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M. Sakai, H. Kawakami, K. Omata, I. Sugai, I. Katayama,
T. Miura, S. Shimizu and K. Horie

Center for Nuclear Study (CNS)

Graduate School of Science, the University of Tokyo
Wako Branch at RIKEN, Hirosawa 2-1, Saitama 351-0198, Japan
Correspondence: `cnsoffice@cns.s.u-tokyo.ac.jp`

Observation of 180^0 correlation of e^+e^- pair originating from $e^+(^{82}Sr)$+Th interactions

M. Sakai
Center for Nuclear Study, the University of Tokyo (CNS), RIKEN, Wako-shi 351-0198, Japan
H. Kawakami, K. Omata, I. Sugai, I. Katayama and T. Miura
High Energy Accelerator Research Organization, Oho 1-1 Tsukuba 305-0801, Japan
S. Shimizu and K. Horie
Department of Physics, Graduate School, Osaka University, Toyonaka, Osaka 560-0043, Japan

Abstract

An electron line previously observed at INS with an energy of 330.3 keV and an associated cross section of 149mb in e^++Th interactions had been implied by the authors to originate from the decay of a new neutral particle. QED predicts a two-photon decay mode of the particle leading to a correlated two-photon coincidence peak at 841.3 keV. Subsequent 2γ-coincidence experiments have revealed a peak-like structure at 841.7keV and an associeted cross section of 15.2μb(upper limit). These energies and cross sections satisfy the relations of $E_\gamma=E_e+m_ec^2$ and $\sigma(2\gamma)/\sigma(e^+e^-)\approx\alpha^2$ expected from a particle production scenario. We report here on a positron and electron coincidence experiment for e^++Th performed at INS with scintillation counters placed on the central trajectory of a β-ray spectrometer. The coincidence time spectra were analyzed with a single line χ^2 fit. This yielded a peak-like structure at the predicted channel and with an area compatible with the previously reported cross section.

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I. INTRODUCTION

A group at the Oak Ridge National Laboratory (ORNL) reported an intriguing observation in 1986[1]. These authors bombarded a Th target with positrons from a ^{68}Ge source and carried out a coincidence experiment between e^+ and e^- scattered out from the back of the irradiated target. They observed a peak at about 340keV and speculated that the peak results from the e^+e^- pair decay of a new neutral particle generated in the scattering of positrons from Th atoms.

I.A. Electron singles experiments

If the hypothesis is correct, one will expect a positron and electron pair to be emitted with equal energy from the irradiated target. A group at the Institute for Nuclear Study, University of Tokyo(INS) started experiments to search for the monochromatic electrons with the INS air-core β-ray spectrometer immediately after the appearance of the ORNL paper and continued the investigation in the period from 1986 to 1992. They used the positron emitters of ^{118}Te(E_{max}=2.70MeV)[2,3] and ^{82}Sr(E_{max}=3.37MeV)[4] and employed a rolled thorium foil with a thickness of a few mg/cm^2 instead of the 40-50 mg/cm^2 target in the ORNL experiment. The thorium foil placed on top of the positron source was located at the source position of the spectrometer. In each of these experiments a narrow electron line was observed, of which the weighted mean energy and cross section are 330.3±0.4keV and 149(1±0.13(stat)±0.25(syst))mb, respectively[5]. Small experimental errors indicate a good reproducibility and an internal consistency between the different experiments.

Comparing the respective yields from the INS and the ORNL results with each other we predict for the ORNL experiment 350 counts which are to be compared with the reported number of events of 500±200[1]. The consistency of the energy and the cross section between the INS and the ORNL data is suggestive that the two groups have observed the same phenomenon. It must be mentioned, however, that the partner positron beam could not be measured in the INS experiments due to a strong background caused by primary decay positrons. Therefore, the INS experimental results only satisfy the necessary but not the sufficient condition for the validity of the proposed hypothesis.

Because of their relatively low statistics and their far reaching theoretical implications both the ORNL and INS results have been met with considerable skepticism by the physics community. Moreover, investigations at Frankfurt[6] and Argonne [7] published immediately after the ORNL paper did not find any evidence for the ORNL result. However, both negative findings have been found not to unambiguously deny the evidence of the ORNL peak, since the conclusions were based on the assumption that the number of genuine events is proportional to the background. This, however, is not the case since the background depends very sensitively on the experimental arrangement. Instead the number of expected events must be calculated from the experimental conditions such as target thickness, spectrometer transmission, measuring time etc.. The Frankfurt paper unfortunately does not give enough information to calculate the number of genuine events. For the Argonne experiment it was calculated to be only 30% of the ORNL experiment due to the small transmission of the used electron and positron spectrometers. This number is far below the experimental sensitivity for the detection of the ORNL peak. For the reasons given both the Argonne and the Frankfurt measurements are in our opinion insufficient to proof the non-existence of this peak.

By some authors the ORNL peak was suspected to originate from the 340 keV Compton peak of the 511 keV annihilation photons. Measuring the Compton electrons scattered out by annihilation photons from the source-target assembly the INS group found instead a flat momentum distribution with a step starting at 340 keV[3]. Consequently, Compton scattering as the origin of the ORNL peak appears to be highly improbable.

I.B. Photon correlation experiments

If the hypothetical neutral particle exists, QED predicts that it alternatively decays by the emission under 180^0 of a correlated, equal-energy photon pair in competition with the e^+e^- pair emission. In this case the photon energy should satisfy the relation of $E_\gamma= E_e+m_ec^2$. The predicted value is 841.3±0.4 keV. The branching ratio R is given by the following formula [8] :

$$R=\sigma(2\gamma)/\sigma(e^+e^-)\geq(\alpha/\pi)^2(M/m_e)^2(1-4m_e^2/M^2)^{-1/2}, \qquad 1)$$

where M stands for the mass of the hypothetical particle and the inequality represents the possibility of coupling to other charged particles beside the electron. In the case of E_e=330.3keV, R is $\geq 7.4\text{x}10^{-5}$. Then, $\sigma(2\gamma)$ is given by $\sigma(2\gamma)\geq 11(1\pm 0.13(\text{stat})\pm 0.25(\text{syst}))\mu b$ by introducing the reported $\sigma(e^+e^-)$ into eq.1.

