Building a Universe from Scratch:
Seeing the World as a Particle Physicist

The Science of Spacetime:

A Physicists Guide to the Galaxy

Robert Clemenson (Rob) - Royal Holloway UoL

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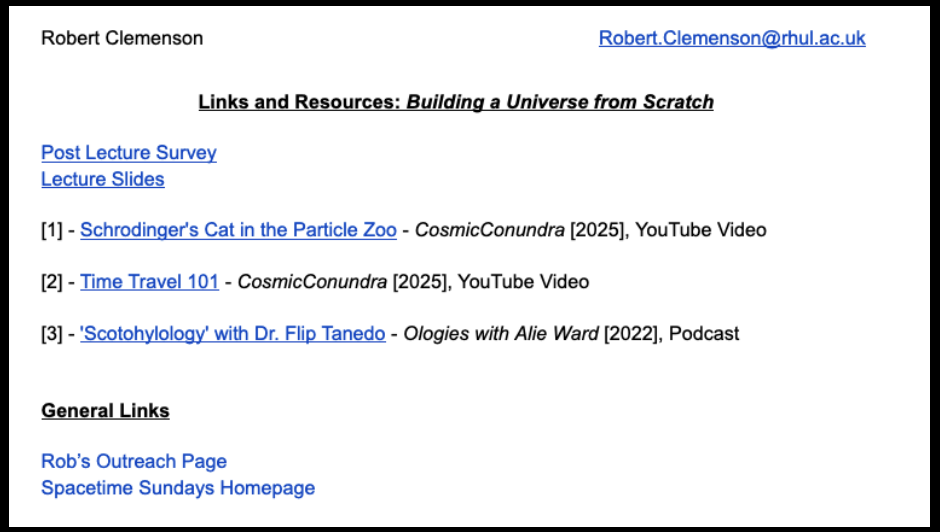
Southend Planetarium – 06.06.2026

Lecture Live Links (LLL)

Throughout the lecture, I will make a couple of references to previous talks, livestreams, and other online materials.

If you would like to check these out after the talk (or view recordings of previous lectures), please feel free to scan the QR code shown here.



Robert Clemenson Robert.Clemenson@rhul.ac.uk

Links and Resources: *Building a Universe from Scratch*

Post Lecture Survey
Lecture Slides

[1] - Schrodinger's Cat in the Particle Zoo - *CosmicConundra* [2025], YouTube Video

[2] - Time Travel 101 - *CosmicConundra* [2025], YouTube Video

[3] - 'Scotohylology' with Dr. Flip Tanedo - *Ologies with Alie Ward* [2022], Podcast

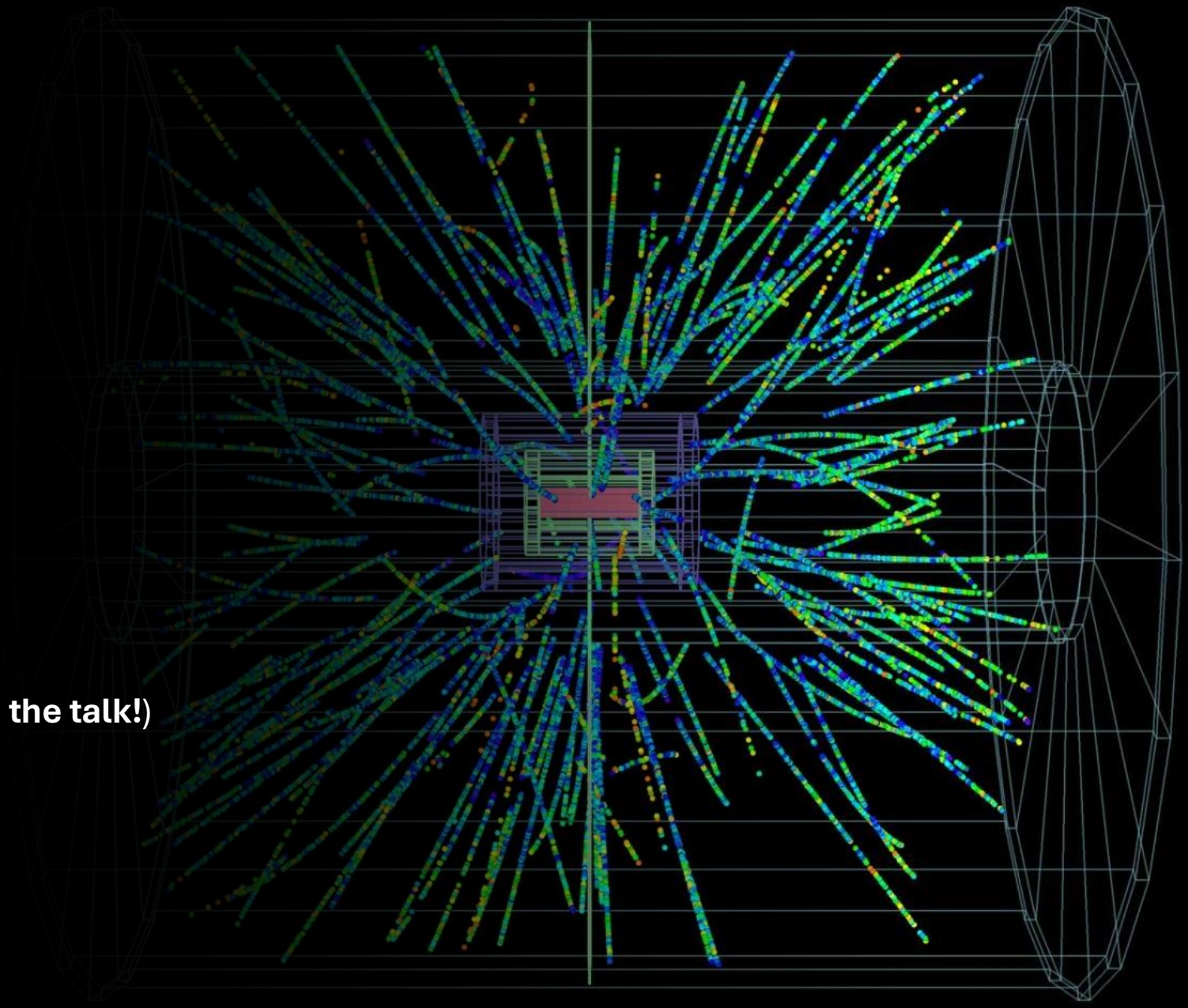
General Links

Rob's Outreach Page
Spacetime Sundays Homepage

Scan the QR code above, or simply click the QR code in the PDF of the lecture slides.

Lecture Overview

- What Science Means to Me
- Matter and Energy
- Quantum Mechanics
- Dark Matter
- Quantum Gravity
- Q&A (**Questions welcome throughout the talk!**)



Part I - What Science Means to Me

Collaboration

“All are architects of Fate,
Working in these walls of Time;
Some with massive deeds and great,
Some with ornaments of rhyme.

Nothing useless is, or low;
Each thing in its place is best;
And what seems but idle show
Strengthens and supports the rest.”

From *The Builders* by Henry Wadsworth Longfellow

Trio of Particle Physicists - University of California, Riverside 2023.

Phenomenology conference bound - Pittsburgh 2022.

Undergrad colleagues reunited - Columbia University, New York 2022.

Mentor and Mentee – The Millikan Library, Caltech 2019.

Mentorship

“When I sitting heard the astronomer where he lectured with much applause in the lecture-room,

How soon unaccountable I became tired and sick,
Till rising and gliding out I wander’d off by myself,
In the mystical moist night-air, and from time to time,
Look’d up in perfect silence at the stars.”

From *When I Heard the Learn’d Astronomer* - Walt Whitman

The teacher who changed my life: Neal Hankinson

My students testing their homemade telescope on the geology department fire escape (to date, the only good thing to come from working in my office until gone 10pm).

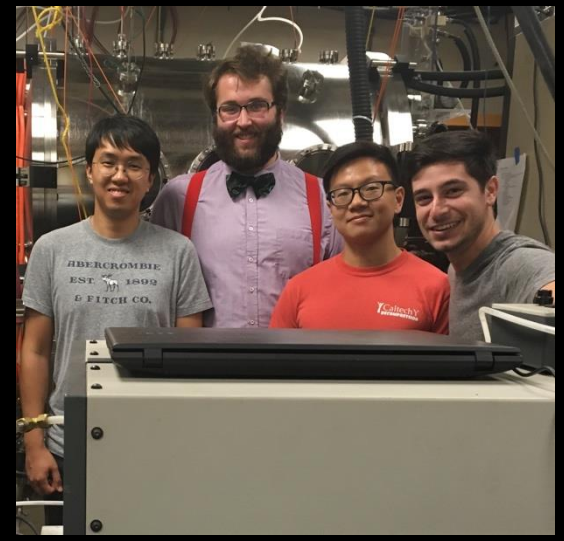
'Teaching’ my <1yr old Goddaughter about nuclear fusion inside the sun.

Discovery

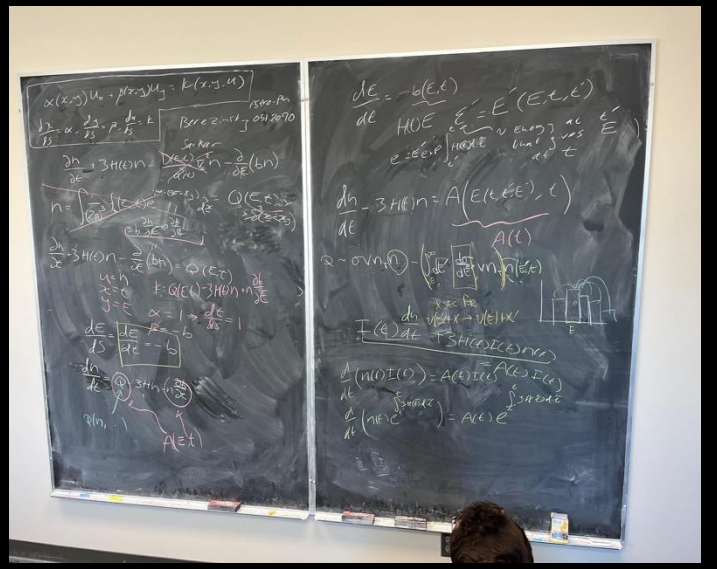
“Tho' much is taken, much abides; and tho’
We are not now that strength which in old days
Moved earth and heaven, that which we are, we are;
One equal temper of heroic hearts,
Made weak by time and fate, but strong in will
To strive, to seek, to find, and not to yield..”

From *Ulysses* - Alfred, Lord Tennyson

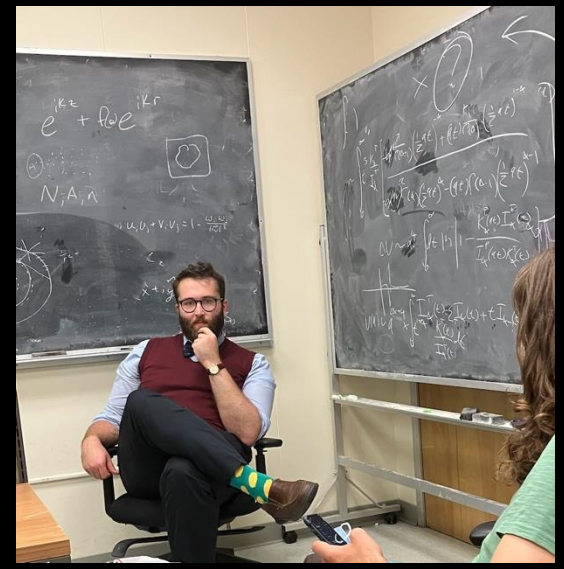
Whiteboard of holographic gauge-gravity calculations, Caltech 2019.



Subset of the Bellan Plasma Physics Group (with visiting Brit), Caltech 2018.



Chalkboard of Supernova Neutrino musings, University of California Irvine 2022



Chalkboard of miscellaneous physics scribbles, University of California Riverside 2023.

Perspective

“To see a world in a grain of sand

And a heaven in a wild flower,

Hold infinity in the palm of your hand

And eternity in an hour.”

From *Auguries of Innocence* -
William Blake

Earthrise, December 24th 1968 – Taken by Apollo 8 Astronaut, William Anders.

Part II - Taking a Closer Look at Matter

Matter

"What is mind? No matter. What is matter? Never mind."

George Berkeley (as quoted by Homer Simpson)

Matter is *stuff*.

Matter has weight, if you could hold it in your hand on the Earth.

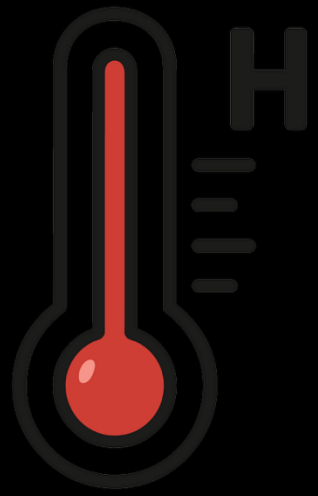
All solids, liquids, and gasses are types of matter.

Rocks, Frogs, and Soup are all made of matter (list is non-exhaustive).

Energy

Energy is something that makes matter move or change.

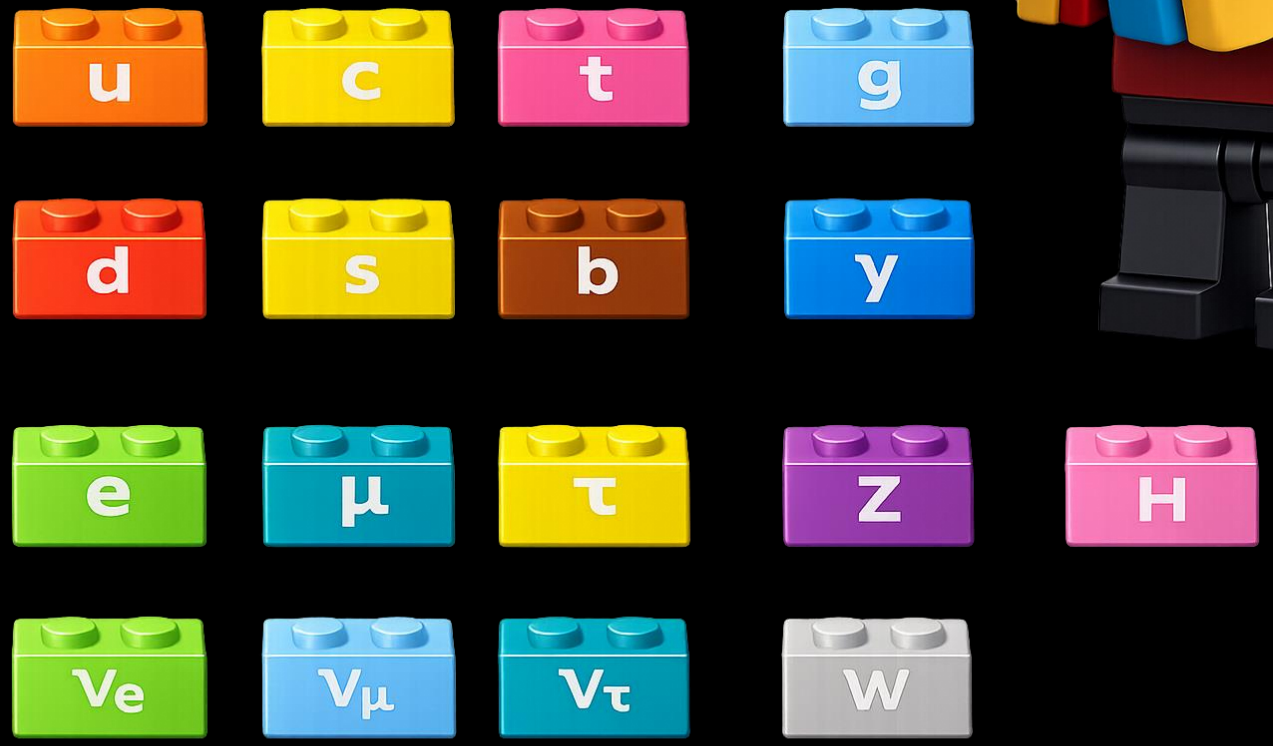
Energy can also be ‘potential’ – meaning it is the potential to cause matter to move or change.



Light, Heat, and Motion are all forms of Energy.

The Particle Physicists Mantra

“To discover the basic building blocks of all the matter in the Universe, and to understand how these building blocks fit together.”



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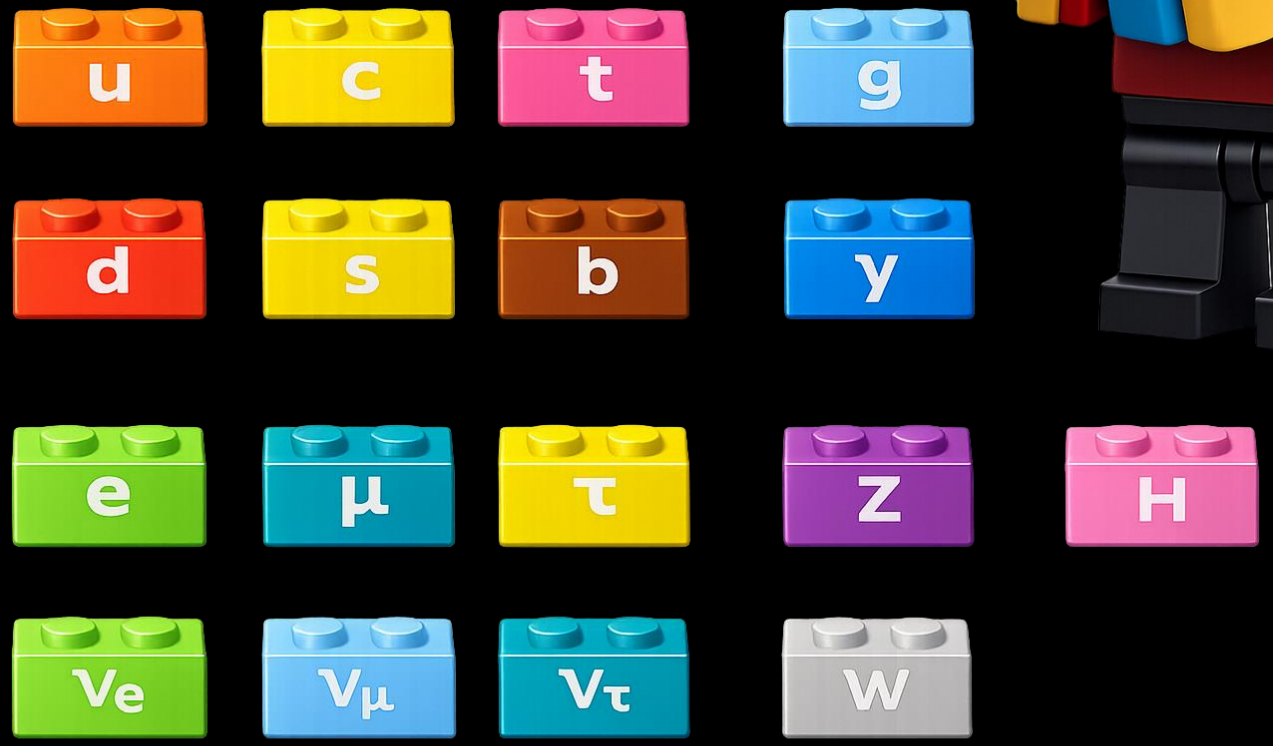
*"To discover the **basic building blocks** of all the matter in the Universe, and to understand how these building blocks fit together."*

What do we mean here?



Looking Closer at Matter…

Take Three Particle Physicists

We are all made out of matter

Human Length Scale ~ 1m

Looking Closer at Matter…

Take Three Particle Physicists

We are all made out of matter

Let’s zoom in a little

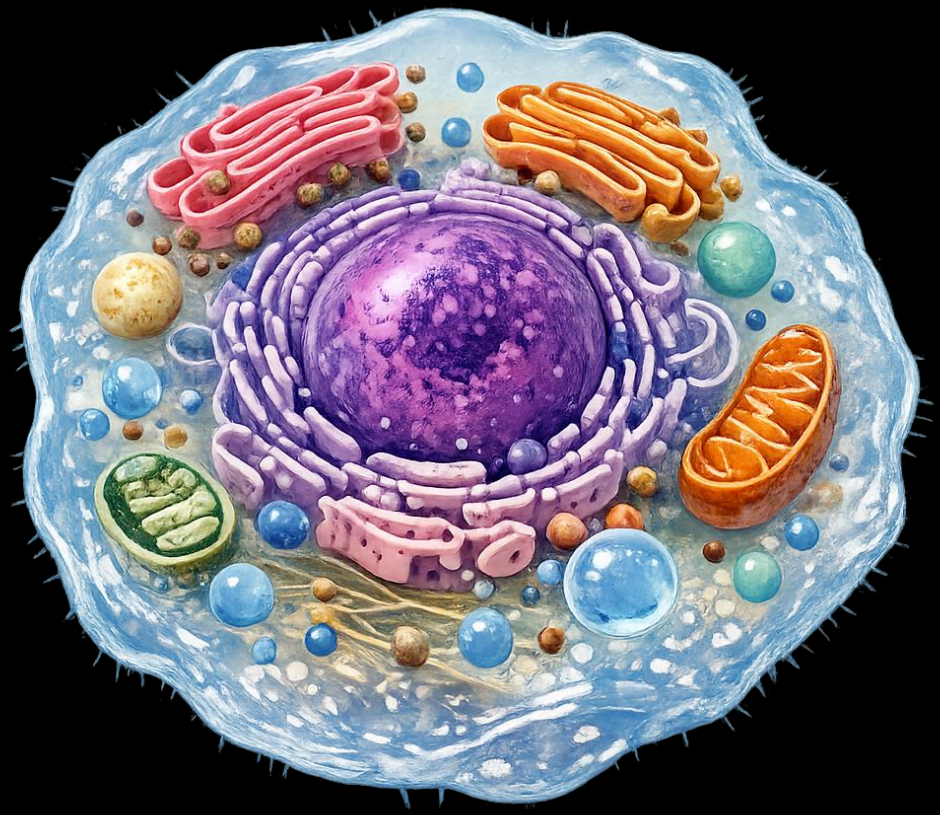
Human Length Scale ~ 1m

Looking Closer at Matter…

Human Cells

All living matter is made up of ‘*cells*’

Cellular Length Scale ~ 100µm



1µm (one micro-meter) is one millionth of a meter

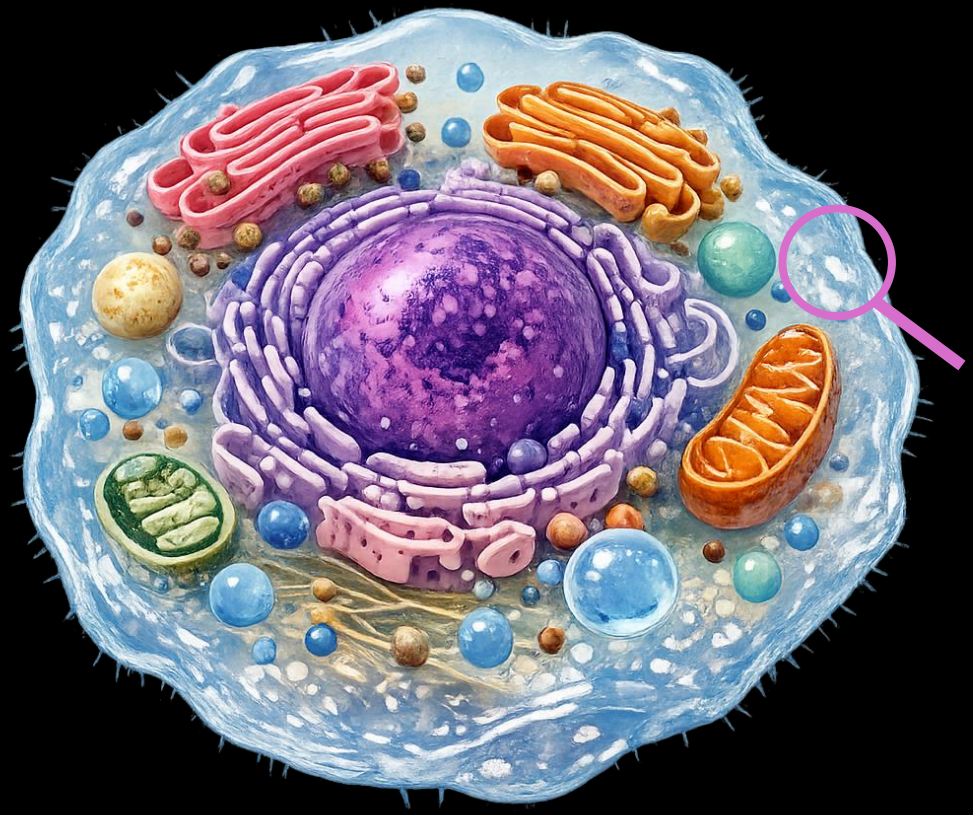
Looking Closer at Matter…

Human Cells

All living matter is made up of *‘cells’*

Let’s zoom in even more

Cellular Length Scale ~ 100µm



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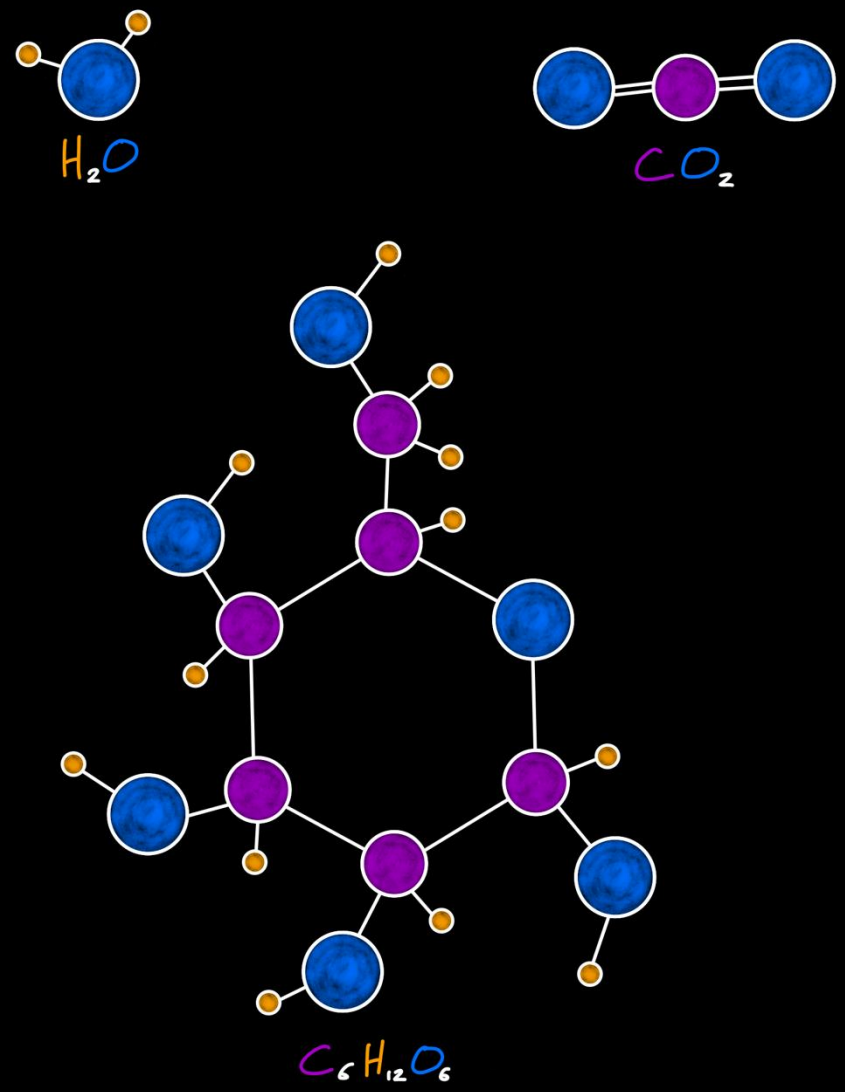
Looking Closer at Matter…

Molecules

All chemical compounds are combinations of the different elements found in the periodic table.

