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UNIVERSE: THE PARTICLES AND THE PRINCIPLES

OUTLINE

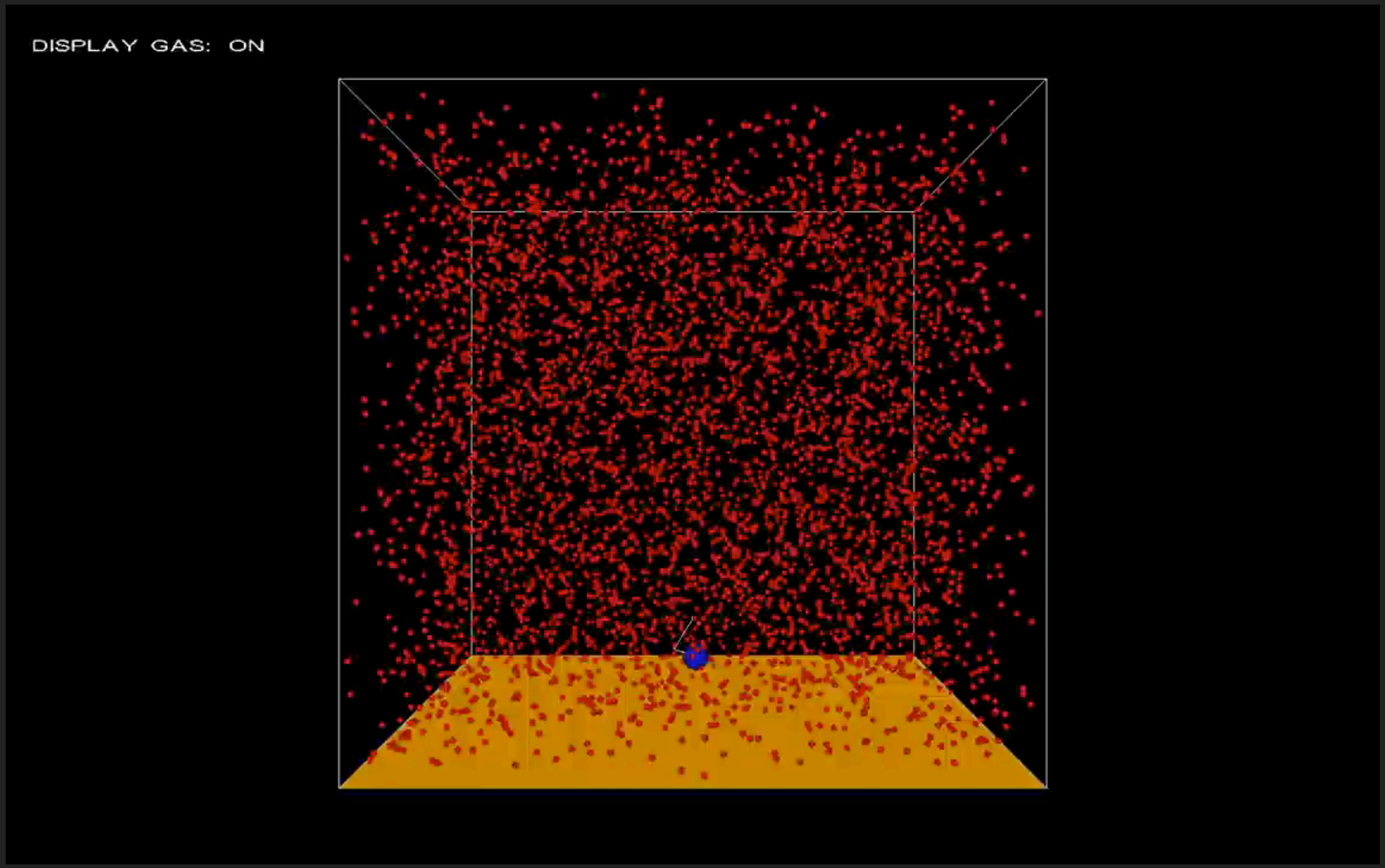
- The known building blocks of the Universe.
- Quantum Mechanics: The language in which we describe the universe.
- The known fundamental forces.
- Dark matter: A new particle or a new principle?

THE SEARCH FOR THE BUILDING BLOCKS OF THE UNIVERSE

- Can we reduce the infinite variety of things to few building blocks?
  - A long philosophical tradition that **speculated** that all matter is made of “atoms”.
    - e.g: Bhagvad Gita Chapter 8 verse 9 “One meditates on the omniscient, primordial, the controller, smaller than the atom”
  - First **empirical** evidence for atoms from Dalton’s work on chemical reactions. (1805)

