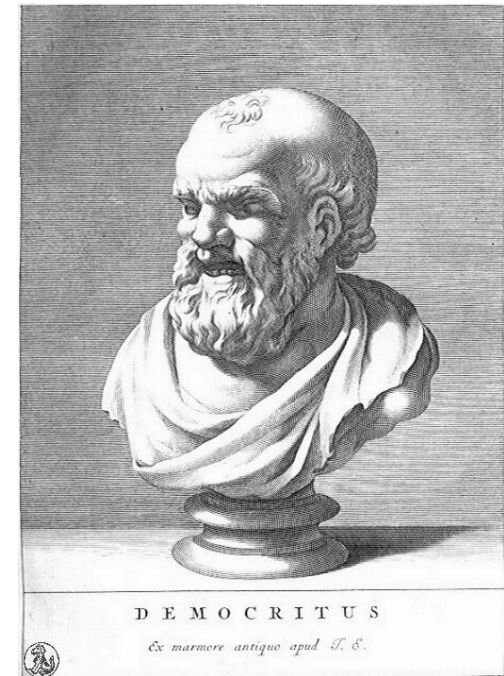


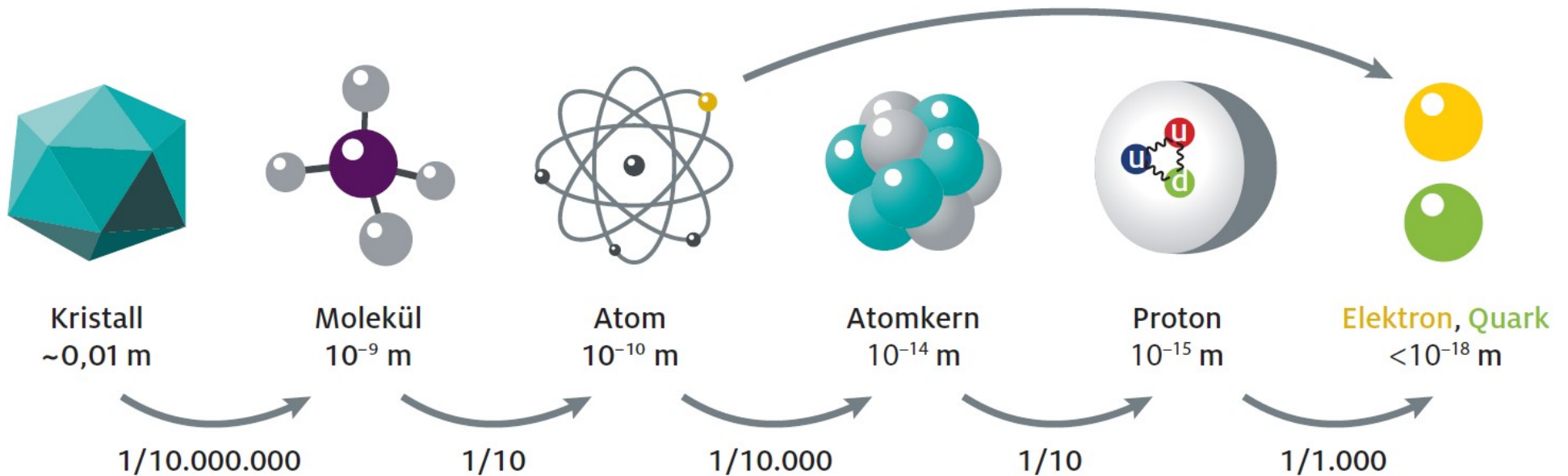
# Einführung in die Physik der kleinsten Teilchen

# Elementarteilchenphysik

- **Demokrit:**  
Nur scheinbar hat ein Ding eine Farbe,  
nur scheinbar ist es süß oder bitter,  
in Wirklichkeit gibt es nur Atome im leeren Raum.
- ➔ **Materie besteht aus elementaren,  
unteilbaren, punktförmigen Teilchen**
- + **Kräfte / Wechselwirkungen  
zwischen den Teilchen**
- **Elementarteilchenphysik: Theorie + Experiment**



# Größenskalen und Auflösung



- Sichtbares Licht: Wellenlänge  $\lambda = 4-7 \times 10^{-7}$  m

➤ Quantenmechanik: Welle-Teilchen-Dualismus

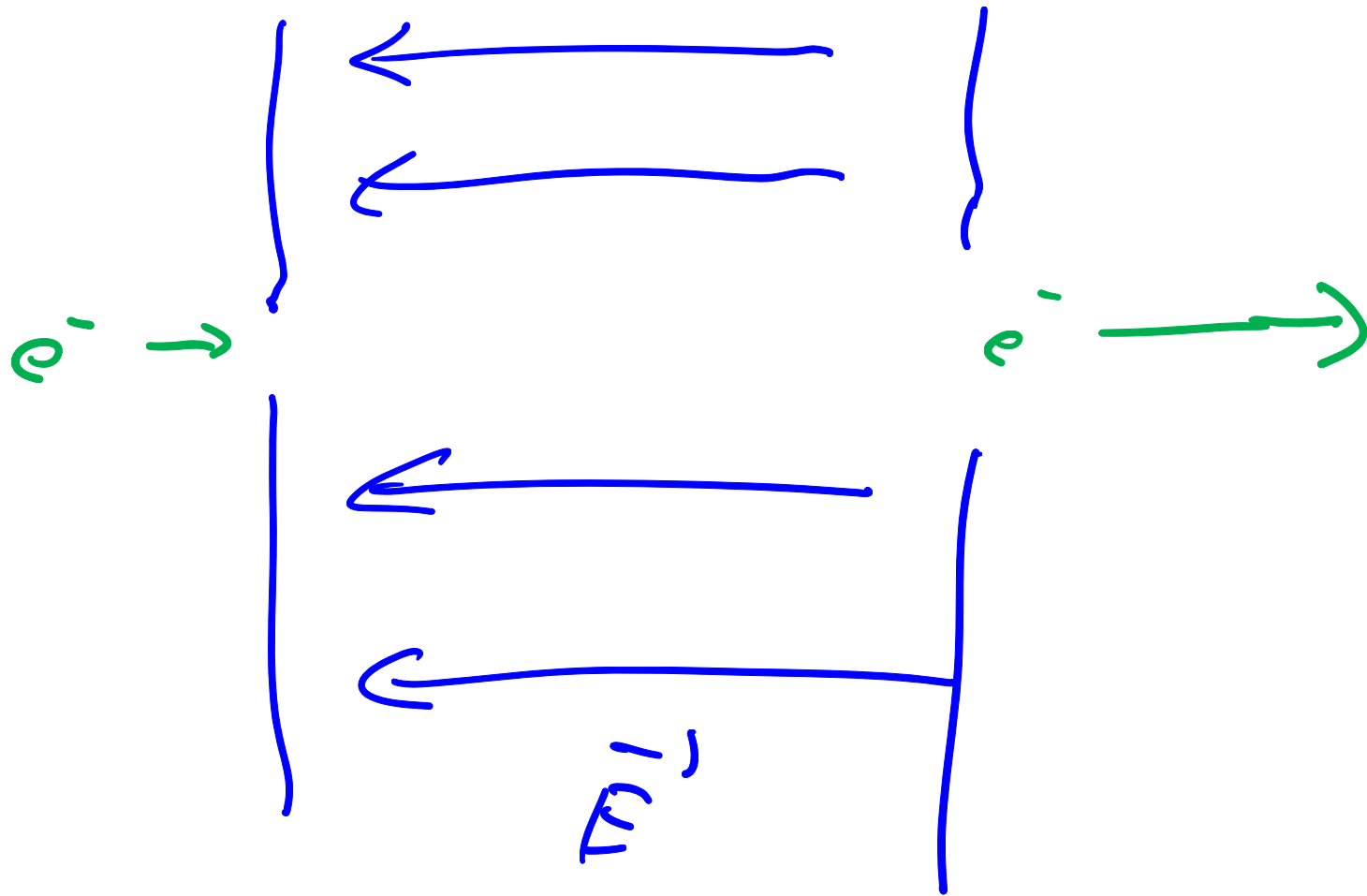
$$\lambda = \frac{hc}{E}, \text{ Impuls } p = \frac{E}{c} \Rightarrow \lambda = \frac{h}{p}$$

