CC-1-3 cyclotron complex

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1. Introduction

The TESLA Accelerator Installation (TAI), in the Vinča Institute of Nuclear Sciences, is a facility for production, acceleration and use of ion beams in science and medicine. It has three parts – the low, medium and high energy parts.

The low energy part of TAI, which was named FAMA, is a user facility for research in the field of modification and analysis of materials with ion beams.

The medium energy part of TAI should become a regional center for routine production of radiopharmaceuticals with a cyclotron delivering proton beams of the energy between 15.5 and 19 MeV and currents above 60 μA.

The high energy part of TAI comprises the VINCY Cyclotron and its experimental channels, and it should become a large-scale user facility for science and medicine with proton beams of the energies between 30 and 75 MeV and currents below 100 μA, and deuteron beams of the energies between 15 and 37.5 MeV and currents below 50 μA.

The programs of use of the facility would include proton therapy of eye tumors, experimental production of novel radiopharmaceuticals for diagnostics and therapy, and research in the fields of materials science and radiation biology.

2. FAMA

Presently, FAMA comprises two ion sources and two experimental channels – for surface modification of materials.

In the beginning of June 2010, the upgrading of FAMA on the basis of the clearing debt of Russia to Serbia began. The corresponding contract comprises:

- the refurbishment of the existing machines and experimental channels;
- the construction of a small proton cyclotron complex for analysis of materials (CC-1-3);
- the construction of two experimental channels for analysis of materials – in vacuum and in air.

The techniques that will be available are:

- Rutherford backscattering spectrometry (RBS);
- proton elastic scattering (PES) spectrometry;
- proton induced X-ray emission (PIXE) spectroscopy;
- nuclear reaction analysis (NRA).

The deliverers of the equipment are the Joint Institute for Nuclear Research, Dubna, Russia, and the D. V. Efremov Scientific Research Institute of Electrophysical Apparatus, St. Petersburg, Russia. The realization of the contract should be finished by the end of April 2013.

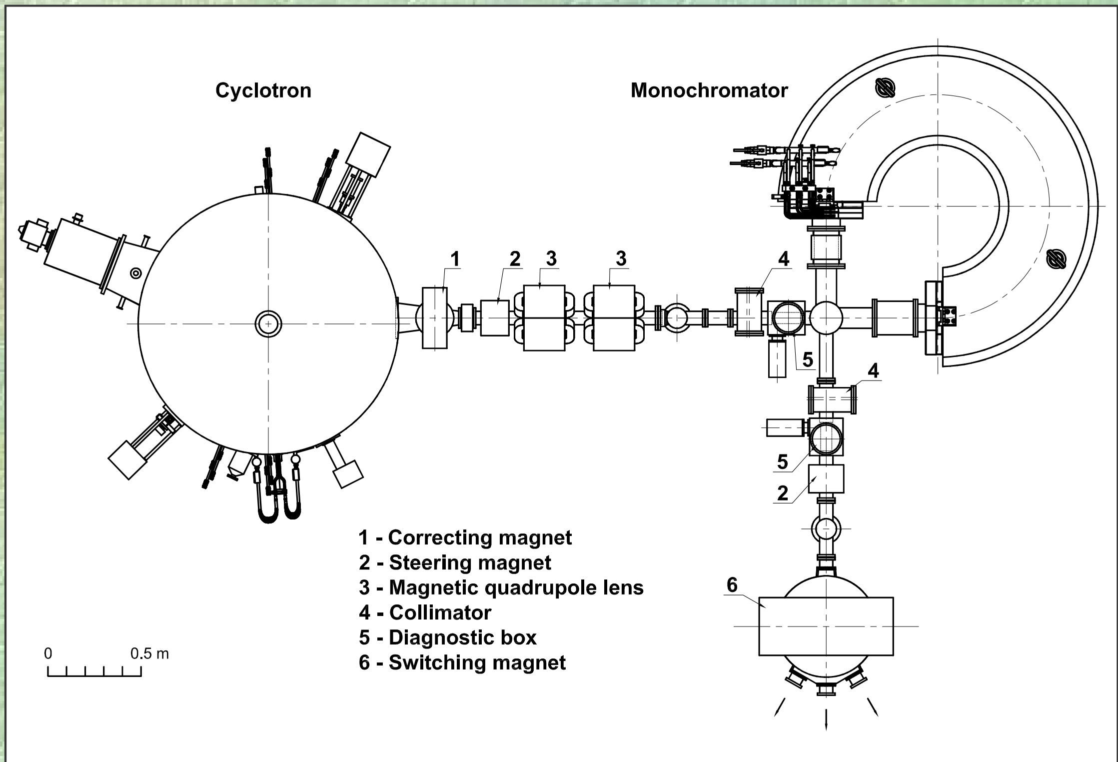
3. CC-1-3 cyclotron complex

The CC-1-3 cyclotron complex will be constructed by the Efremov Research Institute with the active participation of the Vinča Institute. The requirements for the proton beams to be used for analysis of materials are:

- Energy – between 1 and 3 MeV
- Energy precision – below 1 keV
- Energy spread – below 0.1 %
- Current – between 10 and 100 nA

The subsystems of the complex are the following:

