Vorlesung Particle Physics [WS 2020/21]

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Tutorials: Fr. 14:15 (x1) P. Starovoitov
[Total: 6] Fr. 9:15 (x2) S. Hausmann, L. Luwer, K. Briggl
Fr. 11:15 (x1) S. Bachmann, A. Caliva

WEB-pages:
www.kip.uni-heidelberg.de/veranstaltungen ...

Rules: Exercises mandatory! Starting 6.11.
60% requirement for admittance to final exam.
Turn in via Group WEB pages...

Exam: Date to be fixed...

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Prerequisites: PEP 4 (and BA lectures before).

Available in Bib. and as an eBook...

Concept of the lecture:

Lecture designed along single book
[The newest (and best) presently on the market]

SLIDE

Each lecture will be based on particular chapters, which I recommend reading before.

Plan: lecture will put emphasis on important issues and concepts...

Only selected derivation of formulas...
Solves problem of formulas just popping up...

I. Introduction:

Today: Particle Physics is based on an established theory...

The Standard Model of Particle Physics.

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- At first sight: very clear structure...
- Second look: rather complex and difficult...

Particle Physics = Study of

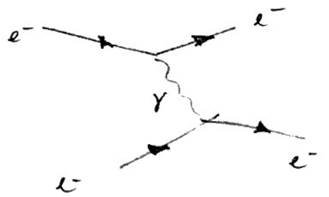
Q: Name matter part, Name force part.

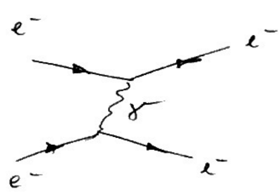
Matter: Fundam. Constituent of the Universe (Matter Particles)

Force: Interactions between particles (Force particles)

Standard Model:

Description of interactions through Feynman Diagrams





	strong	e.m.	weak
Quarks	✓	✓	✓
lept.		✓	✓
Neutr.			✓

Matter particles: Spin $= \frac{1}{2}$

Three generations

Differing largely in mass

ν_e	$Q = 0$	$m \approx 0$	ν_μ	$m \approx 0$
e^-	$Q = -1$	$m = 511$ keV	μ^-	$m = 106$ MeV
ν_τ	$Q = 0$	$m \approx 0$		
τ^-	$Q = -1$	$m = 1.77$ GeV		

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u	$Q = +\frac{2}{3}$	$m = 3$ MeV	c	$m = 1.3$ GeV
d	$Q = -\frac{1}{3}$	$m = 5$ MeV	s	$m = 100$ MeV
t	$Q = +\frac{2}{3}$	$m = 174$ GeV		
b	$Q = -\frac{1}{3}$	$m = 4.5$ GeV		

Mass differences?

Neutrinos?

Forces : Spin = 1

	Photons	γ	Spin = 1	$m = 0$	EM
$W^\pm$ charged	Heavy Gauge Boson	$W^\pm, Z$	Spin = 1	$m = 80.39$ GeV $m = 91.19$ GeV	Weak
carry color charge	Gluons	g	Spin = 1	$m = 0$	Strong

Not included : Gravity.
Force particle : graviton? ; spin = 2 ...

Higgs - Boson.

Nobel Prize: 2013
Discovery: 2012

Mass : $m = 125$ GeV

Spin : $S = 0$

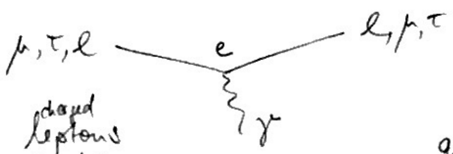
Provides mass to heavy gauge bosons and matter particles due to non-vanishing ...

→ non-zero vacuum expectation value

[ie.: completely different than other particles]
[vacuum : only Higgs field present]

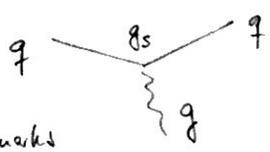
Feynman Diagrams
[Particle Physics Language]

Different Interactions described by different vertices ...



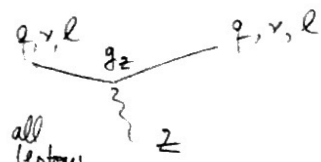
charged leptons
quarks
($W^\pm$)!!

$\alpha \sim e^2 \sim \frac{1}{137}$

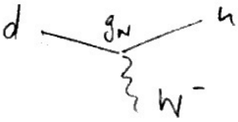


quarks

$\alpha_s \sim g_s^2 \sim O(-1)$



all
leptons
quarks
(Gauge Bosons)



No flavour changing neutral currents.