Gilt auch für Materieteilchen

Lichtgeschwindigkeit  
 $c = 2,998 \times 10^8$  m/s

Plancksches  
 Wirkungsquantum  
 $h = 6,626 \times 10^{-34}$  Js

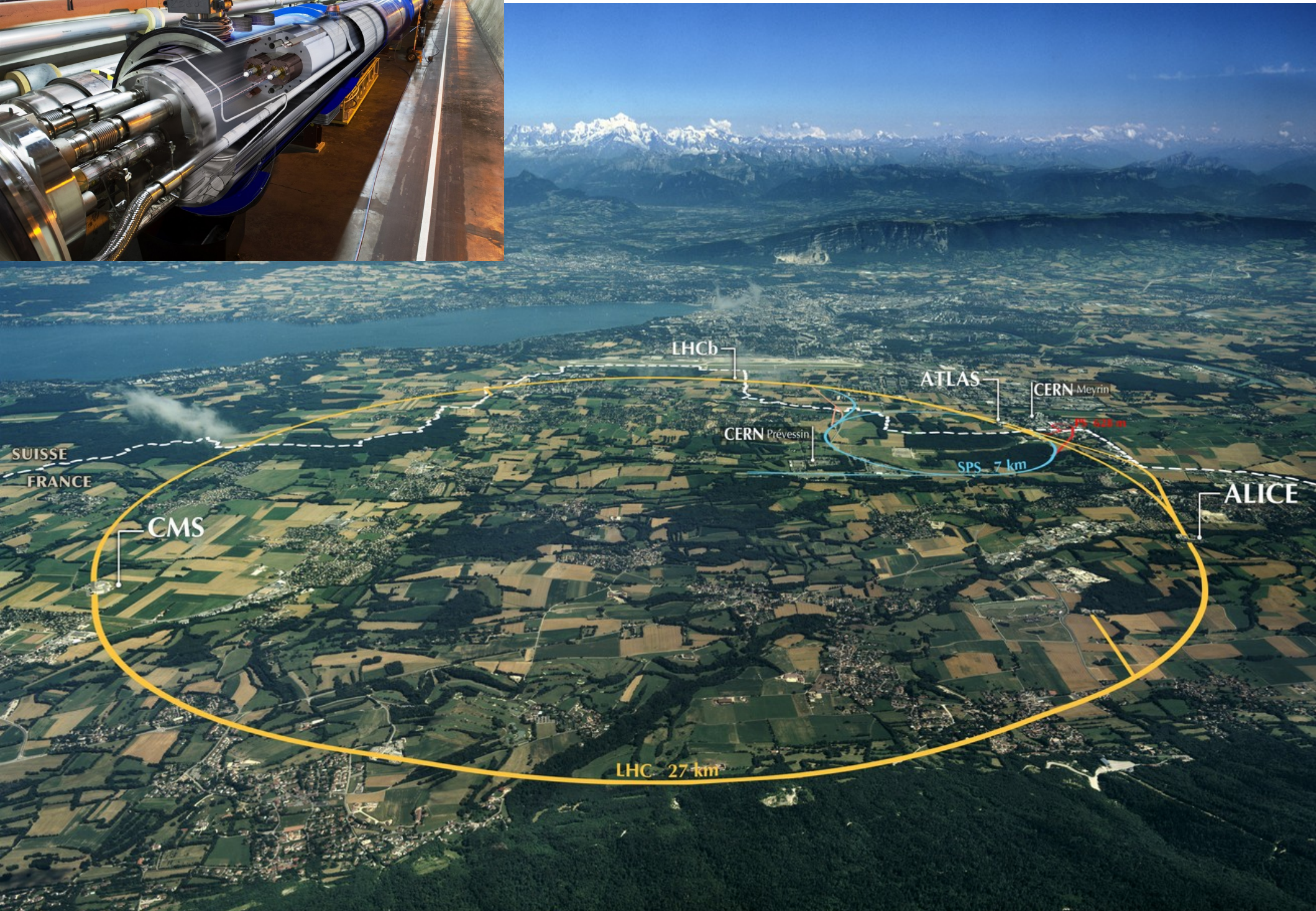
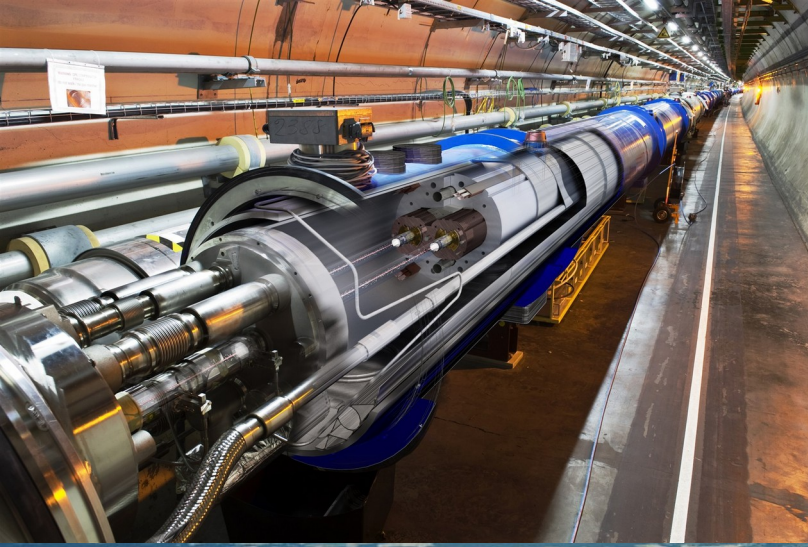
# Beschleuniger