The 2γ coincidence was investigated by a group at the Tandem Accelerator Center, University of Tsukuba with the use of a mini-crystal ball. After five experiments of a total running time of 100 days in the period from 1994 to 1997, a peak like structure at 841.7keV[9] very close to the predicted value was observed. The statistics were, however, insufficient to establish the existence of the hypothetical neutral particle and therefore only an upper limit cross section of 15.2±1.5(syst) μb could be placed for the production of 2γ pairs. This value can be compared with the lower limit deduced above. The upper and lower limits of σ are compatible and do not exclude each other.

I.C. Summary of the previous experiments

The experimental results so far obtained are summarized by referring to I(Ref.[2]), II(Ref.[3]), III(Ref.[4]) and IV(Ref.[9]).

1) The 330.3-keV electron line has been observed in the interaction of positrons from ^{118}Te and a Th target (I and II). The line was also observed with a positron emitter of ^{82}Sr(III). This implies that the appearance of the line is a general phenomenon independent of the type of positron emitter. The small error of the energy and the cross section indicates a good reproducibility. The possibility of the line having a nuclear origin from spontaneous radioactive decays of the thorium target was excluded by the measurement without the positron emitter (II).

2) The line was also observed with a U target (I). The energy of the line and the production cross section are the same within the experimental errors as those obtained for the Th target (I). However, the line was not observed with a Ta target (I) to indicate a strong dependence of the cross section on the atomic number of the target.

3) The electrons were found to originate from the inside of the target by comparing the energy shift and the shape change of the line with those of the neighboring conversion lines in the spectra taken under different scattering conditions (II).

4) The line was observed with electrons emitted backward with respect to the direction of the incident positrons (II). It supports the hypothesis that the electrons are isotropically emitted.

5) The line width was so close to those of the neighboring internal or external conversion lines that the intrinsic width for the decay of the hypothetical particle could not be extracted by comparing the widths with each other (II and III). The narrowness indicating the particle to be generated at rest is incompatible with the scenario that the particle is created in resonant e^+e^- scattering. This may explain the unsuccessful results of Bhabha scattering experiments [10]. The upper bound of the intrinsic width is estimated to be about 1.5 keV, which corresponds to a lifetime greater than 4.3×10^{-19} sec.

6) The 180^0 correlated equal-energy two-photon decay predicted by QED was searched by 2γ coincidence experiments. A peak-like structure was observed at an energy very close to the theoretically expected value. Though only an upper limit of

the cross section could be deduced from the spectral structure due to the limited statistics, it is compatible with the lower limit deduced from lepton experiments (IV).

II. 180^0 e^+e^- CORRELATION EXPERIMENTS

All the data accumulated from lepton and photon experiments are consistent with the hypothesis of the generation and subsequent e^+e^- or 2γ decay of a neutral particle in e^++Th scatterings. However, the experimental results are still inconclusive with the exception of the observed 330.3keV electron line due to a relatively low statistics. The 180^0 correlation of a e^+e^- pair is an important property to be expected from the scenario of the neutral particle decay. Though the 2γ coincidence experiments have provided a suggestive indication for the 180^0 correlation of decay photons [9], that of decay leptons has not been investigated as yet. We report in this paper on a search for 180^0 correlated lepton pairs. Scintillation counters to detect positrons and electrons were placed on the central trajectory of the β-ray spectrometer. The e^+e^- coincidence events were searched in TDC (time to digital converter) time spectra taken by setting the magnetic field to 330.3 keV. Since an unexpected large background appeared in the spectra, we were forced to take background subtracted spectra for detecting the searched events buried in the background. In the background subtracted spectrum of the center scintillator paddle we observed a peak-like structure at a channel calculated from the difference of the flight time between the 776.2-keV conversion electrons and the 330.3-keV relevant electrons. Though the relatively low yield and the inevitable subtraction procedure produced considerable statistical errors in the final results, the location, the intensity and the shape of the line are consistent with the features predicted from the 180^0 correlation of a e^+e^- pair. It may provide a further suggestive data for the existence of the 330.3 keV electron line proposed in the previous electron experiments and prove a e^+e^- pair being emitted under the 180^0 correlation. Such an observation has not been presented earlier.

II.A. Instrumentation

The experiment was performed with the INS air-core β-ray spectrometer (ρ=75cm) used in the previous electron experiments [2-4]. The schematic diagram of the experimental configuration is shown in fig.1. We used a ^{82}Sr source with an initial activity of 12.9MBq deposited on a 3mmx16mm area of a 1.5μm polyester membrane. A rolled thorium metallic foil of 0.8 mg/cm^2 in thickness with the same size as the source was placed on top of the source with a separation of 3mm. This source-target assembly was placed in the source chamber of the spectrometer with the Th-foil in the source position. The target thickness is particularly important for the correlation experiment because leptons easily lose the memory of their direction due to multiple scattering in the target. The baffle of the spectrometer was set for a momentum resolution of $\Delta p/p$=1.0% and Ω=1.2%/4π. For the electron detection, a counter array consisting of five plastic scintillator paddles, 2mm thick and 15mm wide, termed K, L, M, N and O in increasing momentum order, was horizontally placed on the focal plane next to each others with a gap of 10mm between the paddles and arranged with the center counter M to be on the central trajectory. The width of the paddle corresponds to a momentum window of 0.5% of $\Delta p/p$. The length of the flight path from the target to the center detector is 333.2cm. To detect positrons, an extended rectangular chamber, with the same curvature of the main trajectory, was attached on the opposite side of the source chamber. Two plastic scintillators, 2mm thick, 100mm high and 160 mm wide, were vertically placed in a box installed at the end of the chamber. At the other end of the chamber a 30mm thick lead shield with a slit of 62mm high and 37mm wide at the center was placed at a distance of 140mm from the target. The length of the central trajectory for positrons is 78.5cm. As the deflection angle of 60^0 provides a poor momentum separation due to a wide momentum window, the pulses from the positron counters were only used as timing signals.

