Critical view to "IGEX ^{76}Ge neutrinoless double-beta decay experiment: Prospects for next generation experiments"

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Recently, a paper entitled "The IGEX ^{76}Ge neutrinoless double-beta decay experiment: Prospects for next generation experiments" has been published [Phys. Rev. D **65**, 092007 (2002)]. In view of the recently reported evidence for neutrinoless double-beta decay [Mod. Phys. Lett. A **16**, 2409 (2001).; Found. Phys. **31**, 1181 (2002); Phys. Lett. B **586**, 198 (2004).], it is particularly unfortunate that the IGEX paper is rather incomplete in its presentation. We would like to point out in this Comment that and why it would be highly desirable to make more details about the experimental conditions and the analysis of IGEX available. We list some of the main points, which require further explanation. We also point to an arithmetic mistake in the analysis of the IGEX data, the consequence of which are too high half-life limits given in that paper.

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Recently, a paper entitled "The IGEX ^{76}Ge neutrinoless double-beta decay experiment: Prospects for next generation experiments" was published [1]. In view of the recently reported evidence for neutrinoless double-beta decay [2–7], it is unfortunate that the IGEX paper is rather incomplete in its presentation. It would be highly desirable if more details about the experimental conditions and the analysis of IGEX would be made available. In this Comment, we list some of the main points, which require further explanation. We also point to an arithmetic mistake in the analysis of the IGEX data, the consequence of which is too high half-life limits given in that paper.

Before we go into detail, some general points of IGEX should be clarified. The IGEX double-beta experiment stopped operation already in 1999 [8]. Consequently, the authors in [1] show the analysis, which they showed already at the NANP 99 Conference in Dubna and published in the proceedings of that conference [9].

Some general, and fundamental, information about the IGEX experiment is missing. The paper does not give sufficient detail on the history, quality, stability, and run times of the detectors. Also, for example, the small "duty cycle" of the experiment is not explained. The background reached in the experiment is even not mentioned. The statistical methods of analysis are not described. No analysis of the background lines has been published, and no Monte Carlo simulation of the background is presented. No spectrum is shown over the full energy range.

IGEX working with 9 kg of enriched 76 germanium, collected in 8–9 yr of operation altogether *only* 117 mol yr of data. This corresponds to 8.7 kg yr—which means that the IGEX experiment took data only in a short part of its time of operation (or only a small part of the data was selected for analysis).

We shall comment on the following topics.

I. MEASURED SPECTRUM

The authors do not show in [1] the measured spectrum over the full energy range, so they give no feeling for experimental parameters such as energy resolution, stability of the electronics, and understanding of their background. Only in an earlier publication [10] do they show a full spectrum, but compressed to 10 keV per channel. This is by far not adequate to measurements of spectra with germanium semiconductor detectors. Competitive experiments present their data in 0.36 keV or at least 1 keV per channel. They further do not show any identification of background lines (except two lines).

II. PULSE-SHAPED ANALYSIS

The method of pulse-shape analysis (PSA) used in that paper seems not yet to be a technically mature procedure. It makes, among others, use of a visual determination of the shape of the pulses [1,9]. This casts doubt on the reliability of the background determination. It is questionable how in such a way quantitative results can be obtained. It seems unavoidable that in such a way the authors naturally run into the danger of producing too sharp limits for the half-life. It is called a "rudimentary PSD technology" by the authors themselves [10]. The data analyzed with PSA contain about 52 mol yr of data, corresponding to 3.9 kg yr.

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III. STATISTICAL ANALYSIS AND BACKGROUND

The experiment collected 117 mol yr (8.7 kg yr) of data, of them 3.9 kg yr with "visual" PSA. The background in the IGEX experiment is not mentioned in [1], and also not in the NANP Proceedings [9]. It is said in [10] to be 0.2 counts/kg yr keV for part of the data (i.e., usually higher). The authors do not say in the paper [1] (and also not in the NANP Proceedings [9]) how they analyze their data in the range of the potential neutrinoless double-beta decay signal. This is a crucial point. They talk only about standard statistical techniques. Since there are many standard techniques, this makes it difficult to judge the significance of their result.

Furthermore, the usual procedure recommended by the Particle Data Group [11,12] in the case that the count rate is smaller than the expected background rate (which is the case in their spectrum; see their Fig. 2), is to give also the more conservative value obtained when setting the count rate equal to the expected background rate. This would correspond to the "sensitivity" of the experiment according to Feldman-Cousins [13].

This has not been done by the authors of [1].

In the present paper [1], it is announced without giving any details that "standard statistical techniques" lead—for the PSA (pulse-shape analysis) data—to a limit of 1.57×10^{25} yr. This value is obtained by mistake. What the authors do is that, in their Eq. (5) which in general reads (see [10])

$$T^{0\nu}_{1/2} > (N \cdot t \cdot \ln 2)/C,$$

they insert by mistake (the same mistake is found in their paper [9]) for $N \cdot t$ the number of mol years of the *full experiment* (117 mol yr $\cdot \ln 2 \equiv 4.87 \times 10^{25}$ yr), but in the denominator they choose the value for the 90% confidence limit of the number of events attributable to $0\nu\beta\beta$ decay, C, equal to the one which is valid for the *pulse-shape analyzed* spectrum, namely $C = 3.1$. Instead, the latter value should be around $C = 4.5$ for the full spectrum.