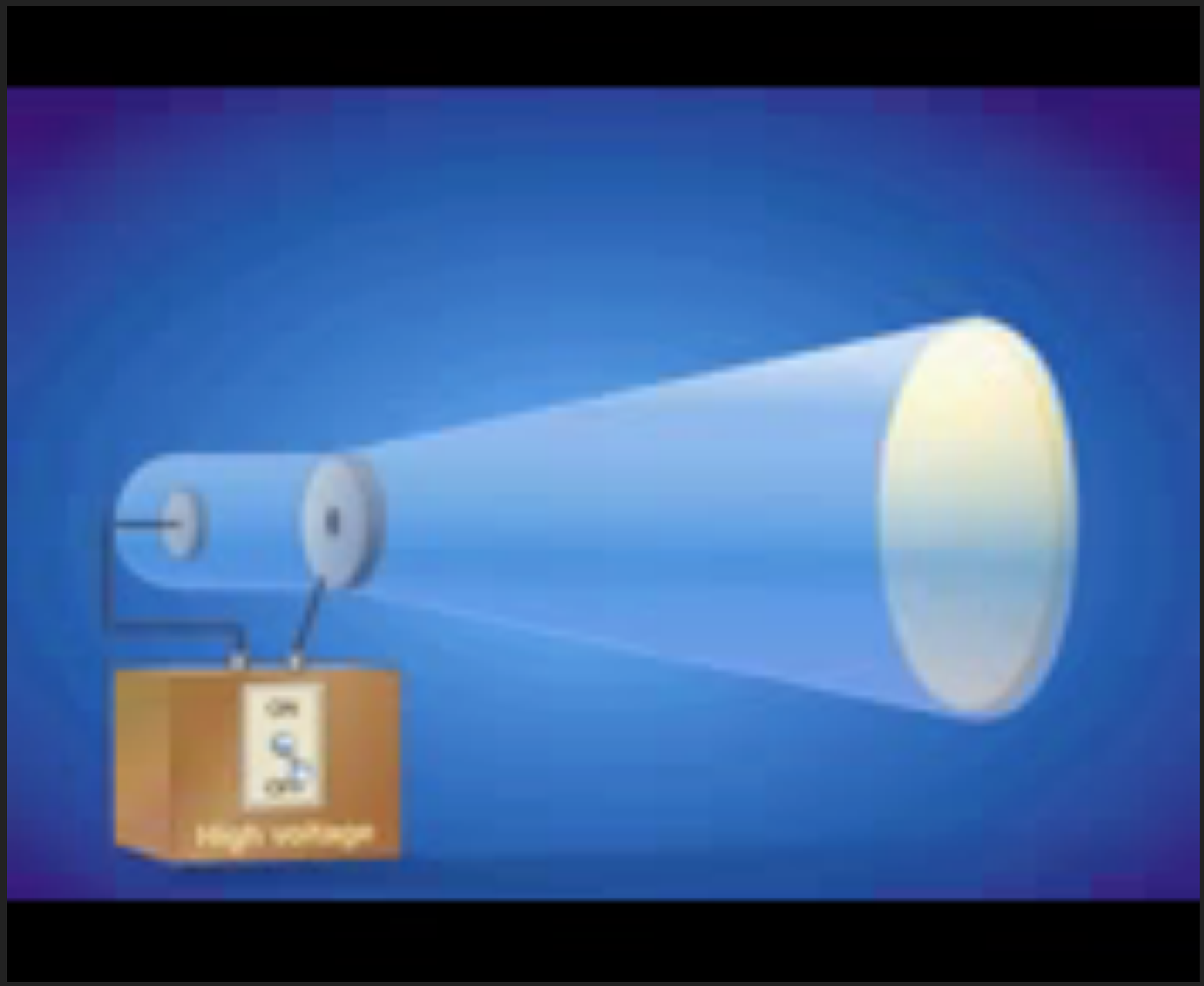
BROWNIAN MOTION AND THE DISCOVERY OF ATOM

- First convincing experimental proof of the existence of atoms and molecules was Albert Einstein's explanation of the Brownian motion



