ISOLDE Workshop and Users meeting 2021

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Book of Abstracts

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Microscopic shell-model calculations with realistic effective interactions

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We present a short overview of the realistic shell-model, in which the effective Hamiltonian is derived microscopically from free nuclear potentials within many-body perturbation theory. In particular, we give a sketch of our theoretical approach, namely the $\hat{Q}$ box-plus-folded diagram method, to determine the one- and two-body matrix elements of the effective interaction and show how three-body contributions, which account for Pauli principle violations in nuclei with more than two valence particles, can be included. A procedure to derive effective decay or transition operators within the same framework as the Hamiltonian is also outlined.
Some selected results are presented by discussing energy spectra as well as electromagnetic and beta decay properties. First, we focus on neutron-rich nuclei around ^{132}Sn, which have been investigated by using as input the CD-Bonn nucleon-nucleon potential renormalized by the $V_{\mathrm{low-k}}$ approach. Then, we report on a study of Ca and Ti isotopic chains north-east of ^{48}Ca. In this study, calculations are carried out starting from a chiral potential with two- and three-body forces, with the aim to investigated the effects of genuine and effective chiral three-body forces on the monopole component of the shell-model effective Hamiltonian.

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Enhanced symmetry energy behind the universality of heavy-element abundances

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The abundance of about half of the stable nuclei heavier than iron via the rapid neutron capture process or r-process is intimately related to the competition between neutron capture and β-decay rates,

which ultimately depends on the binding energy of neutron-rich nuclei. The well-known Bethe-Weizs\"acker semi-empirical mass formula [1,2] describes the binding energy of ground states – i.e. nuclei with temperatures of $T \approx 0$ MeV – with the symmetry energy parameter converging between $23 - 27$ MeV for heavy nuclei. Here we find an unexpected enhancement of the symmetry energy at higher temperatures, $T \approx 0.7 - 1.0$ MeV, from the available data of giant dipole resonances built on excited states. Although these are likely the temperatures where seed elements are created during the cooling down of the ejecta following neutron-star mergers [3] or collapsars\cite{collapsar}, the fact that the symmetry energy remains constant between $T \approx 0.7 - 1.0$ MeV, suggests a similar trend down to $T \approx 0.5$ MeV, where neutron-capture may start occurring. Calculations using this relatively larger symmetry energy yield a reduction of the binding energy per nucleon for heavy neutron-rich nuclei and inhibits radiative neutron-capture rates. This results in a substantial close in of the neutron dripline, which elucidates the long sought universality of heavy-element abundances through the r-process, as inferred from the similar abundances found in extremely metal-poor stars and the Sun.

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Total absorption spectroscopy of 64Ge and 64Ga for their importance in stellar decay rates

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Nucleosynthesis in Type I X-ray bursts (XRB) proceeds eventually through the rp-process near the proton drip-line. Several N=Z nuclei act as waiting points in the reaction network chain. Astrophysical calculations of XRB light curves depend upon the theoretical modelling of the beta decays of interest, with 68Ge being a key nucleus in this context. Several such theoretical calculations have shown that, in these high-density and high-temperature scenarios, continuum electron capture and decay rates from excited states play an important role, in particular for nuclear species at and around the waiting-point nuclei.

In this talk I will report on the status of the analysis of experiment IS570, aimed at the study of the beta decay of the waiting point nucleus ^{64}Ge and its N=Z+2 second-neighbour ^{66}Ge, with the main goal of determining the B(GT) distribution for these decays with the Total Absorption gamma-ray Spectrometer Lucrecia at ISOLDE. More in detail, in this talk the status on the analysis for the isotope ^{64}Ge and ^{64}Ga will be presented, particularly the procedure to clean the main decay spectrum of the pile up, background and daughter contribution. The procedure to calculate the response function of Lucrecia to the decay of ^{64}Ga, as well as preliminary results for this decay will be shown.

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Investigating the key *rp*-process reaction ^{61}Ga(*p*,γ)^{62}Ge reaction via ^{61}Zn(*d*,*p*)^{62}Zn transfer

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Type-I X-ray bursts are interpreted as thermonuclear explosions in the atmospheres of accreting neutron stars in close binary systems \cite{Schatz1}.
During these bursts, sufficiently high temperatures are achieved ($T_{peak} \sim$ 0.8–1.5 GK) such that "breakout" from the hot CNO cycle occurs. This results in a whole new set of thermonuclear reactions known as the *rp*-process \cite{Schatz2}. This process involves a series of rapid proton captures resulting in the synthesis of very proton-rich nuclei up to the Sn–Te mass region.

Recent studies \cite{Cybert, Meisel} have highlighted the ^{61}Ga(p,γ)^{62}Ge reaction as significant in its effect on nucleosynthesis along the *rp*-process path within X-ray bursts, as well as on resultant light curves and final isotopic compositions.
Despite this, the stellar reaction rate at X-ray burst temperature range is effectively unknown.
Like many reactions that occur in explosive astrophysical environments, the ^{61}Ga(p,γ) reaction is expected to be dominated by resonant capture to excited states above the proton-emission threshold in ^{62}Ge.

Studying systems far from stability such as this can prove extremely challenging and, in fact, in many cases impossible at this present time.
Recent investigations of mirror nuclei \cite{Margerin, Pain, Lotay} however have been shown to offer a unique solution to this issue.
The properties of excited states in pairs of mirror nuclei are almost identical, such that spectroscopic information of the neutron-rich system can be used to accurately determine the rates of astrophysical processes within the proton-rich system that cannot be accessed experimentally \cite{Margerin, Pain, Lotay}.

The ISOL Solenoidal Spectrometer at the ISOLDE facility has been used recently to study (d,p) transfer reactions in inverse kinematics \cite{Tang, MacGregor}. In this experiment, we aim to use similar techniques to perform the ^{61}Zn(d,p)^{62}Zn transfer reaction for the first time.
Analysis of excited states in the astrophysically important mirror nucleus ^{62}Zn will then place the first ever constraints on the astrophysical ^{61}Ga(p,γ)^{62}Ge reaction rate in X-ray burst environments, thereby allowing a detailed comparison between the latest theoretical models and astronomical observations.

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Ab initio predictions of atomic nuclei

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Atomic nuclei are strongly-interacting quantum many-nucleon systems whose wave function is governed by the Schrödinger equation. In the early 1990s, Steven Weinberg formulated the (chiral) effective field theory (EFT) method. It promises a way to derive an interaction potential for nucleons that manifestly obeys the symmetries of QCD. However, devising a potential using the tools of EFT is just the beginning of the next problem: to actually solve the many-nucleon Schrödinger equation. Ab initio methods, employed with EFT, approximate exact solutions of the Schrödinger equation and offer a handle on the theoretical uncertainty of the prediction. Reliable theoretical errors make it possible to infer the significance of a disagreement between experiment and theory. I will present recent progress in ab initio predictions of nuclear properties and attempts at quantifying theoretical errors.

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Coulomb excitation of 66Ge

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The Coulomb excitation of ^{66}Ge has been performed for the first time using "safe" bombarding energies at the HIE-ISOLDE facility at CERN. Motivation to study ^{66}Ge arises from the anomalous rotational behaviour of the high-lying first 2_1^+ state observed in even-even isotopes in the $A \sim 70$ region [1]. Low-lying 0^+ excited states have been determined for even-even neutron-deficient Se[2] and Kr[3] isotopes, which are signatures of shape coexistence [4]. In particular, the Germanium and Selenium isotopes have received a considerable amount of interest because they lie between the doubly magic ^{58}Ni and the strongly deformed neutron-deficient ^{76}Sr isotopes. This region has shown a complicated interplay between non-collective and collective degrees of freedom due to large sub-shell gaps at both prolate and oblate deformation for proton and neutron numbers $N, Z = 34, 36$ [4,5]. In addition, macroscopic-microscopic models suggest gamma-softness for ^{64}Ge through oblate-prolate shape coexistence in ^{68}Se and ^{72}Kr to some of the most deformed nuclei at ^{76}Sr and ^{80}Zr.

A particle-γ coincidence experiment using the MINIBALL array and double-sided silicon detectors has allowed the determination of transitional and diagonal matrix elements in ^{66}Ge, yielding new measurements of the reduced transition probability connecting the ground and the 2_1^+ states, or $B(E2; 0_1^+ \rightarrow 2_1^+)$ value, and the spectroscopic quadrupole moment of the 2_1^+ state, $Q_S(2_1^+)$. A relatively large $B(E2) = 29.4(30)$~W.u. has been extracted using beam-gated data at forward angles – less sensitive to second-order effects – as compared with the adopted value of 16.9(7) W.u., but in closer agreement with modern large-scale shell-model calculations using a variety of effective interactions and beyond-mean field calculations. A spectroscopic quadrupole moment of

$Q_S(2_1^+) = +0.41(12)$ eb has been determined using the reorientation effect from the target-gated data at projectile backward angles – more sensitive to the reorientation effect. Such an oblate shape is in agreement with the corresponding collective wavefunction calculated in the present work using beyond mean-field calculations and its magnitude agrees with the rotational model, assuming $B(E2) = 29.4(30)$ W.u.

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Recent results of collinear laser spectroscopy of magic lead isotopes

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High-resolution collinear laser spectroscopy has been recently performed on a long sequence of lead (Z = 82) isotopes using the COLLAPS instrumentation at ISOLDE/ CERN. Hyperfine structures and isotope shifts have been measured and high-precision values of electromagnetic moments and isomeric differences in charge radii between the lowest 3/2, 5/2 and 13/2 states in 187-208Pb are extracted. The experimental trends will be compared to state-of-the-art calculations and discussed in the framework of nuclear structure.

