MADMAX - Prototype Developments and Characterization Studies

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Introduction to MADMAX

The proposed MAgnetized Disk and Mirror Axion eXperiment, or MADMAX, is a novel experiment in the hunt for Axion Dark Matter. It aims to detect axions in the well-motivated mass range of 40-400 μeV[1]. The log-log plot in Figure 1 shows the sensitivity of MADMAX to axion and axion-like particles in the photon-coupling $g_{a\gamma}$ versus mass m_a phase-space[2]. Dielectric haloscopes, such as MADMAX, are a promising approach to explore the parameter space in this mass range.

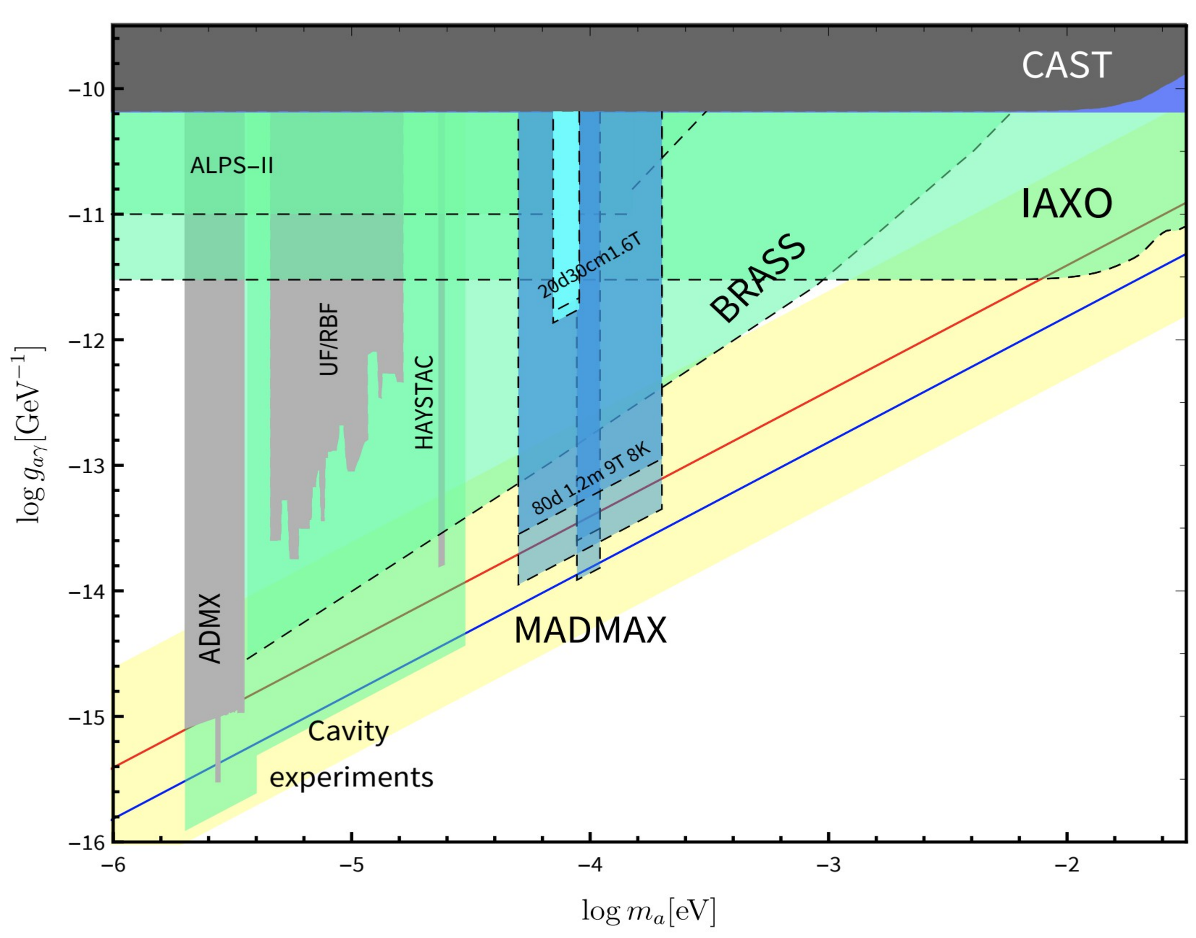

Figure 1: Sensitivity of MADMAX to axion and axion-like particles in the photon-coupling $g_{a\gamma}$ versus mass m_a phase-space[2]. Two scenarios, for 20 and 80 disks, are shown in blue.