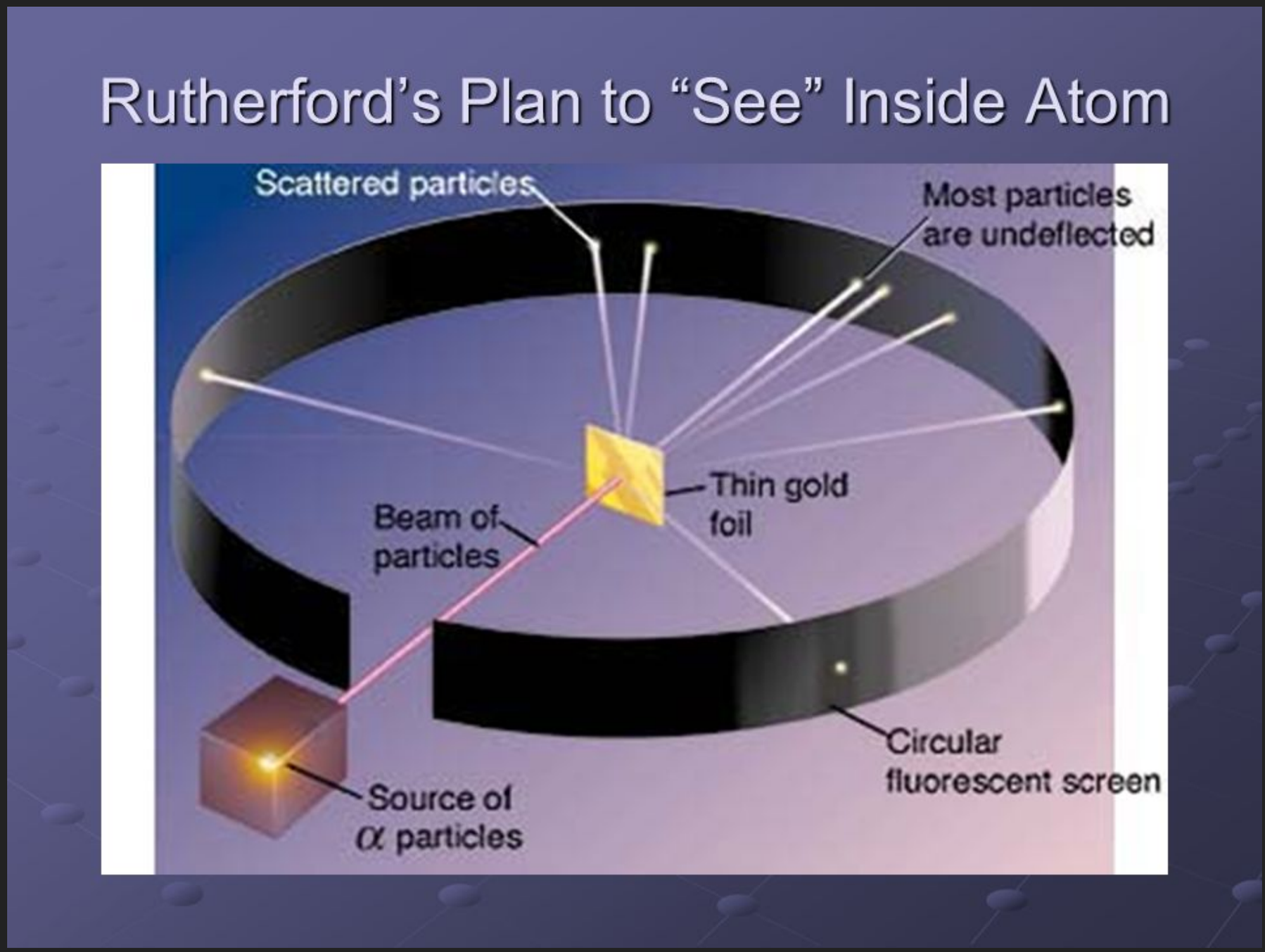
DISCOVERY OF ELECTRON

- J. J. Thomson (1897)
- The first elementary particle to be discovered.
- 2000 times lighter than the hydrogen atom



DISCOVERY OF THE NUCLEUS

- Rutherford's experiment (**Demo**) (1911)
- Mass of an atom is concentrated in its nucleus

