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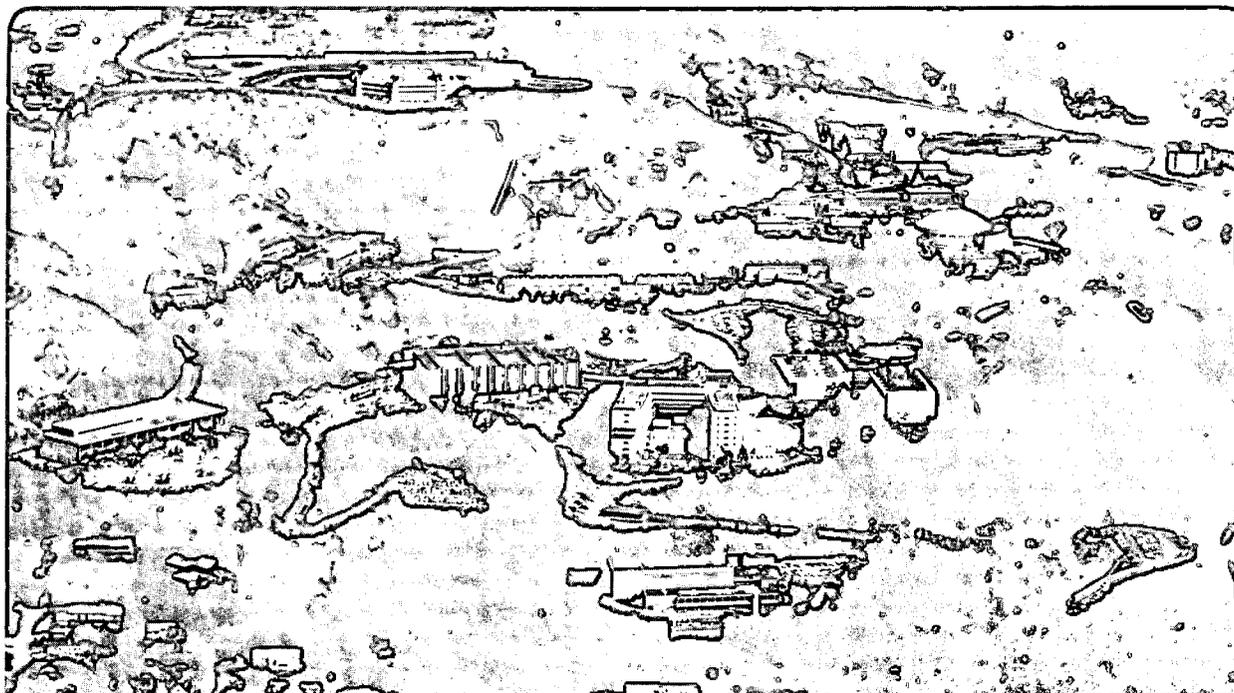
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### A Large Superconducting Thin Solenoid for the STAR Experiment at RHIC

M.A. Green and the STAR Collaboration

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**A LARGE SUPERCONDUCTING THIN  
SOLENOID FOR THE STAR EXPERIMENT AT RHIC**

**M. A. Green  
and the STAR Collaboration**

Lawrence Berkeley Laboratory  
University of California  
Berkeley, CA 94720

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# A LARGE SUPERCONDUCTING THIN SOLENOID FOR THE STAR EXPERIMENT AT RHIC

Michael A. Green  
and the STAR Collaboration  
Lawrence Berkeley Laboratory  
Berkeley, CA. 94720

**Abstract**--This Report describes the 4.4 meter, warm bore diameter, thin superconducting solenoid, for the proposed STAR experiment at the Brookhaven National Laboratory. The STAR solenoid will generate a very uniform central magnetic induction of 0.5 T within a space which is 4.0 meters in diameter by 4.2 meters long. The solenoid and its cryostat will be 0.7 radiation lengths thick over a length of 5.45 meters, about the center of the magnet, making it the largest solenoid less than one radiation length to be built. This report describes a proposed design for the solenoid and cryostat, its flux return iron, its cryogenic system and its power supply and quench protection system.

## I. BACKGROUND

This report describes the preliminary design for a 4.4 meter diameter superconducting solenoid for the Solenoidal Tracker at RHIC (STAR) experiment at the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory in Upton, New York. The STAR experiment [1] will analyze the quark plasma formed when beams of relativistic heavy ions collide. The STAR detector will consist of a Silicon Vertex Tracker (SVT), a Time Projection Chamber (TPC), a Time of Flight (TOF) detector and an Electromagnetic Calorimeter (EMC). The thin superconducting solenoid will be between the TOF and the EMC. Because the EMC will lie outside of the solenoid magnet, the solenoid will have to be thin from the standpoint of the transmission of photons. As a result, the thickness of the solenoid has been set at 0.7 radiation lengths (about 63 mm of aluminum). An alternative proposal being considered is a warm solenoid outside the EMC. This report discusses the superconducting option.

