# FYSC14 compulsory elements

**Monday 4/11 (introduction)**

**Monday 25/11 (lab-prep)**

**Lab period 2 (Separate 2.5 hp grade)**

**Two written assignments to be handed in (25% of final 5 hp grade)**

**Oral exam (75% of final 5 hp grade)**

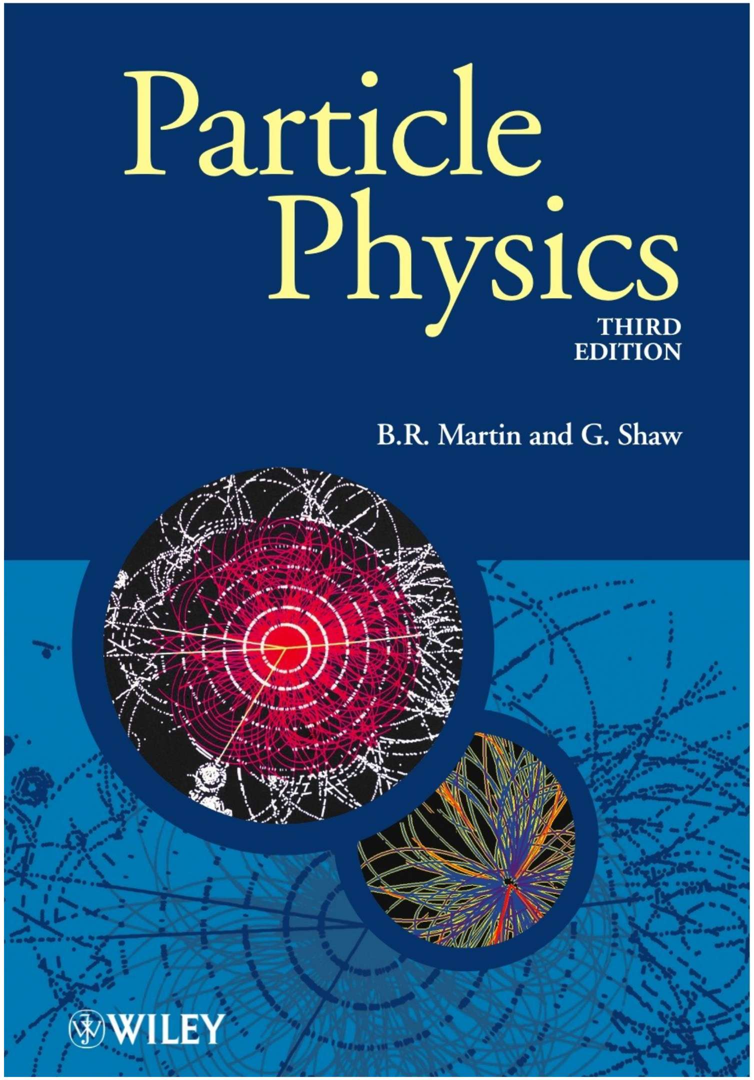
All partial elements of the course: written assignment 1+2, lab, oral exam, DESY trip have to be passed for the course to be passed.

A final ECTS grade will be provided.

# Material

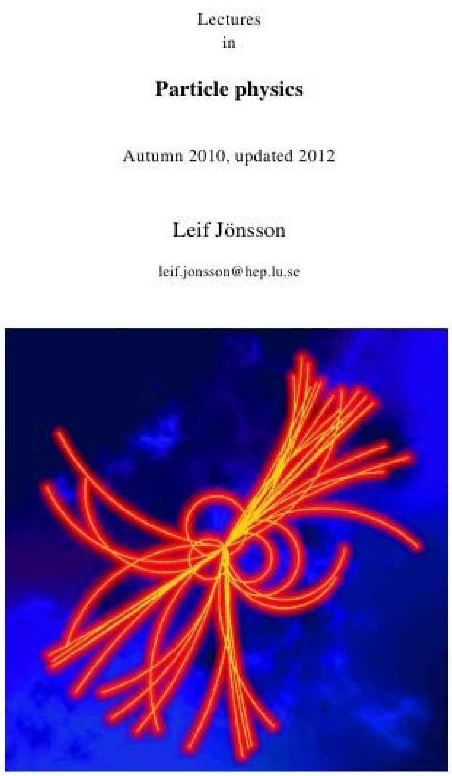
- Please consult also: http://www.utbildning.fysik.lu.se/tibet/template/personal%2CIndex.vm?pageid=241426&siteid=1000

# Lecture materials (1/3) DEFAULT




- This is the official book and this is the one we will follow!

# Lecture material (2/3)
# Condensed, extensive and free!


Lectures
in
**Particle physics**

Autumn 2010, updated 2012

Leif Jönsson

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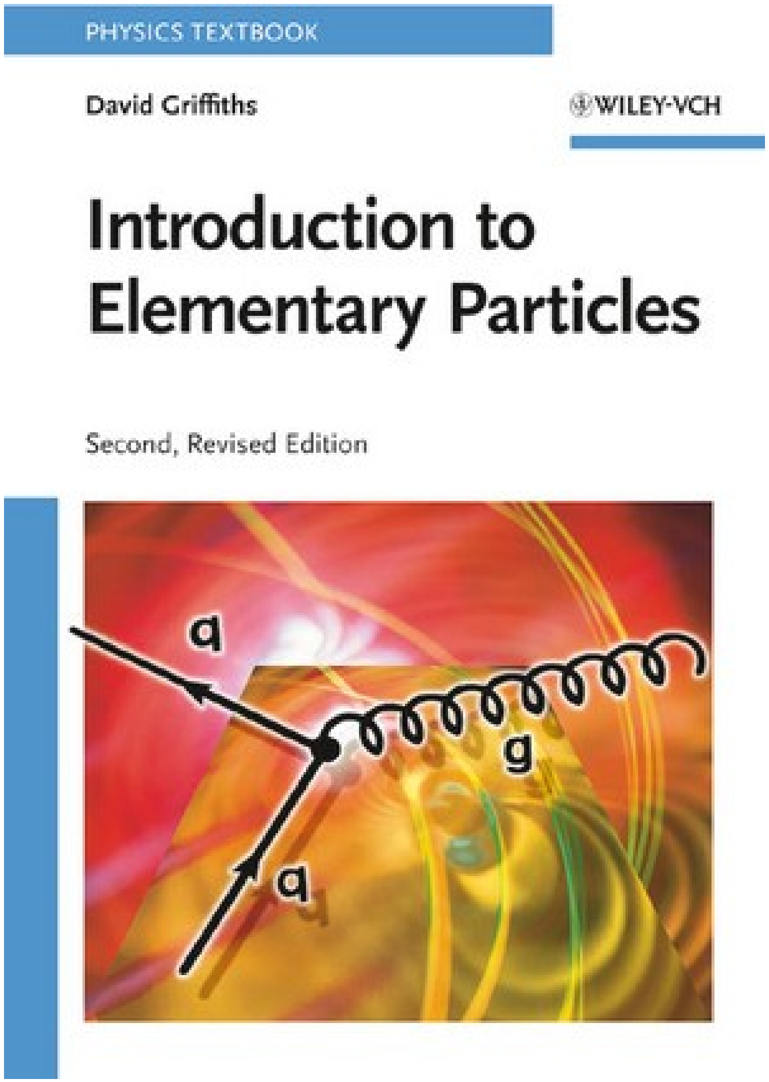
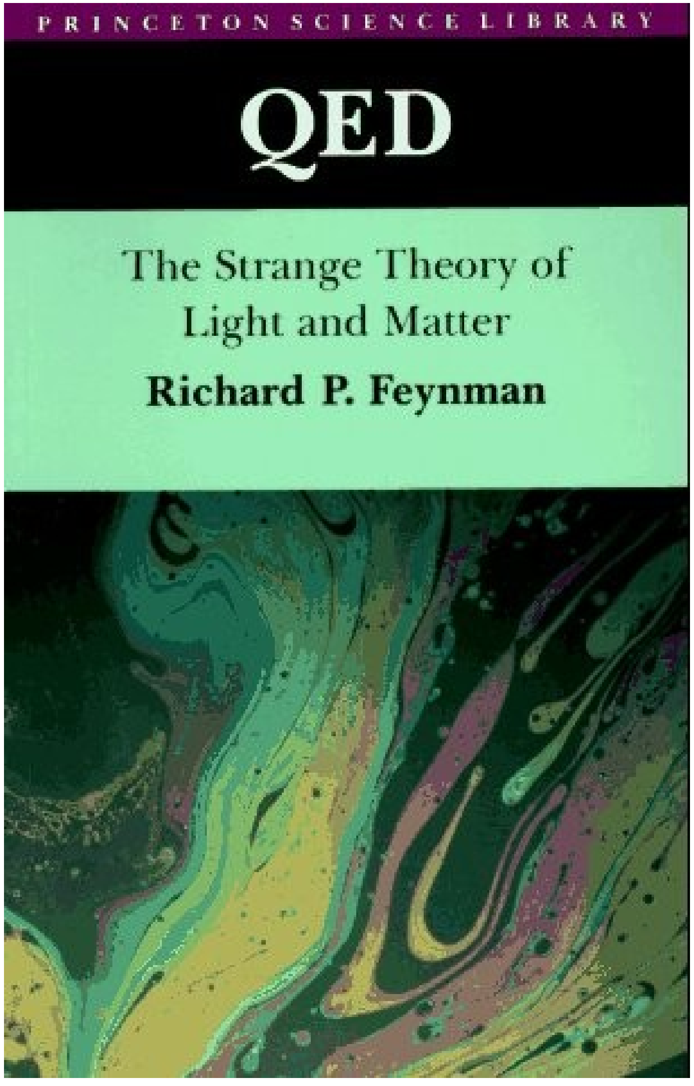
- Leif's notes. Leif was the original lecturer on this course and for many years.
- Chapter 1 is still part of the official colloquium for the course.

