Massive Neutrinos

698. WE-Heraeus-Seminar

July 08 – 11, 2019
at the Physikzentrum Bad Honnef/Germany

WILHELM UND ELSE
HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the 698. WE-Heraeus-Seminar:

Neutrino oscillation experiments have clearly proven that neutrinos mix and have non-zero masses. They provide differences between squared neutrino mass eigenvalues but not the absolute mass values. Cosmology, neutrinoless double beta decay searches and direct neutrino mass investigations with single beta decay and electron capture provide already stringent limits on the neutrino masses. The neutrino oscillation results require at least one of the 3 neutrino masses to weigh 50 meV or more. Already now the course should be set in order to be able to determine such a neutrino mass scale directly or indirectly with the next or next but one generation of experiments. In addition we should be open and sensitive for the unexpected, e.g. sterile neutrinos.

With which experimental method this can work and what effort is necessary is not yet really clear considering that the normal mass hierarchy is favoured in global neutrino oscillation fits with about 2 sigma.

The aim of the workshop is to discuss with national and international experts from experiments as well as from theory in the intensive atmosphere of a WE Heraeus Seminar at the ``Physikzentrum which paths are most promising for determining the neutrino mass scale in the laboratory, or whether this ambitious goal must be reserved only for cosmology. Of course there will be room for related and neighbouring topics as well.

Scientific Organizers:

Prof. Dr. Christian Weinheimer	Universität Münster, Germany E-mail: weinheimer@uni-muenster.de
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Program

Program

Sunday, 7 July 2019

17:00 – 21:00	Registration	
from 18:30	*BUFFET SUPPER / Informal get together*	

Monday, 8 July 2019

08:00	*BREAKFAST*	
09:00 – 09:10	Guido Drexlin Christian Enss Manfred Lindner Christian Weinheimer John F. Wilkerson	**Opening and welcome**

Neutrino phyiscs

09:10 – 09:50	Werner Rodejohann	**Neutrino Mass and Mixing: Theory Overview**
09:50 – 10:25	Giorgio Gratta	**The nEXO neutrinoless double beta decay experiment**
10:25 – 11:05	Kathrin Valerius	**Probing the neutrino mass scale with KATRIN**
11:05 – 11:35	*COFFEE BREAK*	

Double beta decay

11:35 – 12:15	Stefan Schoenert	**Current and future double beta decay experiments with ^{76}Ge**
12:15 – 12:55	Oliviero Cremonesi	**The CUORE experiment**
13:00	*LUNCH*	

Program

Monday, 8 July 2019

Electron capture and cosmology

14:30 – 15:10	Loredana Gastaldo	**^{163}Ho-based experiments**
15:10 – 15:50	Maurits W. Haverkort	***Ab initio* calculation of the electron capture spectrum of ^{163}Ho**
15:50 – 16:30	Steen Hannestad	**Cosmological neutrino bounds**
16:30 – 16:35	**Conference Photo** (in front of the Physikzentrum/Main entrance)	
16:35 – 17:05	*COFFEE BREAK*	

Systematics and white paper

17:05 – 17:45	Beate Bornschein	**Tritium Technology for Neutrino Physics**
17:45 –18:25	Diana Parno	**Systematics in direct neutrino-mass experiments**
18:25 - 18:45	Loredana Gastaldo Kathrin Valerius	**A white paper on direct neutrino mass searches**
18:45 – 19:00	Stefan Jorda	**About the Wilhelm and Else Heraeus Foundation**
19:00	*HERAEUS DINNER at the Physikzentrum* *(cold & warm buffet, free beverages)*	

Program

Tuesday, 9 July 2019

08:00	*BREAKFAST*	

New oppurtunities

09:00 – 09:40	Janina Hakenmüller	**Detecting coherent elastic neutrino nucleus scattering**
09:40 – 10:20	Teresa Marrodán Undagoitia	**Neutrino astrophysics in liquid xenon detectors**
10:20 – 11:00	Ezio Previtali	**Results and future perspectives of bolometric double beta decay experiments at LNGS**
11:00 – 11:30	*COFFEE BREAK*	

Neutrinos and cosmology

11:30 – 12:15	Thomas Schwetz	**Global analysis of neutrino oscillation results**
12:15 – 13:00	Scott Dodelson	**Cosmological neutrino mass constraints from galaxy clustering and weak lensing**
13:00	*LUNCH*	

New direct neutrino mass ideas

14:30 – 15:10	Joseph Formaggio	**Mass Through Frequency: The Project 8 Neutrino Experiment**
15:10 – 15:50	Sebastian Böser	**An atomic tritium source for Project 8**
15:50 – 16:30	Chris Tully	**Relic neutrinos and related techniques with PTOLEMY**
16:30 – 17:00	*COFFEE BREAK*	

Posters I

17:00 – 17:50	**Mini Presentation of Posters I**
17:50 – 19:00	**Poster Session I**
19:00	*DINNER* and discussions in the Lichtenberg-Keller

Program

Wednesday, 10 July 2019

07:30	*BREAKFAST*	

New technologies

08:40 – 09:10	Giorgio Gratta	**Distributed Imaging for liquid scintillation detectors**
09:10 – 09:55	Wolfram Pernice	**Superconducting nanowire single particle detectors**
09:55 - 10:40	Sebastian Kempf	**Readout of large-scale cryogenic microcalorimeters by means of microwave SQUID multiplexing**
10:40 – 11:10	*COFFEE BREAK*	

Tritium-related technologies

11:10 – 11:30	Christian Weinheimer	**Time-of-flight methods at KATRIN**
11:30 – 12:10	Magnus Schlösser	**Future of tritium beta spectroscopy**
12:10 – 12:50	Alejandro Saenz	**Atomic and Molecular Physics for Neutrino-Mass Experiments**
13:00	*LUNCH*	

Wednesday, 10 July 2019

Cosmology and double beta decay

14:30 – 15:10	Julien Lesgourgues	**Do we trust the standard cosmological model?**
15:10 – 15:50	Javier Menendez	**Neutrinoless double-beta decay: insights on nuclear matrix elements**
15:50 – 16:30	Christine Kraus	**Neutrinoless Double Beta Decay with Liquid Scintillator Detectors**
16:30 – 17:00	*COFFEE BREAK*	

Posters II

17:00 – 17:45	**Mini Presentation of Posters II**
17:50 – 19:00	**Poster Session II**
19:00	*DINNER* and discussions in the Lichtenberg-Keller

Program

Thursday, 11 July 2019

07:30	*BREAKFAST*	
08:30 – 09:10	Sergey Eliseev	**Penning-trap mass spectrometry and neutrino mass**
09:10 – 09:50	Andrea Giuliani	**Lithium molybdate scintillating bolometers to search for neutrinoless double beta decay of ^{100}Mo**
09:50 – 10:30	Laura Baudis	**Particle physics with liquid xenon detectors**
10:30 – 11:00	*COFFEE BREAK*	

Sterile neutrinos and double beta decay

11:00 – 11:40	Thierry Lasserre	**Evidences and non-evidences for sterile neutrinos**
11:40 – 12:20	Susanne Mertens	**Search for sterile keV neutrinos**
12:20 – 13:00	Steve Elliott	**Future Double Beta Decay Experiments**
13:00	*LUNCH*	

Future and final discussion

14:30 – 15:15	Karsten Heeger	**Future of Neutrino Physics**
15:15 – 16:00	all	**Final discussions**
16:00 – 16:10	Guido Drexlin Christian Enss Manfred Lindner Christian Weinheimer John F. Wilkerson	**Poster awards and closing remarks**
16:10 – 16:40	*COFFEE*	

End of the seminar and Departure

Posters

Posters

1	Felix Ahrens	**Design and optimisation of a microwave SQUID multiplexer for the ECHo experiment**
2	Arnulf Barth	**Development of metallic magnetic calorimeter arrays with embedded ^{163}Ho for the ECHo experiment**
3	Jan Behrens	**Validation of the KATRIN spectrometer transmission function**
4	Cristina Benso	**Sterile neutrinos, dark matter and laboratory signals**
5	Lutz Bornschein	**Tritium reduction in the KATRIN beam line**
6	Martin Braß	**Ab initio calculation of the calorimetric electron capture spectrum of ^{163}Ho**
7	Christine Claessens	**Detection efficiency in Project 8**
8	Khushoo Dixit	**Quantum correlations and the neutrino mass degeneracy problem**
9	Frank Edzards	**Development of Signal Readout Electronics for the Legend Experiment**
10	Mariia Fedkevych	**Investigations of the KATRIN inter-spectrometer Penning trap**
11	Martin Fertl	**Project 8: First application of CRES to tritium decay**
12	Alexander Fieguth	**Exploring detection possibilities of double beta decays from Xe-124 in future detectors**
13	Fabian Friedel	**Detecting ions with KATRIN: performance and results of the ion conversion to electron (ICE) method**

Posters

14	Alexander Fulst	**Possible imporvement of KATRIN by time-focussing-time-of-flight method**
15	Alexander Göggelmann	**Background studies for the ECHo experiment**
16	Stephanie Hickford	**Estimation of the KATRIN neutrino mass sensitivity**
17	Dominic Hinz	**Radioactivity induced background electrons in the KATRIN spectrometers**
18	Anton Huber	**Search for keV-scale sterile Neutrinos with KATRIN**
19	Mohamed Ismaiel	**Neutrino's charge possible consequence in astrophysics**
20	Leonard Köllenberger	**Search for keV-scale sterile neutrinos with KATRIN**
21	Amitabha Lahiri	**Geometrical contribution to neutrino mass matrix**
22	Alec Lindmann	**Project 8: Atomic Tritium Motivation and Source Design**
23	Alexey Lokhov	**Background reduction with the shifted analysing plane configuration in KATRIN**
24	Eric Machado	**Towards Atomic Tritium in Project 8**
25	Alexander Marsteller	**First operation of the KATRIN Loops tritium gas processing system**
26	Charles Martoff	**The HUNTER Sterile Neutrino Search Experiment**

Posters

27	América Morales	**Resonant supressions on Ultra High Energy Astriphysical Neutrino**
28	Anna Pollithy	**Analysis strategy and background in the KATRIN experiment**
29	Andreas Reifenberger (Co-Author Max Aker)	**R&D to search for keV sterile neutrinos in calorimetrically measured tritium beta spectra**
30	Daniel Richter	**Multichannel microwave SQUID multiplexer readout of large MMC detector arrays**
31	Robert G. Hamish Robertson	**TRIMS: Experimental study of final states in tritium beta decay**
32	Rudolf Sack	**Energy loss and response function in KATRIN**
33	Daniel Siegmann	**TRISTAN Project - Development of a silicon drift detector for the keV sterile neutrino search with KATRIN**
34	Larisa Thorne	**Analysis and systematics of KATRIN: from Krypton calibration to Tritium beta decay, using CMKAT**
35	Ana Paula Vizcaya Hernándes	**Ion retention, blocking and monitoring within the KATRIN experiment**
36	Christian Wittweg	**Observation of two-neutrino double electron capture in ^{124}Xe with XENON1T**
37	Yung-Ruey Yen	**Neutrinoless double beta decay search with EXO-200**

Abstracts of Lectures

(in chronological order)

Particle physics with liquid xenon detectors

Laura Baudis

University of Zurich, Department of Physics, Zurich, Switzerland

Detectors using liquid xenon are widely employed in the field of astroparticle physics. In particular, two-phase time projection chambers are used for direct dark matter detection, searches for the neutrinoless double beta decay of 136-Xe, as well as other rare event searches. After an introduction to the liquid xenon technology, I will discuss existing and future projects, and present their results and expected sensitivities. I will also discuss the main background source, including the challenging neutrino background.

