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# Resolving the discrepancy in the half-life of $^{20}\text{F}$

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We report a new precision half-life measurement of  $^{20}\text{F}$ , performed using the  $\beta$ -counting station of the University of Notre Dame's Nuclear Science Laboratory. The measured half-life of  $11.0160(41)_{\text{stat}}(155)_{\text{sys}}$  s resulting from this work will help resolve the long-standing discrepancy between two earlier sets of high-precision half-life measurements.

## I. INTRODUCTION

Precision measurements of nuclear beta-decay transitions provide a low energy method to probe intricacies of the Standard Model [1], which are typically studied with high energy experiments. One example is the search for second-class currents of the weak interaction that are not included in the Standard Model, but could potentially exist [2]. The Standard Model includes left-handed vector and axial-vector currents for the weak interaction, but the nature of restricting other forms only allows for upper limits of exotic contributions to be determined [3]. Such second-class currents would take the form of scalar or tensor interactions.

One simple test to look for second-class currents is to measure  $ft$  values for relevant nuclear beta-decays [4]. As an example, if mirror beta-decays do not have identical  $ft$  values, this would indicate that the weak interaction does not respect G parity [5]. This has brought attention to specific systems in the past due to the lack of accuracy in experimental measurements required to calculate  $ft$  values. Questions arose from discrepancies in  $ft$  values of the A=12 isobars  $^{12}\text{N}$  and  $^{12}\text{B}$  [6]. This disagreement gave incentive to measure the  $ft$  value of other isobars, such as the A=20 system, and test the Conserved Vector Current (CVC) hypothesis [7]. This required a stronger constraint of experimental quantities needed to determine  $ft$  values, such as the half-life [8]. As such, several half-life measurements of  $^{20}\text{F}$  have been performed in the past, with increasing precision as experimental methods improved.

Prior to this work, the half-life of  $^{20}\text{F}$  had been determined from a number of conflicting measurements, with a Birge ratio, defined by the square root of the chi-squared per degree of freedom [9], of 7.85(15). A Birge ratio this far away from 1 clearly signifies that this is a series of inconsistent measurements. Previous measurements of the half-life are outlined in Table I. Measurements with a precision better than 0.1 s are also shown in Fig. 1. It should be noted that none of the four most precise results are included within the region of the Birge-ratio-inflated

Table I: Previous half-life measurements of  $^{20}\text{F}$ .

Year	Half-life (s)	Ref.
1959	12.5(2.0)	[14]
1959	11.4(1.0)	[15]
1960	11.2(1)	[16]
1962	11.56(5)	[17]
1963	11.36(7)	[18]
1967	10.31(7)	[19]
1967	10.81(11)	[20]
1970	11.03(6)	[7]
1975	10.996(20)	[13]
1976	11.18(1)	[5]
1987	11.03(6)	[12]
1992	11.163(8)	[11]
1995	11.11(4)	[21]
2018	11.0011(75)	[10]

uncertainty band, as given by the red dashed lines on Fig. 1. The most recent measurement [10] conflicts with previous measurements of comparable precision [5, 11], while agreeing with three lower precision measurements [7, 12, 13]. This provides a strong incentive to repeat the measurement with a different apparatus that has different inherent systematic uncertainties. An independent measurement will help resolve discrepancies between previous high precision results. Therefore, the half-life of  $^{20}\text{F}$  has been measured independently at the Nuclear Science Laboratory (NSL) of the University of Notre Dame.

## II. EXPERIMENTAL METHOD

A radioactive ion beam of  $^{20}\text{F}$  was produced from (d,p) transfer reactions in inverse kinematics using a  $^{19}\text{F}$  beam passing through a deuterium gas target. The stable fluorine was produced by a source of negative ions from cesium sputtering (SNICS) and accelerated by an FN Tandem Van de Graaff accelerator with a terminal voltage of 6.6 MV. An analyzing magnet downstream of the tandem

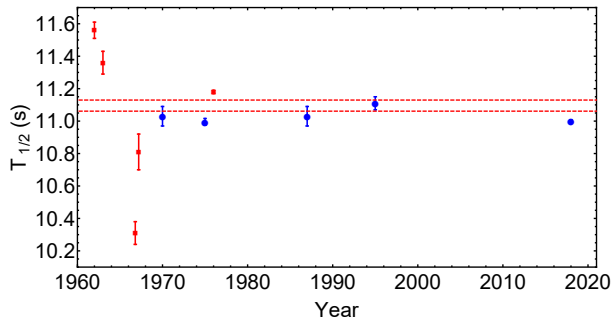


Figure 1: (Color online) All previous half-life measurements along with the Birge-ratio-inflated weighted average depicted by the dashed red lines. The color and shape of each data point indicate the fitting method used in the analysis; red squares indicate least-squares, while blue circles indicate maximum likelihood. See Sec. IV. for more details.