The TPC detector requires a uniform 0.25 T to 0.5 T solenoidal field in order to resolve the particle tracks to better than 200 microns. In order to achieve this level of particle resolution the solenoidal field has to be good to better than 1 part in 1000 over a cylindrical volume which is 4.0 meters in diameter and 4.2 meters long, about the geometric center of the experiment [2]. The magnetic field uniformity is provided by shaping the iron poles which are 6.2 meters apart. The holes in the iron poles provided for low angle particles to pass to external detectors are the largest cause of solenoidal field error. Correction coils may be needed to compensate for these holes.

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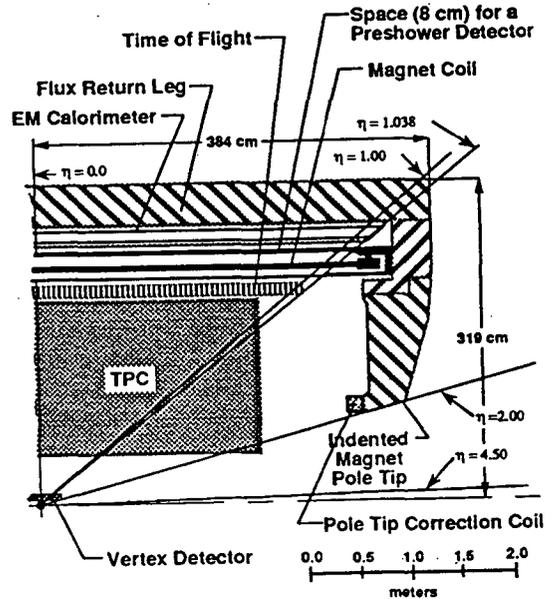


Fig. 1 A Quarter Cross-section View of the STAR Experiment

## II. STAR SOLENOID PARAMETERS

The parameters for the STAR superconducting solenoid are summarized in Tab. 1. The warm bore diameter is dictated by the magnetic field requirements for the TPC detector and the amount of space needed for the TPC outer field cage and the TOF detector. The STAR solenoid cryostat thickness was set at 300 mm so that there would be plenty of room for insulation and shields. The thickness of the outer vacuum vessel is set by buckling of the vessel due to vacuum loading. The radiation thickness of the magnet cryostat is controlled by vacuum vessel buckling and whether the magnet will stand without much deflection under gravity loading rather than stresses in the magnet support structure or the cryostat. Fig. 2 shows the proposed STAR solenoid from the end where the electrical leads and cryogenic services will enter the cryostat. Fig. 2 illustrates the relative thinness of the magnet cryostat compared to its inside diameter

Fig. 3 is a cross-section view of the proposed magnet cryostat at the end (section A-A). This figure shows the single layer of superconducting coil, a correction coil, the coil support structure, the shields and one method of supporting the coil cold mass. The two-phase cooling tube shown in Fig. 3 is one of a number of tubes which are

spaced about 500 mm apart. The magnet is cooled indirectly from two-phase helium flowing in the cooling tubes. The solenoid cryostat is thick at the ends where the cold mass support system and cryostat services are located.

Table 1 Parameters of the STAR Magnet

Cryostat Warm Bore Diameter (m)	4.40
Cryostat Outside Diameter (m)	5.00
Cryostat Outside Length (m)	6.90
Cryostat Minimum Thin Zone Length Inner (m)	5.43
Cryostat Minimum Thin Zone Length Outer (m)	6.09
Gap Between the Iron Poles (m)	6.20
TPC Detector Good Field Diameter (m)	4.00
TPC Detector Good Field Length (m)	4.20
S/C Coil Average Diameter (m)	4.64
S/C Coil Overall Length (m)	6.70
S/C Coil Winding Length (m)	6.20
S/C Coil Minimum Thin Zone Length (m)	5.70
S/C Coil Package Center Thickness (mm)	26
S/C Coil Package End Thickness (mm)	85
Number of Turns of Conductor	1240
Number of Conductor Layers	1
Magnet Design Current (A)	1989
Magnet Design Central Induction (T) #	0.50
Magnet Peak Induction (T) #	1.20
Magnet Self Inductance (H)	5.27
Magnet Stored Energy (MJ) #	10.43
Matrix Current Density (A/mm <sup>2</sup> ) #	41.8
Magnet Radiation Thickness (Radiation Lengths)	0.68
Estimated Superconductor Mass (metric tons)	2.43
Estimated Magnet Cold Mass (metric tons)	8.34
Estimated Overall Magnet Mass (Metric tons)	23.73

