The MADMAX project

Conseil Scientifique IN2P3 sur la matière noire (23 octobre 2023)

1 Executive Summary

The axion (a) is one of the best motivated dark matter candidates, whose interest has gained significant momentum in the last decade. MADMAX is a first-generation experiment for axion direct searches, based on a novel concept (dielectric haloscope), to be validated with small-size prototypes. After inverse-Primakoff conversion under a strong magnetic field $a + \gamma^* \to \gamma$, the dielectric haloscope concept exploits constructive interferences of electromagnetic radiations emitted at dielectric disc surfaces (booster) to enhance the signal. To scan the axion mass range, discs are gradually moving using dedicated piezo motors. With this new concept, MADMAX is one of the very few experiments capable of exploring the axion mass around 100 μeV, favored by the theory. Currently in a challenging and active cutting-edge R&D phase, it first aims to take data at CERN with prototypes operated under a 1.6 T magnetic field at room and liquid helium temperatures in 2022-2025 and produce a first Axion-Like Particle (ALP) search. This will pave the road towards the final detector, to be operated at DESY after 2028 with a strong discovery potential for dark matter axions.

CPPM joined MADMAX in 2020, actively participating to the construction, simulation, test and data analysis of the MADMAX prototype boosters. The CPPM hardware participation focuses on precision mechanics: measurement of the geometry of the dielectric discs at the micron level (exploiting our recognized expertise in 3-dimensional measurements developed for ATLAS pixel detectors), as well as design and construction of the structure to hold the discs in the prototype booster and connect them with the piezo motors. We initiated and are coordinating the tests of all booster prototypes in the CERN Morpurgo magnet. Consequently, we also took the charge to build all the infrastructures needed for the prototype tests in this dipole magnet. Finally we started working on the simulation of the final booster prototype and participating to the analysis of the data taken at CERN in 2022 and 2023. This should lead, in the coming year, to a search for ALPs of mass around 100 μeV with a sensitivity beyond the current reach set by the CAST experiment. CPPM contributions to MADMAX are the first experimental activities at IN2P3 on the well motivated and promising field of direct axion search.

2 Scientific context

The existence of dark matter (DM), supported by a variety of astrophysical and cosmological measurements, is one of the main puzzles in fundamental physics. However, as of today, the nature and properties of DM remain largely unknown. In this context, the theoretically best-motivated dark matter candidates are elementary particles that were postulated to solve shortcomings of the Standard Model (SM) of particle physics (e.g. neutrino masses, hierarchy problem or absence of CP violation in the strong sector). Among those particles, the Peccei-Quinn (PQ) axions [1, 2, 3] were postulated more than 40 years ago to explain the absence of CP violation in the strong sector, although it is allowed in the SM. Indeed, the SM controls CP violation in QCD by one fundamental parameter Θ, which can be inferred from the measurement of the neutron electric dipole moment (nEDM). As nEDM is currently not observed [4, 5], a very strong upper limit is imposed: $|\Theta| < 10^{-10}$. This experimental fact requires an extreme fine-tuning on Θ, which cannot be justified by anthropic reasoning. Axions are in addition excellent DM candidates [6, 7, 8], provided their mass is in the range between $\sim$1 neV and $\sim$1 meV [9]. Similar pseudo-scalar particles not solving the strong CP problem, called axion-like particles (ALPs), are also good DM candidates.

So far, this 1 neV to 1 meV mass range is practically unexplored, despite several attempts. The most competitive experiments rely on the conversion of the galactic halo (thereby called haloscope) or solar (helioscopes) axions to photons inside very intense magnetic fields [10]. For haloscopes, the main challenge consists in boosting the resulting extremely feeble microwave photon signal to be able to detect it with state-of-the-art radiometers, which are sensitive to a photon power of the order of 10^{-22} W. The ADMX experiment, a resonant cavity inserted in a high magnetic field, explored a small mass region around 3 μeV [11]. Such cavity experiments plan to cover the mass range of 2–10 μeV in the coming years. Complementary techniques are necessary to explore the mass range 10–400 μeV. The importance for such an exploration is world-wide recognized, as for instance by the APPEC committee in its recent report [12]: “European-led efforts should focus on axion and ALPs mass ranges that are complementary to the established cavity approach and this is where European teams have a unique opportunity to secure the pioneering role”, and by the Physics Preparatory Group of the European Particle Physics Strategy Update process in its last physics briefing book [13]: “The search for the axion is a central task in particle physics”.

The axion search in the mass range 10–400 μeV will be based on improvements on the magnetic field strength as well as on novel concepts for the photon signal boost, which overcome the limitations from resonant cavities above 10 μeV. New ideas were proposed to escape from the cavity concept by using a tunable cryogenic plasma [15], magnetized dish antenna [16] or moveable magnetized discs with a high dielectric constant [17]. The main idea of the latter concept is to exploit constructive interferences of electromagnetic radiations emitted at several surfaces to enhance the signal. This enhancement is later called “boost factor”. This is achieved through a serie of parallel dielectric discs with a mirror on one end, all within a magnetic field parallel to the surfaces (Figure 1 top left). Provided key experimental parameters for the boost factor (β^2), the B-field (B_e) and the disc areas (A) can be reached, an output power induced by the axion field is produced at the level of 10^{-22} W. Operating the system at cryogenic temperature leads to a detectable signal peak (Figure 1 top right) in a few days. This dielectric disc booster concept is developed by the MADMAX[1] collaboration, which was formed in 2017. It is aiming at a working detector to be operated at DESY in Hamburg (within the DESY axion hub, together with IAXO [18] and ALPS II [19]). The goal of MADMAX is to explore the mass range around 100 μeV, favored by scenarios where the PQ symmetry is broken after inflation [20]. MADMAX is one of the very few experiments with a predicted sensitivity capable to discover the DM PQ axions in this favored mass range (Figure 1 bottom), thereby having a high discovery potential. It published a “white paper” in 2019 [21].

[1] Acronym of MAgnetized Disc and Mirror Axion eXperiment.

