The nuclear electron's mass and Heisenberg uncertainty

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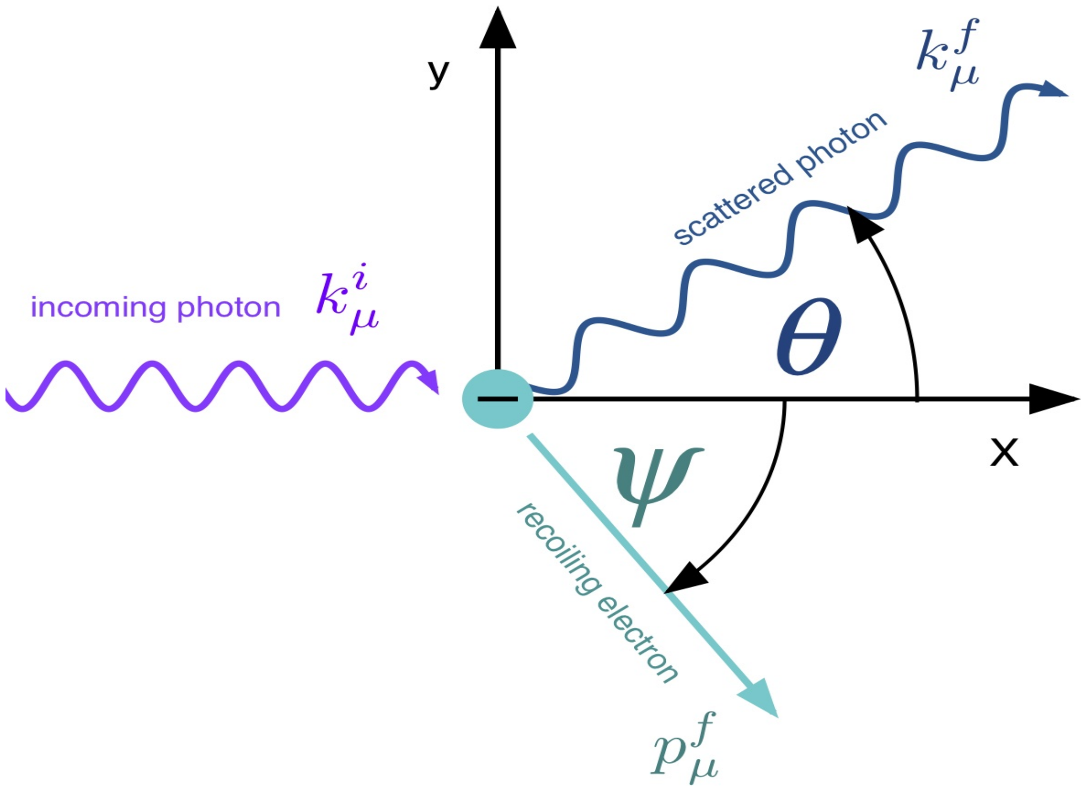
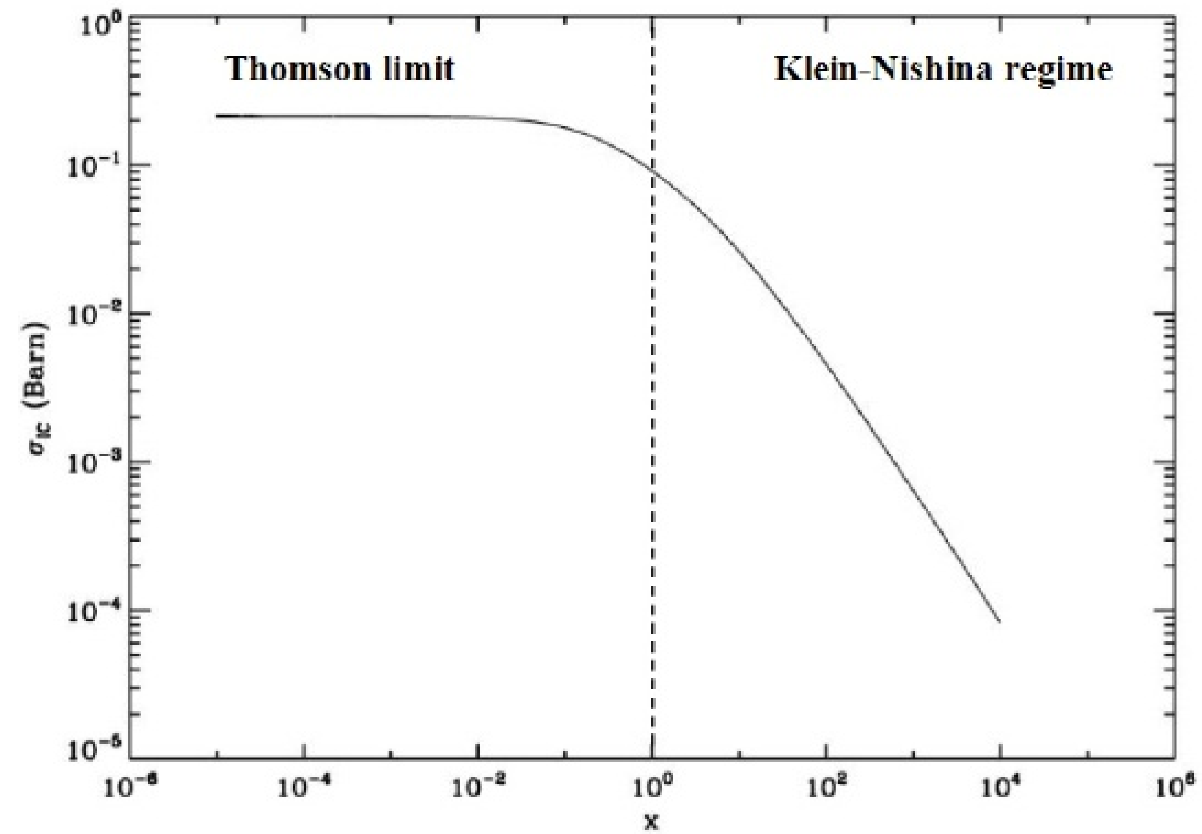
Compton scattering reveals e⁻ charge radius

The electron's spherical charge radius can be precisely measured by Compton scattering:





Photon energy/electron mass

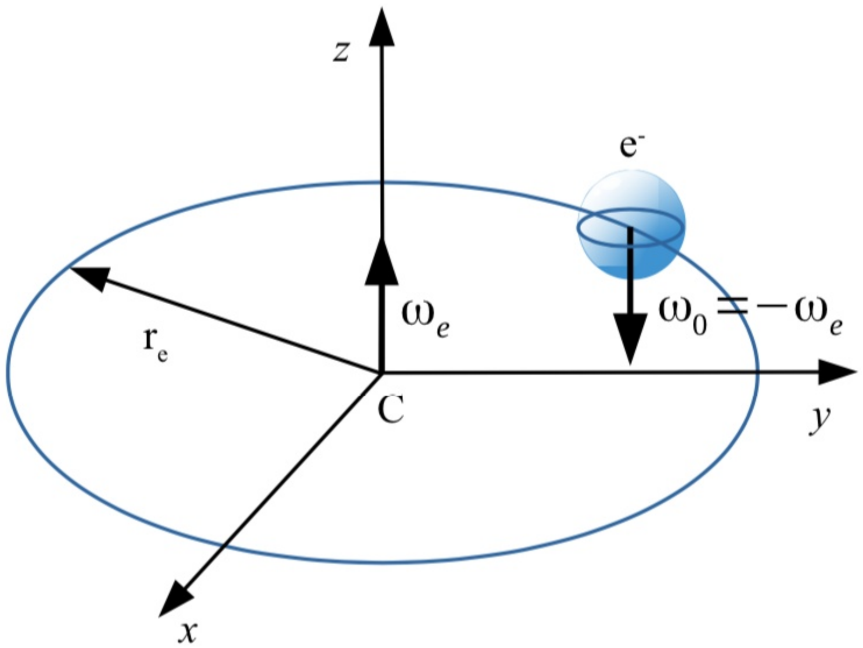
Applying the Klein-Nishina formula, yields the electron's spherical charge radius: $\mathbf{r_0=2.82\ fm}$. This is referred to as the "classical electron radius".

Total electric energy:

$$W_e = \frac{e^2}{32\pi^2\epsilon_0}\int_{r_0}^{\infty}\frac{1}{r^4}\cdot 4\pi r^2 dr = \frac{e^2}{8\pi\epsilon_0}\int_{r_0}^{\infty}\frac{1}{r^2}dr = -\frac{e^2}{8\pi\epsilon_0}\,\frac{1}{r}\Big|_{r_0}^{\infty} = \frac{e^2}{8\pi\epsilon_0 r_0}$$

With r_0=2.82 fm , $\mathbf{W_e=255.5\ keV}$

Zitterbewegung electron radius



Light speed charge circulation at $f=mc^2/h$ frequency yields the Zitterbewegung radius:

r_{ZBW}=386.16 fm

This is referred to as the “reduced Compton radius”.

