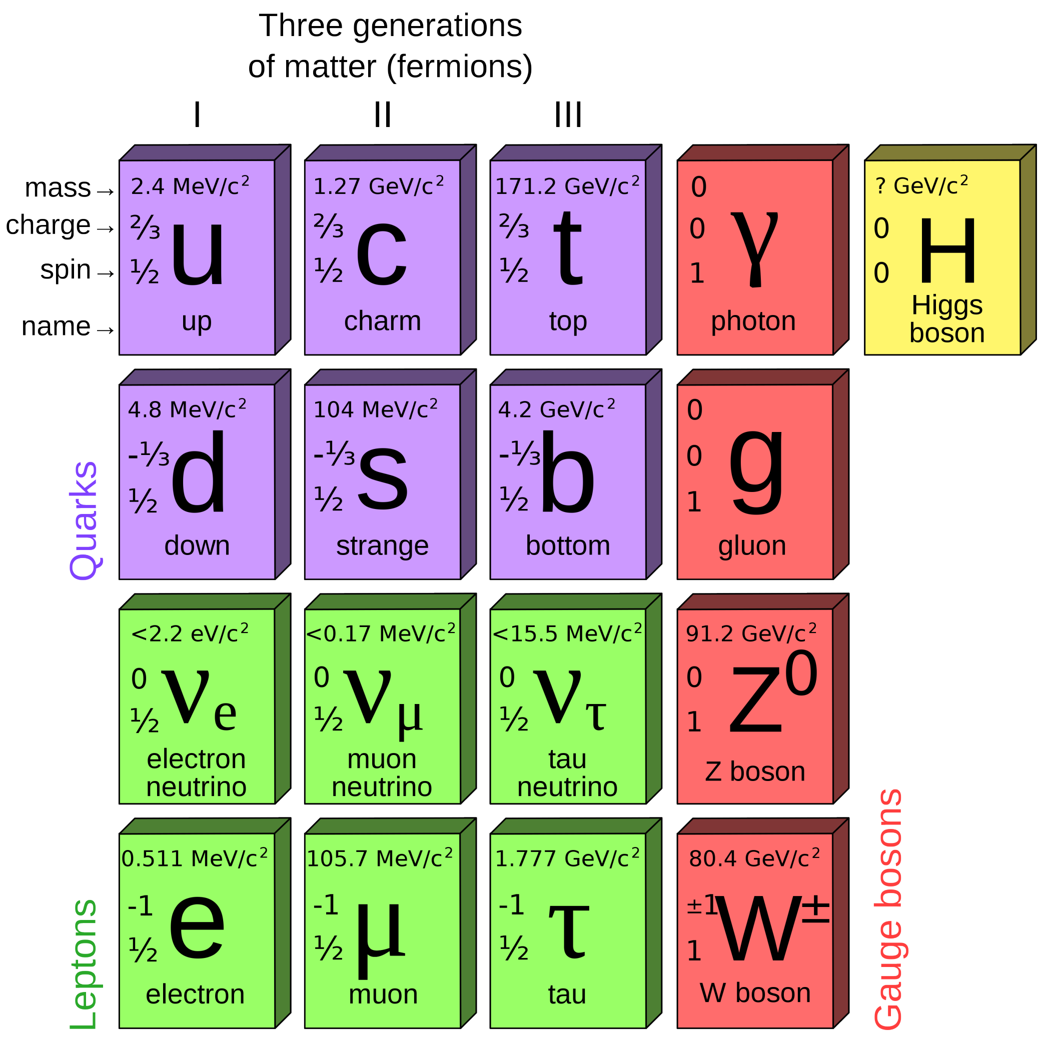
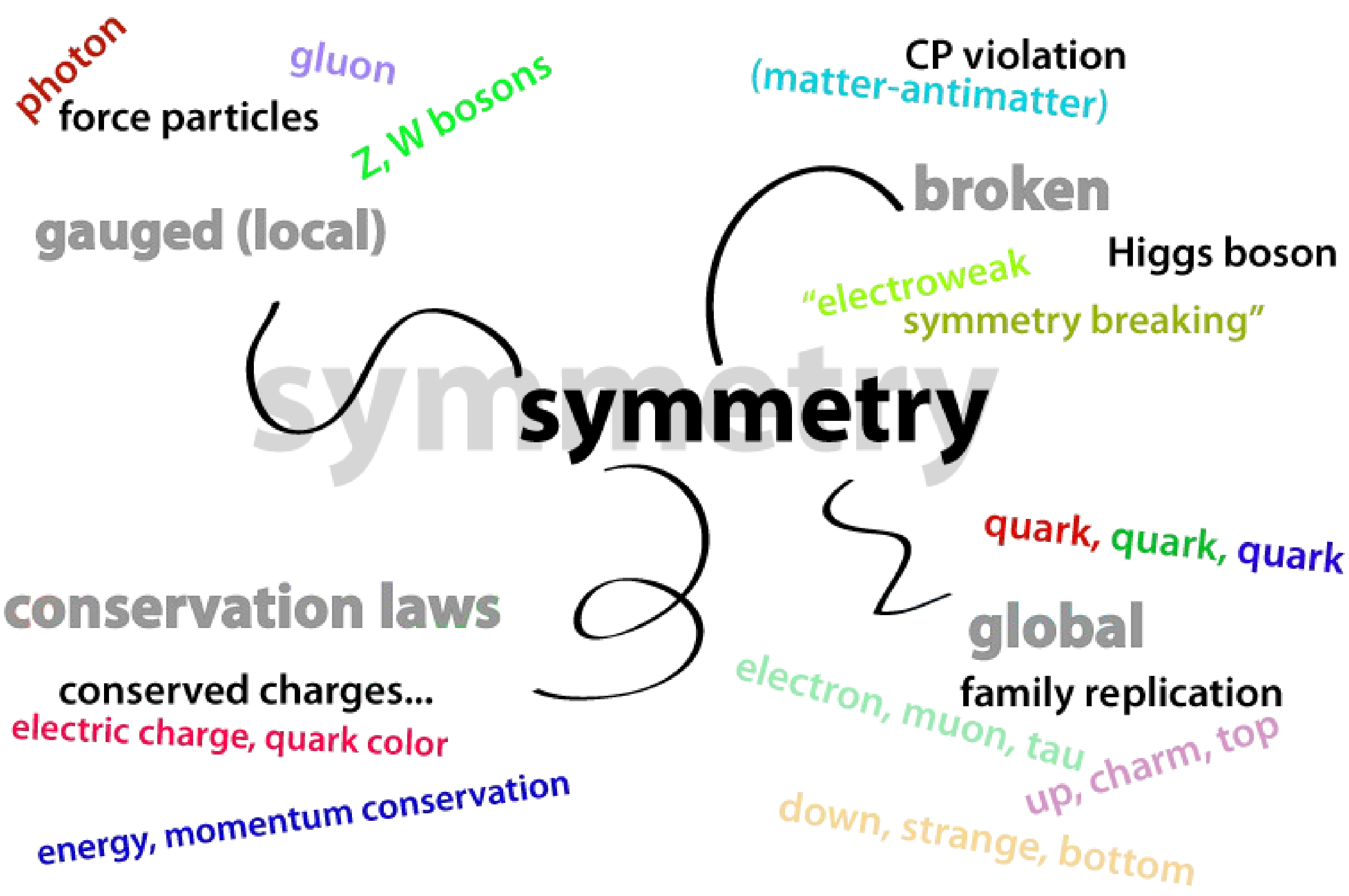
Laws of physics



