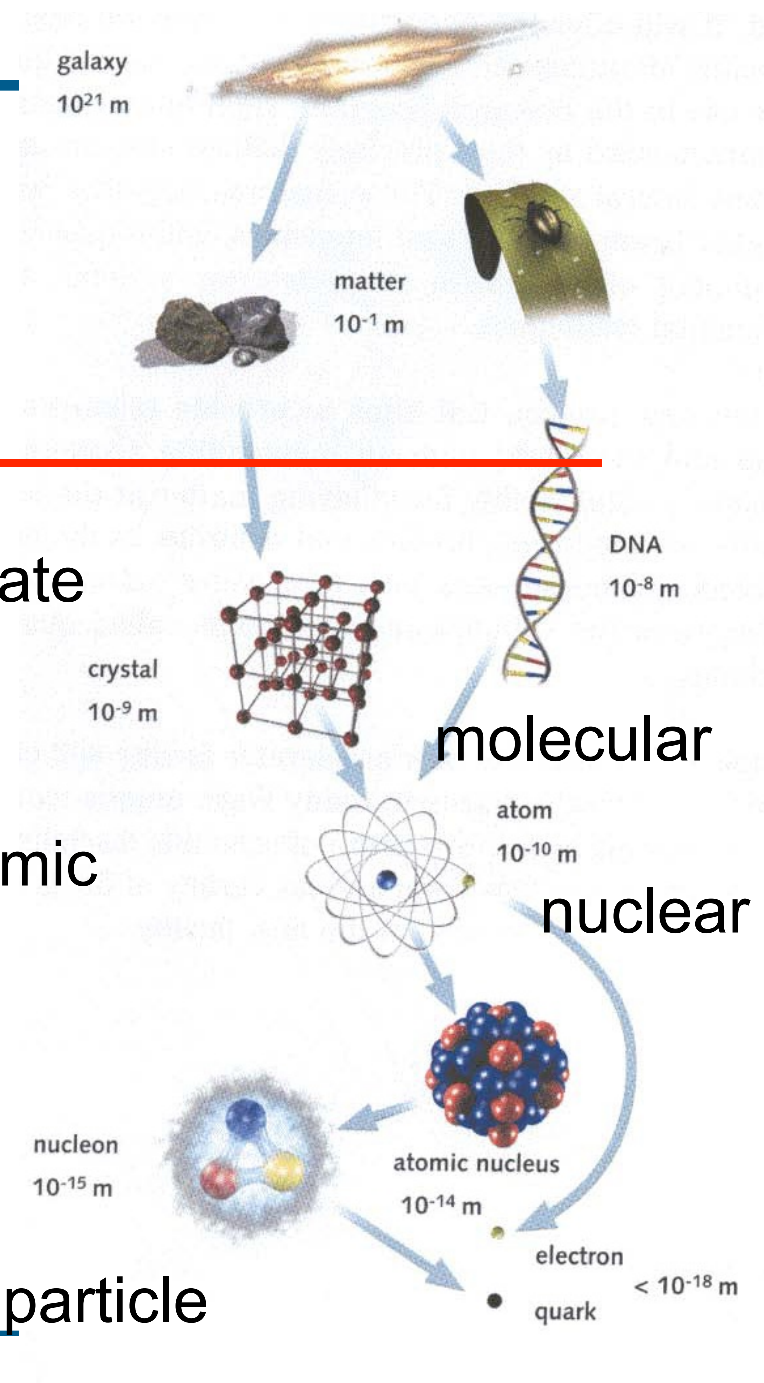
The Universe

Classical world

Quantum world

Study the building blocks of matter and the forces between them



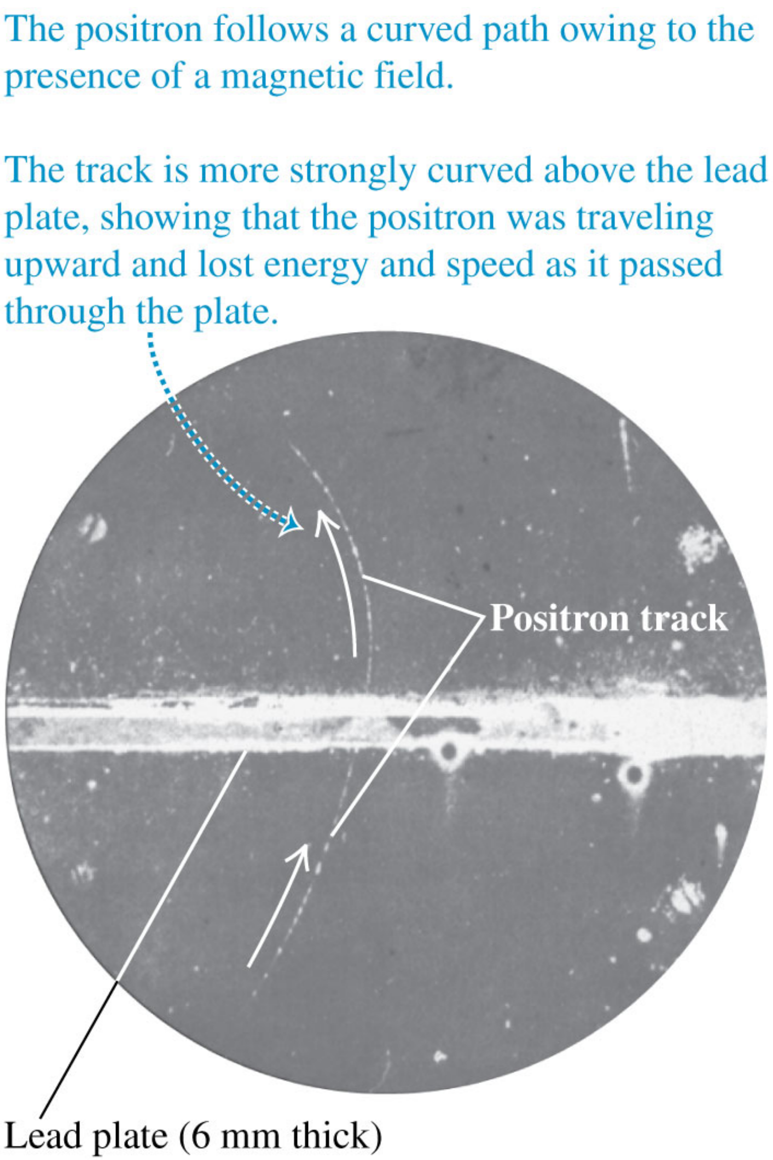
Chapter 44: Particle Physics

- To learn the key varieties of fundamental particles
- To see how accelerators and detectors are used to investigate subatomic particles
- To learn how subatomic particles interact with each other
- To understand how quarks explain the structure of many subatomic particles
- To learn how we probe the standard model of particles and interactions
- To investigate the Big Bang and the expansion of the universe

