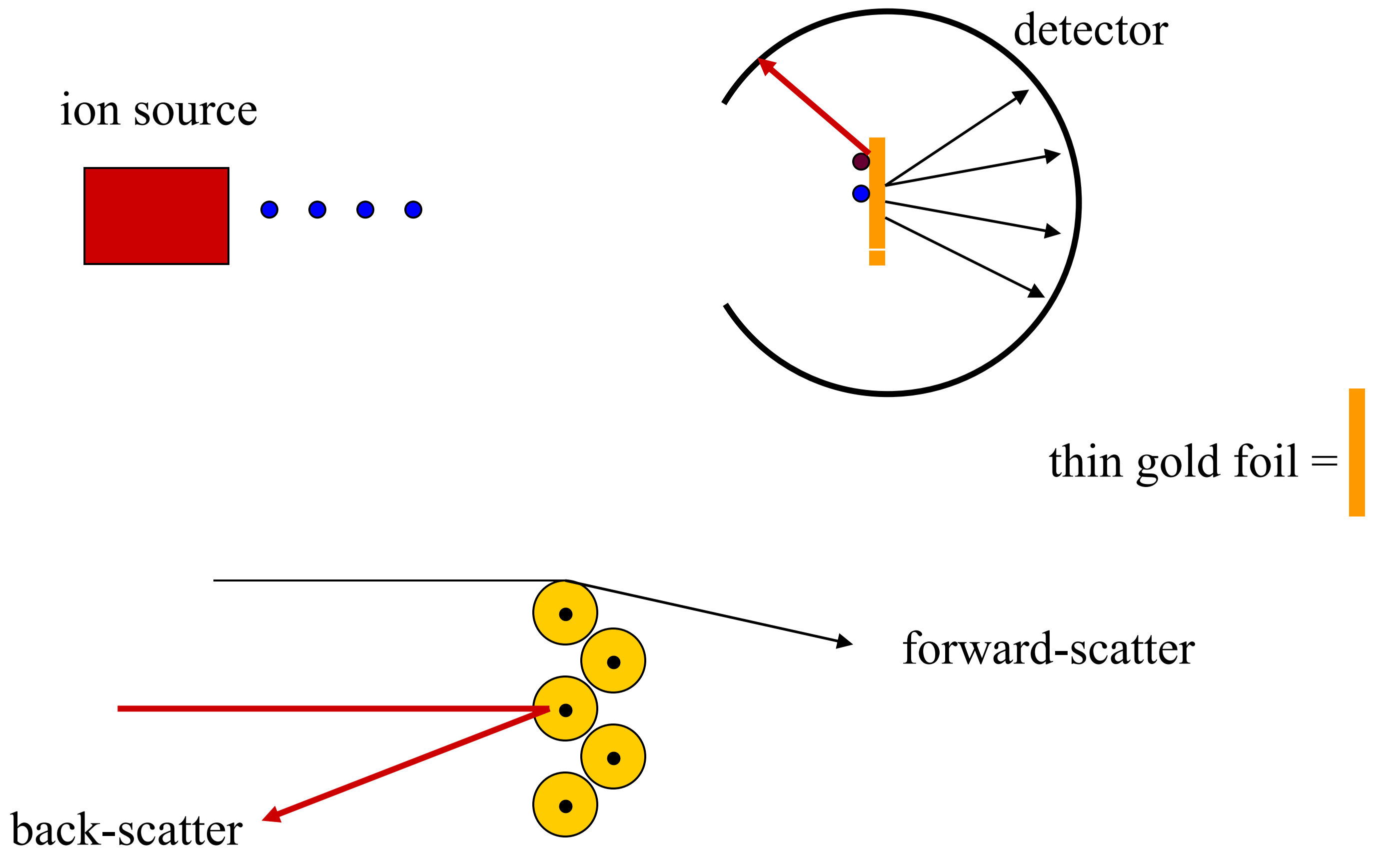
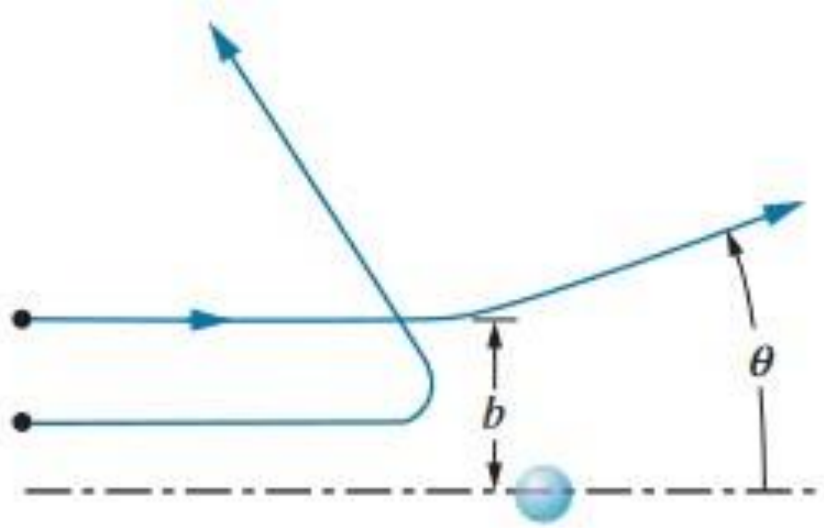
Rutherford's Experiments



- Rutherford made the discovery of the atomic nucleus via this backscattering experiment.
- Determined that the atom was mostly empty space except for a very dense region near its center - **NUCLEUS**

Rutherford Scattering



Point charge z e, m, with speed v and impact parameter b scatters from point charge Z e (infinite mass) through an angle θ

Why is speed unchanged? Does θ increase/decrease with b, E, z, m, Z?

Why can't choose b? Why must foil be thin?

Question #1

If the nucleus actually has a finite size, how can you tell?

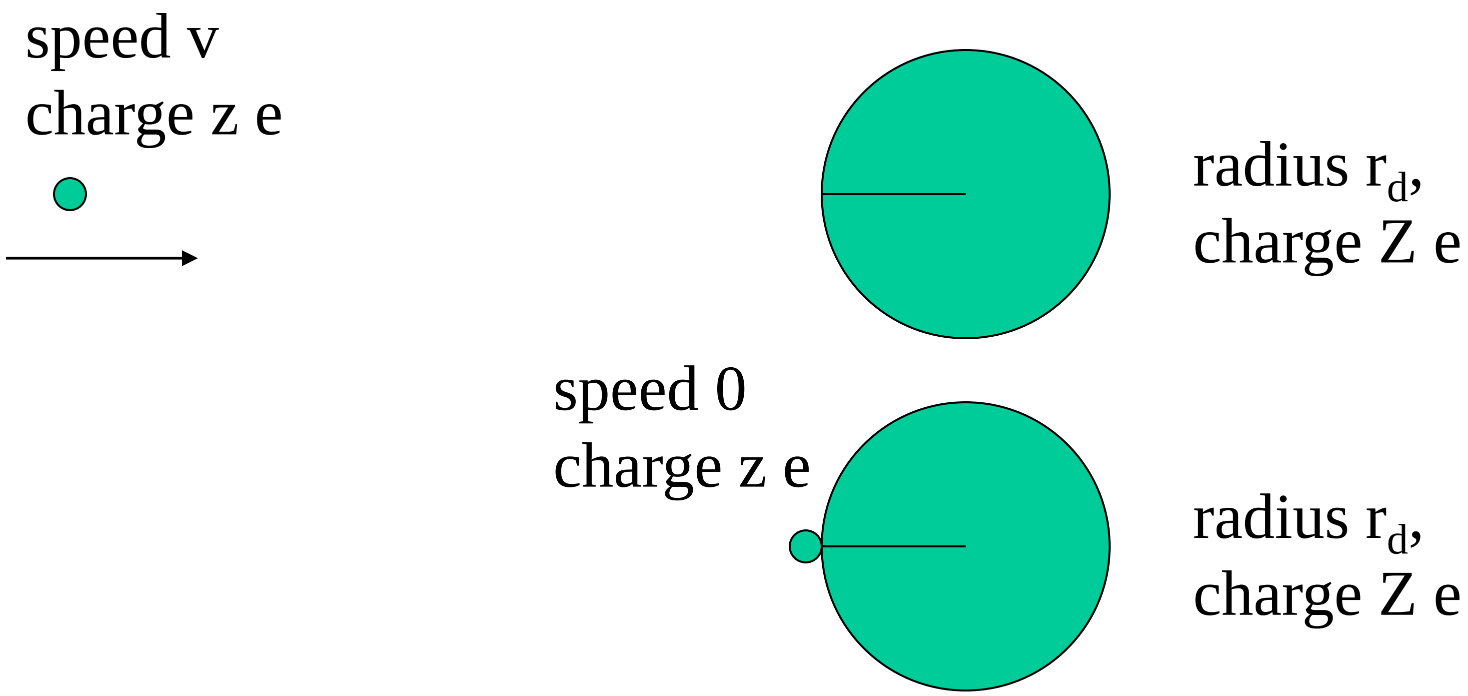
(a) Look for changes of the small angle scattering at small E.

(b) Look for changes of the large angle scattering at small E.

(c) Look for changes of the small angle scattering at large E.

(d) Look for changes of the large angle scattering at large E.

When can nuclei touch?



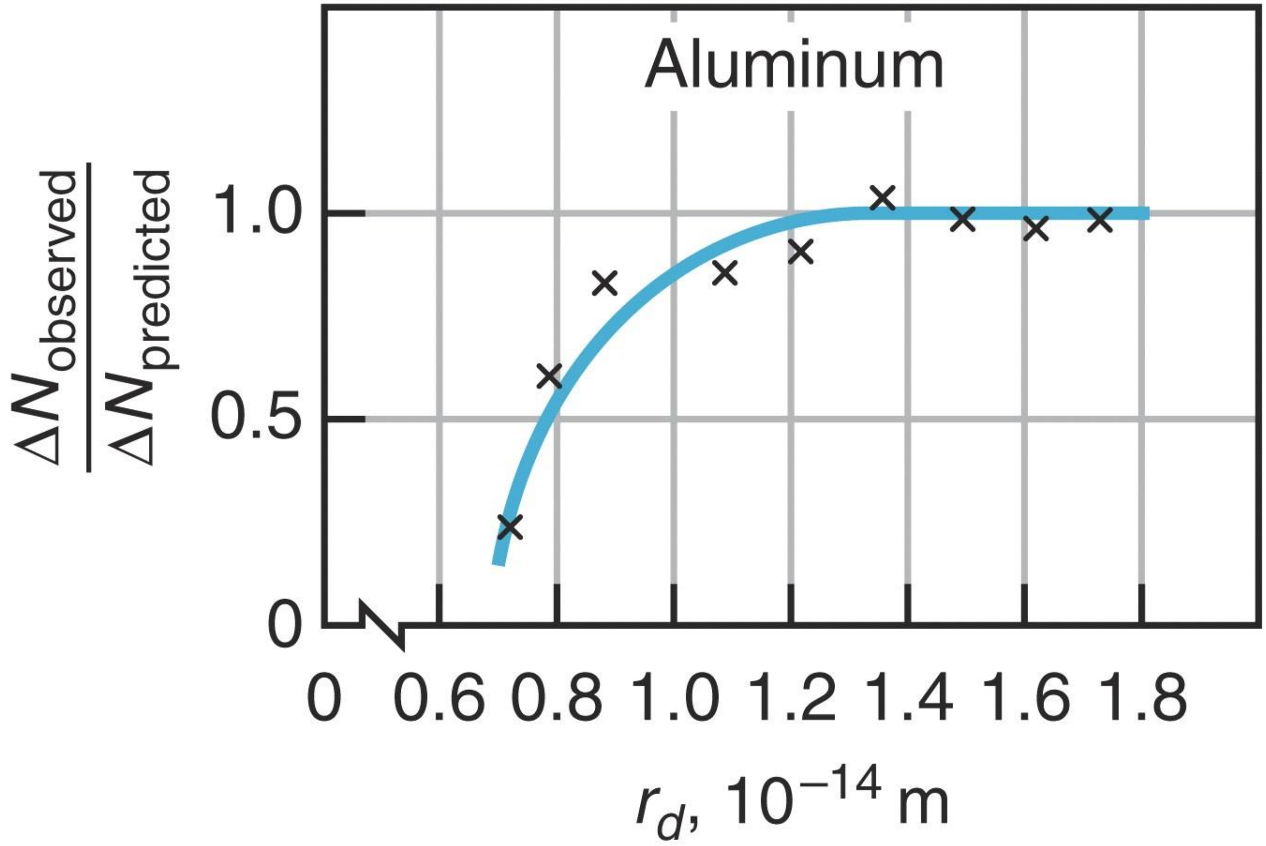
Conservation of Energy

$\frac{1}{2} m v^2$ before

$k e^2 z Z/r_d$ after

First start seeing non-zero size when $r_d = k e^2 z Z/ KE$

Data



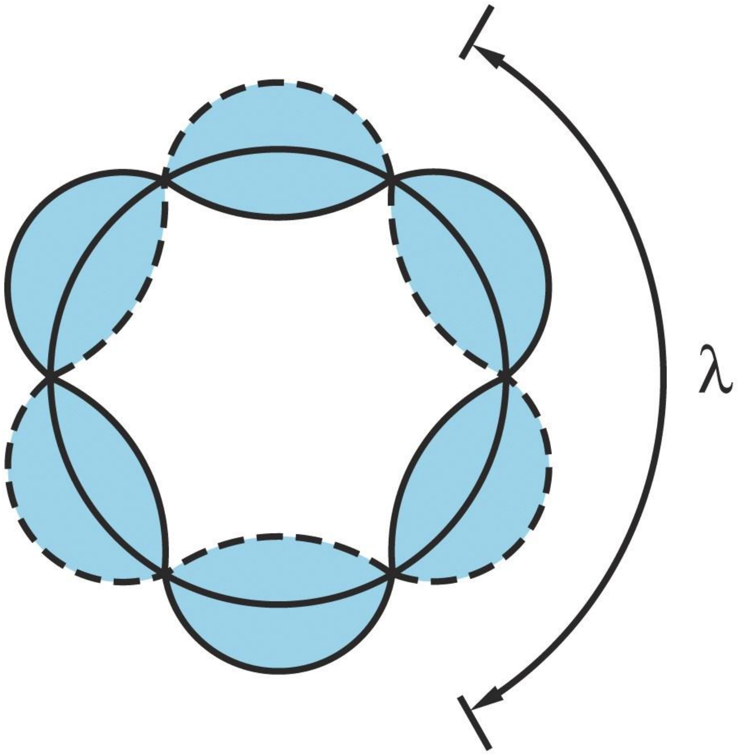
Aluminum has charge 13 e and the alpha has charge of 2 e. What was the speed of the alpha to obtain r_d = 10 fm?

Bohr Condition

$L_n = m\,v\,r = n\,h/2\,\pi \;\Rightarrow\; 2\,\pi\,r = n\,h\,/\,m\,v = n\,\lambda$

Circumference equals integer number of wavelengths.

Standing wave!



Parameters of Bohr Theory

$\alpha = k\, e^2 / c\, \hbar = 1 / 137.04$ Fine Structure Constant

$v_n = (k\, e^2 / \hbar)\,(Z / n) = \alpha\, c\,(Z / n) = 2.19 \times 10^6\ \text{m/s}\,(Z/n)$

$r_n = (\hbar^2 / m\, k\, e^2)\,(n^2 / Z) = a_0\,(n^2 / Z) = 5.29 \times 10^{-11}\ \text{m}\,(n^2 / Z)$

$E_n = -(k\, e^2 / \hbar)^2\,(m/2)\,(Z^2 / n^2) = -\alpha^2\,(m\, c^2 / 2)\,(Z^2 / n^2)$

$= -2.18 \times 10^{-18}\ \text{J}\,(Z^2 / n^2) = -13.6\ \text{eV}\,(Z^2 / n^2)$

$L_n = n\, \hbar = 1.055 \times 10^{-34}\ \text{J s}\ n$

$\tau_n = 2\, \pi\, r_n / v_n = (2\, \pi\, a_0 / \alpha\, c)\,(n^3 / Z^2) = 1.52 \times 10^{-16}\ \text{s}\,(n^3 / Z^2)$

Fundamental Difficulties w/ Bohr Theory

How long does it take to make transition between two energy states?

Spectra imply takes long time compared to period. Which state is electron in while making transition?

Why should we keep Coulomb forces but modify the radiation part of Maxwell's equations?

Why should the angular momentum have equally spaced values?

How is this theory applied to the 2 electrons in a Helium atom?

Other Physics & the H atom

Physical effects that have been left out:

Proton is not infinitely massive (reduced mass)

Relativistic motion of electron (Dirac)

Electron has magnetic dipole moment (LS interaction)

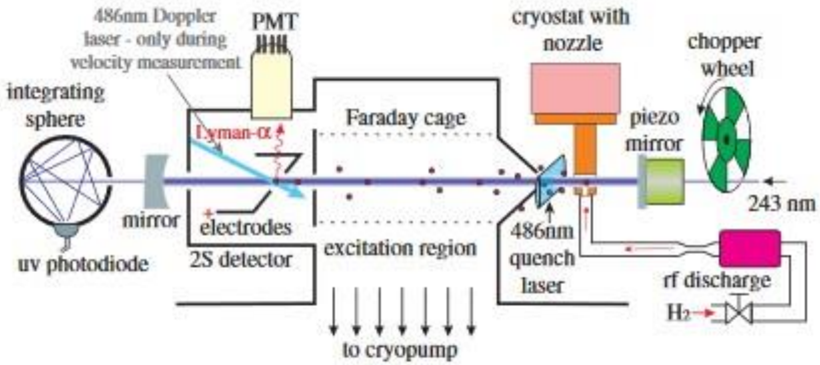
Proton has magnetic dipole moment (SS + SL' interac)

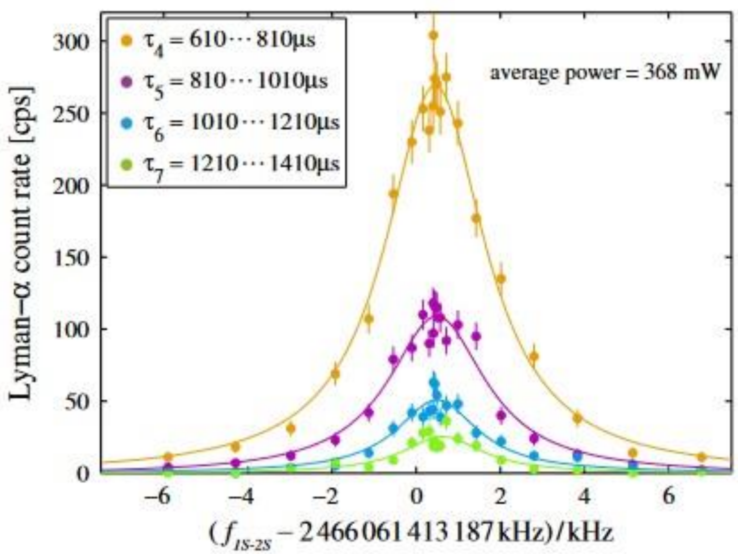
Quantum electro-dynamics (emit/absorb virtual photons)

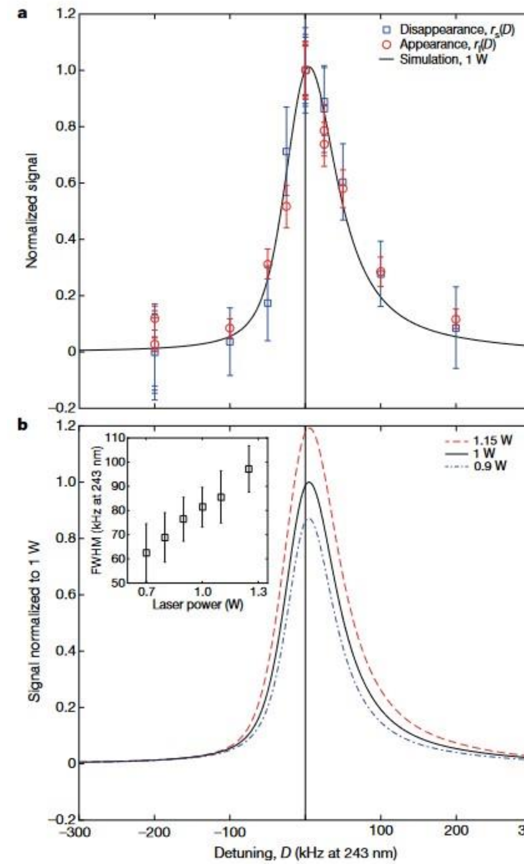
Proton is not point charge (little charged sphere ~1 fm)

Virtual existence of matter/antimatter pairs (Quantum ElectroDynamics)

Measure the 1S-2S frequency







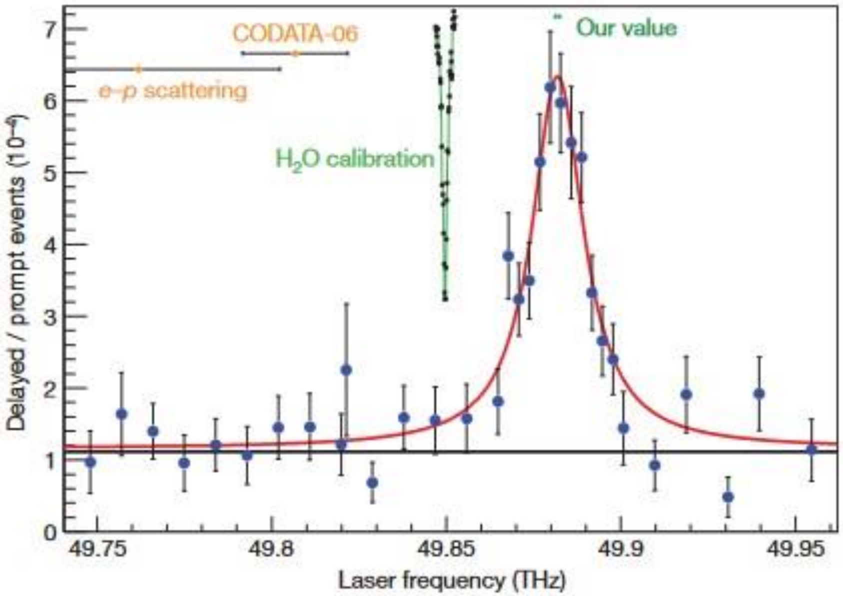
https://www.nature.com/articles/s41586-018-0017-2

https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.107.203001

Fractional uncertainty of 4.2 x 10^{-15}

Fractional uncertainty of 2 x 10^{-12}

Proton Radius Puzzle



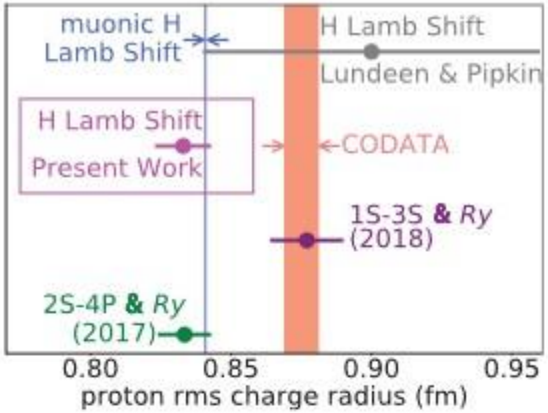


Fig. 5. Summary of proton radius data. Shown are values for the proton RMS charge radius from our measurement, muonic hydrogen, CODATA 2014, and the measurements of Beyer *et al.* (*18*) and Fleurbaey *et al.* (*19*) combined with that of Parthey *et al.* (*20*). Also shown in gray is the value from Lundeen and Pipkin (*6*, *16*).

https://www.science.org/doi/10.1126/science.aau7807
https://www.nature.com/articles/nature09250
https://www.nature.com/articles/d41586-019-03364-z

https://en.wikipedia.org/wiki/Proton_radius_puzzle