was adjusted to select  $^{19}\text{F}^{6+}$  at 46.0 MeV. After impinging on the gas target, the primary beam was stopped by a Faraday cup located at the entrance of the first superconducting magnet of the *TwinSol* radioactive-beam facility [22], which refocused the reaction products past the exit of the magnet. A second solenoid was used to further separate  $^{20}\text{F}^{6+}$  from the other reaction products. The low energy of the primary beam was selected such that the production of additional radioactive species from the reaction of  $^{19}\text{F}$  with the deuterium gas target was energetically forbidden. The  $^{20}\text{F}$  lifetime was then determined using the same technique as for the  $^{17}\text{F}$  [23],  $^{25}\text{Al}$  [24], and  $^{11}\text{C}$  [25] half-life measurements at the NSL; we therefore refer the reader to these publications for more explicit details on the experimental apparatus.

After the production and separation of the radioactive beam using *TwinSol*, ions were implanted on a foil at the NSL  $\beta$ -counting station. A thick tantalum foil was mounted on the end of a paddle that rotates between irradiating and counting positions to help reduce background. The beam was implanted on the target for a period of 33 s ( $\sim 3$  half-lives) and then rotated into the counting position where it remained for 220 s ( $\sim 20$  half-lives). The primary beam was deflected using a steerer upstream of the tandem during the counting phase. The beta particles emitted from the decay were detected with a 1 mm plastic scintillator connected to a photomultiplier tube (PMT) via a light guide. There were a total of 57 runs with various settings, each with 10 to 20 cycles, resulting in about 1000 total cycles.

### III. DATA ANALYSIS

The data analysis followed the well-established, widely used procedure outlined in [26], which was also used for previous half-life measurements using the  $\beta$ -counting station [23–25]. Data analysis was performed separately by

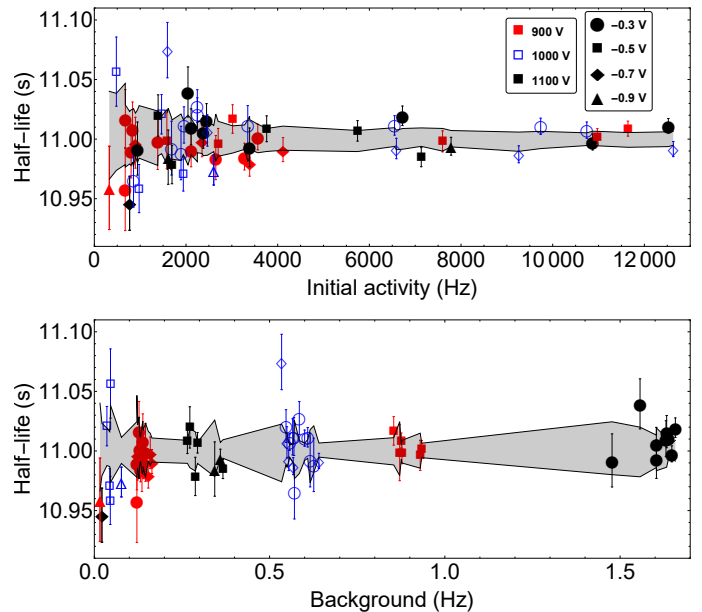


Figure 2: (Color online) The half-life, resulting from summing the cycles from each run individually, is shown as a function of the other fitting parameters; initial activity (top panel) and background (bottom panel). The color of each data point corresponds to the PMT bias used for that run, while the shape corresponds to the discriminator threshold voltage. The shaded region signifies the  $1\sigma$  confidence interval resulting from the fit of 100 artificial data sets mimicking the experimental results.

two different group members. The analysis is presented in detail in the following sections.

#### A. Data pre-selection

During the experiment, the discriminator threshold voltage, PMT voltage, and incoming beam rate were changed to probe for possible systematic biases. The data were first screened individually, on a cycle by cycle basis, for samples with abnormally low counts. Eight cycles, with an abnormally low number of counts, were identified as being incomplete due to premature termination of the cycle and removed from the analysis. Another test was to fit a decay curve to each cycle and observe the residuals from the fit. This method identified 7 cycles with an abnormally low number of counts in the first bin affecting the residuals. This occurred when counting started while the paddle was still rotating into place.