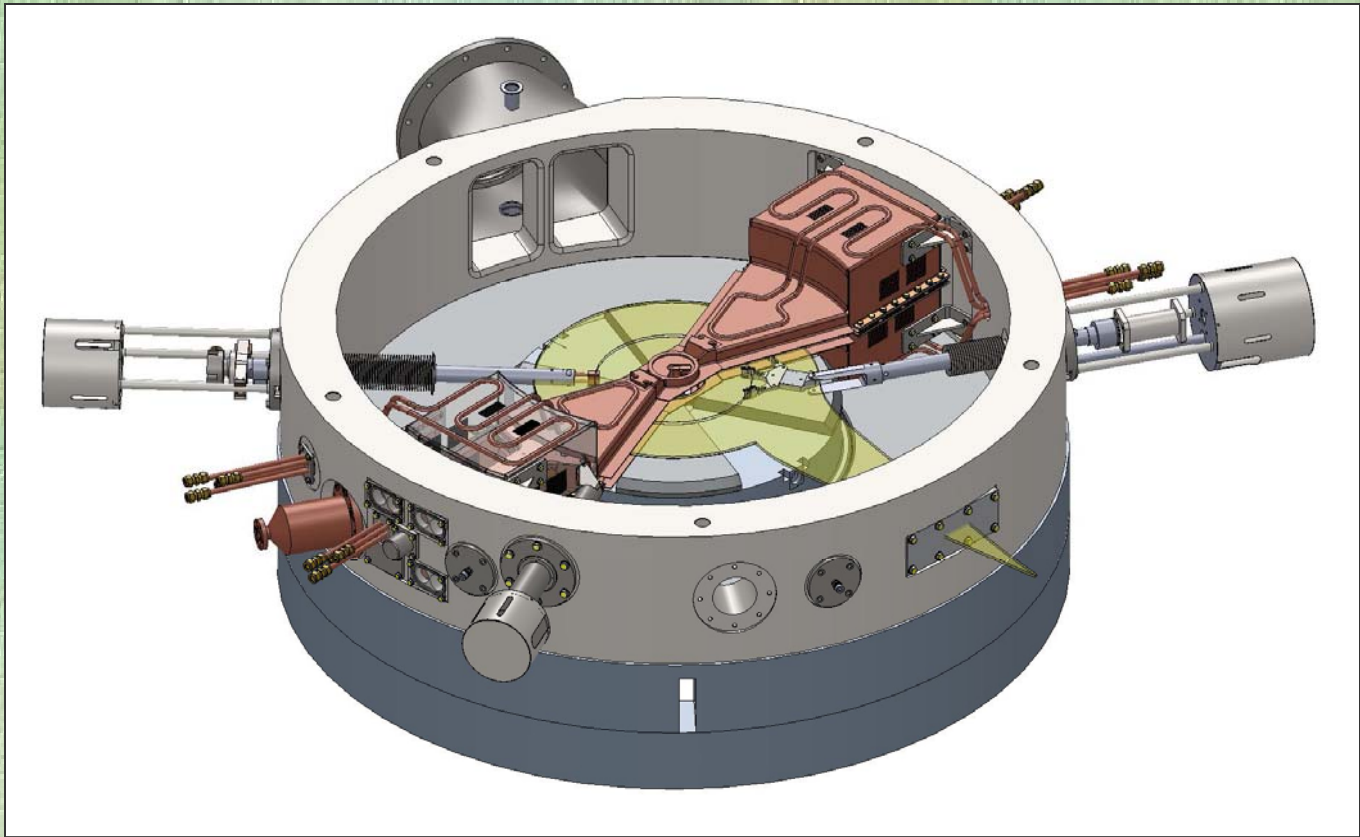
- Cyclotron
- Transport and preparation system
- Vacuum system
- Control and safety system
- Infrastructure systems



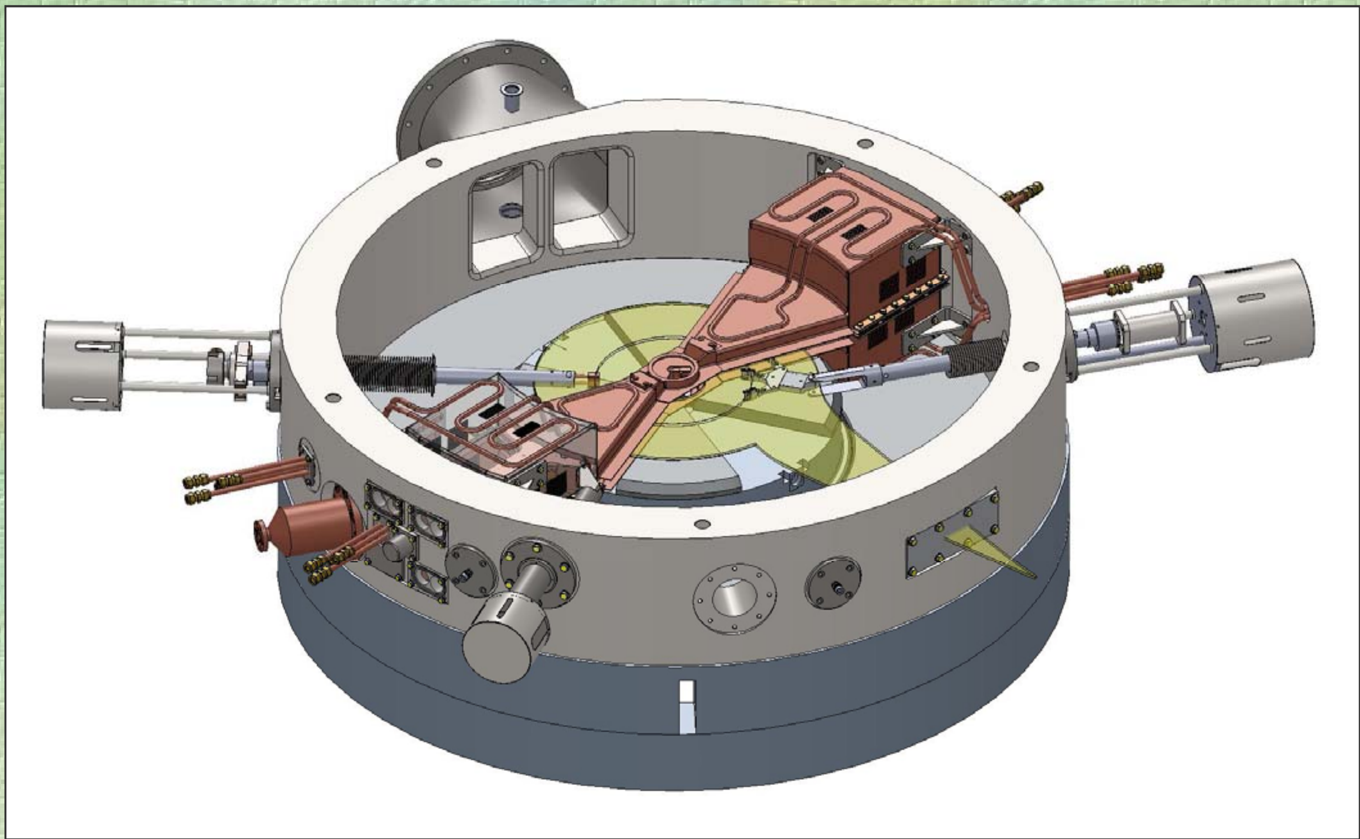
Cyclotron

The cyclotron is of the compact isochronous type and enables the acceleration of negative hydrogen ions. It comprises the electromagnet and vacuum chamber, radiofrequency (RF) system, injection system, diagnostic system, and extraction system.

