NuInt 2024 - 14th International Workshop on Neutrino-Nucleus Interactions

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Instituto Principia

Book of Abstracts

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Alleviating the present tension between T2K and NO ν νA with neutrino New Physics at source

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Since neutrino oscillation was observed, several experiments have been built to measure its parameters. At the present there ia tension between T2K and NOVA. We propose a non-standard neutrino interaction at production. In this scenario, computed by quantum field theory formalism can made a better description of combined data. A new phase from this new interaction can made a role in search for violation of charge and parity symmetry.

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Neutral and Charged forbidden contributions to $\nu-^{40}$Ar cross sections

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The contributions of neutral and charged forbidden and allowed multipole to $\nu-^{40}$Ar cross sections are evaluated within the QRPA and PQRPA models as function of the neutrino energy in the interval of interest for supernova neutrinos. These calculations are important as input for neutrino generator and simulator as the Marley code used for DUNE experiment.

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Electron/positron beam identification analysis in FERMILAB

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In High Energy Physics it is essential the study of the particles that make up everything (at least the known baryonic universe). Carrying out a study of these particles is necessary devices (detectors). These devices interact with particles through known physical processes and then, through a data acquisition system, one can proceed for further analysis. In the MINER⊠A experiment, the cross-section measurements are generally done. As a previous step, they used a mini test detector called Test Beam II (TB II) to see the response of new materials (objectives and scintillators) to different energy bands. In this work, the response of the Beam II test detector to electron and positron beams are studied. The response of this detector is studied for energies in the range of 2 to 8 ⊠⊠⊠. A data/MC comparison is also performed to see discrepancies with the model used, as well as in the analysis of the behavior of electron and positron beams under different parameters (electromagnetic cascade opening angle, electromagnetic cascade starting module and energy absorbed by the calorimeter). Our method has allowed the differentiation of electron and positron beams, unequivocally for the energies in the range 2-6⊠⊠⊠ and, to a lesser extent, in the range 6-8⊠⊠⊠. This is genius result given that previous experiments did not obtain results that could differentiate well electron beams relative to positron beams in these beam energy ranges

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Parallelizing the computation of neutrino oscillation parameters in a general background medium, by using the Jacobi Method

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This work describes an alternative tool for the study of matter effects over neutrino propagation, by numerically describing the mixing amplitudes and mass splittings as a function of a single parameter. It allows the description of these observables in the same manner as it is commonly seen in 2-neutrino phenomenology, identifying resonant mixing and level crossing, except in a N-neutrino scenario. This is accomplished by sequentially applying the Jacobi diagonalization method over a defined and smooth path, in infinitesimal steps, transporting the information about the neutrino mixing and parametrization from one background to another. This transport occurs in the parameter space, thus being reliable even over spatial background discontinuities. Due to the nature of the neutrino mass-flavor mixing, it is possible to describe any background effects, in a model-independent way, by making use of the vacuum mixing only. This is computationally interesting since the workload can be split in two stages, separating the diagonalization from the physical interpretation and fitting of any model in question. The procedure is detailed and benchmarked against known analytical solutions, together with a complexity and computational-time analysis.

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The search for Majorana neutrinos with nEXO

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Neutrinos are the only known fermions with zero electric charge, and thus far the unique candidates to act as their own antimatter counterpart. If indeed a neutrino is its own antiparticle, we can find processes in which lepton number conservation, a global symmetry of the Standard Model, is violated. Such a discovery would have great implications in neutrino physics and their interactions. The most sensitive test for this condition, also known as Majorana neutrinos, is through the search of a hypothetical decay known as neutrinoless double beta decay. The primary focus of the nEXO Collaboration is the search for this process using a liquid xenon time projection chamber, at the tonne-scale rooted on the success of the EXO-200 experiment. Our projections result in a half-life sensitivity beyond 10^{28} yr, sufficient to cover a milestone of this search consisting of the inverted ordering of neutrinos masses. This poster presents the search as well as the nEXO detector and its potential for discovery of new physics.

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Impact of interaction uncertainties on oscillation measurements

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Impact of interaction uncertainties on neutrino cross section measurements

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Systematic uncertainty reduction and residual cross section uncertainties for PRISM

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Impact of neutrino cross section uncertainties on T2K physics measurements

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Meson-exchange currents in quasielastic electron and neutrino scattering in a generalized superscaling approach

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A method that enables the consistent inclusion of meson-exchange currents (MEC) within the framework of the superscaling analisys with relativistic effective mass will be presented. We use a novel definition of the single nucleon tensor, defined as the mean value of the single-nucleon responses by averaging with an energy distribution n() [1]. This single nucleon prefactor is obtained from the 1p-1h matrix element of the OB current combined with the two body current. The averaging definition is extended beyond the scaling region of the ψ variable characteristic of the Fermi gas modifying the momentum distribution through a smeared Fermi distribution [2].
In the generalized scaling analysis, the selected QE data generate a band with scatter of 20% at the maximum (highlighting the extent of scaling violation) that will be parametrized using a simple function f (ψ ∗) ∗ .
Through the inclusion of MEC, we conducted a comparative analisys of the 1p-1h response functions within the context of the RFG, RMF and SuSAM ∗ models. These responses can be expressed in a factorized way as the product of the averaged single nucleon multiplied by the scaling function. A reduction in the transverse response is observed, which is in accordance with previous calculations [3][4].
In this manner, the 1p-1h cross section including MEC is calculated and compared with the calculation without MEC and the experimental data [5][6]. Our examination shows that in the low momentum limit, the predictions of the relativistic model align with those of the non-relativistic model in Fermi gas. The formalism can be extended to calculate the 1p-1h neutrino nuclear responses by including the meson exchange currents using the models already proposed in electron scattering.
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JLab Spectral Functions of Argon in NuWro and Their Implications for MicroBooNE

