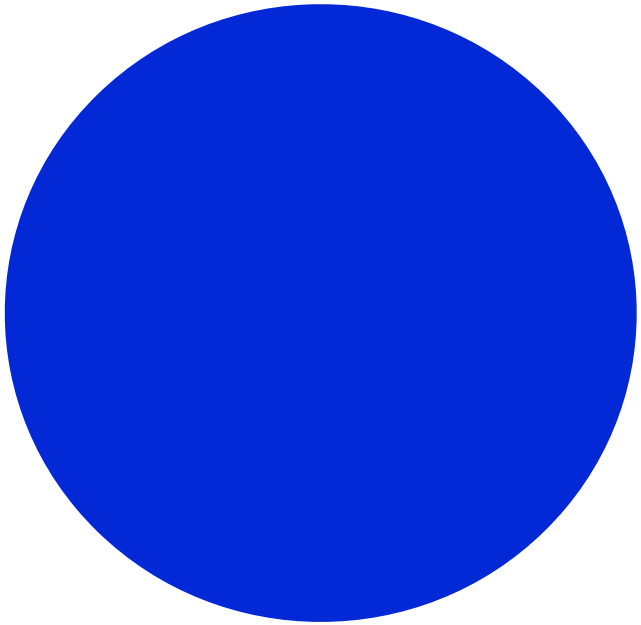
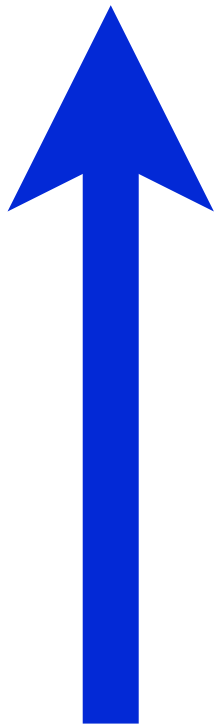
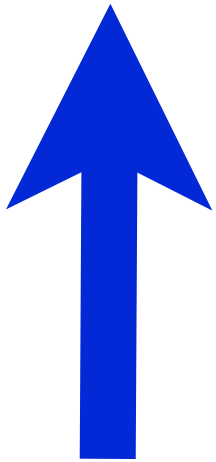
# Spin





| spin | 0 | 1 | 2 |
|---|---|---|---|
| unchanged if we rotate by: | anything | $360^0$ | $180^0$ |

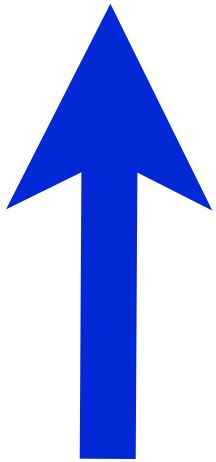
# Fermion Spin



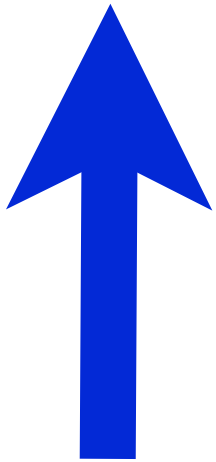
# Fermion Spin

Rotate once

-1



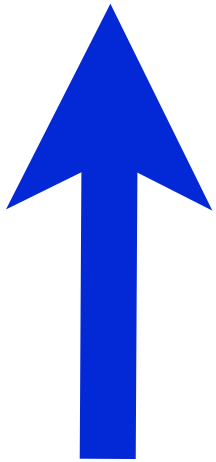
# Fermion Spin



# Fermion Spin

Rotate twice

$-1 \times -1 = +1$



# Bosons and Fermions

## BOSONS

force carriers
spin = 0, 1, 2, ...

**Unified Electroweak** spin = 1

| Name | Mass GeV/$c^2$ | Electric charge |
|---|---|---|
| $\gamma$ photon | 0 | 0 |
| $W^-$ | 80.4 | –1 |
| $W^+$ | 80.4 | +1 |
| $Z^0$ | 91.187 | 0 |

