Probing eV-scale axions with CAST.

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CAST (CERN Axion Solar Telescope) is a helioscope looking for axions coming from the solar core to the Earth. The experiment, located at CERN, is based on the Primakoff effect and uses a magnetic field of 9 Tesla provided by a decommissioned LHC magnet. CAST is able to follow the Sun during sunrise and sunset having four X-ray detectors mounted on both ends of the magnet to look for photons from axion-to-photon conversions. During its First Phase, which concluded in 2004, CAST searched for axions with masses up to 0.02 eV. By using a buffer gas the coherence needed to scan for axions with masses up to 1.20 eV is re-established in CAST's Second Phase. This technique enables the experiment to study the theoretical regions for axions. During the years 2005 and 2006, the use of ^{4}He has already enabled the search for axions with masses up to 0.39 eV. Up to present time, CAST has upgraded its experimental setup to operate with ^{3}He in the magnetic field.

1 Helioscopes axion searches

The strong CP-problem of QCD might be solved by the introduction of a chiral symmetry [1] whose spontaneous breakdown implies the appearance of a new particle [2, 3]:

$$\mathcal{L}_\theta \equiv \mathcal{L}_\mathrm{a} = \left(\frac{\mathrm{a}}{\mathrm{f_a}}\right)\xi\left(\frac{\mathrm{g}^2}{32\pi^2}\right)\mathrm{G}^{\mu\nu}_\mathrm{a}\widetilde{\mathrm{G}}^\mathrm{a}_{\mu\nu}. \quad (1)$$

The axion, as the new particle was named, is a very light pseudoscalar Goldstone boson that could be produced via the so-called Primakoff effect [4] in the presence of strong electromagnetic fields. The solar core is an ideal environment to produce those particles due to the strong electric fields of the solar plasma.

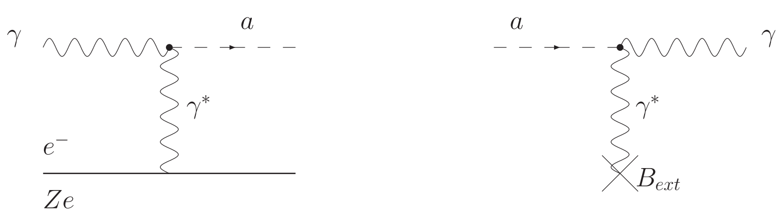

Figure 1: Feynman diagrams for the Primakoff production of axions in the solar core (left) and axion-to-photon conversion in the presence of a magnetic field (right).

In such conditions, a real photon (X-ray) and a virtual photon (electromagnetic field) might couple and result in an axion that is able to reach the Earth's surface. These axions, could be reconverted into X-ray photons in a transverse magnetic field. Therefore, they can be detected by using a magnet pointing to the solar core and an X-ray detector attached to its end [5].

2 The CERN Axion Solar Telescope (CAST)

Twice per day, CAST points towards the Sun making use of a decommissioned superconducting LHC magnet of 9.26 meter length and 9 Tesla field in order to look for a signal of axions according to the expected differential axion flux at the Earth's surface [6]:

$$\frac{d\phi_a}{dE_a} = 6.020 \times 10^{10} \cdot \left[\frac{g_{a\gamma\gamma}}{10^{-10} GeV^{-1}}\right]^2 \cdot E_a^{2.481} e^{-E_a/1.205}\, \mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{keV}^{-1}. \tag{2}$$

Four X-ray detectors are mounted on both sides of the magnet: two sunset Micromegas that replace the previously used Time Projection Chamber [7], a sunsrise Micromegas [8] and a Charge Coupled Device [9]. This latter detector is used together with an X-ray telescope that improves its signal to background ratio. Each one of the detectors is daily aligned with the solar core during 1.5 hours in order to look for a photon arising from an axion-to-photon Primakoff conversion suitable to happen in the magnet of CAST. The probability for such an event can be written as:

$$\mathcal{P}_{a\to\gamma} = \left[\frac{g_{a\gamma\gamma}}{10^{-10} GeV^{-1}}\right]^2 \left[\frac{B_\perp}{2}\right]^2 \cdot \frac{1}{q^2 + \Gamma^2/4} \cdot [1 + e^{-\Gamma L} - 2e^{-\Gamma L/2}\cos qL]. \tag{3}$$

From this we can observe that a possible axion-to-photon Primakoff conversion has the following coherence condition:

$$\left(\mathrm{m_a^2/keV^2}\right) \ll \left(\mathrm{m_\gamma^2/keV^2}\right) + 2\left(\frac{\mathrm{E_a/keV}}{\mathrm{L \cdot keV}}\right). \tag{4}$$

These coherence requirements of the conversion probability restricted CAST's First Phase search to axion masses below 0.02 eV [10, 11].