Detector Design

MADMAX is designed around the concept of the dielectric haloscope, shown in Figures 2 and 3. It is composed of several thin dielectric disks, a reflective mirror, a receiver system, and a strong magnetic field. To suppress thermal noise, the experiment is operated at cryogenic temperatures. In addition to resonant effects in the booster, each dielectric surface emits radiation coherently, leading to a Power Boost Factor, β^2, which is defined as the ratio between the emitted power of the booster system and that emitted by a single mirror alone. The total power emitted by the booster is then related to β^2, the magnetic field strength B_e, and the surface area of the disks, A, as follows.

$$P_\gamma(\nu) = 1.6 \times 10^{-22}\,\mathrm{W} \left(\frac{\beta^2(\nu)}{5\times 10^4}\right)\left(\frac{B_e}{10\,\mathrm{T}}\right)^2\left(\frac{A}{1\,\mathrm{m}^2}\right)\left(\frac{\rho_a}{0.45\,\mathrm{GeV/cm^3}}\right) C_{a\gamma}^2 .$$

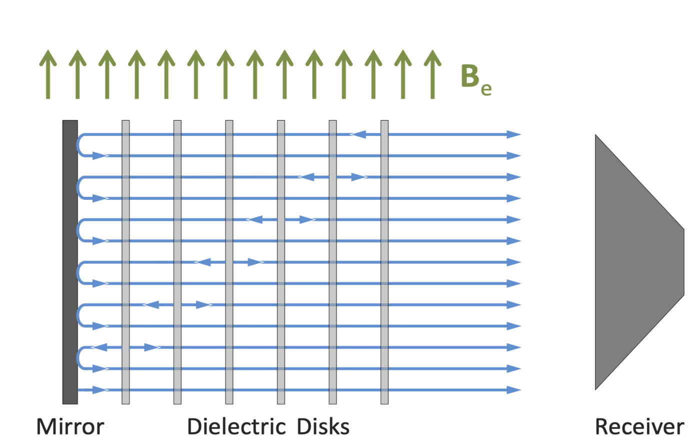

Figure 2: General concept of the dielectric haloscope. B_e indicates the direction of the magnetic field.

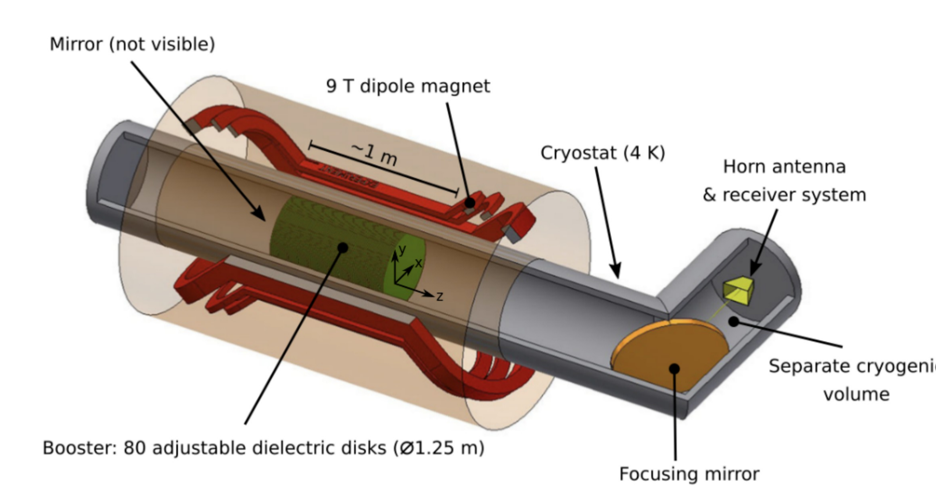

Figure 3: Drawing of the proposed MADMAX dielectric Haloscope.

Proof of principle Setup

A "Proof of Principle" apparatus[3] was constructed to better characterize the electromagnetic properties of the booster and receiver systems. A subset of moveable dielectric disks are mounted in front of a fixed copper mirror. An aluminum mirror focuses the beam onto a receiver antenna, as shown in Figures 4-5. With this set up we can measure the reflectivity and group delay (Figure 6) of the system. The results are compared to simulations. With a near-field probe, the beam shape has also been characterized, as shown in Figure 7.

