Branching ratios in the β decays of ^{12}N and ^{12}B

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Absolute branching ratios to unbound states in ^{12}C populated in the β decays of ^{12}N and ^{12}B are reported. Clean sources of ^{12}N and ^{12}B were obtained using the isotope separation on-line (ISOL) method. The relative branching ratios to the different populated states were extracted using single-alpha as well as complete kinematics triple-alpha spectra. These two largely independent methods give consistent results. Absolute normalization is achieved via the precisely known absolute branching ratio to the bound 4.44 MeV state in ^{12}C. The extracted branching ratios to the unbound states are a factor of three more precise than previous measurements. Branching ratios in the decay of ^{20}Na are also extracted and used to check the results.

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I. INTRODUCTION

The β decays of ^{12}N and ^{12}B provide a probe of the nuclear structure of ^{12}C complementary to nuclear reaction techniques. Using the isotope separation on-line (ISOL) method this approach was recently used to provide new insight into the low energy part of the ^{12}C spectrum just above the 3α threshold at 7.28 MeV [1,2] where several open questions remain. In these new experiments the β-delayed 3α final states were probed with complete kinematics which was not possible in the earlier measurements in the 1950s and 1960s [3–5] where only spectra of individual α particles were recorded.

Weak interaction observables such as Gamow-Teller (GT) strength (B_{GT} values) or log ft values provide sensitive tests of model calculations of the structure of the corresponding populated states. This is because the Gamow-Teller (or Fermi) operators are well known and their modifications in the nuclear medium are well understood. To extract these observables absolute branching ratios to the individual states are needed in order to deduce the partial half-life of each transition. Alternatively, one can determine absolute branching ratios if the branching ratios are given relative to a well-known transition. Neither of these options were possible in the recent experiments [1,2] since none of the ^{12}C states in the continuum had well determined branching ratios and the experiments did not provide internal absolute normalization. Hence, the weak interaction observables have, prior to this work, been derived by normalization to the early experiments [3–5] with resulting uncertainties of the order of 30%.

In the present work we provide precise branching ratios for the unbound ^{12}C states populated in the β decays of ^{12}N and ^{12}B. In order to obtain a link to the earlier measurements [3–5] we perform analyses using both spectra of single α particles and complete kinematics 3α sum spectra. The latter results have also been reported elsewhere [6]. We first give the experimental details, then present the two analyses using single-alpha and triple-alpha data, and finally discuss the combined results and summarize.

II. EXPERIMENTAL METHOD

The measurements were carried out at the IGISOL facility of the Jyväskylä Accelerator Laboratory (JYFL), Finland [7]. ^{12}N was produced with a ^{12}C$(p,n)^{12}$N reaction using a 25 μA, 28 MeV proton beam impinging on a 1400 μg/cm^2 carbon foil, while ^{12}B was produced with a ^{11}B$(d,p)^{12}$B reaction and a 10 μA, 10 MeV deuteron beam on a 500 μg/cm^2 natural boron target. The use of thin targets allows the produced ions to leave the target after which they are thermalized in helium gas, extracted, accelerated to 25 keV and mass separated before reaching the experimental setup. The estimated yields were approximately 3×10^2 ^{12}N/s and 4×10^3 ^{12}B/s.

The beam was stopped in a 33 μg/cm^2 thick carbon foil rotated 45° to the beam direction as shown in Fig. 1. After implantation the ^{12}N and ^{12}B nuclei will β decay to ^{12}C and if excited states are populated the nucleus subsequently decays via 3α breakup or γ emission.

