JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE SUMMER STUDENT PROGRAM

Optimization of the magnet and cryostat of the MPD detector

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Abstract

Within the framework of the research project, two tasks were set. The first task is to build the geometry of the magnet and the cryostat of the MPD detector for further simulations using GEANT4, and also to optimize these geometries to reduce the number of simulated volumes. The original geometry was presented as a ".geo" format file and consisted of 19 independent volumes, 6 of which were part of a cryostat, and 13 a magnet body made of iron. As a result, the number of objects was reduced to 6 (up to 9, if I do not have time to make debug, which will be sad). 3 of which are a magnet body and 3 more are a cryostat, where they are sequentially embedded in each other. The result of this work is the transfer of ASCII geometry to the ROOT geometry, as well as the subsequent optimization of the volumes of the magnet structure and the cryostat of the MPD detector.

Introduction

Within the framework of the research project, the task was to transfer the ASCII geometry of the magnet and the cryostat of the MPD detector to the ROOT geometry. The MPD detector is part of the NICA project.

NICA (Nuclotron-based Ion Collider fAcility) is a new accelerator complex designed at the Joint Institute for Nuclear Research (Dubna, Russia) to study properties of dense baryonic matter.

The Collider will be constructed in a tunnel with additional buildings for two detectors and the electron cooler. Collider will be operated at a fixed energy without acceleration of an injected beam. To provide required linearity of the field the maximum bending field is chosen to be of 1.8 T. Two collider rings are placed one above the other and the beam superposition/separation is provided in the vertical plane. The distance between the ring median planes is chosen to be 32 cm. That is achieved with dipole and quadrupole magnets having two apertures in one yoke. The ring has a racetrack shape with two arcs and two long straight sections. The minimum beta function in the interaction point is 35 cm. The ring acceptance is limited by aperture of the final focus lenses is not less than 40 $\pi \cdot$ mm $\cdot$ mrad. Rms bunch length in the collision mode is 60 cm. The inter-bunch distance is larger than 21 m.

NICA Multi Purpose Detector.

The MPD apparatus has been designed as a 4π spectrometer capable of detecting of charged hadrons, electrons and photons in heavy-ion collisions at high luminosity in the energy range of the NICA collider. To reach this goal, the detector will comprise a precise 3-D tracking system and a high-performance particle identification (PID) system based on the time-of-flight measurements and calorimetry.

The basic design parameters has been determined by physics processes in nuclear collisions at NICA and by several technical constrains guided by a trade-of of efficient tracking and PID against a reasonable material budget. At the design luminosity, the event rate in the MPD interaction region is about 6 kHz; the total charged particle multiplicity exceeds 1000 in the most central Au+Au collisions at $\sqrt{s_{NN}}$ = 11 GeV. As the average transverse momentum of the particles produced in a collision at NICA energies is below 500 MeV/c, the detector design requires a very low material budget. The general layout of the MPD apparatus is shown in Fig. 1. The whole detector setup includes Central Detector (CD) covering ±2 units in pseudorapidity (η).

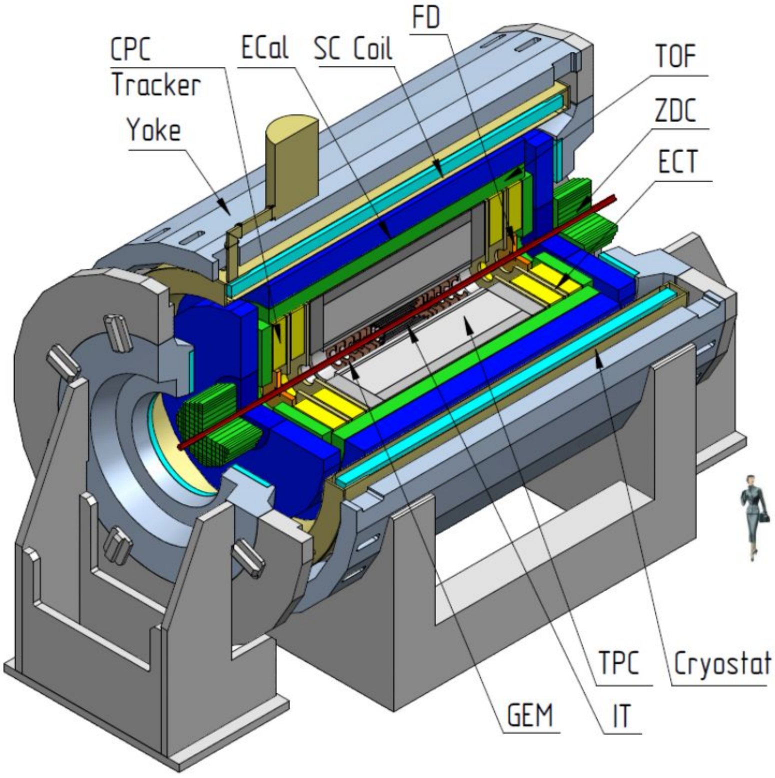


Fig. 1: A general view of the MPD detector with end doors retracted for access to the inner detector components. The detector consist of three major parts: CD-central detector, and (FS-A, FS-B) - two forward spectrometers (optional). The following subsystems are drawn: superconductor solenoid (SC Coil) and magnet yoke, inner detector (IT), straw-tube tracker (ECT), time-projection chamber (TPC), time-of-flight system (TOF), electromagnetic calorimeter (EMC), fast forward detectors (FFD), and zero degree calorimeter (ZDC).

