Parity nonconservation in the γ decay of polarized $17/2^{-}$ isomers in ^{93}Tc

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The determination of the $0^\circ-180^\circ$ asymmetry (A_γ), which arises because of the parity nonconserving matrix element, in the 751-keV γ decay of polarized $17/2^{-}$ isomers in ^{93}Tc with respect to the direction of polarization is reported. A combined analysis of the present results together with those from our earlier work yields an effect of two standard deviations.

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In two previous publications [1,2] we reported on the measurement of the parity nonconserving (PNC) matrix element in the $\frac{17}{2}^{-} \rightarrow \frac{13}{2}^{+}$ γ transition depopulating the $\frac{17}{2}^{-}$ isomer of ^{93}Tc with a combined accuracy of three standard deviations. There exist only a very limited number of statistically significant determinations of a PNC effect in bound nuclear systems. The theoretical interpretation and the extraction of a PNC matrix element require the availability of the corresponding nuclear structure information. The ^{93}Tc case, even though it requires a knowledge of the wave functions in a heavy nucleus, presents a unique possibility for a meaningful shell-model approach because of the $N = 50$ neutron shell closure and hence the possibility of extracting important information regarding the weak part of the nuclear Hamiltonian such as the tensor part of the meson-exchange parametrization [1]. Measurements of parity violation in bound nuclear states at an accuracy level of two standard deviations are generally considered inconclusive. The result of [1,2] at three standard deviations is significant, but only marginally so. Hence a new measurement of the ^{93}Tc case with a superior γ-detection system was called for in order to provide a more significant statistical result. In the present paper we report the results from this new measurement and a combined analysis of the data from all our previous and present data sets. A preliminary account of this experiment was published in Ref. [3].

The experiment was carried out at the Separator of Heavy Ion reaction Products (SHIP) facility [4] at Gesellschaft für Schwerionenforschung mbH (GSI) in a manner similar to that of Ref. [1]. A schematic view of our experimental setup is shown in Fig. 1. A secondary beam of ^{93}Tc^{m} isomers was produced at the UNILAC at GSI in the ^{45}Sc(^{52}Cr, $2p2n$)^{93}Tc reaction. The ^{52}Cr primary beam of 900 pnA at $E_{\mathrm{lab}} = 170$ MeV impinged on a ^{45}Sc target of 1-mg/cm^2 thickness mounted on a rotating wheel. The SHIP velocity filter separated and transferred the ^{93}Tc $\frac{17}{2}^{-}$ isomers of $E_{\mathrm{lab}} = 65$ MeV to the focal-plane area, where they were polarized by an array of sixteen, 15+15-μg/cm^2-thick collodion-carbon foils tilted by 70° with respect to the isomer beam axis. We optimized the SHIP parameters for the maximum transmission of ^{93}Tc isomers by monitoring them in a particle detector at the entrance of the foil stack and by counting the isomer γ rays. The direction of the polarization was changed every one or three (Present1 or Present2; see below) minutes by rotation of the foils by 180° by use of a computer-controlled stepping motor. The ^{93}Tc isomers were subsequently implanted into a Pb stopper of 32.1 mg/cm^2, which preserved the alignment and polarization over the isomer half-life [10.2(3) μsec] [5,6]. The decay γ rays were detected in two Compton-suppressed segmented clover Ge detectors consisting of 4 HPGe crystals 7 cm wide and 14 cm long, each placed at 0° and 180° with respect to the induced polarization. The geometrical attenuation coefficient was $Q^{\mathrm{new}} = 0.70$. The experiment was carried out in two runs, Present1 and Present2, of approximately equal length, and a total of 4.95×10^6 (background subtracted) counts in the $\frac{17}{2}^{-} \rightarrow \frac{13}{2}^{+}$ 751-keV γ line were accumulated in the two detectors. A typical γ-ray spectrum is shown in Fig. 2.