Question: Are there laws for the laws of physics?

- Solid statement: physics is a mathematical compact way of describing nature
- Philosophy/physics: why are the laws as they are?
- Some indication that many laws of nature can be derived from symmetries
- Is that just an easy way to derive them or is there a deeper meaning?
  - The existence of the Higgs indicates that there maybe is a deeper connection

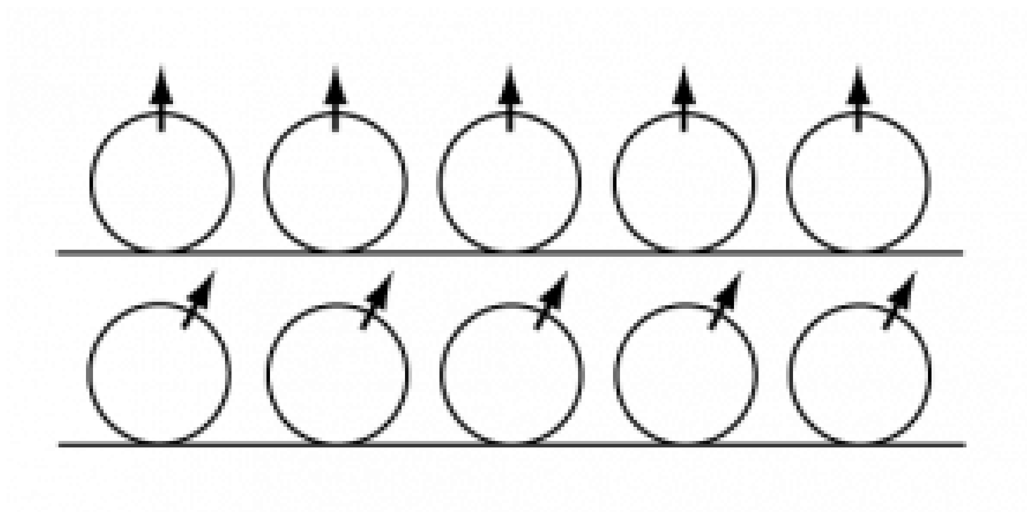
Symmetries


photon
gluon
force particles
Z, W bosons
gauged (local)
CP violation
(matter-antimatter)
broken
Higgs boson
"electroweak
symmetry breaking"
symmetry
quark, quark, quark
global
conservation laws
conserved charges...
electric charge, quark color
energy, momentum conservation
electron, muon, tau
family replication
up, charm, top
down, strange, bottom

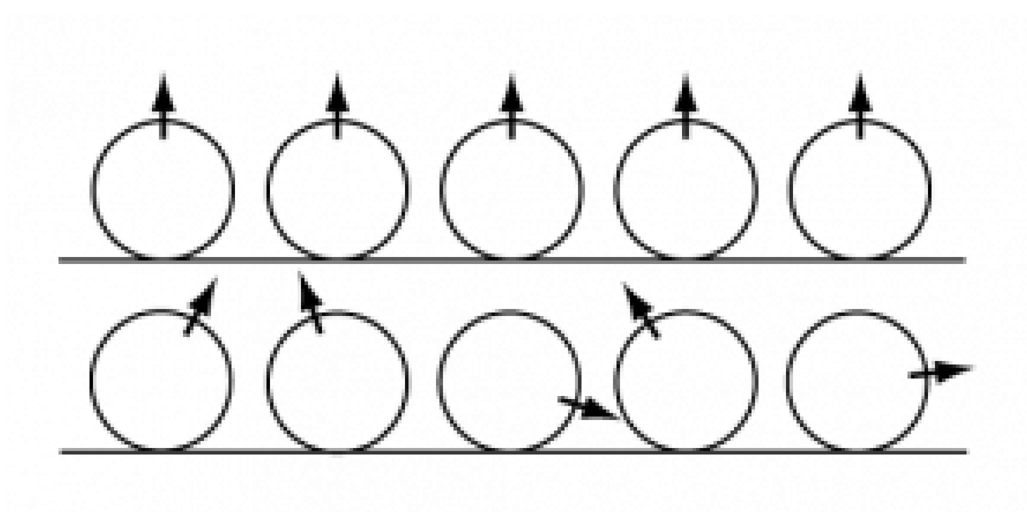
Space-time symmetries (chapter 5)

- Translational symmetry (physics is independent of absolute space) → momentum conservation
- Rotational symmetry → angular momentum conservation
- Time translation invariance (no absolute time) → energy conservation