**Strong (color)** spin = 1

| Name | Mass GeV/$c^2$ | Electric charge |
|---|---|---|
| g gluon | 0 | 0 |

## FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

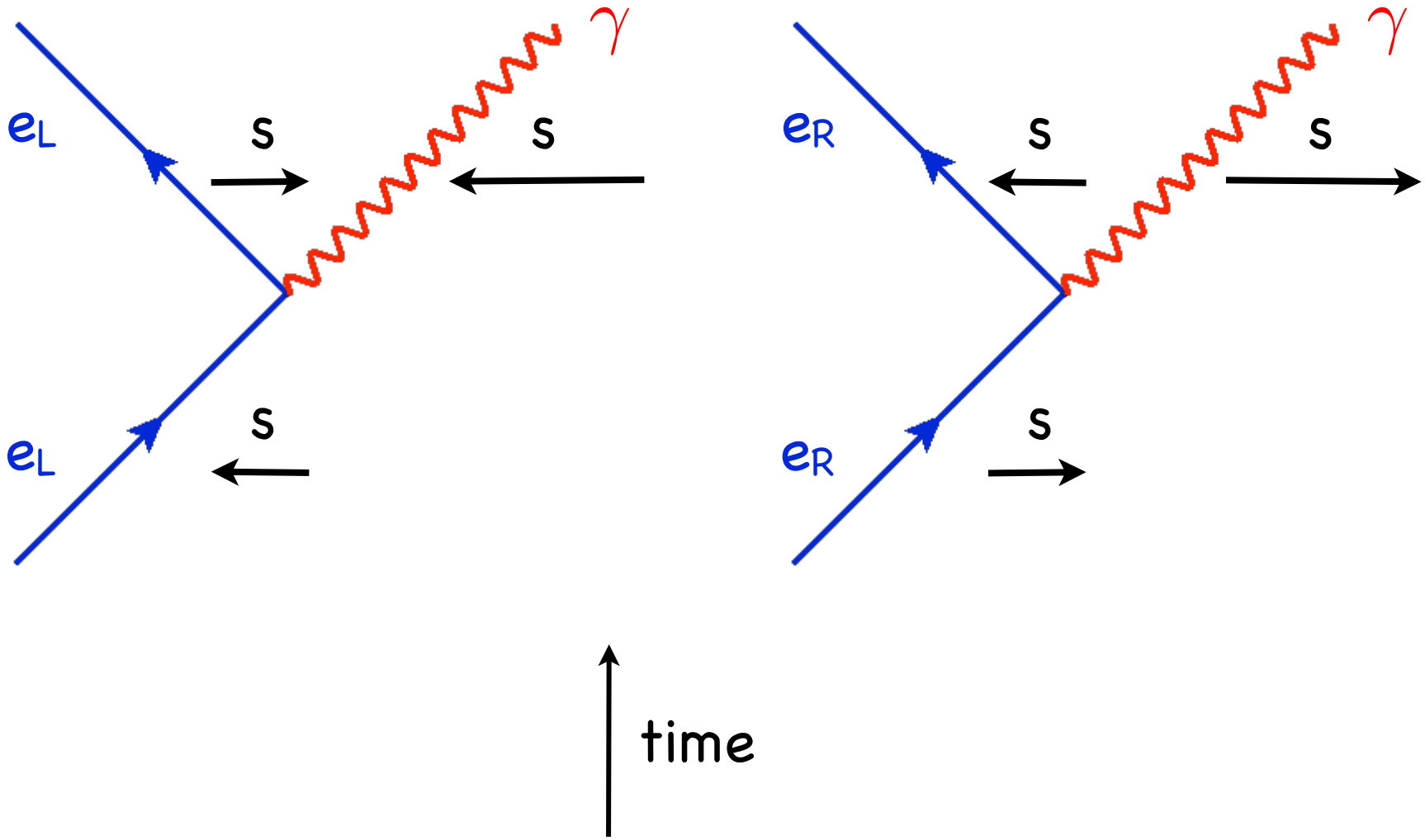
**Leptons** spin = 1/2

| Flavor | Mass GeV/$c^2$ | Electric charge |
|---|---|---|
| $\nu_e$ electron neutrino | $<1\times10^{-8}$ | 0 |
| e electron | 0.000511 | –1 |
| $\nu_\mu$ muon neutrino | <0.0002 | 0 |
| $\mu$ muon | 0.106 | –1 |
| $\nu_\tau$ tau neutrino | <0.02 | 0 |
| $\tau$ tau | 1.7771 | –1 |

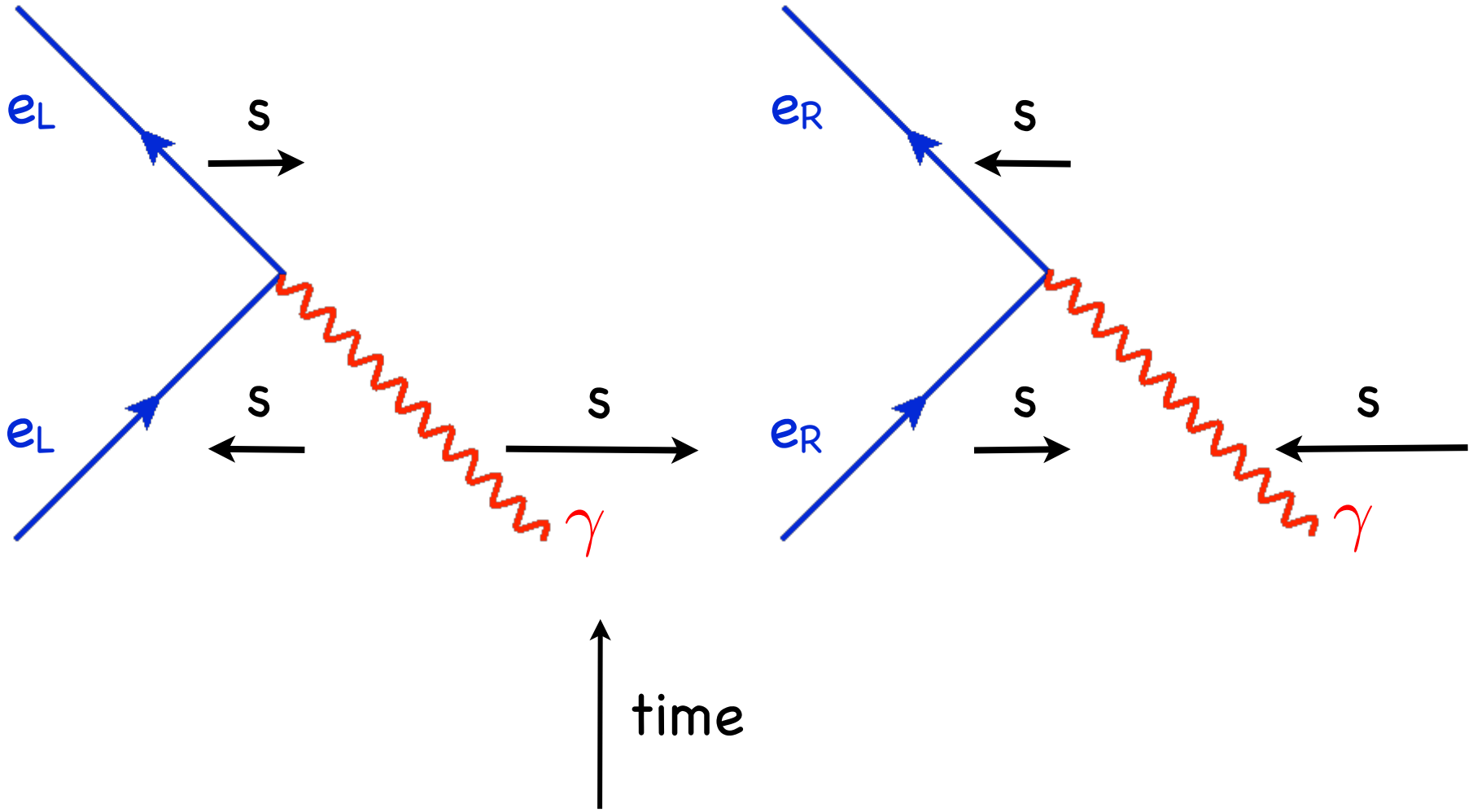
**Quarks** spin = 1/2

| Flavor | Approx. Mass GeV/$c^2$ | Electric charge |
|---|---|---|
| u up | 0.003 | 2/3 |
| d down | 0.006 | –1/3 |
| c charm | 1.3 | 2/3 |
| s strange | 0.1 | –1/3 |
| t top | 175 | 2/3 |
| b bottom | 4.3 | –1/3 |

