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Book of Abstracts

08 – Neutrinos and Nuclei

Foreword

In the present booklet we have collected the one-page abstracts of all contributions (invited, oral and poster) accepted at the INPC2013 Conference in the topic

Neutrinos and Nuclei

The submitted abstracts have been divided into the various topics of the Conference following mostly the indication given by the authors. In few cases, where the subject was on the borderline of two scientific areas or it appeared misplaced, the abstracts have been moved to the booklet of the more appropriate topic.

The abstracts are numbered and arranged alphabetically according to the name of the first author. In the parallel and poster sessions of the Conference, each contribution will be identified by the number of the corresponding abstract.

We wish you a pleasant and stimulating Conference.

The Organizing Committee

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NN 008.	Status of the WITCH experiment and preliminary results for the β-ν angular-correlation coefficient $\alpha_{\beta\nu}$ in the β decay of ^{35}Ar *P. Finlay, G. Ban, M. Beck, M. Breitenfeldt, X. Fabian, X. Flechard, P. Friedag, F. Glück, A. Herlert, A. Knecht, V. Kozlov, E. Liénard, T. Porobic, G. Soti, M. Tandecki, S. Van Gorp, Ch. Weinheimer, E. Wursten, D. Zákoucký, and N. Severijns* Contact email: *paul.finlay@fys.kuleuven.be*
NN 009.	Measurements of 2ν-double-beta decay matrix elements: some surprises in nuclear physics. *D. Frekers* Contact email: *Frekers@Uni-Muenster.de*
NN 010.	Low-energy neutrino and other weak reactions in nuclei *D. Gazit* Contact email: *doron.gazit@mail.huji.ac.il*
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NN 016.	Search for neutrinoless double beta decay in ^{124}Sn *Vandana Nanal* Contact email: *nanal@tifr.res.in*

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NN 021.	Neutrinoless double beta decay rates around mass 130 in the nuclear shell model *N. Yoshinaga, K. Higashiyama* Contact email: *yoshinaga@phy.saitama-u.ac.jp*
NN 022.	Status of the GERDA double beta decay experiment *K. Zuber* Contact email: *zuber@physik.tu-dresden.de*

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Status and Results from the EXO Collaboration

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The Enriched Xenon Observatory (EXO) is an experimental program searching for neutrinoless double beta decay using $^{136}\mathrm{Xe}$. Such a search can shed light on the Majorana nature of the neutrino (whether the neutrino is its own anti-particle), the absolute mass scale of neutrinos, and beyond standard model processes that violate lepton number conservation. The first phase of the experiment, EXO-200, uses 200 kg of xenon with 80% enrichment in $^{136}\mathrm{Xe}$ in a single-phase liquid xenon time projection chamber (TPC). The double beta decay of xenon is detected in the ultra-low background TPC by collecting both the scintillation light and the ionization charge. The detector has been taking low background physics data with enriched xenon at the Waste Isolation Pilot Plant (WIPP) in New Mexico since early May 2011. The results produced from the collaboration include the first observation of two-neutrino double beta decay of $^{136}\mathrm{Xe}$, and a neutrinoless double beta decay search result that places one of the most stringent limits on the effective Majorana neutrino mass. Building on the success of EXO-200, the collaboration is performing feasibility studies and R&D work for a future multi-tonne scale experiment named nEXO. During the talk, I will discuss the latest results from EXO-200 and prospects of neutrinoless double beta decay search with both EXO-200 and nEXO.

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Photon emission in (anti)neutrino neutral current interactions with nuclei

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A good understanding of (anti)neutrino interactions with nuclear targets in the $E_\nu \sim 1$ GeV region is vital to reduce the systematic uncertainties in oscillation experiments aiming at a precise determination of neutrino properties. One of the possible reaction mechanisms is photon emission by neutral-current (NC) interactions:

$$\begin{array}{rcll} \nu(\bar{\nu})\,N & \to & \nu(\bar{\nu})\,\gamma\,N & \text{(on nucleons)} \\ \nu(\bar{\nu})\,A & \to & \nu(\bar{\nu})\,\gamma\,X & \text{(on nuclei, incoherent)} \\ \nu(\bar{\nu})\,A & \to & \nu(\bar{\nu})\,\gamma\,A & \text{(on nuclei, coherent)} \end{array}$$

