Status of World Data on the Formation of Solar $^8B^*$

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Abstract

We review world data on measurements of the cross section for forming solar ^8B by the $^7Be(p,\gamma)^8B$ solar fusion reaction. Previously four Direct Capture (DC) experiments were observed to be grouped into two sets of congruent data: the Filippone-Vaughn and the Parker-Kavangh data sets, with an average disagreement of three sigma between the two data sets. The four modern DC measurements, just the same, can be grouped to two congruent data sets: Weizmann-Seattle and Bochum-Orsay, with $\approx 3\sigma$ disagreement between the two data sets, albeit smaller sigma. We point out that the RIKEN CD experiment previously allowed us to favor the Filippone-Vaughn solution, and today, just the same, the higher accuracy CD GSI data allow us to favor the Weizmann-Seattle modern solution. However, a review of systematic uncertainties in the Seattle data at low energies (< 400 keV) leads to larger systematical error bars. These lessen the "tension" between the Seattle data and the GSI and Weizmann data. In spite of the agreement of the GSI, Weizmann and Seattle data we are still not able to extrapolate $S_{17}(0)$ with high accuracy due to different measured slopes. While the Weizmann and GSI data are in excellent agreement, the Seattle data measured at low energies yield a smaller slope (S' = dS/dE) and an additional uncertainty of the extrapolated $S_{17}(0)$. We demonstrate that future precision experiments to measure the cross section at low energies (< 400 keV) must measure on line the energy profile to accurately measure the cross section at low energies and allow an accurate extrapolation of $S_{17}(0)$.

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I. INTRODUCTION

The cross section of the Direct Capture (DC) $^7Be(p,\gamma)^8B$ reaction measured at low energies and the extrapolated astrophysical cross section factor $S_{17}(0)$, is one the most crucial input to the Standard Solar Model [1]. The first three decades in which this cross section has been debated were plagued by a systematic discrepancy between four measurements [2–5], that were grouped to two groups each including two congruent measurements: the Parker-Kavanagh and the Vaughn-Filippone data sets, with a disagreement between the two groups of data. The two extrapolated $S_{17}(0)$ values disagreed by (only) two sigma, however individual measured cross section factors $[S_{17}(E)]$ disagreed on the average by more than three sigma. This confusion led the INT 1997 workshop [6] to quote a cross section factor with a large uncertainty: $S_{17}(0) \ = \ 19 \ +4 \ -2$ eV b. Indeed the pioneering measurements of the Coulomb Dissociation (CD) of ^8B carried out at RIKEN [7, 8] gave the first indication that the favored data set is of Vaughn-Filippone that yielded smaller $S_{17}(E)$. Later DC measurements [9–13] firmed the consensus that the lower cross section values measured by Vaughn-Filippone are correct.

The purpose of this paper is two fold. On one hand we consider DC measurements at low energies below 400 keV. We demonstrate that in such measurements one must measure directly the effective beam energy (and profile) with high accuracy in order to remove a major systematic uncertainty in extracting the astrophysical cross section factor. We examine critically whether this goal was achieved in the Seattle measurement [13]; the only modern measured at such low energies with precision of 5% or better. We also review the time evolution of the CD RIKEN [7, 8] and GSI [15, 16] experiments and we show that the GSI measurements must be considered as an improvement of the RIKEN measurements with higher precision. As such the GSI measurement can help us to chose between conflicting modern DC measurements, much as the role played by the RIKEN measurement and the older data.

II. MODERN MEASUREMENTS

Four new Direct Capture (DC) measurements were published in this century [9–13] and the data are shown in Fig. 1. The situation with modern measurements of $S_{17}(E)$ appears

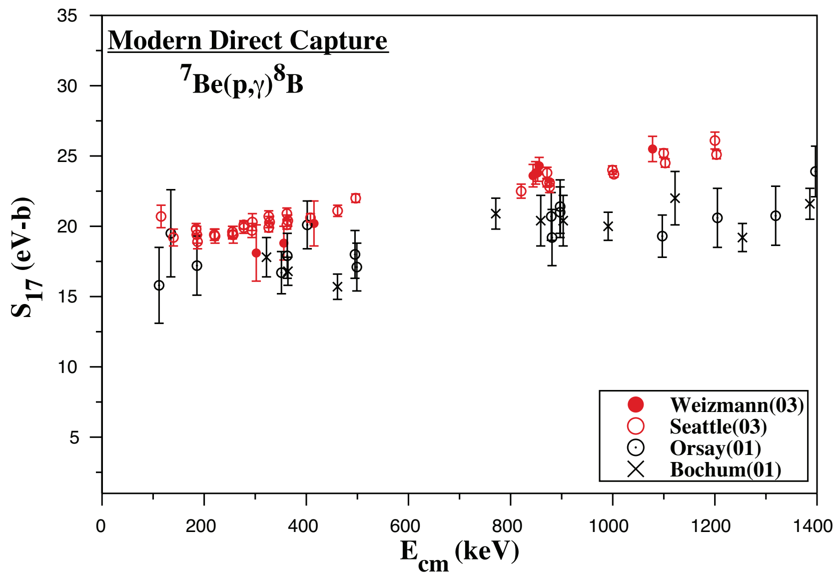

FIG. 1: (Color Online) Modern data on the Direct Capture (DC) $^7Be(p,\gamma)^8B$ reaction from Orsay [9], Bochum [10], Weizmann [11] and Seattle [13]. The Orsay and Bochum groups did not report S_{17} values near the 632.0 keV resonance where the Seattle and Weizmann data agree.

