Internship in Experimental Nuclear Structure

Samurai and Nebula: exotic nuclear decay at the neutron drip line.

The nuclear structure group at LPC Caen is one of the leaders in the study of light nuclei far from stability, especially at the neutron dripline. In this context, several experimental campaigns have been conducted to investigate the heaviest isotopes of nuclei up to Z=9 at the RIKEN accelerator facility in Tokyo, Japan.

The experiments are based on the measurement of all beam velocity reaction products (neutrons, gammas and charged particles) produced in the breakup of different radioactive beams using the SAMURAI spectrometer.

During the internship, the students will be able to work, depending on their preferences, on several possible options:

1. The analysis of reaction channels leading to the 17B+n final state, in order to determine precisely the **17B-n scattering length**. The latter, of the order of -100 fm, is the largest neutron-nucleus scattering length that has been measured.
2. Developing a simulation of the SAMURAI/Nebula-Plus setup with tracking of multiple charged and neutral particles based on C++, ROOT, and Geant4.
3. Developing new algorithms for the **tracking of multiple charged particles** in SAMURAI, based on C++, ROOT.

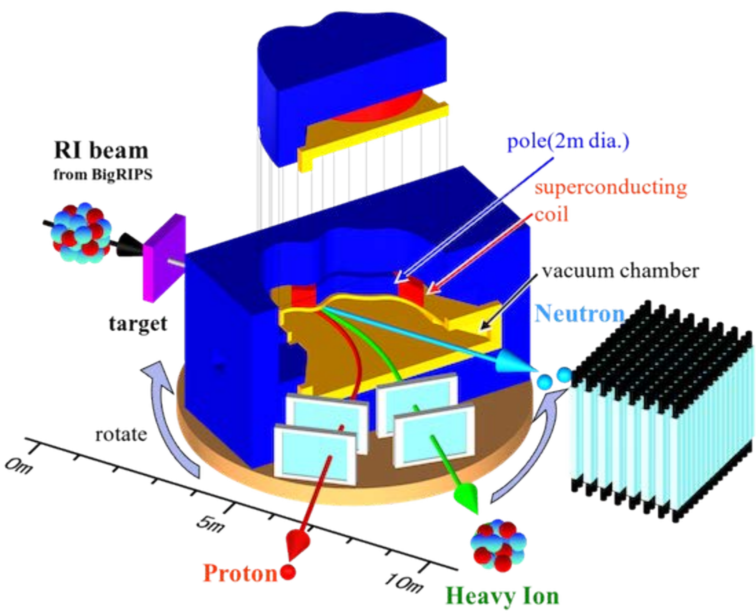

Fig.1 The samurai spectrometer and nebula neutron detector

<u>Candidate profile:</u>

Beyond a broad interest in exploring open scientific questions and basic computing skills, the internship has no specific requirements. The successful candidate will develop their skills in physical interpretation, programming and data analysis with modern, mainstream tools of the nuclear physics community, benefiting from a wide range of expertise present within the nuclear structure research group (7 researchers, 2 PhD students). Depending on the interests of the intern and their abilities and rate of progress, the technical or physics emphasis of the internship may be modified to its personal preferences.

All results and development made during the internship will directly contribute to the advancement of the group's research within the SAMURAI collaboration. The work undertaken here could form the basis for an M2 research project with the group and in the longer term a PhD project.

Supervisors: A. Matta (matta@lpccaen.in2p3.fr), M. Marqués (marques@lpccaen.in2p3.fr), F. Flavigny (flavigny@lpccaen.in2p3.fr), J. Gibelin (gibelin@unicaen.fr)

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

Proposal for a Master2 Internship Research topic
(May 2021)

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 which will result in an order of magnitude improvement in sensitivity compared to current constraints obtained from the LHC.

Internship work

The work within this internship involves both, hands-on activities for the preparation, tests and characterization of detectors to be used for the measurements with the high energy beam as well as Monte-Carlo simulations. The candidate is expected to take part to the analysis of data which will be collected in May-June 2020 with the low energy beam and to be actively involved in tests of scintillator detectors using a digital data acquisition system. This research work is not expected to lead to a PhD thesis this year.