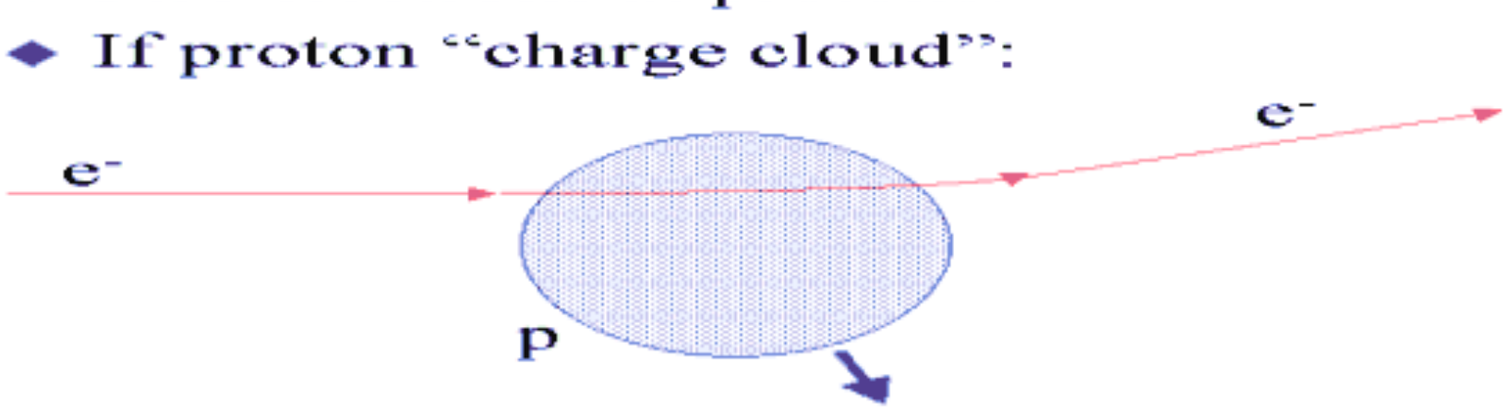


DISCOVERY OF QUARKS: DEEP INELASTIC SCATTERING

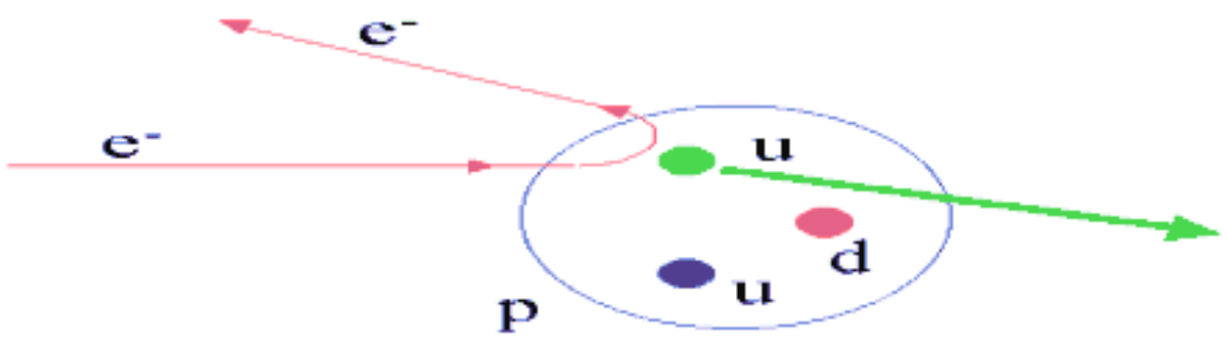
- Doing Rutherford experiment at very high energies (7-8 GeV) (1965-72)
- Again shows the structure of proton as point like objects - quarks and gluons
- Like Rutherford can make quantitative calculations to confirm the picture

Evidence for Quarks: The Basic Idea

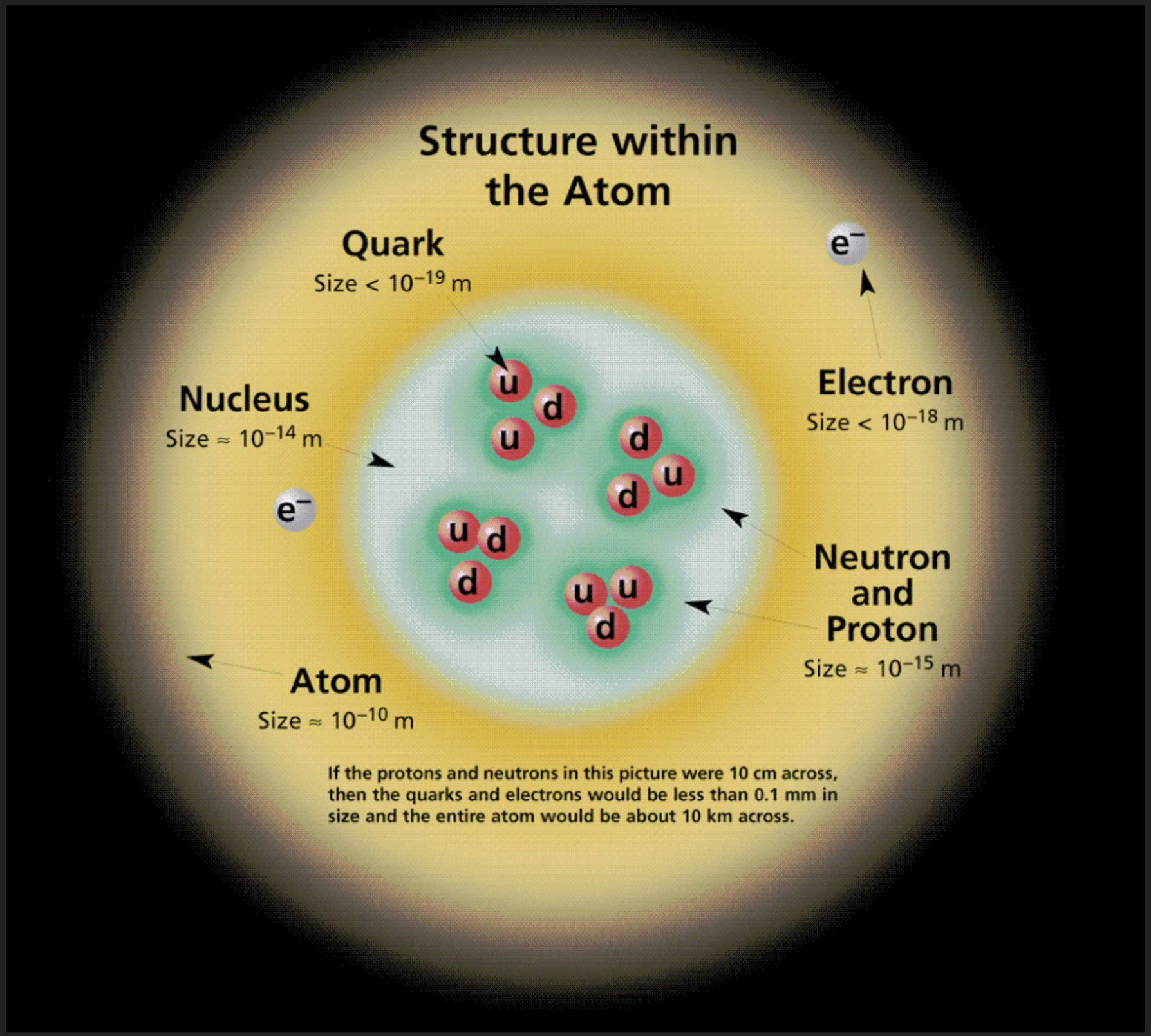
- Fire electrons at protons.
- If proton "charge cloud":