- The electromagnet is of the closed type with the median plane in the horizontal position.
- The magnetic field is formed with a four-sector structure.
- The diameter of the electromagnet yoke is 1400 mm and the diameter of its poles 600 mm.
- The gaps between the electromagnet hills and valleys are 50 and 100 mm, respectively.

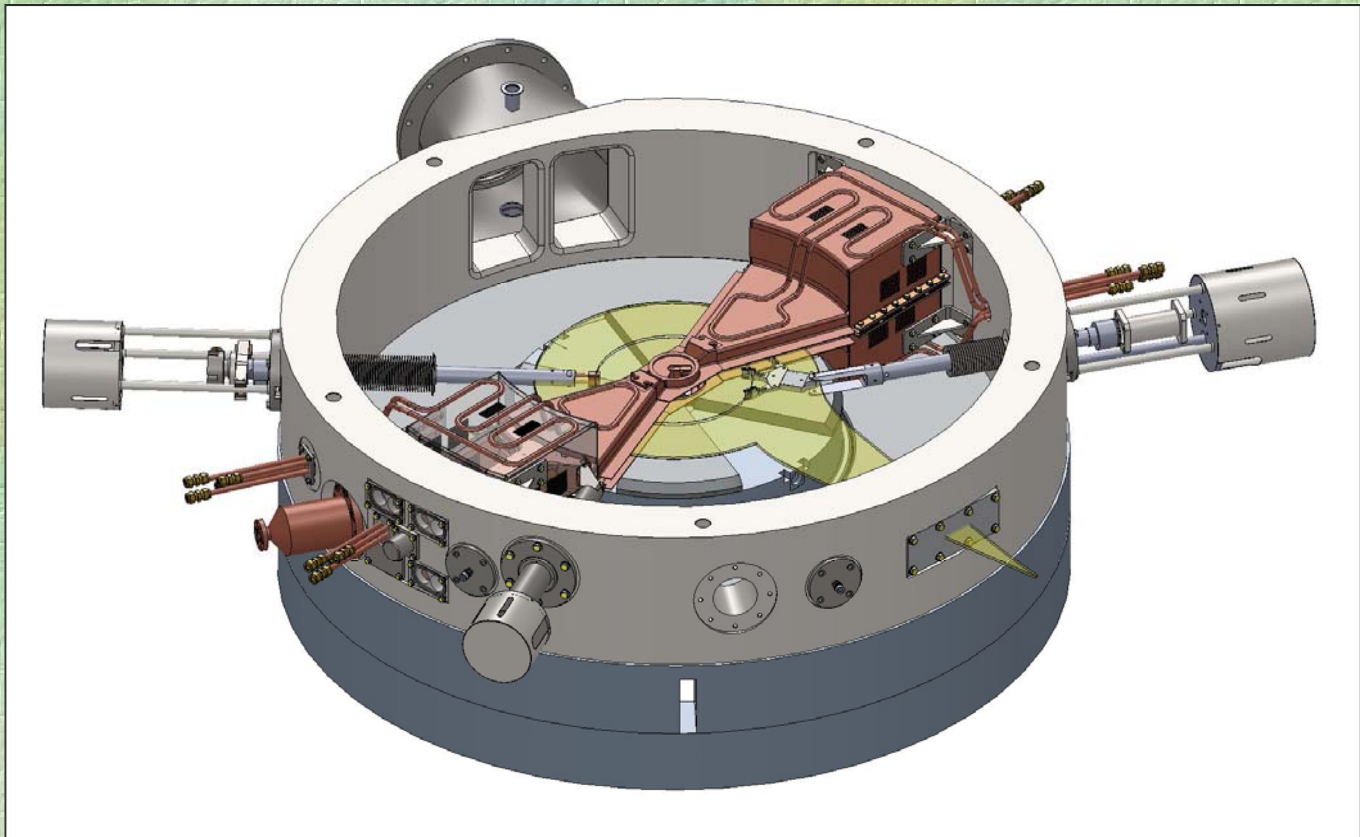


- The average magnetic induction in the median plane is 0.98 T.
- The maximal radius of ion acceleration is 250 mm.
- The power consumption of the electromagnet coils is 5.2 kW.