Location

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

Contacts

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X. Fléchard: flechard@lpccaen.in2p3.fr

Study of atmospheric neutrino oscillations with the KM3NeT/ORCA telescope

LPC Caen – UMR 6534, ENSICAEN, Université de Caen

The neutrino is one of the most enigmatic ingredient of the standard model of particles physics. Despite significant experimental progress and because of its weak interaction with matter, its nature and its fundamental properties remain unknown: Dirac/Majorana, CP violation, mass hierarchy, absolute mass scale, other flavors… However, the neutrino is already being used as a new astrophysical probe. Indeed, given their tiny interaction cross-section, neutrinos travel cosmological distances without being deviated from their initial trajectory and are therefore excellent messengers. The KM3NeT (Cubic Kilometer Neutrino Telescope) project is in line with these topics, with a program dedicated to the determination of the fundamental properties of the neutrino on the one hand and to the mapping of high energy cosmic neutrino sources on the other hand.

The KM3NeT detector is a neutrino telescope installed in the Mediterranean Sea **[1-2]**. Once construction is completed, KM3NeT will consist of two sites: ARCA (Astroparticle Research with Cosmics in the Abyss), optimized for high-energy neutrino astronomy, and ORCA (Oscillations Research with Cosmics in the Abyss) for the study of atmospheric neutrino oscillations. Each site will comprise an array of several hundred vertical detection units immersed at a depth of more than 2000 m. Each detection unit consists of 18 optical modules spaced along its entire height, allowing the detection of Cherenkov light emitted by charged particles produced by the interaction of neutrinos with matter. They will constitute instrumented volumes of several megatons and will allow the observation of several thousand neutrino events per year. To date, about six lines on both sites, have been installed and data collection has already begun.

The proposed internship will be based on the experimental data from the ORCA detector. First, it will consist on extracting the neutrino signal from the detector background, composed of atmospheric muons, disintegrations of the 40K contained in seawater as well as bioluminescence. Then, the properties of the neutrinos (energy and direction) will have to be reconstructed using classification algorithms. The candidate, with an M2 level in subatomic physics, should have received training in nuclear physics, particle physics and radiation-matter interactions. He (she) should relish programming and analyzing data . He (she) should also possess a good editorial level and master English to be able to work within an international collaboration. This internship will offer a complete training of experimental physicists in fundamental particle physics as well as broader skills in data analysis.

[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].

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

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

Fitting AME2020 Masses with HIPSE package

The latest release of the Atomic Mass Evaluation (AME2020) [1] groups together more than 2600 nuclei and has been published last year. This version includes 100 new nuclei compared to the previous release AME2016. So far, this database constitutes the state-of-the-art concerning atomic masses estimations presently available for the nuclear community. I propose here to perform a global fit of the masses using an existing Thomas-Fermi model with a specific Seyler-Blanchard nucleon-nucleon effective interaction [2]. The goal is here to go beyond the estimation of the mean values for the Seyler-Blanchard parameters in order to provide also realistic uncertainties as obtained in Bayesian kind of approaches. The parameter set will then be used to benchmark the Seyler-Blanchard effective interaction with existing experimental data and also theoretical predictions concerning basic static properties of nuclei such as proton and neutron drip-lines, charge radii, neutron skins, and effectives masses. It will also provide some very interesting constraints on the nuclear equation of state at zero temperature, also to be compared with the latest available estimations. The Thomas-Fermi code with Seyler-Blanchard interaction is already available as part of the Heavy Ion Phase Space Explorator (HIPSE) model [3]. The work will here consist of *i)* realizing a complete fit procedure for the atomic masses, *ii)* evaluating its statistical relevance with existing data on basic properties of nuclei, *iii)* deriving the corresponding equation of state for uniform nuclear matter at zero temperature. A basic knowledge of FORTRAN (HIPSE code) and C++ (ROOT) is recommended. Also, some skills in numerical minimization algorithms and statistical methods are welcome.

