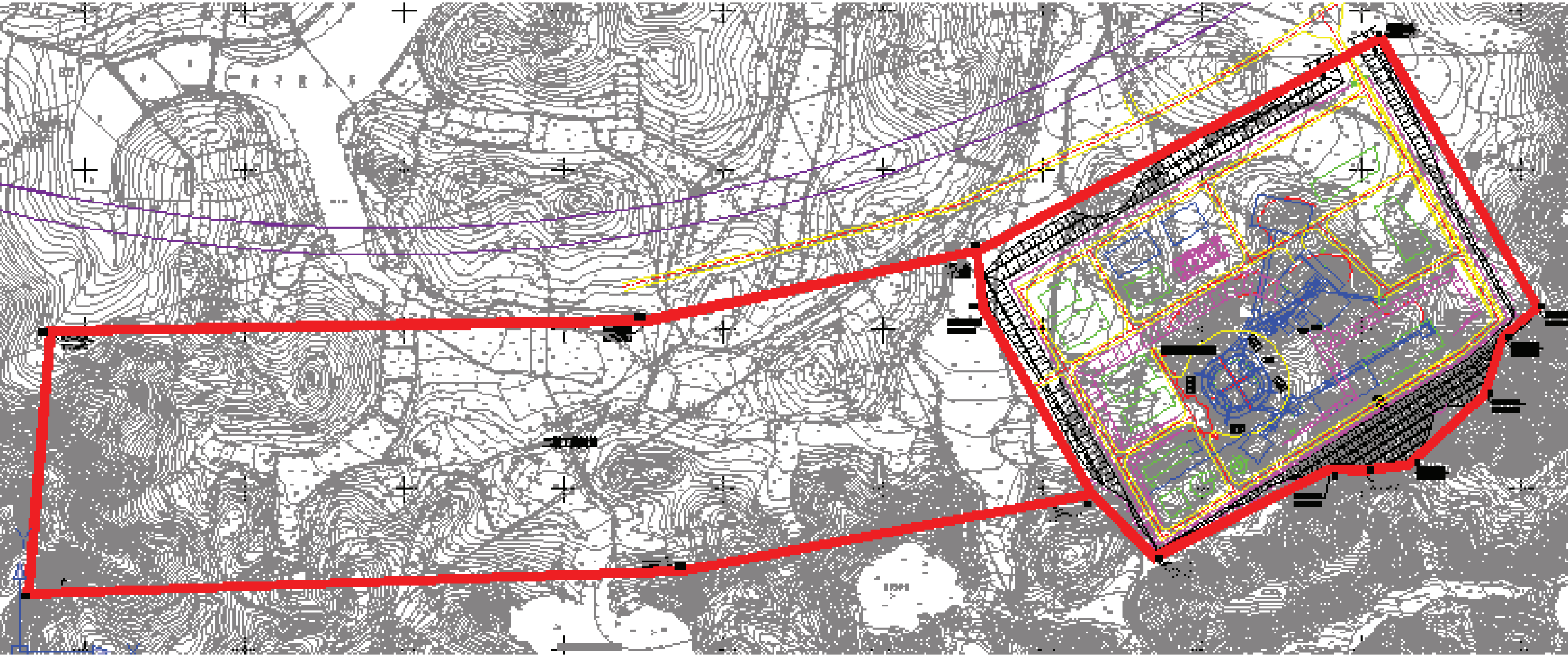
Budget

- Baseline--- the largest big-science project in China
  - 1.7B CNY(~US$250M) from central government for project construction
  - 0.5B CNY and land from Guangdong/Dongguan local government for additional supports
- R&D
  - 35M CNY (received) from CAS for R&D 1
  - 40M CNY (received) from Dongguan government for R&D 2 (included in 0.5B CNY additional supports)
- Operation
  - 0.14B CYN per year from central government

Key Milestones

February 2001	idea of CSNS discussed
June 2005	proposal approved in principle by the central government (CD-0)
January 2006	CAS funded 30M CNY for R&D 1
July 2007	Guangdong funded 40M CNY for R&D 2
December 2007	proposal reviewed
September 2008	proposal approved
October 2009	feasibility study reviewed
April 2010	site preparation start
February 2011	feasibility study approved (CD-1)
May 2011	preliminary design approved (CD-2)
September 2011	construction start (CD-3)
March 2018	Project completion

Site Area



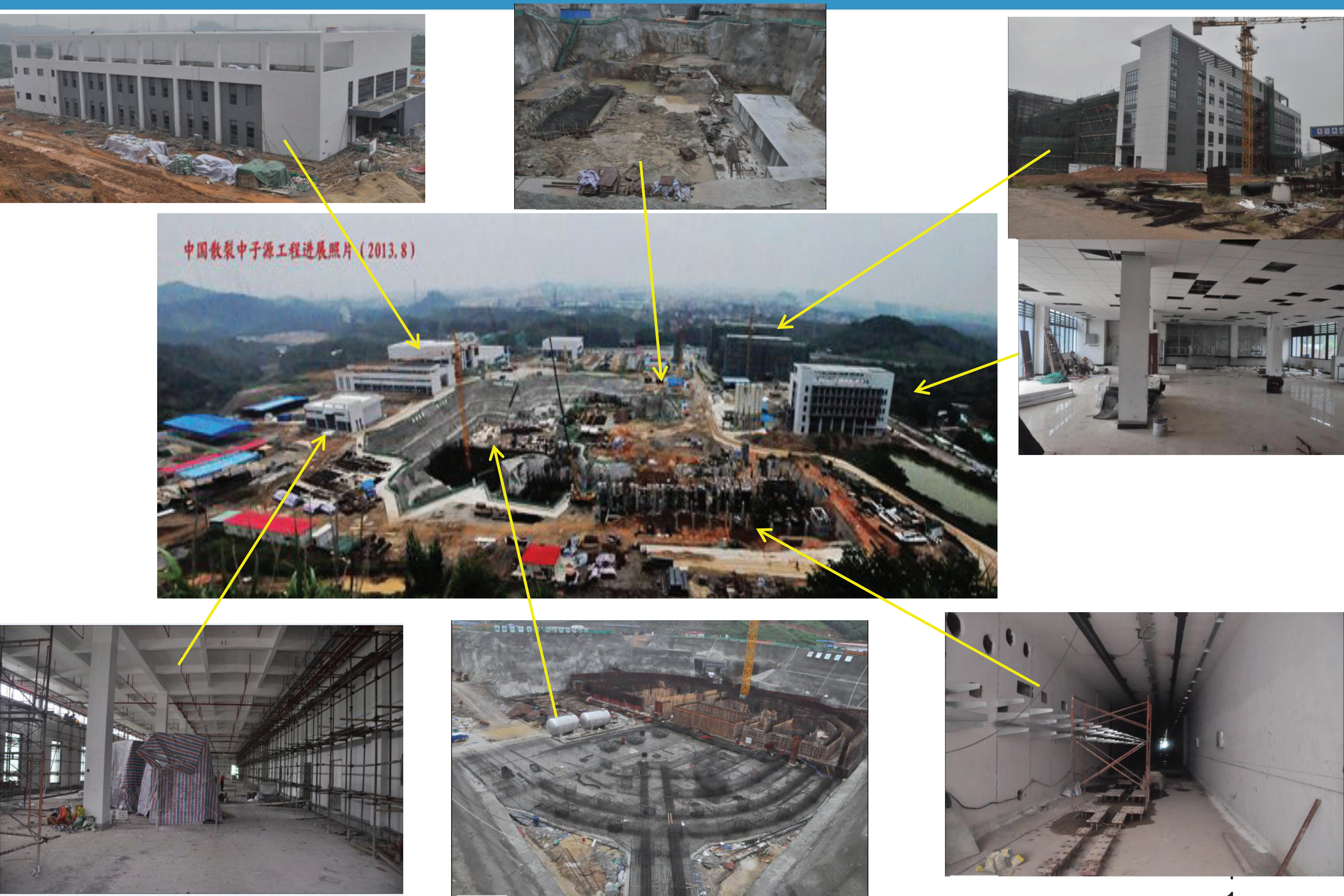
The Guangdong/Dongguan local government committed to provide a land of about 0.667km^2 for IHEP. 0.267km^2 is used for the CSNS construction.

IHEP has set up a new branch at Dongguan for CSNS construction and operation. Civil construction started in 2011.

