China Spallation Neutron Source
Design and R&D

Jie Wei for CSNS teams

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Institute of High Energy Physics, China
Institute of Physics, China
Brookhaven National Laboratory, USA

Outline

- Project overview
- Accelerator design and prototyping
- Target system R&D
- Instrument system R&D
- Summary

Types of SNS accelerators

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- Continuous-wave facilities
  - Driven by a high intensity proton cyclotron
  - 1.2 MW SINQ (PSI) driven by 590 MeV cyclotron
- Long (ms) pulse facilities
  - Driven by a high intensity proton linac
  - 1 MW LANSCE (LANL) driven by 800 MeV linac
- Short (μs) pulse facilities
  - Partial energy linac and rapid-cycling synchrotron(s):
    - ISIS (RAL) driven by 70 MeV linac/800 MeV RCS
    - J-PARC driven by 400 MeV linac/3 GeV RCS/50 GeV MR
  - Full-energy linac and an accumulator ring:
    - SNS (ORNL) driven by 1 GeV linac/accumulator

Accelerators at power frontier

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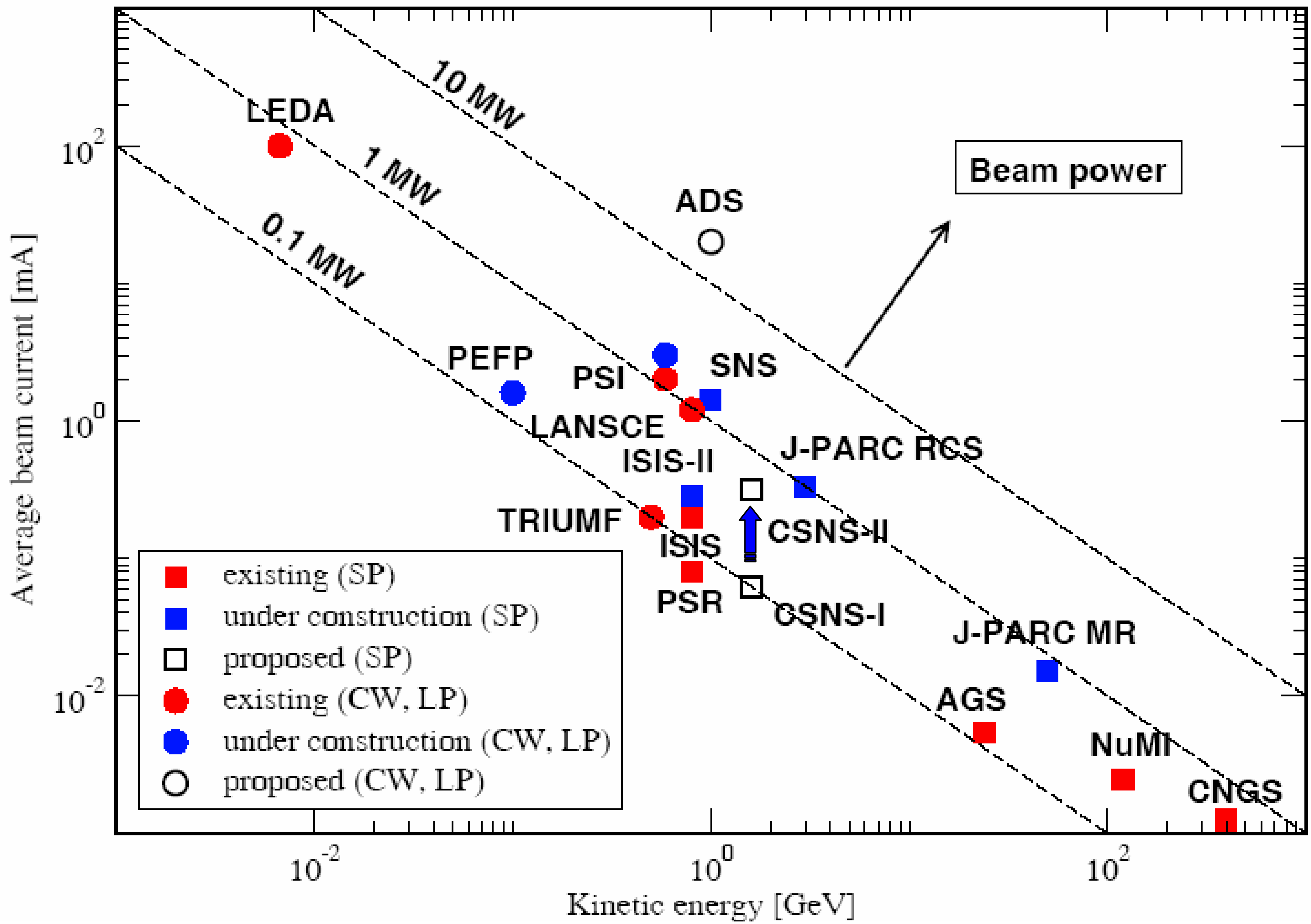

High power accelerator applications

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- CW and long pulse applications

  High average power, high current proton source, high duty factor (~10% or higher) to minimize mechanical shock, ~1 GeV to reduce power deposition in window & cost

  - Irradiation, Rare isotope, …
  - Transmutation of nuclear waste
  - Accelerator driven subcritical power generation

- Short pulse applications

  High peak power, H- ion source for accumulation, pulsed high intensity secondary beam generation (duty factor < 10^{-4})

  - Neutrons, Kaons, neutrinos, muons for neutrinos, muons for muon collider, radioactive isotope (ISOL)

Projects proposed in China

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- China Spallation Neutron Source (CSNS) – Chinese Academy of Sciences and Guangdong
  - Huge domestic demand from the user community
  - Compliments light sources (4 in China) and reactors
  - Bridges the technology towards ADS
- Accelerator Driven Sub-critical programs
  - Compliments fast-breeder reactor (FBR) and pressured water reactors (PWR)
  - Transmutation of waste from nuclear power plants
    - No long-lifetime waste, more abundant fuel (^{238}U), higher safety/possibly lower cost, less proliferation problem
- Proton/ion cancer therapy (synchrotron based)

CSNS layout

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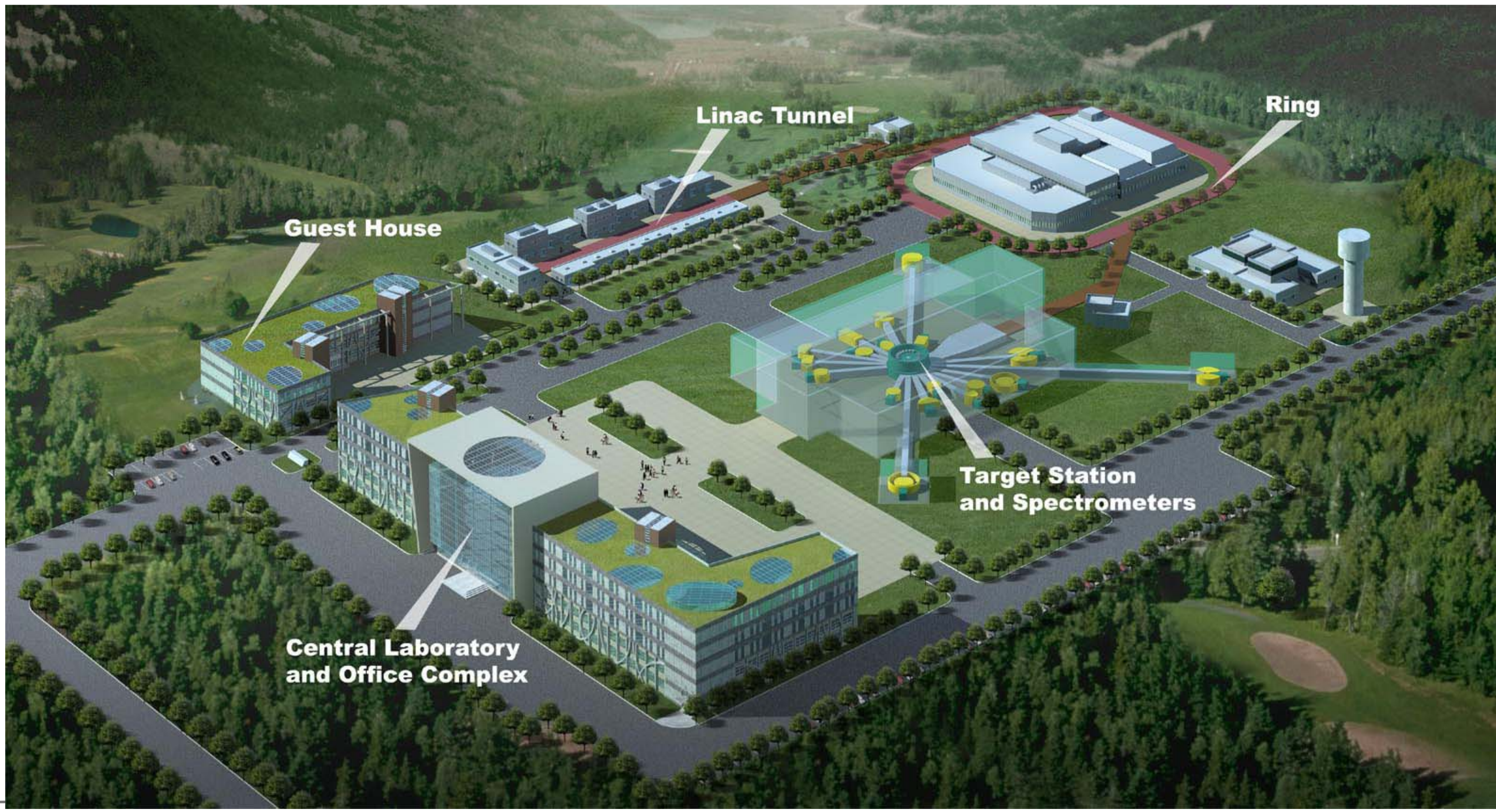
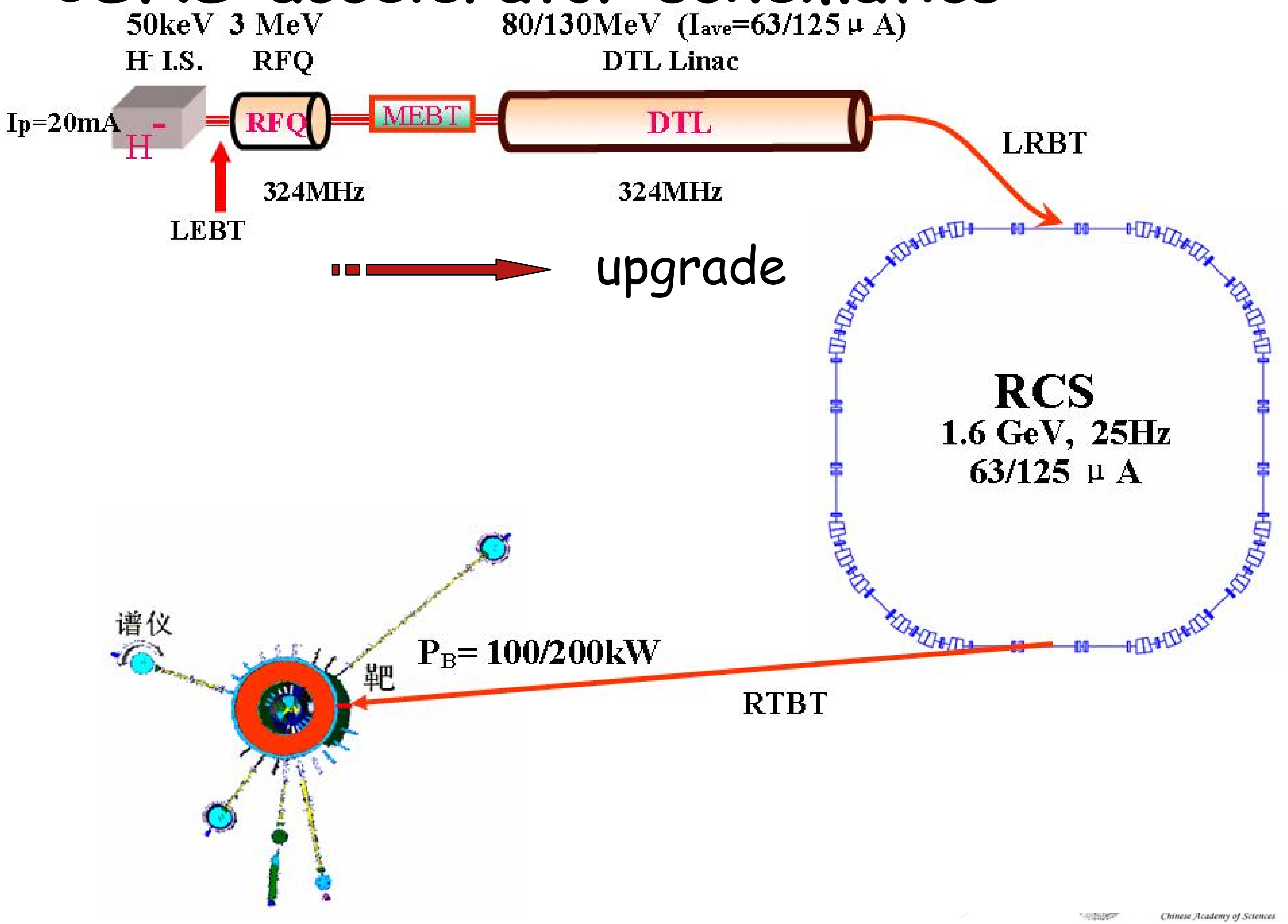
- Linac: H- beam, 81 MeV (DTL) to 250 MeV (SCL)
- Rapid-cycling synchrotron: 1.6 GeV at 25 Hz