The α particles were detected by three double sided silicon strip detectors (DSSSDs) as shown in Fig. 1. This setup was chosen to achieve a large solid angle coverage and due to its large detection efficiency for breakup via the ^{8}Be ground state. Each DSSSD is 60 μm thick and consists of a 50 mm × 50 mm silicon wafer with 16 strips on the front side and 16 on the back orthogonal to the front strips. The strips are 3 mm wide and separated by 0.1 mm. DSSSD2 was an older model with a

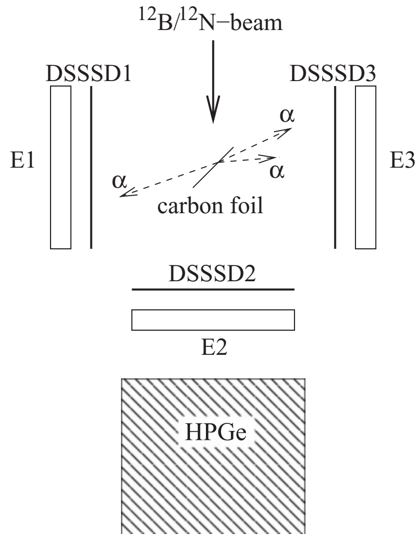

FIG. 1. The experimental setup as seen from above.

630 nm entrance dead layer whereas the two detectors facing each other had a dead layer of 100 nm [8]. All α particles emitted in the decays are fully stopped in the DSSSDs.

Positrons and electrons from the decays leave only a small amount of energy in the DSSSDs, but are detected in the thick silicon detectors behind each DSSSD. In addition a 70% high purity germanium (HPGe) detector was placed with its end cap into a tube going inside the vacuum chamber about 6.5 cm from the implantation point. This makes it possible to detect the 4.44 MeV γ rays from the 2^+ bound state in ^{12}C.

During most of the experiment data acquisition was triggered by the DSSSD front strips, and during some parts of the experiment also by the thick back detectors. The first trigger type is important for the 3α coincidence analysis (Sec. III A), whereas the last type, induced by a β particle, is necessary for the β-γ coincidence analysis leading to an absolute branching ratio normalization (Sec. III C).

The DSSSDs were calibrated using both online and offline sources. Offline, ^{148}Gd and ^{241}Am sources were used for the energy calibration. Online, a source of ^{20}Na produced in the reaction ^{24}Mg$(p,n\alpha)^{20}$Na was used both to test the energy calibration, and to check if the energy loss in the foil and detector dead layer was as expected [9]. In addition the ^{20}Na data provided a test of the absolute branching ratio calculations using β-γ coincidences as described in Sec. III D.

The HPGe detector was calibrated using offline sources of ^{133}Ba, ^{152}Eu, and ^{228}Th. Measurements were performed with the sources at the foil position to provide an absolute efficiency calibration of the detector. However, as the energy range covered by these sources is only up to 1.5 MeV, and the γ peak of interest is at 4.44 MeV, we include an efficiency calibration for the full energy range determined with a different geometry, and scale it according to the low energy absolute efficiency measurement. This latter calibration was performed with offline sources of ^{60}Co, ^{134}Cs, and ^{228}Th and an online source of ^{24}Al emitting γ rays with energies up to about 7 MeV. The absolute efficiency found using the geometry for the present experiment was 1.44(10) times the efficiency calibration for the larger energy range. The absolute efficiency of the HPGe detector at 4.44 MeV was 0.096(10)%.

III. BRANCHING RATIOS

Two independent methods have been used to find the relative branching ratios for the β decay of ^{12}N and ^{12}B to states in ^{12}C. The method described in Sec. III A involves the identification of 3α coincidences and provides accurate values for the relative branching ratios. In the second method (Sec. III B) the single-alpha energy spectra are used, and the method is both complementary to the triple-alpha analysis and resembles earlier work on branching ratio determination from the decays of ^{12}N and ^{12}B [3–5].

In Sec. III C the absolute branching ratios are extracted using the 4.44 MeV γ rays from the 2^+ bound state in ^{12}C.

A. Triple-alpha coincidence analysis

With the present setup, coincident detection of all three α particles is possible with an efficiency in the range of 1–4% depending on the total energy of the three α particles and of the break-up kinematics. The 3α breakups can be divided into two classes: Breakups through the narrow ^{8}Be ground state and breakups corresponding to higher energies in ^{8}Be. More detailed analysis of the second class of breakups is given in [10,11]. Detection efficiencies have been evaluated using Monte Carlo simulations that take into account the break-up kinematics as well as setup geometry, detection thresholds, and particle identification thresholds introduced in the data analysis. Calibration data from ^{20}Na β-delayed α emission were used to fix the overall geometry in the simulations, utilizing the α particles emitted isotropically. Triple coincidence data for breakup through the ^{8}Be ground state was used to evaluate the beam-spot position and size on the thin stopping foil. The efficiency calibration is described in detail in [2] and in [10,12] for this experiment.

