Internship M2

Development of novel machine learning techniques at KM3NeT/ORCA

Groupe GrAMM, LPC Caen - UMR 6534, ENSICAEN, Université de Caen

The neutrino is still one of the less well-known particle of the Standard Model. In the last few decades, A large set of experimental evidence has led to the discovery of neutrino flavour mixing and that neutrino are massive particles which lead to two Nobel Prizes and a Physics Breakthrough price. The picture of neutrino oscillation remains incomplete, and a large international effort is underway to complete our understanding of the role of the neutrino in the Universe. In the coming decade new experiments will shed more light on the nature of the neutrino, the ordering of the mass states and the CP violation parameters driving matter-antimatter asymmetries.

In this context the KM3NeT/ORCA observatory in the Mediterranean Sea aim to measure the mass ordering of the neutrinos using cosmic ray-produced neutrinos in the atmosphere using our planet structure as a way to select upwards high energy neutrinos and the sea as one of the largest instrumented volumes of water. The KM3NeT/ORCA detector sits at 2500 m on the sea floor and will comprise 115 lines equipped with photodetector modules to register the light cascades of high energy particle interactions.

We propose an exciting research project to develop the capabilities of the KM3NeT/ORCA analysis to explore novel machine learning (ML) techniques to reconstruct observable quantities, generate synthetic data or learn about the detector response as it grows in capability.
In this internship you will learn cutting edge ML techniques to optimise and extend the range of ML tools available to the KM3NeT collaboration. More specifically you will investigate the use of unsupervised techniques based on AutoEncoders and tests models based on recent development of generative models like stable diffusion models.

You will be working in a dynamic, international, and fast-growing group of four experienced researchers and a PhD student. You should have some knowledge in nuclear physics, particle physics and radiation-matter interactions. A good level in mathematics and some knowledge of ML Python libraries like pyTorch would be a good starting point. During the internship the student will receive some training and support to develop their knowledge in experimental neutrino physicists and machine learning as well as simulation and data analysis techniques used in many particle physics experiments.

This internship is aimed primarily at students willing to continue into a PhD thesis supported by the Chaire of Excellence ALPHA - *Apprentissage des données pour la physique des neutrinos et dosimétrie* - from the Region Normandie.

[1] https://www.km3net.org/
[2] Letter of Intent for KM3NeT 2.0, Journal of Physics G: Nuclear and Particle Physics, 43 (8), 084001, 2016 [arXiv:1601.07459].

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Laboratoire de Physique Corpusculaire de Caen
(UMR 6534 CNRS-ENSICAEN)

Proposal for a Master Thesis for the spring semester of 2023
(October 2022)

Precision measurement of the Fierz term in ^{6}He decay

Context

Experiments in nuclear beta-decay have been instrumental for the development of our current understanding of weak interactions. Precision measurements in nuclear beta decay provide today sensitive windows to search for new physics beyond the standard electroweak model which describes particles and interactions at the most elementary level. In nuclear beta decay, the "new physics" can be parametrized in terms of "exotic" scalar and tensor interactions. In the past few years, it has been recognized that for interactions involving left-handed neutrinos, measurements from beta decay can be competitive with direct searches performed at particle colliders such as the Large Hadron Collider (LHC) at CERN, provided they address the appropriate observables like for instance the beta-energy spectrum.
After an exploratory work performed at the National Superconducting Cyclotron Laboratory (Michigan State University, USA), in the beta decay of ^{6}He and ^{20}F, we are performing experiments at GANIL with both, fast and slow beams of ^{6}He. In this respect, GANIL offers a unique opportunity for such experiments since it is the only facility worldwide where both beam energies are available. The interest in using both energies resides in the associated systematic effects of experiments, which have to be very carefully studied.
The goal of this project is to perform the most precise measurement of the beta-energy spectrum in ^{6}He decay in order to deduce a parameter, which is related to the presence of exotic tensor interactions. More quantitatively, the final goal of the project is to reach a total uncertainty that will result in an order of magnitude improvement in sensitivity compared to current constraints obtained from the LHC.

Master thesis work

The work within this master thesis involves both, hands-on activities for the preparation, tests and characterization of detectors as well as contributions to data analysis and Monte-Carlo simulations. The candidate will participate in the preparation of an experiment that is expected to take place at GANIL in the summer of 2023 with a fast ion beam and, if possible, participate to the running of the experiment. This includes tests and calibrations of scintillator detectors using a digital data acquisition system. This research work is being considered to lead to a PhD thesis starting in the fall 2023.

Location

The work will be carried out at the Laboratoire de Physique Corpusculaire in Caen.

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PhD position in experimental nuclear physics

Complete fission yields in the Thorium region from inverse-kinematics transfer-induced fission

The fission mechanism is a violent complex reaction in which a heavy nucleus is split in two fission fragments. This process is strongly determined by the nuclear structure along with the nuclear dynamics that drives the system from an initial state to the final break-up through different states of extreme deformation [1].
Despite more than 80 years of intense research on fission, the complex interplay between intrinsic and collective degrees of freedom still prevents from a full microscopic description and hence, the theoretical knowledge of the process is still limited.
From the experimental point of view, the relative production of the different fission fragments, pre- and post-neutron evaporation isotopic fission yields, together with their kinetic energies are good candidates to reveal the mechanism behind the fission process. However, the access to the complete identification of fission fragments is still very challenging due to the large number of produced species – more than 300 different isotopes are produced from one fissioning system – and their low kinetic energy.

GANIL is a pioneer using the inverse-kinematics transfer-reactions to produce in-flight fission [2]. Exotic actinides are produced through multi-nucleon transfer reactions between a heavy beam – Uranium/Thorium – and light targets such as Carbon. The 300 different fragments generated from the fission of the actinides are completely identified in the VAMOS large-acceptance magnetic spectrometer in terms of mass, nuclear charge, and velocity [3]; while a silicon telescope is used to characterize the fissioning system by detecting the residual recoil emitted in the transfer reaction [4].

The fission@VAMOS project [5,6] is undergoing a detection upgrade of the silicon detection system used to tag the fissioning systems produced by transfer reactions. The existing setup will be replaced by a state-of-art device based on highly-segmented silicon detectors (PISTA). This will result in an improved selectivity and precision of the formation condition of the fissioning system (Mass, Atomic charge, and Excitation energy). The detection setup of the VAMOS spectrometer has also been improved with new high-performance gaseous detectors.

The proposed thesis is an experimental project that aim to study the fission process of light actinides in the Thorium region using the VAMOS spectrometer and the PISTA charged particle array. The successful candidate will be in charge of the multi-parameter data analysis of both apparatus, the production and interpretation of results, and dissemination of the experimental data in national and international conferences. This experimental setup is unique worldwide, hence the scientific results of this work are expected to be published on high-impact international journals and the successful candidate will be also in charge of this.

[1] K.-H. Schmidt and B. Jurado, Rep. Prog. Phys. 81 (2018) 106301
[2] M. Caamano et al. Phys. Rev. C 88 (2013) 024605.
[3] M. Rejmund et al., Nucl. Instrum. Methods A **646**, 184 (2011).
[4] C. Rodriguez-Tajes et al., Phys. Rev. C 89 (2014) 024614.
[5] D. Ramos, et al., Phys. Rev. Lett. **123**, 092503 (2019)
[6] D. Ramos, et al. Phys. Rev. C **101**, 034609. (2020)

Expected skills:
The PhD candidate is expected:
- to have a good background in nuclear structure and reactions and in the physics of fission as well as in the radiation-matter interaction.
- to have skills in computing languages such as C++ and knowledge on software packages of data analysis and simulation such as ROOT and GEANT4.
- to be a motivated person with strong communication skills and good English level.
- will join the international researcher team and take an active part in the ongoing experimental program conducted by the group.

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Master Thesis subject:

Simulation of the charge monitoring system for AdV+

Samuel Salvador

Since the discovery of the first gravitational wave in 2015 emitted by the coalescence of a Black Hole Binary (BBH), the well known LIGO (Livingstone and Hanford) and VIRGO terrestrial interferometric detectors underwent several upgrade campaigns in between different Observing runs (O_i). The latest upgrade of VIRGO called Advanced Virgo+ phase I (AdV+ phase I) was active during the run O3. Previously to this run, a defect on the electronic cards driving the electromagnets controlling the mirror positions showed that the surface of the mirrors contained electrostatic charges of unknown source(s). The defects have been corrected for O3 but the continuous reach for improving the detector sensibility might show that for the next upgrade (AdV+ phase II) and the future of interferometric detection, those charges might have a non negligible impact on the noise of the system.

It was then decided that the charges must be monitored and neutralized through different mechanisms by the beginning of Spring 2024. As the neutralizing system is being designed, the process of simulating the charge monitoring system has not started yet.

The planned design of this monitor might consists in using several electrodes located closely to the mirror used to evaluate the response of the interferometer with the application of sine waves of different voltages. However, simulations and tests must be performed before its incorporation in the detection system upgrade for O5.

