Electronic Supplementary Material (ESI) for Materials Advances.


# Electronic Supplementary Information (ESI)

## Modeling ionization quenching in organic scintillators

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## 1 Proton light yield model performance

**Table S1. Model goodness-of-fit for proton light yield data with no parameter constraints. The values correspond to the median $\chi^2$ statistic from the Monte Carlo distribution divided by the number of degrees of freedom. The uncertainty is given by the median absolute deviation.**

| Scintillator | Birks | Chou | Hong et al. | Yoshida et al. | Voltz et al. |
|---|---|---|---|---|---|
| EJ-204 | $(11234 \pm 1510)/31$ | $(1878 \pm 674)/30$ | $(1851 \pm 840)/29$ | $(1270 \pm 694)/28$ | $(1411 \pm 704)/28$ |
| EJ-309 | $(37064 \pm 7857)/46$ | $(2149 \pm 1660)/45$ | $(2369 \pm 1660)/44$ | $(1863 \pm 1562)/43$ | $(2362 \pm 1453)/43$ |
| EJ-276 | $(1976 \pm 525)/21$ | $(129 \pm 42)/20$ | $(463 \pm 145)/19$ | $(93 \pm 25)/18$ | $(95 \pm 18)/18$ |
| Organic glass | $(6708 \pm 1714)/52$ | $(740 \pm 205)/51$ | $(428 \pm 174)/50$ | $(342 \pm 151)/49$ | $(376 \pm 143)/49$ |

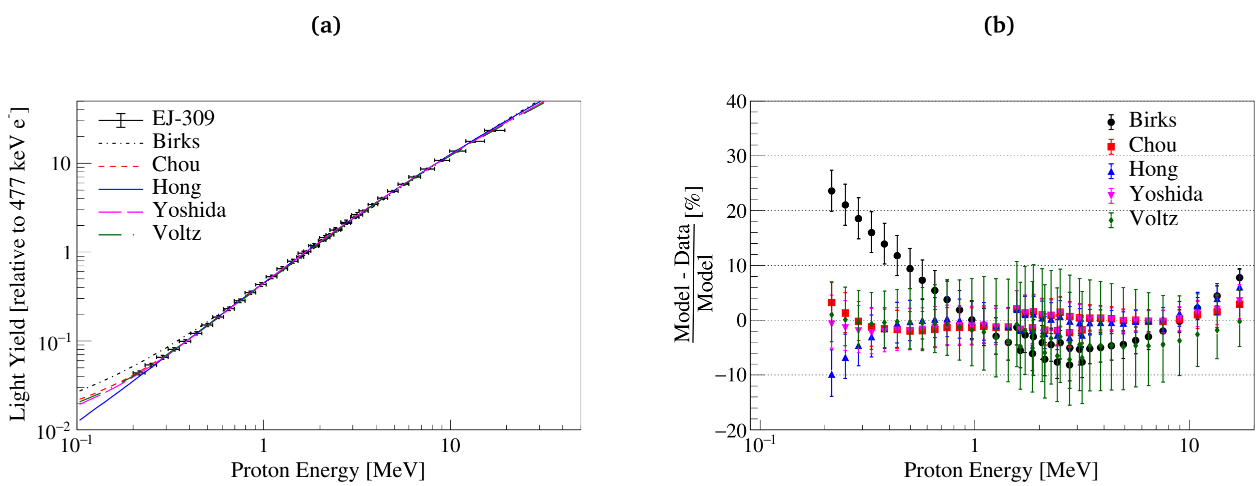


**Figure S1. (a) Specific luminescence models applied to EJ-309 proton light yield data. (b) Standard deviation of model fits to the measured data.**

(a) (b)

