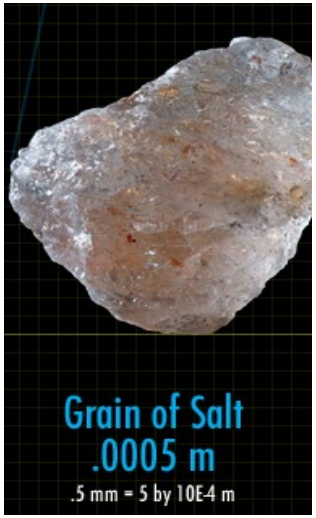
Friedrich-Alexander-Universität
Erlangen-Nürnberg

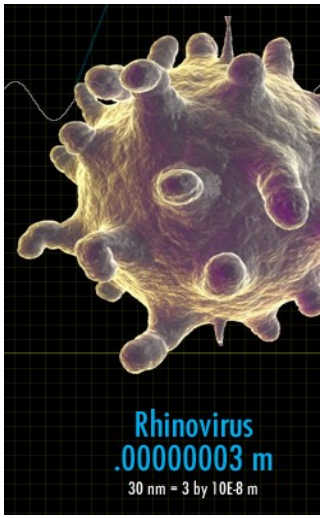
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

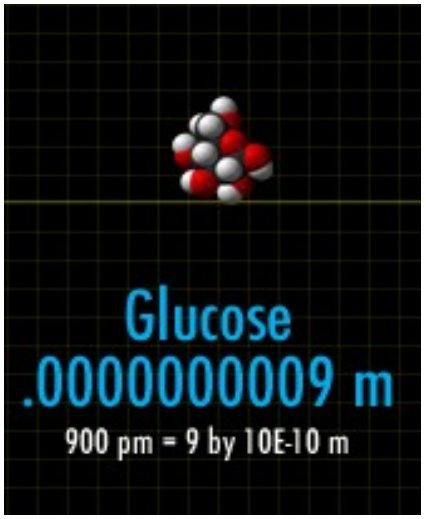
IceCube Masterclass 2025
Astroteilchenphysik

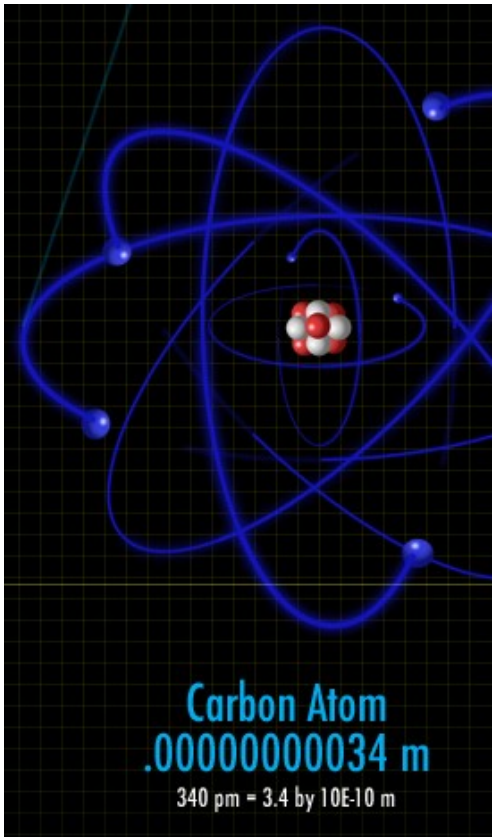
Martin Rongen
Erlangen, 02.10.2025

Teilchenphysik

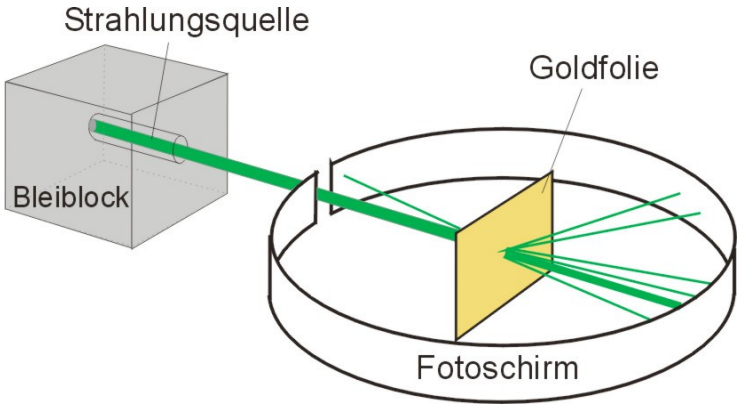


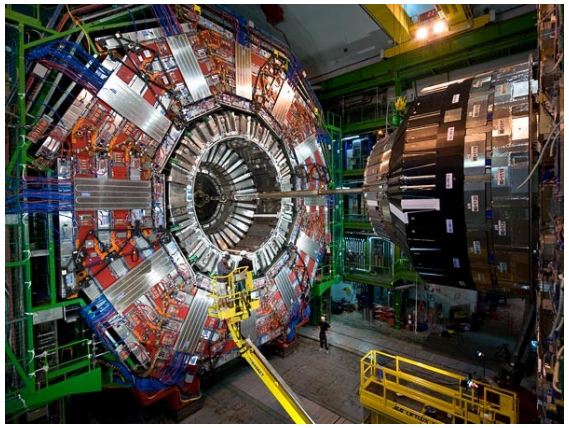




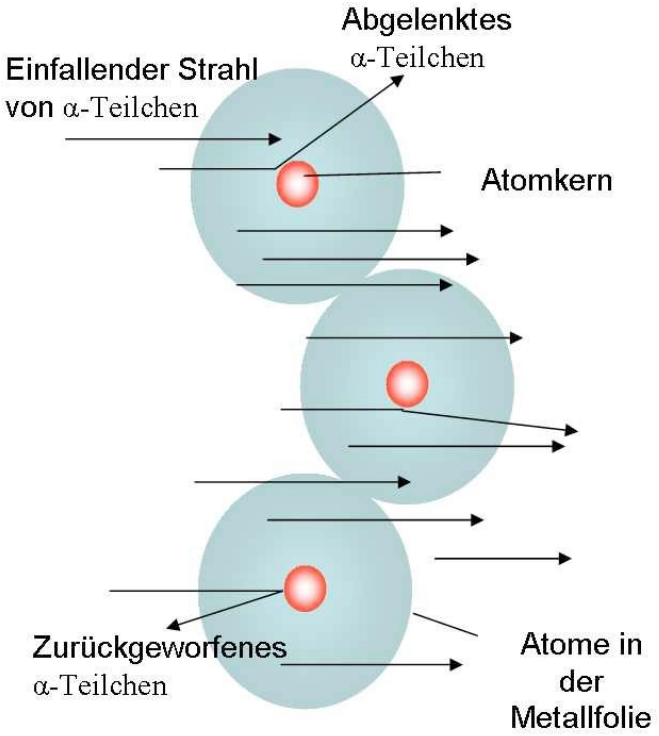


Streuexperimente





CMS Masterclass



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

Das Standardmodell

- Quarks
- Leptonen

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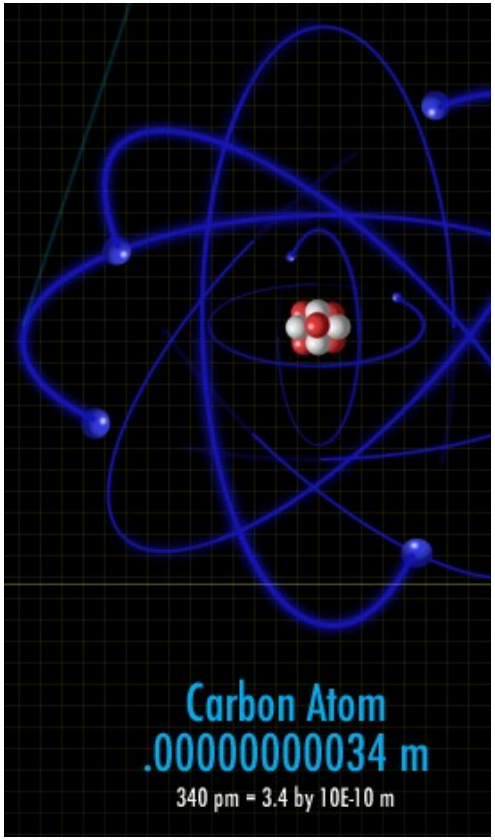
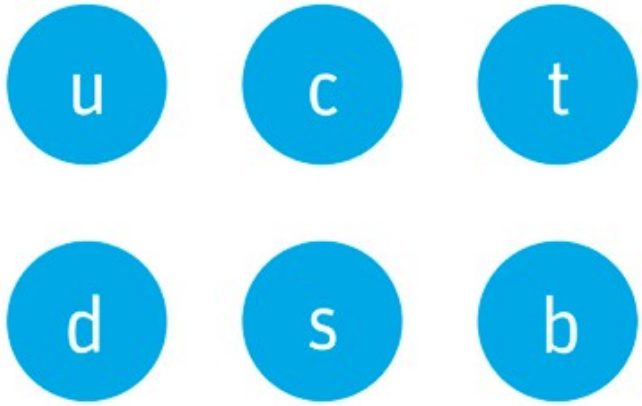
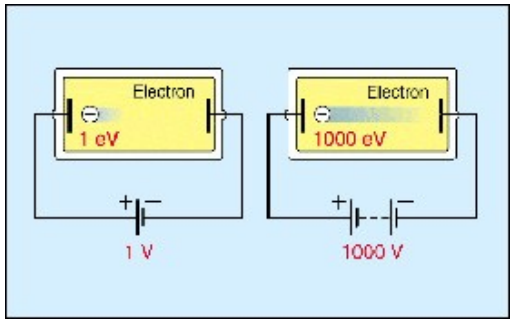