Work to do: The student will have to perform several simulations using a home-made program to evaluate the electric field generated by the electrodes and deduce the force applied to the mirror. Scenarii of voltage configurations will have to be evaluated in order to obtain the most efficient and least time consuming process for monitoring the electrostatic charges.

Required skills: Skills in computing especially in C/C++ or Python and ROOT are required as well as instrumentation knowledge in particular in the basic of electric fields.

Where: LPC Caen, 6, boulevard Maréchal Juin, 14050 Caen, FRANCE

Supervision: Samuel Salvador, salvador@lpccaen.in2p3.fr

Radial flow in central heavy-ion collisions

Multifragmentation (production of multiple intermediate mass nuclear fragments (IMF, defined as $Z \geq 3$)) is well known to exhaust an important part of the reaction cross section for highly dissipative and central heavy-ion collisions in the Fermi energy domain (20 – 100 MeV/nucleon). This process has been shown to be associated to the theoretically predicted liquid-gas phase transition of nuclear matter, and as such allows to pin down the thermodynamical properties of hot and compressed nuclear systems.

Besides the accurate determination of excitation energies and temperatures reached in such central collisions, it is mandatory to study the entrance channel dependence of the decay properties of these excited and compressed nuclear sources. This can be done by measuring the centre of mass kinetic energies of the reaction products in dissipative collisions, which contains several energetic contributions: thermal, Coulomb and radial flow. This latter contribution is proportional to the fragment mass in a hydrodynamical picture while the others are not. Simultaneous measurement of masses and kinetic energies for IMFs in central collisions therefore paves the way to an experimental determination of the radial flow. Moreover, radial flow is strongly connected to the incompressible nature of nuclear matter (incompressibility term of the equation of state) and thus provides important constraints on the densities reached in such collisions, strongly required for thermodynamical studies.

Such a method has never been applied due to the lack of isotopic resolution of previous generation multi-detectors. The performances of the INDRA-FAZIA coupling, together with the high quality beams available at GANIL, will allow to measure in this way the radial flow and thus access densities reached in central heavy-ion collisions for the first time with this innovative method. This analysis will be performed on recent INDRA-FAZIA data measured in 2019 and 2022 at GANIL: Ni + Ni collisions at 32, 52, and 74 MeV/nucleons.

This internship could lead to a PhD thesis in the nuclear dynamics and thermodynamics group of LPC (Caen, France).

Requested skills: nuclear physics, data analysis, bases in object oriented programming
Duration: ~4 months starting from ~February 2023

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PhD position in experimental nuclear physics

In-source laser spectroscopy of neutron deficient Pd isotopes

The study of exotic nuclear matter and related radioactive ion beam technologies is at the forefront of modern subatomic physics. Atomic physics techniques - more specifically, optical measurements of the atomic structure - readily yields fundamental and model-independent data on the structure of ground and isomeric nuclear states. The competition and balance between nuclear shell and collective effects results in a spectacular range of shapes and sizes within nuclear systems. Such shapes and structures perturb the atomic energy levels of atoms and ions at the ppm level and although this is a small absolute effect, it is readily probed and measured by modern laser spectroscopic methods, i.e. in-source laser spectroscopy at Jyväskylä and in-gas jet laser spectroscopy at GANIL-Spiral2. These techniques are particularly suitable for the study of short-lived radionuclides with lifetimes as short as a few milliseconds, and production rates often only a few hundred isotopes/isomers per second.

The IGISOL facility, Jyväskylä, uses the ion guide method of producing exotic radioactive ion beams, providing unique access to refractory elements which cannot be extracted from typical ISOL-based facilities. In-source laser spectroscopy is one of the main workhorses of the facility, with recent developments using hot-cavity ion source techniques offering access for certain elements to the N=50 shell closure.

The S3-LEB facility of GANIL-Spiral2, will produce exotic radioactive beams by fusion-evaporation reactions, the ions of interest will be transmitted through the S3 spectrometer up to the final focal plane where the LEB (Low Energy Branch) set-up will be placed. This specific set-up will allow to access to nuclear properties of exotic nuclei by means of in-gas jet laser spectroscopy.

Both laboratories permit access to regions of the nuclear chart which are currently either inaccessible to the majority of facilities, or are challenging to probe spectroscopically due to the complexity of the atomic structure. One such region lies between the refractory systems of Zr (Z=40) which exhibit strong changes in nuclear shape, and the more single-particle-dominated region around Sn (Z=50). This transitional region serves up a rich landscape of shape transitions, shape coexistence and triaxiality.

Optical information of Pd isotopes has been the subject of two PhD thesis from students of our collaboration (Sarina Geldhof and Alejandro Ortiz-Cortes). The experiments were carried out at IGISOL facility in Jyvaskyla, Finland. The goal of such measurements was to shed light into the shell and shape evolution of the Pd isotopes, from ^{98}Pd to ^{118}Pd. The results led to two articles, one already published (S. Geldhof et al., Phys. Rev. Lett 128, 152501 (2022), focused on the changes of mean-squared charge radii. The results were compared to state-of-the-art energy density (EDF) functionals revealing a clear link between the charge radii and the pairing correlations in neutron-rich nuclei. The second article is about to be submitted (A. Ortiz-Cortes, to be submitted to Phys. Rev. C) and focuses on the odd-mass Pd systems, allowing a detailed analysis of the odd-even staggering of the charge radii to benchmark the Fayans EDF and beyond mean field models including the Gogny parametrization and SCCM methods. These results reveal the shape evolution of the Pd isotopes from strongly oblate deformation in the neutron-deficient region, through soft triaxial shapes at the mid shell and recovering the axial prolate symmetry in the neutron-rich nuclei when approaching the N=82 shell closure.

This thesis will focus on the neutron-deficient Pd isotopes, reaching the N=50 shell closure and beyond. Recent optical information on the Ag chain has been provided, with charge radii measurements crossing the N=50 shell closure for the first time in the immediate vicinity of the self-conjugate ^{100}Sn nucleus (M. Reponen et al., Nature Com. 12,4596 (2021)). It is well-known that there is a kink in the difference of mean-squared charge radii when crossing a shell closure. The result on the Ag chain reveals a difference somewhat larger than expected when compared to other (lighter) isotopic chains where spectroscopic information is available (i.e. Zn and Mo). The results were compared with theoretical calculations that fail to reproduce the observed data. In order to shed light on the N=Z region below ^{100}Sn and the kink in the mean-squared charge radii when crossing the N=50 shell gap, it is necessary to provide new optical information on the nuclei below Sn and moving towards the well-deformed Zr isotopes around N=Z=40. The planned measurements of mean-squared charge radii of the lighter Pd isotopes are of utmost importance and a natural extension to our existing work.

This thesis work will concentrate on the use of laser spectroscopy (and possible variants) to probe ground and isomeric states of neutron-deficient Pd isotopes, produced via heavy-ion induced fusion-evaporation reactions. The extracted data (nuclear spins, magnetic moments and mean squared charge radii) will be analyzed and will serve to provide fundamental insight into the shell evolution and development of nuclear collectivity away from closed. Comparison with state-of-the-art shell model theories will be sought, aiming to provide insight into the effect of triaxiality on the electromagnetic moments in the region.

The doctoral student will spend considerable time working within the laser team of the IGISOL group, thus learning all aspects of ion beam production, manipulation techniques, the use of state-of-the-art laser systems, frequency stabilization and atomic spectroscopy. In parallel, the student will also have an opportunity to take advanced courses in Jyväskylä connected to optical spectroscopy and mass measurement techniques for fundamental nuclear structure. In addition, the student will participate on the commissioning of the S3-LEB set-up at LPC-Caen (France), gaining experience with in-gas jet laser spectroscopy techniques. The thesis work will provide valuable training in methods which may be directly implemented at future large-scale facilities.

Soft and transferrable skills will also be developed including presentation work, scientific writing for publications and so forth. The thesis work will be performed in collaboration with researchers from the UK, Finland, Belgium and elsewhere. Similar efforts are underway at the CARIBU facility, Argonne National Laboratory, and therefore working within international teams will provide valuable experience for a young researcher and networking opportunities required for a possible future career.

