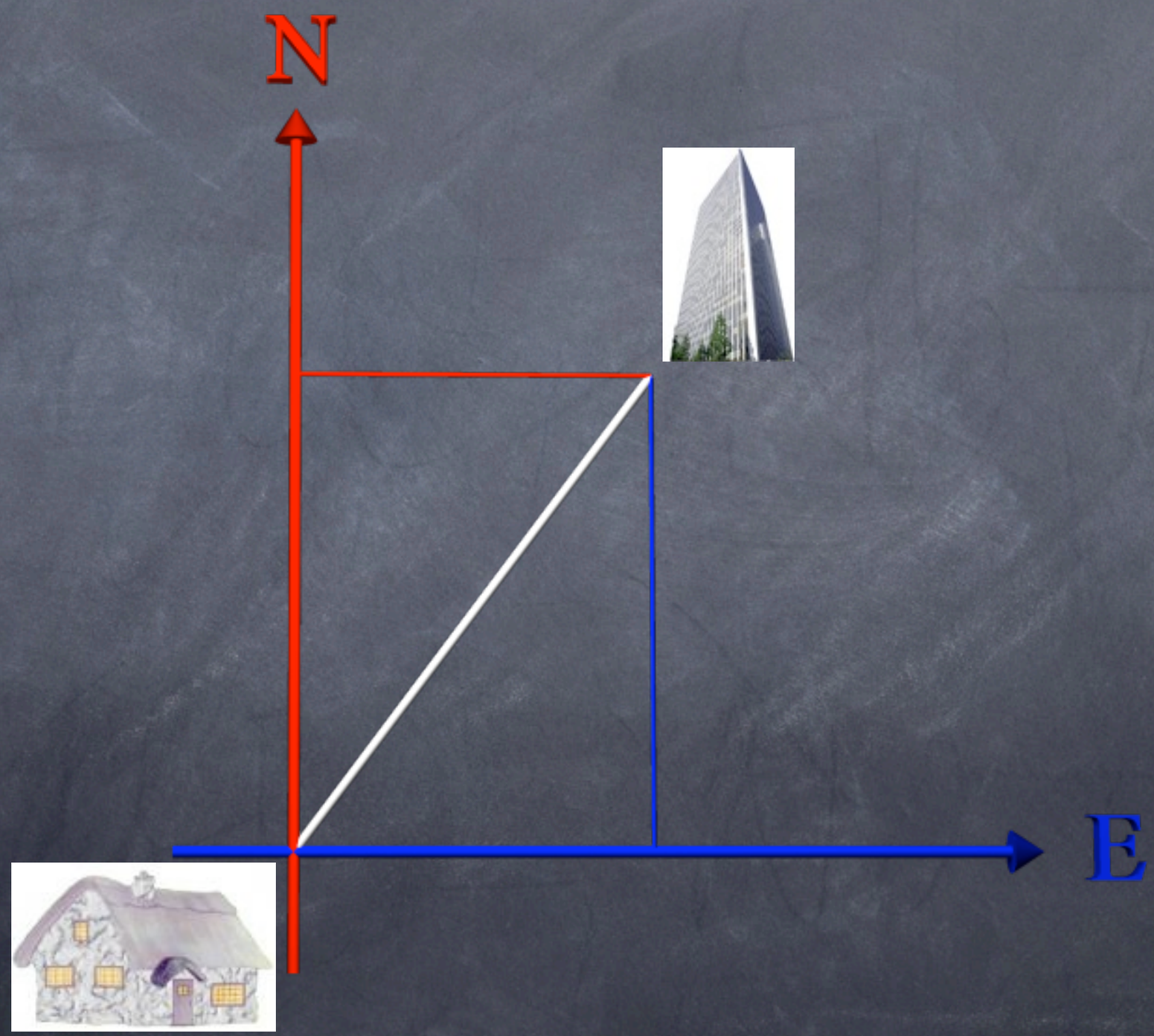
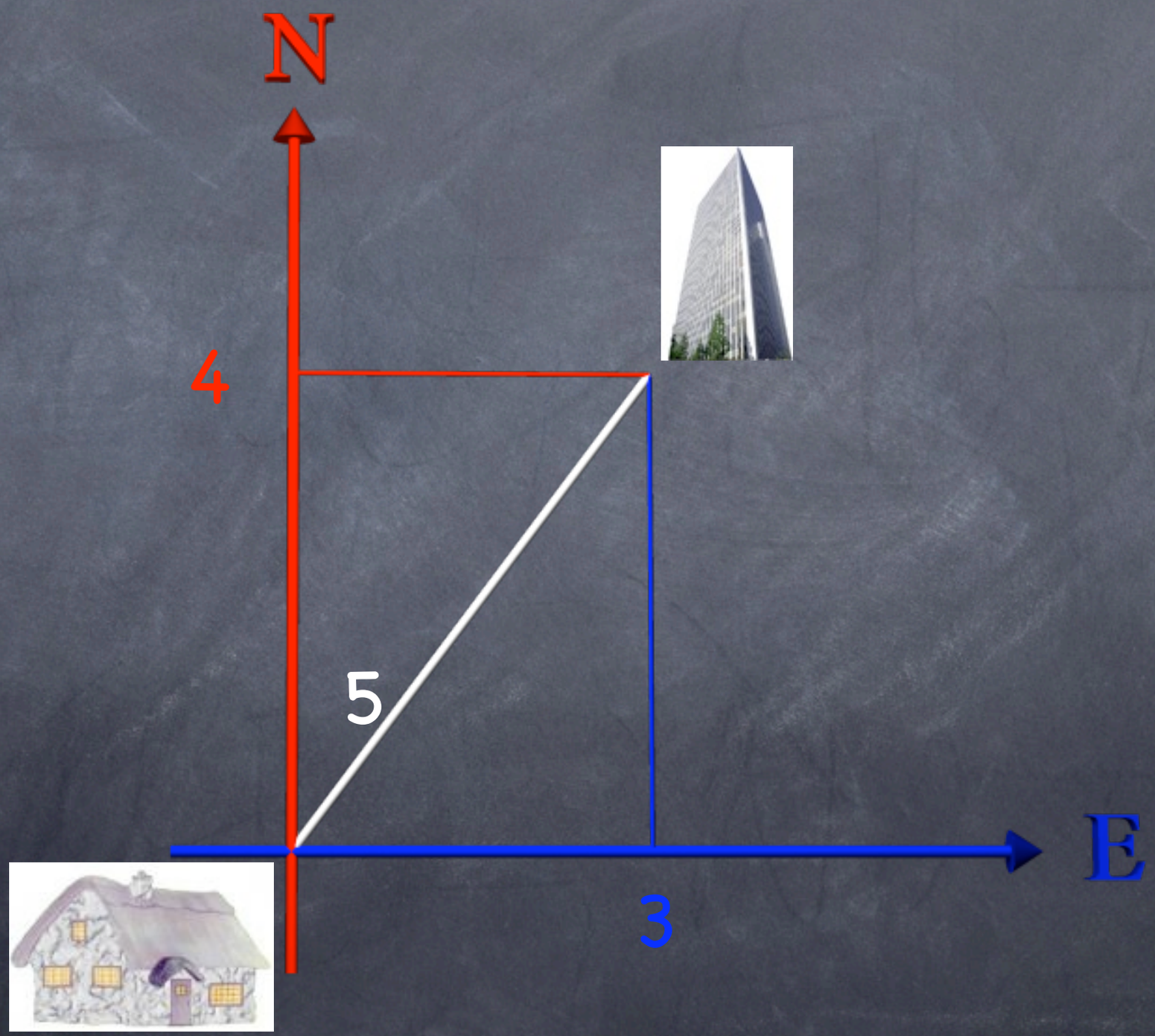
Chapter 9: Symmetry