Tritium Technology for Neutrino Physics

Beate Bornschein

Karlsruhe Institute of Technology, Institute for Nuclear Physics,
Tritium Laboratory Karlsruhe, 76344 Eggenstein-Leopldshafen, Germany

Tritium is not only the isotope of choice for the search of the neutrino mass [1], but it is also suited to provide a very strong and well defined source of low (keV) energy electron antineutrinos. The latter can be used in scattering experiments to search for the magnetic moment of the neutrino [2] or for the measurement of the mixing angle θ_{13} [3].
Such experiments usually need either huge amounts of tritium (kilograms, e.g. [2]) or they require high tritium throughputs (kilograms per year) which is technically feasible only by means of a closed tritium cycle as it is realized for the Karlsruhe Tritium Neutrino Experiment KATRIN [4)].
Since tritium is a beta-emitter with maximum beta-electron energy of 18.6 keV and a half-life of 12.3 years, tritium handling of large amounts is a demanding exercise. The low molecular mass of tritium makes it extremely transportable and as a hydrogen isotopologue it is even able to permeate through metallic confinement barriers. From chemical point of view (hydrogen), it is very reactive, by either donating or accepting an electron to form a chemical bond.
After a general introduction into tritium properties and tritium handling methods, the contribution will address the question of how tritium can be stored, transported, purified and accounted for.
The aim of the contribution is to give the physicists an idea of the technical implications and challenges they will encounter if they want to do neutrino experiments with tritium.

References

[1] S. Mertens, J. of Physics: Conf. Series, **718** 022013 (2013).
[2] L. Bogdanova, Prog. Part. Nucl. Physics **64**, 300-302 (2010).
[3] I. Giomataris et al., Nucl. Phys. B (Proc.Suppl.) **150**, 208-213 (2006).
[4] F. Priester et al., Vacuum **116**, 42-47 (2015).

An atomic tritium source for Project 8

Sebastian Böser

Universität Mainz / PRISMA, Institute of Physics, Mainz, Germany

Precision spectroscopy of the tritium endpoint to date is the most sensitive method to determine the absolute scale of the neutrino masses in the laboratory. Towards this goal, the Project 8 collaboration aims to employ the newly developed technology of Cyclotron Radiation Emission Spectroscopy (CRES). In the contrast to the current approaches that employ molecular tritium, this opens up the possibility to operate with an atomic tritium source. Eliminating the inherent final state excitations in the 3HeT daughter molecules allows to bring down the energy resolution to below 1 eV. In combination with a sufficiently large decay volume, this promises a sensitivity to m_β < 40meV well within the current cosmological bounds. However, atomic tritium recombination on any container surfaces necessitates a magnetic trap, posing significant challenges to the trap geometry and production of a sufficiently cold atomic tritium beam. I will show first studies towards the design and construction of such a source.

The CUORE experiment

O.Cremonesi

(on behalf of the CUORE Collaboration)

INFN – Sez. Milano Bicocca, Milano, Italy

Neutrinoless double beta decay is the only matter-creating process practically accessible with the current technology. Its discovery would demonstrate the non-conservation of lepton number and that neutrinos are Majorana particles, and would indicate a possible solution for the baryon asymmetry of the universe. It would provide also relevant information concerning the absolute mass scale of neutrinos which is still unknown.
CUORE is the first ton-scale bolometric experiment searching for neutrino-less double beta decay of 130Te. It is based at the Gran Sasso National Laboratories and consists of a large cryogenic system hosting 988 TeO2 crystals which operate at a base temperature of ~10mK. It is also characterized by a low background level achieved thanks to a careful selection and cleaning of the construction materials. The effort for the construction and commissioning of the experiment will be reviewed. The current status and results will be discussed.

Cosmological neutrino mass constraints from galaxy clustering and weak lensing

Scott Dodelson[1]

[1]*Carnegie Mellon University, Pittsburgh, PA, US*

Neutrinos are the most abundant matter particles in the universe so leave an imprint on the distribution of matter and radiation. Recent advances in galaxy surveys have enables cosmologists to place interesting constraints on the sum of the neutrino masses. There are a number of theoretical issues to be resolved and the requirement to converge on a robust methodology is becoming more urgent as the projections from upcoming surveys is that they will measure the sum of the neutrino mass, not just give upper limits. I will explore some of the issues in the context of measurements in the Dark Energy Survey of galaxy clustering and weak lensing.

Penning-trap mass spectrometry and neutrino mass

S. Eliseev[1], M. Door[1], P. Filianin[1], W. Huang[1], Ch. König[1,2], K. Kromer[1,2], M. Müller[1,2], Yu. N. Novikov[3], A. Rischka[1], R. X. Schüssler[1], Ch. Schweiger[1], and K. Blaum[1]

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[2] *Fakultät für Physik und Astronomie, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany*

[3] *Petersburg Nuclear Physics Institute, 188300 Gatchina, Russia*

The neutrino mass is still unknown. Currently a few experiments, namely KATRIN, HOLMES and ECHo, are built with the ultimate goal to reach a sub-eV/c^2 uncertainty in the neutrino-mass determination from the analysis of two nuclear beta-decays: beta-decay of tritium and electron capture in ^{163}Ho. All these experiments demand directly and independently determined *Q*-values of these beta-processes. High-precision Penning-trap mass spectrometry is the most suitable tool to deliver these *Q*-values.
This contribution will give a brief overview of PENTATRAP – the most advanced Penning-trap mass spectrometer in the world. The focus will be put on our present activity at PENTATRAP within the framework of the ECHo project. First, the results of our first, "proof-of-principle", measurements, namely the mass differences of various stable xenon isotopes, will be presented. Then, the current measurement of the beta-decay of ^{187}Re and its preliminary results will be reported. Finally, the planned measurement of the *Q*-value of the electron capture in ^{163}Ho with PENTATRAP with a sub-eV uncertainty and its impact on the determination of the neutrino mass will be discussed.

Future Double Beta Decay Experiments

Steven R. Elliott
Los Alamos National laboratory, Los Alamos, New Mexico, USA

At least one neutrino has a mass of about 50 meV or larger. However, the absolute mass scale for the neutrino is unknown and it is unknown if lepton number conservation is violated. Furthermore, the critical question: Is the neutrino its own antiparticle? remains unanswered. Zero-neutrino double beta decay ($0\nu\beta\beta$) can address these issues. In addition, $0\nu\beta\beta$ is sensitive to many sources of potential underlying physics. Although this breadth of science results in caveats related to interpretation, it also means the physics is rich. Recent experimental results have demonstrated the increasing sensitivity of $0\nu\beta\beta$ technologies. Auxiliary studies related to $0\nu\beta\beta$ have aided our understanding of the capability of these experiments. All indications are that upcoming generations of $0\nu\beta\beta$ experiments will be sensitive to neutrino masses in the exciting range below 50 meV.

If the process of $0\nu\beta\beta$ exists, its half-life is very long; greater than $\sim 10^{26}$ years. Hence any search for the rare $0\nu\beta\beta$ peak in a spectrum must minimize the background due to other processes that may take place in a detector. Furthermore, interpreting the neutrino mass implications from a half-life measurement or limit requires an understanding of the transition matrix element, which is technically difficult to calculate. A summary of upcoming efforts in $0\nu\beta\beta$, related technologies, and supporting measurements, will be discussed in the context of the global neutrino program.

Mass Through Frequency:
The Project 8 Neutrino Experiment

J. A. Formaggio, for the Project 8 Collaboration

[1]*Massachusetts Institute of Technology, Cambridge MA, USA*

Neutrino flavor oscillations provided the first break in the Standard Model by proving that neutrinos have nonzero mass, but cannot constrain the absolute mass scale. The most sensitive method to directly measure the mass scale is observation of the tritium beta-decay spectrum endpoint and extraction of the electron antineutrino mass. Project 8 is a next-generation experiment based on the novel Cyclotron Radiation Emission Spectroscopy (CRES) technique to perform a radio-frequency-based measurement of the tritium beta spectrum. I will give an update from the first tritium data collected by the experiment, and discuss the future R & D program to expand the sensitivity of the experiment.

^{163}Ho-based experiments

Loredana Gastaldo

Universität Heidelberg, Kirchhoff Institute for Physics, Heidelberg, Germany

The analysis of low energy electron capture spectra offers the possibility for the determination of the effective electron neutrino mass in the same way as the analysis of low energy beta decay spectra allows for investigating the effective mass of the electron anti-neutrino. Among the nuclides undergoing electron capture, 163Ho is the one which presents the best properties for such experiments. In particular, the energy available for electron capture is the lowest known in Nature, Q_{EC} ~2.8 keV.

Presently two large collaborations are preparing two experiments based on ^{163}Ho which are designed to achieve sub-eV sensitivity on the effective electron neutrino mass: ECHo and HOLMES.

Low temperature micro-calorimeters with enclosed high purity ^{163}Ho source are the best choice to perform high statistics and high energy resolution measurements of ^{163}Ho spectra. The two experiments mainly differ in the technology used for the measurement of the ^{163}Ho spectrum. In ECHo metallic magnetic calorimeters (MMCs) are used while in HOLMES transition edge sensors (TESs). In both case, a SQUID-based microwave-multiplexing technique will be used for the read out of large arrays of detectors.

The analysis of the high statistics ^{163}Ho spectra will rely on the precise knowledge of the expected spectral shape, in particular on the precise determination of Q_{EC} and on the description of the endpoint region. Important steps have been done in this direction and theoretical spectra describe the data with very good accuracy. The background level required in these experiment is considered to be achievable. First characterizations have been performed and methods to suppress identified contribution have been proposed.

The present status of the ECHo and HOLMES experiment will be presented with a discussion on recent results and future perspectives of ^{163}Ho-based experiments.

Lithium molybdate scintillating bolometers to search for neutrinoless double beta decay of ^{100}Mo

A. Giuliani[1]

[1] *CSNSM, Univ. Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, 91405 Orsay, France*

The LUMINEU project has recently set up a technology for the development of high-performance scintillating bolometers containing the nuclide ^{100}Mo [1], in the framework of the R&D activities towards CUPID [2], a proposed next-generation neutrinoless double beta decay experiment exploiting the CUORE infrastructure in the Gran Sasso underground laboratory and capable of reaching a sensitivity of 15-20 meV on the effective Majorana neutrino mass. Using $Li_2{}^{100}MoO_4$ detectors, high energy resolution (5-6 keV FWHM at 2615 keV), excellent alpha background rejection (>99.9%) and extreme radiopurity (below 0.005 mBq/kg for U/Th and below 5 mBq/kg for ^{40}K intrinsic radioactivity) have been demonstrated in multiple tests with remarkable reproducibility. Moreover, with only 0.1 kg × y of ^{100}Mo exposure, the measured two-neutrino double beta decay half-life is one of the most precise values ever reported [3]. The LUMINEU technology is now under test in a medium-scale pilot experiment named CUPID-Mo, which is collecting data in the Modane underground laboratory in France [4]. CUPID-Mo consists of twenty 0.2-kg ^{100}Mo-enriched Li_2MoO_4 scintillating bolometers (containing more than 2 kg of ^{100}Mo) to be operated for at least 0.5 yr, providing a sensitivity to ^{100}Mo neutrinoless double beta decay half-life larger than 10^{24} yr. CUPID-Mo is a very important demonstrator for the implementation of CUPID, as the CUPID-Mo detectors follow closely the configuration chosen for the baseline of this experiment.

References

[1] E. Armengaud et al., Eur. Phys. J. C **77**, 785 (2017)
[2] G. Wang et al., arXiv:1504.03599 (2015)
[3] D.V. Poda et al., AIP Conference Proceedings **1894**, 020017 (2017)
[4] D.V. Poda et al., http://doi.org/10.5281/zenodo.1300960 (2018)

The nEXO neutrinoless double beta decay experiment

Giorgio Gratta

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nEXO is a double-beta decay experiment based on 5 tonnes of xenon enriched to 90% in the isotope 136. The detector consist in a single-phase liquid Xe TPC, evolved from the very successful EXO-200. I will review the design of the experiment, explain the technical tradeoffs and report on the sensitivity of this next-generation experiment.

