R. Harlander, *MasterClass*, Februar 2021

Institute for Theoretical Particle Physics and Cosmology

RWTH AACHEN UNIVERSITY

Materie
Kräfte
Strahlung (Licht, Wärme, …)

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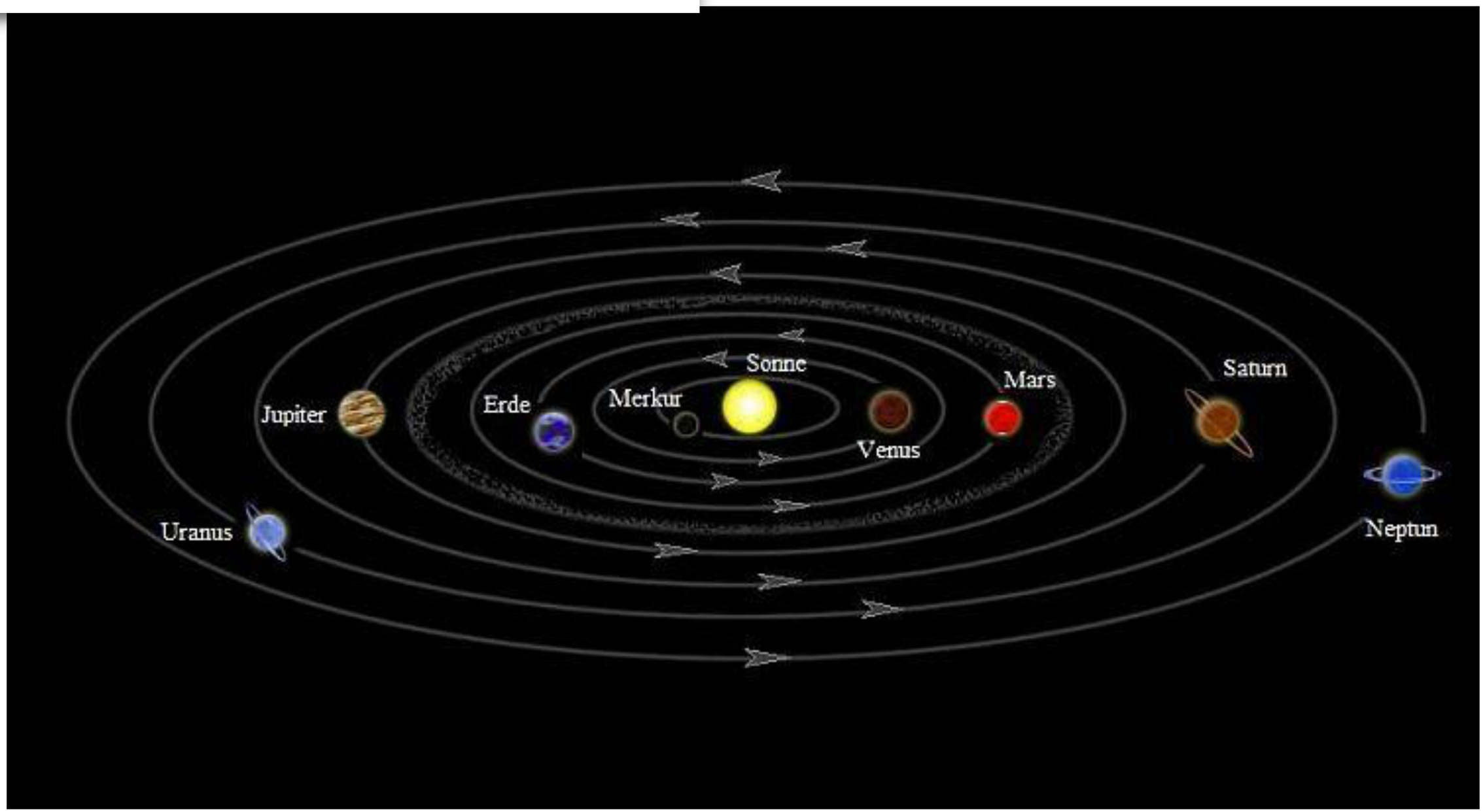
UESAKA

- Schwerkraft (Gravitation)

- Schwerkraft (Gravitation)



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- Schwerkraft (Gravitation)

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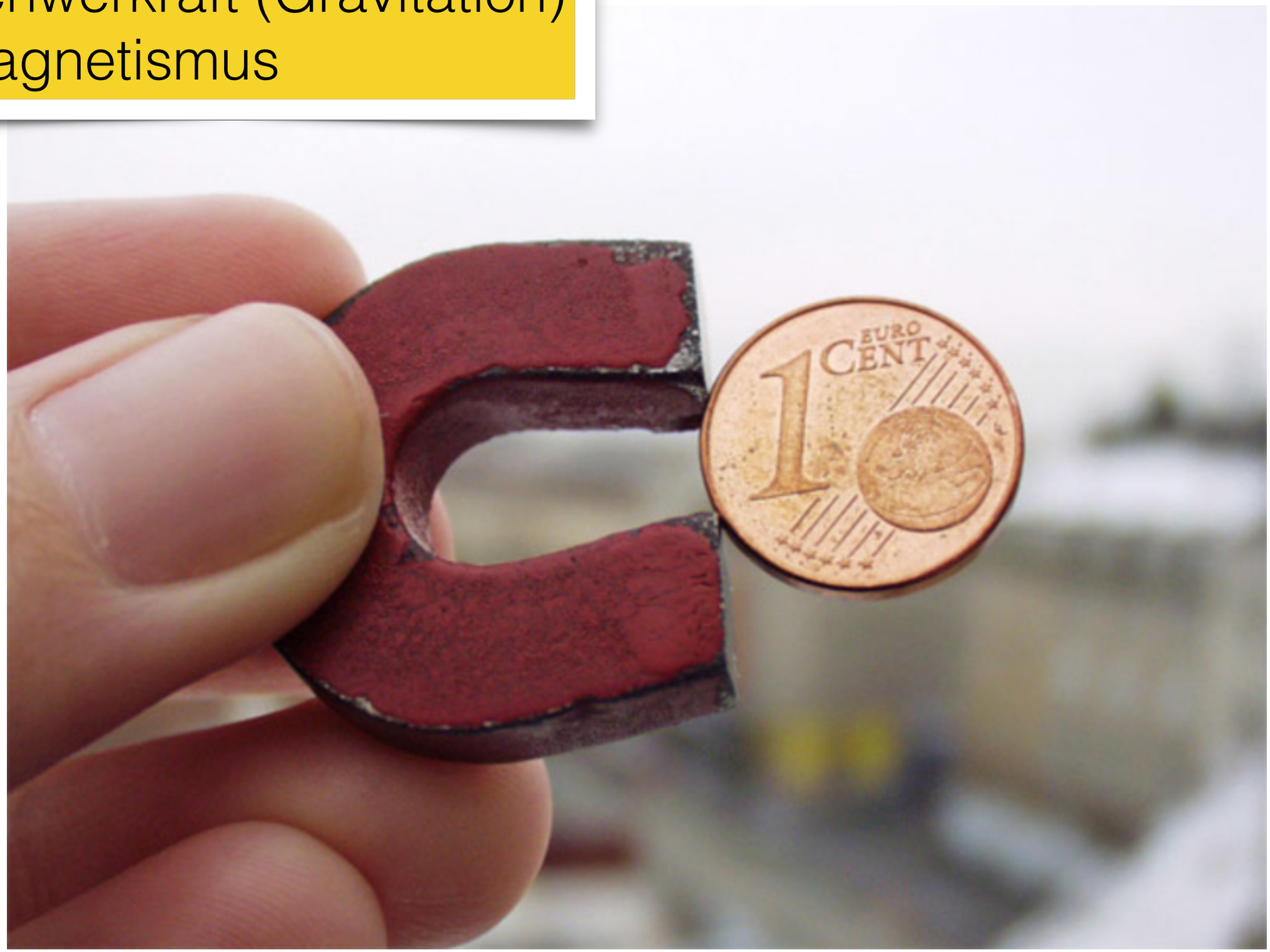
- Schwerkraft (Gravitation)
- Magnetismus



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- Schwerkraft (Gravitation)
- Magnetismus

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- Schwerkraft (Gravitation)
- Magnetismus
- Elektrostatik

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- Schwerkraft (Gravitation)
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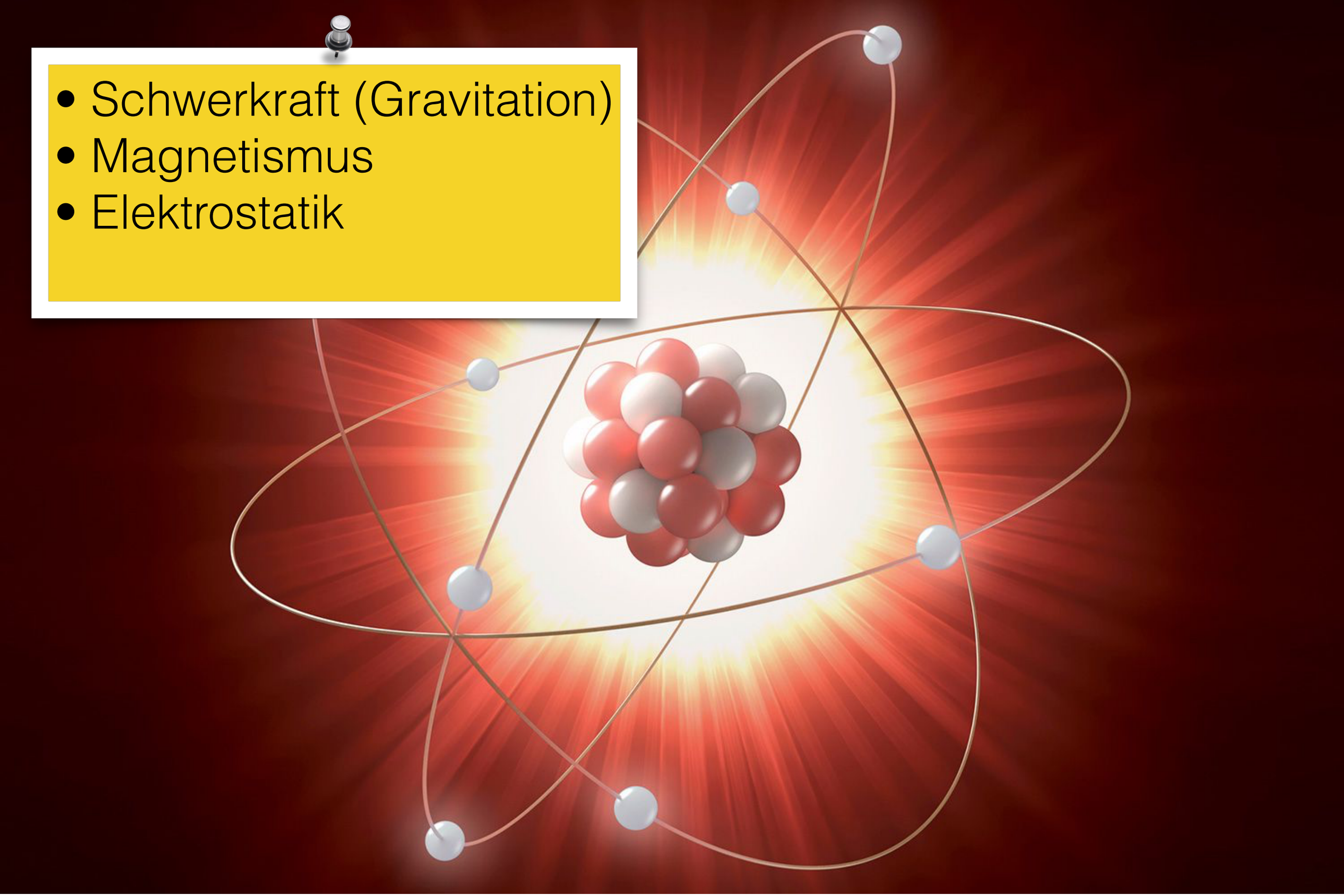

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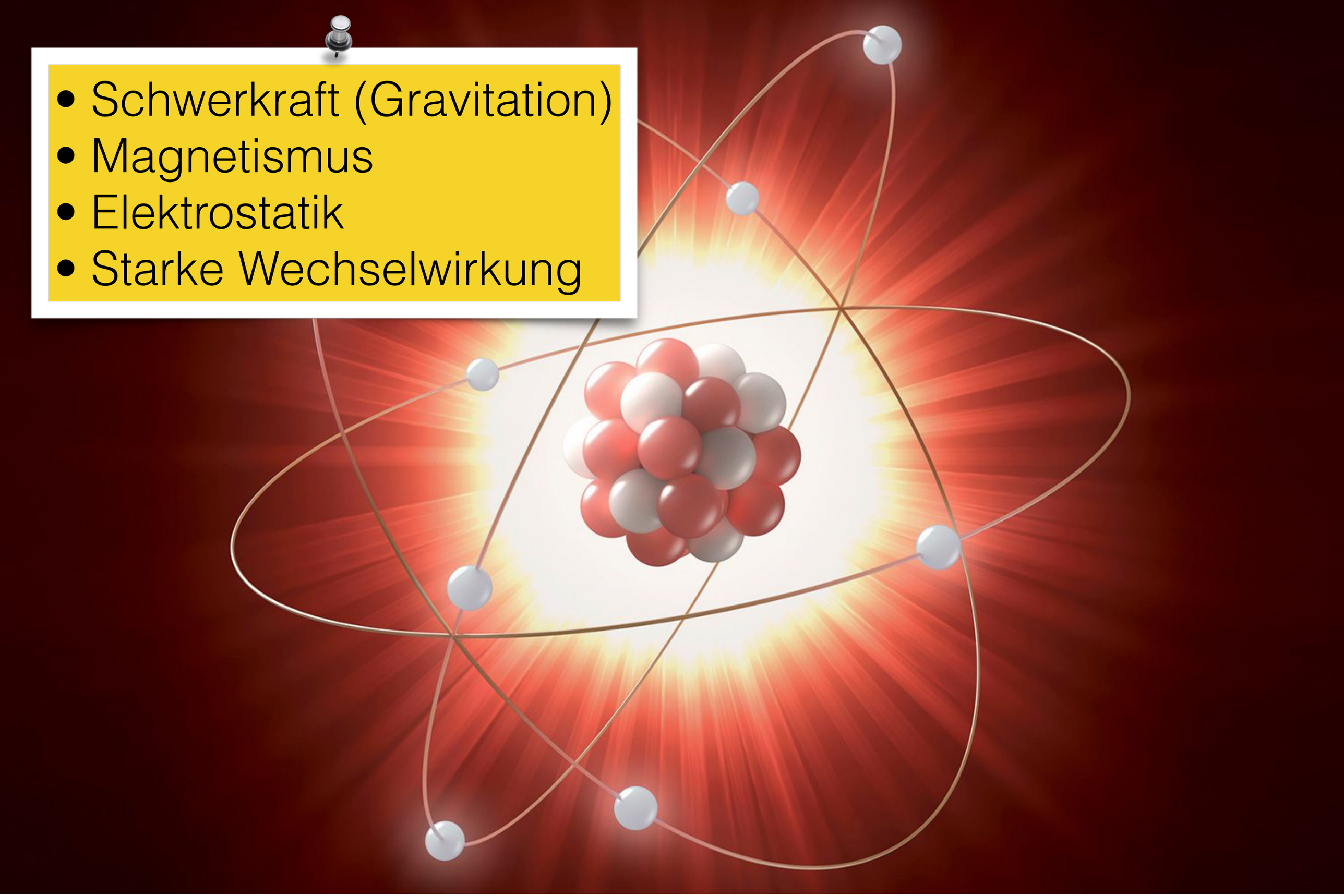
- Schwerkraft (Gravitation)
- Magnetismus
- Elektrostatik
- Starke Wechselwirkung



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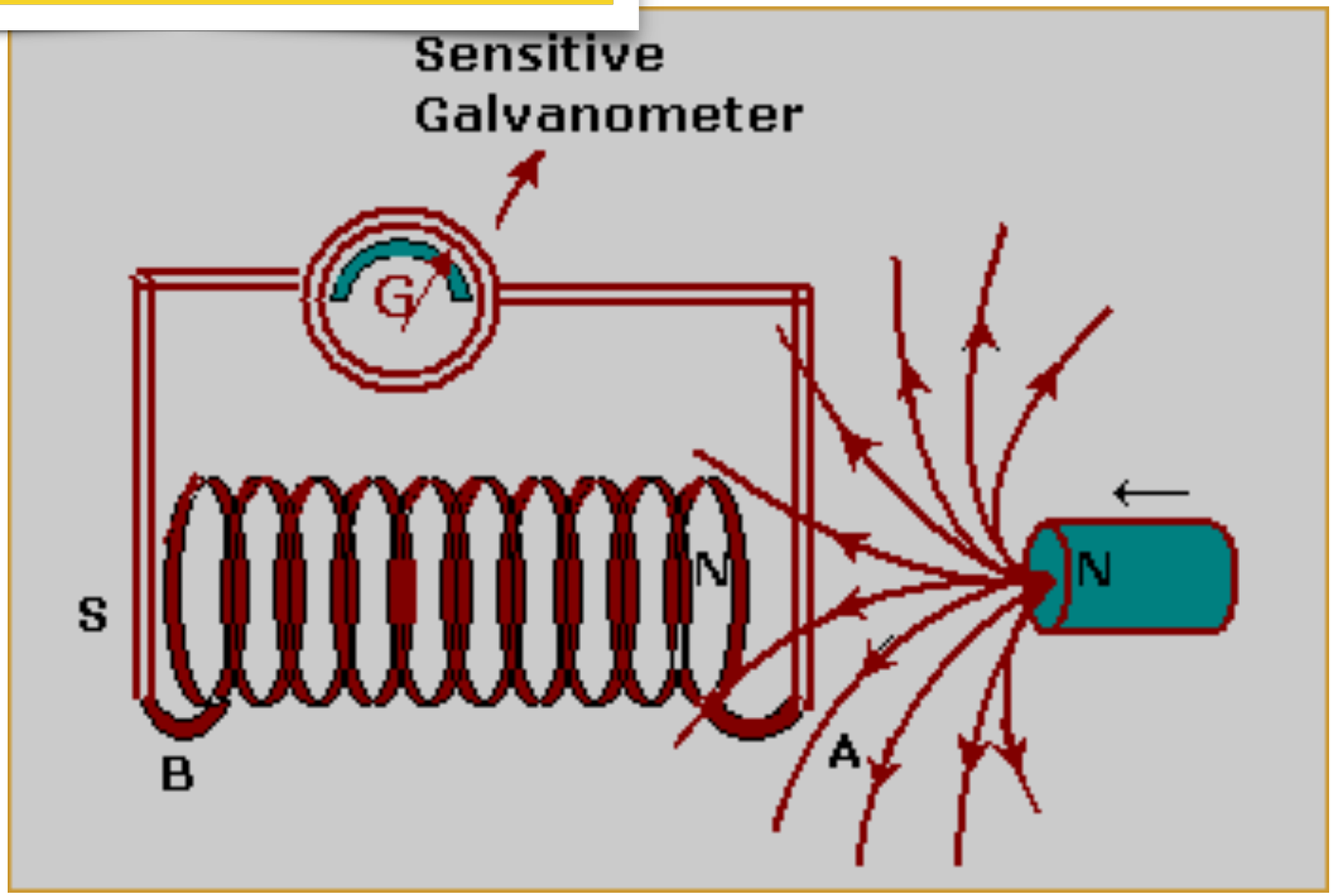

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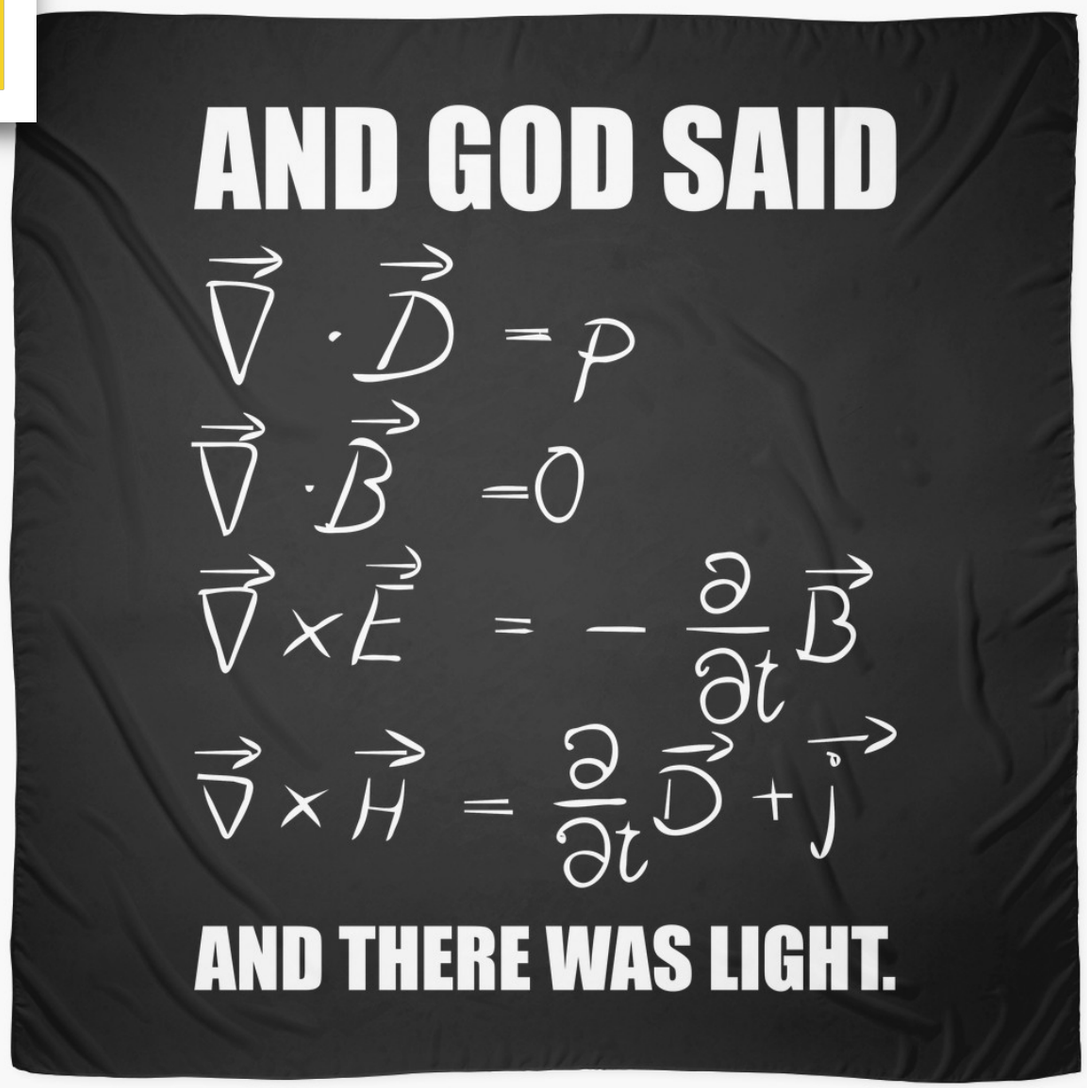

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- Schwerkraft (Gravitation)
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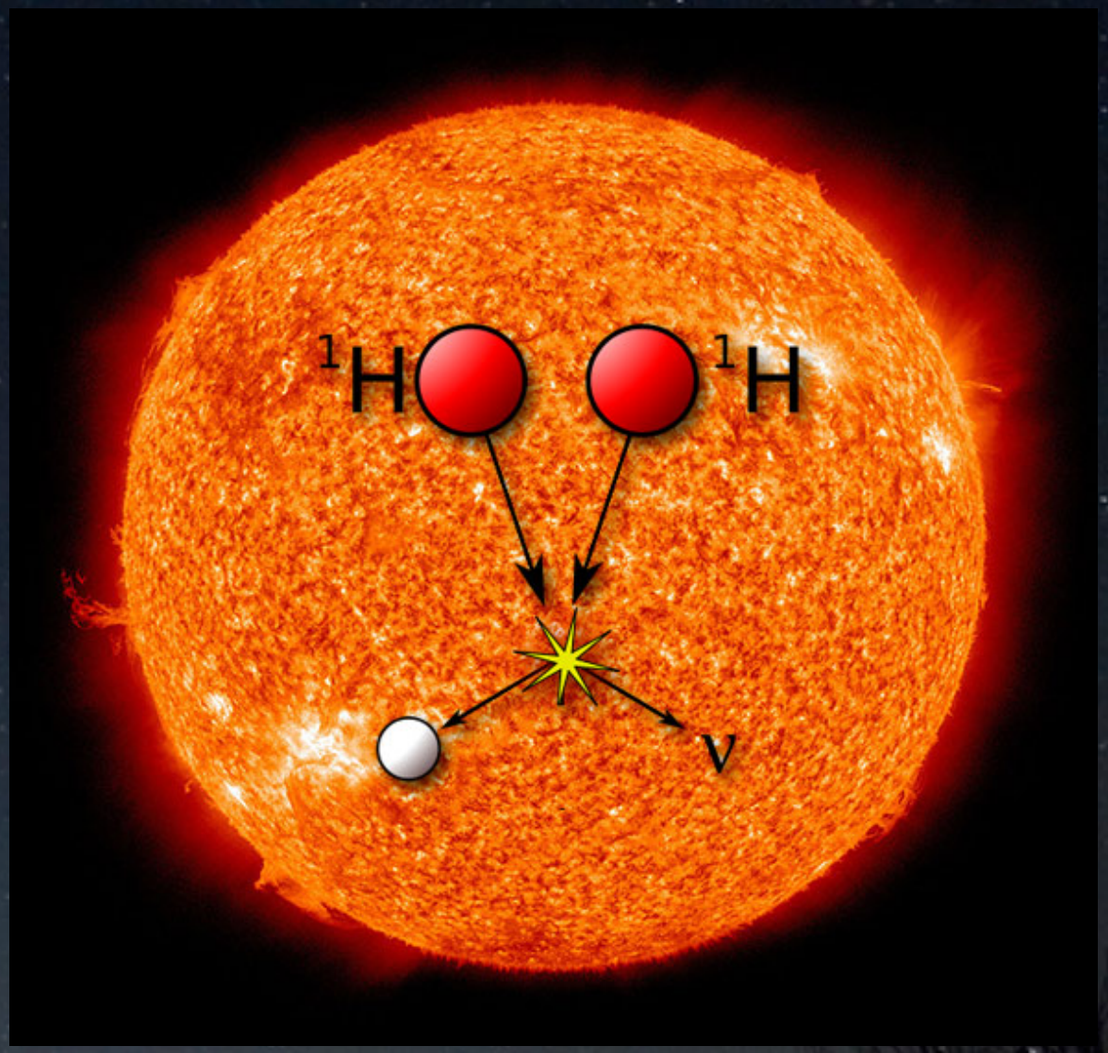