#### B. Individual run sum fit

Each run consisted of ten to twenty cycles with identical systematic settings. The cycles from each run were initially summed and fit individually, using the summed

fit procedure prescribed in Ref. [26], to probe potential systematic biases. Prior to fitting, the data were binned into 200 bins and a correction was applied to the number of counts in each bin due to the effect of dead-time losses of the data acquisition system [26]. The decay rate was then determined for each run by fitting the following equation:

$$r(t) = r_0 \exp[-\ln(2)t/t_{1/2}] + b \quad (1)$$

where  $r(t)$  is the observed decay rate,  $r_0$  is the initial observed rate,  $t_{1/2}$  is the half-life, and  $b$  is the background rate.

Following the nature of a counting experiment, a maximum-likelihood-type fitting routine was used to fit the data. This routine iteratively fit the equation using least-squares fitting, recalculating the weight of each data point with each iteration, until it converged to fit parameters that vary by less than 0.01% from previous iterations [26].

The half-lives resulting from the fit of each individual run are shown by the data points in Fig. 2. The results are displayed as a function of the two other fit parameters: initial activity (top panel) and background (bottom panel). To gauge the statistical nature of these data, an artificial data set was created with an identical initial rate and background as the result of the fit for each run and a half-life of 11.0 seconds. The artificial data was then fit with the identical routine used for the experimental data. One hundred of those data sets were generated and fit and the  $1\sigma$  confidence interval was calculated and then compared with the experimental results. This is depicted by the gray region in Fig. 2. The consistent nature of the experimental results with the  $1\sigma$  confidence band from the artificial data indicate that the data follow a statistical spread.

### C. Systematic subgroup sum fit

To further examine the effect of the various systematic settings used, the runs with identical settings for PMT bias and threshold voltage were added together and the fitting procedure was then repeated with each resulting summed data set. Once again, the procedure was replicated with 100 artificial data sets created according to the resulting fit parameters from the data. This was done to ensure there was no specific combination of settings which caused a significant change in the half-life. The results are shown in Fig 3. While a downward trend in half-life with decreasing PMT bias and discriminator threshold voltage seems to be present, it is consistent with the  $1\sigma$  confidence interval of the artificial data. However, the weighted average of the 12 subgroups yield a large Birge ratio of 1.8(1), which is above the statistical ideal value of one. See Sec. III. E. 4. for further discussion.

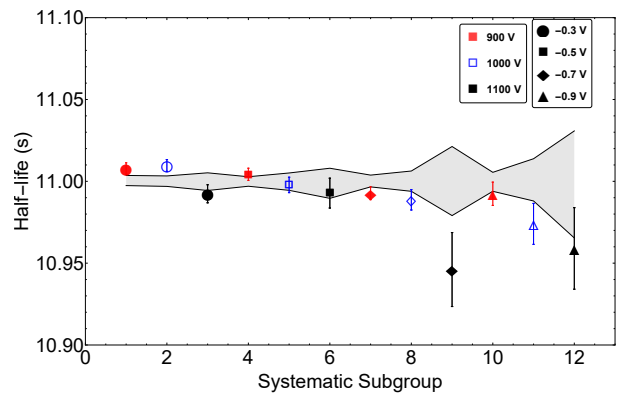


Figure 3: (Color online) Half-life results when data taken with identical systematic settings are combined. Data points along with their uncertainties indicate the result from the sum fit, while the underlaid gray region signifies  $1\sigma$  confidence intervals from artificially created data.

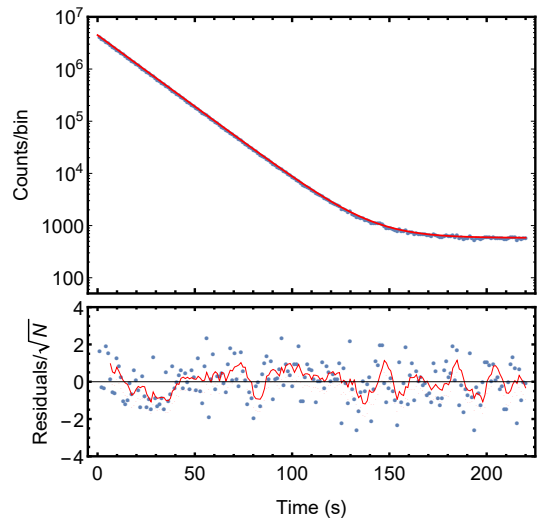


Figure 4: (Color online) The top panel shows a summed beta-decay curve of all cycles with the Eq. 1 fitted result shown as the red line. In the bottom panel are the residuals of the fit divided by the square root of the number of ions in a given bin  $N$ , shown as blue circles, along with a 5 point moving average shown as a red solid line.