The data analysis was carried out with the ROOT-package-based go4 code [7]. Standard double ratios [1] of γ-ray counts were derived:

$$\mathrm{DR} = \sqrt{\frac{rl}{rr}\Big/\frac{ll}{lr}} = \frac{W(\pi)}{W(0)} = \frac{1 - A_\gamma}{1 + A_\gamma}, \quad (1)$$

where e.g., rl refers to the counts in the right detector for the left-polarized isomers. This provides a measurement of the 0°–180° asymmetry (A_γ) of the 751-keV $M2/E3$ transition from ^{93}Tc that is independent of the relative efficiencies of the detectors and of the beam-current fluctuations. Artifacts that are due to the interaction of the isomer beam with the foil

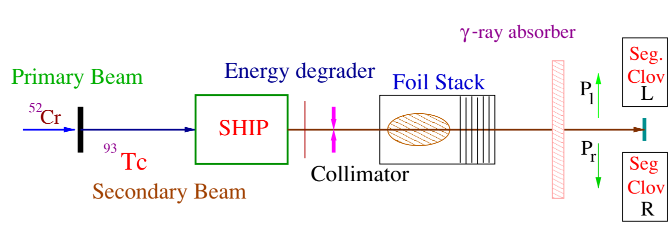

FIG. 1. (Color online) A schematic view of the experimental setup.

TABLE I. The triple ratios TR(i) for all runs. In the last row $\overline{\mathrm{DR}}(i \neq 751)$ are also given to demonstrate the quality (artifacts) of each experiment. Average: weighted average of GSI, LNL1, LNL2, and Present2; Overall: weighted average of Average and Present1.

E_γ (keV)	GSI	LNL1	LNL2	Present2	Average	Present1	Overall
544(^{93}Ru)	1.0004 (13)	1.0017 (12)	1.0010 (13)	0.9991 (12)	1.0006 (6)	1.0048 (18)	1.0010 (6)
629(^{93}Tc)	1.0016 (9)	0.9996 (9)	1.0002 (10)	1.0009 (7)	1.0007 (4)	1.0019 (11)	1.0008 (4)
711(^{93}Tc)	1.0004 (6)	0.9997 (7)	0.9993 (8)	0.9996 (4)	0.9998 (3)	0.9992 (7)	0.9997 (3)
751(^{93}Tc)	0.9977 (9)	0.9989 (9)	0.9984 (10)	1.0003 (7)	0.9990 (4)	1.0001 (11)	0.9992 (4)
1392(^{93}Ru)	0.9970 (14)	1.0008 (14)	1.0004 (16)	0.9997 (11)	0.9995 (7)	0.9983 (15)	0.9993 (6)
1432(^{93}Tc)	0.9989 (7)	1.0002 (7)	1.0003 (8)	1.0004 (3)	1.0002 (2)	1.0001 (6)	1.0001 (2)
$\overline{\mathrm{DR}}(i \neq 751)$	0.9985 (4)	0.9956 (4)	0.9988 (4)	0.9960 (2)	-	0.9994 (3)	-

stack [1] can be eliminated by formation of the triple ratios,

$$\mathrm{TR}(i) = \frac{\mathrm{DR}(i)}{\overline{\mathrm{DR}}(i \neq 751)}, \tag{2}$$

where i goes over all the isomer lines and the denominator is an average for all the isomer lines other than 751 keV. For the γ transitions (other than 751 keV) depopulating the $17/2^-$ isomer as well as for γ rays from ^{93,94}Ru and ^{93,94}Mo isomers (Fig. 2), no PNC asymmetry is expected and the observed asymmetries determine the quality of the experiment. The denominator of Eq. (2) gauges such effects (Table I).

In the end of the Present1 run it was found that the foil stack rotates by an angle slightly (≈0.3°) different from 180°. As the rotation was regular in time, the difference could be accurately incorporated into the analysis. This problem was corrected for the Present2 run, but it leads to an additional error contribution for the results from Present1 in comparison with those from the remaining Present2 and previous data sets. In any case, as is evident from Table I, whether one includes the results of Present1 or not does not alter significantly the final results and conclusions.

