Published 1 sigma error bars hold near nominal; a 95 percent interval needs 3 to 5 sigma

A preregistered coverage test of stated uncertainties against later editions of the PDG, AME and CODATA tables and against proxy truths for the Hubble constant

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Version 1.0, 9 November 2026. Finding F362 in the findings ledger. Signal (tier B).

Abstract

A stated uncertainty is a forecast of where later, better measurements will put a value. We scored that forecast on four reference sources: particle masses and widths in the Particle Data Group tables (2010 to 2025), atomic masses in the Atomic Mass Evaluation (2003 to 2020), the CODATA recommended constants (2002 to 2022) and Huchra's compilation of published Hubble constant values. For each quantity we measured the shift between the first and last edition in units of the first edition's stated sigma. The earlier 1 sigma interval covered 0.68 of later PDG values that moved (n 227) and 0.66 of later AME values (n 2,213, nearly all of which moved), close to the nominal 0.6827. The tails are far heavier than a normal curve. Covering 95.45 percent of later values took 3.8 times the stated sigma for moved PDG values, 4.0 for AME and 4.9 for CODATA. Student t fits to the nonzero shifts gave nu of 1.67 for PDG, 1.22 for AME and 2.17 for CODATA, close to the Cauchy shape. Published Hubble constant values before 1990 covered a proxy truth of 70 km/s/Mpc within 1 sigma in 0.35 of 115 cases. Later tables reuse inputs from earlier ones, which flatters every coverage figure here.

1 What this means for a reader

When a table prints a value plus or minus one sigma, the next edition usually lands about as close as that promise says. Large misses are the problem: shifts of four or five sigma happen far more often than a bell curve allows. If you need 95 percent confidence from a published plus-or-minus, multiply it by three to five, and by more for an astronomical quantity that is still being settled.

2 Introduction

A stated 1 sigma uncertainty is the plus-or-minus a table prints beside a value, meant as one standard deviation of its error. For a normal error, one sigma either side should hold the truth 68.27 percent of the time and two sigma 95.45 percent. Later editions of the same table give a better estimate of the true value, so the share of later values that fall inside an earlier interval, its coverage, can be counted.

Henrion and Fischhoff [5] examined the history of the physical constants, including the speed of light, and found that reported uncertainties were consistently too small, with recommended values often moving by more than their stated errors. Chen, Gott and Ratra [6] built the error distribution of 461 Hubble constant measurements in Huchra's compilation against a central value of 71 km/s/Mpc. They found it non-Gaussian, with 95.4 percent limits at 7.0 times the quoted errors and a shape described by a widened Student t with two degrees of freedom. Bailey [7] analysed about 41,000 measurements of 3,200 quantities from medicine, nuclear and particle physics and interlaboratory comparisons, and found the normalised differences between measurements of the same quantity close to Student t distributions, often almost Cauchy. Its reading is that researchers estimate the size of typical errors well and underestimate the chance of large ones.

This paper asks the same question of edition-to-edition changes in four large tables at once, with a planted

check, a normal-world control, a test that removes unchanged values, and forecasts fixed in advance. Bailey's data include nuclear and particle physics. Our searches on 9 November 2026 did not return a study that scores the PDG mass-width files edition against edition; that is what the searches returned, and it does not show that none exists.