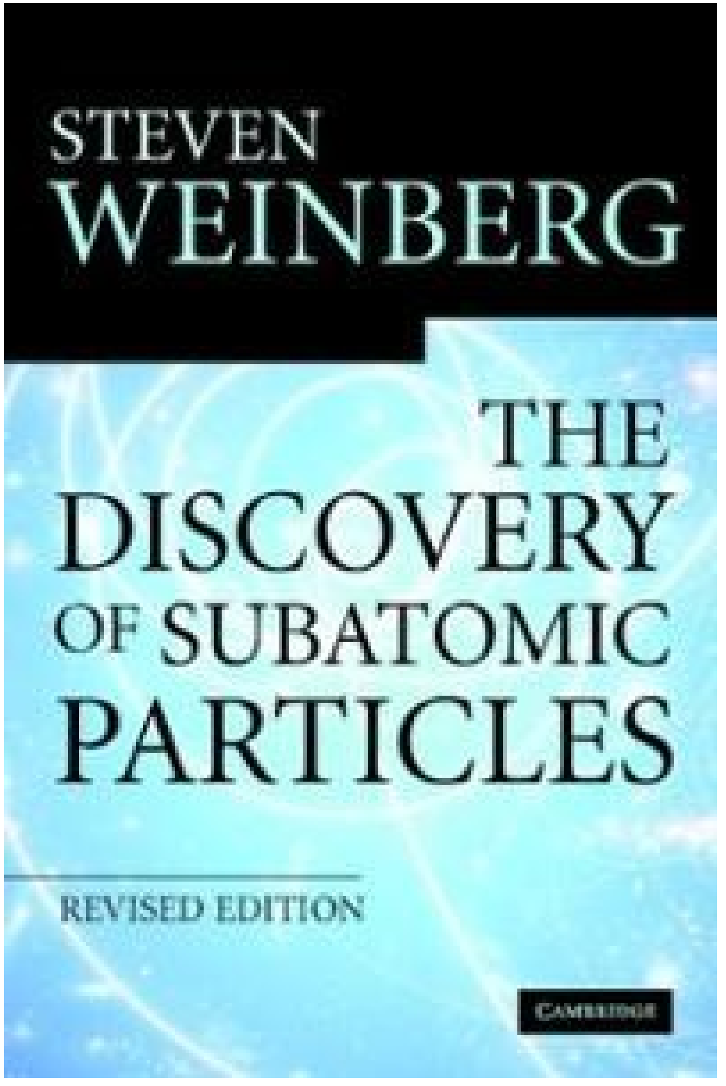
# Lecture material (3/3)
# More focus on theory



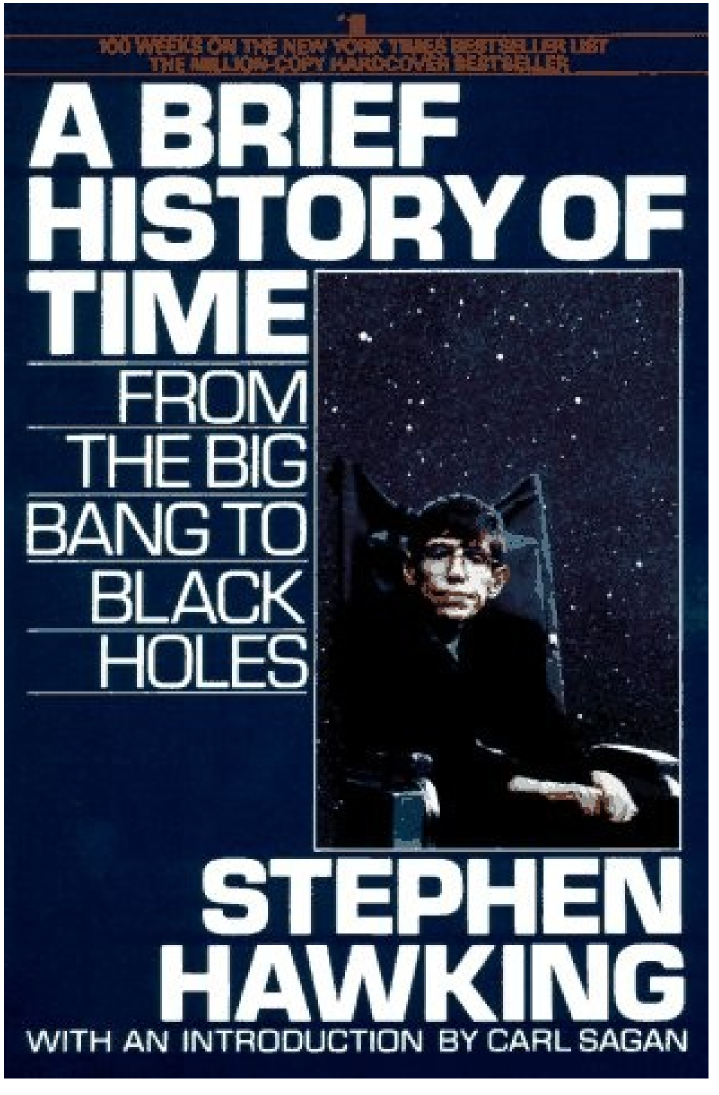

- Griffiths will give you a much better understanding of the Feynman diagrams.

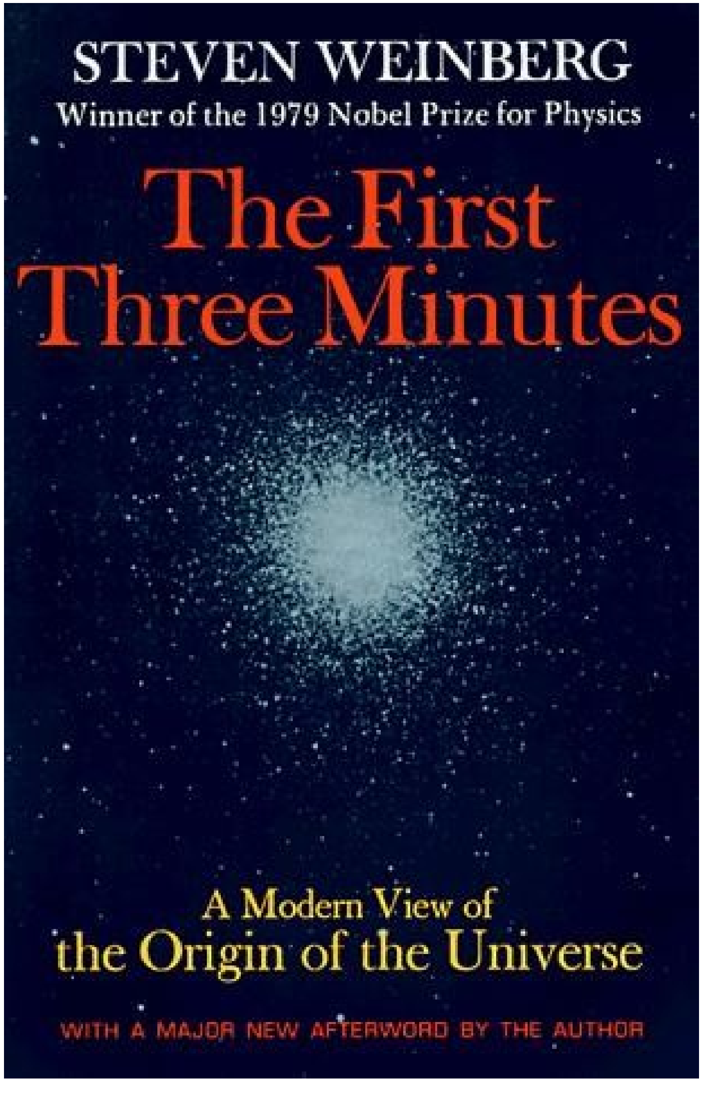
# Popular physics (1/4)



