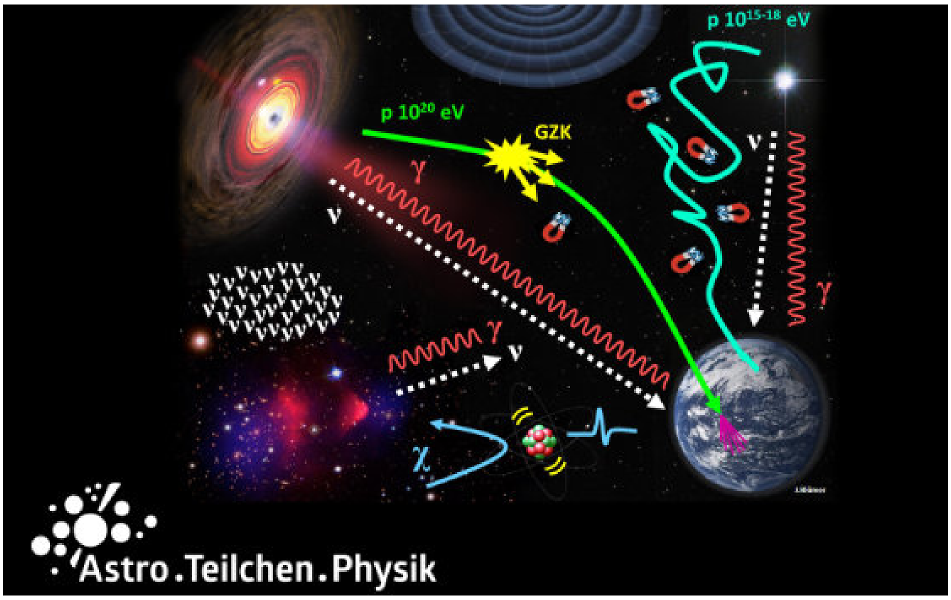
Astroparticle Physics in Germany - Long-Term Strategy 2024

Wednesday, October 16, 2024 - Friday, October 18, 2024

Karlsruhe Institute of Technology (Campus South)



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Thematical topic #1: Astroparticle Theory

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20min presentation, 25min discussion

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Thematical topic #2: Neutrino Properties

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Thematical topic #4: Cosmic Rays

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Thematical topic #5: Gamma Rays

Author: Jim Hinton[1]

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Thematical topic #3: Low-energy Neutrino Astrophysics

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Thematical topic #6: High-energy Neutrino Astrophysics

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Thematical topic #7: Gravitational Waves

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Author: Uwe Oberlack[1]

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Thematical topic #9: Dark Matter

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Introduction and objectives of the meeting

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MuSES: Multi-messenger Studies of Extragalactic Super-colliders

Author: Yuri Kovalev[1]

[1] *MPIfR-Bonn*

The poster presents the advanced ERC project MuSES (ERC grant No 101142396), which will study the physical processes near supermassive black holes that are responsible for launching and propagating relativistic jets in active galactic nuclei (AGN). Project objectives: 1) observational studies of AGN jet geometry, collimation and acceleration; 2) probing the physical mechanism of neutrino production on the basis of multi-messenger blazar data. The prime goal is to use VLBI observations together with other electromagnetic and neutrino data to understand particle acceleration and neutrino production in blazars.

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Overview of the Prioritization Process

Author: Ralph Engel[1]

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Project presentation: LEGEND

Corresponding Author: b.schwingenheuer@mpi-hd.mpg.de

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Project presentation: IceCube-Gen2

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Project presentation: XLZD

Author: Marc Schumann[1]

Co-author: Kathrin Valerius [2]

[1] *University of Freiburg*

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Corresponding Authors: kathrin.valerius@kit.edu, marc.schumann@physik.uni-freiburg.de

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Project presentation: Einstein Telescope

Author: Harald Lueck[1]

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Towards searching for photons with energies beyond the PeV range from galactic PeVatrons

Authors: Chiara Papior[1]; Marcus Niechciol[1]; Markus Risse[1]

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Several gamma-ray observatories have discovered photons of cosmic origin with energies in the PeV (10^{15} eV) range. Photons at these energies might be produced as by-products from particle acceleration in so-called PeVatrons, which are widely assumed to be the sources of a large part of galactic cosmic rays. Based on recent measurements of these PeV γ-sources by LHAASO and HAWC, we extrapolate the energy spectra up to the ultra-high-energy (UHE, here $\geq$10 PeV) regime. The goal of this study is to evaluate if giant air-shower observatories, for example the Pierre Auger Observatory, could contribute to test the UHE luminosity of PeV γ-sources. Possible propagation effects are investigated as well as the required discrimination power to distinguish photon- and hadron-initiated air showers. For present detector setups, it turns out to be challenging to achieve the required sensitivity due the energy threshold being too high or the detection area too small. Dedicated detector

concepts appear to be needed to explore the UHE frontier of PeV γ-sources. Ultimately, this could provide complementary information on the sources of cosmic rays beyond the PeV regime — a key objective of current efforts in multimessenger astronomy.

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Probing Lorentz violation in the ultra-high-energy regime using air showers

Authors: Fabian Duenkel[1]; Marcus Niechciol[1]; Markus Risse[1]

[1] *University of Siegen*

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Current efforts towards a more fundamental theory beyond the Standard Model of Particle Physics open up a window for deviations from exact Lorentz symmetry. To test Lorentz symmetry, one can take advantage of the extreme energies reached by ultra-high-energy cosmic rays (UHECRs). We use the air showers initiated by UHECRs to study the effects of Lorentz violation (LV), focusing on isotropic, non-birefringent LV in the photon sector. New processes, which are forbidden in case exact Lorentz symmetry holds, can significantly change the shower development, specifically vacuum Cherenkov radiation or photon decay. Based on the average depth of the shower maximum (Xmax) and its shower-to-shower fluctuations, world-leading bounds on the strength of LV have been placed. The next step is to investigate and exploit the impact of LV on shower muons. Including shower observables related to muons is expected to significantly improve the sensitivity of LV searches.