Molecular Length Scale ~ 1nm



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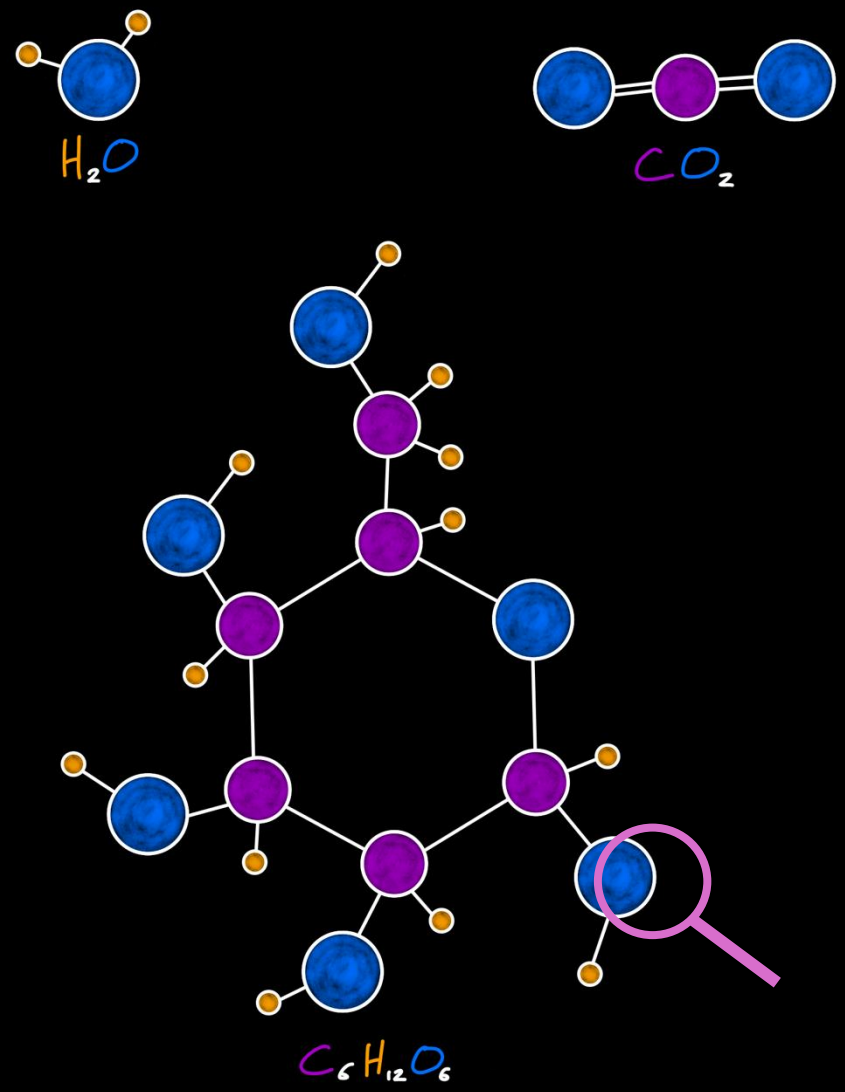

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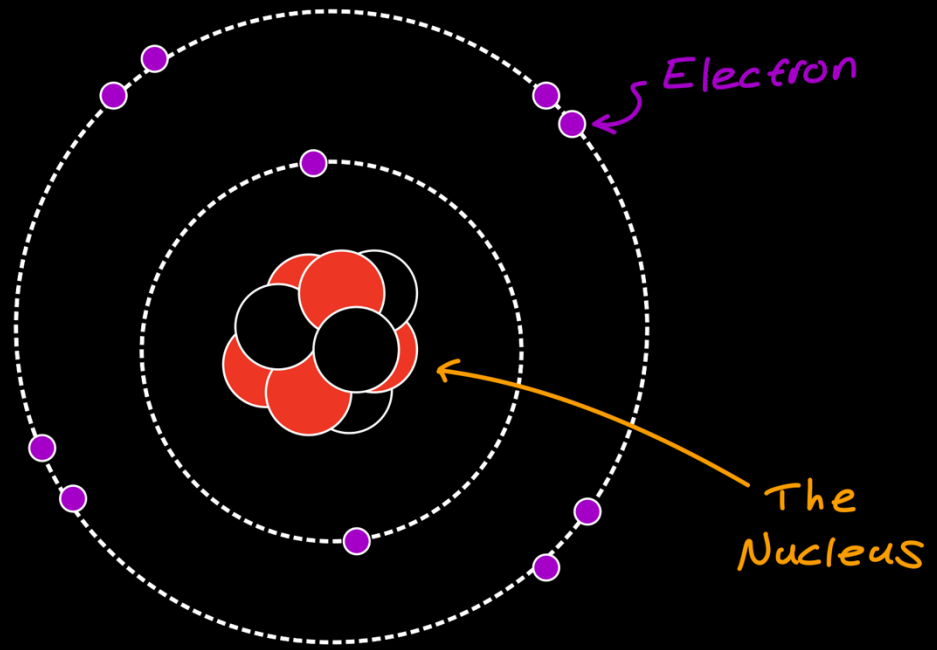
Looking Closer at Matter...

Atoms

All the *stuff* we can see on the Earth is made out of atoms.

We will return later, to things we cannot see...

Atomic Length Scale ~ 0.1nm



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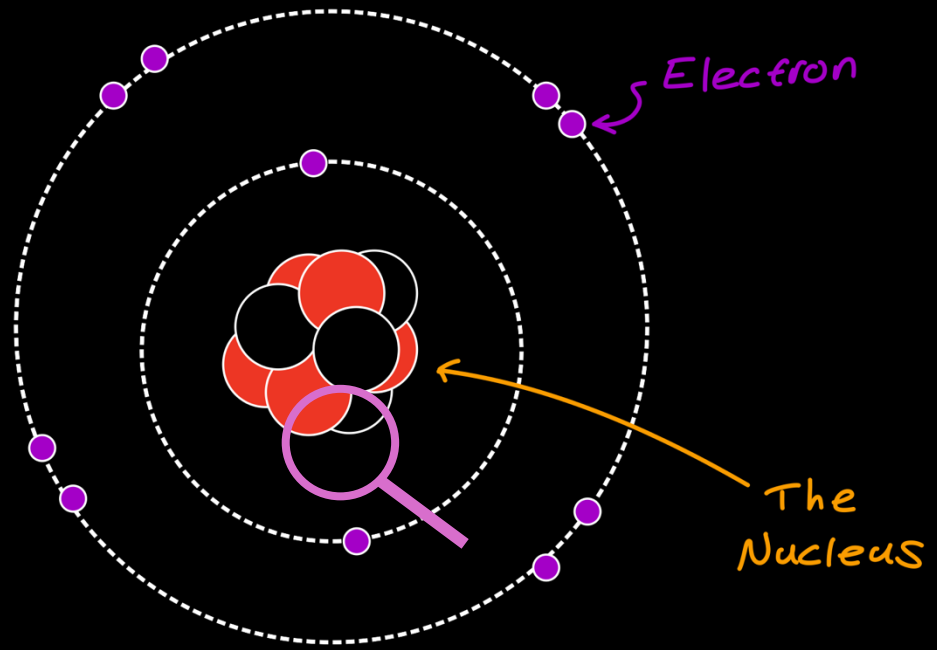

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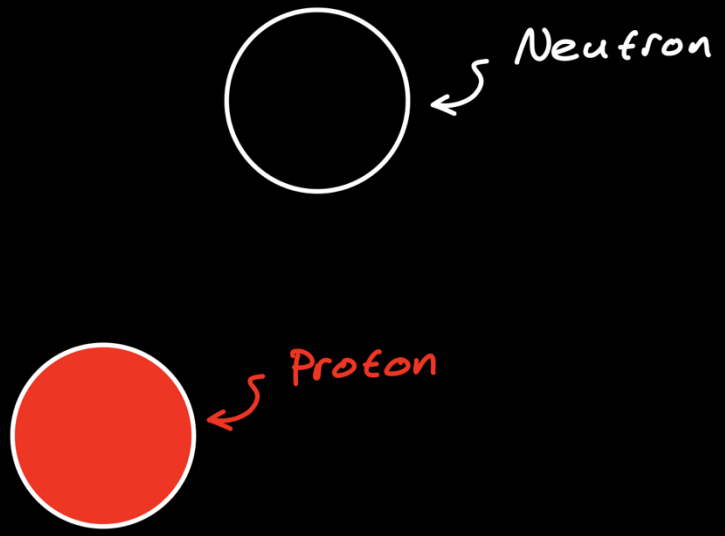
Looking Closer at Matter...

Nuclear Particles

The center of an atom (the nucleus) is made out of particles called Protons and Neutrons.

Nucleon Length Scale ~ 1fm



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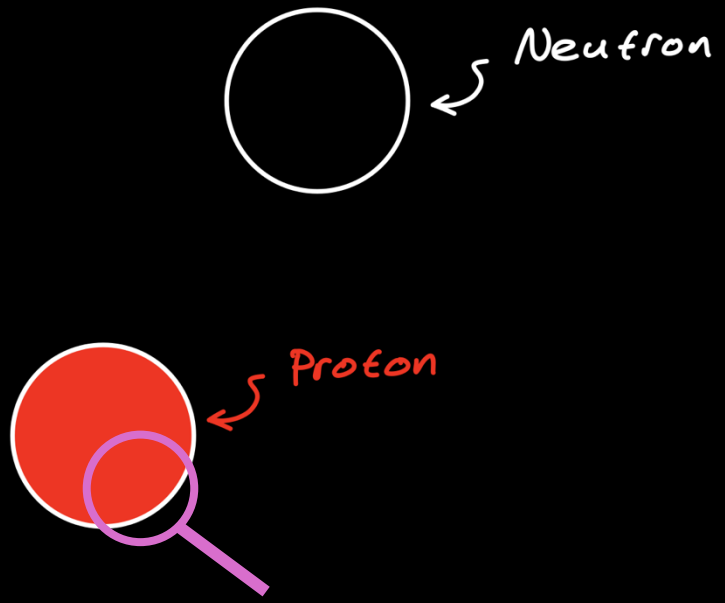

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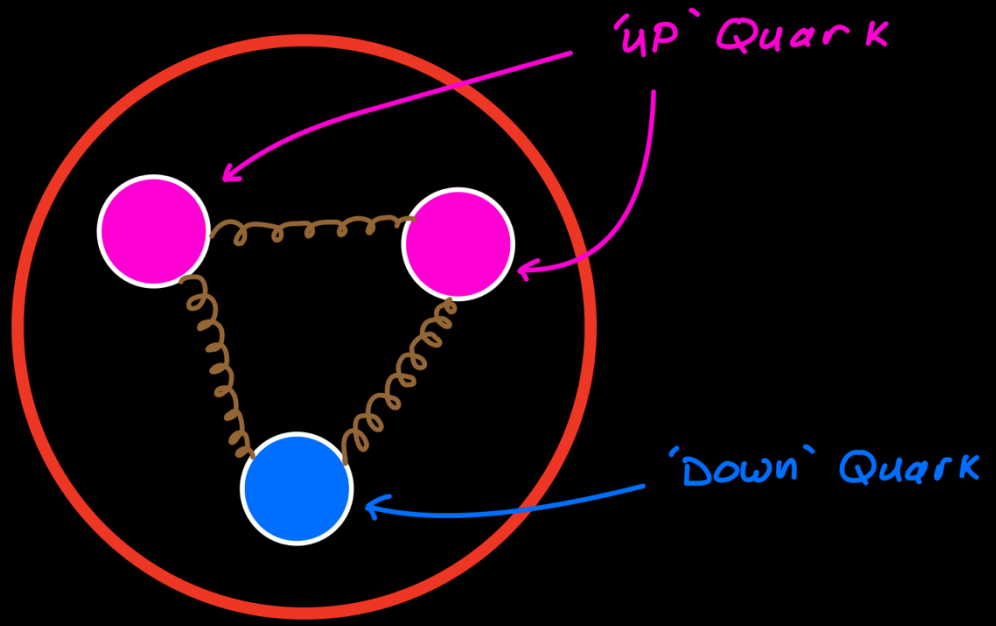
Looking Closer at Matter...

Quarks

Protons and Neutrons are made up of yet smaller particles, called Quarks.

Quark Length Scale ~ 0.1am



1am (one attometer) is one billionth of a billionth of a meter

Looking Closer at Matter...

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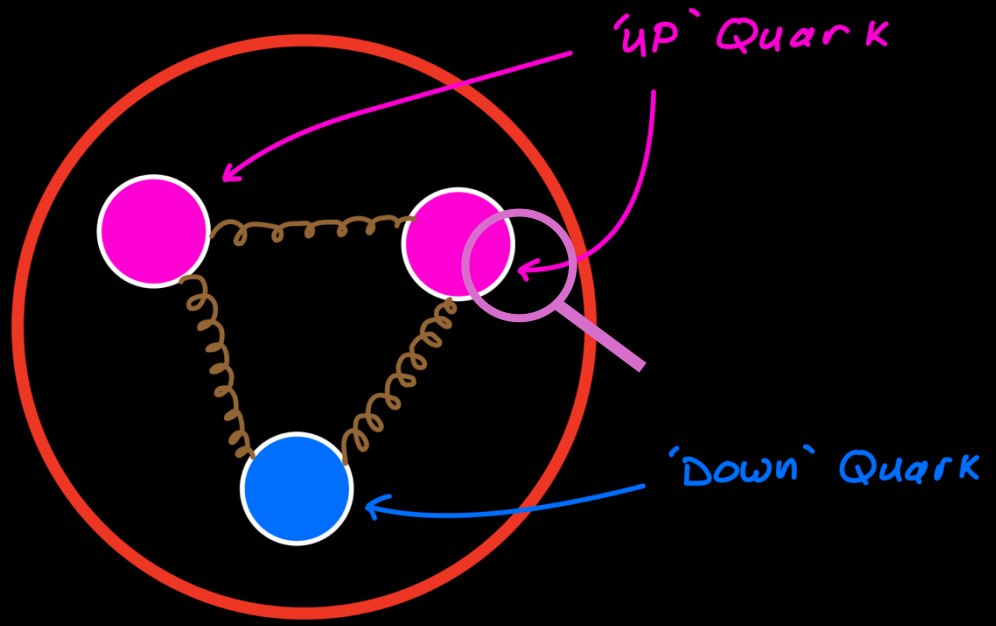
Protons and Neutrons are made up of yet smaller particles, called Quarks.

But what are quarks made of?!

Quark Length Scale ~ 0.1am



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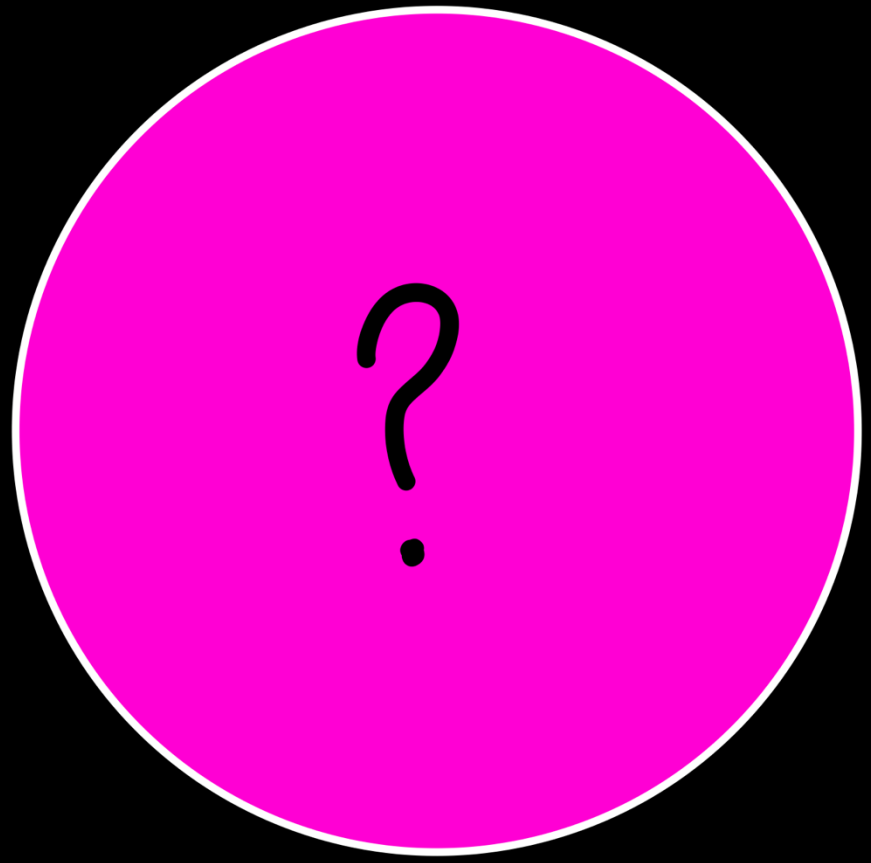
Looking Closer at Matter…

Beyond Quarks?

“But what are quarks made of?!”

We don’t know! Quarks, “*Just are*”!



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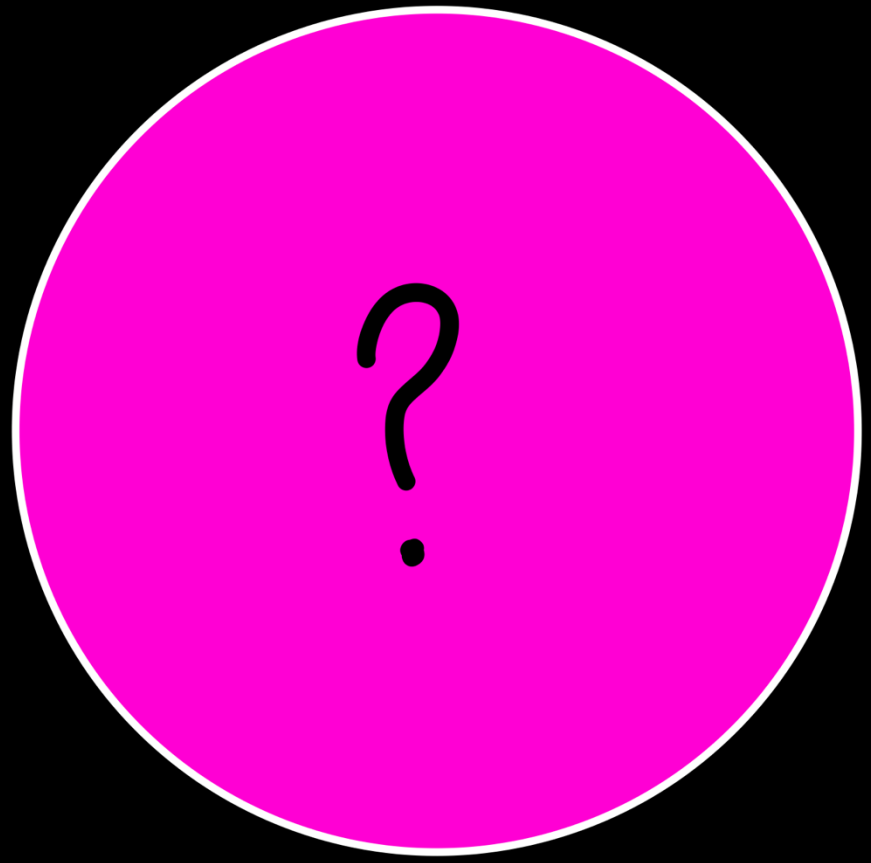


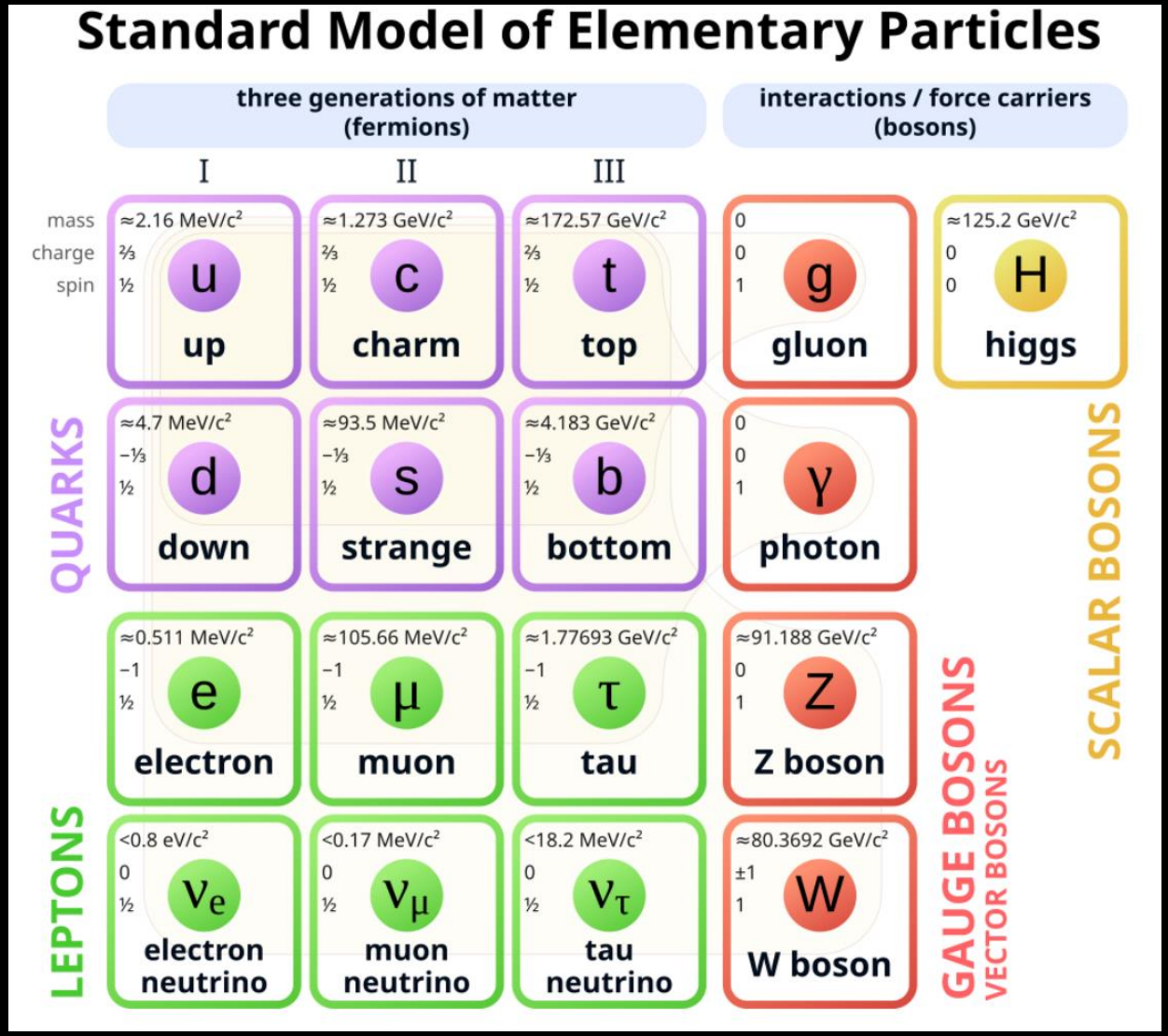
This is what we meant earlier.

