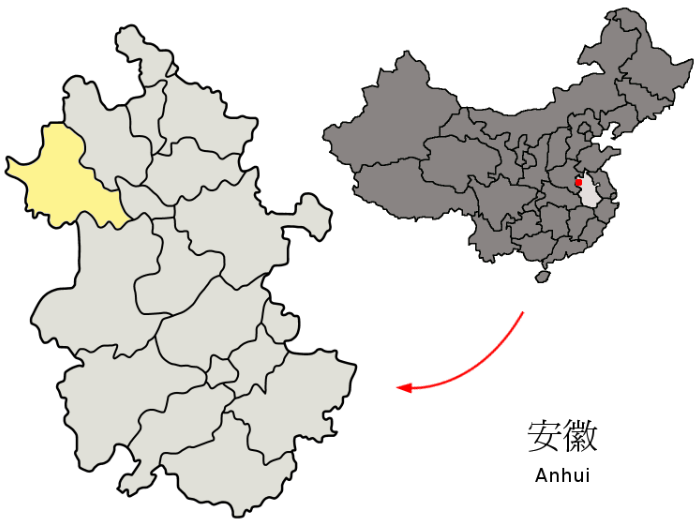
SC-200 cyclotron FR system for

RESEARCH AND DEVELOPMENT OF A COMPACT SUPERCONDUCTING CYCLOTRON SC200 FOR PROTON THERAPY

According to the agreement between the Institute of Plasma Physics (IPP) of the Chinese Academy of Sciences in Hefei (China) and Joint Institute for Nuclear Research, Dubna, (Russia), the project of a superconducting isochronous cyclotron for proton therapy SC200 is developed at JINR.



The cyclotron will provide acceleration of protons up to 200 MeV with maximum beam current of 1 μA. We plan to manufacture in China two cyclotrons: one will operate in Hefei cyclotron medical center the other will replace Phasotron in Medico-technical Center (MTC) JINR Dubna and will be used for further research and development of cancer therapy by protons. The results of testing will be used by ASIPP for a serial SC200 manufacturing.

Introduction

The Medico-technical complex (MTC) JINR annually treated by the proton beam more than 100 people.

The 200 MeV final energy has been chosen for SC200 cyclotron based on the experience of work of the MTC JINR and statistics for necessary depth of treatment provided by HIMAC (Japan) concerning the treated patients (see figure below).

