

# Introduction to Particle Physics

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SWEDISH PHYSICS TEACHERS 2023

# Handout 1

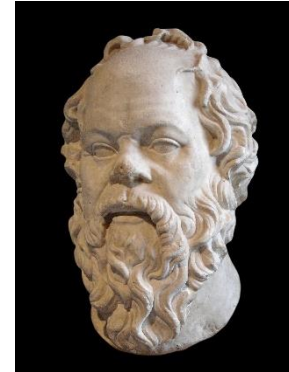
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- Particles and Interactions
- Glimpses on the Standard Model
- Quarks and Particle spectroscopy

Credits to:

C. Grosjean and D. Tong: <https://indico.cern.ch/event/1254879/timetable/>

# SOCRATE, (470-399 B.c.) (PLATO, *APOLOGY*)



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<https://commons.wikimedia.org/w/index.php?curid=96296061>

[So di non sapere – Wikipedia](#)

«So di non sapere»

(consapevolezza della propria ignoranza)

<https://en.wikipedia.org/wiki/Socrates>

Socrates, aware of his own lack of knowledge, professes his own ignorance...and me as well!

# Introduction

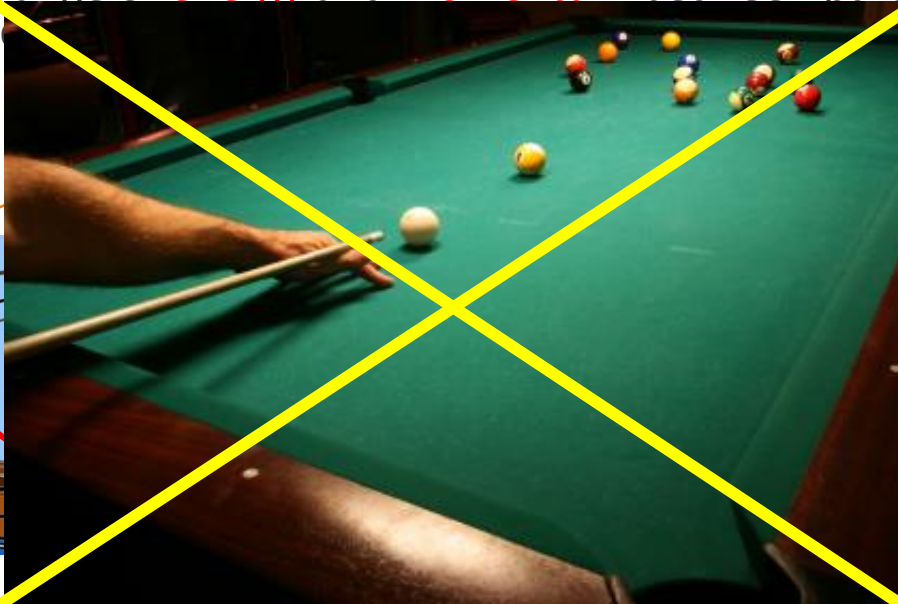
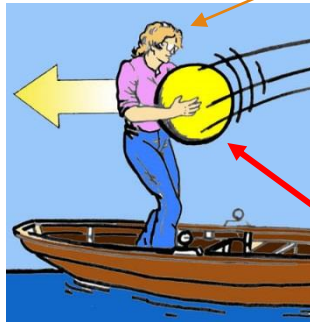
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- Particle Physics: study of **fundamental particles** and **interactions** of the “subnuclear world”
- And what about dark matter and dark energy?



