A European Coordination Network for Dark Matter Infrastructures (DMInfraNet)

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We propose a "Dark Matter Infrastructures Network" (DMInfraNet) for the coordination and support of activities related to dark matter research in Europe and beyond.

I. INTRODUCTION

Elucidating the nature of dark matter is one of the grand challenges of subatomic physics. Consequently, a whole slew of experimental activities is currently ongoing, or being planned, in all parts of the world. These activities cover a large variety of theoretical hypotheses for dark matter candidates and also of experimental techniques.

The absence of a dark matter signal to date means that it is important that all masses and coupling hypotheses of dark matter candidates are covered. The search for dark matter therefore encompasses a variety of approaches:

- direct search for dark matter in the local dark matter halo;
- searches for dark matter candidates produced in the laboratory or the sun;
- indirect search for dark matter through searches for mediator particles/searches for new particles in models with new sectors providing a dark matter candidate.
- indirect searches looking for annihilation products (gamma-rays, neutrinos, ...) of dark matter particles

The first case will directly uncover the nature of dark matter, the second provides us with candidates for dark matter constituents, while the third and fourth cases would open up concrete ways to identify dark matter in future experiments.

The direct detection of dark matter was recently reviewed by APPEC [1]. The 2020 update of the European strategy update [2] contained several remarks on dark matter searches [3] :

- "The particle physics community must further strengthen the unique ecosystem of research centres in Europe. In particular, cooperative programmes between CERN and these research centres should be expanded and sustained with adequate resources in order to address the objectives set out in the Strategy update."

- "A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy. Experiments in such diverse areas [as dark matter and the exploration of flavour and fundamental symmetries (the authors)] that offer potential high-impact particle physics programmes at laboratories in Europe should be supported, as well as participation in such experiments in other regions of the world."

These comments underlined the need for enhanced networking initiatives at the European level. In this context the *Initiative for Dark Matter in Europe and beyond* (iDMEu) was created, stemming out of a joint ECFA-NuPECC-APPEC (JENAS) symposium [4]. iDMEu is a collective effort by a group of particle and astroparticle physicists aiming to set up an online resource meta-repository, a common discussion platform and a series of meetings on everything concerning Dark Matter.

In this paper we propose to complement iDMEu by encouraging and fostering the collaboration of the involved institutions on technical, scientific, organizational and funding aspects in the search for dark matter. We suggest the creation of a European (and beyond) coordination network for the related dark matter activities - the Dark Matter Infrastructures Network (DMInfraNet). We aim at bringing the topics discussed below to the attention of the 2026 update process of the European strategy, possibly resulting in a reference in the update strategy and the recognition as a CERN-supported activity.

II. DARK MATTER ACTIVITIES AND INFRASTRUCTURES IN EUROPE

The necessary technical effort for dark matter experiments often surpasses the abilities of a single group or institute, frequently requiring significant infrastructures. Among these are e.g. underground labs, accelerators, substantial cryogenic installations, strong and large-volume magnetic fields, standardized and large-scale read-out and data management systems, etc.

Locally, these infrastructures are normally complemented by dedicated expertise. The facilities and experiments address a whole slew of dark matter candidates at different mass scales — ranging from the very light WISP-like particles in the (sub-)eV region over light particles in the keV-GeV range up to massive WIMPS and primordial black holes.

The activities are a matrix of labs hosting infrastructure and the actual experiments. While the former is mainly national or regional, the latter are international. Therefore we subdivide the following section into underground facilities accelerator facilities and experiments.

A. Underground facilities and related infrastructures

Underground facilities play a crucial role in low background DM searches. The main facilities in Europe are:

- Boulby in the UK: a dark matter research facility and provider of facilities for large scale material tests
- Gran Sasso (LNGS) in Italy: the largest underground laboratory in the world devoted to neutrino and astroparticle physics
- Modane (LSM) in France: one of the deepest labs in the world in the tunnel of Frejus
- Canfranc (LSC) in Spain: 780 m deep below the Pyrenees at Canfranc.