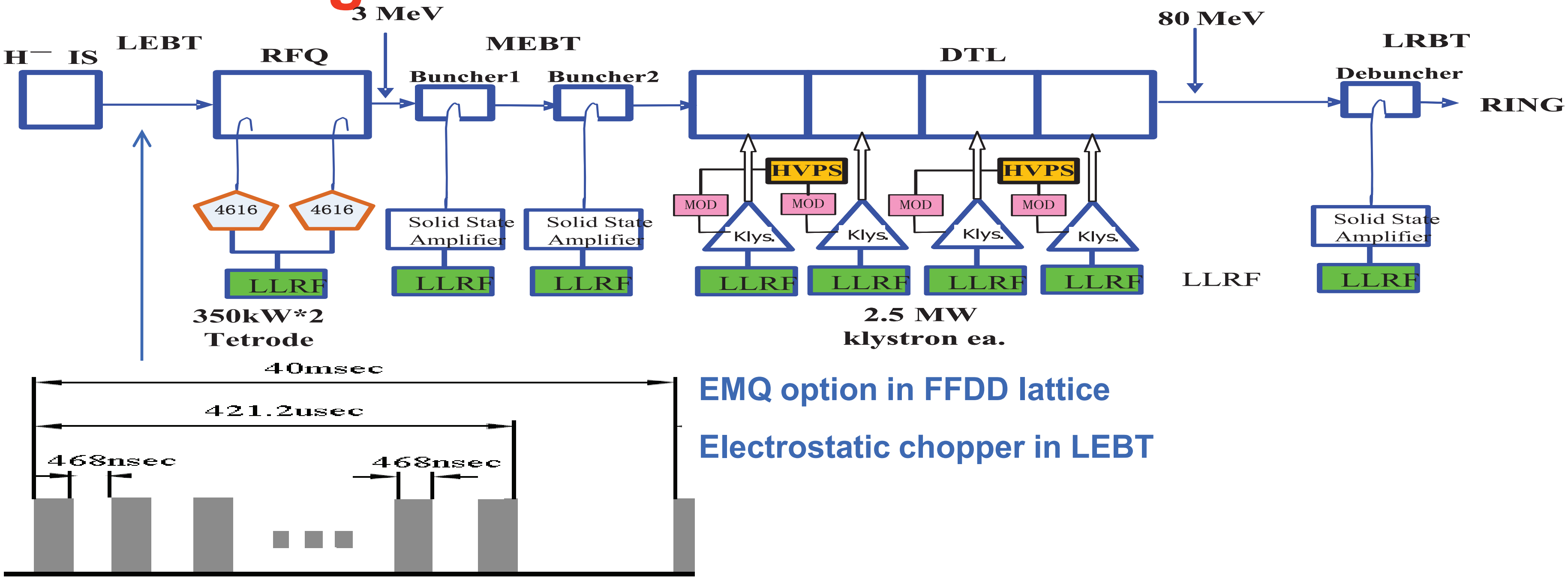
Site Preparation

Sept. 2012

中国散裂中子源



Linac Design

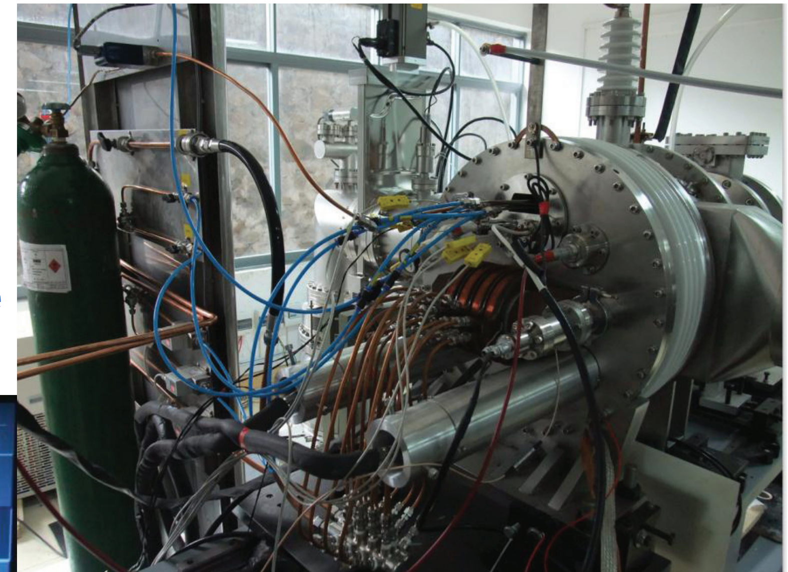


EMQ option in FFDD lattice

Electrostatic chopper in LEBT

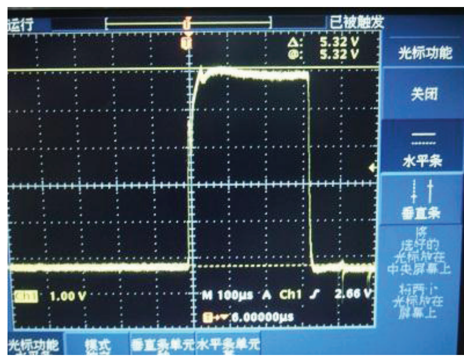
	Ion Source	RFQ	DTL
Input Energy（MeV)		0.05	3.0
Output Energy(MeV)	0.05	3.0	80
Pulse Current (mA)	20/40	20/40	15/30
RF frequency (MHz)		324	324
Chop rate (%)		50	50
Duty factor (%)	1.3	1.05	1.05
Repetition rate (Hz)	25	25	25

Front-end



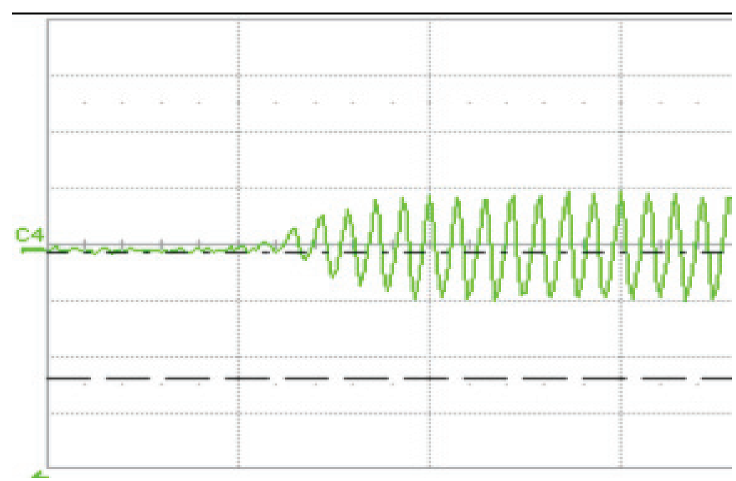
- **H- ion source**

  A Penning source has been set up. It is now under beam extraction test. The first extracted H- beam reached 38 mA.



- **LEBT with a chopper**

  Space charge neutralized LEBT with an electrostatic deflector as a chopper at the entrance of the RFQ. A prototype of the chopper reaches a fast rise time less than 17ns in a proton beam test.



Front-end

- **RFQ**

  A four-vane type RFQ at 324 MHz composed of two coupled resonators. Four modules have been assemblied for field tuning in the new lab at the CSNS site.

- **RF Power**

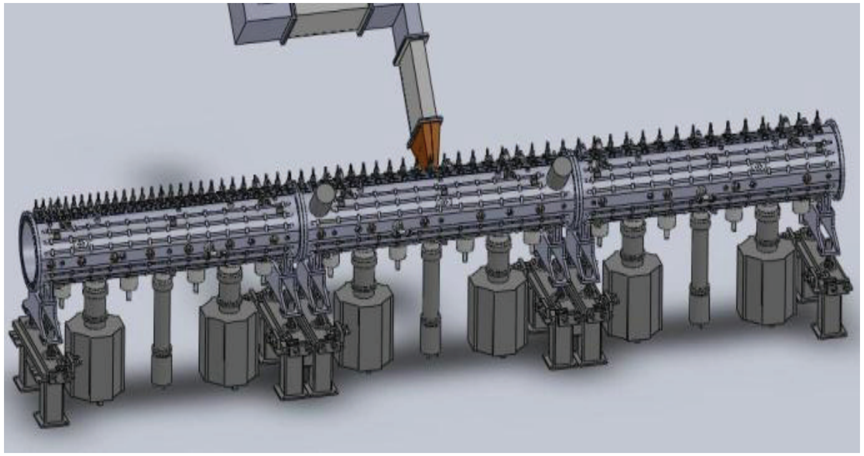
  Two sets of Burle 4616 Tetrode feed 530 kW total RF power to the RFQ. In the power test, one source can reach 400 kW pulse power with pulse length of 700μs at 25 Hz, better than specification.

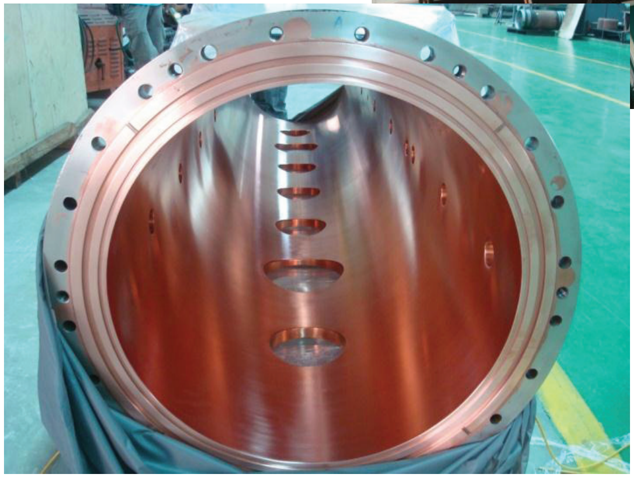
DTL

- **Tank and drift tube**

  The DTL linac is composed of 4 tanks with a total length of 35 m. Each tank is about 9m long and assembled with 3 technical modules. EMQs in FFDD lattice provide focusing in equipartioning design.

- The first tank nearly completed fabrication. Tank is made of a carbon steel tube with copper plated on the inner surface. A feature of the DTL is the use of OFC in all parts of DTs. SAKAE coil is adopted for the quadrupole.



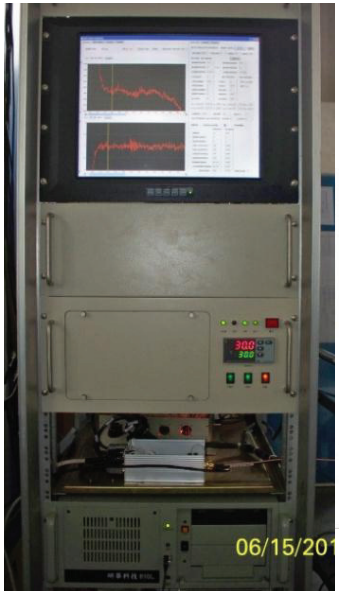


•RF Power

RF power source for DTL is 324 MHz klystron from CPI, with maximum output power of 3 MW. Two sets of 400 Hz AC series resonance high voltage power supply is under manufacture.

