Hadronen im Quarkmodell

Wissenschaftliches Präsentieren

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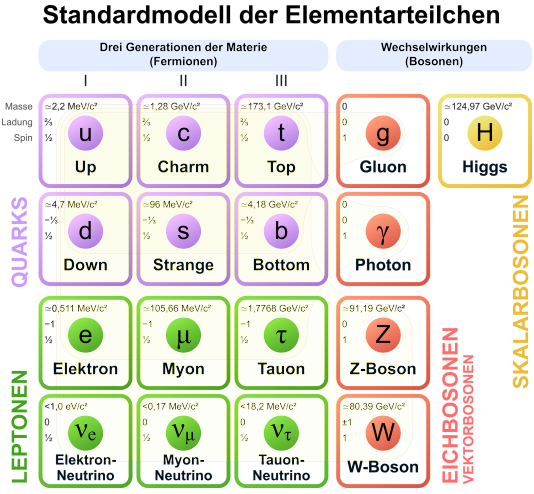
13. Januar 2025

Gliederung

- Das Standardmodell
  - Quarks
- Hadronen
  - Aufbau und Klassifizierung
  - Das SU_3 Dekuplett
- Geschichte: „*Erfindung*“ der Quarks
- Aktuelle Forschung
  - Theoretische Vorhersagen
  - Experimentelle Entdeckung

Das Standardmodell

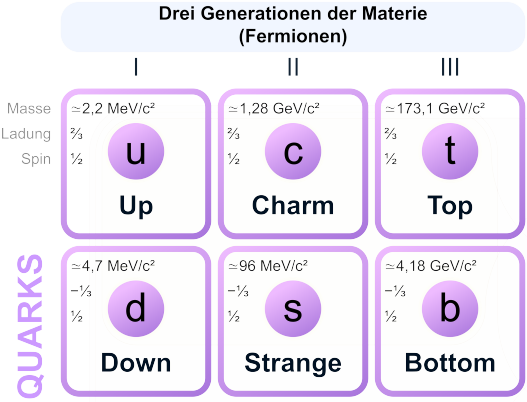
Das Standardmodell der Elementarteilchen



Wikipedia – *Standardmodell*; URL: https://de.wikipedia.org/w/index.php?title=Standardmodell&oldid=250545829

- Beschreibt Elementarteilchen & Wechselwirkungen
- Fermionen (Quarks, Leptonen) & Bosonen (Vektorbosonen, Higgs-Boson)
- Starke, schwache & elektromagnetische Wechselwirkung

Quarks



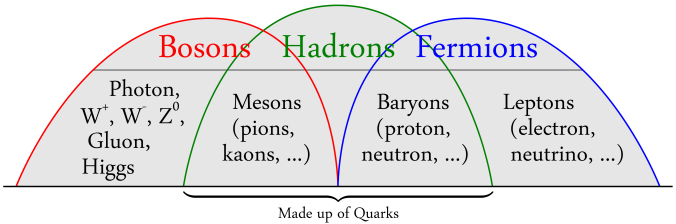
Wikipedia – *Standardmodell*; URL: `https://de.wikipedia.org/w/index.php?title=Standardmodell&oldid=250545829`

- Up, Charm, Top: $+\frac{2}{3}e$
- Down, Strange, Bottom: $-\frac{1}{3}e$
- Up, Down, Strange: leichtere Quarks
- Charm, Bottom: schwerer
- Top: schwerstes Quark
- **Quarks nie isoliert!**

Hadronen

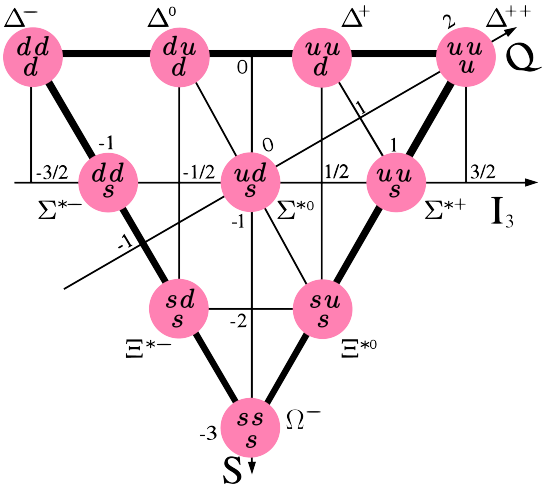
Hadronen: Aufbau und Klassifizierung

- Zusammengesetzt aus Quarks (durch starke WW gebunden)
- Baryonen (drei Quarks: Proton, Neutron, ...)
- Mesonen ($q\bar{q}$, z.B. Pion, Kaon, ...)