In spite of its small cross section, this process is one of the largest backgrounds in $\nu_\mu \to \nu_e$ $(\bar{\nu}_\mu \to \bar{\nu}_e)$ oscillation experiments when photons are misidentified as $e^\pm$ from charge-current quasi-elastic scattering of ν_e $(\bar{\nu}_e)$. The MiniBooNE experiment found no evidence of $\nu_\mu \to \nu_e$ oscillations but a sizable excess of electron-like events was observed in the 200-475 MeV window of reconstructed neutrino energy [1]. A similar excess was absent in the antineutrino mode [2]. A recent study [3] has obtained that this excess can be explained by electron-like photon events but it does not take into account that in a detector made of mineral oil (CH_2), photon emission takes place predominantly in ^{12}C nuclei.

We have investigated this reaction with a microscopic model that takes into account the relevant hadronic degrees of freedom [π, N and $\Delta(1232)$] and is consistent with the symmetries of the strong interactions at low energies. The contribution of N^* resonances from the second resonance region [$N(1440)\,1/2^+$, $N(1520)\,3/2^-$ and $N(1535)\,1/2^-$] has also been computed. The model has been extended to the case of nuclear targets, for both the coherent and incoherent channels, taking into account Fermi motion, Pauli blocking and the in-medium modifications of the $\Delta(1232)$ properties. These nuclear effects cause a considerable ($\sim 30\%$) reduction of the cross section. Using the efficiency for photon detection and other experimental details we obtain the number of photon events at MiniBooNE as a function of the photon energy, angle and reconstructed (anti)neutrino energy. The results are compared to the MiniBooNE estimate based on NCπ^0 direct detection, and with other calculations [3,4]. Finally, we make predictions for the ongoing T2K experiment.

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The MINERνA Neutrino Experiment at Fermilab

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MINERνA (Main INjector ExpeRiment ν-A) is a neutrino scattering experiment using the high intensity neutrino beam (NuMI) produced by the Main Injector at Fermilab. MINERνA will make precision cross-section measurements of neutrino interactions with various nuclear targets (He, C, H_2O, Fe, Pb) at low and medium energy to study nuclear medium effects with a clean weak probe. The first round of measurements using a low energy neutrino beam (few GeV) has been carried out between 2009 and 2012. The next round of measurements with a medium energy beam (5 to 10 GeV with a tail extending up to 20 GeV) will start this summer and continue for several years. Preliminary charged current inclusive and quasi-elastic neutrino scattering measurements of different nuclear targets (C, Fe, Pb) will be presented. Various methods to estimate the neutrino flux will be also discussed.

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Search for resonant double-electron capture

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It is still unknown whether neutrinos are Dirac or Majorana particles. An answer to this question can be obtained from neutrinoless double-electron capture. An observation of this process would prove that the neutrino is a Majorana particle. A measurement of the half-life of this process would allow a determination of the effective Majorana neutrino mass.

In the search for the nuclide with the largest probability for neutrinoless double-electron capture, we have determined the *Q*-values of several potentially suitable nuclides with SHIPTRAP by Penning-trap mass-ratio measurements. The ECEC-transition in ^{152}Gd has been determined to have the smallest half-life of 10^{26} years for a 1 eV neutrino mass among all known 0νECEC-transitions, which makes ^{152}Gd the most promising candidate for the search for neutrinoless double-electron capture. This contribution will summarize the recent experimental results.

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Beta-neutrino correlation measurements with LPCTrap

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The precise measurement of the beta-neutrino angular correlation coefficient a in nuclear beta decay is a sensitive tool to search for exotic couplings presently excluded by the V-A theory of the weak interaction. For instance, the study of a pure Gamow-Teller (GT) transition enables to probe tensor-type couplings while a pure Fermi (F) transition is sensitive to scalar-type interactions. Moreover, in the case of mirror transitions, a precise measurement of a also allows the determination of the mixing ratio between the GT and F contributions. This constitutes an important input for the database of nuclear mirror transitions, leading to the extraction of the V_{ud} element of the CKM matrix [1]. In a beta-neutrino correlation measurement, the most relevant observable is the energy distribution of the recoiling daughter nuclei. In the LPCTrap device, the radioactive nuclei are confined in a Paul trap, allowing the detection of the recoil ions in coincidence with the beta particles [2]. The set-up is presently installed at LIRAT, the low energy beam line of the SPIRAL facility at GANIL. The correlation measurement in the pure GT ^{6}He decay has already reached a relative statistical precision of 0.5%. Particular attention is continuously being devoted to the study of systematic effects. Among them, the sensitivity of the set-up to the charge state distributions of recoiling ions appears to be controlled precisely enough to actually allow determining the shake-off probabilities in the decay of 1+ ions with an excellent precision [3]. As the Paul trap enables to confine any radioactive species, an experiment with ^{35}Ar, which essentially decays through a mirror transition with a large Fermi component (>90%), has been done in June 2012 using the same set-up. These first experiments have clearly shown that LPCTrap is well suited for precise correlation measurements. These different aspects will be discussed during the talk, with a focus on the ^{35}Ar experiment.