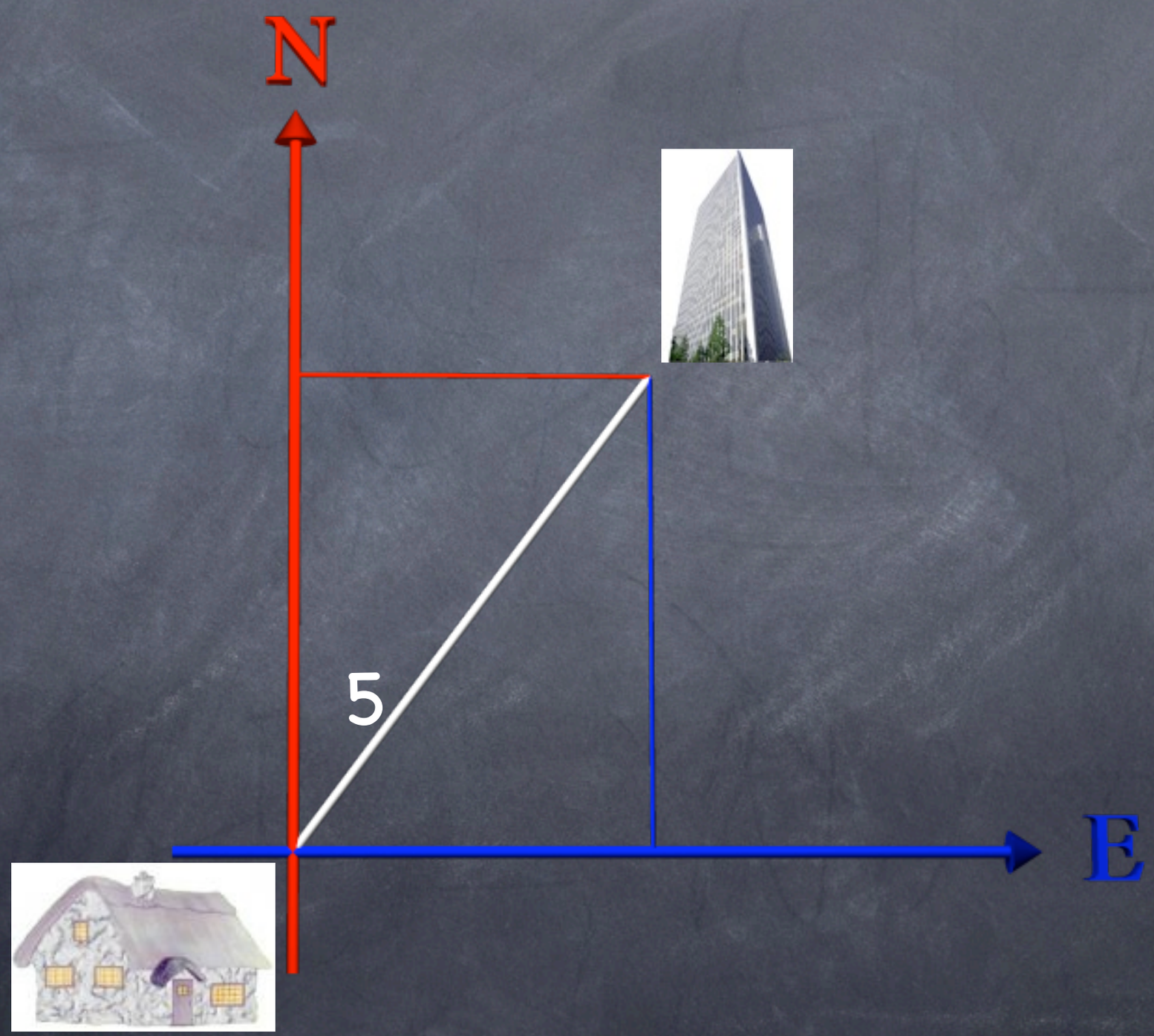
Rotations



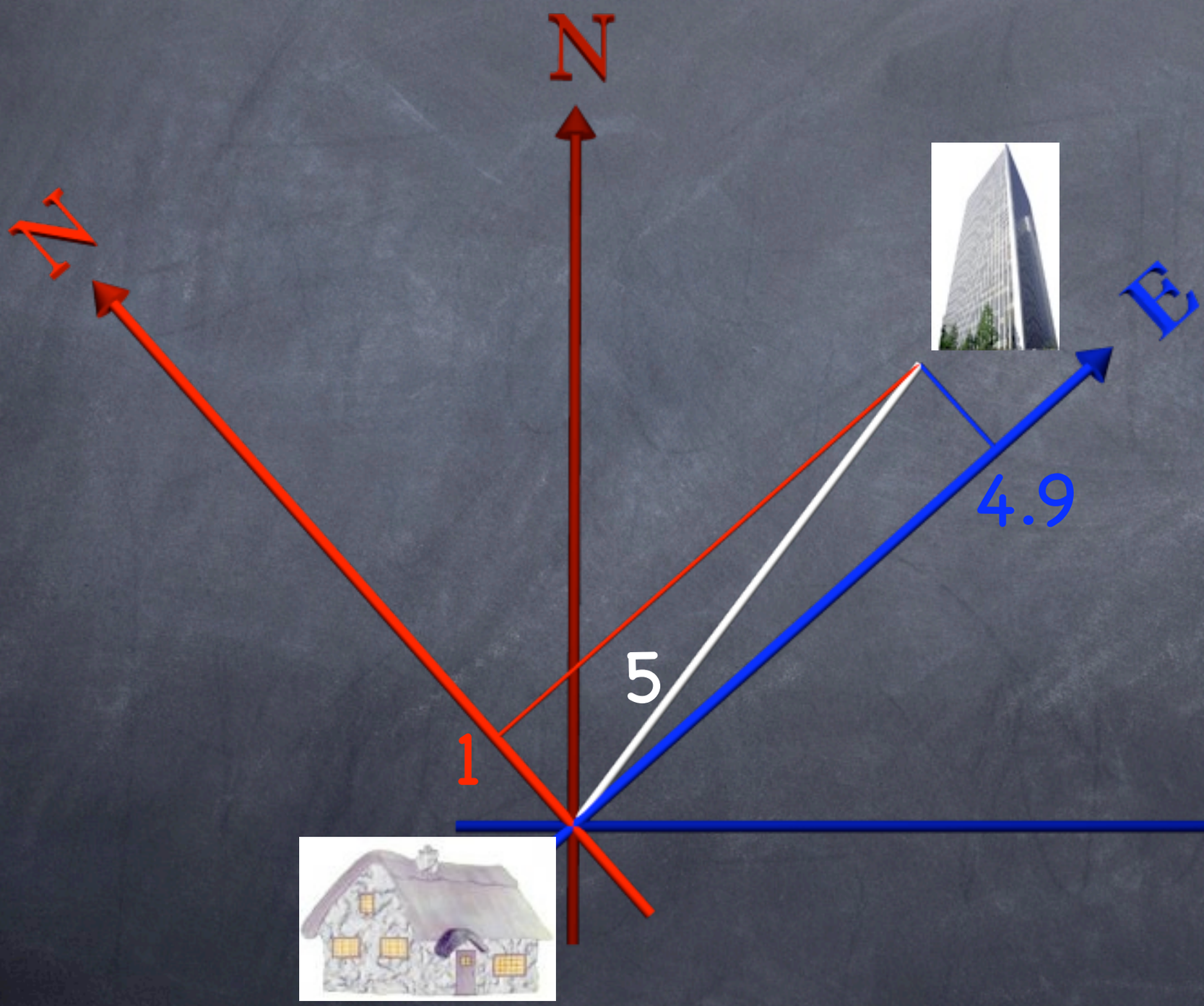
Rotations



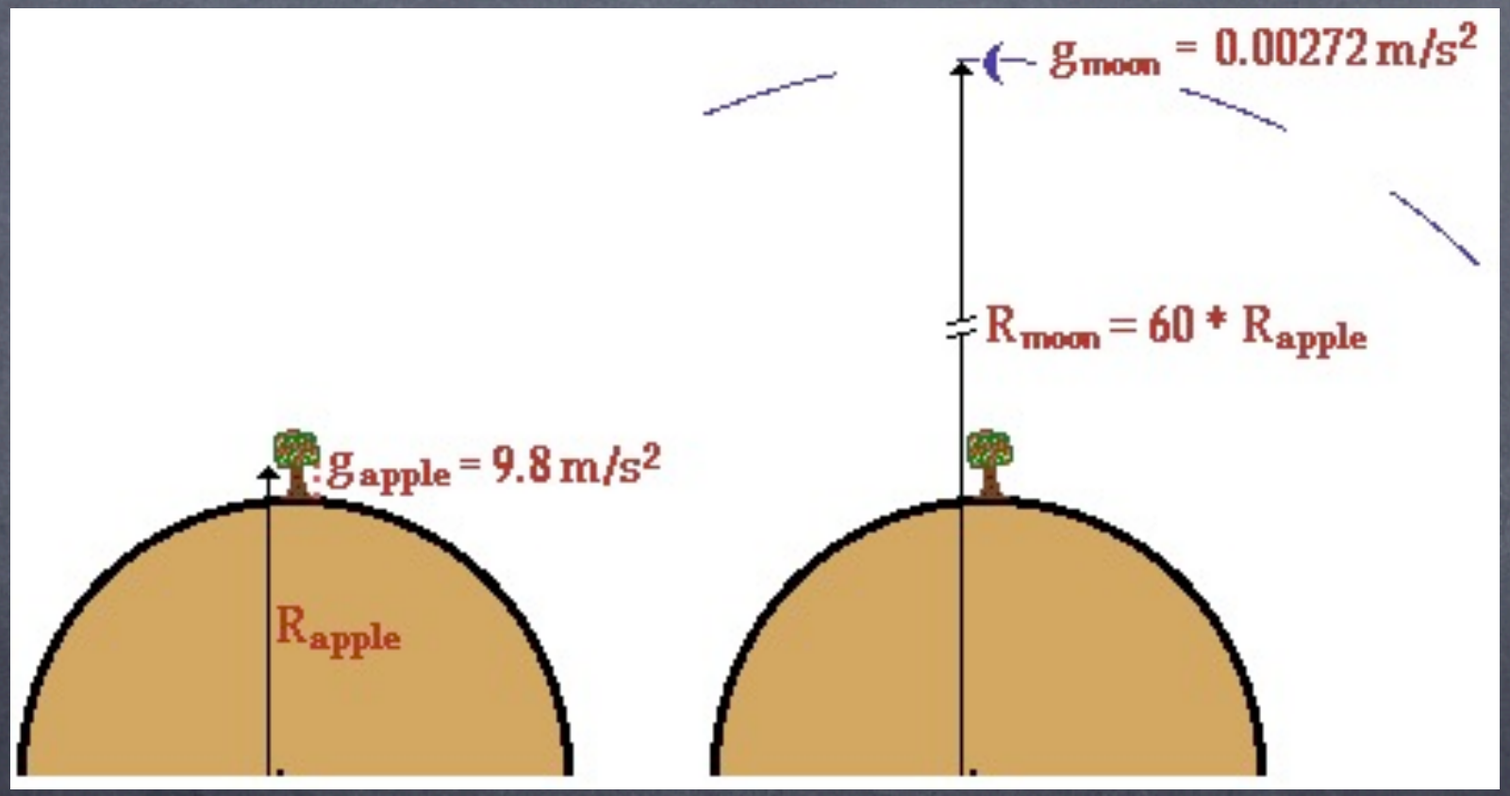
Rotations



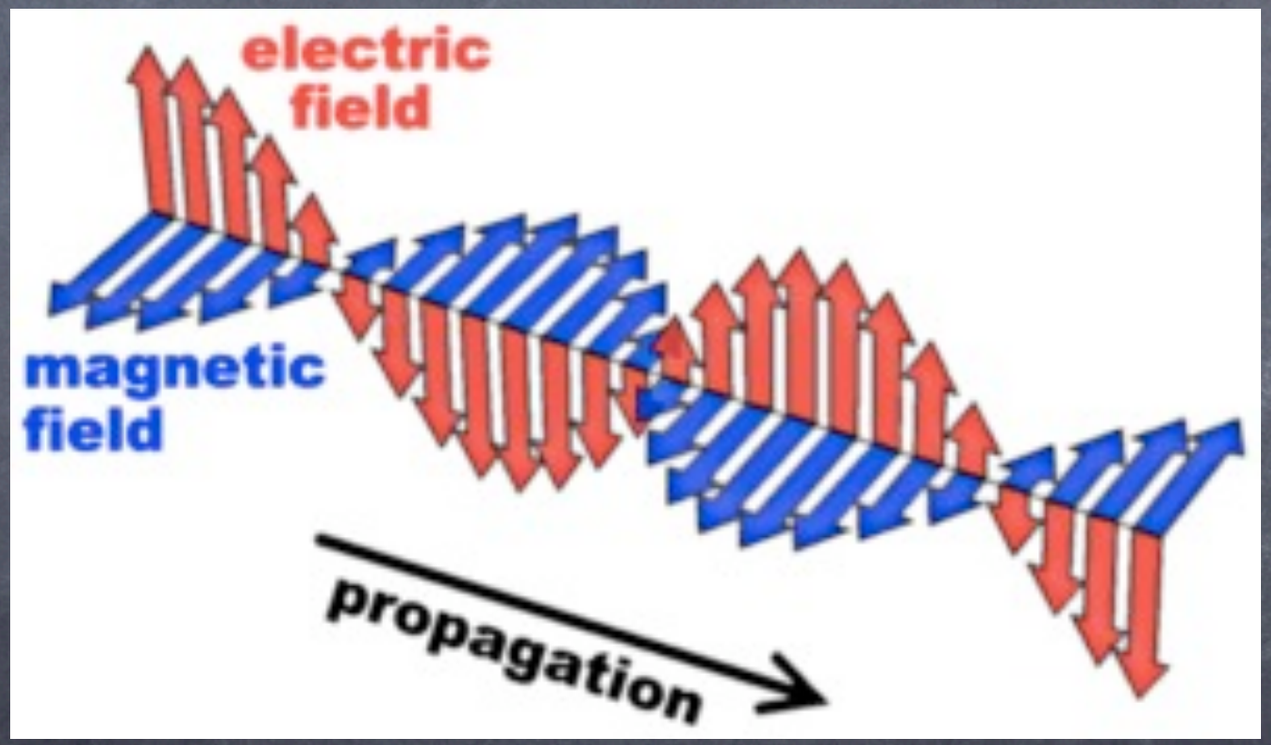
Rotations



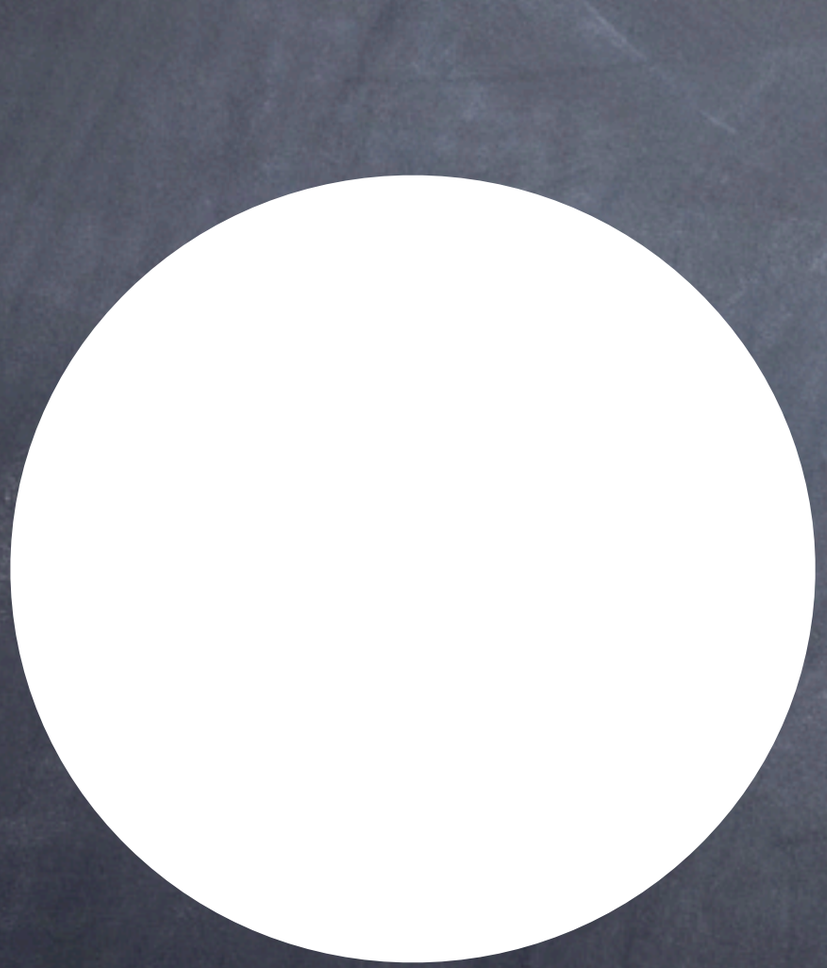
Translational and Rotational Symmetry



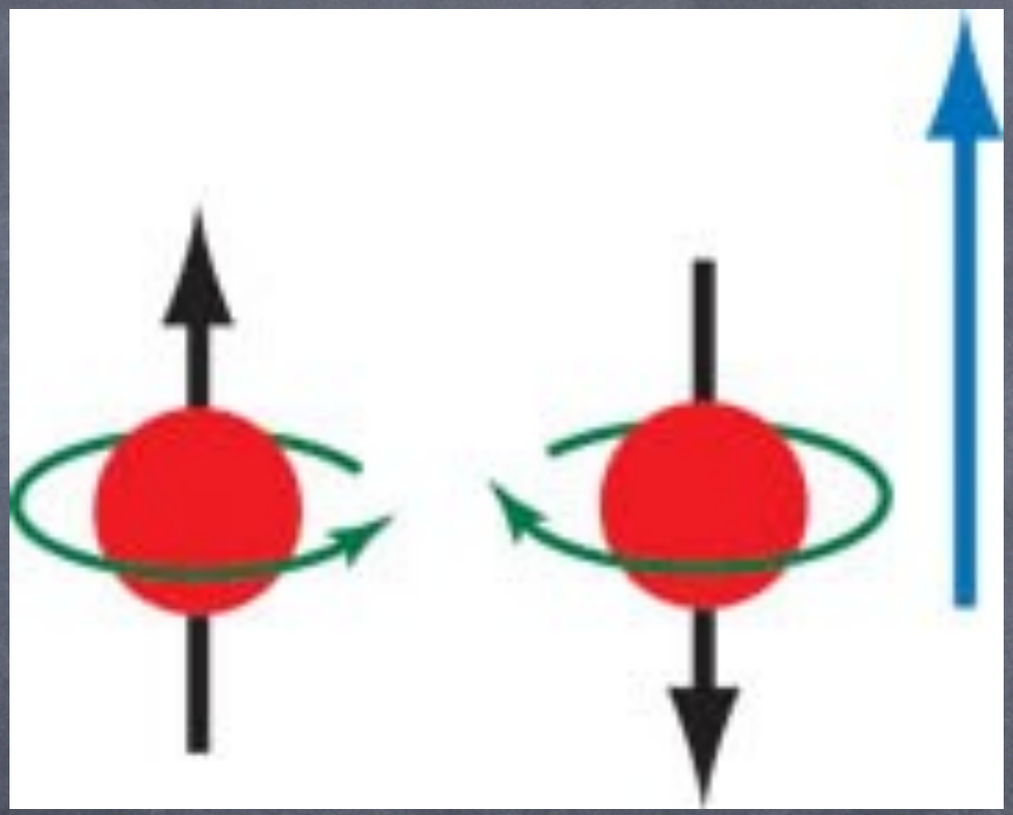
Light Wave



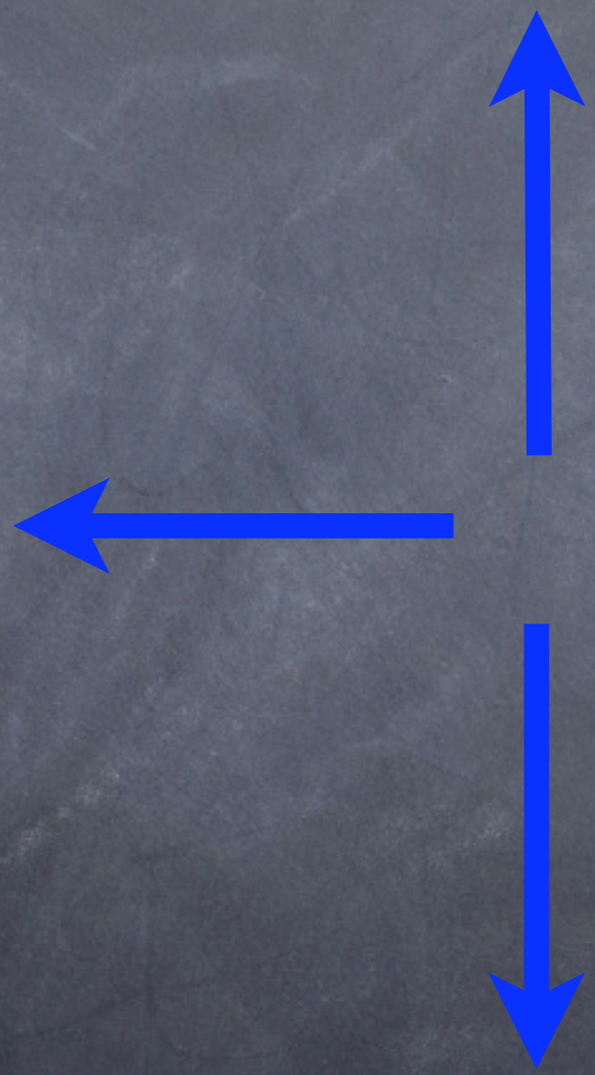
Quantum Spin



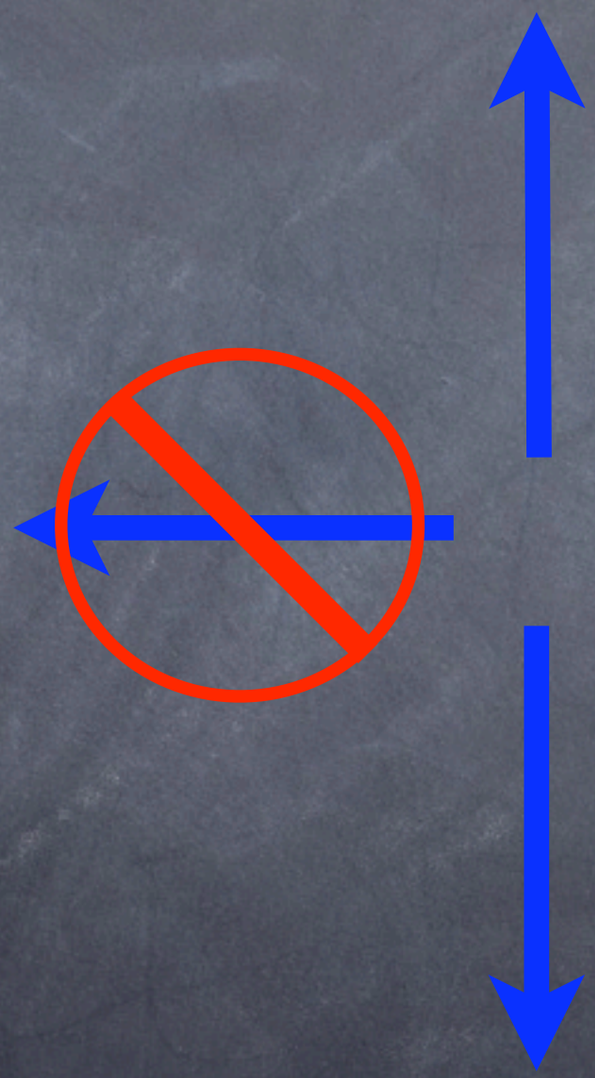
Photon Spin



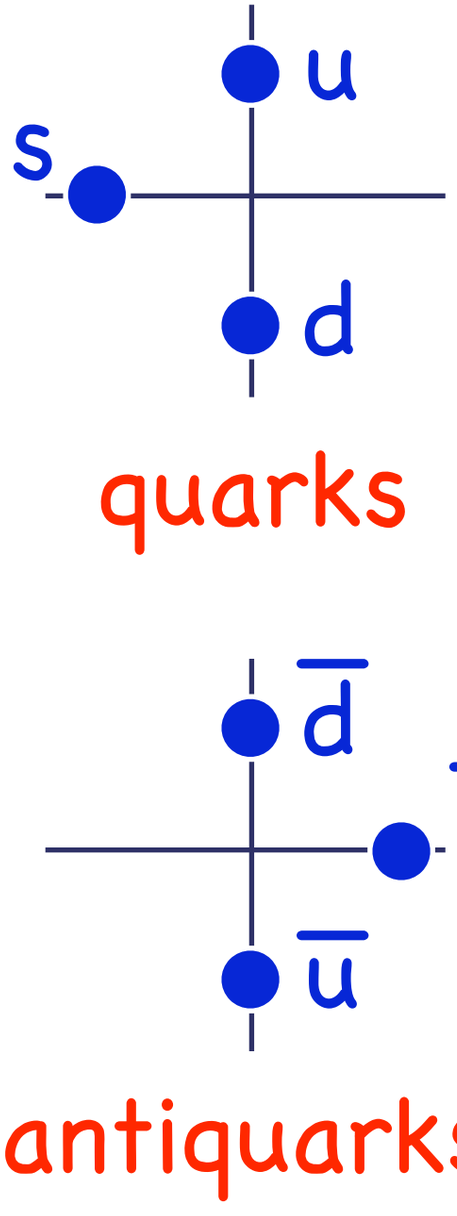
Massive Spin 1 at Rest



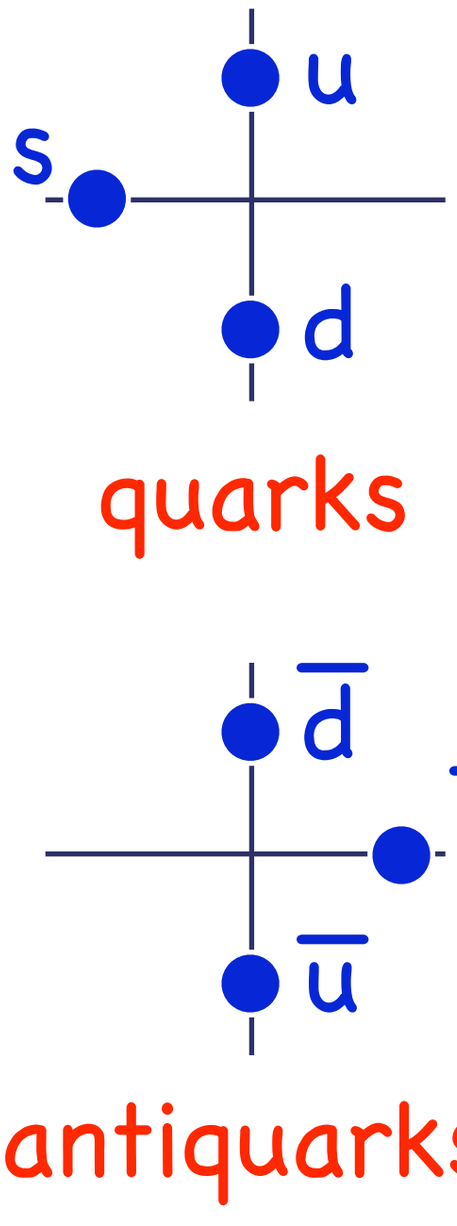
Gauge Symmetry



SU(3) Flavor



SU(3) Flavor


u
s
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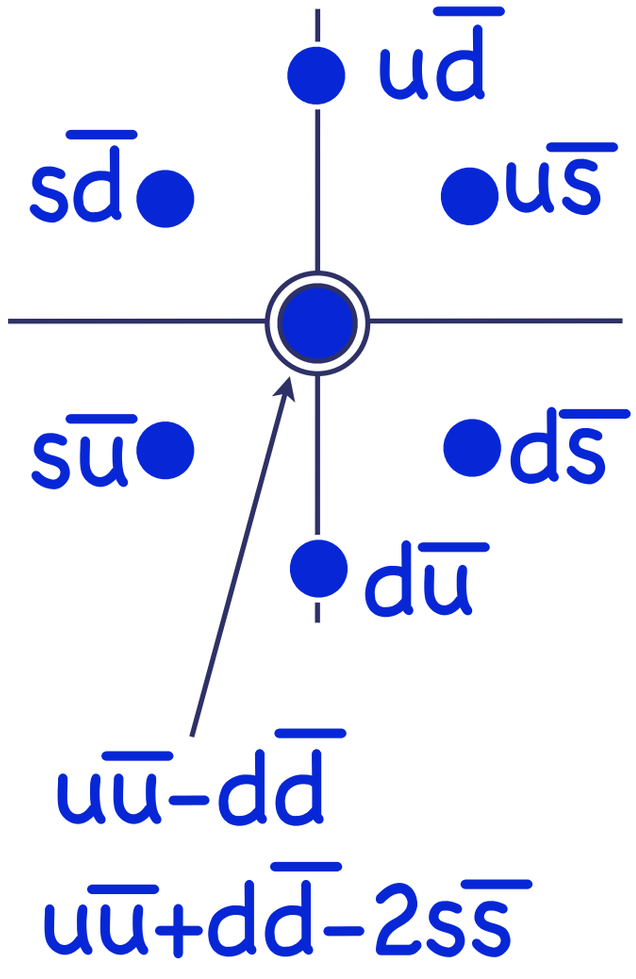
quarks
$\bar{d}$
$\bar{s}$
$\bar{u}$
antiquarks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$u\bar{s}$
$s\bar{u}$
$d\bar{s}$
$d\bar{u}$
$u\bar{u}-d\bar{d}$
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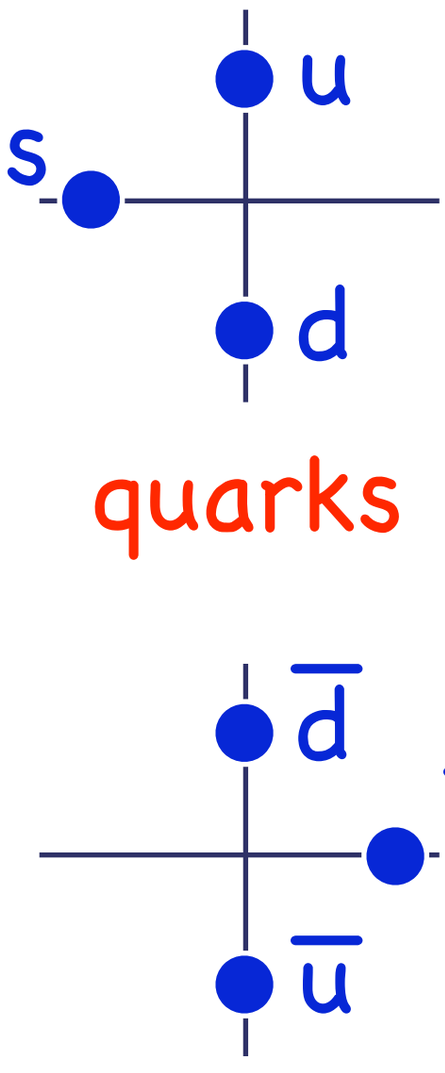
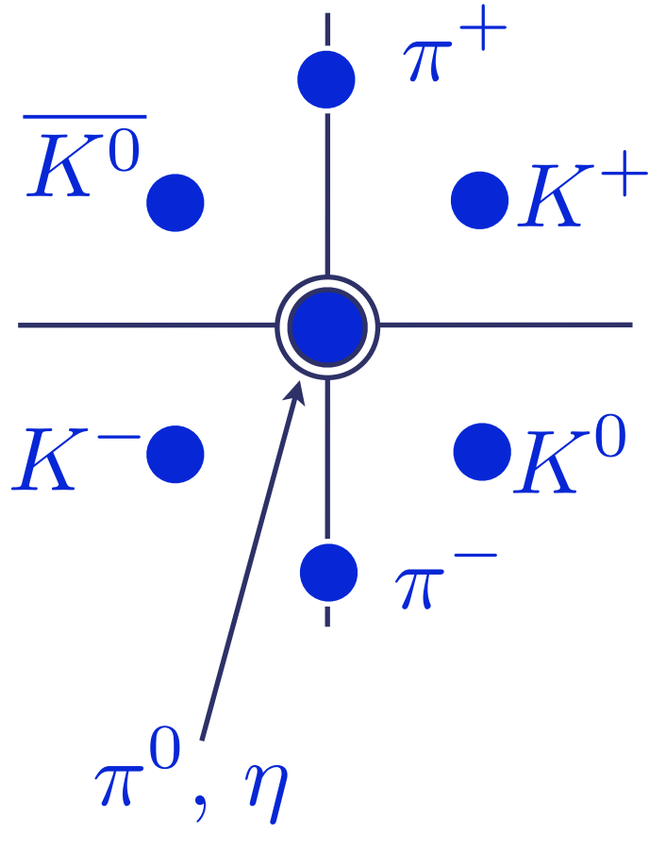
SU(3) Flavor