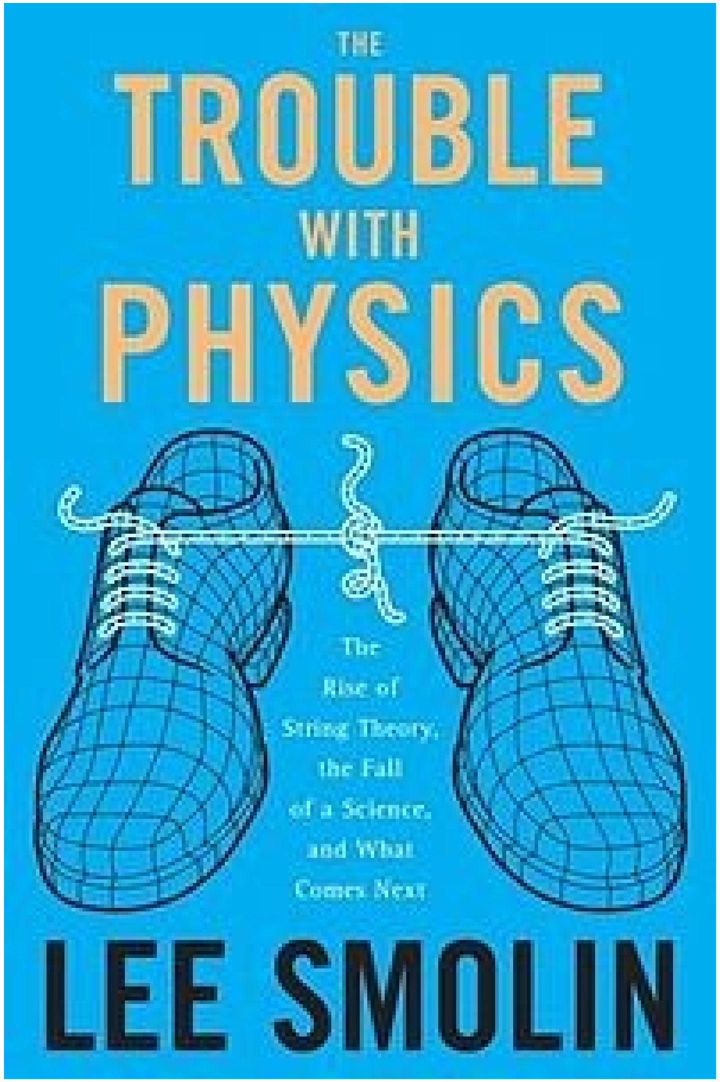



# Popular physics (2/4)



# Popular physics (3/4)




- Not always popular among theorists but I really recommend it

# Popular physics (4/4)

- YouTube contains a lot of nice popular science but also a lot of videos with physics icons

# Questions?

# What is the difference between University and School?

# My opinion

- You are here because you want to be here
- It is your responsibility to learn/study
- The course content requirements and specifications are important for a fair examination
  - They are meant as a minimal knowledge requirement for what we call a physicist

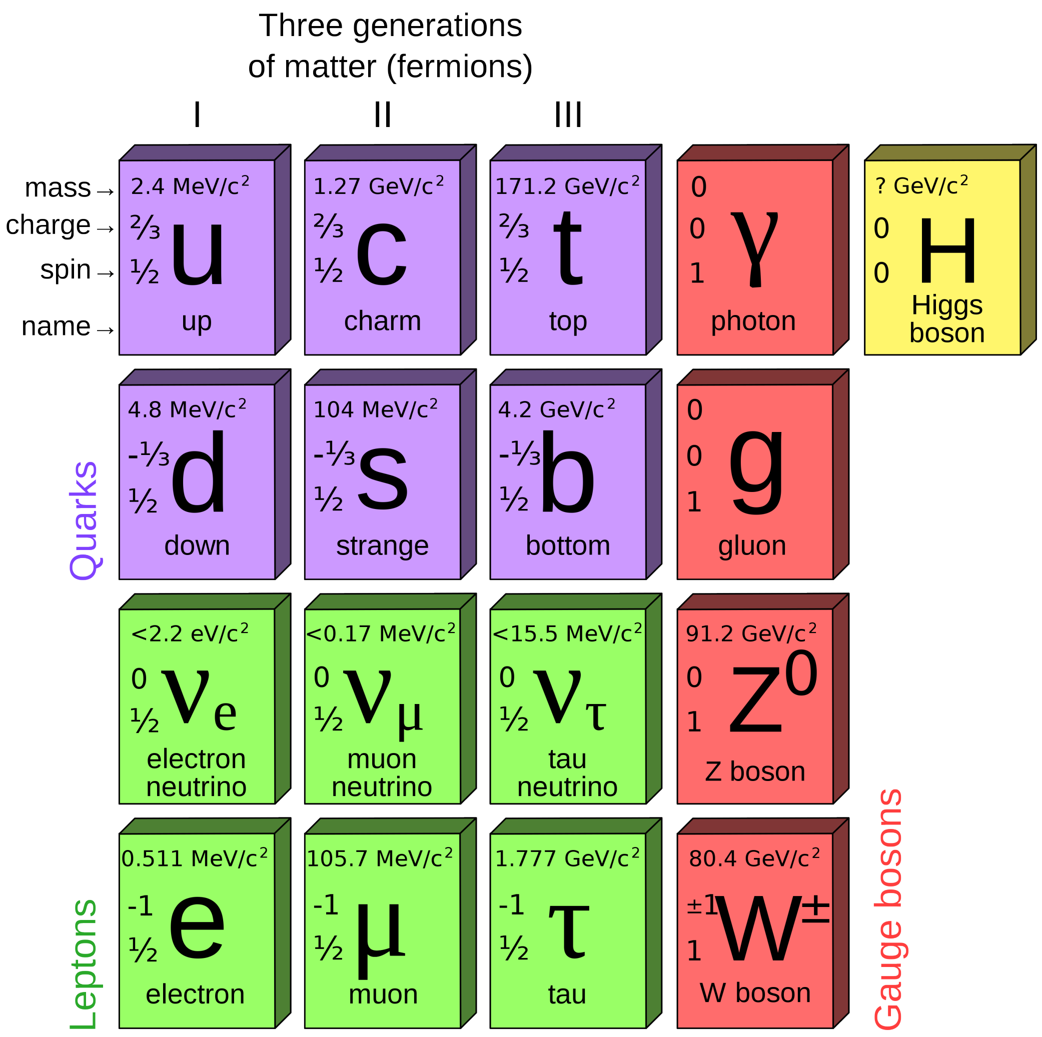
# Introduction

- Today we shall consider the process:

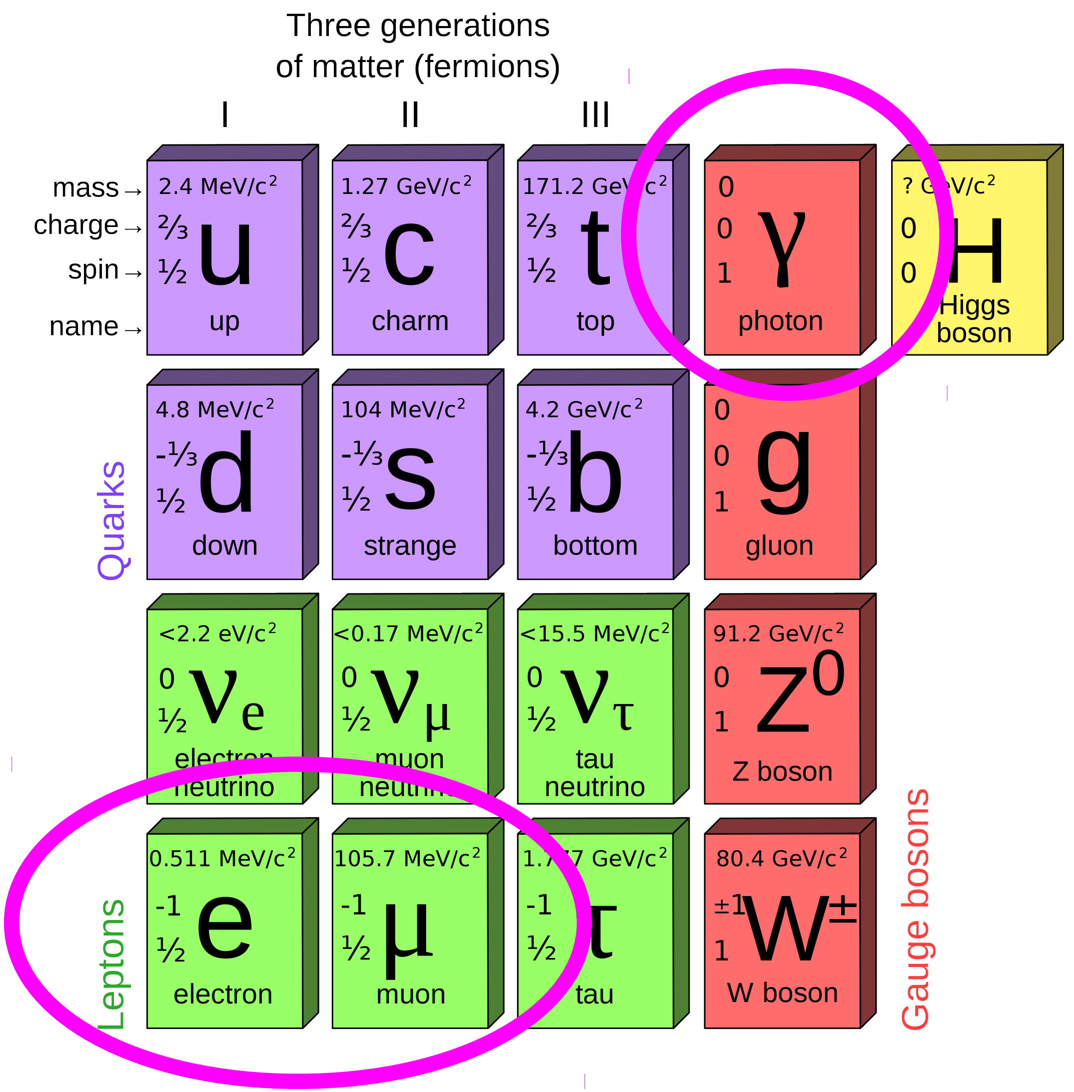
  $e^+ + e^- \rightarrow \mu^+ + \mu^-$

- What does it mean:
  - An electron and a positron (anti-electron) annihilates and forms a negative muon and its anti-particle: the positive muon