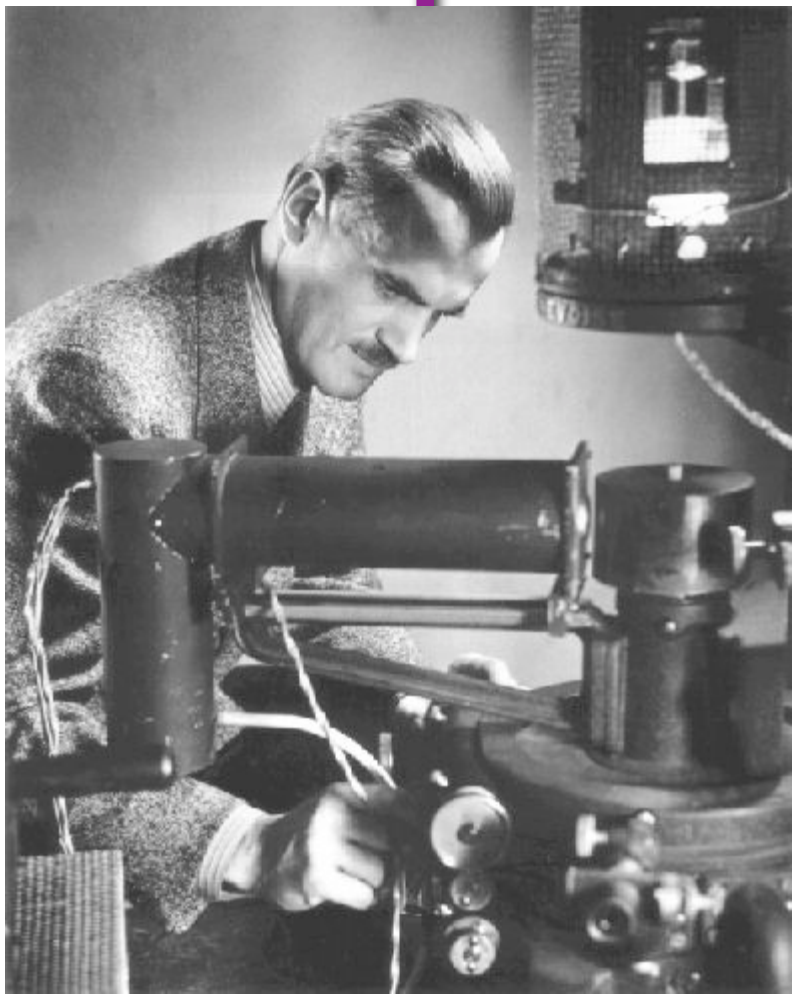
# Emission

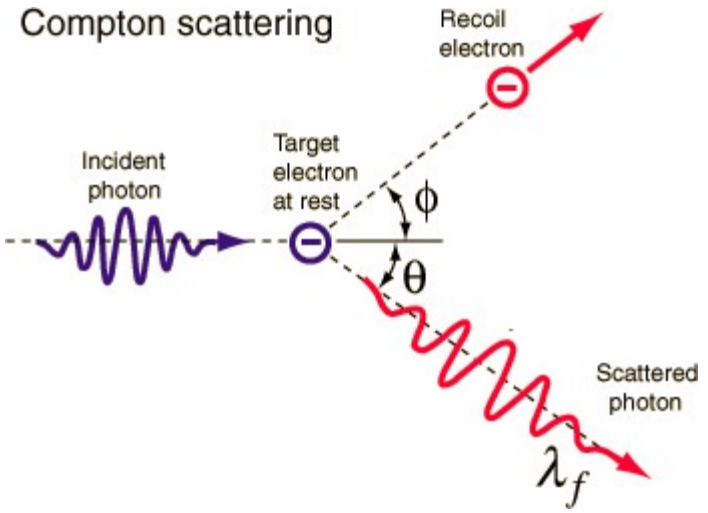


# Absorbtion

