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CRYOGENICS FOR THE CERN SOLAR AXION TELESCOPE (CAST) USING A LHC DIPOLE PROTOTYPE MAGNET

K. Barth, G. Passardi, M. Pezzetti, O. Pirotte, H. Riege,
B. Vullierme, L. Walckiers and K. Zioutas

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CERN
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Barth K., Passardi G., Pezzetti M., Pirotte O., Riege H., Vullierme B., Walckiers L., Zioutas K.

CERN – European Laboratory for Particle Physics, CH-1211 Geneva, Switzerland

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INTRODUCTION

Axions made their first appearance in particle physics as a possible solution to the strong CP problem, which can be summarised in the question: why is the neutron's electric dipole moment at least a factor of 10^{-9} smaller than expected? An attractive solution to this invokes a new symmetry, the Peccei-Quinn symmetry [1]. The spontaneous breaking of this new symmetry predicts the existence of a light neutral pseudoscalar particle, the axion. The axion became even more attractive with the realisation that it is one of the most interesting non-baryonic candidates for the omnipresent dark matter. Axions may also exist as primordial cosmic relicts copiously produced in the early universe.

The experimental axion search is based on the idea that energetic axions might be created continuously in reactions taking place in red giants, supernovae, and in particular inside our sun, this being the nearest and brightest potential axion source in the 1- 15 keV total energy range. Experiments searching for solar axions have the main advantage of being in principle sensitive to a very broad axion rest mass range below ~10 keV.

SOLAR AXION TELESCOPE WORKING PRINCIPLE

The working principle of a solar axion telescope is the Primakoff effect: an incoming axion couples to a virtual photon provided by a transverse field (B) of the telescope's magnet, and is transformed to a real photon which carries the energy and momentum of the original axion. The average energy of the emitted solar axions and therefore of the converted photons is ~ 4.2 keV [2].

Hence the main component of the CERN Axion Solar Telescope (CAST) is a decommissioned 10-m long LHC superconducting dipole prototype magnet (see Figure 1), providing the transverse magnetic field to catalyse the axion-photon conversion. Three different low-background x-ray detectors installed on either end of the beam tubes identify the conversion photons exclusively at times of alignment between the magnet and the core of the sun, providing a unique axion signature. The whole assembly is mounted on a moving platform (-8° to +8° vertical, -40 degrees to +40 degrees horizontal), allowing it to observe the sun for 3.3 hours in total at sunrise and sunset.