TPC

Time-projection chamber (TPC) is the main track detector of the multipurpose detector MPD on the accelerator complex NICA. Registration of information about tracks of charged particles in TPC is carried out by wire proportional chambers with cathode pad readout. The registration electronics are developed using modern technologies such as specialized microcircuits (ASICs), programmable logic integrated circuits (FPGAs), high-speed optical interfaces. The main parameters of the electronic data acquisition and data acquisition system are as follows: total number of channels ~ 95000; data stream - 5 GB / s; low power consumption - less than 100 mW / channel; Signal to noise ratio (S / N) - 30; equivalent noise charge (ENC) <1000e - (Cin = 10-20 pF); suppression of zeros. The article presents the status of works on the creation of recording cameras and data acquisition systems, as well as the results of testing prototypes of the detector electronics cards.

Magnet

The task of this project was to transfer the geometry of the magnet and the cryostat. For this reason, it is worth mentioning the arrangement of a magnet and a cryostat. The magnet itself consists of a barrel 901 cm long and a diameter of 610 cm. The thickness of the walls varies from 18 to 30 cm. A magnet made of iron is made. The lateral part of the barrel of the magnet is a cylinder of 12 segments. Also in the ends of the barrel there are completely cylindrical structures of the inner part of the barrel, in the outer part of the end there is a ring structure consisting of 12 segments.

The cryostat is a structure of steel walls 5 mm thick filled with a vacuum inside which a solenoid is placed. The total length of the cryostat is 806 cm, the inner radius of the solenoid is 229.8 cm, the outer radius is 264 cm.

At the moment, the NICA project is still under construction, however, simulations of future experiments are already underway. Including simulations of collisions in the working area of the detector MPD. To carry out similar simulations, it is necessary to create a detailed model of the detector. Further on the basis of the constructed geometries, a simulation of future experiments is carried out. Various Monte-Carlo generators are used as a source of particles.

Software development

1. Methods

This section should be subdivided by short headings referring to the technique being used or the experiment being explained.

Методы. Этот раздел следует подразделить на короткие заголовки, относящиеся к используемой методике или объясняемому эксперименту.

(В работе использовались следующие инструменты)

The following tools were used in the work:

- ROOT6
- GEANT4
- Monte-Carlo generators

2. Translation and optimization of the magnet from the ASCII geometry into the ROOT geometry

The first task was to convert geometric files of the ".geo" format to root geometry., And also to optimize the number of volumes being built. The original file had 19 volumes executed.

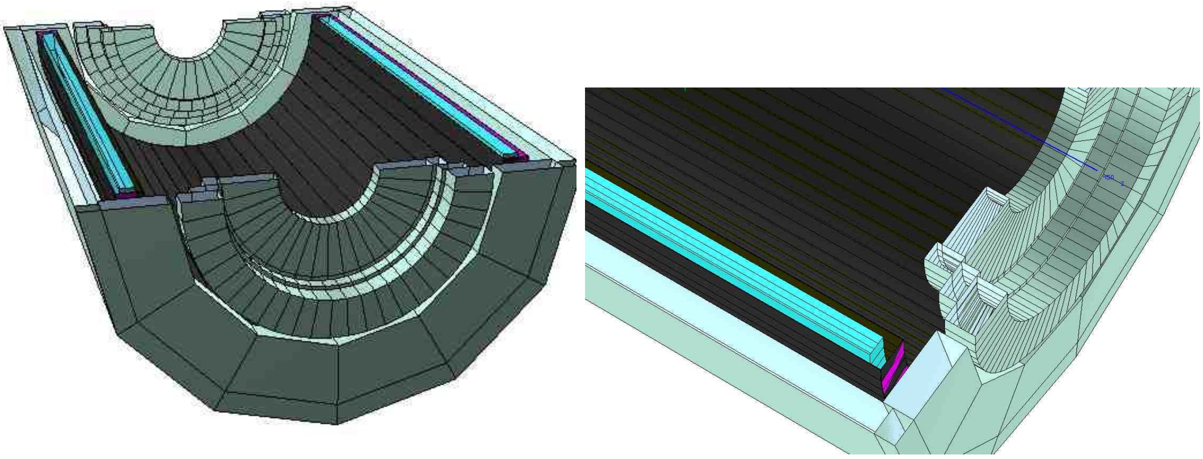


Fig. 2 Structure of the magnet and cryostat in the section in the original geometry.
Clearly visible are all the segments of which the magnet and the cryostat consist.