Introduction

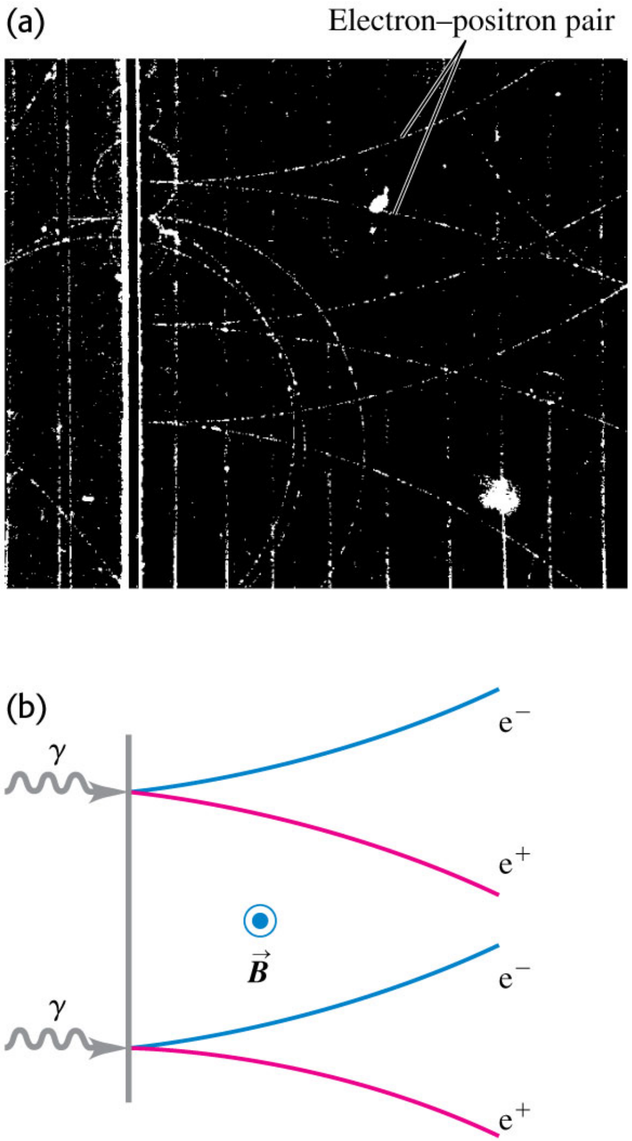
- How much of the universe is composed of "normal" matter?
- What is the world ultimately made of?
- The physics on the microscopic scale is essential to understand the universe on its largest scale.
- How will the universe evolve?

Elementarpartiklar - Historik



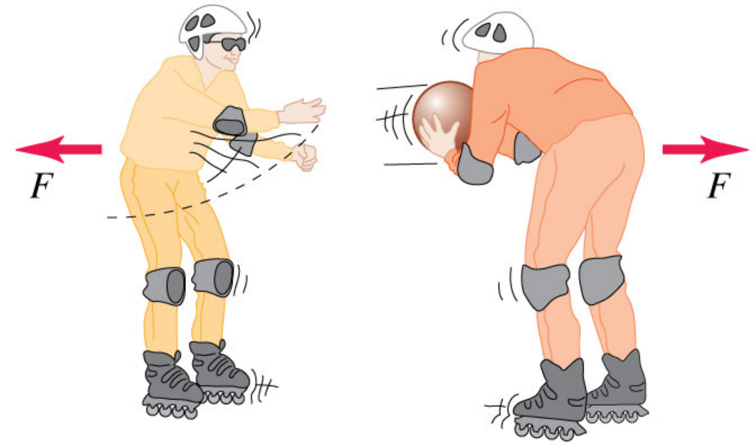
Par-produktion

- conversion when γ interacts with material
(γ is a stable particle)

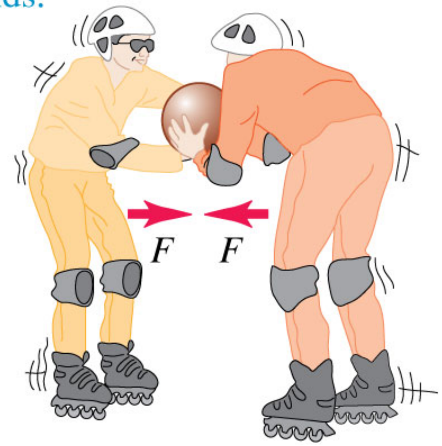


Partiklar som kraftförmedlare

(a) Two skaters exert repulsive forces on each other by tossing a ball back and forth.



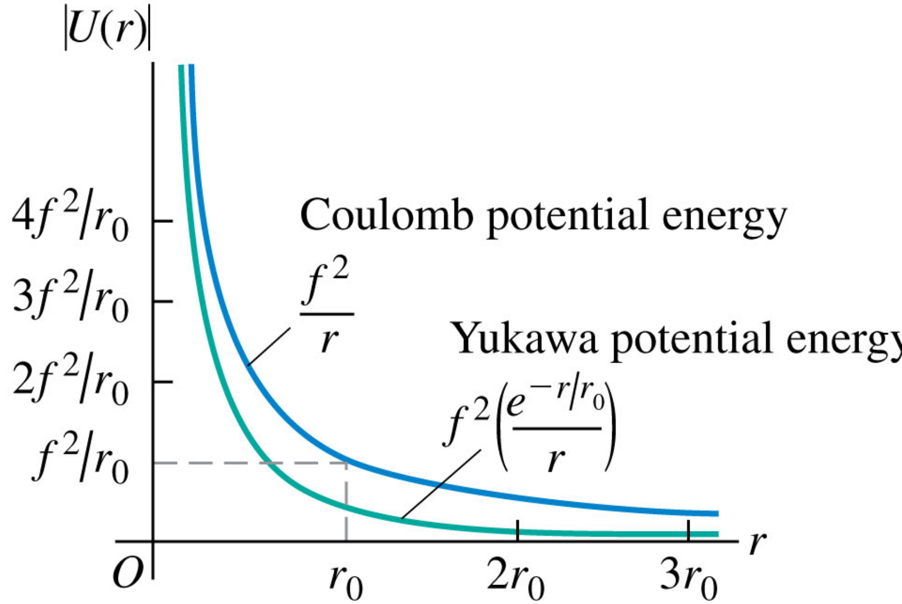
(b) Two skaters exert attractive forces on each other when one tries to grab the ball out of the other's hands.