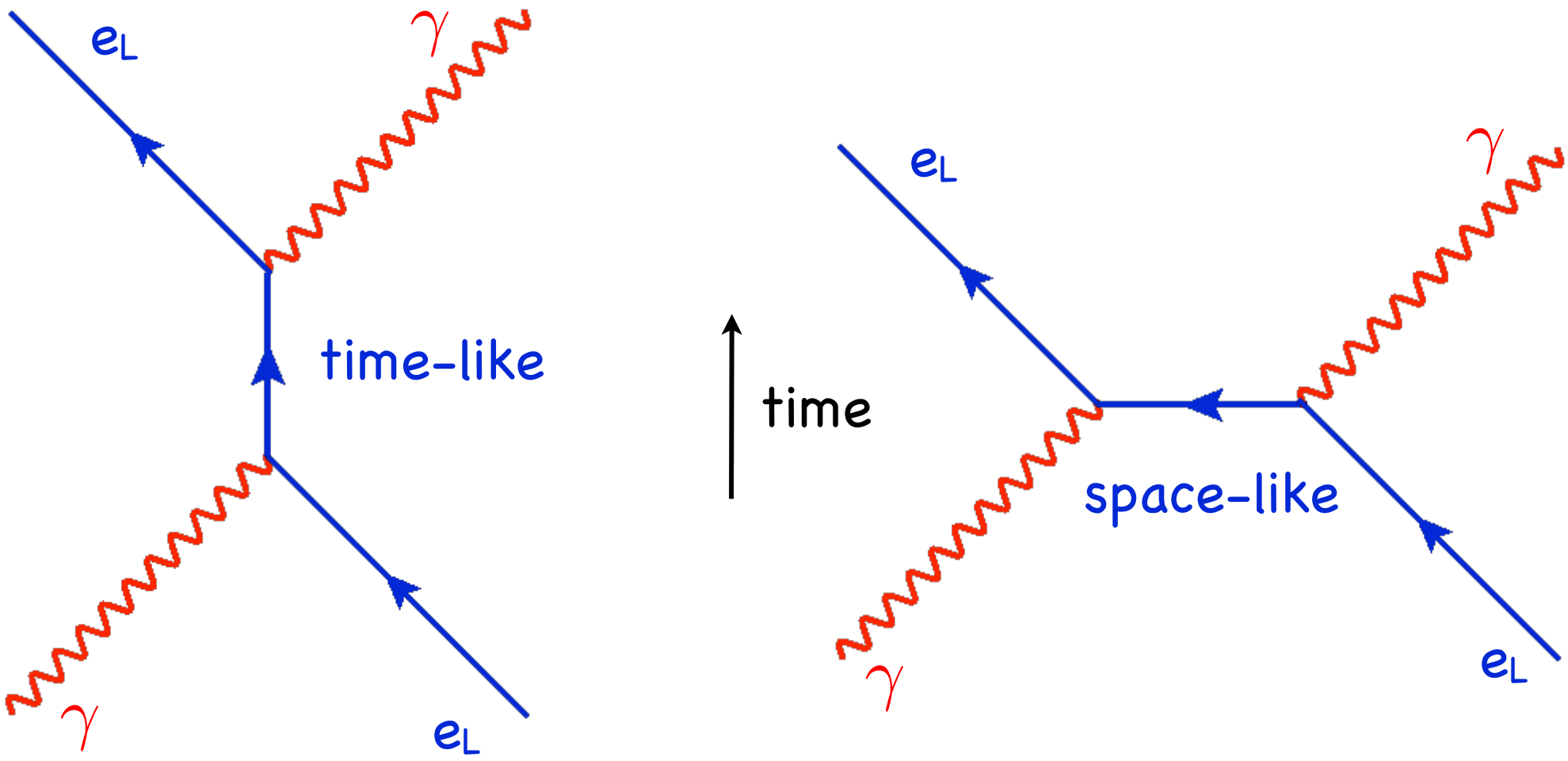


# Compton Scattering



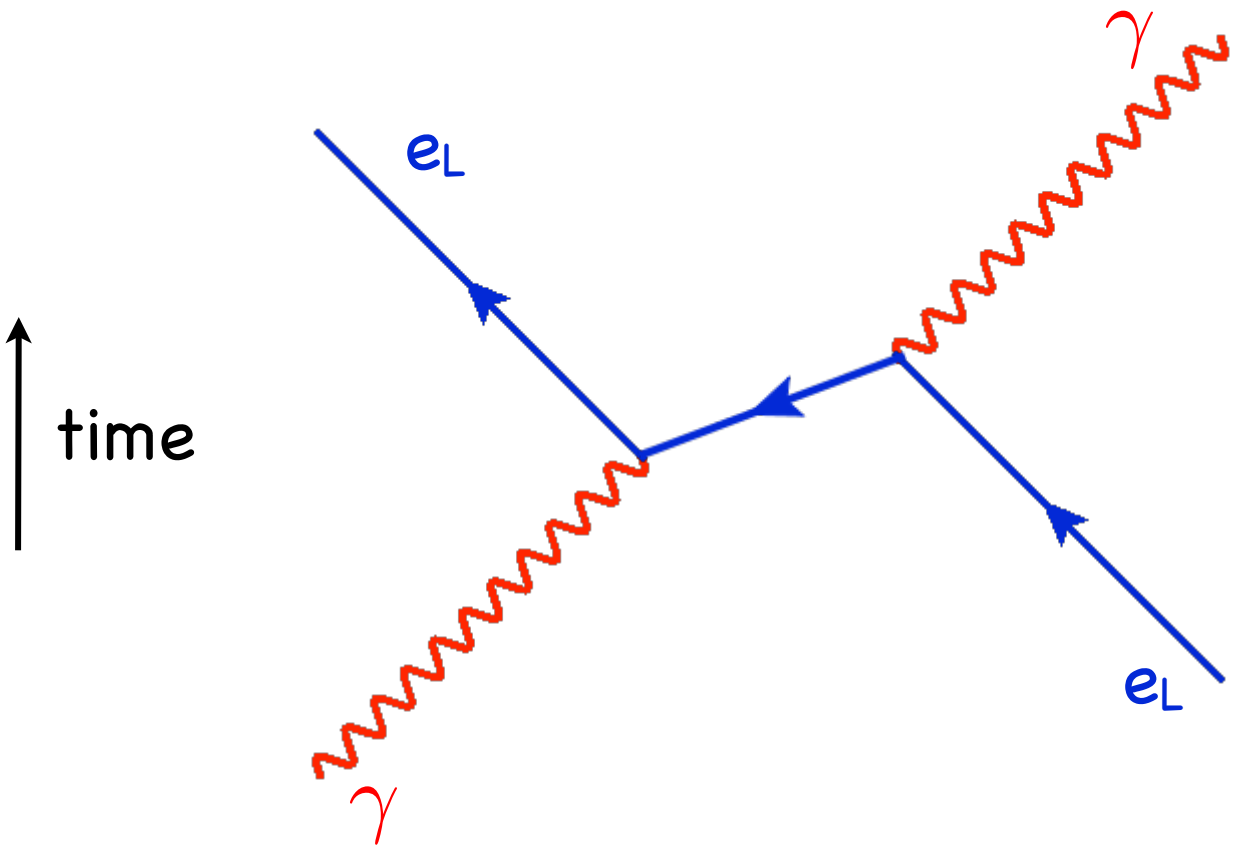


# Scattering

