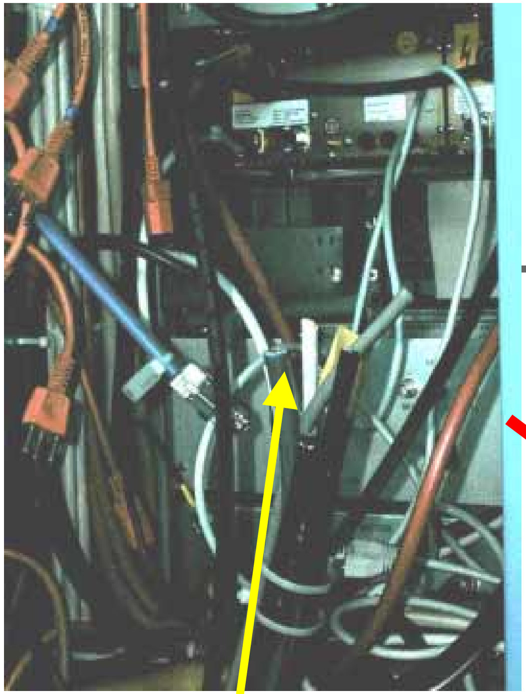
RF Control Deck Recovery



Hundreds Cables were cut during transportation from CERN.

They are re-connected without circuit diagram.

After many tries and tests, OK! It works.

Build-up of Superconducting Lab ($300\ m^2$)

Clean assembly rooms

Total area:40m²,
class 10: 7m²,
class 100:12.6m²,
class 10,000:14m².

Grinding polisher：

Max. Diameter：ϕ420；

Max. Length：575mm；

Speed：0~200rpm。

Water Purification facility

quality:18±0.2MΩ-cm；
Flux：8～20l/m

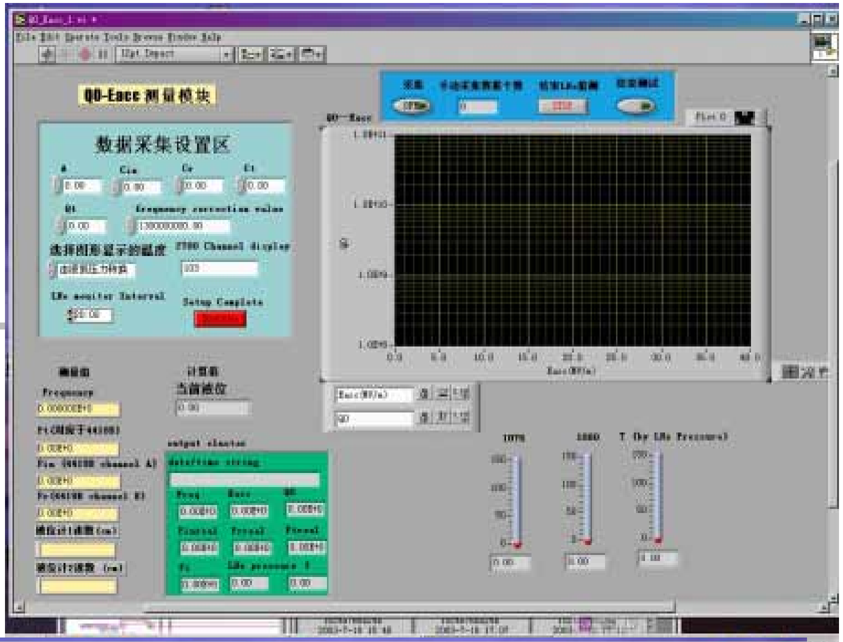
Chemical polishing facility

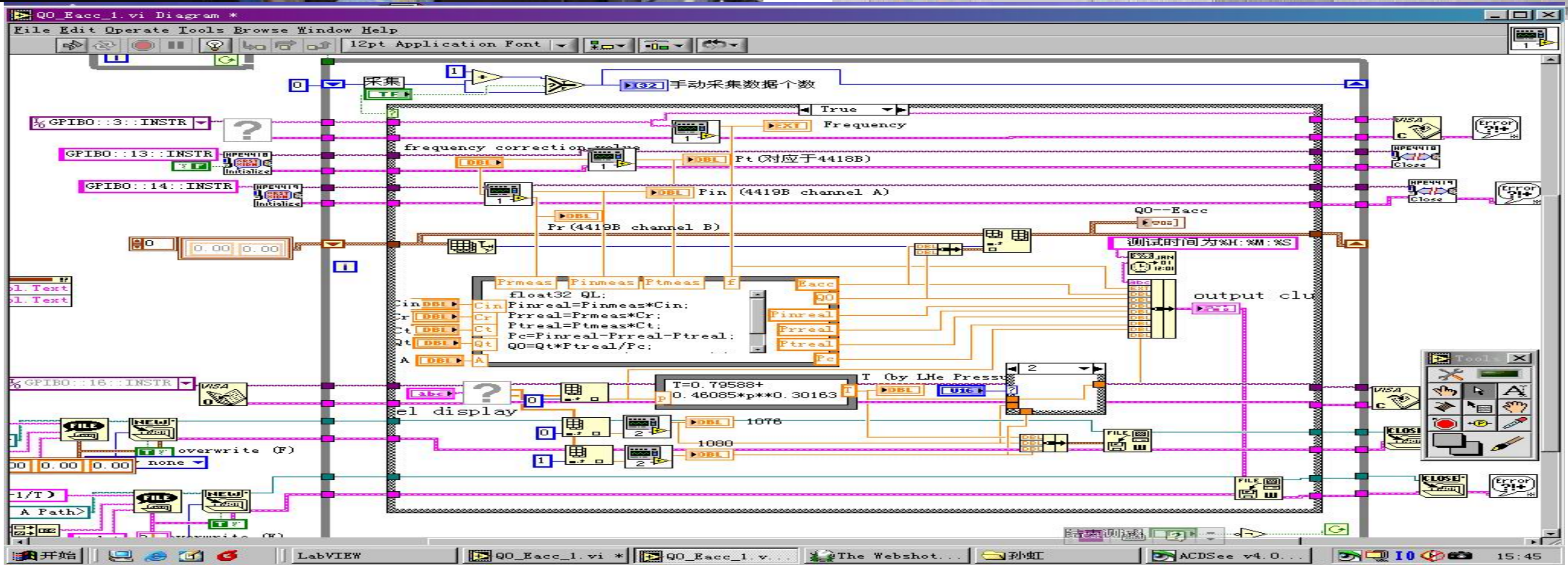
Cryostat for 1.3GHz cavity is under construction.

Inner size：Ø350×2500

Outer size：Ø420 ×3000

Working Temperature：1.5~4.2K





LabView software for the measurement control and data processing.

2. Sub-Critical Blanket

1) In subcritical reactor optimization study, as the first step, we set up the software package for reactor neutronics research to deal with some special issues in reactors blanket, including the existence of external neutron source, deep burnup, complex structure configuration, etc.. Validity of this package has been confirmed by the benchmark of IAEA's standard example.

We also analyzed the influence of uncertainness of nuclear data on the design of neutronics.

- **A Benchmark Issued by IAEA to**
  Analysis of Neutron Performance
  Validates Database and Codes
- **To calculate this benchmark, we developed**
  MCNP-ORIGEN2 and TWODNT code systems
- **Calculations were made to**
  initial enrichment of ^{233}U
  spatial distributions of power density
  void reactivity effects
  spallation source effectiveness etc

subcritical test facility

2) In the reactor physics study, we set up a subcritical test facility of zero power driven by a external neutron source of ^{252}Cf. Based on this facility, some experiments have been conducted, including critical test, measurement of the effective neutron multiplication factor k_{eff} with four different methods, measurement of fission rate at different subcritical points.

DF-3 Zero power facility re-built as external source driven facility with

^{252}Cf as external source

20% enrich.U_3O_8 powder

light water as moderator

Measurement on

k_{eff}

Fission rates

Neutron flux

Purpose of the DF test

- **A experimental facility has been established to measure K-eff, fission rates, and enhancement of external neutrons in a external driven system. The facility consists of a Cf-252 neutron source and a zero power fast facility.**

Nuclear data library

3) Nuclear data library is expended to the higher energy (20MeV) to meet the need of subcritical reactor system optimization. The researches on the theoretical model, calculation method and data evaluation methods for the medium and high energy nuclear reaction have been made. We also studied the dependence of the neutron spectrum and yield by a spallation target on the shape and size of the target.

Target and window’s material

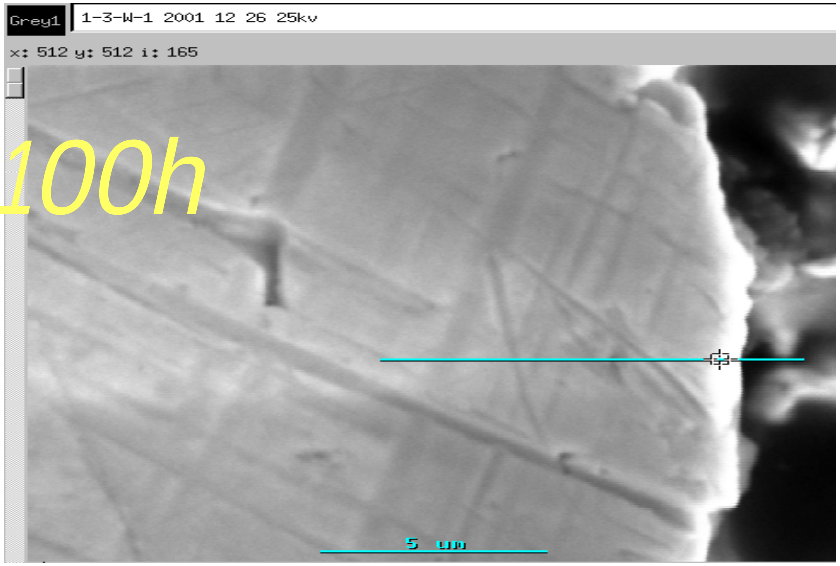
4) The target and window’s material is a rather difficult issue. The radiation damage study of the target and window materials is of great importance for the understanding of the their lifetimes and the safe operation of the ADS. We use heavy ion to irradiate, modeling neutron’ radiation equivalently but much quickly, several kinds of materials for material selection. The compatibility of the target material tungsten with water and sodium has been experimentally studied. Fluid test device is under preparation and some numerical simulations of the thermal engineering problem have been carried out.