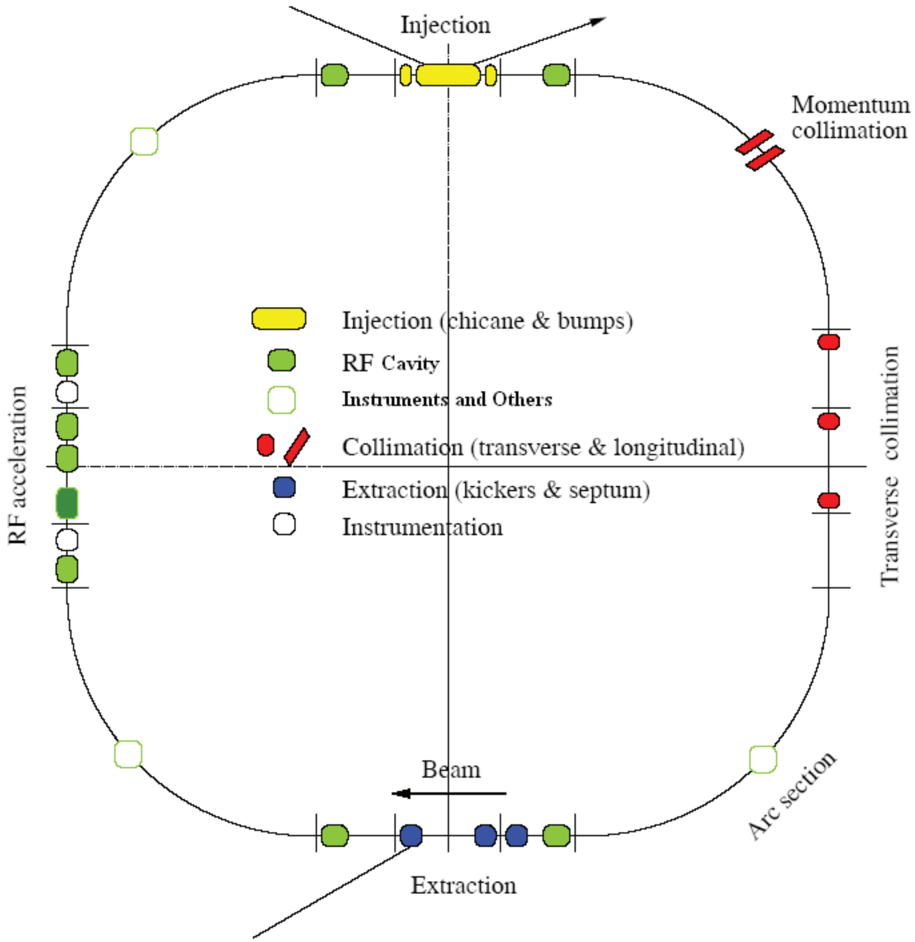
•LLRF

A full digitalized LLRF system was tested with amplitude and phase variations in the cavity less than ±0.25% and ±0.35° with beam loading, much better than the requirements of ±1% in amplitude and ±1° in phase.



RCS Design

- Lattice of 4-fold symmetry, triplet.
- 227.92m circumference.
- Four long straight sections for injection, acceleration, collimation and extraction.
- 24 main dipoles with one power supply.
- 48 main quadrupoles with 5 power supplies.
- Ceramic vacuum chambers for the AC&pulsed magnets.
- 8 RF ferrite loaded cavities to provide 165 kV.



- **RCS Main Dipole**

  Two prototypes were fabricated to address the issue of laminate crack. Based the successful experience we started the mass production at IHEP workshop.

- **RCS Main Quadrupole**

  Overcome crack trouble of the coil epoxy resin. Contracted with IHEP workshop and the first one has been manufactured. 72 hours test run has been conducted without any crack.

  Field measurement show a satisfactory results.

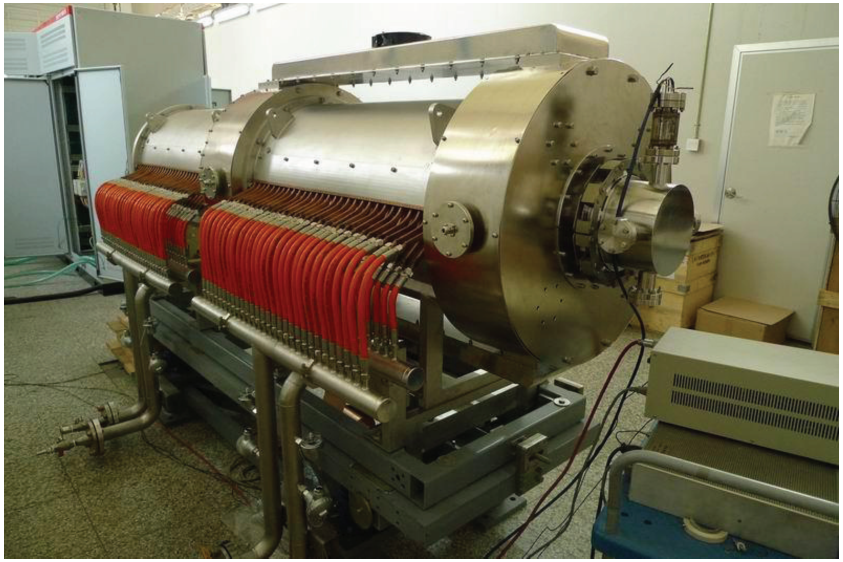
Power supply

White resonant circuit is chosen as the power supply to provide AC+DC current to the main magnets. Power source and choke are now under mass production. To compensate for the field deformation due to the magnet core nonlinearity, harmonic injection technology is successfully introduced into the power supplies in the test of the prototype.

Ring RF

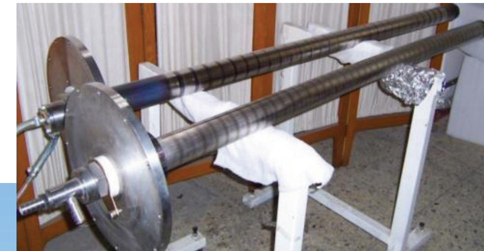
Ferrite loaded cavity's resonant frequency shifts from 1.02 MHz to 2.44 MHz in 20 ms by a bias current supply. Cavity and its RF source design is improved, under mass production.

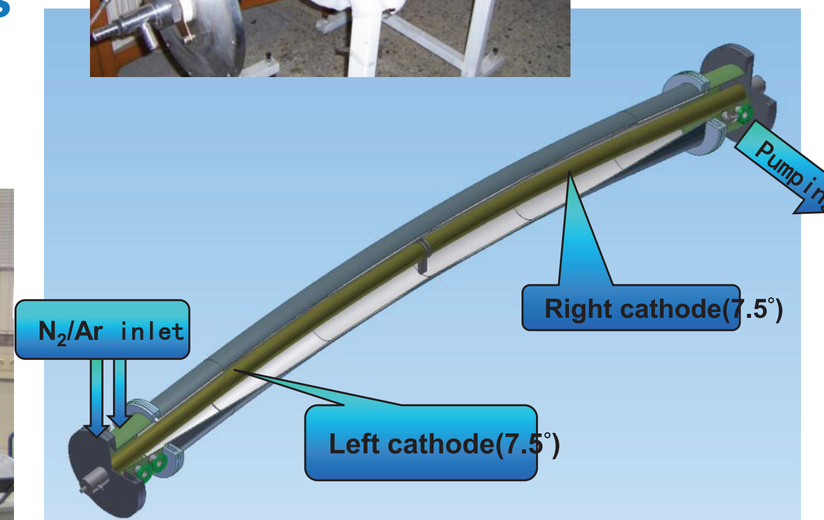
8 sets of 500 kW transmitter have been in mass production.



Ceramic Chamber

Mass production of the ceramic chambers for RCS main Q and D magnets has started. First full-length D chamber has been produced at FRIATECH.

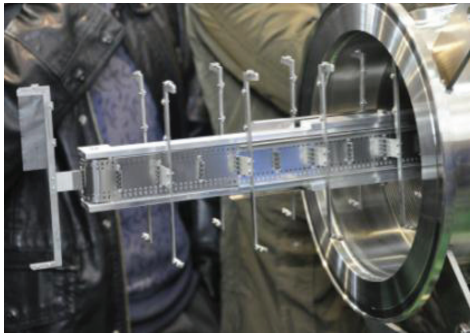


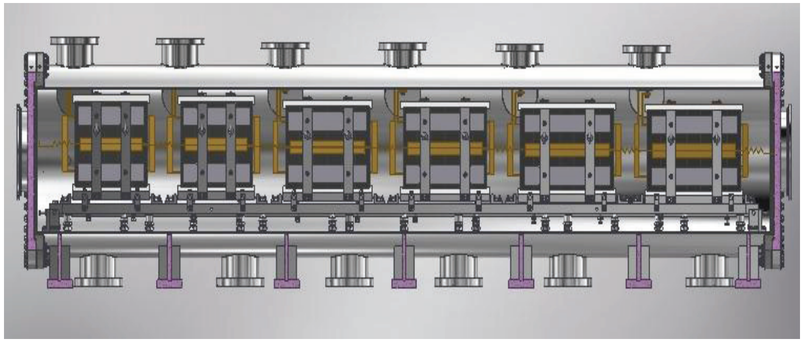


A curved magnetron sputtering facility for TiN coating has be set up at IHEP and glow discharge has been got in the first test for the prototype dipole ceramic chamber.