Das Standardmodell

- Quarks
- Leptonen





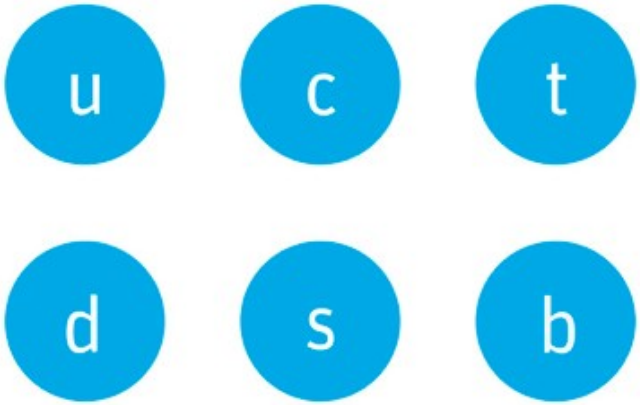
schwerer

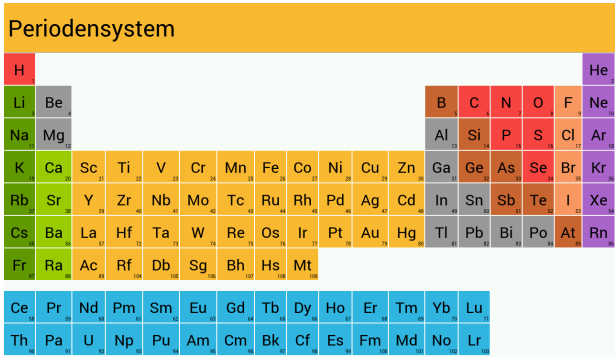
500keV 100MeV 2GeV

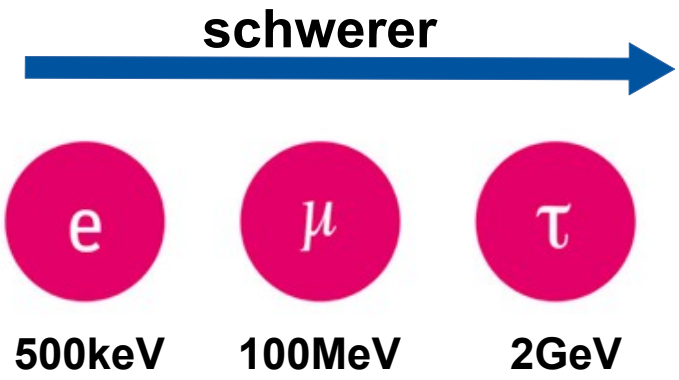
Kilo	10^3
Mega	10^6
Giga	10^9
Tera	10^{12}
Peta	10^{15}