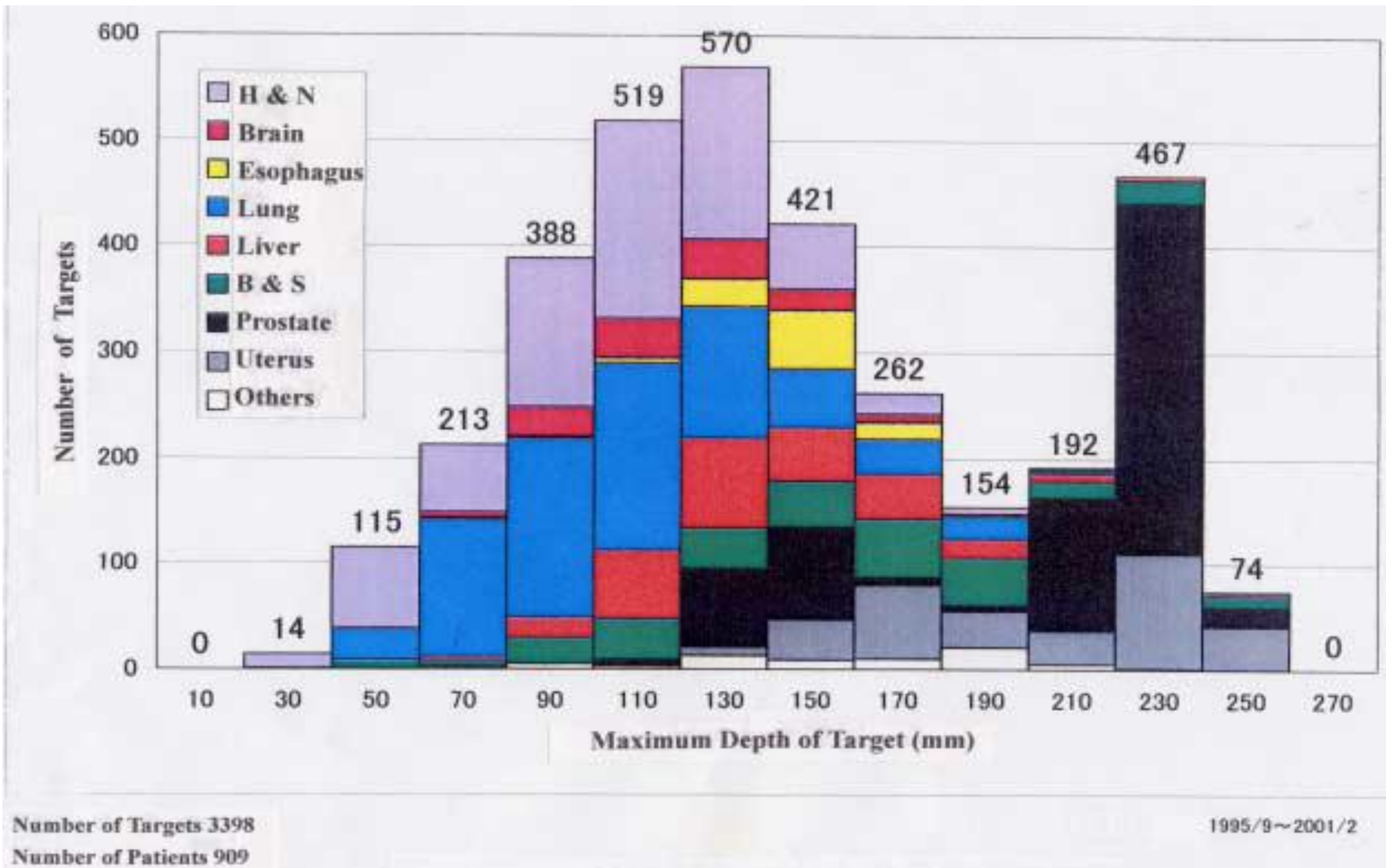
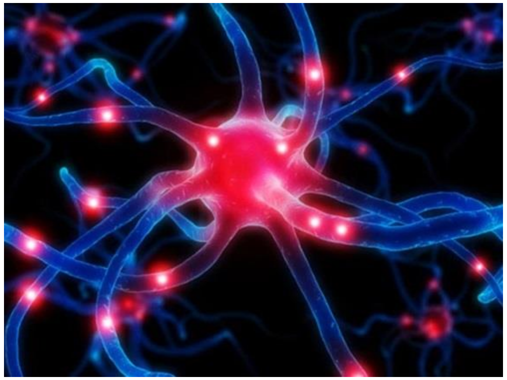


Figure 1: Distribution of maximum depths in HIMAC [1].

