WHO DETERMINES OUR FUNDAMENTAL CONSTANTS?

ALL OF US!

THE RENAISSANCE OF RENORMALIZATION AND HAND-MADE SLIDES

John Ralston

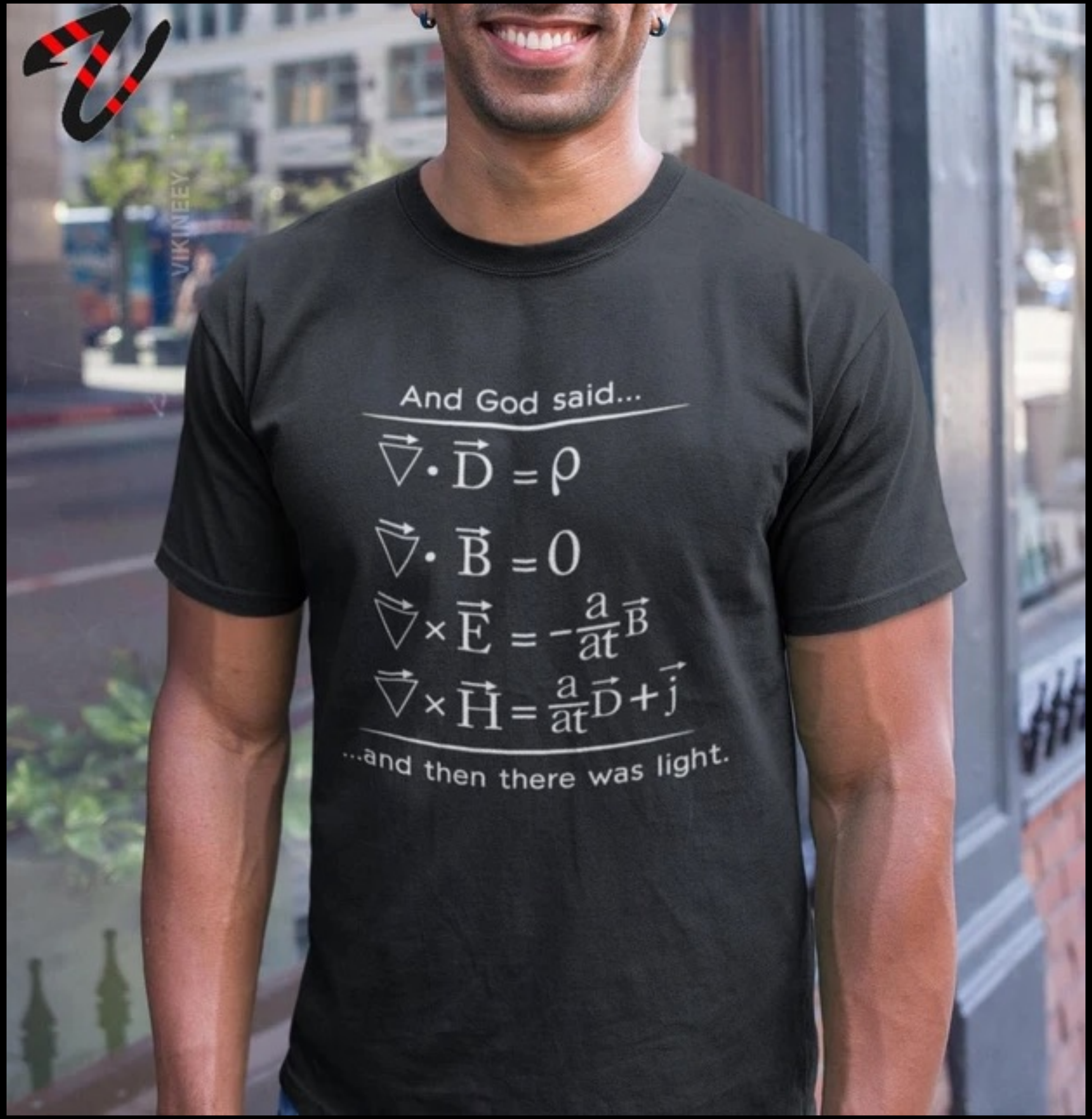
WITH JOHN C. MARTENS

Physics Evolves!

Once upon a time

TO FIND A CONSTANT OF NATURE, LOOK IN A TABLE, OR IN THE ENCYLOPEDIA BRITTANICA

$c = 299792458$ m/s



PRONOUNCE "A BEE OVER A TEE"

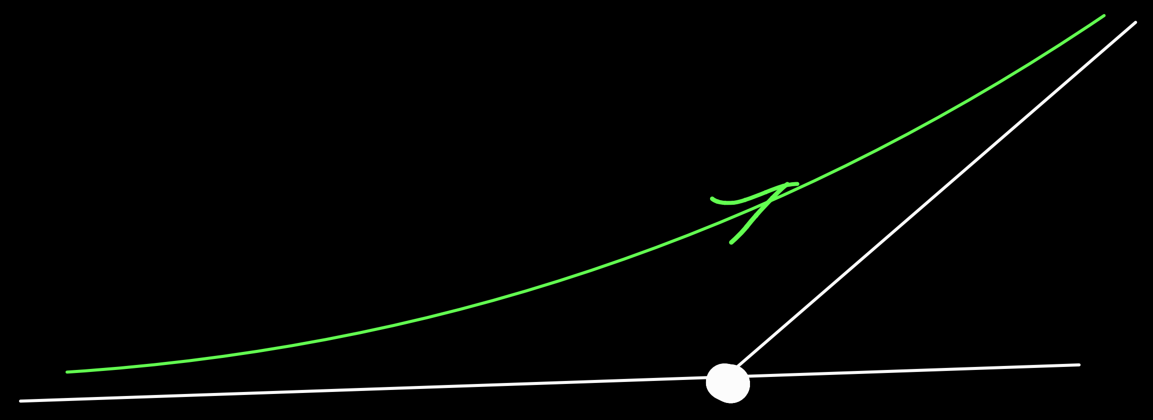
WHAT DO WE MEAN BY A FUNDAMENTAL CONSTANT?

m_e	electron mass
ε_0	permittivity of free space
r_p	proton charge radius
α	fine structure constant