### D. Sum fit

After checking the consistent nature of each subgroup of experimental settings, all cycles from each run were added together and subsequently fit with the same fitting routine. The resulting curve is given in Fig. 4.

The top panel of Fig. 4 shows the sum of the dead-time corrected data for 55 runs with the corresponding fit while the bottom panel gives the normalized residuals. The fit results in a  $^{20}\text{F}$  half-life of 11.0006(15) s, has a reduced  $\chi^2 = 0.99$ , statistical spread of the residuals about a mean of 0.037, and a standard deviation of 1.003. As

the residuals of Fig. 4 indicates, there exists an upward trend at the start of the decay curve that warrants further investigation. One possibility is the presence of unexpected radioactive contaminant. Hence, we performed a fit with an added unknown contaminant to the decay curve in the form

$$r(t) = r_0 \{ \exp[-\ln(2)t/t_1] + \alpha \exp[-\ln(2)t/t_2] \} + b, \quad (2)$$

where  $\alpha$  is the ratio of detected rate for the contaminant and  $^{20}\text{F}$ , and  $t_1$  and  $t_2$  are the half-lives of  $^{20}\text{F}$  and the contaminant respectively. A fitting on the sum of the same 55 runs yield a contaminant half-life of 7(3) s and an abundance ratio of 0.0056(76). Different possibilities for producing contaminants through transfer reactions in the production cell as well as fusion-evaporation reactions with possible contaminant gas in the cell, in the cell titanium windows and in the aluminum support of the implantation foil were investigated. The only possible contaminant found with a half-life near the fitted value is  $^{16}\text{N}$ , which has a half-life of 7.13(2) s [27].

While the primary beam energy and nuclear reaction used to produce  $^{20}\text{F}$  for this experiment were chosen such that the production of radioactive contamination is energetically forbidden at the center of the cell, a small amount of  $^{16}\text{N}$  might have been produced near the entrance window of the gas target. Stopping and Range of Ions in Matter (SRIM) [28] calculations have indicated that the energy of the primary beam once leaving the 4  $\mu\text{m}$  Ti foil will be 36.3(1) MeV with an energy straggling of 0.2 MeV FWHM, which is below the 39.1 MeV energy threshold to produce  $^{16}\text{N}$ . However, if we consider the 25% lower bound in the manufacturing tolerance of the foil from the manufacturer *GoodFellow*, the beam energy entering the gas could be as large as 38.8 MeV with an energy straggling of 0.2 MeV FWHM, which is at the threshold to produce  $^{16}\text{N}$ . The SRIM calculations also revealed that the primary beam undergoes a spreading of approximately 0.6 degrees FWHM as it passes through the entrance window. Once we add this to the results of a separate three-body reaction kinematics calculation that indicated that all the  $^{16}\text{N}$  produced would be emitted at an angle of less than 1.3 degrees, it is possible that a fraction of  $^{16}\text{N}$  has made it through the acceptance angle of *TwinSol* (between 1.7 and 4.5 degrees).

Since there are indications that there could have been a  $^{16}\text{N}$  contaminant present, we fitted the first 55 runs with a contaminant fixed at the half-life of  $^{16}\text{N}$ , 7.13(2) s, while letting the amount of contaminant vary. The resulting  $^{20}\text{F}$  half-life is 11.0144(44) s, the contamination ratio  $\alpha = 0.0056(17)$  and the reduced  $\chi^2 = 0.94$  has also improved. Fig. 5 shows the decay curve fitted with the  $^{16}\text{N}$  contaminant, together with the residuals, which this time are much flatter at around zero.

