NUMEN project @ LNS: Status and perspectives

Original
NUMEN project @ LNS: Status and perspectives / Agodi, C.; Cappuzzello, F.; Aciksoz, E.; Acosta, L.; Aslanouglou, X.; Auerbach, N.; Bellone, J.; Bijker, R.; Bonanno, D.; Bongiovanni, D.; Borello, T.; Boztosun, I.; Bussa, M. P.; Busso, L.; Calabrese, S.; Calabretta, L.; Calanna, A.; Calvo, D.; Carbone, D.; Cavallaro, M.; Lomeli, E. R. C.; Colonna, M.; D'Agostino, G.; De Faria, P. N.; Deshmukh, N.; Ferraresi, C.; Ferreira, J. L.; Finocchiaro, P.; Foti, A.; Greco, V.; Hacisalihoglu, A.; Iazzi, F.; Introzzzi, R.; Kotila, J.; La Via, F.; Lanzalone, G.; Lavagno, A.; Lay, J. A.; Lenske, H.; Linares, R.; Lo Presti, D.; Longhitano, F.; Lubian, J. R.; Medina, N.; Junior, D. R. M.; Muoio, A.; Oliveira, J. R. B.; Pakou, A.; Pandola, L.; Petrascu, H.; Pinna, F.; Rifuggiato, D.; Rodrigues, M.; Russo, G.; Santagati, G.; Santopinto, E.; Sgouros, O.; Solakci, S. O.; Soukeras, B.; Souliotis, G.; Tudisco, S.; Vsevolodovna, R. I. M.; Zagatto, V. A.. - In: POS PROCEEDINGS OF SCIENCE. - ISSN 1824-8039. - (2016). ((Intervento presentato al convegno 9th Neutrino Oscillation Workshop, NOW 2016 tenutosi a ita nel 2016.

Availability:
This version is available at: 11583/2836201 since: 2020-06-17T11:47:23Z

Publisher:
Sissa Medialab Srl

Published
DOI:

29 July 2021

PROCEEDINGS OF SCIENCE

NUMEN project @ LNS: Status and perspectives

Clementina Agodi[1]
Laboratori Nazionali del Sud
Via S. Sofia, 62, 95125 Catania, Italy
E-mail: agodi@lns.infn.it

Coauthors:
Francesco Cappuzzello, Esra Aciksoz, Luis Acosta, Xenofon Aslanouglou, Naftali Auerbach, Jessica Bellone, Roelof Bijker, Danilo Bonanno, Daniele Bongiovanni, Thereza Borello, Ismail Boztosun, Maria Pia Bussa, Luigi Busso, Salvatore Calabrese, Luciano Calabretta, Alessandra Calanna, Daniela Calvo, Diana Carbone, Manuela Cavallaro, Efrain R. Chávez Lomelí, Maria Colonna, Grazia D'Agostino , Pedro Neto De Faria, Nikit Deshmukh, Carlo Ferraresi, Jonas Leonardo Ferreira, Paolo Finocchiaro, Antonino Foti, Vincenzo Greco, Aylin Hacisalihoglu, Felice Iazzi, Riccardo Introzzzi, Jenni Kotila, Francesco La Via, Gaetano Lanzalone, Andrea Lavagno, Josè A. Lay, Horst Lenske, Roberto Linares, Domenico Lo Presti, Fabio Longhitano, Jesus Rios Lubian, Nilberto Medina, Djalma Rosa Mendes Junior, Annamaria Muoio, Josè Roberto B. Oliveira, Athena Pakou, Luciano Pandola, Horia Petrascu, Federico Pinna, Danilo Rifuggiato, Marzia Rodrigues, Giuseppe Russo, Gianluca Santagati, Elena Santopinto, Onofrios Sgouros, Selçuk Oktay Solakci, Basilis Soukeras, George Souliotis, Salvatore Tudisco, Ruslan Idelfonso Magana Vsevolodovna, Vinicious Antonio Zagatto.