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Precision spectroscopy of RaF molecules for fundamental physics

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Molecular spectroscopy represents a unique tool in the search for physics beyond the Standard Model and exploration of the fundamental forces of nature. Compared to atoms, molecules can offer up to eleven orders of magnitude enhanced sensitivity to violations of fundamental symmetries, testing energy scales up to hundreds of TeV. These effects are further enhanced in radioactive molecules, which are particularly sensitive to nuclear parity violating (P-odd) and time-reversal violating (T-odd) effects. A promising candidate for this kind of studies is radium monofluoride (RaF). Containing octupole-deformed nuclei, this molecule is expected to show a high sensitivity for the electron interaction with the P-odd nuclear anapole moment as well as with the P- and T-odd nuclear Schiff and magnetic quadrupole moments. In addition, being laser coolable, RaF is suitable for high-precision studies. In this talk I will present the latest results obtained from a series of laser spectroscopy experiments performed on short-lived RaF isotopologues, at ISOLDE facility at CERN. I will first describe a measurement of the isotope shift of five RaF isotopologues, $^{223-226,228}$RaF. This shows the particularly high sensitivity of radium monofluoride to nuclear size effects, offering a stringent test of models describing the electronic density within the radium nucleus. I will then show preliminary results from a high-resolution laser spectroscopy of ^{223}RaF and ^{226}RaF. Rotational and hyperfine constants of these two isotopologues will be presented, together with a possible laser-cooling scheme for ^{226}RaF. These results represent the first of their kind performed on radioactive, short-lived molecules, opening the way for precision studies and new physics searches in these systems.

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The 186Hg ground state deformation puzzle

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The structure of neutron-deficient Hg isotopes has attracted considerable attention since the 70-s. They present a particular staggering in the mean square nuclear radii, which is unique in the nuclear chart [1]. This phenomenon was interpreted as a change in the ground state structure and consequently on the ground state shape around A=186 [2]. A recent work at ISOLDE has extended the study of the mean square radii in Hg nuclei down to 179Hg and confirmed earlier results for A < 185 [3]. We have recently studied the beta decay of 186Hg using the total absorption technique with the idea of inferring the shape of the ground state of 186Hg from the distribution of the beta strength in the daughter, a method that has been applied earlier for nuclei in the A=80 and A=190 regions (see for example [4,5]). The analysis of total absorption data from this particular case required the development of a new analysis technique because of the existence of highly converted gamma transitions in the 186Au daughter nucleus [6]. The comparison of the results of our measurements with QRPA theoretical calculations shows a quite different picture than expected: 186Hg seems rather mixed in its ground state, with a dominantly prolate component [6]. In this presentation these results will be presented and future perspectives will be discussed.

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The search for "missing links" of nuclear quadrupole moments – a status report

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There are basically two ways to determine precision values for nuclear quadrupole moments (Q): Measurements for stable or reasonably long-lived (mostly ground) states by atomic and molecular spectroscopy and measurements for much shorter-lived excited states using nuclear condensed matter techniques like Moessbauer (MS) or perturbed angular distribution (PAD) (and correlation, PAC) spectroscopy. In all cases the direct experimental result is the product of the electric field gradient (efg) at the nuclear site with Q. The efg for atomic and simple molecular systems can now mostly be calculated by theory with good accuracy, while the present status of density functional calculations of solid-state systems used for short-lived excited states limits the accuracy to the 10 to 20% level. In project IS640 we have overcome this problem by measuring isolated Cd and Hg molecules with PAC. Similar experiments for Pb are planned in IS708, and related ones for In in IS673. A short summary of the still missing relations between the results of Q for short-lived relative to long-lived states for critical elements will be presented.

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2021 at the CRIS experiment

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2021 proved to be another fruitful year for the Collinear Resonance Ionization Spectroscopy (CRIS) collaboration with experimental campaigns on neutron-rich silver isotopes [1] and radium monofluoride molecules [2]. By performing high-resolution resonance ionization spectroscopy on radioactive species in a collinear geometry, the technique is able to exceed the sensitivity offered by traditional fluorescence-detected spectroscopy. The measured hyperfine structures and isotopes shifts give access to electromagnetic properties of nuclear ground and isomeric states allowing predictions from state-of-the-art atomic and nuclear theory to be tested.

Recent highlights from the collaboration include characterizing the nature of the N=32 neutron subshell gap in neutron-rich potassium [3], the evolution of nuclear ground-state properties towards ^{100}Sn [4,5] and challenging the decades-old interpretation of 'texbook'single-particle behaviour in even-N indium isotopes [6]. The technique was also recently used to study the structure of radium monofluoride molecules [7], confirming predictions that it can be directly laser cooled. In addition,

the vibronic structure of these molecules was shown to be highly sensitive to changes in the radium nuclear charge radii [8].

This contribution will discuss recent results and developments as well as outline future plans.

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ISOLDE Target and Ion Sources: Production and Development

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ISOLDE target and ion source units are among the key components in the process chain towards the delivery of radioactive ion beams for nuclear physics experiments. Targets are manufactured on demand, following the physics schedule and beam request. Over the past 50 years more than 1000 isotopes have been produced from over 74 elements, but users constantly seek to study new, often more exotic and complex nuclear systems. It that regard, challenges typically arise from low production yields, short half-lives (ms range) and/or the refractory nature of the respective element. It is thus not surprising that target material development is of great importance next to the annual target production. In this contribution, we will give a summary of the 2021 target production figures, supplemented with some highlights of the delivered beams. In addition, an overview over current target material-related research and developments as well as their respective infrastructural requirements (laboratories and equipment) will be given.

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Beam developments for actinides at ISOLDE

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The demand for new beams at the ISOLDE facility is constantly growing. For refractory elements such as the actinides, experiments face challenging or unknown yield and beam purity. More beam composition information in the actinide region is needed, and further target and ion source developments may be required. Forming volatile molecules has been explored as an avenue to improving the surface desorption process of refractory elements, potentially allowing them to be extracted and delivered as ion beams [1][2]. Volatilization has been successfully shown for carbon [3] and boron [4]. Molecular extraction additionally shifts the mass of interest, changing the isobaric contamination situation. Here we present preliminary results of beam developments for extraction of actinide elements at ISOLDE from thick uranium carbide (UCx) targets with surface ion sources. Two-step resonant ionization laser schemes were used to study laser-ionized atomic actinide beams of the light actinides Ac, Pa, U, Np, and Pu. Beam composition was studied with the ISOLTRAP Multi-Reflection Time-of-Flight Mass Spectrometer (MR-ToF MS) [5], giving identification by ToF mass measurements. CF4 gas was used as a candidate for molecular sideband extraction of the actinide elements via injection of reactive gases and formation of volatile molecules.
Atomic beams of Ac, U, Np and Pu were identified by laser resonance or ToF. Atomic laser-ionized Pa was not observed, and Th was not attempted. Several surface-ionizable actinide fluoride molecules were stable enough to survive the high-temperature surface ion source and were identified with ToF mass measurements at the ISOLTRAP MR-ToF MS. These studies give information on some actinide molecules with low ionization potentials and identify some of the surface-ionized background and challenges involved for experiments interested in these beams. The results serve to facilitate delivery of actinide and actinide molecular beams at ISOLDE.

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Commissioning results for the new electron gun for REXEBIS

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The electron gun of the REXEBIS charge breeder at the REX/HIE-ISOLDE post accelerator has been upgraded from a standard magneto-immersed type to a gun using a non-adiabatic magnetic element. The results from the commissioning of the new design are here presented, emphasizing aspects of interest for the users of the radioactive beams. In particular, the charge breeding efficiency have been studied, and optimal breeding times for a broad range of elements and charge states are given for different electron currents. In addition, complete mass-scans of the extracted beam have been performed from which the level of cathode-originating contaminations could be established. We also briefly discuss the cathode reliability and a possible mitigation strategy for the limited electron emission that was encountered with the new IrCe-type cathode.

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The upgraded ASPIC and ASCII setup: expanding experimental capabilities for solid-state physics at ISOLDE

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During the 1980's and 90's, the Apparatus for Surface Physics and Interfaces at CERN (ASPIC) was instrumental to many Perturbed Angular Correlation (PAC) spectroscopy studies at ISOLDE [1]. The setup was dedicated to surface modification and characterization, coupled with precise control of the position of PAC probes, enabling investigations into the position of adatoms on film surfaces or the magnetic influence of ferromagnetic films on the substrate, amongst other things. However, despite efforts to prevent it, the ASPIC has become inactive in the last decade. Since 2019, the setup has been moved to Göttingen, Germany, where it is currently being refurbished.

In this talk, we present the upgraded ASPIC setup, its capabilities, and present its brand-new companion chamber: the ASPIC's ion implantation chamber (ASCII). This chamber allows deceleration of the 30 −60 keV radioactive isotope beams, down to 10 −50 eV. Use of ultra-low energy implantation in lieu of the old annealing-based catcher system will result in a faster, easier and more efficient control of probe incorporation into the samples. Upon installation in the ISOLDE experimental hall, the two linked chambers will significantly increase the possibilities of conducting solid-state physics experiments, including (but not limited to) PAC and Mössbauer studies on 2D and multiferroic materials [2,3].

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Technical developments / 53

Status for the PUMA experiment at CERN

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The main goal of the PUMA (antiProton Unstable Matter Annihilation) experiment is to use antiprotons as a tool to investigate properties of exotic nuclei. For this, antiprotons produced at the AD/CERN and decelerated by the ELENA storage ring will be captured, cooled and transported to the ISODLE facility where the antiprotons will be mixed with short lived isotopes. During this process, an antiproton can be captured by the nucleus and will subsequently annihilate with a neutron or a proton at the surface of the nucleus itself. The fingerprint of this annihilation will be measured using a time-projection-chamber. With this knowledge of the ratio of protons to neutrons on the outermost part of the nuclei distribution, phenomena like a neutron or a proton halo or neutron or proton skins can be investigated.
This contribution will give an overview of the PUMA experiment, present its status and highlight some of the main physics goals.