What other things "*just are*"?

The Standard Model of Elementary Particles

This is our best theory of matter and its interactions.

Arguably, this is the most experimental successful theory in all of science, with some predictions tested to an accuracy of one part in a trillion.

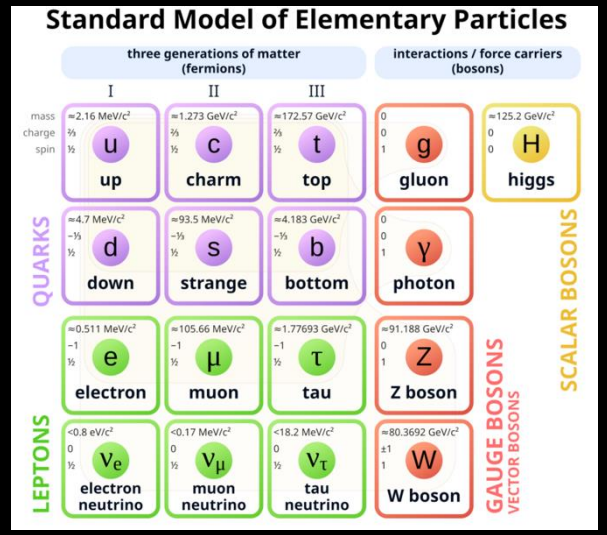


Much more than the Periodic Table

The *Standard Model* is far more than just ‘The Periodic Table, but for Particle Physics’...

Under the bonnet of this seemingly simple and arbitrary list of particles, are layers of complexity, beauty, and mystery.

At its heart, is the bizarre science of *Quantum Mechanics*.



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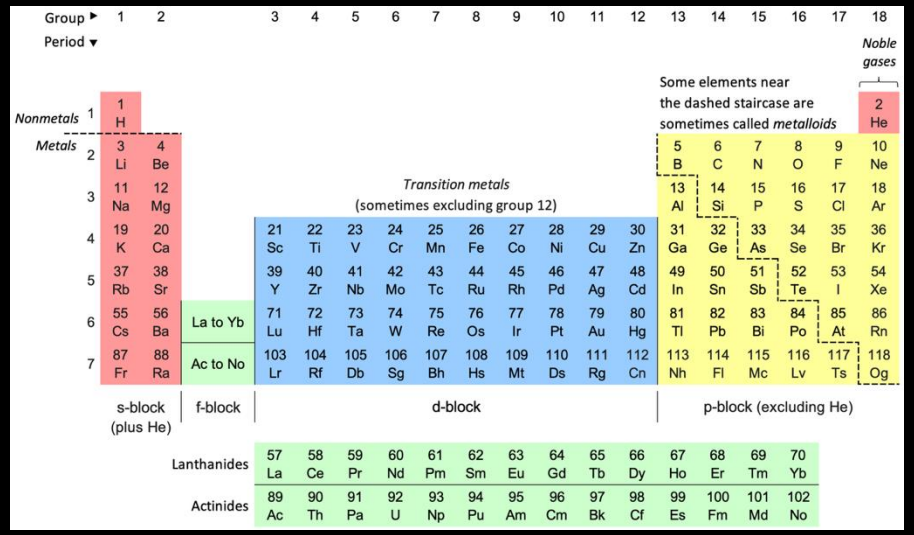
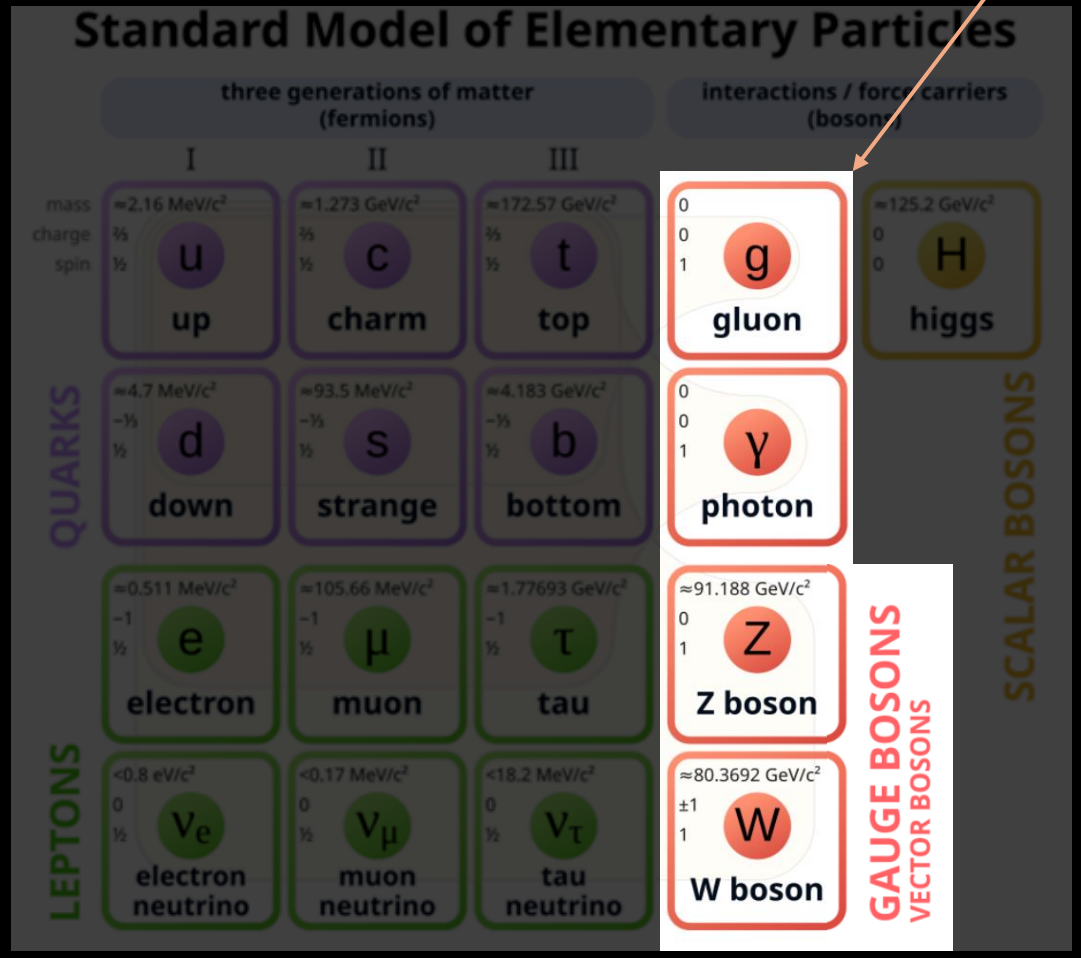


Fundamental Forces

These particles, the '***Gauge Bosons***' communicate (mediate) forces between the Matter Particles.



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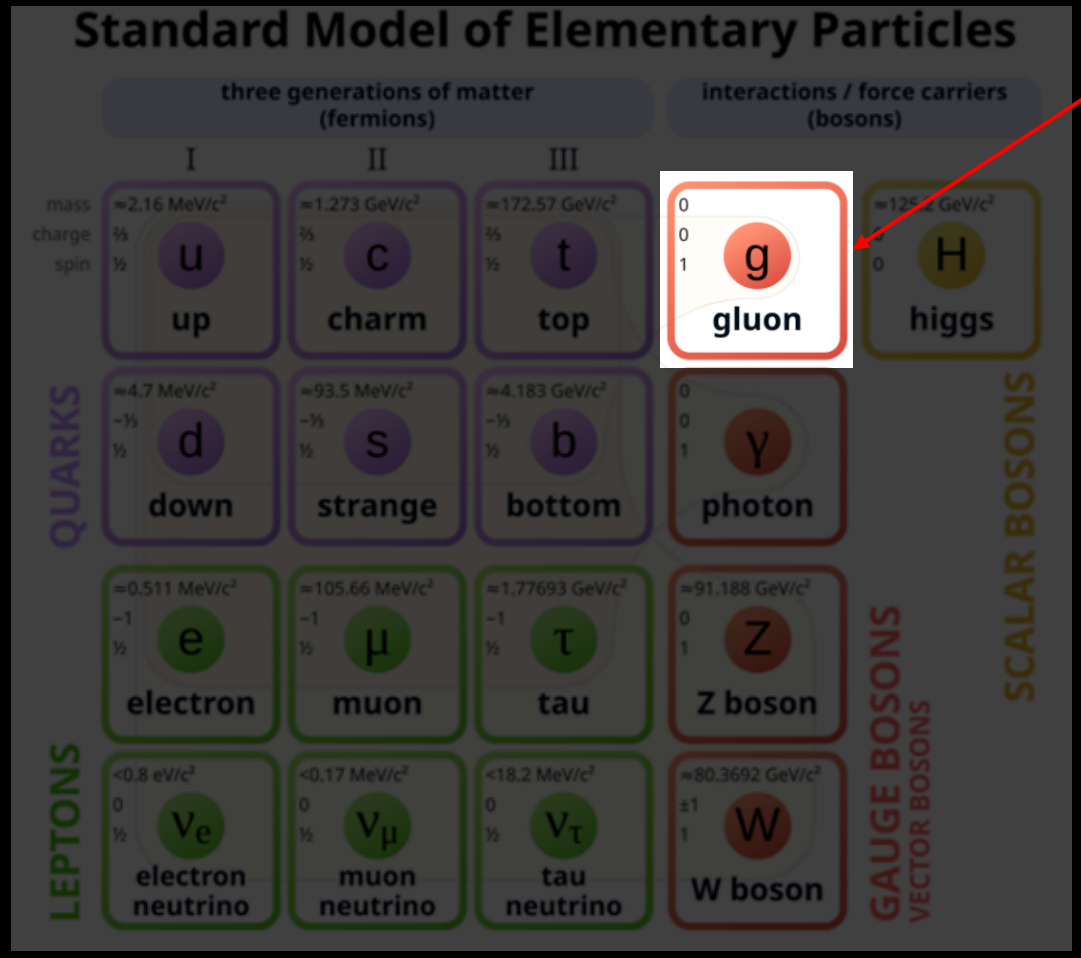

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Gluons mediate the *Strong Nuclear Force*, which holds the nucleus of atoms together.

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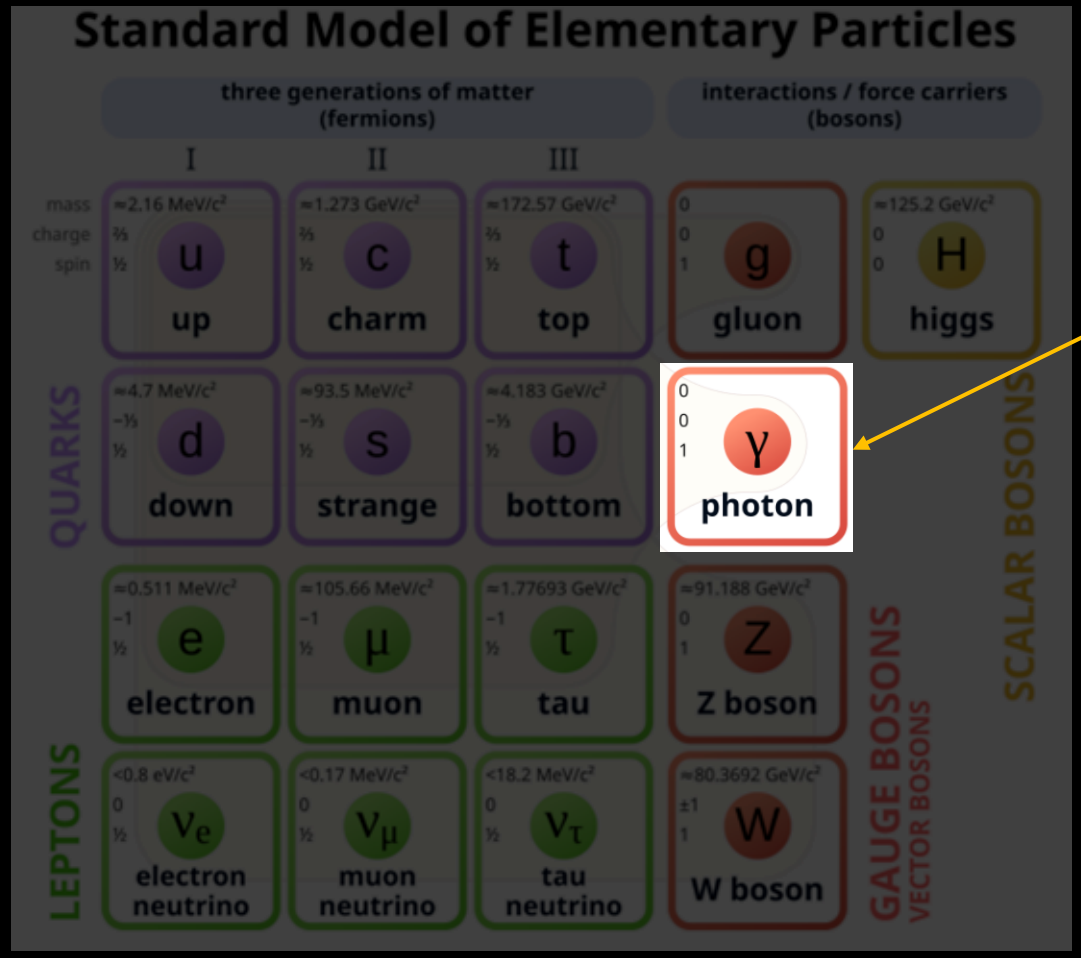

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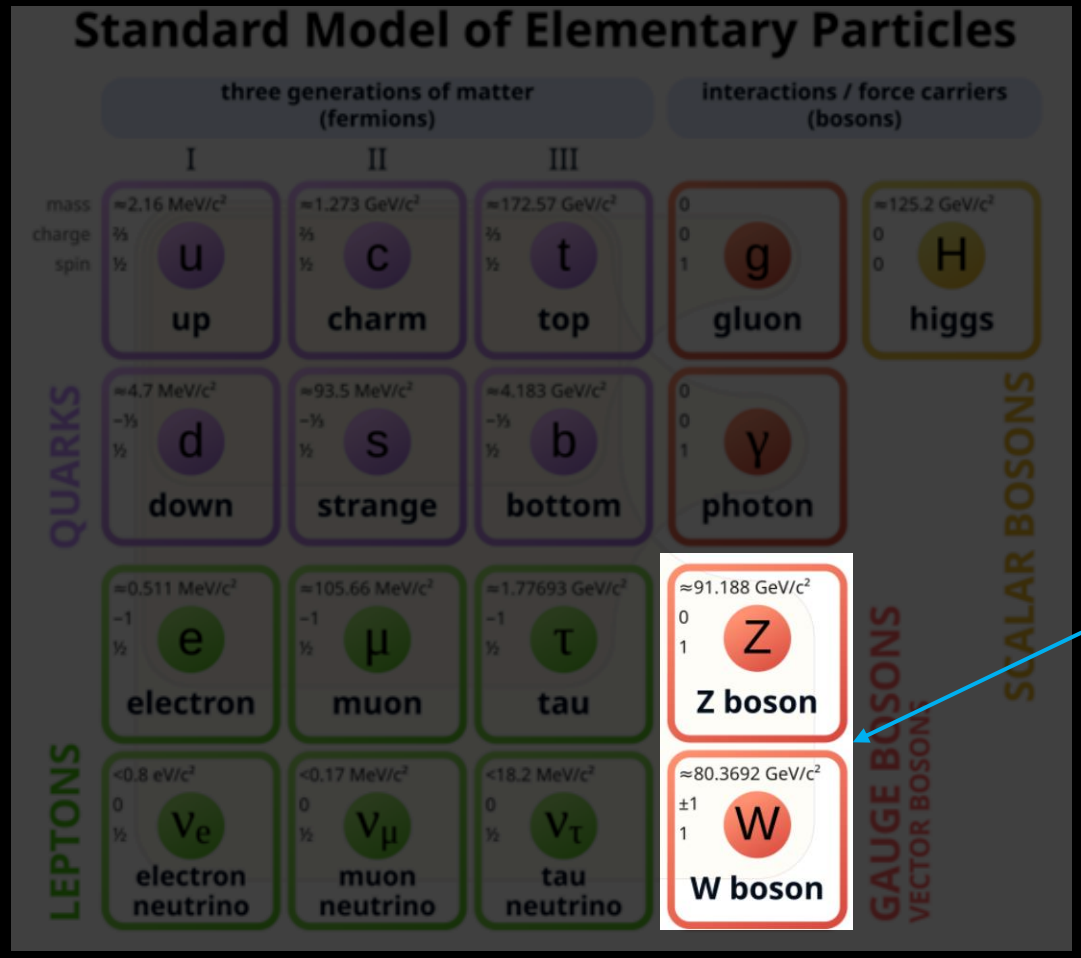
Photons media the *Electromagnetic Force*, which is responsible for all electric and magnetic phenomena.

Fundamental Forces



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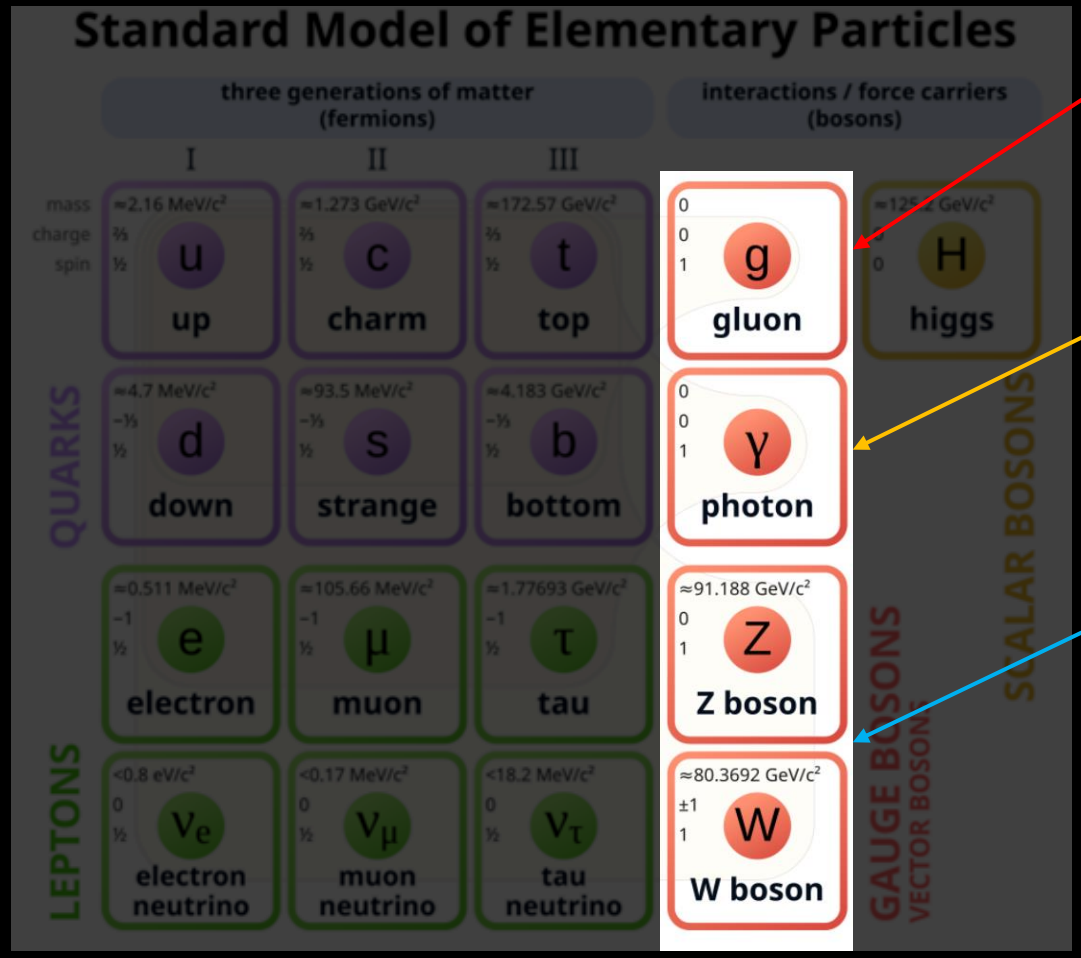

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What is missing?

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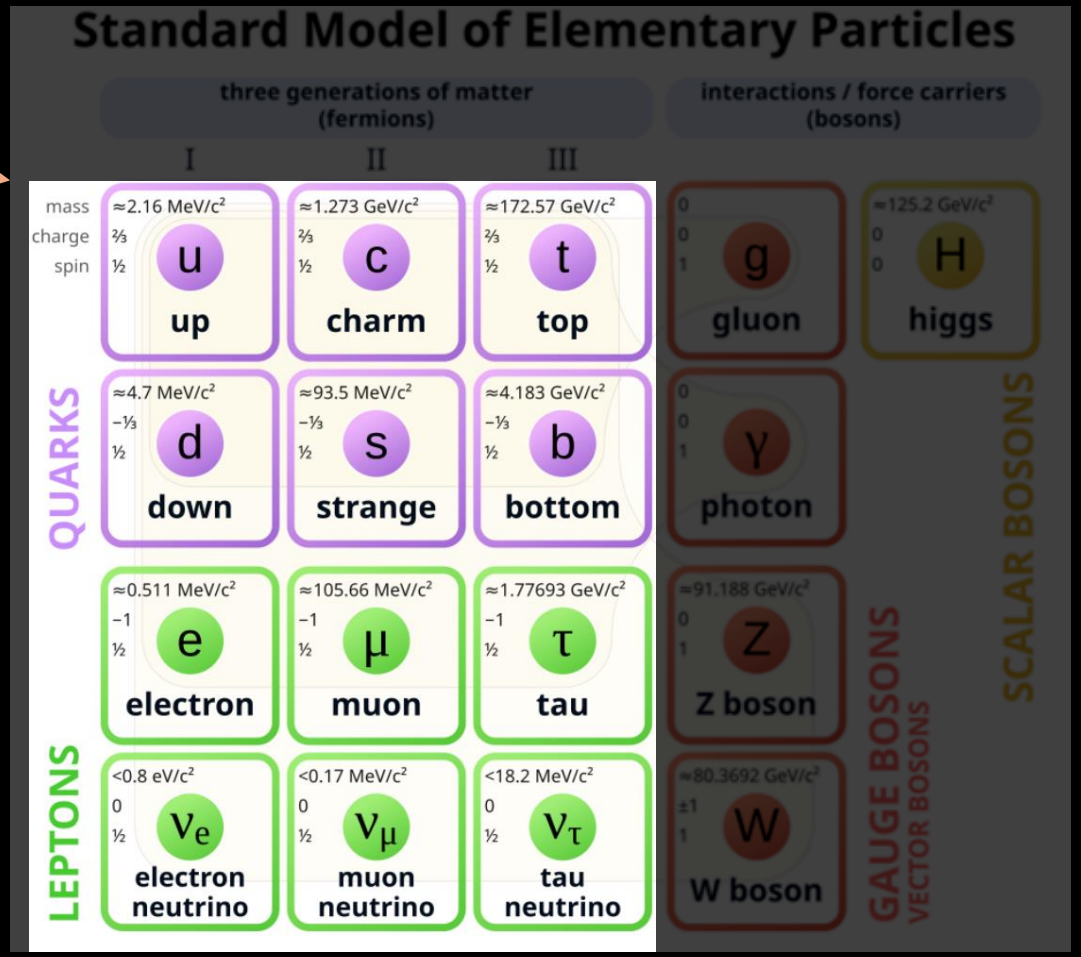
These particles, make up all of the *visible* matter in the Universe.