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The Short-Baseline Neutrino program in Fermilab aims to resolve the nature of the low-energy excess events observed in LSND and MiniBooNE, and analyze with unprecedented precision neutrino interactions with argon, which requires reliable estimate of neutrino cross sections. We report updates of the NuWro generator that bring the state-of-the-art spectral functions to model the ground state properties of the argon nucleus, and improve the accuracy at low energies by accounting for effects of Coulomb potential and nuclear recoil. We discuss these developments in context of electron and neutrino interactions, by comparing NuWro predictions to experimental data from JLab Hall A and MicroBooNE. The MicroBooNE data are described with the Chi square per degree of freedom of 0.7, compared with 1.0 in the local Fermi gas model. Being obtained using the axial form factor parametrization from MINERvA, our results indicate a consistency between the CCQE measurements in MINERvA and MicroBooNE

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Probing Earth's internal structure with high energy neutrino transmission

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The opacity of the Earth for the incidence of high energy neutrinos is directly related to the neutrino-nucleon cross sections and the description of the distribution of matter in the Earth's interior. In this work we investigate the sensitivity of neutrino transmission to the use of different models for Earth's density profile. In particular, we compare neutrino transmission using the PREM density model with three-, two- and one-layer models (core, mantle and crust) and constant densities. To calculate the neutrino-nucleon cross section we used the DGLAP predictions, with the CT14 parametrizations. Our results indicate that neutrino transmission is sensitive to different Earth profile density models at magnitudes that depend on the kinematic region tested and the models compared. We also show that the regeneration of the tau neutrino flux by its decay significantly impacts flux transmission in all models studied. The results achieved indicate that Earth profile density models impact the events observed at neutrino observatories such as IceCube.

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Random Forests for determining muon numbers in extensive air showers relative to their primary energy using KASCADE-Grande data

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This study presented the development and application of two Random Forest (RF) models to KASCADE-Grande data with zenith angles $\theta < 40°$, obtained from the KASCADE Cosmic Ray Data Centre. The

aim was to predict the primary energy and correct the muon number for systematic effects on an event-by-event basis. Model training involved KCDC simulations using the high-energy hadronic interaction model QGSjet-II-04. To refine the RF models, we conducted feature engineering on the magnitudes and fine-tuned the hyperparameters. The results enabled us to estimate the number of muons relative to the primary energy in extensive air shower events across the energy range from 10 PeV to 1 EeV. A comparison was made between the experimental results and the expectations from the QGSJET-II-04 model, considering pure protons and iron nuclei, respectively.

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Constraining Lorentz Invariance Violation Parameters Using Short and Long Baseline Experiments

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The Lorentz Invariance is deeply connected to Special Relativity, which states that the laws of physics are the same for different observers in relative motion. It is the foundation of other successful theories, like quantum field theory, and connected to fundamental symmetries, like charge, parity, and time reversal (CPT), which is essential in the Standard Model of particle physics. Nevertheless, alternative theories proposing that Lorentz Invariance may break in some scales have been considered in the context of neutrino oscillations, as they can explain some anomalies present in experiments like LSND and MiniBoone. The dependence on baseline and energy can distinguish the influence of LIV on these anomalies in contrast with other effects, like Non-Standard Interactions (NSI). In this

work, we perform simulation studies to study the influence of Lorentz-violating parameters in neutrino experiments combining two different baselines. We use the General Long Baseline Experiment Simulator (GLoBES) with a modified probability engine to include LIV parameters.

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First Measurement of Double-Differential Charged Current νμ–Argon Scattering Cross Sections In Kinematic Imbalance Variables With The MicroBooNE Detector

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Making high-precision measurements of neutrino oscillation parameters requires an unprecedented understanding of neutrino-nucleus scattering. In this work, we present the first charged current double-differential cross sections in kinematic imbalance variables. These variables characterize both the transverse and total kinematic imbalance in a neutrino interaction. We use events with a single muon above 100 MeV/c, a single final state proton above 300 MeV/c, and no recorded final state pions. Thus, these variables act as a direct probe of nuclear effects such as final state interactions, Fermi motion, and multi-nucleon processes. Our measurement allows us to constrain systematic uncertainties associated with neutrino oscillation results performed by near-future experiments of the Short Baseline Neutrino (SBN) program, as well as by future large-scale experiments like DUNE.