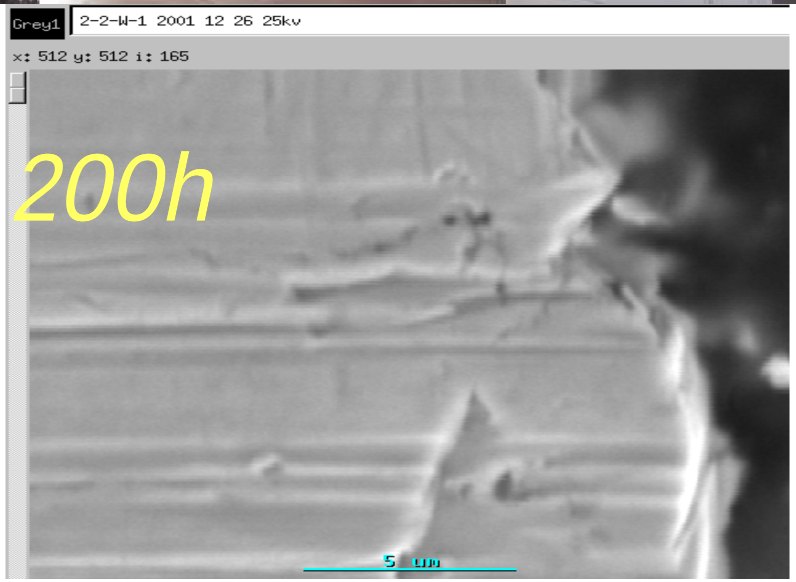
Material Compatibility Tests

Tungsten

in Na at 500 - 700 ℃

in water at 100 ℃





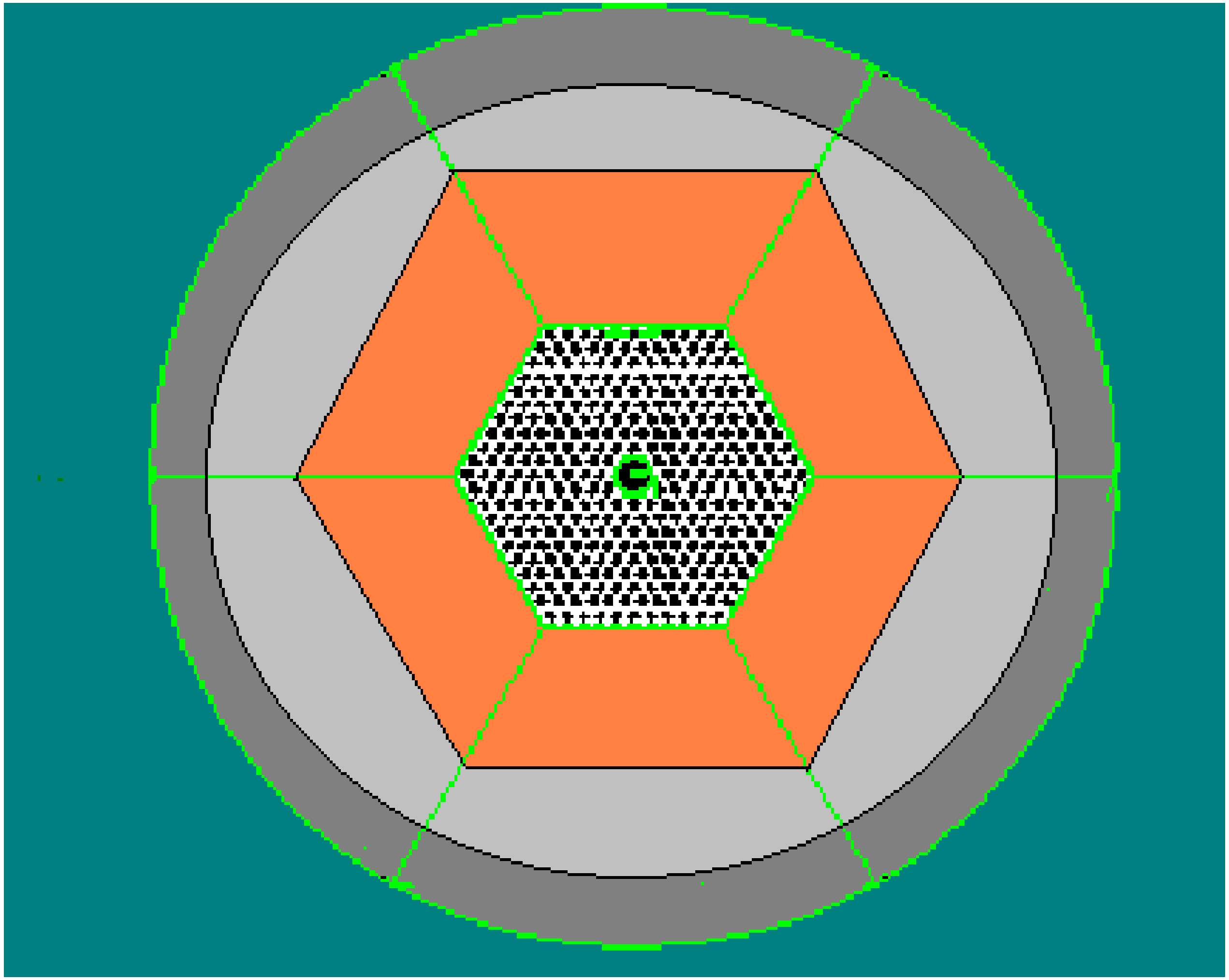
4 Research Plan in Near Future on ADS

VENUS Facility

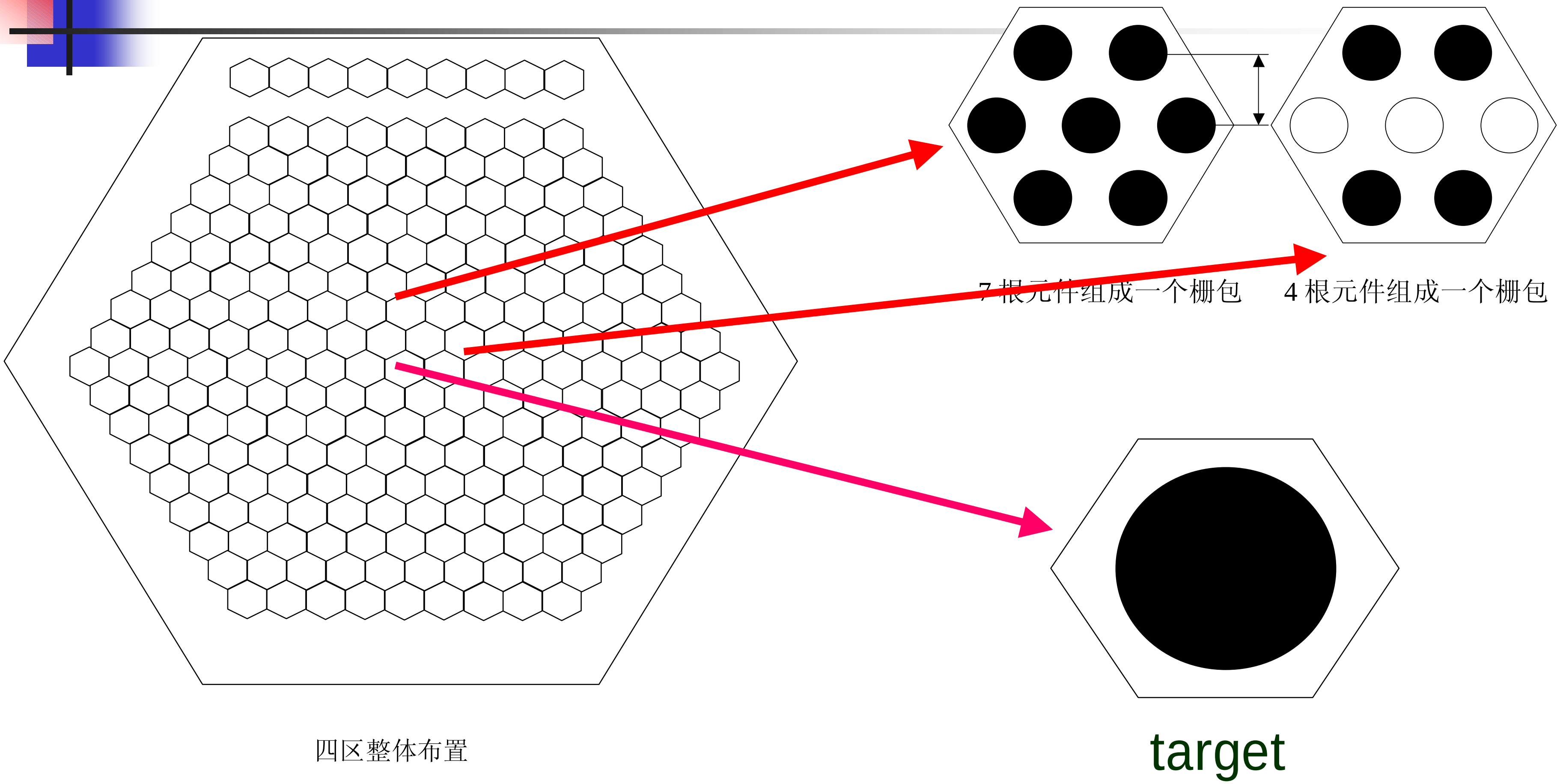
- Consists of
  sub-critical assembly driven by
  pulsed fast external neutron source
- Study
  neutron flux distribution
  neutron energy distribution
  neutron enhancement
  fission rate and k_{eff}

Arrangement of the core

- Source / Buffer
- Driven Zone
- Active Zone
- Reflector
- Shielding



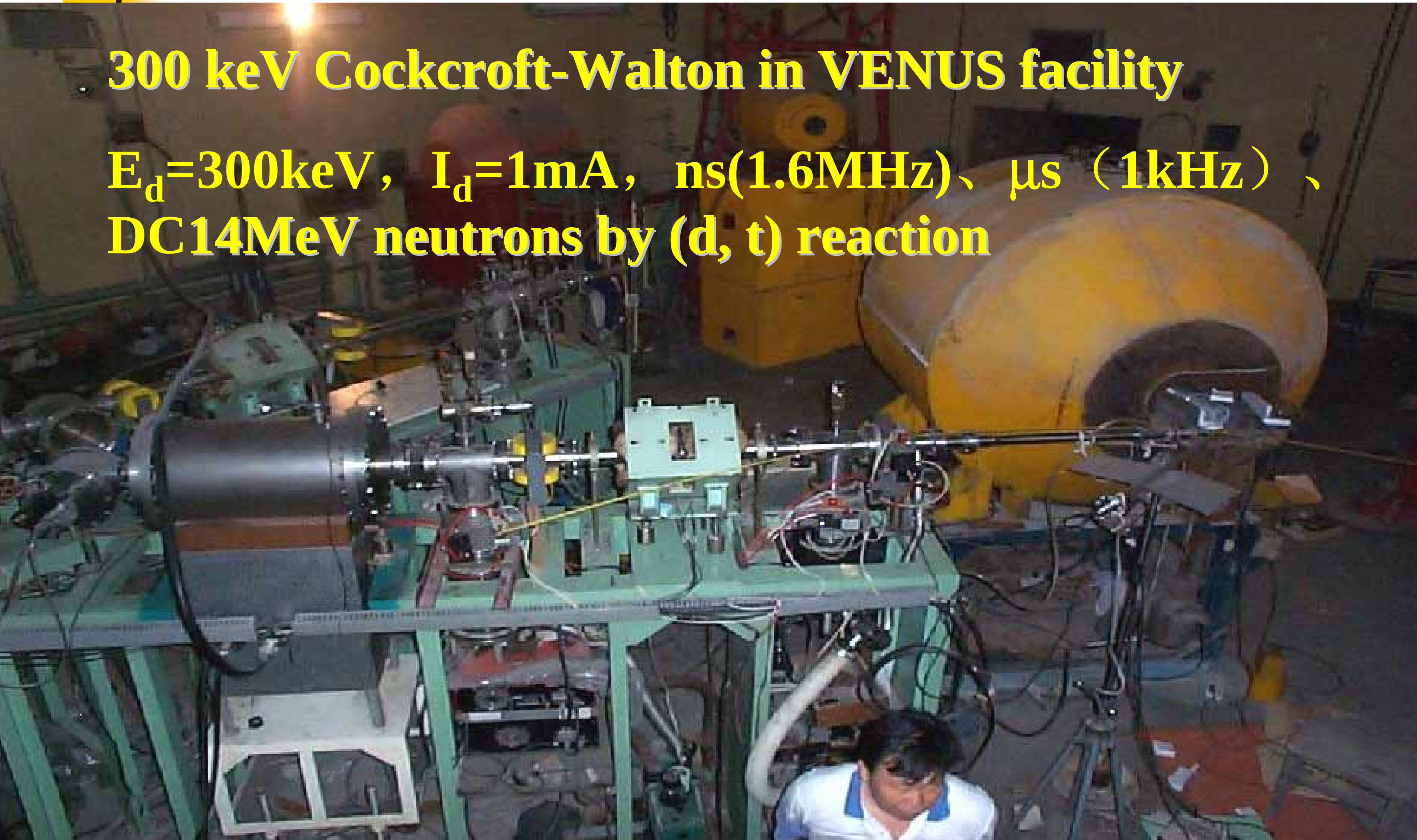
Configuration of the core of VENUS facility



