Training in Advanced Low Energy Nuclear Theory: Report on Nuclear Talent Course on Many-body Methods for Nuclear Physics

The present document aims at giving a summary of the Nuclear Talent course on Many-body methods held at the premises of GANIL, Caen, France, from July 6 to July 24 2015.

I. REPORT ON NUCLEAR TALENT COURSE ON MANY-BODY METHODS FOR NUCLEAR PHYSICS

A. Aims and Learning Outcomes

The aim of the course is to learn how to solve complicated nuclear many-body problems beyond mean field approximations using advanced many-body methods. In this course the focus was on Breuckner Hartree-Fock theory, Coupled Cluster theory and Green's function theory. Hartree-Fock theory, full configuration interaction theory and many-body perturbation theory were also discussed during the first week. The students implemented and derived these methods in their development of a program applied to studies of infinite neutron matter using a cartesian basis. Based on the results, the most likely outcome of this course will be a scientific article where coupled cluster theory at the level of doubles excitations is benchmarked against Green's function at the same level of approximation. The course did also focus on how to write a scientific report via a final assignment which will be graded. A special emphasis was put on how to develop a large numerical project and how to benchmark the results.

All teaching material was available before the course started at the github address `https://github.com/NuclearTalent/Course2ManyBodyMethods`. A simple update on a daily basis gave the students the latest versions of the lecture notes in several formats, PDF files, HTML files with interactive Python programs and iPython notebooks. The material can also be accessed at `http://nucleartalent.github.io/Course2ManyBodyMethods/doc/web/course.html`. The material, with several source files, is freely available and can be used as a resource for new Talent courses and/or for self studies. The students which were not familiar with second quantization and basic many-body topics were asked to use the introductory material which was made available well in advance. This material was used by the more advanced students as well.

B. Detailed Course Content

The detailed content of the course was

- Basic many-body physics, hamiltonians, setup of Slater determinants and single-particle basis. Rehearsal of basic many-body physics and second quantization
- Hartree-Fock theory and many-body perturbation theory
- Full configuration interaction theory
- Bruekcner Hartree-Fock theory
- Coupled cluster theory
- Green's function theory
- Dispersive optical model and correlations and experiment
- Properties of infinite matter with an emphasis on neutron star physics
- Simple properties of nuclear forces
- How to build a scientific project and write a good scientific report

The course ended with a final assignment. The students could select whether they wanted to apply Brueckner Hartree-Fock theory, Coupled Cluster theory or Green's function theory. The final projects are listed at `http://nucleartalent.github.io/Course2ManyBodyMethods/doc/web/course.html`. The final assignment is graded with marks A, B, C, D, E and failed for Master students and passed/not passed for PhD students. Out of 25 students, seven students indicated that they would hand in the final report, with deadline September 30. Four handed in their final reports for grading and eventual credit transfer.

C. Learning outcomes

The main learning outcome within the time span of three weeks, was to have the students understand the basics behind many-body methods like Hartree-Fock theory, Brueckner Hartree-Fock theory, Coupled Cluster theory and Green's function theory. The links between theory and experiment were emphasized, in particular the links between dispersive optical potential models and experiment. The students had to write a program which implemented the Hartree-Fock method in a cartesian basis for neutron matter. Based on this program, more than half the students opted for developing a Coupled Cluster program with doubles excitation only whereas the remaining students developed a Green's function code at a similar level of approximation. All students were able to develop a Hartree-Fock program for infinite matter using a simpler model for the nuclear forces, the so-called Minnesota potential. And most students developed either a Coupled Cluster code or a Green's function code.

D. Teaching

The course was 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 is approximately 170 hours, corresponding to **7 ECTS** in Europe. The days were organized as follows: 9-12 lectures, time for exercises with assistance (including lunch) till 18 (3 hours of allocated exercise sessions per day). The course was held at the premises of GANIL, Caen, France, from July 6 to July 24 in 2015.

E. Teachers and expenses

Carlo Barbieri (University of Surrey), Wim Dickhoff (Washington University, St Louis), Gaute Hagen (Oak Ridge National Laboratory), Morten Hjorth-Jensen (Michigan State University and University of Oslo), and Artur Polls (University of Barcelona). Marek Ploszajczak (Ganil) and Francesca Gulminelli (University of Caen) were the local organizers. Ganil covered all expenses except travel for all students (except two that were supported by FUSTIPEN) and two teachers (Barbieri and Polls). Dickhoff, Hagen, and Hjorth-Jensen had their local expenses covered by FUSTIPEN. The students used the university dormitories. Lunches and dinners were provided by Ganil. All travels were covered by the home institutions.