# The particle zoo



# The particle zoo



# Feynman diagram

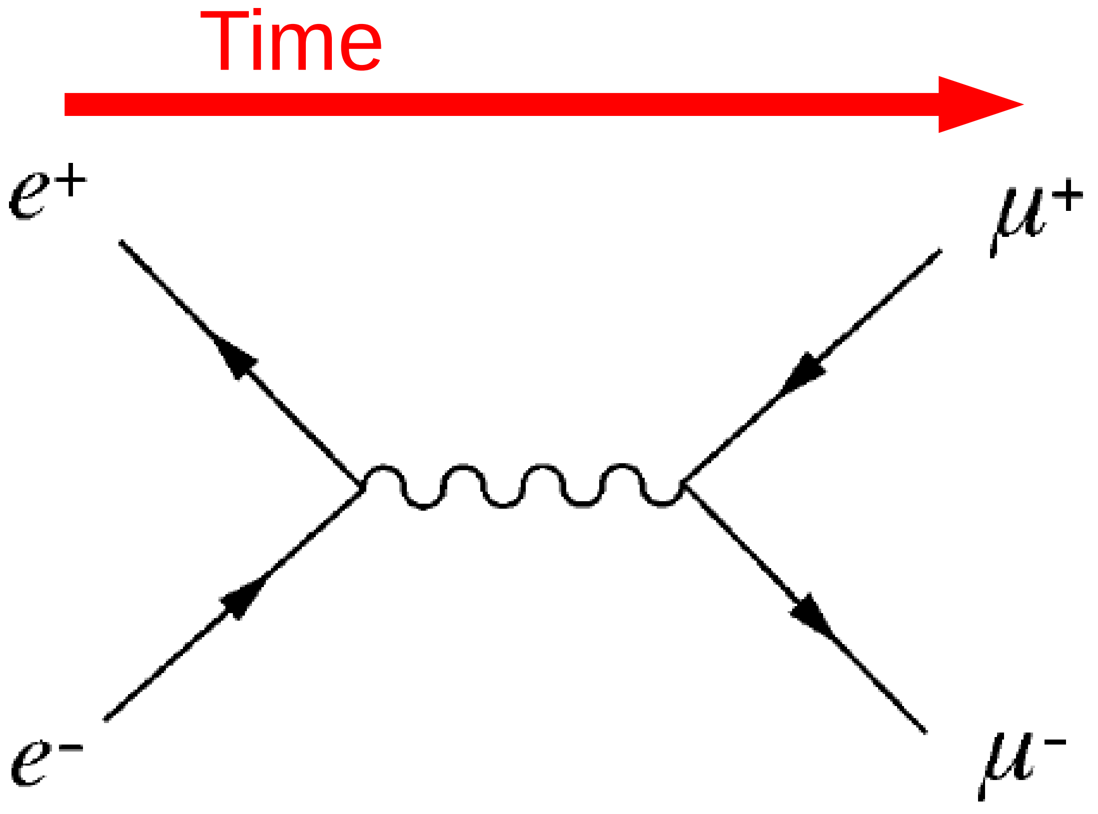



Figure 1.16 Lowest-order Feynman diagram for the process $e^+ + e^- \rightarrow \mu^+ + \mu^-$.

# Feynman diagram
# A calculational tool!

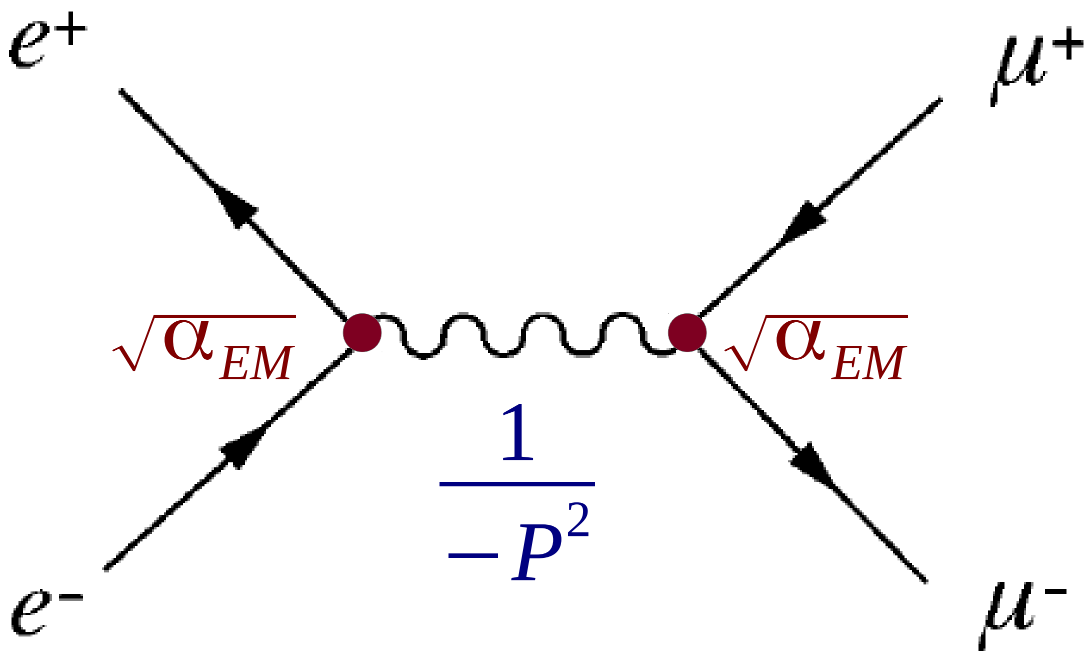



Figure 1.16 Lowest-order Feynman diagram for the process $e^+ + e^- \rightarrow \mu^+ + \mu^-$.

Amplitude $A \propto \frac{\alpha_{EM}}{-P^2}$ Probability $P \propto \frac{\alpha_{EM}^2}{P^4}$

# What is the microscopic picture of a force/interaction

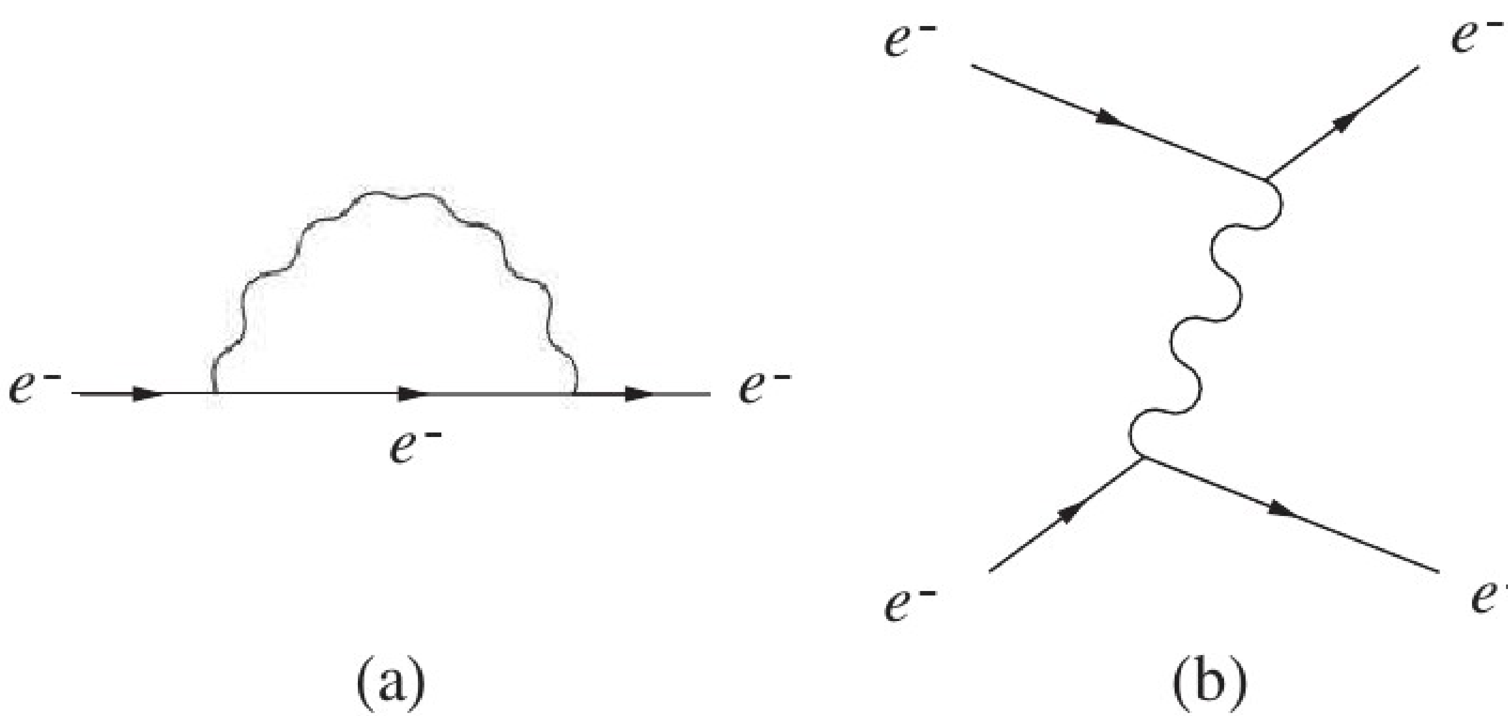



Figure 7.4 The simplest quantum fluctuation of an electron and the associated exchange process.