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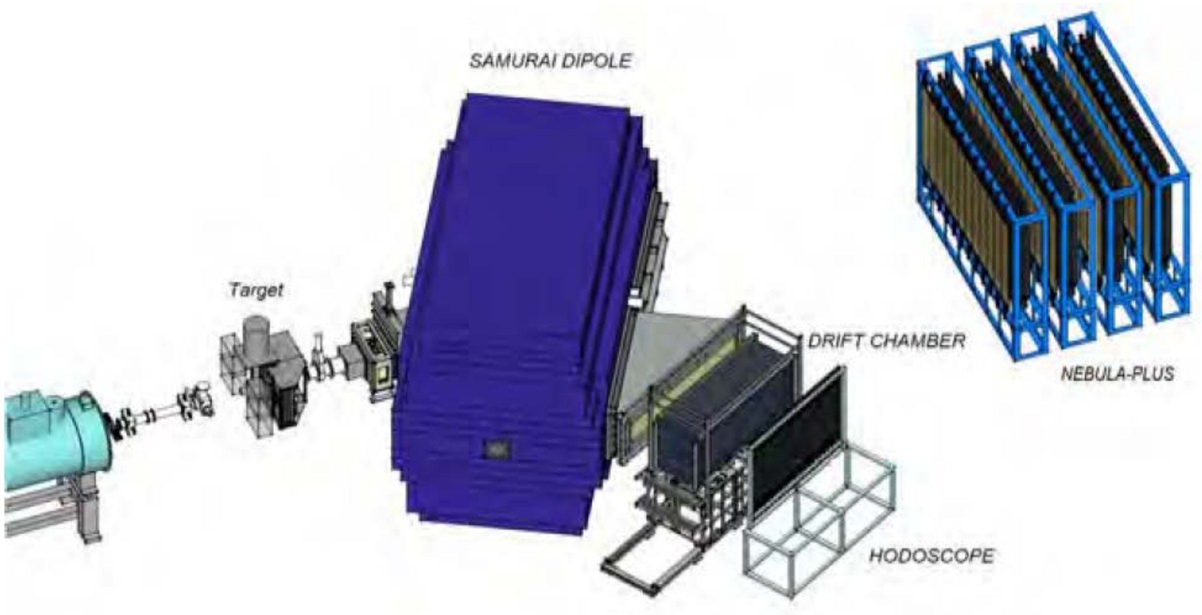
Multi-neutron detection for the investigation of exotic nuclei

Nuclear Structure group LPC-Caen: Master thesis proposal (2023)

The Nuclear Structure group at LPC-Caen studies the properties of light neutron-rich nuclei. In this context, several experiments have been undertaken at the RIKEN-RIBF accelerator facility in Saitama (Japan), probing isotopes at the neutron dripline (^{19}B, ^{22}C…) and beyond ($^{20-21}$B, ^{16}Be, ^{7}H, ^{4}n…). An ANR funded project (EXPAND) has allowed the multi-neutron capabilities of the NEBULA array to be augmented through the addition of two extra walls (the NEBULA-PLUS array, see figure), which will enter service following commissioning in December.



The aim of the internship is the implementation of **multi-neutron decay channels** in a Monte-Carlo simulation of the new NEBULA-PLUS array. The simulation has been developed within the nptool framework based on Root and Geant4, and it is part of a wider program to build a full and consistent simulation of the future SAMURAI experiments carried out by the group at RIKEN.

The candidate will check the response of the NEBULA-PLUS array to 1 neutron, and then explore the cross-talk rejection algorithms needed in the case of the detection of several neutrons in coincidence. Finally, the possible correlations in the decay of 4n channels will be implemented and compared to existing experimental data on the decay of ^{8}He into ^{4}He+4n.

A PhD focusing on an experiment using the SAMURAI+NEBULA-PLUS setup, with a start date of October 2023, will be proposed by the group.

Group members: A. Matta (matta@lpccaen.in2p3.fr), M. Marqués (marques@lpccaen.in2p3.fr), L. Achouri, F. Delaunay, F. Flavigny, J. Gibelin, N. Orr.

PhD position in experimental nuclear physics

Shedding new light on the structure of ^{56}Ni using (n,3n) reaction at NFS

The project proposes to re-investigate the nuclear structure of the doubly magic nuclei ^{56}Ni using the (n,3n) reaction from ^{58}Ni. The nuclei near ^{56}Ni are of particular interest as they are amenable to different microscopic theoretical treatments while studying the competition between single-particle and collective excitations. The collective states in ^{56}Ni involve multiparticle multi-hole excitations across the N=Z=28 shell gap from the 1f7/2 shell to the 2p3/2, 1f5/2, and 2p1/2 orbits. Excitations to the higher lying 1g9/2 orbit are necessary to explain the observed rotational bands in Cu and Zn. At high excitation energies, reaction studies have revealed evidence for hyper-deformed resonances in the ^{56}Ni compound.

While the structure of ^{56}Ni has been intensively investigated using charged particle or heavy ions collisions, the pure neutron probe was never used. The (n,xn) reactions are a long standing reaction mechanism used in the nuclear data evaluation but never used in the framework of nuclear structure. For the first time, using the unprecedented neutron flux at ~ 30MeV of the NFS facility of GANIL-Spiral2, ^{56}Ni can be populated from ^{58}Ni in a (n,3n) reaction opening a new probe and possibly new aspect of the nuclear structure of this doubly magic nucleus.

In this project, we propose to perform a prompt gamma spectroscopy of ^{56}Ni using the EXOGAM array at NFS using the (n,3n) reaction. Such new spectroscopic information is also relevant for nuclear reaction mechanism formalism (like TALYS) and nuclear data evaluation. For nuclear structure, the main motivation is the search for low spin (J=2 or 4) states from 3 to 10 MeV excitation energy possibly populating the 0+ states at 3956 keV, 6654 keV and 7903 keV observed only in $^{58}Ni(p,t)^{56}Ni$ reactions. The experiment (E838_21) was approved at the December 2021 GANIL PAC and should be schedule at the facility in autumn 2023.

This experiment is a pioneering work in the study of the nuclear structure studies using large gamma-array and fast neutron and is only possible at GANIL-Spiral2 today. If successful, this program will open new opportunity at the NFS facility.

Another aspect that will be developed in this thesis is the FAIR approach for the data (https://www.panosc.eu/data/fair-principles/). The nuclear community is going toward the OPEN Science framework and this approach requires the fundamental change of how the big data are recorded and analysed. This aspect will be included in the PhD work using the data collected at NFS as the first example of its kind at GANIL.

Expected skills:

C++ programming, nuclear physics master diploma, working in collaboration, instrumental skills.

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Ion collisions with clusters of serine: chirality and peptide bond formation

Chiral molecules cannot be superimposed with their mirror image like our hands, thus usually one refers to left (L) and right (R) enantiomers. Chirality is pivotal in life, with amino acids, the protein building blocks, being L-chiral in proteins while sugar molecules used in the backbone of DNA are R-chiral. It is believed that such homochirality plays a role in the emergence of life.

Serine is one proteogenic amino acids. It is well know for the chirality preference of its aggregates and more specifically the octamer cluster which exhibits an exceptional stability when homochiral, i.e. formed by homogeneous enantiomers of the serine molecule [1]. The present internship aims two objectives i) to study the chirality preference of serine clusters and ii) to study the formation of peptide bonds within such clusters.

The homochirality preference of serine clusters will be addressed by measuring the relative stability of homogeneous and heterogeneous clusters. Ion collisions with gas-phase clusters will be used to probe the serine clusters. Using the ion beams delivered by ARIBE the low-energy ion beam facility of GANIL (Caen), it is possible to softly ionise clusters by electron capture b the incoming projectile. Moreover one can change the amount of energy deposited in the system by changing the projectile [2]. Serine clusters will be produced by a gas aggregation cluster source. The products of the interaction will be analysed using coincidence time-of-flight mass spectrometry.
Recently, we have demonstrated that ion collisions can induced reactivity inside of clusters of molecules thus playing a role in the molecular complexity. In particular we have shown that it is possible to form polypeptide after the collision of α particles with clusters of β-alanine amino acids [2]. Here the "soft" interaction of low-energy ions plays a pivotal role avoiding the dissociation of transient reactive species. Thus the formation of peptide bonds within clusters of serine will be also addressed using ion collisions. Noteworthy no peptide bonds formation have been observed in clusters of serine by other excitation methods associated with more energy transfer.

These experimental studies at GANIL are part of an emerging collaboration with groups in Spain and Israel. Complementary studies will be performed at SOLEIL, the French national synchrotron, and can be the base of further work the group.

References:

[1] S. C. Nanita and R. G. Cooks, *Angew. Chem. Int. Ed.* **45** (2006) 554.

[2] E. Erdmann et al., *Phys. Chem. Chem. Phys.* **23** (2021) 1859.

[3] P. Rousseau et al., *Nature Comm.* **11** (2020) 3818.

