Ab-initio description of few-particle collisions

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Theoretical description of the quantum-mechanical collisions turns out to be one of the most important and complex problems in theoretical physics. In the last years, following the fast evolution of the computing power, several methods have been developed to solve exactly bound state problem of the systems containing dozens of particles [1-3]. On the other hand exact description of the particle collisions remains limited to N=4 systems. The difficulty is due to the fact that the wave function of the colliding system, unlike the bound state one, is not compact and exhibit complex asymptotic behaviour. Nevertheless very recently three or four different methods have been proposed, which allow to treat problem of multi-particle collisions using bound state like techniques with compact basis [4-7]. One of the PhD supervisors is a leading contributor in this domain [6]. **During the PhD, student will explore this rapidly developing field with many possible multidisciplinary applications in nuclear, atomic, molecular physics and astrophysics.** Student will also have the possibility to learn the variational methods which allow to consider systems beyond N=4 [8].

First realistic application is related with some ongoing projects in CERN [9-11], which aim to produce and manipulate antihydrogen atoms. By manipulating antihydrogen atoms many important properties of the antimatter can be learned. One of such projects is called GBAR (Gravitational Behaviour of Antihydrogen at Rest), aiming to perform the first test of the Equivalence Principle with antimatter by measuring the free fall of ultra-cold antihydrogen atoms. The objective is to measure the gravitational acceleration to better than a percent in a first stage, with a long term perspective to reach a much higher precision using gravitational quantum states of antihydrogen.

Success of these experiments strongly depends on the production rate of the antihydrogen ions ($\overline{H}^{+}$). Antihydrogen production involves two-step process:

$$\overline{p} + Ps \rightarrow \overline{H} + e^{-},$$

followed by

$$\overline{H} + Ps \rightarrow \overline{H}^{+} + e^{-},$$

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here Ps stands for positronium atom, Hydrogen-like bound state of positron and electron.

Good knowledge of the reaction mechanism is required in order to optimise the possible experimental setup. For example these reactions exhibit series of resonances [12]. Tuning antiproton energies to resonance regime may largely boost antihydrogen production rates.

Resonance positions and respective production rates must be calculated exactly for $\overline{p} + Ps \to \overline{H} + e^-$ and $\overline{H} + Ps \to \overline{H}^+ + e^-$ processes, treated as 3- and 4-particle collision, respectively.

Second project aims to determine the neutrino spectrum in beta-decay of ^{9}Li and ^{8}He nuclei by using three-cluster model. Small quantities of these exotic nuclei are produced in scintillating neutrino detectors (like ones used at DoubleChooz experiment) by the impact of the cosmic rays. These nuclei decay by, in particular, emitting neutrons, as:

$$^9Li \to {}^4He + {}^4He + n + \beta^- + \bar{\nu} \quad \text{and} \quad {}^8He \to {}^4He + {}^3He + n + \beta^- + \bar{\nu}$$

and contaminate the neutrino signal, thus presenting one of the most important sources of the background. Knowledge of the $\beta^- + \bar{\nu}$ energy distribution would improve significantly the background subtraction in neutrino experiments, which employ scintillating detectors. In particular, it might help to improve the accuracy of the neutrino mixing angle θ_{13} measured at DoubleChooz by a factor 2.

Student will be also involved in calculating other 3- and 4- body reactions of interest in nuclear physics and nuclear astrophysics**.**

In the further perspective we would like to solve rigorously for the first time 5-body scattering problem, in particular helping to describe the fusion reaction:

$$^2H + {}^3H \to {}^4He + n$$

of interest for ITER and other nuclear fusion facilities.

The candidate should be motivated and interested in theoretical physics, quantum mechanics as well as in advanced numerical computation. Good skills in programming are required.

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