Table I presents triple ratios for all the strong isomer lines, from the GSI, LNL1, and LNL2 runs taken from Ref. [1] and from the present data. The values of $\overline{\mathrm{DR}}(i \neq 751)$ are also given. A correction that is due to the differences in attenuation factors between the previous ($Q^{\mathrm{old}} = 0.85$) and the present ($Q^{\mathrm{new}} = 0.70$) measurements is incorporated into the Present1 and Present2 data, allowing for a direct comparison with the remaining data sets. As can be seen from the "Average" and "Overall" triple ratios, the data from Present1 have a negligible contribution toward improving the statistical significance owing to the additional error contribution just mentioned. The 751-keV data from all the runs are marginally consistent. In view of the small value of the artifacts in all the runs (Table I), their independence of γ-ray energy over a large energy range and the fact that there are no significant differences among the experimental setups, we believe that we can exclude any systematic error in the triple ratios. Figure 3 shows the overall triple ratios of the isomer lines, with triple ratio of 751 keV highlighted.

The A_γ value is obtained from TR(751) with

$$A_\gamma = \frac{1 - \mathrm{TR}(751)}{1 + \mathrm{TR}(751)} \tag{3}$$

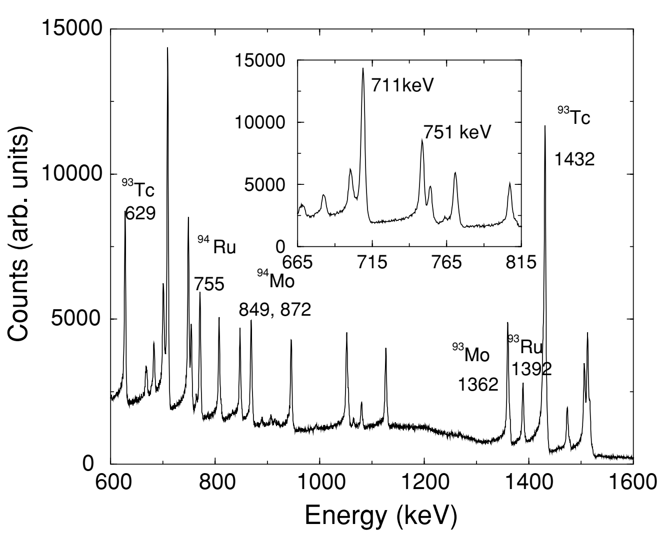

FIG. 2. A typical γ-ray spectrum from a partial data set of one of the Ge crystals.

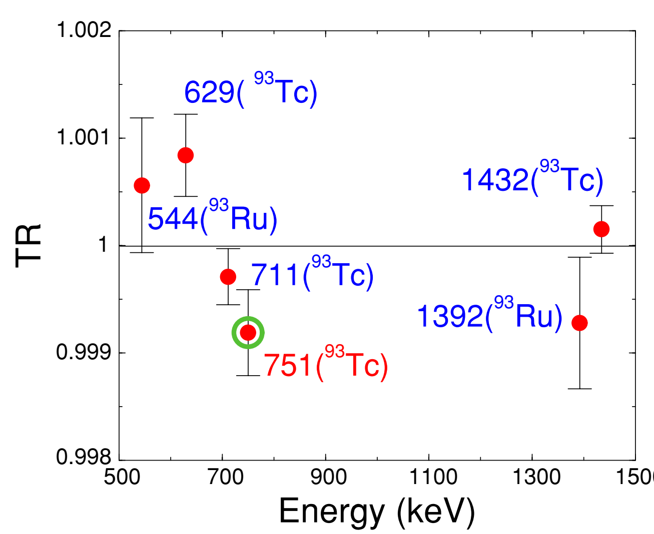

FIG. 3. (Color online) The triple ratios TR(i) for the overall combined values of all the runs for all the relevant isomer lines.

For a full description of the boson exchange nature of the PNC matrix element and the underlying shell-model calculations we refer to Ref. [1]. The overall asymmetry value is found to be $A_\gamma = 4.1(2.0) \times 10^{-4}$ compared with $A_\gamma = 8.4(2.7) \times 10^{-4}$ from Ref. [1]. With two standard deviations, the overall result is on the verge of statistical significance, and the case of the parity violation in the $\frac{17}{2}^-$ ^{93}Tc isomer is now relegated to an "inconclusive" status. Considering the high level of statistical accuracy already achieved, a further measurement would have to involve improved experimental parameters such as isomer production, γ detection efficiency, and higher polarization.

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