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Oxidation kinetics studies for the treatment and disposal of current and future UCx target materials

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Oxidation kinetics studies for the treatment and disposal of current and future UCx target materials

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Uranium carbide-carbon composite (UCx) is the most used target material at ISOLDE (> 65% of the beam time). About 12 UCx targets are produced annually and operated at temperatures up to 2300℃ to promote isotope release. Under these conditions, microstructures are degraded (i.e. loss of porosity, increase of grain size) due to sintering, which results in a loss of radioisotope beam intensity over time.
Over the last decade, new porous target nanostructures were developed to improve their isotope release efficiency while keeping microstructural stability at high temperatures [1,2]. However, new nanomaterials were found highly pyrophoric and require extreme care in all handling procedures. Since actinide carbide materials are not compatible with long-term storage requirements, a safe process for their conversion into stable oxides is investigated.
In this talk, systematic investigations on the oxidation of five different uranium carbide and carbon composite materials will be presented. A combination of characterization and thermal analysis techniques were used to study the reaction mechanism and its kinetics. It was found that, despite their

different characteristics, the materials generally followed a similar reaction pathway. However, the onset oxidation temperatures and kinetics were strongly affected by the sample form, grain size and carbon content.
The study provided valuable inputs for the design of safe oxidation and disposal procedures for current and future UCx composite targets waste at ISOLDE, such as the microporous, high density or nanostructured targets.
This research project has been supported by a Marie Skłodowska-Curie Innovative Training Network Fellowship of the European Commission's Horizon 2020 Programme under contract number 642889 MEDICIS-PROMED.

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ISOLDE Beam Dump Replacement Study (IBDRS) update

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The contribution will give an update of the IBDRS study aiming at the upgrade of the ISOLDE GPS and HRS beam dumps. This challenging project will allow an increase of the proton beam power to ISOLDE. It will require the partial removal of earth shielding covering the target area. For the first time since 1991, when Booster-ISOLDE was built, it will be possible to access the faraday cages and the surroundings of the separator areas, that make this project an unique occasion to consider future perspectives for the ISOLDE facility.

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High yield radioactive ion beam production at the Gamma Factory

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A high yield radioactive ion beam (RIB) can be produced using the intense γ beam of the Gamma Factory (GF) [1,2] facility proposed at CERN. The beam impinging on several thin actinide targets will generate exotic neutron-rich nuclei via the photo-fission reaction. The reaction takes place inside a high areal density with orthogonal extraction cryogenic stopping cell (HADO-CSC) [3] where the produced ions are thermalized in high-purity cryogenic helium and extracted with electric fields. We performed GEANT4 simulations for the ion production and transport inside the targets and gas and

SIMION simulations for space charge impact study and electric fields optimization. The ion yields achieved [4] demonstrate a great opportunity to make available for measurement and study most exotic and short-lived nuclei. In addition, this work presents a solution for accessing the refractory elements complementary to the ISOL-type facilities, opening a window for synergistic activities with the ISOLDE facility.

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Poster Presentations / 1

TAGS SPECTRA ANALYSIS AND BETA DECAY STRENGTH FUNCTION STRUCTURE

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Successful applications of the total absorption γ-spectroscopy $(TAGS)$ for the β-decay strength function $S_\beta(E)$ resonance structure study, methods of $TAGS$ spectra interpretation, and results of analysis of $S_\beta(E)$ structure both for the Gamow-Teller (GT) β^+/EC and GT β^- -decays were summarized in [1,2]. Development of experimental technique allows application of methods of nuclear spectroscopy with high energy resolution for $S_\beta(E)$ fine structure measurement [2-4]. First results of the $S_\beta(E)$ fine structure study were summarized in [2,3].The combination of the $TAGS$ with high resolution nuclear spectroscopy may be applied for detailed decay schemes construction [2]. It was shown [2-4] that the high-resolution nuclear spectroscopy methods give conclusive evidence of the resonance structure of $S_\beta(E)$ for GT and first-forbidden (FF) β-transitions in spherical, deformed, and transition nuclei. High-resolution nuclear spectroscopy methods [2-5] made it possible to demonstrate experimentally the reveal splitting of the peak in the $S_\beta(E)$ for the (GT) β^+/EC-decay of the deformed nuclei into two components.
The operating principle of a total-absorption γ-spectrometer is based on summation of the energies of the cascade γ-rays produced after β-decay to excited levels of the daughter nucleus in 4π-geometry. There are two methods of the $TAGS$ spectra analysis [1]. In the first one it is necessary to identify the total absorption peaks in $TAGS$ spectra and have 4π-spectrometer with exponential energy dependence of the photoefficiency (i.e., the ratio of the number of pulses in the total absorption peak to the number of γ-ray incident on the detector) for γ-ray registration. Only in this case the efficiency of $TAGS$ peak registration does not depend on the details of decay scheme [1,3]. This method gives good results, but can be applied for nuclei with total β-decay energy Q_β less than $5-6MeV$. Quantitative characteristics may be obtain as a rule only for one (β^--decay) peak and for two peaks (β^+/EC-decay) in $S_\beta(E)$ [1-3].
The second method is based on so called response function application, but a lot of assumption must be done for extraction the $S_\beta(E)$ shape from the $TAGS$ spectrum shape. Analysis depends on the assumptions [1] about the decay scheme which as a rule is not known. It is very difficult to estimate the associated systematic errors of such analysis [1] and only qualitative information about $S_\beta(E)$ may be obtained.
$TAGS$ can't distinguish the GT and FF transitions and don't take into account the conversion electron emission, which give the systematic uncertainties, especially for high Z both for $S_\beta(E)$ and decay heat estimation.
In this report some results of $TAGS$ spectra analysis are considered. It is shown that only combination of $TAGS$ with high resolution nuclear spectroscopy methods may give the quantitative information about $S_\beta(E)$.

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Poster Presentations / 2

Comprehensive Test of the Brink-Axel Hypothesis in the Energy Region of the Pygmy Dipole Resonance

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The validity of the Brink-Axel hypothesis, which is especially important for numerous astrophysical calculations, is addressed for ^{116,120,124}Sn below the neutron separation energy by means of three independent experimental methods. The γ-ray strength functions (GSFs) extracted from primary γ-decay spectra following charged-particle reactions with the Oslo method and with the Shape method demonstrate excellent agreement with those deduced from forward-angle inelastic proton scattering at relativistic beam energies.
In addition, the GSFs are shown to be independent of excitation energies and spins of the initial and final states.
The results provide the critical test of the generalized Brink-Axel hypothesis in heavy nuclei, demonstrating its applicability in the energy region of the pygmy dipole resonance.

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Recent developments in the design of the HIE-ISOLDE Superconducting Recoil Separator (ISRS)

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Recent developments in the design of the HIE-ISOLDE Superconducting Recoil Separator (ISRS)
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Abstract
Nuclear physics research developed at international radioactive beam facilities is leading to unprecedented discoveries in the structure and dynamics of nuclei. The radioactive beam facility "Isotope mass Separator On-Line facility"(ISOLDE) at CERN [1] is a world leading infrastructure in basic and applied nuclear physics research, currently producing post-accelerated radioactive beams in the energy range 0.5 - 10 MeV/A with the HIE-ISOLDE linac [2]. The scientific program covers a broad range of topics, from basic nuclear structure to nuclear astrophysics [3]. These studies can benefit from the use of a high-resolution recoil separator, the HIE-ISOLDE Superconducting Recoil Separator (ISRS) [4]. In this contribution we will discuss last technical developments, including beam dynamics, SC magnets and cryostats.
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Cd impurities in Vanadium oxides: a hyperfine interaction investigation using 111mCd nuclei

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The number of metastable phases, the capriciousness at changing external conditions, and lack of accurate description of local behavior already resulted in severe misinterpretation of experimental outcomes for vanadium oxides[1–3]. The scope of already implemented and potential applications of vanadium oxides is, indeed, impressive, particularly as a battery cathode for energy storage[4].

Doping is widely exploited as a means of application-oriented tuning of the material properties. The properties of each particular phase may be tuned by doping to satisfy specific requirements and/or improve the functional performance. In the work here reported, electric quadrupole interaction on ^{111m}Cd nuclei implanted in vanadium pentaoxide doped with different concentrations of Cd were measured with time-differential perturbed angular correlations (TDPAC).

Pure V_2O_5 as well as doped with 1%, 5%, and 10% of Cd were measured at different temperatures. To correlate the results with the possible formation of different phases and compounds, samples of

VO_2, CdV_2O_6, and $Cd_2V_2O_7$ were also measured. The intention is to provide a comprehensive description, at an atomic level, of the doping effects on the local crystal structure and the electronic structure around the impurity and the consequences on the properties of the host oxides. Preliminary results show that the probability of formation of cadmium vanadates is low but the temperature and atmosphere of measurements have an important effect on the local scale.

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Characterization of ionic and highlying states in RaF to guide future experiments

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After the theoretical prediction of Radium monofluoride (RaF) as laser-coolable molecule and a versatile probe of fundamental physics [1] the first spectroscopic identification and characterization was achieved at ISOLDE [2]. This experiment paved the way to study the nuclear structure of short lived Radium isotopes in molecular systems and presented a first step in the effort to search for violations of fundamental symmetries [3]. In these neutralisation-reionisation
experiments a three color laser excitation scheme is used to reduce background to enable measurements of high resolution spectra. So far, however, the character of the intermediate states from which ionization takes place is not established. Furthermore, at the present stage of experiments RaF molecules are rather hot having several vibrational levels occupied. This makes interpretations of rovibrational spectra complicated and would limit the efficiency of laser-cooling
schemes.
In this contribution we study energetically high lying excited electronic states of RaF on the level of relativistic Fock-space coupled cluster calculations. Furthermore, we consider ionic states to explore possibilities for reducing the translational and vibrational energy of RaF molecules.