# Metaphors of Fundamental interactions:

**Interaction:** exchange of **energy** and **momentum** between particles, or the possibility of cr



Repulsive force

Vector Bosons

Attractive force

# Particles and Interactions

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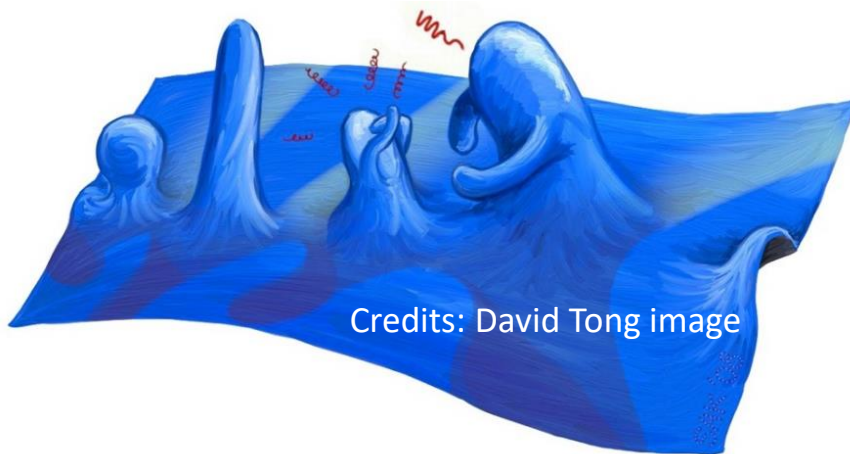
- Classically, a **field** is a mat. function of space-time which values are known all over a given space (e.g.: temperature field ( $T = \phi(x, y, z, t)$ ));
- Particles are **quantum fields** permeating all the universe. Its value is zero almost everywhere **except** where the particle is located.
- The **ripple of the quantum field** is the quanta of the field, that means **the particle!**
  - e-field
  - q's fields
  - $\nu$ 's fields

# Particles and Interactions

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- Interactions as well are described as quantum fields permeating all the universe;
- The ripple of the quantum field is its quanta, that means the **particle mediating the interaction (aka vector bosons)**!
  - **photon-field** mediates the E.M. interaction
  - **8 gluon-fields** mediate the Strong Interaction
  - **2  $W$ 's and  $Z^0$  fields** mediate the Weak interaction

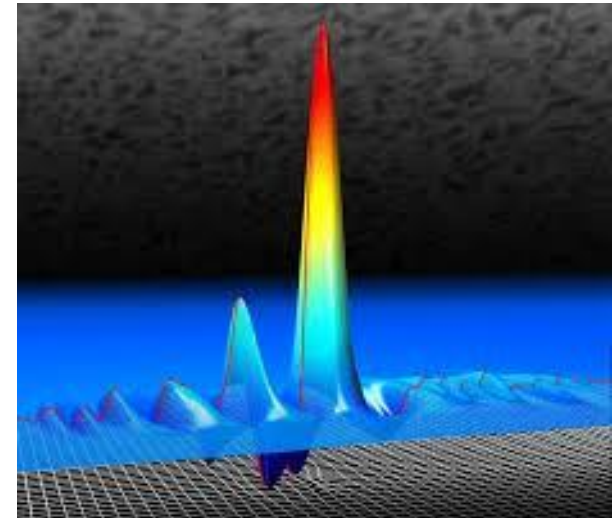
# Pictorial view of a quantum field



Credits: David Tong image

**Particle and Field:** in 1924, L. de Broglie proposed that a particle of energy  $E$  and momentum  $p$ , has an associated **matter field** with **frequency  $\nu = E/h$**  and **wavelength  $\lambda = h/p$** .

...just to figure out the ripple...



<https://www.google.com/>... See the note

Wave-particle duality!



Heisenberg's uncertainty principle

$$\Delta E \Delta t \geq h \quad \text{and} \quad \Delta x \Delta p \geq h$$

Quantum Mechanics!!

- Quantized values of Energy;
- interaction radiation-matter via the photon;
- .....



# Glimpses on the Standard Model

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## THE STANDARD MODEL OF PARTICLE PHYSICS (SM)

-It is a mathematical framework for a unified description of three interactions:

- The Electromagnetic interaction,
- The Weak Interaction (particle decay, radioactivity),
- The Strong Interaction (interaction binding quarks),

-Plus, the Higgs field (providing the mass to the particles).

-The SM is based on Quantum Field Theory.



# Glimpse on Quantum Field Theory

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- QFT = QM+ quantum Fields = Quantum Field Theory
- QM = **Quantum Mechanics**, incorporating the Special Relativity, predicts the existence of the anti-matter: Dirac equation;
- Quantum Fields = **mathematical functions** describing particles and interactions.