A majority of the runs (55 of 57 shown in Fig. 4) had identical time durations, which when summed together

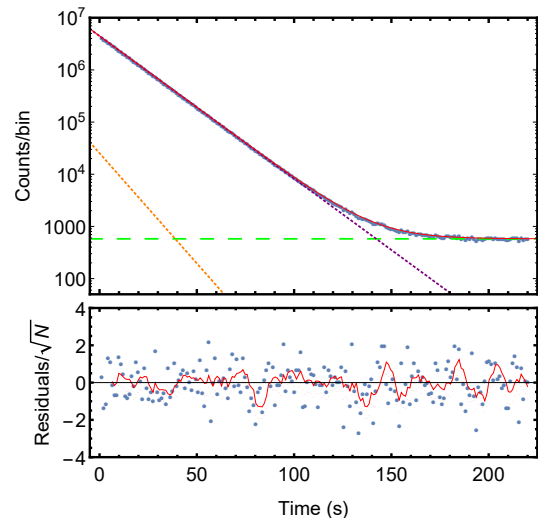


Figure 5: (Color online) The top panel shows a summed beta-decay curve of all cycles with the Eq. 2 fitted result shown in red(solid). The fit includes the influence of the less abundant  $^{16}\text{N}$  as a contaminant in orange (high density dashed), the background in green (low density dashed), and  $^{20}\text{F}$  in purple (high density dashed). In the bottom panel are the residuals of the fit divided by the square root of the number of ions in a given bin  $N$ , shown as blue circles, along with a 5 point moving average shown as the red solid line.

result in the half-life of 11.0144(44) s. The first two cycles taken had a different duration and number of bins, which required them to be summed and fit separately. Since the amount of statistics was too low for these two cycles to get a meaningful fit with a floating  $\alpha$ , we held it fixed at the value  $\alpha = 0.0056$  found for the other 55 cycles, resulting in a  $^{20}\text{F}$  half-life of 11.0258(107) s. The weighted average of the two data sets result in a half-life of 11.0160(41) s.

## E. Systematic uncertainty estimation

Various sources of uncertainty were investigated: the uncertainty in the dead-time determination, inaccuracy in the clock time, the statistical difference in results between the fitting of various subsets of data, and the presence of contamination in the  $^{20}\text{F}$  beam. This resulted in a total systematic uncertainty of 15.5 ms, as outlined in Table II. These sources are described in detail in the following subsections.

### 1. Contamination

In the previous section, the presence of a  $^{16}\text{N}$  contaminant was found to better match the observed decay curve. Naturally, there could have been other reactions

Table II: Sources of systematic uncertainty on the  $^{20}\text{F}$  half-life measurement listed in descending order of influence.

Source	Uncertainty (ms)
Contamination	15.4
Dead time	1.2
Sum fit vs. subgroup fit	1.1
Binning	0.3
$^{16}\text{N}$ half-life	0.1
Clock time	0.1
Fitting routine	$< 10^{-3}$
Total Systematic Uncertainty	15.5

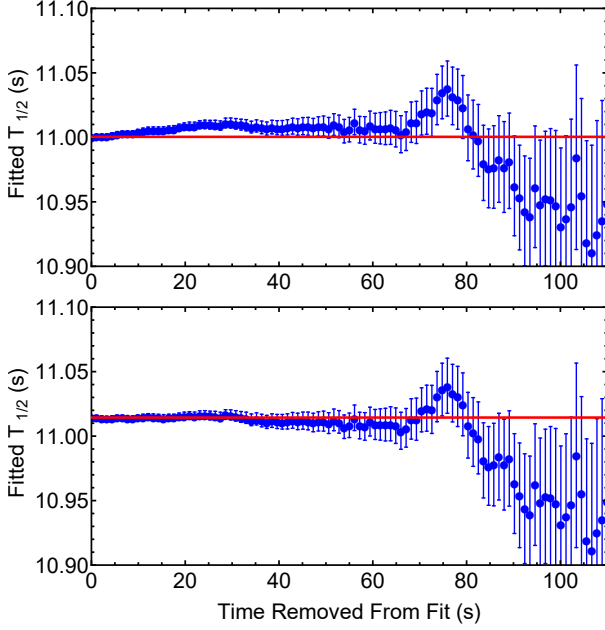


Figure 6: Fitted half-lives for the summed data set as a function of the time removed at the beginning of the sample. The top panel gives results when fit without a contaminant using Eq. 1, while the bottom panel shows results using Eq. 2 which includes the influence of  $^{16}\text{N}$ . Up to 10 half-lives were removed.

with contaminants in the gas or in the windows which might produce a radioactive contaminant that could affect a half-life measurement at this level of precision. The possibility of having such contamination was then investigated by fitting a third component to the decay curve of Eq. 2. No sign of a second contaminant, either shorter or longer-lived was found. Furthermore, the possibility of a very-long lived contaminant has also been studied by fitting a linear component to the decay curve of Eq. 2, yielding a slope consistent with zero.

