Introduction of Particle Physics

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第 1 章

1.1 Elementary Particle Kinematic and Dynamics

1.1.1 Scale

- $$\left.\begin{aligned} Atom &: \sim 10^{-8}\text{cm} \\ Nucleon &: \sim 10^{-12}\text{cm} \\ Proton &: 0.8 \times 10^{-14}\text{cm} \end{aligned}\right\} \textbf{Structure}$$
- $$Electron :< 10^{-16}\text{cm} \leftarrow \textbf{point particle}$$

1.1.2 Units

Natural units:

$$\hbar = c = 1 \Leftarrow \left\{\begin{aligned} \hbar &= 6.58211 \times 10^{-15}\text{Gev} \cdot \text{Sec} \\ c &= 3 \times 10^{10}\text{cm/Sec} \end{aligned}\right\} \Rightarrow \begin{aligned} &1\text{Gev} = (6.6 \times 10^{-25}\text{Sec})^{-1} \approx 1.52 \times 10^{24}\text{Sec}^{-1} \\ &1\text{Gev}^{-1} \approx 6.6 \times 10^{-25}\text{s} \\ &1\text{Sec} = 3 \times 10^{10}\text{cm} \end{aligned}$$

Dimension:

Dimension	Type	
M^0	velocity angular momentum	
M^1	mass energy	momentum
M^{-1}	length time	
M^{-2}	cross section	

$$\begin{aligned} m_e = m_e c = m_e c^2 &\approx \frac{1}{2}\text{MeV} \\ &= \frac{1}{\hbar/m_e c} \approx (4 \times 10^{-11}\text{cm})^{-1} \\ &= \frac{1}{\hbar/m_e c^2} \approx (1.3 \times 10^{-21}\text{Sec})^{-1} \end{aligned}$$

Physical constants

G_F[①] $= 1.16637(2) \times 10^{-5}\text{GeV}^{-2}$ ① *Fermi constant*

M_{pl}[②] $= G_N^{-1/2} = M_{pl} = 1.2 \times 10^{19}\text{GeV}$ ② *Planck mass*

$M_W = 80.41 \pm 0.10\text{GeV}$

$M_Z = 91.187 \pm 0.007\text{GeV}$

$M_e = 0.51099906(15)\text{MeV}$

M_p[③] $= 938.2723(3)\text{MeV}$ ③ *proton mass*

1.1.3 Kinematics

Mass

$$E = \frac{m}{\sqrt{1-v^2}}, \mathbf{p} = \frac{m\mathbf{v}}{\sqrt{1-v^2}} \Rightarrow E^2 - \mathbf{p}^2 = m^2, \tag{1.1.1}$$

here E is energy ,$\mathbf{P}$ is momentum,$\mathbf{v}$ is velocity,and m is rest mass.

Experiment unstable particle

Probability density is given by

$$\boxed{\rho(M) = \frac{\Gamma}{2\pi\left[(M-m)^2 + \frac{\Gamma^2}{4}\right]}} \tag{1.1.2}$$

Fig. 1.1.1 shows Breit-Wigner distribution,where m is the mass, Γ is the width.

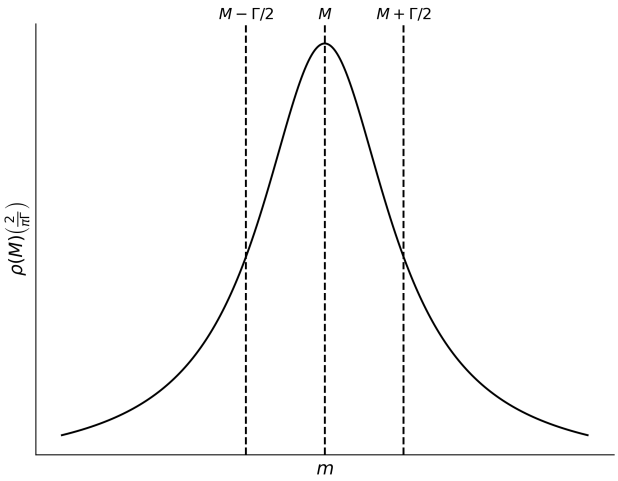

Figure 1.1.1. Breit-Wigner distribution

Lifetime,unstable particles——most of particles are unstable.

$$t \to t + \mathrm{d}t, N \to N - \mathrm{d}N$$
$$\mathrm{d}N = -\tau^{-1}N(t)\mathrm{d}t \Rightarrow N(t) = N(0)e^{-\frac{t}{\tau}},$$

here τ is lifetime and $\boxed{\tau = \frac{1}{\Gamma}}$.

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Proof.

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Some common particles have the following masses,

- photon: $\tau_\gamma = \infty$
- electron: $\tau > 2 \times 10^{23}\mathrm{yr}$
- muon: $\tau = 2.19703(4) \times 10^{-6}$ s
- $\pi^\pm : \tau = 26029(23) \times 10^{-8}$ s
- $\pi^0 : \tau = (84 \pm 06) \times 10^{-17}$ s
- N : $\tau = (896 \pm 10)$s
- Proton: $\tau > 10^{32} y_r$

Electric charge

$$e = 1.60217733(49) \times 10^{-11}\text{C}$$

$$\frac{|q_p| - |q_e|}{|q_e|} < 10^{-21} \quad \leftarrow |q_n| = |q_p| = |q_e| \Rightarrow q_n = 0$$

Why the electric charge of particle is quantized?

Spin

- $Fermon : 1/2, 3/2, 5/2, \cdots$
- $Boson : 0, 1, 2, \cdots$

The spins of common particles are as follows:

Example	H	γ	e	μ	π	p	n	W	Z
Spin	0	1	1/2	1/2	0	1/2	1/2	1	1

Table 1.1. The spins of common particles

1.1.4 Particle classification

In the standard model

(1). Gauge bosons: $\gamma, W^{\pm}, Z$,g(8 gluons) ——Spin 1
(2). Scale boson: Higgs boson H ——Spin=0
(3). Fermions: leptons + quarks ——Spin =1/2

Leptons:

l	Q	l_e	l_μ	l_τ
e	-1	1	0	0
ν_e	0	1	0	0
μ	-1	0	1	0
ν_μ	0	0	1	0
τ	-1	0	0	1
ν_τ	0	0	0	1

Table 1.2. Lepton Table

There are also six antileptons with all the signs reversed position $Q = 1, l_e = -1$.
Lepton are conserved!

$$\underset{1}{e^-} + \underset{1}{e^+} \not\rightarrow \underset{0}{\pi^+} + \underset{0}{\pi^-}$$

Quarks:

q	Q	B
d	$-1/3$	1/3
u	$2/3$	1/3
s	-1/3	1/3
c	2/3	1/3
b	-1/3	1/3
t	2/3	1/3

Table 1.3. Quark Charges and Baryon Numbers

Here B=Baryon,which is also conserved.

$$\underset{1}{p} \not\to \underset{0}{e^+} + \underset{0}{\pi^0}$$

Observed particles

(1). Gauge bosons: $\gamma, W^{\pm}, Z$
(2). Leptons:$e, \mu, \tau, \nu_e, \nu_\mu, \nu_\tau$
(3). Hadrons (强子,strong interaction)

- Mesons(介子):spin=$0, 1, \cdots,$ B=0
- Bargons(重子):spin=$1/2, 3/2,$ B=1