The detected 3α sum energies correspond directly to ^{12}C excitation energies (Fig. 2). To allow the addition of the contributions from the two break-up channels with different kinematics, the spectra for both channels have been corrected by their respective efficiencies. This is done separately for the ^{12}N and ^{12}B β-delayed 3α breakup. The peak at 5.4 MeV 3α energy in the spectra primarily decays through a 1^+ state at 12.71 MeV in ^{12}C. This breakup is well reproduced as a sequential decay through the ^{8}Be 2^+ excited state as analyzed in detail in [11]. At lower energies a broad distribution dominates as assigned 10.3 MeV state in the literature [3,5,13]. We shall refer to this component as "the 10.3 MeV strength" in the following. Above the 12.71 MeV state another broad distribution is apparent in the ^{12}N data.

From the distributions in Fig. 2 the total number of ^{12}C nuclei populated in the 12.71 MeV state is found to be $1.41(^{+14}_{-6}) \times 10^5$ and $3.9(7) \times 10^3$ for the ^{12}N and ^{12}B decays, respectively. By integrating the spectra in Fig. 2, the total number of nuclei populating the 9–12 and 12–16.3 MeV regions are found. By comparing the number of produced nuclei in these energy regions to the number produced in

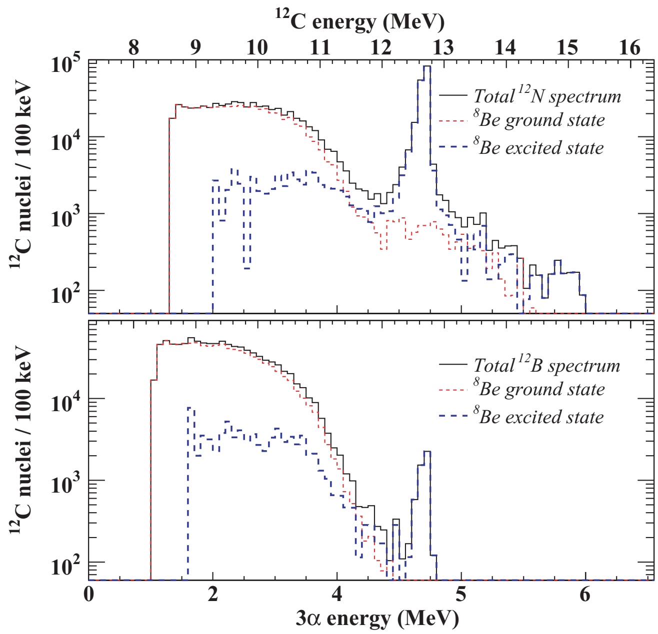

FIG. 2. (Color online) Detection efficiency corrected triple-alpha spectra for ^{12}N and ^{12}B.

the full energy range between 9 and 16.3 MeV, the relative branching ratios shown in Table I have been determined. The contribution from the 12.71 MeV state to the 12–16.3 MeV branching ratio has been subtracted.

B. Single-alpha spectra

Branching ratios to the 10.3 MeV strength and the 12.71 MeV state from ^{12}N and ^{12}B β decays have previously been deduced from the analysis of spectra of individual α particles (single-alpha spectra) in [3–5]. Here we perform a similar type of analysis to facilitate the comparison with these previous measurements.

The single-alpha spectrum results by adding the single-alpha spectra from each populated state. Due to the final state of three particles each state produces a continuous spectrum ranging from close to zero energy up to a maximum value of $\frac{2}{3}(E_{\text{level}} - S_{3\alpha})$, where E_{level} is the level energy in ^{12}C and $S_{3\alpha}$ the 3α separation energy in ^{12}C equal to 7.275 MeV. Each breakup contributes three energies to the spectrum with the individual energies distributed according to the break-up mechanism. Thus, an understanding of the single-alpha spectrum requires that these individual contributions can be determined. In earlier works [4,5] the decay of the 12.71 MeV state was not well understood, but this has since been the subject of detailed studies [11,14]. For the broad contributions below and above the 12.71 MeV state it is necessary to take into account both the break-up mechanism and the shape of the level itself. In earlier works [3–5] only the 10.3 MeV strength was included and assumed to be a single level (parametrized in the R-matrix formalism) decaying sequentially via the ground state of ^{8}Be. Apart from the lowest ^{12}C energies this leads to separate contributions to the single-alpha spectrum from the first emitted α particle (highest in energy) and from the two ^{8}Be α particles (lowest in energy).