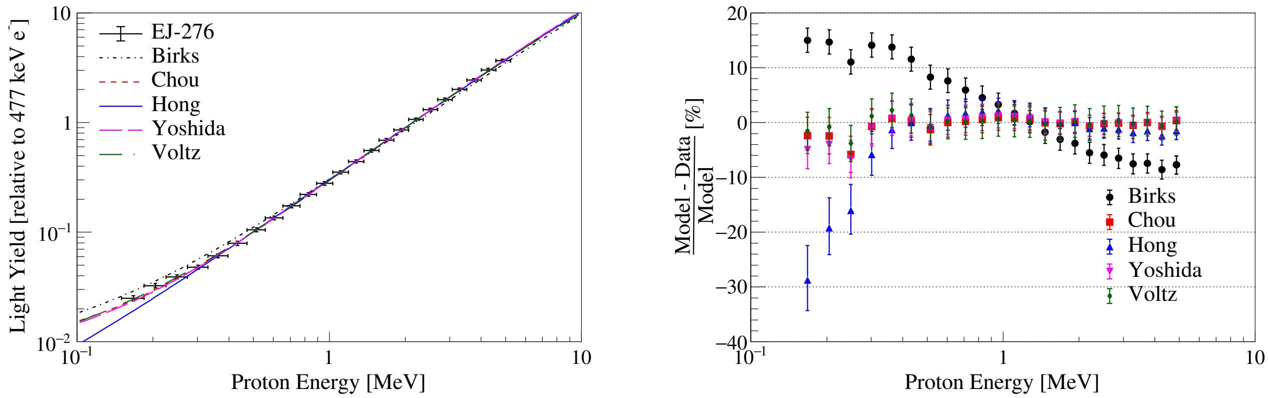


**Figure S2. (a) Specific luminescence models applied to EJ-276 proton light yield data. (b) Standard deviation of model fits to the measured data.**

(a) (b)

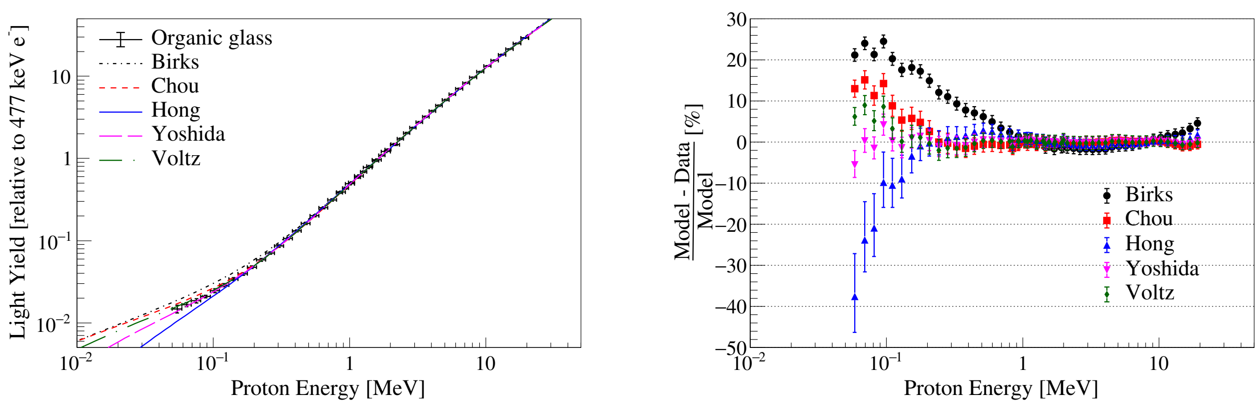


**Figure S3. (a) Specific luminescence models applied to the organic glass proton light yield data. (b) Standard deviation of model fits to the measured data.**

## 2 EJ-204 proton light yield model parameters and covariance

**Table S2. EJ-204 proton light yield model parameters.**

| Model | $S$ or $S_e$ (rel. 477 keV e$^-$) | $S_n$ (rel. 477 keV e$^-$) | $kB$ or $kB_e$ (mg/cm$^2$/MeV) | $kB_n$ (mg/cm$^2$/MeV) | $C$ (mg/cm$^2$/MeV)$^2$ |
|---|---|---|---|---|---|
| Birks | 2.51 | — | 13.1 | — | — |
| Chou | 1.86 | — | 5.50 | — | 7.93 |
| Hong et al. | 2.51 | 2.51 | 9.64 | 3163 | — |
| Yoshida et al. | 2.14 | 2.47 | 7.61 | 284 | 6.12 |

