

Introduction to Particle Physics

SWEDISH PHYSICS TEACHERS 2023

Handout 1

➤ Particles and Interactions

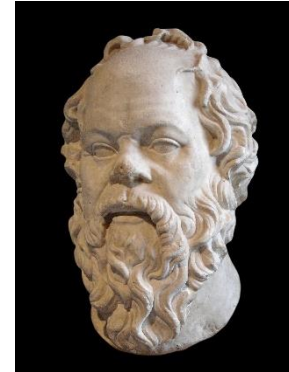
➤ Glimpses on the Standard Model

➤ 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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[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

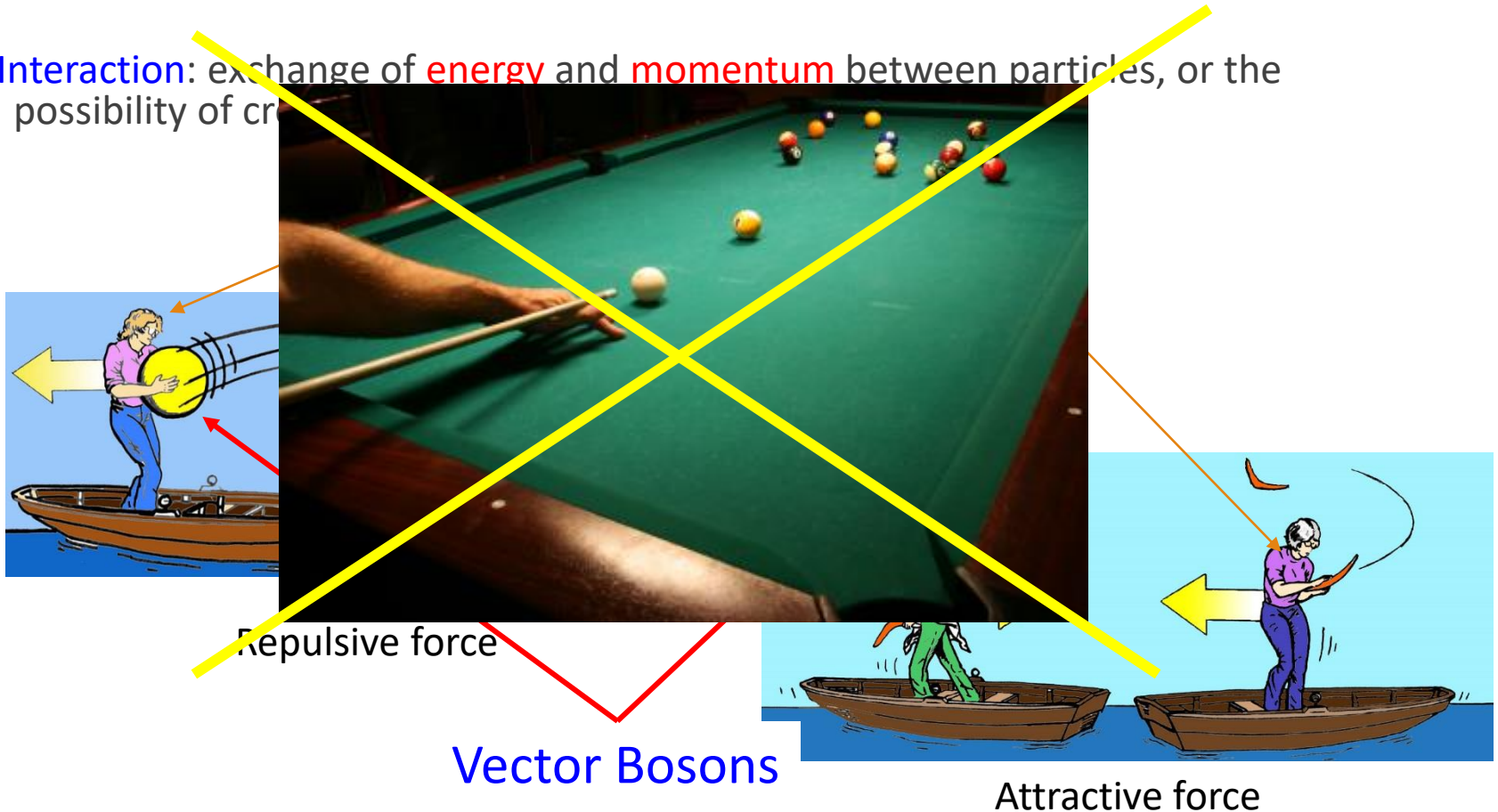
- Particle Physics: study of **fundamental particles** and **interactions** of the “subnuclear world”