Summary:

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KATRIN-like mini MAC-E Filter with a tritium source for the advanced physics lab course

Author: Sarah Untereiner[None]

The KATRIN experiment aims to determine the effective neutrino mass using the kinematics of electrons from the tritium β-decay. The integral energy spectrum of the electrons is measured by an electro-static high-pass filter, using the MAC-E filter principle (Magnetic Adiabatic Collimation and Electrostatic filter). Only electrons with energies above the retarding potential of the filter are counted at the detector at the end of the MAC-E spectrometer.
In order to give students the opportunity to learn more about the experimental principles behind KATRIN, a smaller version of the MAC-E filter setup, called Mini MAC-E, has been built, which will be used in the advanced physics lab course at KIT. With a scale of approximately 1:20 the Mini MAC-E experiment includes all the major components of KATRIN: a tritium source, the spectrometer with adjustable high voltage, a high resolution detector and the magnetic guiding field. Other than KATRIN, the source uses two implanted disks with tritium and ^{83m}Kr that can be exchanged inside the ultra-high vacuum source chamber. This poster shows the design of the physics lab setup and reports on first results. This project has been supported by RIRO (Research Infrastructure in Research-Oriented teaching), which is part of the ExU project at KIT.

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DELight: a Direct search Experiment for Light dark matter with superfluid helium

Author: The DELight Collaboration[None]

To reach ultra-low detection thresholds necessary to probe unprecedentedly low Dark Matter masses, target material alternatives and novel detector designs are essential. One such target material is superfluid ^{4}He which has the potential to probe so far uncharted light Dark Matter parameter space at sub-GeV masses. The new "Direct search Experiment for Light dark matter", DELight, will be using superfluid helium as active target, instrumented with magnetic micro-calorimeters. It is being designed to reach sensitivity to masses well below 100 MeV in Dark Matter-nucleus scattering interactions.

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First glance at the latest science runs of the KATRIN neutrino mass experiment using the KaFit analysis package

Authors: Jaroslav Storek[1]; Khushbakht Habib[2]; Richard Salomon[3]

[1] *KIT*

[2] *Karlsruhe Institute of Technology*

[3] *Uni-muenster*

Performing a precision measurement of the tritium β-decay spectrum, the Karlsruhe Tritium Neutrino (KATRIN) experiment aims at measuring the neutrino mass with a sensitivity better than 0.3 eV/c² (90% C.L.) after 1000 measurement days. The current world-leading upper limit of m_{<i>ν</i>} ≤ 0.8 eV/c² (90% C.L.) was determined from a combined analysis of the first two measurement campaigns (6 million collected electrons until 2019) and a publication including the three subsequent measurement campaigns is in preparation (36 million collected electrons until 2021).
In this poster, we present the most recent measurement phases which feature a significant increase of statistics to more than 125 million collected electrons in the region of interest. Following KATRIN' s model blinding strategy, studies on simulated Asimov data using the KaFit/SSC model within the Kasper framework will be presented to provide an initial overview of this dataset.

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The "LowRad"-project: Background reduction beyond the neutrino fog

Authors: Christian Huhmann[None]; Christian Weinheimer[1]; Daniel Wenz[2]; David Koke[None]; Lutz Althüser[None]; Philipp Schulte[None]

[1] *University of Muenster*

[2] *Unversity of Muenster*

Next generation liquid nobel gas detectors for the search of weakly interacting massive particles (WIMPs) aim to increase their sensitivity down to the neutrino fog. To achieve this ambitious goal, it is imperative to further reduce detector backgrounds dominated by LXe intrinsic isotopes of 85Kr and 222Rn ten-times below the unshieldable solar and atmospheric neutrino background. Already the XENONnT experiment achieved world leading low background levels for 222Rn (< 1 μBq/kg) and 85Kr (0.2 ppt) through their removal via cryogenic distillation, paired with stringent material selections.

In the ERC Advanced Grand project LowRad the technical foundations for the next generation cryogenic krypton and radon removal systems are developed. This includes among other things a krypton concentrator and a cryogenic heat pump. The concentrator aims to reduce the krypton enriched off-gas losses during krypton distillation by another factor 1000 making a continuous online distillation during data taking feasible. The cryogenic heat pump tackles the 20 kW heating and cooling power demands of future radon removal systems, which is required to reduce the 222Rn background to less than 0.1 μBq/kg, or less than 1 atom in 100 mol xenon. On this poster we will present the status of these two systems currently developed.

Acknowledging the support of the ERC AdG project "LowRad" (101055063).

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High energy resolution with a Transverse Energy Compensator for time-of-flight spectroscopy at KATRIN++

Authors: Christian Weinheimer[1]; Richard Salomon[2]; Sonja Schneidewind[2]

[1] *University of Muenster*

[2] *University of Muenster, Institute for Nuclear Physics*

The R&D project KATRIN++ is investigating the extension of the neutrino mass experiment KATRIN in order to achieve a sensitivity of <50 meV and thus be able to reliably determine the neutrino mass in the laboratory if neutrinos have an inverted mass order. To achieve this, a differential measurement method will be applied to significantly increase the statistics and reduce the background rate, while at the same time significantly improving the energy resolution to <0.5 eV. Furthermore, an atomic tritium source would avoid the rotational-vibrational energy broadening of the THe+ molecules in the final state with a standard deviation of about 0.4 eV.

High-resolution differential tritium-beta spectroscopy could be realised with KATRIN++ in two steps: First, the development of a minimally invasive electron marker for the KATRIN beam line is required, e.g. based on the CRES method from project 8 or a quantum sensor method, to determine the start times of the beta electrons. This would then allow the differential measurement of the beta spectrum of tritium in the endpoint region using time-of-flight spectroscopy [1]. Second, to enable the spectroscopy with the energy resolution required for KATRIN++ in the sub-eV range, a novel transverse energy compensator (TEC) [2] is proposed that improves the energy resolution of the KATRIN spectrometer by almost an order of magnitude.

This poster presents the principle of high-resolution differential time-of-flight electron spectroscopy for KATRIN++ and, in particular, the innovative idea of the transverse energy compensator.

Acknowledgement: The work of the authors is supported by DFG (RTG 2149) and by BMBF Verbundforschung (05A23PMA).

[1]: N. Steinbrink, V. Hannen, E. L. Martin, R. G. H. Robertson, M. Zacher and C. Weinheimer, New J. Phys. 15 (2013) 113020.

[2] This idea from C. Weinheimer has been submitted as a provisional patent application under the number 10 2024 126 381 by the University of Münster.

