19th Patras Workshop on Axions, WIMPs and WISPs

Monday, 16 September 2024 - Friday, 20 September 2024

Book of Abstracts

Contents

Afternoon 2 / 2

Detectable Vector Dark Matter

Author: David Cyncynates[1]

[1] *University of Washington, Seattle*

Corresponding Author: davidcyn@uw.edu

Ultralight dark photons are compelling dark matter candidates, but their allowed kinetic mixing with the Standard Model photon is severely constrained by requiring that the dark photons do not collapse into a cosmic string network in the early Universe. In particular, the most minimal dark photon production mechanism is constrained to small kinetic mixings out of range of all proposed direct detection experiments. I will briefly review the origin of these stringent bounds. I will then address the question "what, if anything, are dark photon experiments searching for?"I will argue that the answer to this question motivates the search for correlated signatures if a dark photon is detected in any direct detection experiment.

Afternoon 2 / 3

Axions, Neutrinos, and Rare Decay Anomaly of Belle-II

Author: Newton Nath[1]

Co-authors: Chandan Hati [1]; Jose W F Valle [1]; Julio Leite [1]

[1] *IFIC Valencia*

Corresponding Author: newton.nath@ific.uv.es

Motivated by recent findings from Belle II, where $\mathcal{B}(B^+ \to K^+ \nu\bar{\nu}) = (2.3 \pm 0.5) \times 10^{-5}$, surpassing the Standard Model prediction by 2.7σ, we explore axion-based hypotheses to elucidate this discrepancy.
We examine a model based on the KSVZ-type axion, which not only accounts for the Belle II anomaly but also offers resolutions to the strong CP problem and neutrino mass generation through two-loop mechanisms.

Morning 1 / 4

ADMX Extended Frequency Range (EFR): Searching for 2-4GHz axions with 18 cavities

Author: Stefan Knirck[1]

[1] *Fermi National Accelerator Laboratory*

Corresponding Author: knirck@fnal.gov

ADMX-EFR (Axion Dark Matter eXperiment with Extended Frequency Range) will significantly scale up existing ADMX capabilities. To date, ADMX setups have probed the largest fraction of QCD dark matter axion parameter space at DFSZ sensitivity, using resonant conversion of dark matter axions to photons in a high-Q resonant cavity. ADMX-EFR will use a coherently power combined array of 18 cavities, leveraging a total cavity volume of about 200 liters. The detector is designed to cover the 2-4GHz range (8-16μeV axion mass) with DFSZ benchmark sensitivity over the course of 3 years. It will be enabled by a high-field, large-bore 9.4T MRI magnet, located in the Fermilab

Dark Wave Laboratory. In this talk we outline the conceptual design of ADMX-EFR based on experience from previous ADMX runs and present a detailed sensitivity estimate. We show progress of recent cavity and electronics R&D, including quantum-limited amplification and superconducting cavities.

Morning 1 / 5

Physical Signatures of Fermion-Coupled Axions

Authors: Asher Berlin[1]; Alex Millar[2]; Tanner Trickle[2]; Kevin Zhou[3]

[1] *NYU*

[2] *Fermilab*

[3] *Stanford/SLAC*

Corresponding Authors: asherberlin@gmail.com, knzhou@stanford.edu, amillar@fnal.gov

While there is an abundance of experiments searching for axion dark matter (DM) via its electromagnetic coupling, there are fewer utilizing its derivative coupling to electrons and nucleons. This direct coupling generates dynamical effects through the fermion spin, and therefore spin-polarized targets are a naturally useful target. We propose using spin-polarized or magnetized analogs of layered dielectric haloscopes, which are sensitive to axions through their coupling to electrons. These novel techniques can be powerful probes at both radio frequencies, with sensitivity to currently unexplored parameter space, and optical frequencies, with sensitivity comparable to current astrophysical bounds.

Morning 1 / 6

Direct Dark Matter search with the CRESST-III experiment

Author: Beatrice Mauri[1]

[1] *Max-Planck-Institut für Physik*

Corresponding Author: bmauri@mpp.mpg.de

CRESST-III (Cryogenic Rare Event Search with Superconducting Thermometers) is an experiment located at the LNGS underground laboratories in Italy, focused on the direct detection of low-mass dark matter particles via their scattering off nuclei in cryogenic detectors, using multi-target materials such as $CaWO_4$, Al_2O_3, $LiAlO_2$, and Si.
CRESST-III has the best sensitive calorimeters with a threshold below 100 eV, and it is currently one of the leading experiments in probing sub-GeV dark matter masses. However, an unexplained events population at very low energies (< 200 eV), the so-called "Low Energy Excess", is at the moment limiting the sensitivity of several dark matter experiments in the low mass region.
In this contribution, we present an overview of CRESST-III, highlighting its recent results and the plans for the future.

Morning 1 / 8

Latest Results from the LZ Dark Matter Experiment

Author: Qing Xia[1]

[1] *Lawrence Berkeley National Laboratory*

Corresponding Author: qingxia@lbl.gov

LUX-ZEPLIN(LZ) is a direct detection dark matter experiment located nearly a mile underground at the Sanford Underground Research Facility (SURF) in Lead, South Dakota, USA. Employing a dual-phase Time Projection Chamber (TPC) containing 7 tonnes of active xenon surrounded by veto systems, LZ offers world-leading sensitivity in detecting Weakly Interacting Massive Particles (WIMPs), a highly motivated dark matter candidate. Beyond the quest for WIMPs, the LZ experiment explores diverse new physics phenomena. This presentation will provide an overview of the LZ experiment and report on the most recent status in its operation and searches.

Afternoon 2 / 10

Search for dark photon dark matter using large-scale superconducting quantum computers as detectors

Authors: Shion Chen[None]; Yutaro Iiyama[1]

[1] *University of Tokyo/ICEPP*

Corresponding Authors: iiyama@icepp.s.u-tokyo.ac.jp, shion@cern.ch

Superconducting quantum computers can be ideal detectors for dark photon dark matters in many aspects such as (1) the macroscopically large coupling to photons of superconducting qubits; (2) large detection capacity from the platform that can host O(1000) such bits now and >O(10^6) bits in the near future [1]; (3) the optimal control and readout system minimizing the errors and noises; (4) frequency tunability allowing a wide-band search ability, and so on. In our recent work, we illustrated that a dark photon dark matter resonant to a qubit frequency can excite the qubit [2]. While the single qubit excitation probability can be as high as 10% after ~100us for \epsilon~10^-11, the dark count can be effectively suppressed below 1%. The signal rate can be further enhanced by entangling the qubits through the gate operations [3]. In this presentation, I will provide the overview of the search, discuss the experimental feasibility using the current NISQ machine as well as the prospect using the future FTQC machines, and present some preliminary search results using the IBM-Q.

[1] IBM-Q roadmap, https://newsroom.ibm.com/2023-12-04-IBM-Debuts-Next-Generation-Quantum-Processor-IBM-Quantum-System-Two,-Extends-Roadmap-to-Advance-Era-of-Quantum-Utility
[2] T. Moroi et al. Phys. Rev. Lett. 131, 211001 (2023)
[3] T. Sichanugrist et al. arXiv: 2311.10413

Note to organizers: Given the relevance and complementarity, it would be highly appreciated if this can be a joint talk with Karin Watanabe's contribution in case both are accepted (both are the works done within the same collaboration). Although these two abstracts share the same root idea, they pursue distinctively different approaches; one utilizes an existing fancy but sub-optimal device targeting quick results; the other involves a hardware development for the dedicated setup targeting rather longer term however can reach the ultimate sensitivity. We very much hope our works can deserve a joint talk however if one has to choose one of them, please consider to prioritize Karin Watanabe's contribution in the light of encouraging early career researchers.

Morning 5 / 11

Latest Results and Current Progress of ADMX G2

Author: Michaela Guzzetti[1]

[1] *University of Washington*

Corresponding Author: mguzz28@uw.edu

The Axion Dark Matter eXperiment (ADMX) is one of the world's leading direct detection searches for axion dark matter, currently located at the University of Washington. To date, ADMX G2 has excluded axion-photon couplings predicted by the KSVZ (DFSZ) model for the axion with masses between 2.66-4.2 µeV (2.66-3.3 µeV & 3.9-4.1 µeV). We are currently continuing the search for axion dark matter with masses between 4.13 - 5.78 µeV (1-1.4 GHz). In this talk I will present the latest results from this search, report on the current experimental status, and discuss our next steps.

Morning 2 / 12

Status and prospects of the DALI Experiment

Author: Javier De Miguel[1]

Co-authors: Elvio Hernández-Suárez [2]; Enrique Joven-Álvarez [2]; Chico Otani [3]; J. Alberto Rubiño-Martín [4]; Konstantin Zioutas [5]; (DALI Collaboration)

[1] *RIKEN, IAC, ULL*

[2] *IAC*

[3] *RIKEN*

[4] *IAC, ULL*

[5] *University of Patras*

Corresponding Authors: javier.miguelhernandez@riken.jp, konstantin.zioutas@cern.ch, otani@riken.jp

The Dark photons & Axion-Like particles Interferometer (DALI) proposes a new experimental setup to detect wavy dark matter: the magnetized phased array (MPA). In the MPA haloscope, a large flat mirror is housed in a solenoid-type magnet. The data acquired by each of the antennas forming the MPA are combined by post-processing similar to radio interferometry. A resonator can also be magnetized to enhance the faint signal originating from axion-to-photon conversion via the inverse Primakoff effect (or through kinetic mixing of dark photons), for which we employ a tunable Fabry-Pérot that enables quality factors of Q>20,000 within the ~25 to ~250 µeV range (6-60 GHz). Therefore, DALI can reach sensitivity to benchmark QCD axion models in a sector non-accessible to previous haloscopes.

This versatile experimental approach has synergies with: (A) the dish-antenna haloscope—with the profit that the MPA allows to magnetize more strongly a flat mirror since it fits in a superconducting magnet bore—; (B) the dielectric haloscope—with the advantage that DALI employs a common solenoid instead of a challenging, and much more expensive, large dipole magnet of long and costly construction—; (C) the plasma haloscope—since an MPA would allow the magnetization of metamaterials with a larger surface area—; (D) and even the resonant-cavity haloscope—as the same DALI method for channel combination is potentially transferable to multicavity haloscopes proposed for high-frequency scanning.
DALI brings additional benefits for the *dark sector* detection community: (i) it incorporates an altazimuth mount that improves sensitivity to transient events such as substructures; (ii) DALI, with its MPA architecture, is capable of scanning two (or three) resonant frequencies simultaneously within its band, thus doubling (tripling) its scanning speed; (iii) DALI is designed to require only available equipment, which renders the experiment cost-effective while giving it faster readiness in a highly competitive axion search landscape.

Starting in 2018, the DALI project is currently in the prototyping phase. In this talk, we will also expand on its status, and a proof of concept run in preparation.

Afternoon 2 / 13

ALPs decay in the cosmic background

Authors: Sara Porras Bedmar[1]; Manuel Meyer[2]; Dieter Horns[3]

[1] *University of Hamburg*

[2] *University of Southern Denmark*

[3] *Universität Hamburg*

Corresponding Authors: dieter.horns@desy.de, mey@sdu.dk, sara.porras.bedmar@desy.de

The Cosmic Background (CB) is defined as the isotropic diffuse radiation field with extragalactic origin found across the electromagnetic spectrum. Assuming that dark matter consists of axions with masses on the order of electron volts or higher, we expect a contribution to the CB due to their decay into two photons. Using a model of the astrophysical origin of the CB between X-ray energies and optical wavelengths, we include the contribution of decaying axions. Through a comparison with the most recent direct and indirect CB measurements, we derive novel constraints on the axion parameter space and improve previous limits derived from the CB by roughly an order of magnitude. We also study the contribution of axions decaying in the Milky Way halo and characterize the axion parameters that would explain the excess CB emission observed with the LORRI instrument on-board the New Horizons probe.

Morning 1 / 14

BelleII excess & Muon g-2 illuminating Light DM with Higgs Portal

Authors: Jongkuk Kim[None]; Pyungwon Ko[1]; Shu-Yu Ho[1]

[1] *KIAS*

Corresponding Authors: phyhunter2006@gmail.com, pko@kias.re.kr, jongkuk.kim927@gmail.com

The Belle II collaboration recently announced that they observed the B$\longrightarrow$ K$\nu\nu$ decay process for the first time. However, their result encounters a 2.7σ deviation from the Standard Model calculation. Additionally, Fermilab released new data on muon g -2 away from the SM expectation with 5.1σ. In this talk, I would like to talk about the simplest UV-complete U(1)Lμ−Lτ-charged complex scalar Dark Matter model. Thanks to the existence of light dark Higgs boson and light dark photon, I can explain the observed relic density of DM and resolve the results reported by both Belle II and Fermilab experiments simultaneously. As a byproduct, the Hubble tension can be alleviated.

Morning 1 / 15

First Results of a new Haloscope Setup at Mainz and Prospects for Detecting Ultra High Frequency Gravitational Waves

Authors: Kristof Schmieden[1]; Matthias Schott[2]; Tim Schneemann[1]

[1] *Johannes Gutenberg-Universität Mainz*

[2] *Rheinische Friedrich-Wilhelms-Universität Bonn*

Corresponding Author: tschneem@students.uni-mainz.de

We present the first results for a new microwave cavity haloscope based in Mainz, Germany. Over the past 2 years the experiment has been planned, constructed and now yields the first result in the search for dark photons within a frequency range of approximately 0.1 MHz centered around 8.47 GHz.
This result has been achieved by using a NbN-coated superconducting cavity, which differs inherently from the typical HTS approaches utilizing REBCO or YBCO tapes for superconductivity. In this context the entire setup has been characterized with and without application of an external 14.1 T magnetic field for subsequent searches for axions and gravitational waves.

