REPLY TO A COMMENT OF ARTICLE
“EVIDENCE FOR NEUTRINOLESS DOUBLE BETA DECAY”

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After our publication of the observed first indication for neutrinoless double beta decay in $^{1}$, a number of papers have been published discussing its implications. In addition a ‘Comment’ has been put to the Internet February 7, 2002, $^{34}$ (version 1) critisizing our publication $^{1}$. (Meanwhile six of the nine claims in the ‘Comment’ have been withdrawn $^{34}$ (version 3).) It is the purpose of this note to show that none of their claims is justified (the same is true, from the same arguments, for the criticism raised recently in $^{35}$).

We shall show this by answering this ‘Comment’ point by point.

Point of Criticism 1. ‘There is no discussion of how a variation of the size of the chosen analysis window would effect the significance of the hypothetical peak’.

Reply: This is not true.

Figs. 4-6 of the Letter $^{1}$ show the difference obtained for the probability of the signal when choosing a large (2000-2080 keV) window and a small (2030-2048 and 2032-2046 keV) window.

In high-energy physics the usual procedure in searches for resonances is to analyse an interval of about $\pm 5\sigma$ around the lines. Our small window is in accordance with this.

Moreover, computer-generated spectra using Poisson random number generators for the background and Gaussian random number generators for a line show that a $\pm (4-5)\sigma$ analysis window around a line allows for a reliable analysis (see $^{8,9}$). Details will be published in a forthcoming paper.

Point of Criticism 2. ‘There is no relative peak strength analysis of all the $^{214}$Bi peaks. Quantitative yield evaluations should be made on the low $^{214}$Bi
peaks in the region of interest.’

They add in their section “Relative Strength of the Bi peaks” and in their conclusion: “a simple analysis of the $^{214}$Bi peaks demonstrates that the peak finding procedure used by KDHK produced spurious peaks near the $\beta \beta (0\nu)$ endpoint.”

Reply:

The estimates of the $^{214}$Bi intensities, the authors of [4] present in their section 3, are not correct for two reasons. The first reason is due to the normalization the authors of [4] derived from Fig.1 in [6], which unfortunately contains a normalisation error of about a factor of 9 (see point 5). The other reason is that they did not include summing effects. To understand relative intensities knowledge about the location of the impurities inside the experimental setup is required. This can be taken into account only by simulating the experimental setup which has not been done in [4]. The recent preprint of Feruglio et al. [33] makes the same incomplete approach. Calculation of the expected peak strengths starting from the Table of Isotopes [7], but including the simulation gives values which are much closer to the measured intensities, and in fact are consistent with them within about 2 sigma experimental errors. The results are given in the Table 1.

From the absolute strengths we find confidence levels of 3.7 and 2.6 $\sigma$ for the lines at 2010.71 and 2052.94 keV, respectively. This shows that there are lines, which should not be treated as background.

That the lines are not spurious, can also be seen by analyzing the spectrum measured with natural Germanium by D. Caldwell et al. more than ten years ago [32] who had the most sensitive double beta experiment at that time. These authors have a three times larger statistics for the background than the present experiment and see essentially the same structures in the spectra, as our analysis shows. (As a non-enriched Ge experiment they of course do not see a $0\nu\beta\beta$ signal.)
Table 1. $^{214}\text{Bi}$ is product of the $^{238}\text{U}$ natural decay chain through $\beta^-$ decay of $^{214}\text{Pb}$ and $\alpha$ decay of $^{218}\text{At}$. It decays to $^{214}\text{Po}$ by $\beta^-$ decay. Shown in this Table are the measured intensities of $^{214}\text{Bi}$ lines in the spectrum shown in Fig.1 of Ref. 1 in the energy window 2000 - 2060 keV, our calculation of the intensities expected on the basis of the branching ratios given in Table of Isotopes 7, with and without simulation of the experimental setup, and the intensities expected by Aalseth et al. 34, who do not simulate the setup and thus ignore summing of the $\gamma$ energies.

*) We have considered for comparison the 3 strongest $^{214}\text{Bi}$ lines, leaving out the line at 1120.287 keV (in the measured spectrum this line is partially overlapped on the 1115.55 keV line of $^{65}\text{Zn}$). The number of counts in each line have been calculated by a maximum-likelihood fit of the line with a gaussian curve plus a constant background.

+) The simulation is performed assuming that the impurity is located in the copper part of the detector chamber (best agreement with the intensities of the strongest lines in the spectrum). The error of a possible misplacement is not included in the calculation. The number of simulated events is $10^8$ for each of our five detectors.

**) This result is obtained normalizing the simulated spectrum to the experimental one using the 3 strong lines listed in column one. Comparison to the neighboring column on the right shows that the expected rates for the weak lines can change strongly if we take into account the simulation. The reason is that the line at 2010.7 keV can be produced by summing of the 1401.50 keV (1.55%) and 609.31 keV (44.8%) lines, the one at 2016.7 keV by summing of the 1407.98 (2.8%) and 609.31 (44.8%) lines; the other lines at 2021.8 keV and 2052.94 keV do suffer only very weakly from the summing effect because of the different decay schemes.

+++) This result is obtained using the number of counts for the three strong lines observed in the experimental spectrum and the branching ratios from without including summing effects. For each of the strong lines the expected number of counts for the weak lines is calculated and then an average of the 3 expectations is taken.