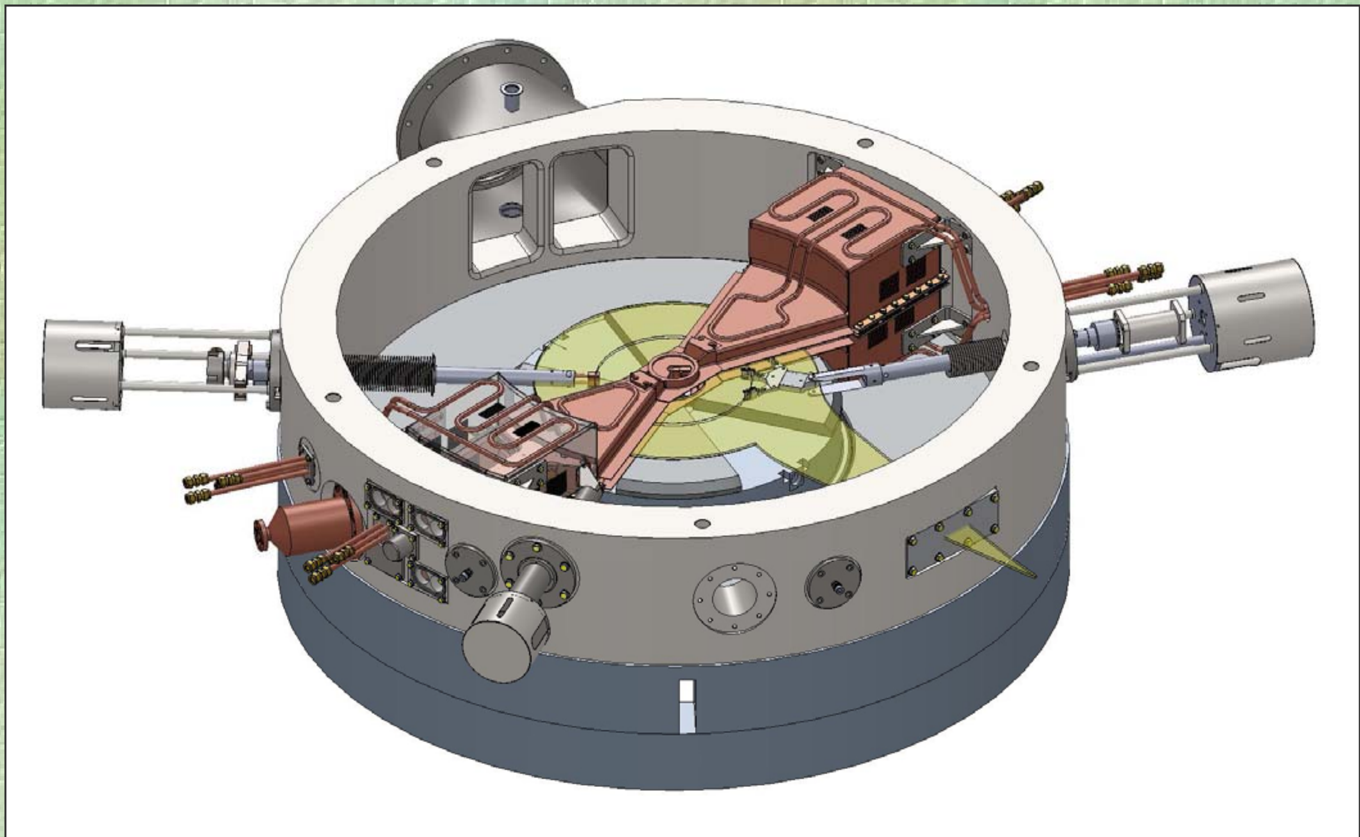
- The height of the cyclotron is 1750 mm.
- The upper part of the electromagnet can be elevated by 500 mm.

The vacuum chamber of the cyclotron consists of a cyindrycal body and the upper and lower plates, which are made of the ferromagnetic material and belong to the magnetic circuit. Each plate is reinforced with an annular extension made of stainless steel.

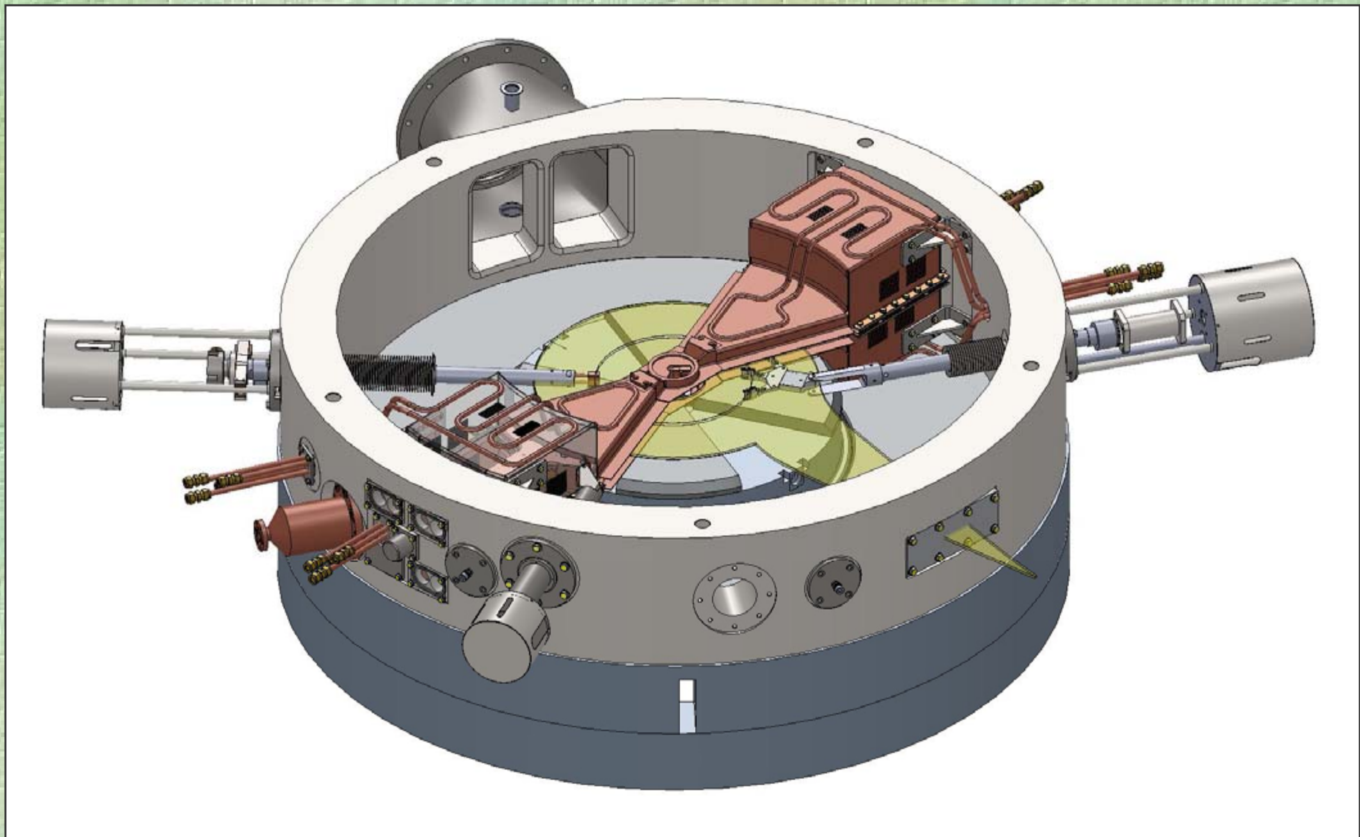


The RF system of the cyclotron includes two λ/4-resonators placed in the vacuum chamber – between the electromagnet valleys.