Furthermore we present a new analysis approach to search for high-frequency gravitational waves (GW) emitted by primordial black hole mergers while explicitly taking into account the often overlooked maximum signal duration inherent in these transient events.

This approach allows any RF-cavity based haloscope to participate in a global network collaboration of GW detectors yielding superior sensitivity to transient events with the ability to resolve the direction of the GW source.

Afternoon / 16

Probing Axions and Axion Like Particles through Cosmic Axion Spin Precession Experiment- High-field

Authors: CASPEr Collaboration[None]; Malavika Unni[None]

Corresponding Author: unnimala@uni-mainz.de

Cosmic Axion Spin Precession Experiment (CASPEr) [1,2,3] investigates pseudoscalar bosons, axions, and axionlike particles (ALPs), through their interactions with standard model particles. Axions offer a solution to the formidable strong CP problem and provide a compelling link to Dark Matter. In this work, we study the coupling of the axion and ALP field with fermions. Utilizing Nuclear Magnetic Resonance (NMR) spectroscopy, we search for the coupling between Axions (and ALPs) and nuclear spins. In the CASPEr highfield setup featuring a 14.1 T superconducting magnet, we explore the frequency range of the axion field from 70MHz to 600 MHz using tunable LC circuits cooled to cryogenic temperatures. In conjunction with a shim coil integrated into the cryostat, we employ an additional shim stack to ensure field homogeneity. We also examine various hyperpolarization techniques and identify the most suitable samples for achieving high sensitivity. The poster presentation will elaborate further details on our experimental setup and the NMR-detection system.

[1]. D. F. J. Kimball et al. "The Search for Ultralight Bosonic Dark Matter"Cham: Springer International Publishing, 2022, ISBN: 978-3-030 95851-0
[2]. P. W. Graham, S. Rajendran, Phys. Rev. D 88, 035023 (2013)
[3]. D. Budker, P. W. Graham, M. Ledbetter, S. Rajendran, A. O. Sushkov,
Phys. Rev. X 2014

Afternoon / 17

Search for Ultralight DM with SNIPE Hunt Experiment.

Author: Abaz Kryemadhi[1]

[1] *Messiah University*

Corresponding Author: akryemadhi@messiah.edu

Ultralight dark matter, such as from dark photons or axion-like particles, can produce a coherent oscillating magnetic field signal at the Earth's surface, arising from the boundary conditions of the

conductive Earth and the ionosphere. The Search for Non-Interacting Particles Experiment (SNIPE) Hunt collaboration utilizes a network of magnetometers placed in RF quiet locations to detect these signals. In our first science run, we established tighter limits on axion-like particle couplings and dark photon mixing parameters for frequencies ranging from 1 to 5 Hz. Efforts are underway to broaden the search to higher frequencies and increase measurement sensitivity. Results from our first science run and current work will be presented.

Afternoon / 18

The Beehive Haloscope: A Strongly Coupled, Phase-Coherent Cavity Array for Axion Detection

Author: Matthew Withers[1]

Co-author: Chao-Lin Kuo [2]

[1] *Stanford University*

[2] *Stanford University and SLAC National Accelerator Laboratory*

Corresponding Authors: withersm@stanford.edu, clkuo@stanford.edu

We present the first experimental study of the "beehive"haloscope recently proposed in [https://arxiv.org/pdf/2404.06627]. Extending the haloscope detection technique toward the post-inflationary mass range (> 4 GHz) suffers from the $d\nu/dt \propto \nu^{-6}$ scaling. The proposed array geometry evades the sensitivity degradation by employing an arbitrary number of overlapping cylindrical cells. Strong coupling between the cells significantly relaxes manufacturing and assembly tolerances and eliminates the need for phase-locking and readout chain proliferation inherent in other cavity array proposals. In this work, results from a first 5-7 GHz room temperature prototype will be discussed. The beehive design is part of a focused program "ADMX-VERA"that targets the cm-wavelengths. The geometry inherits many appealing properties from the conventional coaxial cavity: high Q, compatibility with a solenoid magnet, and simple tuning. This novel and yet simple design has excellent prospects of scaling up to a detector volume greater than several hundred λ^3.

Afternoon / 19

Searching for dark matter with a 1000 km baseline interferometer

Authors: Daniel Gavilán Martín[1]; Grzegorz Łukasiewicz[2]

Co-authors: Arne Wickenbrock [3]; DMITRY BUDKER [4]; Derek Jackson Kimball ; Emmanuel Klinger ; Mikhail Padniuk ; Nathaniel Figueroa ; Szymon Pustelny

[1] *JJohannes Gutenberg-University Mainz*

[2] *Jagiellonian University*

[3] *Johannes Gutenberg University Mainz*

[4] *Helmholtz Institute Mainz*

Corresponding Authors: danielgavilan1999@gmail.com, gregory.lukasiewicz@gmail.com, wickenbr@uni-mainz.de, budker@uni-mainz.de

Axion-like particles (ALPs) arise from well-motivated extensions to the Standard Model and could account for dark matter. In the Milky Way, ALP dark matter constitutes a field oscillating at an as yet unknown frequency. We directly search for such particles through the nucleon interaction. We interfere the signals of two atomic K-3He comagnetometers situated in Mainz, Germany, and in Krakow, Poland. We take into account the ALP dark matter temporal and spatial coherence properties, assuming the Standard Halo Model, to improve the sensitivity and exclude spurious candidates.

The search extends for seven orders of magnitude in ALP mass. In this range, no significant evidence of an ALP signal is found. We thus place a new upper limit in the ALP-neutron and proton coupling improving previous laboratory constraints.

Morning 1 / 20

How And Where Can We Detect High Frequency Gravitational Waves?

Author: Sebastian Ellis[None]

Corresponding Author: sebastian.ellis@unige.ch

We review the recent advances in the understanding of sources of high frequency gravitational waves and how to detect them. Searches for gravitational waves share much in common with searches for wave-like dark matter. We will highlight similarities and differences.

Afternoon 2 / 21

Majoron as a simultaneous origin of baryogenesis and dark matter

Author: Eung Jin Chun Chun[1]

[1] *Korea Institute for Advanced Study*

Corresponding Author: ejchun@kias.re.kr

We propose a scenario where baryon asymmetry is generated spontaneously by the majoron which is also a dark matter candidate. For this, we investigate two distinct scenarios depending on the source of the majoron kinetic motion providing CPV in the background : 1) the misalignment mechanism, and 2) the kinetic misalignment mechanism. The former case can be realized in a very limited parameter space of the majoron mass ~ eV and decay constant ~ 10^6 GeV with an appropriate symmetry non-resotration at high temperatures. The later scenario works successfully for the majoron mass lower than 100 keV, and the seesaw scale below 10^9 GeV. It can be even below the temperature of the electroweak phase transition as long as sufficiently large kinetic misalignment is provided.

Afternoon 2 / 22

High-mass axion searches with novel cavity designs at IBS-CAPP

Author: SungJae Bae[1]

Co-authors: Junu Jeong [2]; SungWoo Youn [2]; Yeonggeun Kim [2]; Yannis Semertzidis [3]

[1] *IBS/CAPP, KAIST*

[2] *IBS-CAPP*

[3] *KAIST and IBS*

Corresponding Authors: jwpc0120@gmail.com, younggeunkim93@gmail.com, yannis@bnl.gov, qotjdwo97@kaist.ac.kr, swyoun@ibs.re.kr

The axion was postulated as a solution to both the strong CP problem and the dark matter mystery. Among the various experiments designed to detect axion dark matter signal, the cavity haloscope is recognized as the most sensitive method. However, its sensitivity decreases significantly at higher mass regions due to volume loss. To address this issue, the Center for Axion and Precision Physics Research of the Institute for Basic Science (IBS-CAPP) has been developing novel cavity designs, such as the multiple cell cavity, wheel mechanism, and tunable photonic crystal. These designs have been successfully demonstrated widely adopted in sensitive searches for high-mass axions. In this presentation, we will review the cavity designs and present the recent experimental results using these designs.

Afternoon / 23

Axion Production in Highly Magnetized Astrophysical Plasmas

Author: Anirudh Prabhu[1]

[1] *Princeton University*

Corresponding Author: aprabhu94@gmail.com

Compact objects such as neutron stars possess some of the strongest electric and magnetic fields in the observed universe. Non-thermal electromagnetic emission from neutron stars is sourced in regions with accelerating electric fields, $\vec{E} \cdot \vec{B} \neq 0$. These regions are also very efficient axion factories. Once produced, axions may (1) convert to photons, giving rise to anomalous electromagnetic signatures, (2) remain gravitationally bound to the neutron star and form dense clouds that can grow over astrophysical timescales, or (3) propagate to Earth and imprint detectable signals in laboratory experiments. In this talk, I will provide an overview of recent work on probing axions with neutron stars, and discuss important next steps in this program.

Morning 2 / 24

Axion Quark Nuggets and Matter-Antimatter asymmetry as two sides of the same coin: theory, observations and future searches

Author: Ariel Zhitnitsky[1]

[1] *University of British Columbia*

Corresponding Author: arz@phas.ubc.ca

In this talk I want to discuss the (unorthodox) scenario when the baryogenesis is replaced by a charge separation process in which the global baryon number of the Universe remains zero. In this, the so-called axion quark nugget (AQN) dark matter model the unobserved antibaryons come to comprise the dark matter in the form of nuclear density nuggets. I specifically focus on several recent papers written with Particle Physics, Nuclear Physics and Astro-physics people to apply these generic ideas to several recent proposals. In particular, I will discuss the broadband search strategy of relativistic axions which always accompany the AQN interaction with surrounding material. I will also discuss how the excess of the observed UV radiation in our galaxy can be understood within the same framework.

I will also mention how a number of mysterious and puzzling observations recorded on Earth could be also originated from the same new paradigm when the DM is in fact represented by strongly interacting objects. .

Afternoon 2 / 25

Supernova axion emissivity with Δ (1232) resonance in heavy baryon chiral perturbation theory

Authors: Shu-Yu Ho[1]; Jongkuk Kim[2]; Pyungwon Ko[1]; Jae-hyeon Park[1]

[1] *Korea Institute for Advanced Study*

[2] *Chung-Ang University*

Corresponding Author: phyhunter2006@gmail.com

In this talk, we evaluate the energy loss rate of supernovae induced by the axion emission process $\pi- + p \longrightarrow n + a$ with the Δ(1232) resonance in the heavy baryon chiral perturbation theory for the first time. Given the axion-nucleon-Δ interactions, we include the previously ignored Δ-mediated graphs to the $\pi- + p \longrightarrow n + a$ process. In particular, the Δ0-mediated diagram can give a resonance contribution to the supernova axion emission rate when the center-of-mass energy of the pion and proton approaches
the Δ(1232) mass. With these new contributions, we find that for the typical supernova temperatures, compared with the earlier work with the axion-nucleon (and axion-pion-nucleon contact) interactions, the supernova axion emissivity can be enhanced by a factor of ~ 4 (2) in the Kim-Shifman-VainshteinZakharov model and up to a factor of ~ 5 (2) in the Dine-Fischler-Srednicki-Zhitnitsky model with small tan β values. Remarkably, we notice that the Δ(1232) resonance gives a destructive contribution to thesupernova axion emission rate at high supernova temperatures, which is a nontrivial result in this study.

Morning 2 / 27

Dark Matter searches with WISPLC experiment

Author: Marios Maroudas[1]

Co-authors: Dieter Horns [2]; Le Hoang Nguyen [1]; Zhongyue Zhang [1]

[1] *University of Hamburg*

[2] *Universität Hamburg*

Corresponding Authors: zhongyue.zhang@desy.de, le.hoang.nguyen@uni-hamburg.de, dieter.horns@desy.de, marios.maroudas@cern.ch

WISPLC is a direct Dark Matter detection experiment located in Hamburg, Germany, looking for Weak-interacting sub-eV particles in a previously unexplored parameter space between 10-11 and 10-6 eV, using the lumped element technique. This consists of a pickup loop capturing the induced flux of converted axion-like particles in the presence of an externally applied magnetic field with the signal being then amplified by an LC circuit. The preliminary data-taking results in the frequency range between 1 and 9 MHz with the first broadband prototype will be presented. We will also discuss the prospects for future improvements to the experiment and the next stages where the resonant scheme will be employed.

