Friedrich-Alexander-Universität
Erlangen-Nürnberg

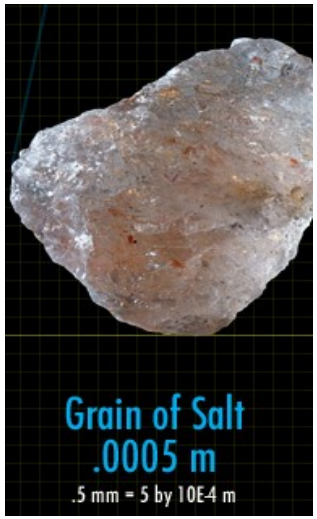
IceCube Masterclass 2026
Astroteilchenphysik

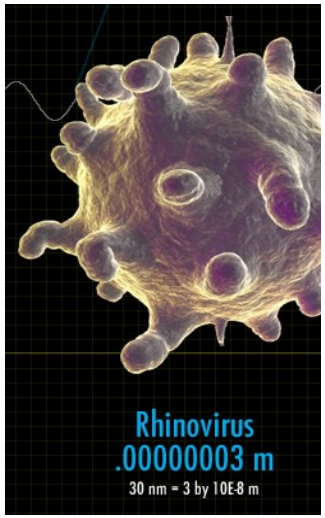


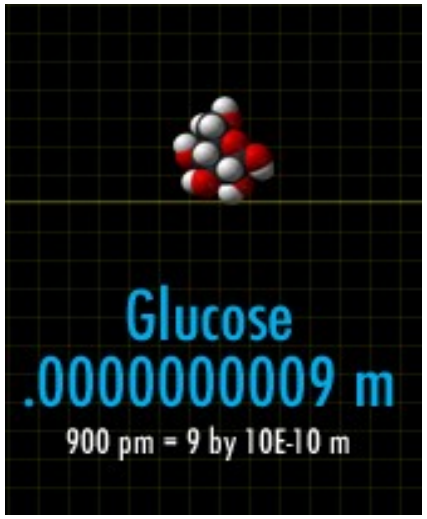
Martin Rongen
Erlangen, 03.11.2026

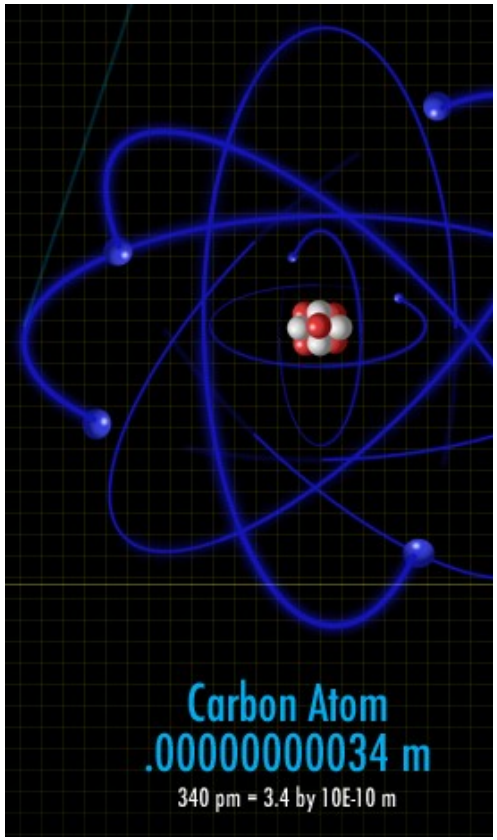
Teilchenphysik



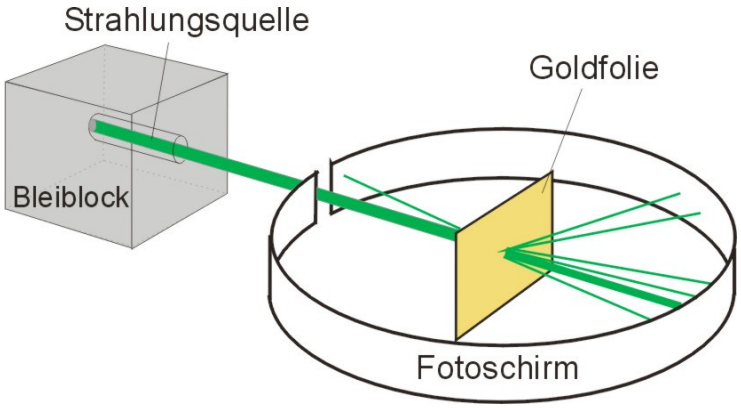


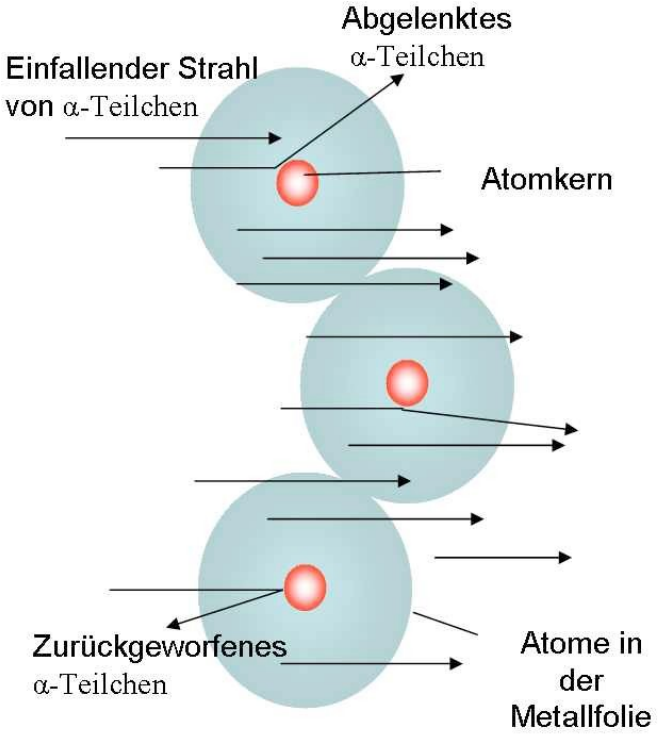






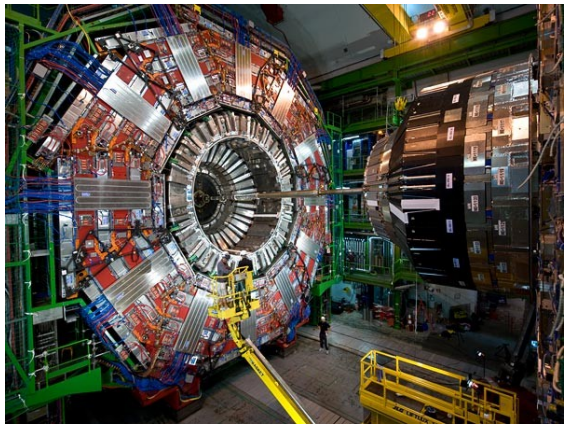
Streuexperimente





Ablenkung und Rückstoß von
α-Teilchen durch die Atomkerne einer
Metallfolie im Rutherford'schen Experiment





CMS Masterclass

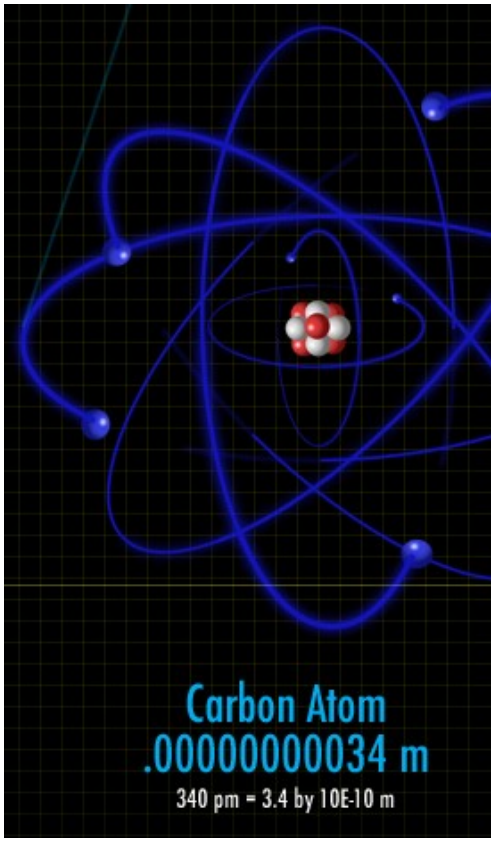
Das Standardmodell

- Quarks
- Leptonen

u

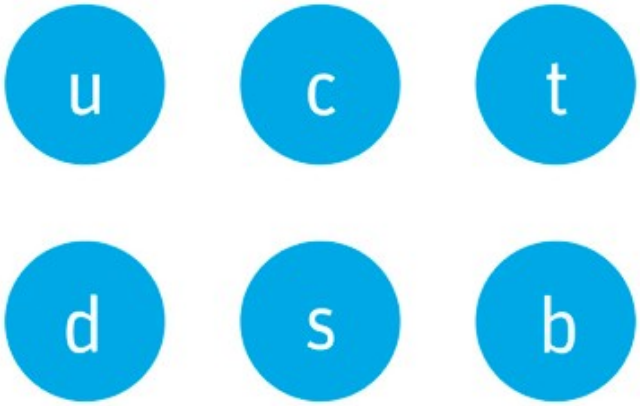
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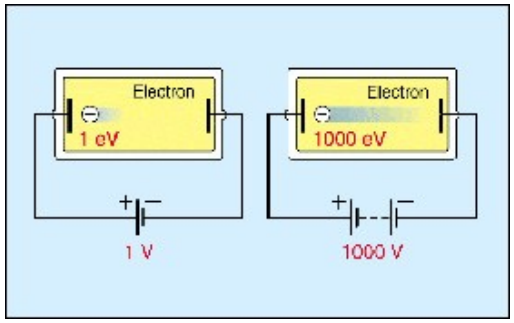
e