Types of therapies

Beam therapy

Drug therapy

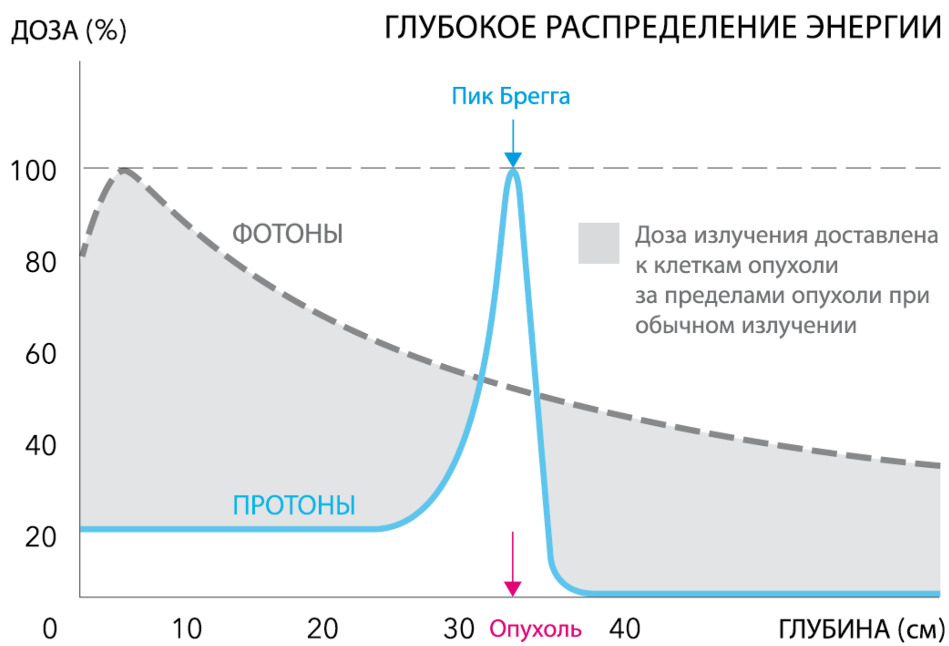


Hormone therapy

Drug therapy

Immune modulation therapy

Why protons?

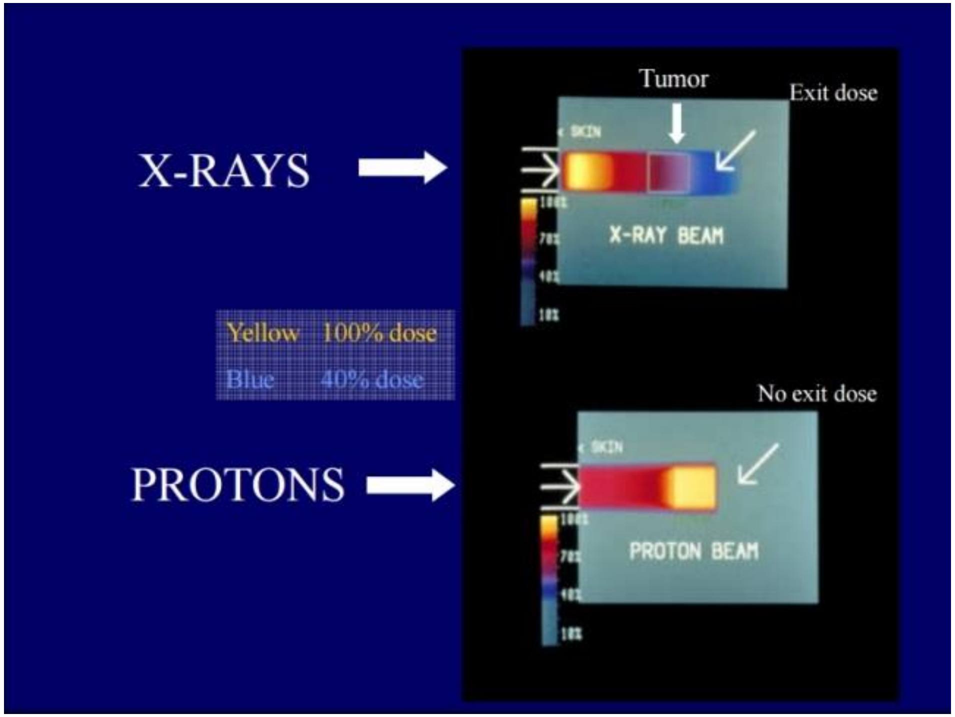

ДОЗА (%)
ГЛУБОКОЕ РАСПРЕДЕЛЕНИЕ ЭНЕРГИИ
Пик Брегга
100
80
60
40
20
ФОТОНЫ
ПРОТОНЫ
Доза излучения доставлена к клеткам опухоли за пределами опухоли при обычном излучении
0
10
20
30
Опухоль
40
ГЛУБИНА (см)


Воздействие ФОТОННОГО излучения


Воздействие ПРОТОННОГО излучения

Why protons?