F. Participants and their home institution and nationalities

The target group for the Nuclear Talent courses is Master of Science students, PhD students and early post-doctoral fellows. There were experimentalists among the applicants. Out of 34 applicants, 26 students were selected. Priority was given to Master of Science students and early PhD students. The applicants who were not admitted, were either post-doctoral fellows or PhD students on the verge of finishing their theses. One student had to cancel the participation two weeks before the course began. In total 25 students attended the course for its full duration. Three of the accepted students were experimentalists.

The students were expected to have operating programming skills in Fortran/C++/Python and knowledge of quantum mechanics at an intermediate level, with basic knowledge of many-body physics. It was a rather heterogeneous group, with some students being rather knowledgeable in advanced quantum mechanics and programming, while other students had a more limited background. Irrespective of this, all students were able to solve the pairing model using many-body perturbation theory and/or Coupled Cluster theory or Green's function theory. Most students were also able to perform Hartree-Fock calculations in a cartesian basis for neutron matter knowledge. Most students were able to implement coupled cluster theory at the level of doubles excitations or Green's function theory at a similar level of approximation.

Of the 25 students, five were Master of Science students and one was a post-doctoral fellow at Ganil. Of the PhD students, the majority were in their first two years. Eleven nationalities (and three continents) and 16 different institutions/affiliations were represented. The students and their respective institutions and nationalities are listed in the table below.

On average, the students performed very well. It was an excellent and very active group. Four students handed in final reports for grading and credit transfer.

Name	Level	Institution	Nationality
David Arturo Amor Quiroz	PhD	Mexico City	Mexico
Mackenzie Atkinson	PhD	Washington University	USA
Pawel Baczyk	PhD	Warsaw University	Poland
Matthew Barton	PhD	Surrey	UK
Nathan Brady	MSc	Univ. of Texas AM Commerce	USA
Bartholome Cauchois	PhD	GANIL	France
Sijie Dai	PhD	Beijing University	China
Quentin Deshayes	PhD	LPC Caen	France
Dong Ding	PhD	Washington University	China
Guoxiang Dong	PostDoc	GANIL	China
Alexandru Dumitrescu	PhD	NIPNE Bucharest	Romania
Quentin Fable	PhD	GANIL	France
Guan Jian Fu	PhD	Shanghai Jiao Tong University	China
Maciek Konieczka	MSc	Warsaw University	Poland
Simon Lecluse	MSc	KU Leuven	Belgium
Justin Lietz	PhD	MSU	USA
Alexis Mercenne	MSc	GANIL	France
Samuel Novario	PhD	MSU	USA
Nathan Parzuchowski	PhD	MSU	USA
Selen Saatchi	PhD	Middle East Tech. Inst. Ankara	Turkey
Robin Smith	PhD	University of Birmingham	UK
Matthias Verlinde	MSc	University of Leuven	Belgium
Herlik Wibowo	PhD	Western Michigan University	Indonesia
Qiang Wu	PhD	State Key Lab., Beijing University	China
Latsamy Xayavong	PhD	CENBG Bordeaux	Laos

II. SUMMARY AND RECOMMENDATIONS

Overall, this course was a very positive experience for both teachers and students. The support from GANIL, and its year-long experiences with running Talent course, was central to the success of the course. Of uttermost importance was Marek Ploszajczak's help with all administrative matters, from housing to essentially all practicalities. Without his help and his enthusiastic support, it is unlikely that this course could ever have been organized. Marek was also present at all lectures and organized a lovely excursion to scenic places in Normady as well as social dinners for students and teachers. Marek's help was highly appreciated by all of us, students and teachers alike.

Even though the students were exposed to quite some tough formalism in a short time period, and they all came with a rather heterogeneous background, they all managed to write codes to study infinite matter with either Hartree-Fock theory, Coupled Cluster theory or Green's function theory. Having well-defined projects prior to the beginning of a course plays a central role in the final success of the course. The interactions between students and teachers in the afternoon sessions were a central part of this success. The reports from the students are included as a separate file.