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New high intensity Heavy - Ion beams @ INFN-LNS: NUMEN project status and perspective

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Abstract. The upgrade project POTLNS to produce high-intensity beams has already started at INFN- Laboratori Nazionali del Sud in Catania (Italy). The POTLNS project was triggered by the NUMEN physics case that aims to provide experimental information on the Nuclear Matrix Elements (NMEs) that enter in the expression of the neutrino-less double beta (0νββ) decay half-life. The tools proposed by NUMEN project are the cross-section measurements of nuclear Double Charge Exchange (DCE) reactions. The search for 0νββ decay is currently a key topic in physics, due to its possible wide implications for nuclear physics, particle physics and cosmology: the NUMEN project could provide a crucial contribution in this search.

1. Introduction

At INFN-Laboratori Nazionali del Sud (LNS) in Catania a significant upgrade of the K800 Superconducting Cyclotron (CS) and of the experimental infrastructure is currently in progress. The upgrade was funded within the POTLNS project [1], triggered by the NUMEN [2] physics case that aims to provide experimental information on the Nuclear Matrix Elements (NMEs) that enter in the expression of the neutrino-less double beta (0νββ) decay half-life. The final objective of POTLNS project is to upgrade the LNS research infrastructure to increase the beam intensity up to 10^{13} pps, for ions with mass $A \leq 40$ and energies in the range of 15-70 MeV/u. The POTLNS was approved in the frame of a national program (PON) aimed at strengthening the research infrastructures identified as priorities according to the European Strategy Forum on Research Infrastructures (ESFRI).

At present, the CS main limitation is due to the extraction system. To overcome this limit a new method, based on stripping of the accelerated ions, will be used to obtain current from 100 W to - 2-10 kW with a beam transport line transmission efficiency to nearly 100% [3-5]. To exploit the high beam power delivered by the upgraded CS, the POTLNS project has included the construction of a new FRAgment In-flight Separator (FRAISE) [6] for Radioactive Ion Beams (RIBs) production. Thanks to high energy dispersion value at the symmetry plane, FRAISE will allow to deliver stable beams with an energy spread of 0.1%, a value which matches one of the mandatory constraints for the NUMEN experimental program.

2. NUMEN project status and perspectives

The NUMEN [2] new idea is to use nuclear Double Charge Exchange (DCE) reactions to stimulate in the laboratory the same nuclear transition occurring in 0νββ decay, to extract from measured cross-sections "data-driven" information on Nuclear Matrix Elements (NMEs) for all the systems candidates to 0νββ decay. The search for 0νββ decay is currently a key topic in physics, due to its possible wide implications for nuclear physics, particle physics and cosmology [7]. This decay represents nowadays the most promising way to probe neutrino properties and search for deviations from the Standard Model. It can exist only if neutrinos are Majorana particles and can provide unique constraints on the neutrino mass scale. Moreover, its observation would prove that total lepton number is not conserved, an observation that could be linked to the cosmic asymmetry between matter and antimatter.

The very tiny values of the DCE cross-sections and the resolution requirement demand the use of precise equipment with a high capacity to select so rare events: crucial for the experimental challenges are the K800 CS and the MAGNEX magnetic spectrometer [8]. The results obtained so far indicate that suitable information can be extracted from DCE reactions [9], however beam intensities much higher than those manageable with the present facility are necessary for the NUMEN ambitious goals to give constraints to the existing theories of NME, model-independent comparative information on the sensitivity of the half-life experiments, complete study of the reaction mechanism. To reach these goals NUMEN has a long-term plan, organized in four phases. The first two phases, already done, demonstrate the experimental feasibility and the possibility, with the developed R&D, to work with high intensity beams. The present phase three is devoted to the upgrade of the whole facility, dedicated to the disassembly of the old one and to the reassembly of the new one. The last phase will be dedicated to the experimental campaign, spanning all the isotopes of interest for $0\nu\beta\beta$ decay search.

The full understanding of the DCE reaction mechanism implies the study of a wide network of nuclear reactions: the new methodology proposed is the multi-channel approach [10-11], to study transition of interest for $0\nu\beta\beta$ in two directions, using (^{20}Ne, ^{20}O) and (^{18}O,^{18}Ne) reaction to study the $\beta^-\beta^-$ and $\beta^+\beta^+$ respectively, to study all the net of the reaction that can contribute to DCE and to perform these studies at different energies to study the reaction mechanism.