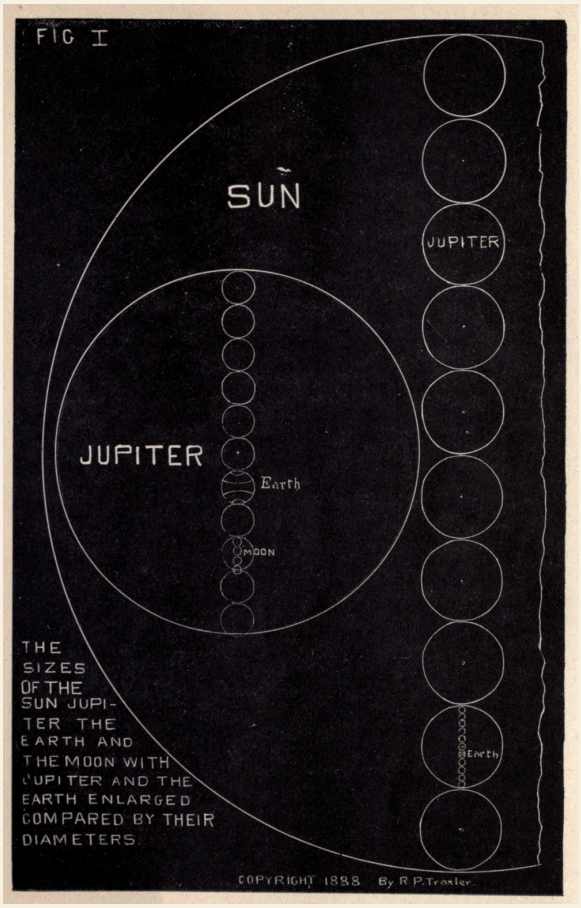


Figure 1. Robert P. Traxler, Fig. I, "The sizes of the Sun, Jupiter, the Earth and the Moon, with Jupiter and the Earth enlarged, compared by their diameters", from The Principles of Mechanics as Applied to the Solar System (San Francisco, 1889) [8]. Traxler drew his plates to argue for a repelling force from the Sun, his own theory in 1889, which physics did not adopt. Traxler compares sizes by laying one body's diameter across another's, much as this paper measures each shift in units of the table's own stated sigma. Public domain; scan from the Internet Archive, University of California Libraries.

3 Preregistration and design

The design was written as a preregistration dated 31 October 2026 and hash-locked on 1 November 2026 at 01:54 UTC. The forecasts were copied from an earlier forecast file written and hashed before any data were read. Before the lock, the file formats of the PDG, AME and Huchra tables were read; no coverage was computed. The decision it informs was stated in the file: whether stated uncertainties, and our own forecast bands, get a correction factor.

The locked file names the tables and editions, the coverage count, a moved-values arm that drops every quantity whose value did not change (an unchanged value counts as covered whatever its sigma), the proxy truth values for the Hubble constant, a planted check (data built so the right answer is known, run through the same analysis), a control (a version of the data with the structure under test removed, scored the same way), the assumptions to be changed one at a time, the forecasts and a kill condition, a rule that decides against the

claim with no room for judgement after the run.

Kill condition, without discretion: if the planted check fails, no coverage claim counts.

The same run also scored our own numeric forecast bands from earlier studies. That arm is reported as a separate finding (F366) and appears here only in the appendix.

4 Data and provenance

- Particle Data Group, Review of Particle Physics, mass and width files for Monte Carlo programs, editions 2010, 2012, 2014, 2016, 2018, 2020, 2022, 2024 and 2025 [1]. Recent editions are released under CC BY 4.0; the terms for older editions were not read. Asymmetric errors were averaged into one sigma.
- Atomic Mass Evaluation, editions 2003, 2012, 2016 and 2020 [2]. The 2016 and 2020 files came from the IAEA Atomic Mass Data Center; the 2003 and 2012 files were refused by the live server and taken from Internet Archive copies of the same addresses. No licence was stated on the pages read. Values marked as estimated were removed.
- CODATA recommended values of the fundamental constants, 2002 to 2022, from the NIST archive of ASCII tables [3]. Values with zero stated uncertainty (exact values) do not enter as earlier values.
- Huchra's table of published Hubble constant estimates, last updated 7 October 2010 [4], from an Internet Archive copy of 2012. No licence was stated. Asymmetric errors were averaged.

All four are public tables of measured values. The files were read as data. If the PDG 2016 file had been identical to 2014 it would have been dropped; it was not.

5 Methods

Shift in units of the earlier sigma

For quantity i with value a_i and stated sigma s_i in the first edition and value b_i in the last, the shift in units of the earlier sigma is

$$z_i = \frac{|b_i - a_i|}{s_i} \tag{1}$$

Only quantities present in both editions with $s_i > 0$ enter.

Coverage and needed multiple

Coverage at m sigma is the share of quantities with $z_i \le m$:

$$C_m = \frac{N(z \le m)}{n} \tag{2}$$

where $N(z \le m)$ counts the quantities whose shift is at most m and n is the number of quantities. The needed multiple k_{68} is the 68.27th percentile of the shifts and k_{95} the 95.45th percentile: the multiples of the stated sigma that would have covered those shares. For honest normal errors both coverages sit at 0.6827 and 0.9545 and the two multiples at 1 and 2.

