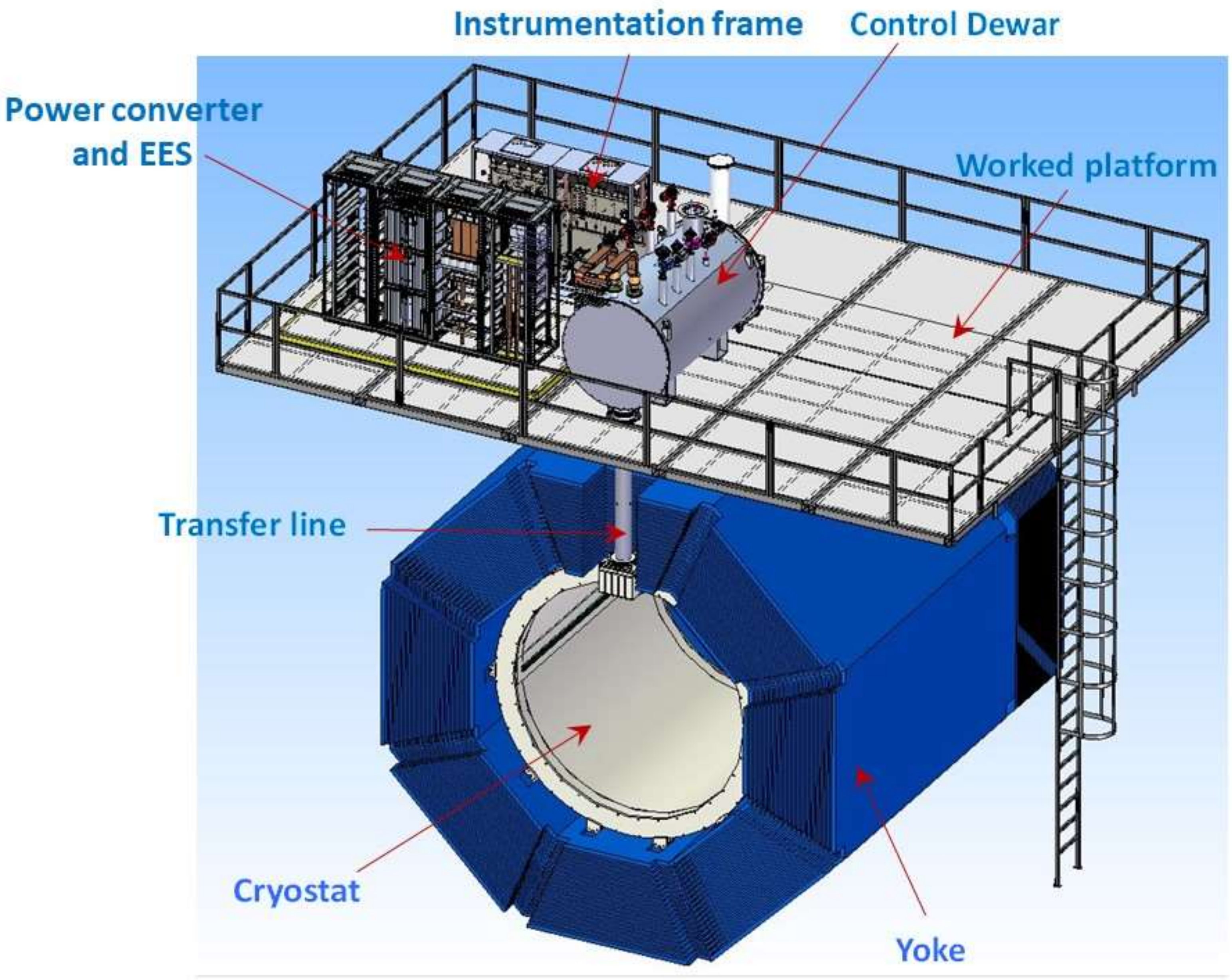
The Budker Institute of Nuclear Physics

SPD magnet

Status of the SPD superconductive solenoid development

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

SPD solenoid



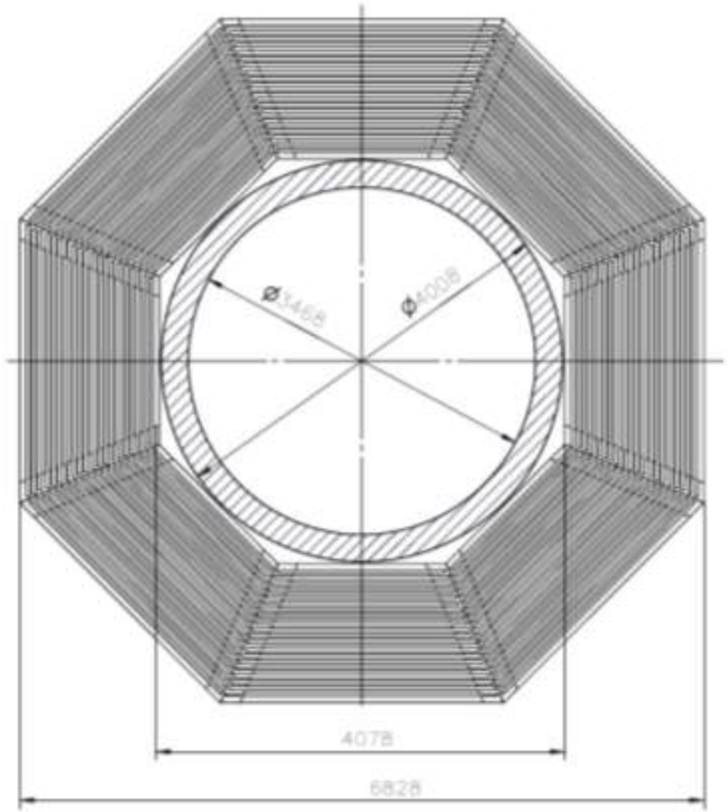
The magnetic field along the solenoid axis should be 1.0 T.

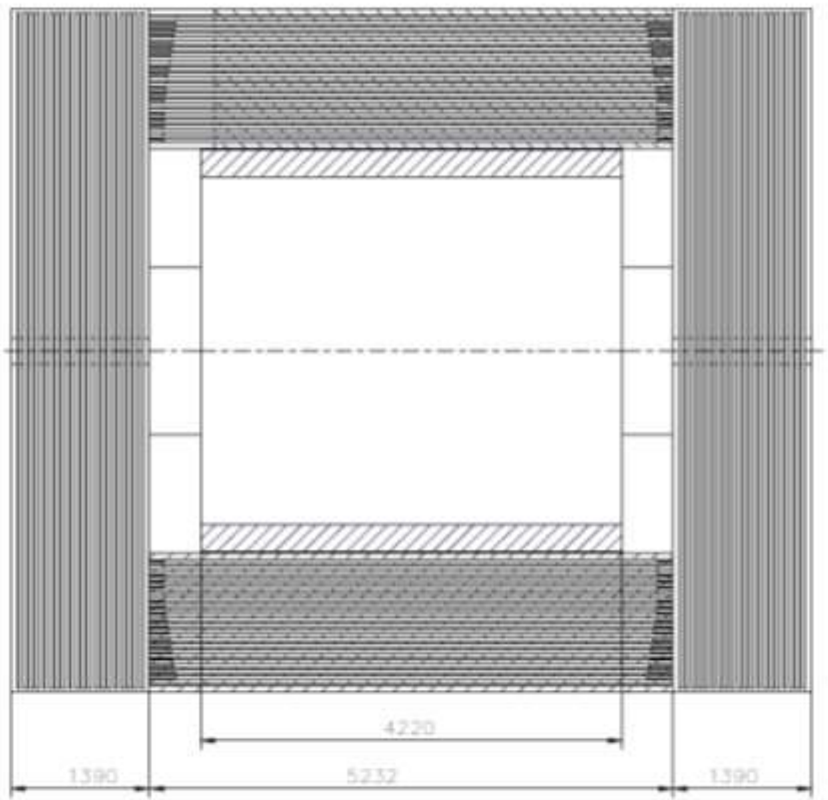
BINP presents our participation in SPD project with the following items:

- 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.

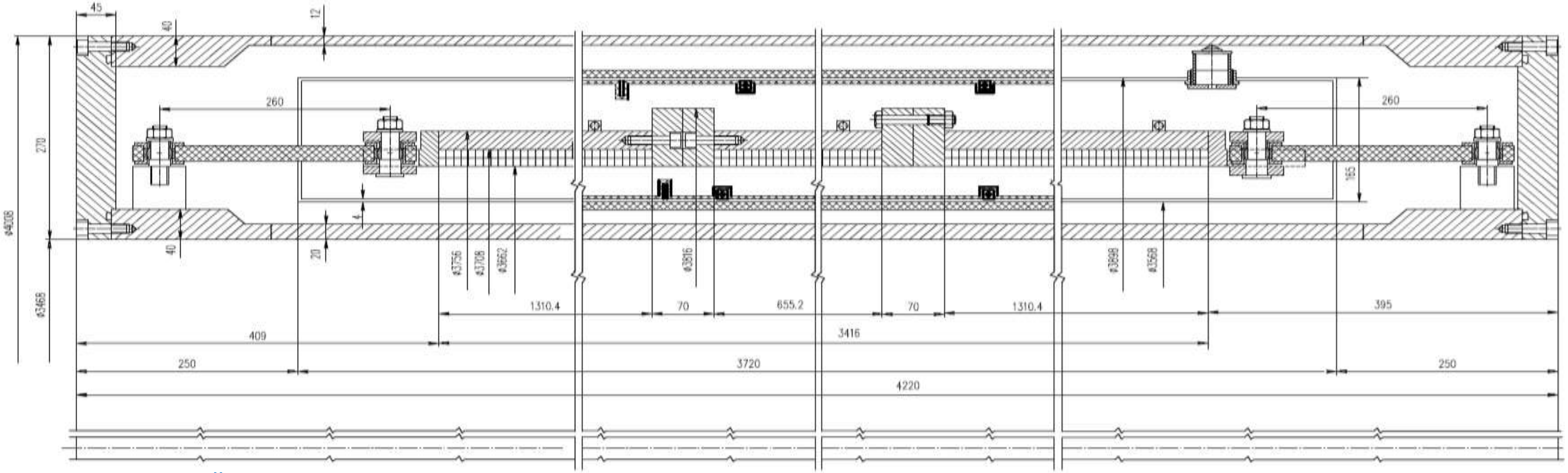
SPD yoke and solenoid

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 (geometry)

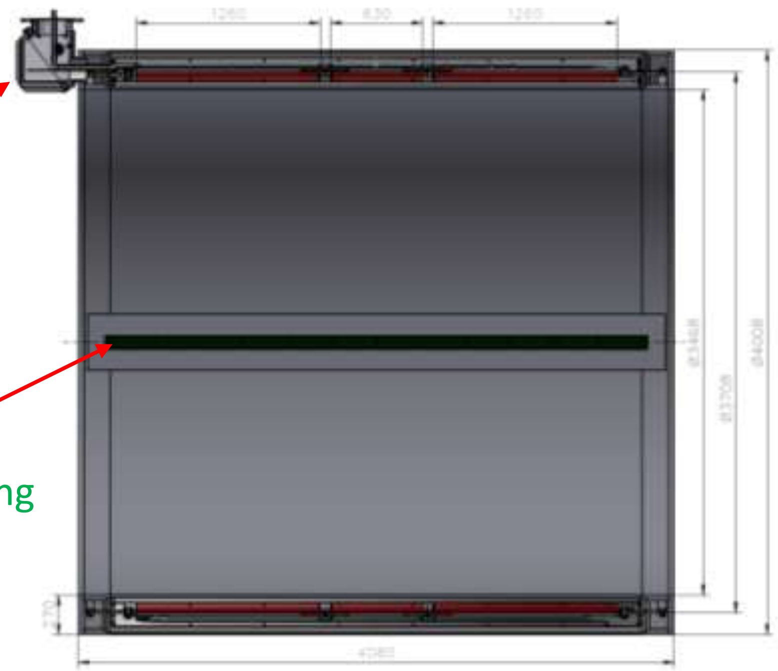


Cryostat: Outer diameter -4008 mm;
Inner diameter - 3468 mm;
Length 4220 mm;
Thickness - 270 mm;
Cold mass: Outer diameter -3756 mm;
Inner diameter - 3662 mm;
Length 3416 mm;
Coils: (2 pieces): Number of layers - 2; Number of turns 2x156=312.
(1 piece): Number of layers - 2; Number of turns 2x78=156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