- **RCS Injection & Extraction**

  The stripping foil facility has been manufactured with 20 carbon foils on a rotating frame. One of the two injection pulsed bump power supplies of 9,000A made in R&D phase can be directly used.



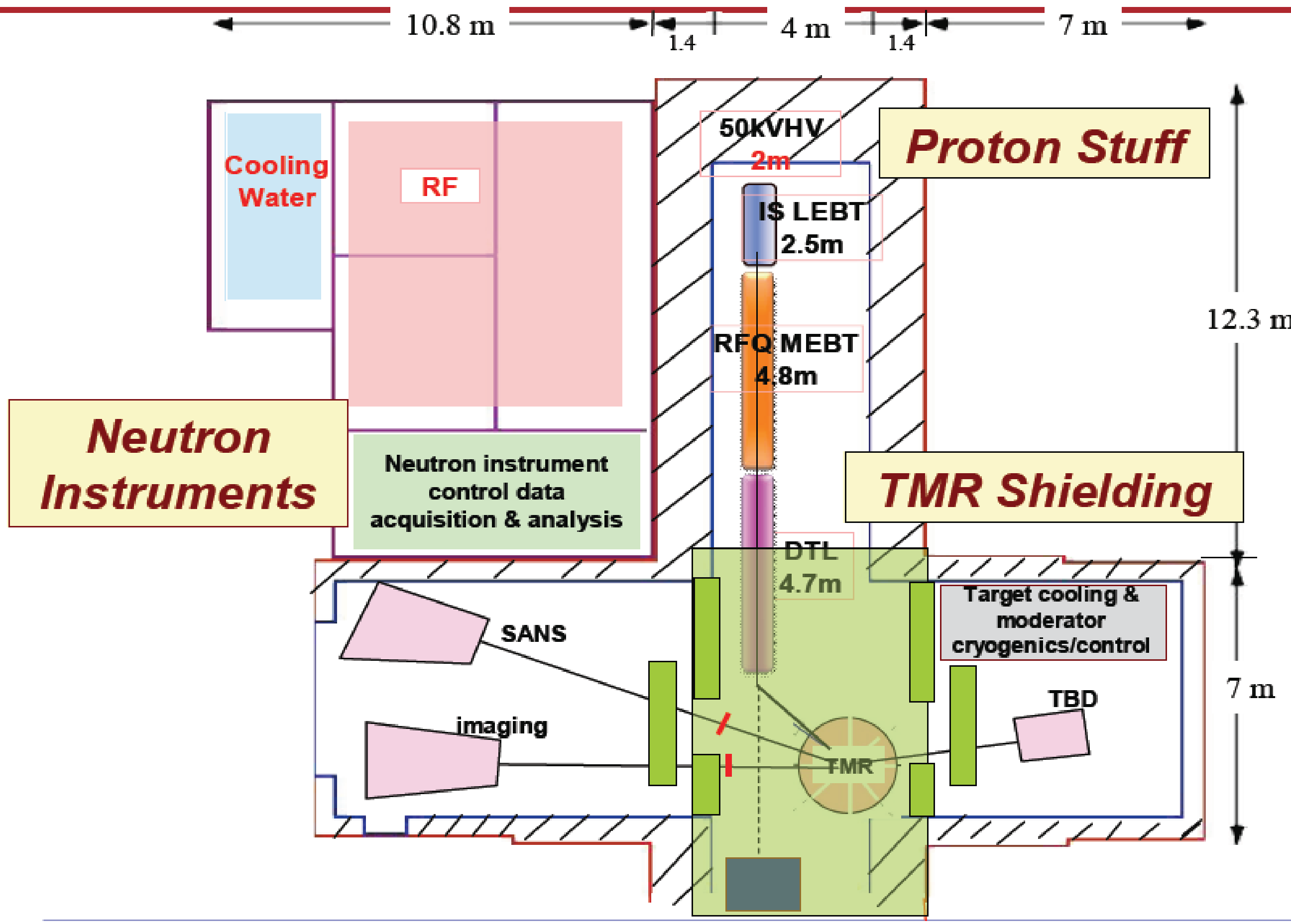



- **8 kicker magnets have been put into mass production and the first one was accepted in Sept. 2013. Their power supplies are now under fabrication and the first one is scheduled in this month.**

1, PROTON ACCELERATOR FOR NEUTRON SOURCE---*CPHS*

In Tsinghua University

Conceptual Layout of the CPHS

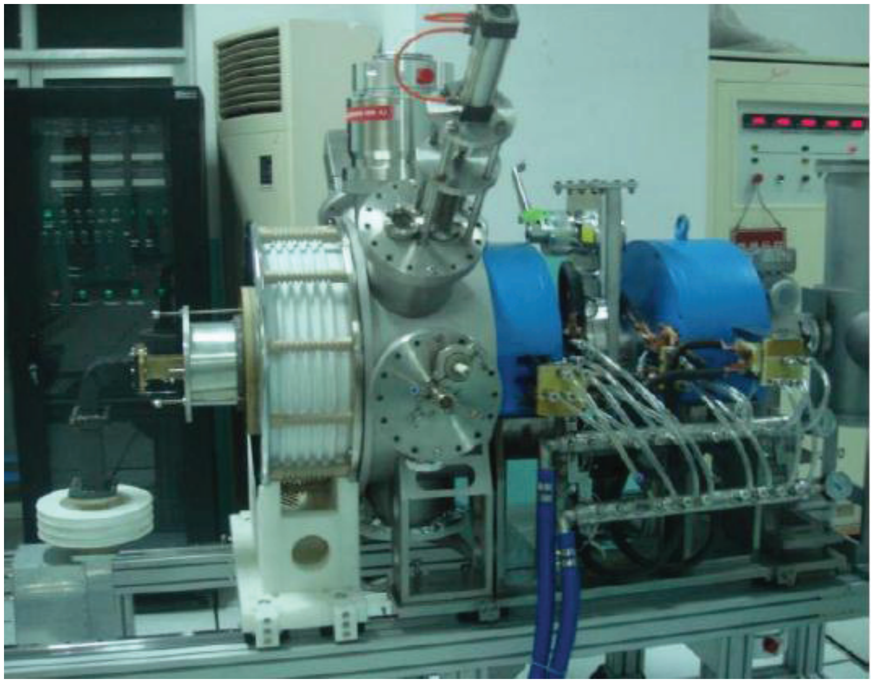


Major parameters of CPHS

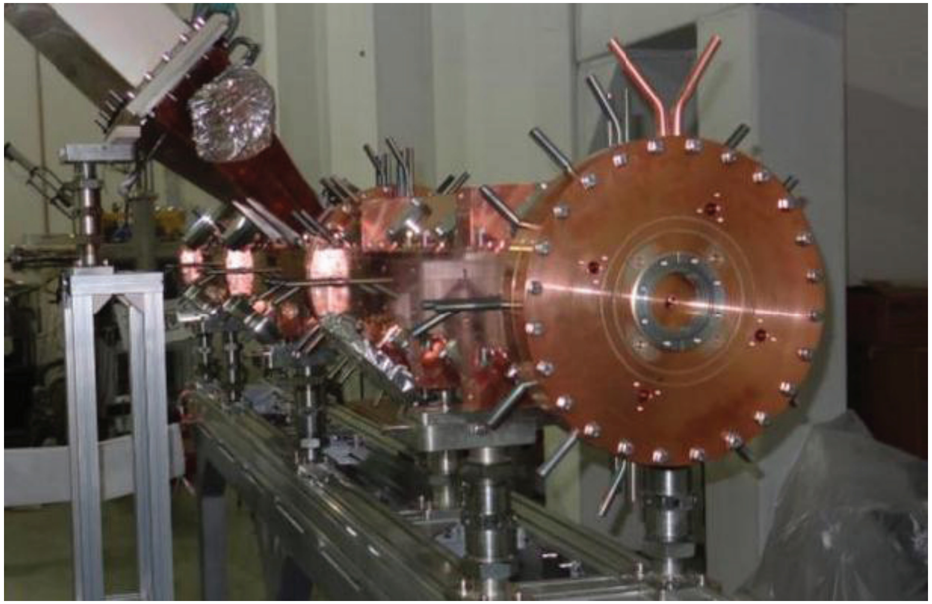
Proton Beam power (kW)	16
Proton Energy (MeV)	13
Average beam current (mA)	1.25
Peak beam current (mA)	50
Pulse repetition rate (Hz)	50
Pulse length (ms)	0.5
Target material	Be
Moderator	H_2O (300k) CH_4 (20k)

Courtesy from Jie Wei

Ion source and RFQ



A 60mA/50 keV ECR ion source has been set up.

