TT 67: Cryogenic Particle Detectors and Other Superconducting Electronics

Time: Friday 9:30–12:00 Location: H4

TT 67.1 Fri 9:30 H4

Towards microcalorimetry with sub-eV energy resolution: Metallic magnetic calorimeters with direct sensor readout — •Matthäus Krantz, Andreas Fleischmann, Christian Enss, and Sebastian Kempf — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

Metallic magnetic calorimeters (MMCs) are energy dispersive single particle detectors typically operated at temperatures below 50 mK. By using a paramagnetic temperature sensor strongly coupled to a matching absorber, state-of-the-art MMCs convert the energy input into a magnetic flux change that is measured by a current-sensing dc-SQUID via a superconducting flux transformer. However, transformer losses and parasitic inductances within the transformer result in a signal reduction ultimately limiting the achievable energy resolution. To challenge this limit we develop MMCs with direct sensor readout for enhanced signal coupling. There, the temperature sensor is placed on top of or within the SQUID loop. Our most recent prototype comprises a gradiometric meander-shaped SQUID inductance and gives reason to expect to significantly lower our current MMC world record energy resolution of 1.6 eV (FWHM) for soft X-rays. We describe the design, microfabrication and optimization of our prototype and discuss the presently achieved performance indicating that we will be able to reach sub-eV energy resolution in the near future.

TT 67.2 Fri 9:45 H4

Development of a Beta Spectrometry Setup using Metallic Magnetic Calorimeters — •Michael Paulsen[1,2], Jörn Beyer[1], Lina Bockhorn[3], Christian Enss[2], Sebastian Kempf[2], Karsten Kossert[3], Martin Loidl[4], Riham Mariam[4], Ole Nähle[3], Philipp Ranitzsch[3], and Matias Rodrigues[4] — [1]Physikalisch-Technische Bundesanstalt, Berlin, Germany — [2]Kirchhoff-Institute for Physics, Heidelberg University, Germany — [3]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [4]CEA, LIST, Laboratoire National Henri Becquerel, Saclay, France

The precise knowledge of beta spectrum shapes is relevant in radionuclide metrology, e.g. when determining the activity of samples containing beta emitting isotopes, as well as in fundamental research or applications such as nuclear medicine. Employing Metallic Magnetic Calorimeters (MMCs) with the radionuclide sample embedded in a 4π absorber geometry has proven to be among the best beta spectrometers in terms of energy resolution, notably for low energy beta transitions. This presentation discusses a new MMC-based beta spectrometer that is being developed within the MetroBeta project that operates at temperatures < 20 mK. We present initial beta spectra measurements of Cl-36 (Emax = 709.5 keV) using the newly developed setup, including a discussion of the data acquisition and evaluation used.

TT 67.3 Fri 10:00 H4

Gamma spectroscopy to measure the ^{229}Th isomer energy using a 2-dimensional array of metallic magnetic microcalorimeters — •Jeschua Geist[1], Daniel Hengstler[1], Christian Schötz[1], Sebastian Kempf[1], Loredana Gastaldo[1], Andreas Fleischmann[1], Christian Enss[1], Georgy A. Kazakov[2], Simon Stellmer[2], and Thorsten Schumm[2] — [1]Heidelberg University — [2]Vienna University of Technology

The isotope ^{229}Th has a nuclear isomer state with the lowest presently known excitation energy, which possibly allows to connect the fields of nuclear and atomic physic with a potential application in a nuclear clock. In order to verify and improve the accuracy of the currently most accepted energy value for this isomere energy, (7.8 ± 0.5) eV, we plan to resolve the 29.18 keV doublet in the γ-spectrum following the α-decay of ^{233}U, corresponding to the decay into the ground and isomer state, to measure the isomer transition energy without additional theoretical input parameters.

We developed the detector array maXs-30 consisting of 8x8 metallic magnetic calorimeters with an expected energy resolution below 6 eV, providing a large detection area of 16 mm^2 to face the low rate of the 29.18 keV transitions. We present a new value for the isomere energy with a detector performance of 11 eV FWHM for photons up to 60 keV, show latest recorded ^{229}Th spectra and discuss different ways to derive the isomer energy from these spectra.