**(a) Birks, Chou, Hong et al. and Yoshida et al.**

| $S$ (rel. 477 keV e$^-$) | $T_0$ (keV) | $B_s$ (mg/cm$^2$/MeV) | $R_d$ | $B_t$ (mg/cm$^2$/MeV) |
|---|---|---|---|---|
| 1.79 | 7.40 | 7.93 | 0.409 | 1.74 |

**(b) Voltz et al.**

**Table S3. EJ-204 proton light yield model parameter covariance matrices.**

| | $S$ | $kB$ |
|---|---|---|
| $S$ | $2.09e-6$ | $3.04e-5$ |
| $kB$ | $3.04e-5$ | $9.00e-2$ |

**(a) Birks**

| | $S$ | $kB$ | $C$ |
|---|---|---|---|
| $S$ | $1.62e-2$ | 0.104 | $-1.61e-3$ |
| $kB$ | 0.104 | 0.748 | $-0.140$ |
| $C$ | $-1.61e-3$ | $-0.140$ | 0.439 |

**(b) Chou**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ |
|---|---|---|---|---|
| $S_e$ | $4.08e-5$ | $2.26e-10$ | $2.76e-4$ | $1.51e-2$ |
| $S_n$ | $2.26e-10$ | $1.09e-12$ | $3.68e-10$ | $-2.44e-6$ |
| $kB_e$ | $2.76e-4$ | $3.68e-10$ | 0.349 | $-319$ |
| $kB_n$ | $1.51e-2$ | $-2.44e-6$ | $-319$ | $3.86e5$ |

**(c) Hong et al.**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ | $C$ |
|---|---|---|---|---|---|
| $S_e$ | $3.14e-2$ | $2.26e-3$ | 0.208 | 13.4 | $-6.98e-2$ |
| $S_n$ | $2.26e-3$ | $3.00e-2$ | $8.24e-3$ | $-2.96$ | $2.11e-2$ |
| $kB_e$ | 0.208 | $8.24e-3$ | 1.49 | 92.5 | $-0.646$ |
| $kB_n$ | 13.4 | $-2.96$ | 92.5 | $3.29e4$ | $-133$ |
| $C$ | $-6.98e-2$ | $-2.11e-2$ | $-0.646$ | $-133$ | 1.09 |

**(d) Yoshida et al.**

| | $S$ | $T_0$ | $B_s$ | $R_d$ | $B_t$ |
|---|---|---|---|---|---|
| $S$ | $1.44e-2$ | 0.315 | $9.53e-2$ | $4.94e-4$ | $1.17e-2$ |
| $T_0$ | 0.315 | 18.8 | $-2.47$ | $-0.186$ | $-0.293$ |
| $B_s$ | $9.53e-2$ | 2.47 | 3.83 | 0.143 | 0.474 |
| $R_d$ | $4.94e-4$ | $-0.186$ | 0.143 | $8.32e-3$ | $2.52e-2$ |
| $B_t$ | $1.17e-2$ | $-0.293$ | 0.474 | $2.52e-2$ | $8.68e-2$ |

**(e) Voltz et al.**

# 3 EJ-309 proton light yield model parameters and covariance

**Table S4. EJ-309 proton light yield model parameters.**

| Model | $S$ or $S_e$ (rel. 477 keV $e^-$) | $S_n$ (rel. 477 keV $e^-$) | $kB$ or $kB_e$ (mg/cm$^2$/MeV) | $kB_n$ (mg/cm$^2$/MeV) | $C$ (mg/cm$^2$/MeV)$^2$ |
|---|---|---|---|---|---|
| Birks | 2.51 | – | 10.4 | – | – |
| Chou | 1.94 | – | 4.55 | – | 6.91 |
| Hong et al. | 2.17 | 2.50 | 4.38 | 4403 | – |
| Yoshida et al. | 1.98 | 2.42 | 4.89 | 168 | 6.13 |