Distributed Imaging in liquid scintillation detectors

Giorgio Gratta

Stanford University, Department of Physics, Stanford, CA, USA

It is generally assumed that scintillation detectors are unsuitable for the imaging of ionization events and one has to settle for a measurement of the total energy. This is the case, for instance, for Borexino and KamLAND. Yet, imaging was commonly used in bubble chambers, owing to the large amount of light injected into the detector from the outside. I will review the fundamental optics principles for this difference and proposed a novel approach that solves this problem in an optimized fashion.

Detecting coherent elastic neutrino nucleus scattering

J. Hakenmüller[1] for the CONUS collaboration

[1] *Max-Planck-Institut für Kernphysik, Heidelberg, Germany*

Coherent elastic neutrino nucleus scattering (CEvNS) is a standard model neutrino interaction, however, it took more than forty years since the prediction [1] for it to be seen in a detector [2]. A detection at neutrino energies below 10 MeV, where the nuclear form factor is almost one, is still eluded so far.

Coherent means that the neutrino interacts with the nucleus as a whole, inducing a tiny recoil, which can be detected. This makes the signature comparable to the one of potential dark matter candidates. Thus, CEvNS is an important tool for understanding the response of dark matter detectors and it will become an inevitable background when the sensitivity of dark matter experiments will reach the so-called "neutrino background floor". Moreover, precision experiments will make it possible to constrain non-standard neutrino interactions.

There are three requirements for the detection of CEvNS: a strong neutrino source with neutrino energies within the coherent regime, a successful background suppression and a very low noise threshold of the detector.

Pion-decay-at-rest sources and reactors are suitable sources, as it is possible to set up experiments in close vicinity and the background can be quantified by time correlations. However, all potentially source-correlated backgrounds, especially neutrons, have to be carefully characterized and shielded [3]. The neutrinos from both sources cover different energies, thus a combination of all results will make a direct detection of the neutron form factor possible. From the scattering of reactor neutrinos within the almost fully coherent regime the normalization can be fixed, while the shape at higher energies is determined from the scattering of neutrinos from a pion decay at rest source.

The talk will cover the common and individual challenges faced by CEvNS experiments. Suitable detection techniques will be discussed with the focus on high-purity low threshold point contact Germanium (HPGe) detectors. The status of the CONUS experiment with 4 kg of HPGe detectors located at the nuclear power plant of Brokdorf, Germany, in an elaborated shield will be presented.

References

[1] D. Z. Freedman, Phys. Rev. D **9**, 1389–1392 (1974)

[2] D. Akimov et al., Science **357** 6356, 1123–1126 (2017)

[3] J. Hakenmüller et al., arXiv:1903.09269 [physics.ins-det] (2019)

Cosmological neutrino bounds

Steen Hannestad

Aarhus University, Department of Physics and Astronomy, Aarhus, Denmark

Over the last decade precision measurements of the cosmic microwave background and the large scale distribution of galaxies have made it possible to use cosmology to probe many aspects of particle physics. Perhaps the prime example is neutrino physics. For example, because neutrinos have a profound impact on how structures form in the Universe, cosmological observations can be used to probe the neutrino mass with high precision. In the talk I will review the status of cosmology as a tool for probing the physics of neutrinos and other weakly interacting particles. I will also outline the future of the field, with particular focus on upcoming projects such as EUCLID and LSST.

Ab initio calculation of the electron capture spectrum of ^{163}Ho

M. Braß[1], and M.W. Haverkort[1] for the ECHO collaboration

[1]*Institute for Theoretical Physics, Heidelberg University, Heidelberg, Germany*

The determination of the electron neutrino mass by electron capture in 163Ho relies on a precise understanding of the deexcitation of a core hole after an electron-capture event. Here we present an *ab initio* calculation of the electron-capture spectrum of ^{163}Ho, i.e., the ^{163}Ho decay rate as a function of the energy distribution between the ^{163}Dy daughter atom and the neutrino. Our current level of theory includes all intra-atomic decay channels and many-body interactions on a basis of fully relativistic bound orbitals as well as the decay into continuum states. We use theoretical methods developed and extensively used for the calculation of core level spectroscopy on correlated electron materials. Our comparison to experimental electron-capture data critically tests the accuracy of these theories. We find that relativistic interactions beyond the Dirac equation lead to only minor shifts of the spectral peaks. The electronic relaxation after an electron-capture event due to the modified nuclear potential leads to a mixing of different edges, but, due to conservation of angular momentum of each scattered electron, no additional structures emerge. Many-body Coulomb interactions lead to the formation of multiplets and to additional peaks corresponding to multiple core holes created via Auger decay. Multiplets crucially change the appearance of the resonances on a Rydberg energy scale. The additional structures due to Auger decay are, although clearly visible, relatively weak compared to the single core hole states and are incidentally far away from the end-point region of the spectrum. As the end point of the spectrum is affected most by the neutrino mass, these additional states do not directly influence the statistics for determining the neutrino mass. The multiplet broadening and Auger shake-up of the main core-level edges do, however, change the apparent linewidth and accompanying lifetime of these edges. The decay into the continuum leads to an asymmetric line shape of the resonances.

References

[1] M. Braß, C. Enss, L. Gastaldo, R. J. Green, and M. W. Haverkort, Phys. Rev. C **97**, 054620 (2018)

[2] P. C.-O. Ranitzsch, C. Hassel, M. Wegner, D. Hengstler, S. Kempf, A. Fleischmann, C. Enss, L. Gastaldo, A. Herlert, and K. Johnston, Phys. Rev. Lett. **119**, 122501 (2017)

Future of Neutrino Physics

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Neutrinos play a central role in our understanding of the cosmos. From the observation of neutrino oscillation to the understanding of large-scale structure formation, massive neutrinos are a key ingredient to our understanding of the Universe at the smallest and largest scales. Recent experiments have precisely measured neutrino oscillation and observed the highest-energy astrophysical neutrinos but fundamental questions about the nature and properties of neutrinos remain: Are neutrinos Majorana particles? What is the absolute mass of neutrinos, and why is it so small? Are there more than three neutrino species? Over the coming years, a diverse suite of terrestrial experiments, astrophysical and cosmological observations, as well as theoretical studies will aim to shed light on these questions and may reveal new physics. This talk will discuss the exciting opportunities in neutrino physics and highlight some of the potential discoveries awaiting us.

Readout of large-scale cryogenic microcalorimeters by means of microwave SQUID multiplexing

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Neutrino physics has always been a very strong driving force for the development of low-temperature microcalorimeters. The latter are used in a variety of experiments such as investigations of the neutrino mass or searches for the neutrinoless double beta decay. A well-known example is the Electron Capture in Ho-163 experiment ECHo which aims to investigate the mass of the electron neutrino by means of a calorimetric measurement of the Ho-163 electron capture spectrum using large microcalorimeter arrays based on metallic magnetic calorimeters (MMCs). Superconducting quantum interference devices (SQUIDs) are naturally the device of choice for MMC readout since they are intrinsically compatible with the MMC operation temperature, show a near-quantum limited noise performance and offer a high system bandwidth.

For single-channel applications or medium-scale detector arrays twos-stage dc-SQUID setups with negative flux feedback are mainly used. However, although they show a very great performance, they can hardly be used for reading out large-scale detector arrays since the number of readout wires, the parasitic heat input as well as the overall system complexity scale linearly with the number of detectors within an array. Hence, SQUID based multiplexing techniques are presently developed in order to allow for upscaling the size of microcalorimeter arrays as required, for example, for performing a competitive neutrino mass experiment.

The likely most suitable cryogenic multiplexer for MMCs is the so-called microwave SQUID multiplexer (µMUX). It uses non-hysteretic, unshunted rf-SQUIDs to transduce the change of magnetic flux within the SQUID loop, e.g. caused by a detector event, into a resonance frequency change of an associated superconducting microwave resonator which can be monitored by a suitable room-temperature electronics.

In this contribution we give an introduction into the basics and different components of a µMUX and summarizes the present status of µMUX development for large-scale MMC based detector arrays. This includes a thorough discussion of the performance of presently developed µMUXs as well as prospects promising to allow for reading out even larger detector arrays.

Neutrinoless Double Beta Decay with Liquid Scintillator Detectors

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Searches for neutrinoless double beta decay with liquid scintillators have high sensitivity due to their ultra-low background environment and high scalability. There are currently two experiment active KamLAND-Zen and SNO+. KamLAND-Zen is located at 1,000 m depth (2,700 m.w.e.) and utilizes a nylon balloon filled with xenon loaded scintillator as the target volume. For SNO+ the target volume is a tellurium loaded liquid scintillator housed within an acrylic sphere. Both experiments have various phases, where KamLAND-Zen has already produced results [1] and SNO+ is in the process of filling with scintillator and eventually loading the tellurium compound in the near future, but has results showing low external backgrounds [2], [3].

This presentation will discuss the current status of both experiments, present recent results and provide an overview of the plans for the next few years.

References

[1] A.Gando *et.al.*(KamLAND-Zen Collaboration), Phys. Rev. Let. **117,** 082503 (2016)

[2] M.Anderson *et. al.*(SNO+ Collaboration), Phys. Rev. D **99**, 012012 (2019)

[3] M.Anderson *et. al.*(SNO+ Collaboration), Phys. Rev. D **99**, 032008 (2019)

Evidences and non-evidences for sterile neutrinos

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We will discuss the physics case for light sterile neutrinos, with emphasis on short-baseline neutrino oscillations. After a review of the observed short-baseline neutrino oscillation anomalies, we discuss the current experimental program and results. Finally, we will address the future perspective in the search for the effects of eV-scale sterile neutrinos.

Do we trust the standard cosmological model?

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In order to trust neutrino bounds from cosmology, we should also trust the cosmological model assumed in the fits to the data. I will summarize why and to which extent most cosmologists trust the LambdaCDM model. I will list a few anomalies and tensions between recent data sets, and discuss their possible interpretation from different points of views. I will mention some of the future experiments that are expected to settle these issues.

Neutrino astrophysics in liquid xenon detectors

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Detectors using liquid xenon as target medium have shown a great potential to directly search for dark matter interactions. In particular, the XENON1T experiment has placed the current most constraining exclusions limits on the cross sections of WIMP dark matter with nuclei [1]. The detector was taking data from 2016 to 2018 containing 2 tons of liquid xenon inside its target. In order to improve its sensitivity by an order of magnitude, an upgrade of the detector is currently being carried out: XENONnT which will contain 6 tons in the target. With the increase of mass in dark matter detectors, neutrino-induced processes start being relevant as backgrounds, but also as signals. This is especially true for the planned DARWIN detector [2] which aims to reach the ultimate sensitivity to nuclear recoils from dark matter interactions down to values where neutrinos start interacting coherently with nuclei. DARWIN will contain approximately 40 t of liquid xenon in its target opening the possibility to measure a variety of neutrino physics processes [3]. This talk will describe the experiments mentioned above focusing on possible astrophysical measurement of neutrinos. For instance, DARWIN will detect the low-energy solar neutrino flux with <1% precision and will be able to measure neutrinos from galactic supernovae. Both the detection via neutrino-electron scattering and via coherent neutrino-nucleus interactions will be discussed. In addition to the description of the signal signatures and expected rates, the backgrounds relevant for this searches will be discussed in detail.

References

1. XENON1T Collaboration, *Dark matter search results from a one ton-year exposure of XENON1T*, PRL **121**, 111302 (2018)
2. DARWIN Collaboration, *DARWIN: towards the ultimate dark matter detector*, JCAP **1611**, 017 (2016)
3. L. Baudis *et al.*, *Neutrino physics with multi-ton scale liquid xenon detectors*, JCAP **1401**, 044 (2014)

Neutrinoless double-beta decay: insights on nuclear matrix elements

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The rare decay of atomic nuclei known as neutrinoless double-beta decay is the most promising attempt to test lepton number conservation in the laboratory. Observation would proof that neutrinos and its own antiparticle, can clarify the origin of the prevalence of matter over antimatter in the universe, and determine the absolute neutrino mass. In spite of formidable experimental efforts, neutrinoless double-beta decay remains elusive, with half-live limits set over 10^25 years in some isotopes.

