A high temperature superconducting demonstrator coil for a novel toroidal magnetic spectrometer for an astroparticle physics experiment in space

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Abstract

A magnetic spectrometer determines the signed rigidity of a charged particles by measuring their trajectories in the presence of a magnetic field. High temperature superconducting (HTS) magnets can operate in space without the use of a cryogenic liquid. While HTS magnets have many potential applications in space, including active magnetic radiation shielding, we propose as a first use case a magnetic spectrometer.

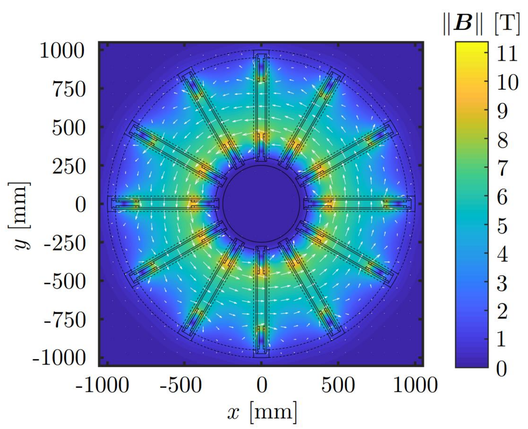
We present the design of an HTS magnetic spectrometer with a toroidal magnet providing a bending strength of 3 T m. The toroidal magnet is about 2 m in outer diameter, 2 m in height, and requires about 60 km of 12 mm wide ReBCO HTS tape. The magnet operates with an engineering current density of 855 A/mm^2 at a temperature of 20 K and a peak magnetic field of about 12 T.

Within the HTS Demonstrator Magnet for Space (HDMS) project, we have designed and are building a small-scale demonstrator coil for the toroidal magnet system. The demonstrator coil consists of two individually built racetrack-like coils enclosed with copper bands that function as current leads and layer jumps. The no-insulation winding method facilitates self-protection against quenches. A lightweight mechanical structure made from aluminium alloy supports the coil.

The Magnetic Spectrometer

Requirements

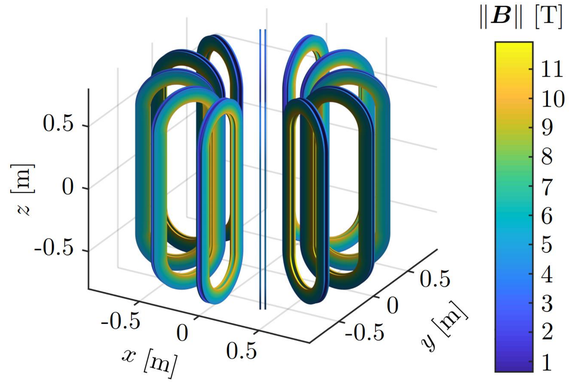
- A vanishing magnetic moment: Obtained with a toroidal coil configuration
- The center is left available for a detector of 500 mm in diameter
- The outer diameter of the toroid should be less than 2 m
- The straight parts of the racetrack coils should be 1 m
- Operating temperature is 20 K (cooling without liquid helium)
- Average bending strength of 3 Tm
- Lightweight mechanical structure



Toroidal magnet configuration: Cross sectional view of the magnetic field showing outlines of the coils and the mechanical structure. The white arrows indicate the direction of the magnetic field.

The Toroidal Magnet

- Each coil pack contains two single-pancake coils
- The entire magnet requires about 60 km HTS ReBCO tape
- Engineering operating current density is 855 A/mm^2 at 20 K and 12 T
- Total stored magnetic energy is 40 MJ and inductance is 19 H
- Copper rings on the inside and on the outside of each racetrack coil bring the current in and out from the windings
- Controlled turn-to-turn resistance to obtain self-quench protection