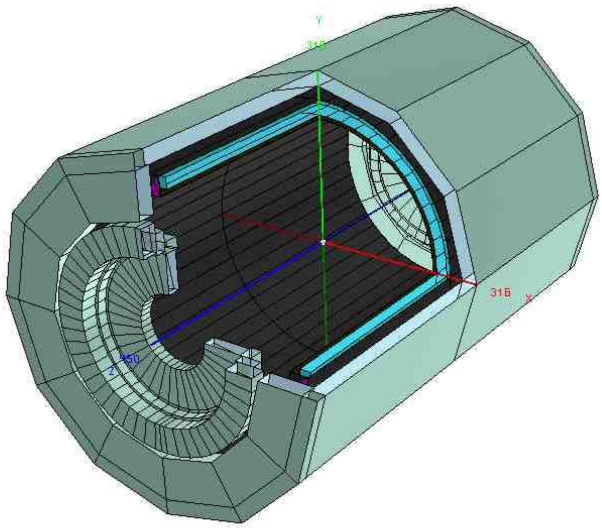


Fig. 3 Magnet of the detector MPD.

The magnet in the original geometry is represented by 12 volumes at the ends of the magnet and 1 in the barrel girdle surrounding the structure. The end volumes are presented as 6 original objects in one end and 6 copies of them constructed from the opposite end. Fig. 4 and Fig. 5 shows a set of all volumes composing the end parts of the magnet. In Fig. 6 shows the barrel of the magnet.

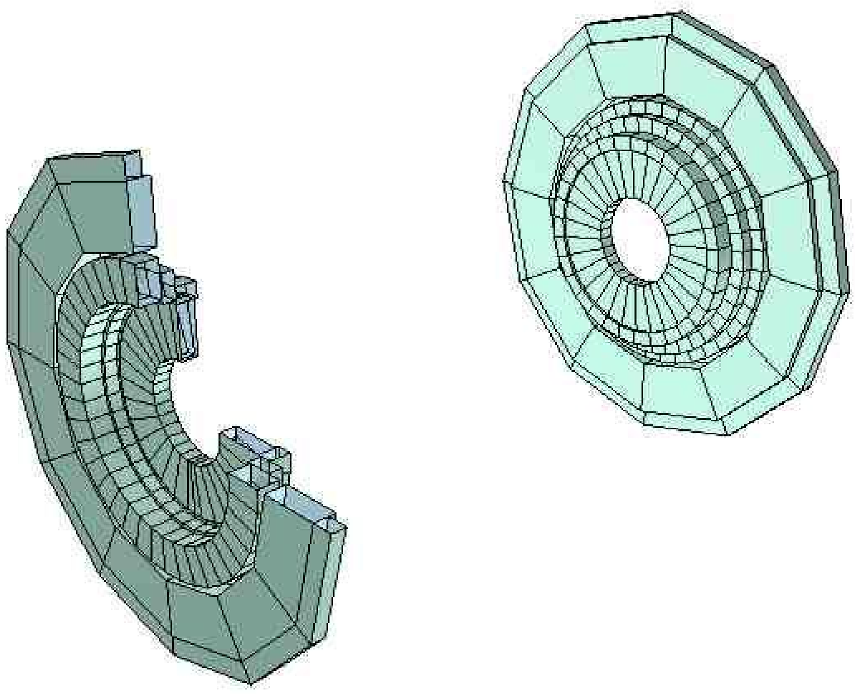


Fig. 4 Volumes constituting the end parts of the magnet.