CSNS accelerator schematics



Challenges

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- Physics:
  - Space charge & halo, electron cloud, fringe field, impedance & instability, diagnostics (same as those for SNS and J-PARC)
- Engineering:
  - High-efficiency, high-yield target & moderator, rapid-cycling technology (power supply, ceramic vacuum chamber, RF shielding, RF system, magnet/coil …), high-intensity source, RFQ, Linac and transport, collimation, remote handling, coating, diagnostics
- Management (budget):
  - SNS: US$1.4B + upgrade funds
  - J-PARC: ~US$1.5B + people
  - CSNS: ~ US$0.2B; (accel.: budgeted < $100M extremely tight)
- Primary challenges:
  - Complete project scope at high quality with limited budget
  - Reserve potential for future development in phases

Design philosophy

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- Fit in China's present economical situation
  - Total phase-I cost ~1.46B CNY (~US$188M)
- An advanced facility with upgrade potential
  - Phase I beam power goal: 120 kW; phase II: 240 kW
  - Expandable to higher power/2nd target
- Adopt mature technology as much as possible
  - First high-intensity proton machine in China
  - High reliability for our users
- Closely collaborate with world leaders & develop domestic technology to control cost
  - Keep final fabrication in China as much as possible

CSNS proposed budget

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	Item	Cost [10k CNY]	Percentage [%]
1	Conventional engineering	44,566	30.4
1.1	Civil construction	19,629	13.4
1.2	Conventional facility	20,223	13.8
1.3	Installation	4,714	3.2
2		92,273	63.0
2.1	Linac	15,950	10.9
2.2	Synchrotron & transports	42,578	29.1
2.3	Target station	16,126	11.0
2.4	Instrumentations	13,810	9.4
2.5	Controls	3,809	2.6
3	Project management	2,666	1.8
4	Contingency	7,000	4.8
Total		146.505	100.0

CSNS project schedule

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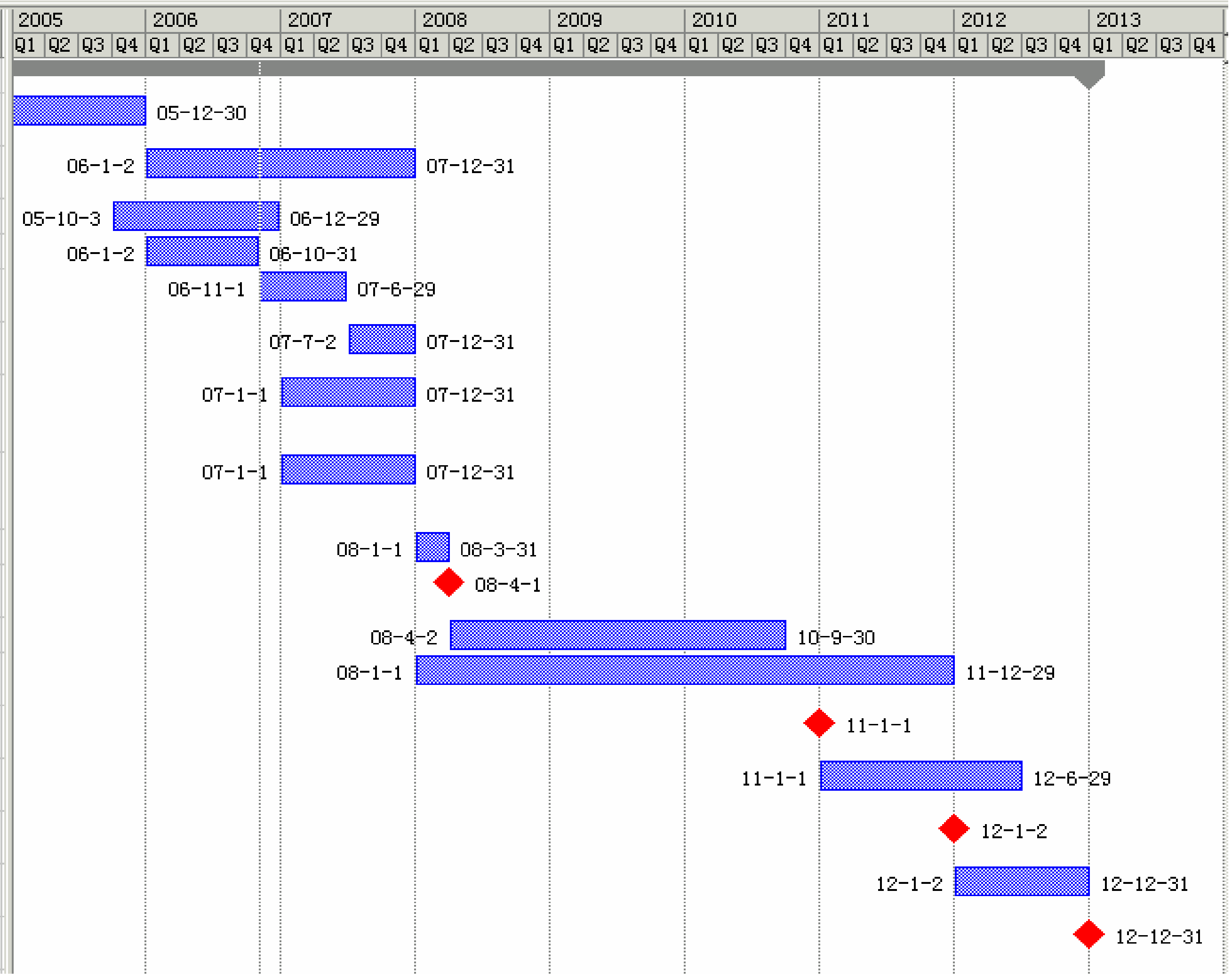
任务名称	工期
⊟ CSNS—Schedule	2871 days
Conceptual Design	1044 days
R&D and Prototype Manufacture	521 days
Site Selection	325 days
Proposal Report	217 days
Feasibility Study Report	173 days
Preliminary Design Report	131 days
Site Investigation and Conventional Facility Design	261 days
The Environment and Radiation Protection Review	261 days
Construction Report	65 days
Starting Construction	0 days
Civil Construction	652 days
Mass production of devices	1044 days
Starting Installation	0 days
Installation and Tuning	391 days
Starting Commissioning	0 days
Devices and Beam Commissioning	261 days
First Beam to Target	0 days



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Limited R&D fund for prototyping

- Funds are very limited (US$3.8 M)
- Limited prototyping efforts
  - Five accelerator systems:
    - DTL (half tank), Ring magnet (2), RF cavity (1), vacuum duct (2), magnet power supply (1)
  - Target body material tests, moderator & cooling system, decouple & poison
  - Neutron super-mirror guide, background chopper, neutron detector
- Much more R&D funding is needed; schedule is extremely tight