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Beta-decay and fundamental interactions / 10

Beta-decay studies to explore physics beyond the weak-interaction standard model

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The standard model (SM) of weak interaction describes all weak decays with an amazing precision. It contains two interaction types (or currents): vector currents and axial-vector currents. However, by requiring only Lorentz invariance, three more currents, scalar, tensor, and pseudo-scalar, are also allowed. For these "exotic"currents, only limits are defined today. Search for these currents and thus for physics beyond the standard model can be carried out in high-energy physics (e.g. at LHC) by searching for new particles as carriers of these new interactions. An alternative approach is possible via high-precision experiments with nuclear beta decay.
We will present the WISArD experiment at ISOLDE and new data acquired to search for deviations in the beta-neutrino angular correlation from SM predictions to constraint the strength of these exotic currents. In this experiment, the beta-delayed proton emission of 32Ar is used to deduce, from the shape of the energy distribution of proton peaks, the kinematical condition, under which the protons have been emitted and thus to gather information about the beta-neutrino angular distribution.
A different approach to search for beyond standard model interactions is to measure with high precision the properties of super-allowed 0+ -> 0+ beta decays. The corrected Ft value of these transitions enables one to determine limits of scalar currents via the Fierz interference term. In this context, an experiment recently carried out at ISOLDE with a 10C beam will be presented.

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Weak interaction studies with 32Ar decay

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Nuclear beta decay has represented for more than half a century a blooming testing ground for the Standard Model (SM), contributing particularly to the development of the theory of the electroweak interaction. The broad variety of nuclear states and beta transitions provide a highly remarkable tool to be competitive with high-energy physics experiments in searching for the possible presence of non-SM contributions to the firmly established vector - axial-vector (V-A) description of the weak interaction [1]. Particularly, the joined experimental determination of the beta-neutrino angular correlation coefficient ($a_{\beta\nu}$) and the correlated Fierz term (b_F) in pure Fermi and Gamow-Teller transitions directly allows to set new stringent limits on the existence of scalar and tensor currents, respectively.

The most forthcoming way to retrieve $a_{\beta\nu}$ would be to measure the correlation between the leptons emitted in the decay; yet, as a direct measurement of the neutrino is almost impossible, the $a_{\beta\nu}$ coefficient can be determined from the recoil of the daughter nucleus, which can be measured either directly by means of trap measurements or via the kinematic shift it induces on the energy

distribution of the β-delayed particles emitted in case of unstable daughter nuclei, as foreseen in the WISArD experiment at CERN.

The WISArD (Weak Interaction Studies with ^{32}Ar Decay) experiment [2] aims at a precise measurement of both the $a_{\beta\nu}$ and the b_F coefficients for both Fermi and Gamow-Teller transitions by using, differently from previous measurements [3], the kinematic energy shift of the β-delayed protons emitted in the same or the opposite direction to the β-particle from ^{32}Ar. A proof-of-principle experiment, though limited in statistics and performed via a still rudimental experimental set-up, has been successfully accomplished at ISOLDE in November 2018, already leading to the third best measurement of $a_{\beta\nu}$ for Fermi transitions [4]. After determining and estimating the systematic errors, a consistent upgrade of the experimental set-up has been commissioned and realized through the past two years, potentially permitting to reach the aimed precision of the permil level on the determination of both $a_{\beta\nu}$ and b_F. In this talk, the new experimental campaign conduced at ISOLDE in October 2021, along with the enhancements in the newly dedicated detection set-up, will be presented and the first preliminary results will be discussed.

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Beta-decay and fundamental interactions / **23**

Indium Energy Spectrum Shape (InESS) at WISArD

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The Standard Model of Particle Physics (SM) has been a great success describing three of the four fundamental interactions. At the same time, it does not resolve mysteries such as the matter-antimatter asymmetry observed in the Universe, the occurrence of dark matter and dark energy, nor the origin of CP symmetry breaking. Furthermore, the theory includes a large number of free parameters. Possible extensions referred to as Beyond Standard Model (BSM) physics are experimentally accessible through particle collisions, i.e., at LHC, or through high-precision experiments. The latter are indirect searches and the goal of the WISArD collaboration at ISOLDE.

During LS2 we benefited from the availability of the WISArD solenoid, providing a strong magnetic field, to perform a beta spectrum shape measurement. These electron energy measurements are typically impacted by the backscattering effect from the detector, which de-forms the observed energy. We built a detector set-up with two plastic scintillators coupled to SiPMs installed face-to-face. In this configuration, the high magnetic field provides a closed system and a 4π solid angle. Thus, adding both detector signals within an integration time window allows the reconstruction of the full electron energy for backscattered events.

The isotope of choice was ^{114}In motivated by scientific and practical reasons. The ground state decays through a pure Gamow-Teller beta transition that is theoretically well-described [1]. Practically, its relatively long-living isomeric state ($T_{1/2} \approx 50$ d) and commercial availability were essential to our measurement during LS2 and the absence of radioactive beam delivery at ISOLDE. One drawback when interested in BSM physics is the lack of independent information on the nuclear structure contributions for ^{114}In. This necessitates their inclusion into the spectrum fit.

At the end of 2020, the detector set-up was characterized, using converted electron sources (^{137}Cs and ^{207}Bi) as well as a continuous beta source (^{90}Sr). For ^{114}In two different source activities, i.e. 1 kBq and 5kBq, were used to cross-check pile-up effects.
The talk will present details on the detector set-up, the performed measurements and the status of the analysis.
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Ultraviolet Spectroscopy of the Actinium-229 beta decay: On the way to the first identification of the 229Th low-energy isomer?

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A unique feature of thorium-229 is its isomer with an exceptionally low excitation energy, proposed as a candidate for future optical clocks [1]. The small decay width is expected to outperform the accuracy of current state-of-the-art atomic clocks by an order of magnitude [2]. The current best values of the excitation energy are 8.28(17)eV and 8.10(17)eV [3,4]. These were determined using two different measurement techniques whereby the isomer is populated in the alpha decay of uranium-233. The development of an optical clock requires however knowledge of the excitation energy by at least an order of magnitude more precise. Spectroscopic experiments searching for a direct signature of the radiative decay have to-date been unsuccessful, partially due to the background induced in the preceding alpha decay.

An alternative approach using the beta decay of actinium-229 is studied as a novel method to populate the isomer with high efficiency and in low background conditions [5]. Produced online at the ISOLDE facility, actinium is laser-ionized and implanted into a large-bandgap crystal in specific lattice positions, suppressing the electron conversion decay channel of the isomer. A favourable feeding pattern is significantly increasing the population of the isomer compared to uranium-233 and the lower energy deposit of the beta compared to the alpha decay results in a significantly reduced luminescence background.

In this contribution, a dedicated setup developed at KU Leuven for the implantation of an actinium-229 beam into large-bandgap crystals and the vacuum-ultraviolet spectroscopic study of the emitted photons is presented and the preliminary results from a recent experimental campaign at ISOLDE are presented.

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Beta-decay and fundamental interactions / 22

Many facets of beta-delayed neutron emission from very neutron rich nuclei

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The recent beta delayed neutron emission experiments near 132Sn with VANDLE, and BRIKEN arrays enabled detailed studies of nuclei with very large Qb and small Sn. This allows exploring the underlying physics more thoroughly. The modeling of beta-delayed neutron emission requires the knowledge of beta-decay strength distribution and neutron emission model. The latter customarily uses the Hauser-Feshbach (HF) model, which implies neutron emission from the compound nucleus. Multi-neutron emission studies near 78Ni appear to be well described well using this approach, although level densities have to be adjusted to fit the experiment. However, in the decay of 134In, we observed a substantial discrepancy between the model prediction and experiment. This leads us to question the universality of the HF treatment and the need to development of more sophisticated models of beta-delayed neutron emission.

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First β-decay spectroscopy of 135In and new β-decay branches of 134In

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The β decay of the neutron-rich 134In and 135In was investigated experimentally with the aim of providing new insights into the nuclear structure of the tin isotopes above N=82. Better understanding of exotic nuclides from the 132Sn region is required for accurate modeling of the rapid neutron capture nucleosynthesis process (r process), due to the A≈130 peak in the r-process abundance pattern being linked to the N=82 shell closure [1, 2]. Because a vast number of nuclei involved in the r process are β-delayed neutron (βn) emitters, new experimental data that can verify and guide theoretical models describing βn emission are of particular interest. Neutron-rich isotopes 134In and 135In –being rare instances of experimentally accessible nuclides for which the β3n decay is energetically allowed [3] –constitute representative nuclei to investigate the competition between βn and multiple-neutron emission as well as the γ-ray contribution to the decay of neutron-unbound states.

The β-delayed γ-ray spectroscopy measurement was performed at the ISOLDE Decay Station. Three β-decay branches of 134In were established, two of which were observed for the first time [4]. Population of neutron-unbound states decaying via γ rays was identified in the two daughter nuclei of 134In, 134Sn and 133Sn, at excitation energies exceeding the neutron separation energy by 1 MeV. The βn- and β2n-emission branching ratios of 134In were determined and compared with theoretical calculations. The βn decay was observed to be dominant β-decay branch of 134In even though the Gamow-Teller resonance is located substantially above the two-neutron separation energy of 134Sn. Transitions following the β decay of 135In are reported for the first time, including γ rays tentatively attributed to 135Sn [4]. A transition that might be a candidate for deexciting the missing neutron single-particle ν1i13/2 state in 133Sn was observed in both β decays and its assignment is discussed. Experimental level schemes of 134Sn and 135Sn are compared with shell-model predictions, including calculations considering particle-hole excitations across the N=82 shell gap [5].

