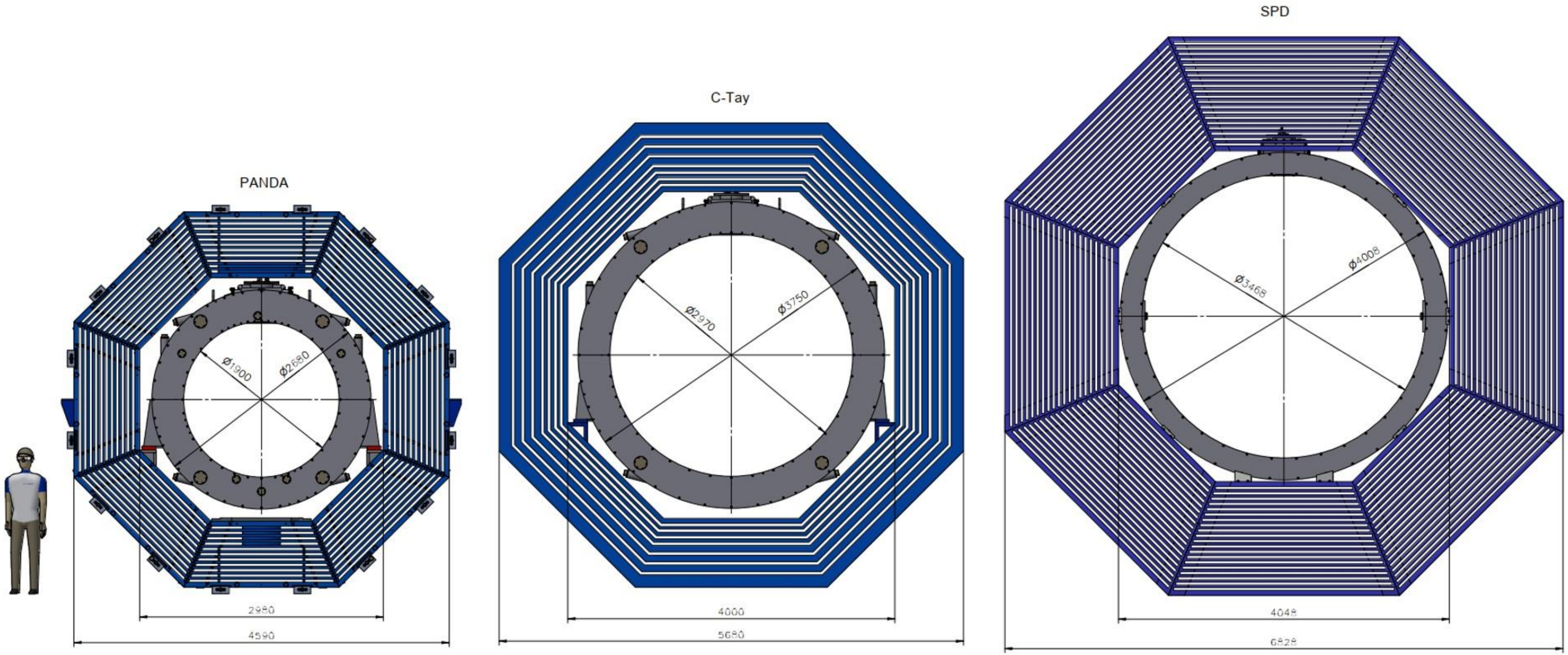
The Budker Institute of Nuclear Physics

SPD magnet

Status of the SPD superconductive solenoid development

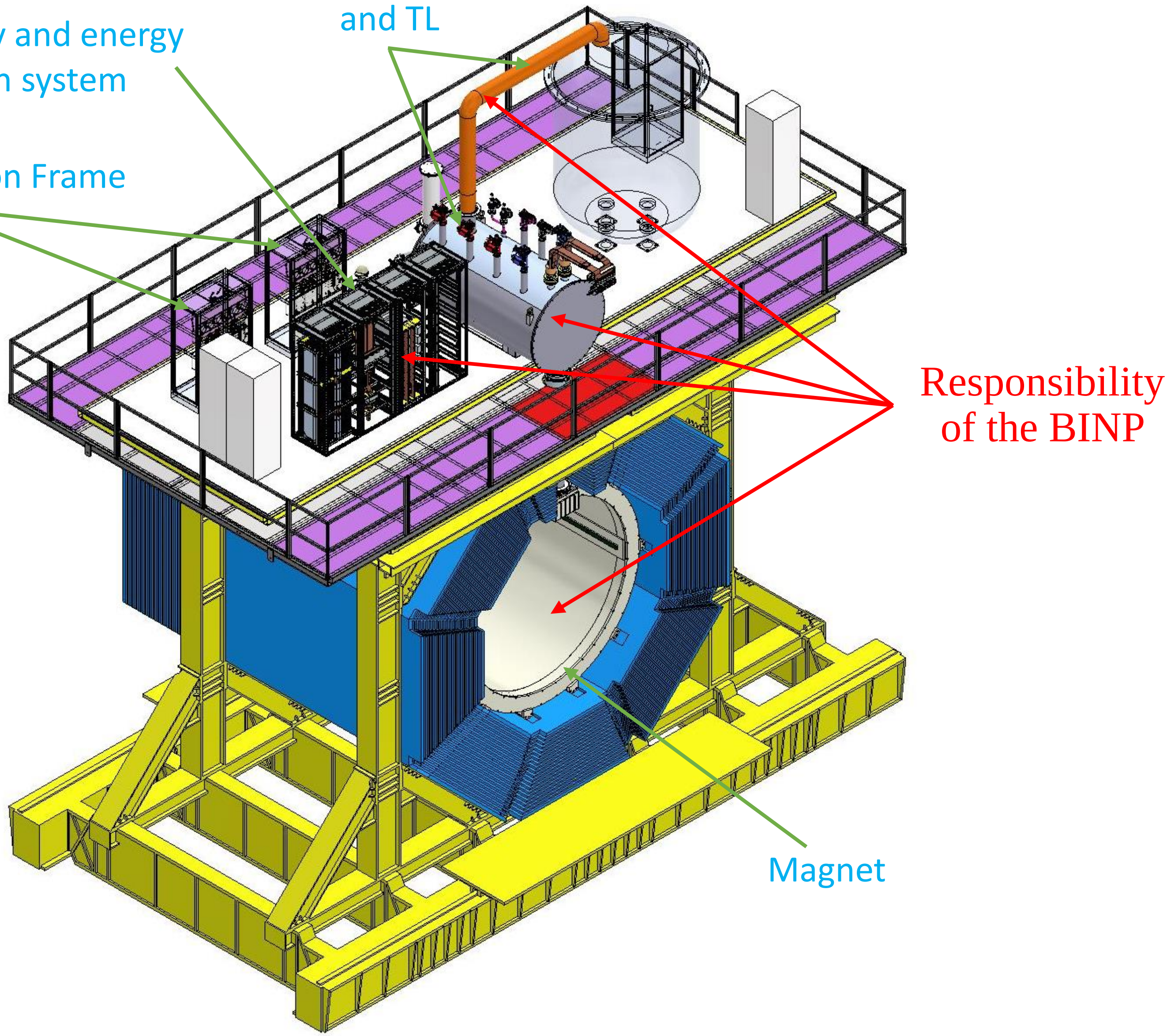
E. Pyata, S. Pivovarov, BINP, SPD Magnet

PANDA & C-tay & SPD Magnet.



This slide shows 3 magnet projects for detectors: PANDA (FAIR), D=2680 mm, L=3090 mm; C-tay factory (BINP), D=3750 mm, L=3700 mm; and SPD (JINR), D=4008 mm, L=4220 mm.

SPD Магнит with Control Dewar



The magnetic field along the solenoid axis should be 1.0 T.

BINP presents our participation in SPD project with the following items:

- Magnetic and engineering design of the magnet including tools and support;
- Production and delivery of the magnet (consisting of the cryostat with cold mass, alignment components, proximity cryogenics, supports);
- Power converter, energy extraction system, quench protection and instrumentation.

SPD development

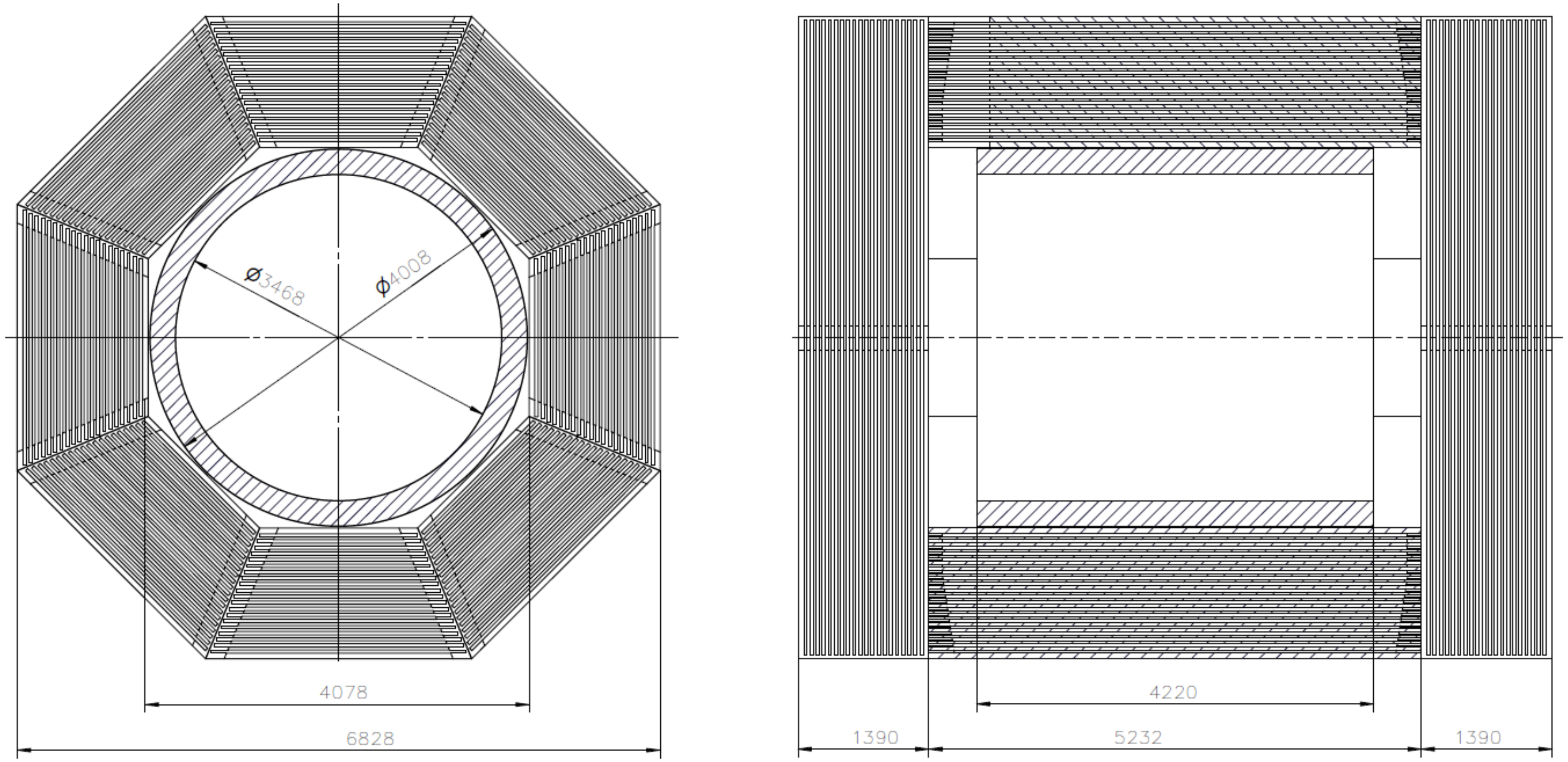
- Magnetic analysis of the magnet including of calculations of the magnetic forces is done. Using the Maxwell tensor method, the magnetic forces acting on the elements of the solenoid (barrel part of the yoke, endcaps) and coils were calculated. The results of the calculations were presented at a workshop at JINR on December 17, 2023. Magnetic field map of the SPD solenoid is ready. This topic will be presented in more detail in the report by E.I. Antokhin.

- Design of the proximity cryogenics with flow scheme and all instrumentation for cryogenics and insulation vacuum for the cryostat and control Dewar, current leads is in progress. Selection of equipment and instruments for the SPD solenoid cryogenic system is carried out. 3D model of the distribution box with cryogenic piping was developed. Thermal loads on 4.5K cryogenic systems and 60K heat shields are estimated. This topic will be presented in more detail in the report by T.V. Bedareva.

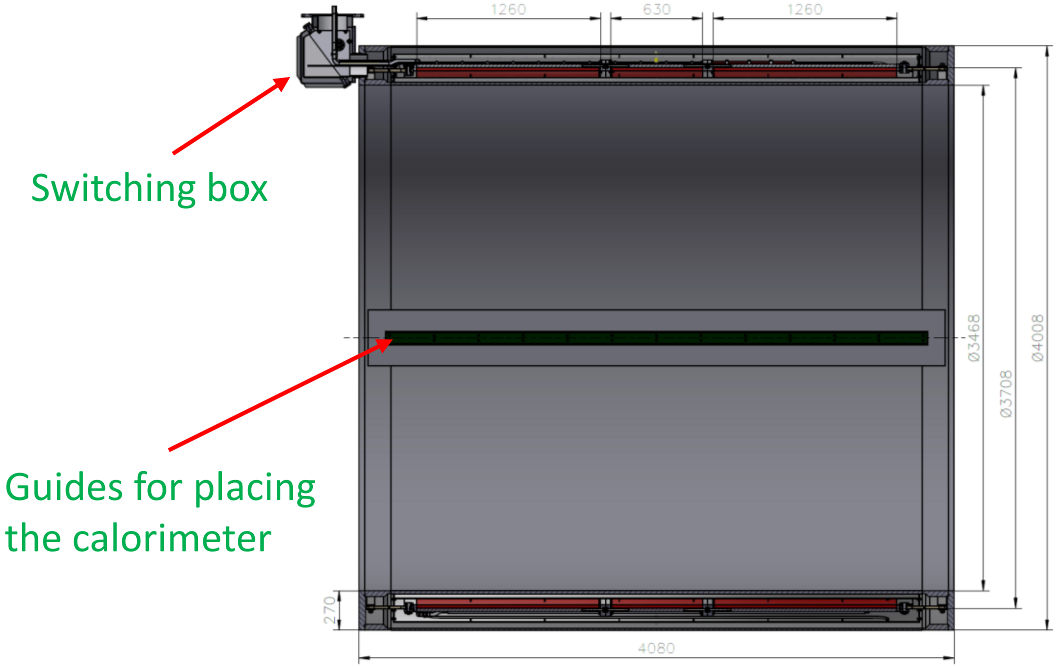
- Design of the power supply system and energy extraction system is in progress. Selection of equipment and instruments for the SPD solenoid cryogenic system is carried out. This topic will be presented in more detail in the report by A.I. Erokhin.

