Proposal for a Nuclear Talent course at the ECT* in 2017: Theory for Exploring Nuclear Structure Experiments

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Proposal for a Nuclear Talent course at the ECT* in 2017

We would like to propose a three-week Nuclear Talent course on Theory for exploring nuclear structure experiments at the ECT* for the summer of 2017. A similar course was run and organized at Ganil by Rick Casten and Piet van Isacker in 2014. The course was oversubscribed with more than 60 student applications, clearly demonstrating the need in the community for the selected topic. We believe such a course has a strong potential to attract many students, theorists and experimentalists alike.

Below we give a short motivation for the proposed course and the rationale behind the Nuclear Talent initiative. Thereafter we detail our course plans with learning outcomes, objectives and teaching philosophy, as well as various organizational and practictal matters.

Motivation

To understand why matter is stable, and thereby shed light on the limits of nuclear stability, is one of the overarching aims and intellectual challenges of basic research in nuclear physics. To relate the stability of matter to the underlying fundamental forces and particles of nature as manifested in nuclear matter, is central to present and planned rare isotope facilities.

Important properties of nuclear systems which can reveal information about these topics are for example masses, and thereby binding energies, and density distributions of nuclei. These are quantities which convey important information on the shell structure of nuclei, with their pertinent magic numbers and shell closures or the eventual disappearence of the latter away from the valley of stability.

During the last decade, the study of nuclear structure and the models used to describe atomic nuclei are experiencing a renaissance. This is driven by three technological revolutions: accelerators capable of producing and accelerating exotic nuclei far from stability; instrumentation capable of detecting the resulting reaction products and gamma radiation, often on an event-by-event basis, in situations where data rates may be many orders of magnitude less than has been traditional; and computing power adequate to analyze the resulting data, often on-line, and to carry out sophisticated theoretical calculations to understand these nuclei at the limits of stability and to unravel what they tell us about nuclei and their structural evolution.

The nuclear shell model plays a central role in guiding our analysis of this wealth of experimental data. It provides an excellent link to the underlying nuclear forces and the pertinent laws of motion, allowing nuclear physicist to interpret complicated experiments in terms of various components of the nuclear Hamiltonian and to understand a swath of nuclei by following chains of isotopes and isotoones over wide ranges of nucleon numbers. The nuclear shell model allows us to see how the structure of nuclei changes and how the occupation of specific nucleonic orbits affects the interplay of residual interactions and configuration mixing. The computed expectation values and transition probabilities can be directly linked to experiment, with the potential to indicate new phenomena and guide future experiments. Large-scale shell-model calculations represent also challenging computational and theoretical topics, spanning from efficient usage of high-performance computing aspects to consistent theories for deriving effective Hamiltonians and operators. Alltogether, these various facets of nuclear theory represent important elements in our endeavors to understand nuclei and their limits of stability. It is the goal and motivation of this course to introduce and develop the nuclear structure tools needed to carry out forefront research using the shell model as the central tool. The various projects will focus on the development of a shell-model code for simpler systems like *sd*-shell nuclei, giving the participants the essential ideas of configuraton interaction methods. During the first two weeks the aim is to develop such a shell-model code. With these insights, the students can divert into several directions the last week, from the usage of the NushellX suite of nuclear structure programs to further developing their own shell-model program. After completion, it is our hope that the participants have understood the overarching ideas behind central theoretical tools used to analyse nuclear structure experiments.

Introduction to the Talent Courses

A recently established initiative, Training in Advanced Low Energy Nuclear Theory, aims at providing an advanced and comprehensive training to graduate students and young researchers in low-energy nuclear theory. The initiative is a multinational network between several European and Northern American institutions and aims at developing a broad curriculum that will provide the platform for a cutting-edge theory for understanding nuclei and nuclear reactions. These objectives will be met by offering series of lectures, commissioned from experienced teachers in nuclear theory. The educational material generated under this program will be collected in the form of WEB-based courses, textbooks, and a variety of modern educational resources. No such all-encompassing material is available at present; its development will allow dispersed university groups to profit from the best expertise available.

The Nuclear Talent initiative has (as of May 2016) organized and run successfully nine advanced courses since the summer of 2012. Three of these courses have been run and organized (in a very successful way) at the premises of the ECT*. We hope thus, if this course gets approved by the board of directors of the ECT*, that we can continue this successful and very fruitful collaboration. The course organized by Giuseppina Orlandini *et al* at the ECT* last summer had more than fifty applicants. On average, the Nuclear Talent courses we have organized till now have had close to 40 applicants per course. We have normally accepted between 20 and 25 students, of which approximately five or slightly more have been either local students and/or fully self-supported. In 2016 the Nuclear Talent initiatives will run two courses, one in the US and one in Europe.

Aims and Learning Outcomes

This three-week TALENT course on nuclear theory will focus on the interpretation of data on the structure of nuclei using the Nuclear shell model as main tool.

Format: We propose approximately forty-five hours of lectures over three weeks and a comparable amount of practical computer and exercise sessions, including the setting of individual problems and the organization of various individual projects.

The mornings will consist of lectures and the afternoons will be devoted to exercises meant to shed light on the exposed theory, the computational projects and individual student projects. These components will be coordinated to foster student engagement, maximize learning and create lasting value for the students. For the benefit of the TALENT series and of the community, material (courses, slides, problems and solutions, reports on students' projects) will be made publicly available using version control software like *git* and posted electronically on github.