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Beta-decay and fundamental interactions / 48

γ-ray spectroscopy of ^{213}Fr populated in the EC/β^+ decay of ^{213}Ra. Shell model interpretation.

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On behalf of IS608/IS650 IDS-Bucharest-York-Leuven Collaboration

The level structure of the semi-magic ^{213}Fr nucleus has been studied by means of EC/β^+ decay of the ^{213}Ra 1/2$^-$ ground state up to an excitation energy of 3.6 MeV. It is the first observation of the low spin states, with J≤7/2, above the previously known (7/2$^-$)→9/2$^-_{gs}$ sequence. This contribution represents a follow-up of the preliminary experimental results obtained during the IS608 campaign and partially from the IS650, both performed at the ISOLDE Decay Station. Being a mid-shell nucleus, with 5 protons above the doubly magic ^{208}Pb, ^{213}Fr exhibits interesting features like the l-forbidden M1 transition that proceeds between the $h_{9/2}$ and $f_{7/2}$ pseudo-spin partners (7/2$^-$ →9/2$^-_{gs}$) and different decay patterns of the relatively low lying states, possibly given by the seniority conservation. It represents a challenging case to be interpreted theoretically, therefore shell model calculations became crucial to unraveling its intrinsic structure. Spin and parity assignments were made for the newly discovered levels on the basis of the systematics and the theory predictions within the KHPE valence space. Its ground state is expected to be of dominant $\pi h^5_{9/2}$ character if one compares it with its ^{209}Bi (Z=83) and ^{211}At (Z=85) isotones. Indeed, the calculations revealed that the $\pi(h^5_{9/2}; J)$ configurations have a dominant role (up to 90%) in the structure of the ground state and of the low energy states from the ground state band. A proton pair scattering was observed to be highly probable from the $h^3_{9/2}$ orbit to either $f^2_{7/2}$ or $i^2_{13/2}$, with $h^3_{9/2}f^2_{7/2}$ and $h^3_{9/2}i^2_{13/2}$ components also present in the structure of the states that belong to the $h^5_{9/2}$ multiplet. To extend the comparison with ^{211}At, the newly built level scheme of ^{213}Fr clearly manifests structural patterns. Apart from the first and the second excited states (both with J=7/2$^-$), the levels seem to group, as closely spaced levels, resembling multiplets. An interesting developed feature is given by their rather parallel cascades to the ground state. A multiplet of states only decays to one of the 7/2$^-$ states and not to the other one.

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Recent beta-delayed fission investigations at ISOLDE and future possibilities

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Beta-delayed fission (βDF) provides a means to obtain a wealth of information on fission of exotic isotopes [1,2]. On top of that, it plays an important role in the nucleosynthesis as it contributes to the termination and fission recycling in the r process and thus impacts final abundances of elements in the Universe [3].

In βDF process, an excited state populated in the daughter nucleus via β decay undergoes fission. The excitation energy is limited by Q_β value, which is typically less than 12 MeV. Therefore, βDF allows us to study so called low-energy fission, which is sensitive to nuclear structure. It enables investigation of fission properties (such as fission fragment mass distributions, fission barriers, etc.) of isotopes for which other approaches to low-energy fission studies would be extremely difficult or currently impossible [1,2].

This contribution will mainly focus on βDF investigations that took place at ISOLDE in recent years, namely the study of ^{188}Bi [4] and the search for βDF in ^{178}Au. Both isotopes have two long-lived β-decaying states, which we studied individually by employing selective power of RILIS to obtain isomerically separated beams. This mode of measurement gives an additional possibility to explore spin dependence of fission, because of the strong spin selectivity of β decay. Future plans and possibilities for βDF studies using IDS will be discussed as well. The aim will be to probe the neutron-rich region around actinium, which is more relevant to r process compared to neutron-deficient regions studied in detail until now.

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β^-decay spectroscopy study of the ^{232}Ra β^-decay chain

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The ^{232}Ra β^-decay chain was investigated through β and γ-ray spectroscopy at CERN-ISOLDE. A radioactive beam of ^{232}Fr and ^{232}Ra was implanted on the ISOLDE Decay Station tape, where the γ-rays originating from the β^-decay chains ^{232}Fr-^{232}Ra-^{232}Ac-^{232}Th were registered using a mixed array consisting of (4 HPGe- 2 $LaBr_3$(Ce)–1 Beta) detectors arranged in close geometry. The production yields were measured for different experimental conditions of UC_x targets, also involving the formation of ^{213}RaF molecular beam inducing a substantial contamination.

Prior to our study, K.-L. Gippert et *al.* used the multinucleon transfer reaction to produce the ^{232}Ra precursor. Due to low statistics and the absence of γ-γ coincidences, only a few γ-ray transitions were associated with ^{232}Ac. In the present work, we report on revised and considerably extended level schemes for ^{232}Ac (24 new γ-rays, 19 new levels) and ^{232}Th (67 new γ-rays, 36 new levels), revealing the existence of new structures lying at higher energy and a different β-strength distribution. Thanks to our low γ-ray/X-ray energy capabilities, few K-$shell$ internal conversion coefficients have been newly extracted for ^{232}Ac, providing clues to assign multi-polarities to the related transitions. An isomeric state at E_x = 97.7 keV, on top of which a newly discovered structure is build, was identified and measured in ^{232}Ac with HPGe detector array using the standard electronic timing technique.

The experimental results will be discussed and confronted to the systematics present neighbouring nuclei, where similar structures/mechanisms are observed.

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Digital acquisition systems for neutron tube and solid-state detectors

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We will present a new acquisition system aimed at highly segmented detectors. The system is tailored around the specific needs of segmented solid-state detectors, in particular silicon detectors, and reduces the number of modules needed, thus simplifying the setup, reducing time, and saving money. The system counts 64 channel preamp and digitizer for the independent readout of detectors with high channel density, some preliminary benchmarks will be presented as well as overall capabilities. The second acquisition system has been developed for the MICADO project, an EU funded project to improve already state-of-the-art measurement techniques for nuclear waste characterization. In this talk we will illustrate the readout system for the active/passive neutron interrogation which uses He3 tubes and comprises of a signal amplifier and a neutron pulse train recorder.

News from HIE-ISOLDE / 37

Studies of shape coexistence in 140Sm

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The shape of atomic nuclei can vary vastly, several shapes can even coexist within the same nucleus in certain regions of the nuclear chart. Shape coexistence is believed to be present at higher excitation energies in the N=78 isotones 140Sm and 142Gd [1], where the nucleus of interest is 140Sm in this case. 140Sm has previously been studied in a coulomb excitation experiment performed by M. Klintefjord et. al. [2] at REX-ISOLDE where results showed considerable gamma-softness and the resulting level scheme follows the theoretical prediction of a triaxial nucleus [3], but further investigation is needed to conclude. A new coulomb experiment on 140Sm has been performed using HIE-ISOLDE, yielding data of incredible quality which has also let us vastly improve the level scheme of this nucleus. Preliminary results from this dataset will be presented as well as a deeper look into gamma-softness as well as the possibility of 140Sm having shape coexistence.

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News from HIE-ISOLDE / 9

Physics motivation for the EPIC upgrade proposal of ISOLDE

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The presentation will outline the variety of scientific goals that drive the need for a new experimental hall and higher RIB beam intensities at ISOLDE, CERN. The proposed developments will lead to an increased capacity and capability for producing more intense, higher-quality, radioactive ion beams

for precision studies on very exotic isotopes from He (Z=2) up to Ac (Z=89), using low-energy and post-accelerated beams. By also exploiting synergies with other CERN facilities (e.g. AD, n_TOF) as well as other scientific communities (e.g. quantum technologies, quantum chemistry, particle physics, ⋯), the range of science done at ISOLDE and its scientific output will be further enhanced. The ideas presented are the result of discussions with the ISOLDE User community at the occasion of two dedicated EPIC workshops, held in 2019 [https://indico.cern.ch/event/838820/] and 2020 [https://indico.cern.ch/event/928894/], which were attended by more than 130 and 210 persons, respectively.
The technical upgrades and consolidation plans of the existing facility are presented in a separate talk, along with a proposal for a new ISOLDE experimental hall.

News from HIE-ISOLDE / 19

Measurement of the ^{7}Be(d,p)^{8}Be* reaction at 5 MeV/A

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The IS554 experiment involved the measurement of the ^{7}Be(d,p)^{8}Be* reaction at 5 MeV/A. The scattering chamber at the third beamline of HIE-ISOLDE was used, with an array of double-sided silicon strip detectors (DSSD) covering an angular range of 8^{o}- 165^{o}. The ^{7}Be beam was incident on a CD_2 target of thickness 15 μm and the average beam intensity was $\sim$ 5 x 10^{5} pps. We measured resonance excitations in the above transfer reaction up to about 22 MeV. The high-lying resonances in the context of the unsolved cosmological lithium problem were studied. I would discuss the results from the experiment.