SPD yoke and solenoid

The cryostat of the magnet with the coils, cold mass and thermal shields is located inside the yoke. Outside diameter of the cryostat is 4008 mm and a gap between the yoke and the cryostat about 20 mm. Radially a free diameter of 3468 mm is left for the SPD detectors. The length of the magnet is 4220 mm and the magnet should be installed symmetrically inside the yoke.



SPD Magnet



Cryostat: Outer diameter -4008 mm;
Inner diameter - 3468 mm;
Length 4220 mm;
Thickness - 270 mm;
Cold mass: Outer diameter -3756 mm;
Inner diameter - 3662 mm;
Length 3416 mm;
Coils: (2 pieces): Number of layers - 2; Number of turns 2x156=312.
(1 piece): Number of layers - 2; Number of turns 2x78=156
Total number of turns - 780

Weight: - cryostat - 16700 kg
- shield - 1000 kg
- cold mass - 5390 kg
Total: ~23 t

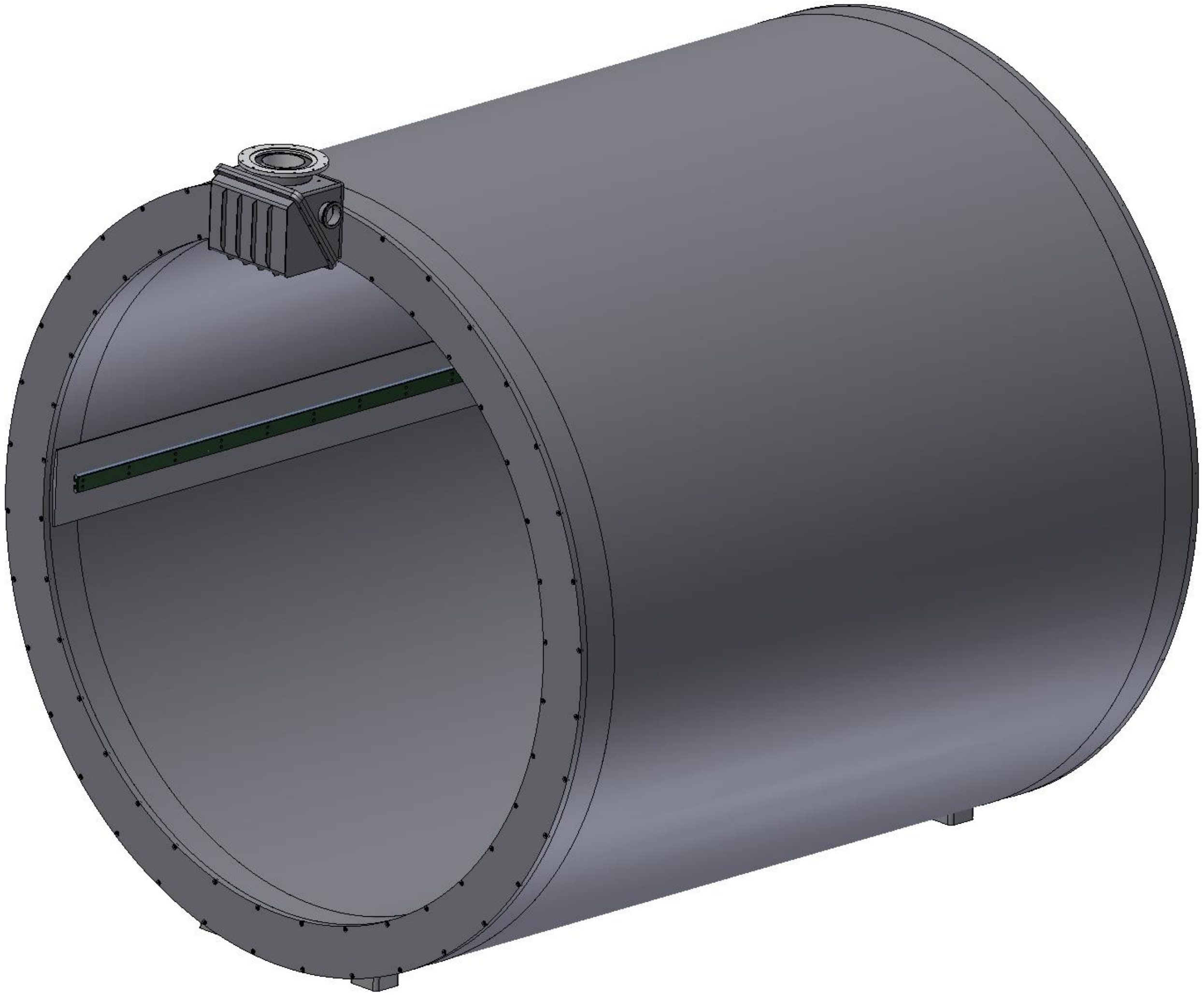
The main characteristics of the magnet:

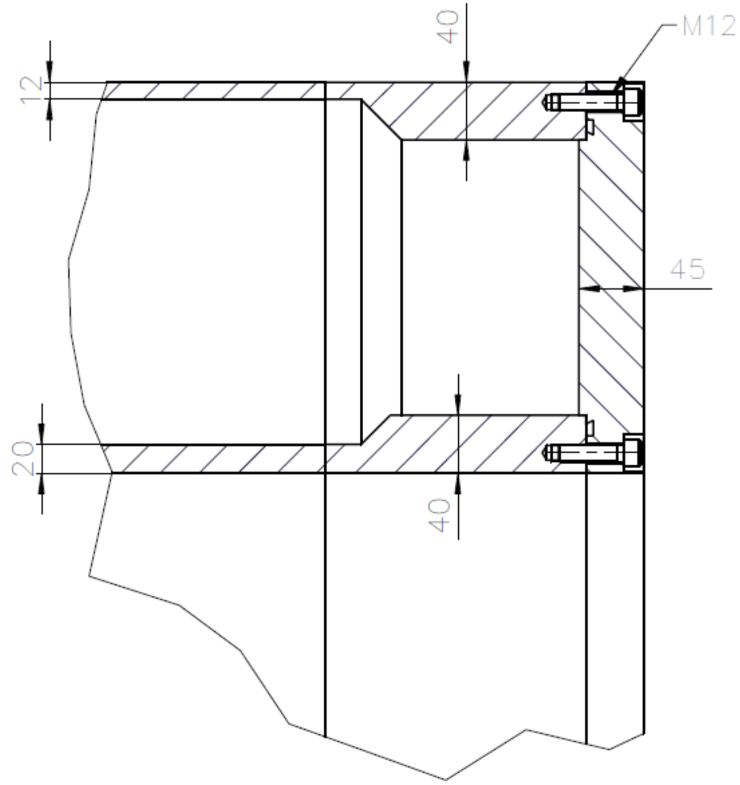
Magnetic field along the axis - **1.0T** with uniformity ± 2%;

The superconductive solenoid consists of three coils, the **current** is **5200 A.**

Conductor type: Rutherford type cable consists of 8 strands with a diameter of 1.4 mm and a Cu / NbTi ratio of one, extruded into a matrix of high purity aluminum A996, the conductor cross-section at a temperature of 4.5K is 7.90mm in width and 10.90mm in height;

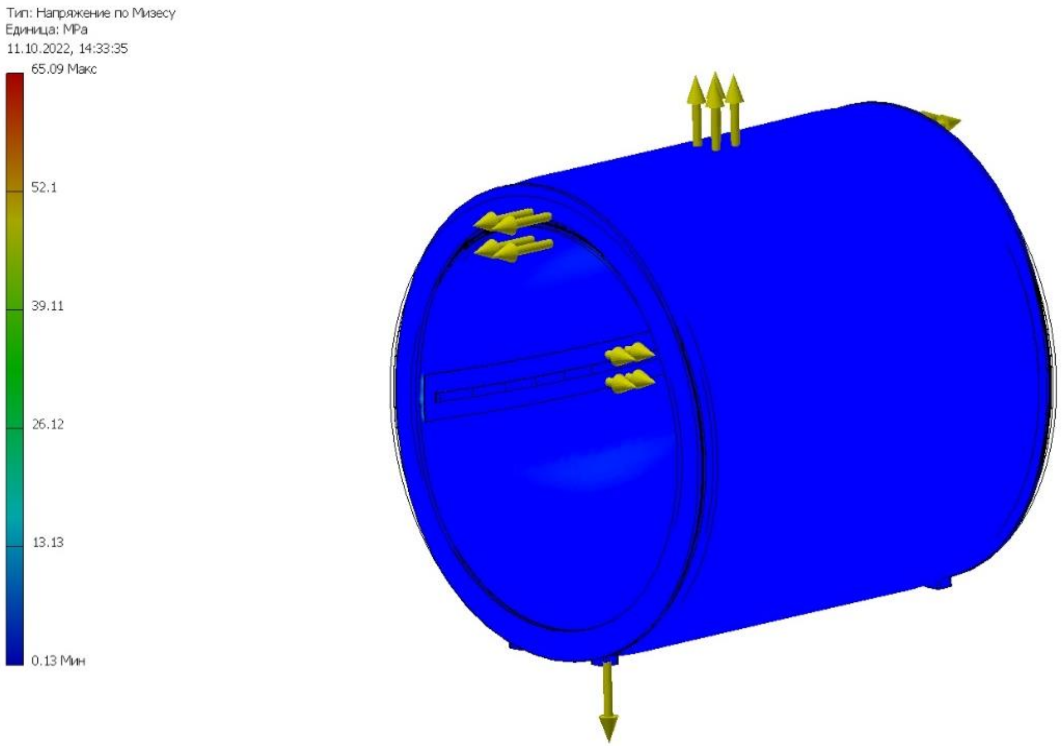
Cryostat

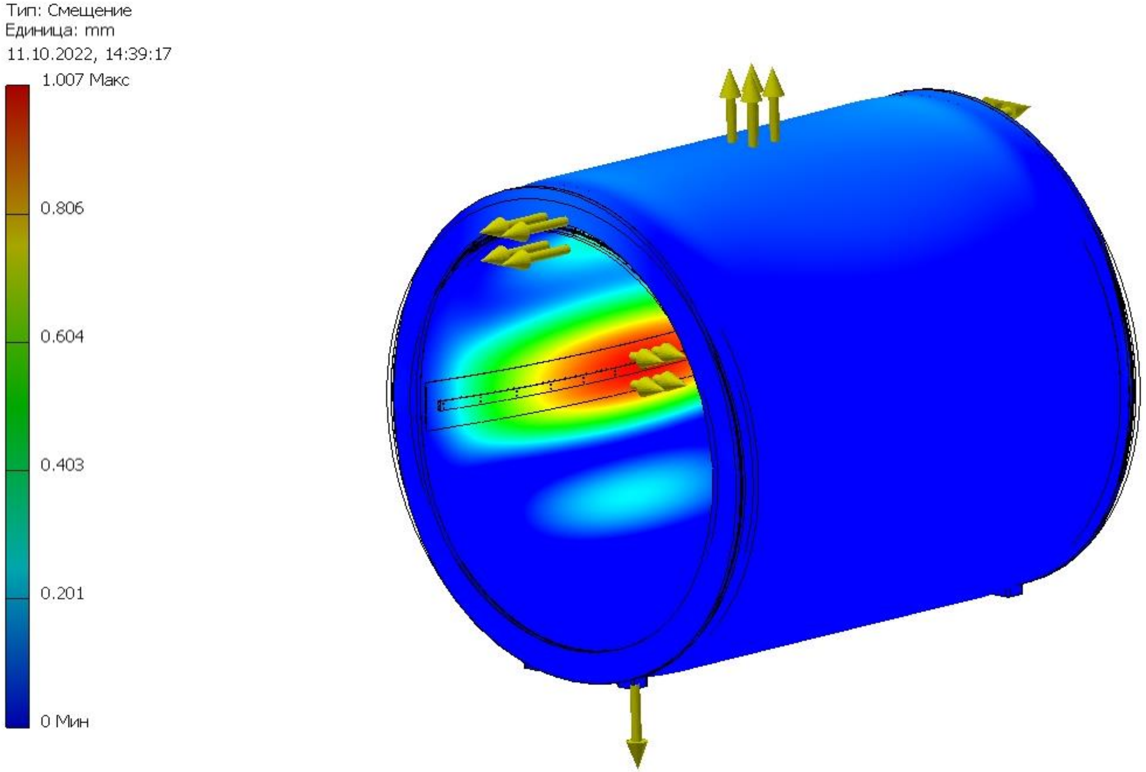




Inner diameter is 4008 mm, Outer diameter is 3468 mm, length is 4220 mm. The thickness of the outer shell is 12 mm, the inner shell is 20 mm, the thickness of the flanges is 45 mm. The thickness at the ends of the shells is 40 mm. Material: St. Steel. The weight of Cryostat is ~16.7 t

Cryostat (calculation)
Operation condition (p=0.05 MPa) + weight.