Das Standardmodell

- Quarks
- Leptonen

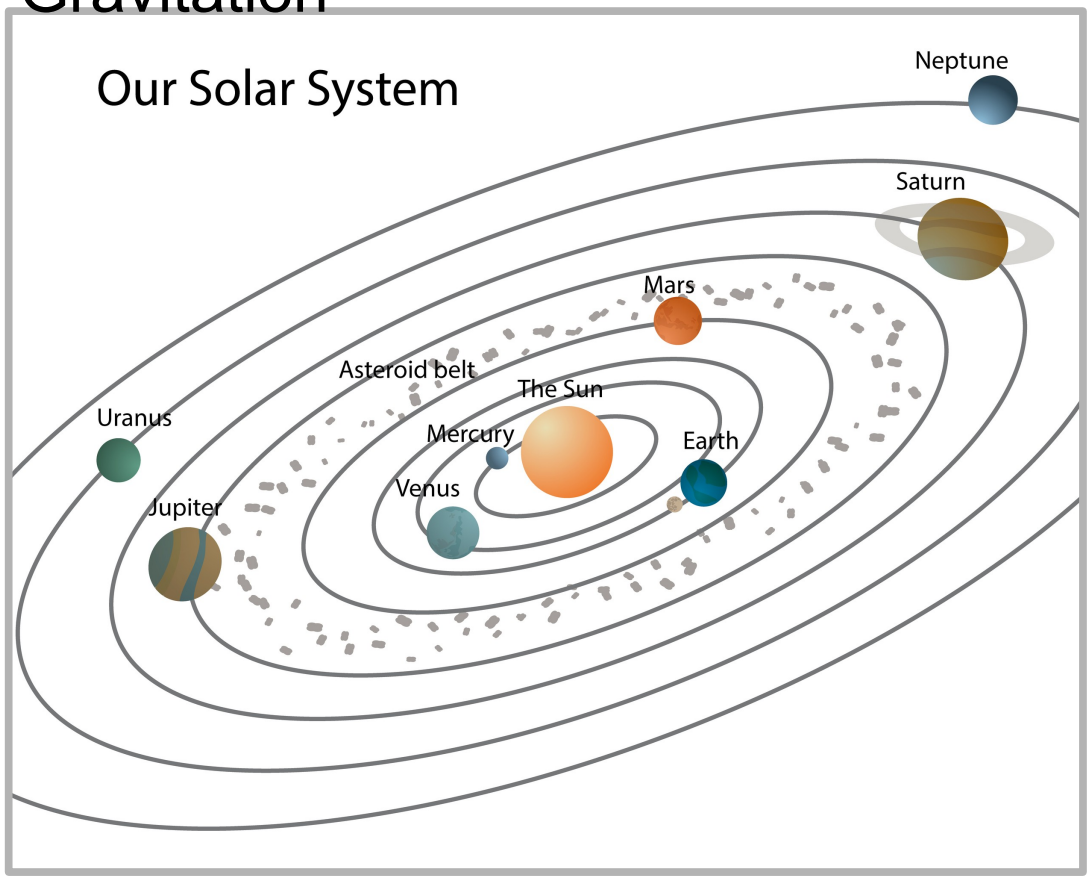






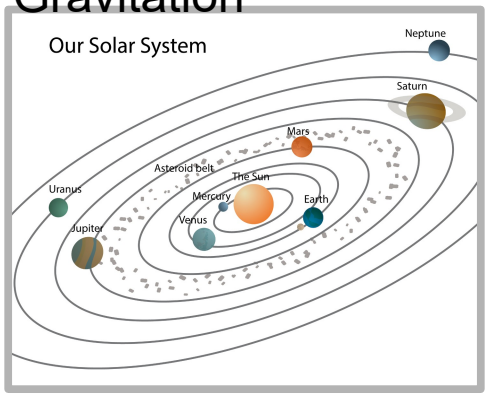
Die Kräfte

Gravitation

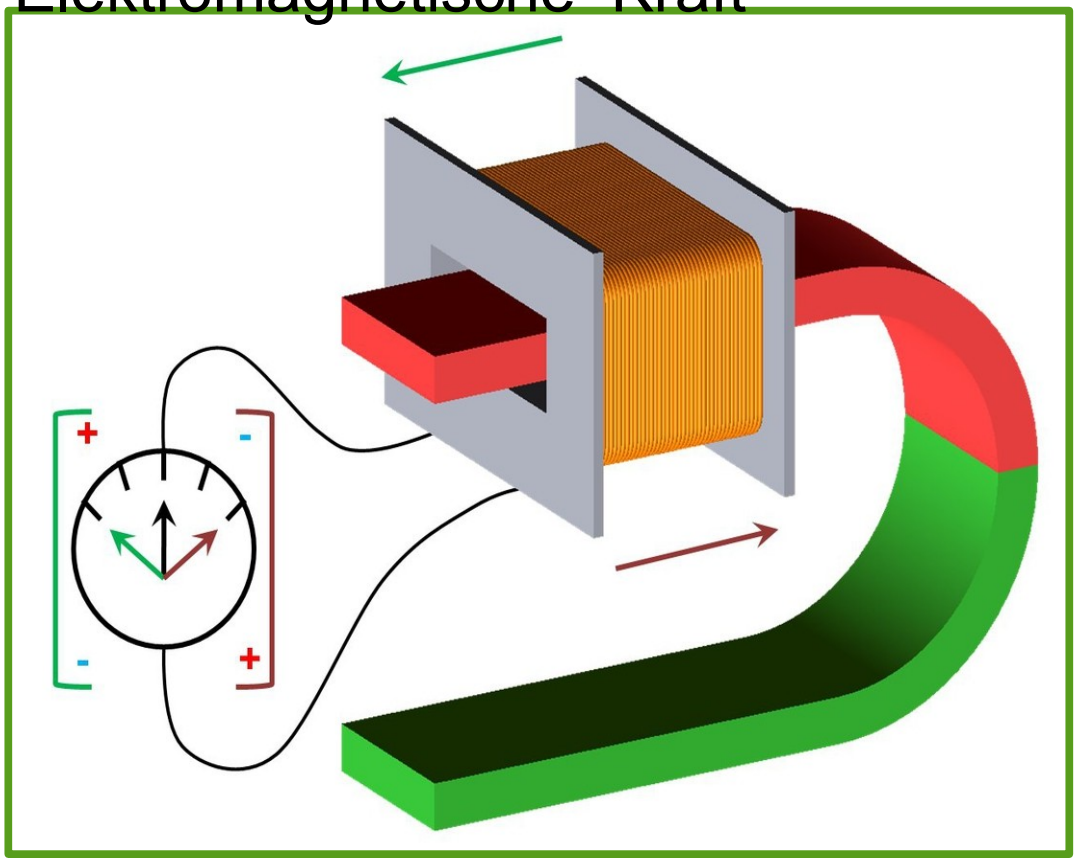


Die Kräfte

Gravitation

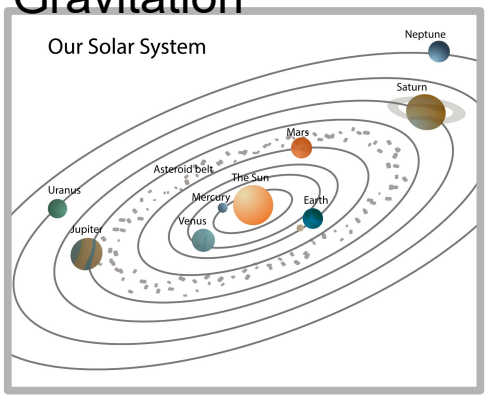


Elektromagnetische Kraft

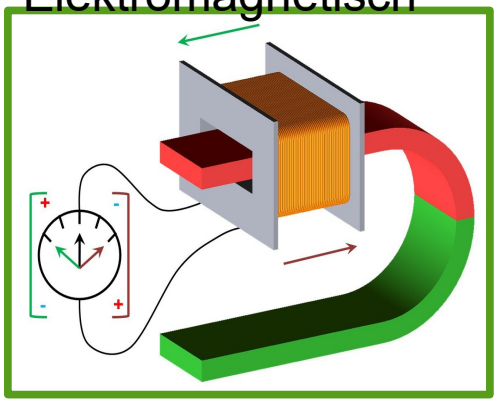


Die Kräfte

Gravitation

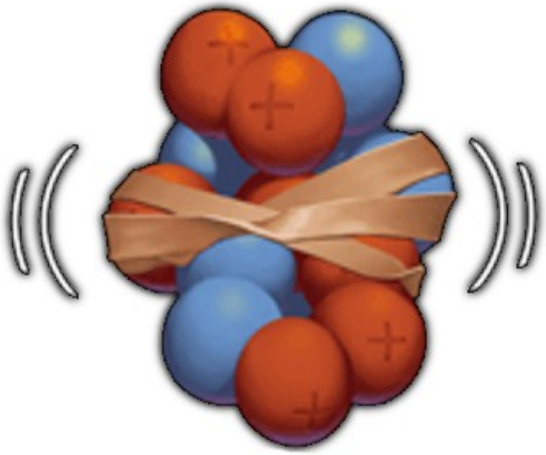


Elektromagnetisch



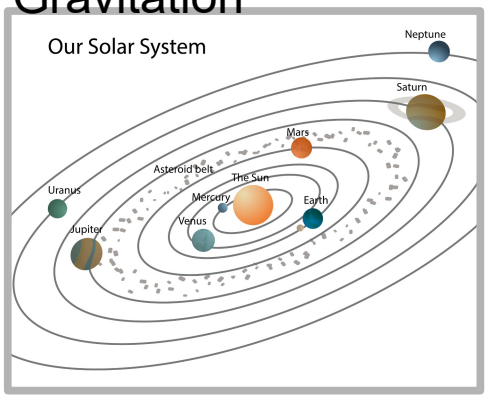
Starke Kraft

Atomkern

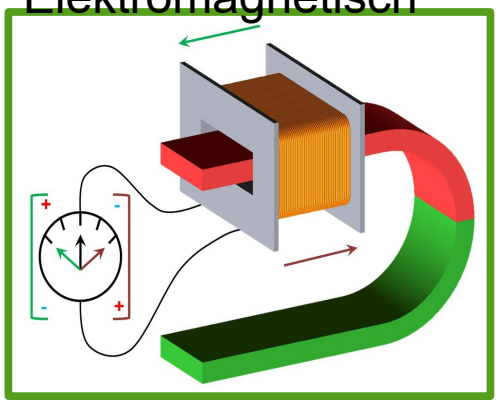


Die Kräfte

Gravitation



Elektromagnetisch



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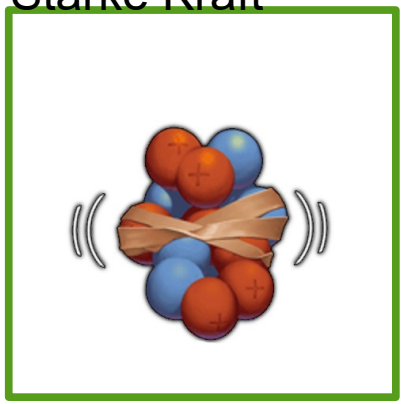
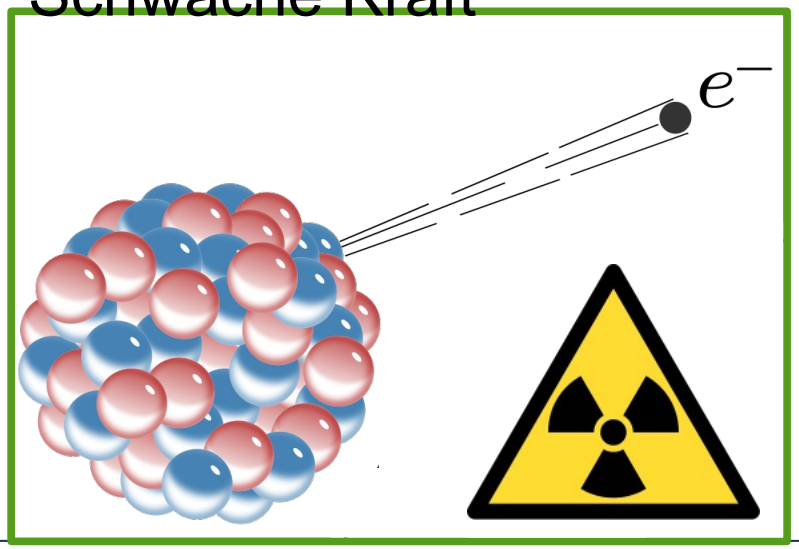
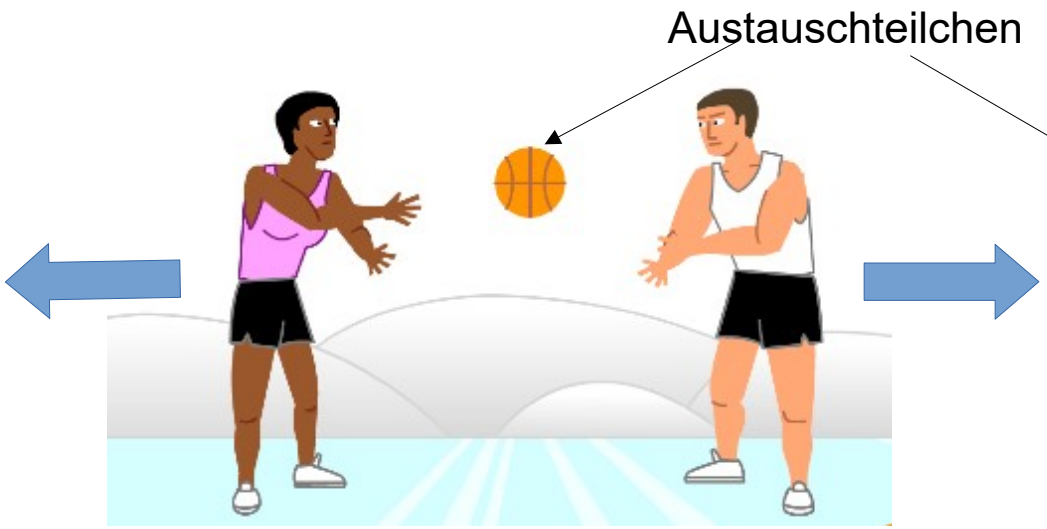
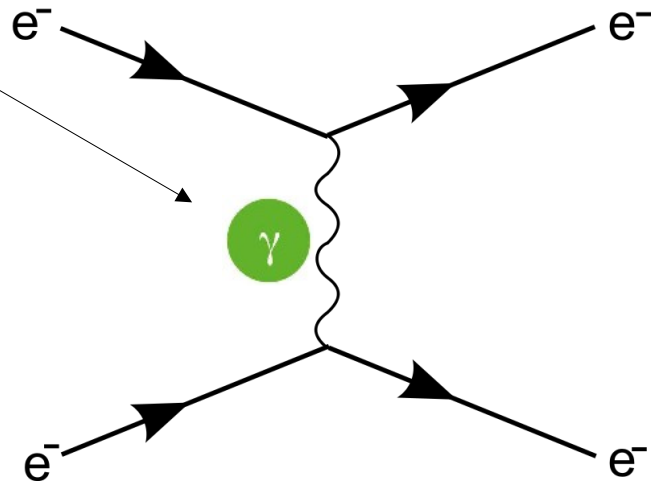