Ion source & LEBT

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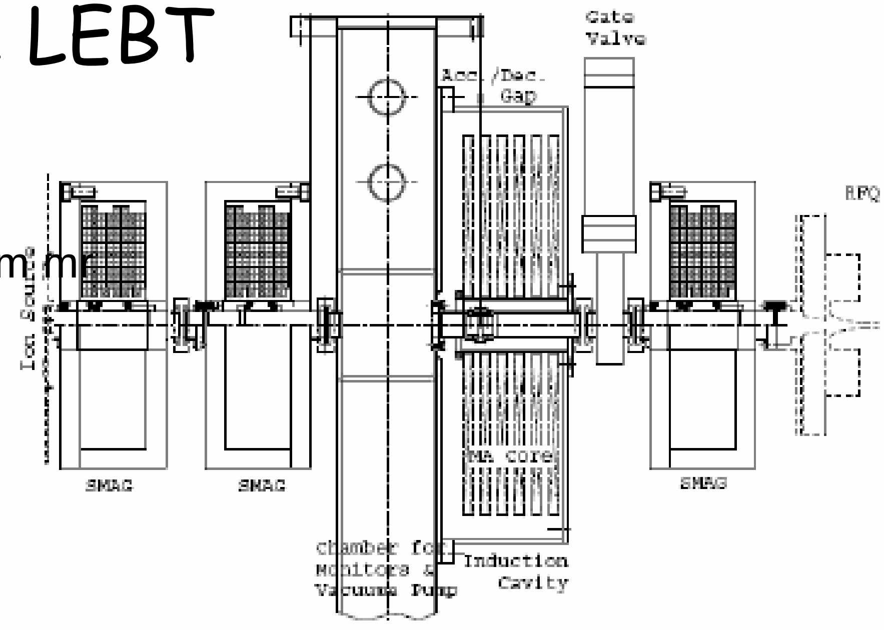
- Ion source
  - Collaborating with & assisted by ISIS: Penning H^- source
  - Backup: SNS type RF source with external antenna
- LEBT & pre-chopper
  - J-PARC type magnetic LEBT

Ion species: H-
Repetition rate: 25 Hz
Output energy: 50 keV
Transverse emittance (rms normalized): 0.2 pi mm mr
Lifetime: 30 days

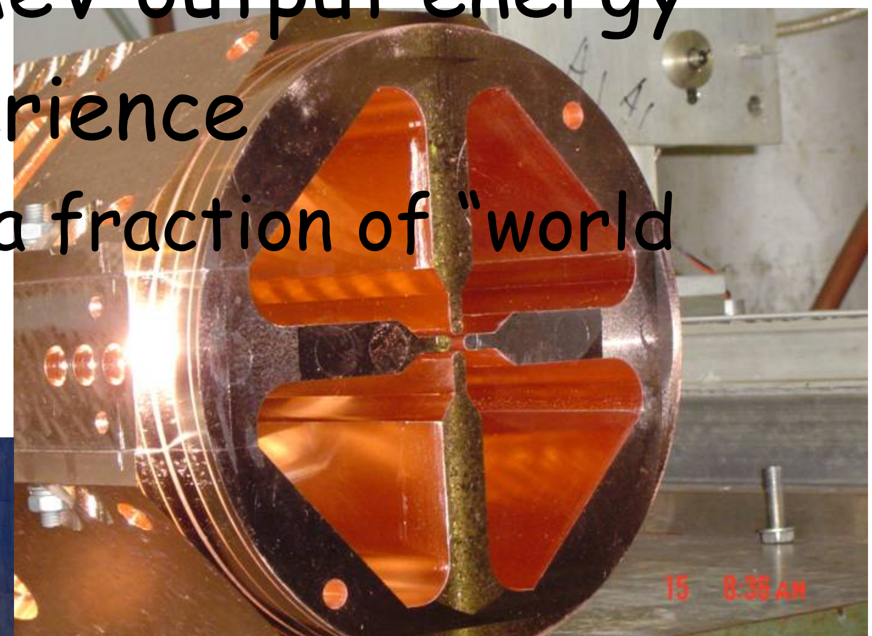
	Current [mA]	Pulse length [us]
Phase I	20	400
Phase II	40	400

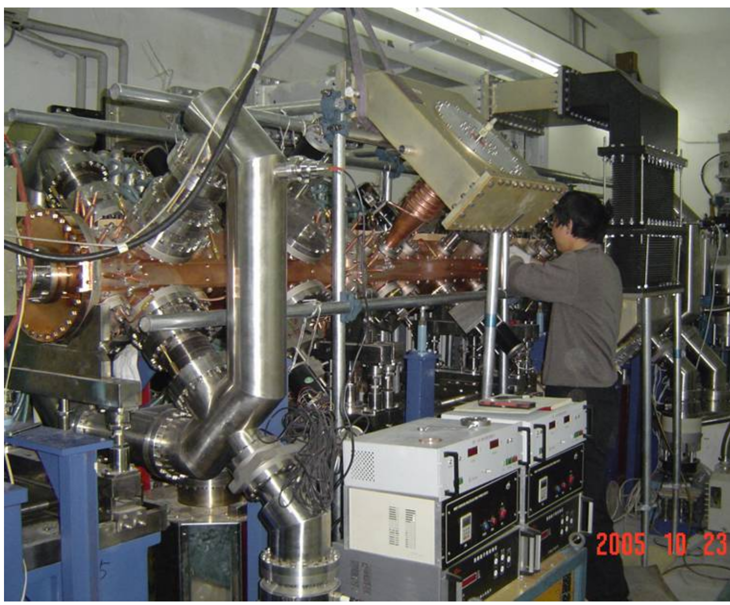


RFQ

H.F. Ouyang, Z.H. Zhang, J. Li et al

- Following the ADS/RFQ design (352MHz)
- 324 MHz, 4-vane, 3 MeV output energy
- Domestic vendor experience
  - World class quality at a fraction of "world standard" cost





Commissioning success in 2006

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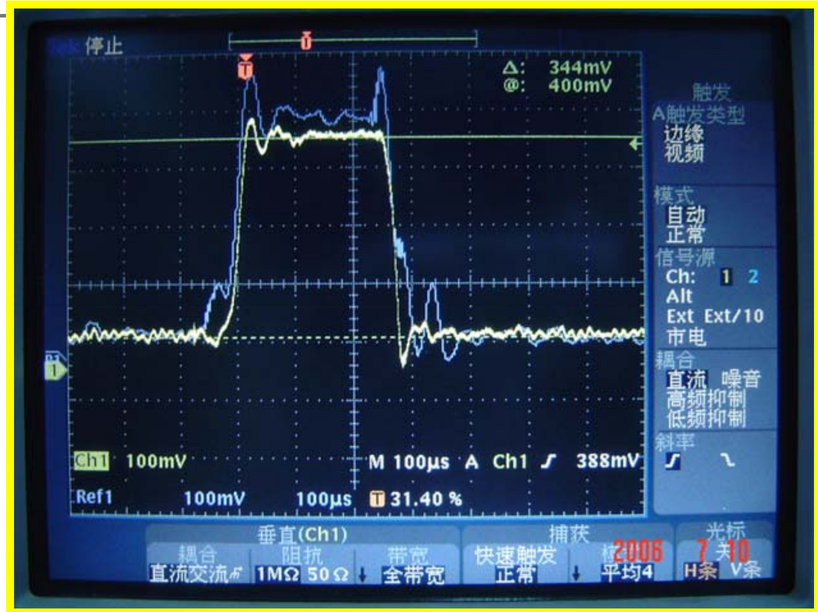

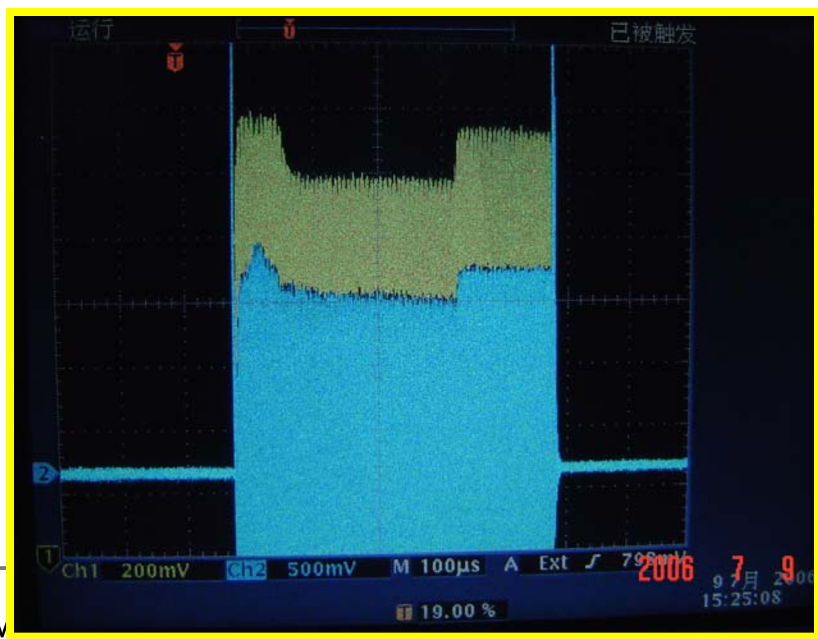

RFQ 出入口ACCT信号:

入口 I_{in}=44mA

出口 I_{out}=41mA.