[1] O. Naviliat-Cuncic and N. Severijns, Phys. Rev. Lett. 102 (2009) 142302
[2] X. Fléchard et al., J. Phys. G: Nucl. Part. Phys. 38 (2011) 055101
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Neutrinoless Double Beta decay and Determination of Neutrino Mass

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The main aim of the neutrinoless double beta decay (-$0\nu\beta\beta$decay) is the determination of the absolute values of the neutrino masses. This is only possible, if (i) the light Majorana neutrino exchange is the leading contribution to the $0\nu\beta\beta$. (ii) The second condition is a reliable calculation of the nuclear matrix elements. They determine the accuracy of the extracted electron Majorana neutrino mass from the measurement.

In this talk the present status of the precision of the nuclear matrix elements given with theoretical ”error bars” [1,2]. These uncertainties include different Quasi-particle Random Phase Approximations (QRPA, Renormalized QRPA, selfconsistent QRPA), different treatments of short range correlations , single nucleon basis sizes, different realistic nucleon-nucleon forces. The approaches treat the nucleus spherical and deformed [3,4]. Results from the Shell Model, from the Interacting Boson (IBA) Approach and from the angular momentum projected Hartree Fock Bogoliubov method without and with deformation as generator coordinate are also discussed.

In the second part other mechanisms than the light Majorana neutrino exchange are investigated [5]: Grand Unifications (GUT's), Supersymmetry (SUSY) and even additional dimensions allow also the neutrinoless double beta decay. How can one measure, which of these mechanisms is the leading one? A possibility to evaluate $0\nu\beta\beta$-decay matrix elements phenomenologically is also discussed.

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I want to thank Sergey Petcov, Vadim Rodin, Fedor Simkovic, John Vergados and Petr Vogel, with whom these results have been obtained.
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[5] A. Faessler, A. Meroni, S. T. Petcov, F. Simkovic, J. Vergados, Phys. Rev. D**83**, 14003 (2011).

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Contribution of recently measured nuclear data to reactor antineutrino energy spectra predictions

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The aim of this work is to study the impact of the inclusion of the recently measured beta decay properties of some nuclei (for instance $^{102;104;105;106;107}$Tc, ^{105}Mo, and ^{101}Nb) in the calculation of the antineutrino energy spectra arising after the fissions of the four fissible isotopes $^{235;238}$U, and $^{239;241}$Pu, the main contributors to the fissions in PWRs. These beta feeding probabilities have been found to play a major role in the gamma component of the decay heat for ^{239}Pu in the 4-3000 s range [1]. They have been measured using the Total Absorption Spectroscopy (TAS) technique, coupling for the first time a total absorption spectrometer to a double Penning trap at the JYFL facility of the University of Jyväskylä. Following the fission product summation method presented in the reference [2], the calculation was performed using the MCNP Utility for Reactor Evolution code coupled to the experimental spectra built from beta decay properties of the fission products taken in evaluated databases JEFF3.1, JENDL (experimental data supplemented by Gross theory spectra), supplemented by ENSDF data, the data measured by Tengblad et al. and the TAS data measured by Greenwood et al. in the nineties. For the remaining unknown nuclei, a rough approximation assuming 3 equiprobable decay branches is used. The antineutrino energy spectra are computed after the formulae adopted by P. Huber [3].

The result of this work has been published in [4]: the latest TAS data quoted above are found to have a significant effect on the Pu isotope energy spectra and on the energy spectrum of ^{238}U. These results show the importance of the measurement of new TAS data for a better assessment of the reactor antineutrino energy spectrum, of importance for fundamental neutrino physics experiments as well as neutrino applied physics. The analysis of some newly measured nuclei is presently on going in our group [5] and a new experiment devoted to measure 9 extra nuclei of interest in reactor antineutrino energy spectrum reconstruction is schedule for middle 2013 at the JYFL of Jyväskylä.

