

# The fundamental constants and the need for a self-consistent, global approach

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work done in collaboration with John Ralston

arXiv:1810.XXXXX

[www.constantfinder.org](http://www.constantfinder.org) (soon!)

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CONSTANT — FINDE $R_{\infty}$  — 

[www.constantfinder.org](http://www.constantfinder.org) on loading ...



Open-source software for the determination of the fundamental constants

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### Instructions

Expand the collapsible menus to specify fit-type, input data, and theory alternatives. When done, click 'Evaluate' or 'Generate' in the header. 'Evaluate' prints global fit results in the browser window under the 'Results' section. 'Generate' exports the global fit results to a Mathematica notebook file. The notebook file also contains an analytic expression for the chi-squared function used in the global fit, enabling deeper analysis. More details can be found under FAQ and in [arXiv:1810.XXXXX](https://arxiv.org/abs/1810.XXXXX). Please cite [arXiv:1810.XXXXX](https://arxiv.org/abs/1810.XXXXX).

Note: the site is designed for use with Google Chrome and Firefox.

Fit-Type

# Procedure

## 1. Choose fit-type

Fit-Type

Chi-squared  Chi-squared with pull

## 2. Choose/adjust/add input data

Electron anomalous moment,  $a_e$

$a_e$  [ arXiv:1009.4831 ]

Experimental Value

0.00115965218072

Experimental Uncertainty

$2.8^{+13}$

Theory Uncertainty

0

Additional input data

New +

Select type of input data:

eH   $\mu$  H  eD   $\mu$  D   $a_e$    $a_p$    $\lambda_e$

Specify input data:

# Procedure(cont'd)

3. Add any new physics; Other = [your model here]

## Theory Alternatives

Specify any additional theory inputs

- None
- Model X or "no-name" boson [ arXiv:1606.06209 ]
- Other

4. Evaluate in-browser or generate Mathematica nb for in-depth analysis

Evaluate in browser.

EVALUATE

Generate Mathematica nb.

GENERATE

# EX:

## Analysis 1

assuming SM  
physics: proton  
size puzzle  
gone! Muon g-2  
anomaly remains

## Theory Alternatives

Specify any additional theory inputs

- None
- Model X or "no-name" boson [ arXiv:1606.06209 ]
- Other

## Global Fit Results

Evaluate in browser.

EVALUATE

Generate Mathematica nb.

GENERATE

Fitted values:

```
dalp -0.0735618 ± 0.02198
rr 0.840881 ± 0.000261597
rrD 2.12647 ± 0.00547901
```

Chi-squared:

Sector	Chi-squared
eH	7.1949
eD	4.2455
muH	0.000754973
ae	0.197676
amu	15.6748
enass	0.0000143215
total	27.3137
dof	16

## Analysis 2

assuming SM +  
'no-name'  
boson: proton  
size puzzle AND  
muon g-2  
anomaly gone!

## Theory Alternatives

Specify any additional theory inputs to global chi-squa

- None
- Model X or "no-name" boson [ arXiv:1606.06209 ]

Specify value of  $m_X$  in MeV.

$m_X$ :

- Other

## Global Fit Results

Evaluate in browser.

EVALUATE

Generate Mathematica nb.

GENERATE

Fitted values:

```
dalp -0.0692326 ± 0.0220082
rr 0.841154 ± 0.000270757
rrD 2.12655 ± 0.00547884
alpx 3.81687 × 10-8 ± 9.80602 × 10-9
```

Chi-squared:

Sector	Chi-squared
eH	6.003
eD	4.20616
muH	0.000680496
ae	1.13934
amu	0.013997
enass	0.0000143215
total	12.1632
dof	15

# How are the fundamental constants determined?

Fundamental constants  $\alpha$ ,  $R_\infty$ ,  $r_p$ ,  $r_d$ ,  $\lambda_e$   
are determined by ML fit to experimental data.

Most basic incarnation\* corresponds to minz of a  $\chi^2$  function.

$$\chi^2 = \sum_j \frac{(d_j - t_j(\theta_\ell))^2}{\sigma_j^2}$$

$d_j$  and  $t_j$  are the  $j$ th data and theory values,  
where  $t_j$  is a function of the fundamental constants  $\theta_\ell$ .