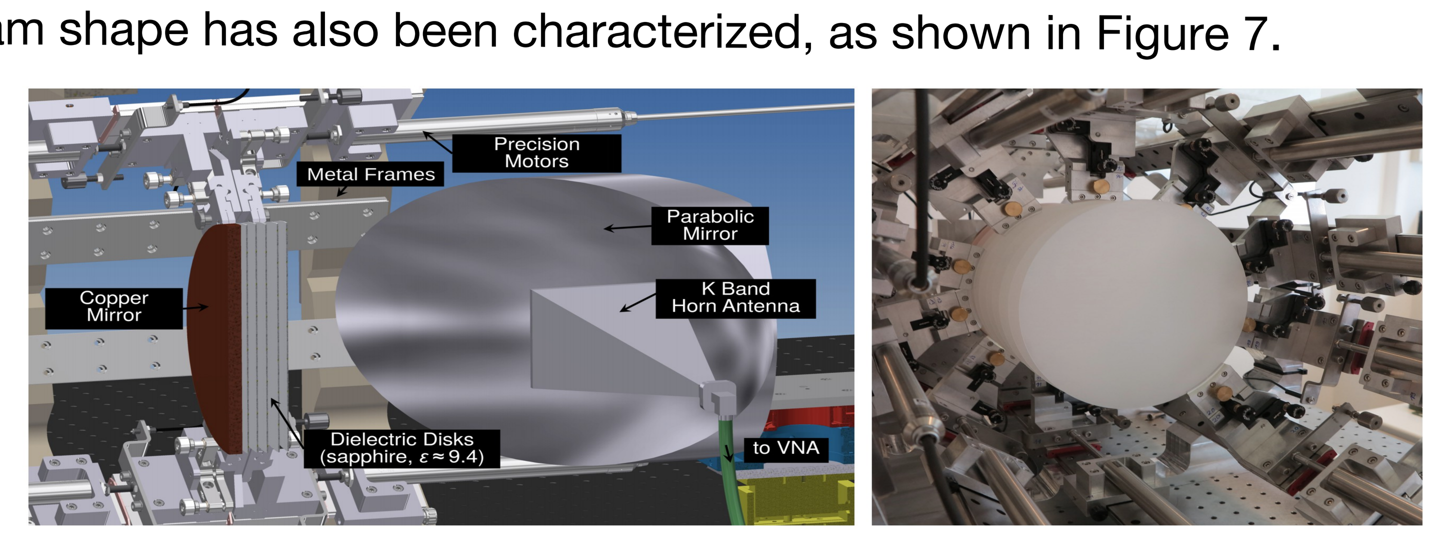

Figure 4: Drawing (left) and photo (right) of the Proof of Principle apparatus at MPI in Munich.

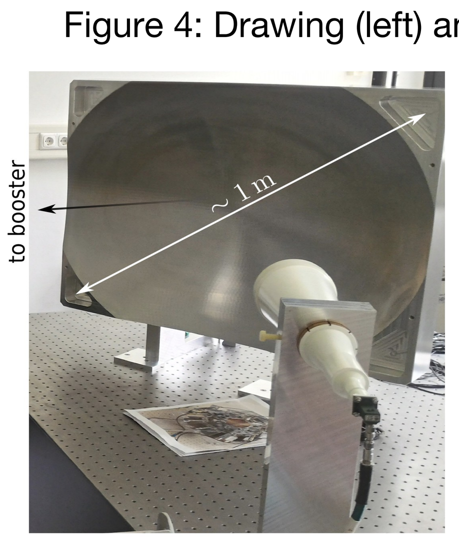

Figure 5: Focusing mirror and antenna.

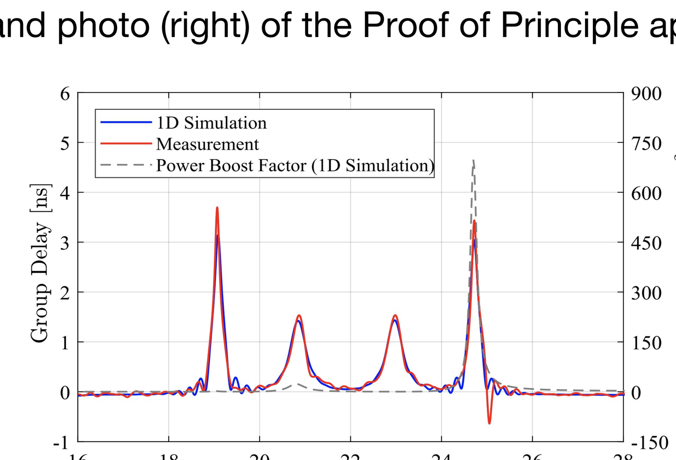

Figure 6: Group delay measurements compared to 1D simulations.