The key point of proton therapy is superior dose distribution, allowing physicians to precisely aim the highest dose at the tumor and avoid healthy tissues. Consequently, it shows many advantages over x-ray therapy.



Proton therapy:

- Targets tumors and cancer cells with precision and minimal exit dose
- Reduces overall toxicity
- Reduces the probability and/or severity of short- and long-term side effects on surrounding healthy tissues and organs (e.g. reduces likelihood of secondary tumors caused by treatment)
- Precisely delivers an optimal radiation dose to the tumor
- Can be used to treat recurrent tumors, even in patients who have already received radiation
- Improves quality of life during and after treatment
- Increases the long-term, progression-free survival rates for certain types of tumors

Proton therapy is especially appropriate for cancers with limited treatment options and those where conventional x-ray radiotherapy presents an unacceptable risk to the patient, e.g. eye or brain tumors, tumors close to the brain stem or spinal cord, etc.

Main Parameters

Magnet type	Compact, SC coil, warm yoke
Pole diameter (m)	1.24
Magnet diameter (m)	2.2
Magnet height (m)	1.22
Hill gap, max/min (m)	0.04-0.005
Valley gap, max/min (m)	0.6/0.53
Yoke material	St.1010
Extraction radius (m)	0.6
Average magnetic field ($R_o/R_{extr.}$) (T)	2.9/3.5
Excitation current (1 coil) (A*turns)	750 000
Magnetic field in the coil (T) max.	4.5
Cryostat and coils weight (t)	5
Total magnet weight (t)	30

Table 1: Parameters of the magnet system of the SC200 cyclotron.

SC200 is an isochronous superconducting compact cyclotron.
Superconducting coils will be enclosed in cryostat, all other parts are warm.

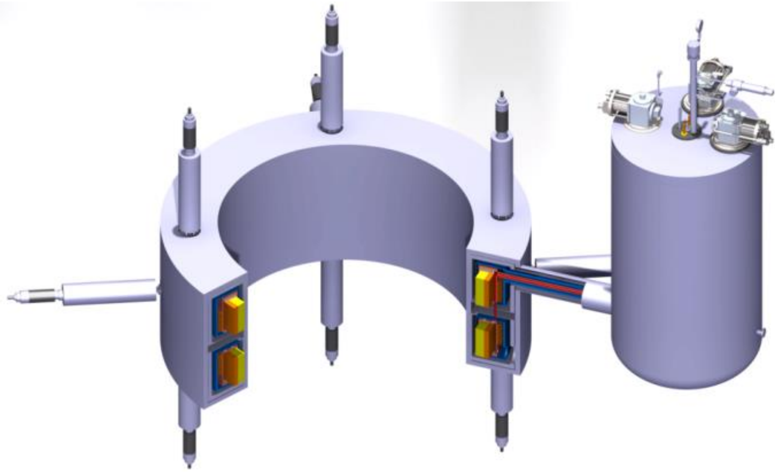
Internal ion source of PIG type will be used.

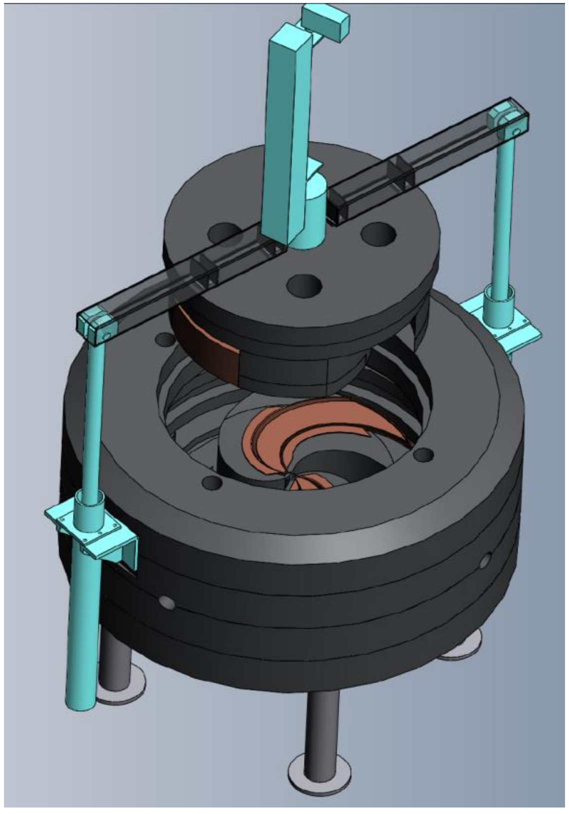
It is a fixed field, fixed RF frequency and fixed 200 MeV extracted energy proton cyclotron.