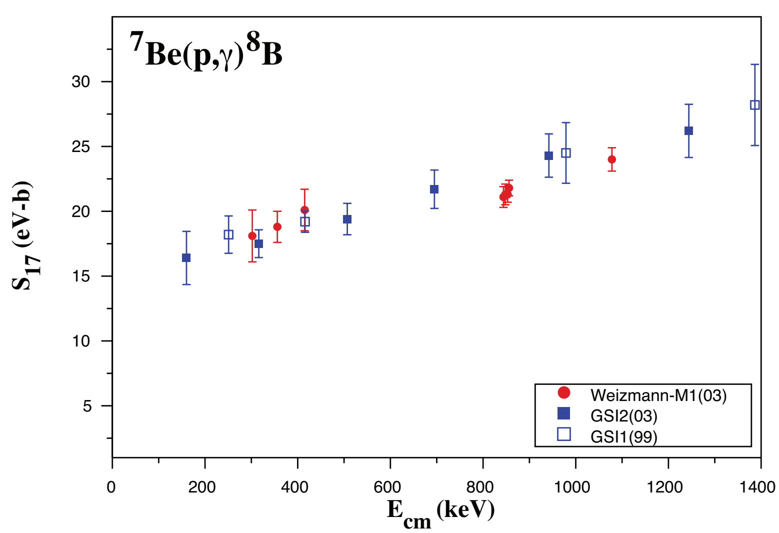

FIG. 2: (Color Online) A comparison of the Weizmann DC data [11] with the GSI1 [14] and GSI2 [15] CD data. The M1 contribution of the 632.0 keV resonance was subtracted from the DC data.

just the same; the four measurements can be grouped to two groups of congruent data: the Orsay-Bochum [9, 10] and the Weizmann-Seattle [11, 13] data sets, with a large systematical discrepancy between them. For example we note from Fig. 1 that there is not a single measured data point of the Bochum measurement [10] in agreement with the Seattle data

[13]. The disagreement between data points is once again on the average more than three sigma, albeit with a considerably smaller ($\approx \frac{1}{2}$) sigma than previously obtained.

The systematical disagreement between DC data does not allow us to derive a world average of DC results as for example suggested in Ref. [13]. A more accurate conclusion requires the exclusion of data and a choice for the correct data. In the past most authors averaged $S_{17}(0)$ results even when the data on $S_{17}(E)$ disagreed by three sigma, since the disagreement on $S_{17}(0)$ is reduced to approximately two sigma. But we do not adopt the procedure of averaging the results $[S_{17}(0)]$ of data $[S_{17}(E)]$ that disagree by three sigma.

As in the case of the data measured in the previous century the CD data measured with high precision at GSI [14–16] allow us to chose between the conflicting Weizmann-Seattle and Bochum-Orsay data sets. The method of CD is independent of DC measurements and the impressive agreement between the Weizmann data and the GSI data shown in Fig. 2 is sufficient to conclude on one hand the very validity of the CD method, and on the other hand the validity of the Seattle-Weizmann larger cross section. Such observational arguments are accepted in Physics in spite of the fact that they appear to be circular [17]. Alternatively, one may chose a more provisional conclusion that if a consensus will converge on the Seattle-Weizmann data set, than it will also give credence to the CD method.

The experiments carried out at RIKEN [7, 8] and GSI [14–16] have been developed over a decade by several people using similar analyses. These four experiments represent a time evolution of increasingly improved experiments with increasing accuracy. One major qualitative difference between the GSI experiments and the RIKEN experiments is the tracking of the ^8B beams prior to the CD event in the lead target. The invariant mass spectrum (aka relative energy spectrum) is independent of the ^8B beam direction, but the tracking of ^8B beams is essential for precision measurement of the angular distribution (and indeed the angular correlations that were reported only in the GSI experiments). The tracking among other factors considerably improved the accuracy of the GSI experiment over the RIKEN experiments. Thus the GSI and RIKEN results cannot be considered as independent results and one cannot use a simple algebraic average to extract an average CD result as suggested in Ref. [13]. Clearly the $S_{17}(0)$ results reported in these four experiments are correlated and the latest improved result must be given additional larger weight (beyond the weight of the inverse of the error bar). Furthermore, the MSU result [18] contains a correction for an E2 component that has not been confirmed by any of the other CD experiments including

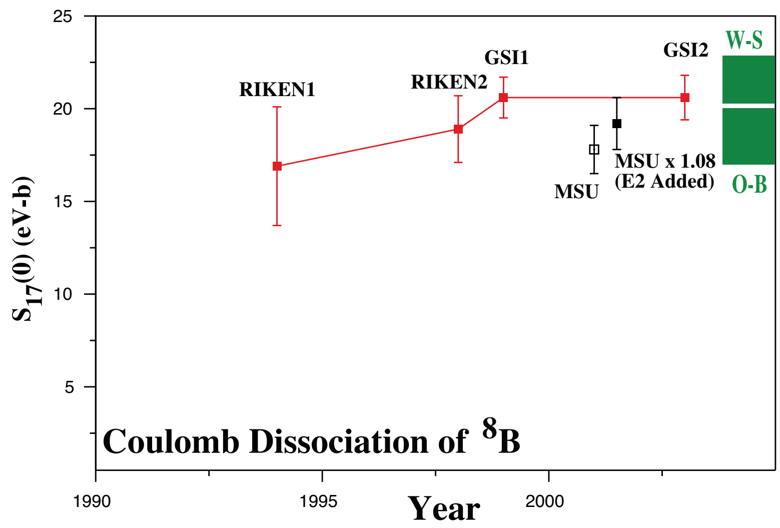

FIG. 3: (Color Online) The time evolution of the RIKEN-GSI CD results on $S_{17}(0)$. The shown $S_{17}(0)$ were extracted using only the extrapolation procedure of Ref. [20]. The MSU result are shown together with adding back the E2 component (8%), as discussed in the text. The range of $S_{17}(0)$ extrapolated by Weizamann and Seattle (W-S), and Orsay and Bochum (O-B) are indicated.