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

SPD Magnet

Switching box



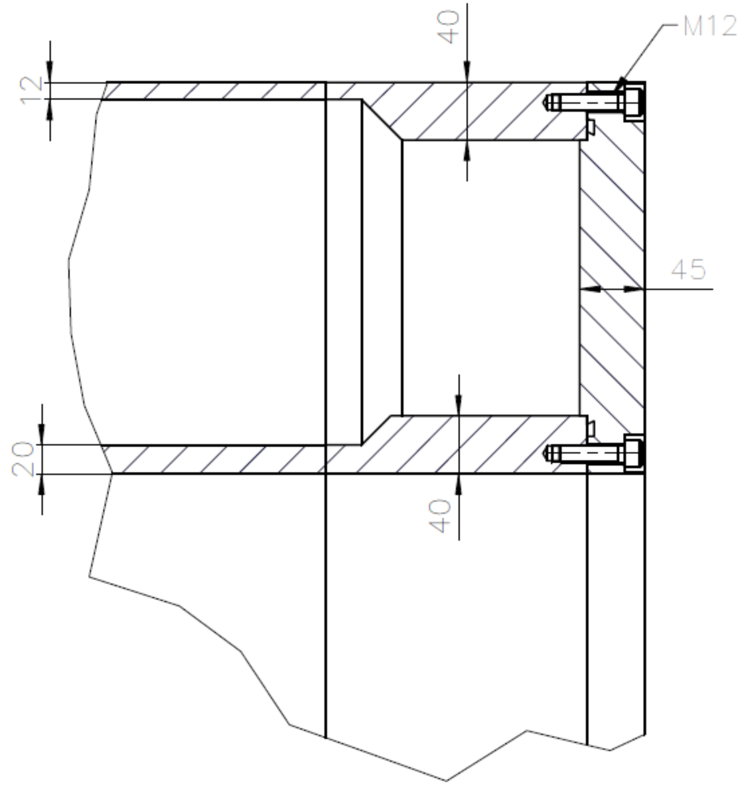
Guides for placing the calorimeter

The main characteristics of the magnet:

Magnetic field along the axis - **1.0T** with uniformity ± 2%;
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 Al996, the conductor cross-section at a temperature of 4.5K is 7.90mm in width and 10.90mm in height;

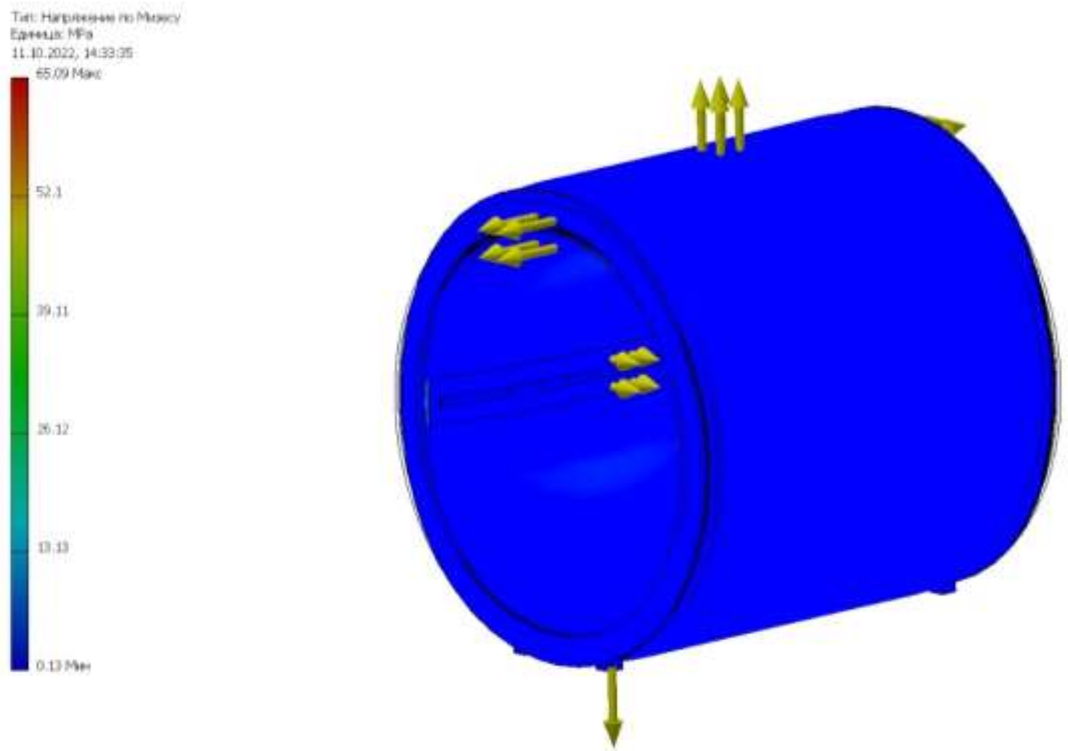
It is planned to base the calorimeter on a cryostat, for this purpose, there are special guides on the inner shell of the cryostat.

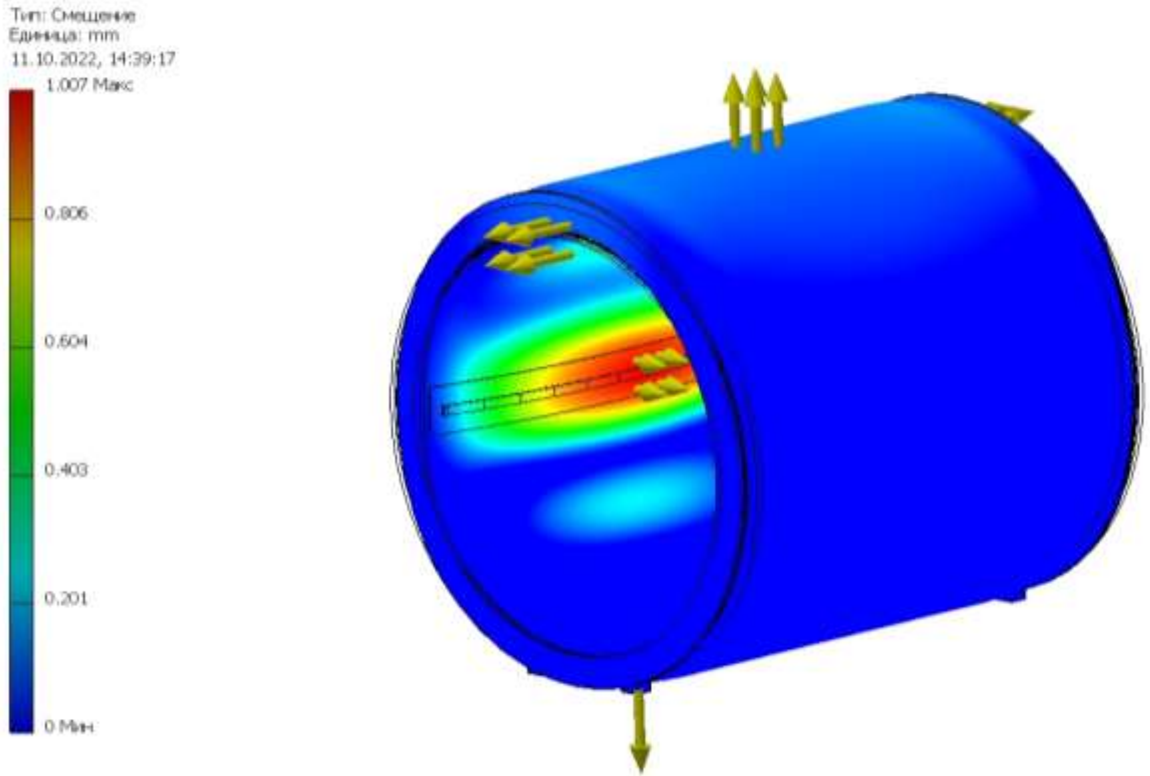
Cryostat



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.

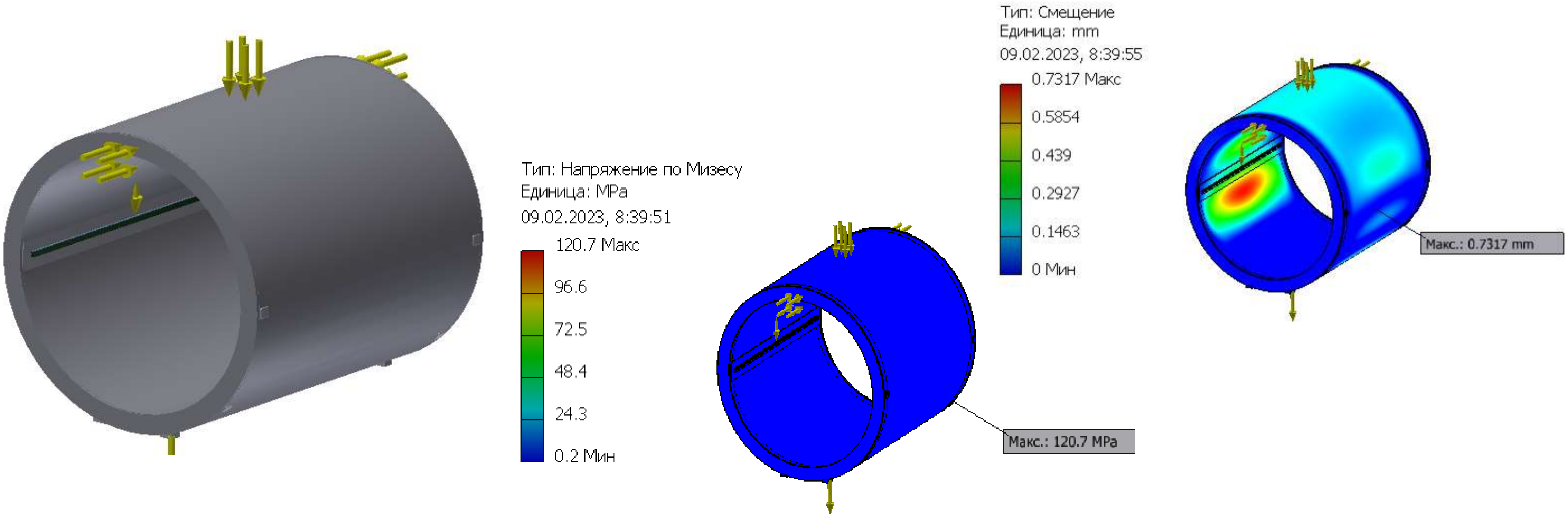




The maximum equivalent stress is 65 MPa. The maximum deformation is 1 mm.