II.B. Measuring procedure

To search for coincidence events we employed a TDC with the electrons supplying the start and the positrons, the stop signals. The spectrum was recorded in 500 channels with a time bin size of 0.4ns each, covering the TDC dynamic range of 200ns. A delay line of 100ns was inserted in the positron circuit to displace the coincidence spectrum by 250 channels. The location of the coincident event of an E-keV lepton is given by

$$P(E)=250+[T_+-T_-]+[t_+(E)-t_-(E)]\,, \qquad 2)$$

where T_+ and T_- are the delay time of the cables between the output of the detector and the input of the electronics and $t_+(E)$ and $t_-(E)$ stand for the flight time of leptons taking between the target and the detector. $t_+(E)$ and $t_-(E)$ can be calculated while T_+ and T_- being related to the effective cable length must be measured. To determine $T_+ - T_-$, we used the coincidence between the 762.2 keV K-conversion electrons of the ground state transition from the 776.5-keV first excited state in ^{82}Kr and the decay positrons from ^{82}Sr feeding this state. The spectra of all the electron counters were taken simultaneously by setting the magnetic field to 762.2 keV. The spectra are presented in fig.2. The channel number and the counts of the peak for each spectrum are K(276.5 ; 37), L(258.3 ; 156), M(258.7 ;240), N(254.8 ;40) and O(255 ; 15), respectively. The different peak position results from the different time shift of $T_+ - T_-$. The variation in the number of counts reflects the momentum distribution of the focused electrons so that the K and O counters set at the most inner and outer side of the counter array, respectively, have fewer count than the more central paddles. Therefore, we will only treat the spectra of the center M counter and the adjacent L and N counters in the following discussion. The time spectra are to be generated by the convolution of $\Gamma t_+(E)$ and $\Gamma t_-(E)$ where $\Gamma t_+(E)$ and $\Gamma t_-(E)$ are the flight time distribution of positrons and electrons, respectively. $\Gamma t_+(E)$ has a broad profile due to a wide t_+ distribution of the relevant positrons with a wide momentum spread, while $\Gamma t_-(E)$ should be very narrow because the electron scintillator paddles should be very narrow momentum acceptance for the electrons that thus all have nearly the same flight time of t_-(762.2keV)= 30.3ch. Therefore, the spectral shape is mostly determined by $\Gamma t_+(E)$ so that it has a similar broad shape almost independent of the magnetic field due to the wide momentum window of the positron counters. The mean flight time of $\Gamma t_+(E)$ is about 6.9ch corresponding to positron energy of 1.0 MeV. Introducing P(762.2keV), t_+ and t_- quoted above into eq.2, $T_+ - T_-$ for L, M and N were obtained 31.7, 32.1 and 28.2 channel, respectively. Then eq.2 can be written:

$$P(E)=281.7 +[t_+(E) - t_- (E)] , \qquad 3\text{-}1)$$

$$P(E)=282.1 +[t_+(E) - t_- (E)] \qquad 3\text{-}2)$$

and

$$P(E)=278.2 +[t_+(E) - t_- (E)] \quad . \qquad 3\text{-}3)$$

for L, M and N, respectively.

II.C. Search for an 180^0 correlated lepton pair

Spectra were taken by setting the magnetic field to the predicted electron energy of 330.3keV. In addition background spectra were taken by increasing the magnetic field by 5% which corresponds to 356.6 keV. The total running time involved was 14 days. Spectra L, M and N together with the background spectra L_b, M_b and N_b are presented in fig.3.

II.C-1. *Background*

Since we found in the spectra an unexpected common structure consisting of a flat component and three bumps p_1, p_2 and p_3 as indicated in the figure, we tried to understand the nature of the background by accumulating spectra with different magnetic field settings. The normalized spectra are shown in fig.4 where we employed the sum spectra of L+M to increase the statistics because L and M have almost the same time shift as remarked in fig.2. The energy corresponding to the field strength and the normalization factor are presented in fig.4.

The flat component mainly constitutes accidental coincidences between intense scattered 498.8-keV conversion electrons originating from the 514.0-keV transition in a contaminant ^{85}Sr amounting to several ten % of ^{82}Sr and decay positrons or scattered photons. The low intensity of the flat component in the spectra obtained with a magnetic field corresponding to the energy beyond the conversion electron energy is consistent with this interpretation.

The narrow bump p_1 appears at a constant position independent of the magnetic field and the counter species. It implies p_1 to be independent of the cable length. It could be interpreted as electronic cross talk. Since p_1 only appears strongly in the 330.3-keV and 356.6-keV spectra with an intensity dependence of energy similar to that of the flat component, this phenomenon might be associated with the high electron counting rate.

The bump p_2 may result from true coincidences between electrons in the relevant energy range generated in the Compton scattering of the 776.5-keV photons from the target placed at the source position and the decay positrons feeding this level. This interpretation may be justified by the fact that p_2 keeps about the same shape due to the independence of $\Gamma t_{+}(E)$ of the field strength and moves to the low channel side as the magnetic field is decreased. This trend is seen in fig.4 where the reversed triangles represent the maximum bump position calculated by eq.3-1. It is worth noting that the quantity of the shift is larger than the calculated one and this discrepancy enlarges as the electron energy decreases. In the low energy region, the counter receives electrons scattered inside the spectrometer beside the directly entering ones. As the flight time of the scattered electrons is longer than that of the focused ones due to their longer path length, $\Gamma t_{-}(E)$ shifts to the lower channel side. In the case of $\Gamma t_{-}(330.3\mathrm{keV})$, if we assume that the effective path length of scattered electrons is longer by 10% than that of the focused electrons, the calculated maximum of p_2 shifts to the observed maximum position.

The maximum of p_3 appears to be independent of the field strength including the case in which no magnetic field is applied, but it depends on the counter species, that is, on $T_{+} - T_{-}$. It implies that p_3 is related to photon scatterings. Introducing the maximum position of p_3 at around 270 channel for L and M into eqs.3-1 and -2, we obtain $t_{-}(E) \approx 19 \pm 1$ch($\approx$7.6ns) which corresponds to a photon flight path of about 230cm. This length agrees in order of magnitude with the total path length of a photon leaving from the source, being scattered on the wall of the spectrometer facing directly the source, and entering the electron detector.

II.C-2. *180^0 correlated 330.3-keV lepton pair*

The expected location of the coincidence peak of the 180^0 correlated 330.3-keV lepton pair can be estimated by introducing the flight time of 8.3ch for t_+(330.3keV) and 35.0ch for t_-(330.3keV) into eq.3-1 –2 and -3. The derived peak channel is found to be 255.0, 255.4 and 251.5 ch for L, M and N, respectively, indicated by arrows in fig.3. Unfortunately, the position is nearly on the top of the bump p_2, so that the relevant peak could be buried in the bump. We attempted to unearth the peak by employing the background subtraction procedure.