SORRY, $\Rightarrow$ THESE ARE NOT SELF-DEFINING EXPERIMENTAL OBSERVABLES $\Rightarrow$ OLD WORDS GOT NEW DEFINITIONS

RUTHERFORD 1911 CLASSICAL PHYSICS

$\vec{F} = m\vec{a}$



Impact $b = \frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 m v^2} \cot\frac{\theta}{2}$

$\vec{F} = \frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 r^2}\hat{r}$

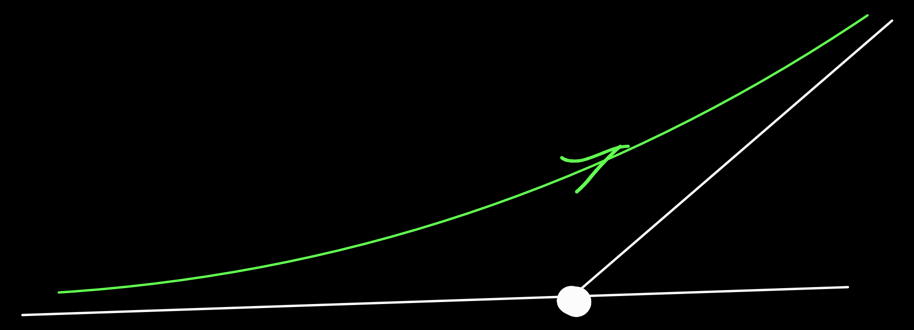
$$\frac{d\sigma}{d\cos\theta} \sim \pi \left|\frac{db^2}{d\cos\theta}\right|$$

$$\frac{d\sigma}{d\Omega} = \left(\frac{Z_1 Z_2 e^2}{8\pi\varepsilon_0 m v^2}\right)^2 \frac{1}{\sin^4(\theta/2)}$$

ALL PARAMETRS KNOWN IN ADVANCE
FROM CLASSICAL PHYSICS

RUTHERFORD 1911 CLASSICAL PHYSICS

$\vec{F} = m\vec{a}$



Impact $b = \dfrac{z_1 z_2 e^2}{4\pi\varepsilon_0 m v^2} \cot\dfrac{\theta}{2}$

$\vec{F} = \dfrac{z_1 z_2 e^2}{4\pi\varepsilon_0 r^2}\hat{r}$

$$\frac{d\sigma_{RUTH}}{d\Omega} = \left(\frac{z_1 z_2 e^2}{8\pi\varepsilon_0 m v^2}\right)^2 \frac{1}{\sin^4(\theta/2)}$$

ALL PARAMETRS KNOWN IN ADVANCE FROM CLASSICAL PHYSICS

YET ASSISTANTS GEIGER & MARSDEN DO INCORRECT QUANTUM MECHANICAL EXPERIMENT

CROWTHER DOES INCORRECT QUANTUM MECHANICAL e^- BEAM EXPERIMENT

$d\sigma_{MOTT} \neq d\sigma_{RUTH}$ "IN LIMIT $\hbar \to 0$"

COULOMB FORCE MODEL INCONSISTENT

AFTER QUANTUM MECHANICS,
THE QUANTUM THEORY
DEFINES QUANTUM PARAMETERS

$$i\hbar \frac{\partial \psi}{\partial t} = -\frac{\hbar^2}{2m_e}\nabla^2\psi - \frac{e^2}{4\pi\varepsilon_0 r}\psi \qquad \text{MKSA}$$

$$i \frac{\partial \psi}{\partial t} = -\frac{\hbar}{2m_e}\nabla^2\psi - \frac{e^2 c}{4\pi\varepsilon_0 \hbar c r}\psi$$

$$\frac{\hbar}{m_e} \to \lambda_e \qquad \frac{e^2}{4\pi\varepsilon_0 \hbar c} \to \alpha$$