Schwache Kraft

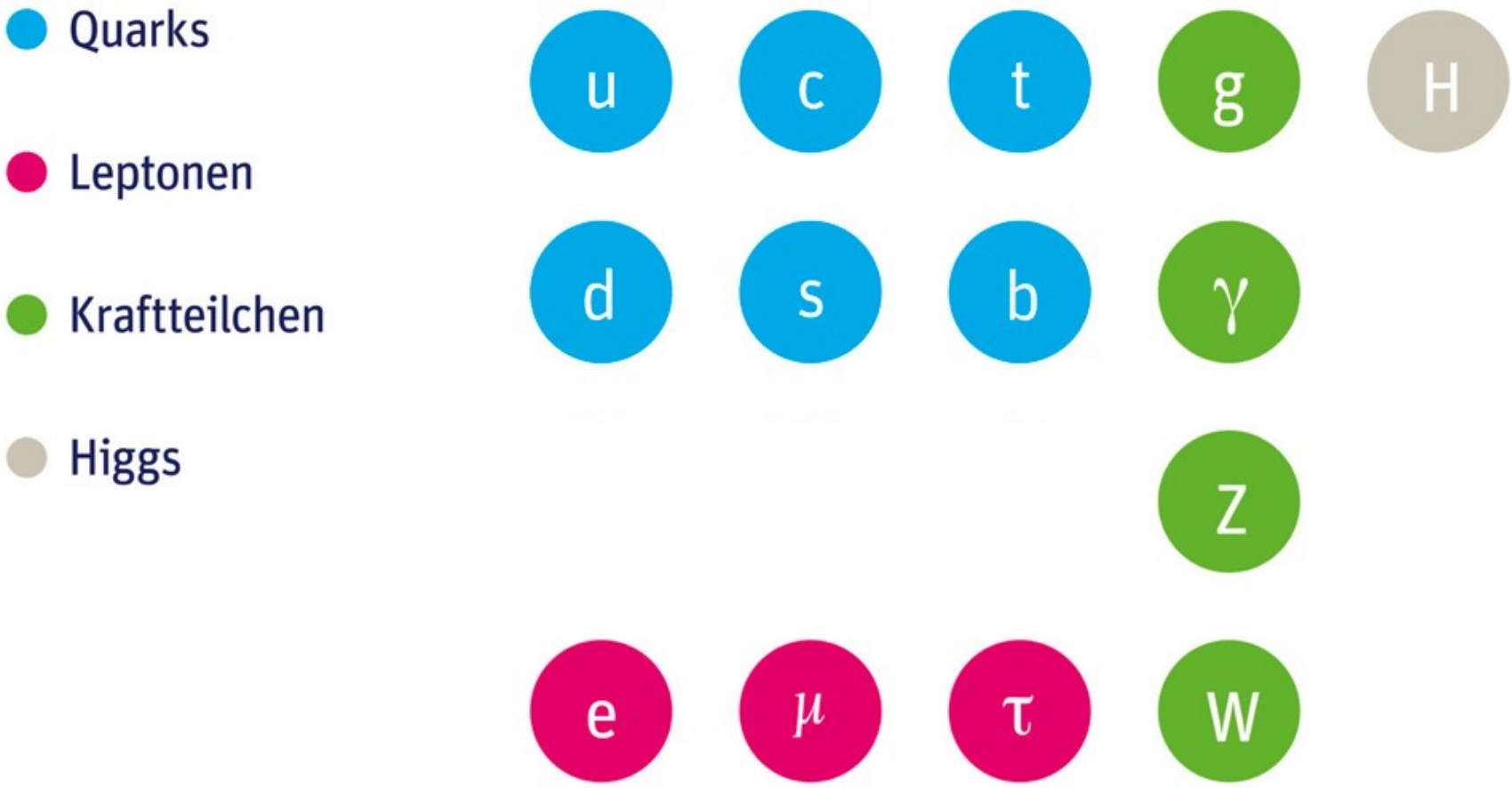


Die Kräfte im Teilchenbild

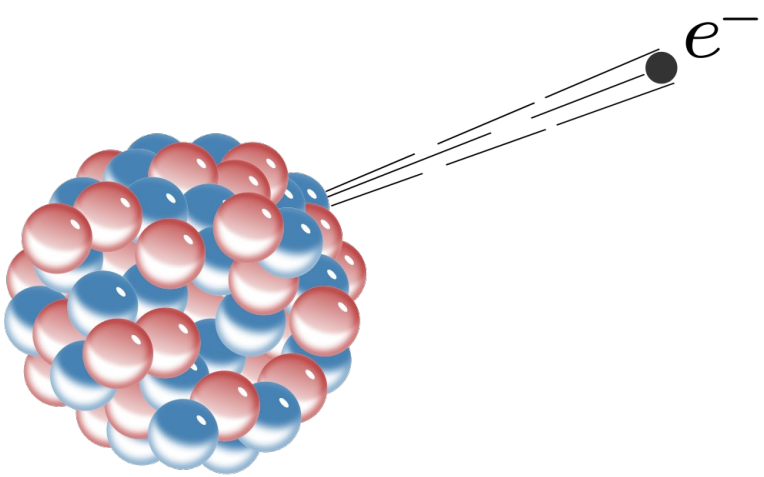


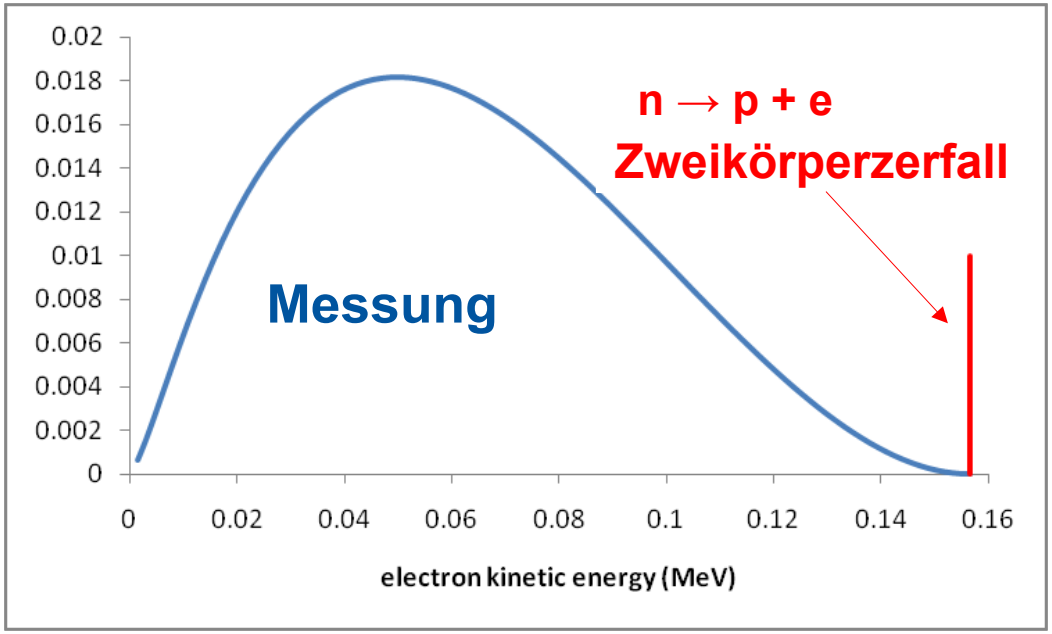


Die vollständige(?) Standardmodell

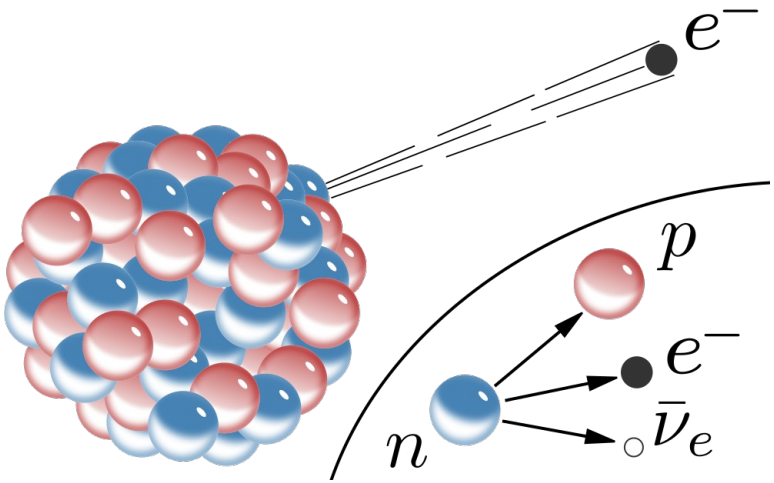


Der β-Zerfall

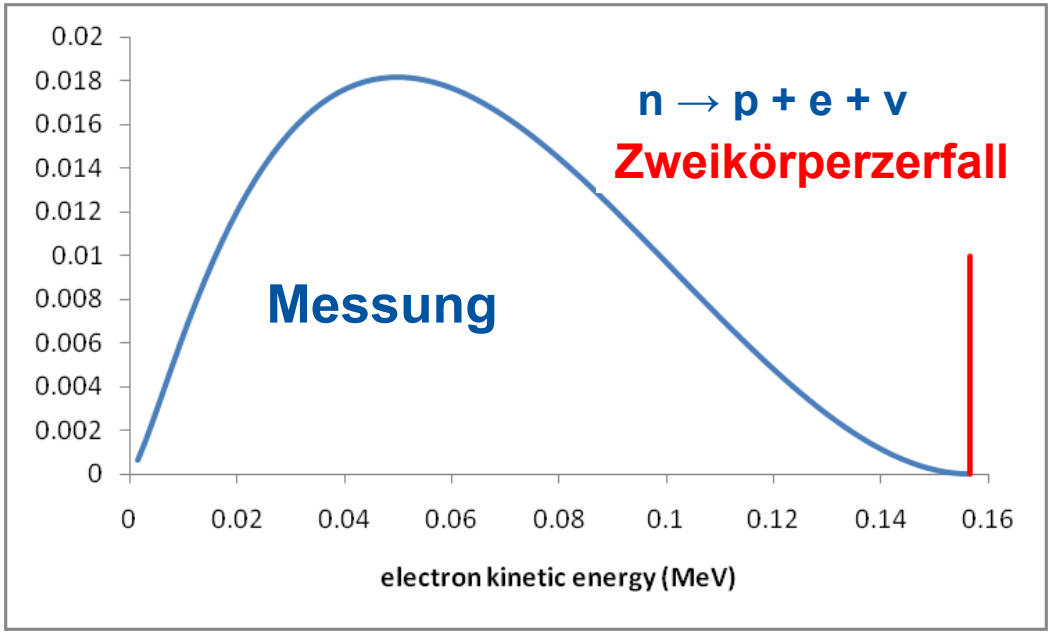




Der β-Zerfall



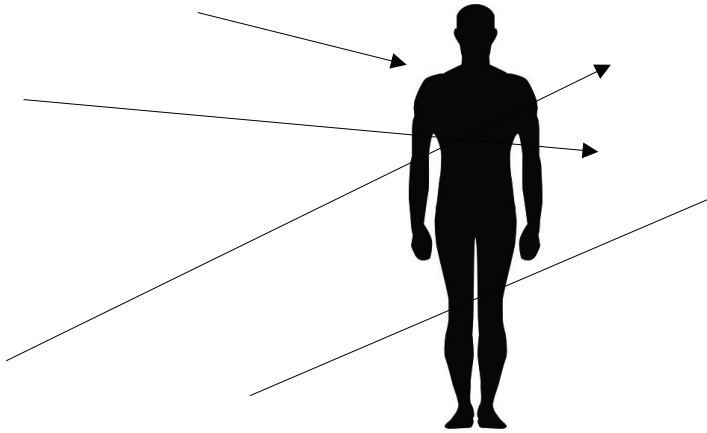
I have done a terrible thing, I have postulated a particle that cannot be detected.