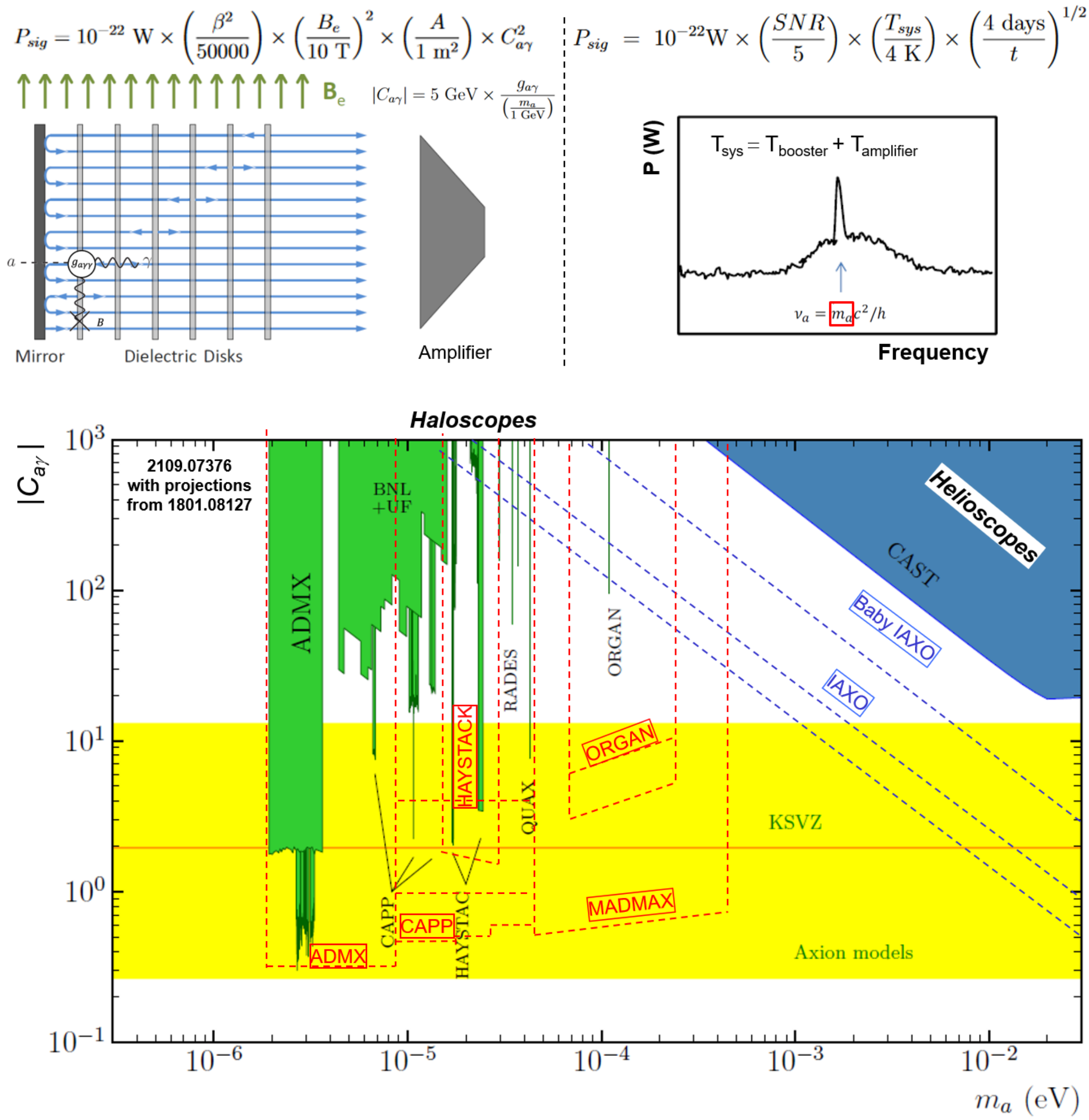

Figure 1: Top: Sketch of the dielectric disc booster concept. In the B_e field, photons emitted at the dielectric surfaces are reflected by the leftmost mirror and other surfaces to be measured coherently by a receiver. Key values of the experimental parameters to reach 10^{-22} W are given. Bottom: Sensitivities for DM axions and ALPs on the axion-photon coupling ($g_{a\gamma}$) divided by the axion mass versus the axion mass (m_a), assuming the axions provide the full local galactic DM density of 0.3 GeV/cm^3. KSVZ is a benchmark class of QCD axion models and the yellow band around its line indicate reasonable variations of the model parameters. Published haloscope and helioscope experiments are shown in green and blue shaded areas [14], while the experiment projections are shown in red and blue dotted lines, respectively [9]. MADMAX projection assumes a setup with 80 dielectric discs each with an area of 1 m^2 and a magnetic field of 10 T and 10 years data taking.

3 The MADMAX project

The MADMAX baseline design is shown in Figure 2. The booster is composed of several discs (1 mm thickness, spaced by O(1) cm) with a high dielectric constant ($\epsilon \geq 9$) located in a cryostat at cryogenic temperature (4 K) and operating in a high magnetic field. The scan of the mass range is possible by gradually moving the discs using dedicated piezo motors sliding along rails. The magnet, needed to convert the axion to photons via the inverse Primakoff effect, is a dipole with a large aperture to host the cryostat. The photon signal amplified by the booster is directed with a focusing mirror to a receiver chain, sensitive to very high frequency (10–40 GHz). The low noise pre-amplifier (LNA) is a High Electron Mobility Transistor (HEMT), that could be upgraded to more recent technologies (see section 4). This LNA is connected to a receiver chain consisting of a heterodyne system and a DAQ. The heterodyne system converts the booster signal in steps from the GHz regime to a frequency readable by the DAQ sampler system in the 0–50 MHz regime. The receiver output gives a power that is calibrated with a noise diode to an equivalent system temperature (T_{sys} in K), strongly correlated to the boost factor. The receiver system operated at liquid helium temperature was demonstrated to be sensitive to an artificially injected 18.4 GHz "fake axion signal" with a power of 10^{-22} W and a width of 10 kHz within less than two days of integration time for a frequency band of 50 MHz [21].