# at the Magnet Design Current

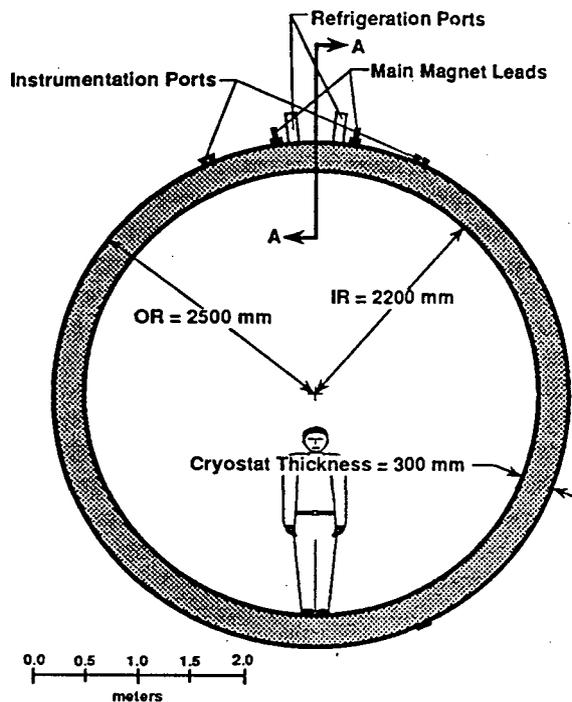


Fig. 2 An End View of the STAR Magnet Cryostat (See Fig. 3 for Section A-A)

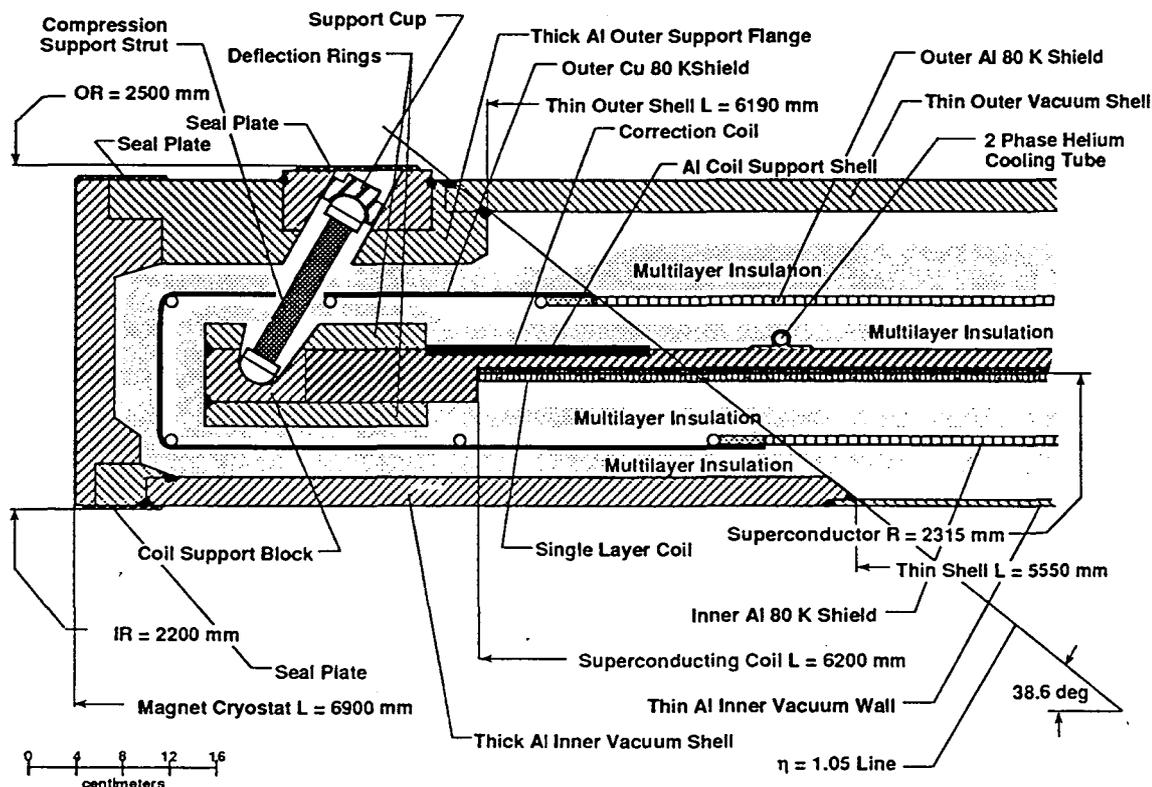


Fig. 3 A Cross-section View of the End of the STAR Superconducting Thin Solenoid Cryostat Showing the Cold Mass Support System and the Thick End Section of the Magnet and the Cryostat Vacuum Vessel