Keywords : Atomic masses, Thomas-Fermi model, Seyler-Blanchard interaction, drip-lines, charge radii, neutron skins, nuclear equation of state, minimization algorithms, statistical methods, data analysis.

Location : Laboratoire de Physique Corpusculaire de Caen
Duration : September 2021 – January 2022

Contact :
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Phone : +33(0)2 31 45 29 62 (office), +33(0)6 70 19 31 69 (mobile)

References

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https://iopscience.iop.org/article/10.1088/1674-1137/abddb0/pdf,
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[2] W.D. Myers, and W.J. Swiatecki, *Nuclear properties according to the Thomas-Fermi model*, Nuclear Physics A**601** (1996) 141-167

[3] D. Lacroix, A. Van Lauwe, and D. Durand, *HIPSE : an event generator for nuclear collisions at intermediate energies*, Physics Review C**69**, 054604 (2004)

INTERNSHIP OFFER:
Study of the interplay between the nuclear charge and the energy loss in the FALSTAFF spectrometer.

GANIL

May 10, 2021

Introduction

The fission process is a violent reaction in which a heavy nucleus is splitted in two components, the 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 split through different states of deformation.

More than 300 different isotopes are produced in fission and the relative production between them reveals the mechanism behind the process. The nuclear charge is a key point in the identification of fission fragments but, despite of the high energy released in the process, the fragments are emitted with very low energy and the experimental access to their nuclear charge is still very challenging.

The FALSTAFF spectrometer offers a new opportunity to measure the nuclear charge of the fragments thanks to its axial ionization chamber, where the energy-loss profile of each fragment can be determined. The aim of this internship is to develop an analytical tool that will connect those energy-loss profiles with the corresponding nuclear charges.

Description of the work

The fission process has intrigued physicist for a long time from both, experimental and theoretical points of view. The role of the nuclear structure in fission is of particular interest. It is well known that, at low excitation energy, the fission products of most of the actinides follow a distribution where a light fragment with mass around 110 and a heavy fragment with mass around 140 are much more produced than the symmetric fission, where both fragments have similar masses. Only the microscopic structure of the nuclei can explain this behavior however, nuclear structure depends on the number of protons and neutrons separately while most of the experiments measures the fission-fragments masses. This makes very complicated to understand the role of both protons and neutrons in fission.

Only the simultaneous measurement of the mass and the nuclear charge of the fragments can provide precise information but the measurement of Z is still very challenging in standard spontaneous and neutron-induced fission. A new setup based on two position-sensitive Secondary Electrons Detectors and an Axial Ionization Chamber, the FALSTAFF spectrometer, has been built in order to measure the nuclear charge and the mass of the fragments at the same time. FALSTAFF is arriving to GANIL this summer and it will be operational in fall.

The aim of this internship is to explore the possibilities that this new apparatus offers in terms of nuclear charge identification. The candidate will develop analytical tools to identify the nuclear charge of the fragments based on the energy-loss profile registered in the axial ionization chamber. The main task will be the implementation of a neural network able to assign a nuclear charge to each energy-loss profile. The accuracy of this tools will be evaluated with GEANT4 simulations already developed by the collaboration as well as with real data from the spectrometer. The candidate will have also the opportunity of perform experimental work in the characterization of the spectrometer.

The intern will become familiar with the most recent tools and techniques used in the nuclear field, as well as she/he will be familiar with experimental work in a real experimental enviroment.

Requirements

Programing skills and prior knowledge of C++ will be required. Previous knowledge on the ROOT framework would be desireable.

Contact

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Jean-Eric Ducret (ducret@ganil.fr)

CENTRE DE RECHERCHE SUR LES IONS,
LES MATÉRIAUX ET LA PHOTONIQUE

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PLATEFORME D'ACCUEIL AUPRÈS DU GANIL

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 by 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 training period in 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.