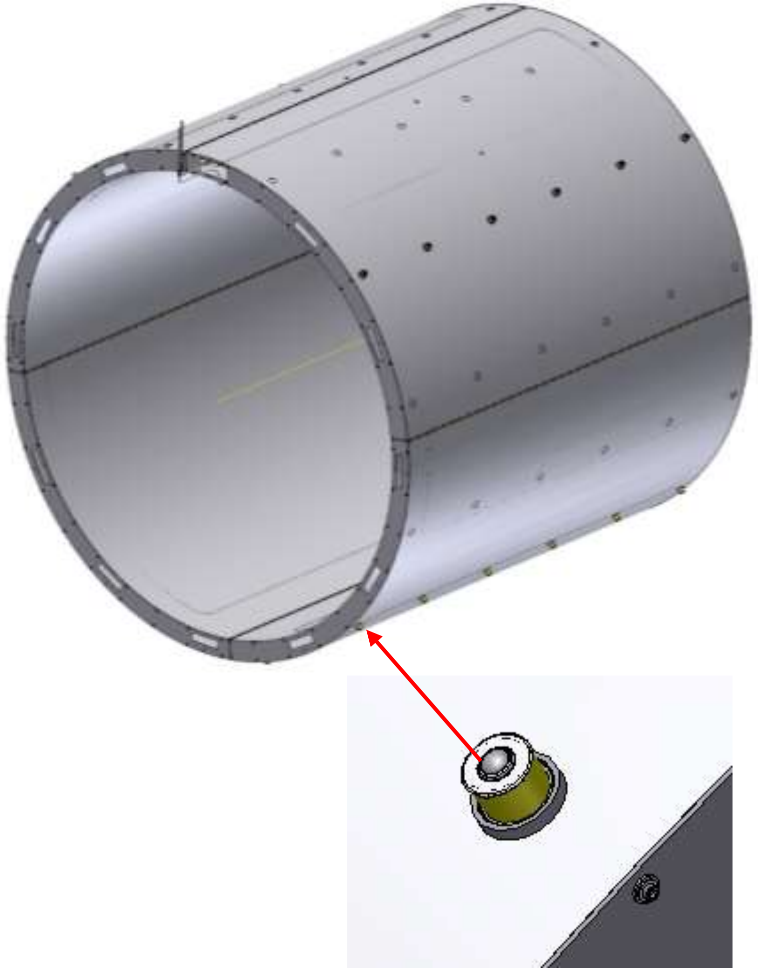
Cryostat (calculation)

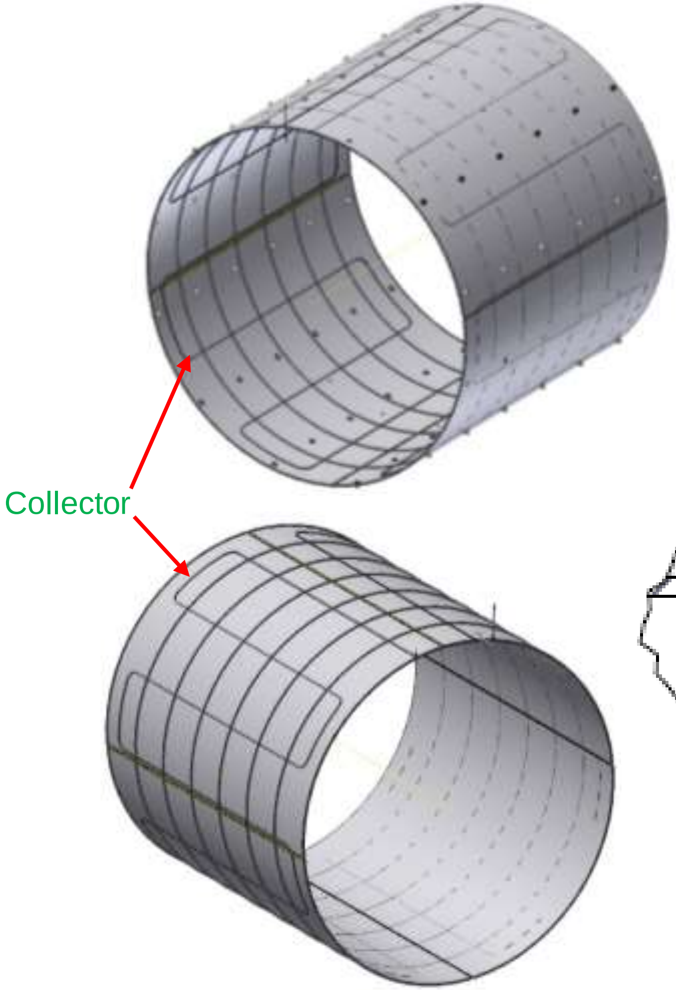
Operation condition (p=0.1 MPa), weight + weight of calorimeter (60t)

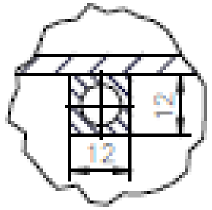


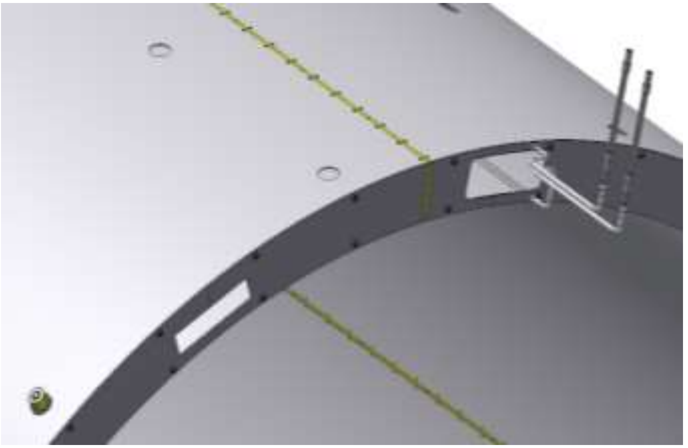
It is suppose that the calorimeter will be based on guides located along the magnet in the middle plane.
The maximum equivalent stress is 120 MPa. The maximum deformation is 0,7 mm.

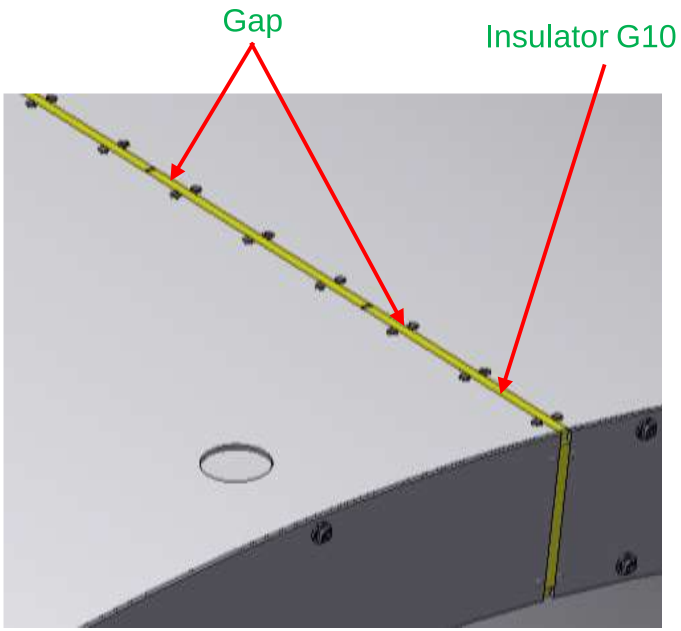
Thermal shield 80K







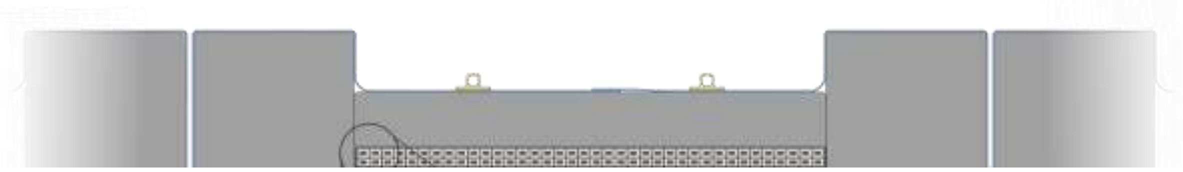




Material - aluminum alloy AMg-5. Outer diameter - 3898 mm, inner diameter - 3568 mm, length - 3720 mm. Wall thickness - 4 mm, Shield weight ~1 t

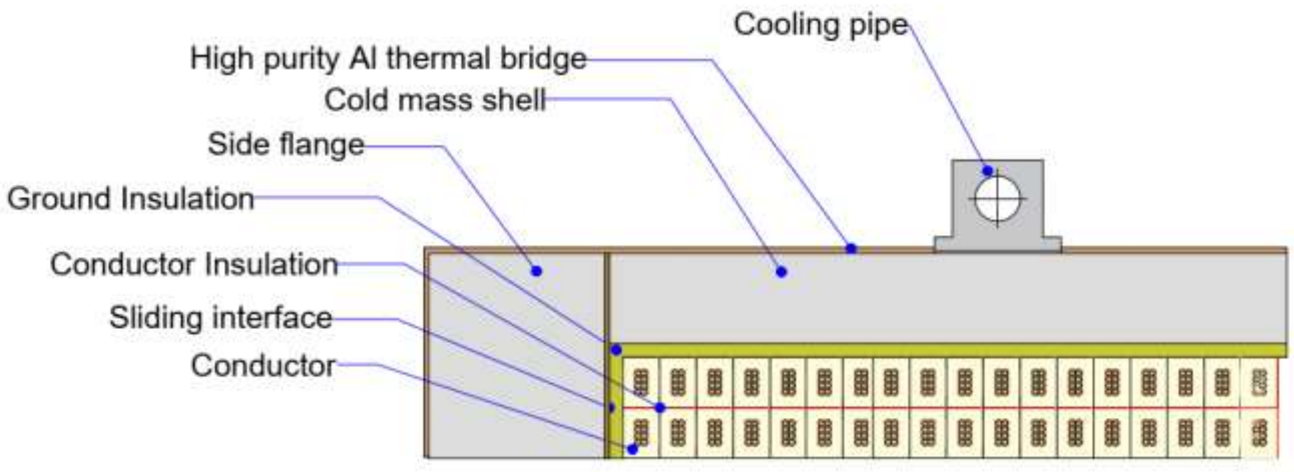
For the collector, a 12x12 with 8 mm hole Al profile welded to the shell of the shields is used. The shield is divided around the perimeter into 4 parts using СТЭФ insulators. Outside the shield is covered with 30 layers of MLI and inside surface of the shield is covered with 10 layers of MLI . The shield is positioned in the cryostat using ball bearings with an insulating ring (4 rows at the bottom and 2 rows at the top).

Cold Mass (design)



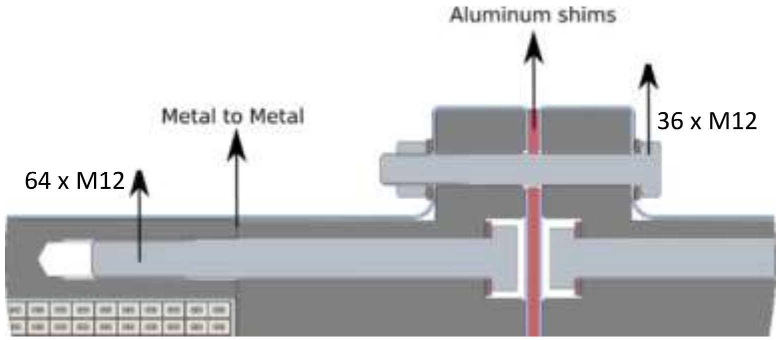
2 coils x 2 layers - 312 turns
1 coil x 2 layers - 156 turns

Magnetic field - 1 T
Current - 5.2 kA



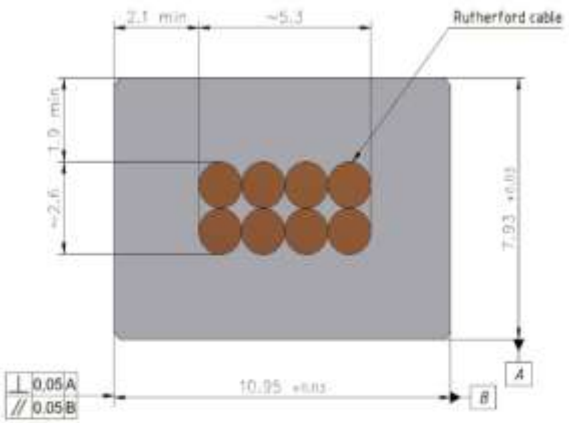
Conductor mechanical and electrical parameters.

