Notes from the 3rd Axion Strategy Meeting

O.K. Baker*, G. Cantatore†, J. Jaeckel** and G. Mueller‡

*Department of Physics, Yale University, P.O. Box 208120, New Haven, CT 06520
†Università and INFN Trieste, via Valerio 2, 34127 Trieste, Italy
**Institute for Particle Physics Phenomenology, Durham University, Durham DH1 3LE, UK
‡Department of Physics, University of Florida, PO Box 118440, Gainesville, FL 32611, USA

Abstract. In this note we briefly summarize the main future targets and strategies for axion and general low energy particle physics identified in the “3rd axion strategy meeting” held during the AXIONS 2010 workshop. This summary follows a wide discussion with contributions from many of the workshop attendees.

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INTRODUCTION

Low energy experiments can be a powerful probe of particle physics beyond the current Standard Model. The classic examples are experiments searching for axions such as cavity searches for dark matter axions, axion helioscopes, light shining through a wall experiments as well as laser polarization experiments. Over the last few years it has also been realized that these and similar experiments can indeed provide an interesting probe not only of axions, but of a wide variety of particles suggested in realistic extensions of the Standard Model. In addition to the strong-as-ever motivation to find the axion this has significantly strengthened the physics case for these experiments and has also led to a general stepping up of all the experimental efforts.

The purpose of the “3rd axion strategy meeting” was to provide a round table environment for the community of physicists, both theorists and experimentalists, working in axion, and more generally in WISP physics, to freely float ideas and informally discuss them in order to discern the global trend of the field and identify interesting and promising directions for future developments. In this note we will briefly summarize the results of the discussion.

The ADMX experiment is currently the only experiment sensitive enough to probe the preferred region for the QCD axion (which is not yet excluded by astrophysics) and in particular also one of the regions suggested by astrophysical puzzles – the region where axion is dark matter. But the ADMX experiment is intrinsically narrowband and can not probe the entire mass range in any reasonable time [1, 2]. Moreover, ADMX is based on the assumption that a significant fraction of the dark matter is made of axions – an assumption that is natural only in a limited range of axion parameters. The discussion focussed on the status of the current experiments [3, 4, 5], potential ways to improve the sensitivity of the optical experiments [6, 7] to complement and go beyond the ADMX experiment in particular by probing larger mass ranges. Currently, most experiments are
HEADING TOWARDS THE AXION LINE

Although important new motivation in the form of a variety of hidden sector particles has arisen over the last few years, one of the main targets of the community remains to discover the standard QCD axion. The following discussion therefore focussed on the potential improvement of axion searches. However, it should be stressed that basically all improvements in axion searches directly translate into similar improvements for general WISP searches. Furthermore, it should also be noted that for some WISPs such as, e.g. hidden sector photons the laboratory experiments already probe interesting parameter space untested by astrophysics. Therefore, experiments working towards reaching the axion line receive very good motivation from their significant discovery potential for these particles.

Strong astrophysical bounds require that the future laboratory experiments that can successfully probe the QCD axion must significantly improve in sensitivity towards smaller couplings but also towards larger masses (see Fig.1). The main technologies discussed to close the gap were light-shining-through-walls (LSW) experiments and helioscopes.

Helioscopes [3, 4] use a strong magnetic field to convert relativistic solar axions to X-rays. CAST [3] has reached a sensitivity in coupling of $10^{-10}$ GeV$^{-1}$ for masses smaller than 20 meV and is currently the most sensitive broadband observatory-type experiment...
in the world. Improvements could come from advances in the efficiency of the X-ray telescopes and from reductions in the dark current of the X-ray detectors. However, fundamentally, the sensitivity scales with the magnetic field, the length, and the cross sectional area. Increases in the length and cross sectional area will reach practical limits as the telescope has to track the sun to detect solar axions or will only be sensitive during short periods of time. The resonant amplification of the generated X-rays was also disregarded as the solar axions are incoherent and any resonant amplification in one frequency region will suppress signals in other frequency regions. The net effect would be a reduction in the signal. The main avenue of approach here leads to stronger magnetic fields and perhaps wider apertures.

LSW experiments first convert an optical photon into a relativistic axion inside a strong magnetic field. The axion then propagates through ‘a wall’ into a second strong magnetic field region where it converts back into an optical photon. Over the last years LSW experiments have improved considerably. The next step seems to be the use of optical cavities in the production and in the regeneration regions. In the production region this has been pioneered by the ALPS experiment\(^1\). Installing a second resonant cavity in the regeneration region seems to be a viable option [10, 11] and many groups are pursuing it. An example is the effort by a collaboration led by groups at Fermilab and the University of Florida to set up a resonant regeneration experiment [6]. The goal is using 6+6 Tevatron magnets (5 T field, 48 mm bore diameter). The present stage is proposal preparation and a pilot version of the setup with 2 m + 2 m long 0.5 T permanent magnets which is forseen for the near future at the University of Florida. This LSW experiment can in principle reach sensitivities in the $10^{-11}$ GeV$^{-1}$ range and will ultimately be limited by the ability to handle the laser power and optical losses inside the cavities.