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[2] Th. Mueller et al., Phys. Rev. C 83, 054615 (2011).
[3] P. Huber, Phys. Rev. C 84, 024617 (2011).
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[5] A.A. Zakari Issoufou's abstract @ this conference

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Status of the WITCH experiment and preliminary results for the β-ν angular-correlation coefficient $a_{\beta\nu}$ in the β decay of ^{35}Ar

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High-precision measurements of weak-interaction observables offer a powerful probe of physics beyond the Standard Model complementary to that provided by direct searches at colliders like the LHC. In particular, β-decay kinematic correlation measurements can be sensitive to the presence of scalar and tensor current interactions, which are assumed to be absent in the standard electroweak model [1].

The WITCH spectrometer [2] is a unique apparatus designed to determine the β-ν angular correlation coefficient $a_{\beta\nu}$ via the shape of the recoil-ion energy distribution. It consists of a double Penning trap system for the preparation and storage of a scattering-free source, coupled with a MAC-E type retardation spectrometer and large position-sensitive MCP detector to detect the recoiling daughter ions.

The commissioning phase of the apparatus has come to a close and the first physics results for $a_{\beta\nu}$ in the decay of ^{35}Ar have been obtained at the end of 2011 [3]. Many upgrades to the system have been implemented in the interim, culminating in the first high-statistics data taking run, which was performed in November 2012. Details of the analysis of this new data set, including preliminary results, will be presented.

[1] N. Severijns *et al.*, Rev. Mod. Phys. **78**, 991 (2006).
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[3] S. Van Gorp *et al.*, Phys. Rev. Lett. (2012, submitted).

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Measurements of 2ν-double-beta decay matrix elements: some surprises in nuclear physics.

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I will talk about high-resolution charge-exchange reactions of (n,p) and (p,n) type at intermediate energies, which directly connect to the nuclear matrix elements in double-beta ($\beta\beta$) decay. Here, the (n, p) type reactions are realized through (d,^{2}He) reactions, where ^{2}He refers to two protons in a singlet $^1S_0$ state and where both of these are momentum analyzed and detected by the same spectrometer and detector. These reactions have been developed and performed exclusively at KVI, Groningen (NL). The (p, n) type (^{3}He,t) reaction was developed at the RCNP facility in Osaka (Japan) allowing measurements with a resolution of 30 keV at incident energies of 420 MeV. Using both reaction types one can extract the Gamow-Teller transition strengths B(GT$^+$) and B(GT$^-$), which define the two "legs" of the $2\nu\beta\beta$ decay matrix elements. The high resolution available in both reactions allows a detailed insight into the excitations of the intermediate odd-odd nuclei and, as will be shown, some rather unexpected and surprising features are being unveiled. Special emphasis will be placed on the $\beta\beta$ decay nuclei ^{76}Ge, ^{96}Zr, ^{100}Mo and also recent results for ^{128,130}Te and ^{136}Xe will be presented as well. In the case of ^{76}Ge, an extreme fragmentation of low-energy B(GT) strength is observed, contrary to ^{96}Zr and ^{100}Mo, where the entire low-energy GT-strength is concentrated in a single level, which in the case of ^{100}Mo also happens to be the ground state of ^{100}Tc. Also, the pathologically large half-life of the ^{136}Xe $2\nu\beta\beta$ decay [1] finds a natural explanation.

I will also talk about future directions using ion traps at the TRIUMF radioactive beam facility in Vancouver (Canada) to measure electron-capture branching ratios of the intermediate odd-odd nuclei, which are poorly known or not known at all. Together with the β^- decay, these decays define the ground-state properties of the intermediate nucleus and thereby also connect to the nuclear $\beta\beta$ decay matrix elements of both, the 2ν and the 0ν part. The setup and first test measurements have been completed and some results will be communicated [2].

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A. Gando et al., Phys. Rev. C 85, 045504 (2012).

[2] I express appreciation to my collaborating partners from the KVI, the RCNP and from TRIUMF, who I cannot entirely list in this abstract, but who I will give credit to in the presentation.