**(a) Birks, Chou, Hong et al. and Yoshida et al.**

| $S$ (rel. 477 keV $e^-$) | $T_0$ (keV) | $B_s$ (mg/cm$^2$/MeV) | $R_d$ | $B_t$ (mg/cm$^2$/MeV) |
|---|---|---|---|---|
| 1.86 | 2.54 | 10.9 | 0.54 | 1.90 |

**(b) Voltz et al.**

**Table S5. EJ-309 proton light yield model parameter covariance matrices.**

| | $S$ | $kB$ |
|---|---|---|
| $S$ | $1.00e-3$ | $5.44e-3$ |
| $kB$ | $5.44e-3$ | $0.279$ |

**(a) Birks**

| | $S$ | $kB$ | $C$ |
|---|---|---|---|
| $S$ | $2.43e-2$ | $0.165$ | $-8.37e-4$ |
| $kB$ | $0.165$ | $1.25$ | $-0.170$ |
| $C$ | $-8.37e-4$ | $-0.170$ | $0.534$ |

**(b) Chou**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ |
|---|---|---|---|---|
| $S_e$ | $3.53e-2$ | $4.28e-3$ | $0.258$ | $-26.3$ |
| $S_n$ | $4.28e-3$ | $1.06e-2$ | $3.55e-2$ | $-5.87$ |
| $kB_e$ | $0.258$ | $3.55e-2$ | $2.35$ | $-629$ |
| $kB_n$ | $-26.3$ | $-5.87$ | $-629$ | $5.39e5$ |

**(c) Hong et al.**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ | $C$ |
|---|---|---|---|---|---|
| $S_e$ | $2.38e-2$ | $1.40e-2$ | $0.163$ | $-1.74$ | $-2.74e-3$ |
| $S_n$ | $1.40e-2$ | $6.86e-2$ | $0.101$ | $-28.4$ | $8.23e-2$ |
| $kB_e$ | $0.163$ | $0.101$ | $1.25$ | $-16.2$ | $-0.162$ |
| $kB_n$ | $-1.74$ | $-28.4$ | $-16.2$ | $5.79e4$ | $-165$ |
| $C$ | $-2.74e-3$ | $8.23e-2$ | $-0.162$ | $-165$ | $0.966$ |

**(d) Yoshida et al.**

| | $S$ | $T_0$ | $B_s$ | $R_d$ | $B_t$ |
|---|---|---|---|---|---|
| $S$ | $7.98e-3$ | $1.93e-2$ | $0.265$ | $3.53e-4$ | $5.82e-3$ |
| $T_0$ | $1.93e-2$ | $26.2$ | $-4.90$ | $-0.164$ | $-0.378$ |
| $B_s$ | $0.265$ | $-4.90$ | $22.0$ | $0.226$ | $0.638$ |
| $R_d$ | $3.53e-4$ | $-0.164$ | $0.226$ | $8.76e-3$ | $2.10e-2$ |
| $B_t$ | $5.82e-3$ | $-0.378$ | $0.638$ | $2.10e-2$ | $5.73e-2$ |

**(e) Voltz et al.**

## 4 EJ-276 proton light yield model parameters and covariance

**Table S6. EJ-276 proton light yield model parameters.**

| Model | $S$ or $S_e$ (rel. 477 keV e$^-$) | $S_n$ (rel. 477 keV e$^-$) | $kB$ or $kB_e$ (mg/cm$^2$/MeV) | $kB_n$ (mg/cm$^2$/MeV) | $C$ (mg/cm$^2$/MeV)$^2$ |
|---|---|---|---|---|---|
| Birks | 2.51 | — | 17.5 | — | — |
| Chou | 2.43 | — | 13.3 | — | 9.55 |
| Hong et al. | 2.51 | 2.51 | 12.5 | 5286 | — |
| Yoshida et al. | 2.46 | 2.51 | 13.6 | 4.18 | 8.95 |