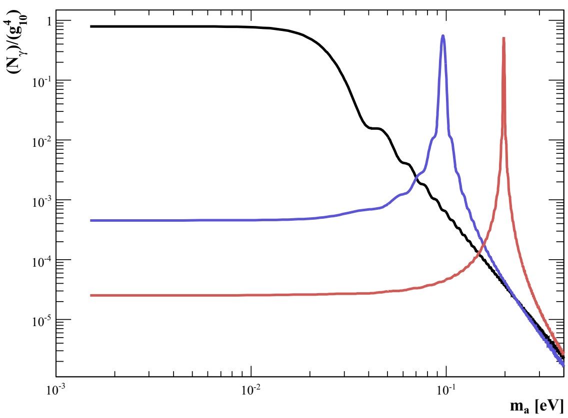

Figure 2: Expected photons arriving CAST for the First Phase (black line) and for two different settings of CAST's Second Phase (red and blue lines). It can be observed how CAST's First Phase loss of coherence is restored during the Second Phase.

However, the loss of coherence over the full magnet length as encountered in CAST's First Phase (vacuum) has been restored for the Second Phase of the experiment. This has been accomplished by filling the magnet with a buffer gas such that the photon acquires an effective mass (see figure 2). The CAST experiment has been upgraded in order to be able to have gases at various pressures in the magnet bores. A complete gas system has been designed and built to control the use of the buffer gas and monitor its density.

Cooling the superconducting CAST magnet down to 1.8 K by using superfluid Helium causes the employed gas in the magnet conversion region to saturate. ^{4}He for instance, is able to restore CAST's coherence for axions masses up to 0.39 eV. However, at the given temperature it saturates when its pressure reaches 16.4 mbar. Therefore, in order to extend the search for axion masses up to 1.20 eV, the use of a lighter gas like ^{3}He is required (see figure 3).

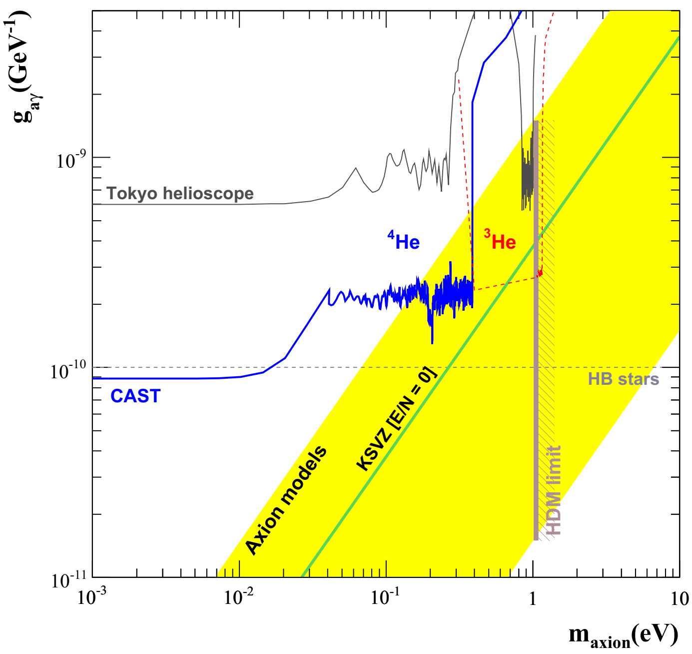

Figure 3: CAST exclusion plot for axion mass versus coupling constant to photon in the experimental panorama of the rest of stelar axion search experiments. In the figure, it can be observed the result achieved by CAST during its first and the ^{4}He run of Second Phase [11] (thick blue line). The thin red line is the expectation for the ^{3}He run of CAST's Second Phase. In light grey the results from the Tokyo helioscope [13–15]

The CAST data taking procedure during the Second Phase was choosen in a way such that it allows for scans of axion masses from 0.02 to 1.20 eV. For the ^{4}He run, during 2005 and 2006 the ^{4}He gas density was increased in the magnet bore daily by a certain number of atoms. The overall range of pressure inside the bore reached from 0 to 13.43 mbar. This mechanism has already allowed CAST to restore the coherence of axion masses up to 0.39 eV (see figure 3). The ^{3}He run of CAST's Second Phase is ongoing and the Primakoff coherence condition has already been fulfilled for axions of masses up to 0.66 eV.

3 Conclusion

During its First Phase, while having vacuum in the magnet bores, CAST looked for traces of axion-to-photon conversions via the Primakoff effect for axions coming from the solar core. However, coherence restrictions constrainted the axion search to masses below 0.02 eV [10, 11].

CAST's Second Phase has already started and the extension of sensitivity using ^{4}He gas has been accomplished during the years 2005 and 2006. The analysis of the ^{4}He run has finished [12] and the final result can be seen in the figure 3. The extension of sensitivity in CAST up to axions masses of 1.20 eV is being accomplished by using ^{3}He and axions masses have already been probed up to 0.66 eV.

4 Bibliography

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