Das Standardmodell

- Quarks
- Leptonen





schwerer



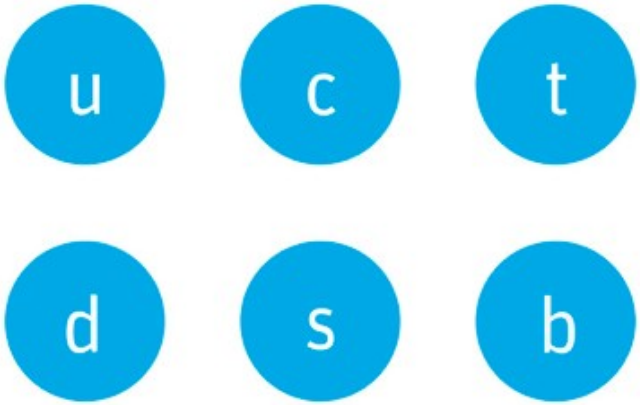


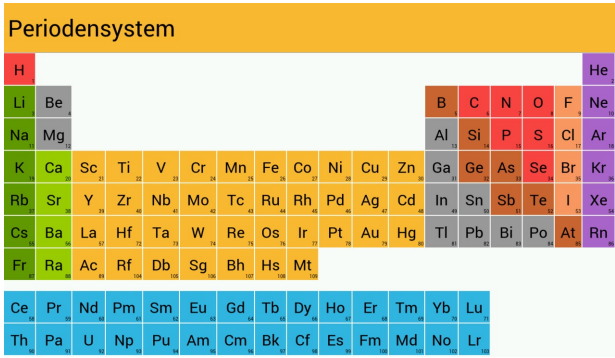
500keV 100MeV 2GeV

Kilo	10^3
Mega	10^6
Giga	10^9
Tera	10^{12}
Peta	10^{15}

Das Standardmodell

- Quarks
- Leptonen





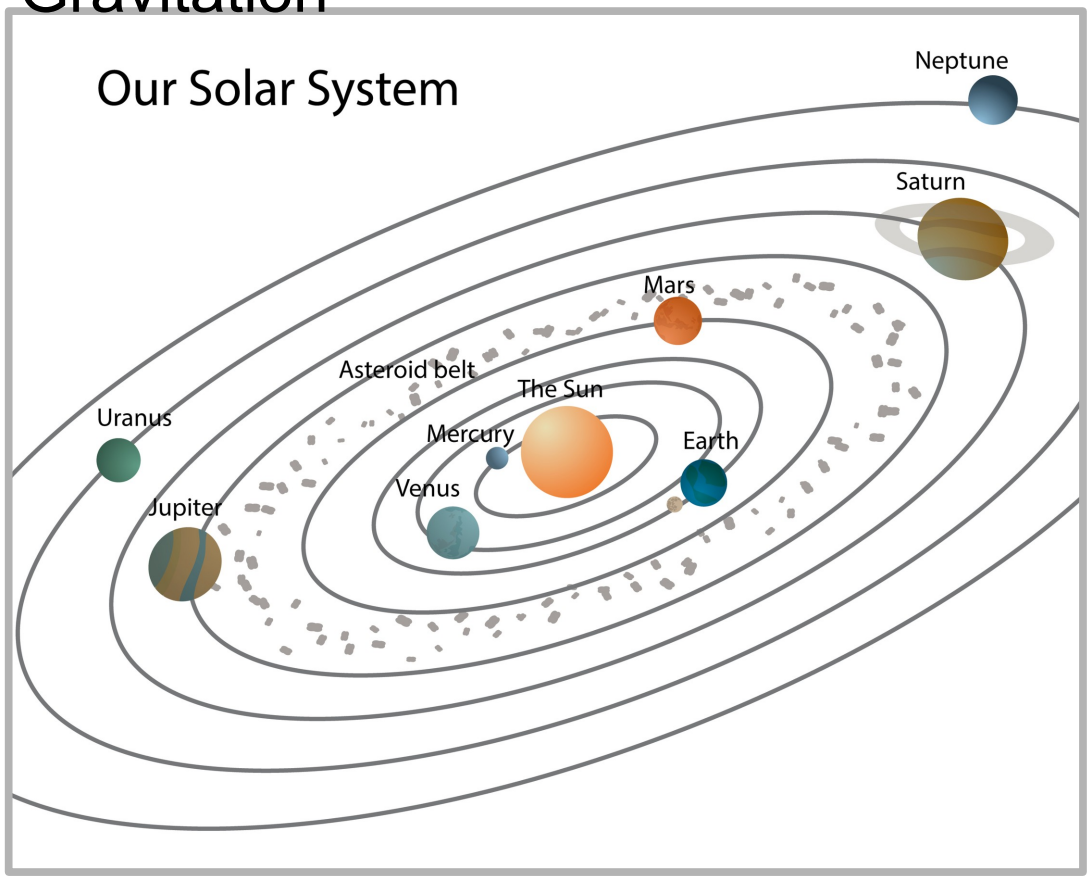
schwerer



500keV **100MeV** **2GeV**

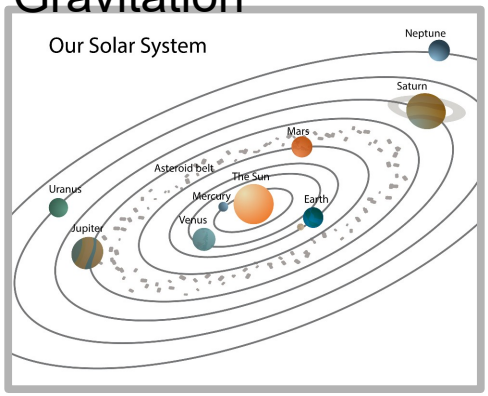
Die Kräfte

Gravitation

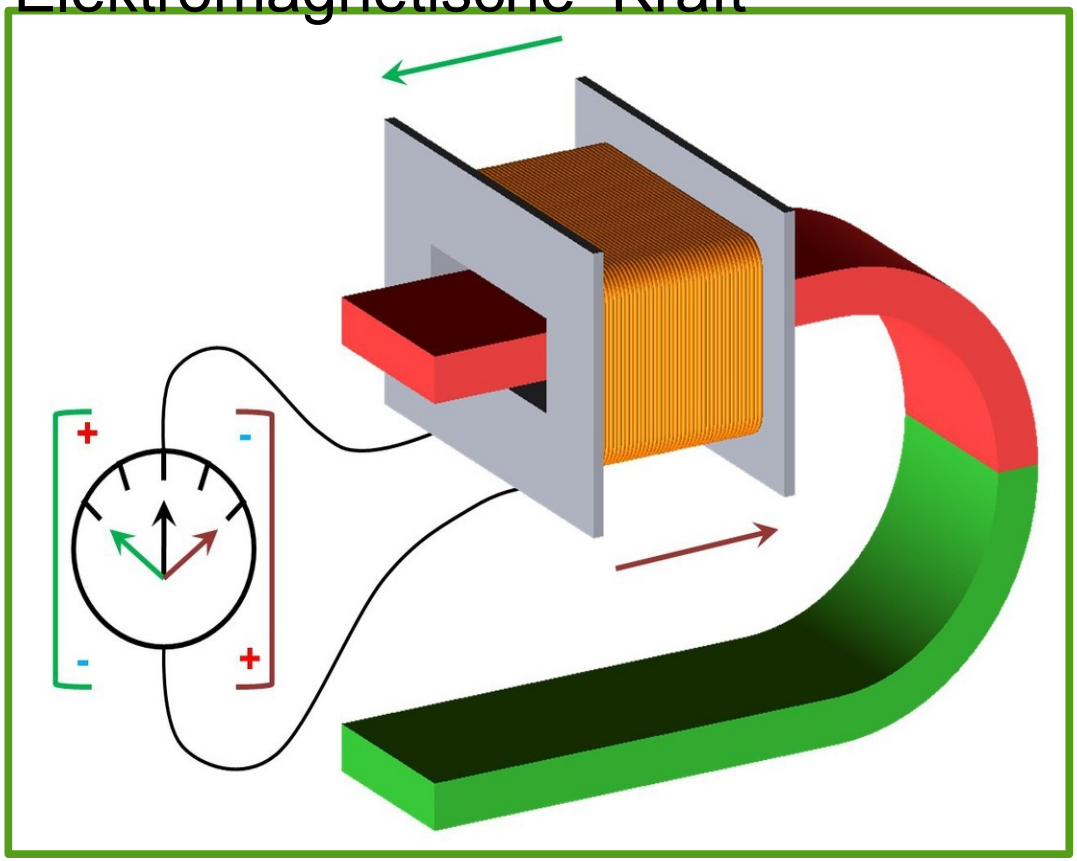


Die Kräfte

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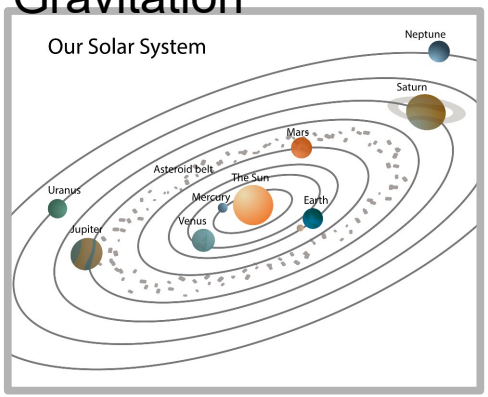