External neutron source

300 keV Cockcroft-Walton in VENUS facility

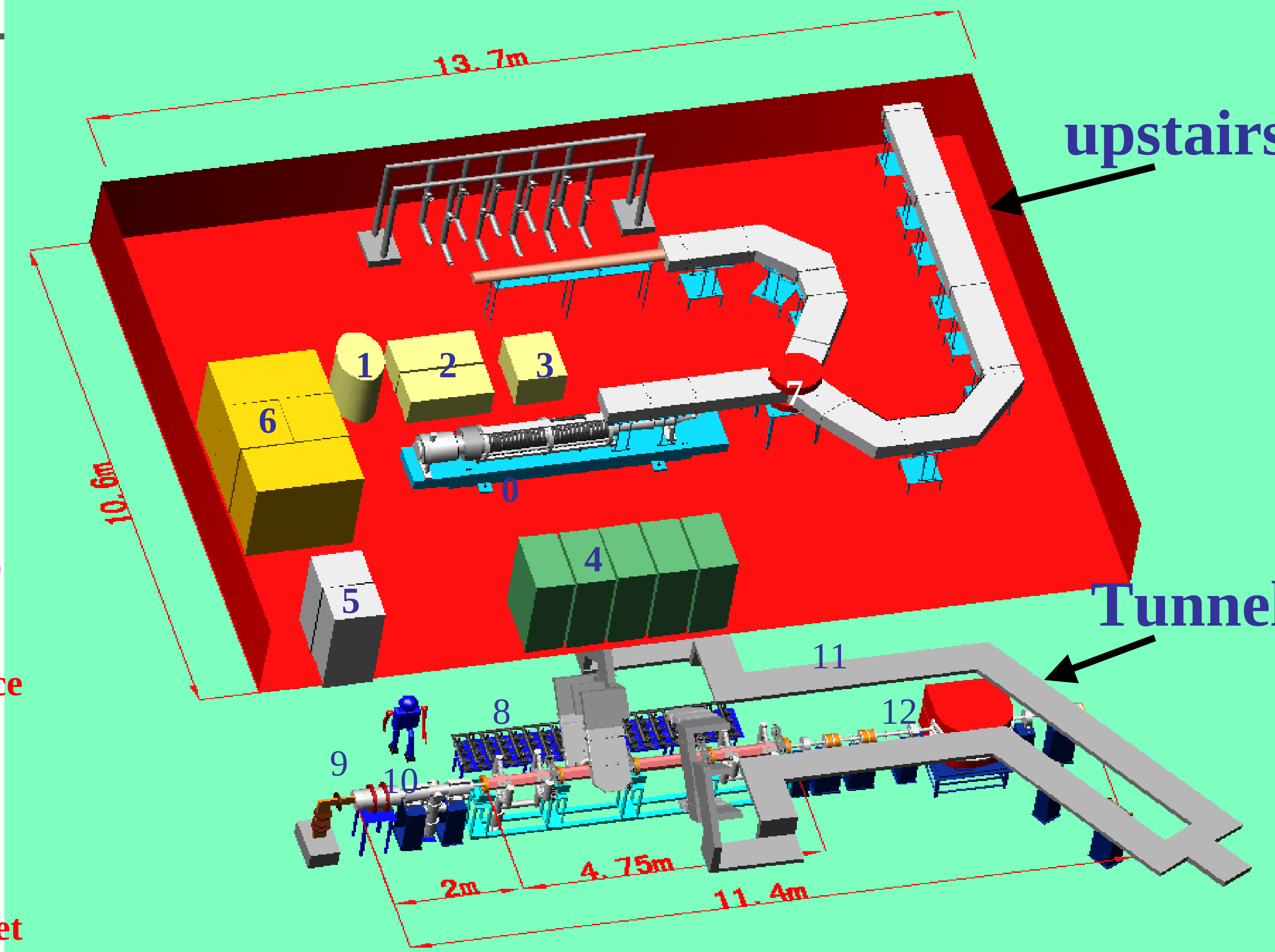
E_d=300keV， I_d=1mA， ns(1.6MHz)、μs（1kHz）、DC14MeV neutrons by (d, t) reaction



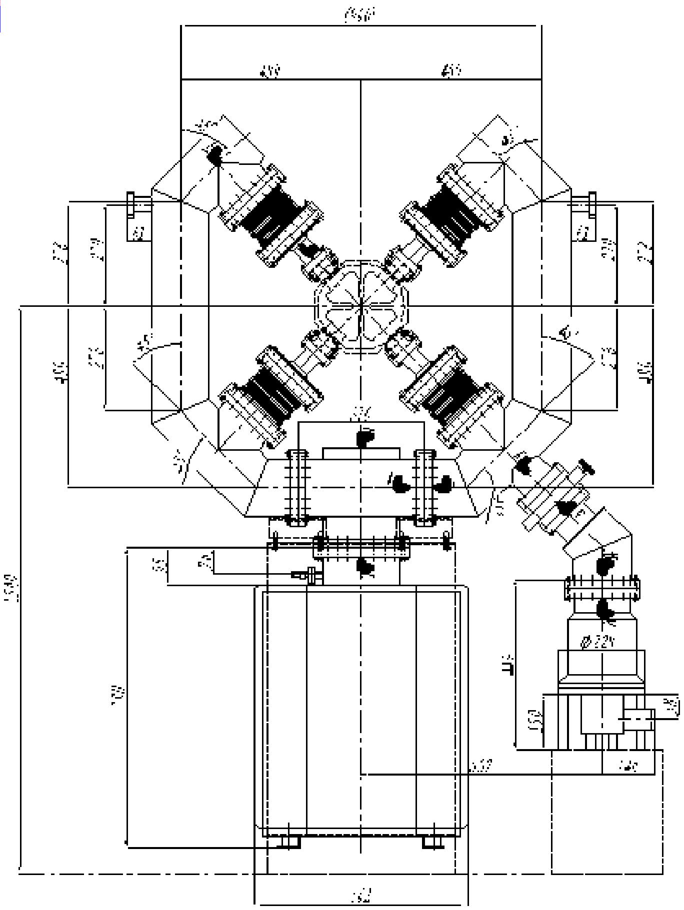
Main Control Room of 3.5MW Swimming Pool Reactor

RFQ Linac

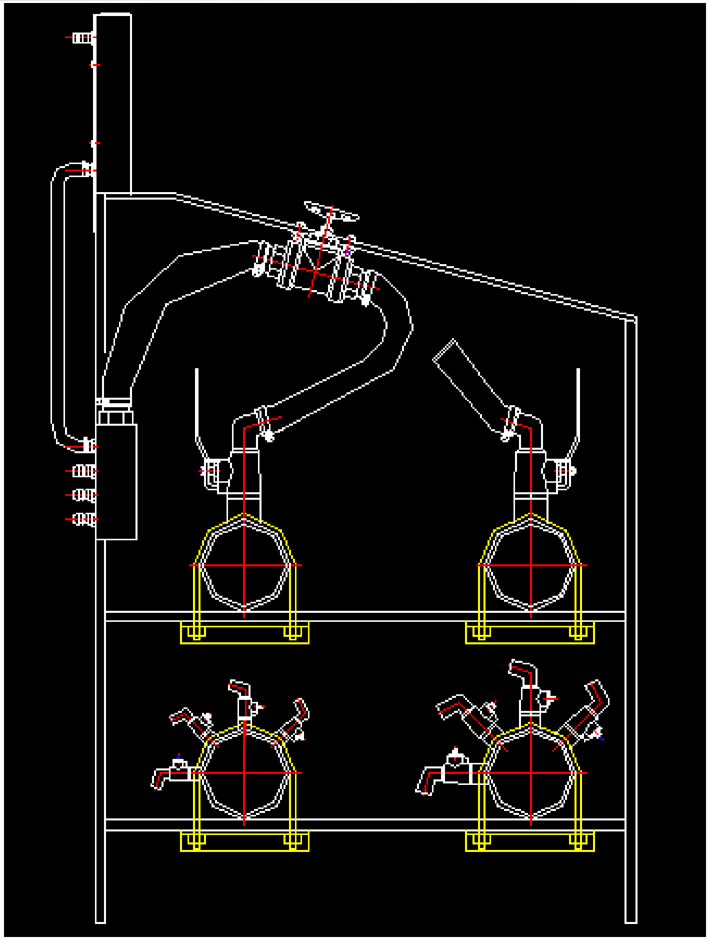
0:Klystron
1: Modulator
2:Capacitors
3:Crowbar
4:Control deck
5:Breaker
6:Thyristors& Rectifiers
7:Circulator
8:Cooling-water distributor
9.ECR-ion source
10.LEBT
11. Waveguide
12 MEBT with analyzing magnet



