Budker INP
Novosibirsk

Short overview of BINP current work on superconducting magnets and HEL superconducting magnets specifications

Alexey Bragin
on behalf of BINP laboratory
of superconducting magnets

Budker Institute of Nuclear Physics, Novosibirsk, Russia

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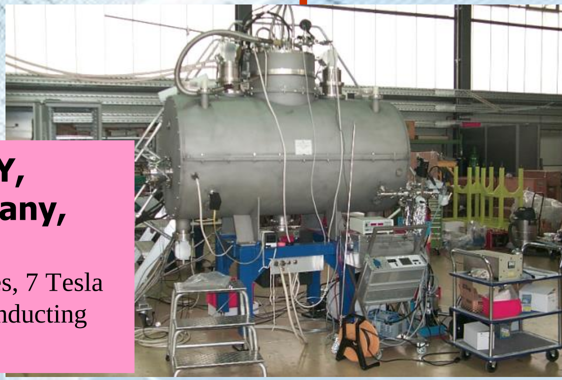
Outline

- BINP experience in insertion device development and other superconducting magnets
- Main parameters of HEL superconducting solenoids
- Additional details and parameters to be defined

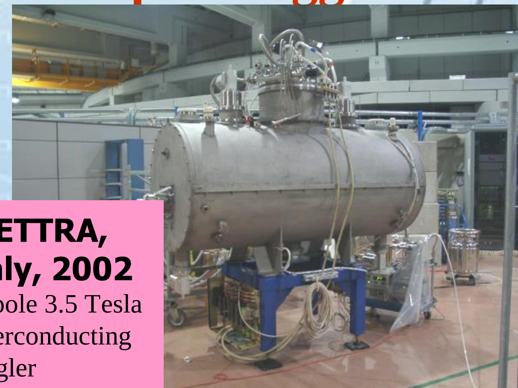
Our team routine work is making the superconducting insertion devices

- BINP superconducting wigglers
- First wiggler was made in 1979
- 2005 – 2 Tesla 63 pole SCW for CLS, Canada
- 2006 – 3.5 Tesla 49 pole for DLS, England
- 2006 – 7.5 Tesla 21 pole SCW for Siberia-2, Moscow
- 2007 – 4.2 Tesla 27 pole SCW for CLS, Canada
- 2009 – 4.2 Tesla 49 pole SCW for DLS, England
- 2009 – 4.1 Tesla 35 pole SCW for LNLS, Brasil
- 2011 - 2.1 Tesla 119 pole SCW for ALBA, Spain
- 2012 - 4.2 Tesla 63 pole SCW for Australian Synchrotron
- 2013 – 7.5 Tesla 15 pole SCW for Louisiana St. University, USA
- 2013 – cryostat upgrade for 3.5 Tesla SCW ELETTRA, Italy
- 2013 – cryostat upgrade for 7 Tesla SCW for HZB (BESSY), Germany
- 2013 – 2.5 Tesla 44 pole SCW for ANKA, Germany
- 2015 – 3 Tesla 68 pole SCW for ANKA-CLIC, Germany and CERN
- 2018 – two wigglers will be manufactured for Dortmund and Moscow
- 2019 – one wiggler will be manufactured for Moscow SR center
- 2019 – superconducting undulator with short period