Tail shape

A folded Student t distribution with a scale and degrees of freedom nu was fitted by maximum likelihood to the nonzero shifts. Small nu means heavy tails; nu of 1 is the Cauchy distribution, and a normal curve has nu without limit.

Intervals

The interval on each 1 sigma coverage comes from a bootstrap: quantities are redrawn with replacement 300

times and the coverage recomputed; the 95% interval is the middle 95 percent of the redrawn values.

The Hubble constant

Huchra's table has no later edition of each entry. Each published value was scored against a proxy truth fixed in advance, 67.4, 70 or 73 km/s/Mpc, reported separately, and the values published before 1990 were scored against 70.

Changes of assumption

Each was run apart: the moved-values arm; the top 1 percent of shifts removed; the last pair of editions alone; and, for CODATA, one row per distinct shift rounded to two decimals, since many constants are derived from the same inputs. A shrink test asked, for each quantity in three or more editions, whether its stated error fell faster than its edition-to-edition steps. An out-of-sample test fitted the needed multiples on the earlier half of the editions and applied them to the later half.

6 Controls and planted checks

The planted check built 4,000 shifts in a world where the stated sigma is half the true error and the errors follow a Student t with three degrees of freedom. The true k_{68} is

$$k_{true} = 2q_3 \tag{3}$$

where q_3 is the 0.84135 quantile of that t distribution. On a planted world with stated errors set to half the true error, the method recovered the needed multiple as 2.405 against a true 2.394. The fitted nu was 3.002 against a true 3. The kill condition did not fire.

The honest normal world draws standard normal shifts at the PDG sample size (347) and scores the same shortfall

$$S = 0.6827 - C_1 \tag{4}$$

Over 500 draws the shortfall had mean 0.0005 and 95th percentile 0.040, the top of its null distribution. The real PDG shortfall over all values was -0.110: the PDG tables over-cover, so the preregistered hypothesis that their shortfall exceeds chance failed (p from draws 1.0).

7 Results

Table 1 gives every field and Figure 2 draws the same numbers. The earlier 1 sigma interval covered 0.68 of later PDG values that moved (n 227) and 0.66 of later AME values (n 2,213, nearly all of which moved), close to the nominal 0.6827. The 95% intervals on those two coverages are 0.63 to 0.74 for PDG and 0.65 to 0.68 for AME; only 0.3 percent of the AME values did not move. At 2 sigma both fall short of 0.9545, at 0.85 and 0.82.

Covering 95.45 percent of later values took 3.8 times the stated sigma for moved PDG values, 4.0 for AME and 4.9 for CODATA. Student t fits to the nonzero shifts gave nu of 1.67 for PDG, 1.22 for AME and 2.17 for CODATA, close to the Cauchy shape.

Over all PDG values, including the 0.35 that never moved, the tables over-cover at 1 sigma (0.79). In the last PDG step, 2024 to 2025, 0.96 of 421 values did not move. Coverage that counts those values says more about which values were carried forward than about how honest the stated errors are.

The CODATA step from 2018 to 2022 covered only 0.47 at 1 sigma. A later reading of this run, made after the lock and recorded as a separate finding, traced most of that step to one input: 99 of the 273 rows moved by 4.2 to 4.7 of their 2018 sigma when the fine-structure constant moved by 4.55 of its own. The CODATA 2022

Table 1. Coverage of the last edition by the first edition's stated intervals. k68 and k95 are the multiples of the stated sigma needed to cover 68.27 and 95.45 percent. nu is the fitted Student t degrees of freedom on nonzero shifts.

