The Hidden Microscopic World of Particles

"Exploring the smallest building blocks of nature".

Scale of Matter

"How small can we really go?"

Magnifying Game

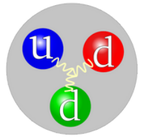
Cat

..... cm

Cell

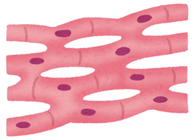
..... cm

Elementary Particles



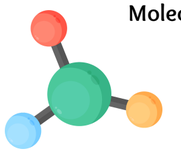
..... cm

Tissues



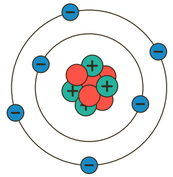
..... cm

Molecule



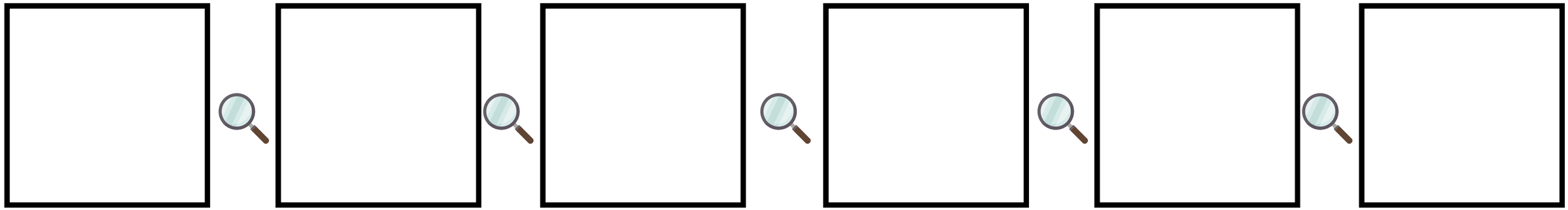
..... cm

Atom



..... cm

Value	Sl symbol	Name
10^{-1} m	dm	decimetre
10^{-2} m	cm	centimetre
10^{-3} m	mm	millimetre
10^{-6} m	μm	micrometre
10^{-9} m	nm	nanometre
10^{-12} m	pm	picometre
10^{-15} m	fm	femtometre
10^{-18} m	am	attometre
10^{-21} m	zm	zeptometre
10^{-24} m	ym	yoctometre



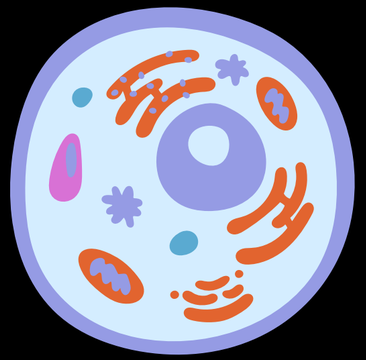
Classical Physics

CAT

30 cm

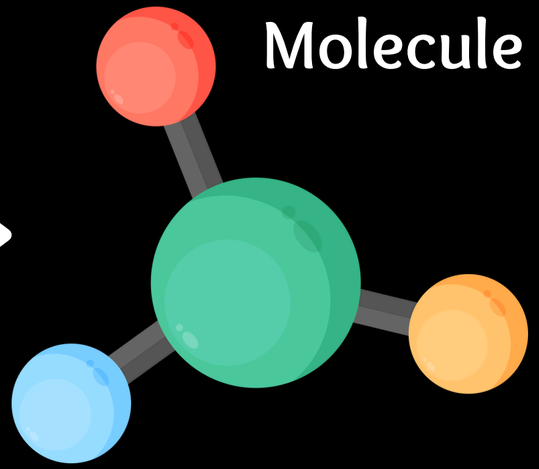
Tissues

30 um =
30 x 10^(-6) cm



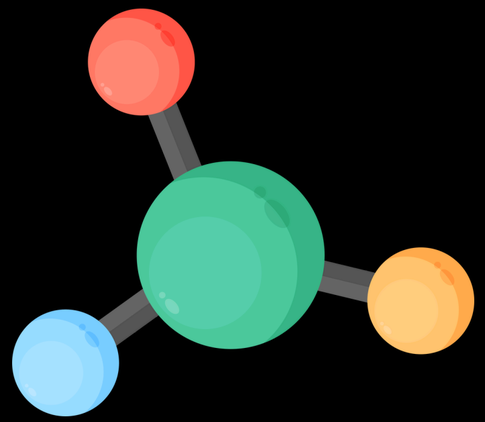
Cell

Molecule

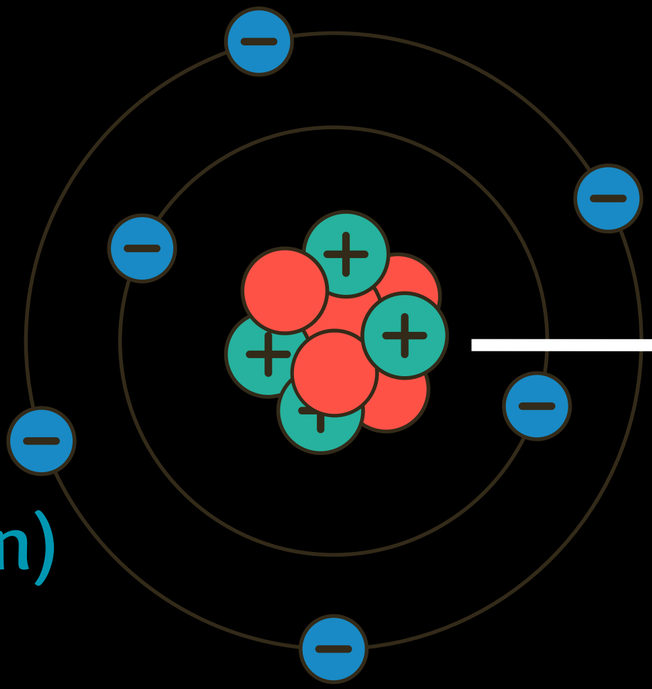


0.1 nm =
10^(-8) cm

Quantum Physics



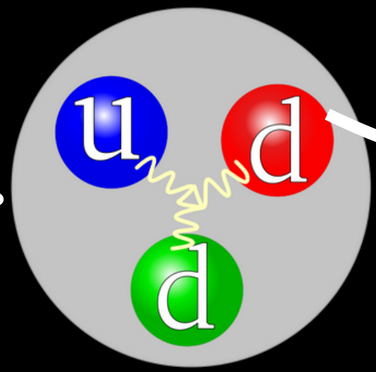
ATOM



1 fm (proton)
= 10^{-13} cm

<0.1 fm (proton) = 10^{-15}
cm

quarks



ELEMENTARY
PARTICLES

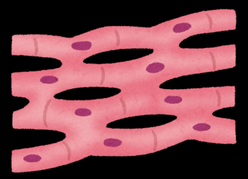
Scale of Matter

"How do we "see" something so small?"