The half-life deduced from the full data then would be $T^{0\nu}_{1/2} < 1.1 \times 10^{25}$ yr, as stated correctly in their earlier paper [14] (where they give $T^{0\nu}_{1/2} < 1.13 \times 10^{25}$ yr) instead of the given $T^{0\nu}_{1/2} < 1.57 \times 10^{25}$ yr. The Feldman-Cousins (FC) [13] sensitivity of the experiment is

$$T^{0\nu}_{1/2(\mathrm{full})} < 0.52 \times 10^{25} \text{ yr.} \tag{1}$$

For the PSA spectrum, the value to be inserted into the numerator should be 52.51 mol yr ln2 $= 2.2 \times 10^{25}$ yr, which yields the following with their $C = 3.1$ for the halftime limit:

$$T^{0\nu}_{1/2(\mathrm{PSA})} < 0.71 \times 10^{25} \text{ yr.}$$

Here it should be noted that $C = 3.1$ is depending on the width of the energy range analyzed. If this energy range is increased by only 20%, C will become 3.8 and

$$T^{0\nu}_{1/2(\mathrm{PSA})} < 0.58 \times 10^{25} \text{ yr.}$$

The FC sensitivity in this case is

$$T^{0\nu}_{1/2(\mathrm{PSA})} < 0.28 \times 10^{25} \text{ yr.} \tag{2}$$

These corrected estimates of the half-life limits from the IGEX data correspond more naturally to those deduced from an experiment having almost 1 order of magnitude higher statistics [15], which yielded a limit of 1.3×10^{25} yr, from the full data of a statistical significance of 53.9 kg yr.

IV. THE EFFECTIVE ν MASS

Starting from their incorrectly determined half-life limit, the authors claim a range of effective neutrino mass of (0.33–1.35) eV.

These numbers given by [1] and already earlier in [9] unfortunately have been uncritically cited in several theoretical papers (see, e.g., [16]).

The effective neutrino mass limit $\langle m \rangle$ deduced from the half-life limit should read for different matrix elements correctly, as given in Table I. It is seen that the numbers deducible from IGEX are almost a factor of 2 larger than reported by the authors of [1].

For comparison, we give in Table I the values corresponding to the half-life limit of 1.3×10^{25} yr (90% C.L.) by the HEIDELBERG-MOSCOW experiment with the full data taken in 53.9 kg yr [15]. They are consistent with the present claim [2–4,6] of an effective mass with best value of 0.39 eV [3].

V. NUCLEAR STRUCTURE

The discussion of nuclear structure and matrix elements is incomplete and seems superficial. It ignores recent work (after 1996). We just refer to [23–25]. It carries along calculations which are known to have deficiencies, e.g., the quasi-random-phase approximation (QRPA) calculations of Ref. [18,19] which they mix in their Ref. [25] with a paper not yielding any information about $0\nu\beta\beta$ matrix elements at all. These calculations suffer from not using a realistic nucleon-nucleon potential. It also carries along the weak-coupling limit shell model (Ref. [17]) which contains a by far too low configuration space. They carry along further the so-called large-scale shell model [22], which as a result of its limited configuration space does not fulfill the Ikeda sum rule (see, e.g., the review [26]) and, consequently, systematically underestimates the matrix element (leading to a corresponding overestimate of the effective neutrino mass). It might be mentioned that the calculation of [21] gave the *prediction* most close to the experimental

TABLE I. The effective neutrino mass limits deduced from the half-life limits with different matrix elements. Also shown are the neutrino masses deduced from the best value of $T^{0\nu}_{1/2} = 1.5 \times 10^{25}$ yr determined in [2–4].

Model	$\langle m \rangle$ eV positive evidence [2–4] (best value) $T^{0\nu}_{1/2} = 1.5 \times 10^{25}$ yr)	$\langle m \rangle$ eV from latest results (2001) [15] HEIDELBERG-MOSCOW 90% C.L. (full data) 1.3×10^{25} yr	$\langle m \rangle$ eV from our (conservative) analysis of Aalseth *et al.* data (90% C.L.) 0.5×10^{25} yr	$\langle m \rangle$ eV from Aalseth *et al.* [1] 90% C.L. claimed
Weak-coupling shell model [17]	0.34	<0.37	<0.59	<0.33
QRPA [18]	1.37	<1.47	<2.40	<1.35
QRPA [19]	0.97	<1.04	<1.67	<0.94
QRPA [20]	0.39	<0.42	<0.69	<0.39
QRPA [21]	0.39	<0.42	<0.69	<0.39
Large-scale shell model [22]	1.07	<1.15	<1.86	<1.05
RQRPA [23]	0.53	<0.57	<0.92	<0.52
SQRPA [24,25]	0.44–0.52	<(0.47–0.56)	<(0.78–0.90)	<(0.44–0.51)

$2\nu\beta\beta$ decay half-life of ^{76}Ge of $(1.74^{+0.18}_{-0.16}) \times 10^{21}$ yr [27,28]. It underestimates the later measured 2ν matrix element by only 31%.

VI. CONCLUSION

Summarizing, it is unfortunate, particularly in view of the recently reported evidence for neutrinoless double-beta decay [1–6], that the IGEX paper—apart from the too high half-life limits presented, as a consequence of an arithmetic error—is rather incomplete in its presentation. It does not give sufficient information on the experimental conditions and the analysis to judge the significance of their given results. It would be highly desirable if some basic points discussed in this Comment would be clarified and made available to scientific discussion.

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