RIKEN1 [19], RIKEN2 [8], GSI1 [14] and GSI2 [16]. The MSU model was also used to search for evidence of an asymmetric yield (in the transverse momentum) in the GSI2 data [16]. A stringent upper limit on the E2 component was observed to contradicts the MSU result. The overwhelming evidence against an E2 correction negates a simple inclusion of the MSU data in an algebraic average as done in Ref. [13]. A better choice is to consider the MSU result with the (8%) E2 correction added back, as shown in Fig. 3.

A reasonable approach to deriving a "CD result" for $S_{17}(0)$ seems to be an inspection of the time evolution of the CD results as shown in Fig. 3. The time evolution of the CD results clearly indicates experiments that are consistent with each other (with the E2 correction added back into the MSU result). The accuracy of the CD results was improved over time while the extrapolated $S_{17}(0)$ values increased to favor the (one sigma) range of the Weizmann-Seattle data set over the Orsay-Bochum range as shown in Fig. 3. Note that in this figure we use only the extrapolation procedure of Descouvemont and Baye [20] unlike some of the previous analyses of CD data that used a few other extrapolation procedures and quoted smaller $S_{17}(0)$ that are due to the different theoretical model used for extrapolating $S_{17}(0)$.

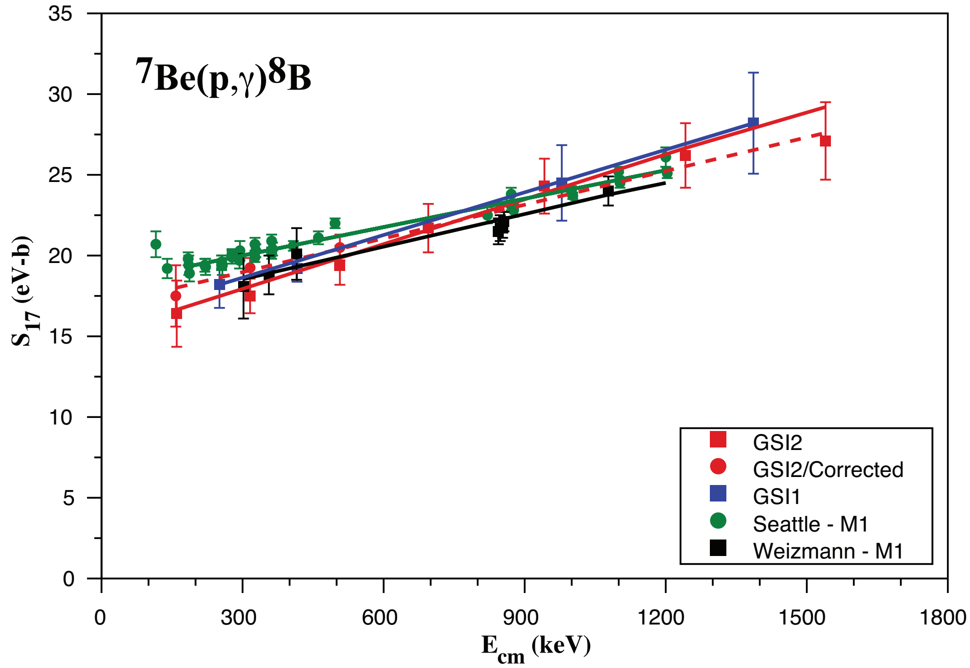

FIG. 4: (Color Online) A comparison of the Weizmann DC data and GSI CD data. The M1 contribution of the resonance at E_{cm} = 632.0 keV has been subtracted from the Weizmann data.

The GSI1 and GSI2 results are: $S_{17}(0)$ = 20.6 $\pm$ 1.2 $\pm$ 1.0 eV b and $S_{17}(0)$ = 20.6 $\pm$ 0.8 $\pm$ 1.2 eV b, respectively. A simple average of all CD results (weighted by $\frac{1}{\sigma}$) yields $S_{17}(0)$ = 20.0 $\pm$0.8 eV b. An average with the weight of the GSI result that is twice that of RIKEN (in addition to the $\frac{1}{\sigma}$ weight) yields S_{17} = 20.3 $\pm$0.8 eV b. The Weizmann result: $S_{17}(0)$ = 21.2 $\pm$0.7 eV b and the Seattle result: $S_{17}(0)$ = 22.1 $\pm$0.6 $\pm$0.6 eV b. An average weighted by the inverse of the error bars of the GSI, Weizmann and Seattle result yields $S_{17}(0)$ = 21.2 $\pm$0.7 eV b.