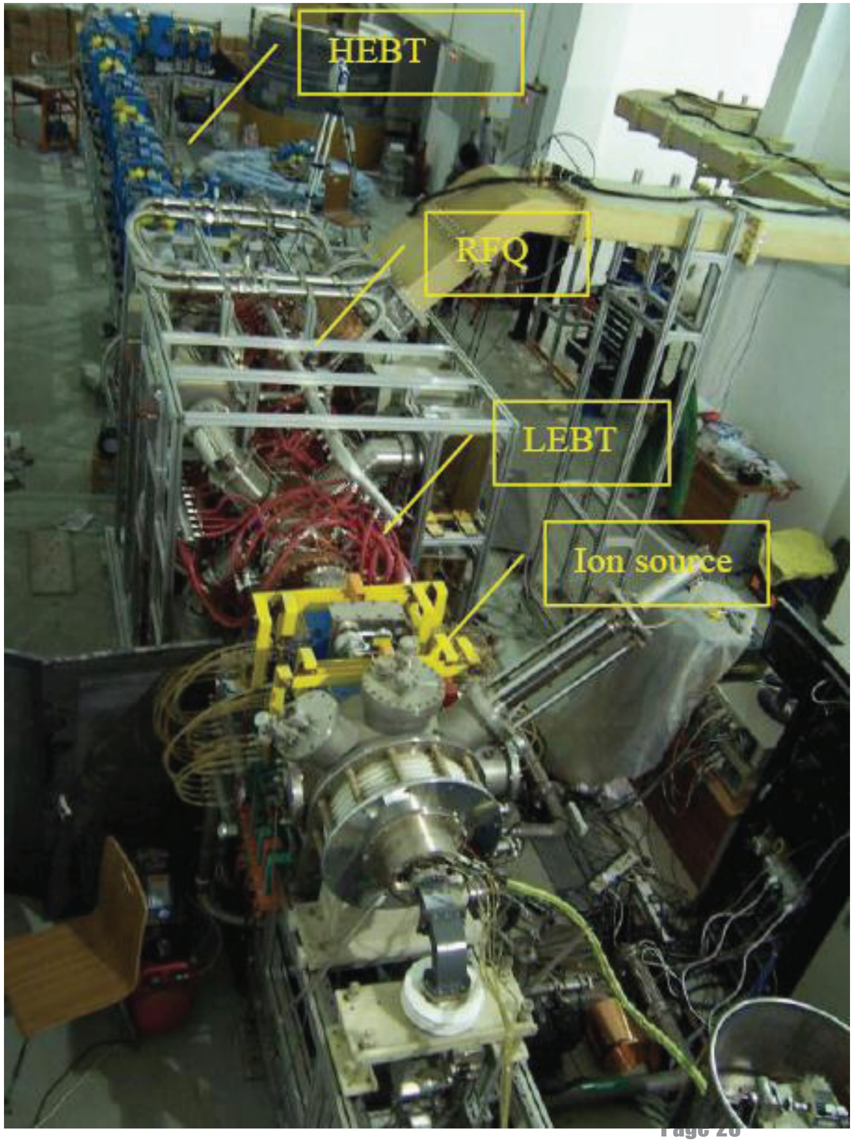


3 MeV/325 MHz RFQ of four vane structure. In the first run, it output 44 mA peak current with pulse length of 50us, at 50Hz.

DTL and HEBT

Extraction energy (MeV)	13
Peak current (mA)	50
RF frequency (MHz)	325
RF peak power (MW)	1.2
Emittance norm. rms (um)	0.2
Average current(mA)	1.25
RF duty factor(%)	3
Synchronous phase (degree)	-30 to -24
Accelerating field (MV/m)	2.2 to 3.8
Focusing magnet type	PMQ
Quad gradient (kG/cm)	8.46
Cell number	40
Length(m)	4.4

DTL is under development at present



PROTON ACCELERATOR FOR ADS --- CADS

Nuclear Power Development in China

year	Nuclear capacity（GW）	Total capacity（GW）	Nuclear ratio	Electricity ratio of nuclear
2015	40（+18）	—	—	—
2020	58（+30）	1500	4%	6%
2030	200	2000	10%	15%
2050	400	2500	16%	22%

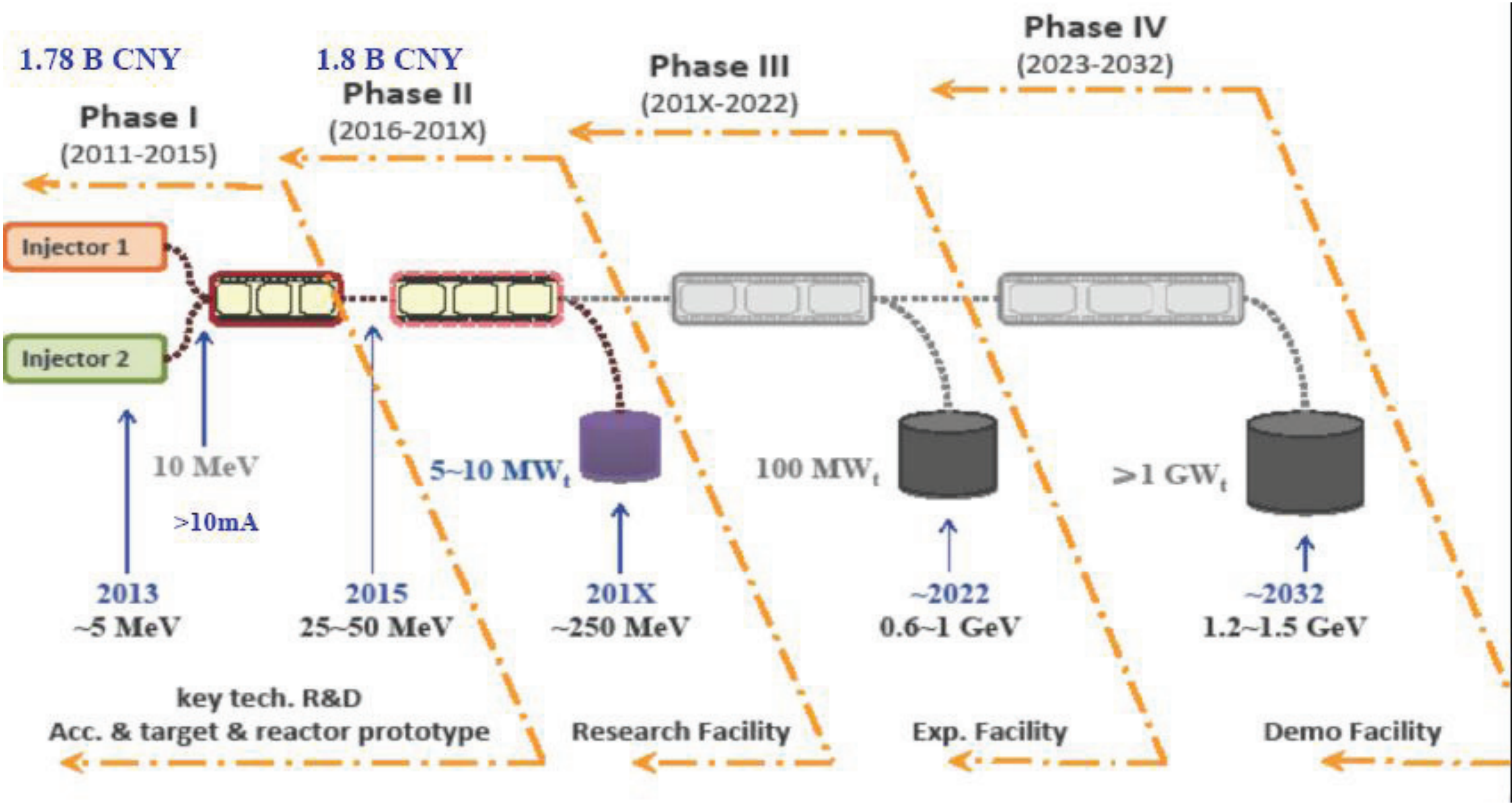
Site selection

Shandong province?

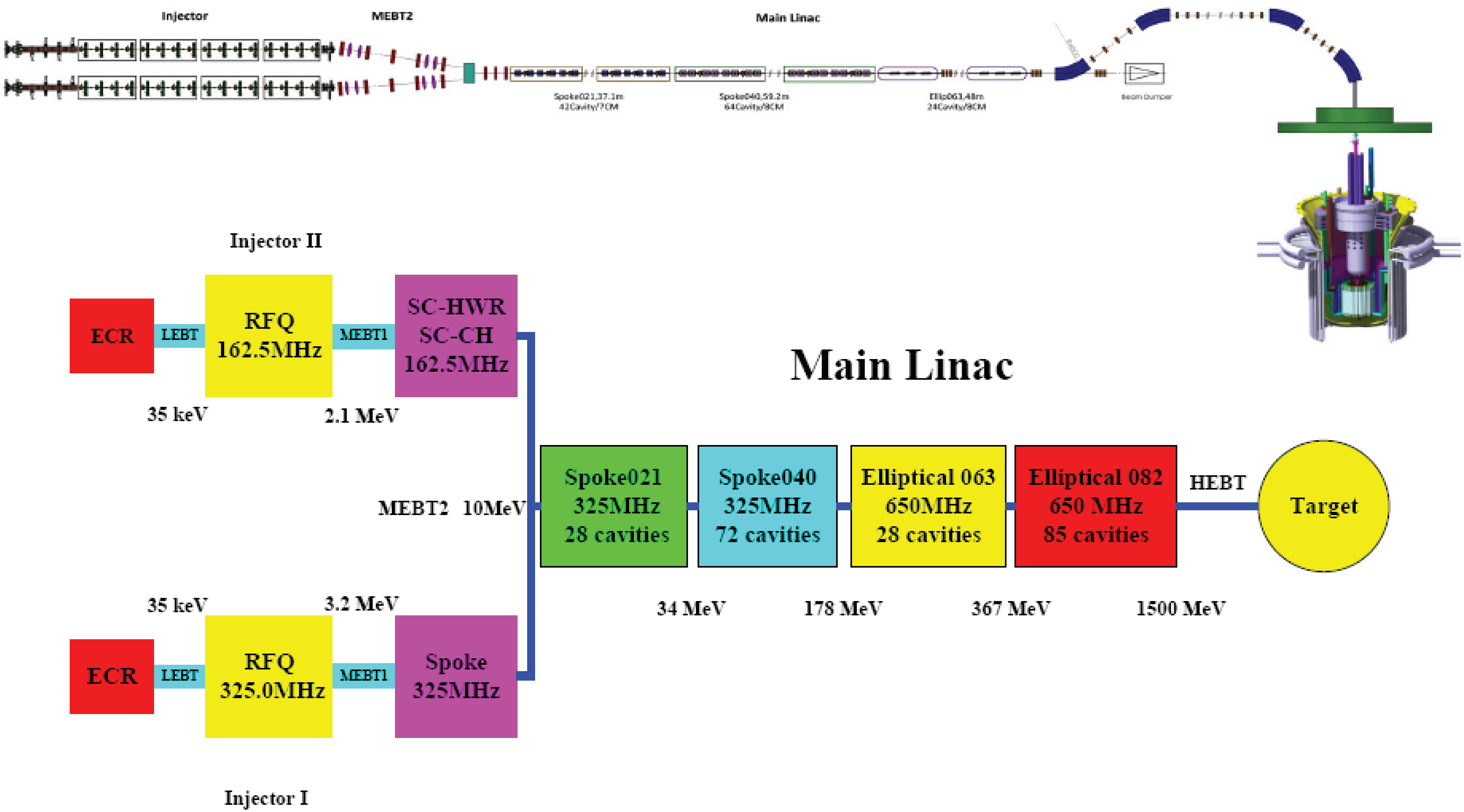
Haiyang NPP (largest NPP)