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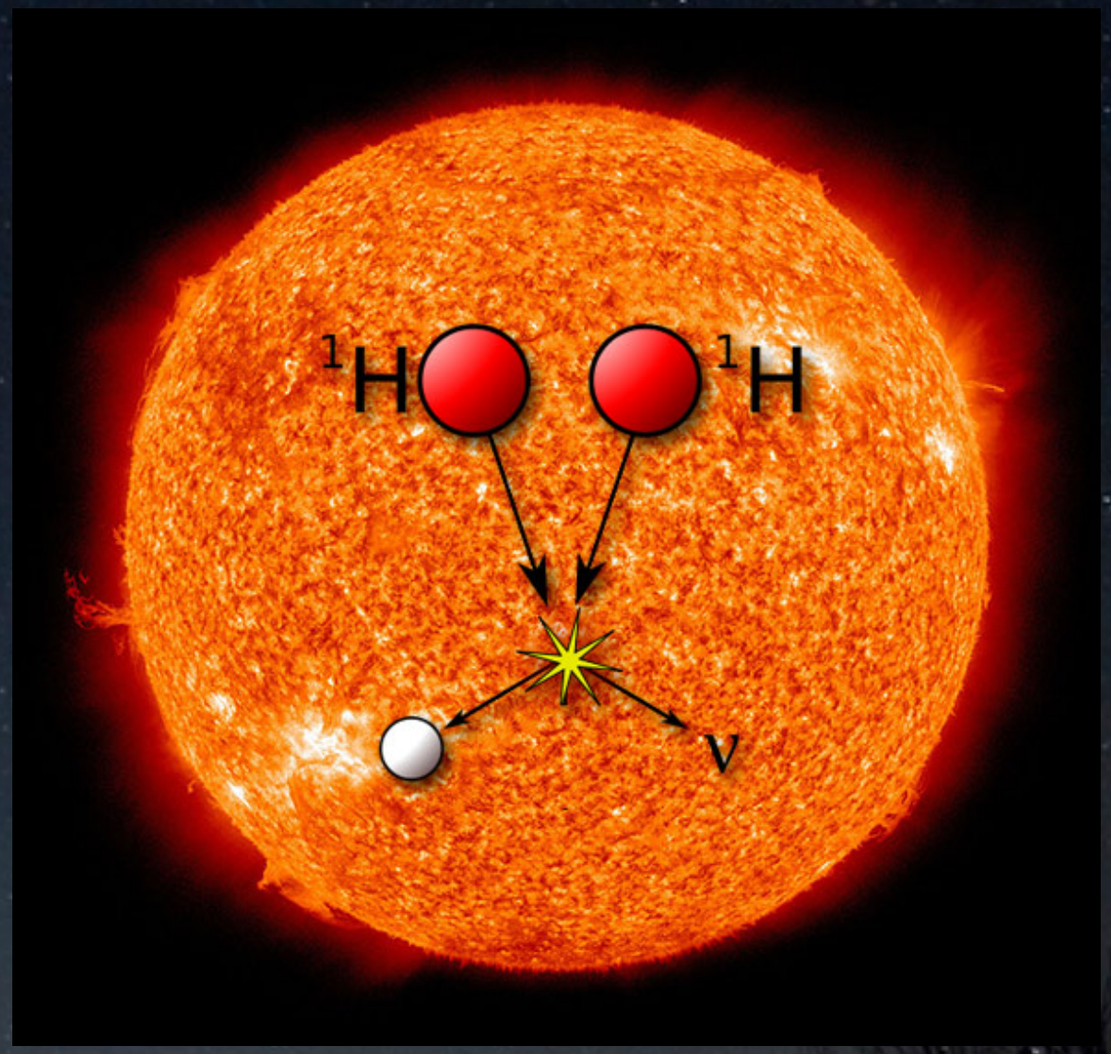

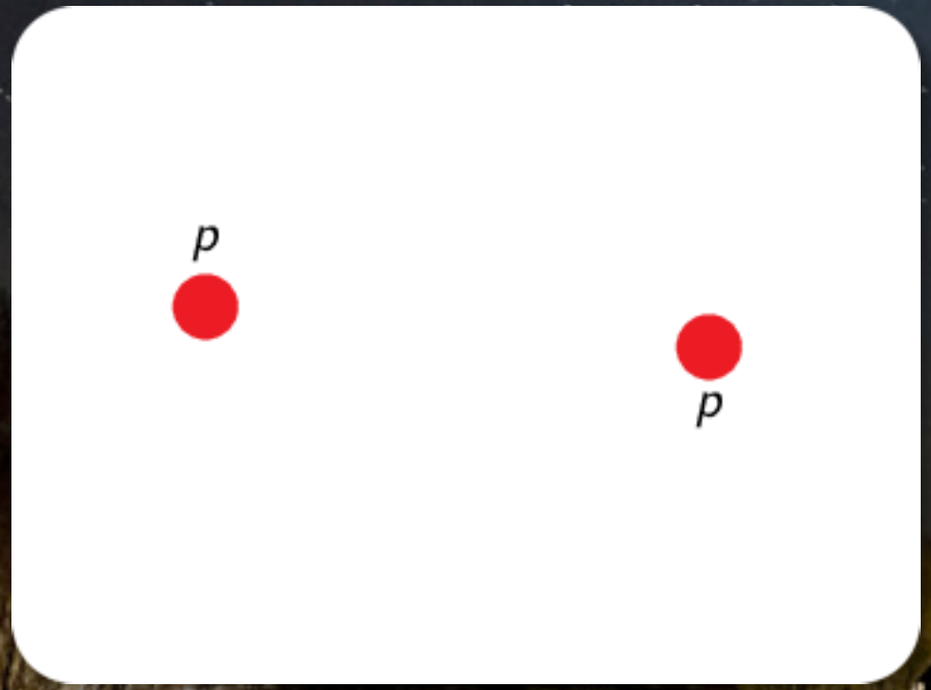

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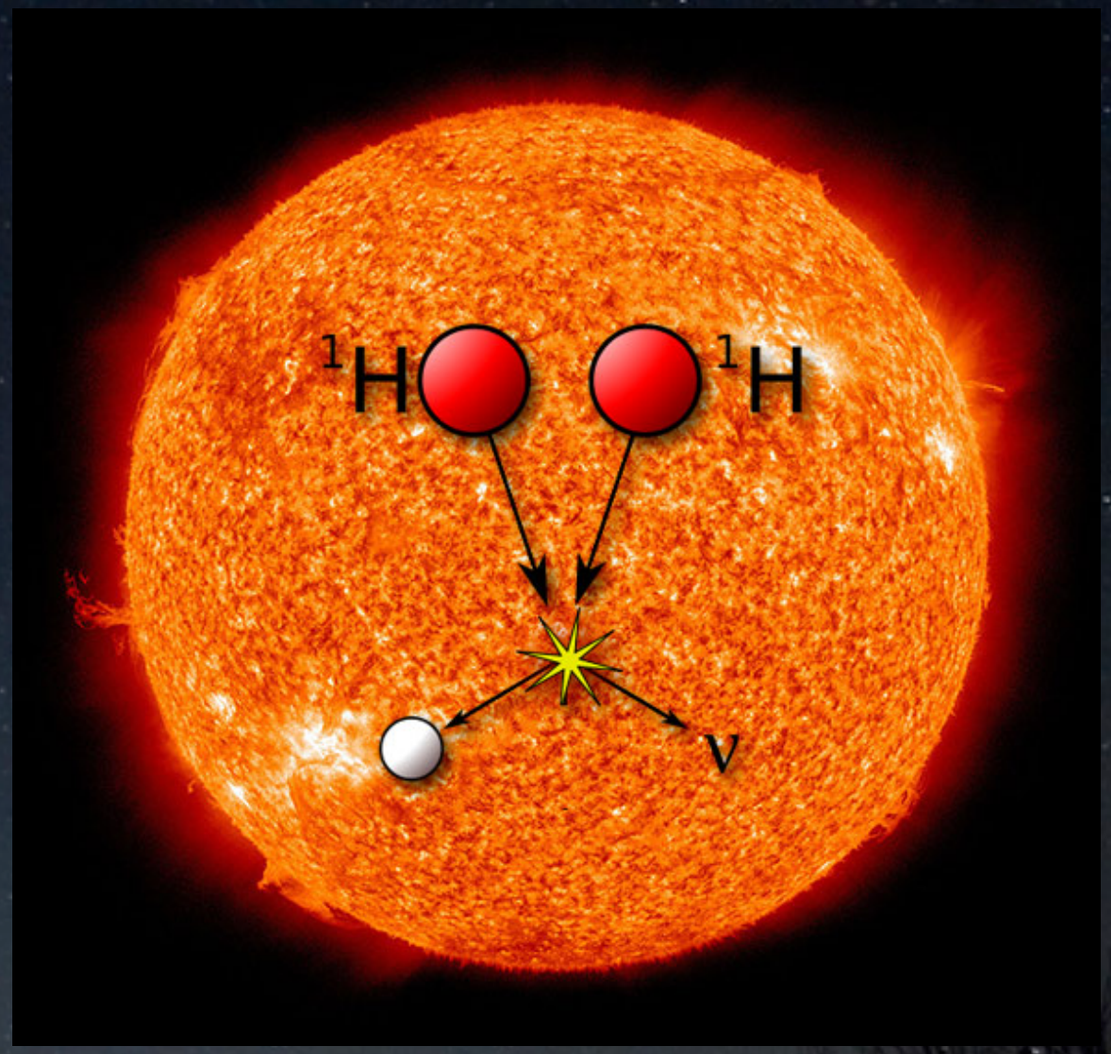

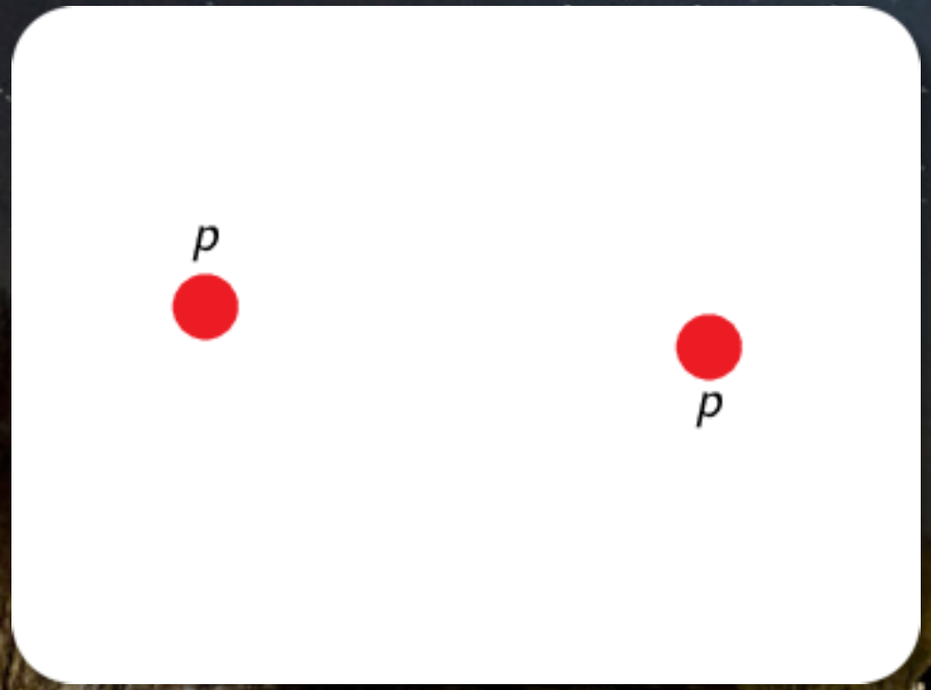

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Quantenmechanik

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Quantenmechanik

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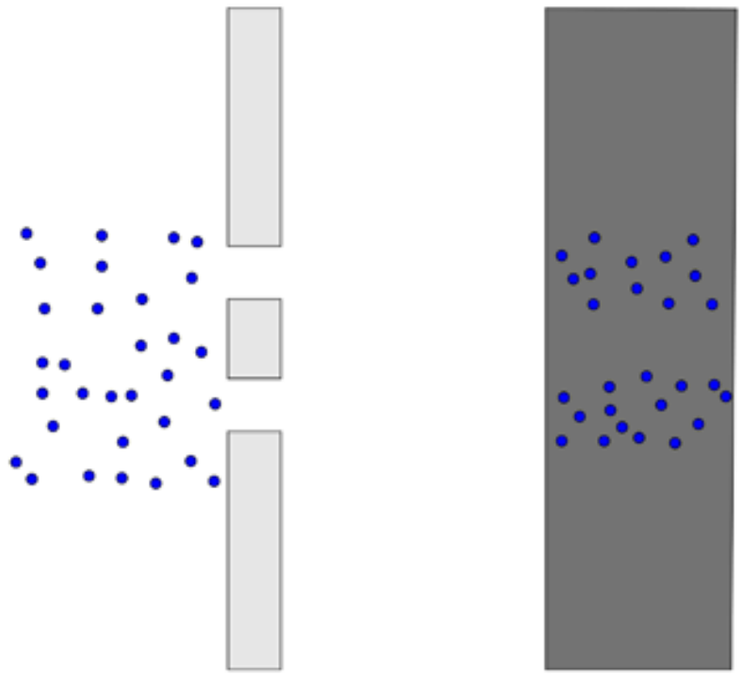
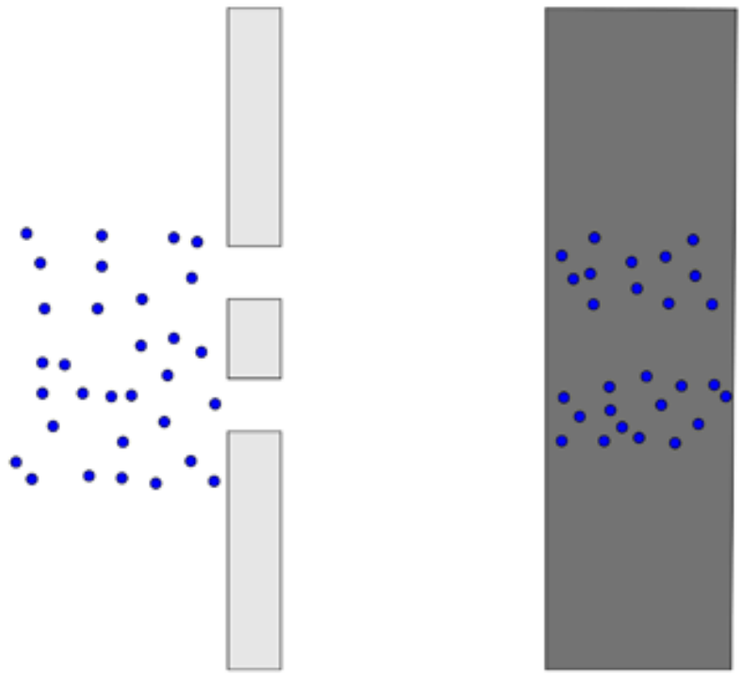
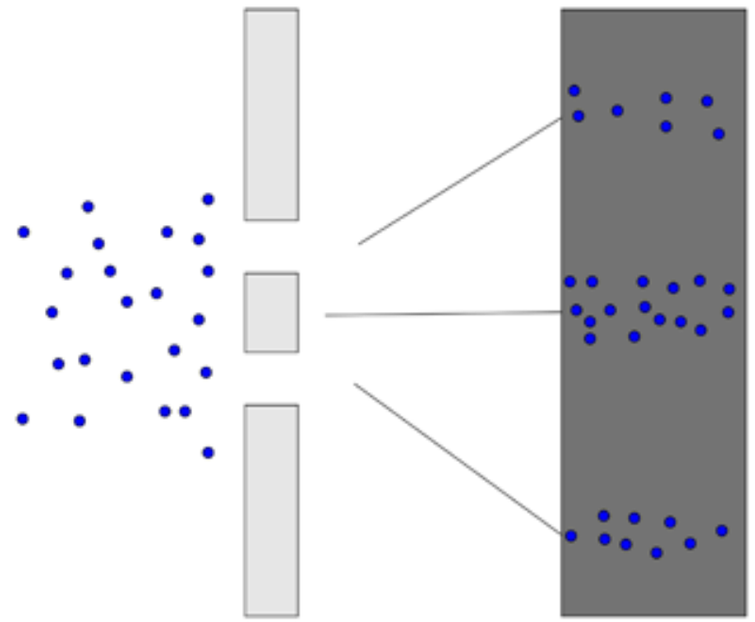
Quantenmechanik

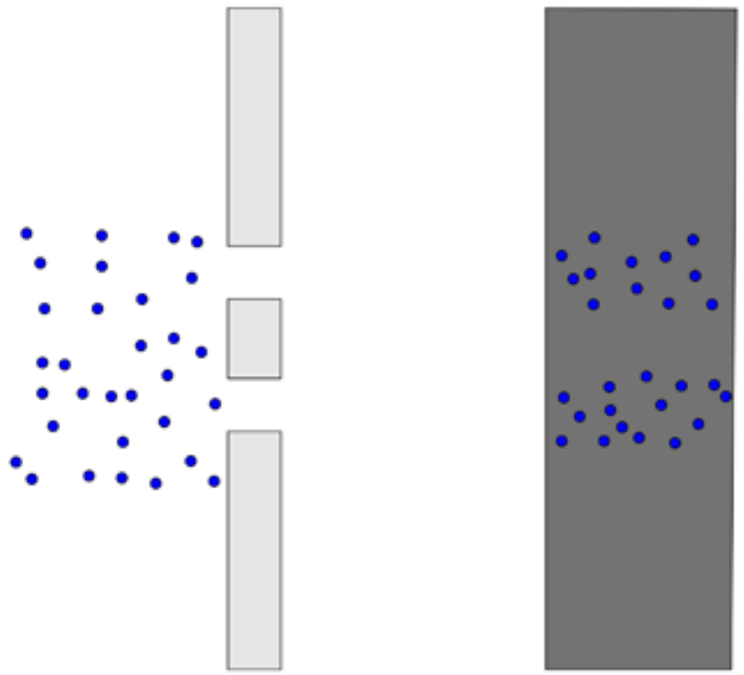


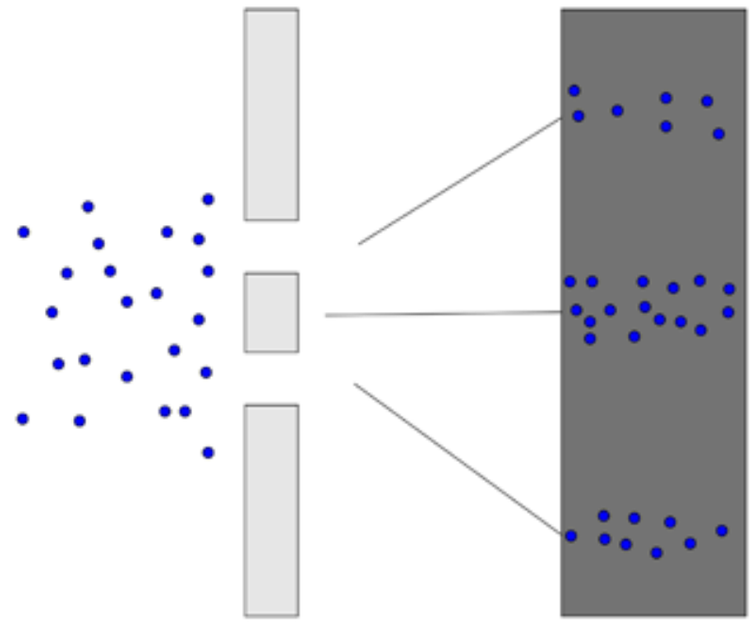
Quantenmechanik

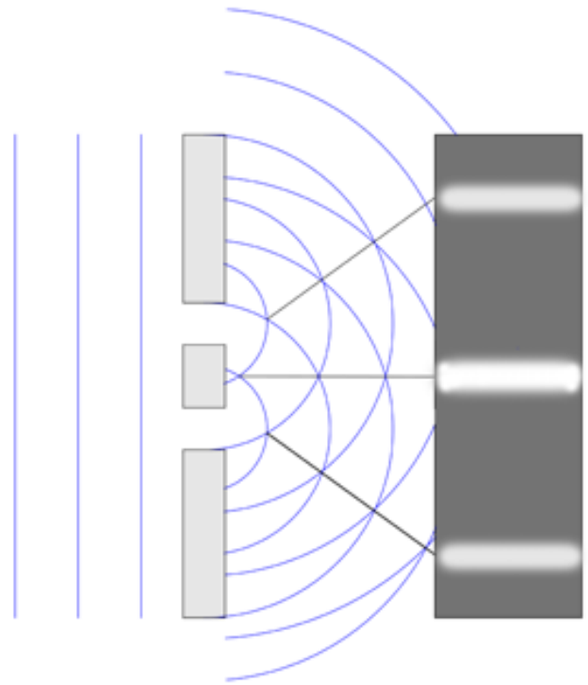




Quantenmechanik







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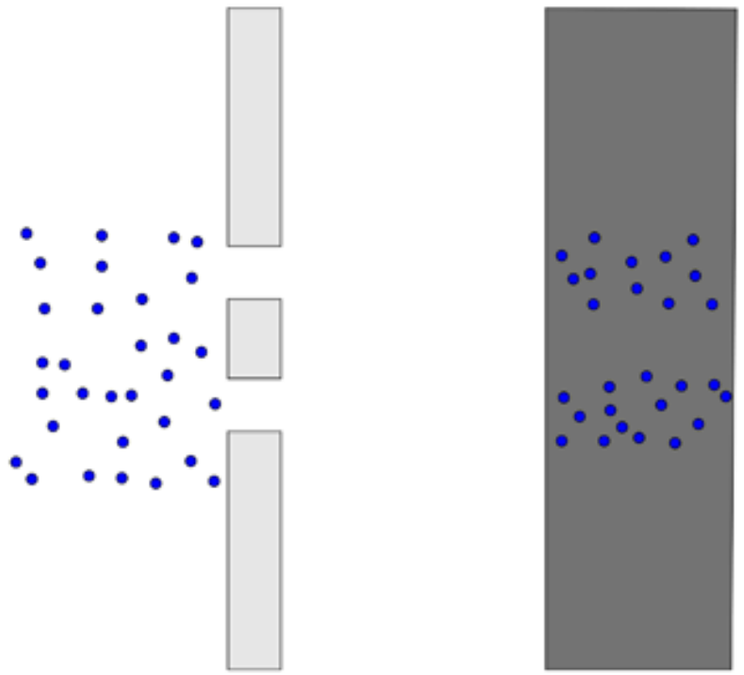

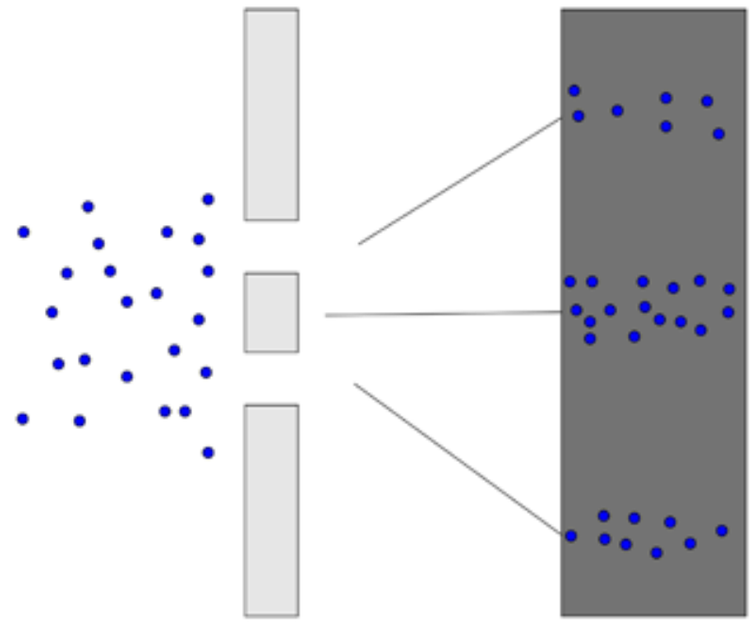

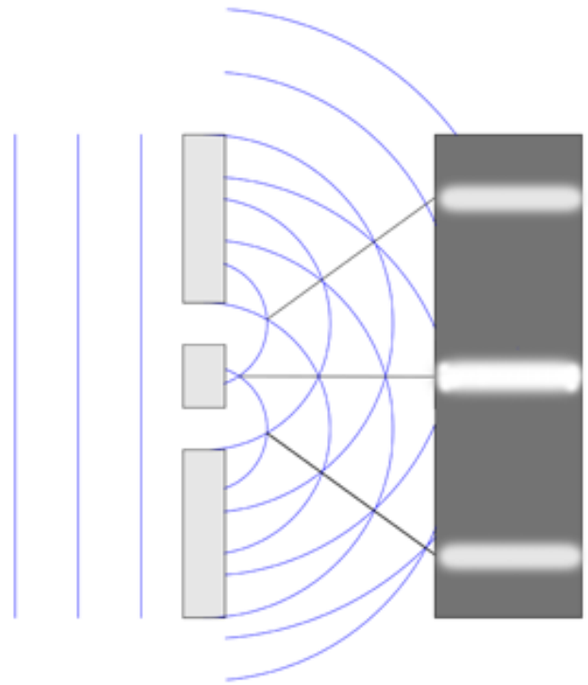

Welle-Teilchen-Dualität

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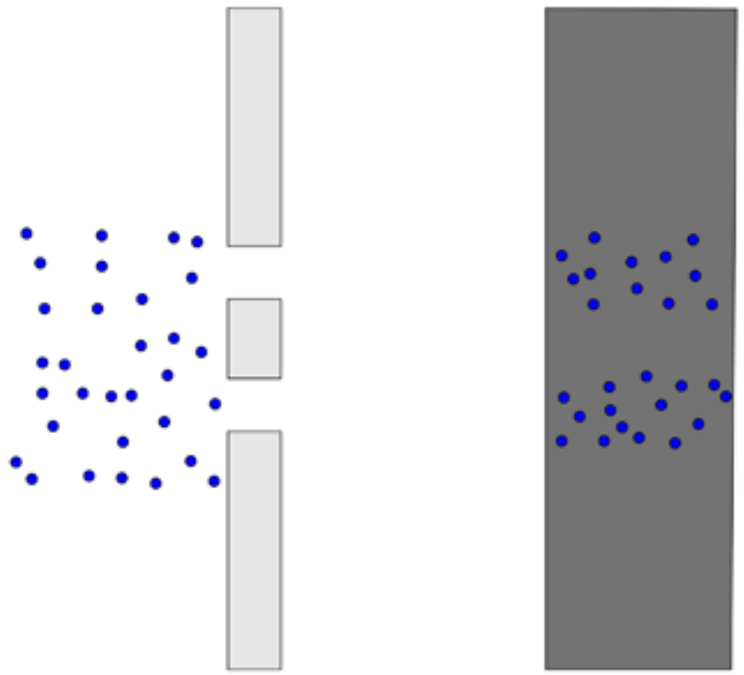