In Fig. 4 we compare the measured cross section factors of the GSI CD experiment and the Seattle and Weizmann DC experiments. An excellent agreement between these data sets is observed at higher energies. We note that the ^7Be targets used in the Seattle experiment and the ^7Be target used in the Weizmann experiments are very different. The Weizmann and Seattle measurements use a method which is altogether different than the CD method that was used at GSI. In this context we must view this agreement as very impressive.

However, at low energies, below 420 keV, we observe a slight disagreement where the Seattle data are found to be systematically larger than all the data points of Weizmann, GSI1, GS2 and the GSI2 corrected data, as shown in Fig. 4. Even though the data points appear in agreement within the quoted error bars, the systematical deviation from the Seattle results, in particular the systematical deviation of the three lowest energy data points measured at Weizmann, and indeed the different slopes are of major concern when one attempts to extrapolate $S_{17}(0)$ with high accuracy of the order of $\pm 3\%$. Note that the linear curve ($S_{17} = aE\ + b$) that fits very well the Weizmann data yields: $SQRT(\Sigma((S_{17} - aE - b)/\sigma)^2)/(N-2) = 1.9$, with N = 9. Indicating that all the nine data points measured between 300 - 400 keV are systematically on the average 1.9σ above the linear curve that fits very well the Weizmann data.

Indeed the different slope measured by Weizmann and the agreement of the slope measured by Weizmann with the slope measured in CD experiments were already noted in Fig. 19 of Ref. [13]; S' = dS/dE = 5.2 ± 0.6, 7.6 ± 1.2, and 8.0 $\pm$ 1.5 ev b/MeV, for the Seattle, Weizmann and GSI data, respectively.

The differing slopes do not allow for an accurate extrapolation of $S_{17}(0)$ [21]. It was shown [21] that the ill determined slope, S' = dS/dE, does not allow us to determine the d-wave component with high accuracy. The d-wave component must be "subtracted" [22] from the measured data to yield an accurate extrapolation of the s-wave that dominantes at solar energies. An additional (asymmetric) error must be added to the extrapolation due to the ill determined slope [21]. An error of +0.0 -2.0 eV b, slightly larger than the difference between the central values of the Seattle and GSI extrapolated $S_{17}(0)$ result (1.5 eV b), seems like a reasonable conservative estimate of the error due to the different slopes.

III. THE SEATTLE MEASUREMENT

The measurement performed at Seattle at energies below 400 keV [13] require detailed consideration of the systematical error. These consideration are specific for the (major) challenges posed by such a measurement at very low energies with a thick target, as we discuss below.

A. Center of Mass Energy

The astrophysical cross section factor is deduced from the measured yield and cross section using: $S(E)\ = \sigma \times E \times exp(2\pi\eta)$, where σ is the measured cross section, E the

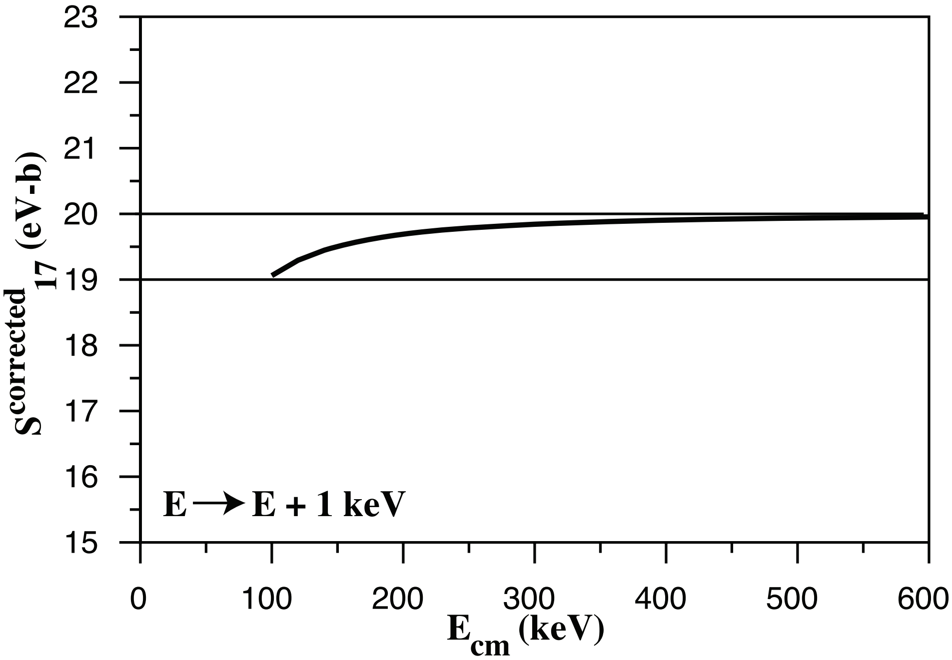

FIG. 5: The effect of under estimating the average (effective) center of mass energy in the target for a data point with $S_{17} = 20.0$ eV b. The corrected $S_{17} < 20.0$ are shown.

center of mass energy, and $\eta = Z_1 \times Z_2 \times \frac{\alpha}{\beta}$, with $\alpha = \frac{1}{137.036}$ the fine structure constant and $\beta = \frac{v}{c}$. At low energy a very accurate knowledge of E must be achieved. In Fig. 5 we demonstrate the effect of an under estimate of the center of mass energy by 1.0 keV at energies below 400 keV. The under estimate of E (by 1.0 keV) leads to multiplication by the larger factor $[exp(2\pi\eta)]$ and thus the extracted S_{17} is over estimated. As shown in Fig. 5 at E = 100 keV an under estimate of the energy by 1.0 keV leads to an over estimate of S_{17} by 1.0 eV b for an "assumed" $S_{17} = 20.0$ eV b. Such a large (5%) systematical error is clearly unacceptable if one is to determine S_{17} with high accuracy (±3%).