Contact:

Patrick Rousseau patrick.rousseau@unicaen.fr 02.31.45.48.06

M2 internship for the n2EDM experiment

LPC - Caen

The search for the electric dipole moment of the neutron

The search for electric dipole moment (EDM) of elementary particles or composite system (electron, neutron, Hg and so on …) probes the CP symmetry. The breaking of this symmetry is chased because it is one of the conditions required to account for the baryogenesis. The LPC Caen is involved in an experiment aiming at measuring the EDM of the neutron. The experiment is carried out at the Paul Scherrer Institute (PSI) where the neutron source provides the most intense beam of Ultra Cold Neutrons worldwide.

The project has two phases. The first phase (nEDM) is over. A new worldwide limit on the neutron EDM was published in 2020. The phase II (n2EDM) has started and a new highly sensitive spectrometer is under construction. An improvement of one order of magnitude is expected on the statistical and the systematic errors. The experiment commissioning is planned for 2022.

The ongoing developments

The laboratory is in charge of the neutron detection, the measurement of the neutron polarisation, the manufacturing of the non-magnetic vacuum tank and the design and the manufacturing of the coils system (B0, correcting coils, guiding coils, spin flippers).

The internship topic

The student will work on UCN detection. The detector is gaseous. It uses a gas mixture made of CF_4 (500 mbar) and ^3He (15 mbar). In the detector, neutrons are captured by ^3He nuclei, which produces a proton and a triton. Both particles released their energy inducing the scintillation of the CF_4 gas. The corresponding light pulse is then measured by three PMTs working in coincidence. Four detectors need to be built for the final setup of the experiment. The candidate will have to test the PMTS and select the most performant ones. Then, the test of full detectors will have to be carried out. Two detector must be operational for November 2021.

For further information, please write an email to lefort@lpccaen.in2p3.fr .

Master Internship project – Erasmus Mundus

Place : Grand Accélérateur National d'Ions Lourds (GANIL)

Title : Qualification tests of the final emissive sheet detectors for S3

Project type : nuclear instrumentation

Scientific context and project details:

The future installations of GANIL (SPIRAL2, S3…) impose new constraints for the detection systems and in particular for the primary or secondary beam detectors. The beams generated have generally a high emittance, it is therefore necessary to have detectors capable of giving the position and the passage time of the nuclei one by one (up to 10^6/s) for a good reconstruction of the kinematics of the reactions. The masses of the nuclei and their energy (a few MeV / n) require in particular the use of an emissive foil detector. These detectors are already used in different configurations (Micro-channels or low pressure MWPC).

Beam detectors for S3/SIRIUS are currently being manufactured. These are low pressure 2D proportional chamber detectors. The aim of the internship is to participate in the tests of these detectors in the laboratory in order to confirm their spatial and temporal performances and to prepare beam test in 2022.

After a bibliography period, the student will get involved in the installation of detectors on the test systems, in the measurements, in the analysis of the results and possibly in simulations.

Prerequisites:

Skills are required in detector physics, nuclear physics and computer science (C / C ++).

Contact : Julien Pancin pancin@ganil.fr

Erasmus Mundus internship subject:

Tests and validation of a particle tracking gaseous detector based on µ-RWell technology

Samuel Salvador

Either for nuclear or high energy physics experiments, particle tracking devices are mandatory equipment for trajectory reconstruction and particle identification. Two main technologies are actually clashing for the leadership: solid-state based detectors and gaseous detectors. Each of them has their own pros and cons but in order to maintain the material and the financial budgets as low as possible, the gaseous technology often wins this debate.

In our case, the development of a large acceptance mass spectrometer dedicated to fragmentation cross-section measurements of a carbon beam in hadrontherapy has led us to consider the gaseous detectors as our main tracking devices. Substituting from the Gaseous Electron Multipliers (GEMs) in the high gains, low discharge rates micro-pattern gaseous detectors (MPGD), the newly developed µ-RWell detector seems appropriate for particle tracking by having a very stable operation across a wide range of conditions. They are easier to handle, less susceptible to gain fluctuations and offer the same overall performances.

However, as a fairly new technology, their performances must be optimised and evaluated as a function of several operating conditions such as the gas mixture and the applied voltage.