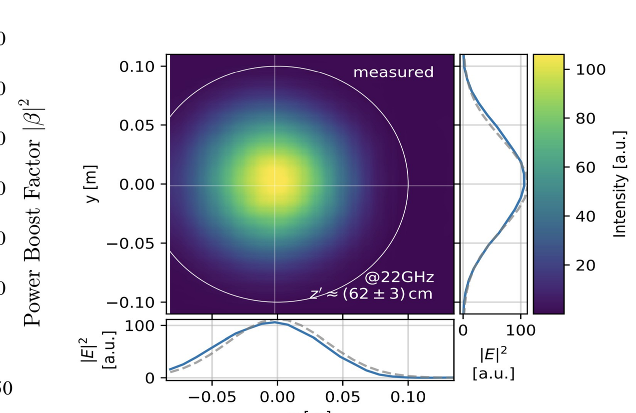

Figure 7: Beam shape measurements in front of the mirror.

Summary and Outlook

MADMAX is a novel approach to search for Axion Dark Matter using the principle of the dielectric haloscope. As an initial step, a first Proof of Principle apparatus has been developed and is currently aiding in characterizing the electromagnetic response of the booster system. These studies, together with simulations, as shown in Figure 7, will guide the development of the next phase of the experiment, a Prototype detector, and the eventual full-scale MADMAX detector.

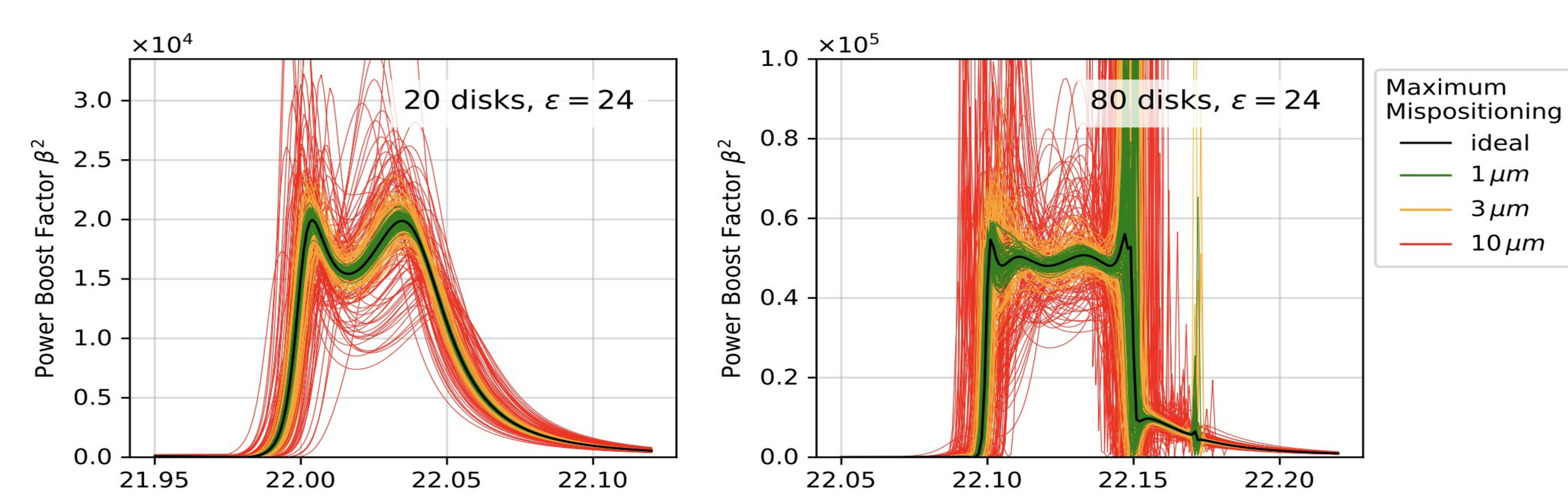

Figure 7: Effect of disk misalignment on the power boost factor for a 20 disk Prototype (left) and 80 disk full-scale MADMAX (right).

References
[1] "A new experimental approach to probe QCD axion dark matter in the mass range above 40 μeV," P. Brun et al. [MADMAX Collaboration], Eur. Phys. J. C (2019) 79, arXiv:1901.07401.
[2] MADMAX collaboration, S. Beurthey, N. Bohmer, P. Brun, A. Caldwell, L. Chevalier, C. Diaconu et al., Madmax status report, 2020.
[3] J. Egge, S. Knirck, B. Majorovits, C. Moore and O. Reimann, A first proof of principle booster setup for the MADMAX dielectric haloscope, 2001.04363.