In addition to these large facilities infrastructures and expertise is available in many labs:

- EACH SIGNING LAB SHOULD HAVE AN ENTRY EITHER HERE OR IN THE NEXT SECTION
- NAME OF LAB.....
- University of Zaragoza:..
- Subatech Nantes: designed and patented the cryogenic system Restox for the Xenon experiment.
- LPNHE Paris: XeLab a cryogenic TPC test platform

B. Accelerator related facilities

Prominent examples for accelerator facilities providing beams for indirect and direct dark matter searches are:

- CERN [5]: the SPS provides the beam for the bemas for fixed target/beamdump experiments
- LNF: the Beam Test Facility (BTF) provides an intense beam of positrons, e.g., provides the the positron beam from the DAΦNE Linac to the PADME experiment.
- DESY: the ELBEX beamline at the European XFEL will provide high rates of 17 GeV electrons.
- ELSA [6]: provides an intense electron beam of 3.5 GeV for the Lohengrin experiment.

Accelerator related infrastructures are magnets and RF cavities as well as cryogenics and mechanical platforms. RF-cavities are part of the signal detection chain for dark matter experiments. Here are some examples:

- ADD YOUR LAB HERE
- NAME....:
- DESY (Hamburg): DESY provides a 1.2 T magnet for the test beam (PCMAG), is working on a 9 T magnet. DESY also plans a versatile magnet infrastructure on a movable platform. The cryo-platform at DESY, a versatile cryogenic facility provides helium at 4K to up to three experiments in the HERA north area. DESY's expertise in RF is essential for signal detection.
- Mainz hosts the MAMI accelerator for electrons up to 1.6 GeV. MAMI mostly serves experiments inquiring into the structure of hadrons, but MAMI also allows e.g. for tests of nuclear models important for neutrino experiments, and for other other BSM-related measurements.
- LNF (Frascati): infrastructure for axion searches and hosts the QUAX and PADME experiments
- LNL (Legnaro): provides the infrastructure for axion searchs hosting several QUAX experiments
- CEA: leading expertise in magnet design
- IJCLab: important platforms in Orsay are the expertise on RF and its cryo-platform.
- CPPM Marseille: precision mechanics from pixel detector development applied to dark axion searches
- IFIC Valencia: **[AI-Valencia: The IFIC High-Gradient (HG) Radio-Frequency (RF) laboratory hosts a high-power infrastructure for testing HG S-band normal-conducting RF**

accelerating structures to the study of HG phenomena. In addition, IFIC will be the host of a carbon ion accelerator. This accelerator has started construction.]

C. The DRD collaborations

The DRD collaborations, cretaed as a follow up of the previous strategy update, are of great importance for collaborative detector development for dark matter searches: The Gaseous Detectors of **DRD1** are relevant for direct searches (TPCs) as well as as **DRD2** with liquid Detectors. Indirect searches rely heavily on the developments of **DRD4** semi-conductors and **DRD6** calorimetry. Transverse to both indirect and direct searches is the development of highly performant electronics in **DRD7**. Innovative approaches are pursued in **DRD5** quantum Sensors which enables sensitivity to sub-eV energy deposits from dark matter interactions.

D. Experiments

The experiments can be subdivided into different categories depending on the type of dark matter particle they are searching for. For simplicity no separation is made between experiments ongoing and in preparation.