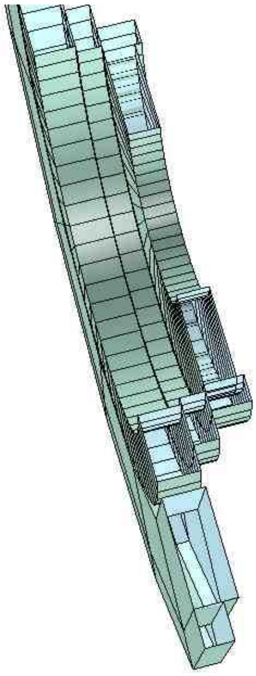


Fig. 5 This figure shows that the butt consists
of 6 independent objects of iron

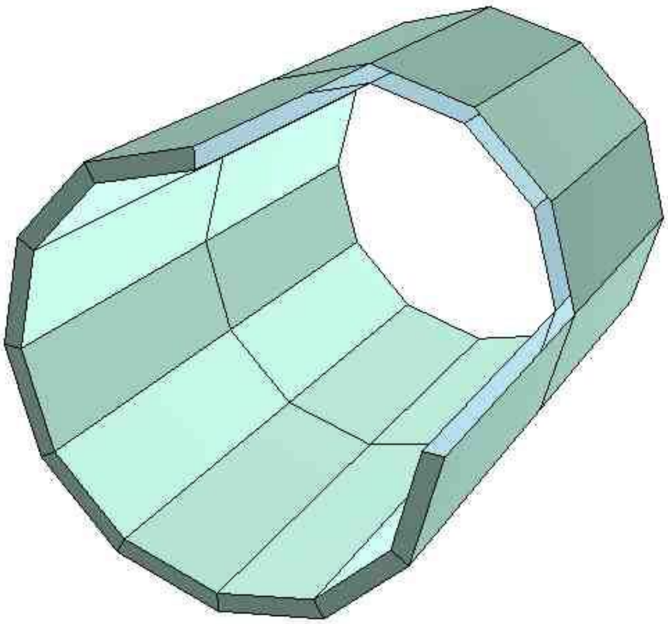


Fig. 6 The barrel of the magnet

So, apparently the magnet is 13 independent volumes, this amount is small in comparison with the number of objects in the detectors, which is estimated in hundreds and thousands, however, it was decided that it also needs to be optimized.

Part of the volumes at the ends are initially made in the form of volumes of the Tube type, cylinders simply put. The remaining end volumes and barrels are made in the form of volumes of Pgon type consisting of 12 trapezoidal sectors filling the angle of 360 degrees.

Figure 7 shows the geometry of the cryostat. The initial geometry was constructed as follows. Inside the space was placed the volume of vacuum in the form of a volume of the Tube type, represented in the figure in the form of a volume of lilac color. Then 4 volumes of steel with a thickness of 5 mm were placed inside the vacuum volume adjacent to the boundaries of the volume of the vacuum. In Figure 6, they are represented by volumes of dark green color. These volumes are the steel walls of the cryostat. All wall volumes were also presented in the form of volumes of the Tube type. Also in the vacuum volume was a volume of the Tube type, which is a solenoid made of Copper material. The figure shows the volume of blue.

