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CAST microbulk micromegas in the Canfranc Underground Laboratory

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Abstract

During the last taking data campaigns of the CAST experiment, the micromegas detectors have achieved background levels about 5 to 9 $\times 10^{-6}$keV^{-1}cm^{-2}s^{-1} between 2 and 9 keV. This performance has been possible thanks to the introduction of the microbulk technology, the implementation of a shielding and the development of discrimination algorithms. It has motivated new studies towards a deeper understanding of CAST detectors background. One of the working lines includes the construction of a replica of the set-up used in CAST by micromegas detectors and its installation in the Canfranc Underground Laboratory. Different contributions to the detectors background have been evaluated and an upper limit $< 2 \times 10^{-7}$keV^{-1}cm^{-2}s^{-1} for the intrinsic background of the detector has been obtained.

Keywords: micromegas, microbulk, axions, ultra-low background, Underground Physics, Rare Event Searches

1. The CAST experiment and its micromegas detectors.

The principle of an axion-helioscope[1] consists of the conversion into photons of some of the axions[2][3] generated in the Sun in presence of a transverse magnetic field. The solar axion flux could then be identified as an excess of photons registered by X-ray detectors (the axion spectrum ranges from 1 to 10 keV) during the time the helioscope is aligned with the Sun. The CERN Axion Solar Telescope, CAST[4][5], is the best realization until now of an axion-helioscope thanks to the powerful LHC dipole prototype and to the sensitivity of its X-rays detectors.

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There are three main requirements for low background detectors: the use of low radicativity materials, a shielding againts environmental radiation and good discrimination capabilities. The successive introduction and continuous improvement of these strategies has led to a constant decrease of the background level in CAST micromegas detectors (Fig. 4).

In the new generation of micromegas[7], called microbulk[8][9], all the readout is contained in a 80 μm foil(Fig. 1 left). This foil has been measured showing good radiopurity[10]. The rest of the mechanical structure of the detector is made of Plexiglass (also radiopure) with the exception of the drift cathode, which is made of steel. A thin window (only 4 μm of aluminized mylar) and the operation at slighty overpressure (1.35 bar) optimize the detector efficiency for X-rays detection.

The detector is covered by a shielding composed of a inner 5 mm thickness copper layer and 25 mm thickness of archeological lead (Fig. 1 center). Nitrogen is flushed to avoid Radon emanations nearby the detector. Moreover the micromegas allows a descriptive characterization of the registered events, providing both spatial (two-dimensional strips readout and time (mesh pulse recording) features. This information is used to discriminate X-rays events from other interactions[11][13, Chap. 4 and 5]. The typical background rate during current operation phase in CAST[6] has been from 5 to 9 $\times 10^{-6}$keV^{-1}cm^{-2}s^{-1} from 2 to 9 keV.

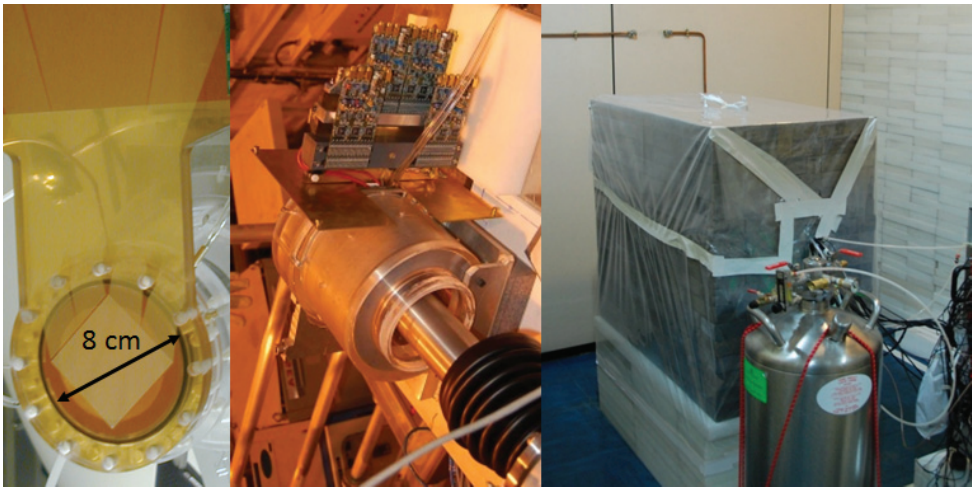

Fig. 1. From left to right: pixelized strip readout; micromegas foil (containing amplification structure plus readout plane) glued on a PCB racket; the detector connection to the magnet bore in CAST during an intermediate installation where lead shielding can be observed; the 20 cm thick shielding in the LSC with the Nitrogen dewar.

2. Work motivation, methodology and measurements

Improving present CAST micromegas performance needs a carefully characterization of the detectors. That is motivated by the next CAST data taking campaigns and by the IAXO project R&D towards a new generation of axion helioscopes[12]. The goal of this work is to study the influence of changes in the detector environment on the detector background. With each change, we aim to remove, or substantially reduce, a specific background source. Comparisons between different set-ups and detectors were made too, trying to itemize the several causes which are susceptible of having an influence and evaluate its strength. A new set-up, that essentially reproduces the CAST one (as described in the previous section), was built in the University of Zaragoza. It is completed with a CAST microbulk detector; the experiment's acquisition is also replicated and the same analysis programs are used to process the data.