The task of measuring precisely the center of mass energy at low energies (< 400 keV) is particularly demanding when one is dealing with a thick target that includes a variety of elements with varying stoichiometry. The lack of direct measurement of the beam energy profile requires knowledge of energy loss in the target with high accuracy. As we show below all these effects limited the accuracy of the Seattle measurement at low energies.

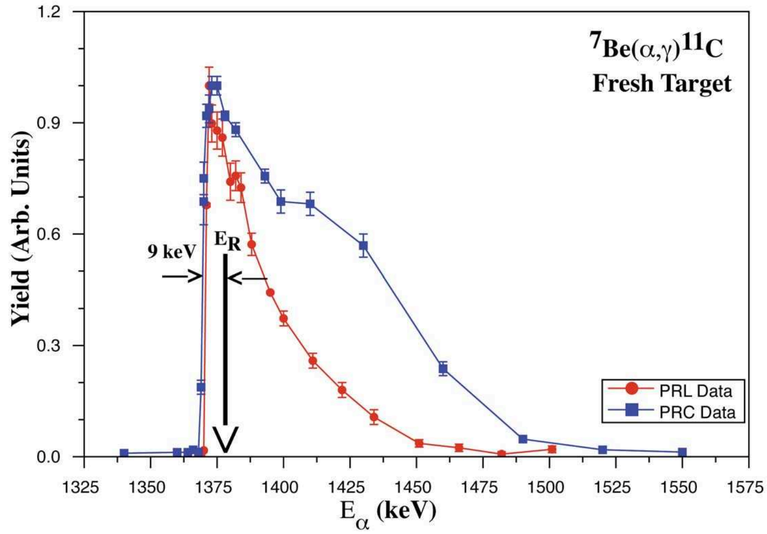

FIG. 6: (Color Online) The fresh target excitation function measured by the Seattle group as published in both their PRL paper [12] and PRC paper [13]. The known measured resonance energy, at 1.378(2) MeV, is indicated.

B. Energy Calibration

The beam energy calibration is discussed in both Ref. [12] and [13]. In both the PRL [12] and PRC [13] publications target thickness measurements are reported using the $^7Be(\alpha,\gamma)^{11}C$ reaction as shown here in Fig. 6 of this paper with data scanned from the publication since the numerical values were not released to this author. It is evident from Fig. 6 that in both the PRL publication and the PRC publication the shown calibration data are off by 9 keV; the measured narrow $\frac{5}{2}^-$ resonance in ^{11}C is well known [23] to be at 1.378(2) MeV. This author informed his colleagues at Seattle of the mistake [24] but as of yet no Erratum has been published by the Seattle group. We do not know how the mistake was repeated in two publications separated by one year, and we do not know whether a correction would simply shift of the alpha-beam energy by 9.0 keV and leave the measured profiles unaffected. An explanation of how to correct these data must be obtained for example in order to know whether the target width for the alpha beam is approximately 85 keV, as shown in Fig. 6 of [13], or whether it is in fact larger (or smaller). In this paper we assume that a correction only involves a shift of the measured alpha-beam energy by 9 keV and the profiles are left unchanged as reported in Fig. 6 of [13]. In addition we do not include this error in our error budget of the Seattle experiment.

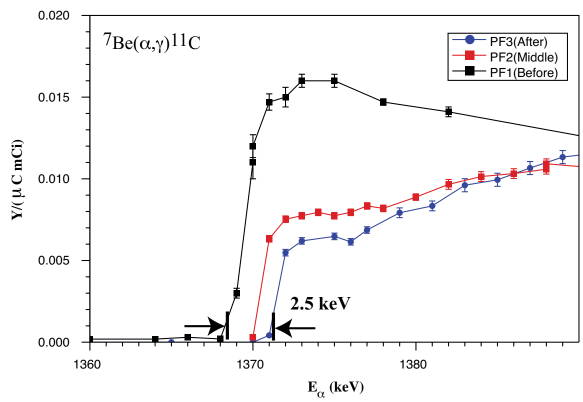

FIG. 7: (Color Online) The three excitation function measured by the Seattle group, in the beginning (PF1), in the middle (PF2) and at the end (PF3) of their measurement with the target labeled BE3, as shown in Fig. 6 of [13].

C. Carbon Buildup

Not withstanding the mistake discussed in the previous section IIIB we note in Fig. 7 that the profiles measured in the beginning (PF1), the middle (PF2) and at the end (PF3) of the experiment show a significant shift of the leading edge of the excitation curve measured with a narrow resonance in ^{11}C using the $^7Be(\alpha,\gamma)^{11}C$ reaction. Most disturbing is the shift of approximately 1.5 keV between the measurements of the PF1 and PF2 profiles. An additional shift of 1.0 keV is observed after measuring the PF2 profile. In between measuring the PF1 and PF2 profiles, the authors [13] report of a heating accident. We may conclude from the data shown in Fig. 7 that this incident may have also increased the carbon buildup. This implies that the entire data measured with the BE3 target (after measuring the PF2 profile) were collected with an energy shift. Taking into account the different dE/dX for 150 keV protons and 1.378 MeV alphas with the published $^7Be :^{12} C : Mo$ stoichiometry, see below, we may conclude that the lowest data point measured at E_{cm} = 115.6 keV is off by at least 0.5 keV. Such a shift leads to an upward correction of the measured S_{17} at 115.6 keV by 0.4 eV b or an error of +0.4 -0.0 eV. This error decreases to zero at 400 keV, see Fig. 5, and should be added (albeit varying) to the common mode error which is listed to be 2.3% (= 0.5 eV b at 115.6 keV) [13]. However, such an upward correction will increase "the tension" between the Seattle data and GSI-Weizmann data.