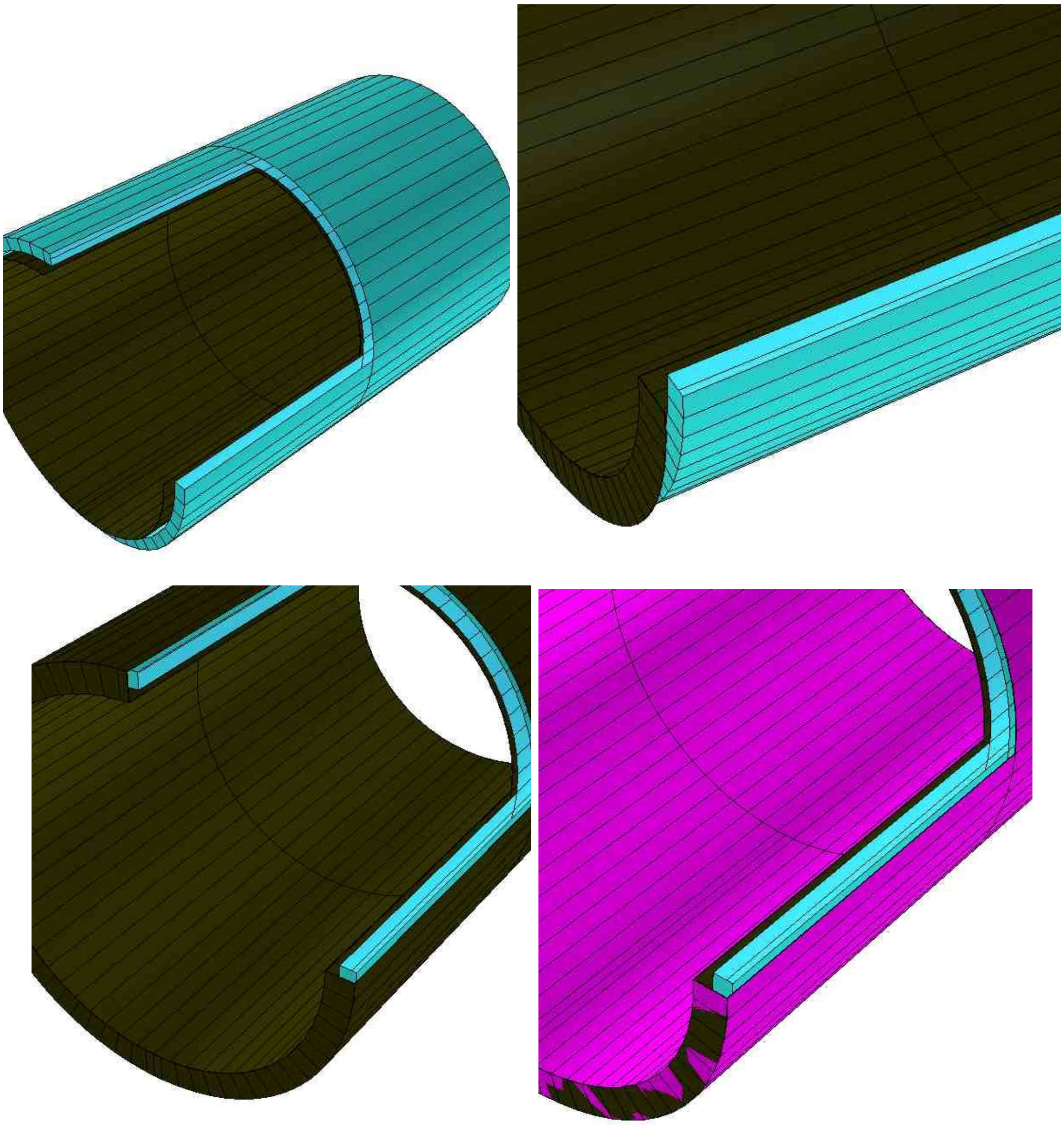


Fig. 7 Inside the cryostat the cryostat solenoid (blue), the cryostat walls of steel (black), the vacuum between the solenoid and the steel walls (lilac)

The first action on the way to solving the problem was the complete transfer of geometry from the ".geo" format to the geometry of the "root" format. As a result, all elements were completely transferred, without changing the structure and size.
The next step was the optimization process. As a result, the structure of the cryostat, the end parts of the magnet originally presented as structures of the Tube type, as well as the barrel and end pieces made in the form of structures of the Pgon type were changed.