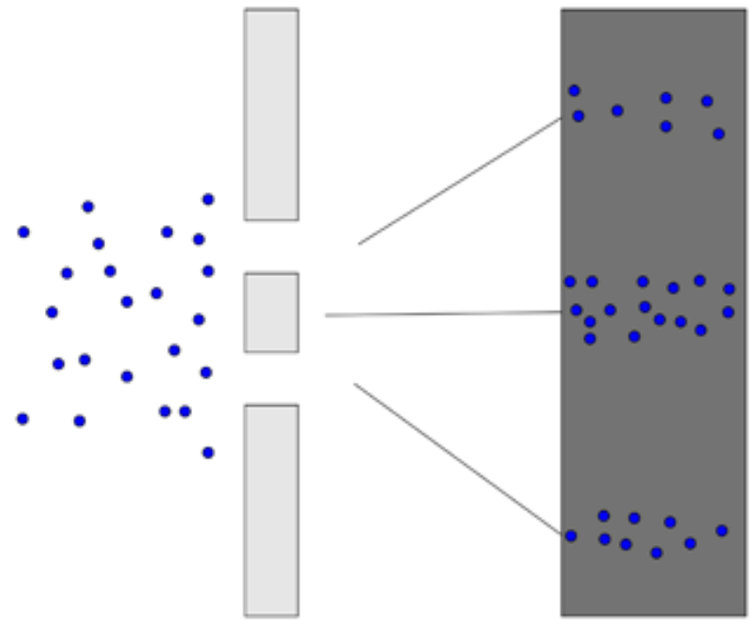

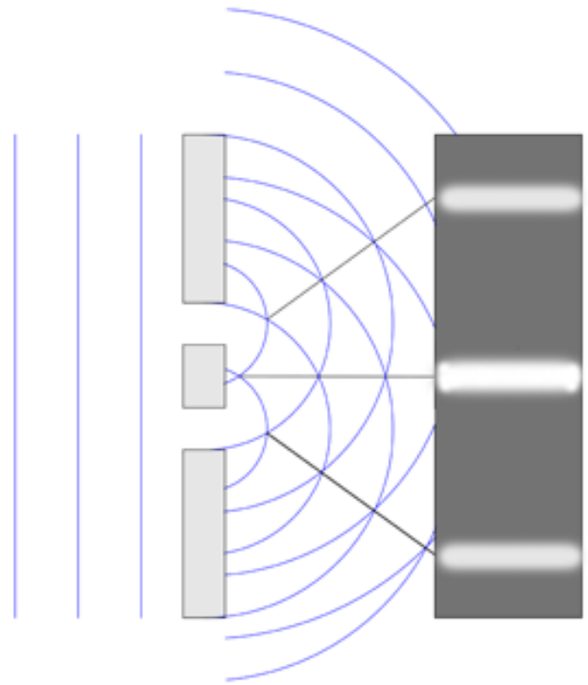

Welle-Teilchen-Dualität

Wahrscheinlichkeiten

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Quantenmechanik

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Quantenmechanik

Relativitätstheorie

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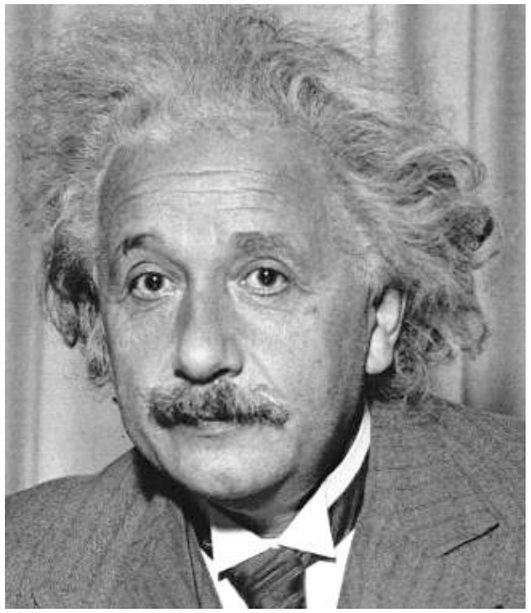
Relativitätstheorie

Einstein

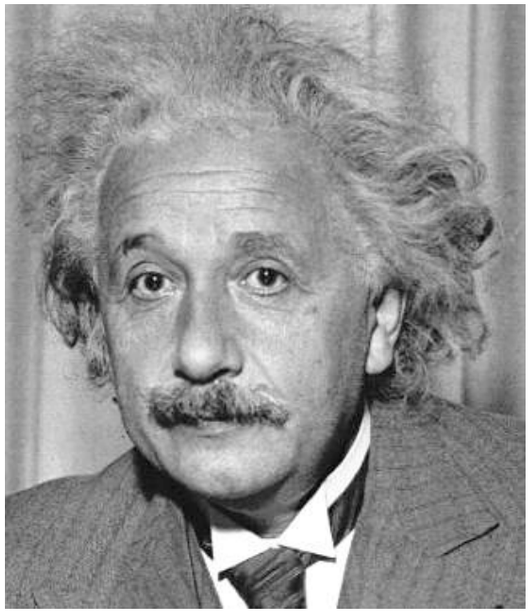


1879-1955

$$E = m \cdot c^2$$

Relativitätstheorie

Einstein



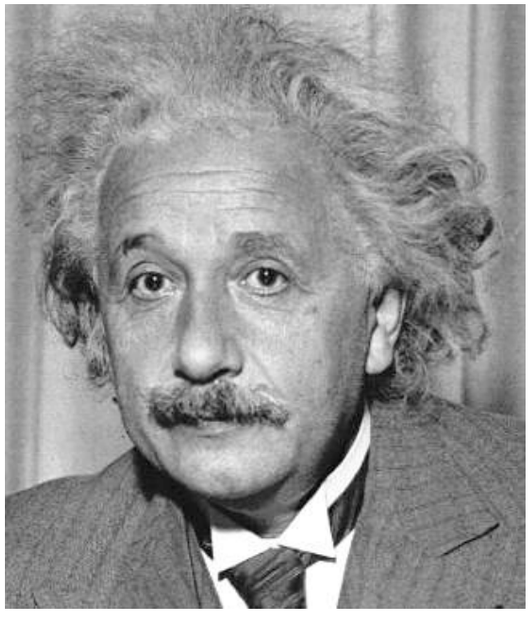
1879-1955

$$E = m \cdot c^2$$

c = 299.792 km/s ≈ 1 Mrd km/h

Relativitätstheorie

Einstein



1879-1955

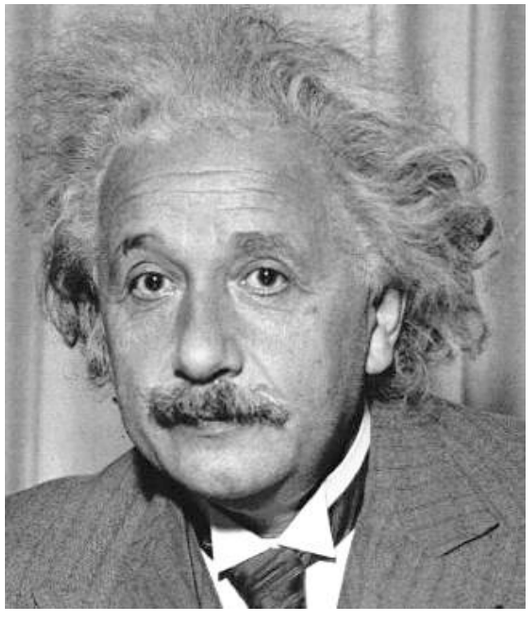
$$E = m \cdot c^2$$

c = 299.792 km/s ≈ 1 Mrd km/h

$$m = \frac{m_0}{\sqrt{1 - \beta^2}}$$

Relativitätstheorie

Einstein



1879-1955

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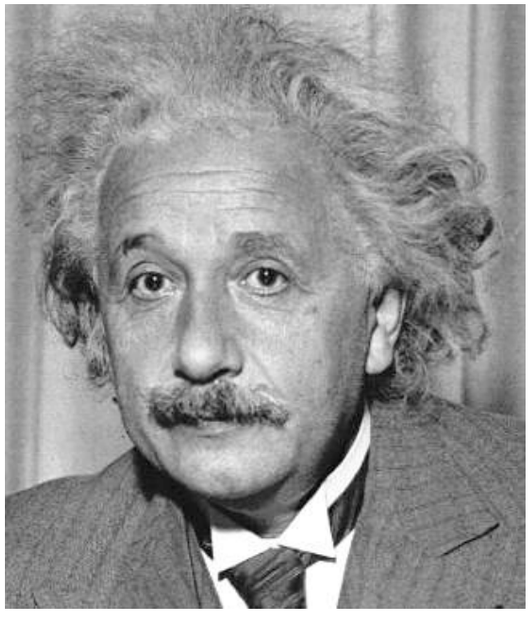
$$\beta = \frac{v}{c}$$

Relativitätstheorie

Einstein



1879-1955

$$E = m \cdot c^2$$

c = 299.792 km/s ≈ 1 Mrd km/h

$$m = \frac{m_0}{\sqrt{1 - \beta^2}}$$

$$\beta = \frac{v}{c}$$

- es ist immer $v \leq c$
- $v = c \quad \Leftrightarrow \quad m_0 = 0$

Quantenmechanik

Relativitätstheorie

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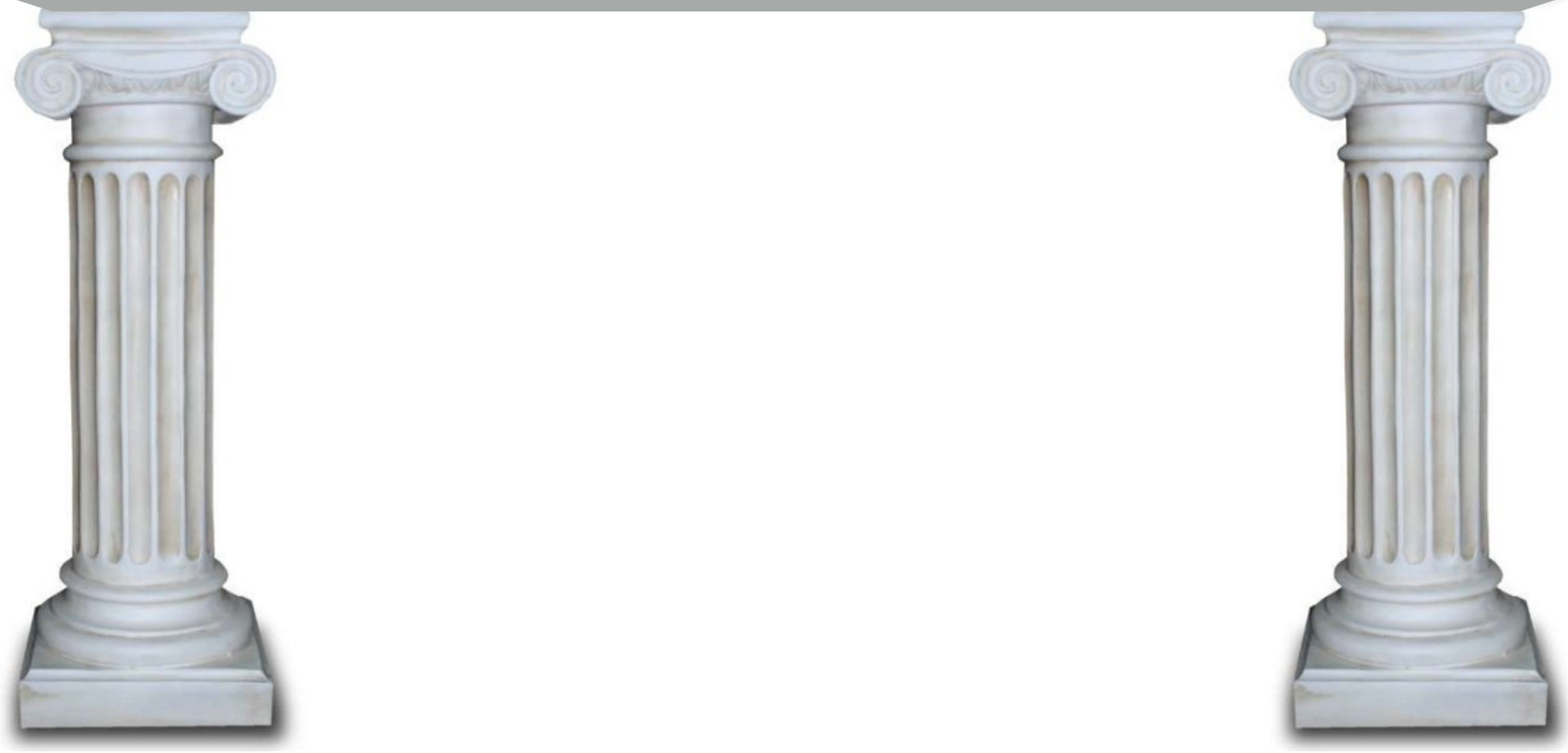
Quantenfeldtheorie



Quantenmechanik

Relativitätstheorie

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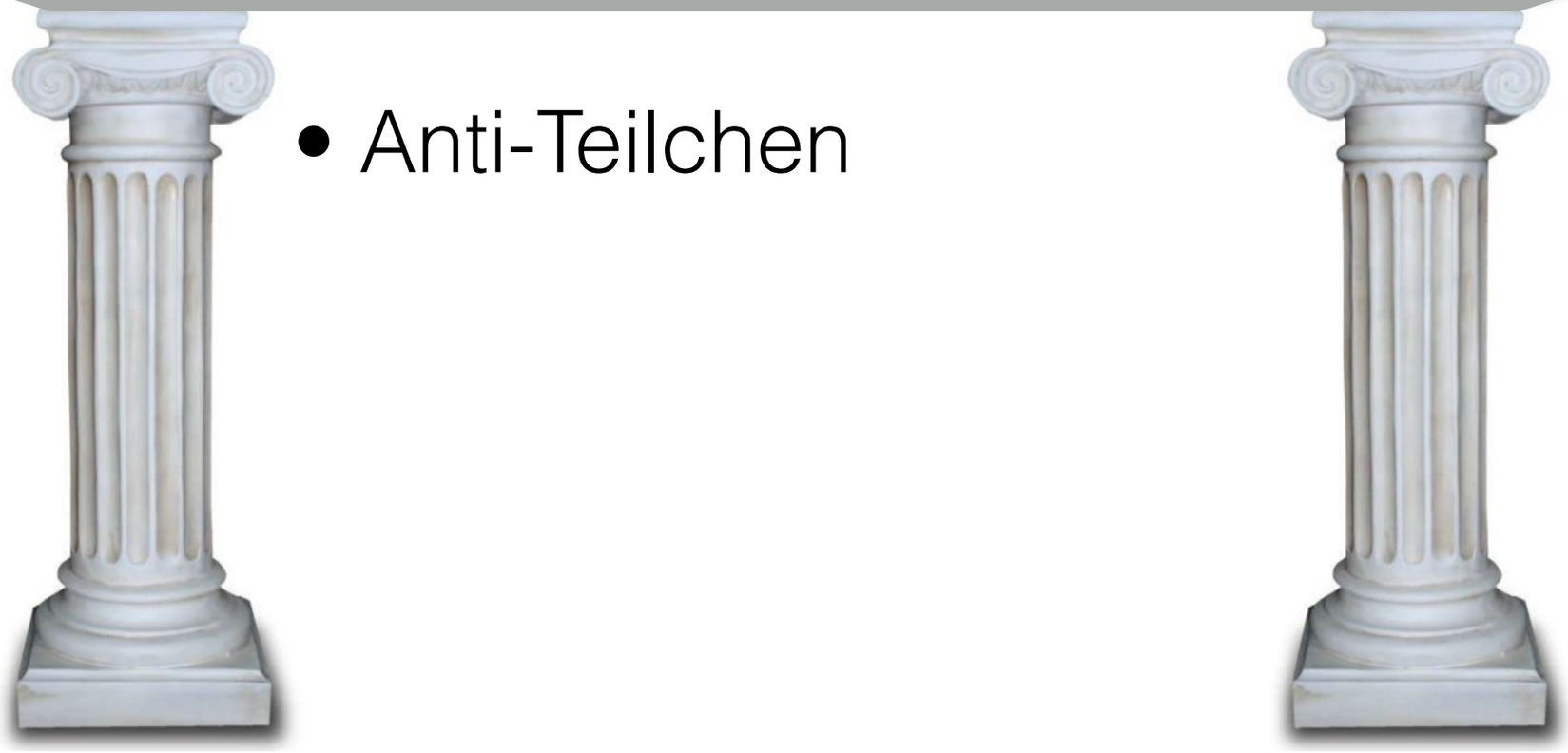
Quantenfeldtheorie



- Anti-Teilchen

Quantenmechanik

Relativitätstheorie

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Quantenfeldtheorie

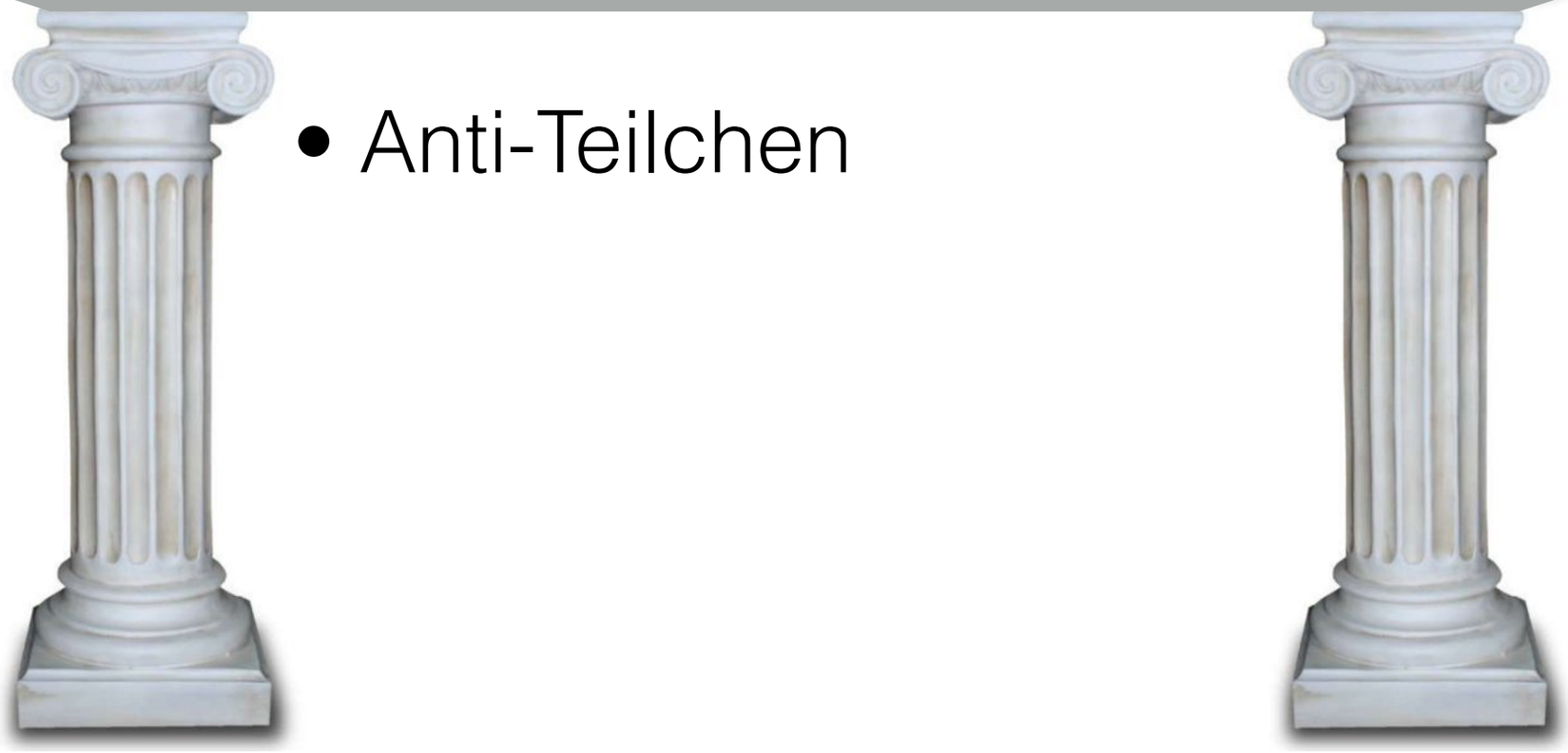
- Anti-Teilchen

  Elektron — Positron
  Proton — Antiproton
  …

Quantenmechanik

Relativitätstheorie

Quantenfeldtheorie



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Quantenfeldtheorie

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Quantenfeldtheorie

- Anti-Teilchen
- Teilchenerzeugung/-vernichtung

Quantenmechanik

Relativitätstheorie

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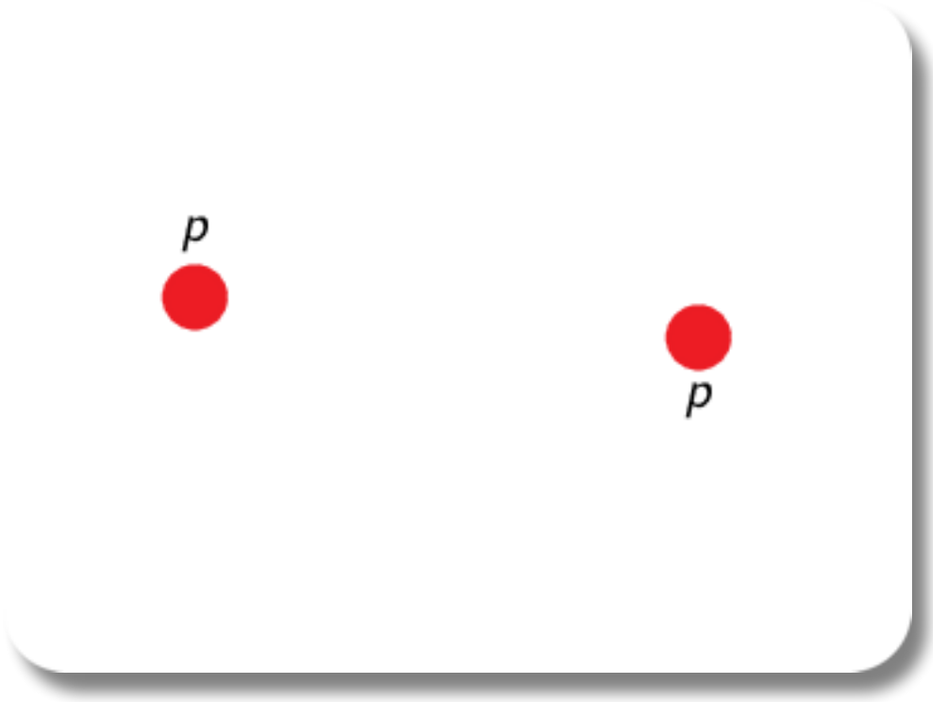
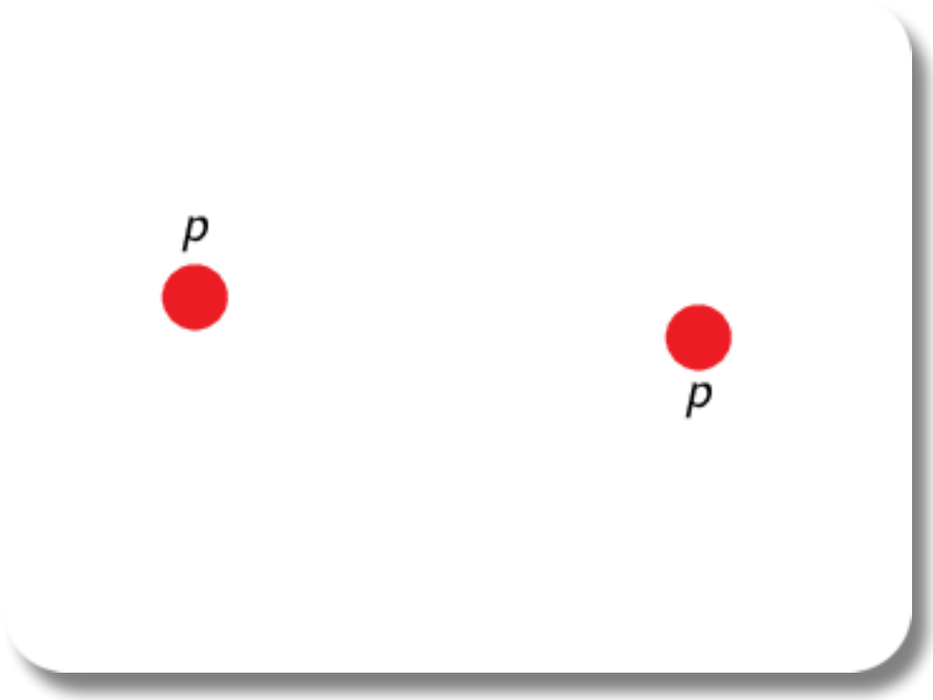
Teilchenerzeugung/-vernichtung

Teilchenerzeugung/-vernichtung



Teilchenerzeugung/-vernichtung



Aber: Impuls, Energie, Ladung, Drehimpuls,… erhalten!