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



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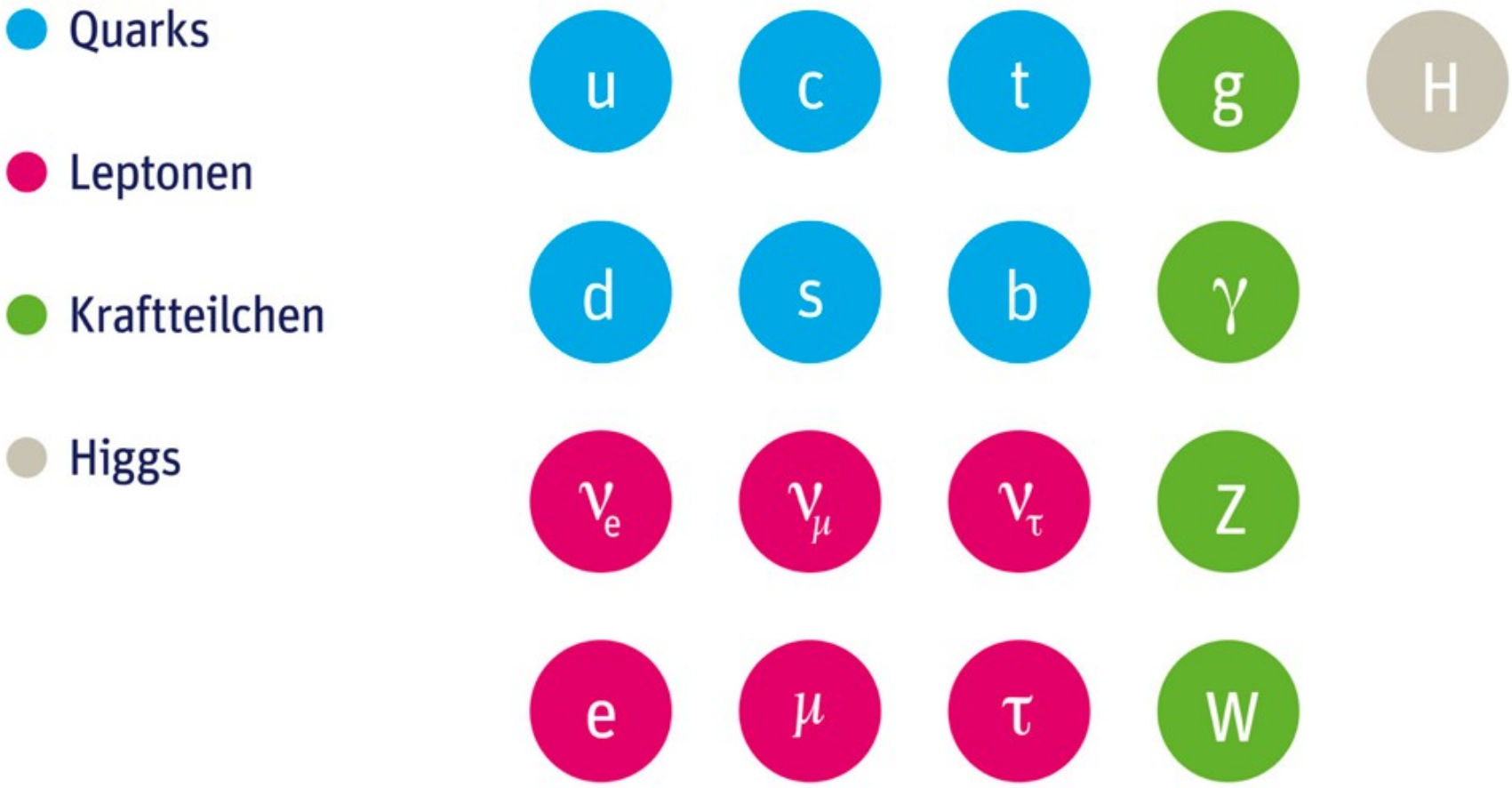
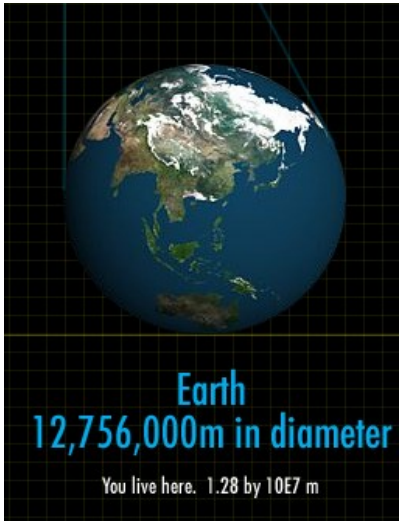
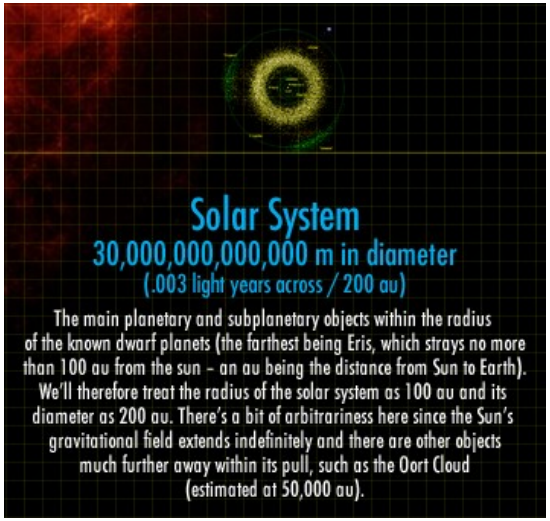
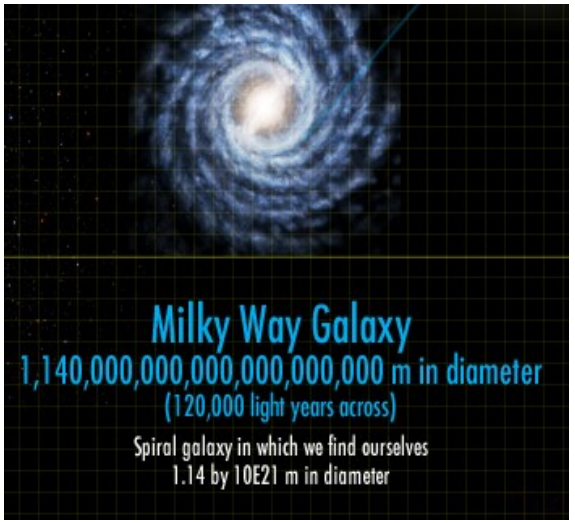
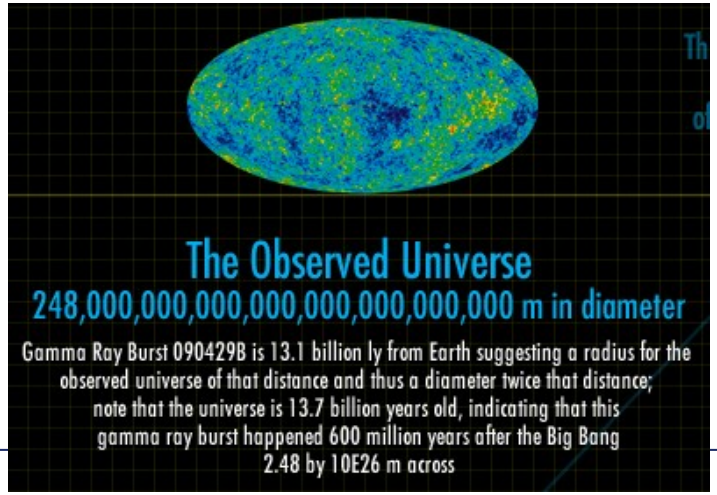


