INPC 2013

INTERNATIONAL NUCLEAR PHYSICS CONFERENCE

FIRENZE, ITALY 2-7 JUNE 2013

Book of Abstracts

05 - Fundamental Symmetries and Interactions in 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

Fundamental Symmetries and Interactions in 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

Fundamental Symmetries and Interactions in Nuclei (SY)

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SY 012.	Search for Time-Reversal Invariance Violation in Nuclei *V. Gudkov, Y.-H. Song* Contact email: *gudkov@sc.edu*
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High Precision Experiments with Cold and Ultra-Cold Neutrons

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The talk addresses some questions of particle and nuclear physics and concerns the search for possible deviations from the Standard Model (SM) of particle physics with cold and ultra-cold neutrons. The deviations are expected to be the phenomenological outcome of more fundamental theories, unifying all forces induced shortly after the Big Bang.

Precise symmetry tests of various kinds are coming within reach with proposed neutron facilities, where count rates of neutron decay products are increased by a factor 100 compared to best experiments. The goal is neutron beta-decay spectroscopy, where the spectra and angular distributions of the emerging decay particles will be distortion-free on the level of 10^{-4}.

Next, we present a novel direct search strategy with neutrons based on a quantum bouncing ball in the gravity potential of the earth. The aim is a test of Newton's gravity law with a quantum interference technique, providing a constraint on any possible new interactions on the level of accuracy. Many extensions to the standard model naturally predict deviations from Newton's law at short distances that should be detectable. If the reason is that some undiscovered dark matter or dark energy particles interact with a neutron, this should result in a measurable energy shift of the observed quantum states. The experiment has the potential to find or exclude these hypothetical particles in full parameter space.

Our goal is insight into the answers to fundamental questions: Firstly, what is dark energy? Is it a cosmological constant, or is it a scalar field such as quintessence or a dynamic quantity whose energy density can vary in time and space? This proposal has – compared to other methods - the unique potential to decide: either to find a signal or rule out certain realizations of quintessence completely. Secondly, what is dark matter? The concept is the detection of very light bosons through the macroscopic forces which they mediate, leading to a deviation from Newton's law at short distances, exactly in the range of this experiment. Thirdly, are the four basic forces – electromagnetism, the weak force, the strong force and gravitation - unified at high energies?

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Measurement of the Weak Nucleon-Nucleon Interaction by Polarized Cold Neutron Capture on Protons

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The NPDGamma Experiment at the Spallation Neutron Source at Oak Ridge National Laboratory is measuring the parity-odd correlation between the neutron spin and the direction of the emitted photon in the capture of cold neutrons on protons. A parity violating asymmetry from this process is directly related to the strength of the hadronic weak interaction between nucleons [1]. The experiment run first with heavier nuclear targets to check systematic effects, false asymmetries, and backgrounds. Since early 2012 the experiment has been running with a 16-liter liquid parahydrogen target. Data taking is continuing through most of 2013 when statistics for a 10^{-8} asymmetry measurement will be achieved. The experiment performance will be discussed as well as the status of the analysis of $5x10^{-8}$ asymmetry measurements.

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Relativistic pseudospin and spin symmetries in nuclei - recent results

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Pseudospin symmetry in nuclei has been a topic in nuclear physics since the late 60's, when it was introduced to explain the near degeneracy of some single-particle levels near the Fermi surface. The subject was revived in 1997 when Ginocchio was able to related it with a symmetry of the Dirac equation with scalar S and vector V mean-field potentials such that $V = -S + C$ where C is a constant. However, this symmetry cannot be realized exactly in nuclei because it turns out that the sum potential $V + S$ provides the binding of nucleons in nuclei. This spurred much research about pseudospin symmetry in nuclei, including such topics as its very nature (how it is broken, whether is perturbative or not), the role of isospin, the effect of tensor potentials and the implications for the structure of radial functions or even supersymmetric features of the symmetry. Most of the studies used relativistic mean-field self-consistent calculations or mean-field external potentials such as Woods-Saxon or the harmonic oscillator, including the so-called Dirac oscillator. These studies have been extended also to anti-nucleon systems and more recently to ressonant states as well as to Coulomb potentials, and often include a similar symmetry, called spin symmetry, realized when $V = S + C$, and which is related to spin-orbit coupling. We present the last results and our view of what was learned about the pseudospin and spin symmetries applied to nucleon and quark systems, as well as some of the challenges that lie ahead.

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Early Results from the Qweak Experiment

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A subset of results from the recently completed Jefferson Lab Qweak experiment will be reported. This experiment, sensitive to physics beyond the Standard Model, exploits the small parity violating asymmetry in elastic $\vec{e}p$ scattering to make the first direct measurement of the proton's weak charge Q_W^p. The experiment employed a 180 µA longitudinally polarized 1.16 GeV/c electron beam on a 35 cm long liquid hydrogen target. Scattered electrons in the angular range $6^\circ < \theta < 12^\circ$ corresponding to $Q^2 \approx 0.026$ (GeV/c)^2 were detected in one of eight Cerenkov detectors arrayed symmetrically about the beam axis. The goals of the experiment were to provide a measure of Q_W^p to 4.1%, which implies a measure of $\sin^2(\theta_W)$ to 0.3%, and to provide a tight constraint on a combination of the vector weak quark charges C_{1u} and C_{1d}. Aspects of the experimental method will be described, with a focus on the challenges presented and met by the world's highest power LH_2 target. The new constraints on C_{1u} and C_{1d} provided by the subset of the experiment's data analyzed to date will also be shown.

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Laboratory Search for Spin-dependent Short-range Force from Axion-Like-Particles using Optically Polarized ^{3}He gas

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The possible existence of short-range forces between unpolarized and polarized spin-1/2 particles has attracted the attention of physicists for decades. These forces are predicted in various theories and provide a possible new source for parity (P) and time reversal (T) symmetry violation. We use an ensemble of polarized 3He gas in a cell with a 250 μm thickness glass window to search for a force from pseudoscalar boson exchange over a sub-millimeter range. This interaction would produce a NMR frequency shift as an unpolarized mass is moved near and far from the polarized ensemble. We report a new upper bound with a factor of 10 to 30 improvement on the product $g_s g_p^n$ of the scalar couplings to the fermions in the unpolarized mass, and the pseudoscalar coupling of the polarized neutron in the 3He nucleus for force ranges from 10^{-4} to 10^{-2} m, which corresponds to a mass range of 2×10^{-3} to 2×10^{-5} eV for the pseudoscalar boson. This represents the most sensitive search that sets a direct limit in the important "axion window".

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Prospects for electric-dipole-moment measurements in Radon

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A permanent electric dipole moment (EDM) of a particle or system would arise due to breaking of time-reversal (T), or equivalently charge-conjugation/parity (CP) symmetry. Over the past five decades, a number of experiments on the neutron, atoms and molecules have only set upper limits on EDMs, and the search continues, motivated in large part by the expectation that beyond Standard-Model physics CP violation is required to explain the baryon asymmetry of the universe. In addition, new techniques and access to systems in which the effects of CP violation would be greatly enhanced are driving the field forward. One example of a system that may be favorable for significant advances is radon, specifically the isotopes ^{221,223}Rn, where the combination of significant octupole collectivity and relatively closely spaced opposite parity levels would increase the nuclear Schiff moment by orders of magnitude compared to other diamagnetic atoms, i.e. ^{199}Hg. A number of technical and nuclear-structure issues must be addressed in order to assess the prospects for an experiment of significant impact. Among the technical challenges are developing an on-line EDM experiment at an isotope-production facility that will collect and make measurements on the short-lived species (half lives are $\approx$ 25 min). We have developed and tested a system for high-efficiency collection and spin-exchange polarization of noble-gas isotopes that has been tested at the TRIUMF ISAC facility (experiment S929). Nuclear-structure issues include determining the octupole collectivity as well as the spacing of opposite parity levels. A series of experiments are planned or underway at ISOLDE (IS475 and IS552), NSCL at Michigan State University (experiments 11502 and 12006) and ISAC (S929) to study the nuclear structure of isotopes in this mass region. I will report on progress on all these fronts and comment on how we learn about the basic physical parameters of CP violation from EDM measurements.

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Measurement of the hyperfine structure of antihydrogen

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The ASACUSA collaboration at the Antiproton Decelerator of CERN is planning to measure the ground-state hyperfine splitting of antihydrogen using an atomic beam line. The setup consists of a cusp trap as a source of partially polarized antihydrogen atoms emitted toward a radiofrequency spin-flip cavity [1,2]. A superconducting sextupole magnet serves as spin analyser before the detection of the atoms in an antihydrogen detector.

Monte Carlo simulations show that the antihydrogen ground-state hyperfine splitting can be determined in a beam at a relative precision of $\sim 10^{-7}$.

Antihydrogen is the simplest atom consisting entirely of antimatter. Since its matter counterpart is one of the most precisely measured atoms in physics, a comparison of antihydrogen and hydrogen at the 10^{-7} level would already offer one of the most sensitive tests of CPT symmetry.

My talk will discuss the theoretical background and present the latest experimental developments as well as the coming years program to achieve the above mentioned precision.

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Precision Measurement of the $\pi^+ \to e^+\nu$ Decay

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In the Standard Model (SM), lepton universality refers to the identical electroweak gauge interactions among the charged leptons. The measurement of the branching ratio

$$R_{e/\mu} = \frac{\Gamma(\pi \to e\nu)}{\Gamma(\pi \to \mu\nu)} \tag{1}$$

is one of the most stringent tests of lepton universality between the first two generations. Theoretical calculations [1-4] can be very precise in calculating $R_{e/\mu}$ since strong interaction dynamics cancels out in the ratio and structure dependent terms appears only through electroweak corrections. The calculated SM value is $R^{SM}_{e/\mu} = 1.2352(2) \times 10^{-4}$. The current experimental precision (fig. 1) is 20 times worse than the previous theoretical result, and therefore a new experimental effort is needed for matching the theoretical precision. The current experimental value is $R^{PDG}_{e/\mu} = (1.230 \pm 0.004) \times 10^{-4}$. A new measurement of $R_{e/\mu}$ will provide improved constraints to new physics beyond the SM or uncover new scenarios if a disagreement will be found. Many new physics scenarios predict violation of lepton universality and therefore $R_{e/\mu}$ becomes a very sensitive probe, especially for new pseudo-scalar interactions, where the mass reach extends up to 1000 TeV [7] at the level of expected experimental precision. The PIENU experiment at TRIUMF aims at measuring $R_{e/\mu}$ with a precision five times larger the previous experiments ([5],[6]). The experimental technique is based on a high-purity pion beam stopped in an active target. The two decay modes of the pion are detected at the same time with the same detectors and acceptance: in the ratio many uncertainties cancel providing a high-precision measurement. The PIENU detector system is able to accurately measure timings and energies (fig. 2) of the decay positrons from the $\pi \to e\nu$ and $\pi \to \mu \to e$ decay chains. Preliminary results from a blind analysis will be presented.