Morning 2 / 28

GrAHal-CAPP for axion dark matter search with unprecedented sensitivity in the 1-3 micro-eV mass range

Authors: Pierre Pugnat[1]; Philippe Camus[2]; Ohjoon Kwon[3]; Rafik BALLOU[4]; HeeSu Byun[5]; Woohyun Chung[6]; Thierry Grenet[2]; Pierre Perrier[2]; Yannis Semertzidis[7]; Arthur Talarmin[2]; Jérémy Vessaire[2]

[1] *LNCMI-Grenoble, CNRS & Université Grenoble-Alpes*

[2] *Institut Néel, CNRS & Université Grenoble-Alpes*

[3] *Institute for Basic Science / Center for Axions and Precision Physics research*

[4] *Institut Neel, CNRS & Université Grenoble-Alpes*

[5] *CAPP-IBS*

[6] *IBS-CAPP*

[7] *KAIST and IBS*

Corresponding Authors: rafik.ballou@neel.cnrs.fr, philippe.camus@neel.cnrs.fr, jeremy.vessaire@neel.cnrs.fr, pierre.perrier@neel.cnrs.fr, yannis@bnl.gov, o1tough@gmail.com, thierry.grenet@neel.cnrs.fr, pierre.pugnat@lncmi.cnrs.fr, gnuhcw@gmail.com, arthur.talarmin@neel.cnrs.fr, hsbyun@ibs.re.kr

A collaboration between CNRS-Grenoble and IBS-CAPP Daejeon plans to build a Sikivie's type haloscope for axion/ALPs dark matter search at the Dine-Fischler-Srednicki-Zhitnitskii (DFSZ) sensitivity for the 300-600 MHz range. It will be based on the large bore superconducting magnet of LNCMI Grenoble providing a central magnetic field up to 9 T in 810 mm warm bore diameter. This magnet has been successfully powered up to 8.5 T achieving the first steps of the electrical commissioning phase. The design principles of the cryostat with its double dilution refrigerators to cooldown below 50 mK, the light Cu RF-cavity of 700 mm diameter together with its tuning rod(s) and first stages of the measurement chain, are presented. Perspectives for the targeted sensitivity assuming less than 2-year integration time is given.

Morning 5 / 29

Axion Searches with IAXO and BabyIAXO

Author: Johanna von Oy[1]

Co-author: for the IAXO Collaboration

[1] *University of Bonn*

Corresponding Author: vonoy@physik.uni-bonn.de

For the search for axions, helioscopes are one of the original experiments that were introduced by Sikivie in 1983. Helioscopes are built with the idea that the Sun is a major source for axions thanks to its high core temperature. These axions would be produced through the Primakoff effect, processes relying on the axion-electron coupling and other mechanisms. In a helioscope, those solar axions can then couple to X-ray photons in a magnetic field which then in turn can be detected.

Following previous experiments like CAST, IAXO (the International AXion Observatory) will be a next-generation helioscope. It is planned to be built at DESY in Hamburg just like its predecessor BabyIAXO. The latter will not only be a proof of concept for the different components of IAXO but has its own physics potential.

IAXO will consist of a 20 m long magnet that is mounted on a drive system to be able to track the Sun for a minimum of 12 hours a day. This magnet will be connected to 8 setups consisting of an X-ray focusing optic and a detector each.

This talk will give an overview of the plans for both IAXO and BabyIAXO as well as their physics potential. In addition to aiming for an axion-photon coupling sensitivity in the range of $10^{-12}\mathrm{GeV}^{-1}$ and $2\times10^{-11}\mathrm{GeV}^{-1}$ respectively, both experiments will be able to also search for axion-like particles (ALPs), dark matter axions in a haloscope stage and other physics cases. This talk will also go into detail about the developments towards building BabyIAXO and the progress of its different components.

Morning 4 / 30

Cosmology and terrestrials signals of sexaquark dark matter

Author: Marianne Moore[1]

[1] *MIT*

Corresponding Author: mamoore@mit.edu

The sexaquark, a hypothetical stable and neutral six-quark state, has been recently proposed as a dark matter candidate. Here, I argue it is very unlikely sexaquarks could consistently compose more than a billionth of the dark matter abundance for a wide range of scattering cross sections and annihilation rates. To draw these conclusions, I connect the sexaquark freeze-out abundance to annihilation signals in neutrino experiments. I will show how the sexaquark cosmology enforces that a large contribution to dark matter is only possible with a similarly large antisexaquark population. This population, however, would leave a stark annihilation signal in a detector such as Super-Kamiokande. I will summarize with how sexaquarks as a large component of the dark matter is incompatible with current observational data.

Afternoon / 31

SERAPH: Dark Matter Searches with SRF Cavities and Transmon Qubits

Author: Raphael Cervantes[None]

Corresponding Author: raphaelc@fnal.gov

The Superconducting Quantum Materials and Systems Center, led by Fermi National Accelerator Laboratory, is one of five research centers funded by the U.S. Department of Energy as part of a national initiative to develop and deploy the world's most powerful quantum computers and sensors. SQMS will also apply the same technologies used for quantum computing, such as SRF cavities and superconducting qubits, to search for fundamental physics.

This presentation will focus on the SERAPH experiment, a family of superconducting haloscopes being developed by SQMS to search for wavelike dark matter like axions and dark photons. In this presentation, I will focus on the progress of the current phase of SERAPH, which will search dark photon dark matter using a widely-tunable SRF cavity (4-7 GHz) with Q>10^8. In parallel, SQMS has recently developed superconducting transmon qubits with leading coherence times. I will report new results for SQMS dark matter searches implementing these qubits to subvert the Standard Quantum Limit noise.

Morning 2 / 32

The DarkSide-20k experiment

Author: Malgorzata Irena Haranczyk[None]

Corresponding Author: malgorzata.haranczyk@uj.edu.pl

The DarkSide-20k detector is currently under construction at the LNGS laboratory in Italy and is a crucial part of the Global Argon Dark Matter Collaboration's (GADMC) plan to probe the dark-matter parameter space down and into the neutrino fog. DarkSide-20k is a two-phase Time Projection Chamber with low-radioactivity acrylic walls and optical readout using Silicon Photomultipliers (SiPMs). The inner detector volume is nested in two veto detectors. Notably, DarkSide-20k will be filled with 50 tonnes (20 tonnes fiducial) of Underground Argon, minimizing the cosmogenically-produced background of Ar-39. Unique technical solutions have been developed to ensure excellent sensitivities for direct dark matter searches. We will discuss the design, implemented background reduction techniques, expected sensitivity, and the current status of DarkSide-20k

Morning 2 / 33

Single-Photon Detection for Axion Haloscopes with RAY

Authors: Eleanor Graham[1]; Reina Maruyama[1]

[1] *Yale University*

Corresponding Authors: reina.maruyama@yale.edu, eleanor.graham@yale.edu

Single-photon readout is a compelling technique for the next generation of dark matter haloscope experiments; it would entirely eliminate the quantum measurement noise seen in linear amplifier readout. The Rydberg/Axions at Yale (RAY) collaboration is developing single-photon detectors based on Rydberg atoms, highly-excited atomic states with exquisite sensitivity to electric fields. These detectors can be used for axion dark matter searches between 40 μeV and 200 μeV (10 GHz and 50 GHz) and would be compatible with a wide variety of haloscope cavity designs. I will present our recent work (Phys. Rev. D 109, 032009) detailing our single-photon detector concept and its potential to offer scan rate enhancements up to a factor of 10^4 over traditional linear amplifier readout. I will also share updates on our progress towards building a proof-of-principle Rydberg atom single-photon detector.

Morning 2 / 35

Superconducting Quantum Sensors for Fundamental Physics Searches

Author: Gulden Othman[1]

Co-authors: Axel Lindner [2]; Christina Schwemmbauer [2]; Elmeri Rivasto [3]; Friederike Januschek [4]; José Alejandro Rubiera Gimeno [2]; Katharina-Sophie Isleif ; Manuel Meyer [5]

[1] *University of Hamburg*

[2] *DESY*

[3] *University of Southern Denmark (SDU)*

[4] *Deutsches Elektronen-Synchrotron (DESY)*

[5] *University of Southern Denmark*

Corresponding Authors: gulden.othman@desy.de, christina.schwemmbauer@desy.de, friederike.januschek@desy.de, axel.lindner@desy.de, isleifk@hsu-hh.de, rivasto@cp3.sdu.dk, jose.rubiera.gimeno@desy.de, mey@sdu.dk

Superconducting Transition Edge Sensors (TESs) are a promising technology for fundamental physics applications due to their low dark-count rates, good energy resolution, and high detection efficiency. On the DESY campus, we have been developing a program to characterize quantum sensors for fundamental physics applications, particularly focused on TESs. We currently have one fully equipped dilution refrigerator for TES characterization, and a second dilution refrigerator is being prepared. In this presentation, we will summarize the current status of our TES characterization, including recent calibration efforts and efficiency measurements, as well as simulations to better understand the TES behavior. Additionally, we will summarize physics applications we are already exploring or planning to explore. We will give the latest results on a direct dark matter search with our TES, where exploiting low-threshold electron scattering in superconducting materials allows us to search for MeV-scale dark matter. We are also working toward performing the first measurement of the even number photon distribution (beyond one pair) of a quantum-squeezed light source. Finally, if it proves to meet the requirements, our TES detector may be used as a second, independent detection system to search for an axion signal at the ALPS II experiment.

Afternoon 2 / 36

Recent Results from the XENONnT Experiment

Author: Matteo Guida[1]

[1] *Max-Planck-Institut für Kernphysik (MPIK)*

Corresponding Author: matteo.guida@mpi-hd.mpg.de

The XENONnT experiment, operating since 2020, is at the forefront of the quest for the dark matter candidate Weakly Interacting Massive Particles (WIMPs), leveraging a 5.9-tonne liquid xenon target. Its world-leading lowest electronic recoil background has also rendered it a versatile instrument for investigating a broad spectrum of phenomena beyond the Standard Model. This talk will focus on the latest results from XENONnT, providing an overview of the experiment and insights into the data analysis methods employed.

Afternoon 2 / 37

Maglev for Dark Matter

Author: Saarik Kalia[1]

[1] *University of Minnesota*

Corresponding Author: kalias@umn.edu

Ultraprecise mechanical sensors offer an exciting avenue for testing new physics. While many of these sensors are tailored to detect inertial forces, magnetically levitated (Maglev) systems are particularly interesting, in that they are also sensitive to electromagnetic forces. In this talk, I will propose the use of Maglev systems to detect dark-photon and axion dark matter. Several existing laboratory experiments search for these dark-matter candidates at high frequencies, but few are sensitive to frequencies below 1 kHz (corresponding to dark-matter masses m_{DM}
$lesssim 10^{-12}\,\mathrm{eV}$). As mechanical resonators, Maglev systems are sensitive to lower frequencies, and so can probe parameter space currently unexplored by laboratory experiments. I will propose the use of two systems as dark matter detectors: levitated superconductors and levitated ferromagnets. Both of these systems respond to oscillating magnetic fields. Dark-photon dark matter and axion dark matter which couples to photons can source such magnetic fields, driving the motion of these systems. Axion dark matter which couples to electrons can also drive the motion of levitated ferromagnets. These responses are resonantly enhanced when the dark matter Compton frequency matches the system's trapping frequency. I will show that in the Hz
$lesssim f_{\mathrm{DM}}$
$lesssim \mathrm{kHz}$ frequency range these techniques can achieve the leading sensitivity amongst laboratory probes of both dark-photon and axion dark matter.

Afternoon 2 / 38

Approaching the Quantum Limit in Axion Detection at IBS/CAPP

Author: Sergey Uchaikin[1]

Co-authors: Boris Ivanov [2]; Jinmyeong Kim [3]; Arjan F. van Loo [4]; Yasunobu NAKAMURA [4]; Saebyeok Ahn [1]; Seonjeong Oh [1]; Minsu Ko [3]; Yannis Kyriakos Semertzidis [5]

[1] *Institute for Basic Science, Center for Axion and Precision Physics Research*

[2] *Center for Axion and Precision Physics Research of Institute for Basic Science*

[3] *Department of Physics, KAIST*

[4] *RIKEN Center for Quantum Computing (RQC); Department of Applied Physics, Graduate School of Engineering, The University of Tokyo*

[5] *KAIST/IBS*

Corresponding Authors: b.ivanov@ibs.re.kr, yannis@kaist.ac.kr, uchaikin@ibs.re.kr, oh@ibs.re.kr, arjanvanloo@g.ecc.u-tokyo.ac.jp, ambritjm@kaist.ac.kr, yasunobu@ap.t.u-tokyo.ac.j, saebyeok.ahn@ibs.re.kr, ko@ibs.re.kr

In the presentation, we will detail our five-year work at the Center for Axion and Precision Physics Research (CAPP) in developing and optimizing quantum-noise-limited amplifiers based on flux-driven Josephson Parametric Amplifiers (JPAs) for axion detection experiments. Our research focuses on achieving the lowest noise performance to enhance the scanning speed for detecting potential axion signals in the 1-6 GHz frequency range. We developed a split-band technique for JPAs, extending the effective bandwidth of the 1-2 GHz amplifiers up to 300 MHz while maintaining noise characteristics. We will discuss the technical challenges, implemented solutions, details of the read-out systems, and future prospects for this technology.

Afternoon 2 / 39

Recent Advances of Dark Matter Search from COSINE-100

Author: Gyunho Yu[1]

[1] *Institute for Basic Science*

Corresponding Author: tksxk752@naver.com

The Standard Halo Model predicts that dark matter detection on Earth should exhibit annual modulation. The DAMA/LIBRA experiment, utilizing NaI(Tl) crystal detectors, reported detecting an annual modulation signal that aligns with dark matter characteristics, achieving a significance of over 13 sigma. However, this result has not been replicated by any other experiment. To directly test DAMA/LIBRA's controversial claim, the COSINE-100 experiment was launched at the YangYang Underground Laboratory (Y2L) in Korea. Using 106 kg of NaI(Tl) crystals, COSINE-100 aims to scrutinize DAMA/LIBRA's findings through model-independent and model-dependent analyses. Operational from September 2016 to March 2023, COSINE-100 has amassed approximately six years of data. This presentation will detail the latest results from COSINE-100 and outline the planned upgrades to COSINE-100U, which include enhanced detector capabilities and relocation to a new site at Yemilab, Korea. The new encapsulation method and improved operational environment are designed to increase the sensitivity of dark matter detection. Further prospects of COSINE-100U will also be discussed.