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IRFU : Institut de recherche sur les lois fondamentales de l'univers

Selected for Hemantika Sengar

Saclay

DPhN/LEARN

Simulation numérique d'un dispositif de mesure des réactions de capture et de fission à n_TOF (CERN)

Spécialité Physique nucléaire

Niveau d'étude Bac+5

Formation Ingenieur/Master

Unité d'accueil DPhN/LEARN

Candidature avant le 01/02/2023

Durée 6 mois

Poursuite possible en thèse oui

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Autre lien
https://irfu.cea.fr/dphn/Phocea/Vie_des_labos/Ast/ast_visu.php?id_ast=4210

Résumé

L'objet du stage est de réaliser les simulations numériques nécessaires à la mesure des rendements de capture et de fission du plutonium-241 auprès de l’installation n_TOF du CERN

Sujet détaillé

Le plutonium (Pu) est produit dans les réacteurs à eau actuels qui utilisent de l'uranium (U) pour combustible. Le Pu-239 est produit par capture neutronique sur U-238 puis double décroissance β (U-238(n,γ)U-239 --> Np-239 --> Pu-239). Les Pu-240 et Pu-241 sont produits par captures successives sur le Pu-239. En fin de cycle, lorsque le combustible est usé, les isotopes fissiles du plutonium (Pu-239, Pu-241) contribuent significativement à la production d'énergie. Dans le cas d'un réacteur utilisant du plutonium pour combustible la contribution du Pu-241 est importante dès le début de cycle. Le Pu-241 est mal connu en raison des difficultés inhérentes à son étude, d'une part du fait de sa courte demi-vie (~14 ans) et d'autre part de sa décroissance en Am-241 dont la section de capture très élevée perturbe la mesure. L'Agence pour l'Énergie Nucléaire recommande donc d'améliorer la précision des sections de capture et de fission du Pu-241.
La section de capture du Pu-241 est environ 4 fois plus faible que celle de fission dans le domaine en énergie d'intérêt. Afin de réaliser une mesure précise de la capture il faut donc développer un dispositif permettant de détecter les gammas et d'identifier ceux provenant de la fission. Dans l'expérience proposée auprès de la source de neutrons n_TOF du CERN, les gammas issus des réactions (n,γ) et (n,f) sont détectés par un calorimètre 4pi (TAC – Total Absorption Calorimeter) tandis que les événements de fission sont identifiés par une chambre à fission (CaF) contenant les échantillons de Pu-241 placée au centre du TAC. Cette mesure permettra d’améliorer la précision de la section efficace de capture tout en apportant des informations complémentaires sur la réaction de fission (gammas prompts et section efficace).

Afin de concevoir les éléments du dispositif expérimental (CaF et échantillons notamment) et de démontrer la faisabilité de la mesure il est nécessaire de réaliser des simulations numériques. Au cours du stage le/la candidat/e contribuera à la préparation de l'expérience au sein de l'équipe d'accueil. Il/Elle réalisera les simulations numériques du dispositif expérimental (TAC + Chambre à Fission + échantillons) au moyen du code Geant4 et proposera des spécifications préliminaires pour le design de la Chambre à fission et des échantillons de Pu-241.
Le stage a vocation à être suivi d'une thèse de doctorat sur le même sujet, sous réserve d'acceptation du dossier (sujet, candidat, financement...).

Mots clés

Physique nucléaire, Neutronique, Réaction nucléaire, Structure nucléaire, Données nucléaires

Compétences

Codes de transport des particules (Geant4) et d'évolution; Programmation en ROOT et C/C++; Techniques de mesures

Logiciels

Geant4, ROOT, C/C++

Numerical simulation of an experimental setup for measuring capture and fission reactions at n_TOF (CERN)

Summary

The goal of the internship is to perform the numerical simulations necessary for the measurement of the capture and fission yields of plutonium-241 at the n_TOF facility at CERN

Full description

Plutonium (Pu) is produced in current power reactors that use uranium (U) for fuel. Pu-239 is produced by neutron capture on U-238 and then double ? decay (U-238(n,?)U-239 --> Np-239 --> Pu-239). Pu-240 and Pu-241 are produced by successive captures on Pu-239. At the end of a cycle, when the fuel is spent, the fissile isotopes of plutonium (Pu-239, Pu-241) contribute significantly to energy production. In the case of a reactor using plutonium as fuel, the contribution of Pu-241 is important from the beginning of the cycle. Pu-241 is not well known because of the difficulties inherent to its study, on the one hand because of its short half-life (~14 years) and on the other hand because of its decay into Am-241 whose very high capture cross-section disturbs the measurement. The Nuclear Energy Agency therefore recommends to improve the accuracy of the capture and fission cross sections of Pu-241.
The capture cross section of Pu-241 is about 4 times smaller than the fission cross section in the energy range of interest. In order to realize an accurate measurement of the capture it is thus necessary to develop a device for the detection of gammas and the identification of those coming from the fission. In the proposed experiment at the CERN n_TOF neutron source, gammas from the (n,?) and (n,f) reactions are detected by a 4pi calorimeter (TAC) while fission events are identified by a fission chamber (CaF) containing Pu-241 samples placed in the center of the TAC. This measurement will improve the accuracy of the capture cross section while providing additional information on the fission reaction (prompt gammas and cross section).
In order to design the elements of the detectors (CaF and samples in particular) and to demonstrate the feasibility of the measurement, it is necessary to carry out numerical simulations. During the internship, the candidate will contribute to the preparation of the experiment within the host team. The candidate will carry out numerical simulations of the experimental set-up (TAC + Fission Chamber + samples) using the Geant4 code and will propose preliminary specifications for the design of the Fission Chamber and the Pu-241 samples.
The internship is intended to be followed by a PhD thesis on the same subject, pending approval of the subject, candidate, funding, etc...

Keywords

Nuclear physics, Neutronics, Nuclear reaction, Nuclear structure, Nuclear data

Skills

Geant4 simulation code; Programmation with ROOT and C/C++ languages; Experimental techniques

Softwares

Geant4, ROOT, C/C++

PhD position in theoretical nuclear physics

Systematic studies of the continuum-coupling correlations in near-threshold states

Light weakly bound or resonant nuclei play an important role in various stellar nucleosynthesis processes. The comprehensive understanding of these nuclei requires a correct description of the multi-particle continuum. In this context, recent studies demonstrated an importance of the residual continuum-coupling correlation energy for the understanding of eigenstates, their energy and decay, in the vicinity of the decay channel(s).
It is proposed to study salient effects of the coupling between discrete and continuum states near various particle-emission thresholds using the Gamow Shell Model, i.e. the shell model in the complex-energy plane. This model provides the unitary formulation of a standard nuclear shell model in the open quantum system framework for the description of well bound, weakly bound and unbound nuclear states.
The residual continuum-coupling correlation energy has not yet been studied systematically. It is believed that the dependence of this residual continuum energy correction on the particle separation energy and on different components of the nucleon-nucleon continuum couplings, allows to understand the basic features of many near-threshold nuclear phenomena, such as the clusterization, or the change of effective spectroscopic factors in knock-out reactions with the asymmetry of proton-neutron separation energies.

Expected skills:
Advanced quantum mechanics I/II, nuclear structure and reaction theory
Good programming skills in C++ and/or Python.

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Master project - Can gravitational waves tell us if there are "hybrid" neutron stars?

Host unit: **LPC, Caen**

Contact: Dr. **Marco Antonelli** antonelli@lpccaen.in2p3.fr

Prof. **Francesca Gulminelli** gulminelli@lpccaen.in2p3.fr

Dr. **Anthea Fantina** anthea.fantina@ganil.fr

Neutron stars (NS) are the test bed for our understanding of ultra dense nuclear matter at low temperature. Their *macroscopic* properties (mass, radius, moments of inertia, tidal deformability) can be obtained by solving the hydrostatic equations in General Relativity. This guarantees a clear correspondence between the macroscopic properties and the equation of state of nuclear matter.

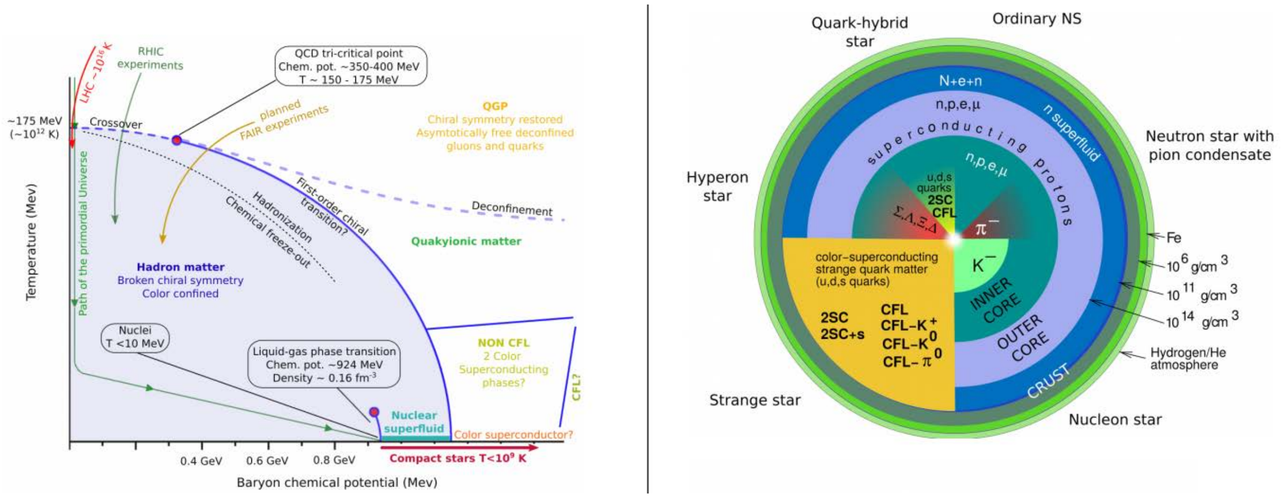

Figure 1: Left - Neutron Stars are probes for the high density and low-temperature part of the phase diagram of dense matter. Right - the internal composition of a neutron star depends on our understating of both strong and weak interactions, that is reflected on the accuracy of the theoretical models for the equation of state of dense matter. Neutron stars that are not purely nucleonic are called *"hybrid"*.