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	



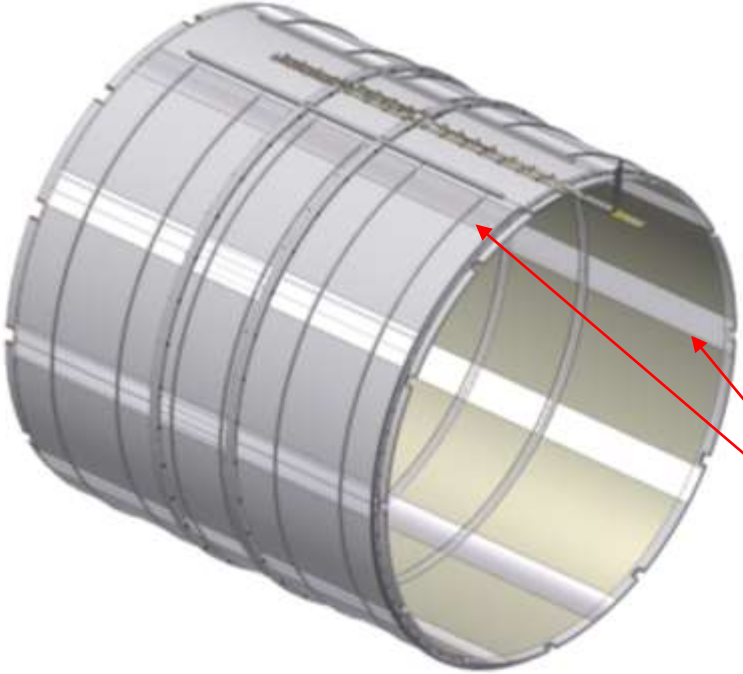
Rutherford cable, 8 strands, extruded in Al matrix

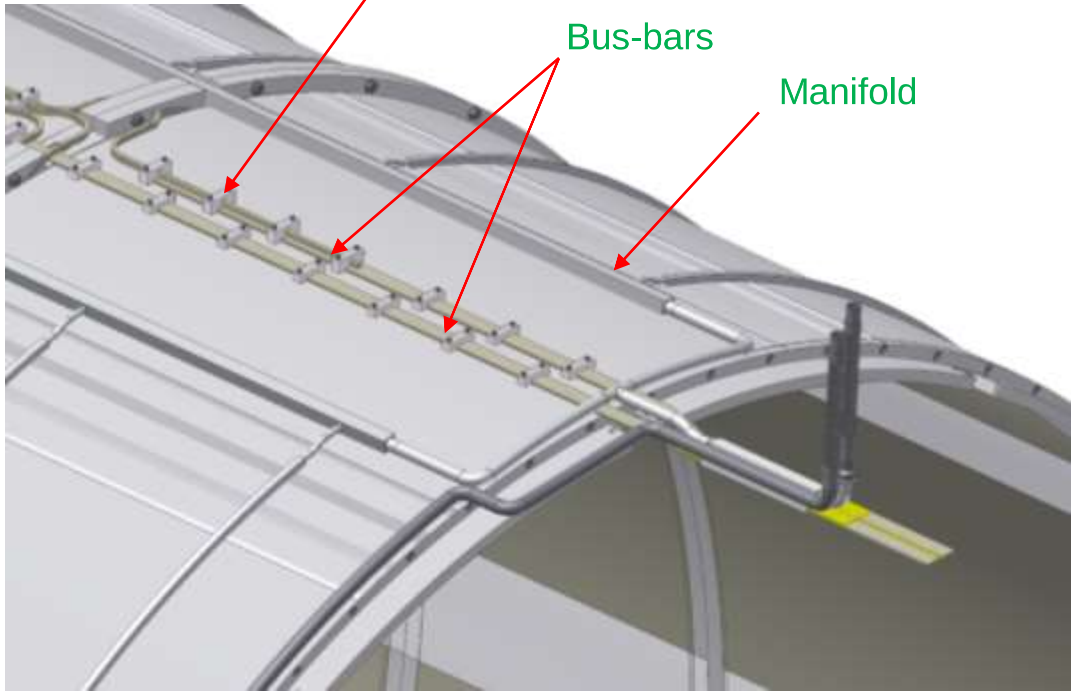
10.95 мм x 7.93 мм,
NbTi / Cu d=1.4 мм



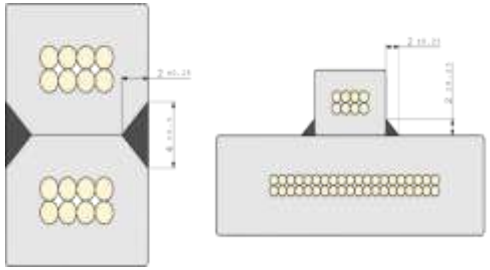
Rutherford cable is used to wind the coils. The cold mass consists of three coils, The coils are fixed together using bolts. If necessary, we will use special shims between the sections of the coils.

Cold Mass



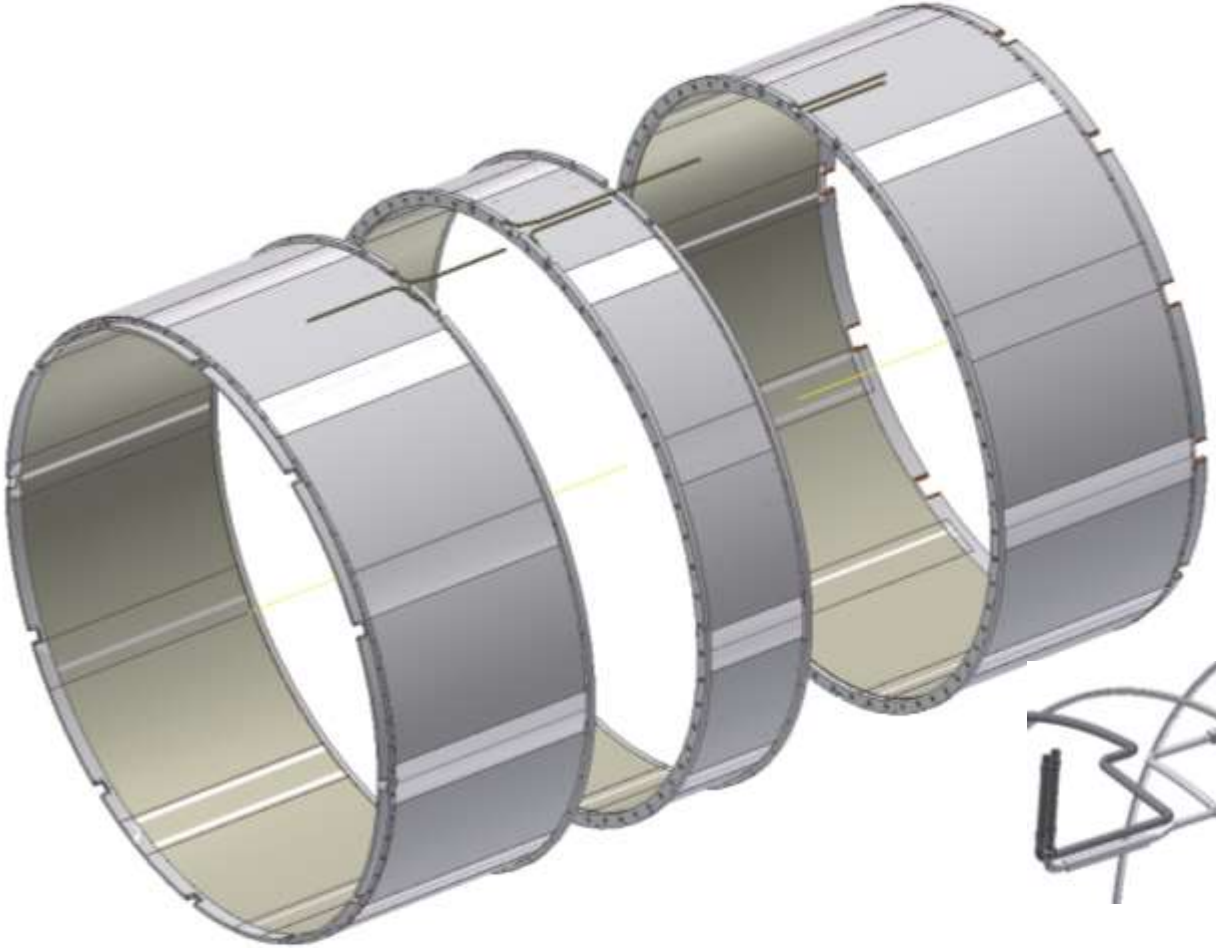


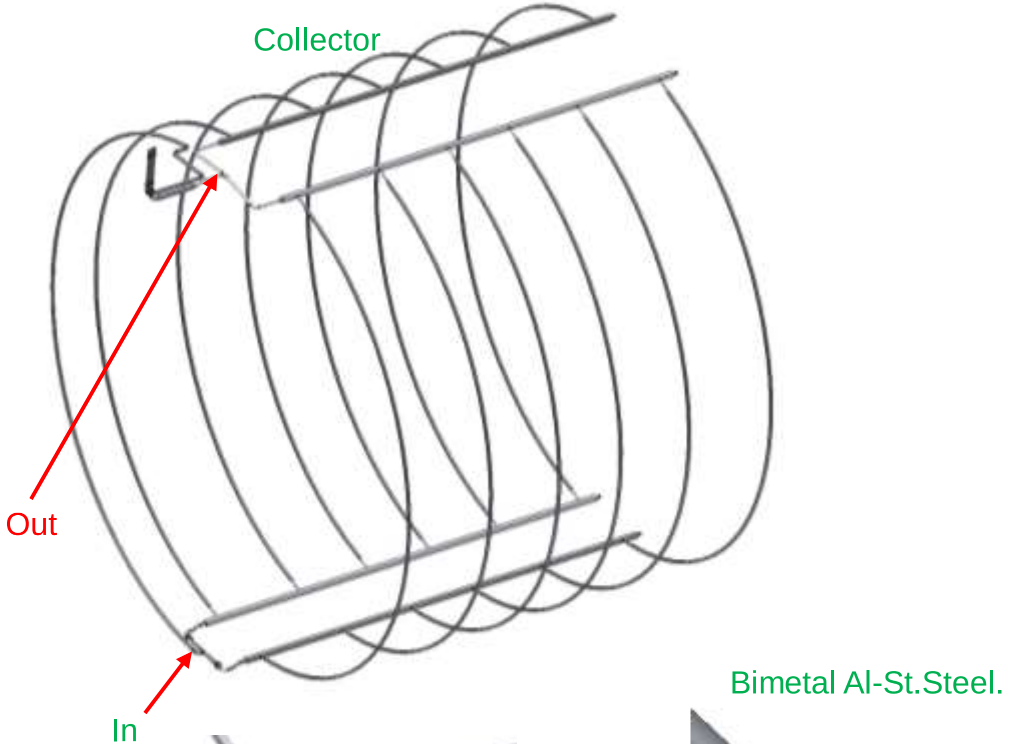
coil-to-coil and layer-to-layer joints

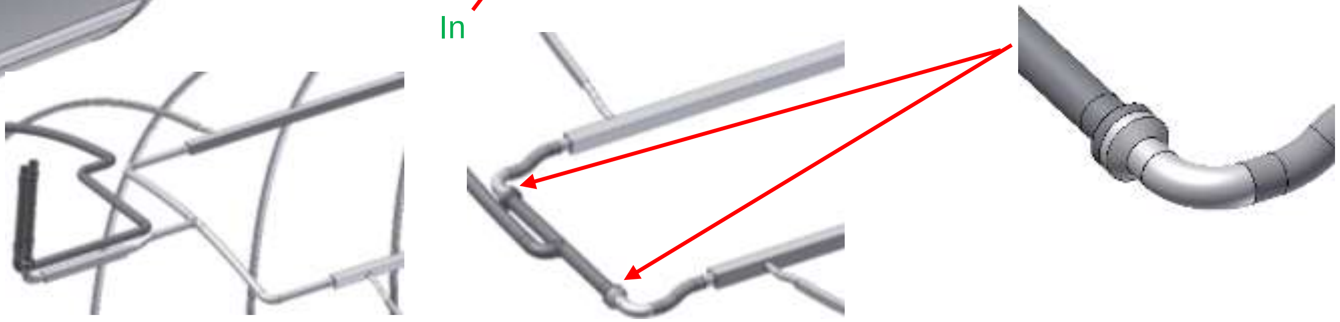


The connection of the coils to the current leads is made through bas-bars with a cross section of 32 by 5.6 mm. The connection is made by welding. Thermal bridges made of high purity aluminum are used for temperature equalization.