Afternoon 2 / 40

Results from the ALPS II first science campaign

Author: Aaron Spector[1]

[1] *Deutsches Elektronen Synchrotron - DESY*

Corresponding Author: aaron.spector@desy.de

The Any Light Particle Search II (ALPS II) is a light-shining-through-a-wall (LSW) style experiment currently running at DESY in Hamburg, Germany, that is probing the universe for axions and axion-like particles at masses below 0.1 meV. LSW experiments use an entirely laboratory based approach, in which a beam of axions is generated, via the Sikivie effect, as a high power laser traverses a strong magnetic field. The axion beam then passes through a wall which blocks the laser light. On the other side of the wall another region of strong magnetic field converts a small fraction of the energy in the axion beam back into an electromagnetic field. In addition to magnet strings each providing 106

m of 5.3 T fields, ALPS II will also use high-finesse optical cavities both before and after the wall to amplify the power of the regenerated field by up to 9 orders of magnitude. Along with a heterodyne system whose intrinsic background is equivalent to only a few photons over the entire integration time of the data run, this design makes ALPS II the most ambitious LSW experiment ever built. From January to May of this year ALPS II completed its first science campaign utilizing a ~120 m optical cavity, with a finesse of ~26,000, after the wall. This campaign consisted of a scalar axion search in which 700,000 seconds of data where acquired, as well as a pseudo scalar search which resulted in 1.2 million seconds of data. This talk will give an overview of LSW experiments and the ALPS II optical system, along with a discussion of the results from the first science campaign and plans for the future including the implementation of a ~120 m cavity before the wall.

Morning 5 / 42

Challenges and improvements of the TREX-DM, low-mass WIMP search

Author: Theopisti Dafni[1]

[1] *CAPA/Universidad de Zaragoza*

Corresponding Author: tdafni@unizar.es

The race for the discovery of the Dark Matter is as lively as ever; the axion and the WIMP are the two main particle candidates that could solve the mystery. The absence of signal in the typical mass window for the WIMP, of the order of 100GeV, has pushed the search to lower masses. The TREX-DM experiment is looking for low-mass WIMPs of the scale of 1-10 GeV/c2: it is a high-pressure gas Time Projection Chamber, equipped with Micromegas detectors, and is located at the Canfranc Underground Laboratory (LSC, 2500 m.w.e.). The requirements for TREX-DM to be competitive are very low background level (order 1-10 c/keV/day/kg) and low energy threshold (below 1keVee). TREX-DM carries the advantage of being able to change the gas and the pressure in order to optimise energy transfer and detector performance. We will comment on the current performance (background of the order 100 c/keV/day/kg) and the strategies followed to improve it. Emphasis will be given to three parts: surface contamination measurements and mitigation and the new, high-sensitivity detector developed for that purpose, with the aim to reduce the current background levels by a factor 10 (or 100); gain improvements with the use of a preamplification stage, that would lower the threshold at least a factor 10; and low energy volume calibrations, necessary to assess this performace.

Afternoon / 43

Background Discrimination for the TES-Based Detection System of ALPS II: Machine Learning and A Cryogenic Optical Filter Bench

Author: Elmeri Rivasto[1]

Co-authors: Axel Lindner [2]; Christina Schwemmbauer [2]; Friederike Januschek [2]; Gulden Othman [3]; Jose Alejandro Rubiera Gimeno [2]; Katharina-Sophie Isleif [4]; Manuel Meyer [5]

[1] *University of Southern Denmark*

[2] *Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany*

[3] *Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany*

[4] *Helmut-Schmidt-University, Hamburg, Germany*

[5] *CP3-Origins, University of Southern Denmark, Odense, Denmark*

Corresponding Authors: mey@sdu.dk, katharina-sophie.isleif@desy.de, christina.schwemmbauer@desy.de, friederike.januschek@d jose.rubiera.gimeno@desy.de, gulden.othman@desy.de, axel.lindner@desy.de, elmeri.rivasto@protonmail.com

The Any Light Particle Search (ALPS II) expects an axion-photon reconversion rate of 1 photon per day, setting an upper limit for the required background in the foreseen Transition Edge Sensor (TES) based experiments. We present two distinct software and hardware based approaches contributing to achieving this goal: i) discriminating background events using state-of-the-art machine learning (ML) models and ii) physically limiting the background originating from black-body photons using a cryogenic optical filter bench. Regarding the ML-based approach, the use of data-informed simulation of TES pulses has enabled extensive optimization of the utilized models. Despite effectively distinguishing between most background events, the black-body photons coupled to the optical fiber still need to be physically reduced to meet the desired sensitivity. We are currently building a custom optical filter bench that can be operated inside the dilution refrigerator at 40 K. The transmission of 1064 nm photons has been optimized by using an ultra-narrow pass filter that can be remotely rotated with respect to the laser beam in order to compensate for the effects of thermal contraction. We have further applied the possibility to fine tune the positions of the used fiber collimators while the system is cold by attaching them to remotely controllable piston stages. The presentation discusses the practical implementation and the limits of the two above introduced methods in background discrimination and reduction for ALPS II.

Morning 3 / 44

Updated axion search results from HAYSTAC's Phase II operation in the mass range above 17 µev

Author: Xiran Bai[1]

[1] *Yale University*

Corresponding Author: xiran.bai@yale.edu

The Haloscope At Yale Sensitive To Axion CDM (HAYSTAC) Experiment is actively searching for QCD axions using a resonant microwave cavity enhanced by a quantum squeezed state receiver (SSR). Because the axion's mass and coupling strength are unknown, a crucial metric is the scanning rate across the parameter space. Integration of the SSR into the HAYSTAC experiment has allowed for a scan rate enhancement of up to 2x. More recently, HAYSTAC has improved its system stability, enabling the SSR to operate reliably across a wide range of axion masses. I will discuss HAYSTAC's latest results in the mass range between 17-20 µev, current status, and future plans.

Afternoon / 45

Search for dark photons around 34.4 µeV using direct excitations of superconducting qubits

Authors: Karin Watanabe[1]; Kan Nakazono[1]; Tatsumi Nitta[2]; Shion Chen[None]; Toshiaki Inada[1]; Koji Terashi[1]; Ryu Sawada[3]

[1] *Tokyo University*

[2] *The University of Tokyo*

[3] *University of Tokyo, Project assistant professor*

Corresponding Authors: watanabe-karin595@g.ecc.u-tokyo.ac.jp, shion@cern.ch, sawada@icepp.s.u-tokyo.ac.jp, tnitta@icepp.s.u-tokyo.ac.jp

We present the results of the search for dark photons using superconducting qubits based on the method which has been recently proposed (Moroi+, Phys. Rev. Lett.'23). Wave-like dark matter such as axions and dark photons can induce an electric field via the small kinetic mixing with ordinary photons. This electric field excites a superconducting qubit when it is in resonance. Thus, a particular qubit frequency corresponding to the dark matter mass exhibits a sharp peak in the excitation rate when the frequency is swept. In this talk, we will show the result of the search for the dark photon around at 8.33GHz corresponding to the unexplored mass around 34.4 μeV, using a superconducting qubit fabricated in our group. This result opens the path towards a wide band search or axion search under a strong magnetic field performed in the near future.

Afternoon / **46**

Towards axion searches using superconducting qubits

Author: Tatsumi Nitta[1]

[1] *The University of Tokyo*

Corresponding Author: tnitta@icepp.s.u-tokyo.ac.jp

Several ideas are proposed utilizing superconducting qubits in dark photon searches such as the single photon counter, direct excitation, and cavity tuning with superconducting qubits. Here, we introduce activities to operate qubits in a strong magnetic field to expand these dark photon searches to axion searches. In particular, we discuss our strategy to tolerate a strong magnetic field from the point of view of superconducting thin layers and Josephson junctions.

Morning 3 / **47**

First results from a cavity haloscope experiment with a novel frequency tuning system using a qubit

Authors: Kan Nakazono[1]; Karin Watanabe[2]; Koji Terashi[2]; Ryu Sawada[3]; Shion Chen[None]; Tatsumi Nitta[1]; Toshiaki Inada[2]

[1] *The University of Tokyo*

[2] *Tokyo University*

[3] *University of Tokyo, Project assistant professor*

Corresponding Authors: tnitta@icepp.s.u-tokyo.ac.jp, watanabe-karin595@g.ecc.u-tokyo.ac.jp, shion@cern.ch, nakazono@icepp.s.u-tokyo.ac.jp, sawada@icepp.s.u-tokyo.ac.jp

We propose and experimentally demonstrate a novel method for cavity frequency tuning in cavity haloscope experiments by coupling with a superconducting qubit. Compared to the existing tuning-rod approach, this alternative method addresses a few advantages: (a) easy implementation, (b) reduction of electromagnetic wave leakage, and (c) fast scanning because there is no thermal noise derived from the friction while tuning. In this presentation, I will summarize our detection setup, data analysis method, and the first results of our search for the dark photon around 36.1 μeV.

Afternoon / **48**

Axion streams and implications for haloscopes

Authors: Ciaran O'Hare[None]; Giovanni Pierobon[None]; Javier Redondo[None]

Corresponding Author: g.pierobon@unsw.edu.au

A consequence of QCD axion dark matter being born after inflation is the emergence of ultra-small-scale substructures known as miniclusters. Although miniclusters merge to form minihalos, their

intrinsic granularity is expected to remain imprinted on small scales in our galaxy. However, encounters with stars will tidally strip mass from the miniclusters, creating pc-long tidal streams that act to refill the axion voids left in between the miniclusters.

We investigate whether or not this stripping rescues experimental prospects from the worst-case scenario in which the majority of axions remain bound up in unobservably small miniclusters. We find that the density sampled by the Earth on mpc-scales will be around 70-90% of the known local DM density, and at a typical point in the solar neighbourhood, we expect most of the dark matter to be comprised of debris from $\mathcal{O}(10^2 - 10^3)$ overlapping streams. The latter are a unique prediction that constitutes a way for haloscopes to distinguish between pre and post-inflationary axion cosmologies.

Morning 3 / 49

Observing axions from supernovae through their many (loop-induced) couplings

Author: Eike Ravensburg[1]

[1] *SDU Odense*

Corresponding Author: ravensburg@cp3.sdu.dk

Supernova (SN) explosions could emit vast amounts of axions, and axionlike particles, in a short time. In this talk, we will show how the spectrum of these axions is calculated to unprecedented precision in recent years. In particular, in the SN plasma quantum-loop effects can dominate axion production or absorption processes, and can also play a vital role in their conversion to visible particles once they escape the stellar remnant. The relevant interactions of axions with leptons, photons, nucleons, and pions can all induce one another on the quantum level mdash; with phenomenologically relevant implications in many of these combinations. Taking these considerations into account, we derive accurate predictions for the number and energy of axions emitted in a SN, as well as a large range of observable signatures caused by this emission. Among those are gamma-ray bursts originating from axions that escaped the stellar remnant and subsequently decay or convert into photons (through tree or loop-level processes). We show that those bursts could have also been detected from extragalactic SNe such as SN 2023ixf with the Fermi-LAT, and how we can use the absence of a detection to constrain the axion parameter space. We present our findings of a wide range of significantly improved bounds on axions from supernovae.

Morning 3 / 50

The Axion Longitudinal Plasma HAloscope (ALPHA)

Author: Maximiliano Silva-Feaver[1]

Co-author: ALPHA Collaboration

[1] *Yale University*

Corresponding Authors: alpha_institutional_board@googlegroups.com, maximiliano.silva-feaver@yale.edu

The axion is a well-motivated dark matter candidate with an extensive range of mass unexplored experimentally. New string production models for the post-inflation QCD axion predict higher axion masses than we have explored with modern haloscopes. While traditional tunable cavity-based haloscopes have proven exquisitely sensitive at lower frequencies, their sensitivity drops off at higher frequencies due to decreasing cavity volume. The Axion Longitudinal Plasma HAloscope (ALPHA) overcomes these limitations by constructing metamaterial resonators operating in the 10-100 GHz frequency range with no volume constraints. I will present the status of the first phase of the ALPHA

haloscope sited at Yale. The Yale site will operate a cavity in the 10-20 GHz range in a 14-16 Tesla magnetic field at mK temperatures, with a readout using quantum-limited parametric amplifiers. The ALPHA haloscope at Yale is targeting 1) a demonstration of improved sensitivity operation of metamaterial resonators in a high-field, large-bore magnet and 2) KSVZ limited constraints on the axion coupling over the 40-80 μeV mass range.

Afternoon / **51**

Quantum sensors for RADES haloscopes

Author: David Díez Ibáñez[1]

[1] *University of Zaragoza - CAPA*

Corresponding Author: daviddiez@unizar.es

The RADES collaboration has been exploring different haloscope designs to improve the sensitivity to relic axions in certain masses. From multicavities, to increase volume at higher frequencies, to superconducting tapes, to achieve high quality factors, several technologies are being tested in order to increase the reach of conventional haloscope strategies.