To date, the internal composition in the core of a neutron star is a mystery. It is possible that, in the inner core, nucleons are so squeezed together by gravity that their partons start to leak out. This means that, somewhere in the core, a phase transition between nuclear matter and quark matter is a real possibility. Is there any signature of such a transition in the gravitational wave data collected by Virgo, Ligo and the (yet to come) Einstein Telescope?

We will use Bayesian techniques to study how much a purely nucleonic equation of state is favoured (or unlikely) with respect to one with a phase transition to quark matter. Can we distinguish from purely nucleonic stars and *"hybrid"* ones from astrophysical observations?

Reference: Mondal & Gulminelli (2022), *Can we decipher the composition of the core of a neutron star?* `arXiv:2111.04520v2[nucl-th]`

<u>**Master project** - Relativistic bulk viscosity and energy cascade</u>

Host unit: **LPC, Caen**
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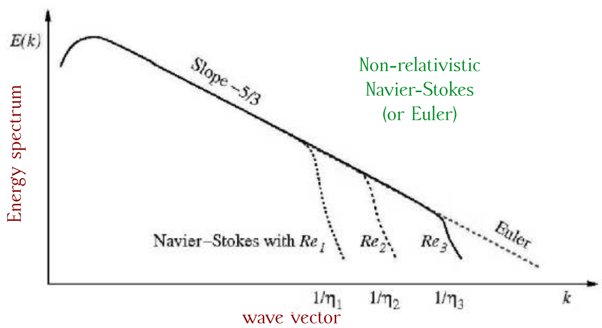
The faithful inclusion of the effects of bulk viscosity induced by the presence of chemical reactions is an important issue for simulations of core-collapse supernovae, binary neutron star mergers and neutron star oscillations, where particle abundances are locally pushed out of chemical equilibrium by rarefaction and compression of the fluid elements.



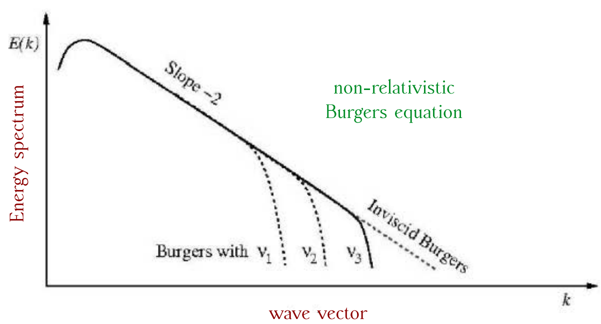


Figure 1: Energy cascade for Navier-Stokes/Euler equations and for the viscous/inviscid Burgers equation. Energy cascades from high wavelengths to lower wavelength at a predicted rate of $-5/3$ for the Navier-Stokes/Euler case. For Navier-Stokes, the kinetic energy drops drastically upon reaching a certain wavelength, referred to as the Kolmogorov scale. Similarly, for the Burgers equation the energy cascade proceeds until viscosity begins to exert its influence. In this case the slope is -2. How does this look like for a relativistic fluid with bulk viscosity or chemical reactions?

The problem is complex and requires a vast knowledge of mathematical and numerical techniques, but the simpler problem of the "shocktube" is a pedagogical one. The shocktube is a one 1+1 dimensional problem where two different thermodynamic states of a fluid are initially separated by a wall. The evolution starts when the wall is instantaneously lifted.

This simple model allows to start to understand subtle issues of relativistic hydrodynamics, like the implementation of bulk viscosity or the energy cascade, namely the transport of energy injected at the macroscopic scale (via perturbations of long wavelength) down to the microscopic scale, where the mechanical energy of fluid flow is converted into heat.

The simplest case of turbulence and energy cascade is probably given by the Burgers equation: in the reference frame moving with the sound velocity, one-dimensional weakly compressible flows are described by this equation. We will study a similar setting in relativity, and see how energy is transported across the scales of the problem when chemical reactions and switched on.

References: Camelio et al. (2022), *Simulating bulk viscosity in neutron stars: I - Formalism* `arXiv.2204.11809`, *II - Evolution in spherical symmetry* `arXiv.2204.11810` – Radice and Rezzolla (2014), *Universality and intermittency in relativistic turbulent flows of a hot plasma*, `arxiv.1209.2936`

Master project: Do pulsars diffuse in the P-$\dot{P}$ diagram?

Host unit: **LPC, Caen**
Contact: Dr. **Marco Antonelli** antonelli@lpccaen.in2p3.fr
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Pulsars (neutron stars with rotation period P) are among the most stable clocks in the Universe: since they emit a radio beam, we detect pulsed radiation with period P, exactly like for a lighthouse (Fig 1). Since angular momentum is lost (the pulsar is emitting!), the period evolves in time. It is typically possible to measure its average time derivative $\dot{P} > 0$ (the period increases in time, meaning that the pulsar is slowing down).

The parameters P and $\dot{P}$ are almost constant over the time-span of a human life. Therefore, each pulsars corresponds to a well defined point in the $P - \dot{P}$ plane. The resulting scatter plot is know as $P - \dot{P}$ diagram, see Fig 1.

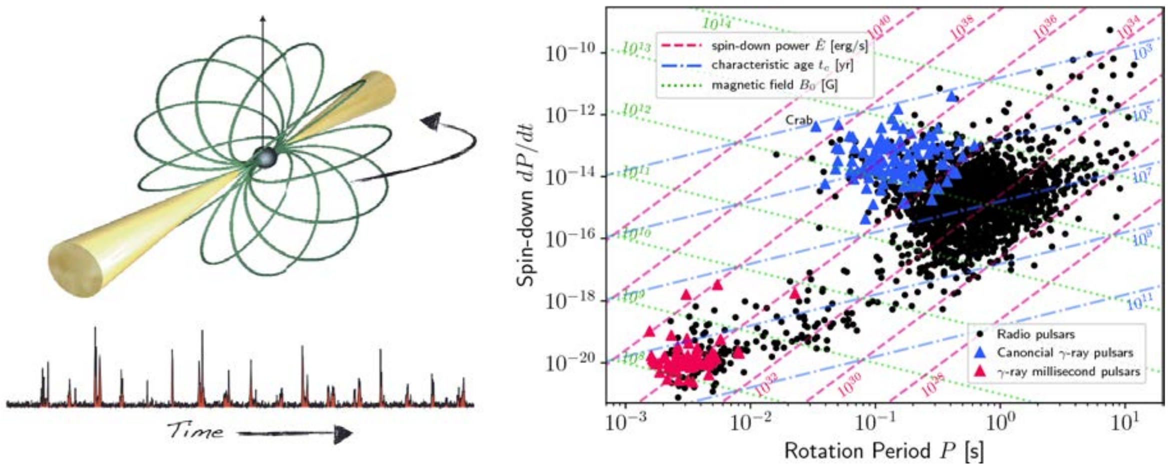

Figure 1: Left: A pulsar is a rotating neutron star emitting beamed radiation that behaves as a lighthouse: each time that the radiation beam sweeps the field view of the radio telescope we detect a pulse. Right: The $P - \dot{P}$ diagram of the known pulsar population: do fluctuations in the spin-down process induce diffusion in the $P - \dot{P}$ plane?

Project: we will set up a mathematical model for the slow time evolution of $P(t)$ in terms of a *Stochastic Ordinary Differential Equation* (SODE): this allows us to account for the fluctuations associated to both the angular momentum losses and the turbulent internal dynamics of the neutron star. Each SODE defines a related Partial Differential Equation of the diffusive type (like the Heat Equation), called *Fokker-Planck* equation. The Fokker-Planck is a powerful tool that is used in many fields (from Finance to Biology) that defines the average dynamics of an ensemble of objects that evolves randomly according to the SODE. Therefore, solutions of the Fokker Planck equation tell us how the distribution of points in the $P - \dot{P}$ plane evolves in time: is the observed distribution consistent with a diffusion process? This is relevant question if we want to understand the current observed population of pulsars and its evolution in the $P - \dot{P}$ diagram.

Reference: Johnston & Karastergiou, *Pulsar braking and the P-Pdot diagram*, MNRAS 467, 2017

PhD position in accelerator physics

Heavy ions beam dynamics in the SPIRAL2 linac and in the S^3 separator

The SPIRAL2 linear accelerator and its RFQ is optimized for light ions (protons, deuterons, helium), but it will also deliver heavier ions (O, Ne, Ar,…Ni) with great efficiency for the research topics of the S^3 spectrometer. The first objective of the PhD, is to propose and study the methods allowing to tune a heavy ion beam in 26 independent accelerating RF cavities in a fast and reproducible way up to S^3 (extrapolated tuning, energy dispersion control, study of a modification of high-energy lines).
The S^3 electromagnetic separator will use the beams from the linac to create and purify radioactive ions with a high efficiency. The complexity of its superconducting magnets requires an optimization of many parameters. Thanks to numerous hexapolar and octupolar corrections, we will be able to reduce the beam optical aberrations. The commissioning of the separator will require numerous measurements with beams and the development of an algorithm to optimize the optics for the 2 different operating modes (convergent mode for optimum transmission and dispersive mode for the measurement of the ratio M/ Q radioactive ions). The second objective is to provide the simulation tools to nuclear physicists allowing them to prepare their experiments at S^3 and to adjust the parameters of the spectrometers during the experiments. The thesis work will be based on beam dynamics simulations and experimental measurements with beams.