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Cross Section Systematics in DUNE

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For the operation of precision neutrino experiments, the understanding of neutrino interactions with matter are preconditioned requirements of all detections and measurements of neutrinos. The largest uncertainties in estimating neutrino-nucleus interaction cross sections arise in the incomplete understanding of nuclear effects. In the study of neutrino oscillations and nuclear scattering processes, obtaining an interaction model with associated uncertainties is of sub- stantial interest for the neutrino physics community. This report presents studies of simulated CC 2p-2h interactions, in which a neutrino interacts with a bound pair of nucleons. This interaction mode is very poorly constrained by current data. A comparison of three leading CC 2p-2h models is presented, along with a number of uncertainty parameters that have been implemented to account for model-to-model discrepancies in the DUNE oscillation analysis.

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LIV Studies for Inverted Hierarchy Scenario

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The Standard Model is highly successful in describing the behavior of particles and the nongravitational forces that govern their interactions. However, its limitations hinder our ability to explain certain phenomena, like the observed matter-antimatter asymmetry. Such limitations led to the development of extensions to the Standard Model. Unified theories, such as string theory and loop quantum gravity, suggest that Lorentz Invariance Violation may occur at the Planck Scale, but direct measurements at this scale are currently impossible. Nevertheless, this violation could be observable at a lower energy scale accessible to current experiments under the Standard Model Extension (SME) framework. Long-baseline experiments with neutrinos are crucial in advancing our understanding of physics beyond the Standard Model. Nevertheless, such studies mainly concern the normal hierarchy of neutrino masses. In this study, we investigate the influence of LIV parameters on the inverted hierarchy scenario. We present the probabilities, event rates, and sensitivity studies for long-baseline neutrino experiments.

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Muon-neutrino charged-current cross sections from MicroBooNE: first simultaneous measurements of final states with and without protons for Muon-neutrino scattering on argon

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A detailed understanding of muon neutrino charged-current interactions on argon is crucial to the study of neutrino oscillations in current and future experiments using liquid argon time projection chambers. To help fill this need, MicroBooNE has produced a comprehensive set of cross section measurements which simultaneously probe the leptonic and hadronic systems by dividing the inclusive channel into final states with and without protons. Data-driven model validation utilizing the conditional constraint formalism is employed to detect mismodeling that may bias the nominal flux averaged cross section results, which are extracted with the Wiener-SVD unfolding method. The results are compared to widely used event generator predictions revealing significant mismodeling of final states without protons, possibly due to insufficient treatment of final state interactions. These are first differential muon neutrino-argon cross section measurements made simultaneously for final states with and without protons, and provide novel information that will help stimulate the improvement of event generator modeling.

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Data-driven model validation for neutrino-Argon inclusive measurements at MicroBooNE

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Neutrino-nucleus cross section measurements are needed to improve interaction modeling to enable upcoming precision oscillation measurements and searches for physics beyond the standard model. There are two methods for extracting cross sections, which rely on using either the real or nominal flux prediction for the measurement. We examine the different challenges faced by these methods. Furthermore, the necessity for model validation in both procedures is addressed, and differences between “traditional” fake-data based validation and data-driven validation are discussed.

Data-driven model validation leverages goodness-of-fit tests enhanced by the conditional constraint procedure. This procedure aims to validate a model for a specific measurement so that any bias introduced in unfolding will be within the quoted uncertainties of the measurement. Results are shown for the first measurement of the 3D differential cross section $d^2\sigma(E_\nu)/d\cos(\theta_\mu)dP_\mu$ for inclusive muon-neutrino charged-current scattering on argon in MicroBooNE using a nominal-flux-prediction unfolding and data-driven model validation.

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GiBUU-Based Monte Carlo Simulation for Neutrino Experiments

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This poster presents a Monte Carlo simulation implemented with the GiBUU model tailored for neutrino experiments. Specifically, we focus on its implementation, generating events in a generic liquid argon time projection chamber and comparing them with other neutrino event generators such as GENIE. The simulation generates realistic neutrino event samples, contributing to the prediction and interpretation of experimental outcomes. Our results demonstrate the robust performance of the GiBUU-based simulation framework and validate its performance against the original GiBUU cross-section model. Additionally, we outline our current efforts in developing infrastructure to address systematic uncertainties in the GiBUU model. By advancing simulation techniques, implementing neutrino-nucleus scattering models following different physics approaches, and building techniques to address systematical uncertainties, this work contributes to the refinement and reliability of neutrino experimental analyses.

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The development of the R-LDH Innovative media for O2 Capturing in Liquid Argon

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In this work, we have explored the potential of oxygen capturing in Liquid Argon (LAr) of the innovative CuO dispersive layered double hydroxide media (R-LDH). Low temperature experiments in the LAr Purification Cryostat (PuLArC) at IFGW/Unicamp were performed using LAr circulation through two filters, one containing the R-LDH material and the other the BASF commercial copper material (Cu-02265 - proposed as a reference O_2 getter media by Fermilab) for comparison. Interestingly, the experiments performed in PuLArC revealed that the R-LDH innovative media was capable of capturing O_2 from recirculating LAr in PuLArC, reducing the O_2 contaminants concentration to 80% of its initial values after 200 min of LAr circulation. As for the reference media BASF Cu-S0226, this media reduced the O_2 concentration to 40% of its initial value in the same time window. This result demonstrated a putative higher potential of the innovative R-LDH media for O_2 capturing in LAr and invoke further tests of this media in the PuLArC and in larger scale LAr cryostats, possibily at Fermilab and CERN.