- 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



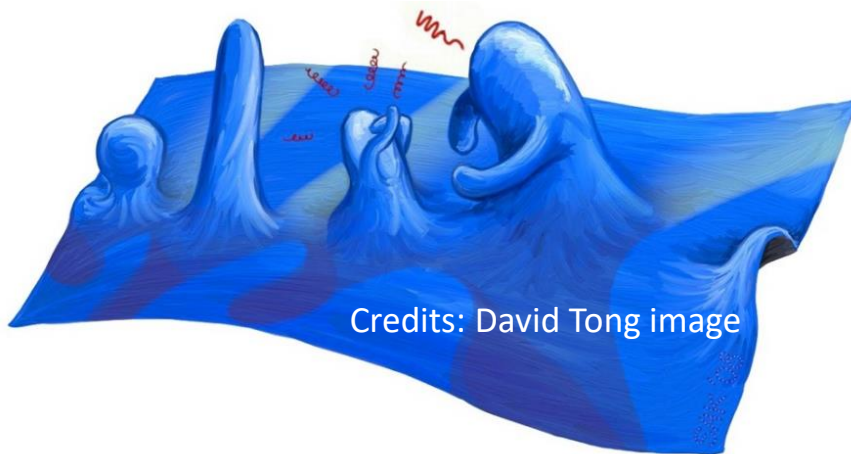
Particles and Interactions

- 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
 - ν 's fields

Particles and Interactions

- 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

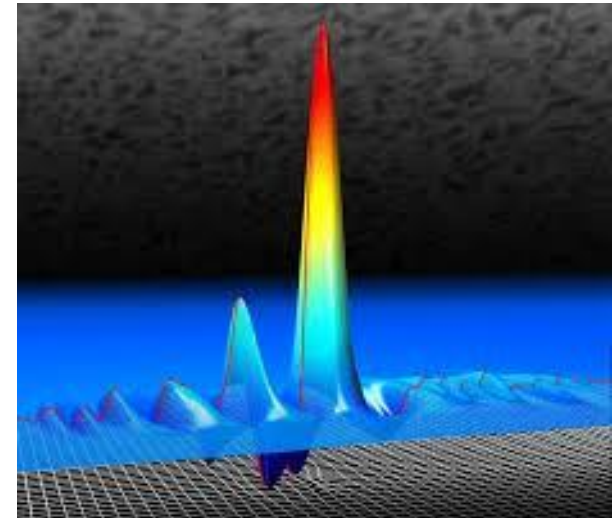
Pictorial view of a quantum field



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

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

- 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	γ	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	 u up	 c charm	 t top
	 d down	 s strange	 b bottom
	 e electron	 μ muon	 τ tau
LEPTONS	 ν_e electron neutrino	 ν_μ muon neutrino	 ν_τ tau neutrino

- Corresponding 6 anti-matter families exist!

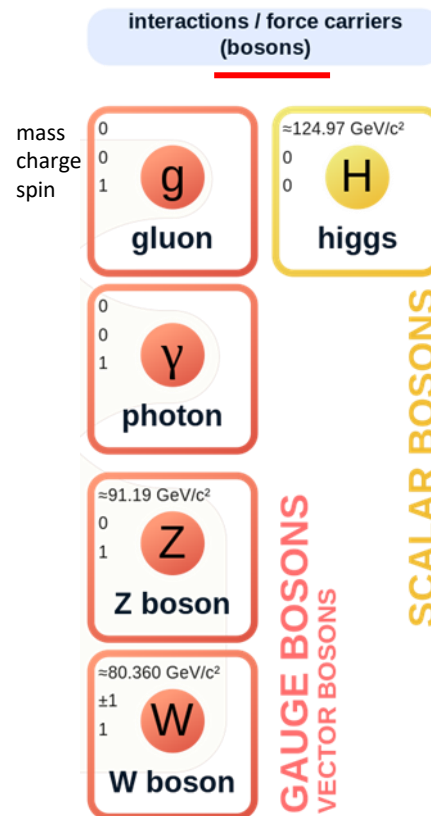
➤ 3 Anti-quarks families;

➤ 3 Anti-leptons families.