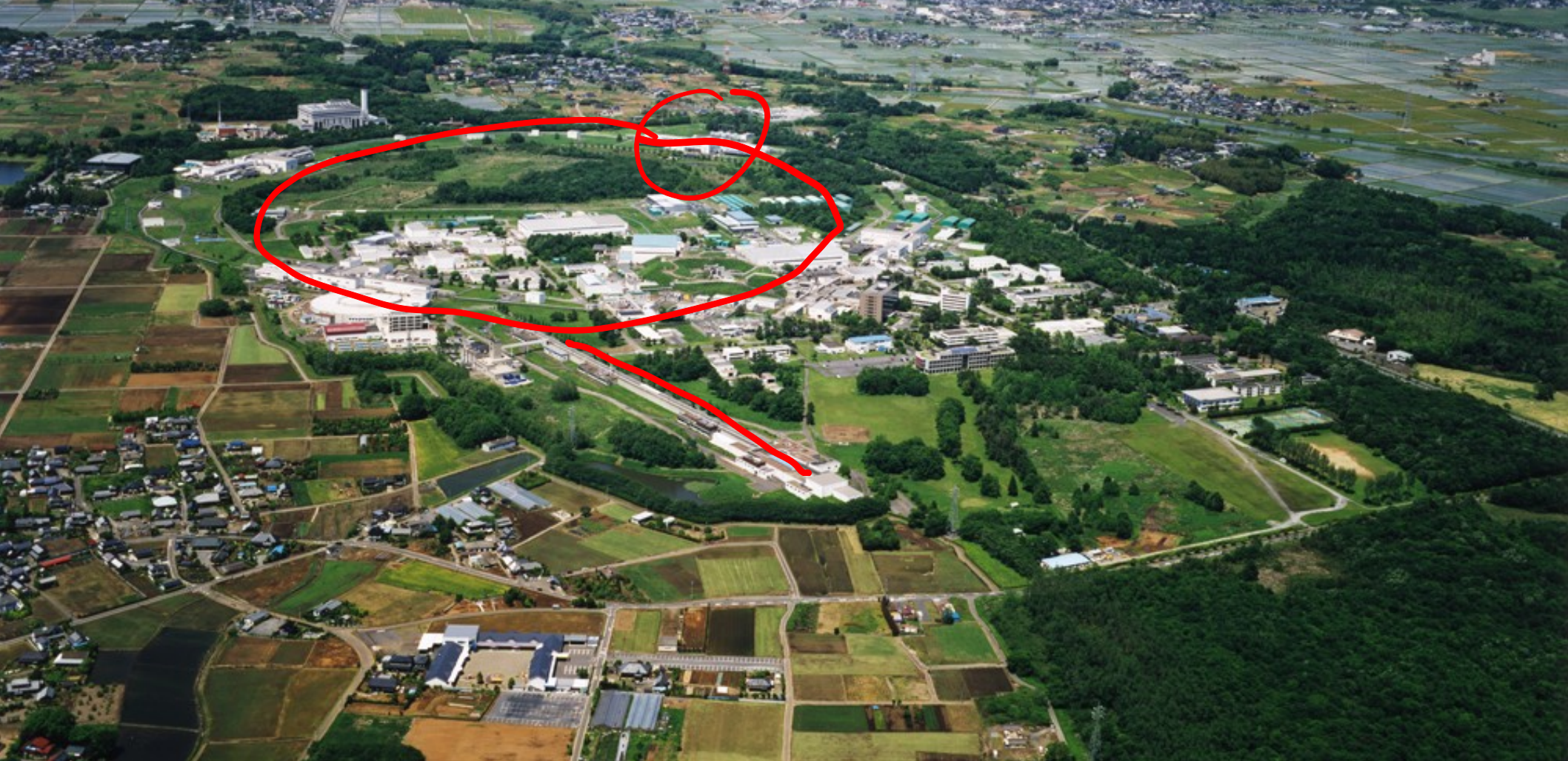
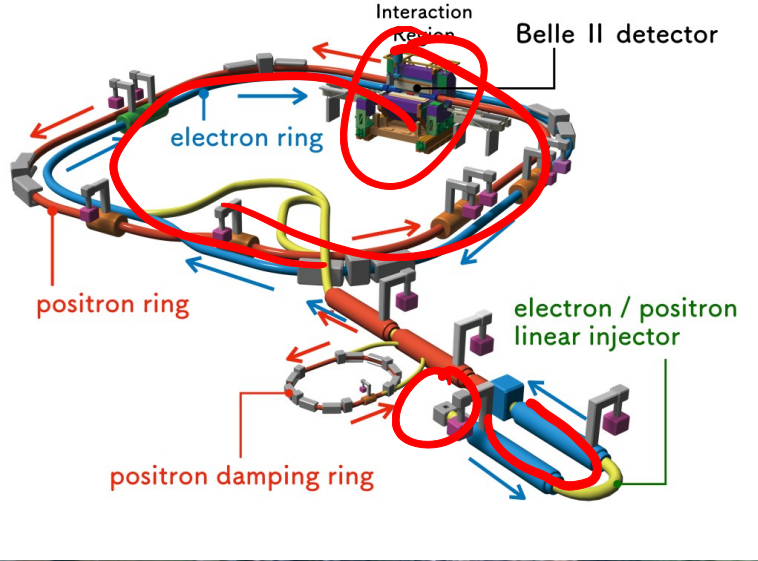
$$\Delta E = q \Delta U$$

