Chinese ADS Project and Proton Accelerator Development

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Outline

1. Introduction
2. ADS road map and accelerator progress in China
3. CSNS progress
4. CPHS in Tsinghua University
5. Conclusion

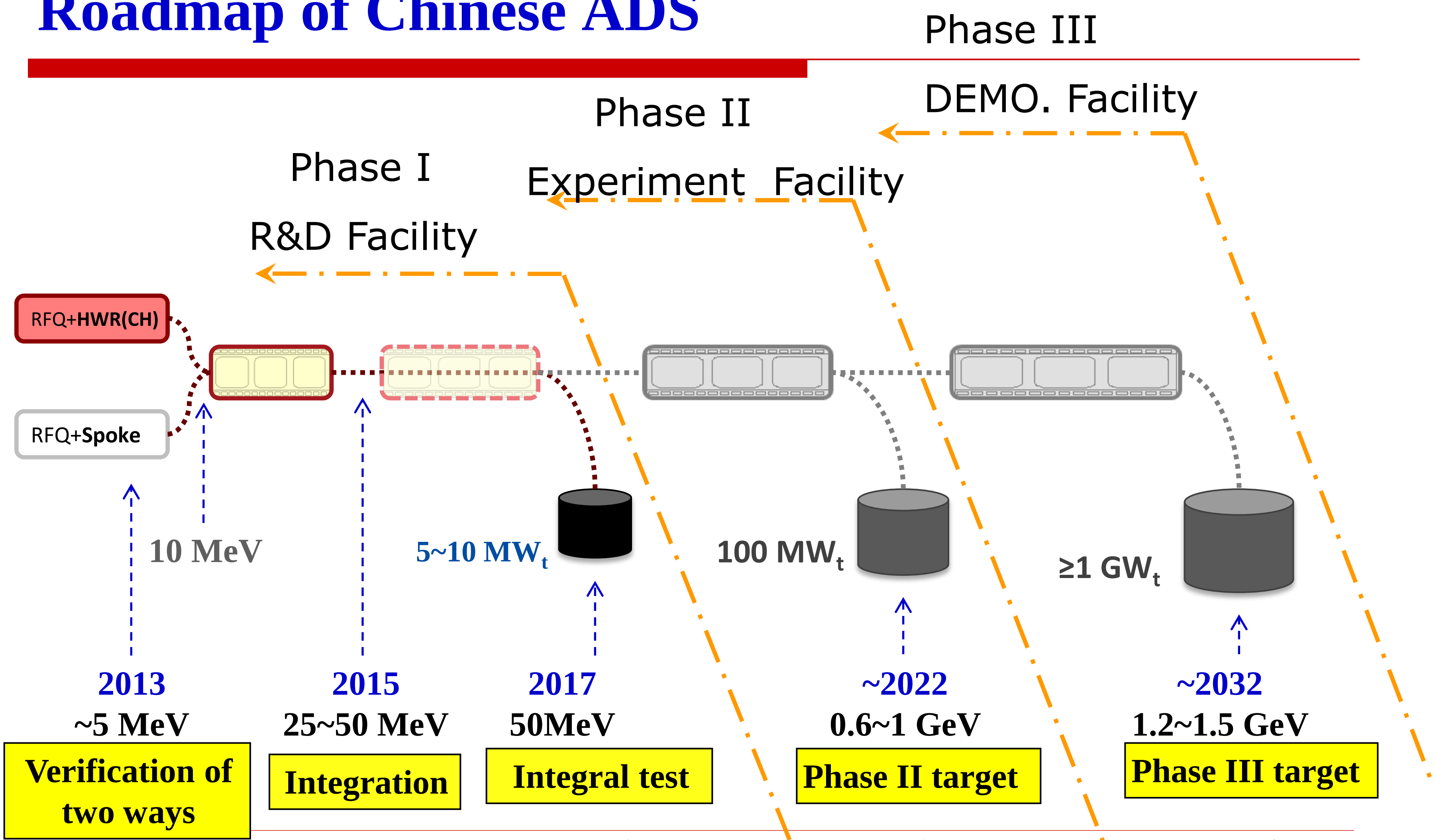
1. Introduction

- Proton accelerator are more and more used in the nuclear energy, material sciense, biology, medicine, etc. ,
- Development of proton accelerator is getting into a high speed in China,
- Key technology studies are common : Ion Source, RFQ, Low-β SC cavities, High power coupler, SSA RF source, Cryogenics, Control & Instrumentation…
- This presentation introduce the proton accelerators in China (ADS, CSNS, CPHS) .

2. ADS Road Map

and Accelerator Progress in China

Roadmap of Chinese ADS



ADS R&D Phase I Budget

R&D Phase I（50MeV）budget has been approved；

R&D Budget： 1.8 Billion CNY；

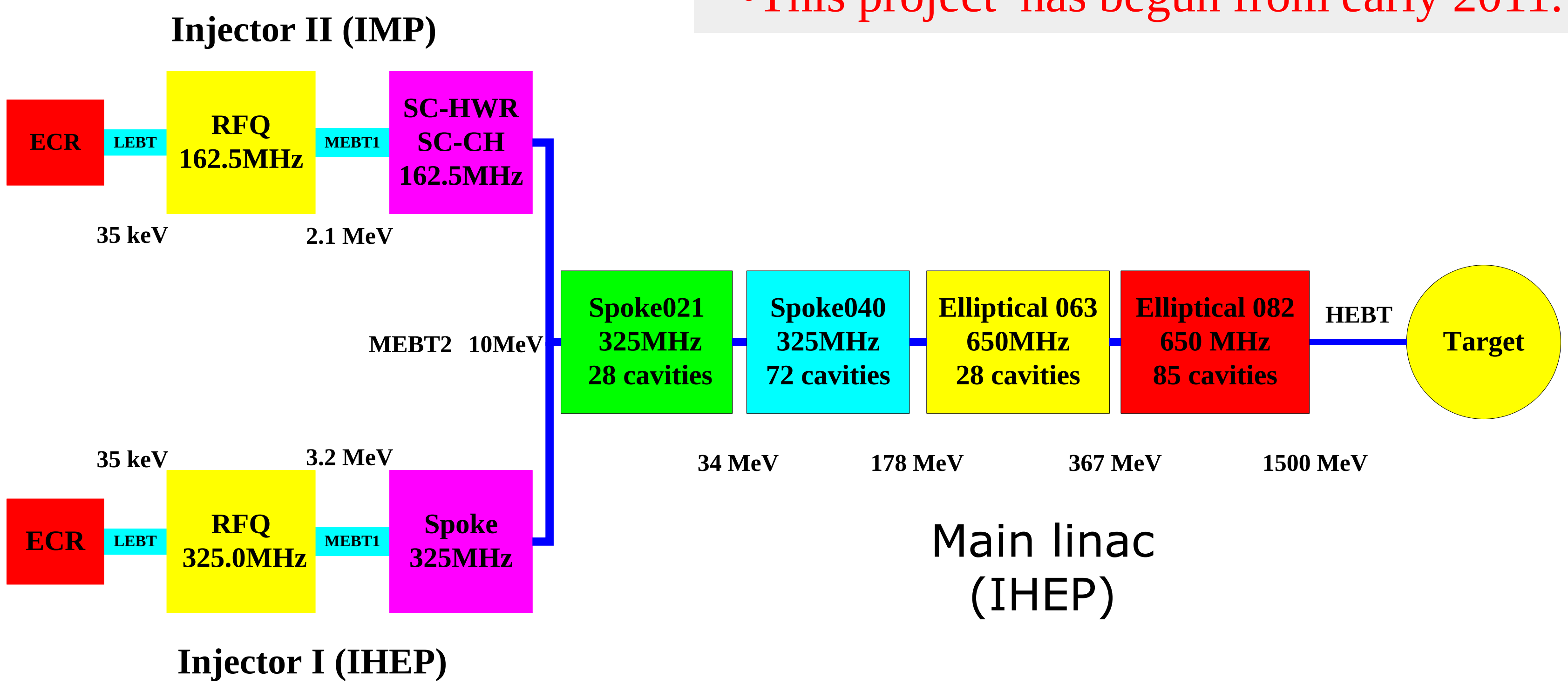
Linac Budget： 0.65 Billion CNY。

ADS Proton Beam Requirments

Particle	Proton	
Energy	1.5	GeV
Current	10	mA
Beam power	15	MW
Frequency	162.5/325/650	MHz
Duty factor	100	%
Beam Loss	<1 (0.3)	W/m
Beam trips/year	<25000 <2500 <25	1s<t<10s 10s<t<5m t>5m

Layout of Proton Accelerator

- This project has begun from early 2011.