First we assume the spectra of fig.3 to have the same spectral shape independent of field setting because they are taken with the magnetic fields corresponding to only slightly different energies of 330.3keV and 356.6keV and produced mostly by background events as described in II.C-1. Second we calculate the total sum counts, S(•), for each spectrum, where • stands for the relevant spectra. The background subtracted spectra D_M, D_L and D_N for the M, L and N counters are obtained by the following operations: $M\text{-}S(M)[M_b/S(M_b)+L_b/S(L_b)]/2$, $L\text{-}S(L)[M_b/S(M_b) + L_b/S(L_b)]/2$ and $N\text{-}S(N)\ N_b/S(N_b)$. They are presented in fig.5. For the background subtraction we used the sum spectrum of $[M_b/S(M_b)+L_b/S(L_b)]/2$ to improve on the statistics of the D_M and D_L spectra by making use of the equal time shift of M and L mentioned at the end of II.B. The dashed line is the result of a χ^2 fit, which will be described in the next paragraph. The line being very close to the zero line might prove the plausibility for the present subtraction procedure.

. A peak search was carried out with the use of the program MINUIT of the CERN-library [11] for the spectral region around 255ch, at which a peak is predicted to appear if the 330.3keV correlated e^+e^- pairs are really emitted from the target. A single line χ^2 fit was attempted for 101(0.4ns) bins from 200 - 300 channel where we took a Gaussian shape and a constant part as a fitting function. Furthermore we assume a single line to be in the interval from 250 to 260 channels. We found a peak-like structure in D_M but no indication for it in D_L and D_N. The result is shown in Fig.6. This yielded for the peak-like structure a position of 255.2±0.6 ch, an area of 108.2±45.7 counts and a FWHM of 1.15±0.51 ns with a reduced χ^2 of 1.17. The observed location is close to the predicted value of 255.4 ch. The narrow width can be explained by the following way. Since e^+ and e^- emitted under the 180^0 correlation traverse on the central trajectory with a given momentum, $\Gamma t_+(E)$ and $\Gamma t_-(E)$ should be very narrow so that the coincidence peak resulting from a convolution of two time distributions will take also a very narrow width.

Applying the methods of statistical evaluation we derived the total intensity of the coincident electrons on the focal plane. Since no yield was observed in the adjacent L and N paddles, the line focused to the center of the M paddle was assumed to have a Gaussian shape with a standard deviation of σ. Most of the intensity falls on the M paddle of 15mm and the adjacent gaps of 10 mm each, that is, on the interval of 35mm. The momentum window of the interval corresponds to 1.17% of $\Delta p/p$ because the 15mm paddle width is equivalent to 0.5% of $\Delta p/p$ as mentioned in II.A. As a measure of spread, we assume 4σ for the interval, that is, $\sigma = 0.292\%$ of $\Delta p/p$. In this case the interval receives 95.4% of intensity. Though the remainder of 5% of the intensity may spill over the adjacent paddles, the intensity is below the detectable level of the detectors so that it does not present a contradiction to the observation of no yield in the adjacent paddles. Since the momentum window of M is 0.5% equivalent to 1.71σ, it receives 0.607 of the total intensity according to the table of integral of Gaussian distribution. The total intensity that is obtained by dividing the observed yield by this figure is given 178 ± 75(stat). FWHM defined as 2.345σ is obtained to be 0.68%. It is to be compared with 1.25% and 1.50% for the 762.2-keV and 498.8- keV spectra, respectively, taken by sweeping the magnetic field with the singles measuring mode. The narrowness in comparison with those from the singles experiments will be discussed in the next paragraph.

II.C-3. *Production cross section*

The consistency of the production cross sections was studied by comparing the respective yields from the present and previous results with each other. The total number of the particles produced in the target during the measuring period was calculated by the same prescription as in the previous papers. Here, we take into account the reduction of the solid angle of primary positrons to the target because in the present experiment the source was separated from the target contrary to the previous ones where the target and the source were attached directly. By using the reported cross section, we obtained the number of particles produced in the target to be $2.13 \times 10^5 (1 \pm 0.13 (\mathrm{stat}) \pm 0.34 (\mathrm{syst}))$. The large systematic error results from the uncertainties in the solid angle and the effective target thickness for the bombarding positrons and from the error involved in the employed reported cross section. The acceptance probability of the paired leptons was determined with the use of a MONTE CARLO simulation method by generating back-to-back e^+e^- pairs where the computation was executed by taking into account the multiple scattering in the target. We also tried the simulation by generating single electrons. The electron distribution on the focal plane was obtained by a computer tracing of the electron trajectory. The computation revealed that the event distribution on the focal plane is much more concentrated at the center in the case of the correlated lepton pairs than in the case of the single electrons. It may result from the special property of the TDC coincidence method applied to the observation of the 180^0 correlation. It rejects scattered leptons and selects only directly emitted lepton pairs. It is consistent with the observation of the unexpected narrow momentum profile of the coincident events mentioned at the end of the preceding subparagraph. The acceptance probability was deduced from the total number of electrons in the focal plane produced by the simulation method. We obtained $1.1\text{x}10^{-2}$ and $0.6\text{x}10^{-3}$ for the single electrons and the correlated lepton pairs, respectively. The former value is close to $1.2\text{x}10^{-2}$ which is the formally accepted value for the 1% resolution setting. The expected yield from the present experiment is deduced by multiplying the produced total number of events by the calculated acceptance probability. The predicted yield then is obtained to be 128 ±17(stat)±44(syst), which is to be compared with the observed yield of 178± 75(stat).

III. CONCLUSION

We attempted to observe the 180^0 correlation of a lepton pair from the decay of a new neutral particle with the use of a TDC time coincidence technique and a large β-ray spectrometer. As each constituent of the relevant lepton pair emitted back to back from the target traverses on the central trajectory with the given velocity corresponding to 330.3 keV, the relevant leptons would have a very narrow flight time distribution. Therefore, the 180^0 correlated e^+e^- pairs should take a very narrow shape in the TDC coincidence time spectra obtained with the signals from positron and electron scintillation counters placed on the central trajectory. The time spectra for 330.3 keV revealed only in the background subtracted spectrum of the center counter a narrow peak at the predicted position calculated by their flight time. The narrowness and the location of the peak are suggestive for the existence of e^+e^- pairs emitted back-to-back from the irradiated target. The yield from the present experiment agrees in order of magnitude with that derived by the total number of generated particles calculated by the reported cross section and the acceptance probability obtained by a MONTE CARLO simulation method. However, the present experiment is short of claiming the presence of the relevant particle due to the relatively low statistics.