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Low-energy neutrino and other weak reactions in nuclei

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Chiral symmetry allows a systematic construction of a low-energy effective Lagrangian, that enables a consistent and controlled description of static and dynamic properties of nuclei. I will discuss recent work, which starts from this consistency of currents and forces in chiral effective field theory, and leads to better description of nuclear forces, beta decays, and rare reactions. This opens a rainbow of opportunities, from checking the limits of the standard model to describing the micro-physics of astrophysical phenomena.

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Novel Approaches to Calculate Nuclear Matrix Elements for Double Beta Decays

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Neutrinoless double beta decay is a unique process that could reveal physics beyond the Standard Model of particle physics [1]. If observed, it would prove that neutrinos are Majorana particles, and it could provide information regarding the neutrino masses and their hierarchy, provided that reliable nuclear matrix elements (NME) can be obtained [1,2]. The two-neutrino double beta decay is an associate process that is allowed by the Standard Model, and it was observed for about ten nuclei. The NME associated with this decay mode could be even more difficult to calculate [3,4,5], but they can be directly related to the experimental half-lives, and they can be constrained using data from charge-exchange reactions. The present contribution offers a brief overview of the theoretical challenges associated with these two processes, emphasizing the tools necessary to reliably calculate the associated nuclear matrix elements. It also emphasizes the role of the competing mechanisms that could contribute to the neutrinoless double beta decay half-life [1].

In particular, the special case of ^{136}Xe is analyzed. Recent experimental results for its two-neutrino double beta decay mode provide a rather small NME [6]. We propose a novel shell model approach that can accurately described this small NME without artificially decreasing the Gamow-Teller quenching factor. Having tuned the wave functions to described the two-neutrino double beta half-life, we used them to calculate the neutrinoless NME. Using the recent experimental upper limit of the associated neutrinoless half-life [6] we derive lower limits for the neutrino physics parameters, and in particular, assuming that the dominant mechanism contributing to the decay is the exchange of light left-handed Majorana neutrino, we provide lower limits for the effective neutrino mass [1].

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MINERνA Charged Current Inclusive Analysis

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The MINERνA is a few-GeV neutrino scattering experiment that has been taking data in the NuMI beam line at Fermilab since November 2009. The experiment will provide important results, both in support of neutrino oscillation searches and as a pure weak probe of the nuclear medium. For this, MINERνA employs a fine-grained detector, with an eight ton active target region composed of plastic scintillator and a suite of nuclear targets composed of helium, carbon, iron, lead and water placed upstream of the active region. In this talk, we present the current status of the charged current inclusive analysis for neutrinos and antineutrinos in plastic scintillator.

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Neutrino-nucleus interactions: from nuclear dynamics to neutrino oscillations

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Neutrino physics has undergone a spectacular development in the past decade, following the discovery of neutrino oscillations. In the neutrino oscillation experiments nuclear targets are involved, hence the knowledge of neutrino-nucleus scattering is crucial. We present a theory of neutrino interactions with nuclei aimed at the description of several partial cross sections, namely quasielastic and multinucleon emission, coherent and incoherent single-pion production [1]. We compare our approach to the available neutrino experimental data on carbon. We put a special emphasis on the multinucleon emission channel which is related to the two particle-two hole excitations. As we suggested [1,2,3], this channel can account in particular for the unexpected behavior of the quasielastic cross section measured by MiniBooNE. The impact of the multinucleon emission channel on the neutrino energy reconstruction procedure [4] (which is based on the quasielastic kinematics), hence on the determination on the neutrino oscillation parameters, is also analyzed in connection with the recent T2K and MiniBooNE results [5].

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The Role of Sterile Neutrinos in Nuclear Weak Processes and the Search for Neutrino-like Dark Matter

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Sterile neutrinos with masses of a few keV are important as extensions of the Standard Model of particle physics. They are also serious dark matter candidates as suggested by recent cosmological and galactic observations and simulations [1]. With this in mind we explore the role of heavy sterile neutrinos in nuclear weak processes through their mixing with the light active neutrinos or, in other words, through the exchange of generalized vector bosons with smaller couplings.

We consider firstly nuclear beta decays, in particular the cases of Rhenium 187 and Tritium which are involved in two ongoing experiments, MARE and KATRIN. The production of a keV sterile neutrino in those beta decays could show up as a small kink in the spectrum of the emitted beta particle which takes place within an energy region of the beta spectrum different from the one suitable to measure the mass of the light active neutrino.