RFQ Subsystem setup

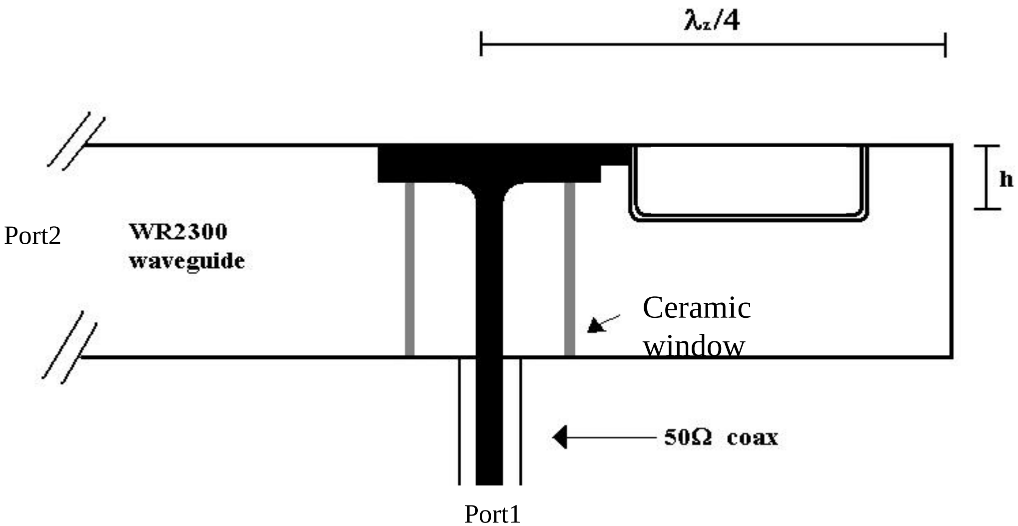


Vacuum pump guide

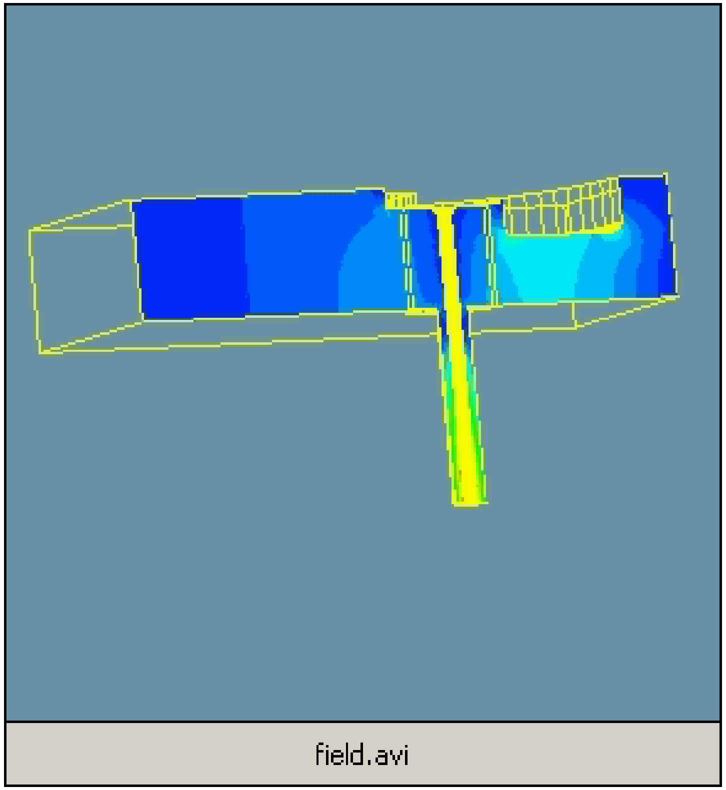


Cooling water distributor

RF-power transmission

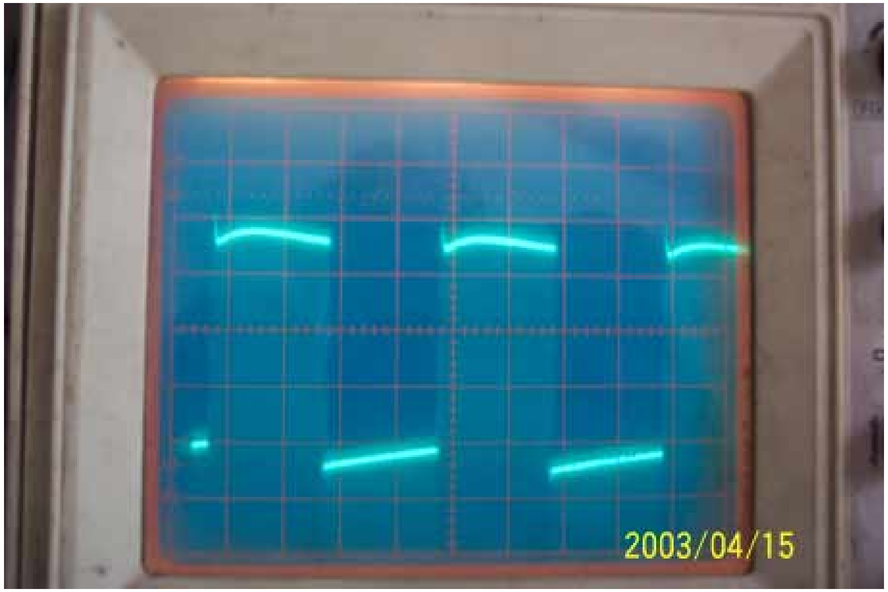


Waveguide-coaxial transition



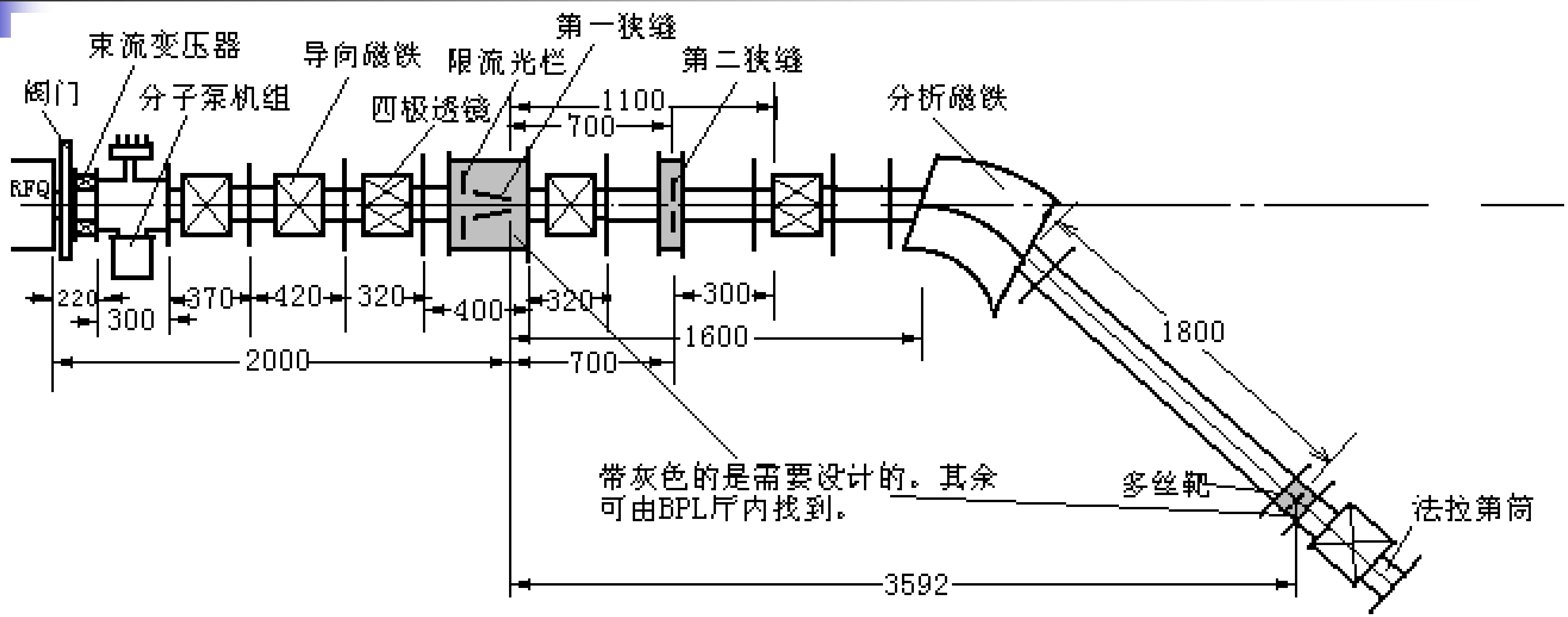
Kicker in LEBT

The Kicker in the LEBT will soon be setup for beam test.



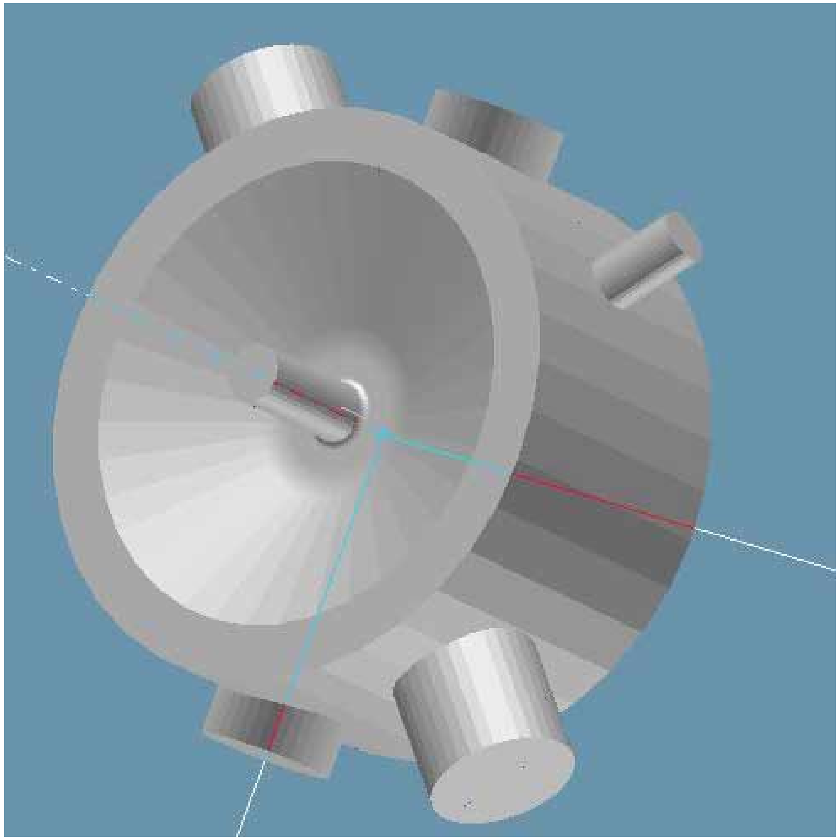
Pulse shape of the power supply of the kicker(rise-time 35μs).

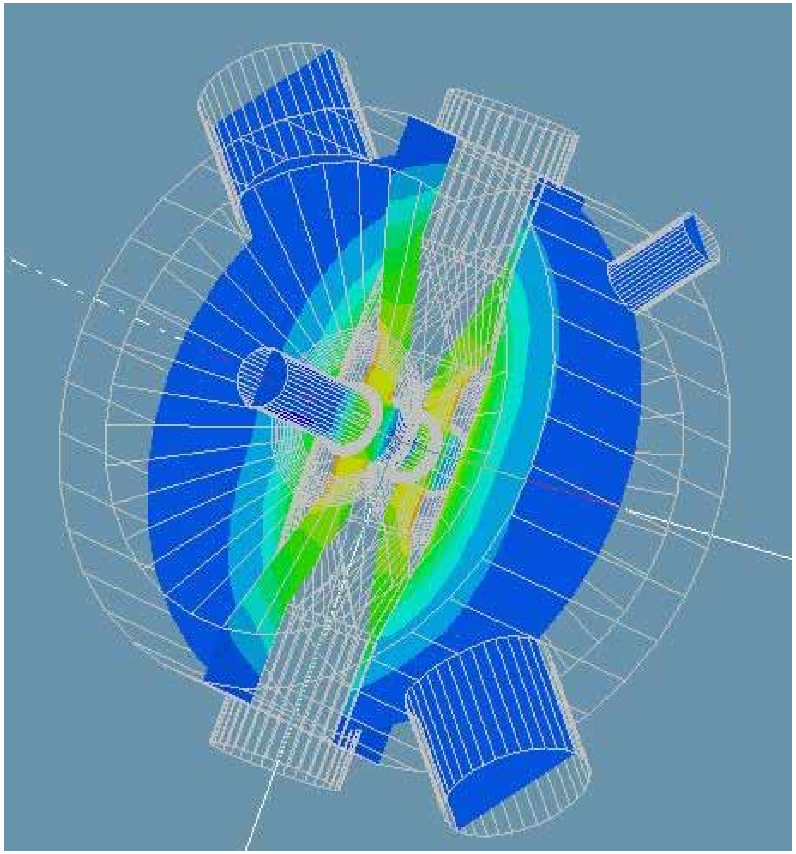
MEBT



MEBT for the beam diagnostics is designed.

Spoke cavity

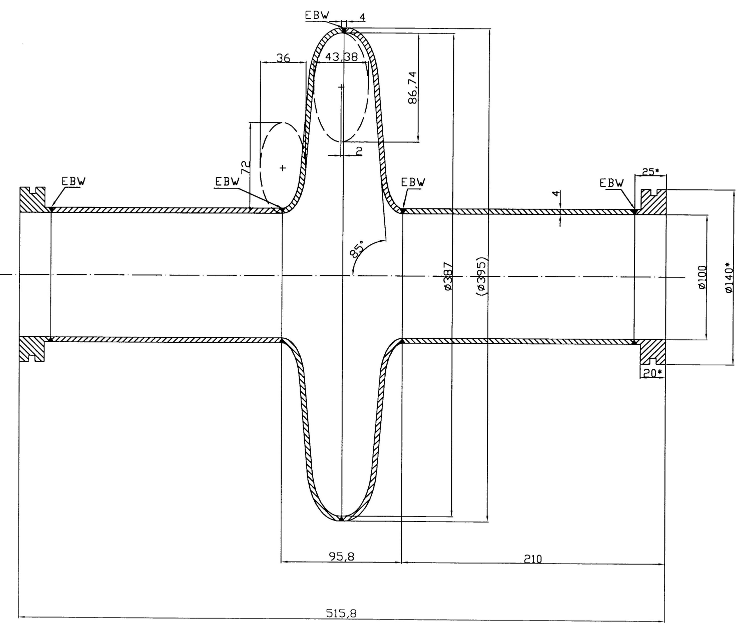




Superconducting spoke cavity is under preliminary design study.

Low-Beta spherical cell

A 700MHz/ β =0.45 cell has been designed for fabrication



	Five-cell	Single cell (with beam pipe)
Frequency（MHz）	703.655	696.812
Eacc[MV/m]	9 ~ 10	9 ~ 10
Esp/Eacc	3.538	3.319
Bsp/Eacc[mT/(MV/m)]	8.546	8.15
Esp[MV/m]	31.84 ~ 35.38	29.87 ~ 33.19
Bsp[mT]	76.91 ~ 85.46	73.35 ~ 81.5
kcell	1.89%	(Ri=50mm)

5. Consideration in near future

A moderate style multi-purpose verification system is under consideration. In the conceptual study, we consider:

- **Low energy accelerator (150MeV/3mA proton linac)**
- **Modified existed swimming pool light water sub-critical reactor**

Proposal of CSNS

1, Introduction

1. It is well known 21st century will be an era of material science, life science and information science.

2. Neutron is an ideal probe to study and develop these sciences. So the demand from users of the neutron source is getting rapidly increased.(3 SR)

3. Chinese experts of neutron science and of accelerators had a series of discussions and finally most of them agreed that to build a modest spallation neutron source with beam power of 100kW at China in next 5-7 years,it would be a suitable choice.

4, At present, Chinese Academy of Sciences encourages Institute of Physics and Institute of High Energy Physics to jointly start feasibility study of CSNS, and based this study, to submit a proposal to our government.

Guidance principle of CSNS:

1, **It should be fit in China's present economic situation. Total cost of CSNS should less than 150 M$.**

2, It should be an advanced machine in the world and can be used to do important multi-disciplinary scientific research work.

3, It should have potential for further upgrading.(0.2MW for phase 2)

4, The technology should be mature.