MAGNEX is a large acceptance magnetic spectrometer that combines the advantages of traditional magnetic spectrometry with those of a large angular (50 msr) and momentum (-14%, +10.3%) acceptance detector. The main MAGNEX upgrade goal is sustaining high rates, while maintaining the current resolution and sensitivity [12-13].

The new Focal Plane Detector (FPD) will be done by a new Gas-Tracker, that must guarantee a good resolution of the phase space parameters (X_{foc}, Y_{foc}, $\boldsymbol{\theta}_{foc}$,$\boldsymbol{\varphi}_{foc}$) at the focal plane for the precise and accurate particle trajectory reconstruction and a new Particle Identification (PID) Wall, downstream the tracker, that must allow to identify ions of atomic species and their isotopes, without ambiguity, sustaining high intensity beams. The new Gas-Tracker [14] will consist of a Thick Gas Electron Multiplier (THGEM) within electron multiplication region, based on three THGEM layers, with an active volume of 1200x116x108 mm^3, the module is in the construction phase. The new PID Wall will consist of a wall of 720 telescopes, made of SiC and CsI, arranged in 36 towers of 20 telescopes each. SiC was chosen among the radiation-hard materials thanks to the NUMEN R&D in the frame of INFN SiCilia project [15]. Construction of the first three towers is underway.

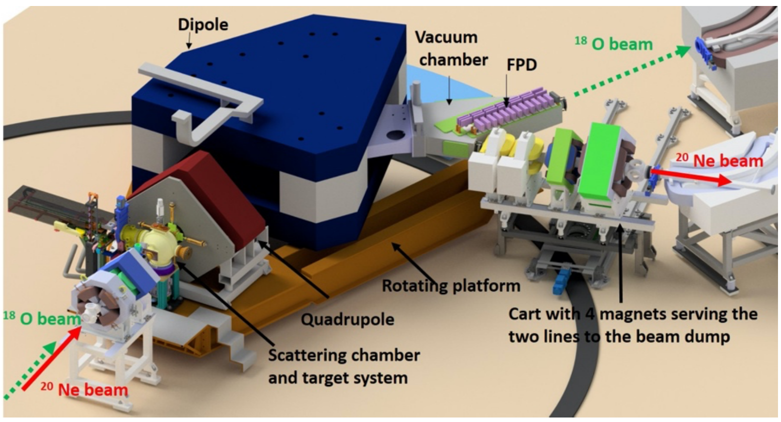

Fig.1 Three-dimensional view of the of future MAGNEX configuration

Typical MAGNEX energy resolution for a NUMEN experiment is about 500 keV (FWHM) at 15 MeV/u that is enough for many systems. For deformed nuclei and for all experiments at high beam energies energy resolution it is necessary an array of γ-detectors to work in coincidence with the FPD. The main challenge for this system is to distinguish very few good DCE events in the region of interest, in experimental conditions dominated by a very high rate of signals coming from the projectile-target interactions. With this aim it is foreseen an array, called G-NUMEN, that will consist of 110 $LaBr_3$ crystal scintillator, coupled to standard PM tubes, disposed in rings covering a total solid angle of 20% of the unit sphere of 38 mm diameter. The construction of a Demonstrator made of 15 detectors is under way at LNS.

Another key issue of the upgrade is the new target system [16-17]. The main constraints in the design of the NUMEN target come from the resolution on the energy measurement of the DCE reaction products and the required of an active cooling system due to a significant (≈ 1 W) power deposited with high beam intensities. Moreover, the targets should be thin (≈ 10^{18} atoms/cm^2) and uniform to preserve a good energy resolution for the ejectiles detected by MAGNEX FPD. The proposed solution is to use for each isotope a 2 μm thick backing of Highly Oriented Pyrolytic Graphite (HOPG), whose high thermal conductivity promotes the heat dissipation in a copper sample holder, in contact with the cold head of a cryocooler, to quickly transfer the heat to the cooler. The robotic arm for target manipulation and the target holder system are already done [18], first integration of these elements is ongoing in laboratory since the experimental hall is in preparation. In this frame, also the development of suitable front-end and read-out electronics, for a fast read-out of the detector signals, a high signal to noise ratio and adequate hardness to radiation and the implementation of a suitable architecture for data acquisition, storage and data handling are ongoing.