The single-alpha spectra for ^{12}N and ^{12}B decay are shown in Fig. 3. Compared to the corresponding spectra from previous measurements, Fig. 3 in [3], Fig. 7 in [4], and Fig. 2 in [5], a significant improvement is seen. This is primarily because of the reduced energy loss of the β-delayed α particles when using the ISOL method compared to the previous measurements where the α particles were emitted from within the targets used to produce ^{12}N and/or ^{12}B.

To analyze the single-alpha spectra we take advantage of the improved knowledge on the breakup of the states available today. We take the description of the single-alpha spectrum from the 12.71 MeV state from [11]. This mainly influences the ^{12}N spectrum, but can also be seen at the highest energies for ^{12}B. For the broad distributions below and above the 12.71 MeV state we now know that higher energies in ^{8}Be contribute to the breakup, see Fig. 2 and [10], but they contribute less than 10% for the 10.3 MeV strength, hence, for the purpose of comparison we maintain here the simple assumption on the break-up mechanism. For the description of the shape of these regions we go beyond the one-level assumption used earlier and use instead the same three-level R-Matrix model as used in [2], including one 0^+ and one 2^+ state besides the 0^+ Hoyle state. The corresponding parameters (level positions, reduced widths, and feeding parameters) we deduce by performing a combined fit to the spectra for ^{12}N and ^{12}B. Only the data above 1.2 MeV 3α energy are included in the fit to avoid the low energy cutoff and the β background.

TABLE I. Relative branching ratios for the decays of ^{12}N and ^{12}B to the triple-alpha continuum. The branching ratios are given relative to the sum spectrum from 9 to 16.3 MeV. The branching ratio to the 12–16.3 MeV region does not include the 12.71 MeV state.

^{12}N			^{12}C	^{12}B		
Comb.	Triple-α	Single-α	Energy (MeV)	Single-α	Triple-α	Comb.
0.765(12)	0.75(2)	0.772(14)	9–12	0.995(2)	0.9940(10)	0.9940(10)
0.209(12)	0.21(2)	0.207(15)	12.7	0.0054(11)	0.0058(10)	0.0056(8)
0.042(10)	0.042(10)	$0.017(^{20}_{3})$[a]	12–16.3		0.0011(5)	0.0011(5)

[a]It is estimated that the single-alpha determination in this branch is less reliable than the triple-alpha determination. Therefore the combined result is only from the latter.