***) Without simulation of the experimental setup. The numbers given here are close to those in the neighboring left column, when taking into account that Aalseth et al. refer to a spectrum which contains a normalization error of a factor of 9 (see also point 5).
Thus the statement in the 'Comment' about the spuriosity of the peaks has no basis.

Point of Criticism 3. 'There is no null hypothesis analysis demonstrating that the data require a peak.'

Reply: This is not true.

Our fit-procedure allows for the case: only background, line intensity zero. In this sense the null hypothesis is included.

Point of Criticism 4. 'There is no statement of the net counting rate of the peaks other than the 2039 keV peak.'

Reply: The intensities will be published in an extended paper, but see Table 1.

Point of Criticism 5. 'There is no presentation of the entire spectrum. As a result it is difficult to compare relative peak strength.'

Reply: This is true for this Letter. The full spectrum will be published in a detailed paper. However, practically the same spectrum has been published in a recent publication 6. In Fig.2 of 6 the spectrum is given measured with detectors 1-5 for 47.4 kg y. Unfortunately Fig. 1 in 6 gives the spectrum measured with one detector only - not of all detectors as stated there - and erroneously normalized to 47.4 kg/y. The authors of 6 apologize for this confusing error.

Point of Criticism 6. 'There are three unidentified peaks in the region of analysis that have greater significance than the 2039 keV peak. There is no discussion of the origin of these peaks.'

Reply: It is true that there are lines in the range beyond 2060 keV, which at present cannot be identified. This is, however, not relevant for the conclusions concerning the signal at 2039 keV.

Point of Criticism 7. 'There is no discussion of the relative peak strengths before and after the single-site event cut. This is needed to evaluate... the model of the peaks’ origins.'
Reply: The essential point can be concluded from the numbers given in the Letter [1], namely, that more than 90% of the signal remains after the single site cut. It has been stated in [1], that the analysis of the signal at 2039 keV before correction for the efficiency yields 4.6 events (best value). It has been also stated that, corrected for the efficiency to identify an SSE signal, the value is 8.3 events. When normalized to the same running time as in the full spectrum we obtain more than 90% of the peak contents in the full spectrum. Correspondingly the half-life deduced from the single-site signal at $Q_{\beta\beta}$ is (within errors) the same as concluded from the full (single + multiple site signal) spectra (see Table 2 in [1]). We add here, that in contrast the weak $^{214}$Bi lines are considerably reduced (best values to about 25% or less. The same reduction factors are found for the stronger $^{214}$Bi lines e.g. at 1238, 1764, 2204 keV and, e.g., the 2614 keV Th line.

Note, moreover, that if the signal - consisting of single site events - would be due to a gamma line, it could only be the double escape peak of the $\gamma$-ray, and one would thus expect a strong full energy peak at 2039+1022 keV. Such a full energy peak is not observed in the spectrum.

Point of Criticism 8. 'No simulation has been performed to demonstrate that the analysis correctly finds true peaks or that it would find no peaks if none existed. Monte Carlo simulations of spectra with varying numbers of peaks confirming the significance of found peaks are needed.'

Reply: This it not true.

Of course, such simulations have been performed [8]. They are important to prove the correctness of our computer programs - but not in the sense that one would have to prove the Bayesian or Maximum Likelihood methods, which are well established.

As mentioned in the reply to Question 1, we have made numerical simulations which e.g. show, on the basis of 1000 simulated spectra containing no line, that the probability to find a line originating from statistical fluctuations, at a given energy above a confidence level of 95%, is about 4.2 percent. The simulations thus show, that our analysis programs calculate the probabilities for the existence of a line in a correct way.
In particular they confirm that the signal at $Q_{\beta\beta}$ can be faked by statistical fluctuations only with the small probability $(1 - K_E) \sim 3\%$.

An important point of the analysis is, that we can use the exact energy position of the line ($Q_{\beta\beta}$ is known with very high accuracy to be $2039.006(50)$ keV) and the width of the line (determined from known strong $\gamma$-lines in the spectrum), as well as its shape (Gaussian), as an input into the search procedure. This is the reason, that the method can do more the naked eye.

Point of Criticism 9. 'There is no discussion of how sensitive the conclusions are to different mathematical models. There is a previous Heidelberg-Moscow publication that gives a lower limit of $1.9 \times 10^{25}$ y (90\% confidence level). This is in conflict with the “best value” of the new KDHK paper $1.5 \times 10^{25}$ y. This indicates a dependence of the results on the analysis model and the background evaluation'.

Reply: This is not true. There is no discrepancy between the results obtained in 1 and 6. In 6 we exclude on a 90\% c.l., with the method used there, the number of counts

$N < 19.8$ (full spectrum)
$N < 9.3$ (SSE spectrum)

With the data in Mod. Phys. Lett. A, with the Bayesian analysis, we get at 90\% c.l., when using the same energy window of analysis (2000 - 2080 keV) and assuming all structures in this range to be background

$N < 15.0$ (full spectrum)
$N < 8.3$ (SSE spectrum)

According to the Particle Data Group (Eur. Phys. J. C15 (2000) 1) some slight dependence of the result on the method of analysis would be not surprising.

Summarizing, the criticism made in the 'Comment' is, in view of the Replies given here, not justified in any of the points raised (the same is true, from the same arguments, for the criticism raised recently in 3).

We think that it remains useful and inspiring to have informed the neutrino community about our evidence for a $2.2\sigma - 3.1\sigma$ result on the $0\nu\beta\beta$ decay.
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