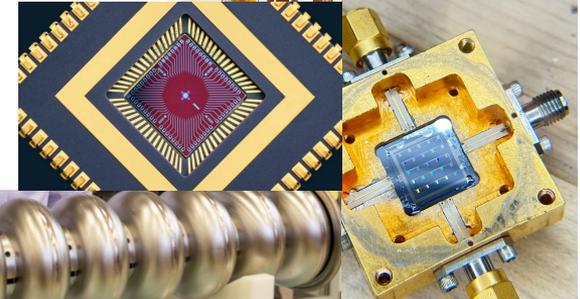


Welcome to

CPAD RDC8 Quantum & Superconducting Detectors

Rakshya Khatiwada & Aritoki Suzuki
10/07/2025



CPAD R&D Coordination (RDC) groups

Brings together the CPAD community in a more persistent way than the annual workshops alone, to coordinate R&D efforts and to forge collaboration.

RDC	Topic	Coordinators
1	Noble Element Detectors	Jonathan Asaadi, Carmen Carmona
2	Photodetectors	Shiva Abbaszadeh, Flavio Cavanna
3	Solid State Tracking	Sally Seidel, Tony Affolder
4	Readout and ASICs	Angelo Dragone, Mitch Newcomer
5	Trigger and DAQ	Jinlong Zhang, (TBN)
6	Gaseous Detectors	Prakhar Garg, Sven Vahsen
7	Low-Background Detectors (incl. CCDs)	Noah Kurinsky, Guillermo Fernandez-Moroni
8	Quantum and superconducting Detectors	Aritoki Suzuki, Rakshya Khatiwada
9	Calorimetry	Marina Artuso, Minfang Yeh
10	Detector Mechanics	Andy Jung, Eric Anderssen
11	Fast Timing	Gabriele Giacomini, Matt Wetstein

Subscribe to RDC mail-list: https://cpad-dpf.org/?page_id=1549

Our Goal

1. Foster a collaborative, supportive, and coordinated environment for new ideas, blue sky efforts, and non-project specific R&D
2. Provide a platform to link together facilities, expertise and people to tackle technology challenges across HEP/NP
3. Facilitate new funding mechanism for R&D through development of work packages and proposals

Activities: Regular meeting with the community, work package development based on community feedback, CPAD workshop organization for RDC8 etc.

Main highlights of Past year:

- Organized CPAD 2024 workshop at University of Tennessee, Knoxville
- Coordinated and facilitated funding mechanisms for **University Comparative Review and DOE QuantiSED 2.0** NOFO through several coordination talks and discussion sessions.
- Developed and finalized **RDC8 work-packages**. (Solicited feedback with the community)

RDC R&D Priorities:

<https://docs.google.com/document/d/1sc-W2Fblbv8dmrXPkAvoEIDRNfHtK7Xw/ed>

Coordinating Panel for Advanced Detectors
RDC R&D Priorities
CPAD 2025

Contacts: Jonathan Asaadi (CPAD vice-Chair), Jinlong Zhang (CPAD Chair)

Introduction

These generic detector R&D priorities were developed based on the key challenges identified by the 2021 Snowmass Instrumentation Frontier report [1], which concurred and broadened the Priority Research Directions in the 2019 DOE HEP Detector R&D Basic Research Needs (BRN) report [2]. The list was presented initially at CPAD Workshop 2024, synthesized for the Instrumentation Community Input to the European Strategy for Particle Physics (ESPP) 2026 Update [3].

US R&D Collaborations (RDCs) were established with generic R&D focus, and are organized along specific technology directions or common challenges, and aim to define and follow roadmaps to achieve specific R&D goals, as described in the 2023 P5 Report [4]. The RDC coordinators have been continuously articulating the R&D priorities by working with the community. Each priority item is described in this document as a work package (WP) with brief definition and concise dictionary text. A complete version of this document will be made

Work Packages

Thank you for your inputs - Detailed work-package can be found here:

https://docs.google.com/document/d/1lCIXozlkaBEDqnQcAH3q_tUNpVFRReUooNKZ4cWOEdA0/edit?tab=t.0#heading=h.410yn0o6io6n

CPAD chairs have made the concise work-package public

RDC-8:

Quantum and Superconducting Sensors

Gianpaolo Carosi, Clarence Chang, Andrew Geraci, Rakshya Khaitiwada, Timothy Kovachy, Matthew Shaw, Swati Singh, Ariyoki Suzuki, Silvia Zorzi

Table of Contents

[Introduction](#)
[Pairbreaking, Photon & Phonon Sensors](#)
[Coherent Wave Sensors](#)
[AMO, clocks, interferometry, NMR, Optomechanical Sensors](#)
[Theory, Simulation & Novel Material](#)

Introduction

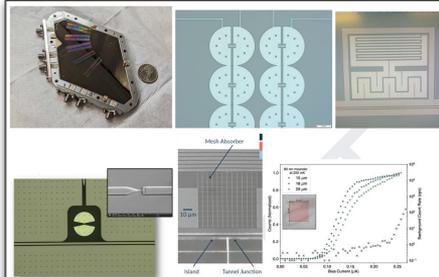
RDC-8 covers the development of quantum and superconducting sensors. This RDC addresses a broad spectrum of topics within this rapidly evolving field. To effectively cover the field, the RDC is divided into four sub-categories: Pair-breaking photon/phonon sensors, coherent wave sensors, AMO clocks, interferometry NMR, optomechanical sensors, and novel material and theoretical developments. In the subsequent sections, we outline the work packages for each subcategory, highlighting key developments aimed to advance the frontiers of fundamental physics research.

Pairbreaking, Photon & Phonon Sensors

This subcategory includes, but is not limited to, devices such as MKIDs, TESes, MMCs, SNSPDs, QCDs, and SC Qubits.

RDC8-WP1a: Pairbreaking phonon and photon detectors and bolometers

We recommend the development of phonon and photon sensing detector technology that can significantly surpass present limits in one or more of the following metrics: (1) energy threshold for single-excitation sensing, spectral resolution, or noise performance (2) detection efficiency at the lowest energy thresholds (3) dark count rate, including low-energy backgrounds (4) active area and channel count. Such detectors may include single photon and phonon counters, as well as direct detectors and bolometers. These new sensor capabilities will enable transformative discoveries in the fields of direct dark matter, dark energy detection, and cosmology among other HEP science goals articulated in the P5-report. Successful proposals will incorporate aspects of sensor research and development, theory and materials research, scalable readout electronics, integration into experimental instrumentation, and mitigation of backgrounds. It is expected that a multidisciplinary team will be required to successfully address these technology development objectives.



Images of examples of pair-breaking detectors being developed for IHEP experiments. Top left: Photo of a 4-pixel dual polarization mm-wave Microwave Kinetic Inductance Detectors (MKIDs) spectrometer for cosmological studies using mm-wave Line Intensity Mapping. Top center: Photo of a few low-Tc Quasiparticle-trap assisted Electrothermal-feedback Transition Edge Sensors (QETs) being developed for low-mass particle dark matter searches. Top right: Photo of a low-Tc MKID being developed for low-mass particle dark matter searches. Lower left: Photo of a transition qubit based detector for use in either low mass dark matter or axion dark matter searches. Bottom center: Photo of a charge qubit based detector for use in axion dark matter and dark photon searches. Bottom right: Photo and data from a low threshold Superconducting Nanowire Single Photon Detector (SNSPD).

Coherent Wave Sensors

This subcategory includes, but is not limited to, devices such as JPA, TWPA, KIPA, Squeezed state receivers, microwave to optical transducers, SRF cavities, superconducting/LC circuits, rf quantum upconverters, mechanical tuning of cavities.

This work package aims to advance coherent wave sensors and measurement techniques to surpass the quantum limit sensitivity. The 2024 P5 report emphasizes the need to investigate the nature of dark matter across a broad mass range through experimental studies and collaborative research with Quantum Information Science (QIS) to achieve sensitivity beyond the Standard Quantum Limit (SQL).

RDC8-WP2a: High Q electromagnetic sensors and supporting technologies

RDC8-WP2a focuses on high-Q electromagnetic sensors and supporting technologies. It is recommended to support R&D regarding the design and optimization of high-Q resonators. These advancements are

crucial for detecting dark photons, axions, or gravitational waves. Additionally, it is recommended to explore material science and R&D efforts to broaden current physics searches by extending coherence times (increase quality factor), achieving B-field tolerance, and maximizing frequency tunability in resonators designed for high coupling to dark matter or gravitational coherent sources.