Classical Physics → Quantum Physics

Cat

Tissues



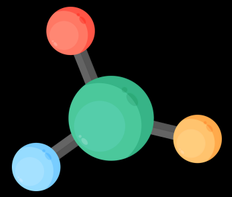
15 cm

Ruler

Screw Gauge

Cell

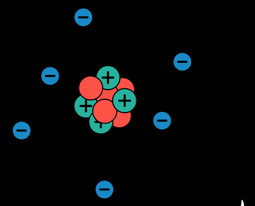
Molecule



50 cm

Microscope

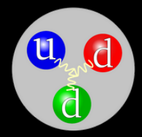
Atom



Electron Microscope

250 cm

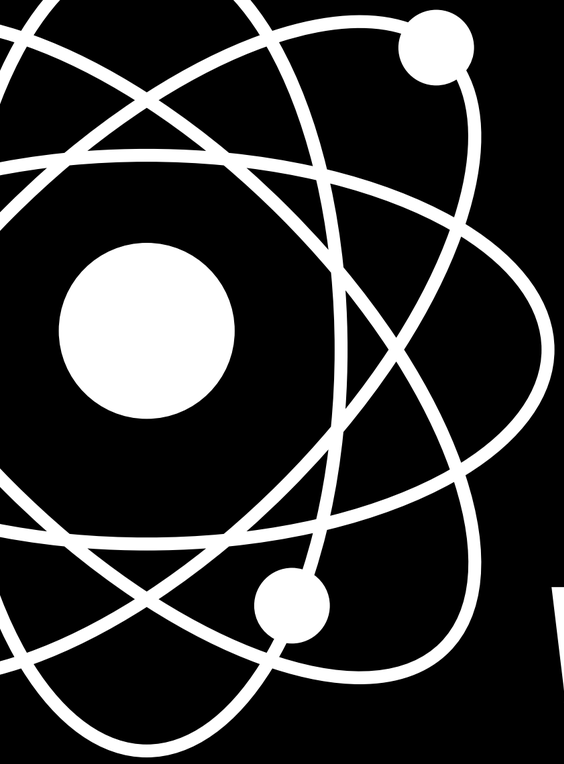
Elementary particles



Particle Accelerators

27 km

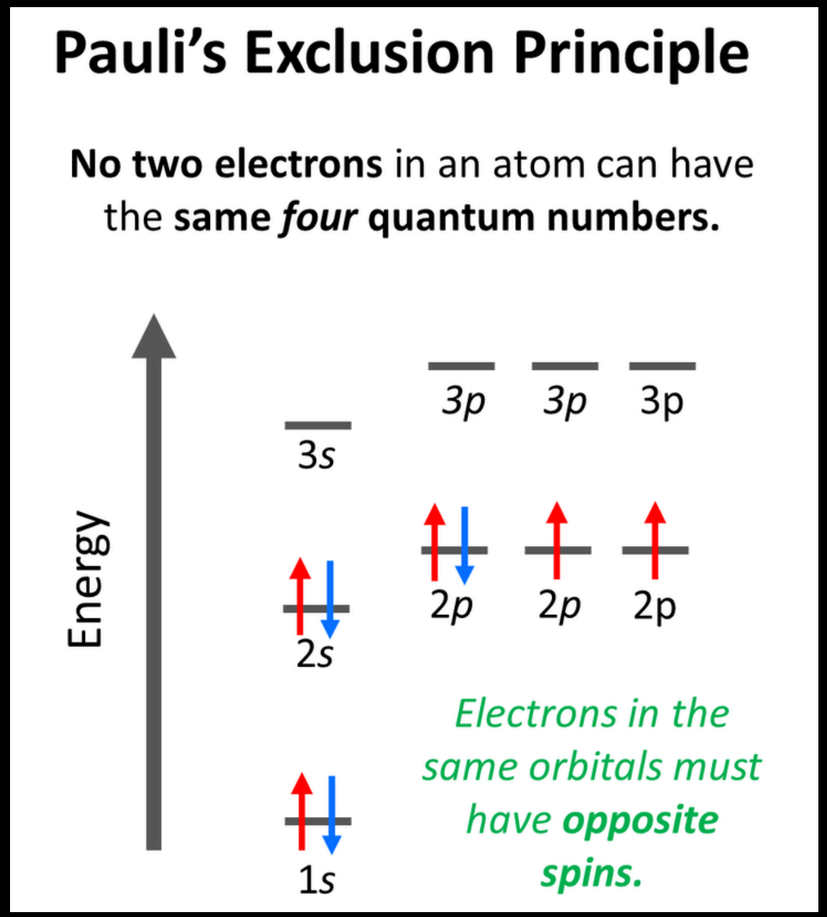
Detection

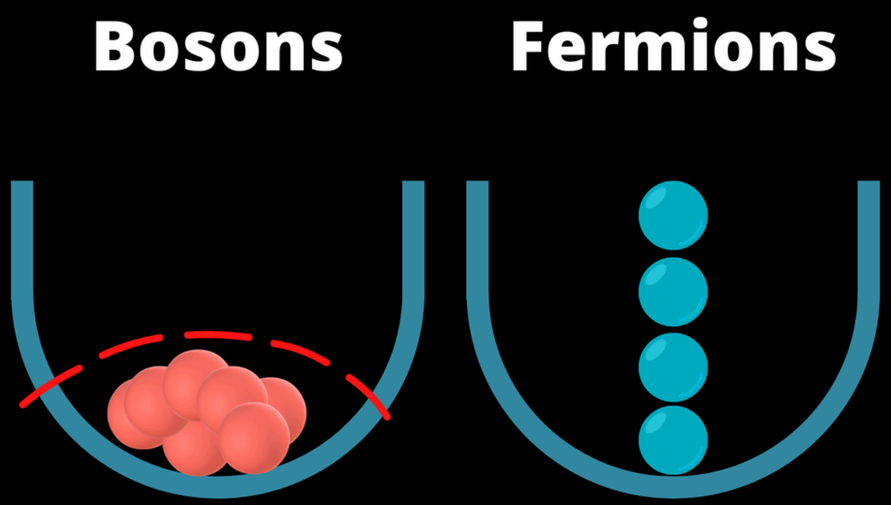


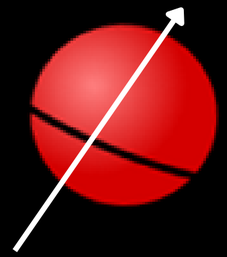
What is Particle Physics?

Particle physics is the field of science that studies the smallest building blocks of matter(Fermions) and the fundamental forces(Bosons) that govern their interactions.

Wolfgang Pauli



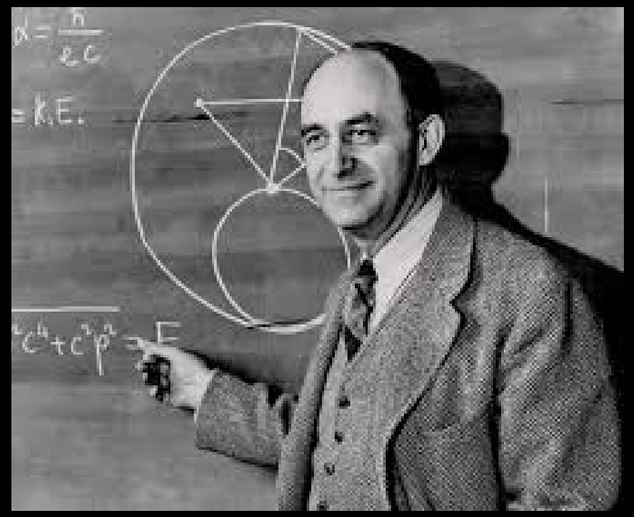




FERMION

Matter Particles

Makes up the matter in the universe



Spin – Half Integer values of spin

s= 1/2 , 3/2 ,5/2 .....

Enrico Fermi

$$|S_{electron}\rangle = \pm 1/2\ |\uparrow\rangle$$

BOSON

Force carriers / Exchange particles

Mediates interactions between fermions

Spin – Whole Integer values of spin

s=0 , 1 , 2 , 3.....

$$|S_{photon}\rangle = \pm 1\ |\downarrow\rangle$$

S. N. Bose

Quantum Numbers Game (Pauli Chairs)

You are electrons!

Lets place you in your position.

n = 0/1

l = -n,..,n

s = up/down

Pauli's Rules:

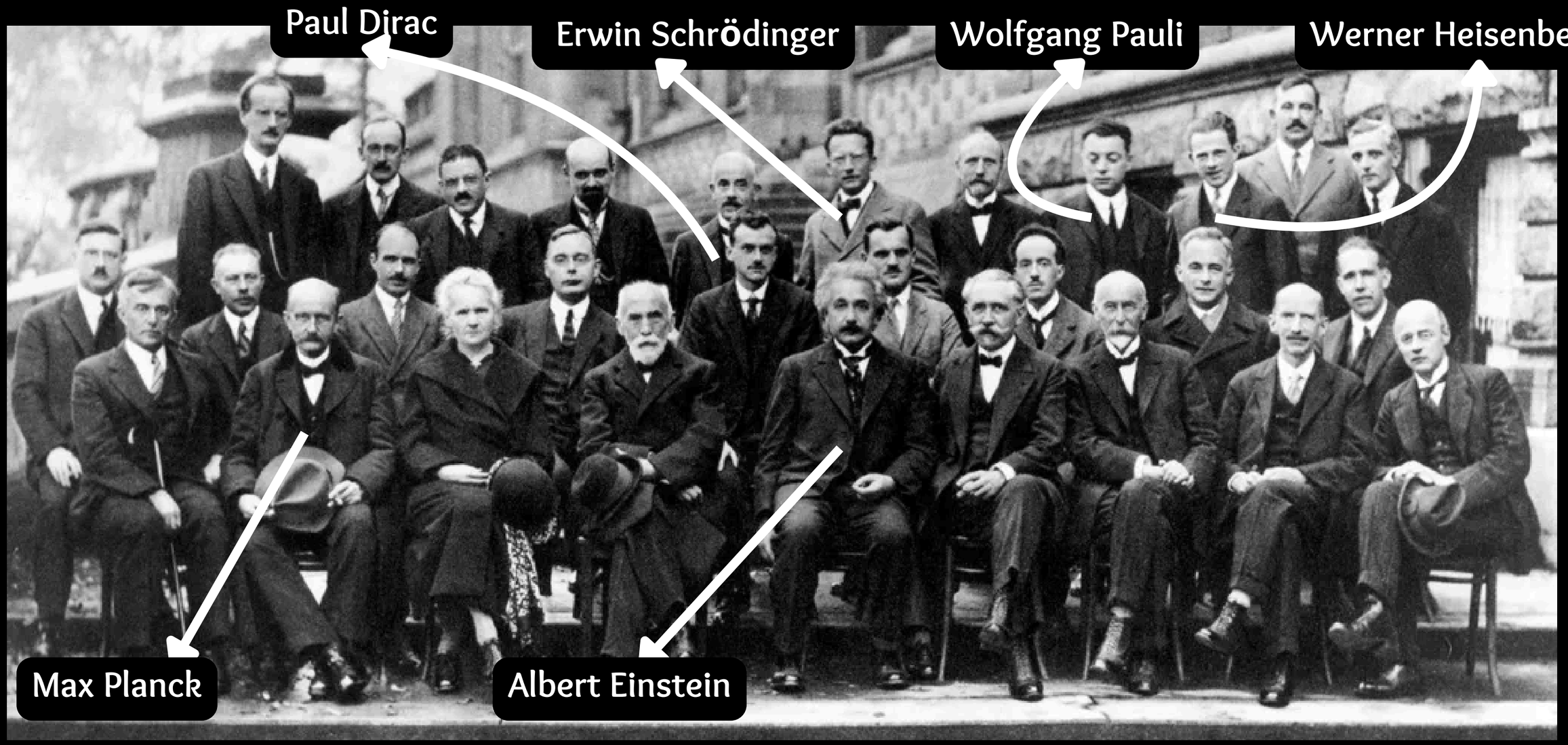
1. lowest number sits first
2. MOST IMP! No two identical numbers sit together

Quantum Mechanics

"How do physics laws behave at the microscopic scale?"

Founders of Quantum Mechanics

"Who were the first ones to discover the microscopic universe and it's physics?"



1927 in Brussels

Founders of Quantum Mechanics

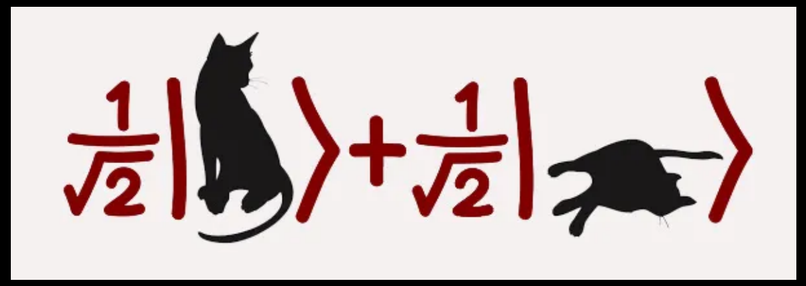
Schrödinger's Cat

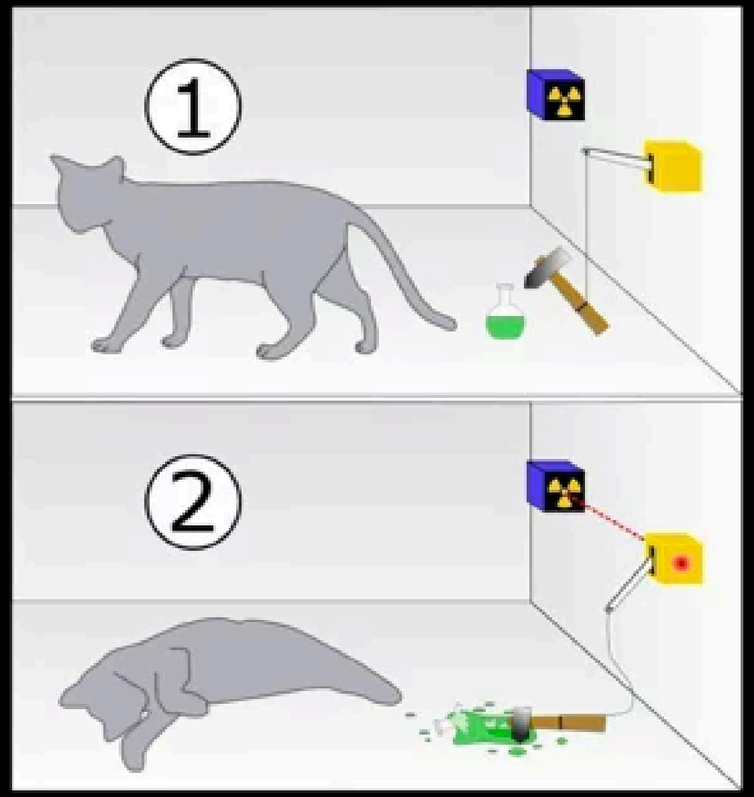
"Can something be alive and dead at the same time?"