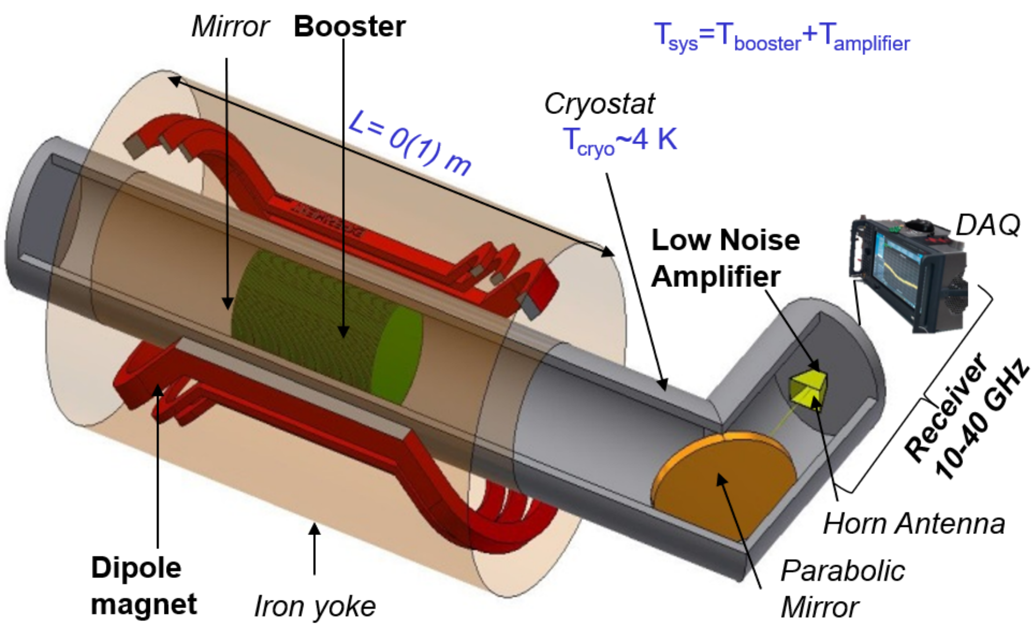

Figure 2: Baseline design of the MADMAX approach with the magnet (red racetracks), the booster consisting of the mirror (copper disc at the far left) and dielectric discs (green), and the receiver consisting of the horn antenna (yellow) and the low noise pre-amplifier inside a separated cryostat. The focusing mirror is shown as an orange disc at the right.

Towards the realization of such a demanding apparatus, the MADMAX collaboration has developed a staged approach of various prototypes to prove different aspects of the haloscope booster concept (Table 1). The booster system is, next to the magnet (discussed in section 4), the essential part of the experiment for obtaining a large enough enhancement of the axion induced signal in the targeted mass range. The two main challenges for the booster, tackled in parallel by the prototypes, are mechanical feasibility and calibration of the booster radio frequency (RF) behavior in the O(10) GHz regime. MADMAX is therefore currently in a challenging and active cutting-edge R&D phase. The different prototypes of Table 1 have been / will be built and tested inside the Morpurgo magnet, a large bore 1.6 T magnetic field that the CERN Research Board has granted for access during the SPS shutdown periods until 2025 [22].

Name	Goal	Set-up	Available
P200	Piezo motors + mechanics	1 moveable disc, ϕ=200 mm	2022
CB100	RF studies + first physics	3 fixed discs, ϕ=100 mm	2021
CB200	RF studies + first physics	3 fixed discs, ϕ=200 mm	2023
OB300	ALP scan around 100 μeV	3–20 moveable discs, ϕ=300 mm	2024–25

Table 1: Different test setups built to validate the MADMAX concept.

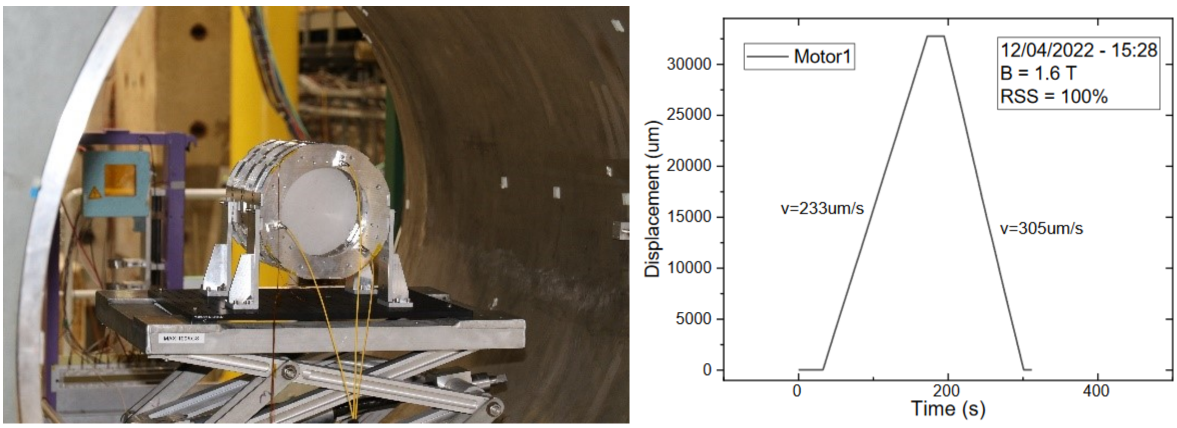

Figure 3: Left: Picture of P200 in the Morpurgo magnet at CERN in April 2022. The yellow wires provide the signal from the interferometers. Right: Measurement of the displacement of the P200 disc versus time (hence disc velocity) during tests in the Morpurgo magnet (1.6 T).