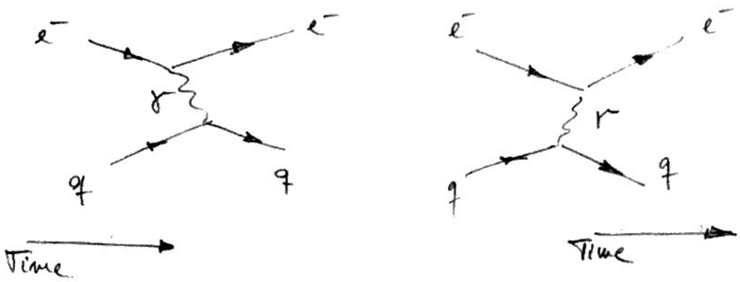
$\alpha_{W/Z} \sim 1/30$
[but : $1/M_W^2$]

Flavour changing charged current.

up/down-type quarks
leptons/neutrinos

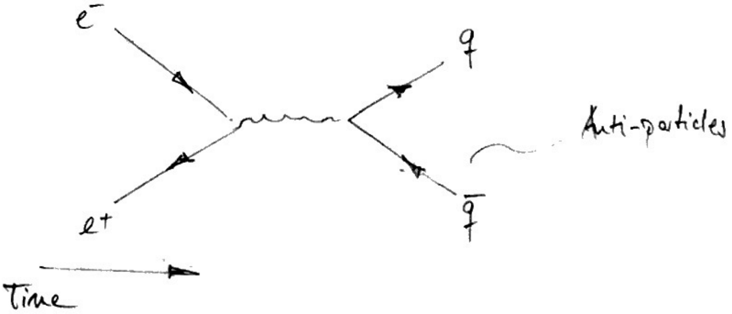
Particle - Particle - Interaction:

Initial State



Final State

Scattering Process



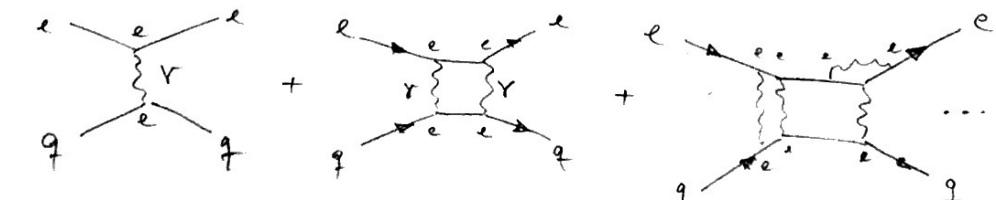
Annihilation Process

We will learn this

Feynman Diagrams are much more than a pictorial representation of the fundamental physics underlying a particular process. From QFT it is possible to derive simple mathematical rules to calculate transition probability.

For each process we have an infinite number of diagrams ...

Need all to be added ...



With: $\alpha = \frac{e^2}{4\pi} \ldots$

T.Prob. $\sim |M_{fi}|^2 \sim \alpha^2 \sim e^4$ $\qquad \sim \alpha^4 \sim e^8$ $\qquad \sim \alpha^8 \sim e^{16}$

With $\alpha \sim 1/137$ this gets smaller and smaller ...

Calculation of diagrams yields probability for a process ...

Coupling large $\rightarrow$ probability large

Coupling small $\rightarrow$ probability small

Strong

e.m.

Weak

Extra subtlety .. due to mass of propagator ...

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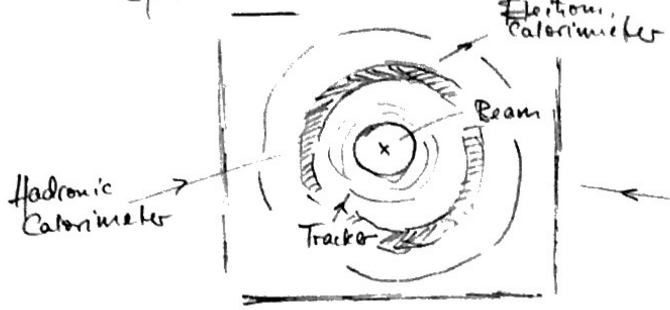
Detection of particles ...
[stable particles only; i.e.: electron & proton & $\mu, \pi^\pm, K^\pm$; $\tau > 10^{-10}$ s]

Flight distance: $\gamma\beta c\tau$

Typical detector:



Typical Detector for Collider Experiment.

Based on: Ionization (Bethe - Bloch) → Scintillation, Gas Detectors, Silicon Detectors, Streamer Tubes, Emulsion
Bremsstrahlung
Cherenkov Radiation
Transition Radiation
+ Photon Interactions
+ Hadronic Interactions ...

[See lecture on Particle Detectors SS 2021

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II. Underlying Concepts

Particle physics - as described here - is concerned with

high-energy interactions of relativistic particles
[HEP: high-energy (particle) physics]

$\boxed{\hbar c = 197 \text{ MeV fm}}$

i.e.:
Need relativistic formulation of QM → relativ. QM, for cross section calculations ..

Natural units: $\hbar = c = 1$

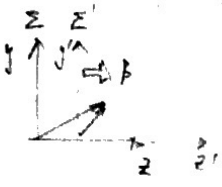
Also: $\varepsilon_0 = \mu_0 = 1$ [Heaviside - Lorentz]

$$x^\mu = (x^0, x^1, x^2, x^3) = (ct, x, y, z) = (t, x, y, z)$$

$$p^\mu = (p^0, p^1, p^2, p^3) = (E/c, p_x, p_y, p_z) = (E, p_x, p_y, p_z)$$

Contravariant four vectors

Lorentz - transform of contravariant 4-vectors!



$$\begin{pmatrix} t' \\ x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} \gamma & 0 & 0 & -\gamma\beta \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\gamma\beta & 0 & 0 & \gamma \end{pmatrix} \begin{pmatrix} t \\ x \\ y \\ z \end{pmatrix}$$

i.e.: $X' = \Lambda X$