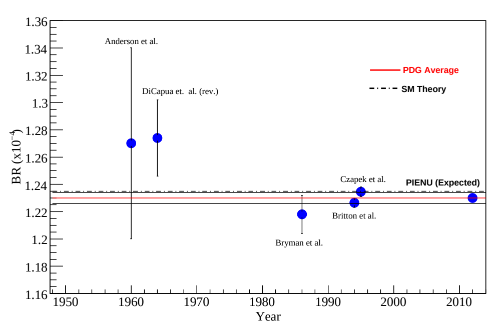

Figure 1: *History of the $R_{e/\mu}$ experimental results and the foreseen PIENU precision reach.*

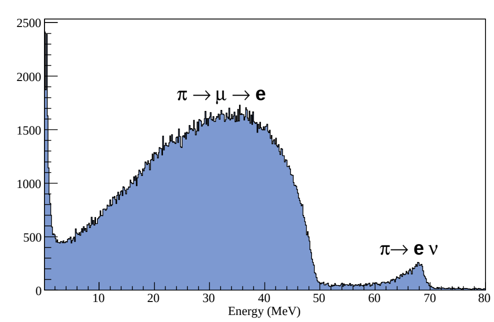

Figure 2: *Energy spectrum of the two decays obtained from the PIENU NaI calorimeter.*

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Anti-proton and Anti-hydrogen Studies at ATRAP

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Significant experimental efforts continue to be dedicated to basic nucleon properties of the anti-proton such as its charge-to-mass ratio [1], magnetic moment, or -by means of spectroscopy of anti-hydrogen-its charge radius or magnetic form factor. When compared to their matter-counterparts, precision measurements of anti-protons and anti-hydrogen will further provide very stringent tests of CPT (charge conjugation, parity and time reversal) symmetry as fundamental to our formulation of physics in terms of Lorentz invariant, local quantum field theories.

At ATRAP, this type of research is currently pursued along two aspects. The first goal is to perform precise spectroscopy of anti-hydrogen in a magnetic atom trap. Here, a milestone has recently been accomplished by simultaneously trapping 5 anti-hydrogen atoms on average with confinement times of 15 to 1000 s- long enough to ensure that they have reached their ground state [2]. The second goal is to precisely determine the anti-proton's magnetic moment $\mu_{\overline{p}}$. By utilizing one-particle methods in a Penning trap [3,4,5] ATRAP has performed the first direct measurement of $\mu_{\overline{p}}$ with a precision of 4.4 parts per million [6], a 680 fold improvement over the literature value [7]. These techniques can be applied for both, proton and anti-proton, and ultimately promise a gain in experimental precision of $\mu_{\overline{p}}$ by at least a factor of 10^3 in addition to the present measurement.

This talk will present recent progress in ATRAP's anti-hydrogen efforts as well as the first direct measurement of the anti-proton's magnetic moment.

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*collaboration spokesperson
†participating in anti-hydrogen studies only

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Fundamental Symmetry Tests with the ALPHA Antihydrogen Trap

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The ultimate goal of the ALPHA experiment at CERN is to test symmetry between matter and antimatter at highest possible precision via comparisons of the properties of atomic hydrogen with its antimatter counter-part, antihydrogen. After several years of development, we achieved the first major milestone, tapping of antihydrogen, in 2010. Subsequently, in 2011, ALPHA has reported confinement of antihydrogen for as long as 1000 seconds, an increase by a factor more than 5000 from the initial result. Most recently in 2012, ALPHA has succeeded in performing the first spectroscopic measurement on antihydrogen atoms by driving its hyperfine transitions with microwaves. Currently, ALPHA is going through a major upgrade to construct an entirely new apparatus, ALPHA-2, which will allow laser access to the trapped anti-atoms, and provide improved magnetic field configurations for microwave spectroscopy. Possibilities for a measurement of antimatter-gravity interactions are also being explored. This talk will discuss the recent achievements and the future prospects of ALPHA experiment.

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The MOLLER Experiment: A high precision measurement of the electron weak charge.

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The MOLLER experiment is currently under development and is planned to take place at the Jefferson Laboratory Continuous Electron Beam Accelerator Facility (CEBAF), following the completion of its upgrade to 12 GeV. The Moller collaboration proposes to make a measurement of the weak charge of the electron, $Q^e_W = 1 - 4\sin^2\theta_W$, with a precision of 2.3% by measuring the parity-violating asymmetry in electron-electron (Møller) scattering. This measurement will provide an ultra-precise measurement of the weak mixing angle, $\sin^2\theta_W$, which is on par with the two most precise collider measurements at the Z0-pole. The world average of the two most precise independent determinations of $\sin^2\theta_W$ is consistent with other electroweak measurements and the Higgs boson mass M_H, but they actually differ by 3 standard deviations. Choosing one or the other central value ruins this consistency and implies very different new high-energy dynamics. The proposed measurement, which aims to achieve a sensitivity of $\delta(sin^2\theta_W) = \pm 0.00029$, is the only method available in the next decade to directly address this issue at the same level of precision and interpretability. At this precision, the measurement would be a probe of physics beyond the Standard Model with sensitivities to mass scales of up to 7.5 TeV, if a deviation from the Standard Model expectation is seen. I will provide an overview of the physics this experiment addresses and discuss the experimental design.

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Search for Time-Reversal Invariance Violation in Nuclei

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The important advantage to the search for Time-Reversal invariance violation (TRIV) in neutron nuclei interactions is the possibility of an enhancement of T-violating observables by many orders of magnitude due to the complex nuclear structure (see, i.e. paper [1] and references therein). Moreover, the variety of nuclear systems to measure T-violating parameters provides assurance that a possible "accidental" cancelation of T-violating effects due to unknown structural factors related to the strong interactions in the particular system would be avoided. Taking into account that different models of the CP-violation may contribute differently to a particular T/CP-observable, which may have unknown theoretical uncertainties, TRIV nuclear effects could be considered valuable complementary experiments to electric dipole moment (EDM) measurements.

The comparison of the ratio of TRIV to parity violating (PV) coupling constants λ with the constrains on the coupling constants from the EDM experiments gives us the opportunity to estimate the possible sensitivity of TRIV effects to the value of TRIV nucleon coupling constant, which we call a "*discovery potential*" for neutron scattering experiments [2], since it shows a possible factor for improving the current limits of the EDM experiments. Then, taking the DDH "best value" [3] of $h_\pi^1 \sim 4.6 \cdot 10^{-7}$, nuclear enhancement factors, and assuming that the parameter λ could be measured with an accuracy of 10^{-5} on the complex nuclei, one shows that the existing limits on the TRIV coupling constants could be improved by two orders of magnitude, assuming that the π-meson exchange contribution is dominant for PV effects. However, there is an indication [4] that the PV coupling constant h_π^1 is much smaller than the "best value" of the DDH. Should it be confirmed by the $\vec{n} + p \to d + \gamma$ experiment, the estimate for the sensitivity of λ to the TRIV coupling constant may be increased up to two orders of magnitude. This might increase the relative values of TRIV effects by two orders of magnitude, and as a consequence, the discovery potential of the TRIV experiments could be about 10^4.

As a result we show that the TRIV effects in neutron transmission through a nuclei target are very unique TRIV observables being free from FSI, and are of the same quality as the EDM experiments. These TRIV effects are enhanced by about 10^6 due to the nuclear enhancement factor. In addition to this enhancement, the sensitivity to TRIV interactions in these effects might be structurally enhanced by about 10^2 if PV π-nucleon coupling constant is less than the "best value" DDH estimate. Therefore, these types of experiments with high intensity neutron sources have a discovery potential of about $10^2 - 10^4$ for the improvement of the current limits on the TRIV interaction obtained from the EDM experiments.

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Towards atomic parity violation experiments with laser trapped francium isotopes

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In atoms, extremely weak electric dipole transitions between states of the same parity are induced by the parity-violating exchange of Z-bosons between the electrons and the quarks in the nucleus, an effect known as atomic parity violation (APV). By measuring this amplitude we can study neutral-current weak interactions with atomic physics methods and search for *new* physics such as extra gauge bosons and leptoquarks. APV is strongly enhanced in heavy atoms, making francium an interesting choice for a new APV experiment. TRIUMF's ISAC radioactive beam facility is now delivering intense beams of francium isotopes to our new laser trapping facility, where we plan to carry out APV experiments with cold, trapped, samples of Fr atoms. We report on first results, the measurement of hyperfine anomalies and isotope shifts in several Fr isotopes, and give an outlook on upcoming experiments.

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Probing fundamental interactions by an Electrostatic Ion Beam Trap

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One of the possibilities to study fundamental interactions and the underlying symmetries is via precision measurements of the parameters of beta decay of trapped radioactive atoms and ions. For example, determining the beta-neutrino angular correlation coefficient in a trap can probe the minute experimental signal that originates from possible tensor or scalar terms in the weak interaction, thus probing possible new physics of beyond-the-standard-model nature. For precision measurements of this correlation, traps are mandatory since the recoiling nuclei, subsequent to the beta decay, are at sub-keV energies.

We have embarked on an experimental scheme to establish a novel experimental set-up to study the beta-neutrino correlation by studying the decay of the trapping light radioactive ion beam inside an Electrostatic Ion Beam Trap. This method exhibits several advantages compared to other commonly used trapping schemes in terms of concept, efficiency and ease of operation. The first nuclide under study is ^{6}He, to be produced using use neutron-induced reactions and subsequent ionization in an electron ion beam source/trap (EBIT) for ionization. The $^{6}He^{+}$ radioisotopes will be stored in an electrostatic ion beam trap (EIBT), commonly used in atomic and molecular physics. The entire apparatus has been built at the Weizmann Institute. The method, the results of commissioning runs and future plans will be discussed.

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Constraints on Spin-Dependent Short-Range Interaction between Nucleons Using a 3He/129Xe Comagnetometer

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We report on the search for a new spin-dependent P- and T-violating interaction between nucleons mediated by light, pseudoscalar bosons such as the axion which was invented to solve the strong CP problem. Our experimental approach is to use an ultra-sensitive low-field magnetometer based on the detection of free precession of co-located ^{3}He and ^{129}Xe nuclear spins using SQUIDs as low-noise magnetic flux detectors [1]. In the presence of an unpolarized mass the precession frequency shift was measured to determine the coupling of pseudoscalar particles to the spin of the bound neutron. For the force range from 10^{-4} m – 10^{-1} m, corresponding to the preferred mass range between 2μeV and 2 meV for the axion or axion-like particles, we improved the bounds on the products of scalar and pseudoscalar couplings ($g_s g_p$) by up to 7 orders of magnitude. This talk will cover the experimental techniques to reach the improved sensitivity limits.

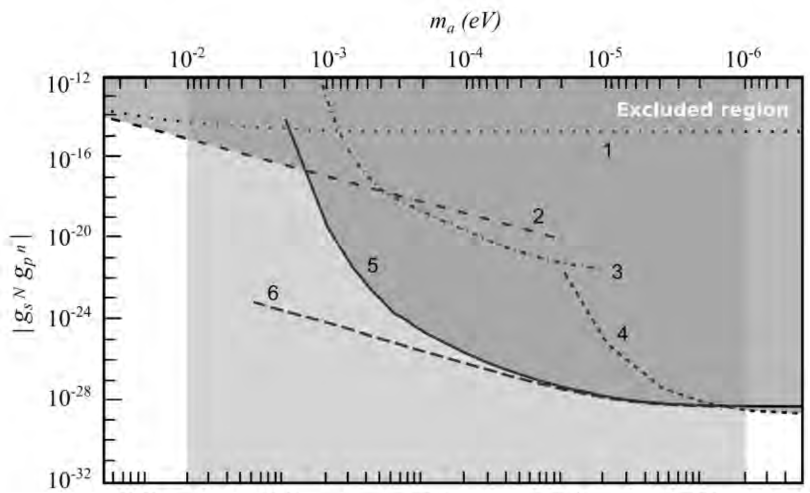

Figure 1: *The experimental 95% confidence upper limit on* $\left|g_s^N g_p^n\right|$ *plotted versus λ, the range of the Yukawa-force (dark grey area). The axion window is indicated by the light grey area. (1-4): results from other experiments, (5): this experiment.*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Active nuclear spin maser oscillation with double cell

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A permanent electric dipole moment (EDM) of a particle, atom, or molecule is an observable directly violating the time reversal symmetry, and hence will be an evidence for unknown CP-violating phases beyond the Standard Model. The present study aims at measuring the EDM in ^{129}Xe atoms to a size of $|d| = 10^{-28}$ *e*cm. In the EDM measurement, we employ the active nuclear spin maser [1] which enables us to sustain the spin precession of ^{129}Xe in a long measurement duration. The spin precession of ^{129}Xe is detected optically through Rb atoms which are polarized by contact with ^{129}Xe. A magnetic field is generated according to the phase in the direction orthogonal to the spin precession, in order to prevent the transverse spin relaxation.