- The inner electrode of each resonator consists of a cylindrically shaped stem terminated by a triangularly shaped dee.
- The outer electrode of each reasonator consists of a box terminated by the anti-dee following the shapes of the valleys.



- The eigenfrequency of the resonators is 59.7 MHz, being four times larger than the proton orbital frequency.
- The dee voltage amplitude is 25 kV.
- The active power consumption in each resonator is 1.6 kW.
- The resonators also include an eigenfrequency trimmer, an inductive coupler, and an RF probe.



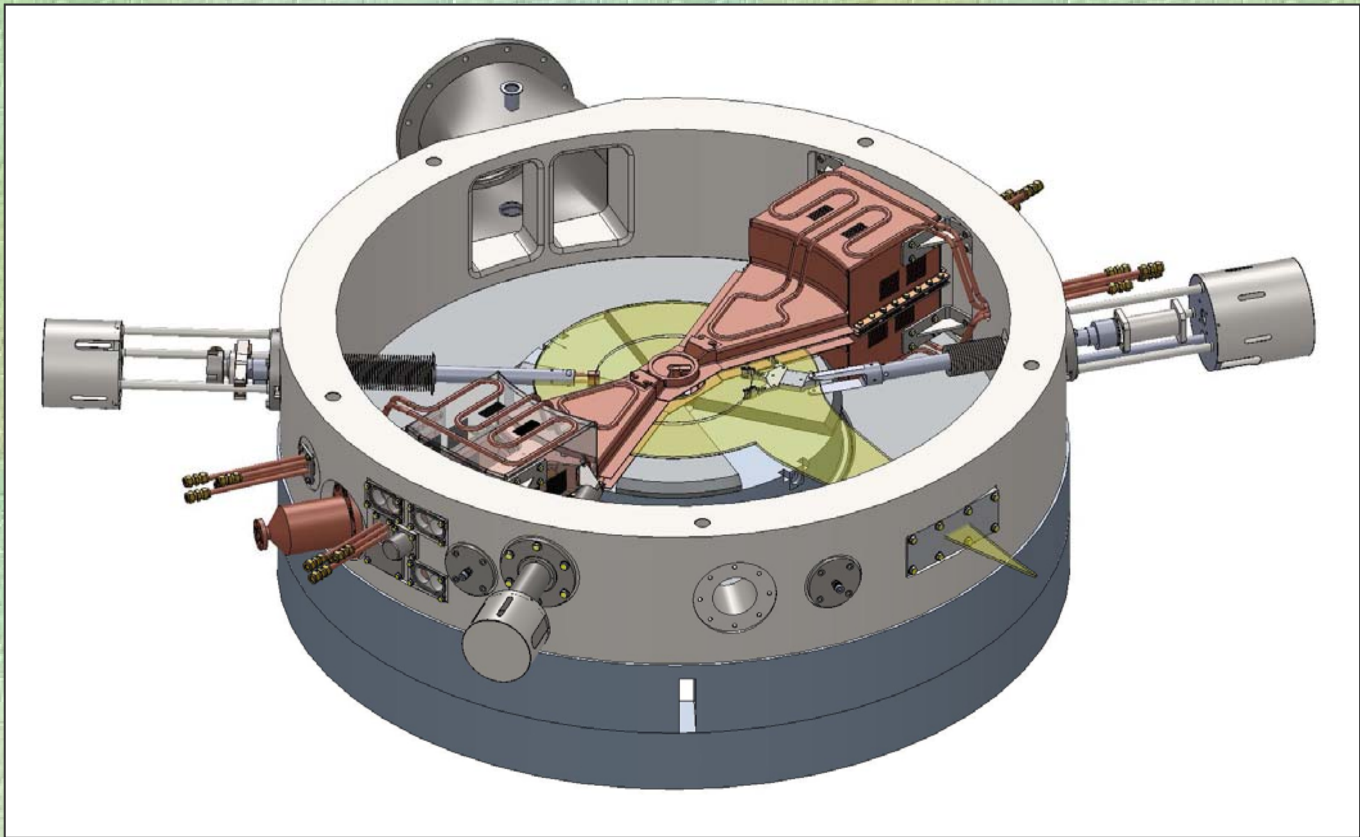
The RF generator includes a power amplifier and a control and stabilization modul.

- The stability of its operating frequency is 1×10^{-7}.
- The stability of the dee voltage amplitude 1×10^{-3}.
- The accuracy of the phase difference between the dee voltages $\pm0.5°$.
- The output power of the generator is 5 kW.
- The generator is connected to the resonators by a flexible coaxial feeder.

The injection system of the cyclotron is placed below the electromagnet. It includes a source of H^- ions with an acceleration and focusing system, two electrostatic lenses and a spiral inflector.