92% transmission; 6% duty

First digital LLRF developed in China

S. Fu, H.F. Ouyang, Z.H. Zhang et al

黄色：RFQ腔内射频场信号，凹部：束流负载。

蓝色：输入耦合器反射信号，凹部：束流负载使反射下降。

Drift tube linac prototyping

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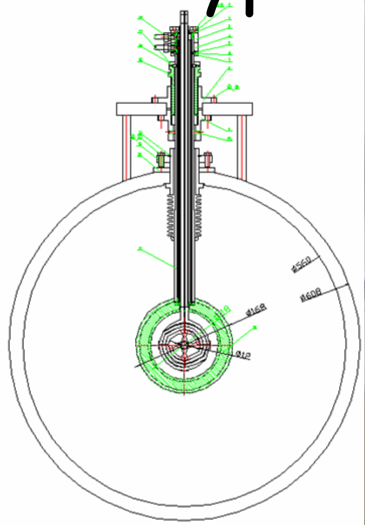
- Phase I to 81 MeV with four DTL tanks
- 324 MHz with duty factor < 3% (frequency chosen by several projects/programs)
- Tank: Electro vs. explosive forming explored – seeking collaboration with PEFP
- EM quad, J-PARC type coil



Linac RF system

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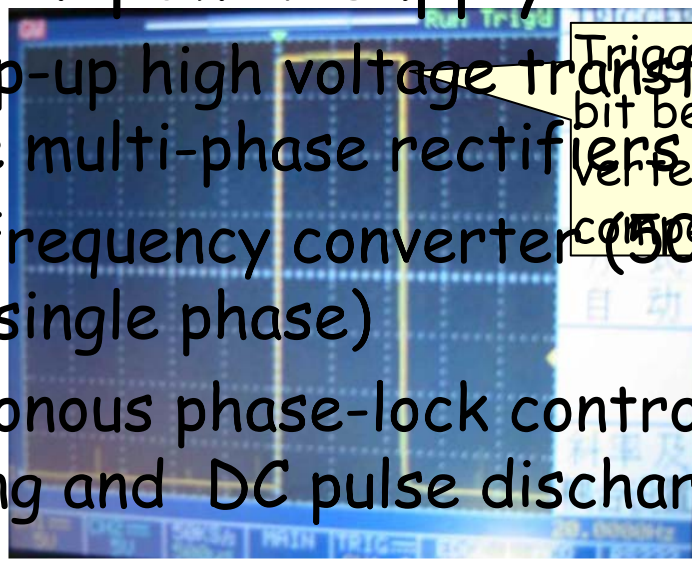
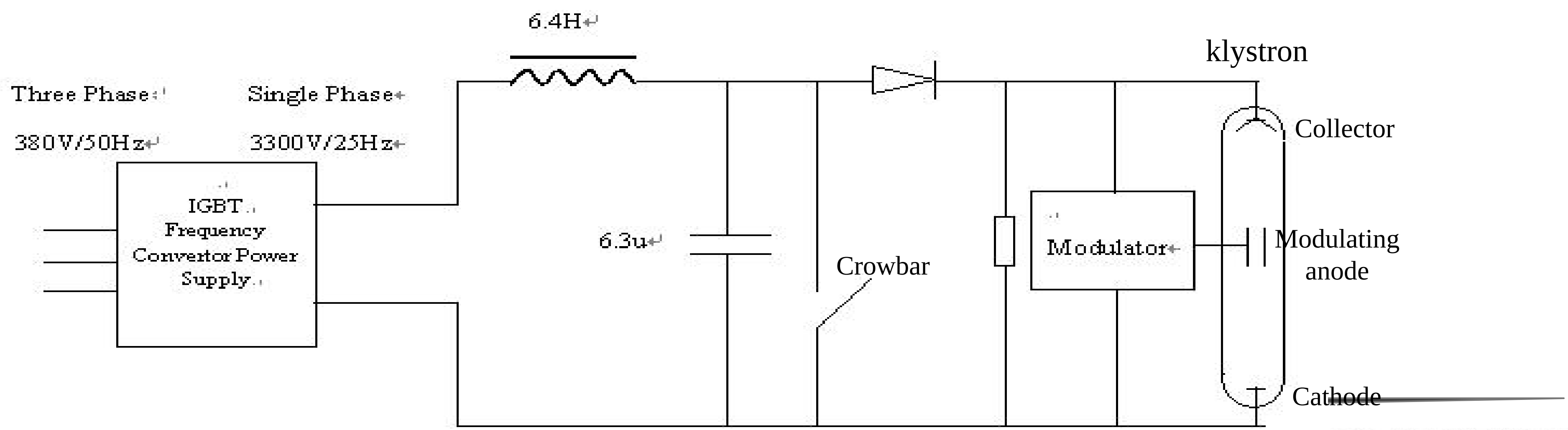
- R&D on HV power supply
  - No step-up high voltage transformers and high voltage multi-phase rectifiers
  - IGBT frequency converter (50 Hz 3-phase mains to 25 Hz single phase)
  - synchronous phase-lock control between AC charging and DC pulse discharging





Rapid cycling synchrotron layout

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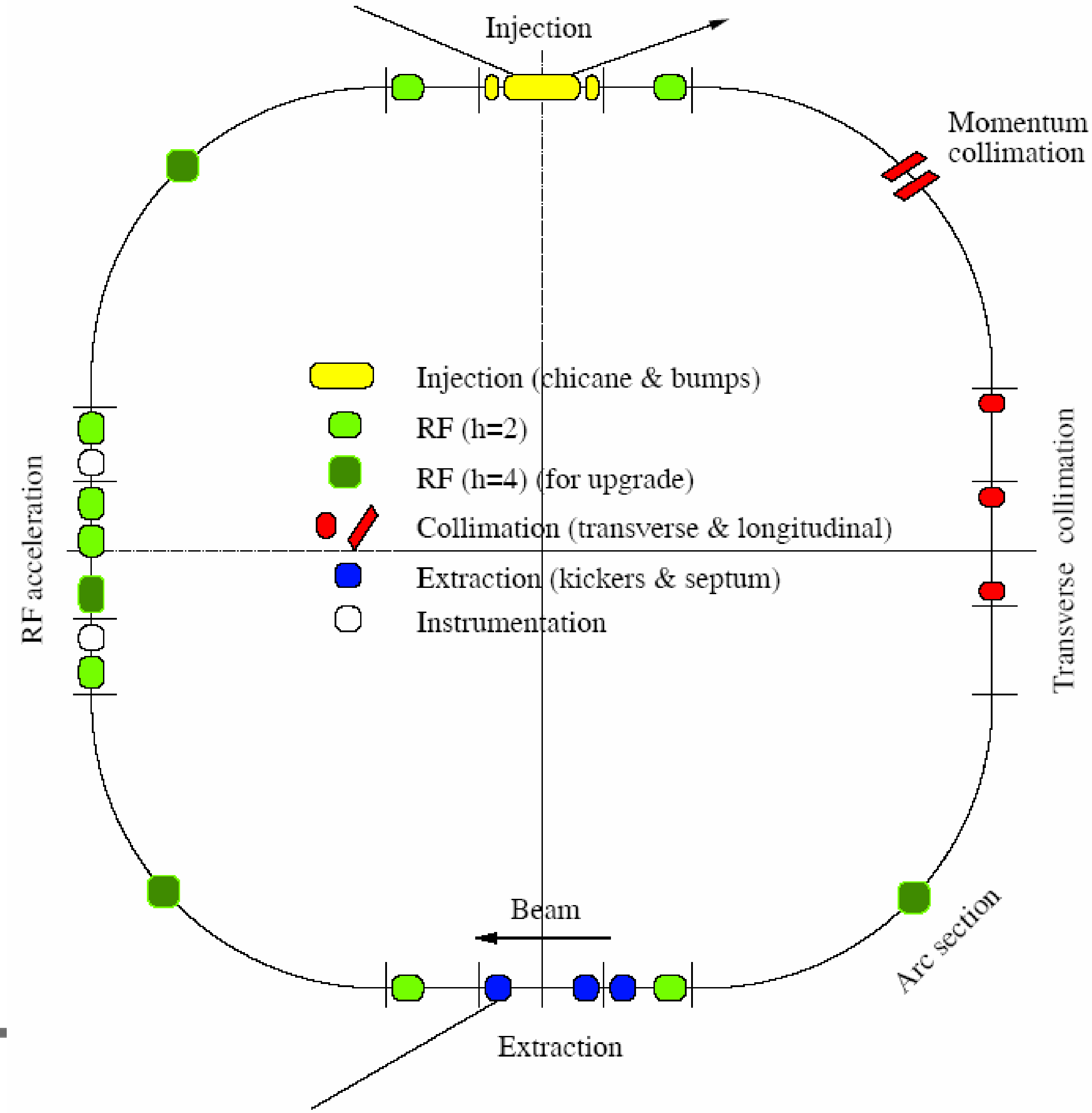

Ring lattice

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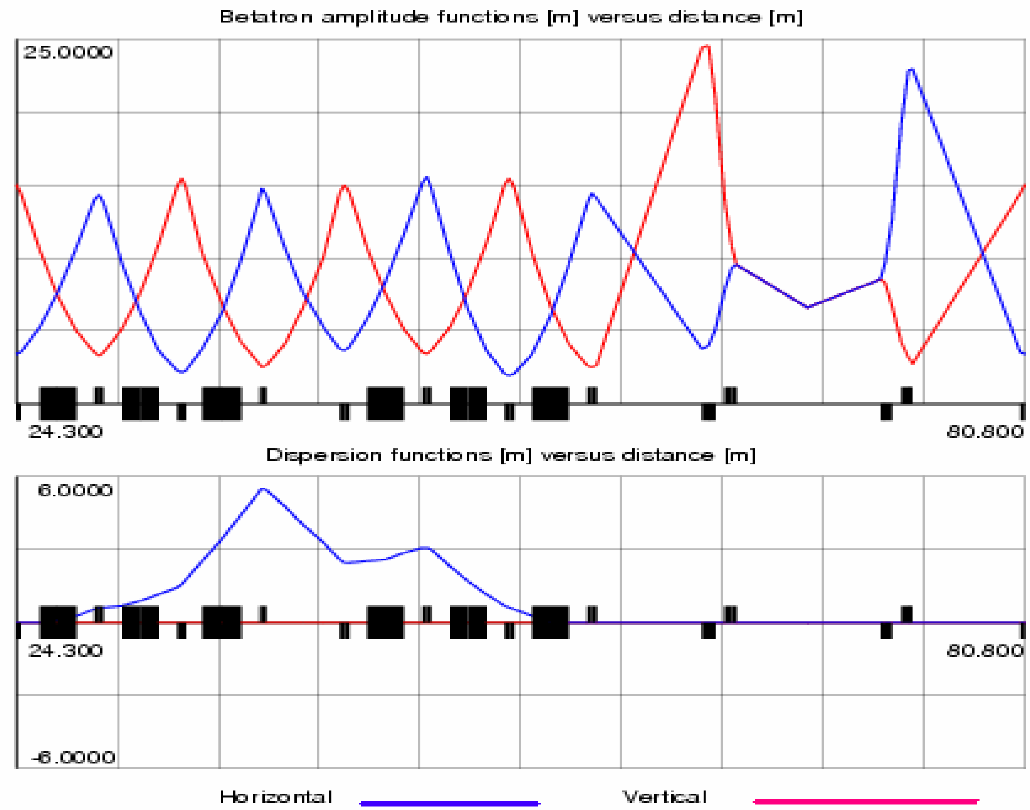
- Four-fold symmetry
  - Separated functions
- FODO arc
  - Easy correction
- Dispersion-free doublet straight
  - long, uninterrupted straight for collimation & injection
- Missing-gap momentum collimation
  - High efficiency