Total magnetic energy:

$$W_m = \frac{1}{2}\phi_e I_e = \frac{1}{2} \cdot 2\pi\frac{\hbar}{e} \cdot \frac{ec}{2\pi r_e} = \frac{\hbar c}{2r_e}$$

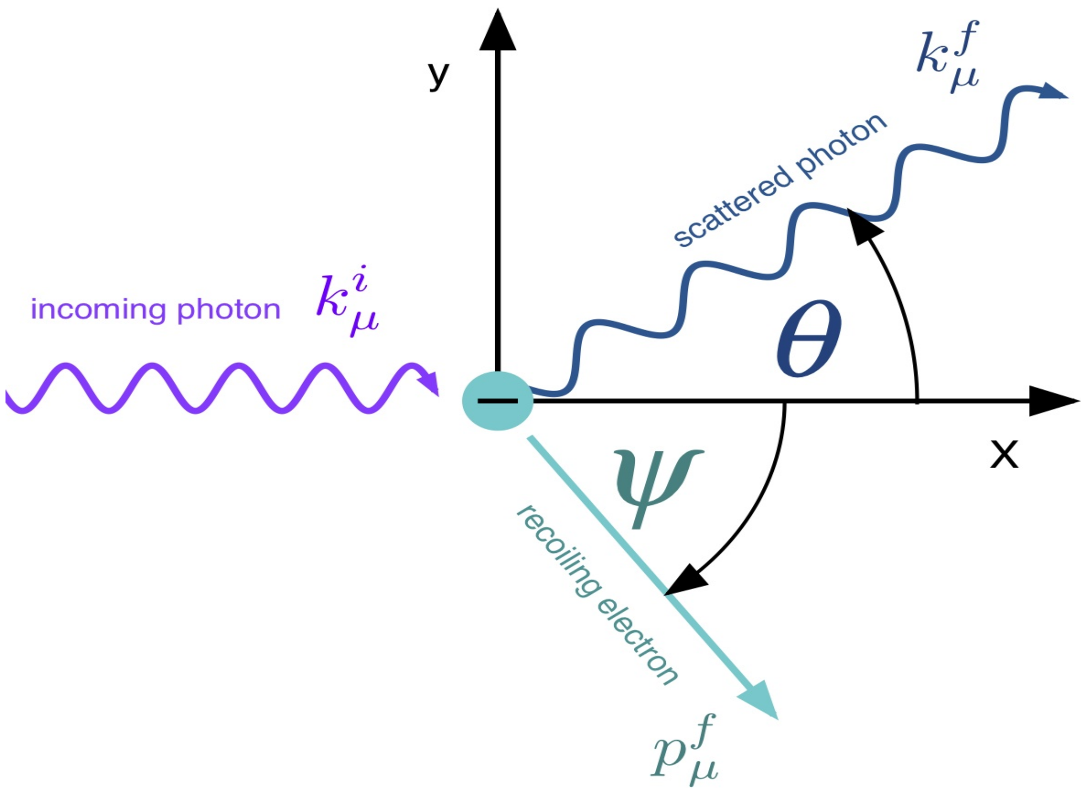
With r_{ZBW}=386.16 fm, **W_m=255.5 keV**

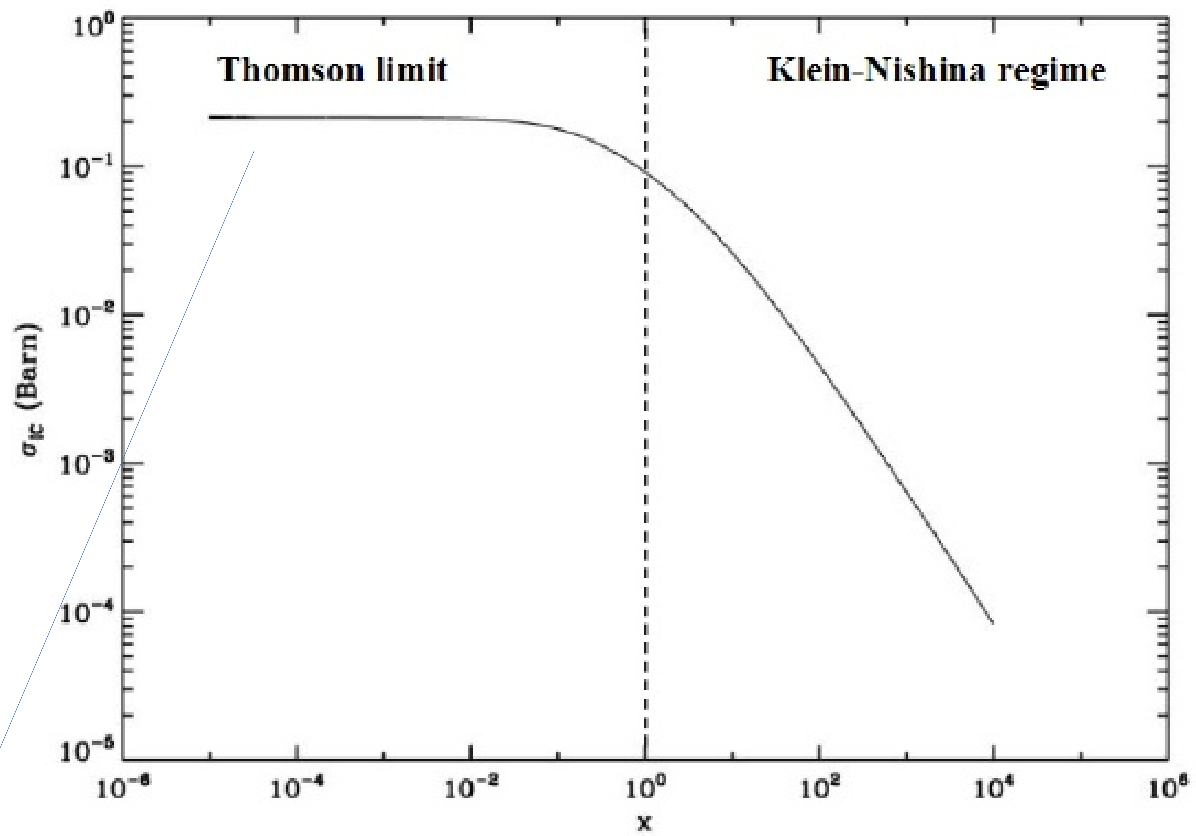
} Mass is inversely proportional with the ZBW radius

The electron mass is electromagnetic field energy.

The Zitterbewegung radius in light scattering

The electron's Zitterbewegung radius matches with the experimentally measured Thomson scattering radius:





Photon energy/electron mass

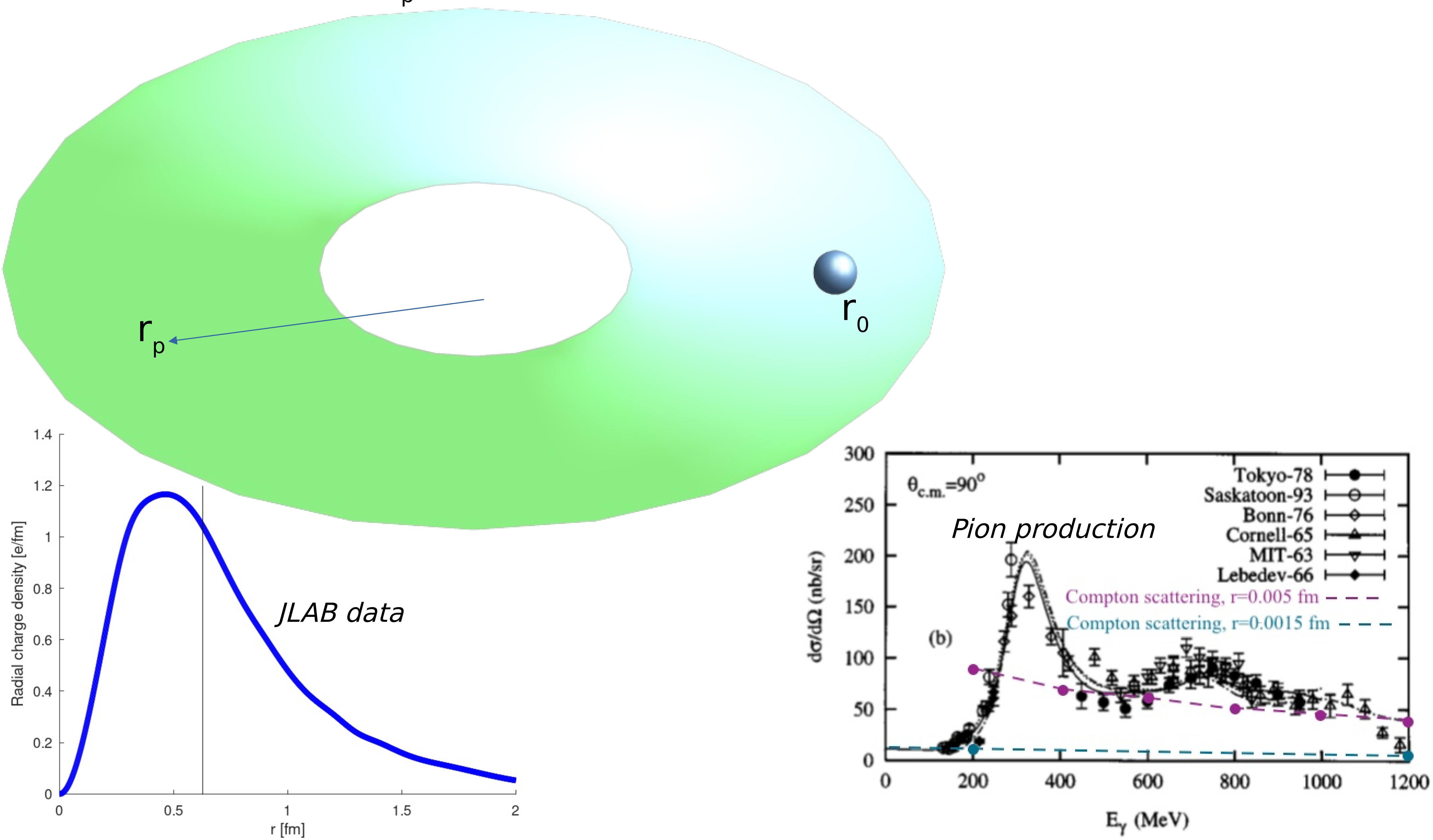
Thomson scattering radius is compatible with the r_{ZBW}=386.16 fm reduced Compton radius

At low light frequency, light scatters off from the whole electron structure.