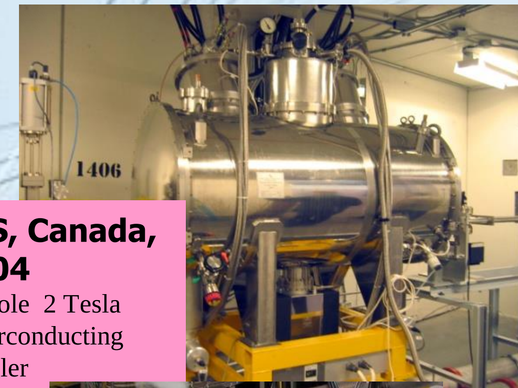
Superconducting multipole wigglers



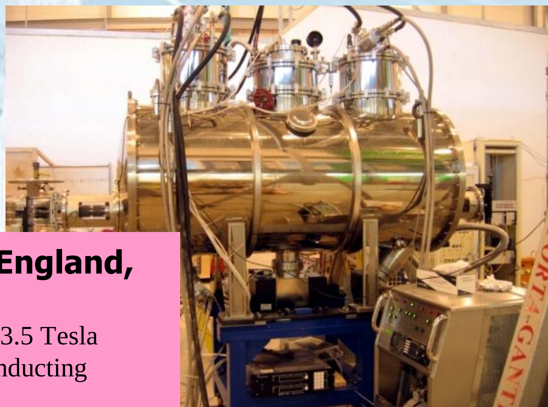
BESSY, Germany, 2002
17-poles, 7 Tesla superconducting wiggler



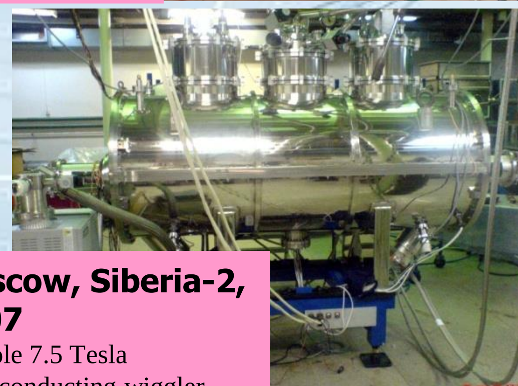
ELETTRA, Italy, 2002
49-pole 3.5 Tesla superconducting wiggler



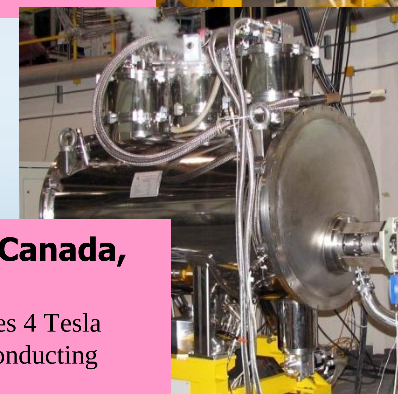
CLS, Canada, 2004
63-pole 2 Tesla superconducting wiggler



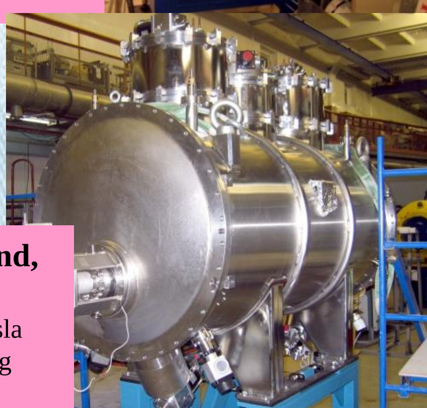
DLS, England, 2006
49-pole 3.5 Tesla superconducting wiggler