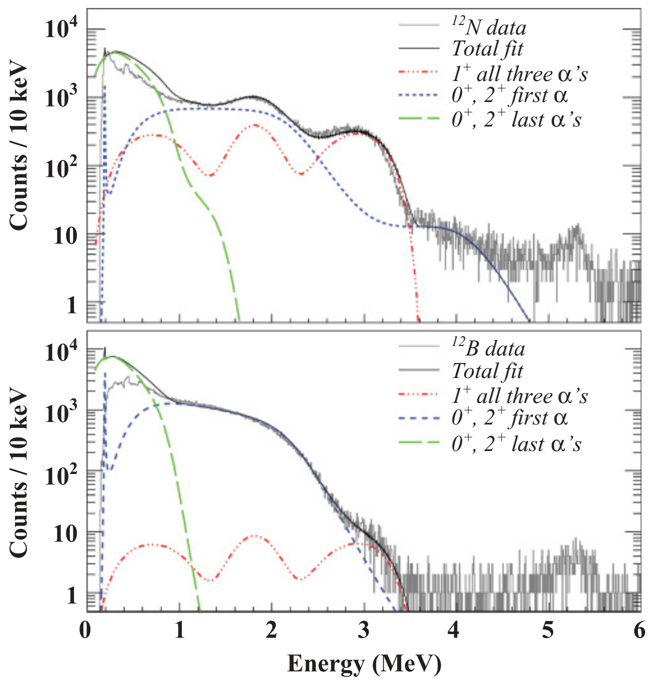

FIG. 3. (Color online) Single-alpha spectra for ^{12}N and ^{12}B decay. The dot-dashed curves show the contribution from the 1^+ state, the finely dashed line is the contribution from the first emitted α particle from the decay of broad states below and above the 12.71 MeV state. These breakups are here assumed to be via the ground state of ^{8}Be, such that the energy of the first α particle is equal to 2/3 of the energy available in the breakup. The coarsely-dashed line shows the two last alphas in the breakup emitted isotropically in the center-of-mass frame.

The different components of the spectra are shown in Fig. 3 with the 12.71 MeV state giving a distribution with three peaks and the broad states giving separate contributions for the first emitted and secondary emitted α particles.

For ^{12}N there is a deviation between the data and the fit around 3.5 MeV, which is caused by a deficiency in the simulated spectrum for decay via the 1^+ state. As discussed in [11] the Coulomb repulsion between the first emitted α particle and the two α particles from ^{8}Be, which is neglected in the simulation, causes a small distortion of the spectrum. The small peak at 5.3 MeV is due to background from a ^{223}Ra source in the beam-line used for beam tuning.

Relative branching ratios from the single-alpha spectra are found by integrating the curves. The contribution from the 1^+ state is 1/3 of the integral since three α particles from each decay contribute to the dot-dashed curve. Also, the small gamma width of the 1^+ state is taken into account. The relative branching ratios found using the single-alpha analysis are also shown in Table I. As mentioned above we assume here that the broad states below and above the 12.71 MeV state break up solely through the ground state in ^{8}Be. As mentioned earlier, from the triple-alpha analysis we know this assumption to be wrong in particular for the region above the 12.71 MeV state. To allow for this we add systematic errors to the relative branching ratios in Table I estimated from the now known ratios of breakup through higher energies in ^{8}Be vs. the ground state peak. It is gratifying that the relative branching ratios extracted by the two methods are consistent with each other. Since this is the case we also provide the combined results of the two methods in Table I.

C. Absolute branching ratio calculations

The analysis of the single- and triple-alpha spectra is limited to calculating relative branching ratios between α-decaying states, since the number of implanted ^{12}N and ^{12}B nuclei is not directly measured in this experiment. Absolute values can then only be found by adopting a previously determined branching ratio to one of the states, and these are poorly determined for the 10.3 MeV strength and the 12.71 MeV state. The branching ratio to the 7.654 MeV state is known somewhat better, but this state is not measured here due to the low energy cutoff. The 4.44 MeV state in ^{12}C has a very well-determined branching ratio, but since it is below the 3α threshold it only decays via γ emission. To use this state in the absolute normalization the 4.44 MeV γ rays from the decay of this state must be detected, and for this purpose the HPGe detector was added to the setup. The back detectors are included in the trigger during parts of the experiment, since the 4.44 MeV γ rays are coincident with β particles.

The measured number of 4.44 MeV γ rays is given by

$$N_{\gamma\beta} = \mathrm{BR}_\gamma N(^{12}\mathrm{N}/^{12}\mathrm{B})\epsilon_\gamma\epsilon_\beta, \tag{1}$$

where BR_γ is the branching ratio to the 4.44 MeV state, $N(^{12}\mathrm{N}/^{12}\mathrm{B})$ is the number of decaying nuclei, ϵ_γ is the Ge detector efficiency at 4.44 MeV, and ϵ_β is the efficiency of the back detector which we assume to be energy independent.