**(a) Birks, Chou, Hong et al. and Yoshida et al.**

| $S$ (rel. 477 keV e$^-$) | $T_0$ (keV) | $B_s$ (mg/cm$^2$/MeV) | $R_d$ | $B_t$ (mg/cm$^2$/MeV) |
|---|---|---|---|---|
| 1.76 | 8.15 | 7.67 | 0.230 | 1.29 |

**(b) Voltz et al.**

**Table S7. EJ-276 proton light yield model parameter covariance matrices.**

| | $S$ | $kB$ |
|---|---|---|
| $S$ | $3.19e-5$ | $3.53e-4$ |
| $kB$ | $3.53e-4$ | $0.227$ |

**(a) Birks**

| | $S$ | $kB$ | $C$ |
|---|---|---|---|
| $S$ | $1.90e-2$ | $0.165$ | $2.11e-2$ |
| $kB$ | $0.165$ | $1.72$ | $-0.265$ |
| $C$ | $2.11e-2$ | $-0.265$ | $1.97$ |

**(b) Chou**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ |
|---|---|---|---|---|
| $S_e$ | $2.81e-16$ | $-2.21e-13$ | $2.12e-11$ | $3.65e-7$ |
| $S_n$ | $-2.21e-13$ | $2.67e-4$ | $1.31e-3$ | $-1.50$ |
| $kB_e$ | $2.12e-11$ | $1.31e-3$ | $1.13$ | $-1283$ |
| $kB_n$ | $3.65e-7$ | $-1.50$ | $-1283$ | $1.78e6$ |

**(c) Hong et al.**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ | $C$ |
|---|---|---|---|---|---|
| $S_e$ | $1.25e-2$ | $1.45e-4$ | $0.110$ | $-0.132$ | $9.49e-3$ |
| $S_n$ | $1.45e-4$ | $2.44e-3$ | $-7.57e-5$ | $-0.629$ | $7.18e-3$ |
| $kB_e$ | $0.110$ | $-7.57e-5$ | $1.26$ | $1.88$ | $-0.392$ |
| $kB_n$ | $-0.32$ | $-0.629$ | $1.88$ | $963$ | $-14.0$ |
| $C$ | $9.49e-3$ | $7.18e-3$ | $-0.392$ | $-14.0$ | $2.10$ |

**(d) Yoshida et al.**

| | $S$ | $T_0$ | $B_s$ | $R_d$ | $B_t$ |
|---|---|---|---|---|---|
| $S$ | $1.01e-2$ | $0.149$ | $6.89e-2$ | $1.08e-3$ | $1.14e-2$ |
| $T_0$ | $0.149$ | $6.73$ | $0.654$ | $1.96e-3$ | $0.112$ |
| $B_s$ | $6.89e-2$ | $0.654$ | $0.875$ | $2.80e-2$ | $0.180$ |
| $R_d$ | $1.08e-3$ | $1.96e-3$ | $2.80e-2$ | $1.63e-3$ | $8.84e-3$ |
| $B_t$ | $1.14e-2$ | $0.112$ | $0.180$ | $8.84e-3$ | $5.32e-2$ |

**(e) Voltz et al.**

## 5 Organic glass proton light yield model parameters and covariance

**Table S8. Organic glass proton light yield model parameters.**

| Model | $S$ or $S_e$ (rel. 477 keV e$^-$) | $S_n$ (rel. 477 keV e$^-$) | $kB$ or $kB_e$ (mg/cm$^2$/MeV) | $kB_n$ (mg/cm$^2$/MeV) | $C$ (mg/cm$^2$/MeV)$^2$ |
|---|---|---|---|---|---|
| Birks | 2.44 | – | 9.83 | – | – |
| Chou | 2.14 | – | 6.69 | – | 4.24 |
| Hong et al. | 2.29 | 2.51 | 7.88 | 1058 | – |
| Yoshida et al. | 2.19 | 2.43 | 7.15 | 190 | 2.90 |

**(a) Birks, Chou, Hong et al. and Yoshida et al.**

| $S$ (rel. 477 keV e$^-$) | $T_0$ (keV) | $B_s$ (mg/cm$^2$/MeV) | $R_d$ | $B_t$ (mg/cm$^2$/MeV) |
|---|---|---|---|---|
| 2.05 | 13.2 | 8.91 | 0.453 | 1.73 |