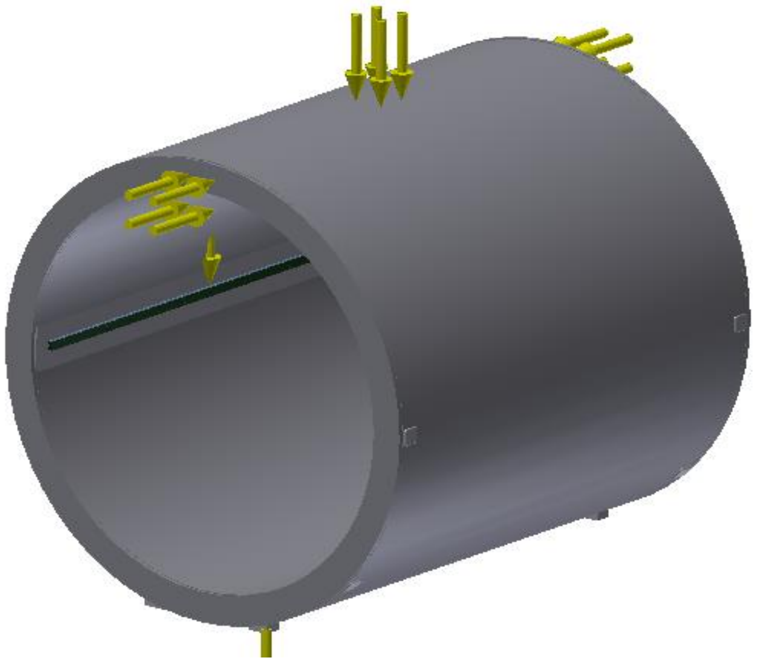


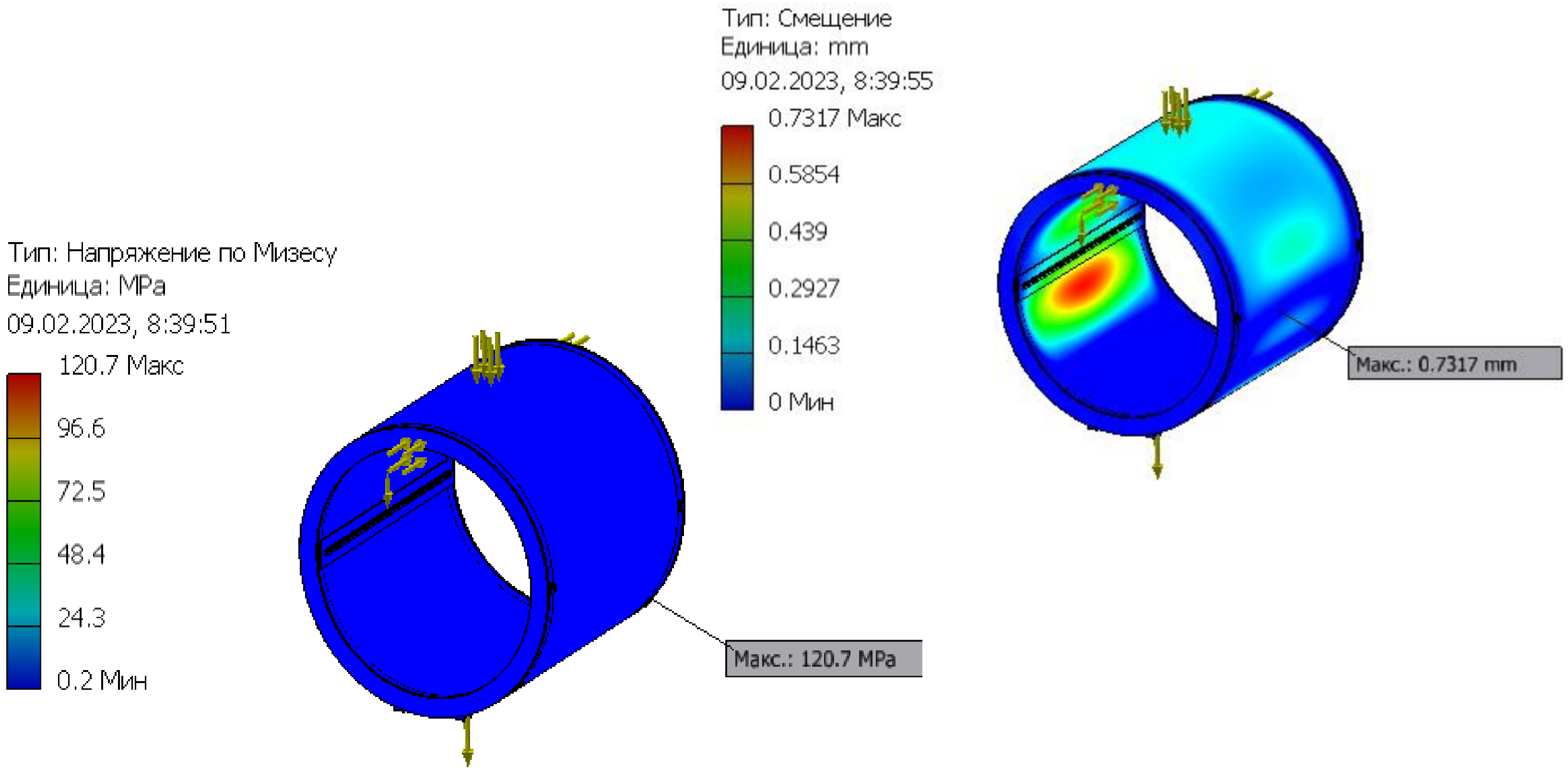


The maximum equivalent stress is 65 MPa. The maximum deformation is 1 mm.

Cryostat (calculation)

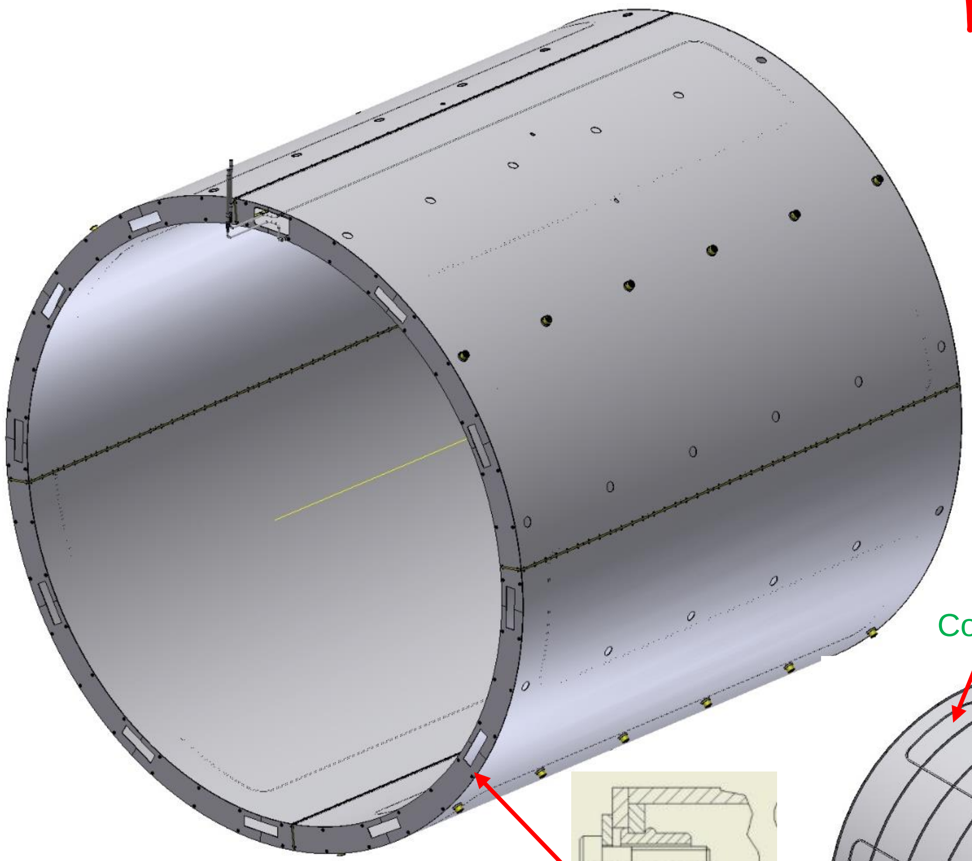
Operation condition (p=0.1 MPa), weight + weight of calorimeter (60t)

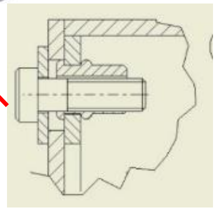


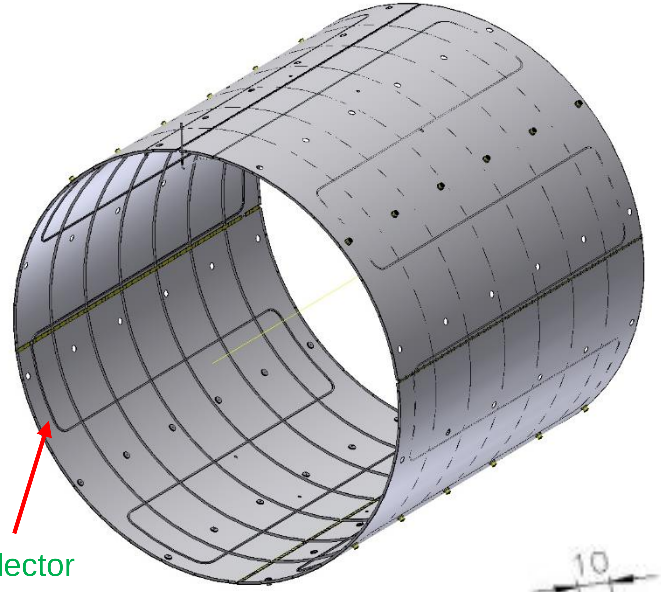


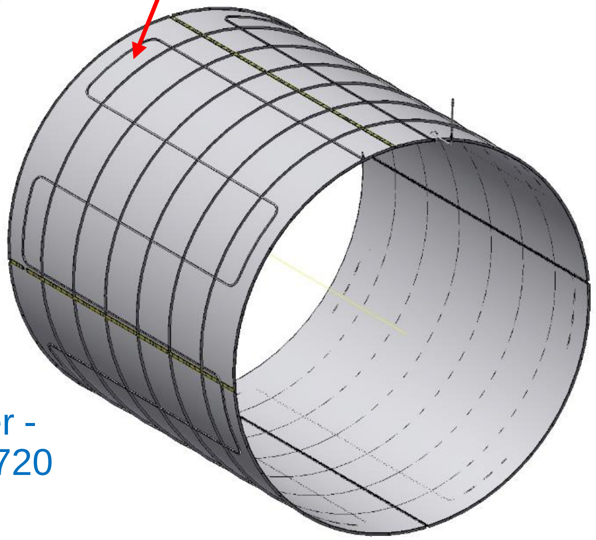
It is suppose that the calorimeter will be based on guides located along the magnet in the middle plane.
The maximum equivalent stress is 120 MPa. The maximum deformation is 0,7 mm.

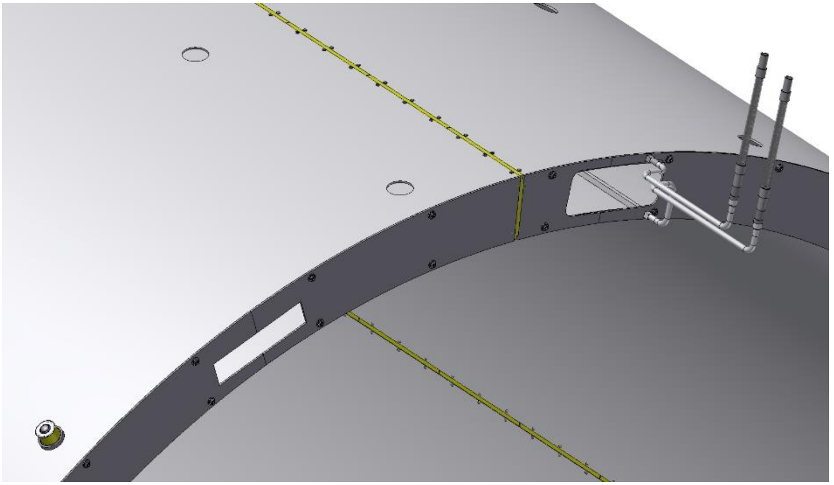
Thermal shield 80K

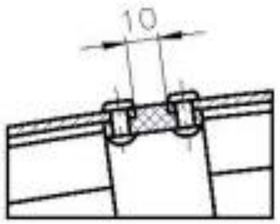


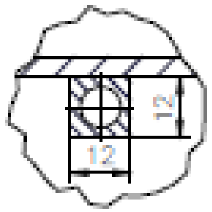


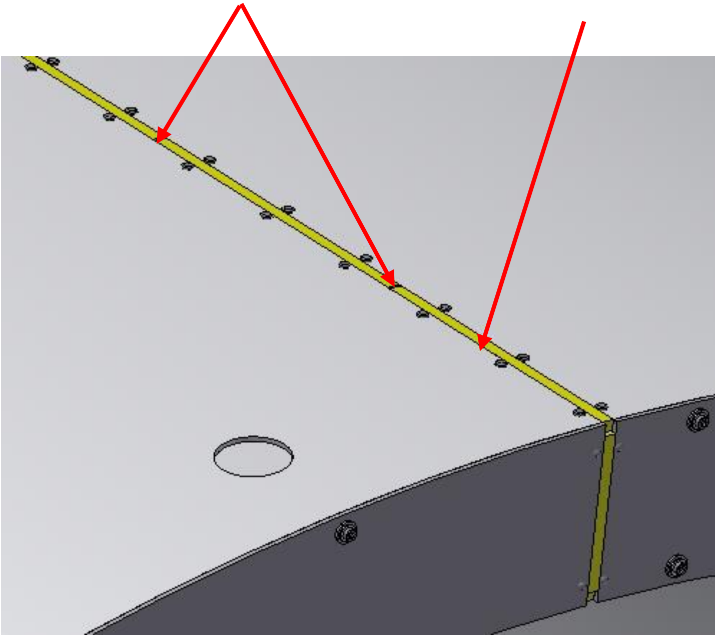








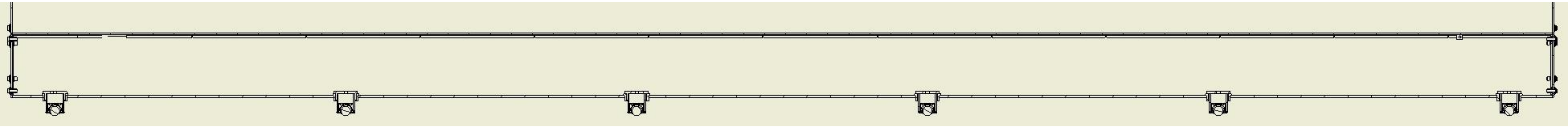


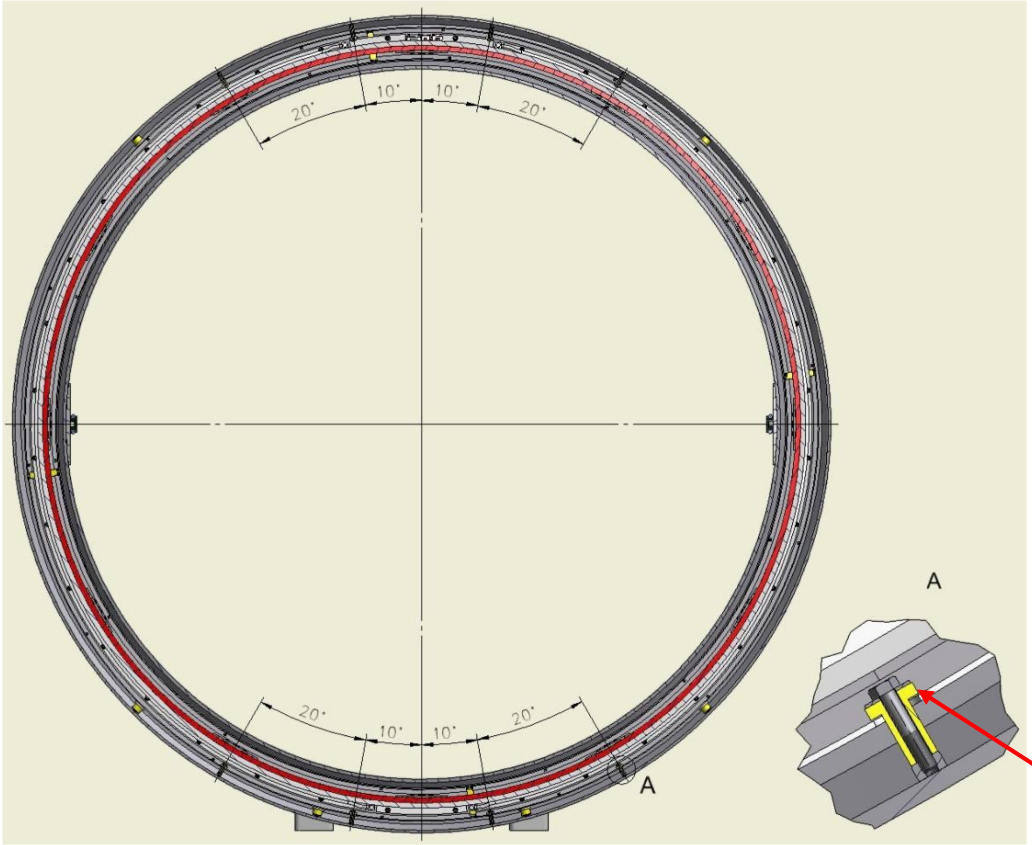


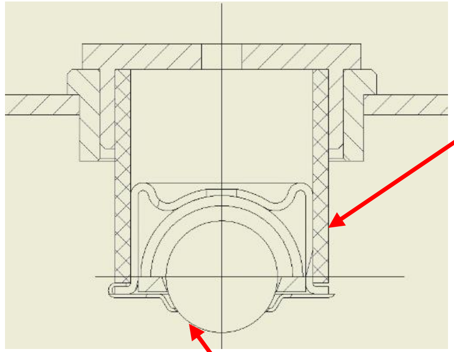
Material - aluminum alloy AMg-5. Outer diameter - 3898 mm, inner diameter - 3568 mm, length - 3720 mm. Wall thickness - 4 mm, Shield weight ~1 t