We then expand our study to other charged and neutral weak processes in nuclei allowing for the direct detection of relic or dark-matter heavy sterile neutrinos. Those processes include heavy neutrino capture and scattering by nuclei, again as mixtures with active neutrinos. A non-conventional kinematics arises in those cases where the mass of the incident neutrino largely surpasses the one of the nuclear target.

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Neutrino Interactions with Nuclei

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Present-day long baseline experiments with neutrino beams all use nuclear targets to extract axial properties of the nucleon and neutrino oscillation parameters. This extraction requires knowledge about the neutrino energy. Since the incoming neutrino energy is not fixed, but instead smeared over a wide range (several 100 MeV to several GeV), in any single event it must be reconstructed from the measured outgoing lepton and hadron energy and angular distributions. For this reconstruction it is essential, first, to understand the initial reaction mechanism of neutrinos with the target nucleus. Second, the final state interactions have to be described with state-of-the art theoretical methods. The main difficulty here is that during the propagation of the produced hadrons throughout the nucleus these undergo final state interactions (fsi): the hadrons can be absorbed, produced and change their kinematics. This can drastically change the typical final-state-signature of the initial mechanisms and thus lead to a misidentification of the reaction mechanism. In this talk we discuss interactions of neutrinos with nuclei in the energy ranges relevant for the MiniBooNE, T2K, NOνA, MINERνA and MINOS experiments. It is stressed that any theoretical treatment must involve all the relevant reaction mechanisms: quasielastic scattering, pion production and DIS. In addition, also many-body interactions play a role and in particular the final state interactions have to be described as well as the primary reaction mechanisms. We show how a misidentification of the reaction mechanism due to fsi can affect the energy reconstruction and illustrate this for the example of the T2K experiment [1]. We also discuss how the newly measured pion production cross sections, as reported recently by the MiniBooNE collaboration, can be related to the old cross sections obtained on elementary targets. The new data, which could give access to the axial transition form factor of the Δ resonance, seem to be compatible only with the old BNL data [2]. We also discuss the meson production processes at the higher energies of the NOνA, MINERνA and MINOS experiments [3]. Here final state interactions make it impossible to gain knowledge about the elementary reaction amplitudes. In all the present studies the GiBUU implementation of transport theory [4] was used to describe the reaction mechanism from the initial interaction all the way to the final state.

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Search for neutrinoless double beta decay in ^{124}Sn

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The mass and nature of neutrinos play an important role in theories beyond the standard model. The nuclear β decay and double beta decay can provide the information on absolute effective mass of the neutrinos, which would represent a major advance in our understanding of particle physics. At present, neutrinoless double beta decay is perhaps the only experiment that can tell us whether the neutrino is a Dirac or a Majorana particle. Given the significance of the 0νββ, there is a widespread interest for these rare event studies employing a variety of novel techniques. An essential criterion for detector design is the high energy resolution for a precision measurement of the sum energy of two electrons emitted in 0νββ decay. The low temperature bolometric detectors are ideally suited for this purpose.

In India, efforts have been initiated to search for 0νββ in ^{124}Sn ($Q_{\beta\beta}$=2.28 MeV, 5.8% abundance) at the upcoming underground facility of India based Neutrino Observatory (INO). A custom built cryogen free dilution refrigerator has been installed at TIFR, Mumbai for the development of Sn prototype bolometer. A base temperature of 10 mK has been achieved in this setup. This talk will briefly describe efforts towards Sn bolometer development.

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The EXO experiment

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The Enriched Xenon Observatory (EXO) is an experimental program designed to search for the neutrino-less double beta decay of ^{136}Xe. The current phase of the experiment, EXO-200, uses 200 kg of liquid xenon with 80% enrichment in ^{136}Xe, and also serves as a prototype for a future 1-10 ton scale EXO experiment. The detector has been taking low background physics data with enriched xenon at Waste Isolation Pilot Plant (WIPP) in New Mexico since early May 2011. After reporting the first observation of two-neutrino double beta decay of ^{136}Xe in fall 2011, the collaboration has completed several detector upgrades and fine tuned detector performance for the search of neutrinoless double beta decay. In our first search result with an exposure of 32.5 kg-yr, no signal is observed with a background of 1.5×10^{-3} Ct/ kg/yr/keV in the 1 sigma region of interest. This sets a lower limit on the half-life of the neutrinoless double-beta decay in ^{136}Xe, $T_{1/2} > 1.6 \times 10^{25}$ yr (90% CL), corresponding to effective Majorana masses of less than 140-380 meV, depending on the matrix element calculation.