Elektromagnetische Kraft

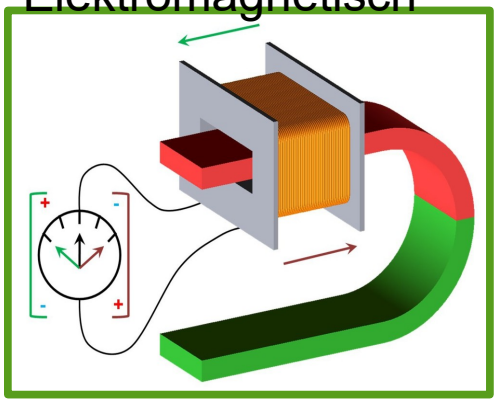


Die Kräfte

Gravitation

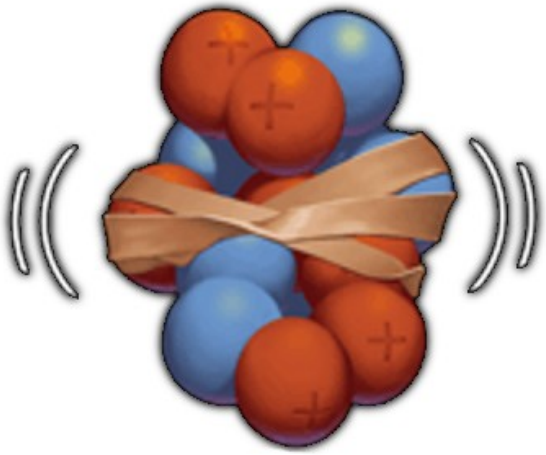


Elektromagnetisch



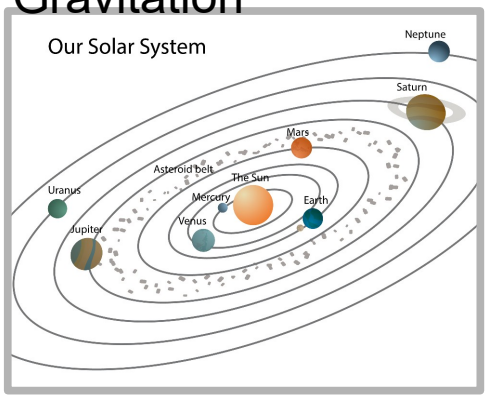
Starke Kraft

Atomkern

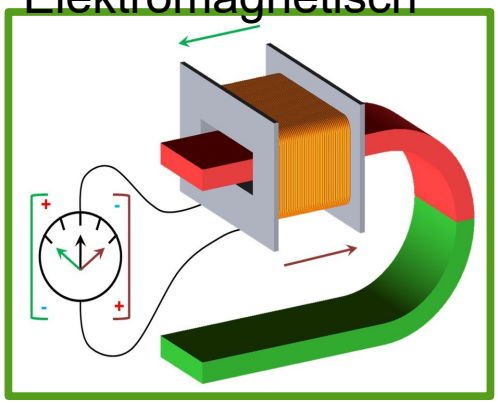


Die Kräfte

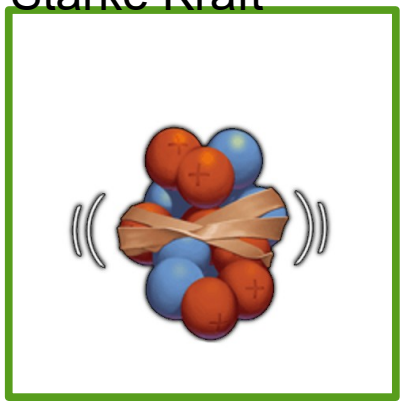
Gravitation



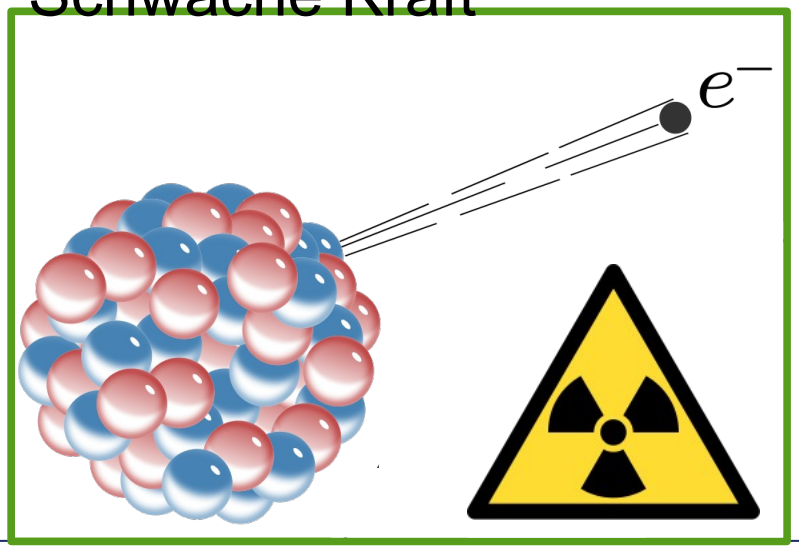
Elektromagnetisch



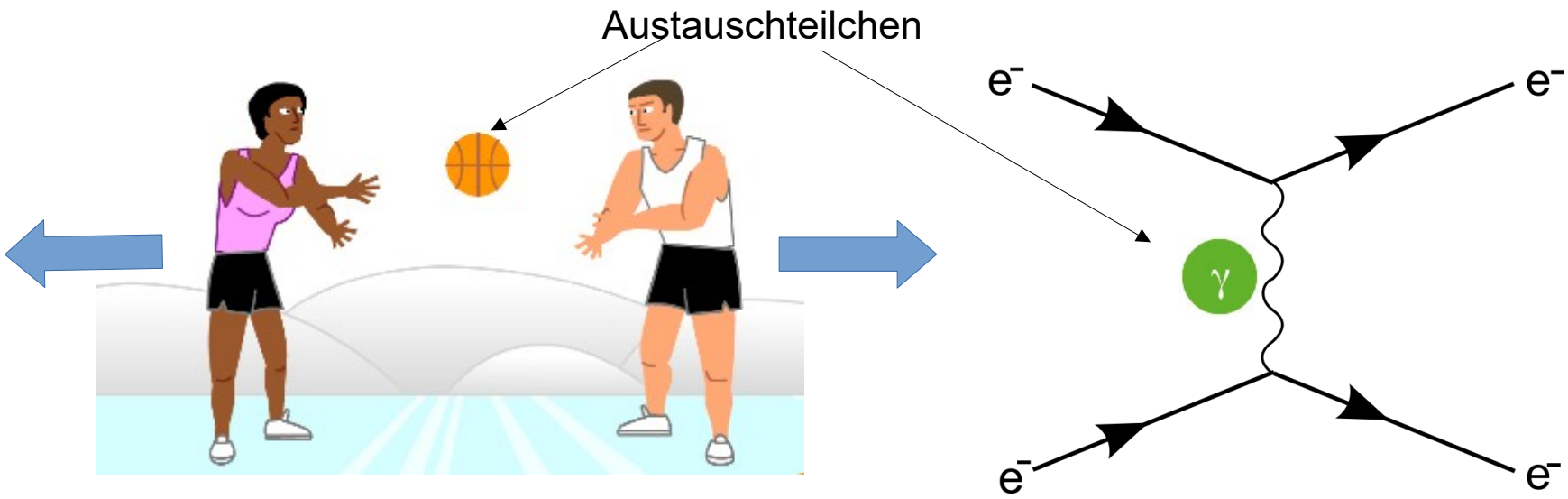
Starke Kraft



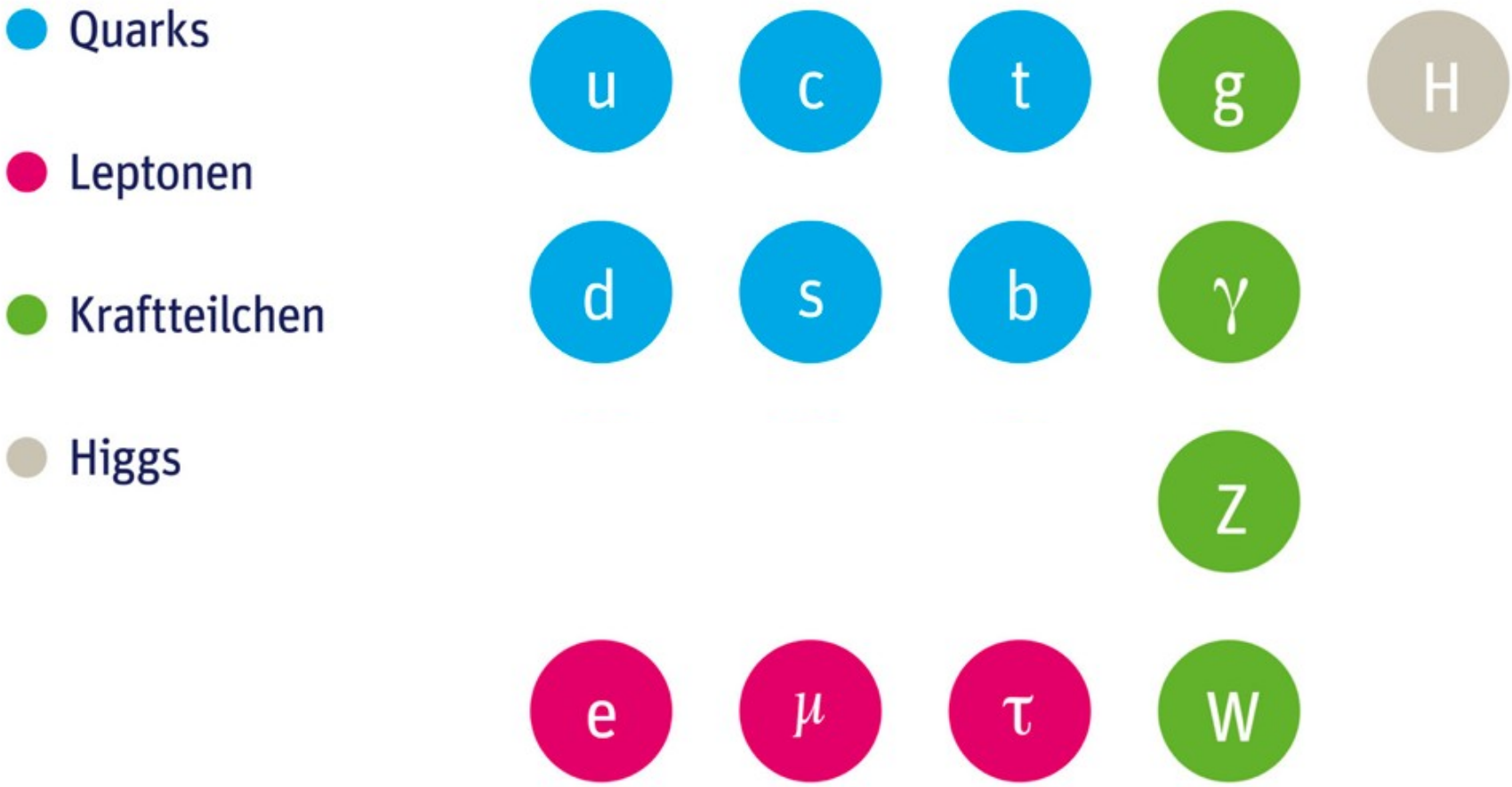
Schwache Kraft