For the collector, a 12x12 with 8 mm hole Al profile welded to the shell of the shields is used. The shield is divided around the perimeter into 4 parts using G10 insulators. Outside the shield is covered with 30 layers of MLI and inside surface of the shield is covered with 10 layers of MLI .

Shield

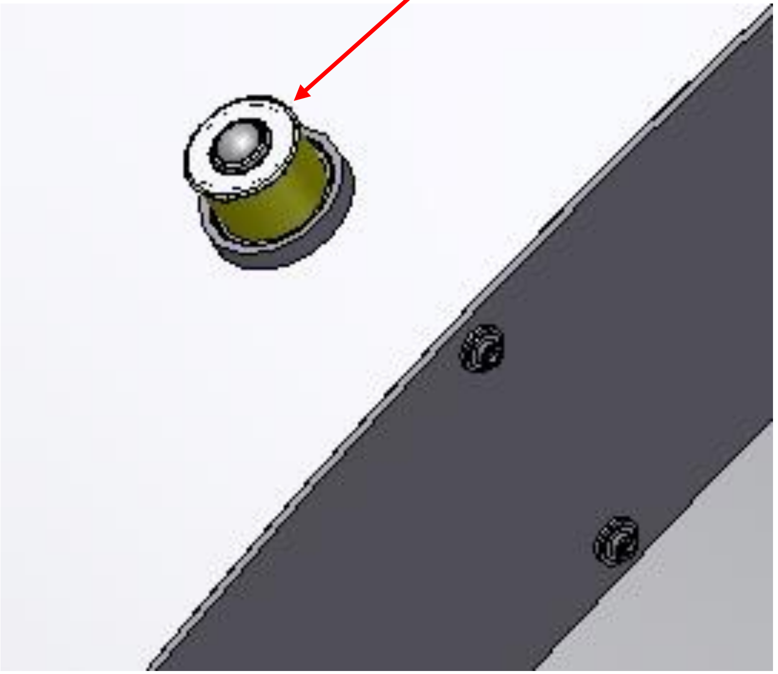




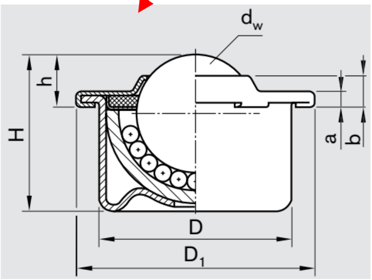


Ring (G10)

Support



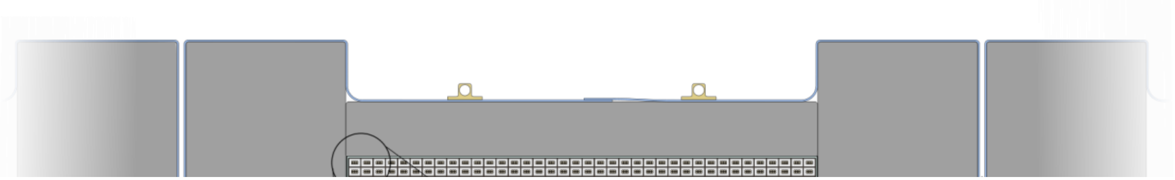
Balls transfer units



Bush(G10)

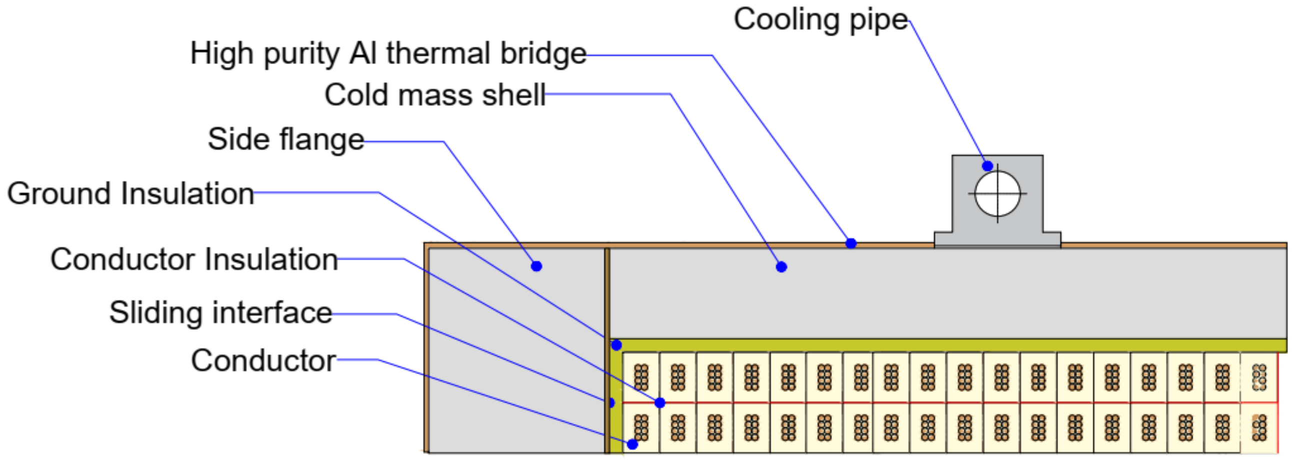
The shield is positioned in the cryostat using ball bearings with an insulating ring (4 rows at the bottom and 2 rows at the top). In the axial direction, the shield is fixed in the central part with help of bolts through the insulating bush - 4 point at the top and 4 point at the bottom.

Cold Mass (design)



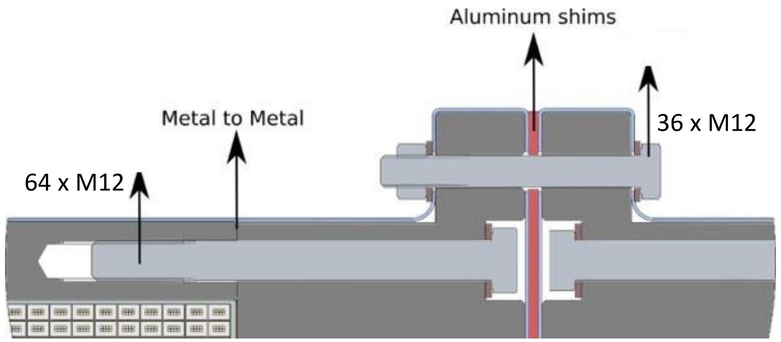
2 coils x 2 layers - 312 turns
1 coil x 2 layers - 156 turns

Magnetic field - 1 T
Current - 5.2 kA



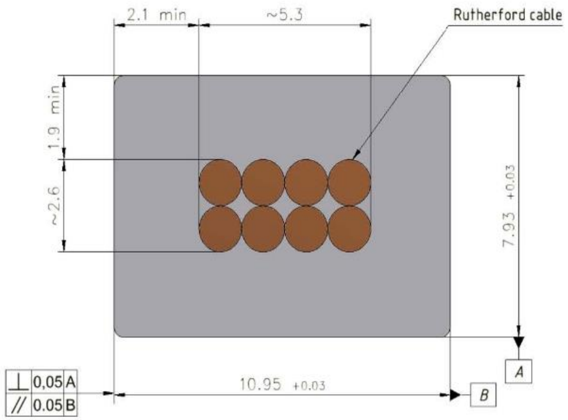
Conductor mechanical and electrical parameters.

Thickness (after cold work) at 300 K	mm	7.93	± 0.03
Width (after cold work) at 300 K	mm	10.95	± 0.03
Critical current (at 4.2 K, 5 T)	A	> 14690	
Critical current (at 4.5 K, 3 T)	A	> 16750	
Overall Al/Cu/sc ratio		10.5/1.0/1.0	
Aluminum RRR (at 4.2 K, 0 T)		> 600	
Al 0.2% yield strength at 300 K	MPa	> 30	



Rutherford cable, 8 strands, extruded in Al matrix

10.95 мм x 7.93 мм,
NbTi / Cu d=1.4 мм



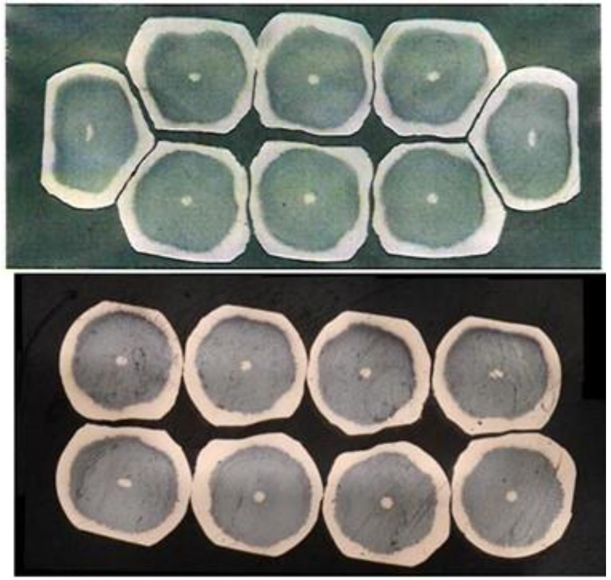
Rutherford cable is used to wind the coils. The cold mass consists of three coils, The coils are fixed together using bolts. If necessary, we will use special shims between the sections of the coils.

SPD superconductive conductor

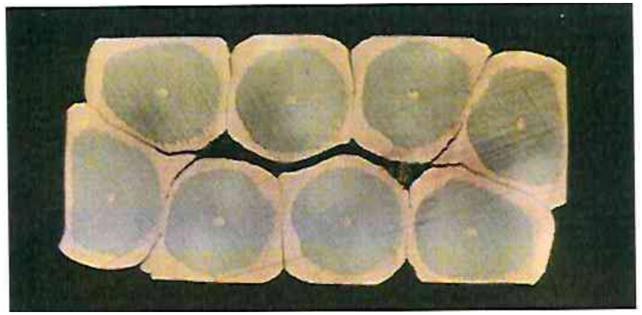
SPD Rutherford cable parameters were selected and a 100 meter long sample was produced for further development. Cryogenic tests were performed on individual strands after cable fabrication. The parameters correspond to the technical specification. These works were carried out jointly with VNIIRP.

Results of cable geometric dimensions control

Parameter	Unit	Value	Tolerance	Test
Diameter filament	µm	< 20	-	18
Diameter strand	mm	1.400	± 0.005	1.4 ± 0.05
Cu/SC ratio	-	1.00	± 0.05	0,95
Surface coating	-	none	-	-
NbTi Jc (at 4.2 K, 4.05 T)	A/mm2	> 2800	-	-
Critical current (at 4.2 K, 4.05 T)	A	> 2600	-	> 2660
n-value (at 4.2 K, 4.05 T)	-	> 30	-	34 for 8T
Conductor RRR	-	> 100	-	165
Twist direction	-	left	-	left
Twist pitch	mm	25	± 5	49
Number of strands	-	8	-	8
Cable width	mm	5.3	± 0.1	6,1 ± 0.05
Cable thickness	mm	2.60	± 0.05	2,6 ± 0.05
Transposition angle	degree	20.0	± 0.5	14
Twist direction	-	right	-	right
Critical current degradation of extracted strand (at 4.2 K, 4.05 T)	%	< 5	-	1,5
RRR of extracted strands	-	> 60	-	72