Einheit: Elektronenvolt  $eV = 1,6 \cdot 10^{-19} J$

# LHC @ CERN



# SuperKEKB @ KEK



# Materieteilchen

## Quarks

q [e]

+2/3

-1/3

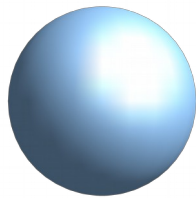
**up**



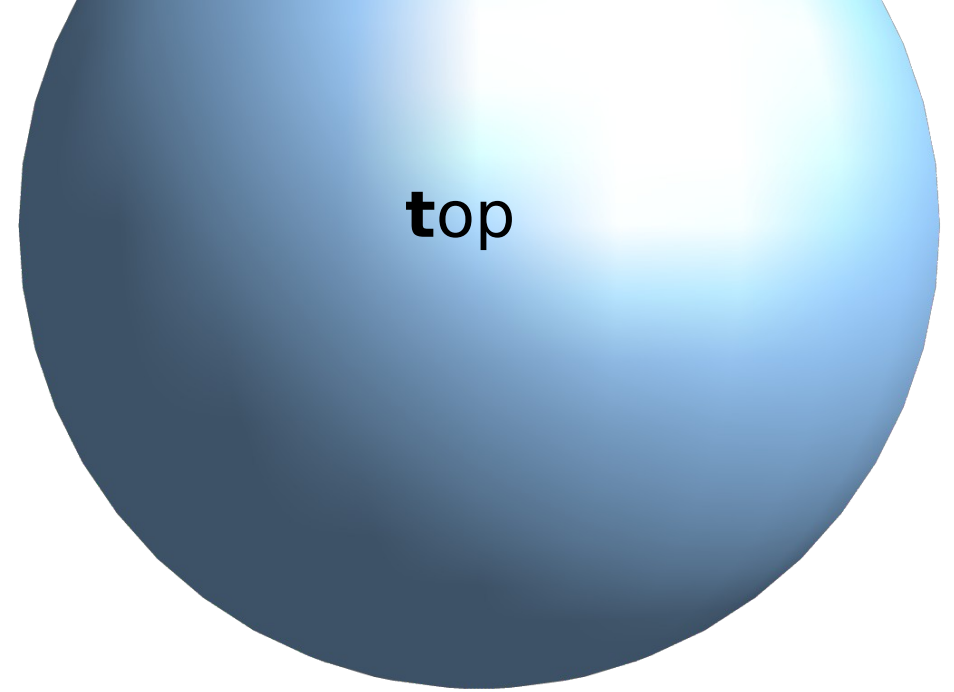
**down**



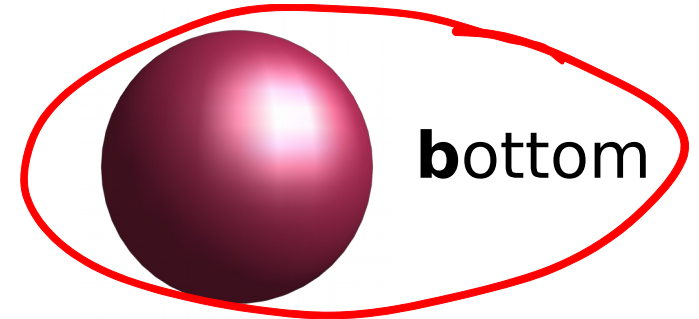
**charm**



**strange**



**top**



**bottom**

## Leptonen

-1

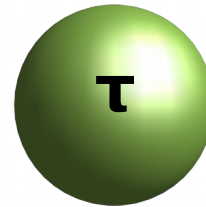
**e**



**μ**



**τ**



0

**ν<sub>e</sub>**

**ν<sub>μ</sub>**

**ν<sub>τ</sub>**

# Wechselwirkungen

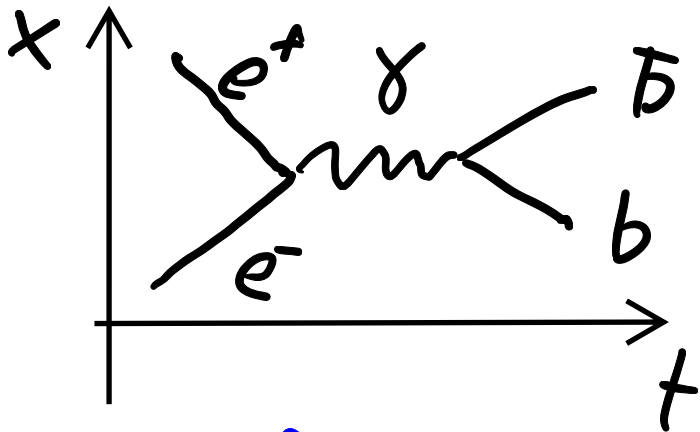
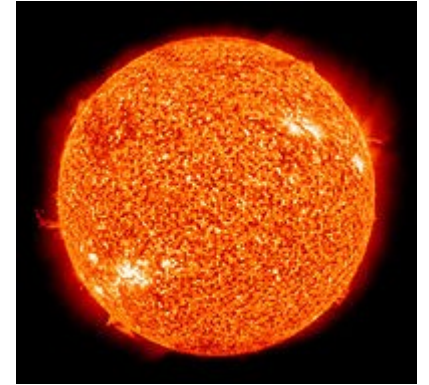
Elektromagnetische Kraft