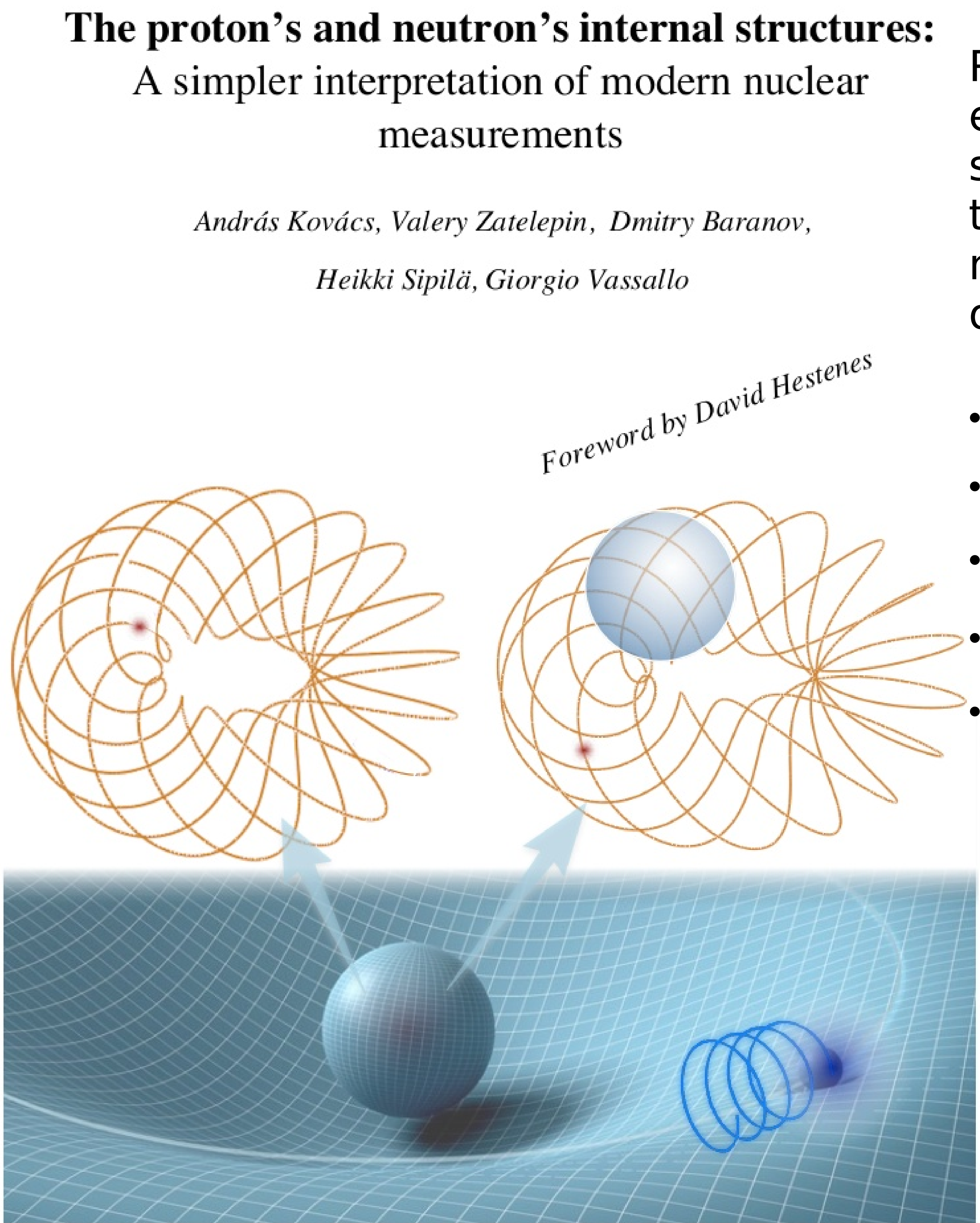
Proton size

Compton scattering measures the radius of the spherical proton charge.
Experimental result: r_0=0.0015 fm.

Scattering and spectroscopy measure the mean radius of the proton structure.
Experimental result: r_p=0.84 fm.



Electron ZBW model application to proton



Recently published book: an electron's and a proton's internal structures can be described through analogous approach, the main difference being the topology of their Zitterbewegung.

- Spherical charge radius: 0.0015 fm
- Poloidal radius: 0.463 fm
- Toroidal radius (mean r_p): 0.831 fm
- Dipole magnetic moment: $\mu=2.9\mu_N$
- Presence of toroidal magnetic moment

The above parameters can be calculated from the proton mass

The proton’s elementary charge status implies that the neutron comprises a proton and a negative elementary charge.

Nuclear electron decay vs. capture

Let us refer to the neutron's negative charge as a "nuclear electron": e_n.

Decay of a heavier particle into a lighter one releases neutrino radiation.
Examples:

$$\mu \rightarrow e + \nu$$
$$e_n \rightarrow e + \nu$$

Neutron decay is thus the e_n decay process.

The **QM state change** of any particle releases single-frequency transversal electromagnetic radiation (gamma radiation).
Examples:

$$e + p \rightarrow H + \gamma \; (13.6 \; eV)$$
$$\mu + p \rightarrow \text{'muonic } H\text{'} + \gamma \; (2.8 \; keV)$$
$$e_n + p \rightarrow n + \gamma$$

The radiated gamma energy is the binding energy of e_n capture.

Nuclear electron mass measurement

Let us consider the QM state change of e_n, upon its nuclear capture by a (M,Z) isotope. This is (M,Z)→(M,Z-1) transmutation. The mass-energy balance equation is:

$$m_{en}+m_Z= m_{Z-1}+E_\gamma/c^2$$

where E_γ is the observed gamma radiation (binding energy)

The same transmutation can be also achieved by ordinary electron capture. In that case, the mass-energy balance equation is:

$$m_e+m_Z= m_{Z-1}+E_{ec}/c^2$$

where E_{ec} is the electron capture energy

Using the above two equations, we can calculate m_{en} as follows:

$$m_{en}c^2= m_ec^2+E_\gamma-E_{ec}$$

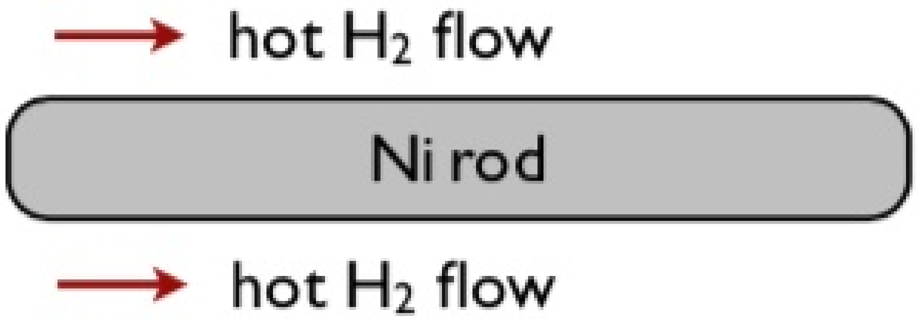
In the following, we use the above equation to experimentally determine the nuclear electron mass.

Nuclear electron mass from ^{58}Ni capture

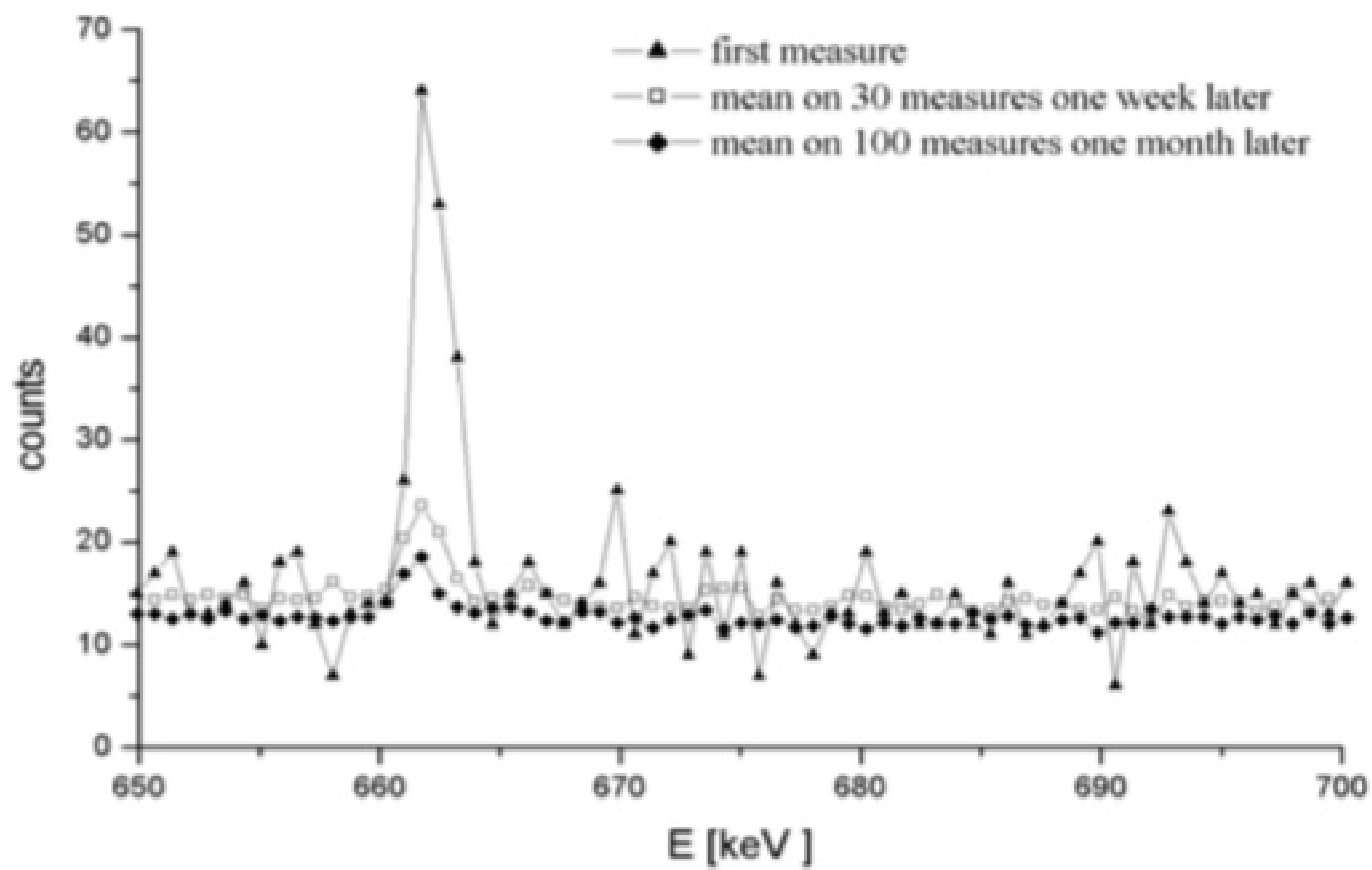
Using a Ni rod under H_2 flow, interesting nuclear phenomena appeared*:

- Detection of neutrons
- The appearance of a 661.5 keV gamma peak (diminishes with time), which the authors could not explain.

Experimental set-up:



Gamma radiation measurement:



* *S. Focardi et al "Evidence of electromagnetic radiation from Ni-H Systems", proceedings of the ICCF-11 (2004)*

Nuclear electron mass from ^{58}Ni capture

The of appearance of neutrons is a signature of nuclear reactions.

The observed E_γ =661.5 keV radiation energy does not match with any radioactive isotopes around nickel. Suppose this gamma peak originates from e_n nuclear capture by ^{58}Ni, which is the most electron capture capable nickel isotope.