RDC8-WP2b: Quantum techniques and devices to meet and surpass the SQL

RDC8-WP2b focuses on quantum techniques and devices aimed at surpassing SQL. Developing techniques for enhanced coherent signal detection is recommended, including correlated measurements, back action-evading methods (such as quantum upconverters), quantum nondemolition (QND) photon counters, and squeezed state receivers. Interesting technology R&D may include correlated arrays of quantum sensors or qubits to amplify the sensitivity of coherent dark matter detection, devices paired with techniques to evade the standard quantum limit, and correlated measurement techniques for enhanced coherent signal detection.



Photo of the Josephson Junctions in an RF Quantum Upconverter.

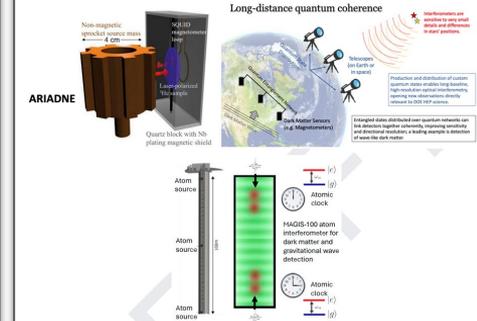
AMO, clocks, interferometry, NMR, Optomechanical Sensors

This subcategory includes, but is not limited to, techniques and devices such as AMO, clocks, interferometry, NMR, optomechanical sensors: neutral atoms, trapped ions, magnetometers, spin precession, optomechanical devices, optical-RF-magnetic levitation, cantilevers etc. entangled probe to beat the SQL with optical readout etc.

RDC8-WP3a: Optimizing detector sensitivity, scalability, readout and control

Research and development is needed to optimize the sensitivity and scalability for quantum sensors based on quantum ensembles or devices. Relevant examples of ensemble-based quantum sensors include atomic clocks, atomic interferometers, and spin-polarized samples, while device-based quantum sensors involve platforms such as optomechanical sensors or optical cavities. It is of interest to improve the signal-to-noise of these sensing platforms, including optimization of device design (e.g. by using larger volumes, higher density and/or polarization), readout (e.g. via quantum measurement, control and parameter estimation techniques), and overcoming noise (e.g. spin projection noise). Such optimized sensors can be used to search for a variety of physics beyond the standard model, such as dark matter and

dark energy, along with tests of fundamental symmetries (e.g. CP violation), relativistic physics (e.g. gravitational wave detection) and the foundations of quantum mechanics. Gravitational wave detectors using atomic clocks and/or interferometers have the potential to provide a window into the high energy physics of the early Universe, which may enable studies of energy scales that are otherwise inaccessible.



Theory, Simulation & Novel Material

Advancing the theory, modeling, and simulation of sensors and materials is a crucial aspect of developing high-performance sensors.

RDC8-WP4a: novel/blue sky theory and simulation relevant to probe science drivers and materials.

Research and development needed in theoretical and simulation activities: 1) Theoretical development to explore experimental methods that utilize quantum and superconducting devices to probe fundamental physics. 2) Modeling of device physics and performance limitations in quantum sensors, including superconducting detectors, which encompasses the development of algorithms and simulation tools and techniques to enhance quantum sensing. For example, development of a simulation package for phonon propagation in crystals, study of low bandgap materials, exploration of novel quantum materials such as topological insulators, development of theoretical models of surface/interface physics of microfabricated devices, study of resource distribution across quantum networks, and protocols for back-action evasion.