SCHRÖDINGER CAT

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|alive\rangle + |dead\rangle\right)$$

Erwin Schrödinger





Superposition

Quantum Mechanics

"Why can't we predict exactly what happens in the quantum world?"
and "How do we identify the particles?"

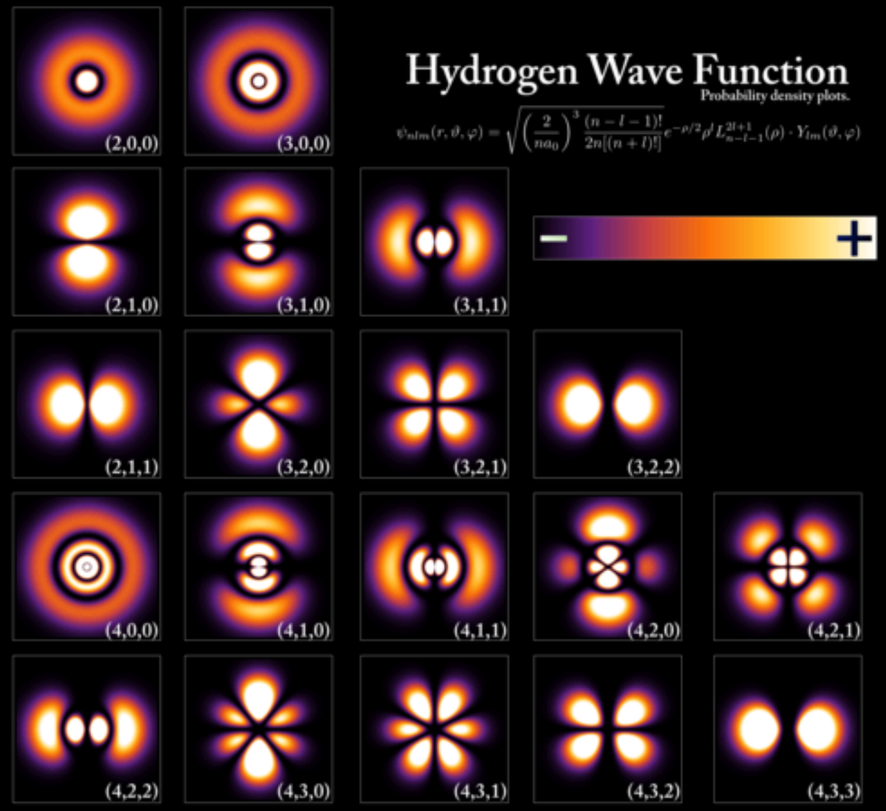
Probabilistic Nature

$$|\psi\rangle = a\,|\uparrow\rangle + b\,|\downarrow\rangle$$

superposition

$$P|\uparrow\rangle = |a|^2,\ P|\downarrow\rangle = |b|^2$$

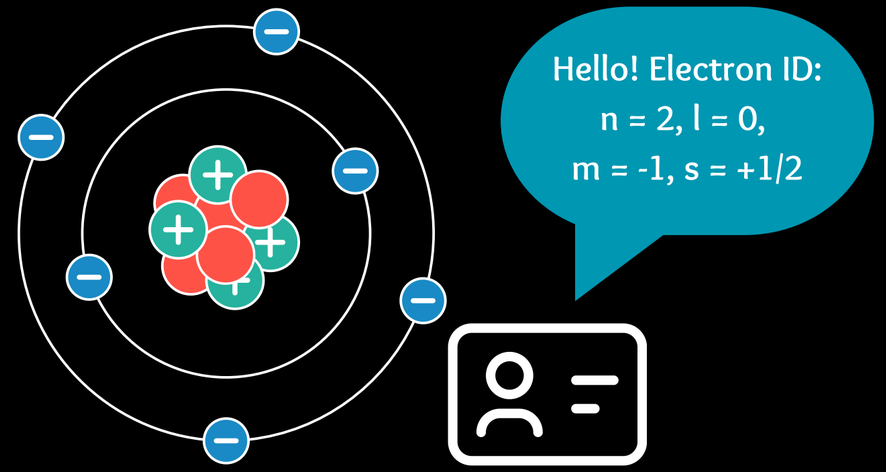
$$|a|^2 + |b|^2 = 1$$



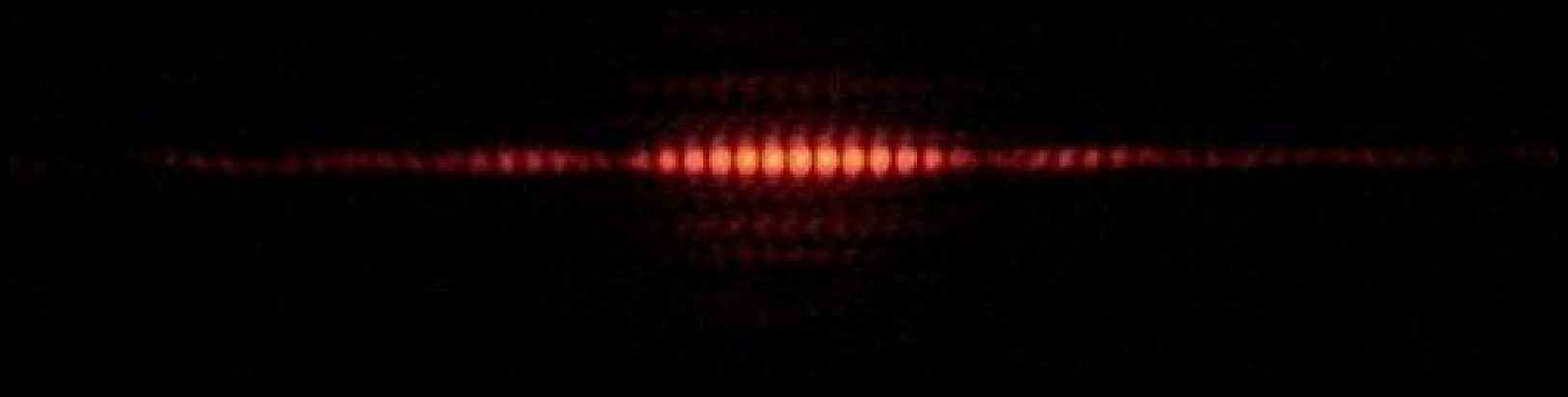
Quantum Numbers (Particle ID card)

- Energy level (n)
- Angular momentum (l)
- Magnetic number (m)
- Spin (s)

Number	Symbol	Possible Values
Principal Quantum Number	n	$1, 2, 3, 4, \ldots$
Angular Momentum Quantum Number	ℓ	$0, 1, 2, 3, \ldots, (n-1)$
Magnetic Quantum Number	m_l	$-\ell, \ldots, -1, 0, 1, \ldots, \ell$
Spin Quantum Number	m_s	$+1/2, -1/2$



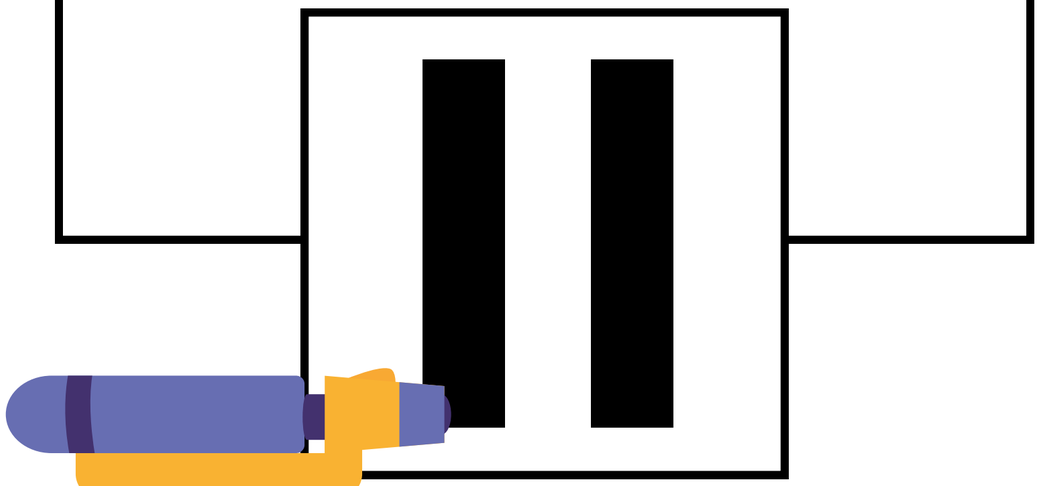
Double Slit Experiment & Wave–Particle Duality



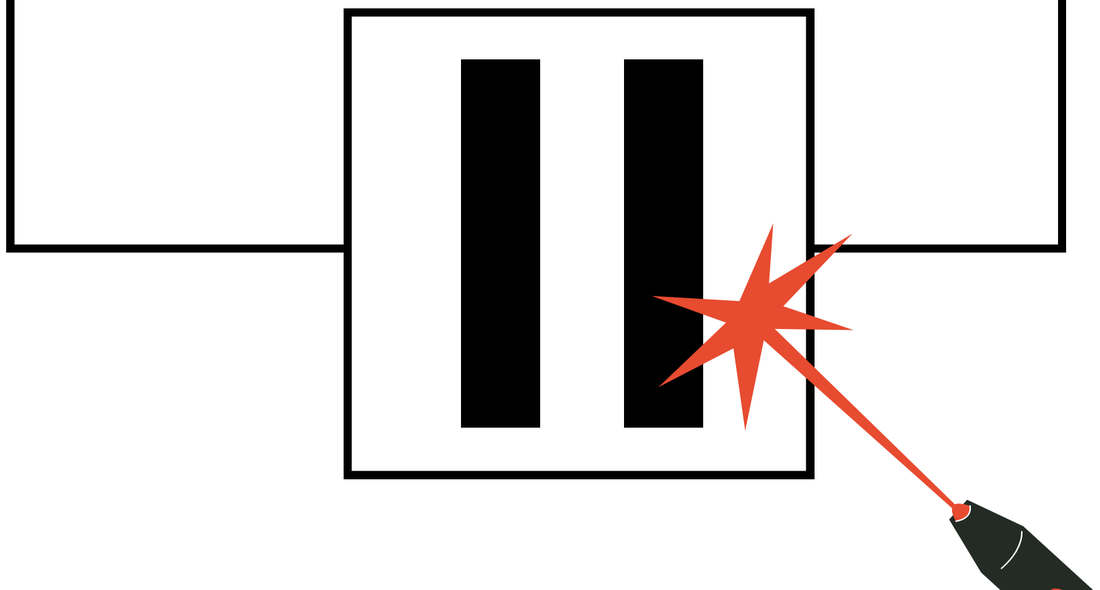
“What happens if you shoot tiny particles through two slits?”