Expected skills:
good knowledge in accelerator physics, scientific computing (C++), math skills.

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Centre de Recherche sur les Ions, les Matériaux et la Photonique CEA – CNRS – ENSICAEN – Université de Caen

<u>Master Thesis Proposal:</u> Measure of ion-induced electron emission from biomolecules and radiosensitizers using a Velocity Map Imaging spectrometer

Ion collision with biologically relevant molecules has received increasing interest due to applications to radiation biology. Studies of the collision between multiply charged ions and molecules in the gas phase help understanding the fundamental mechanisms involved at the molecular level (fragmentation, electron emission). In the past years, absolute total or differential cross-sections for electron emission have been measured for nucleobases and amino acids. Experiments were mainly performed with bare ions such as proton, C^{6+} or O^{8+} with a kinetic energy of a few MeV. More recently, radiosensitizing agent such as halogenated nucleobases have also been investigated and it shows that the electron emission cross section is 2.4 times higher for iodouracil than uracil in the energy range [3-330]eV upon 5.5MeV/u C^{4+} collision. Such increase cannot be explained by the number of valence electrons in each molecules but rather results in the collective excitation (atomic giant resonances) of 4d correlated electrons in I atom.

Enhancement of ionizing radiation damage in biological matter due to the presence of radiosensitizer has been shown but much effort has still to be made to understand the basic mechanism and physical processes explaining this effect. We will contribute to this general endeavor by measuring absolute electron emission cross section from halogenated nucleobases.

To do so, a new crossed beam experimental set-up dedicated to the measurement of absolute cross-sections for ion-induced electron emission from atoms, molecules and nanoparticles has been recently be built. Absolute cross section are directly estimated from the number of emitted electrons Ne-, the number of projectile ion beam Np, the density ρ of the target beam (measured with a quartz crystal microbalance), the detector efficiency ε and the length l of the collision volume due to the beams overlap. Electrons are detected using a Velocity Map Imaging (VMI) spectrometer that allows collecting, at once, electrons with different kinetic energies emitted in a solid angle of 4π steradians without the need to rotate an energy analyser spectrometer. The image on the detector represent the 2D projection of the electron cloud produced by the ionization of the target and by applying an inverse Abel transform we can reconstruct the full momentum (energy and emission angle) of the emitted electrons in order to get the electron yield as a function of angle (θ), energy (Ee-~r²) or both (see Figure 1). This method, using direct determination of absolute cross section rather than normalization to known scattering processes and VMI technique rather than standard electron spectrometer, is new but has been proven accurate.

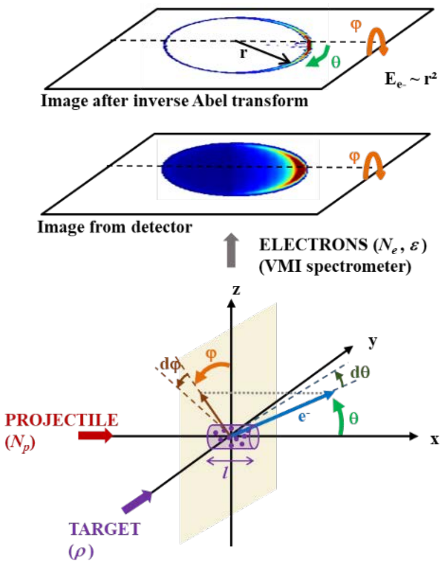

Figure 1 : Set-up schematic principle

During his/her internship, the student will participate in the measurement and analysis of the absolute cross sections of the electrons emission from biomolecules and radiosensitizers during the measurement campaigns planned for 2023 on the GANIL beamlines (C^{4+}@1MeV/u and C^{5+}@10meV/u). Moreover, in between beamtimes, measurement using a low energy ion gun (a few keV) will be used to characterize the experimental set-up.

<u>Duration:</u> 4 months, but negotiable up to 6 months under certain conditions

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Internship M2

Enhancing gamma-ray dose estimation with machine learning techniques and a novel directional spectrometer

Groupe GrAMM, LPC Caen - UMR 6534, ENSICAEN, Université de Caen

The task of mapping accurately radiation fields is central to many activities at nuclear facilities or at healthcare settings where personal dose needs to be accurately monitored. It is also an important task that would enable the practical development of techniques of online dosimetry where workers are tracked in environment and their dose are calculated in real time.
In environments where the radiation fields are unknown mapping 3D fields helps with planning and protecting people from hazardous level of radiations.

In all these settings, mapping of the radiation fields usually requires different detector systems with measurements done by highly qualified personnel, or more recently, using drones and ground-based robotic platforms. Taking advantage of a multimode detector system called nFacet 3D which provides directional and spectrometric information could speed up this difficult and time-consuming task and enable new ways of working protecting better radiation workers and the public.

We propose a research project to develop the gamma-ray energy and dose measurements using the nFacet 3D detector data. You will develop the Monte Carlo simulation and machine learning-based techniques with the goal to reconstruct the corresponding Compton Edge and estimate the dose equivalent quantities from a variety of gamma-ray radiations.

You will be working in a dynamic, fast-growing group of four experienced researchers and PhD students. You may be travelling to perform tests in the field and present your work at group meetings and meet the various actors from the local nuclear sector ecosystem. You should have a M2 level in subatomic physics or equivalent, should have knowledge in nuclear physics, particle physics and radiation-matter interactions. A good level in software with some knowledge of Python ML libraries, sensing and imaging would be a very good start.

This internship is aimed primarily at students willing to continue into the PhD thesis supported by the Chaire of Excellence ALPHA - *Apprentissage des données pour la physique des neutrinos et dosimétrie* - from the Region Normandie.

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Benoît GUILLON - guillon@lpccaen.in2p3.fr - Tél : 0231452547

Laboratoire de Physique Corpusculaire – Bâtiment D – ENSICAEN - 6 boulevard Maréchal Juin – 14050 CAEN Cedex

INTERNSHIP PROPOSAL

Title of the internship : Study and test of an in-situ plasma conditioning technique to improve the surface properties of superconducting accelerator cavities for Spiral2.

Level (L3, M1, M2)	M2
For M2, can be followed with PhD? (indicate the title of the PhD)	Study of "in-situ" plasma conditioning to improve the surface properties of accelerator components
Period / length of the internship (indicate the year)	From March 2023 / 5 or 6 months
Supervisor	David Longuevergne
Team/Service	MAVERICS
Pole	Accélérateur
Phone	01 69 15 79 44
Mail	david.longuevergne@ijclab.in2p3.fr

Description of the internship

General context: superconducting cavities and plasma conditioning

Accelerator cavities are the heart of a particle accelerator. They transform the electromagnetic energy of a radio-frequency (RF) wave into kinetic energy to the beam of charged particles. High frequency electromagnetic fields (of the order of 50 MHz to 1 GHz) resonating in such superconducting Niobium structures (of the order of ten MegaVolts / m) allow powerful accelerations (several tens of kilowatts of RF power) continuously and this by dissipating only a few Watts in liquid helium.

Over the years, it has been observed for cavities in operation in accelerators, a continuous degradation of their performance with the appearance or reinforcement of the parasitic field emission phenomenon. This phenomenon, caused by surface pollution promoting the emission and acceleration of electrons by electromagnetic fields, causes the generation of ionizing X radiations. This poses safety problems but also increases the thermal load in the liquid helium bath. This generally involves dismantling the accelerator cryomodule in order to reprocess the accelerating cavities.

In recent years, a very promising treatment, applied to the SNS accelerator for example, allowed to avoid the complete dismantling of faulty cryomodules. This involves generating a reactive plasma by RF excitation of the fundamental mode of the cavity using the RF system already in place. This "in-situ" treatment proves to be very effective in reducing the phenomenon of field emission.

MAVERICS team (Materials for Accelerator, Dynamic Vacuum and Innovative Research for Superconducting Cavities) and the Vacuum & Surfaces platform of the accelerator department of IJCLab have recently started studying this technique in order to optimize it and apply it to accelerator systems.

<u>Context of the internship: Spiral2</u>

The accelerator department is heavily involved in the design and construction of future large superconducting linear accelerators such as Spiral2, ESS, MYRRHA and most recently PIP-II. IJCLab integrated, tested and delivered to GANIL 7 accelerator cryomodules for the SPIRAL2 accelerator which is now in operation in Caen, France.

Some cavities show a degradation in their performance due to the appearance of field emission phenomenon. IJCLab has started a collaboration with GANIL to study and test this technique on quarter-wave type cavities.