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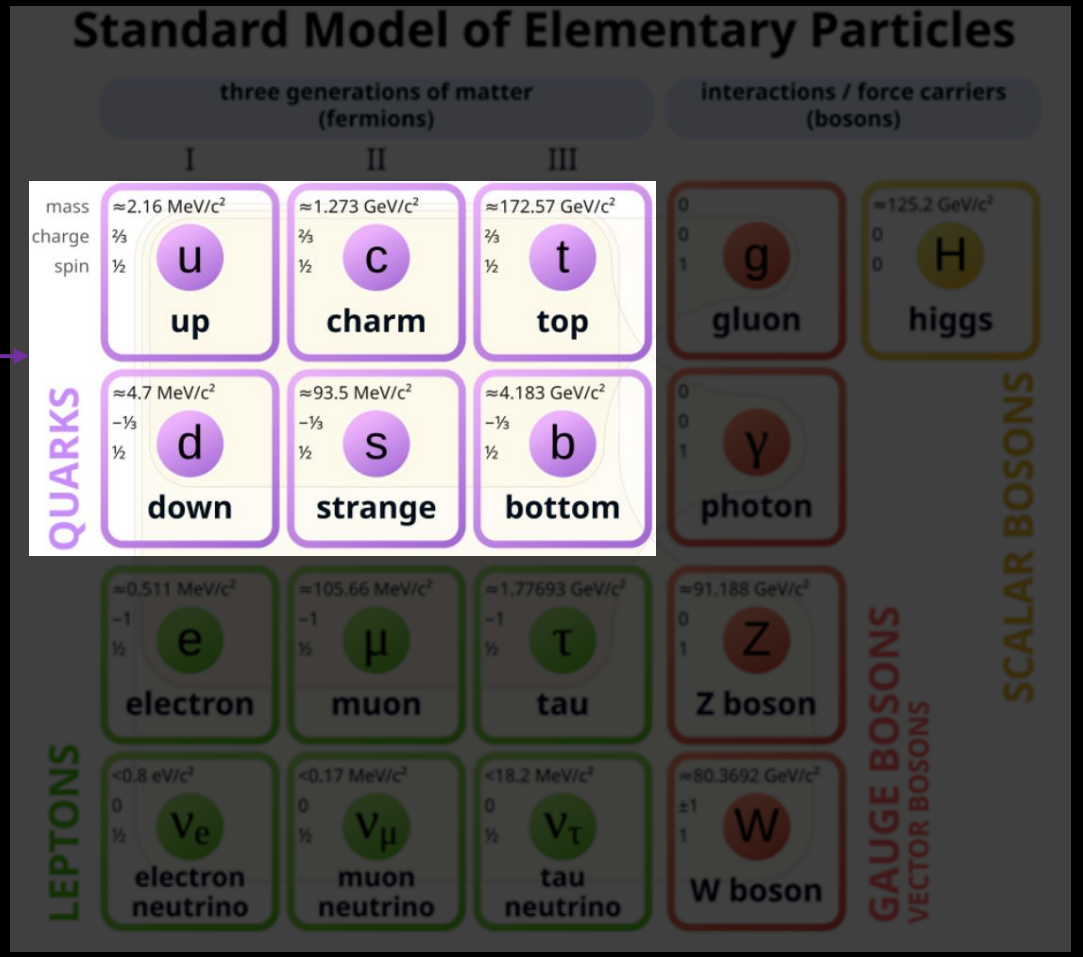
The Leptons include the Electron and its two heavier siblings – and three types of Neutrino (a nearly massless particle of zero charge).



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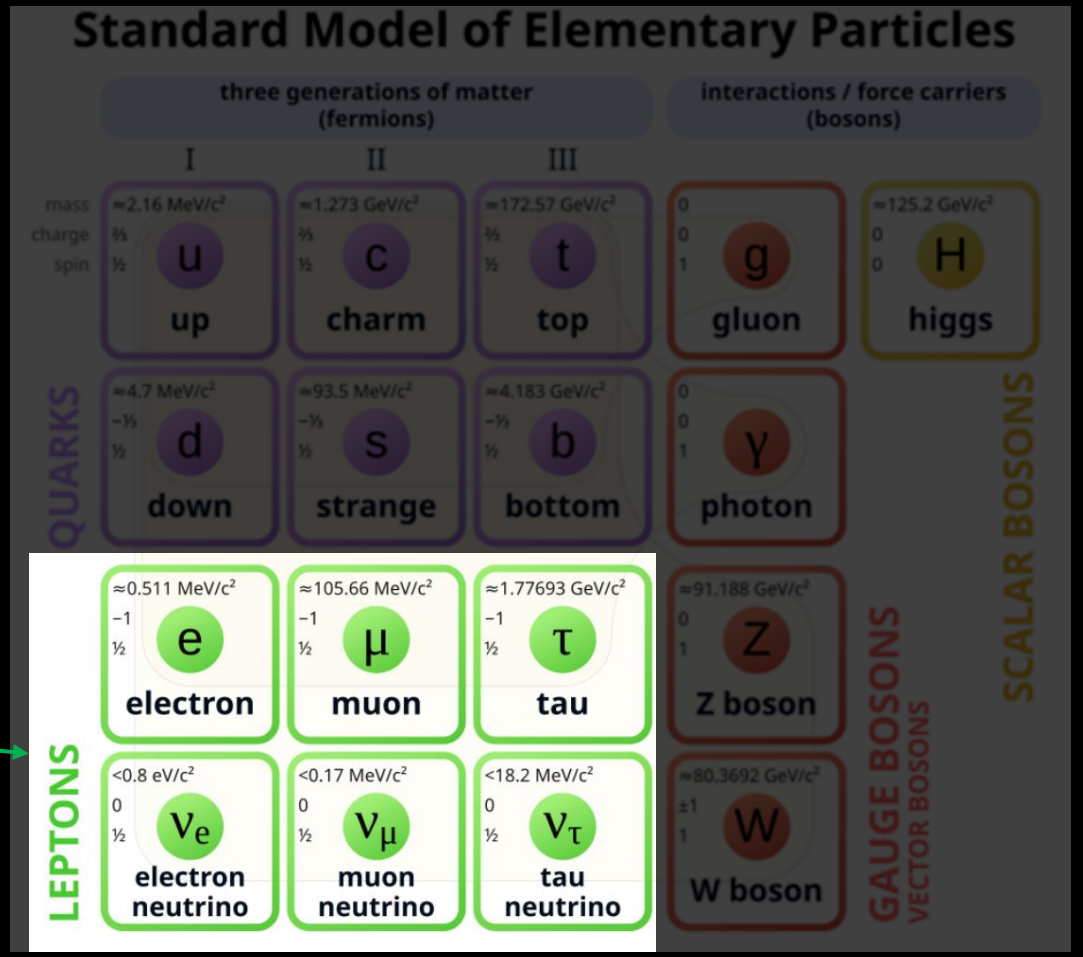

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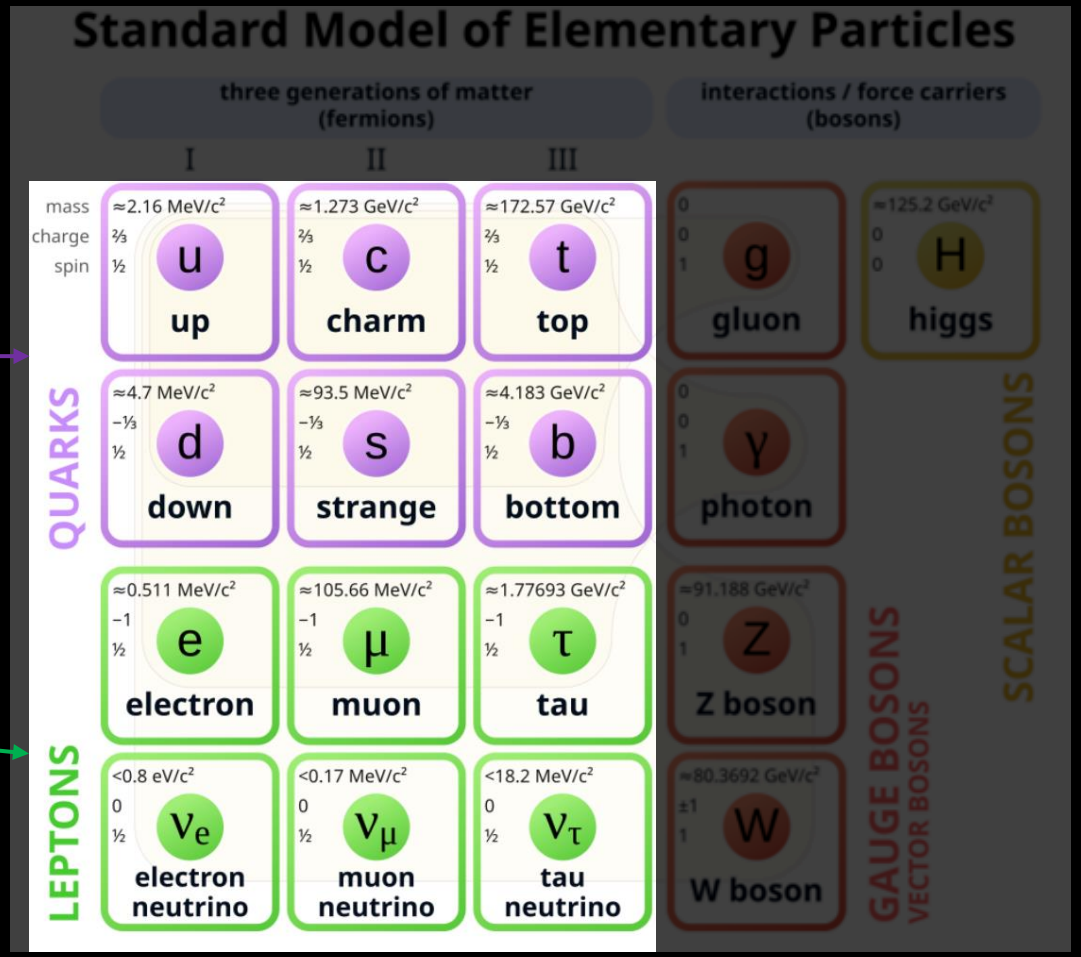
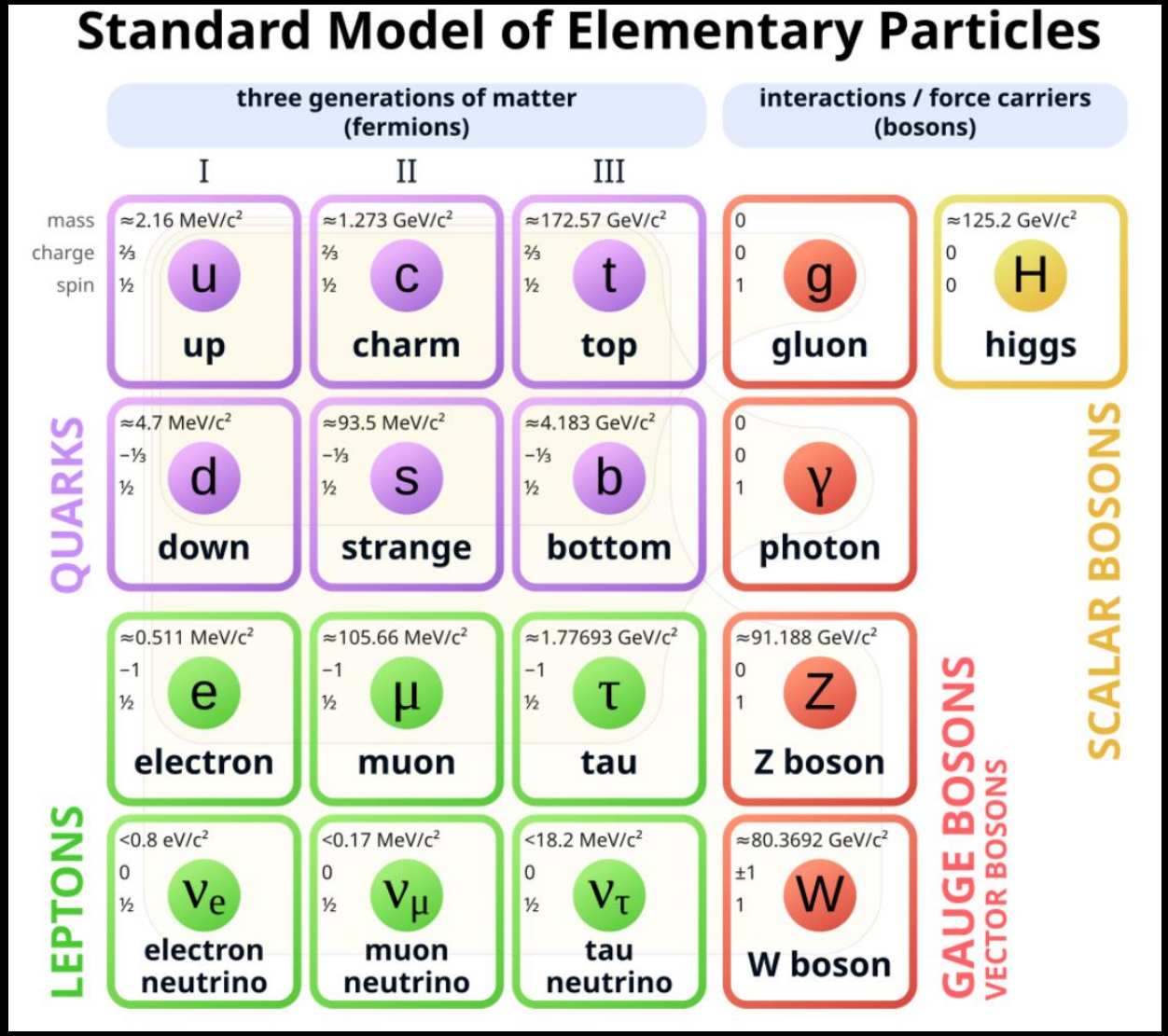


Are we Finished?

"To discover the basic building blocks of all the matter in the Universe, and to understand how these building blocks fit together."

Does the *Standard Model* describe all Matter, and all Interactions of Matter?



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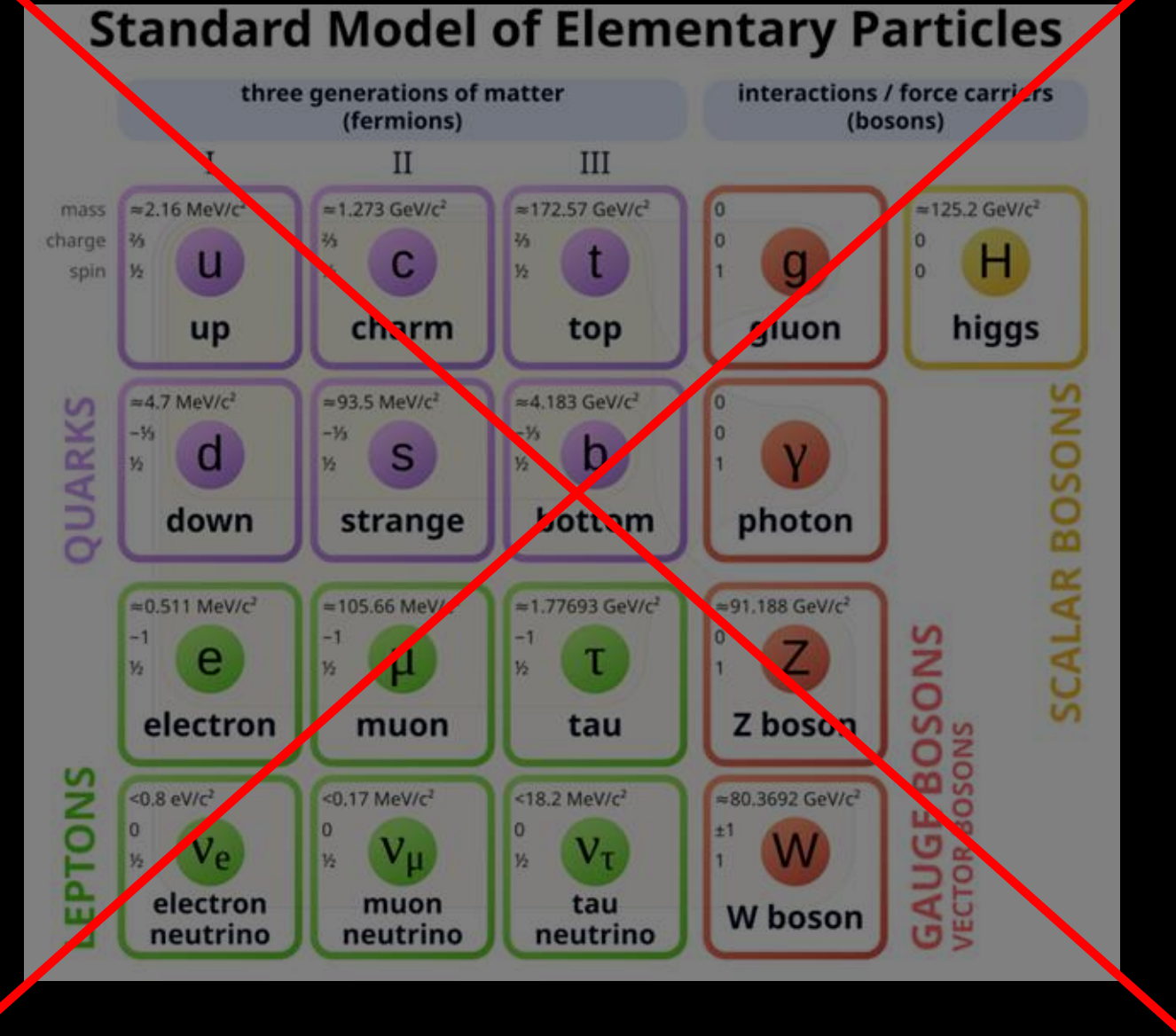

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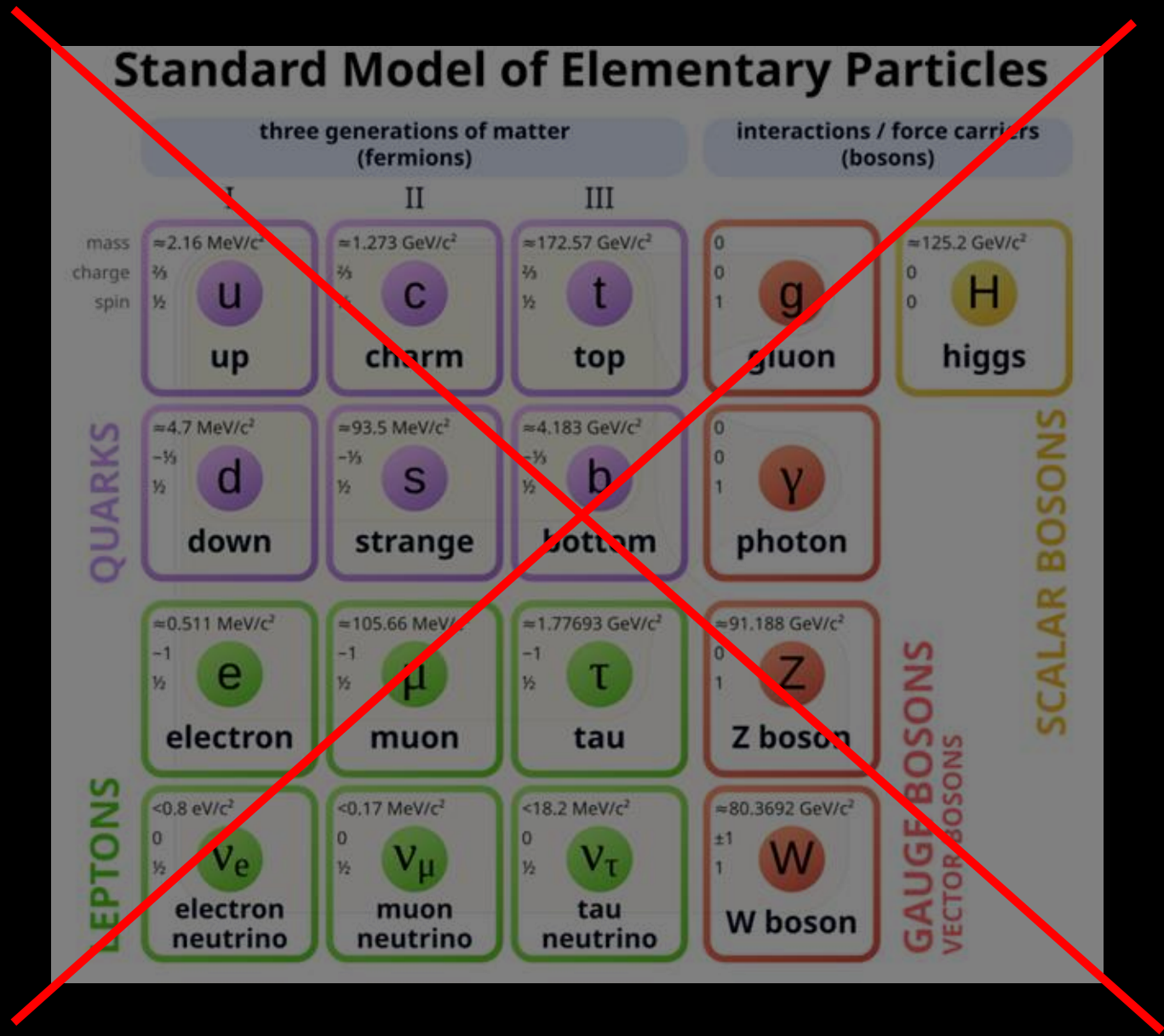
We will talk more about what is missing later…



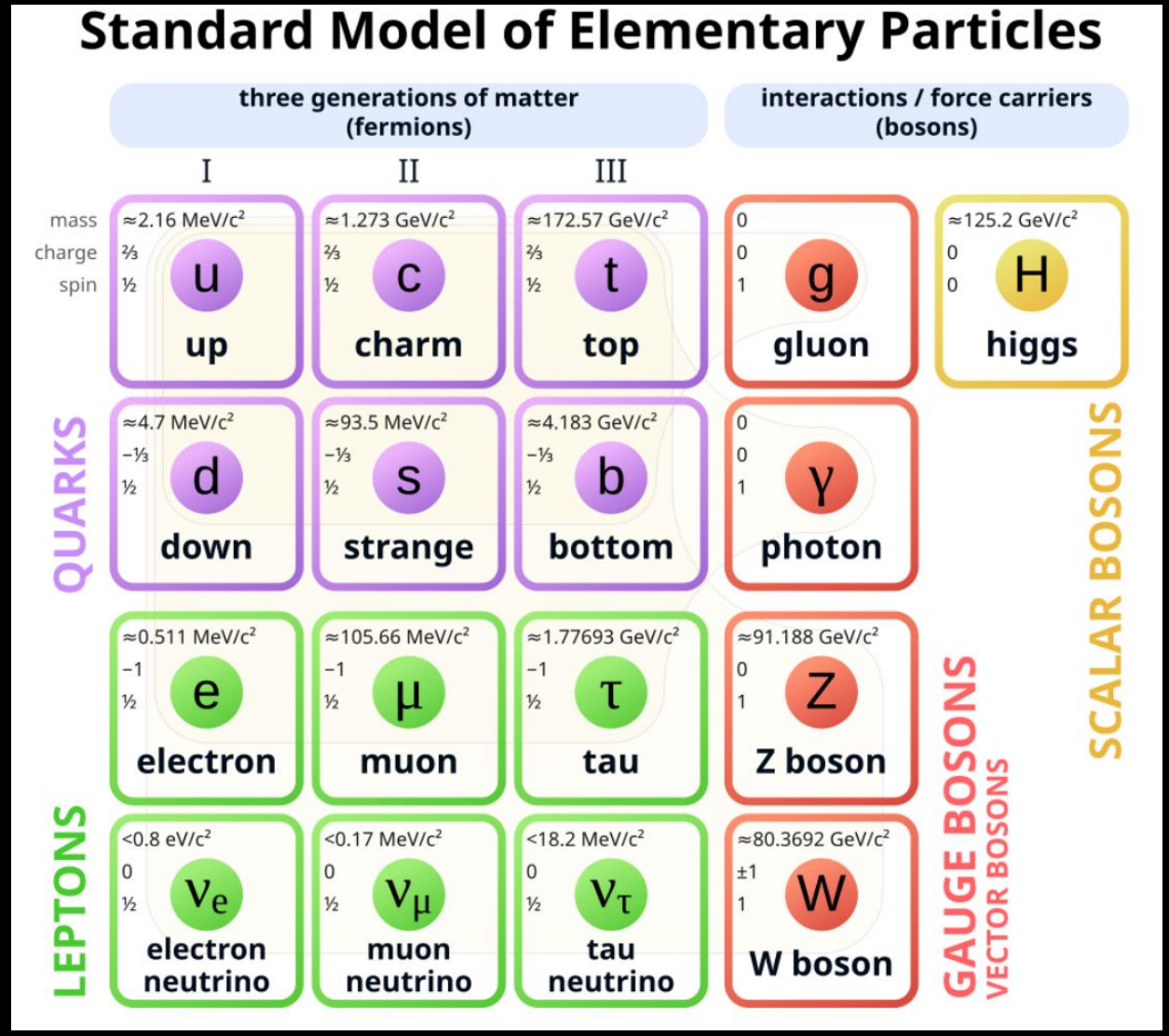
Part III - Quantum Mechanics

What is a Particle?