D. Thick Target

The profiles measured using the $^7Be(\alpha,\gamma)^{11}C$ with E_α = 1350 - 1550 keV, are used to calculate the profile for the nominal proton beam energy, E_p = 149.9 keV discussed in [13], to yield the varying proton beam energy in the target:

$$E_p \; = \; 149.9 - \; (E_\alpha - E_R) \times [R(^7Be) \times \omega(^7Be) \; + \; R(^{12}C) \times \omega(^{12}C) \; + \; R(Mo) \times \omega(Mo)] \quad (1)$$

where,

$$R(A) \; = \frac{\frac{dE}{dX}_{150 \;\; keV \;\; p+A}}{\frac{dE}{dX}_{1378 \;\; keV \;\; \alpha+A}} \qquad (2)$$

and $\omega(A)$ is the stoichiometric fraction. The resultant profiles are shown in Fig. 8 as a function of E_{cm}. It yields a thick target with ΔE_{cm} = 29 keV with a substantial tail that extends to lower energies. The listed error σ_{vary} = 0.5 eV b at $\bar{E}_{cm}$ = 115.6 keV [13], implies a knowledge of the center of mass energy with an accuracy of 0.5 keV, as shown in Fig. 5. Such an accuracy is indeed a formidable task as we demonstrate below.

In the same figure we also show the variation of the cross section across the target calculated for S_{17} = 20.7 eV b and in Fig. 9 we show the predicted yield. The two measured profiles, PF1 and PF2, are sufficiently different. This together with the substantial low energy tail are of major concern as we discuss below.

The average cross section is calculated using equ. (6) of [13]:

$$< \sigma > = \frac{\Sigma \; PF(E) \times \sigma(E)}{\Sigma \; PF(E)} \qquad (3)$$

The profiles were interpolated to yield a continuous profile with 1 keV steps. The value of $< \sigma >$ yields the effective center of mass energy $\bar{E}_{cm}$ = 115.6 keV that is quoted in [13], as shown in Fig. 8. For these calculation we used the published stoichiometry [13] of: $^7Be :^{12} C : Mo$ = 0.58 : 0.08 : 0.34, and the corresponding R values = 0.393:0.402:0.344, calculated using SRIM2003 [25] which is identical to the values calculated by the current SRIM2008.

The tabulated R values [equ. (2)] are shown in Table I with dE/dX listed in the NIST [26] and Northcliffe and Schilling [27] tabulations, and calculated by SRIM2003 [25] and SRIM2008 [25]. We note that the NIST R-values agree with the SRIM values for ^7Be and ^{12}C but disagree for Mo. In contrast the Nothhcliffe and Schilling R-values agree with the