All the experimental data accumulated so far from the three types of experiments: the electron singles experiments, the 2γ coincidence experiments, and the present e^+e^- coincidence experiment, are mutually consistent with the scenario of "a new neutral particle is produced in the interaction of positrons and thorium atoms and subsequently decays by emitting a 180^0 correlated e^+e^- or 2γ pair with the branching ratio of $\sigma(2\gamma)/\sigma(e^+e^-)$ predicted by the QED". The experiments so far carried out consist of searches for rare events in the milieu of large backgrounds mainly caused by the source put on the target. We will pursue our objective to further clarify this mysterious phenomenon by means of another type of experiments where the source will be set separated from the target by a distance to reduce the background. We will expect to realize a significant improvement in statistical accuracy and to obtain convincing data for the presence of the hypothetical neutral particle within the next couple of years.

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Figure captions.

Fig. 1. Schematic diagram of the experimental installation.

Fig. 2. TDC spectra of the array paddles with the 762.2-keV setting. The different peak position is due to the different T_+-T_- value of each counter. The variation in the number of counts reflects the momentum distribution of the focused electrons on the focal plane.

Fig. 3. TDC spectra. L, M and N are taken by setting the magnetic field to 330.3keV and L_b, M_b and N_b with the magnetic field increased by 5% corresponding to 356.6 keV. The latter spectra are used for the reference background. The arrows indicate expected locations of the relevant coincidence peak derived from eqs.3-1, -2 and -3.

Fig. 4. TDC L+M sum spectra. The spectra are taken with six different field

strengths to study the nature of the background systematically. To increase the statistics we use the sum spectra of L+M because L and M have the same time shift. They are normalized by the decay number of each experimental series. The normalized factor is shown in the round bracket. The reversed triangles represent the calculated position of p_2.

Fig. 5. Background subtracted spectra D_M, D_L and D_N for M, L and N counters. They are produced by the following operations, respectively: $M-S(M)[M_b/S(M_b)+L_b/S(L_b)]/2$, $L-S(L)[M_b/S(M_b)+L_b/S(L_b)]/2$ and $N-S(N)N_b/S(N_b)$. A peak-like structure appears at a channel close to the predicted 255.4 ch in D_M. The dashed lines denote the constant part derived by the χ^2 fit. S(*) are referred to the text.

Fig. 6. Goodness of fit resulting from the χ^2 test. The full line is the experimental spectrum. The dashed line is the best fitted one.

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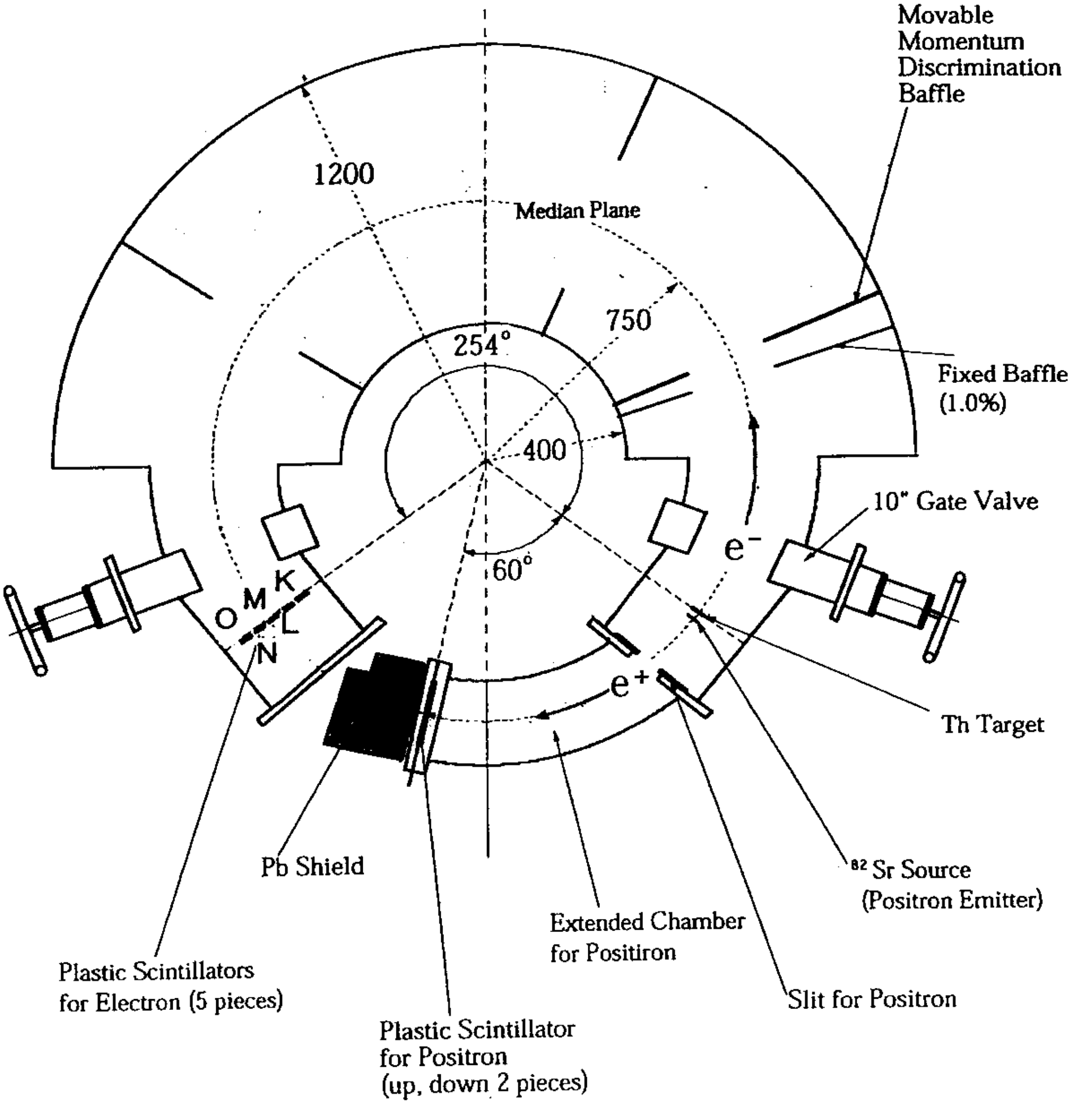
Movable
Momentum
Discrimination
Baffle
1200
Median Plane
750
254°
400
Fixed Baffle
(1.0%)
10" Gate Valve
e⁻
60°
K
M
O
L
N
e⁺
Th Target
Pb Shield
⁸² Sr Source
(Positron Emitter)
Extended Chamber
for Positiron
Slit for Positron
Plastic Scintillators
for Electron (5 pieces)
Plastic Scintillator
for Positron
(up, down 2 pieces)

