CAST: Status and Latest Results

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In July 2011, CAST finished the data-taking of its nominal programme, having scanned axion masses up to $\sim 1.18\,\mathrm{eV/c^2}$. Here we present the first results of the data taken in 2008, first year of the last data-taking campaign when ^{3}He was used inside the magnet bores. No excess of signal over background has been recorded, and an upper limit has been set to the axion-to-photon coupling to $2.3\times10^{-10}\,\mathrm{GeV^{-1}}$ for axion masses between 0.39 and 0.64 eV. CAST remains the most sensitive axion helioscope and for the first time crosses the benchmark line of the KSVZ model at the upper end of the spectrum.

1 Introduction

The CERN Axion Solar Telescope (CAST) is looking for axions and axion-like particles since 2003. The axions are hypothetical particles arising in models which may explain the CP problem of strong interactions and can be Dark Matter candidates. With the help of a decommissioned LHC dipole magnet hopes to convert axions produced by the Primakoff process in the solar core into detectable x-ray photons. These photons would carry the energy and the momentum of the original axion. CAST is the most sensitive axion helioscope built so far. Its sensitivity is based on three points, a powerful magnet, an x-ray focusing device and low-background detectors. The magnet employed in CAST is an LHC dipole prototype, which can reach 9 T along the 9 m of its length. With the help of a moving platform, it is aligned with the center of the sun for 90 min twice a day. A total of four detectors are connected at the two ends of the magnet, two looking at sunrise and two at sunset.

CAST has been taking data since 2003. During 2003 and 2004 the experiment operated with vacuum in the magnet bores (CAST phase I) and set the best experimental limit on the axion-photon coupling constant in the range of axion masses up to $0.02\,\mathrm{eV/c^2}$ [1, 2]. For CAST, above this mass the sensitivity is degraded due to coherence loss. The experimental setup was upgraded in 2005 in order to extend the sensitivity to higher axion masses. For this purpose, the experiment has to operate with the magnet bores filled with a buffer gas whose density has to be increased in appropriate steps to cover equally a range of higher axion masses. During 2005 and 2006, ^{4}He was used as a buffer gas and the experiment scanned the range of axion masses from $0.02\,\mathrm{eV/c^2}$ to $0.39\,\mathrm{eV/c^2}$ and set the most restrictive limit on the axion-photon coupling constant for this range of masses [3]. Furthermore, for the first time the theoretically favoured region of masses has been probed. Due to the condensation of ^{4}He at high pressures (aprox. 14 mbar at 1.8 K, the operating temperature of the CAST magnet), the system had to be thoroughly upgraded to use ^{3}He as a buffer gas. In parallel, CAST has been looking into other related searches, such as high energy axions [4], 14.4 keV axions from M1 transitions in the sun [5] and low energy axions in the visible [6].

2 Upgrades and latest results

After the ^{4}He data-taking, several upgrades were necessary in order to prepare for data taking with ^{3}He. The most important of these was the design and installation of a sophisticated ^{3}He gas system. As mentioned above, in order to scan over a range of axion masses, CAST fills the cold bores with gas in incremental steps. It is essential to know and reproduce the exact gas density inside the bores but also to ensure that the density remains homogeneous along the bores. To achieve the desired gas density, the amount of gas introduced into the cold bores

*Deceased.

needs to be accurately calculated, with the help of several temperature and pressure sensors, strategically placed in the magnet and the gas system. A lot of effort has been invested from the collaboration in order to perform extensive simulations for a most detailed model of the system under the different configurations and the calculations of the gas density, which have to be performed through computational fluid dynamic (CFD) simulations. The achieved agreement between the simulated and measured parameters allow us to believe that despite the variations in the value of the temperature and gas density, this latter remains homogeneous along the magnet.

During the ^{3}He data taking, the CAST x-ray detectors were upgraded as well. The number of Micromegas detectors was increased from one to three, when the Time Projection Chamber (TPC) with a multi-wire proportional readout [7] that had covered both bores of the sunset end of the magnet was replaced. The two sunset microbulks use the shielding that was already in place for the TPC detector, while the sunrise detector counts with a dedicated shielding since the latest upgrade [8, 9, 10]. The microbulk detectors belong to the latest generation of Micromegas and the ones installed in CAST have obtained background levels down to 5×10^{-6} counts keV^{-1} cm^{-2} s^{-1} in the energy range of interest, already one order of magnitude better that the previous ones [11]. On the other hand, the x-ray mirror telescope with a pn-CCD chip [12] covering the other bore of the sunrise side remained unchanged.