Local gauge symmetries

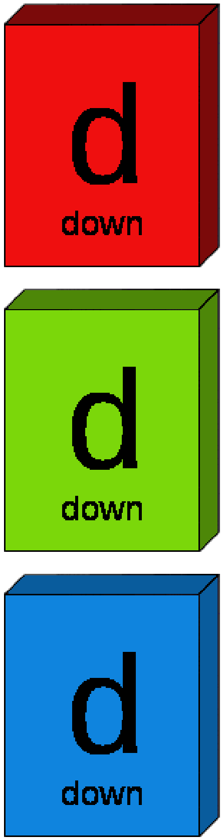


Global rotation



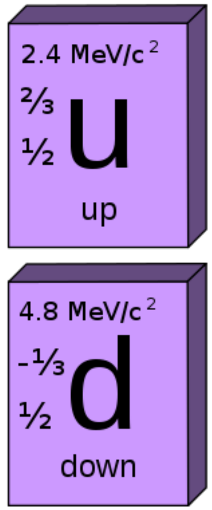
Local rotation

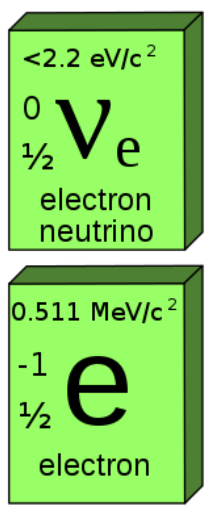
Rotation in abstract color space



- Color space is 3 dimensional (r, g, b)
- Rotation group: SU(3)
- Requiring that physics is invariant under local gauge transformations → QCD + 8 gluons
  - Gauge bosons

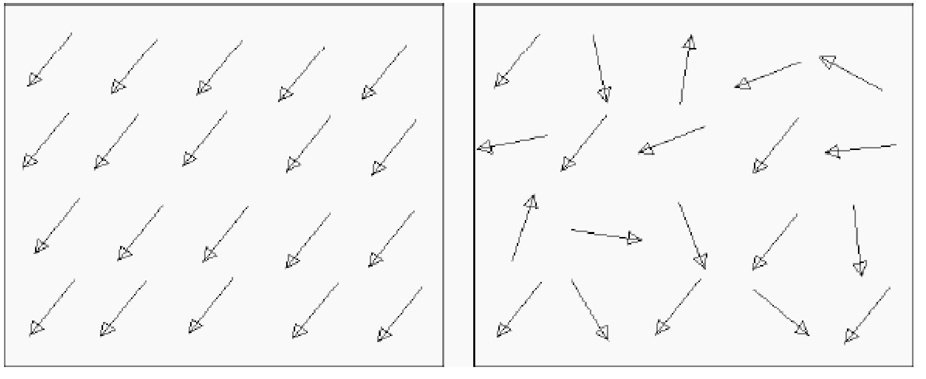
Rotation in abstract weak spinor space





- Weak spinor space is 2 dimensional (u_L, d_L) or (ν_L, e_L)
- Rotation group: SU(2)
- Requiring that physics is invariant under local gauge transformations → weak force + 3 bosons (W+, W0, W-)
- Note that this for left handed particles

Rotating phase of wavefunction



- 1 dimensional (phase)
- Rotation group: U(1)
- Requiring that physics is invariant under local gauge transformations → EM (Maxwell equations) + 1 B field