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Ring magnet

C.T. Shi, C.D. Deng et al

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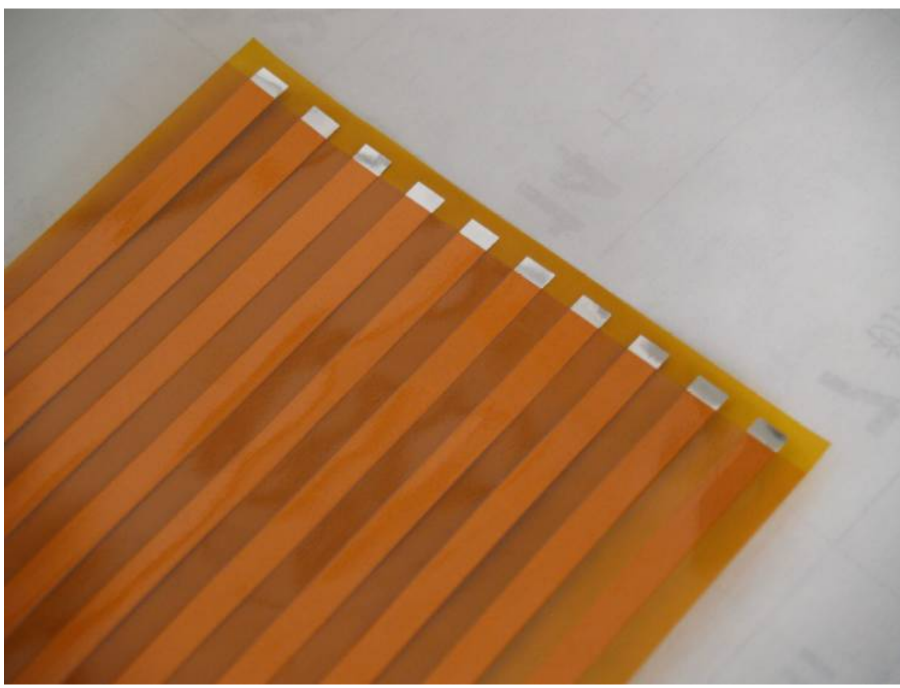
- Large aperture, laminated magnets with eddy-current cuts near the ends and plates
  - Dipole: stranded Al wire coil; successfully developed by 3 domestic vendors
  - Quad: considering split hollow-Cu wire
  - Can be used for rapid cycling medical machines

Ring vacuum

- Ceramic vacuum chamber of
  - Metallic brazing (J-PARC) anc
- Possible external wrap-on R
- Quadrupole duct developed
- Dipole duct: parallel develop
  (assistance from ISIS and .



Ring radio-frequency system

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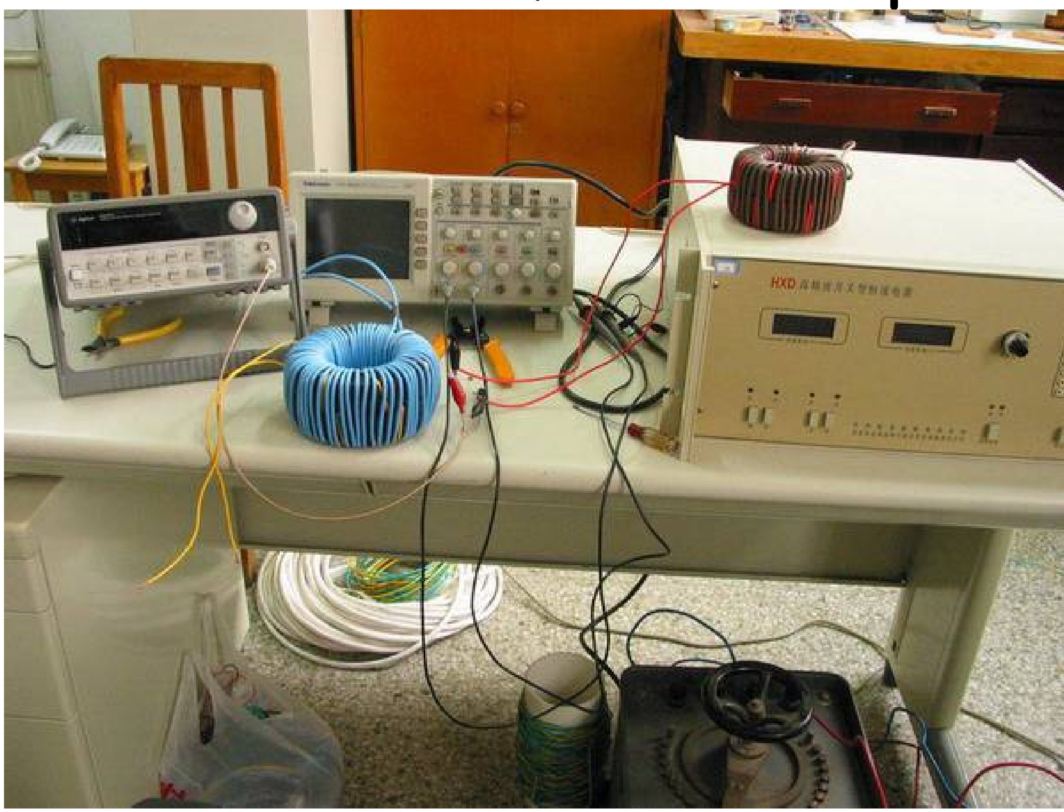
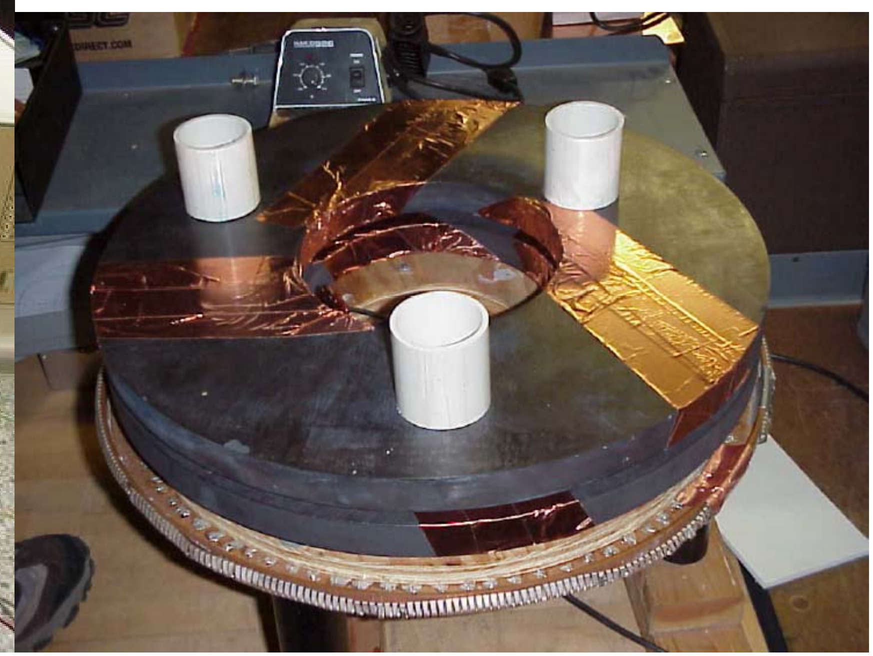
- Ferrite-loaded RF cavity 1 – 2.5 MHz
- Test of ferrite rings supplied by BNL etc.
- Controls: feed-forward, dynamic tuning, feedback, radial & phase loops





Target material R&D

(X.J. Jia et al)

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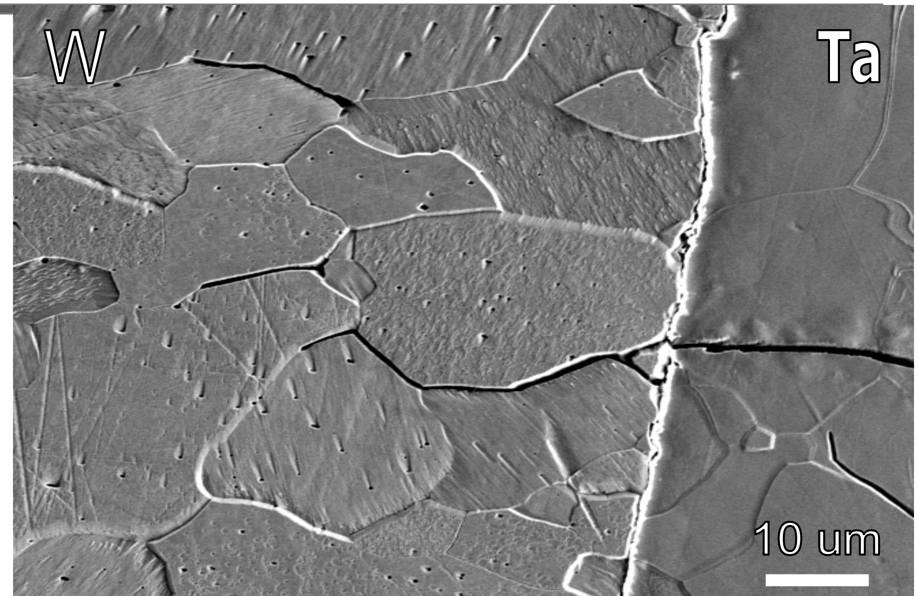
- Corrosion test of Tungsten
- Ta cladding by Hot Isostatic Pressing
- Plasma coating (air or vacuum) coating
  - Uniformity, strength, porosity
- Supersonic plasma spray (Ta-Ni-W)
- W-Re alloy