The number of α decays from an excited state in ^{12}C detected in the DSSSDs and triggered by a back detector is given by

$$N_{\alpha\beta} = \mathrm{BR}_\alpha \frac{\Gamma_\alpha}{\Gamma} N(^{12}\mathrm{N}/^{12}\mathrm{B})\epsilon_\alpha\epsilon_\beta, \tag{2}$$

where BR_α is the branching ratio to the α-emitting state, Γ_α/Γ is the relative α-decay width, and ϵ_α is the assumed constant detection efficiency of the DSSSD. Comparing this with Eq. (1) the branching ratio to the α-emitting state can be found as

$$\mathrm{BR}_\alpha = \mathrm{BR}_\gamma \frac{N_{\alpha\beta}}{N_{\gamma\beta}} \frac{\epsilon_\gamma}{\epsilon_\alpha} \frac{\Gamma}{\Gamma_\alpha}. \tag{3}$$

The gamma spectra for the β decay of ^{12}B and ^{12}N are shown in Fig. 4. The dominant peaks in the spectra are the 511 keV peaks from electron-positron annihilation, the 4.44 MeV peak and its single and double escape peaks, and the 1460 keV line of background radiation from ^{40}K. The Compton continuum is also visible in both spectra, and a significant background of bremsstrahlung is especially prominent in the ^{12}B spectrum.

$N_{\alpha\beta}$ is found from the β-gated single-alpha spectra for ^{12}N and ^{12}B. The absolute branching ratio to the sum spectrum in the range 9–16.3 MeV is used for normalization. The absolute branching ratios from this experiment are shown in Table II compared to the literature values from [13]. (Note that

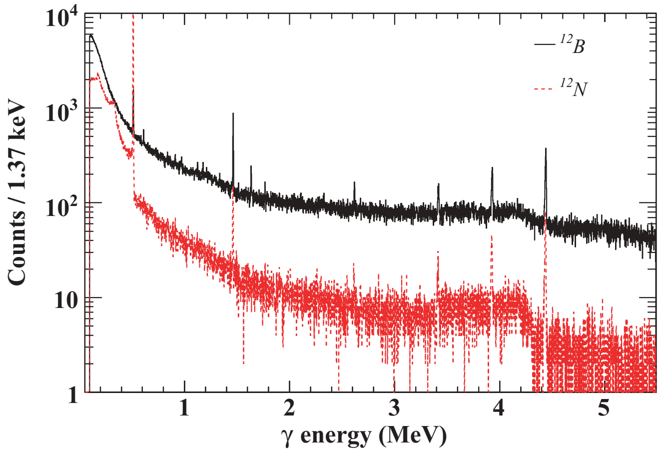

FIG. 4. (Color online) β-gated gamma spectra for ^{12}B and ^{12}N.

these results have been combined with new complementary data to obtain the more precise values given in [6]). For completeness we also add information for states not accessible in the present experiment. For ^{12}B decay two different values for the branching ratio to the 4.44 MeV state are given in the literature [13], and here we choose to use 1.283(40)%. To get the branching ratios using the other value, 1.182(19)%, multiply the results by the factor 1.182/1.283.

It should be noted that beam contaminants are not an issue in these branching ratio determinations. The triple-alpha method is only sensitive to coincidences of three α particles, and is therefore background free. The single-alpha data could be affected by an α background, but due to the production method utilizing light target nuclei (^{12}C and ^{11}B) and subsequent separation, an online production of α-emitting background nuclei can be excluded. Only α-emitting background nuclei produced offline would contribute to the single-alpha spectra (a small background peak is seen in the spectra in Fig. 3).

TABLE II. Absolute branching ratios.

^{12}N		^{12}C	^{12}B	
Literature	BR (%)	Energy (MeV)	BR (%)	Literature
Value[a] (%)	This work		This work	Value[a] (%)
1.90(3)	–	4.44	–	1.283(40)[b]
2.7(4)	–	7.65	–	1.5(3)[c]
0.44(15)	0.39(5)	9–12	0.060(7)	0.08(2)
0.31(12)[c]	0.105(14)	12.7	$3.4(6) \times 10^{-4}$	?
?	0.021(6)	12–16.3	$7(3) \times 10^{-5}$[d]	?
0.0044(15)[c]	–	15.1	–	–

[a]Literature values from [13].
[b]An alternative value of 1.182(19) is given in [13], but has not been used in this evaluation.
[c]The value can be updated to 1.2(3)% for the 7.654 MeV state, 0.28(8)% for the 12.71 MeV state and 0.0038(8)% for the 15.11 MeV state, see Sec. IV.
[d]This value can be determined more acurately with the data described in [6] to $10(2) \times 10^{-5}$.