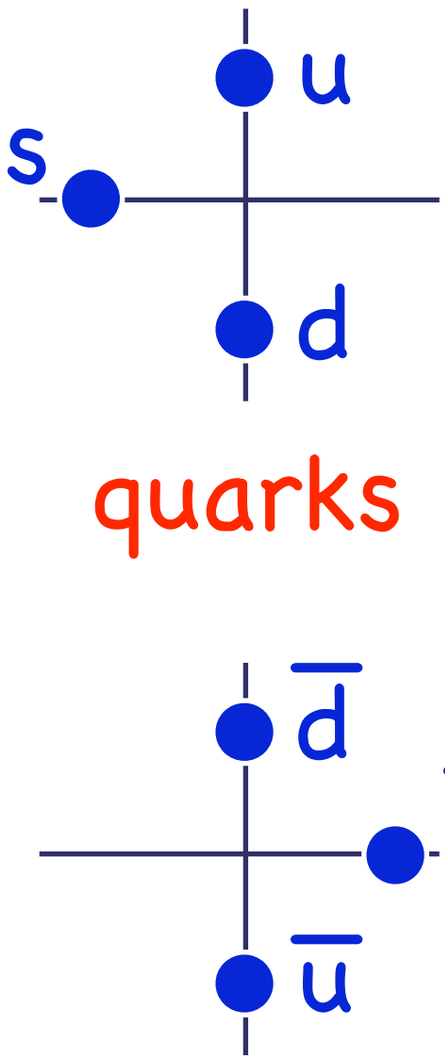
quarks

antiquarks



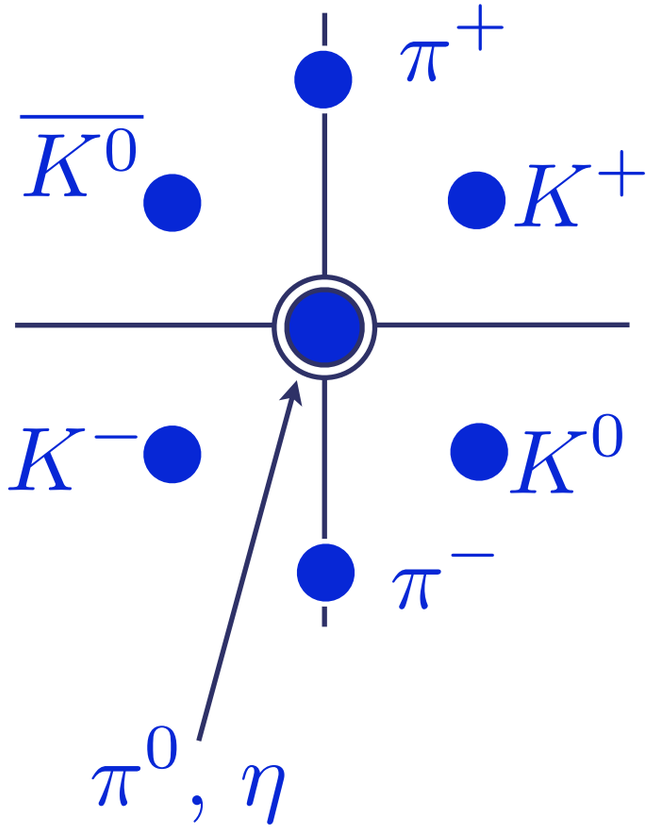
mesons

SU(3) Flavor

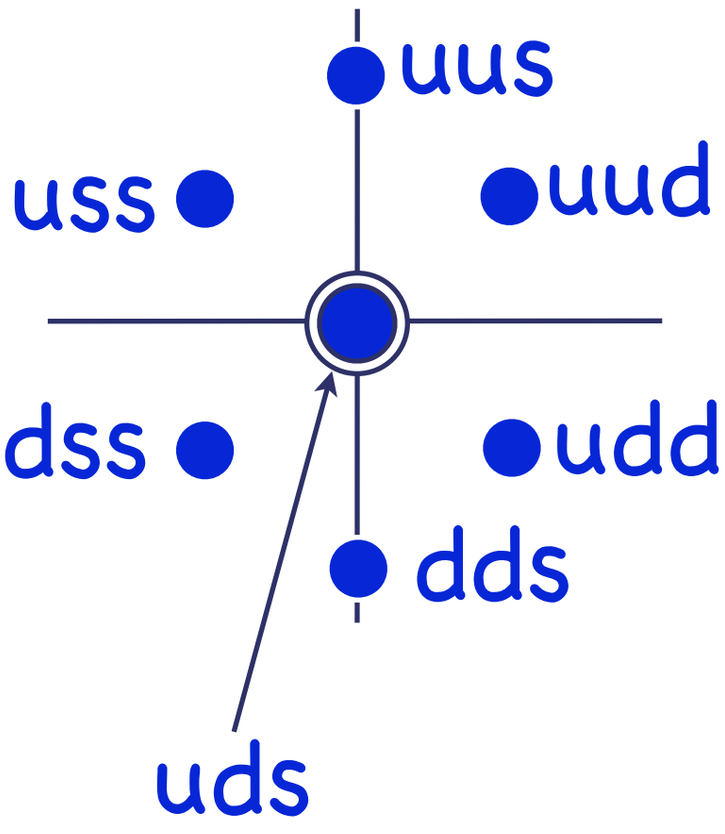


quarks

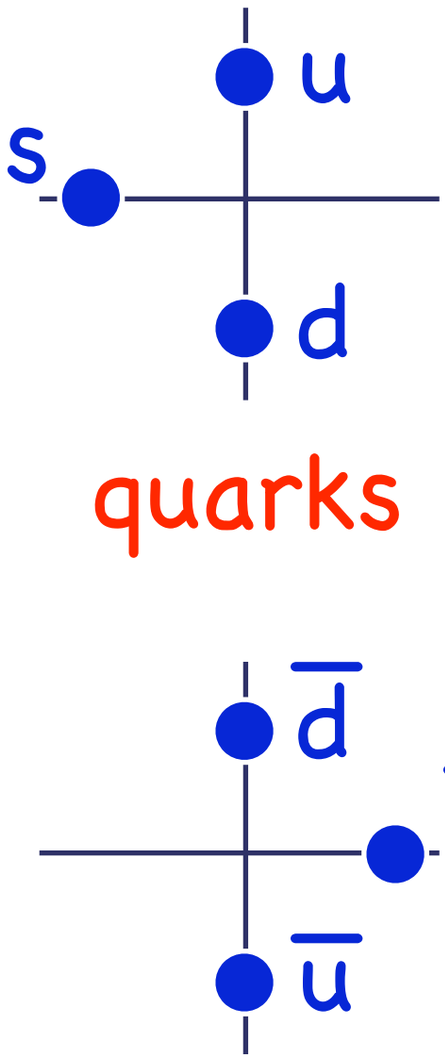
antiquarks



mesons

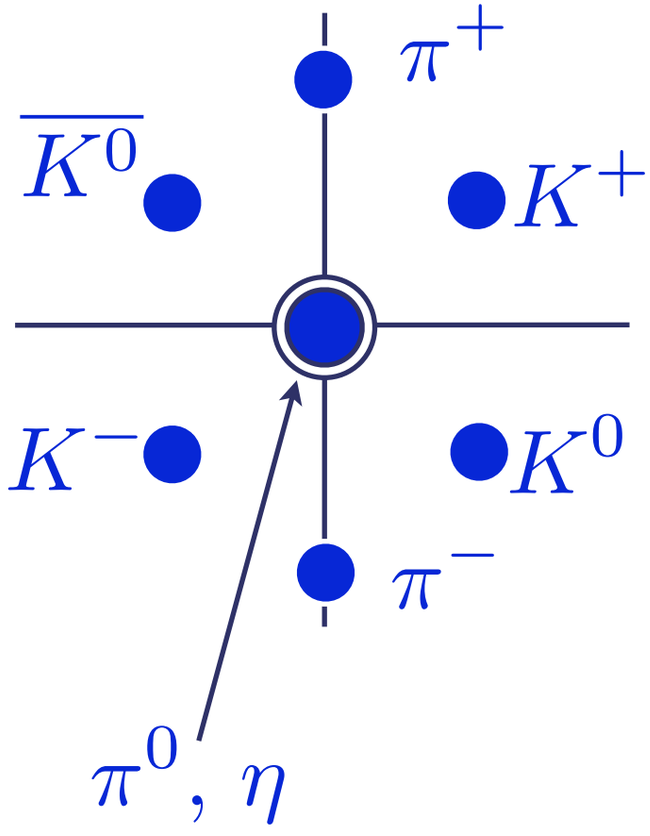


SU(3) Flavor

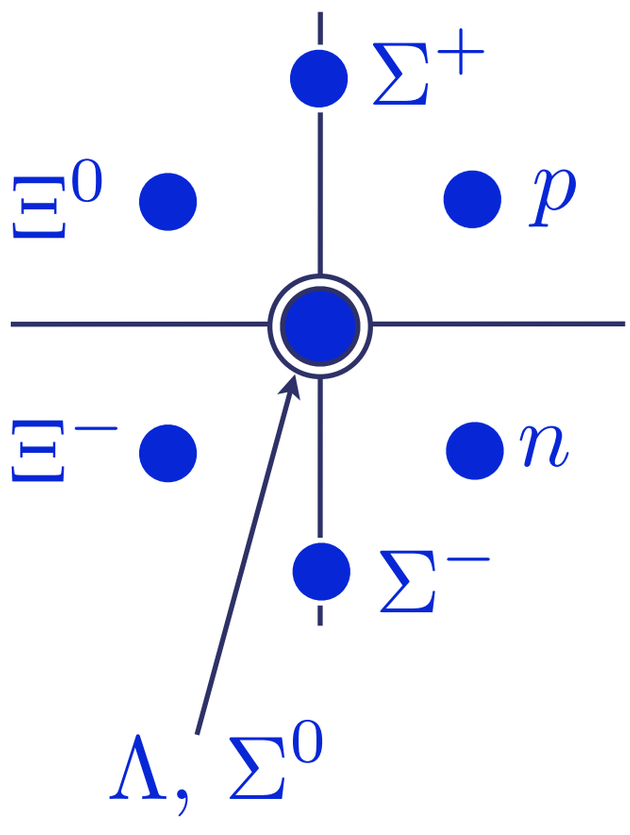


quarks

antiquarks

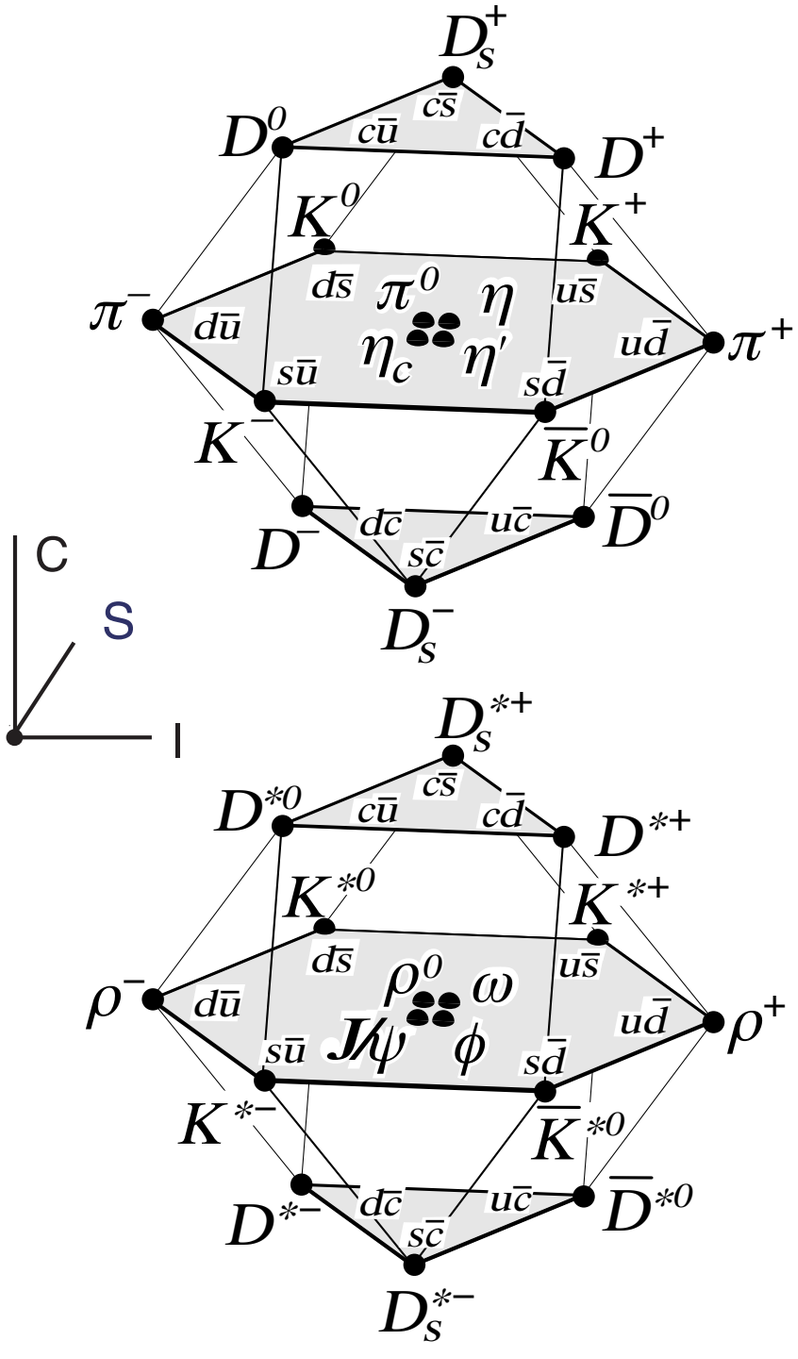


mesons

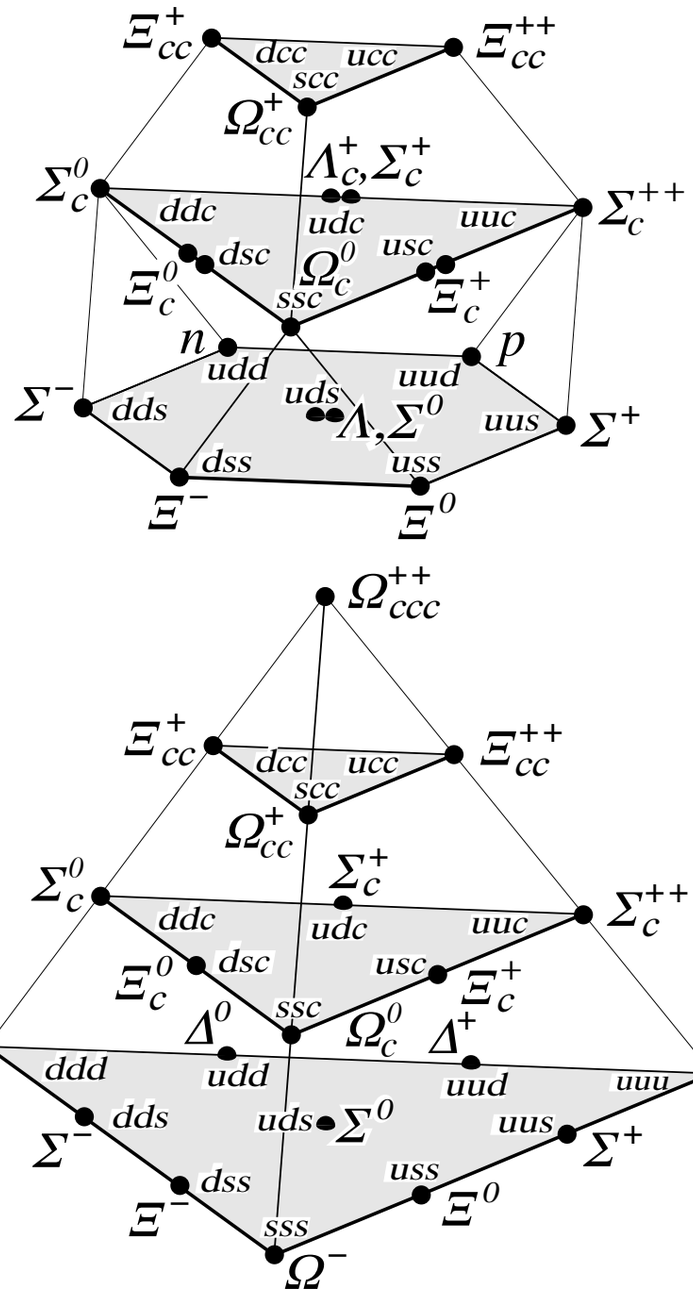


baryons

4 Flavors



mesons



baryons

QED Potential

1/r potential:

Fourier Transform

$$J^\mu(x)\frac{e^2}{|x-y|}J_\mu(y) \quad \longleftrightarrow \quad J^\mu\frac{e^2}{q^2}J_\mu$$

QED Potential

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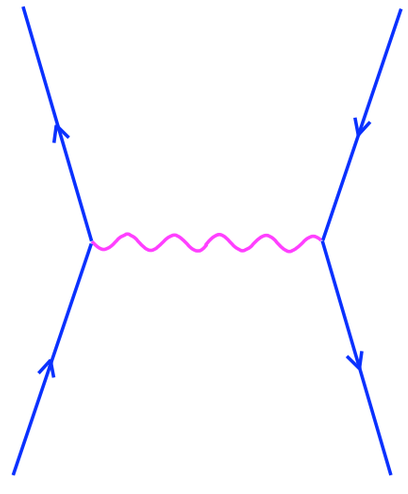
Fourier Transform

$$J^\mu(x)\frac{e^2}{|x-y|}J_\mu(y) \quad \longleftrightarrow \quad J^\mu\frac{e^2}{q^2}J_\mu$$



elastic scattering amplitude

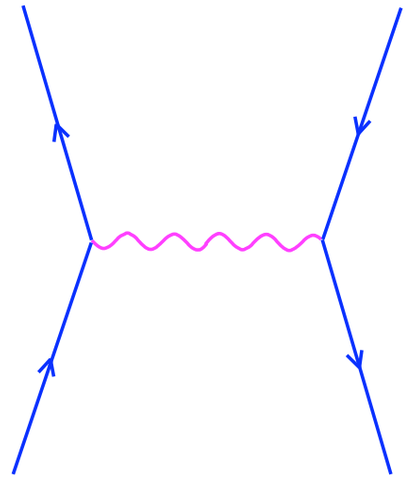
QED Potential

1/r potential:

Fourier Transform

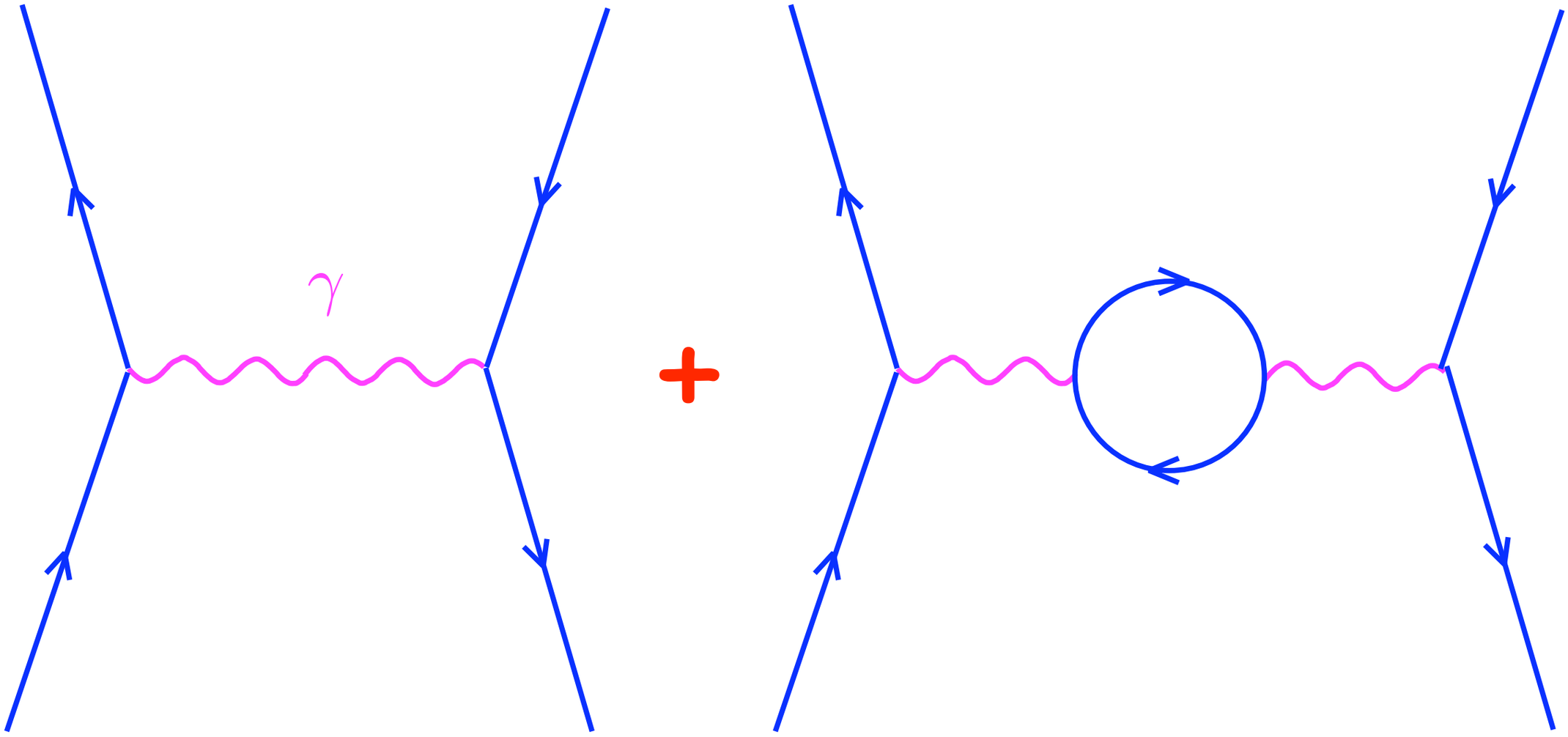
$$J^\mu(x)\frac{e^2}{|x-y|}J_\mu(y) \quad \longleftrightarrow \quad J^\mu\frac{e^2}{q^2}J_\mu$$

$$\alpha = \frac{e^2}{4\pi} \approx \frac{1}{137}$$



elastic scattering amplitude

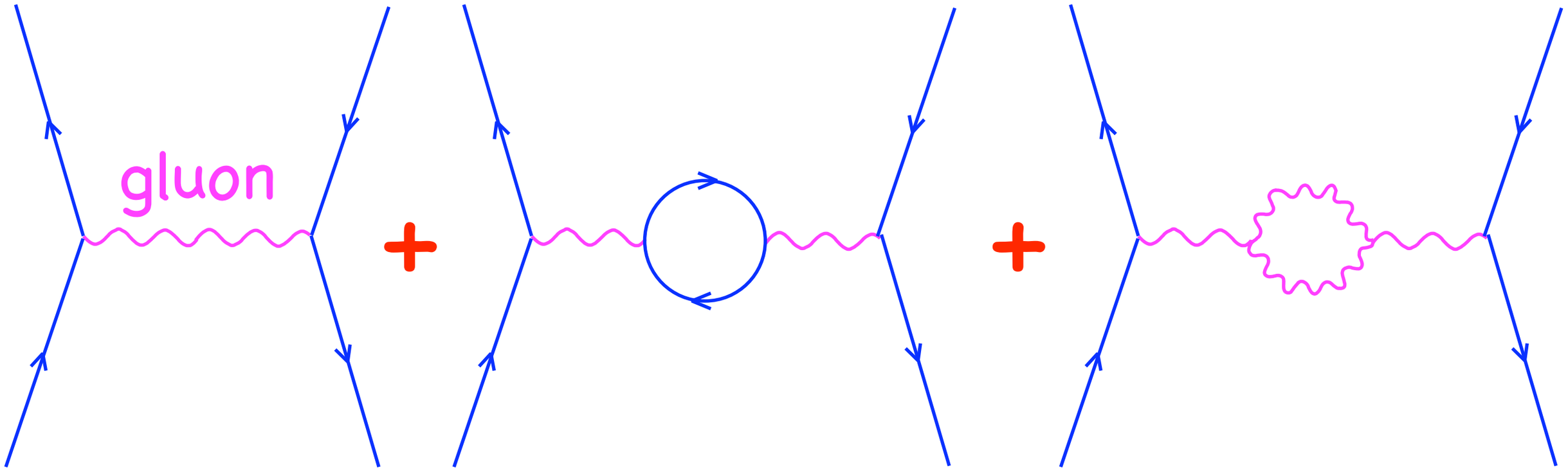
Quantum Corrections



coupling is distance dependent

$$\alpha(10^{-10}\ \mathrm{m}) \approx \frac{1}{137} \qquad \alpha(10^{-17}\ \mathrm{m}) \approx \frac{1}{128}$$