Moscow, Siberia-2, 2007
21-pole 7.5 Tesla superconducting wiggler

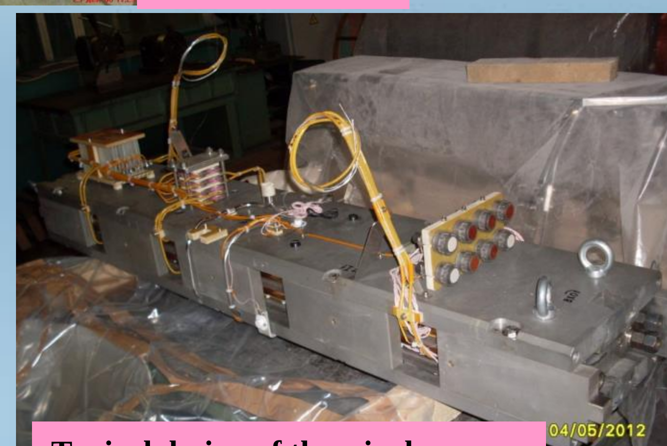


CLS, Canada, 2007
27- poles 4 Tesla Superconducting wiggler



DLS, England, 2008
49-pole 4.2 Tesla superconducting wiggler

LNLS, Brazil, 2009
35-pole 4.2 Tesla superconducting wiggler

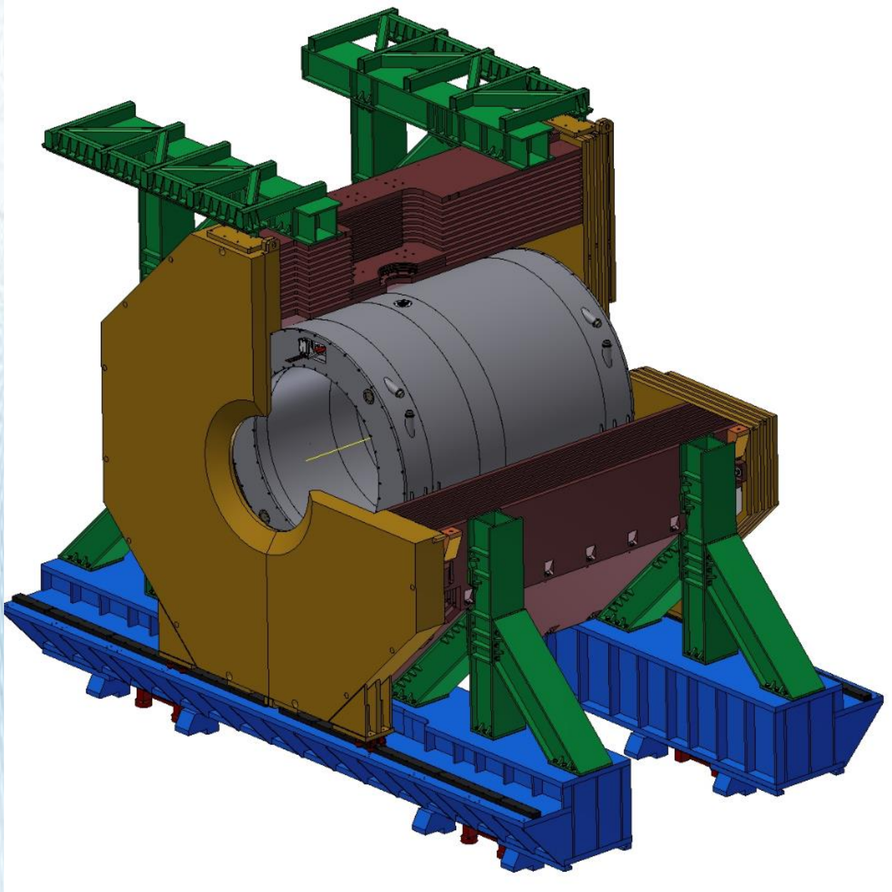


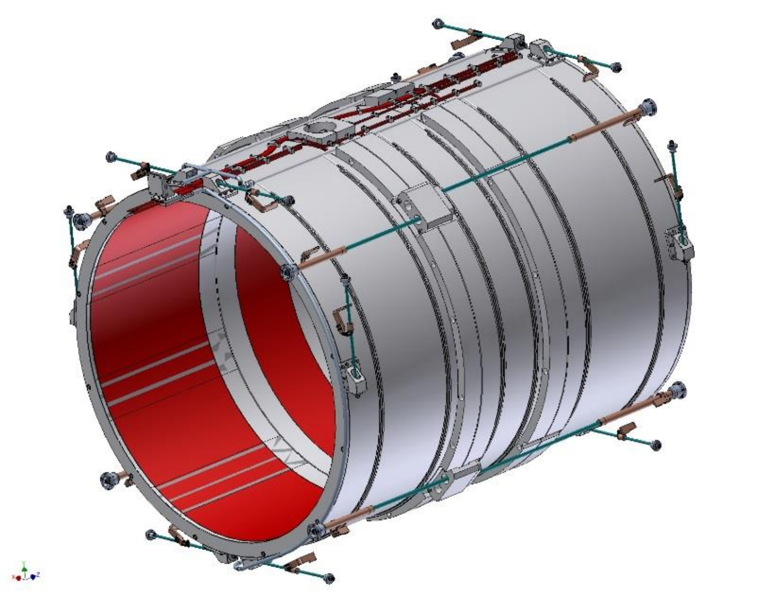
Typical design of the wigglers

Two large detector magnets are being made in BINP