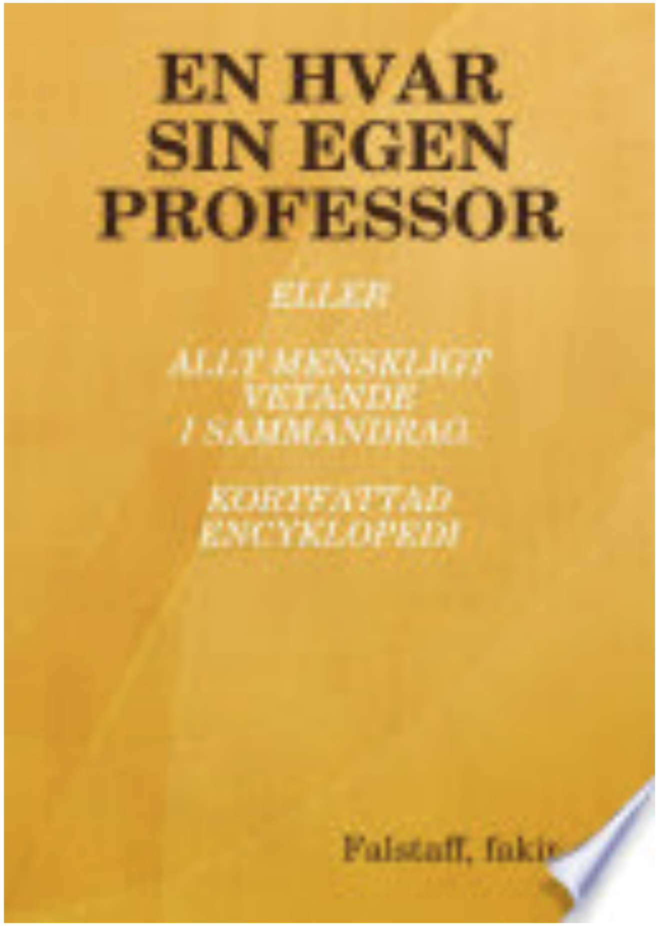
Partiklar som kraftförmedlare

- Fig 44.5 visar Yukawas potential-energy funktion.

- 1935 Yukawa:



Standardmodellen



Ersatt av PDG…

Leptons

- *Leptons* do not experience the strong interaction.
- Table 44.2 summarizes the characteristics of the six leptons.

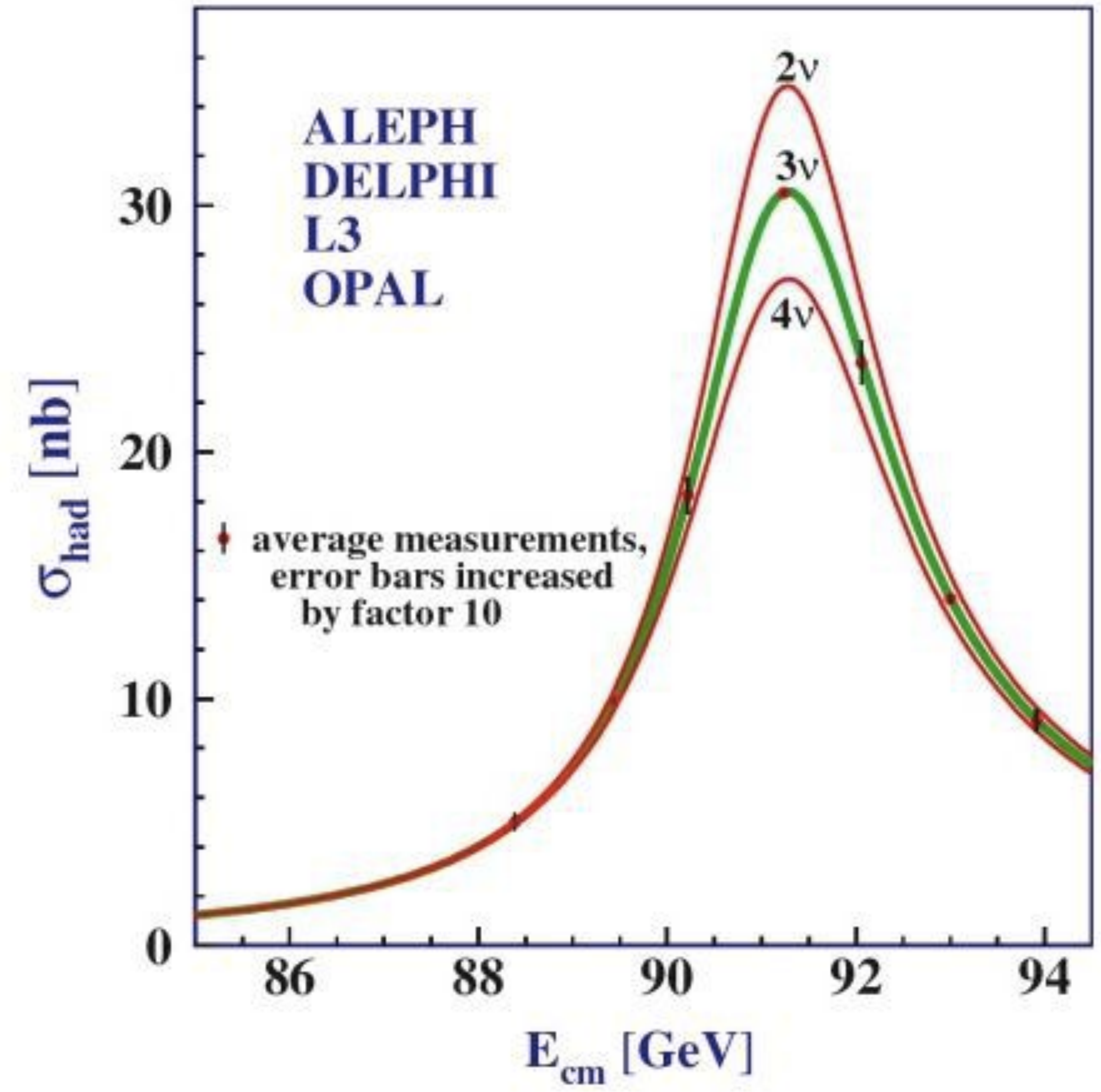
Misleading!

Table 44.2 The Six Leptons

Particle Name	Symbol	Antiparticle	Mass (MeV/c^2)	L_e	L_μ	L_τ	Lifetime (s)	Principal Decay Modes
Electron	e^-	e^+	0.511	+1	0	0	Stable	
Electron neutrino	ν_e	$\overline{\nu}_e$	$<3 \times 10^{-6}$	+1	0	0	Stable	
Muon	μ^-	μ^+	105.7	0	+1	0	2.20×10^{-6}	$e^- \overline{\nu}_e \nu_\mu$
Muon neutrino	ν_μ	$\overline{\nu}_\mu$	<0.19	0	+1	0	Stable	
Tau	τ^-	τ^+	1777	0	0	+1	2.9×10^{-13}	$\mu^- \overline{\nu}_\mu \nu_\tau$
Tau neutrino	ν_τ	$\overline{\nu}_\tau$	<18.2	0	0	+1	Stable	or $e^- \overline{\nu}_e \nu_\tau$