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The Tritium Laboratory for Astroparticle Physics Research

Authors: Beate Bornschein[1]; Caroline Rodenbeck[2]; David Hillesheimer[3]; Deseada Diaz Barrero[None]; Dominic Batzler[4]; Florian Priester[5]; Johanna Wydra[None]; Joshua Kohpeiß[3]; Jürgen Wendel[None]; Le Than-Long[5]; Leonard Hasselmann[6]; Lutz Bornschein[7]; Magnus Schlösser[8]; Marco Roellig[9]; Marsteller Alexander[5]; Max Aker[None]; Melzer Christin[None]; Michael Sturm[None]; Neven Kovac[10]; Robin Größle[5]; Schäfer Peter[5]; Schnurr Ulrich[None]; Simon Niemes[9]; Stefan Welte[5]; Valentin Hermann[11]; Genrich Zeller[12]

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[11] *TLK*

[12] *KIT-TLK*

The Tritium Laboratory Karlsruhe (TLK) of the Institute for Astroparticle Physics (IAP) located at KIT Campus North contributed in advancing the understanding of the radioactive hydrogen isotope tritium and its technical use for applications in nuclear fusion, astroparticle physics and beyond. Two of its outstanding features are its license to handle up to 40 grams of tritium, and its unique closed tritium cycle that allows reprocessing of tritiated gases. During its three decades of operation, the TLK has gained extensive knowledge in tritium handling. It is continuously maintained and upgraded, enabling it to provide a world-leading state-of-the-art research facility within the Helmholtz Association.

One of TLK's outstanding achievements is operating the tritium source of the KATRIN experiment, the world-leading endeavor for direct measurement of the neutrino mass based on tritium beta decay. At TLK the closed tritium loop for KATRIN was developed and is running smoothly since 2018. Its successful operation enabled the measurements leading to the currently best upper limit on the neutrino mass.

The IAP and TLK are committed to the future of tritium neutrino research and we are pursuing R&D towards generating and handling atomic tritium.

In this contribution, we present the TLK and its unique infrastructure contributing to ongoing and future neutrino experiments.

Summary:

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Cosmic-ray Physics with IceCube-Gen2

Author: Fahim Varsi[1]

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The IceCube Neutrino Observatory, located at the geographic South Pole, consists of a cubic-kilometer in-ice neutrino detector and a square-kilometer array of ice-Cherenkov detectors. It is designed for neutrino astronomy, cosmic ray physics, multi-messenger astronomy, and particle physics. The next-generation expansion, IceCube-Gen2, is currently in development with enhanced detection sensitivities to advance these scientific goals. IceCube-Gen2 is planned to include: (1) an in-ice neutrino detector spanning approximately 8 km^3, increasing neutrino detection sensitivity nearly five times compared to IceCube; (2) in-ice radio antennas covering around 400 km^2 to extend the sensitivity to neutrino sources beyond EeV energies; (3) a surface array of scintillator detectors and radio antennas for detecting cosmic-ray air showers in the energy range of several hundred TeV to a few EeV; and (4) the original IceCube detector. The proposed surface array, in correlation with in-ice muons with energies exceeding 300 GeV, will enhance the study of cosmic-ray and hadronic physics. This contribution will highlight the cosmic-ray physics potential of IceCube-Gen2.

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Highlights from the Pierre Auger Observatory

Author: Fiona Ellwanger[None]

The Pierre Auger Observatory in the west of Argentina close to Malargüe was built to explore the origin and production of ultra-high energy cosmic rays. Comprised of 1660 water-Cherenkov detectors in an area of more than 3000\,km^2 it is the largest observatory of its kind. Besides measuring the shower footprint with these surface detectors, 24 fluorescence telescopes at four sites are able to observe the showers directly as they move through the air producing fluorescence light during clear moonless nights. Including three additional fluorescence telescopes overlooking a more dense array consisting of 61 water-Cherenkov detectors the energy range from 10^{16} beyond 10^{20}\,eV is probed. Phase I of the observatory covers more than 17 years of operation (January 2004 to October 2021). The data collected during phase I shows a trend from a lighter composition at lower energies becoming heavier at higher energies. The anisotropy for cosmic rays at energies above 8×10^{18}\,eV that can be described by a dipole indicates an extragalactic origin of ultra-high energy cosmic rays. These and a plethora of further results from the Pierre Auger Observatory provide major advances in the understanding of the ultra-high energy cosmic ray phenomena and lay the foundation for second-phase studies with the upgraded AugerPrime detector.

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R&D towards an atomic hydrogen source for future neutrino mass experiments

Authors: Caroline Rodenbeck[1]; Larisa Thorne[2]

Co-authors: Alec Lindman [3]; Alexander Marsteller [4]; Aya El Boustani [2]; Beate Bornschein [5]; Brunilda Mucogllava [2]; Christian Matthé [2]; Daniel Kurz ; Darius Fenner [2]; David Hillesheimer [6]; Elias Lütkenhorst [4]; Fabian Piermaier [2]; Florian Hanß [4]; Florian Priester [7]; Leonard Hasselmann [8]; Magnus Schlösser [9]; Marco Roellig [10]; Martin Fertl [2]; Maxim Astaschov [2]; Maximilian Hüneborn [2]; Michael Sturm ; Robin Größle [7]; Sebastian Böser [11]; Sebastian Koch ; Stefan Welte [7]; Thomas Thümmler [12]; Tobias Geier [4]

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The neutrino mass is one of the still-to-be-solved puzzles of particle physics. Measuring the neutrino mass is possible by performing precision spectroscopy of the tritium beta-decay spectrum at its endpoint. Until now, experiments following this approach use molecular tritium and are therefore limited by the broadening of the molecular final state distribution.

For future experiments aiming for sensitivities as low as the lower boundaries obtained by neutrino oscillation experiments (0.05\,eV/c^2 in case of inverted ordering, or 0.009\,eV/c^2 for normal ordering), atomic tritium sources are essential.

Research on atomic tritium sources is performed at the Johannes Gutenberg University (JGU) in Mainz in the context of the Project 8 experiment and at the Tritium Laboratory Karlsruhe (TLK) of the Karlsruhe Institute of Technology (KIT) in the context of the KATRIN++ program.

Currently, the focus of the JGU group is on developing and characterizing a high-flow atomic source using inactive hydrogen, whereas the focus of the TLK group is on operating a source with tritium for the first time. Subsequently, in a joint venture, these lines of research will be merged to create the Karlsruhe Mainz Atomic Tritium experiment (KAMATE).

The poster will present the current developments for atomic sources at JGU and KIT, and how we combine them into a joint effort to realize an atomic tritium source for future neutrino mass experiments.

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Real-scale R&D for XLZD

Authors: Andrew Stevens[1]; Jaron Grigat[1]; Julia Müller[1]; Marc Schumann[1]; Robin Glade-Beucke[1]; Sebastian Lindemann[2]; Tiffany Luce[1]

[1] *University of Freiburg*

[2] *Universitaet Freiburg*

The central TPC of the future XLZD observatory for rare events is a cylinder of approximately 3m linear scale that contains a total of 60t of cryogenic liquid xenon. Scaling the detector technology from the currently operational instruments XENONnT and LZ is challenging and requires full-scale R&D and later testing of detector components. The unique PANCAKE Facility in Freiburg allows testing flat components, such as TPC electrodes, at the relevant scale in cryogenic liquid or gaseous xenon environments. The poster presents the facility and the currently ongoing activities.