DOUBLE SLIT EXPERIMENT

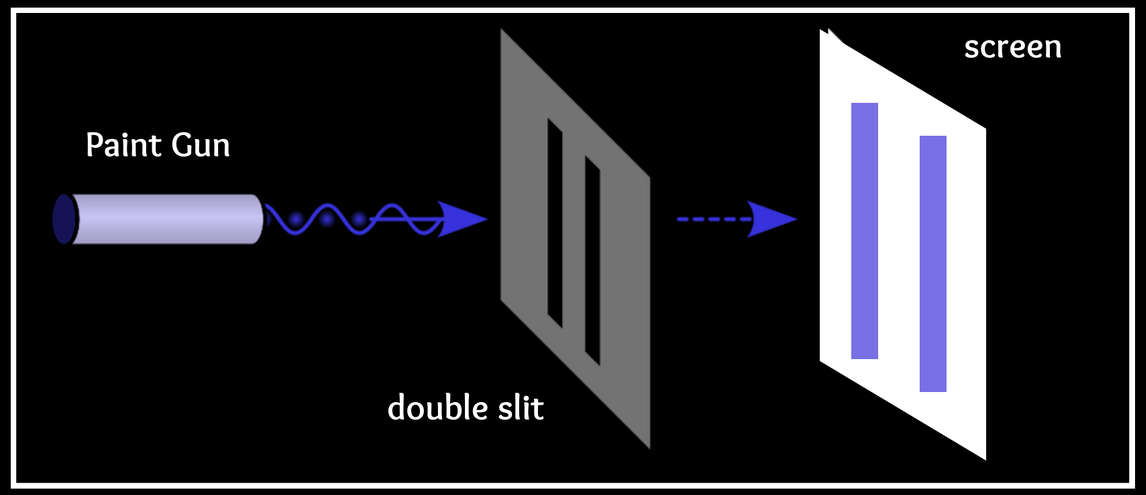
Draw what happens
with a paint gun

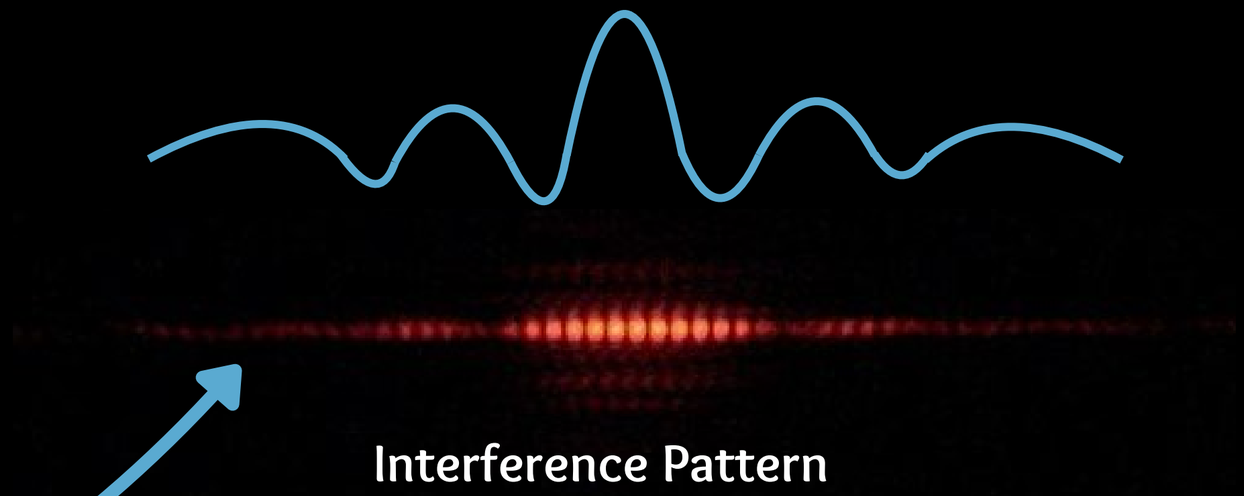


Draw what happens
with laser

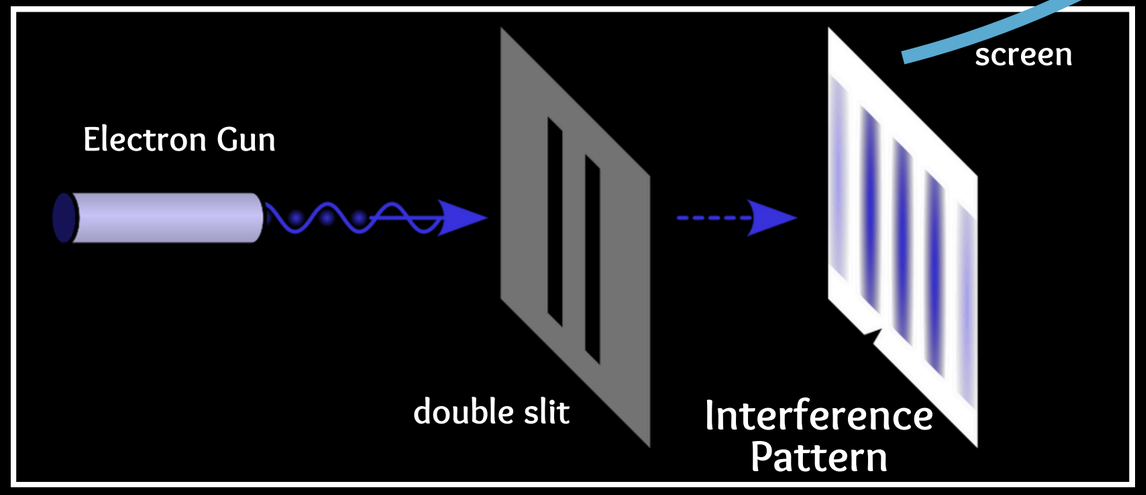


Classical Physics: Double Slit Experiment



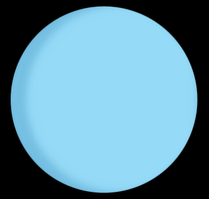


Interference Pattern



Double Slit Experiment (Quantum)

Fundamental Particles (Photon, electron) act as particles and waves.



Heisenberg Uncertainty Principle

"Why can't we know everything about a particle at once?"

HEISENBERG'S UNCERTAINTIY PRINCIPLE

Momentum

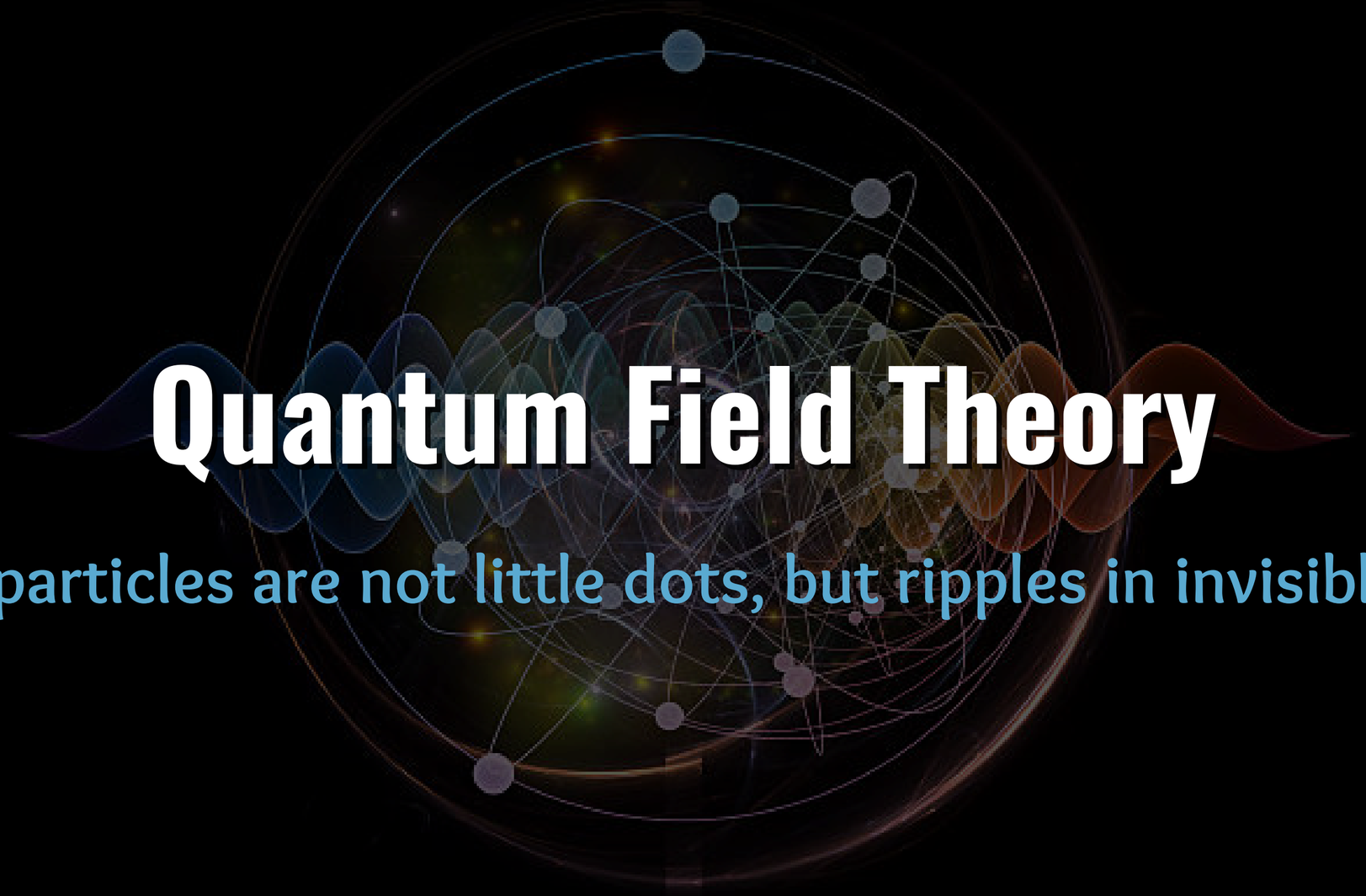
Position

$$\Delta x \cdot \Delta p \geqslant h/4\pi$$

$$\Delta E \cdot \Delta t \geqslant h/4\pi$$

the more accurately we know the position of a particle,
the less accurately we know the momentum

Werner Heisenberg



Quantum Field Theory

"What if particles are not little dots, but ripples in invisible fields?"