2 PARAMETER THEORY

λ_e, α

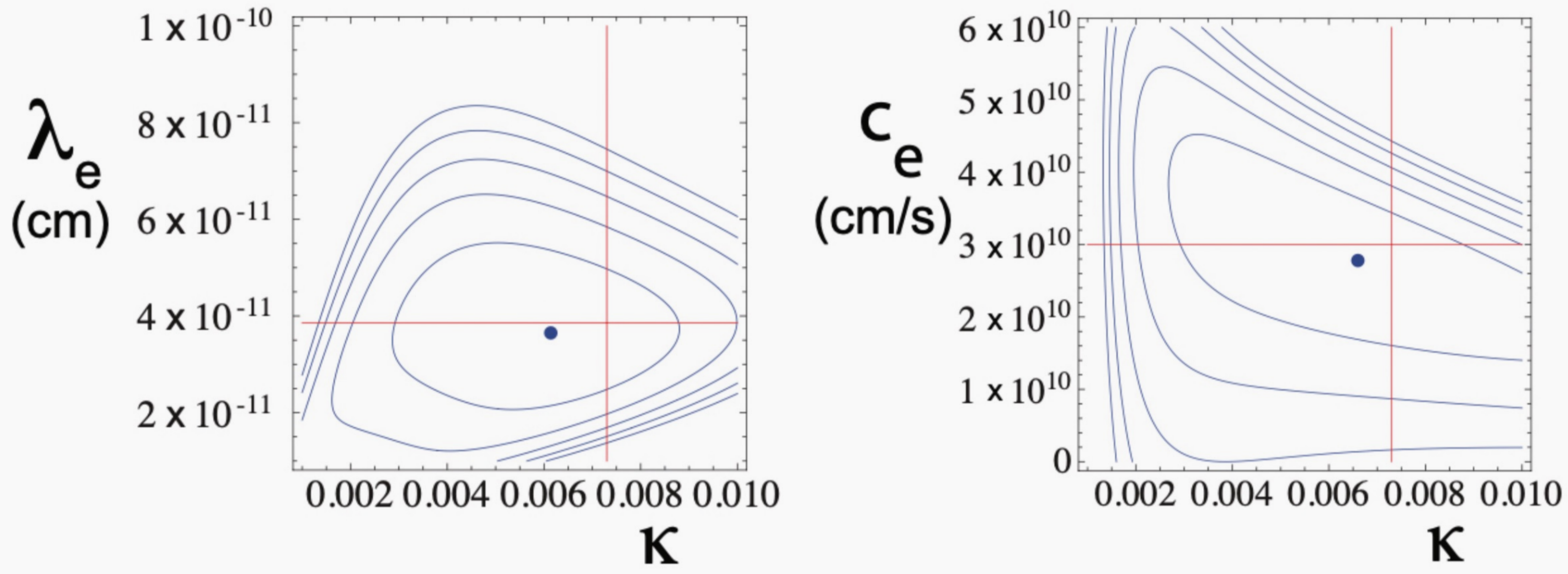
DIRECT FROM EXPERIMENT

FORMER MKS
$e, \varepsilon_0, \hbar, m_e$
ARE GONE

NO USE FOR $\hbar$

eliminating Planck's constant. The electron mass is determined about 67 times more precisely, and the unit of electric charge determined 139 times more precisely. Improvement in the experimental value of the fine structure constant allows new types of experiment to be compared towards finding "new physics." The long-standing goal of eliminating

Figure 5. Contours of χ^2, the summed-squared differences of data versus fit obtained from the independent relations given in Table 1. *Left panel*: As a function of parameters κ and λ_e with $c_e \to c$. *Right panel*: As a function of parameters κ and c_e with λ_e given by Compton's value. Dots shows the points of minimum $\chi^2 \sim 0.24$ in both cases. Contours are $\chi^2 = 1, 2, 3...$ Lines show modern values $c = 3 \times 10^{10} cm/s$, $\lambda_e = 3.87 \times 10^{-11}$, $\kappa = 1/137$ all lie inside the range of $\Delta\chi^2 \lesssim 1$.



DATA BEFORE 1929

JPR

International Journal of Quantum Foundations **6** (2020) 48-87

AFTER QUANTUM FIELD THEORY,

BARE THEORY PARAMETERS "g_B"

ARE NOT EVEN OBSERVABLE

NOR IS A UV CUTOFF Λ OBSERVABLE

AND THIS FACT DOES NOT ORIGINATE IN REGULATING DIVERGENCES

FIT $g_R(\mu)$ TRIVIAL

$$\text{DATUM 1} = D_1\left(g_B, \tfrac{1}{\varepsilon}, \mu\right) = D_1\left(g_R(\mu)\right)$$

$$\text{DATUM 2} = D_2\left(g_B, \tfrac{1}{\varepsilon}, \mu\right) = D_2\left(g_R(\mu)\right)$$

PREDICT D_2 NOT TRIVIAL

↑

EXPERIMENT

TO WORK

NEEDS A UNIVERSAL CONSPIRACY

$$g_B, \tfrac{1}{\varepsilon}, \mu = \frac{1}{\varepsilon} + \gamma + \log\mu + \log(4\pi)$$

ALL SAME g_R IN EVERY CASE.

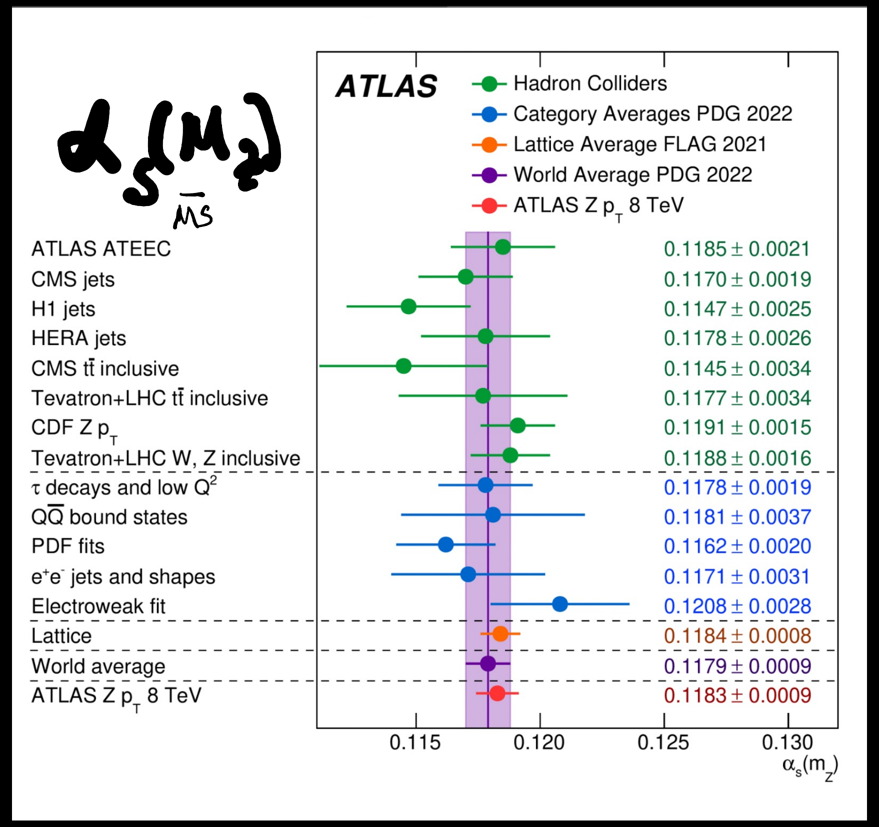
THIS DEFINES A

"RENORMALIZABLE THEORY"

Scheme Dependence

Scheme Dependence

THE UNOBSERVABLE THEORY CONVENTIONS DEFINE THEIR OWN SCHEME



MAGNIFICENT OBSESSION TO CONFORM WITH $\overline{MS}$ SCHEME

IS IT A CULT

MINIMIZING COPYS OF $\gamma + \ln 4\pi$ IN NOTES

SCHEME DEPENDENCE IS ALSO A BAYESIAN FACT OF DATA ANALYSIS

UNITS AND CONSTANTS ARE A SCHEME

We do not care about actual SI definitions partly because we do not consider seriously the legal side of SI and due to that we believe that we may ourselves interpret and correct SI definitions if necessary. Physicists serve as experts only while decisions are made by authorities. The SI system has been created for a legal use and trade rather than for scientific applications.