PANDA detector – solenoid and iron yoke ~ 250 tons

Solenoid parameters	Values
Inner radius of the winding, mm	1048
Outer radius of the winding, mm:	1140
Total length of the solenoid, mm	2828
Number of turns in the solenoid (12*78 + 6*35)	1146
Number of layers	6
Length of one turn, m	6.75
Operating current Io, A	4960
Test current, Io*1.05, A	5208
Magnetic field on the coil Bmax, T	2.95
Io/Ic ratio along the load line, %	30
Operating temperature, K	4.5
Temperature of current sharing, K	6.7
Stored energy of the magnet, MJ	21
Cold mass, kg	5283
Cold mass of the SC cable without insulation, kg	2251
Inductance of the magnet at full current, H	1.68
E/M ratio for cold mass, kJ/kg	4.0
E/M ratio for SC cable mass, kJ/kg	9.3





Two large detector magnets are being made in BINP, cont.

CBM detector dipole magnet

Iron yoke mass is ~ 150 tons

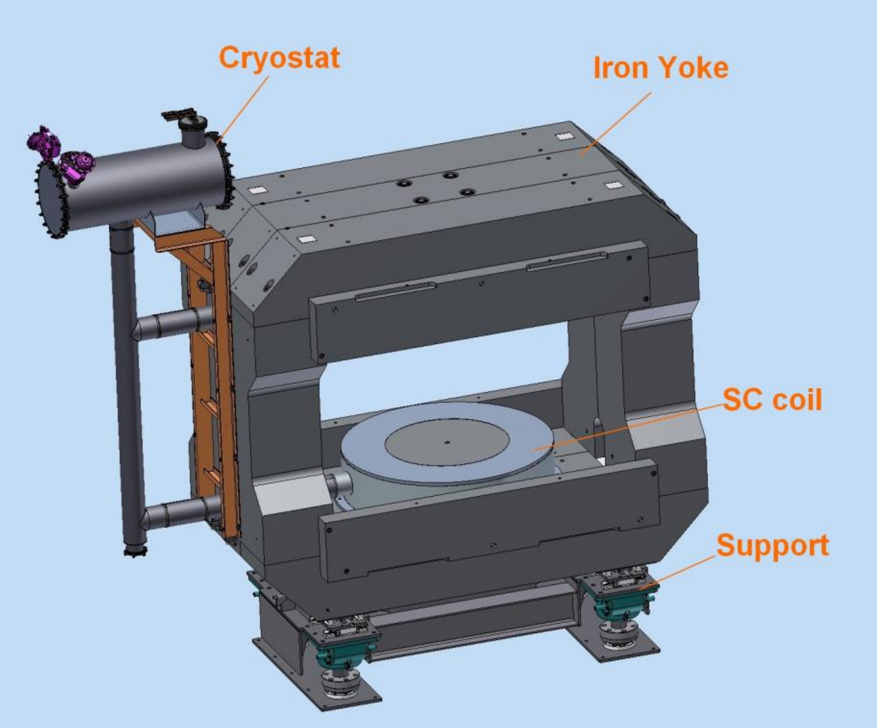
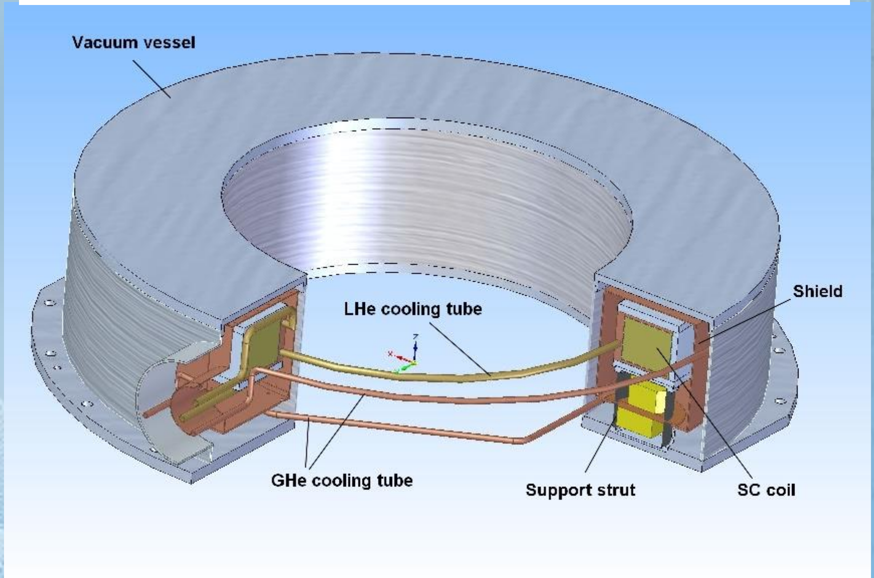