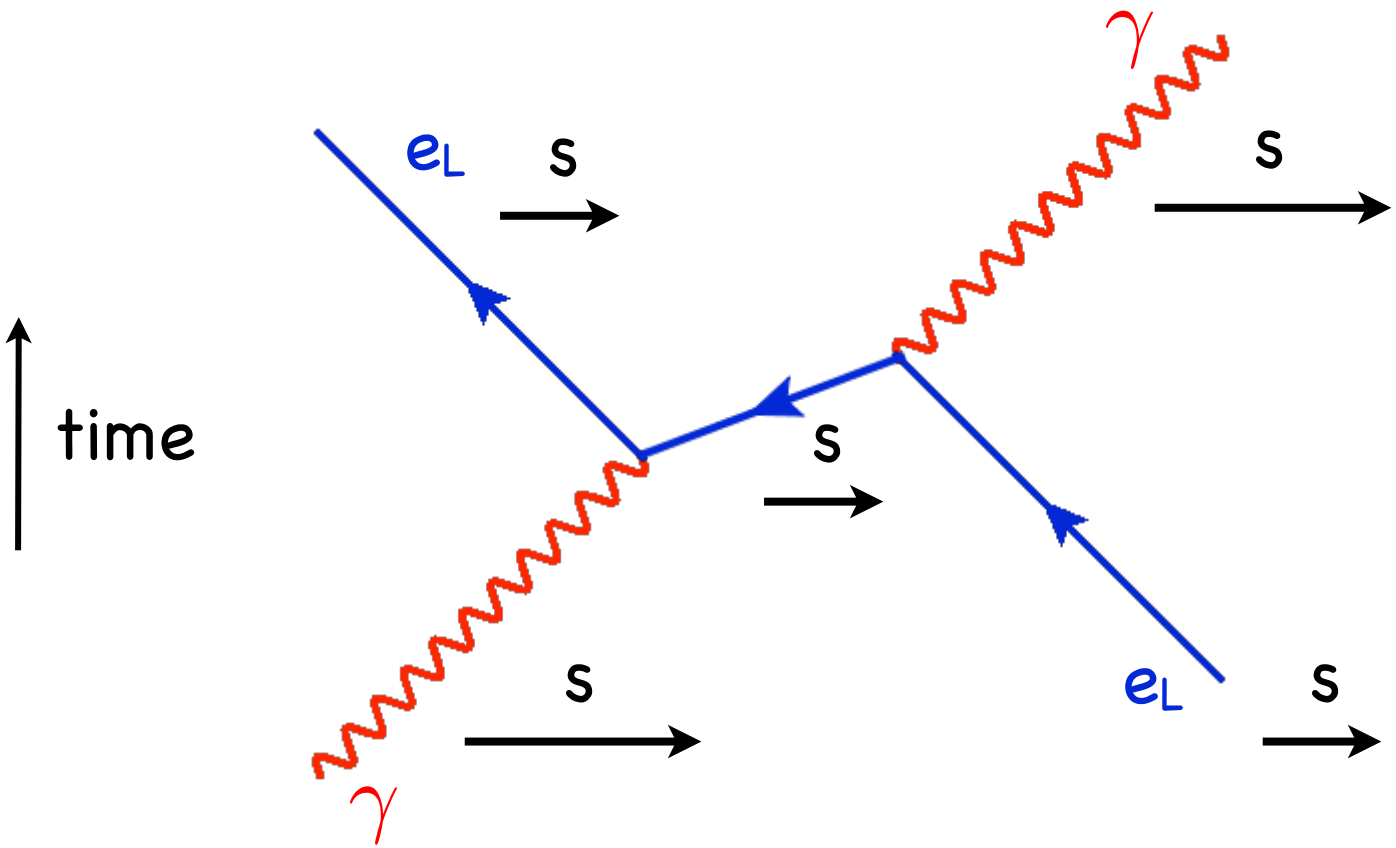



boost changes space or time ordering

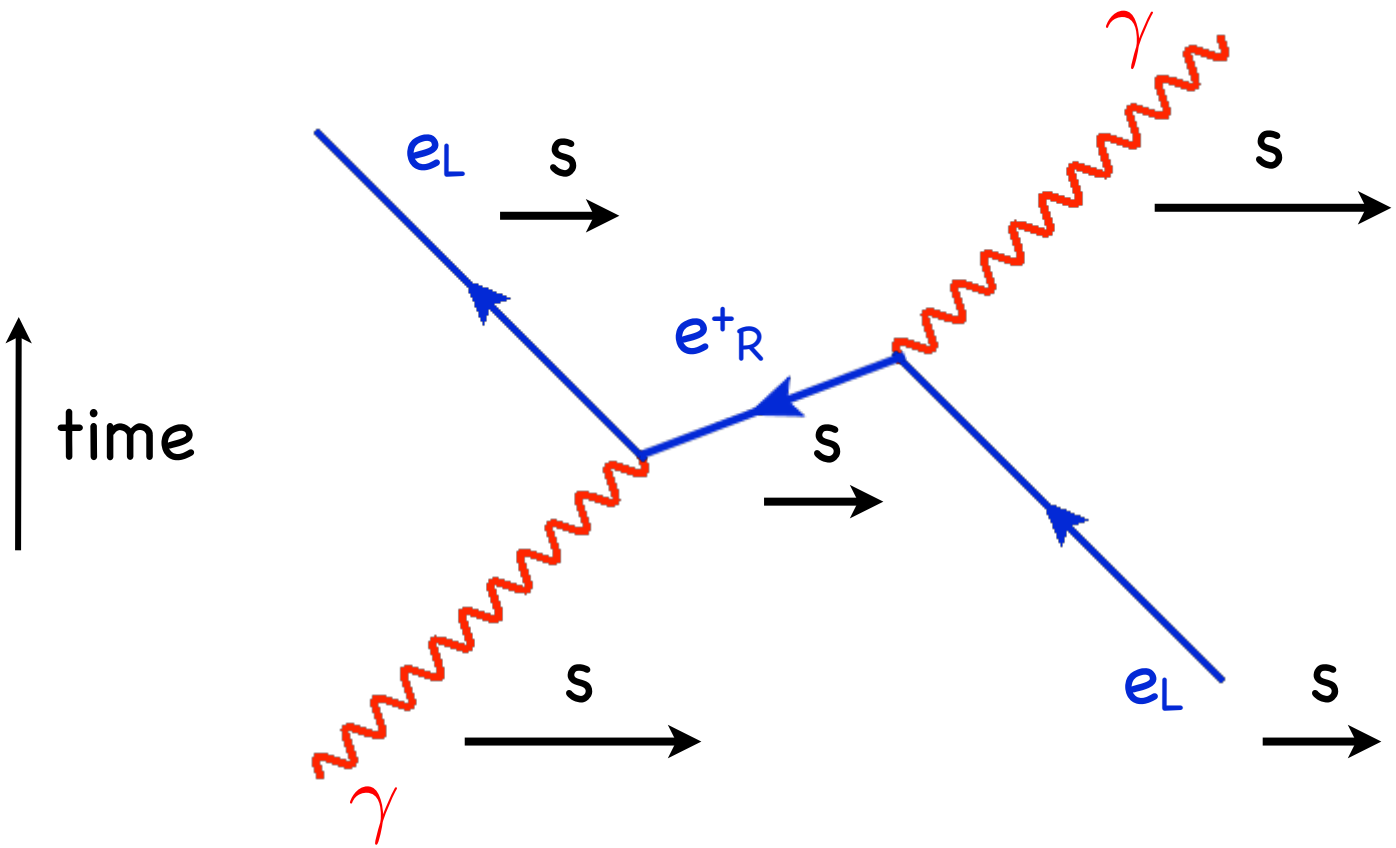