Karshenboim, S.~G.,
"Fundamental physical constants: looking from different angles",
Canadian Journal of Physics, 83, 767, 2005

$$p(\text{data} \mid \vartheta_\ell)\, p(\vartheta_\ell) \rightarrow p(\vartheta_\ell \mid \text{data})$$

PARAMETERS ϑ_ℓ

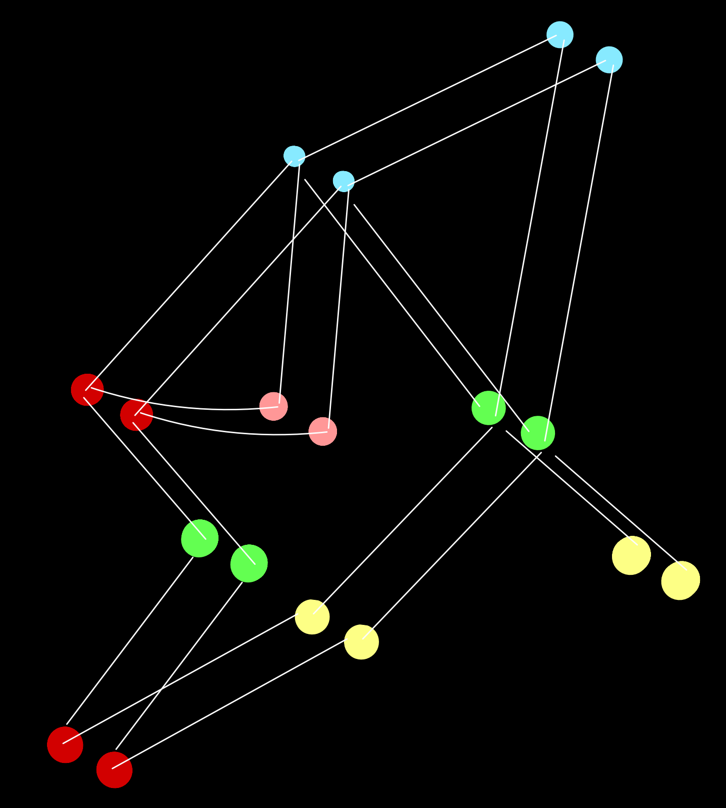
DIFFERENT ASSUMPTIONS MUST BE EXPLORED AND DIVULGED

EVERYTHING IS CONDITIONAL

- ON THEORY
- ON METHOD
- ON DATA AVAILABLE AND USED

DECISIONS MUST BE MADE

DON'T BLAME PEOPLE FOR MAKING DECISIONS!



"VALUE ADDED" IS A NETWORK OF RELATIONSHIPS, NOT A TABLE OF NUMBERS

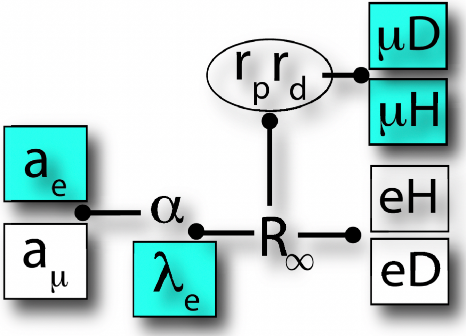
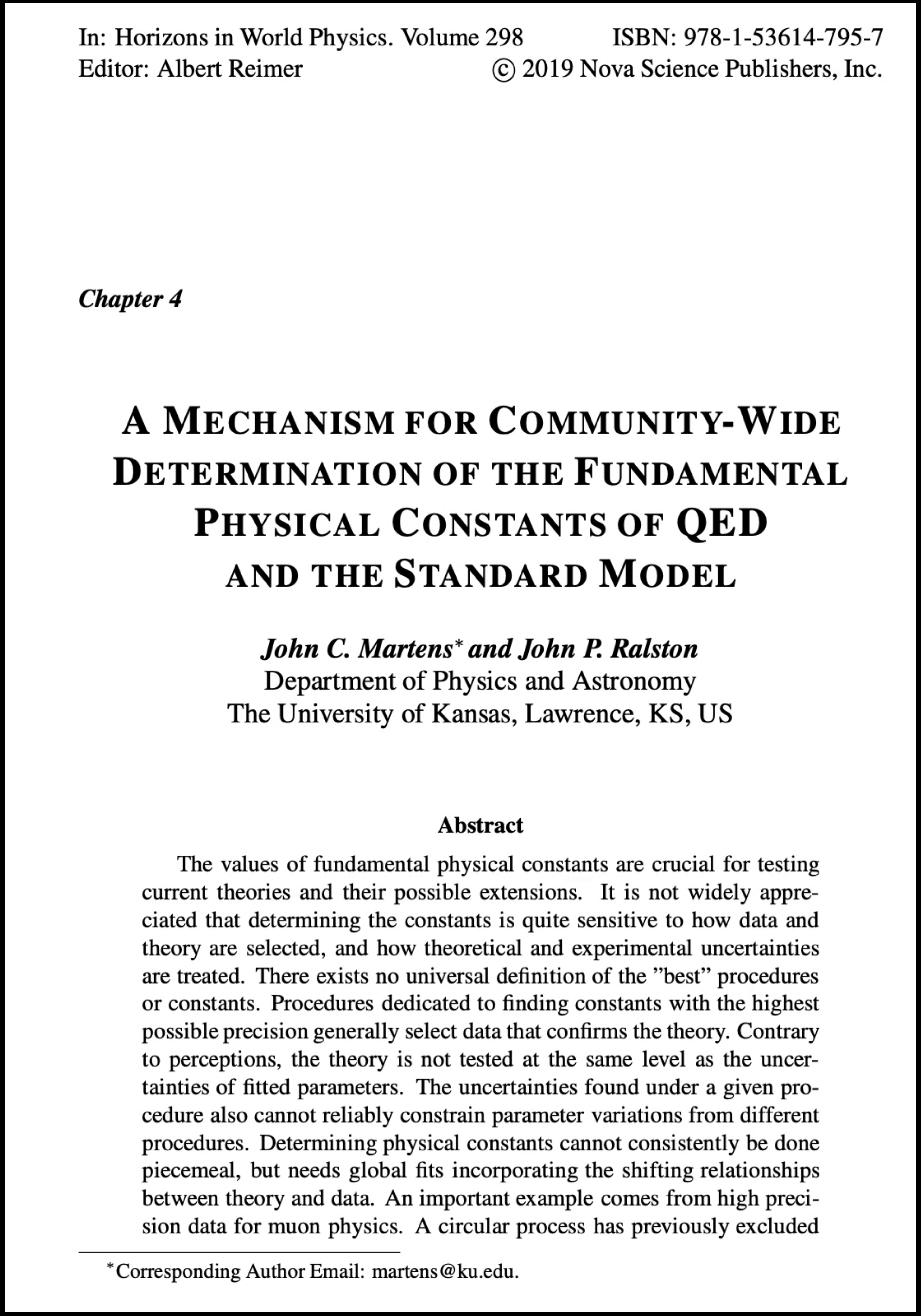