- A total of 24 fundamental fermions, exists.

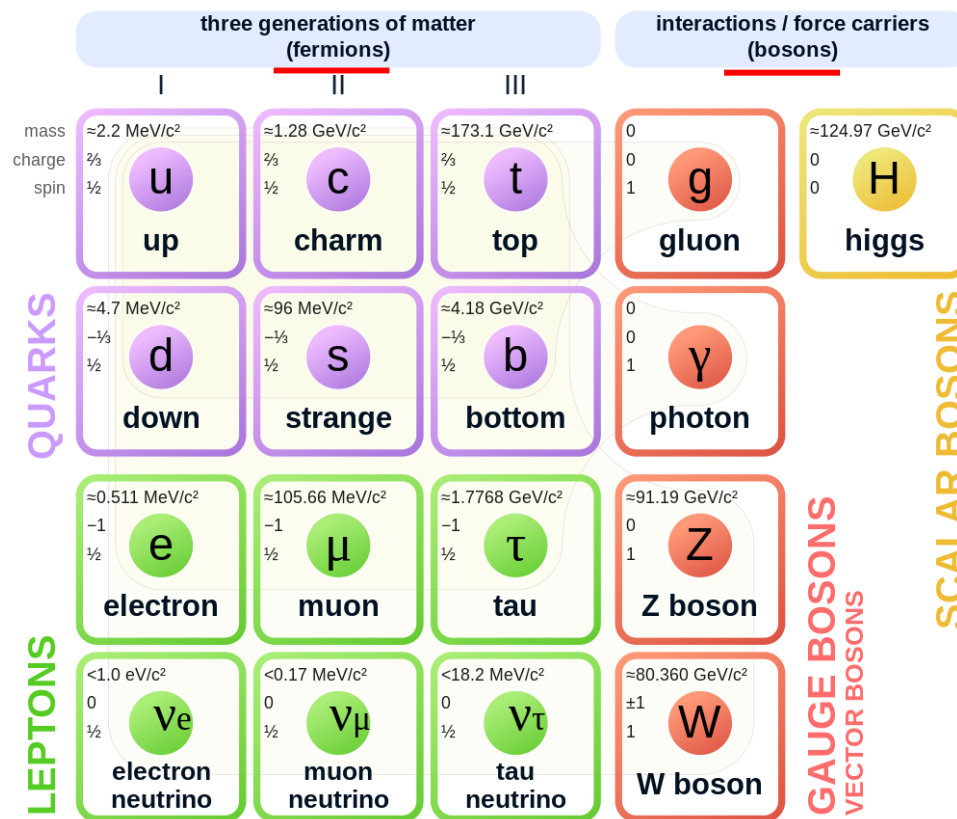
Keystones of the Standard Model

Interaction fields (aka vector bosons)