For ^{58}Ni, E_{ec}=-381.6 keV. $m_e c^2$=511 keV

Using the above parameters, we calculate m_{en}:

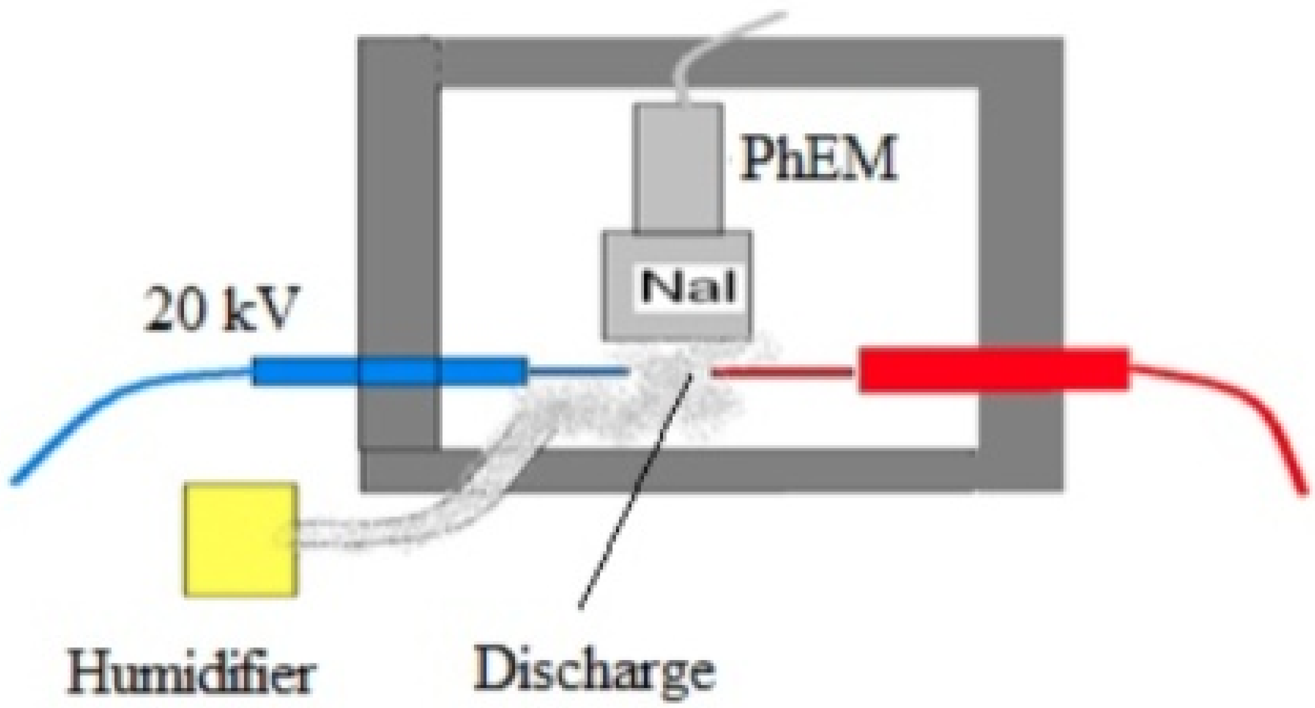
$$m_{en}c^2 = m_e c^2 + E_\gamma - E_{ec} = \mathbf{1554\ keV}$$

Nuclear electron mass from ^{1}H capture

The phenomenon of neutron production by lightning was studied in many works*.

It was determined that such neutrons originate from the $^{14}N \rightarrow {}^{13}N + n$ fission reaction.

We produced lab-made lightning strikes:



*A.V. Gurevich et al "Strong Flux of Low-Energy Neutrons Produced by Thunderstorms", Physical Review Letters, Volume 108 (2012)

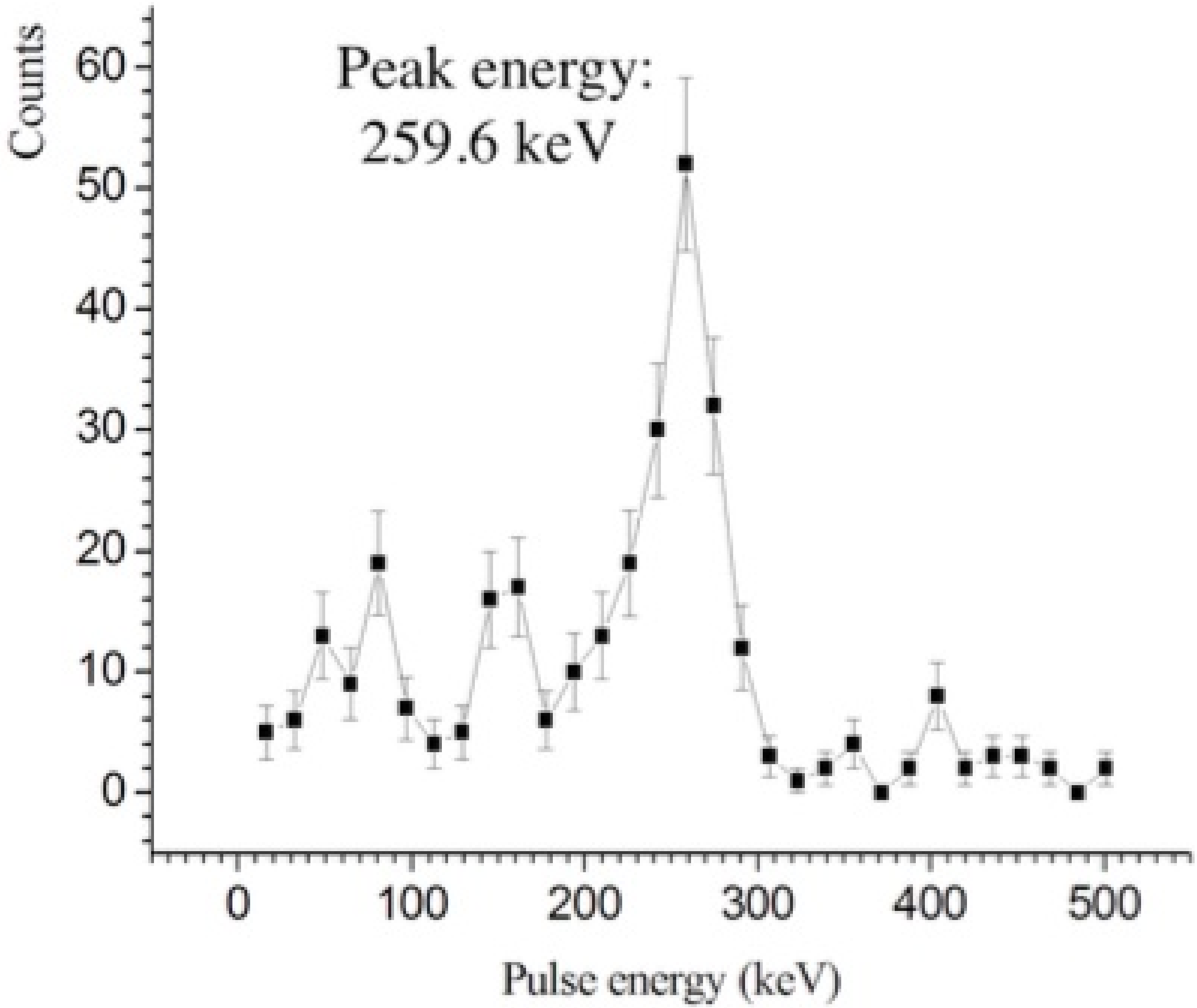
L. P. Babich "Thunderstorm neutrons", Physics-Uspekhi, Volume 62.10 (2019)

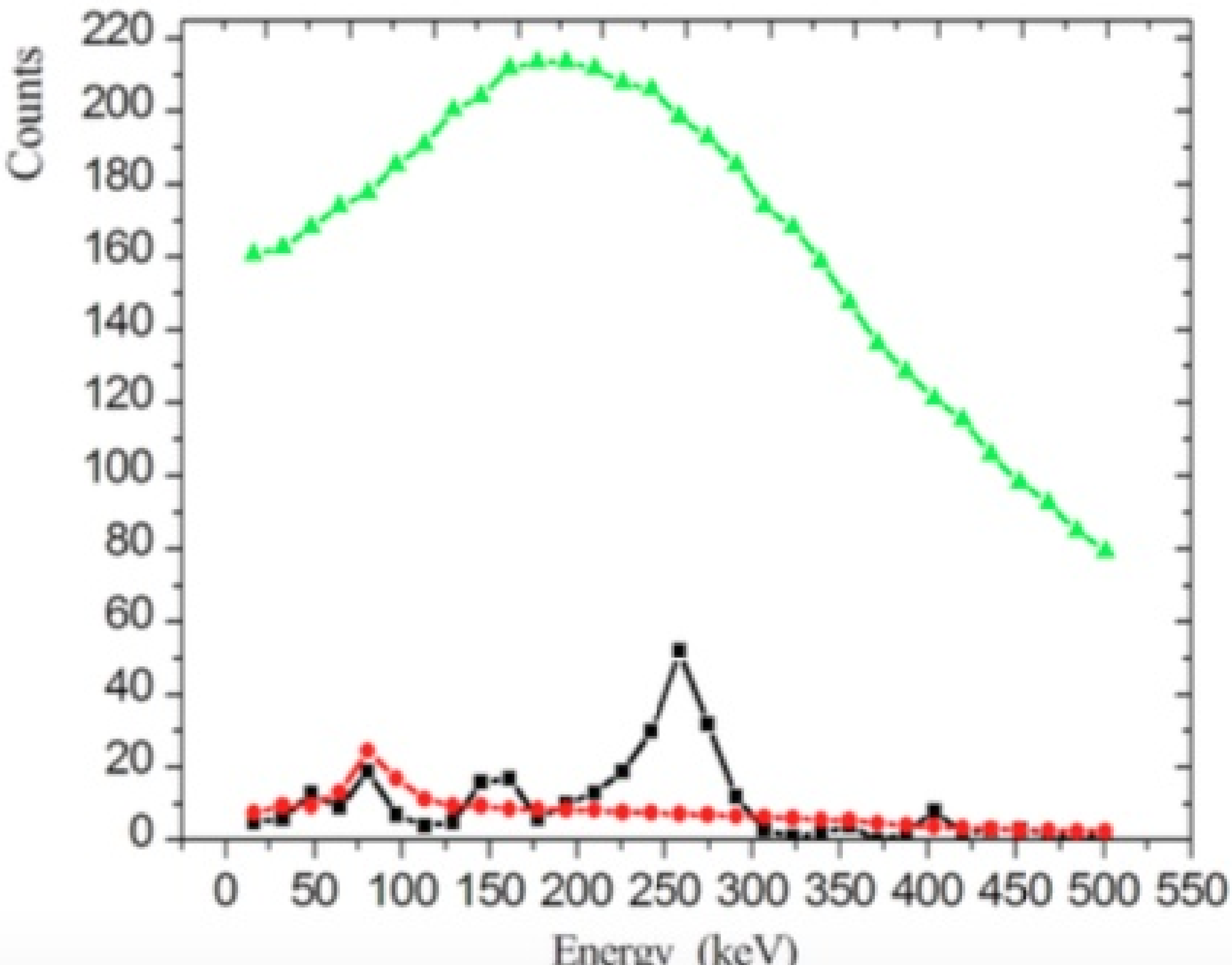
T. Enoto et al "Photonuclear reactions triggered by lightning discharge", Nature, Volume 551 (2017)

Nuclear electron mass from ^1H capture

We detected a gamma peak at 260 keV:

(the small peak at 150 keV is possibly the Compton shoulder of the 260 keV signal peak)





The use of lead shielded chamber was essential.