Astrophysik

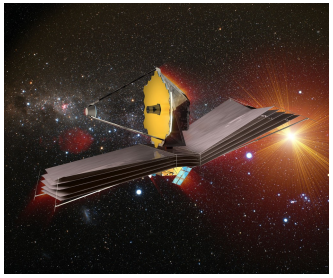


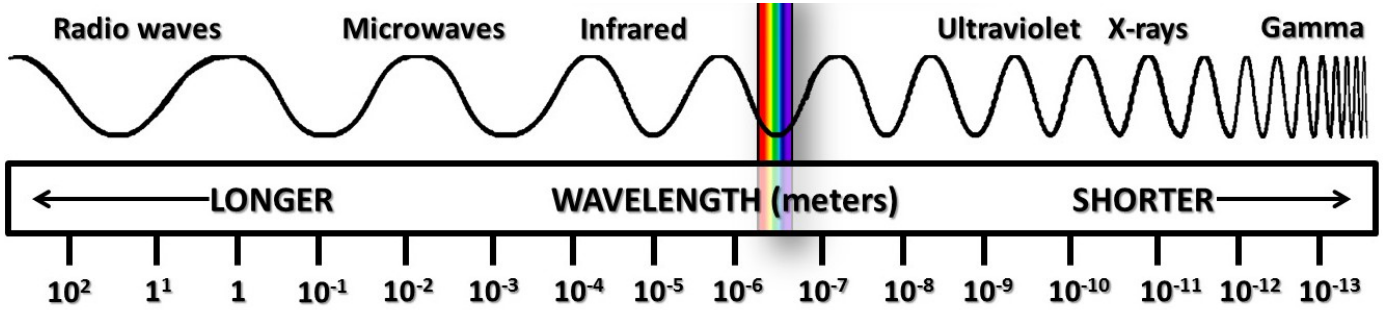


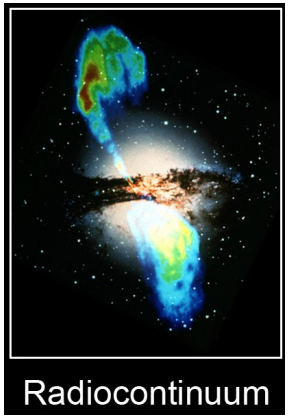




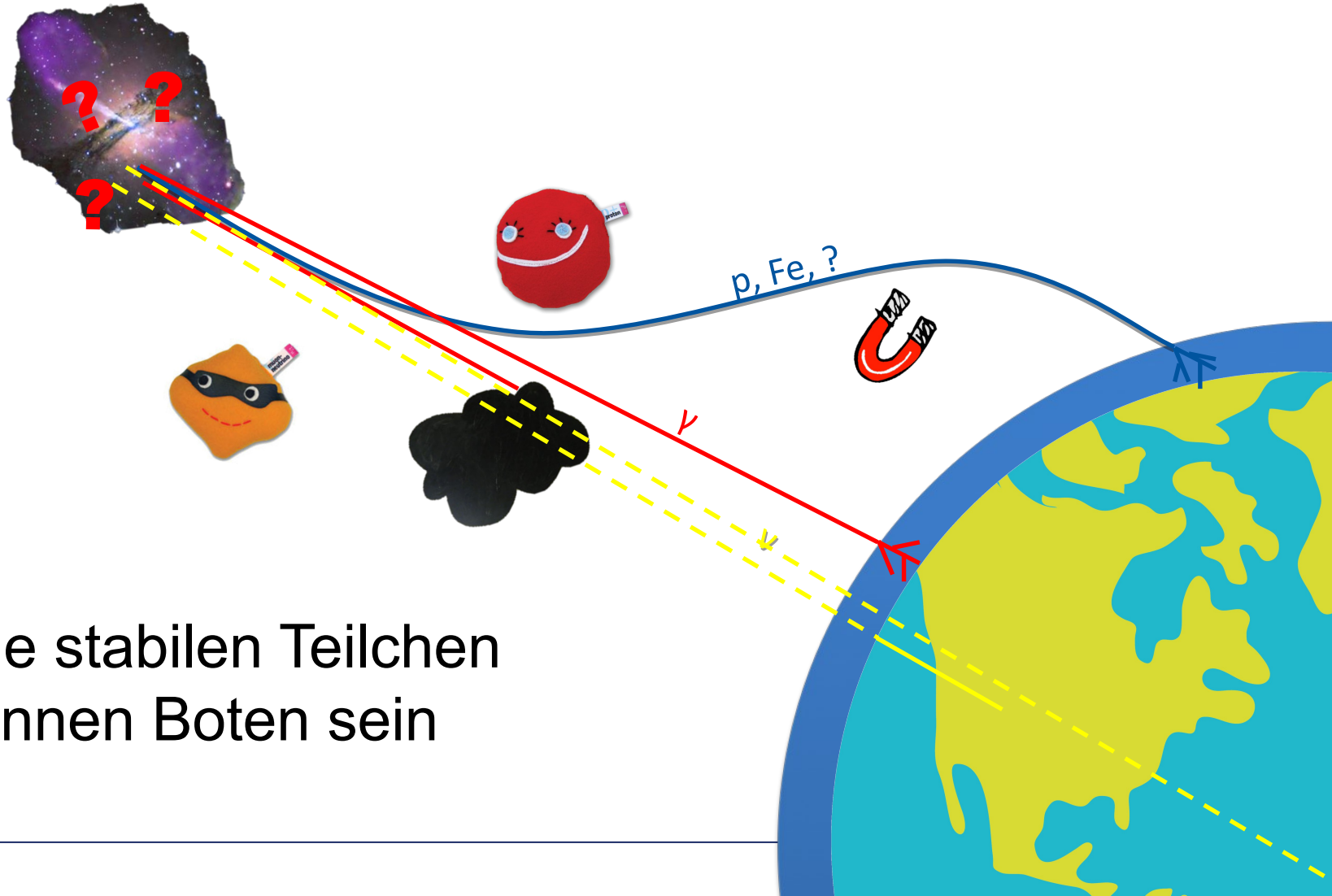
Photon-Astronomie





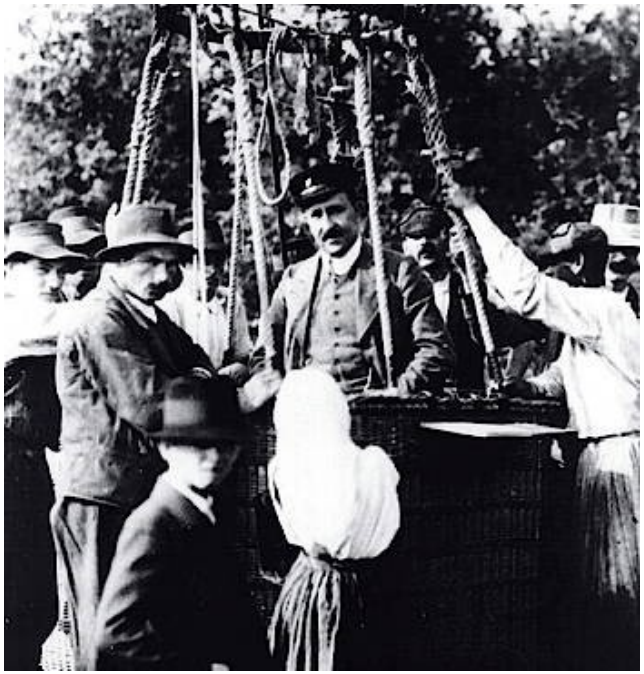


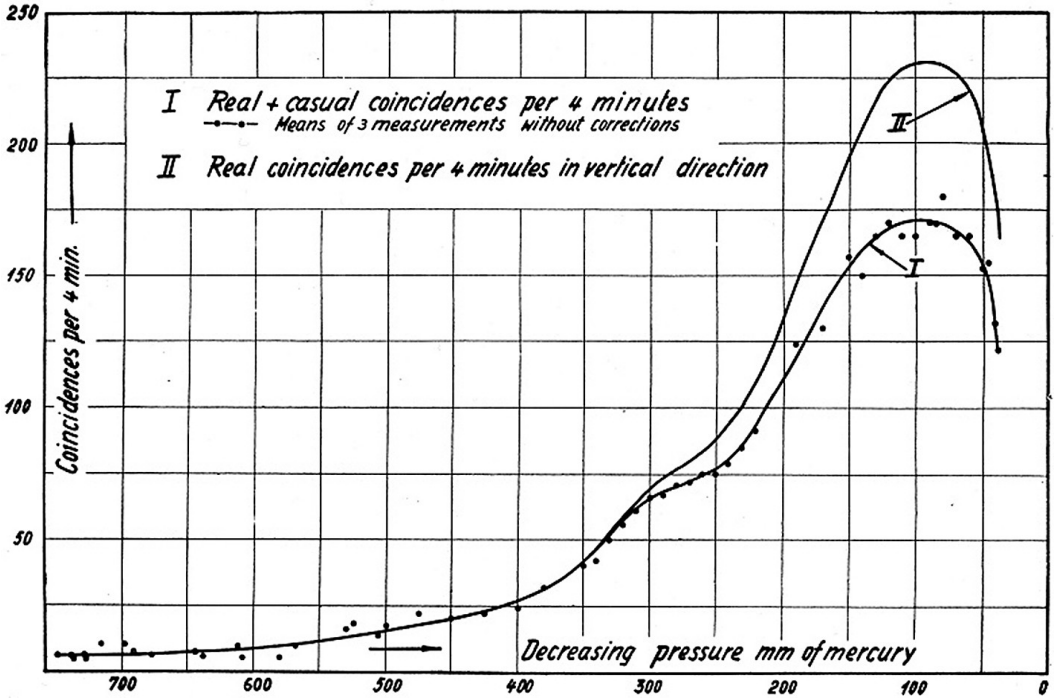
Was hat das mit Teilchenphysik zu tun?



- Alle stabilen Teilchen können Boten sein

Höhenstrahlung

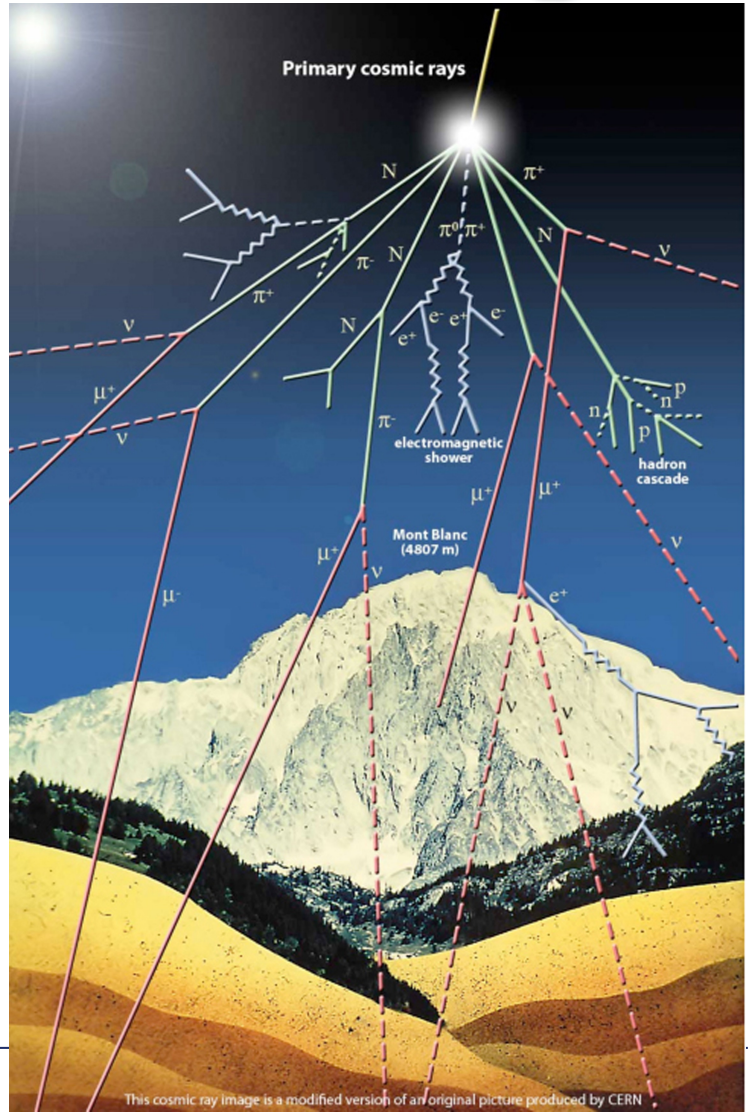




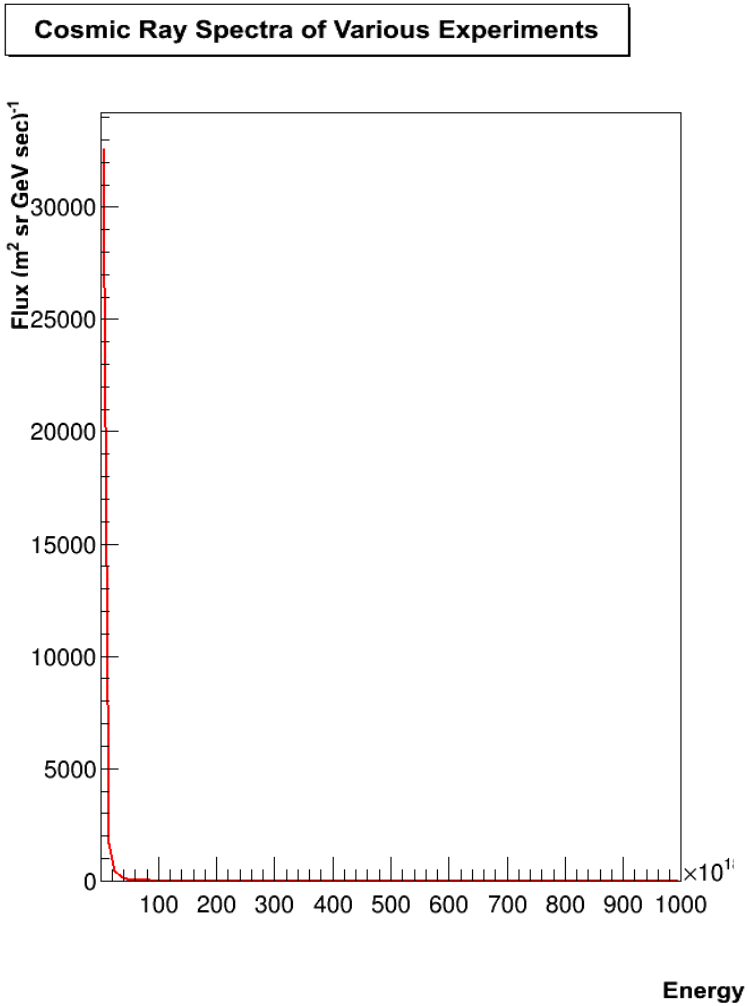
- Radioaktivität nimmt (entgegen der Erwartung) mit der Höhe zu
  → die Erde muss von geladenen Teilchen getroffen werden