The first step was to fully understand the mechanical feasibility of the booster in a strong B-field and cryogenic environment. The P200 prototype (Figure 3 left), consisting in one 20 cm diameter sapphire disc moved in an open booster, has been developed for that purpose. The disc is suspended inside the booster mechanical structure using a support ring designed, machined and certified at CPPM (section 4). Three piezoelectric motors developed for the MADMAX purpose and certified [23] are moving the disc along ceramic rails. Three commercial interferometer arms are measuring the position of the ring and serve as feedback to the motors. The system has been successfully tested in 2022 at CERN, both at cold and in a magnetic field. For the latter, the disc was displaced by O(10) cm with an average velocity above the target of 0.1 mm/s (Figure 3 right). A publication is being submitted.

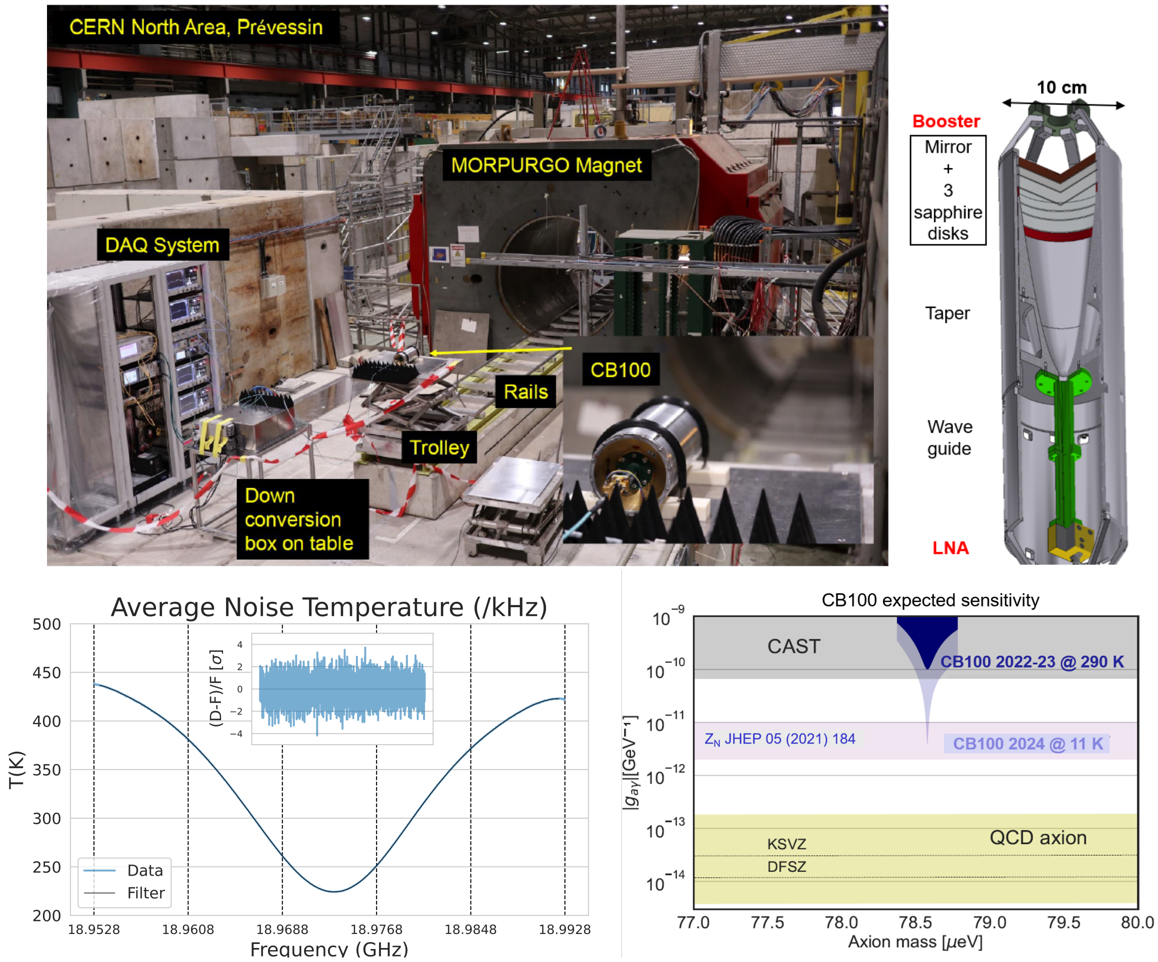

Figure 4: Top: CERN set-up around the Morpurgo magnet (left) and CB100 sketch (right). Bottom Left: System temperature variation in the 50 MHz frequency range around 19 GHz where the boost factor is effective (corresponding to 78.5 μeV). The inset shows the residuals with respect to a Savitsky-Golay filter expressed in σ of the noise. Bottom right: Expected sensitivity of CB100 operated in Morpurgo at warm in 2022–2023 (dark blue) and at cold in 2024 (light blue).

The tests of the CB100, CB200 and OB300 boosters, to check the RF behaviour and perform first physics, proceed by periods of one month per year during the beam shut-down in the North Area at CERN and began in 2022 (Figure 4 top left). CB100, tested in 2022 and 2023 at room temperature, is a closed booster (well defined boundary RF conditions) with 3 non-moveable discs of 10 cm diameter (Figure 4 top right). It was first checked that the environment, not radio quiet at CERN, does not perturb the measurement. The measurement of the system temperature in a 50 MHz range, corresponding to where the boost factor is effective, could then be carried on in 2022 (10 hours) and 2023 (21 days, as shown in Figure 4 bottom left). In both cases, a clear dip at the frequency of the expected boost factor is visible, due to destructive interferences of the LNA noise injected in the booster. To perform a physics measurement, a model describing the system noise temperature is needed, which includes pre-amplifier parameters, propagation lengths and couplings of the different booster components. Dedicated measurements have been performed to derive these parameters. They are also used to model the boost factor, which is expected to be about 1000. The analysis is on-going and should enable to perform a first ALP search around 19 GHz, corresponding to 78.5 μeV, see Figure 4 bottom right. The programme for the 2024 slot is to test the already existing CB200 at room temperature and test CB100 at liquid helium temperature in a "home-made" G10 cryostat built by the CERN cryolab team. This should lead to a sensitivity beyond the current reach set by the CAST experiment [24], see Figure 4 bottom right.

