Particle Physics

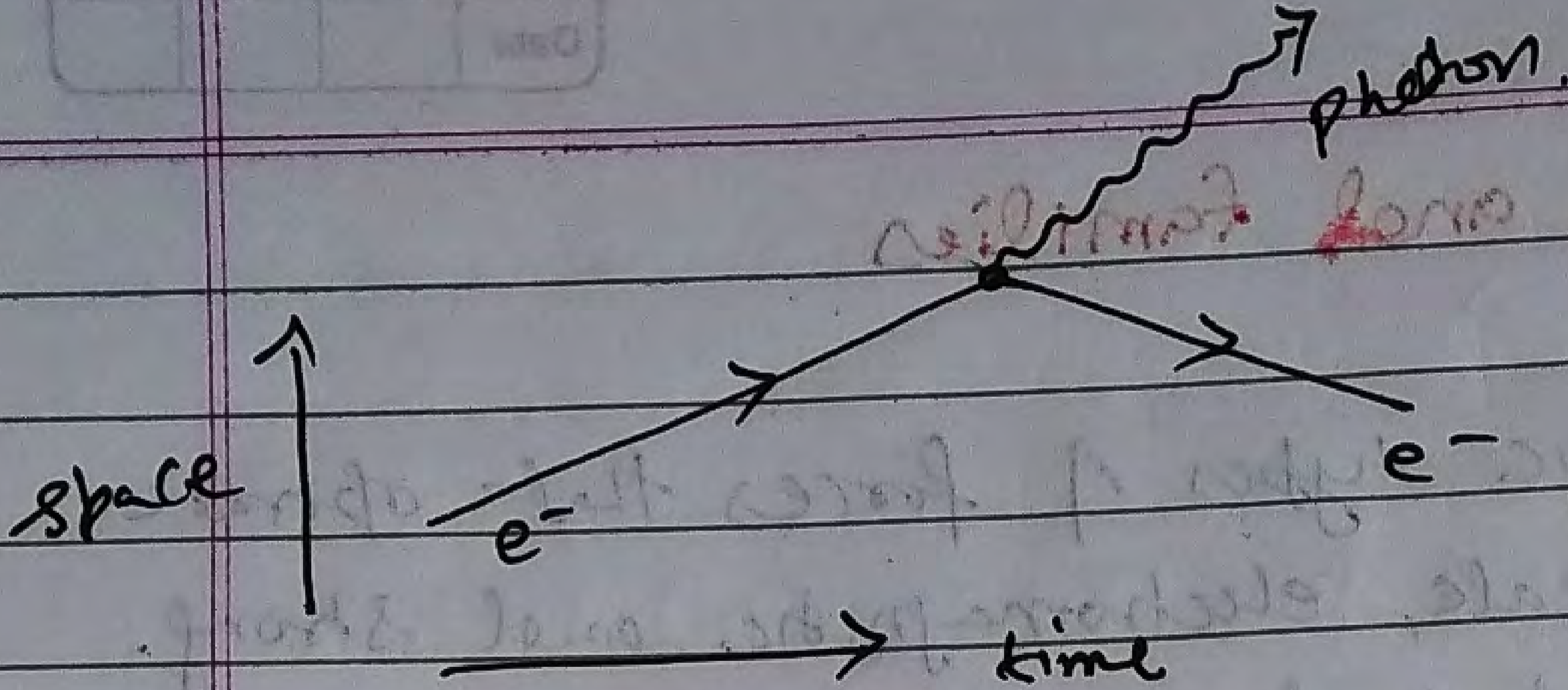
Particle interactions and families

There are three basic types of forces that operate between particles: weak, electromagnetic, and strong. (neglecting gravity, which do not have any measurable effects on the scale of particle).
Each of these forces have relative strength parameter, each operate over a specific distance and having specific time scale to operate.

Each force is governed by the exchange of field particles or quanta. The field quanta can themselves be regarded as elementary particles with definite sets of properties.