2.1. Surface and underground comparisons

In a first comparison (Fig. 2 left) the environment is changed from 200 meters above the sea level at the Zaragoza lab to 2500 m.w.e depth in the Canfranc Underground Laboratory. Moving the detector to

Canfranc, the cosmic muons are reduced by a factor $\times 10^4$[14]. In contrast, the radon concentration is much more intense than at surface and highly variable, with typical values from 100 to 200 Bq/m^3. The trigger rate at Canfranc was ~ 0.2 Hz, about 5 times lower than at surface; however, after application of offline cuts, the final background remained very similar $\sim 5 \times 10^{-6}$keV^{-1}cm^{-2}s^{-1} in the 2-9 keV energy range(Figure 2 left). Therefore the cosmic rays cause ~ 80% of the events registered in the detector in the surface; but the final background, which is obtained after the application of discrimination algorithms, is practically not altered by them.

In a second comparison (Fig. 2 right), apart from the surface (this time from the CAST experimental area) to underground translation, the set-up is slightly changed too. The main difference in the background is the presence of two fluoresce peaks in the CAST spectrum. The first peak is really composed by the fluorescences of the steel components (Cr, Fe, Ni at 5.4, 6.4 and 7.0 keV) which are related with the stainless steel cathode and the vacuum pipe that connect the detector to the superconductor magnet (Fig. 1 center). The second peak, at 8.0 keV, is a copper fluorescence orginated in the micromegas. None of the spectra taken with the test set-up represented in Figure 3 presents these peaks. The intensification of the fluorescences must be due to the shielding opening in CAST set-up, which is needed to connect to the detector and the magnet, as it was mentioned before. This picture has been confirmed by Monte Carlo simulations of the CAST set-up and, in addition, by the important suppression recently observed in the fluorescence peaks with the micromegas currently taking data by means of an improvement of the front-shielding near the opening region.

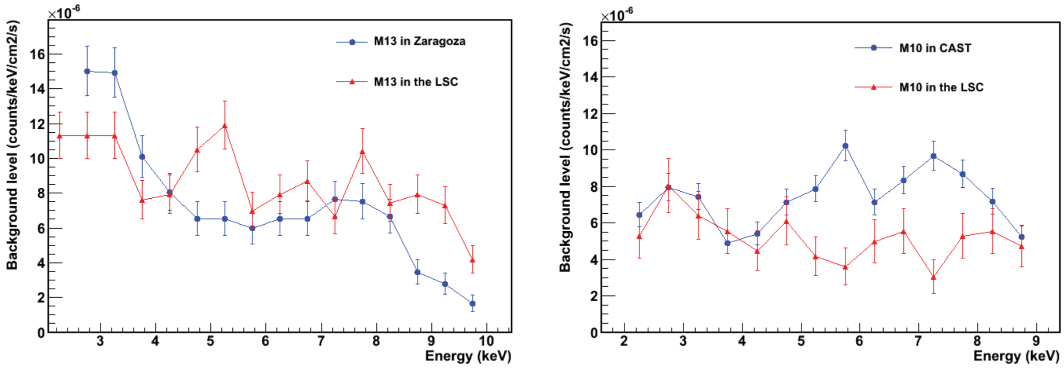

Fig. 2. Left: final background spectra taken in identical conditions in the Zaragoza's test-bench (surface) and in the LSC (2500 m.w.e. deep) with the M13 detector.Right: final background spectra taken with the M10 detector in the CAST experiment (sunrise side, Autumn 2008) and in the LSC (Winter 2011) in similar shielding configurations.

Finally, a third comparison can be made between the spectra taken by two different detectors in identical conditions: test set-up in Canfranc underground. The first detector (Figure 3, left) was a CAST spare detector which suffered from some physical deffects. In contrast, the second one (Figure 3, right) was at service in CAST obtaining a notable improvement in the final background compared with previous detectors[13, Chap. 7 Sec. 5]. The fact that the background level obtained with the best detector is appreciably lower means that the status of the micromegas, which preserves its discrimination capabilities, is a relevant factor (specially for low energies). However the fact that both levels are quite similar may point out that the remaining background is due to real X-rays, and thus unavoidable in this set-up.

Regarding the influence of radon in the final background level, it can be said that it is not a limiting factor with this set-up. Even when the radon flow was interrupted, there was not a clear effect. The stainless steel cathode, in principle the unique compound of the micromegas chamber which is not particularly radiopure, was also rejected to have a relevant contribution at this background level as not change was reported by the replacement of it by a replica which was built in copper.