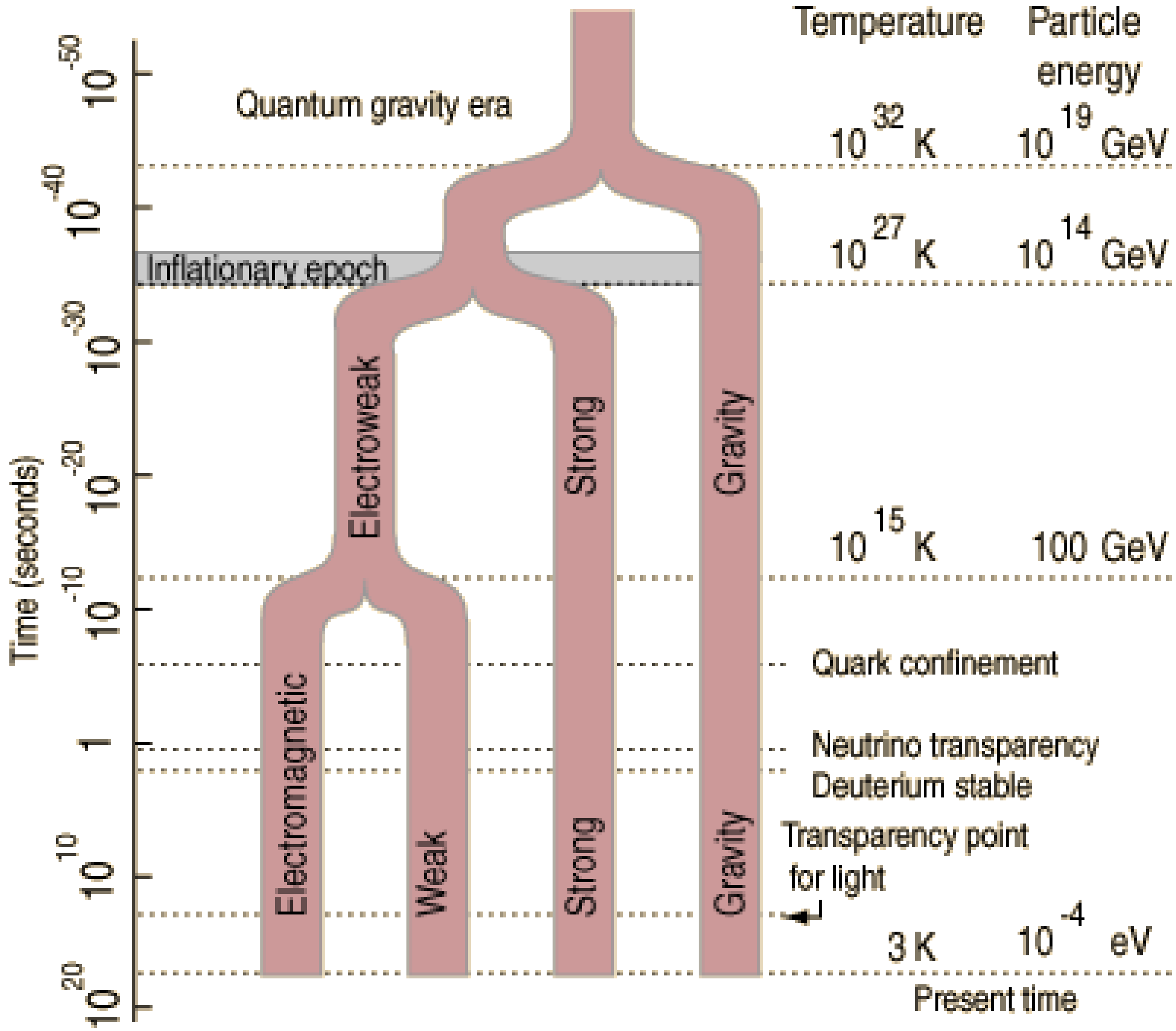
Standard model

- It seems that if we assume the existence of the fermions then by
- Assuming Gauge symmetry under U(1) x $SU(2)_{weak}$ x $SU(3)_{color}$ we can derive the known interactions:
  - Gauge bosons
  - Lagrangian for interactions
- So in some sense the forces can be derived from this underlying principle

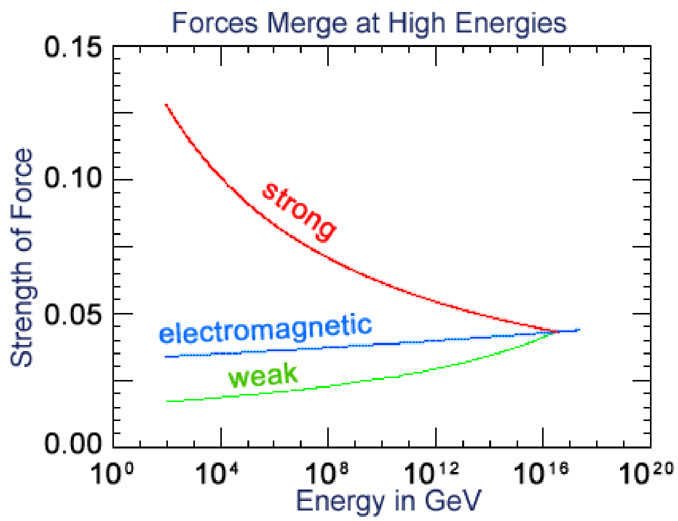
Symmetries

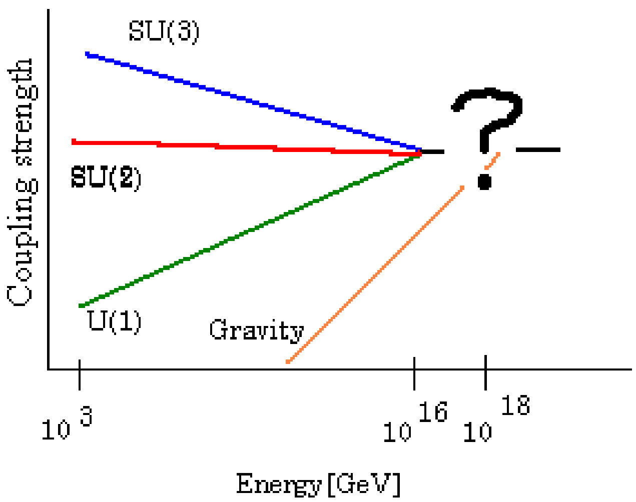
- Is the symmetries an economic way to derive the forces?
- Or do they give us insight into how nature really works? A deep principle for why the forces are like they are?
- At least they have played a huge rule in how theoretical physics have developed e.g. QCD and electroweak theories (and the confidence in those theories)
  - But also for theories beyond the standard model!

Grand unified theories



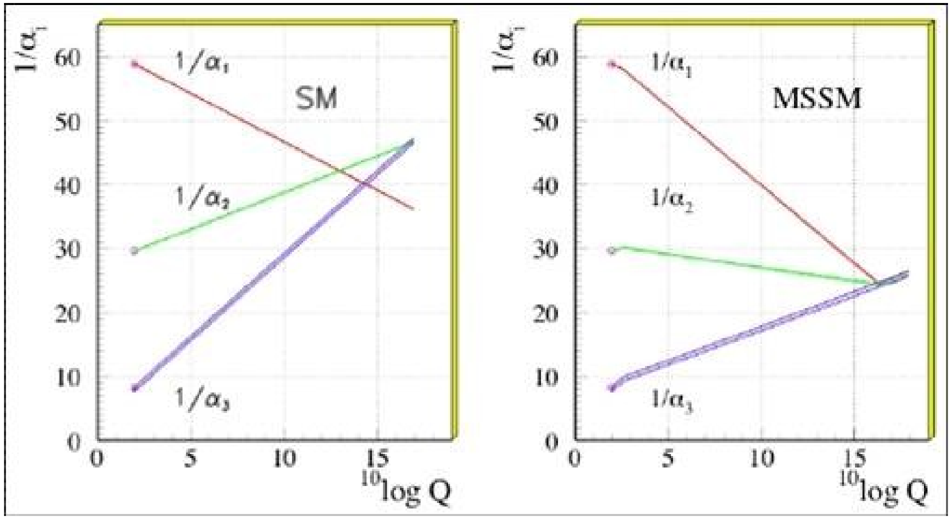
Motivation





- Experimentally we observe that the strength of the couplings roughly approach at high energies