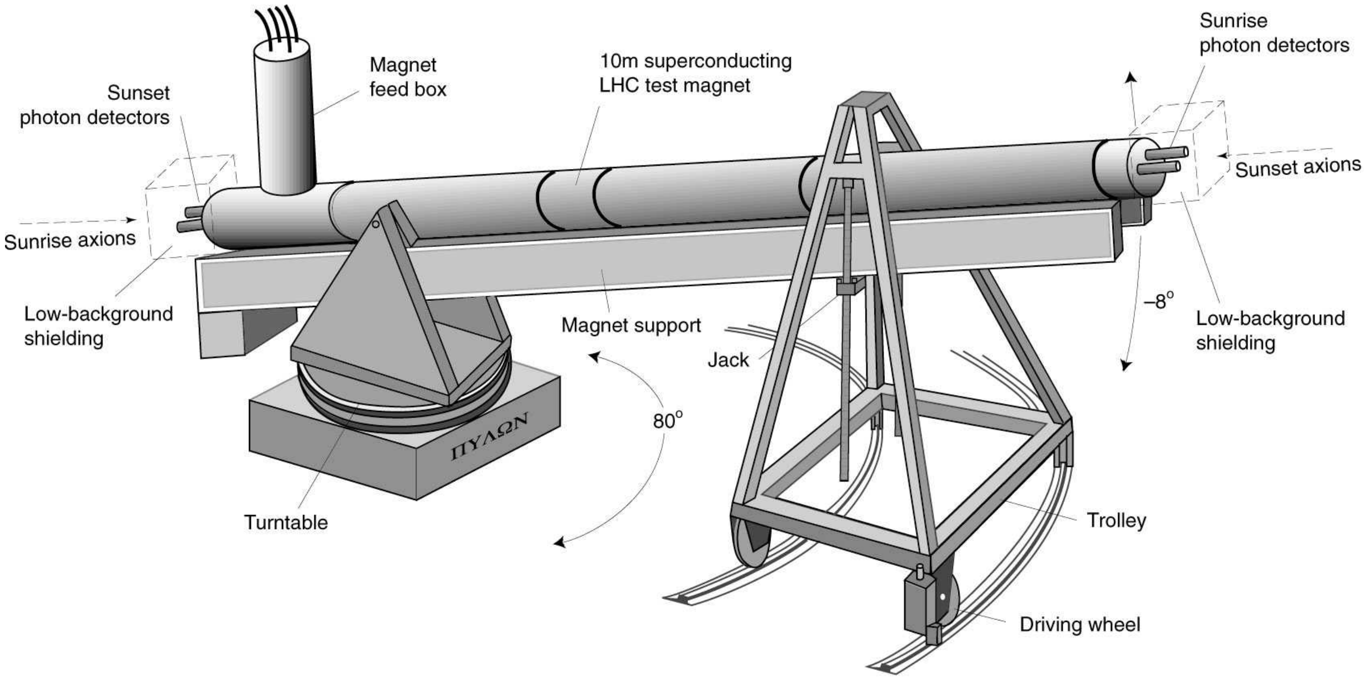

Figure 1 Simplified layout of the CERN Axion Solar Telescope (CAST)

The probability for this coherent axion-to-photon conversion is proportional to (B x L) ^{2}, where L is the length of the magnetic field B. The straight-bore twin-aperture LHC dipole prototype used by CAST can produce a magnetic field of up to 9.5 T over a length of 9.5 m (B x L = 91 Tm) with an angular resolution of 10 mrad [3], thus making it a 100 times more efficient as an axion-photon-converter than the best competing setup, presently in operation at the university of Tokyo (B x L = 9.2 Tm) [4].

The aperture of the LHC magnet beam pipes (42.5 mm) is around five times larger then the predicted solar axion source image size, therefore the x-ray detectors must be correspondingly large, implying a high level of noise. To overcome this problem the x-ray mirrors will be mounted, focusing the conversion photons emerging parallel from the 50 mm magnet aperture to a millimeter spot.

CRYOGENICS FOR THE SUPERCONDUCTING MAGNET OF CAST

To obtain the maximum field of around 9 – 9.5 T in the prototype magnet it has to be cooled and operated in superfluid helium below 1.9 K. The use of superfluid helium ensures full liquid filling of the helium vessel and permits operation on a variable slope. In order to minimize the cost and labour time, the whole cryogenic infrastructure needed to cooldown the magnet from ambient temperature and to supply it with liquid helium (at 4.5 K) has been recovered from the cryogenics of the dismounted e^+e^-- collider LEP2 (helium buffers and gas bags) and the former DELPHI experiment (helium liquefier, recovery and purification systems) and adapted for use with CAST. To cooldown and operate the magnet at 1.9 K a new roots pumping group has been purchased and installed. The main characteristics of the cryogenic system are listed in Table 1.

Cryogenic and electrical feed to the former LHC prototype magnet is done through the same magnet feed box (MFB) already used with the cryogenic LHC test benches [5], but which was adapted to the new cryogenic infrastructure needed by CAST. Since the x-ray detectors and the focussing mirror system is installed outside the magnetic field on either end of the beam tube, the warm bore inserts (anti-cryostats) originally installed inside the magnet aperture to house measurement equipment were no longer needed and dismounted to decrease the heat load on the superfluid helium bath. The modified flow scheme of the MFB as well as its interface via in total seven flexible transfer lines, needed to connect to the liquid helium supply, gaseous helium pumping group and quench recovery system is shown in Figure 2. The flexible lines were designed for allowing the movement of the telescope without interrupting its cryogenic operation.