Within the NUMEN project, theoretical developments [19] aim at reaching a full description of the Double Charge Exchange (DCE) reaction cross section, including also competing channels that may lead to the same outcome, and at investigating the possible analogies with 0νββ [20].
Experimental measurements of Double Charge Exchange and Multi-Nucleon Transfer reactions induced by heavy ions are characterized by small cross sections under a large background due to other reaction channels, therefore an accurate control of the signal to background ratio is mandatory. We have introduced a method to quantify the particle identification impurity and background of the MAGNEX magnetic spectrometer for the measurement of cross sections in heavy ion quasi-elastic reactions of interest for the NUMEN project [21]. It was deduced a procedure to estimate the expected background equivalent cross section spectrum that provides quantitative indications of the minimum cross sections significantly measurable by the present MAGNEX spectrometer experimental set-up. The procedure was applied to the ^{116}Cd (^{20}Ne, ^{20}O)^{116}Sn DCE reaction data but can be extended to any other system or reaction channel. In this specific case, the deduced cross section background value in the ground-state to ground-state region amounts to 0.30 ± 0.03 nb. It should be noted that, similar results are expected considering the same reaction channel. The background equivalent cross section values determined in [21] will guide the way towards the next experimental upgrade of the MAGNEX facility, foreseen by the next phase of the NUMEN project.

New high intensity Heavy - Ion beams will be available at INFN-LNS in the next future. The upgrade of the whole experimental research infrastructure will allow to significantly improve the overall NUMEN discovery potential. New scenario in a wide window of physics studies will be possible with the new intense beams at INFN-LNS.

References

[1] C. Agodi et al. Universe 7 (2021) 3, 72 DOI: universe7030072
[2] F. Cappuzzello, C. Agodi et al. Eur. Phys. J. A (2018) 54: 72 DOI: 10.1140/epja/i2018-12509-3
[3] L. Calabretta et al., Modern Phys. Lett. A 2017, 32, 1740009
[4] G.D'Agostino et al., www.accelconf.web.cern.ch/AccelConf/Cyclotrons2016/papers/tuc03.pdf
[5] A. Calanna Il Nuovo Cimento 2017, C40, 101
[6] A.D. Russo et al. Nucl. Inst. Meth. Phys. Res. Sect. B 2020, 463, 418–420

[7] H. Ejiri, J. Suhonen and K. Zuber 2019 Phys. Rept. 797 1–102
[8] F. Cappuzzello, C. Agodi, D. Carbone, M. Cavallaro Eur. Phys. J. A 2016, 52
[9] F. Cappuzzello et al., Eur. Phys. J. A 51:145 (2015)
[10] S. Burrello et al., Phys. Rev. C 2022, 105(2), 024616
[11] D. Carbone et al., Phys. Rev. C 102 (2020)
[12] F.Capuzzello et al., Int. Jour. of Modern Phyiscs A 36 (30) (2021) 2130018
[13] M. Cavallaro et al., Nucl. Inst. and Meth. B, 463 (2020)
[14] I. Ciraldo et al. accepted for publication in Nucl. Inst. and Meth. in Phys. Research, A
[15] S. Tudisco et al., Sensors 2018, 18, 22, 891
[16] F. Pinna et al., Physica Scripta 95 (2020)
[17] D. Sartirana et al., Mechanisms and Machine Science 84 (2020) 535-543
[18] D. Calvo et al., Nucl.Inst. Meth. Phys. Res. Sect. A Vol. 1041 2022, 167336
[19] H. Lenske, J. Bellone, M. Colonna and D. Gambacurta, Universe 2021, 7(4)
[20] F. Cappuzzello et al.,Progress in Particle and Nuclear Physics 2022-10
[21] S. Calabrese et al. Nuclear Inst. and Methods in Physics Research, A 980 (2020) 164500