Cold Mass

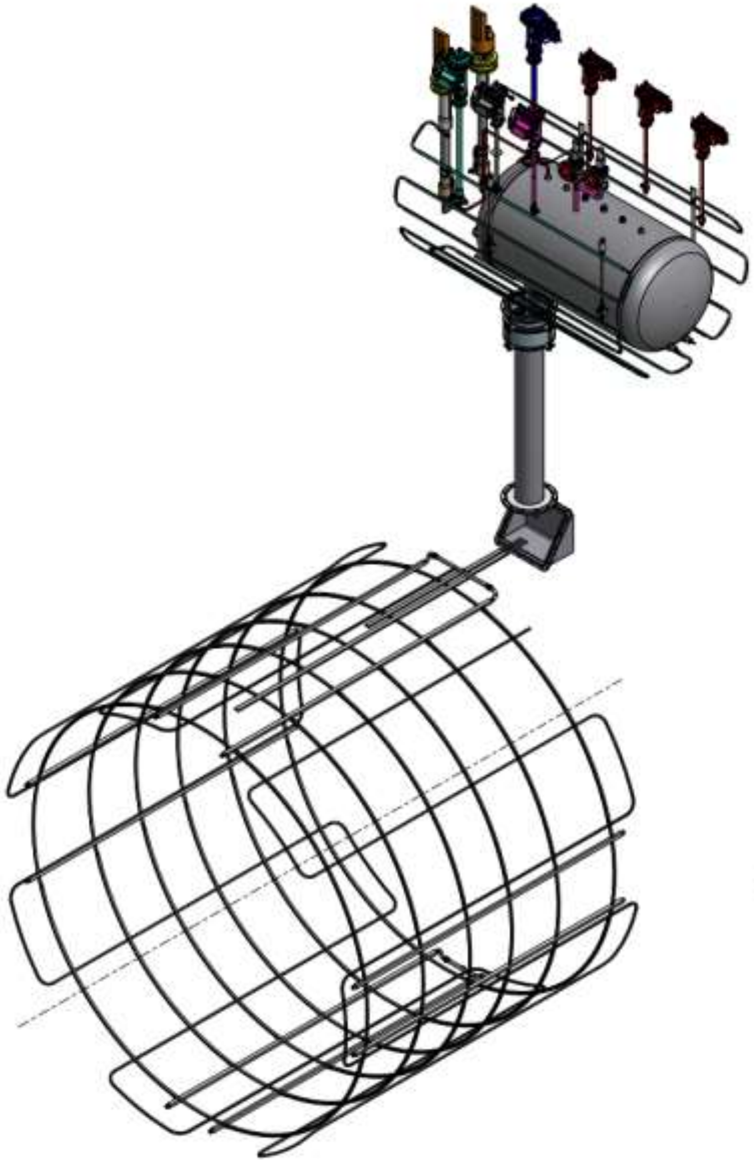


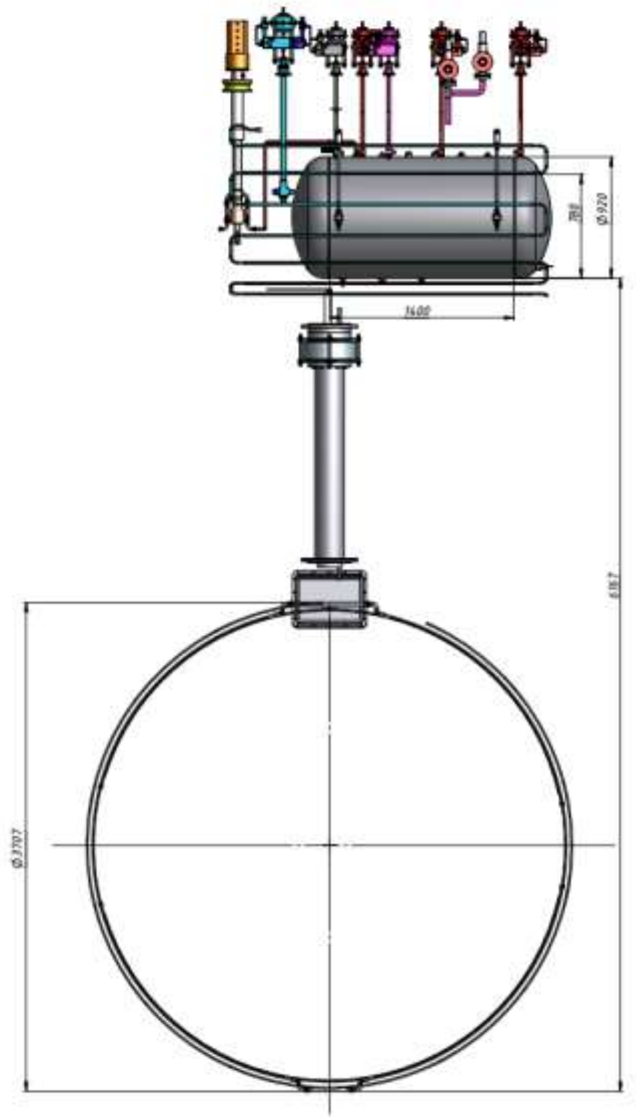




For front and back coils, cable length ~ 3600 meters; for the central coil the cable length is ~1800 meters.
For cooling, a tube with a cross section of 14x14 mm and a hole of 10 mm is used, welded to the shell of the cold mass. Bimetallic adapters are used to connect aluminum profiles to stainless steel pipes.

SPD solenoid. Cold mass cooling design.



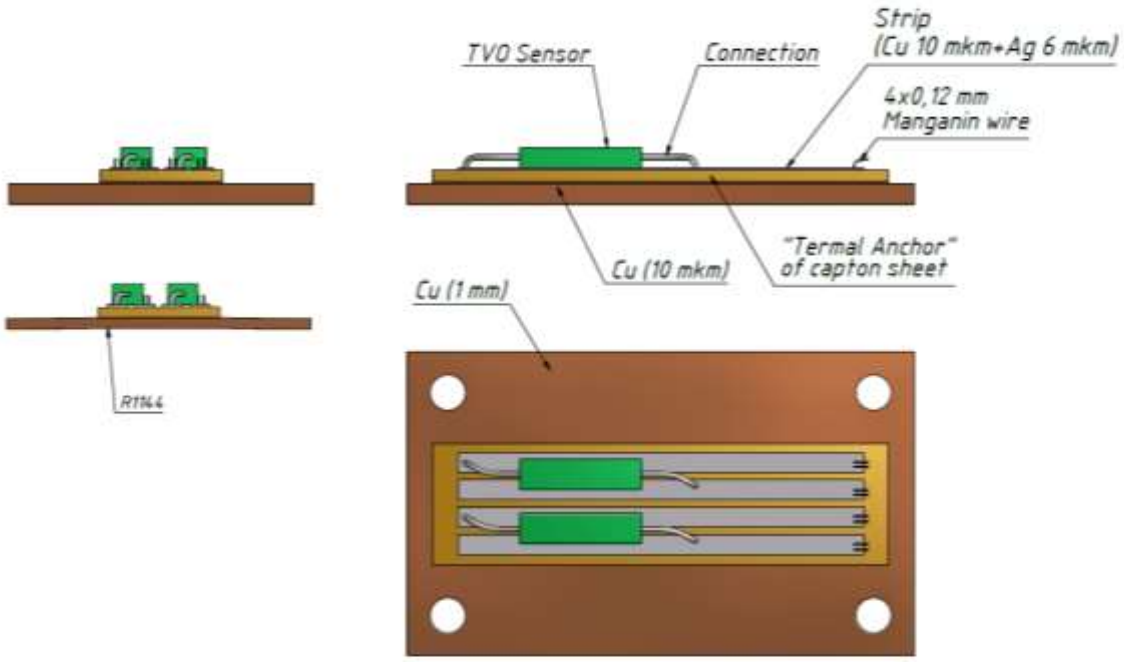


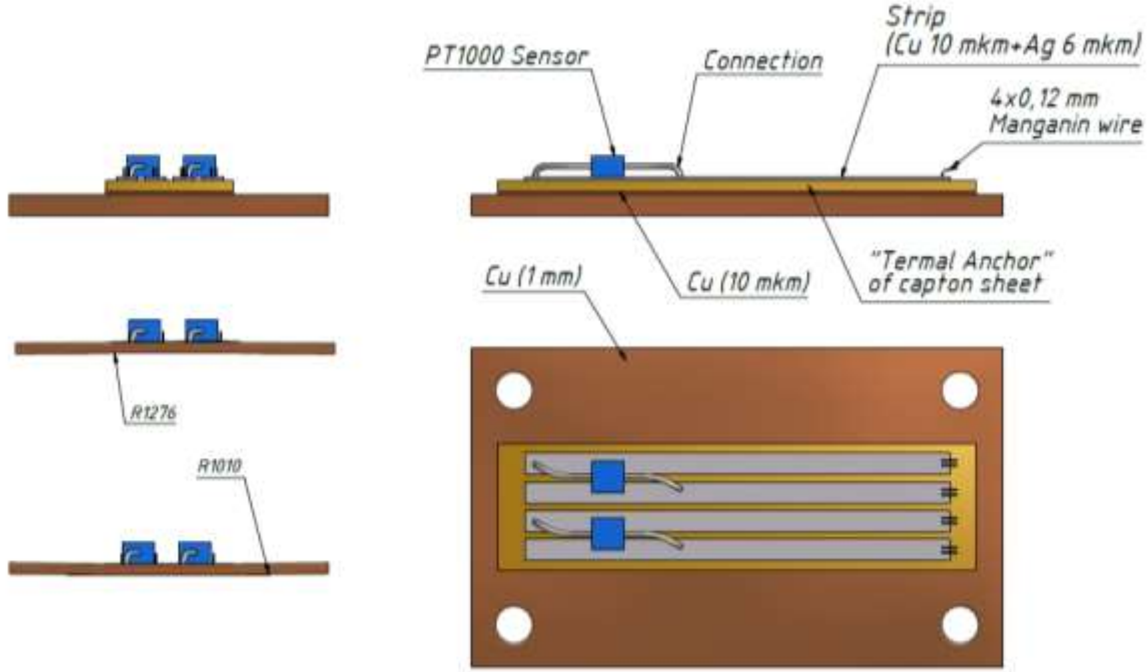
It is planned to use the thermosiphon method of cooling the superconducting coil due to the natural convection of two-phase helium.