As with previous TALENT courses, we envision the following features for the afternoon sessions:

- We will use both individual and group work to carry out tasks that are very specific in technical instructions, but leave freedom for creativity.
- Groups will be carefully put together to maximize diversity of backgrounds.
- Results will be presented in a conference-like setting to create accountability.
- We will organize events where individuals and groups exchange their experiences, difficulties and successes to foster interaction.
- During the school, on-line and lecture-based training tailored to technical issues will

be provided. Students will learn to use and interpret the results of computer-based and hand calculations of nuclear models. The lectures will be aligned with the practical computational projects and exercises and the lecturers will be available to help students and work with them during the exercise sessions.

- These interactions will raise topics not originally envisioned for the course but which are recognized to be valuable for the students. There will be flexibility to organize mini-lectures and discussion sessions on an ad-hoc basis in such cases.
- Each group of students will maintain an online logbook of their activities and results.
- Training modules, codes, lectures, practical exercise instructions, online logbooks, instructions and information created by participants will be merged into a comprehensive website that will be available to the community and the public for self-guided training or for use in various educational settings (for example, a graduate

course at a university could assign some of the projects as homework or an extra credit project, etc).

Objectives: At the end of the course the students should have a basic understanding of

- Configuration interaction methods (nuclear shell-model here) as a central tool to interpret nuclear structure experiment
- Have an understanding of the

Course Content and detailed plan

Week 1.

	Lecture Topics	
Monday	Introduction and discussion of data	Discussion of separation
	Hamiltonians and mean field	Discussion of harm
Tuesday	Mean field models and Hartree-Fock theory	Discussion of harm
Wednesday	Second quantization and shell-model basics	Discussi
	Experiments and data that justify a mean-field interpretation	
Thursday	Shell-model code for a simple pairing problem	Prop
	Basic shell-model algorithm	How to
Friday	Writing a shell-model program for the simple pairing problem	V

Week 2.

	Lecture Topics	Proje
Monday	Shell-model Hamiltonians and the *sd*-shell as case	Extend shell-model to
	Efficient computations of Hamiltonians matrices	
Tuesday	Effective Hamiltonians and angular momentum algebra	Bit representations of state fur
Wednesday	Effective Hamiltonians from data	Continue wo
Thursday	Electromagnetic decays, theory and experiment	Computing angular
	Onebody transitions and what can be measured	
Friday	Electromagnetic decays, theory and experiment	Finalize shell
	Introducing NushellX	Demonstrations of Nush

Week 3.

	Lecture Topics	Projects and exerc
Monday	Electromagnetic decays and NushellX calculations	Individual projec
	More on onebody operators and transition densities	
Tuesday	Beta-decays and Gamow-Teller transitions, theory and experiments	Individual projec
Wednesday	Beta-decays and Gamow-Teller transitions, theory and experiments	Individual projec
	Using NushellX for studies of beta-decays	
Thursday	Two-body transition operators and double-beta decay	Individual projec
	Spectroscopic factors and experiment	
Friday	Double-beta decay and wrap-up of course	Work on final proj

Teaching

The course will be taught as an intensive course of duration of three weeks, with a total time of 45 h of lectures, 45 h of exercises and a final assignment of 2 weeks of work. The total load will be approximately 160-170 hours, corresponding to **7 ECTS** in Europe. The final assignment will be graded with marks A, B, C, D, E and failed for Master students and passed/not passed for PhD students. A course certificate will be issued for students requiring it from the University of Trento.

The organization of a typical course day is as follows:

Time	Activity
9am-12pm	Lectures, project relevant information and directed exercises
12pm-2pm	Lunch
2pm-6pm	Computational projects, exercises and hands-on sessions
6pm-7pm	Wrap-up of the day and eventual student presentations

If approved byt the ECT* board of directors, our preferred time slot would be from the second half of June till the second half of July.

Teachers and organizers

The organizers are

1. Alex Brown, National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA
2. Morten Hjorth-Jensen, National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA

Morten Hjorth-Jensen will also function as student advisor and coordinator.
The teachers are

1. Alex Brown, National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA
2. Alexandra Gade National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA
3. Robert Grzywacz at Oak Ridge National Laboratory and Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996-1200, USA
4. Morten Hjorth-Jensen at National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA
5. Post-doctoral fellow and advanced graduate student to be added later

Audience and Prerequisites

Students and post-doctoral fellows interested in models for nuclear structure, phenomenological techniques for interpreting and predicting the structure of stable as well as exotic nuclei. The material will be of interest, and accessible, to both theorists and experimentalists, and will include learning the practical use of shell-model approaches in order to interpret and study nuclear structure experiments.

The students are expected to have operating programming skills in in compiled programming languages like Fortran or C++ or alternatively an interpreted language like Python and knowledge of quantum mechanics at an intermediate level. Preparatory modules on second quantization, Wick's theorem, representation of Hamiltonians and calculations of Hamiltonian matrix elements, independent particle models and Hartree-Fock theory are provided at the website of the course. Students who have not studied the above topics are expected to gain this knowledge prior to attendance. Additional modules for self-teaching on Fortran and/or C++ or Python are also provided.

Admission

The target group is Master of Science students, PhD students and early postdoctoral fellows. Also senior staff can attend but they have to be self-supported. The maximum number of students is 20-25, of which only at most 15 can receive full local support.

The process of selections of the students will be managed in agreement with the ECT*.