We recently acquired few µ-RWell detectors produced by the CERN workshop where the stripped anode patterns (x and y) allowing for position measurements are connected together on each plane by a network of resistors. This particular scheme called resistive read-out enables the measure of the position of interaction of the primary particle while requiring less electronic channels.

Work to do: The student(s) will have to set-up the detector and the experiment to be able to measure the detector performances in terms of energy and spatial resolution under several operating conditions. The gas mixtures will have to be explored in species and proportions starting on the literature data. The detector will mostly be tested in-house with radioactive sources but a proton beam experiment might be considered.

Where: LPC Caen, 5, boulevard Maréchal Juin, 14050 Caen, FRANCE

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

Developping a Bayesian method for the determination of the physical parameters of a phenomenological model by comparison with experimental data

The subject of the internship deals with the extensive comparison of a phenomenological model with experimental data in the field of nuclear reactions at intermediate energies. Such reactions are studied to extract the nuclear temperature, the mean density and the transport properties of nuclear matter in central collisions in the Fermi energy domain. To this end, a Bayesian method will be developped to estimate the most probable values of these quantities with help of a very large set of experimental data collected by the INDRA Collaboration.

The work will consist in inplementing a statistical method using Bayesian inference. After analysis of the problem, the candidate will choose the best approach to quantify the parameters and their associated uncertainties. She or he will develop the corresponding computer code.

Contact person : Dominique Durand, LPC Caen

durand@lpccaen.in2p3.fr

Alpha-decay of super-heavy elements: handling very low statistics

Erasmus-Mundus Internship
Nuclear physics and data analysis

Supervisor: David Boilley, boilley@ganil.fr

Only a handful of the heaviest elements were synthesized. There were identified by their alpha decay chains. In particular, the half-life is one of the observables that is used for the *Z* identification through the Geiger-Nuttall formula.

What the uncertainty in the half-life when only few events were detected? What is the reliability of the Geiger-Nuttal formula? Is it accurate enough to determine the *Z* number?

Determining the value of the parameters entering the various models if one of the challenges in any modelling activity. Various statistical methods have been developed over the years that will be explored in the present work. In particular, Bayesian methods proved to be very effective in case of low statistics.

The goal of the internship is to use state-of-the-art statistical methods to answer to the questions above. Once this preliminary work is achieved, the ultimate goal of the internship is to estimate the probability that the expected element was synthesized considering the whole decay chain.

Request skills: computing

Master Internship project – Erasmus Mundus

Place : Laboratoire de physique corpusculaire (LPC)

Title : Microphysics ingredients for neutron stars

Project type : nuclear astrophysics : theoretical

Background information

The problem of modelling the structure of neutron stars is currently one of the leading topics in nuclear astrophysics and the physics of compact objects, and this problem has gained further momentum since the detection in 2017 of the first gravitational wave signal resulting from the fusion of two neutron stars. This major discovery of the LIGO/VIRGO collaboration not only opens the way to a true multi-messenger astronomy of compact objects, but also creates new links between the community of gravitational waves and that of nuclear theorists who model the internal structure of neutron stars and the observable signals that result from them.

The theory team of LPC has recently joint the VIRGO collaboration, contributing to the theoretical modelling of star matter and the development of advanced statistical tools to connect theoretical uncertainties to the confidence intervals of astronomical observables.

The main competence of the team is to provide quantitative predictions of the key parameters that govern the emission of measurable signals from compact objects, based on the uncertainties associated with the underlying microphysics.

Objectives of the project

Depending on the interests of the student(s), two different subjects can be overseen:

1) A first project consists in studying the relation between the observational measurements on neutron stars (mass and radii of isolated neutron stars, and tidal polarizability extracted from the gravitational wave signal) and the internal composition of the core of the star. The dominant uncertainties are due to the theoretical modelling of the equation of state, and can be managed via a Bayesian analysis with the meta-model technique recently developed by our team. This project is more numerically oriented, and the student(s) will get acquainted with statistical analyses and Bayesian techniques.
2) A second project concerns the computation of transport coefficients (thermal and electrical conductivity, shear viscosity) in the inner crust of neutron stars, which are key quantities ruling the magneto-thermal evolution of the star. This project is in close connection with the one proposed by A.Fantina and requires analytical developments in a domain which is at the border between nuclear physics, plasma physics, and non-equilibrium statistical mechanics.