The aim of the NUMEN project is to access the Nuclear Matrix Elements (NME), involved in the half life of the neutrinoless double beta decay (0νββ), by measuring the cross sections of Heavy Ions (HI) induced Double Charge Exchange (DCE) reactions with high accuracy. First evidence of the possibility to get quantitative information about NME from experiments is shown in the reaction 40Ca(18O,18Ne)40Ar at 270 MeV, performed with MAGNEX spectrometer using Superconducting Cyclotron (CS) beams at INFN - Laboratory Nazionali del Sud (LNS) in Catania. Preliminary tests on 116Sn and 116Cd target are already performed. High beam intensity is the new frontiers for these studies.

Neutrino Oscillation Workshop
4 - 11 September, 2016
Otranto (Lecce, Italy)

---

[1] Speaker

The $0\nu\beta\beta$ decay, besides establishing the Majorana nature of neutrinos, has the potential to shed light on the absolute neutrino mass and hierarchy. For that purpose, it is critical that the associated NMEs are reliably known.

From an updated comparison of the main NME calculations, obtained with various nuclear structure frameworks [1]-[8], there are still significant differences. In addition some assumption common to different competing calculation, like the unavoidable truncation of the many body wave-function, could cause overall systematic uncertainties.

To access quantitative information, relevant for $0\nu\beta\beta$ decay NME, the NUMEN project proposes to use HI-DCE reactions as a tool [21], [22]. These reactions are characterized by the transfer of two charge units, leaving the mass number unchanged, and can proceed by a sequential multi nucleon transfer mechanism or by a double meson exchange.

Despite $0\nu\beta\beta$ decay and HI-DCE reactions are mediated by different interactions, they present a number of similarities. Among that, the key aspects are that the initial and final nuclear states are the same and the structure of the operator in both cases present the same components. At present time a complete and coherent theory of HI-DCE reactions does not exist: in a simple approach one can assume a two-step model which contains all the relevant features. So we try a simplified approach based on the well known relationship between single charge exchange (CEX) reactions and beta decay. Moreover for single charge exchange, under specific conditions [9],[10], the cross section can be factorized in independent factors, where the quantity named "unit cross-section" behaves as an universal property of the nuclear response, depending smoothly on the projectile energy and on the target mass. In this way it is computable all along the nuclear chart. In the case of HI-DCE data analysis are typically more involved, due to the projectile degrees of freedom and the sizable amount of momentum transfer. A significant simplifications comes from the strong absorption of the scattering waves in the inner part of the impinging systems and the consequent surface localization. In a simple model, under the hypothesis of surface localization, we can assume that HI-DCE is just a second order CEX, so we can make a generalization to DCE for the factorization of the cross section in a nuclear structure term, that contain the NME, and a nuclear reaction factor in analogy with CEX. To extract a "unit-cross sections" from DCE systematic cross sections measurements is the most ambitious goal of the project, that requires also a step forward in the development of the theory. The other NUMEN goals, in the same way groundbreaking and reachable in a short-term, are: a new generation of DCE constrained of $0\nu\beta\beta$ NME theoretical calculations and the ratio of measured cross sections, that can give a model independent way to compare the sensitivity of different half-life experiments.

In literature a lack of data persists because of the technical difficulties to measure very low cross sections at zero degrees and due to the difficult to disentangle the contribution of the competing processes, leading to the same final state.

At INFN-LNS we perform the DCE reaction ^{40}Ca(^{18}O,^{18}Ne)^{40}Ar at 270 MeV, with the aim to measure accurately the cross section at zero degrees [11]. For this reason we have chosen a particularly advantageous system, using a beam of ^{18}O and a double magic target as ^{40}Ca, choosing the bombarding energy in such a way to mismatch the competing transfer reactions leading to the same final [12]. Crucial for the main experimental challenges involved has been the use of the simple turn CS beams [13] delivered at LNS and the use MAGNEX, a modern high resolution and large acceptance magnetic spectrometer with high resolution in energy, mass and angle [14]. This facility has been proven to be very effective for accurate nuclear structure and dynamics studies [15],[16],[17],[18],[19],[20]. In this "pilot experiment" we have shown [11], for the first time, high resolution and statistically significant experimental data on heavy-ion double charge exchange reactions in a wide range of transferred momenta and that precious informations towards NME determination could be at our reach. To move towards nuclei candidates for $0\nu\beta\beta$ decay one needs to overcome some experimental limits as it is proposed in the NUMEN project [15]. The challenge is to measure rare events under a very high flux of heavy ions. The project is divided into four successive phases [16], among that Phase2 is crucial to allow us to optimize the experimental conditions and open a new challenging research field, carrying out an experimental investigation of few candidate nuclei for the $0\nu\beta\beta$ decay. In this framework, we already perform some tests both with the (^{18}O,^{18}Ne) reaction as a probe for the $\beta^+\beta^+$ like transitions and the (^{20}Ne,^{20}O) as a probe for $\beta^-\beta^-$.