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Evaluation of the Leggett-Garg inequality by means of the neutrino oscillations observed in reactor and accelerator experiments

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The study of neutrino oscillation and its quantumness was studied by means of the Leggett-Garg inequality, which is based on the concept of macrorealism. This research considered the results from the Daya Bay and RENO reactor experiments, as well as the MINOS and NOvA accelerator experiments. It was found that Daya Bay and MINOS exhibit a strong violation of the Leggett-Garg inequality, while the indications from RENO and NOvA data are weaker.

The phenomenon of neutrino oscillation is significant in this context as it allows for the study of quantum phenomena, such as the survival probability of a neutrino flavor, at macroscopic distances. These studies are made possible by the aforementioned experiments.

The results demonstrate that the violation of the Leggett-Garg inequality is more pronounced for a smaller baseline-to-energy ratio in all the data sets considered. This is an important factor to consider when searching for evidence of quantum mechanical decoherence in neutrino oscillations. The findings imply that there is a characteristic value for each neutrino flavor beyond which the inequality is not satisfied.

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Development and application of the nuclear deexcitation simulator NucDeEx for precise prediction of neutrino-nuclear interactions

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In recent years, neutron multiplicity associated with neutrino-nucleus interactions has become important observable in large neutrino detectors such as Super-Kamiokande, KamLAND, and JUNO. The neutron multiplicity can be measured by detecting gamma rays emitted by neutron capture by taking delayed coincidence. It is expected to improve the results of various physics analyses by using the measured neutron multiplicity to enhance flavor identification or signal-to-background ratio. However, predicting neutron multiplicity is a challenging topic because neutrino-nucleus interactions involve highly uncertain nuclear effects.
Among the various processes involved in neutrino-nucleus interactions, nuclear deexcitation plays an important role in neutron multiplicity. This process emits various particles while transitioning to the ground state when the residual nucleus has exciting energy after the nucleon is knocked out. One issue is that most widely used neutrino interaction generators omit this process or describe it with a simplified model. Another issue is that the energy of deexcited particles is as low as a few MeV and, therefore, unobservable, i.e., un-constrainable, by most accelerator neutrino detectors due to higher detection thresholds. This feature of deexcitation requires us to rely on precise nuclear theory and experiments to verify it.
In this study, I developed a nuclear deexcitation simulator, NucDeEx, based on the nuclear calculation software TALYS. Since TALYS contains sophisticated nuclear models and parameters, NucDeEx can precisely simulate the nuclear deexcitation process. In addition, NucDeEx can be easily integrated with the neutrino interaction generators and other hadron simulators, such as Geant4 and the hadron cascade model INCL. The source code of NucDeEx and the interfaces and build scripts necessary for use with the above software are available on the web. Thus, a wide range of applications are expected. In this talk, I will present an overview of NucDeEx, its performance evaluation with nuclear experiments, the impact of integrating NucDeEx into neutrino interaction generators, and its application and prospects for other hadron simulators.
Paper: Phys. Rev. D 109, 036009
NucDeEx GitHub: https://github.com/SeishoAbe/NucDeEx

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Bounds on Lorentz Violation Parameters: present and future

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String theory and loop quantum gravity suggest that Lorentz Invariance Violation may occur at the Planck scale. Nevertheless, this violation could be observable at a lower energy scale accessible to current experiments under the Standard Model Extension (SME) framework. This study aims to investigate and catalog current bounds for the Lorentz Invariance Violation (LIV) parameters using data from experiments. We also will study new bounds that new experiments will impose on these parameters. The methodology of this work is quantitative, using bibliographic research and data collection from academic materials and articles. This work is expected to result in a repository of parameter values for neutrino physics, facilitating data access and interpretation.

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Nitrogen removal from liquid Argon using Li-FAU, an innovative Brazilian method

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Liquid argon (LAr) is at the core of Time Projection Chamber (TPC) used in neutrino experiments. Nitrogen, oxygen, and water are the main contaminants in LAr that compromise the quality of physics a LArTPC can deliver. It is crucial to keep them as low as possible. In particular nitrogen is known to absorb the LAr scintillation light, one of the 2 key observables in LArTPCs. This poster outlines an experiment performed in the ICEBERG test stand at the Noble Liquid Test Facility (NLTF, Fermilab) to capture nitrogen from LAr using Li-FAU, an innovative method developed and previously tested in the Liquid Argon Purification Cryostat (PuLArC) at IFGW/Unicamp. Confirming the results obtained in PuLArC, this test shows that Li-FAU filtered the nitrogen injected multiple times into 2,625 L of LAr down to <1 ppm concentration over cycles of 96 h.