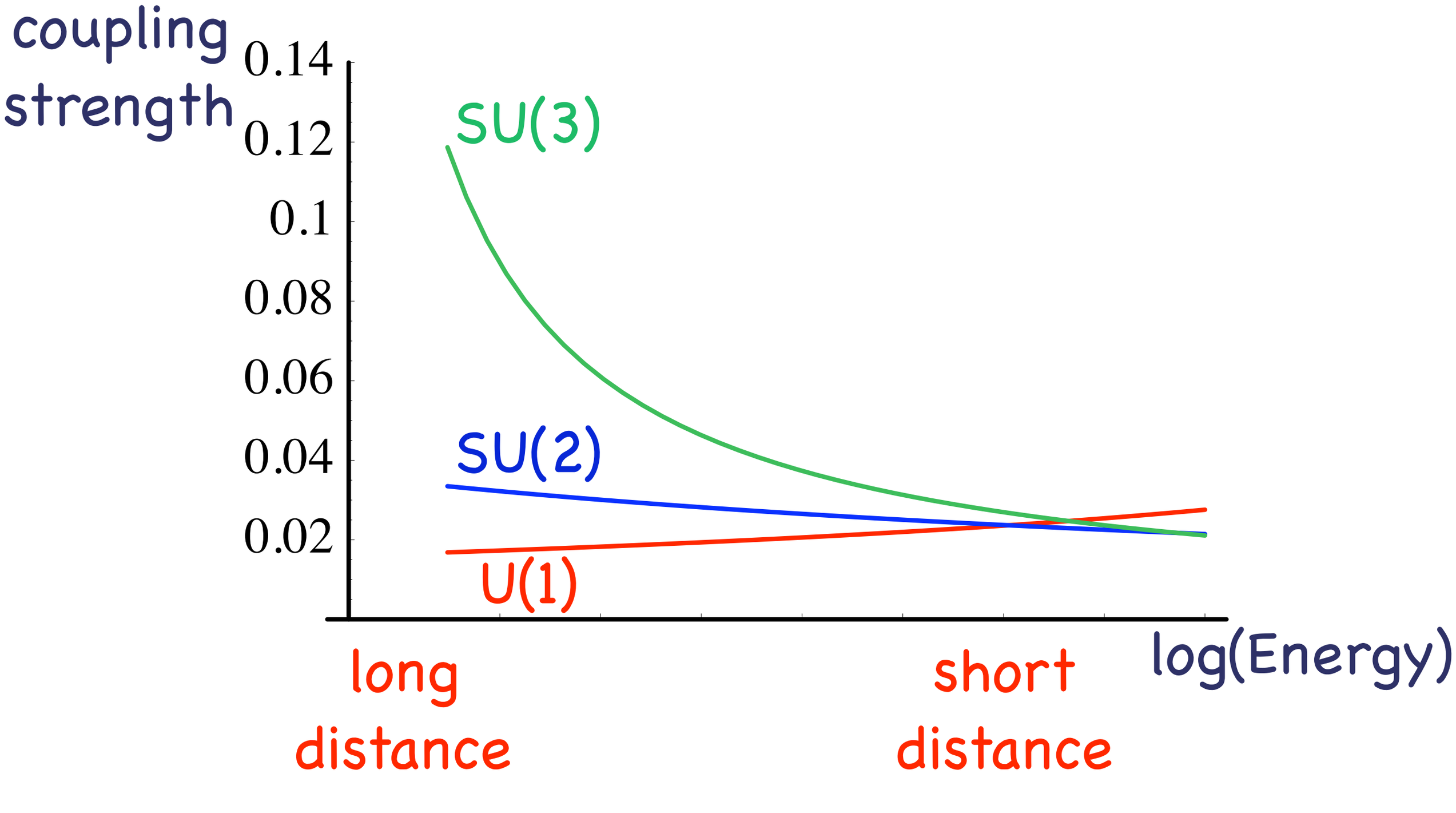
Quantum Corrections



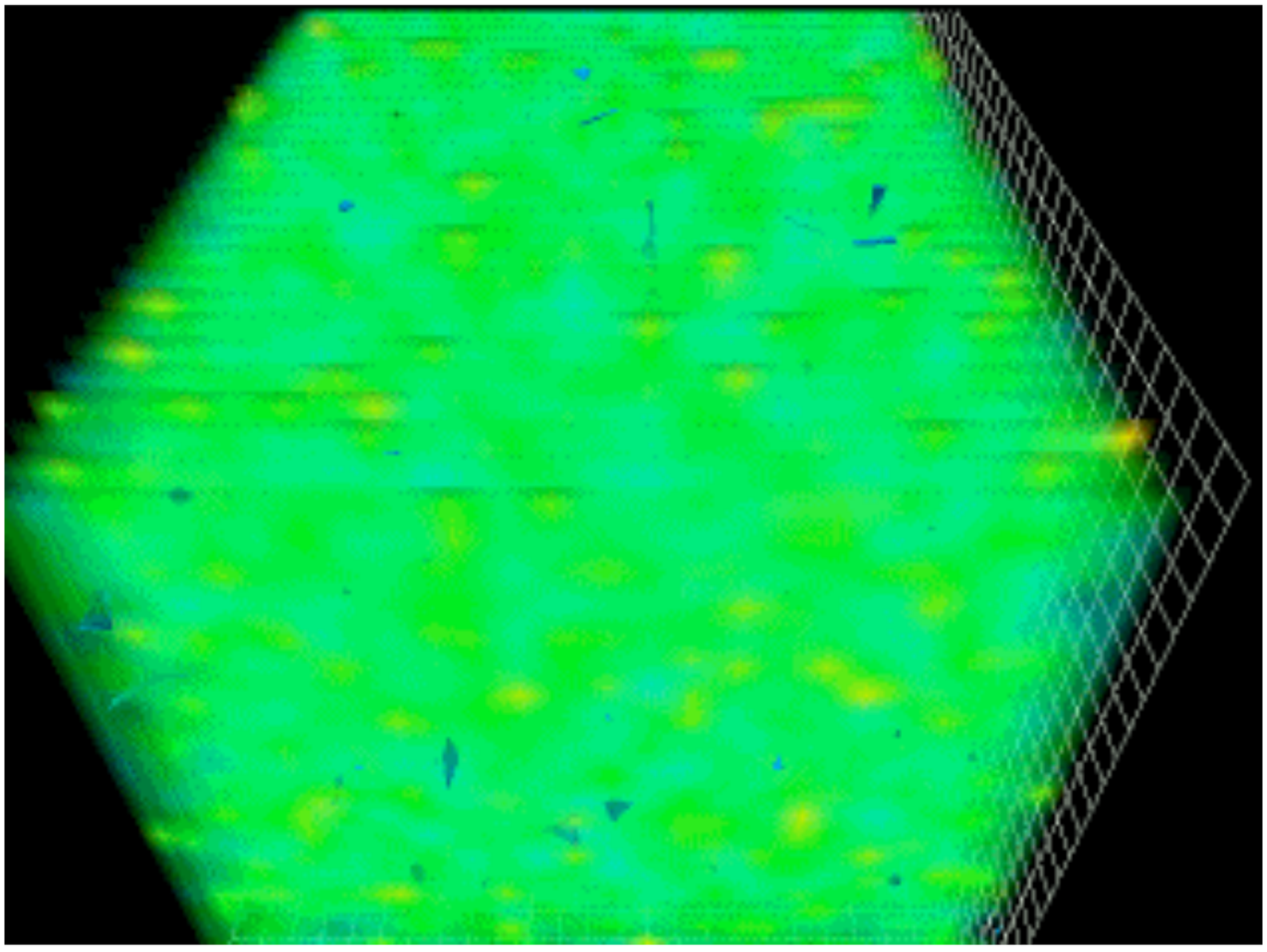
gluons contribute
with opposite sign

QCD coupling gets stronger at larger distances

Running Coupling

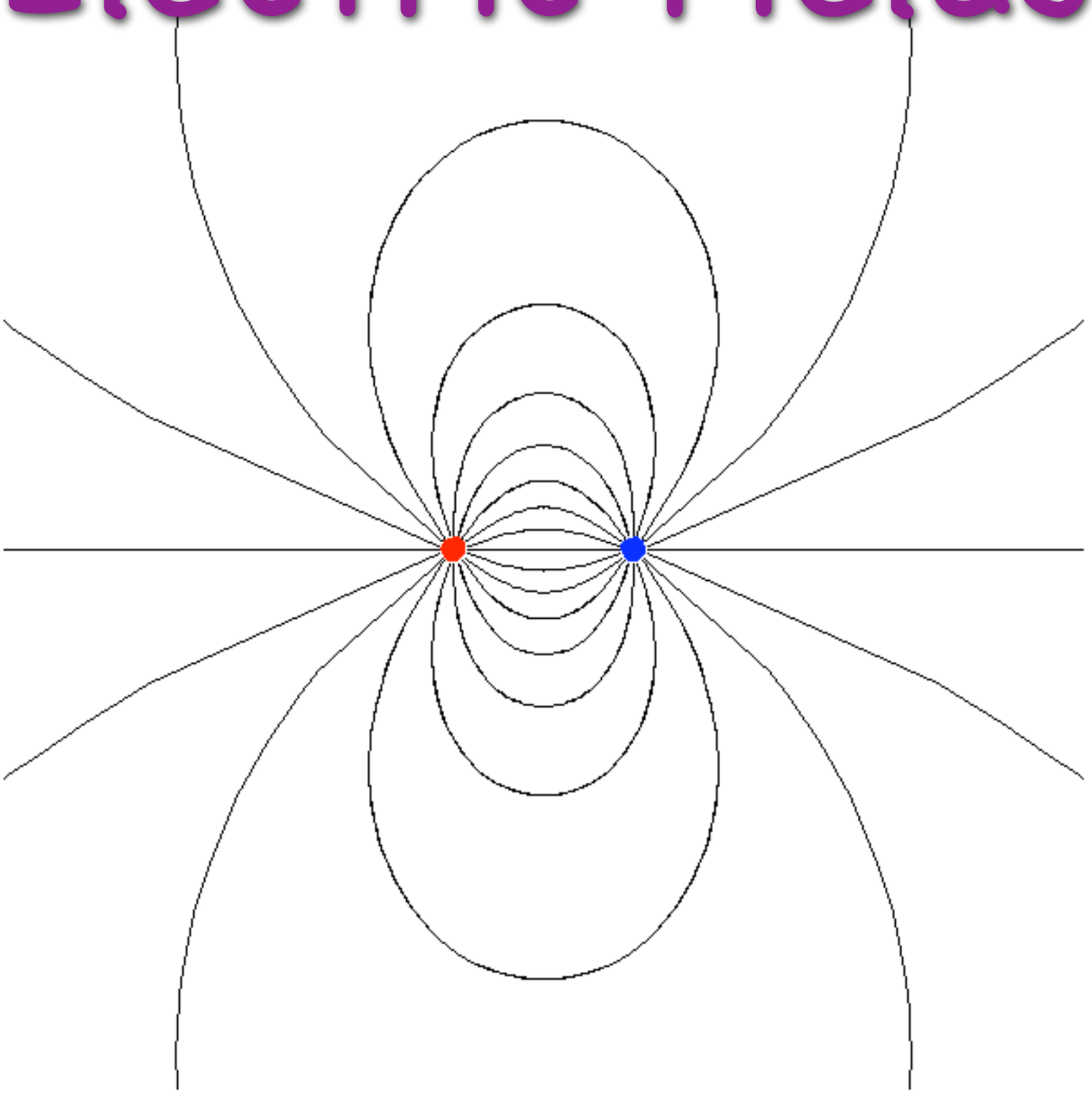


Strong Coupling

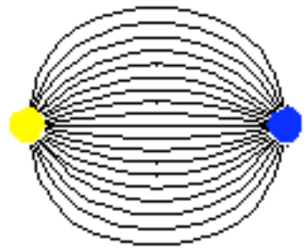


http://bit.ly/qcdvac

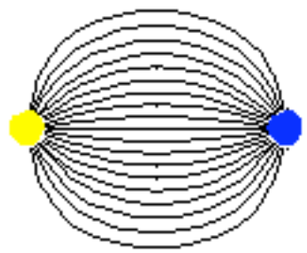
Electric Fields

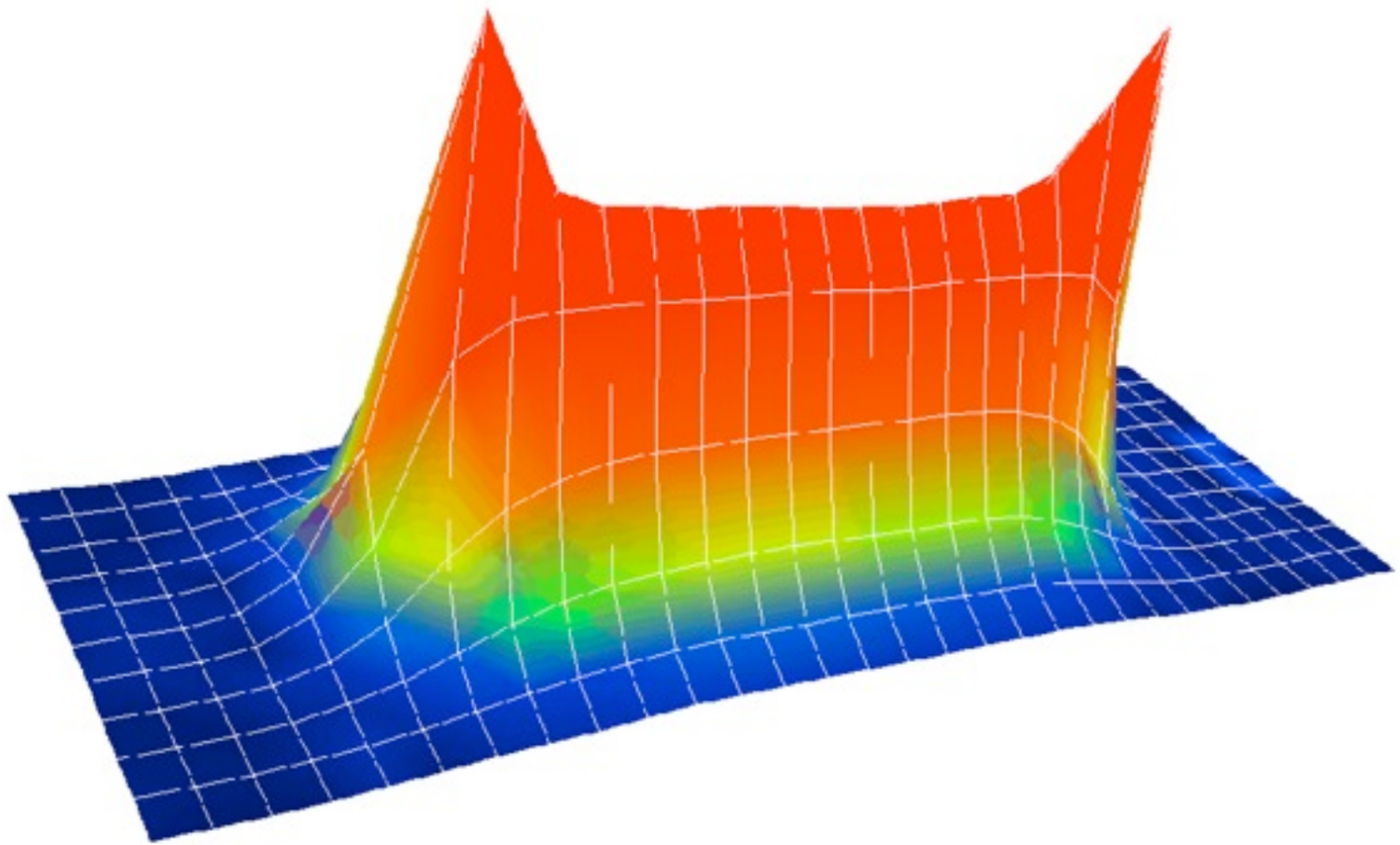


"Color" Fields

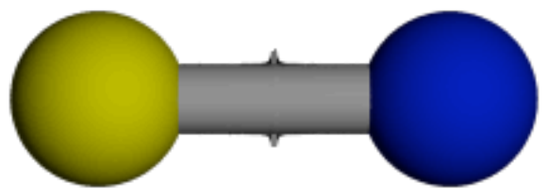


"Color" Fields

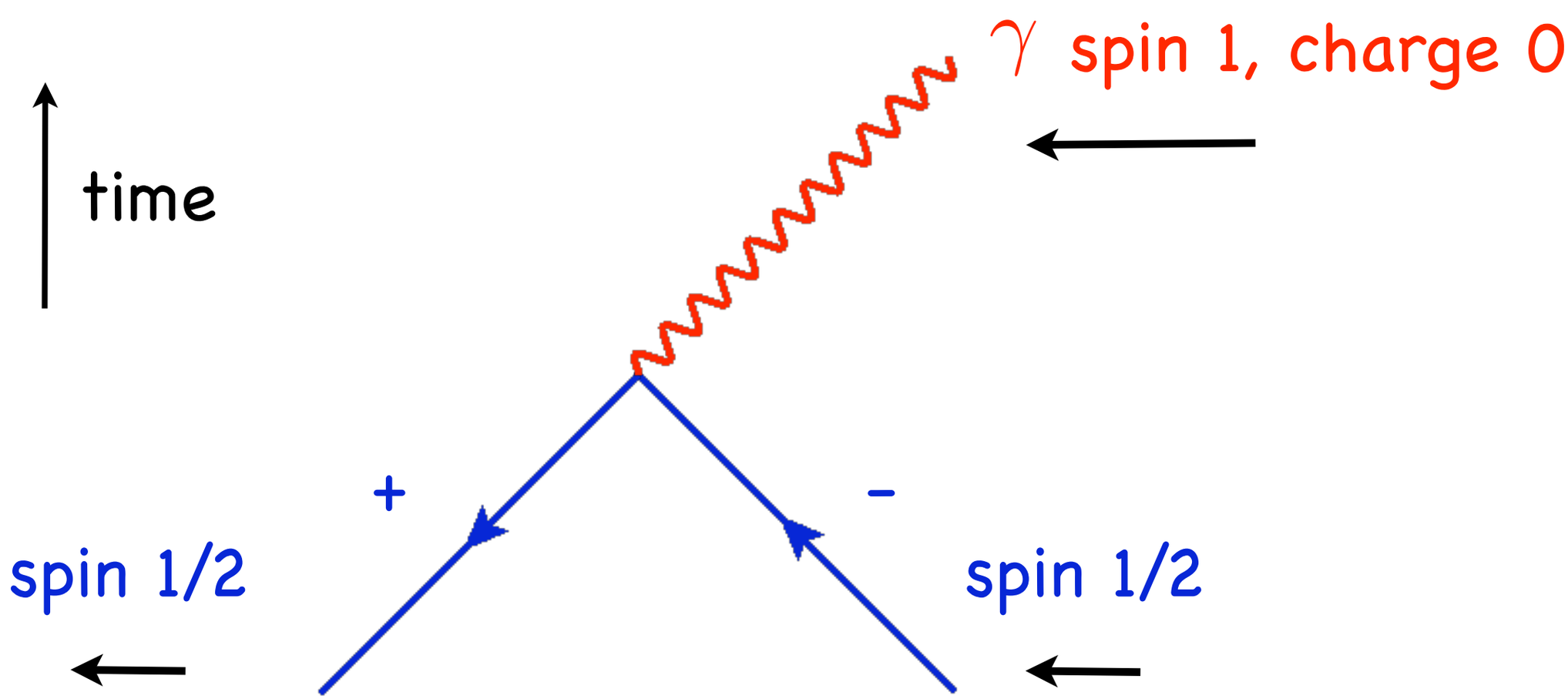




Flux Tube -> Meson

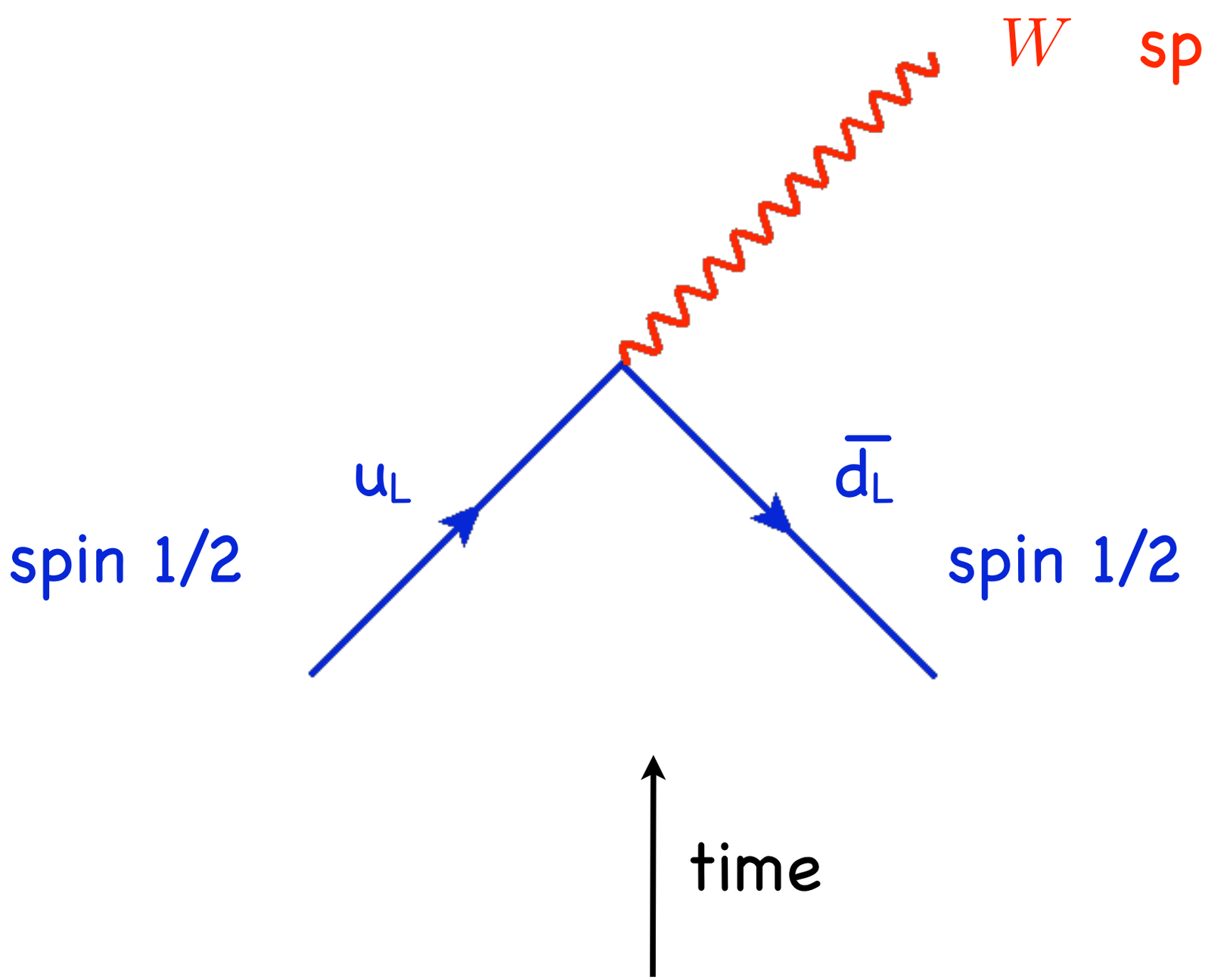


U(1)



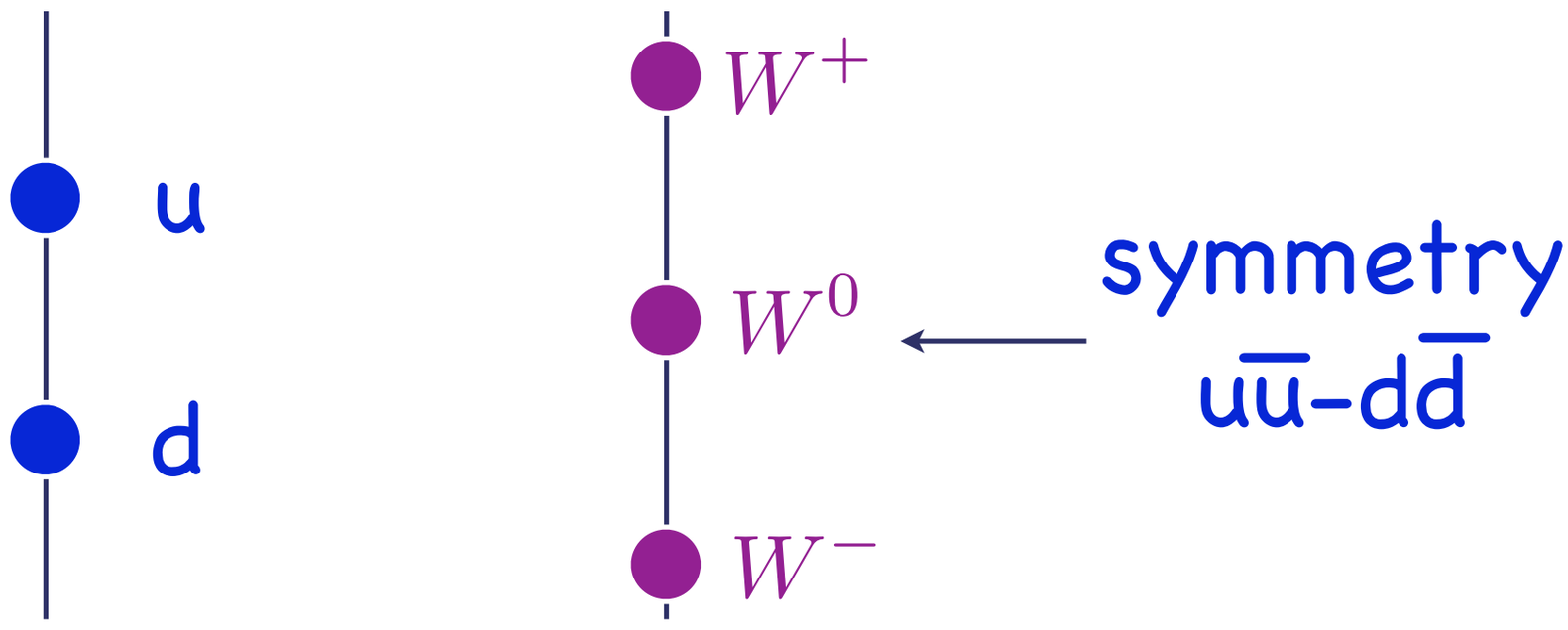
spin and charge must add up

$SU(2)_L$



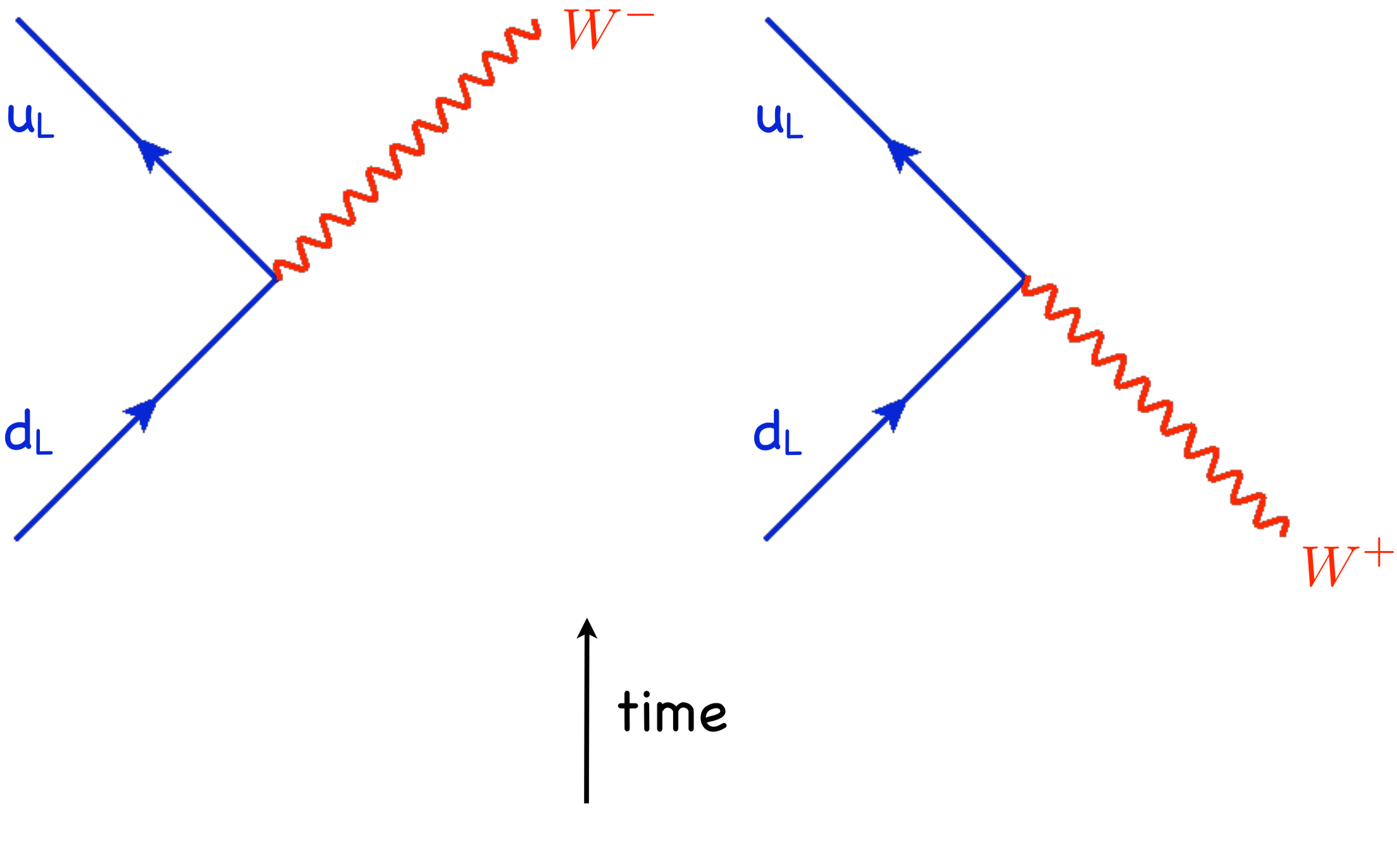
SU(2) Gauge Bosons

adding SU(2) charges
works just like spin: $\pm\frac{1}{2} \pm \frac{1}{2} = -1, 0, 1$