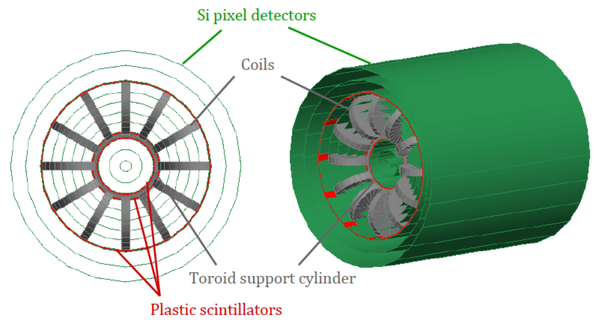


Magnetic field on coil surface: Peak field is about 12 T

Detector System

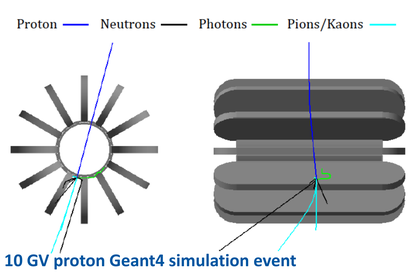
Baseline detector system:

- A tracker, composed of silicon pixel detectors, which measure the charged particle trajectories in the magnetic field
- Plastic scintillators, which provide the trigger to select the desired event topologies.

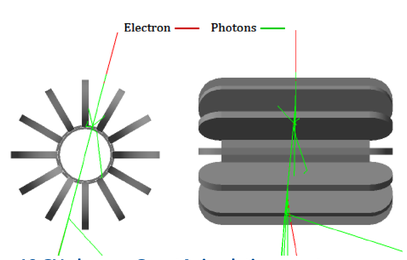


Particle Trajectory Simulations

- Geant4 simulations were carried out to predict the behavior of charged particles passing through the magnetic field and possibly colliding with the mechanical structure of the magnet.



10 GV proton Geant4 simulation event



10 GV electron Geant4 simulation event

HTS Demonstrator Magnet for Space (HDMS)

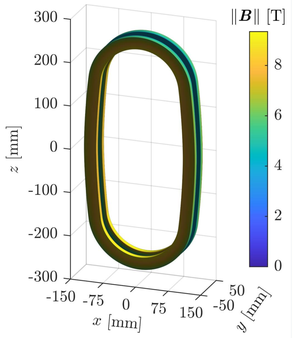
Building the HTS Demonstrator Magnet for Space (HDMS) coil should prove it feasible to build the full toroidal magnet system.

Conductor specification

- The coil requires 750 km of 12 mm wide, 0.1 mm thick, HTS ReBCO tape
- Minimum engineering critical current density: J_e = 600 A/mm^2 at 4.2 K and 20 T
- Will be tested at temperatures in the range 4.2 K – 77 K.

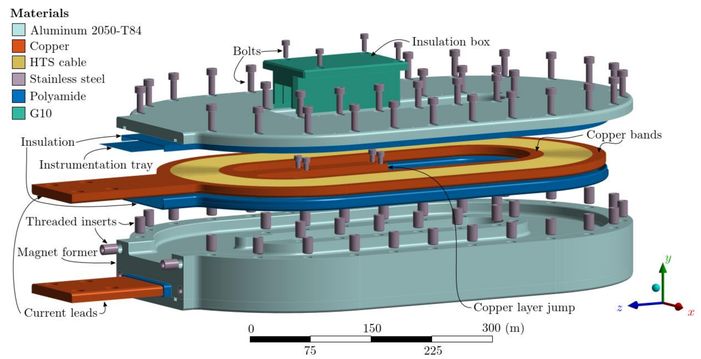
Coil design

- A small-scale coil pack of the toroidal magnet
- Maximum calculated engineering operating current density: 1065 A/mm^2 at 4.2 K and a peak field of 9.3 T.



Mechanical structure

- A lightweight aluminium alloy structure mechanically supports the coil



Conclusion

- We have developed a conceptual design of a twelve coil HTS toroidal magnet system for a magnetic spectrometer
- The magnet provides an average bending strength of 3 T
- The complete magnet system requires 60 km of 12 mm HTS tape with an engineering critical current density of 855 A/mm^2 at 20 K and 12 T
- A detector system composed of silicon pixel detectors and plastic scintillators is being designed
- A demonstrator coil is being produced at the CERN magnet laboratory
- The demonstrator coil has a calculated maximum peak magnetic field of about 9.3 T at 4.2 K