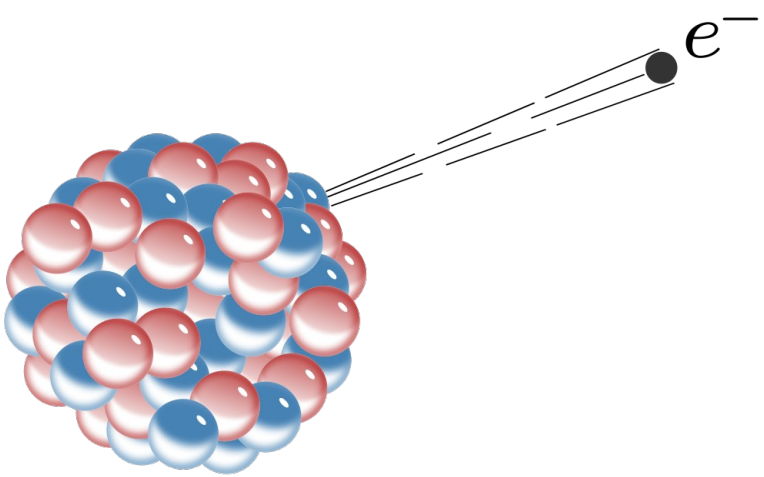
Die Kräfte im Teilchenbild

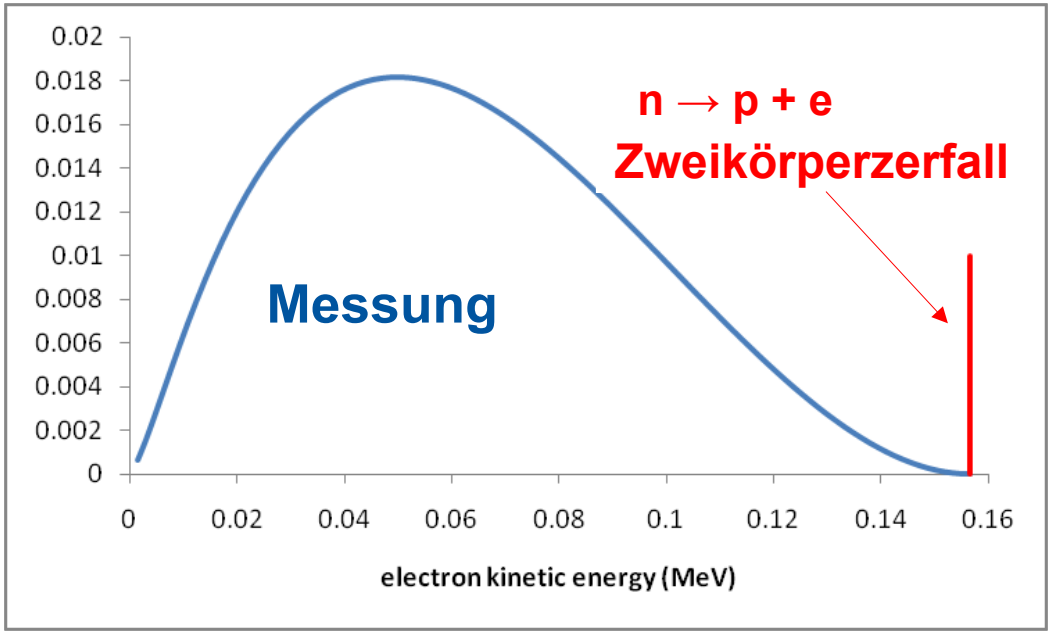


Die vollständige(?) Standardmodell

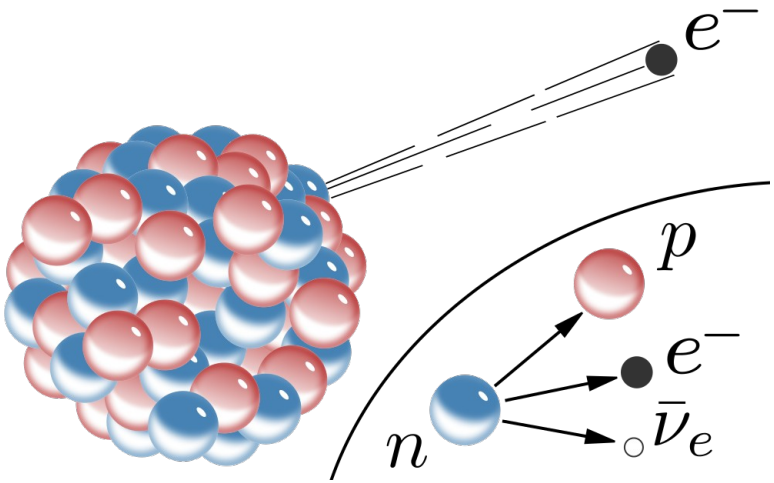


Der β-Zerfall



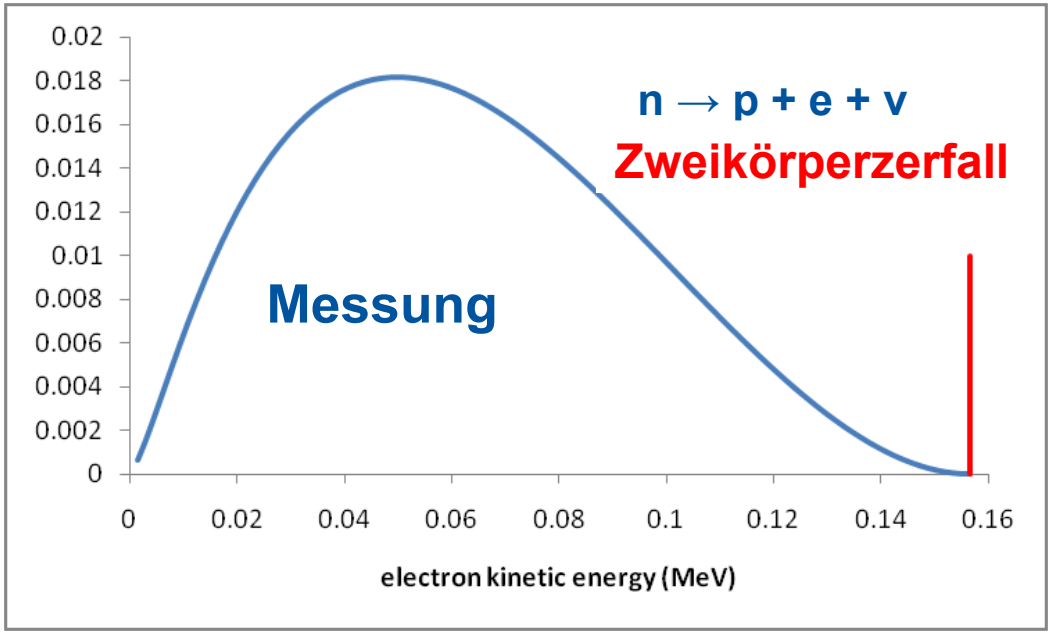


Der β-Zerfall





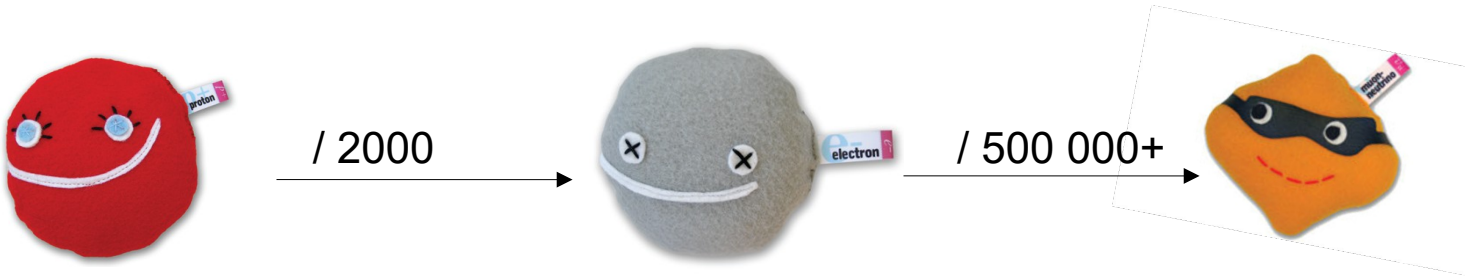
I have done a terrible thing, I have postulated a particle that cannot be detected.



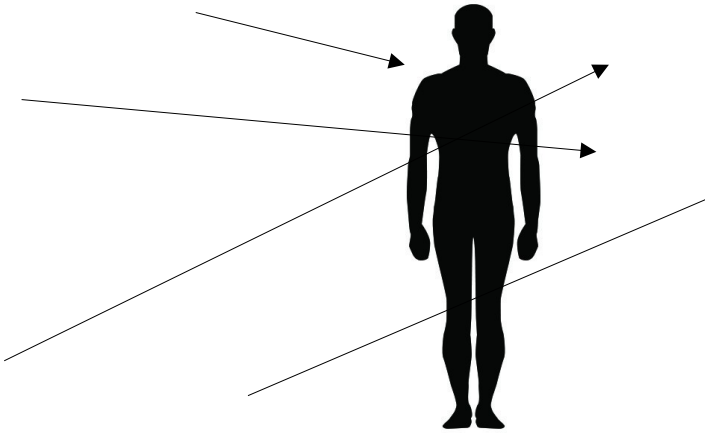


Das Neutrino

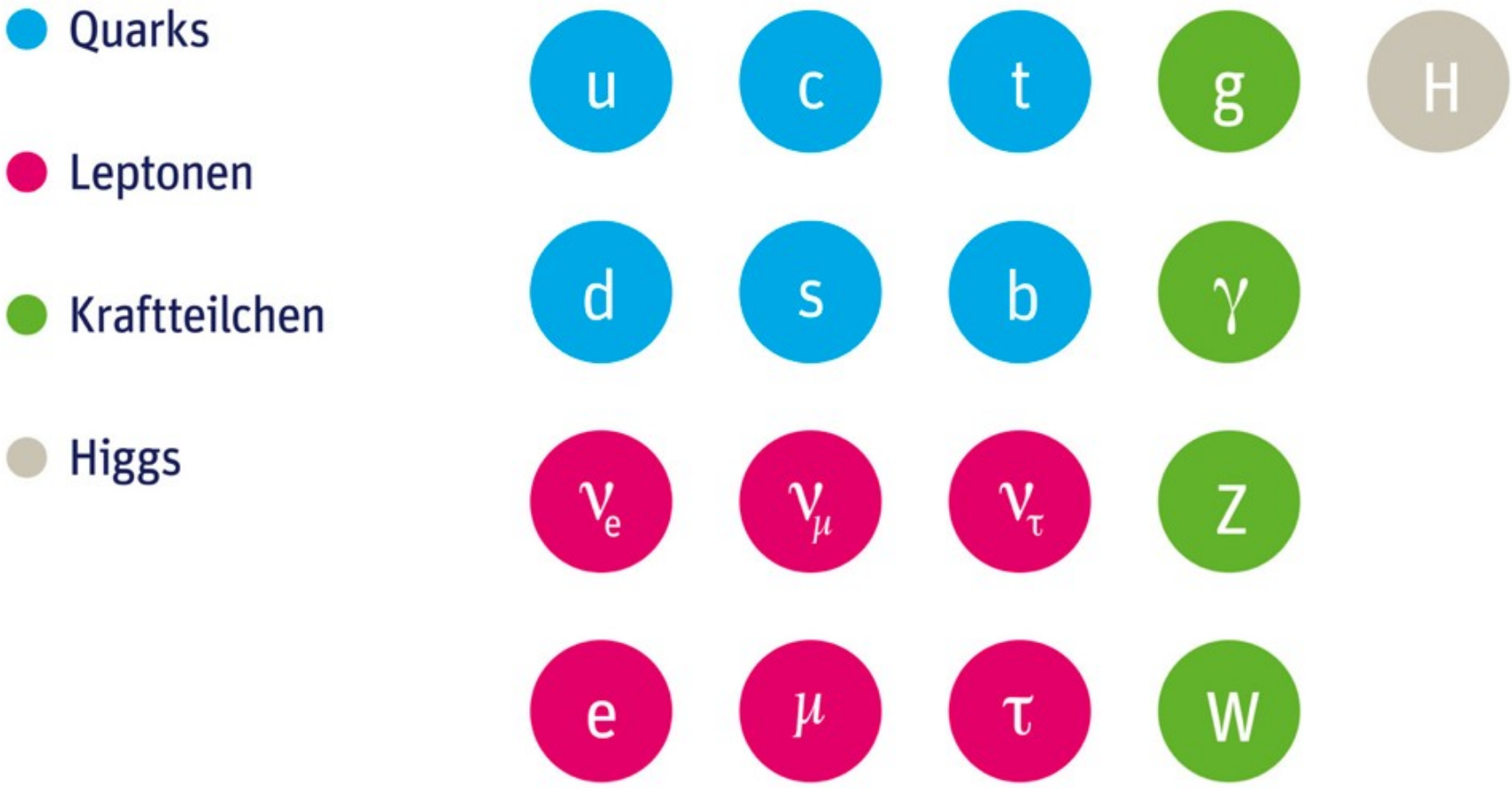
- Elektrisch ungeladen und fast masselos
- Masse:



- “Geisterhaft”, nimmt nur an schwacher WW teil
  (10^{-11} Wahrscheinlichkeit beim Flug durch die Erde @ 1 MeV)
- Durch euch fliegen etwa $5 \cdot 10^{14}$ Sonnenneutrinos pro Sekunde

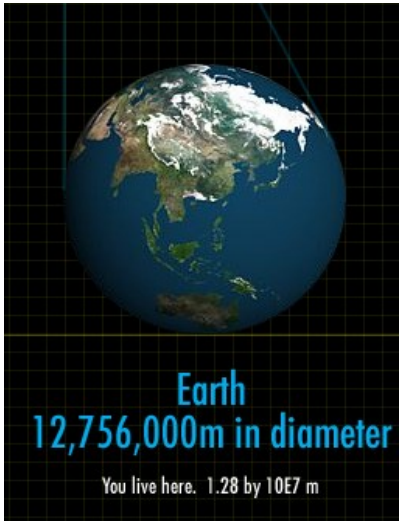


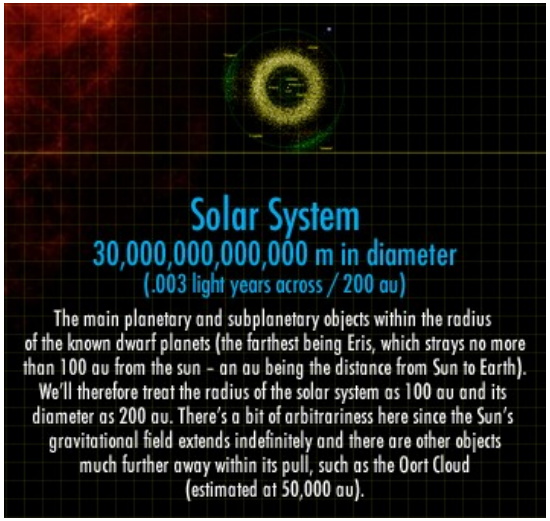
Die vollständige(?) Standardmodell

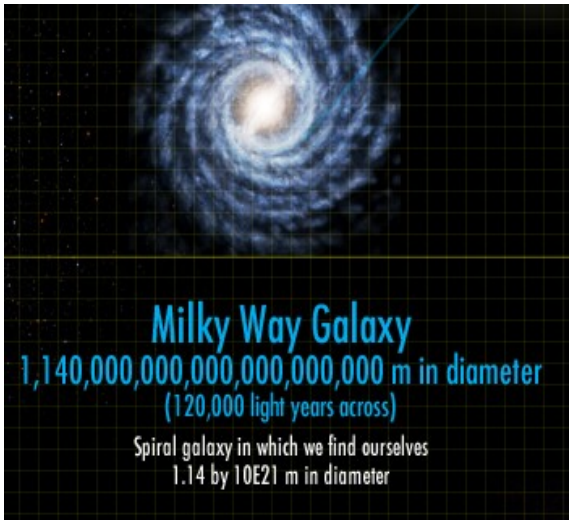


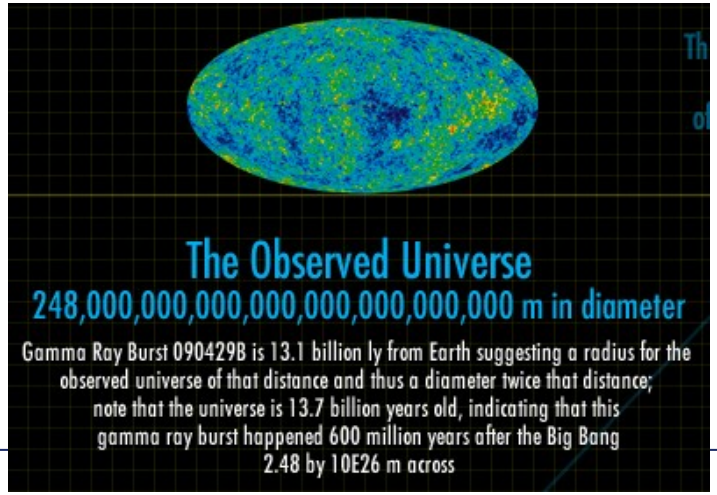
Astrophysik





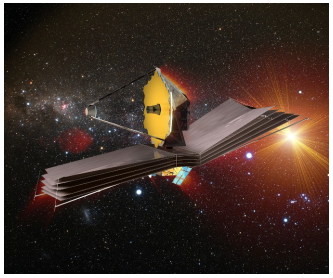






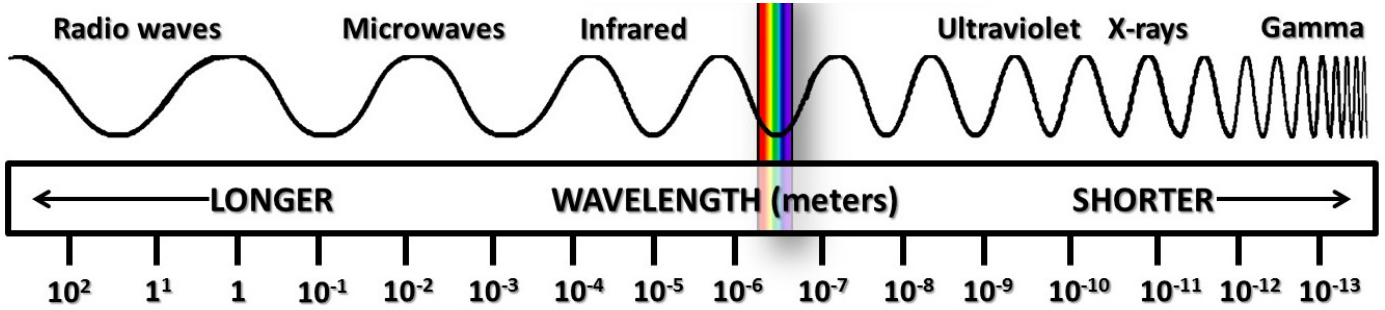
Photon-Astronomie

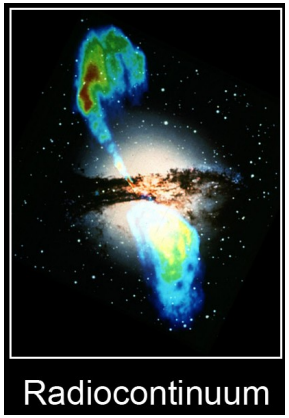










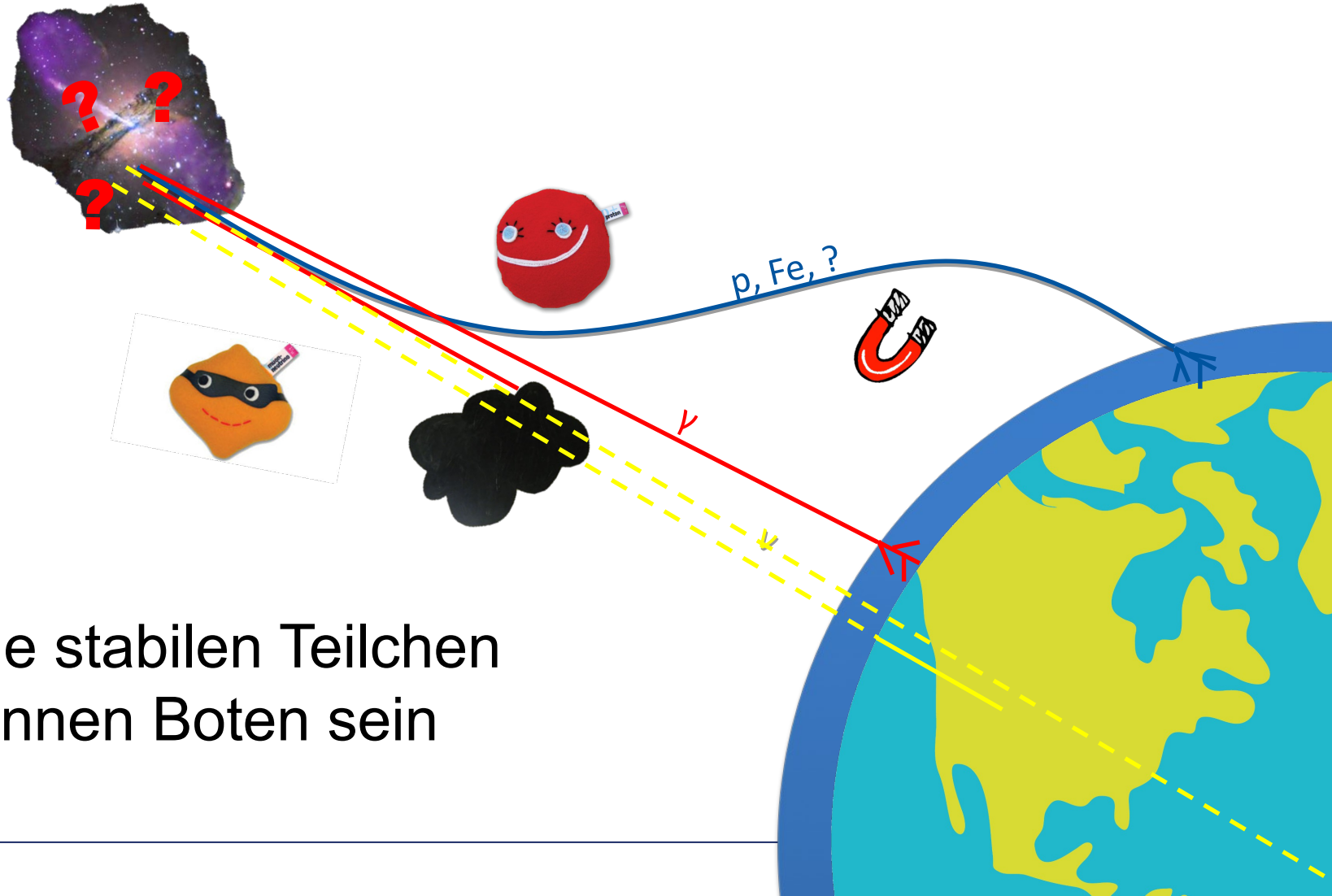