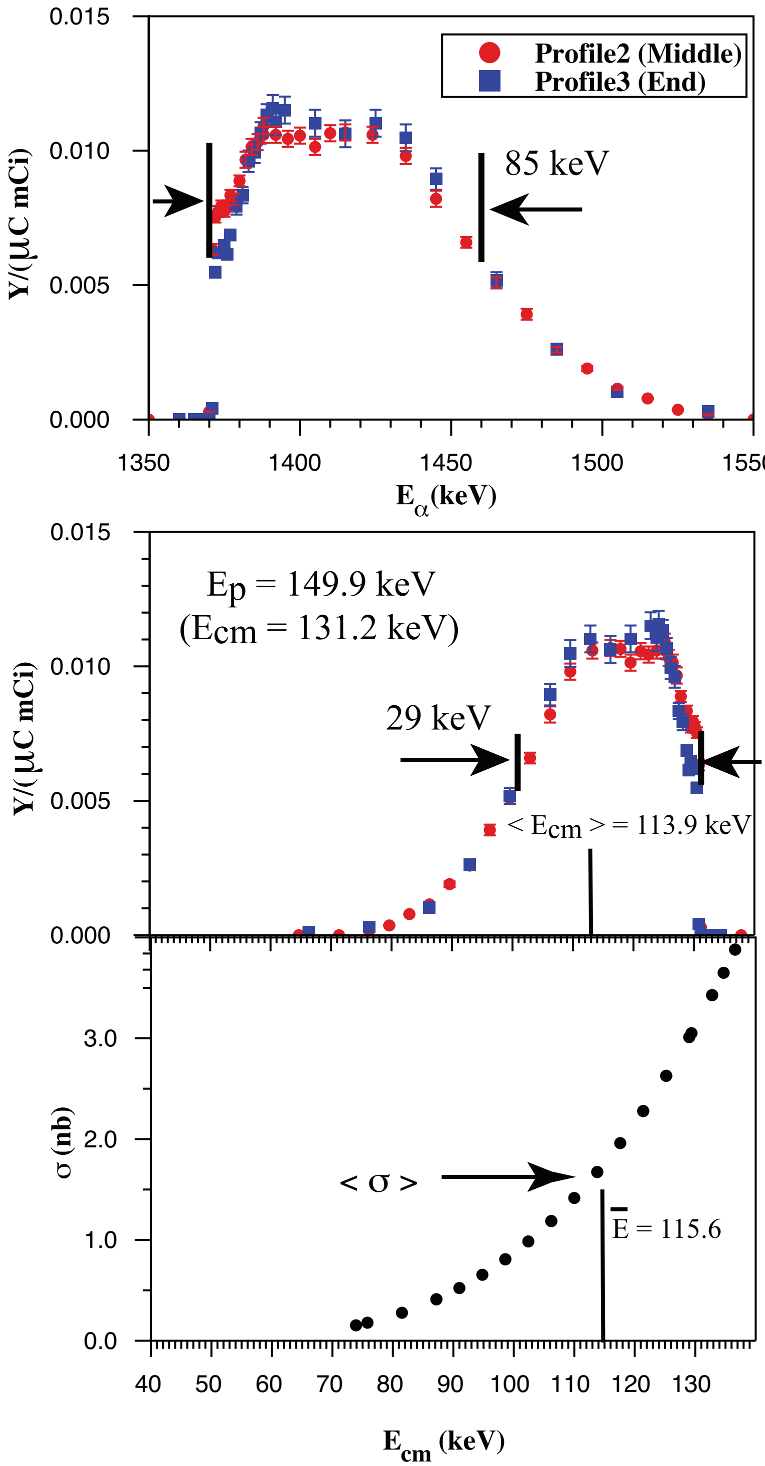

FIG. 8: (Color Online) Target (BE3) width and profile measured using a sharp resonance of the $^{7}Be(\alpha,\gamma)^{11}C$ reaction, in the middle (PF2) and at the end (PF3) of the measurement, as shown in Fig. 6 of [13]. The target profile predicted for $E_p = 149.9$ keV is shown together with the predicted variation of the cross section (for $S_{17} = 20.7$ eV b) over the $\Delta E_p = 33$ keV wide target with a tail extending to very low energies. The calculated $< E_{cm} >$, $< \sigma >$ and $\bar{E}_{cm}$ are indicated.

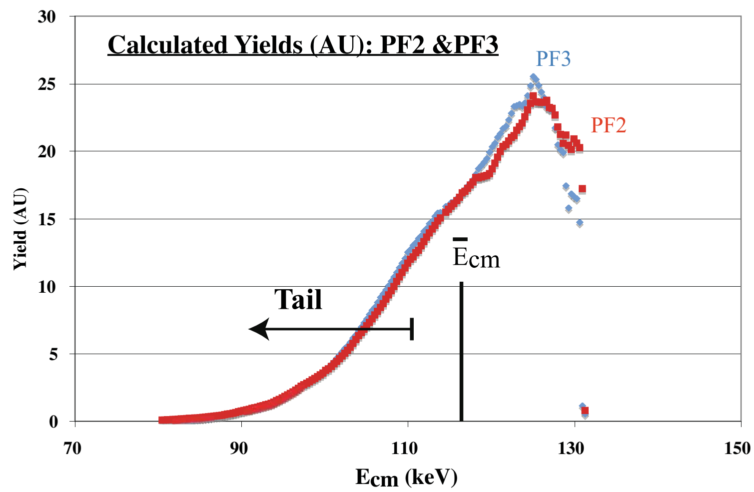

FIG. 9: (Color Online) The calculated yield using the two target profile measured in the middle (PF2) and at the end (PF3) of the measurement. The contribution from the tail of the ^{7}Be distribution, shown in Fig. 8, is indicated.

SRIM values on ^{7}Be and Mo but disagree on ^{12}C. The dispersion of the tabulated dE/dX [which is doubled for the ratio R(A)] and the estimate of the error in the energy loss of 150 keV protons, in itself is of concern. For example SRIM estimate of the accuracy of dE/dX for proton and alpha-particles is 4.2% and 4.1%, respectively [25]. Hence the ratio R is calculated with only 8.3% accuracy. At $\bar{E}$ = 115.6 keV this implies an uncertainty of at least $\Delta\bar{E}$ = ±1.2 keV which propagates to an error of at least ±1.2 eV b in the measured S_{17} at 115.6 keV. Still, in this analysis we do not include this error in the error budget of the Seattle experiment and we use the SRIM tabulations as done in Ref. [13].

We used PF2 and PF3 shown in Fig. 8 to calculate $< \sigma >$ and solve for $\bar{E}_{cm}$ as discussed in [13]. With the published stoichiometry of: $^{7}Be :^{12} C : Mo = 0.58 : 0.08 : 0.34$, and the corresponding R values = 0.393:0.402:0.344, calculated using SRIM2003, we obtain from the profiles PF2 and PF3 $\bar{E}_{cm}$ values that differ by 0.4 keV. In a more realistic calculations we varied the ^{7}Be fractional stoichiometry according to the ^{7}Be profiles, starting with 0.6 in the front of the target, rising to a maximum of 0.98 and falling down to 0.00 in the tail. Such a ^{7}Be profile yield an average stoichiometric value for the ^{7}Be fraction of 0.58, in agreement with the value measured in [13] using the backscattering of the produced ^{8}B. These calculations result an additional uncertainty leading to a total uncertainty of 0.6 keV. This uncertainty alone propagates to an uncertainty in S_{17} which is larger than the listed

$\sigma_{vary} = 0.5$ eV b at $\bar{E} = 115.6$ keV.