- If proton contains point charges, some of time see:



INWARDS BOUND

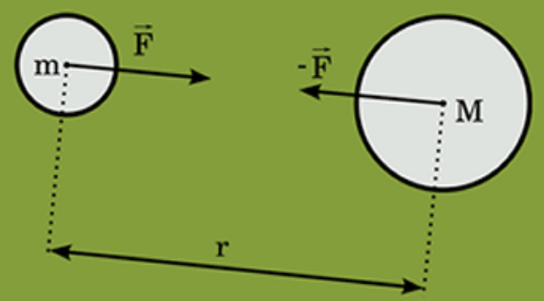


QUANTUM MECHANICS: THE LANGUAGE IN WHICH WE UNDERSTAND THE UNIVERSE

- In classical mechanics for a given force law we can calculate the trajectories of the interacting particles.
- In quantum mechanics for a given force law we can **only calculate the probabilities** of finding the particles at various points at different times.
- If the particles are very massive these probabilities approach certainty and reproduce the results of classical mechanics.

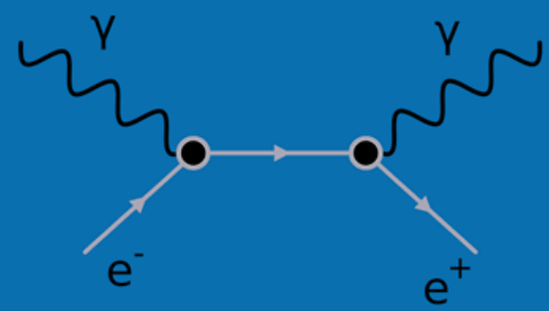
FOUR FUNDAMENTAL FORCES

$$G_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + g_{\mu\nu}\Lambda = \frac{8\pi G}{c^4}T_{\mu\nu}$$



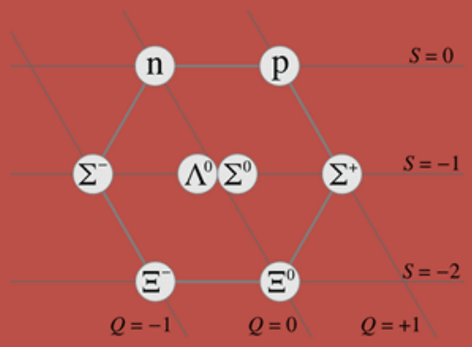
Gravity

$$\mathcal{L} = \bar{\psi}\left(i\gamma^\mu D_\mu - m\right)\psi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$



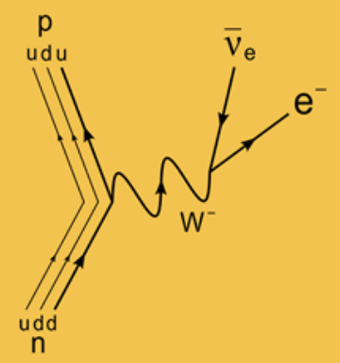
Electromagnetism

$$\mathcal{L} = \bar{\psi}_i\left(i\gamma^\mu\left(D_\mu\right)_{ij} - m\delta_{ij}\right)\psi_j - \frac{1}{4}G^a_{\mu\nu}G^{\mu\nu}_a$$