**(b) Voltz et al.**

**Table S9. Organic glass proton light yield model parameter covariance matrices.**

| | $S$ | $kB$ |
|---|---|---|
| $S$ | $2.71e-3$ | $1.28e-2$ |
| $kB$ | $1.28e-2$ | $0.101$ |

**(a) Birks**

| | $S$ | $kB$ | $C$ |
|---|---|---|---|
| $S$ | $2.80e-3$ | $2.59e-2$ | $-2.45e-2$ |
| $kB$ | $2.59e-2$ | $0.333$ | $-0.394$ |
| $C$ | $-2.45e-2$ | $-0.394$ | $0.672$ |

**(b) Chou**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ |
|---|---|---|---|---|
| $S_e$ | $2.13e-2$ | $7.01e-5$ | $1.47e-2$ | $-2.93$ |
| $S_n$ | $7.01e-5$ | $6.03e-4$ | $7.50e-4$ | $-0.452$ |
| $kB_e$ | $1.47e-2$ | $-7.50e-4$ | $0.276$ | $-159$ |
| $kB_n$ | $-2.93$ | $0.452$ | $-159$ | $1.45e5$ |

**(c) Hong et al.**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ | $C$ |
|---|---|---|---|---|---|
| $S_e$ | $2.84e-3$ | $2.66e-3$ | $2.61e-2$ | $1.44$ | $-2.93e-2$ |
| $S_n$ | $2.66e-3$ | $5.87e-2$ | $2.41e-2$ | $0.434$ | $-2.68e-2$ |
| $kB_e$ | $2.61e-2$ | $2.41e-2$ | $0.325$ | $21.1$ | $-0.438$ |
| $kB_n$ | $1.44$ | $0.434$ | $21.1$ | $4779$ | $-46.6$ |
| $C$ | $-2.93e-2$ | $-2.68e-2$ | $-0.438$ | $-46.6$ | $0.856$ |

**(d) Yoshida et al.**

| | $S$ | $T_0$ | $B_s$ | $R_d$ | $B_t$ |
|---|---|---|---|---|---|
| $S$ | $1.88e-3$ | $9.38e-2$ | $2.19e-2$ | $1.10e-4$ | $1.05e-3$ |
| $T_0$ | $9.38e-2$ | $15.4$ | $0.969$ | $8.22e-4$ | $3.13e-2$ |
| $B_s$ | $2.19e-2$ | $0.969$ | $0.617$ | $1.07e-2$ | $3.65e-2$ |
| $R_d$ | $1.10e-4$ | $8.22e-4$ | $1.07e-2$ | $6.54e-4$ | $2.17e-3$ |
| $B_t$ | $1.05e-3$ | $3.13e-2$ | $3.65e-2$ | $2.17e-3$ | $8.96e-3$ |

**(e) Voltz et al.**

## 6 Proton and Carbon Light Yield Models

**Table S10. Model parameters obtained through simultaneous fit of the EJ-204 proton and carbon light yield data.**

| Model | $S$ or $S_e$ (rel. 477 keV e$^-$) | $S_n$ (rel. 477 keV e$^-$) | $kB$ or $kB_e$ (mg/cm$^2$/MeV) | $kB_n$ (mg/cm$^2$/MeV) | $C$ (mg/cm$^2$/MeV)$^2$ |
|---|---|---|---|---|---|
| Birks | 2.51 | — | 13.2 | — | — |
| Chou | 2.51 | — | 12.9 | — | 0.416 |
| Hong et al. | 2.51 | 2.05 | 12.8 | 89.7 | — |
| Yoshida et al. | 2.51 | 2.51 | 12.8 | 86.3 | $2.69e-3$ |

**(a) Birks, Chou, Hong et al. and Yoshida et al.**

| $S$ (rel. 477 keV e$^-$) | $T_0$ (keV) | $B_s$ (mg/cm$^2$/MeV) | $R_d$ | $B_t$ (mg/cm$^2$/MeV) |
|---|---|---|---|---|
| 1.68 | 11.0 | 4.32 | $9.37e-2$ | 0.275 |