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Single-particle state evolution along the $N = 127$ isotone chain using the d(^{212}Rn, p)^{213}Rn reaction

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The study of single-particle states can provide insight into properties of nuclear structure. In light neutron-rich systems, features of single-particle states along isotonic chains have highlighted changes in shell closures, such as the weakening of $N = 20$ and formation of $N = 16$ [1, 2]. In heavier closed-shell stable nuclei, trends have been seen in the behaviour of high-j states from the filling of other high-j orbitals, the effects of which have been attributed to the tensor interaction [3]. From the availability of radioactive beams at ISOLDE, these studies can be extended in the region around $N = 126$. Currently, states up to $Z = 84$ are known with spectroscopic factors and assignments

[4, 5]. Above this, only the energies of states are available with tentatively assigned orbital configurations and no spectroscopic information. In order to probe single-particle nature beyond this, the reaction $d(^{212}$Rn, $p)^{213}$Rn has been performed at the ISOLDE Solenoidal Spectrometer (ISS) with a 7.63 MeV/u radioactive beam at an intensity of $\sim10^6$ pps. States have been identified up to $\sim$4 MeV. The aim is to extract and calculate single-particle centroids for the neutron outside of $N = 126$. These will provide information on the magnitude of monopole shifts caused by the interaction between the neutron and protons filling the $\pi 0h_{9/2}$ orbital. These data will also be used to inform modern shell-model calculations in this region of the nuclear chart. Preliminary data from measurements, made in September, will be presented.

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Other facilities / 55

Exploring the landscape between the doubly magic ^{40}Ca and ^{56}Ni isotopes using collinear laser spectroscopy at IGISOL

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The study of isotopes between the doubly magic ^{40}Ca and ^{56}Ni using laser spectroscopy techniques is challenging due to the difficulty of their production and the complexity of their atomic structure. Thus, experimental data remains scarce, despite the great interest to study for example the N=Z isotopes in the region, including exploration of the evolution of the nuclear properties towards N=20, and a measurement of the nuclear charge radius and electromagnetic moments of the proton emitter isomer in ^{53m}Co.
In this talk, new measurements of the charge radii of $^{48-54}$Cr (Z=24) will be shown and the developments allowing to access ionic transitions for the study of Co (Z=27) and Fe (Z=26) will be discussed. These will help to provide more insight into the evolution of the nuclear properties between the doubly magic ^{40}Ca and ^{56}Ni isotopes.

Other facilities / 49

The ARIEL target stations

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The ARIEL facility will add two new target stations for radioactive ion beam production at TRIUMF, one capable of accepting a 100 kW electron driver beam and the other a 50 kW proton driver beam. While TRIUMF's ISAC facility is already capable of operating high power targets for 50 kW proton driver beams, the exploitation of an electron driver beam has presented a fresh set of challenges. An electron-gamma (e-y) converter is required upstream of the target, with the resulting y-rays used to irradiate target materials. The spatial profile of the y-rays requires significant changes to the dimensions and orientation of the target compared to existing solutions. The resulting A-symmetric irradiation and proximity to the converter results in new requirements for target heating and new approaches for power dissipation.

The design of the target stations has now matured and a full working prototype of the ARIEL target module front-end has been assembled and is currently being tested. The results of these tests will be presented, together with an update on the progress of the overall ARIEL target station development.

Other facilities / **15**

Studying shape coexistence with SAGE at MARA

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One of the goals of modern nuclear physics research is to understand the origin of coexisting nuclear shapes and exotic excitations and their relation to the fundamental interactions between nuclear constituents. Despite of huge amount of both theoretical and experimental efforts, many open questions remain [1 and references therein]. In order to verify and understand these subjects in more detail, complementary approaches are needed.

This talk will give an insight into shape coexistence studies around neutron-deficient Pb nuclei. In particular, it will focus on series of simultaneous in-beam electron and γ-ray spectroscopy experiments conducted last spring employing the SAGE spectrometer [2] at the MARA separator [3] at JYFL, Finland. Their relation to the forthcoming Coulomb excitation studies at MINIBALL [4] at HIE-ISOLDE, CERN [5] will also be discussed.

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Other facilities / **4**

The HiCARI project at the RIBF

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In-beam gamma-ray spectroscopy at the Radioactive Isotope Beam Factory (RIBF), RIKEN, Japan has primarily been carried out in the moderate energy resolution regime using the high-efficiency NaI array DALI2. To perform high-resolution gamma-ray spectroscopy, a high-purity germanium array, known as the HIgh-resolution Cluster Array at the RIBF (HiCARI), was realised at the RIBF. The array comprised six Miniball detectors, two GRETA-type tracking detectors, and four clover detectors sourced from around the world.

Three experimental campaigns, exploring many key regions of the nuclear chart, were carried out during 2020 and 2021, yielding excellent preliminary results across a range of physics topics. This talk will provide an overview of the RIBF, details of the HiCARI configuration, and presentation of a the preliminary results from the recent campaigns.

Poster Presentations / 32

Theory complements β-NMR studies: correlation time of 23Na+ in liquids

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The molecular environment around different ions in liquids and solids can be determined experimentally using the technique of β-NMR, based for example on the relaxation time T1. However, to interpret T1 correctly in liquids, one needs to take into account the underlying dynamics, which can be done by combining β-NMR results with calculations of the molecular correlation times. Several theoretical methods can be used, such as molecular dynamic (MD), density functional theory (DFT), or a combination of quantum mechanics with molecular mechanics (QM/MM).
To complement β-NMR studies on short-lived 26Na in different ionic liquid hosts, in the present work MD simulations have been applied to study the dynamics of water molecules around the Na+ ion (using the Amber software), before the application in ionic liquids. The obtained correlation time value is in good agreement with other computational results. This method can be now applied to other environments, like ionic liquids.
The poster will present the theoretical approach, the obtained results compared to literature values, and will present them in the context of β-NMR studies performed at ISOLDE.

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Density Functional Theory study of Cd impurities in Molybdenum Trioxide

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Transition metal oxides semiconductors (TMOs) are known for their special optical and electrical properties with wide-ranging applications, including gas sensing, storage devices such as Li-ion batteries, solar cells, and catalysts[1,2]. Among different types of TMOs, there is a class of materials that are distinguished by their unique layered structure and multiple oxidation states, such as MoO_3, WO_3, and V_2O_5. The molybdenum trioxide (MoO_3) is known for its photo-, thermo- and electro-chromism, high catalytic activity[3]. The MoO_3 has found in different structural phases including the orthorhombic phase, α-MoO_3; monoclinic phase, β-MoO_3; metastable phase at high-pressure conditions, β′-MoO_3; and hexagonal phase, h-MoO_3[4]. Among them, the α-MoO_3 is the most stable crystal phase and it has a layered structure consisting of van der Waals bonded sheets of distorted edge-sharing Mo–O_6 octahedra in which Mo atoms are bounded by three distinct types of oxygen atoms[5].

In this research, the structural properties and hyperfine parameters of ^{111m}Cd(^{111}Cd) impurities in α-MoO_3 are investigated by first-principle calculations in the framework of density functional theory (DFT). The Perdew–Burke–Ernzerh of generalized gradient approximation (GGA-PBE), and GGA-PBE plus Hubbard-U corrections for onsite Coulomb interactions are used in the DFT calculations. In the calculations performed, the effect of van der Waals forces between layers is employed using the DFT-D3 method[6]. To interpret the experimental results, different configurations around the Cd atom including the different types of oxygen vacancies are simulated. The comparison of experimental data with calculated hyperfine parameters indicates that the Cd atom is predominantly located in the interstitial lattice site of MoO_3, and also the oxygen vacancy is most likely to form on the 2-fold coordinated (O_2) atoms.

The results of this work demonstrate the benefit of first-principle calculations for solving the outstanding questions arising from the experiment.

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Poster Presentations / 38

Production and purification of 129m,131m,133mXe for a new medical imagine technique, gamma-MRI

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The gamma-MRI is a novel imaging modality that should allow the simultaneous exploitation of the sensitivity of gamma detection (SPECT) and the spatial resolution and flexibility of MRI. The approach uses highly-polarized gamma-emitting nuclei, which exhibit anisotropic gamma-ray emission that will be used for signal detection –decrease in the number of gamma rays emitted longitudinally to the spin (and magnetic field). The first nuclei used in the project will be 11/2$^-$ spin ^{129m}Xe ($T_{1/2}$=8.88 days), ^{131m}Xe ($T_{1/2}$=11.84 days) and ,^{133m}Xe ($T_{1/2}$= 12.19days).

The efficient production and purification of the ^{129m,131m,133m}Xe is one of the first milestones in the gamma-MRI project. This poster will concentrate of two main methods of production tested so far: neutron irradiation of enriched stable ^{128}Xe (product: ^{129m}Xe) and ^{130}Xe (product: ^{131m}Xe) at the ILL reactor in Grenoble, and collection of ^{129m,131m,133m}Xe in gold foils at GLM chamber at ISOLDE. Preliminary data analysis shows that both methods provide xenon isotopes that have a very low level of contaminants and that can be extracted it efficiently.

The poster will present the production parameters, experimental setups, and the Xe activities and purities reached for both production paths. A third method, which is being optimized (extraction of ^{131m}Xe from Na^{131}I powder used in nuclear medicine), will be also briefly mentioned.

Poster Presentations / **46**

Recent developments in β-NMR at VITO

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β-NMR is a unique technique to measure various nuclear properties with a sensitivity that is up to ten orders of magnitude greater than conventional NMR. The two main factors contributing to this enhancement are optical pumping that generates a large degree of nuclear polarisation, and efficient detection of the asymmetrically emitted β-particles from the hyperpolarised decaying isotope. While it has historically been well established in solid state physics, the focus is now shifting towards studies in liquids, from chemical reactions up to the dynamics of macromolecules.
To enable such studies, the VITO beamline has undergone several major upgrades and extensions, such as, the installation of a superconducting solenoidal magnet with sub-ppm homogeneity and a new detector array.
The new data acquisition system based on fast analogue-to-digital converters with integrated FPGA is a key part of the improvements. It allows for a real time characterisation of each β-particle on every detector channel. The corresponding properties of all β-events are saved, including, for instance, time of arrival, amplitude and time over threshold. Thus, the system enables an unprecedented acquisition of temporally resolved data during all measurements. This leap forward opens versatile possibilities for post processing and analysis to aid studies with biological samples.