We have been using the term '*Particle*' quite liberally, without really pausing to think about what this term means.

Classical Physics would have us believe that these particles behave rather like snooker balls, pinging around and bumping off each other.

The reality is far more interesting.

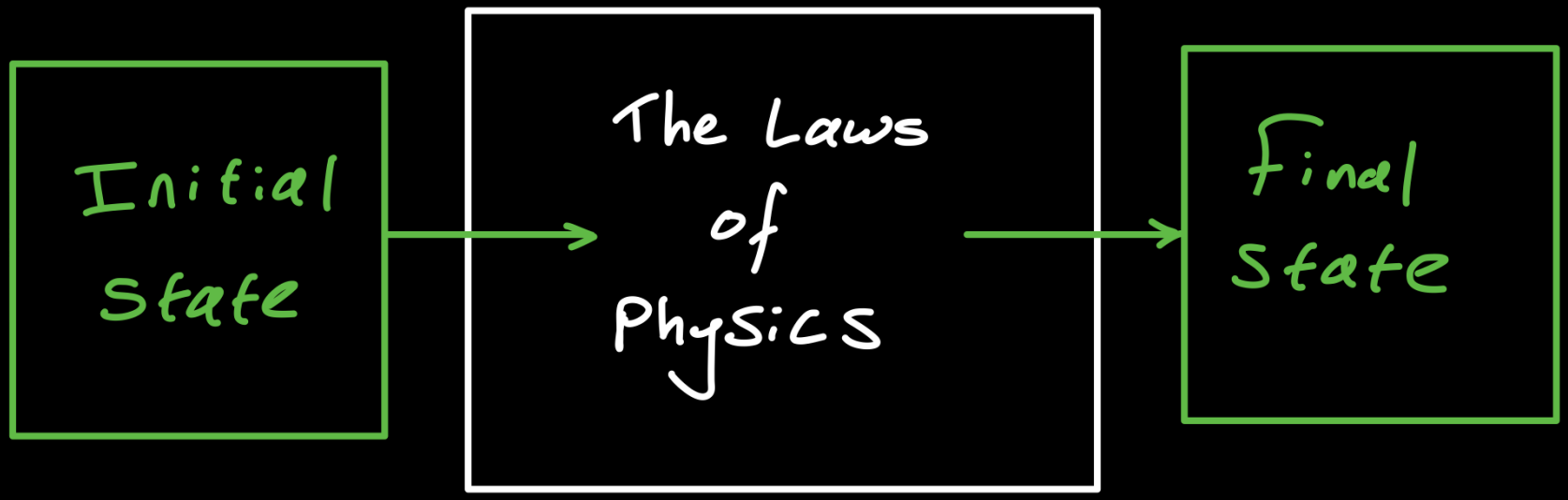


Classical Physics

LLL [1]

Up until around 1926, it was believed that the laws of physics could be used in an entirely deterministic way.

This kind of physics is called Classical Physics.



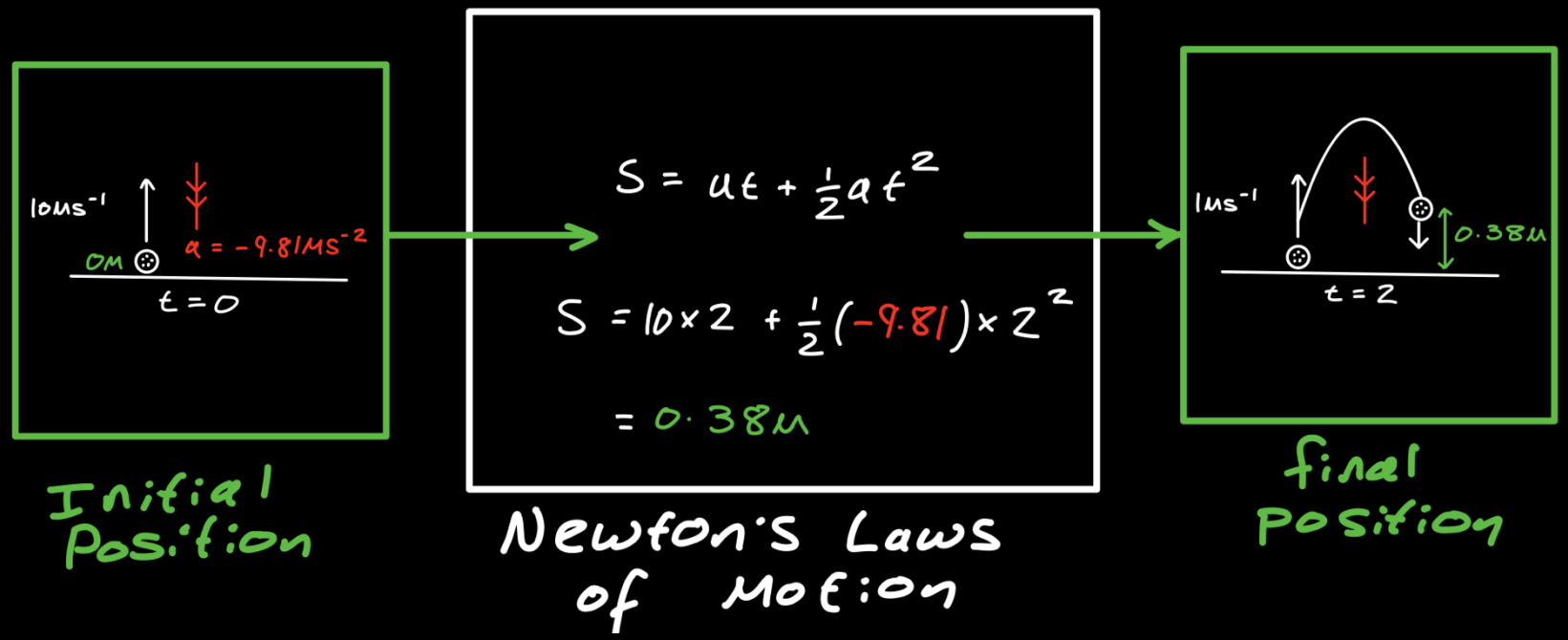
With sufficient information about the initial state of a system, sufficient knowledge of the laws of nature, and sufficient computational power (biological, or mechanical) to perform calculations: The final state of a system can always be worked out.

Classical Physics

LLL [1]

For Example:

If we hit a golf ball vertically upwards at a certain speed, we can apply Newton's laws of motion to work out exactly where the golf ball will be and how fast it is moving some time later.



With sufficient information about the initial state of a system, sufficient knowledge of the laws of nature, and sufficient computational power (biological, or mechanical) to perform calculations: The final state of a system can always be worked out.

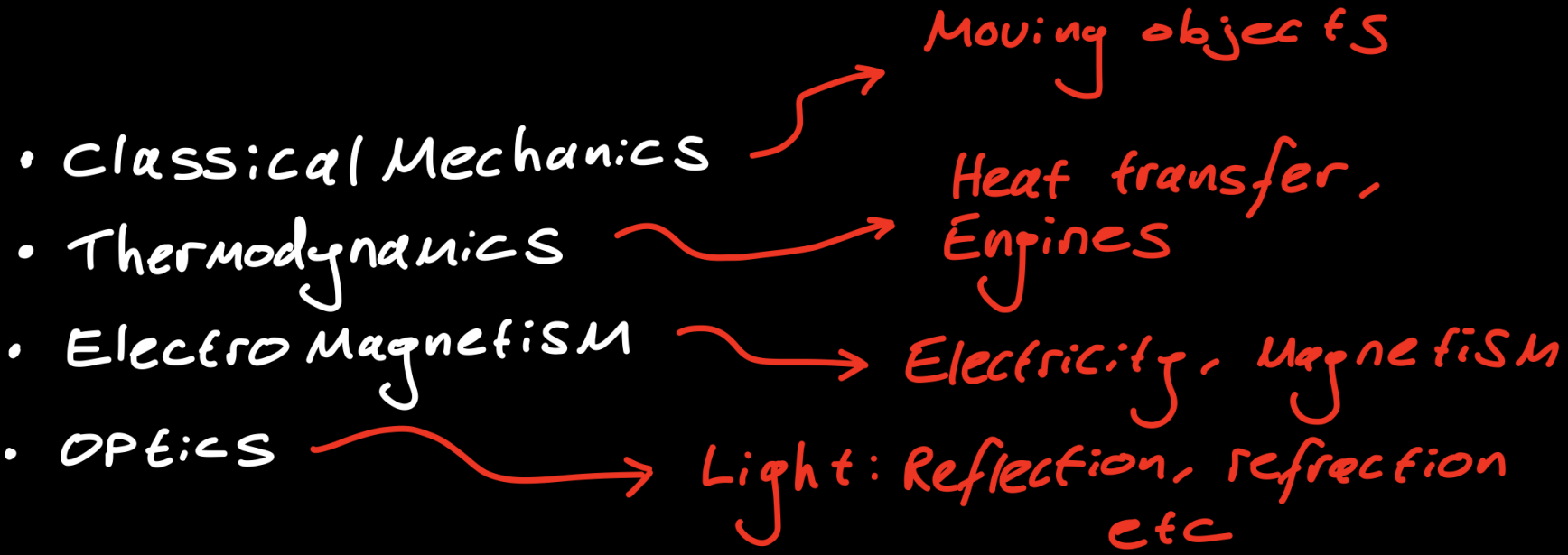
Classical Physics

LLL [1]

Classical Physics can be broadly divided into four areas.

Classical Physics is still extremely useful today.

Classical Mechanics is what took us to the moon!



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Classical Physics

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Classical Mechanics is what took us to the moon!

Quantum Mechanics disabuses us of this notion.

With sufficient information about the initial state of a system, sufficient knowledge of the laws of nature, and sufficient computational power (biological, or mechanical) to perform calculations: The final state of a system can always be worked out.

The Laws of Quantum Mechanics

LLL [1]

In 1926, Erwin Schrödinger provides us with one of the fist concrete mathematical laws of Quantum Theory, an equation which bears his name.

$$ih\frac{\partial\psi}{\partial t} = -\frac{h^2}{2\mu}\frac{\partial^2\psi}{\partial t^2} + V(x)\,\psi$$

Schrödinger's Equation.

Schrödinger’s equation is a complex valued, second order, partial differential equation.

This is usually not tackled until the second year of a physics degree!

The Laws of Quantum Mechanics

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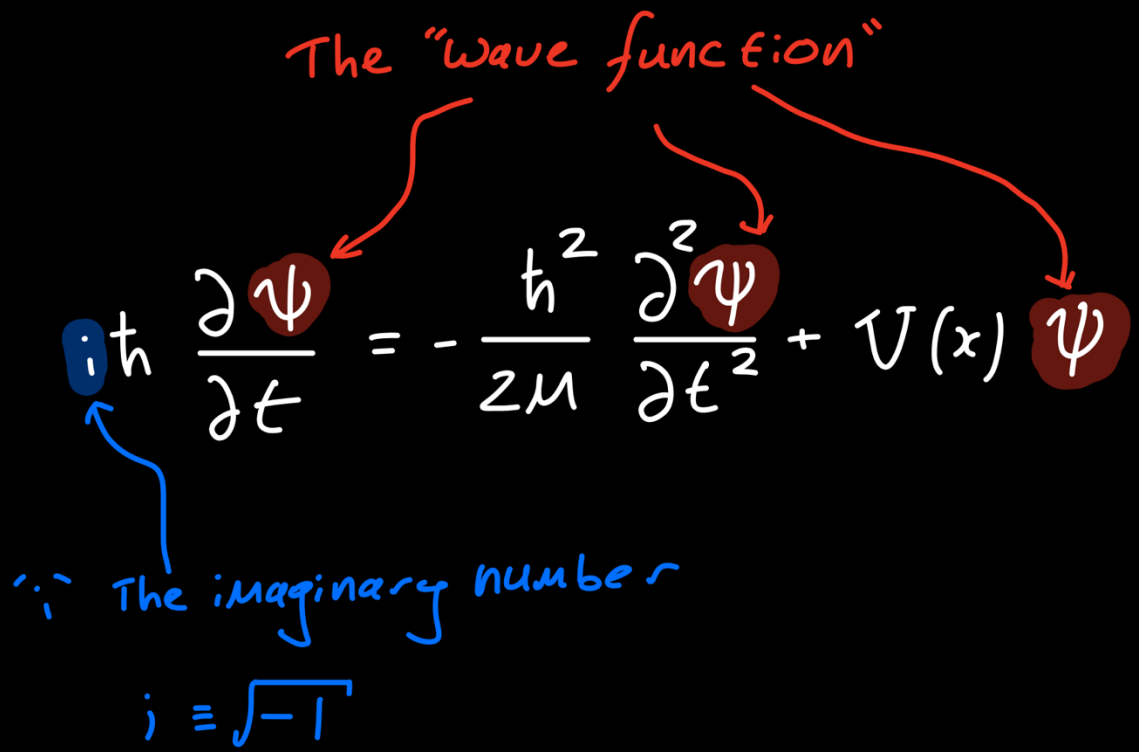


Schrödinger's Equation.

This equation introduces the wave-function.

A mathematical variable, which looks like a wave, but is interpreted as a probability...

Schrödinger's equation is a complex valued, second order, partial differential equation.

This is usually not tackled until the second year of a physics degree!

The Laws of Quantum Mechanics

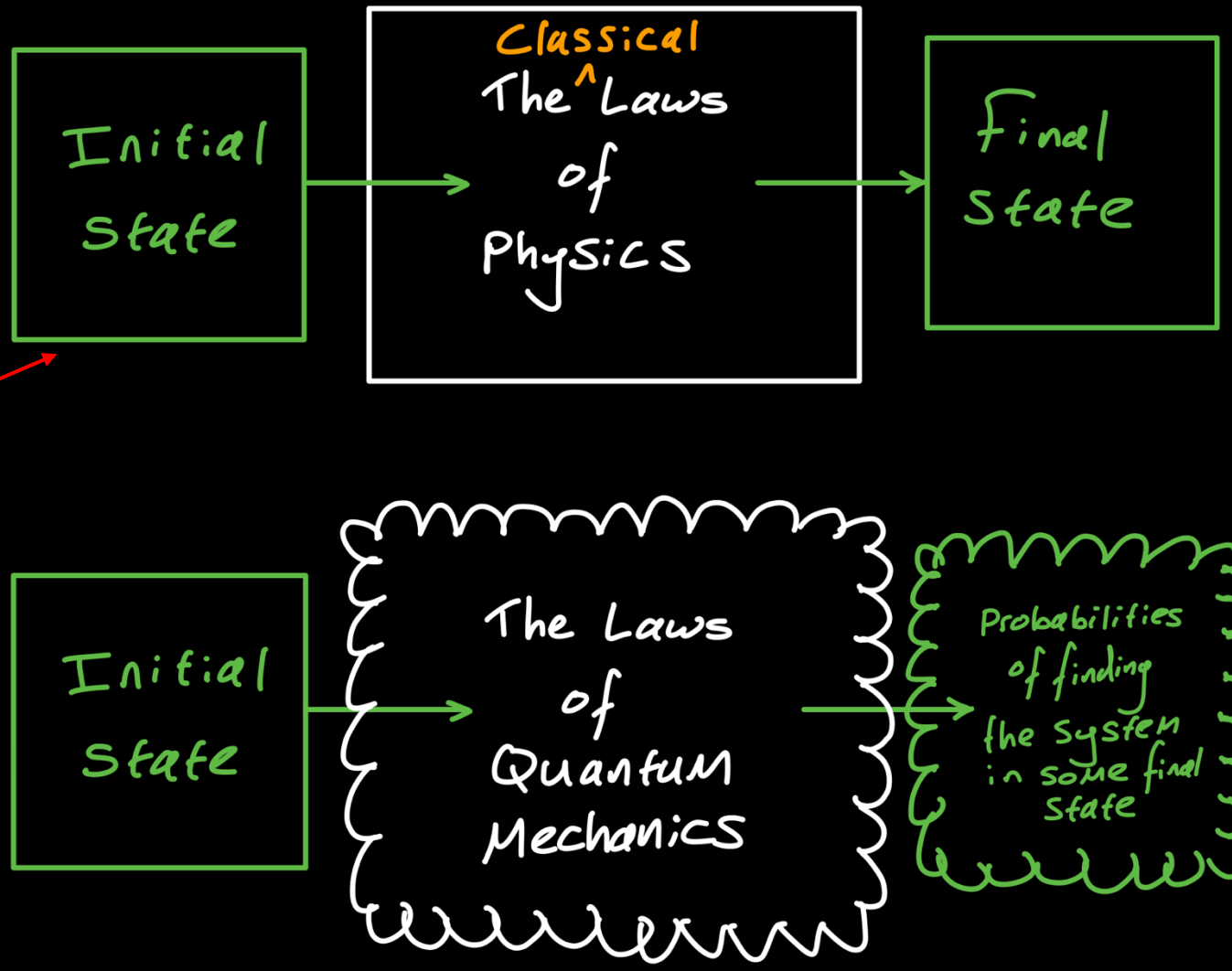
LLL [1]

'...interpreted as a probability...'

This is the key insight into grasping the quantum mechanical description of nature.

The fully deterministic view of Classical Physics, is replaced by the probabilistic view of Quantum Physics.

The Laws of Quantum Mechanics do not allow us to compute the exact trajectory of subatomic particles, in the way we did for a golf ball at the start of the lecture...

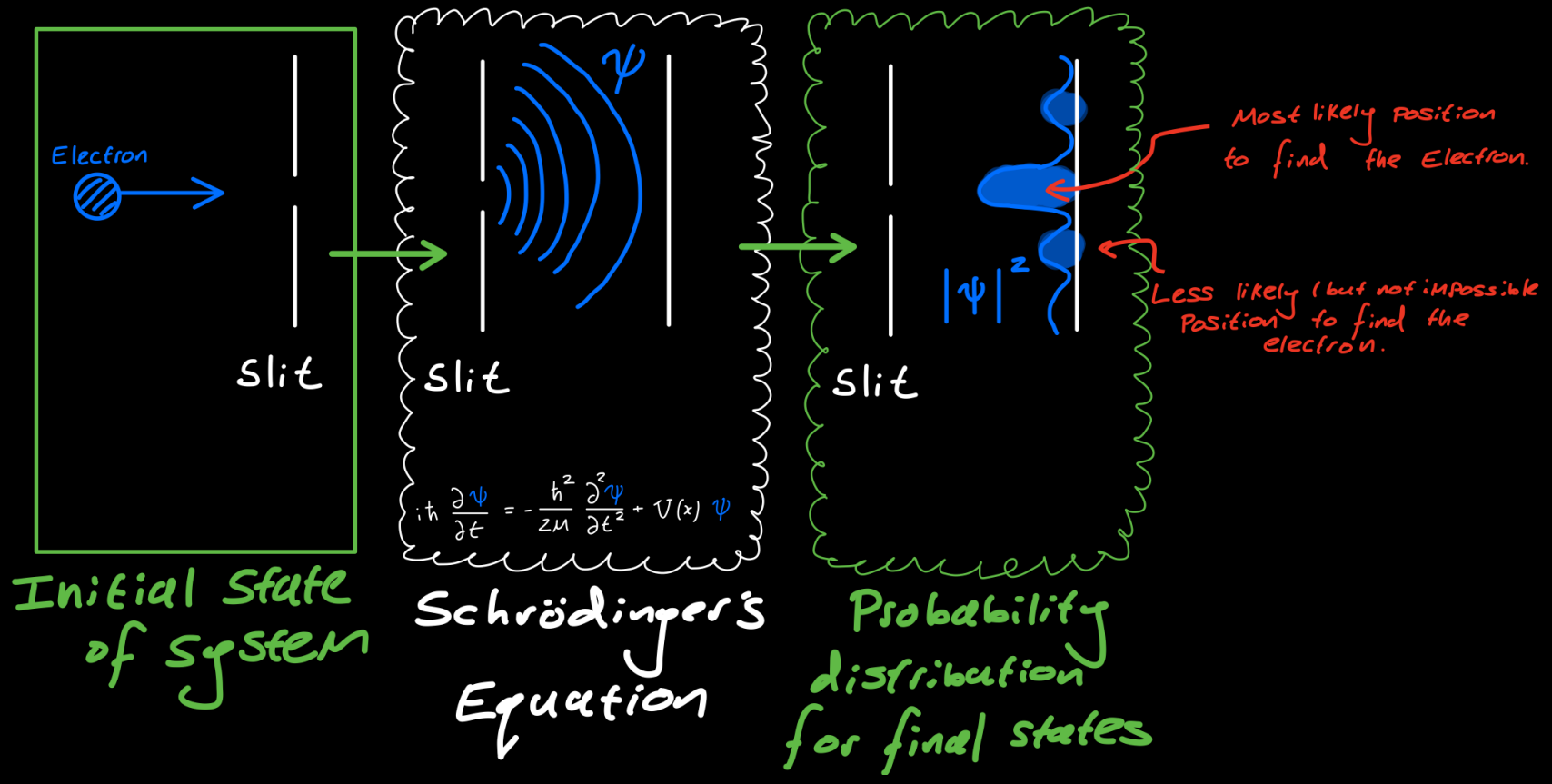


The Laws of Quantum Mechanics

LLL [1]

The output of Schrödinger's equation is a probability distribution, describing the relative likelihood of the electron being found at a given location.

The greater the value of the wavefunction at a given point in space, the greater the probability of finding the electron there.



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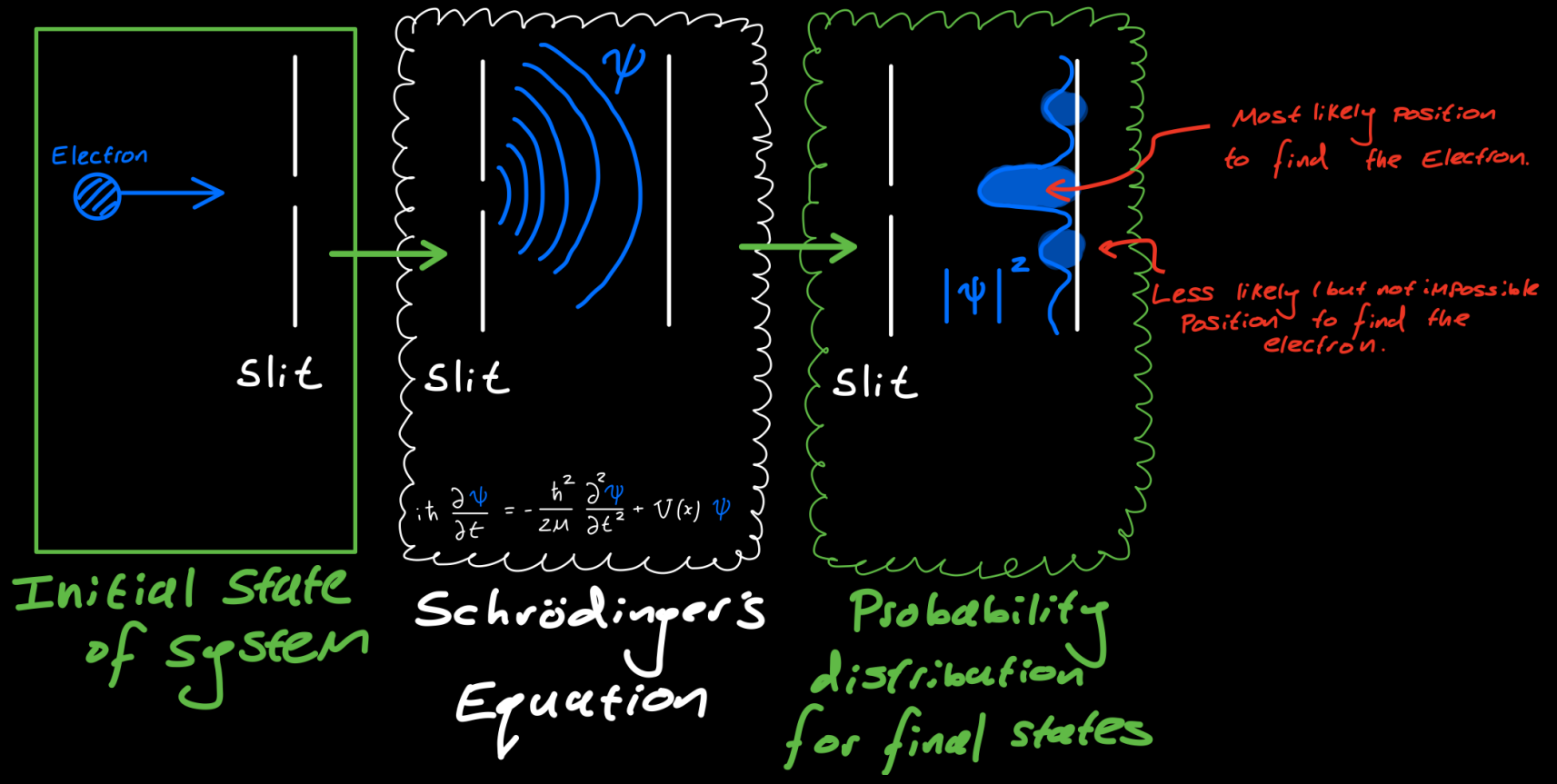

But SURELY... The electron must really be SOMEWHERE.