TABLE 1 Main characteristics of cryogenic equipment for CAST

Equipment	**Unit**	**Value**
Cryoplant: (ex-DELPHI plant)		
Compressor suction	(MPa)	0.104
Compressor discharge	(MPa)	1.4
Nominal throughput	($g\ s^{-1}$)	160
Cooling power at 4.5 K		300 W & 3.5 g/s
70-80 K		2500 W
Storage:	(m^3 STP)	2440
Gas storage at 1.4 MPa	(m^3)	160
Gas bags + buffer at 0.1 Mpa	(m^3)	200
Helium Pumping Group:		
Suction pressure	(kPa)	1.54
Discharge pressure	(MPa)	0.102
Nominal throughput	(g/s)	2.0

The cooling of the magnet in a pressurised superfluid helium bath is performed using a hollow-finger heat exchanger made of copper with a developed area of 1 m^2. The exchanger is fed with liquid helium drawn from the bottom of the 4.5 K bath and later sub-cooled in a copper mesh heat exchanger before Joule-Thomson expansion to saturation at 1.54 kPa. The heat load to the superfluid helium bath is transported by conduction along the magnet length to the heat exchanger with a nominal capacity of around 50 W at 1.9 K. The 4.5 K saturated helium bath, which intercepts residual heat at the lower end of the 18 kA vapour-cooled current leads, is thermally and hydraulically separated from the pressurised helium II enclosure by two small diameter lambda plates, which allow feed through of the superconducting current bus and instrumentation wiring. An electro-pneumatically-actuated “respirator” valve at the bottom of the 4.5 K bath allows liquid filling and pressure compensation upon density changes between 4.5 K and 1.8 K. Emergency relief and helium discharge after a resistive transition is performed through two DN50 industrial-type cold valves, the first one (opening time of 120 ms) discharging the magnet helium content into the 4.5 K vessel, the latter de-pressurises the corresponding liquid helium buffer volume, which is secured in addition by a 0.3 MPa safety relief valve to atmosphere, at 0.17 MPa to the gas bags to limit helium loss. Ultimate protection of the pressurized helium enclosure relies on a DN50 nickel rupture disk, which has a design pressure of 2 MPa, operates at 1.9 K and is connected to an evacuated pipe closed by a “warm” rupture disk with a design pressure of 0.03 MPa. The vacuum between the rupture disks is monitored using a “helium guard”, pressurised with 0.1 MPa, to prevent any external air inleak, which could disturb the cold rupture disk functioning due to a cryo-pumped frost layer.

STATUS OF THE CRYOGENICS FOR CAST INSTALLATION AND PROSPECTS

The full external cryogenic infrastructure (liquefier, helium buffers, gas bags and purification system) was re-installed and adapted for CAST in the second half of 2001. A successful commissioning run was performed in December 2001 during which the nominal cooling power of approx. 800 W at 4.5 K could be measured using the heater in the helium phase separator of the cold box.

The dipole magnet including MFB and cryostat were installed on the moving platform beginning of 2002 and the manufacturing of the seven semi-flexible transfer lines, needed to interconnect MFB with the pumping group and cold box, was started and finished by June 2002. In parallel the 1.9K roots pumping group was ordered and a temporary set was installed in April 2002. Thus presently the cryogenic system is in its final commissioning phase and a first cooldown and operation of the magnet is expected to be done in August 2002. Also the entire cryogenic control system, including the helium pumping group and MFB was upgraded for long-term automatic operation and remote monitoring by the centralized cryogenic control room.