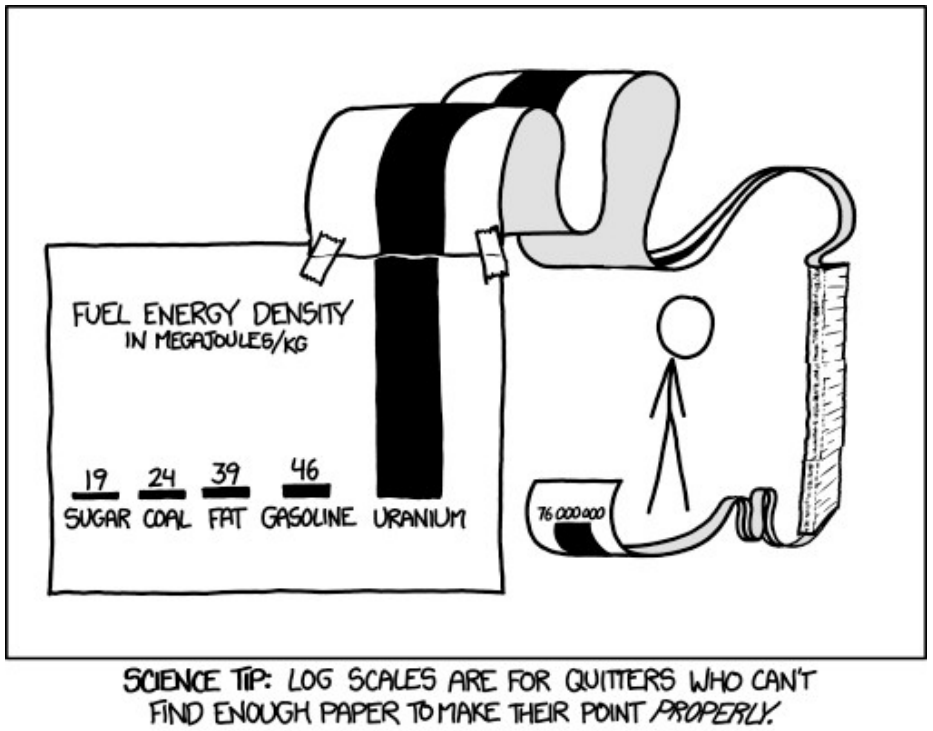
Luftschauer

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

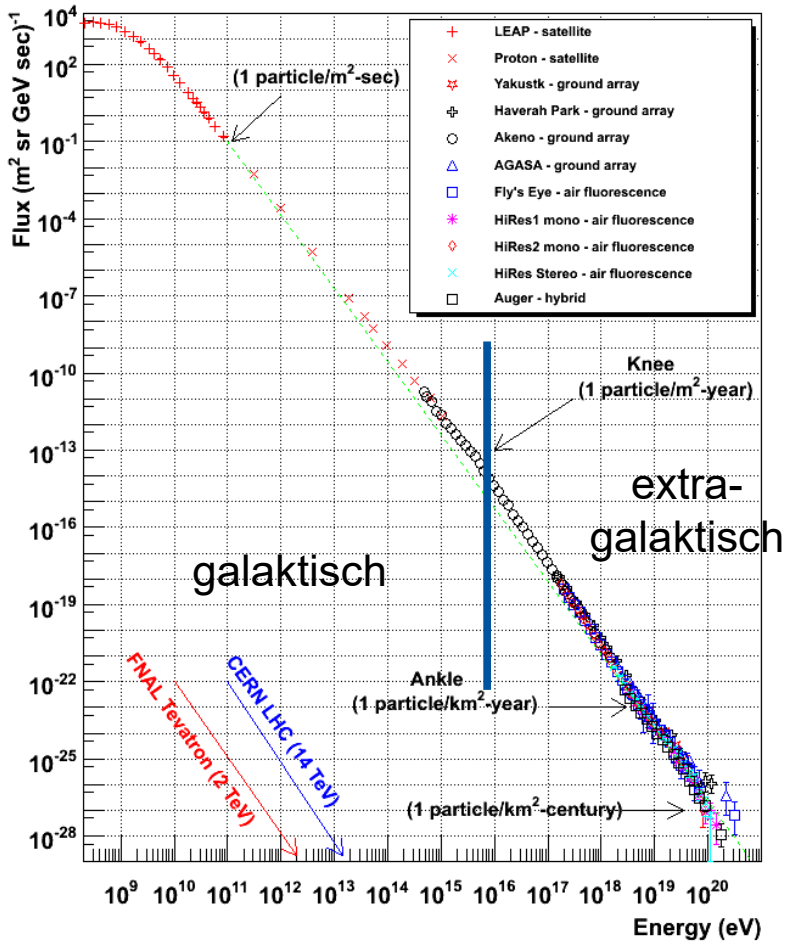


Energiespektrum





Energiespektrum



- Doppellogarithmisch Achsen
- (Eine Größenordnung pro Strich)

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

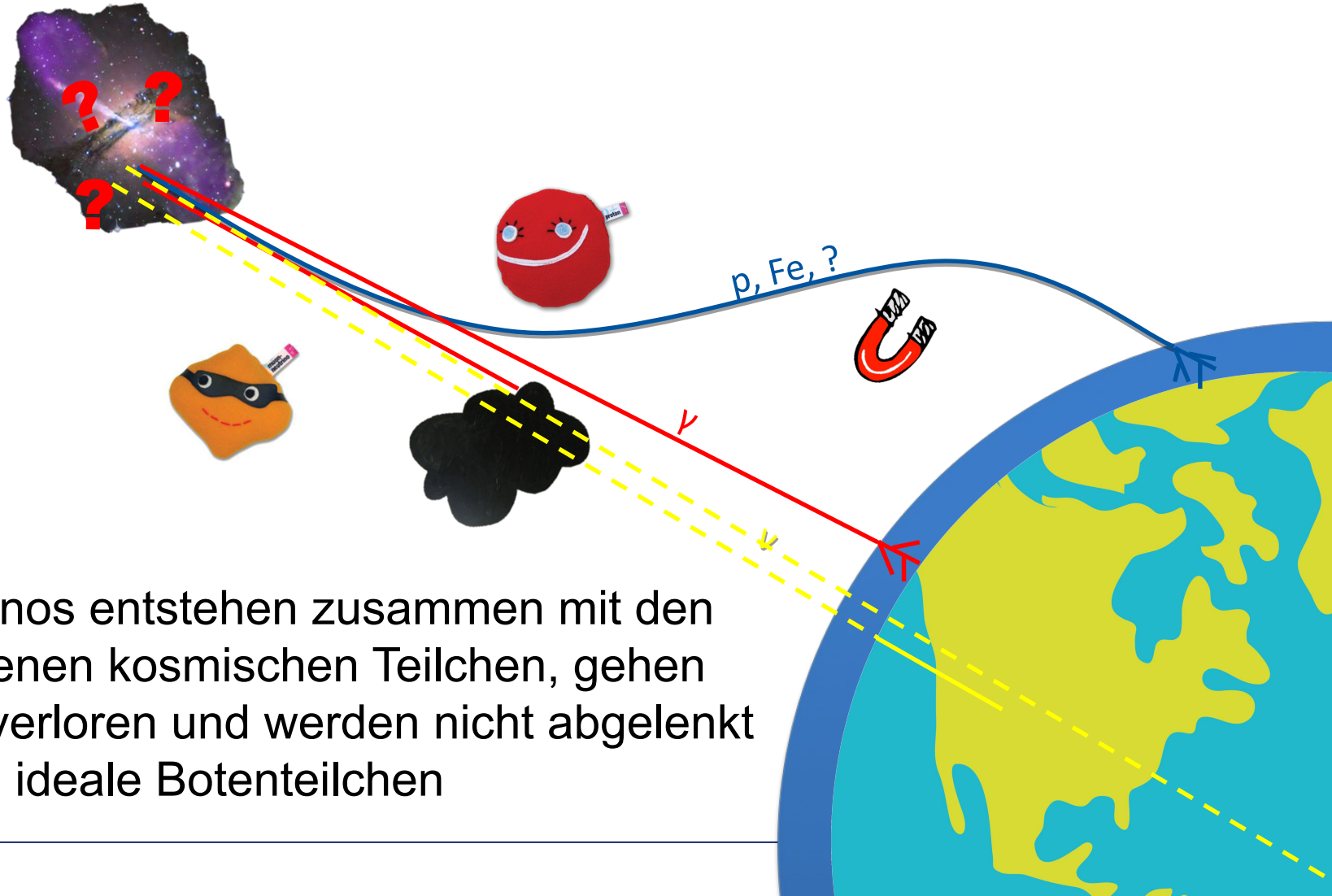
- Substrukturen geben Aufschluss über veränderte Herkunft

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**

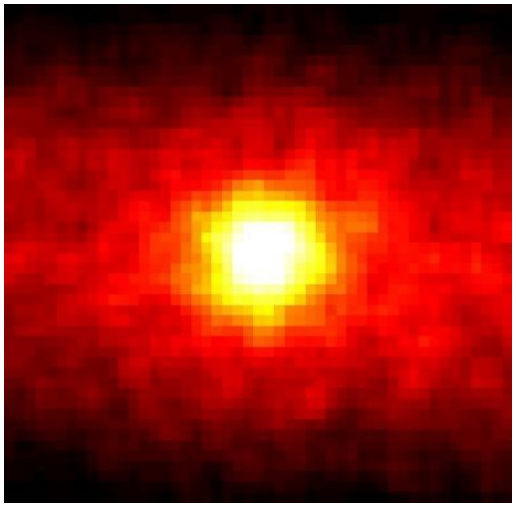
Neutrino-Astronomie



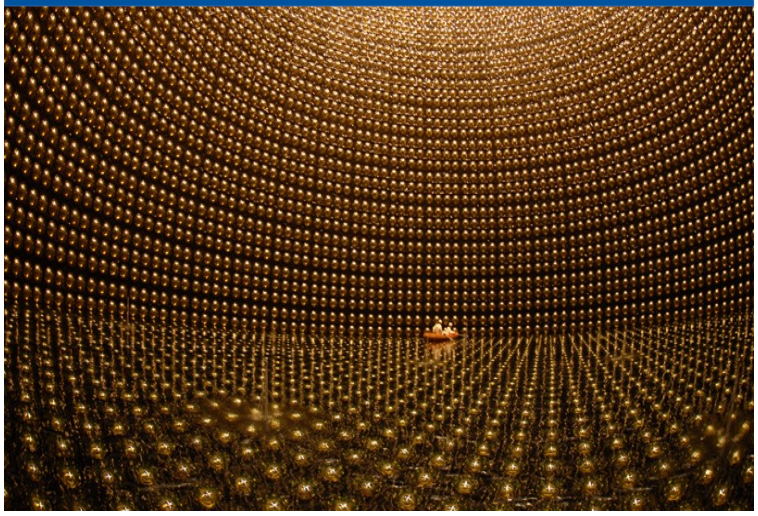
- Neutrinos entstehen zusammen mit den geladenen kosmischen Teilchen, gehen nicht verloren und werden nicht abgelenkt
  → ideale Botenteilchen