Quantenfeldtheorie

- Anti-Teilchen
- Teilchenerzeugung/-vernichtung

Quantenmechanik

Relativitätstheorie

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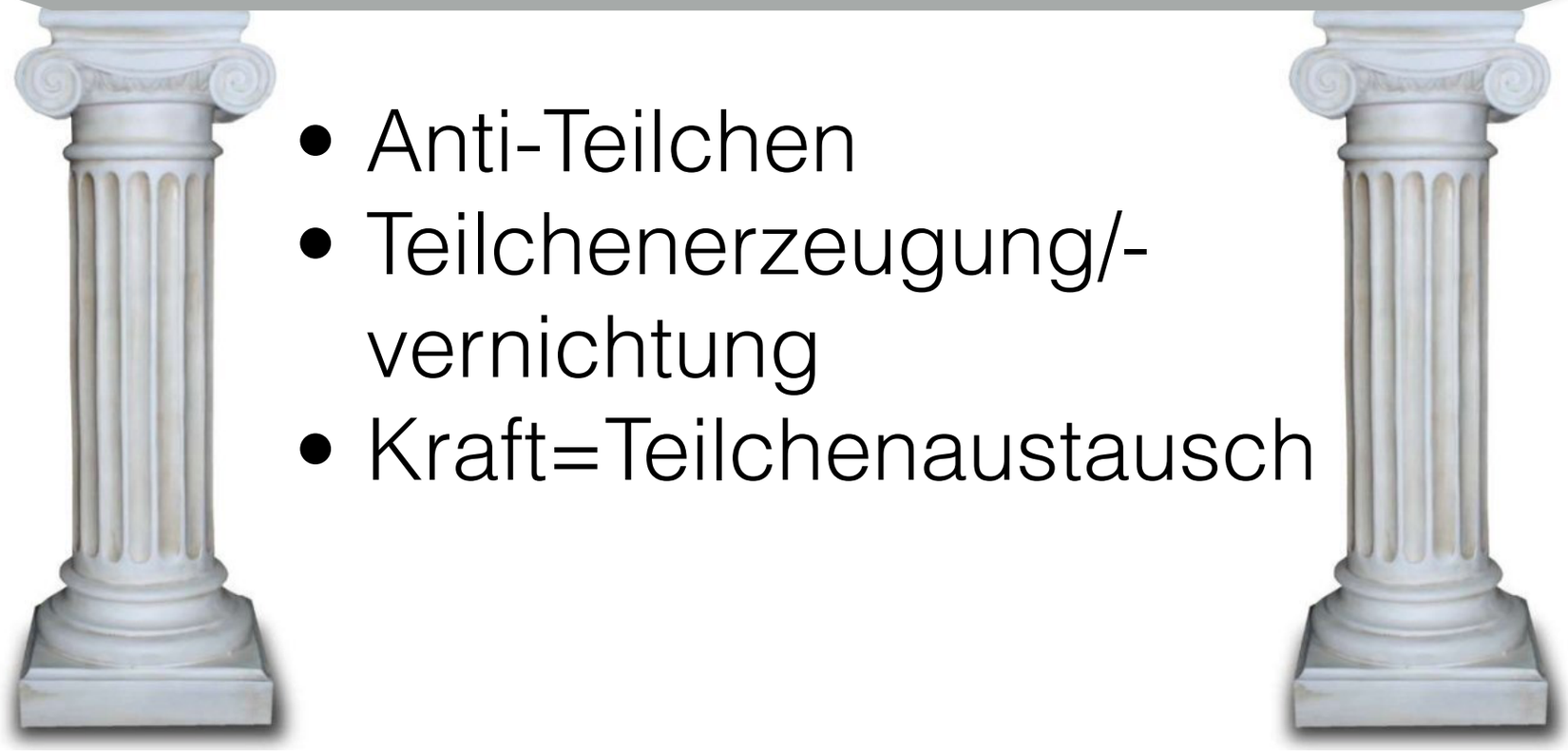
Quantenfeldtheorie

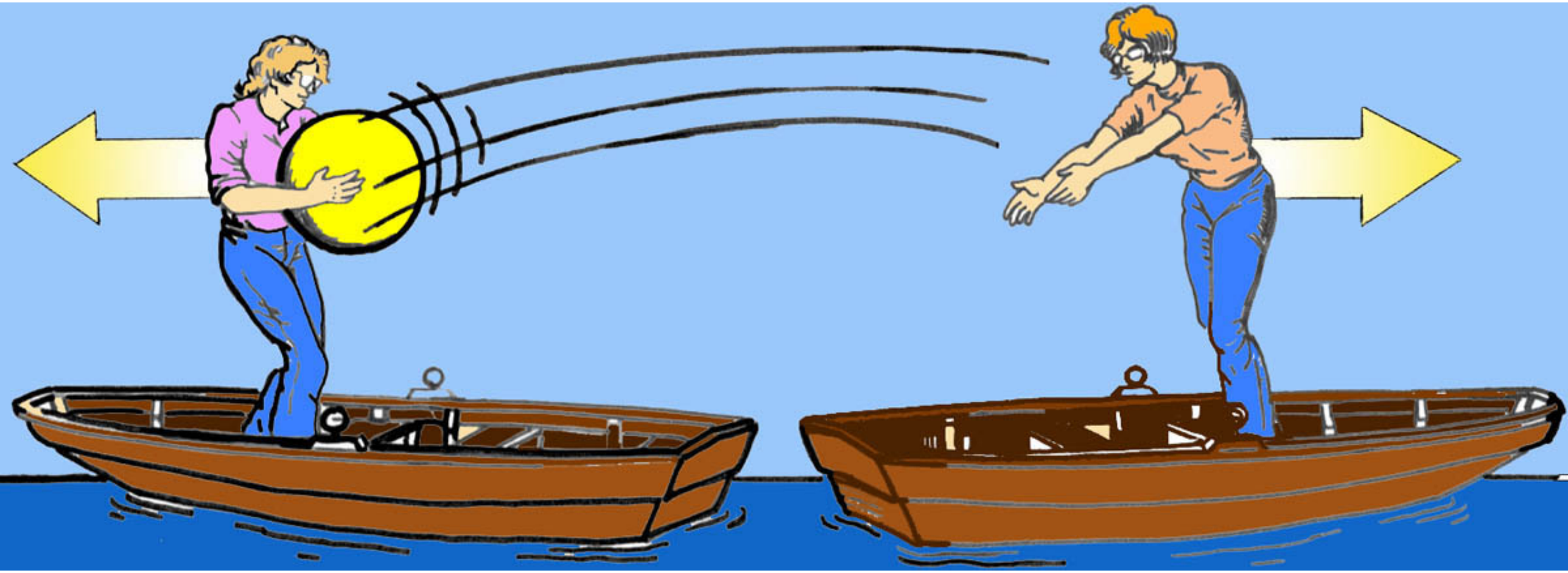


- Anti-Teilchen
- Teilchenerzeugung/-vernichtung
- Kraft=Teilchenaustausch

Quantenmechanik

Relativitätstheorie

Quantenfeldtheorie: Kraft durch Teilchenaustausch



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Quantenfeldtheorie: Kraft durch Teilchenaustausch

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Quantenfeldtheorie: Kraft durch Teilchenaustausch

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Quantenfeldtheorie: Kraft durch Teilchenaustausch

Feynman-Diagramm

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Quantenfeldtheorie: Kraft durch Teilchenaustausch

Feynman-Diagramm

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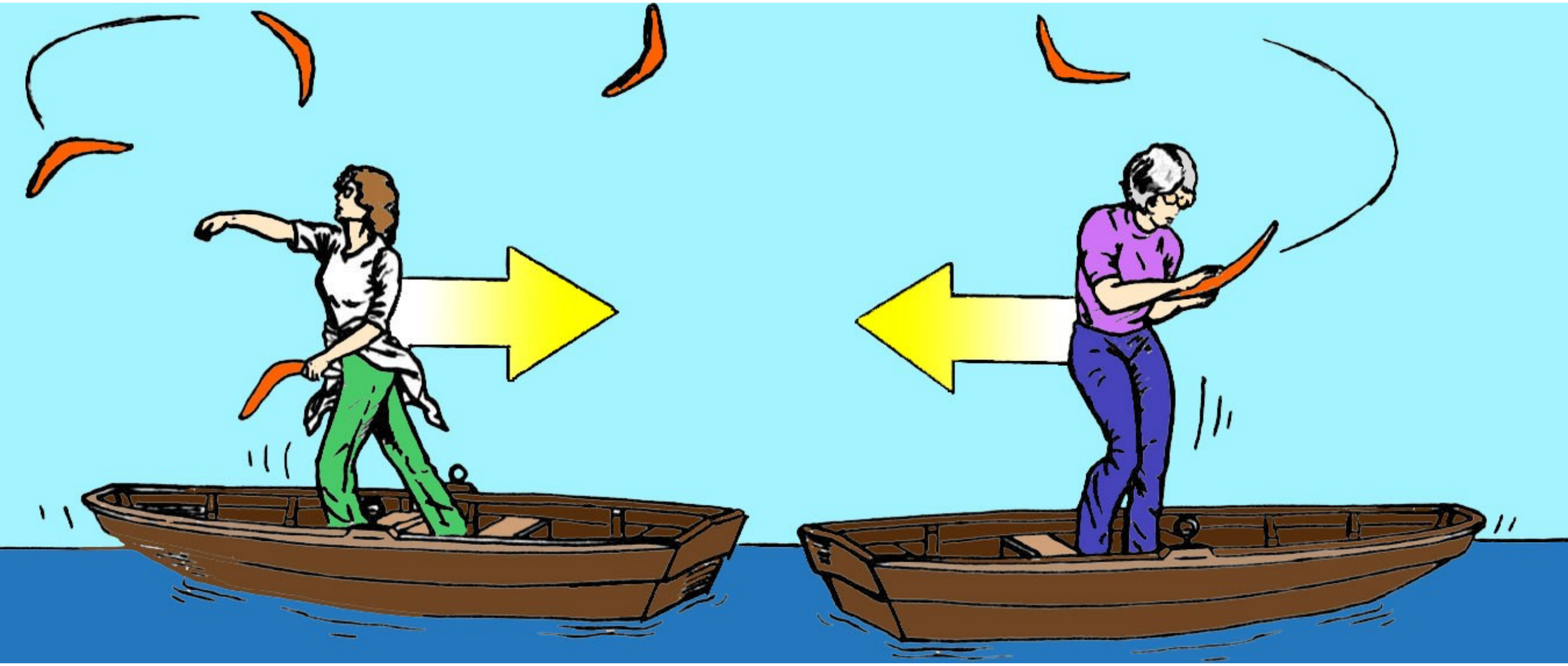
Quantenfeldtheorie: Kraft durch Teilchenaustausch



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Kraft = Austauschteilchen

- Schwerkraft (Gravitation)
- Elektromagnetismus
- Starke Wechselwirkung
- Schwache Wechselwirkung

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Kraft = Austauschteilchen

- Schwerkraft (Gravitation)
- Elektromagnetismus ↔ Photon
- Starke Wechselwirkung
- Schwache Wechselwirkung

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- Starke Wechselwirkung ↔ Gluonen
- Schwache Wechselwirkung ↔ W-, Z-Boson

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Kraft = Austauschteilchen

- Schwerkraft (Gravitation) ↔ Graviton(?)
- Elektromagnetismus ↔ Photon
- Starke Wechselwirkung ↔ Gluonen
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Photon

Institute for Theoretical Particle Physics and Cosmology
RWTH AACHEN UNIVERSITY

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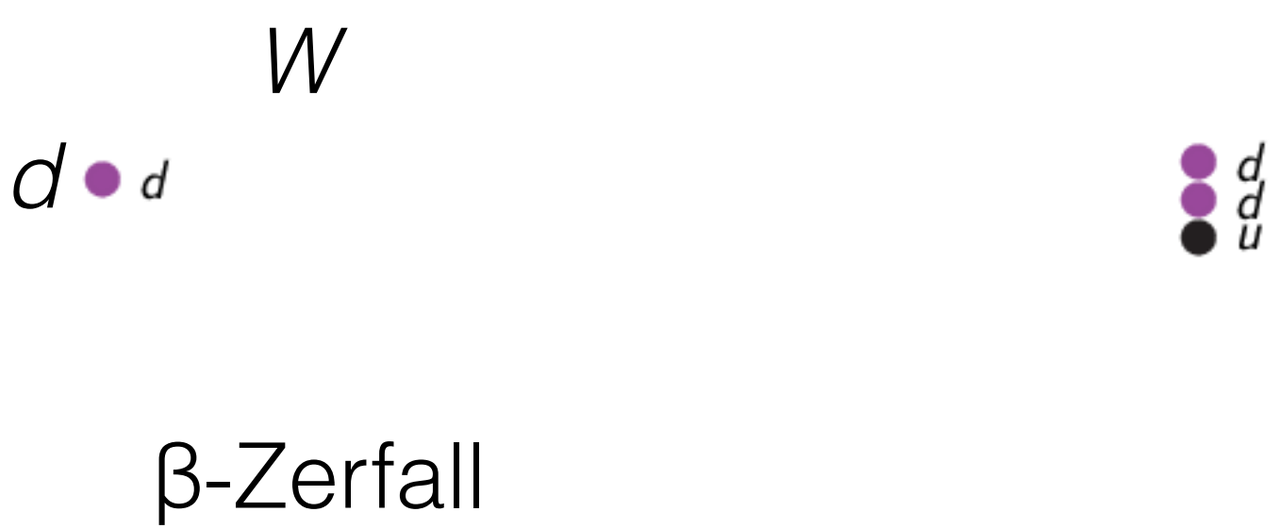
Photon

β-Zerfall



β-Zerfall

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Photon

β-Zerfall

Institute for Theoretical Particle Physics and Cosmology
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Photon

β-Zerfall

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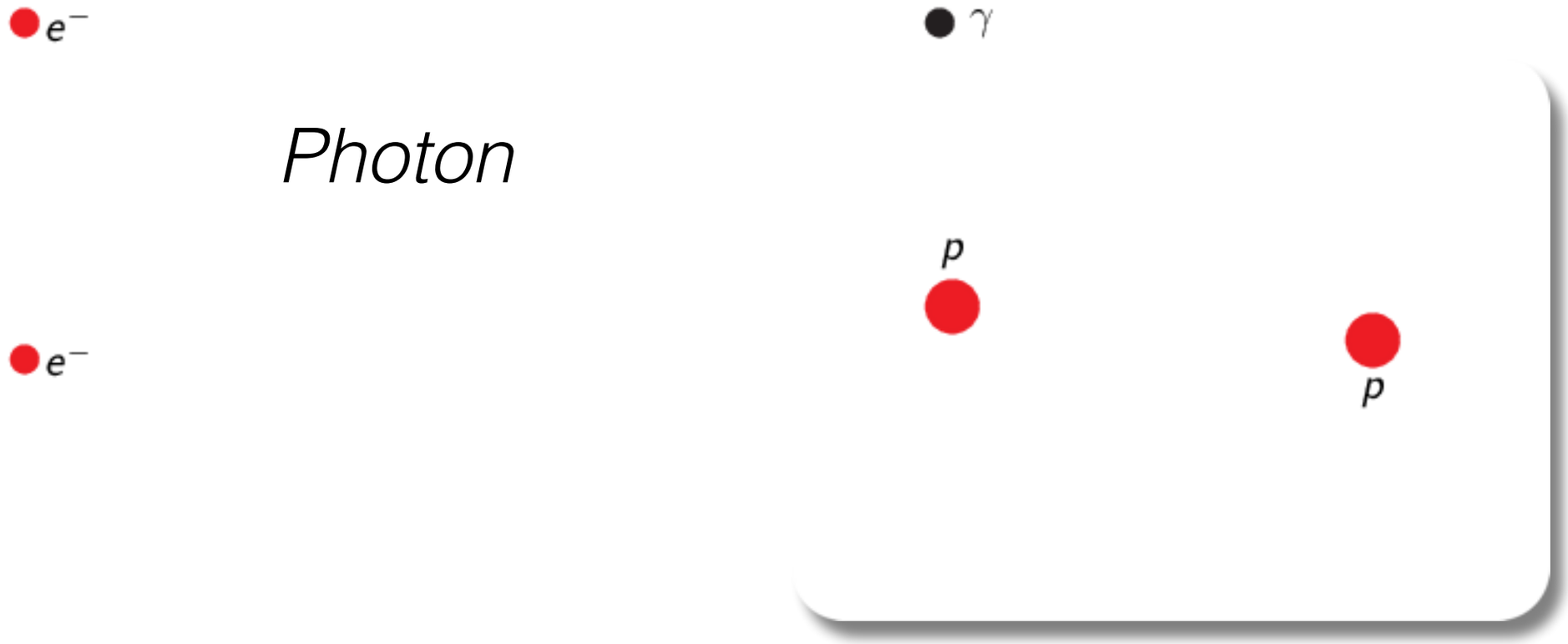

β-Zerfall

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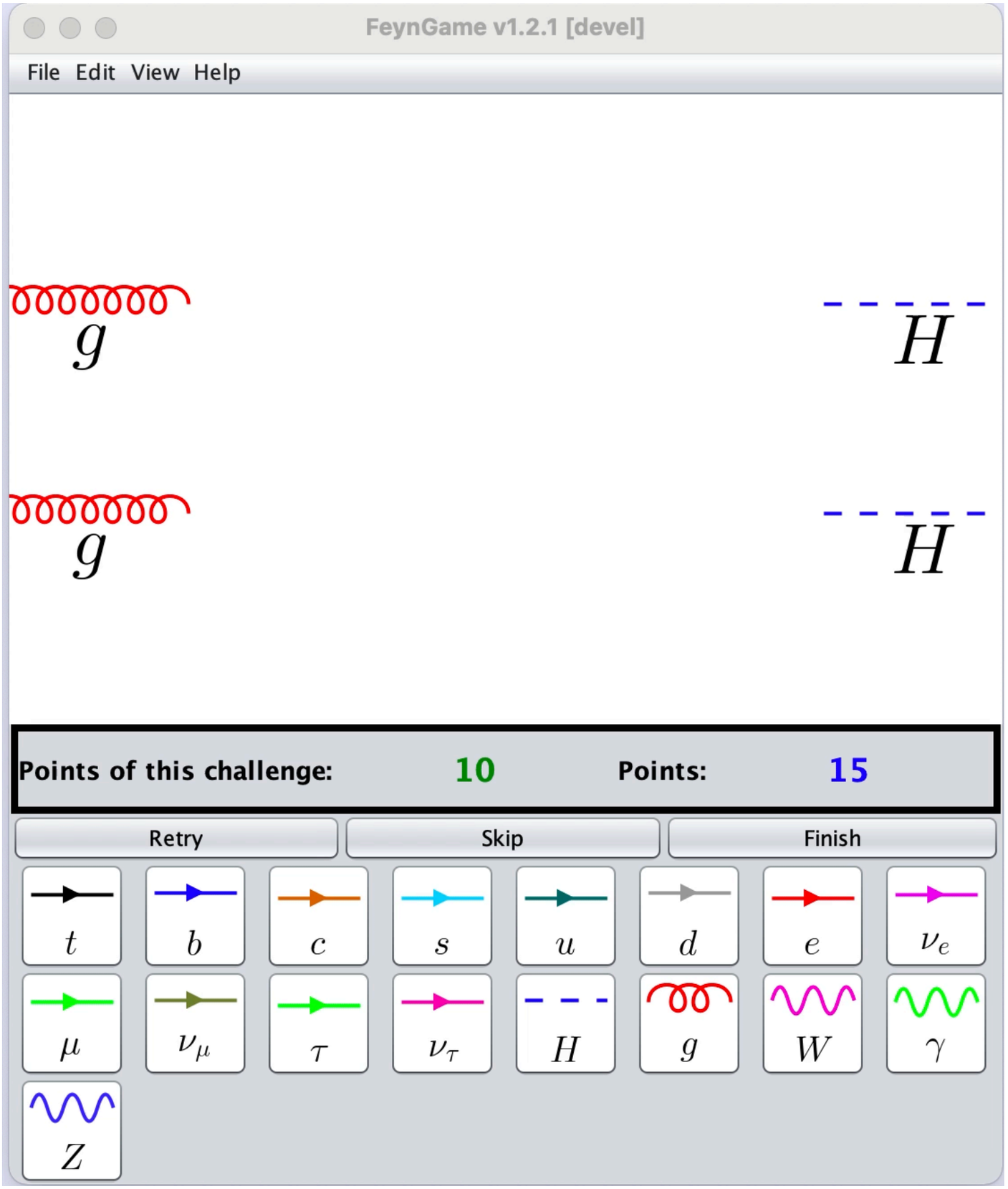
FeynGame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File Edit View Help
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H
g
H
Points of this challenge: 10 Points: 15
Retry
Skip
Finish
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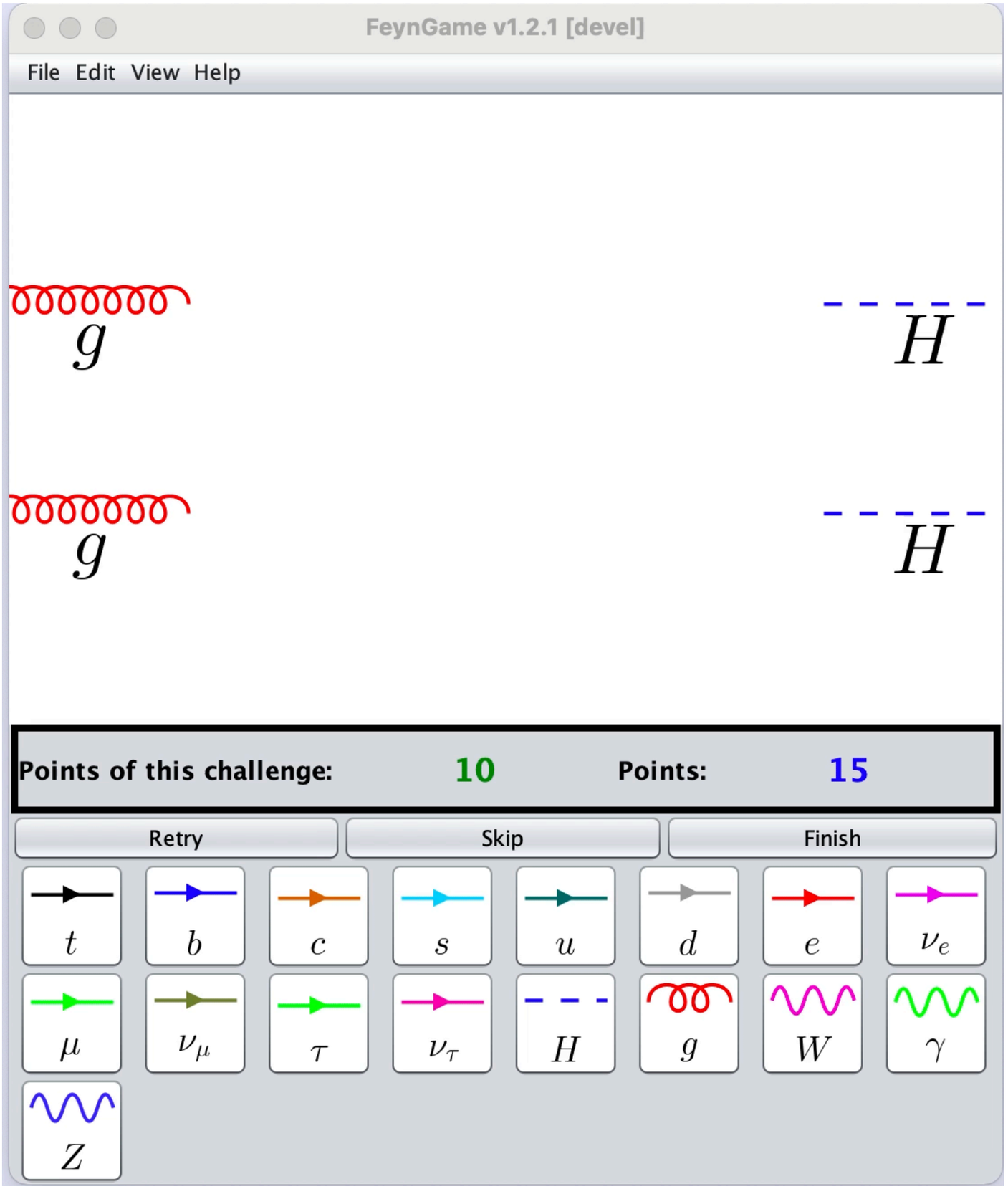
γ
Z

FeynGame


FeynGame v1.2.1 [devel]
File Edit View Help
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g
H
Points of this challenge: 10 Points: 15
Retry
Skip
Finish
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ν_μ
τ
ν_τ
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g
W
γ
Z

Kraft = Austauschteilchen

- Schwerkraft (Gravitation) ↔ Graviton(?)
- Elektromagnetismus ↔ Photon
- Starke Wechselwirkung ↔ Gluonen
- Schwache Wechselwirkung ↔ W-, Z-Boson

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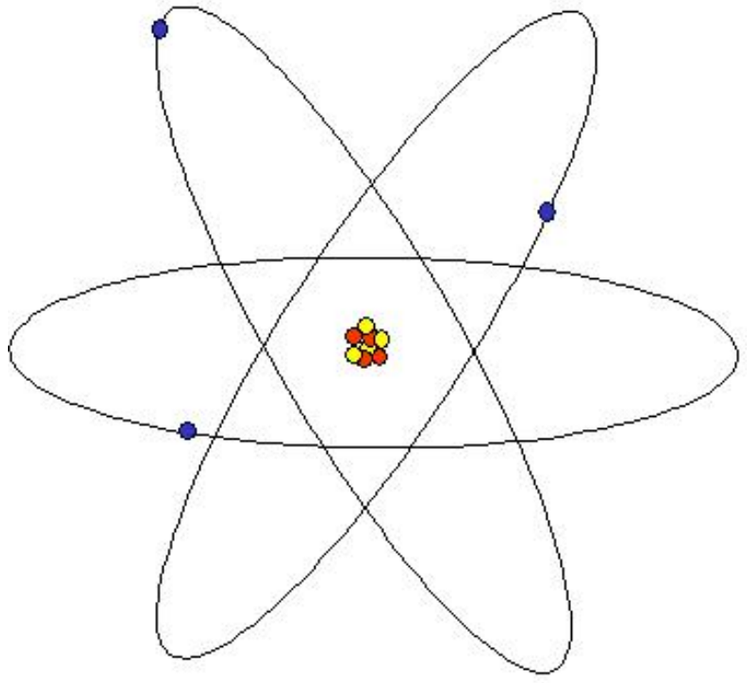
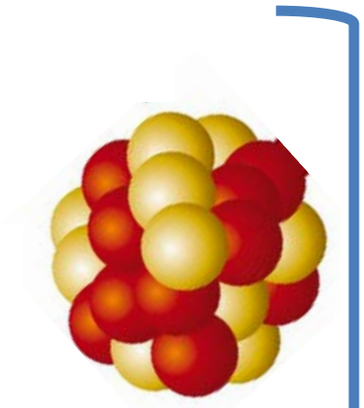
Die kleinsten Teilchen