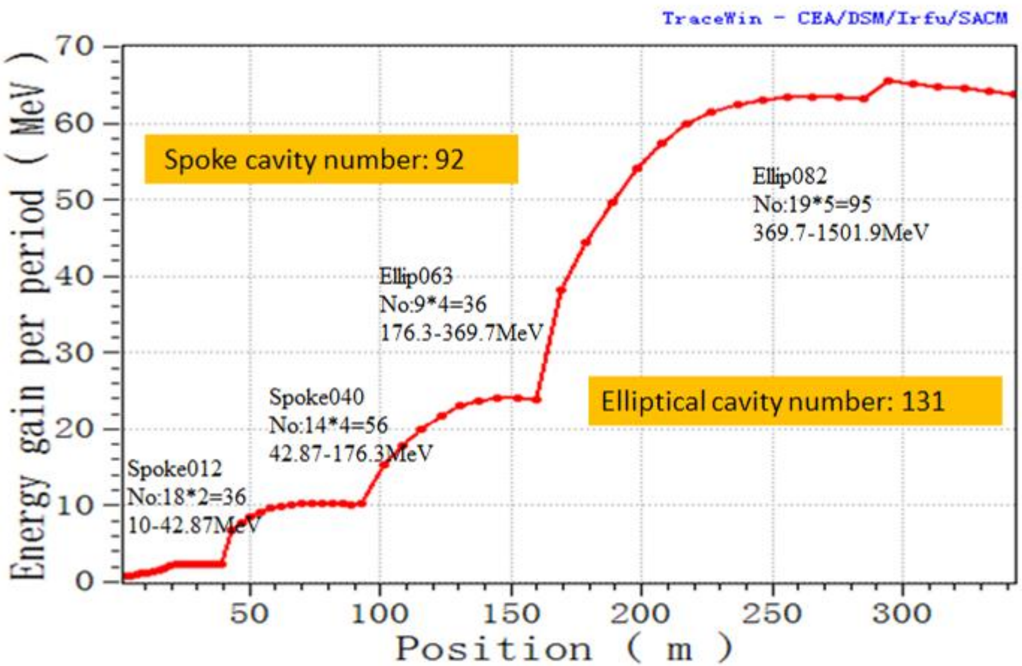


Key Parameters for the Physics Design

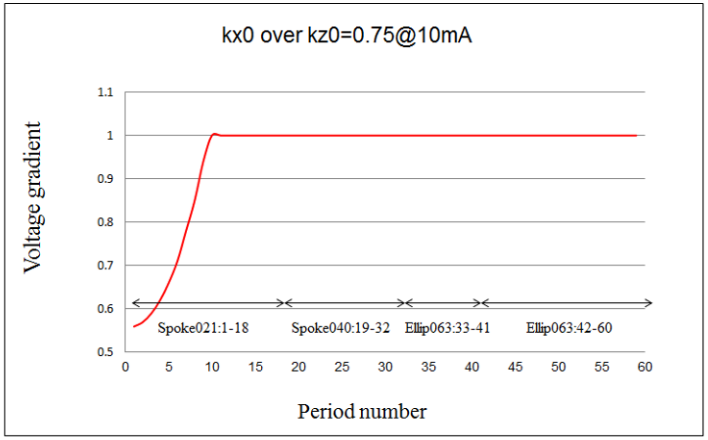
- SC spoke cavities: Epeak<32.5 MV/m, Bpeak<65 mT
- SC elliptical cavities: Epeak<39 MV/m, Bpeak<65 mT
- Operation temperature for all SC cavities: 1.8 K
- Apertures for SC cavities: 35 mm for E<10 MeV; 40 mm for Spoke021; 50 mm for Spoke040; 100mm for Ellip063 and Ellip082. HWR cavities for Injector II: 40 mm
- Phase advance per cell (zero current, both transverse and longitudinal): <90 degree
- RF frequency
  - Injector-I: 325 MHz
  - Injector-II： 162.5 MHz
  - Main linac: 325 MHz (Spoke sections) and 650 MHz (Elliptical sections)
- Maximum magnetic field for solenoids: 5 T

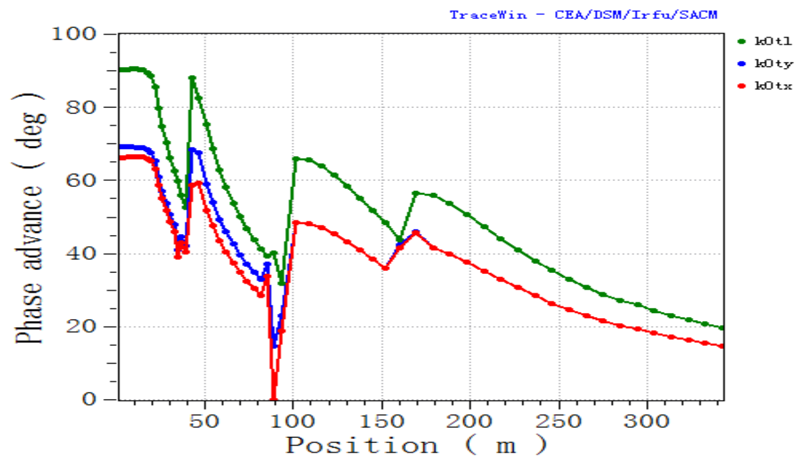
Linac Design

Total: 223cavities, 342.5m



* Note: The nominal gradient of 6 last period of Ellip082 section is 1.04.



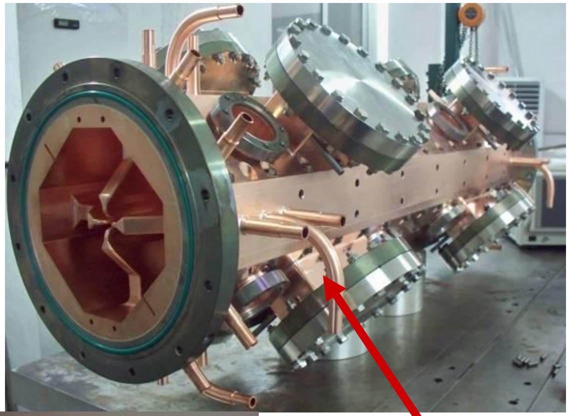


RFQ of Injector I -- Parameters

Parameters	Value	Parameters	Value
Frequency (MHz)	325	Cavity power dissipation (kW)	272.94 [1.4* Psuperfish (194.96)]
Injection energy (keV)	35	Total power (kW)	320.94
Output energy (MeV)	3.2128	Avg. Copper power/Length (kW/m)	41.68
Beam current (mA)	15	Avg. Copper power/Area (W/cm^2)	3.25
Beam duty factor	100%	Max. copper power/Area (W/cm^2)	3.77
Inter-vane voltage V (kV)	55	Input norm. rms emittance(x,y,z)(πmm.mrad)	0.2/0.2/0
Beam transmission	98.7%	Output norm. rms emittance(x/y/z) (πmm.mrad/MeV-deg)	0.2/0.2/0.0612
Average bore radius r_0 (mm)	2.775	Vane length (cm)	467.75
Vane tip curvature (mm)	2.775	Gap1(entrance) (cm)	1.10
Maximum surface field (MV/m)	28.88 (1.62Kilp.)	Gap2(exit) (cm)	1.10
		Accelerator length (cm)	469.95

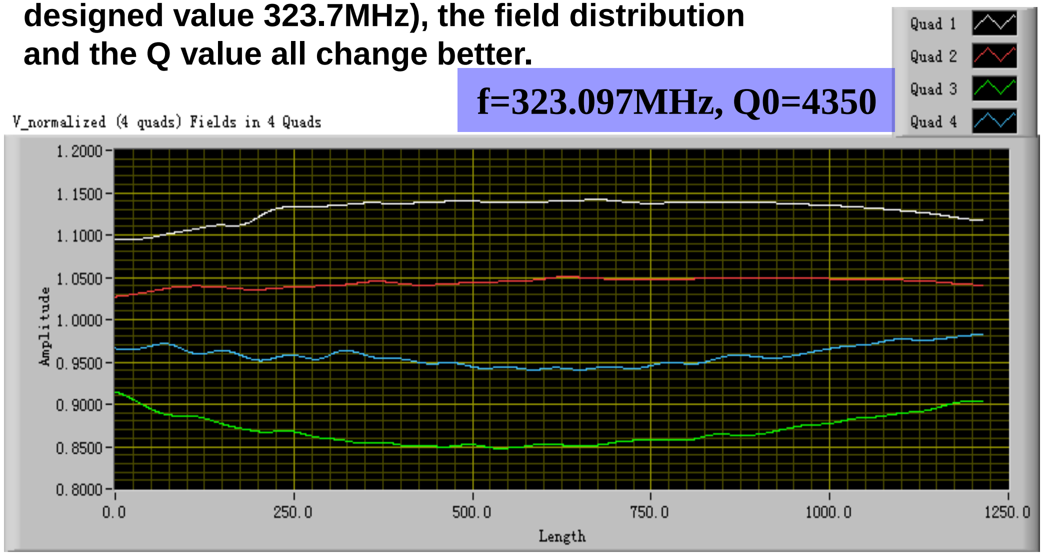
RFQ of Injector I -- Fabrication

The1st module has been brazed.