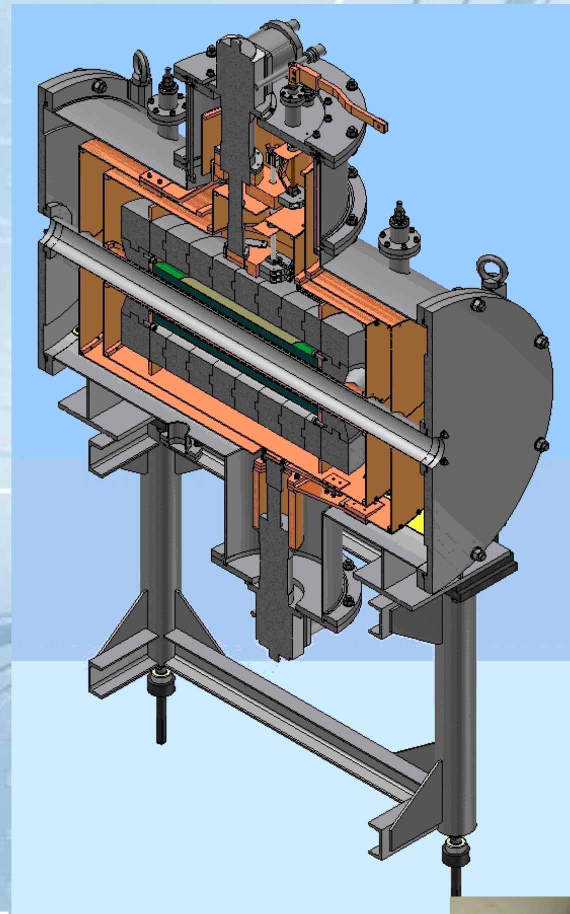
Table 1 Superconducting coil parameters

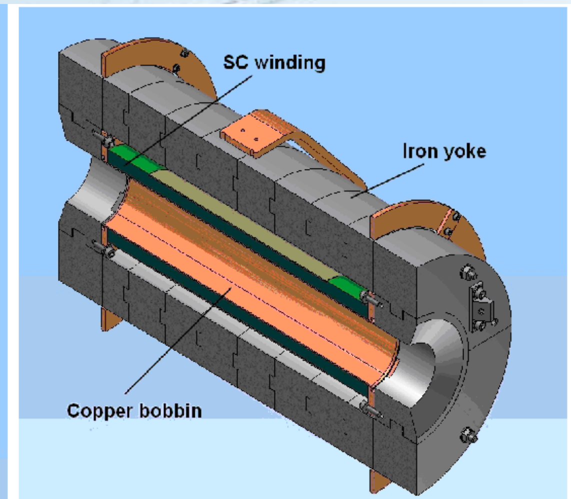
Coils parameters	Values
Inner diameter of the winding, mm	1390
Cross section sizes of the winding:	
height, mm	131
radial thickness, mm	160
Number of turns in one coil	1749
Number of layers in one coil	53
Interlayer insulation, mm	0.3
Operating current Io, A	686[1]
Test current, Io*1.05, A	720
Magnetic field on the coil Bmax, T	3.9
Io/Ic ratio along the load line, %	57
Io/Ic at fixed B, %	25
Operating temperature, K	4.5
Temperature of current sharing, K	6.8
Stored energy of the magnet, MJ	5.1
Cold mass of one coil, kg	1800
Cold mass of one coil winding, kg	790
Inductance of the magnet at full current, H	21.2
E/M ratio for two windings, kJ/kg	3.2
Mutual inductance between the coils, H	0.21
Vertical force on one coil toward the yoke, MN	3.1

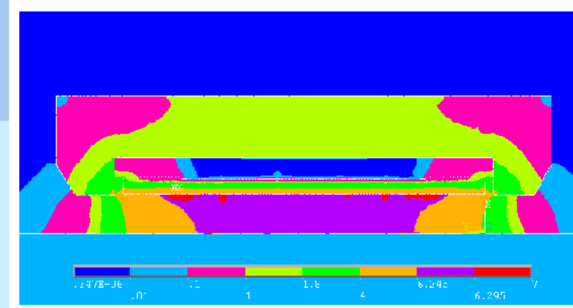


Solenoid for THz spectroscopy – closest example for HEL solenoid

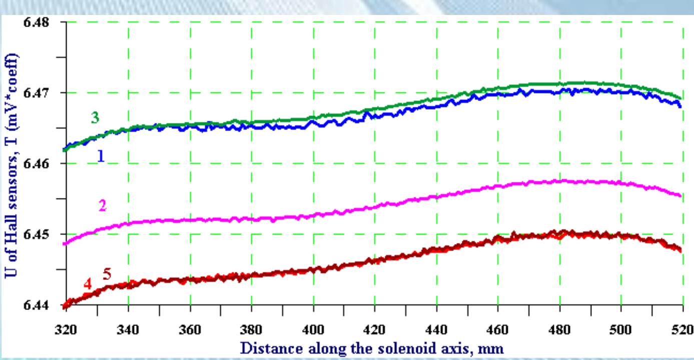
Internal radius of winding, mm	52
External radius of winding, mm	74
Winding warm length, mm	500
Turn number 550*20 + 560	11 560
Maximal magnetic field on the winding, T	6.48
Operating current, A	240
Inductance ($2E/I^2$), H	3.31
Magnetic field in the solenoid, T	6.45
Stored energy, kJ	90







One training quench happened at 5.9 T!



The solenoid after vacuum impregnation with epoxy filled with Al2O3 powder.