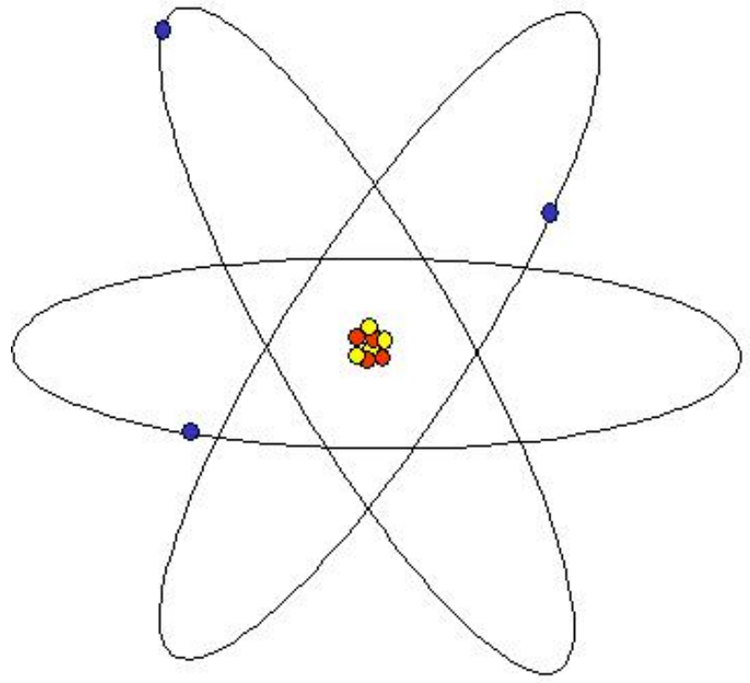
Atom

10^{-10} m

Die kleinsten Teilchen



Atomkern



Atom

Elektron e

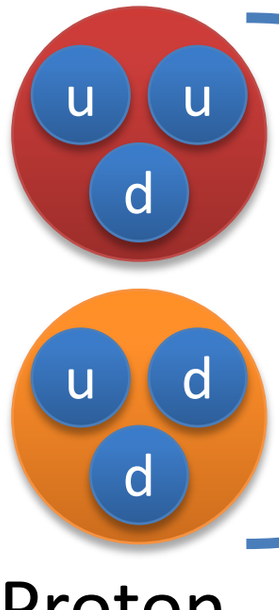
$<10^{-18}$ m

10^{-15} m

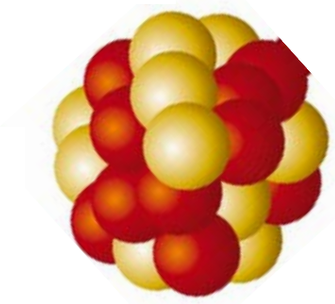
10^{-14} m

10^{-10} m

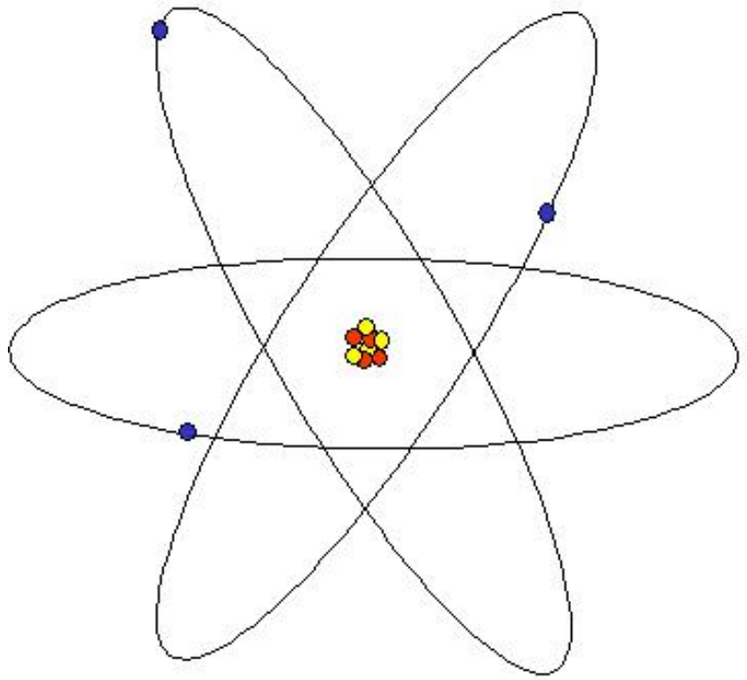
Die kleinsten Teilchen



Proton
Neutron



Atomkern



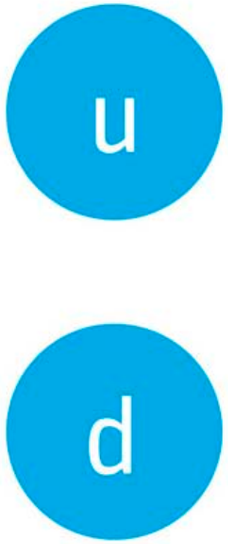
Atom

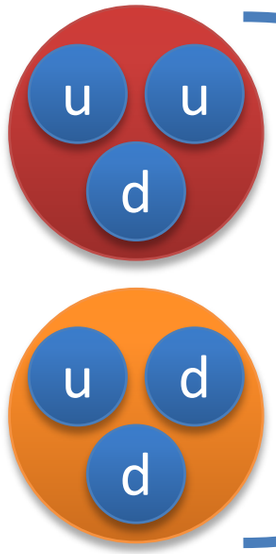
Elektron 

$<10^{-18}$ m 10^{-15} m 10^{-14} m 10^{-10} m

Die kleinsten Teilchen

Quarks





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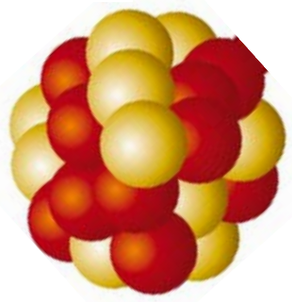
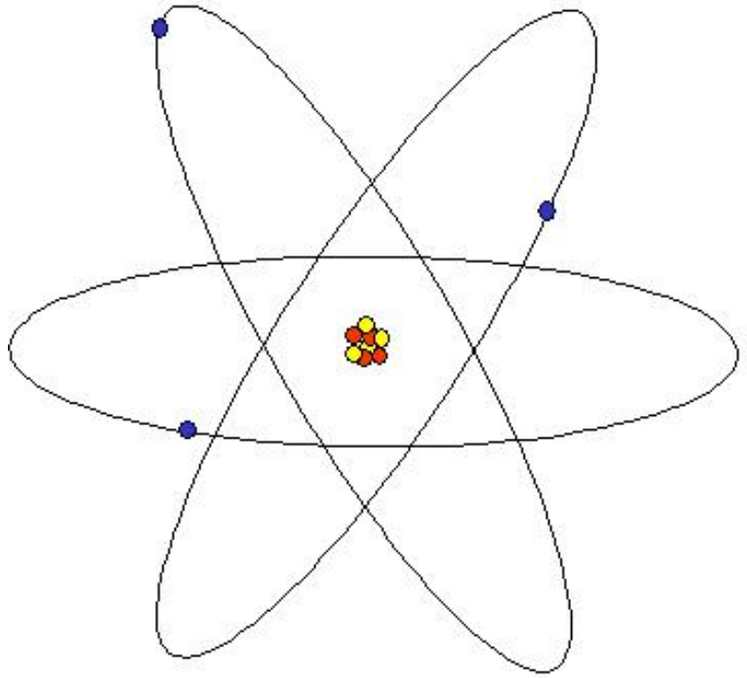
Neutron



Atomkern



Atom

Elektron

$<10^{-18}$ m

10^{-15} m

10^{-14} m

10^{-10} m

Streuexperimente

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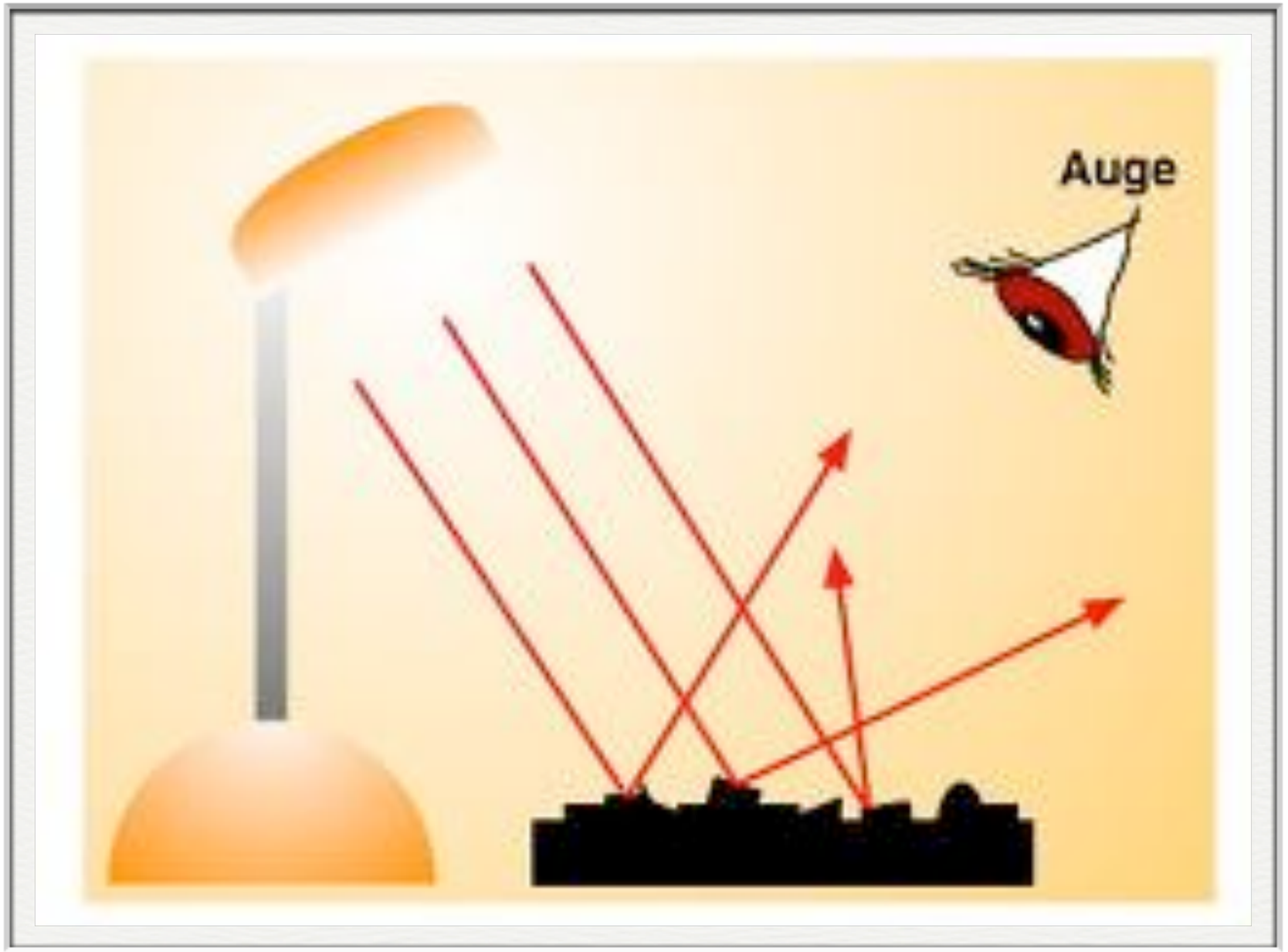
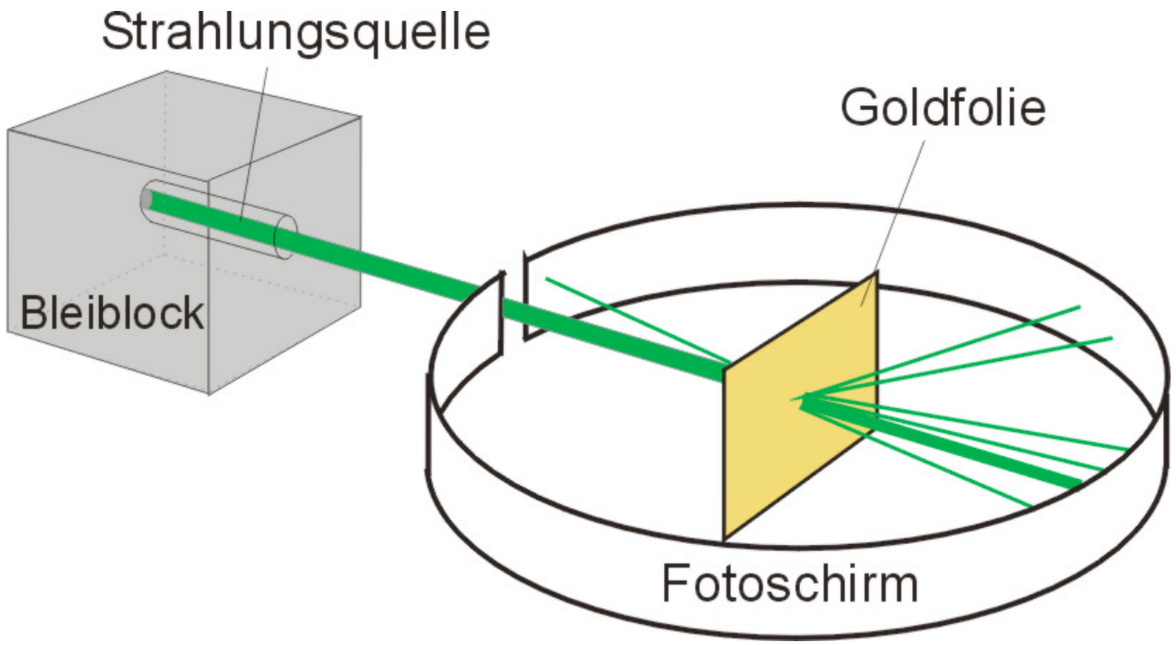
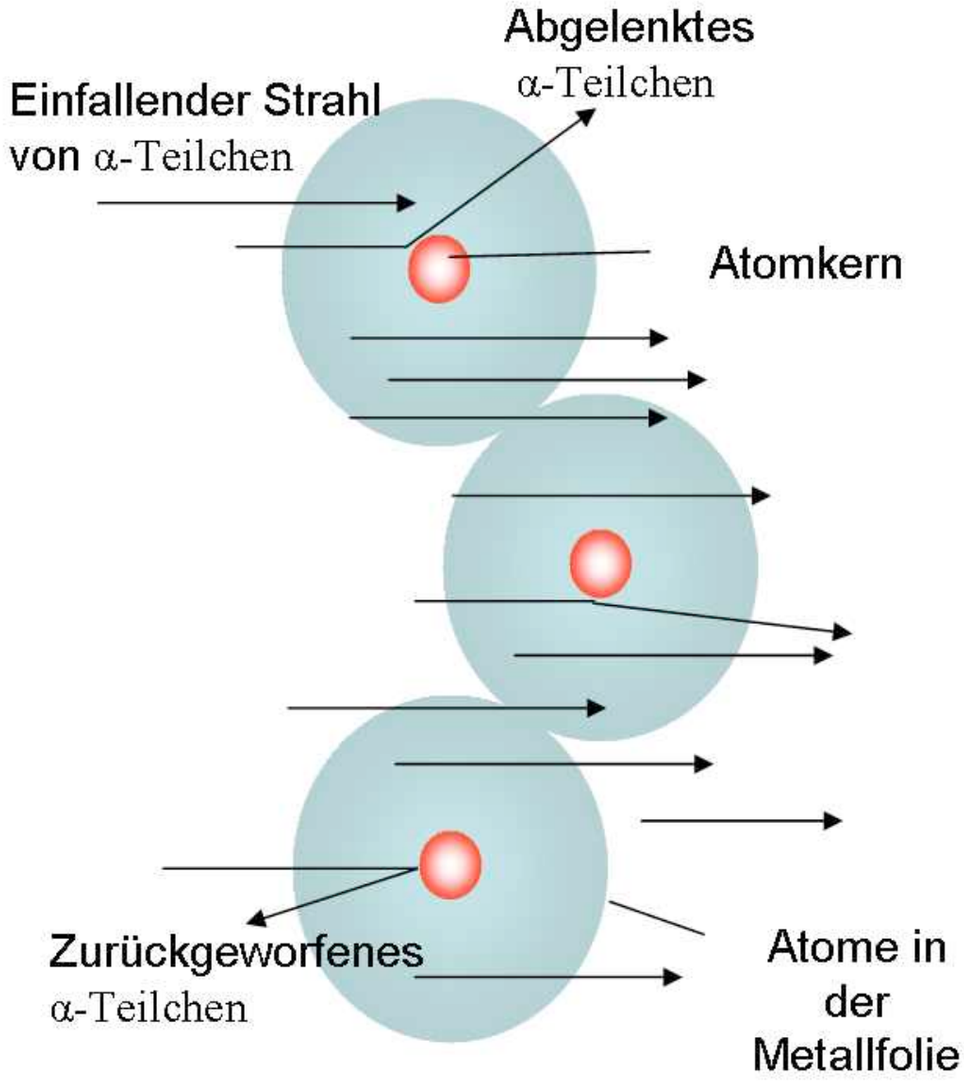
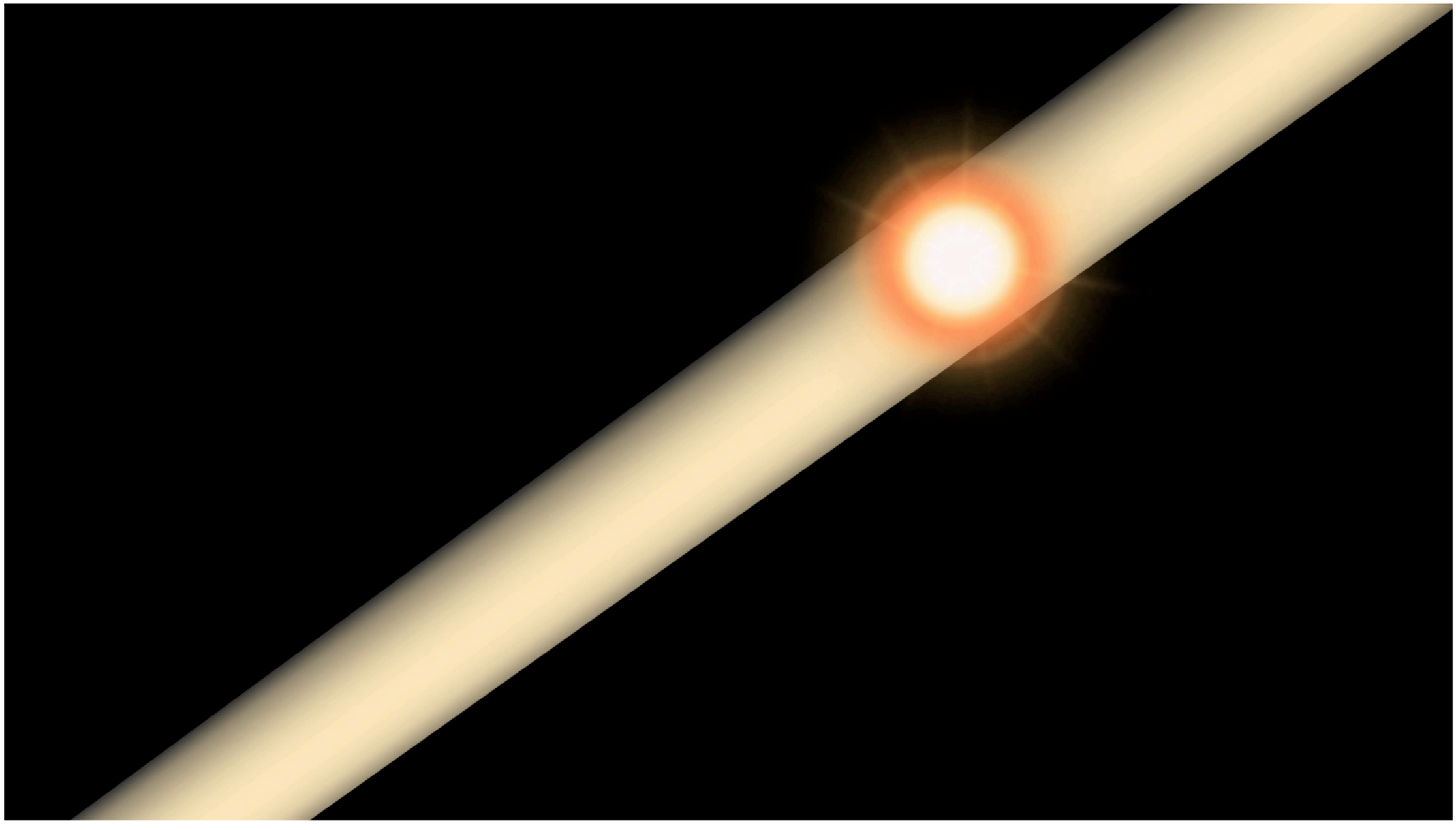
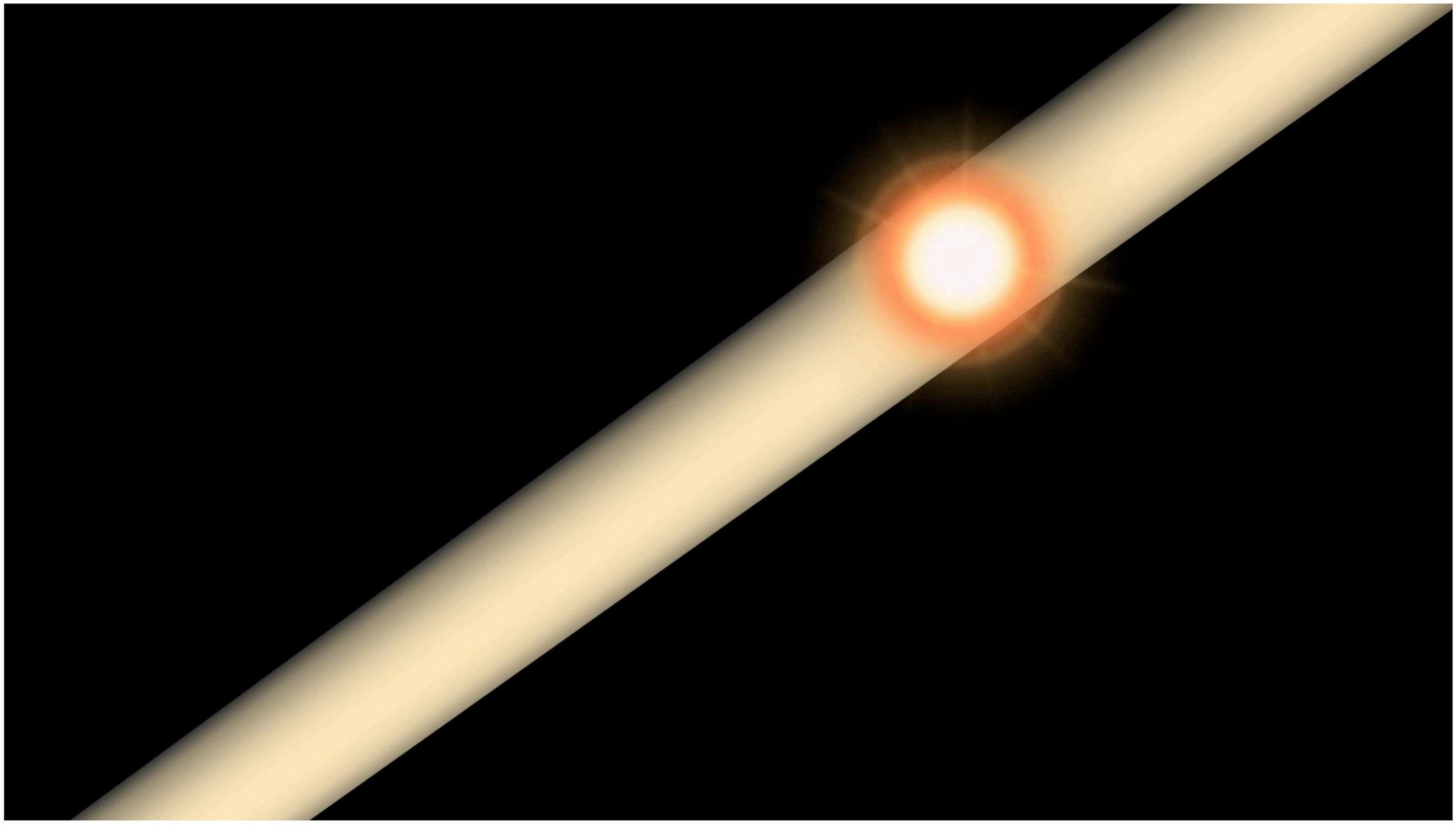

Auge

Rutherford Experiment



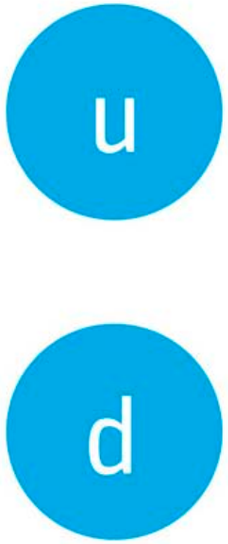


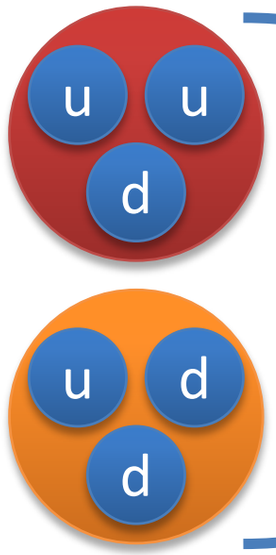




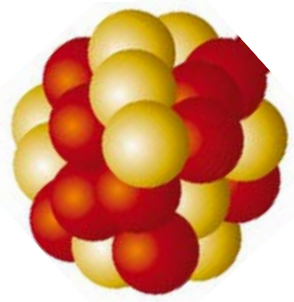
Die kleinsten Teilchen

Quarks

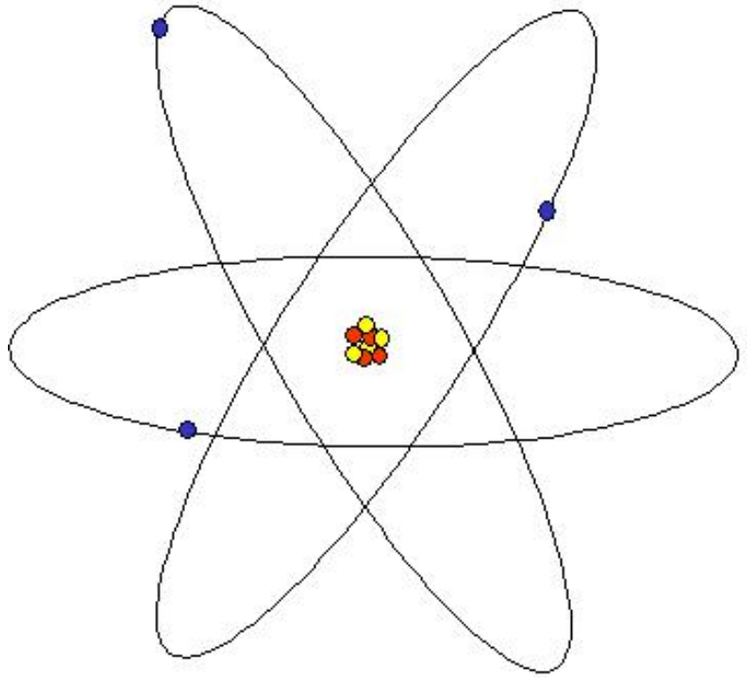




Proton
Neutron



Atomkern



Atom

Elektron

$<10^{-18}$ m

10^{-15} m

10^{-14} m

10^{-10} m

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- Quarks
- Leptonen

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Schwer nachzuweisen!