After brazing, the resonant frequency (the designed value 323.7MHz), the field distribution and the Q value all change better.

f=323.097MHz, Q0=4350



Coupler on test

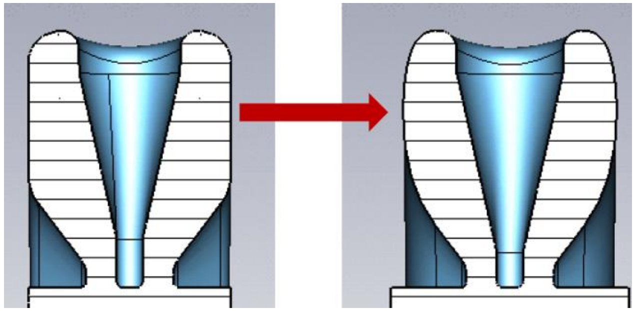
Vacuum leakage check is done after brazing, only one leakage position located at the vacuum flange brazing joint is found (1.9*10E-9 Pa .m^3/s). After copper-plated at the leakage position, the total leakage now is in the order of 10E-11 Pa .m^3/s.

Machining for the fourth module underway

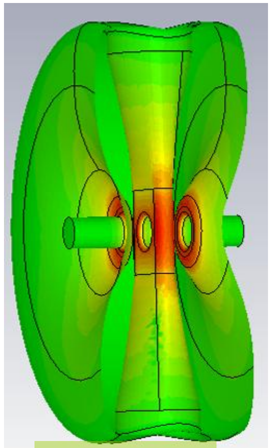
Spoke012 Cavity (β=0.12) of Injector I

Main Geometrical parameters	Units	Value
Diameter of cavity	mm	468
Length of cavity	mm	180
Diameter of beam tube	mm	35
RF parameters	Units	Value
E_{peak}/E_{acc}		4.54
B_{peak}/E_{acc}	mT/(MV/m)	6.37
G	Ω	61
Transition Time Factor		0.76
R/Q@β=0.12	Ω	142

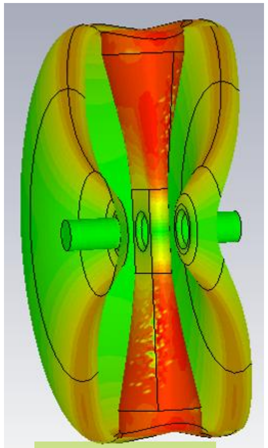
Note: Effective length for Eacc is defined as βλ



The Convex end wall (right) is adopted,which has better mechanical performance than the flat one (left).



E-field



B-field

Spoke012 Cavity -- Fabrication

Fabrication of spoke012 cavity will be completed in Oct, 2012. And the vertical test may be done at the end of 2012.

Spoke bar after cut

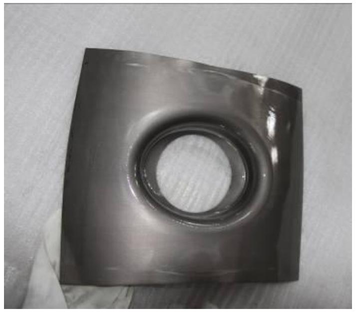
EBW of endwall and beam tube

Deep drawing of endwall

Deep drawing of spoke bar

EBW of spoke bar

Coupler slice



Spoke slice

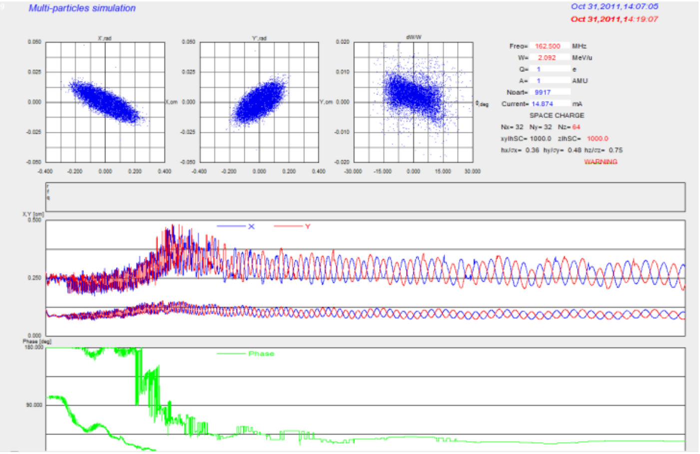
325MHz/10KW Solid State Amplifier for Spoke012

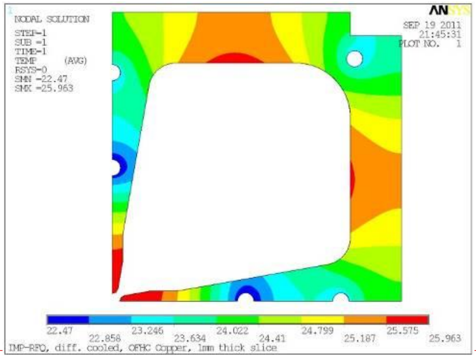
Testing Item	Requirements
frequency	325 MHz ± 3 MHz
RF standard	Continuous tuning
Output Power	≥10kW（CW）
Harmonic	≤-50dBc
Random Harmonic	≤-80dBc
Amplitude stability	≤ ±1%
Phase stability	≤±1°
Output interface	50Ω coaxial

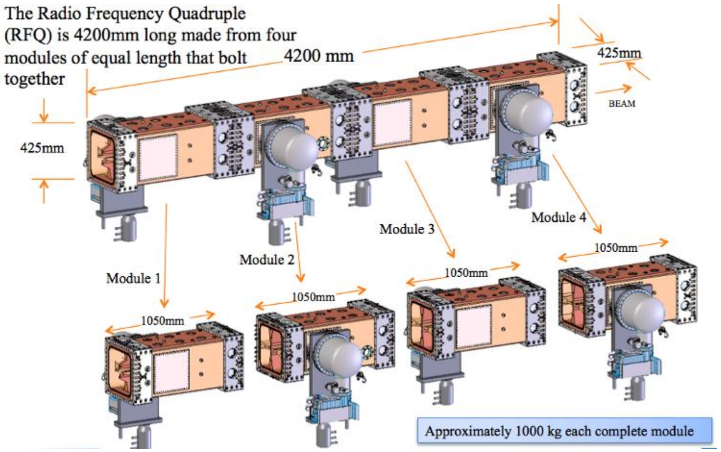
It has been tested, all specifications are reached.

