Meson Exchange Current contributions in semi inclusive lepton-nucleus scattering

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Project of the *Espace de Structure et de réactions Nucléaires Théorique*

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I. SCIENTIFIC ISSUE

Neutrino physics has undergone a spectacular development in the last decades, following the discovery of neutrino oscillations and nowadays has entered the precision era that needs a reduction of systematic errors to the level of a few percent. The experiments measure the rate of neutrino interactions, which is the convolution of three factors: the neutrino flux, the interaction cross section and the detector efficiency. The detectors of modern accelerator-based neutrino oscillation experiments are composed of complex nuclei (^{12}C, ^{16}O, ^{40}Ar, ^{56}Fe...). In the hundreds-MeV to few- GeV energy region, the neutrino-nucleus cross sections are known with a precision not exceeding 20 %, hence represent one of the most important sources of systematic uncertainties. A large contribution to such uncertainty is due to the very poor knowledge of the hadronic two-body current contribution. A workshop totally dedicated to this topic was organized at ESNT in 2016 [1]. At that time, the effort of the community was focused on the modeling of the so-called "inclusive" neutrino interaction processes, where the charged lepton is the only particle detected in the final state. Today there is a rapidly increasing experimental and theoretical interest in "semi-inclusive" process where, beyond the charged lepton, one hadron, often a proton, is detected in coincidence. This kind of measurements is possible in tracker detectors, as the near detector of present (T2K) and future (HK) neutrino oscillation experiments in Japan and like the present (MicroBooNE) and future (DUNE) detectors based on liquid argon technologies in USA. On the theoretical side, very few fully microscopic calculations of semi-inclusive neutrino interactions processes exist in the literature, and they are essentially related to the quasielastic excitation [2]. A complete calculation of two-body meson-exchange current (MEC) contribution to the semi-inclusive process with one lepton and one proton in the final state is still missing.
The aim of the present project is to spend one week at the ESNT to work on two aspects related to the this subject. The first aspect concerns the development of the formalism and of the numerical code to describe the semi-inclusive electron-nucleus cross section by adapting the previous studies of De Pace et al. [3], which focused on the inclusive process. To consider first the electron-scattering process is a natural choice since any model pretending to describe neutrino cross sections should first be validated by comparing its predictions with electron scattering data, which are more numerous and more precise than the neutrino ones and furthermore are available for fixed kinematical conditions since electron beams are monochromatic, which is not the case of neutrino beams. The second aspect concerns the

generalization of the previous calculations to the neutrino case, including beyond the vector current contributions, already present in electromagnetic excitations, also the axial ones, typical of the weak excitations. For both aspects the analytical and numerical effort is important. The ongoing studies are well advanced but not yet finalized. One week of close collaboration would contribute to finalize the first part and to push forward the second. Furthermore, one-week stay could contribute to open the way for future collaboration with theorists of DPhN working on many-body nuclear physics by using quantum field theory approach and with experimentalists of DPhN and DPhP involved in electron scattering and neutrino experiments. Also for this purpose, two seminars will be given by Valerio Belocchi and Marco Martini.

II. GOALS OF THE WORKSHOP

In summary, the goals of the project are:
Goal 1 Finalize the ongoing studies on MEC contributions to semi-inclusive electron-nucleus cross sections.
Goal 2 Push forward the ongoing studies on MEC contributions to semi-inclusive neutrino-nucleus cross sections.
Goal 3 Discuss with the members of DPhN and DPhP on theoretical and experimental aspects of electron and neutrino cross sections.

[1] M. Martini, M.B. Barbaro, S. Bolognesi, M. Ericson, N. Jachowicz,``Two-body current contributions in neutrino-nucleus scattering," ESNT workshop (2016) https://esnt.cea.fr/Phocea/Page/index.php?id=59
[2] J.M. Franco-Patino, R. Gonzalez-Jimenez, S.Dolan, M.B. Barbaro, J.A. Caballero, G.D. Megias and J.M. Udias,``Final state interactions in semi-inclusive neutrino-nucleus scattering: Applications to the T2K and MINERvA experiments," Phys. Rev. D 106 (2022) no.11, 11300.
[3] A. De Pace, M. Nardi, W.M. Alberico, T. W. Donnelly and A. Molinari, ``The 2p-2h electromagnetic response in the quasielastic peak and beyond," Nucl. Phys. A 726 (2003), 303-326.

III. ESNT SEMINAR TALKS

29 January 2024 11-12h, Marco Martini, IPSA and Sorbonne Université Paris, marco.martini@ipsa.fr*: "Neutrino-nucleus cross sections for neutrino oscillation experiments: status and challenges".*

30 January 2024 11-12h, Valerio Belocchi, Torino University and INFN, valerio.belocchi@unito.it*: "Inclusive and semi-inclusive lepton-nucleus scattering in quasielastic region and beyond".*