Table	Editions	n	Within 1 sigma	Within 2 sigma	k68	k95	nu
PDG, moved values	2010 to 2025	227	0.68	0.85	1.00	3.8	1.67
PDG, all values	2010 to 2025	347	0.79	0.90	0.56	3.1	not fitted
AME	2003 to 2020	2,213	0.66	0.82	1.10	4.0	1.22
CODATA	2002 to 2022	211	0.85	0.92	0.75	4.9	2.17
CODATA, last step	2018 to 2022	273	0.47	0.56	4.4	4.7	not fitted
Hubble constant, truth 67.4	to 2010	544	0.49	0.74	1.66	5.4	not fitted
Hubble constant, truth 70	to 2010	544	0.53	0.75	1.67	6.5	not fitted
Hubble constant, truth 73	to 2010	544	0.49	0.70	2.0	7.7	not fitted
Hubble constant before 1990, truth 70	before 1990	115	0.35	0.55	2.9	9.8	not fitted

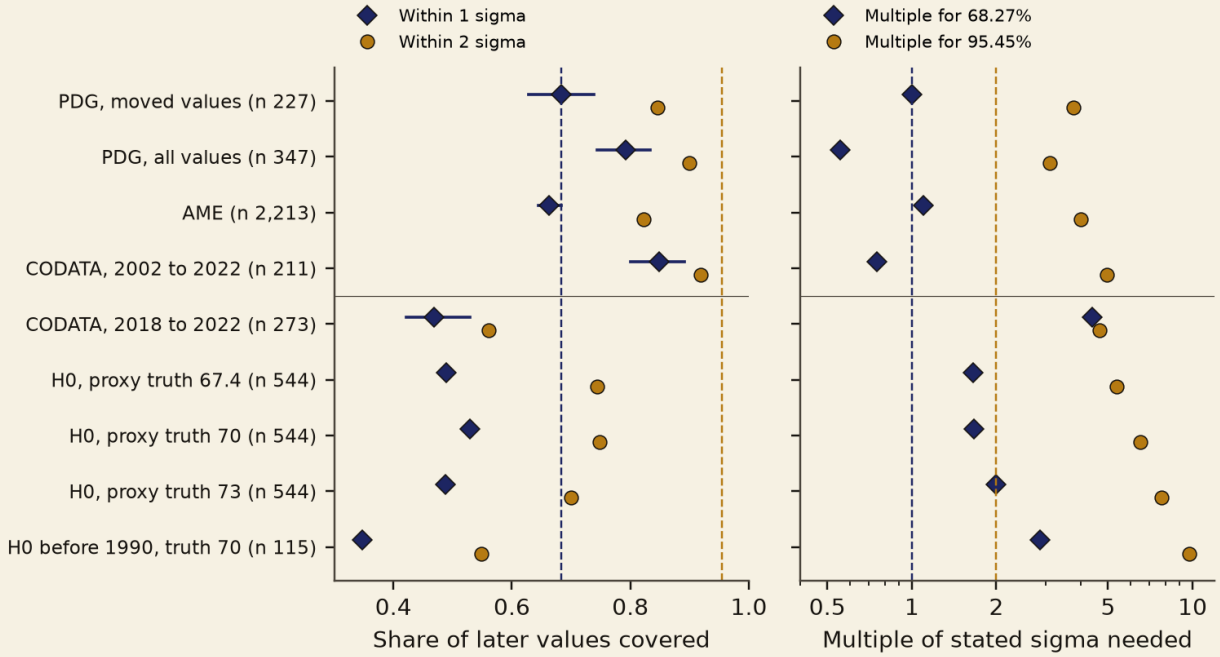


Figure 2. Left: share of later values inside the first edition's 1 sigma (diamonds, with bootstrap 95% intervals where computed) and 2 sigma (circles) intervals; dashed lines mark 0.6827 and 0.9545. Right: the multiple of the stated sigma needed to cover 68.27 percent (diamonds) and 95.45 percent (circles); dashed lines mark 1 and 2. Drawn from the run's result file.

adjustment reports that move; we did not re-read the report for this paper. The rows are not independent: kept to one row per distinct shift, CODATA has 76 rows, with 1 sigma coverage 0.63 and k_{95} 5.1.

Published Hubble constant values before 1990 covered a proxy truth of 70 km/s/Mpc within 1 sigma in 0.35 of 115 cases. Over all 544 values the needed k_{95} was 5.4 to 7.7 depending on the proxy, the worst field in the set at every proxy. Ten published speed-of-light values from before 1983, scored against the defined value, covered 0.5 at 1 sigma; six of those came from fetched sources and the rest were transcribed, so we give that row no weight.

