

SSC DETECTOR SOLENOID DESIGN NOTE #34

LARGE DETECTOR SOLENOID PARAMETERS

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GENERAL

Overall inner diameter	8.900 m, 29.20 ft, 350.4 in
Overall outer diameter	11.272 m, 36.98 ft, 443.7 in
Radial thickness	1.186 m, 3.89 ft, 46.7 in
Overall length	16.250 m, 53.31 ft, 639.8 in
Design operating central field	1.7 T
Stored energy at 1.7 T	1400 MJ
Total weight of coils and cryostats	~ 1600 tonnes (metric tons)

COIL

Number of coil modules	8
Nominal length of coil module	2 m
Active length of coil module	1.812 m, 5.94 ft, 71.34 in
Calculated excitation per module for 1.7 T	2.81 MA _t (same for all 8)
Maximum operating current	5 kA
Turns per module	616
Turns per layer	88
Layers per module	7
Excitation available per module	3.08 MA _t at 5 kA
Total self inductance	112 H
Ground insulation on ID	75 mm, 2.953 in, G-10
Ground insulation on OD	75 mm, 2.953 in, G-10
Turn-to-turn insulation	2.62 mm, 0.103 in, G-10 buttons on string

Layer-to-layer insulation	5 mm, 0.197 in, slotted G-10
Approximate length of conductor per module	18.4 km, 11.5 miles
Approximate total length of conductor	147 km, 92 miles

CONDUCTOR

General	Cu/Nb-Ti cable, soldered to additional copper
Overall dimensions	18 mm x 26 mm, 0.71 in x 1.02 in
Peak field at conductor	1.8 T
Short sample current specification	10 kA, 3×10^9 A/m ² at 4.5 K and 2 T
Cu:SC area ratio	~140
Conductor (~copper) current density at 5 kA	1.07×10^7 A/m ² ~ 11 A/mm ²
Specification of stabilizer copper	CDA 101, ASTM B170-1
Copper RRR, completed coil, 2 T	100
Copper resistivity at 4.5 K & 2 T	1.55×10^{-10} Ω-m
Full surface heat flux at 5 kA	9.4 mW/cm ²
Critical current margin	1.1
Critical field margin	1.94
Cryostable current margin	4.48
Fraction of short sample along load line	0.611
Temperature margin	2.26 K

QUENCHING

Fast discharge resistor	0.10 Ω
Nominal fast discharge time constant (inductance/fast discharge resistance)	1120 s
$\int_0^{\infty} J^2(t) dt \sim (0.5)J_0^2 L/R$	6.41×10^{16} A ² -s-m ⁻⁴
$\int_0^{\infty} I^2(t) dt$	~14000 x 10 ⁶ , 14000 MIITS
Maximum hot spot temperature	90 K

Initial (max.) eddy current heating in coil during fast discharge	697 W (8 modules)
Energy deposited in coil during fast discharge	390 kJ (8 modules)
Initial (max.) eddy current heating in helium vessel during fast discharge	1481 W (8 modules)
Total initial eddy current heating	2178 W
Energy deposited in helium vessel during fast discharge	829 kJ (8 modules)
Total energy deposited in liquid helium during fast discharge	1219 kJ
Liquid helium boiled during fast discharge	475 L
CHARGING AND SLOW DISCHARGING	
Power supply voltage	100 V
Constant voltage charge rate	0.893 A/s
Charge time with constant voltage	93 min
Slow dump resistor	0.02 Ω
Slow discharge time constant	5600 s
Exponential slow discharge time, 5 - 3.75 kA	1600 s
Linear slow discharge time, 3.75 - 0 kA	5600 s
Total slow discharge time from 5 kA	7200 s, 2 h
Eddy current heating--100-V charge--8 modules	87 W, 488 kJ, 190 L LHe
Eddy current heating--slow discharge--8 modules	87 W-max, 381 kJ, 150 L LHe

ELECTROMAGNETIC FORCES WITH IRON YOKE

With all 8 coils energized to 1.7 T, 2.81 MA

Axial force on 8-m cold mass	Negligible
Max axial compressive force in 2-m coil module	13.3 MN, 3 Mlbf
Max radial pressure	1.16 MPa, 168 psi
Max axial stress in conductor	2 MPa, ~ 300 psi

Max axial decentering force, with 25 mm axial offset	12.4 MN, 2.8 Mlbf
Radial force constant	8 kN/mm, 46 klbf/in
With 7 coils energized to 2.81 MA _t , one coil deenergized	
Max. axial force on 8-m cold mass	54.2 MN, 12.2 Mlbf
Specification for axial support system	54.2 MN, 12.2 Mlbf
Specification of radial support system	0.2 MN, 45 klbf in any direction plus 664 tonnes, 1.46 Mlbf cold mass