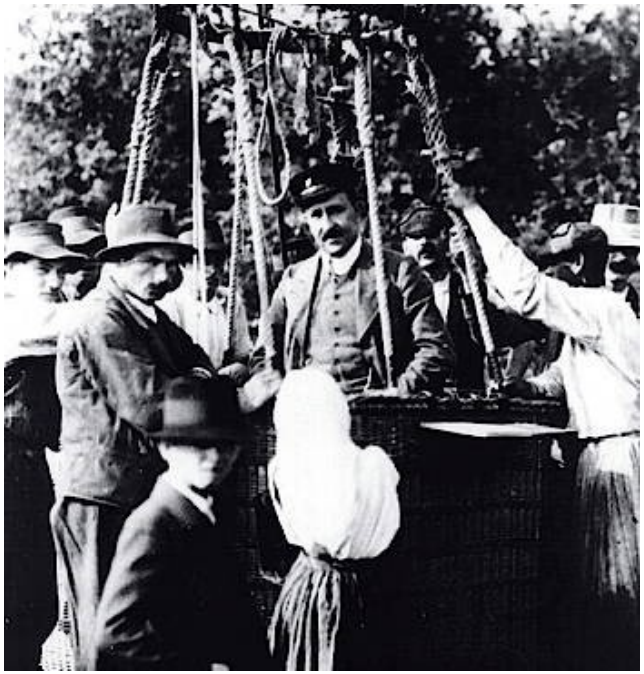


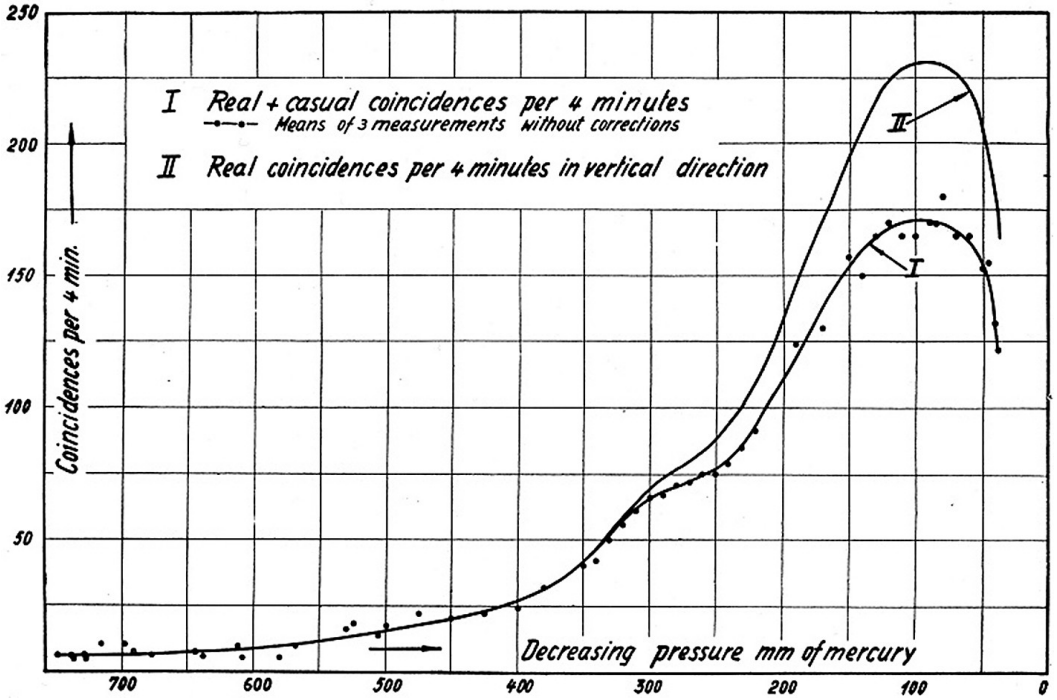
Was hat das mit Teilchenphysik zu tun?



- Alle stabilen Teilchen können Boten sein

Höhenstrahlung



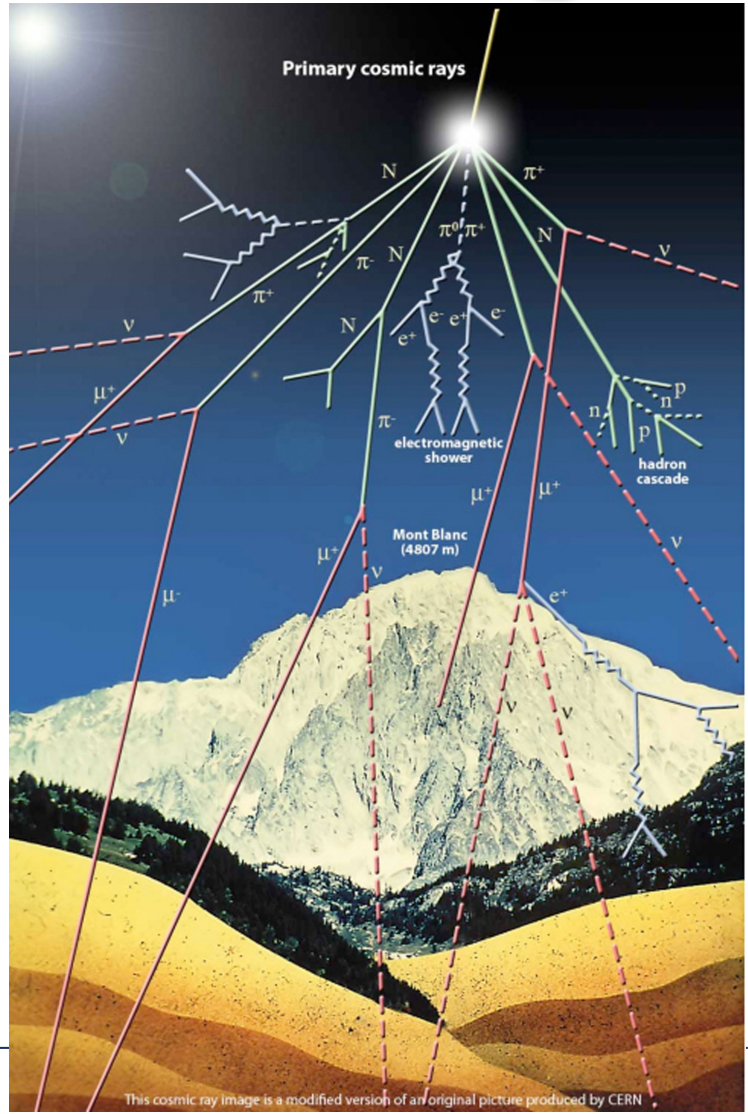


- Radioaktivität nimmt (entgegen der Erwartung) mit der Höhe zu
  → die Erde muss von geladenen Teilchen getroffen werden

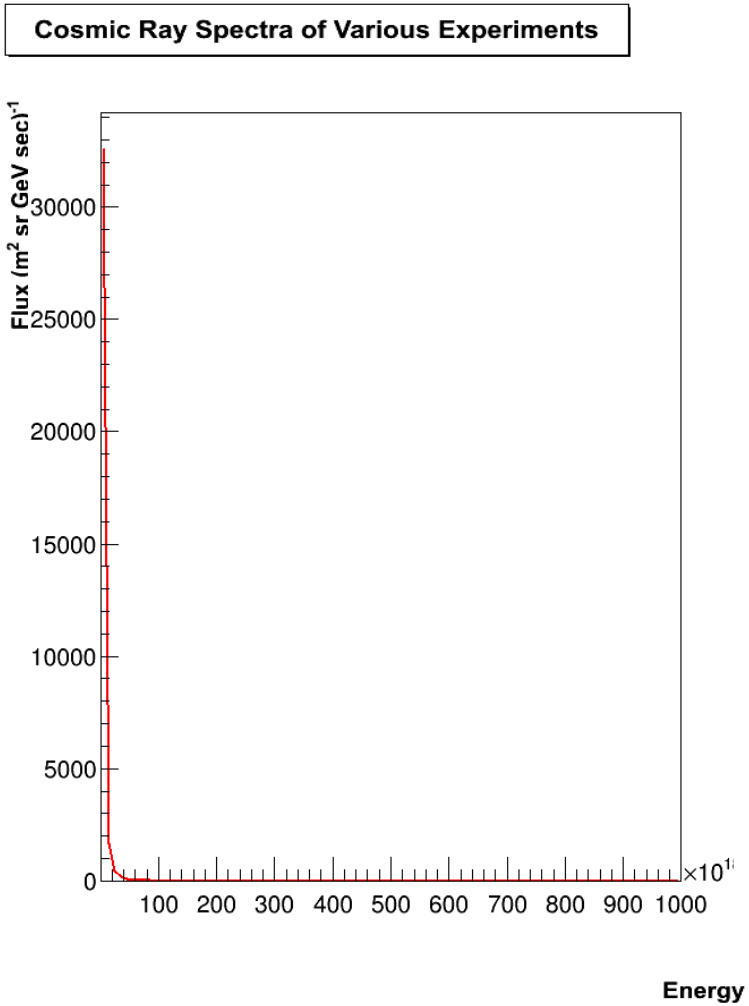
Luftschauer

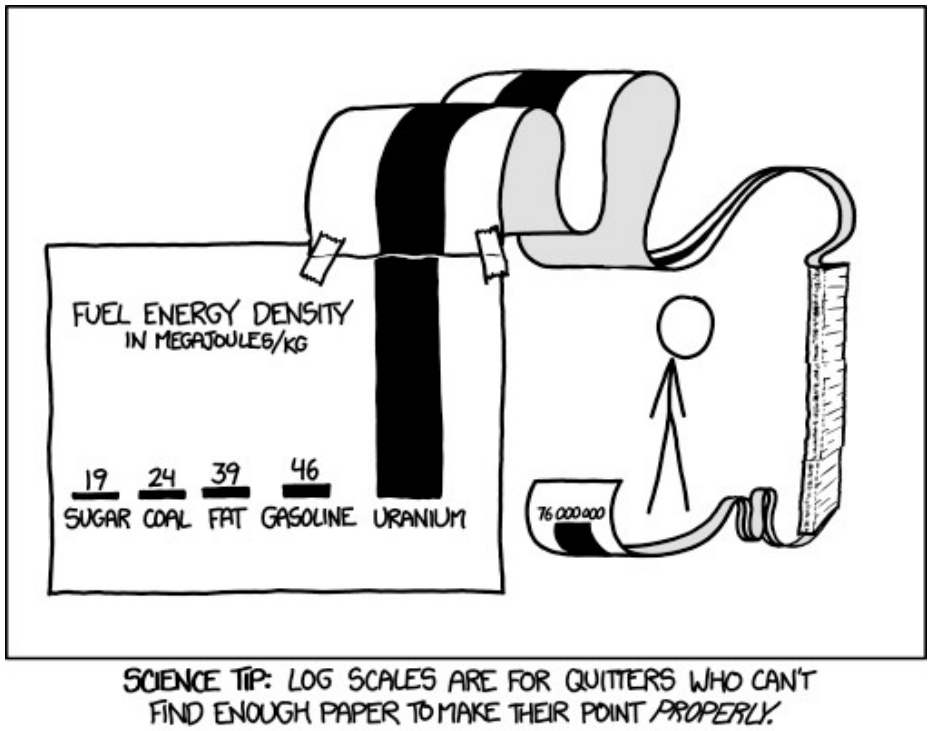
- Primärteilchen interagiert hoch in der Atmosphäre und bildet Schauerfront
- Sekundärteilchen zerfallen (teilweise) auf dem Weg zum Boden