The previous developments of the active spin maser have improved the precision of determination of the frequency to $\delta\nu = 9.3$ nHz for one-shot measurement within a limited duration [1,2]. However, systematic uncertainty arises from long-term drifts in frequency, amounting even to 400 μHz, which mainly arises from drifts in the external magnetic field and frequency shifts due to contact interaction with the polarized Rb atoms. A co-magnetometer using ^{3}He was incorporated to the nuclear spin maser system in order to cancel out the former drifts which were commonly sensed by ^{129}Xe and ^{3}He. On the other hand, the latter one could not be removed even by the ^{3}He co-magnetometer because the strengths of the Rb-^{129}Xe and Rb-^{3}He contact interaction are different [3,4]. Therefore we decided to employ a double cell [5] in which the gas volume is divided into an optical pumping part and an optical detection part in order to reduce the spin polarization of Rb in the optical detection part and thus to suppress the frequency shift due to the contact interaction.

In this work, we studied operation of the active nuclear spin maser in a double cell configuration. Optimum settings for the parameters of the double-cell maser operation either for ^{129}Xe and ^{3}He, such as the magnitude of the feedback field, phase and the gas temperature, were estimated through tests using a single cell where the pumping part and the detection part were unified. Using the optimized parameters thus obtained, the active spin maser in the double cell configuration was actually operated. The performance of the maser in this new operation mode may undergo difference arising from the diffusion of the gas between the two regions of cell. The difference will be discussed with the comparison to that using the single cell. The improvement in the frequency precision will also be discussed in the presentation.

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Development of narrowband lasers for spectroscopy of antiprotonic atoms

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We describe several types of solid state, organic dye, and semiconductor diode lasers developed by the ASACUSA collaboration of CERN, to carry out laser spectroscopy of antiprotonic atoms. These lasers were based on the technique of continuous-wave injection seeding of pulsed lasers that covered the wavelength regions 264–1154 nm, with laser peak powers of up to 1 MW and spectral resolutions of 6–40 MHz. The optical frequency of the lasers were stabilized against a femtosecond frequency comb. The devices were recently used to measure the transition frequencies of antiprotonic helium atoms to a fractional precision of $\sim 10^{-9}$ [1,2]. Efforts are currently underway to improve the precision and stability of these lasers.

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Parity Violating Measurements of Neutron Densities

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The recent PREX experiment at Jefferson Laboratory has demonstrated a new technique that uses parity violating electron scattering to measure neutron densities of a heavy nucleus. This electroweak reaction is free from most strong interaction uncertainties. We describe the experiment, present first results for 208Pb, and discuss some of the implications for nuclear structure, atomic parity violation, and neutron rich matter in astrophysics. We discuss second-generation experiments PREX-II, to more accurately measure the neutron radius of 208Pb, and CREX to measure the neutron radius of 48Ca. Finally we present some possibilities for even more ambitious measurements.

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Experimental search for electric dipole moment in ^{129}Xe atom using active nuclear spin maser

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A permanent electric dipole moment (EDM) of a particle, atom, or molecule is an observable directly violating the time reversal symmetry, and hence probes CP-violating phases beyond a frame of the Standard Model of elementary particles. The present study aims at measuring the EDM in a diamagnetic atom of ^{129}Xe to a size of $|d| = 10^{-28}$ $e$cm, stepping into a domain below the present upper limit $|d| < 4.1 \times 10^{-27}$ $e$cm [1] by one order of magnitude. The value of EDM is determined from difference between the frequencies of ^{129}Xe spin precession measured with the electric field applied parallel and antiparallel to the magnetic field. The EDM search to a size of $|d| = 10^{-28}$ $e$cm requires an improvement in the frequency precision down to a level of 1 nHz under an electric field of 10 kV/cm.

In the present EDM measurement we employ an active nuclear spin maser [2] which enables us to sustain the spin precession of ^{129}Xe in a long measurement duration. The active spin maser operates as follows: the longitudinal polarization of ^{129}Xe spin is produced through spin exchange with Rb atoms which are optically pumped. Then the ^{129}Xe spin starts precession, which is detected optically through Rb atoms which are repolarized by contact with ^{129}Xe. By referring to the precession signal thus obtained, a magnetic field rotating in the transverse plane is generated such that its direction is kept orthogonal to transverse component of spin, which thus prevents the transverse spin relaxation. The previous developments of the active spin maser have improved the precision of frequency determination to $\delta\nu = 9.3$ nHz for a one-shot measurement within a limited duration [2,3]. A comagnetometer using ^{3}He has been incorporated to the nuclear spin maser system in order to cancel out a long-term drift in the external magnetic field, by taking advantage that it directly measures the magnetic field that acts on the volume where the ^{129}Xe spin precesses. Both the ^{129}Xe gas and the ^{3}He gas are contained in a cell of which the gas volume is divided into an optical pumping part and an optical detection part, in order to reduce the longitudinal spin polarization of Rb atoms in the optical pumping part and thus to suppress the frequency shift due to polarized Rb atoms. Electrodes are attached to the both sides of the optical detection part in order to apply an electric field of 10 kV/cm.

With the success in the above developments, the EDM search for ^{129}Xe to a size of $|d| = 10^{-28}$ $e$cm has been ready and the measurement is now being started. The developments and the status of the measurement will be presented.

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[3] T. Inoue et al., Physica E 43, 847 (2011).

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Development of the measurement system toward the electron EDM search experiment using the laser cooled Fr atom

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A permanent electric dipole moment (EDM) of a particle, an atom or a molecule violates the time reversal invariance. If it has a finite value, it would represent a clear evidence for the physics beyond the standard model (SM) of elementary particles. Until now, the experimental limit for the electron EDM is $|d_e| < 10.5 \times 10^{-28}$ e·cm [1]. The upper limit already enters the region predicted by the several types of the models of supersymmetry, which are the major candidates for theoretical models beyond the SM. In this respect, EDM search experiments have already stepped into the phase in which the experimental upper limits would urge the theories to modify their predictions.

We have constructed a laser-cooled francium (Fr) factory at Cyclotron and Radioisotope Center (CYRIC), Tohoku University to perform the highly sensitive search for the electron EDM [2]. Fr has the largest enhancement factor of the electron EDM in alkali atoms. Although Fr has no stable isotope, some isotopes of Fr, such as ^{210}Fr, have the long life time enough to perform the EDM search experiment. Fr is produced through the nuclear fusion reaction ^{197}Au + ^{18}O → $^{215-x}$Fr + xn by using the gold target and the oxygen beam accelerated by AVF cyclotron. The laser cooling and trapping techniques can be applicable to Fr atoms. As a result, a long coherence time would be realized and systematic errors caused by the motion of the atom are drastically suppressed. A high vacuum environment for the laser cooling will allows us to apply the high electric field. In addition, the field inhomogeneity can be suppressed, since the trapped atoms are spatially localized.

Recently, we have developed an electric field application system under the vacuum environment. Electrodes are made of oxygen free copper to suppress magnetic field fluctuations around the EDM measurement region. A typical leakage current across the electrodes is 10 pA at the electric field of 25 kV/cm. Until now, we have successfully applied the electric field of 50 kV/cm without discharge for 10 sec. The magnetic field fluctuation around the measurement region is investigated. The magnetic field fluctuation is the main source of the false EDM signal. We introduce a trial magnetic shield made of a high permeability magnetic material to suppress influences from the environmental magnetic field. A residual field fluctuation inside the shield was suppressed to be below 0.1 nT. The laser cooling system is also being developed by using the Rb atom that has a similar chemical property of Fr atom. After the construction of a magneto-optical trapping system, a development of an optical dipole trap (ODT) system is in progress. Since the ODT technique needs no magnetic field and field gradient, it supply a desirable condition for the EDM search experiment. The present statuses of the electric field application, magnetic field stability and the ODT will be presented.

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Search for a permanent EDM using laser cooled radioactive atom

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Understanding certain observed phenomenon such as matter-antimatter asymmetry in the universe which can not be explained within the purview of the standard model (SM), requires the knowledge which can be obtained from more sophisticated experiments to search for the permanent electric dipole moment (EDM) of the electron with laser cooled radioactive atom. At Cyclotron and Radioisotope Center (CYRIC), Tohoku University, the EDM experiment with Francium (Fr), which is a radioactive and heaviest alkali element with the largest enhancement factor about 895 of the electron EDM, is now in progress. The important points to overcome the current accuracy limit of the EDM are to realize the high intensity Fr source and to reduce the systematic error due to the motional magnetic field and inhomogeneous applied field. To reduce the dominant component of the systematic errors mentioned above, we confine the Fr atoms in the small region with the Magneto-Optical Trap (MOT) and the optical dipole trap and optical lattice using the laser cooling and trapping techniques. The newly developed thermal ionizer with molten target (^{197}Au) already produces the Fr of ~10^6 ions/s with the primary beam (^{18}O) intensity 200 nA, which is sufficient to measure the electron EDM with the accuracy of 10^{-29}e・cm [1]. Also the double MOT system with optical dipole trap is ready and we are doing the test experiment to understand the systematics of the developed experiment. In this report, the present status of the experimental development of the EDM search with Fr will be shown and the expected measurement accuracy and future plan are discussed.

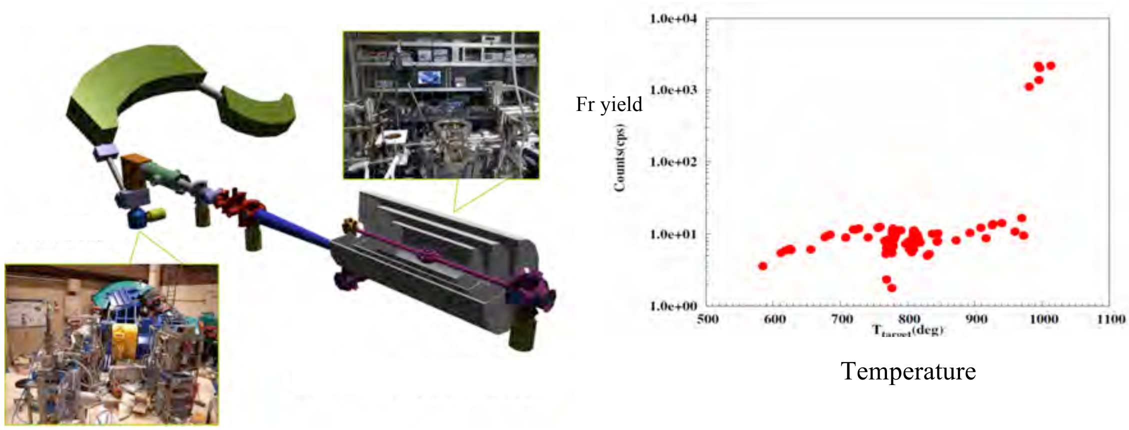

Figure 1: *The left figure shows the overview of the laser cooled Fr experiment at CYRIC. The Fr is produced by the fusion reaction with ^{18}O beam and ^{197}Au target. The right is the target temperature dependence of Fr yield. Above the melting point of the target, the high yield of the Fr is achieved.*

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Electroweak Interaction and Parity Nonconservation in Heavy Finite Fermi-Systems: Spin-Dependent Effects and Weak Interaction Enhancement

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During the past decades the nuclear and optical experiments to detect parity nonconservation (PNC) and hyperfine (hf) structure have progressed to the point where PNC amplitudes can be measured with accuracy on the level of a few percents in certain heavy isotopes and significantly worse in some nuclei (Mössbauer spectroscopy) [1-3]. Nowadays the PNC in the finite Fermi-systems has a potential to probe a new physics beyond the Standard Model. Speech is about an electroweak interaction and PNC as in heavy nuclear systems as in heavy atomic ones.