The decay rate depends critically on nuclear matrix elements that reflect the nuclear structure of the initial and final nuclei, and that need to be calculated from nuclear theory. A reliable knowledge of these matrix elements is key to predict neutrinoless double-beta decay half-lives---this is, to anticipate the reach of experiments---and to fully extract all physics information from a future measurement.

The value of the nuclear matrix elements is uncertain, because calculations using the best available nuclear many-body methods disagree by a factor two or three [1]. More sophisticated, ab initio approaches may settle this discrepancy. In addition, all nuclear matrix element determinations are subject to additional corrections related to the proper treatment of the neutrinoless double-beta decay operator in nuclei [2, 3]. These corrections have yet to be reliably evaluated.

My talk will summarize the status of nuclear matrix element calculations, including novel insights toward testing current predictions. In addition, I will discuss how to obtain more reliable nuclear matrix elements using ab initio many-body approaches, and an improved treatment of the neutrinoless double-beta decay operator.

References

[1] J. Engel and J. Menéndez, Rept. Prog. Phys. **80**, 046301 (2017).
[2] V. Cirigliano et al., Phys. Rev. Lett. **120** 202001 (2018).
[3] P. Gysbers et al., Nat Phys. **15**, 428 (2019).

Search for sterile keV neutrinos

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Sterile neutrinos appear in minimal extensions of the Standard Model of particle physics. If their mass is in the keV regime, they are viable dark matter candidates. In this talk both indirect astrophysical and cosmological limits and new ideas for laboratory-based searches will be presented. Special focus will be put on a possible future upgrade of the KATRIN experiment with a novel multi-pixel detector system, which would allow to search for the characteristic signature of sterile neutrinos in tritium beta decay.

Systematics in Direct Neutrino-Mass Experiments

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Some two decades after the Mainz and Troitsk experiments established the current limit on the neutrino-mass scale (< 2 eV) from tritium beta decay, a new generation of experiments is coming online. KATRIN, which began data-taking with tritium this spring, aims for a neutrino-mass sensitivity of 0.2 eV at the 90% confidence level; Project 8 (^{3}H), HOLMES (^{163}Ho), and ECHO (^{163}Ho) ultimately aim to match or improve on this sensitivity. However, the observable in these experiments is the square of the effective neutrino mass. A tenfold improvement in the sensitivity therefore requires a hundredfold improvement in the uncertainties.

With two decay isotopes and three spectroscopic approaches (MAC-E filter, cyclotron radiation emission spectroscopy, and microcalorimetry), these modern experiments present a range of disparate systematic uncertainties. I will survey a selection of these uncertainties, from decay physics to detector acceptance, as well as the strategies used to control them.

*This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Award Number DE-SC0019304.

Superconducting nanowire single particle detectors

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Superconducting nanowires have emerged as superior devices for detecting single photons over a broadband wavelength range. Operated at moderate cryogenic temperatures, they allow for unifying essentially all desired detector characteristics in a single device, providing near-unity detection efficiency, high timing resolution and very low noise [1]. Originally, such devices were implemented for applications in optical quantum technologies and in particular for quantum communication systems. Yet, increasingly, their superior performance also finds applications in the detection of other entities, such as detection of high energy particles [2] and single electrons [3]. In this talk I will give an overview over the operation of superconducting nanowire detectors and highlight the state-of-the-art in the field. Prospects for spatially resolving detectors will be given with respect to detector arrays and scalable detector platforms.

References

[1] S. Ferrari, et al, Nanophotonics **7**, 1725 (2018)
[2] H. Azzouz, et al., AIP Advances **2**, 032124 (2012)
[3] M. Rosticher, et al., Appl. Phys. Lett. **97**, 183106 (2010)

Neutrino Mass and Mixing: Theory Overview

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Neutrino mass and lepton mixing remains the only testable physics beyond the SM that is testable in the lab. We will review what we have learned, what remains to be learned, and what the implications of current and future measurements are. Motivations to expect additional physics beyond the 3-Majorana neutrino paradigm are given, and the consequences as well as possible origins of some cases are discussed. Mechanisms to generate neutrino mass have many consequences beyond pure neutrino physics, which will be outlined.

Atomic and Molecular Physics for Neutrino-Mass Experiments

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Due to the increasing precision of neutrino-mass experiments, the importance of atomic and molecular physics for the analysis of those experiments becomes more important. Almost 50 years ago, the relevance of the atomic final states of tritium atoms for extracting an upper bound for the neutrino mass from corresponding nuclear ß-decay experiments had been pointed out by K.-E. Berqvist [1]. Since the electron released in the decay is shared by the emitted (anti)neutrino, the ß electron, and the remaining daughter atom or molecule, the energy left in the atomic or molecular system has to be known, if the neutrino mass should be extracted from the measured energy distribution of the electron. Similarly, also the neutrino-mass experiments measuring the energy release in electron capture processes, for example in holmium, requires the information of the transition probability distribution into the different final atomic states for extracting the neutrino mass or an upper limit to it. Therefore, new generations of neutrino-mass experiments based on nuclear ß decay or electron capture are (and need to be) accompanied by (improved) atomic and molecular theory. In fact, the required support may extend beyond the evaluation of the atomic or molecular final-state distributions. For example, in tritium neutrino-mass experiments the emitted ß electron passes through the tritium sample. Since inelastic collisions modify the energy spectrum, their knowledge is also vital for the analysis. This overview talk will describe different aspects of atomic and molecular physics questions in the context of the neutrino-mass experiments, the refinements done to theory over the years, and describe the present status of the atomic and molecular theory especially for the tritium neutrino-mass experiment KATRIN.

References

[1] K.-E. Bergkvist, Physica Scripta **4**, 23 (1971).

Future of tritium beta spectroscopy

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Precision measurements of neutrino flavor oscillations have allowed to determine the squared mass difference of the three different neutrino mass eigenstates.
However, up to the current day, an accurate laboratory measurement of the absolute neutrino mass scale remains an experimental challenge. One of the favored options is a highly sensitive measurement of the spectral shape of the tritium beta spectrum near the kinematic endpoint of 18.6 keV.
Besides the determination of the neutrino mass, tritium beta spectroscopy allows to study predictions from physics beyond the Standard Model. One class of new particle candidates are sterile neutrinos. In case they exist and would mix with the active neutrino flavors, a kink-like signature below the tritium endpoint at an energy corresponding to the sterile neutrino mass would manifest itself.
The most advanced tritium experiment is the Karlsruhe Tritium Neutrino Experiment (KATRIN) which is recording neutrino mass data since March 2019. It has a design sensitivity of 200 meV/c². In order to achieve this goal, a molecular gaseous tritium source with a luminosity of 10^{11} beta-decays per second and an integrating spectrometer with a resolution of < 1eV is employed.
In order to push the sensitivity to the next level, an improvement of systematical and statistical uncertainty is necessary. That will be achieved by employing improved and stronger tritium sources and differential electron measurement, better control and understanding of processes in the system which lead to smearing or shifts of the beta-electron energies as well as by a better reduction of background events.
The presentation will start from a view on the currently active KATRIN experiment and will discuss the limits of sensitivity for neutrino mass measurements and sterile neutrino mass searches. From there on possible directions from improvement are discussed. That will include novel detection technologies as well as viable tritium sources.

Current and future double beta decay experiments with ^{76}Ge

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The conjecture that neutrinos are their own antiparticles, referred to as Majorana fermions, would point to a physical mechanism that explains their small masses. Majorana neutrinos would generate neutrinoless double-β (0νββ) decay, a matter-creating process without the balancing emission of antimatter. So far, 0νββ decay has eluded detection. The GERDA collaboration [1] searches for the 0νββ decay of Ge-76 by operating bare germanium detectors in an active liquid argon shield. With a total exposure of 82.4 kg·yr, no signal has been observed in GERDA and a lower half-life limit of $T_{1/2} > 0.9 \cdot 10^{26}$ yr (90% C.L.) could be derived. The $T_{1/2}$ sensitivity assuming no signal is $1.1 \cdot 10^{26}$ yr. The MAJORANA collaboration [2] operates enriched germanium detectors in a high-purity copper cryostat. With 26.0±0.5 kg-yr of enriched exposure a lower limit on $T_{1/2}$ of 2.7×10^{25} yr (90% CL) with a median sensitivity of 4.8×10^{25} yr (90% CL) could be achieved. The LEGEND collaboration [3] builds on the successful GERDA and MAJORANA work and will operate in a first stage, named LEGEND-200, about 200 kg of enriched HPGe detectors in the upgraded GERDA infrastructure with a discovery sensitivity greater than 10^{27} years. The subsequent LEGEND-1000 stage will be a tonne-scale HPGe array with a discovery sensitivity greater than 10^{28} years corresponding to an effective Majorana mass between 10 and 20 meV, dependent on the choice of nuclear matrix elements. While LEGEND-200 is largely funded and will start operations in 2021, LEGEND-1000 is currently in its preparatory phase.

References

[1] Agostini et al. (GERDA Collaboration), Improved Limit on Neutrinoless Double-β Decay of 76Ge from GERDA Phase II, Phys. Rev. Lett. 120 (2018) 132503 (arXiv:1803.11100)

[2] S.I Alvis et al. (Majorana Collaboration), A Search for Neutrinoless Double-Beta Decay in 76Ge with 26 kg-yr of Exposure from the MAJORANA DEMONSTRATOR, arXiv:1902.02299

[3] N. Abgrall et al. (LEGEND Collaboration), The Large Enriched Germanium Experiment for Neutrinoless Double Beta Decay(LEGEND).AIP Conf. Proc., 1894(1):020027, 2017

Global analysis of neutrino oscillation results

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We discuss the phenomenology of three-flavour neutrino mass and lepton mixing and present the current status of a global analysis of neutrino oscillation data (NuFit-4.0) within that framework. We highlight the interplay of complementary data sets for the determination of sub-leading parameters, such as the octant of theta23, the neutrino mass ordering and leptonic CP violation. Then we consider the hypothesis of sterile neutrinos with eV-scale masses. We argue that recent short-baseline reactor data favour this hypothesis at moderate significance. An explanation of the LSND and MiniBooNE anomalies in terms of eV sterile neutrino oscillations is highly disfavoured by global data.

References

1. I. Esteban, M.C. Gonzalez-Garcia, A. Hernandez-Cabezudo, M. Maltoni and T. Schwetz, Global Analysis of Three-Flavour Neutrino Oscillations: Synergies and Tensions in the Determination of theta23, deltaCP, and the Mass Ordering, JHEP **1901** (2019) 106 [arXiv:1811.05487].
2. M. Dentler, Á. Hernández-Cabezudo, J. Kopp, P.A.N. Machado, M. Maltoni, I. Martinez-Soler and T.~Schwetz, Updated Global Analysis of Neutrino Oscillations in the Presence of eV-Scale Sterile Neutrinos, JHEP **1808** (2018) 010 [arXiv:1803.10661]

Relic neutrinos and related techniques with PTOLEMY

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The Universe has expanded by a factor of over one billion between the present-day and the early thermal epoch known as the neutrino decoupling. We observe these dynamics in many forms: the recession of galaxies (Hubble Expansion), the dim afterglow of the hot plasma epoch (Cosmic Microwave Background) and the abundances of light elements (Big Bang Nucleosynthesis). The epoch of neutrino decoupling produced a fourth pillar of confirmation – the Cosmic Neutrino Background. These early universe relics have cooled under the expansion of the Universe and are sensed indirectly through the action of their diminishing thermal velocities on large-scale structure formation. Experimental advances open up new opportunities to directly detect the CNB, an achievement which would profoundly confront and extend the sensitivity of precision cosmology data. A recent PTOLEMY publication [1] describes the underlying technique for achieving CNB sensitivity and redefines the future direction of neutrino mass measurements. PTOLEMY, an experiment at the LNGS, is a novel method of 2D target surfaces, fabricated from Graphene, that forms a basis for a large-scale relic neutrino detector. The discussion of PTOLEMY focusses on experimental challenges, recent developments and the path forward to discovery sensitivity. Techniques related to mass measurement sensitivity will also be discussed.