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Contact: F.Gulminelli gulminelli@lpccaen.in2p3.fr . This project will be carried out within the Theory and Phenomenology group of the LPC. A PhD student and a postdoc will be associated with the trainee's supervision.

Master Internship project – Erasmus Mundus

Place : Grand Accélérateur National d'Ions Lourds (GANIL)

Title : FORMATION AND CRYSTALLIZATION OF THE NEUTRON-STAR CRUST

Project type : nuclear astrophysics : theoretical

Scientific context and project details:

Neutron stars are among the densest objects in the Universe. Being born from core-collapse supernova explosions, they are initially very hot. Therefore, their outer layers (the so-called crust) are expected to be made of a dense liquid composed of various nuclear species immersed in a background of electron (and eventually neutron/proton) gas. As the neutron star cools down, it is generally assumed that this plasma crystallizes and remains in full thermodynamic equilibrium until eventually reaches a cold solid crystalline phase.

In the latter hypothesis, the final structure of the crust would be that made of layers, each of which consists of only one nuclear species. However, it is likely that the star does not maintain full equilibrium after crystallization. Therefore, the picture of the crust made of one-species layers is challenged, and a co-existence of various nuclear species could still persist after crystallization. This, in turn, can have important consequences on the neutron-star properties and dynamics, such as its cooling.

During the Master internship, a theoretical study of the crystallization of the neutron-star crust will be performed. In particular, the internship will be focused on the study of the properties of the (hot) crust during its formation and crystallization. The presence of the different nuclear species in nuclear statistical equilibrium at finite temperature and the liquid-solid transition during the crust formation will be analysed. Different nuclear models will be used, thus assessing the impact of theoretical uncertainties in this astrophysical scenario.

Prerequisites:

- Physics courses at bachelor level;
- Understanding of program languages (e.g. Fortran) and linux-based system at bachelor level.

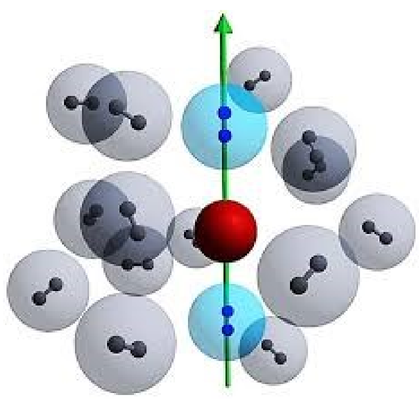
Contact : A. F. Fantina fantina@ganil.fr; F. Gulminelli gulminelli@lpccaen.in2p3.fr.

Theoretical study of alkali atoms embedded in hydrogen cluster $(H_2)_n$

The spectroscopy of alkali atoms experiences a renewed interest to perform metrology experiment to provide upper limit to the electron dipole moment. The existence of such a dipole moment is a test for particle theory like the standard model and beyond. Such a dipole is extremely weak but it might nevertheless perturb the precession dynamics of the hyperfine states of the atom. To have some chance to measure a weak signal, the target should be as dense as possible. Embedding atoms in inert matrices such as hydrogen or noble-gas solids is a possible way to enhance significantly the atomic density. A drawback of such method is the perturbation of the embedded alkali atom by the inert matrix and the possibility of multiple trapping sites. However, each trapping site possesses its own absorption and emission spectrum and we can perform a trapping site analysis by rather conventional method of visible spectroscopy associated to the atomic 6s-6p transitions.