This agreement can be made better with SUSY

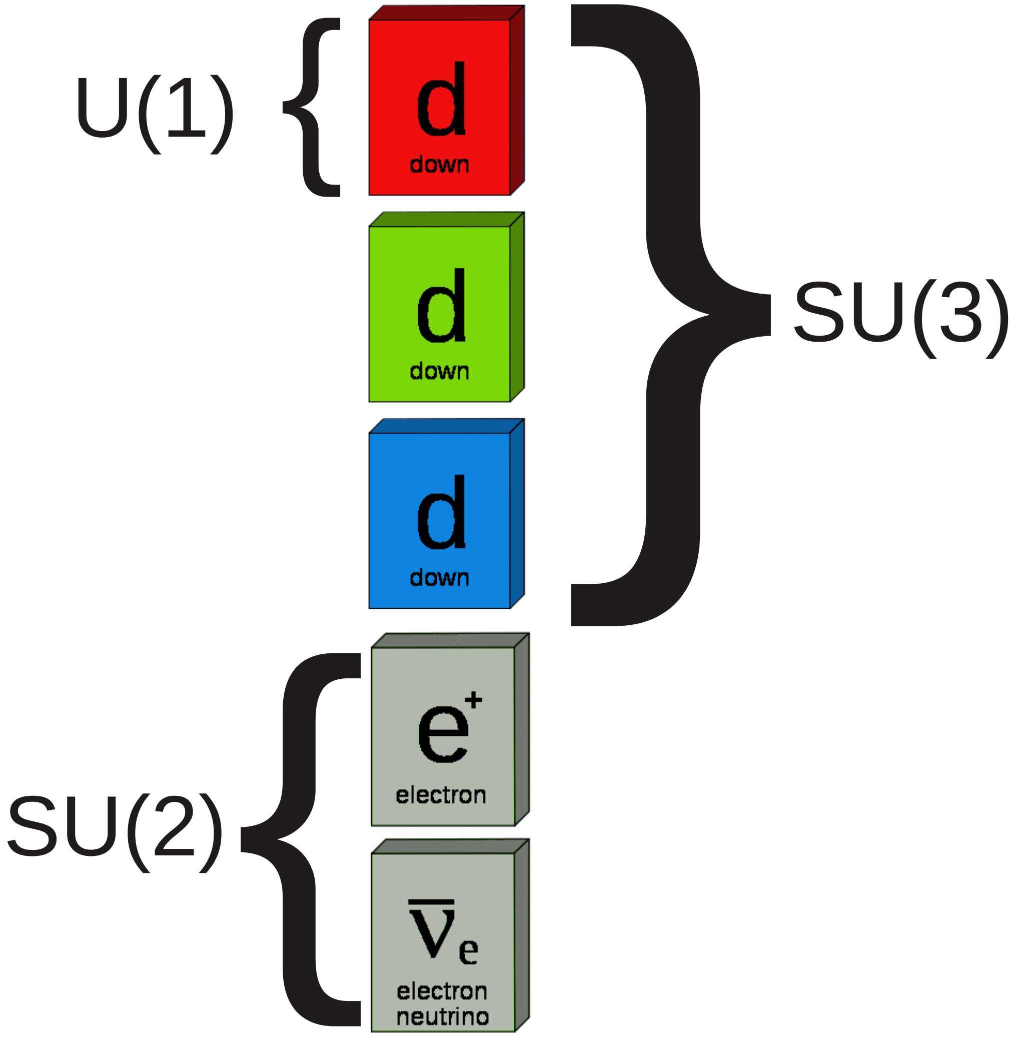


- So this could be another indication for SUSY

Also raises more fundamental question

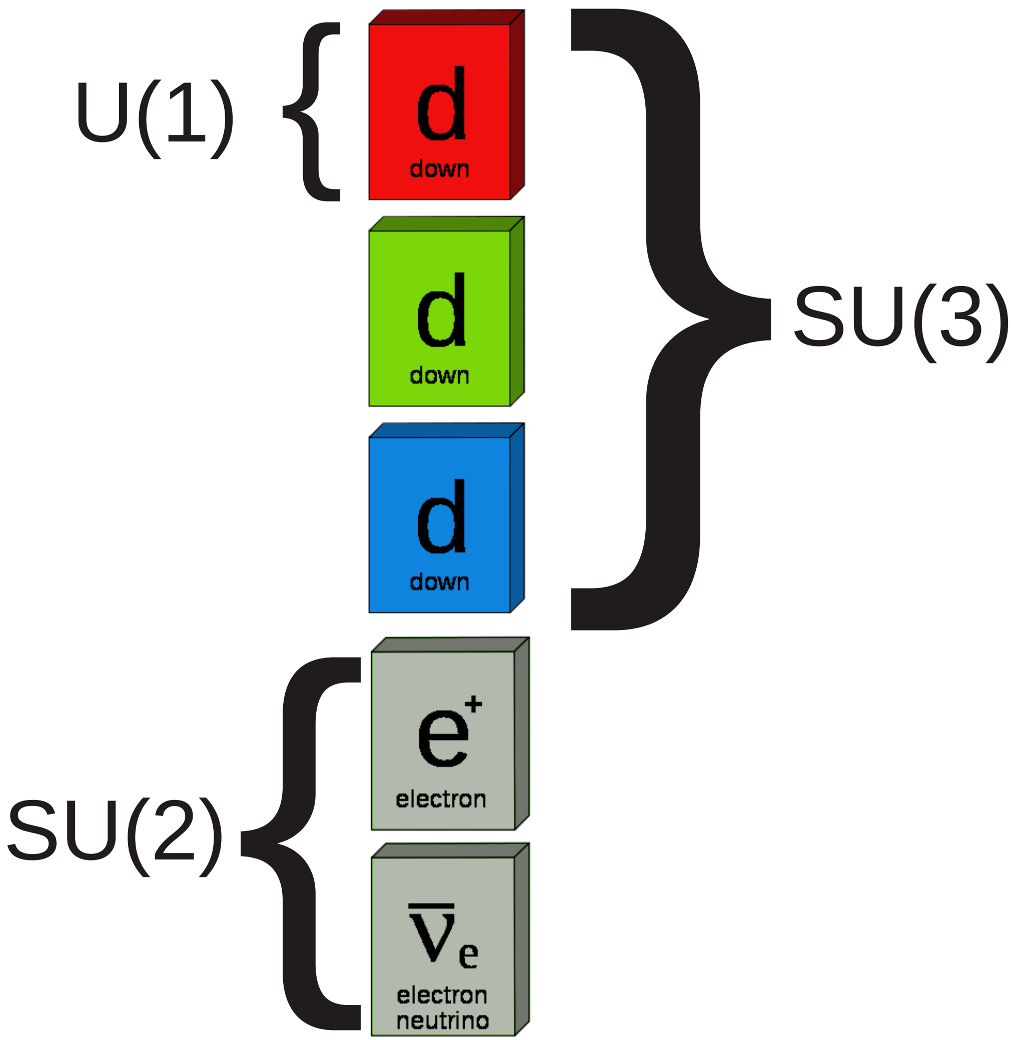
- Are all forces unified at the Planck scale?
  - Including gravity
- Does the strong force and the electro-weak force unify at some higher scale?