References

[1] M.G. Betti *et al.*, "A Design for an Electromagnetic Filter for Precision Energy Measurements at the Tritium Endpoint", Progress in Particle and Nuclear Physics, Volume **106**, 120-131, https://doi.org/10.1016/j.ppnp.2019.02.004.

Probing the neutrino mass scale with KATRIN

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Neutrino properties, in particular the still unknown scale of the neutrino rest mass, bear a fundamental relevance for current research topics in cosmology, theoretical particle physics, and astroparticle physics.

Precision measurements of the kinematics of weak decays offer a direct and nearly model-independent approach to measure the neutrino mass scale in a laboratory experiment.

The Karlsruhe Tritium Neutrino experiment (KATRIN) is searching for the minute imprint of the neutrino mass in the endpoint region of the tritium beta-decay spectrum. KATRIN employs a high-intensity gaseous molecular tritium source and a high-resolution electrostatic filter with magnetic adiabatic collimation to target a neutrino-mass sensitivity of 0.2 eV/c^2, thus improving on the previous generation of direct neutrino mass experiments by an order of magnitude.

After an extensive commissioning phase, KATRIN has entered neutrino-mass data-taking in spring 2019. This talk presents results of the successful technical and physics commissioning, outlines analysis methods and the spectrum model used to infer the neutrino mass, and gives an outlook on both near-term intermediate analysis goals and long-term perspectives of the experiment.

Time-of-flight methods at KATRIN

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The KArlsruhe TRItium Neutrino experiment KATRIN has started to determine the neutrino mass directly with an unprecedented sensitivity. KATRIN is investigating the shape of the tritium beta spectra near its endpoint with a huge spectrometer of MAC-E-Filter type. It combines ultra-high energy resolution with large solid angle acceptance, but possess the disadvantage to be an integral spectrometer: All beta electrons above a certain threshold are counted. A differential method could make use of the electron energy information much better and would allow increasing KATRIN's sensitivity significantly.

One differential way obtaining additional spectral information on the transmitted electrons is to determine the time-of-flight of the electrons through the setup (see New J. Phys.15 (2013) 113020). The arrival time at the detector is measured already with a sufficient time resolution of 50 ns. Defining the start time is easy for artificial electron sources like the pulsed laser-driven photoelectron gun. The time-of-flight method provides already an unprecedented precision for determining the energy losses of electrons in KATRIN's gaseous molecular tritium source.

Determining the start time of a tritium beta decay electron is ta huge challenge. An "electron tagger" is required, which registers the electron flying into the main spectrometer with a very minor change of the electron's energy and momentum. A cryogenic quantum device, e.g. based on a superconducting transition or a SQUID amplifier might have a chance to do this.

Another option of using time-of-flight information is the "time-focusing time-of-flight" idea, where a post-bunching within an additional delay-line focuses a certain electron energy to a certain arrival time bin. This could be used to obtain spectroscopic information or to veto special backgrounds.

Abstracts of Posters

(in alphabetical order)

Design and Optimisation of a Microwave SQUID Multiplexer for the ECHo experiment

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Microwave SQUID multiplexing is, to our present knowledge, the most promising way to read out large metallic magnetic calorimeter detector arrays as they are used for the Electron Capture in 163-Holmium (ECHo) experiment investigating the effective electron neutrino mass. Each channel of a microwave SQUID multiplexer consists of a non-hysteretic, unshunted rf-SQUID which is used for detector readout and which is inductively coupled to a high quality superconducting GHz 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 detector is transduced into a resonance frequency shift of the corresponding resonator. By capacitively coupling different resonators to a common feedline and by monitoring the transmission of an adequate frequency comb along this feedline many detector channels can be read out simultaneously. In order to implement a microwave SQUID multiplexer meeting the requirements of the ECHo experiment, we pursue several design approaches differing from each other, for example, with respect to the resonator geometry. With our latest designs we investigate both multiplexers based on well-established transmission line resonators and multiplexers relying on lumped element resonators. The latter allow for a post-production tile-and-trim process to adjust the resonance frequency and thereby improving the frequency cross-talk level. Additionally, we optimise our rf-SQUID designs for instance in order to reduce parasitic couplings between input coil and modulation coil. In this contribution, we will discuss our findings related to the investigations of different multiplexer designs and in particular demonstrate the power of the tile-and-trim process.

Development of metallic magnetic calorimeter arrays with embedded ^{163}Ho for the ECHo experiment

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The Electron Capture in ^{163}Ho collaboration (ECHo) plans to reach a sub-eV sensitivity level on the effective electron neutrino mass via the analysis of a high energy resolution and high statistics electron capture spectrum of ^{163}Ho. Large arrays, of the order of 100 pixels each, of metallic magnetic calorimeters (MMCs) with enclosed ^{163}Ho, read out utilizing microwave SQUID multiplexing, have been selected to achieve this goal. With first prototypes of MMCs having ^{163}Ho ions implanted in their absorbers and operated at about 15 mK, energy resolutions of below 5 eV were achieved. We show results obtained in the characterization of an MMC array in terms of activity, energy resolution and intrinsic background of single pixels. We present the design of next generation MMC arrays for the ECHo collaboration and discuss the processes to reliably embed a high purity Ho-163 source in the detector absorbers. In conclusion, we discuss how the production of MMC arrays, including microfabrication and ^{163}Ho enclosing, can be scaled up to cope with the requirement of the upcoming phases of the ECHo experiment.

Validation of the KATRIN spectrometer transmission function

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The KArlsruhe TRItium Neutrino (KATRIN) experiment aims to determine the mass of the electron antineutrino with a sensitivity of 0.2 eV/c² (90% C.L.). The measurement of the shape of the tritium β-spectrum facilitates a model-independent investigation of the absolute neutrino mass scale. The setup consists of a 70 m long beam line that magnetically guides electrons from a gaseous, windowless tritium source to a silicon detector. The energy analysis of the electrons takes place in an electrostatic spectrometer (MAC-E filter) with an energy resolution of about 1 eV.

To determine the neutrino mass from the measurement, a sophisticated fit model is applied to the data. The model includes the transmission characteristics of the main spectrometer that depend on the electromagnetic fields. Due to the large size of the spectrometer (ca. 20 m length and 5 m radius) and unavoidable mechanical inaccuracies, it is necessary to validate the model by dedicated measurements. The poster presents studies carried out during measurement campaigns in 2018 and 2019. These include a direct determination of the electromagnetic fields with an electron source (similar to the design described in [1]), as well as comparisons between large-scale field calculations with sensor data. An outlook will be given to further improvements to our understanding of the main spectrometer transmission characteristics and the contribution to the overall systematic uncertainties.

This work is supported by the Helmholtz Association (HGF), the Ministry for Education and Research BMBF (05A17PM3, 05A17PX3, 05A17VK2, and 05A17WO3), the Helmholtz Alliance for Astroparticle Physics (HAP), and the Helmholtz Young Investigator Group (VH-NG-1055).

References

[1] J. Behrens *et al.*, EPJ C **77:** 410 (2018)

Sterile Neutrinos, Dark Matter and Laboratory Signals

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Sterile neutrinos represent the first and most natural extension of the matter content of the Standard Model, being motivated by their well fitting as solution for three major problems in particle physics and cosmology, such as the neutrino masses problem, the baryonic asymmetry problem and the Dark Matter (DM) puzzle. As for a sterile neutrino with a O(keV) mass, contemplated as DM candidate and produced in the early universe through admixtures via the Dodelson-Widrow mechanism, strong constraints on the active-sterile mixing angle are imposed by the measurements of the total DM abundance and by the observations in the X-ray band. These exclude a large region of the parameter space and put at risk the possibility of getting a signal of their existence in laboratory experiments in the near future. In this poster, the introduction of a critical temperature above which sterile neutrinos are not produced, and the reduction of the contribution of the radiative decay process thanks to a new scalar particle, are presented as methods whose combination would bring back a previously excluded region of the parameter space in which sterile neutrino signals could be detected by terrestrial experiments such as the KATRIN experiment.

References

1. M. Tanabashi et al. (Particle Data Group), Phys. Rev. **D98**, 030001 (2018)
2. A. D. Sakharov, Pisma Zh. Eksp. Teor. Fiz. **5**, 32-35 (1967); P. Di Bari, Contemp.Phys. **53,** 315-338 (2012); E. K. Akhmedov et al., Phys. Rev. Lett. **81**, 1359-1362 (1998).
3. P. F. De Salas et al., Phys. Rev. **D92**, 123534 (2015).
4. F. Bezrukov et al., JCAP **1706**, 051 (2017).
5. A. Boyarsky et al., Ann. Rev. Nucl. Part. Sci. **59**, 191-214 (2009).

Tritium reduction in the KATRIN beam line

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The objective of the KArlsruhe TRItium Neutrino Experiment (KATRIN) is to determine the absolute neutrino mass with a sensitivity of 0.2 eV/c^2 (90% CL) after reaching the projected systematic and statistic sensitivity [1]. It therefor precisely measures the shape of the tritium beta spectrum near its kinematic endpoint. This comprises about three full years of data taking plus the required measurements for evaluating systematic effects. During this time, KATRIN will make use of the Windowless Gaseous Tritium Source (WGTS), which is part of the inner tritium Loop. The molecular tritium gas of high isotopic purity (> 95%) is injected from a temperature stabilized buffer vessel into the center of the beam tube of the WGTS magnet cryostat, building a density profile of nearly triangular shape with a source column density of $5 \cdot 10^{17}$ molecules/cm^2. The tritium gas is then pumped out by turbo molecular pumps, purified and refilled into the buffer vessel. This unique closed tritium cycle has a throughput of about 40 g per day.

The decay electrons have to reach the spectrometer and detector section (SDS) without losing energy. Therefore, the source is open to the transport section that is in between the source region and the SDS. Hence tritium reaching the KATRIN spectrometers, would lead to an increasing background rate. For that, the transport section has to ensure an adiabatic transport of the electrons from the source to the SDS and to reduce the amount of tritium transported to the entrance to SDS by 14 orders of magnitude with respect to the tritium injection rate in the source [2]. This is an at least four orders of magnitude more stringent limit then it is given by the radiation safety regulations.

The design of the KATRIN beam line addresses both, neutral tritium (molecules) reduction and tritium ion reduction with the differential pumping section (DPS) and the cryogenic pumping section (CPS) [3]. KATRIN has started operation with tritium in May 2018. This contribution will show the realization of tritium reduction in the KATRIN beam line as well as the results during the first KATRIN runs with tritium.

References

[1] KATRIN collaboration, KATRIN design report 2004, FZKA report **7090**, (2005)

[2] F. Friedel et. al., *Time-dependent simulation of the flow reduction of D2 and T2 in the KATRIN experiment*, Vacuum **159,** 161-172 (2019)

[3] M. Klein, Ph.D. thesis, Karlsruher Institut für Technologie (KIT), (2018)

This work is supported by the Helmholtz Association (HGF), the Ministry for Education and Research BMBF (05A17PM3, 05A17PX3, 05A17VK2, and 05A17WO3), the Helmholtz Alliance for Astroparticle Physics (HAP), and the Helmholtz Young Investigator Group (VH-NG-1055).

