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STUDY OF THE NEUTRON-PROTON WEAK INTERACTION AT THE ILL REACTOR

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Résumé - L'appareil, construit par une collaboration ISN-Grenoble-Harvard, a été installé sur le faisceau du polariseur PN7 dans le but de détecter une corrélation $\sigma_n \cdot k_\gamma$ dans le système à deux nucléons (n-p). Cette expérience doit être un test de la contribution des courants neutres faibles à l'interaction nucléon-nucléon. La description et les performances de l'appareil, ainsi que les résultats des premiers tests sont donnés.

Abstract - We present a description of the ISN-Harvard apparator, installed on the PN7 polarizer for detecting the $\sigma_n \cdot k_\gamma$ correlation in the two nucleon (n-p) system. This experiment would be a crucial test on the weak neutral current contribution to the nucleon-nucleon weak interaction Performances and preliminary test results are given.

Introduction

The search for a parity violation in the NN system (n-p interaction) is based on the hypothesis of the universality of weak interaction (characterized by parity violation). The γ ray asymmetry from the $\vec{n} + p \to d + \gamma$ reaction is only due to the $\Delta I = 1$ isospin contribution of the weak NN interaction and more precisely to the π meson exchange (one of the N-N-M vertex being assumed to be weak). It confers a particular interest on this experiment as it would be the best test (in the low energy domain) of the weak neutral force between hadrons. Due to the $\Delta S = 0$ rule only the N-N or N-$\bar{N}$ systems can receive a contribution from this force (exchange of the Z° intermediate vector boson of the Weinberg-Salam model).

The N N interaction is understood as the superposition of the strong nuclear force (which is parity conserving) and the weak force (parity non-conserving) with the relative intensities 1 and 10^{-8} - 10^{-9}. It is very difficult to detect such effects and a low statistical precision is usually obtained

The estimation of the effect is

$$|A| \simeq 5 \times 10^{-8}$$

and the present experimental upper limit is

$$A < 2 \times 10^{-7} \quad \text{ISN-Harvard 1975 (ref. 1).}$$

The above estimation is based on the "best values" of the weak meson coupling constants given by Desplanques-Donoghue and Holstein (Ref. 2) and the description due to Desplanques - Missiner (ref. 3) of weak processes.

Principle of the experiment

The capture of polarized neutron by a proton form a high energy oriented scattering state which decays with a 2.2 MeV γ ray to the deuteron ground state.

$$n + p \longrightarrow (n\ p) \longrightarrow d + \gamma$$
$$({}^3S_1 + {}^3\tilde{P}_1) \qquad (M_1 + \tilde{E}_1)$$

Any parity impurity in this process has effects on the γ ray characteristics, especially on its angular distribution through the interference of the regular M_1 and irregular $\tilde{E}_1$ transitions giving rise to pseudoscalar quantities such as the γ asymmetry coefficient A_γ inquired here. The γ angular distribution can be written as ($\vec{P}$ being the beam polarization) :

$$W \ \alpha \ 1 + A \, . \, |\vec{P}| \, . \cos (\vec{P}, \vec{k}\gamma)$$

As the detection of a $\vec{P}.\ \vec{k}\gamma$ correlation is the aim of the experiment, the equivalence of parity conjugate systems ensures the equiprobability for processes with positive and negative correlations. Among the different experimental possibilities the best one is the most symmetrical set up. This could be achieved with two detectors of same quality for correlation detection at the same time (forward and backward detection relative to beam polarization). To compensate any difference, compared to an ideal geometry, we periodically invert the set up by two current sheets (spin flip) and also by reversing the magnetic fields applied along the beam path.

Thus any uncorrelated spin effects will be averaged over the different configurations and will cancel.

From the statistical point of wiew we need.

- A high nuclei density target : large size liquid parahydrogen target
- a high flux, low energy, high degree of polarization beam
- a set of high efficiency accurate detectors

The low energy beam fed from the PN7 apparatus (λ^{*} = 4.5 A°) allows the scattering to be done on the whole molecule (without spin flip because parahydrogen has J = 0 angular momentum) without transition to the ortho state (ΔE = 14.7 m eV). Furthermore it ensure that the n-p nuclei are in S state (with relative angular momentum l = 0) avoiding appearence of regular P states (with l = 1) in agreement with parity conservation.