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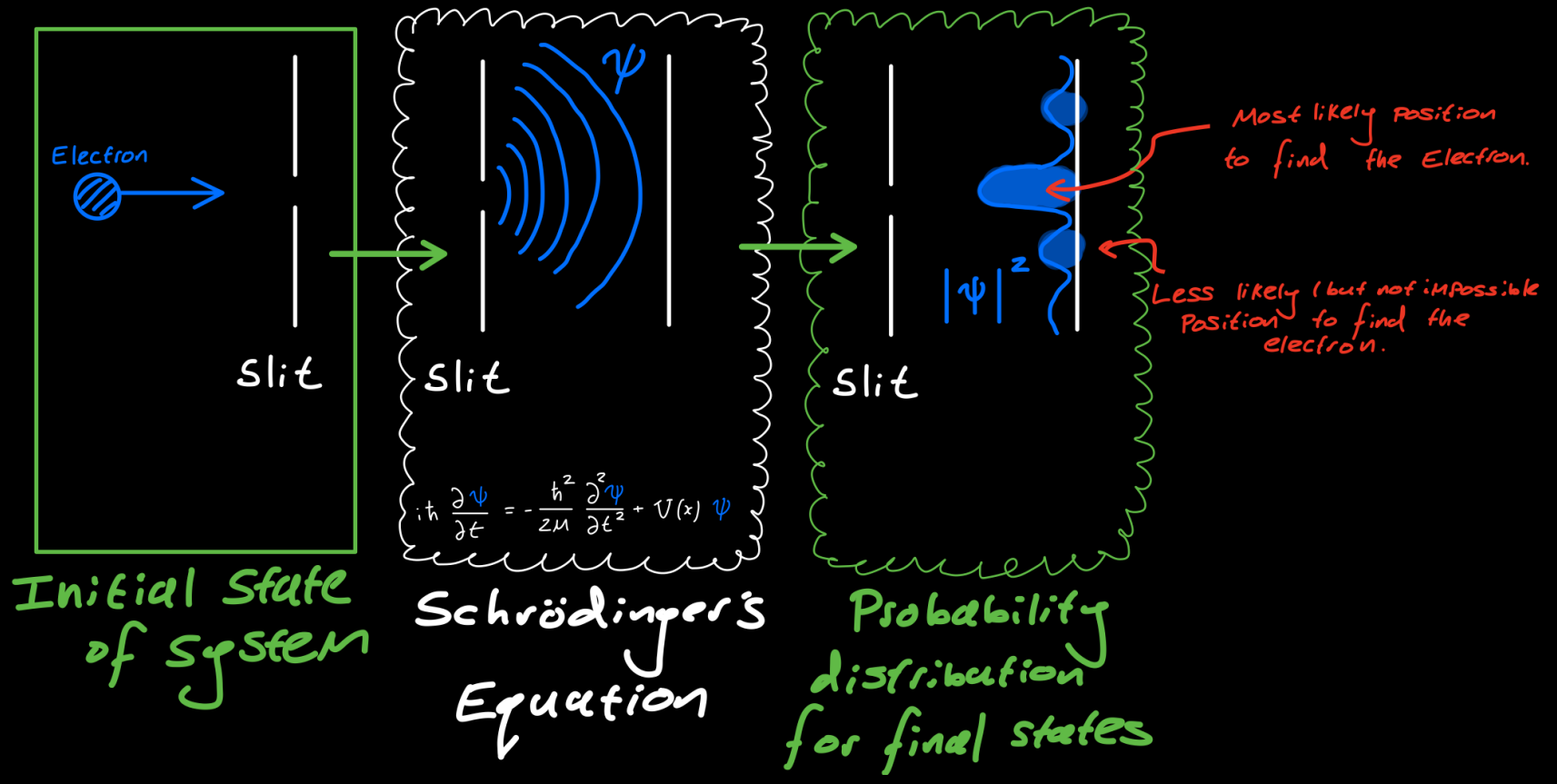

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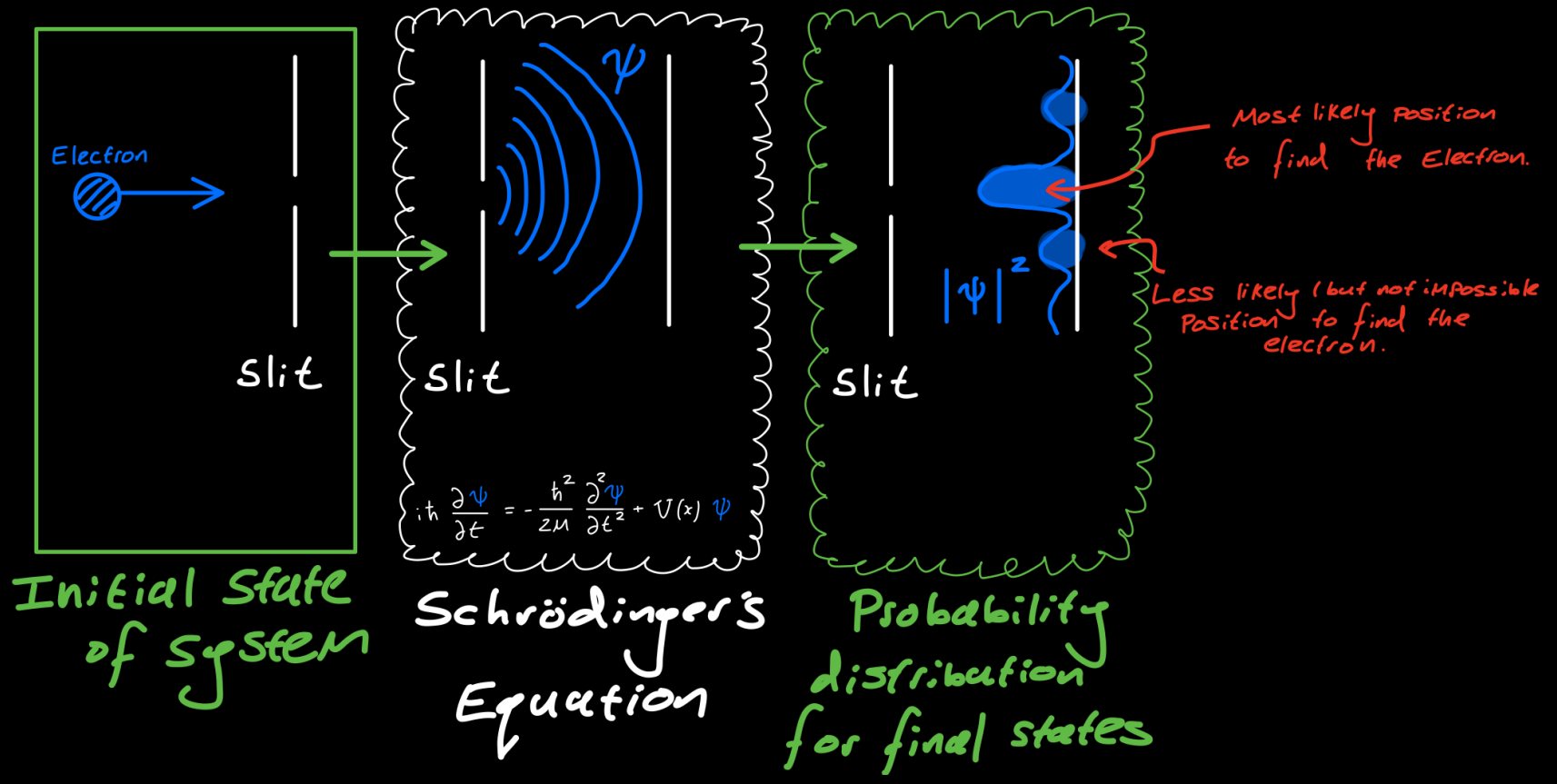


But SURELY... The electron must really be SOMEWHERE.

YES, AND NO

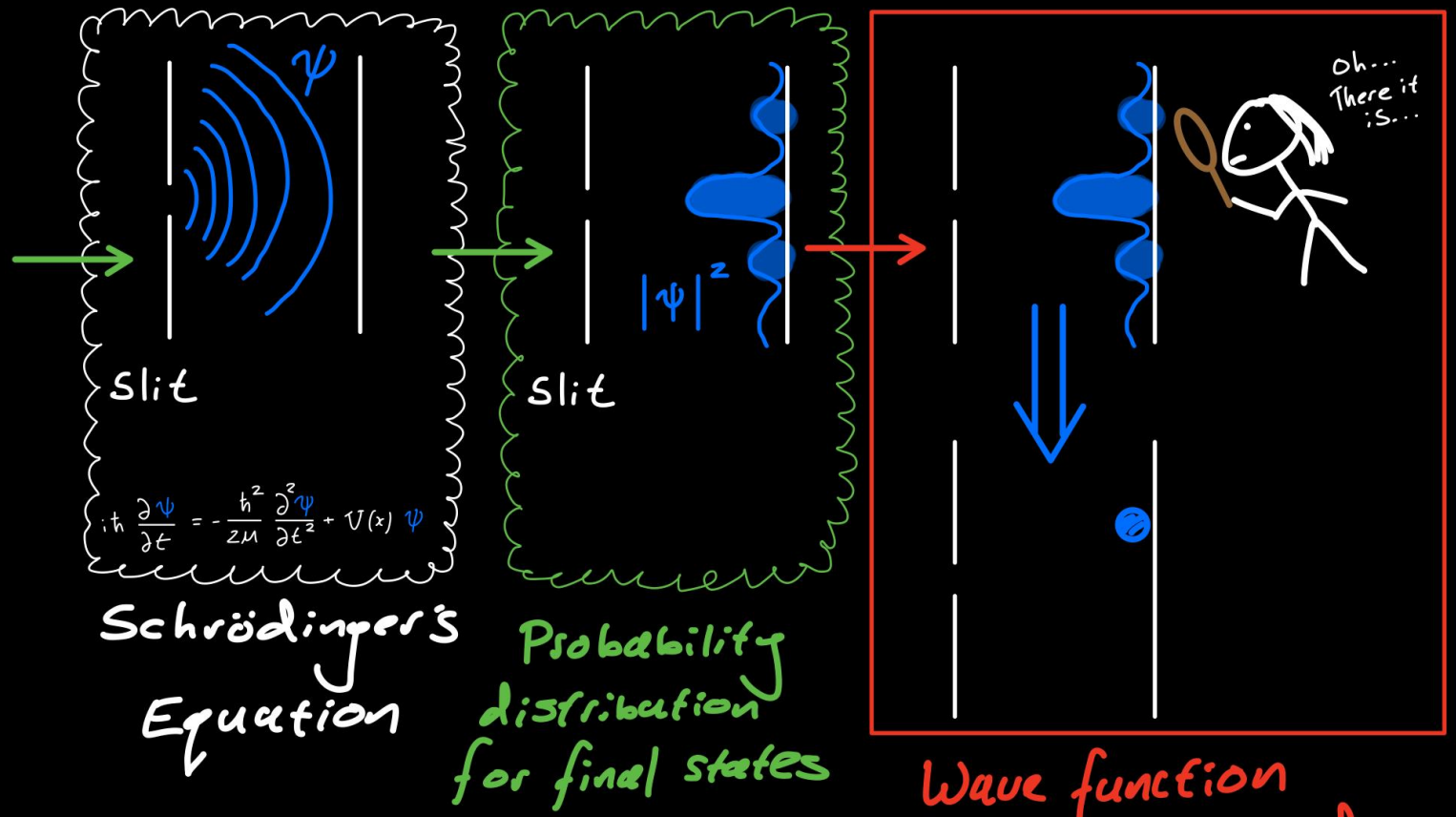
The Laws of Quantum Mechanics

LLL [1]

There is a fourth step… Making an observation.

When the electrons position is measured (e.g. by an experiment). It's position becomes definitive.

We call this the 'collapse of the wave-function'.

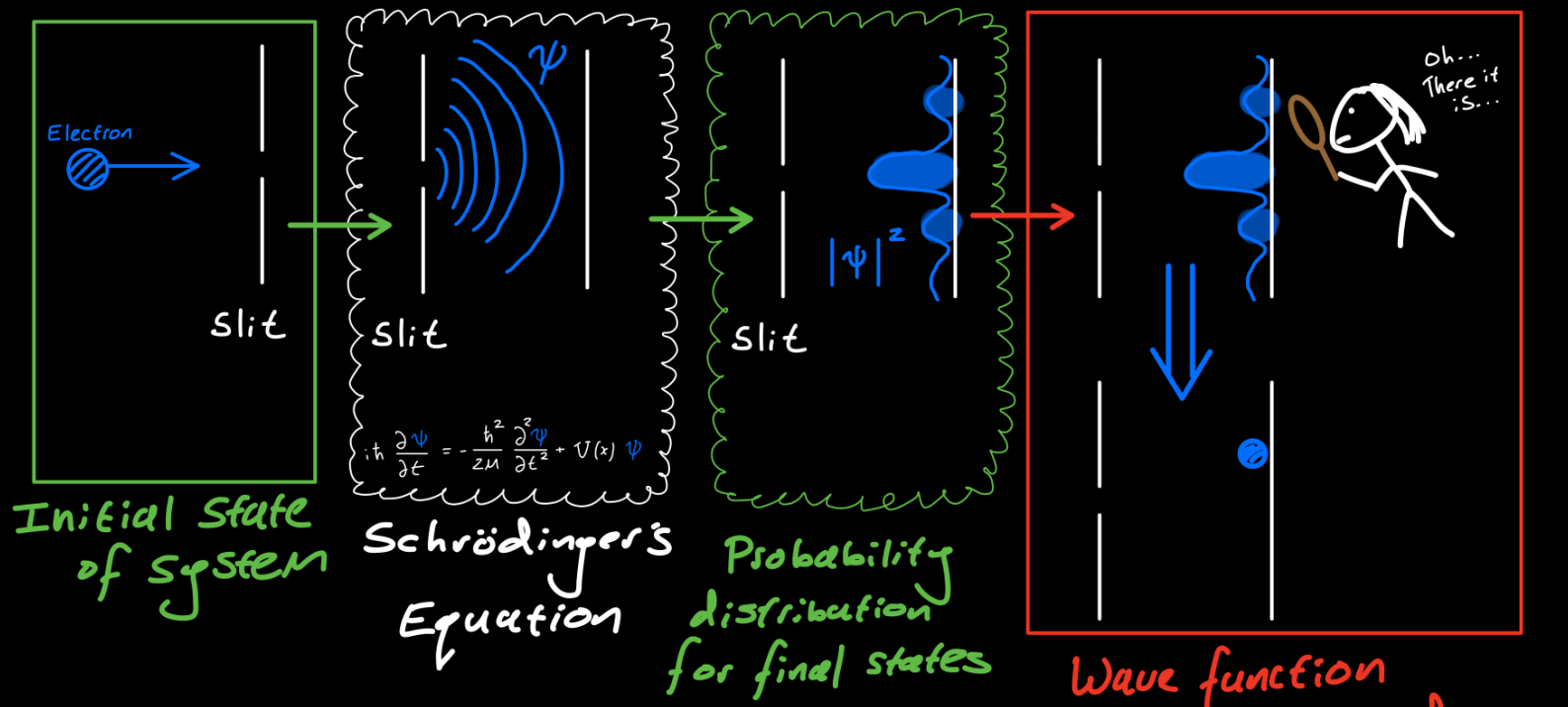


The Laws of Quantum Mechanics

LLL [1]

I will summarize everything I want you to know about Quantum Mechanics below:

Matter behaves as a fuzzy cloud of probability (governed by Schrödinger's equation), until it is observed, then it does not.



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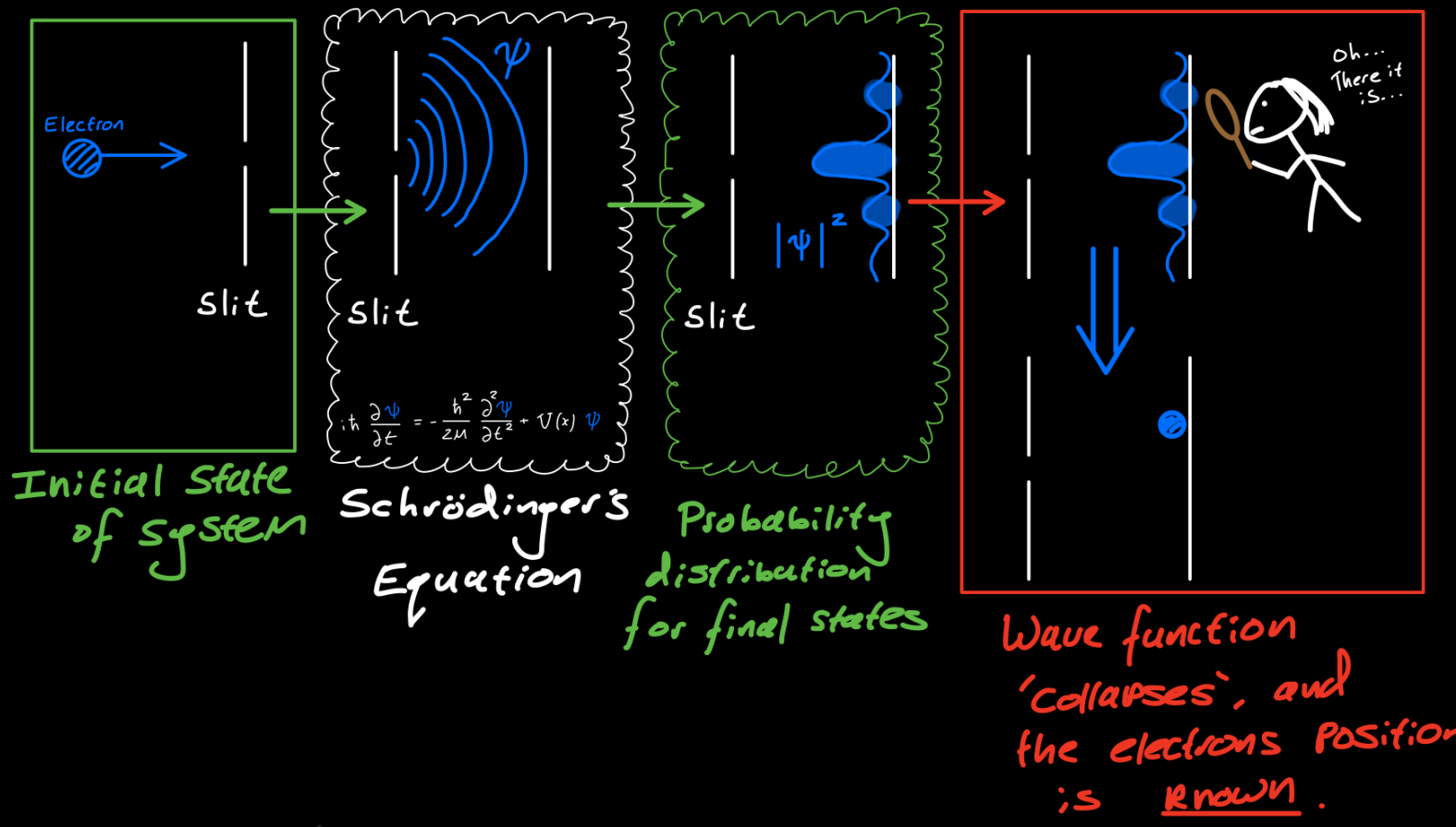
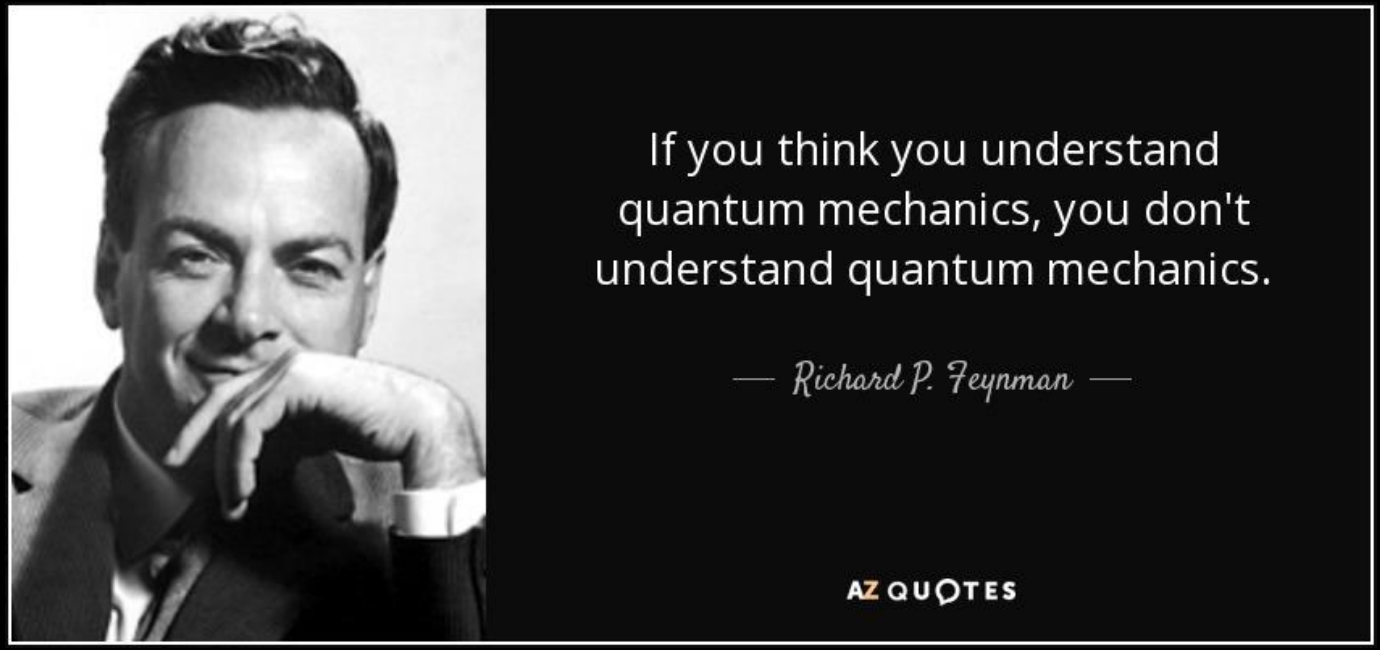
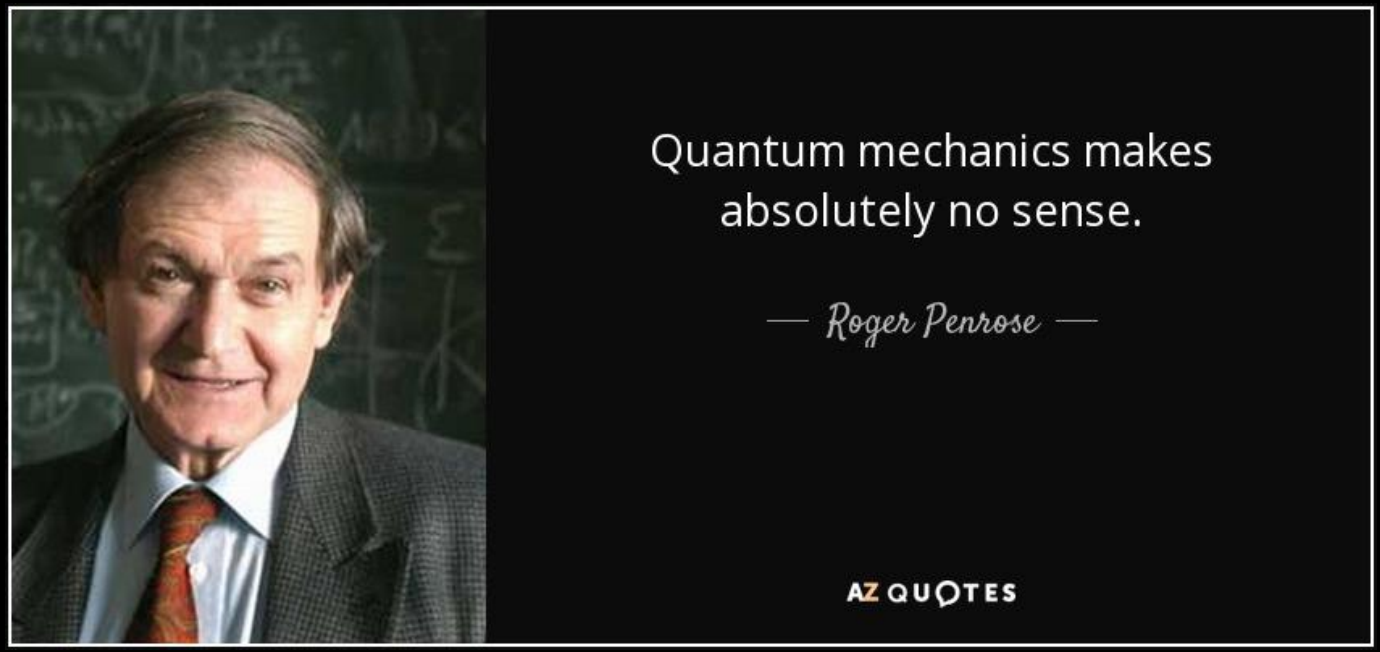


The Laws of Quantum Mechanics

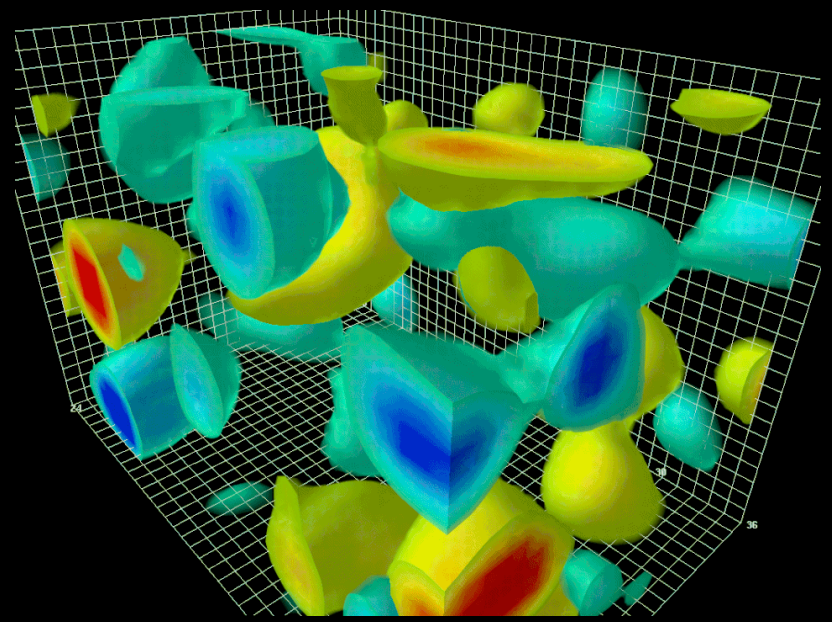
Not remotely simple!....