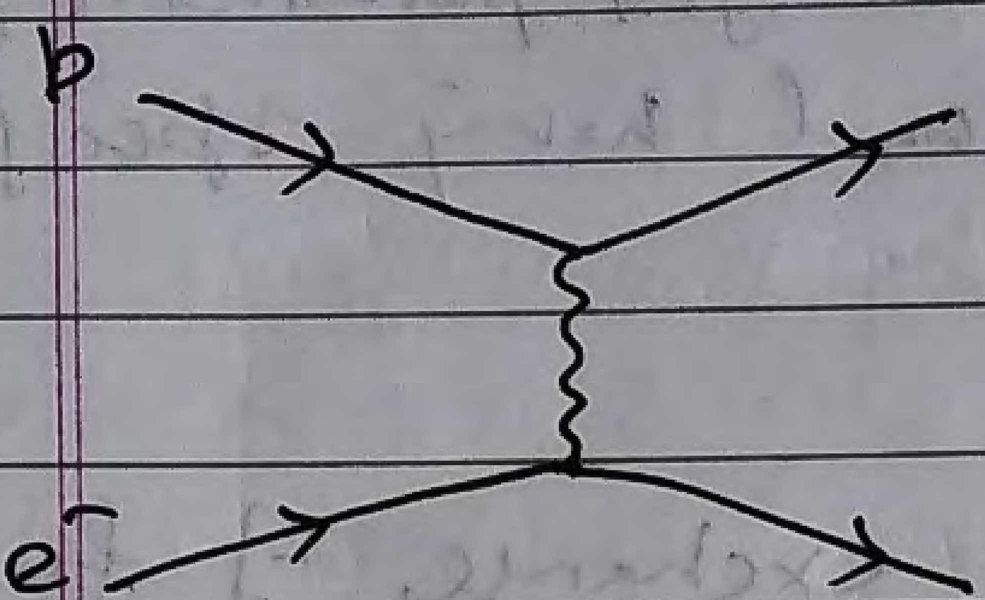
Interaction	field quanta	Relative strength	Range (m)	distance behaviour	Acts on	Affected particles
Gravitation	gravitons (yet to be observed)	1	∞	$1/r^2$	Mass, Energy	All particles
Weak	W and Z bosons	10^{25}	10^{-18}	$\frac{1}{r}e^{-mr}$	Flavor	Left handed fermions
Electromagnetic	Photons	10^{36}	∞	$1/r^2$	Electric charge.	Electrically charged
Strong	Gluons	10^{38}	10^{-15}	r	Color charge.	Hadrons.

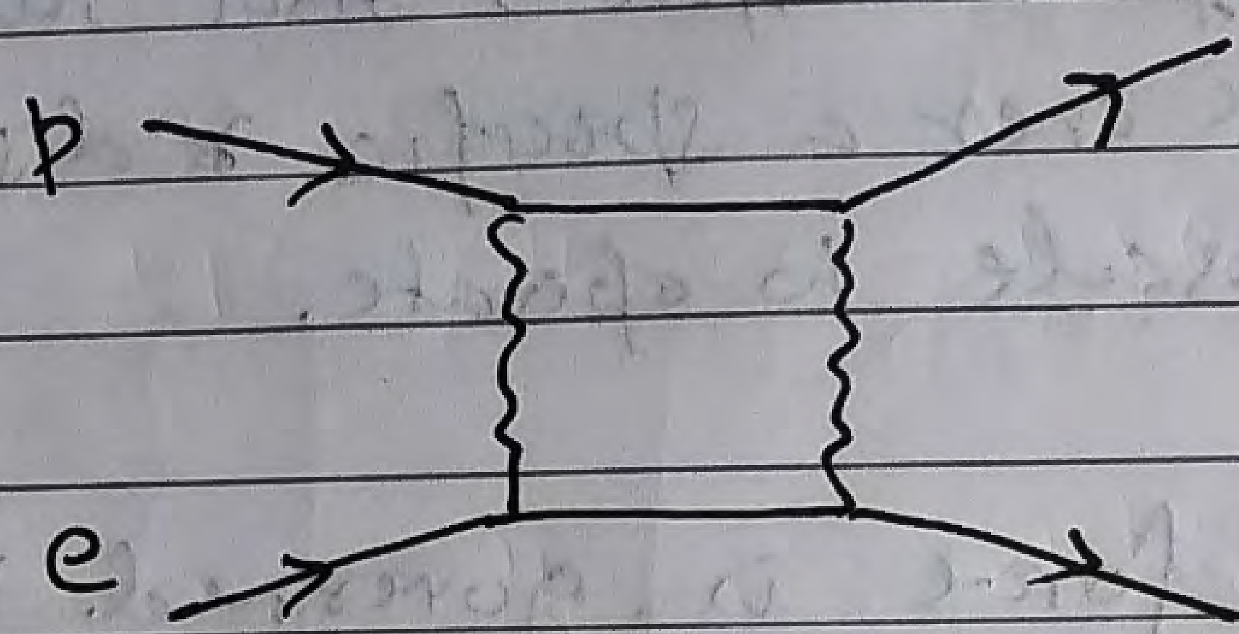
Feynman diagram:-
A useful way of graphical representation of interaction in which emission & absorption of field quanta are illustrated (not in detail but with few examples in next page.)

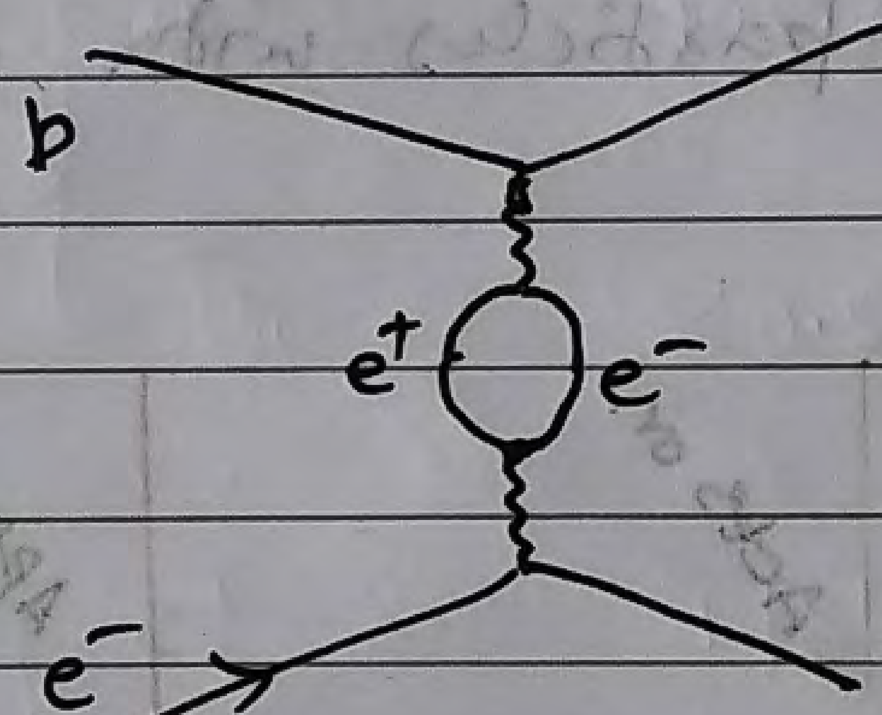


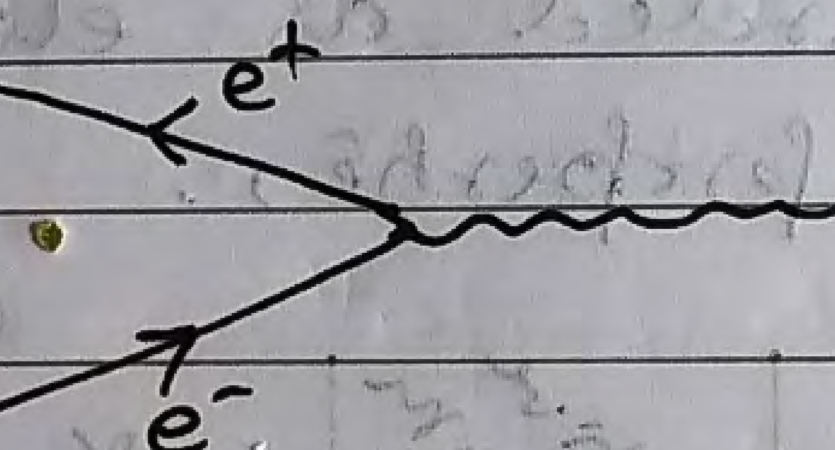
does not occur for free electron.

e-p interaction.



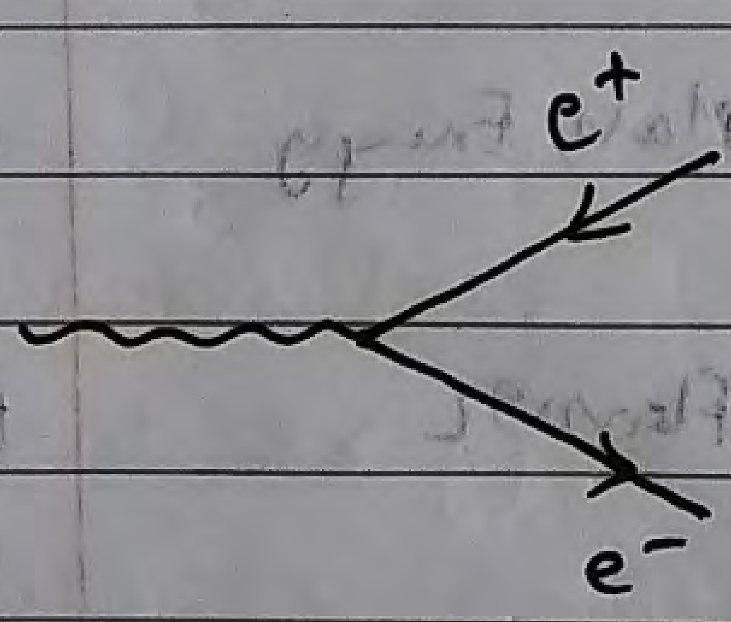




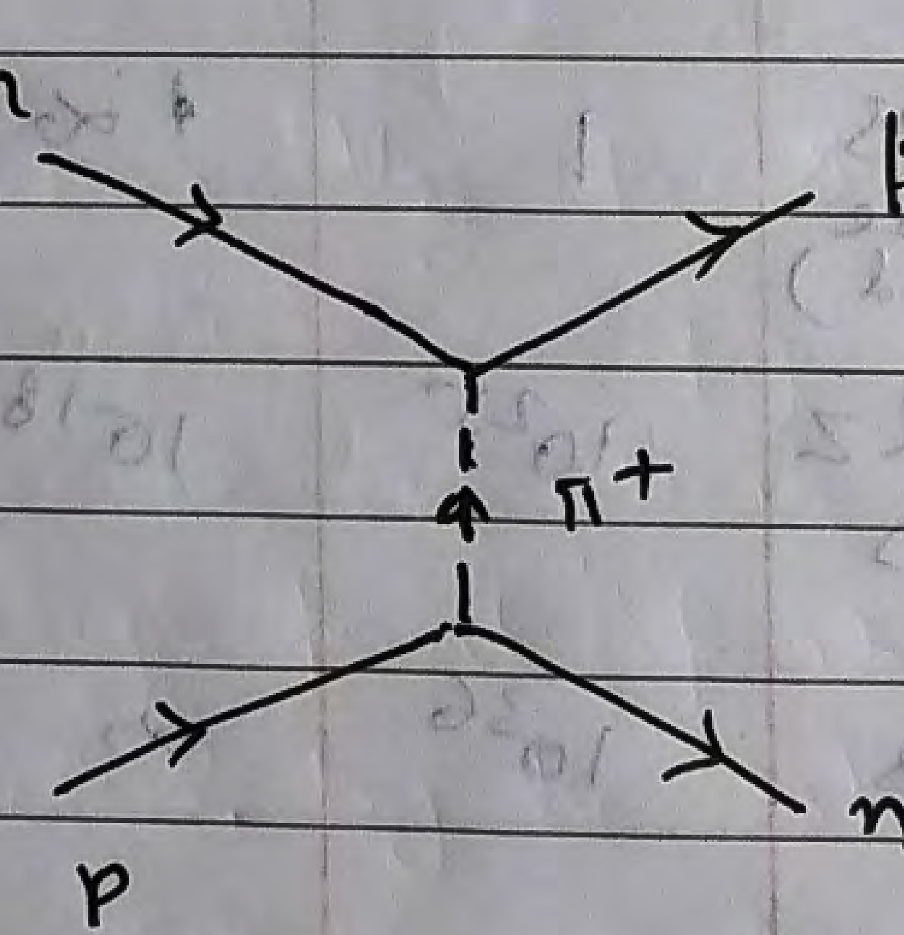


Annihilation.

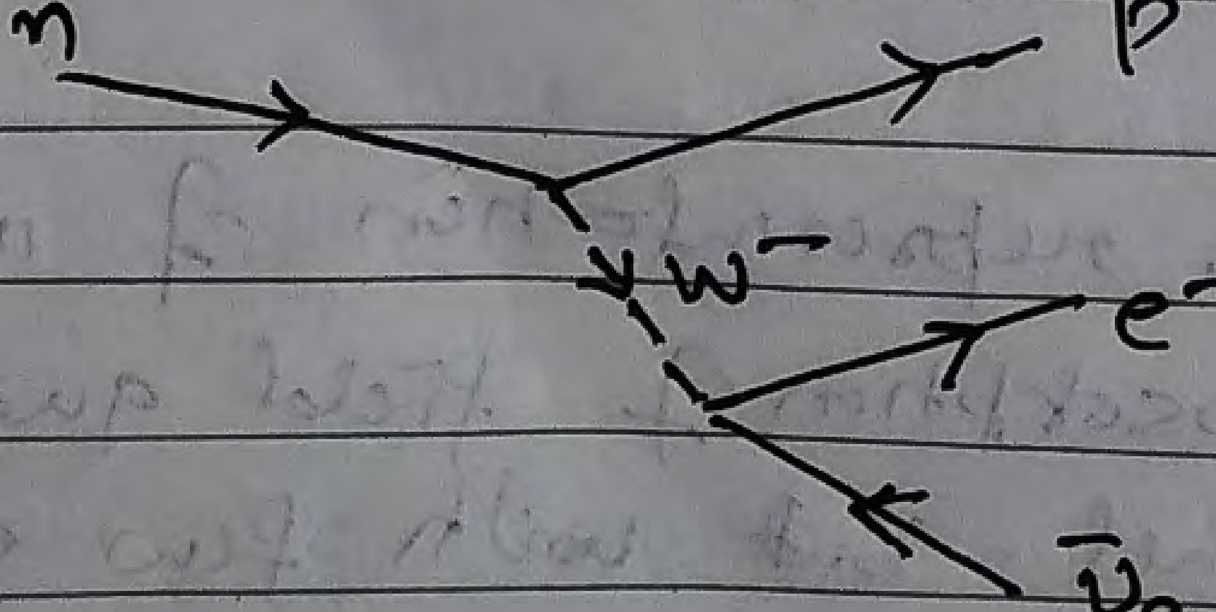
antiparticle traveling backward in time



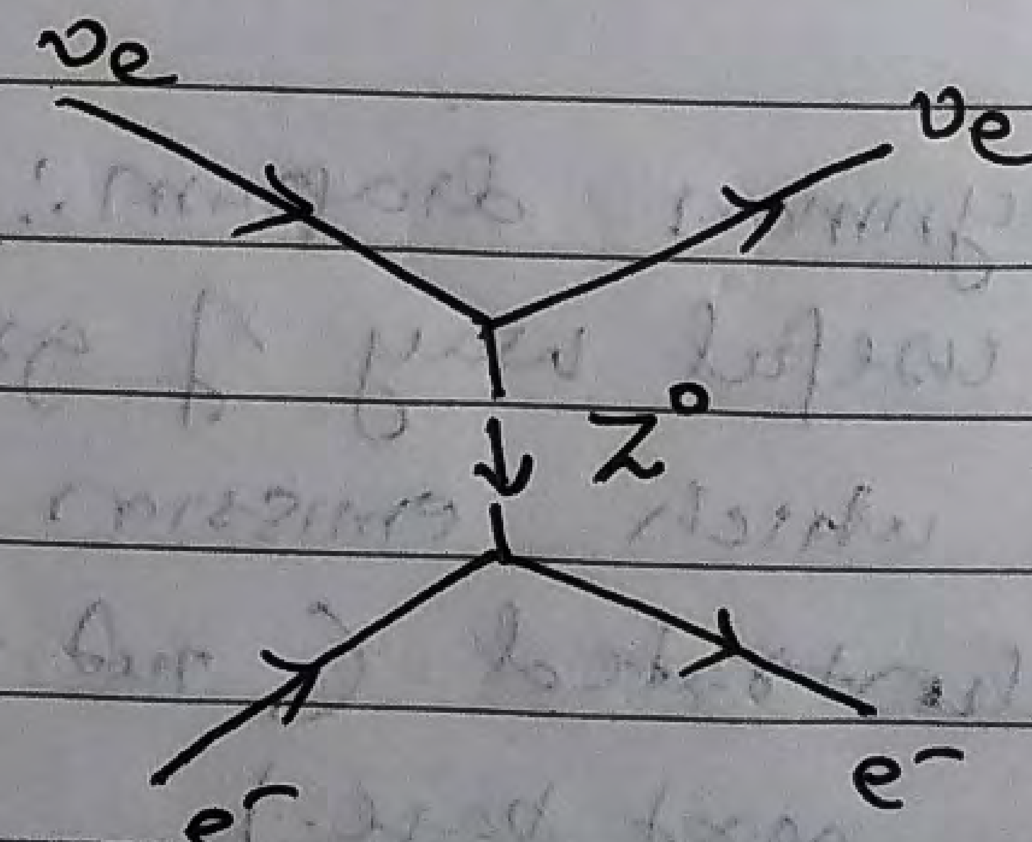
pair production



(strong interaction



β-decay (weak decay)



Neutral-current weak interaction

Elementary particles

1) Field Particles (. can/are regarded as elementary particles).

	Particle	Mass	charge	Spin	range
Photons	γ	0	0	1	∞
	$W^{\pm}$	81 GeV/c^2	± 1	1	10^{-18}
	Z^0	93 GeV/c^2	0	1	
	Gluons (8)	0	0	1	10^{-15}
	Graviton	0	0	2	∞

At high engy electromagnetic & weak force are combined to form a single force called electroweak force i.e. em & weak are completely equivalent to each other. This theory of electroweak interactions was postulated by S. Weinberg & A. Salam. The pure electroweak force would be mediated by four massless spin-1 particles a triplet (of charges +1, 0, −1) and a singlet (uncharged). At lower engyes (< 246 GeV) the symmetry b/t weak and em forces is broken, and the three of the four exchanged particles lose their massless character to become the weak boson $W^{\pm}$, Z^0. The fourth particle remains massless and it is ordinary photon of em.

In 1983 proton-antiproton collider detected $W^{\pm}$, Z^0 indirectly through the following decay reaction.

$$W^{\pm} \longrightarrow e^{\pm} + \nu$$

$$Z^0 \longrightarrow e^{+} + e^{-}$$

strong force is mediated by π mesons b/t nucleons. Electromagnetic & weak force are truly fundamental processes. But the strong b/t nucleon through π meson is not elementary in nature because nucleons & mesons are composite particles made up of quarks.

2. Leptons (light elementary particle).

Particle	Anti-part	Mass(MeV/c²)	charge	spin	Lifetime(s)	Decay Modes
e^-	e^+	0.511	±1	1/2	stable	
ν_e	$\bar{\nu}_e$	< 46 eV/c²	0	1/2	stable	
μ^-	μ^+	105.66	±1	1/2	2.2×10^{-6}	$\to e\,\nu_e\,\nu_\mu$
ν_μ	$\bar{\nu}_\mu$	< 0.50	0	1/2	stable	
τ^-	τ^+	1784	±1	1/2	3.4×10^{-13}	$\to \mu\,\nu_\mu\,\nu_\tau$; $\to e\,\nu_e\,\nu_\tau$; $\to \pi\,\nu_\tau$; $\to e\,\nu_\tau$
ν_τ	$\bar{\nu}_\tau$	< 164	0	1/2	stable	

leptons are true elementary 'point' particles.
leptons are totally unaffected by the strong interaction but appears identical in em & weak interaction.
e, μ, & τ only differ in their mass and properties related to mass.
leptons ~~are~~ ~~is~~ classified into three pairs of two each shown by {.

only τ lepton can decay into mesons.

3. Hadrons (heavy particle) — 3a Mesons / 3b Baryons

Mesons & Baryons are not elementary particle because they are made up of quarks.

3(a) Mesons

They are strongly interacting particles with integer spin.
π- mesons are the lightest members of the mesons family.
free mesons can be produced in nucleon-neucleon collisions and they decay rapidly to lighter member ; photons, or leptons either through the strong, electro-magnetic, or weak interactions.

$$\text{meson} \xrightarrow{\text{decay}} \text{meson (strong interaction)}$$
time ~ $10^{-22} - 10^{-23}$ ~~sec~~ sec

$$\text{meson} \xrightarrow{\text{decay}} \text{photons (em interaction)}$$
time ~ $10^{-16} - 10^{-18}$ sec.

$$\text{meson} \xrightarrow{\text{decay}} \text{leptons (weak interaction)}$$
time ~ $10^{-8} - 10^{-10}$ sec.

Unusual production and decay of mesons observed and explained through the introduction of additional properties named strange, charm, bottomness (or beauty) and topness (or ~~the~~ truth).
Example of mesons made up of normal quark (up & down) ~~or can be called not strange quarks~~.
$\pi, \eta, \rho, \omega, \phi, \eta'$
Some mesons with properties such as strange, charm, bottomness & topness.

$K^{\pm}, K^0, K^{*+}\ K^{*0}$ strange mesons
$D^{\pm}, D^0, D^{*+}\ D^{*0}$ charm mesons.
B^+, B^0 Bottomness mesons
F strange & charm both.

3(b) Baryons

Baryons are strongly interacting heavy particles with half-integer spins ($\frac{1}{2}, \frac{3}{2}, \frac{5}{2} \ldots$).
The lightest members are the proton and neutron.
There are several baryon produced in nucleon-nucleon ~~interaction~~ interaction but the life time is $\sim 10^{-22}$ sec.
Just like mesons, baryons also shows same properties like strangeness, charmness, bottomness & truthness while decay and ~~for~~ during production.
Example.
non-strange baryons are. $n, p, \Delta^{+}, \Delta^{++}, \Delta^{0}, \Delta^{-}$
strange baryons are $\Sigma^{+,-,0}$, $\Xi^{0,-}$, Ω^{-} many more around 100 in list.

We will discuss some more properties of Hadrons later once ~~we~~ go through the Quark Model.

we ~~k~~ now know that mesons & Baryons are composite particles so hardly treat them as elementary particle at high engy but at low engy we can observe their substructure so they can be treated as fundamental particle (but not point like)