Figure 6: Schematic of the global fit assuming Standard Model physics. A line between a fit parameter and a data sector indicates a dependency. Strong dependencies are indicated by blue data sectors. For instance, a_e (blue) dominates the fit to α, while a_μ, which depends directly on α, does not. The Rydberg is strongly dependent on μH and μD data because the experimental and theoretical uncertainties of that data are very small.


In: Horizons in World Physics. Volume 298
Editor: Albert Reimer
ISBN: 978-1-53614-795-7

Chapter 4

A Mechanism for Community-Wide Determination of the Fundamental Physical Constants of QED and the Standard Model

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Abstract

The values of fundamental physical constants are crucial for testing current theories and their possible extensions. It is not widely appreciated that determining the constants is quite sensitive to how data and theory are selected, and how theoretical and experimental uncertainties are treated. There exists no universal definition of the "best" procedures or constants. Procedures dedicated to finding constants with the highest possible precision generally select data that confirms the theory. Contrary to perceptions, the theory is not tested at the same level as the uncertainties of fitted parameters. The uncertainties found under a given procedure also cannot reliably constrain parameter variations from different procedures. Determining physical constants cannot consistently be done piecemeal, but needs global fits incorporating the shifting relationships between theory and data. An important example comes from high precision data for muon physics. A circular process has previously excluded

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A NEW IDEA
OPEN SOURCE COMMUNITY DETERMINATION

LET EVERYONE EXPLORE
THEIR OWN UNIVERSE

SCHOLARS READ
THEIR PAPERS
AT MEETINGS

THEY THINK WORDS
ARE IMPORTANT
TO GET RIGHT

REMBRANT

Contradictions in the determination of fundamental physical constants have existed for years. Yet the problem has seldom been recognized. Instead, an implicit agreement led to constant determinations based on selecting some data for high precision, while excluding other data. We show that global fits are quite sensitive to how data and theory are selected, and how theoretical and experimental uncertainties are treated. The high sensitivity of constants to procedural decisions is disturbing.

The modern era of high precision measurements has created a new situation in fundamental physics. The main scientific reason to concentrate on high precision constants is to test theory and explore theoretical alternatives. Posing scientific alternatives is not mere speculation: Science exists by posing alternatives. An alternative theory does not change one constant, but generally disrupts the network of relationships involved in the global determination of many constants. Yet this is not generally understood: Most of the time, a new experiment or a new theory variation will deal with one constant that gets attention, as if determining the other constants were independent, and written in stone.

Scientists generally assume that tables of fundamental constants have been determined with extreme objectivity. Yet compiling fundamental constants is a form of data analysis. There are no universal rules for data analysis, while there are sensible guidelines. The actual decisions scientists make depend on the field they happen to inhabit.

We find it is not possible to rely on any particular constant nor its uncertainty without taking into account the universe of assumptions and correlations that led to the constant. In effect, the constants of the 21st century are mutually dependent on a finite perturbative renormalization scheme that defines their limitations. A true global approach however requires well in excess of 30,000 characters of Mathematica code.

We have developed a website, called Constant Finder (http://www.constantfinder.org), which allows users to pose alternatives to QED within a global framework, often within seconds. Anyone interested can determine the fundamental constants on the basis of data, uncertainties, and theory inputs of their choosing.

deuterium, and $m_e/$ comes from atomic recoil and mass ratio experiments. Symbol θ_X stands for any additional parameters. A basic fit is expressed with

$$\begin{aligned}\chi^2 &= \frac{(a_e^{exp} - a_e^{theory}(\alpha,\, \theta_X))^2}{\sigma^2(a_e)} + \frac{(a_\mu^{exp} - a_\mu^{theory}(\alpha,\, \theta_X))^2}{\sigma^2(a_\mu)} \\ &+ \sum_j^{N_H} \frac{(\Delta f_{eH,j}^{exp} - \Delta f_{eH,j}^{theory}(\alpha,\, R_\infty,\, r_p,\, \theta_X))^2}{\sigma^2(\Delta f_{eH})} + \sum_j^{N_D} \frac{(\Delta f_{eD,j}^{exp} - \Delta f_{eD,j}^{theory}(\alpha,\, R_\infty,\, r_d,\, \theta_X))^2}{\sigma^2(\Delta f_{eD})} \\ &+ \frac{(\Delta f_{\mu H}^{exp} - \Delta f_{\mu H}^{theory}(r_p,\, \theta_X))^2}{\sigma^2(\Delta f_{\mu H})} + \frac{(\Delta f_{\mu D}^{exp} - \Delta f_{\mu D}^{theory}(r_d,\, \theta_X))^2}{\sigma^2(\Delta f_{\mu D})} \\ &+ \frac{(4\pi c R_\infty/\alpha^2 - (m_e/h)^{exp})^2}{\sigma^2(m_e/h)}\end{aligned} \tag{4}$$

The terms in the order shown will be called $\chi^2(a_e)$, $\chi^2(a_\mu)$, and so on. The parameters we typically vary are displayed explicitly in the expression above, while others whose variations are safely suppressed are set to reference values given on the website.