As the number of photon incidents upon each detector is of the order of 10^9/sec, only the mean value of this flux is suceptible to measurement (exactely the mean continuous voltage at the photomultipliers anode). Two digital voltmeters (ADC, 16 bits resolution) are used to convert these signals before analysis. We took a special care in the design and choice of electronic components to avoid contribution of drift and pick up signals.

Performance of the apparatus

The beam at the exit of polarizer has a polarization of 97 % and a flux of 4 10^8n cm^{-2} s^{-1} over a 15 cm^2 cross section with a cut off wave-length of 4.5 Å (ie En = 4 meV). The efficiency of each spin flipper was measured to be of the order of 94 %

- The effective polarization of captured neutrons in the 35 l target is estimated to be 92 % of incident polarization due to the remaining ortho-hydrogen at 20K thermal equilibrium (0.2 %). The probability for neutron to stop in hydrogen is of the order of 71 % which correspond to a signal over noise ratio at least equal 8. Each detector (400 l of liquid scintillator NE 235) have an efficiency of about 17 % (including solid angle) which correspond to the creation of more than 20 photo-electron per γ and MeV.

Validity of the experiment/ Preliminary tests

- ^{60}Co zero test

The distribution of capture photon being mainly symmetrical, we can simulate it with an unoriented radioactive source. This measurement ckecks the quality of the set-up (sensitivity to drift, influence of magnetic fields on detection process...). But above all it is an absolute zero check of the apparatus in the sense that the source own fluctuations were negligible (which is not the case with the beam whose fluctuations are of the order of 1 %).

This test was performed with a 114mCi ^{60}Co source. The uncertainty of individual measurements is $\simeq 2.5\ 10^{-5}$ i e about $6\ 10^{-8}$/day, so that for a 40 days experiment we have measured

$$A = (0.5 \pm 1.1) \times 10^{-8}$$

- Empty target zero test.

Here we carried out a measurement of background asymmetry (B4 C associated asymmetry). The accuracy to be obtained lies in the range of 10^{-7} to assert that any significative effect greater than 1×10^{-8} is due to hydrogen (the signal to noise ratio being in this case is estimated to be ~ 10). For a total of 120 h runs we measured the asymmetry

$$A = (9.7 \pm 12) \times 10^{-8}$$

that is after correction for mean polarization and geometrical factor

$$A = (9.7 \pm 15_{\text{stat.}} \pm 1_{\text{cal}}) \times 10^{-8}$$

- Calibration of the set up

Very few experimental results exist for this mode of detection. We take advantage of an experiment of the same type performed by the Leningrad group on 35 chlorine (ref. 4) that is $A = (-27.8 \pm 4.9) \times 10^{-6}$
For that test we use a target of about 40 gr of chemically pure Na Cl powder. Our measurement for a 12 h run gave the raw result

$$A\ (\text{Na Cl}) = (-1.31 \pm 0.07) \times 10^{-5}$$

that is after corrections

$$A\ (^{35}\text{Cl}) = (-\ 21 \pm 1_{\text{stat}} \pm 2_{\text{cal}})\ 10^{-5}$$

confirming the magnitude and the sign of the effect detected at Leningrad.

- Natural tin test

The ^{117}Sn isotope is one of the nuclei which have been the most inquire upon weak nuclear interaction with many different technics and the effect is well proven and known. A direct measurement of natural tin associated effect was undertaken with a metallic target. We observed for a three days run the raw asymmetry.

$$A = (-1.91 \pm 0.95) \times 10^{-6}$$

which correspond to the value.

$$A = (-2.5 \pm 1.2 \text{ stat} \pm 0.2_{\text{cal}}) \times 10^{-6}$$

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References

1) J.F. Cavaignac, B. Vignon, R. Wilson - Phys. Lett. 67B, (1977) 148

2) B. Desplanques, J.F. Donoghue B.R. Holstein - Ann. Phys. (N.Y.) 124 (1980) 449

3) B. Desplanques, J. Minimer - Nucl. Phys. A300, (1978) 286 ; Phys. Lett. 84B (1979) 363.

4) V.A. Vesna et al - JETP Lett. 36 (1983) 209