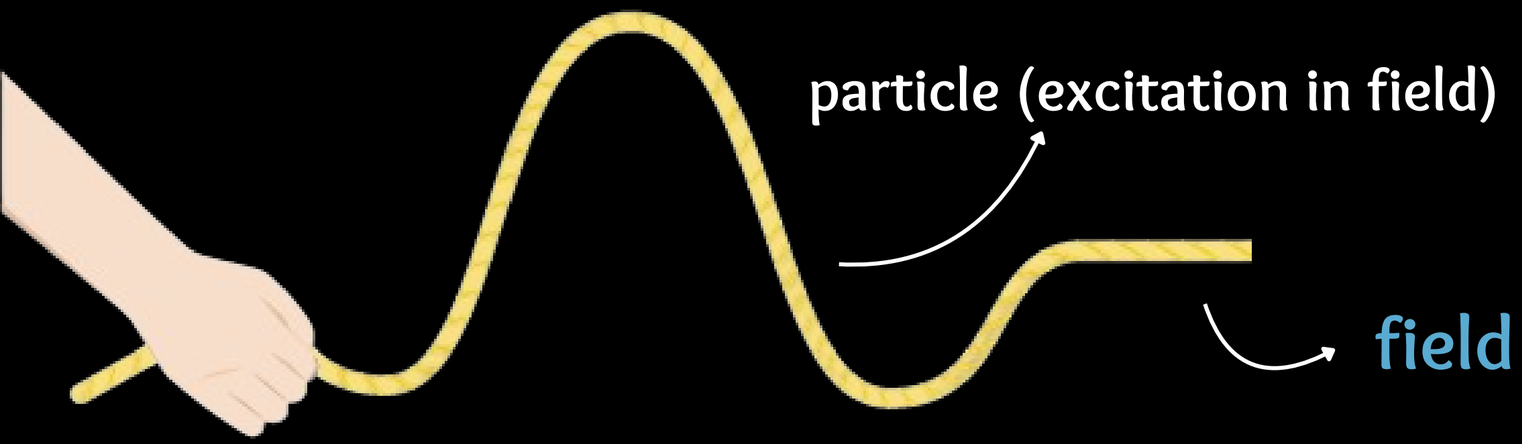
Particles and Ladder Operators

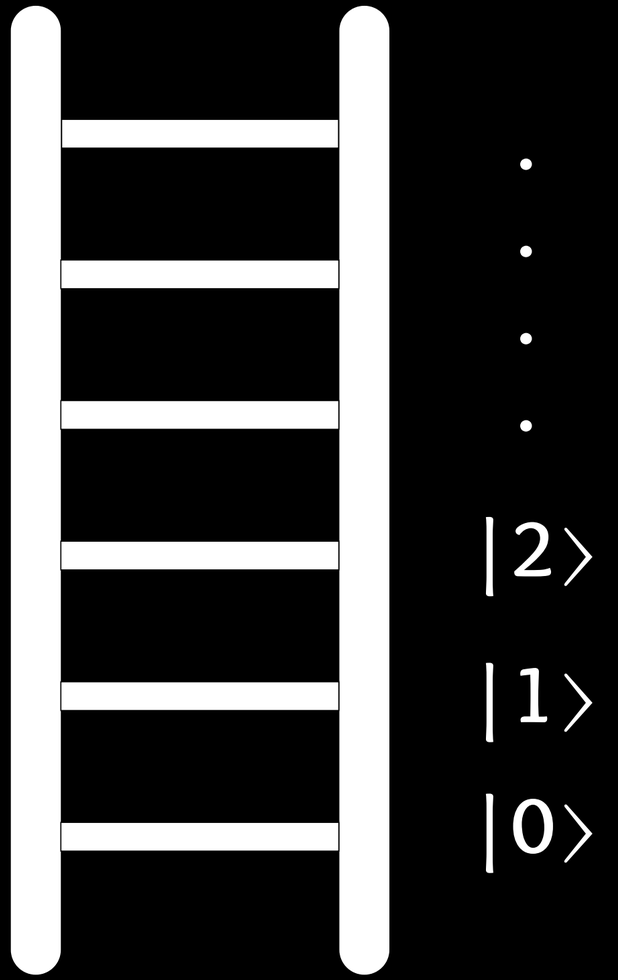
$$a^\dagger|n\rangle = \sqrt{n+1}\,|n+1\rangle$$

$$a|n\rangle = \sqrt{n}\,|n-1\rangle$$

QUANTUM FIELD THEORY (QFT)

Every fundamental particle has a field, & particles are excited states / quanta of their fields.





Quantum fields have energy levels

Ladder Operators:

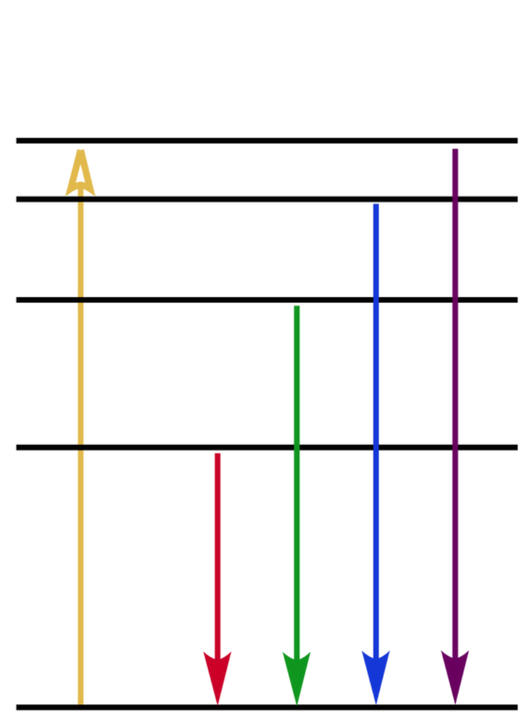
- $a^\dagger$ (creation operator) → adds a particle
- a (annihilation operator) → removes a particle

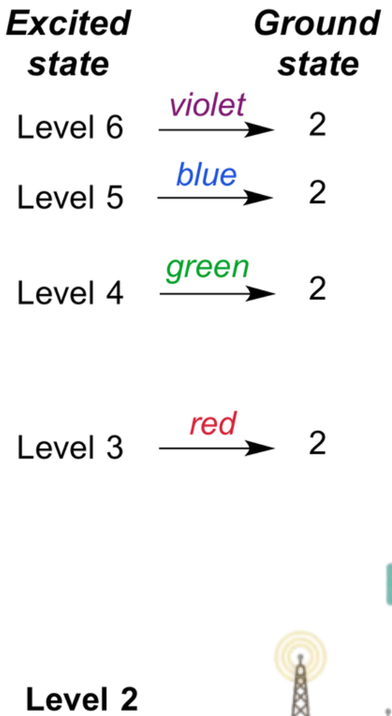
Photon and Colours

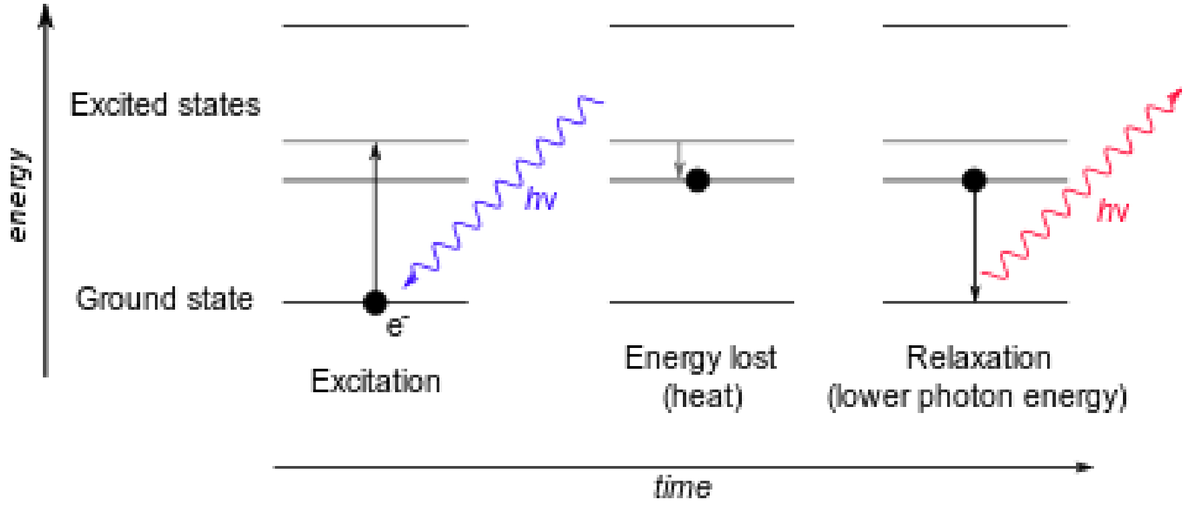
"How do we see colours in objects"

COLOUR!