In the reaction test: ^{116}Sn + ^{18}O at 15 MeV/A we have measured at $0^\circ < \theta_{lab} < 10^\circ$: DCEX reaction ^{116}Sn(^{18}O,^{18}Ne)^{116}Cd; CEX reaction ^{116}Sn(^{18}O,^{18}F)^{116}In ; 2p-transfer ^{116}Sn(^{18}O,^{20}Ne)^{114}Cd; 1p-transfer ^{116}Sn(^{18}O,^{19}F)^{115}In.

In the reaction test ^{116}Cd + ^{20}Ne at 15 MeV/A and 22 MeV/A we have measured at $0^\circ < \theta_{lab} < 8^\circ$: DCEX reaction ^{116}Cd(^{20}Ne,^{20}O)^{116}Sn; CEX reaction ^{116}Cd(^{20}Ne,^{20}F)^{116}In; 2p-transfer ^{116}Cd(^{20}Ne,^{18}O)^{118}Sn; 1p-transfer ^{116}Cd(^{20}Ne,^{19}F)^{117}In.

For both kind of reactions data reduction is in progress.

References

[1] J.Menédez https://arxiv.org/abs/1605.05059

[2] Y. Iwata, N. Shimizu, T. Otsuka, Y. Utsuno, J. Menéndez, M. Honma and T. Abe,Phys. Rev.Lett.116, 112502 (2016)

[3] A. Neacsu and M. Horoi, Phys. Rev. C93, 024308 (2016)

[4] J. Barea, J. Kotila and F. Iachello, Phys. Rev. C91, 034304 (2015)

[5] J. Hyvärinen and J. Suhonen, Phys. Rev. C87, 024613 (2015)

[6] F. Šimkovic, V. Rodin, A. Faessler and P. Vogel, Phys. Rev. C87, 045501 (2013)

[7] N. López Vaquero, T. R. Rodríguez and J. L. Egido, Phys. Rev. Lett.111, 142501(2013)

[8] J. Yao, L. Song, K. Hagino, P. Ring and J. Meng, Phys. Rev.C91, 024316 (2015)

[9] T. N. Taddeucci et al. Phys. Rev. C 28 (1983) 2511

[10] T.N. Taddeucci et al. Nucl. Phys. A469 (1987) 125

[11] F. Cappuzzello,M. Cavallaro, C. Agodi et al. Eur. Phys. J. A (51: 145 (2015)

[12] D.M.Brink, et al., Phys. Lett. B 40 (1972) 3

[13] F. Cappuzzello, C. Agodi, M. Bondì et al. Nucl.Instr. and Meth. A 763, 314 - 319 (2014)

[14] F. Cappuzzello, C. Agodi, D. Carbone et al. Eur. Phys. J. A 52 :167 (2016)

[15] F. Cappuzzello et al. Journ.of Phys. Conf. series 630 (2015) 012018

[16] M. Cavallaro et al. Acta Physica Polonica, 47 (2016) 929

[17] F. Cappuzzello et al. Journ. of Physics Conf. series 730 (2016) 012006

[18] F. Cappuzzello, D. Carbone, M. Cavallaro, M. Bondì, C. Agodi et al. NATURE Communications **6**, 6743 (2015)

[19] D. Pereira et al., Phys. Lett. B 710, 426 (2012)

[20] F. Cappuzzello, C. Rea et al. Physics Letters B 711, 347 (2012)

[21] C. Agodi, F.Cappuzzello et al. Nuclear and Particle Physics Proceedings ,265 28-30 (2015)

[22] C. Agodi et al. AIP Conference Proceedings, 686 (2015) 020001