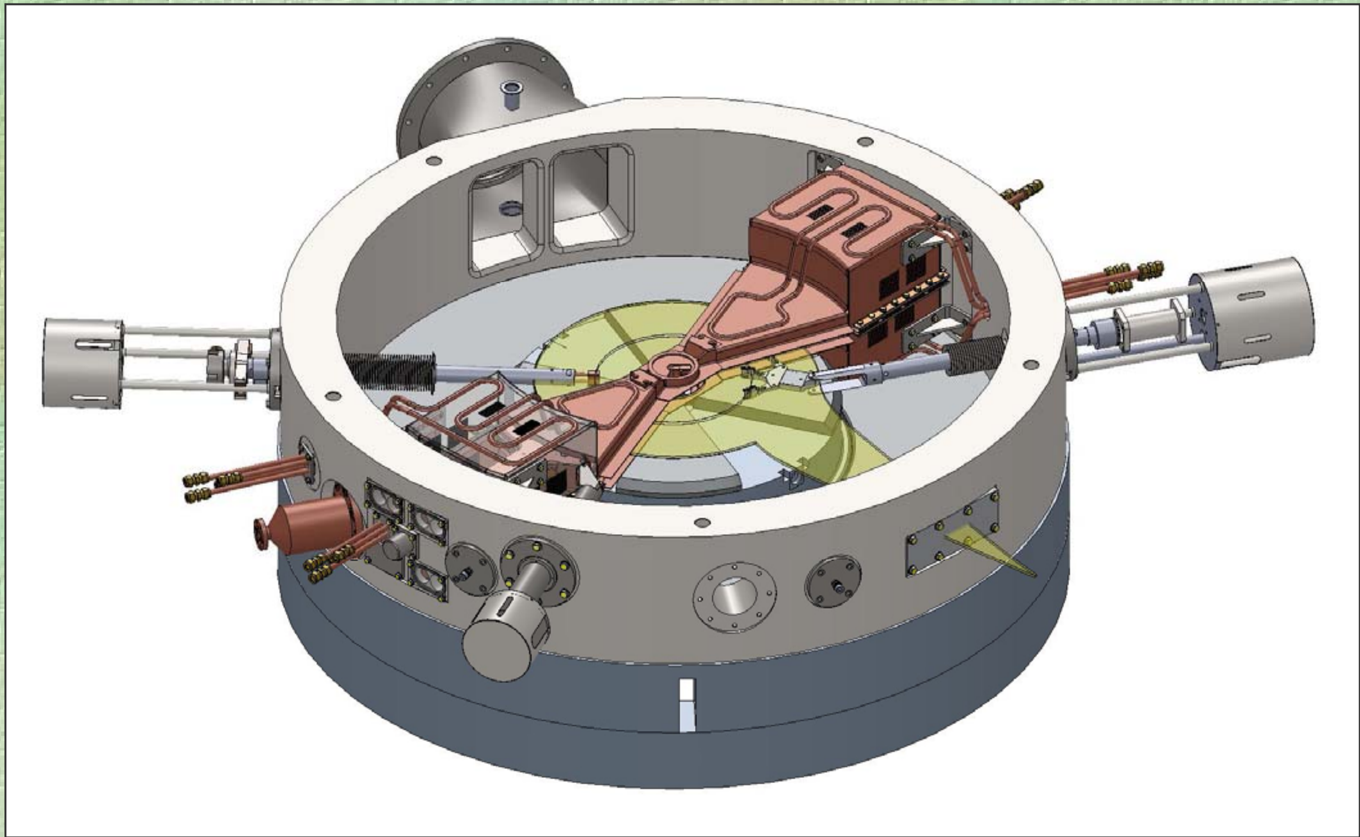
- The energy, maximal current and corresponding normalized emittance of the ion beam at the exit of the system are 11.5 keV, 0.5 mA and 0.3 π mm mrad, respectively.

The diagnostic system of the cyclotron comprises two proton beam current and profile monitors, which enable one to measure the characteristics of the beam in the radial range from 100 to 250 mm.



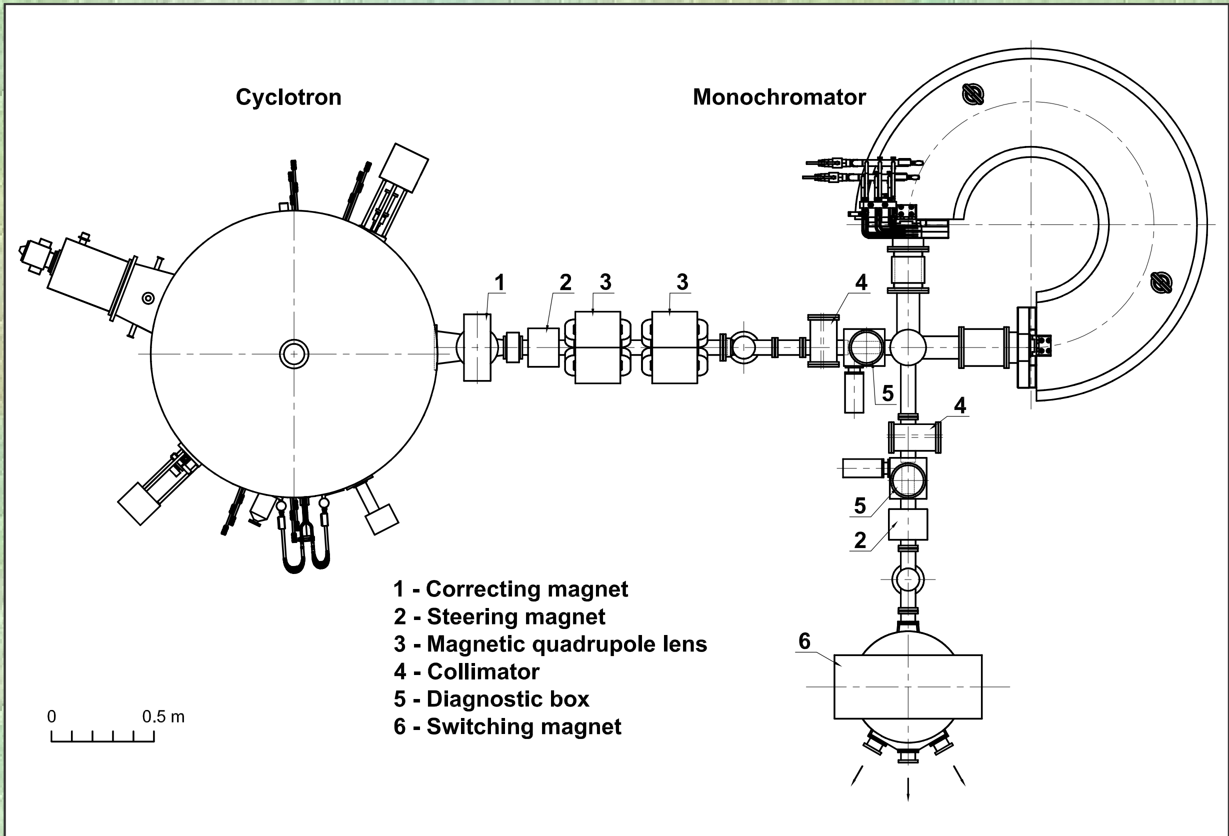
The extraction system of the cyclotron is based on a stripping foil made of carbon in which H^- ions are converted into protons.

