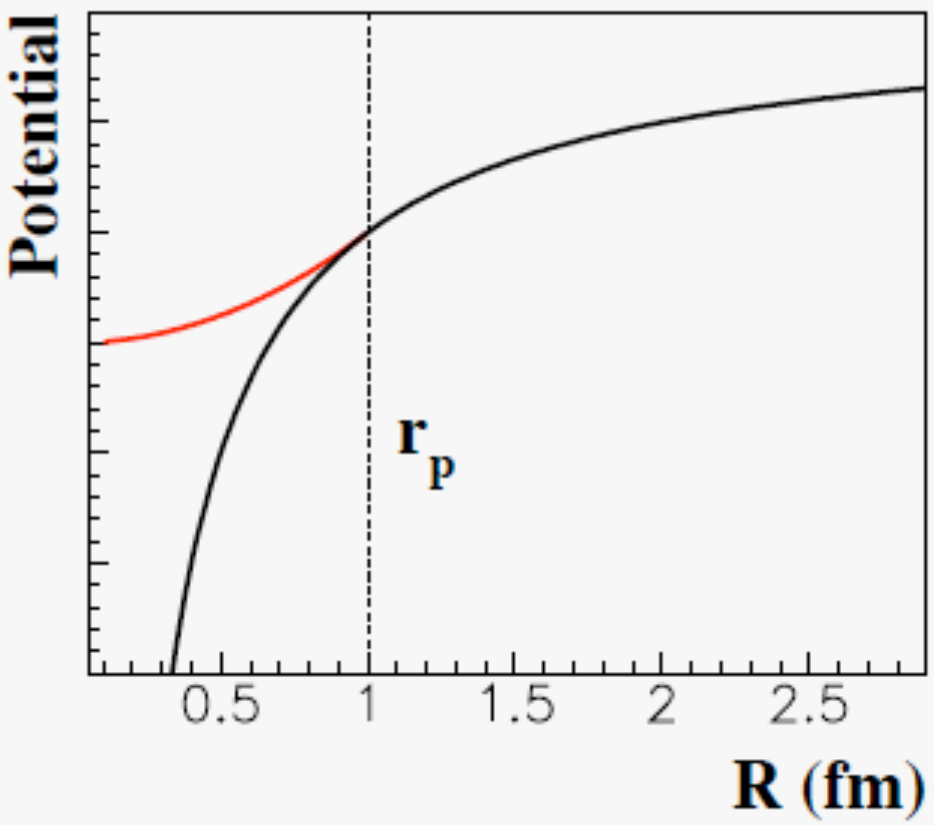
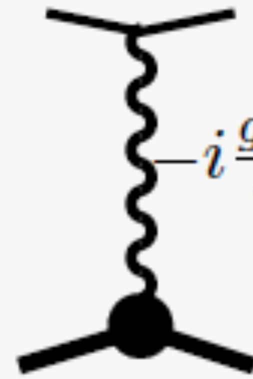
QED IS endangered by the proton's charge rms radius

QED is NOT endangered by the proton's running radii

The leading proton finite size contribution





$$\frac{1}{q^2} \longrightarrow \frac{F(q^2)}{q^2}$$

rms: root mean square

$$\boxed{r_p^2 \equiv \int d^3r\, \rho(\mathbf{r}) r^2}$$

$$F(\mathbf{q}^2) = \int d^3r\, \rho(\mathbf{r}) e^{-i\mathbf{q}\cdot\mathbf{r}} \simeq Z\left(1 - \frac{\mathbf{q}^2}{6} r_p^2 + \cdots\right)$$

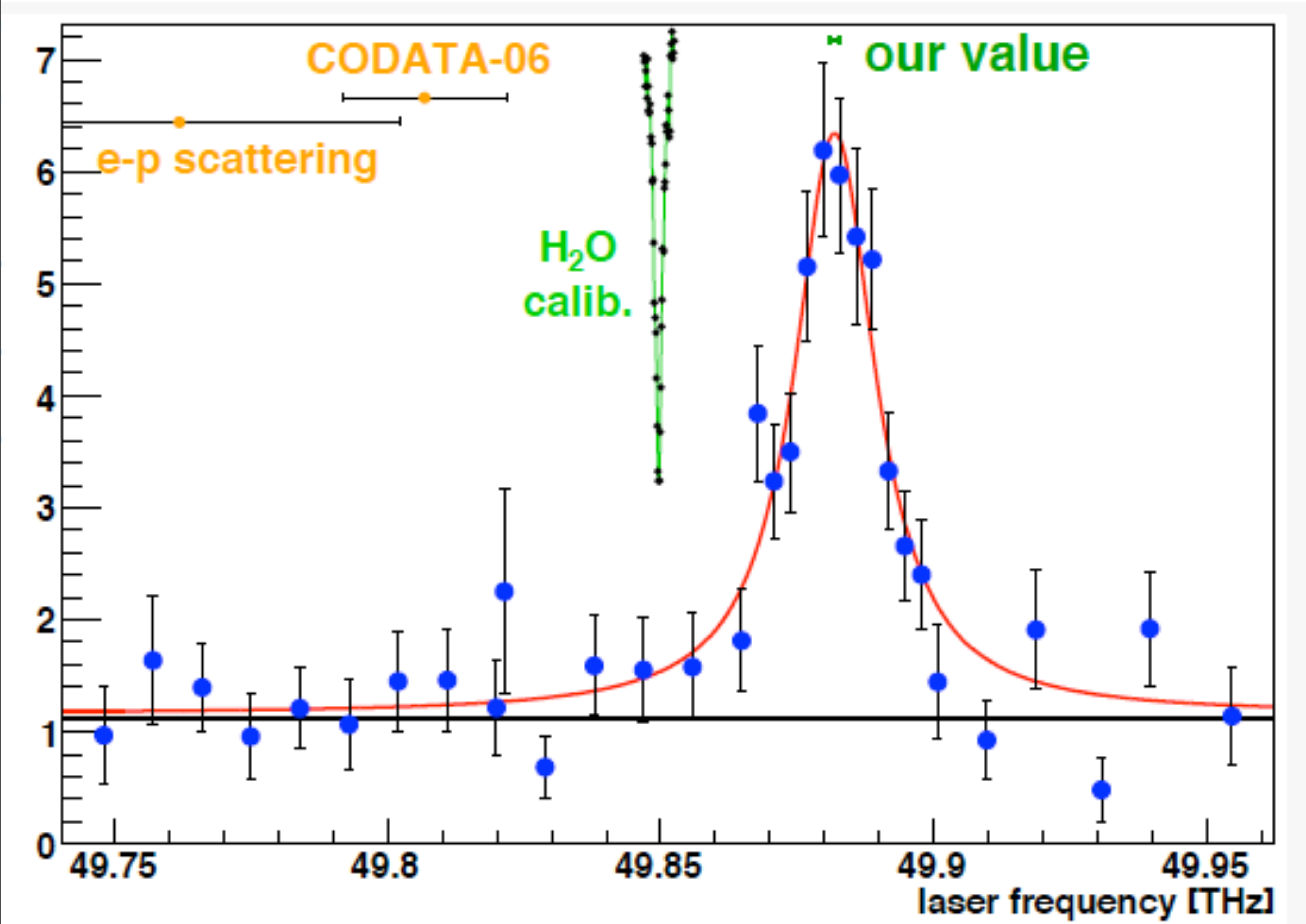
$$\Delta V(r) = V(r) - \left(-\frac{Z\alpha}{r}\right)$$

$$\Delta V(\mathbf{q}) = \frac{4\pi Z\alpha}{\mathbf{q}^2}\left(1 - F(\mathbf{q})\right) \simeq \frac{2\pi(Z\alpha)}{3} r_p^2$$

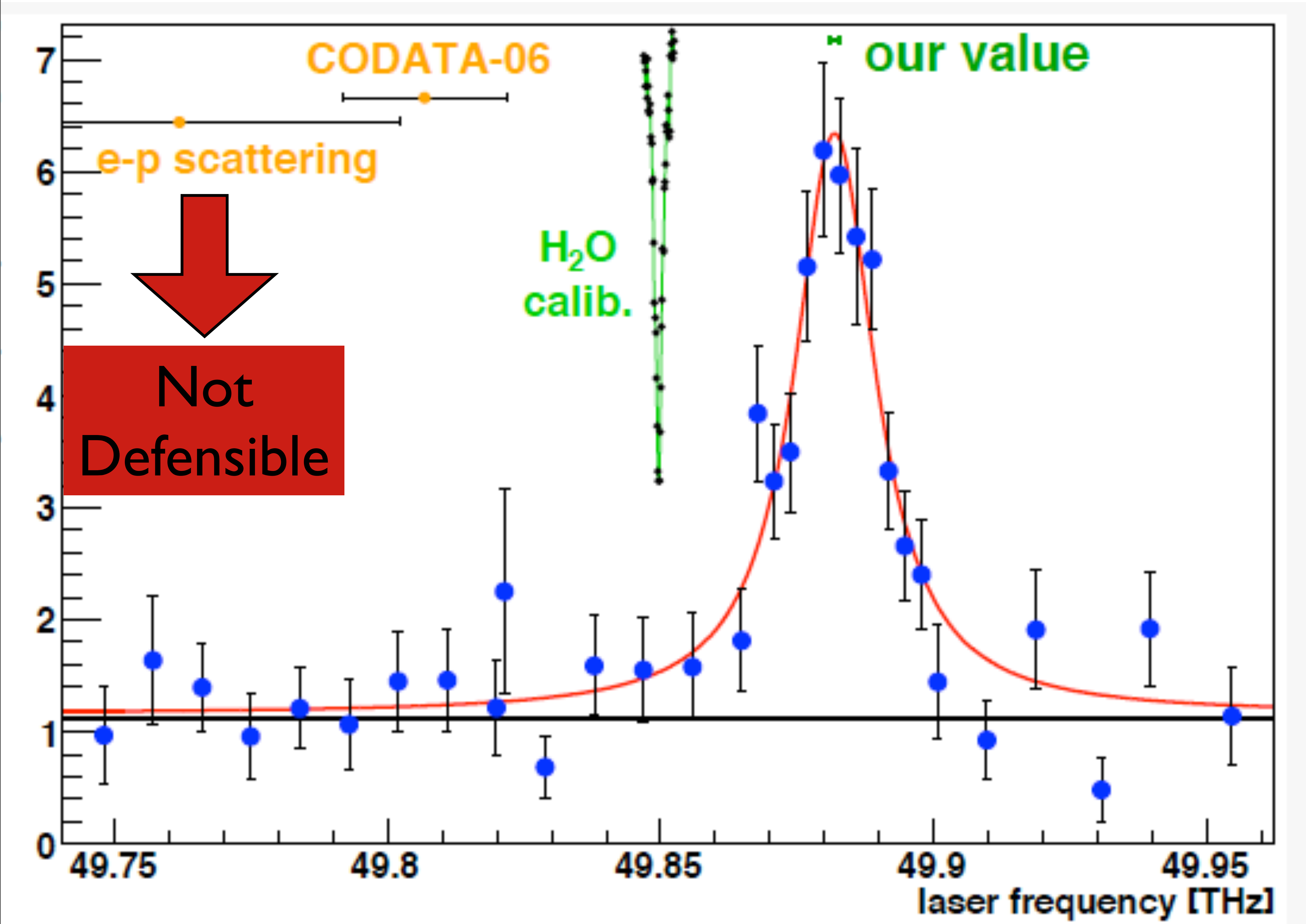
$$\Delta V(r) = \frac{2\pi(Z\alpha)}{3}\, r_p^2\, \delta(r)$$ Not Quite Right

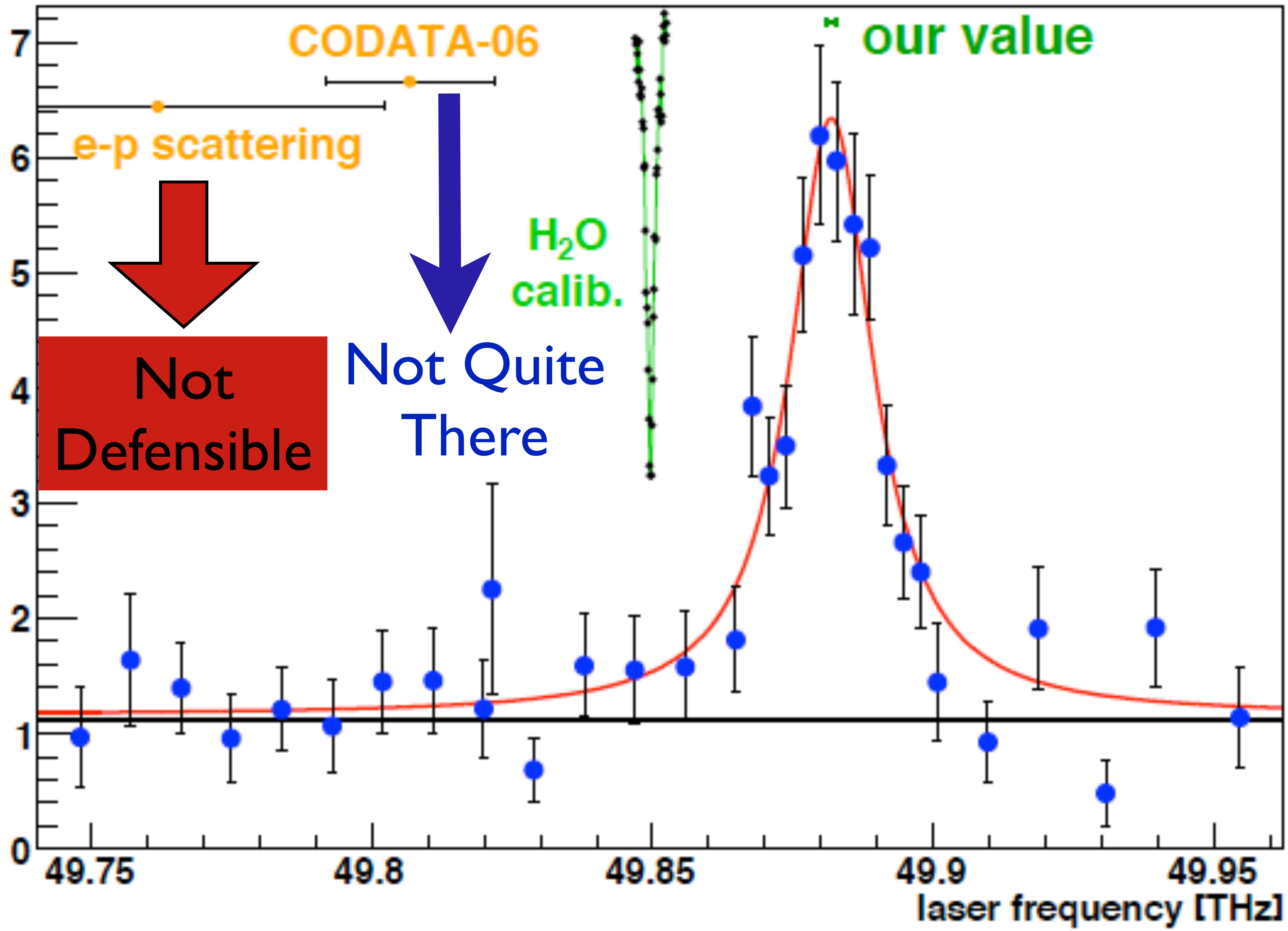
$$\boxed{\begin{aligned} \Delta E^{FS} &= \frac{2\pi(Z\alpha)}{3}\, r_p^2\, |\Psi_n(0)|^2 \\ &= \frac{2(Z\alpha)^4}{3n^3} m_r^3\, r_p^2\, \delta_{l0} \end{aligned}}$$

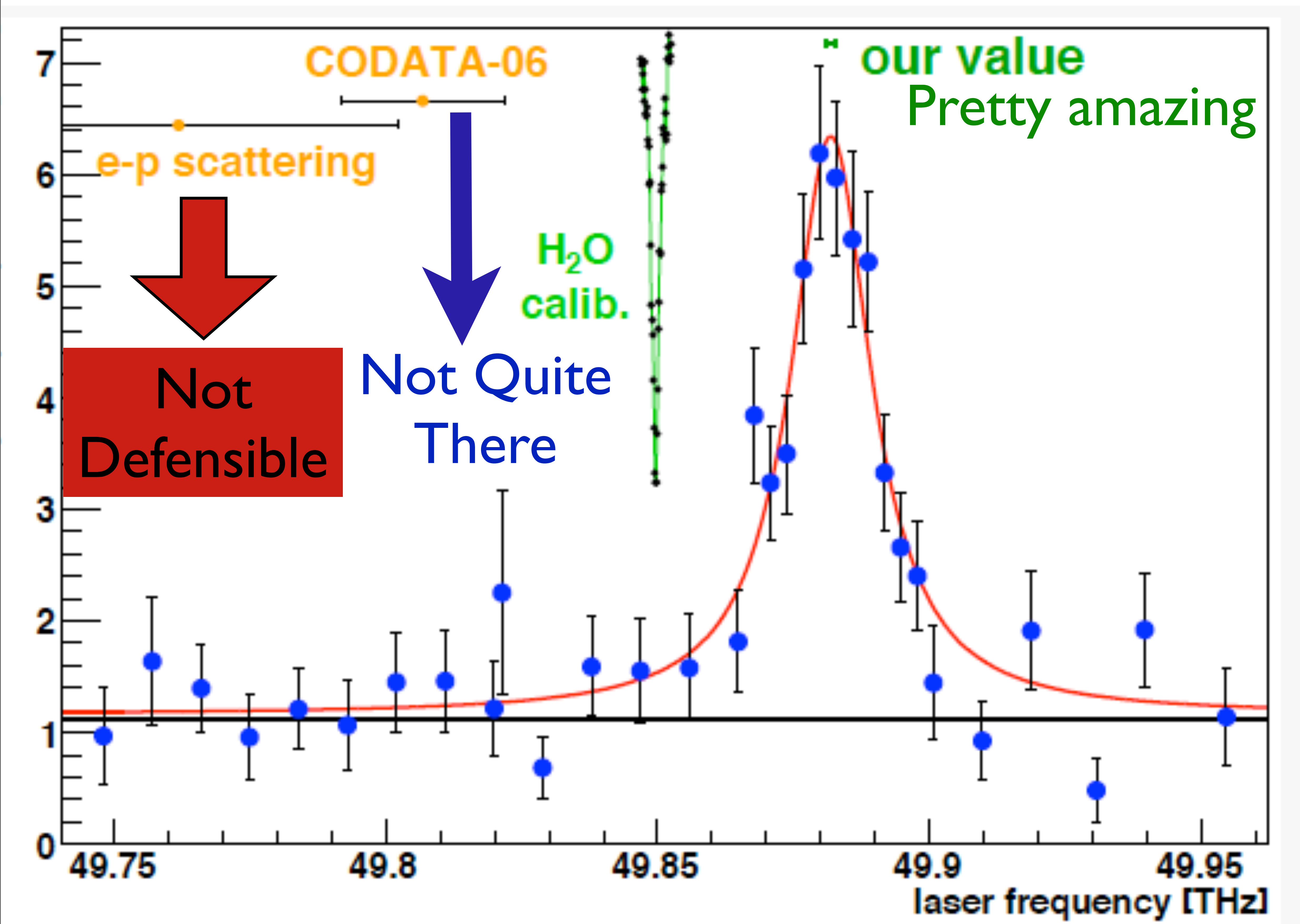
$$m_r \equiv \frac{m_\ell\, m_p}{m_\ell + m_p}$$



CODATA-06
our value
e-p scattering
H2O calib.
0
1
2
3
4
5
6
7
49.75
49.8
49.85
49.9
49.95
laser frequency [THz]


CODATA-06
our value
e-p scattering
Not
Defensible
H_2O
calib.
7
6
5
4
3
2
1
0
49.75
49.8
49.85
49.9
49.95
laser frequency [THz]

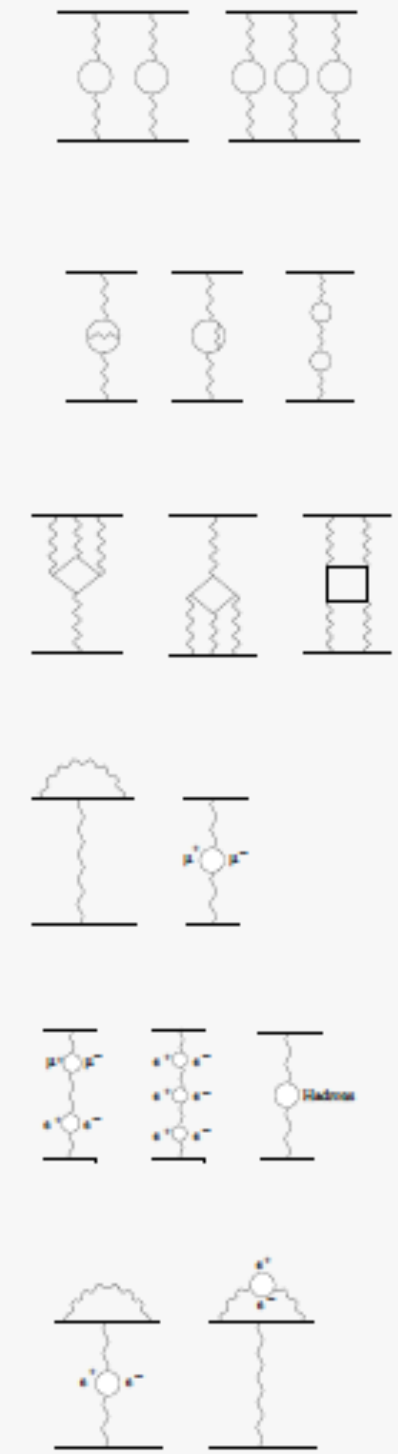

CODATA-06
our value
e-p scattering
H_2O
calib.
Not Defensible
Not Quite There
7
6
5
4
3
2
1
0
49.75
49.8
49.85
49.9
49.95
laser frequency [THz]



CODATA-06
e-p scattering
H2O calib.
our value
Pretty amazing
Not Defensible
Not Quite There
49.75
49.8
49.85
49.9
49.95
laser frequency [THz]
0
1
2
3
4
5
6
7

Contributions to the μp Lamb shift

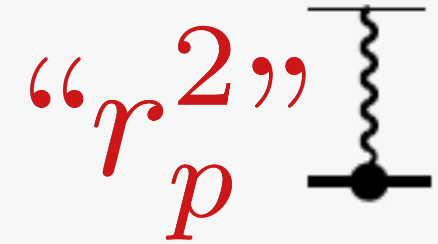
#	Contribution	Value	Unc.
3	Relativistic one loop VP	205.0282	
4	NR two-loop electron VP	1.5081	
5	Polarization insertion in two Coulomb lines	0.1509	
6	NR three-loop electron VP	0.00529	
7	Polarisation insertion in two and three Coulomb lines (corrected)	0.00223	
8	Three-loop VP (total, uncorrected)		
9	Wichmann-Kroll	-0.00103	
10	Light by light electron loop ((Virtual Delbrück)	0.00135	0.00135
11	Radiative photon and electron polarization in the Coulomb line $\alpha^2(Z\alpha)^4$	-0.00500	0.0010
12	Electron loop in the radiative photon of order $\alpha^2(Z\alpha)^4$	-0.00150	
13	Mixed electron and muon loops	0.00007	
14	Hadronic polarization $\alpha(Z\alpha)^4 m_r$	0.01077	0.00038
15	Hadronic polarization $\alpha(Z\alpha)^5 m_r$	0.000047	
16	Hadronic polarization in the radiative photon $\alpha^2(Z\alpha)^4 m_r$	-0.000015	
17	Recoil contribution	0.05750	
18	Recoil finite size	0.01300	0.001
19	Recoil correction to VP	-0.00410	
20	Radiative corrections of order $\alpha^n(Z\alpha)^k m_r$	-0.66770	
21	Muon Lamb shift 4th order	-0.00169	
22	Recoil corrections of order $\alpha(Z\alpha)^5 \frac{m}{M} m_r$	-0.04497	
23	Recoil of order α^6	0.00030	
24	Radiative recoil corrections of order $\alpha(Z\alpha)^n \frac{m}{M} m_r$	-0.00960	
25	Nuclear structure correction of order $(Z\alpha)^5$ (Proton polarizability)	0.015	0.004
26	Polarization operator induced correction to nuclear polarizability $\alpha(Z\alpha)^5 m_r$	0.00019	
27	Radiative photon induced correction to nuclear polarizability $\alpha(Z\alpha)^5 m_r$	-0.00001	
	Sum	206.0573	0.0045

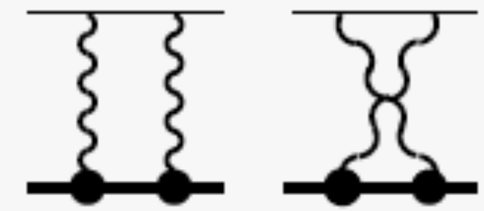


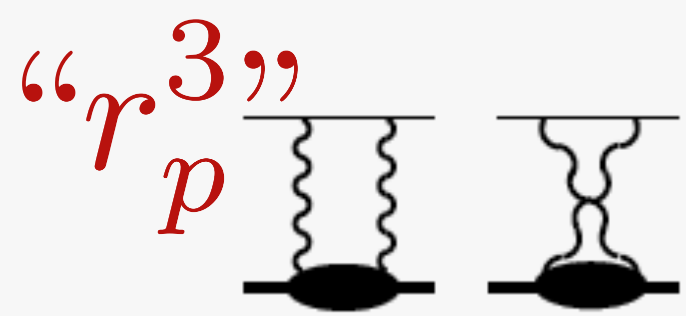
Lamb shift prediction

- radius dependent contributions

Contribution	Value	
Leading nuclear size contribution	-5.19745	$< r_\mathrm{p}^2 >$
Radiative corrections to nuclear finite size effect	-0.0275	$< r_\mathrm{p}^2 >$
Nuclear size correction of order $(Z\alpha)^6 < r_\mathrm{p}^2 >$	-0.001243	$< r_\mathrm{p}^2 >$
Total $< r_\mathrm{p}^2 >$ contribution	-5.22619	$< r_\mathrm{p}^2 >$
Nuclear size correction of order $(Z\alpha)^5$	0.0347	$< r_\mathrm{p}^3 >$
Nuclear size correction of order $(Z\alpha)^6 < r_\mathrm{p}^4 >$	-0.000043	$< r_\mathrm{p}^2 >^2$







- A1 collaboration at MAMI, Mainz has started the reevaluation of the various proton moments: $< r_\mathrm{p}^2 >, R_\mathrm{Zemach}, < r_\mathrm{p}^4 > \ldots$

New evaluations of structure leads to a shift $< 10\%$ of the measured discrepancy.

$$E(2S_{1/2}^{F=1} - 2P_{3/2}^{F=2}) = 209.9779(49) - 5.2262\, r_\mathrm{p}^2 + 0.0347\, r_\mathrm{p}^3 \ \mathrm{meV}$$ (HFS+FS included)

Ladies & Gentlemen

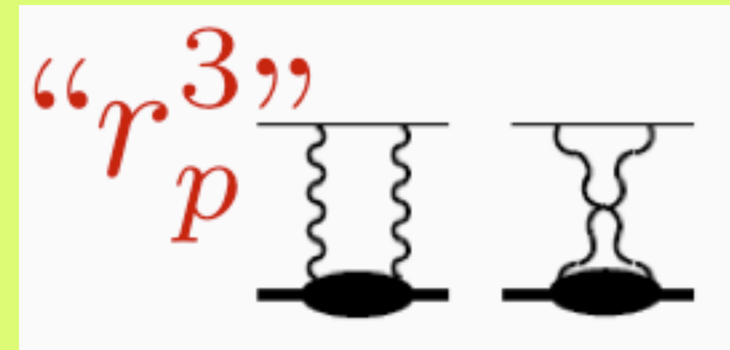
Ladies & Gentlemen

THE THIRD ZEMACH MOMENT

$$L^{\rm th}\left[\langle r_p^2\rangle, \langle r_p^3\rangle_{(2)}\right] =$$ (in meV, with r in fermi)

$$209.9779(49) - 5.2262\,\langle r_p^2\rangle + 0.00913\,\langle r_p^3\rangle_{(2)}$$

$$\Delta E_3(n) = \frac{\alpha^5}{3\,n^3}\, m_r^4\, \delta_{l0}\, \langle r_p^3\rangle_{(2)}$$



$$\langle r_p^3\rangle_{(2)} \equiv \int d^3r_1 d^3r_2\, \rho(r_1)\rho(r_2)|\mathbf{r}_1 - \mathbf{r}_2|^3$$

For a dipole form factor

$$\left[\langle r^3\rangle_{(2)}\right]^2 = (3675/256)\left[\langle r^2\rangle\right]^3$$

with

$$r_p \equiv \sqrt{\langle r_p^2\rangle}$$

$$L_{\rm th}(r_p) = 209.9779(49) - 5.22619\, r_p^2 + 0.0347\, r_p^3$$

It is intrepid to use a model of the proton

$$G_E(Q^2) = \frac{1}{\left[1 + \frac{|Q^2|}{0.71\,\mathrm{GeV}^2}\right]^2}$$

... to challenge QED

THE RUNNING RMS P-RADIUS

$$\langle r_p^2 \rangle$$

$$\frac{2\pi\alpha}{3}\langle r_p^2\rangle|\Psi_{2,0}(0)|^2$$

The slope of FF at $\mathbf{q}^2 = 0$

the F.T. of $\delta(\vec{\mathrm{r}})$

$$\int_0^\infty e^{i\vec{q}\vec{r}} d^3q \quad (\text{all } q)$$

Rephrase "atomic" result:

$$\langle r_p^2\rangle|_{(0,\infty)} \simeq \frac{\langle r_p^2\rangle|_{(\alpha m_r, m)}}{1 - 4\,\alpha\, m_r\,\sqrt{\langle r_p^2\rangle|_{(\alpha m_r, m)}/6}}$$

$$\mathbf{q} = \mathcal{O}(\alpha\, m_r) \text{ up to } \mathbf{q} \sim m/4$$

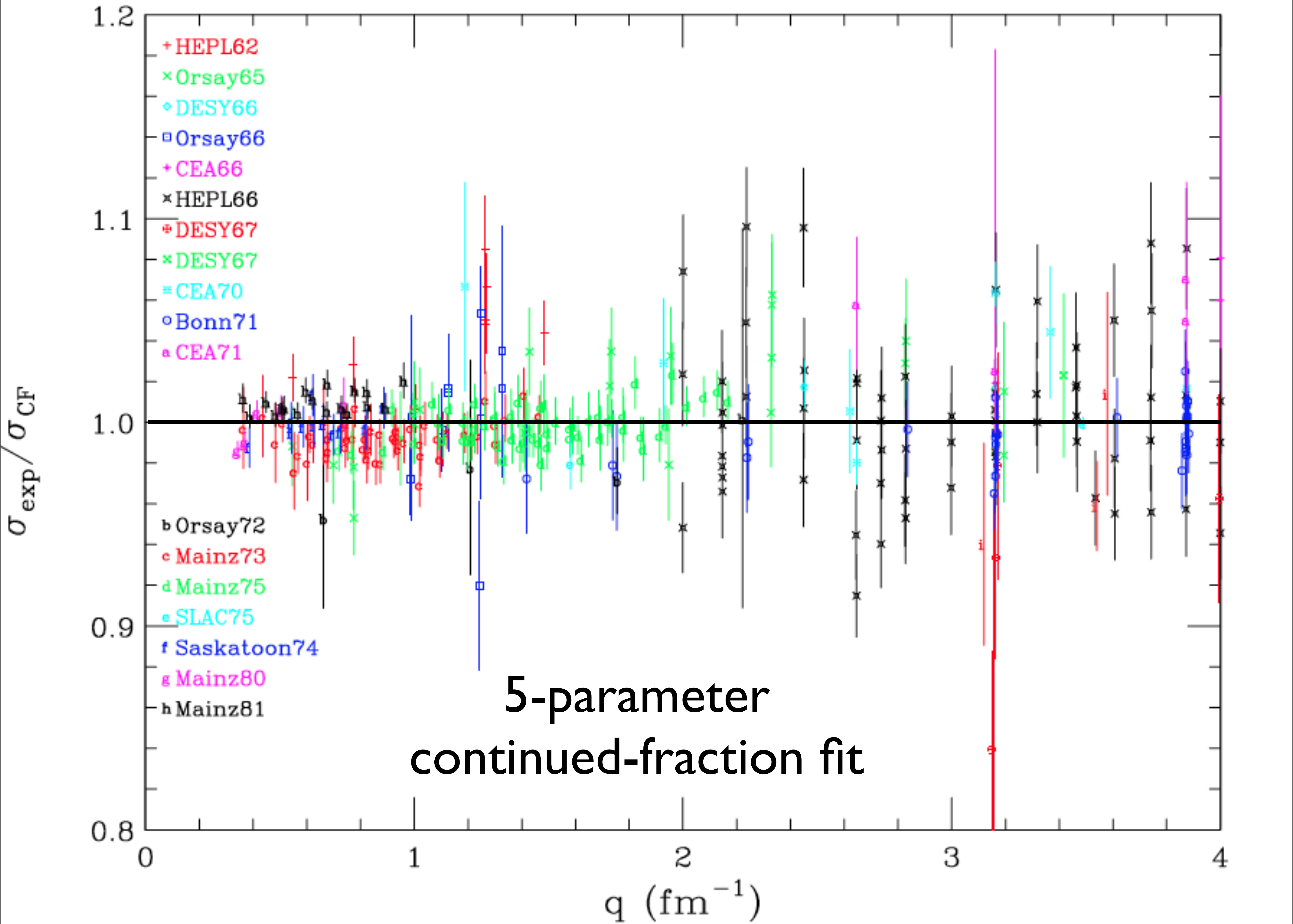
Momentum range is which the proton is "probed" in the atom

Correction is form-factor dependent

Extracting

$$\langle r_p^2 \rangle$$

from electron-proton scattering data


1.2
1.1
1.0
0.9
0.8
0
1
2
3
4
q (fm^{-1})
$\sigma_{\text{exp}}/\sigma_{\text{CF}}$
HEPL62
Orsay65
DESY66
Orsay66
CEA66
HEPL66
DESY67
DESY67
CEA70
Bonn71
CEA71
Orsay72
Mainz73
Mainz75
SLAC75
Saskatoon74
Mainz80
Mainz81
5-parameter continued-fraction fit

$$f(z,n) = \frac{2^{-n/2}\, e^{-z/2}\, z^{\frac{n}{2}-1}}{\Gamma\left[\frac{n}{2}\right]}$$

$$p(\chi^2, n_{\mathrm{dof}}) = \int_{\chi^2}^{\infty} f(z, n_{\mathrm{dof}})\, dz = \frac{\Gamma(n_{\mathrm{dof}}/2, \chi^2/2)}{\Gamma(n_{\mathrm{dof}}/2)}$$

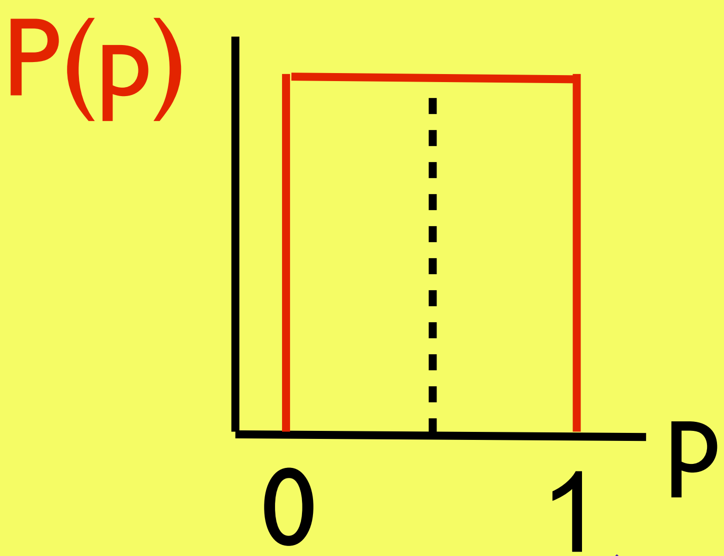
1

The data are tickled to agree with H

H and the data do not agree

$$f(z,n) = \frac{2^{-n/2}\, e^{-z/2}\, z^{\frac{n}{2}-1}}{\Gamma\left[\frac{n}{2}\right]}$$

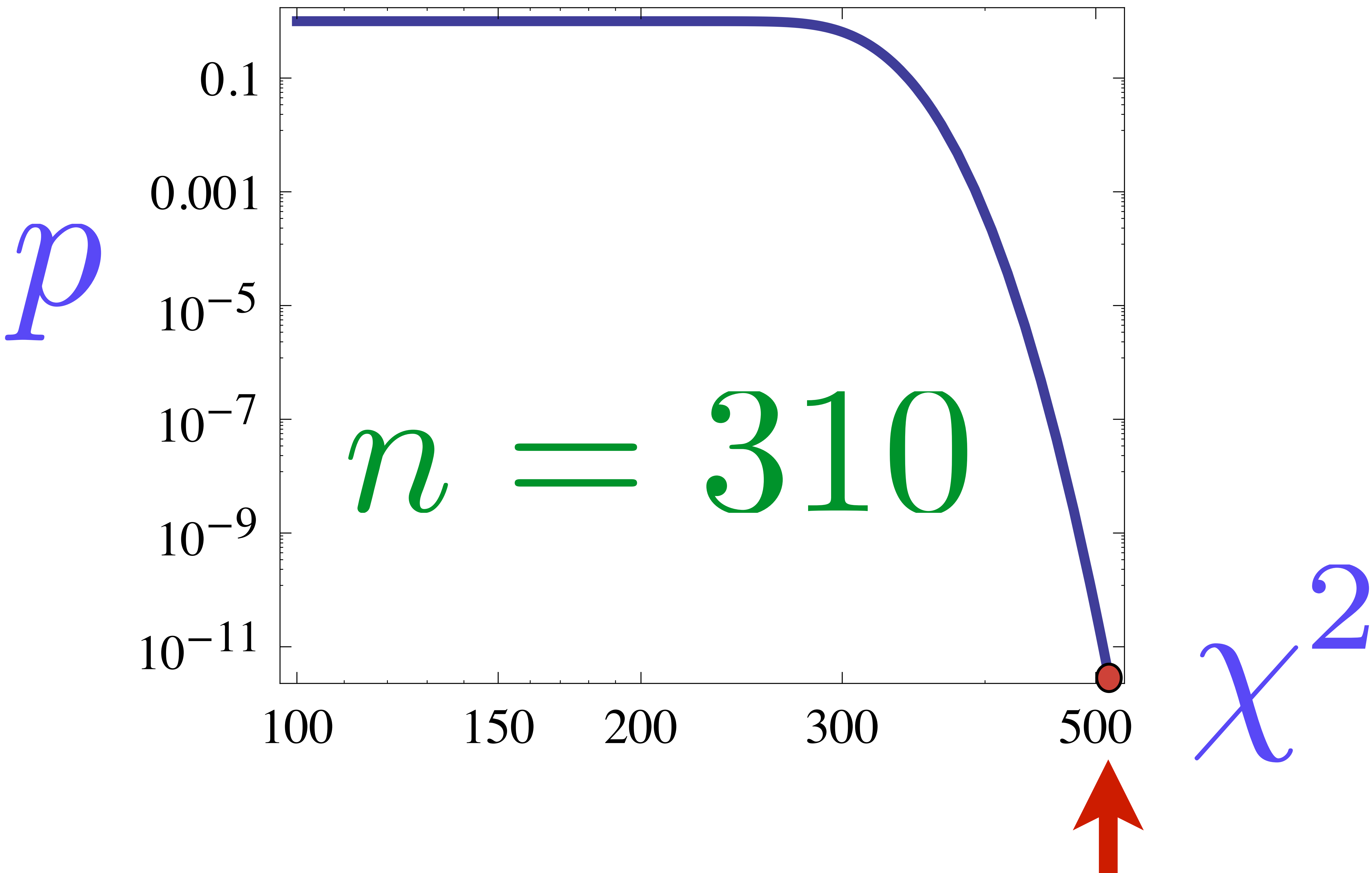
$$p(\chi^2, n_{\mathrm{dof}}) = \int_{\chi^2}^{\infty} f(z, n_{\mathrm{dof}})\, dz = \frac{\Gamma(n_{\mathrm{dof}}/2, \chi^2/2)}{\Gamma(n_{\mathrm{dof}}/2)}$$



H correct
Data good

The data are tickled to agree with H

H and the data do not agree



$$p(512, 310) \simeq 3.92 \times 10^{-12}$$

what to say ??????

what to say ??????

¡¡¡¡™

% & !! §°≠≠¢

¢¶∞§**

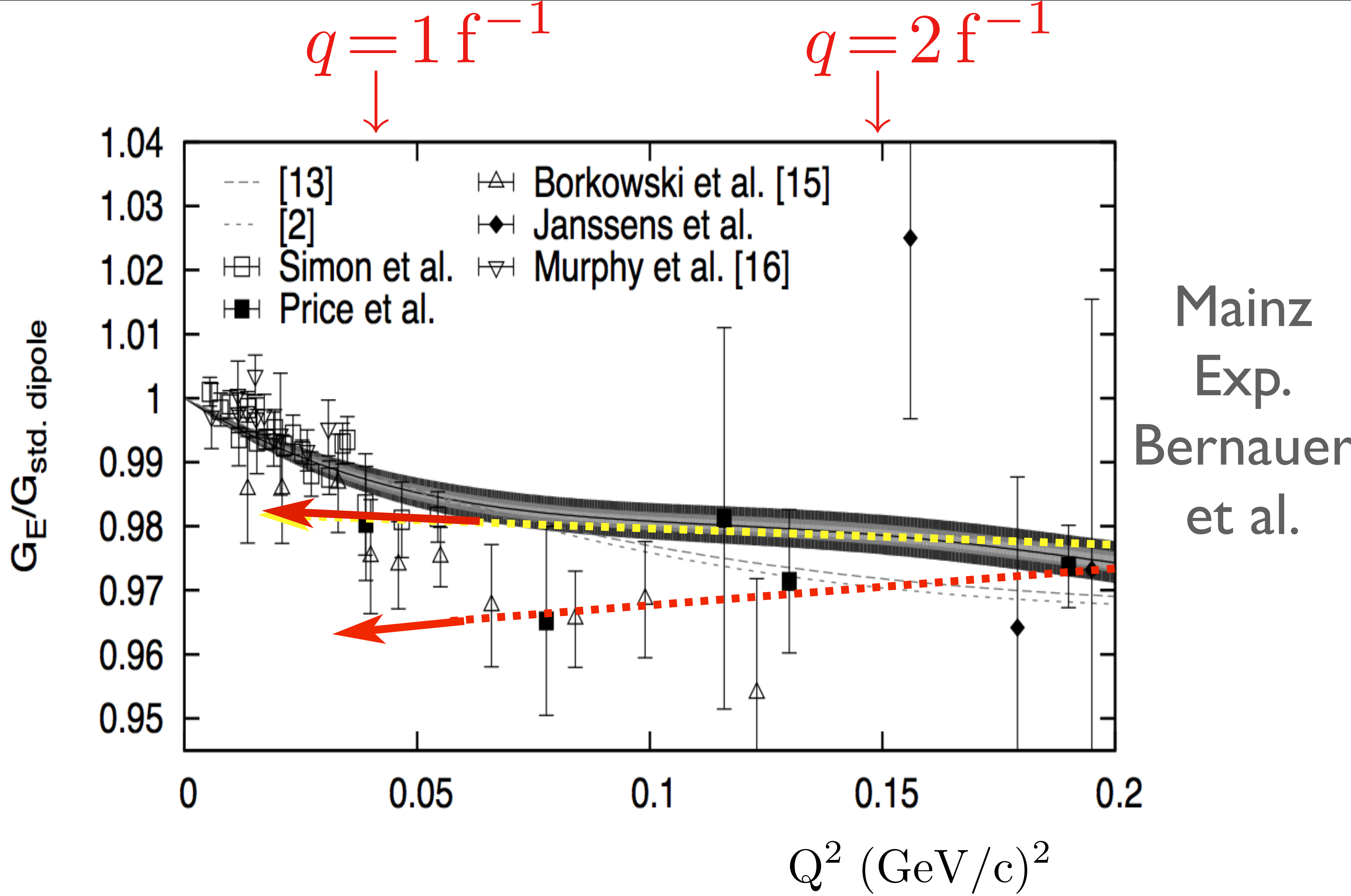
!!!!!!!!!!!!!!!!!!!!!!

Ig Nobel Peace Prize 2010

Stephens, Atkins, and Kingston of Keele University, for confirming the widely held belief that swearing relieves pain.

¡¡¡ $ & # £ ∞ § ¶ !!!

REFERENCE: "Swearing as a Response to Pain," Richard Stephens, John Atkins, and Andrew Kingston, Neuroreport, vol. 20 , no. 12, 2009, pp. 1056-60.



$$p(\text{most flexible}) = 1.9 \times 10^{-4}$$

$$\sqrt{\langle r_p^2 \rangle}(\text{polynom}) =$$

$$0.883(5)_{\text{stat}}(5)_{\text{syst}}(3)_{\text{model}}\ \text{fm}$$

$$\sqrt{\langle r_p^2 \rangle}(\text{spline}) =$$

$$0.875(5)_{\text{stat}}(4)_{\text{syst}}(2)_{\text{model}}\ \text{fm}$$

THEOREM

Proton form factors

at low Q^2

Parton-Distribution Functions

at low x

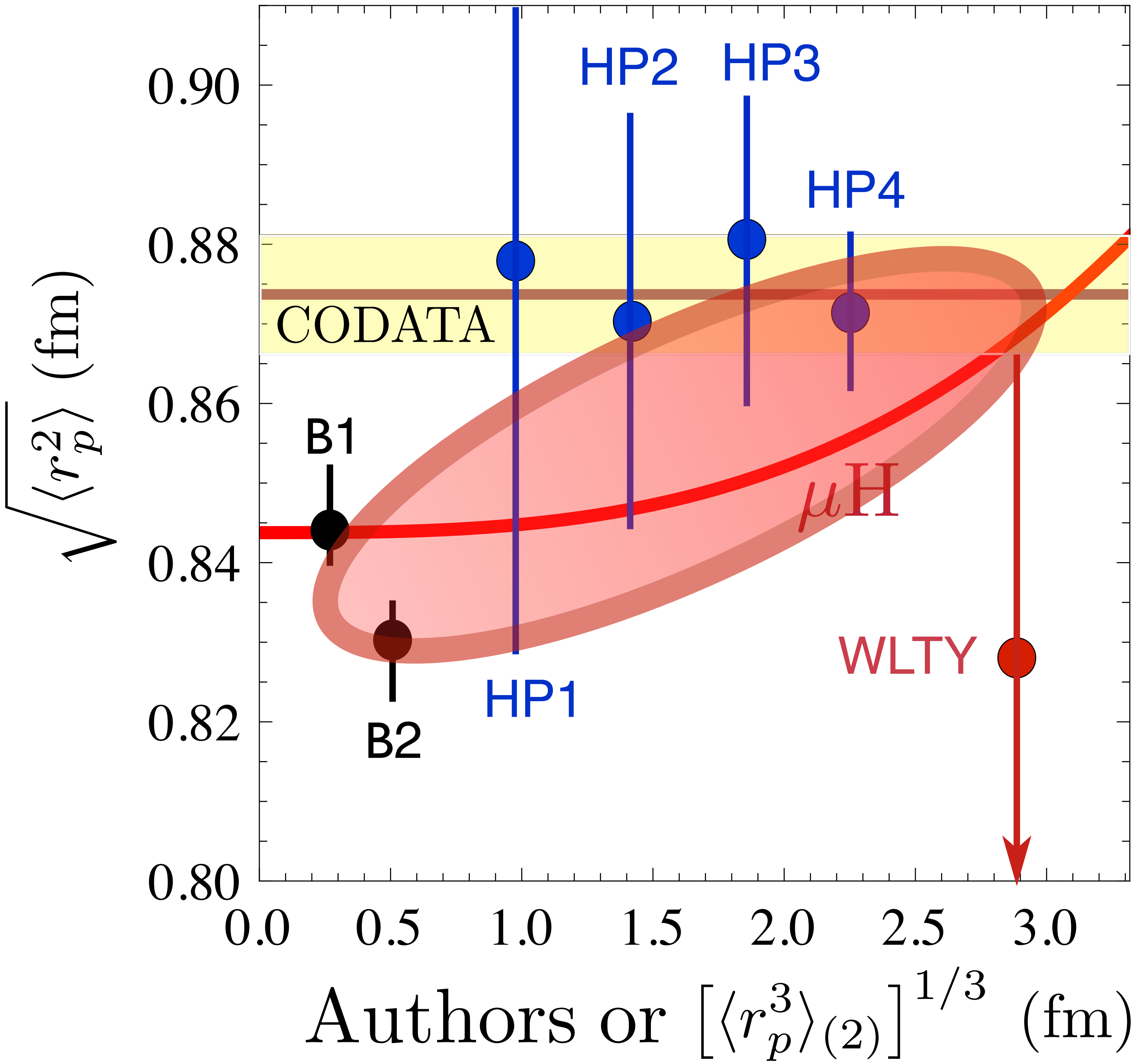
Study form-factor with the same neural- network techniques

only instances ??

Extracting

$$\langle r_p^3 \rangle_{(2)}$$

from (the same) electron-proton scattering data



TH

Belushkin, Hammer & Meissner, PR C75 (2007) 035202.

Hill & Paz, arXiv:1008.4619v1.

Wang et al., Phys. Rev. D 79 094001 (2009).

?

Ig Nobel Management Prize 2010

Pluchino, Rapisarda, and Garofalo of the Univ. of Catania, for demonstrating mathematically that organizations would become more efficient if they promoted people at random.

REFERENCE: "The Peter Principle Revisited: A Computational Study," Alessandro Pluchino, Andrea Rapisarda, and Cesare Garofalo, Physica A, vol. 389, no. 3, February 2010, pp. 467-72.

BASTA