Target station

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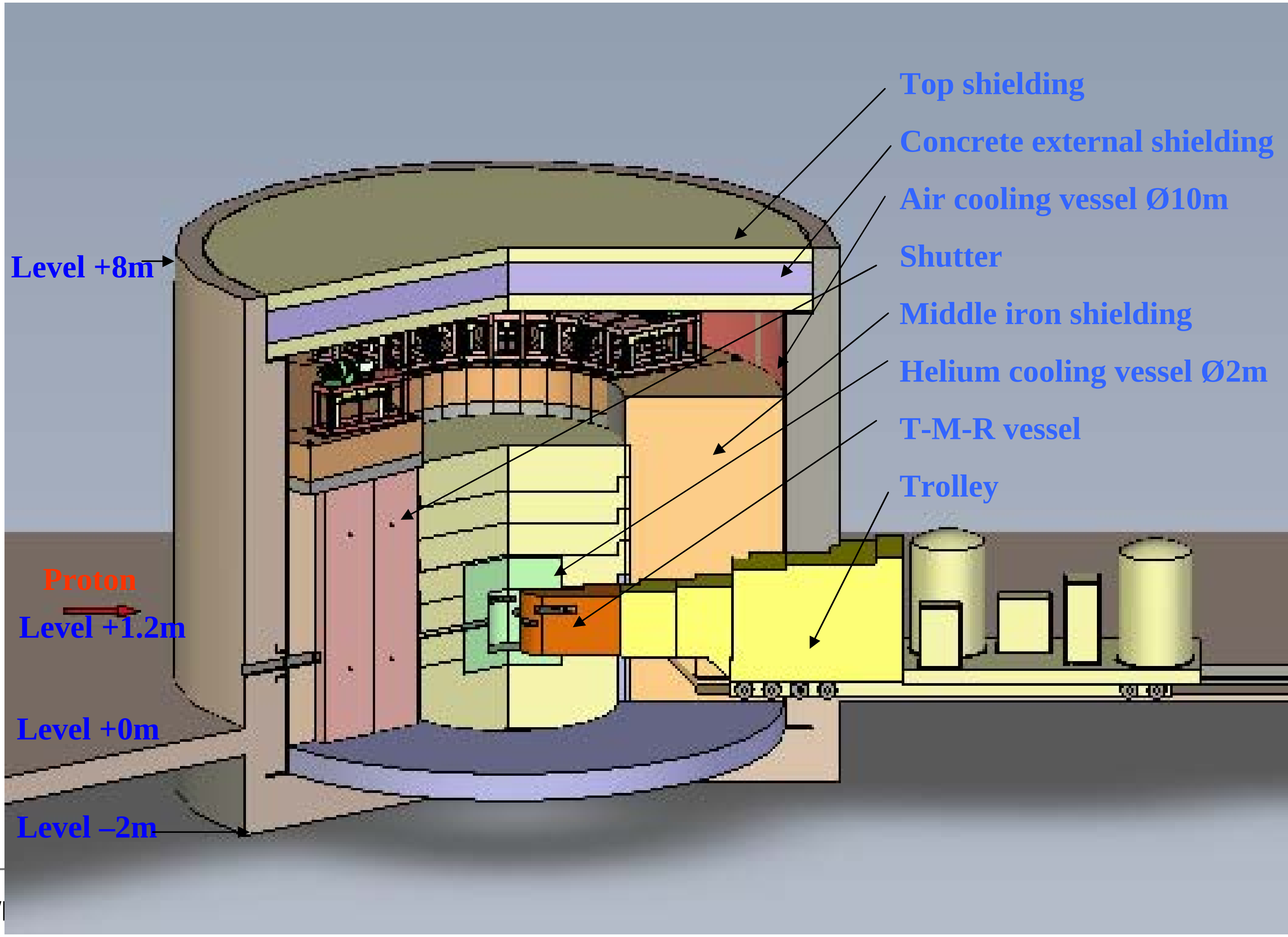

Instrument layout

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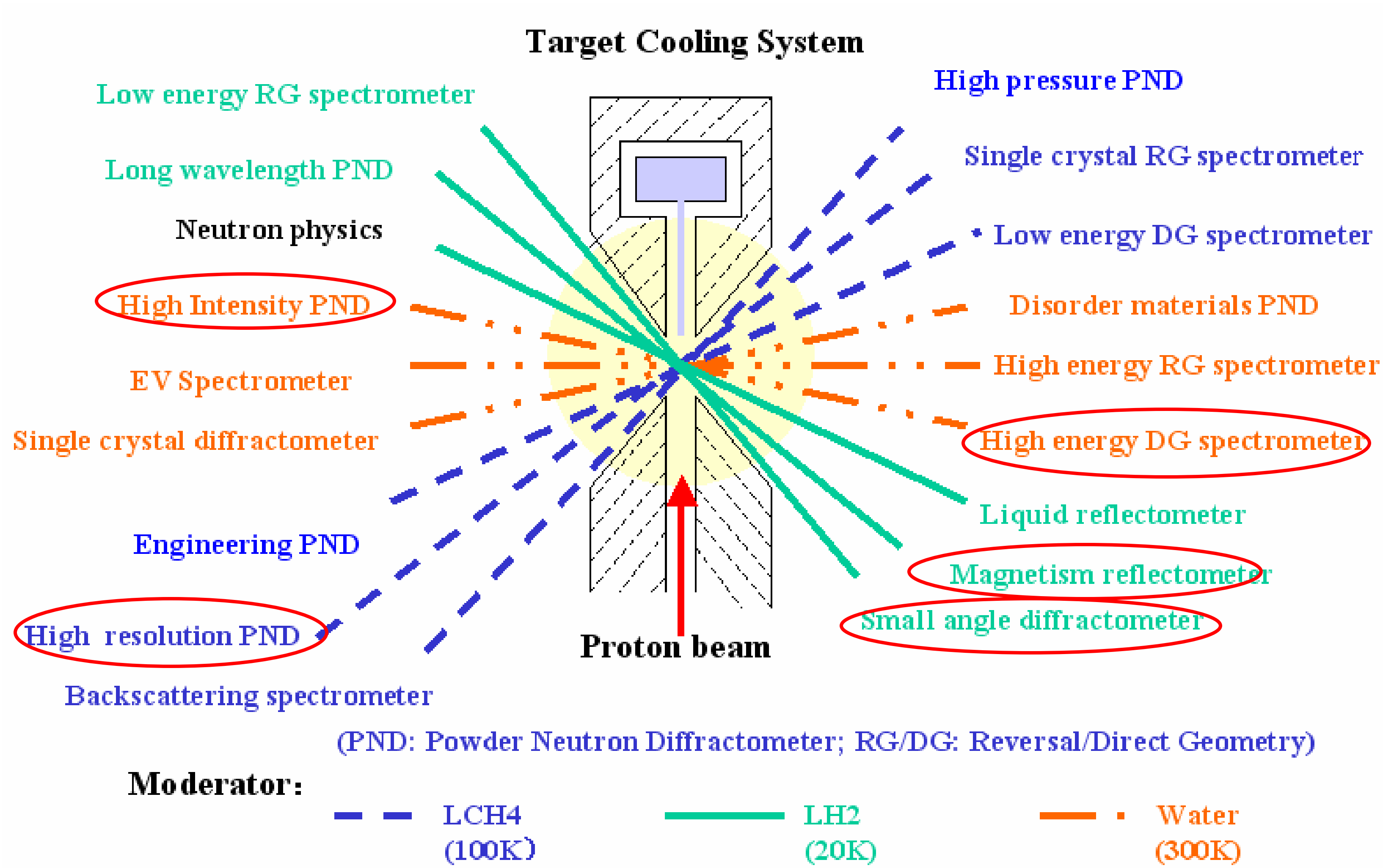

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CSNS in perspective

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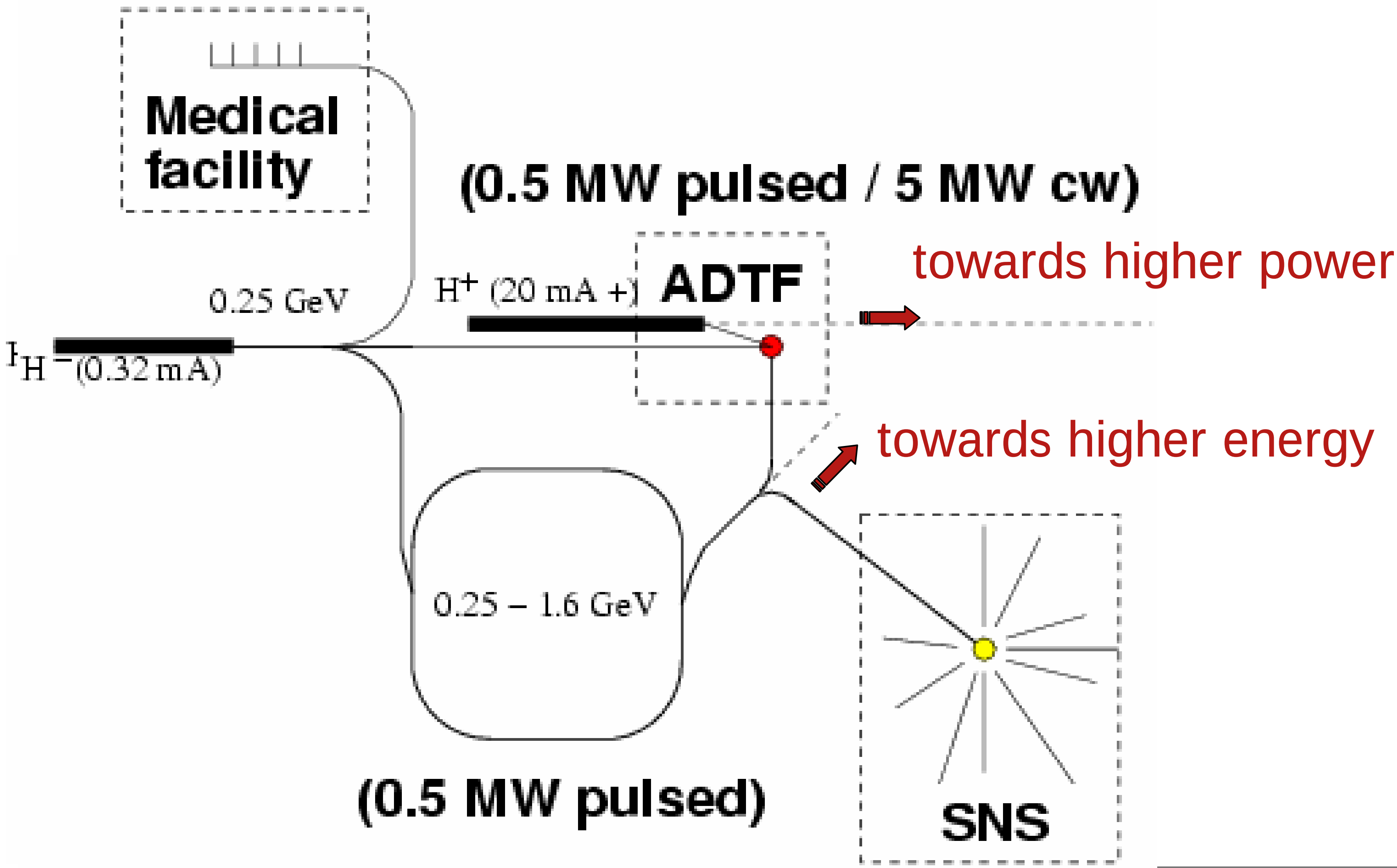