Example 44.4

How many “generations”? ~3.00 +- 0.01



Example 44.5

Fermioner

Leptons and quarks, half integer spin

Leptons

	particle				antiparticle			
	L_e	L_μ	L_τ	Lepton	$\overline{Lepton}$	L_e	L_μ	L_τ
1	1	0	0	e^-	e^+	-1	0	0
	1	0	0	ν_e	$\bar{\nu}_e$	-1	0	0
2	0	1	0	μ^-	μ^+	0	-1	0
	0	1	0	ν_μ	$\bar{\nu}_\mu$	0	-1	0
3	0	0	1	τ^-	τ^+	0	0	-1
	0	0	1	ν_τ	$\bar{\nu}_\tau$	0	0	-1

quarks

kvark	Q (e)	B	S	C	$\hat{B}$	T	$\overline{kvark}$	Mass GeV/c^2
u	+2/3	1/3	0	0	0	0	$\bar{u}$	0.002
d	-1/3	1/3	0	0	0	0	$\bar{d}$	0.005
c	+2/3	1/3	0	1	0	0	$\bar{c}$	1.3
s	-1/3	1/3	-1	0	0	0	$\bar{s}$	0.1
t	+2/3	1/3	0	0	0	1	$\bar{t}$	173
b	-1/3	1/3	0	0	1	0	$\bar{b}$	4.2

Fundamental particles

Form composite particles, hadrons
Baryons, B=1, three quarks, half integer spin
Mesons, B=0, quark-antiquark, integer spin

Summary : 4 Krafter

Kraft, vxv	Förmedlare	Boson massa	Räck vidd (m)	Rel. Styrka vid 1fm	Typisk livstid (s)	Bevarade kvanttal	Påverkar	via
Stark[1]	Gluon	0	∞	1	10^{-23} - 10^{-22}	Q B $SC\hat{B}T$	Hadroner Kvarkar	Color charge.
Elektro magnet	γ	0	∞ $1/R^2$	10^{-2}	10^{-20} - 10^{-16}	Q B $SC\hat{B}T$ L_e L_μ L_τ	Hadroner Kvarkar Leptoner	Electric charge
Svag	W^+W^- Z^0	80.4 GeV/c^2 91.2 GeV/c^2	10^{-18}	10^{-13}	10^{-15} - 12min	Q B ($SC\hat{B}T$ ändras max 1 enhe[3]t) L_e L_μ L_τ	Kvark Lepton	Quark flavor
Gravi-tation	Graviton (hypotes)	0?	∞ $1/R^2$	10^{-41}				mass

[1]Stark växelverkan också mellan nukleoner i kärnan. Pioner utbytespart med massa ca 140MeV/c^2

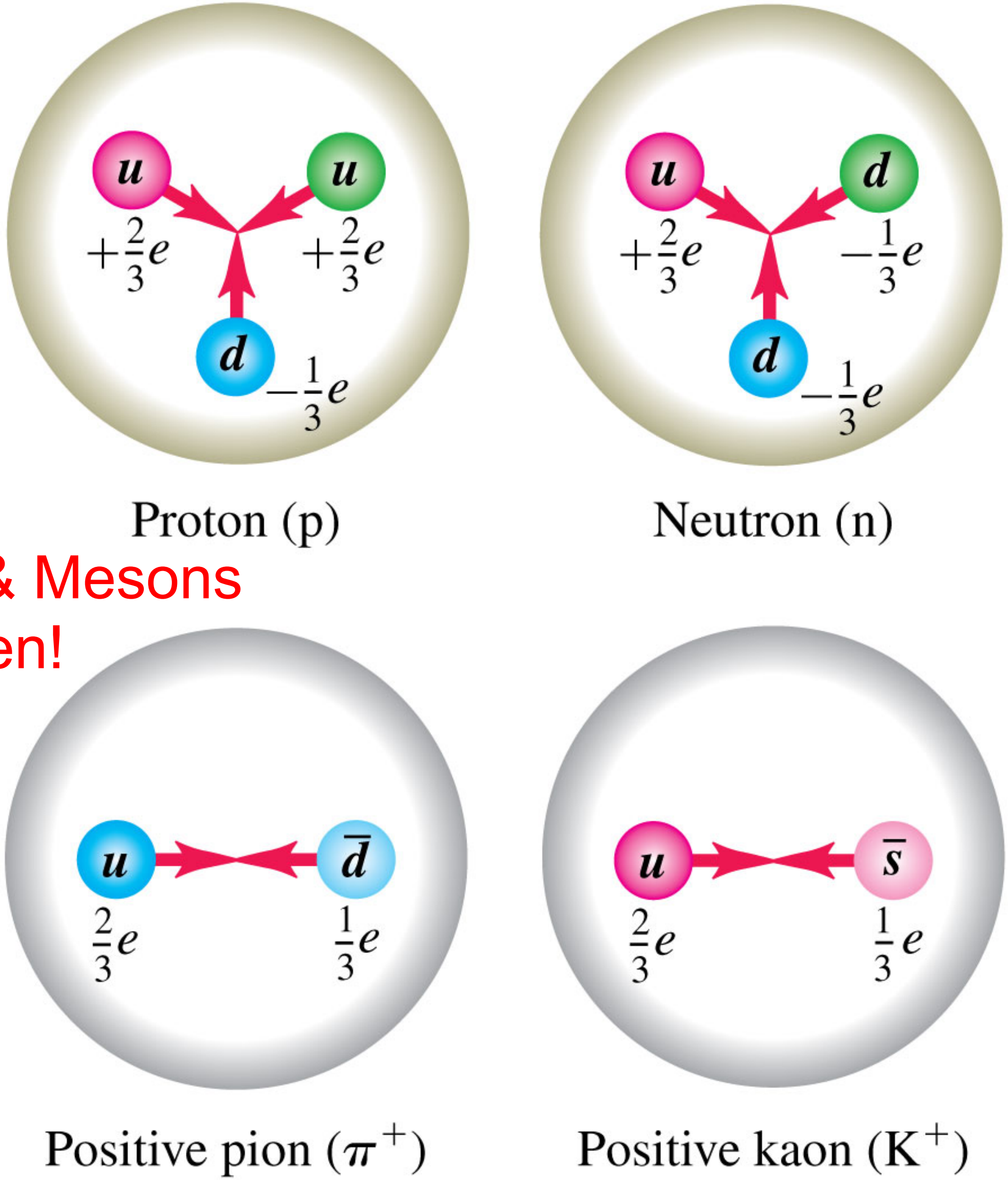
[2]Styrkan vid ca 1fm avstånd

[3]Vid svag växelverkan behöver $SC\hat{B}T$ ej bevaras. Ändrar sig högst 1 enhet

Baryon
3 quarks

Hadrons = Baryons & Mesons
Free quark never seen!