In our paper we systematically apply our combined nuclear (relativistic mean field approach) and relativistic (QED) many-body perturbation theory method [3] to precise studying spin-independent and spin-dependent (SD) PNC effect in heavy systems. There are presented the results of the calculating the nuclear magnetic moments, hf structure, PNC amplitudes for a set of elements: ^{133}Cs, ^{137}Ba^{+}, ^{205}Tl, ^{223}Fr, ^{173}Yb with account of the exchange- correlation, Breit, weak e-e interactions, radiative, nuclear (magnetic moment distribution, finite size, neutron "skin") corrections. Comparison with the SM and other data [1] is done. As exciting example we list our Q_W value of ^{173}Yb Q_W=-92.31 [the PNC amplitude $9.707\cdot10^{-10}$ie_a] that differs of the SM Q_W=-95.44. The nuclear SD PNC interactions due to nuclear anapole moment (k_a contribution), Z- exchange interaction from nucleon axial-vector (A_nV_e) currents (k_2), the combined hf and spin-independent Z exchange interaction from nucleon vector (V_nA_e) currents (k_{hf}) are studied. As example, in table 1 we present our results compared with the data on different contributions to the PNC spin-dependent contributions in the isotope of ^{133}Cs, obtained by different groups [1-2].

Table 1: *Theoretical data on SD PNC in ^{133}Cs (in terms of the coefficients k_a, k_2, k_{hf})*

Reference	[1a]	[2a]	[2b]	Our data
$\Sigma\ k_i$	0.1169	0.1118	0.112	0.1159
k_2	0.0140	0.0140	0.0111	0.0138
k_{hf}	0.0049	0.0078	0.0071	0.0067
k_a	0.0980	0.090	0.0920	0.0954

In quantum many-body systems with dense spectra of excited states weak perturbation can be significantly enhanced. The PNC enhancement is studied too and new possibilities are examined. Using the PNC effects one can study quantum chaos in many –body systems, nuclear fission , distribution of neutrons in nuclei etc.

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Near-infrared laser spectroscopy of antiprotonic helium atoms

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The antiprotonic helium atom ($\overline{p}He^+$) is a three body system consisting of an antiproton, an electron, and a helium nucleus [1,2]. The $\overline{p}He^+$ atoms are metastable (i.e., they have microsecond-scale lifetimes against antiproton annihilation) when antiprotons populate Rydberg states with large principal ($n \sim 38$) and angular momentum ($L \sim n-1$) quantum numbers. Laser spectroscopy of the $\overline{p}He^+$ atoms has been performed by the ASACUSA (Atomic Spectroscopy and Collisions Using Slow Antiprotons) collaboration at the Antiproton Decelerator of CERN [3-6]. The $\overline{p}He^+$ atoms were irradiated by pulsed lasers which induced transitions between the metastable states and short-lived states (i.e., they have nanosecond-scale lifetimes against Auger emission of the electron), and then the antiprotons were rapidly absorbed and annihilated in the helium nuclei.

At the ASACUSA experiment, we will attempt to observe the transition $(n, L) = (40, 36) \rightarrow (41, 35)$ at wavelength $\lambda = 1154.9$ nm. This wavelength is longer than that of any transition observed in the $\overline{p}He^+$ atoms so far. From this experiment, we may derive the population of the antiprotons in the metastable state $(40, 36)$, and the lifetime of the Auger-dominated short-lived state $(41, 35)$. The latter value can be compared with the results of three-body calculations [7]. The detection of the resonance may be difficult, however, since past measurement of the (n, L) distributions [4] indicates that the population in the state $(40, 36)$ is relatively low.

For this experiment, we have developed a nanosecond near-infrared laser utilizing stimulated Raman scattering. The laser consisted of a nanosecond titanium sapphire (Ti:S) laser [8] and a Raman cell filled with H_2 gas at room temperature and a pressure of 6×10^5 Pa. The Ti:S laser produced a light pulse at $\lambda = 780.4$ nm, with pulse length of 7 ns and pulse energy of 35 mJ. The pulsed light was shifted to $\lambda = 1154.9$ nm by a vibrational Stokes shift in the Raman cell (single pass, 3-m-long), and pulse energy of 7 mJ was obtained. The method of the laser spectroscopy is similar to Ref. [3]. The $\overline{p}He^+$ atoms will be produced by stopping antiprotons in a cryogenic helium gas target [9]. Charged pions produced from the antiproton annihilations induced by the laser pulse will be detected by a Cherenkov counter [10].

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Measurement of the transverse single spin asymmetry A_N in polarized elastic *pp* collisions in the CNI region at STAR

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We report a high precision measurement of the transverse single spin asymmetry A_N in polarized elastic proton-proton scattering, at small four-momentum transfer squared, $0.003 \leq |t| \leq 0.035 \mathrm{GeV}^2/\mathrm{c}^2$ at $\sqrt{s} = 200$ GeV performed by the STAR collaboration at RHIC. In this range of $|t|$ and $\sqrt{s}$, A_N arises from the interference between electromagnetic (Coulomb) spin-flip and hadronic (nuclear) non-flip amplitudes and is also a sensitive probe of the hadronic spin-flip amplitude, so called Coulomb Nuclear Interference (CNI). The reported measured values of A_N and its t-dependence were extracted from the sample of about 20 million elastic events recorded with *Roman Pots* in the STAR Detector system. The results reported here are in agreement with hypothesis of no hadronic spin-flip contribution to the elastic proton-proton scattering at this high energy, which as a consequence, leads to a significant constraint of the theoretical models that require hadronic spin-flip.

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First data from the measurement of the electric dipole moment of the neutron at PSI

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The observed baryon asymmetry in the universe cannot be explained by the standard model (SM) of particle physics and standard cosmology. An important issue therein is the small charge/parity reversal symmetry (CP) violation predicted by the SM. The existence of a finite permanent neutron electric dipole moment (nEDM) implies CP violation. Some extensions to the SM, e.g., minimal super symmetric ones, include additional sources of CP violation and also predict a rather large value for the nEDM [1]. While the value that is predicted by the SM is still out of experimental reach, some of the extension models have been already excluded by the present experimental upper limit of the nEDM ($2.9 \times 10^{-26}\,e$cm @90%CL) [2]. A limiting factor of these measurements was the low neutron count rate.

At PSI a new source for ultracold neutrons (UCN) was built to perform a next generation measurement of the nEDM. The source – based on solid deuterium at 5 K – went into operation in 2011. After tuning, we got first nEDM data in 2012. The data was taken with an upgraded version of the apparatus which provided the present best limit of the nEDM. While the performance of the UCN source is still being raised, the nEDM experiment has already reached a new record daily statistical sensitivity. The improvements originate mainly from a longer precession time and a better final polarization of the neutrons. Additional advances are being realized now and will further increase the sensitivity.

In parallel to the ongoing measurement, we are designing and constructing a new spectrometer, n2EDM, to take full advantage of the PSI UCN source and to further improve on systematic uncertainties. Major improvements will be due to the better adaptation to the UCN source, an enhanced magnetic shield, a differential measurement with a double UCN chamber and very advanced magnetometry. The new apparatus should be ready by 2015.

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A novel approach to measure the electric dipole moment of ^{129}Xenon

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Permanent electric dipole moments (EDM) are promising systems to find manifestations of new CP violation. The properties of the diamagnetic atom ^{129}Xe make it a particularly interesting candidate for an EDM search, as it enables new experimental strategies. Although the current experimental limit of $d_{\mathrm{Xe}} < 4.0 \cdot 10^{-27}$ ecm is many orders of magnitude higher than the Standard Model (SM) prediction, theories beyond the SM usually require larger EDMs.

Our EDM search is based on microscopic hyper-polarized liquid xenon droplets, placed in a low-field NMR setup (see figure 1). This approach allows for the unique configuration of performing multiple measurements in parallel. Employing superconducting pick-up coils and highly sensitive LTc-SQUIDs for detection of the xenon spin precession we aim to increase the sensitivity to an EDM of ^{129}Xe by three orders of magnitude.

In our experimental setup both Ramsey-type spin precession experiments with static electric field and an implementation of a conceptually new EDM measurement technique can be realized at similar sensitivity. A novel method using rotating electric fields allows thorough investigation of systematic effects.

I will present both an overview of the xenon EDM experiment and an update on the experimental status.

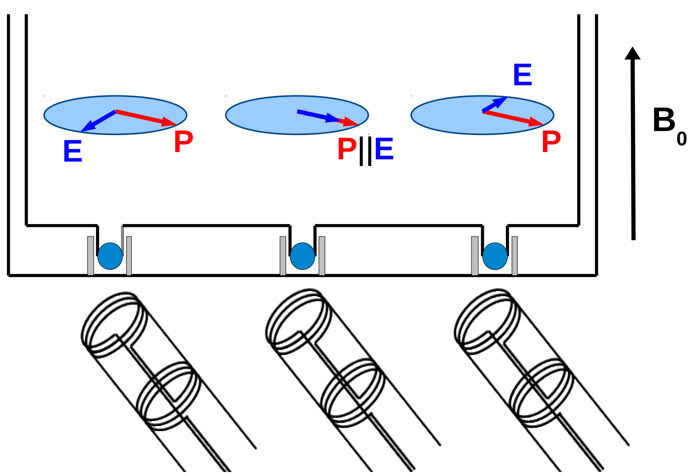

Figure 1: *Simultanous measurement of spin-precession signals of three hyperpolarized liquid xenon droplets with opposite electric field directions and a reference measurement with co-rotating electric field. Induction signals are detected by superconducting gradiometer pickup coils with a sensitivity* < 100fT.

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High-Precision Half-life Measurements for the Superallowed β^+ Emitter ^{14}O

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High-precision measurements of the β decay ft values for superallowed Fermi β transitions between nuclear analog states of spin $J^\pi = 0^+$ and isospin $T = 1$ provide demanding, and fundamental, tests of the properties of the electroweak interaction. These transitions directly probe the vector weak current and can be used to constrain the presence of induced or fundamental weak scalar currents. The measurement of the ft values for superallowed β emitters have been used to validate the conserved vector current (CVC) hypothesis to better than 2 parts in 10^4, as well as provide the most precise determination of V_{ud}, by far the most precisely measured element of the Cabibbo-Kobayashi-Maskawa (CKM) matrix and essential for testing CKM unitarity—a fundamental property of the electroweak Standard Model [1]. Half-life measurements for the lightest of these emitters, ^{10}C and ^{14}O, are of particular interest as it is the low-Z superallowed decays that are most sensitive to a possible scalar current contribution.

There are two methods for measuring the superallowed β decay half-life of ^{14}O; one can directly count the β particles or measure the γ activity since 99.4% of ^{14}O decays result in the emission of a 2.3 MeV γ-ray. Comparing the experiments that detected the 2.3 MeV γ-rays and those that perform β counting measurements yields results that disagree with each other at the level of 0.11% or 1.5σ. The same systematic discrepancy, at a level of 0.09% or 1.4σ, exists for the current ^{10}C half-life measurements. This motivates the need for a new set of high-precision half-life measurements for ^{10}C and ^{14}O via both γ-ray photopeak and direct β counting techniques at TRIUMF's Isotope Separator and Accelerator (ISAC) facility [2] to address the systematics between the methods used. The detector set-up used consists of the 8π γ-ray Spectrometer—a spherically symmetric array consisting of 20 Compton suppressed High-Purity Germanium (HPGe) detectors—and the Zero-Degree Scintillator—a fast plastic scintillator placed behind the tape transport system within the 8π.

The first of several experiments, specifically looking at ^{14}O, was performed at TRIUMF's Isotope Separator and Accelerator (ISAC) facility in November 2011. This presentation will highlight the importance of these measurements on setting limits on scalar currents in beta decay and the half-life results for ^{14}O.