CPAD 2025 - RDC 8 sessions: Tuesday

13 talks

14:00	Introduction Woodlands AB	<i>Aritoki Suzuki et al.</i> 14:00 - 14:05
	Development of Iridium Platinum Bilayer-based Athermal Phonon Detectors Woodlands AB	<i>Dr Gensheng Wang</i> 14:05 - 14:20
	Superconducting Hafnium films for detectors Woodlands AB	<i>Kaja Rotermund</i> 14:20 - 14:35
	Development of microwave multiplexed readout for athermal phonon TES-based detectors Woodlands AB	<i>John Groh</i>  14:35 - 14:50
15:00	Toward a meV Kinetic Inductance Phonon-Mediated (KIPM) detector for low mass dark matter searches Woodlands AB	<i>Junwen Xiong</i> 14:50 - 15:05
	Phonon sensitive kinetic inductance device with low-Tc hafnium for light dark matter search Woodlands AB	<i>Xinran Li</i> 15:05 - 15:20
	Radiation-Induced Correlated Events in Layered Superconducting Detectors Woodlands AB	<i>Samuel Watkins</i> 15:20 - 15:35
	Enhanced Phonon Collection Efficiency in Aluminum MKIDs with Phonon Reflective Coating Woodlands AB	<i>Kungang Li</i> 15:35 - 15:50
17:00	Transmon-based single microwave photon detectors for QCD axion searches in the classical window Woodlands AB	<i>Osmond Wen</i> 16:30 - 16:45
	Progress of Qubit-based Sensors for meV Phonon Detection Woodlands AB	<i>Brandon Sandoval</i> 16:45 - 17:00
	Environmental Engineering of Qubit-Based Detectors Woodlands AB	<i>Daniel Molenaar</i> 17:00 - 17:15
	Examining the effect of various radioactive sources on superconducting qubits protected through gap-engineering <i>Doug Pinckney</i>	
	Utilizing the Quantum Zeno Effect in superconducting qubit based particle sensors Woodlands AB	<i>Olivia Seidel</i> 17:30 - 17:45
18:00	Quantum Charge Sensing with cCPT Amplifiers for Modular Rare-Event Detectors Woodlands AB	<i>Caleb Fink</i>  17:45 - 18:00

CPAD 2025 - RDC 8 sessions: Wednesday

11:00	Geant4 Condensed Matter Physics Simulations of Kinetic Inductance Phonon-Mediated Detectors <i>Woodlands AB</i>	<i>Selby Dang</i> 11:00 - 11:15
	Phonon and Quasiparticle Transport in Superconductors and novel materials <i>Woodlands AB</i>	<i>Israel Hernandez</i> 11:15 - 11:30
	Accurate Phonon Transport Across Interfaces in G4CMP for sub-eV Detector Simulations in the BeEST Experiment <i>Caitlyn Stone-whitehead</i>	
	Readout and Noise Sensing Schemes for Qubit-Based Detectors <i>Woodlands AB</i>	<i>Kester Anyang</i> 11:45 - 12:00
12:00	Event reconstruction analysis on radiation-induced correlated errors in superconducting qubits <i>Woodlands AB</i>	<i>Emanuela Celi</i> 12:00 - 12:15
	A quantum-enhanced two-cavity Haloscope for high-mass QCD axion detection <i>Woodlands AB</i>	<i>Christian Boutan</i> 16:30 - 16:45
	Axion Search with HAYSTAC Phase III Multi-Rod Cavity Upgrade <i>Woodlands AB</i>	<i>Claire Laffan</i> 16:45 - 17:00
17:00	A Dark Photon Dark Matter Search with a Widely-Tunable SRF Cavity <i>Woodlands AB</i>	<i>Raphael Cervantes</i> 17:00 - 17:15
	Searching for Axions with Magnetic Resonance Force Microscopes <i>Woodlands AB</i>	<i>Muhammad Hani Zaheer</i> 17:15 - 17:30
	Discussion on RF amplifiers, simulation, test infrastructure <i>Woodlands AB</i>	<i>Aritoki Suzuki et al.</i> 17:30 - 18:00
18:00		

9 talks

1 discussion



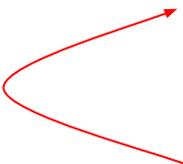
Please bring your ideas on common challenges, technology gaps, etc.

CPAD 2025 - RDC 8 sessions: Thursday

14:00	Toward a general-purpose ultra-low-external interference ... <i>Yen-Yung Chang</i>
	Calibrating Interactions in Low-Threshold, Phonon-Media... <i>Grace Bratrud</i>
	Effect of Defect Formation on Low-Threshold Detector Ph... <i>Nader Mirabolfathi</i>
15:00	Stored energy releases: material problem in dark matter s... <i>sergey pereverzev</i>
	Suppressing high energy events in superconducting devi... <i>Jacob Bargemann</i>
	Understanding the Origin of Non-ionizing Phonon Bursts ... <i>Matt Pyle</i>
16:00	