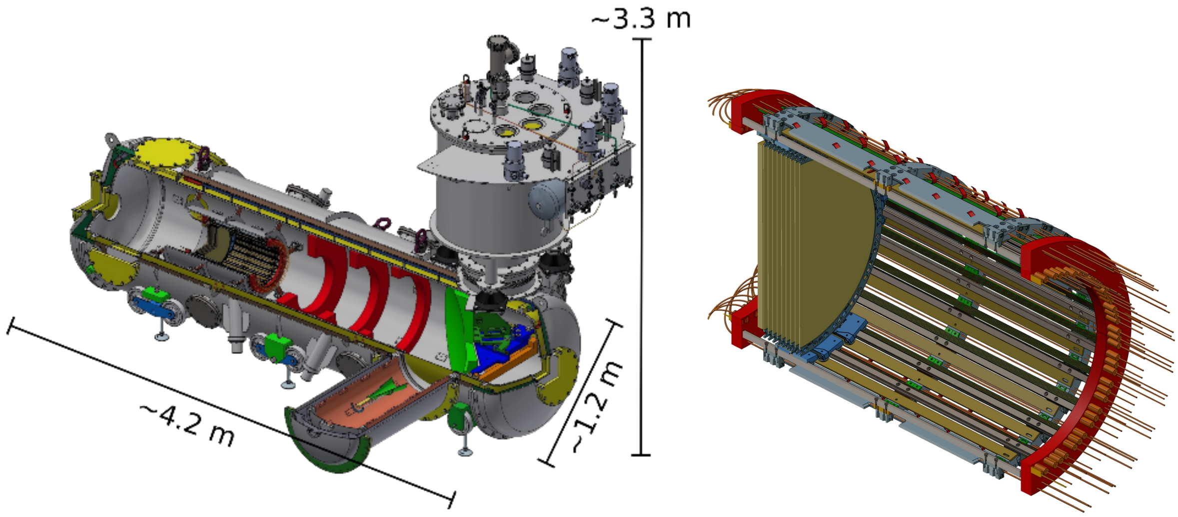

Figure 5: Sketch of the prototype cryostat (left) and of the OB300 booster (right).

The prototype programme should be completed by a test of OB300, an open booster composed of 3 to 20 moveable discs of 300 mm diameter. It will be operated in a prototype of the MADMAX cryostat (Figure 5 left) currently in construction. The first discs for OB300 have already been produced and the booster mechanics is presently being finalized and will be completed by the end of 2023 (Figure 5 right). The booster assembly and cryostat certification will happen in 2024 at DESY in an RF shielded experimental hall. These tests will lead to search for ALPs of mass around 100 μeV. This will pave the road towards the final detector, to be operated at DESY after 2028 with a strong discovery potential. The overall schedule of the project is summarized in Figure 6.

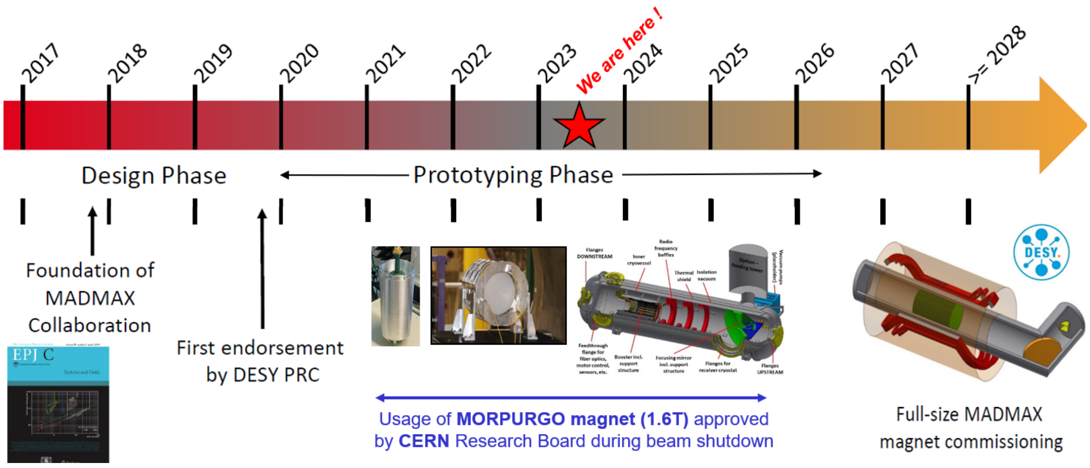

Figure 6: Foreseen schedule for the MADMAX experiment.

Scientific reviews of the MADMAX project have already been conducted at DESY (PRC) and at CERN (SPSC). The CERN Research Board has endorsed the use of the Morpurgo magnet to test the prototypes. An excerpt of the recommendations from the DESY Physical Review Committee [25] is given below:

- Physics: "The committee enthusiastically endorses the physics goals of the MADMAX proposal, claiming ultimate sensitivity for a very large axion frequency range 10–100 GHz in two phases"; "there are several straightforward models of cosmology that lead to axions in the frequency range targeted by MADMAX to be the dominant contribution to dark matter";

- Technology: "The committee is impressed by the ingenuity of this new method to search for axions as dark matter particles in the frequency range of 10–40 GHz (40–160 μeV) in first phase and 40–100 GHz (160–400 μeV) in second phase"; "Despite being well-motivated the targeted mass range is very difficult to reach in other experiments. Therefore, this presents a unique window of opportunity where the MADMAX collaboration is at least several years ahead of potential competitors."

- Overall: "Therefore, the MADMAX experiment has significant discovery potential not only for a new particle, but also for discovering a main constituent of dark matter."; "The detection of axions will open the field of axion astrophysics and provide insight to the formation of galaxies, but also the strong interactions and it will most certainly secure a Nobel Prize for the experiment."