Our goal is to search the equilibrium geometry of a Cs or Rb atom trapped in a cluster of hydrogen $(H_2)_n$. In a first step, the student will investigate the 3-dimensional potential energy surface of CsH_2 and RbH_2 molecules. This fist study will provide us the binding energy, equilibrium distance and the H_2 orientation with respect to the alkali CS or Rb. Then the student will optimize the geometry of the system at different levels of *ab initio* theory (DFT, MP2 and CCSD(T)) and by varying the cluster size. The simulation codes (MOLCAS and GAUSIAN) exist at CIMAP and the student will mainly adapt the input files to the system.

In a second step, the student will compute the vibrational spectrum of each cluster. Since the rotational energy of the H_2 molecule is relatively large with respect to the vibrational energy of the H_2-alkali modes, the harmonic approximation often used to study the vibrational spectrum breaks down. We will thus develop a simplified model to account for hydrogen vibration based on the decoupling of the fast and slow motions. We shall thus solve the model for the CsH_2 and RbH_2 molecules in a first time and then develop the calculations for larger clusters.



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Internship (Master level)

Study of the role of the resonance zone in the first heating phase of electron cyclotron ion-sources

Corresponding physicists: Laurent Maunoury & Jean-Éric Ducret, GANIL

GANIL has a long expertise of building and using ion sources based on the electron cyclotron-resonance (ECR) principle, to provide ion beams for physics experiments. Since a few years, a research program was started to improve the modelling of the ECR ion sources with the aim of improving their performances towards higher intensities and stability as well as to optimize the production of metallic ions of high charge states. Different developments and studies have been made through this program to understand both the first heating instants of the ECR ion sources with the microwave absorption inside the sources as well as the modelling of the plasma, from which high-charge ions are extracted to produce beams, leading *e.g.* doctorate theses and scientific publications. In the proposed internship, the students will focus on the so-called resonance zone of the ECR electromagnetic-field distribution, its definition, characteristics such as its volume, thickness etc. and its role in the dynamics of the electron heating. The internship will start by a review of the modelling of electron-cyclotron heating, which will be afterwards applied to the case of the axisymmetric ion-source developed at GANIL with the Pantechnic company. Using Monte-Carlo simulations, the characteristics of the resonance zone will be quantified and the electron-cyclotron-heating time distributions will be estimated. The consequences of these calculations on the plasma formation may be investigated at the end of the internship if time allows it.

Effective model for the evaluation of the dose deposition for hadrontherapy.

A very simple model has been developed by J.Colin and J.M.Fontbonne (LPC Caen) to compute the dose deposited by a charged projectile in liquid water. To be used in other materials it is necessary to determine the parameters of this model for these materials and to correlate the values of these parameters to the known characteristics of the materials (mass densities charge densities, chemical formulas, etc.). For heavy projectiles (carbon and heavier), it is also necessary to take into account the reduction of the number of projectiles and the contribution of the secondary fragments which are produced by a collision of the projectile with a nucleus of the material target. The student will have to:

- Determine the parameters of the simple effective dose deposition model for materials of medical interest (human tissues, clinical phantoms) by fitting the ranges obtained by SRiM.
- Establish the relationship between these parameters and the physical and/or chemical characteristics of the materials.
- Build an effective model to take into account the diminution of the number of projectiles and the contribution of secondary fragments produced by nucleus-nucleus collisions.
- Build the complete model which will allow to compute the dose deposition knowing the projectile characteristics (nature, energy) and the materials that the projectile will travel through.
- If there is enough time, compare the results of this effective model with Monte-Carlo simulations (GEANT4, FLUKA, ...).

Required skills :
knowledge in ion-matter interactions, programming skills in C++, knowledges of the GEANT4 and ROOT frameworks would be a plus.

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Scintillation dosimetry in protontherapy

Radiotherapy is an important modality in treatment cancer. In this domain, proton beams have ballistic superiority against photon beams. Nevertheless, the use of protontherapy to treat small volume tumors (typically less than 27 cm^3) is limited because of the lack of well adapted dosimetry tools for small beams quality assurance.

To answer this issue, a research project has been funded by the Normandie Region to develop an innovative dosimetry system based on a scintillating block of $10 \times 10 \times 10$ cm^3 and an ultra-fast camera. The camera is able to register the scintillation produced by 7 µs beams at a frequency of 1 kHz. By recording the scintillation from several points of view (thanks to mirrors or several cameras), the system will provide 3 dimensional dose distributions with a sub-millimeter spatial resolution.