Of major concern is the large tail of the ^7Be distribution and the non-negligible yield that arises from the tail as shown in Fig. 9. We note from the outset that the effect of the tail is to additionally reduce the average center of mass energy, $< E_{cm} >$ by approximately 4.0 keV. Note that $< E_{cm} >$ should not be confused with $\bar{E}_{cm}$ [13] (and indeed the two values were mistakenly interchanged at the end of section IIIB of [13]).

In order to estimate the uncertainty in $\bar{E}$ due to the tail of the ^7Be distribution one must understand the structure of this tail. It could arise from thermal migration of all material present in the target and the backing, in which case the target stoichiometry is preserved locally in the tail. It could also arise from implanting recoil ^7Be, in which case quite possibly bubbles and channels made out of pure ^7Be are formed. Such bubbles are well known to form when implanting low energy ions [28]. Or it could be made out of a few ^7Be atoms immersed in the Mo backing. It is impossible to favor or rule out any of these models of the structure of the tail. Each scenario leads to substantially different $^7Be : Mo$ stoichiometry.

TABLE I: Tabulated energy loss in units of $\frac{MeV}{mg/cm^2}$

Source	Element	$dE/dX_{150\ keV\ p+A}$	$dE/dX_{1378\ keV\ \alpha+A}$	Ratio
NIST:	^7Be	0.564	1.453	0.387
	Mo	0.260	0.673	0.386
	^{12}C	0.662	1.628	0.407
NS:	^7Be	0.676	1.697	0.398
	Mo	0.209	0.616	0.339
	^{12}C	0.633	1.855	0.341
SRIM2003:	^7Be	0.580	1.475	0.393
	Mo	0.228	0.662	0.344
	^{12}C	0.664	1.650	0.402
SRIM2008:	^7Be	0.580	1.475	0.393
	Mo	0.228	0.662	0.344
	^{12}C	0.664	1.650	0.402

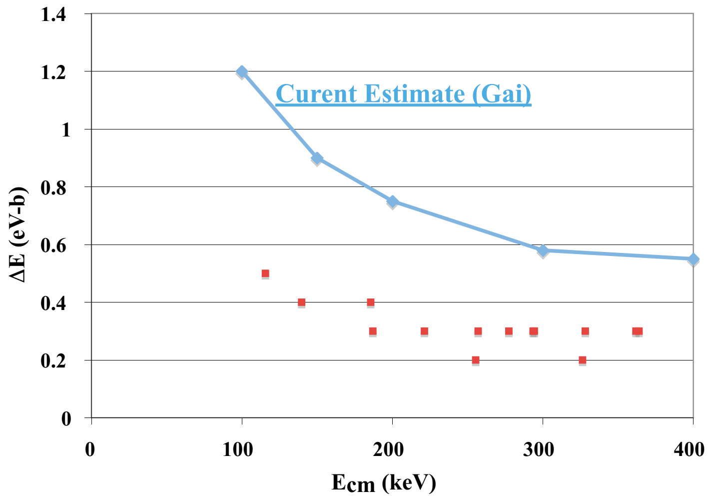

FIG. 10: (Color Online) Systematic errors of the Seattle data calculated in this work compared to the Seattle published errors (labeled as σ_{vary} in Table III of [13]).

We note that the measured profiles probe the number of ^7Be atoms per unit of energy loss. It is hard to separate a reduction in the yield due an increase in dE/dX Vs a decrease in the number of ^7Be nuclei. A detailed examination of the model stoichiometries of the three scenarios increase the total uncertainty of $\bar{E}_{cm}$ from 0.6 keV to 1.2 keV. This uncertainty propagates to an error in S_{17} which is more than 1.0 eV b, or twice the quoted uncertainty σ_{vary} at 115.6 keV [13]. Similar consideration at E_{cm} = 150.0, 200.0, 300.0 and 400.0 keV yield the uncertainties shown in Fig. 10, which are on the average twice of the published error [13] that are also shown in Fig. 10.

IV. CONCLUSION

We have examined the systematical errors of the Seattle measurement of S_{17} below E_{cm} = 400 keV. We judge the published error too small and suggest an increase of the published error. This increase leads to three data sets that are in excellent agreement; the GSI-Weizmann-Seattle data set. Future experiments at low energies must include an on line measurement of the target profile and the average beam energy. Such a measurement can be made possible by measuring the recoil protons from ^7Be beams, or by measuring the back scattered protons from a very thin implanted ^7Be target. Such a thin target can be prepared by implanting ^7Be into a thin aluminum foil as done in [28]. A measurement of the cross section relative to elastic scattering is also essential for a precise measurement of the slope. The systematically different slopes, S' = dS/dE, measured in these three experiments, require an additional error (e.g. +0.0 -2.0 eV b) due to extrapolation [21].

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[17] As an example we note that Newton First Law of Inertia is only correct in an inertial frame of reference. But an inertial frame of reference is defined as frame in which Newton's first law is verified. Such a circular definition can not be accepted in an axiomatic theory, but Physicist are content with this circular definition since it can be resolved by a single observation that allows an observer to deduce the correctness of Newton's Law of Inertia and in the same time the fact that one is making an observation in an inertial frame of reference.

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