TT 67.4 Fri 10:15 H4

Saturation power measurement for a non-degenerate parametric amplifier based on a dispersion engineered SQUID array. — •Ivan Takmakov[1,2], Patrick Winkel[1], Farshad Foroughi[3,4], Luca Planat[3,4], Javier Puertas Martinez[3,4], Wolfgang Wernsdorfer[1,2], Alexey Ustinov[1,2,5], Ioan Pop[1,2], and Nicolas Roch[3,4] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, Germany — [2]Institute of Nanotechnology, Karlsruhe Institute of Technology, Germany — [3]Universite Grenoble Alpes, Institut NEEL, France — [4]CNRS, Institut NEEL, France — [5]Russian Quantum Center, National University of Science and Technology MISIS, Russia

Saturation power is one of the most important characteristics of an amplifier. For a Josephson Parametric Amplifier (JPA) its accurate measurement imposes a challenge. A JPA is typically operated at 20mK and the attenuation of coaxial cables changes when they are cooled down. Thus a calibration is required to know the power of a microwave signal at the input of a JPA.

We present measurements of saturation power of a Dimer Josephson Junction Array Amplifier (DJJAA). The amplifier is based on a dispersion engineered SQUID array. In order to measure the amplifier's saturation power, in front of a DJJAA we connect a transmon qubit coupled to a transmission line. The transmission through this chip depends on the power of a signal. Using this dependence we can measure the signal power at the qubit sample and thus perform a calibration for the saturation power measurements.

TT 67.5 Fri 10:30 H4

Towards a SQUID-based Traveling Wave Parametric Amplifier — •Luca Planat, Arpit Ranadive, Karthik Bharadwaj, Olivier Buisson, Rémy Dassonneville, Farshad Foroughi, Wiebke Guichar, Sébastien Léger, Cécile Naud, Javier Puertas-Martínez, and Nicolas Roch — Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, 38000 Grenoble, France

Superconducting Parametric Amplifiers are key to research fields involving microwave signals in the quantum regime, such as superconducting qubits or NEMs because of the large gain they provide and their noise performance. Large interaction time between a weak microwave signal, a strong coherent pump tone and a non-linear medium is required to obtain enough gain. Up to now, this was achieved by coupling the non-linear medium to a resonator. But this is also possible by using distributed non-linear media and working in transmission, thus overriding issues of limited bandwidth due to resonant cavities. When the medium is a Josephson junction, this new class of amplifier is called Josephson Traveling Wave Parametric Amplifier (J-TWPA) [1]. We will present our on-going effort to develop a SQUID-based TWPA. It will allow to tune in situ the characteristic impedance of the TWPA to have a perfect impedance match with the rest of the electronic setup, despite the uncertainty of the electrical properties of the device due to the fabrication process.

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[1] C. Macklin et al., Science 350, 6258 (2015)

TT 67.6 Fri 10:45 H4

Microwave SQUID Multiplexing of Metallic Magnetic Calorimeters — •Mathias Wegner, Daniel Richter, Felix Ahrens, Christian Enss, and Sebastian Kempf — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

To our present knowledge the most suitable device for reading out large-scale detector arrays consisting of hundreds or thousands of metallic magnetic calorimeters (MMCs) is a microwave SQUID multiplexer (μMUX). Each channel of a μMUX consists of a non-hysteretic rf-SQUID which is used for detector readout and which is inductively coupled to a superconducting microwave $\lambda/4$ resonator with unique resonance frequency. Due to the magnetic flux dependence of the SQUID inductance as well as the mutual interaction between the SQUID and the associated resonator, the signal of the MMC is transduced into a resonance frequency shift of the related resonator.

While the basic multiplexer model developed in the context of transition edge sensors was sufficient for developing our first prototype

μMUX devices, it does not include important aspects which need to be considered for an optimized MMC readout. In particular, the model does not describe the readout power dependence as well as the impact of the parasitic shunts of the Josephson junction and the influence of the MMCs on the μMUX characteristics.

In this contribution we present a refined version of the μMUX model which includes these aspects. Besides, we show that we gain a very good agreement between measured data and our refined multiplexer model.

TT 67.7 Fri 11:00 H4

Efficient Filter Solutions for Frequency Demultiplexing of Microwave-SQUID coupled Metallic Magnetic Calorimeters — •Nick Karcher, Oliver Sander, and Marc Weber — Karlsruhe Institute for Technology, Eggenstein-Leopoldshafen, Germany

For the Electron Capture in Ho^{163} (ECHo) experiment, metallic magnetic calorimeters deliver the required energy resolution of $\leq 5\,\mathrm{eV}$ for the Holmium decay energy spectrum. To gather the statistics for the spectrum 12000 calorimeters are planned. Microwave SQUID multiplexing can be used to connect several hundred metallic magnetic calorimeters via a single coax pair to a room temperature DAQ system.