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Entering the next phase of UHE cosmic-ray studies with the Radio Detector of the Pierre Auger Observatory

Author: Max Büsken[1]

Co-author: Pierre Auger Collaboration

[1] *Karlsruhe Institute of Technology - ETP*

Ultra-high energy cosmic rays (CRs) are messengers that open a window to understanding the most extreme environments in the universe. In order to find out what the sources of these particles are, giant arrays of detectors on earth measure the signals from extensive air-showers that are created in the interaction of those CRs with the atmosphere. While the studies made with these detector arrays enter into a new phase of sensitivity, the now-matured radio detection technique is becoming a key player. At the Pierre Auger Observatory in Argentina, the deployment of the new Radio Detector (RD) is currently being finalized. When completed, it will consist of 1660 radio antennas, one installed on each of the Surface Detector stations of the Observatory, covering an area of 3000 km^2. The RD will detect air showers with inclinations above 60 degrees and provide a clean measurement of the electromagnetic shower component. In combination with measurements from the water-Cherenkov detectors, studies of the muon content of air-showers and of the CR mass composition will be possible with unprecedented sensitivity. Furthermore, the RD will be able to independently probe the absolute CR energy scale of the Pierre Auger Observatory. In this contribution, we present the current status and prospects of the Radio Detector.

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Electrode Design & Characterisation for the XLZD Observatory

Authors: Alexey Elykov[1]; Sebastian Vetter[2]; Vera Hiu-Sze Wu[2]

[1] *Karlsruhe Institute of Technology (KIT)*

[2] *Karlsruhe Institute for Technology*

The newly established XLZD (XENON, LZ, DARWIN) collaboration aims to construct and operate the ultimate multi-tonne xenon-based direct detection astroparticle observatory. Hosting a time projection chamber (TPC) with more than 60 tonnes of liquid xenon at its core, with a keV-range threshold and an ultra-low radioactive background it will aim to probe the entire parameter space for WIMP dark matter down to the so-called neutrino fog. The scientific research program also includes searches for solar axions, axion-like particles, as well as measurements of the solar neutrino flux and a probe of the Majorana nature of neutrinos. High-voltage electrodes, spanning three meters in diameter, will lie at the heart of the XLZD TPC, playing multiple key roles in signal generation and reconstruction; hence, their performance is of paramount importance. The electrodes need to be feasible to produce, mechanically robust, sufficiently transparent to light propagation and have minimal spurious electron and light emission from their surface. A large-scale R&D program at KIT aims to tackle these challenges. Here, we will present our recent work on the design, simulation, production, assembly and subsequent testing of high-voltage electrodes.

Summary:

Poster session leading into social dinner buffet / 90

Cosmic Ray Observations with the Square Kilometre Array

Author: Keito Watanabe[1]

Co-author: Tim Huege [2]

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Building on the successful cosmic ray observations with the LOw Frequency ARray (LOFAR) telescope, the low frequency part of the Square Kilometre Array (SKA), currently undergoing construction in Australia, will serve as a next-generation cosmic ray observatory in the coming decade. It is planned to have an extremely homogeneous and dense antenna layout of roughly 60,000 antennas in an area of 1 km2. With its wide frequency band of 50 - 350 MHz, SKA will be able to measure cosmic rays with energies of 10^{16} to 10^{18} eV with an expected energy resolution of better than 5%. Current simulations show that SKA will not only be able to reconstruct $X_{\max}$ within a resolution of < 10 g cm^{-2} but also reconstruct other composition-dependent shower variables that can resolve ambiguities of the cosmic-ray mass composition and the differences between hadronic interaction models. With the development of novel reconstruction frameworks that benefit from its unprecedented accuracy, SKA will further be capable of detecting substructures within the air shower and also possibly detecting PeV gamma ray-induced air showers.

Summary:

Poster session leading into social dinner buffet / 91

Liquid Argon Instrumentation for Background Suppression in the LEGEND-200 Experiment

Author: Rosanna Deckert[1]

[1] *Technical University of Munich*

LEGEND-200 is an experiment designed to search for neutrinoless double beta decay of Ge-76. Located deep underground at LNGS, it operates up to 200 kg of enriched high-purity germanium (HPGe) detectors in a liquid argon (LAr) cryostat. The HPGe detectors are surrounded by the LAr instrumentation, which detects scintillation light emitted upon interactions with ionizing radiation, thus tagging and rejecting backgrounds. The time profile of the LAr scintillation light emission is characteristic of different radiation types, enabling particle discrimination. This poster presents the background suppression performance of the LAr instrumentation in physics data taking and special calibration runs. We introduce the Event Topology Classifier utilized to discriminate between beta/gamma and alpha radiation with the LAr detector system. Lastly, we present a test statistic-based approach exploiting the time profile between LAr and HPGe signals, which enhances the existing energy-based LAr Anti-Coincidence condition and improves the background suppression of LEGEND-200.

This work is supported by the U.S. DOE and the NSF, the LANL, ORNL and LBNL LDRD programs; the European ERC and Horizon programs; the German DFG, BMBF, and MPG; the Italian INFN; the Polish NCN and MNiSW; the Czech MEYS; the Slovak SRDA; the Swiss SNF; the UK STFC; the Canadian NSERC and CFI; the LNGS, SNOLAB, and SURF facilities.

Summary:

Poster session leading into social dinner buffet / 92

Germanium Detector Design: Towards a Tonne-Scale Neutrinoless Double-Beta Decay Experiment

Author: David Hervas Aguilar[1]

[1] *TUM*

Neutrinoless double-beta decay (0νββ) poses an exciting way of probing the absolute neutrino mass and the Majorana nature of the neutrino. Regardless of the mechanism involved in its production, the observation of 0νββ implies new physics, exhibiting lepton number violation, and providing insight into the matter-antimatter asymmetry in the universe. Ge detector technology is extremely well suited for this challenge. The Large Enriched Experiment for Neutrinoless Double-beta Decay (LEGEND), is making use of this technology to search for 0νββ in Ge-76-enriched detectors in the first phase of its experimental program, LEGEND-200. The LEGEND collaboration is pushing Ge detector technology to new scales. Detectors up to four times more massive than those originally deployed in previous Ge-76 experiments are currently operated in LEGEND-200. Such large detectors –up to 4 kg –contribute to the isotopic mass of the experiment while retaining excellent energy resolution and background rejection capabilities. With advances in Ge crystal production, even larger detectors are envisioned, which would lead to lower backgrounds in the proposed 0νββ tonne-scale experiment, LEGEND-1000.