Laser polarization (LPol) experiments can in principle reach sensitivities similar to light-shining-through-walls (LSW) experiments. In these experiments the detection of the axion coming from the conversion of a linearly polarized photon in an external field is based on sensing either the delay experienced by the photon when it briefly oscillates into a massive axion, or the disappearance of the photon itself due to the production of a real axion. The delay causes birefringence, while the disappearance causes an apparent rotation, actually a dichroism.

LPol experiments have the advantage that only one long interaction region is required. However, the birefringence caused by QED effects in vacuum creates a background which would be larger and indistinguishable from an axion signal, unless birefringence measurements are combined with rotation measurements. Also, in practice, all the necessary optical elements have an intrinsic birefringence which severely limits the attainable sensitivity. For these reasons LPol experiments appear to be less promising than LSW experiments.

In cavity experiments like ADMX using cold dark matter axions, the mass and the resonance frequency of the cavity have to agree within the bandwidth of the cavity in order to achieve an enhancement of the signal due to resonant regeneration. For a given

\[^1\] It should be noted that BFRT also had mirrors to enhance the production probability, but the setup used was an optical delay line and not a cavity
cavity frequency the experiment is sensitive only in a very limited mass bandwidth. In order to explore an appreciable range of the, a priori unknown, axion mass, one has to measure cavity power after tuning the cavity at a given frequency, then slightly change the frequency of the cavity, measure again and so on in order to scan over the axion masses. This process takes time. With the next stage of ADMX, roughly a decade of axion masses will be explored, and future developments may allow to extend this by another decade. Extension beyond the mass range $1 - 100 \mu eV$ seems challenging. Moreover, cavity searches for dark matter axions build on a strong assumption, namely that all (or at least a sizeable part) of the dark matter is axions. In contrast, LSW or helioscope experiments have their own production mechanisms and do not rely on this assumption.

Following these arguments, LSW and helioscope experiments appear to be the most promising experiments beyond ADMX. Both of them require stronger magnets and larger interaction regions to reach the QCD axion range. But there are differences in the way the two experiments scale with size. While the sensitivity of the helioscope experiments scale with the cross sectional area, LSW experiments only require cross sections which exceed the cross sections of the diverging laser beams. Scaling up the length of both types of experiments would improve the sensitivity but at the same time reduce the probed mass range. This mass range can be shifted towards higher masses using techniques to maintain the phase matching between the electrical and the axion field. These techniques could include refractive materials inside the cavity such as a dilute gas or phase shifting glass plates or by alternating (periodically poling) the magnetic field. Note that the introduction of material into the LSW cavities will increase the optical losses and will limit the finesse of the cavities.

In addition to the above, new frequency regimes may be explored. For example helioscopes could also search in the eV regime. Currently, calculations of the flux are underway. Moreover, there are also efforts to run an LSW experiment with microwave cavities. This promises good sensitivity towards small couplings. However, the mass range is somewhat limited by the lower frequency/energy radiation.

A GLOBAL DESIGN INITIATIVE

An additional area of intense discussion was the future “strategy” of the community. The development of stronger and larger magnets appears to be the key to increase the sensitivity of helioscope and LSW experiments into the QCD axion range. However, the longer and stronger approach faces two main challenges. First of all the development of stronger magnets is costly both in time and in money. Yet, here the axion searches may profit from developments from other programs such as the “new intensity frontier” program at Fermilab, where magnets with field intensities up to 14 T are studied. Our community should approach Fermilab and other labs (such as CERN) involved in magnet development and request that these magnets have large enough sufficient apertures for our experiments. This request will carry more weight if our community acts as a coherent community and promotes only a very limited number of potential experimental designs. This is not the case at present.

Secondly, as discussed above longer magnets increase the sensitivity towards smaller
couplings for low mass axions but decrease the sensitivity for larger masses making it even more difficult to reach the QCD axion line. The development of potential phase matching techniques or alternative designs appears to be necessary before any large scale experiments beyond the currently planned experiments can proceed.

Furthermore, increasing size (and cost) of the experiments does require a consolidation of the experimental efforts, preceded by the convergence on a main production/detection technique. The extreme form would be the selection of a single site for a large scale experiment. Yet, at the same time a diverse community of experimental groups is probably a very positive feature to explore a variety of experimental techniques. The general agreement at the end was that the "world experiment" should for the moment be left as an open issue. It would also be useful to prepare a summary document with ideas and relevant numbers which could be used for funding agencies.

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