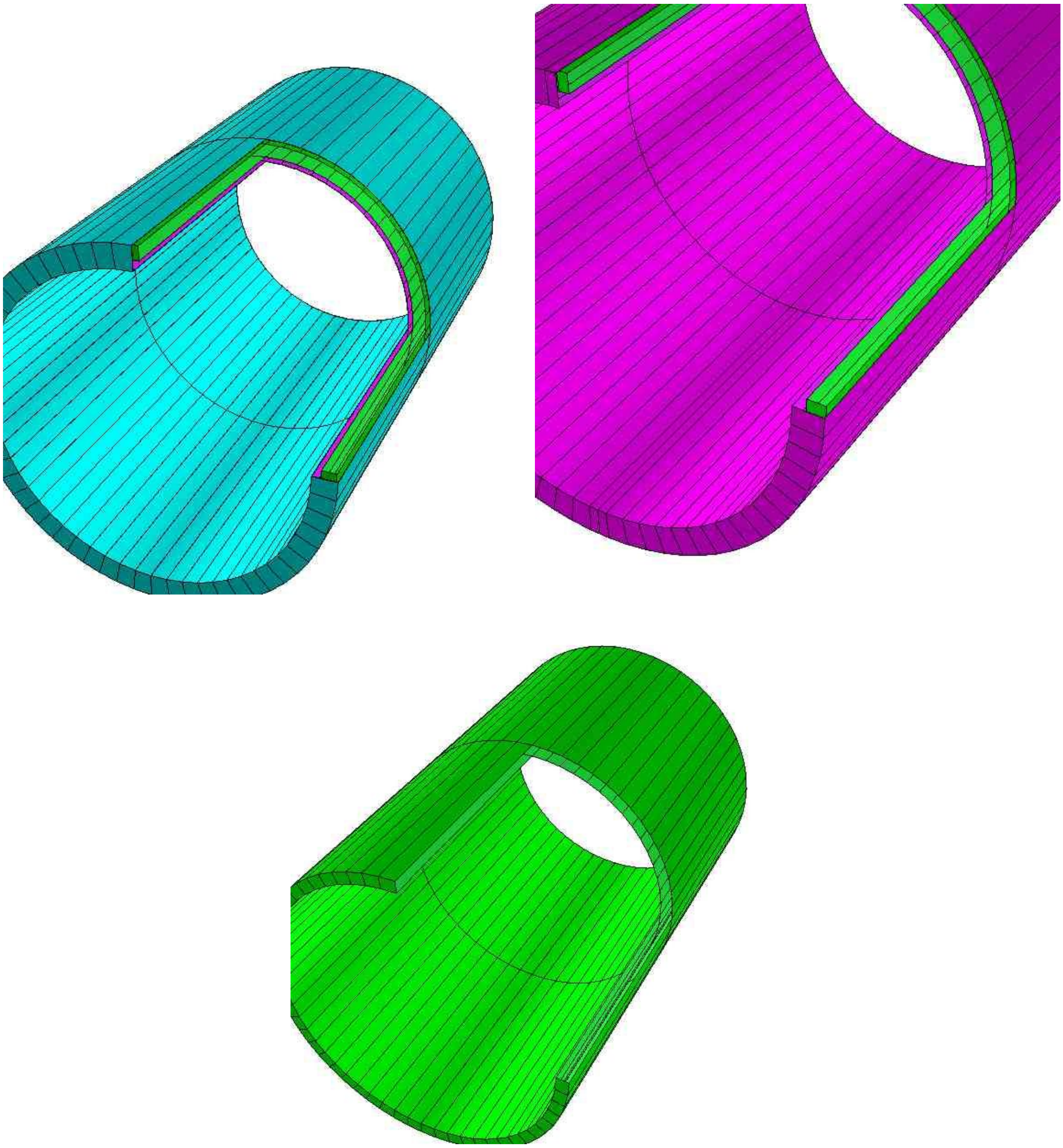


Fig. 8 Cryostat assembly. The steel walls of the cryostat (blue), the volume of the vacuum (lilac), the solenoid (green)

The first change was made to the cryostat. The first volume, in which the rest were subsequently invested, was a volume of the Tube type made of steel, which is the cryostat wall. Then a volume of

vacuum was invested in this volume. The volume of the vacuum was put in such a way as to preserve the original dimensions of the steel walls. Further inside the volume of the vacuum was enclosed a volume of the same type as the previous one, representing the solenoid.
Thus, if we compare the quantity of volumes after making changes and the initial one, we can see that the quantity of volumes has been reduced by half. At the same time, all the parameters of the cryostat system were retained.

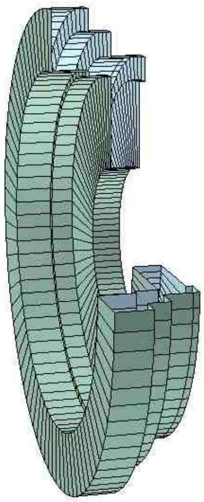


Fig. 9 The end part of the magnet is made in the form of one volume

Further, the volume of the magnet was optimized. The first volumes were changed using a set of volumes of the Tube type. Instead of Tube, the Pcon structure used in the rut geometry was used to construct complex structures based on a cylinder with varying radii or displacements along the Z axis. As a result, the structure shown in Figure 9 was obtained. This structure completely repeats the structure constructed from 4 volumes in the source file . However, here we have one monolithic volume.

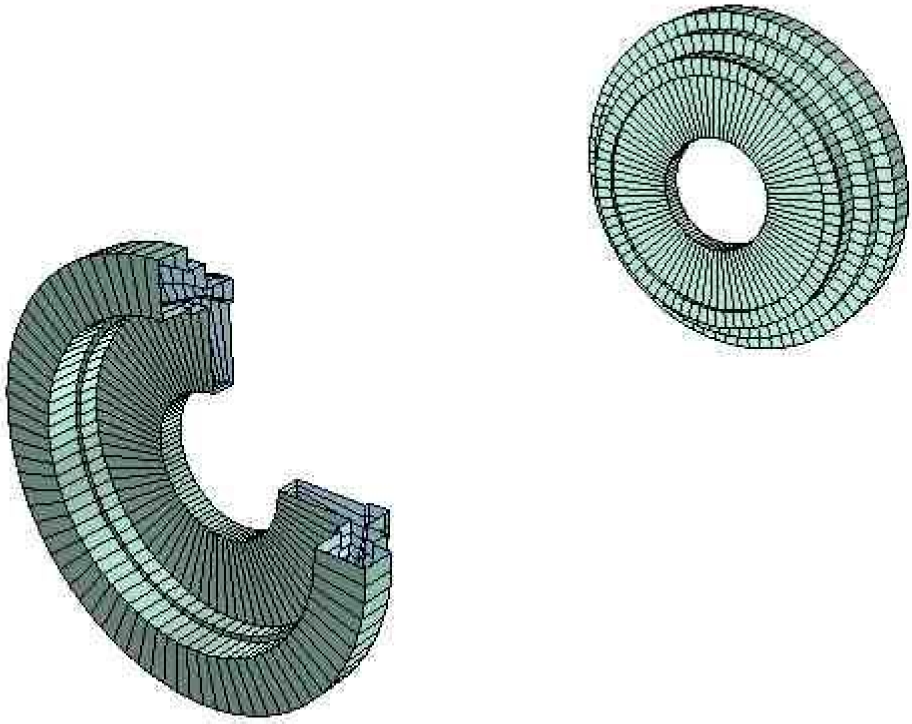


Fig. 10 Two end pieces made with Pcon

Thus, in the ends of the magnet instead of 8 original volumes, 2 volumes were obtained, completely repeating the original structure.
Next, changes were made related to the optimization of 5 volumes made with Pgon, namely 4 volumes at the ends of the magnet and barrel.