# What is the microscopic picture of a force/interaction

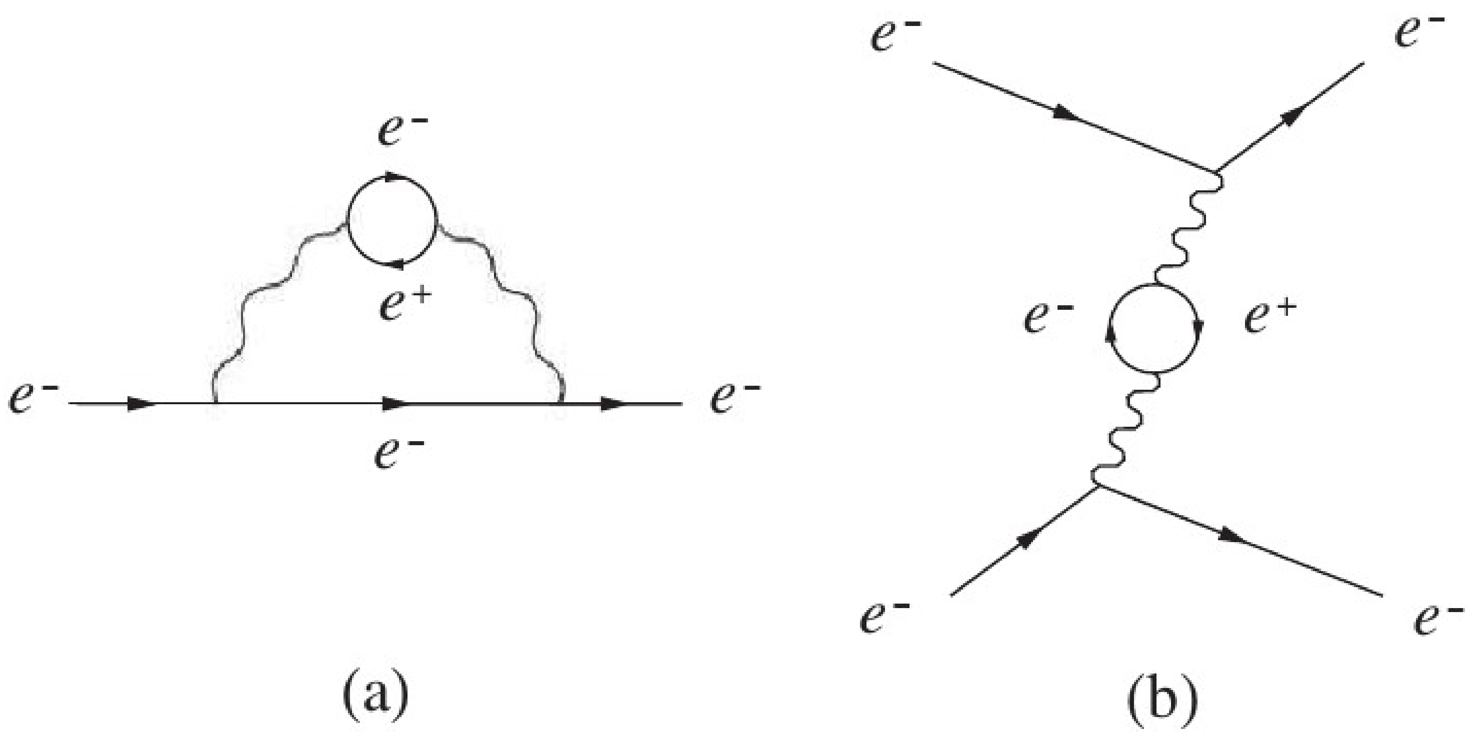



Figure 7.5 A more complicated quantum fluctuation of the electron, together with the associated exchange process.

Question: how important are these higher order diagrams?

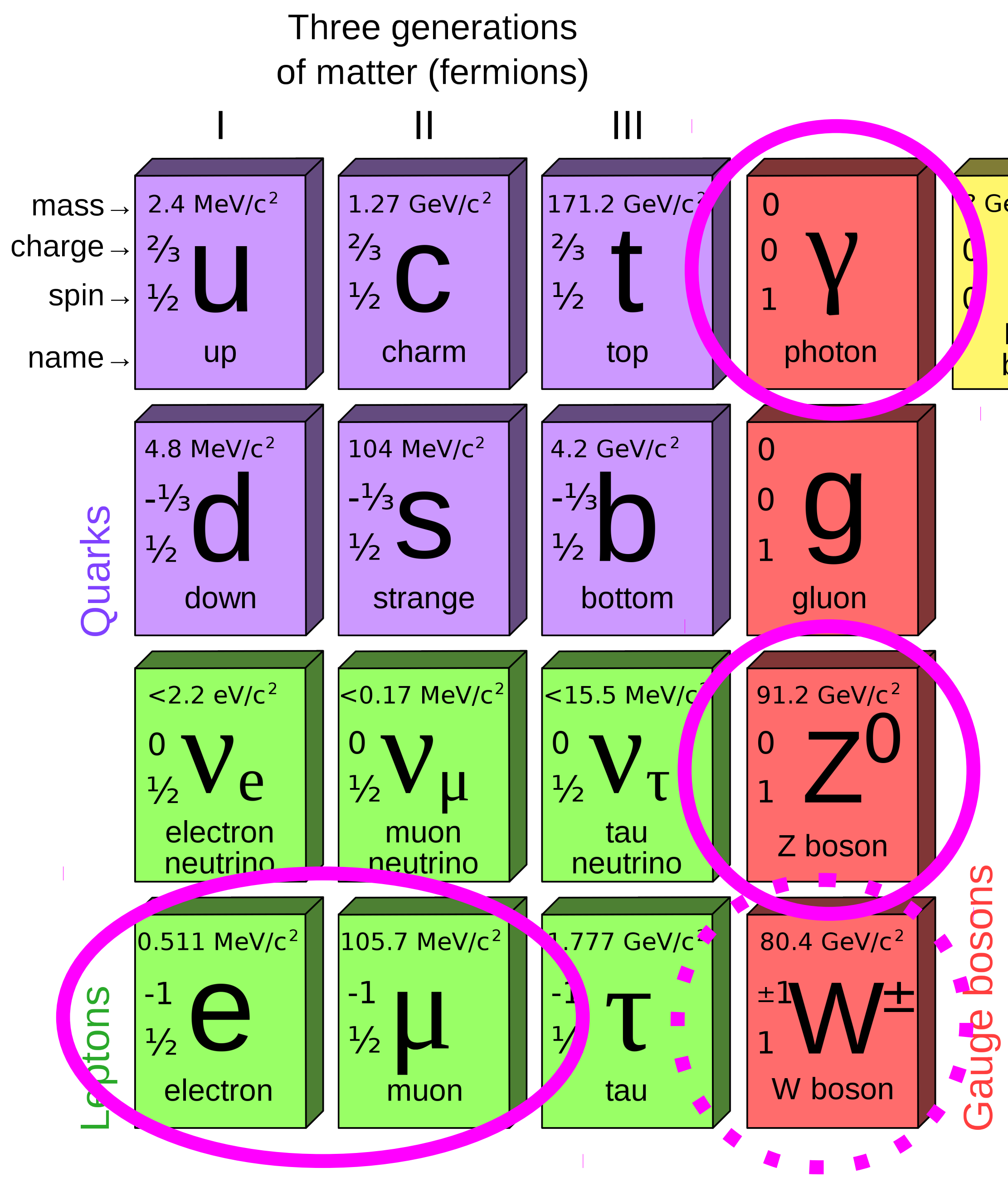
# This is the trick of perturbation theory

As $\alpha \sim 1/137$ then higher order diagrams contribute very little to probabilities/cross sections

=>

Often it is enough to calculate lowest order diagrams for percent level precision!