- It includes a mechanism for the precise radial and azimuthal positioning of one of the three foils placed on a common holder.
- The maximal proton beam current after the extraction is 20 μA and the beam energy spread 10-20 keV.

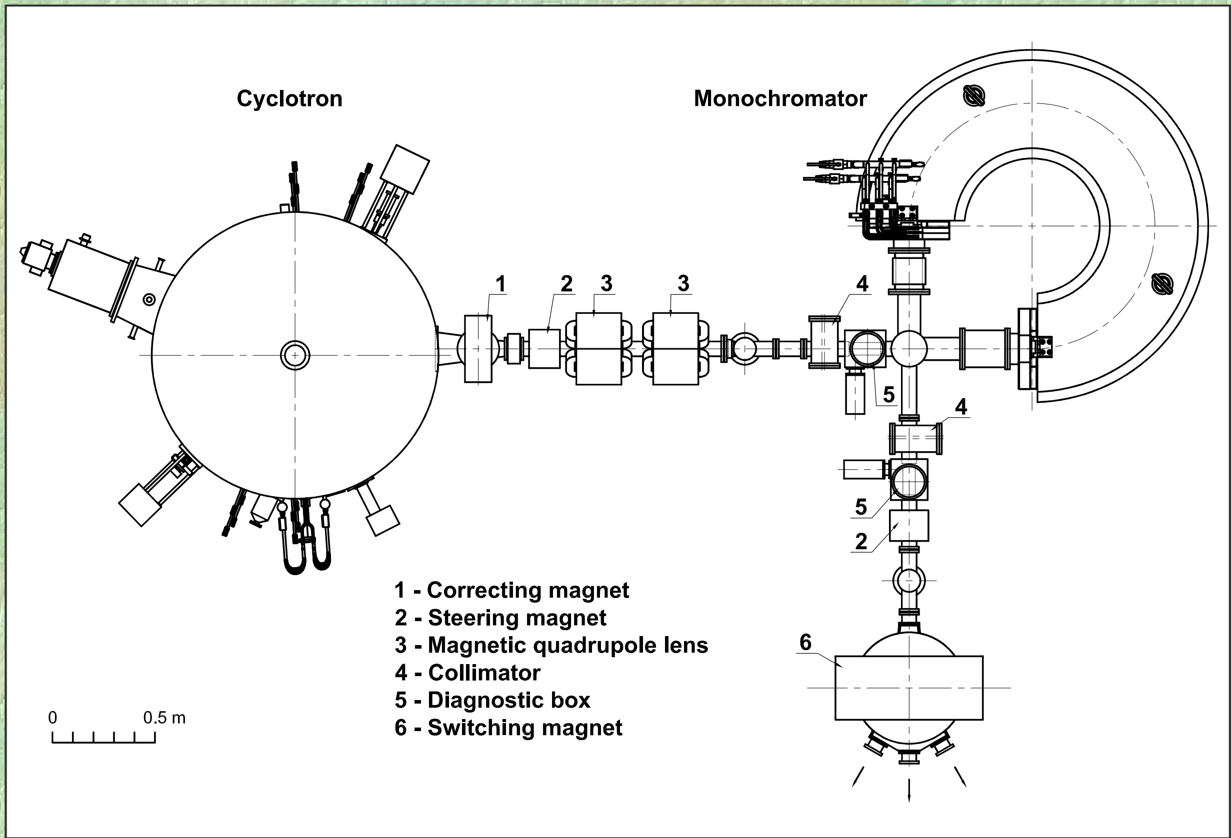


Transport and preparation system

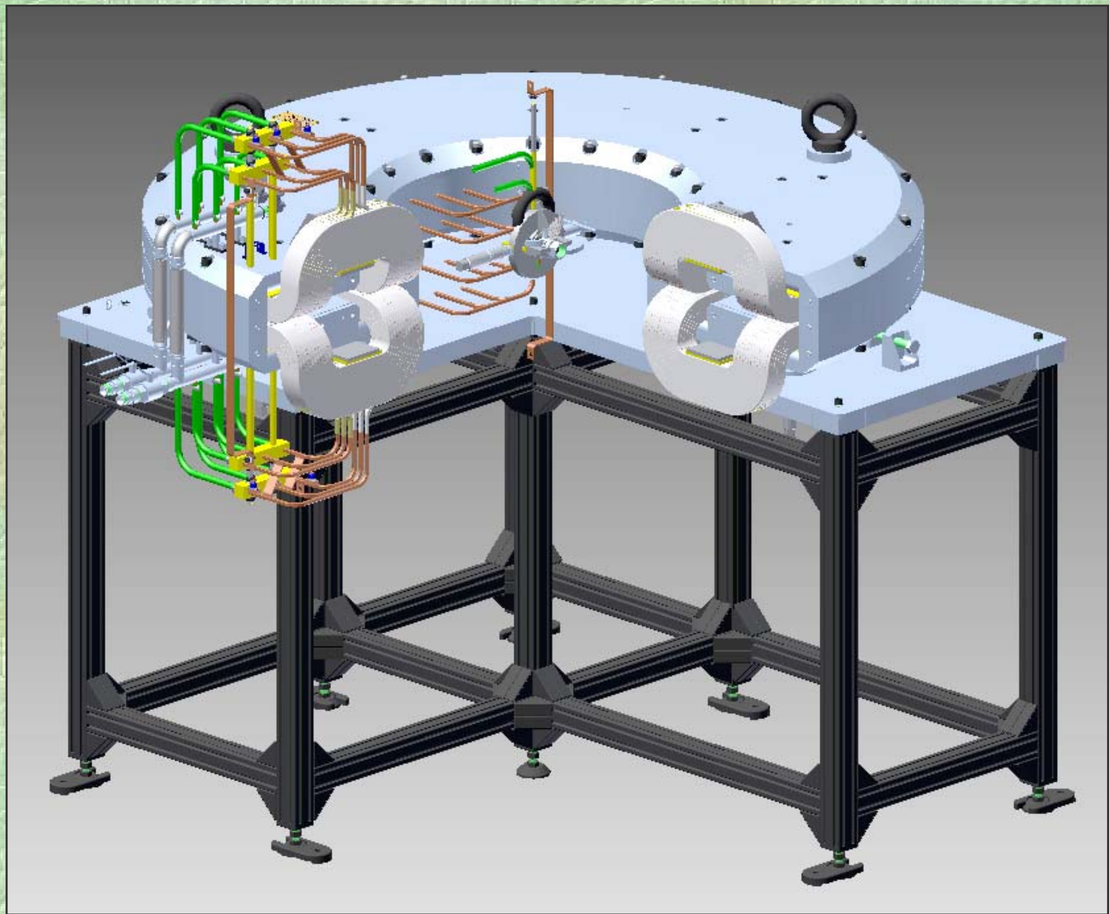
The transport and preparation system of the complex includes a correcting magnet, two steering magnets, two magnetic quadrupole lenses, a monochromator and a switching magnet.