The volume of liquid helium is 10 - 20 liters

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

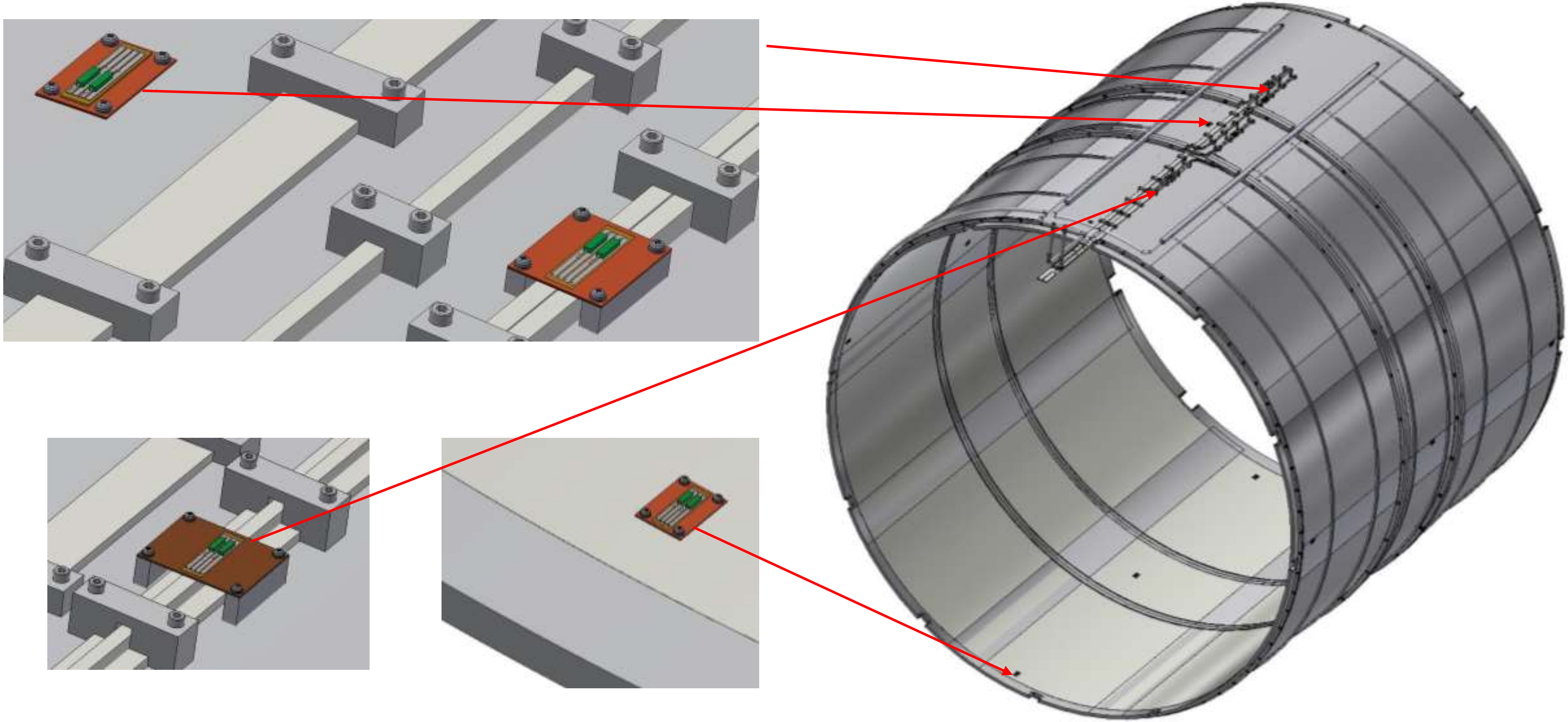
Temperature Sensors TVO and PT1000





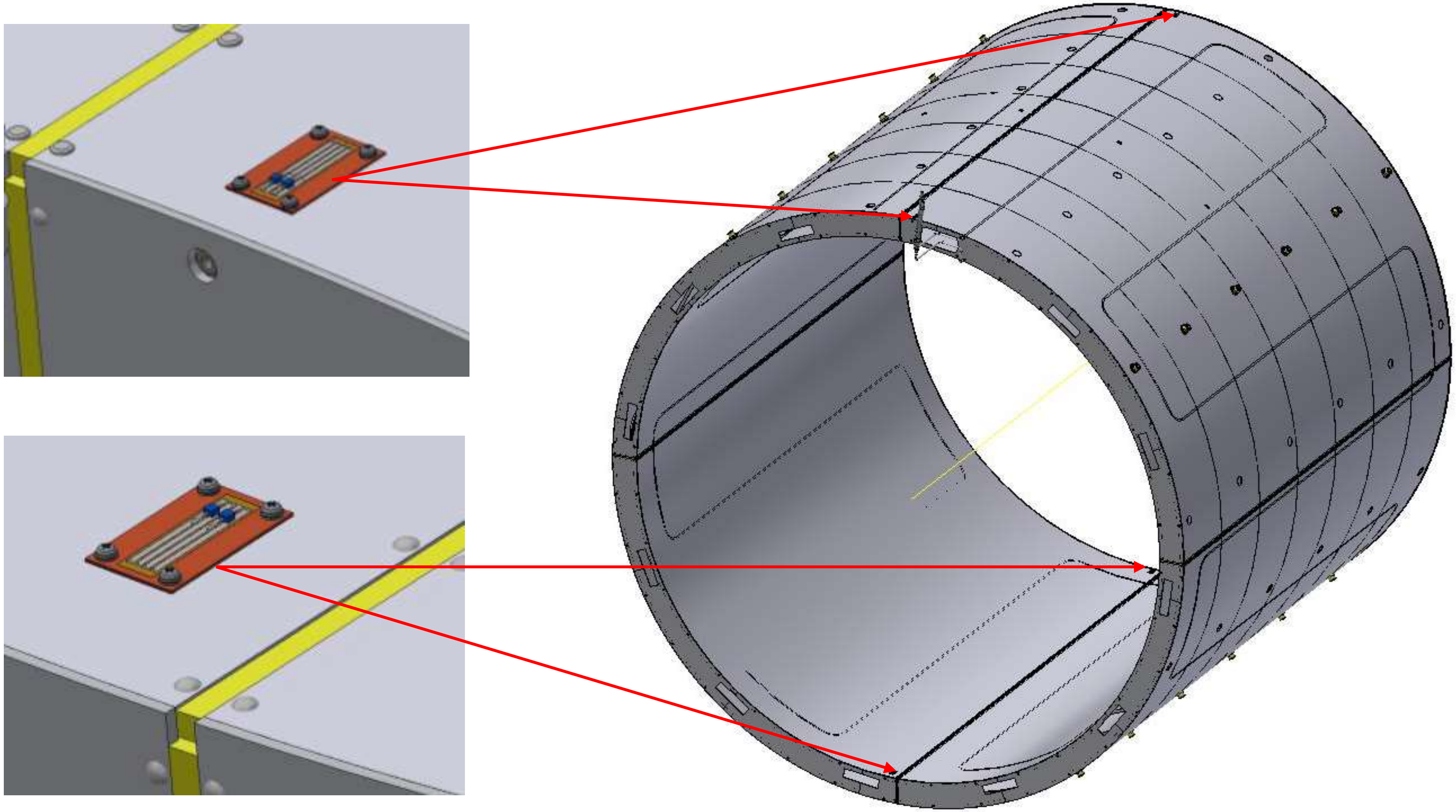
For temperature control, temperature sensors for Cold mass - TVO (4.5K), for Shield- PT1000 (60K) are used (Dual sensors are used).

The Cold mass of the Magnet. Temperature Sensor (TVO) Position.



It is planned to place about 30 sensors TVO on the Cold mass on the outer and inner shell and bus-bars.

Shield. Temperature Sensor (PT1000) Position.



It is planned to place 8 sensors PT1000 on the Shield on the outer and inner shield.

The Cold mass of the Magnet.
(Quench heaters)

All Polyimide Heaters

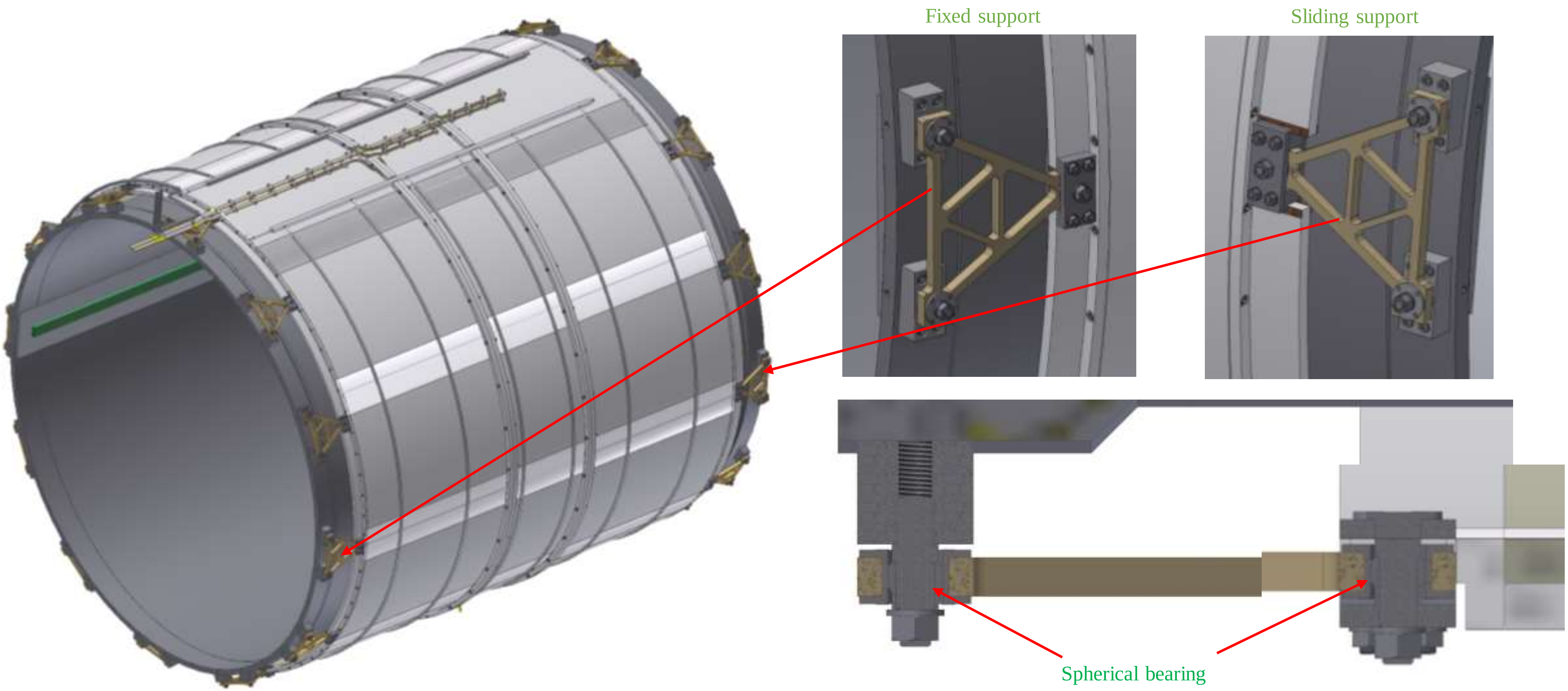
All-Polyimide Heaters are a high performance alternative to Minco's standard polyimide flexible heaters. They enable higher temperatures and watt densities than any other flexible film heater.

Benefits of All-Polyimide Heaters:

- Maximum operating temperature of 260°C
- Provide heat where it's needed to reduce operating costs
- Fast and efficient thermal transfer
- Uniform thermal performance by custom profiling
- Customized options for turnkey thermal solutions

It is planned to place three double Quench heaters

SPD Magnet (Suspension system)

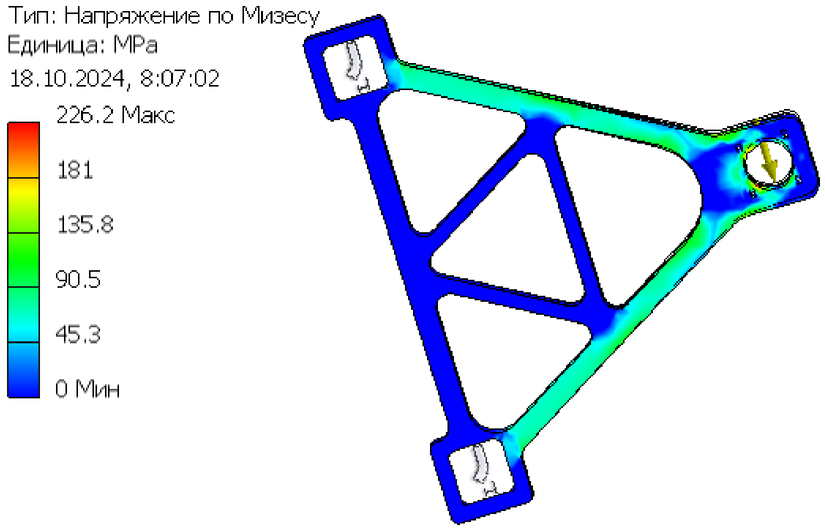


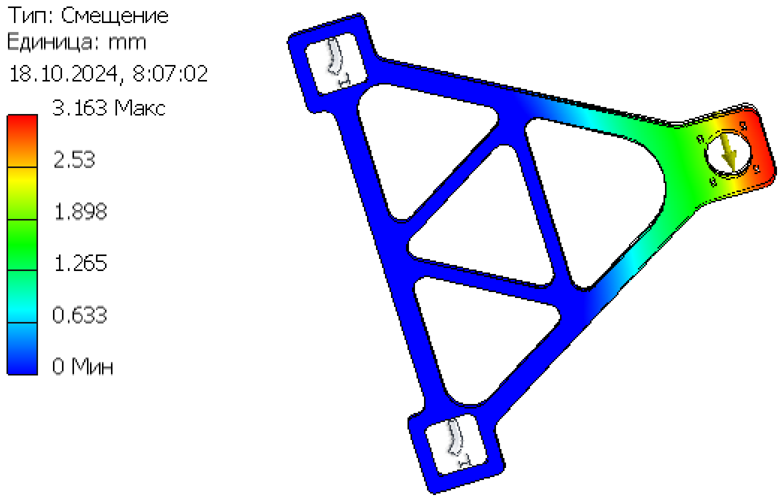
Fixation of the cold mass is made with help of triangular suspensions made of СТЭФ-1, 12 pieces on each side. On one side the supports are fixed, on the other side its are sliding to compensate for temperature changes in the length of the coil. The Suspensions have spherical bearings to avoid bending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

Suspension (recalculation). Load from the weight of the cold mass and radial magnetic forces with a radial displacement of 5 mm.