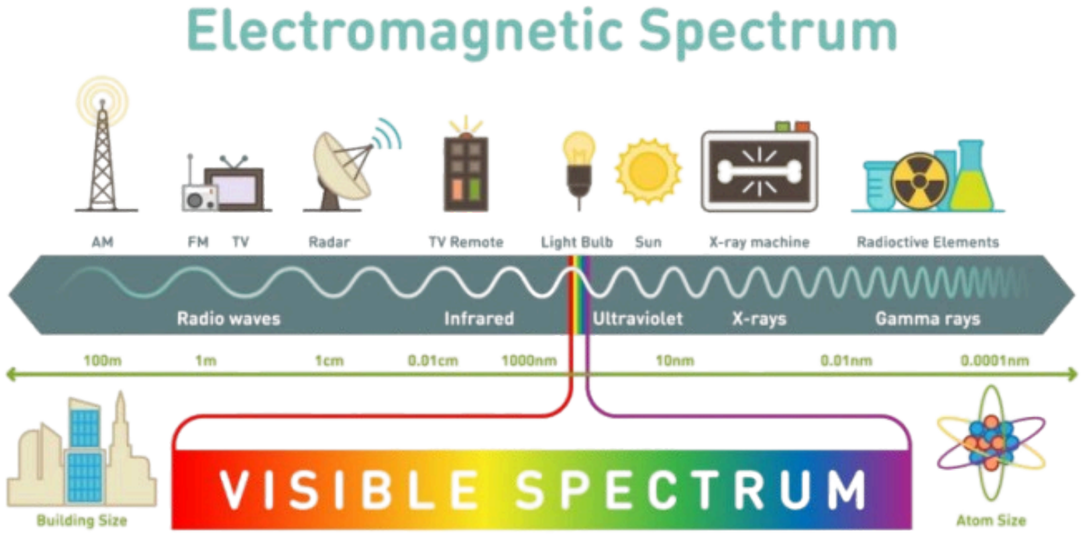
$E = h\nu = hc/\lambda$

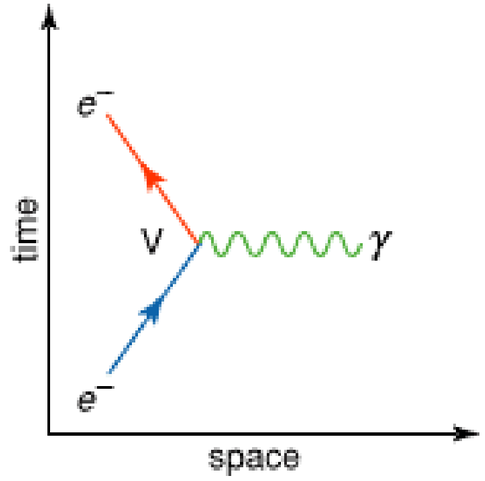






$e^- \longrightarrow e^- + \gamma$





The Standard Model of Particle Physics

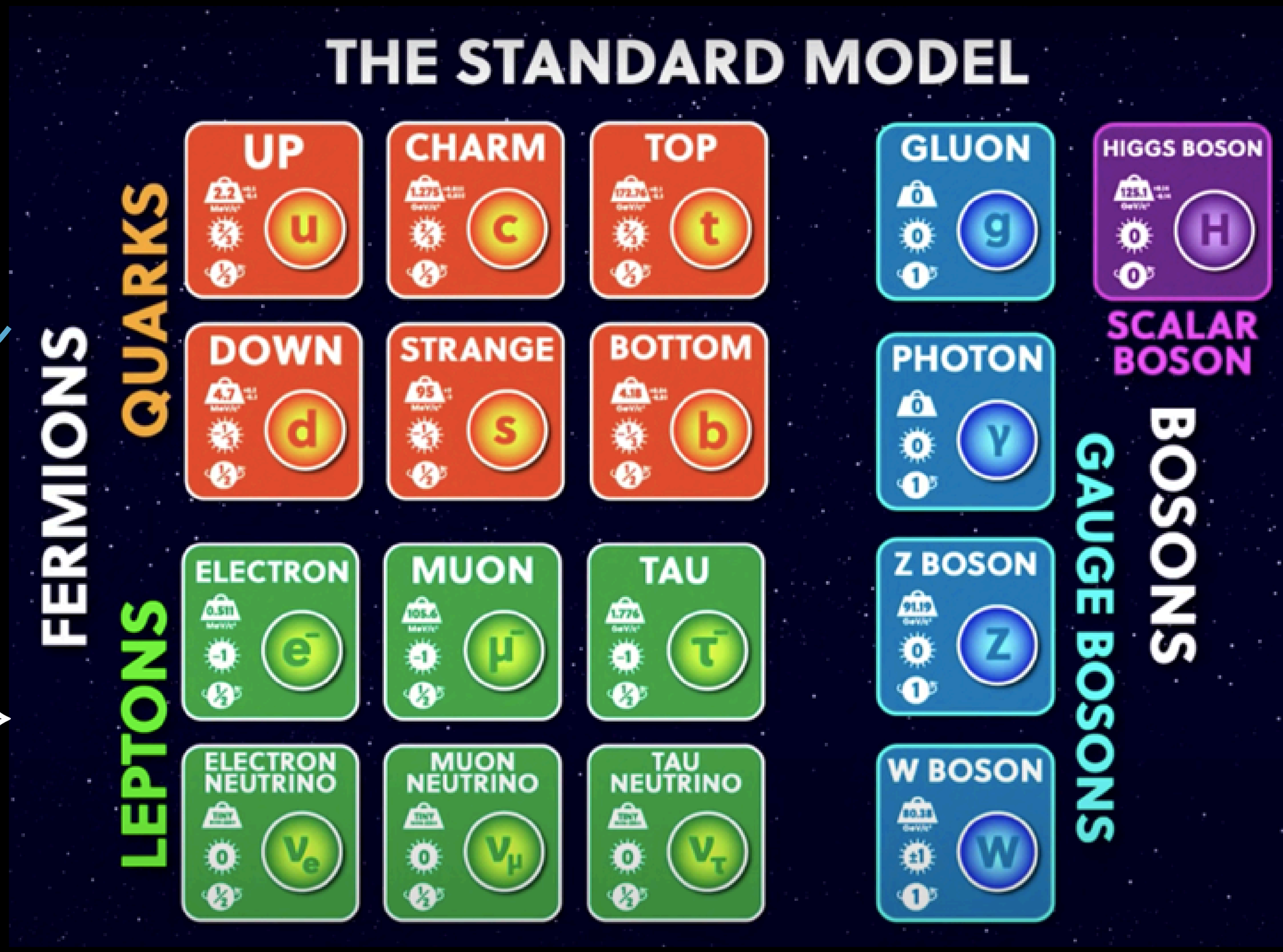
"If everything is made of particles, what's the periodic table of the universe?"

For every matter particle, there is an antiparticle ($\bar{q}$) that exists with opposite charge

HADRONS

MESONS
Quark + Antiquark
($q\bar{q}$)

BARYONS
3 QUARKS(qqq)



Let's Build Hadrons!

CHARGES ADD UP

MESONS ($q\bar{q}$)

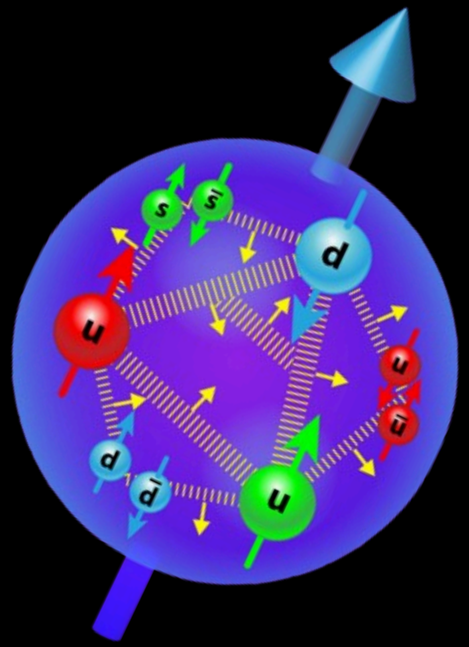
Recipe : Quark + Antiquark

Symbol	Name	Quark Content	Charge
π^+	pion	$u\,\bar{d}$	+1
π^0	pion	$u\,\bar{u} + d\,\bar{d}$	0
K^-	kaon	$s\,\bar{u}$	-1

HADRONS(qqq)

Recipe : 3 QUARKS

Symbol	Name	Quark Content	Chg
p	proton	uud	+1
$\bar{p}$	antiproton	$\bar{u}\,\bar{u}\,\bar{d}$	-1
n	neutron	udd	0



Forces of Natures

“What holds the universe together? Could atoms fall apart?”

Fundamental Forces of Nature

QUANTUM FIELD THEORY (QFT)

Every fundamental particle has a field, & particles are excited states / quanta of their fields. Forces are carried by fields, hence bosons are called force carriers.

Forces of Nature:

1. EM Force
2. Weak Force
3. Strong Force
4. Gravity

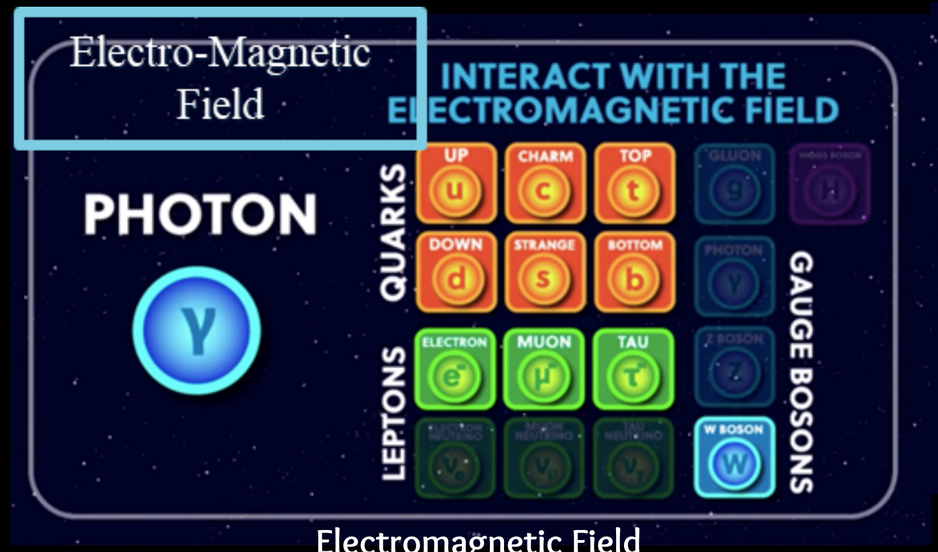
(Not explained by SM)

Higgs Field Interaction

Responsible for giving mass to the fundamental particles

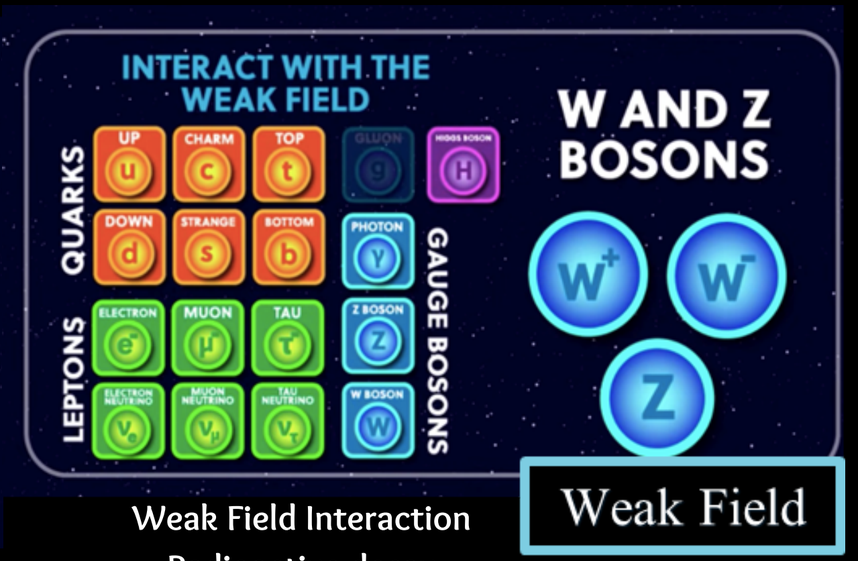
Strong Field Interaction

Glues the quarks together



Electromagnetic Field

Interacts with particles with charge. Don't interact with themselves



Weak Field Interaction

Radioactive decay

Place the Particles

TYPE	FERMION	FORCE	BOSON
Quarks		Electro-Magnetic Force(EMF)	
		Strong Force	
Leptons		Weak Force	
		Higgs Mechanism	

PHOTON

GLUON

ELECTRON - NEUTRINO

DOWN QUARK

W BOSON

HIGGS BOSON

UP QUARK

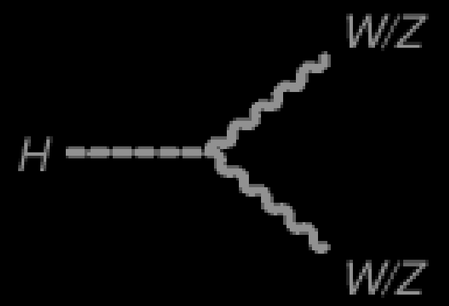
ELECTRON

The Standard Model of Particle Physics: Higgs Mechanism

"Why do particles have mass at all? Why isn't everything like light?"