[1] J. C. Hardy and I. S. Towner, Phys. Rev. C 79, 05502 (2009);

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High-precision half-life and branching ratio measurements for superallowed Fermi β^+ emitters at TRIUMF – ISAC

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High-precision measurements of the ft values for superallowed Fermi β transitions between nuclear analog states of spin $J^\pi = 0^+$ and isospin $T = 1$ provide demanding, and fundamental, tests of the properties of the electroweak interaction. These transitions directly probe the vector weak current and can be used to constrain the presence of induced or fundamental weak scalar currents. The measurement of the ft values for superallowed β emitters have been used to validate the conserved vector current (CVC) hypothesis to better than 2 parts in 10^4, as well as provide the most precise determination of V_{ud}, by far the most precisely measured element of the Cabibbo-Kobayashi-Maskawa (CKM) matrix and essential for testing CKM unitarity—a fundamental property of the electroweak Standard Model [1].

A program at TRIUMF's Isotope Separator and Accelerator (ISAC) facility is in place to perform high-precision half-life and branching ratio studies for several of these superallowed β emitters. These experiments are performed using both a 4π gas proportional β counter and the 8π γ-ray Spectrometer, a spherically symmetric array consisting of 20 Compton-suppressed High-Purity Germanium (HPGe) detectors, and its ancillary detection systems such as the Zero-Degree Scintillator, the Scintillating Electron-Positron Tagging Array, and the Pentagonal Array for Conversion Electron Spectroscopy.

These experiments also provide demanding tests of the theoretical corrections necessary to account for isospin symmetry breaking effects in superallowed decays as well as setting limits on scalar currents in beta decay, where the low-Z superallowed decays are most sensitive to a possible scalar current contribution. In particular, this presentation will focus on recent highlights from high-precision half-life and branching ratio measurements for the superallowed emitters ^{26}Al^m [2, 3], ^{74}Rb [4], and ^{14}O [5].

[1] J. C. Hardy and I. S. Towner, Phys. Rev. C 79, 055502 (2009);
[2] P. Finlay *et al.*, Phys. Rev. Lett. 106, 032501 (2011);
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[4] R. Dunlop *et al.*, submitted to Phys. Rev. C;
[5] A. T. Laffoley *et al.*, in preparation.

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Parity and time-reversal symmetry violation in A=2-4 nuclei

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Parity and/or time-reversal symmetry violating components of the nucleon-nucleon interaction play an important role in understanding the main features of the Standard model. These effects has been rather intensively studied during the last decade, moreover new spallation neutron facilities, such as the SNS at the Oak Ridge National Laboratory or the J-SNS at J-PARC, may provide new data of very high accuracy.

In this presentation I will review current status of the theoretical calculations of parity-violating and/or time reversal invariance-violating observables in few-nucleon systems. In particular, I will concentrate on low energy nucleon scattering on mass A=1-3 targets as well as nuclear EDM calculations in A=2-3 nuclei.

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The neutron electric dipole moment experiment at the FRM-II reactor

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Since the 1950's people have been searching for electric dipole moments (EDMs) of fundamental particles, but so far no EDM has been found. The discovery of a neutron electric dipole moment (nEDM) would provide an unambiguous indication of time reversal violation in a fundamental system, a necessary ingredient for the explanation of the matter anti-matter asymmetry in the universe. Current experimental limitations on the nEDM are roughly 6 orders of magnitude above the Standard Model (SM) prediction and so searches for the nEDM provide powerful tests of physics beyond the SM. Our new nEDM experiment currently under construction at the Technische Universitaet Muenchen is seeking to improve this limit up to 2 orders of magnitude to few 10^-28 ecm with a very competitive schedule. A contextual overview of our developments and progress will be given, including the installation of a world-record magnetically shielded environment.

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Antihydrogen formation mechanisms

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In fundamental physics it is important to make possible the comparison of the spectral lines in the two companions systems of hydrogen and antihydrogen atoms. The mixing of antiprotons and positrons ad AD at CERN has resulted in a copious production of antihidrogen atoms in different experimental apparatus and projects. Contrary to the hydrogen formation in the Universe where the radiative capture of an electron by a proton is the main mechanism, in the different AD experiments the antihydrogen formation has occured following mainly the 3-body process where 2 positrons partecipate with the antihydrogen to the antiatom formation. The very different conditions (densities and temperatures up to 10000 K) experimented in the ATHENA apparatus have produced antihydrogen atoms possibly by means of the radiative capture too. We will discuss different samples of antihydrogen atoms and the correlated formation mechanisms in the ATHENA apparatus.

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New precision era of experiments on strong interaction with strangeness at DAFNE/LNF-INFN

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The strong interaction of antikaons (K^-) with nucleons and nuclei in the low-energy regime is complicated due to sub-threshold resonances like $\Lambda(1405)$. Rather direct access to the antikaon-nucleon scattering lengths is provided by x-ray spectroscopy of transitions to low-lying states in light kaonic atoms like kaonic hydrogen, deuterium and helium isotopes.
Recently a series of precision measurements on these kaonic atoms was performed very successfully by the international SIDDHARTA Collaboration [1] at the DAFNE electron-positron collider of LNF-INFN (Frascati, Italy). DAFNE represents a world-wide unique source of nearly mono-energetic K^- from the decay of Φ vector mesons produced in electron-positron collisions at the resonance energy of 1.02 MeV. With the increased luminosity of DAFNE and advanced large area solid-state x-ray detectors with timing capability (silicon drift detectors) a powerful measurement system was developed which allows for precision x-ray measurements in the harsh environment of a particle accelerator.
Consequently, new precision data on the strong interaction observables (i.e. energy shift and broadening of atomic states) were delivered by SIDDHARTA [2] which have important impact on the theory of low-energy strong interaction with strangeness. Presently, the follow-up experiment, SIDDHARTA-2 (see Fig.1), is in preparation aiming at a first determination of the strong interaction observables in kaonic deuterium at the highest priority while other measurements (radiative transition measurements in other light and heavier kaonic atoms) are as well foreseen. With the kaonic deuterium data the antikaon-nucleon isospin-dependent scattering lengths can be extracted for the first time. The talk will give an overview of the present status of experimental studies and will provide an outlook to future perspectives in this fascinating research field.

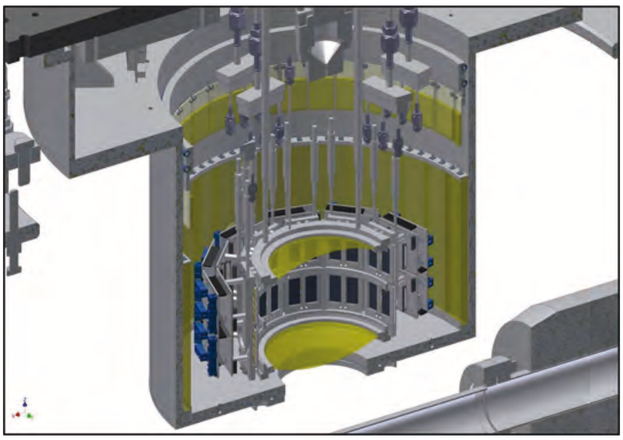

Figure 1: *Cross section of the SIDDHARTA-2 experimental apparatus which is in preparation now. A cryogenic gas target is surrounded by a ring-shaped array of x-ray detectors (silicon-drift detectors).*

[1] http://www.lnf.infn.it/esperimenti/siddharta/;
[2] M. Bazzi et al., Physics Letters B 704 (2011); M. Bazzi et al., Physics Letters B 697 (2011) 199.

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Nuclear Matrix Elements for Fundamental Symmetries

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Massive detectors with extremely low backgrounds are now sensitive to processes that will test fundamental symmetries. Theoretical nuclear matrix elements (NMEs) are crucial to predict the rate of these processes and to obtain information from measurements.

The calculation of these NMEs involves a reliable description of nuclei involved in the transition and the hadronic currents that describe the interaction. The experimentally relevant nuclei have medium-mass, so the preferred nuclear structure method to describe them is the Shell Model (SM) [1]. We have performed state-of-art large-scale SM calculations to describe these nuclei, which give very good agreement with experimental spectroscopic properties. The hadronic currents commonly employed are one-body (1b) currents based on phenomenology. We have employed, for the first time in medium-mass nuclei, a more systematic approach using currents derived from chiral effective field theory (EFT) [2]. In particular two-body (2b) currents, the leading correction to the standard 1b currents, are predicted.

Recent results addressing two different processed will be presented. Lepton-number conservation is thus far an exact symmetry, but its violation is being pursued in neutrinoless double-beta decay experiments. Detection would imply the Majorana nature of neutrinos and, together with the NMEs, will tell us about the neutrino hierarchy and masses. Supersymmetry (SUSY) is proposed in extensions of the Standard Model. These models predict weakly interacting massive particles (WIMPs), which are prominent candidates for Dark Matter. Several experiments are running to detect the scattering of WIMPs off nuclei. The NMEs (called structure functions) are necessary to relate the experimental results with SUSY models predictions. The effect of these 2b currents have been shown to be $\sim 20\% - 30\%$ [3], [4].

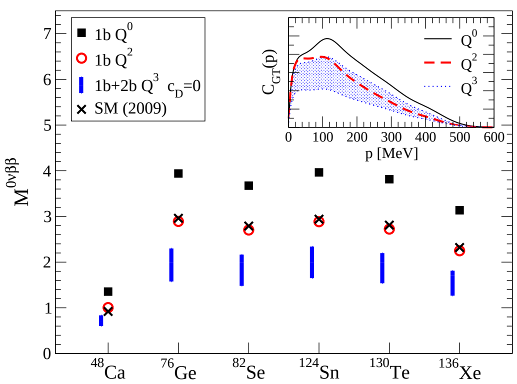

Figure 1: *Nuclear matrix elements of neutrinoless double-beta decay calculated at different orders in chiral EFT (Q^0, Q^2 and Q^3) [3].*

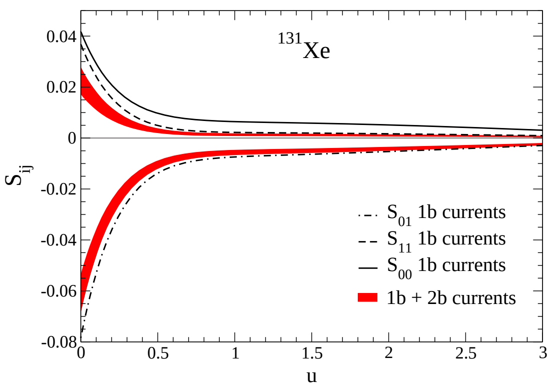

Figure 2: *Structure function components of the WIMP scattering off ^{131}Xe calculated at orders Q^2 and Q^3 in chiral EFT [4].*

[1] E. Caurier, G. Martínez-Pinedo, F. Nowacki, A. Poves, and A. P. Zuker, Rev. Mod. Phys. **77**, 427 (2005).
[2] E. Epelbaum, H.-W. Hammer and U.-G. Meißner, Rev. Mod. Phys. **81**, 1773 (2009).
[3] J. Menéndez, D. Gazit and A. Schwenk, Phys. Rev. Lett. **107**, 062501 (2011).
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T-Violation experiment at TRIUMF-ISAC using polarized ^{8}Li

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The MTV experiment (Mott Polarimetry for T-Violation Experiment) starts physics data taking at TRIUMF-ISAC, aiming to achieve the highest precision test of time reversal symmetry in polarized nuclear beta decay by measuring a triple correlation (*R*-correlation), motivated to search for a new physics beyond the Standard Model [1]. In this experiment, the existence of non-zero transverse electron polarization is examined utilizing the analyzing power of Mott scattering from a thin metal foil. Backward scattering electron tracks ("V-tracks") are measured using a planer multi-wire drift chamber. The first physics data taking of the MTV experiment was performed at TRIUMF-ISAC in 2010 using an 80% polarized ^{8}Li beam at 10^{7}pps, achieving the highest statistical precision of order of 0.1% on the *R*-parameter comparing to the previous study performed at PSI [2]. Analysis results from this experiment will be presented in the conference with the systematic error analysis.