One of the most promising technologies under development is the quantum sensing. Haloscope sensitivity is limited by the standard quantum noise in the amplifiers. This noise floor is unavoidable even reducing further the temperature so a new scheme is needed in order to speed up searches. Making use of quantum sensors, a single photon counter can be developed. This sensor, instead of measuring power, measures the number of photons in the cavity, which allows going beyond the standard quantum limit.
Single photon counters in the GHz regime have been applied for different purposes, like measuring spins (Wang, Z. et al. Single-electron spin resonance detection by microwave photon counting. Nature, 2023). For haloscope experiments, first proof of concept was done in 2020 (Dixit, A. et al. Searching for Dark Matter with a Superconducting Qubit, Phys. Rev. Lett., 2021). In this work the feasibility of the technology was demonstrated using superconducting qubits called transmons in a haloscope without magnetic field.

The RADES collaboration is following their path and during last year, with the help of new collaborators with expertise in quantum research, we have had the opportunity to test different configurations improving both the cavity and the transmon design. These efforts have been supported recently with an ERC Synergy grant awarded for the DarkQuantum project, from professors I.G. Irastorza (U. Zaragoza), T. Kontos (ENS Paris), S.Paraoanu (Aalto U., Helsinki) and W. Wernsdorfer (KIT, Karlsruhe), which will also boost the development of RADES haloscope for BabyIAXO magnet.

Here, first measurements of quantum sensors developed for future RADES haloscopes are presented: experimental setup, measuring protocol, limitations and future steps, as well as current design and first prototype for RADES BabyIAXO haloscope.

Afternoon / **52**

Status of DOSUE-RR Experiment for Dark Photon Dark Matter Search at $m_{\mathbf{DP}} \sim 1$ meV

Author: Keigo Hanimura[1]

Co-authors: Shunsuke Adachi [1]; Hiroki Takeuchi [1]; Junya Suzuki [1]; Osamu Tajima [1]; Shunsuke Honda [2]; Tac Nakajima [3]; Hideo Ogawa [4]; Yutaka Hasegawa [5]

[1] *Kyoto University*

[2] *University of Tsukuba*

[3] *Nagoya University*

[4] *Osaka Metropolitan University*

[5] *National Institute of Information and Communications Technology*

Corresponding Authors: suzuki.junya.4r@kyoto-u.ac.jp, syskbks11@gmail.com, takeuchi.hiroki.74w@st.kyoto-u.ac.jp, y.hasegawa@omu.ac.jp, ogawah@omu.ac.jp, hanimura.keigo.58c@st.kyoto-u.ac.jp, sadachi5@gmail.com, nakajima@isee.nagoya-u.ac.jp, osamu.tajima@kek.jp

Dark photon is one of the candidates for cold dark matter, predicted by a part of string theories and high-scale inflation models. Dark photons interact with ordinary photons via tiny kinetic mixing with them. Owing to this interaction, the dark photons convert into millimeter-wave light at the electromagnetic boundaries, such as the surface of a metal plate. The frequency of the conversion photon corresponds to the mass of dark photon because of the energy conservation ($h\nu \simeq mc^2$); for example, a signal at 240 GHz corresponds to the mass of 1 meV. To detect the conversion photon from the dark photon in various frequency bands, we, the DOSUE-RR collaboration, have developed cryogenic millimeter-wave receivers. We have already performed the searches for conversion photons in the frequency range of 10–26.5 GHz. Since there is still an unexplored range up to O(100 GHz), we are focusing on the frequency range of 170–260 GHz as the next target. However, in this frequency range, there is no good low-noise amplifier to detect the tiny signal from the dark photons. To keep low noise, we installed a Superconductor-Insulator-Superconductor (SIS) mixer, which is commonly used in cutting-edge radio telescopes. This device allows us to down-convert the signal frequency from around 200 GHz to ~10 GHz, and to detect the signal with a low noise level of $< O$(100 K). In this presentation, I will discuss the current status including receiver evaluation and future plans of the DOSUE-RR.

Morning 3 / 53

Search for axion quark nugget at CAPP

Author: Jinsu Kim[1]

Co-authors: Ohjoon Kwon [1]; Danho Ahn [1]; Yannis Kyriakos Semertzidis [2]; Soohyung Lee [1]; Woohyun Chung [1]; Andrei Matlashov [1]; Sergey Uchaikin [1]; Arjan Ferdinand van Loo [3]; Yasunobu Nakamura [3]; HeeSu Byun [1]; Seongtae Park [1]; Seonjeong Oh [1]

[1] *IBS-CAPP*

[2] *IBS-CAPP and KAIST*

[3] *Center for Quantum Computing, RIKEN*

Corresponding Authors: seongtaep@gmail.com, danho.ahn@ibs.re.kr, gnuhcw@gmail.com, o1tough@gmail.com, yeaji719@ibs.re.kr, soohyunglee@ibs.re.kr, kjs098@ibs.re.kr, hsbyun@ibs.re.kr, uchaikin@ibs.re.kr

Axion quark nuggets are hypothetical particles composed of (anti-)quarks in a unique phase called the color superconducting state, surrounded by an axion domain wall. This model proposes an alternative candidate for cold dark matter compared to conventional halo-axions. Under the hypothesis that anti-matter axion quark nuggets could annihilate with Earth matter, releasing relativistic axions, we performed the first AQN experiment using a haloscope at the Center for Axion and Precision Physics Research (CAPP). This experiment employed a high-temperature superconducting microwave cavity that achieved a Q-factor exceeding one million in an 8-T magnetic field, alongside a quantum-noise-limited flux-driven Josephson parametric amplifier. Our investigation targeted the axion rest mass range between 4 μeV and 9 μeV. Data analysis focused on detecting daily modulation in the signal as predicted by the model. This presentation provides a detailed account of the experiment and reports the results.

Morning 3 / 54

NuSTAR as an Axion Helioscope

Authors: Elisa Todarello[1]; Jaime Ruz[None]; Julia Vogel[2]

Co-authors: Brian Grefenstette ; Chul Soo Kim ; David Smith ; Hugh Hudson ; Iain Hannah ; Igor Irastorza ; Javier Trujillo Bueno ; Marco Regis ; Marco Taoso ; Maurizio Giannotti ; Tomás O'Shea

[1] *Turin University*

[2] *University of Zaragoza*

Corresponding Authors: jvogel@unizar.es, elisa.todarello@to.infn.it

The nature of dark matter in the Universe is still an open question in astrophysics and cosmology. Axions and axion-like particles (ALPs) offer a compelling solution, and traditionally ground-based experiments have eagerly, but to date unsuccessfully, searched for these hypothetical low-mass particles that are expected to be produced in large quantities in the strong electromagnetic fields in the interior of stars. In this talk, I offer a fresh look at axions and ALPs by leveraging their conversion into X-rays in the magnetic field of the Sun's atmosphere rather than a laboratory magnetic field. Unique data acquired with the Nuclear Spectroscopic Telescope Array (NuSTAR) during the solar minimum in 2020 allows to set stringent limits on the coupling of axions to photons using state-of-the-art magnetic field models of the solar atmosphere. I report pioneering limits on the axion-photon coupling strength of 6.9×10^{-12} GeV^{-1} at 95% confidence level for axion masses
m_a
$lesssim 2 \times 10^{-7}$ eV, surpassing current ground-based searches and further probing unexplored regions of the axion-photon coupling parameter space up to axion masses of m_a
$lesssim 5 \times 10^{-4}$ eV.

Afternoon / 55

An idea to measure the arrival direction of wavy dark matter using the Moon

Author: Osamu Tajima[1]

[1] *Kyoto University*

Corresponding Author: tajima.osamu.8a@kyoto-u.ac.jp

Identifying the arrival direction of wavy dark matter is important after finding a signal of it. In particular, dish antenna experiments aim to detect sharp radio signals converted from dark photon or axion at the boundary of the electromagnetic field, e.g., metal plate converter. We expect to understand the mass and coupling constants of the wavy dark matter when we find the conversion radio signal. To identify the arrival direction of the wavy dark matter, the receiver system has to achieve fine angular resolution, $\ll 0.1^{\circ}$. Thus, we need a huge aperture (~ 100 m) telescope or similar distant interferometer, such as the ALMA telescope. In addition, we have to set the converter far away from the receiver, $> 1,000$ km, which must be outside of the Earth. The Moon is one of the candidate places to set the converters. Distributing the converters in the radius of ~ 2 km on the Moon, and identifying the location of the conversion signal gives us knowledge about the arrival direction of the wavy dark matter to the Moon. The revolution of the Moon also modulates the location of the conversion. We will present this idea as well as discussions related to it.

Morning 2 / 56

Measuring the electric dipole moment of the electron using polar molecules in a parahydrogen matrix

Authors: Giuseppe Messineo[1]; Phydes Collaboration[None]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: giuseppe.messineo@pd.infn.it

The electric dipole moment of the electron (eEDM) is a sensitive probe for new physics beyond the Standard Model that can also provide indirect evidence for the existence of dark matter. We propose a novel experimental method to measure the eEDM using polar molecules (BaF) embedded in a cryogenic matrix of parahydrogen. By exploiting the large internal molecular field available in BaF molecules and the efficient cooling and large concentrations of molecules enabled by the parahydrogen matrix, the proposed experiment has the potential to improve the current eEDM limits, offering valuable insights into CP violation sources and the origin of matter-antimatter asymmetry in the universe. Furthermore, our measurements could indirectly offer insights into the nature of dark matter since many extensions of the Standard Model that account for dark matter predict an eEDM large enough to be within the measurement range of planned experiments. We will discuss the experimental setup we developed to produce parahydrogen and grow cryogenic crystals alongside the necessary steps for creating and integrating BaF molecules into these matrices.

Afternoon 4 / 57

High Frequency Dish Antenna Experiments: TeraBREAD and InfraBREAD

Author: Andrew Sonnenschein[None]

Corresponding Author: sonnenschein@fnal.gov

The BREAD Collaboration is conducting R&D towards wide band dish antenna searches for axions using a unique coaxial antenna design which is well suited for deployment in large solenoid magnets and compatible with sub-kelvin detectors. We will discuss the overall BREAD (Broadband Reflector Experiment for Axion Detector) program and its technology development, focusing on plans for detectors in the THz and infrared regions of the spectrum. Future experiments are being planned to share the use of a large-bore 9.4 Tesla MRI magnet recently acquired by Fermilab for the ADMX-EFR project.

Afternoon 2 / 59

ADMX-VERA: A large volume haloscope for higher axion frequencies

Author: Andrew Yi[1]

Co-authors: Chao-Lin Kuo [2]; Chelsea Bartram [1]

[1] *SLAC National Accelerator Laboratory*

[2] *Stanford University and SLAC National Accelerator Laboratory*

Corresponding Authors: clkuo@stanford.edu, andrewyi@slac.stanford.edu, cbartram@slac.stanford.edu

Axions, which provide a solution to the strong CP problem, are one of the most prominent candidates for dark matter. The axion parameter space spans many orders of magnitude in mass, and a variety of search techniques will be needed to cover such a wide range. Haloscopes look for axion-photon conversion in a magnetic field, but they face the challenge of being smaller in volume as the axion

mass and its corresponding frequency increases. This reduction in volume scales linearly to the expected axion signal power. The ADMX-VERA (Volume Enhanced Resonant Axion) experiment is a pathfinder experiment that targets axions in the higher frequency range of 4 - 32 GHz and addresses the volume issue with a tunable "shell cavity" concept which can access the high frequency resonant modes without significantly sacrificing the volume. We discuss quantum sensing techniques that will be deployed with ADMX-VERA, as well as the shell cavity design. Finally, we describe a unique feature of the readout, which uses microwave slot antennas that are coherently added through an impedance-matching summing tree structure.

Morning 4 / 60

From concept to reality: Advancements in the MADMAX Axion Experiment

Author: Juan P.A. Maldonado[1]

[1] *Max Planck Institute for Physics*

Corresponding Author: maldonad@mpp.mpg.de

MADMAX, the MAgnetized Disc and Mirror Axion eXperiment, is a novel dielectric haloscope concept to detect the axion in the mass range 40-400 ueV through enhancement of the inverse Primakoff process. In this overview talk, I will review the experiment's design concept and discuss the status of ongoing research on the critical path of the experiment, including advancements in magnet development, and main prototype cryostat. The status of the first MADMAX room temperature and cryogenic runs performed in Spring 2024 will be presented.

Morning 4 / 61

Status and Recent Results from the BREAD Gigahertz Pilot Experiment

Author: Gabe Hoshino[1]

[1] *University of Chicago*

Corresponding Author: gyhoshino@uchicago.edu

We present the status and recent results of the room temperature BREAD gigahertz pilot experiment (GigaBREAD) which is looking for axion-like particles in the $\sim 50\ \mu$eV range. Reflector-based searches allow for wave-like dark matter searches at higher mass regimes where resonant cavity searches lose sensitivity due to scaling limitations. BREAD is a novel reflector concept which is optimized to fit inside solenoidal magnets to conduct searches for axions and axion-like particles. Last year, we conducted a pilot dark photon search using the GigaBREAD apparatus [PRL 132 (2024) 131004]. Following this successful dark photon search, we have been working to extend the sensitivity of GigaBREAD to axion-like particles by placing the reflector in a 4 T solenoidal magnet at Argonne National Laboratory.