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Properties of neutrinoless double beta decay nuclear matrix elements studied along isotopic chains

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Neutrinoless double beta decay ($0\nu\beta\beta$) is the most promising process to disentangle the Majorana nature of the neutrino, its effective mass and the mass hierarchy. In this process, an even-even nucleus can not energetically decay into the odd-odd neighbor but it is allowed into the even-even nucleus with two protons more and two neutron less.

In this contribution we analyze nuclear matrix elements (NME) of neutrinoless double beta decay calculated for several isotopic chains (*pf*-shell nuclei and Cadmium isotopes). Energy density functional methods including beyond mean field effects such as symmetry restoration and shape mixing are used. Strong shell effects are found associated to the underlying nuclear structure of the initial and final nuclei. Furthermore, we show that NME for two-neutrino double beta decay evaluated in the closure approximation display a constant proportionality with respect to the Gamow-Teller part of the neutrinoless NME. This opens the possibility of determining the $0\nu\beta\beta$ matrix elements from $\beta\pm$ Gamow-Teller strength functions. Finally, the interconnected GT role of deformation, pairing, configuration mixing and shell effects in the NMEs will be discussed.

Rare weak decays and nuclear structure

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Weak interactions, as the name indicates, are indeed weak if we measure weakness in terms of time scales of processes they generate, say in atomic nuclei where they prompt disintegration phenomena in the time scale of seconds. However, notable exceptions to this state of affairs are caused by (a) extremely small decay energies (Q-values), (b) initial and final nuclear states with large difference in angular momentum and (c) weak-interaction processes of higher order. These extreme conditions of decay lead to processes that involve time scales far beyond the seconds scale, to scales much longer than the age of the Universe. Typically such processes have half-lives of the order of 10^{20} years (practically the age of the Universe squared!) and thus can be called 'ultra slow'. The related transitions need special experimental facilities and dedicated experimental techniques in order to be detected. The detection sites of such rare processes need to be protected against cosmic rays, i.e. the flux of particles from outer space. This is why the dedicated experiments go underground, in deep mine shafts or under huge amount of massive mountain rock. Hence the related scientific effort is appropriately called 'underground physics', or to contrast it with the research done in particle accelerator facilities, 'non-accelerator physics'.

In Fig. 1 below an example of the above-listed points (b) and (c) is given. Here the mother nucleus ^{96}Zr decays to states in ^{96}Nb via ultra-slow beta transitions, retarded by the large differences in angular momentum between the initial state (spin 0) and the final states (spins 4-6). In addition to the ultra-slow beta transitions there is a very interesting ultra-slow direct transition from ^{96}Zr to the ground state of ^{96}Mo. In this case the decay jumps past the nucleus ^{96}Nb and goes directly to the ground state of ^{96}Mo and thus it falls into the category (c) in our classification of ultra-slow processes. These higher-order transitions form a class of transitions called generically the nuclear double beta decay.