Removing the top 1 percent of shifts changed 1 sigma coverage by about 0.01 (PDG 0.80, AME 0.67, CODATA 0.86) and lowered k_{95} to 2.8 for PDG, 3.6 for AME and 3.2 for CODATA. The largest single shift, the alpha particle molar mass in CODATA at 74 sigma, comes from the 2019 redefinition of the SI changing the molar mass rows.

The largest PDG shift (12.7) and the largest AME shift (silicon-32, 64) were not traced.

Needed multiples did not carry forward in time where values moved. Fitted on CODATA 2002 to 2014 and applied to 2014 to 2022, k_{68} of 0.65 lowered 1 sigma coverage from 0.40 to 0.32, and k_{95} of 1.46 reached 0.79 where 0.9545 was the aim. In AME, 2016 to 2020 hardly moved, and coverage stayed at 0.94.

The shrink test found stated errors falling faster than the steps between editions in 0.66 of 287 CODATA quantities, 0.52 of 104 PDG quantities and 0.25 of 2,227 AME quantities. No general rule that uncertainty shrinks faster than values settle follows from that.

Table 2 sets the forecasts against the outcomes. Of the ten forecast verdicts in the result file, six held.

Table 2. Forecasts fixed before any data were read, against the run.

Quantity	Forecast (band)	Outcome
PDG, all values, within 1 sigma	0.55 (0.40 to 0.68)	0.79
PDG, all values, within 2 sigma	0.80 (0.65 to 0.92)	0.90
PDG, k68	1.5 (1.2 to 2.2)	0.56
PDG, k95	2.5 (1.5 to 5)	3.1
PDG, nu	3 (1.5 to 6)	1.67
CODATA 2002 to 2022, within 1 sigma	0.35 to 0.70	0.85
PDG moved values below all values	yes	0.68 against 0.79
CODATA errors fall faster than steps	in more than half	0.66

8 Discussion

The pattern matches Bailey [7]: the core of a stated uncertainty is about right and the tails are not. Our fitted nu values, 1.2 to 2.2, sit at or below the heavy end of what that paper describes, and nearer the Cauchy shape. Our Hubble constant result agrees with Chen, Gott and Ratra [6] in kind: they put 95.4 percent limits at 7.0 times the quoted errors against a central value of 71, and we find 6.5 against 70 on a larger version of the same compilation.

In these tables the fault sits in the tails. Bailey draws the same distinction: underestimating every sigma by one factor widens a normal curve without giving it heavy tails. In our tables, the 1 sigma multiple sits near 1 while the 95.45 percent multiple sits near 4. A single scaling of every error bar cannot fix both.

The CODATA step from 2018 to 2022 shows how the tails arise in a table built from shared inputs: one input moves and carries many derived values with it. Henrion and Fischhoff [5] found the reported uncertainties of the constants too small across their history. A correction factor fitted on quiet years will miss the next one, which is what the out-of-sample test found.

9 Limitations

- Later tables reuse inputs from earlier ones (shared inputs), so the later edition is not independent of the earlier one. That flatters every coverage figure here. Editions that share no inputs would be the cleaner test.
- The Hubble constant numbers depend on the proxy truth chosen. Read them per proxy.
- PDG editions before 2010 could not be reached. The older AME files came through the Internet Archive and their terms were not read.
- An unchanged value counts as covered. The moved-values arm removes those values but keeps quantities whose change was small for reasons of bookkeeping.
- Needed multiples fitted on early CODATA editions did not carry forward. The 3 to 5 sigma figure describes the past and will miss when a shared input breaks.
- Our forecast of 0.55 for PDG coverage over all values missed at 0.79, because 0.35 of those values never moved.

- Scoring was by our own code and was not blind.

10 Verified

Verified: on 9 November 2026 every n, coverage, needed multiple and nu in Table 1, the PDG and AME coverage intervals, the 0.35 unchanged PDG share, the Hubble constant values at all three proxies, the changes of assumption, the out-of-sample and shrink results, the planted recovery (2.405 against 2.394) and the honest normal control were re-read from the run's result file. They match the findings ledger, the dated append-only list of our results. The preregistration's SHA-256 matches the hash recorded in the result file. The figure was drawn by a script that reads only that result file. The 2018 to 2022 CODATA tracing (99 of 273 rows, 4.55 sigma) was read from the ledger entry for the later reading; this run's result file does not hold it. The study was not re-run for this paper. The cited papers were found by searches run on 9 November 2026 and read at the level of abstracts and search summaries; their full texts were not read for this paper.