Idea: look for a bigger group that contains the weak and strong symmetry groups



- Georgi-Glashow model
- Based on SU(5) rotating (d_{red}, d_{green}, d_{blue}, e+, $\bar{\nu}$)
- Nice feature: sum of electric charges should be 0

What extra interactions do you get?



- Try to think through what additional interactions you get
- Hint: “rotation” like

Old and new interactions

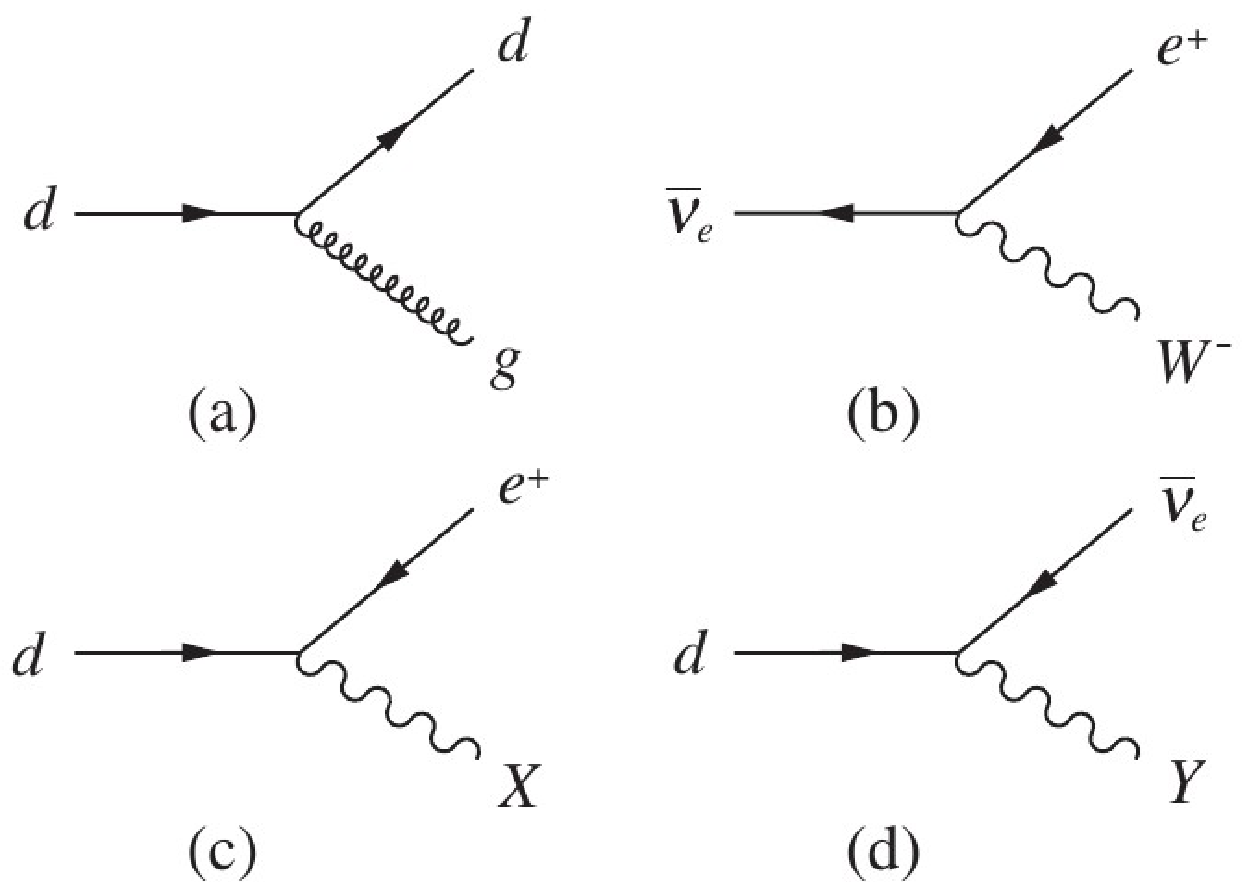


Figure 11.2 Two familiar processes (a, b) that can occur within the family of particles (11.3), together with two new processes (c, d) whose existence is predicted by grand unified theories.