2, preliminary consideration of CSNS

CSNS Phase I: Conceptual design

- **Repetition rate ： 25 Hz**
- **Average proton current： 65 -125 μA**
- **Proton kinetic energy： 1.6 GeV**
- **Average beam power： 100 kW -200kW**
- **Target: Tungsten(to be discussed)**
- **Moderators: Solid CH_4(to be discussed)**
- **Spectrometers:**

  HRPD (high resolution powder deffractormeter),

  Reflectormeter,

  SANS (small angle neutron scattering),

  Chopper spectrometer(inelastic)

Four Spectrometers

The four initial instruments will be set up (HRPD, DGS, SANS and REF) at the outset. It covers major parts of science areas.

Target

Main Parameters of the Target Station of CSNS

Total beam power at target	100 KW
Kinetic Energy of proton	1.6Gev
Time structure of proton pulse	$< 1\mu s$
Energy content of each proton Pulse	4KJ
Repetition rate	25 Hz
Proton beam diameter at target(elliptical)	$3 \times 10\ cm^2$
Target	Tungsten cladding with Tantalum D_2O cooled
Moderators	RT H_2O, L H_2, L CH_4,(Solid CH_4)
Reflector	Pb/Be, D_2O cooled

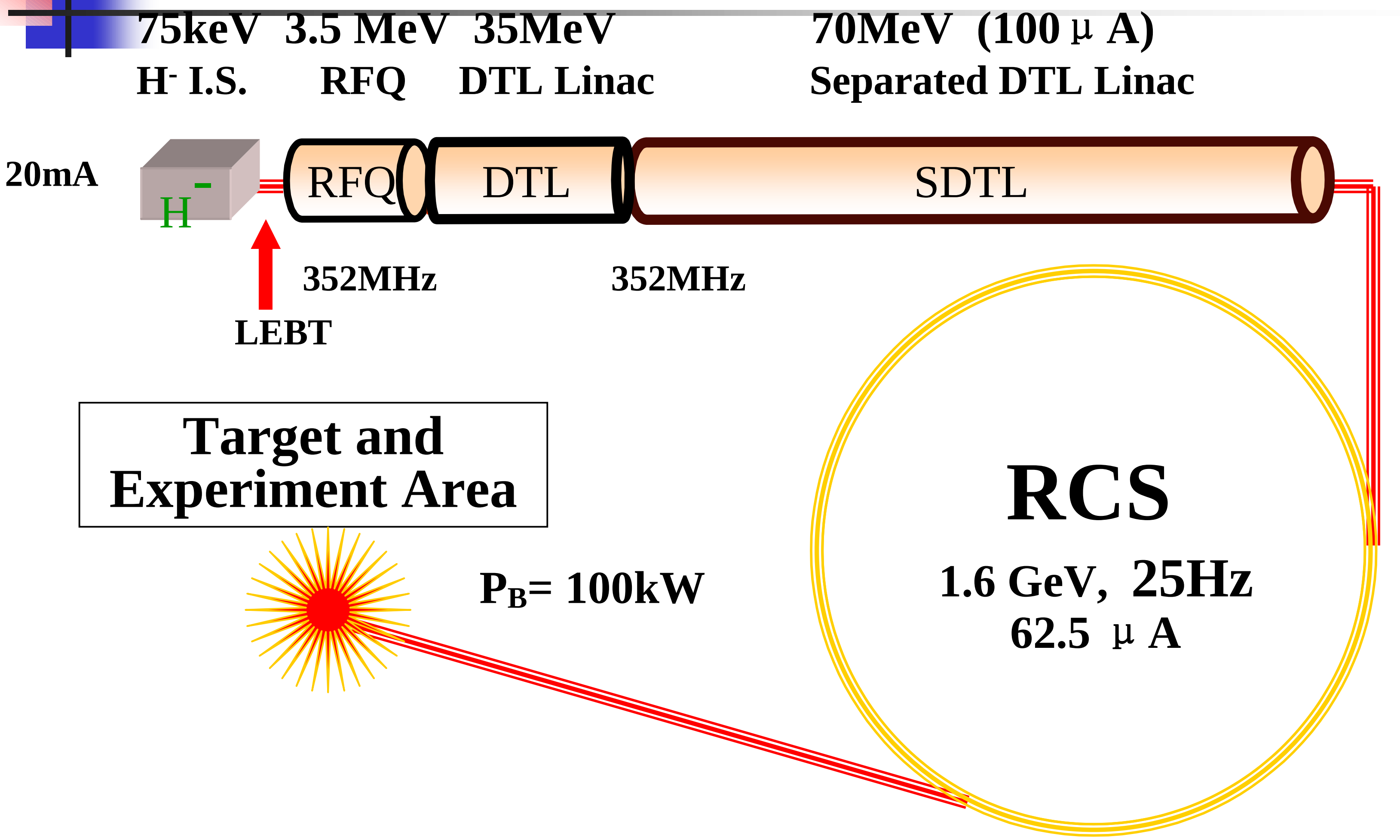
- Monde Carlo calculation (Neef 1995)

Monde Carlo calculation give a total deposited power of 47KW i.e. 47% of total beam power. If 20% margin is added to give the design value for total deposited power in the target, i.e. 60KW.

Accelerator
Design Guidance

- **Low beam losses:** to ensure the radioactivity induced by the lost particles on machine is low enough to allow manual maintenance on the linac.
- **High reliability:** to provide beam more then 240 days per year.
- **Low cost:** parameter optimization for low investment and operation cost.
- **Upgrade feasibility:** phased development to higher beam power to meet the demand from users of multi-disciplines in future.

Schematic plot of CSNS Accelerator



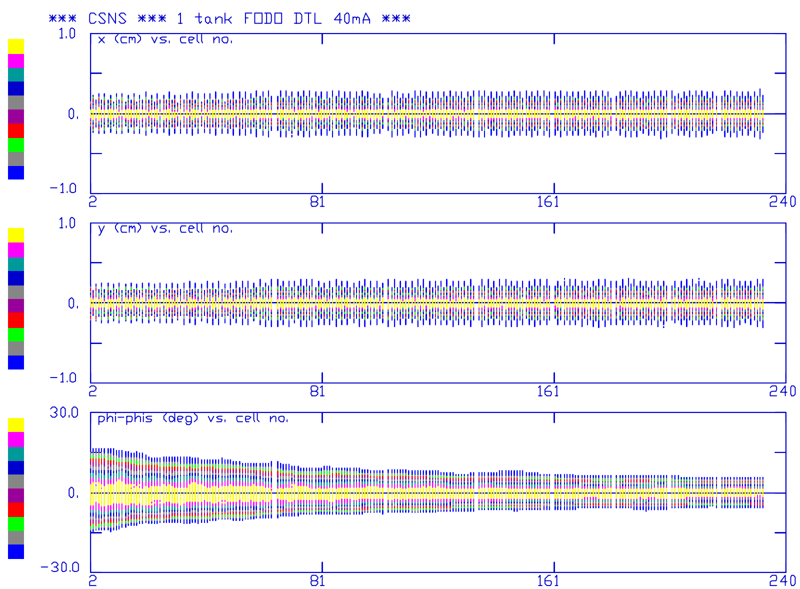
Main Parameters of the Linac

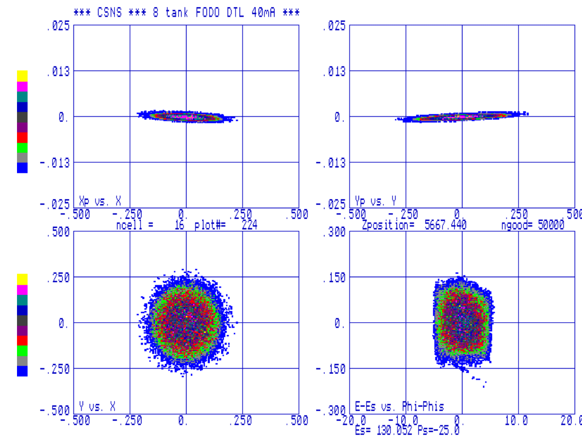
	Ion Source	RFQ	DTL
Input Energy（MeV)		0.075	3.5
Output Energy(MeV)	0.075	3.5	70/130
Pulse Current (mA)	20/40	20/40	20/40
RF frequency (MHz)	2.4GHz	352.2	352.2
Duty factor (%)	0.5	0.5	0.5
Repetition cycle (Hz)		25	25

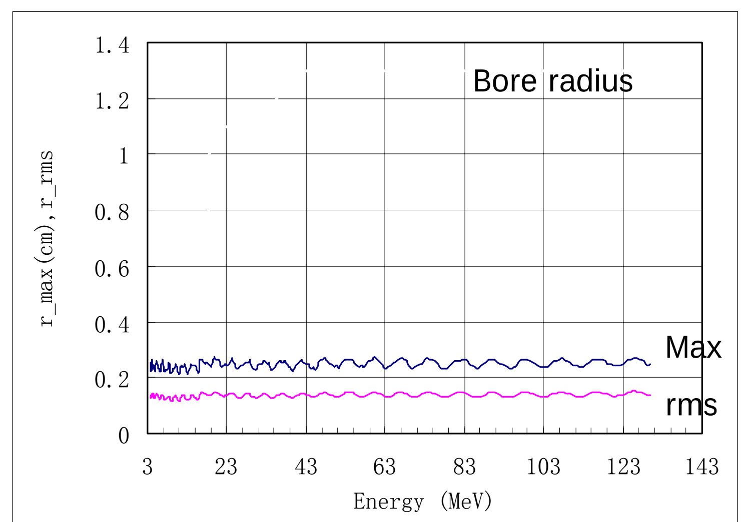
DTL tanks are designed

Tank	1	2	3	4	5	6	7	8	Total
E_{out} （MeV）	18	35	53	70	87	102	116	130	
$P_{cu+beam}$ （MW）	1.92	2.03	2.06	2.01	2.09	2.06	1.97	1.96	16.1
Length(m)	7.38	7.45	7.79	7.64	6.88	6.75	6.43	6.36	56.68
N_{cell}	64	38	31	26	21	19	17	16	232
E_0 （MV/m）	2—3	3	3	3	3	3	3	3	
φ_s (0)	39-25	25	25	25	25	25	25	25	
N_{post}	32	38	31	26	21	19	17	16	200