The WIMP searches using liquified noble elements such as Argon and Xenon:

- XENONnT [7]: Utilizes a liquid xenon detector to search for signals of interactions between WIMPs and atomic nuclei, playing a leading role in the WIMP scenario search.
- LUX-ZEPLIN [8]: direct detection search for cosmic WIMP dark matter particles with a large liquid xenon time projection chamber installed at SURF.
- DarkSide [9]: Based on a dual-phase argon time projection chamber (TPC), under construction at LNGS, with the objective to achieve a 90% exclusion sensitivity for WIMP-nucleon cross-sections O($10^{-48} cm^2$) at 100 GeV WIMP mass scale.
- XLZD [10, 11]: collaboration of Xenon, LUX-ZEPLIN and Darwin to prepare the next generation Xenon experiment.
- GADMC (Global Argon Dark Matter Collaboration) [9]: Collaboration of DEAP, DarkSide, CLEAN and ArDM experiments to build a detector with a liquid argon mass above 20 tonnes (DarkSide-20k) at the LNGS.
- ARGO: a multi-100-ton experiments to reach the neutrino floor/fog at SNOLAB

There are several NaI-based experiments:

- DAMA/LIBRA [12]: Uses thallium-doped sodium iodide crystals to detect annual variations in the interaction rate of WIMPs with ordinary matter, claiming the observation of an annually modulated signal that could indicate the presence of WIMPs.
- ANAIS [13]: is based on about 100 kg of NaI(Tl) scintillators to measure Wimps, in particular the expected annual modulation expected from the earth's motion around the sun. The current results are inconsistent with DAMA-LIBRA.
- COSINUS [14]: Based on cryogenic scintillating calorimeters with undoped sodium iodide (NaI) crystals, providing an independent verification of the DAMA/LIBRA results with a different detection technology.
- SABRE [15]: Utilizes highly pure sodium iodide (NaI) crystals to detect dark matter, confirming or refuting the results of the DAMA/LIBRA experiment by comparing results from the southern hemisphere.

Experiments aiming primarily at lower masses are:

- CRESST [16]: For sub-GeV dark matter search, uses cryogenic detectors to search for dark matter signals through the interaction of WIMPs with the nuclei of target materials at extremely low temperatures, with improved techniques for discriminating beta/gamma background.
- TREX-DM [17]: searches for WIMPs with a low background chamber installed at the LSC with Micromegas operated with different Argon and Neon mixtures. Deisgned to detect WIMPs with massed of the order of 10 GeV, its sensitivity region is being extended to lighter masses below 1 GeV.
- DAMIC-M [18]: is based on Wimp detection with thick and ultra low noise CCDs to be installed at LSM.
- TESSERACT [19]: Multi experiment project of the installation of Transition Edge Sensors (TES) in the LSM in France. The experiments are expected to provide sensitivity down to masses of 10 MeV.

Developments for directional detection, aiming at increasing the sensitivity in the neutrino fog/floor are:

- DRIFT [20]: the experiment operated at Boulby is based on a low pressure gaseous chamber enabling detection of Wimp dark matter through directional measurements.
- CYGNO [21]: Employs a high-resolution gaseous time projection chamber (TPC) with optical readout using scientific CMOS (sCMOS) sensors, aiming to detect WIMPs with masses above 1 GeV, exploiting the directionality capability offered by high granularity readout.

- CYGNUS [22]: aims to exploit multiple TPC operated at atmospheric pressure to measure the direction of the nuclear recoil in WIMP-nucleous interactions to improve the sensitivity for dark matter searches when reaching the neutrino floor/fog.

Searches for axions and axion like particles are performed with:

- (Baby)IAXO [23]: IAXO is a helioscope designed to search for axions and axion-like particles produced in the sun, for which BabyIAXO is scaled version conceived to test all IAXO subsystems. BabyIAXO is expected to be sensitive to axion-photon couplings down to $1.5 \cdot 10^{-11}\mathrm{GeV}^{-1}$, and masses up to 0.25eV
- QUAX$_{a\gamma}$ [24, 25]: search for axion dark-matter through the axion-photon coupling with two Sikivie's haloscopes in a mass range around 40 μeV corresponding to frequencies of operation of about 10 GHz. Two haloscopes, located at LNL and LNF, are both composed by a resonant cavity surrounded by a superconducting solenoid-magnet and inserted in a dilution refrigerator.
- QUAX$_{ae}$ [26]: a ferromagnetic haloscope searching for axion dark matter
- QUAX$_{gpgs}$ [27]: search for a 5-th force induced by the monopole-dipole coupling mediated by a pseudoscalar boson.
- RadioAxion [28]: aims to detect axion dark matter by observing time-modulated changes in the decay constants of Americium-241 (alpha decay) and Potassium-40 (electron-capture decay).
- CADEx [29]: searches for axions at the LSC using a microwave resonant cavity haloscope in a high static magnetic field coupled to a highly sensitive detecting system. It is sensitive to masses of several hundred μeV.
- MADMAX [30]: the MAgnetized Disk and Mirror Axion eXperiment (MADMAX) employs a dielectric haloscope with precisely positioned sapphire disks and a mirror to resonantly enhance the axion-induced microwave signal in a strong magnetic field. The sensitivity is in the μeV mass range.
- ALPS II [31]: the second generation of the Any Light Particle Search experiment ALPS II has been in operation since 2024. It is a light-shining-through-a-wall-experiment looking for axions and similar particles in the sub-milli-eV regime.
- LUXE(-NPOD) [32]: will reach and go beyond the Schwinger limit at high energy and high intensity, it will also perform searches for axion-like dark matter particles using the accelerator as a beam dump.
- Lohengrin [6]: a light dark matter search experiment ELSA based on the fixed-target missing momentum based technique for searching for dark-sector particles.
- PADME [33]: the PADME experiment, is devoted to the search for any new light particle in the mass range 2 MeV $\leq M \leq$ 23 MeV. While originally focusing on probing various Dark Photon models, the chosen experimental technique is suitable also for addressing ALPs and light dark higgs-boson scenarios.
- SHiP [5]: designed to search for feebly interacting particles, search for light dark matter through recoil signatures.

???? At Hamburg University experiments on axions/a-like WISPFI, BRASS, WISPLC and WISPDMX. At Mainz axion-experiments like CASPER and SUPAX. At MPI Munich the RADES experiment on axions.

III. DARK MATTER: A EUROPEAN AFFAIRE

The infrastructures and experiments are collaboratively built and exploited by teams from many different countries. Some examples (in alphabetical order) are given in the following. This results in a strongly correlated matrix.

France For WIMP searches, the IN2P3 labs LPNHE Paris and Subatech Nantes are involved in the Xenon experiment at LNGS as well as being members of the XLZD collaboration. Both labs also participate in the DAMIC-M experiment which will be installed at LSM. The CPPM Marseille is involved in DarkSide.

CPPM Marseille and IJCLab are participating in the axion-like particle searches in the MADMAX experiment. Saclay is part of the BabyIAXO experiment.

The Tesseract project is carried by the IP2I Lyon, LPSC Grenoble and IJCLab

The expertise on highly granular calorimeters of IJCLab has led to participation in LUXE-NPOD as well as contributing to the study of the Lohengrin detector.

[CG: At Grenoble, GrAHal axion experiment, and the facility for intense magnetic fields EMFL. Also Laboratoire PhLAM (CNRS) with molecular clocks (variation of fundamental constants due to dm))]

Germany Dark matter searches in Germany have strong contributions from the Helmholtz centres DESY and KIT and also numerous activities at universities. At DESY, the international axion search experiments ALPS II, BabyIAXO and MADMAX are operated / prepared, as is the strong-field QED and new physics search experiment LUXE-NPOD. At KIT and at the Max Planck Institute for Nuclear Physics (MPI-K), the Darwin/XLZD experiment is pursued; MPI-K is also involved in XENON. University activities comprise the

ELSA machine and Lohengrin experiment (Bonn), activities at MAMI in Mainz, and also in Mainz and elsewhere the GNOME network of magnetometers for exotic fields.

Italy The activity for searching WIMP dark matter in Italy is mainly centered on one of the largest and most important infrastructures in the world: the National Laboratory of Gran Sasso (LNGS) of INFN. This facility, in collaboration with other worldwide and INFN laboratories, hosts very important experiments for the WIMPs and sub-GeV dark matter search.