The Higgs Mechanicsm

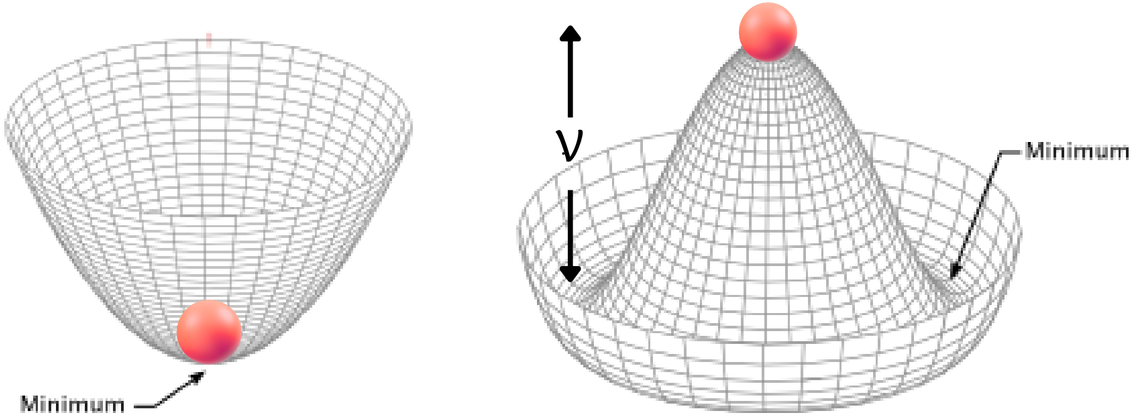
Higgs gives mass to fundamental particles



$$\Phi = \begin{pmatrix} \varphi^{+} \\ \varphi^{0} \end{pmatrix} \quad \nu + H$$

$$m_{photon} = 0$$

Spontaneous Symmetry Breaking

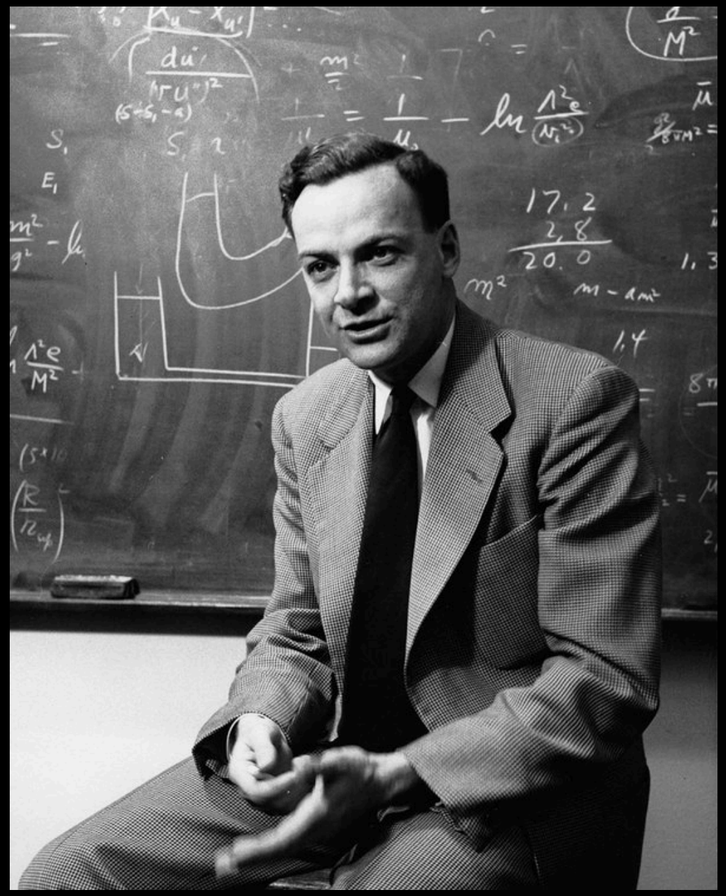


Higgs Potential

The Standard Model of Particle Physics: Feynman Diagrams

"Why are physicists drawing diagrams for particle physics"

Feynman Diagrams



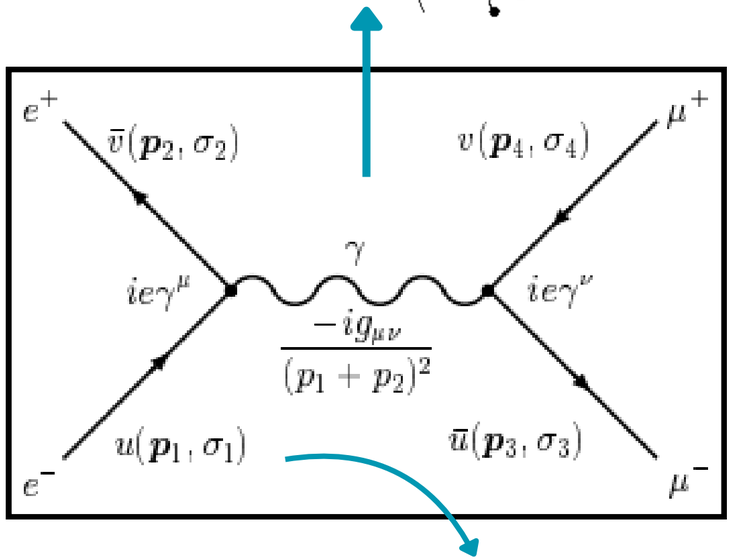
Richard Feynman

EXTERNAL LINES

spin 1/2 fermion (in,out) — u $\bar{u}$

spin 1/2 antifermion (in,out) — $\bar{v}$ v

spin 1 photon (in,out) — ε_μ ε_μ^*



Feynman Rules

INTERNAL LINES (PROPAGATORS)

spin 1/2 fermion — $\frac{i(\not{p}+m)}{p^2-m^2}$

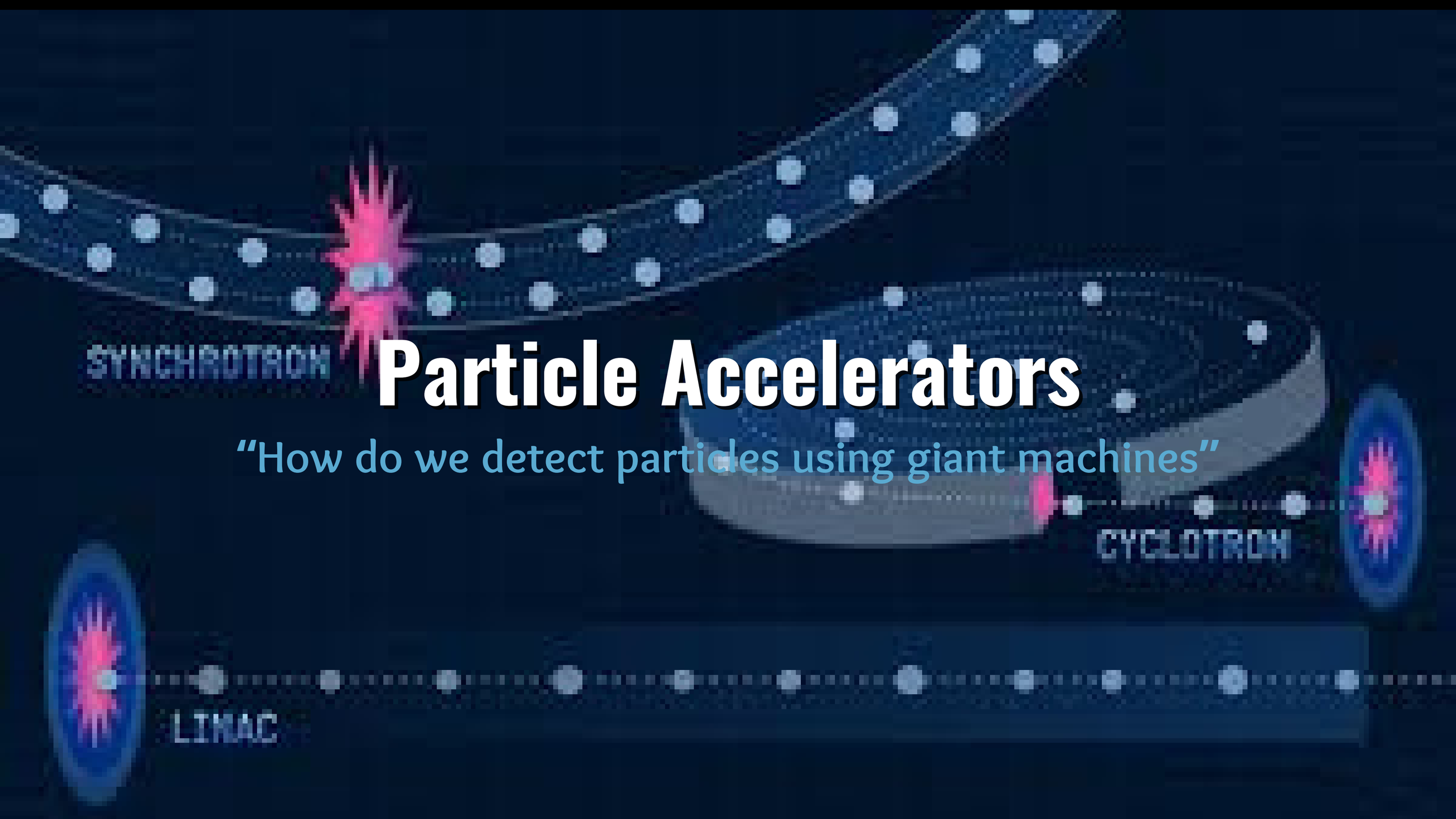
Massive spin 1 boson — $\frac{-i(g_{\mu\nu}-p_\mu p_\nu/M^2)}{p^2-M^2}$

massless spin 1 photon — $\frac{-ig_{\mu\nu}}{p^2}$

VERTEX FACTORS

spin 1/2 (–e) – photon — $ie\gamma^\mu$

$$-i\mathcal{M} = [\bar{u}(\boldsymbol{p}_3, \sigma_3)(ie\gamma^\nu)v(\boldsymbol{p}_4, \sigma_4)] \frac{-ig_{\mu\nu}}{(p_1+p_2)^2} [\bar{v}(\boldsymbol{p}_2, \sigma_2)(ie\gamma^\mu)u(\boldsymbol{p}_1, \sigma_1)]$$



Particle Accelerators

"How do we detect particles using giant machines"