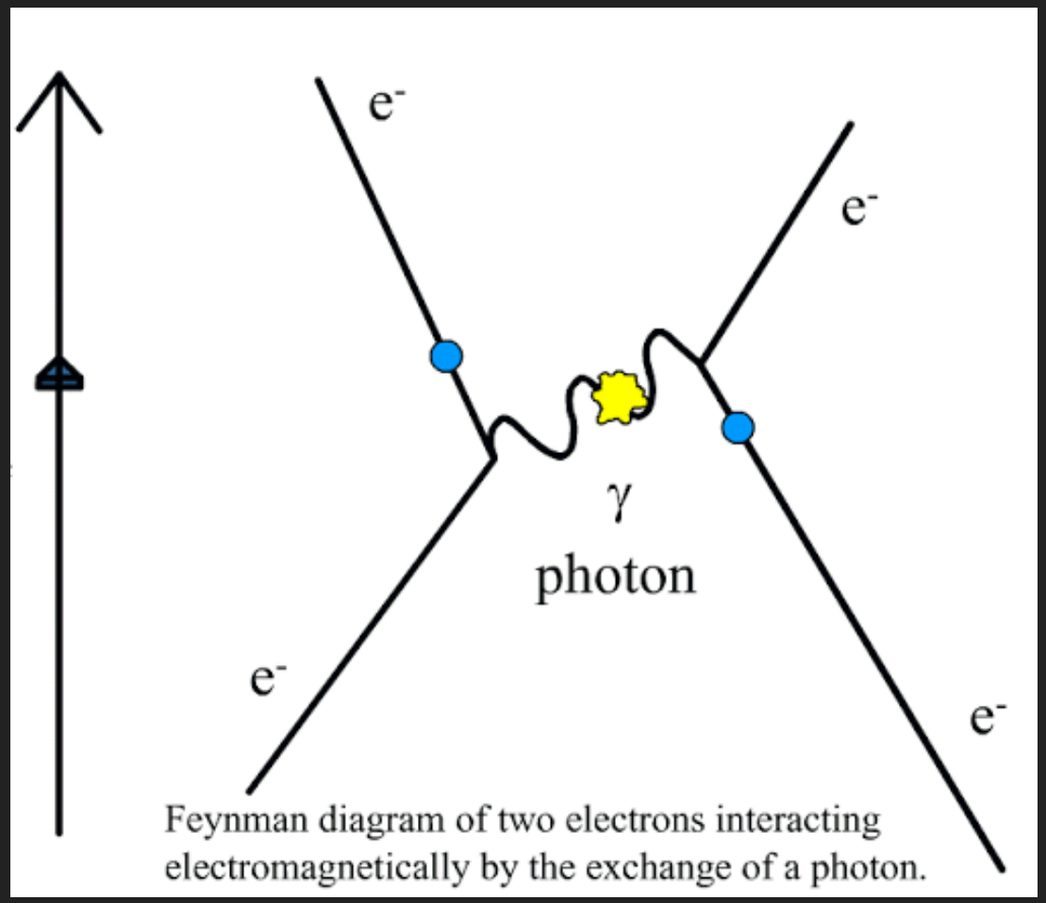
Strong

$$\mathcal{L} = g\left(\bar{\nu}_{eL}, \bar{e}\right)\gamma^\mu\left\{\begin{pmatrix} -\sqrt{1+\xi^2}Z_\mu & 0 \\ 0 & \frac{\xi A_\mu}{\sqrt{1+\xi^2}} - \frac{\xi^2}{\sqrt{1+\xi^2}}Z_\mu \end{pmatrix} + \frac{1-\gamma^5}{4}\begin{pmatrix} -\sqrt{1+\xi^2}Z_\mu & -\sqrt{2}W^+_\mu \\ -\sqrt{2}W_\mu & \sqrt{1+\xi^2}Z_\mu \end{pmatrix}\right\}\begin{pmatrix}\nu_{eL} \\ e\end{pmatrix}$$