**(b) Voltz et al.**

**Table S11. Covariance matrices for model parameters obtained through simultaneous fit of the EJ-204 proton and carbon light yield data.**

| | $S$ | $kB$ |
|---|---|---|
| $S$ | $1.22e-20$ | $-1.27e-12$ |
| $kB$ | $-1.27e-12$ | $7.73e-2$ |

**(a) Birks**

| | $S$ | $kB$ | $C$ |
|---|---|---|---|
| $S$ | $1.52e-20$ | $2.68e-13$ | $2.04e-13$ |
| $kB$ | $2.68e-13$ | $0.112$ | $-2.66e-2$ |
| $C$ | $2.04e-13$ | $-2.66e-2$ | $1.09e-2$ |

**(b) Chou**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ |
|---|---|---|---|---|
| $S_e$ | $1.17e-7$ | $2.47e-6$ | $1.89e-7$ | $2.88e-4$ |
| $S_n$ | $2.47e-6$ | $0.154$ | $-4.61e-2$ | $5.73$ |
| $kB_e$ | $1.89e-7$ | $-4.61e-2$ | $0.100$ | $-4.51$ |
| $kB_n$ | $2.88e-4$ | $5.73$ | $-4.51$ | $433$ |

**(c) Hong et al.**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ | $C$ |
|---|---|---|---|---|---|
| $S_e$ | $1.01e-5$ | $-3.02e-8$ | $3.52e-5$ | $3.09e-4$ | $-5.76e-6$ |
| $S_n$ | $-3.02e-8$ | $3.40e-4$ | $-2.67e-4$ | $2.31e-2$ | $-3.28e-5$ |
| $kB_e$ | $3.52e-5$ | $-2.67e-4$ | $0.100$ | $-4.37$ | $3.88e-5$ |
| $kB_n$ | $3.09e-4$ | $2.31e-2$ | $-4.37$ | $371$ | $-2.03e-2$ |
| $C$ | $-5.76e-6$ | $-3.28e-5$ | $3.88e-5$ | $-2.03e-2$ | $1.40e-4$ |

**(d) Yoshida et al.**

| | $S$ | $T_0$ | $B_s$ | $R_d$ | $B_t$ |
|---|---|---|---|---|---|
| $S$ | $4.37e-5$ | $-9.77e-4$ | $2.25e-6$ | $-6.19e-7$ | $-1.11e-6$ |
| $T_0$ | $-9.77e-4$ | $0.932$ | $7.55e-3$ | $4.70e-4$ | $1.69e-3$ |
| $B_s$ | $2.25e-6$ | $7.55e-3$ | $2.35e-2$ | $1.23e-3$ | $3.00e-3$ |
| $R_d$ | $-6.19e-7$ | $4.70e-4$ | $1.23e-3$ | $9.63e-5$ | $2.40e-4$ |
| $B_t$ | $-1.11e-6$ | $1.69e-3$ | $3.00e-3$ | $2.40e-4$ | $6.36e-4$ |

**(e) Voltz et al.**

**Table S12. Model parameters obtained through simultaneous fit of the EJ-309 proton and carbon light yield data.**

| Model | $S$ or $S_e$ (rel. 477 keV e$^-$) | $S_n$ (rel. 477 keV e$^-$) | $kB$ or $kB_e$ (mg/cm$^2$/MeV) | $kB_n$ (mg/cm$^2$/MeV) | $C$ (mg/cm$^2$/MeV)$^2$ |
|---|---|---|---|---|---|
| Birks | 2.51 | — | 10.5 | — | — |
| Chou | 2.22 | — | 6.81 | — | 5.05 |
| Hong et al. | 2.42 | 2.51 | 7.61 | 2258 | — |
| Yoshida et al. | 2.17 | 2.51 | 6.46 | 10.7 | 5.09 |