Mean magnetic field of the cyclotron will be in the range of 2.9T-3.5T (center-extraction).

Extraction will be organized with an electrostatic deflector and magnetic channels.

Currently for proton acceleration we are planning to use 2 accelerating RF cavities, operating on the 2nd harmonic mode.



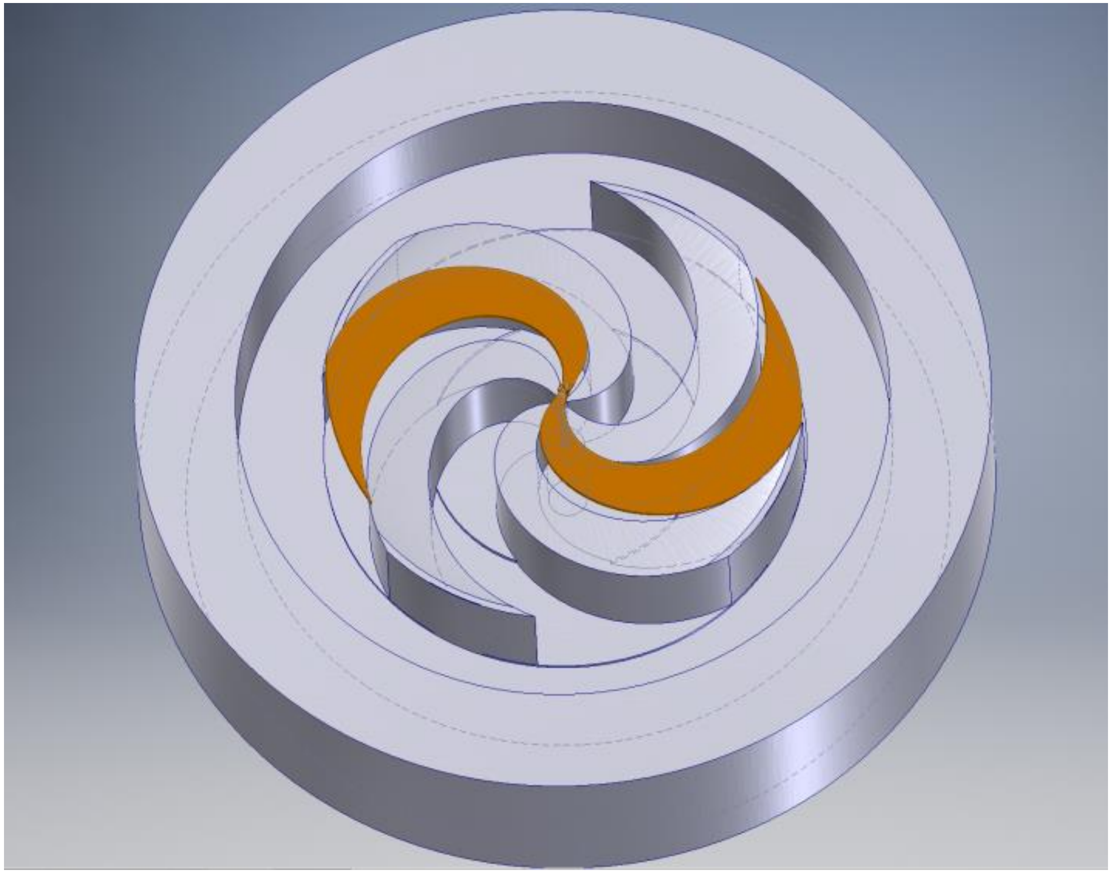


The proton beam with energy 200 MeV can irradiate all of the tumor localizations with a maximum depth of 25 cm.