To conclude on the overall MADMAX project, the prototyping phase has started in 2021. It should end in 2026 after the finalisation of the prototypes realisation and tests that will pave the road for the final detector design.

4 IN2P3 contributions and prospects

As described in section 3, MADMAX is presently conducting a staged cutting-edge R&D phase. The tasks are shared within the collaboration, and we first mention French contributions, before detailing IN2P3 contributions:

- The receiver system needs challenging developments of (close to) quantum limit detector at 10 GHz with prospects to increase the frequency range up to 30 GHz. A first travelling wave parametric amplifier (TWPA [26]) for frequencies up to 12 GHz has been produced and characterized by the NEEL institute from Grenoble (INP) [27].
- The dipole magnet for the final experiment should reach a B^2A value around 100 T^2m^2, which is unique and very challenging[2]. CEA-Saclay is one of the two innovation partners of MADMAX (outside of the collaboration) for this project. A demonstration of quench detection feasibility has been conducted successfully [28], representing the most important milestone for a safe operation of the magnet. The construction of a demonstrator setup is presently being prepared.

CPPM is part of the MADMAX collaboration since 2020, following positive recommendations of the CPPM scientific council (see Appendix A). It has commitments in the mechanical realisation of the prototypes booster as well as in the data taking of the prototypes at CERN. Its contributions can be summarized as:

1. <u>Precision mechanics</u>:

   - Fabrication of the disc support rings for the prototype boosters. CPPM is responsible for the design and construction of the mechanical structure to hold the discs and connect them with the piezo motors (called rings) that will allow to move them precisely. Indeed, MADMAX needs a very precise mechanics of its moveable dielectric discs in order to reach its physics goals, with a planarity at the level of 10 microns. Moving the discs is a key feature to scan the axion mass, the distance between the discs (from millimeters to centimeters) being inversely proportional to the mass of the searched axion. After an intensive and successful R&D made in 2021, a first support ring of 20 cm diameter has been built (Figure 7 top left), meeting all the specifications. One disc has been inserted into this ring and has been installed in the P200 prototype with minor change in shape (Figure 7 bottom). The RMS of the measurements is below 10 μm for each disc side, before and after its mounting on the ring. Work is ongoing for 30 cm diameter rings, needed for the other prototypes. The goal is to construct 3 support rings for the next prototype, composed of 3 discs of 30 cm for tests in 2024, and up to 20 discs for tests in 2025.
   - Precision 3D measurement of discs and rings for the prototype boosters. CPPM exploits its recognized expertise in 3-dimensional measurements, largely developed for ATLAS pixel detectors, to precisely measure the geometry of the prototype

[2] For the final MADMAX, two times nine double pancake skateboard coils need to be constructed using NbTi as superconducting cable strand.

dielectric discs before and after they have been inserted in the rings. They have to be controlled at the micron level. Several discs have already been measured with micrometer precision (Figure 7 top right). The main task will be in 2024/2025 for the 20 discs prototype booster.

- Integration of the prototype booster in the crytostat. CPPM is designing a supporting structure to position the prototype booster in the cryostat, see Figure 5. With adjustable rails, the structure will allow to align the booster with respect to the other elements of the prototype. The mechanical design is ongoing and the construction should be achieved in 2024. Moreover, CPPM has to deliver the installation tools for the insertion of the booster and of the focusing mirror in the cryostat. This integration will first happen in Hamburg in 2024 and then at CERN in 2025, for which two different set of tools are needed.

2. Coordination of the prototype tests at CERN. Since the approval by the September 2020 CERN council of the usage of the Morpurgo magnet (located on the H8 line in the North area in Prévessin) during the beam shutdown [22], CPPM is in charge of coordinating the activity at CERN around the Morpurgo magnet and is responsible for the tests. This includes the complete refurbishing of the zone (Figure 4 top left) and the fabrication and installation of the mechanical infrastructures for the prototype tests at warm and at cold. For warm tests, CPPM has produced and installed the rails to slide the electronic racks, and the support plate for the prototype (see Figure 8). This is completed since January 2022. For cold tests, CPPM has built and will install the rails for the prototype cryostat. This has represented the main financial investment. In the future, minor adjustments of the infrastructures will have to be done. As detailed in section 3, tests of the CB100 and P200 have already been done in 2022 and 2023, and the test programme will continue in 2024 and 2025 with bigger prototypes and at cold.

3. Simulation and data analysis. A PhD student started his thesis at CPPM in october 2022 and is presently working on the simulation tools developed by the MADMAX collaboration [29, 30] to optimise the OB300 booster that will be included in the prototype cryostat. The planarity and thickness of four discs have been measured at CPPM (see above) and only three will integrate OB300. The optimal disc positions and orientations in the booster are presently being derived from the simulations. We also participate to the data analysis of the P200 and CB100 data collected in 2022 and 2023, that will lead to two publications.

Besides these ongoing activities at CPPM, 3 scientists from IJCLab (2 physicists and 1 engineer) have the will to join the MADMAX collaboration in the coming months. Their possible involvement, already discussed with the MADMAX collaboration, still has to be precisely defined but could be centered on the noise mitigation. As this involvement is still the subject of internal discussions at IJCLab, it is not further discussed in this document.