<u>Goals :</u>

The work will consist of:

- Operate the plasma conditioning bench recently started at IJCLab,

- Study and optimize the generation of plasma in a Spiral2 cavity

- Study the impact of operational parameters (gas flow, pressure, RF power, etc.) and propose optimal parameters.

- Characterize the improvement of the surface condition thanks to the means of analysis available at IJCLab on the Vacuum & Surface platform (confocal microscope, electron microscope, etc.)

- Write a summary report.

Description of the team/service

The internship will take place within the MAVERICS team (Materials for Accelerators, Dynamic Vacuum and Innovative Research on Superconducting Cavities) of the accelerator department of IJCLab. The team is composed of a professor, 2 physicists, 2 research engineers, 2 post-docs and 1 doctoral student.

The MAVERICS team's research themes focus in particular on the following activities:

• Study of thin film materials and surface treatments (plasma, UV) to limit the phenomenon of multipacting (electron multiplication) in RF superconducting cavities, power couplers and beam lines of high energy accelerators.

• Development of new advanced techniques for surface treatments (thermal, innovative polishing methods, S-I-S superconducting multilayers) of niobium in order to improve the performance of RF superconducting cavities.

• Study of dynamic vacuum in accelerators and of all the phenomena that contribute to it (stimulated desorption, collective phenomena such as electron clouds in the LHC) in connection with the surface properties of the materials of the vacuum chambers.

• Study of changes by irradiation of the surface properties of materials and the influence of these changes on secondary electronic emission and molecular desorption.

For its research, the team relies mainly on the equipment of the "Vacuum and Surfaces" platform, which has equipment for UHV analysis and material characterization. It also works in collaboration with players in the field (CERN, LPSC Grenoble, CEA-IRFU, GANIL, LNF, GSI).

Master thesis proposal:

Radioresistance of Complex Organic Molecules in Space

"Where do we come from" is one of the important fascinating open questions of science and philosophy. How did life emerge, what is the origin of organic matter in the universe? Could life also emerge on other worlds than our Earth? Complex organic molecules have indeed been observed in space (comets, meteorites, molecular clouds). We need to study their radio resistance in order to know if they are sufficiently resistant to survive in a cold environment under irradiation. If so, they may be at the origin of life on earth or elsewhere. We have already started this program with nucleobases and pyridine [PhD thesis Gabriel Silva Vignoli Muniz 2018, Prudence Ada Bibang 2021]. We have shown that these molecules are sufficiently resistant to survive in dense clouds under cosmic ray irradiation. We plan now to extend the studies to other classes of molecules including nucleobase, amino acids and PAHs (Polycyclic Aromatic Hydrocarbons). These studies are also pertinent for radiobiology (exposure to ionizing radiation, cancer treatment).

Our set-up IGLIAS is capable of simulating space conditions (low temperature, vacuum, irradiation by GANIL beams and UV). It will be equipped with a new oven allowing evaporating complex molecules from powders onto cooled substrates. The effects of radiation (and) temperature on the structure and composition of the samples is quantified by infrared absorption spectroscopy and mass spectrometry. During the Master internship, this oven will be commissioned: determine the deposition rate as function of the temperature, prepare layers of nucleobases, amino acids and PAHs and measure their thickness by infrared absorption. First irradiation experiments should also be performed. The master could be followed by a Ph. D. thesis.

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Where? At CIMAP-Ganil.

Simulations of PNS experiments in the thermalized VENUS-F subcritical reactor partially unloaded

Master thesis proposal, Nuclear Waste Management Group, LPC Caen

The GUINEVERE facility [1], located at SCK / CEN Research Center (Mol, Belgium) couples the deuteron accelerator GENEPI-3C [2], built by the CNRS/IN2P3, and the fast neutron reactor VENUS-F via a tritium target. Mainly made of highly enriched uranium and lead, the VENUS-F reactor allows one to study a large variety of configurations and a large reactivity range thanks to a marked modular character. The facility was operated from 2011 to 2019 in the framework of the Euratom FP7 FREYA and H2020 MYRTE projects, and then within a collaboration between CNRS and SCK. One of the main objectives was the development of an on-line measurement methodology for the reactivity of an accelerator driven subcritical reactor (ADS).

One important by-product of this large series of experimental campaigns dedicated to subcritical reactors was a study of a potential improvement of the safety of the core loading of standard critical power reactors through the measurement of the reactor response to a pulsed external neutron source. Indeed such measurements provide estimates of the reactivity of the reactor while being loaded, which could allow one to detect fuel loading errors. A first experiment was conducted in 2019 in VENUS-F and gave very promising results [3] which triggered a renewed interest in reactor core loading surveillance using external neutron sources.

However, a complete set of experiments remain to be performed in a reactor more representative of standard Pressurized Water Reactors (PWR). The master thesis proposal is about determining the feasibility of such representative experiments in a modified version of VENUS-F, whose neutron spectrum could be thermalized by introducing hydrogenous materials in the fuel assemblies. This internship will consist in:

1) simulating and optimizing a new design of VENUS-F, its instrumentation and several loading steps;
2) simulating Pulsed Neutron Source (PNS) experiments in this modified VENUS-F in order to assess the feasibility of reactivity measurement in a thermalized VENUS-F and its representativeness of PWR behavior.

The simulations will be carried out using the stochastic neutron transport codes MCNP and/or Serpent 2. Basic knowledge in radiation measurements, Monte Carlo simulations and/or neutron physics is necessary.

References

[1] A. Billebaud, *et al.*, (2009), "The GUINEVERE Project for Accelerator Driven System Physics", *Proceedings of Global 2009, Paris, France.*

[2] M. Baylac, *et al.* (2009), *Proceedings of the International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators (AccApp '09), Vienna, Austria 2009*

[3] A. Bailly *et al., (2022), "Study of reactor core loading monitoring within the SALMON program", Proceedings of PHYSOR 2022, Pittsburgh, Pennsylvania, USA, May 15th -20th, 2022*

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Proposition de stage de fin d'étude

Ob'dO

Master thesis proposal

Niveau : Master de Physique M2, ingénieur 3A

Spécialité « Physique nucléaire – Simulations Numériques »

Dans le cadre d'un projet de collaboration, le Laboratoire de Physique Corpusculaire de Caen (UMR 6534) et la société Ob'dO (Colombelles) proposeront, à partir du printemps 2023, un stage de 4 à 6 mois à une étudiante ou un étudiant en M2 de Physique ou en 3ème année d'école d'ingénieur dont le sujet est : « Etude et développement d'un moteur de simulation d'environnement radiatif et couplage avec un dispositif de formation professionnelle en radioprotection »

Ce stage à un double objectif. Il s'agira dans un premier temps de poser les bases de l'architecture du moteur de physique SIERRA, développé au LPC Caen, pour la simulation de rayonnement dans un environnement radiatif de type industriel ou médical. Ce travail consistera à définir les composants logiciels principaux et les interfaces fondamentales d'un simulateur permettant de :

- définir des sources de rayonnement : source radioactive
- définir la géométrie de l'environnement étudié : salles, mobilier, disposition des sources ;
- définir les éléments de variabilité temporelle : déplacement de mobilier, déplacement de source, modification de la géométrie des sources, évolution de l'activité des sources ;
- planifier un programme de simulation pour le calcul de cartes (2D/3D/4D) de débit de dose ;
- réaliser les calculs de cartes de débit de dose au moyen d'outils numériques pour simuler le transport et les interactions des particules dans la matière (approche Monte-Carlo, calculs déterministes) ;
- valider les résultats physiques au moyen de méthodes dédiées ;
- mettre en forme et publier les résultats des calculs en temps-réel ou en temps différé.

Le second volet du stage consistera à définir une interface logicielle entre le moteur de simulation SIERRA et le système développé par la société Ob'dO afin d'y intégrer des fonctionnalités avancées de modélisation physique attendues du moteur SIERRA. L'interface avec le système Ob'dO impliquera de développer un prototype de protocole de communication basé sur un modèle de données des cartes de débit de doses ainsi qu'un protocole de paramétrisation de scenarii pédagogiques.

Le stage s'appuiera sur le développement de prototypes logiciels de manière à pouvoir explorer et valider les solutions proposées et offrir aux équipes du LPC et d'Ob'dO un cadre de réflexion et de travail commun. La mise en œuvre de quelques cas d'utilisation simples, définis par les deux partenaires, permettra d'apporter une preuve de principe de la faisabilité du projet. Le développement des composants du moteur SIERRA impliquera d'acquérir des compétences en programmation dans les langages C++, CMake et Bash dans un environnement sous Linux. Le projet utilisera un modèle de développement « Open source ». Le logiciel git sera utilisé comme gestionnaire de version et d'intégration. Les logiciels GEANT4 et Bayeux pourront également être utilisés comme simulateurs de référence pour la physique.