Beam dynamic is simulated with PARMILA code

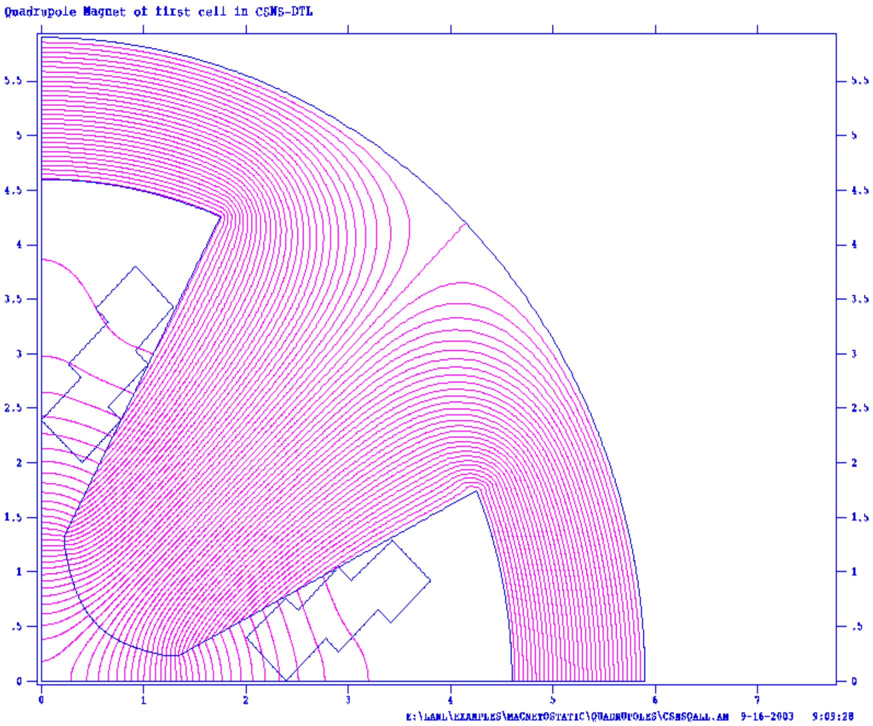


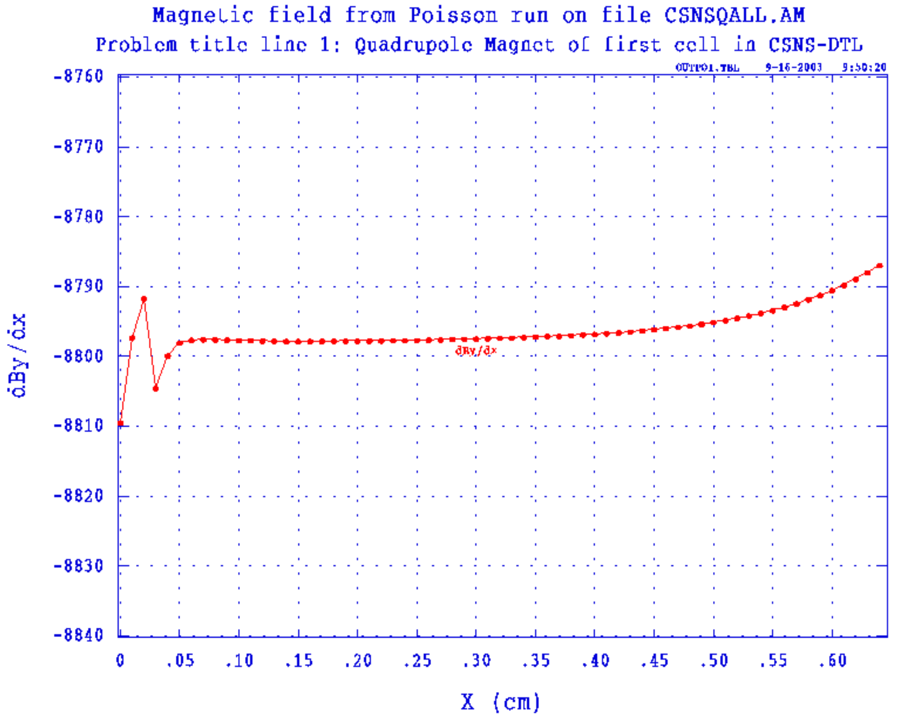




The beam is well matched with a FODO lattice, almost no halo generation. The beam radius (Max & rms) is much smaller than the bore radius.

The quadrupole magnet in the 1st drift tube is designed. It uses halo-conductor coil with about 600A (35mm long)





The field gradient error is less than 0.2% within bore radius.

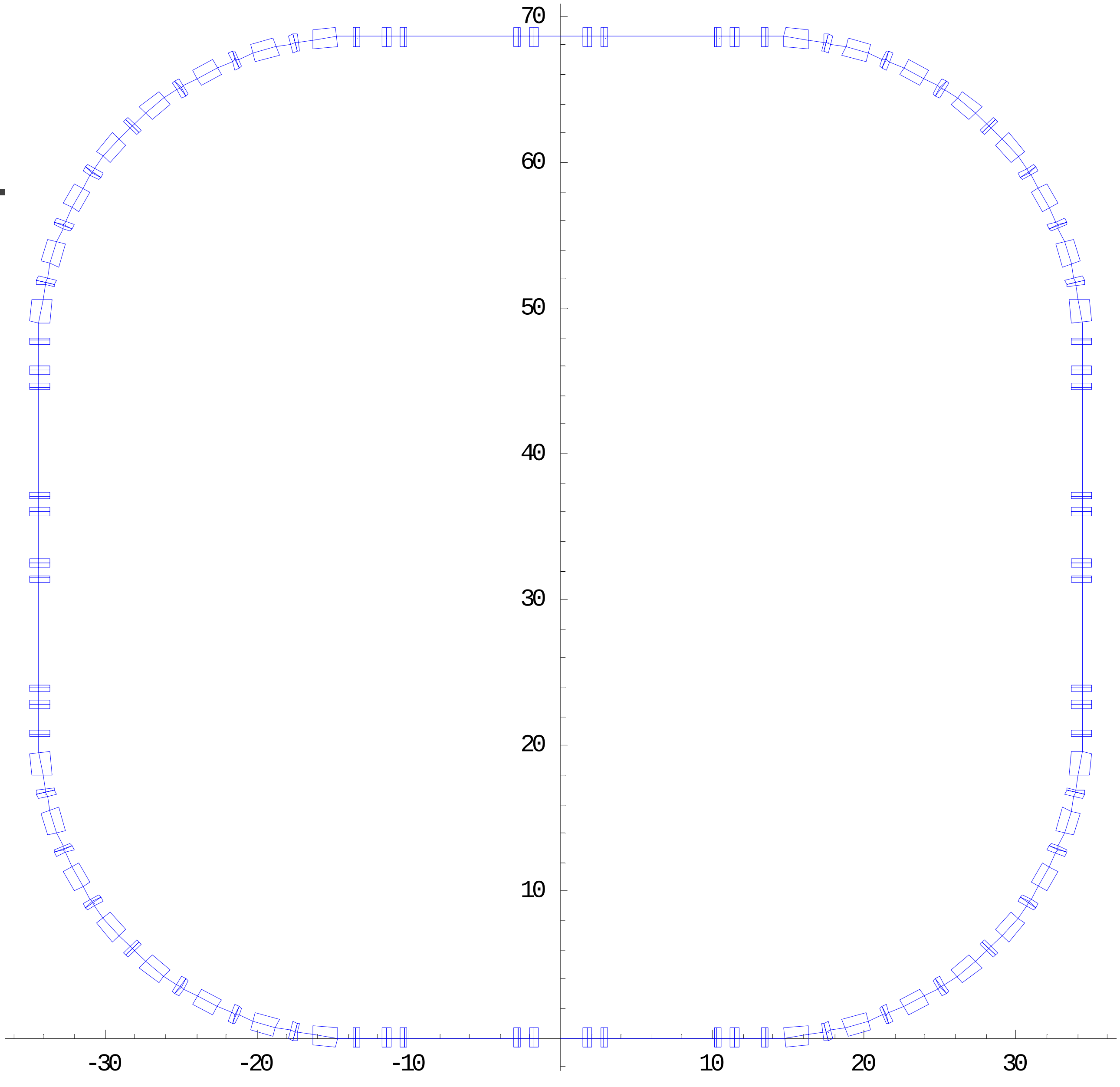
main parameters of RCS

Kinetic energy (inj.)	70 MeV	Kinetic energy (ext.)	1.6 GeV
γ at injection	1.0746	γ at extraction	2.7053
β at injection	0.3661	β at extraction	0.9292
Beam momentum (inj.)	0.369 (GeV/c)	Beam momentum (ext.)	2.359 (GeV/c)
Magnetic rigidity (inj.)	1.231 (T·m)	Magnetic rigidity (ext.)	7.867 (T·m)
Bunching factor (inj.)	0.4	Repetition frequency	25 Hz
Emittance at injection	286.4 π mm·mrad	Tune shift due to s.c. (inj.)	–0.2
No. of particle/cycle	1.56×10^{13}	Output current	62.5 μA
Beam power (ext.)	100 kW		

Linear lattice

- **A 4-fold symmetric lattice is chosen.**
- **A FODO type lattice is adopted in arcs.**
- **8 bends are included in one arc, with a bending angle of 11.25 degree for each bend.**
- **Each cell in arcs has a phase advance of 90 degree in horizontal and quasi-90 degree in vertical.**
- **FOFDOD lattice is used in straight sections.**
- **Two 7-meter long straight sections locate between two arcs.**

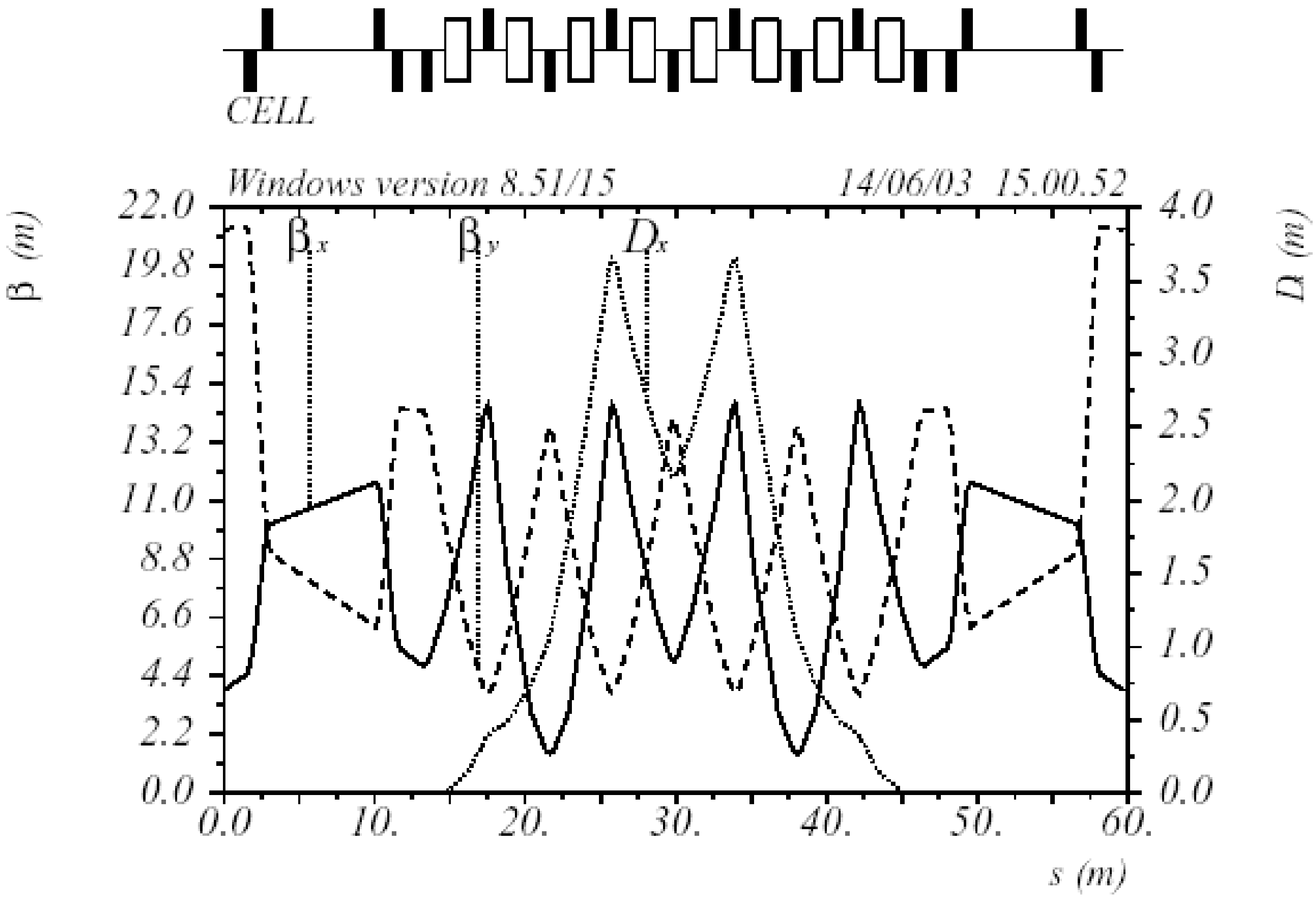
Layout of RCS



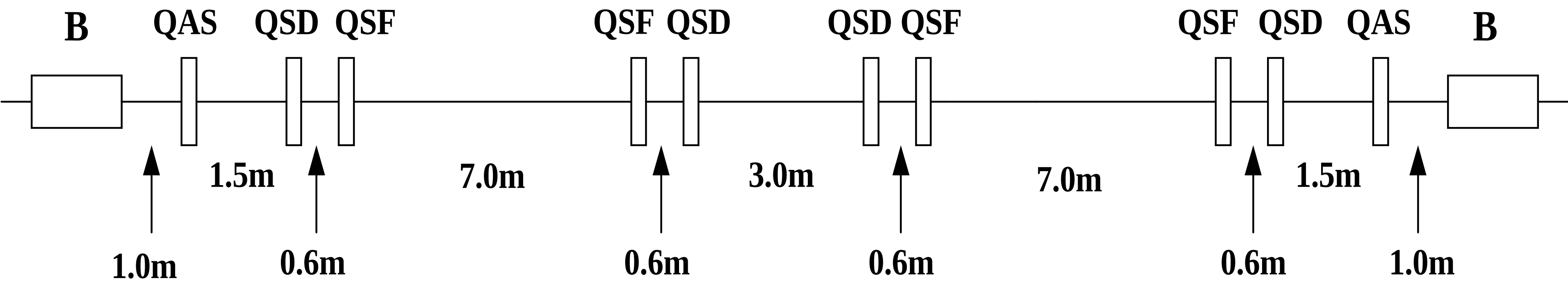
Criteria for matching the linear lattice

- $\beta_{x,y}$ < 25 m, η< 4 m for small aperture.
- Small betatron function in the straight section.
- Enough drift spaces for various elements accommodation.
- As same length of quadrupoles as possible.
- As less power supplies of quadrupoles as possible.
- Gradient of quadrupoles less than 5.5 T/m.
- Horizontal and vertical tunes (integer parts) are split by an integer for a small coupling resonance.