Ab initio calculation of the calorimetric electron capture spectrum of 163Holmium

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The determination of the electron neutrino mass by electron capture (EC) in 163Ho relies on a precise understanding of the deexcitation of a core hole after an EC event. Our ab intio calculation of the EC spectrum of 163Ho includes all intra-atomic decay channels and many-body interactions on a basis of fully relativistic bound-orbitals as well as an energy dependent life-time broadening caused by Auger-Meitner processes. The electronic relaxation after EC leads to mixing of different edges due to the modified nuclear potential, but due to conservation of angular momentum of each scattered electron, no additional structures emerge. Many-body Coulomb interactions result in the formation of multiplets and additional peaks corresponding to multiple core-holes created via scattering subsequent to EC. Multiplets change the appearance of the resonances on a Rydberg energy scale. These additional structures do not directly influence the statistics for determining the neutrino mass, as the end-point of the spectrum is affected mostly by the mass itself. The multiplet broadening and shake-up of the main core-level edges do however change the apparent line-width and accompanying lifetime of these edges. Fitting core level edges by a single resonance thus leads to an underestimation of the core hole lifetime. Further Auger-Meitner processes lead to a strongly energy dependent life-time broadening and hence asymmetric line-shapes. Especially this effects the endpoint region by an increase in intensity. Therefore, a precise understanding of these processes is necessary for the determination of the neutrino mass.

Detection efficiency in Project 8

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The Project 8 collaboration aims to measure the absolute neutrino mass scale from the distortion of the tritium beta decay spectrum near the endpoint. To this end, the collaboration has successfully established Cyclotron Radiation Emission Spectroscopy (CRES), a new frequency-based approach to detect electrons and determine their kinetic energy [1]. As we will extract the neutrino mass from the shape of the tritium spectrum, it is essential to quantify any dependence of the electron detection efficiency on frequency or, equivalently, energy. Incorporating this efficiency in our analysis is crucial for an accurate measurement of the endpoint and the extraction of the neutrino mass. In this contribution, I will demonstrate the influence of the detection efficiency and its integration in our analysis with the example of the first-ever tritium CRES spectrum.

References

[1] D. M. Asner *et al.*, Rev. Lett. 114, 162501 (2014)

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Quantum correlations and the neutrino mass degeneracy problem

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Many facets of nonclassicality are probed in the context of three flavour neutrino oscillations including matter effects and CP violation. The analysis is carried out for parameters relevant to two ongoing experiments NOνA and T2K, and also for the upcoming experiment DUNE. The various quantum correlations turn out to be sensitive to the mass hierarchy problem in neutrinos. This sensitivity is found to be more prominent in DUNE experiment as compared to NOνA and T2K experiments. This can be attributed to the large baseline and high energy of the DUNE experiment. Further, we find that to probe these correlations, the neutrino (antineutrino) beam should be preferred if the sign of mass square difference Δ_{31} turns out to be positive (negative).

References

[1] K. Dixit, J. Naikoo, S. Banerjee, A. K. Alok, Eur. Phys. J. C **78**:914 (2018).
[2] S. Banerjee, A.K. Alok, R. Srikanth, B. C. Hiesmayr, Eur. Phys. J. C **75**, 487 (2015).
[3] J. Naikoo, A.K. Alok, S. Banerjee, S.U. Sankar, G. Guarnieri, B.C. Hiesmayr (2017). arXiv:1710.05562 [hep-ph]

Development of Signal Readout Electronics for the Legend Experiment

— Frank Edzards for the Legend Collaboration
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Legend is a future ton-scale experimental program searching for neutrinoless double beta decay ($0\nu\beta\beta$) in the isotope ^{76}Ge using high purity germanium detectors. The observation of $0\nu\beta\beta$ decay would establish lepton number violation, provide information on the neutrino mass and open a window to understand matter dominance in our universe.

The signal readout electronics is one of the most important components of a $0\nu\beta\beta$ decay experiment since it facilitates the conversion of charges produced in the detectors into appropriately shaped voltage signals. In the first stage of the experiment, Legend-200, a readout solution consisting of discrete electronic components will be used. To achieve the ambitious background goal of Legend-1000, it is of paramount importance to reduce the radioactive background further.
One possibility to achieve this is by using highly integrated readout electronics based on application specific integrated circuit (ASIC) technology. In this contribution, we will present first results of prototype readout electronics for the Legend experiment.

Investigations of the KATRIN inter-spectrometer Penning trap

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The KArlsruhe TRItium Neutrino experiment (KATRIN) is a direct low-background measurement of the neutrino mass from the kinematics of tritium β-decay with an intended sensitivity of 0.2 eV/c^2 (90% C.L.). It uses a tandem of two electrostatic spectrometers of MAC-E filter type to analyze energies of β-electrons generated in WGTS (windowless gaseous tritium source). In the region between the spectrometers, a Penning trap is created by their retarding potentials combined with the magnetic field produced by a common superconducting magnet. Even at the ultra-high vacuum conditions of KATRIN electrons may get trapped in this Penning trap creating additional background. They could even produce discharges which may interrupt the data-taking process and damage parts of the spectrometer and detector section of KATRIN. As a countermeasure, electron catchers were implemented in the beamline part between the two spectrometers to remove trapped electrons. The system was tested at various pressure conditions and showed its effectiveness for suppression of the Penning trap effects. Details of the measurements and experimental results will be presented. This work is supported under BMBF contract number 05A14PMA and 05A17PM3 as well as by the Research Training Group 2149 of DFG.

Project 8: First application of CRES to tritium decay

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Neutrino flavor oscillation experiments prove that neutrinos do have non-zero masses. Extensions to the Standard Model of Particle Physics have been developed to explain the non-zero masses and can be directly tested by a measurement of the absolute neutrino mass scale. The mass of the electron antineutrino $m_{\bar{\nu}_e}$ can be determined from the highest precision measurement of the β^--decay spectrum of tritium around its endpoint region (Q = 18.6 keV). The current state of the art experiment stretches all technological limits to probe the range of $m_{\bar{\nu}_e}$ down to 200 meV/c^2. The Project 8 collaboration envisions a completely new path to measure $m_{\bar{\nu}_e}$. The recently demonstrated technique of Cyclotron Radiation Emission Spectroscopy (CRES) allows for a frequency-based measurement of the decay electron energy. I will present this new approach and the collaboration's staged approach to devise an experiment that combines CRES with an atomic tritium source to achieve a neutrino mass sensitivity of 40 meV/c^2, below the minimum $m_{\bar{\nu}_e}$ predicted for the inverted neutrino mass ordering scheme. I will discuss results from the very first application of CRES to the continuous decay spectrum of tritium.

This work is supported by the Cluster of Excellence "Precision Physics, Fundamental Interactions, and Structure of Matter" (PRISMA+ EXC 2118/1) funded by the German Research Foundation (DFG) within the German Excellence Strategy (Project ID 39083149), the US DOE Office of Nuclear Physics, the US NSF, and internal investments at all institutions.

Exploring detection possibilities of double beta decays from Xe-124 in future detectors

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The efforts to find the neutrinoless double beta decay are growing with new experiments around the corner. Detectors like LEGEND or nEXO will explore the parameter space of the lepton number violating decay up to half-lives as large as 10^28 yrs. All these activities look at isotopes decaying from the neutron-rich side of the mass parabola. On the proton-rich side a detection of decays involving double positron emission or related processes would contribute to shed light on the nature of the neutrino. The recent discovery of the two neutrino double electron capture of an isotope of this type, Xe-124, with a half-life of 1.8 x 10^22 yrs proved that also future dark matter detectors (e.g. XENONnT or LZ) can participate in the search for double beta decays. The presented contribution here will underline the possibilities of future detectors from both fields, neutrinoless double beta decay and direct dark matter search, to detect the various other decay modes of Xe-124. It will show how backgrounds and therefore sensitivities evolve for different scenarios of the undetected two-neutrino modes, which can provide useful information for nuclear matrix element calculations. It also explores the feasibility to look for the impactful neutrino-less decay modes as an addition to existing efforts.

Detecting ions with KATRIN: performance and results of the ion conversion to electron (ICE) method

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The aim of the KArlsruhe TRItium Neutrino (KATRIN) experiment is to determine the effective mass of the electron antineutrino with a sensitivity of 200 meV/c² (90% C.L.). This will be achieved by measuring the beta-spectrum of tritium close to the kinematic endpoint of 18.6 keV. Besides electrons also ions are created from beta decay or subsequent ionization mechanisms inside of the source section of KATRIN. All charged particles are guided magnetically through the flux tube. Tritium ions entering the spectrometer volume would produce a significant background signal and effectively contaminate the vessel and detector wafer surface. In order to prevent this KATRIN is equipped with ring electrodes, for ion blocking and dipole electrodes, for ion removal. In the spectrometer section residual ion fluxes can be measured using a special spectrometer setting where ions are converted to electrons which are subsequently measured with the detector. The ion conversion to electron (ICE) mechanism allows to measure ion fluxes as small as 1000 ions/s. In the fall of 2018, the KATRIN collaboration did a commissioning campaign with inactive deuterium gas marking a milestone for ion analysis with the following results. The performance of the ion blocking and removing devices have been successfully tested. Furthermore, the sensitivity and characteristics of the ICE method have been studied in detail with major implications for operating the system in a proper and safe way during neutrino mass measurement operation.

This work is supported by the Helmholtz Association (HGF), the Ministry for Education and Research BMBF (05A17VK2), the Helmholtz Alliance for Astroparticle Physics (HAP), and the DFG graduate school KSETA (GSC 1085).

Possible improvement of KATRIN by time-focusing-time-of-flight method

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The KArlsruhe TRItium Neutrino (KATRIN) experiment aims at a direct and model independent determination of the electron antineutrino mass with a sensitivity of 0.2 eV/c^2.

In its design configuration the statistical sensitivity of KATRIN will reach $\sigma_{stat}(m_{\nu e}^2)$=0.018 eV^2/c^4 after 3 years of measurement time. Investigations have shown that the sensitivity can be improved by up to a factor of 5 in the ideal case using Time-of-Flight (TOF) methods [1]. This improvement is possible because the flight time of an electron depends on its kinetic energy, enabling the measurement of a differential spectrum compared to the integrated spectrum measured by a MAC-E filter in standard mode. However, this requires a well known start time of the electrons, which is not easy to acquire. Here, a different method called time-focusing-Time-of-flight (tfTOF) is presented, were electrons are accelerated depending on their arrival time at a dedicated Time-of-Flight section. If the waveform of the time varying voltage is chosen optimally, all electrons of a given energy arrive at the same time at the detector, regardless of when they started. A MAC-E filter of type of the KATRIN main spectrometer has good properties to perform such a flight time analysis, because it is long (~22 m), electron momenta are aligned in longitudinal direction and their energy is small because of the large retarding potential. The tfTOF concept is introduced and illustrated with a simple toy model. A Monte Carlo study has been performed, starting from particle tracking simulations, accessing the potential benefits to the KATRIN experiment.

The method itself is described in detail and results from the MAC-E filter study are presented.
This work is supported under BMBF contract number 05A14PMA and 05A17PM3 as well as by the Research Training Group 2149 of DFG.

References

[1] N. Steinbrink et al., New J. Phys. 15 (2013) 113020

Background studies for the ECHo experiment

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The ECHo experiment is designed to determine the effective electron neutrino mass by analyzing the endpoint region of the calorimetrically measured Ho-163 electron capture spectrum. To reach sub-eV sensitivity on the effective electron neutrino mass, the identification and reduction of the background is extremely important. We consider three main contributions to the background in the Ho-163 spectrum: Intrinsic background due to unresolved pile-up events, events due to radioactive contamination in the detector and detector set up and events induced by cosmic radiation, especially muons. In this work, we present the strategies developed by the ECHo collaboration to reduce the background in the experiment. In particular, we discuss the use of an active muon veto, which is installed around the ECHo cryostat to discriminate muon induced events, and present simulations of contaminations based on screening measurements. In the summary, we will report on the contribution of muon induced and natural radioactivity background.