RFQ of Injector II

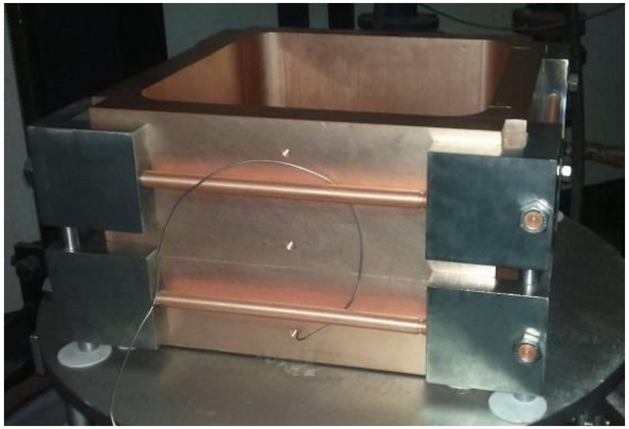
Parameters	Value	Unit
Frequency	162.5	MHz
Injection Energy	35	KeV
Output Energy	2.1	MeV
Beam current (CW)	15	mA
Vane Tip Voltage	65	kV
RFQ Length	4.16	meters
Transmission	99.6	%
Transverse ε (x,y)	0.3	π.mm.mrad
Longitudinal ε	0.92	keV-ns
TWISS, α_x, α_y	-1.16, 1.43	
Modulation m_{max}	2.35	
Total # of Cells	191	
ρ/r_0	0.75	

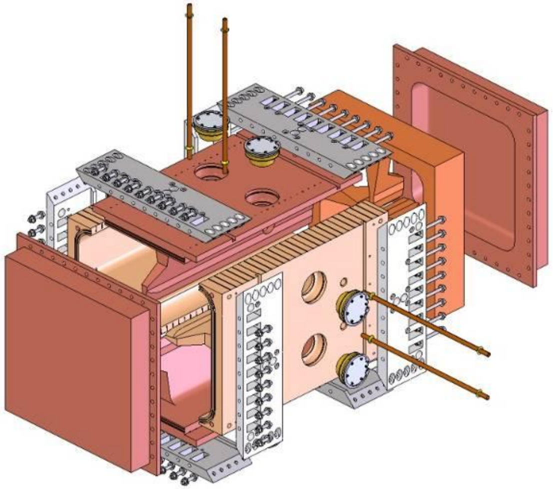


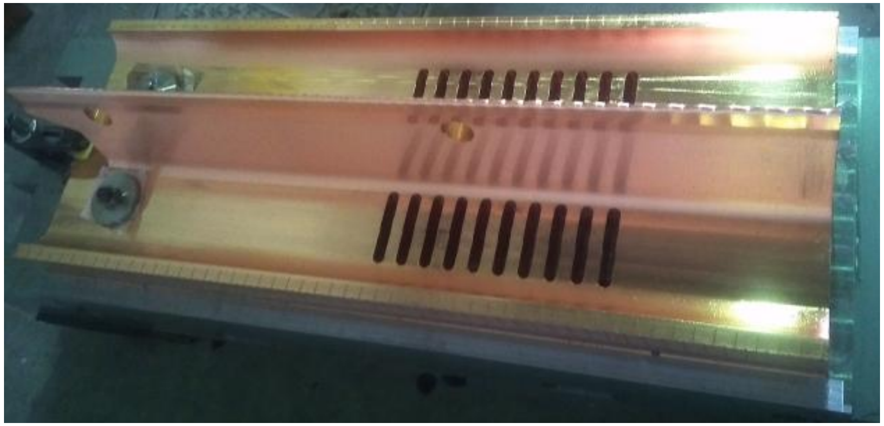




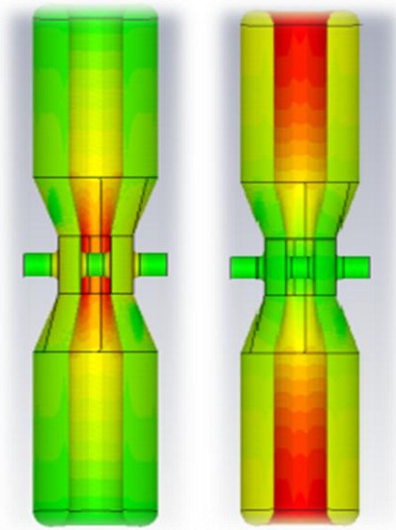
RFQ Testing Model of Injector II

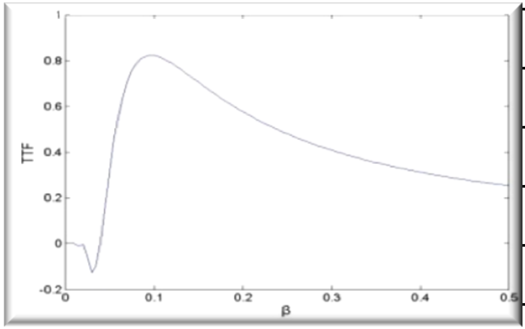






HWR Cavity of Injector II



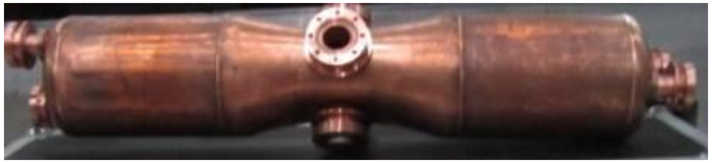


TTF

Parameters

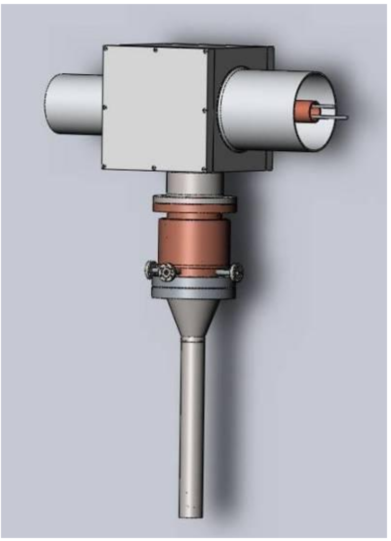
Parameters	
Frequency	162.5MHz
Gβ	0.09
E_{peak}/E_{acc}	5.34
B_{peak}/E_{acc}	10.92mT/Mv/m
R_a/Q_0	148
E_{peak}	25 MV/m
B_{peak}	50 mT
E_{acc}	4.7 MV/m
U_{acc}	0.78 MV
$G=R_s*Q_0$	28.5 Ω
W	4 J
P_{diss}	2.9 W
Q_0(4.4K)	1.40E+09

Copper Model



Fabrication would be finished in 2012.9.

HWR Coupler for Injector II



Window

HWR coupler

Testing (2012.7)

Coupler power exceeds 20 kW (CW, designed value), 2012.7

162.5MHz/20KW Solid State Amplifier for HWR

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

It has been tested, all specifications are reached.

3. CSNS Progress

Design Goal

Beam power (kW)	Repetition (Hz)	Beam current (μA)	Energy (GeV)	Max neutron flux* ($n/cm^2/s$)
100	25	63	1.6	2×10^7

*** Measured at 14m from modulator**

- Design goal will be met three years after acceptance.
- Project acceptance goal is 1/10 beam power goal.

***Acceptance Goal**

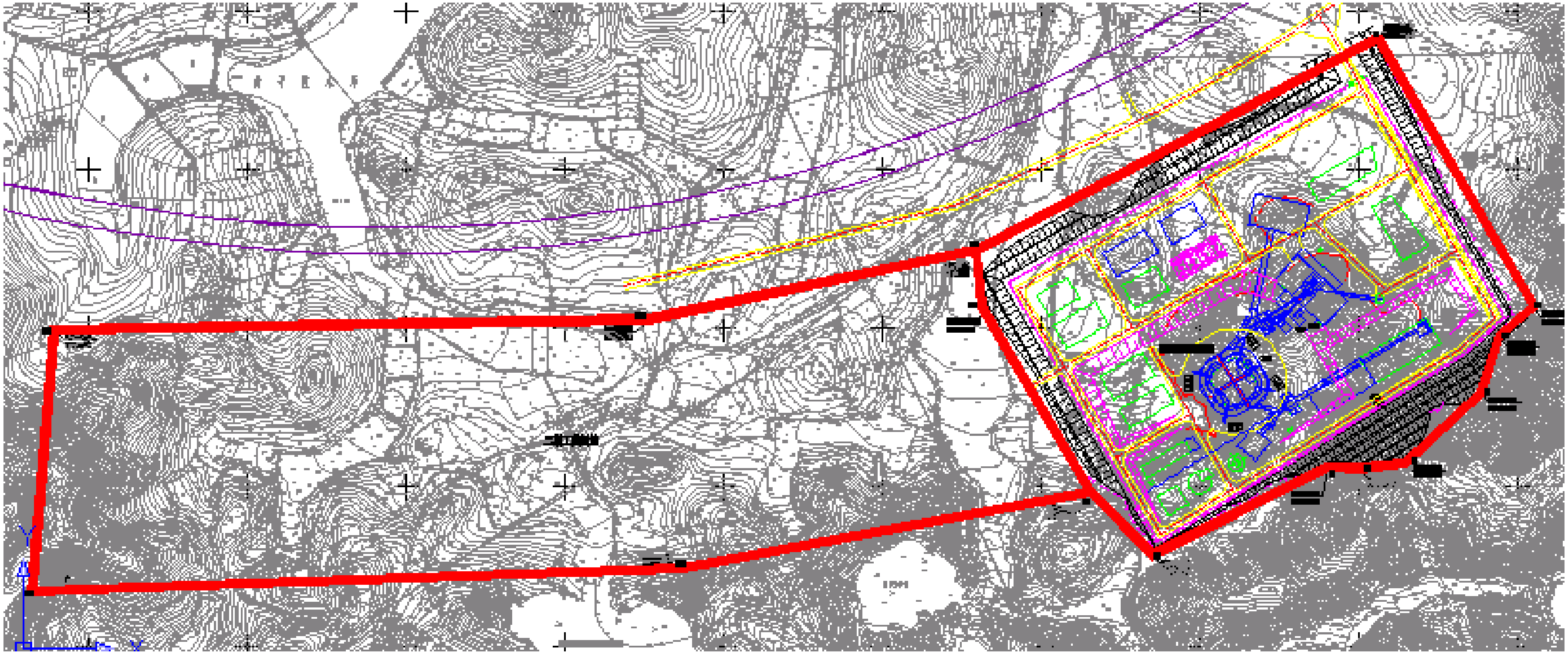
Beam power (kW)	Repetition (Hz)	Beam current (μA)	Energy (GeV)	Max neutron flux* ($n/cm^2/s$)
10	25	6.3	1.6	10^5