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Status of the Measurement of the Elastic and Quasi-elastic Scattering of Protons on Carbon Nuclei in EMPHATIC

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In long-baseline neutrino oscillation experiments, Monte Carlo (MC) simulations based on hadron interactions and decays are used to predict the neutrino flux. The 10%-level systematic uncertainty of the predicted neutrino fluxes from these simulations is dominated by uncertainties in hadron interaction cross sections due to limited hadron scattering data. EMPHATIC aims to reduce the neutrino flux uncertainty by providing additional data. Using a table-top-sized spectrometer located at the Fermilab Test Beam Facility (FTBF), its physics program includes precise measurements of hadron scattering and production cross sections at various beam momenta and target species that are relevant for GeV-scale neutrino production. Using simulation, we have developed a simple single-track reconstruction algorithm that has a momentum resolution of 3-4%. We will demonstrate the progress in developing one of EMPHATIC's first track reconstruction algorithms – an important step in making a new single-track forward scattering measurement ($p + C \longrightarrow p + C$ at several beam momenta) using Phase 1 data collected between 2022 and 2023.

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Probing light vector mediators with coherent scattering at future facilities

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Future experiments dedicated to the detection of Coherent Elastic Neutrino-Nucleus Scattering may be powerful tools in probing light new physics. In this paper we study the sensitivity on light Z' mediators of two proposed experiments: a directional low pressure Time Projection Chamber detector, νBDX-DRIFT, that will utilize neutrinos produced at the Long Baseline Neutrino Facility, and several possible experiments to be installed at the European Spallation Source. We compare the results obtained with existing limits from fixed-target, accelerator, solar neutrino and reactor experiments. Furthermore, we show that these experiments have the potential to test unexplored regions that, in some case, could explain the anomalous magnetic moment of the muon or peculiar spectral features in the cosmic neutrino spectrum observed by IceCube.

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Ant colony in Sensitivity Studies

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This work proposes an adaptation of the parameter verification method for CPT violation and CPT conservation in LIV parameters, as implemented in previous works by other authors using the GLoBES software. The adaptation will be based on the ant colony methodology (ACM) developed in the author's previous works.
The main objective is to reproduce the graphs and values obtained by other authors using the aforementioned ant colony methodology.
The ACM implementation will be calibrated, executed across various scenarios, and its results analyzed and compared to existing literature. The goal is to validate ACM as a tool for LIV parameter verification and efficient limit simulation.

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Nuclear effects in single pion production: hadron final state interactions

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Single pion production (SPP) is an important interaction mechanism in accelerator-based neutrino experiments, contributing significantly to total cross-sections and impacting precision measurements. Its study is essential for understanding neutrino oscillations, distinguishing signal from background, and refining theoretical models, which will help to reduce systematic errors in the neutrino energy reconstruction 1.

Therefore, a realistic SPP model that covers the whole energy range in neutrino experiments and accounts for final state interactions (FSI) is crucial. The current operator within the Hybrid model consists of several Feynmann diagrams including four nucleon resonances (P_{33}, D_{33}, P_{11} and S_{11}) and background terms from Chiral Perturbation Theory (ChPT) and an extension to the high energy region performed via Regge phenomenology [2]. This model is embedded in a sophisticated nuclear framework: the bound state is described as a Dirac solution within relativistic mean field (RMF) potentials. The final nucleon is in the relativistic distorted wave impulse approximation (RDWIA), a Dirac continuum state computed with energy dependent RMF potentials (EDRMF), so orthogonality between nucleon initial and final states is naturally implemented [3,4].
In recent work [5], we addressed the effect that the asymptotic approximation in the current operator has on inclusive and semi-inclusive cross sections. This is a step forward into a more complete and consistent treatment of SPP on the nucleus.

In a next step we implement FSI for the final pion, i.e., we describe the pion wave function with a RDWIA formalism. The pion continuum states are hence computed as solutions of the Klein-Gordon equation with a suitable nucleus-pion potential. The treatment of the final hadron wave functions,

with distortion effects from the residual nucleus, is the only way of taking into account elastic FSI within a consistent, fully relativistic and quantum-mechanical framework.

In this contribution we will present our latest results from Ref. [5] and new updates towards the inclusion of the pion distortion within our model.

1 L. Alvarez-Ruso *et al.*, Prog. Part. Nuc. Phys. 100 (2018)
[2] R. González-Jiménez *et al.*, Phys. Rev. D 95, 113007 (2017)
[3] R. González-Jiménez *et al.*, Phys. Rev. C 100, 045501 (2019)
[4] A. Nikolakopoulos *et al.*, Phys. Rev. D 107, 053007 (2023)
[5] J. García-Marcos *et al.*, Phys. Rev. C 109, 024608 (2024)

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Refining Neutrino Final State Interactions in carbon and lead: Insights from extrapolating between extremes

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Neutrino interactions with nucleons can lead to Final State Interactions (FSI), where the resulting hadrons scatter within the nucleus. However, current FSI models are often extrapolated to heavier nuclei, leading to possible discrepancies with experimental data. The MINERvA experiment employs five sets of nuclear targets, and it features an electromagnetic calorimeter (ECAL) situated at the back side of the detector, consisting of alternating layers of 2mm-thick lead and plastic scintillator. The substantial amount of lead interleaved within the ECAL, approximately 4 tons (fiducial) in total, offers the opportunity to isolate a high-statistics sample of neutrino-lead interactions. By analyzing the data collected by MINERvA's ECAL, we aim to improve our understanding of neutrino interactions with heavy nuclei and refine FSI modeling techniques. This poster provides insight into FSI model expectations scaling between hydrocarbon and lead, focusing on adapting simulation weights to mimic GENIE 3's A-dependent pion fate, with the MINERvA experiment's simulation baseline simulation based on GENIE 2.12.6. This ensures consistency with updated physics frameworks and enabling more accurate comparisons with experimental data.