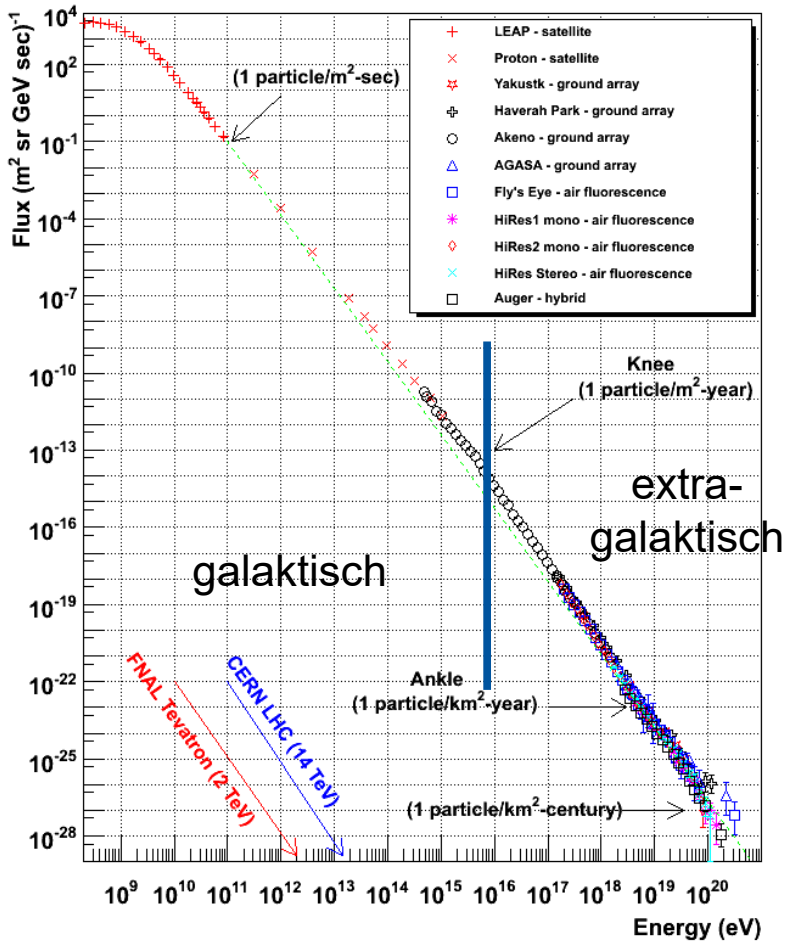


Energiespektrum





Energiespektrum



- Doppellogarithmisch Achsen
- (Eine Größenordnung pro Strich)

- Anzahl ~ $E^{-2,x}$

- Substrukturen geben Aufschluss über veränderte Herkunft

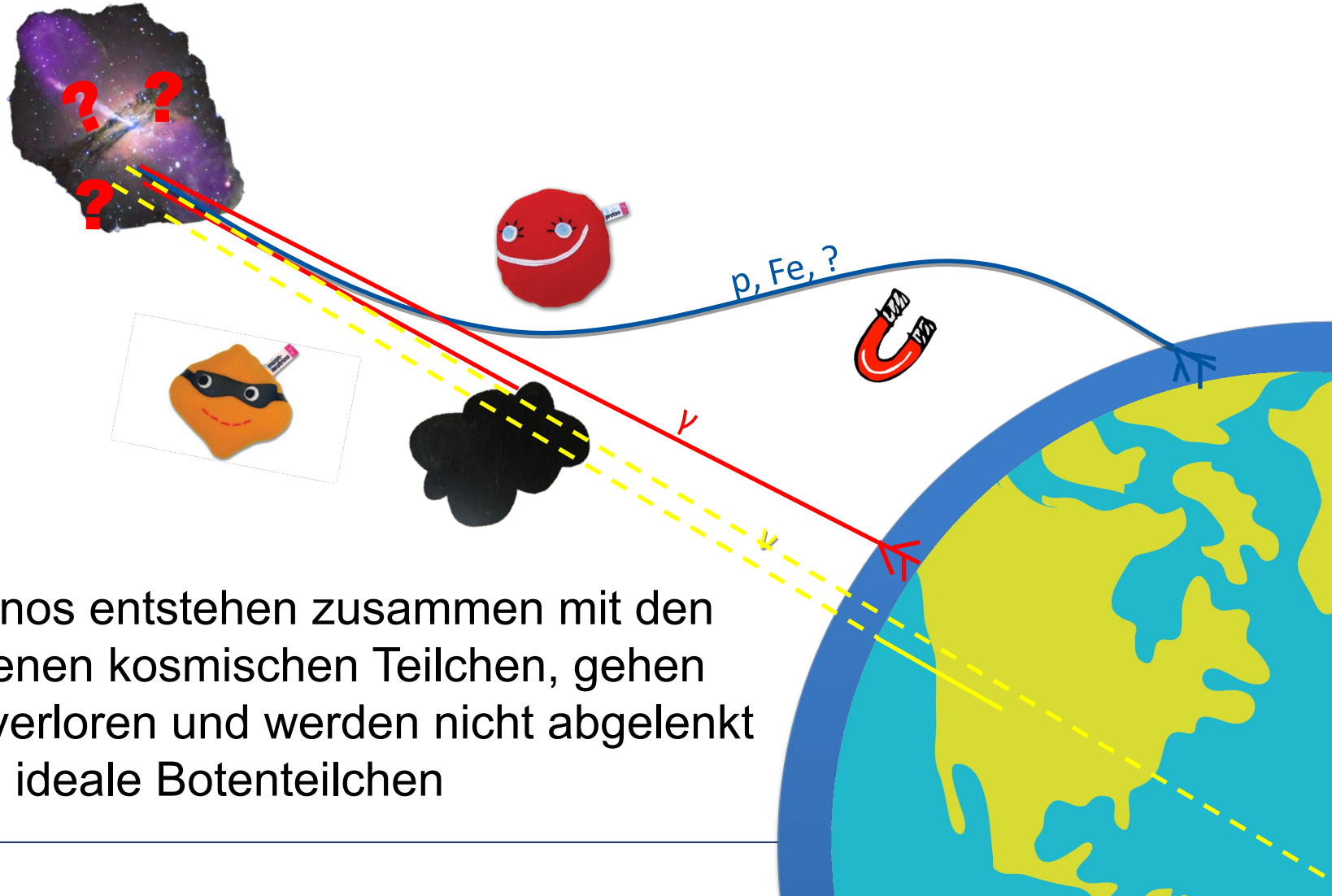
Richtung

Die geladenen Teilchen werden in intergalaktischen Magnetfelden abgelenkt und zeigen nicht mehr auf ihren Ursprung



→ **trotz Jahrzehnten an Forschung kennen wir die Quellen der kosmischen Strahlung kaum**

Neutrino-Astronomie

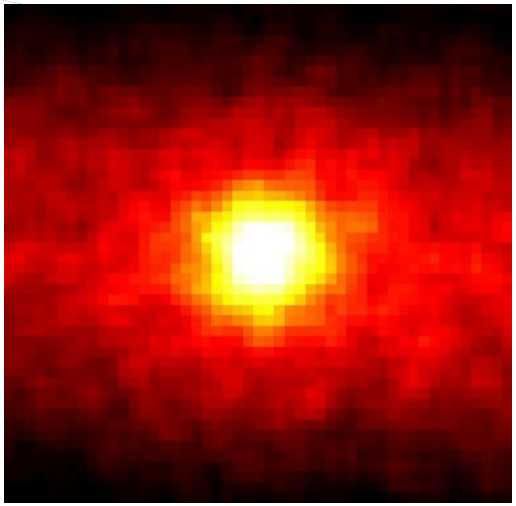


- Neutrinos entstehen zusammen mit den geladenen kosmischen Teilchen, gehen nicht verloren und werden nicht abgelenkt
  → ideale Botenteilchen

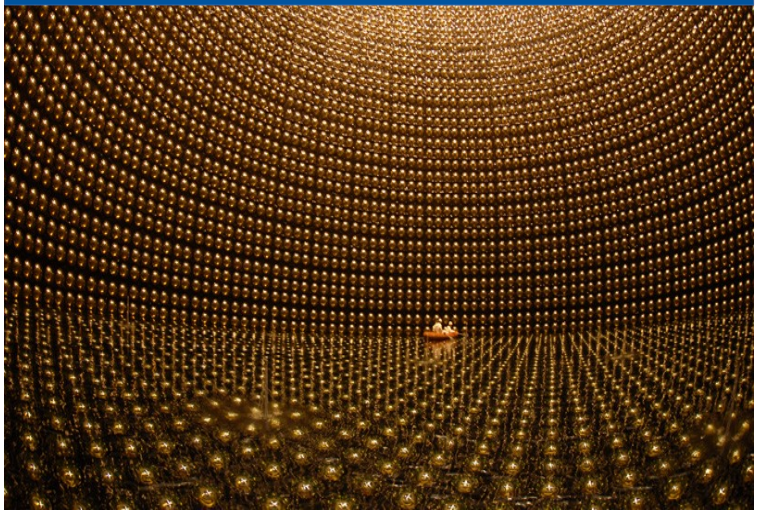
Neutrino - Quellen

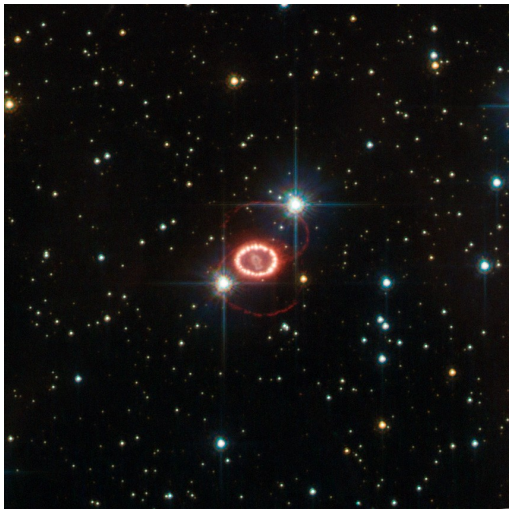
- Sonne (7·1010 pro cm2 und Sekunde)
  ~5000 pro Jahr gemessen
- SN1987a (Sternexplosion)
  24 Neutrinos gemessen