Fig. 1

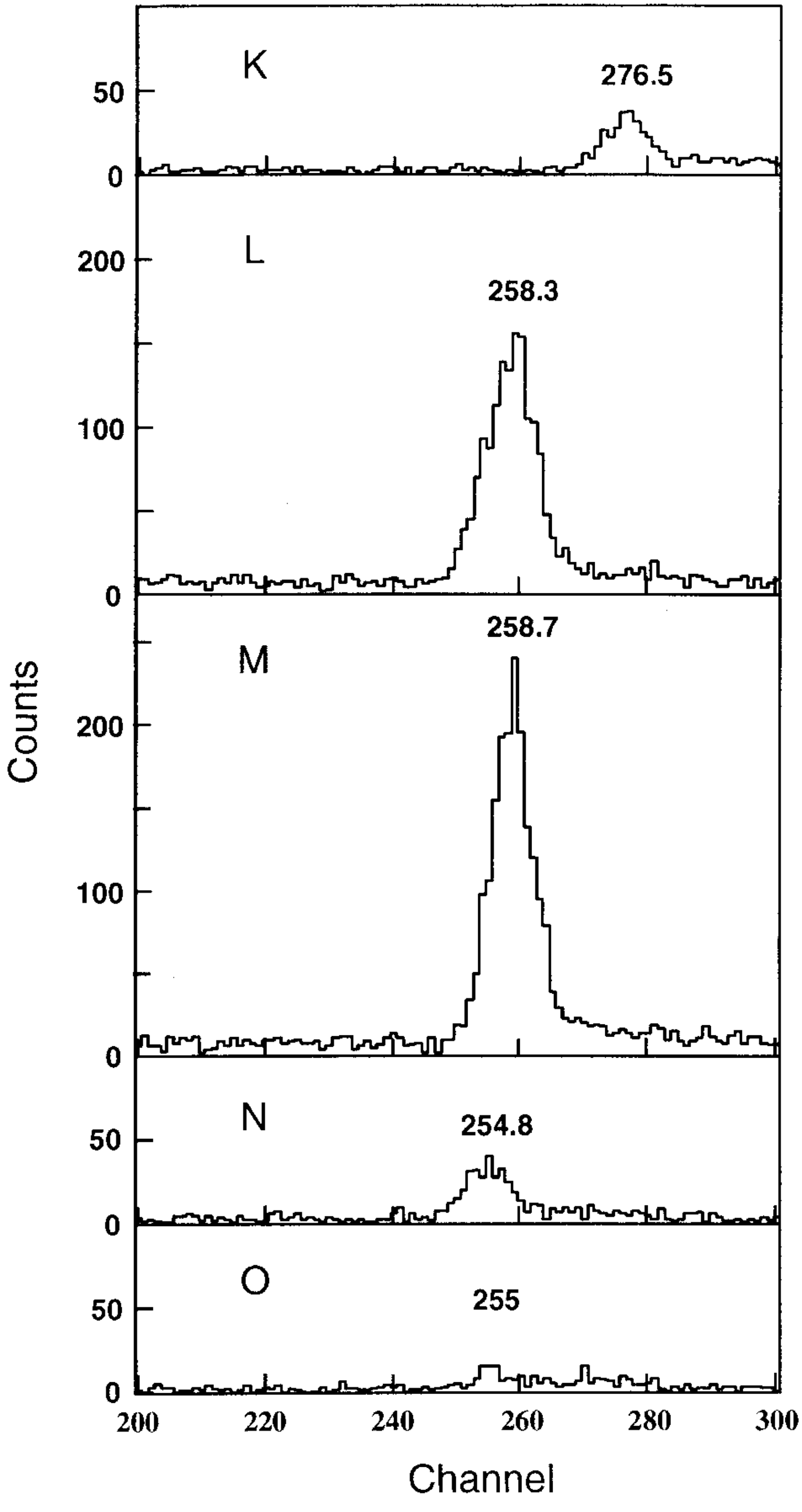
K
276.5
L
258.3
M
258.7
N
254.8
O
255
Counts
0
50
0
100
200
0
100
200
0
50
0
50
200
220
240
260
280
300
Channel

Fig. 2

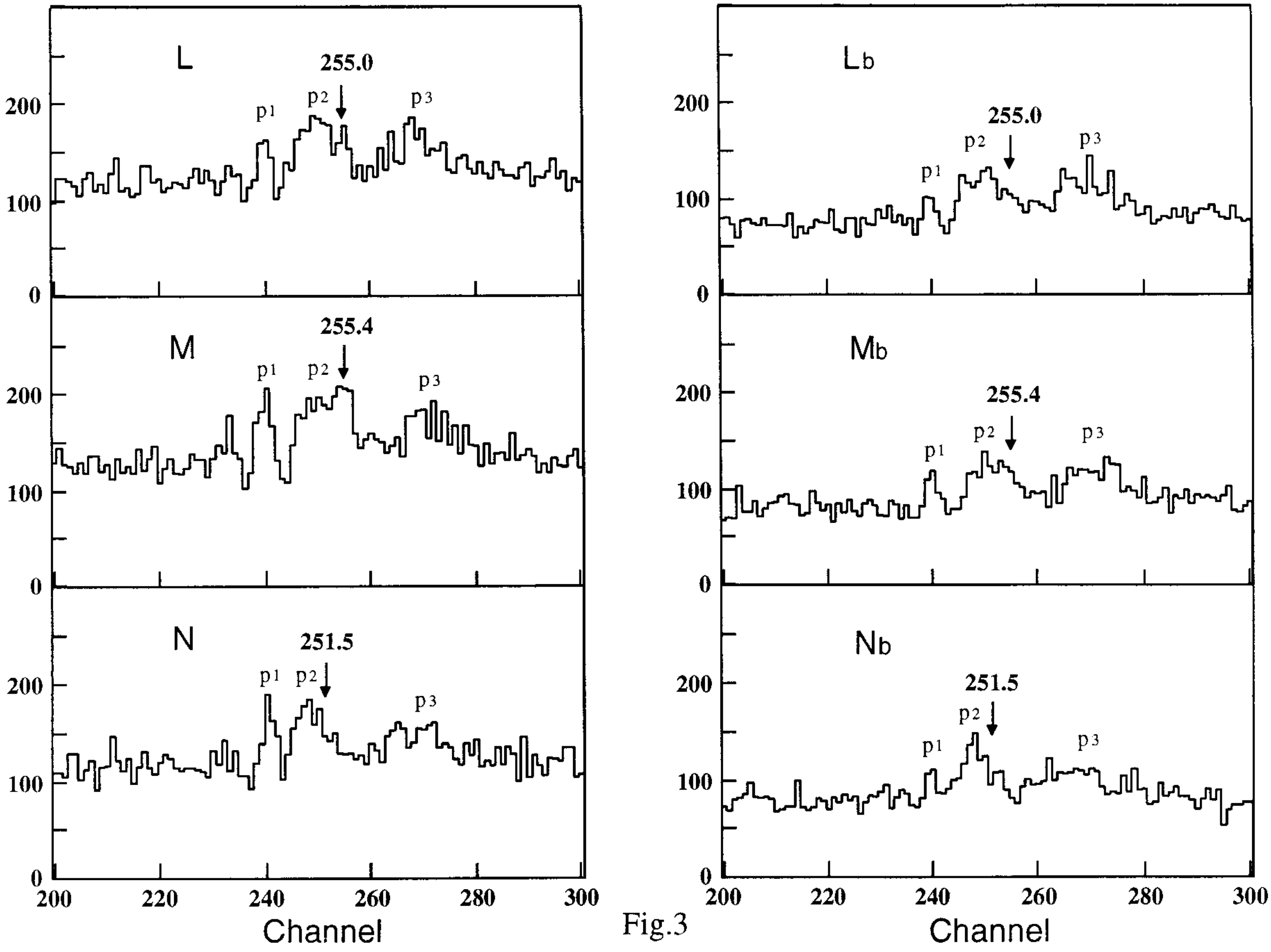
L
255.0
p1
p2
p3
M
255.4
p1
p2
p3
N
251.5
p1
p2
p3
Lb
255.0
p1
p2
p3
Mb
255.4
p1
p2
p3
Nb
251.5
p1
p2
p3
0
100
200
200
220
240
260
280
300
Channel
Channel