FIRST VALIDATE YOUR CODE(S)

TWO PEOPLE
TWO CODES
TWO MACHINES
COMPARE OUTPUTS

Table 3. Experimental data compared to calculations by the Constant Finder. Calculated values are based on a Standard Model fit to Table 2 data. Fitted constants for the fit appear in Line 1, Table 4

Experimental datum	Experimental value	Fitted value	σ_{expt}
$\nu_H(2S1/2 - 8S1/2)$ [Hz]	$7.70649350012000 \times 10^{14}$	$7.70649350015089 \times 10^{14}$	8600.
$\nu_H(2S1/2 - 8D3/2)$ [Hz]	$7.70649504450000 \times 10^{14}$	$7.70649504448244 \times 10^{14}$	8300.
$\nu_H(2S1/2 - 8D5/2)$ [Hz]	$7.70649561584200 \times 10^{14}$	$7.70649561577394 \times 10^{14}$	6400.
$\nu_H(2S1/2 - 12D3/2)$ [Hz]	$7.99191710472700 \times 10^{14}$	$7.99191710480623 \times 10^{14}$	9400.
$\nu_H(2S1/2 - 12D5/2)$ [Hz]	$7.99191727403700 \times 10^{14}$	$7.99191727407767 \times 10^{14}$	7000.
$\nu_H(2P1/2 - 2S1/2)$ [Hz]	$1.05784500000000 \times 10^{9}$	$1.05783220761556 \times 10^{9}$	9000.
$\nu_H(2S1/2 - 2P3/2)$ [Hz]	9911200000	9911209318	12000.
$\nu_H(2P1/2 - 2S1/2)$ [Hz]	1057862000	1057832208	20000.
$\nu_D(2S1/2 - 8S1/2)$ [Hz]	$7.708590412457 \times 10^{14}$	$7.7085904124256 \times 10^{14}$	6900.
$\nu_D(2S1/2 - 8D3/2)$ [Hz]	$7.708591957018 \times 10^{14}$	$7.70859195700519 \times 10^{14}$	6300.
$\nu_D(2S1/2 - 8D5/2)$ [Hz]	$7.708592528495 \times 10^{14}$	$7.70859252845263 \times 10^{14}$	5900.
$\nu_D(2S1/2 - 12D3/2)$ [Hz]	$7.99409168038 \times 10^{14}$	$7.99409168041396 \times 10^{14}$	8600.
$\nu_D(2S1/2 - 12D5/2)$ [Hz]	$7.994091849668 \times 10^{14}$	$7.9940918497316 \times 10^{14}$	6800.
$\nu_D(2P1/2 - 2S1/2)$ [Hz]	1059280000	1059220261	60000
$\nu_D(2S1/2 - 2P3/2)$ [Hz]	9912610000	9912815235	300000
$\nu_D(2P1/2 - 2S1/2)$ [Hz]	1059280000	1059220261	60000
a_e	0.00115965218072	0.00115965218078	2.8×10^{-13}
a_μ	0.00116592089	0.00116591840	6.3×10^{-10}
$\Delta E_{LS}(\mu H)$ [meV]	202.3706	202.3705	0.0023
$\Delta E_{LS}(\mu D)$ [meV]	202.8785	202.8785	0.0034
λ_e [m]$/10^{-12}$	2.4263102367	2.4263102356	1.1×10^{-9}