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Studying Neutrino-Nucleus Interactions at SBND with Muon Neutrino CC Events

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The Short-Baseline Near Detector (SBND) is a 100-ton scale Liquid Argon Time Projection Chamber (LArTPC) neutrino detector positioned in the Booster Neutrino Beam (BNB) at Fermilab, as part of the Short-Baseline Neutrino (SBN) program. Located only 110 m from the neutrino production target, SBND is expected to record millions of neutrino interaction events every year allowing neutrino-argon cross-section measurements with unprecedented precision. This poster will present progress towards the first measurement of the muon-neutrino charged-current inclusive cross section in SBND.

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New developments in the Ghent Model for Single Pion Production

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Single-pion production constitutes an important contribution to neutrino-nucleus cross sections in the region regime covered by current and future accelerator-based neutrino-oscillation experiments. To analyse and interpret the data of these experiments, it is absolutely necessary to have good models for these cross sections available.

The Ghent model 1 for single-pion production consists of a low-energy part described by the three-level vertices of resonances on top of a background described by a Lagrangian from chiral perturbation theory (ChPT). This model can be extended to higher energies using Regge theory.

In order to improve the performance of the model, we reformulated our description in terms of helicity amplitudes and a multipole expansion. The advantage of this procedure, is that cross section contributions are separated in parts with fixed quantum numbers, providing more flexibility for further refinement of the model. Using this scheme makes it possible to effectively unitarize the whole background, taking into account the pion-nucleon scattering phases provided by pion-nucleon scattering data. Further, we modified the delta decay width and formfactors to incorporate Watson's theorem [2] and included meson exchange diagrams in the background, to obtain a better agreement with other models and data.

In this contribution we will present the results of these efforts in the vector sector. Work on implementing these developments in the axial part of neutrino-induced single pion production is in progress. In a next step, we will incorporate the updated description of the pion production off the nucleon in our nuclear model [3] to study the impact of these modifications on the total neutrino cross section and the comparison with data.

1 R. González-Jiménez, N. Jachowicz, K. Niewczas, J. Nys, V. Pandey, T. Van Cuyck, and N. Van Dessel Phys. Rev. D 95, 113007 (2017)

[2] L. Alvarez-Ruso, E. Hernández, J. Nieves, and M.J. Vicente Vacas Physical Review D93, 014016 (2016)

[3] A. Nikolakopoulos, R. Gonz\'alez-Jim\'enez, N. Jachowicz, and J.M. Udías Phys. Rev. D 107, 053007 (2023)

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Neutrons from CCQE-like Antineutrino Interactions in MINERvA's Various Nuclear Targets

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The MINERvA collaboration has demonstrated both an ability to detect neutrons from GeV-scale antineutrino interactions, and entangled deficiencies in the modeling of their production and detection. These deficiencies present problems for oscillation experiments as misunderstanding the neutron content in the final state will bias energy estimators which assume a particular final state (e.g. CCQE-like) or rely on calorimetric information. This poster describes a cross section analysis to further the study of GeV-scale neutron production. The analysis studies the neutron production in

CCQE-like interactions across MINERvA's range of nuclear targets: carbon, iron, water, and lead. It will provide insight into the effect of the nuclear environment on neutron production and subsequent detection in antineutrino CCQE-like interactions, across a broad range of nuclei.

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Influence of complex phases from off-diagonal parameters that violate Lorentz invariance in DUNE

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The existence of oscillating massive neutrinos poses a challenge to the standard model of particle physics (SM). Even standard oscillation theory cannot replicate the experimental results, such as the anomalies in the LSND and MiniBooNE data, pushing physicists to look for new alternatives, such as exploring physics Beyond the Standard Model (BSM). Utilizing a model involving Lorentz Invariance Violation (LIV) represents a possibility for understanding these phenomena. The fact that neutrinos are sensitive to measuring LIV is very relevant. To assess the numerical implications of a novel Hamiltonian introducing Lorentz-breaking parameters within the framework of the DUNE experiment, we employ the General Long Baseline Experiment Simulator (GLoBES) software. By modifying probability generators, we simulate the event count in the detector, focusing mainly on investigating the parameter phases from off-diagonal terms that conserve CPT symmetry while breaking Lorentz invariance.