The next generation cylindrical drift chamber (CDC) has also been developed after the first run aiming to suppress the dominant systematic effects in the planer drift chamber, which arises from combination of the parity violating beta-emission angular distribution and the asymmetric planer geometrical acceptance. It cannot be canceled by the beam spin flipping, so usage of a symmetric acceptance detector can drastically reduce this systematic effect. We have commissioned the CDC at TRIUMF from 2011, and finished testing the full detector setup. The next physics run are scheduled to be performed in 2013. Project status together with the technical R&D aspects of the next generation experiment using the CDC will also be introduced in the conference.

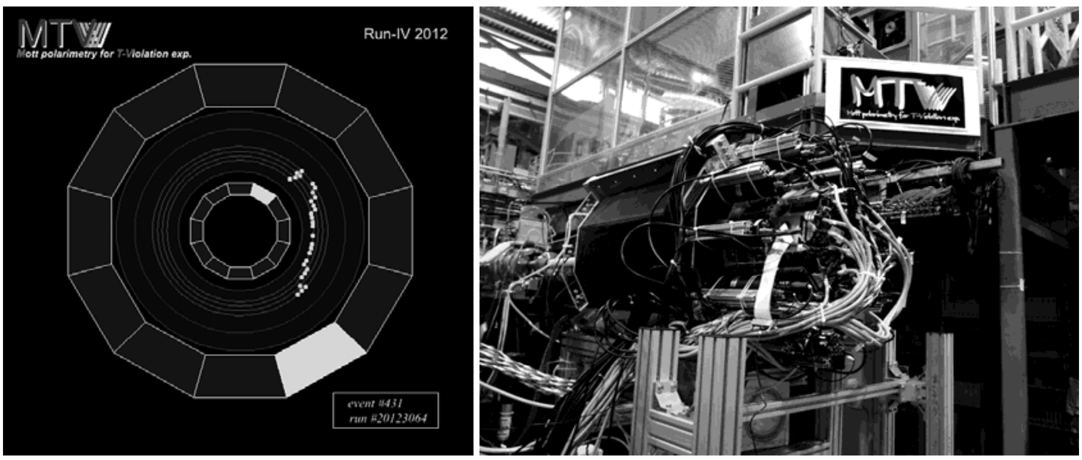

Figure 1: *A typical V-Track event (Left) measured using the CDC setup (Right).*

[1] J. Murata et al., J. Phys. CS 312, 102011 (2011).
[2] R. Huber et al., Phys. Rev. Lett. 90, 202301 (2003).

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Optimization of a ^{3}He co-magnetometer for the EDM measurement of ^{129}Xe

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A permanent electric dipole moment (EDM) can probe CP-violating phases beyond the Standard Model of elementary particles through the CPT theorem. We study the atomic EDM in ^{129}Xe atoms experimentally. The present upper limit for the ^{129}Xe atomic EDM is $|d| < 4.1\times10^{-27}$ *e*cm [1], and the present study aims at measuring the EDM in ^{129}Xe atoms to a size of $|d| = 10^{-28}$ *e*cm. The EDM search to a size of 10^{-28} *e*cm requires the improvement of the precision in frequency down to a level of 1 nHz. The previous developments of the active nuclear spin maser have improved the precision of frequency determination to $\delta\nu = 9.3$ nHz for a one-shot measurement [2,3]. However, systematic uncertainty arises from a long-term drift in frequency originating from drifts in the external magnetic field, and a frequency shift due to contact interaction with the polarized Rb atoms.

A co-magnetometer using ^{3}He has been incorporated to the nuclear spin maser system in order to cancel out the former drift, by taking advantage that it directly measures the field *B* that exerts on the ^{129}Xe spins. The ^{3}He co-magnetometer is based on the concurrent operation of ^{129}Xe and ^{3}He masers. Thus, ^{129}Xe atoms and ^{3}He atoms are contained in a same cell. According to the mechanism of the active spin maser, the following two processes regarding the interaction with Rb atoms are related to its performance. First the longitudinal polarization is produced through spin exchange with Rb atoms which are optically pumped. Then the spin precession of ^{129}Xe is detected optically through Rb atoms which are transversely polarized by contact with ^{129}Xe. It must be noted that the spin exchange rate between Rb and ^{3}He is much smaller than that between Rb and ^{129}Xe [4,5]. Therefore, the partial pressure is a critical parameter in determining the performance of the co-magnetometer.

In order to find the appropriate settings for parameters such as the partial pressure for the ^{129}Xe/^{3}He cell for the best performance of the co-magnetometer, the measurements were made of the longitudinal and transverse relaxation times for both ^{129}Xe and ^{3}He, by means of the adiabatic fast passage NMR method and the free induction decay. The result of the measurements will be reported and the optimization of the maser parameters will be discussed in the presentation.

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Leading Questions in an Extended Standard Model

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We would like to discuss the language [1] to write an extended Standard Model – using renormalizable quantum field theory as the framework; to start with certain basic units together with a certain gauge group [2]. Specifically we use the left-handed and right-handed spinors to form the basic units [3] together with $SU_c(3)\times SU_L(2)\times U(1)\times SU_f(3)$ as the gauge group. We could write down the extended Standard Model [4], though the details of the Higgs mechanism remains to be worked out. The same general quest appeared about forty years ago - the so-called "How to build up a model". It is timely to address the same question again especially since we could now put together "Dirac similarity principle" and "Higgs minimum hypothesis" as two additional working rules [5].

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Final results of μp capture rate Λ_S and pseudoscalar coupling g_P

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We present the final results of muon capture on the proton $\mu^- + p \rightarrow \nu_\mu + n$, an experiment which was conducted by the MuCap collaboration at the Paul Scherrer Institute. Our method was a high precision lifetime measurement of the μp singlet state, rate $\lambda(\mu^-)$, which in comparison with the free μ^+ lifetime, rate $\lambda(\mu^+)$, yields the μp singlet capture rate $\Lambda_S = \lambda(\mu^- p) - \lambda(\mu^+)$. From Λ_S the pseudoscalar coupling constant g_P can be deduced using low energy chiral perturbation theory (ChPT). A description of this experiment and its results is published in [1].

The apparatus consisted of an active central detector, a 10-bar hydrogen time projection chamber (TPC) which registered every single muon stop, and a surrounding electron detector, 2 sets of cylindrical wire chambers and a plastic counter hodoscope, which registered the electrons from muon decay. During three major experimental runs in 2004-2007, a total statistics of 1.2×10^{10} good events was collected from which Λ_S was determined to 1% accuracy. The most difficult systematical challenges of this experiment were to keep the hydrogen gas in the TPC ultra-clean with purity levels of ~10ppb, and to avoid or correct in the data analysis any effects which would distort the exponential decay curve.

A major problem of previous experiments was the formation of pμp molecules and the poorly known transition rate λ_{op} between molecular ortho or para states. As shown in Fig. 1, this made the interpretation of observed capture rates difficult. By the choice of low gas density, MuCap was nearly insensitive to this problem and thus produced a clear cut result of g_P, in excellent agreement with the ChPT prediction.

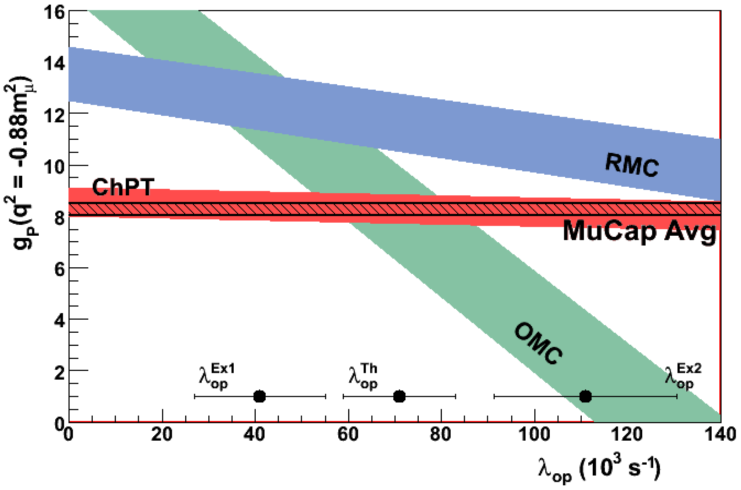

Figure 1: *Extracted values of pseudoscalar coupling g_P plotted versus the poorly known molecular transition rate λ_{op}. In contrast to earlier experiments (OMC at Saclay, RMC at TRIUMF), MuCap is rather insensitive to this parameter..*

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Nab: a new program of precision measurements of neutron beta decay

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Nab is a new program of measurements at the Fundamental Neutron Physics Beamline (FnPB) of the Spallation Neutron Source (SNS) in Oak Ridge, TN, comprising precise studies of neutron beta decay [1,2]. Nuclear beta decay in general, and neutron decay in particular, offer a means to study the weak interaction with great precision. Its theoretical description in the standard model (SM) is relatively simple, and is thus overconstrained by the set of available observables. High precision of the SM theoretical treatment, and inherently high sensitivity to departures from the basic $V - A$ description, make neutron beta decay an attractive platform for searches for signals of new physics. The Nab experiment aims to measure beta decays of the unpolarized neutron precisely, with the goal to determine a, the electron–neutrino correlation with precision of $\delta a/a = 10^{-3}$, and b, the Fierz interference term, a distortion of the beta spectrum never before measured in neutron decay, with an uncertainty of $\delta b \simeq 3 \times 10^{-3}$. These results will lead to a new precise determination of the ratio $\lambda = G_A/G_V$ and to significant reductions in the allowed limits for both right- and left-handed scalar and tensor currents. Alternatively, the experiment will detect a nonzero signal consistent with certain realizations of supersymmetry.

The Nab experiment will use the newly available FnPB intense cold neutron beam. A novel, optimized asymmetric magneto-electrostatic spectrometer has been designed to achieve the required narrow momentum response function, and thus to accomplish the ambitious physics goals of the experiment. The key principle of measurement is to detect both the electron and the proton in neutron beta decay. Electron energy will be measured directly in the newly developed, large segmented Si detectors, sufficiently thick to stop the beta electrons. Protons will be detected subsequent to a 4 m long drift, after being accelerated to 30 keV. Proton momentum will be deduced from their time of flight, with the electron signal serving as the start time reference. Prior to entering the long drift region, protons will go through a sharp magnetic filter, and then undergo rapid magnetic field expansion which longitudinalizes their momenta and ensures that the drift time relatively narrowly reflects their full momentum. The measurement will not be statistics-limted, thus allowing ample time for detailed systematic studies of the detector system response.

Detailed realistic GEANT4 Monte Carlo simulations have been performed in order to minimize the width of the detector response function, eliminate or minimize particle trapping, and generally to reduce systematic uncertainties of the measurement. In addition, major milestones have been achieved on the development of detectors and other key components of the apparatus.

The same apparatus is planned to be used in a follow-up project, abBA, to measure A, the beta asymmetry, and B/C, the neutrino/proton asymmetries, using a polarized cold neutron beam. Together, Nab and abBA will significantly improve the precision of λ over current levels, and provide stringent constraints on non-$V - A$ couplings related to possible new physics outside the SM.

The project has received full funding, and is in the construction stage. We will present a details of the experimental motivation, experimental method, instrument design and development, and project plans.