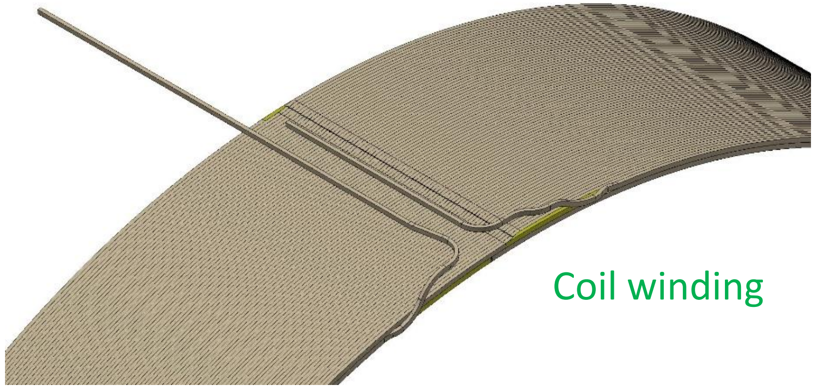


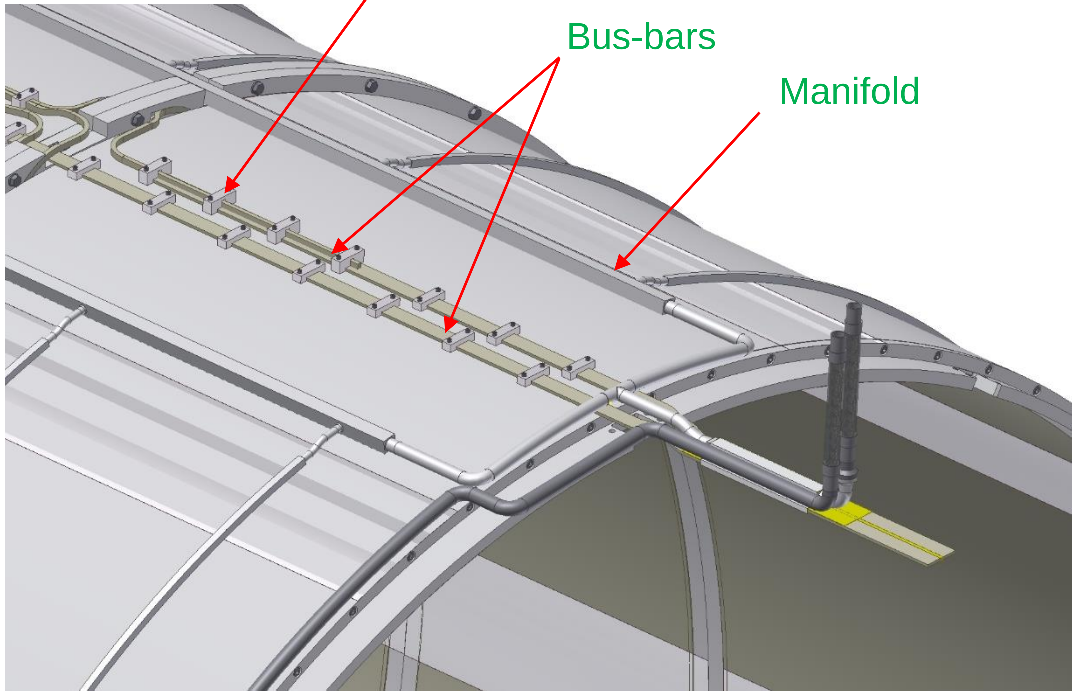
Cable 6,1 × 2,6 mm², angle 14°, twist pitch 49 mm

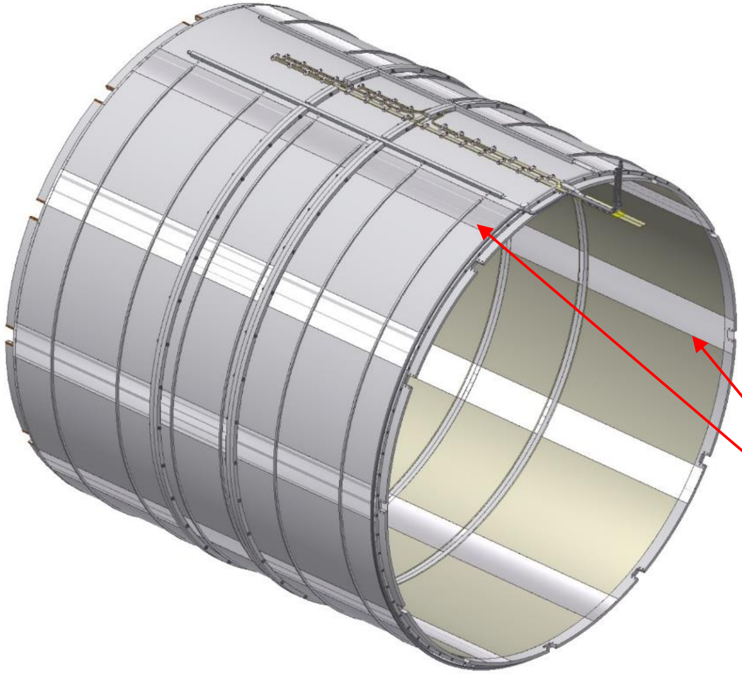


Cable 5,3 × 2,6 mm², angle 20°, twist pitch 25 mm

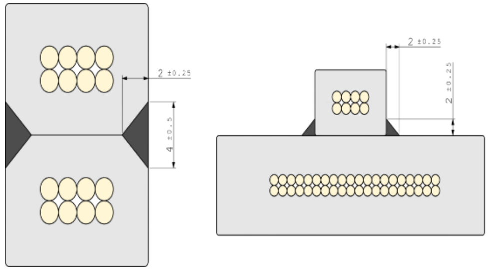
Cold Mass





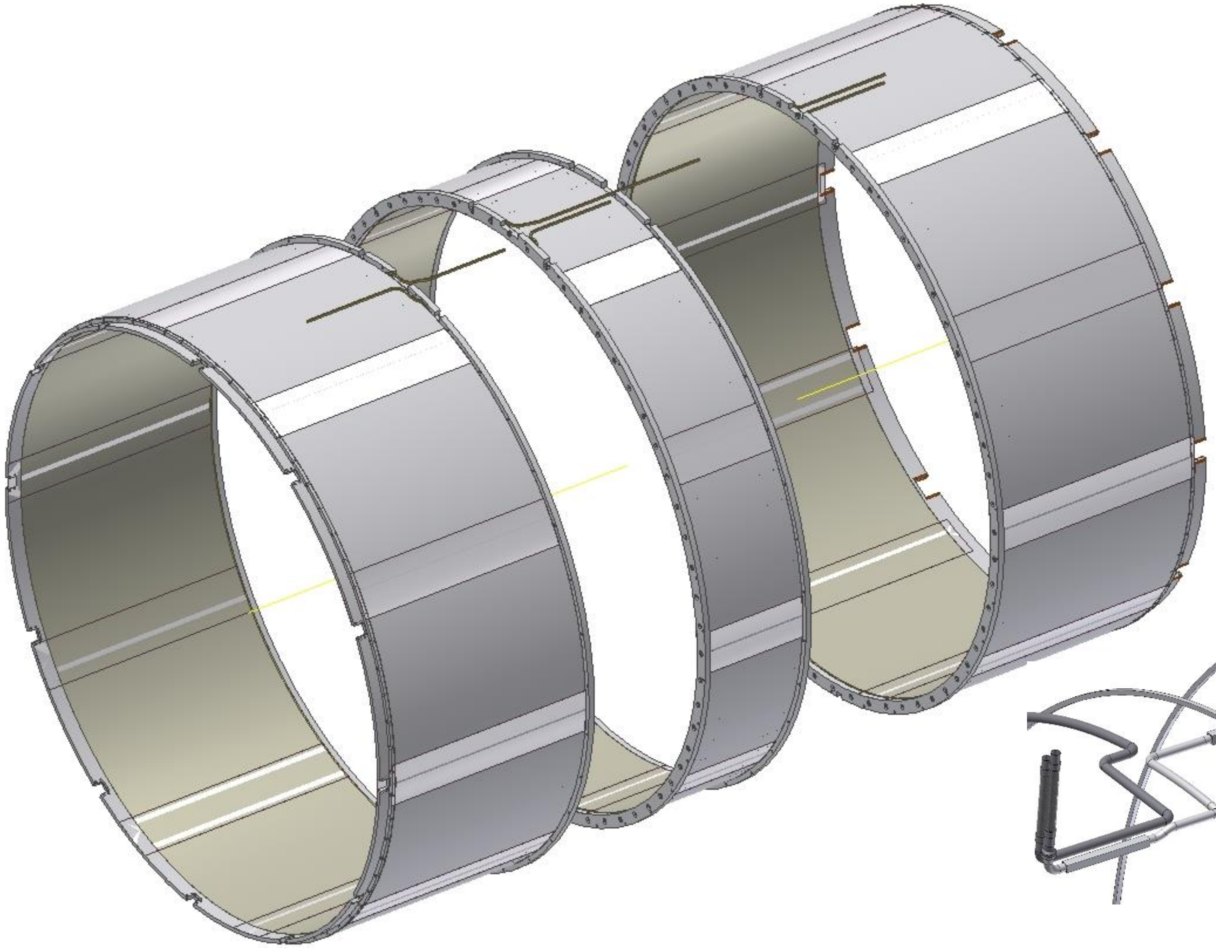


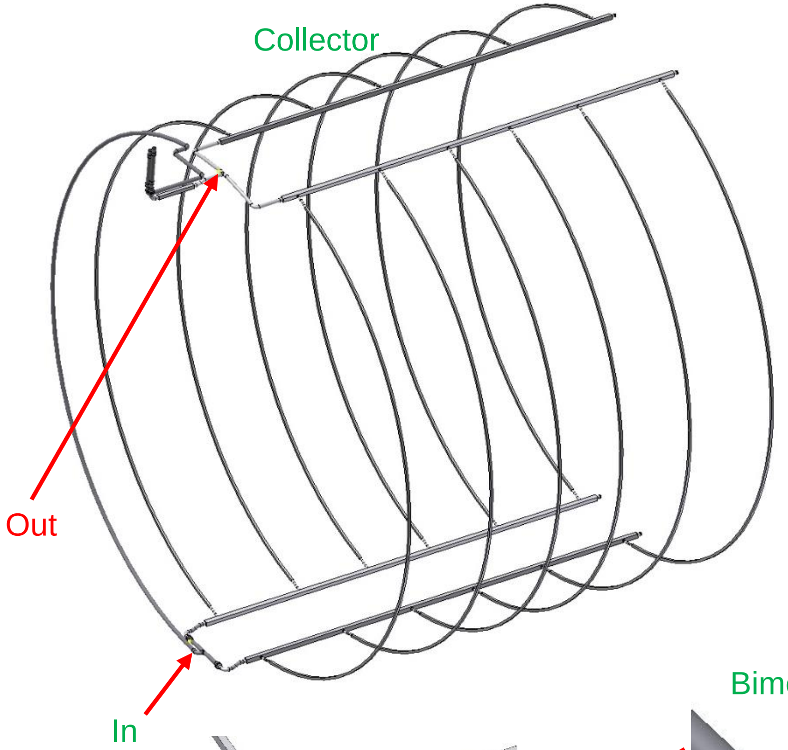
coil-to-coil and layer-to-layer joints

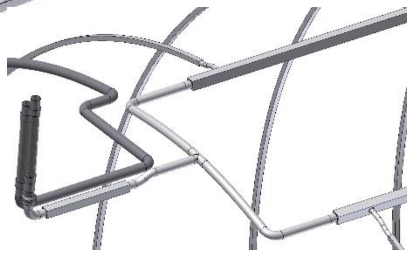


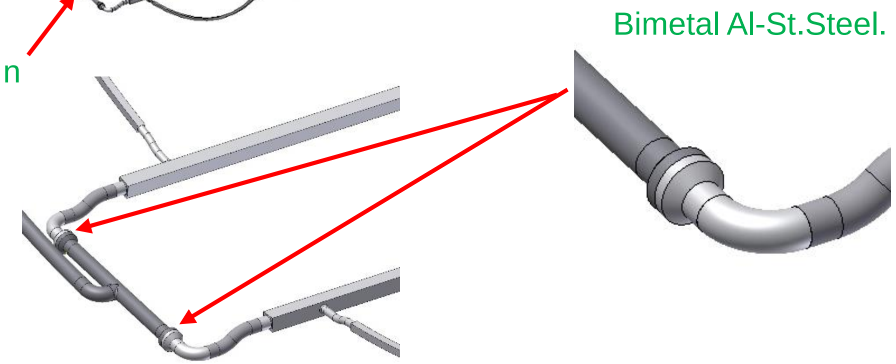
Inner diameter is 3662 mm, Outer diameter is 3756 mm, The length is 3416 mm, The weight of cold mass is ~5,4 t.
The connection of the coils to the current leads is made through bas-bars with a cross section of 32 by 5.6 mm
Thermal bridges made of high purity aluminum are used for temperature equalization.

Cold Mass





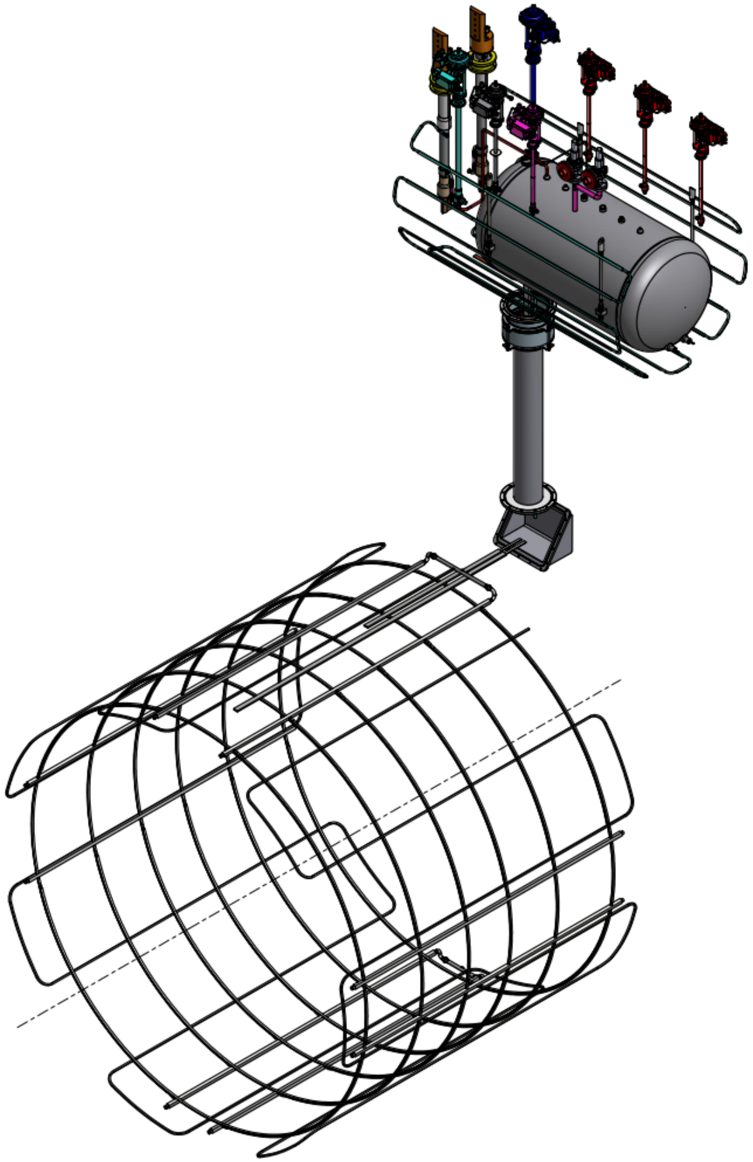


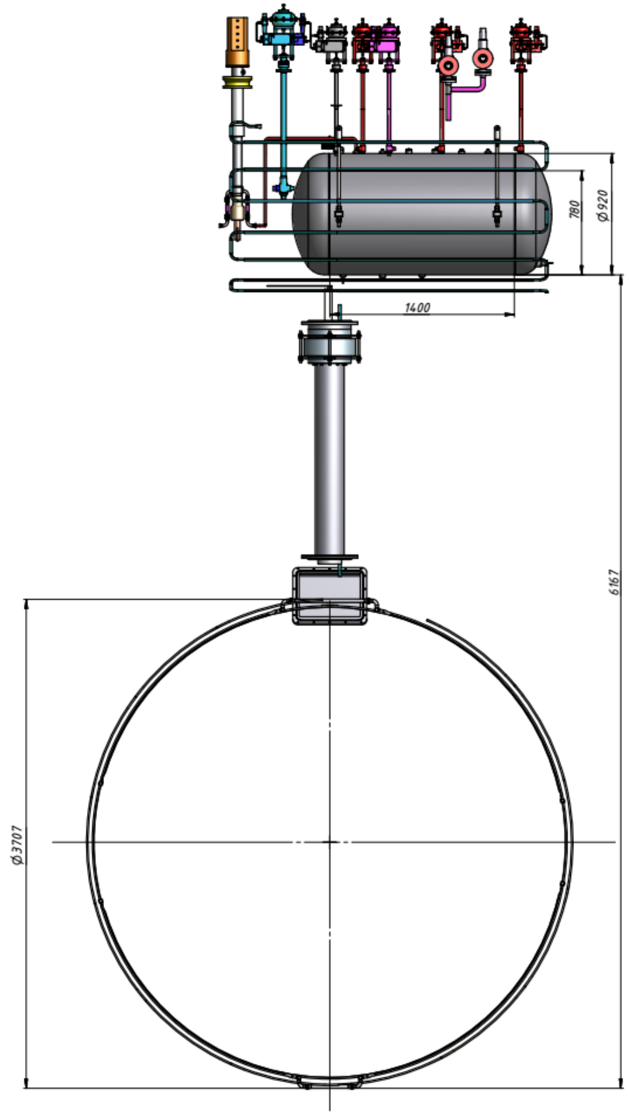


The magnet consists of 3 coils: front and back have 2 layers of 312 turns, cable length ~ 3600 meters; the central coil has 2 layers of 156 turns, the cable length is ~1800 meters.