SC200 cyclotron will also be used for eye melanoma treatment at energies 60-70 MeV after degrading beam energy.

Taking into account the fact, that the size and cost of the cyclotron are approximately determined by the maximum proton energy, it was decided to limit the maximum proton energy to 200 MeV.

Profiling of the pole shape and vertical profile of the sectors was used to shape the required isochronous magnetic field.



View of the computer model of the magnet with accelerating cavities.

ACCELERATION SYSTEM

Magnetic field modelling and beam dynamics have determined orbital frequency of the ions equal to about 45 MHz. To operate on 2-th harmonic, the RF system has to achieve frequency of 90 MHz. We are planning to use two normal conducting RF cavities for ion beam acceleration in the SC200 cyclotron.

The geometry of the RF cavity is restricted by the size of the valley of the magnet. We have fitted the double gap delta cavity inside the valley of the magnet. Azimuth extension of the cavity (between middles of accelerating gaps) is 50 degrees. We have chosen the accelerating gap to be equal to 7 degrees.

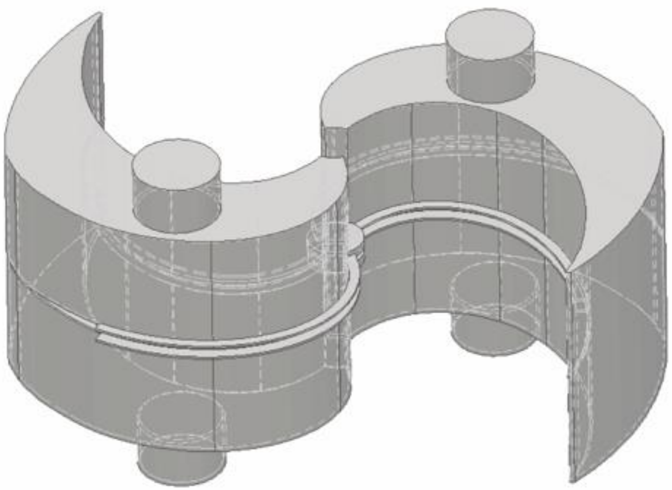
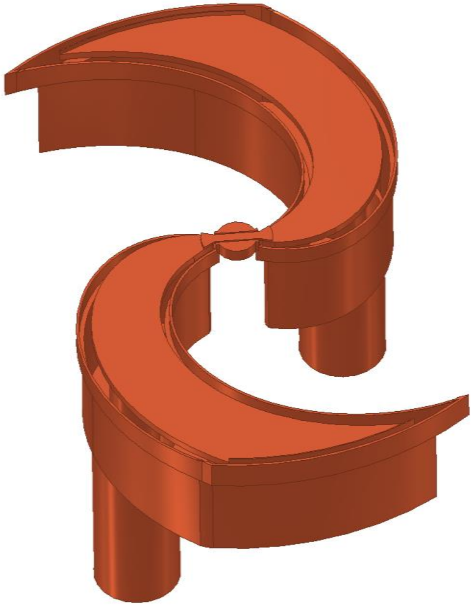


Figure 6: Computer model of the accelerating cavity.

RF cavities	warm
Number of cavities	2
Operating frequency, MHz	90
Harmonic number	2^{nd}
Radial extension of the cavity, m	0.63
Radial extension of the dee, m	0.61
Number of stems	1
Diameter of the stem, m	0.09
Radial position of the stem, m	0.365

Table 2: Parameters of accelerating system.

Two RF cavities, connected in the centre will be working on the 2nd harmonic on approximately 90MHz.