# Scattering



# Scattering

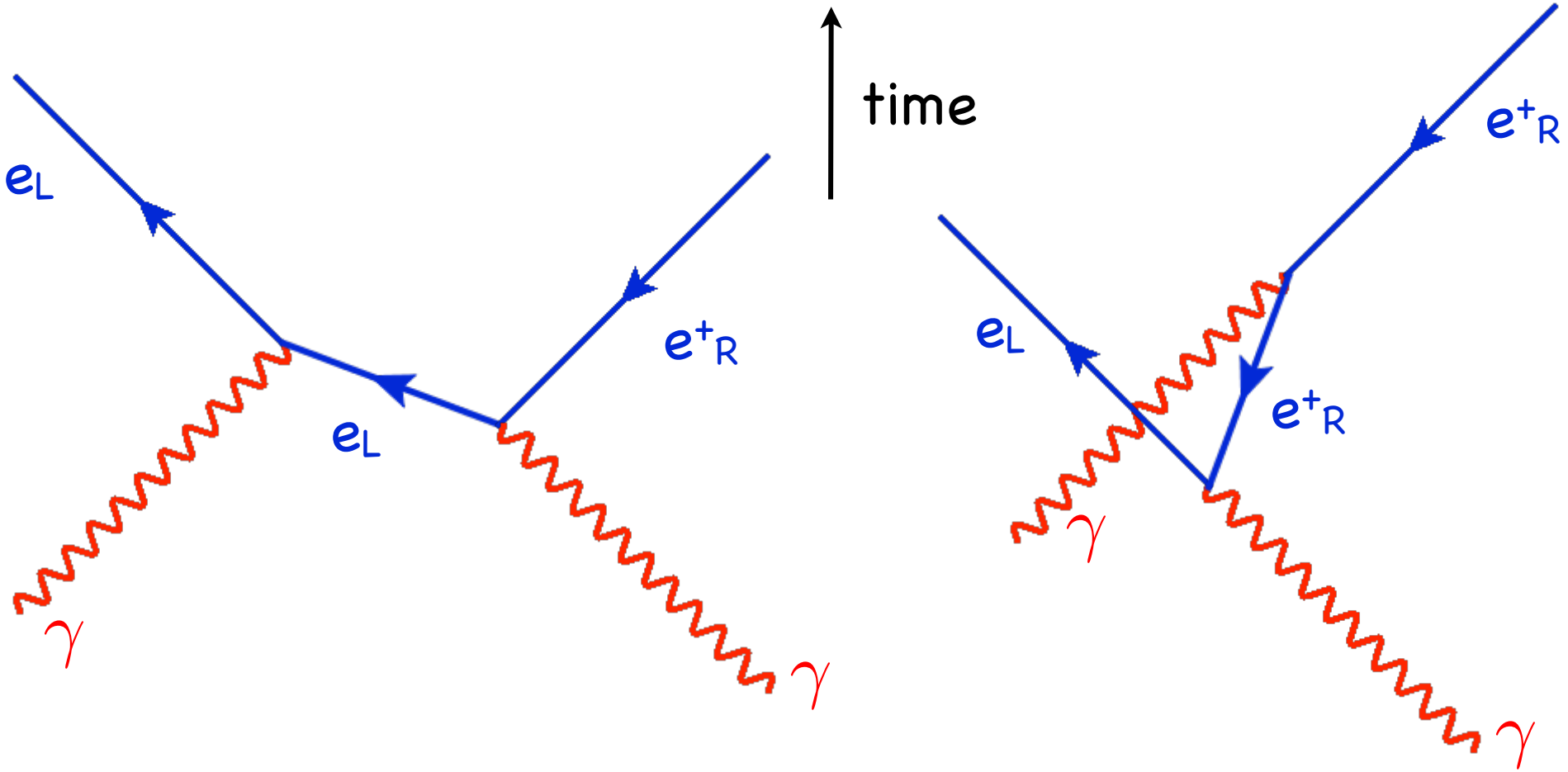


# Scattering

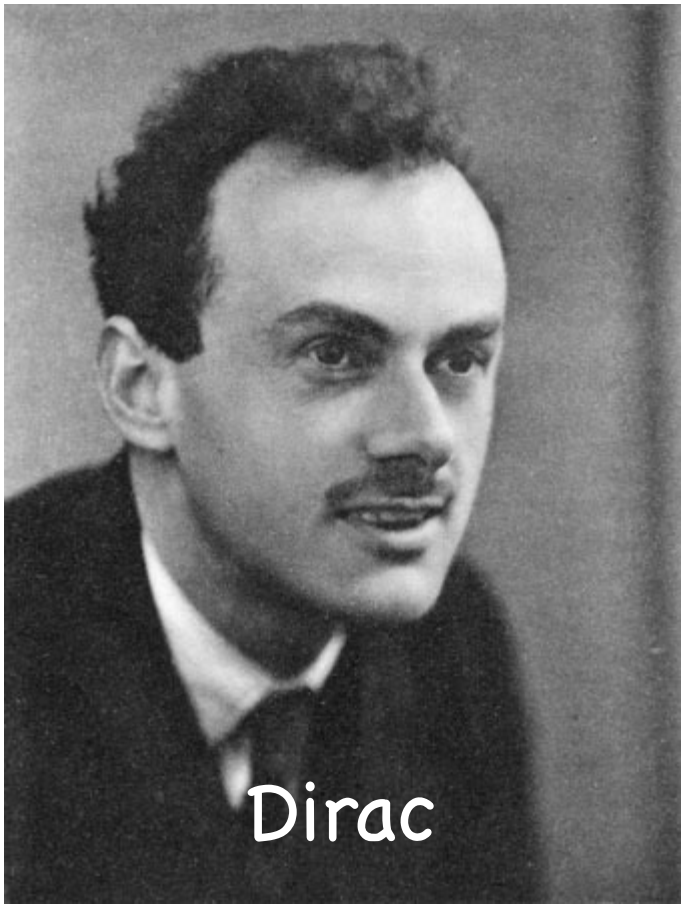



antimatter!