Poster Presentations / **47**

Finding Laser-Coolable Molecular Ions

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Molecular ions containing heavy nuclei can provide advantages from an experimental and theoretical point of view compared to their neutral counterparts. With ion traps [1] the effective time that can be used for cooling of molecules is increased significantly and after steering the ions through an mass selector one is not necessarily dependent on an additional neutralization process. Meanwhile the accompanying electric charge provides enhanced relativistic effects rendering molecular ions interesting for the search of New Physics [2].

In this contribution, small molecular ions are investigated theoretically in their ground and excited states to explore usability in experiments, laser-coolability and possibility to enhance signatures of New Physics. We show potential energy curves together with relevant molecular properties evaluated together within the two-component zeroth order regular approximation (ZORA).

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Applications I / 14

identifying point defects in technologically important semiconductors

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Impurities and their complexes, whether introduced deliberately or accidentally during fabrication dominate the properties of semiconductors devices. Determining the actual elemental and physical structure of a defect responsible for undesirable effects in devices can be remarkably difficult. A good example is the Boron-oxygen degradation mechanism in Silicon solar cells. This defect degrades the performance of commercial cells by as much 10% (relative) of their efficiency. With the exponential uptake of solar energy around the planet this one defect is losing the energy equivalent of millions of tons of carbon every year. Yet despite this effect being known about for over 40 years there is still no consensus over what the defect is or how it degrades the cell. The Manchester Defects group have worked in this field for over 40 years, using a wide range of electrical and optical techniques to identify defects in semiconductors. The speaker will give an overview of this work and will discuss how ISOLDE could be used to solve some of the most difficult to attack problems in this important field

Applications I / 7

Radiotracer studies of diffusion in multi-principal element alloys

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Single-phase multi-principal element alloys, termed as high-entropy alloys (HEAs), are in focus of an intensive research now, both for fundamental understanding and technological applictions. A "sluggish"diffusion concept [1] helped to boost an interest from many diffusion groups and to improve our knowledge on diffusion in the multicomponent alloys. In the overview, the current state-of-the-art of diffusion research in the multi-principal element alloys is presented. Whereas tracer diffusion might be considered as sluggish when the diffusion rates in FCC CoCrFeNi and CoCrFeMnNi HEAs are analysed [2-4], the concept becomes ambiguous when the element diffusivities in the FCC $\mathrm{Ni}_x(\mathrm{CoCrFeMn})_{1-x}$ alloys are considered [5]. In HCP AlHfScTiZr HEAs, Zr diffusion is recently found [6] to be even enhanced with respect to that in pure α-Zr even when considered at the same homologous temperatures. The origin of such behaviour is analysed. The importance of diffusion measurements using the ISOLDE facilities is highlighted.

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Applications I / 35

IS668 EC-SLI: First results on lattice location of implanted 27Mg, 45Ca and 89Sr in diamond

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Among the many point defect colour centers in diamond, which are currently being intensively investigated for their applications in processing of quantum information, a Mg-related center has recently attracted special attention [1-3]. It is assumed that the center consists of a single Mg atom with one vacancy attached to it (MgV), which can also be pictured as a Mg atom occupying a bond-center site within a double vacancy, the so-called split-vacancy configuration [2-3]. This Mg colour center is a very efficient single photon emitter (theoretically predicted Debye-Waller factor of the zero phonon line 0.54 [3], compared to 0.03-0.04 for NV-, and 0.60 for SnV) for which also rather high creation yields up to 50% were reported following ion implantation [2].
The present study serves to probe possible configurations of implanted Mg in the diamond lattice, and to quantify the site occupancy as a function of implantation temperature. For that purpose, we have used the on-line beta− emission channeling method from short-lived 27Mg (t1/2=9.5 min) implanted at low fluences into CVD-grown diamond single crystals. Here we report on preliminary results obtained during our July 2021 beam time.
The 27Mg studies are supplemented by ongoing off-line lattice location experiments with the long-lived radioactive group-II probes 45Ca (164 d) and 89Sr (50.5 d). This should allow for a more systematic study, where lattice site preference of several implanted group II impurities can be probed, looking also for correlations with the ionic size of the impurity (0.72 Å for Mg2+, 1.00 Å for Ca2+,

1.18 Å for Sr2+).

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Emission channeling and ab initio calculations for the study of Ca color centers in diamond

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Diamond is a material with multiple promising color centers for quantum technologies. In this work, emission channeling (EC) measurements and ab initio calculations were performed to study Ca defects in this material. The present work forms part of a more systematic study into the properties of group II elements in diamond, with EC experiments performed for the ^{27}Mg, ^{45}Ca, and ^{89}Sr, experiment IS668. Density functional theory (DFT) was used to optimize the structure of 165 Ca defects, including multiple high symmetry sites of the diamond lattice, varying number of vacancies and five charge states, and a select few, based on EC input, were studied at the hybrid level. Formation, adiabatic charge transition and binding energies were calculated for all configurations. From them, it was possible to conclude that the bond-center (BC) configuration with two vacancies had the smallest formation energy, 13.36 eV for its neutral charge state. Shifting the formation energies by the difference between hybrid and generalized gradient approximation calculations for BC configuration, allowed vacancy formation energies within 0.5 eV from hybrid calculations in literature. A similar deviation is expected for the remaining results using this approach. The BC defect was studied for several charge states (-2 to +2). It shows D_{3d} symmetry and introduces five defect-localized levels in diamond's energy gap, with two exceptions. For the positive charge states, +1 and +2, the lowest lying localized level is below the valence band maximum. No defect levels were found sufficiently close to the band edges for thermal ionization at room temperature. Results from β^- EC measurements following low fluence implantation of ^{45}Ca (3×10^{12} ions/cm^2, 30 keV) performed at ISOLDE were analysed. To do so, a data driven approach was followed, performing many fits which were filtered and scored. Such scores were used to decide the sites to include in multi-site fits (up to three sites). This approach provided good results, guiding the analysis of the current work, however, a significant fraction of patterns was discarded, as such, the criteria used might be too strict. From the collected patterns, a Gaussian distribution around the BC site was found in the as implanted state, which is consistent with DFT results, and, after annealing, such contribution was reduced in favor of other sites, but no concrete assignment was possible as multiple configurations lead to similar quality fits. Such new sites have been formed during annealing, however, the BC is the minimum energy configuration from DFT, which is inconsistent with the creation of a significant fraction of other sites. Two hypotheses were presented to explain such inconsistency. One could consider the migration of vacancies away from Ca and towards other defects, mainly C interstitials. This would in turn make other sites more energetically favorable consistent with some of the models from the EC fits. Another option is that the lowest energy calcium defect was not found in the simulations performed. Due to the large number of vacancies after implantation, determined from the SRIM calculations, and the positive binding energies obtained, one could consider complexes with more vacancies. Starting from the BC site, from symmetry considerations, one would expect that Ca would

be close to the <100>-split site, which is also observed in some of the best EC fits for the after annealing patterns. DFT calculations with more vacancies are thus a logical next step for correlation with EC measurements.

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Workshop Photo

Applications II / 5

Joining Physics and Biology: Towards applications of β-NMR

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Nuclear magnetic resonance (NMR) is among the oldest and most widespread techniques in biological and chemical studies, yet observing any but the half dozen most common nuclei remains taxing. β-NMR is not just trying to amend this by putting new nuclei, like alkali metals, back on the NMR-menu, but actively exploiting their properties to gain signal enhancements and novel measurement modi. Due to the combination of Hyperpolarization, β-asymmetry detection, a wide range of available isotopes and real-time beam implantation, β-NMR has already proven its potential to advance the field of magnetic resonance, both in solid and liquid state.
Recently, the VITO-setup at ISOLDE has been upgraded significantly allowing for the first peeks into possible applications. New detection systems, higher magnetic field strengths and improved data acquisition have allowed for high-resolution spectra of alkali metals in low-vapor pressure solvents. Among these were Ionic Liquids, a special class of solvent used in battery-technology and product purification, as well as Deep Eutectic Solvents, known as the green solvents. Both will be used to eventually measure structure and dynamics of biological macromolecules from a novel perspective.

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A study of the combined hyperfine interactions in bismuth ferrite by using the Time Differential Perturbed Angular Correlation (TDPAC) spectroscopy

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This work presents the study of the coupling between the local electric and magnetic fields in multiferroic bismuth ferrite (BiFeO3 or BFO) using Time Differential Perturbed Angular Correlation (TDPAC) spectroscopy. The measurements were carried out below the Néel temperature TN (643 K), after the implantation of the 111In (111Cd) probe. The TDPAC spectra display the coupling between the electric and magnetic interaction, which is consistent with the spectra generated from the accepted theoretical models found in the literature. The temperature dependence of the quadrupole frequency observed close to magnetic transition temperature shows anomalous behaviour, whereas the magnetic dipole frequency decreases with increasing temperature and follows a power-law trend. With the support of ab-initio DFT simulations, we are able to discuss the site-assignment for the probe nucleus, and thus, we can conclude with reasonable certainty, that under our experimental conditions, the 111In probe substitutes the Fe-atom at the B-site.
Key words: BiFeO3, multiferroic, magnetoelectric coupling, γ-γ angular correlations.