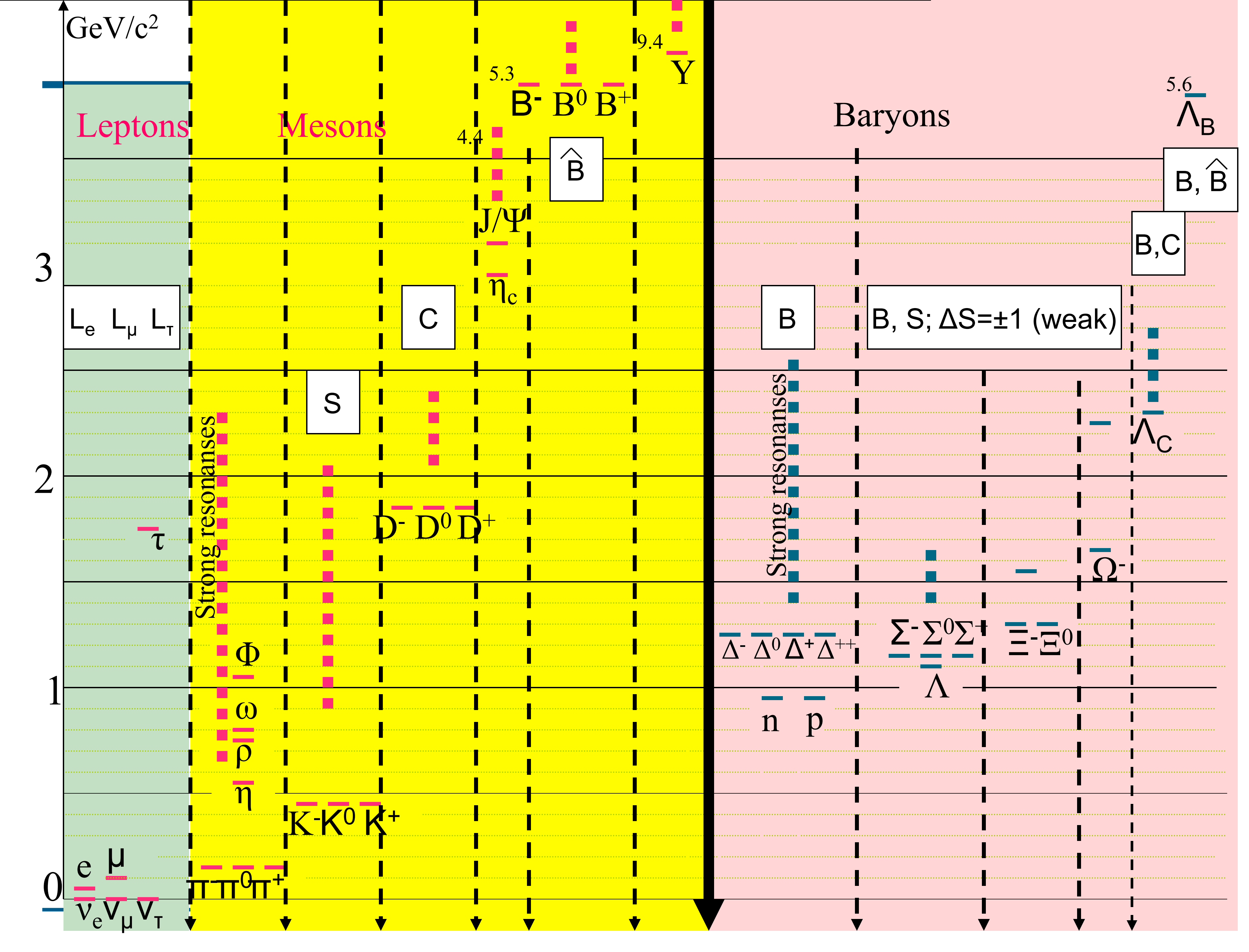
Meson, integer spin
Quark-antiquark



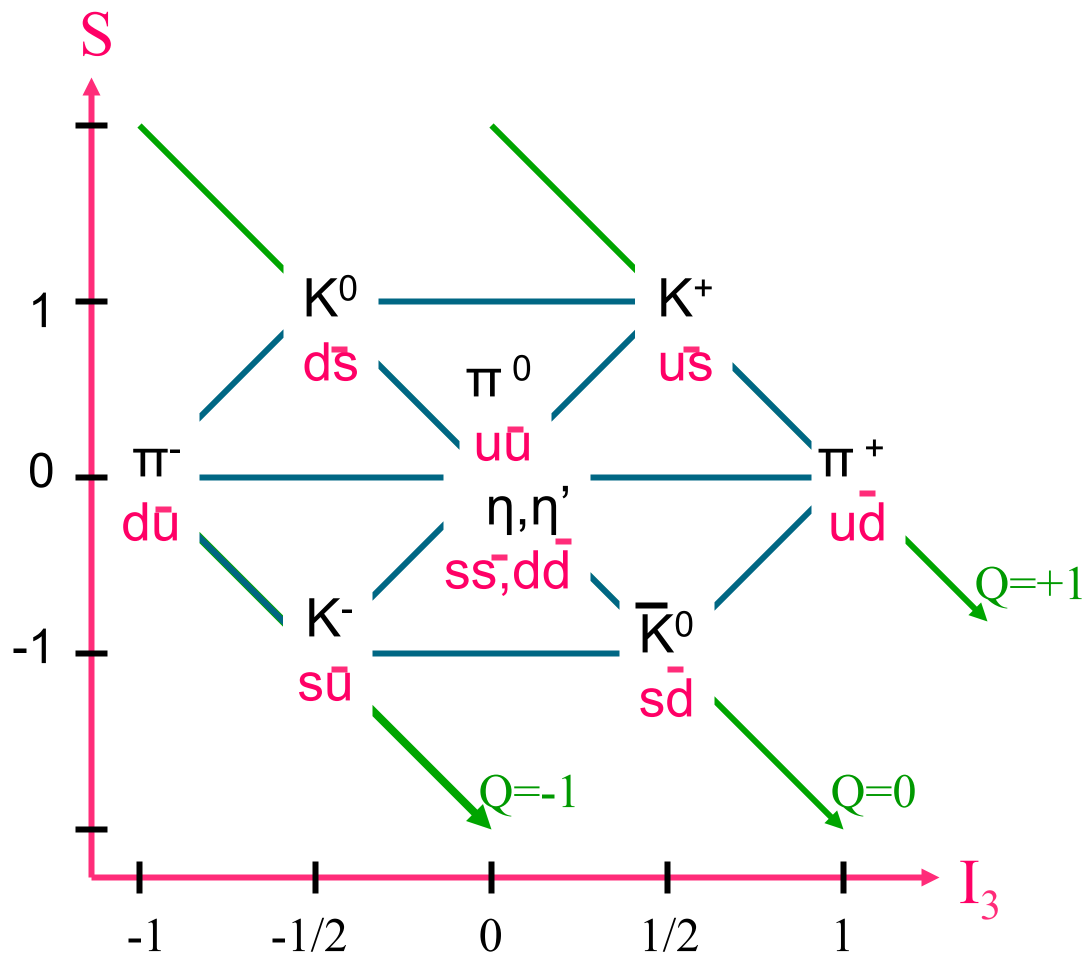
Some hadrons and their properties

Table 44.3 Some Hadrons and Their Properties

Particle	Mass (MeV/c^2)	Charge Ratio, Q/e	Spin	Baryon Number, B	Strangeness, S	Mean Lifetime (s)	Typical Decay Modes	Quark Content
Mesons								
π^0	135.0	0	0	0	0	8.4×10^{-17}	$\gamma\gamma$	$u\bar{u}$, $d\bar{d}$
π^+	139.6	+1	0	0	0	2.60×10^{-8}	$\mu^+\nu_\mu$	$u\bar{d}$
π^-	139.6	−1	0	0	0	2.60×10^{-8}	$\mu^-\bar{\nu}_\mu$	$\bar{u}d$
K^+	493.7	+1	0	0	+1	1.24×10^{-8}	$\mu^+\nu_\mu$	$u\bar{s}$
K^-	493.7	−1	0	0	−1	1.24×10^{-8}	$\mu^-\bar{\nu}_\mu$	$\bar{u}s$
η^0	547.3	0	0	0	0	$\approx 10^{-18}$	$\gamma\gamma$	$u\bar{u}$, $d\bar{d}$, $s\bar{s}$
Baryons								
p	938.3	+1	$\frac{1}{2}$	1	0	Stable	—	uud
n	939.6	0	$\frac{1}{2}$	1	0	886	$pe^-\bar{\nu}_e$	udd
Λ^0	1116	0	$\frac{1}{2}$	1	−1	2.63×10^{-10}	$p\pi^-$ or $n\pi^0$	uds
Σ^+	1189	+1	$\frac{1}{2}$	1	−1	8.02×10^{-11}	$p\pi^0$ or $n\pi^+$	uus
Σ^0	1193	0	$\frac{1}{2}$	1	−1	7.4×10^{-20}	$\Lambda^0\gamma$	uds
Σ^-	1197	−1	$\frac{1}{2}$	1	−1	1.48×10^{-10}	$n\pi^-$	dds
Ξ^0	1315	0	$\frac{1}{2}$	1	−2	2.90×10^{-10}	$\Lambda^0\pi^0$	uss
Ξ^-	1321	−1	$\frac{1}{2}$	1	−2	1.64×10^{-10}	$\Lambda^0\pi^-$	dss
Δ^{++}	1232	+2	$\frac{3}{2}$	1	0	$\approx 10^{-23}$	$p\pi^+$	uuu
Ω^-	1672	−1	$\frac{3}{2}$	1	−3	8.2×10^{-11}	Λ^0K^-	sss
Λ_c^+	2285	+1	$\frac{1}{2}$	1	0	2.0×10^{-13}	$pK^-\pi^+$	udc


GeV/c²
Leptons
Mesons
Baryons
3
2
1
0
Le Lμ Lτ
S
C
B
B, S; ΔS=±1 (weak)
B,C
B, B̂
B̂
Strong resonanses
Strong resonanses
e
μ
νe νμ ντ
τ
π- π0 π+
η
ρ
ω
Φ
K- K0 K+
D- D0 D+
ηc
J/Ψ
4.4
5.3
B- B0 B+
9.4
Υ
n p
Λ
Δ- Δ0 Δ+ Δ++
Σ- Σ0 Σ+
Ξ- Ξ0
Ω-
ΛC
5.6
ΛB