- **Upgradeable to 500kW at 25Hz in the second phase.**

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)

Site Area



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

Conceptual Picture

IHEP will set up a new branch at Dongguan for CSNS construction. Artificial view of the campus of the site.

Site Scene


中国散裂中子源装置地A点拍摄（09.5.9）
May 2009: before land breaking

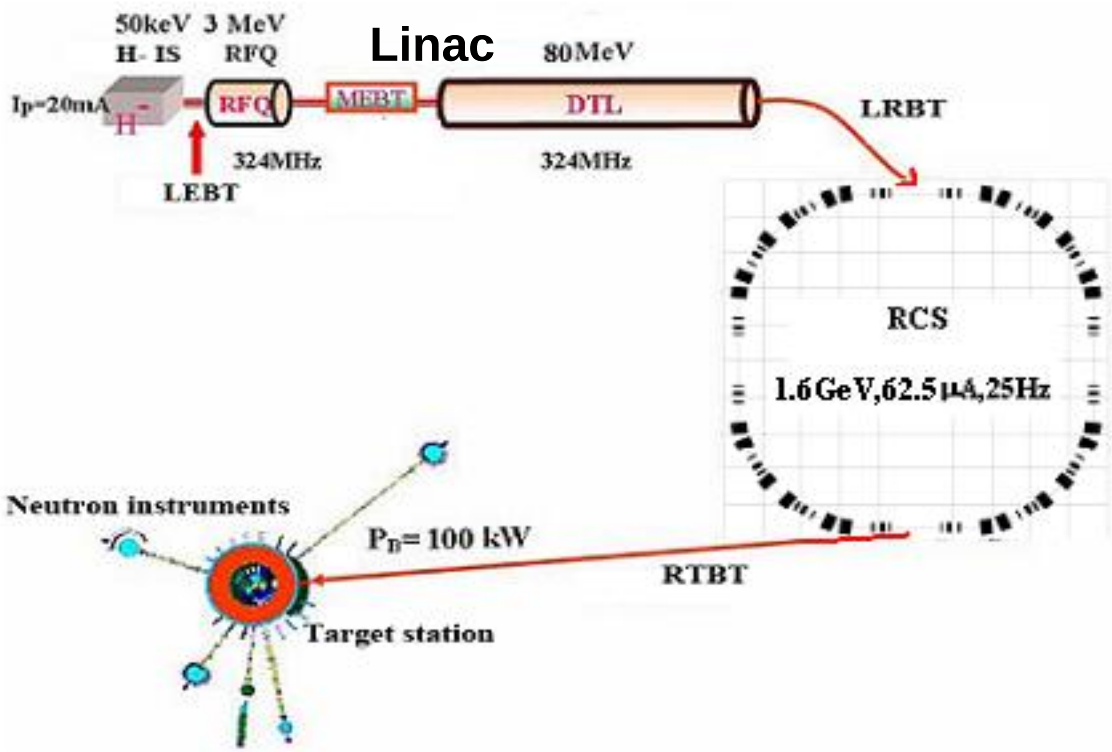

2011.8.18中国散裂中子源装置地A点拍摄
Aug 2011: land was prepared

Budget

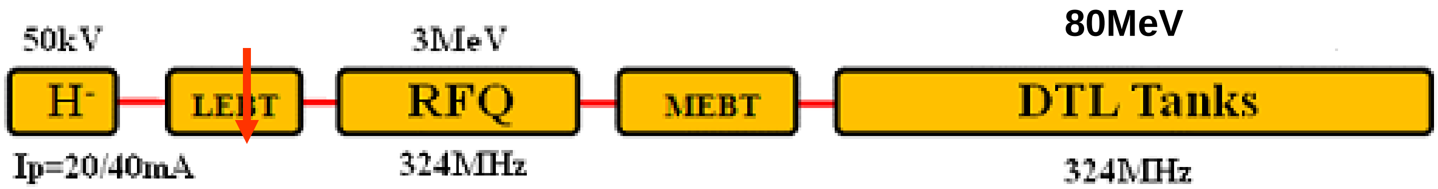
- Baseline--- the largest big-science project in China
  - 1.7B CNY(~US$250M) from central government for project construction
  - 0.5B CNY and land from Guangdong/Dongguan local government for additional supports
- R&D
  - 35M CNY (received) from CAS for R&D 1
  - 40M CNY (received) from Dongguan government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

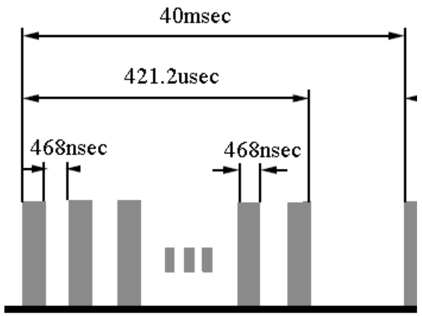
Layout of CSNS

- **The phase-I CSNS facility consists of an 80-MeV H^- linac, a 1.6-GeV RCS, beam transport lines, a target station, and 3 instruments.**



Linac Design

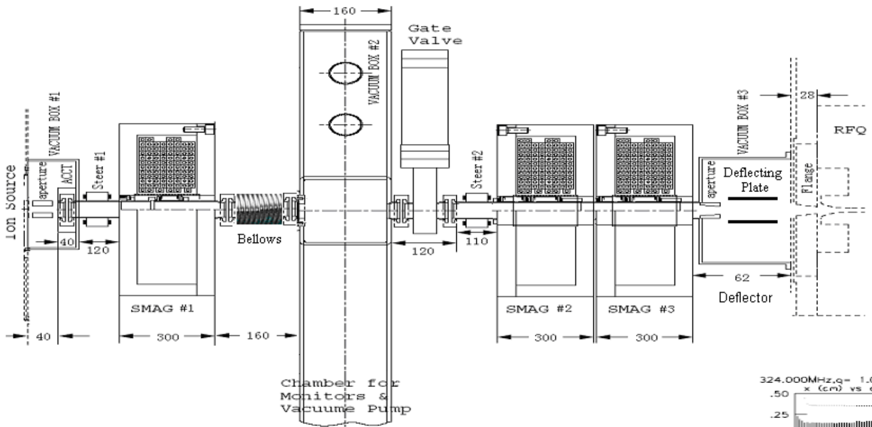




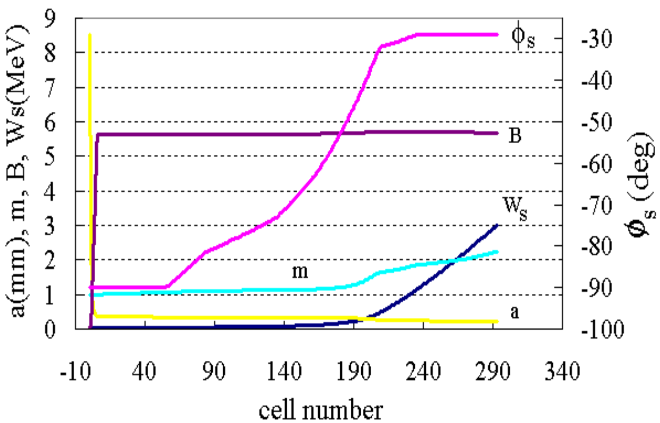
Electrostatic chopper only in LEBT in Phase-I