For cooling, a tube with a cross section of 14x14 mm and a hole of 10 mm is used, welded to the shell of the cold mass. Bimetallic adapters are used to connect aluminum profiles to stainless steel pipes.

SPD solenoid. Cold mass cooling design.



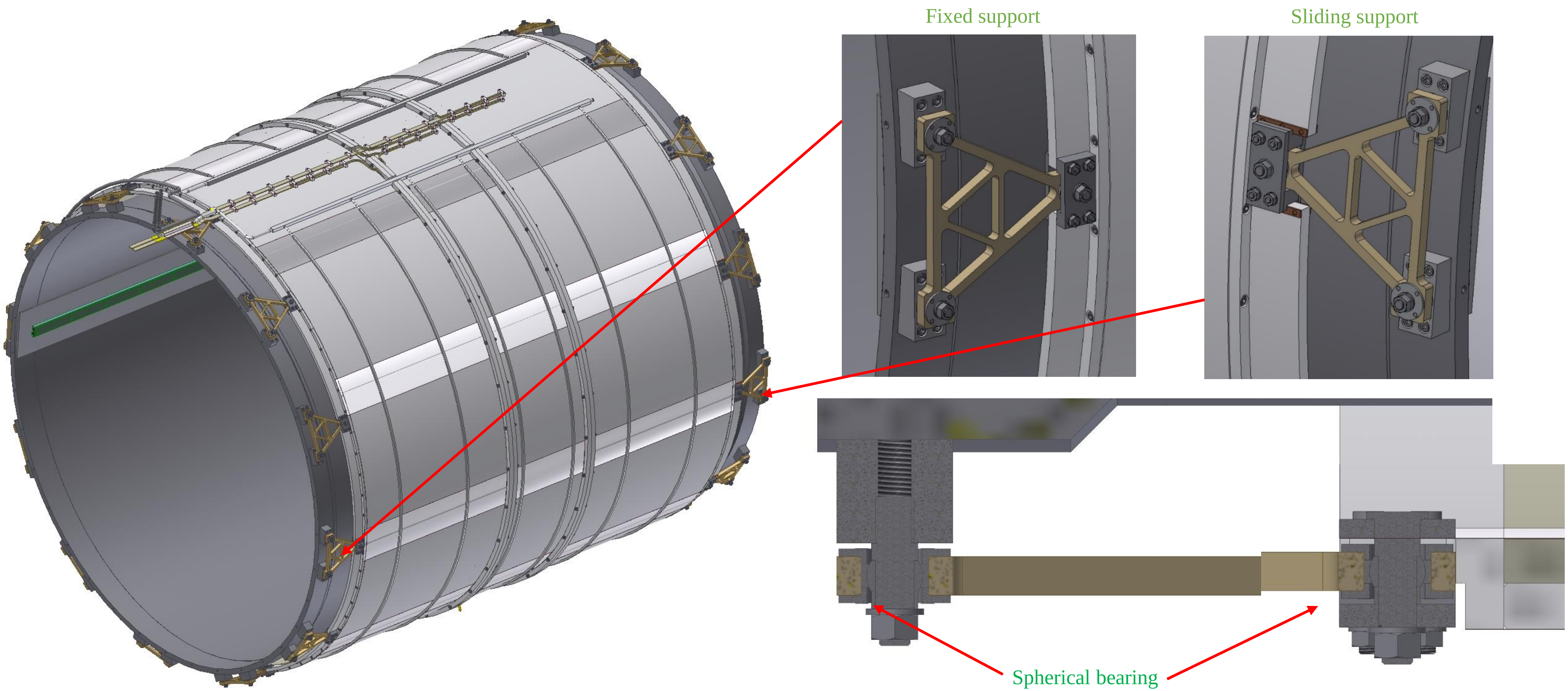


It is planned to use the thermosiphon method of cooling the superconducting coil due to the natural convection of two-phase helium.

The volume of liquid helium is 10 - 20 liters

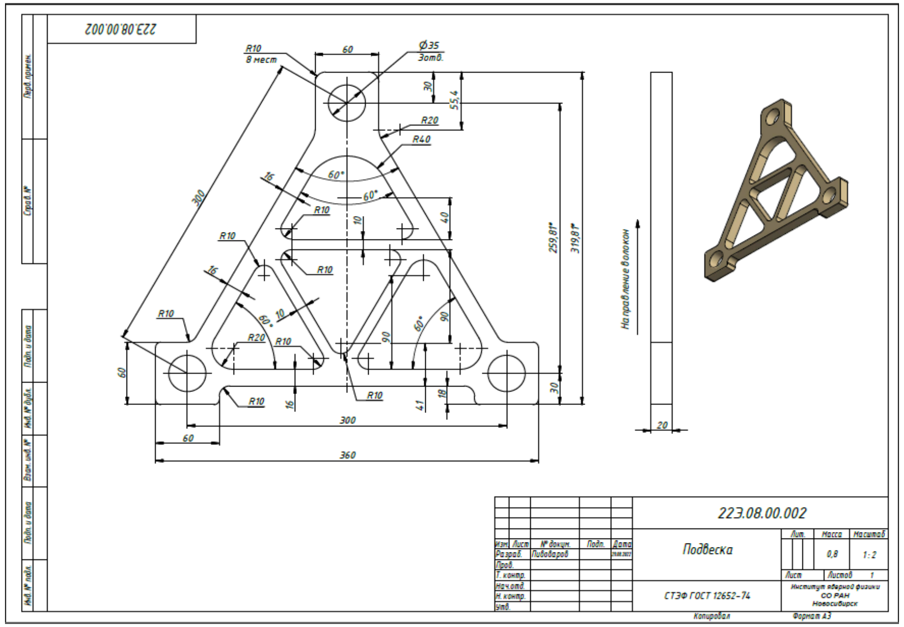
Helium mass flow SPD - 9-10 g/sec.

SPD Magnet (Suspension system)

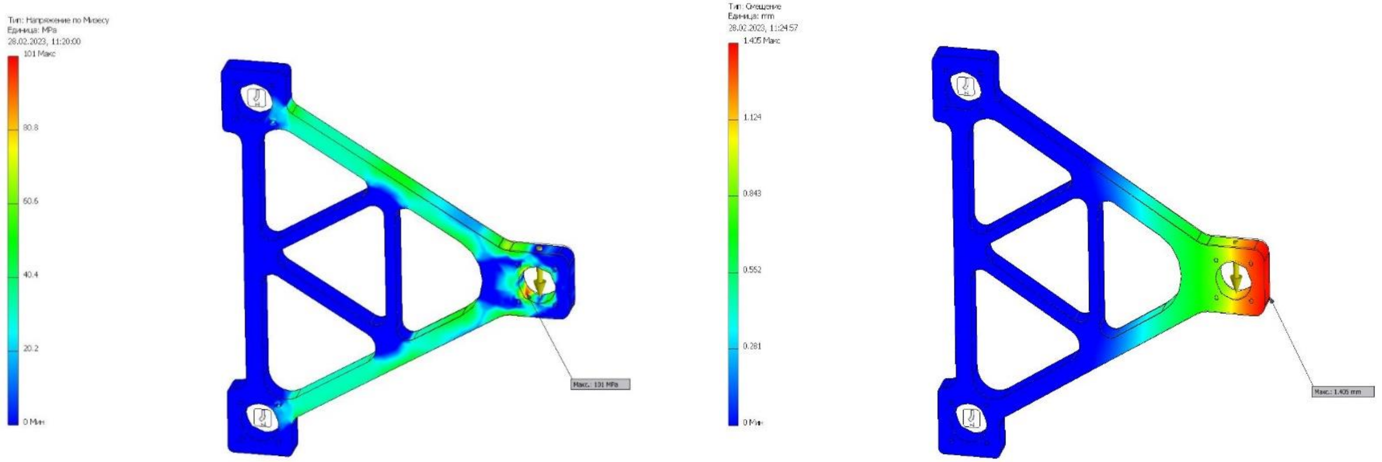


Fixation of the cold mass is made with help of triangular suspensions made of STEF-1, 12 pieces on each side. On one side the supports are fixed, on the other side its are sliding to compensate for temperature changes in the length of the coil. The Suspensions have spherical bearings to avoid bending during thermal changes in the dimensions of the cold mass.

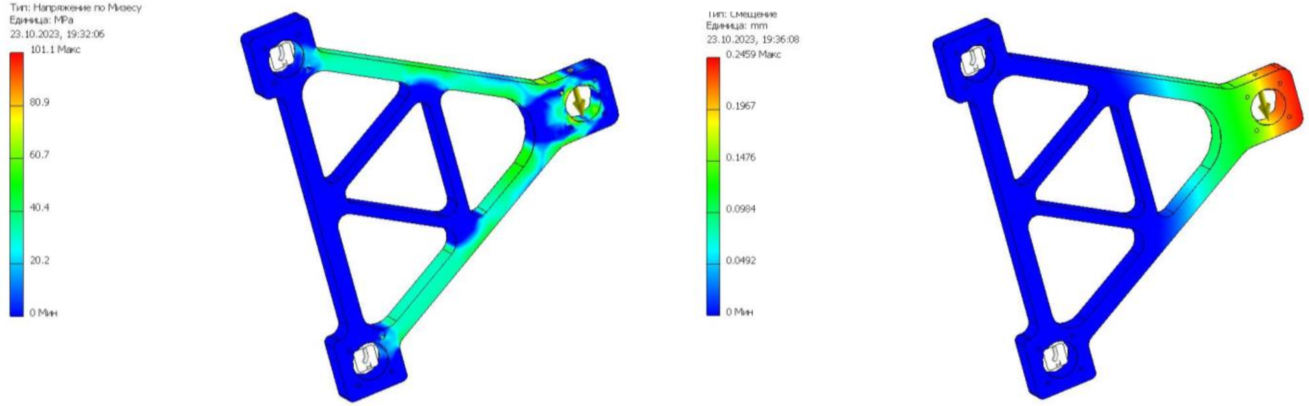
Suspension Calculation for cross force P = 1,5 t.



Material – СТЭФ-1



Material – Carbon

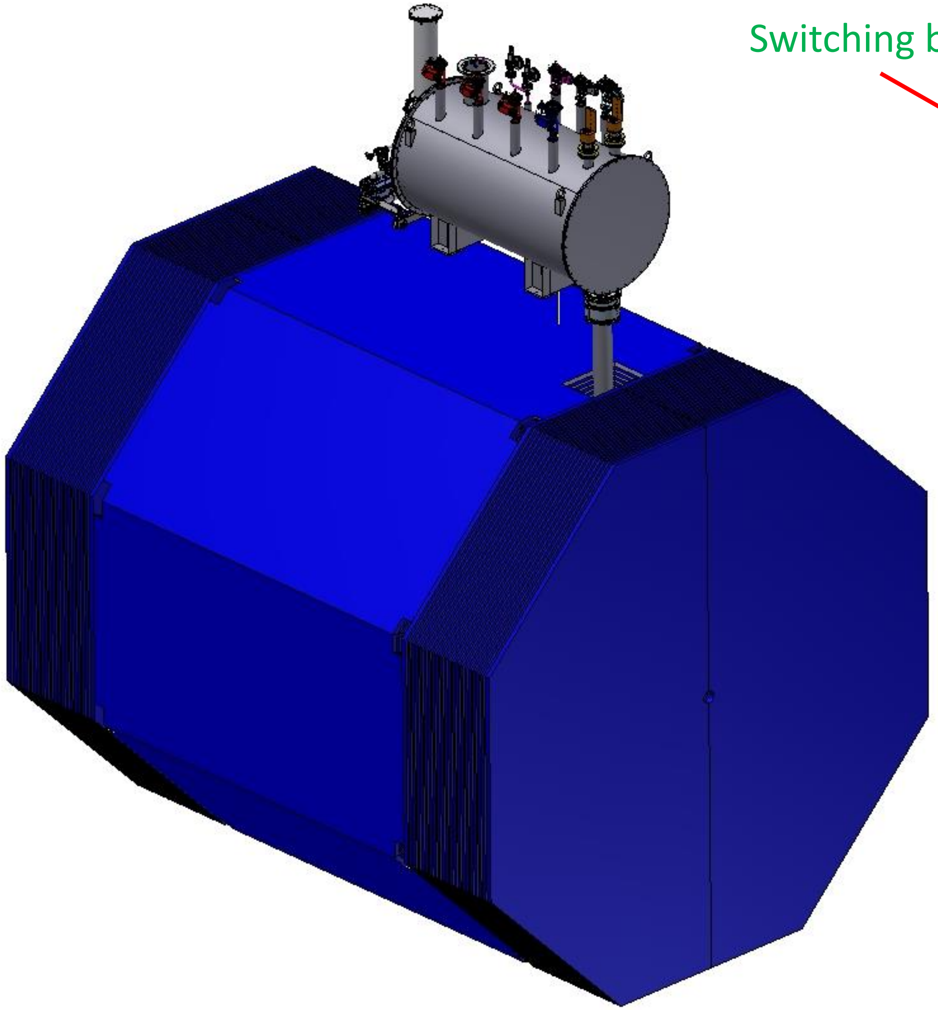


Material	Max. equivalent stress	Max. deformation	Permissible stress
СТЭФ-1	100 MPa	1,4 mm	132 Мпа
Carbon	135 MPa	0,53 mm	1075 MPa

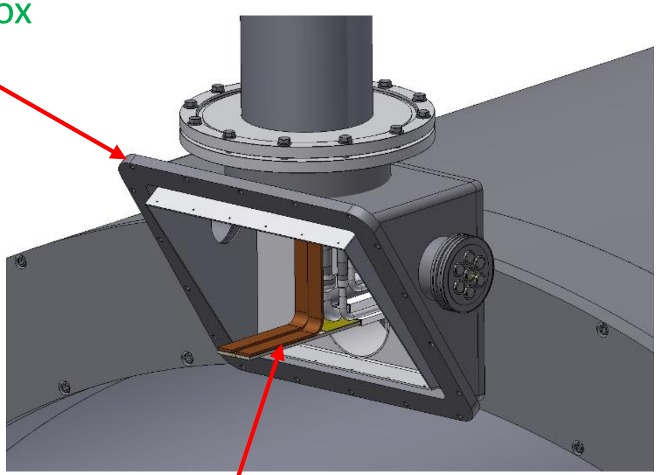
Calculations were made for suspensions of СТЭФ and Carbon. The results are presented in the table.