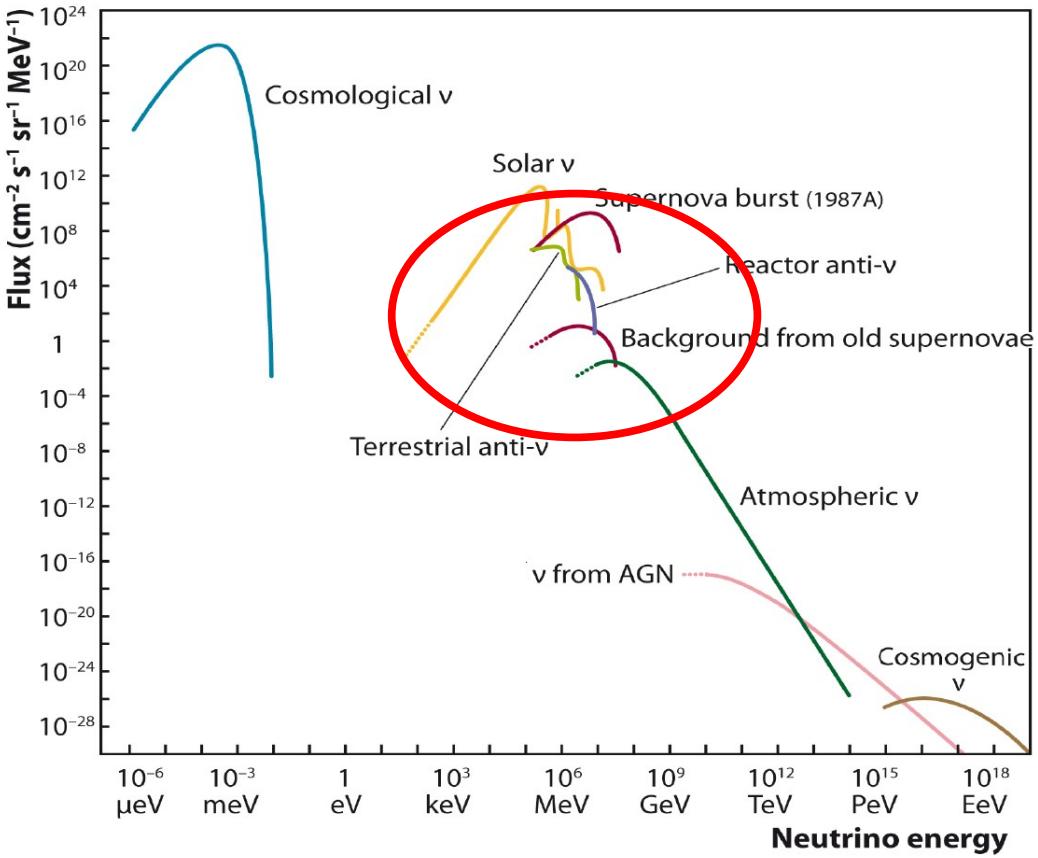
Detektor ~ 0,00003 km^3





Herausforderung 1

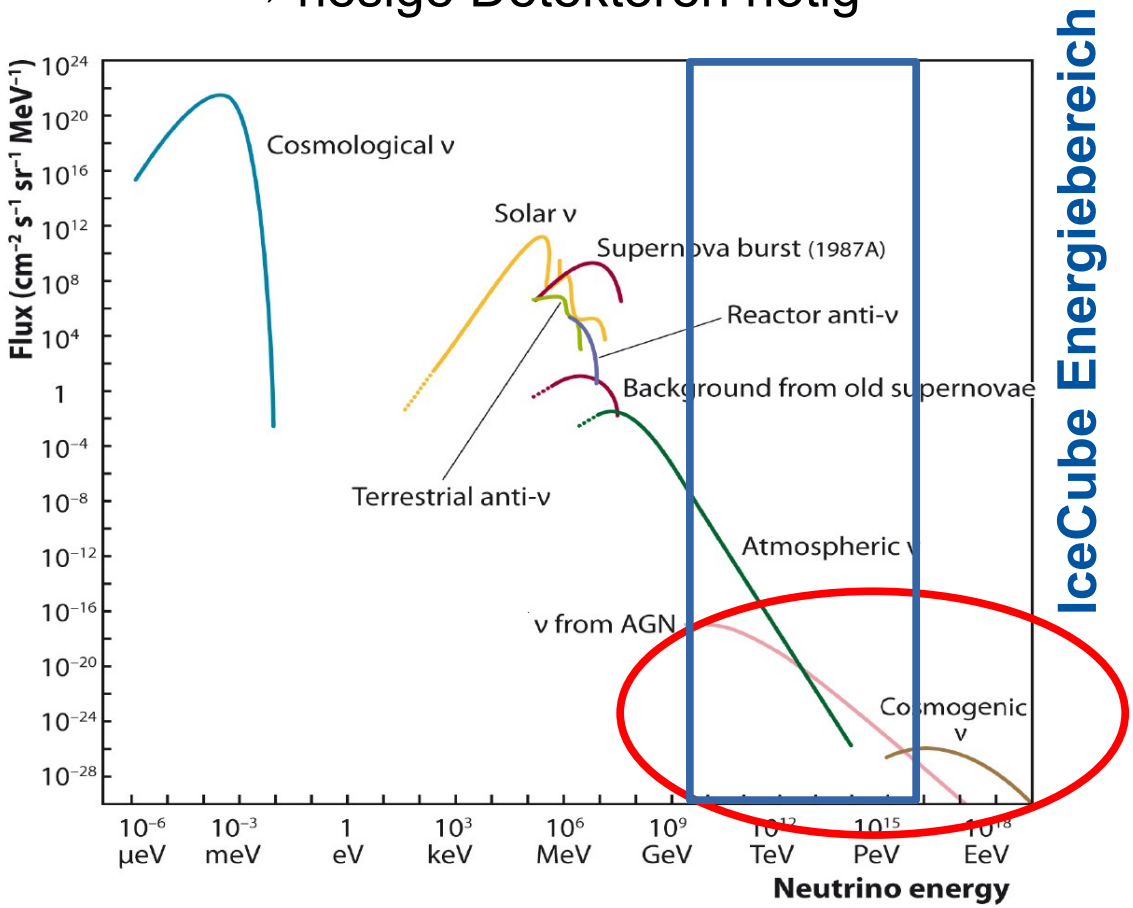
- Nur wenige Ereignisse pro km^2 und Jahr erwartet
  → riesige Detektoren nötig





Herausforderung 1

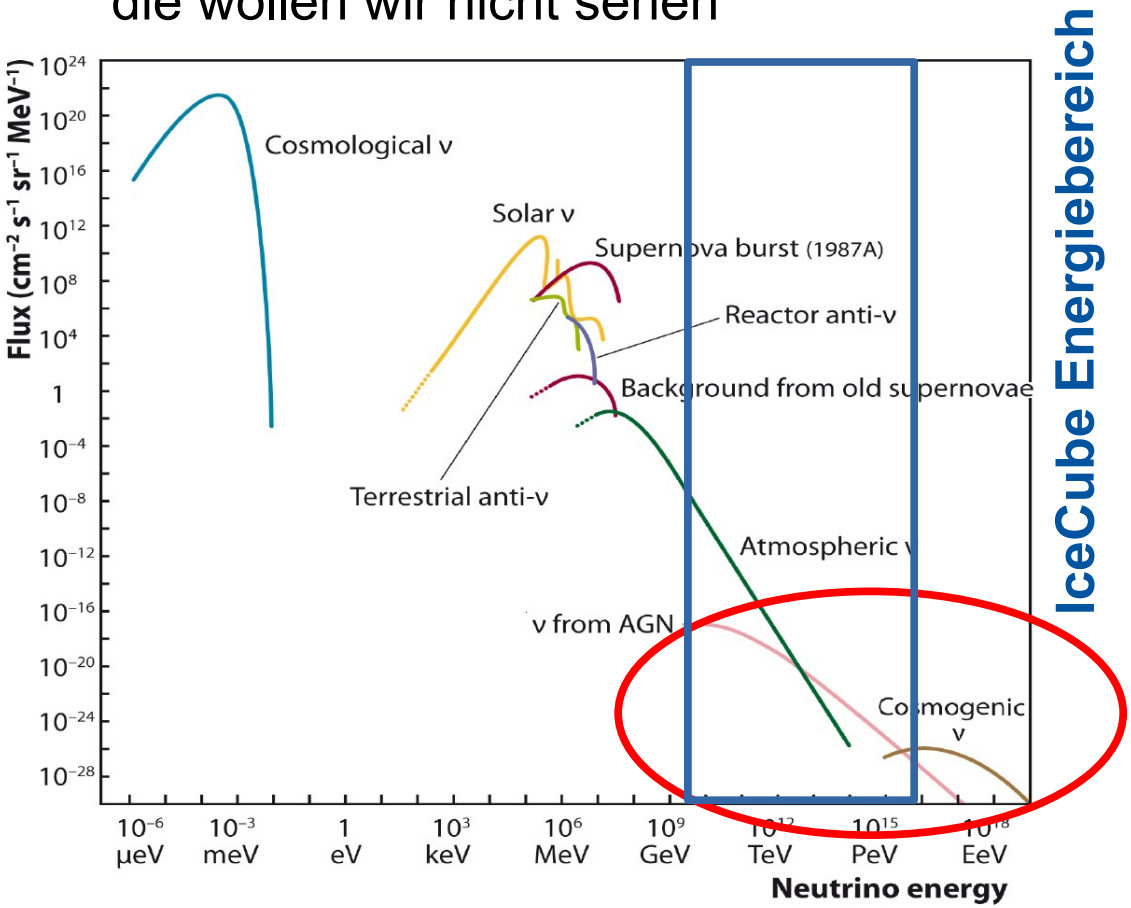
- Nur wenige Ereignisse pro km^2 und Jahr erwartet
  → riesige Detektoren nötig





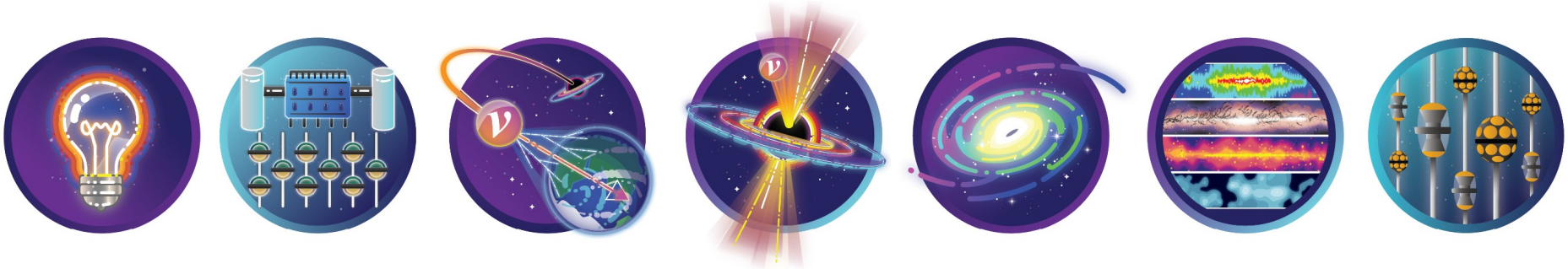
Herausforderung 2

- Neutrinos entstehen auch in den Luftschauern geladener Teilchen, die wollen wir nicht sehen





Wir haben 2013 die ersten extrasolaren Neutrinos gefunden (wie siehe nächsten Vortrag), aber die Himmelskarte füllt sich nur langsam.



1988
TELESCOPE IN THE ICE
ENVISIONED

2011
ICECUBE
COMPLETED

2013
ASTROPHYSICAL NEUTRINOS
DISCOVERED

2018
BLAZAR TXS 0506+056
NEUTRINO EMISSION IDENTIFIED

2022
ACTIVE GALAXY NGC 1068
NEUTRINO EMISSION IDENTIFIED

2023
MILKY WAY
NEUTRINO EMISSION IDENTIFIED

2026
ICECUBE UPGRADE
COMPLETED



Nobelpreis 2026