Starke Kraft



Schwache Kraft



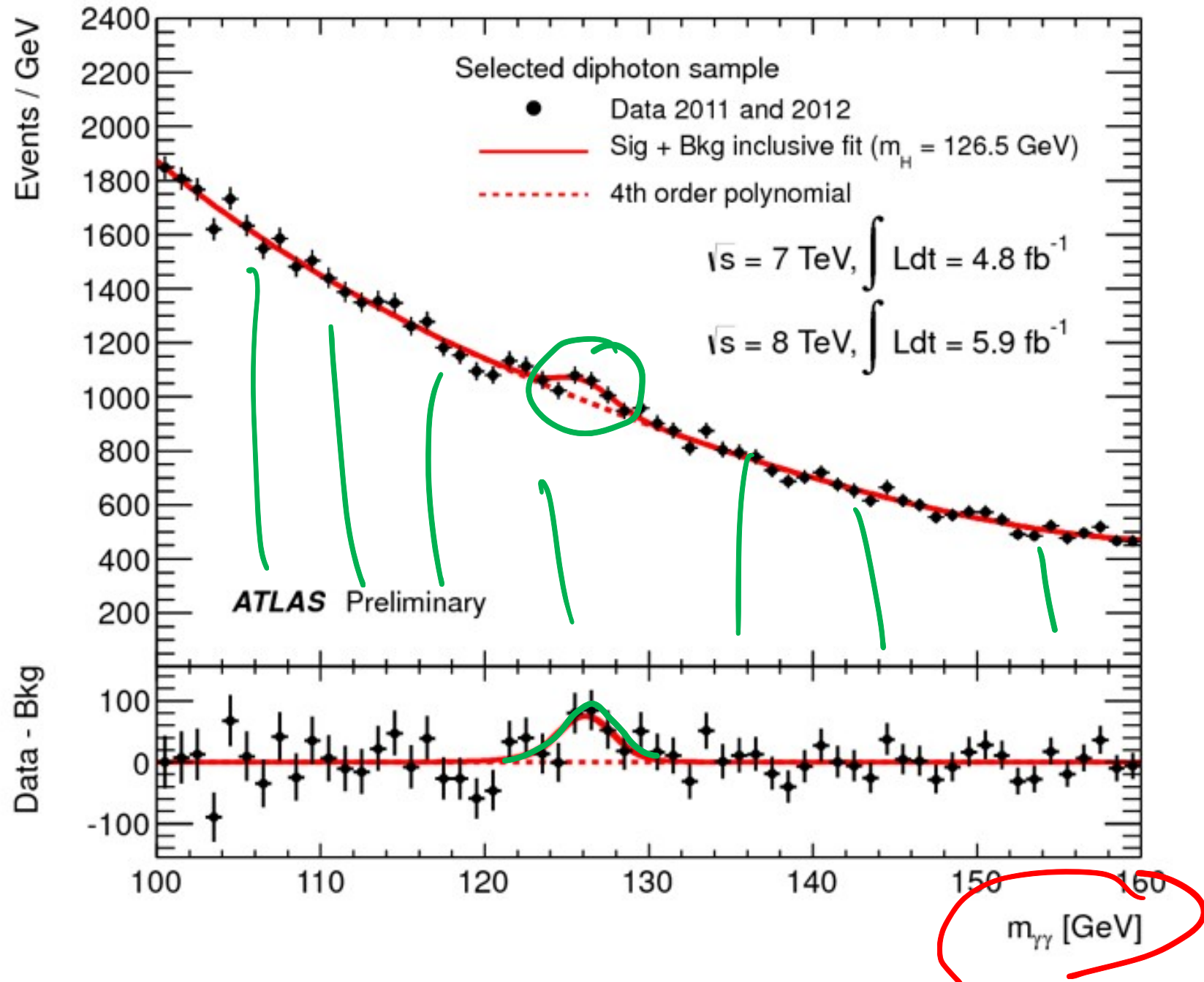
→ Standardmodell

(Gravitation)

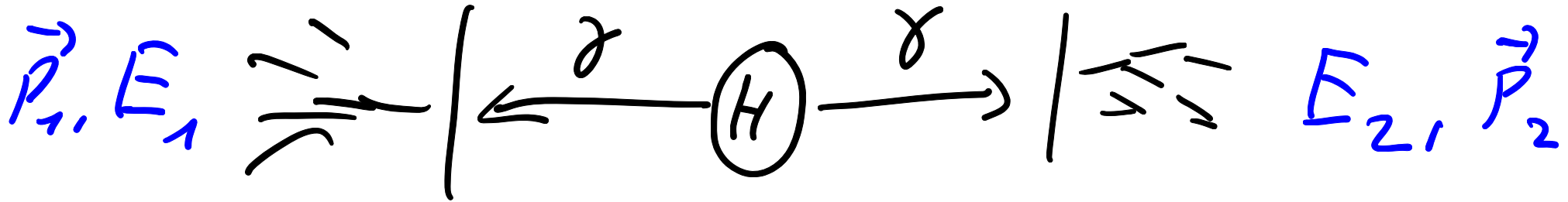
Higgs



# Beispiel Higgs



# Energie, Impuls, Masse



› Energie- und Impulserhaltung:

$$E_H = E_1 + E_2, \quad \vec{p}_H = \vec{p}_1 + \vec{p}_2$$

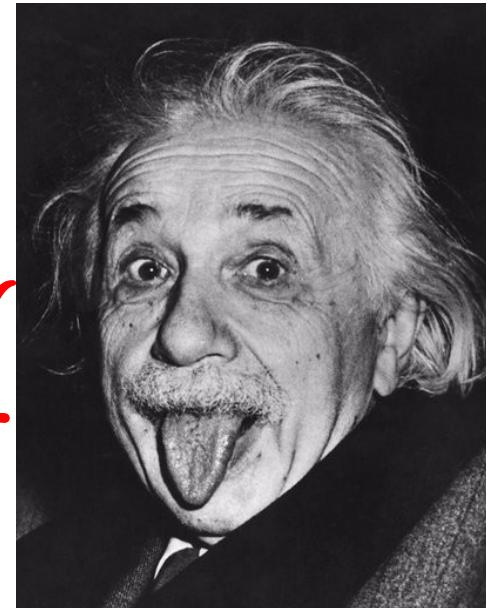
› Relativitätstheorie:

$$E^2 = p^2 c^2 + m^2 c^4$$

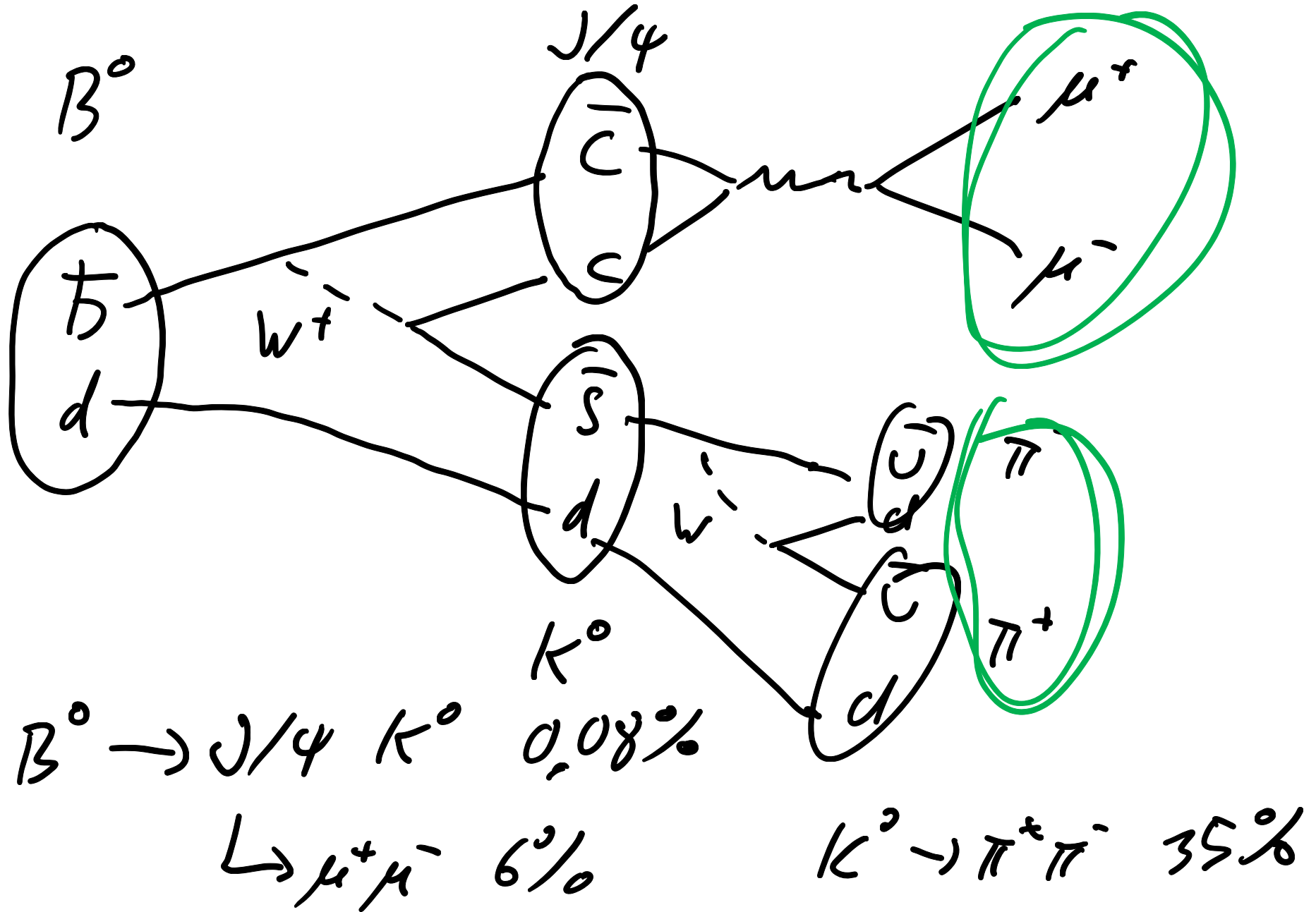
(für  $p=0$  :  $E = mc^2$ )

$$m = \frac{1}{c^2} \sqrt{E^2 - p^2 c^2}$$

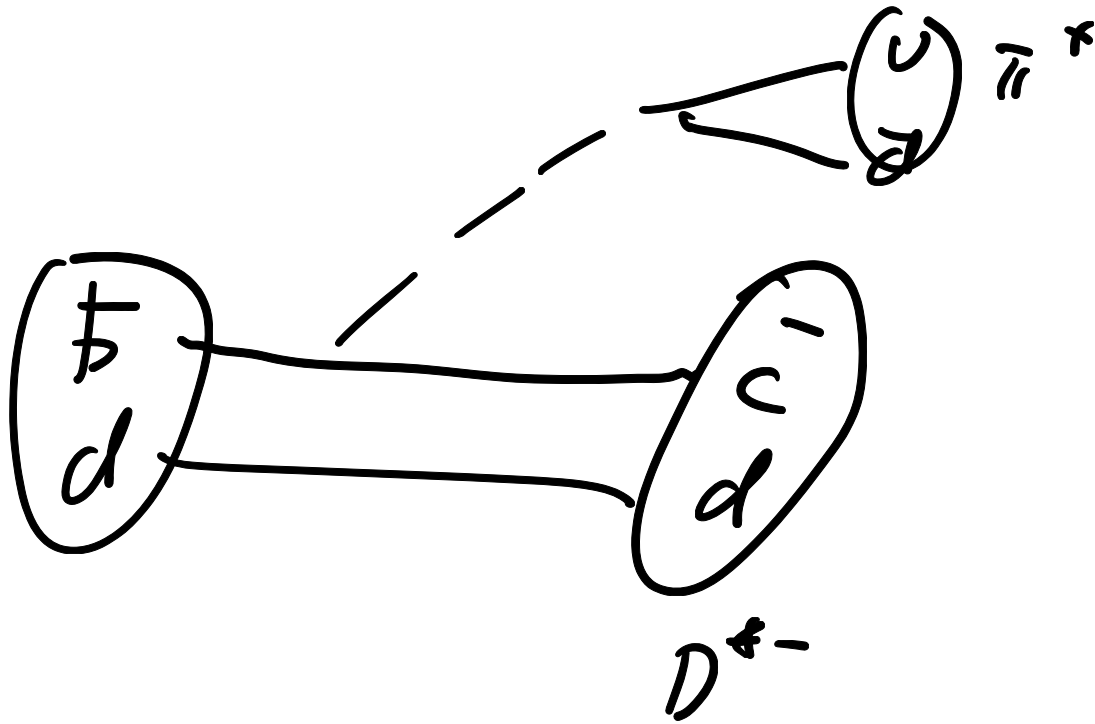
Red annotations:  $\leftarrow -p^2 c^2$ ,  $E^2 - p^2 c^2 = m^2 c^4$ ,  $\sqrt{E^2 - p^2 c^2} = mc^2$