Mesons, Spin 0



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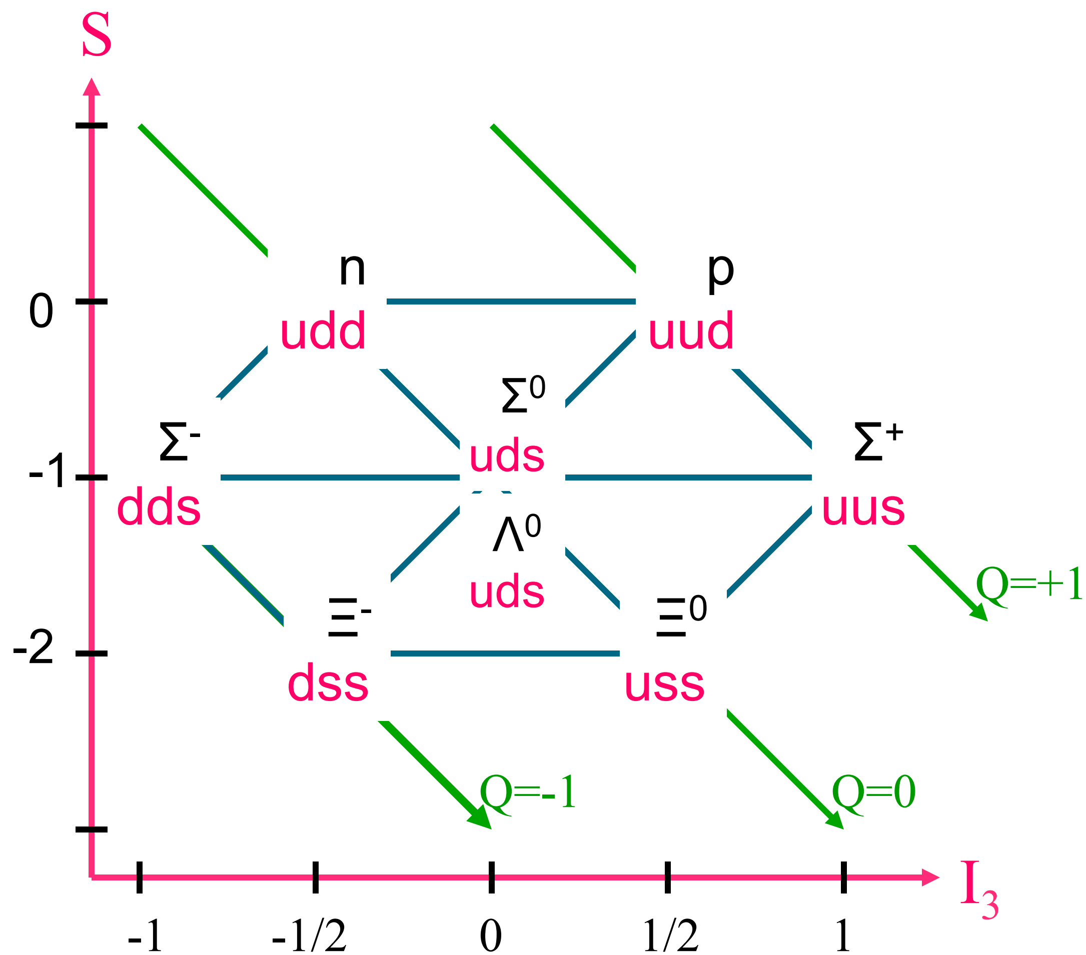
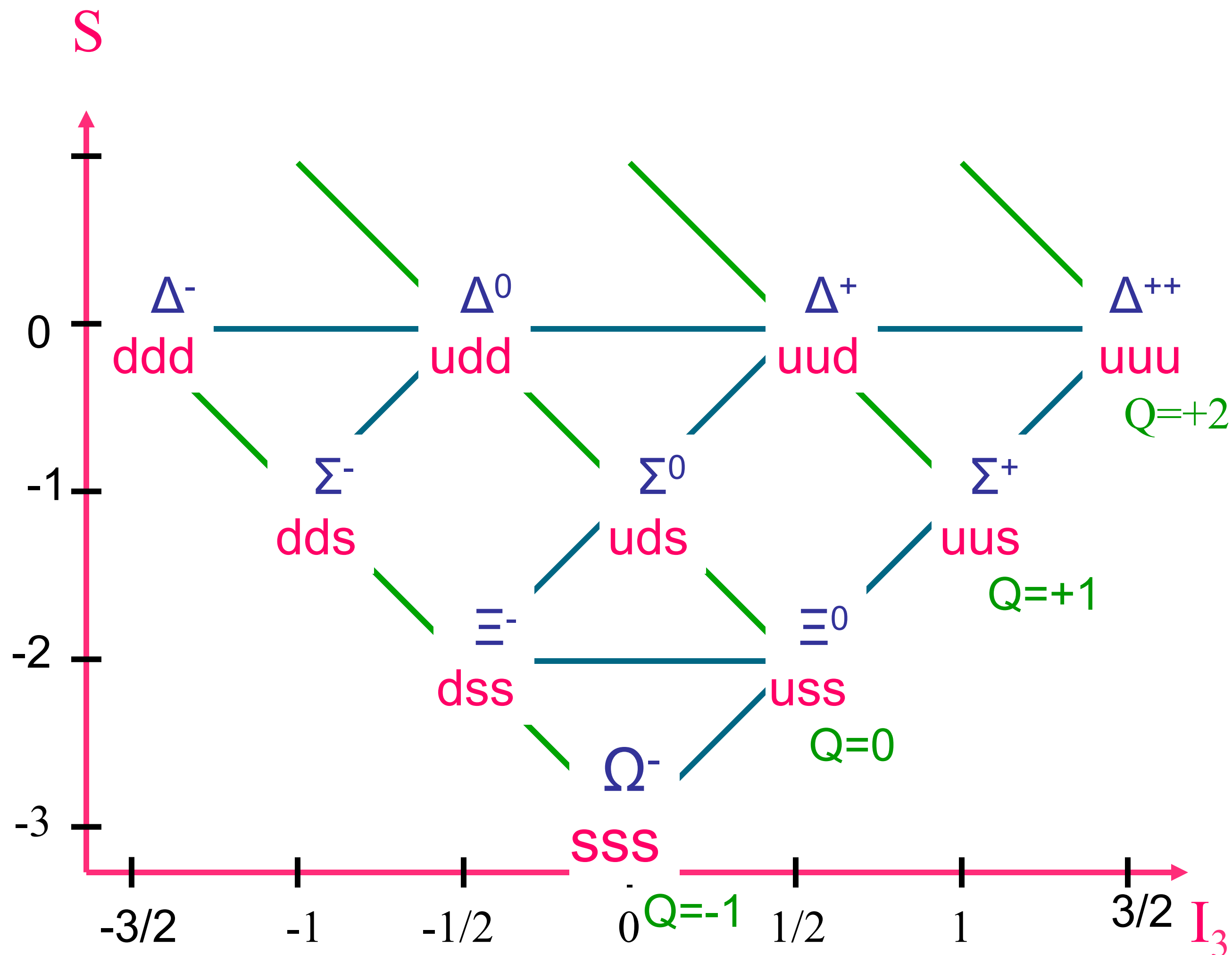
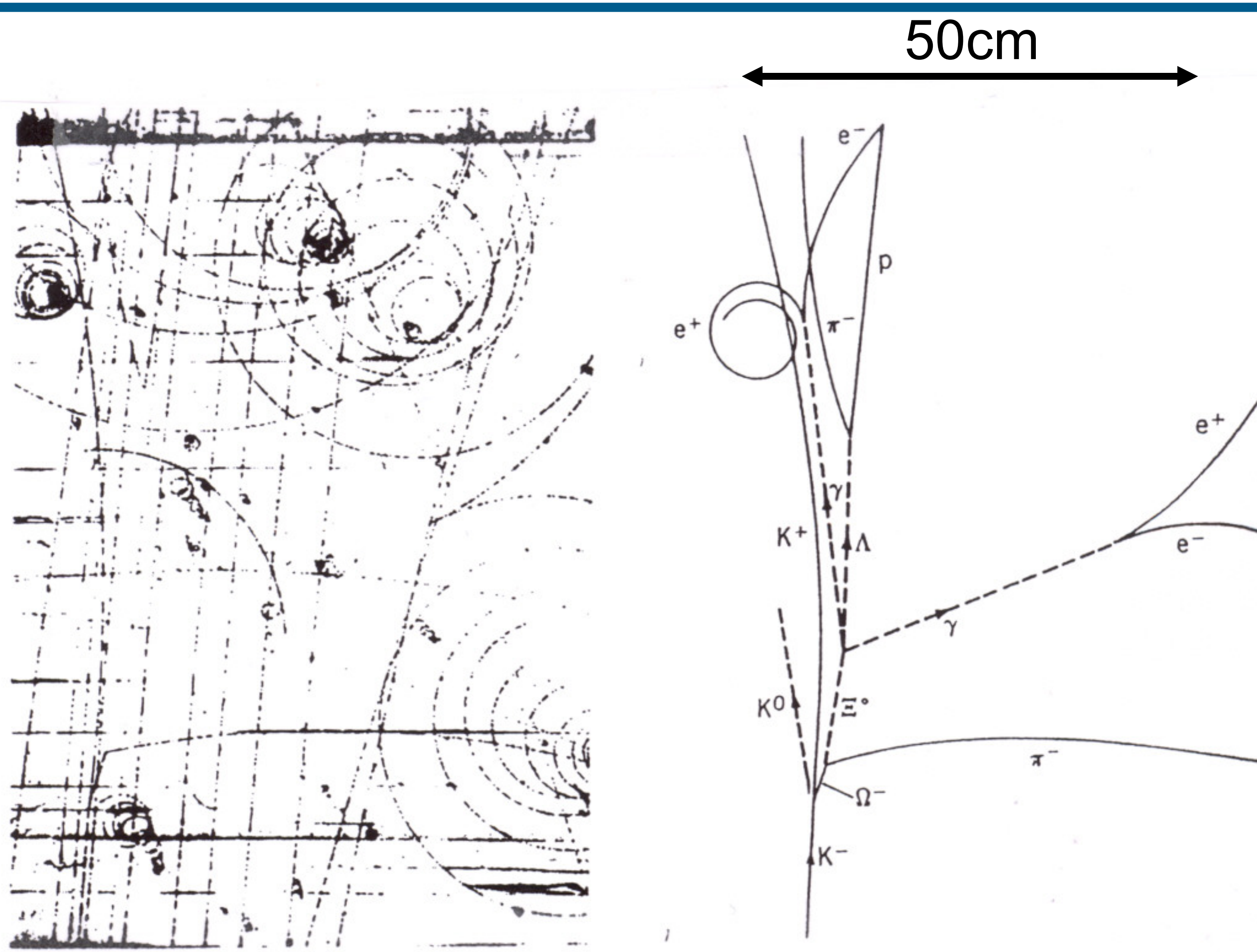
Baryons, Spin 1/2



Baryons, Spin=3/2



Hydrogen bubble chamber picture



Basic reaction: $K^- + p \rightarrow \Omega^- + K^0 + K^+$

Example 44.7

Sönderfalls-räkning

Standard Model

quarks
leptons
forces betweem them

Explains a lot with fantastisk precision.
Also all observations at LHC.
The found Higgs is a SM Higgs

Strong interaction – QCD, Quantum Chromo Dynamics
El. magn interaction - QED, Quantum Electro Dynamics
EM and Weak united: Electro-weak theory

Why are we not satified with that ?