Then, we performed a so-called channel-removal analysis, where initial sections of the decay curve are progressively removed and each time the remaining data are fitted. In the absence of contamination, a plot of the

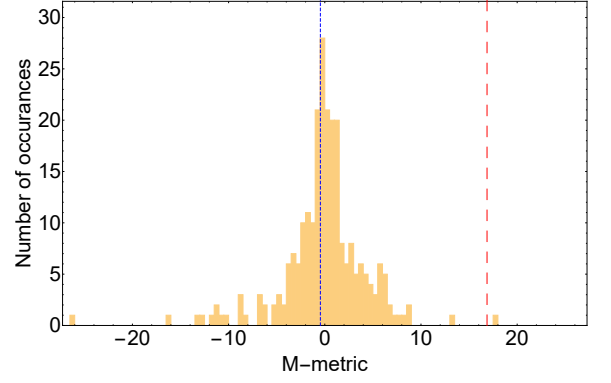


Figure 7: (Color online)  $M$ -metric as defined by [29] for Monte Carlo generated data shown in yellow. This results from 250 calculations of 968 cycles mimicking the experimental data. The experimental result without consideration of a contaminant, 16.9, is given by the red dashed line. This represents the non-consistent nature of the data in Fig. 6 with a sample absent of contamination, while the addition of  $^{16}\text{N}$  to the decay rate reduces the value to  $-0.46$  as shown by the blue line with denser dashing.

half-life as function of the time removed from the start of the decay should not present a systematic upward trend, but rather oscillate about the half-life resulting from zero bins removed. The top panel of Fig. 6, which is a channel removal applied on the summed fit without the  $^{16}\text{N}$  contaminant fitted, shows an effect consistent with the presence of a short-lived contaminant in the measurement. This can be seen by the initial steady increase in half-life followed by its plateauing as bins are being removed. The bottom panel of Fig. 6, which includes the  $^{16}\text{N}$  contaminant in the fit, on the other hand, shows that the fitted half-life oscillates around its original value as channels are removed.

The statistical significance of the changes in half-life with the number of bins removed has been investigated further by calculating a  $M$ -metric value as first introduced in [29], defined as:

$$M = \sum_{x=1}^{11} \text{sgn} [T_{1/2}(x) - T_{1/2}(0)] \left[ \frac{T_{1/2}(x) - T_{1/2}(0)}{\sigma_x} \right]^2, \quad (3)$$

where  $x$  is the number of leading channels removed,  $\text{sgn}$  is the signum function, and  $\sigma_x$  is the statistical error associated with the fit after removing  $x$  channels of 1 s duration. This metric helps to explore rate-dependent and diffusive systematic effects for highly correlated data [29] such as the results from the channel removal analysis. The  $M$ -metric for the experimental results obtained if no  $^{16}\text{N}$  is included is 16.9, while the metric goes down to  $-0.46$  once  $^{16}\text{N}$  is included. To compare these results to a Monte Carlo distribution, a  $M$ -metric was calculated for 250 calculations of 968 cycles (total number of cycles which passed data pre-selection) with the average initial



count rate (4057 Hz) and background (0.55 Hz) seen in the experiment. Fig. 7 shows that less than 1% of the time we get a  $M$ -metric with an absolute value that is greater or equal to the experimental  $M$ -metric of 16.9, while -0.46 falls in the bulk of the distribution. Hence, this is one more indication that  $^{16}\text{N}$  contamination could be present with no other apparent contaminant.

Since the presence of  $^{16}\text{N}$  has been inferred in the data analysis but cannot be confirmed independently, to be conservative, an additional systematic error of 15.4 ms corresponding to the difference between the sum fits without  $^{16}\text{N}$ , 11.0006 s, and with  $^{16}\text{N}$  was added. Also, the effect of the 20 ms uncertainty on the  $^{16}\text{N}$  half-life on the fitted  $^{20}\text{F}$  half-life was studied by performing fits with  $t_2 = 7.11$  s and 7.15 s and we took half the difference in the  $^{20}\text{F}$  half-life, 0.1 ms, as systematic uncertainty.