Part IV – Quantum Fields

Quantum Mechanics
+
Special Relativity

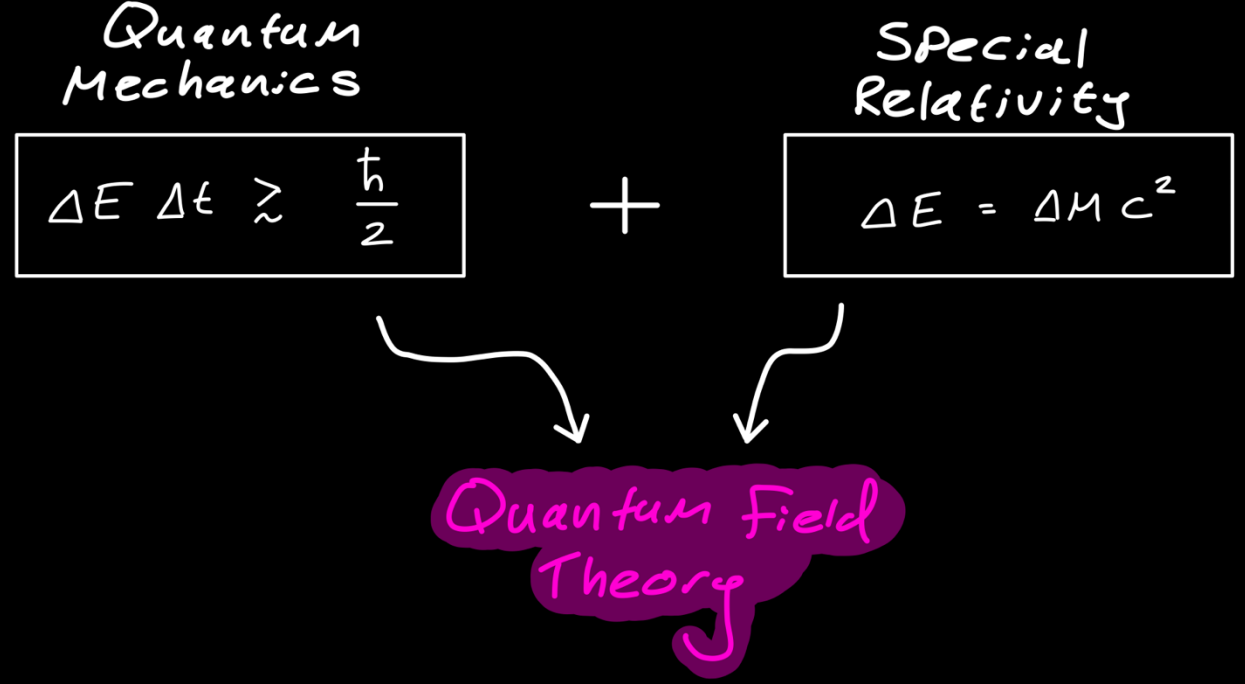


LLL [2]

Special Relativity is Einstein's 1905 Theory of space and time (we will touch on this more, in two weeks time).

Later in 1926, efforts were being made to create a more complete quantum theory of light, which respects Special relativity.

This fusion of Quantum Mechanics and Special Relativity, is called **Quantum Field Theory**.



Quantum Mechanics
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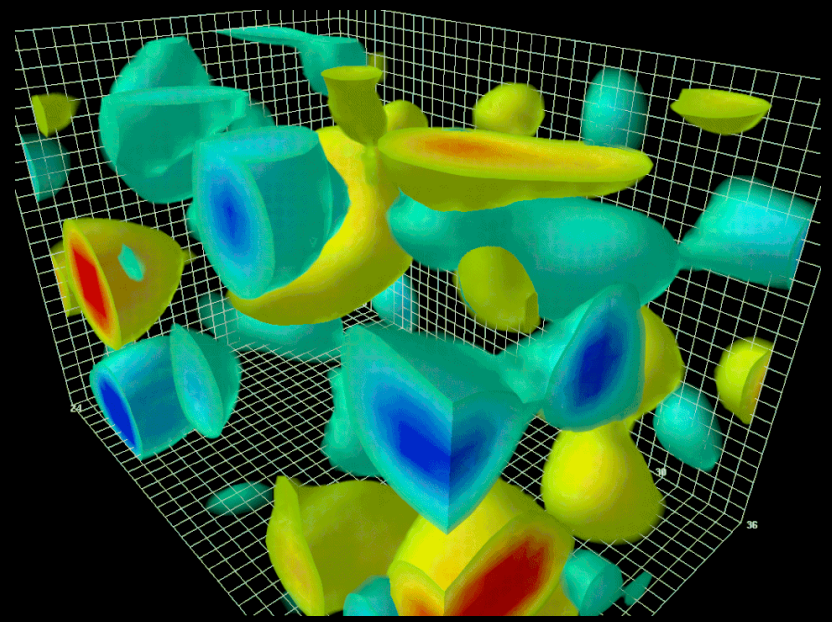
Special Relativity

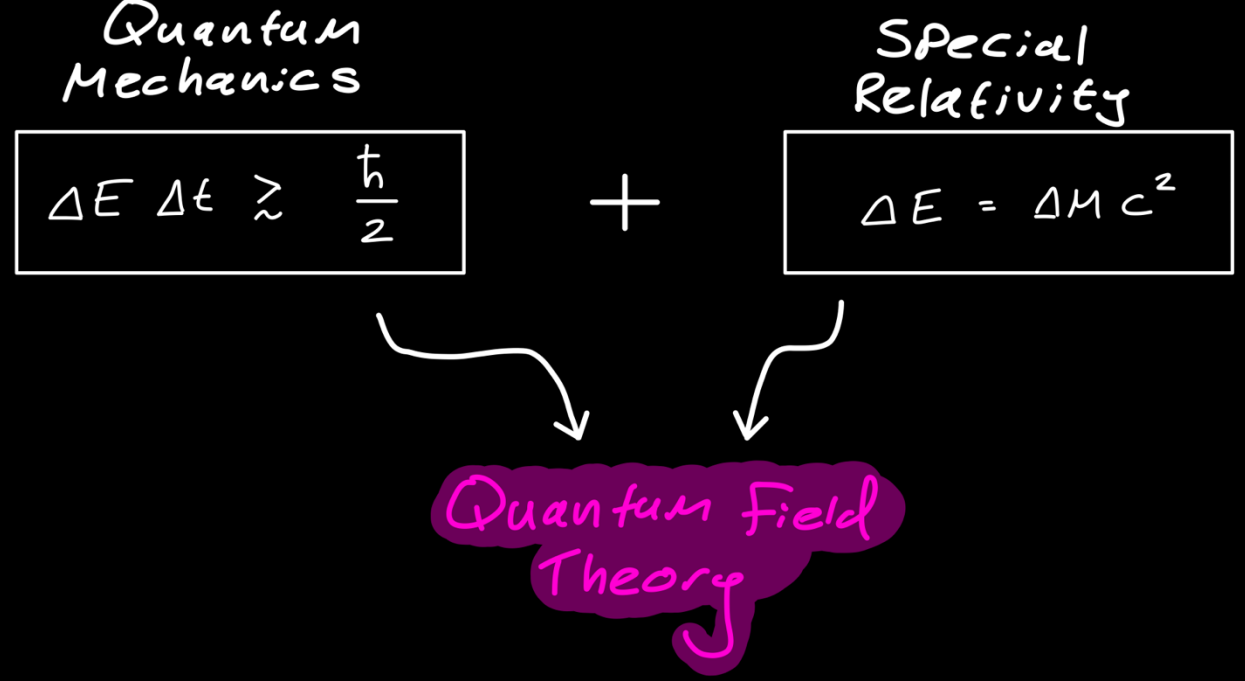


LLL [2]

Quantum Field Theory describes matter particles, at the most fundamental level, as excitations of some undulating underlying '*Quantum Fields*'.

Particles pop into existence and dissolve back into the vacuum a short time later.

This *fizz* of of creating and annihilating particles fills the entire Universe.



So what is matter? Particle or Field?!

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It’s both!

So what is matter? Particle or Field?!

It’s both!

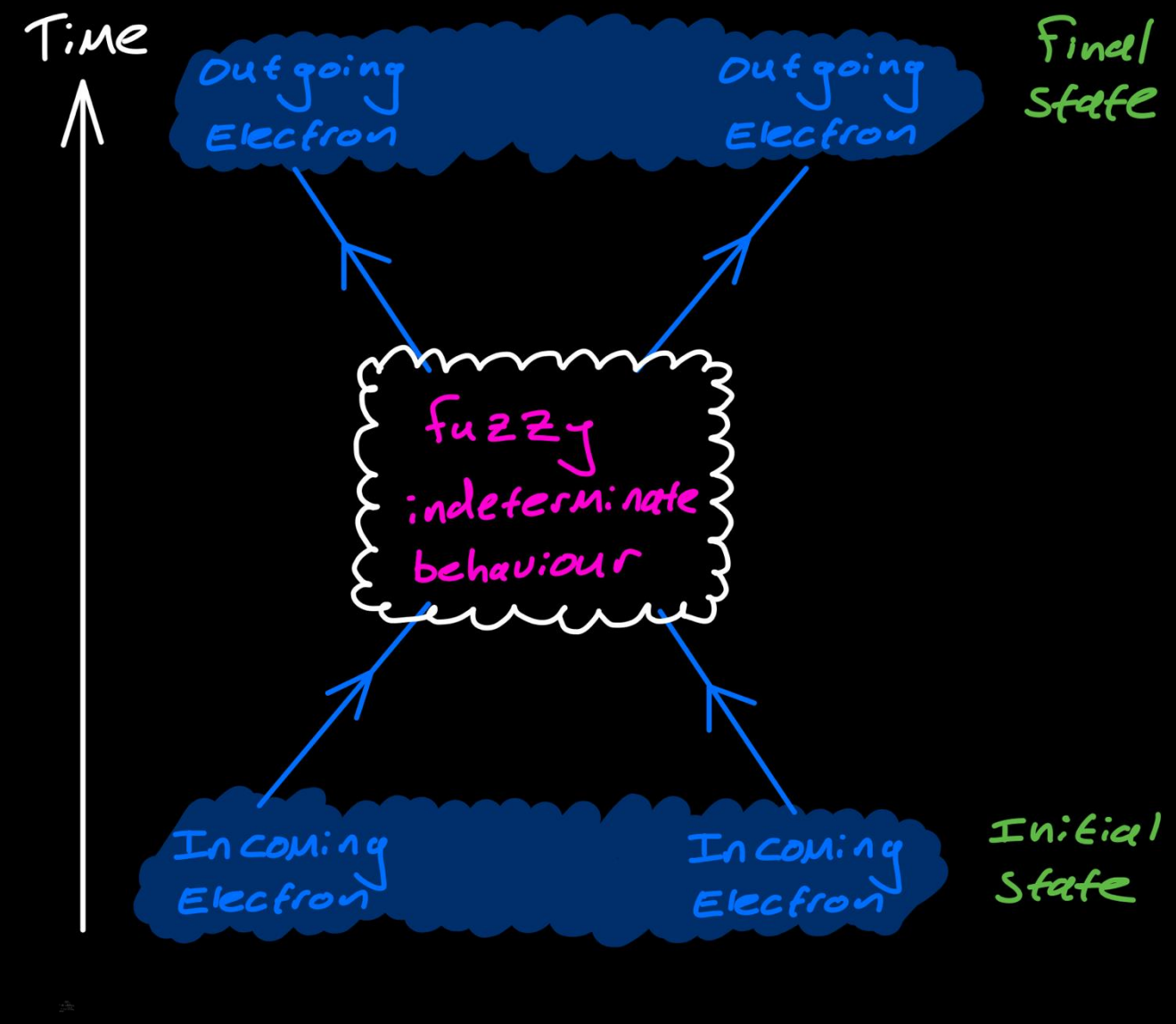
Sort of..

Electron Scattering

When we make measurements, we can observe particles at a definitive location... But what goes on in-between our observation is indeterminate.

Consider two electrons moving towards each other, and then repelling.

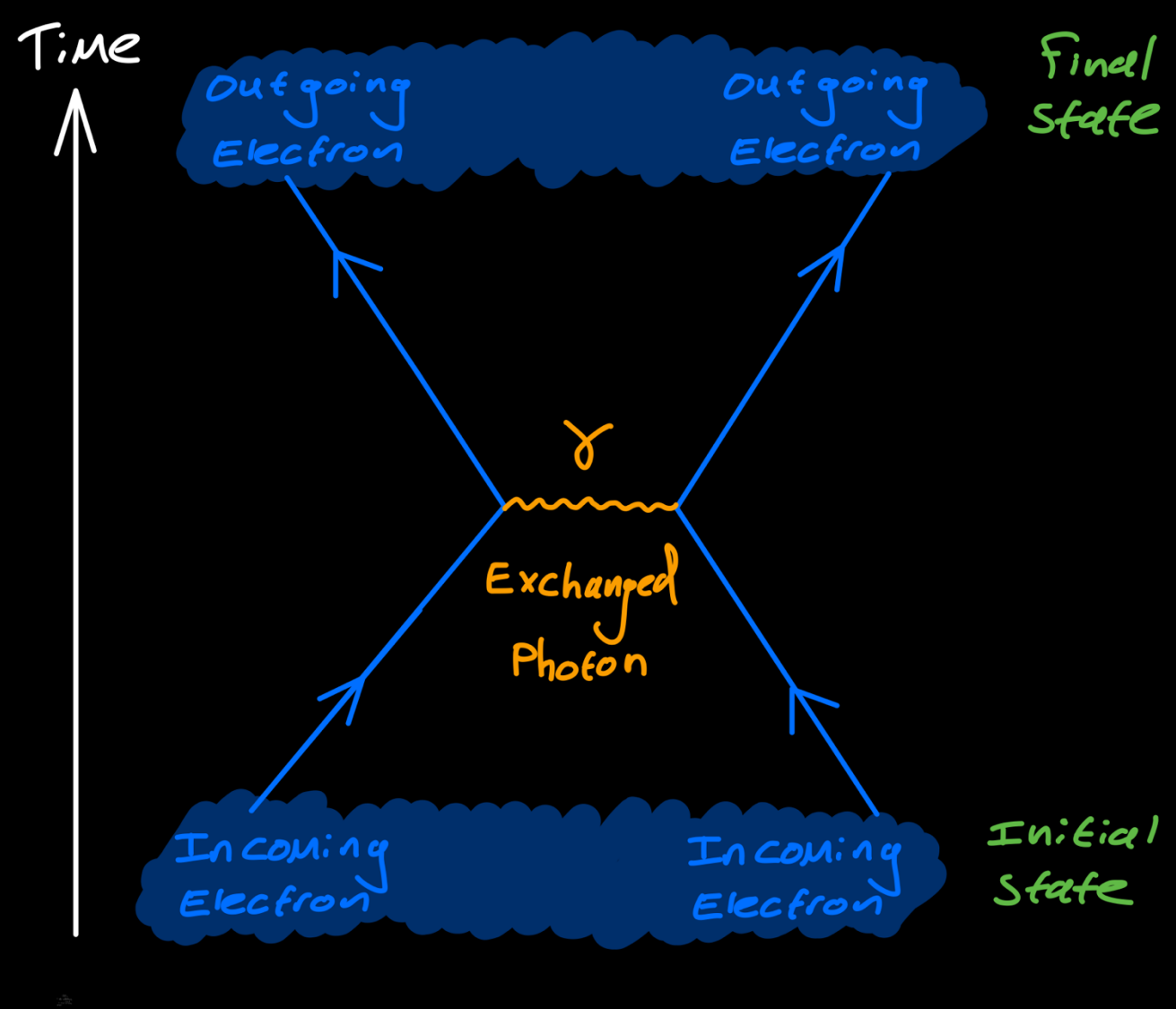
This force is controlled by the Electromagnetic Force.



Electron Scattering

In particle physics, the Electromagnetic Force is communicated by the exchange of a photon of light (the force carrying particle of the Electromagnetic Force).

The rules of Quantum Field Theory, worked out in the 1920's tell us that two electrons may exchange a single photon.



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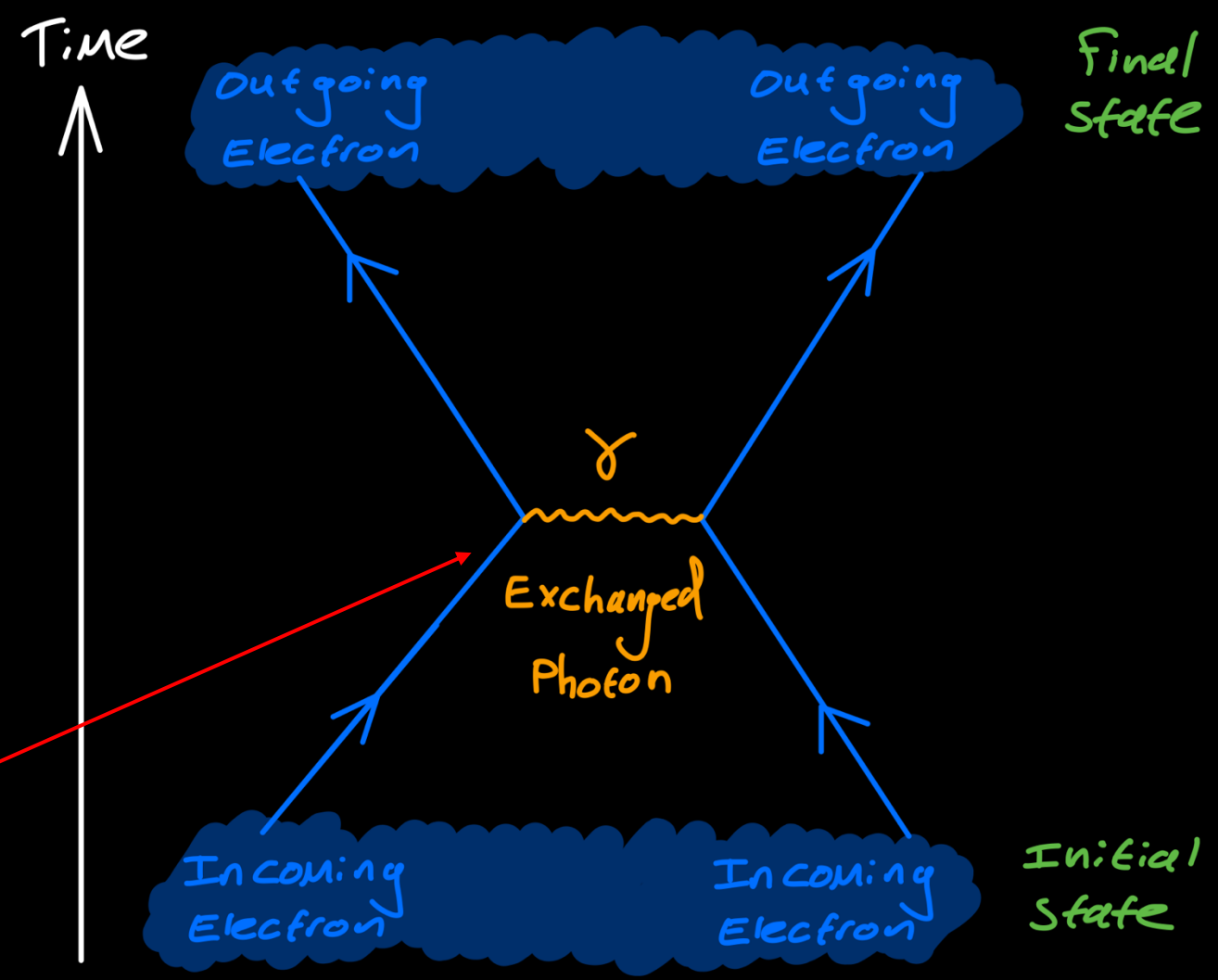