ELECTROMAGNETIC FORCES WITHOUT IRON YOKE

Max. testing current (current giving axial conductor stress equal to maximum with eight coils)	4.06 kA
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DIMENSIONS OF COIL-CRYOSTAT-VACUUM VESSEL

Radial dimensions

Inner vacuum shell, ID	8.900 m, 29.20 ft, 350.4 in
Inner vacuum shell, OD	8.958 m, 29.39 ft, 352.7 in
Inner vacuum shell thickness	29 mm, 1.142 in
Inner radiation shield, OD	9.108 m, 29.88 ft, 358.6 in
Inner radiation shield thickness	1 mm, 0.039 in
Inner LHe shell, ID	9.308 m, 30.54 ft, 366.5 in
Inner LHe shell, OD	9.424 m, 30.92 ft, 371.0 in
Inner LHe shell thickness	58 mm, 2.283 in
Inner ground insulation thickness	75 mm, 2.953 in
First conductor layer, ID	9.574 m, 31.41 ft, 376.9 in
Layer insulation thickness	5 mm, 0.197 in
Last (eighth) conductor layer, OD	9.998 m, 32.80 ft, 393.6 in
Outer ground insulation thickness	75 mm, 2.953 in
Outer LHe shell, ID	10.148 m, 33.29 ft, 399.5 in

Outer LHe shell, OD	10.288 m, 33.75 ft, 405.0 in
Outer LHe shell thickness	70 mm, 2.756 in
Outer radiation shield, OD	10.888 m, 35.72 ft, 428.7 in
Outer radiation shield thickness	1 mm, 0.039 in
Outer vacuum shell, ID	11.038 m, 36.21 ft, 434.6 in
Outer vacuum shell, OD	11.102 m, 36.42 ft, 437.1 in
Outer vacuum shell thickness	32 mm, 1.260 in
Module interconnection region, OD	11.272 m, 36.98 ft, 443.8 in
Axial dimensions	
Vacuum vessel, overall length	8.000 m, 26.25 ft, 315.0 in
Vacuum vessel annular head thickness	35 mm, 1.378 in
2-m module, outside length	1.950 m, 6.40 ft, 76.8 in
2-m module annular head thickness	35 mm, 1.378 in
2-m module inside length	1.880 m, 6.17 ft, 74.0 in
Push bar thickness	20 mm, 0.787 in
Ground insulation thickness	24 mm, 0.945 in
Turn-to-turn insulation thickness	2.62 mm, 0.103 in
2-m coil length, conductor-to-conductor	1.812 m, 5.945 ft, 71.34 in
Intercoil gap, conductor-to-conductor	138 mm, 5.433 in
Midplane gap, conductor-to-conductor	568 mm, 22.36 in
Yoke gap, conductor-to-iron	300 mm, 11.8 in

CALCULATED WEIGHTS

2-m coil module, cold mass

Coil form (outer LHe vessel shell and annular heads)	42.27 tonnes
Axial push bars	0.65 tonnes
Insulation	19.11 tonnes
Conductor	78.00 tonnes

Inner LHe vessel shell	25.88 tonnes
Total module cold mass	165.91 tonnes
2-m vacuum module	
Radiation shields	1.22 tonnes
Outer shell	16.88 tonnes
Total 2-m coil and vacuum module	184.01 tonnes
Inner vacuum shell (8 m)	50.61 tonnes
Vacuum vessel annular flat heads	20.46 tonnes
Total 8-m assembly, w/o support system, storage dewar and interconnecting piping	807 tonnes

LIQUID NITROGEN CRYOGENIC SYSTEM

Cooling mode	forced flow of subcooled liquid
Average fluid temperature	83 K
Total flow rate	410 g/s
Number of circuits	10 to 12
Expected heat load	5 kW

LIQUID HELIUM CRYOGENIC SYSTEM

Cooling mode	thermosiphon
Number of circuits	14
Module flow rate, gas fraction	25 g/s at 1% gas by weight
Support intercept flow rate, gas fraction	50 g/s at 7% gas by weight
Heat load per 8-m assembly	115 W + 18 L/h (one pair of current leads)
Volume of LHe in coil modules	~10 000 L
Number of storage dewars	2
Capacity of storage dewars	5000 L each
Total heat load of magnet system	230 W + 36 L/h (two pairs of current leads)
Specified refrigerator capacity	1600 - 1800 W

COOLDOWN REFRIGERATOR

Total cold mass	1328 tonnes
Cooldown system	LIN-GHe HTX, with turbo expander
Cooldown time	15 to 20 days