# The weak force



# An additional process!

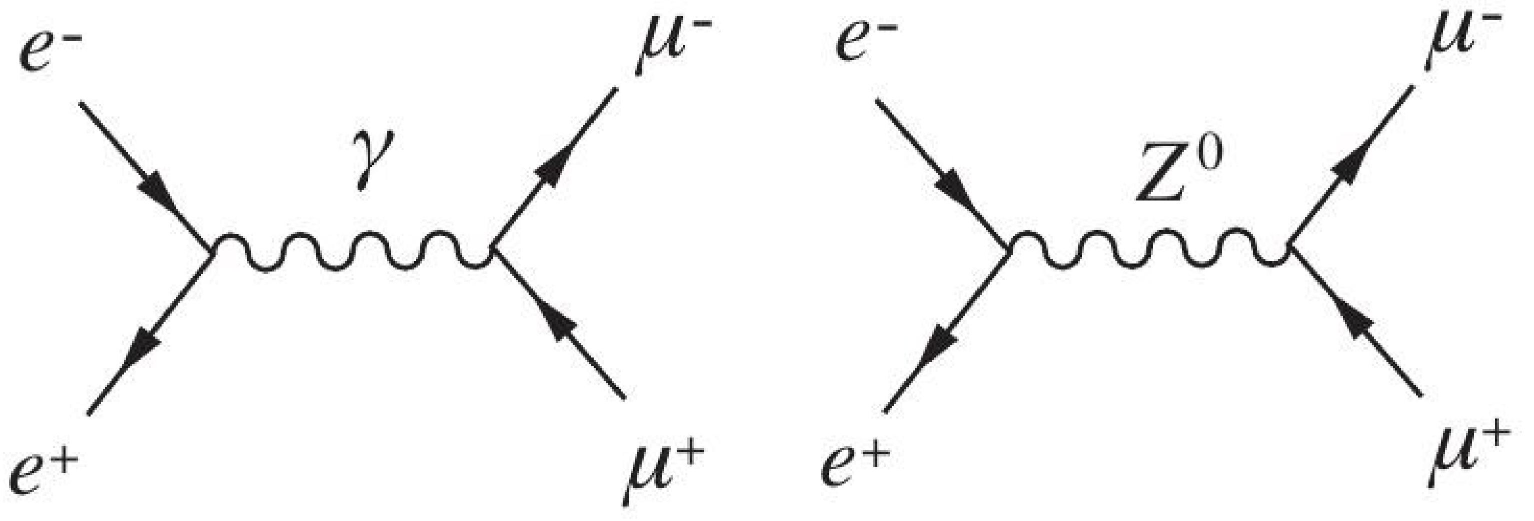



Figure 9.2 The two dominant contributions to the reaction $e^+ + e^- \rightarrow \mu^+ + \mu^-$ in the unified theory.

# Where is the difference? (1/2)

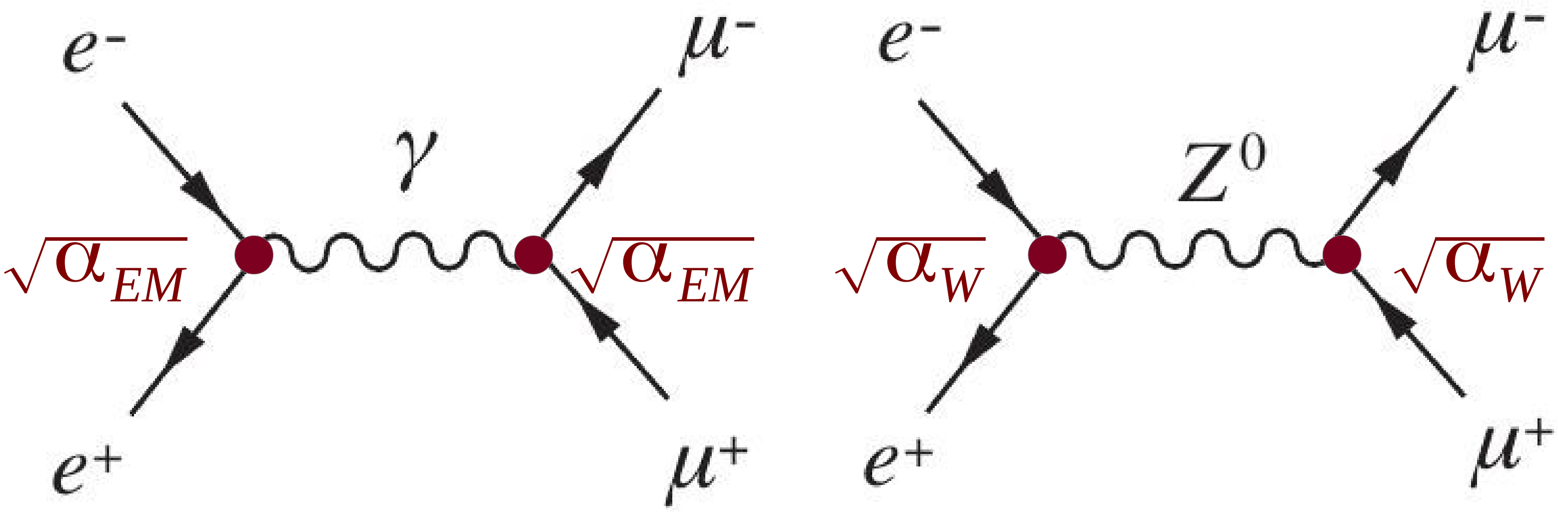



Figure 9.2 The two dominant contributions to the reaction $e^+ + e^- \rightarrow \mu^+ + \mu^-$ in the unified theory.

In fact couplings are similar: $\sqrt{\alpha_{EM}} \sim \sqrt{\alpha_W}$

# Where is the difference? (2/2)

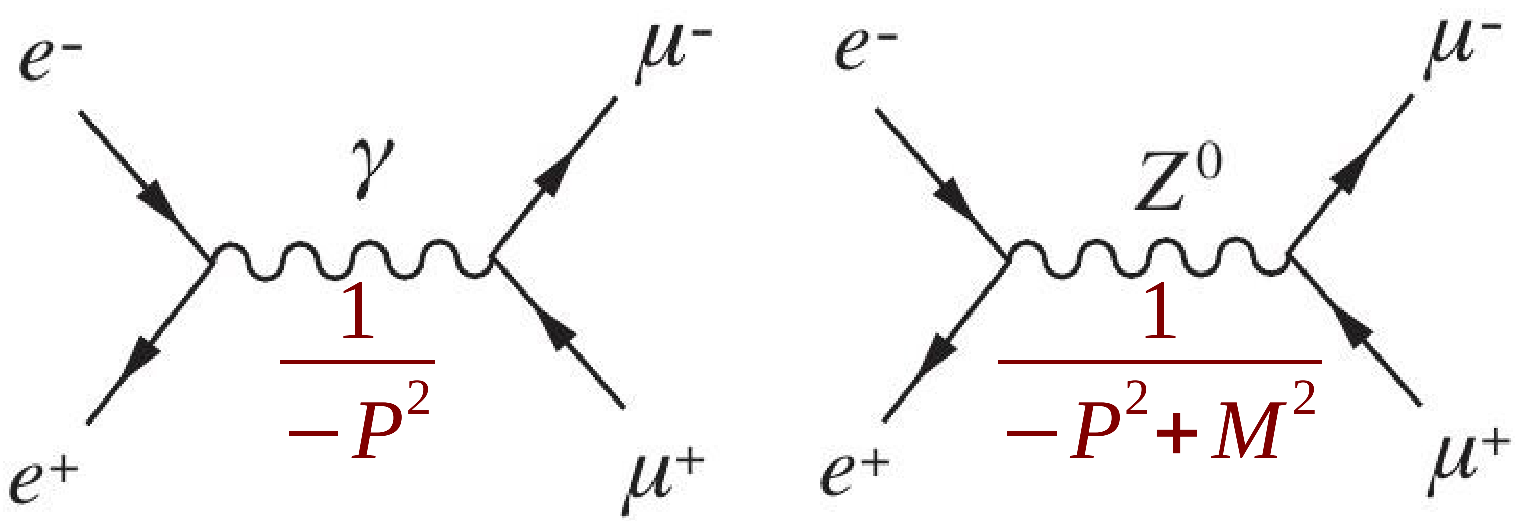



Figure 9.2 The two dominant contributions to the reaction $e^+ + e^- \rightarrow \mu^+ + \mu^-$ in the unified theory.

Huge difference as Mz~90 GeV (~ 90 proton masses!)

# What is the effect (1/2) ?

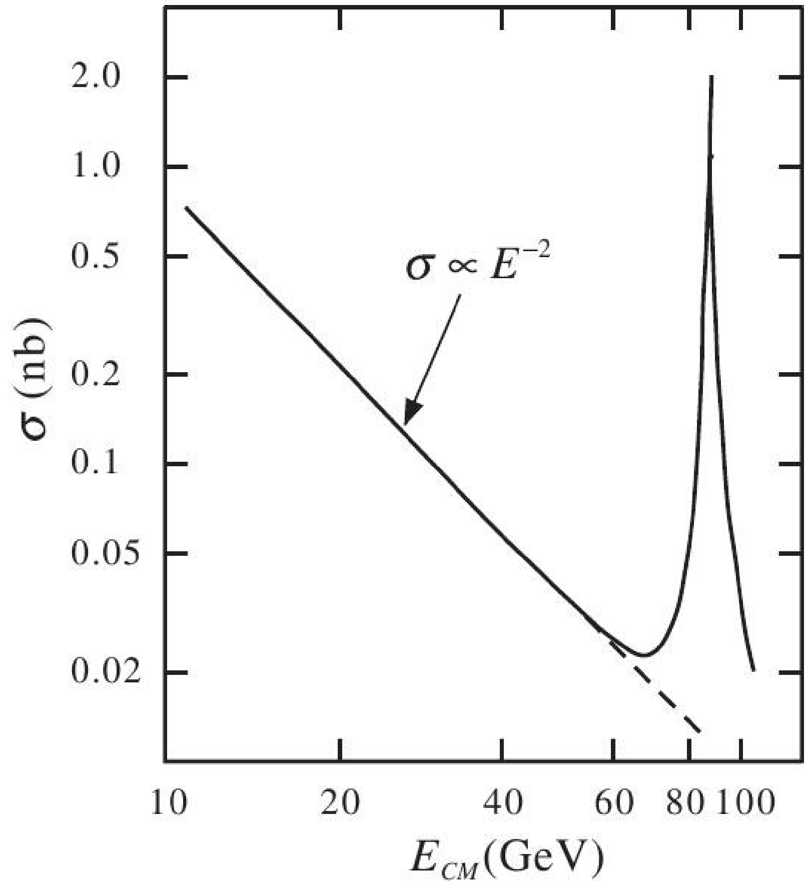



Figure 9.9 Total cross-section for the reaction $e^+ + e^- \to \mu^+ + \mu^-$ as a function of the total centre-of-mass energy (9.20). The dashed line shows the extrapolation of the low-energy behaviour (9.17) in the region of the $Z^0$ peak.