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Summary

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- CSNS is progressing with limited funds under tight schedule
- Priority: quality/user reliability, cost, future potential
- To accomplish the project with an extremely tight budget, we must
  - Develop domestic technology
  - Seek world-wide collaboration

- C1 Accelerator system development (front end & linac)
  - D. Faircloth (ISIS), (D.C.Faircloth@rl.ac.uk) ok
  - K. Hasegawa (J-PARC), (hasegawa.kazuo@jaea.go.jp) ok
  - H.F. Ouyang (ouyanghf@mail.ihep.ac.cn) ok
- D1 Accelerator system development (ring)
  - S. Henderson (SNS), (shenderson@ornl.gov) ok
  - A. Chao (SLAC), (achao@slac.stanford.edu) ok (may not attend)
  - S. Wang (wangs@ihep.ac.cn) ok
- F1 Accelerator and target/experiment interface
  - G. Murdoch (SNS), (murdochgr@ornl.gov)
  - J.Y. Tang (tangjy@ihep.ac.cn) ok
- G1 Accelerator commissioning and operations
  - D. Findlay (ISIS), (D.J.S.Findlay@rl.ac.uk) ok
  - J. Galambos (SNS), (jdg@ornl.org) ok
  - S.N. Fu (fusn@ihep.ac.cn) ok
- H1 Accelerator projects in China
  - J. Xia (IMP), (xiajw@impcas.ac.cn)
  - Z.T. Zhao (SSRF), (Zhaozt@ssrc.ac.cn) ok
- J1 Medical applications
  - S. Peggs (BNL), (peggs@bnl.gov) ok (f)
  - L. Teng (ANL), (teng@aps.anl.gov) ok (f)
  - Q. Qin (qinq@ihep.ac.cn) ok
- K1 ADS, RIA, Drivers
  - J, Lagniel (CEA), (jean-michel.lagniel@cea.fr) ok
  - W.T. Weng (BNL), (weng@bnl.gov) ok
  - X.L. Guan (CIAE), (gxl@iris.ciae.ac.cn) ok

Thank you!

Main accelerator parameters

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Table 1: CSNS accelerator primary parameters.

Project Phase	**I**	**II**	**II'**
Beam power on target [kW]	120	240	500
Proton energy on target [GeV]	1.6	1.6	1.6
Average beam current [μA]	76	151	315
Pulse repetition rate [Hz]	25	25	25
Proton per pulse on target [10^{13}]	1.9	3.8	7.8
Pulse length on target [ns]	$<$400	$<$400	$<$400
Linac output energy [MeV]	81	134	230
Ion source/linac length [m]	50	76	86
Linac RF frequency [MHz]	324	324	324
Macropulse ave. current [mA]	15	30	40
Macropulse duty factor [%]	1.1	1.1	1.7
LRBT length [m]	142	116	106
Synchrotron circumference [m]	230.8	230.8	230.8
Ring filling time [ms]	0.42	0.42	0.68
Ring RF frequency [MHz]	1.0-2.4	1.3-2.4	1.6-2.4
Max. uncontr. beam loss [W/m]	1	1	1
Target material	tungsten		
Moderators	H_2O, CH_4, H_2		
Number of spectrometers	5	18	$>$18

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CSNS target design

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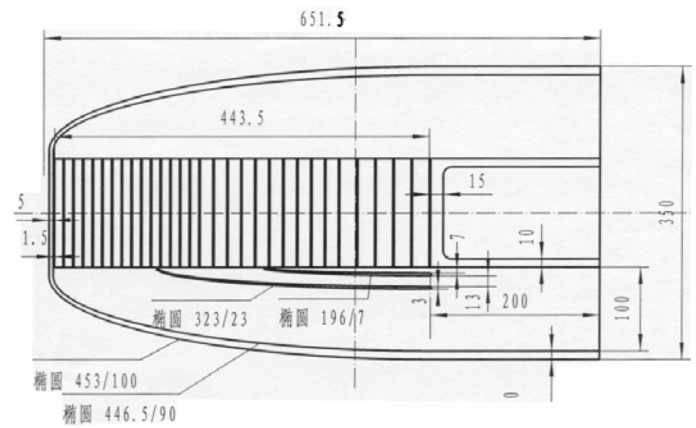
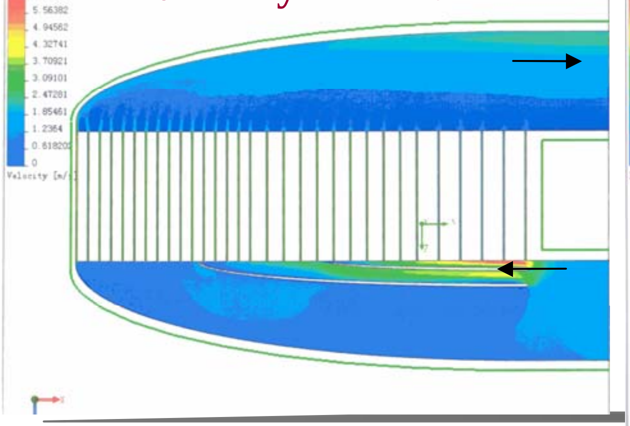
CSNS Tungsten Target

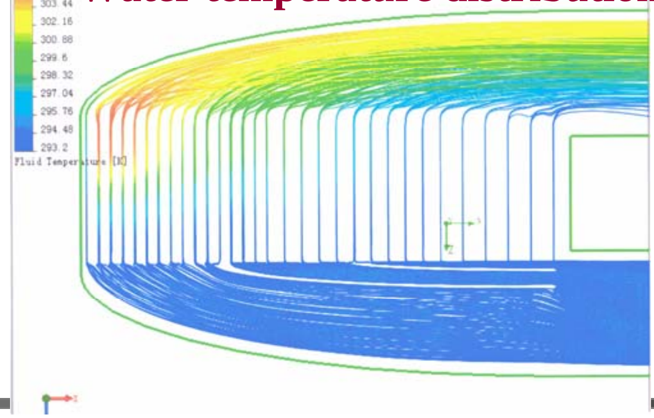
- cladding with Tantalum
- 40 high x 100 wide x 400 long (mm)---pieces stacking
- Heavy water cooling, 1.5mm gaps between both disks for cooling



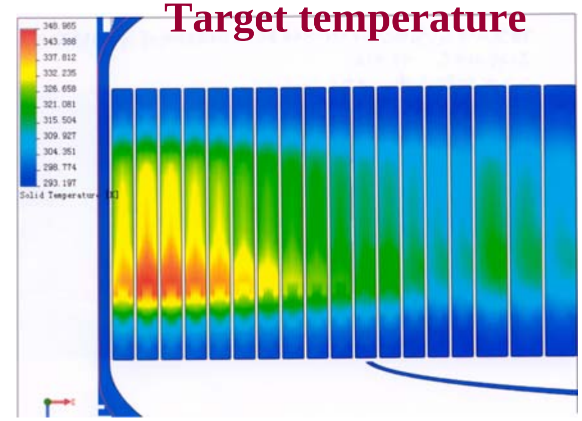
Velocity distribution



Water temperature distribution



Target temperature



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CSNS moderator configuration