From the beam dynamics point of view the choice of 2nd harmonic is not the best solution, as the acceleration rate will be lower compared to 4th harmonic which seems like a natural choice for a cyclotron with 4 sector structure. However operating on 180MHz would raise problems with the extraction of particles from the ion source and the generators on 180MHz are not widely available as compared to 90MHz ones. As we avoid all critical resonances and extraction scheme does not require high acceleration rate we are able to use just 2 cavities on 2nd harmonic.

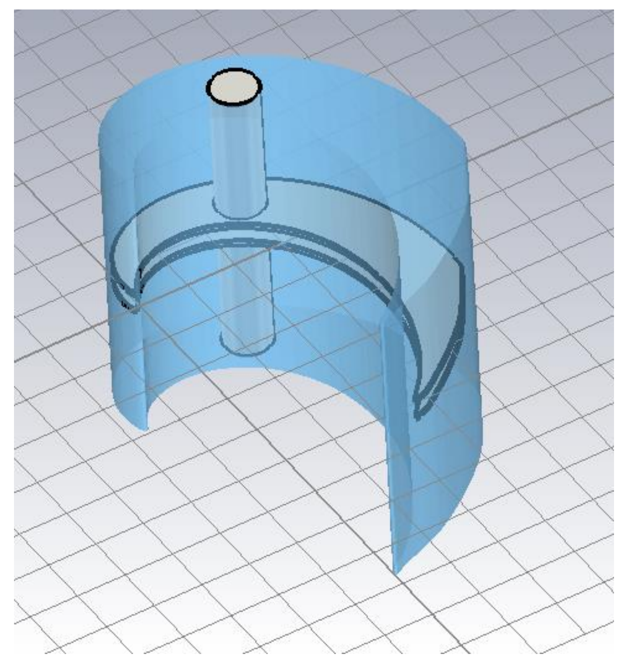
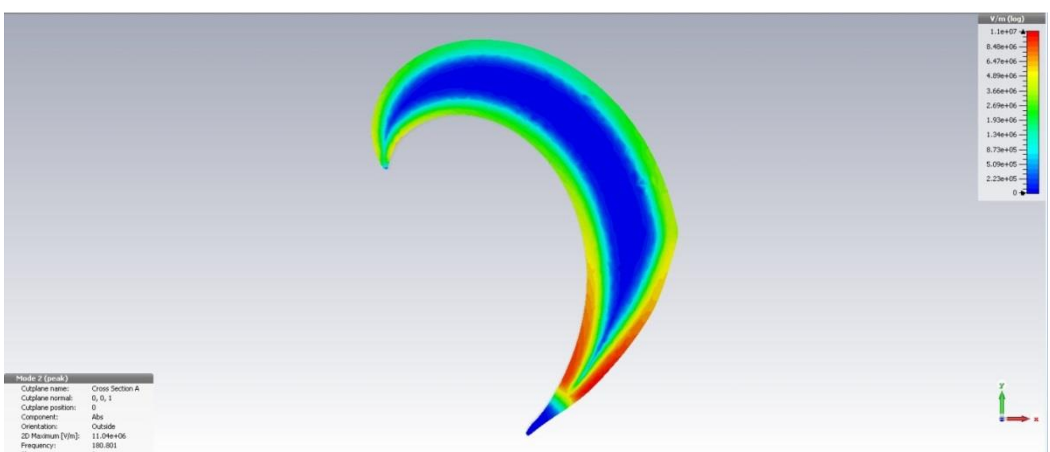


Figure 3: Overview of 3D model of RF system and Electric Field distribution (image below)



