The International Axion Observatory (IAXO): MPGD development

The International Axion Observatory

IAXO is a large-scale axion helioscope that will look for axions and axion-like particles (ALPs) produced in the Sun with unprecedented sensitivity. The near term goal of the collaboration is the construction and operation of BabyIAXO, an intermediate experimental stage of IAXO that will be hosted at DESY. BabyIAXO is conceived to test all IAXO subsystems (magnet, optics and detectors) at a relevant scale for the final system and thus serve as prototype for IAXO, but at the same time as a fully-fledged helioscope with relevant physics reach in itself, and with potential for discovery. BabyIAXO is now under construction and its commissioning is expected for 2023. The BabyIAXO baseline program would oideally verlap with the IAXO design and construction with a provisional commissioning in 2027.

Axions are predicted by the Peccei-Quinn mechanism proposed to solve the long-standing strong-CP problem in the standard model (SM) of particle physics. More generic axion-like particles (ALPs) appear in diverse extensions of the SM (and notably in string theory). Axions and ALPs are invoked in a number of cosmological and astrophysical scenarios. Most relevantly, axions are very well suited candidates to compose all or part of the cold dark matter (DM). ALP fields appear in models of inflation, dark radiation or even dark energy. A number of long-standing astrophysical anomalies could also be solved by the presence of axions or ALPs.

A rapidly growing landscape of experiments are now attempting the detection of these particles. The efforts are roughly classified in three areas, depending on the source of axions: laboratory, solar or dark matter axions. If axions compose the DM they could be detected by axion haloscopes or other axion DM detection techniques that are now being developed by an increasing number of groups. Sensitivity to relevant QCD axion model parameters may thus be achieved although, of course, the predicted sensitivities are always dependent on (at present) untestable cosmological assumptions. Truly model-independent searches can only be carried out in purely laboratory searches (like e.g. in light-shining- through-wall experiments), but in this case the sensitivities are insufficient to reach QCD axion parameters. Axion helioscopes looking for solar axions represent the only approach that combines relative immunity to model assumptions (solar axion emission is a generic prediction of most axion models) plus a competitive sensitivity to parameters largely complementary to those accessible with other detection techniques. The most advanced axion helioscope is the CERN Axion Solar Telescope (CAST), active for more than 15 years at CERN. CAST has probed some QCD axion models in the 0.1–1 eV mass range. The latest CAST result sets an upper bound on the axion-photon coupling of $g_{a\gamma} < 0.66 \times 10^{-10}$ GeV^{-1} up to $m_a \sim 0.02\,\mathrm{eV}$ [1]. This value competes with the strongest bound coming from astrophysics. Advancing beyond this bound is now highly motivated, not only because it would mean to venture into regions of parameter space allowed by astrophysics, but also because some of the aforementioned astrophysical anomalies would seem to hint at precisely the range of parameters at reach.

IAXO is a new-generation large-scale axion helioscope that aims to search for solar axions with a signal-to-background ratio of about 4-5 orders of magnitude better than CAST. This translates into a factor of $\sim$20 in terms of the axion-photon coupling constant $g_{a\gamma}$. IAXO follows the conceptual layout of an enhanced axion helioscope, in which all the magnet aperture is equipped with focusing optics. This sensitivity relies on the construction of a large superconducting 8-coil toroidal magnet optimized for axion research. Each of the $\sim 60\,\mathrm{cm}$ diameter magnet bores features X-ray optics focusing the signal photons into small $\sim 0.2\,\mathrm{cm}^2$ spots that are imaged by low background X-ray detectors. A detail conceptual design of IAXO was published by the collaboration [2]. BabyIAXO is conceived as a first experimental stage towards IAXO representative of the final infrastructure, and therefore they constitute risk-mitigating prototypes for IAXO. The physics case of the experiment has been reviewed in detail in [3].

The IAXO collaboration was formalized in July 2017. At the moment the IAXO collaboration encompasses 20 institutions from all over the world. United States institutes (LLNL, MIT's Laboratory of Nuclear Science and Barry University) are driving the telescope development and are involved in phenomenology studies. Moreover the deputy spokesman of the collaboration, Julia Vogel, is from LLNL. The physics program of IAXO was already reviewed very positively by CERN SPSC in the past [4] and in May 2019 by the DESY PRC [5]. Very recently, the outcome from the the European Strategy meeting for Particle Physics is very positive for axions with explicit mention of the DESY axion program.

Detectors state of the art

The required BabyIAXO sensitivity imposes very stringent constraints on the background levels needed for the X-ray detectors i.e 10^{-7} $\mathrm{c/keV/cm^2/s}$ a factor 10 better than current levels.

The baseline detection technology in BabyIAXO are small Time Projection Chambers with pixelated Micromegas readouts built with the microbulk technology [6]. These detectors have been object of intensive low-background development within the CAST experiment [7–9].The quest for lower background levels, achieved after progressive understanding of background sources responsible for energy depositions in the Region Of Interest, refinement of event analysis methods and improvements of the detector shielding.

Other technologies like GridPix, Metallic Magnetic Calorimeters, Neutron Transmutation Doped sensors, Transition Edge Sensors and Silicon Drift Detectors are interesting due to their excellent energy resolution, energy threshold, efficiency and the possibility to use ultra-pure materials with respect to radioactive impurities. Their background rejection in the region of interest is being studied in detail. In particular, the Gridpix technology was installed and operated in the CAST experiment from 2014 with an energy threshold of 300 eV and achieving background levels of 10^{-5} $\mathrm{c/keV/cm^2/s}$ [10, 11].

IAXO MPGD challenges

The BabyIAXO detector design will largely be based on the last CAST detectors, but with a number of improvements. A substantially improved muon veto system should allow to bring the detector background to a level of $\sim 10^{-7}$ $\mathrm{c/keV/cm^2/s}$. Additional improvements beyond this level are possible, moving to a Xe-based operation and new radiopure electronics. The final effect of these improvements in the background level remains to be quantified, but could potentially lead to the $\sim 10^{-8}$ $\mathrm{c/keV/cm^2/s}$ levels. In addition it is important to improve the sensitivity of the detectors towards very low photon energies (1 keV), in order to become fully sensitive to axions produced via the axion-electron coupling. This requires ultrathin windows and very low-threshold electronics. For the Gridpix technology different improvements are foreseen to further improve the background, like improving the radiopurity of the Gridxpix detector by developing new polyimide PCBs and finding radiopure materials for the detector chamber. In addition, Timepix3 will be introduced into the next detector generation allowing a fully three dimensional reconstruction of the charge cloud that will be exploited for further background rejection. Furthermore, dead-time free readout can be achieved. With the combination of all these efforts, background levels similar to the ones obtained with the Micromegas detector should be at reach.

Contacts

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