# What is the effect (2/2) ?

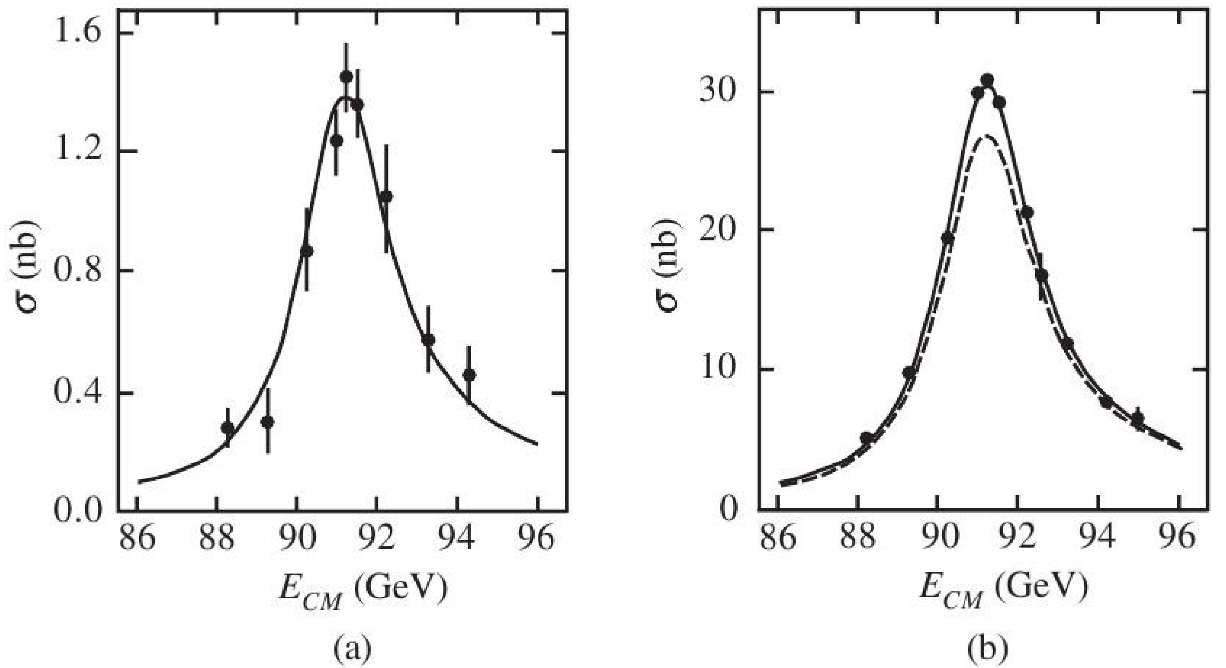
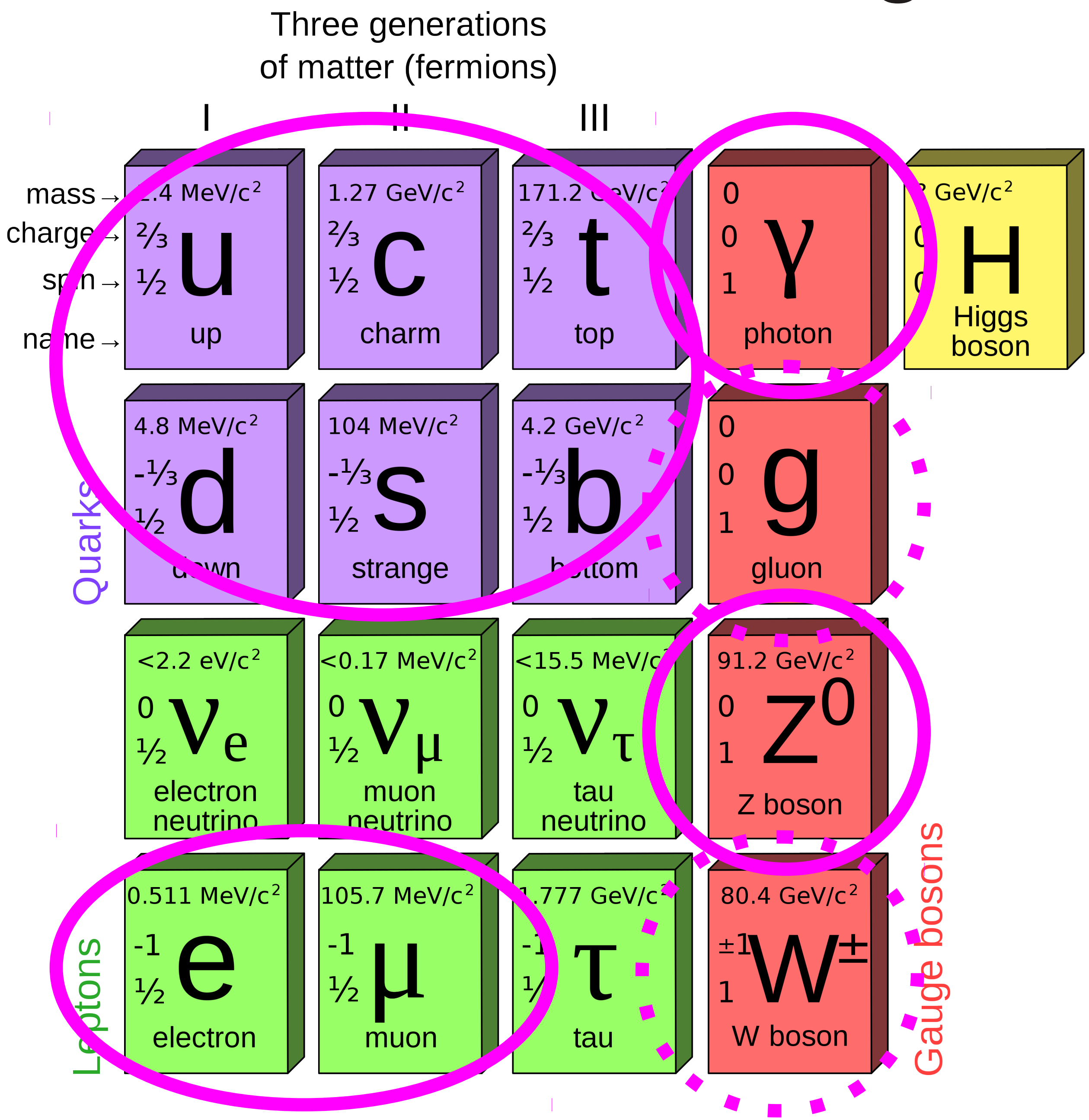



Figure 9.10 Measured cross-sections for (a) $e^+ + e^- \to \mu^+ + \mu^-$ and (b) $e^+ + e^- \to$ hadrons, in the region of the $Z^0$ peak. The solid and dashed lines show the predictions of the standard model on the assumptions that there are three and four types of light neutrinos, respectively. (Reprinted from Akrawy, M. Z., *et al.*, *Physics Letters B*, **240**, 497. Copyright 1990, with permission from Elsevier.)