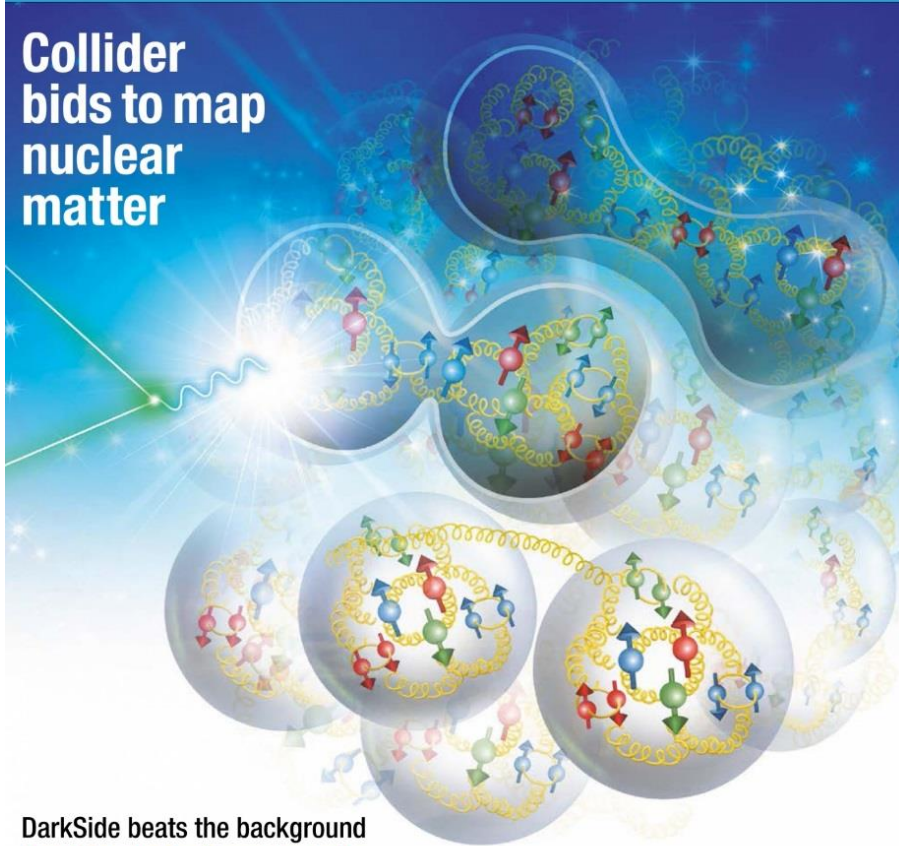


Keystones of the Standard Model

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

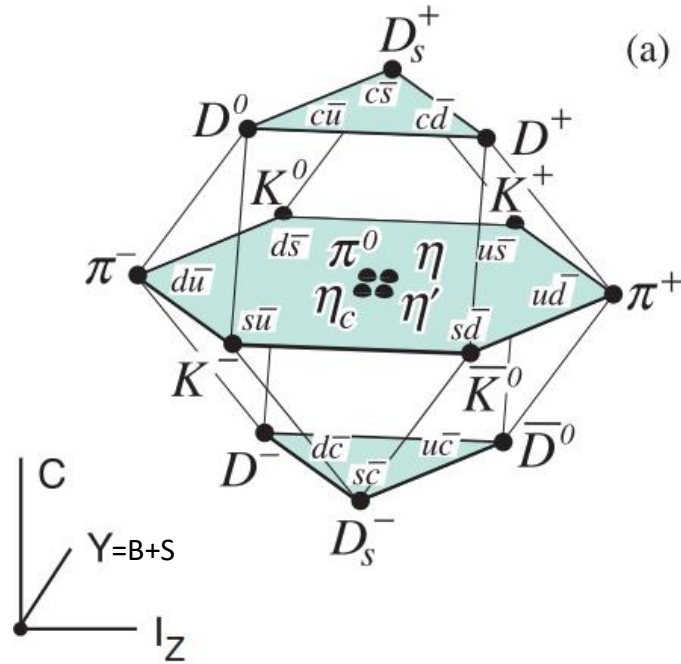
Valence quarks: give the particle identity. Hundreds of states (particles) can be arranged;

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);

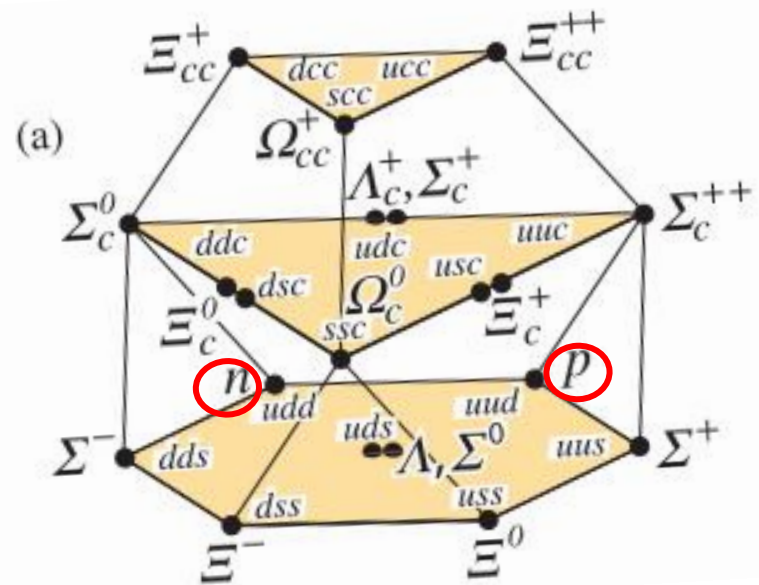
The Exchange of gluons hold together quarks in a nucleon and nucleons in a nucleus.

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

Mesons and Baryons spectroscopy: static quark content



Multiplets of mesons ($q\bar{q}$)
made of u,d, s and c quarks



Multiplets of baryons made of
u,d, s and c quarks

Summary

- 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.