tested in March 2018

HEL SC solenoids

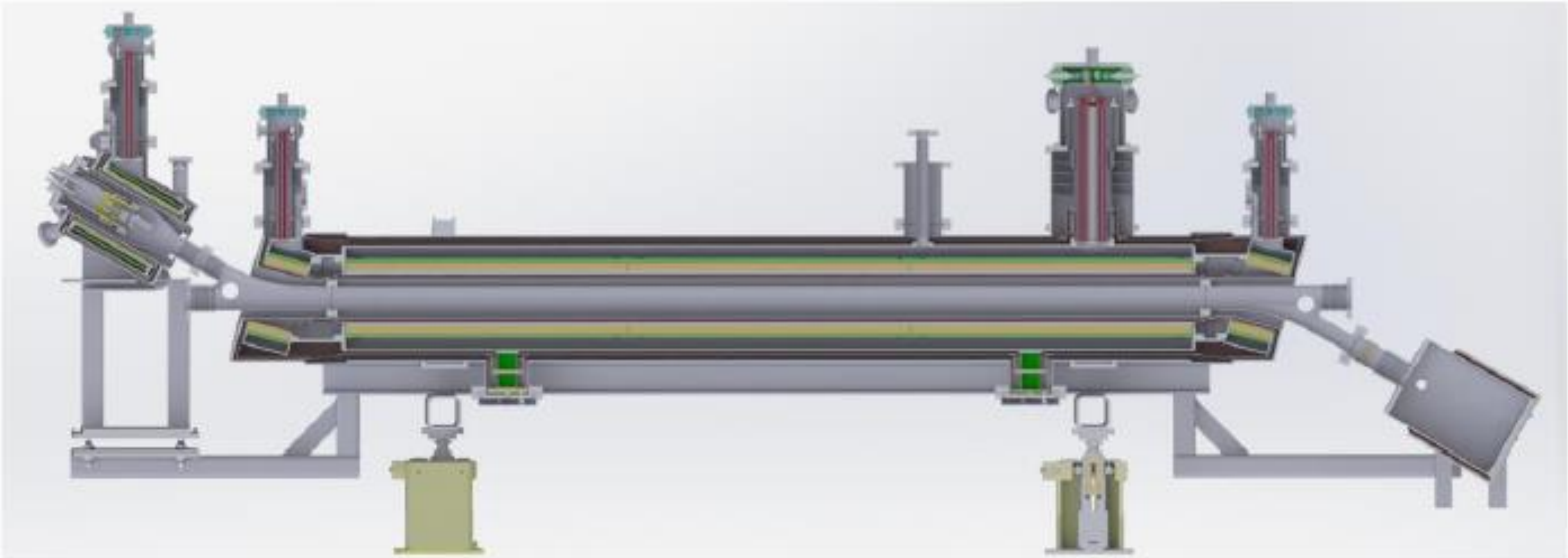


Figure 17: longitudinal cross section of the HEL. On the left the e-gun cryostat, in the centre the main solenoid and on the right the collector.

For simplicity all the solenoids and all the correctors are wound using the same Nb-Ti wire. The insulated wire has a rectangular cross section of 0.8 mm x 1.25 mm with a copper to superconductor area ratio of about 4. The critical current measured at 5 T and 4.2 K is at least 400 A. These values are indicative and typical of a wire for MRI applications. They can slightly change in function of the producer that will be chosen.

