

NUMEN Project : challenges in the investigation of double charge-exchange nuclear reactions, towards neutrino-less double beta decay

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Abstract

An innovative technique to access the nuclear matrix elements entering the expression of the life time of the double beta decay by relevant cross sections measurements of double charge exchange reactions is proposed. A key aspect of the project is the use of the MAGNEX large acceptance magnetic spectrometer, for the detection of the ejectiles, and of the LNS K800 Superconducting Cyclotron (CS), for the acceleration of the required high resolution and low emittance heavy-ion beams, already in operation at INFN Laboratory Nazionali del Sud in Catania (Italy).

1 Introduction

Neutrinoless double beta decay, $0\nu\beta\beta$, is at the present time strongly pursued both experimentally and theoretically [1]. Its observation will determine whether the neutrino is a Dirac or Majorana particle and will provide a measurement of the average neutrino mass, which is one of the most fundamental problems in physics. An innovative technique to access the Nuclear Matrix Elements (NME) entering the expression of the life time of the neutrinoless double beta decay by relevant cross sections of double charge exchange reactions is proposed. The basic point is the coincidence of the initial and final state wave-functions in the two classes of processes and the similarity of the transition operators, which in both cases present a superposition of Fermi, Gamow-Teller and rank-two tensor components with a relevant implicit momentum transfer. First pioneering experimental results obtained at the INFN-LNS laboratory for the $^{40}\text{Ca}(^{18}\text{O},^{18}\text{Ne})^{40}\text{Ar}$ reaction at 270 MeV, give encouraging indication on the capability of the proposed technique to access relevant quantitative information.

First experimental results, obtained at the INFN-LNS laboratory in Catania, for the $^{40}\text{Ca}(^{18}\text{O}, ^{18}\text{Ne})^{40}\text{Ar}$ reaction at 270 MeV, in a wide range of transferred momenta, give encouraging indication on the capability to access quantitative information towards the determination of the Nuclear Matrix Elements for $0\nu\beta\beta$ decay [2]. On the basis of the above mentioned ground-breaking achievement, we propose an ambitious project, NUMEN, with the aim to go deep insight in the HI-DCE studies on nuclei of interest in $0\nu\beta\beta$ decay, looking forward at the $0\nu\beta\beta$ NME determination [3].

There are a number of important similarities among DCE and $0\nu\beta\beta$ decay processes, despite they are mediated by different interactions, also the description of NMEs extracted from DCE and $0\nu\beta\beta$ presents the same degree of complexity, with the advantage for DCE to be “accessible” in laboratory. However a simple relation between DCE cross sections and $\beta\beta$ -decay half-lives is not trivial and needs to be explored.

2 The Project

The availability of the MAGNEX spectrometer [4] for high resolution measurements of very suppressed reaction channels was essential for the first pilot experiment. Moreover the measurement of DCE high resolution energy spectra and accurate cross sections at very forward angles are key points to identify the transitions of interest [5]. The concurrent measurement of the other relevant reaction channels allows to isolate the direct DCE mechanism from the competing transfer processes. These are at least of 4th-order and can be effectively minimized by the choice of the proper projectile-target system and incident energy [6].

However with the present set-up it is difficult to suitably extend this research to the “hot” cases, where $\beta\beta$ decay studies are and will be concentrated.

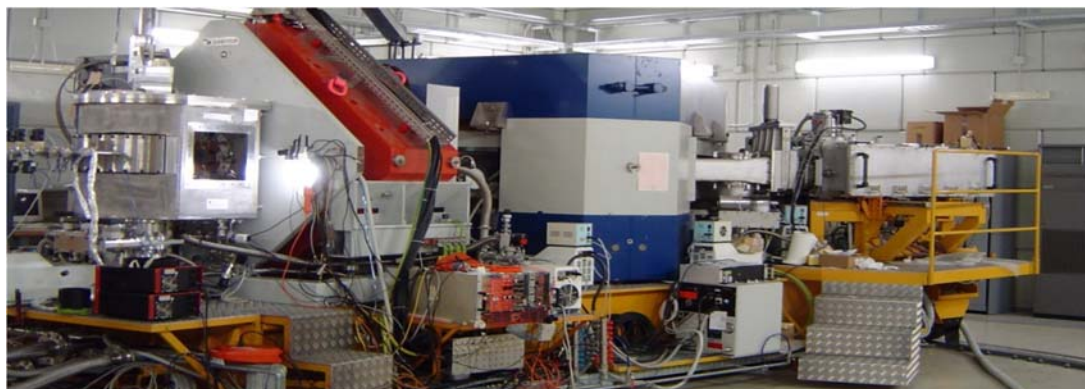


Fig.1: A view of MAGNEX spectrometer at Laboratori Nazionali del Sud in Catania.