11 Corrections

- 31 October 2026: a review of our ledger noted that later tables reuse inputs and that the Hubble constant truth is a proxy. Both are stated in the limitations, and Hubble coverage is reported per proxy.
- 9 November 2026: a first publication note said the ledger's count of forecasts held could not be reproduced. That note was wrong and was withdrawn the same day: the result file has ten forecast verdicts, and six pass (cov2, k95, nu, moved, shrink, own_hold), so 6 of 10 forecasts held, as the ledger says. Every preregistered verdict is listed in the appendix.
- 9 November 2026: first published version.

12 Reproduction

- Data: download the PDG mass-width files for 2010 to 2025, the AME mass tables for 2003, 2012, 2016 and 2020, the NIST CODATA ASCII tables for 2002 to 2022, and Huchra's Hubble constant table.
- Match quantities between the first and last edition of each table and compute eq. 1 with the first edition's stated sigma.
- Report coverage at 1 and 2 sigma, eq. 2, the 68.27th and 95.45th percentiles of the shifts, a folded Student t fit to the nonzero shifts, and a bootstrap interval on the 1 sigma coverage.
- Repeat with unchanged values removed, the top 1 percent removed and the last pair of editions alone. For the Hubble constant, fix candidate truths in advance and report each.
- Preregistration SHA-256: fd8fcf7aeea1db717bce5553792bfbc63c88d7e69ee503256ccf7fc5215e2ec1. Plan SHA-256: adcbbf0f6bd1d24178e5ebaafcf3c7a5de1cca88489f5e5cdf7b1a754dec662c. Run 20261101T015415Z. Result SHA-256: 808cc6bdfb4881a9ef594399a848dc0cde0ecacfd73497e0e5f42b70524c613d.
- Cost: the analysis took under two seconds on one desktop CPU and the two controls under one second.

13 Appendix A. The preregistered verdicts

Each verdict is a set of rules written before the run, read off by code. A verdict passes only when every rule holds. Values are read from the run's result file. The last three rows belong to the arm on our own forecast bands, reported as a separate finding.

14 Glossary

Each term is defined where it is first used in the text. The same definitions, with the field each comes from and what each excludes, are collected here.

Table 3. Preregistered verdicts and the rule that decided each one.

Verdict	Deciding rule	Value	Holds
Kill not fired	planted multiple within 0.15 of truth (relative); planted own-band check within 0.15; at least 50 own bands	0.004; 0; 175	yes
PDG within 1 sigma	all values, between 0.40 and 0.68	0.79	no
PDG within 2 sigma	all values, between 0.65 and 0.92	0.90	yes
PDG k68	between 1.2 and 2.2	0.56	no
PDG k95	between 1.5 and 5	3.1	yes
PDG nu	between 1.5 and 6	1.67	yes
CODATA within 1 sigma	between 0.35 and 0.70	0.85	no
Moved below all	PDG moved coverage below all-values coverage (0.79)	0.68	yes
CODATA shrink	errors fall faster than steps in more than half	0.66	yes
PDG shortfall	shortfall above the honest normal world's 95th percentile (0.040)	-0.110	no
Own bands hold	hold share between 0.40 and 0.70	0.65	yes
Own bands factor	80th-percentile widening between 1.5 and 5	1.36	no
Own bands beat shuffle	hold share above the shuffled 95th percentile (0.223)	0.65	yes