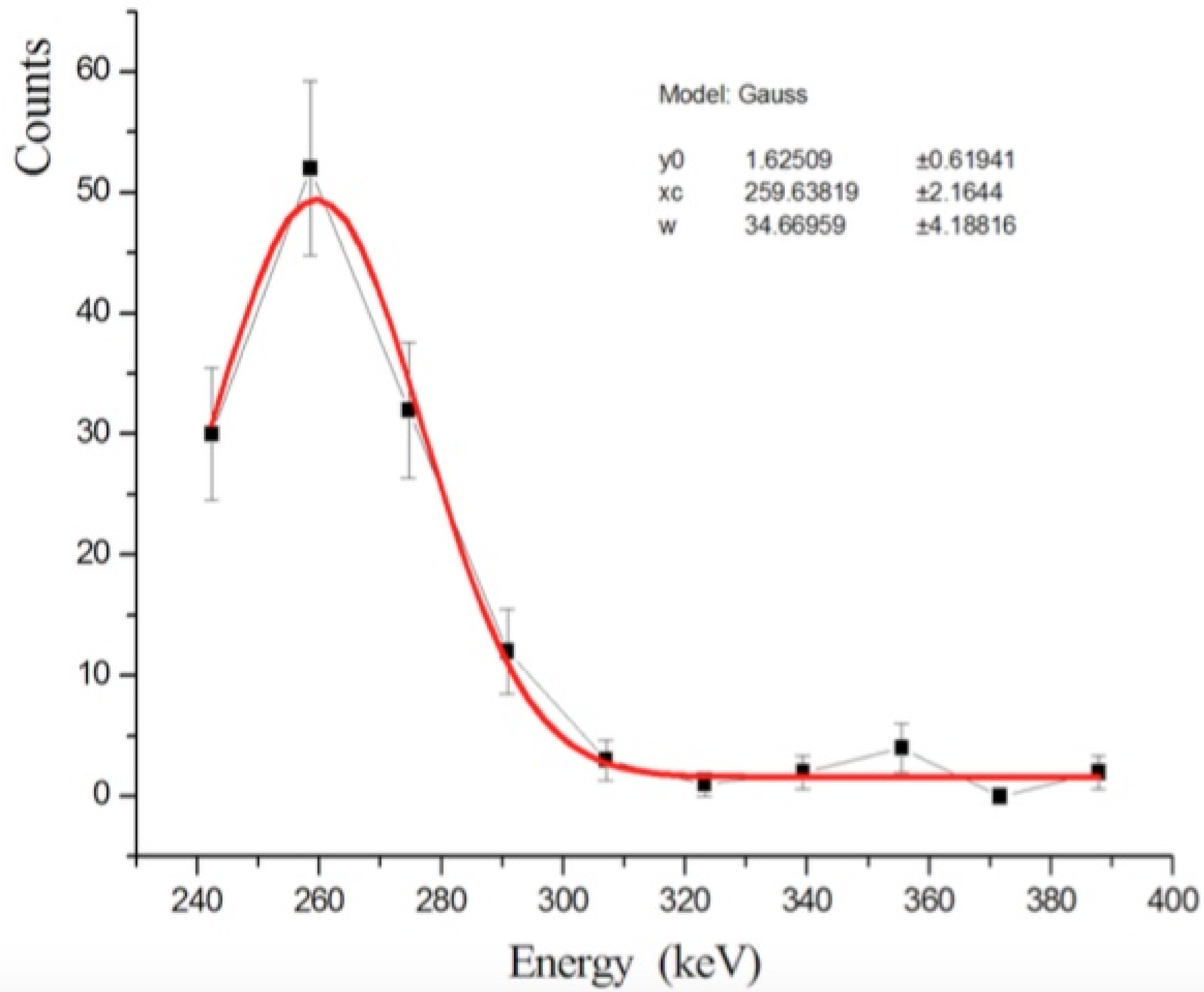
Green: unshielded background

Red: shielded background

Black: shielded signal

Nuclear electron mass from ^1H capture

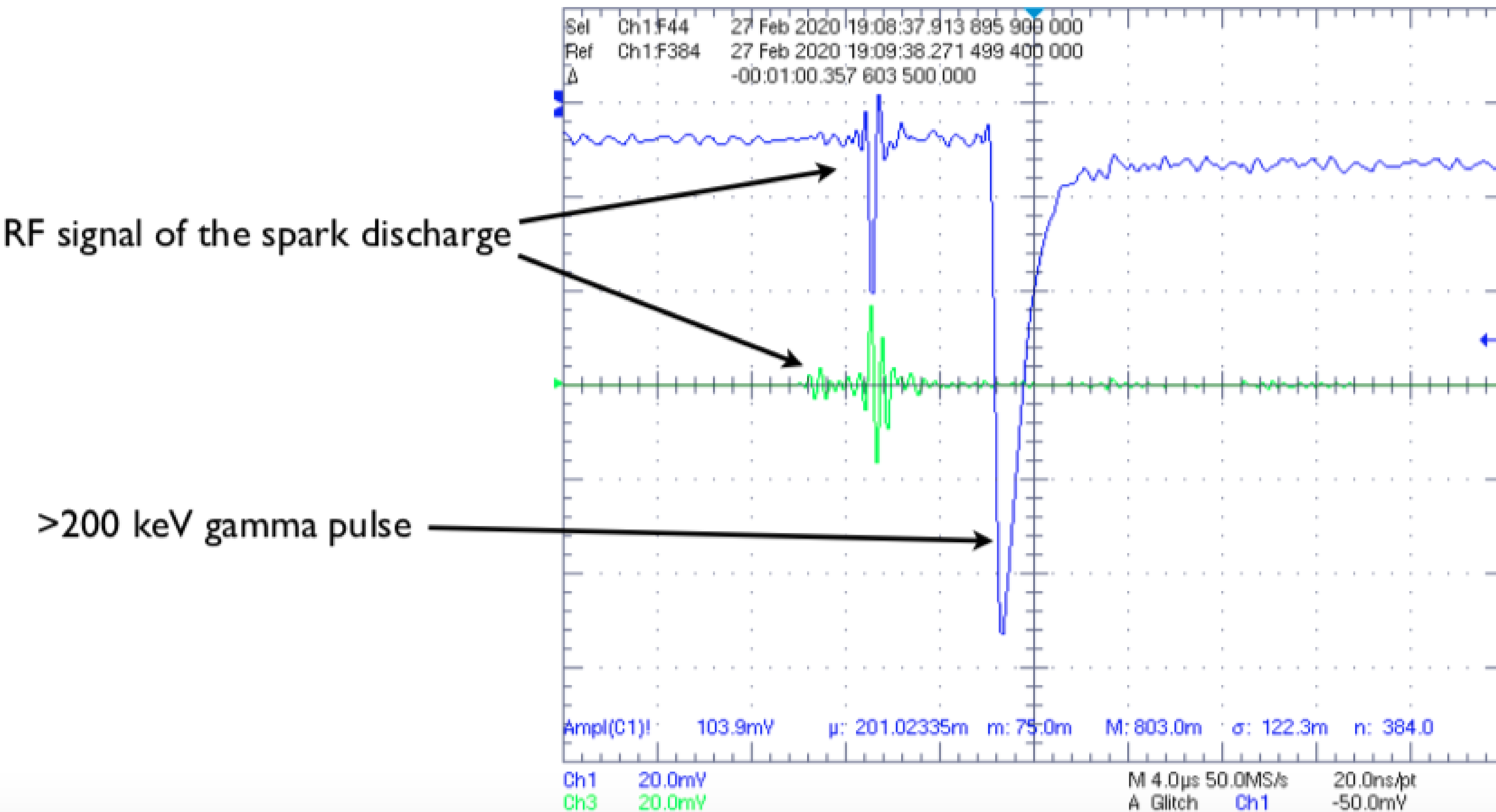
Using Gauss curve fitting, the peak center-point is determined to be at 259.6 keV:



Nuclear electron mass from ^{1}H capture

To investigate the time correlation between the gamma ray signals and the electric discharge sparks, we use an oscilloscope to register gamma ray and RF signals.

The oscillogram recording was triggered when two conditions were met by the gamma signal: i) the duration of the signal is more than 1.5 microseconds, and ii) the signal amplitude is more than 50 mV (corresponds to >200 keV gamma photon energy)



Nuclear electron mass from ^{1}H capture

The observation of gamma peaks is correlated with electric spark events.

Suppose that the E_γ =259.6 $\pm$ 2 keV energy originates from e_n nuclear capture by ^{1}H, which is the most electron capture capable isotope in our experiment.