The present limit of low beam current we have experienced both for the CS accelerator and for the MAGNEX focal plane detector must be sensibly overcome. For a systematic study of the many “hot” cases of $\beta\beta$ decays an upgraded set-up, able to work with two orders of magnitude more current than the present, is thus necessary. This goal can be achieved by a substantial change in the technologies used in the beam extraction and in the detection of the ejectiles. For the accelerator the use of a stripper induced extraction is an adequate choice.



Fig.2: A view of K800 Superconducting Cyclotron at Laboratori Nazionali del Sud in Catania.

For the spectrometer the main foreseen upgrades are:

1. The substitution of the present Focal Plane Detector (FPD) [7] gas tracker with a GEM tracker system;
2. The substitution of the wall of silicon pad stopping detectors with a wall of telescopes based on SiC-CsI detectors;
3. The enhancement of the maximum magnetic rigidity;
4. The introduction of an array of detectors for measuring the coincident γ -rays.

In this framework we propose four phases in the NUMEN project, looking forward to do, in the same time, both the experimental and the up-grade activity, as indicated in the following Phases of the project.

2.1 Phase 1: the experiment feasibility

The pilot experiment : $^{40}\text{Ca}(^{18}\text{O}, ^{18}\text{Ne})^{40}\text{Ar}$ reaction at 270 MeV, with the first experimental data on heavy- ion double charge-exchange reactions in a wide range of transferred momenta, was already done. The results demonstrate the technique feasibility.

2.2 Phase 2: toward “hot” cases optimizing experimental conditions and getting first results

The necessary work for the upgrading of both the accelerator and MAGNEX will be carried out still preserving the access to the present facility. Due to the relevant technological challenges connected, in which test, with and without beam will be crucial, the Phase2 is foreseen to have a duration of a 3-4 years. In the meanwhile, experiments with integrated charge of tens of mC (about one order of magnitude more than that collected in the pilot experiment) will be performed. These will require several weeks (4-8 depending on the case) data taking for each reaction, since thin targets (a few 1018 atoms/cm2) are mandatory in order to achieve enough energy and angular resolution in the energy spectra and angular distributions. The attention will be focused on a few favorable cases, like for example $^{116}\text{Sn}(^{18}\text{O}, ^{18}\text{Ne})^{116}\text{Cd}$ reaction at 15 and 30 MeV/u and the $^{116}\text{Cd}(^{20}\text{Ne}, ^{20}\text{O})^{116}\text{Sn}$ reaction at 15 and 25 MeV/u, with the goal to achieve conclusive results for them.

2.3 Phase 3: the facility upgrade

Once all the building block for the upgrade of the accelerator and spectrometer facility will be ready at the LNS a Phase3, connected to the disassembling of the old set-up and re-assembling of the new will start. An estimate of about 18-24 months is considered.

2.4 Phase 4: the experimental campaign

The Phase 4 will consist of a series of experimental campaigns at high beam intensities (some pμA) and long experimental runs in order to reach in each experiment integrated charge of hundreds of mC up to C, for the experiments in coincidences, spanning all the variety of candidate isotopes for $0\nu\beta\beta$ decay, like: ^{48}Ca , ^{82}Se , ^{96}Zr , ^{100}Mo , ^{110}Pd , ^{124}Sn , ^{128}Te , ^{130}Te , ^{136}Xe , ^{148}Nd , ^{150}Nd , ^{154}Sm , ^{160}Gd , ^{198}Pt .

3 Perspectives

Once selected the optimal experimental condition for the different cases in the Phase2, with the upgrades, both of CS and the MAGNEX array, the Phase4 will be devoted to collect data addressed to give, with an accurate analysis, a rigorous determination of the absolute cross sections values and their uncertainties for all the system of interest, to the challenging determination of the $0\nu\beta\beta$ decay nuclear matrix elements, that is the ambitious goal of NUMEN Project.

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