Twiss parameters in one superperiod



- **Long straight sections between arcs**



Main parameters of the RCS lattice

Circumference	**238.8 m**	**Bending radius**	**8.149 m**
No. of superperiod	**4**	**Length of cell in arc**	**8.25 m**
Max. β in arc (x/y)	**14.6/14.3m**	**Max. β in long S.S. (x/y)**	**11.7/9.0m**
Max. β in dipole (x/y)	**11.0/10.4m**	**Max. η in arc**	**3.66m**
Max. β in arc quads (x/y)	**14.6/14.3m**	**Max. β in S.S. quads (x/y)**	**11.9/21.7m**
Transverse tunes (x/y)	**6.37/5.32**	**Natural chromaticity (x/y)**	**–6.86/–7.06**
Momentum compaction	**0.0373**	**Transition energy**	**5.175**
Rev. period @ inj.	**2.1758 μs**	**Rev. period @ ext.**	**0.8572 μs**
Emittance	**254 π mm·mrad**	**Bunching factor @ inj.**	**0.3**

Acceptance

- **In arc regions (full aperture of vacuum chamber)**

Horizontal: $2\times\left(\sqrt{2\times\varepsilon_x\beta_x}+D_x\times 1\%+5[\mathrm{mm}]\right)$

Vertical: $2\times\left(\sqrt{2\times\varepsilon_y\beta_y}+5[\mathrm{mm}]\right)$

- **A momentum acceptance of ±1% is assumed.**

- **Dispersion free regions**

Horizontal: $2\times\left(\sqrt{2\times\varepsilon_x\beta_x}+5[\mathrm{mm}]\right)$

Vertical: $2\times\left(\sqrt{2\times\varepsilon_y\beta_y}+5[\mathrm{mm}]\right)$

- $\varepsilon_x=\varepsilon_y$

Some parameters of magnets

Dipoles

No. of dipole	32	Good field @ injection (cm×cm)	22.20×15.42
Magnetic length	1.6 m	Good field @ extraction (cm×cm)	16.67×10.09
Bending radius	8.149 m	Gap height	18.42 cm
Bending angle per dipole	11.25°	Sagitta	3.924 cm
Field @ injection	0.1511 T	Up-ramp period	19.5 ms
Field @ extraction	0.9654 T	Ramp rate	0–41.76 T/s

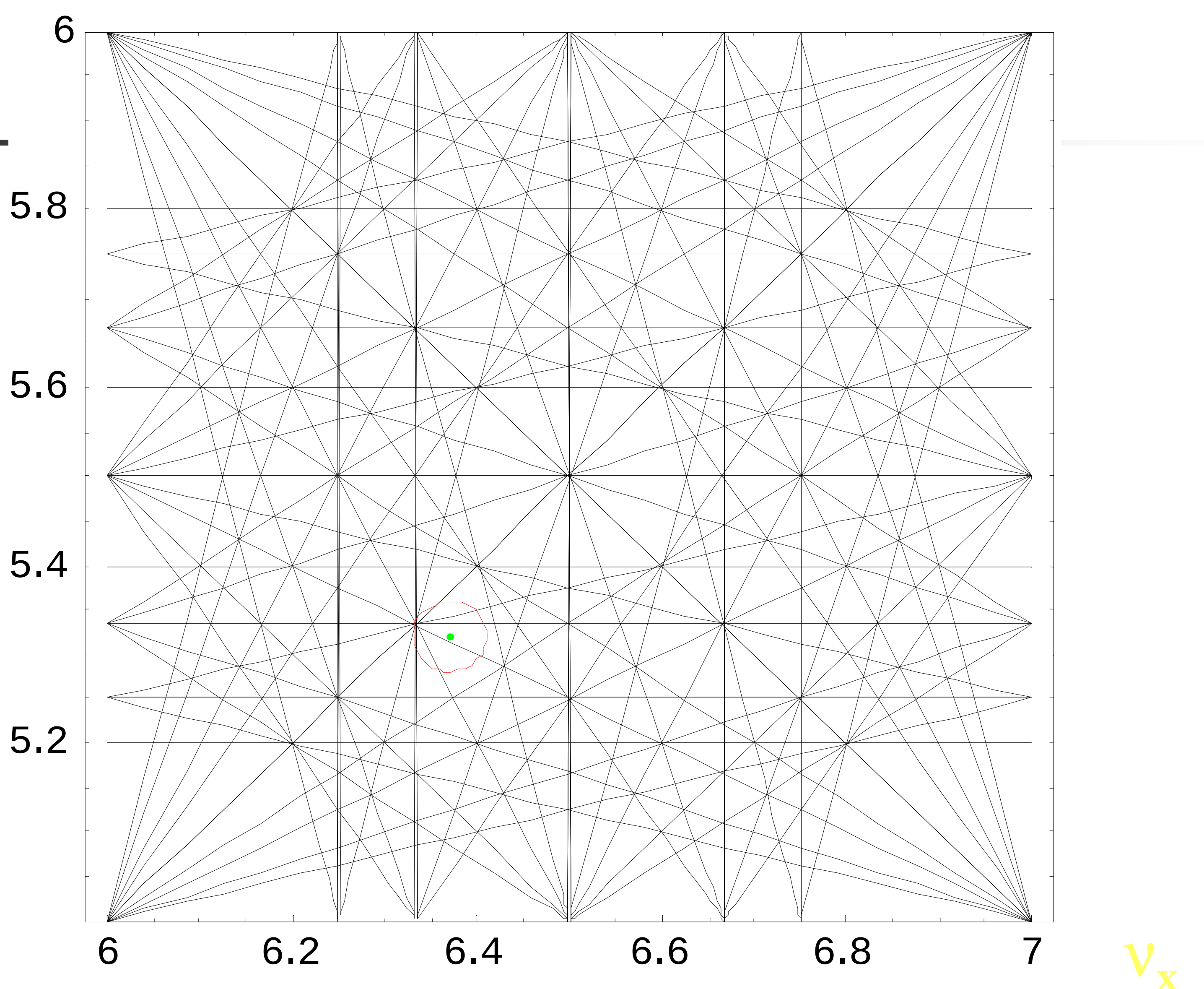
✓ Top and bottom chamber thickness + baking clearance = 3 cm

Quadrupoles

No. of quads (arc+S.S)	28+40	No. of power supplies	5
Good field @ injection (arc & S.S. quad,cm×cm)	25.6×17.9 16.4×21.8	Good field @ extraction (arc & S.S. quad,cm×cm)	19.2×11.7 10.7×14.1
Magnetic strength ($B'/B\rho$, arc quads)	0.67 m^{-2} 0.55 m^{-2}	Magnetic gradient (B', arc quads, T/m)	0.85 – 5.40 0.67 – 4.29
Magnetic strength ($B'/B\rho$, S.S. quads)	0.68 m^{-2} 0.28 m^{-2} 0.64 m^{-2}	Magnetic gradient (B', S.S. quads, T/m)	0.84 – 5.38 0.34 – 2.19 0.78 – 5.01
Peak field at pole tip at extraction (arc quads)	0.77 T 0.61 T	Peak field at pole tip at extraction (S.S quads)	0.67 T 0.27 T 0.62 T
Diameter (arc & S.S quads)	28.6 cm 24.8 cm	Magnetic length	0.5 m

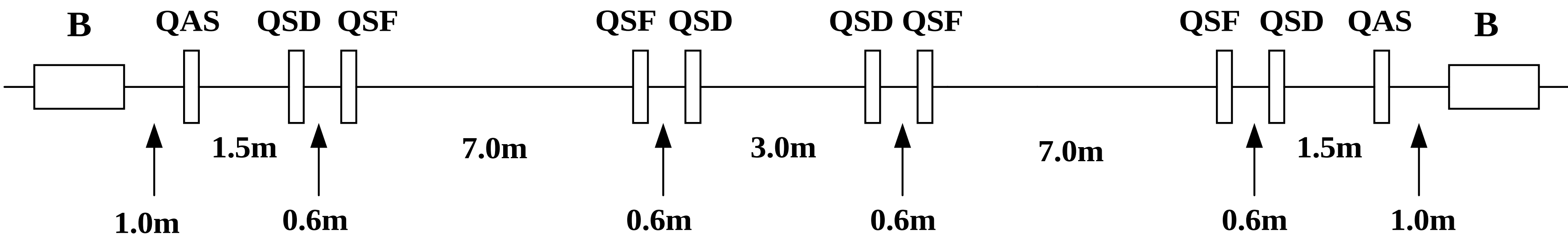
- ✓ Chamber thickness + baking clearance = 3 cm

Tune grid graph

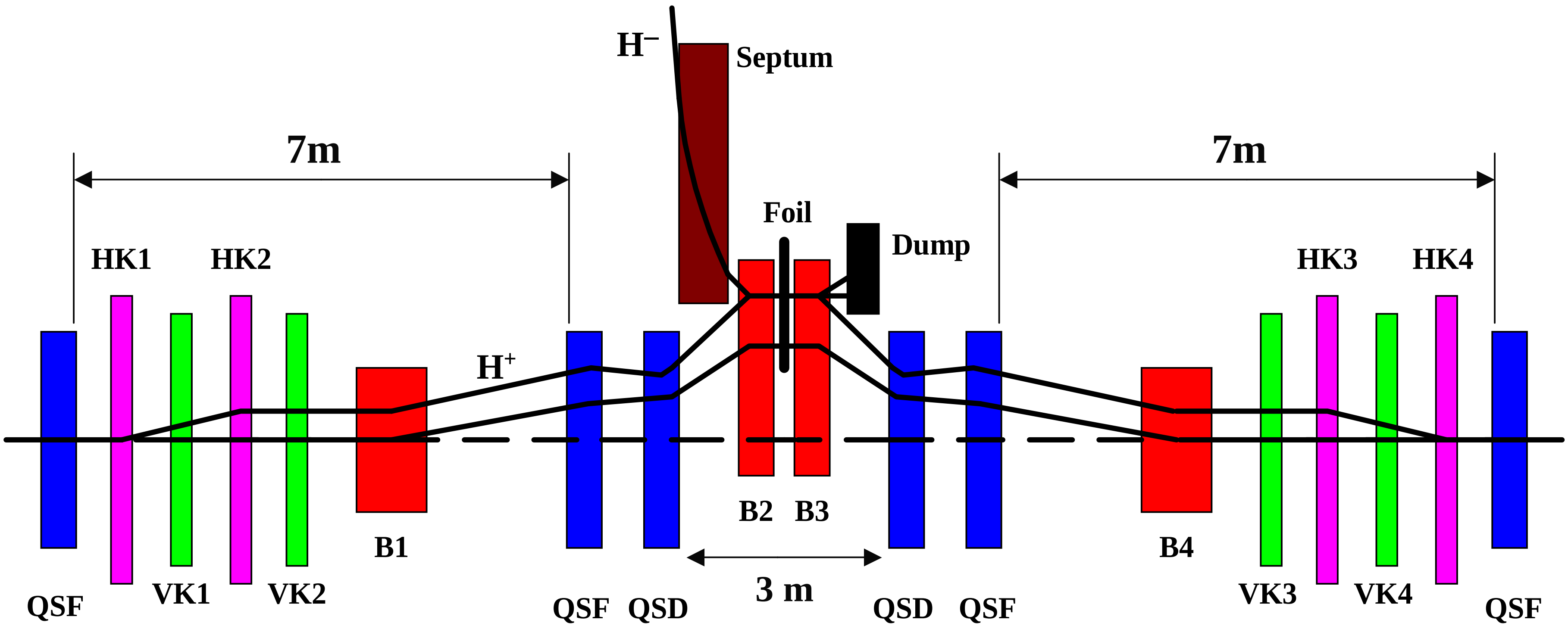


Preliminary Study on Injection

- **Injection happens in the long straight sections.**
- **Fast kickers and bumps are used to make orbit and painting.**
- **A stripping foil, located in the center of the two long straight sections, is used to obtain proton from H^-.**
- **A possibility of higher injection energy, 130 MeV, is considered.**