For ^{1}H, E_{ec}=-782.4 keV. $m_e c^2$=511 keV

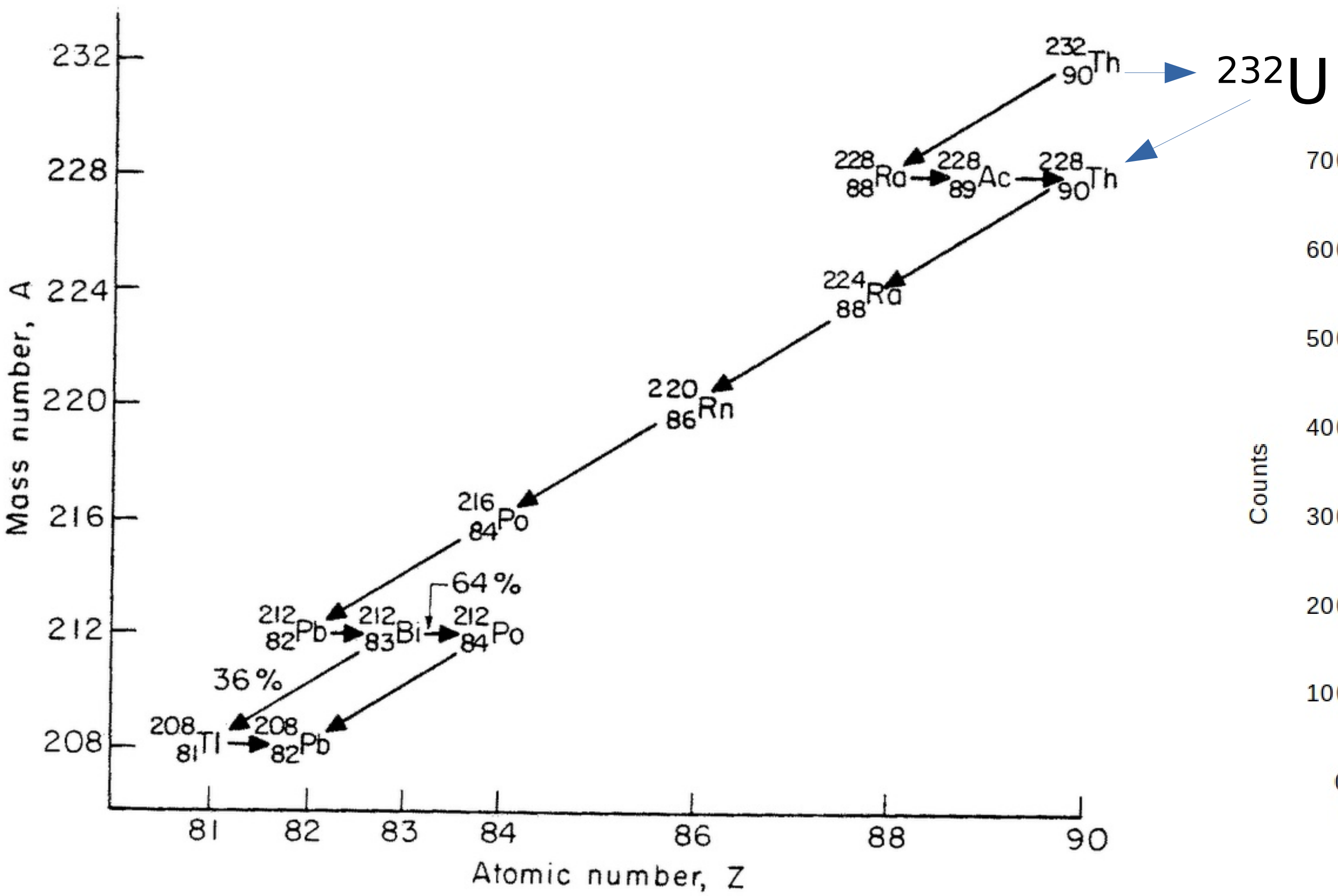
Using the above parameters, we calculate m_{en}:

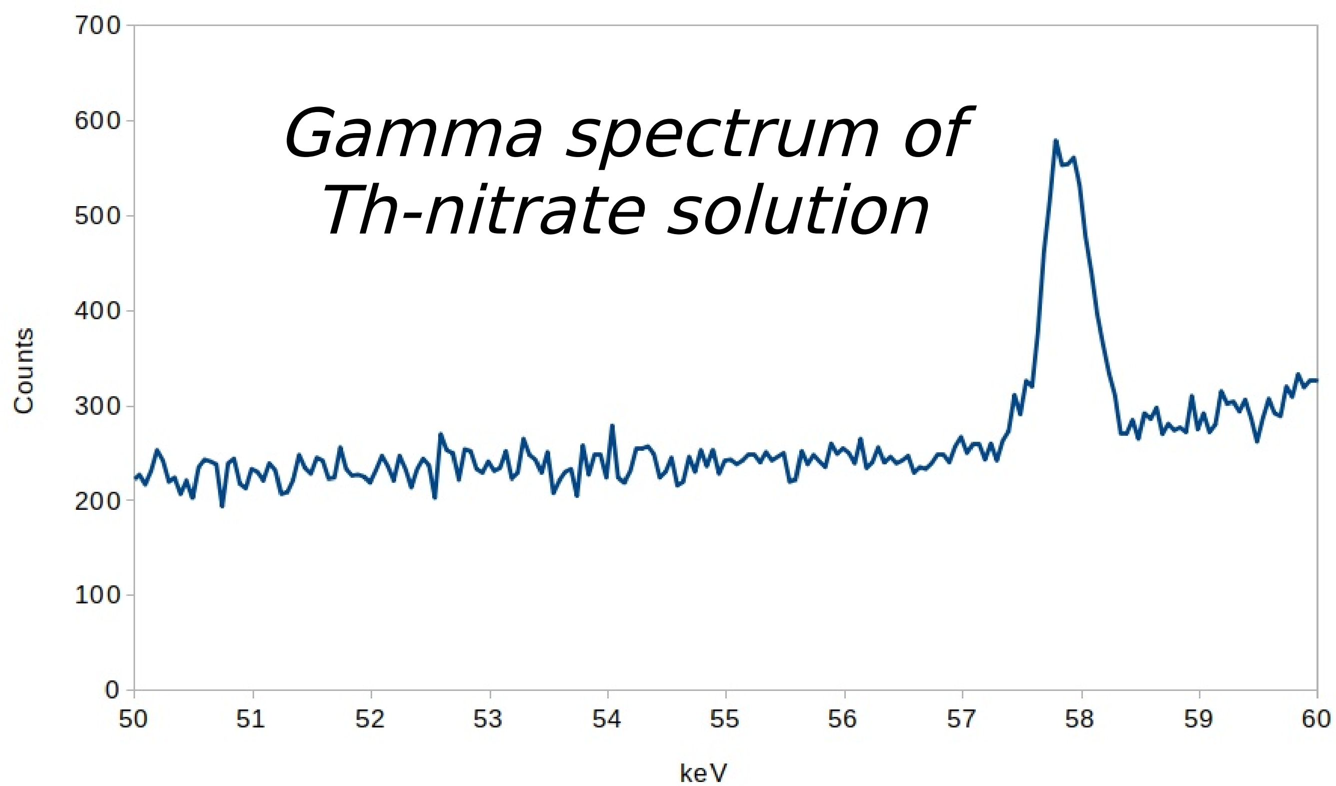
$$m_{en}c^2 = m_e c^2 + E_\gamma - E_{ec} = \mathbf{1553 \pm 2\ keV}$$

Nuclear electron mass from ^{14}N capture

Experiment idea: generate free e_n particles by knocking them out from ^{232}Th. The required energy is naturally provided by the 5-6 MeV alpha-particles of the thorium decay chain.

After e_n particle dissociation from ^{232}Th, a ^{232}U nucleus shall be left behind, whose decay generates a characteristic 57.8 keV gamma line. We made a high-precision gamma spectrum measurement on water-dissolved thorium-nitrate salt, and observed the anticipated 57.8 keV peak. **The e_n particle dissociation reaction may occur in the thorium-nitrate solution**.





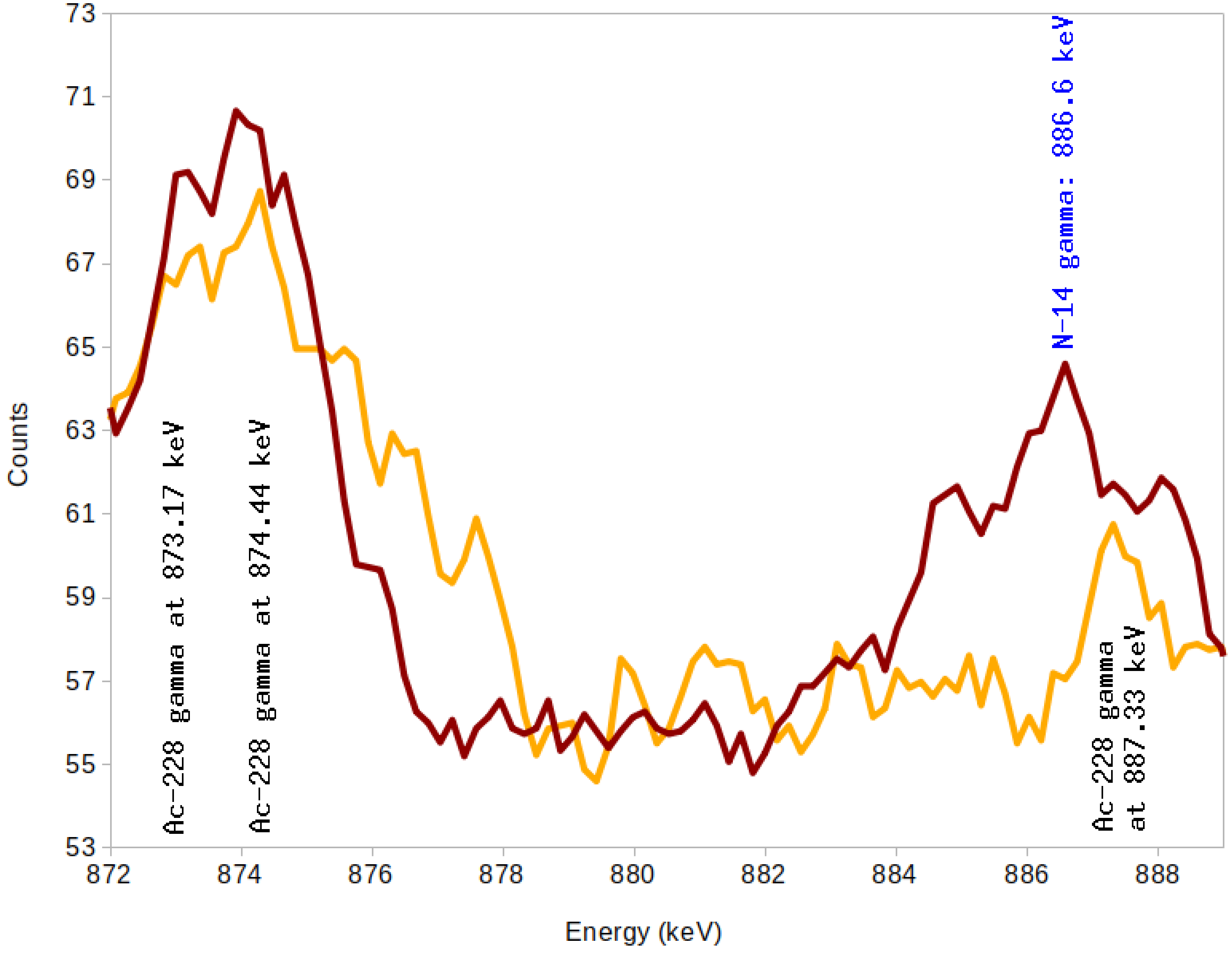
Nuclear electron mass from ^{14}N capture

We compared the gamma spectrum of two solutions.