- **stated 1 sigma uncertainty**. The plus-or-minus a table prints beside a value, meant as one standard deviation of the value's error; for a normal error the interval of one sigma either side holds the truth 68.27 percent of the time and two sigma 95.45 percent. Field: metrology (the standard uncertainty of the GUM) and physics data tables. Excludes an expanded uncertainty already multiplied by a coverage factor, and any bound meant to hold always.
- **coverage**. The share of cases in which an interval drawn round an earlier value contains the value that later replaced it; here the interval is one or two of the earlier value's own stated sigma either side. Field: statistics and metrology. Excludes the share of intervals that contain the true value, which no later table can supply.
- **preregistration**. A dated written plan for a study, fixed and hash-locked before any result is seen: the question, the data, the statistic, the controls, the forecasts and the kill conditions. Field: research method (metascience). Excludes a plan revised after looking at the outcome, and a protocol written only for the record after the run.
- **moved-values arm**. The same coverage count repeated after dropping every quantity whose value did not change between the two editions, since an unchanged value counts as covered whatever its stated uncertainty. Field: research method, our usage. Excludes a test of whether the unchanged values were right.
- **proxy truth**. A value fixed in advance and used in place of the unknown true value where no later edition settles it; here three values of the Hubble constant, 67.4, 70 and 73 km/s/Mpc, each reported on its own. Field: research method, our usage. Excludes a claim that any of the three is the true value.
- **planted check**. Data built so that the right answer is known, run through the same analysis before the real data, to show that the analysis can see the effect when it is there. Field: research method; called a positive control in experimental science. Excludes any check made on the real data, which cannot show what the analysis misses.
- **control**. A version of the data with the structure under test removed (for example shuffled or pooled), scored the same way as the real data, so the real score has something to beat. Field: statistics and experimental design. Excludes a comparison with a different dataset or with a published number.
- **kill condition**. A rule written in the preregistration that, when met, decides against the claim with no room for judgement after the run. Field: research method (our usage, after Popper's falsification). Excludes reasons found after the run for setting a result aside.
- **shift in units of the earlier sigma**. The size of the change in a quantity's value between an earlier and a later edition of a table, divided by the uncertainty stated in the earlier edition. Field: statistics, our usage; called a normalised residual in metrology. Excludes the sign of the change, and any uncertainty in the later value.

- **needed multiple**. The multiple of the stated sigma that would have covered 68.27 or 95.45 percent of the later values; it is the matching percentile of the shifts in units of the earlier sigma, written k68 and k95. Field: metrology, our usage; a coverage factor fitted after the fact. Excludes a factor known before the later values were published.
- **Student t distribution and its tail index nu**. A bell-shaped family with heavier tails than the normal curve; its degrees of freedom nu set the tail weight, so small nu means large shifts are common, nu of 1 is the Cauchy distribution and nu without limit is the normal curve. Field: statistics. Excludes skewed or bounded shapes.
- **Cauchy distribution**. The Student t distribution with nu equal to 1, whose tails are so heavy that its mean and variance do not exist. Field: probability. Excludes any distribution with a finite variance.
- **bootstrap**. Redrawing the quantities of a table with replacement, here 300 times, and recomputing the coverage each time; the middle 95 percent of the recomputed values is the interval. Field: statistics, resampling. Excludes uncertainty from the choice of editions or from shared inputs, which resampling quantities does not touch.
- **95% interval**. The range that holds the middle 95 percent of the bootstrap or control draws for a number; we report it beside the number. Field: statistics. Excludes a statement that the true value lies inside with 95 percent probability.
- **honest normal world**. Simulated shifts drawn from a standard normal distribution at the PDG sample size, so that every stated sigma is exactly right, scored the same way as the real shifts. Field: statistics, our control. Excludes heavy tails and shared inputs.
- **null distribution**. The spread of scores a control gives over many random draws; its 95th percentile is the bar a real score must clear. Field: statistics. Excludes a theoretical distribution assumed rather than drawn from the data.
- **p value (from draws)**. The share of control draws scoring at or above the real score, with one added to the count and to the number of draws, so it is never zero. Field: statistics. Excludes a p value from a textbook formula that assumes a distribution.
- **shared inputs**. Measurements or derived values that feed both an earlier and a later edition of a table, so that the two editions are not independent and agree more than independent work would. Field: metrology and data evaluation. Excludes measurements made only for the later edition.
- **findings ledger**. The append-only, dated list of every result we have recorded, numbered F1, F2 and on; corrections are added as new dated lines and old entries are never rewritten. Field: our records. Excludes a curated list of successes.
- **verdict**. The pass or fail of one preregistered rule set against the run's numbers, read off by code. Field: research method (our usage). Excludes an interpretation written after reading the numbers.

15 References

[1] Particle Data Group. Review of Particle Physics, mass and width tables for Monte Carlo programs, one file per edition, 2010 to 2025. https://pdg.lbl.gov. Retrieved 31 October 2026.

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