Fig.3

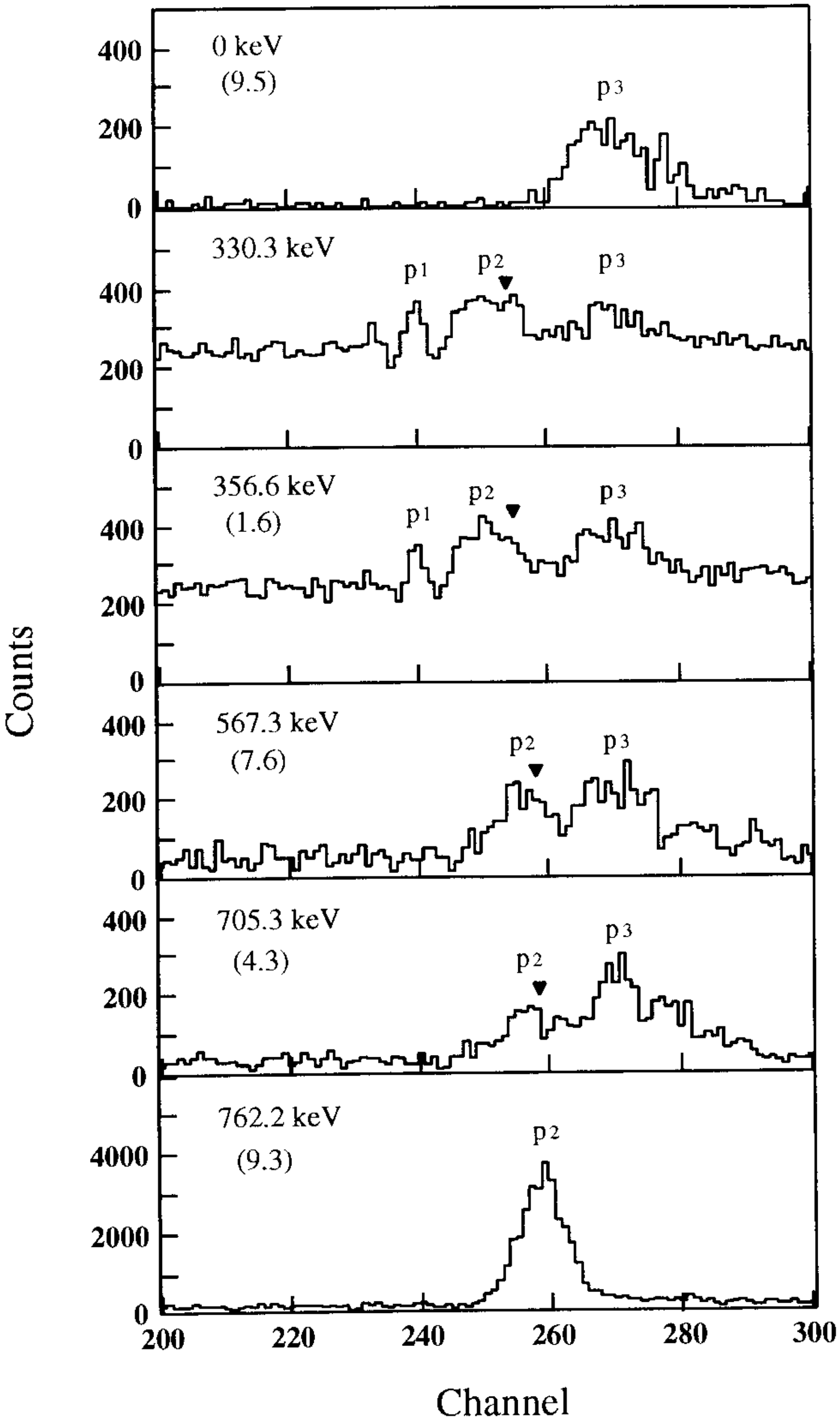
0 keV
(9.5)
p3
330.3 keV
p1
p2
p3
356.6 keV
(1.6)
p1
p2
p3
567.3 keV
(7.6)
p2
p3
705.3 keV
(4.3)
p2
p3
762.2 keV
(9.3)
p2
Counts
0
200
400
2000
4000
200
220
240
260
280
300
Channel