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Construction and performance test of improved magnetic field stabilization system for EDM measurement

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A permanent electric dipole moment (EDM) of a particle is the observable which directly violates the time reversal symmetry and hence the CP symmetry because of CPT theorem. The EDM has sensitivity to CP-violating phases contained in physics beyond the standard model (SM) of elementary particles. Thus, the search for EDM constitutes a stringent test which discriminates the gap between the SM and a model beyond it. We aim at measuring the EDM of ^{129}Xe atoms using a technique of the active nuclear spin maser. The EDM search to a size of $|d| = 10^{-28}$ *e*cm requires frequency precision of 1 nHz under an electric field of 10 kV/cm. The active spin maser enables us to sustain the spin precession of ^{129}Xe for unlimitedly long time. The long-term measurement is essential to improve the precision of the determination of the frequency because it is, in principle, proportion to $T^{-3/2}$, where T denotes the measurement duration.We have achieved the precision of frequency determination of 9.3 nHz in a limited measurement duration of 30,000 s [1,2]. However the improvement in the precision seems to saturate for $T > 30{,}000$ s, presumably because of fluctuations in the external magnetic field. Further improvement in the precision may require reduction of the fluctuations in the external magnetic field.

Then, we have constructed a new experimental setup for the EDM measurement. The setup consists of a new triple-layer magnetic shield, a ferrite magnetic shield [3], and a coil to generate the static magnetic field. Each layer of the triple-layer magnetic shield has a cylindrical structure. The gaps between the layers are expanded to 200 mm for enhanced magnetic flux absorbencies. The shielding factor is measured to be 10^4 which is 10 times better than the previous one. A ferrite shield made of MnZn is expected to reduce a thermal noise thanks to its high magnetic permeability of about 2300 H/m. The coil is designed through simulation study, so that the homogeneity of the magnetic field in the center of the setup is optimized while the surface current in the shield generated by the coil is kept low. Performance of the composite setup will be given in the presentation.

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Development of francium atomic beam for the search of the electron electric dipole moment

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The existence of the permanent electric dipole moment (EDM) of the elementary particles is one of the direct signatures indicating the violation of the time reversal symmetry. The value of the electron EDM would be enhanced in the francium (Fr) atom with the factor of 895 [1]. Furthermore, the laser cooling and trapping techniques can be applied to the e-EDM measurement to elongate an interaction time between external electric field and atoms. These advantages would improve the sensitivity of the e-EDM measurement. We are constructing the laser cooled Fr factory to search for the e-EDM at Cycrotron and Radioisotope Center (CYRIC), Tohoku University [2].

By the end of 2012, we developed Fr thermal ionizer that can produce 10^6 Fr ions/sec by the fusion reaction with 100 MeV ^{18}O primary beam and ^{197}Au target. We also constructed Fr ion transport beam line to deliver the Fr ions about 10 m to avoid noises due to the nuclear reaction and the electromagnetic field of the magnets installed in the primary beam line. In the next step, an efficient Fr ion to atom conversion and Fr atom transportation to Magneto-Optical Trap (MOT) are keypoints to perform the precise measurement of the e-EDM.

To convert the 5 keV Fr ion beam to the thermal atomic beam, a new type of Fr ion to atom converter was developed. This is based on the principle of the "orthotropic" type Fr source [3]. Using the cycles of the surface ionization and neutralization, we can make the thermal Fr atomic beam from ion beam minimizing the loss of the number of the atoms. With this apparatus, we succeeded in performing the MOT of neutralized rubidium atoms whose chemical properties are similar to that of Fr.

For the efficient transportation, the use of transverse cooling and Zeeman slower to collimate and decelerate the Fr thermal atomic beam from the ion to atom converter are designed. Using these apparatus together, a high efficiency of a few percent of the produced Fr can be applied to the Fr-EDM measurement. This may allow us to explore $|d_\mathrm{e}| \sim 10^{-28}\, e \cdot \mathrm{cm}$ region that is below the current experimental limit of the e-EDM.

At the conference, we report the present development status of the Fr atomic beam using these apparatus.

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Determination of the antiproton-to-electron mass ratio by two-photon laser spectroscopy of antiprotonic helium atoms

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The ASACUSA experiment at CERN recently measured the atomic transition frequencies of antiprotonic helium ($\bar{p}$He) to a fractional precision of 2.3-5 parts in 10^9 by non-linear two-photon laser spectroscopy [1]. Antiprotonic helium is a metastable three-body atom [2] consisting of a normal helium nucleus, a ground-state electron, and an antiproton occupying a Rydberg state with high principal and angular quantum numbers n and l, so that $n \sim l + 1$. We irradiated the isotopes $\bar{p}^3$He and $\bar{p}^4$He with two laser beams, which excited nonlinear two-photon transitions of the antiproton of the type $(n, l) \rightarrow (n - 2, l - 2)$. By allowing the atom to simultaneously absorb a photon from each of the two counter-propagating laser beams of similar wavelength, the broadening of the resonance lines caused by the Doppler effect was partially canceled. This resulted in the observation of sharp spectral lines, from which the transition frequencies could be precisely obtained. By comparing these experimental frequencies with the results of three-body QED calculations [3], we derived an antiproton-to-electron mass ratio of 1836.1526736(23), which agrees with the proton-to-electron value known to a similar precision [4].

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Development of electric-field applying system for the measurement of EDM in ^{129}Xe atom

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A permanent electric dipole moment (EDM) of a particle, atom or molecule is an observable that violates the time reversal symmetry and hence the CP symmetry because of the CPT theorem. The search for the EDM tests the validity of the Standard Model and may establish the presence of a new physics beyond the standard model. Experimentally, the EDM is determined from difference between the frequencies of spin precession measured with the elecrtric field parallel and antiparallel to the magnetic field. In order to achieve the measurement of EDM in ^{129}Xe atoms to a size of $|d| = 10^{-28}$ *e*cm, frequency precision of 1 nHz is required under an electric field of 10 kV/cm. Previously the precision of frequency determination has been improved to 9.3 nHz [1,2] in a limited measurement duration. The application of a high electric field is also essential to the EDM measurement. The previous setup for the electric field, however, suffered from a voltage limit at 1.5 kV beacause of a discharge in the system. In this study, therefore, we have developed a new system for the electric field application.

A leakage current in the circuit is an indicator for the stability of high voltage applied. The leakage current may be due to Rb adsorbed on the cell wall or due to small discharges occuring at curcuits in the system other than the cell itself. In order to identify and fix the problems encountered in the previous circuit, the leakage current in the circuit was studied. First, the leakage current flowing through the whole HV applying system was measured with a glass cell being installed between the electrodes. Next, the leakage current was measured without a glass cell. The leakage current in the latter case was found to be lower than that in the former case by a factor of about 10^{-3}. From this comparison of the two cases, it is concluded that the leakage current mainly occurs due to Rb on the cell wall. Thus we have established a HV applying system that affords electric fields up to 10 kV/cm without a cell installed, and are going to test it with a cell containing Rb of amount as small as possible.

The leakage current may cause two problems: electrical noises in the circuit which prevent precision measurements, and magnetic fields produced by the leakage current [3]. The leakage-induced magnetic field may severely affect the ^{129}Xe spin precession. The problems expected and the solutions to them will be discussed in the presentation.

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Search of non-standard strong gravity at nuclear scale using electron spin Geodetic precession

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According to the large extra dimension model (ADD model) published in 1998 [1], Newton's gravitational inverse square law is predicted to be violated at sub-millimeter scale and have stronger distance dependence than the inverse square law at a microscopic scale. The ADD model is motivated to resolve the "hierarchy problem", by providing a geometric understanding of why gravitational interaction is extremely weaker than other three gauge interactions. Many of table-top experiments to test inverse square law have been performed [2], on the other hand, an electron-nuclear scattering experiment is challenged in the present MTV-G project to examine in unexplored nuclear scale region. We utilized an electron transverse polarimeter built for the MTV experiment [3], which aims to search a violation of time reversal symmetry using polarized nuclei at TRIUMF. In the MTV experiment, existence of electron transverse polarization emitted from beta-decay of polarized nuclei is tested as a signal of the T-Violation.

Gravitational field generated around nuclei can be order of magnitude larger than the Newtonian prediction, according to the ADD model. An electron spin precession in a nuclear scattering process is expected to have sensitivity to the strong gravitational field, because of an enhanced precession effect arising from the Geodetic precession predicted by the general relativity theory as a result of the strong warped space-time around the nuclear-mass. In this MTV-G experiment, longitudinally polarized electrons emitted from a 37MBq Sr-90 source are scattered by a thin metal foil via Coulomb scattering. During this scattering process, the longitudinal polarization is transferred to a transverse polarization by Thomas precession and the Geodetic precession. For the electron tracking detector of the MTV experiment has excellent sensitivity of the transverse polarization, we utilize this detector and have performed the first attempt from 2011, to search the existence of the strong gravitational field. Details of the experiment and results, together with the future plan will be presented in the presentation.

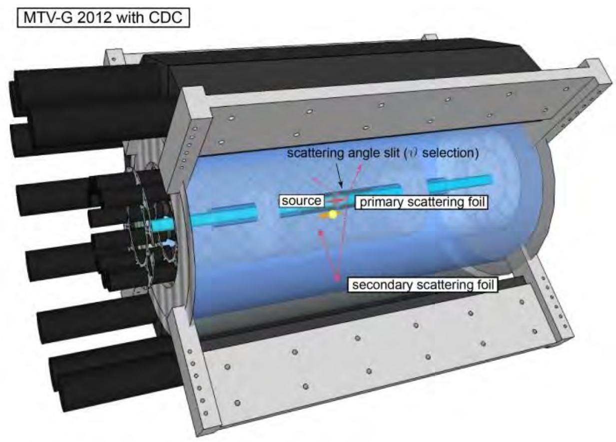

Figure : *MTV-G setup using MTV-CDC.*

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Subtractive renormalization of N3LO chiral potentials

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We apply the renormalization with multiple subtractions to N3LO chiral potentials and study the running of the contact interactions with the renormalization scale μ. Here we consider the NN interactions developed by Entem and Machleidt [1] and by Epelbaum, Glöckle and Meissner [2]. This method has been applied to the N2LO potential [3] and the renormalization group invariance was explicitly verified by the exact (non-perturbative) solution of the corresponding non-relativistic Callan-Symanzik equation [4]. Figure 1 shows the scale dependence of the phase shifts for the uncoupled F-waves, which have no contact interactions. Other channels, like D-waves and P-waves, where the interaction has contact terms in addition to the pion exchanges, will also be considered.

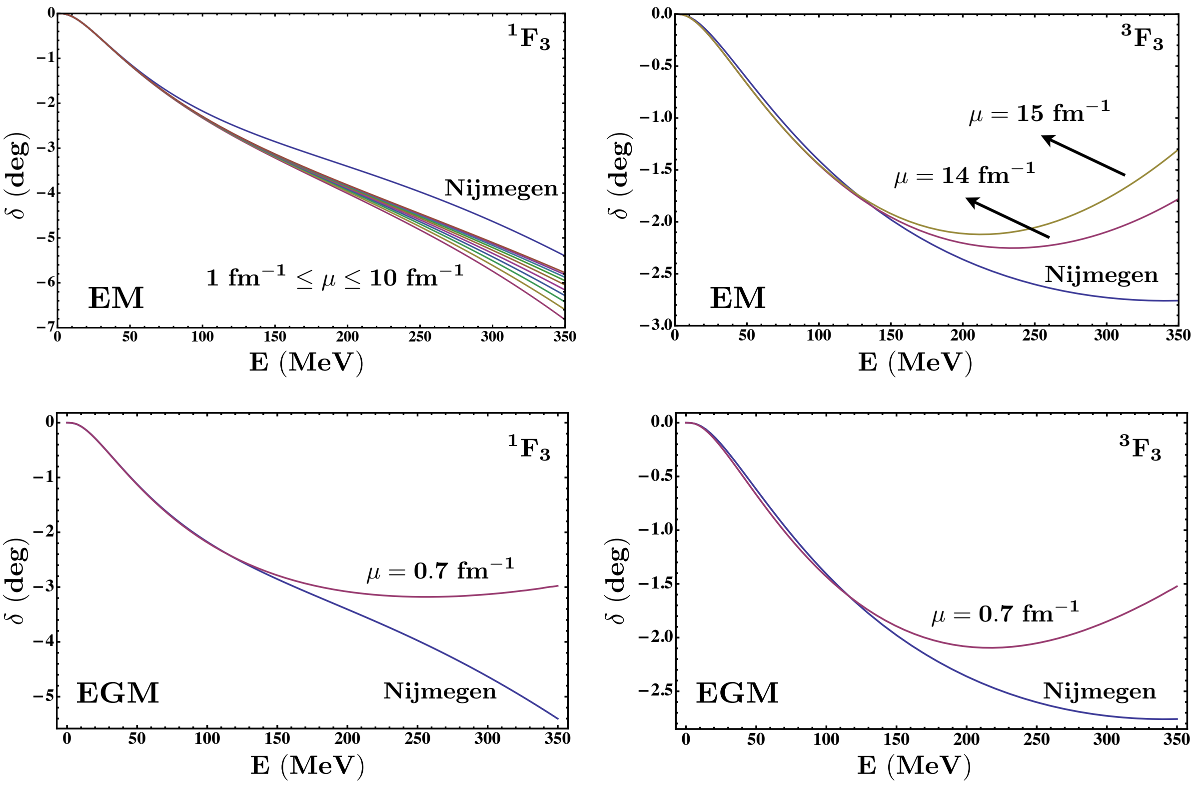

Figure 1: *Phase shifts for the uncoupled F-waves for the Entem and Machleidt (EM) and the Epelbaum, Glöckle and Meissner (EGM) N3LO potentials for some values of the subtraction point* μ.