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Professor Based ReWeight for GENIE Generator

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Interaction generators for neutrinos are essential tools to predict the final states of neutrino interactions from atmospheric and accelerator sources. Those final states would be important input to quantify the relation between the visible energy in our detector and the neutrino energy, whose distribution is affected by oscillation. This understanding is crucial for experiments such as JUNO, DUNE, and Hyper-Kamiokande. GENIE is one of the neutrino generators that specialise in the GeV region. Much work is being done to tune GENIE models' parameters to obtain for the best description of experimental datasets. In addition, the parameters extracted from the tuning have very well motivated statistical uncertainties that will make the analyses more robust as based on better motivated inputs. Once the initial inputs are defined, it will be crucial to understand the how the uncertainties would affect the predictions. Reweighting is a powerful approach to propagate those model uncertainties through GENIE. There are many restrictions in the current reweight approaches, the main being that only a subset of parameters can be reweightable. This work aims to utilize the Professor tool to model GENIE as respondence functions. This approach unifies the workflow of tunning and reweight, allowing us to propage the uncertainty obtained from the tuning using a reweight infrastructure. This will enable us to do reweight all parameters, including previously unweightable parameters, e.g. hadronization parameters.

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Hybrid model for single-pion production incorporated in the NuWro event generator nuclear framework

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Precise modeling of GeV neutrino interactions with nuclei underpins our understanding of data from atmospheric and accelerator neutrino experiments. Single pion production, a critical channel in these interactions, demands accurate representation as required by future experiments like DUNE and Hyper-K. The current NuWro single pion production model, while valuable, relies on a single Delta resonance and a non-resonant background obtained from Pythia. While Pythia excels in describing interactions with very high W values, its effectiveness diminishes at both lower and intermediate W values, leading to limitations in capturing single pion production accurately. To address these limitations, we propose a new single pion production model in NuWro. This model incorporates additional resonances and utilizes the Chiral Perturbation Theory (ChPT) method for a more comprehensive description of the non-resonant background, specifically focusing on the lower and intermediate W region. This refined approach demonstrably improves agreement with MINERvA transverse kinematic imbalance data compared to the previous model, paving the way for a more nuanced understanding of neutrino interactions.

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Impact of neutrino cross section uncertainties on NOvA physics measurements

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Impact of neutrino cross section uncertainties on MicroBooNE and SBN measurements

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Characterization of Neutral-current background induced by atmospheric neutrinos using neutrino event generators and the TALYS deexcitation package

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High-energy neutrino-matter interaction cross-sections in neutrino event generators

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Flux Overview

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Fermilab Beams

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J-PARC neutrino beam performance, monitoring and flux prediction, constraints and uncertainties

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MicroBooNE - 2

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SBND

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LIT+coupled cluster, SF from coupled cluster

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DWIA comparisons to recent measurements

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Telegrapher equation for photon diffusion in LArTPCs with photon removal at the boundaries

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LArTPCs are important detectors in several experiments and light propagation predictions inside the LArTPC play an important role in their capabilities. This work explores an analytical approach to predict light propagation. We present an analytical solution to a relativistic photon diffusion equation in terms of the physical parameters relevant to the DUNE detectors' physics and account for photon absorption at the boundaries through physical considerations, instead of solving it as a boundary value problem. We then compare our results to Geant4 simulations and find similar outcomes.

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MicroBooNE - 1

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MicroBooNE - 2

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ICARUS status and plans for measurements related to nu-Ar interactions with no mesons in the final state and/or QE- and 2p2h-like interactions

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Meson exchange currents in relativistic mean field

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Short time approximation

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DWIA comparison to recent experimental data

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Extended superscaling with two-particle emission in electron and neutrino scattering

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Improving neutrino reconstruction in LArTPCs by including charge and light signal

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The use of liquid argon time projection chambers for neutrino experiments provides good tracking resolution and PID capabilities. Analysis are typically based on the ionization electron (charge) collection but argon is also a prolific scintillator. We discuss how to better model the combined charge and scintillation light emission in argon and how the use of both signals together can improve neutrino energy resolution and impact the sensibility to parameters such as neutrino delta-CP phase and mass hierarchy.

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Electrons for Neutrinos

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Future long-baseline neutrino oscillation experiments, such as the Deep Underground Neutrino Experiment (DUNE), aim to measure neutrino oscillation parameters with unprecedented precision.
Such sensitivity demands precise characterization of the incoming neutrino energy, which can only be determined via comprehensive cross-section models. In particular DUNE, which flux peaks at 2.5~GeV, will be dominated by pion-production events. Far from ideal, current neutrino pion-production Monte Carlo simulations strongly rely on empirical models which fail to describe neutrino pion-production data at the few-GeV energy range on deuterium and heavier targets. The Electrons for Neutrinos collaboration (e4nu) proposes a novel alternative to leverage neutrino simulations by exploiting the similarities between electrons and neutrino interactions with matter. The e4nu collaboration is working towards a single-differential semi-inclusive pion production measurement with electron-scattering CLAS6 data at 1, 2, 4~GeV on Carbon. The results offer a new insight to exclusive pion-production properties and pion final-state-interactions in the nuclear environment and can be used to validate theory models and neutrino event-generators.