	High Energy Particle Detection with Large Area Superconducting Microwire Array <i>Christina Wenlu Wang</i>	16:30 - 16:45
	Investigation of Low-Energy Event Detection through Meissner Screening probed by a Superconductor-NV Center ense... <i>Pratyank Sau</i>	
17:00	Towards long-distance phase coherence for large-area quantum sensors. <i>Andrew Cameron</i>	17:00 - 17:15
	On-Sky Demonstration of a Superconducting Filter Bank Spectrometer on SPT-SLIM <i>Cyndia Yu</i>	17:15 - 17:30
	The SuperCDMS-HVeV Program: Results and New Directions <i>Prof. Enectali Figueroa-Feliciano</i>	17:30 - 17:45
	Discussion on material R&D, test infrastructure <i>Aritoki Suzuki et al.</i>	17:45 - 18:00
18:00		

6 joint session talks
5 talks
1 discussion

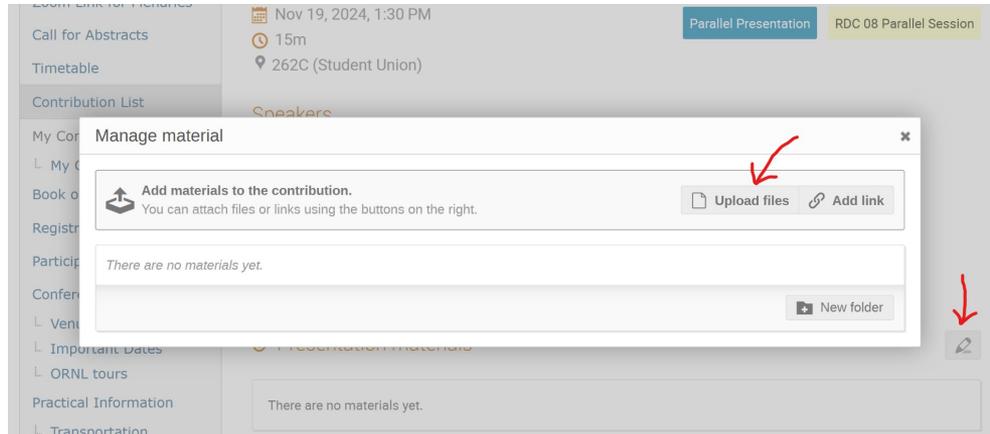


Please bring your ideas on common challenges, technology gaps, etc.

Thank you for your contributions!

Please upload your talks to indico.