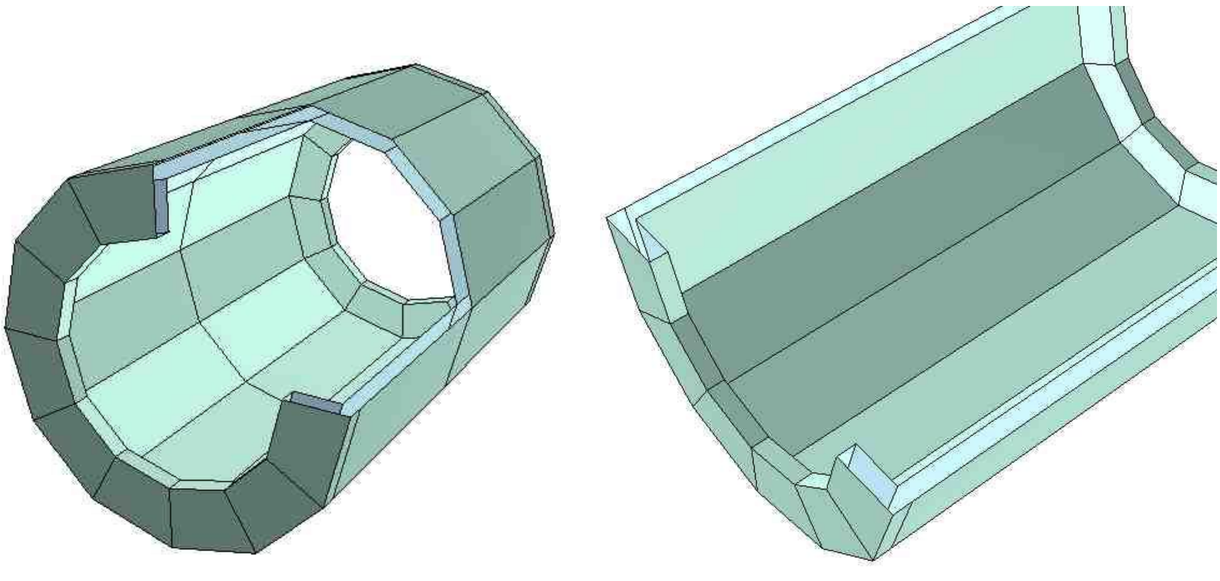


Fig. 11 Barrel magnet and part of the end volumes after optimization

In the original geometry, there were 5 volumes made using Pgon, and also consisting of one material. These volumes can be considered as one whole volume. In this case, it was decided to combine these volumes into one executed also using Pgon. The result can be seen in Figure 11.