Nevertheless, scintillation dosimetry presents several difficulties such as optical deformation and scintillation quenching which occurs with particles of high linear energy transfer (LET).

The objective of this training will be to study the response of a prototype developed by the GANIL and the LPC Caen. He/She will analyze measurements performed with proton beams to determine dose linearity and dose rate linearity of the system. He/she will also compare the dose distribution measured by the system to the one planned by the Treatment Planning System (TPS). Measurements might be performed at the proton therapy center Cyclhad to compare our system with a commercially available dosimeter (ionization chamber matrix or gafchromic films).

The student must have a formation in nuclear physics with a good knowledge of the detection of radiations and their interactions with matter. Knowledge in radiotherapy and dosimetry would be a plus.

The student will perform experiment analysis and comparison between different systems with the R software. The candidate must thus have an interest for analysis and potentially for Monte Carlo simulations.

This training should not be followed by a PhD thesis.

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Influence of ligand binding on DNA G-quadruplex and duplex radio-induced denaturation

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The structure-function paradigm is of outstanding importance in biology, as can be noticed by considering proteins such as collagen, antibiotics such as vancomycin or DNA strands. Denaturation of these biomolecules due to loss of their structure (unfolding, conformational change…) can thus be very harmful for living organisms, and occurs under the action of external factors such as heating, change in pressure or chemical environment, but also ionizing radiation. Direct radiation effects on proteins and DNA strands such as fragmentation, cross-linking or release of small neutral molecules have been studied, but structural changes have scarcely been investigated, despite their importance in many fields, especially medicine. Indeed, techniques such as radio- or proton-therapy or tomography use ionizing radiation: X and gamma rays, but also ion beams. On the other hand, gas-phase experimental studies by means of mass spectrometry (MS) have brought a wealth of information on biomolecular systems, thanks notably to a perfect control of their stoichiometry. These last years, in collaboration with the group of T. Schlathölter from the University of Groningen (Netherlands), we have probed the response upon ionizing radiation (photons and ion beams) of collagen mimetic peptides,[1–4] vancomycin/receptor noncovalent complexes involved in molecular recognition[5] but also DNA G-quadruplexes.[6] The latter are stable DNA structures found in telomeres (*cf.* figure 1), the protective end-caps of chromosomes in most eukaryotic organisms. With aging, the length of telomeres reduces, but cancer cells use an enzyme called telomerase to keep this length constant. Therefore, telomerase inhibition is a promising strategy in cancer therapy. Since G-quadruplexes prevent telomerase to bind DNA, ligands that stabilize this structure might help in this way.

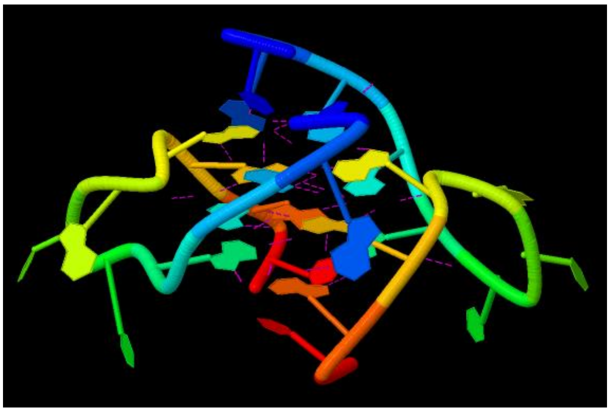

Figure 1: DNA G-quadruplex structure.

In this internship, the selected student will perform experiments consisting in irradiating DNA-ligand noncovalent complexes and analyzing the products by mass spectrometry. G-quadruplexes will be compared to duplexes, which are the usual DNA structures. He/she will also acquire and analyze data, write summaries, and give short talks to present the obtained results to other researchers. All these tasks require strong team-working abilities but also self-sufficiency.

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