TT 39: Focus Session: Frontiers in Cryogenic Particle Detection

Time: Wednesday 15:00–18:30 Location: HSZ 03

Invited Talk TT 39.1 Wed 15:00 HSZ 03
Magnetic Micro-Calorimeters: Present success stories, concepts and visions — •Andreas Fleischmann — Heidelberg University, Heidelberg, Germany

Micro-calorimeters are energy dispersive detectors, which can be optimized for the detection of various kinds of particles, ranging from single visible photons over x-ray to hard gamma-rays, including alpha- and beta-particles as well as neutral molecules with some keV of kinetic energy. Operated in a purely thermal mode, micro-calorimeters can achieve arbitrarily good energy resolution, provided a low enough detector temperature. And indeed, in the last decade single channels as well as arrays of micro-calorimeters have become indispensable instruments in numerous fields of science ranging from quantum information, molecular and atomic physics over astro-particle physics to nuclear forensics and homeland security. In this review talk we will present some of the fascinating detector systems, discuss the physics and design considerations of magnetic micro-calorimeters and try to identify promising paths for future developments.

Invited Talk TT 39.2 Wed 15:30 HSZ 03
Ultra-Sensitive Microwave Kinetic Inductance Detectors from the Optical to the Far Infrared — •Jochem Baselmans[1,2], Pieter de Visser[1], Stephen Yates[1], Lorenza Ferrari[1], Vignesh Murugesan[1], David Thoen[2], and Akira Endo[2] — [1]SRON Netherlands Institute for Space Research — [2]Delft University of Technology

Near future space-based observatories for the far-infrared and for the optical will need large arrays of cryogenic detectors with unprecedented sensitivity. Aluminium based Microwave Kinetic Inductance Detectors (MKIDs) are the most promising for these applications. MKIDs are superconducting resonators whose resonant frequency and Q factor are modified due to photon absorption. They are read-out using a microwave readout signal at the unperturbed resonant frequency. These devices can be well described using the standard Mattis-Bardeen theory, with the added complexity that the quasiparticle energy distribution is modified by the absorption of readout photons with E = $hf_{readout} << \Delta$. At $T<T_c/8$ this process creates excess quasiparticles proportional to $\sqrt{P_{readout}}$, which limits the sensitivity. Since decreasing $P_{readout}$ is impossible due to excess noise sources we reduce the device volume. This results in a Noise Equivalent Power $NEP = 6 \cdot 10^{-20}\ W/\sqrt{Hz}$, 4-5 times better than previously reported For optical MKIDs, capable of single photon spectroscopy, an additional issue is the escape of high energy phonons from the aluminium film into the substrate. I will discuss recent experiments that use thin membranes to significantly reduce the phonon loss. This drastically increases the resolving power to 50 for 402 nm photons.

Invited Talk TT 39.3 Wed 16:00 HSZ 03
LTS dc-SQUID sensors for TES and MMC readout — •Jörn Beyer — Physikalisch-Technische Bundesanstalt, Berlin, Germany

The superconducting quantum interference device (SQUID) is a highly sensitive detector for magnetic flux or any physical quantity that can be efficiently converted into flux. Current sensors based on LTS SQUIDs are practically unrivalled to operate two categories of superconducting cryogenic detectors, namely transition edge sensors (TESs) and metallic magnetic calorimeters (MMCs). Applications of TES detectors range from the bolometric detection of sub-millimeter waves to calorimetric detection of X- and gamma-rays. MMCs so far address primarily high-energy applications, for instance spectrometry of soft and hard X-rays or radionuclide spectrometry. In this contribution, basic technology and design concepts of LTS dc-SQUID current sensors are presented. Efficient signal coupling as well as circuit configurations such as SQUID cascades, SQUID arrays, SQUID sensors with differential output and SQUID-based multiplexers will be discussed. LTS dc-SQUIDs already provide adequate performance for a range of readout applications of single TESs and MMCs as well as of arrays of these detectors. Still, further improvement of sensor functionality and noise is possible. Refined lithographic technology can be employed to realize SQUID sensors with sub-micrometer-sized Josephson junctions as well as fine-pitch superconducting pick-up coils. Recent progress on these developments will be presented.