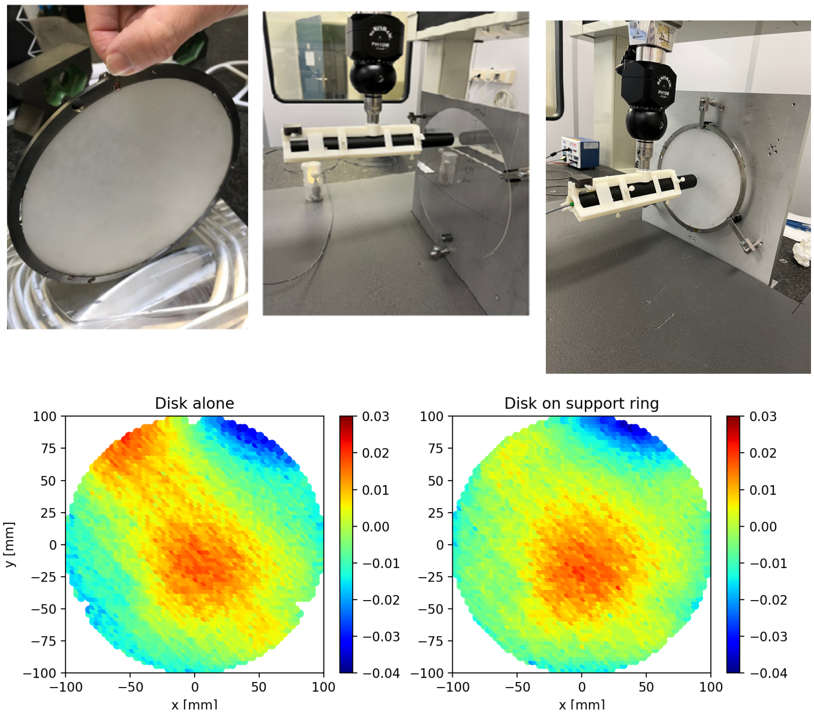

Figure 7: Pictures of the first MADMAX disc mechanical support designed and built at CPPM with a sapphire disc mounted, used for P200 (top left) and of the 3D optical setup used to measure the disks (top center and right). Bottom: Precise measurement in vertical position of one disc surface flatness before (left) and after (right) its mounting on the support ring. The color scale unit is in mm.

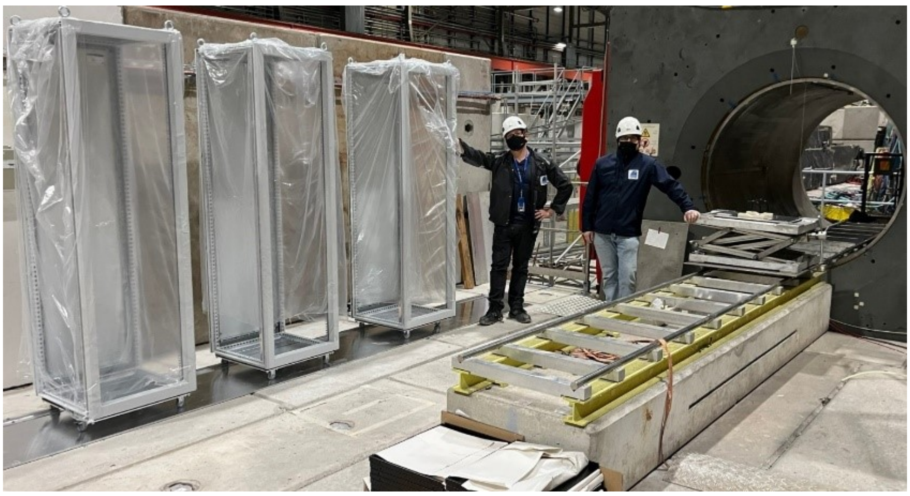

Figure 8: Installation of the mechanical infrastructures around the Morpurgo magnet at CERN by CPPM members.

Our contributions to MADMAX are the first experimental activities at IN2P3 on the well-motivated and promising field of direct axion search. This is in line with statements from the last APPEC strategic document (see section 2) and from the October 2018 IN2P3 scientific council [31]: "Il faut noter que les axions sont un candidat générique à la matière noire, également physiquement motivé, et ce depuis plusieurs dizaines d'années. L'un des piliers des WIMPs étant mis à mal par l'absence de signe de nouvelle physique dans les résultats du LHC, cette alternative doit être gardée à l'esprit (. . .)". Participating actively to the MADMAX medium-scale experiment will allow to increase the French visibility in the dark matter field, at low cost with respect to the high discovery potential. This is moreover complementary to ongoing IN2P3 involvement in direct searches for WIMPs. Note that a workshop will take place in Annecy in September 2023, in the framework of the "Intensity Frontier" GDR, gathering the French community on axions and other light particles. We will present the MADMAX status. Last but not least, the "CNRS Helmholtz Dark Matter Laboratory" DMLab, an International Research Laboratory (IRL), was created on Jan 1, 2023 by CNRS/IN2P3 and is located at DESY. In DMLab, CNRS partners with the Helmholtz centers DESY, GSI and KIT. The aim is to address various challenges in dark matter physics in French-German cooperation. The prominent topic is the direct dark matter searches and MADMAX is recognized as central project in DMLab.

5 IN2P3 human and financial resources

The MADMAX collaboration, which was formed in 2017, consists of ∼50 scientists from 10 institutes from Germany, France, Spain and USA. The current physicists and engineers from IN2P3 who are part of the MADMAX collaboration are shown in Figure 9. As of today, this amounts to 4 FTE: 2 FTE physicists (shared between permanent and PhD) and 2 FTE permanent engineers. The PhD has been recruited end of 2022, as a "thèse internationale" from the CNRS/MITI AAP thanks to the DMLab. As mentioned in section 4, scientists from IJCLab will probably join the collaboration in the coming months. As this involvement is still the subject of internal discussions at IJCLab, it is not yet included/quantified in Figures 9 and 10.

We have the following responsibilities in the MADMAX collaboration: member of the collaboration board (F. Hubaut), technical coordinator in 2020 and since 2023 (P. Karst), coordinator of the CERN tests and member of the MADMAX Physics Board (P. Pralavorio). At CPPM, F. Hubaut is the scientific coordinator and P. Karst is the technical coordinator. Finally, F. Hubaut is coordinator of the MADMAX IN2P3 master project. We acquired visibility in the collaboration very quickly, and are part of all executive bodies of the MADMAX collaboration (technical coordination, collaboration board and physics board). Note that P. Karst became the technical coordinator of the collaboration in 2020, had to stop after one year for personal reasons and resumed in this role since September 2023.