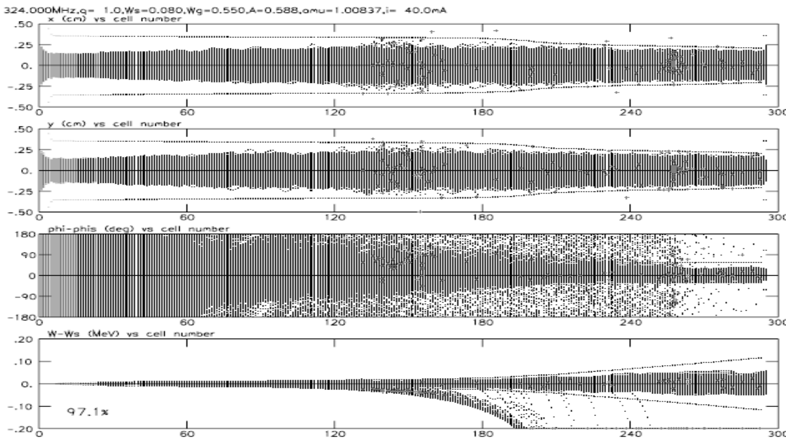
	Ion Source	RFQ	DTL
Input Energy（MeV)		0.05	3.0
Output Energy(MeV)	0.05	3.0	80
Pulse Current (mA)	20/40	20/40	15/30
RF frequency (MHz)		324	324
Chop rate (%)		50	50
Duty factor (%)	1.3	1.05	1.05
Repetition rate (Hz)	25	25	25

Front-end Design



A Penning H- ion source and a three-solenoids LEBT with space charge neutralization.





97% transmission rate in design

RFQ

- RFQ is under fabrication.

Major and minor vanes under fabrication: cooling water channels have been drilled and the ends have been plugged.

DTL Design

Tank parameters of CSNS DTL

Tank number	1	2	3	4
Output energy (MeV)	21.67	41.41	61.07	80.1
Length (m)	8.51	8.56	8.78	8.8
Number of cell	64	37	30	26
RF driving power (MW)	1.35	1.32	1.32	1.34
Total RF power (MW)	1.91	1.92	1.92	1.93
Accelerating field (MV/m)	2.86	2.96	2.96	3.0
Synchronous phase (degree)	-35 to -25	-25	-25	-25

- **The total RF power with a 30mA beam in a tank is about 2MW. Each tank is fed by a 2.5MW klystron.**
- **FFDD lattice is used.**

Linac Upgrade Options（PhaseII） - SC Linac

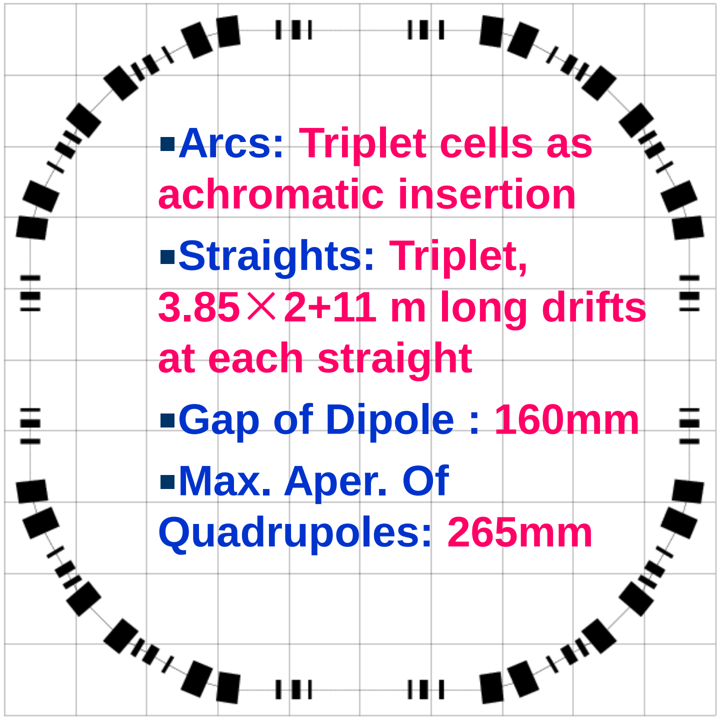
Elliptical Cavity from 130-250MeV

Energy Range (MeV)	130-250
RF frequency (MHz)	972
Geometry βg	0.52
Particle β range	0.48-0.61
Eacc (MV/m)	13.02
Energy gain (MeV/m)	1.92
Epk/Eacc	3.72
Bpk/Eacc(mT/(MV/m))	6.7
Cell No/ Cavity	6
Cell No/ Cryo	6
Cell No.	240
Length (m)	62

Spoke Cavity from 80-250MeV

Energy Range (MeV)	80-250
RF frequency (MHz)	324
Geometry βg	0.5
Particle β range	0.39-0.61
Eacc (MV/m)	5.6
Energy gain (MeV/m)	3.1
Epk/Eacc	4.46
Bpk/Eacc(mT/(MV/m))	7.1
Cell No./ Cavity	3
Cell No/ Cryo	9
Cell No.	108
Length (m)	56

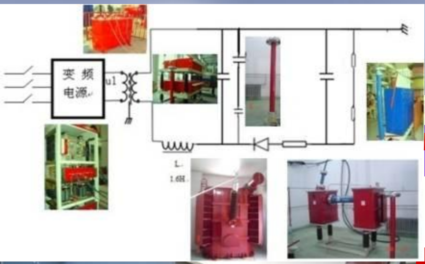
RCS Major Parameters



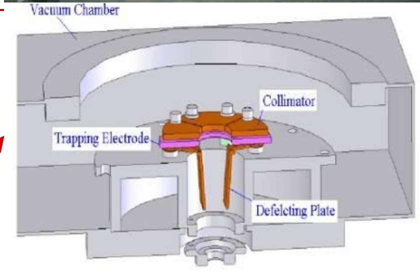
- **Arcs: Triplet cells as achromatic insertion**
- **Straights: Triplet, 3.85×2+11 m long drifts at each straight**
- **Gap of Dipole : 160mm**
- **Max. Aper. Of Quadrupoles: 265mm**

Lattice consists of 16 triplet cells, with a gap in the middle of arc and dispersion free straight section .

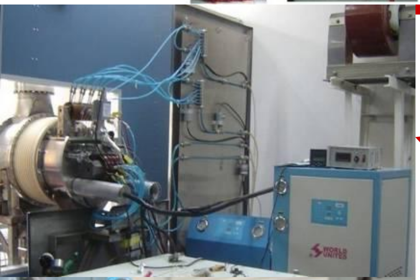
Circumference (m)	227.92
Superperiod	4
Number of dipoles/quadrupoles	24/48
Number of long drift	12
Total Length of long drift (m)	75
Betatron tunes (h/v)	4.82/4.80
Chromaticity (h/v)	-4.3/-8.2
Momentum compaction	0.041
RF harmonics	2
RF Freq. (MHz)	1.0241~2.44
RF Voltage (kV)	165
Trans. acceptance (πμm.rad)	540