Summary:

Poster session leading into social dinner buffet / 93

ALMOND: An LNGS Mobile Neutron Detector

Author: Melih Solmaz[None]

Co-authors: Alfredo Ferella ; Felix Kratzmeier ; Francesco Pompa ; Kathrin Valerius ; Klaus Eitel

Environmental neutrons introduce a source of background to rare event searches, such as dark matter direct searches, neutrinoless double beta decay experiments and in cross section measurements for nuclear astrophysics, which take place in deep underground laboratories. Most of these neutrons are produced at the walls of the experimental hall by means of intrinsic radioactivity of the rock and concrete. The flux and spectrum of the ambient neutrons vary greatly with time and location. Precise knowledge of this background is necessary to instrument effective shielding and veto mechanisms, leading to an improvement in the sensitivity of the neutron-susceptible underground experiments. With this poster, we give an overview of the design of a mobile low-flux neutron spectrometer for the LNGS underground laboratory in Italy and present the construction and the initial calibration efforts as well as the outlook towards the deployment and commissioning at LNGS. This project is supported by the German Federal Ministry of Education and Research (BMBF) under the grant number 05A21VK1.

Summary:

Poster session leading into social dinner buffet / 94

Underground Nuclear Astrophysics

Author: Eliana Masha[1]

Co-authors: Anup Yadav [2]; Axel Boeltzig [1]; Daniel Bemmerer [1]; Kai Zuber [3]; Konrad Schmidt [1]; Peter Hempel [2]

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In the last three decades, underground accelerator laboratories have been essential for studying nuclear reactions at energies relevant to stellar environments, where cosmic-ray-induced background radiation would otherwise obscure the signals of interest.
Presently, there are only four such laboratories worldwide, two of them in Europe: The Felsenkeller shallow-underground laboratory in Dresden, Germany, with its 5\,MV accelerator \cite{Szucs19-EPJA} and the LUNA (Laboratory for Underground Nuclear Astrophysics) laboratory at Gran Sasso, Italy, with its 0.4\,MV and newly added 3.5\,MV accelerators \cite{Broggini18-PPNP}.

Felsenkeller, shielded by 45 meters of rock, hosts not only the accelerator but also Germany's lowest-background HPGe detector, called "TU1" \cite{Turkat23-APP}. The lab is uniquely positioned near the planned underground facility of the nascent Deutsches Zentrum für Astrophysik (DZA), which may provide a platform for interdisciplinary research in nuclear astrophysics and particle physics.

Both laboratories provide a combination of natural shielding along with advanced active and passive techniques to achieve high sensitivity for studying astrophysically significant processes, such as Big Bang nucleosynthesis, solar fusion \cite{Skowronski23-PRC}, and advanced capture reactions essential for heavy element formation. The poster will review recent progress at LUNA and Felsenkeller. Through the EU-supported ChETEC-INFRA EU project (2021-2025), both Felsenkeller and LUNA are freely accessible to all the scientific community, promoting international partnerships and advancing the field of nuclear astrophysics.

Summary:

Poster session leading into social dinner buffet / 95

Towards the LEGEND-1000 experiment: The search for Neutrinoless Double-Beta Decay in Ge at the tonne-scale

Author: Simon Sailer[1]

[1] *MPIK*

The Large Enriched Germanium Experiment for Neutrinoless ββ decay (LEGEND) searches for 0νββ in the 76Ge isotope.
A discovery would reveal the Majorana nature of neutrinos and prove lepton number non-conservation.
The proposed LEGEND-1000 phase consists of 1000 kg of enriched (>90%) Germanium detectors immersed in underground-sourced liquid argon, located at the underground facility LNGS in Italy.
For 10 years of the live-time the experiment aims to achieve a 3σ discovery sensitivity for the half-live of the 0νββ decay in Ge76 of at least 10^18 years.

Summary:

Poster session leading into social dinner buffet / 96

Implications from 3-dimensional modeling of gamma-ray signatures in the Galactic Center

Author: Julien Dörner[1]

Co-authors: Julia Tjus [2]; Paul Simon Blomenkamp ; Horst Fichtner ; Anna Franckowiak ; Memo Zaninger

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The Central Molecular Zone (CMZ) is one of the most extreme and close by astrophysical environments and of particular interest for studies of non-thermal processes. It is also one of the first known sources of cosmic-ray acceleration to PeV energies within our Galaxy. The emission of TeV gamma rays in the CMZ is affected by the source position and the distribution of the gas, photons and magnetic field within this region.

For the first time we model the TeV emission in a realistic three-dimensional distribution of gas and use a complex magnetic field comprising the large-scale field structure and small-scale imprints of molecular clouds as well as non-thermal filaments.
Additionally, we test different anisotropies of the diffusion tensor defined by the ratio of the diffusion coefficients perpendicular and parallel to the local magnetic field direction. For comparison we compute a two-dimensional gamma-ray distribution measurements and make predictions for CTA.

Summary:

Poster session leading into social dinner buffet / 97

Sensitivity studies for a next-generation neutrino-mass experiment using tritium β-decay

Authors: Svenja Heyns[None]; Neven Kovac[1]

[1] *Institute for Astroparticle Physics, Karlsruhe Institute of Technology*

The Karlsruhe Tritium Neutrino (KATRIN) experiment probes the absolute neutrino mass scale by precision spectroscopy of the tritium β-decay spectrum. With the data taken by the end of 2025, a final sensitivity better than 300 meV/c^2 (90\% C.L.) is anticipated by the collaboration with a total of 1000 days of measurement.

Taking the next steps in enhancing the sensitivity, for instance towards the regime of inverted mass ordering, requires a paradigm shift and novel technological approaches to significantly improve statistics, energy resolution, and background suppression. In this work, we explore two key strategies: (1) implementing a differential detector technique with sub-eV energy resolution (quantum sensor detector array, time-of-flight measurement) to resolve each electron's energy individually while covering the entire energy interval of interest simultaneously and (2) exploring a large-volume atomic tritium source. These modifications would allow for high statistics to be acquired more quickly and with ultra-high energy resolution. In this poster presentation, we introduce the conceptual framework for simulations to investigate the requirements by technology and limits by physics to confine the achievable sensitivity on the neutrino mass with a differential measurement.