# Pair Creation



# Antimatter



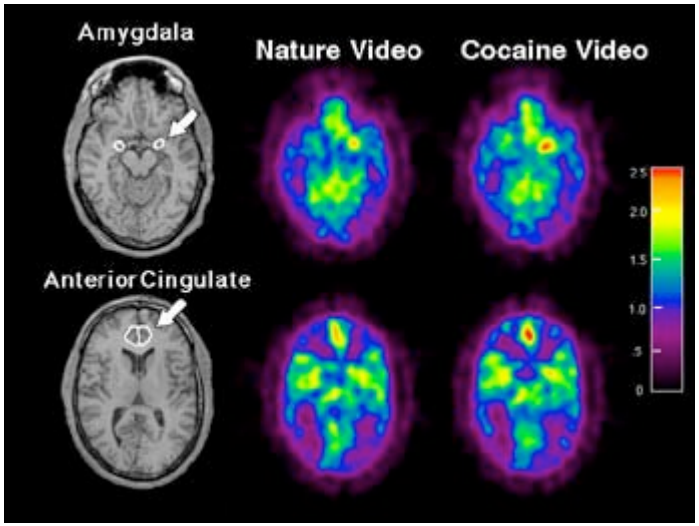

relativity

+

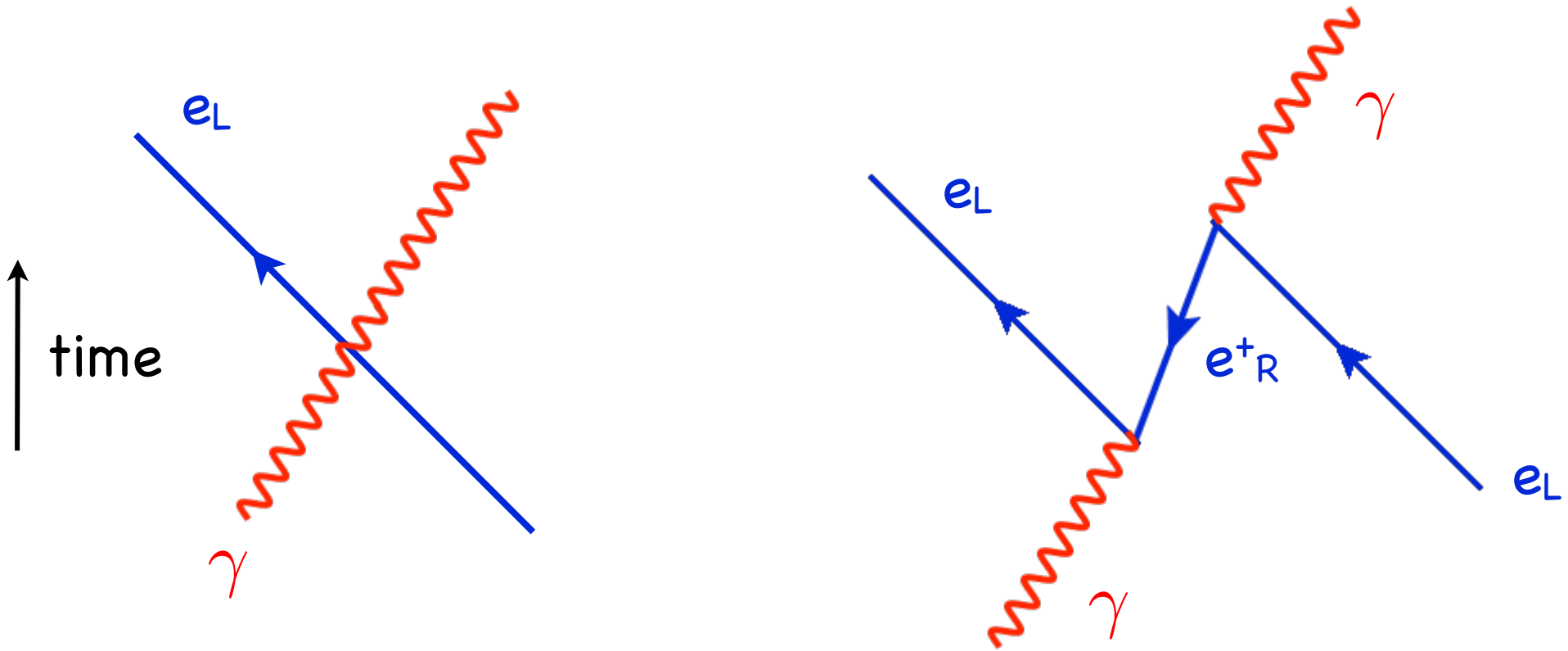
quantum physics



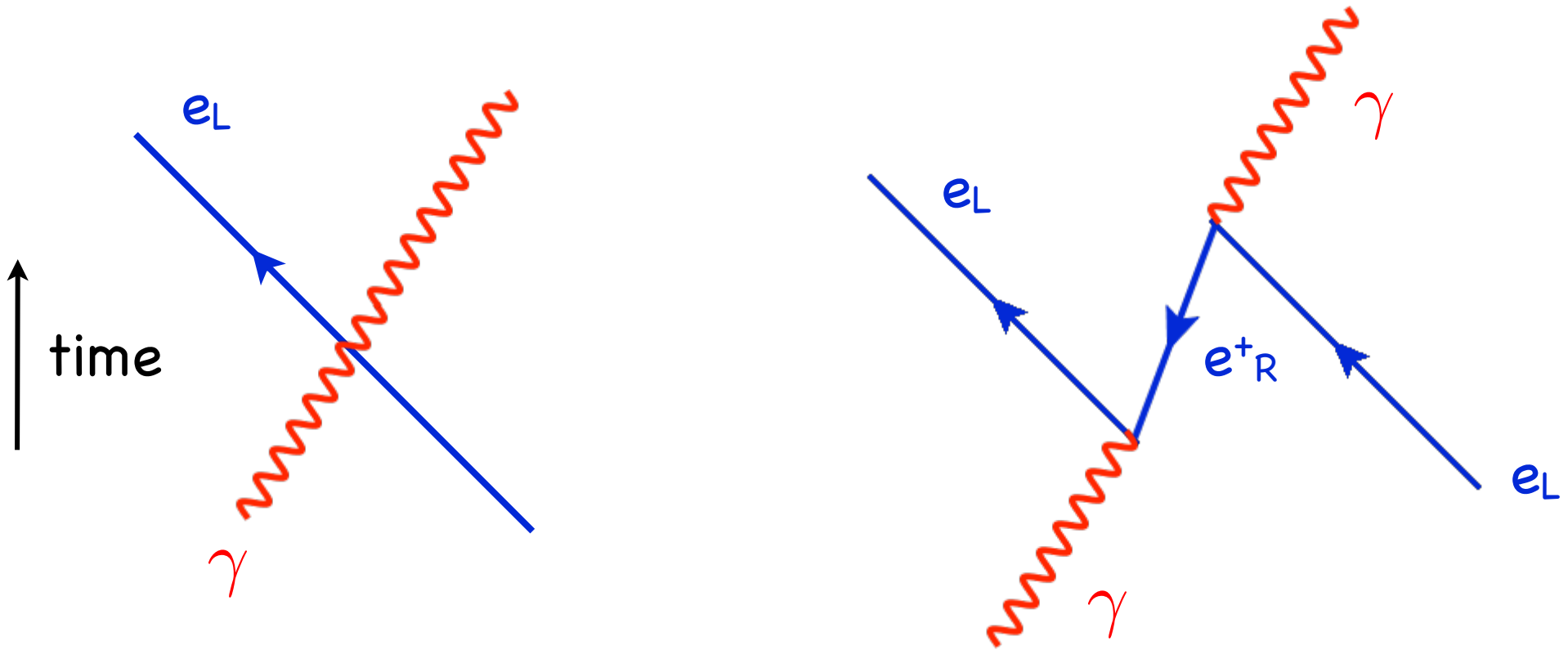
antimatter



# Interchange



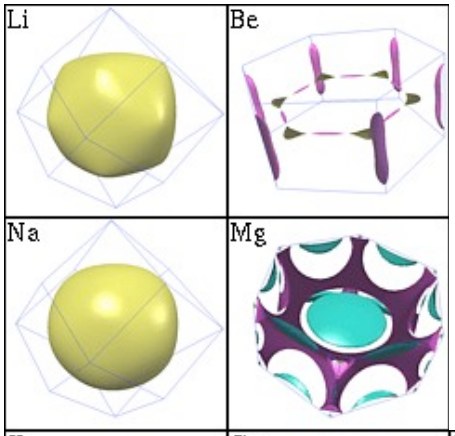
# Interchange

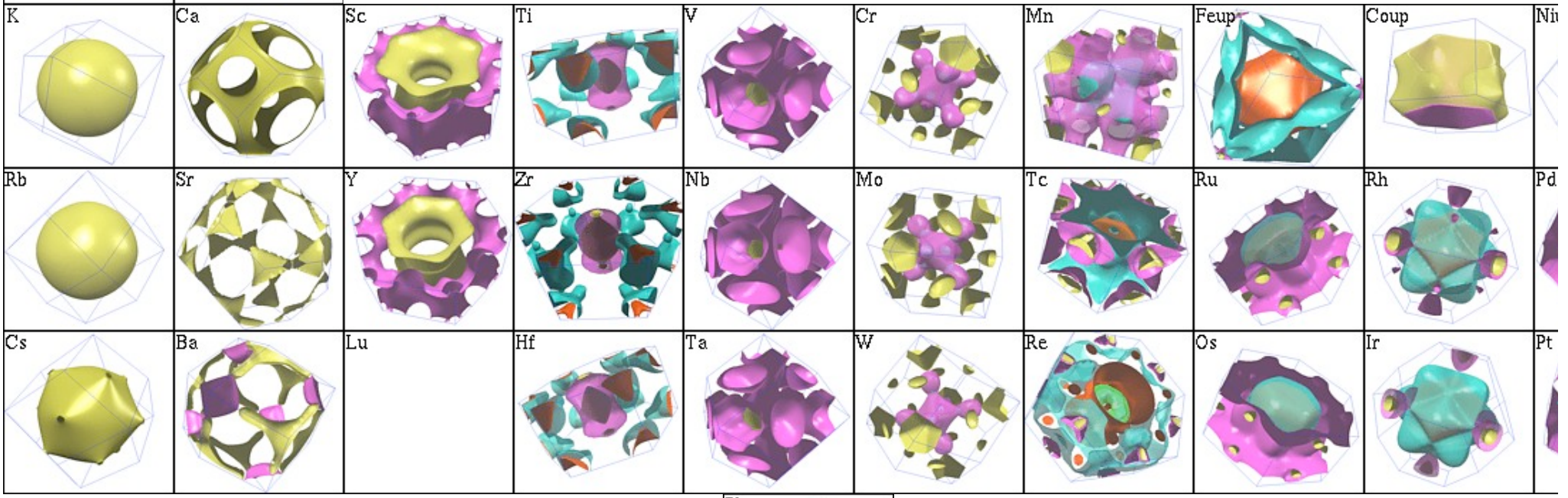


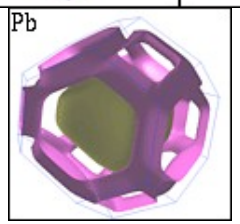

interchange = rotation

# The Fermi Surface Database

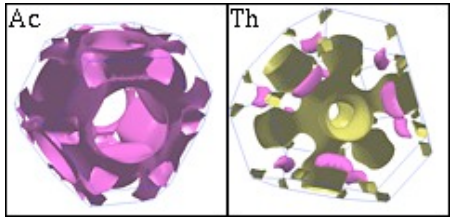
(click icons)




**



# White Dwarf

stabilized against collapse by degeneracy pressure of electrons

radius $R$, e mass $m_e$, nucleon mass $M_p$, e's per nucleon $q$

assume constant density:

$$V = \tfrac{4}{3}\pi R^3, \qquad \rho = \frac{NM_p}{V}$$

$$E = \frac{\hbar^2}{10\pi^2 m_e}\frac{\left(3\pi^2 Nq\right)^{5/3}}{V^{2/3}} = \frac{\hbar^2}{10\pi^2 m_e}\frac{\left(3\pi^2 Nq\right)^{5/3}}{(\pi/3)^{2/3}R^2} = \frac{2\hbar^2}{15\pi m_e}\frac{\left(\frac{9}{4}\pi Nq\right)^{5/3}}{R^2}$$