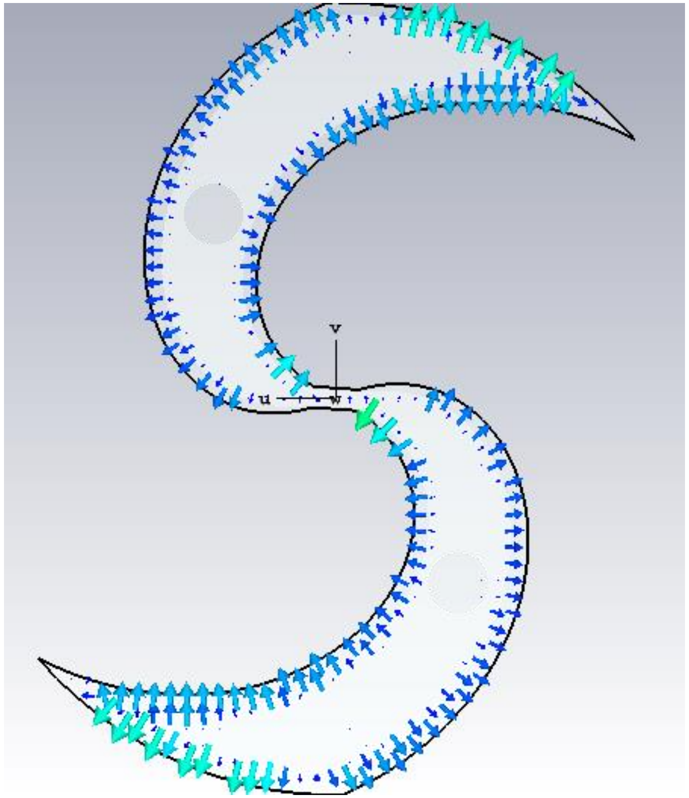


Figure 4: Vector plot of the electric field in the median plane.

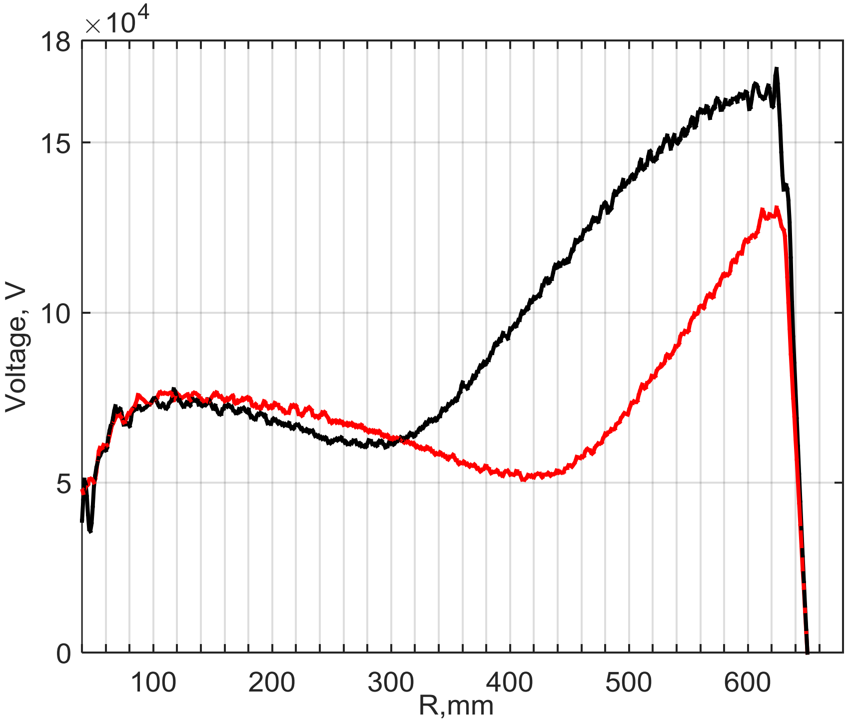


Figure 5: Voltage distribution along radius.

Frequency of the cavity with 1 stem reaches 90 MHz with quality factor about 7500. Calculated peak losses for two cavities are equal 75 kW.

Voltage value along accelerating gaps was calculated by integrating of the electric field in the median plane of the resonant cavity.

However the work still has to be done to optimize parameters of the cavity.

CONCLUSION

The work on design of the proton superconducting cyclotron SC200 continues.

Manufacturing of SC200 systems and elements will be done during the 2017.

Assembling, tuning and testing SC200 should be finished in 2018.

Figure 7: Proton therapy centers worldwide

THANK YOU FOR YOU ATTENTION