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The Hyper-K Intermediate Water Cherenkov Detector and the Water Cherenkov Test Experiment

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The Intermediate Water Cherenkov Detector (IWCD) is a planned component of the Hyper-K long baseline neutrino experiment with vertical mobility capable of scanning a region of the JPARC

accelerator-made neutrino beam spectrum. It will contribute to control systematic uncertainties arising from neutrino interaction cross sections and extrapolation of the beam flux between the Hyper-K near and far detectors. A key aspect of IWCD is its high granularity and fast time response thanks to an advanced photo-detection system based on multi-photomultiplier (mPMT) devices developed to deliver excellent Cherenkov ring reconstruction. The Water Cherenkov Test Experiment (WCTE) at CERN is designed to test this system, along with the capabilities of the calibration and reconstruction techniques planned for IWCD. It will use a beam produced at the CERN accelerator to also measure lepton interactions relevant to constraint uncertainties from physics models at a range of energies covering an important region of the IWCD phase space.This poster presents a short summary of both IWCD and WCTE, including their designs, plans and goals.

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Measuring muon antineutrino charged-current interactions without mesons in the final state, in the NOvA Near Detector

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NOvA is a long-baseline neutrino experiment based at Fermilab in the US, with the primary aim of measuring neutrino and antineutrino oscillations. This will enhance our understanding of electroweak interactions by measuring the neutrino mixing angles, CP-violating phase and neutrino mass ordering. To measure these oscillations, we first need to have a deep understanding of how neutrinos and antineutrinos interact with matter. Antineutrino interaction cross sections are, at present, particularly poorly constrained, and processes such as meson exchange currents are not well understood in the antineutrino sector.

This analysis will develop a cross-section measurement of muon antineutrino interactions without mesons (e.g. pions or kaons) in the final state, in the NOvA near detector. A high-statistics, high-purity sample is obtained through a cut-based selection process implementing machine learning techniques. The sample is dominated by quasi-elastic and meson exchange current interactions which are sensitive to nuclear effects such as final-state interactions. The cross section will be extracted as a function of the incoming neutrino energy and the kinematics of the outgoing particles.

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CEvNS and BSM physics with the CONNIE experiment.

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The CONNIE experiment is dedicated to detecting Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) of reactor antineutrinos using high-resistivity silicon CCDs at the Angra-2 reactor, and underwent significant advancements in 2021. Introducing two Skipper-CCD sensors with sub-electron readout noise, CONNIE became the pioneering project to employ Skipper-CCDs for reactor neutrino detection and achieved a record detection threshold of 15 eV. This work presents an overview of the sensors performance and the latest findings derived from 300 days of data collected during 2021-2022, totaling an exposure of 18.4 g-days. A comparison of event rates during reactor-on and off periods

reveals no excess, resulting in upper limits on the neutrino interaction rates at 95% confidence level, consistent with earlier findings. Additionally, searches for Physics Beyond the Standard Model yield constraints on simplified models with light vector mediators. New studies include a dark matter search employing diurnal modulation techniques and a quest for relativistic millicharged particles produced in the reactor. The promising outcomes achieved with a minimal sensor mass underscore the potential of Skipper-CCDs in probing rare neutrino interactions, motivating the future plans to expand the detector mass with a Multi-Chip-Module of Skipper-CCDs.

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Neutrino-induced single pion production and the reanalyzed bubble chamber data

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Photo-, Electro- and Weak Single Pion Production Model

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Pion Production at MINERvA

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Pion Production in NOvA

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Determination of the spectral functions of argon at JLab

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Electron Scattering in Generators

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Empirical fits to inclusive electron-carbon scattering data obtained by deep-learning methods

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Charged particles interaction measurements in ProtoDUNE

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Lattice QCD

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NUISANCE and global fits

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T2K Near Detector Upgrade

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Resonance and QE contributions to inclusive nucleon structure functions

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The Physics of SIS – TMC and HT

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Superscaling in the inelastic region: The SuSAv2-inelastic model

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Neutrino Cross Sections for collider neutrinos

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MicroBooNE

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T2K latest results and prospects on NC and CC pion production

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Impact of Cross Section Uncertainties on BSM Searches

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Double Beta Decay within the Relativistic QRPA

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In nature there are about 50 nuclear systems where the single beta-decay is energetically forbidden, and double beta-decay turns out to be only possible mode of disintegration. It is the nuclear pairing force which causes such an "anomaly", by making the mass of the odd-odd isobar, (N-1,Z+1), to be greater than the masses of its even-even neighbors, (N,Z) and (N-2,Z-2). The modes by which the double beta decay can take place are connected with the neutrino and antineutrino distinction. The Quasi-Particle Random Phase Approximation (QRPA) has turned out be the most simple model for calculating the nuclear wave function involved in the single and double beta-decay transitions. In this work we perform a self-consistent relativistic QRPA (RQRPA) calculation of double beta-decay based on relativistic BCS (RBCS) mean field theory results for odd-odd intermediate nuclei ^{48}Sc, ^{76}As, ^{82}Br, ^{100}Tc, ^{128}I, and ^{130}I. We use the parameter set NL3 for interactions between protons, neutrons, σ, ω, ρ mesons and fotons. The RQRPA equations are solved for the residual pion and rho interaction by employing the same parameters used in the RBCS, and experimental values for the pion and nucleons. The RQRPA results for the double beta-decay matrix elements are similar to those obtained within the QRPA and the shell model. Motivated by the results obtained here, we intend to calculate the neutrinoless decay in order to estimate the neutrino mass.

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