## 2. Dead time

The uncertainty in the determination of the dead time,  $\tau = 56.89(9) \mu\text{s}$ , will also affect the  $^{20}\text{F}$  half-life. Hence, as done in the previous section, sum fits with  $\tau = 56.80$  and  $\tau = 56.98 \mu\text{s}$  were performed. Half of the difference between the two results was taken as the systematic uncertainty. The resulting value, 1.2 ms, was added in quadrature to the other systematic uncertainties.

## 3. Sum fit vs. subgroup fit

In **Sec. III. C.** all 57 half-life measurements of  $^{20}\text{F}$  have been grouped according to the PMT bias and threshold voltage used. It was found that without including a  $^{16}\text{N}$  in the fit, a large Birge ratio of 1.8(1) is obtained. Fig. 8 shows the same study but with the inclusion of a  $^{16}\text{N}$  contaminant in the fit. By decreasing the PMT bias and discriminator threshold voltage, the detection system becomes less sensitive to lower energy beta particles, and since  $^{16}\text{N}$  and  $^{20}\text{F}$  have different beta-decay  $Q$ -values and hence different beta-decay spectral shape,  $\alpha$  was floated separately for each subgroup. The bottom panel of Figure 8 shows the fitted value for  $\alpha$  while the top panel shows the fitted value for the  $^{20}\text{F}$  half-life. As it can be seen, the fitted half-lives suffer less of a trend with decreasing PMT bias and discriminator threshold voltage. At the same time, the fitted  $\alpha$  follow an increasing trend with decreasing PMT bias and discriminator threshold voltage. This is consistent with the higher  $Q$ -value of 10.4 MeV for the beta-decay of  $^{16}\text{N}$  versus the 7.0 MeV  $Q$ -value for the decay of  $^{20}\text{F}$ . Decreasing the PMT bias and the threshold voltage both results in less sensitivity at low-energy, where a greater proportion of the  $^{20}\text{F}$  beta particles, as compared to  $^{16}\text{N}$ , will fall. Hence, a large  $\alpha$  will be seen in those cases. Finally, we took the weighted average of the 12 subgroups

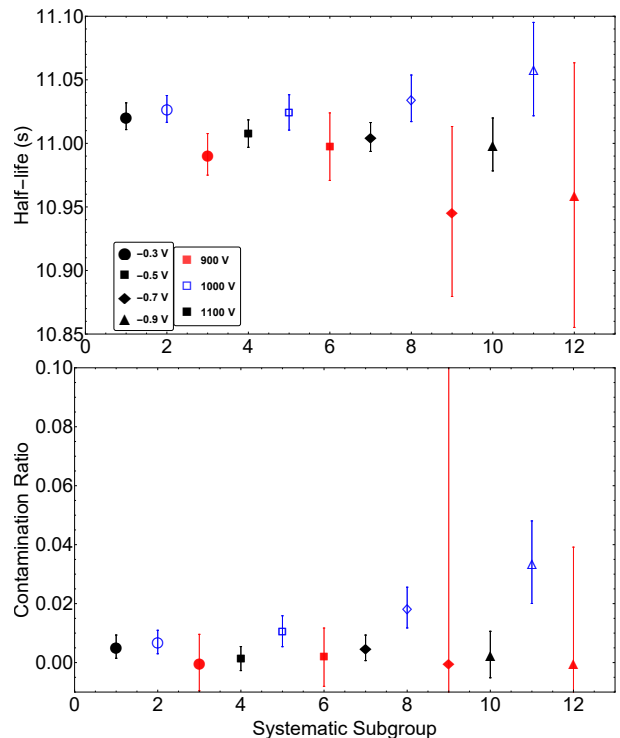


Figure 8: (Color online) Results from fitting subgroups of runs depending on the systematic settings used. The groupings are indicated by shape and color, indicating discriminator threshold voltage and PMT bias respectively. Eq. 2 is used for these fits, where the contamination ratio  $\alpha$  is floated. The top panel gives the half-life resulting from the fit while the bottom panel shows the contamination ratio.

resulting in a half-life of 11.0149(44) s and a Birge ratio of 0.98(14).

The weighted average of the half-lives resulting from the fits of runs grouped by settings were compared to the sum fit value. The difference between these two values, 1.1 ms, was taken as a systematic contribution.

## 4. Binning

The effect of the choice of binning on the fitted half-life has also been tested. While we chose to fit using 200 bins for the analysis (to minimize the number of bins with zero counts in individual runs), as a systematic check we also performed fits using 500 and 1000 bins. The largest deviation from the resulting half-life came from a binning of 1000 bins. The half-lives between the two results differed by 0.3 ms, so this was also added as a small contribution to the overall uncertainty.