Estimation of the KATRIN neutrino mass sensitivity

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The *KArlsruhe TRItium Neutrino* (KATRIN) collaboration aims to determine the neutrino mass with a sensitivity of $0.2\,\mathrm{eV}/c^2$ (90 % CL). This will be achieved by measuring the endpoint region of the tritium β-electron spectrum. The required statistics are obtained from a high intensity gaseous tritium source and a good energy resolution near the endpoint of molecular tritium at 18 574 eV is obtained using a MAC-E filter spectrometer with high angular acceptance.

The first KATRIN neutrino mass measurement campaign took place during April and May of this year. The main goal of this measurement was to obtain enough statistics, and understanding of systematics, in order to improve upon the current 2 eV mass limit. A key systematic parameter is the column density stability which was monitored by several different monitoring systems throughout the measurement campaign. The projected sensitivity from this measurement phase, as well as planned improvements to our understanding of the systematics contributions, will be presented in this poster. An outlook towards the final KATRIN sensitivity after three years of measurement time will also be shown.

This work is supported by the Helmholtz Association (HGF), the Ministry for Education and Research BMBF (05A17PM3, 05A17PX3, 05A17VK2, and 05A17WO3), the Helmholtz Alliance for Astroparticle Physics (HAP), and the Helmholtz Young Investigator Group (VH-NG-1055).

Radioactivity induced background electrons in the KATRIN spectrometers

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The Karlsruhe Tritium Neutrino (KATRIN) experiment aims to measure the effective neutrino mass of electron anti neutrinos in a model-independent way by precise determination of the beta spectrum of molecular tritium. To achieve the sensitivity of *m_v* = 0.2 eV/c^2 (90% C.L.) on the effective neutrino mass, knowledge of statistical and systematic uncertainties as well as the background processes is essential. This poster focuses on the contributions of radioactive decays as the major source of backgrounds in the KATRIN spectrometers and their countermeasures.
This work was supported by BMBF (05A17VK2) and the HGF.

Search for keV-scale sterile Neutrinos with KATRIN

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A sterile neutrino with a mass up to 18.6 keV would be visible in the beta-decay spectrum of tritium. The KATRIN experiment is designed to determine the absolute neutrinos mass by measuring the beta-decay spectrum of gaseous tritium close to its endpoint. Beyond that, it's unprecedented tritium source luminosity and spectroscopic quality could be used to measure the entire beta-spectrum to search for a sterile neutrino.

The first part of the two posters focuses on the general use of the KATRIN experiment for the search of sterile neutrinos and presents several different scenarios that allow the usage of the current KATRIN experimental setup. In contrast, the second part introduces future hardware upgrades such as the TRISTAN detector. Finally, we show different sensitivity studies and results of first tritium data that was taken in May 2018. A new unreached sterile neutrino parameter space was studied.

The two posters illustrate the common work of Anton Huber, Marc Korzeczek and Leonard Köllenberger (among others) and will be presented by all of us during the seminar.

This work was supported by GRK1694, BMBF (05A17VK2), KSETA, the HGF and the Friedrich-Ebert-Stiftung.

Neutrino's charge possible consequence in astrophysics

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Although standard model (SM) neutrino is considered as neutral particle, recent experiments showed that neutrino has a non-zero magnetic moment involved physics beyond SM, this new electromagnetic interaction contribution enhances several neutrino processes i.e. oscillation, scattering, and Spin. This work investigates the propagation trajectories of galactic neutrinos in extreme magnetic field condition that exist in neutron stars and for what limit could affect the neutrino flux measured at Earth.

Search for keV-scale sterile neutrinos with KATRIN

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The KATRIN experiment is designed to determine the absolute neutrino mass, by measuring the endpoint region of the β-decay spectrum of gaseous tritium, with an unprecedented sensitivity of 200 meV (90 % CL). By extending the measuring range further into the spectrum, the KATRIN experiment can also be used to search for keV-scale sterile neutrinos. Within the spectrum, a sterile neutrino would be manifested as a kink. A sterile neutrino with a mass up to 18.6 keV could therefore be observed in the tritium spectrum.

In July 2018, during the "first tritium" campaign, the KATRIN experiment was comissioned and operated with tritium for the first time, including an extended measurement 4 keV into the spectrum. In this poster sensitivity studies from these measurements are presented. These sensitivity studies give insight into the exclusion in the sterile parameter space with the current KATRIN setup. Furthermore, future hardware upgrades such as the TRISTAN detector will be introduced. This upgrade will take advantage of the full source activity over an extended energy range, which will enhance the attainable sterile neutrino parameter space.

This work is supported by the Helmholtz Association (HGF), the Ministry for Education and Research BMBF (05A17PM3, 05A17PX3, 05A17VK2, and 05A17WO3), and the Helmholtz Alliance for Astroparticle Physics (HAP).

Geometrical contribution to neutrino mass matrix

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The dynamics of fermions on curved spacetime requires a spin connection, which contains a part called contorsion, an auxiliary field without dynamics but fully expressible in terms of the axial current density of fermions. Its effect is the appearance of a quartic interaction of all fermions in the action, leading to a nonlinear Dirac equation involving all fermions present. Noting that left and right-chiral fermions may couple to contorsion by different strengths, we show that all fermions gain an effective mass when propagating through fermionic matter. This may have an observable effect on neutrino oscillations. In particular we find that different neutrino flavors can mix even if they have zero rest mass in vacuum, without requiring fields beyond the Standard Model.

References

[1] S. Chakrabarty and A. Lahiri, **arxiv:1904.06036**

Project 8: Atomic Tritium Motivation and Source Design

A. Lindman[1] **for the Project 8 Collaboration**

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Project 8 is a phased approach to measuring the absolute neutrino mass with Cyclotron Radiation Emission Spectroscopy [1] of tritium β decay electrons. I will discuss the motivations for an atomic T source in light of engineering feasibility and our design sensitivity [2], including recent results from a hydrogen test stand. All existing tritium-based m_ν experiments use molecular T_2, which has a relatively broad final state spectrum. An atomic T source and a □10 m^3 fiducial volume atom trap will enable Project 8's design sensitivity. Parallel technology development efforts in the collaboration aim to deliver a trap with magnetic field uniformity of 10^{-7}, filled with T having a T_2 contamination less than 10^{-6} and instrumented with a spatially resolving antenna array to read out the femtowatt CRES signals. In such a trap, one year of runtime with 10^{18} T atoms should provide 40 meV sensitivity to the neutrino mass.

This work is supported by the US DOE Office of Nuclear Physics, the US NSF, the PRISMA+ Cluster of Excellence at the University of Mainz, and internal investments at all institutions.

References

[1] D. M. Asner et al. (Project 8 Collaboration), Phys. Rev. Lett. **114**, 162501 (2015)

[2] A. A. Esfahani et al. (Project 8 Collaboration), J. Phys. G **44 5**, 054004 (2017)

Background reduction with the shifted analyzing plane configuration in KATRIN

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To measure the effective electron antineutrino mass m_ν with a sensitivity of 0.2 *eV/c*^{2} the KATRIN experiment requires the level of background of about 10 *mcps*. One of the sources of the background electrons are the Rydberg atoms, created in the decay of ^{210}Po, entering the spectrometer and ionized by thermal radiation. This yields low-energy electrons, almost uniformly distributed over the vessel volume. We present here a technique to reduce this volume-dependent background of the KATRIN main spectrometer by using a specific configuration of the electromagnetic fields (so called shifted analyzing plane with a reduced fluxtube), that effectively decreases the volume of the fluxtube of electrons while preserving the energy resolution and allowing for the required neutrino mass sensitivity. The dedicated tests, which were performed recently, investigated the background reduction in this configuration and studied the EM fields at the shifted analyzing plane by calibration measurements using the gaseous krypton conversion electrons as a reference source.

Towards Atomic Tritium in Project 8

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Rotational and vibrational excitations of molecular tritium (T_2) perturb the beta spectrum endpoint, which limits neutrino mass sensitivity in T_2-based experiments to about 100 meV. Atomic tritium opens a path for Project 8 to reach a neutrino mass sensitivity goal of 40 meV. To that end, the collaboration is developing techniques needed to produce, cool, and trap atomic tritium in a way that is compatible with Cyclotron Radiation Emission Spectroscopy. These efforts include a hardware testbed for characterizing the beam from a custom-designed, coaxial-current hydrogen atom source. The scope of the testbed will include magnetic focusing and cooling of the beam, for eventual integration with an atomic hydrogen-trapping demonstrator. Here, progress is presented on the construction and commissioning of the atom source and hardware testbed. This work is supported by the US DOE Office of Nuclear Physics, the US NSF, the PRISMA Cluster of Excellence at the University of Mainz, and internal investments at all institutions.

First operation of the KATRIN Loops tritium gas processing system

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The KATRIN experiment aims to measure the neutrino mass via high precision spectroscopy of the tritium beta decay with a target sensitivity of $200\,\mathrm{meV}/c^2$. To achieve this, a tritium source with high luminosity and low systematics is needed: the Windowless Gaseous Tritium Source (WGTS). This source consists of a stabilized stream of tritium gas with a purity of $>95\,\%$ tritium, contained inside a $30\,\mathrm{K}$ cold tube. In order to minimize systematic effects, the WGTS needs to be stabilized in all these parameters on the $0.1\,\%$ level. To achieve this stability while also generating the necessary throughput of approx. $40\,\mathrm{g\,d^{-1}}$ of tritium, a dedicated closed gas cycle, called the Loops system, is used. The Loops system is a complex gas processing system which consists of an inner cycle generating the WGTS gas column, and an outer cycle which interfaces the KATRIN experiment with the TLK (Tritium Laboratory Karlsruhe) infrastructure for gas purification and hydrogen isotope separation. With the completion of this system in early 2018, followed by commissioning tests with deuterium, the KATRIN experiment was ready for operation with tritium. The operation with tritium started in mid 2018 with the tritium commissioning phase First Tritium where the basic operability with traces of tritium ($0.5\,\%$ tritium in deuterium) and compliance with radiation safety regulations was proven. In March 2019, the latest measurement campaign started, for the first time using pure tritium gas with concentrations and throughputs up to the nominal values.

This poster will give an overview of the experiences gained during this latest campaign. The results regarding stability, observed isotopic effects, and operative performance will be presented.

This work is supported by the Helmholtz Association (HGF) , the Ministry for Education and Research BMBF (05A17PM3, 05A17PX3, 05A17VK2, and 05A17WO3).

APR19-001390

The HUNTER Sterile Neutrino Search Experiment

Charles Jeff Martoff, Eric R. Hudson, Paul Hamilton, Peter F. Smith, Christian Schneider, Andrew L. Renshaw, Peter Daniel Meyers, Basu R. Lamichhane, Xunzhen Yu, Eddie Chang, Frank C. Malatino (Temple University, UCLA, University of Houston, Princeton University)

The HUNTER experiment (Heavy Unseen Neutrinos from Total Energy-momentum Reconstruction) is a search for sterile neutrinos with masses in the keV range. The neutrino missing mass will be reconstructed from 131-Cs electron capture decays occurring in a magneto-optically trapped sample of atoms. Reaction-microscope spectrometers will be used to detect all charged decay products with high solid angle efficiency, and LYSO scintillators read out by silicon photomultiplier arrays detect x-rays, each with sufficient resolution to reconstruct the neutrino missing mass. The overall design of this W> M. Keck Foundation-funded experiment will be discussed and simulations shown. Upgrades which would improve the mixing angle sensitivity by orders of magnitude will be described.

We thank the W. M. Keck Foundation and our respective universities for financial support of HUNTER.

0.1. Resonant supressions on Ultra High Energy Astriphysical Neutrino

0.1.1. Abstract / América Morales, Universidad de Guanajuato, Division de Ciencias e Ingenierias, León, Guanajuato, Mexico

Recent observations of extragalactic neutrinos flow detected by IceCube differ from the theoretical predictions, as the number of events recorded in the detector is lower than expected by some theoretical models. This na-turally raises the question, "What processes may be reducing the flow of extragalactic neutrinos coming to earth?"

