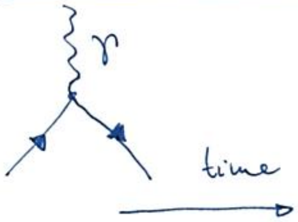
Summary - Particle Physics - Elementary particle dynamics

Quantum electro dynamics: QED

- → interaction trough photons γ
- → only charged particles
- → primitive vertex:



(not a real physical phenomena)

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combine 2 or more vertices to represent physical phenomena

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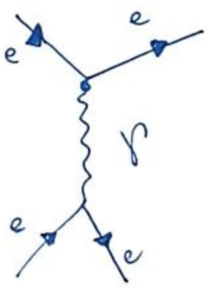
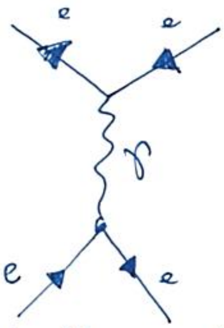
Feyman diagrams

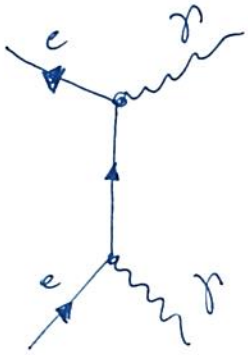
Examples:



Møller scattering (same charges)



Bhabha scattering (opposite charge)



pair annihilation
$e^- + e^+ \to \gamma + \gamma$

crossing symmetry: rotating or twisting the diagrams
- internal lines: virtual particles, describe the mechanism of the interaction
- external lines: real particles, describe what physical process is occuring
- Feyman diagrams are symbolic: they represent interactions

To analyse a particular proces:
- draw all possible diagrams
- evalute the contribution of each and sum them
  ↳ each vertex introduces a factor of $\alpha = \frac{e^2}{\hbar c} = \frac{1}{137}$ finestructure constant
- the sum total of the Feyman diagrams represents the process

→ Energy and momentum conservation

2) <u>Quantum chromodynamics</u> QCD

- interaction trong: gluons
  - only quarks (colour plays a similar role to charge in QED)
    - ↳ 3 different colours (r, g, b)
    - → colours must be conserved
    - → gluons carrie 2 units of colour → 8 different gluons

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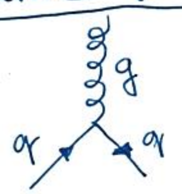
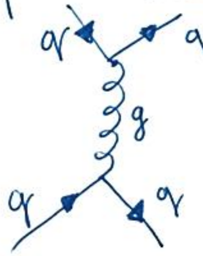
gluons can couple to other gluons
→ glueballs: bound state of gluons with no quarks

- <u>primitive vertex</u>:



simplest <u>example</u>:



- coupling constant for the strong force varies with distance
  ↳ running coupling constant: large distance - big
  small distance - small

→ <u>assymptotic freedom</u>: the colour of particles gets shielded by virtual particles in vaccum

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similar to <u>vacuum polarization</u>, which is a QED effect of shielding the charge by virtual particles
→ we measure the effective charge

<u>quark polarization</u>: depends on the number of quarks

<u>gluon polarization</u>: depends on the number of gluons

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these 2 influence the coupling constant

→ natural particles can carrie charge but no overall colour
↳ quarks are confined in colourless bound states

(3) Weak interactions

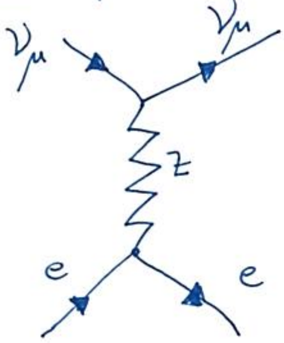
- → all fermions interact trough the weak force
- → interaction trough $W^{\pm}, Z$ bozons
- → 2 kinds of interaction: - <u>charged</u> : $W^{\pm}$
  - <u>neutral</u> : Z

Neutral

→ fundamental vertex:

→ any process mediated by γ can also be mediated by the Z

<u>Example</u> :



$\nu_\mu + e^- \to \nu_\mu + e^-$ scattering

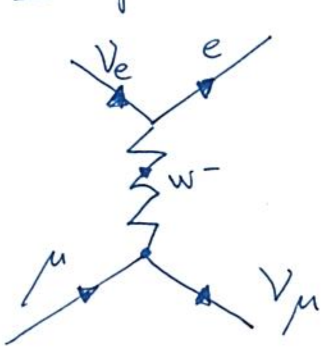
→ neutral weak interaction violates parity → can be experimentally tested

charged

→ <u>can change flavour</u>: the only interaction causing ~~pure~~ true <u>decays</u>

<u>fundamental vertex</u> :

<u>Example</u> :



$\mu^- + \nu_e \to e^- + \nu_\mu$
neutrino - muon scattering

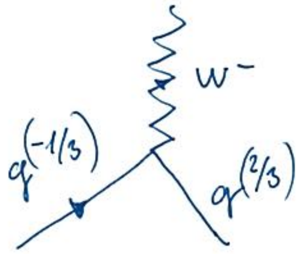
decay of μ : $\mu^- \to \nu_\mu + e^- + \bar{\nu}_e$

1) quarks in the weak interaction

-> leptonic weak vertices connect members of the same generation
↳ conservation of lepton number

-> not the same for quark -> we can connect different generations
-> cross generational decays

fundamental vertex:



-> colour doesn't change
-> flavour changes -> W doesn't carry flavour!
-> charge get carried away by W^-

-> this vertex can couple to other quarks : hadronic process
or to ~~other~~ leptons : semileptonic process

semi leptonic processes: β decay, e^- capture, π decay $(\pi^- \to e^- + \bar{\nu}_e)$
$(\pi^- \to \mu^- + \bar{\nu}_\mu)$

purely hadronic process: $\Delta^0 \to p + \pi^-$

strangeness changing interactions: cross generational decay: $s \to u$
$s \to d$ etc...
↳ the coupling of the quarks is described by the Kobayashi-Maskawa matrix

In the electroweak interaction or GWS theory: W and Z can couple to each other (similar to gluons) and they can also couple to γ

Decays:

-> generally every particle tends to decay into a lighter particle unless prevented from it by a conservation law

-> stable particles: γ, e^-, p^+, ν, (n)

-> unstable particles have a characteristic mean lifetime: τ

$$t_{1/2} = (\ln 2)\tau$$

(5) → decays are governed by one of the 3 forces
→ depending on the force the <u>mean lifetimes</u> are very different

- strong decay : 10^{-23} s shortest
- electromagnetic decay : 10^{-16} s
- weak decay : 10^{-3} s longest

→ if there is a γ → electromagnetic
→ if there is a ν → weak
→ generally a decay is faster if there is a large mass difference between the decaying particle and the products (more energy release)

<u>Conservation laws</u> :

<u>Kinematic</u> from special relativity :

- energy
- momentum
- angular mom

<u>Dynamical</u> conservation laws based on the fundamental vertices :

- charge
- colour
- baryon number (quark number)
  - baryon : 1
  - antibaryon : -1
  - meson : 0
- lepton number
- flavour : violated by the weak interaction
  "approximately" conserved
- OZI rule : - related to assymptotic freedom
  - coupling trough high energy gluons → supressed
  - Feynman diagram rule : if the gluons can be cut with a straight line without crossing external lines
  → the process is OZI supressed e.g. ϕ decay