BACKGROUND STUDIES OF THE PN-CCD DETECTOR OF CAST

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A backside illuminated pn-CCD detector in conjunction with an X-ray mirror optics is one of the three detectors used in the CERN Axion Solar Telescope (CAST) to register the expected photon signal. A background study performed for this detector shows that the level $(8.00\pm0.07)\times10^{-5}$ counts cm^{-2} s^{-1} keV^{-1} between 1 and 7 keV is to be dominated by the external gamma background due to natural activities at the experimental site, while radioactive impurities in the detector itself and cosmic neutrons contribute a much smaller fraction.

1. Introduction

The CERN Axion Solar Telescope (CAST) is intended to search for solar axions using a decommissioned 9.26 m long Large Hadron Collider (LHC) superconducting magnet providing a 9 T magnetic field. The magnet is installed on a platform that permits horizontal movement from azimuthal angle 46º to 133º and a vertical movement of ±8º. As a consequence, it can follow the Sun three hours per day, 1.5 hours each during sunset and sunrise. The rest of the day is dedicated to background measurements.

Three X-ray detectors are installed on the ends of the magnet to search for an excess of X-rays coming from axion conversions inside the magnet during

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alignment with the Sun. The detectors are a Time Projection Chamber (TPC), a Micromesh Gaseous Structure (MICROMEGAS), and a Charge Coupled Device (CCD) in combination with an X-ray mirror telescope. The CCD and MICROMEGAS detectors observe the sun at sunrise, while the TPC detector, covering two magnet bores, observe at sunset.

During 2003 and 2004 the experiment operated with vacuum inside the magnet pipes (CAST Phase I). No signal above background was observed in 2003 data, implying an upper limit to the axion-photon coupling[1] of $g_{a\gamma\gamma} \leq 1.16 \times 10^{-10}$ GeV^{-1}. The CAST experimental setup was transformed to be able to fill the axion conversion volume with a buffer gas in 2005 (CAST Phase II) in order to increase the sensitivity to higher axion mass.

2. The CCD detector and the X-ray telescope

The X-ray telescope of CAST consists of a Wolter I type X-ray mirror optics[2] focusing a potential axion signal on a small area of the CCD detector which is located in the focal plane of the optics. The detector is a fully depleted back side illuminated pn-CCD with a depletion depth of 280 μm and a pixel size of 150 x 150 μm^2, optimized for the 0.2-10 keV energy range. Further enhancement of the sensitivity is achieved by adding a passive shield consisting of a combination of internal and external lead-copper components.

3. Background sources

The most important background contribution is expected from external gamma rays, produced mainly by primordial radio-nuclides like ^{40}K and the radioactive natural chains from ^{238}U, ^{235}U and ^{232}Th in laboratory soil, building materials and experimental set-up as well as by ^{222}Rn in air.

Intrinsic radioactive impurities (either primordial or cosmogenically induced) in the detector materials are important in experiments looking for rare event signals because of their alpha, beta and gamma emissions.

Cosmic rays on the Earth's surface are dominated by muons and neutrons. While muon interactions (as those of other charged particles) can be rejected by off-line analysis, signals from neutrons are an irreducible.

4. Background simulations

4.1 *The Code*

The GEANT4 package[3] has been used for simulations with the G4NDL 3.7 library for neutrons. In the first simulations for neutrons and external gamma backgrounds a simplified description of the detector was implemented. A much more detailed geometry for the detector was defined to carry out simulations of the radioactive impurities in the detector components (see Figure 1).

An energy calibration with a ^{55}Fe source was first simulated and compared to the corresponding experimental spectrum where the photopeaks have been reproduced quite well.

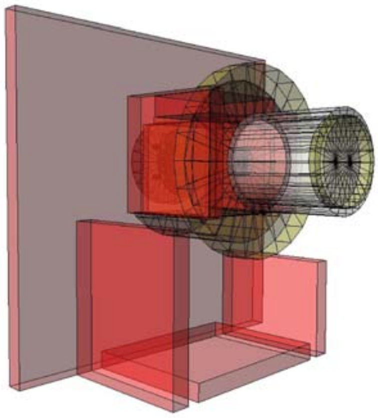

Figure 1. View of all simulated components, including shields, aluminum vessel and connection to telescope.

4.2 *External Gamma Background*

In order to evaluate the contribution of the environmental gamma background to the CCD counting rate and the effect of the four different shielding configurations (no shield, internal copper shield, internal copper shield and external lead shield and finally internal lead-copper shields and external lead shield) the response of the detector to photons has been studied.

Radon level measurements of the experimental site using a Ge spectrometer has been used as input for determing the expected detector response. A mean radon concentration of 10 Bq m^{-3} has been assumed. The total contribution from radon up to 7 keV is found to be ~10^{-6} counts cm^{-2} s^{-1} keV^{-1}, almost negligible compared to the measured background rate in the CCD detector. A counting rate of a 3-4x10^{-5} counts cm^{-2} s^{-1} keV^{-1} is then attributed to the measured activities of the experimental site walls.

4.3 *Neutrons*

Simulations have estimated the counting rate due to cosmic neutron background in the region up to 10 keV as 6x10^{-6} counts cm^{-2} s^{-1} keV^{-1}, other neutron background contribution due to radioactivity or muon induced neutron are at least one order of magnitude lower than the experimental background levels of the CCD detector, and therefore, not very significant at the present level of sensitivity.

4.4 *Intrinsic radioactive impurities*

The levels of radioactive impurities in the main components of the CCD detector were measured in the Canfranc Underground Laboratory in Spain, using an ultra-low background germanium detector, can be found in a database of radiopurity of materials[4] inside the ILIAS program (Integrated Large Infraestructures for Atroparticle Science). Activity comes mainly from the radioactive chains ^{235}U, ^{238}U, ^{232}Th and the isotope ^{40}K.

Table 1.Total contribution to CCD counting rate between 1 and 7 keV from natural radioactivity of the individual components in units of counts cm^{-2} s^{-1} keV^{-1}

Detector Component	Differential Flux
CCD Board	$(5.83\pm0.41)\times10^{-7}$
CCD Chip	$< 2.2\times10^{-5}$
Ceramics	$(1.17\pm0.14)\times10^{-6}$
Sockets	$(1.34\pm0.15)\times10^{-6}$
Front Cooling Mask	$< 3.6\times10^{-7}$
Back Cooling Mask	$< 2.6\times10^{-7}$

The total contribution to the background from the radioactivities measured in Table 1 is 2.6x10^{-5} counts cm^{-2} s^{-1} keV^{-1}. Compared to the measured background level in the CCD detector impurities from detector components account for up to ~33% of the counting rate according with the simulations.

5. Conclusions

Using the simulated response of the CCD detector to the external gamma background, an estimate of the contribution of this background component has been attempted, finding that measured radon levels in the air of the CAST site could produce on average ~1% of the registered counting rate, while just the measured activities from ^{238}U, ^{232}Th radioactive chains and the isotope ^{40}K in the walls of the CAST hall could justify more than 50% of this counting rate.

The response of the CCD to neutrons of different energies has also been simulated. They do not seem to be a very relevant source of the CCD background, producing just a few per cent of the observed counting rate.

Finally, the contribution to the CCD counting rate of the internal radioactive impurities of the main detector components measured with a Ge spectrometer at the Canfranc Underground Laboratory could justify at most 33% of the measured according to simulations.

Taking into account each of these contributions, a quite complete model for the background measured by the CCD detector has been obtained.

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