R&D Items passed acceptance

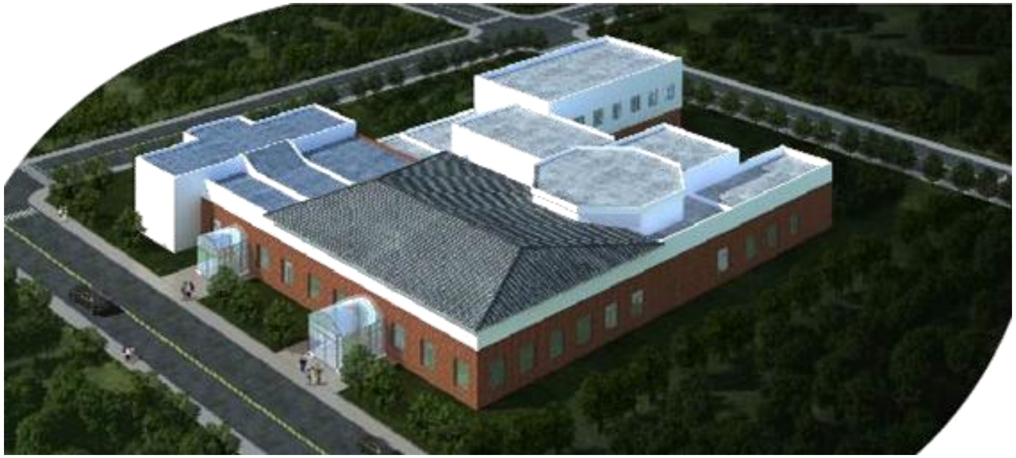


Date	Item
2008.06.05	Linac RF pulsed power source
2009.12.04	RCS injection bump magnet PS
2010.05.27	H^- ion source test stand
2010.06.10	LEBT electrostatic pre-chopper
2010.06.21	RCS injection bump magnet
2010.07.12	RCS dipole field measurement system
2010.07.14	RCS extraction kicker magnet PS
2010.07.26	RCS extraction kicker magnet
2010.10.21	RCS ceramic vacuum chamber
2010.11.12	RCS dipole power supply
2010.12.17	RCS ferrite loaded RF cavity
2010.12.31	Bandwidth limited chopper
2011.04.15	RCS quadrupole & field measurement



4. CPHS in Tsinghua University

CPHS
Compact Pusled Hadron Source
TSINGHUA UNIVERSITY



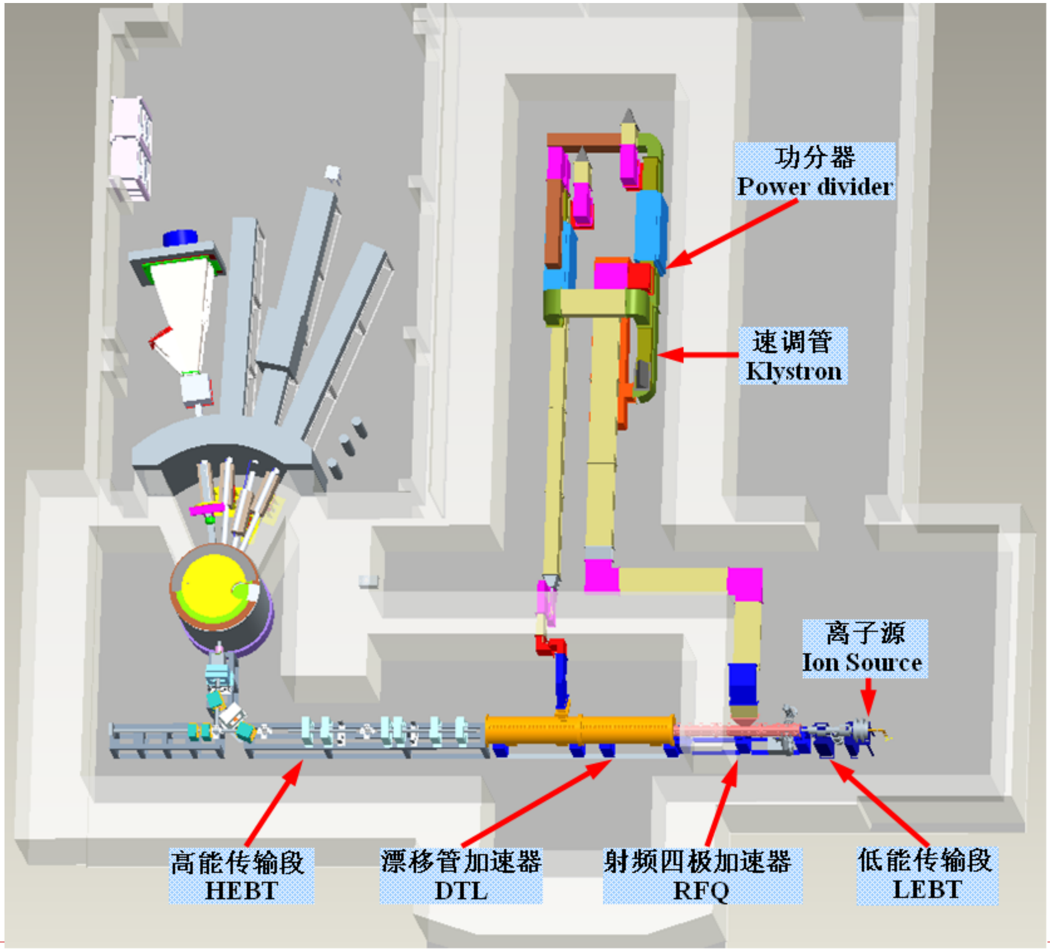
Introduction to CPHS

CPHS (Compact Pulsed Hadron Source):

- **Four neutron beam lines** are planned in the **CPHS** project at Tsinghua University, among which two lines are being constructed for the Small Angle Neutron Scattering (**SANS**) and **neutron imaging**.
- The neutron will be generated by the proton beam bombarding a **Beryllium target**. The **13 MeV proton linac** contains the ECR ion source, LEBT, RFQ, DTL and HEBT.

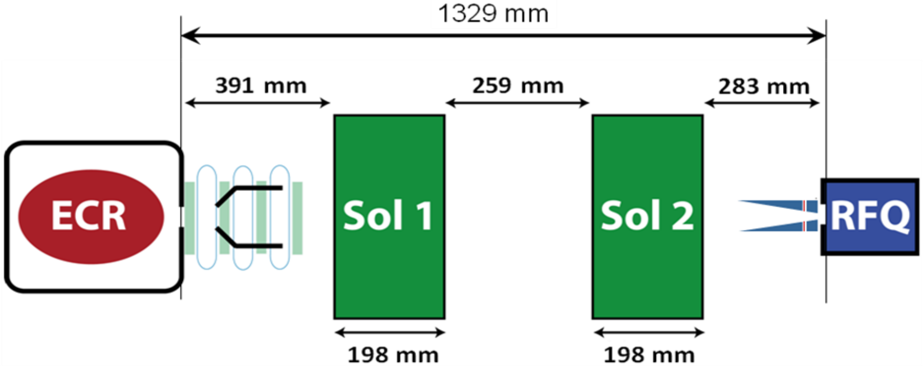
Main parameters of the CPHS accelerator system		
Beam power	16	kW
Beam energy	13	MeV
Average current	1.25	mA
Pulse repetition rate	50	Hz
Protons per pulse	1.56×10^{14}	
Charges per pulse	2.5×10^{-5}	C
Pulse energy	0.325	kJ
Pulse length	500	μs
Peak current	50	mA
Beam duty factor	2.5	%
RF frequency	325	MHz
Output energy of the ion source	50	keV
Output energy of the RFQ	3	MeV
Output energy of the DTL	13	MeV

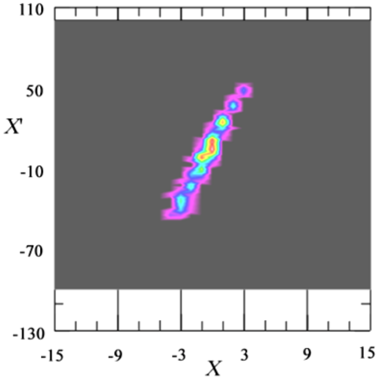
Layout of CPHS Accelerator

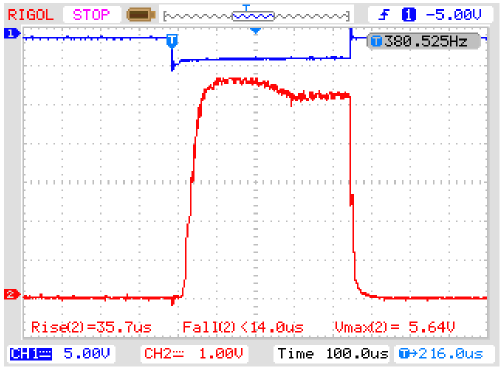


ECR source and LEBT

Output energy	50	keV
Output current	60	mA
Microwave frequency	2.45	GHz
Microwave average power	1.5~2.0	kW
Normalized RMS emittance	0.2	π mm·mrad