LATER
"dalp"
$= \frac{\delta\alpha}{\alpha} / 10^{-10}$

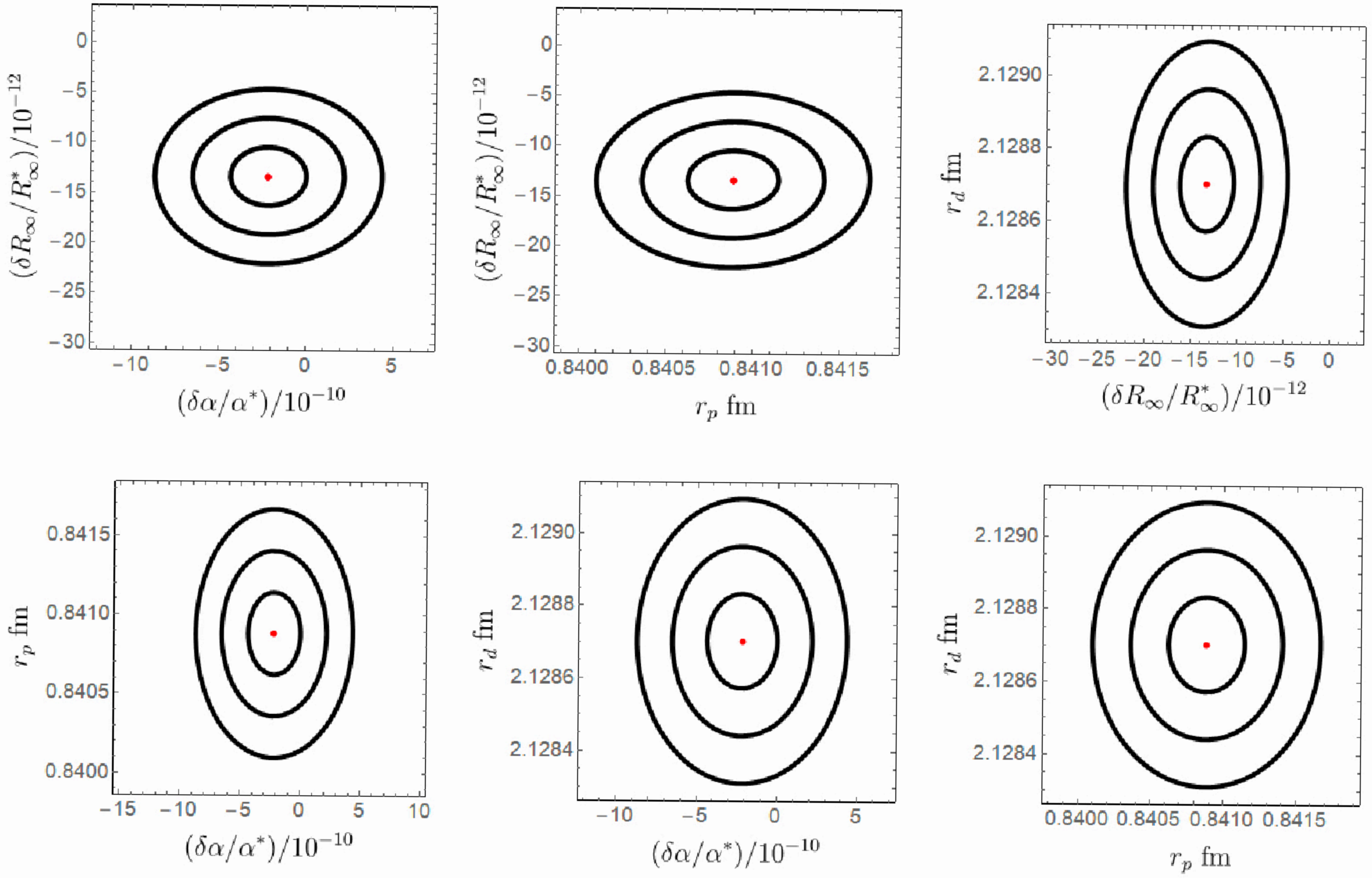


Figure 8: 1, 2, and 3σ chi-squared contours for the full global fit in fit-parameter space. In each subplot the fit parameters not shown are fixed at the best fit values of Line 1, Table 4.

line	omit	χ^2	dof	$\chi^2_{\lambda_c}$	$\chi^2_{\mu H}$	$\chi^2_{\mu D}$	$\chi^2_{a_e}$	$\chi^2_{a_\mu}$	χ^2_{eH}	χ^2_{eD}
1	*none*	27.5	17	0.18	0.0012	0.000095	0.042	15.7	7.4	4.3
2	λ_c	27.3	16	–	0.0012	0.000095	0	15.7	7.3	4.2
3	μH	25.1	16	0.18	–	0.00043	0.043	15.7	4.8	4.4
4	μD	27.3	16	0.18	0.00076	–	0.042	15.7	7.2	4.2
5	$\mu H, \mu D$	22.8	15	0.19	–	–	0.045	15.7	3.3	3.5
6	a_e	27.3	16	0.000013	0.0012	0.000094	–	15.7	7.3	4.3
7	a_μ	11.8	16	0.18	0.0012	0.000095	0.042	–	7.3	4.3
8	a_e, a_μ	11.6	15	0	0.0012	0.000094	–	–	7.3	4.3
9	$\mu H, \mu D, a_\mu$	7.1	14	0.19	–	–	0.044	–	3.3	3.5
10	eH	20.0	9	0.18	0	0	0.042	15.7	–	4.1
11	eD	23.1	9	0.18	0.00062	0	0.042	15.7	7.2	–
12	eH, eD	15.7	1	0	0	0	0	15.7	–	–
13	$eD, \mu D$	23.1	8	0.18	0.00062	–	0.042	15.7	7.2	–

Table 6: Contributions to χ^2 for global fits with different observables omitted. *dof* stands for the number of degrees of freedom. Standard Model physics is assumed. The a_μ sector, when it appears in the global fits, contains only one experimental observable while contributing 15.7 units of chi-squared. All other sectors across all fits have well-controlled contributions to χ^2.