Summary:

Poster session leading into social dinner buffet / 98

Magnetic microcalorimeters for future neutrino mass experiments and dark matter searches

Authors: Fabienne Adam[None]; Lena Hauswald[None]; Michael Müller[None]; Martin Neidig[1]; Friedrich Carl Wagner[None]; Mathias Wegner[None]; Sebastian Kempf[2]

[1] *IMS - KIT*

[2] *Institute of Micro- and Nanoelectronic Systems*

Magnetic microcalorimeters (MMCs) are cryogenic single-particle detectors that combine an outstanding energy resolution, a fast signal rise time, a wide energy bandwidth as well as an almost ideal linear detector response. For this reason, MMCs are highly suited for precision experiments or rare-event searches in astroparticle physics as well as neighboring physics fields.

In this contribution, we discuss our recent detector R&D efforts for two novel and very promising experiments, i.e. the Direct Search Experiment for Light Dark Matter (DELight) as well as the future neutrino-mass experiment KATRIN++. For the former, we will develop MMC-based athermal phonon detectors, while the latter will rely on thermal MMCs as used for high-resolution X-ray spectroscopy with great success. We will outline challenges related to both experiments and will conclude with a short discussion of our strategy to overcome these challenges.

Summary:

Poster session leading into social dinner buffet / 99

The background model of LEGEND-200

Author: Luigi Pertoldi[1]

[1] *Technical University of Munich*

The LEGEND-200 experiment at Laboratori Nazionali del Gran Sasso is searching for neutrinoless double beta decay using high-purity germanium (HPGe) detectors enriched in ^{76}Ge, immersed in a liquid argon cryostat instrumented to detect scintillation light. A background model has been developed based on Monte Carlo simulations and data from the first year of science runs –including special background characterization data and results from an ongoing radioassay campaign of the experimental components. This model is informing the planning of future hardware modifications to further reduce background levels. Additionally, a quantitative model of the liquid argon instrumentation data and HPGe pulse shape discrimination is in development, which will enable background characterization after all analysis cuts.

Summary:

Poster session leading into social dinner buffet / 100

Radio Detection of Cosmic Ray Air Showers with GRAND using an autonomous trigger

Author: Lukas Gülzow[1]

Co-authors: Jelena Köhler [2]; Markus Roth [3]; Tim Huege [2]

[1] *IAP*

[2] *KIT*

[3] *KIT, Germany*

Ultra-high energy (UHE) cosmic rays and neutrinos induce particle cascades in the atmosphere, called extensive air showers. The Giant Radio Array for Neutrino Detection (GRAND) is designed for measuring the radio emission of inclined air showers to cover a larger detection area. It will consist of multiple sub-arrays and a total area of 200 000 km² with one radio antenna per square kilometre.

At full capacity, GRAND will detect UHE neutrinos, gaining information on the sources they share with UHE cosmic rays. In contrast to existing arrays, GRAND will operate on radio events alone, hence efficient radio triggering techniques are in development.

*NUTRIG project, ANR-DFG Funding
Programme (490843803)*

Summary:

Poster session leading into social dinner buffet / 101

Tau Appearance with KM3NeT/ORCA6

Author: Nicole Geißelbrecht[1]

[1] *ECAP*

KM3NeT is a neutrino telescope currently under construction in the Mediterranean Sea. Its densely instrumented ORCA part is optimised for the detection of atmospheric neutrinos in order to study neutrino oscillations, measure the oscillation parameters, and eventually determine the neutrino mass ordering.
KM3NeT/ORCA is also sensitive to tau appearance, i.e. the observation of tau neutrinos produced through neutrino oscillations. Their detection allows us not only to measure the charged current tau neutrino cross section, but also to probe the unitarity of the PMNS matrix and to constrain its elements.
This contribution presents the first measurement of tau appearance with KM3NeT/ORCA6, an early detector configuration of about 5% of the final detector volume, corresponding to an exposure of 433 kton-years.

Summary:

Poster session leading into social dinner buffet / 102

A New Approach to Neutrino Detection and the Search for the Neutrinoless Double Beta Decay: Slow Scintillation Media and Hybrid Cherenkov/Scintillation Techniques

Authors: Hans Steiger[1]; Manuel Böhles[2]; Meishu Lu[1]

Co-authors: Alberto Garfagnini [3]; Franz von Feilitzsch [1]; Lothar Oberauer [1]; Michael Wurm [2]; Raphael Stock [1]; Ronja Huber [1]; Ulrike Fahrendholz [1]

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One of the most promising approaches for the next generation of neutrino experiments is the development of large hybrid Cherenkov/scintillation detectors, made possible by recent advancements in photodetection technology and liquid scintillator chemistry. This poster discusses the development of a potential future detector liquid with notably slow light emission. The properties of this cocktail—such as scintillation efficiency, transparency, and light emission time profile—are compared to those of liquid scintillators currently used in large-scale neutrino detectors. Additionally, we present the optimization of wavelength shifter admixtures for a scintillator with particularly high light emission.

Furthermore, we studied the pulse-shape discrimination capabilities of the novel medium using a pulsed particle accelerator-driven neutron source. Moreover, purification methods based on column chromatography and fractional vacuum distillation for the co-solvent DIN (Diisopropylnaphthalene) are discussed. The scintillation cocktails were also successfully loaded with Te-diols, resulting in a potentially suitable medium for the effective search for the neutrinoless double-beta decay of Te-130. Separately, a setup called the Munich Scintillation Cherenkov Separator (MSCS) was realized, commissioned, and tested. This setup achieved the separation of Cherenkov and scintillation light in both slow scintillation media and conventional fast organic liquid scintillators. All these new developments will be introduced, discussed, and summarized in this poster.

Summary:

Poster session leading into social dinner buffet / 103

Taking up open science for astroparticle physics in KM3NeT

Author: Jutta Schnabel[1]

Co-authors: Kay Graf [2]; Rodrigo Gracia [3]; Tamas Gal [4]; Thomas Eberl [5]

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The movement of open science has gained momentum in recent years, demanding a cultural change in science towards sharing of research data, software and processes, with open science policies requested for most major project. The KM3NeT collaboration has responded to this demand not only by endorsing a policy, but is actively developing its computing infrastructure and processes towards the goal of collaborative research. In this contribution, the current implementation, collaborations and opportunities for open science will be presented.

Summary:

Poster session leading into social dinner buffet / 104

Large Language Models: New Opportunities for Access to Science

Author: Jutta Schnabel[1]

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Corresponding Author: jutta.schnabel@fau.de

The adaptation of large-language models (LLMs) like ChatGPT for information retrieval from scientific data, software and publications is offering new opportunities to simplify access to and understanding of science for persons from all levels of expertise. They can become tools to both enhance the usability of the open science environment we are building as well as help to provide systematic insight to a long-built corpus of scientific publications.
In this contribution, the uptake of Retrieval Augmented Generation (RAG)-enhanced chat applications in the construction of the open science environment of the KM3NeT neutrino detectors will be

used as a focus point to explore and exemplify prospects for the wider application of LLMs for our science.