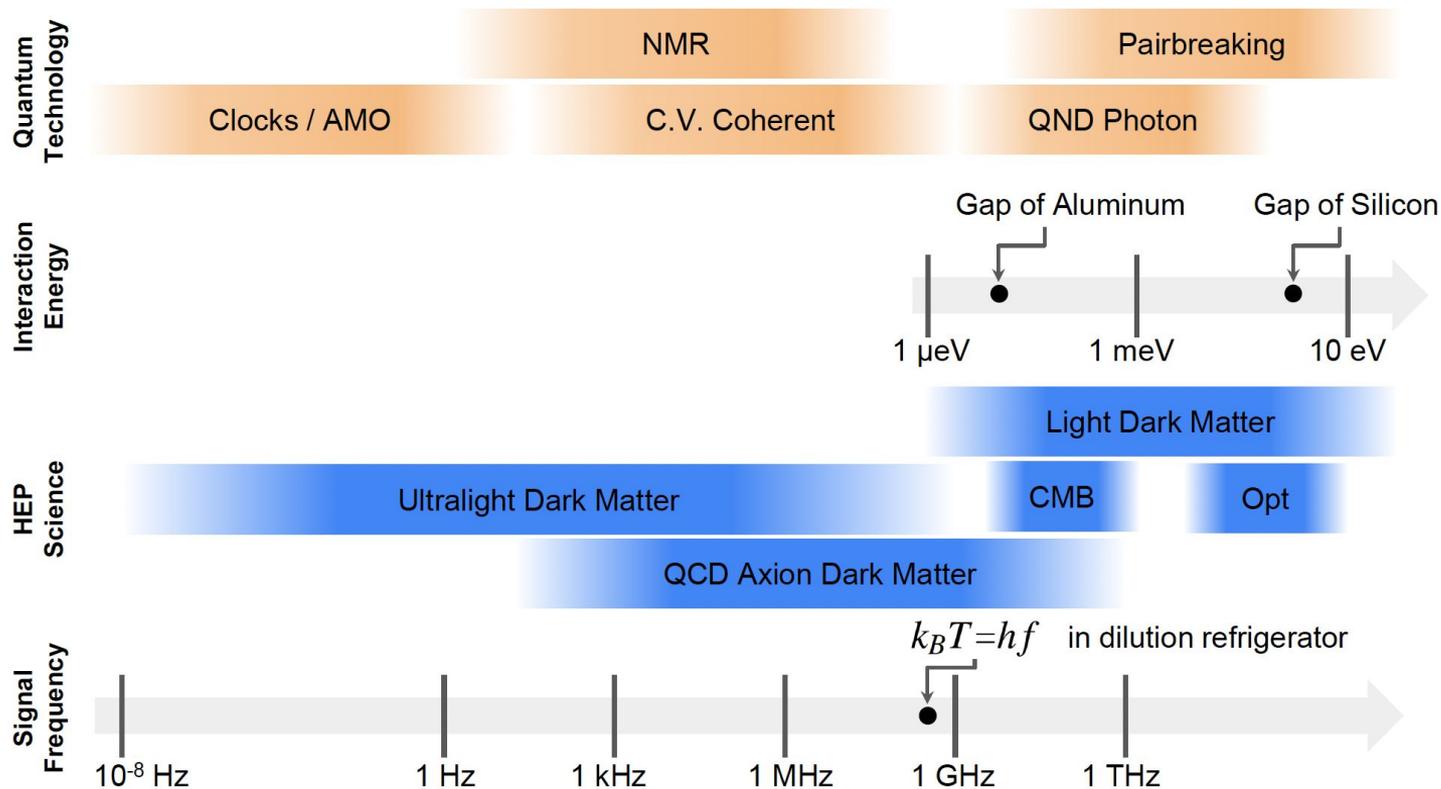
If you need help, send your slides to asuzuki@lbl.gov with session info



Let's enjoy talks and discussions over next four days

Supplementary Slides

Science Drivers and Energy Scale



Source: QIS for HEP report [arXiv:2311.01930](https://arxiv.org/abs/2311.01930)

Who are we?

RDC-8 Sub-Groups

- One of the largest CPAD RDCs
 - We base collaboration and R&D ideas from **Basic Research Needs (BRN)** and particularly, **QIS for HEP workshop, 2023.** 
Report [arXiv:2311.01930](https://arxiv.org/abs/2311.01930)
- 1) **Pairbreaking sensors:** Matt Shaw, Clarence Chang
MKIDs, TESes, SNSPDs, QCDs, SC Qubits and variants etc.
- 2) **Coherent wave sensors:** Silvia Zorzetti
JPA, TWPA, KIPA, Squeezed state receivers, microwave to optical transducers, SRF cavities, rf quantum upconverters, mechanical tuning of cavities, etc.
- 3) **AMO (interferometry, NMR, Optomechanical) clocks sensors:**
Neutral atoms, trapped ions, magnetometers, spin precession, optomechanical devices, optical-RF-magnetic levitation, cantilevers etc. entangled probes that beat SQL with optical readout etc.
- 4) **Novel materials & Theory:**
Quantum and metamaterials, Low bandgap materials (Dirac, Weyl, Sapphire), High T_c materials, spin liquids, NV centers etc. New theories/ideas that can be tested with detectors, specific technology model building etc.

arXiv > hep-ex > arXiv:2311.01930 Search...
Help | Advance

High Energy Physics – Experiment

[Submitted on 3 Nov 2023]

Quantum Sensors for High Energy Physics

Aaron Chou, Kent Irwin, Reina H. Maruyama, Oliver K. Baker, Chelsea Bartram, Karl K. Berggren, Gustavo Cancelo, Daniel Carney, Clarence L. Chang, Hsiao-Mei Cho, Maurice Garcia-Sciveres, Peter W. Graham, Salman Habib, Roni Harnik, J. G. E. Harris, Scott A. Hertel, David B. Hume, Rakshya Khatiwada, Timothy L. Kovach, Noah Kurinsky, Steve K. Lamoreaux, Konrad W. Lehnert, David R. Leibrandt, Dale Li, Ben Loer, Julián Martínez-Rincón, Lee McCuller, David C. Moore, Holger Mueller, Cristian Pena, Raphael C. Pooser, Matt Pyle, Surjeet Rajendran, Marianna S. Safronova, David I. Schuster, Matthew D. Shaw, Maria Spiropoul, Paul Stankus, Alexander O. Sushkov, Lindley Winslow, Si Xie, Kathryn M. Zurek