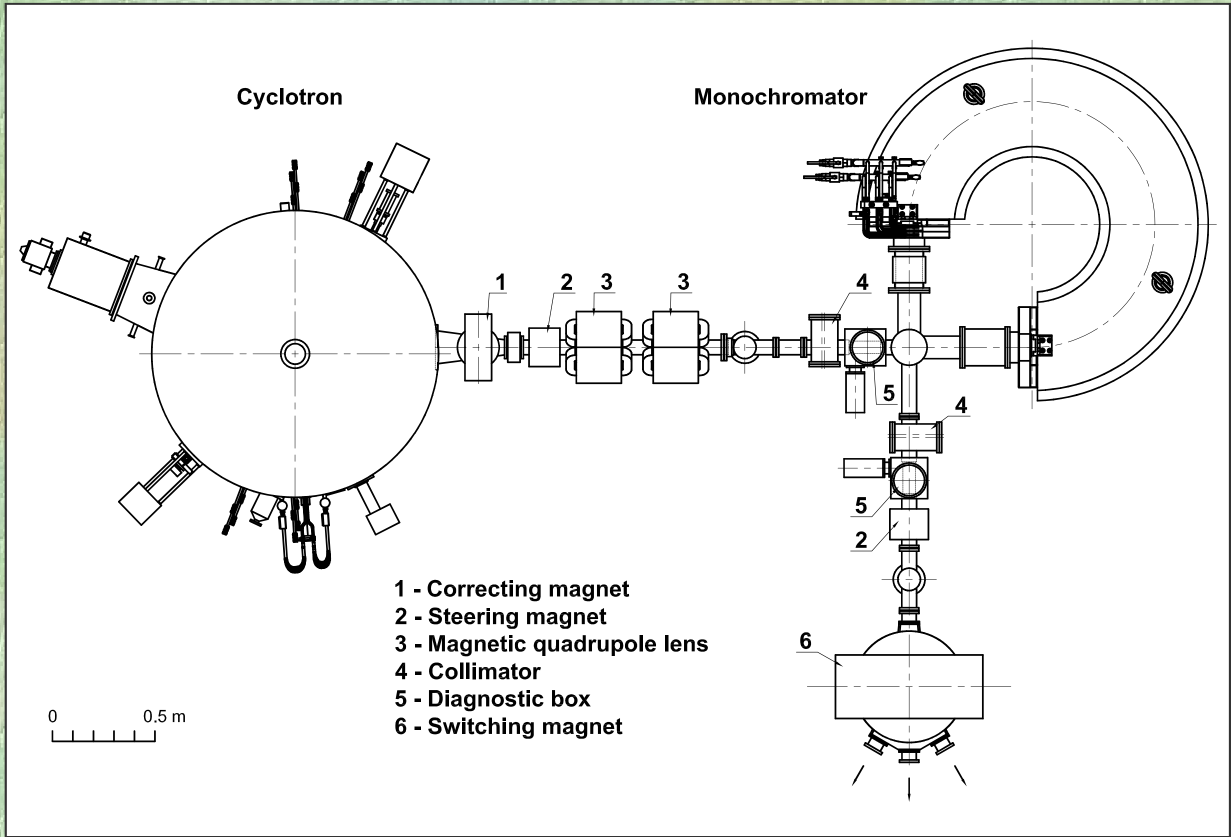
The correcting and steering magnets are used to correct the direction of the proton beam after the extraction from the cyclotron and along the system, the quadrupole lenses are employed to focus the beam at the entrance of the monochromator, the monochromator is used to define the energy and reduce the energy spread of the beam, and the switching magnet is employed to direct the beam toward the target to be analyzed.



- The radius of the monochromator is 600 mm, its effective bending angle is 270°, and it has the variable collimators of the widths of 0.5-2 mm at its entrance and exit.
- It ensures that the energy spread of the beam at its exit is reduced below 0.1 %.



The switching magnet can bend the beam for ±15°. It enables one to connect to the complex three experimental channels. The transport and preparation system also includes two diagnostic boxes, placed before and after the monochromator, each of them containing a beam profile monitor and a Faraday cup.



Vacuum, control and safety, and infrastructure systems

The vacuum system of the complex includes:

- a cryogenic pump of the pumping speed of 2400 l/s for evacuating the vacuum chamber of the cyclotron;
- two turbomolecular pumps of the pumping speeds of 1600 and 540 l/s for the injection system of the cyclotron;
- two turbomolecular pumps of the pumping speed of 300 l/s each for the transport and preparation system of the complex;
- the corresponding rotary vane pumps as the roughing and backing pumps.

The operating pressure in the vacuum chamber and vacuum tubes of the transport and preparation system will be below 3×10^{-6} mbar.

The control and safety system of the complex has a distributed architecture and is based on the Mitsubishi and Advantech controllers. It includes two central industrial computers, an industrial computer for controlling the RF system, and two operator personal computers.

The data exchange within the system is performed through an Ethernet network, for the higher level communication, and the ProfiBus DP and RS-485 networks, for the lower level communication.

The infrastructure systems of the complex are the power distribution lines, cooling water lines, compressed air lines, and exhaust gas lines. They are connected to the corresponding infrastructure systems in the basement of the C hall of TAI.

The maximal total power consumption of the complex is 40 kW and the maximal total cooling water consumption 80 l/min.

So far, the design documentation has been made and the fabrication of the parts of the complex has begun. Its assembling and commissioning in the Vinča Institute is planned to be finished by the end of December 2012.