- Ap1000×(I: 6 + II:2)

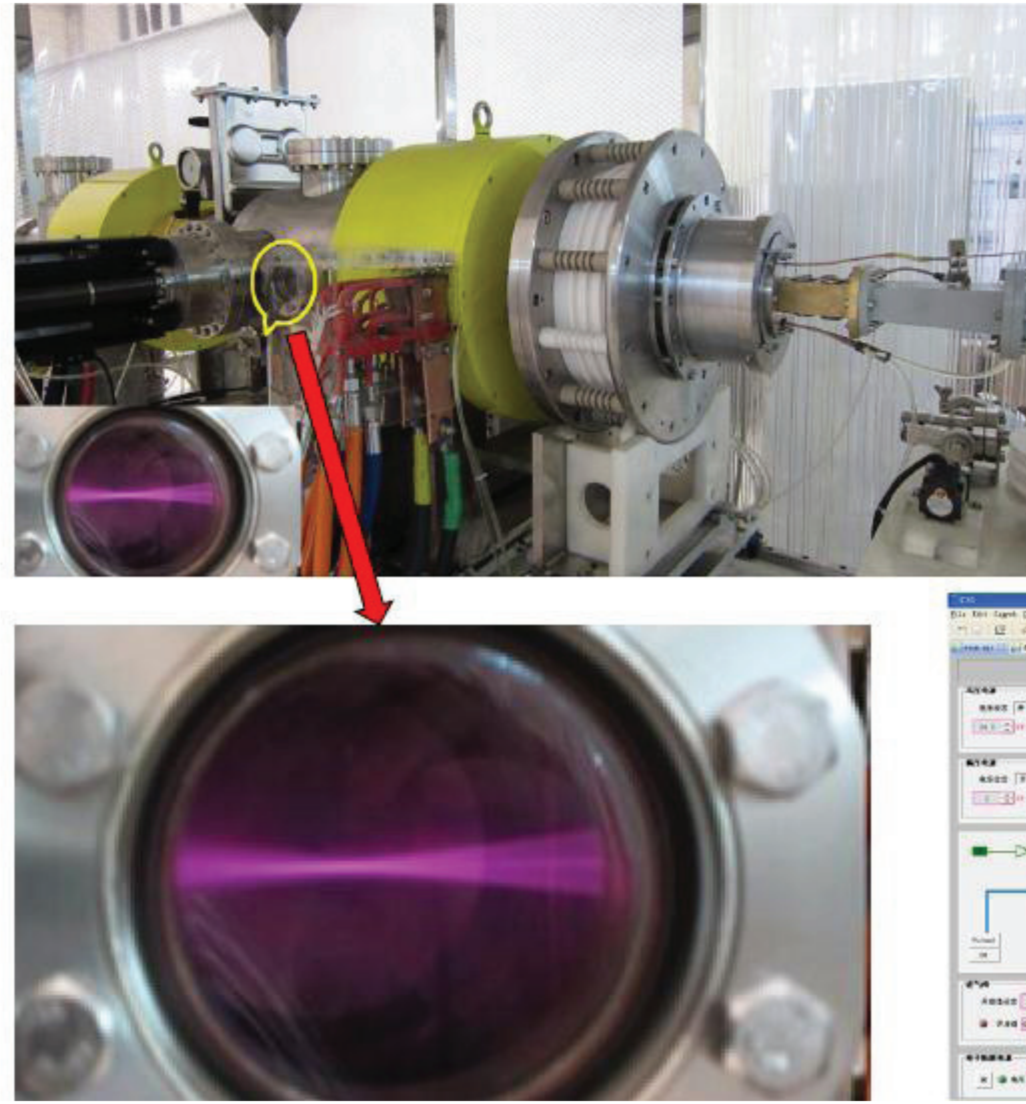
ADS Roadmap in China



CADS Layout


Injector
MEBT2
Main Linac
Injector II
ECR
LEBT
RFQ 162.5MHz
MEBT1
SC-HWR SC-CH 162.5MHz
35 keV
2.1 MeV
Main Linac
MEBT2 10MeV
Spoke021 325MHz 28 cavities
Spoke040 325MHz 72 cavities
Elliptical 063 650MHz 28 cavities
Elliptical 082 650 MHz 85 cavities
HEBT
Target
34 MeV
178 MeV
367 MeV
1500 MeV
35 keV
3.2 MeV
ECR
LEBT
RFQ 325.0MHz
MEBT1
Spoke 325MHz
Injector I

ECR ion source and LEBT



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.

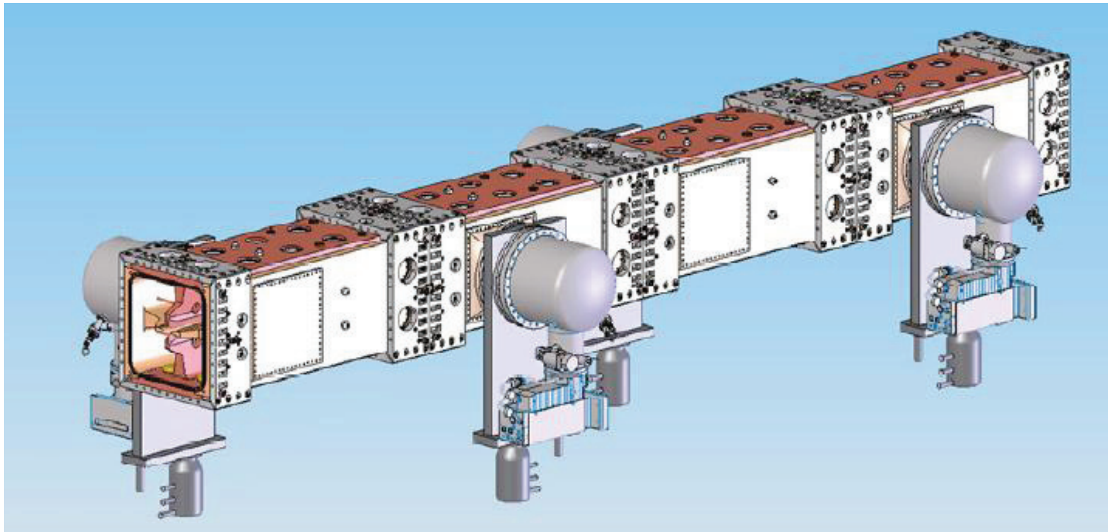
325MHz RFQ for injector-I

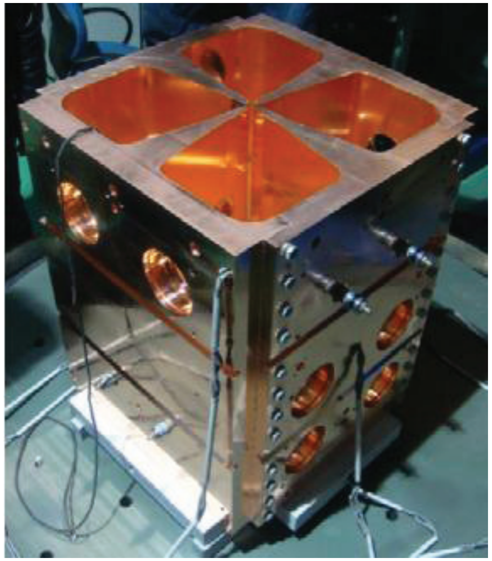
Parameters	Value
Frequency (MHz)	325
Injection energy (keV)	35
Output energy (MeV)	3.2128
Pulsed beam current (mA)	15
Beam duty factor	100%
Inter-vane voltage *V* (kV)	55
Beam transmission	98.7%
Average bore radius r_0 (mm)	2.775
Vane tip curvature (mm)	2.775
Maximum surface field (MV/m)	28.88 (1.62Kilp.)
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

Four vane RFQ has been fabricated and the field tuning has been completed. Now under installation in the tunnel.