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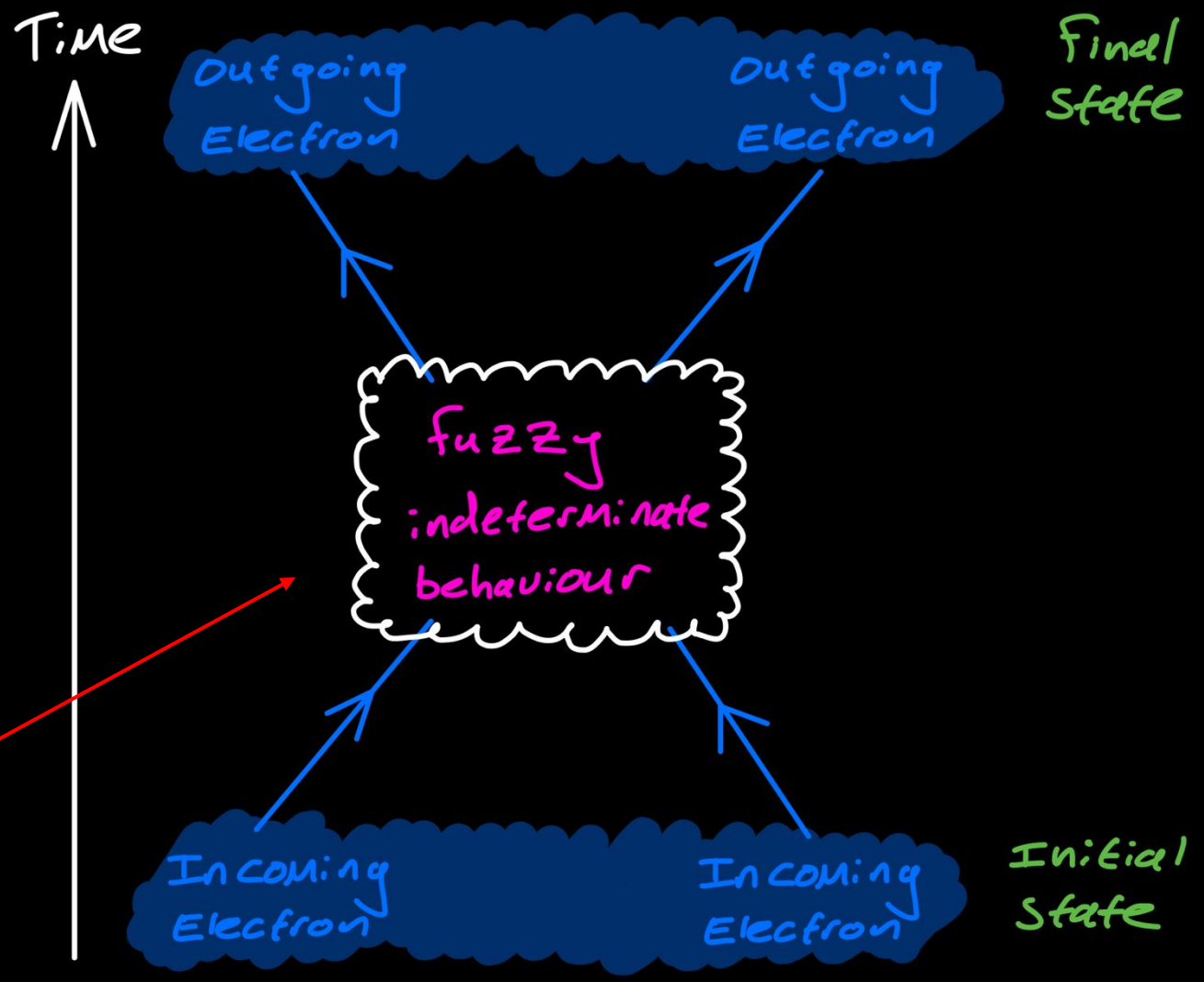
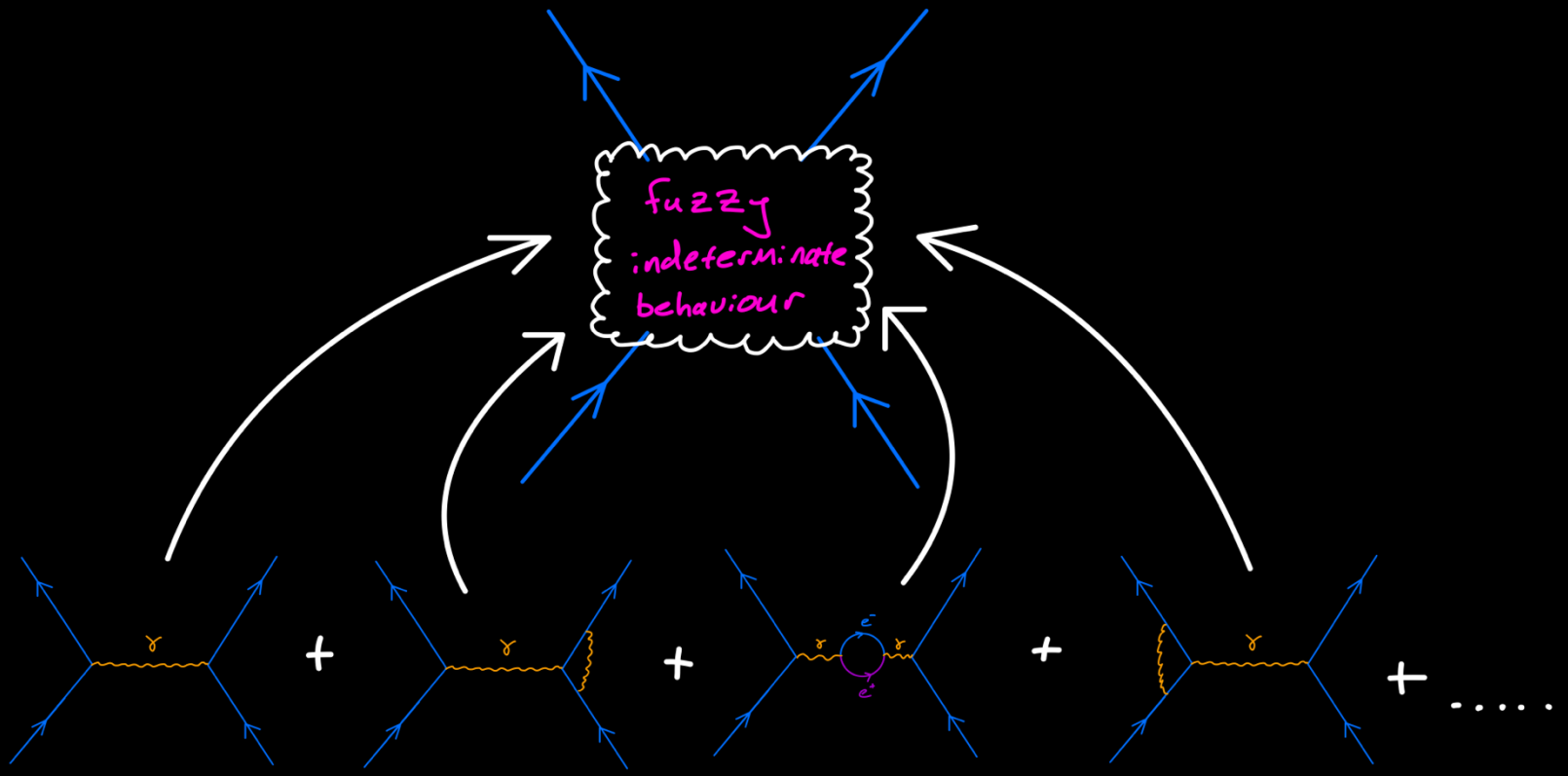


Electron Scattering

The single photon exchange we saw before is *one* possibility, of an infinitude!

To calculate the probability of this scattering interaction occurring, we have to add up the probability of all of these possible interactions!

This diagrammatic technique of representing particle interactions (and the mathematical machinery that is hidden behind them) owes itself to Richard Feynman.



The Feynman Diagram expansion of electron scattering.

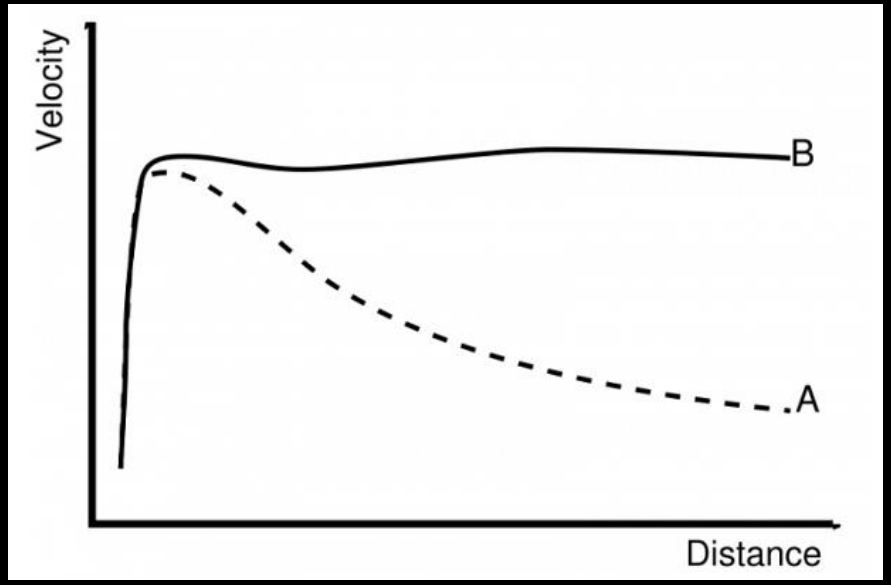
Part V – Unsolved Mysteries

Dark Matter

The rotation of the galaxy suggests an excess of non-visible matter, gravitationally interacting and changing the rotation of the galaxy.

If Dark Matter is not accounted for, our calculations for the rotational speeds of stars in the outer regions of the galaxy are totally wrong.

Comparing the observed rotation curves for various galaxies with the theoretical prediction, accounting for the presence of dark matter, we find that about 95% of the matter in the Universe is Dark Matter.



Galaxy Rotation Curves.
A: Predicted Curve. B: Observed Curve.

LLL [3]

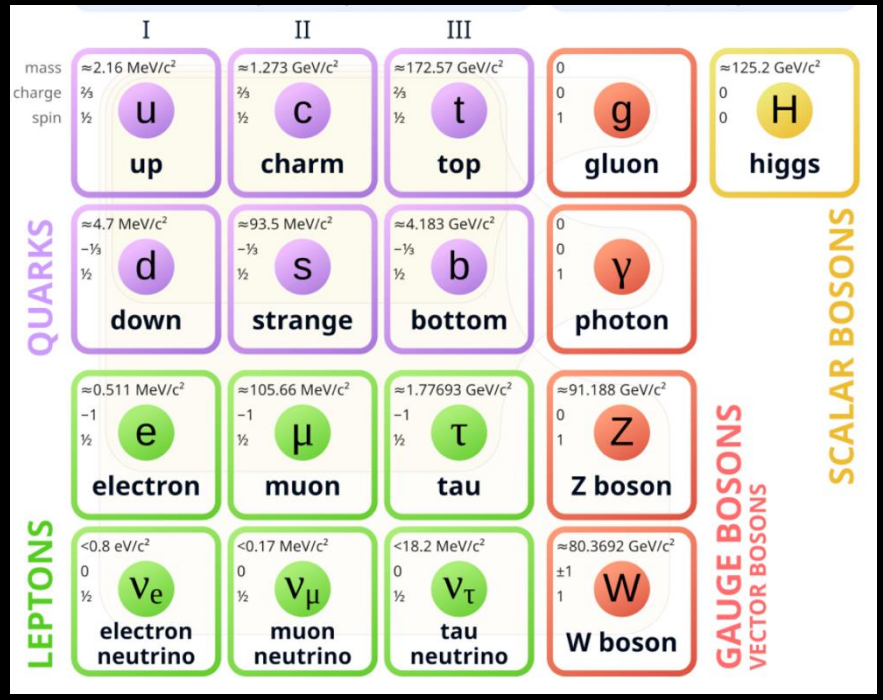
Dark Matter

But what is Dark Matter?

We don’t know!

The *Standard Model* describes all of the known visible matter, and most of the known forces in our Universe. It does not include DM.

Many models: including extra dimensions, WIMPs, axions, primordial black holes. Some models even doubt whether DM is a particle, instead it as a gap in our understanding of how gravity works on large scales.



LLL [3]

The Hunt for Dark Matter

- Direct Detection Experiments:

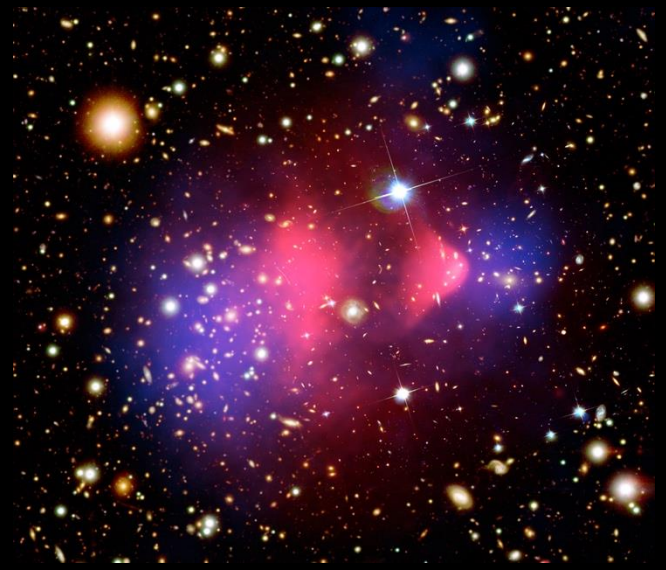
Search for instances of Dark Matter particles colliding with detectors on the Earth. Very tough, as Dark Matter only interacts gravitationally, and *perhaps* by the weak force.

- Indirect Detection Experiments:

Search for the particles produced by Dark Matter particles interacting, rather than the direct interactions themselves.

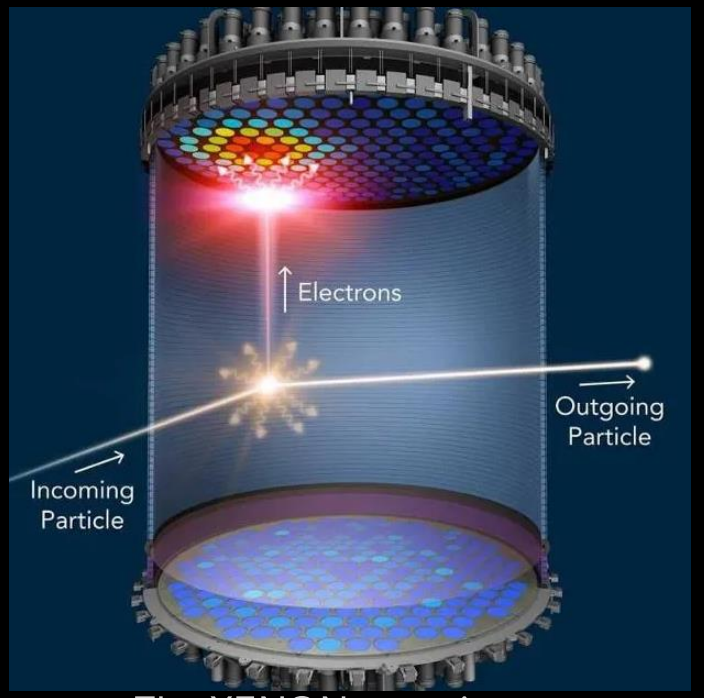
- Astrophysical Detection:

Looking to the cosmos for evidence of Dark Matter. E.g. the bullet cluster.



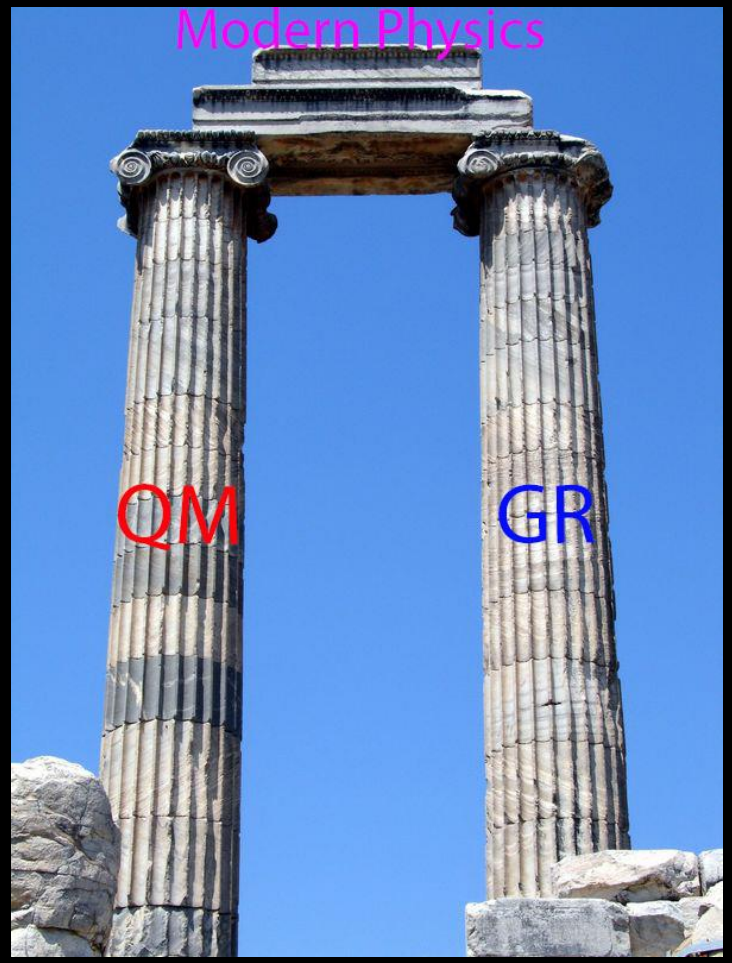
The Bullet Cluster

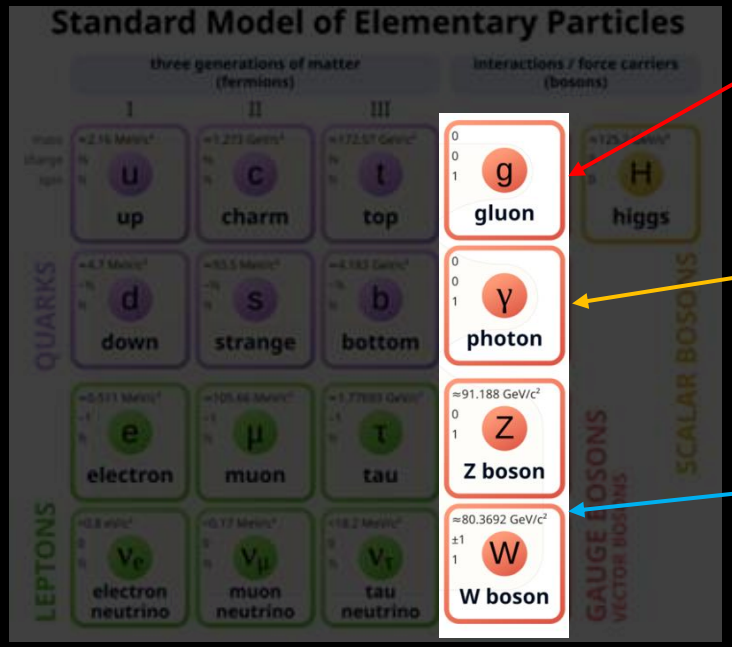
LLL [3]



The XENON experiment

Quantum Gravity

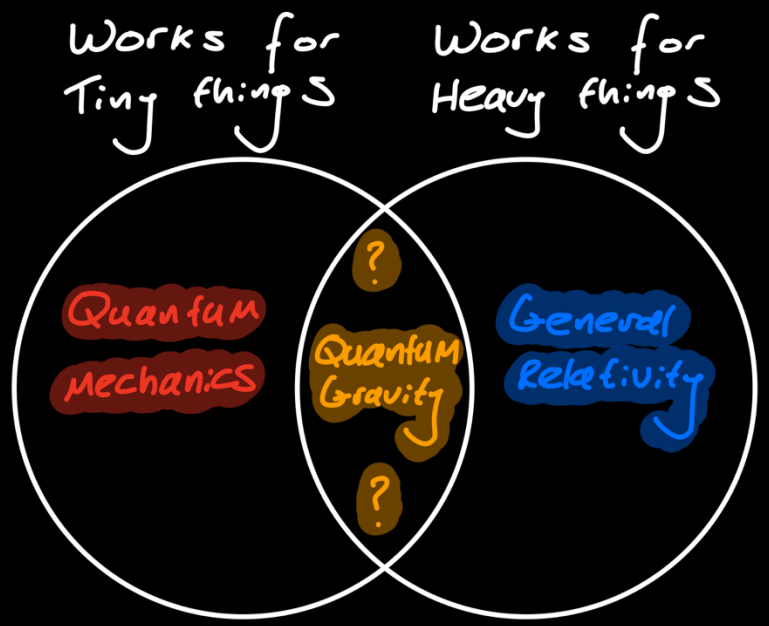




Gluons – *Strong Nuclear Force*

Photons - *Electromagnetic Force*

Z and W Bosons - *Weak Nuclear Force*



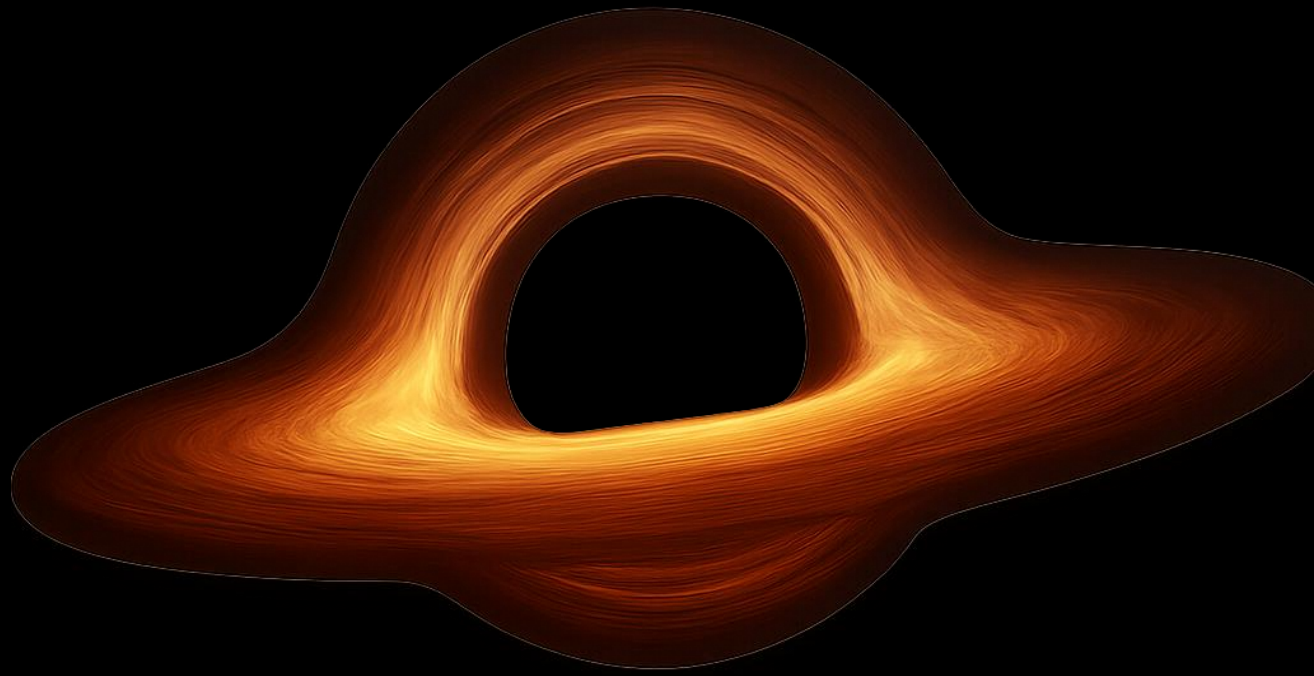
But what about Gravity?

Questions!

Coming Up…

The Science of Spacetime:
A Physicists Guide to the Galaxy

Every other Saturday 11:30am in the Beecroft Gallery Lecture Theatre



~~*Building a Universe from Scratch (06/06)*~~

Black Holes: Monsters of the Cosmos (20/06)

The Physics of Science Fiction: Tardises, Teleports, and beyond… (04/07)

“Not Even Wrong”: The Strangest Ideas in Theoretical Physics (18/07)

Spacetime Sundays

Southend's First Science Community Drop-in:

part office-hour, part lecture, part book club

Approximately every other Sunday 11am-12pm in the Beecroft Gallery Foyer

Upcoming dates:

14/06

28/06

19/07

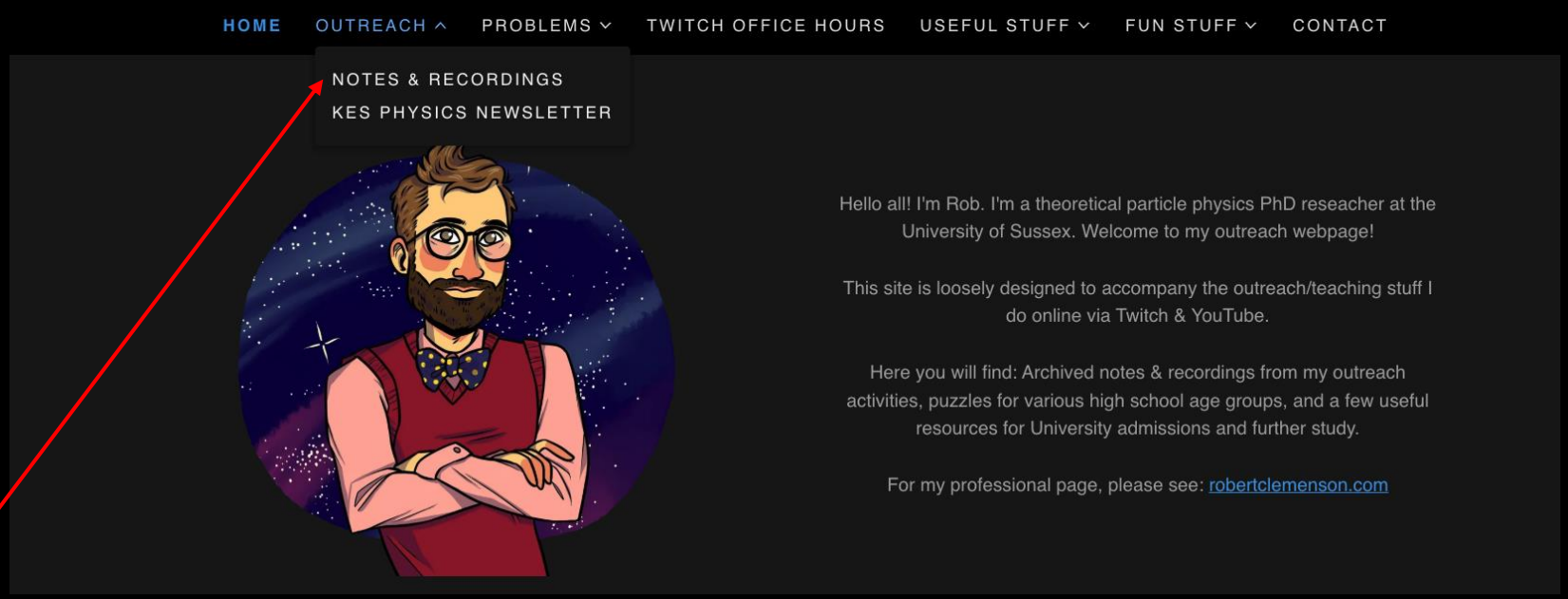
02/08

Join the Mailing List for Updates!

Visit:

Spacetime-Sundays.com

Lecture Slides



These lecture slides are available on my outreach website:

CosmicConundra.com