Morning 5 / 62

Nonstandard Uses for Axion Haloscopes

Author: Gray Rybka[1]

[1] *University of Washington*

Corresponding Author: grybka@uw.edu

Axion haloscopes are powerfully sensitive tools designed explicitly to search for cold axion dark matter. Uniformly distributed dark matter axions are expected to produce a constant signal in a haloscope, but there is the potential to search for transient signals as well. I will discuss ideas in searches for nonstandard astrophysical axion sources, as well as non-axion signals such as gravitation. For some of these, searches are being performed in existing data, others require modifications of future axion experiments to execute, and some end up being fundamentally misaligned with haloscope design and require a completely different design.

Morning 5 / 63

WISP Searches on a Fiber Interferometer under a Strong Magnetic Field

Author: Josep Maria Batllori Berenguer[None]

Co-authors: Dieter Horns [1]; Marios Maroudas [2]

[1] *Universität Hamburg*

[2] *University of Patras*

Corresponding Authors: dieter.horns@desy.de, josep-maria.batllori@desy.de, marios.maroudas@cern.ch

WISPFI (WISP Searches on a Fiber Interferometer) is a novel table-top experiment designed to detect photon-axion conversion using resonant mixing. The experiment employs hollow-core photonic crystal fibers (HC-PCF) to fulfill the resonant condition, which can be precisely tuned by adjusting the gas pressure within the fiber. This technique enables the probing of an unexplored axion mass range (28 meV–100 meV) and achieves the two-photon coupling levels anticipated for the QCD axion.

The experiment is based on a partial-free space Mach-Zehnder-type interferometer that measures the photon reduction in the sensing arm, which is positioned within an external magnetic field. Two lasers at different wavelengths of 1535nm and 1570nm are used together with an optical switch to modulate the axion signal at a frequency of 100kHz. Noteworthy advancements are presented concerning the data-taking of the currently built prototype, and the outline of the next steps and future upgrades of the experiment is discussed.

Afternoon / 65

Fundamental Physics Search with SRF Cavities (SHANHE Collaboration)

Author: Yifan Chen[1]

[1] *Niels Bohr International Academy*

Corresponding Author: yifan.chen@nbi.ku.dk

The search for ultralight boson dark matter and high-frequency gravitational waves has widely employed electromagnetic resonant detectors, such as cavities and LC circuits. This talk will highlight recent experimental advancements within the SHANHE Collaboration using superconducting radiofrequency (SRF) cavities for detecting dark photon dark matter and investigating galactic dark photons. Additionally, it will explore the future potential of these detectors in probing dark sectors, with a particular focus on upgrades that enable them to function simultaneously as resonant and broadband instruments.

Morning 5 / 66

Axion constraints from white dwarf cooling in 47 Tucanae

Author: Leesa Fleury[1]

Co-author: Jeremy Heyl [1]

[1] *University of British Columbia*

Corresponding Authors: lfleury@phas.ubc.ca, heyl@phas.ubc.ca

Astrophysical objects such as white dwarfs, the remnants left by most stars after nuclear burning in the core has finished, are increasingly popular targets to search for evidence of axions. If axions interact with electrons, then axions could be produced at an appreciable rate in the dense, electron-degenerate core of a white dwarf via axion bremsstrahlung from electrons. The emission of these axions would provide an additional mechanism by which white dwarfs can lose energy and thus affect the rate of white dwarf cooling. Hints of axions have been suggested based on observations of the cooling of white dwarfs in the Galactic disc and halo, but the statistical analysis of these populations of white dwarfs is complicated by the variability of some key parameters important for comparing models of white dwarf cooling with observations, such as the white dwarf birthrate and distance. Conversely, globular clusters like 47 Tucanae provide populations of white dwarfs for which many of these key parameters are well controlled. In this talk, I will present the results of a detailed statistical analysis of the cooling of white dwarfs in 47 Tucanae to look for indirect evidence of axions. White dwarf cooling models were created by performing stellar evolution simulations that incorporated energy loss due to axion bremsstrahlung, and these cooling models were compared to observations from the Hubble Space Telescope. This analysis provides a new constraint on the axion-electron coupling that improves upon previous bounds by nearly a factor of two and excludes the range of values favoured by the axion hints from the cooling of Galactic white dwarfs.

Morning 3 / 68

Search for axion dark matter with a transmon-based photon counter

Authors: Antonello Ortolan[1]; Caterina Braggio[1]; Emmanuel Flurin[2]; Giovanni Carugno[1]; Giuseppe Ruoso[1]; Jaime Travesedo[2]; Luis Pallegoix[2]; Raffaele Di Vora[1]; Zhiren Wang[2]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *CEA Saclay*

Corresponding Authors: antonello.ortolan@lnl.infn.it, giuseppe.ruoso@lnl.infn.it, raffaele.divora@pd.infn.it, caterina.braggio@pd.infn.it, giovanni.carugno@pd.infn.it

We report about a significant advancement in the search speed of axion dark matter with cavity-based haloscopes. Our approach combines a 3D cavity with a transmon-based single microwave photon counter (SMPD) devised to detect itinerant photons, a circuit-QED architecture compatible with the strong magnetic fields required for axion-to-photon conversion.
In the SMPD, an incoming photon is converted to a qubit excitation via a four-wave-mixing process, and the overall efficiency of the detection process in the present device is about 50%. The SMPD is cyclically operated following a measurement protocol that allows for tuning of the cavity frequency to probe different axion masses, beyond monitoring with metrological methods the power from the cavity as well as the background.
In the reported pilot experiment we use a hybrid surfaced cylindrical NbTi-copper cavity mounted

to the based stage of a dilution refrigerator. With the 2 Tesla magnetic field we apply during the experiment, the cavity maintains a high quality factor, of about a million for its axion-sensitive mode TM010, and it can be tuned by a triplet of sapphire rods controlled by a cryogenic nanopositioner. We demonstrate a remarkable 20-fold enhancement in the search speed compared to quantum-limited linear amplifiers, and report a new axion-photon coupling limit of $g_a < 7 \times 10^{-14}$ GeV^{-1} over a frequency window of 0.4 MHz centered around 7.36 GHz.

Afternoon 4 / 69

Advancements in Axion Research at IBS-CAPP

Author: Woohyun Chung[1]

[1] *IBS-CAPP*

Corresponding Author: gnuhcw@gmail.com

IBS-CAPP has established a state-of-the-art axion detector facility in Korea, equipped with multiple dilution refrigerator systems. Currently, four axion detectors operate simultaneously on low-vibration pads. The flagship experiment, CAPP-MAX, utilizes a 12 Tesla Nb3Sn superconducting magnet with a 32 cm bore and a 36-liter ultra-light cavity, enhanced by quantum noise-limited amplifiers. This setup enables the acquisition of axion dark matter physics data at a rate exceeding 1 MHz per day across the 1 GHz axion frequency range, achieving sensitivity comparable to DFSZ levels. This achievement highlights CAPP's commitment to pioneering technologies and innovative R&D in axion dark matter search experiments. Significant efforts have concentrated on developing quantum noise-limited amplifiers and high-temperature superconducting cavities capable of sustaining Q-factors exceeding 10 million, even at 8 Tesla. Currently, we are collecting axion dark matter physics data using quantum amplifiers across frequencies ranging from 1 to 2 GHz. Installation of a superconducting cavity with a Q-factor exceeding 1 million is scheduled for this summer. In my presentation, I will provide an overview of CAPP's ongoing axion research initiatives, R&D endeavors, and future directions.

Afternoon 4 / 71

The ORGAN Experiment: Results, Status, and Future Plans

Author: Ben McAllister[1]

[1] *Swinburne University of Technology*

Corresponding Author: bmcallister@swin.edu.au

We present the status and plans of The Oscillating Resonant Group AxioN (ORGAN) Experiment Collaboration, which develops microwave cavity axion haloscopes. ORGAN is a collaboration of various Australian universities, with the main experiment hosted at The University of Western Australia.

The ORGAN Experiment is a high mass haloscope (~60-200 micro-eV) broken down into various phases, having commenced in 2021, and running until 2026 [1]. Phase 1 recently concluded, excluding ALP Cogenesis models of dark matter in the relevant mass ranges [2,3], along with scalar dark matter and dark photon limits. Phase 2 is in research and development, expected to commence in late 2024/early 2025 and achieve deeper sensitivity. Active avenues of research and development for ORGAN Phase 2 include novel high frequency cavity design [4,5], superconducting materials, and single photon counting –we will report on the status of R&D in these areas.

ORGAN-Q is a pathfinder experiment (~25 micro-eV), designed as a testbed for various techniques to be integrated into the main ORGAN Experiment in Phase 2, such as quantum-limited amplification,

and other improvements. It commenced in late 2023, and recently concluded [6]. We will report on the results, and the components to be integrated in ORGAN Phase 2.

ORGAN-Low Frequency is a lower-mass experiment hosted at Swinburne University, designed to utilise an MRI magnet and novel cavities to push into the low frequency regime, and search for different models of dark matter. It is currently in development, expected to commence in late 2024.

We will summarize each experiment in terms of the relevant experimental details, current status, run plans, and projected reach.

1. Ben T. McAllister, Graeme Flower, Eugene N. Ivanov, Maxim Goryachev, Jeremy Bourhill, Michael E. Tobar, 'The ORGAN experiment: An axion haloscope above 15 GHz', Physics of the Dark Universe 18, 67-72
2. Aaron P. Quiskamp, Ben T. McAllister, Paul Altin, Eugene N. Ivanov, Maxim Goryachev, Michael E. Tobar, 'Direct Search for Dark Matter Axions Excluding ALP Cogenesis in the 63-67 micro-eV Range, with The ORGAN Experiment', Science Advances 8, Issue 27
3. Aaron P. Quiskamp, Ben T. McAllister, Paul Altin, Eugene N. Ivanov, Maxim Goryachev, Michael E. Tobar, 'Exclusion of Axionlike-Particle Cogenesis Dark Matter in a Mass Window above 100 micro-eV', Phys. Rev. Lett 132, 031601
4. Ben T. McAllister, Aaron P. Quiskamp, and Michael E. Tobar, 'Tunable Rectangular Resonant Cavities for Axion Haloscopes', Phys. Rev. D 109, 015013
5. Aaron P. Quiskamp, Ben T. McAllister, Gray Rybka, and Michael E. Tobar, 'Dielectric-Boosted Sensitivity to Cylindrical Azimuthally Varying Transverse-Magnetic Resonant Modes in an Axion Haloscope', Phys. Rev. Applied 14, 044051
6. Forthcoming Article

Afternoon 4 / 72

The XLZD liquid-xenon Observatory and the DARWIN R&D programme

Author: Yanina Mariana Lourdes Biondi[1]

[1] *KIT*

Corresponding Author: yanina.biondi@kit.edu

Liquid xenon time projection chambers are nowadays recognized as one of the most sensitive technologies for dark matter direct detection. The ultimate goal of these experiments is to explore the allowed parameter space for nuclear recoils down to the neutrino fog before coherent neutrino-nucleus scattering begins to dominate the detector signals. Achieving this objective necessitates maintaining an ultra-low background level, *while scaling up active target mass by about a factor of 10 compared to current-generation detectors. Such an observatory will be suited* as well for the search of a large number of other rare-event searches such as solar neutrinos, neutrinoless double beta-decay of 136-Xe without isotopic enrichment, axions and axion-like particles, neutrinos from supernovae and different rare nuclear processes. The DARWIN programme is currently addressing the challenges of constructing and operating a _large_dual-phase TPC, as envisioned by the XLZD (XENON-LZ-DARWIN) collaboration. This presentation will cover the ongoing R&D efforts undertaken within the DARWIN project.

Afternoon 4 / 73

Advancements in Axion Haloscope Sensitivity: CAPP-MAX with High-Temperature Superconducting Cavities

Author: Ohjoon Kwon[1]

Co-authors: Danho Ahn ; Dojun Youm [2]; Jinsu Kim [3]; Lee Jiwon [2]; Seongtae Park [4]; Woohyun Chung [3]; Yannis Semertzidis [5]

[1] *Institute for Basic Science / Center for Axions and Precision Physics research*

[2] *KAIST*

[3] *IBS-CAPP*

[4] *CAPP/IBS*

[5] *KAIST and IBS*

Corresponding Authors: gnuhcw@gmail.com, kjs098@ibs.re.kr, yannis@bnl.gov, danho.ahn@ibs.re.kr, o1tough@gmail.com, seongtaep@gmail.com, ljw0278@kaist.ac.kr

The axion haloscope is a highly sensitive detector that converts axions into photons within a resonant cavity immersed in a strong magnetic field. The experiment's sensitivity is significantly influenced by the cavity's characteristics, including volume, form factor, physical temperature, and the Q-factor. A higher Q-factor extends the duration of axion signals within the cavity, expediting axion searches and reducing thermal dissipation. However, the intense magnetic field within the haloscope system renders conventional superconducting cavities ineffective for achieving a high Q-factor. To overcome this challenge, CAPP has utilized high-temperature superconducting (HTS) materials, specifically rare-earth barium copper oxide (ReBCO), to construct superconducting haloscope cavities. The flexibility of the ReBCO film allowed us to create HTS cavities in any 3D shape by affixing well-biaxially textured ReBCO film to the cavity's inner wall. This innovative approach led to a world-record Q-factor exceeding 10^7 at 5.4 GHz, even under an 8T magnetic field. Currently, we are applying this technology to large-scale cavities (>30 liters) for CAPP's Main Axion Experiment (CAPP-MAX), the world's most sensitive haloscope, which utilizes 12 Tesla magnetic fields and quantum noise-limited amplifiers. Detailed results will be presented at the workshop.