162.5MHz RFQ for injector-II (collaborated with LBNL&Fermilab)

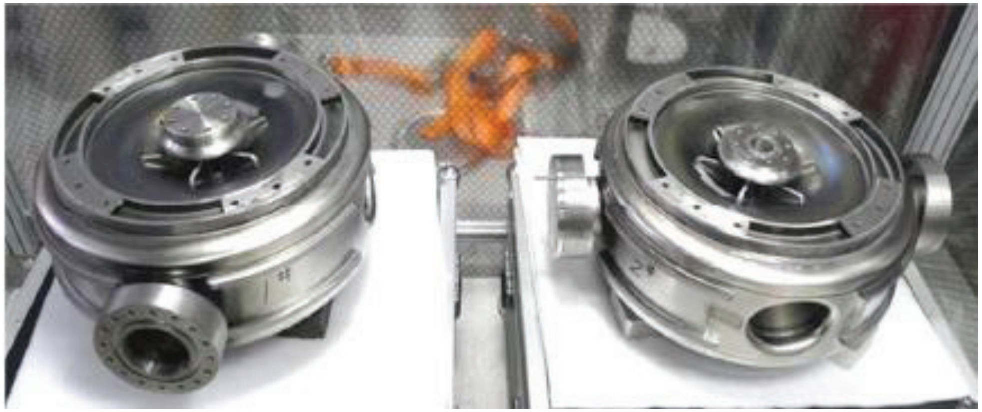
Parameter	Value
Ion species	Proton
frequency [MHz]	162.5
Inter-vane voltage V (kV)	65
Average bore radius r_0 (cm)	0.5731
Vane tip curvature (cm)	0.4298
ρ / r_0	0.75
Vane length / Total length (cm)	419.2 / 420.8
m_{max}	2.38
Number of cells	192 (including 2 T cell)
Maximum surface field (MV/m)	15.7791
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%

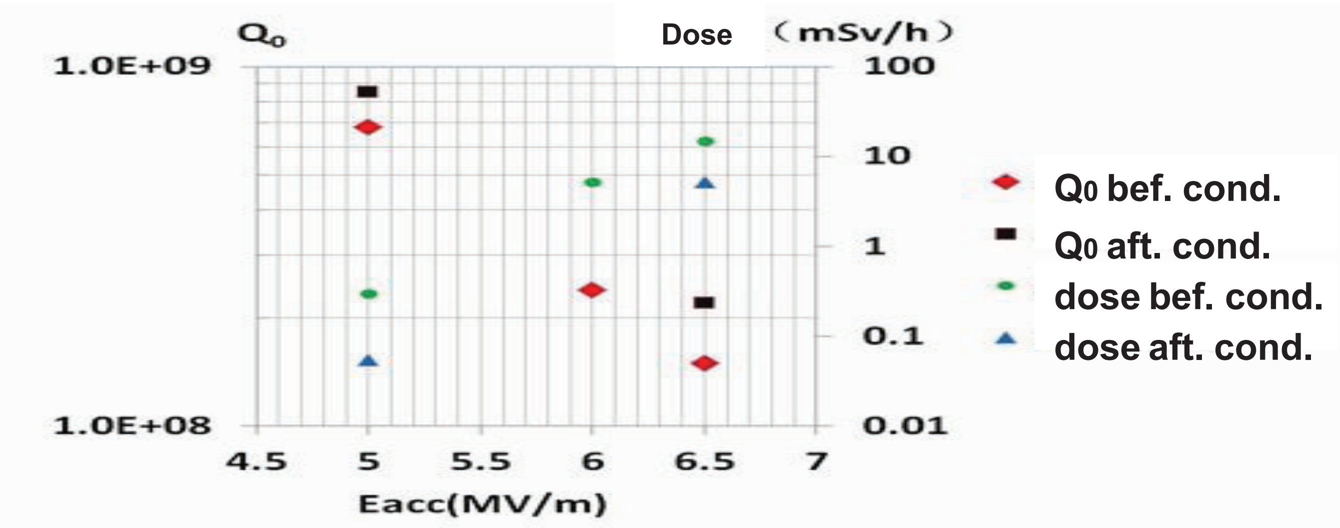




Spoke 012 for Injector I

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



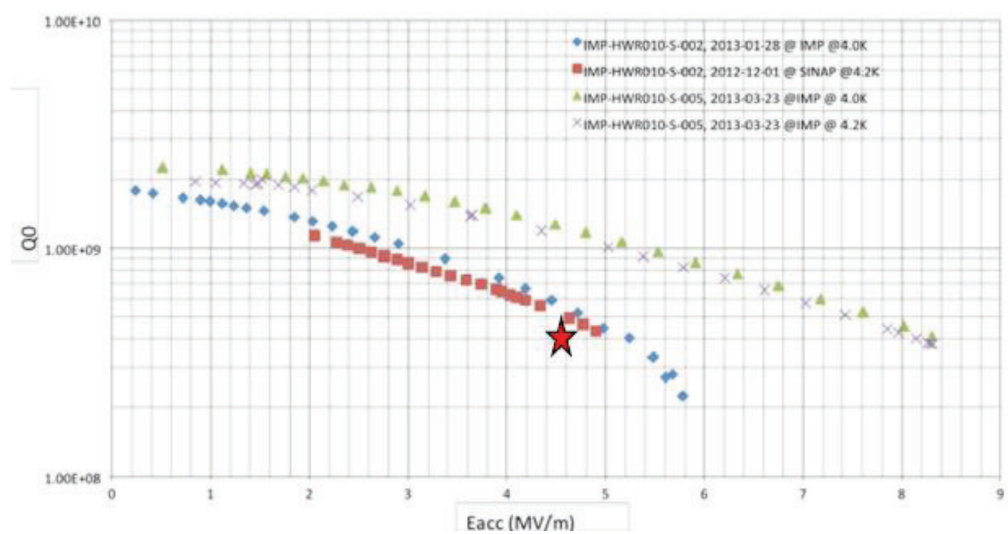


Horizontal test has been conducted in last week.

HWR 010 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

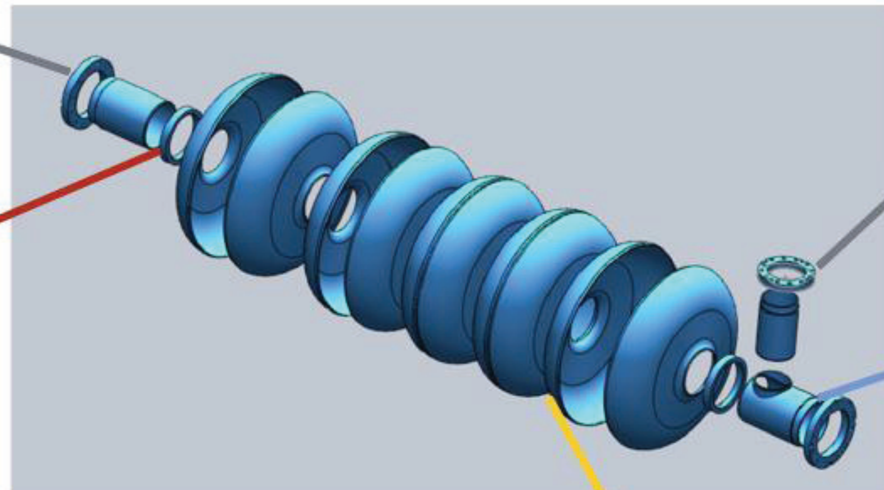
IMP-HWR010-S-002 and 005 Q0 vs. Eacc VTA Results



Spoke 021 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

Elliptic 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

Power coupler and cryostat development

325MHz, Spoke
CW, 10kW
Tested

325 MHz, RFQ
CW, 100 kW
Tested

162.5MHz, HWR
CW, 20kW
Tested

A cryostat at 4K for horizontal test of spoke cavity has been set up.

Solid state RF power source

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.