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The E36 experiment at J-PARC

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The E36 experiment is planned to run at the J-PARC K1.1BR kaon beamline in 2014-15 using a stopped kaon beam along with the TREK target and large-acceptance spectrometer setup as shown in Figure 1. The decay products of stopped positive kaons will be observed by a superconducting toroidal magnet and charged-particle tracking detectors (C1-C4) with high momentum resolution, combined with a 768 element CsI(Tl) photon calorimeter with large solid angle. Redundant particle identification will be achieved with high resolution time-of-flight (TOF) detectors, aerogel Cherenkov detectors, and lead glass counters (PGC). With the aim to test lepton universality in the $K_{e2}/K_{\mu2}$ ratio with an accuracy of 0.25%, the experiment is highly sensitive to new physics beyond the Standard Model such as a charged Higgs-mediated LFV SUSY contribution [1]. Experiment E36 will provide completely different systematics than the existing in-flight decay experiments NA62 [2] and KLOE [3]. A further goal of E36 is to search for a heavy sterile neutrino in two-body kaon decay, along with additional searches for exotic decay modes. An overview of the planned experiment, results from recent R&D activities, and the current project status will be presented.

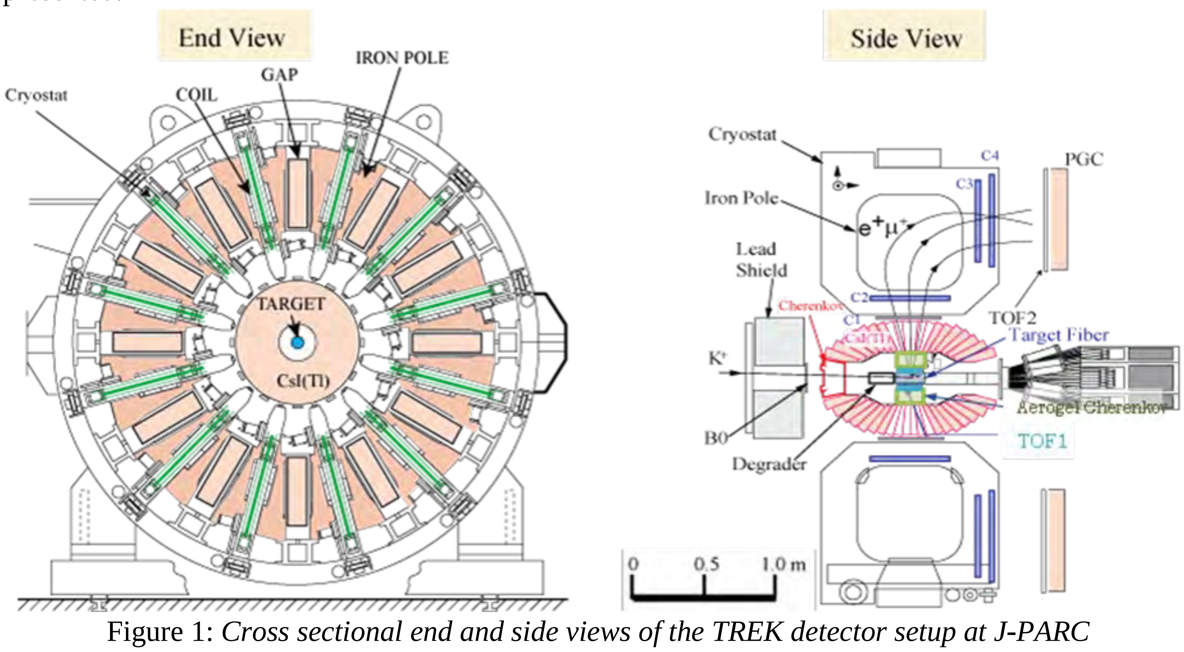

Figure 1: *Cross sectional end and side views of the TREK detector setup at J-PARC*

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A study of the Dirac equation with the Cornell potential

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The Cornell potential is among the most appealing interactions in particle physics. The Cornell potential contains a confining term besides the Coulomb interaction and has successfully accounted for the particle physics data [1]. Unfortunately, to our best knowledge, the potential does not possess exact solutions under all common equations of quantum mechanics, that is, the nonrelativistic Schrödinger equation, and relativistic Dirac, Klein-Gordon, Proca, and Duffin-Kemmer-Petiau (DKP) equations. Here, we focus on Dirac equation, with equal scalar and vectorial components, because the interesting properties: avoid the Klein paradox and be reduced to a Schrödinger like equation . This provide a reliable theoretical basis for hadronic and nuclear spectroscopy, see, for instance, the talk by Thomas, for the case with quarkonium. [2] . There are many studies under various interactions within the past two decades ([3] and many references therein). Nevertheless, none of these papers has investigated the symmetry limits under the Cornell potential. This is definitely due to the complicated nature of the resulting differential equation which cannot be solved by common analytical techniques of quantum mechanics. In our study, we make use of a study based on the approach to large r, which solution tends to be the Airy function.

After deal with the angular, the radial parts to be solved are:

$$\frac{dF(r)}{dr} = -\frac{\kappa F(r)}{r} + [\epsilon + m]G(r)$$

$$\frac{dG(r)}{dr} = \frac{\kappa G(r)}{r} - [\epsilon - m - V(r)]F(r) \tag{1}$$

with $V(r) = \lambda r - \frac{\sigma}{r}$. We suppose a solution like

$$F(r) = Ai(a_n + br).f(r) \tag{2}$$

, where $Ai(a_n + br)$ is the already known solution for the case $\sigma = 0$ and $k = -1$, with $b = \lambda^{1/3}$, a_n is the n-esima root of Airy function, that give us the energy. By including the new potential term and the angular momentum term, the energy changes from ϵ to $\epsilon' + \delta$. Therefore, we have

$$\frac{\partial^2}{\partial r^2}(Ai.f(r)) - \frac{\kappa(\kappa+1)}{r^2}(Ai.f) + (\epsilon' + \delta + m).(\epsilon' + \delta - m - \lambda r + \frac{\rho}{r})Ai.f = 0 \tag{3}$$

After rearranging the equation above, we may find an equation similar to that of hydrogen atom and obtain a spectrum that is related to the energies of the exclusively confining case $V(r) = \lambda r$.

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Testing Lorentz invariance in β decay

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In theories aiming to unify the Standard Model with gravity, Lorentz invariance may be broken. Although Lorentz symmetry appears to hold well, few experiments have been performed that consider its violation in the weak interaction. We have started a theoretical and experimental research program to this effect. We consider a Lorentz violating correction of the W-boson propagator, characterized by a tensor. With this extension of the Standard Model the β-decay rate will depend, on how the spin of the parent nucleus and the emission direction of the β and ν particles are oriented in absolute space. We explore the consequence for allowed Fermi and Gamow-Teller transitions and the spin degrees of freedom in the latter.

Experimentally we exploit the Gamow-Teller transition of polarized ^{20}Na, where we can test the dependence of the β-decay rate on the spin orientation of ^{20}Na. The polarization is measured using the β asymmetry, while the decay rate is measured by the γ yield. A change in the γ rate, when reversing the spin, implies Lorentz invariance violation. The decay rate should depend on sidereal time and the polarization direction relative to the rotation axis of the earth. The method of the measurement will be presented, together with the first results.

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Shell model estimate of electric dipole moment in medium and heavy nuclei

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The existence of a finite permanent electric dipole moment (EDM) of a particle or an atom indicates violation of time-reversal symmetry (*T*). It implies simultaneous violations of charge conjugation (*C*) and parity symmetry (*P*) through the *CPT* invariance. The standard model predicts tiny EDMs, which are too small to be detected in present experimental accuracy. However, many extensions of the standard model, such as a supersymmetric theory, naturally produce much larger EDMs. Thus, an experimental measurement of the EDM is one of the best probes for the physics beyond the standard model. The EDM of a neutral atom with closed electron subshells is mainly induced by the nuclear Schiff moment, since the electron EDM is very small and the nuclear EDM is shielded by outside electrons owing to the Schiff theorem [1]. Nuclear Schiff moments for various nuclei were calculated in terms of the nuclear mean field theories [2,3] and some collective models [4,5]. However, no study has yet been made from the nuclear shell model point of view.

The nuclear Schiff moment is induced mainly by two different sources of mechanism. One comes from the nucleon intrinsic EDM. The other comes from the two-body nuclear interaction which violates *P* and *T* invariance. In this work, we estimate the Schiff moments of ^{129}Xe and ^{199}Hg assuming the both sources. In order to describe the nuclear structure of these nuclei, we have used the pair-truncated shell model (PTSM) [6,7]. In this model, the collective nucleon pairs with angular momenta of zero and two are its basic ingredients. It is found that energy spectra of the low-lying states are almost perfectly reproduced. Using the theoretical results of the PTSM, we predict the Schiff moments for ^{129}Xe and ^{199}Hg by making use of the neutron intrinsic EDM and the two-body interaction violating *P* and *T* invariance. The theoretical results will be presented and discussed in this conference.

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Investigations of the charge symmetry breaking reaction $dd \to \alpha\pi^0$ with WASA-at-COSY experiment

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Investigations of charge symmetry breaking is one of the most important topics for the WASA-at-COSY experiment. The study concentrates on the charge symmetry forbidden $dd \to \alpha\pi^0$ reaction. The aim is to compare the experimental results with Chiral Perturbation Theory (χPT) predictions gaining information on the up and down quarks mass difference. First steps toward a theoretical understanding of the $dd \to \alpha\pi^0$ reaction have been taken [1,2]. It was found that the existing data are not sufficient for a precise determination of the parameters of the χPT and new data are required. These new data should comprise the measurement of the charge symmetry forbidden $dd \to \alpha\pi^0$ reaction and the charge symmetry conserving $dd \to {}^3\mathrm{He}n\pi^0$ reaction at sufficiently high energy where p-wave contribution becomes important.

Preliminary experimental results of the investigation of the $dd \to \alpha\pi^0$ reaction with the WASA-at-COSY detector setup at a beam momentum of 1.2 GeV/c will be presented. Preliminary total cross section and the differential distributions of this reaction were obtained. Results and data analysis will be discussed.

For the next step of the $dd \to \alpha\pi^0$ reaction measurements with higher statistics and different beam energy the modification of the detection setup is planned. Possible scenarios will be discussed.

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