Afternoon 4 / 74

Detection of Axion Anti-quark Nuggets via their interactions in kt liquid detectors

Authors: Ionel Lazanu[1]; Mihaela Parvu[1]

[1] *Faculty of Physics, University of Bucharest*

Corresponding Authors: mihaela.parvu@unibuc.ro, ionel.lazanu@g.unibuc.ro

In the standard lambda cold dark matter (ΛCDM) model of cosmology, the distribution of matter and energy in the Universe is as follows: 5% is represented by ordinary matter, 26.8% by dark matter, and 68.2% by dark energy. However, the nature of dark matter and dark energy is not yet known. In the context of particle physics, dark matter may consist of one or several new particles, which are expected to be either massive or very light, millicharged or electrically neutral, uncoloured, weakly interacting, and stable. Unfortunately, none of these hypothetical
particles have been observed so far. The axion (anti)Quark Nuggets (AQN / A$\bar{\text{Q}}$N) model, proposed by Ariel Zhitnitsky in 2003 [1], builds on Edward Witten's idea [2] and involves 'new fields'representing 'new phases'(color superconducting) of quarks from the Standard Model and is able to explain the distribution of different forms of matter and energy.
Following a concise review of the primary characteristics of axion antiquark nuggets, in this contribution, we investigate potential experimental signatures that could be used to detect these stable supermassive particles in upcoming surface and underground experiments using liquefied noble gases (LAr, LXe) as Time Projection Chambers (TPCs) or water Cherenkov detectors. These anticipated signals are examined concerning the unique features of each detection system. Starting from the emission mechanisms of A$\bar{\text{Q}}$Ns considered in accordance with their struc-
ture, we investigate the expected signals: (a) atoms or molecules from the environment can be captured by the A$\bar{\text{Q}}$N, penetrate up to its core, and undergo annihilation; (b) the annihilation of positrons from the electrosphere and the emission of gamma radiation [3]. The analysis of the particles and radiation resulting from these interaction mechanisms is

analysed with the aim of exploiting them for the direct detection in the liquid materials considered in this contribution.

References
[1] A. Zhitnitsky. 'Nonbaryonic'dark matter as baryonic colour superconductor. J. Phys. G, 30:S513–S517, 2004.
[2] E. Witten. Cosmic Separation of Phases. Phys. Rev. D, 30:272–285, 1984.
[3] F. Majidi et al. The Glow of Axion Quark Nugget Dark Matter: (I) Large Scale Structures, 2024.

Afternoon 2 / 75

MADMAX Data Acquisition and Calibration

Author: Erdem Oez[1]

[1] *RWTH Aachen*

Corresponding Author: oez@physik.rwth-aachen.de

The MADMAX experiment aims to search for dark matter axions in the frequency range 10-100 GHz using a configuration where large thin dielectric disks are stacked in parallel under a strong magnetic field.

When searching for a narrow signal using a large bandwidth, data acquisition plays a critical role. Here we describe a data acquisition system based on a spectrum analyzer. In addition we present the power calibration, and another important component of the experiment where the signal amplification factor (boost factor) is deduced using the bead-pull method [1] in an open booster system.

[1] J. Egge et al., Experimental determination of axion signal power of dish antennas and dielectric haloscopes using the reciprocity approach, JCAP 04 (2024) 005 [arXiv:2311.13359]

Afternoon 2 / 76

Quantum Sensors for the Hidden Sector

Author: Ian Bailey[1]

[1] *Lancaster University*

Corresponding Author: ian.bailey@physics.org

Quantum Sensors for the Hidden Sector (QSHS) is a new UK-based collaboration working on resonant cavity detectors for halo axions. Our search facility, an 8.5mK dilution refrigerator containing a 20cm bore, 20cm long experimental volume threaded by an 8T magnetic field, was funded by STFC in 2021, and is now running at the University of Sheffield. The collaboration is developing a variety of low-noise electronics and high quality factor resonators, and we plan to install and test several low noise readout configurations within the next year. I will describe the Sheffield facility and the status of the quantum electronics under development.

Morning 4 / 77

Recent results and future perspective in the search for Axion dark matter with QUAX

Author: Alessio Rettaroli[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: alessio.rettaroli@lnf.infn.it

In recent years, we witnessed an increasing growth in the research of light Dark Matter (DM) candidates, addressing in particular axions and axion-like particles (ALPs).
The axion observation technique is based upon its in- verse Primakoff conversion into one photon, stimulated by a static magnetic field.

Here, recent results of the QUAX experiment are presented.
In particular, the recently assembled haloscope in the LNF site was able to collect data with an 8.8 GHz copper resonant cavity in a 9T field. The cavity was equipped with a tuning rod mechanism moved by piezo motors at a temperature of 20 mK, allowing to exclude the existence of dark matter axions with coupling $g_{a\gamma\gamma}$ down to 0.861×10^{-13} GeV^{-1} in the mass window $(36.5241 - 36.5510)$ μeV.

Next-future improvements are also presented here, since there is much room for improvement to reach the sensitivity to the KSVZ line. These are improving the fabrication of the metallic rod, the inclusion of a JPA (which we already tested) to reduce the noise, and we are testing YBCO superconducting cavities for their resilience to the magnetic field.

Moreover, recent results with the QUAX haloscope at LNL are also presented, featuring a data collection with a dielectric cavity and a Traveling-Wave JPA as a broadband preamplifier.

Afternoon / 78

A Machine Learning Approach for Dark Matter Search Analysis: From Savitzky-Golay to Autoencoder

Author: Kaan Özbozduman[1]

[1] *CERN*

Corresponding Author: kaan.ozbozduman@cern.ch

In the quest to improve the analysis procedure for dark matter (DM) axion searches in haloscope experiments, we propose integrating deep learning (DL) techniques into the current methodology. Specifically, as a first step towards full DL integration in the procedure, we aim to show the well-known Savitzky-Golay filter used for spectral shape removal can be replaced by a deep convolutional autoencoder filter. This transition seeks to address three key challenges: better preservation of grand spectrum noise distribution, reduced axion signal attenuation, and lower spectral pollution around EMI/EMC parasites. We will present the first results of this new analysis path enriched by the innovative approach that enhances accuracy and reliability in identifying potential axion signals. If successfully applied, this method can also be adopted by other DM searches both narrow-band and wide-band, including the axion anti quark nuggets proposed by A. Zhitnitsky, which are also a source of transient DM axions.

Afternoon 2 / 82

Search for Axion Quark Nuggets at the LHC

Author: Konstantin Zioutas[1]

Co-authors: Abaz Kryemadhi [2]; Andreas Mastronikolis [3]; Ariel Zhitnitsky [4]; Dieter Horns [5]; Dmitry Budker [6]; Giovanni Cantatore [7]; Kaan Özbozduman [3]; Marin Karuza [7]; Marios Maroudas [1]; Ophir Ruimi [8]; Serkant Cetin [9]; Yannis Kyriakos Semertzidis [10]; Christos Zamantzas [3]

[1] *University of Patras*

[2] *Messiah University*

[3] *CERN*

[4] *University of British Columbia*

[5] *Universität Hamburg*

[6] *JGU/HIM, UC Berkeley*

[7] *Istituto Nazionale di Fisica Nucleare*

[8] *HUJI, JGU/HIM*

[9] *Istinye University*

[10] *KAIST/IBS*

Corresponding Authors: akryemadhi@messiah.edu, konstantin.zioutas@cern.ch, mkaruza@phy.uniri.hr, yannis@kaist.ac.kr, budker@uni-mainz.de, ophir.ruimi@mail.huji.ac.il, christos.zamantzas@cern.ch, andreas.mastronikolis@cern.ch, dieter.horns@desy.de, arz@phas.ubc.ca, kaan.ozbozduman@cern.ch, serkant.cetin@cern.ch, marios.maroudas@cern.ch, giovanni.cantatore@ts.infn.it

Axion Quark Nuggets (AQNs) [1] have been suggested to solve the Dark Matter (DM) and the missing Antimatter problem in the universe, and have been proposed as an explanation of various observations [2-4]. Their size is in the μm range, and their density is equal to the nuclear density with an expected flux of about 1/km^2/year. For the typical velocity of DM constituents (250 km/s), the solar system bodies act as highly performing gravitational lenses, including the inner Earth and the Moon towards the Earth; Here we assume that DM streams or clusters are impinging, e.g., on the Earth, as was worked out for DM axions and WIMPs [5-6]. Interestingly, in the LHC beam, unforeseen beam losses are possibly triggered by Unidentified Falling Objects (UFOs), which are believed to consist of dust particles with a size in the μm range and a density several orders of magnitude lower than AQNs. It has been suggested [7] that streaming DM constituents incident on the Earth should result in jet-like structures ("hairs") exiting the Earth. Such ideas open novel directions in the search for DM. We suggest a new analysis of the UFO results at the LHC, assuming that they are eventually, at least partly, due to AQNs, while other potential signatures are being investigated. Specifically, a re-analysis of the existing data from the 4000 LHC beam monitors is proposed, arguing that dust and AQNs should behave differently. The feasibility of this idea has been presented within the Roadmap of DM models for Run 3 at CERN.

[1] A. R. Zhitnitsky, JCAP 0310, 010 (2003), https://arxiv.org/abs/hep-ph/0202161
[2] D. Budker et al., Phys. Rev. D 101, 043012 (2020), https://journals.aps.org/prd/abstract/10.1103/PhysRevD.101.04301
[3] A. R. Zhitnitsky, Phys. Lett. B 828, 137015 (2022), https://arxiv.org/abs/2110.05489
[4] D. Budker et al., Symmetry 14, 459 (2022), https://www.mdpi.com/2073-8994/14/3/459
[5] Y. Sofue, Galaxies 8, 42 (2020), https://www.mdpi.com/2075-4434/8/2/42
[6] A. Kryemadhi et al., Phys. Rev. D 108, 123043 (2023), https://journals.aps.org/prd/abstract/10.1103/PhysRevD.108.12
[7] G. Prezeau, ApJ 814, 122 (2015), https://iopscience.iop.org/article/10.1088/0004-637X/814/2/122

Afternoon 4 / 83

CMB Birefringence Constraints on Ultra-light Axion Dark Matter

Author: Pranjal Trivedi[1]

Co-author: Guenter Sigl [2]

[1] *University of Hamburg*

[2] *Universität Hamburg*

Corresponding Authors: guenter.sigl@desy.de, pranjal.trivedi@hs.uni-hamburg.de

The isotropic birefringence (all-sky rotation of linear polarization) of the cosmic microwave background (CMB) sourced by axion-like particle (ALP) dark matter is predicted to contain distinct signals from oscillating ultra-light axions at recombination as well as from local dark matter. Using Planck upper limits while incorporating allowed axion fractions of dark matter, we find strong constraints on the axion-photon coupling. These can improve over CAST limits by up to 5 and 2 orders, respectively for recombination and local dark matter axions. Forecast constraints (SO, LiteBIRD, CMB-S4, & CMB-HD) tighten further by 1-2 orders, extending to higher axion mass.

Hints of a detection (at ~3σ) of isotropic CMB birefringence from a re-analysis of Planck and WMAP data are considered, in light of our new axion dark matter signals. Certain regions of parameter space for ultra-light axion dark matter could explain this detection, if confirmed. We also present coupling constraints from searches for time-oscillation of the birefringence in the Planck data.

CMB birefringence constraints scale only weakly with ALP fraction of dark matter. They remain unaffected by uncertainties common in other astrophysical ALP probes: strength and spectrum of magnetic fields, over-density of ALPs in structures and the source's intrinsic polarization orientation.

Afternoon 2 / 84

Cosmological bounds on three scenarios of axion-like particles and condensates from non-equilibrium QFT

Author: Amedeo Maria Favitta[1]

Co-authors: Lucia Rizzuto [1]; Roberto Passante [1]

[1] *Università degli studi di Palermo and INFN*

Corresponding Authors: roberto.passante@unipa.it, amedeomaria.favitta@unipa.it, lucia.rizzuto@unipa.it

We derive and review cosmological constraints on axion-like particles (ALPs), produced thermally via freeze-in through their interaction with gluons, photons and Standard Model (SM) fermions and non-thermally through the misalignment mechanism and decay of topological defects. In particular, we discuss the QCD, the photophilic and the photophobic ALP scenarios where the ALPs couple respectively to gluons and a hidden gauge sector generating a mass $m_{a,0}$ for the particle [1], couple primarily to photons and primarily to SM fermions [2].
We develop our calculations with a Liouville-Von Neumann equation, as in Ref. [3], and an approach through a Boltzmann transport equation, calculated through the 2PI effective action, as in Ref. [4].
We apply our results to evaluate the decay of condensates of the ALP field to free ALPs, gravitational waves, gluons, photons and SM fermions. Furthermore, we evaluate the production of thermal ALPs in the presence of ALP condensates.
Finally, we study the resulting cosmological constraints in the parameter space $(m_a, g_{a\gamma\gamma})$, coming from the observative bounds on the birefringence of the CMB, the ALP contribution to the effective number of ultrarelativistic species ΔN_{eff} and from other known bounds on ALPs.

[1] A.Lella, E. Ravensburg, P. Carenza and M.C.D.Marsh, Supernova limits on 'QCD axion-like particles', arXiv:2405.00153 [hep-ph].
[2] S. Baumholzer, V.Brdar and E.Morgante, Structure Formation Limits on Axion-Like Dark Matter, JCAP **05** (2021), 004.
[3] S. Cao and D. Boyanovsky, Nonequilibrium dynamics of axionlike particles: The quantum master equation, Phys. Rev. D **107**, 063518 (2023).
[4] Ai, WY., Beniwal, A., Maggi, A. et al. From QFT to Boltzmann: freeze-in in the presence of oscillating condensates. J. High Energ. Phys. **2024**, 122 (2024).