Fig.4

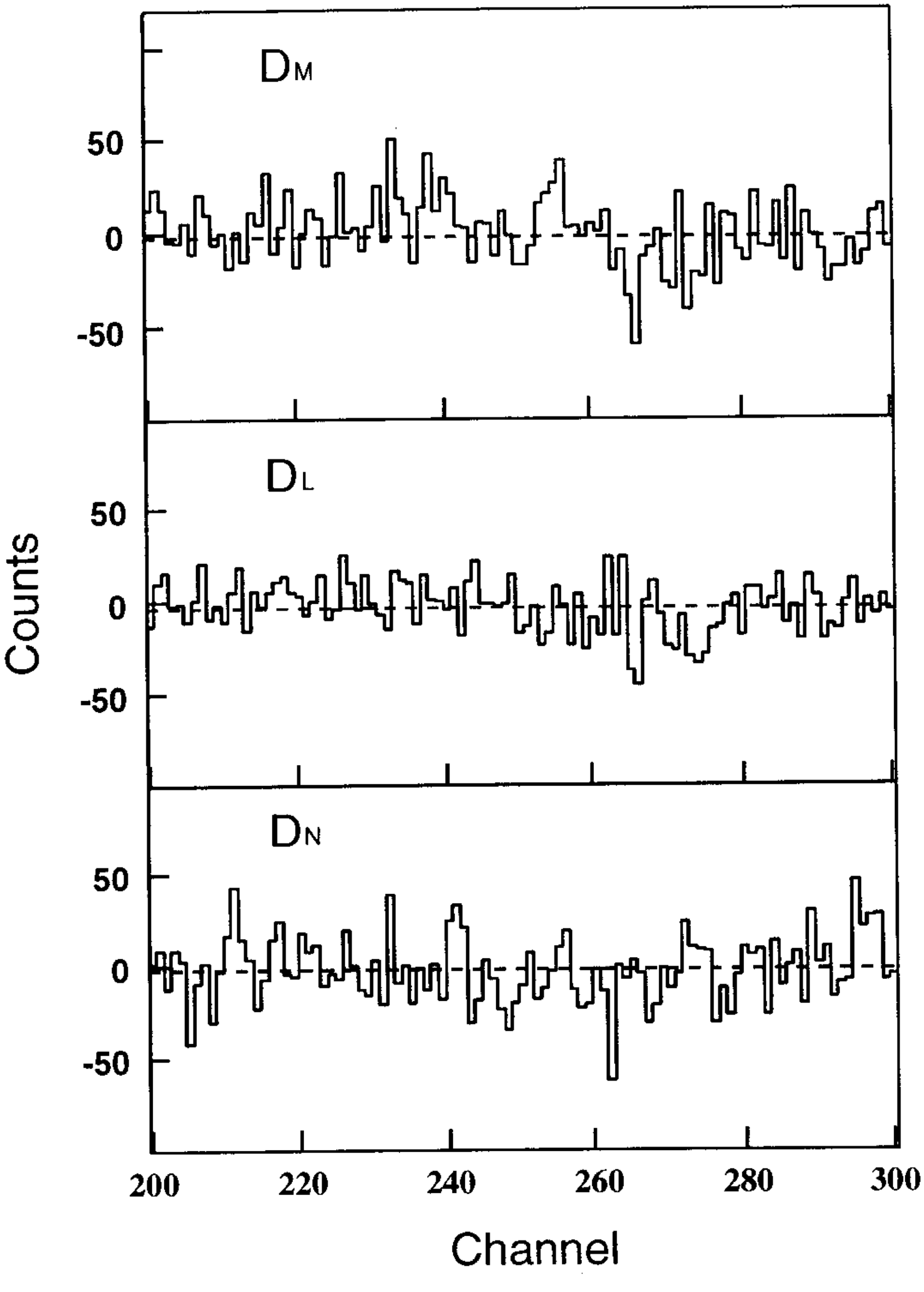
DM
DL
DN
50
0
-50
50
0
-50
50
0
-50
Counts
200
220
240
260
280
300
Channel

Fig.5

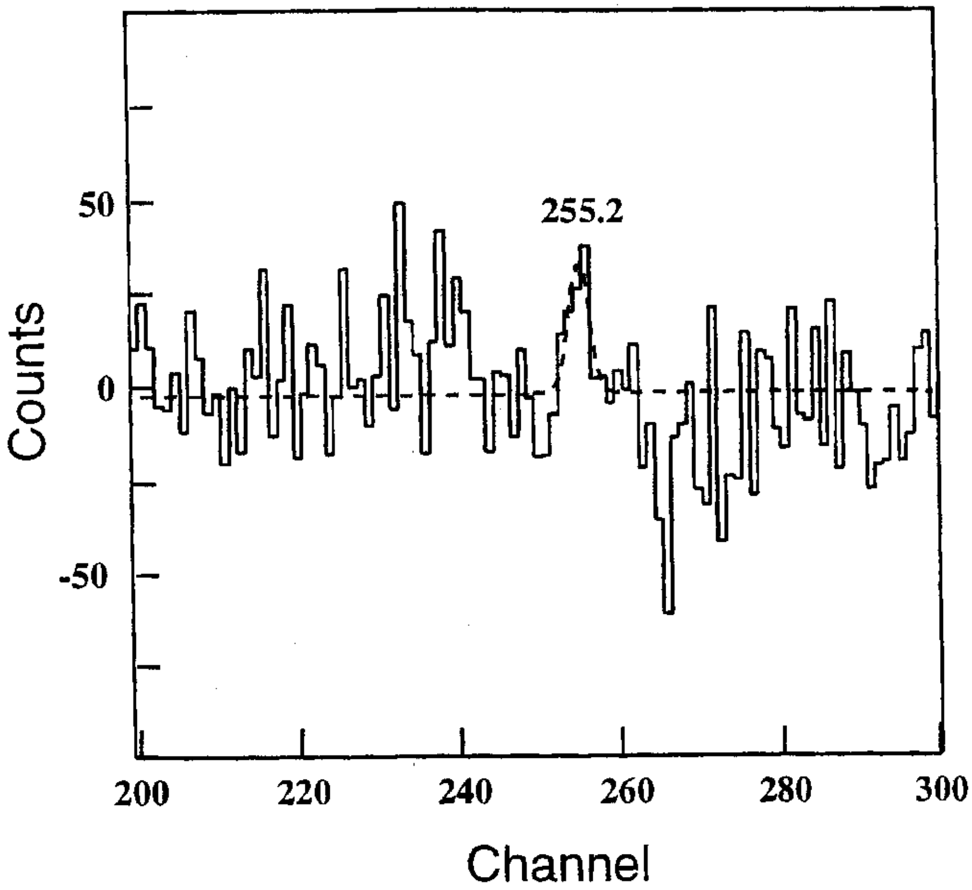

Fig. 6