aus: Wikipedia – *Hadron*; URL: `https://en.wikipedia.org/w/index.php?title=Hadron&oldid=1261830067`

Das SU_3 Dekuplett



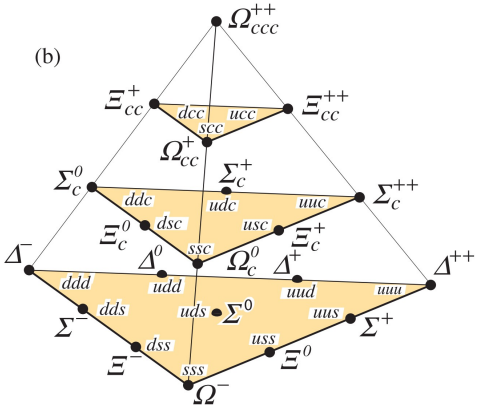
Wikipedia – *Δ-Baryon*, https://de.wikipedia.org/w/index.php?title=%CE%94-Baryon&oldid=247028912

- S: Strangeness
- Q: Ladung
- I_3: Isospin

	up	down	strange
S	0	0	-1
Q	$+\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$
I_3	$\frac{1}{2}$	$-\frac{1}{2}$	0

→ **Einführung der *Farbladung***

Erweiterung des SU_3 Dekupletts



Das 20-Plet mit einem SU_3 Dekuplett.
(C. Amsler, T. DeGrand und B. Krusche 2017)

- Erweiterung des SU_3 Dekupletts
- weitere Dimension: Charm
- Neue, schwere Hadronen

Geschichte: „*Erfindung*“ der Quarks

Gell-Mann: Zusammensetzung der Hadronen

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" [1-3], we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "bootstrap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone [4]. Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

Even if we consider the scattering amplitudes of

ber $n_t - n_{\bar{t}}$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles d^-, s^-, u^0 and b^0 exhibit a parallel with the leptons.

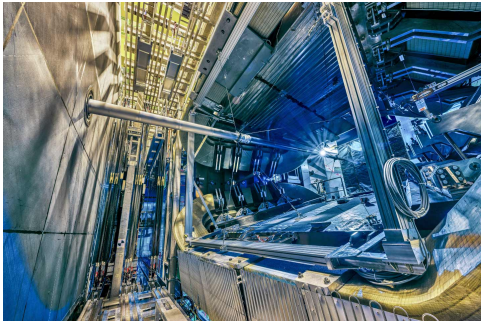
A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" [6] q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q\,q\,q)$, $(q\,q\,q\,q\,\bar{q})$, etc., while mesons are made out of $(q\,\bar{q})$, $(q\,q\,\bar{q}\,\bar{q})$, etc. It is assuming that the lowest baryon configuration $(q\,q\,q)$ gives just the represen-

Gell-Mann 1964; Zweig 1964, S. 214

Die Suche nach Pentaquarks

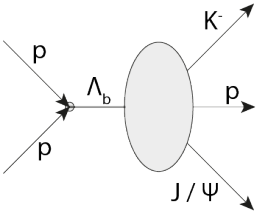
Pentaquarks: Theoretische Vorhersagen

- Idee von Gell-Mann (1964) wurde durch Högaasen und Sorba (1978) und Strottman (1979) erweitert:
  Theorie: $\mathrm{qqqq\bar{q}}$
- Lipkin (1987) erfand den Begriff Pentaquark
- Jedoch keine experimentellen Hinweise

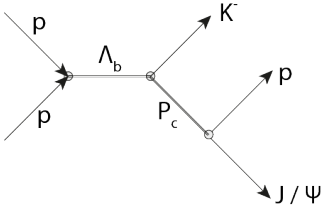


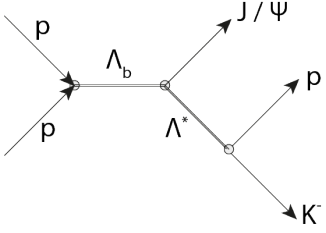
Der LHCb Detektor am CERN
Foto © Maximilien Brice, Julien Ordan | CERN
BMBF-Forschungsschwerpunkt LHCb 12.01.2025