Moreover, LNGS and INFN laboratories host many R&D projects (e.g., Nucleus, BULLKID, etc.) and collaborate worldwide on the dark matter search strategy [1], participating in the most important underground, cosmic rays, and space experiments, searching for direct and indirect dark matter candidates.

The search for light dark-matter candidates such as dark photons and axions is concentrated at the INFN National Laboratories of Frascati (LNF) and Legnaro (LNL) with some activity on this topic at LNGS and at EGO-VIRGO.

Frascati, explicitly mentioned in the previous European Strategy, has put together a program for dark matter search [34] which includes axion searches leveraging expertise, e.g., on RF cavities, and dark photon searches with a fixed target program of their beam test facility. This activity is carried out by two experiments PADME and QUAX@LNF. PADME exploits the positron beam at LNF

The QUAX$_{a\gamma}$ experiment has two haloscopes, located at LNL [24] and LNF [25]. A second haloscope will be build at LNF recycling a 3 m bore NbTi magnet for the FLASH experiment [35]. FLASH will search for high frequency gravitational waves and axions at a frequency around 100 MHz.

At LNL axions are searched through the axion-electron coupling with the QUAX$_{ae}$ experiment [26] and with the QUAX$_{gpgs}$ experiment [27].

At LNGS, the RadioAxion experiment [28] aims to detect axion dark matter.

Finally, dark-photon dark-matter that could couple to gravitational-wave interferometers was searched using data from Advanced LIGO and Virgo [36].

[SC: *I suggest including a mention to INFN and universities involved in dark matter underground experiments.]*

Spain for the direct detection of WIMPs and in close connection with the Canfranc Underground Laboratory, the University of Zaragoza is mainly involved in ANAIS and TREX-DM, CIEMAT in DarkSide-20K and IFCA in DAMIC-M. In Spain CADEx axion experiment at Canfranc and DALI experiment at IAC (Canarias). **[AI-Valencia: Additionally, the University of Zaragoza, IFIC Valencia and other groups are contributing to BabyIAXO for axions.]**

[AI-Valencia: IFIC is also involved in the preparation of LUXE, LUXE-NPOD and Lohengrin through its expertise on the development of collider detectors such as the highly granular electromagnetic calorimeter. IFIC is also contributing to the ELBEX project.]

UK In UK AION atom interferometer, Boulby.....

Austria is involved in the direct dark matter detection experiments CRESST and COSINUS hosted at LNGS. The MaglevHunt experiment, currently under construction, uses levitating mechanical sensor to detect DM and will be operated in Austria.

Others?

IV. THE STRATEGIC VALUE AND BENEFITS OF DMINFRANET

The raison d'être for DMInfraNet is that the next generation of experiments will mostly be beyond the scope of a single lab. Their preparation will thus require the timely — i.e. taking place now! — preparation of the necessary infrastructure and expertise, supported by a strong network of linked labs who bundle their competences to create significant synergies.

On the technical, scientific and organizational side, the DMInfraNet is designed to aim

- *Provide a mechanism to become a recognized experiment at CERN*
- for an improved flow of information on existing expertise, on available infrastructures and facilities, and on their planning;
- to set up the necessary communication structures and collaborative tools;
- to provide explicit support in the field of the network members' expertise;
- to provide access to the infrastructures and facilities;
- to provide a common framework for solutions to common questions such as a software eco-system;
- to implement a common approach to computing, data storage and data access issues, also in view of increasing open and FAIR data requirements.

Finally, on the funding side, it is the explicit interest of the network to prepare grounds for common future funding applications on the European level with the aim of setting up new experiments and necessary infrastructures for their development and construction at the various institute locations.

V. CONCLUSIONS

In summary, the Dark Matter Infrastructures Network DMInfraNet aims at providing support for a coherent search for dark matter across technologies, experiments, and institutions.

Beyond mutual technical, scientific and organizational support between the partners, the network is geared towards preparing common funding applications and, ultimately, be recognised as an official CERN-supported activity.

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