La candidate ou le candidat devra posséder une formation initiale de niveau master en physique nucléaire et/ou des particules ainsi qu'une formation en programmation informatique (Python, C++, techniques orientées objet) et en calcul scientifique (méthodes de l'analyse numérique, techniques Monte-Carlo). Elle ou il devra s'impliquer non seulement dans les aspects du projet liés à la physique des rayonnements, à la modélisation et la simulation numérique, mais également à ce qui a trait aux spécificités du produit et des services de la société Ob'dO (communication radio, technologies embarquées, cahier des charges clientèle). Elle ou il devra faire preuve d'autonomie et de créativité et d'une capacité au travail en équipe. Elle ou il devra respecter d'éventuelles clauses de confidentialité liées au projet. Elle ou il devra être francophone avec une maîtrise suffisante de l'anglais (écrit et parlé).

Ce stage s'inscrit dans un parcours incluant la préparation d'une thèse de doctorat en physique nucléaire sur la période 2023-2026 dans le cadre de la collaboration LPC/Ob'dO et d'un dispositif CIFRE. Le stage sera hébergé au sein du LPC Caen à 80 % et au sein de la société Ob'dO à 20 %. L'encadrement sera assuré conjointement par les physiciens du LPC et les ingénieurs de la société Ob'dO. Le stage sera rémunéré selon les dispositions réglementaires.

La candidate ou le candidat à ce stage – et potentiellement à la thèse de doctorat envisagée (financement non garanti à ce jour) – devra transmettre, avant le 15 novembre 2022, un curriculum vitae détaillé ainsi qu'une lettre de motivation (en français). Le recrutement donnera lieu à une audition avec les deux équipes du projet.

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Master thesis : Calculation of effective cross sections with Monte Carlo transport codes

Context

Nowadays, the need for nuclear isotopes is becoming more and more important. Isotopes are used for various applications: nuclear medicine, industry and research. The Arronax gas pedal in Nantes is a C70 cyclotron that can accelerate light particles (proton, deuton, alpha) up to 70 MeV. Arronax regularly produces isotopes for nuclear medicine: 44,47Sc, 64,67Cu, 68Ge, 82Sr... In addition, Arronax is conducting various R&D programs with academic and industrial partners to study the production of new nuclear isotopes. The nuclear isotope production mode of Arronax is based on nuclear reactions induced by different projectiles (p, d, α).

To quantify the production of a given radionuclide, it is necessary to know the effective cross section of the nuclear reaction which is in play but also those of the impurities which are produced by the parasitic nuclear reactions.

Specific subject

The effective cross-section can be measured experimentally with a high accuracy by several techniques including the stacked-foils technique used at Arronax. However, due to technical and operational constraints and complexities (costs), many nuclear reactions have not been measured or have only been measured over a limited energy range. It is therefore essential to use computational codes to obtain estimates of the missing information. We use for example TALYS which is a nuclear code specifically developed to calculate the cross sections of reactions induced by neutrons and by light charged particles or the TENDL database which was calculated from TALYS.

In the last ten years, several Monte-Carlo nuclear transport codes have been developed: PHITS (JAEA, Japan), FLUKA (CERN/INFN, Europe) and MCNP (LANL, USA). These codes use physical phenomenological models such as INCL (Liège Instra-nuclear cascade), GEM (Generalized Evaporation model) ... directly resulting from research carried out in fundamental nuclear physics, in particular in the field of nuclear dynamics and thermodynamics.

. For several years, several research teams in the world have used them to calculate the effective cross sections of medical isotope production. The first results show in general a reasonable agreement between the calculated values and the experimental values. However, a complete comparison between the calculations and the available experimental data is still missing. Therefore, it seems interesting to us to realize a systematic benchmark between these calculation codes and the results of the Arronax experiments in order to evaluate their prediction qualities.

Thesis objectives

The objective of the internship will be to work on calculations of cross sections, reaction rates, activities, radiation protection... The intern will use both the tools traditionally used by Arronax (TENDL) and also Monte-Carlo calculation codes: PHITS (JAEA), GEMINI/PACE 4 (USA), HIPSE (LPC Caen), FLUKA (CERN/INFN)
The internship work will be divided into four phases:
1) Perform calculations and systematically evaluate code cross-section predictions versus experimental data from Arronax
2) To study the sensitivity of the calculations by adjusting some calculation parameters. These are sometimes inadequate for the Arronax energy range.
3) Determine a calculation scheme adapted for future applications of Arronax
4) To carry out calculations for other applications of a collaborative project between Arronax and an industrial partner

Duration of the internship

6 months

Profile of the trainee

- Master 2 in nuclear physics
- Good knowledge in nuclear physics, especially concerning the interaction between radiation and matter.

- Taste for scientific calculations
- At ease with computer programming
- Ability to work independently and remotely
- Intellectual curiosity
- Ability to adapt
- Good level of English

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Other researchers involved in the work: A. Guertin, E. Nigron

This work could lead to a PhD thesis with an important component of experimental cross sections measurements.

Master Thesis

Evaluation of a Timepix3 counting chip hybridized to a Si semiconductor for 2D monitoring by X-ray fluorescence spectrometry

Located on the Saclay plateau in the Paris region, the CEA List is recognized for its expertise in the field of ionizing radiation measurement, with applications in the industrial, nuclear and security fields. To do this, CEA List relies on developments in instrumentation, signal processing methods and digital tools.

For several years, CEA List teams have been developing X-ray and Gamma-ray measurement systems for nuclear applications [1,2] based on technologies developed by the international Medipix collaboration supported by CERN. Presently, one of the objectives is to widen the fields of application by developing, among others, means of on-line monitoring in X-ray fluorescence spectrometry. Within the framework of these developments, this imaging technique would be applied to the control of the flow, or during a process of additive manufacturing of metal parts.

In this context, this internship aims at evaluating the performance of a pixelated detector equipped with Timepix3 electronics [3], successor of Timepix [4], hybridized with a silicon semiconductor for X-ray fluorescence measurement and imaging applications. The work will consist in setting up an experimental characterization bench, to evaluate the performances of Timepix3 in terms of energy and spatial resolutions of the detector, as well as the measurement rates and calibration strategies. The student will also rely on Monte Carlo simulation codes of particle transport, such as MCNP, Geant4, PENELOPE or Phoebe (the latter is a code developed at the CEA List), in order to dimension a collimator, which is necessary to obtain a 2D X-ray fluorescence mapping of the analyzed samples [5]. The samples studied will typically be metallic alloys used for applications in the field of metallic additive manufacturing or so-called "strategic" materials, such as rare earths.

To carry out this work, the student will need to have knowledge of ionizing radiation/matter interactions as well as computer programming languages (Python / C, C++, Matlab...). Knowledge of Monte Carlo particle transport codes would be a plus. The trainee will receive a gross monthly stipend and will benefit from the transportation facilities of CEA Saclay.

Situé sur le plateau de Saclay en région parisienne, le CEA List est reconnu pour son expertise dans le domaine de la mesure des rayonnements ionisants avec notamment des applications dans le domaine industriel, nucléaire et sécuritaire. Pour cela, le CEA List s'appuie sur des développements en instrumentation, en méthodes de traitement du signal mais aussi sur le développements d'outils numériques.
Depuis plusieurs années, les équipes du CEA List développent des moyens de mesure de rayonnement X et Gamma pour des applications dans le domaine du nucléaire [1,2] s'appuyant sur des technologies issues de la collaboration internationale Medipix portée par le CERN. Désormais, un des objectifs est d'élargir les domaines d'application en développant, entre autre, des moyens de *monitoring* en ligne en spectrométrie par fluorescence X. Dans le cadre de ces développements, cette technique d'imagerie serait appliquée à du contrôle au défilement, ou durant un procédé de fabrication additive de pièces métalliques.

Dans ce contexte, ce stage a pour but d'évaluer les performances d'un détecteur pixellisé muni d'une électronique Timepix3 [3], successeur de Timepix [4], hybridé avec un semi-conducteur silicium pour des applications de mesure et d'imagerie par fluorescence X. Le travail consistera à mettre en place un banc de caractérisation expérimentale, pour évaluer les performances de Timepix3 en matières de résolutions en énergies et spatiales du détecteur, ainsi que les cadences de mesure et les stratégies d'étalonnage. L'étudiant s'appuiera aussi sur des codes de simulation Monte Carlo de transport de particules, de type MCNP, Geant4, PENELOPE ou Phoebe (ce dernier est un code développé au CEA List), pour notamment dimensionner un collimateur, nécessaire pour obtenir une cartographie 2D par fluorescence X des échantillons analysés [5]. Les échantillons étudiés seront typiquement des alliages métalliques utilisés pour des applications dans le domaine de la fabrication additive métallique ou bien des matériaux dit ''stratégique'', comme les terres rares. Pour mener à bien ce travail, l'étudiant devra posséder des connaissances en interactions rayonnement ionisant/matière ainsi qu'en langage de programmation informatique (Python / C, C++, Matlab…). Des notions sur l'utilisation de codes Monte Carlo de transport de particules seraient un plus. Le stagiaire percevra une gratification mensuelle brute et bénéficiera des facilités de transport du CEA Saclay.

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Lieu : CEA Saclay

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