**(a) Birks, Chou, Hong et al. and Yoshida et al.**

| $S$ (rel. 477 keV e$^-$) | $T_0$ (keV) | $B_s$ (mg/cm$^2$/MeV) | $R_d$ | $B_t$ (mg/cm$^2$/MeV) |
|---|---|---|---|---|
| 1.70 | 1.86 | 5.67 | 0.192 | 0.468 |

**(b) Voltz et al.**

**Table S13. Covariance matrices for model parameters obtained through simultaneous fit of the EJ-309 proton and carbon light yield data.**

| | $S$ | $kB$ |
|---|---|---|
| $S$ | $2.56e-3$ | $1.32e-2$ |
| $kB$ | $1.32e-2$ | $0.304$ |

**(a) Birks**

| | $S$ | $kB$ | $C$ |
|---|---|---|---|
| $S$ | $5.67e-2$ | $0.416$ | $-7.98e-2$ |
| $kB$ | $0.416$ | $3.23$ | $-0.847$ |
| $C$ | $-7.98e-2$ | $-0.847$ | $0.951$ |

**(b) Chou**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ |
|---|---|---|---|---|
| $S_e$ | $2.10e-2$ | $1.99e-4$ | $0.165$ | $-17.9$ |
| $S_n$ | $1.99e-4$ | $5.47e-4$ | $2.70e-3$ | $-1.16$ |
| $kB_e$ | $0.165$ | $2.70e-3$ | $1.83$ | $-576$ |
| $kB_n$ | $-17.9$ | $-1.16$ | $-576$ | $5.20e5$ |

**(c) Hong et al.**

| | $S_e$ | $S_n$ | $kB_e$ | $kB_n$ | $C$ |
|---|---|---|---|---|---|
| $S_e$ | $6.06e-2$ | $-8.92e-4$ | $0.443$ | $3.15$ | $-0.103$ |
| $S_n$ | $-8.92e-4$ | $2.46e-3$ | $-7.72e-3$ | $-2.97$ | $1.50e-2$ |
| $kB_e$ | $0.443$ | $-7.72e-3$ | $3.42$ | $27.8$ | $-1.01$ |
| $kB_n$ | $3.15$ | $-2.97$ | $27.8$ | $1.05e4$ | $-50.4$ |
| $C$ | $-0.103$ | $1.50e-2$ | $-1.01$ | $-50.4$ | $1.10$ |

**(d) Yoshida et al.**

| | $S$ | $T_0$ | $B_s$ | $R_d$ | $B_t$ |
|---|---|---|---|---|---|
| $S$ | $2.55e-3$ | $7.69e-2$ | $-1.99e-2$ | $-1.29e-3$ | $-1.47e-3$ |
| $T_0$ | $7.69e-2$ | $9.72$ | $-1.12$ | $-5.96e-2$ | $-7.38e-2$ |
| $B_s$ | $-1.99e-2$ | $-1.12$ | $0.685$ | $2.76e-2$ | $3.65e-2$ |
| $R_d$ | $-1.29e-3$ | $-5.96e-2$ | $2.76e-2$ | $1.48e-3$ | $1.92e-3$ |
| $B_t$ | $-1.47e-3$ | $-7.38e-2$ | $3.65e-2$ | $1.92e-3$ | $2.58e-3$ |

**(e) Voltz et al.**

**Table S14. Model goodness-of-fit for proton and carbon light yield data with no parameter constraints. The values correspond to the median $\chi^2$ statistic from the Monte Carlo distribution divided by the number of degrees of freedom. The uncertainty is given by the median absolute deviation.**

| Scintillator | Birks | Chou | Hong et al. | Yoshida et al. | Voltz et al. |
|---|---|---|---|---|---|
| EJ-204 | $(15627 \pm 1464)/43$ | $(15470 \pm 1409)/42$ | $(14136 \pm 1465)/41$ | $(13808 \pm 1443)/40$ | $(4632 \pm 1143)/40$ |
| EJ-309 | $(56658 \pm 10261)/54$ | $(18643 \pm 3376)/53$ | $(13409 \pm 3364)/52$ | $(10578 \pm 3164)/51$ | $(4798 \pm 661)/51$ |