TABLE III. Relative α intensities and branching ratios for states in ^{20}Ne.

($E\alpha$) (MeV)	(E^{20}Ne) (MeV)	Rel. α intensity		BR$_\alpha$ (%)	
		This work	Ref. [15]	This work	Ref. [15]
2.15	7.42	100.00	100.00	15.6(17)	16.0(2)
2.48	7.83	3.7(3)	3.7(4)	0.58(8)	0.583(10)
3.80	9.48	1.6(2)	1.51(3)	0.25(4)	0.241(5)
4.43	10.27	16.3(3)	17.31(9)	2.6(3)	2.88(4)
4.68	10.58	0.45(6)	0.553(15)	0.070(12)	0.088(3)
4.89	10.84	0.91(8)	1.09(3)	0.19(5)	0.174(5)

This does not affect the absolute normalization which was determined using α spectra coincident with a β decay.

D. β decay of ^{20}Na

The absolute branching ratio normalization is strongly dependent on the efficiency calibration of the germanium detector, and to validate this, absolute branching ratios have been calculated for the β^+ decay of ^{20}Na to ^{20}Ne measured during the same experiment.

States in ^{20}Ne above the 4.73 MeV threshold are unbound and decay via α emission to ^{16}O. Absolute branching ratios to these states are found by normalizing to the γ-emitting 1.63 MeV bound state. The measured α spectrum is shown in Fig. 5 (the peaks below 1 MeV are from ^{16}O recoils). The peaks in the spectrum are well separated, so $N_{\alpha\beta}$ is simply found by integration.

The calculated branching ratios are given in Table III where the literature values and relative α intensities are also shown. For the most intense peak at 2.15 MeV the agreement between this work and [15] is excellent, whereas there are some minor disagreements for the weaker peaks at higher energies. However, the values agree within 10%, and as a test of our determination of the germanium detector efficiency the consistency between this work and [15] is satisfactory.

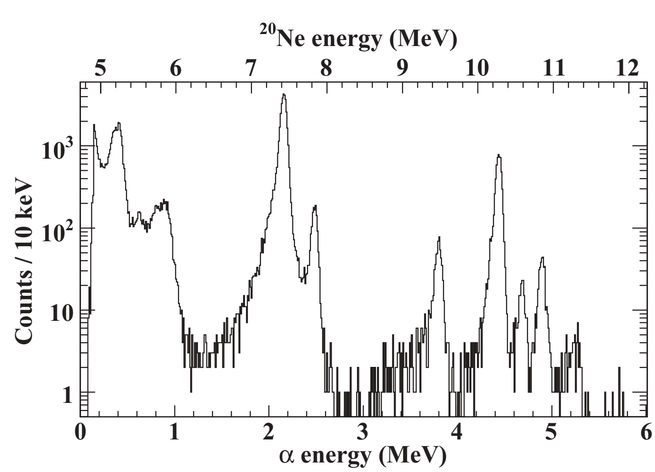

FIG. 5. β-gated α spectrum for ^{20}Na.

IV. DISCUSSION

We begin by discussing the branching ratios presented in Table II starting with the 7.654 MeV state. For ^{12}B β decay the literature branching ratio is a combination of two experimental results [16,17], where the latter determined the branching ratio relative to that of the 4.44 MeV state by analyzing a β-gated gamma spectrum. Here an updated value of 1.2(3)% can be deduced using the current values for the branching ratio to the 4.44 MeV state and for the gamma width of the 7.654 MeV state. For ^{12}N β decay the literature branching ratio to the 7.654 MeV state is a combination of two experimental results [18,19] both using a Kurie-plot analysis of the positron spectrum to deduce the branching ratio. In Table II we do not give a value for the branching ratio to the 7.654 MeV state since this state is not directly measured in this experiment. However, this value could be extracted by using the fit described in Sec. III B. This fit includes interference between the 7.654 MeV state and a higher lying 0^+ state, as also described in detail in [2]. The branching ratios extracted in this way are 5.2(8)% and 1.7(3)% for the ^{12}N and ^{12}B decay, respectively. As discussed elsewhere [6,20], there is reason to believe that the branching ratios to the 7.654 MeV state are significantly smaller, and therefore the value from the fit described in Sec. III B cannot be trusted.