LHCb: Untersuchung von Λ_b^0 Zerfällen



- Aaij, Adeva u. a. (2015): Untersuchung von $\Lambda_b^0 \to J/\psi\, K^- p$ Zerfällen.
- Zerfälle könnten minimalen Quarkanteil von $c\bar{c}uud$ enthalten.
  $\to$ Charmonium Pentaquarks (P_c)



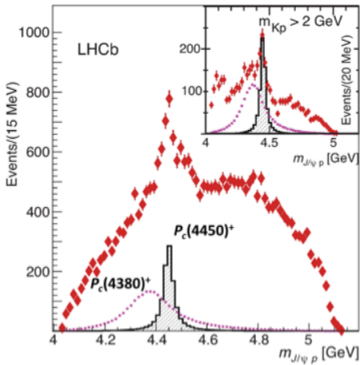


Feynmandiagramme der Zerfallskanäle von $\Lambda_b^0 \to J/\psi\, K^- p$

Eigene Darstellung nach Daten von Aaij, Adeva u. a. (2015)

Ergebnis der LHCb 2015 Messungen

$$\Lambda_b \to J/\psi p K^-$$



PRL 115, 072001 (2015)

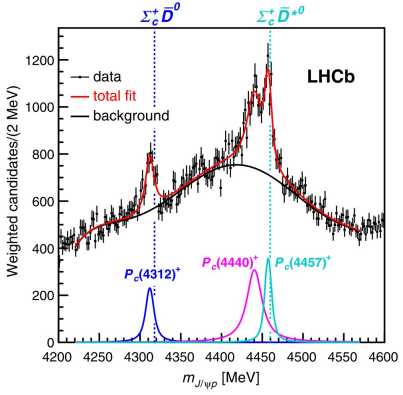
Aaij, Adeva u. a. 2015

- Messung von $P_c^+(4380)$ und $P_c^+(4450)$

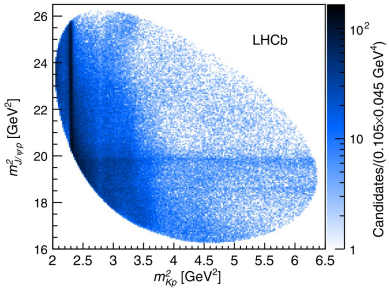
„The significance of each of these resonances is more than 9 standard deviations“

Aaij, Adeva u. a. 2015, S. 1

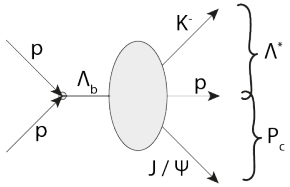
LHCb 2019: Genauere Messung und weitere Pentaquarks



Aaij, Abellán Beteta u. a. 2019



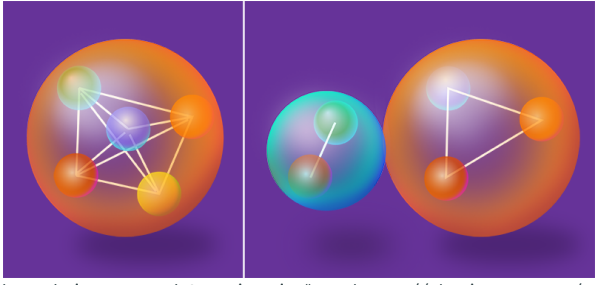
Dalitz-Plot der $\Lambda_b^0 \to J/\psi\, K^-\, p$ Kandidaten.



Eigene Darstellung des Λ_b^0 Zerfalls.

Fazit

- Im **Standardmodell** werden Elementarteilchen und Wechselwirkungen beschrieben.
- **Hadronen** bestehen aus 2, 4 (Mesonen), 3 oder 5 (Baryonen) Quarks.
- Quarks sind unterschiedlich schwer und **nie isoliert**
- **Pentaquarks** bestehen aus $\mathrm{qqqq\bar{q}}$ und wurden 2015 am LHCb entdeckt.



aus: Kenneth Hicks – „Elusive Pentaquark Comes into View“; URL: https://physics.aps.org/articles/v8/77

Vielen Dank der Aufmerksamkeit!

Fragen?

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