Man sieht, dass man nichts sieht.

„Fehlende Energie“ (→ später)

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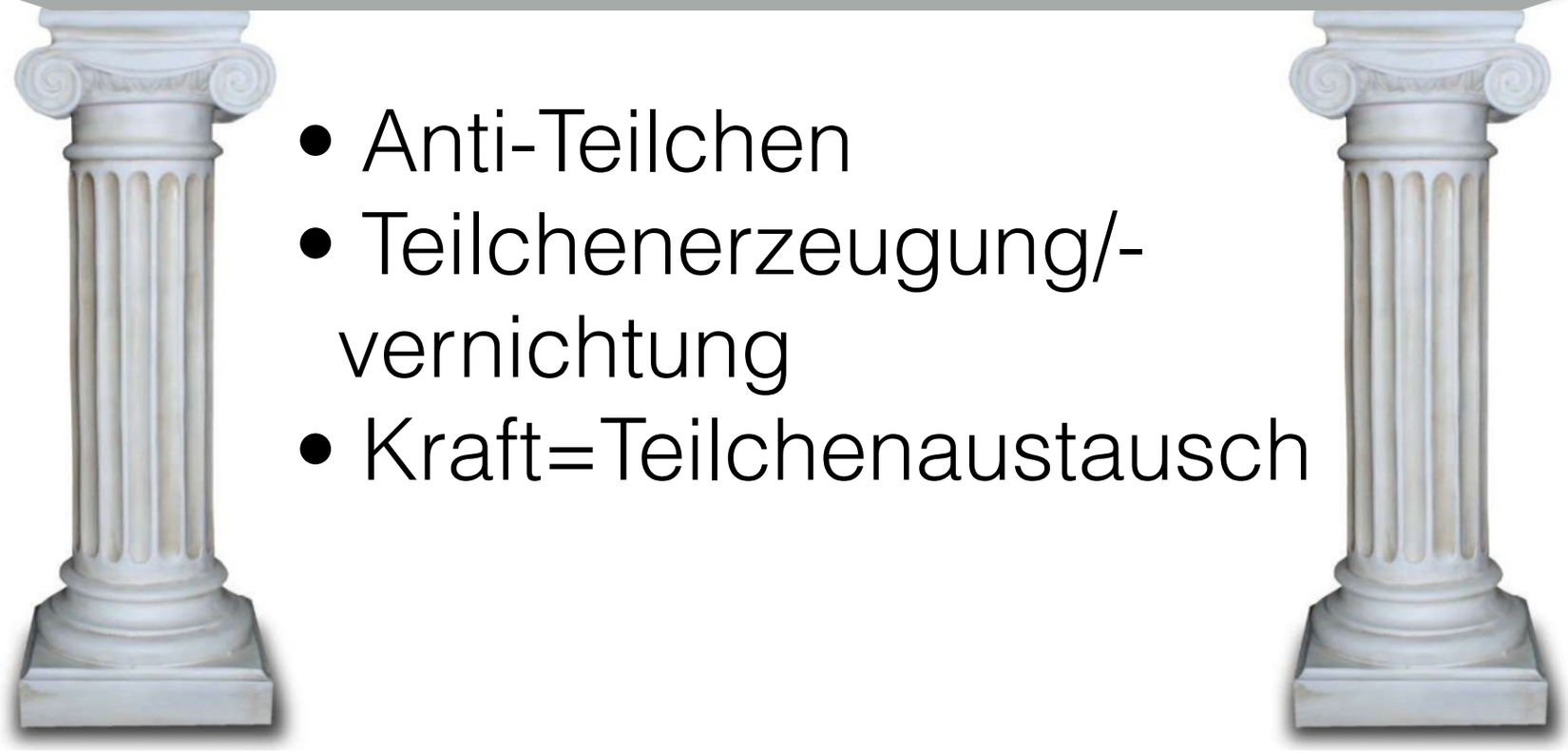
Mehr brauchen wir nicht!

Quantenfeldtheorie

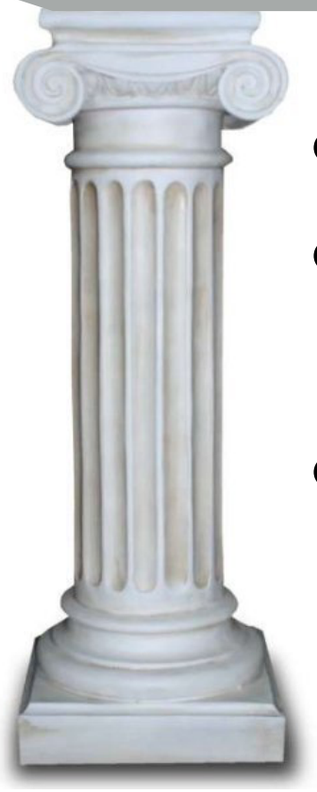


- Anti-Teilchen
- Teilchenerzeugung/-vernichtung
- Kraft=Teilchenaustausch

Quantenmechanik

Relativitätstheorie

Quantenfeldtheorie



- Anti-Teilchen
- Teilchenerzeu
  vernichtung
- Kraft=Teilcher

Quantenmechanik

$$E = m \cdot c^2$$

e

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- Leptonen

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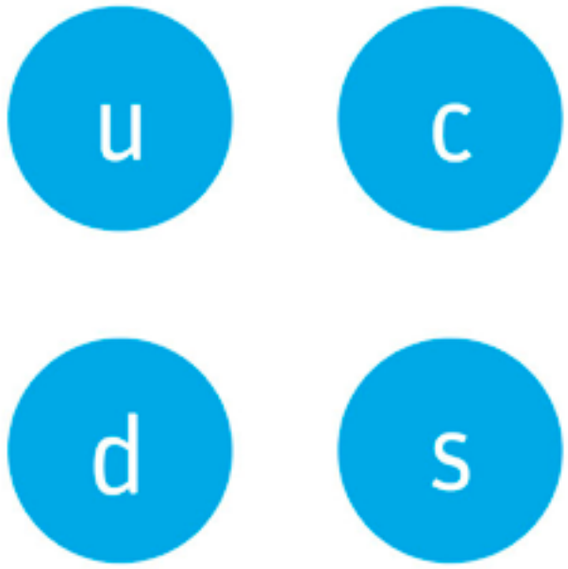
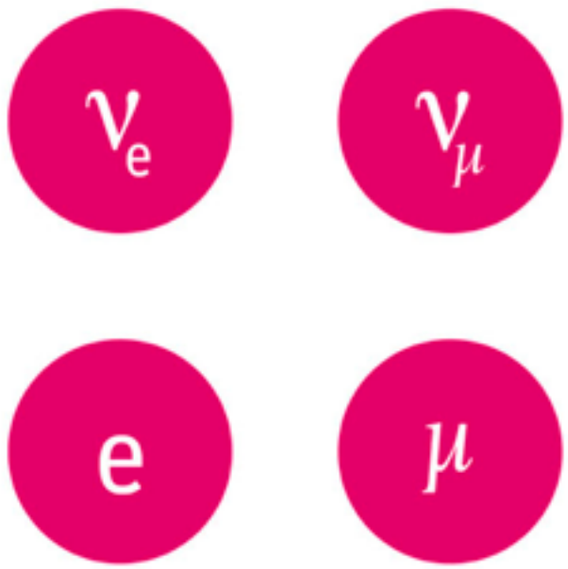
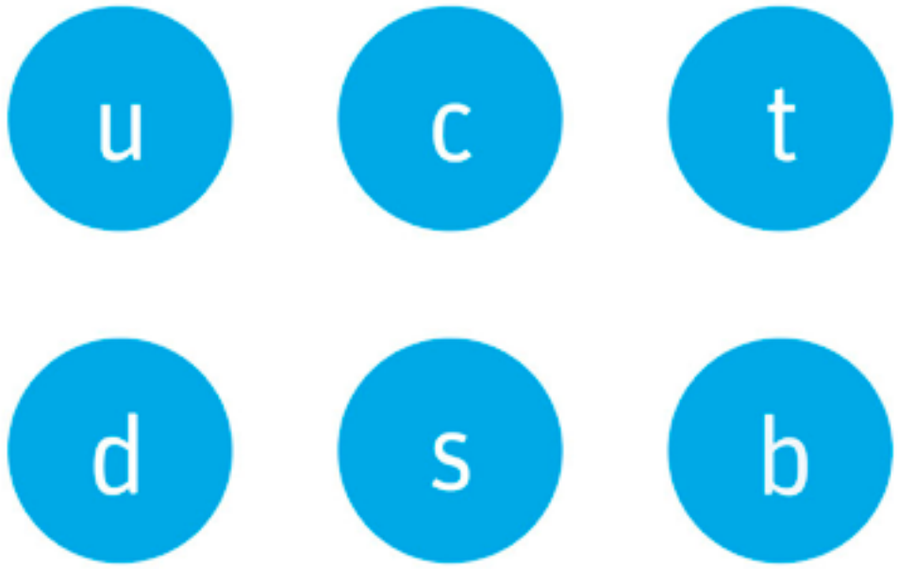
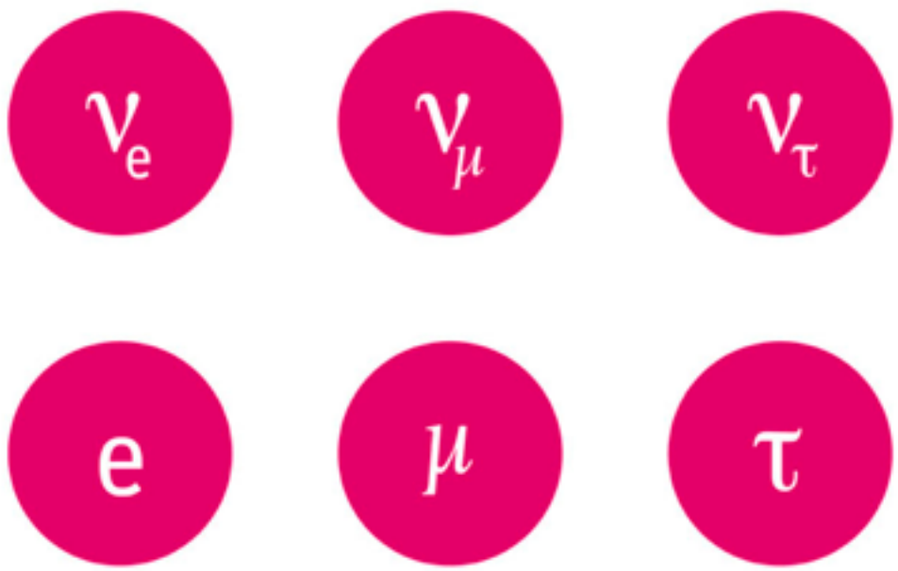
- Quarks
- Leptonen





- Quarks
- Leptonen





Namen

- Quarks
- Leptonen

u	c	t
up	charm	top
d	s	b
down	strange	bottom

ν_e	ν_μ	ν_τ
Elektron-	Myon-	Tau-Neutrino
e	μ	τ
Elektron	Myon	Tau

Antimaterie

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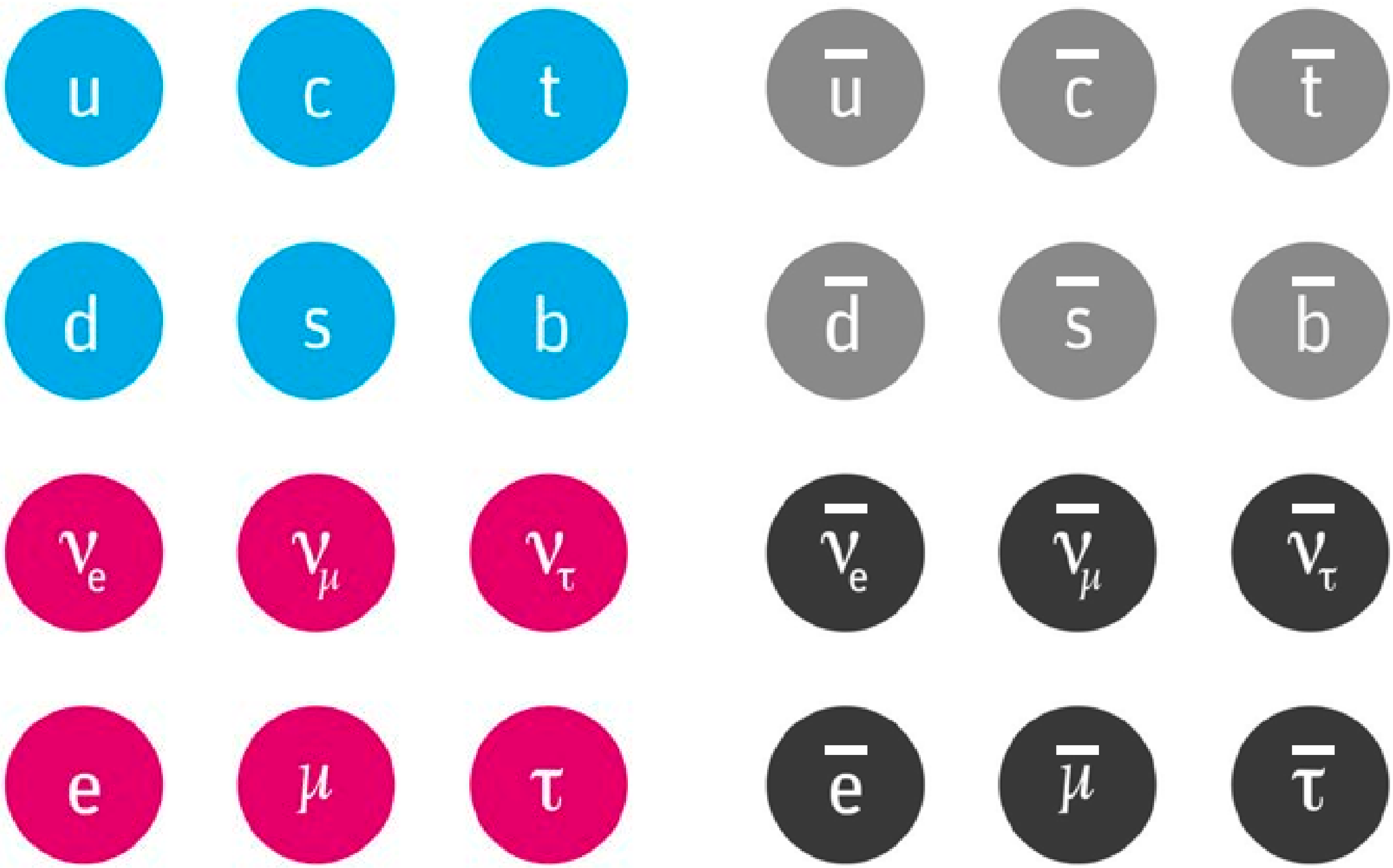

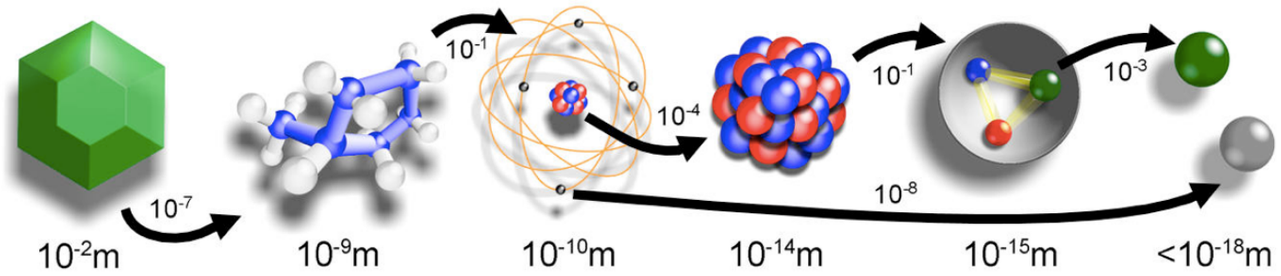
10^{-1}
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10^{-1}
10^{-3}
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10^{-8}
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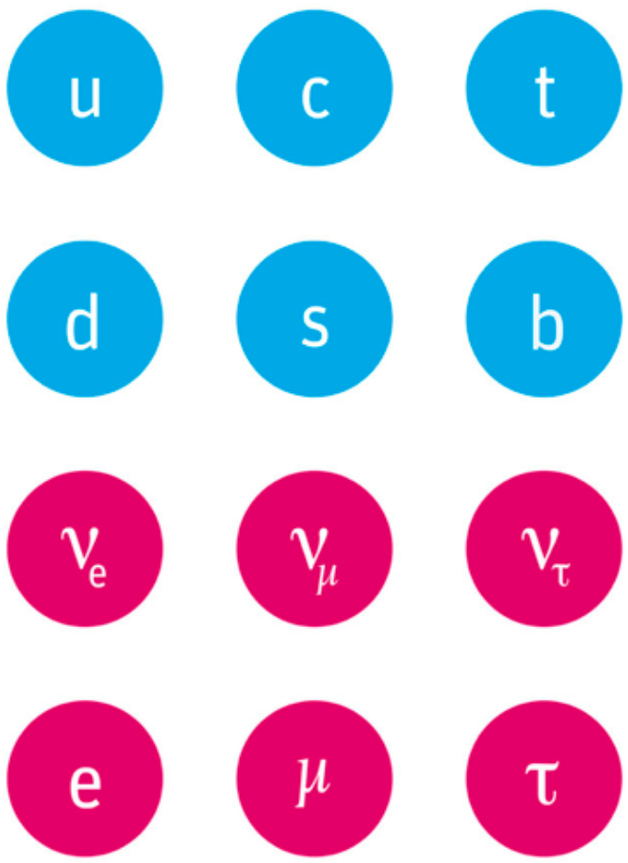
10^{-9}m
10^{-10}m
10^{-14}m
10^{-15}m
<10^{-18}m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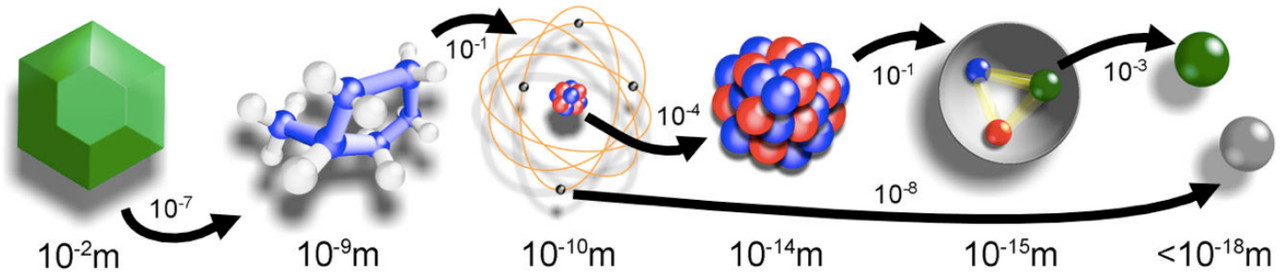
10^{-1}
10^{-4}
10^{-1}
10^{-3}
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10^{-8}
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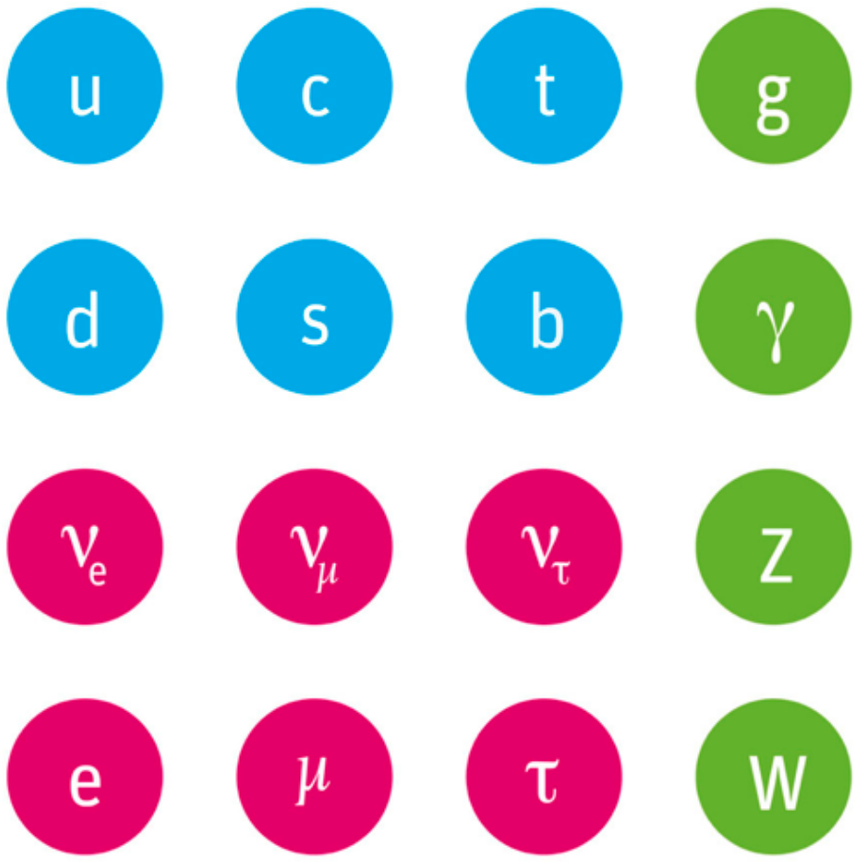
u
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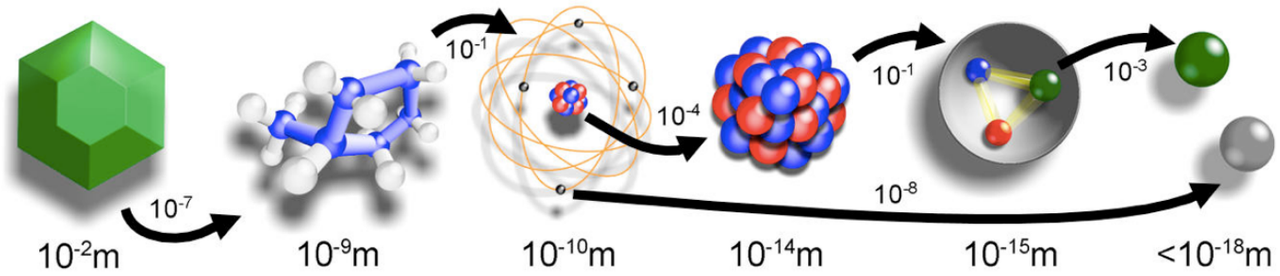
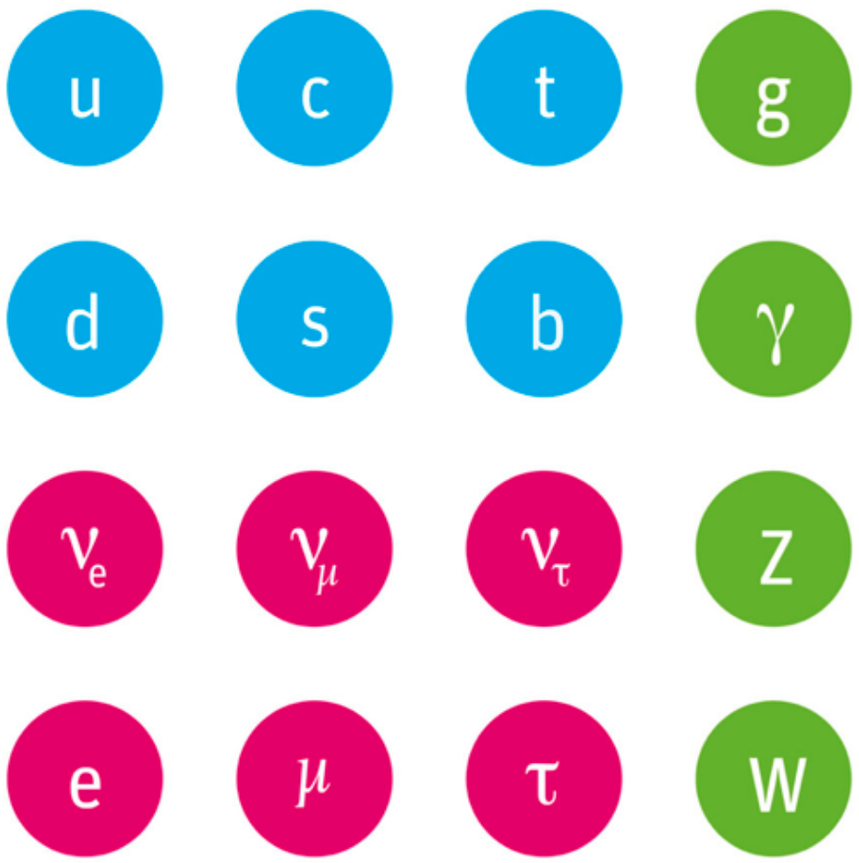
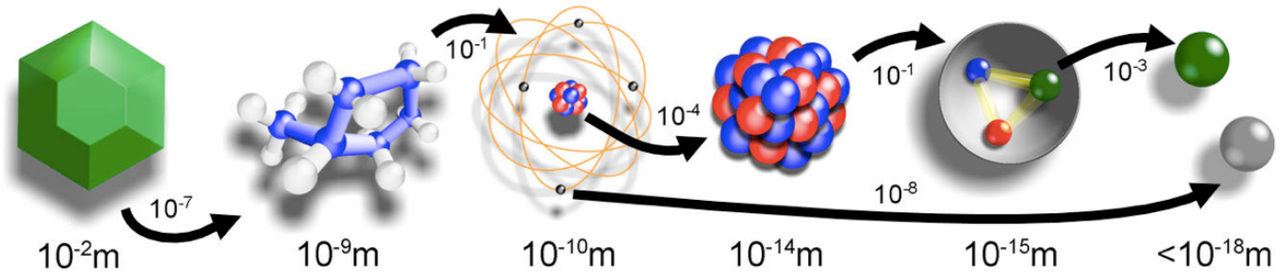
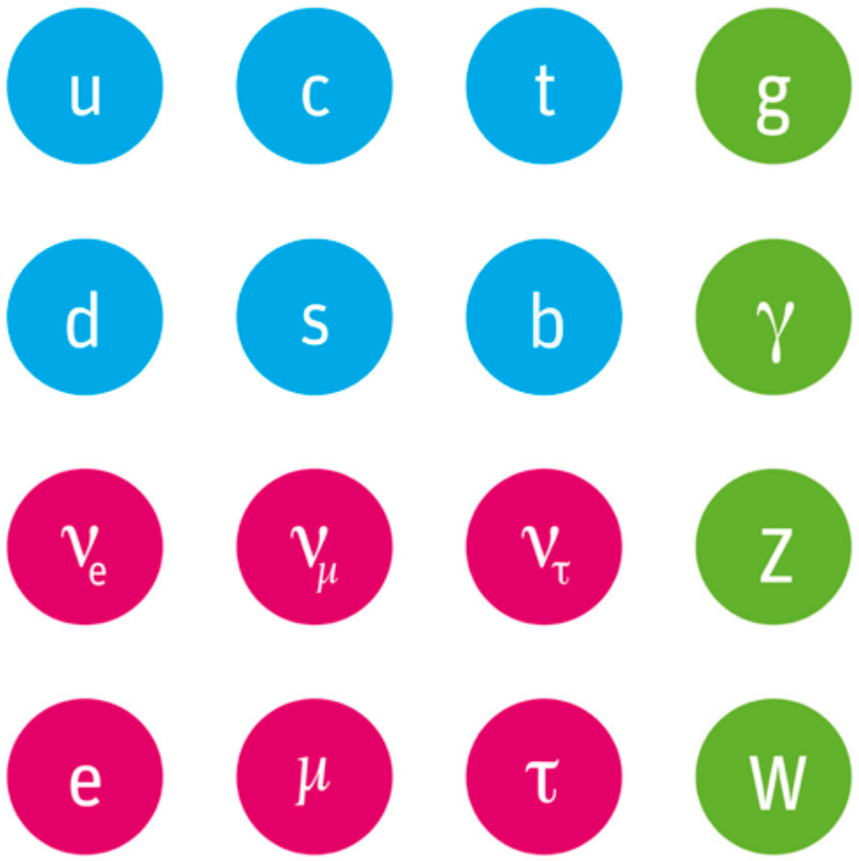