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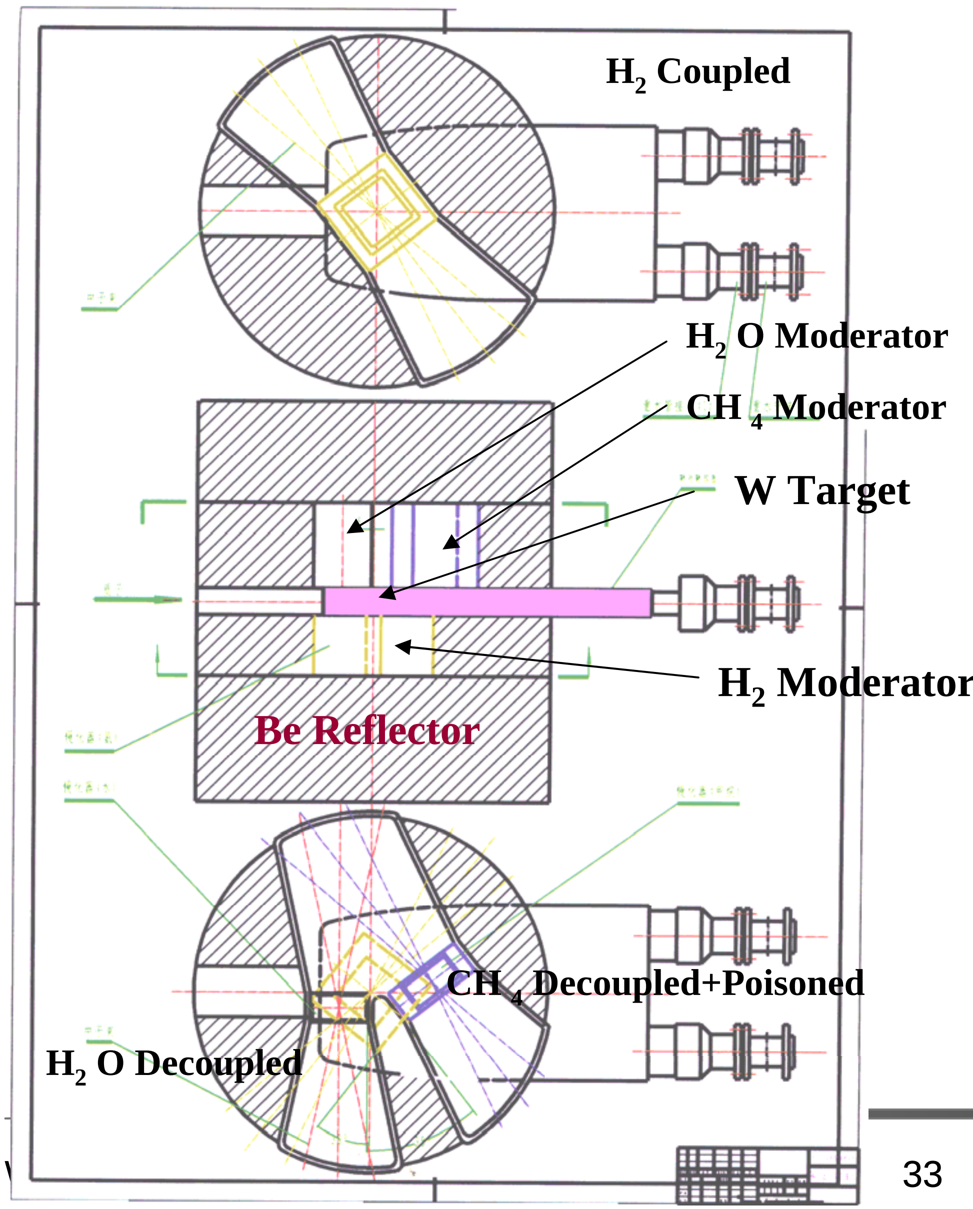

CSNS Be/Fe Reflector

Be Ø800 x 1000mm

Iron Ø$_{in}$800/ Ø$_{out}$2000mm x 1000mm

Moderators

Top upstream **H_2O, Decoupled**

300 K

Top downstream **CH_4 ,Decoupled+Poisoned**

100 K

with premoderator

Bottom **H_2 ,Coupled**

20 K

with premoderator

Monte Carlo simulation for instruments

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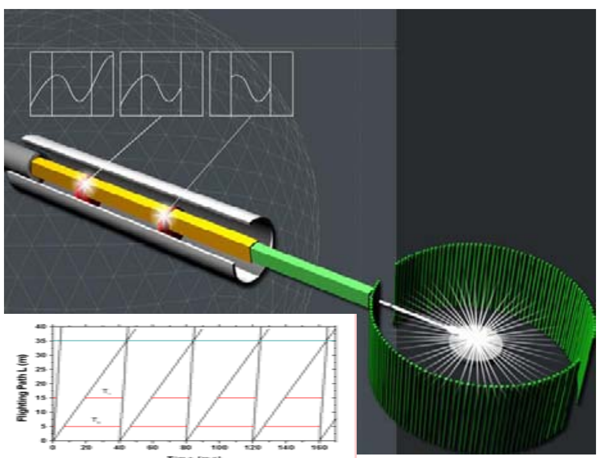
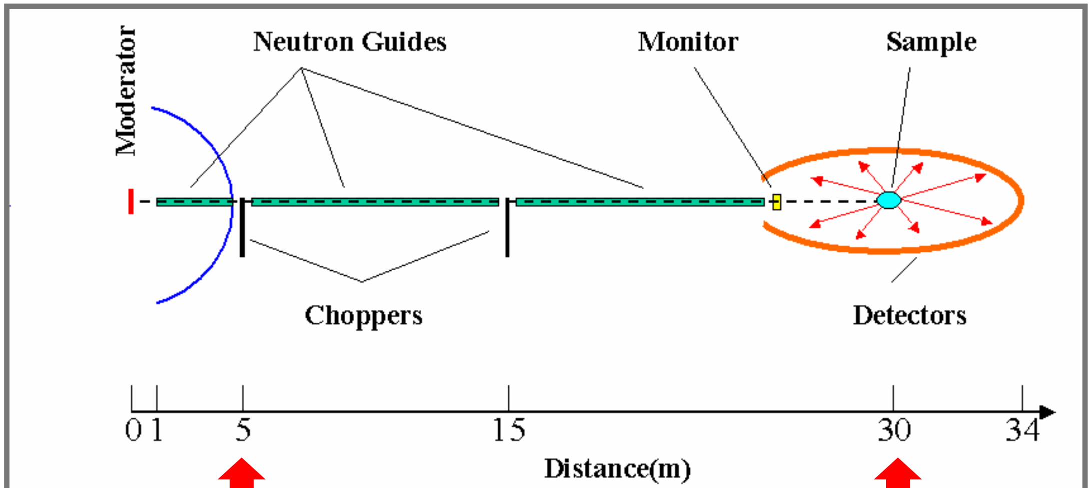
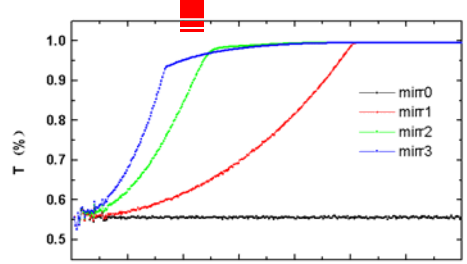
Example: Monte Carlo Simulation to optimize the neutron optics for the high intensity powder diffractometer

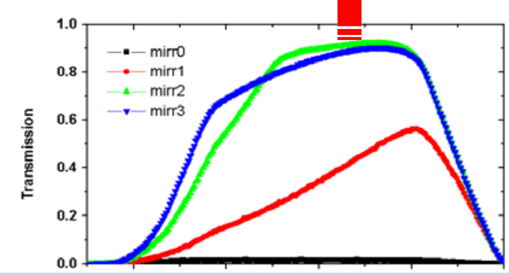
Wavelength range: 0.3~5 Å

Resolution: ~0.2%









The neutron transmission of different neutron guides

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Target materials

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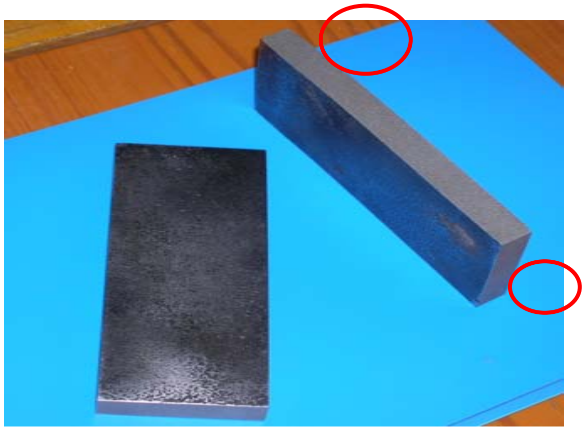
Tungsten becomes brittle by radioactive damage and easily corrodible under heavy water coolant.

•Ta cladding on W by hot isostatic press.

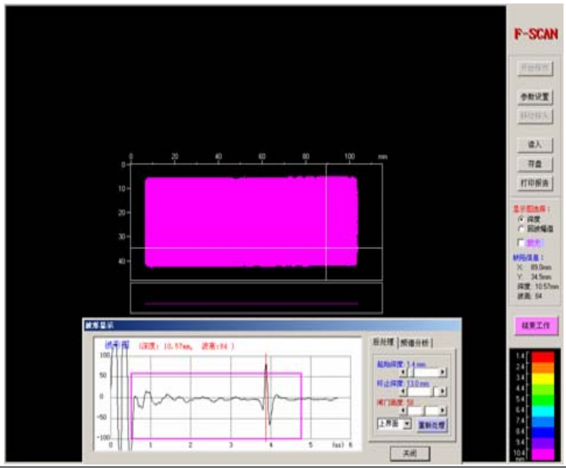
• Fabrication of W-Re (Re 25%) alloy.

W-Re alloy (Re 25%)

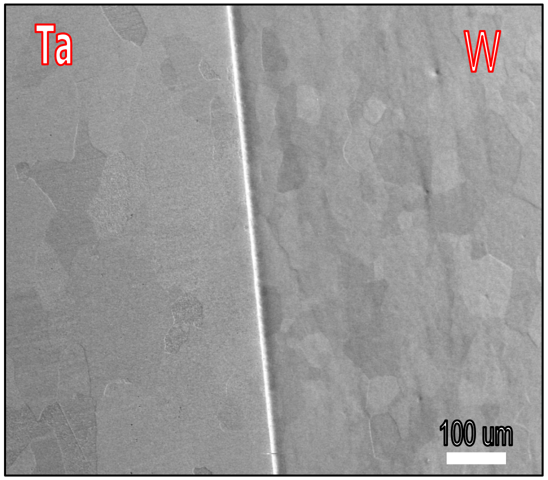


W-Ta cladding by HIP

Homogeneity by supersonic



Ta-W interface



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Sputtering system for neutron guide

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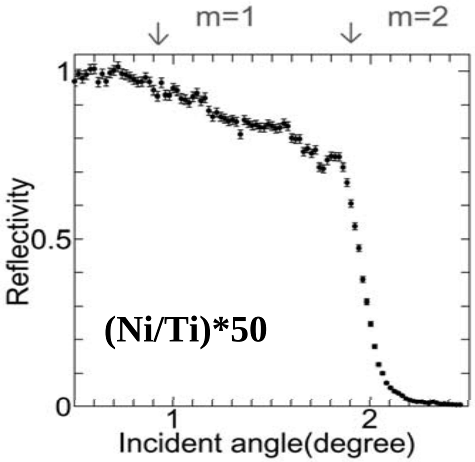
Neutron guide is an important neutron optical components to transfer neutrons efficiently to sample studied.

- **Small neutron supermirror film with m = 2 deposited successfully.**

- **New sputtering system to fabricate large area supermirror film.**



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