# What about the strong force?



# Another process:
# ee → qqbar

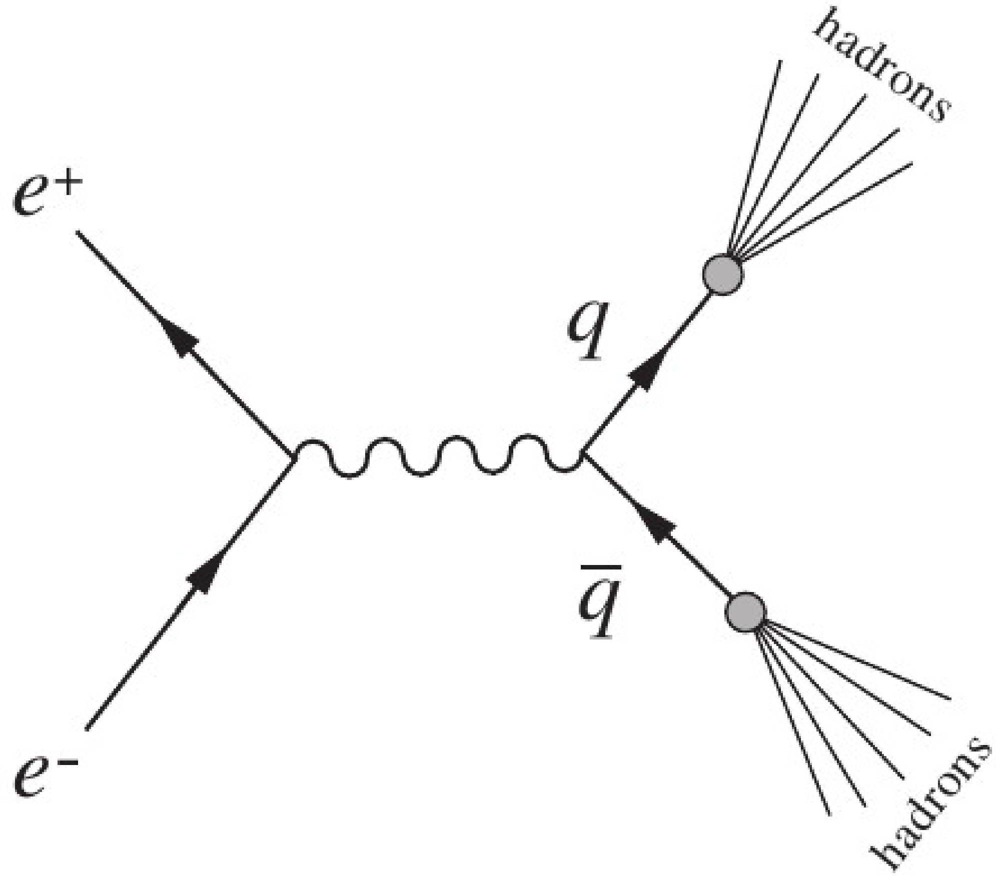



Figure 7.10 Basic mechanism of two-jet production in electron–positron annihilation.

# What about the ratio?

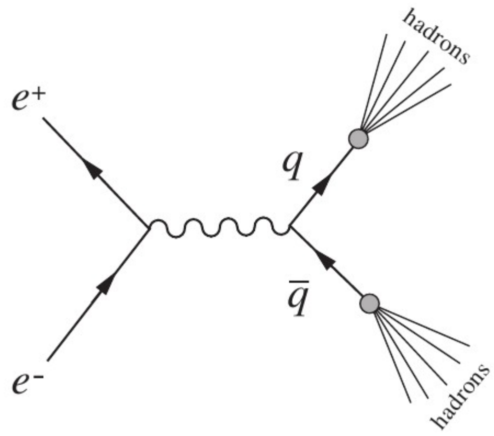



Figure 7.10 Basic mechanism of two-jet production in electron–positron annihilation.

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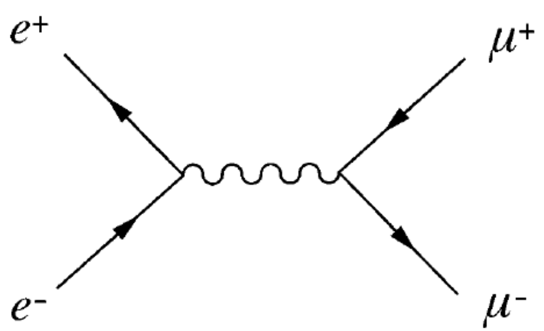
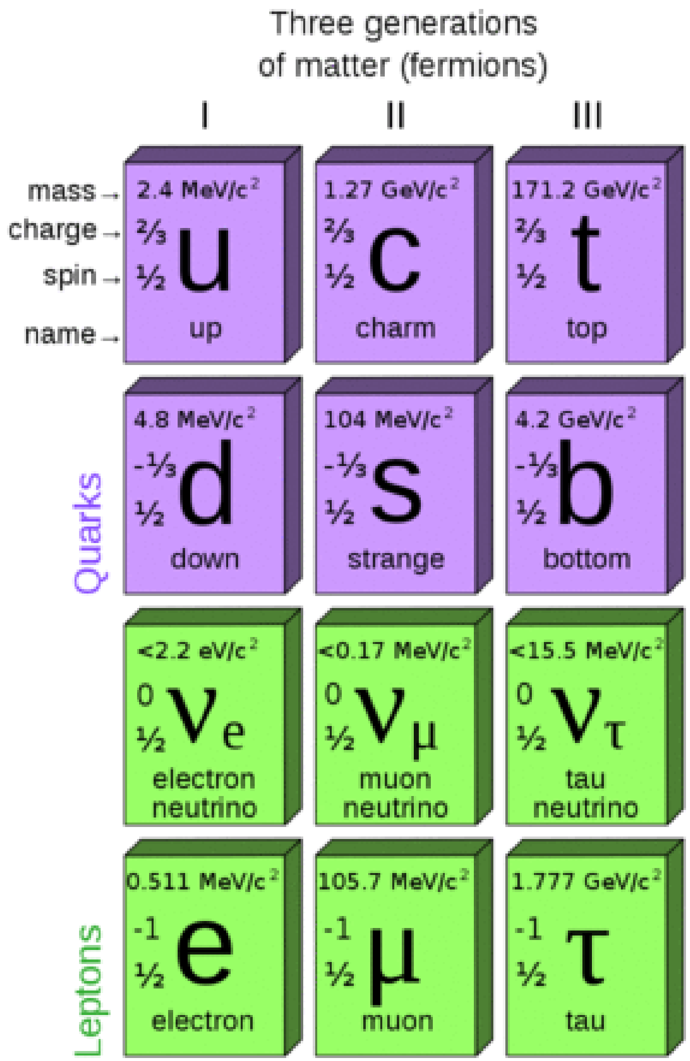



Figure 1.16 Lowest-order Feynman diagram for the process $e^+ + e^- \rightarrow \mu^+ + \mu^-$.

# The charge difference




**q=+2/3**

**q=-1/3**

**q=-1**

- Due to different charges:
- A ~ q
- P ~ $q^2$
- Pqq ~ 4/9 + 1/9 + 1/9 + 4/9 + 1/9

  (up to threshold)
- Pμμ ~ 1
- Ratio: 11/9

# What about the ratio?

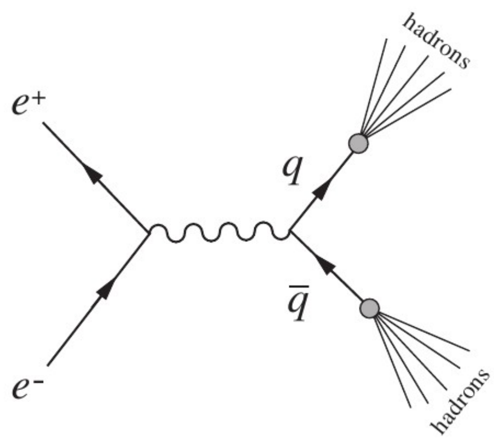



Figure 7.10 Basic mechanism of two-jet production in electron–positron annihilation.

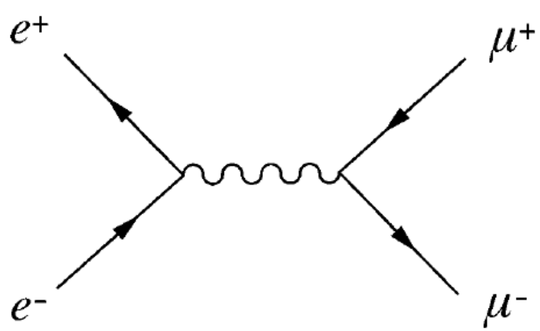



Figure 1.16 Lowest-order Feynman diagram for the process $e^+ + e^- \to \mu^+ + \mu^-$.

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R ≠11/9

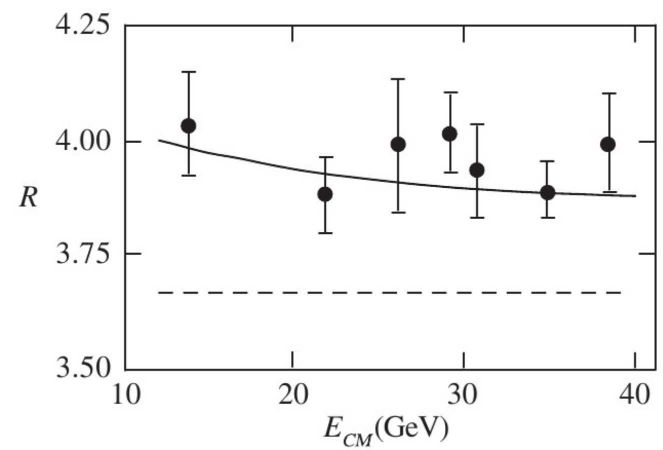


Figure 7.16 Comparison between the measured values of the cross-section ratio $R$ of Equation (7.18) and the theoretical prediction (7.22) for three colours, $N_C = 3$. The dashed line shows the corresponding prediction (7.21) omitting small contributions of order $\alpha_s$. (Data from the compilations of Wu, 1984, and Behrend *et al.*, 1987.)

There are 3 types of quark(charge)s: red, green, blue!

# The particle zoo