Layout of the straight sections with injection elements



- **B1 ~ B4 make an orbit bump of 40 mm at the exit of QSD.**
- **HK1 ~ HK4 can produce another 40 mm bump in painting.**
- **VK1 ~ VK4 produce 80 mm bump at the exit of QSD in painting.**

RCS parameters for injection

Parameters	E_T = 70 MeV	E_T= 130 MeV
γ of injection beam	1.075	1.139
Momentum of injection beam	0.369 GeV/c	0.511 GeV/c
Revolutionary frequency	0.4596 MHz	0.6002 MHz
Revolutionary period	2.1758 μs	1.6661 μs
Magnetic rigidity	1.2313 T·m	1.7036 T·m
Emittance of inj. Beam	4 π mm·mrad	4 π mm·mrad
Emittance after painting	254 π mm·mrad	254 π mm·mrad
Time of injection	1 ms	0.8 ms
Turns of injection	460	480
Repetition rate	25 Hz	25 Hz

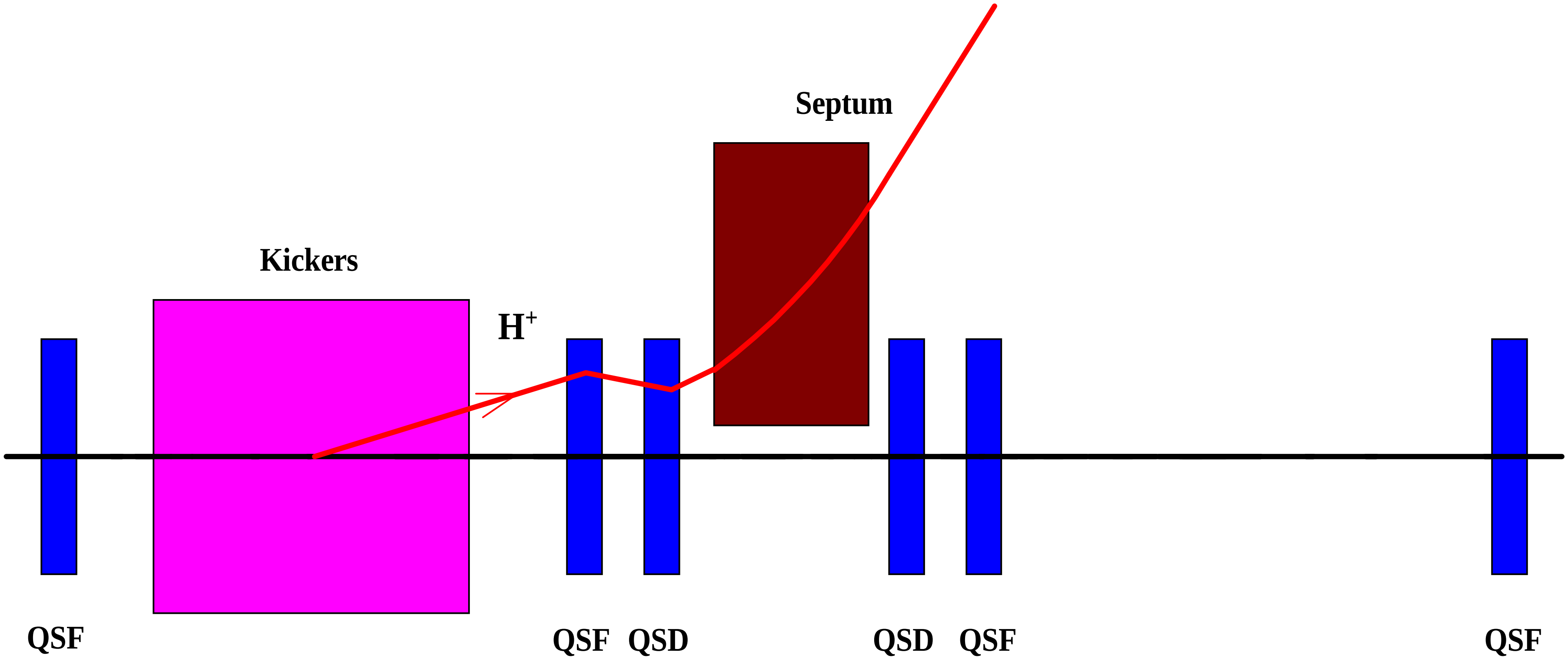
Main parameters of injection elements (70 MeV)

		Element 1 & 4	Element 2 & 3
Bump	Effective length	1.0 m	0.5 m
	Max. bending angle	12.92 mrad	13.10 mrad
	Max. magnetic field	159.05 Gs	322.53 Gs
Hori. kicker	Effective length	0.3 m	0.3 m
	Max. bending angle	15.53 mrad	11.27 mrad
	Max. magnetic field	637.50 Gs	462.62 Gs
Vert. kicker	Effective length	0.3 m	0.3 m
	Max. bending angle	16.69 mrad	10.48 mrad
	Max. magnetic field	684.85 Gs	430.08 Gs

Extraction

- **Single turn extraction is adopted.**
- **One long S.S and a 3-meter long S.S will accommodate extraction elements.**
- **Kickers bend the beam away horizontally, together with a septum.**

Schematic layout of extraction region



RCS parameters for extraction

Extraction energy	1.6 GeV	γ of extraction beam	2.705
Magnetic rigidity	7.867 T·m	Unnormalized emit.	101πmm·mrad
Rev. frequency	1.1665 MHz	Rev. period	0.8572 μs
Repetition rate	25 Hz	Bunch number	2(h=2), 4(h=4)

Extraction kicker and septum parameters

Kicker	No. of kicker	5
	Total effective length	4.5 m
	Total kick angle	21.62 mrad
	Magnetic field	378 Gs
	Horizontal gap	15 cm
	Vertical gap	10 cm
Septum	Total effective length	2.5 m
	Bending angle	182 mrad
	Magnetic field	5.727 kGs
	Thickness	1.5 cm
	Horizontal gap	15 cm
	Vertical gap	15 cm

Key Technologies

- **Magnet system**
- **Power converter system**
- **Radio-frequency system**
- **Vacuum system**
- **H^- Injection**
- **Extraction**
- **……**

- **Because of high intensity and rapid cycling all hardware systems become very complex and difficult .We lack of experience.**
- **A delegation have visited JPARC RCS recently and our experts learned a lot from this visiting.**
- **Designing of hardware systems are just starting.**
- **Because IHEP is busy for constructing BEPC2, before the approval of CSNS at least we have two or three years for detail design and main technologies developing.**
- **Meantime we need to exploit the possibility of using FFAG as the spallation neutron source.**

- **1.6 GeV (100 kW-200 kW)**
- **For 100 kW need 62.5 μa.**

Total number of particles ~$3.75x10^{14}$(25Hz)

- **Particles/pulse~$1.5x10^{13}$.**
- **S.C.limit : 1.5x 10^{13} ($3.1x10^{13}$)**

70MeV (130MeV) linac injection, $\delta\nu = 0.3$

(for emi ~250 pi mm mrad, b=0.3).

Scaling FFAG ,one possible choice.

1.5GeV Proton FFAG

No. of sector 60 B field 2.5 T

packing factor 42 % phase advance 114/60 deg.

k-value 100 orbit excursion 0.61m

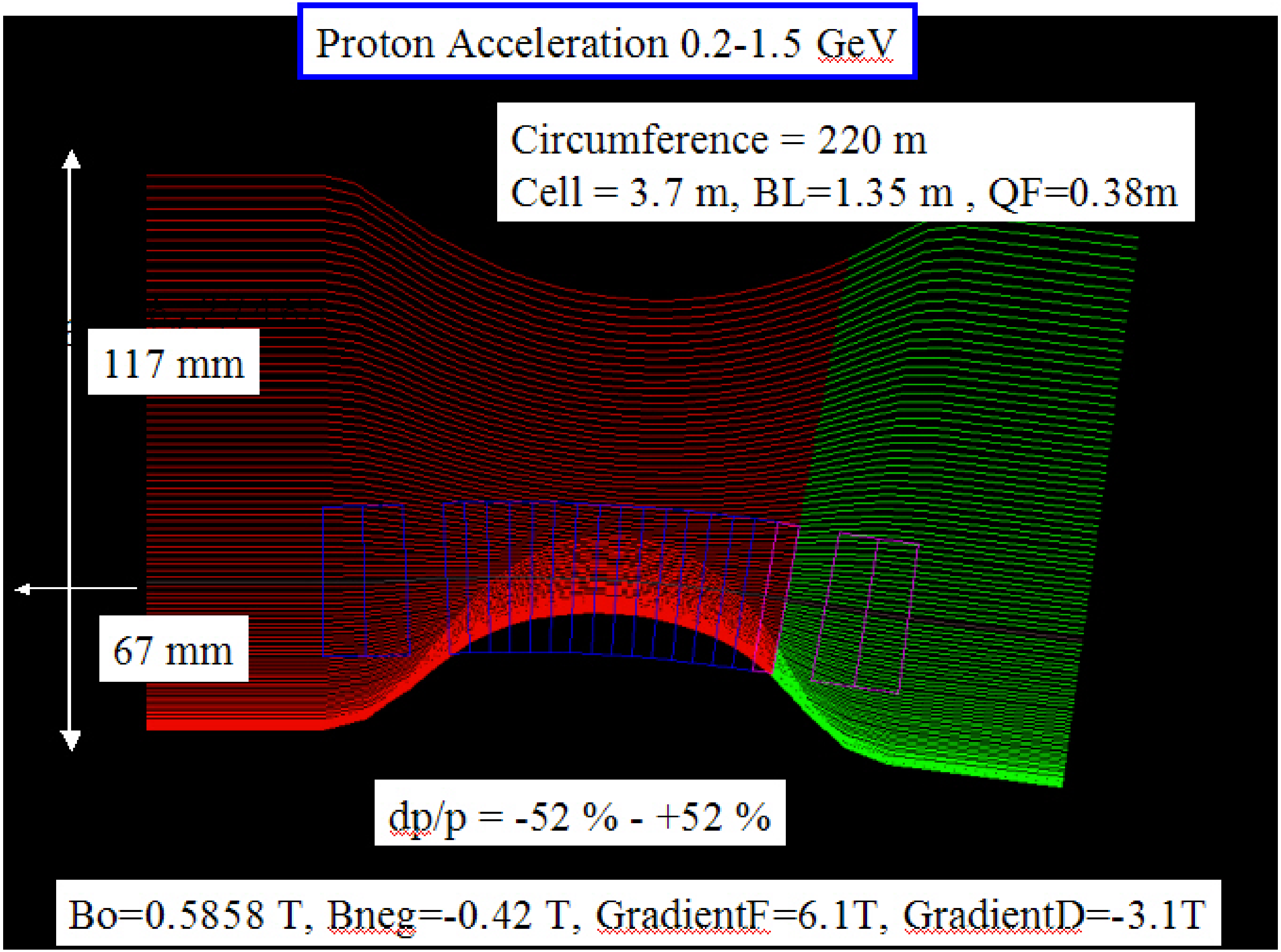
radius 50 m

Injection: Linac 50ma 0.05ms 1.5×10^{13}, 25Hz.

Pf/Pi=6.1 (for 70/1600) one stage

Pf/Pi=2.95 (70/500), 2.16(500/1600) two stage.

Non-scaling FFAG



N=57 periods

Linear gradient

nux/cell =0.4-0.1

nuy/cell=0.4-0.1

nux=21.1-8.176

nuy=25.3-2.9496

Summary

- **ADS and CSNS in China are just at the starting stage. They can share the technology achievements in HPPA from each other, and then both can be promoted.**

- **CSNS may become a new developing direction of IHEP after BEPCII upgrade project is finished.**

- **International cooperation is highly demanded.**

Thank You for attention