The TPC shielding of the CAST experiment

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Abstract. Sunset solar axions traversing the intense magnetic field of the CERN Axion Solar Telescope (CAST) experiment may be detected in a TPC detector, placed at one side of the magnet, as point-like X-rays signals. This signal could be masked, however, by the inhomogeneous radioactive background of materials and experimental site. Here we present the shielding built to reduce and homogenize the radioactive background levels of the TPC detector.

1. Introduction
The axion is a light pseudoscalar particle resulting from the Peccei-Quinn mechanism to enforce strong-CP conservation. This particle may exist as primordial cosmic relics copiously produced in the very early universe and is, therefore, one of the Dark Matter candidates. Production of axions may also happen in the solar hot plasma due to electromagnetic field fluctuations of charged particles.

CAST (Cern Axion Solar Telescope) [1] is an experiment looking for axions coming from the solar core. Its LHC decommissioned magnet of almost ten meters length and 9 tesla of magnet intensity might convert these axions into X-rays via the Primakoff effect. A moving structure allows the magnet to track the sun during the sunset and the sunrise. Then, the expected axion signal entering a detector from the magnet would be an X-ray peaking at 4 keV while the opposite part of the magnet is pointing to the sun. Three detectors cover the four bores of the magnet: a Time Projection Camber (TPC), a Charged Coupled Device (CCD), working with a X-Ray focusing telescope, and a Micromegas detector. The first results from the analysis of 2003 data imply an upper limit to the axion-photon coupling $g_{a\gamma} < 1.16 \times 10^{-10}$ GeV$^{-1}$ [2].

The background, and its inhomogeneity, is a source of errors since these data must be subtracted to the the solar tracking data to obtain the final signal. For this reason, a detailed study of background reductions due to a suitable shielding design for detectors has been undertaken. Here we present the case of the TPC.

2. The TPC detector and shielding
The CAST TPC has a conversion volume of $10\times15\times30$ cm$^3$ filled with Ar$(95\%)/$CH$_4$(5\%) gas at atmospheric pressure. The 10-cm-drift direction, is parallel to the magnet beam axis and perpendicular to the section of $15\times30$ cm$^2$ covering both magnet bores. Two 6-cm-diameter windows, consisting of very thin mylar foils (3 or 5 $\mu$m) stretched on a metallic strongback, allow the X-rays coming from the magnet to enter the chamber.

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During the 2003 data taking period, the detector shielding set-up consisted just of a copper box with N\(_2\) gas flux. The full shielding was installed in 2004 and is composed of:

- **Copper box, 5 mm thick**: it is used mainly as a Faraday cage to reduce the electronic noise and also for mechanical support purposes.
- **Lead wall, 2.5 cm thick**: to reduce environmental gamma radiation.
- **Cadmium layer, 1 mm thick**: to absorb the thermal neutrons slowed down by the outer polyethylene wall.
- **Polyethylene wall, 22.5 cm thick**: it slows the medium energy environmental neutrons down, reduces also the gamma contamination and helps to the mechanical stability of the whole structure.
- **Plastic bag**: it tightly closes the entire set-up and allows us to flush the inner part with pure N\(_2\) gas coming from liquid nitrogen evaporation in order to purge this space of radon.

3. Site background
The CAST experiment is located at one of the buildings of the SR8 experimental area at CERN. The most important contribution to the background comes from an inhomogeneous gamma radiation due to the radioactive chains and potassium in laboratory soil, building [3] and experiment materials. The TPC detector should be blind to most of these radiations. However, Compton interactions in the surroundings produce photons of much lower energies causing a non negligible and inhomogeneous background.

Radon is also present anywhere and is able to penetrate through the shielding towards the detector. Moreover its concentration can vary widely depending on causes such as walls or soil proximity and ventilation but also on atmospheric pressure, temperature or humidity.

The neutron component of the background is below the level of the typical gamma background by three or four orders of magnitude, but neutron signals in detector could mimic those from X-rays. The dominant sources of this background are cosmic rays, neutrons induced by muons in surrounding materials, (\(\alpha, n\)) reactions on light elements and the spontaneous fission.

4. Monte Carlo Simulations
The background level (in the 3-7 keV range of interest) and simulated spectra for different shielding configurations tested during 2004 have been compared to the most simple case of a 5-mm-thick copper box shielding installed in 2003.

   Gamma simulations have been performed using the GEANT4 code [4] because of its geometry and energy detection capabilities. Simulations show that the maximum reduction (98%) is achieved just by adding 5 cm of lead (weight restrictions forbid wider layers). We prefer, however, a shielding made of 5 mm copper plus 2.5 cm lead plus 22.5 cm polyethylene: it reduces gamma background (around a 96%), serves besides as a neutron moderator and, very important for a moving structure, the pieces give a good mechanical stability to the whole system.

   The FLUKA code [5] has been used to understand the effects of the different layers of shielding on neutrons. The number of neutrons capable to produce a deposit of visible energy in the TPC due to cosmic neutrons increases by 10% in the 2.5-cm-layer of lead due to production of secondary neutrons. However, this number decreases down to 20% after the complete shielding thanks to the 22.5 cm of polyethylene.

5. TPC measurements
During the two data taking periods of the experiment (years 2003 and 2004) the TPC has recorded not only solar tracking data, when the opposite part of the magnet is pointing to the sun, but also background data at any other time of the day. In order to get a better control of
the background, given its spatial inhomogeneity, these measurements have been performed at precise horizontal and vertical positions.

The analysis of the 2003 background data showed that, to lower the rates and to ensure a higher degree of homogeneity, a more suitable shielding was needed. After its installation in 2004, we got rate reductions higher than 50%, reaching even 70% at some positions (see Figure 1). Moreover, the background is now fairly homogeneous showing, however, similar patterns of variations.

Figure 1. Background data for 2003 (squares) and 2004 (circles). Measurements correspond to 7 vertical positions and 7 horizontal positions of the TPC. The 49 cell numbers run first vertically and then horizontally.

6. Conclusion
The aim of this work has been the design, construction and test of suitable shielding for the CAST TPC detector. The requirements were to get a certain reduction of the background levels coming from external sources but also a decrease in the background inhomogeneity observed in the experimental site. The TPC and the shielding are on a moving structure and this fact imposes some restrictions on the total weight and size.

The 2004 data confirm a reduction of background levels in a factor between 2 and 3.5 (the highest for positions close to most intense gamma sources) as well as a quite acceptable degree of homogeneity. For this period most of the contamination could correspond to internal sources, being the differences among measurement positions due mainly to radon intrusion.

Therefore, thanks in part to the shielding installed in the TPC, the 2004 CAST-TPC data, under analysis at the moment, will allow to improve the 2003 CAST experiment results.

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