Afternoon 2 / 86

Precision Multi-Mode Microwave Characterisation of Single Crystal Calcium Tungstate for Dark Matter Searches

Author: Elrina Hartman[1]

[1] *Department of Physics, UWA*

Corresponding Author: elrina.hartman@research.uwa.edu.au

Scheelite, or calcium tungstate (CaWO4), is a scintillating dielectric material of significant interest for its potential application in a myriad of contexts. It plays a key role in detection of rare events such as neutrinoless double β-decay, radioactive decay of very long-living isotopes and searches for weakly interacting massive particles (WIMPs), a candidate for dark matter (DM). In addition to existing applications, we propose to use a large single crystal of CaWO4 configured as a microwave cavity bolometer for highly sensitive readout. This may be suitable for WIMP DM detection and offers scope for qubit-based sensing methods.
In this work, we investigate whether such detection schemes can be realised in a single crystal architecture at low temperatures, and what effects the residual impurity spin ensemble defects display. To that end, we report the findings of precision multi-mode microwave electron spin resonance (ESR) spectroscopy, as developed in, to identify the paramagnetic residual impurities present in a high-purity CaWO4 sample, as well as the crystal's temperature dependent dielectric properties.
Dilute ion spin ensemble defects in the low-loss single crystal sample of CaWO4 were experimentally observed at 30 mK. A cylindrical resonator hosts whispering gallery modes with high Q-factors of up to 3 × 107 , equivalent to a loss tangent of ~ 3 × 10−8. Measurements of numerous high Q-factor photon-spin interactions between 7 to 22 GHz revealed the presence of Gd3+ , Fe3+, and another trace species, inferred to be rare-earth, at concentrations on the order of parts per billion.
The phonon coupling to microwave resonances was also explored in the pursuit of the development of a novel sensing approach, by parameterising the change in permittivity of the crystal with temperature. This innovative method of bolometry may be achieved by utilising the temperature dependence (O(300) MHz/K) of high-Q resonances. These findings motivate further exploration of prospective uses of this low-loss dielectric material for applications in precision and quantum metrology, as well as searches for dark matter.

Morning 4 / 87

New techniques to Search for wave-like dark matter and test fundamental physics using precision low-energy measurements.

Author: Michael Tobar[1]

[1] *Department of Physics, UWA*

Corresponding Author: michael.tobar@uwa.edu.au

In this presentation I will provide an update on research at the Quantum Technologies and Dark Matter Laboratories at the University of Western Australia to develop new techniques to search for wave-like dark matter candidates and to test fundamental physics using precision low-energy metrology.

In particular we will focus on techniques which utilize low-loss and low-noise electromagnetic oscillators [1,2], that search for signs of axions, scalar dark matter, quantum gravity. And high frequency gravitational waves [3-8]

This work was funded by the ARC Centre of Excellence for Engineered Quantum Systems, CE170100009, and Dark Matter Particle Physics, CE200100008

[1] EN Ivanov, ME Tobar, Noise Suppression with Cryogenic Resonators, arXiv:2403.18427
[2] EN Ivanov, ME Tobar, Frequency Stable Microwave Sapphire Oscillators, arXiv:2403.18419
[3] JF Bourhill, ECI Paterson, M Goryachev, ME Tobar, Searching for Ultra-Light Axions with Twisted Cavity Resonators of Anyon Rotational Symmetry with Bulk Modes of Non-Zero Helicity, arXiv:2208.01640
[4] ME Tobar, AV Sokolov, A Ringwald, M Goryachev, Searching for GUT-scale QCD Axions and

Monopoles with a High Voltage Capacitor, arXiv:2306.13320
[5] G Tobar, I Pikovski, ME Tobar, Detecting kHz gravitons from a neutron star merger with a multi-mode resonant bar, arXiv:2406.16898
[6] RY Chiao, NA Inan, M Scheibner, J Sharping, DA Singleton, ME Tobar, Gravitational Aharonov-Bohm Effect, arXiv:2311.07764
[7] WM Campbell, ME Tobar, S Galliou, M Goryachev, Improved constraints on minimum length models with a macroscopic low loss phonon cavity
[8] WM Campbell, M Goryachev, ME Tobar, The Multi-mode Acoustic Gravitational Wave Experiment: MAGE, arXiv:2307.00715

Morning 1 / 89

Discovery of the Axion quasiparticle

Author: Suyang Xu[1]

Co-authors: David Marsh [2]; Jan Schutte-Engle [3]; Jianxiang Qiu [1]

[1] *Harvard University*

[2] *King's College London*

[3] *University of California, Berkeley*

Corresponding Authors: jqiu@fas.harvard.edu, suyangxu@fas.harvard.edu, janschue@berkeley.edu, david.j.marsh@kcl.ac.uk

We report the observation of the Axion quasiparticle in the condensed matter system, 2D MnBi2Te4. Its electronic properties feature a nonzero theta angle that relates electric and magnetic fields within the material. We observed coherent oscillation of this theta angle in real time at a frequency of 44 GHz by exciting a specific magnetic coherent mode (the out-of-phase antiferromagnetic magnon), thereby demonstrating the existence of the Axion quasiparticle based on its definition. This Axion quasiparticle can not only serve as a condensed matter simulation of the real Axion particle but also function as an Axion detector, as previously proposed. Interestingly, this detector operates in the sub-THz regime, which is both the most challenging and the most promising regime for detecting Dark Matter Axions. New and improved theoretical estimates of the coupling and damping in this material make this prospect appear promising.

Morning 4 / 92

First stars and galaxies in fuzzy dark matter universe

Author: Anastasia Fialkov[1]

[1] *IoA, Cambridge University*

Corresponding Author: anastasia.fialkov@gmail.com

Ultra-light axions is one of the most widely considered models of dark matter. In my talk, I will focus on the formation of cosmic web, first structures, stars and galaxies in a fuzzy dark matter universe. We model star and galaxy formation using a hydrodynamical code AREPO coupled to the ultra-light dark matter component solved using Schrodinger-Poisson code. We explore properties of the first objects and compare the results to the control CDM case.

Morning 4 / 93

First NA62 search for long-lived new physics particle hadronic decays

Authors: Angela Romano[1]; OTHER SPEAKER[None]; Samet Lezki[None]

[1] *University of Birmingham*

Corresponding Author: angela.romano@cern.ch

The NA62 experiment at CERN, designed to measure the highly-suppressed decay $K^+ \to \pi^+\nu\bar{\nu}$, has the capability to collect data in a beam-dump mode, where 400GeV protons are dumped on an absorber. In this configuration, New Physics (NP) particles, including dark photons, dark scalars and axion-like particles, may be produced and reach a decay volume beginning 80m downstream of the absorber. A search for NP particles decaying in flight to hadronic final states is reported, based on a blind analysis of a sample of 1.4×10^{17} protons on dump collected in 2021.

Morning 4 / 94

A search for axionlike dark matter with the CASPEr-gradient Low-Field experiment

Author: Julian Walter[1]

[1] *Helmholtz-Institut, GSI Helmholtzzentrum für Schwerionenforschung, 55128 Mainz, Germany // Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany*

Corresponding Author: juwalter@students.uni-mainz.de

Axions and other light pseudoscalar bosons with masses below $1\,\mathrm{eV}/c^2$, collectively referred to as axionlike particles (ALPs), are among the most well-motivated dark matter (DM) candidates.
The Cosmic Axion Spin Precession Experiment (CASPEr)\,[1] aims at detecting axionlike DM with nuclear magnetic resonance techniques.
CASPEr-Gradient in Mainz probes the coupling of nuclear spins to a galactic DM halo consisting of ALPs.
Here, a spin-polarized sample within a leading field could acquire a measurable transverse magnetization due to the effect of the ALP field gradient, which acts as a pseudo-magnetic field\,[2].
The Low-Field apparatus of CASPEr-Gradient was designed to search for ALPs with Compton frequencies between $1\,\mathrm{kHz}$ and $4.3\,\mathrm{MHz}$, corresponding to an approximate mass range of 10^{-12} to $10^{-8}\,\mathrm{eV}/c^2$.
We report the first measurement on a thermally polarized liquid methanol sample at a $317\,\mathrm{G}$ leading field, where we scanned for ALP signals within a $250\,\mathrm{Hz}$ bandwidth around $1348500\,\mathrm{Hz}$.

[1] D. F. J. Kimball et al. "Overview of the Cosmic Axion Spin Precession Experiment (CASPEr)" . In: \emph{Microwave Cavities and Detectors for Axion Research.} Cham: Springer International Publishing, 2020, pp.~105–121. ISBN:~978-3-030-43761-9

[2] P. W. Graham and S. Rajendran. "New observables for direct detection of axion dark matter". In: \emph{Phys. Rev. D}~88 (3 Aug. 2013), p.~035023. DOI: 10.1103/PhysRevD.88.035023.

Afternoon 2 / 95

Vortex Stability in Ultralight Scalar Solitons

Author: Anthony Mirasola[1]

Co-authors: Chanda Prescod-Weinstein [2]; Mark Neyrinck [3]; Nathan Musoke [2]

[1] *University of Illinois Urbana-Champaign*

[2] *University of New Hampshire*

[3] *Ikerbasque, the Basque Foundation for Science*

Corresponding Authors: mark.neyrinck@gmail.com, chanda.prescod-weinstein@unh.edu, aem8@illinois.edu, nathan.musoke@unh.edu

Galaxies and their dark-matter haloes are commonly presupposed to spin. But it is an open question how this spin manifests in haloes and soliton cores made of scalar dark matter (SDM, including fuzzy/wave/ultralight-axion dark matter). One way spin could manifest in a necessarily irrotational SDM velocity field is with a vortex. But recent results have cast doubt on this scenario, finding that vortices are generally unstable except with substantial repulsive self-interaction. We introduce an alternative route to stability: in both (non-relativistic) analytic calculations and simulations, a black hole or other central mass at least as massive as a soliton can stabilize a vortex within it. This conclusion may also apply to stellar-scale Bose stars.

Morning 1 / 96

Introduction

Morning 2 / 97

Overview of astrophysical tests of DM

Author: Sownak Bose[1]

[1] *Durham University*

Corresponding Author: sownak.bose@durham.ac.uk

To be filled.

Morning 3 / 100

TBA

Co-authors: Peter Graham ; Surjeet Rajendran

TBA

Morning 4 / 101

Quantum Sensor for dark matter and GW searches

Author: Michael Doser[1]

[1] *CERN*

Corresponding Author: michael.doser@cern.ch

TBA

Morning 5 / 102

Closing remarks

Afternoon 2 / 103

Optimisation of the signal to noise ratio in haloscope detectors.

Corresponding Authors: ahipp@ufl.edu, tanner@phys.ufl.edu

The signal from an axion haloscope has a certain spectral content, set by the axion rest mass, mc2, and the relative kinetic energy K of the axions at the detector. For virialized halo axions, the ratio of these energies is K/mc2 ~ 10-6. If the detector is operating at 1 GHz, the signal emitted would have a spectral width of 1 kHz. On account of the high Q ~ 105 of the cavity, the detector is sensitive only over 10–20 kHz but its voltage output is likely sampled at 100 kHz, giving a 50 kHz wide spectrum when Fourier analyzed. The user may choose to measure the signal with a spectral resolution of 1 kHz, requiring 2 ms of measurement time, or perhaps at 10 or 100 Hz, requiring 200 or 20 ms respectively. In reality, to improve signal to noise, the voltage is measured for, say, 100 sec and then various averaging techniques are used to produce a medium-resolution spectrum. How should the parameters of these averages be determined? By analysis and by simulations, we will argue that the 100 sec time series should be Fourier analyzed in 1 or 2 ms chunks, producing spectra in which the signal is just barely resolved spectrally, and then the large number (N = 5×104 or 105) of spectra should be averaged. The strength of the signal in the average is the same as in the individual spectra whereas the noise is reduced by the square root of N. Moreover, because every point in the time series contributes in the Fourier transform to each point in the frequency spectrum, a shorter time series contains a smaller noise signal. The SNR versus resolution is not sharply peaked but is definitely maximized by the approach outlined above.

Supported by the DOE through grant DE-SC0010296.

Morning 3 / 104

New Theoretical and Experimental Perspectives on Axions

Author: Surjeet Rajendran[None]

Corresponding Author: surjeet@jhu.edu

It is sometimes claimed that the Strong CP problem can be solved by invoking mechanisms that impose CP as a symmetry of the theory. I will argue that these solutions do not work. The strong CP problem arises from the fact that the CP invariant QCD Hamiltonian possesses states that violate CP. It is thus a problem of state selection - why are we in a state of QCD which respects CP even though there are many states that violate CP? Imposition of CP as a symmetry is a restriction on the Hamiltonian - but it cannot be used to restrict the states of the theory. Since the strong CP problem is a question of state selection as opposed to the symmetries of the Hamiltonian, it can only be solved through dynamical mechanisms that can relax any initial non-CP preserving state to a CP preserving state. The axion is the only known dynamical way to achieve this, considerably elevating

the theoretical motivations for its existence. After presenting this argument, I will discuss a proposal to find axions with a mass around 100 GHz using nonlinear optical materials.