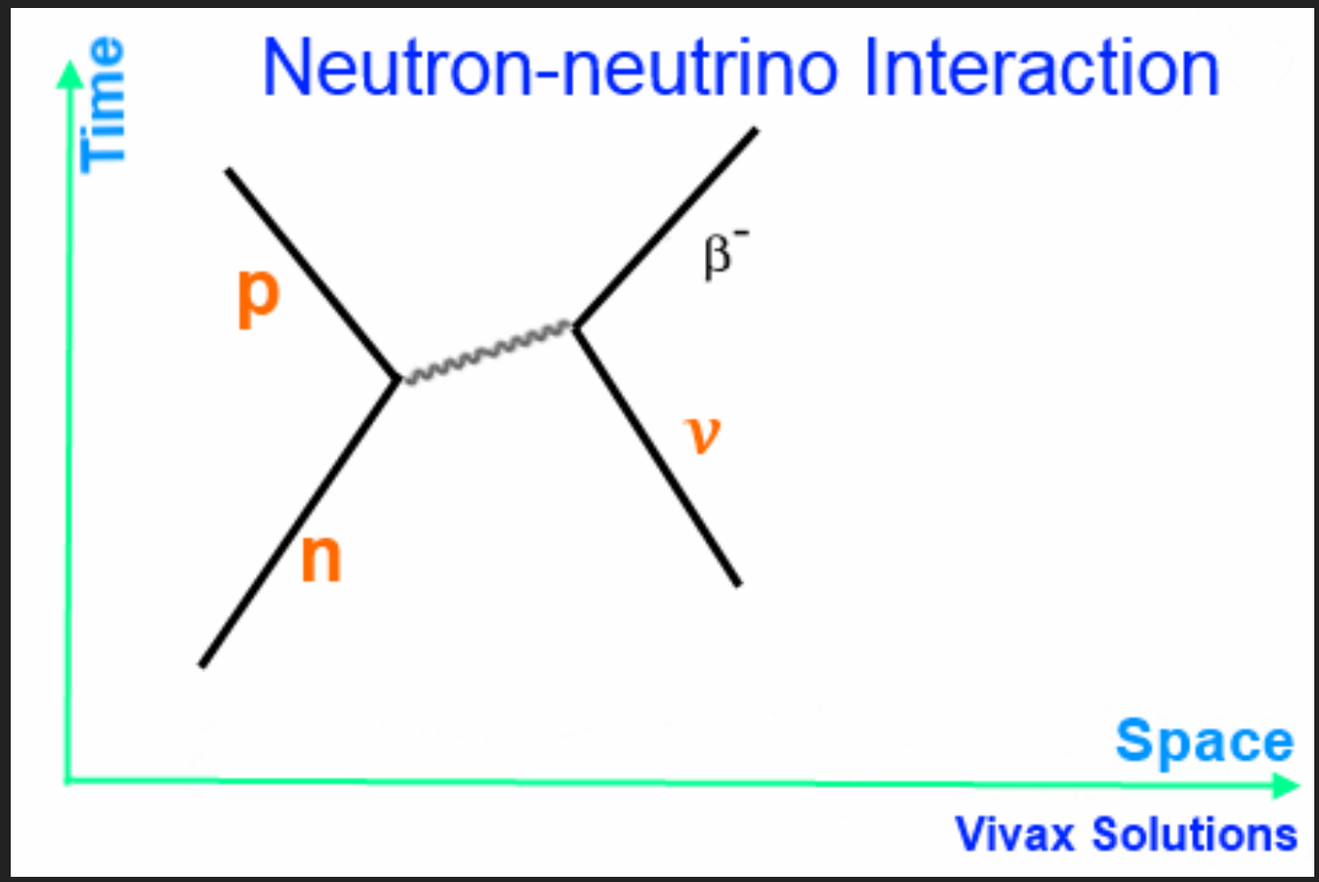


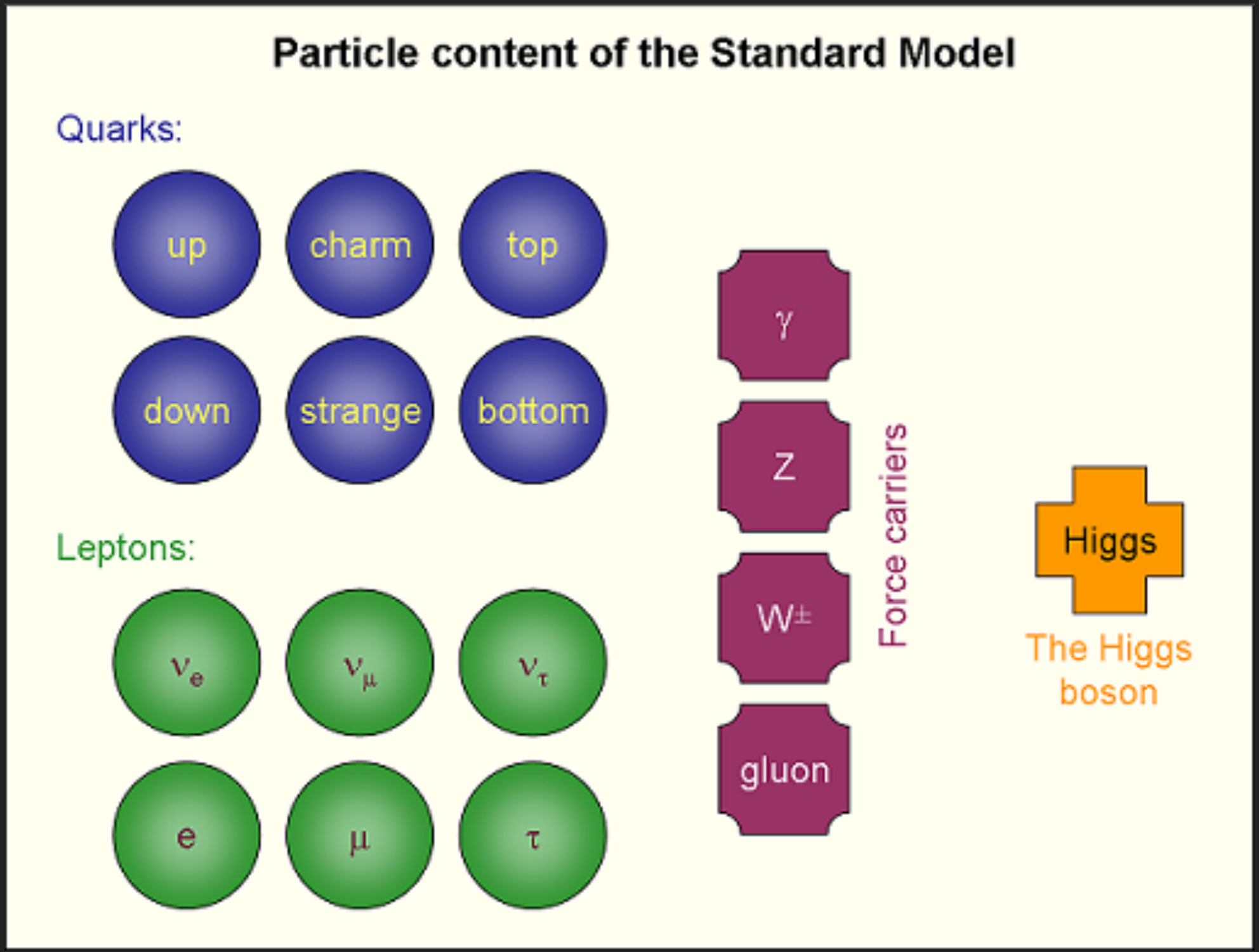
Weak

FEYNMAN DIAGRAMS: A TOOL FOR CALCULATING QUANTUM MECHANICAL PROBABILITIES

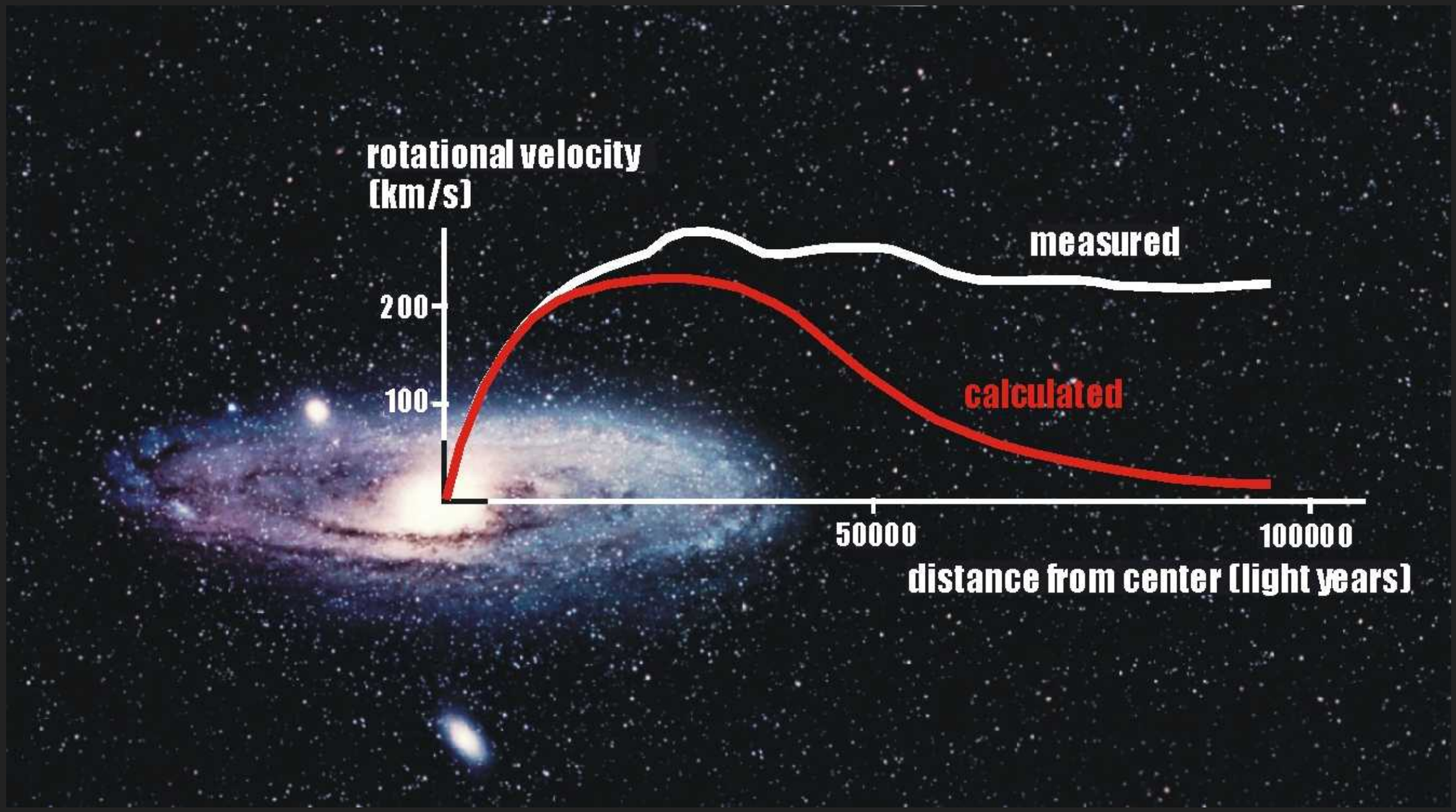


Feynman diagram of two electrons interacting electromagnetically by the exchange of a photon.




Particle content of the Standard Model
Quarks:
up
charm
top
down
strange
bottom
Leptons:
ν_e
ν_μ
ν_τ
e
μ
τ
γ
Z
W±
gluon
Force carriers
Higgs
The Higgs boson

IS THIS THE END OF THE STORY? NO!



Do we need a new particle? Dark Matter?

Do we need new law of gravity?