Proton can decay

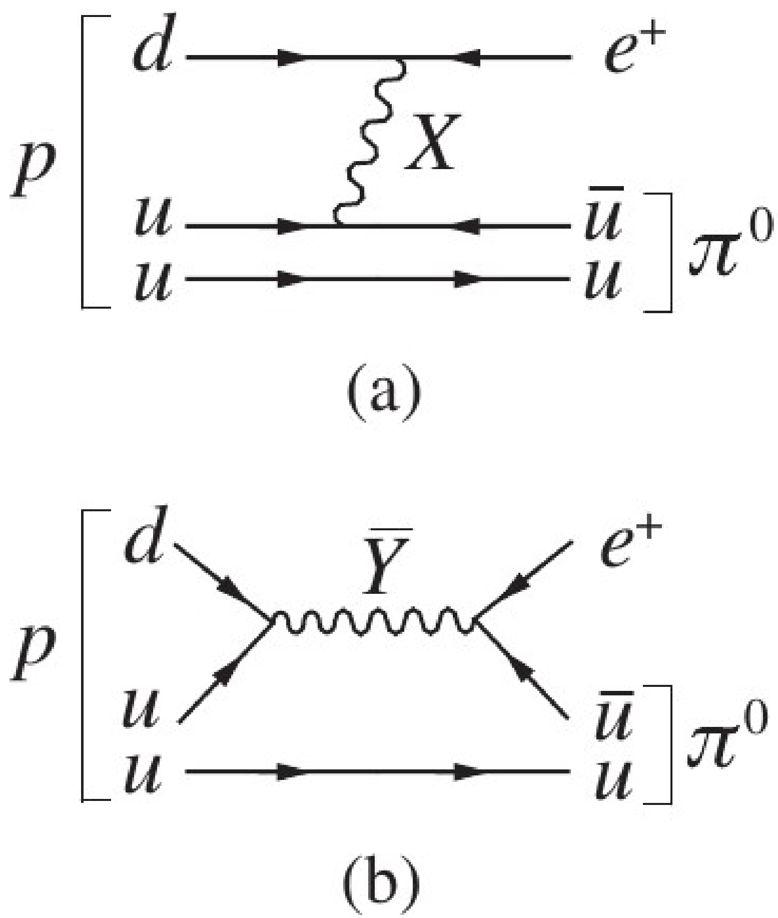
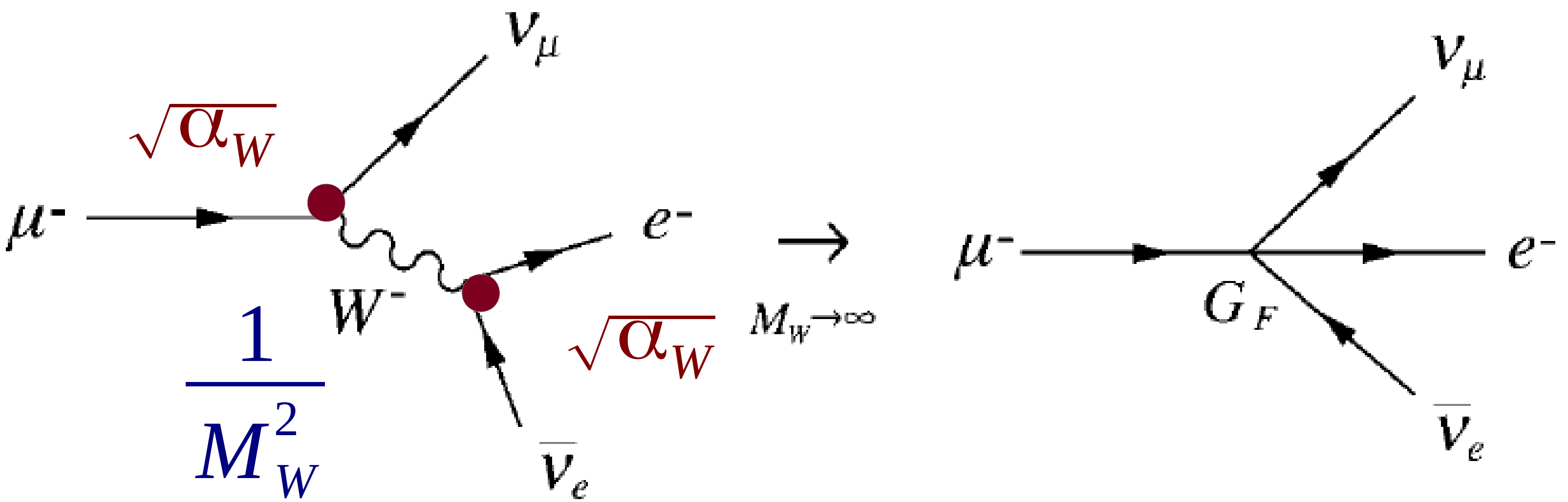


Figure 11.4 Examples of processes that contribute to the proton decay reaction (11.6).

How can we calculate this? Guesstimate point interaction



$$\frac{G_F}{\sqrt{2}} = \frac{g_W^2}{M_W^2} = \frac{4\pi\alpha_W}{M_W^2} \qquad (2.17)$$