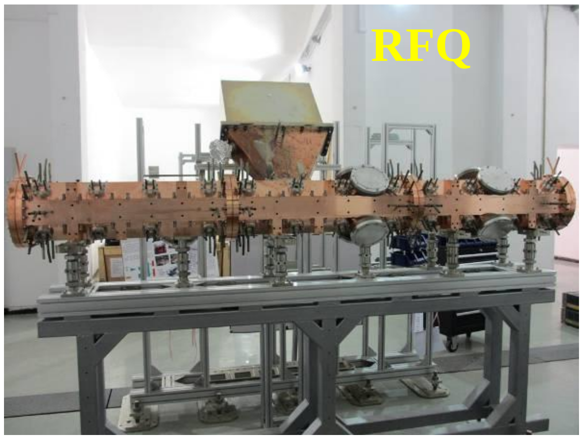




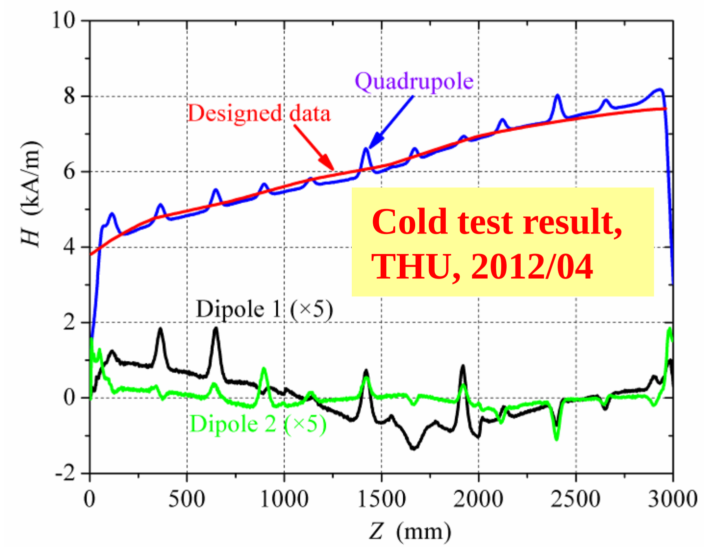
Phase space and proton pulse measured at the end of the LEBT.

The maximum output proton beam reaches 60 mA

RFQ



Quadrupole error: ±3%; Dipole component: ±4%



Parameters	Value	Unit
Type	Four vane	
Frequency	325	MHz
Input beam energy	50	keV
Output beam energy	3.0	MeV
Peak beam current	50	mA
Emittance (norm. rms)	0.2	πmm· mrad
Maximum surface field	32.1	MV/m
Pulse length	0.5	ms
Pulse repetition rate	50	Hz
RF peak power	537	kW
Beam duty factor	2.5	%
Section number	3	

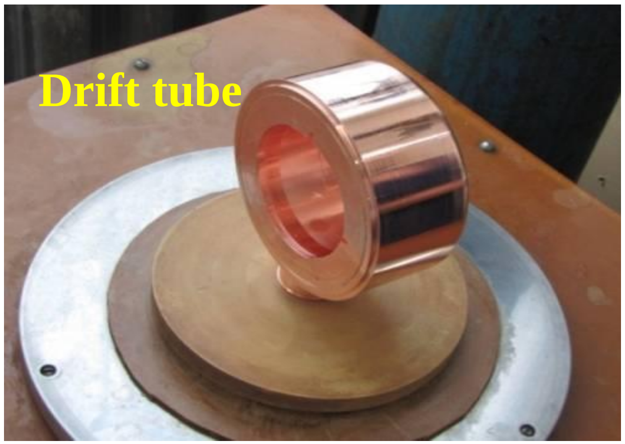
Main characteristics：

1）High transmission with shorter length: coupling plates are not necessary;

2）Optimization design of the peak field and the multipole field: vane-tip geometry are tailored as a function of longitudinal position;

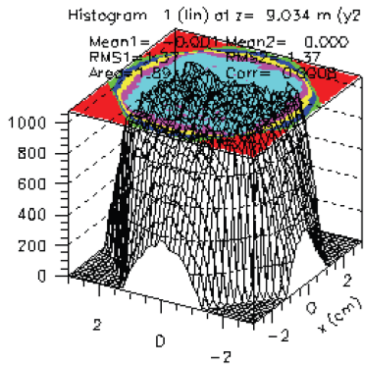
3）No MEBT.

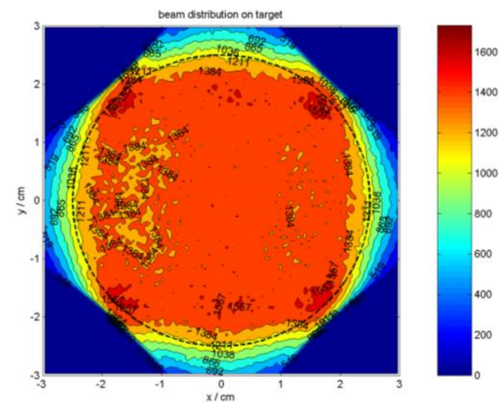
DTL



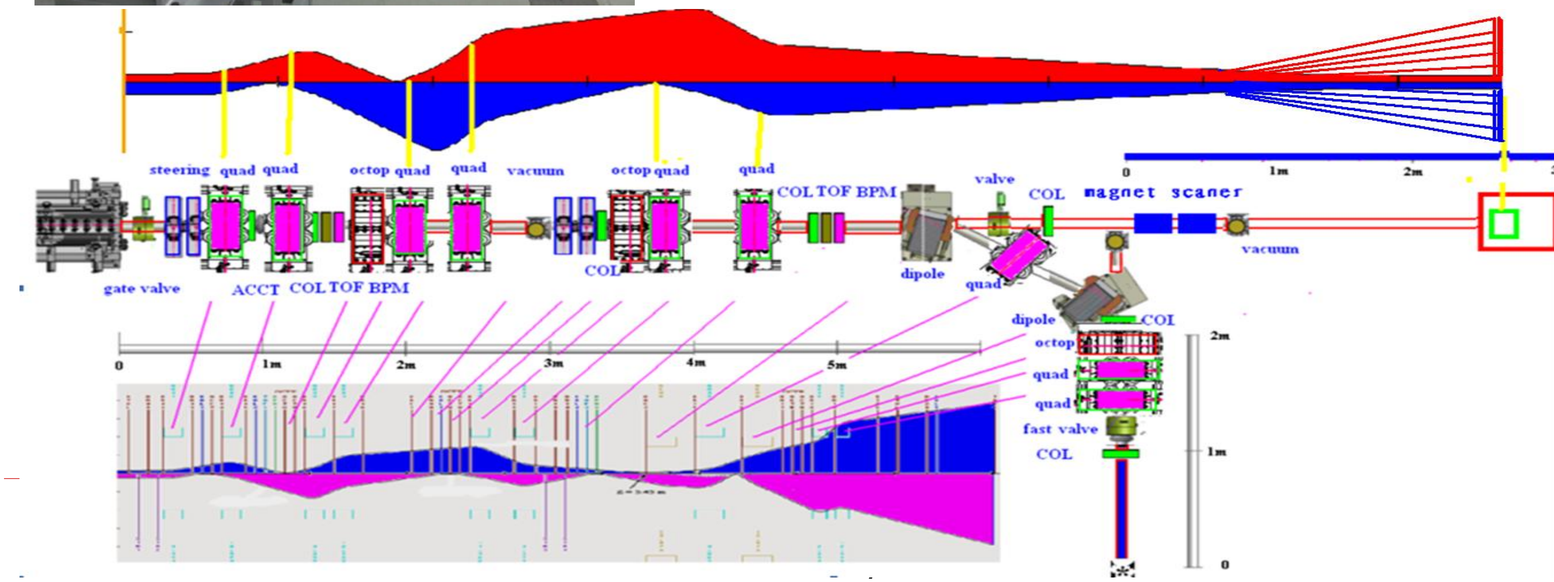
Input/output energy	3.0/13	MeV
Peak current	50	mA
Synchronous phase	-30→-24	Degree
Accelerating field	2.2→3.8	MV/m
Peak power	1.2	MW
Lens gradient	84.6	T/m
Lens effective length	4	cm
Cell number	40	
Total length	4.37	m

Others





Beam distribution on the target.



5. Conclusion

- China has started several projects including ADS, CSNS CPHS program, and being to speed up them from the basic study to real facility .
- The key technologies in high intensity proton accelerator are severe challenges for us, overcoming is underway .
- There are many common interests in the high power proton acceleration technology for the Labs involved in proton accelerators. Close international cooperation are expected.

Thanks for your attention！