# Fundamental Interactions

## PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic	Strong	
				Fundamental	Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	$W^+$ $W^-$ $Z^0$	$\gamma$	Gluons	Mesons
Strength relative to electromag for two u quarks at:	$10^{-41}$	0.8	1	25	Not applicable to quarks
for two protons in nucleus	$10^{-41}$	$10^{-4}$	1	60	
	$10^{-36}$	$10^{-7}$	1	Not applicable to hadrons	

# Keystones of the Standard Model

## Matter fields (aka fermions)

three generations of matter (fermions)			
	I	II	III
mass	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
QUARKS	 <b>u</b> up	 <b>c</b> charm	 <b>t</b> top
	 <b>d</b> down	 <b>s</b> strange	 <b>b</b> bottom
	 <b>e</b> electron	 $\mu$ muon	 $\tau$ tau
LEPTONS	 $\nu_e$ electron neutrino	 $\nu_\mu$ muon neutrino	 $\nu_\tau$ tau neutrino

- Corresponding 6 anti-matter families exist!

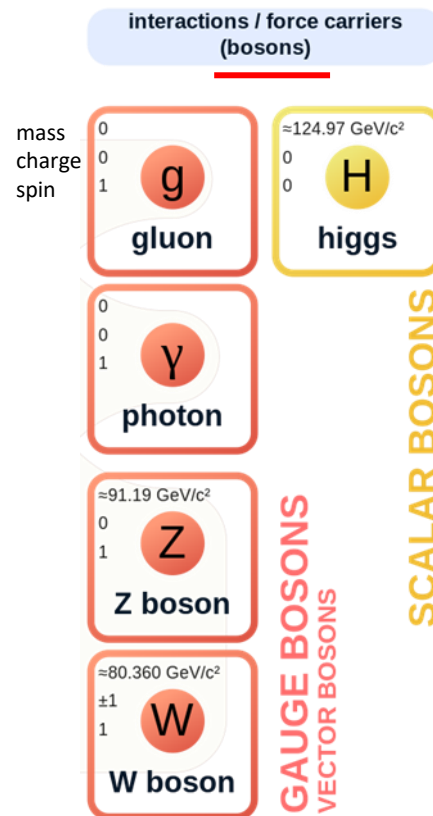
➤ 3 Anti-quarks families;

➤ 3 Anti-leptons families.

- A total of 24 fundamental fermions, exists.