### 5. Clock time

The clock frequency has been measured using a Tele-dyne Lecroy 500 MHz oscilloscope to be 99.9996(10) Hz. Therefore, fits were performed with clock values determined by the upper and lower limits of the uncertainty. This resulted in a small contribution to the overall uncertainty of 0.1 ms.

### 6. Fitting routine

The data analysis used in the half-life determination follows a widely used method [26], as done in previous precision half-life measurements with the  $\beta$ -counting station. To investigate the impact of the fitting routine on the value of the half-life a second fitting routine, which minimized a  $\chi^2$  determined by Poisson statistics, was used to double check the fit [30]. The second method converged on fit parameters resulting in a  $\chi^2$  of 0.94 for the same data shown in Fig. 5. Half the difference between the two methods,  $1.0 \times 10^{-4}$  ms, was taken as an additional systematic uncertainty.

## IV. $^{20}\text{F}$ HALF-LIFE

The new  $^{20}\text{F}$  half-life measurement of  $11.0160(41)_{\text{stat}}(155)_{\text{sys}}$  s is well within  $1\sigma$  of the half-life value of  $11.0011(69)_{\text{stat}}(30)_{\text{sys}}$  s recently published by the NSCL group [10].

We performed an evaluation of all the published half-lives and included our new measurement. Following the procedure of the Particle Data Group [31], measurements without reported error were not considered. Then, as done in previous half-life evaluations [32, 33], we kept only the results with a reported uncertainty that is smaller than 10 times the uncertainty of the most precise measurement. Most of the measurements excluded are pre-1960. Also, following the evaluation procedure from [33], all previous measurements using a single least-squares fit in their analysis (which is known to introduce a systematic bias in the half-life values not present in maximum-likelihood fitting) have been rejected in this evaluation of the  $^{20}\text{F}$  half-life. These excluded results are shown in red in Fig. 1, and excluded from Fig. 9. It should be noted that two precise measurements [5, 11] discrepant with the new world average by more than  $13\sigma$  have been removed. The article of the 1976 measurement [5] mentioned that a least-square fitting procedure was used to analyze the data and a private communication with one of the authors of the 1992 measurement [11] also revealed use of the same technique [34].

The weighted average of all precise results yields a half-life of  $11.0062(63)$  s. The Birge ratio of the world data is 1.3(2) with the new measurement. Using the practices

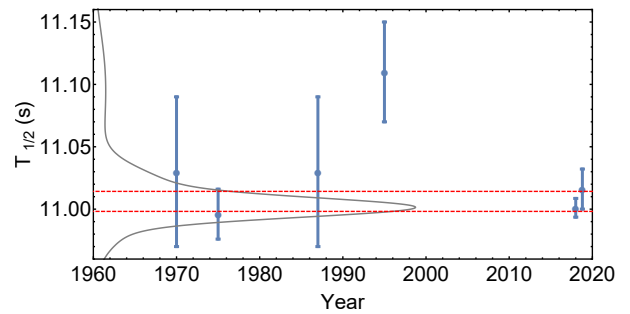


Figure 9: (Color online)  $^{20}\text{F}$  half-life measurements considered in this evaluation [7, 10, 12, 13, 21]. The scaled uncertainty on the overall  $^{20}\text{F}$  half-life of  $11.0062(80)$  s is represented by the dashed red lines.

from the Particle Data Group [31], and scaling the uncertainty by the Birge ratio, gives a  $^{20}\text{F}$  half-life value of  $11.0062(80)$  s. Fig. 9 shows all the half-life measurements considered in the evaluation together with an ideogram indicating the relative weight of each measurement. The solid gray curve shows a sum of normal distributions centered at each individual measurement with a relative height defined by  $\sigma_i^{-2}$  and a width of  $\sigma_i$ , where  $\sigma_i$  is the uncertainty of the measurement. The single peak of the ideogram indicates the consistent nature of the measurements used in the evaluation.

## V. CONCLUSION

The long standing discrepancy in the half-life of  $^{20}\text{F}$  has been known for over 30 years [11]. The result from this work disagrees with two of the precision measurements from the past [5, 11], while affirming the validity of the high precision measurement reported more recently [10]. The new world average including this work is  $11.0062(80)$  s. A consistent set of measurements has been determined by only considering results which utilized maximum likelihood fitting.

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