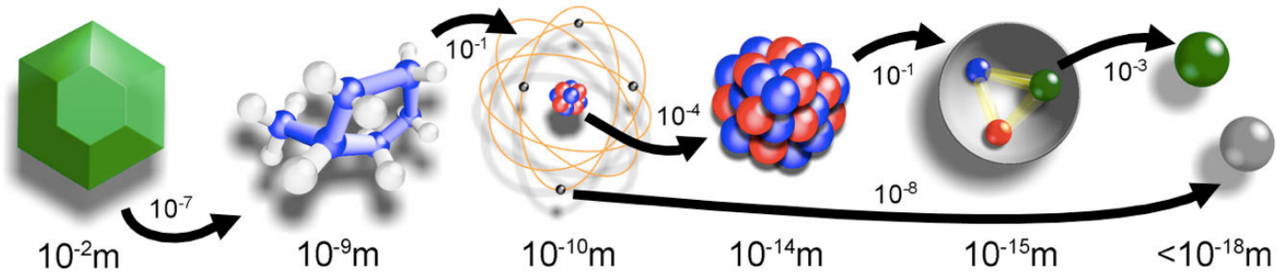
$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi} \not{D} \psi + h.c.$$





$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$
$$+ i\bar{\psi} \not{D} \psi + h.c.$$
$$- \bar{\psi} m \psi + \frac{1}{2} A_\mu m^{\mu\nu} A_\nu$$





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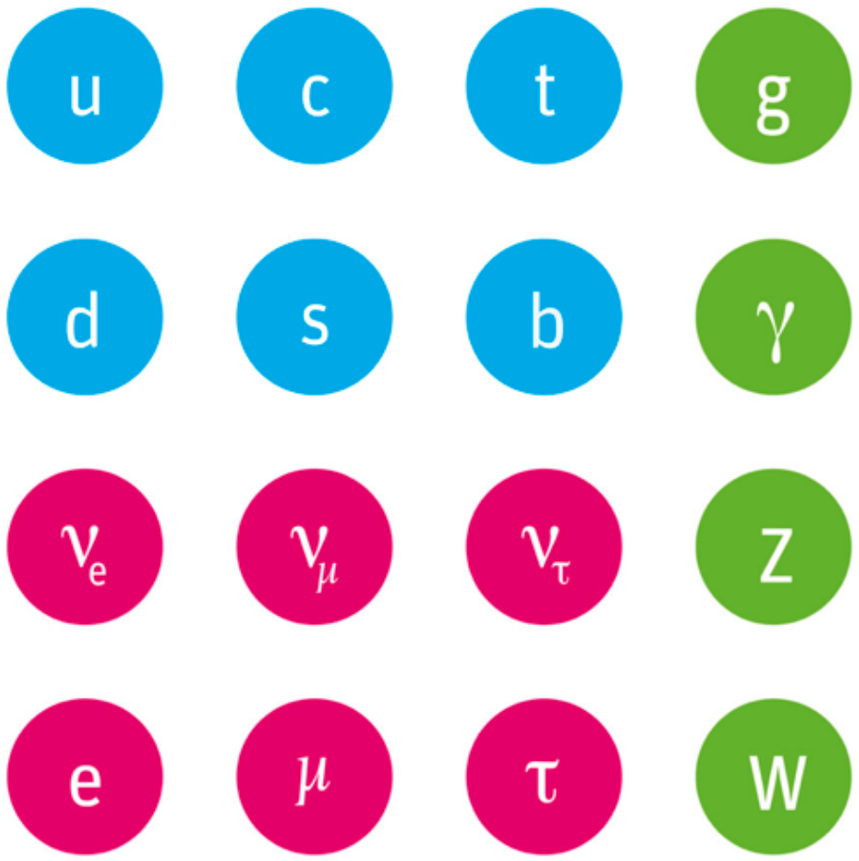
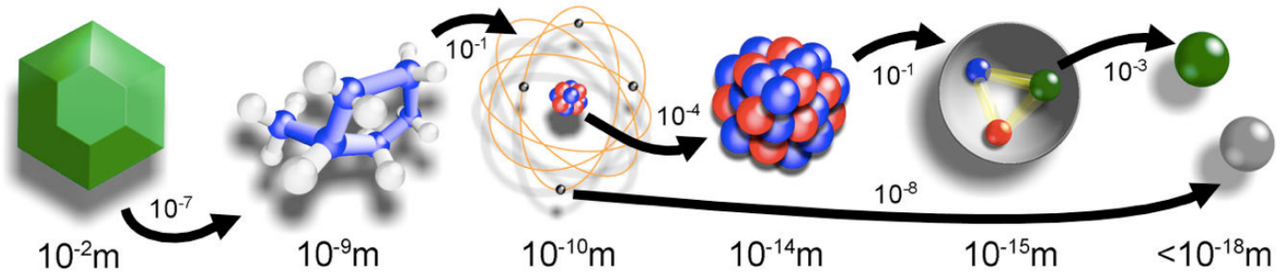
$$- \bar{\psi} m \psi + \frac{1}{2} A_\mu m^{\mu\nu} A_\nu$$



⇒Wahrscheinlichkeiten > 1



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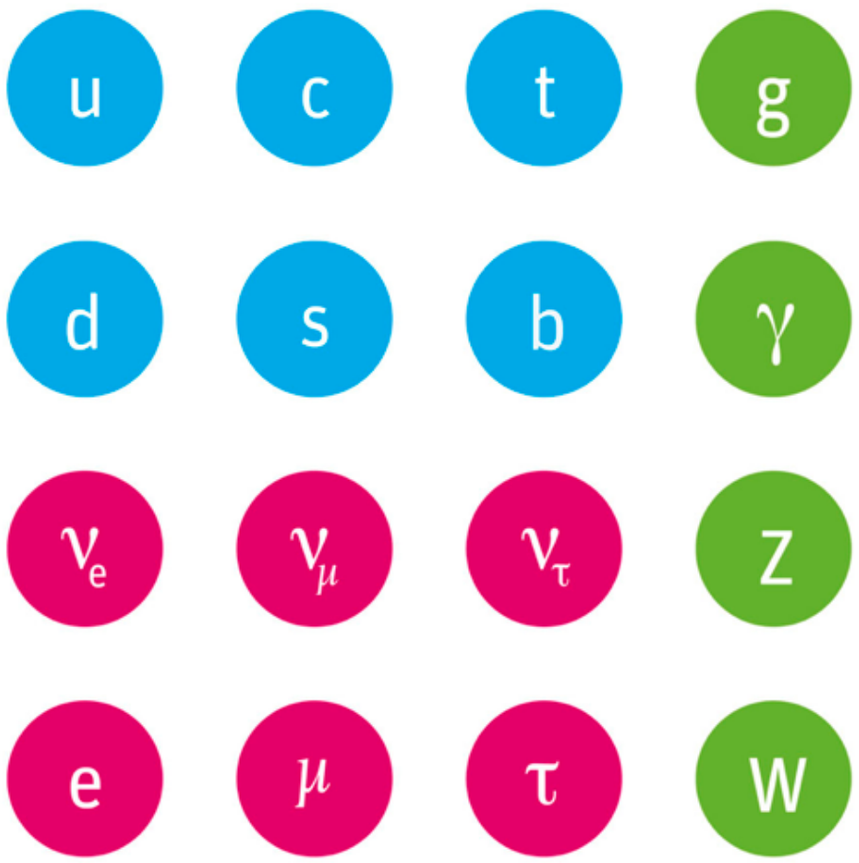

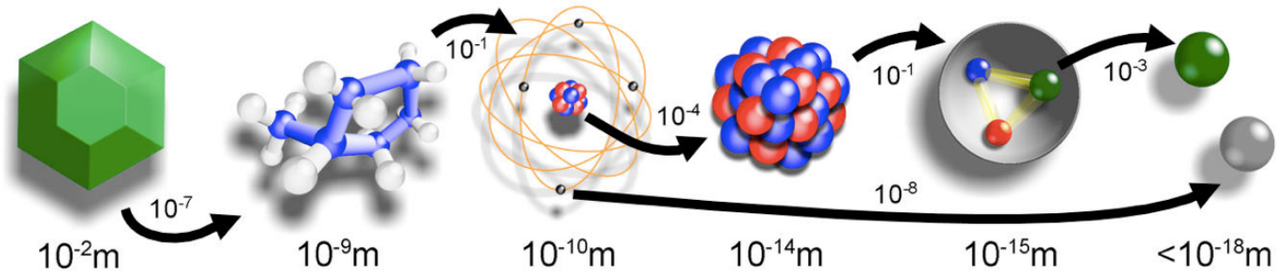

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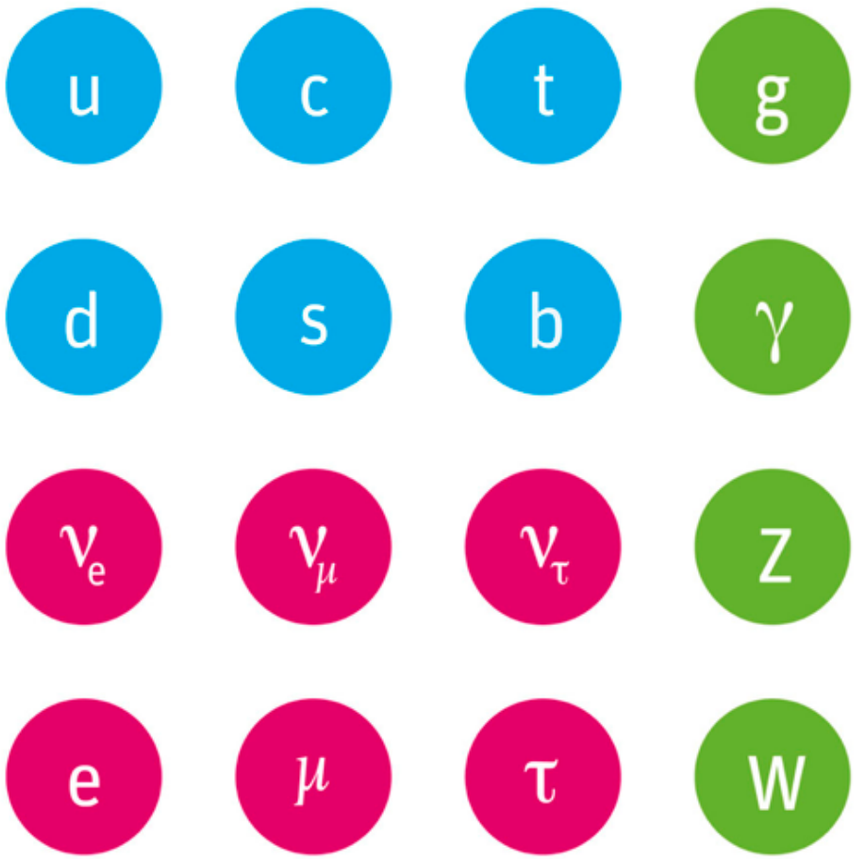

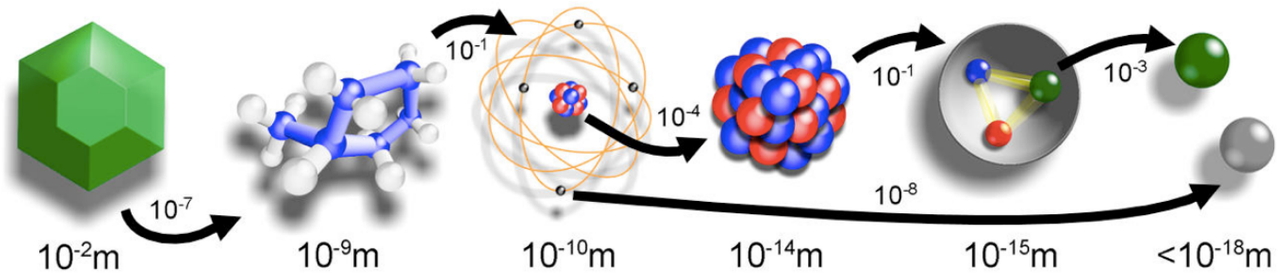

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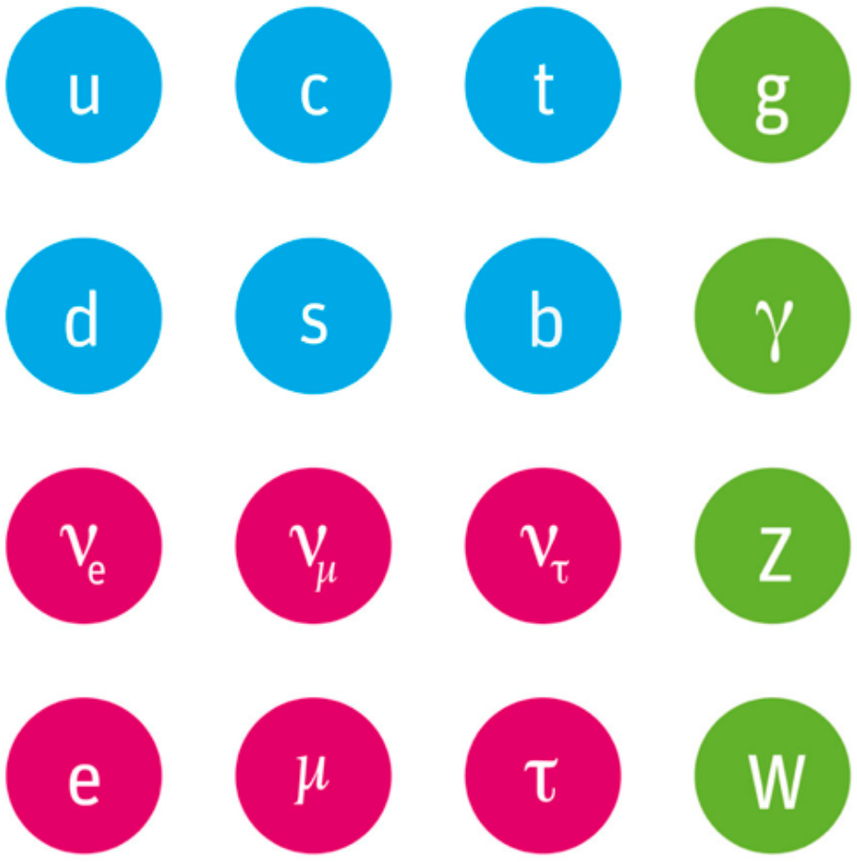
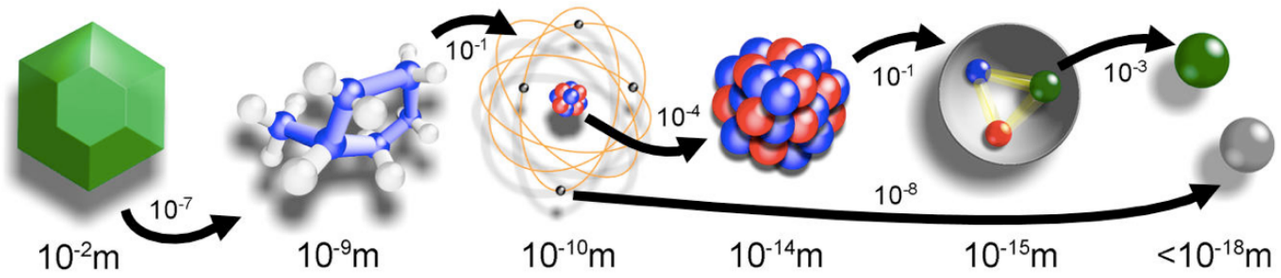
$$+ i \bar{\psi} \not{D} \psi + h.c.$$
$$- \bar{\psi} y \psi \phi + h.c.$$
$$+ |D_\mu \phi|^2 - V(\phi)$$





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$$+ i \bar{\psi} \not{D} \psi + h.c.$$
$$- \bar{\psi} y \psi \phi + h.c.$$
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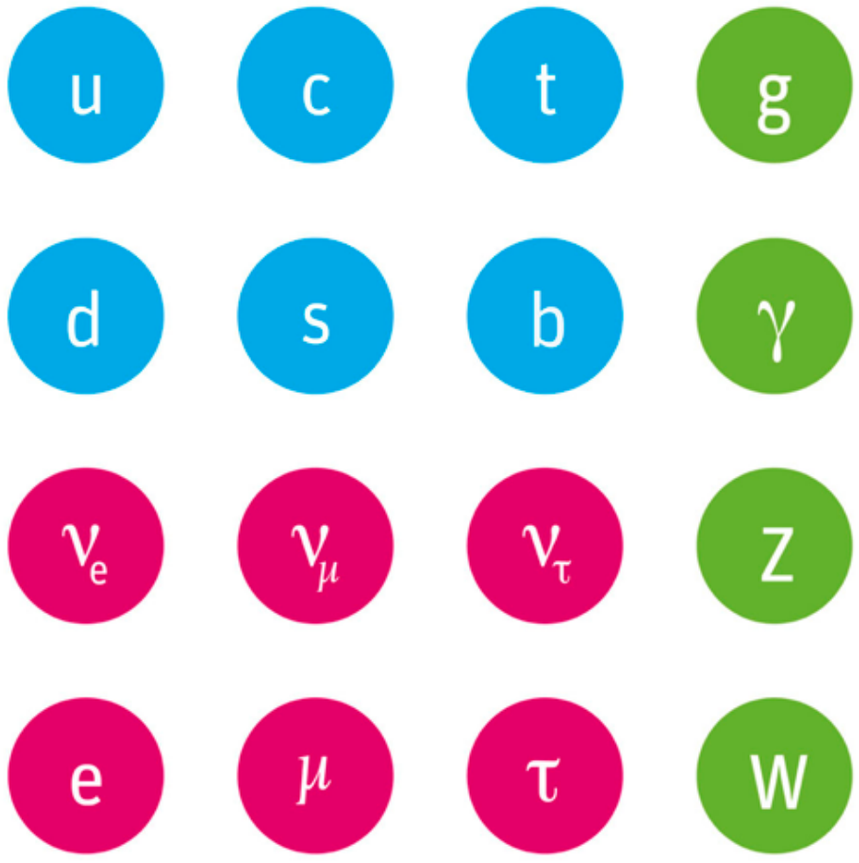

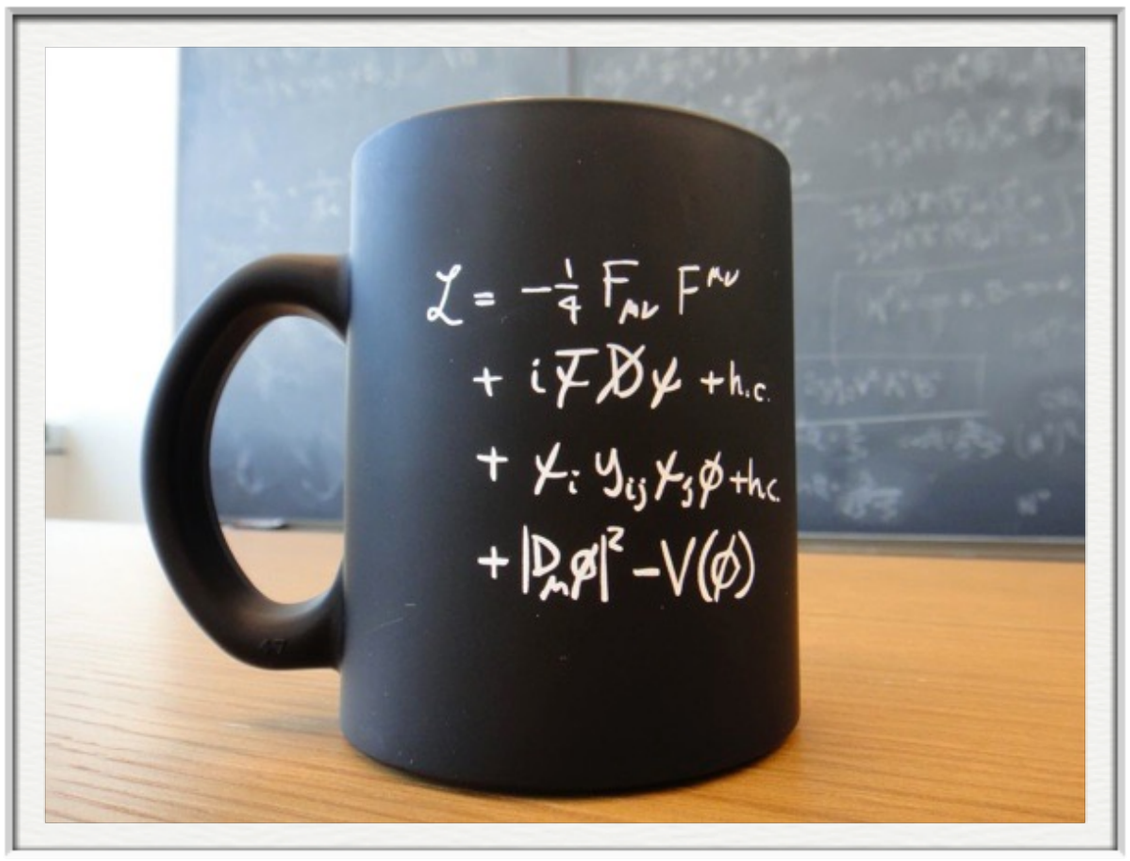

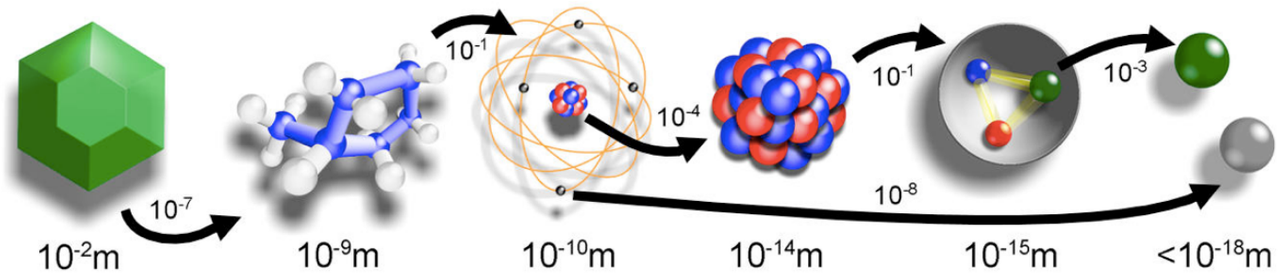

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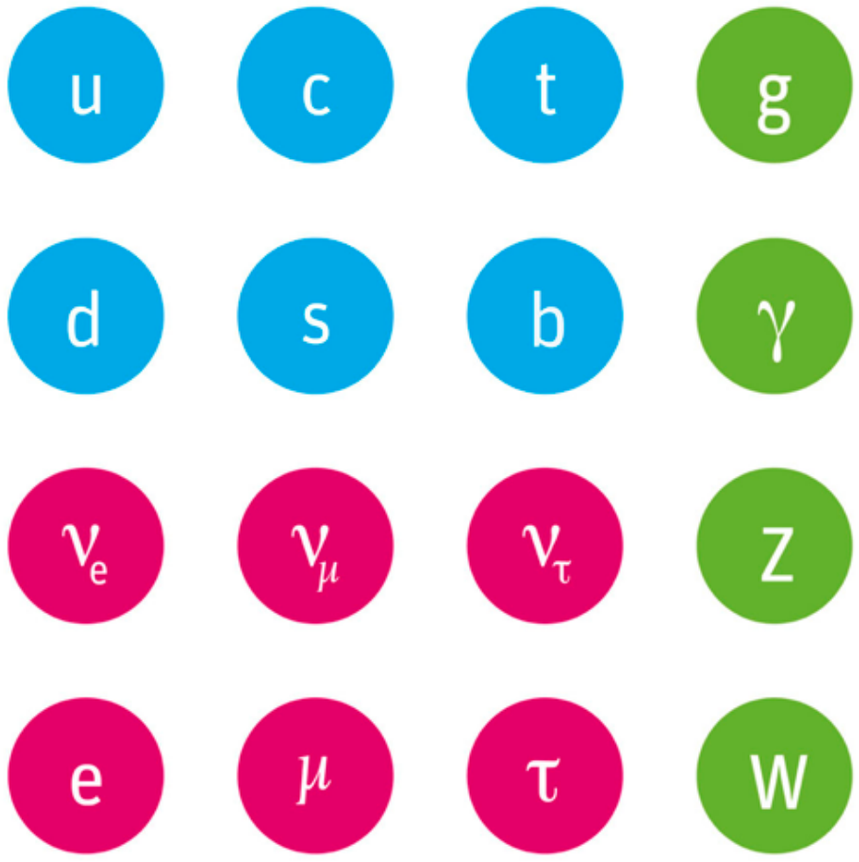
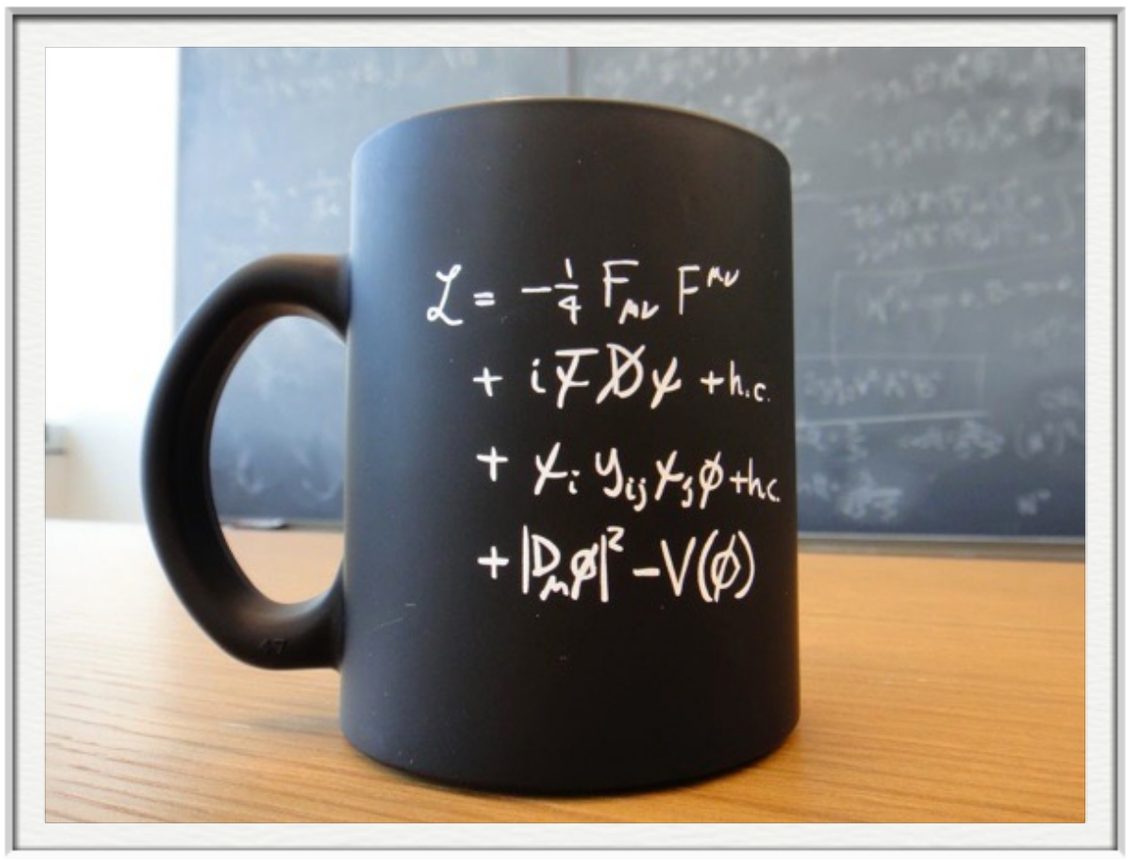
$$+ |D_\mu \phi|^2 - V(\phi)$$