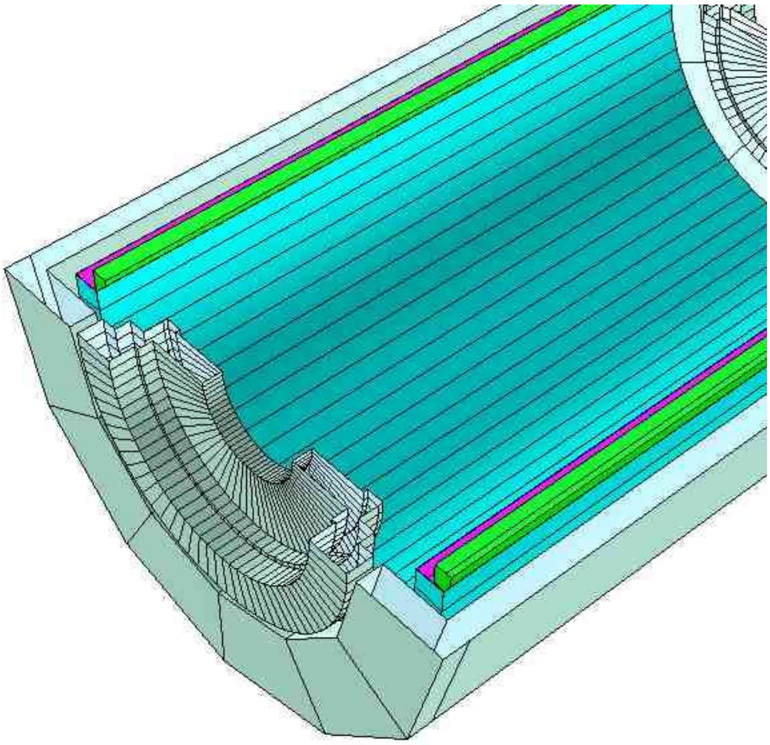


Fig. 12 Magnet and cryostat after transfer to new geometry and optimization

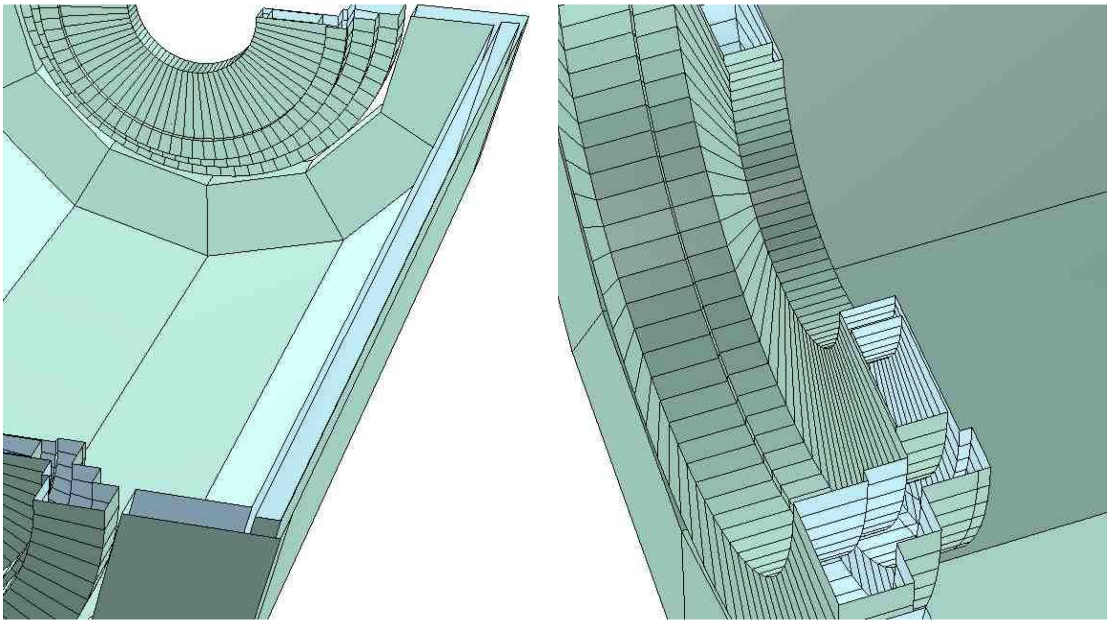
Figure 12 shows the result of the transfer of a magnet and a cryostat to a new geometry and optimization of all volumes. When comparing Figures 2 and 12, it can be seen that both versions of the magnet are identical in size and proportions and differ only in the number of volumes used for the construction. 19 volumes for the original geometry and 6 for the new geometry of the ".root" format.

3. Debugging the root geometry

After the transfer and optimization of the magnet and cryostat, an attempt was made to simulate the passage of particles. However, the broach program issued an error. A geometry check was performed, as a result of which it was found that the problem does not arise from errors in the geometry, but because of the presence of a bug in the used root.

It was found that the fall occurs when the magnet starts. This bug is apparently related to the level of filling volumes. This conclusion was made, because the error occurred precisely when building magnets having only a single embedding in the cave, while there were no errors in the construction of a cryostat having an attachment of several levels of errors.

As a result, to test the theory that the error arises not due to any errors in the construction of geometry, namely, because of the bug in the root itself, additional volumes were invested in the volumes of the magnet.



ig. 13 The end and barrel of the magnet after investing in their volumes of additional volumes of iron

When comparing Fig. 13 with Figures 9 and 11, it can be seen that volumes of iron are enclosed in the volumes of the barrel and end elements.

After making this change, the simulation process began without any errors. As a result, it was concluded that a bug was found associated with the level of investment of volumes. In this regard, debugging was carried out in order to detect the problem and eliminate it.

The new task consists of debugging to detect the problem and fix it. Which according to primal assumptions can be connected with the peculiarities of fairroot. The implementation of this task will be carried out outside the framework of the process under discussion. In addition, according to the latest data, new drawings will soon be received, in accordance with which the current geometry will be modified to carry out more accurate simulations.

Thus, as a result of this project, the geometry was transferred and optimized. As a consequence of the work done, a new task for the future work is more global than the initial one.

Actual results

As a result of the Summer Student Program, the ROOT6 and GEANT4 tools were mastered, with the help of which the task set by the head was accomplished to transfer the geometry of the magnet and the cryostat from the ASCII geometry format to the ROOT format. Volume optimization was also carried out in order to reduce their quantity. The resulting geometry is transferred with the exact observance of the initial geometry dimensions.

Also, a new task was formulated to determine the problems associated with the work of ROOT in constructing geometries that arise when objects are once embedded in a cave. This task is the main one for the future work.

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