Strong motivation for investing in quantum sensing arises from the need to investigate phenomena that are very weakly coupled to the matter and fields well described by the Standard Model. These can be related to the problems of dark matter, dark sectors not necessarily related to dark matter (for example sterile neutrinos), dark energy and gravity, fundamental constants, and problems with the Standard Model itself including the Strong CP problem in QCD. Resulting experimental needs typically involve the measurement of very low energy impulses or low power periodic signals that are normally buried under large backgrounds. This report documents the findings of the 2023 Quantum Sensors for High Energy Physics workshop which identified enabling quantum information science technologies that could be utilized in future particle physics experiments, targeting high energy physics science goals.

Comments: 63 pages, 8 figures, Quantum Sensors for HEP workshop report, April 26–28, 2023

Subjects: **High Energy Physics – Experiment (hep-ex)**; High Energy Physics – Phenomenology (hep-ph); Quantum Physics (quant-ph)

Cite as: arXiv:2311.01930 [hep-ex]
(or arXiv:2311.01930v1 [hep-ex] for this version)
<https://doi.org/10.48550/arXiv.2311.01930>

RDC8 representative Institutions

DOE Labs (22 responses)

- Argonne National Laboratory
- Fermilab
- Los Alamos
- Livermore
- LBNL
- Pacific Northwest National Laboratory
- Sandia National Laboratories
- SLAC

National Labs (6 responses)

- Jet Propulsion Laboratory
- NIST

University (11 responses)

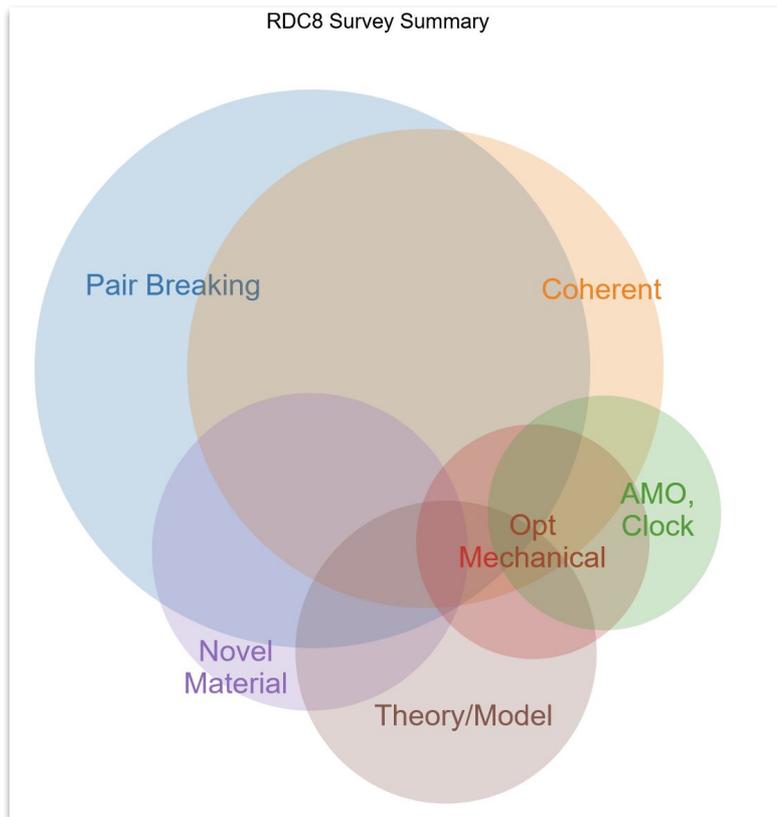
- Boston University
- Caltech
- Cornell
- UC Santa Barbara
- University of Chicago
- University of Delaware
- University of Florida
- University of Oklahoma

Non-US University (2 responses)

- Humboldt University Berlin
- The University of Western Australia

Responses from both labs and universities as well as from international institutions