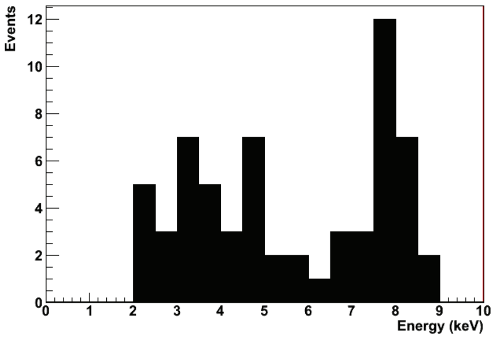

Fig. 3. Final background spectrum taken with the 20 cm thick lead shielding. A background level of about 1 count/day (30 times lower than the nominal value in CAST) was stable during 41.4 days of live time. A final amount of 41 counts formed a spectrum with a small, but clear, copper fluorescence peak.

2.2. *Shielding upgrade and internal configurations*

The next step was to increase the outer shielding with a 20 cm thick of lead extra layer (Fig. 1 right) right). The idea is to evaluate the relative weights from internal contamination and external radiation to the CAST background. Even when cosmic muons can be directly rejected by the CAST detector, the same may not be true for the secondary particles produced by the muon interactions, particularly in the shielding. In order to clearly separate different contributions, this test should be done first underground.

The shielding upgrade yielded an important reduction of both the trigger rate, by a factor ~40, and the final background by a factor ~30. This fact stands for the interactions in the chamber to have almost exclusively an external origin and stablishes an upper limit for the micromegas detector intrinsic background below $2 \times 10^{-7}\text{keV}^{-1}\text{cm}^{-2}\text{s}^{-1}$ in the 2-9 keV range. It must be noted that we consider the detector as the sum of the microbulk and the chamber structure with a copper cathode.

This background could still be influenced by the radioactivity of the shielding materials. The most internal layer of the shielding is made of radiopure copper, thought inside the Faraday cage the detector internal cavity is not perfectly closed, as a gap is needed by the calibrator to access to the detector. Moreover, it must be noted that no archeological lead has been used for the shielding in the test set-up (in contrast with actual CAST set-ups).

With aim of clarifying this a new setting was tried: the chamber window was closed with a 1.5 mm layer of copper, just leaving a small hole for calibrations. If an important contribution to the background were due to soft X-rays comming from the shielding walls, they could access the chamber volume only trought the transparent chamber window, which has been blocked in the second setting. No apprecible change was detected in the background level and shape (Table 1).

	Window closed	Window open	All the period
2-7 keV	1.5 ± 0.9	1.6 ± 0.9	1.5 ± 0.6
2-9 keV	1.8 ± 0.8	1.7 ± 0.8	1.7 ± 0.3

Table 1: Final background levels expressed in $10^{-7}\text{keV}^{-1}\text{cm}^{-2}\text{s}^{-1}$.

3. Summary and conclusions

The LSC is a useful test bench for CAST detectors as it allows us to analyze the relative weight of the different physical contributions to CAST micromegas background. A direct comparison of the background of the same set-up at surface and underground shows that, even when cosmic rays dominate the trigger rate at surface, muons are efficiently rejected by the micromegas. An important part of the CAST background, specially the fluorescence peaks, is related with the intrusion of gammas from the connection between the detector and the magnet bores. This is already being reduced by means of upgrading the shielding of the line.

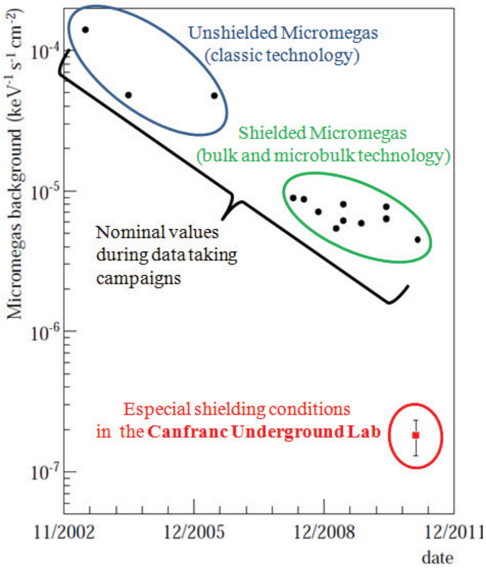

Fig. 4. History plot of the background levels for CAST micromegas detectors. The new point goes away the general tendency, roughly exponential, because it does not correspond to the context of the true CAST experiment, but it means a first evaluation of the potential of the newest micromegas technology in an underground laboratory, the most suitable environment for Rare Event Searches.

The CAST micromegas final background level is dominated by the environmental gamma flux, as it is clear from the 30 times reduction obtained by shielding upgrade, which leads to an upper limit for the micromegas detector intrinsic background below $2 \times 10^{-7} \mathrm{keV}^{-1} \mathrm{cm}^{-2} \mathrm{s}^{-1}$ in the 2-9 keV range.

The new point this work added to the CAST micromegas background history (Fig. 4) must be considered as a limit for the future evolution of CAST micromegas background imposed by the intrinsic radioactivity, although new techniques may bring more radiopure micromegas. The work is ongoing to identify more concrete origins for the internal contaminations. This level can also represent a first indication for micromegas in the new context of underground experimentation.

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