$\theta_\ell$  are free parameters, fixed by minz.

$\sigma_j$  is the  $j$ th experimental uncertainty.

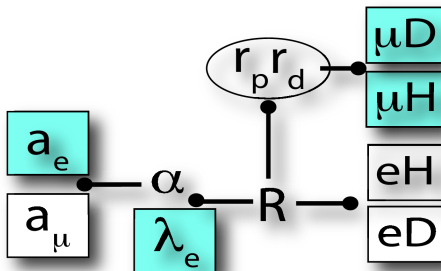
*\*Correlations, pull parameters are higher order effects, safely ignored for present purposes*

# How are the fundamental constants determined?

$\chi^2 = \sum_j \frac{(d_j - t_j(\theta_\ell))^2}{\sigma_j^2}$  can be broken out into 'data sectors'

Sectors:  $a_e$ ,  $a_\mu$ ,  $eH$ ,  $eD$ ,  $\mu H$ ,  $\mu D$ ,  $\lambda_e$  (neglecting scattering data)

Global picture



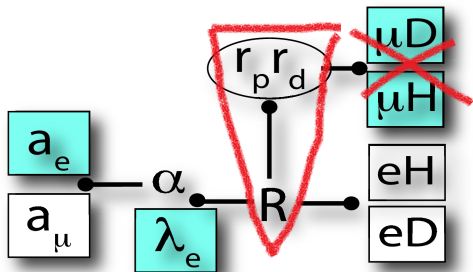
Values of constants sensitive to which sectors (and which data in which sectors) are included in fit.

# How are the fundamental constants determined?

NIST standardizes values of constants  
NIST fits constants using only *elec-  
tronic* data; *does not confront muon  
expt'l anomalies*

**Rationale:** STANDARDIZATION

*"We own the fundamental constants!"  
-Bill Phillips*

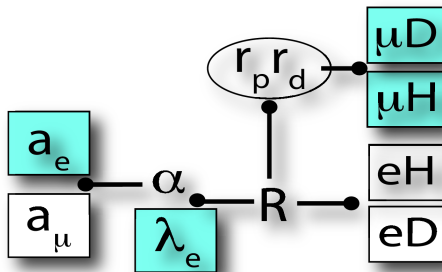


**NIST = NO MUONS**  
*piecemeal fit*

NIST sectors:  $eH$ ,  $eD$ ,  $\lambda_e$  ( $\alpha$  det'd upstream from fit to  $a_e$ )



# How are the fundamental constants determined?



## SELF-CONSISTENCY REQUIRES A GLOBAL FIT

If you:

add data, remove data, change data, change theory, add BSM physics to QED-verse ... *re-do global fit to constants.*

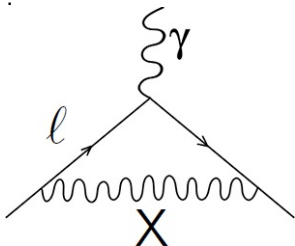
[www.constantfinder.org](http://www.constantfinder.org) makes it easy.

Ex: **No-name model** 1606.06209 Ralston, JM  'bottom-up' pheno

Particle  $X$ : mass  $m_X$ , coupling  $\alpha_X = |g_\ell g_p|/4\pi = g_\ell^2/4\pi \ell X$

**Moments:**  $a_e, a_\mu$

**Spectroscopy:** eH,  $\mu$ H



**Yukawa:**

$$V_X = \pm \alpha_X \cdot e^{-m_X r} / 4\pi r$$

$$\Delta E_X \sim \pm (m_e \alpha / n)^3 \cdot \alpha_X \cdot (1/m_X^2)$$

First-order PT ok if  $\alpha_X/m_X^2$  small enough.

Collected results: Part I ( $m_\chi = 50\text{MeV}$ )

Line 1 fit solves muon  $g - 2$  and proton size, with  $\chi^2$  for each sector under control.

Note:  $\alpha^*$ ,  $R_\infty^*$ ,  $r_p^*$ ,  $r_d^*$  all shifted by multiple  $\sigma$  compared to NIST values.

 $\chi^2$  budget

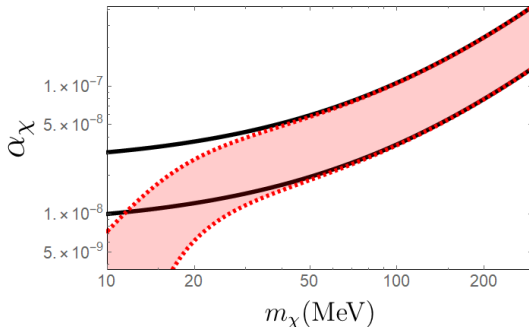
line	omit	$\chi^2$	dof	$R_B$	$\Delta\chi^2$	$\chi^2_{\lambda_c}$	$\chi^2_{\mu H}$	$\chi^2_{\mu D}$	$\chi^2_{a_e}$	$\chi^2_{a_\mu}$	$\chi^2_{eH}$	$\chi^2_{eD}$
1	none	12.5	15	.91(10)	15.0	1.0	0.0011	0.000096	0.24	0.019	7.0	3.3
9	$\mu H, \mu D, a_\mu$	6.9	13	.73(11)	0.23	0	-	-	0	-	3.3	3.0

## Fitted values

line	omit	$(\delta R_\infty/R_\infty^*)/10^{-12}$	$(\delta\alpha/\alpha^*)/10^{-10}$	$r_p$ fm	$r_d$ fm	$\xi$ MeV $^{-2}/10^{-11}$
1	none	-12.5(2.9)	-5.1(2.3)	0.84115(27)	2.12879(13)	1.52(39)
9	$\mu H, \mu D, a_\mu$	2.5(9.6)	0.0(5.0)	0.883(20)	2.1428(97)	-1.1(2.3)

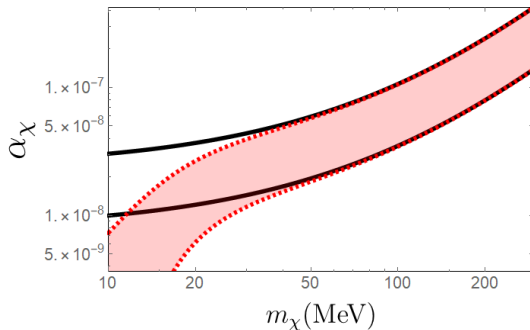
## Collected results: Part II

$m_\chi$ MeV	$\Delta\chi^2$	$(\delta R_\infty/R_\infty^*)/10^{-12}$	$(\delta\alpha/\alpha^*)/10^{-10}$	$r_p$ fm	$r_d$ fm	$\xi$ MeV $^{-2}/10^{-11}$
15	6.6	-10.9(3.1)	-10.6(3.9)	0.84157(37)	2.12894(16)	4.3(1.7)
25	12.4	-11.4(3.0)	-8.9(2.9)	0.84147(31)	2.12890(14)	3.45(98)
50	15.0	-12.5(2.9)	-5.1(2.3)	0.84115(27)	2.12879(13)	1.52(39)
100	15.5	-13.0(2.9)	-3.6(2.2)	0.84101(26)	2.12875(13)	0.70(18)
150	15.6	-13.1(2.9)	-3.1(2.2)	0.84097(26)	2.12873(13)	0.49(12)
200	15.6	-13.1(2.9)	-3.0(2.2)	0.84096(26)	2.12873(13)	0.40(10)
300	15.6	-13.2(2.9)	-2.8(2.2)	0.84094(26)	2.12872(13)	0.320(81)



**Red** band is region in the  $(m_\chi, \alpha_\chi)$  plane favored by the no-name analysis. Solid **black** lines define a piecemeal solution region that solves muon  $g - 2$  anomaly with  $\alpha$ ,  $R_\infty$ ,  $r_p$ , and  $r_d$  fixed at NIST values. **Piecemeal = falsely restrictive!**

# Conclusions



**Piecemeal fits = falsely restrictive**  
**Global fits = necessary (for self-consistency)**  
For all your global fit needs: [www.constantfinder.org](http://www.constantfinder.org)

THANKS