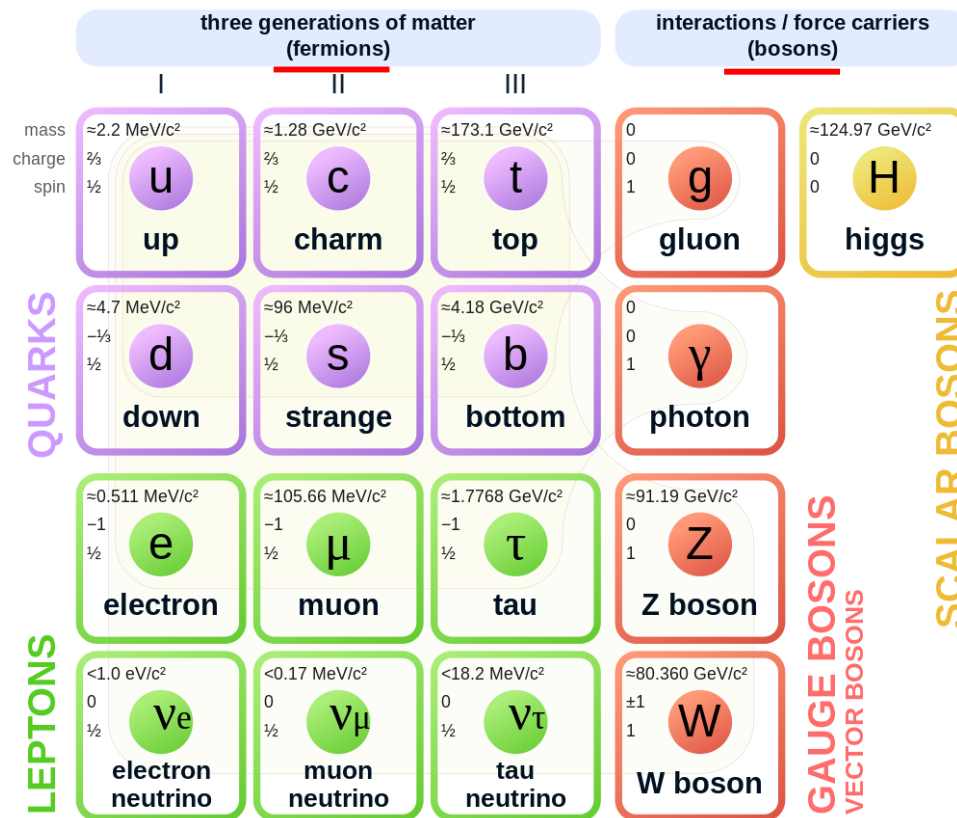
# Keystones of the Standard Model

## Interaction fields (aka vector bosons)

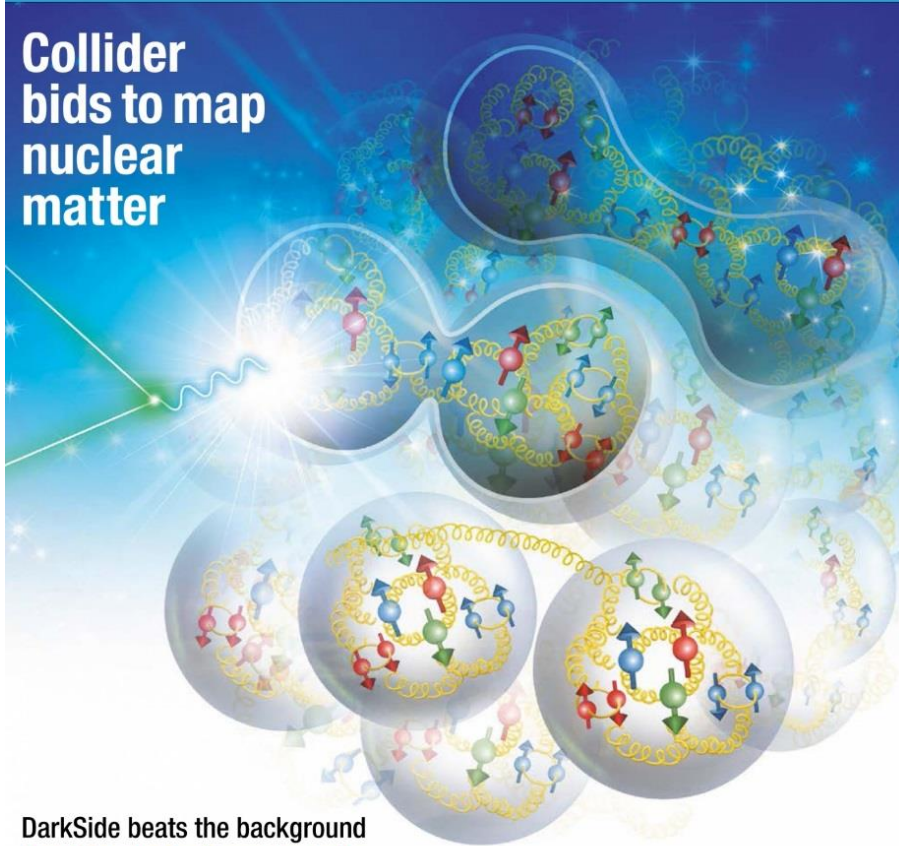


# Keystones of the Standard Model

## Standard Model of Fundamental Particles



## Collider bids to map nuclear matter



DarkSide beats the background  
Speaking up for European unity  
AIMS: empowering Africa's youth

**Valence quarks:** give the particle identity. Hundreds of states (particles) can be arranged;

**Particle Spectroscopy:** valence quarks with different strong charges (colors) and different Kinematic status (angular momentum and energy levels ) result in particles with different masses (excitation levels);

The Exchange of gluons hold together quarks in a nucleon and nucleons in a nucleus.

**Sea quark :** paired  $\bar{q}q$ ;





# Summary

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- Particles and Interactions are quantum fields;
- The particle-wave duality results in the Heisenberg uncertainty principle. Energy quantization and more → Quantum Mechanics;
- The QM incorporate the SR and predicts the existence of the anti-matter (Dirac equation);
- The **Quantum Field Theory** (QFT) describes interactions between particle fields by means of mediator fields;
- The **Standard Model**: is a mathematical framework providing a unified description of the three interactions; plus, the Higgs field. The SM is a QFT;
- Particle spectroscopy: by the valence quarks (quarks and anti-quarks), hundreds of particles (states) can be built.