Introduction to nuclear physics with accelerated beams
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The scientific motivations of nuclear physics are often considered to be difficult to understand for the other communities, as it seems that there is not a *single* central question to our field, but many questions that may not be considered as so fundamental.

On the one hand, I think that our community is partly responsible for this misunderstanding in trying to defend many topics on the same footing. On the other hand, I also think that there is a large number of fascinating topics that are relevant to nuclear physics from the sub- *fm* scale to the size of a star of up to 10 *km* size for neutron stars and 10^5km or more for stars on their main sequence. It is important to stress that nuclear physics allows the understanding of a large number of astrophysical processes, starting from our closest star the sun, novae, X-ray bursts, core-collapse supernovae, up to the densest and most compacts objects in the universe emitting gravitational waves during the merging of two neutron stars and existing only during a few 100 of milli-seconds.

It is important to remind that three of the four existing forces strongly impact the properties of a nucleus (e.g. with respect to binding energy and decay), and that all the existing forces are required to model a neutron star, which is a kind of giant nucleus on average, but which could contain hyperons or to have a core that experience phase transition to the quark and gluon plasma. The atomic nucleus is a unique system in quantum mechanics as it is composed of two fluids in mutual interaction, protons and neutrons, which could abruptly change the properties between neighboring nuclei. It is also unique as it is responsible for its own mean field potential, which can therefore change significantly while the number of protons and neutrons occupying various orbitals is varied. This leads to rich phenomena in shell structure properties and for instance, to the appearance of magic number (8, 20, 28, …) when a large energy gap is present between occupied and valence orbits. While the concept of magicity was well-established from the 40's (Maria Goeppert-Mayer) up to the late 70's, the vast number of experimental investigations carried out worldwide has led to a complete change of paradigm.

Suppose for a while that our world exist in a very different context. If we imagine ourselves leaving on a planet composed of neutron-enriched matter, in the suburb of a neutron star for instance, then none of the magic nuclei 8, 20 and 28 observed in the valley of stability would have been found. Thinking about magic nuclei may even be inconceivable there. Indeed, in place of a much larger excitation energy (by a factor of 3-4) corresponding to promoting nucleons across the shell gaps for magic nuclei, no enhancement would have been found at 8, 20, 28 for neutron-rich nuclei. This feature came as a striking surprise for theoreticians. It was progressively realized that hitherto unknown components of the nuclear force are present far from stability, with decisive impact of central, spin-orbit and tensor components, depending on the region of the chart of nuclides that is under study.

Travelling from the neutron drip-line towards the so-called valley of stability by adding protons to these neutron rich nuclei, herewith equilibrating their number, shed light to totally new phenomena which would be difficult to understand from a "neutron rich side". The proton-neutron forces in presence create shell gaps and magic nuclei, and make them more stable and therefore more abundant than their neighbors. It turns out that these magic nuclei such as C, O, Ca are indeed so crucial for “our” life and it is important to understand how they are formed in stars. For heavier neutron rich nuclei, such a dramatic disappearance of magicity (50, 82 and 126) has not been evidenced so far, and we need to explore systems farther from stability to understand why. Note that these magic nuclei will be the main progenitors of stable nuclei, after their decay back to stability. We dispose of a stronghint of their relative resistance to the N/Z ratio from the observation of twin peaks in the abundance curve of the elements, whose location is connected to the existence of shell gaps at 50, 82 and 126. One of these twin peaks at lowest mass is connected with a nucleosynthesis scenario involving a large neutron number as compared to protons and is typically present in neutron star mergers, while the one at higher mass is connected with a process involving less neutrons and occurring close to stability, as in the dredge up of red giant stars. The recent discovery of the merging of two neutron stars has demonstrated, by its late kilonova electromagnetic emission and reddening, that r-process nuclei as Lanthanides (present in most of the advanced technology objects nowadays) are copiously produced there.

Summarizing this part, we could say that *the role of nuclear physics would be to understand the production of energy and elements in the universe (comprising earth).* This poses many questions as: how does a core-collapse supernova explodes, what happen after the merging of two neutron stars (kilonovae), what is the role of neutrino and electron interactions in these transient objects, how well the (neutron-rich) matter incompressibility is governing the fate of the implosion a nascent neutron star or a black hole? How is the diversity of elements synthesized in stars and in the cosmos? Coming back to earth, one could ask ourselves what is the best way to produce energy? Is it possible to synthesize a super-heavy element that was not formed in any stellar process, or was not strong enough to survive since then?

But nuclear physics is not only restricted to this already vast endeavor. It is amazing to realize all the effects that the interactions between these nucleons can lead to. One can quote quantum vibration, rotation and back-bending ‘similar’ to neutron star glitches, superfluidity (usually BCS), various modes of matter compressibility or dipole motions of protons and neutrons in phase or out of phase whose understanding impact the equation of state of nuclear matter, existence of magic nuclei, phase transitions leading for instance to the vaporization of a nucleus.

Close to the proton or neutron driplines, new phenomena appear as the nucleus behaves as an open quantum system. There, the formation of clusters and halo nuclei and perhaps of gigantic Effimov states is observed, some major symmetries are broken, softer degrees of compression and dipole modes are observed and need to be understood and connected to stellar objects, and the emergence of a Bose Einstein condensate is also searched for at the drip line. New concepts need to be used, in synergy with other disciplines. The study of nuclei at the drip line requires very high-intensity secondary beams.

All these phenomena represent challenges for theoreticians for which the ultimate goal would be to be able to *model all observed phenomena from the fm scale of nucleus to size of stars, using interactions based on first principles*. The field is extremely active, with a lot of synergies with other disciplines. For instance, cold atom gases stand for a highly controllable system where the (very simple) interaction between its constituents can be modified at wish to explore limits, such as the unitary one, where a close connection exists with nuclear systems. Nuclear many-body theories can also be tested in such systems. The modeling of chemistry and of chemical reactions are largely rooted into density functional theory in a similar way as it is in nuclear physics. Cross-fertilization between various fields linked by being the play-ground of many-body physics have been very important in the past and will continue to inspire theorists in the future.

The present scientific council will show which accelerators (with energies ranging from few MeV/A at SPIRAL 1 to GeV/A at FAIR), instruments (gamma-ray detectors AGATA, PARIS and nu-ball, neutron detector EXPAND, charged-particle detector GRIT), and reactions (e.g. fusion, transfer, Coulomb excitation, knock-out) are needed to explore the experimental physics items mentioned above.