PROTON ACCELERATOR FOR THERAPY---APTRON

SNS CHINESE ACADEMY OF SCIENCES 中国散裂中子源

APTron --- Advance Proton Therapy facility in Shanghai by SINAP

Phase I

Gantry room1

capable of transporting protrons 70~250MeV

Fixed room2

horizontal for eye, head and neck tumor

Fixed room1

horizontal for experimental activities

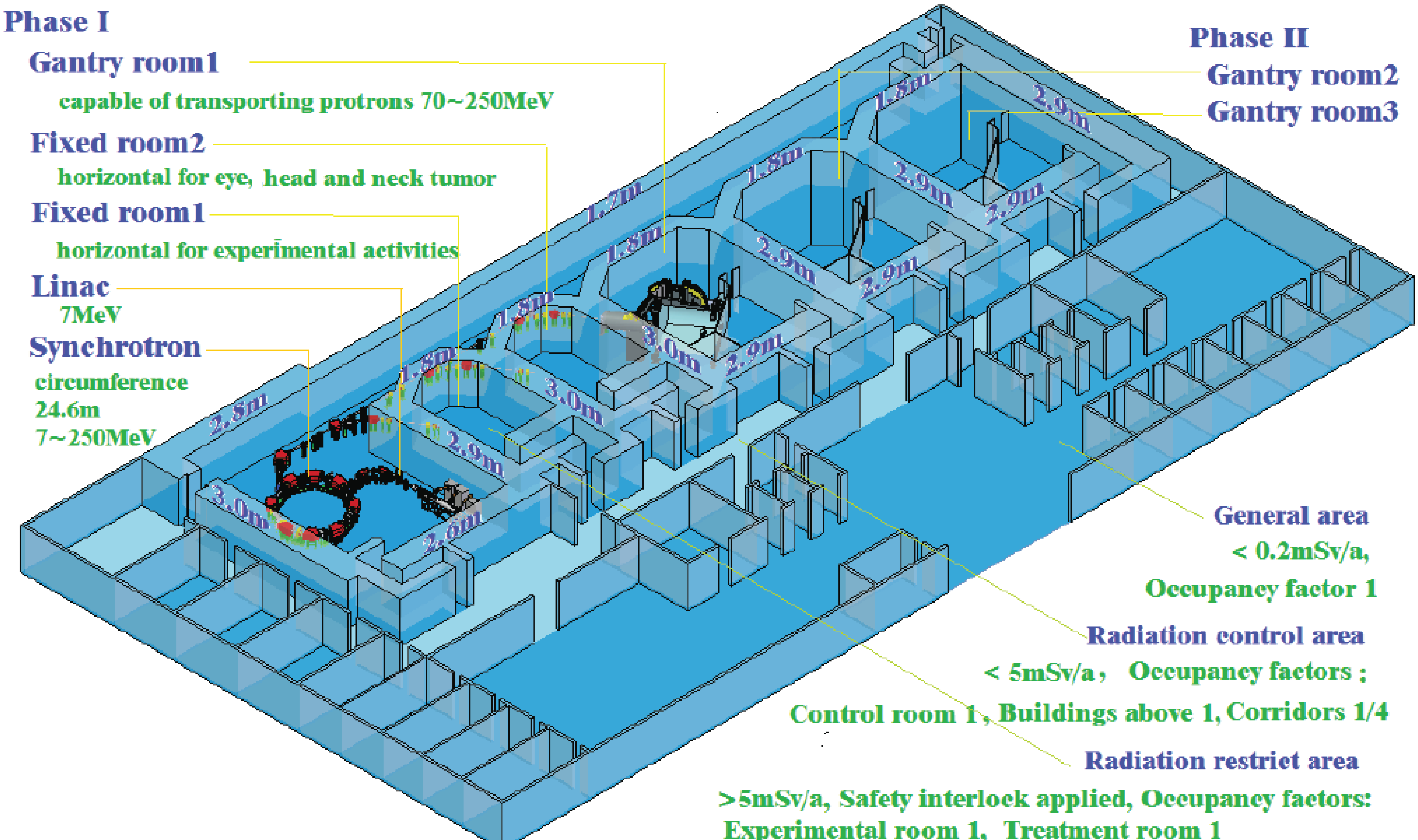
Linac

7MeV

Synchrotron

circumference 24.6m

7~250MeV



Phase II

Gantry room2

Gantry room3

General area

< 0.2mSv/a,

Occupancy factor 1

Radiation control area

< 5mSv/a， Occupancy factors :

Control room 1, Buildings above 1, Corridors 1/4

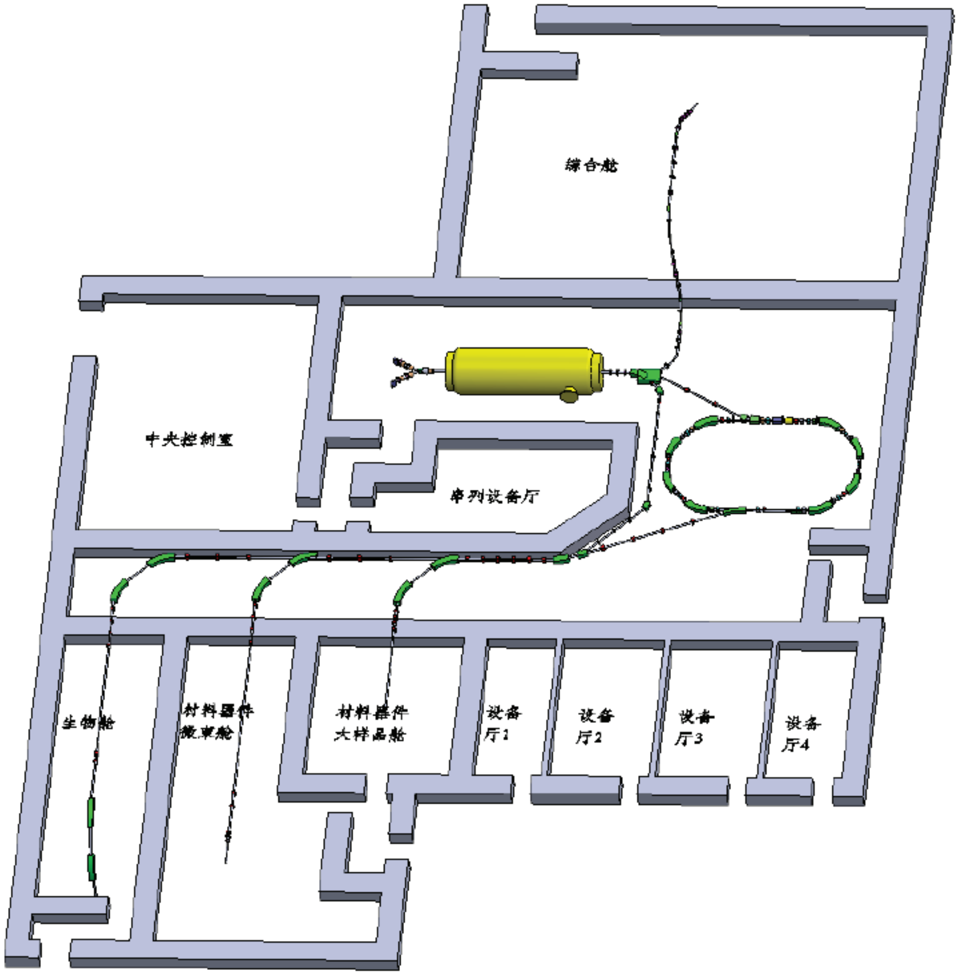
Radiation restrict area

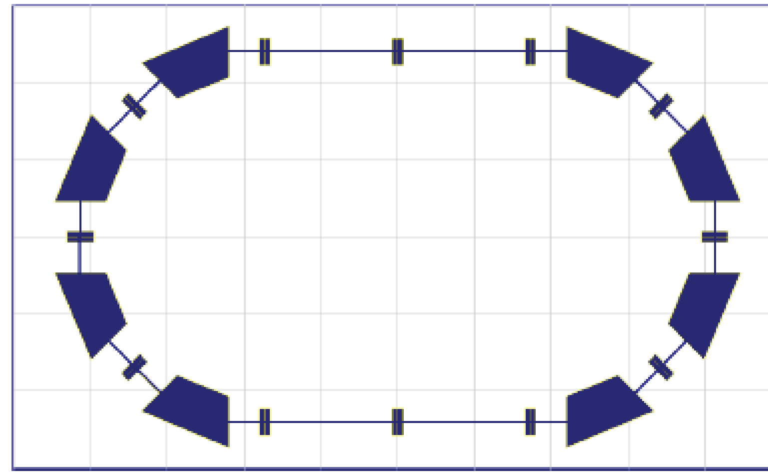
>5mSv/a, Safety interlock applied, Occupancy factors:

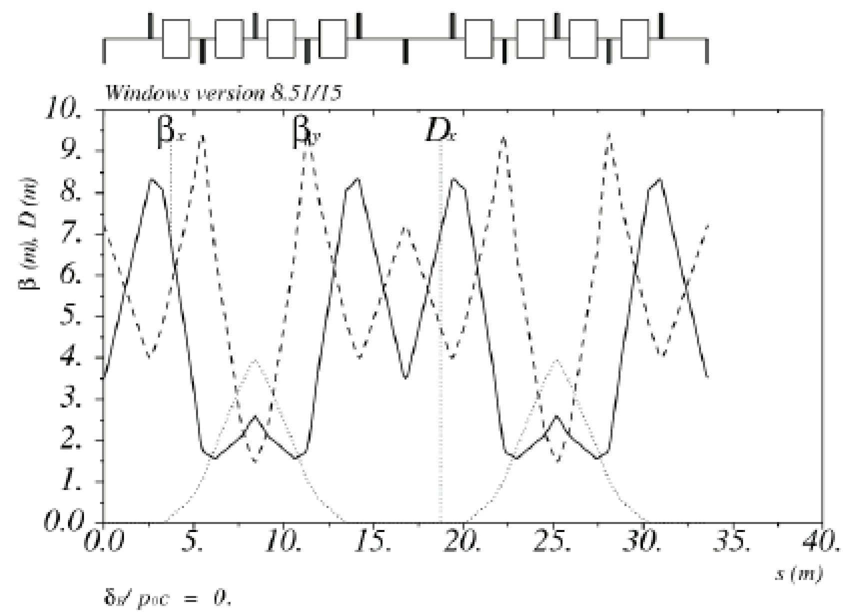
Experimental room 1, Treatment room 1

PROTON ACCELERATOR FOR SPACE RADIATION EFFECTS

The project has been approved in principle by Chinese government







SUMMARY

1, Proton accelerator becomes a new direction in Chinese accelerator community.

2, CSNS project started construction in 2011 and will be completed in 2018.

3, C-ADS roadmap (2010-2032) has been updated and some key technologies of CW proton linac are under development.

4, Other proton accelerators are under construction or planed for various application: small neutron source, proton therapy and space radiation effect research.

5, All these activities are supported by the fruitful collaboration with worldwide accelerator community.

Acknowledgements

Hesheng Chen, Yunlong Chi, Shouxian Fang, Li Ma, Weimin Pan, Jingyu Tang, Sheng Wang, Yuan He, Hongwei Zhao, Xialing Guan, Deming Li and teams from IHEP, IMP Tsinghua U and SHIAP.

Friends from J-PARC, SNS, Fermilab, MSU, LBL, LNL-INFN, Jlab

Thank you very much for your attention