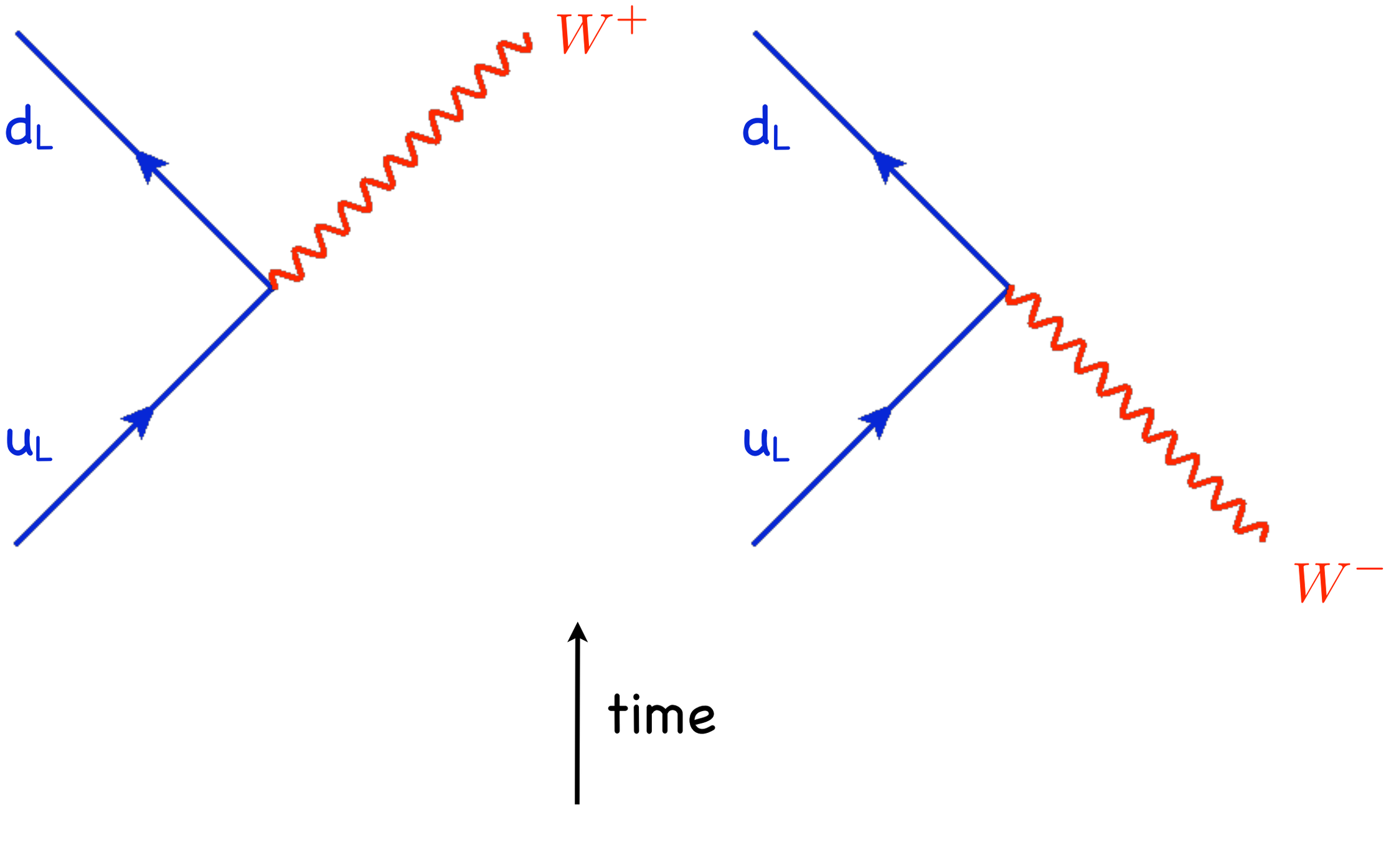


three weak gauge bosons

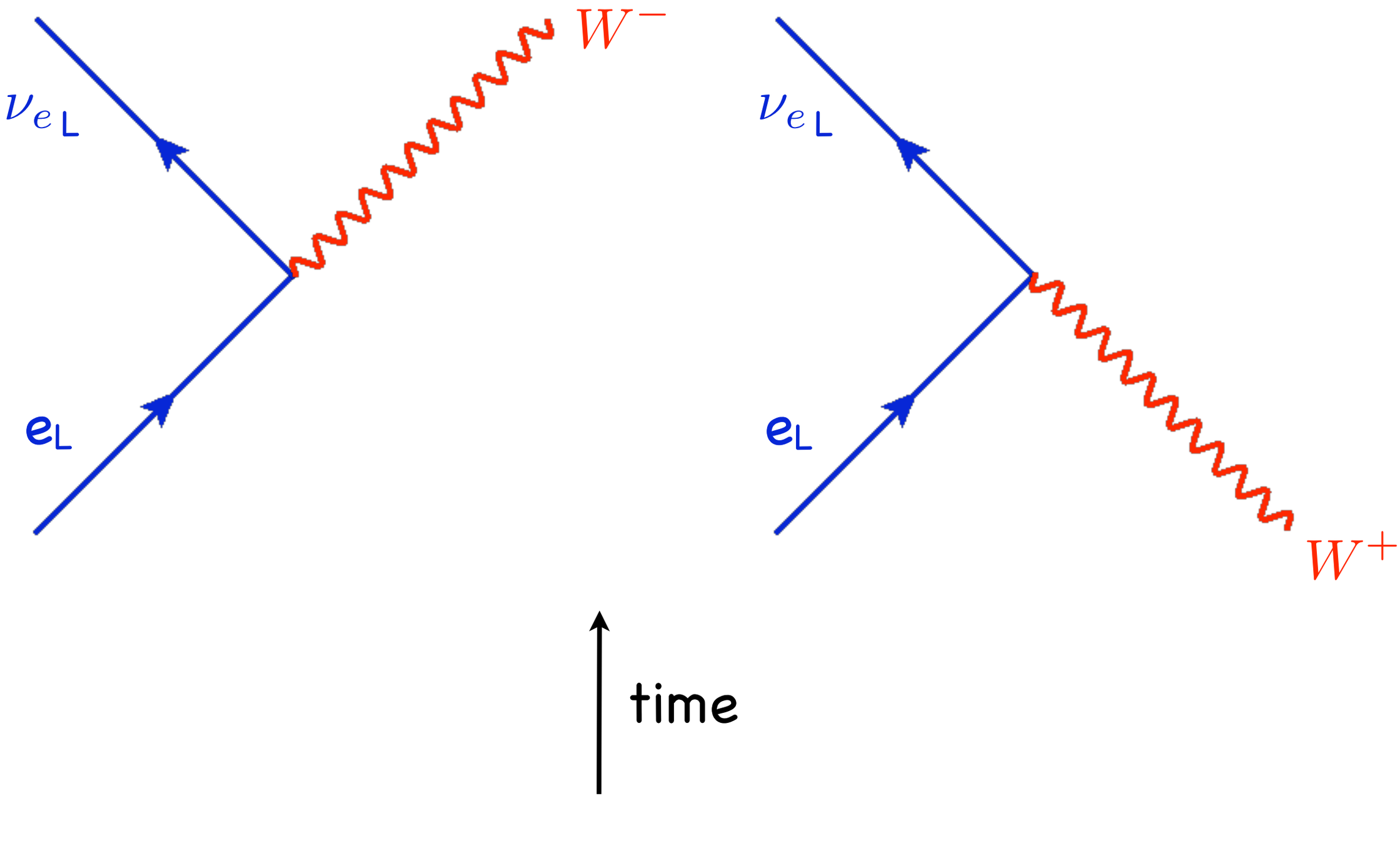
$SU(2)_L$ Weak Interactions



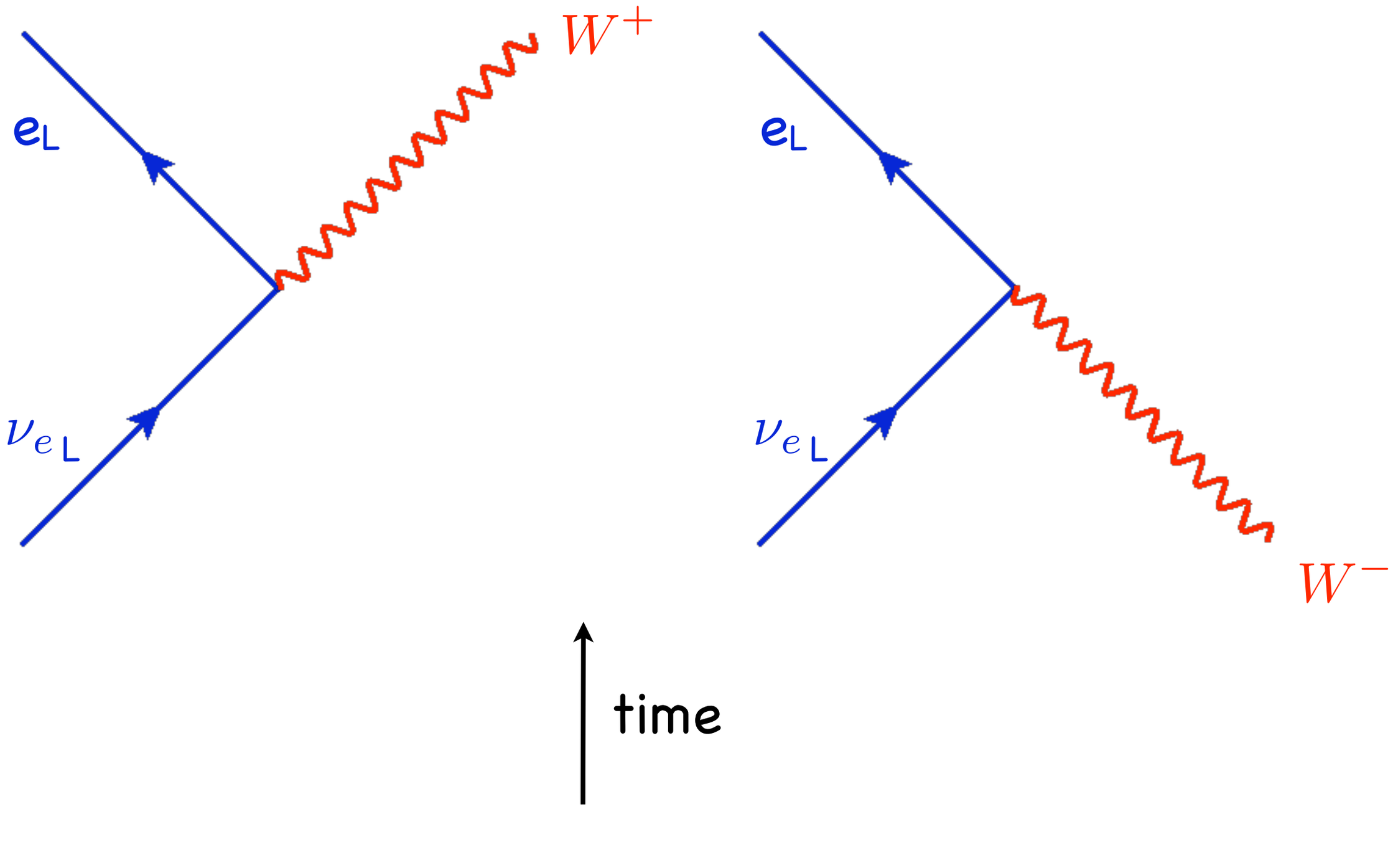
$SU(2)_L$ Weak Interactions



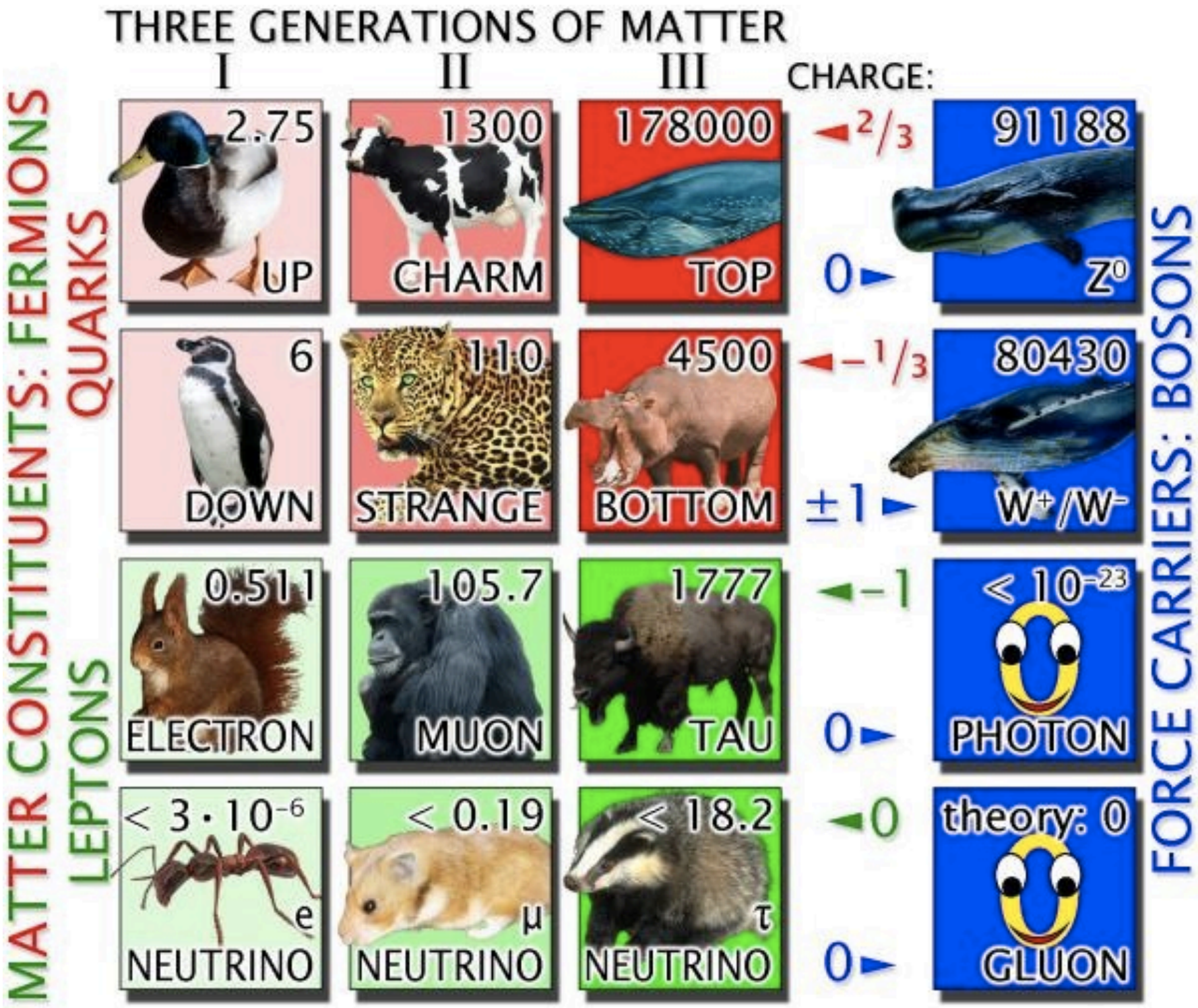
$SU(2)_L$ Weak Interactions



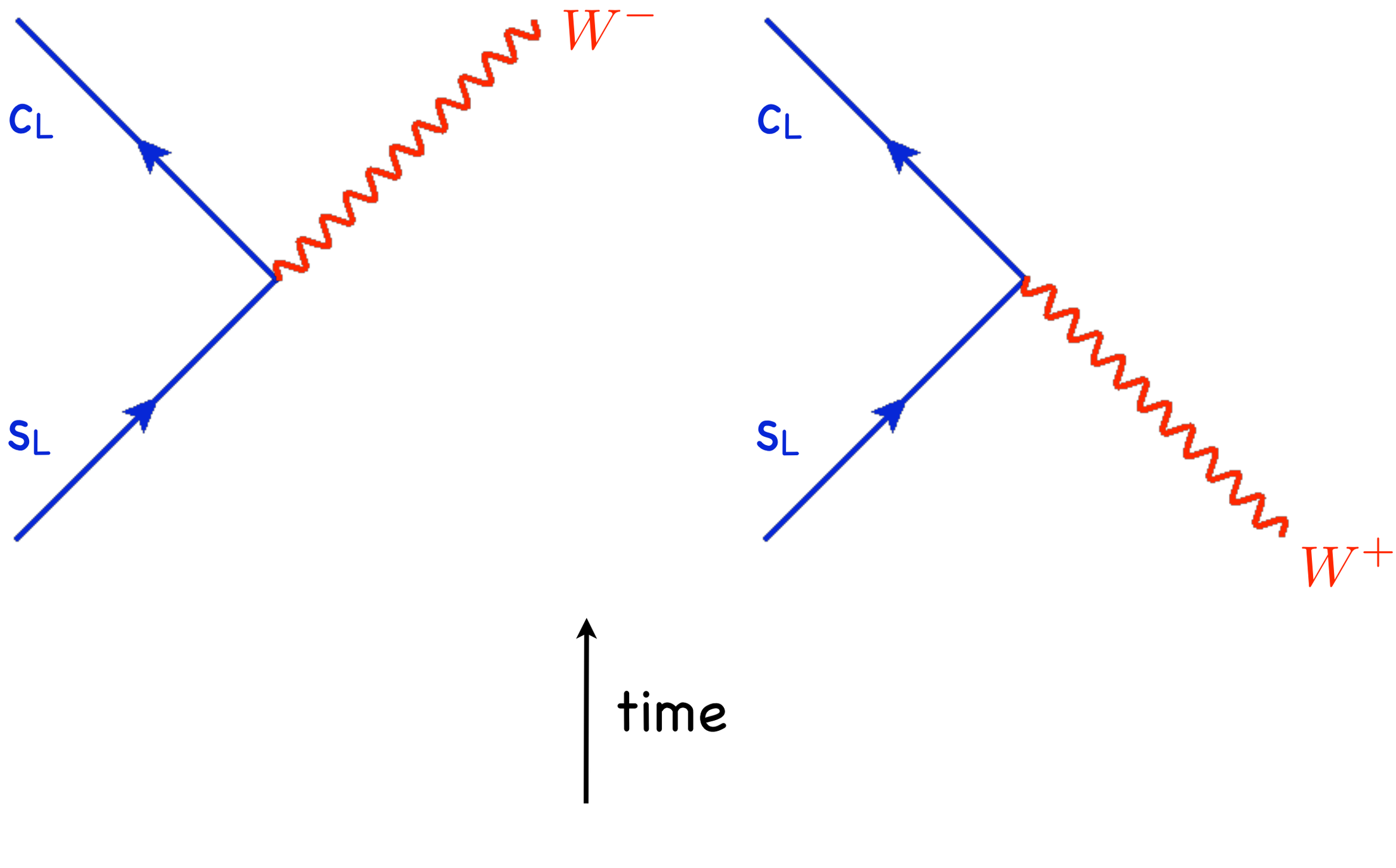
$SU(2)_L$ Weak Interactions



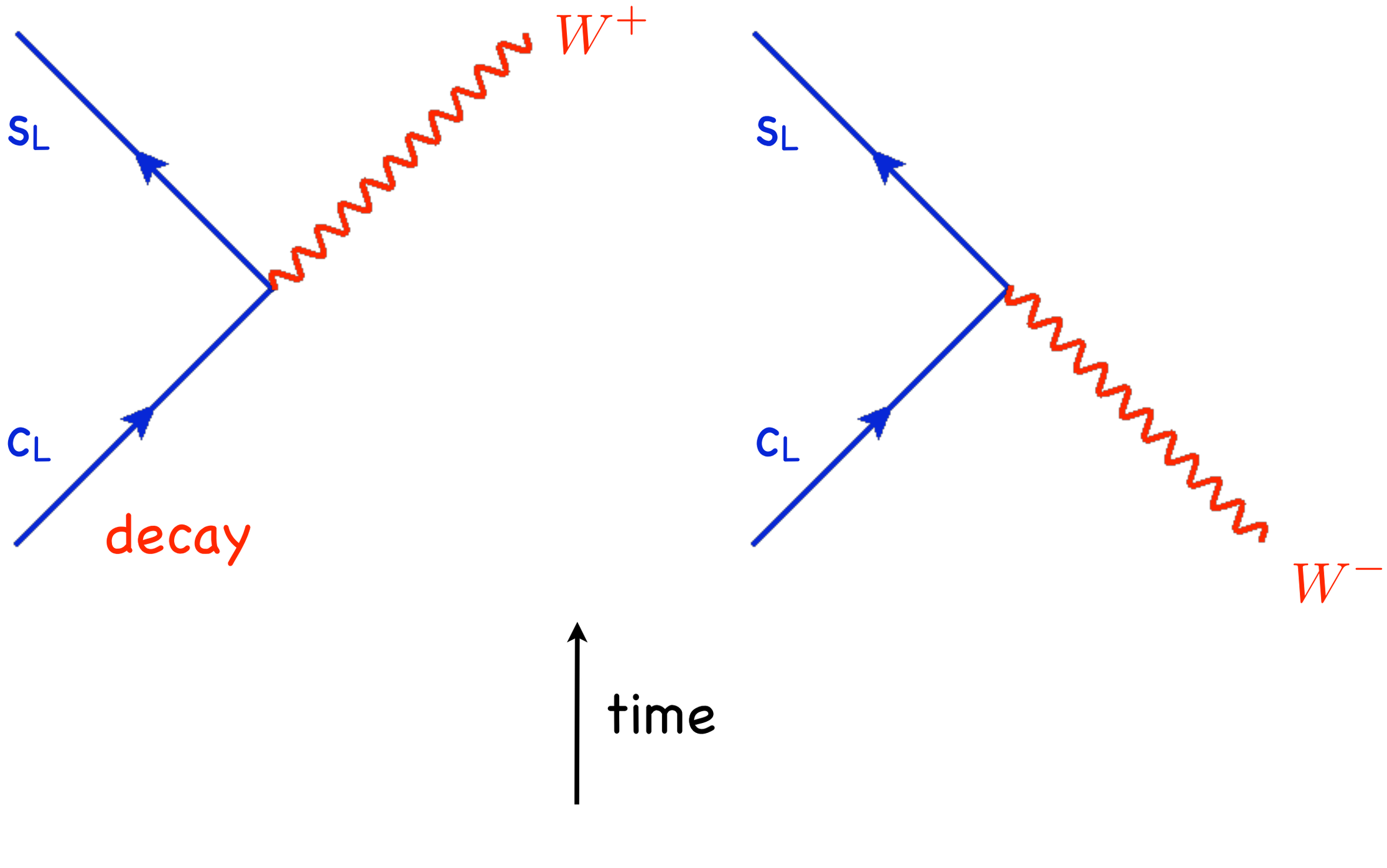
Standard Model



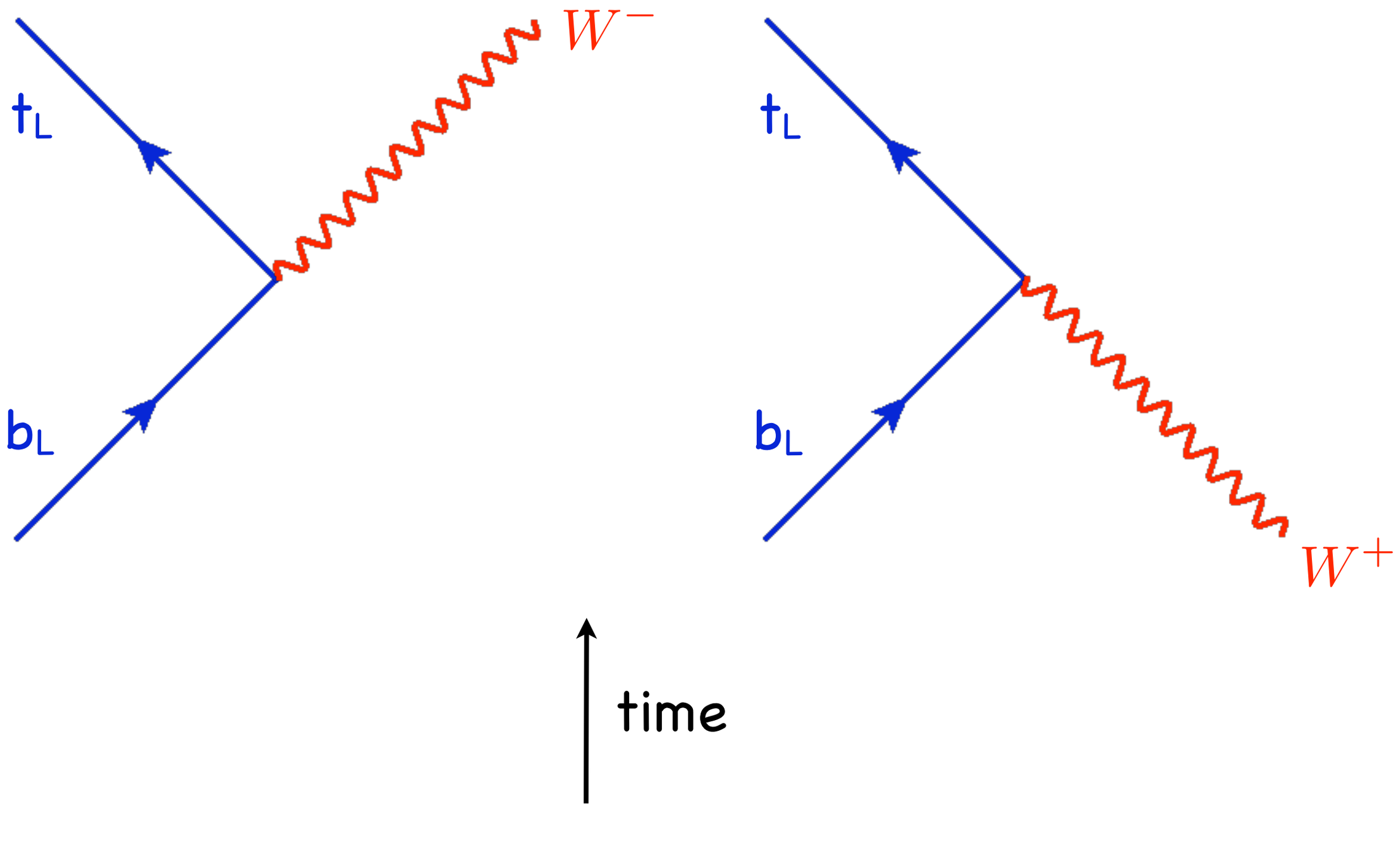
$SU(2)_L$ Weak Interactions



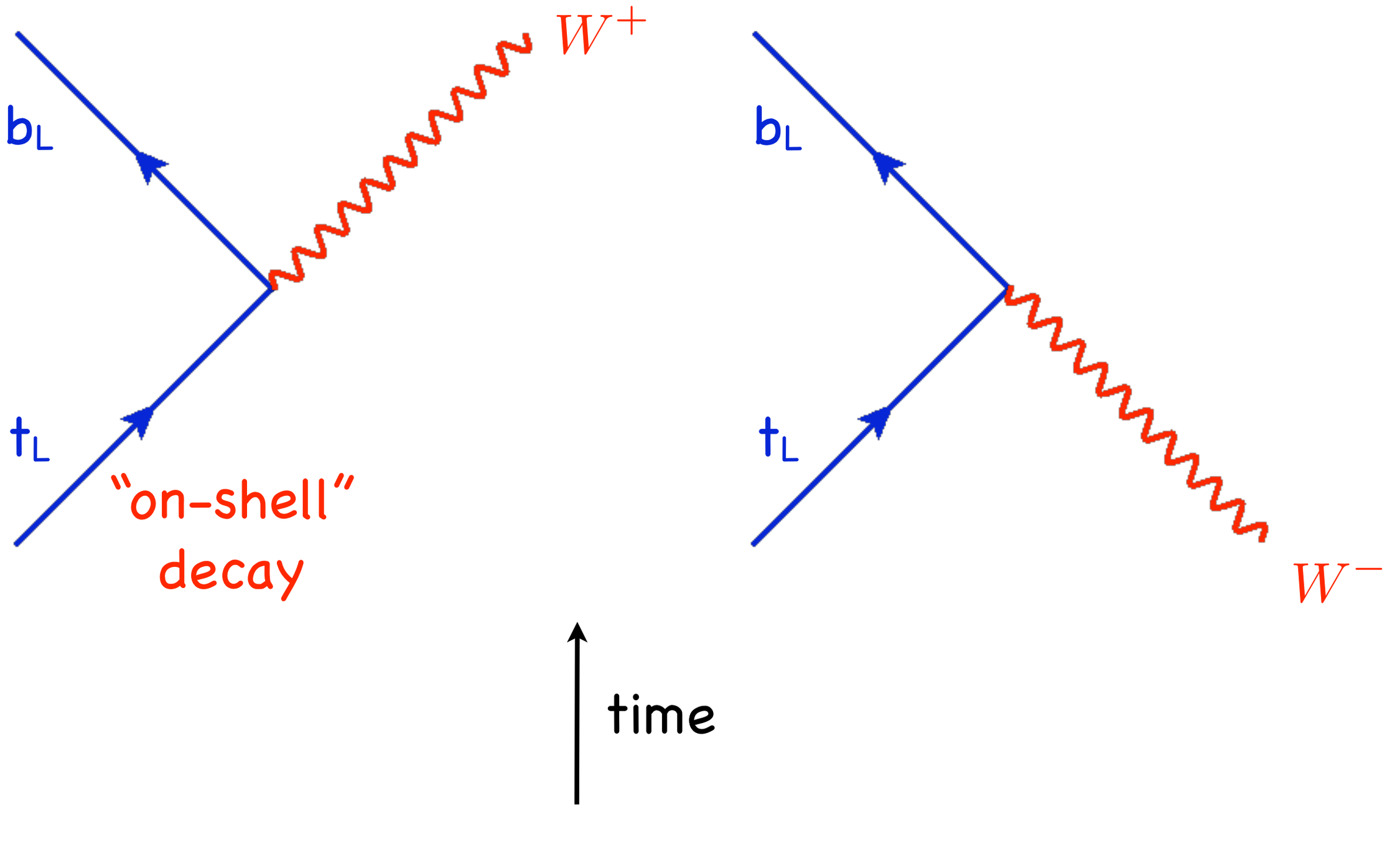