We have made and tested the СТЭФ suspension at 300K and 100K. Destruction of the suspension 300К - 3920 kg and 100К - 4250 kg. Deformation at 1,5 t was 5 mm (300K).

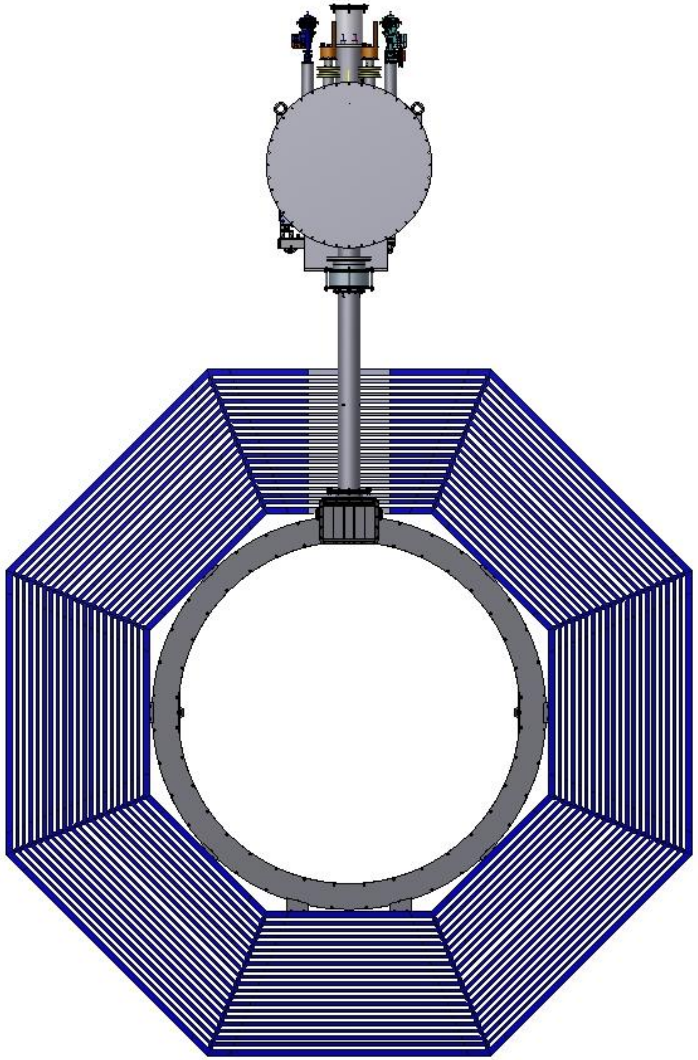
SPD Магнит with Control Dewar



Switching box

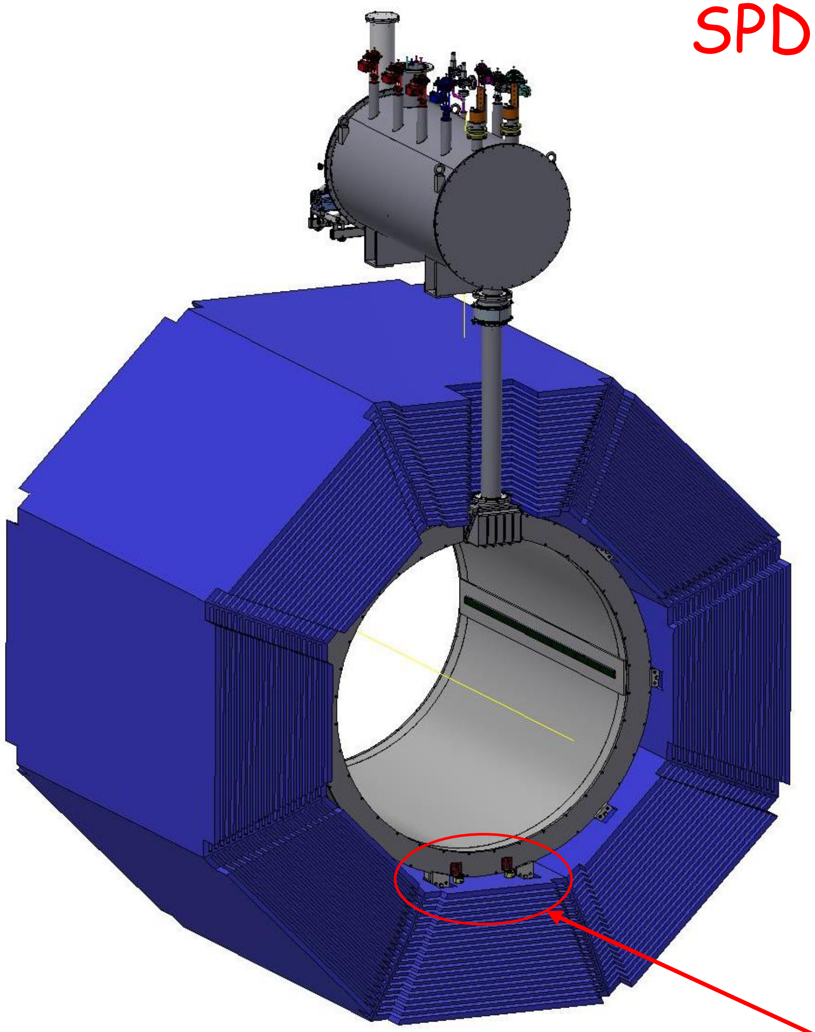


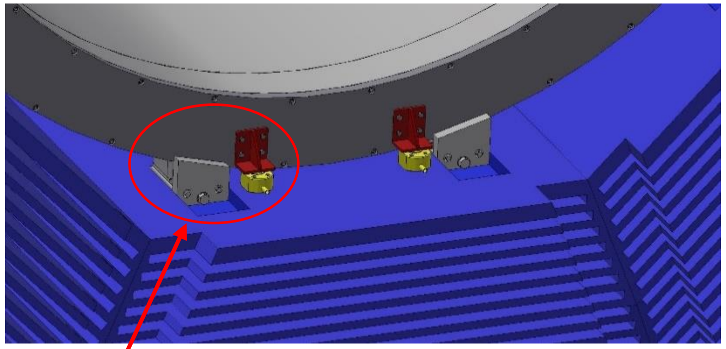
Connection of current
leads with Bas-bars coils.

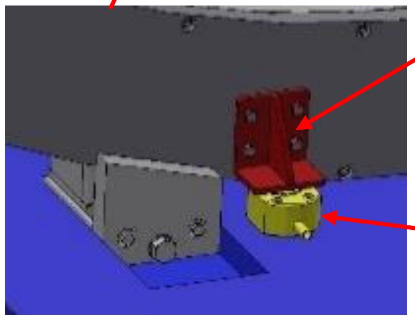


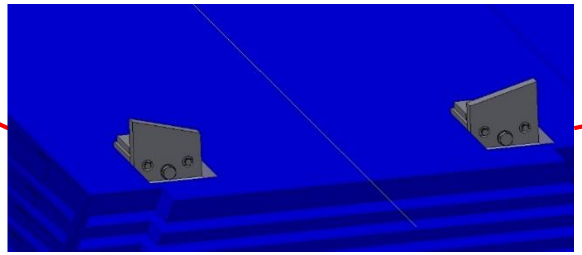
The connection of the coil with the current leads is carried out in a special box located outside the cryostat.

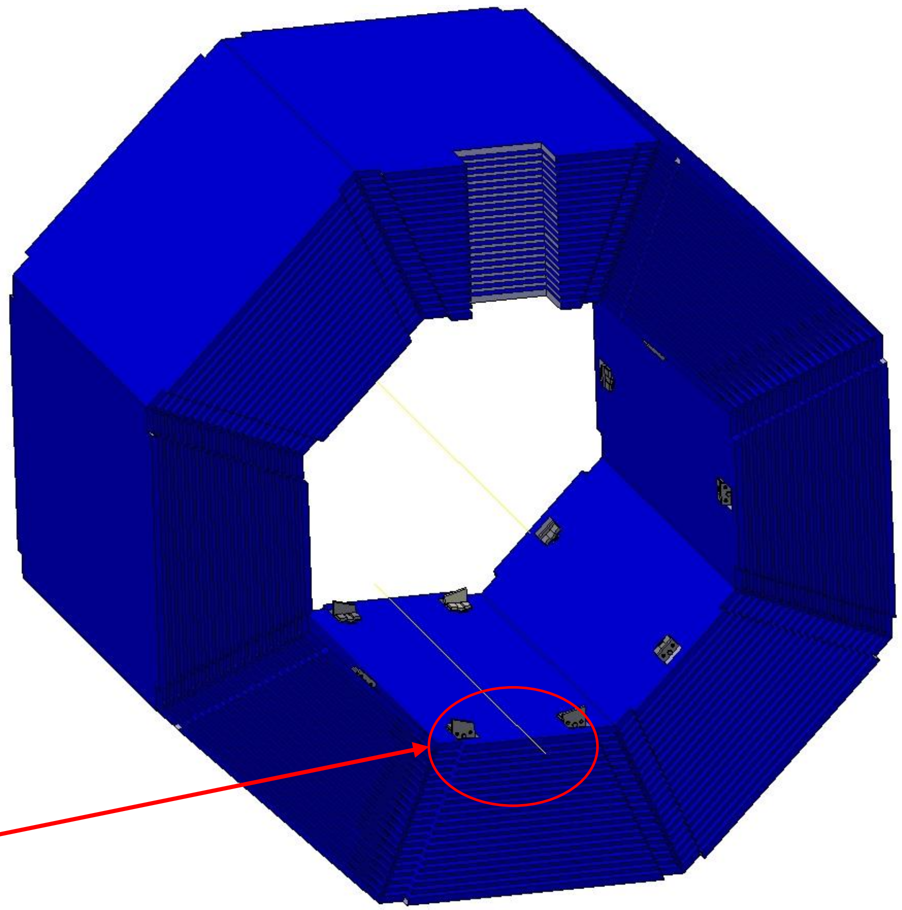
SPD Magnet (positioning and fixation)