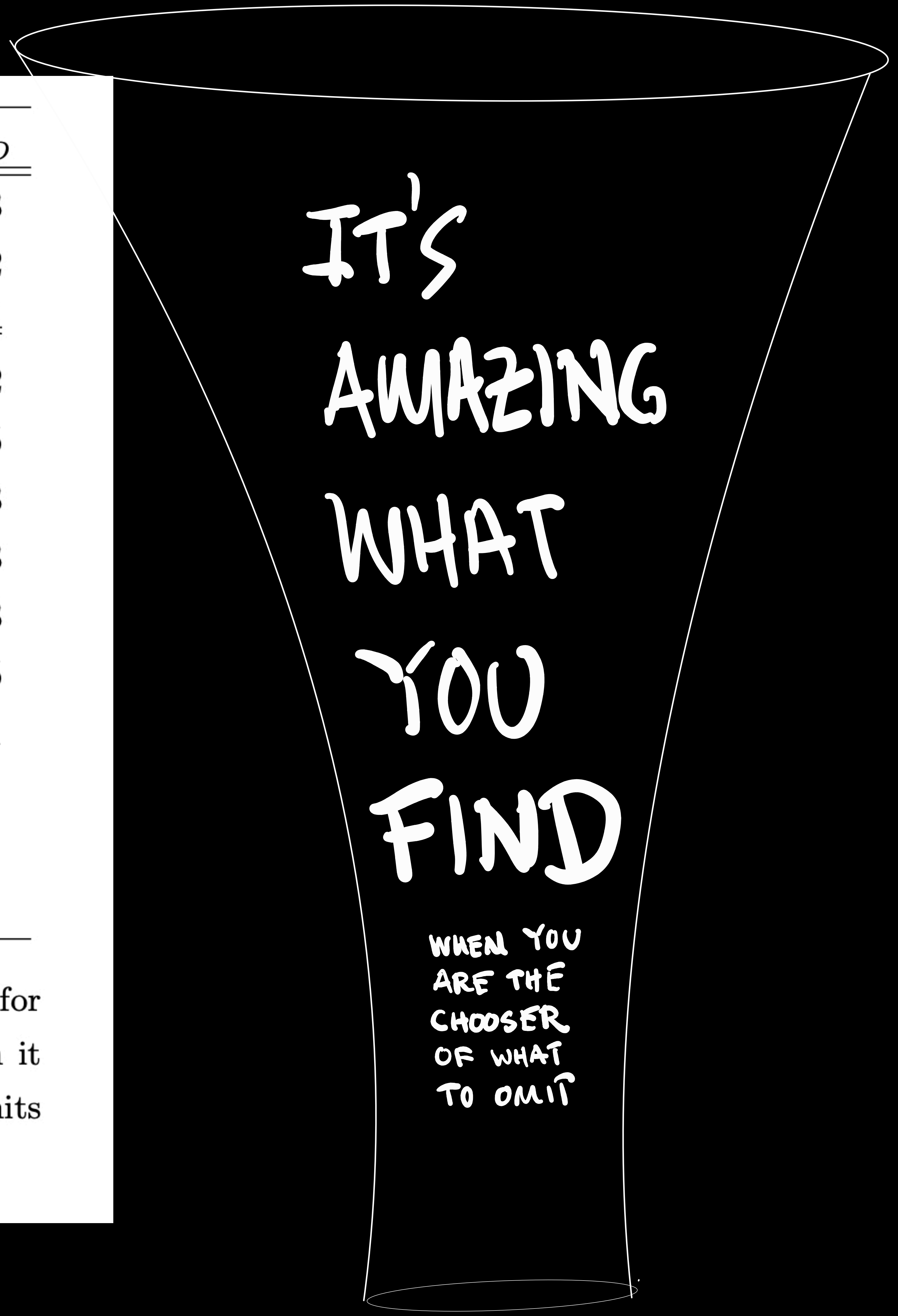
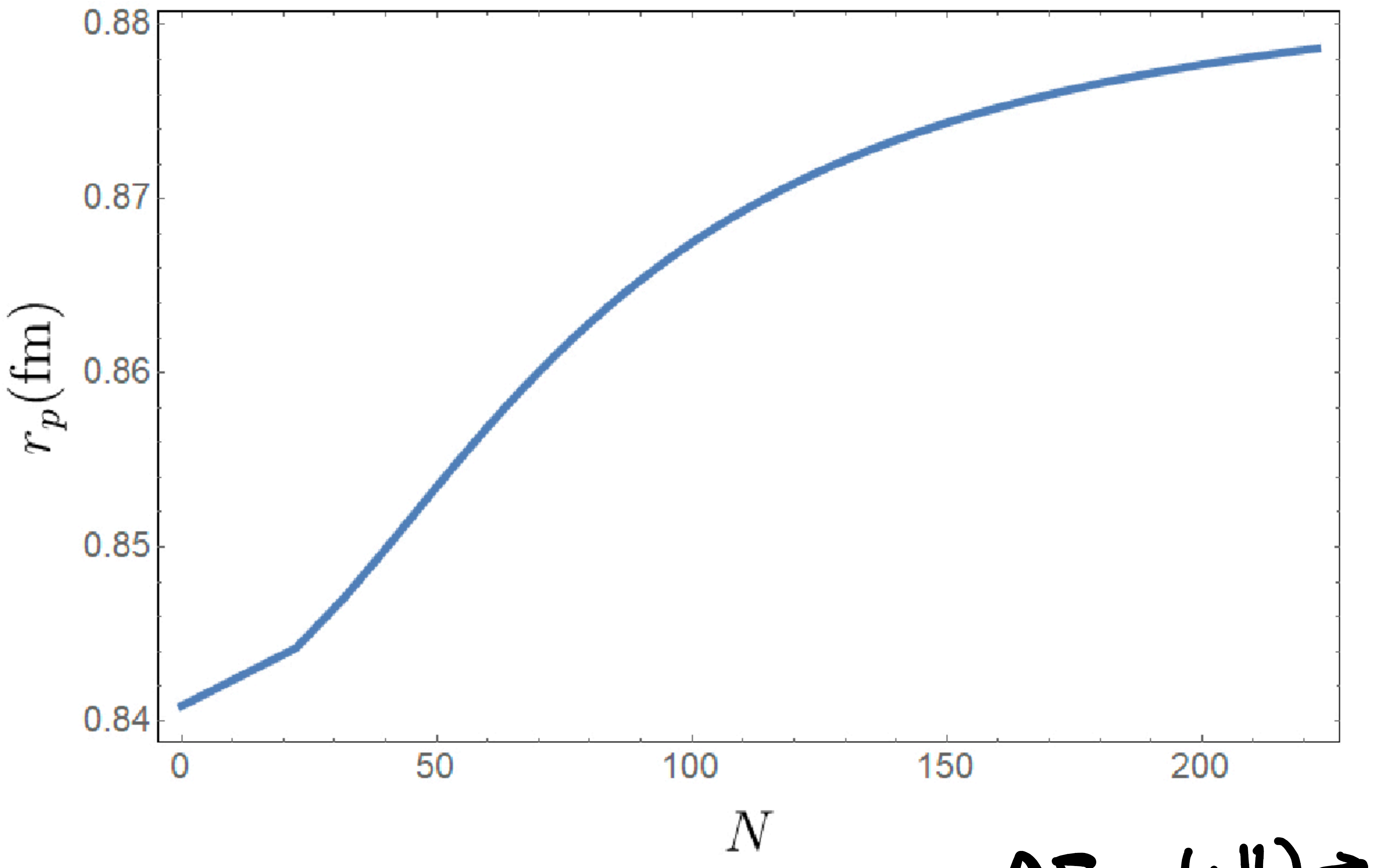


Figure 10 rather clearly shows the effect of *including* μH data. The figure is made adjusting the experimental uncertainty $\sigma(\mu H)$ as a free parameter, while otherwise defined by Line 3 of Table 4. As $\sigma_{\mu H}$ is increased, the fitted r_p approaches the value from eH. Increasing $\sigma_{\mu H}$ by a factor above 200 (!) dilutes its information enough to be the same as omitting it.

For simplicity the muonic deuterium (μD) datum has been omitted in making Figure 10. When included, the μD datum dominates the fit to r_d exactly parallel to the above. When the Rydberg is fit by generic least squares using eH, eD, μH, μD the muonic data is decisive, unless decisions are made to render it otherwise.



$\Delta E_{LS}(\mu H) \rightarrow N\sigma_{LS}$

2019

Figure 10: The change in the fitted value of r_p from adjusting the experimental error of the μH datum $\Delta E_{LS}(\mu H) \rightarrow N\sigma$, where σ is the experimental uncertainty. As N is increased r_p moves from .84 fm, the value favored by the μH datum, to .88 fm, the value favored by the eH sector. The global fit here is the same as Line 1, Table 4 omitting muonic deuterium.

but will it run today?

http://constantfinder.physics.ku.edu:8080/ROOT-2/home.jsp

- It works!
- Cosmetics and Web Interface Need Improving

  Looking for Collaboration!

  A TRUE OPPORTUNITY TO BE CREATIVE
- We have money: Patent Royalties
- THIS CAN'T BE STOPPED.

  IT'S THE FUTURE!

THANKS!