Red: the gamma spectrum obtained with Th-nitrate being dissolved in concentrated NH_4NO_3 solution.

Orange: the gamma spectrum obtained with same Th-nitrate concentration, but without NH_4NO_3 salt.

The appearance of a 886.6 keV peak is well observable in the case of NH_4^+ presence.



Nuclear electron mass from ^{14}N capture

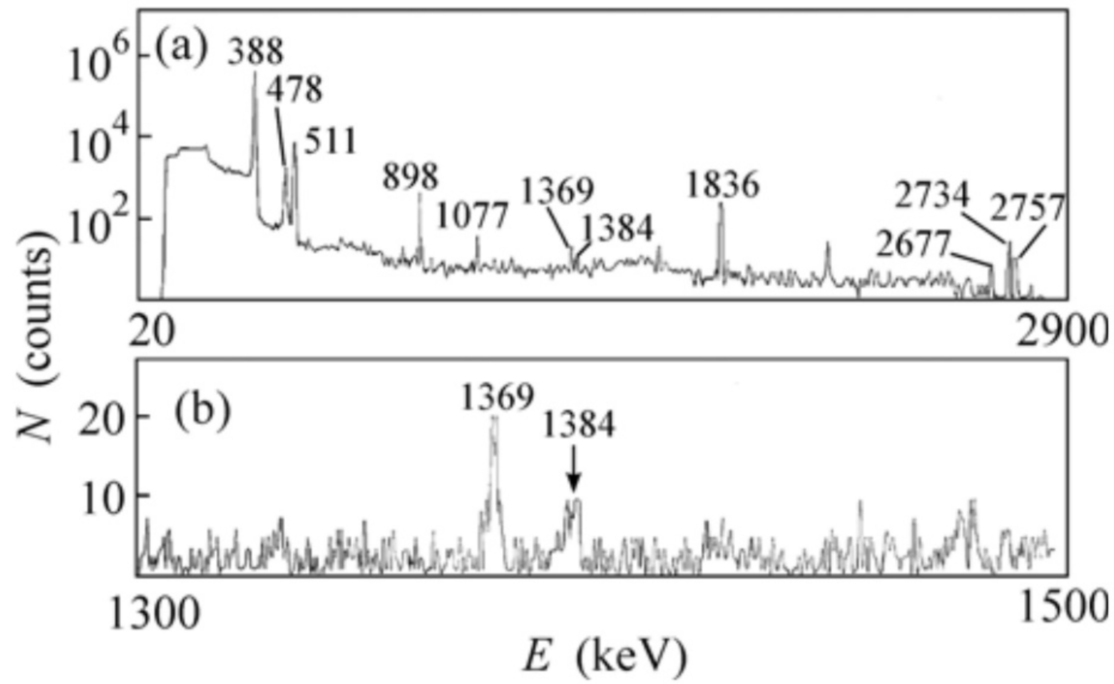
Suppose that the E_γ =886.6 keV energy originates from e_n nuclear capture by ^{14}N, which is the electron capture capable isotope in our experiment.

For ^{1}H, E_{ec}=-156.5 keV. $m_e c^2$=511 keV

Using the above parameters, we calculate m_{en}:

$$m_{en}c^2 = m_e c^2 + E_\gamma - E_{ec} = \mathbf{1554\ keV}$$

Nuclear electron Compton scattering



The 898, 1836, and 2734 keV gamma peaks correspond to ^{88}Y. The 1077 keV gamma peak corresponds to ^{86}Y. Although there is 200 times as much ^{88}Sr than ^{86}Sr, the half-life of ^{86}Y is 200 times shorter than the ^{88}Y half-life; it is therefore anticipated that their decay radiation has peaks of comparable intensity. Regarding ^{87}Y, its gamma peaks are at 389 and 485 keV; these peaks are not visible because of the nearby larger the larger radiation of other isotopes. The 511 keV gamma peak corresponds to the positron emission by these yttrium isotopes.

The above-discussed yttrium isotopes are produced from the corresponding strontium isotopes via the emission of an electron. We can write the observed Compton scattering reactions as follows:

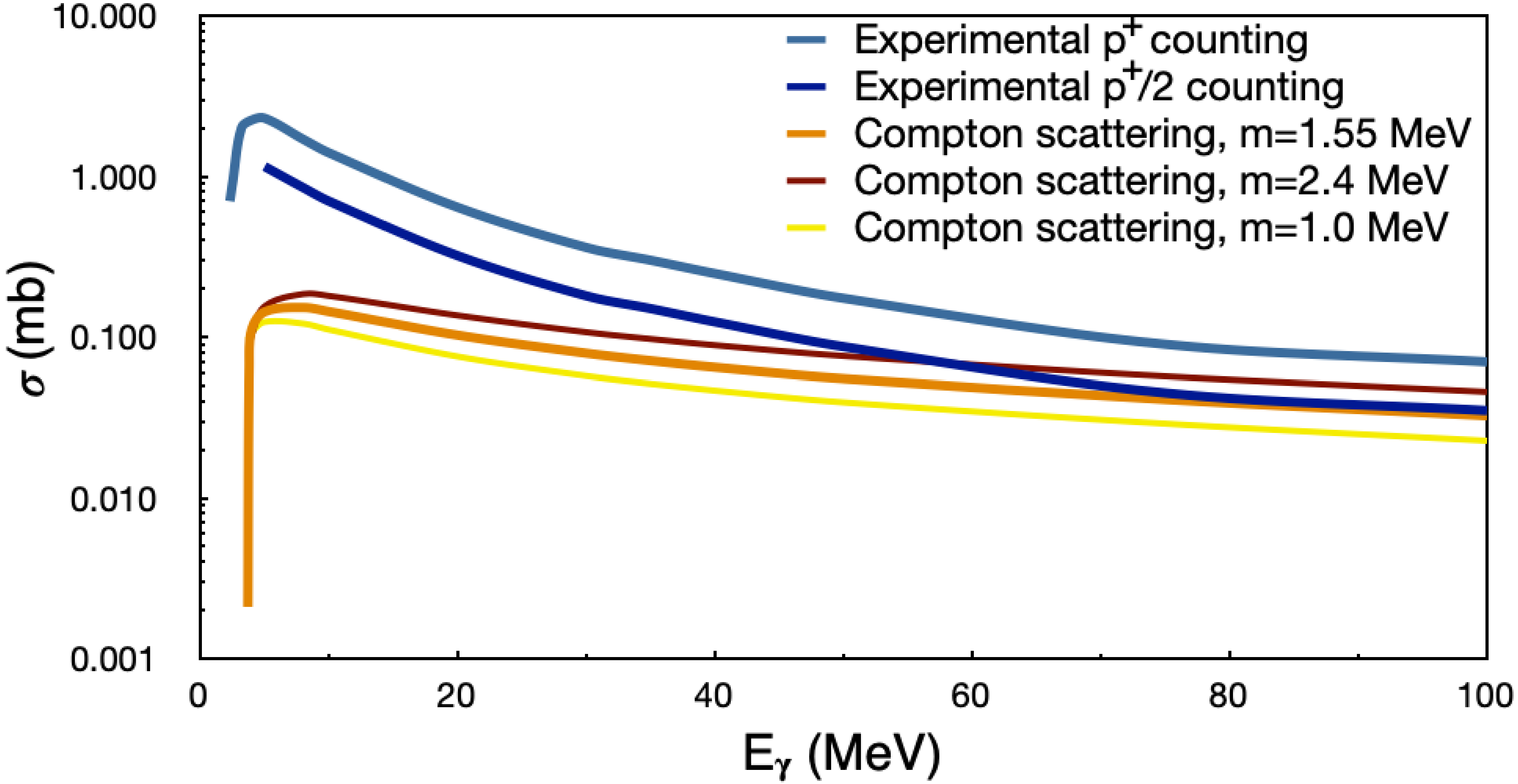
$$^{88}Sr + \gamma\,(< 62\,MeV) \rightarrow {}^{88}Y + e_n^- \rightarrow {}^{88}Y + e^- + \bar{\nu}_e$$

$$^{86}Sr + \gamma\,(< 62\,MeV) \rightarrow {}^{86}Y + e_n^- \rightarrow {}^{86}Y + e^- + \bar{\nu}_e$$

B. G. Novatsky et al Possible Observation of Light Neutron Nuclei in the Alpha Particle Induced Fission of ^{238}U, JETP Letters, Volume 96.5 (2012)

Nuclear electron Compton scattering

Is high-energy photo-dissociation a Compton scattering process?
High-energy deuteron photo-dissociation cross section data:



The calculated cross section (Nishina-Klein formula) converges into the experimental data at high energy with m=1.55 MeV. Implications:

- Within the nucleus, nuclear electrons remain to be 1.55 MeV mass particles
- High-energy photo-dissociation is the nuclear electron's Compton scattering.
- The photo-electric effect is significant only in the <50 MeV regime

By comparing high-energy electron vs. nuclear electron Compton scattering, we also obtain the nuclear electron's spherical charge radius: 0.4-0.5 fm.

Nuclear electron summary

- The nuclear electron model is inspired by proton theory considerations.
- Experiments show that the nuclear electron mass is 1554 keV. Nuclear beta decay is the nuclear electron's decay into and electron.
- The nuclear electron is short-lived in a free particle state, but stabilized by sufficiently high nuclear binding energy.
- The proposed nuclear electron model can be further validated by searching for more gamma peaks, corresponding to nuclear electron capture by other isotopes.