$SU(2)_L$ Weak Interactions



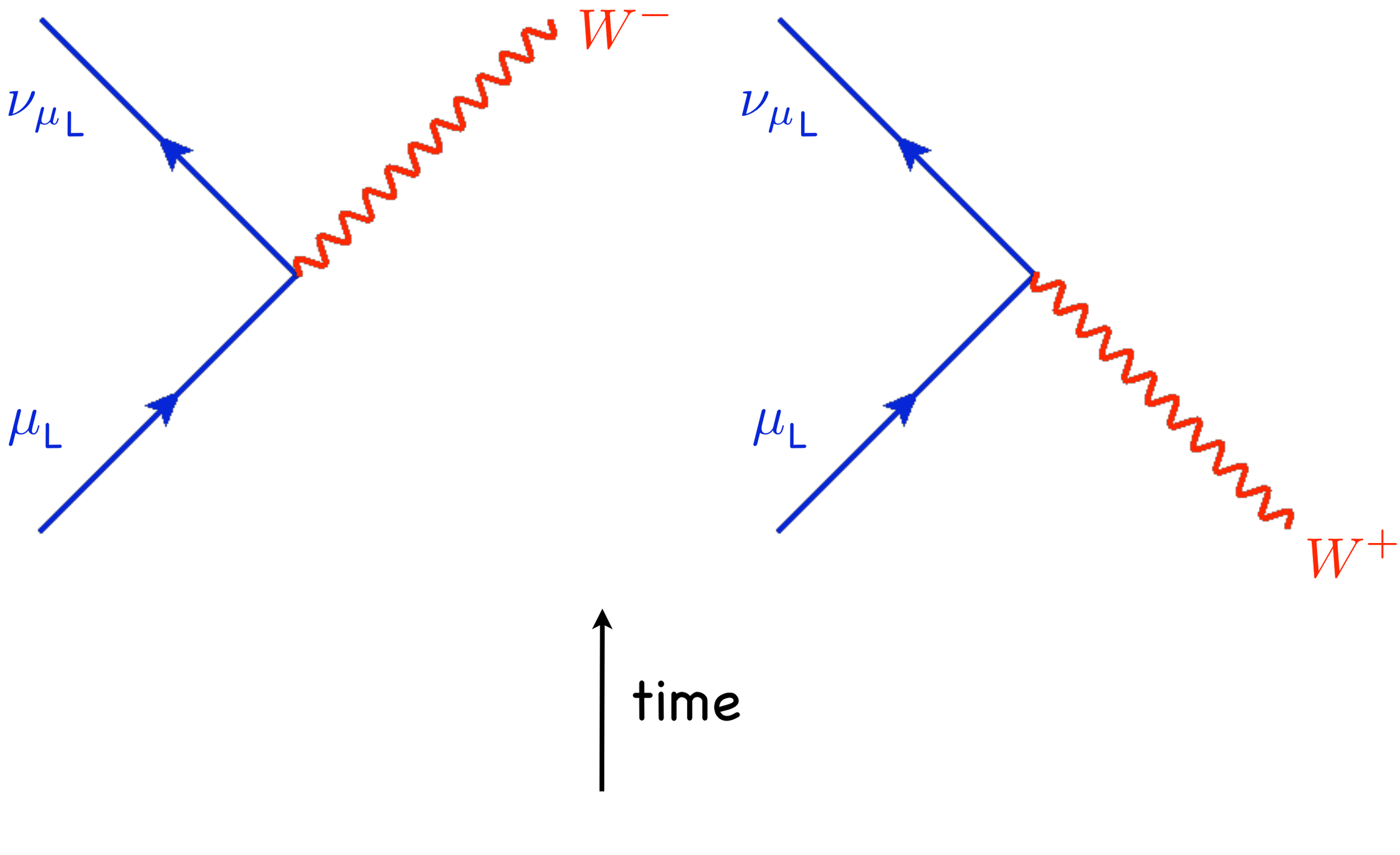
$SU(2)_L$ Weak Interactions



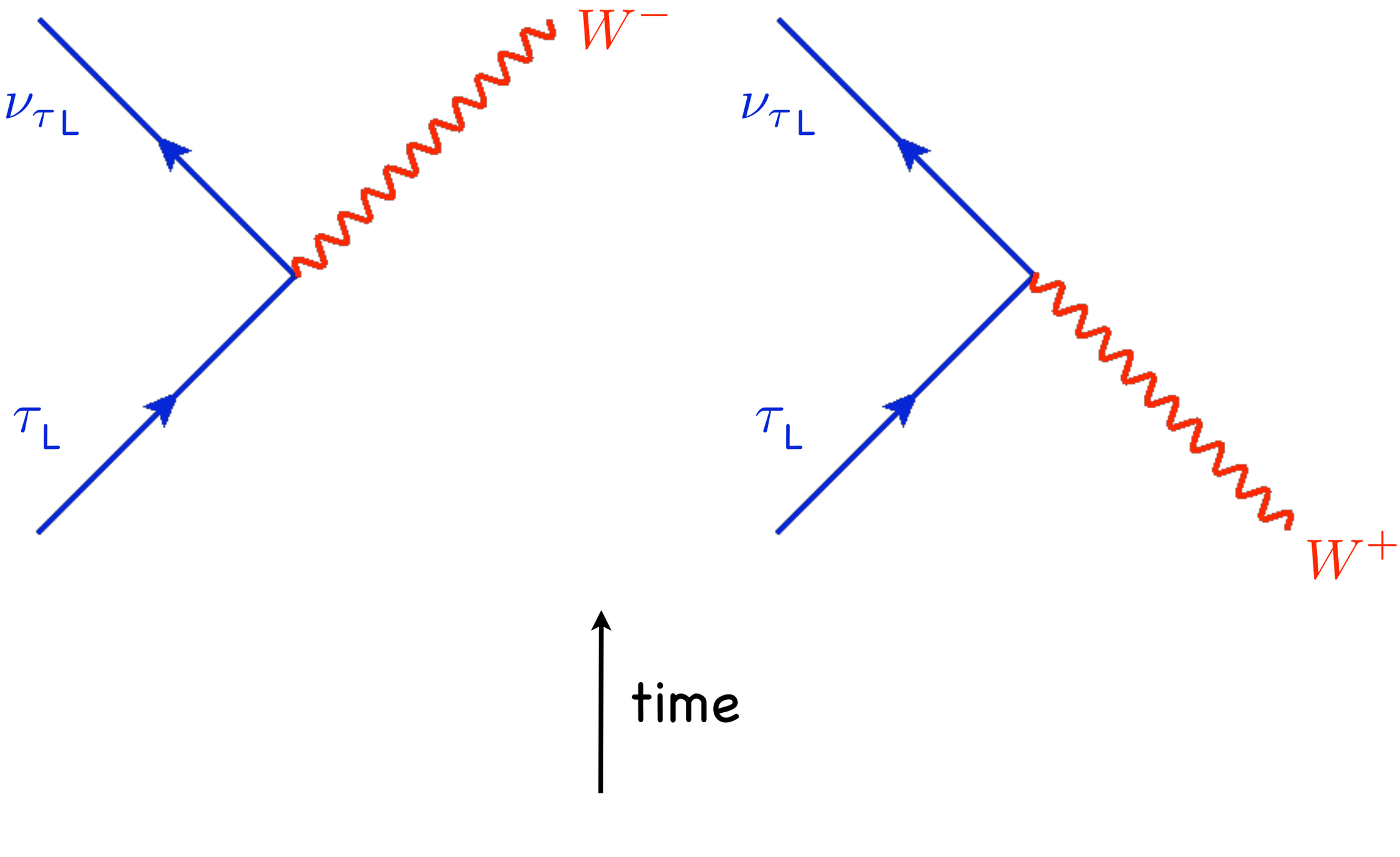
$SU(2)_L$ Weak Interactions



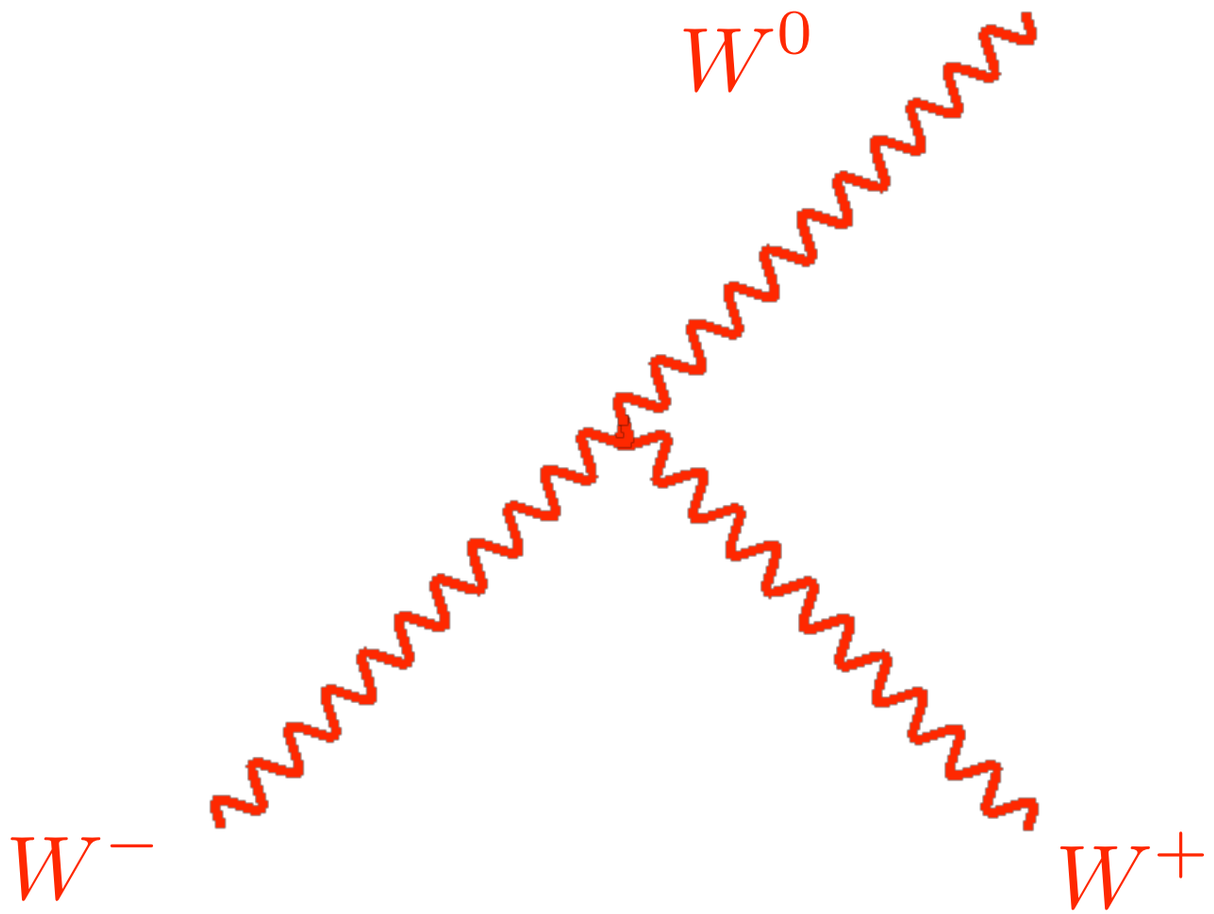
$SU(2)_L$ Weak Interactions



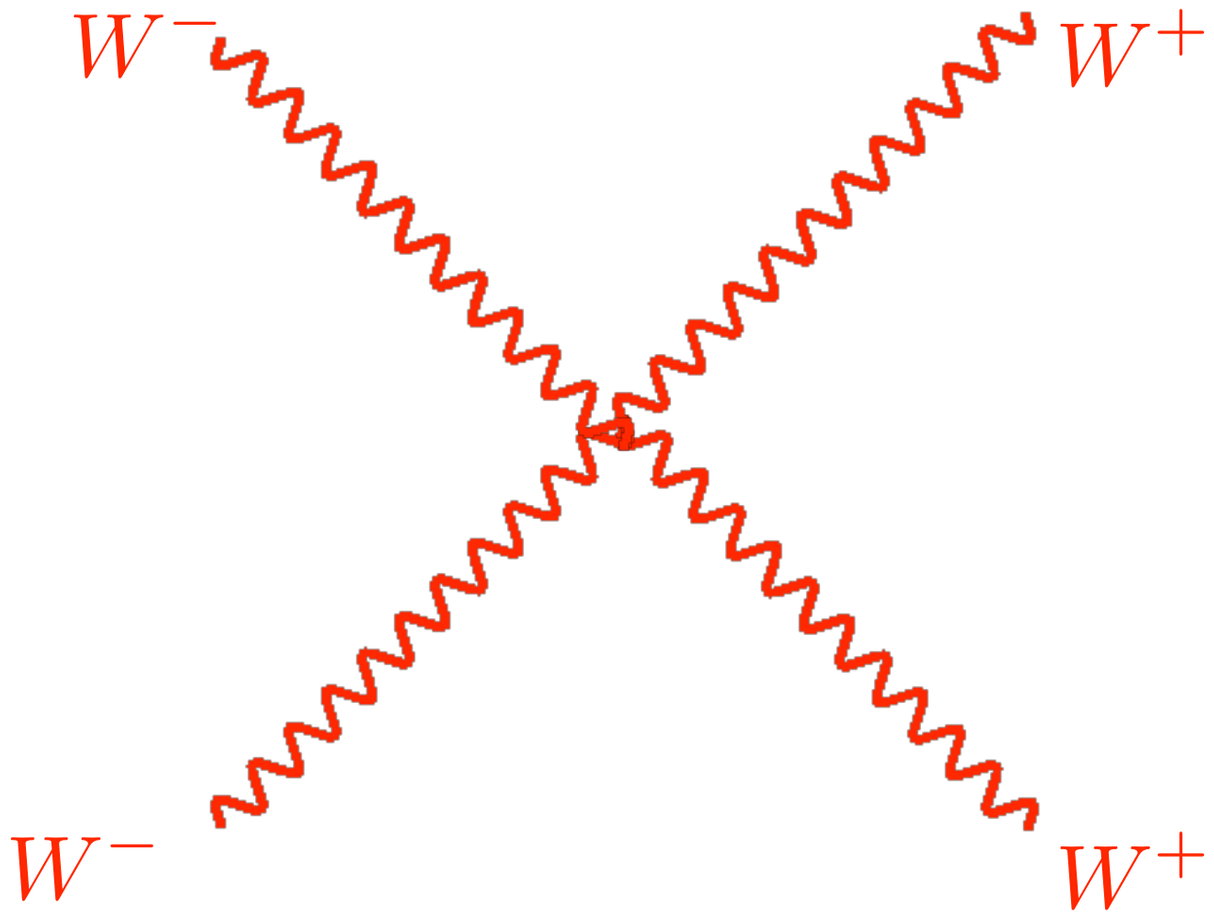
$SU(2)_L$ Weak Interactions



$SU(2)_L$ Weak Interactions

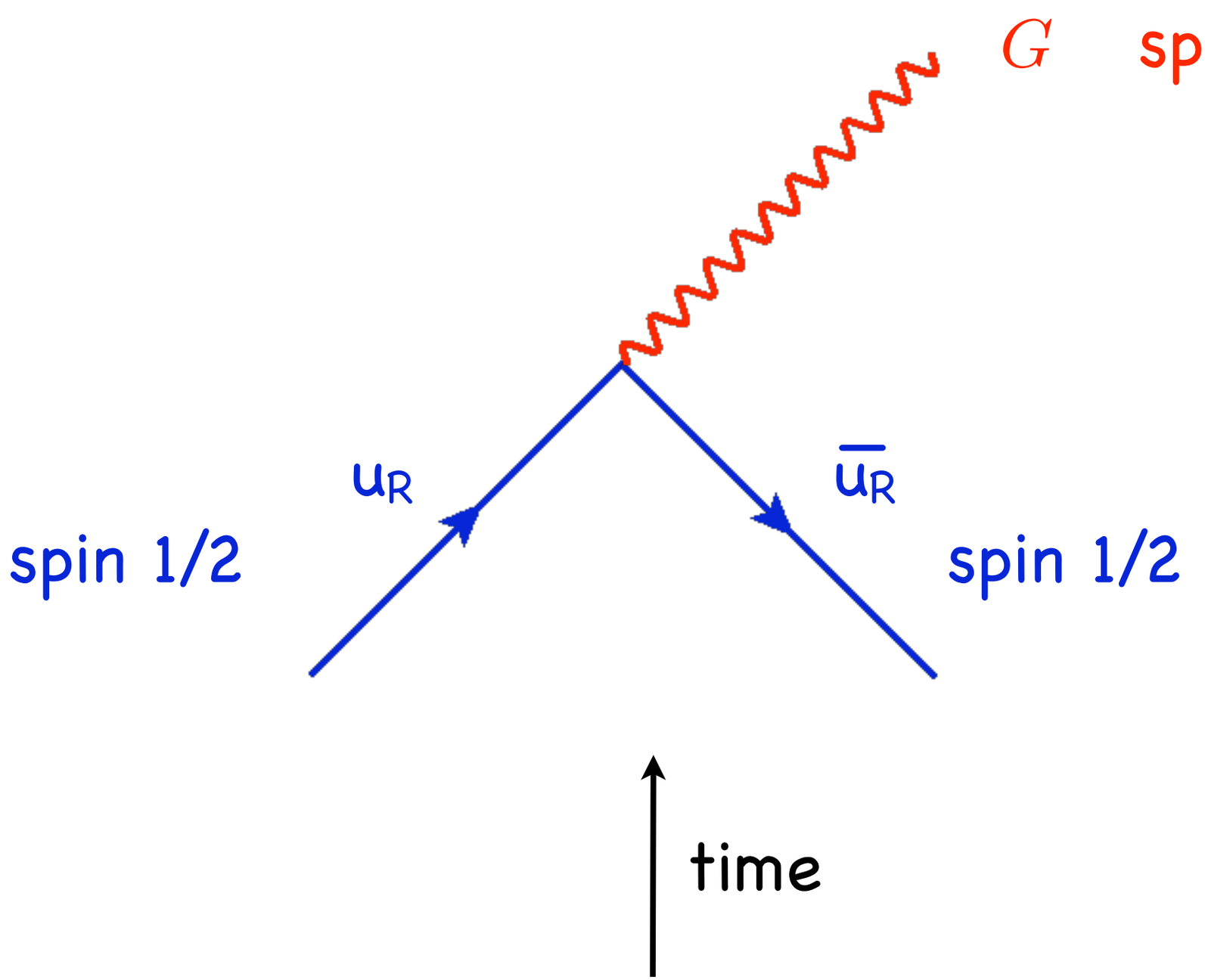


$\sim g$



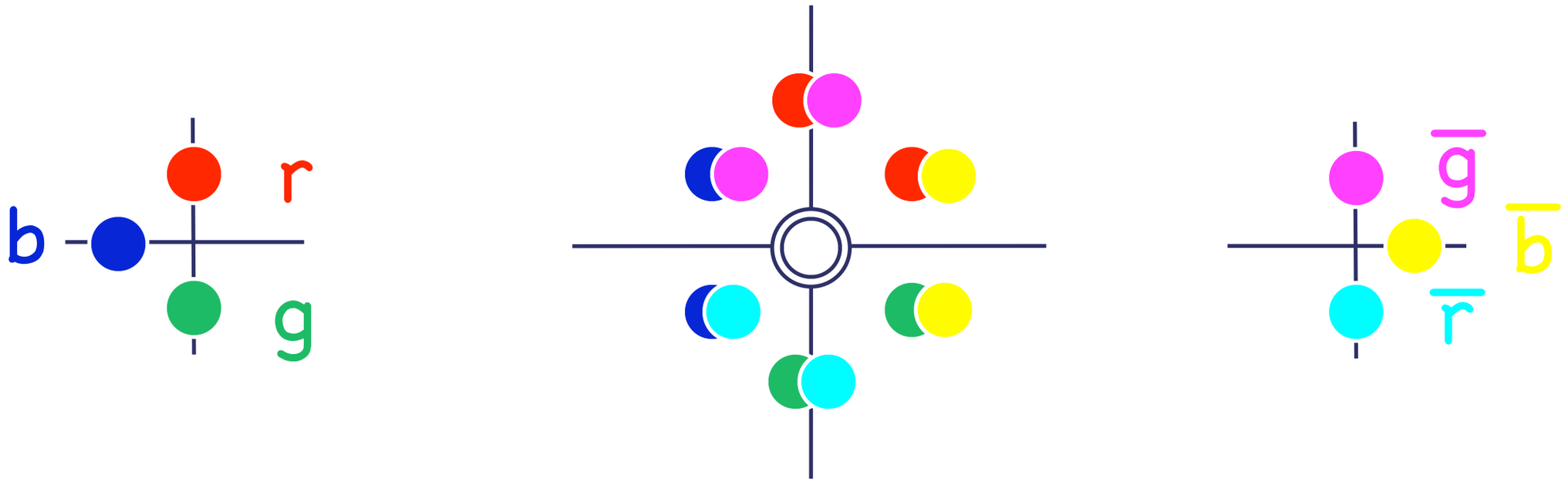
$\sim g^2$

$SU(3)_c$



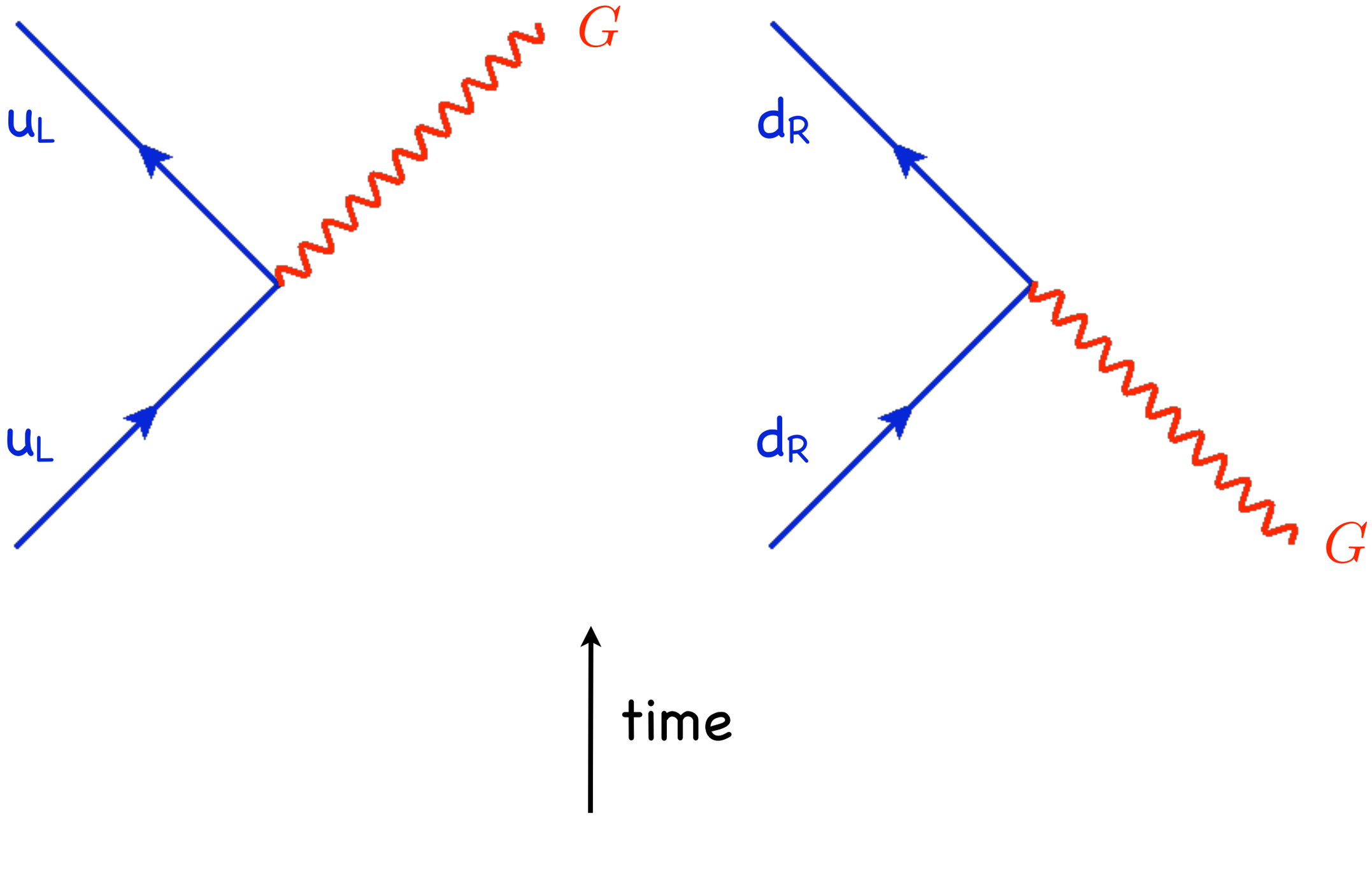