GUT approximation

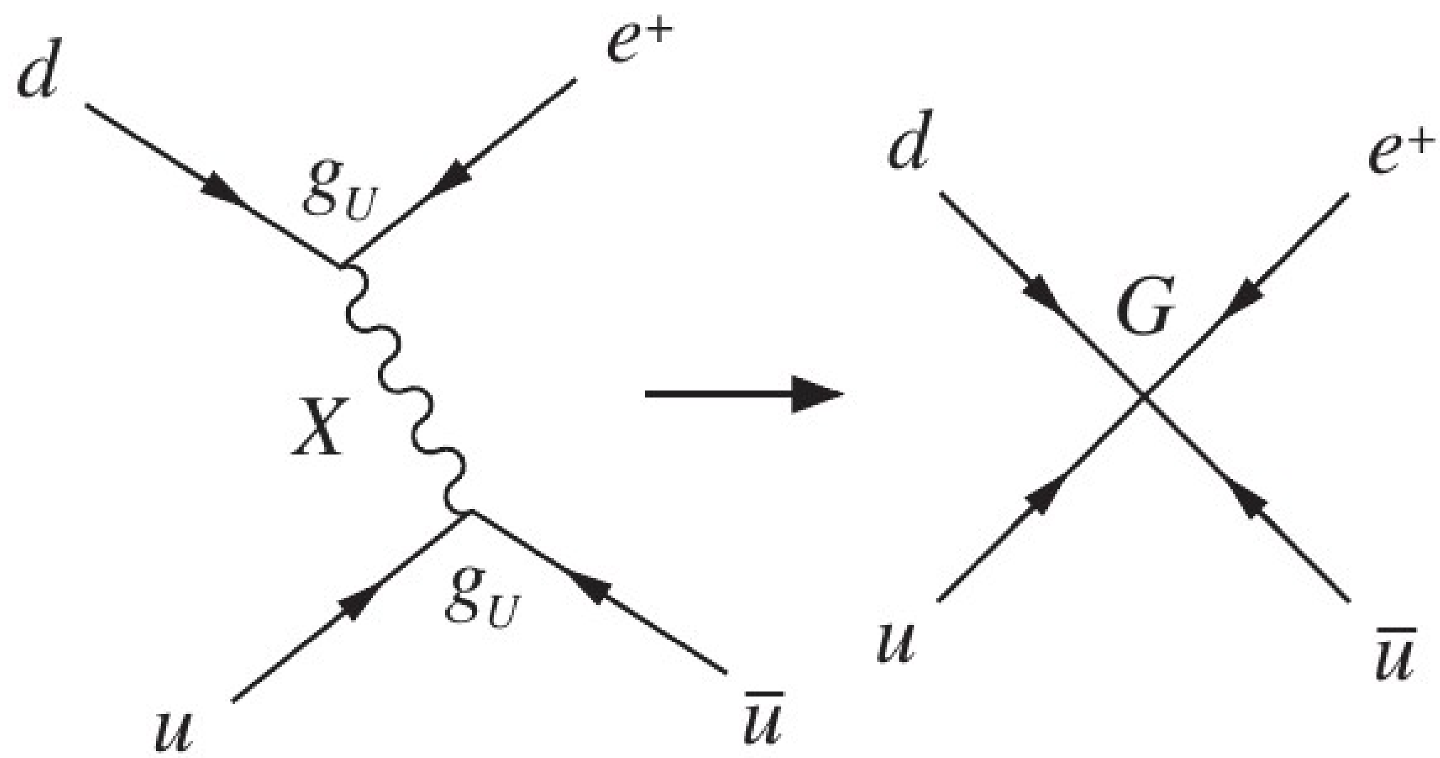
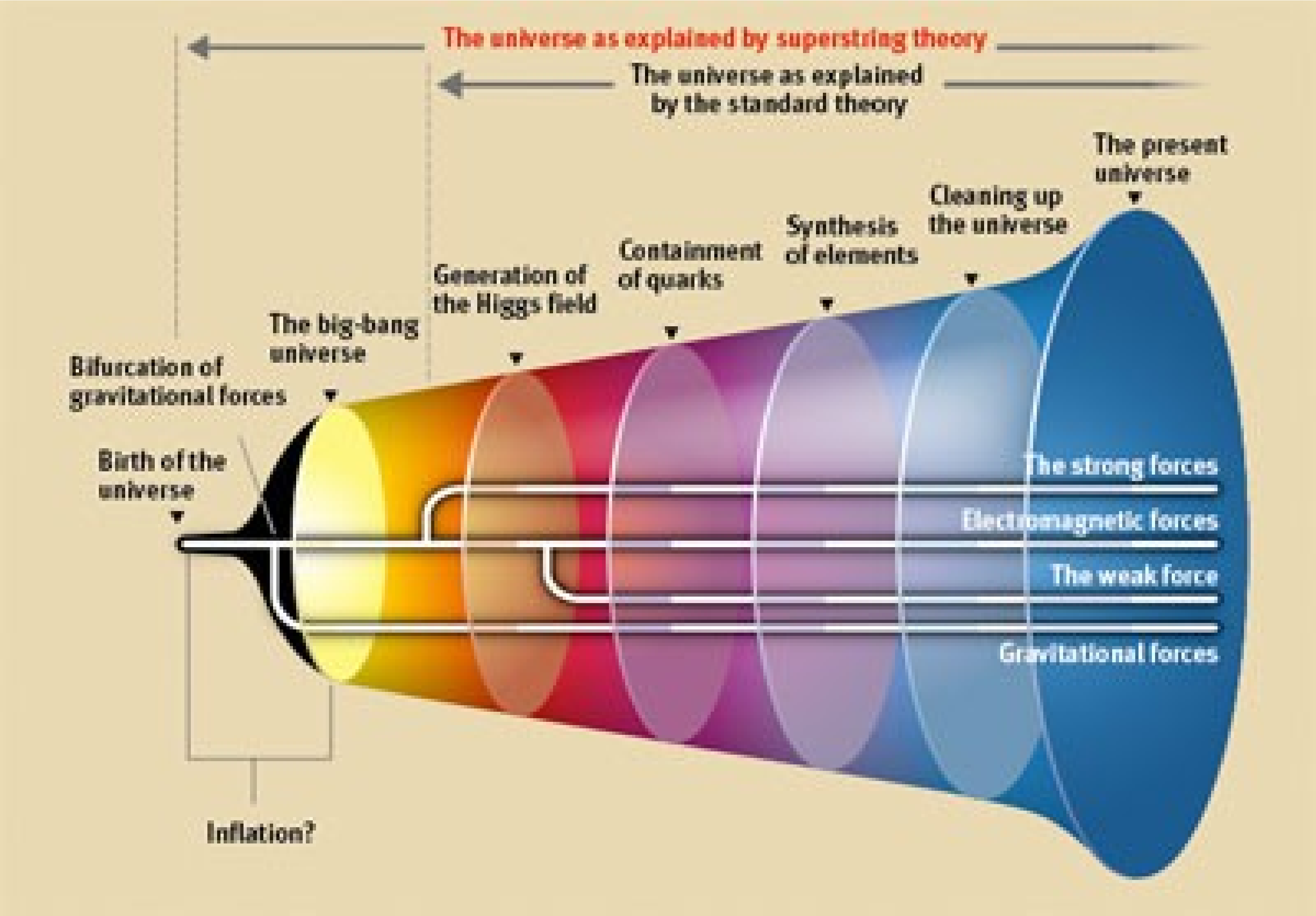


Figure 11.5 The zero-range approximation to an X-boson-exchange process.

What does one find?

- Theoretically one finds lifetimes of ~10^{30} years
- Experimentally one has ruled out that the lifetime is shorter than 10^{32} years
- No evidence for these decays (that might also have been able to explain baryon anti-baryon asymmetry)
- By adding additional physics one can find higher lifetimes, but then it is again not so natural
- So far no evidence for any GUT


The universe as explained by superstring theory
The universe as explained by the standard theory
The present universe
Cleaning up the universe
Synthesis of elements
Containment of quarks
Generation of the Higgs field
The big-bang universe
Bifurcation of gravitational forces
Birth of the universe
The strong forces
Electromagnetic forces
The weak force
Gravitational forces
Inflation?

The end