Magnetic force on coils				
	comp.	Left coil	Central coil	Right coil
F, kN y +5 mm	X (horiz.)	0	0	0
	Y (vert.)	32.2	20.1	32.4
	Z (long.)	4752.8	-0.3	-4753.3

Material	Max. equivalent stress	Max. deformatio n	Permissibl e stress
СТЭФ-1	226 MPa	3,1 mm	289 Мпа

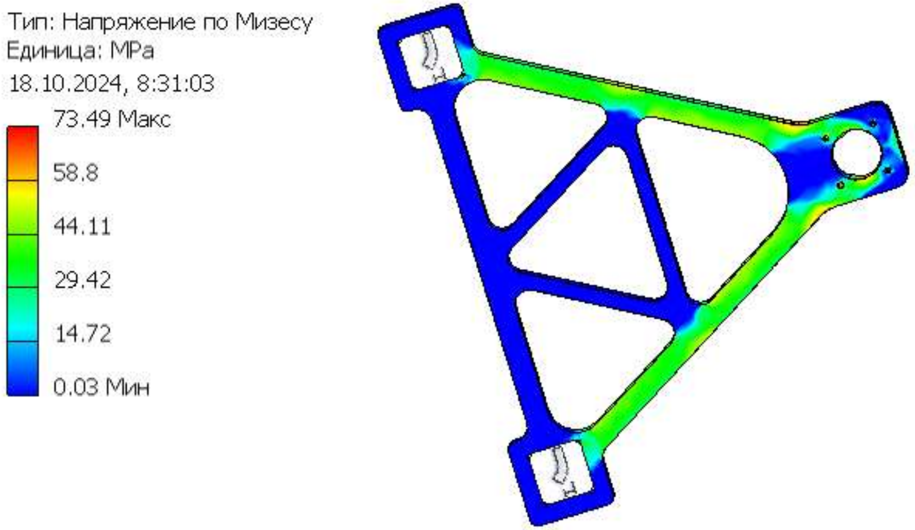




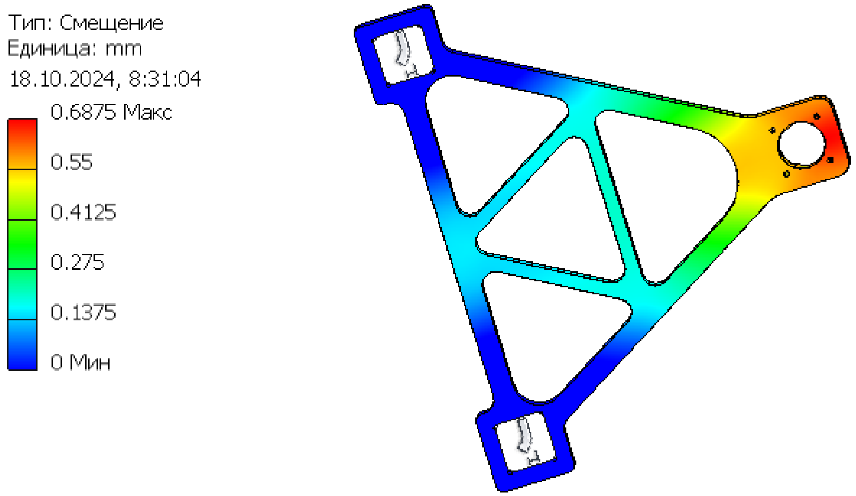
The maximum equivalent stress is 226 MPa. The maximum deformation is 3,1 mm.

Suspension (recalculation)
Load from axial magnetic forces at a displacement of 5 mm.

Magnetic force on coils				
	comp.	Left coil	Central coil	Right coil
F, kN z +5 mm	X (horiz.)	0	0	0
	Y (vert.)	0	0	0
	Z (long.)	4521.4	-69.6	-4743.4

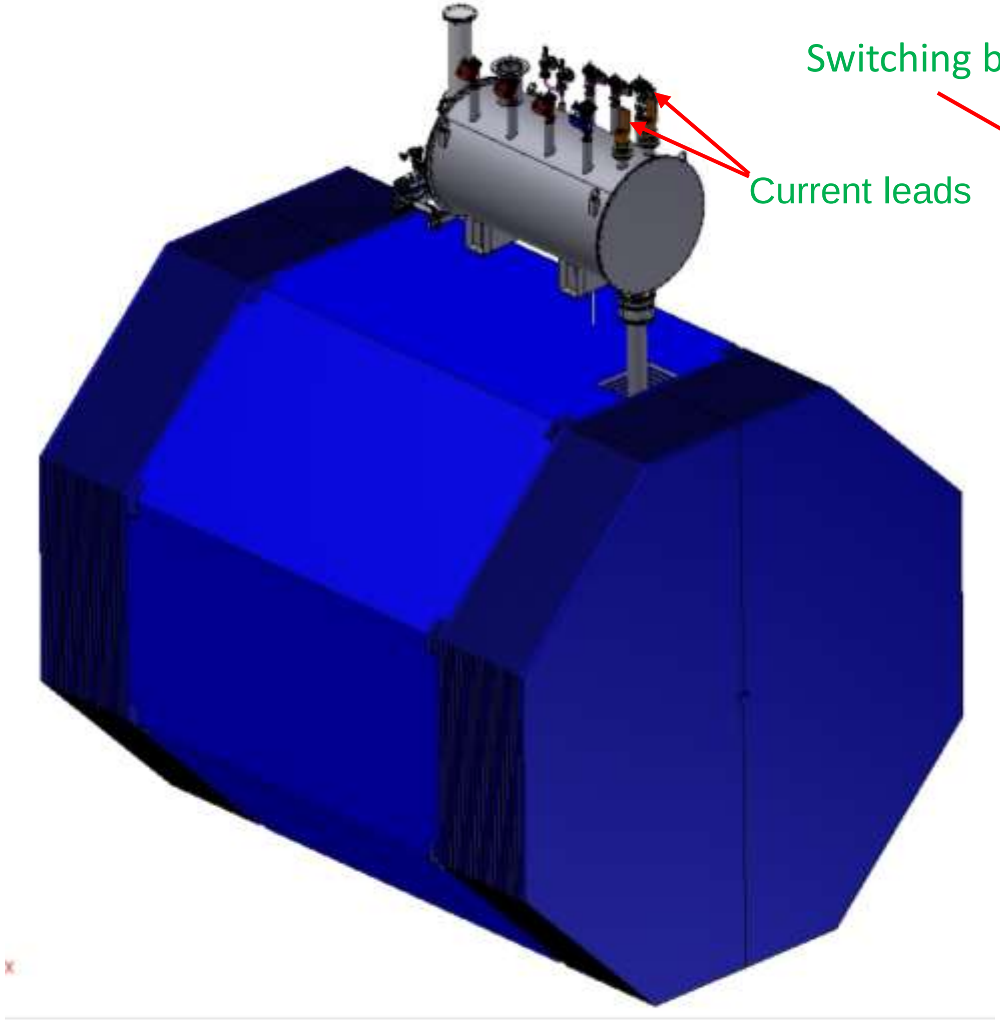


Material	Max. equivalent stress	Max. deformation	Permissible stress
СТЭФ-1	73.5 MPa	0.7mm	289 Мпа



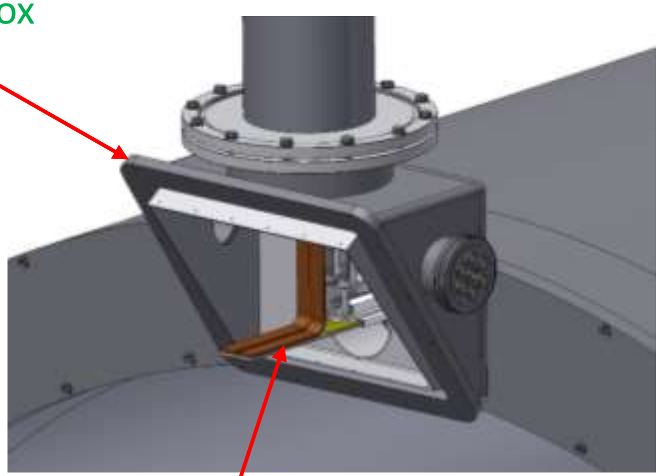
The maximum equivalent stress is 73.5 MPa. The maximum deformation is 0.7 mm.
We plan for a cold mass positioning better than 1mm.