For the 10.3 MeV strength the literature value is dominated by the results in [4], which reports the branching ratio to the 1–3 MeV region of the single-alpha spectrum in both decays. For ^{12}B the 10.3 MeV strength dominates in this region, and hence their number can be directly compared to our result. Our value is consistent with this number, but more precise. For the ^{12}N case the role of the 12.71 MeV state was not known in [4], and their extracted branching ratio of 0.44(15)% should therefore not be used as the branching ratio to the 10.3 MeV strength as done in [13]. Although the 12.71 MeV state has a small width it gives rise to a broad and complicated single-alpha spectrum which is added to the single-alpha spectrum from the 10.3 MeV strength, see Fig. 3. The authors of [4] discuss qualitatively how their results should be updated in their later publication [21] (after the role of the 12.71 MeV state had been clarified in [5]). A good coincidence detection of the 3α breakup is of course a powerful tool to unravel this as demonstrated here. The sum of our results for the 10.3 MeV strength and the 12.71 MeV branch is 0.50(6)%, which is consistent with [4].

Feeding to the 12.71 MeV state has been previously only observed in the decay of ^{12}N. A search for this branch in the ^{12}B decay is discussed in [21], but no upper limit is given. For the ^{12}N decay the number quoted in the evaluation [13] is solely from the same experiment [21]. Again, that number can be updated using the current values for the 4.44 MeV branching ratio and the 12.71 MeV gamma width. This gives an updated value of 0.28(8)% [the branching ratio to the 15.11 MeV state was measured in the same experiment, here an updated value of 0.0038(8)% applies]. Our result for the 12.71 MeV branching ratio for ^{12}N is marginally consistent with this updated value, but is a factor of ten more precise. Support for our lower value comes from the value of 0.20(5) for the ratio of the ^{12}N branching ratios to the 12.71 MeV state and the 10.3 MeV strength [5]. As mentioned above, our combined branching ratio to the 10.3 MeV strength and the 12.71 MeV state is consistent with the result of [4].

Our branching ratios given in Table II constitute a significant improvement in precision as compared to earlier measurements. Our single-alpha spectra are measured under much improved conditions by using the ISOL method. In addition, by having triple-alpha spectra we have two largely independent measurements of the relative branching ratios. The consistency between the single-alpha and triple-alpha results lends further support to our results. For future reference, it should be noted that our absolute branching ratios have been normalized to the branching ratios to the 4.44 MeV state in both decays.

As mentioned in the Introduction, the ultimate goal of this work is to extract weak interaction observables such as log ft values or B_{GT} values, which can be compared to theory. From the branching ratios in Table II this is only possible for the 12.71 MeV state since the other values are not assigned to individual states. For the 12.71 MeV state we find log $ft = 3.94(6)$ and log $ft = 3.79(9)$ for ^{12}N and ^{12}B, respectively. For ^{12}N the literature value is log $ft = 3.52(14)$. A more detailed discussion is given in [6].

V. CONCLUSION

We have determined branching ratios to the triple-alpha continuum populated in the β decays of ^{12}N and ^{12}B. A key ingredient in obtaining a higher accuracy was the use of the ISOL method, which allows the implantation of the ^{12}N and ^{12}B activities in thin foils leading to reduced and controllable energy loss corrections. We analyze both single-alpha and triple-alpha data and find that these two complementary methods give consistent results.

The advantage of the triple-alpha method is that the contributions from the different initial states can be separated based on their energy alone and hence information on the break-up distributions of the individual states is only required to determine the detection efficiency. The disadvantage is that the energy dependent detection efficiencies have to be determined and this enters into the overall systematic uncertainty on the extracted branching ratios. The single-alpha spectra do not need to be efficiency corrected, but the contributions of individually populated states can only be separated by having a model of the break-up spectra from each state. Without complete kinematics data the single-alpha analysis is the only one possible, as was the case with previous measurements [3–5].

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