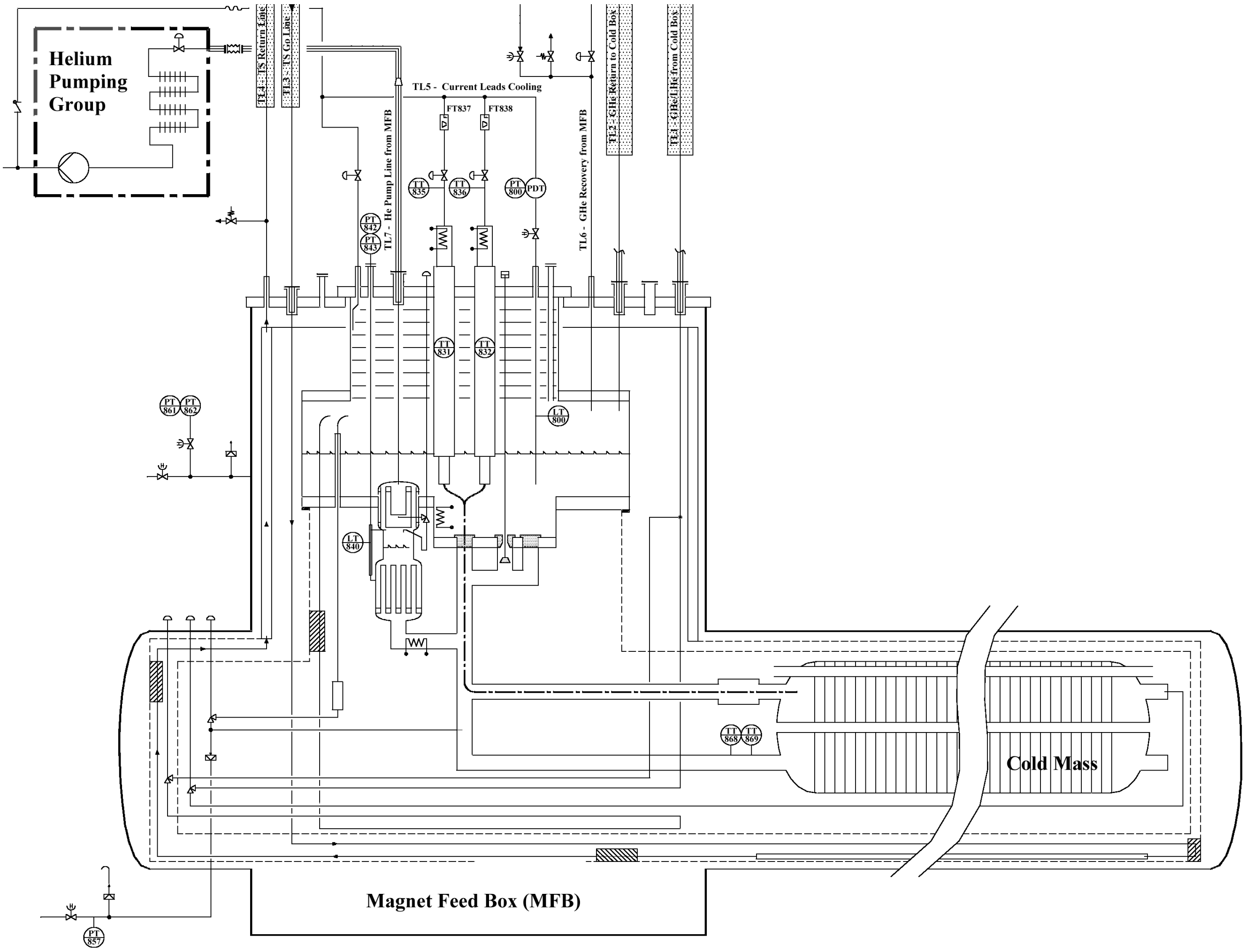

Figure 2 Modified flow scheme of the Magnet Feed Box (MFB) for CAST

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