SPD Магнит with Control Dewar

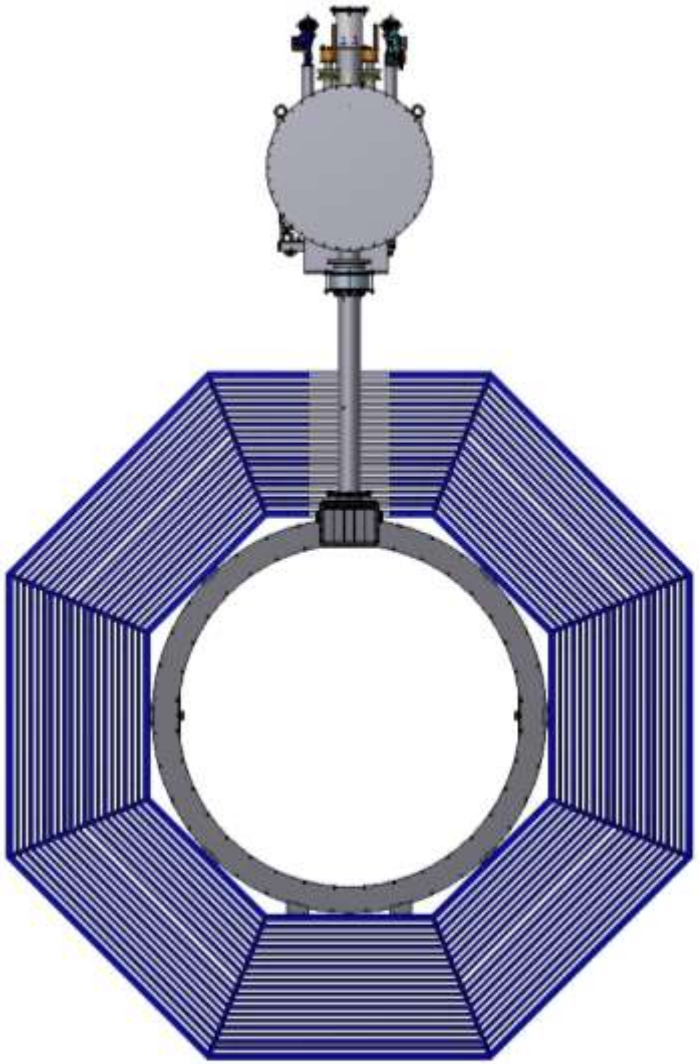


Current leads

Switching box

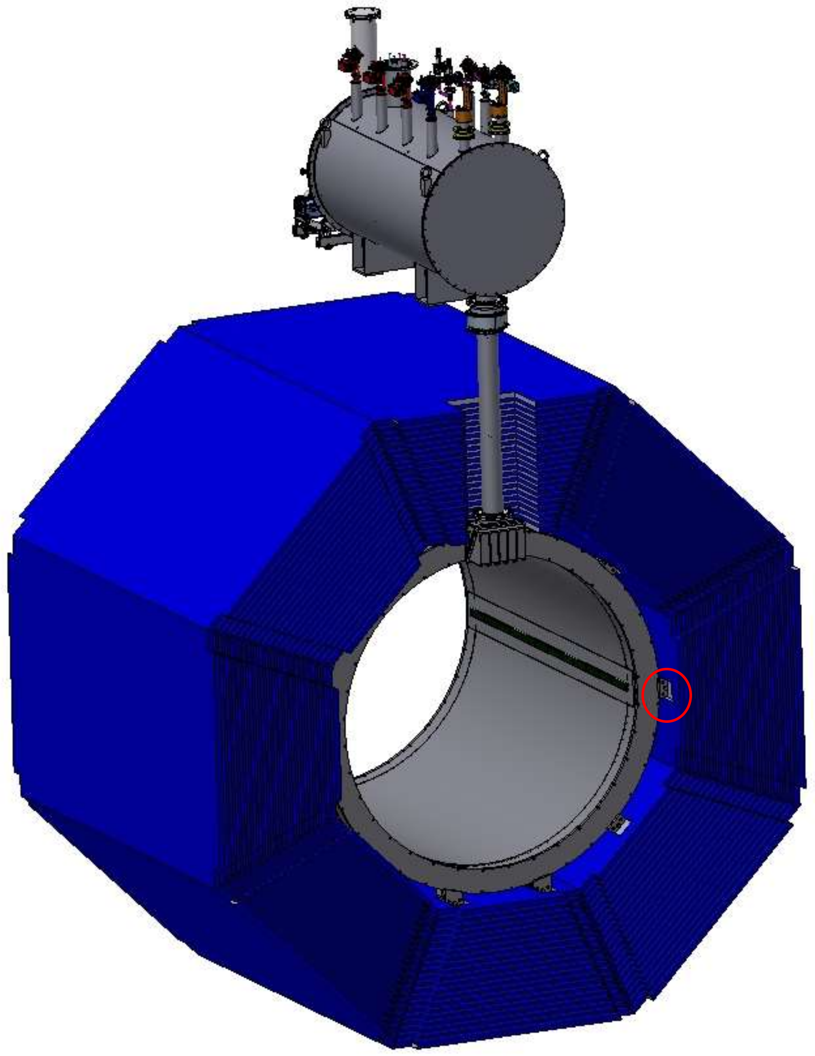


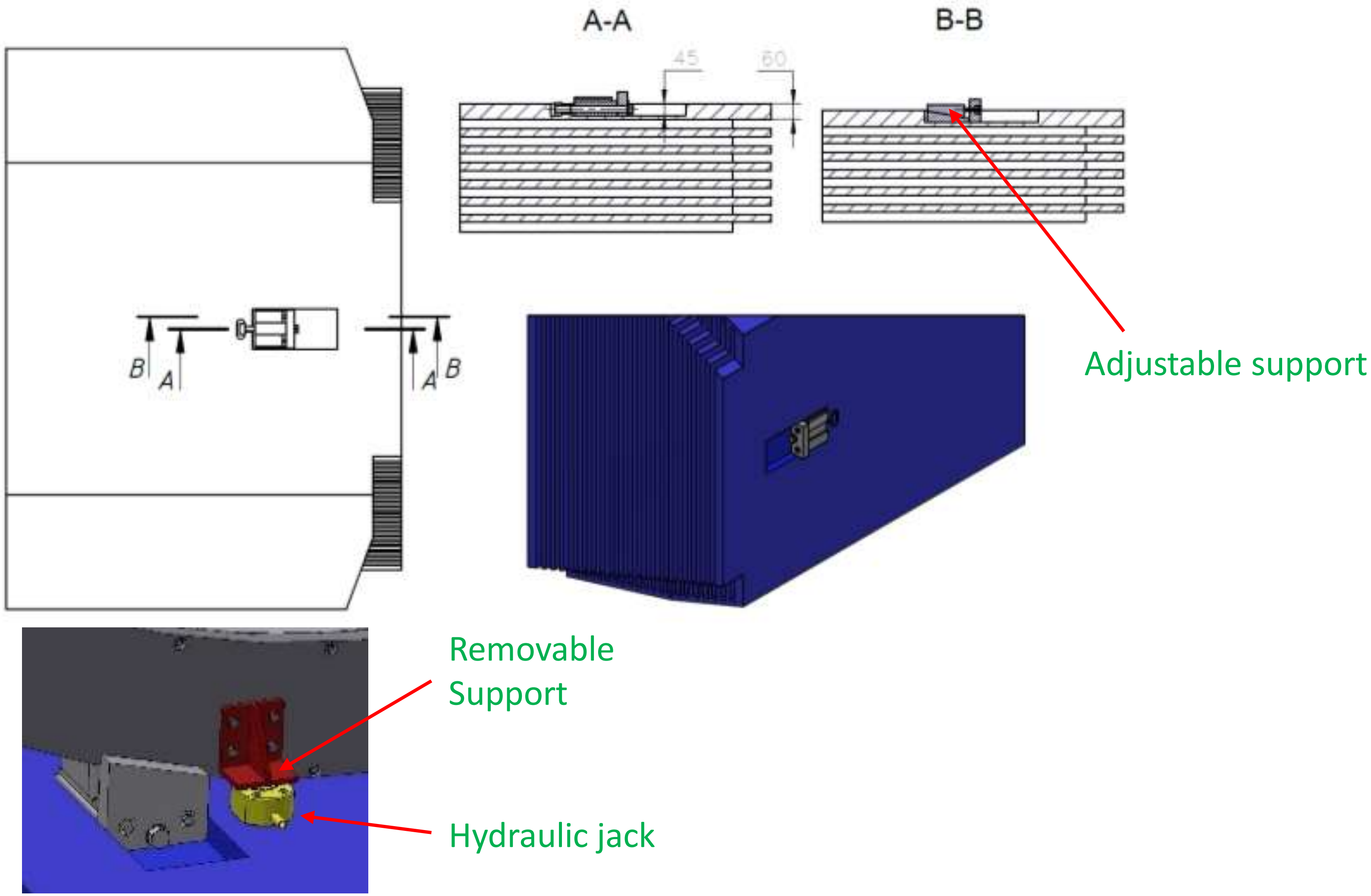
Connection of current leads with Bas-bars coils.



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

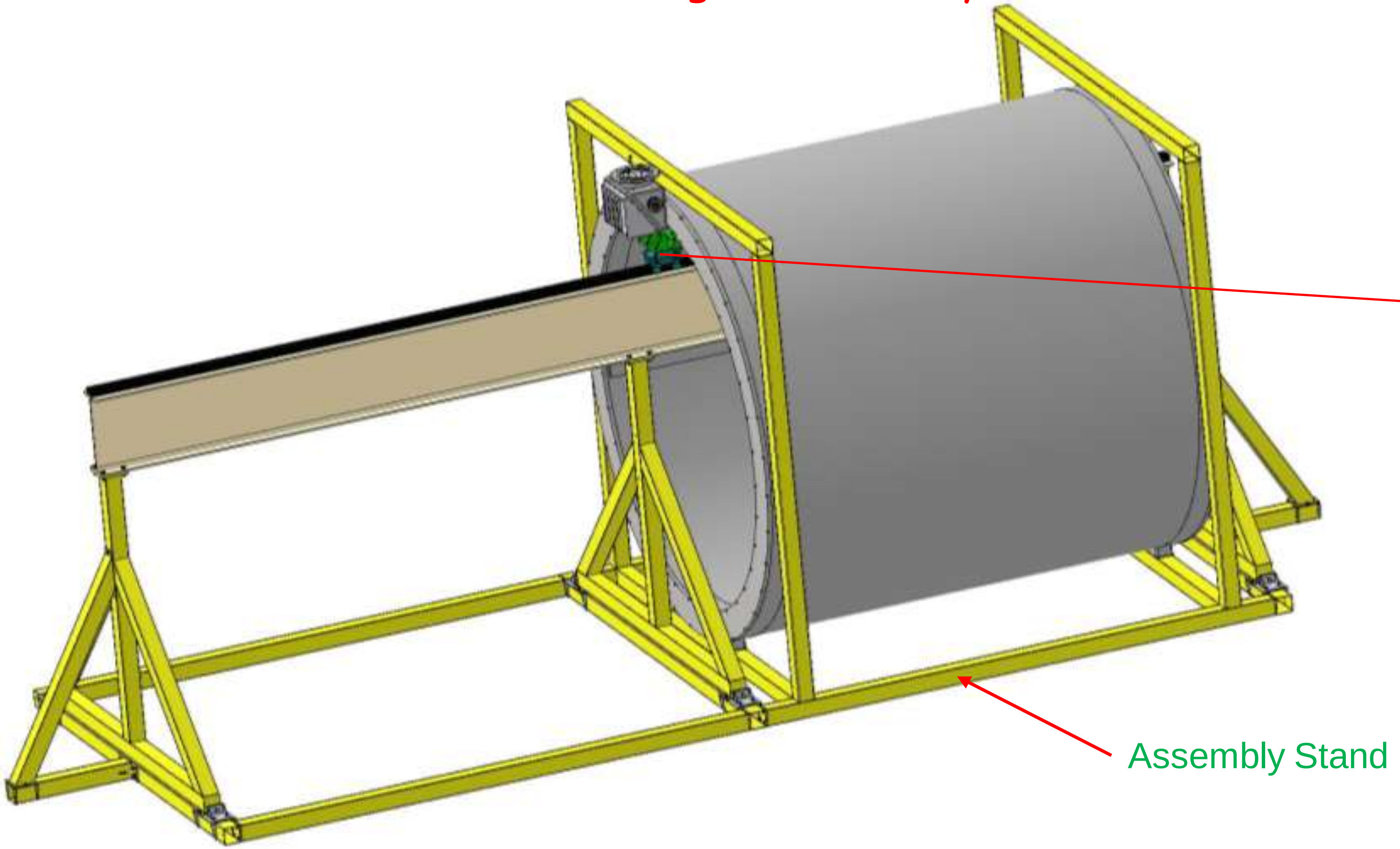
SPD Magnet (fixation)



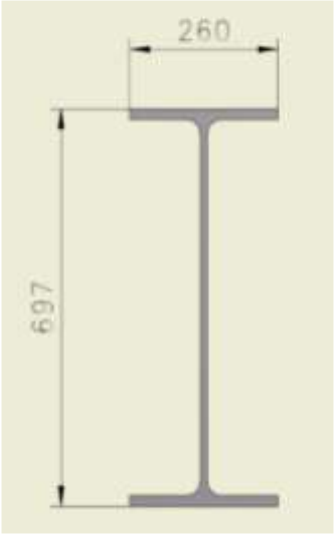


The cryostat is fixed in an iron yoke by means of special adjustable supports fixed on octants .
The wedge surface of the support allows you to fix the cryostat after positioning the magnet using hydraulic jacks.

Magnet assembly Stand



Roller skate Boerkey



To assemble the magnet, a special Stand with an I-beam - 700 GOST 26020-83, 10 meters long, with a guide rail and a roller system (Roller skate Boerkey model AM-H) for rolling up the magnet elements, is used.

The stand design is shown on the slide. 3D model of the stand is ready.

SPD heat loads

Table 1. Estimated heat loads of the SPD solenoid			
T = 4,5 K	Heat loads, W		
	Worked condition	Without m.f.	With m.f.
Cryostat			
Radiation	7,8	7,8	7,8
Supports	3,6	3,6	3,6
Eddy current loss in casing	-	-	11,50*
Eddy current loss in conductor	-	-	0,09*
Current leads, 4,5 kA B=1.0 T	10	8	8
Control Dewar			
Radiation	0,50	0,50	0,50
Supports of the LHe vessel	0,26	0,26	0,26
Cold control valves	0,93	0,93	0,93
Safety relief valves	4,30	4,30	4,30
Vacuum barrier	0,35	0,35	0,35
Transfer line			
Radiation	0,12	0,12	0,12
Supports	0,32	0,32	0,32
Total	*28,18*	*26,18*	*37,77*
*** Data of PANDA solenoid**			

SPD heat loads

T=60K	Heat loads, W		
	Normal condition	Without magnetic field	Current ramping
Cryostat			
radiation	160,00	160,00	160,00
supports thermal shields	12,00	12,00	12,00
eddy current loss in thermal shields	-	-	47,00
Control Dewar			
radiation	11,60	11,60	11,60
supports thermal shields	6,50	6,50	6,50
supports Helium vessel	9,12	9,12	9,12
cold valves	11,70	11,70	11,70
safety relief valves	1,10	1,10	1,10
vacuum barrier	1,18	1,18	1,18
Transfer line			
radiation	1,05	1,05	1,05
supports	2,35	2,35	2,35
Total	216,60	216,60	263,60

Status of SPD solenoid design

- Magnetic design of the magnet including of calculations of the magnetic forces. Magnetic map is ready. Magnetic analysis of magnet components in progress;
- Engineering design of the magnet including of calculations of all loads and forces;
- Design of the superconductive conductors, coils and cold mass;
- Design of the cryostat with alignment components, supports and suspend system;
- Development of the procedures for assembly of the magnet.

- Design of the proximity cryogenics with flow scheme and all instrumentation for cryogenics and insulation vacuum for the cryostat and control Dewar, current leads;
- Design of the power supply system and energy extraction system;
- Development quench protection and detection scheme;
- Development of the worked conditions of the cryogenic system;
- Define the list of FAT and SAT and requirements for tests;
- Documentation which will include: 3D models, assembling drawings of important components, part lists, welding procedures, thermal calculations, calculations of the thermo-syphon circuit, mechanical calculations and a mechanical analysis with failure modes (e.g. loss of insulation vacuum), description of the cryogenic control system as well as Process and Instrumentation Diagrams for the cryogenic process.

Design works: 2023 – December 2024

Thank you for your attention!