PARTICLE ACCELERATORS AND THEIR WORKING

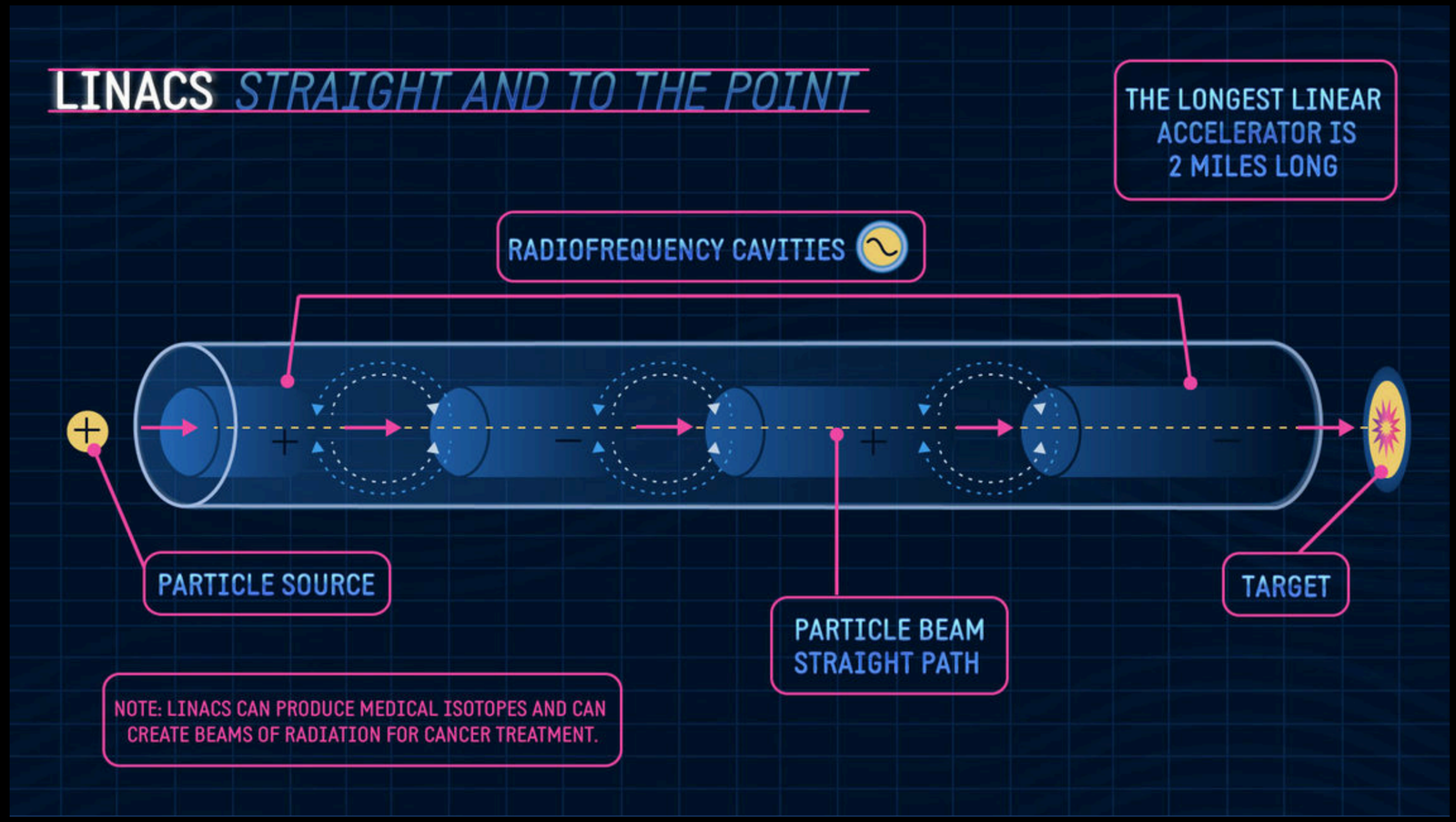
Particle acceleration uses electric & magnetic fields to speed up charged particles.

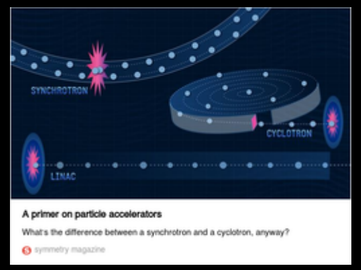
Lorentz force:

$$F = qE + q(v \times B)$$

Longitudinal Dynamics Acceleration

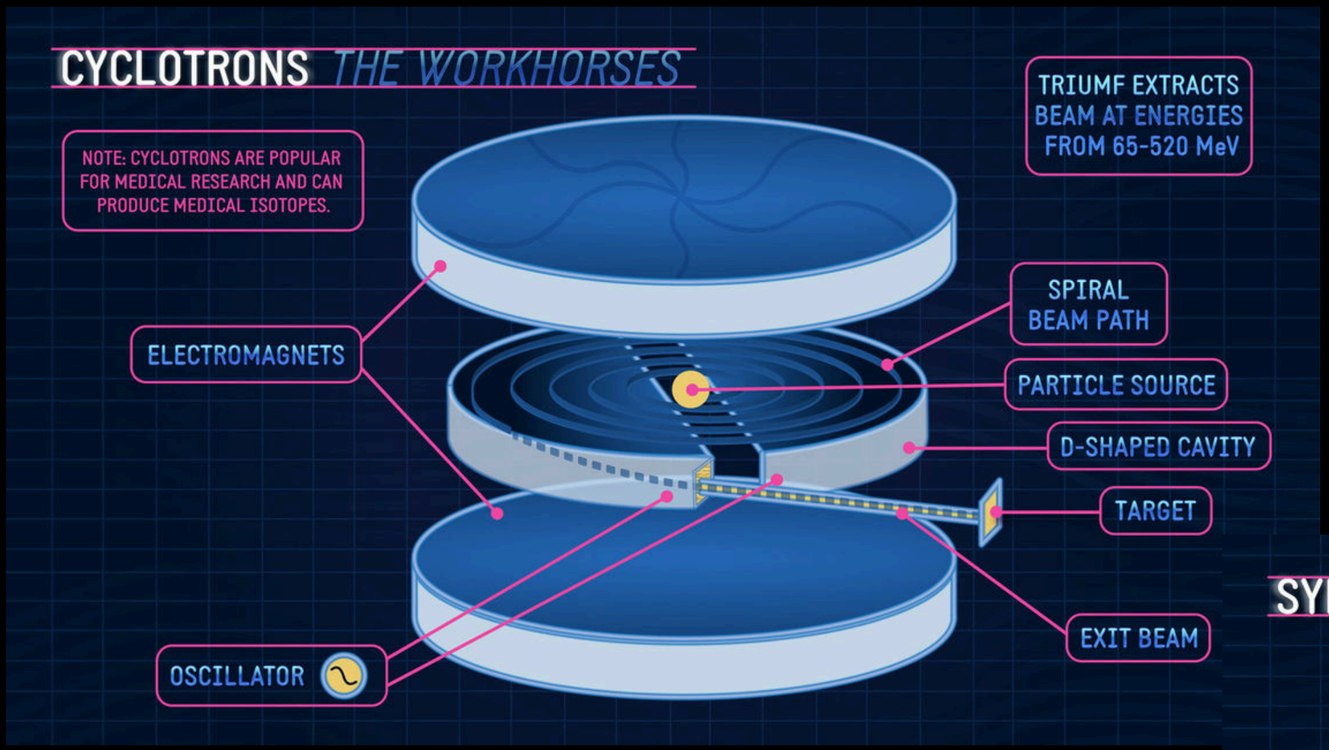
Transverse Dynamics Bending & Focusing





Linear accelerators (LINACs): particles move in a straight line

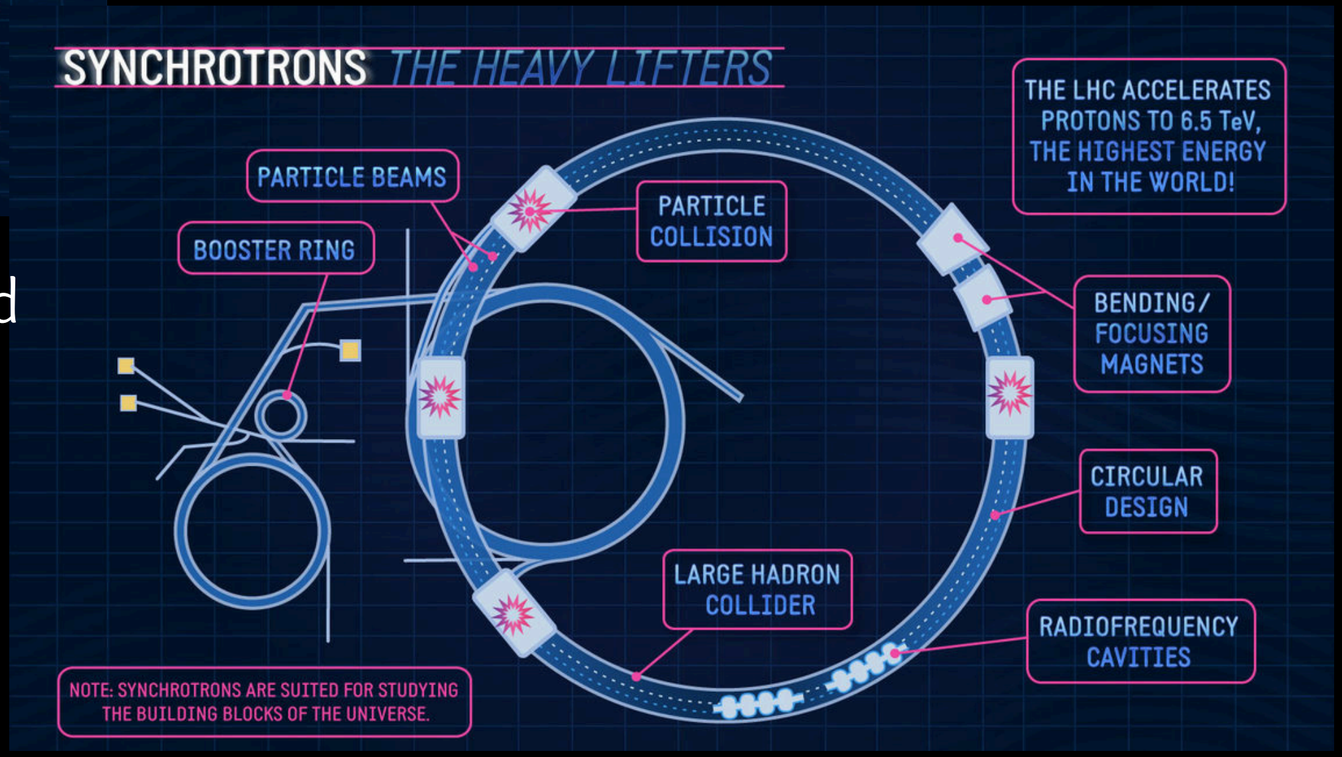
PARTICLE ACCELERATORS



Cyclotron: spiral motion in a magnetic field

LHC: world's most powerful synchrotron (27 km ring)

Synchrotron: circular path with varying magnetic field



Why study Particle Physics?

"Why do we spend billions smashing particles?"

THANK YOU FOR YOUR ATTENTION