Nuclear Physics courses and which competences should our students have?

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Motivation and questions

- Develop structured courses/modules which will provide our students with a modern education in nuclear physics
- Modules/courses should contain a high-level of synchronization
- A computational perspective is essential. In 2020 it is expected that one out of two jobs in the STEM fields will be within computing
- What kind of competences should our students have?
- Should we develop learning outcomes?

What are our needs and how do we contribute to the community as a whole?

Local situation at MSU

We have at MSU a

- basic survey course PHY802 and three basic nuclear physics courses
- structure,
- reactions and dynamics and
- Nuclear Astrophysics.

These basic courses have a duration each of 30-40 hours (2-3 credits).
We have also advanced courses on Special topics in Nuclear Physics like PHY 989.

Nuclear structure course/module PHY981

- Experimental information
- Single-particle properties and mean-field
- second quantization
- Hartree-Fock theory
- Nuclear forces
- Shell model
- Transitions (EM and β-decays
- Computational elements: build a Hartree-Fock code and/or a shell model code (diagonalization)
- etc

Nuclear dynamics course/module PHY982

- Direct reaction theory and applications
- Reactions of light and heavy ions, from low to relativistic energies
- Single-channel scattering
- Integral forms for scattering. Generalizing to many channels
- Collective couplings. Single-particle couplings. Coupling to the continuum
- Transfer reactions. Breakup reactions
- Adiabatic reaction models. Semiclassical approximations (Eikonal and time-dependent approaches)
- Capture and fusion reactions
- R-matrix methods
- Microscopic models for reactions
- Several computational exercises
- etc

Nuclear astrophysics course/module PHY983

- Neutrinos
- Equation of state for dense matter
- Masses - Stability and Decay
- Reaction Rates
- Beta decay Rates
- The Life of Stars: Stellar burning stages, Hydogen burning, Other burning stages
- The Death of Stars: Supernovae, Neutron Stars and White Dwarfs
- Beyond Iron I: r-process, s- and p-process
- Hydrogen burning at the extremes, the rp process
- etc

Advanced modules and more needs, NSCL

- PHY 989 Special topics in nuclear physics, fall 2015 (Pawel and Bill), advanced reaction theory
- Alex taught PHY 989 on Nuclear shell model studies, based on the background (and learning outcomes) from PHY 981, nuclear structure, fall 2016
- Scott B and MHJ taught a 2 credit module on nuclear forces fall 2017. Bill Lynch and Pawel taught also PHY 989 with an emphasis on advanced reaction theory topics

Student background and our education

- Heterogenous group of students with varying background
  - Only few students have a good training in scientific computing
  - Learn computing by looking at recipes, no deep learning and competence
  - Difficult to transfer to new problems
- Need a more coherent education in computational science and physics
  - FRIB/NSCL and PA in collaboration with CSME develop strategies for including computational elements in basic education and graduate education. Dual PhD.

Computing competence is in general weak or lacks totally.

What about recommending the following to our graduate students?

- Basic courses
  1. PHY 802
  2. PHY 981
  3. PHY 982
- Additional knowledge and courses
  1. Quantum field theory
  2. Course on Nuclear Forces (not every year), from LQCD to EFT
  3. Advanced module on nuclear structure and reacton theories
  4. Many-body theory for the nuclear many-body problem
  5. More
- The dual PhD with CMSE as a way to enhance the computing skills

To think of

- How many basic courses can an institution offer, and which courses should be offered?
- How can the FRIB theory alliance be used to coordinate an advanced training in nuclear physics?
- How to integrate the (*ad hoc*) Nuclear Talent courses/initiative in our education?
- Most courses offered are theoretical ones. We need a better coordination between theory and experiment.
- Is it possible to integrate material developed in different Talent courses, offering thereby a coherent source for educating the next generation of nuclear physicists? Keyword: Modularization of topics.
- Role of computations.