Summary:

Poster session leading into social dinner buffet / 105

New Gas Target Setup for Nuclear Astrophysics Experiments at the Felsenkeller Underground Laboratory

Author: Anup Yadav[1]

Co-authors: Daniel Bemmerer [2]; Konrad Schmidt [2]

[1] *Helmholtz-Zentrum Dresden-Rossendorf (HZDR)*

[2] *Helmholtz-Zentrum Dresden-Rossendorf*

Precise cross-section measurements in nuclear astrophysics demand targets with high thickness, purity, and stability. Traditional methods often struggle to achieve these requirements simultaneously. To address this challenge, we present a newly developed jet and extended windowless gas target system. Furthermore, the gas target is free of chemical contaminations.
We have developed a gas target that combines both jet and windowless extended gas targets, capable of operating in either mode with minimal adjustments. This setup has been thoroughly characterized at the HZDR center in Rossendorf and is currently undergoing recommissioning at the Felsenkeller underground lab. To enhance real-time monitoring of the gas jet, we employed advanced interferometry techniques.
Characterization of the jet target included absolute thickness determination using alpha energy loss methods and relative measurements via laser interferometry. Together, these approaches provide a comprehensive understanding and precise control of the target's properties.
With the jet gas target, we achieved a thickness of 10^18 atoms/cm² at moderate inlet pressure, which is ideal for a wide range of nuclear reactions. Upon completion of the recommissioning process, the system will be fully operational, facilitating new opportunities for nuclear astrophysics research.
The author will report the detailed insights into this innovative gas target system's development, characterization, and operational capabilities, highlighting its potential to improve precision in cross-section measurements for nuclear astrophysics.

Summary:

Poster session leading into social dinner buffet / 106

KATRIN with TRISTAN detectors

Authors: Anthony Onillon[1]; Dominic Hinz[2]; Markus Steidl[3]; Martin Descher[None]; Susanne Mertens[1]

[1] *TU Munich*

[2] *KIT*

[3] *Karlsruhe Institute of Technology*

The Karlsruhe Tritium Neutrino (KATRIN) experiment was designed to measure the absolute neutrino mass scale based on a high-precision measurement of the tritium β-decay spectrum, close to its endpoint. Its unprecedented tritium source luminosity and spectroscopic quality makes it a unique instrument to also search for physics beyond the Standard Model (BSM). Most notably, a keV-scale sterile neutrino would manifest with a characteristic signature several keV away from the endpoint. This poster summarizes the physics potential of such a search, the technical challenges to optimize the beamline for it and the status of the advanced preparations to start in 2026.

Summary:

Poster session leading into social dinner buffet / 107

PUNCH4NFDI's Contributions to Collaborative Physics Research

Author: Victoria Tokareva[1]

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The German National Research Data Infrastructure (NFDI) fosters FAIR data management and the sharing of digital research objects across diverse scientific fields. PUNCH4NFDI brings together Germany's astroparticle, particle, astrophysics, hadron, and nuclear physics communities to collaborate on the development and utilization of hardware and software infrastructures that facilitate the sharing of digital research objects and interdisciplinary data analysis within a unified digital ecosystem. Recent milestones achieved by the consortium include significant advances in data management, such as the prototyping of federated Compute4PUNCH and Storage4PUNCH services; the development of an overarching metadata schema and tools; adoption and use of software for reproducible analysis and workflow management for diverse use cases; progress in conceptualizing digital research products and ensuring data irreversibility; and the dissemination of knowledge through outreach and educational initiatives. PUNCH4NFDI's efforts are well integrated into NFDI's broader mission, as well as European and international initiatives.
Initially approved for five years of substantial funding, PUNCH4NFDI has submitted its midterm progress report to the DFG and is scheduled for evaluation in February 2025. The consortium is preparing to submit its PUNCH4NFDI-2.0 proposal in the summer of 2025. This poster outlines the consortium's structure, recent achievements, and its contributions to the collaborative efforts of the astroparticle physics community.

Summary:

Poster session leading into social dinner buffet / 108

Experimental characterization of an atomic hydrogen source

Author: Leonard Hasselmann[1]

Co-authors: Beate Bornschein [2]; Caroline Rodenbeck [3]; Daniel Kurz ; Florian Priester [4]; Magnus Schlösser [5]; Marco Roellig [6]; Michael Sturm ; Robin Größle [4]

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The absolute value of the mass of the neutrino remains an unsolved puzzle of particle physics. One way to measure the neutrino mass is spectroscopy of electrons from the tritium beta decay. The current best limit on the effective anti-electron neutrino mass of $m_\nu < 0.45\,\mathrm{eV\,c^{-2}}$ $(90\,\%\,\mathrm{C.L.})$ was published by the KATRIN collaboration in 2024. KATRIN measures the beta-decay electron spectrum from molecular tritium. The sensitivity of molecular tritium experiments is limited by the broadening due to the molecular excitation states. One approach to overcome this molecular barrier

is to use atomic tritium sources for future experiments.
We are currently commissioning and assembling an experimental setup (called BeATE) to characterize a commercially available hydrogen cracking system (Tectra H-flux). For this, we are testing and optimizing the performance of the system and source with protium and deuterium using different skimmers to trim the beam and reduce molecular background due to recombination at wall contacts. A Hiden DLS-10 quadrupole mass spectrometer (QMS) with a cross-beam ionizer is used as beam diagnostic tool. After first experiments with inactive hydrogen, this setup will be used to demonstrate the production of atomic tritium.
In this poster, we show the current status of the characterization and development of BeATE. Furthermore, the design and implementation of a loop for the tritium supply of the setup is presented.

Summary:

Poster session leading into social dinner buffet / 109

Deployment of Water-based Liquid Scintillator in ANNIE

Author: Johann Martyn[1]

[1] *Johannes Gutenberg-Universtät Mainz*

The Accelerator Neutrino-Neutron Interaction Experiment (ANNIE) is a 26-ton water Cherenkov neutrino detector on the Booster Neutrino Beam (BNB) at Fermilab. Among its primary physics goals is the measurement of the final-state neutron multiplicity of neutrino interactions, as well as the measurement of the charged current cross section of muon-neutrinos.
Another main goal of ANNIE is the investigation and development of new detector technologies, such as Water-based Liquid Scintillator (WbLS). WbLS is a novel detector medium which aims to provide a hybrid neutrino detection signal, combining the advantages of both Cherenkov and scintillator detectors. This poster summarizes the recent, first deployment of a 366l WbLS target vessel inside ANNIE, as well as an outlook on the currently ongoing second deployment of the same vessel.