What about Heisenberg uncertainty?

QM waves: the de-Broglie frequency is real

Consider an electron moving at kinetic speed v. In relation to light-speed, its speed is characterized by $\beta = \frac{v}{c}$, $\gamma_L = (1-\beta^2)^{-\frac{1}{2}}$ and rapidity w defined as $\gamma_L = \cosh w$. It follows that $\cosh^2 w - \sinh^2 w = 1$, $\tanh w = \beta$, and $\sinh w = \gamma_L \beta$.

In the electron's rest frame, its Zitterbewegung is a time-wise oscillation. A relativistic boost rotates the time and space axes into each other according to the following hyperbolic rotation matrix:

$$\begin{pmatrix} ct' \\ x' \end{pmatrix} = \begin{pmatrix} \cosh w & -\sinh w \\ -\sinh w & \cosh w \end{pmatrix} \begin{pmatrix} ct \\ x \end{pmatrix}$$

Therefore, the time-wise Zitterbewegung oscillation of the rest frame acquires a spatial oscillation component in the boosted reference frame. Specifically, the Zitterbewegung frequency of the rest frame is $\frac{\omega}{2\pi} = \frac{m_0 c^2}{h}$, and this is commonly referred to as the De Broglie frequency. The quantum mechanical wavenumber of the rest frame is: $k_0 = 0$. The corresponding wavenumber in the boosted frame is:

$$\frac{k}{2\pi} = \frac{\omega}{2\pi}\frac{\sinh w}{c} - k_0 \cosh w = \frac{\omega}{2\pi}\frac{\sinh w}{c}$$

Evaluating the right side of the above equation, we obtain:

$$\frac{k}{2\pi} = \frac{m_0 c^2}{h}\frac{\gamma_L v}{c^2}$$

Rearranging the above equation, we finally obtain:

$$\hbar k = (\gamma_L m_0)\, v = mv = p_{kinetic}$$

We recognize the above result as the basic postulate of quantum mechanics. However, it is no longer a postulate in our case: the appearing quantum mechanical wave is simply the Lorentz transformed component of the electron's Zitterbewegung oscillation.

Heisenberg uncertainty

Recall the derivation of QM wavenumber:

$$\hbar k = (\gamma_L m_0)\, v = mv = p_{kinetic}$$

Let us write the $\triangle x \cdot \triangle p \geq \frac{\hbar}{2}$ uncertainty relation as $\triangle x \cdot \triangle (\hbar k) \geq \frac{\hbar}{2}$

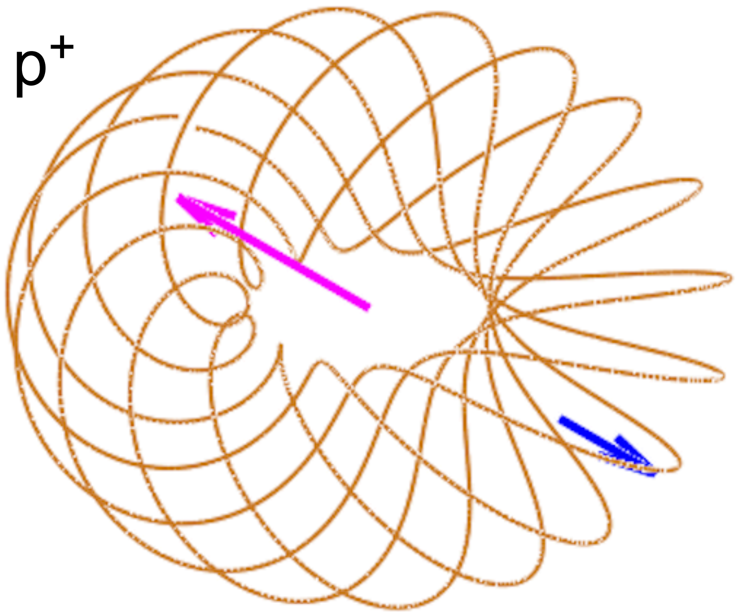
Recall that the QM wavenumber is just the Lorentz-transformed component of the Zitterbewegung frequency. **It is therefore the Zitterbewegung frequency that really determines the position uncertainty!**

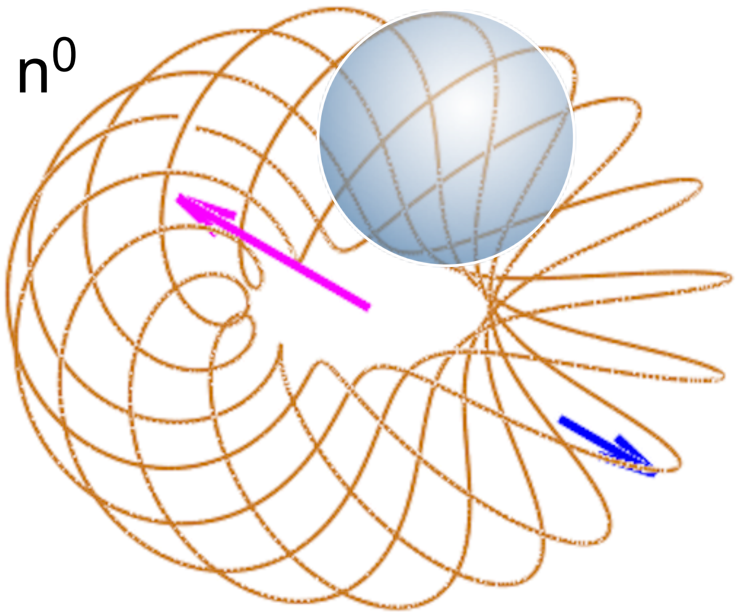
For free particles, f_{ZBW} is proportional to *m*.
In contrast, the proton-bound nuclear electron acquires a much higher Zitterbewegung frequency.

ZBW frequencies within the neutron

The proton-bound nuclear electron's Zitterbewegung frequency can be estimated from its magnetic moment contribution:

$\mu_p = 2.79\mu_N$ $\mu_n = -1.91\mu_N$





The contribution of negative charge: $\mu_- = \mu_n - \mu_p = -4.7\mu_N$

By definition, 1 μ_N is the magnetic moment of an energetic positron, whose relativistic mass is the proton mass.

The Zitterbewegung frequency corresponding to $-4.7\mu_N$ magnetic moment is that of an electron-like particle, whose relativistic mass is: $m_p/4.7 = 200$ MeV

These results clarify Heisenberg uncertainty in the nuclear context.

Detailed theory and experiment description:

The proton's and neutron's internal structures:
A simpler interpretation of modern nuclear measurements

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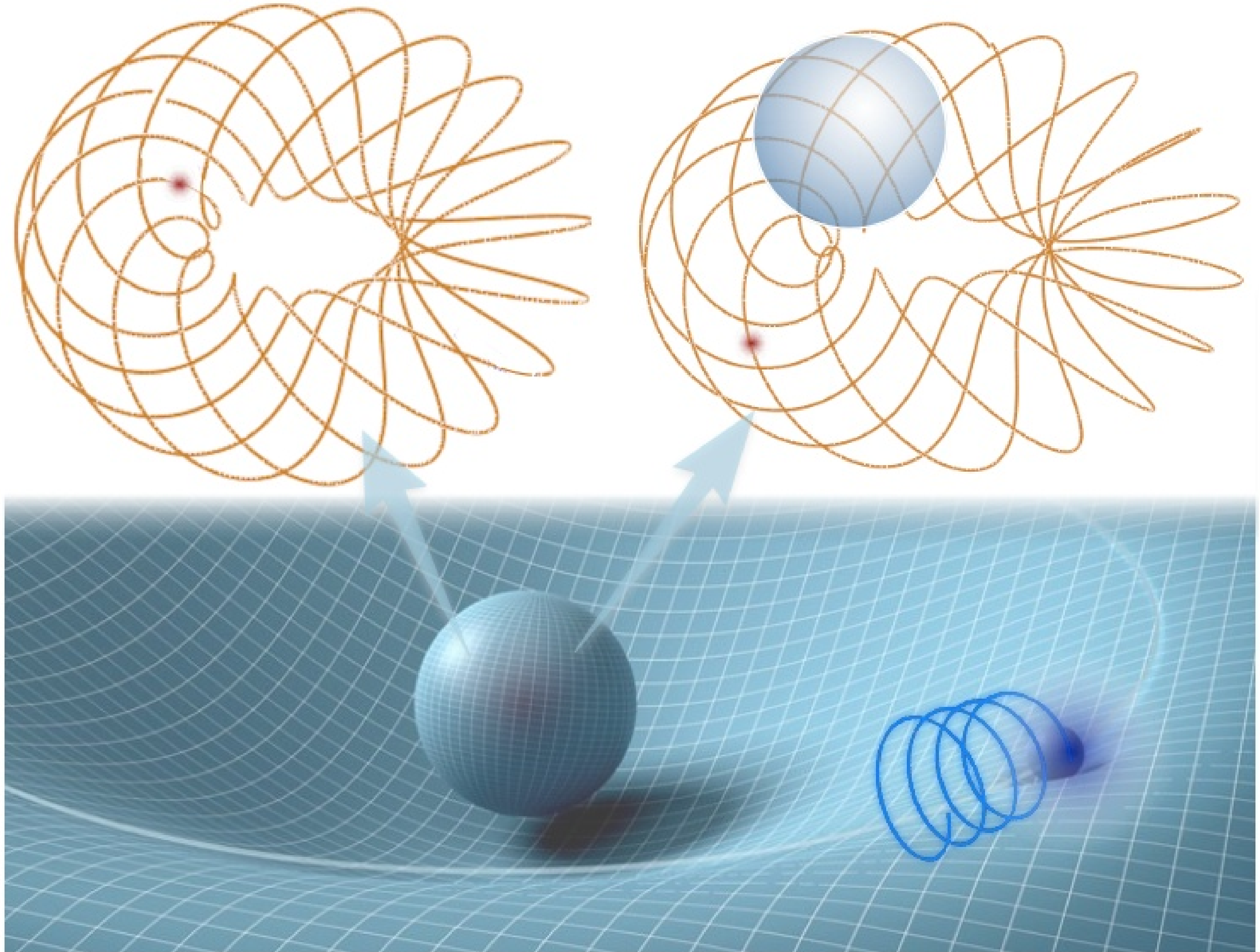
Foreword by David Hestenes



Thank you for your attention!