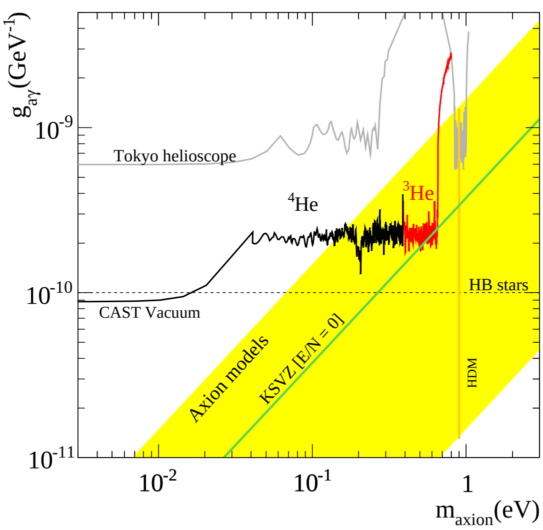

Figure 1: The CAST exclusion plot after the different phases of the experiment: in vacuum [1, 2], ^{4}He [3] and ^{3}He [13] phase. The limit achieved in the ^{3}He CAST phase for axion mass range between 0.39 eV and 0.64 eV. The results from the Tokyo helioscope [14, 15, 16], horizontal branch (HB) stars [17], and the hot dark matter (HDM) bound [18] are also shown. The yellow band represents typical theoretical models with. The green solid line corresponds to E/N = 0 (KSVZ model).

Here we present the results obtained from the data-taking in 2008, the first year of operation with ^{3}He. The axion mass range scanned was between 0.39 eV and 0.64 eV. The data analysis performed is similar to the results obtained with ^{4}He gas. The differences are mainly due to the overall reduction of background rates achieved by CAST detectors with respect to the ones of the ^{4}He phase, as well as the reduced ^{3}He density setting exposure time of the overall data taking period. Figure 1 presents these results: CAST has extended the last exclusion plot towards higher axion masses, probing further inside the theoretically favoured region and excluding the axion-photon coupling down to 2.3×10^{-10} GeV^{-1} for axion masses between 0.39 and 0.64 eV [13], the exact value depending on the pressure setting. It is the first time that the limit given by the KSVZ model is crossed.

2.1 The next steps

Currently, the collaboration is analysing the remaining of the data, from the campaigns of 2009 through the summer of 2011. In parallel, there are preparations in course regarding the short- and long–term future of the experiment. Given the latest upgrades of the system, the first idea would be to repeat the measurements with ^{4}He in the magnet bores. Focusing on the detectors which now obtain rather low backgrounds, one can expect an improvement on the limits already set by CAST which will lower the sensitivity in the range of most interest and will probably probe the KSVZ line at lower masses. As a second step, the vacuum-phase of CAST could be revisited. Work is also done towards lowering the detector thresholds; in this way, when the system will be back to vacuum operation, other studies could be foreseen, regarding paraphotons [19] and solar chameleons [20]. A feasibility study of a new generation axion helioscope is ongoing [21]. This initiative includes the construction of a new toroidal magnet with much larger magnetic volume, together with exhaustive use of x-ray optics and low background detectors. A sensitivity of more than one order of magnitude in the axion-to-photon coupling beyond CAST seems feasible.

3 Conclusions

CAST presents the first results of the data taken when using ^{3}He as buffer gas inside the magnet bores. The axion-to-photon coupling has been excluded to 2.3×10^{-10} GeV^{-1} for axion masses between 0.39 and 0.64 eV. The remaining of the data taken, which have reached axion masses up to 1.18 eV are being analysed. Short term prospects include revising some ^{4}He and vacuum configurations, given the improved performance of the detectors. For the longer term, studies of a new generation axion helioscope are ongoing

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