$SU(3)_c$ Gauge Bosons

adding SU(3) charges:

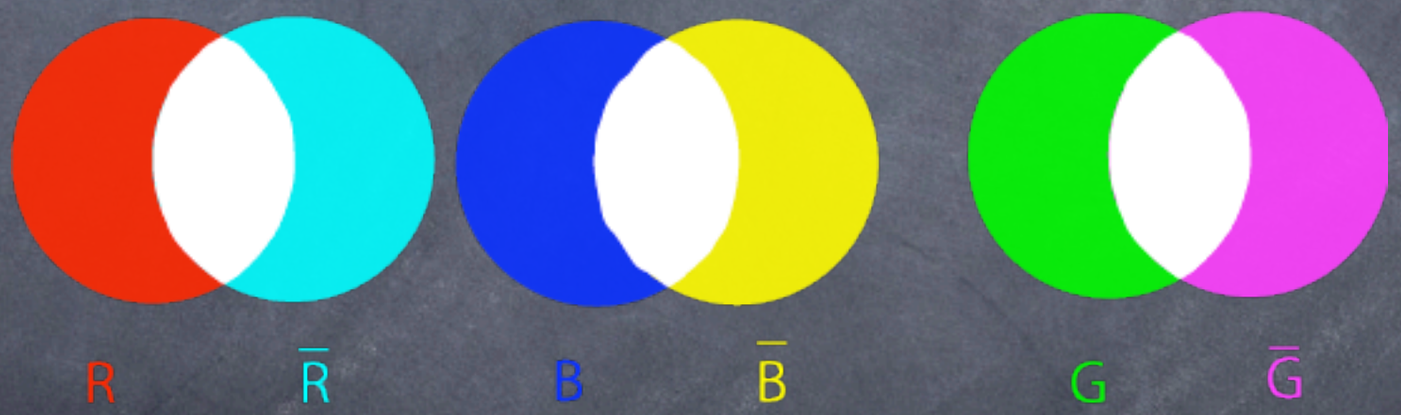


three quarks eight gluons three antiquarks

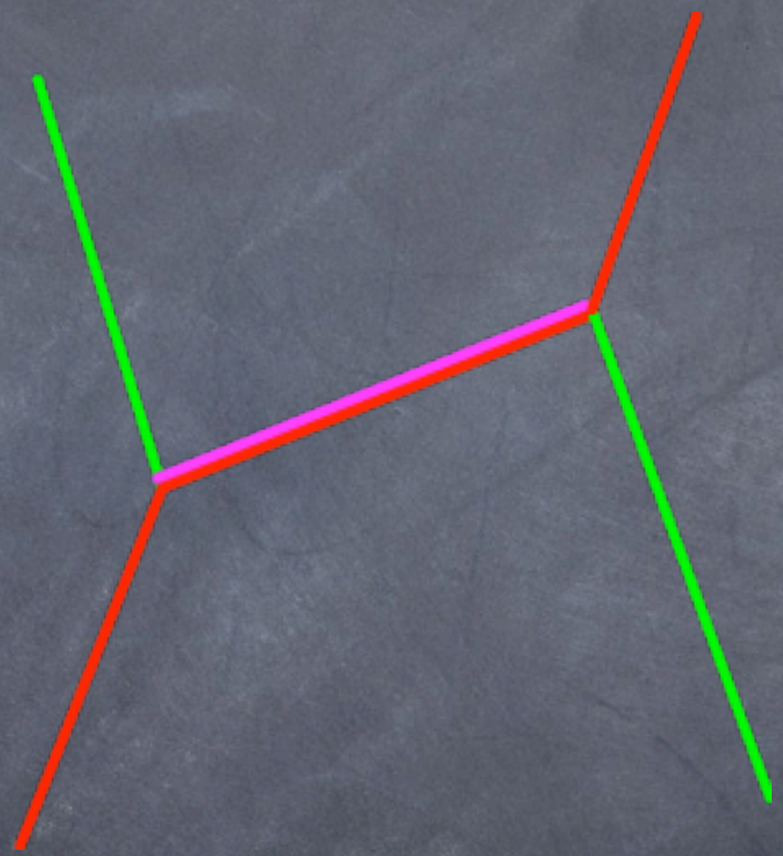
SU(3) Color Interactions



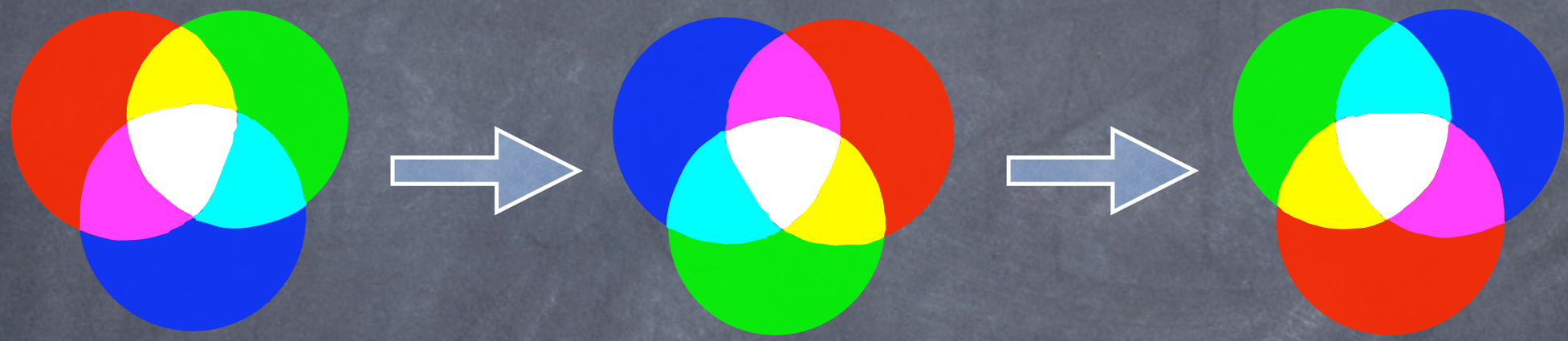
Colors



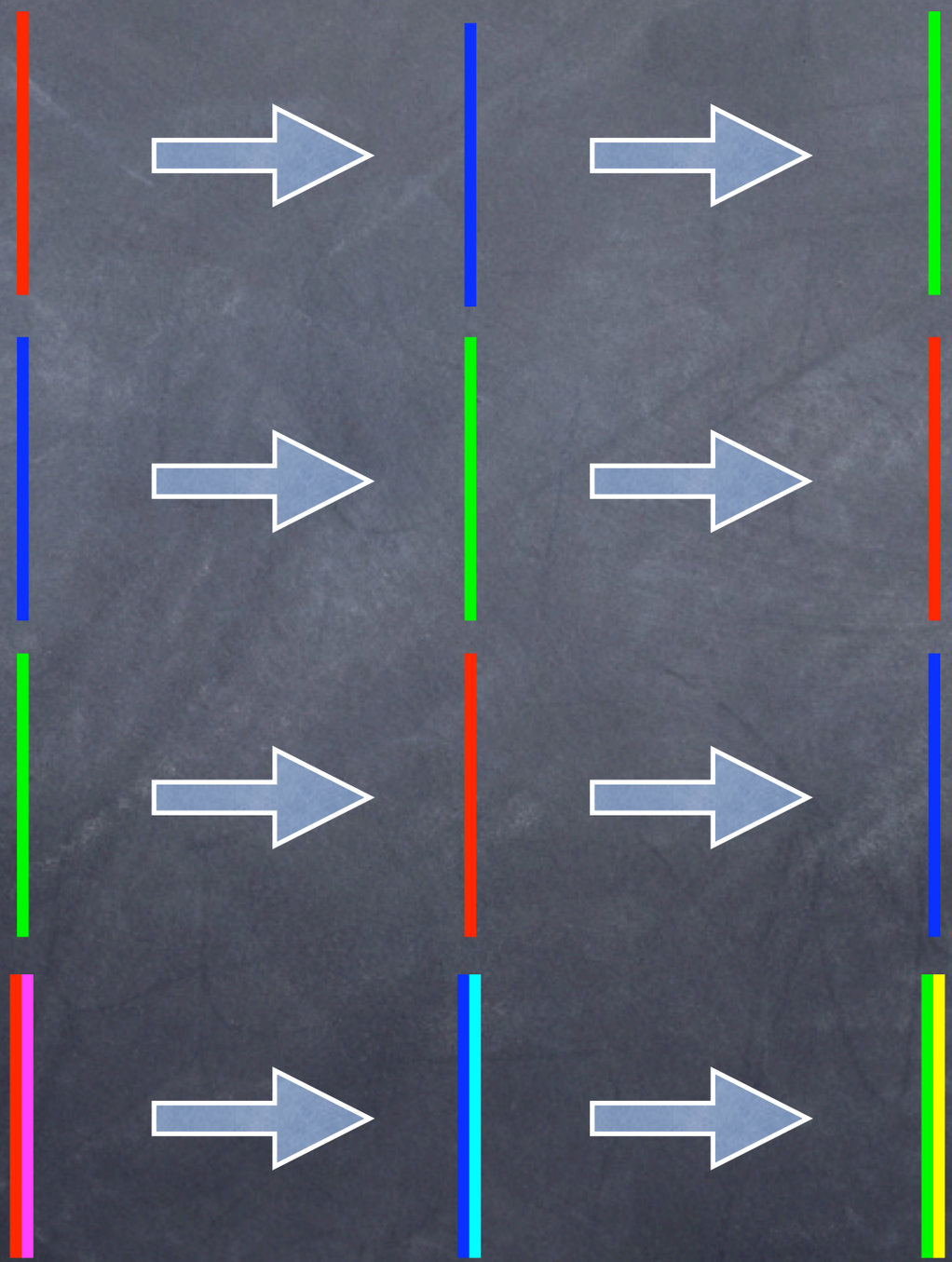
Color Exchange



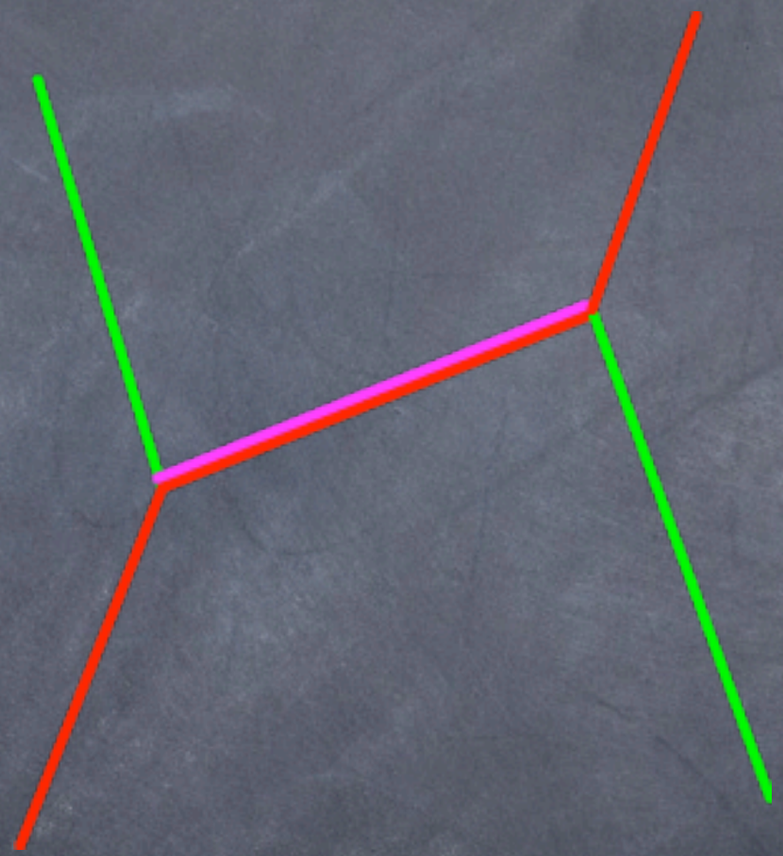
Color Gauge Symmetry



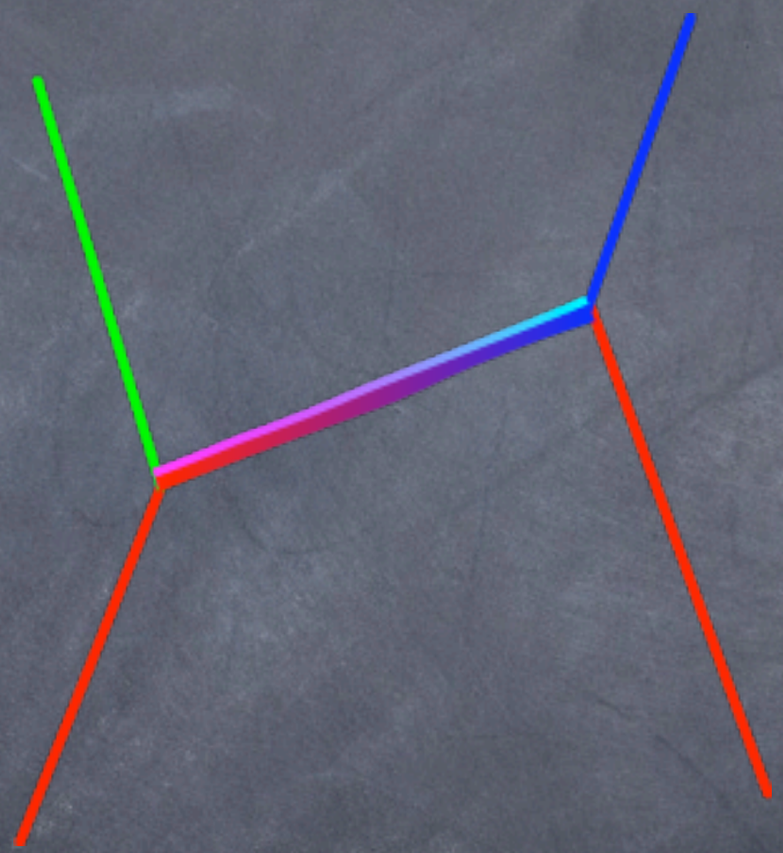
Color Gauge Symmetry



Color Exchange



Local Color Symmetry



Local Color Symmetry