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A particular EFG Temperature Dependence for 181Ta(TiO2): An electron-gamma TDPAC study

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In this work, we report on the hyperfine parameters of the implanted 181-Ta probe in the rutile structure of the single crystal TiO2 using the e −γ time differential perturbed angular correlation (e −γ TDPAC) technique. The outcome was compared with γ −γ TDPAC results. The experiments were performed under vacuum within the temperature range of 50 K - 427 K. It is found that after annealing at 873 K, the 181-Ta probe substitutes the Ti lattice site with a unique nuclear quadrupole interaction. This allowed for the precise measurement of the largest electric field gradient (Vzz) and asymmetry parameter (η). The hyperfine parameters that are obtained from the e −γ TDPAC spectroscopy agrees with that of the γ −γ TDPAC spectroscopy at room temperature, apart from a calibration factor, both from our experiments and literature [1][2]. Surprisingly, we have detected a parabolic increase of Vzz with a concave curvature at the low temperature regime (50 K - 427 K), as opposed to the linear increase at the high temperature regime (600 K - 1200 K) as found in the literature [1][2]. We hypothesize that there exist a Vzz maxima at a unique temperature of around 500 K. Although there are precise ab-initio methods that modelled the linear increase at the high temperature regime, there is a lack of such insight for the parabolic increase at the low-temperature regime. Hence, we are performing Density Functional Theory (DFT) calculations on Ta-doped TiO2

considering lattice parameters over a broad temperature range of 0 K −1200 K to obtain deeper insights into this particular temperature dependence of our experimentally measured Vzz.

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Medical imaging: from ISOLDE to the clinic?

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Cutting-edge instrumentation has been at the core of relevant discoveries in nuclear physics, and has paved the way for innovative applications and translation to other fields. State-of-the-art detector systems also play a very important role in medical imaging. They have been essential to some of the new developments in positron emission tomography (PET). One of the lines of research of the Nuclear Physics Group at Universidad Complutense deals with the development of instrumentation for nuclear physics with special focus on fast gamma scintillator detectors for fast timing measurements and time-of-flight PET (TOF-PET). In this presentation I will try to address the use of gamma detection systems in several applied fields connected to nuclear physics, and how technical developments have helped extending their scope or even opening new possibilities.

One of the applications of scintillator detectors is related to PET, which has become one of the most relevant medical molecular imaging modalities, used both in cancer diagnosis and in monitoring its response to therapy. I will discuss multiplexed PET image modalities and highlight the latest trends in medical instrumentation towards the ultimate goal of TOF-PET millimetre resolution based on ultrafast scintillator detectors.

The second example of the use of fast scintillator detectors is range verification in protontherapy. While it is recognized that external beam radiotherapy using protons has an advantage over photon therapy due to the maximum energy loss at the end of the proton range, uncertainties in the patient dose deposition still persist, preventing its full exploitation. A way to mitigate this limitation is detecting the induced gamma activity to better locate the distal end of the proton dose distribution.

Finally the presentation will address *gamma-MRI*, a new proposal for the combination of the high resolution of magnetic resonance imaging, the high sensitivity of PET, and the simplicity of single photon emission compute tomography, based on gamma detection of anisotropic emission from hyperpolarised metastable isotopes.

Trapping for nuclear physics / 6

News From the ISOLTRAP Mass Spectrometer

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Recent technical developments and experimental results from the ISOLTRAP mass spectrometer at ISOLDE/CERN will be presented in this contribution. During CERN's Long Shutdown 2 (LS2), a large variety of technical upgrades and maintenance work have been performed. Most significantly, a new offline reference ion source has been built and commissioned, combining a surface ion source and a laser ablation ion source. First results from the commissioning work will be shown, along with ideas for high-precision Q-value measurements of laser-ablated long-lived isotopes. Furthermore, since the restart of CERN after LS2 in June 2021, ISOLTRAP has performed several experiments on exotic radioisotopes and aided target and ion source developments at ISOLDE. Preliminary results for measuring ground and isomeric states in the neutron deficient region around 100Sn using Multi-Reflection Time-of-Flight Mass Spectrometry will be given.

Trapping for nuclear physics / 36

Studying negative ions in an MR-ToF device

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Negative ions lack a long-range Coulomb force. Instead, the long-range attraction is governed by an induced dipole potential which arises from the polarization of the atomic core by the additional electron. This leads to an enhanced importance of electron-electron correlation. The electron affinity (EA), which is the energy gained by attaching an electron to a neutral atom, is a quantity that gives information about the electron-electron correlation. It can be experimentally determined using the photodetachment process, where a photon with sufficient energy is used to detach an electron from a negative ion.

An accurate description of electron correlation is important for improving theoretical calculations such as for the specific mass shift which is required for extracting nuclear charge radii from experiments. We are now interested in measuring the isotope shift in the EA's of 35Cl and 37Cl. This was first experimentally measured and calculated by Berzinsh et al., where the results obtained agreed in magnitude but not in sign [1]. Following this, Carette and Godefroid were able to improve the computational method to result in a value that not only agreed with experiment but also achieved a higher precision than in the experiment [2].

Since this improved calculation, the isotope shift of 35Cl and 37Cl has not been remeasured, therefore we propose to experimentally determine this to a higher precision. To achieve this, we have coupled a negative ion source to the MR-ToF of the MIRACLS proof of principle experiment [3–5]. With MIRACLS, we can achieve a higher sensitivity by a factor of 40-700 for collinear laser spectroscopy by reflecting ion bunches in the MR-ToF which allows for increased observation time. Due to this method, the efficiency of photodetachment will increase allowing us to use continuous wave lasers which will provide us with higher precision due to the narrowband. Following the measurement with 35Cl and 37Cl, we will extend this to 36Cl which is a long-lived radionuclide. We have already artificially produced 36Cl, but studying it requires the MR-ToF technique due to low availability and to limit contamination.

After this proof-of-principle study has been complete, we can use MIRACLS to make EA measurements on short-lived radioactive isotopes that require online production. This will be especially useful to apply to elements that have lower production yields such as polonium and the actinides.

Here, we present recent developments and milestones with the negative ion collaboration at MIRACLS including the detection method via neutral particles.

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Trapping for nuclear physics / 40

Doppler- and sympathetic cooling for the investigation of short-lived radionuclides

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Ever since its introduction in the mid 1970s, laser cooling has become a fundamental technique to prepare and control ions and atoms for a wide range of precision experiments. In the realm of rare isotope science, for instance, specific atom species of short-lived radionuclides have been laser-cooled for fundamental-symmetries studies[1] or for measurements of hyperfine-structure constants[2] and nuclear charge radii[3].
Nevertheless, because of its simplicity and element-universality, buffer-gas cooling in a linear, room-temperature Paul trap is more commonly used at contemporary radioactive ion beam (RIB) facilities. Recent advances in experimental RIB techniques, especially in laser spectroscopy and mass spectrometry, would however strongly benefit from ion beams at much lower beam temperature as in principle attainable by laser cooling. In addition, sympathetic cooling of ions which are co-trapped

with a laser-cooled ion species could open a path for a wide range of sub-Kelvin RIBs.
In a proof-of-principle experiment with the MIRACLS setup, we demonstrate that laser cooling is compatible with the timescale imposed by short-lived radionuclides as well as with existing instrumentation at RIB facilities. To this end, a beam of hot 24Mg+ ions is injected into a linear Paul trap in which the ions are cooled by a combination of a low-pressure buffer gas and a 10-mW, cw laser beam of ~280 nm. Despite an initial kinetic energy of the incoming ions of a few eV at the trap's entrance, temporal widths of the extracted ion bunch corresponding to an ion-beam temperature of around 6 K are obtained within a cooling time of 200 ms. Moreover, sympathetic cooling of co-trapped K+ and O2+ ions is demonstrated. As a first application, a laser-cooled ion bunch is transferred into a multi-reflection time-of-flight mass spectrometer. This improves the mass resolving power by a factor of 4.5 compared to conventional buffer-gas cooling.
The presentation will include the experimental results of our laser-cooling studies as well as a comparison to our 3D simulations of the cooling process which paved the way for further improvements of the technique. An outlook to future experiments with laser- and sympathetically cooled ions at radioactive ion beam facilities will be given.

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Advanced MR-ToF technology for collinear laser spectroscopy and beam purification at ISOLDE

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Low energy branches of radioactive Ion Beam (RIB) facilities and experiments are faced with an ever increasing need to deliver high-quality ion beams and use them more efficiently. Experiments are commonly limited by isobaric contamination, resulting in decreased signal-to-noise ratios, systematic uncertainties caused by impure ion samples, or the need to process ever larger quantities of ions to reach more exotic isotope species of interest. This challenge is shared by various research activities at RIB facilities across different fields, such as nuclear physics, solid state physics, and medical isotope production.

A novel Multi-Reflection Time-of-Flight (MR-ToF) Mass Spectrometer operating at an unprecedented ion beam energy of 30 keV is currently being built at MIRACLS [1,2] to address these challenges. The new system will serve both as an advanced beam purification apparatus and a high-sensitivity, high-resolution Collinear Laser Spectroscopy (CLS) experiment. The extended ion sample observation time, gained by trapping and repeatedly probing a bunched ion beam, will enable CLS measurements with a significant boost in experimental sensitivity. For closed two-level systems such as even-even Mg or Cd isotopes, for instance, the improvement factor in sensitivity compared to conventional florescence-based CLS is estimated to be 30-700, depending on half-life, mass and spectroscopic transition of the ions of interest. The 30-keV MR-ToF device will in a later phase serve as a first-generation 'high-energy' advanced beam purification apparatus at ISOLDE, capable of delivering isobarically purified ion samples to downstream experiments, such as PUMA [3].

In this contribution the MIRACLS system and its application to CLS measurements and ion beam purification are presented, as well as the synergies between these aspects and the integration of the device into ISOLDE.

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Closing Remarks and Prize announcements

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