Nom des personnes	Statut	2021	2022	2023	2024
CPPM		**100%**	**125%**	**200%**	**200%**
Hubaut	DR	50%	50%	50%	50%
Pralavorio	DR	50%	50%	50%	50%
Dahbi	PhD		25%	100%	100%
TOTAL (FTE)		**1,00**	**1,25**	**2,00**	**2,00**

Nom des personnes	Statut	2021	2022	2023	2024
CPPM		**180%**	**200%**	**200%**	**210%**
Beurhey	IR	10%	10%	10%	10%
Karst	IR	50%	60%	80%	90%
Gallo	IE	40%	40%	40%	30%
Labat	IE	80%	90%		
Roset	AI			70%	80%
TOTAL (FTE)		**1,80**	**2,00**	**2,00**	**2,10**

Figure 9: IN2P3 physicists (top) and engineers (bottom) in the MADMAX project.

Since the approval of the “fiche de projet” end of 2022 [32], IN2P3 has been participating to the funding of our activities in MADMAX: 23 (resp. 7) k€ have been allocated to CPPM in 2023 (resp. 2022), as seen in Figure 10 top. This table also synthesizes the requests to IN2P3 for 2024–2025, which cover the construction and tests of the MADMAX prototypes. They should mainly allow to cover the construction of the prototypes booster mechanics and the construction of the interfaces between the prototypes and the Morpurgo magnet at CERN. On top of that, around 3 k€ have been allocated in 2022 and 2023 by the DMLab to CPPM for missions to DESY of the international PhD and for the DMLab annual meeting. As indicated in Figure 10 bottom, the project activities since 2019 have been funded by CPPM “ressources propres” (RP), an IEA (International Emerging Actions, in 2020–2021 for a total of 11 k€) and a PHC (Programme Hubert Curien, in 2020–2021 for a total of 18 k€ allocated to missions and which have not been spent because of Covid). It should be noted that an ANR/DFG PRCI proposal is submitted every year, so far without success.

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	2021	2022	2023	2024	2025
Equipements	**- €**	**7 000 €**	**13 000 €**	**40 000 €**	**40 000 €**
Mécanique du booster proto			10 000 €	30 000 €	30 000 €
Interfaces CERN		7 000 €	3 000 €	10 000 €	10 000 €
Missions	**- €**	**- €**	**10 000 €**	**12 000 €**	**12 000 €**
Missions PhD DESY/CERN			4 000 €	5 000 €	5 000 €
Missions groupe DESY/MPI			4 000 €	5 000 €	5 000 €
Missions ingénieurs CERN			2 000 €	2 000 €	2 000 €
TOTAL	**- €**	**7 000 €**	**23 000 €**	**52 000 €**	**52 000 €**

	Financements	2021	2022
Equipements		**70 000 €**	**16 000 €**
Mécanique du booster proto	IEA+RP labo	12 000 €	13 000 €
Interfaces CERN	IEA+RP labo	58 000 €	3 000 €
Missions		**1 000 €**	**3 000 €**
Missions groupe DESY/MPI	PHC+RP labo		2 000 €
Missions ingénieurs CERN	RP labo	1 000 €	1 000 €
TOTAL		**71 000 €**	**19 000 €**

Figure 10: Financial funds from IN2P3 (top) and from outside (bottom).

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A Excerpt from the CPPM scientific council

Extraits du compte-rendu de la séance du 20 mai 2020 du CS du CPPM :

"Le conseil scientifique tient à féliciter les promoteurs de l'équipe pour la clarté et la qualité de leurs exposés écrits et oraux. Le conseil est impressionné par l'étude prospective raisonnée, qui les a conduits à choisir les projets DarkSide et MadMax pour leurs futures activités. Le conseil scientifique souligne la pertinence de ce choix dans le contexte actuel : l'absence d'observation directe de nouvelles particules dans le domaine du TeV (prédites, par exemple, par la supersymétrie) et la nécessité d'aller explorer d'autres domaines pour répondre aux questions ouvertes actuelles. (. . .) De son côté, MadMax concrétise une idée originale proposée récemment pour explorer une partie jusqu'ici inaccessible du domaine de masse autour de 100 μeV favorisé pour un Axion qui pourrait expliquer à la fois la conservation de CP par l'interaction forte et la matière noire de l'Univers. Le conseil scientifique approuve le choix de ces deux projets et les engagements techniques proposés car ils sont en parfaite adéquation avec les compétences du CPPM. (. . .) L'activité initiée sur MadMax est très structurante pour cette collaboration : le Laboratoire y assume la coordination technique, ce qui lui donne une grande visibilité internationale et a contribué à consolider significativement le projet en termes d'organisation; par ailleurs, les développements menés sur les mesures mécaniques 3D des plaques d'amplificateur photonique seront un des points clefs de ses performances, et s'appuient au mieux sur les compétences acquises par le CPPM sur la mécanique de précision des détecteurs de vertex. De plus, l'équipe du CPPM a été pionnière avec DESY dans la construction d'un projet de laboratoire international de recherche IRL CNRS-Helmholz. Ce projet est en état avancé de discussion à présent. Aussi, l'implication des promoteurs de l'équipe dans les projets DarkSide et MadMax devrait leur permettre d'obtenir des résultats scientifiques majeur dans les dix prochaines années. Concernant ce dernier point, le conseil scientifique tient à féliciter l'implication actuel des promoteurs de l'équipe sur des analyses du projet DarkSide-50 et tiens à souligner l'importance de participer à ces analyses avant la mise en service des expériences DarkSide-20K et MadMax.

Recommandations :

- Le conseil scientifique (CS) recommande fortement à la direction du CPPM d'approuver la création de cette nouvelle équipe "Matière Noire".
- Le CS recommande à la direction du CPPM d'approuver la participation du CPPM dans les projets DarkSide et MadMax.
- Le CS soutient l'initiative du groupe de placer le prototype de MadMax dans l'aimant au CERN et prendre les premières données de recherche d'Axion pour un domaine en masse autour de 100 μeV pendant les arrêts techniques de SPS.

(. . .)"