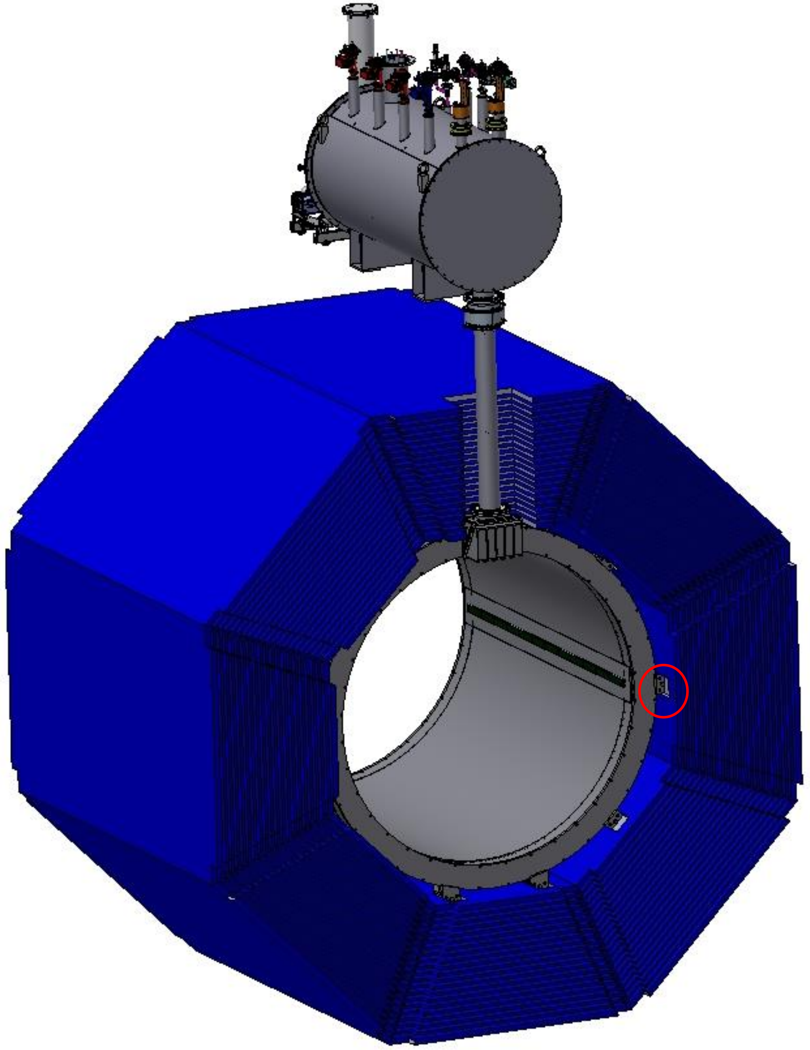


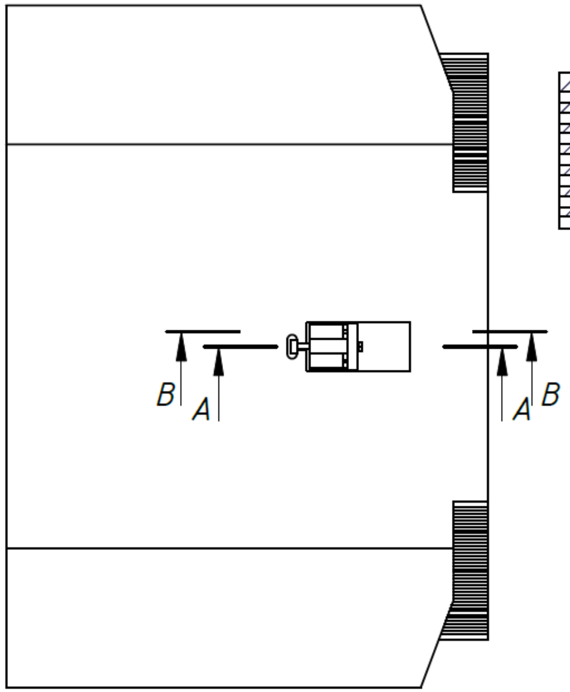


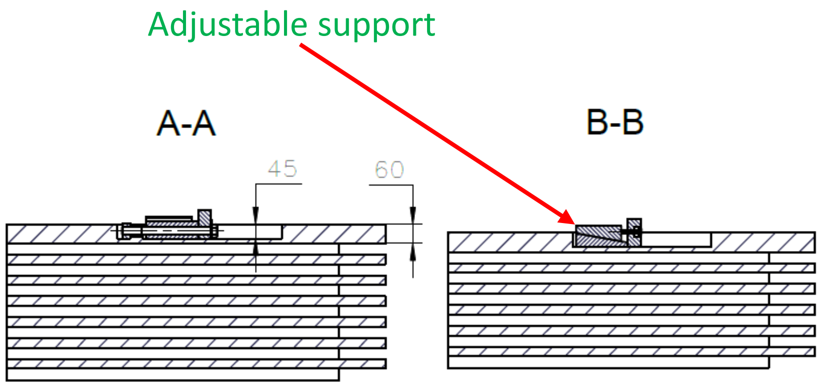


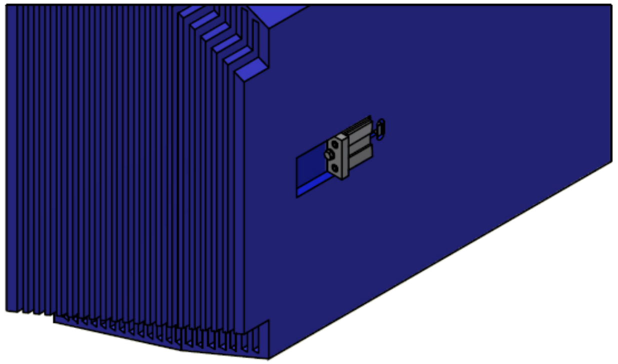
The magnet is positioned inside the iron yoke using hydraulic jacks.

SPD Magnet (fixation)



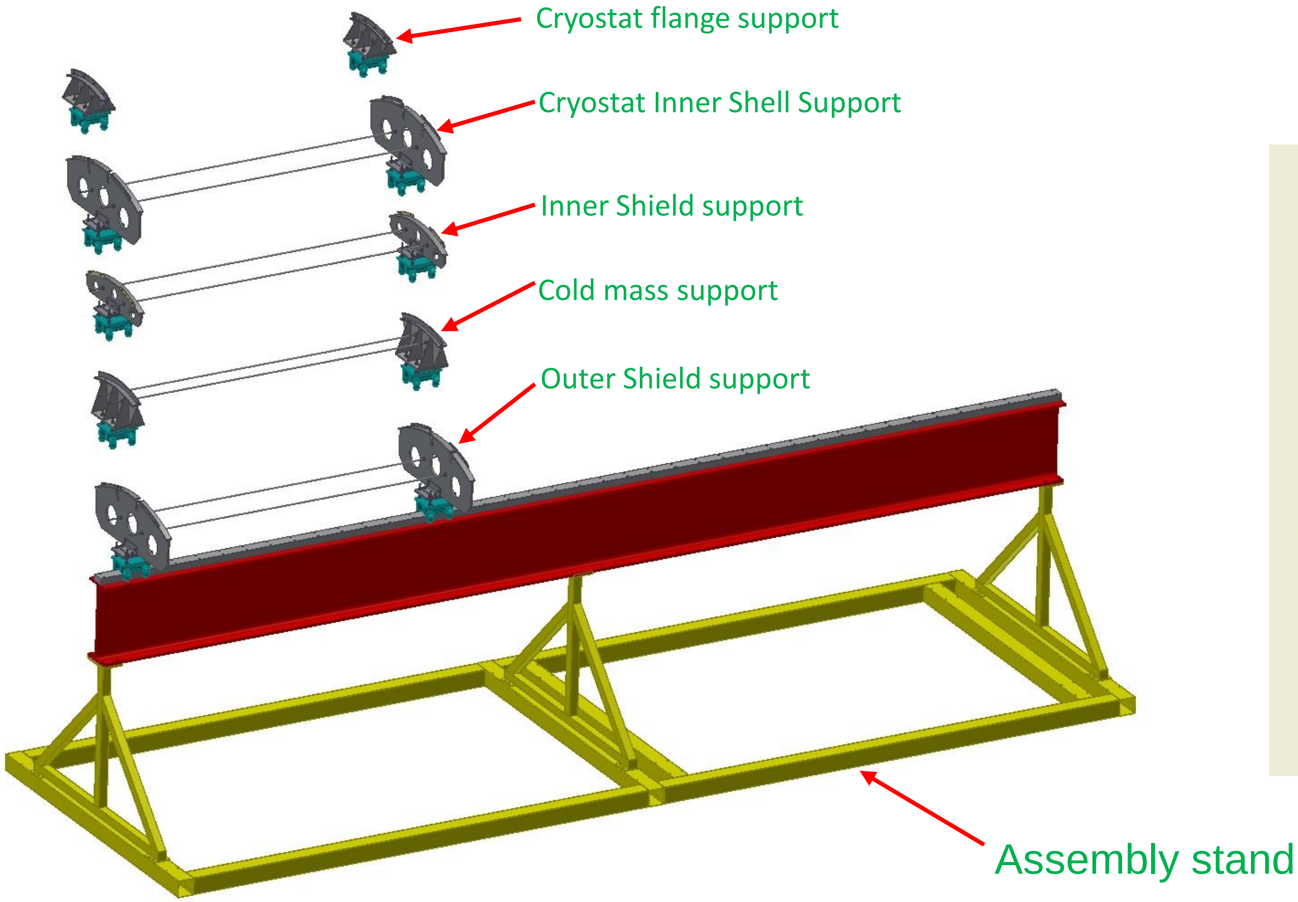


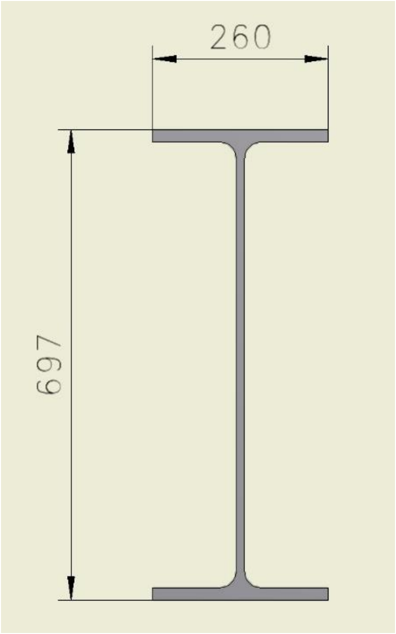




The cryostat is fixed in an iron yoke by means of special adjustable supports fixed on octants .
The wedge surface of the support allows you to fix the cryostat after positioning the magnet using hydraulic jacks.

Magnet Assembly Procedure

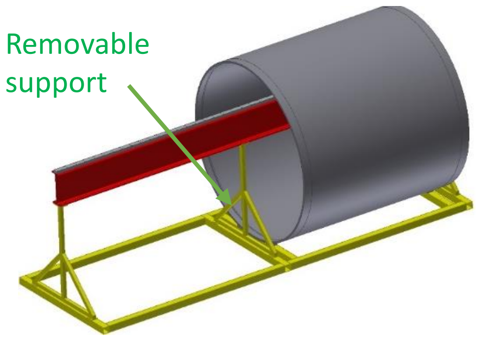




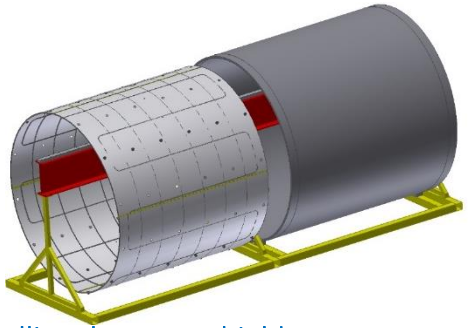
To assemble the magnet, a special stand with an I-beam - 700 GOST 26020-83, 9 meters long, with a guide rail and a roller system (Roller skate Boerkey model AM-H) for rolling up the magnet elements, is used.

Such a scenario was used to assemble the PANDA magnet, which was successfully assembled, disassembled and reassembled.

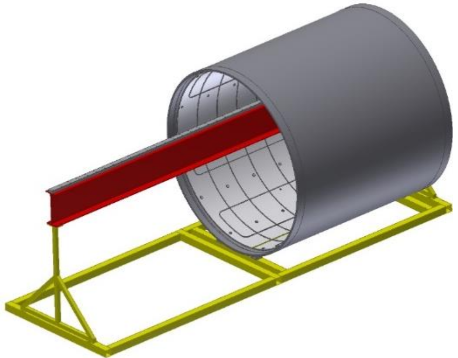
Magnet Assembly Procedure



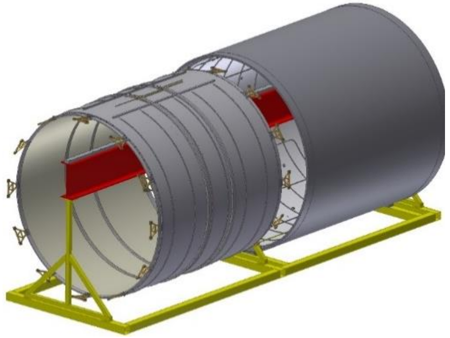
Installing the outer shell



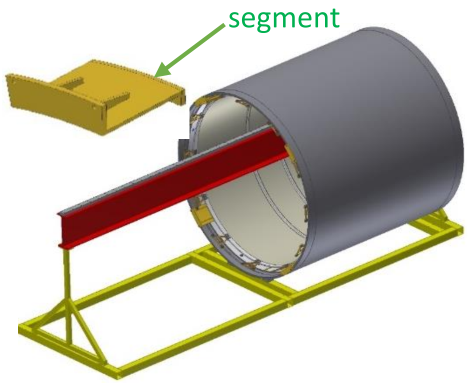
Installing the outer shield



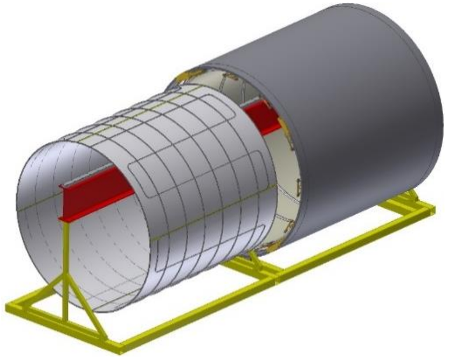
Position the outer shield



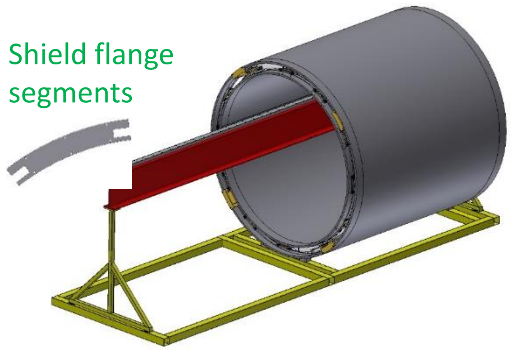
Installing the Cold Mass



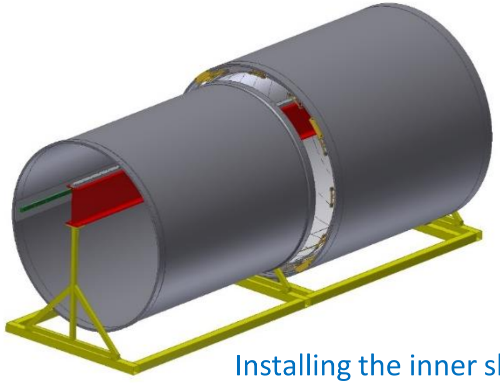
Position the Cold Mass.
fixing on temporary segments



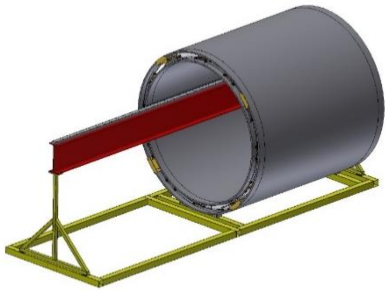
Installing the inner shield



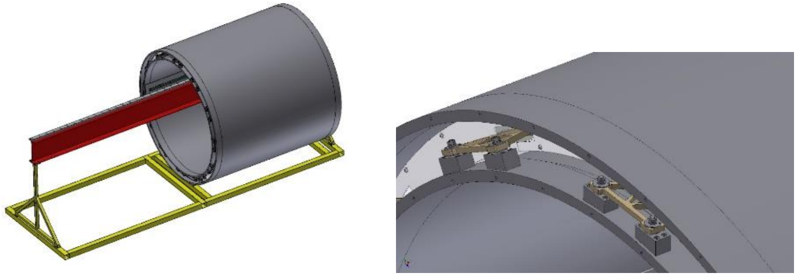
The Inner shield position. Partial installation of the shield flange segments



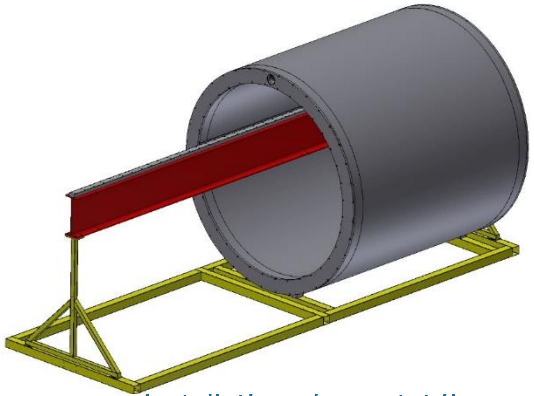
Installing the inner shell



The Inner shell position.



Fixing of the cold mass on the inner shell. Removal of the temporary segments after fixing the cold mass. Installation all shield flange segments.



Installation of cryostat flanges

Thank you for your attention!