PROCEEDINGS OF SCIENCE

Exploring high mass regions for axion dark matter at IBS/CAPP

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The Center for Axion and Precision Physics Research (CAPP) of the Institute for Basic Science (IBS) in Korea has completed the construction of the infrastructure for axion dark matter search experiments. An experiment utilizing a 9 T superconducting magnet with a 127 mm bore diameter placed in a He-3 cryogenic system is currently under preparation. This experiment will explore a broad range of axion mass of 10 to 30 μeV (equivalent frequency range of 2.8 to 7 GeV) by employing a new cavity design, multiple-cell cavity, which provides a capability of searching relatively high mass regions. We present the status of the experiment and discuss the future prospects. (This work was supported by IBS-R017-D1-2018-a00 / IBS-R017-Y1-2018-a00.)

The 39th International Conference on High Energy Physics (ICHEP2018)
4-11 July, 2018
Seoul, Korea

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PoS(ICHEP2018)820

The axion is a consequence of the PQ mechanism proposed to solve the strong-CP problem and considered as a cold dark matter candidate. A methodological approach to detect the axion signal employs cavity haloscopes, where axions are converted into photons under a strong magnetic field.

To date, haloscope experiments have been sensitive to relatively low mass regions. The multiple-cavity design was introduced and an in-depth study was performed for its application to high mass axion searches. We develop a new concept of cavity design, multiple-cell cavity (dubbed "pizza cavity"), which consists of a single large cavity, fitting into a magnet bore, with metal partitions placed at equidistant intervals to make multiple identical cells. This design is superior to the conventional multiple-cavity design in terms of detection volume, simplicity of the experimental setup, and facilitation of the phase-matching mechanism. Experimental demonstration using a double-cell cavity verifies that this new design is promising for searching high mass regions in cavity-based axion experiments.

IBS/CAPP at KAIST has been establishing state-of-the-art experiments for axion dark matter searches since 2013. An experiment, named CAPP-9T MC, currently under preparation, exploits the pizza cavity design utilizing a He-3 cryogenic system and a 9 T superconducting (SC) magnet.

The major components of the He-3 refrigerator include a charcoal sorption pump, 1 K pot and He-3 pot. By keeping the charcoal temperature at $\sim$40 K and the 1 K pot temperature as low as possible, the system can be operated in continuous (non-evaporating) mode with He-3 gas in condensed state, cooling the He-3 plate down to less than 2 K. A custom-made solenoid magnet with 5" diameter bore was fabricated using NbTi wire to generate the central magnetic field of 9.0 T at 81.0 A at a helium reservoir. A capability of operation in persistent mode reduces the heat load on the 4 K cold mass and provides the stability of the magnetic field.

Multiple-cell cavities with 110 mm inner diameter and 220 mm inner height are designed to maximize the sensitivity. They are suspended by four copper rods from the He-3 plate to the middle of the magnet bore. A tuning system employs a single piezo actuator on the bottom of the cavity which rotates frequency tuning rods, made of alumina, simultaneously. A cryogenic readout chain consists of a series of low noise HEMT amplifiers. Operation of the He-3 system in continuous mode enables us to maintain the cavity temperature at 2.0 K.

The CAPP-MC experiment consists of three stages depending on the cell multiplicity of the detector: double-cell, quadruple-cell and octuple-cell. Each stage will cover a frequency range of 2.8−3.3, 3.8−4.5 and 5.8−7.0 GHz, respectively, with a target sensitivity of 10 times the KSVZ QCD axion model. Figure 1 shows the experimental sensitivities projected by CAPP-9T MC.

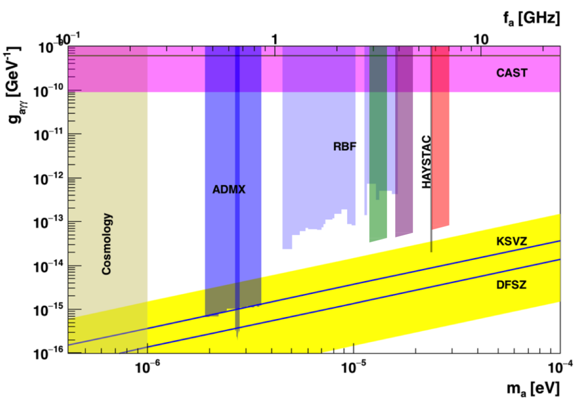

Figure 1: Projected sensitivities for the CAPP-MC experiment in the parameter space of the axion-to-photon coupling vs. axion mass. The expected coverage regions by the double-cell, quadruple-cell, and octuple-cell cavities are represented by the green, purple, and red filled vertical areas, respectively.