We will show an FPGA based software-defined radio DAQ system which can generate the required stimulation frequency comb and is capable of processing the sensor modulated signals. The multiplex bandwidth of a channel is between $4-8\,\mathrm{GHz}$ with a complex baseband of 800 MHz. It relies on five 1 GS/s, 16 Bit DA and 14 Bit AD converters. For a large number of channels (>100) the necessary channelization hardware resources within the FPGA drives the cost. We will present a novel channelization scheme. Compared to a purely digital down conversion (DDC) based solution it reduces the required resources by almost 85% by utilizing a combination of poly-phase filtering, and DDC at a clock rate of 500 MHz.

TT 67.8 Fri 11:15 H4

Quantum discord in squeezed microwaves — •Kirill G. Fedorov[1,2], Stefan Pogorzalek[1,2], Minxing Xu[1,2], Michael Fischer[1,2,3], Edwar Xie[1,2,3], Qi-Ming Chen[1,2], Achim Marx[1], Frank Deppe[1,2,3], and Rudolf Gross[1,2,3] — [1]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, Technische Universitaet Muenchen, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), Schellingstrasse 4, 80799 Muenchen, Germany

Quantum discord is known as a general measure for quantum correlations in bipartite systems. It encompasses all nonclassical correlations including entanglement. Quantum discord has many intriguing fundamental properties many of which require experimental verification such as the asymptotic robustness towards environmental noise. We experimentally investigate quantum discord in propagating two-mode squeezed (TMS) microwave states generated with the help of superconducting Josephson parametric amplifiers. We exploit asymmetric noise injection into these TMS states which allows us to demonstrate the robustness of quantum discord as opposed to the sudden death of entanglement. Finally, we discuss the relevance of quantum discord as a resource in quantum communication and sensing , in particular with respect to remote state preparation and quantum radar protocols.

We acknowledge support by the German Research Foundation through FE 1564/1-1, Elite Network of Bavaria through the program ExQM, EU Quantum Flagship project QMiCS, and Excellence Cluster MCQST.

TT 67.9 Fri 11:30 H4

Quantum one-time pad with propagating squeezed microwaves — •Stefan Pogorzalek[1,2], Kirill G. Fedorov[1,2], Qi-Ming Chen[1,2], Michael Fischer[1,2,3], Michael Renger[1,2], Edwar Xie[1,2,3], Achim Marx[1], Frank Deppe[1,2,3], and Rudolf Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

Quantum communication protocols employ nonclassical correlations as a resource for an efficient transfer of quantum states. The closely related field of quantum cryptography deals with the secure transfer of information by exploiting quantum correlations. As a fundamental quantum communication protocol, remote state preparation (RSP) achieves both an efficient and secure transfer of a quantum state. We focus on the latter property by relating the RSP scheme to an extension of the cryptographic protocol known as the one-time pad to the quantum regime. In particular, we achieve the transfer of a quantum squeezed state with 1.6 dB of squeezing below the vacuum over a distance of 35 cm of superconducting cable. At the same time, the classically communicated signal reveals nearly no information about the transferred quantum state.

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TT 67.10 Fri 11:45 H4

Quantum Fourier Transform in Oscillating Modes — •Qi-Ming Chen[1,2], Frank Deppe[1,2,3], Michael Renger[1,2], Michael Fischer[1,2,3], Stefan Pogorzalek[1,2], Edwar Xie[1,2,3], Kirill G. Fedorov[1,2], Achim Marx[1], and Rudolf Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

Quantum Fourier transform (QFT) is a key ingredient for many kinds of quantum algorithms. Traditional realizations of QFT requires a large number of qubits or a moderate number of qubits with a complex procedure of qubit recycling mechanism, which limit its application in present-day platforms. We address this problem by mapping the qubit state to an oscillating mode with an infinite-dimensional Hilbert space, and realize QFT in two coupled oscillating modes through cross-Kerr interaction. This method provides the possibility of realizing high-precision QFT without scaling up the dimension of the quantum circuit, which paves the way for realizing various quantum algorithms in the near future.

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