### III. SOLENOID SUPERCONDUCTOR

The superconductor for the STAR solenoid is proposed to a pure aluminum (Residual Resistivity Ratio (RRR) greater than 1000) matrix. The superconductor within the pure aluminum matrix is a standard niobium titanium alloy which is co-drawn in a copper matrix. The copper matrix superconductor is in turn co-extruded in the pure aluminum matrix. The aluminum to superconductor ratio will be about 40; the copper to superconductor ratio will be 0.8. The diameter of the filaments should be less than 50  $\mu\text{m}$ . The pure aluminum matrix superconductor will be very stable at low field. The conductor critical current should be over 4000 A at 1.2 T and 4.5 K.

### IV. SOLENOID POWER SUPPLY AND QUENCH PROTECTION

The STAR solenoid has a low stored energy at its design field for a magnet of this size (10.6 MJ). The current density in the solenoid superconductor matrix is also low ( $42 \text{ A mm}^{-2}$ ). As a result, the  $E_j^2$  limit for the magnet coil is less than  $2 \times 10^{22} \text{ A}^2 \text{ m}^{-4} \text{ J}$  which means that the coil can be protected by a simple resistor across the leads. The support structure for the coil acts as a shorted secondary circuit, so quench back [3] can also be incorporated as part of the quench protection of the magnet. A 0.15 ohm dump resistor will dump the STAR solenoid in about 20 seconds. Half of the coil stored energy will end up in the STAR coil. The coil hot spot temperature should be less than 70 K. The dump resistor can be an air cooled stainless steel resistor with a mass which is less than 100 kg.

The charge time for the STAR magnet is not as issue because the time constant for eddy currents in the iron pole pieces is greater than 5000 seconds. The coil charge time has been set at 3600 s (1 hour). After charging, the magnet will have to sit for several hour while the eddy current in the iron pole pieces die down. For a STAR magnet having a superconductor that is nominally 5 mm by 10 mm, a power supply that can deliver 2500 A at 8 V (The magnet current at full design field is about 2000 A.) will charge and discharge the solenoid in less than one hour [4].

### V. THE CRYOGENIC COOLING SYSTEM

The STAR solenoid will be indirectly cooled with two-phase helium flowing in tubes attached to the solenoid coil support shell. This type of cooling system has a number of advantages: 1) The helium flow circuit is usually direct which means that the cool down of the magnet is simplified. 2) The helium vessel and its associated radiation thickness is eliminated; the cost of the magnet is reduced. 3) Helium flow in tubes is much safer than a bath cryostat. 4) Flow for gas cooled leads can be directly taken off of the flow circuit. Indirect tubular cooling has been the cooling system of

choice for virtually all of the large detector magnets that have been built.

Two types of tubular cooling systems were investigated for STAR [5]. These include: 1) The forced two phase cooling system where flow from the J-T circuit from the helium refrigerator drives the two phase helium through the coil cooling tube. Most of the thin solenoids which have been built use this system of cooling. The advantage of this type of cooling system is simplicity of the cool down and the fact that the cooling circuit consists of a single series circuit. 2) The second system is a gravity feed two-phase cooling system which has the advantage that it will cool the coil even when the refrigerator is not operating. It has been used on three recent thin solenoids. With the gravity feed system, cool down of the cold mass is more difficult because there are many parallel circuits. The gravity feed cooling system is a bit more complex.

### VI. CONCLUSION

The proposed STAR solenoid will be the largest solenoid less than one radiation length thick. The size of the magnet rather than its stored energy or the magnetic field provides the limits to the design. Existing technology can be applied to the solenoid coil, the power supply, the quench protection system and the solenoid cryogenic system. The limits on the radiation thickness are derived from buckling of the cryostat outer vacuum shell under atmospheric load and the desire to be able to maintain the cylindrical shape of the solenoid while it is being transported from the vendor to RHIC, and while it is mounted in the experiment.

### VII. ACKNOWLEDGEMENT

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LAWRENCE BERKELEY LABORATORY  
UNIVERSITY OF CALIFORNIA  
TECHNICAL INFORMATION DEPARTMENT  
BERKELEY, CALIFORNIA 94720