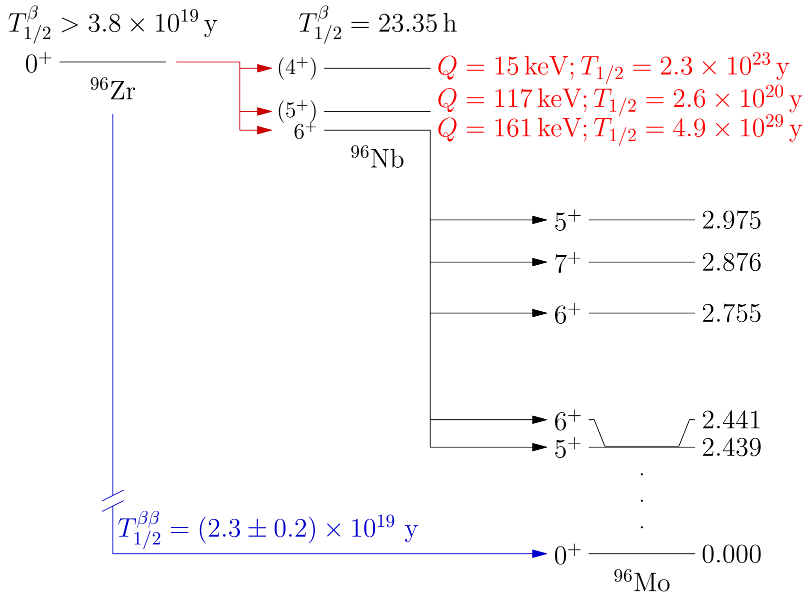

Figure 1: *Ultra-slow beta-decay transitions from the ground state of ^{96}Zr to states in ^{96}Nb, and the subsequent beta decay to states in ^{96}Mo. Shown is also the direct double-beta-decay transition to the ground state of ^{96}Mo.*

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CANDLES - Search for neutrino-less double beta decay of ^{48}Ca -

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CANDLES is the project to search for neutrino-less double beta decay ($0\nu\beta\beta$) of ^{48}Ca. $0\nu\beta\beta$ is acquiring great interest after the confirmation of neutrino oscillation which demonstrated nonzero neutrino mass. Measurement of $0\nu\beta\beta$ provides a test for the Majorana nature of neutrinos and gives an absolute scale of the effective neutrino mass.

Among double beta decay nuclei, ^{48}Ca has an advantage of the highest Q-value (4.27 MeV). This large Q-value gives a large phase-space factor to enhance the $0\nu\beta\beta$ rate and the least contribution from natural background radiations in the energy region of the Q-value. Therefore good signal to background ratio is ensured in the measurement of $0\nu\beta\beta$.

In order to search for $0\nu\beta\beta$ of ^{48}Ca, we proposed CANDLES system by using CaF_2 scintillators[1]. The CANDLES system aims at a high sensitive measurement by a characteristic detector structure and ^{48}Ca enrichment. The detector structure realizes a complete 4π active shield by immersion of the CaF_2 scintillators in liquid scintillator. The active shield leads to a low background condition for the measurement. On the other band, ^{48}Ca enrichment is also effective for the high sensitive measurement, because natural abundance of ^{48}Ca is very low (0.19%). This means that an improvement of sensitivity by enrichment is a maximum of 20 times for the neutrino mass. However ^{48}Ca enrichment is generally difficult and expensive. Therefore we started the study of ^{48}Ca enrichment and succeeded in obtaining enriched ^{48}Ca although it is a small amount.

We installed the CANDLES III system, which contained 350 g of ^{48}Ca without enrichment, at the Kamioka underground laboratory. Now we installed a light-concentration system to a good energy resolution. A photo-coverage was about twice larger than the one without the light-concentration system. And we started a $0\nu\beta\beta$ measurement and have data of a measurement time for 3 months.

Here we will report the result of the measurement in 2012 and the expected sensitivity with the light-concentration system.

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Neutrinoless double beta decay rates around mass 130 in the nuclear shell model

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The observation of the neutrinoless double-β decay can determine whether the neutrino is a Majorana particle or not. In theoretical nuclear side it is particularly important to estimate three types of matrix elements, namely, Fermi (F), Gamow-Teller (GT), and tensor (T) matrix elements.

Three methods have been used so far to evaluate the nuclear matrix elements, the shell model (SM) in its original version [1] and in very recent large scale versions [2], and the quasiparticle random-phase approximation (QRPA) in its early form [3] and in the microscopic interacting boson approximation [4]. Unfortunately there still remain large ambiguities in estimating those nuclear matrix elements in various methods. In this paper, we carry out the full-fledged shell model calculations [5], the pair truncated shell model calculations [6] and the generator coordinate method calculations to check the sensitivity of the results to assumptions made concerning the single-particle energies and the strengths of interactions. In the conference we present the main results on this issue.

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Status of the GERDA double beta decay experiment

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The GERDA experiment [1] located in the Gran Sasso Underground Laboratory of INFN is using enriched Ge-semiconductor detectors directly within a LAr cryostat for the investigation of the double beta decay of ^{76}Ge. The experiment has a two phase approach. Phase I is using the detectors of the former Heidelberg-Moscow and IGEX experiments while Phase II will use in addition BEGe detectors optimized for pulse shape analysis. The design and performance during data taking of the experiment will be presented. The status of the preparation for Phase II will be outlined. First results of the data taking of GERDA will be given among them the identification of background components and a new half -life measurement of the 2 neutrino double beta decay of Ge-76 [2].

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