We discuss Standard Model (SM) dispersion of extragalactic neutrinos with three diferent fluxes of neutrinos and show that in SM processes theres isn't a significant reduction in the flow of extragalactic neutrinos that can explain de IceCube data. However, an interaction between neutrinos and dark matter might induce a resonant effect in the oscillation probability, therefor on the number of events detected on Earth.

Analysis Strategy and Background in the KATRIN Experiment

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The **Ka**rlsruhe **Tri**tium **N**eutrino (KATRIN) experiment aims to determine the effective electron antineutrino mass with a sensitivity of 200 meV (90% C.L.) by investigating the energy spectrum of tritium beta-electrons close to the endpoint.
Over the whole data-taking period several thousand spectra will be recorded with each of the 148 detector pixels. Therefore analysis strategies have to be developed to combine the complete dataset and obtain a single neutrino mass result. This contribution discusses different options for the analysis strategies including treatment of systematic effects based on the new analysis framework 'Fitrium'.
Fitrium is also suitable to investigate implications of background mitigation techniques. Assuming that highly excited Rydberg atoms are a dominating source of the KATRIN background, low-energy electrons are created homogeneously inside the main spectrometer through ionization. The background due to these electrons can be mitigated by manipulating the magnetic flux tube in a way as to reduce the volume observed by the detector. However, such an approach leads to potentially large inhomogeneities of the electric and magnetic fields thereby impacting the transmission properties of the beta-electrons. Different ways of accessing the field values as well as first results are shown.

R&D to search for keV sterile neutrinos in calorimetrically measured tritium beta spectra

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Sterile neutrinos with mass in the keV range are promising Dark matter candidates. That fact that the corresponding heavy mass eigenstate would mix with the standard mass eigenstates allows for searching for the existence of such particles by searching for a kink in beta spectra.

We explore the possibility of detecting such a kink in calorimetrically measured tritium beta spectra. We plan to enclose tritium in high energy resolution metallic magnetic calorimeters (MMCs) arrays. The originality of this approach is to make use of the calorimetric technique to measure the complete energy emitted in a tritium beta decay besides the one of the electron antineutrino. With these detectors we will be able to measure with extremely low energy loss and a very good energy resolution of a few eV FWHM over the complete energy range.

We discuss which are the challenges for performing a calorimetric measurement of the tritium beta spectrum, in particular regarding to the fabrication of MMCs detector arrays in which tritium could be reliably enclosed. We describe the present status of the R&D activities and show preliminary results in the detector fabrication and loading.

Multichannel microwave SQUID multiplexer readout of large MMC detector arrays

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The Electron Capture in Holmium experiment (ECHo) aims for the investigation of the electron neutrino mass by measuring a high-statistics 163-Ho spectrum using large arrays of metallic magnetic calorimeters (MMCs). Microwave SQUID multiplexing (μMUXing) appears to be the most suitable technique for the readout of such arrays. Here, each detector is read out by a non-hysteretic rf-SQUID, which is inductively coupled to a superconducting microwave resonator. A signal in the detector changes the magnetic flux dependent SQUID inductance resulting in a resonance frequency shift of the related resonator. By coupling many of these circuits, each having a unique resonance frequency, to a common transmission line, hundreds or even thousands of detectors can be simultaneously read out by monitoring the amplitude and phase of the resonators.

The full readout system consists of the cryogenic microwave SQUID multiplexer chip combining the detector signals into a single readout line, a multiplexing-compatible linearization technique as well as room-temperature electronics for the generation and processing of readout signals. Over the last years, the cryogenic microwave SQUID multiplexer has been developed at Heidelberg University, whereas a software defined radio based read electronics has been developed at Karlsruhe Institute of Technology. So far, all components have been developed and tested individually. Very recently, we combined all three components to a full readout system for the first time to perform the first true multi-channel readout of MMCs using a microwave SQUID multiplexer.

In this contribution, we will introduce the principle of microwave SQUID multiplexing as well as the utilized linearization technique and readout electronics. We will then discuss the performance of the full μMUX based readout system including a comprehensive analysis of detector events, noise spectra as well as inter-channel crosstalk.

TRIMS: Experimental study of final states in tritium beta decay

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Molecular tritium serves as the source for sensitive experiments, such as KATRIN, to measure neutrino mass. Molecular excitations before and after the decay modify the spectral shape, and are determined from theory. The TRIMS (Tritium Recoil Ion Mass Spectrometer) apparatus has been constructed [1] to make a new measurement of the branching ratio to the bound molecular ion HeT^+ and other ionic final states, following the decay of both T_2 and its isotopologue HT. Two measurements of the bound-state branch made in the 1950s disagree strongly with modern theory. We report on the performance of the completed instrument and on the analysis of data from it.

References

[1] L. I. Bodine *et al.,* Phys. Rev. **C 91**, 035505 (2015).

Energy loss and response function in KATRIN

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The KATRIN experiment aims to measure the effective electron antineutrino mass with a sensitivity of 0.2 eV/c^2 using a gaseous tritium source combined with the MAC-E filter technique. The precise knowledge of the response function of the KATRIN setup is crucial for achieving this goal. The electrons of the tritium beta decay are influenced by several effects including, geometrical resolution of the MAC-E filter, stability and variations of the electromagnetic fields, temperature and pressure along the beam-line, energy losses due to synchrotron radiation and scattering in the source. The latter is one of the main systematics of the KATRIN response. Therefore it is measured specifically with an angular selective and mono energetic electron gun and the full experimental KATRIN setup to determine the energy loss function at the energies close to the tritium end point (18.6 keV) with the required precision. We use a time of flight based method to measure the integrated as well as a quasi differential energy loss function, which allows us to determine the shape of the function with unprecedented precision.

We present the main components of the KATRIN response function, their possible influence on the sensitivity to the neutrino mass and the preliminary results on energy losses in electron-deuterium scattering measured at KATRIN in 2018.

This work is funded by GRK2149 and BMBF 05A17PM3.

TRISTAN Project - Development of a silicon drift detector for the keV sterile neutrino search with KATRIN — Daniel Siegmann on behalf of the KATRIN Collaboration — Max Planck Institute for Physics — Technical University of Munich

The KATRIN (Karlsruhe Tritium Neutrino) experiment investigates the energetic endpoint of the tritium beta-decay spectrum to determine the effective mass of the electron anti-neutrino with a sensitivity of 200 meV (90% C.L.) after an effective data taking time of three years starting in March 2019.

After the data taking for the neutrino mass survey is completed the TRISTAN (TRitium Invetigations of STerile to Active Neutrino mixing) project can upgrade the current detector in the KATRIN experiment to search for the signature of a keV sterile neutrino in the entire tritium beta decay spectra. One of the greatest challenges is to handle high signal rates up to 100 Mcps as a result of the strong activity of the KATRIN tritium source. Therefore, a novel 3500 multi-pixel silicon drift detector is being designed which is able to handle rates up to 100 kcps in each pixel while maintaining an excellent energy resolution of 300 eV (FWHM) at 20 keV.

To fulfill these requirements multiple smaller 7 channel prototypes were designed and characterized while the first 166 pixels TRISTAN prototype is under production. In the poster the major results of the characterization measurements as well as the current status and the next steps for the 166 pixel module are shown.

Analysis and systematics of KATRIN: from Krypton calibration to Tritium beta decay, using CMKAT

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The Karlsruhe Tritium Neutrino (KATRIN) experiment aims to make a precision measurement of the effective neutrino mass by leveraging the kinematics of tritium beta decay, with a sensitivity of 0.2eV (90% C.L.). Recent run campaigns[1,2], both in standard mode (using molecular tritium) and calibration mode (using ^{83m}Kr), have provided a wealth of data. The models which are used to fit these data are described by a convolution of the decay physics with a response function to encode details of the experimental setup. In order to achieve the design sensitivity levels, our understanding of systematics must be under control. To this end, we explore KATRIN systematics, as well as their effects on certain model fit parameters. A summary of preliminary results using the analysis package CMKAT's optimized fit strategy will be given here, as well as an outlook to both the immediate and extended future.

References

1. M. Arenz et al, *First transmission of electrons and ions through the KATRIN beamline*, JINST 13 P04020 (2018)
2. K. Altenmueller et al, *High-resolution spectroscopy of gaseous 83mKr conversion electrons with the KATRIN experiment*, arXiv:1903.06452 (2019)

Ion retention, blocking and monitoring within the KATRIN experiment

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The KATRIN (KArlsruhe TRItium Neutrino) experiment aims to measure the effective neutrino mass with an unprecedented design sensitivity of 0.2 eV at the 90% confidence level. The electron antineutrino is produced in tritium beta decay together with the beta-electron and a positive ion. Magnetic fields guide charged particles through the energy-analyzing retarding spectrometers towards the KATRIN detector. In this process, ions act as a background source as they further ionize residual gas and produce secondary electrons. We have tested the ion-blocking mechanisms implemented in the source and transport section, where ions are blocked with positive potentials created by ring electrodes, and found the preferred settings with the highest blocking efficiency. We also found that it takes weeks for complete neutralization to occur in these blocking devices. Finally, some ions strike electrodes along the beamline, creating a current that allows us to monitor the tiny ion flux that enters the spectrometer section. We will share results from these tests and prospects for future operations.

Observation of two-neutrino double electron capture in ^{124}Xe with XENON1T

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Two-neutrino double electron capture (2vECEC) is a second-order Weak process with predicted half-lives that surpass the age of the Universe by many orders of magnitude. Indications for 2vECEC decays have only been seen for two isotopes, ^{78}Kr and ^{130}Ba, and instruments with very low background levels are needed to detect them directly with high statistical significance. The 2vECEC half-life provides an important input for nuclear structure models and its measurement represents a first step in the search for the neutrinoless double electron capture processes (0vECEC). A detection of the latter would imply the existence of lepton number violation and the Majorana nature of neutrinos. The XENON1T dark matter experiment located at Laboratori Nazionali del Gran Sasso recently achieved the first direct observation of the Standard Model 2vECEC in ^{124}Xe [1]. The significance of the signal is 4.4σ and the corresponding half-life $T_{1/2} = (1.8 \pm 0.5_{stat} \pm 0.1_{sys}) \times 10^{22}$ yr is the longest ever measured directly. This demonstrates that the low background and large target mass of xenon-based Dark Matter detectors make them well suited to measuring other rare processes and it highlights the broad physics reach for the next-generation of experiments currently under construction.
This poster will give an overview of XENON1T experiment. Double electron capture processes, their signatures, and their connection to nuclear theory as well as neutrino physics will be presented. All analysis steps will be shown with a focus on energy calibration and background modelling. A short discussion on prospects for future 0vECEC searches will also be included. The work of the author is supported by Deutsche Forschungsgemeinschaft (DFG) through the Research Training Group GRK2149: Strong and Weak Interactions - from Hadrons to Dark Matter.

References

1. XENON Collaboration, Nature **568**, 532-535 (2019)

Neutrinoless double beta decay search with EXO-200

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The EXO-200 experiment, which ran from 2011 to 2018 at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, USA, searches for the neutrinoless double beta decay ($0\nu\beta\beta$) of Xenon-136. The single-phase liquid xenon time projection chamber (TPC) design uses ~150 kg of enriched xenon as both the source and the detector medium, where both ionization and scintillation are measured. With topological discrimination between signal and background and good energy resolution, improved by both hardware upgrades and software advances, EXO-200 has achieved a half-life sensitivity that is among the world's best. We present a new search for $0\nu\beta\beta$ decay using the entire data-set collected by the collaboration, from Sep 2011 to Feb 2014 and then from May 2016 to Dec 2018, totaling a Xe-136 exposure of 234.1 kg•yr. A $0\nu\beta\beta$ half-life lower limit of 3.5×10^{25} yr at 90% confidence level was found. The successes of EXO-200 contribute to the design of the next-generation tonne-scale detector, nEXO.