Summary:

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AugerPrime: Status and first results

Authors: David Schmidt[1]; for the Pierre Auger Collaboration[None]

[1] *Karlsruhe Institute of Technology*

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With the knowledge and statistical power derived from two decades of measurements, the Pierre Auger Observatory has significantly advanced our understanding of ultra-high-energy cosmic rays whilst unearthing an increasingly complex astrophysical scenario and tensions with hadronic interaction models. The field now demands primary mass as an observable with an exposure that only the surface array of the Observatory can provide. Access to the primary mass hinges on the disentanglement of the electromagnetic and muonic components of extensive air showers. To this end, a scintillator and radio detector have been installed atop each existing water-Cherenkov detector of the surface array, whose dynamic range has also been enhanced through the installation of small area PMTs. The timing and signal resolution of all detector stations have additionally been improved with upgraded station electronics, and underground muon counters have been installed in a region of the array with denser spacing. As the commissioning of the final components of AugerPrime

reaches its conclusion and the enhanced array comes fully online, we present on the design, status, and first results of this now multi-hybrid detector.

Summary:

Poster session leading into social dinner buffet / 111

Low-background radioactivity counting with the most sensitive HPGe detector in Germany

Author: Marie Pichotta[1]

Co-author: Bjoern Lehnert [1]

[1] *TU-Dresden*

This poster presents an ultra low-level ⊠-ray counting setup in the shallow-underground laboratory Felsenkeller in Dresden, Germany. It includes a high-purity germanium detector of 163% relative efficiency within passive and active shields. The passive shield consists of 45 m rock overburden (140 meters water equivalent), 40 cm of low-activity concrete, 15 cm of high purity lead, 10 cm of oxygen-free radiopure copper, and an anti-radon box. The active veto is realized by five large plastic scintillation panels surrounding the setup. All together, these shieldings attenuate the remaining background rate down to 116(1) cts/kg/d in an energy interval of 40-2700 keV. This is the lowest background of any HPGe detector in Germany, among the lowest worldwide, and enables studies of samples well below 1 mBq. In addition to the design of the setup, the underlying analysis techniques will be presented.

Summary:

Poster session leading into social dinner buffet / 112

KATRIN++ - Development of New Detector Technologies for Future Neutrino Mass Experiments with Tritium

Authors: Andreas Kopmann[1]; Beate Bornschein[2]; Fabienne Adam[None]; Ferenc Glück[3]; Frank Simon[4]; Kathrin Valerius[5]; Magnus Schlösser[6]; Marie Christine Langer[7]; Markus Steidl[5]; Michael Müller[None]; Neven Kovac[8]; Rudolf Sack[9]; Sebastian Kempf[10]; Svenja Heyns[None]; Woosik Gil[11]

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Currently, the tightest constraints on the absolute scale of neutrino mass are obtained by the KATRIN (KArlsruhe TRItium Neutrino) experiment, giving an upper limit on the mass of electron antineutrino of 0.45 eV (https://doi.org/10.48550/arXiv.2406.13516). Final projected sensitivity of the KATRIN experiment will be in the vicinity of 0.3 eV, and should be reached at the end of 2025.
Going beyond this limit, and eventually fully excluding inverted mass ordering, will be the task for future neutrino mass experiments. In this regard, development of new detector technologies is of utmost importance, with quantum sensor arrays currently being the front runners due to their exceptional performance and excelent energy resolution.
We report on our R&D efforts aiming to demonstrate the feasibility of developing and operating large quantum sensor array for detection of external electrons in a KATRIN-like setup, as a basis for the next generation neutrino mass experiments with tritium. We present the results of our first measurement campaigns with ^{83m}Kr, serving as a proof of principal measurements for ultra-high resolution electron spectroscopy with metallic microcalorimeters, and discuss our strategy for the future.

Summary:

Poster session leading into social dinner buffet / 113

MOTION, a liquid xenon time projection chamber platform for high voltage development in dark matter detectors

Author: Yanina Biondi[1]

[1] *UZH*

MOTION is a time projection chamber with 80 kg of liquid xenon (LXe), serving as a testing platform for high-voltage (HV) delivery of around -200 kV and stability in LXe for next-generation dark matter detectors. The objective of this detector is to study the breakdown voltage of liquid xenon, which might depend on different factors such as surface area of the conductor and the purity of the liquid xenon, among others. The detector also serves as a platform to study spurious electron emission from electrodes, as well as the development of high voltage feedthroughs made out exclusively of radiopure materials.

Summary:

Strategy paper / 114

Intro: overarching topics for the strategy paper

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Currently in the outline of the strategy book:

5.1 An Environment for Educating Excellent Young Scientists
5.2 Knowledge and Technology Creation and Transfer
5.3 Cooperation with Technology Enterprises and Industry
5.4 International Dimension
5.5 Research Data as a Cultural Heritage

5.6 Sustainability
5.7 Gender, Diversity, Inclusion
5.8 Outreach
5.9 Strengthening Science in Remote Regions

and
4.6 Computing

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Computing and data

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Education and outreach

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Knowledge transfer and industry cooperations

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Diversity and inclusion

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Further overarching topics relevant for the strategy paper

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- Educating excellent young scientists
- Knowledge and technology transfer, cooperation with industry
- International dimension
- Sustainability
- Diversity and inclusion

Poster session leading into social dinner buffet / 120

The TRISTAN detector upgrade for the keV sterile neutrino search with KATRIN

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The KATRIN experiment's search for keV sterile neutrinos requires an upgraded detector system to perform precision electron spectroscopy at high count rates. The detector upgrade, the TRISTAN detector, is composed of 166-pixel silicon drift detector modules. Production and characterization of the first TRISTAN modules is summarized, and a detector energy resolution of $< 300\,\mathrm{eV}$ (FWHM) for $20\,\mathrm{keV}$ electrons at rates of 10^5 counts per second is shown. Integration of the TRISTAN detectors into the KATRIN beamline are projected to provide sensitivity to sterile-to-active mixing of keV sterile neutrinos at the level of $\sin^2(\theta) \approx 10^{-6}$.

Application of the same detector technology in the search for axions, as the detector system for IAXO, and for measurement of the polarization of hard X-rays from Cygnus X-1, as part of the ComPol project, are also presented.

Summary: