Particle Physics 1

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In This Course $E \gg MeV$

- ☑ $P = (E, \vec{p})$ And $E^2 = \vec{p}^2 + m^2$ And $\vec{p}^2 = |\vec{p}|^2$
- ☑ Natural units: $\hbar = c = 1$ and dimensionless, $\hbar = \dfrac{h}{2\pi}$

$$E = h\nu = \hbar\omega \longrightarrow [h] = \frac{[E]}{[\nu]} = \frac{[E]}{[\frac{1}{T}]}$$

$\hbar$ is dimensionless $\Rightarrow$ $[E] = [T]^{-1}$ And $[\nu] = \dfrac{[L]}{[T]}$ so

c is also dimensionless ⇒ [L] = [T]

$\hbar c$ = 197 MeV×fm

eV for E

eV^{-1} for L,T

$c = 3 \times 10^8$ m/s

$\hbar = 1.05 \times 10^{-34}$J/s

1 fm = 10^{-15}m

1 MeV = 10^6 eV

1 eV = 1.6× 10^{-16} c.v = 1.6× 10^{-19} J

Decays

- ☑ Particle a decays to b+c+d+…+z

Neutrons, Protons, Electrons

Neutrons are unstable, Protons and Electrons are stable

Decay caused by existence of fundamental Interactions

$$a \longrightarrow b+c$$

→ Interaction

- ☑ Gravity is too weak at subnuclear state
- ☑ Electromagnetic
- ☑ Weak Force
- ☑ Strong Force

→ Can cause decay of particles

Decays

- Energy-Momentum conservation always in all decays

$$n \longrightarrow p + e^- + \bar{\nu}_e$$ β^- decay

$$^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + \alpha$$ α decay $\alpha = {}^{4}_{2}He$

$$^{*}N \longrightarrow N + \gamma$$ γ decay

$$\mu^- \longrightarrow e^- + \bar{\nu}_e + \nu_\mu$$ Weak decay

$$\pi^0 \longrightarrow \gamma + \gamma$$ EM decay

- Baryons + Electrons: visible matter

Hadrons

Baryons:neutrons, protons

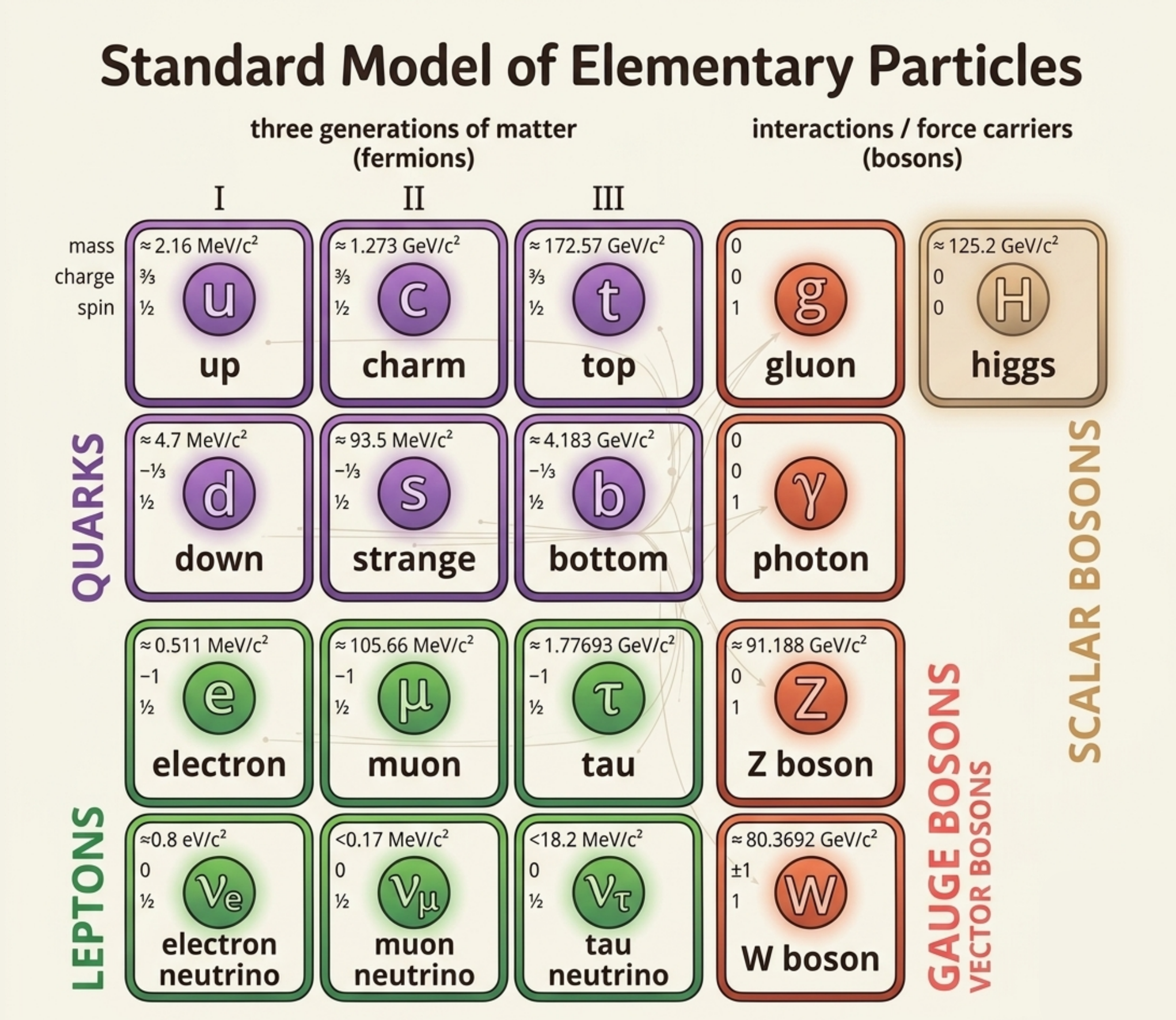
Mesons: π, k

Strong Interaction

Decays

☑ Leptons: $e^-, \mu^-, \bar{\nu}_e, \nu_\mu \cdots$

No strong interactions
Only weak and EM



Decays

- Baryons: bound state of 3 quarks q_1, q_2, q_3

uud: proton

$$Q = +\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = \frac{3}{3} = +1$$

udd: neutron

$$Q = +\frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0$$

- Mesons: $q_i \bar{q}_j$

u$\bar{d}$: π^+ pions $\bar{d}$ = anti particle of d quark, anti d

$$Q_{\bar{d}} = -Q_d$$

Q: d=$-\frac{1}{3}$, $\bar{d}$=$+\frac{1}{3}$ Q: u=$+\frac{2}{3}$, $\bar{u}$=$-\frac{2}{3}$

Leptons and Quarks are fundamental elementary particles

Baryons and Mesons (hadrons) are not elementary

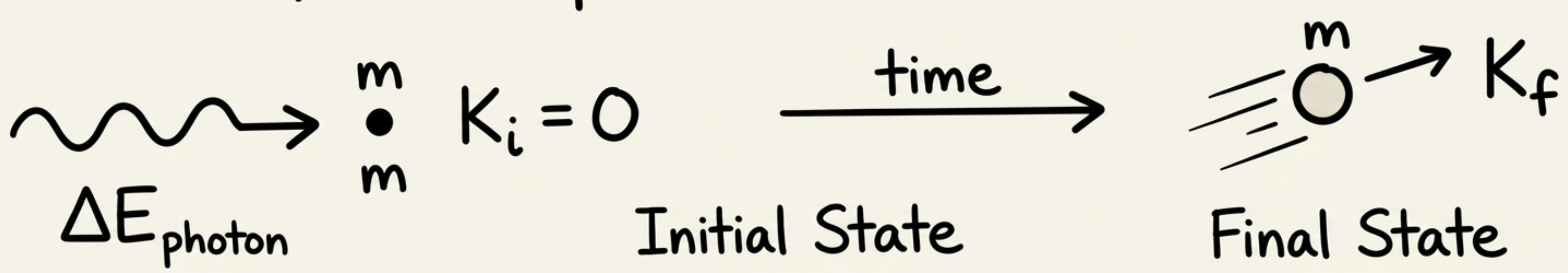
But they're bound, composite states

Decays

☑ Elementary particles?

all transferred energy becomes kinetic energy for the particle

Particle at rest, then a photon (ΔE) arrives.



$K_f = 0 + \Delta E_{photon}$

$K_f = \Delta E_{photon}$

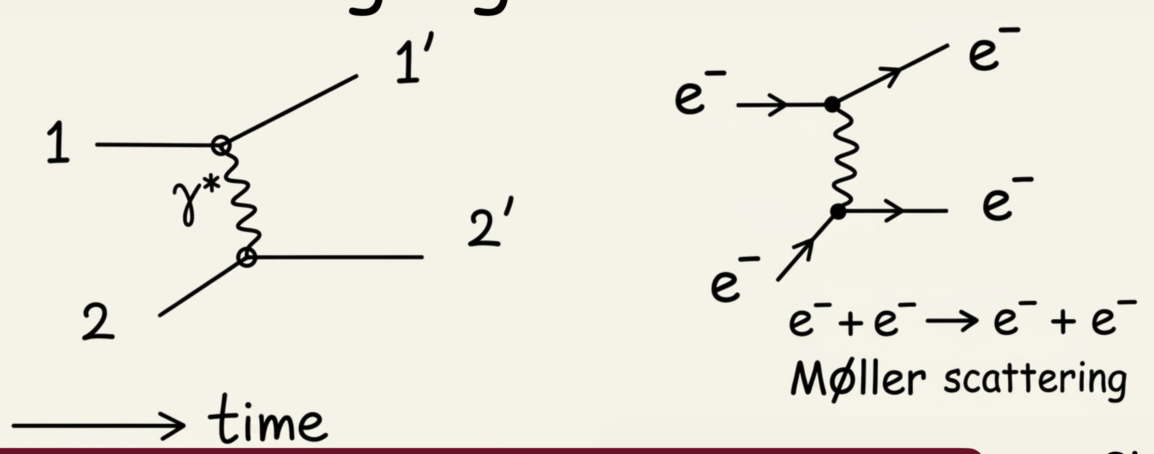
$$K_f = \Delta E_{total} = \Delta E_{photon}$$

For a fundamental particle, <u>all</u> incoming energy (ΔE_{photon}) is converted into Kinetic Energy (K_f).

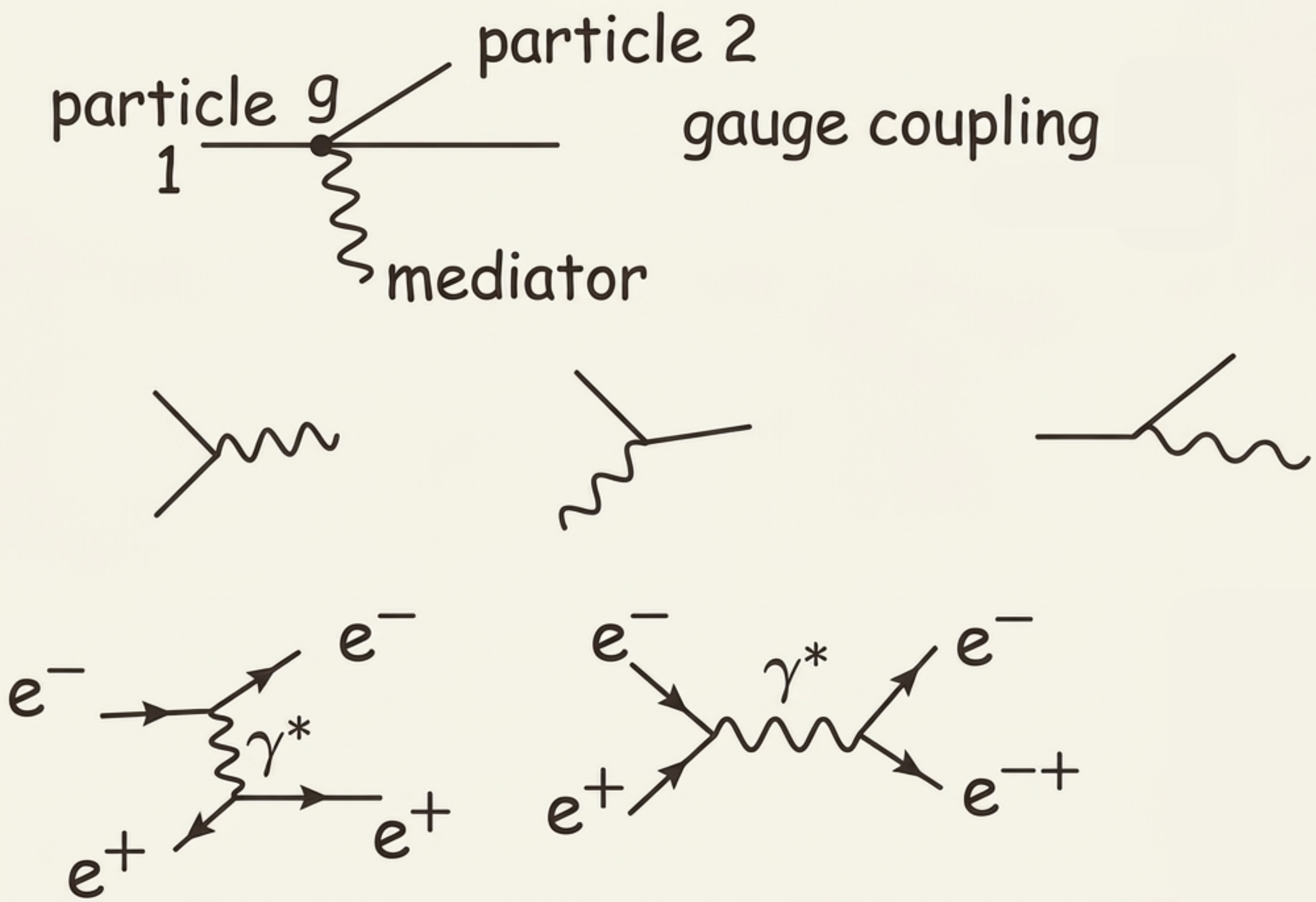
Elementary particles do not have internal degrees of freedom

(Think about rotational energy of a rigid body)

☑ Mediators of forces for gauge interactions:



Decays



Interaction vertices

Decays

- ☑ N-particle decay a $\longrightarrow$ b+c+…+d
- ☑ 2-body decay a $\longrightarrow$ b+c

Example of unstable particles t=0 N= N_0 particles

Γ: probability of decay per unit time N(t) = N(0) $e^{-\Gamma t}$ Particles at time t surviving

$$\frac{N(t)}{N(0)} = e^{-\Gamma t} \leq 1$$ Probability of survival

$[\Gamma] = T^{-1} = [E]$ in natural units

Lifetime: property of unstable particles

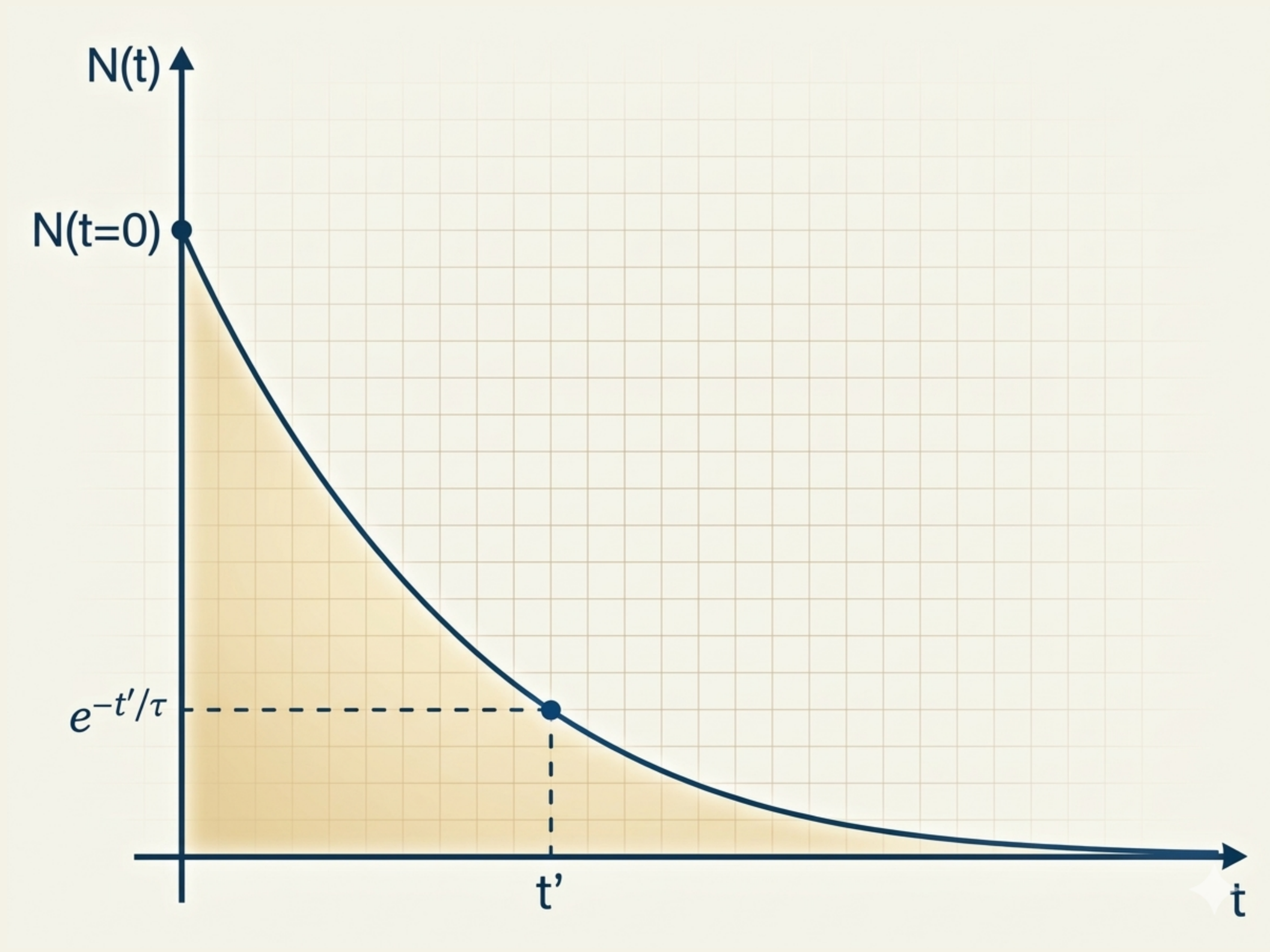
Average life of ——— unstable particles

has to take in to account decay probability.(weighted average)

Decays

- ☑ $\tau = <t> = \frac{\int_0^\infty t e^{-\Gamma t} dt}{\int_0^\infty e^{-\Gamma t} dt} = \frac{1}{\Gamma}$

$$N(t) = N_0\, e^{-t/\tau}$$

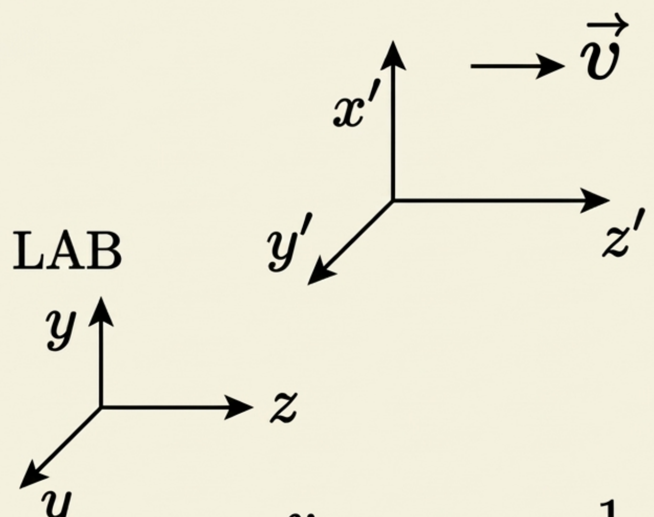


Muons

- Muons: $\tau = 2.2 \times 10^{-6}$ sec

  τ: is in reference frame where particle at rest

  in the lab the effective lifetime will be longer



$$\beta = \frac{v}{c}, \quad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

$$\begin{cases} t = \gamma\,(t' + \beta z') \\ x = x' \\ y = y' \\ \quad = \gamma\,(\beta t' + z') \end{cases}$$

$$\tau_{LAB} = \gamma\tau$$

$$\beta = \frac{|\vec{p}\,|}{E} \qquad \gamma = \frac{E}{m} \qquad \beta\gamma = \frac{|\vec{p}\,|}{m}$$

Conservation

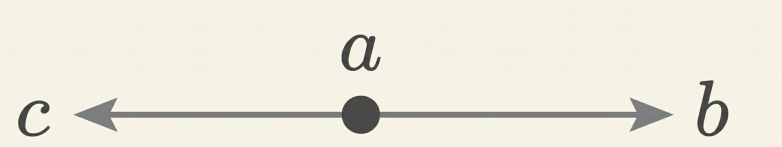
☑ a $\longrightarrow$ b + c

Energy and momentum must be conserved

$E_a = E_b + E_c$ energy conservation. E=$\sqrt{p^2 + m^2}$ E = m + k

Definition of kinetic energy

In ref with $\overrightarrow{P}_a = 0 \quad \longrightarrow \quad E_a = m_a$



$\vec{0} = \overrightarrow{P}_b + \overrightarrow{P}_c$ Momentum conserved -> $\overrightarrow{P}_b = -\overrightarrow{P}_c$

$$m_a = E_b + E_c = m_b + k_b + m_c + k_c = (m_b + m_c) + (k_b + k_c)$$

Q = $m_a - m_b - m_c = k_b + k_c \geq 0$

Decays are possible only if Q≥0

$a \longrightarrow b + c + d + \cdots + z$

Q = $m_a - m_b - m_c - m_d - \cdots - m_z \geq 0$

If Q small $\longrightarrow$ small prob for decay

Thank You!