15 min. break.

Invited Talk TT 39.4 Wed 16:45 HSZ 03
CRESST and NUCLEUS: The low-energy frontier of Dark Matter and neutrino physics — •Raimund Strauss — Technische Universität München

The CRESST and NUCLEUS experiments are moving the low-energy frontier in astroparticle physics with cryogenic calorimeters. Their common detector technology is based on single crystals equipped with tungsten transition-edge-sensors that are operated at temperatures of about 10mK. CRESST has achieved the world-best energy thresholds for nuclear recoils in the 10eV regime and is currently the leading experiment for sub-GeV Dark Matter searches. In this talk, I will present recent results on low-mass Dark Matter acquired during the latest measurement campaign at the Gran Sasso underground laboratory (LNGS) in Italy, and discuss the future Dark Matter program of CRESST. The NUCLEUS experiment aims for the exploration of coherent-elastic neutrino nucleus scattering (CEvNS) at a nuclear power reactor. It opens a new window to study the fundamental properties of neutrinos and to probe physics beyond the Standard Model of Particle Physics. Accessing energies down to the 10 eV regime enables to fully exploit the strongly enhanced cross section of CEvNS which leads to a miniaturization of neutrino detectors. A new detector concept based on gram-scale cryogenic calorimeters establishes a fiducial-volume cryogenic detector. NUCLEUS is fully funded and will be installed at the CHOOZ nuclear power plant in France. I will present first results from a prototype cryogenic detector and discuss the extensive physics program of NUCLEUS.

Invited Talk TT 39.5 Wed 17:15 HSZ 03
Large Array of Superconducting Transition-Edge Sensors for High Sensitive Photon and Particle Detectors — •Luciano Gottardi — SRON - Netherlands Institute for Space Research, Utrecht , The Netherlands

Superconducting Transition-Edge Sensors (TES) have proven to achieve very high sensitivity in detecting small temperature changes. TES-based detectors are employed in many low temperature imaging instruments in the field of gamma-ray spectroscopy, X-ray and infrared astrophysics, CMB-polarization experiments and optical instrumentation. We will present the cutting-edge technology of the X-ray Integral Field Unit on board of the future ESA Advanced Telescope for High-Energy Astrophysics (Athena). The detector baseline consists of 3200 micro-calorimeters based on superconducting MoAu transition-edge sensors (TES's) from NASA-Goddard read out in the MHz bandwidth using Frequency Division Multiplexing (FDM), based on Superconducting QUantum Interference Devices (SQUIDs) from SRON/VTT. The proposed design calls for devices with high quantum efficiency and a breakthrough energy resolution of 2.5 eV at 5.9 keV. The focus of this paper will be on our recent efforts in the optimization of the NASA/Goddard MoAu and the SRON TiAu TES pixel design to improve on the superconducting transition uniformity, the noise, and to minimize non-linearity effects. This technology is potentially interesting as well for the development of high resolution X-ray cameras for monitoring the quality of the plasma in nuclear fusion reactors or for the search of axions-like particles.

TT 39.6 Wed 17:45 HSZ 03
Beta Spectrometry Measurements with Metallic Magnetic Calorimeters — •Michael Paulsen[1,2], Jörn Beyer[1], Lina Bockhorn[3,4], Christian Enss[2], Sebastian Kempf[2], Karsten Kossert[4], Martin Loidl[5], Riham Mariam[5], Ole Nähle[4], and Matias Rodrigues[5] — [1]Physikalisch-Technische Bundesanstalt (PTB), Berlin, Germany — [2]Kirchhoff-Institute for Physics, Heidelberg University, Germany — [3]Institut für Festkörperphysik, Leibniz University, Hannover, Germany — [4]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [5]CEA, LIST, Laboratoire National Henri Becquerel, Saclay, France