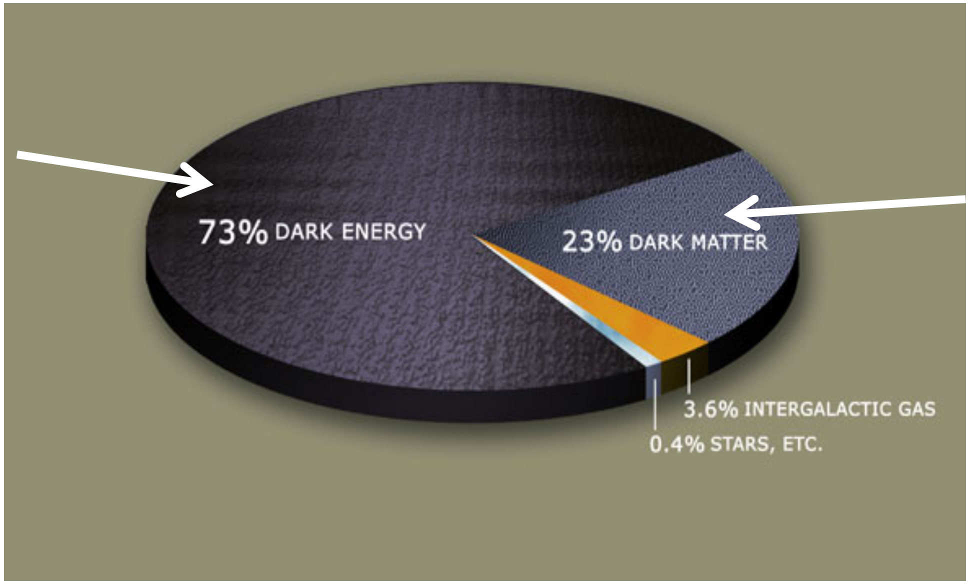
Astrophysics implies there is more

- Why no antimatter in the Universe. Should be just as much as matter?
- What is the dark matter?
- What is the dark energy that makes the expansion accelerate
- The neutrino should not have mass according to SM. But it has…

- Is there a more fundamental level with fewer building blocks? String theory is there. But can it be proven?

Dark Matter

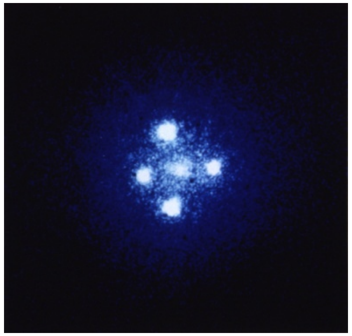
Universums expansion accelererar
Dark Energy



Gravitation effects Much larger than what the observed mass should give

Dark Matter

En observation, Gravitational lensing



Linsverkan kring Mörk materia

Normal galaxlins

Particle physics meets cosmology

In the lab (LHC):

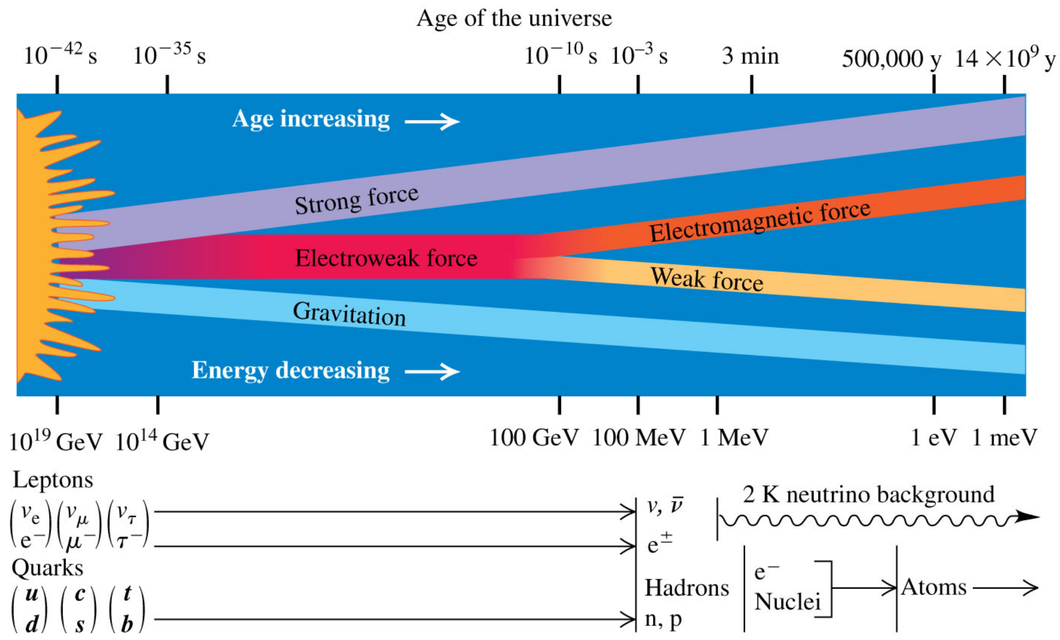
- Make new heavy particles which are Dark Matter candidates?
- WIMPs ”weakly interacting massive particles”
- At LHC, 10 times heavier particles possible to make. Heavier than the heaviest nuclei.

Observe high energy radiation form the Universe:

- Detect DM particles directly
- Detect DM particles indirectly by annihilation to $\gamma\gamma$
- Ice Cube – Ice at antarctis neutrinodetector for DM decay products.
- CTA- Atmosphere used as calorimeter for gammas (desert in Namibia)
- Fermi satellite looking for high energy gammas

The beginning of time

- The early universe was extremely dense and hot.
- Follow the text discussion of temperatures, uncoupling of interactions, and the standard model of the history of the universe, using Figure 44.20 below.



The future of the universe

- If the average density of the universe is less than the *critical density*, the universe should expand forever. If it is greater, the universe should stop expanding and then contract.
- Most of the matter in the universe is mysterious nonluminous *dark matter*.
- Invisible *dark energy* seems to be causing the expansion of the universe to speed up.