$$dE_{grav} = -\frac{GM(r)}{r}dM = -\frac{G\left(\rho\frac{4}{3}\pi r^3\right)}{r}\rho\, 4\pi r^2 dr = -\frac{16}{3}\pi^3 G\rho^2\, r^4 dr$$

$$E_{grav} = -\frac{16}{3}\pi^3 G\rho^2 \int_0^R r^4 dr = -\frac{16}{15}\pi^3 G\rho^2\, R^5 = -\frac{3}{5}\pi^3\frac{GN^2M_p^2}{R}$$

$$E_{tot} = E + E_{grav} = \frac{A}{R^2} - \frac{B}{R}$$

$$\frac{dE_{tot}}{dR} = -2\frac{A}{R^3} + \frac{B}{R^2} = 0$$

$$2A = BR$$

# White Dwarf

$$R = \frac{2A}{B} = \frac{4\hbar^2}{15\pi m_e}\left(\frac{9}{4}\pi N_q\right)^{5/3}\frac{5}{3\pi^3 G N^2 m^2}$$
$$= \left(\frac{9\pi}{4}\right)^{2/3}\frac{\hbar^2}{GM_p^2 m_e}\frac{q^{5/3}}{N^{1/3}} = \frac{7.6\times 10^{25}\text{m}}{N^{1/3}}$$

for a solar mass $N \approx 1.2 \times 10^{57}$, $R \approx 7 \times 10^6$ m

$$E_F = \frac{\hbar^2}{2m_e}\left(3\pi^2\frac{Nq}{V}\right)^{2/3} = \frac{\hbar^2}{2m_e R^2}\left(\frac{9\pi}{4}Nq\right)^{2/3} = 1.9\times 10^5 eV$$

$$E_{rest} = m_e c^2 = 5.11\times 10^5 eV$$

$\uparrow N \Rightarrow R \downarrow\ E_F \uparrow$, more relativistic