Precise measurements of beta spectra shapes are relevant in radionuclide metrology, e.g. when determining the activity of samples containing beta emitting isotopes and in fundamental research. Metallic Magnetic Calorimeters (MMCs) are energy-dispersive low-temperature detectors that are particularly suitable for beta spectrometry as they can be employed for wide energy ranges while having high energy resolution. We present beta spectra of ^{99}Tc ($E_{max} = 293.8\,$keV) and ^{36}Cl

(E_{max} = 709.5 keV) measured with MMC-based beta spectrometers along with a discussion of how systematic bremsstrahlung effects can be reduced for high energy spectra ($E_{max} > 500$ keV) using a dedicated absorber preparation or an unfolding algorithm.

TT 39.7 Wed 18:00 HSZ 03

Development and optimisation of metallic magnetic calorimeter arrays towards ECHo-100k — •Federica Mantegazzini, Arnulf Barth, Christian Enss, Andreas Fleischmann, Loredana Gastaldo, Robert Hammann, Sebastian Kempf, Clemens Velte, and Tom Wickenhäuser — Kirchhoff-Institute of Physics, Heidelberg University, Germany

The Electron Capture in ^{163}Ho (ECHo) experiment has been designed for the determination of the effective electron neutrino mass exploiting the electron capture spectrum of ^{163}Ho. The detector technology is based on metallic magnetic calorimeters (MMCs) loaded with ^{163}Ho and operated at millikelvin temperature. For the first phase of the experiment, ECHo-1k, MMC arrays consisting of 72 pixels have been microfabricated and implanted with high purity ^{163}Ho source reaching an activity of about 1 Bq per pixel. The implanted detectors have been successfully operated and characterised, reaching an energy resolution below 5 eV. For the next phase of the experiment, ECHo-100k, the planned activity per pixel is 10 Bq and the required number of pixels simultaneously operated will be 12000. Therefore, a new dedicated MMC array chip which allows for highly efficient ^{163}Ho implantation and multiplexed read-out as well as optimised detector performances has been designed and produced. We present preliminary results obtained in the characterisation of the ECHo-100k chip and we discuss the future plans towards the next phase of the ECHo experiment.

TT 39.8 Wed 18:15 HSZ 03

MOCCA: operating a full 4k-pixel molecule camera for the position and energy resolved detection of neutral molecular fragments — •Dennis Schulz[1], Steffen Allgeier[1], Christian Enss[1], Andreas Fleischmann[1], Lisa Gamer[1], Loredana Gastaldo[1], Julia Hauer[1], Sebastian Kempf[1], Oldřich Novotný[2], Sebastian Spaniol[2], and Andreas Wolf[2] — [1]Kirchhoff-Institute for Physics, Heidelberg University — [2]Max-Planck-Institute for Nuclear Physics, Heidelberg

The MOCCA detector is a high-resolution, large-area molecule camera based on metallic magnetic calorimeters and read out with SQUIDs that has the ability to detect neutral molecule fragments with keV kinetic energies. MOCCA is an array of 64 × 64 quadratic pixels with a side length of 700 μm and covers a total detection area of 4.5 cm × 4.5 cm with a filling factor of 99.5 %. It will be deployed at the Cryogenic Storage Ring CSR at the Max Planck Institute for Nuclear Physics in Heidelberg, a storage ring built to prepare and store molecular ions in their rotational and vibrational ground states, enabling studies on electron-ion interactions. To reconstruct the reaction kinematics, MOCCA is able to measure the energy and position of multiple incident particles hitting the detector simultaneously.

We present the fabrication of Through-Wafer Vias together with new measurements of a full-scale MOCCA detector, demonstrating the readout principle, multi-hit capability, and energy resolution of less than 200 eV, combined with a very low cross-talk between pixels.