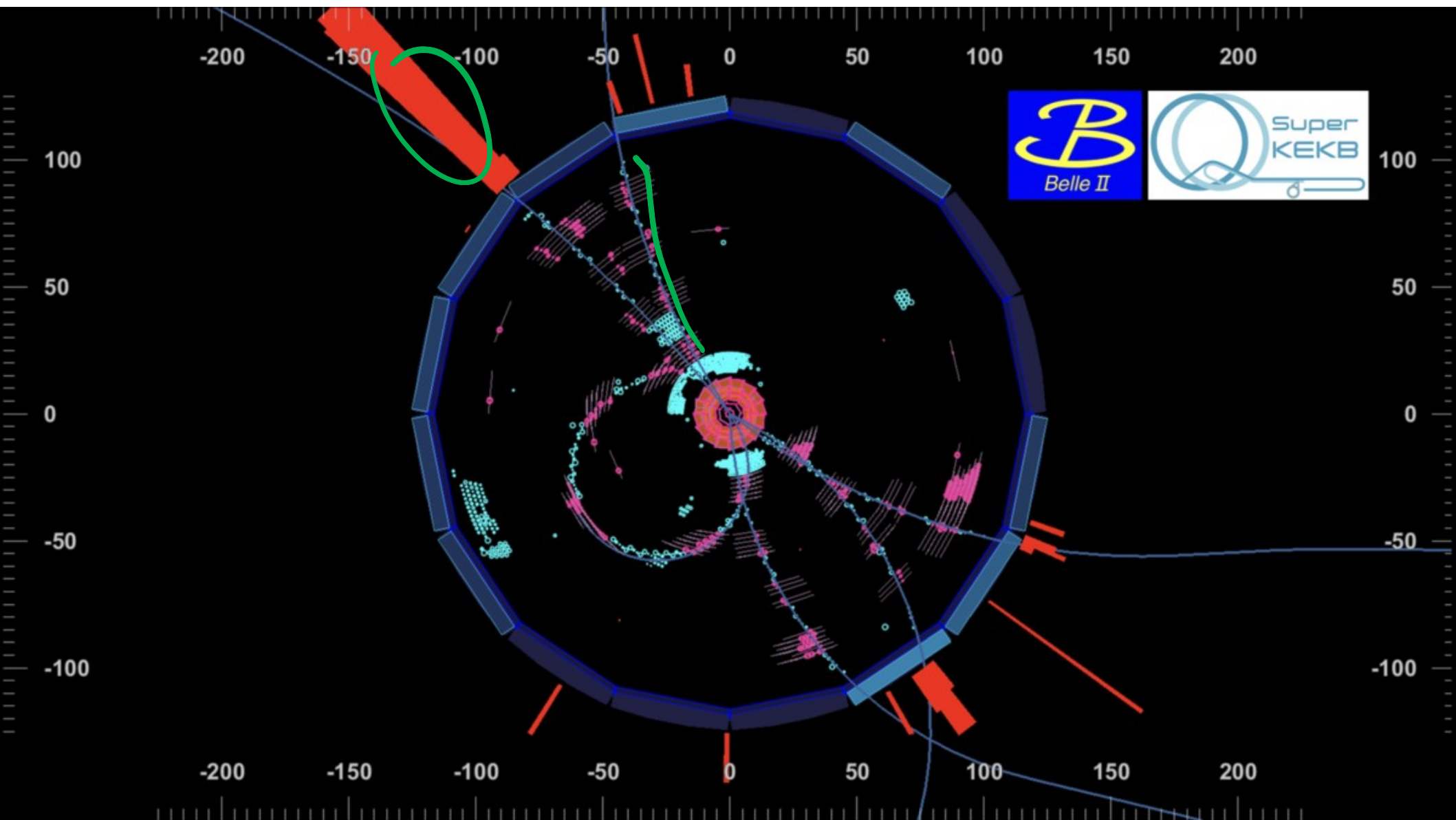
# Zerfallsketten von Hadronen



# Zerfallsketten von Hadronen



# Ereignis im Belle II Detektor



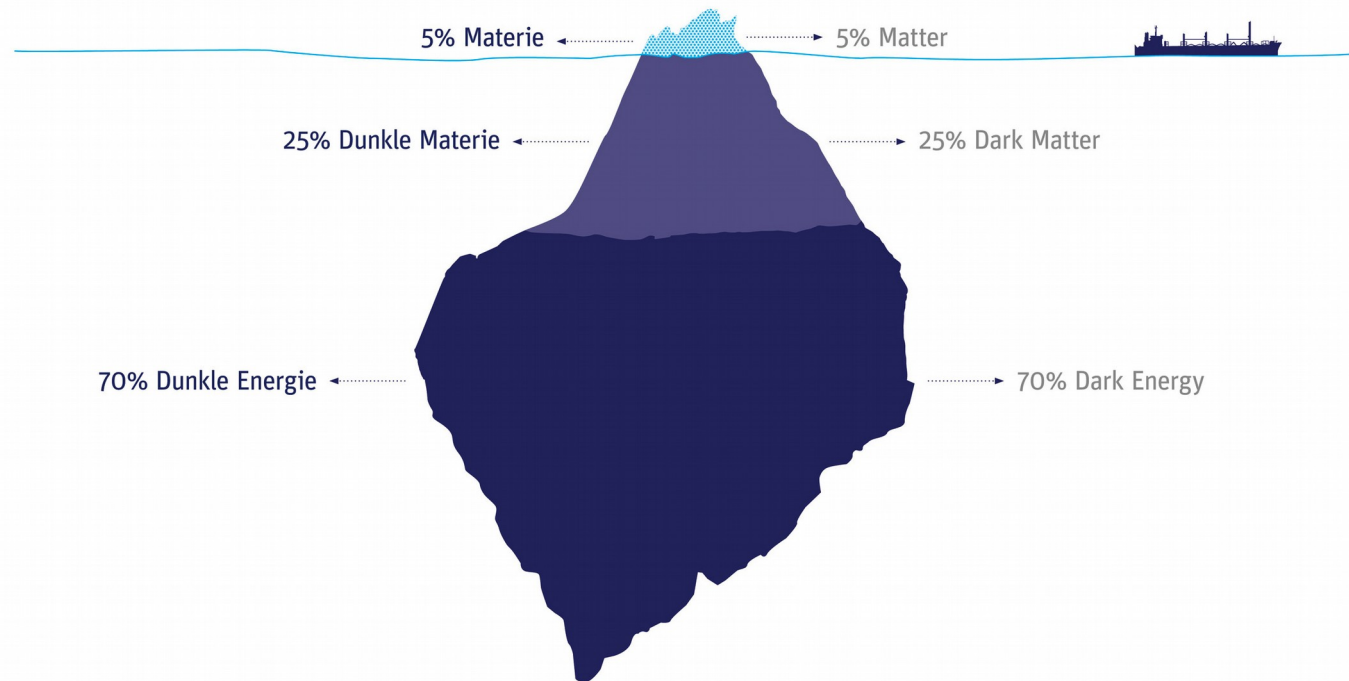
# Offene Fragen

Parameter des  
Standardmodells

Asymmetrie zwischen  
Materie und Antimaterie  
Im Universum

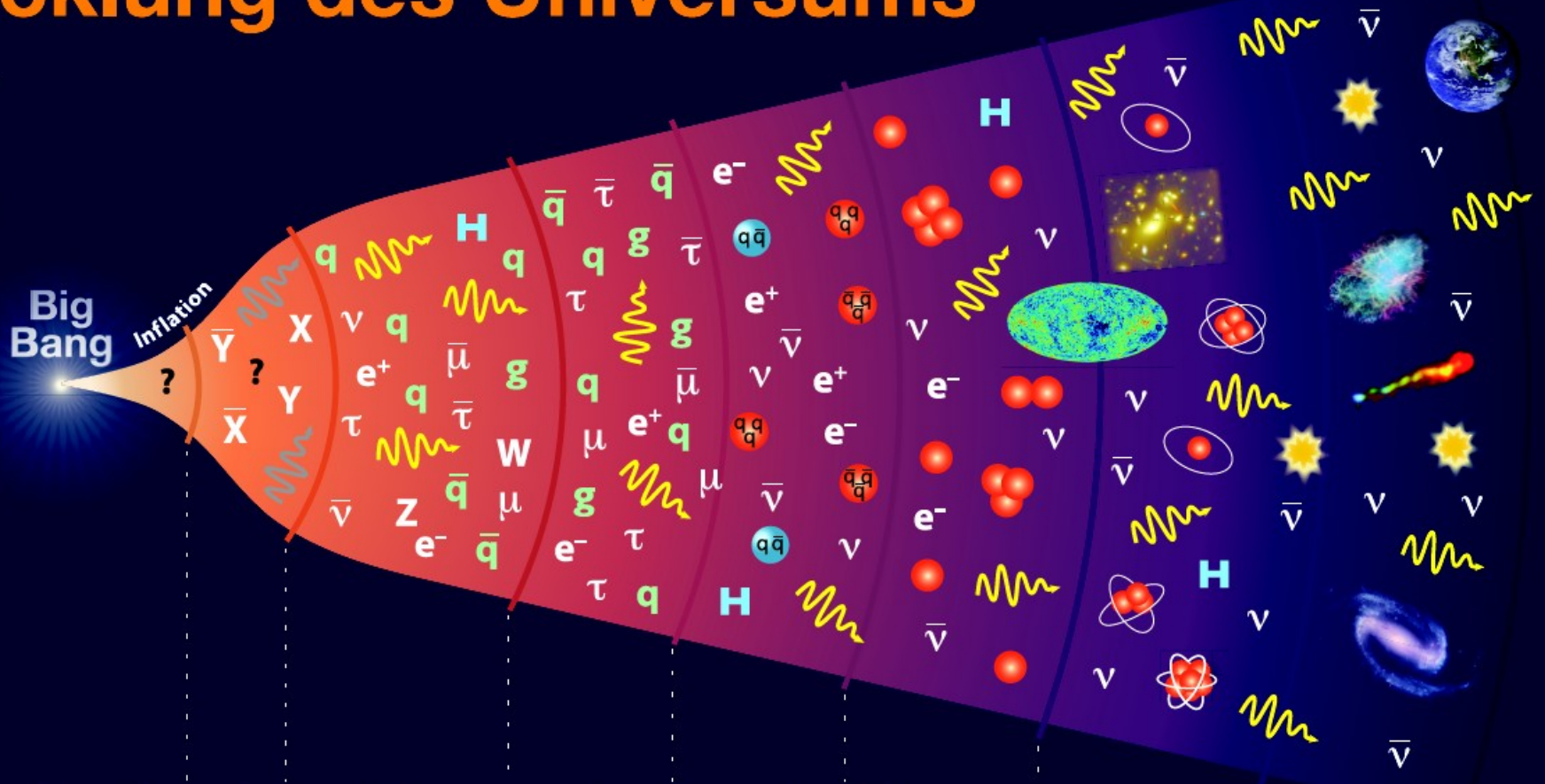
Theorie  
inklusive  
Gravitation

???



# Entwicklung des Universums

<b>H</b>	Higgs
	X-Kraft
<b>X, X̄</b>	X-Bosonen
<b>Y, Ȳ</b>	Y-Bosonen
<b>g</b>	Gluon
<b>q, q̄</b>	Quarks
<b>e<sup>-</sup></b>	Elektron
<b>e<sup>+</sup></b>	Positron
<b>ν, ν̄</b>	Neutrinos
<b>μ, μ̄</b>	Myonen
<b>τ, τ̄</b>	Tauonen
	Photon
<b>W, Z</b>	Bosonen
	Meson
	Baryon
	Ion
	Atom
	Stern



## Exzellenzcluster Universe – Forschungsbereiche:



Zeit (Sekunden, Jahre)	$10^{-44}s$	$10^{-36}s$	$10^{-10}s$	$10^{-5}s$	$10^2s$	$4 \times 10^5 J.$	$10^9 J.$	$13.7 \times 10^9 J.$
Temperatur (Kelvin)	$10^{32}$	$10^{29}$	$10^{16}$	$10^{12}$	$10^9$	3000	15	2.7
Energie (GeV)	$10^{19}$	$10^{16}$	1000	$10^{-1}$	$10^{-4}$	$3 \times 10^{-10}$	$10^{-12}$	$2.3 \times 10^{-13}$

# Belle II Detektor