Cross-section of the main solenoid

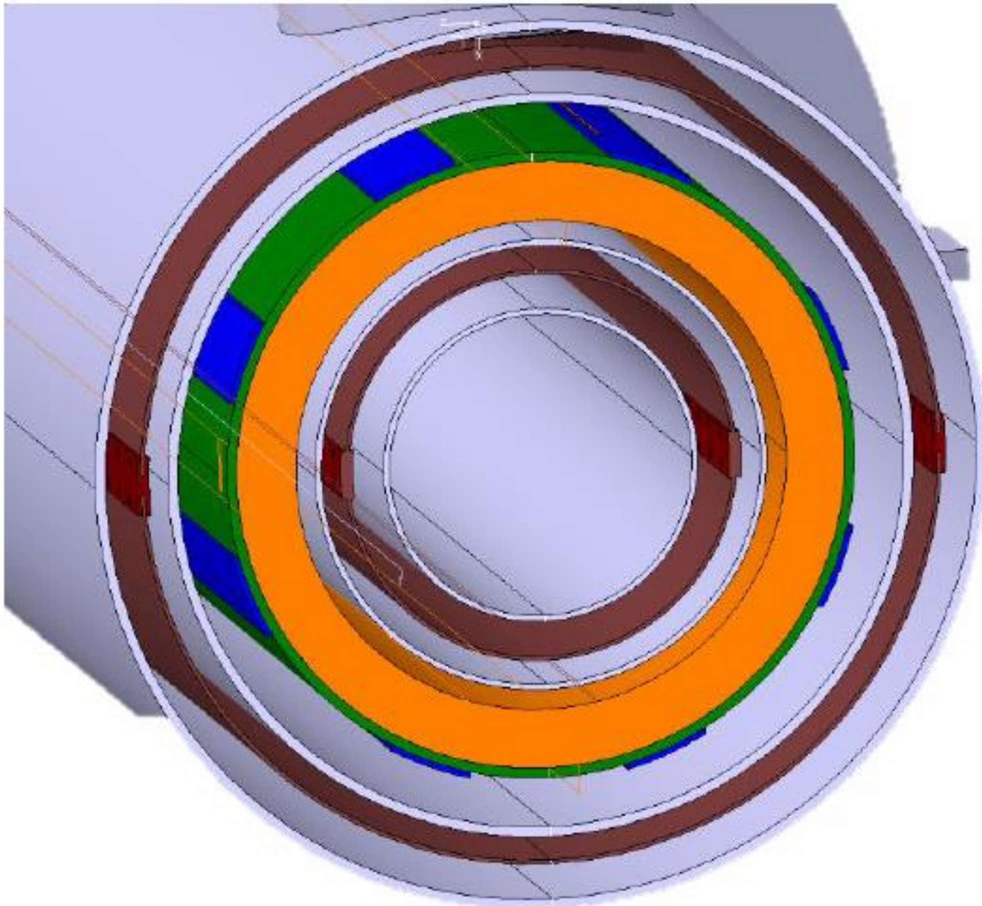


Figure 18: cross section of the HEL cryostat. In the centre there is the bore for the room temperature vacuum chamber (not shown here). The bore diameter is 135 mm. Then from inside to outside in grey the room temperature vacuum tank, in brown the thermal screen, in grey the helium tank wall, in orange the main solenoid, in blue the corrector coils generating a horizontal and a vertical dipole. Then follow the helium tank wall, the thermal screen and the vacuum tank. The overall external diameter is 454 mm

Parameters

Main solenoid

Total length	3 m
Number of turns (per layer and per m of length)	800
Number of layers of superconductor	25
Total thickness of the coil (after curing)	~ 27 mm
Coil inner diameter	200 mm
Nominal field	4 T
Maximum operation field	6 T
Current at 4 T	160 A
Inductance (total for the 3 m)	47.4 H

Stored energy E ~ 0.61 MJ

Minimal cost is within 2-3 M$

Bending solenoids

Total length	0.15 m
Number of turns (per layer)	120
Number of layers of superconductor	25
Total thickness of the coil (after curing)	~ 27 mm
Coil inner diameter	220 mm
Current (with main solenoid at 4 T)	160 A
Inductance	2.8 H

E ~ 0.04 MJ

Axial force between the coils is not high

The force at 4 T is of the order of 45000 N.

SC wire of rectangular cross-section, Cu/Sc ~ 4.

Load line point is ~ 30%

Cooling helium 4-5 K

Gaseous helium for shields and the supports interception

Gas cooled current leads

Additional demands and parameters

•Detail fixed configuration of the magnets is needed. The solenoid is sectioned or not? BINP team has a technology of splicing NbTi wires with < 10^{-12} Ohm resistance.

•The demand to the field uniformity is not clear.

•The design work should be done including 3D magnetic field analysis.

•Charging time, minimal?

•Quench recovery time, minimal?

•Energy extraction system? It may be useful for existing proposal to use wire of high Cu/Sc ratio and low load line point.

•Quench protection analysis should be done

•Minimal heat loads?

Conclusions

- BINP has enough experience to make such solenoids. In existing work BINP makes magnets with larger sizes and higher parameters
- Additional demands and parameters of the HEL superconducting solenoids should clarified
- Some design work should be done for detail cost estimations