RDC8 Interests



Sample size: 42

Pair breaking : 34

Coherent : 25

AMO, Clock : 6

Opt Mech : 6

Novel Material : 11

Theory : 10

Other : 1

A lot of interest in **pair breaking and coherent groups**.
Good overlaps between groups as well

Synergy with other RDCs

Sample size: 31/42 (multiple answers possible)

1. Noble Element Detector : 3
2. **Photodetectors** : **21**
3. Solid State Tracking : 2
4. **Readout and ASICs** : **13**
5. Trigger and DAQ : 3
6. Gaseous Detectors : 0
7. **Low Background Detectors** : **21**
8. This RDC
9. Calorimetry : 3
10. Detector Mechanics : 3
11. Fast Timing : 6

We have synergy with almost every other RDCs. Three RDCs stood out

We have a combined session with RDC 7 on Thursday

CPAD workshop organization and time table (Nov 7 ~ Nov 10)

Meeting notes: https://docs.google.com/document/d/129Olig_V0OTugSFRCaFVPf3QEk9fxQJhXghy2nHNWLk/edit?usp=sharing

Tuesday: RDC8 Session #1

- Open/Intro (Rakshya/Toki)
- Pair breaking subgroup intro (Clarence Chang/Matt Shaw)
- Coherent subgroup intro (Silvia Zorzetti/Gianpaolo Carosi)

Wednesday: RDC8 Session #2

- ECFA DRDq (Mike Doser)
- AMO, clock, NMR subgroup intro (Swati Singh)
- Novel Material & Theory subgroup intro (Sinead Griffin)

Wednesday: RDC8 Session #3

- 8 contributed talks

Thursday: RDC8

- 6 contributed talks

Thursday: RDC8 Session #4

- 4 contributed talks
- 1.0 hour Work package discussion

Thursday: RDC7+8 Low Backgrounds in Quantum Sensors

- 3 contributed talks
- 1.0 hour Work package discussion

Friday: RDC8 Session #5

- 6 contributed talks

Discussions!!

Suggested topics for discussion

1. How can we collect/share information beyond survey?
2. Did the subgroup summary capture all of your interest/activities? If not, what are those?
3. What are common challenges we can tackle?
4. What should be the content/structure of work packages?
5. Suggestions on activities and how to efficiently hold discussions about work packages?

Pair Breaking

Number of Interests: 34

Sub-group lead(s)

- Clarence Chang (Argonne), Matt Shaw (JPL)

Summary of topics

- Superconducting detector development (MKID, TES, SNSPD, Qubit / Quantum Capacitance), Readout electronics (Frequency-domain multiplexing, Cryogenic Electronics, ASIC development, High-density interconnects), New approaches to detector calibrations and backgrounds
Science Targets
- Dark Matter (wave and particle), cosmology, collider physics (ultra-fast timing, radiation hardness), neutrino physics.

Existing Collaborations

- SQMS, BREAD, SPICE/HERALD, TESSERACT, RICOCHET, SuperCDMS, SPT

Facility needs

- Nanofabrication, cryogenic testing, calibration and backgrounds

Ideas for work packages

- Scalable CMB Detector Arrays (Beyond CMB-S4). Low-threshold, large-area SNSPDs, Phonon-mediated MKIDs, Ultra-low-threshold TES, Qubit-based THz and mm-wave photon counting, quantum-limited parametric amplifiers.

Coherent

Number of Interests: 25

Sub-group lead(s)

- Gianpaolo Carosi (LLNL), Silvia Zorzetti (FNAL)

Summary of topics

- Precision measurements, axions (haloscopes, light shining through wall), dark matter, detection of keV mass, frequency converters, weak signals detection, wave-like DM

Science Targets

- DM, axion detection

Existing Collaborations

- ADMX, ORGAN, MAGIS-100, SQMS, BREAD
- Nat. Labs: SLAC, ANL, Fermilab, LBNL

Facility needs

- Dilution refrigerators, underground cryogenic facilities, cleanrooms, device fabrication, nanofabs, test and production facilities for superconducting devices.

Ideas for work packages

- Phonon physics, qubit-based detection, low noise amplifiers (low-frequency SQUID, JPAs), digital electronics, optomechanical systems, low dark counts single-photon detectors, microelectronics and ASICs, quantum entanglement and sensors networks