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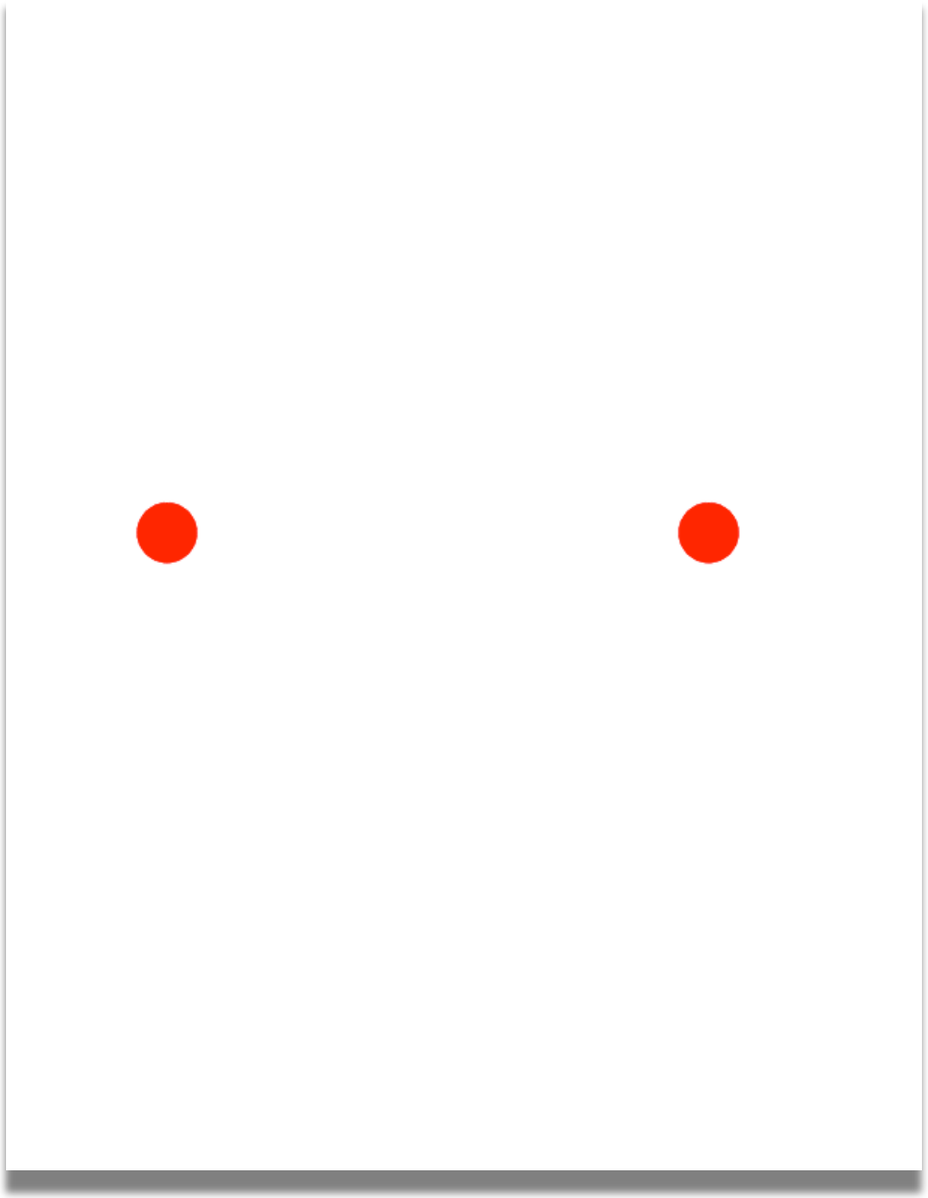

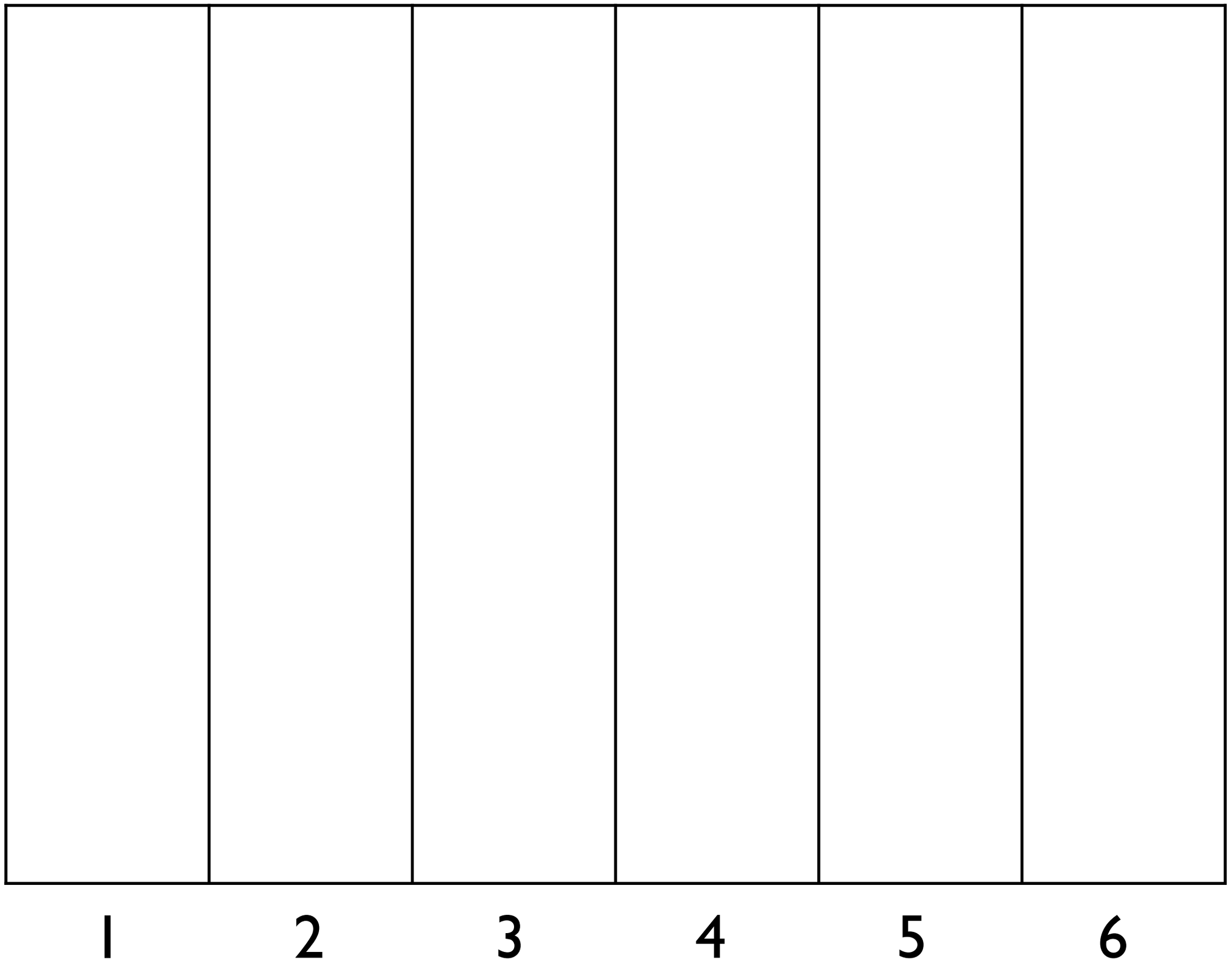
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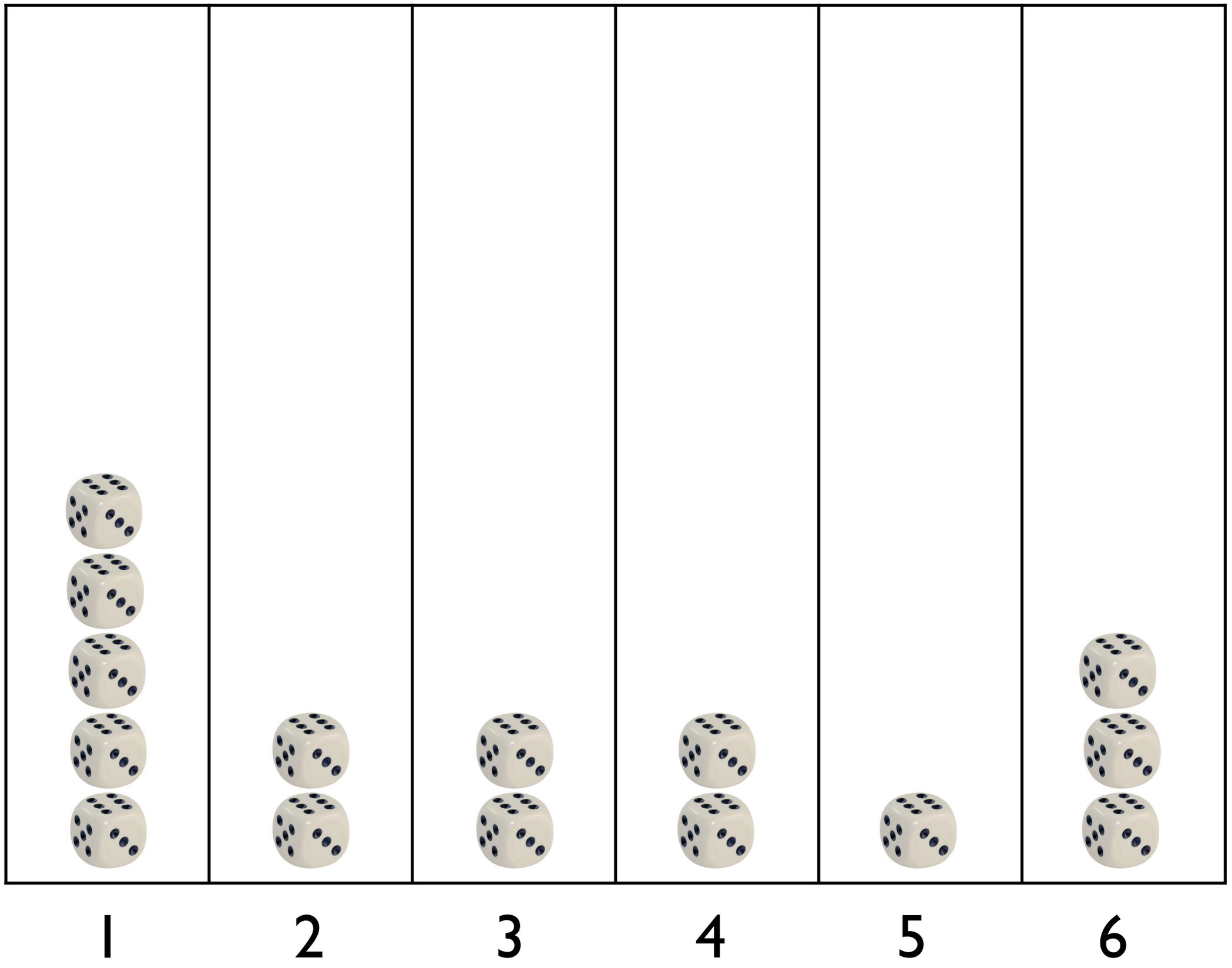

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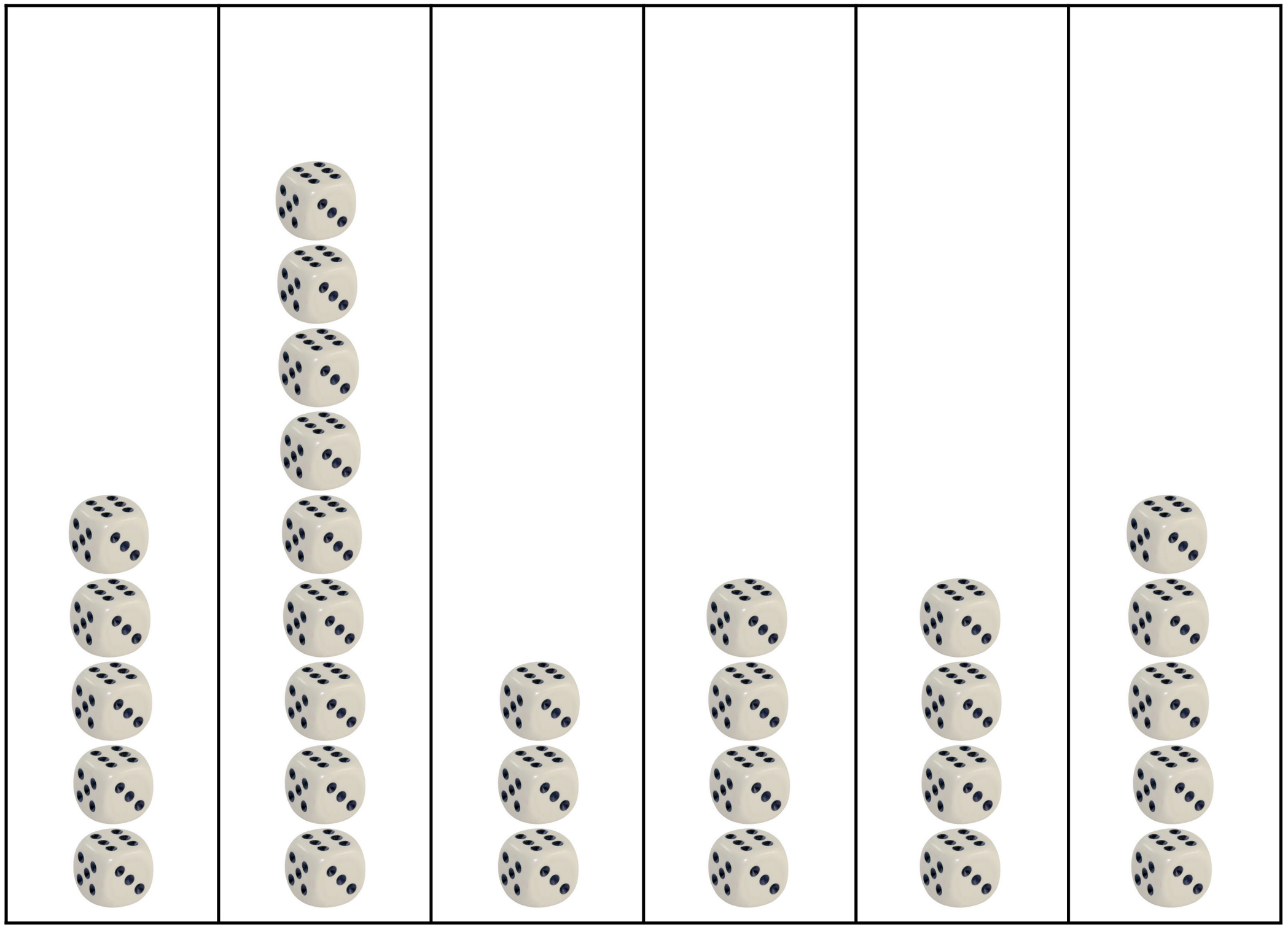
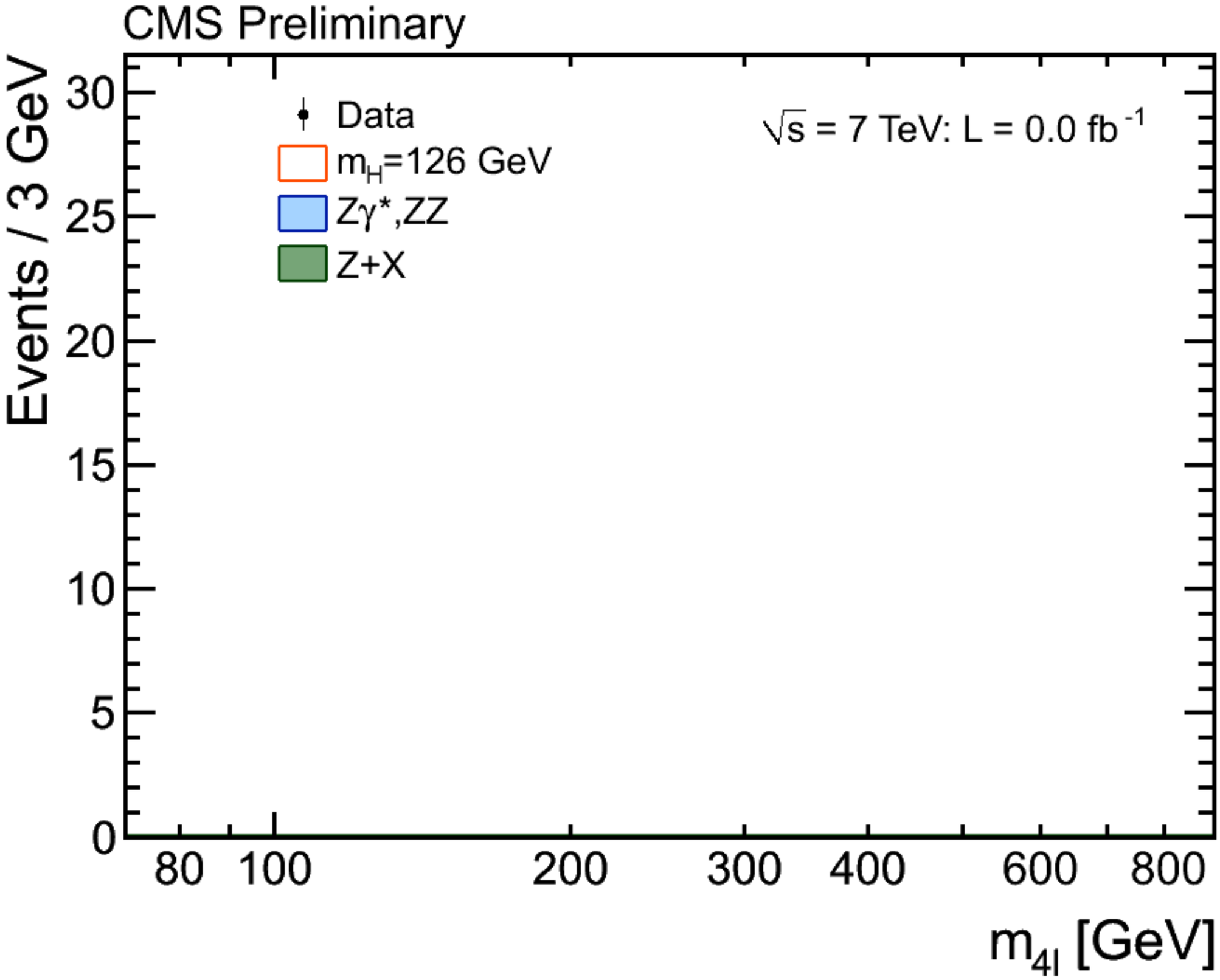


1 2 3 4 5 6

So entsteht langsam die „Signifikanz“



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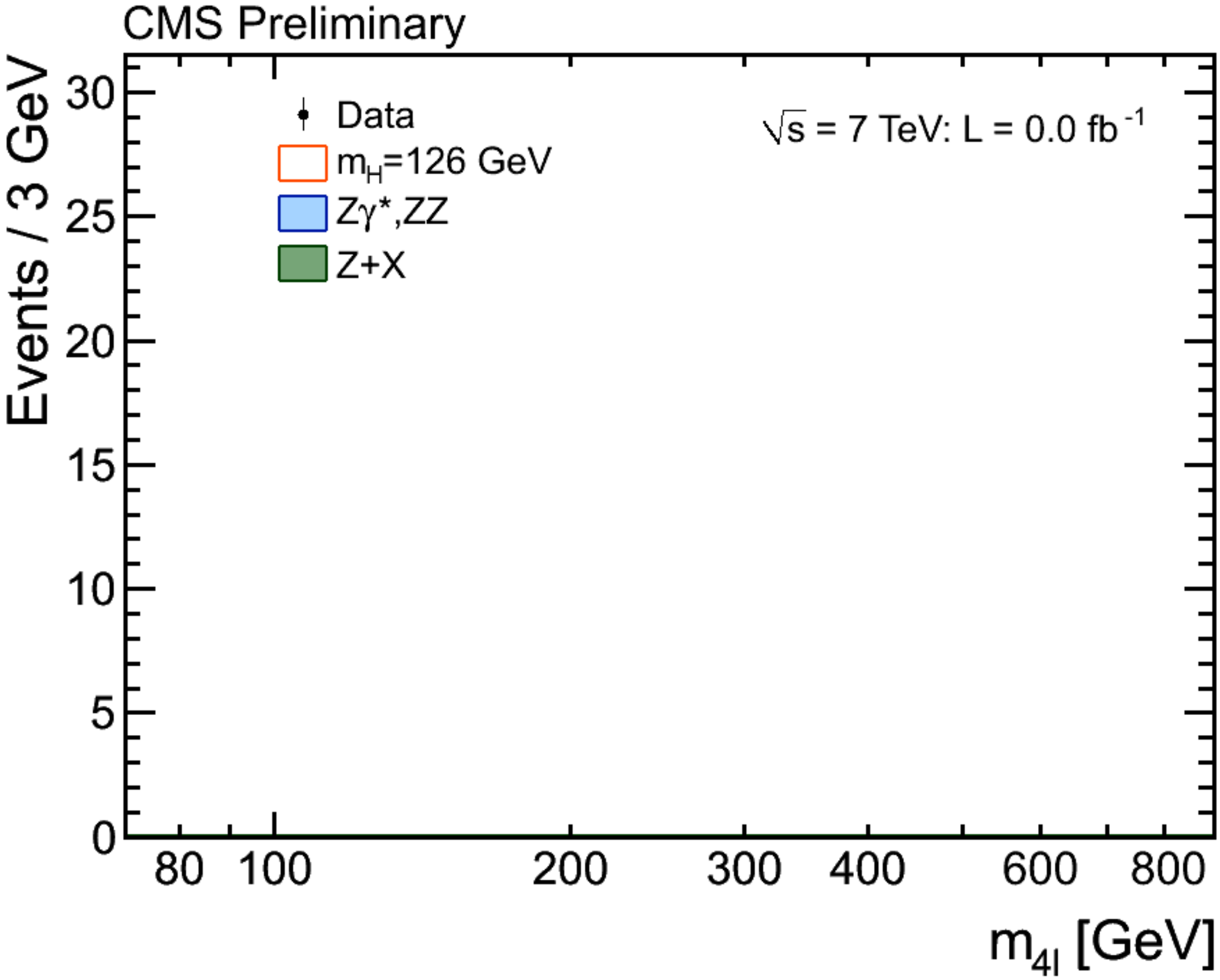

Materie
Kräfte
Strahlung (Licht, Wärme, …)

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Teilchen

R. Harlander, *MasterClass*, Februar 2021

Institute for Theoretical Particle Physics and Cosmology
RWTH AACHEN UNIVERSITY

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– Home –

Brief CV

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LHCHXSWG

LHC and Philosophy

P^{3}H

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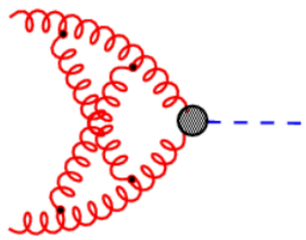
[detailed help] multi-search window Submit

Feel free to stop by my ~~office~~ zoom room to discuss physics, philosophy, politics, ...
I'll be there again on **Thursday, 11 Feb 2021, 12:00h CET**.

What's new? (older news)

- Topics for bachelor theses
  27 Jan 2021
- Higgs-mass predictions in the MSSM and beyond
  01 Jan 2021
- Workshop 2021: Virtual entities in science
  30 Sep 2020



One of my favorite Feynman diagrams

I am a professor for theoretical particle physics at RWTH Aachen University.

My main research field is to understand and predict phenomena at particle colliders. Within the last few years, I have been mostly interested in the physics of Higgs bosons in and beyond the Standard Model.

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