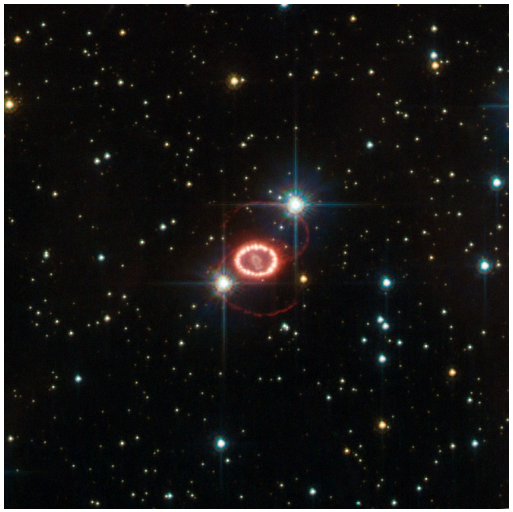
Neutrino - Quellen

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



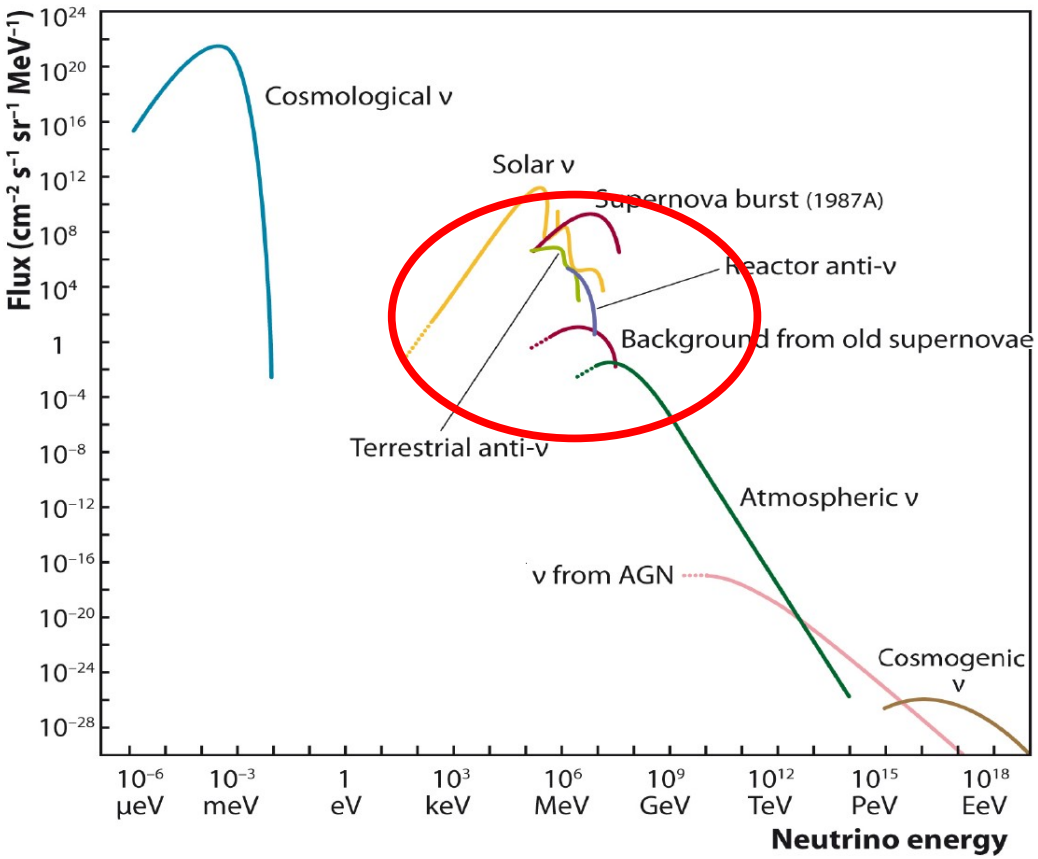
Detektor ~ 0,00003 km^3





Herausforderung 1

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



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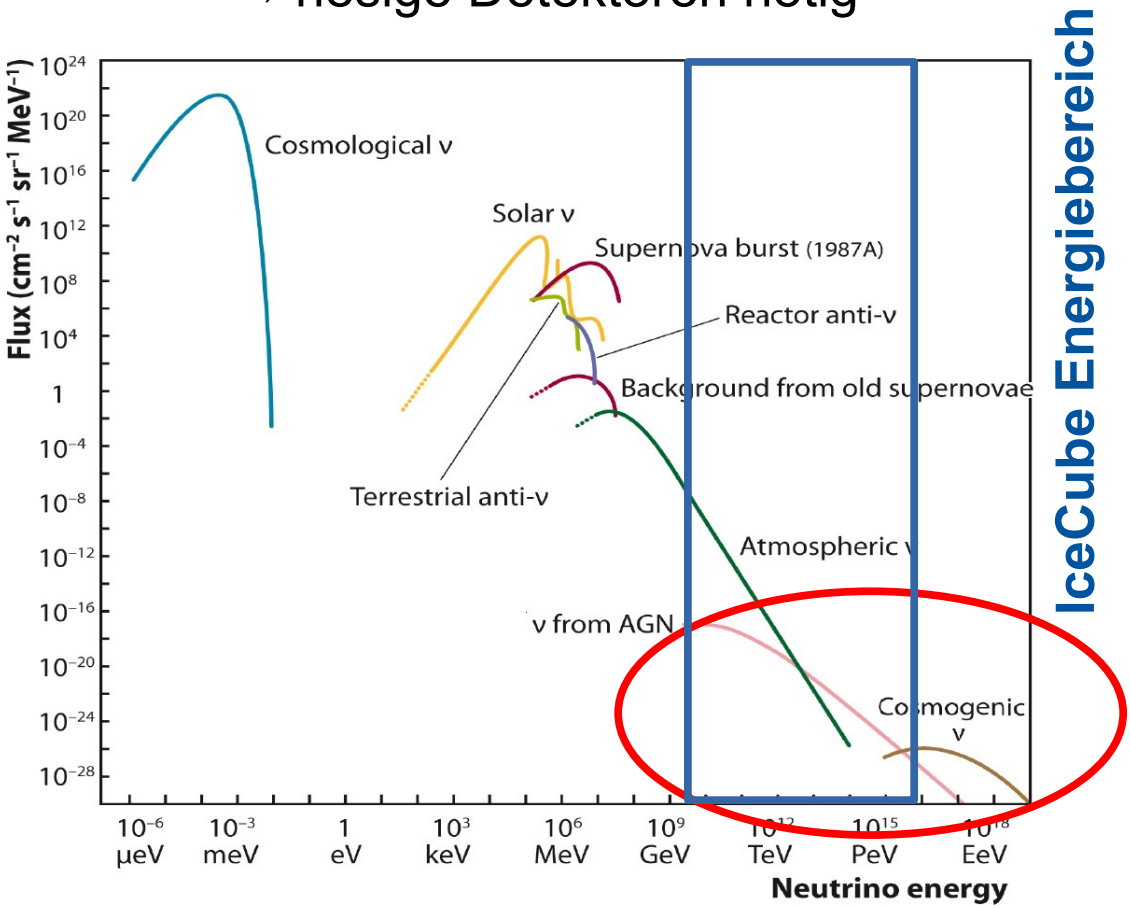
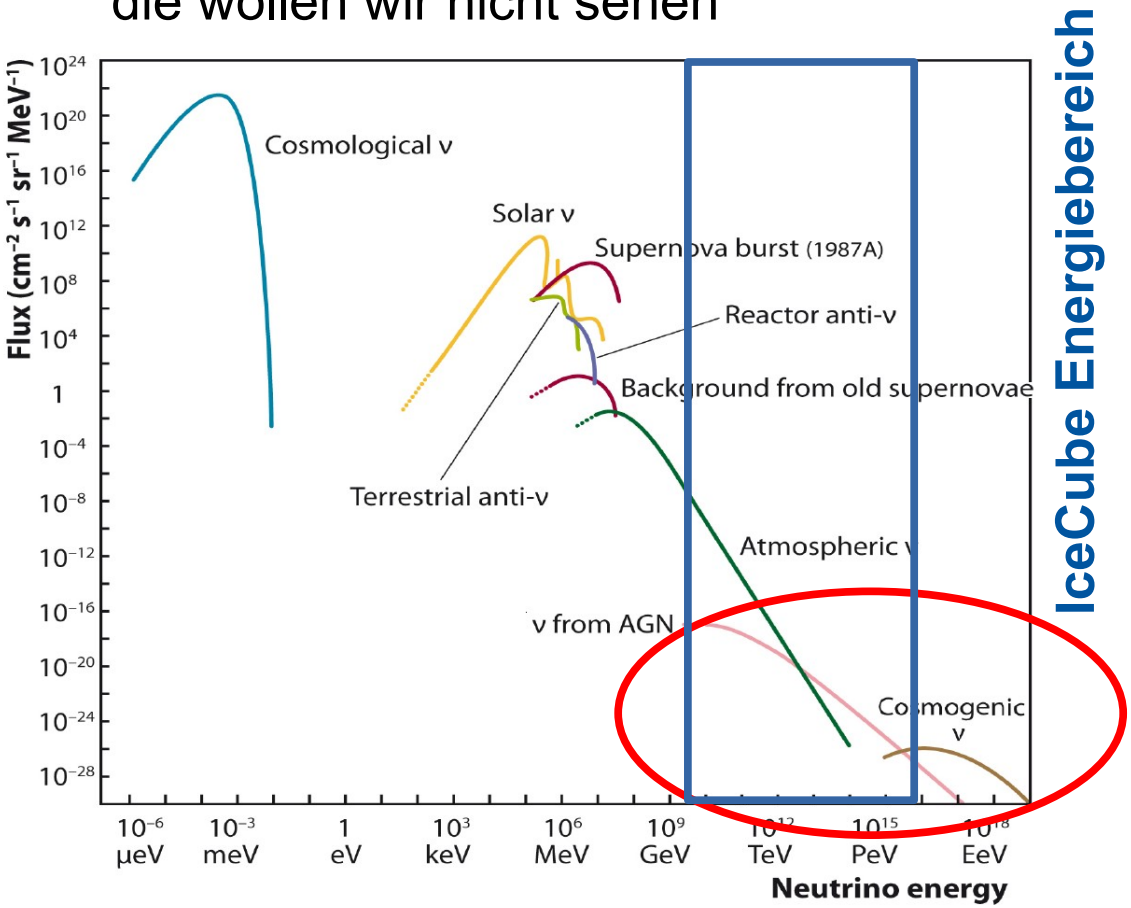
  → riesige Detektoren nötig

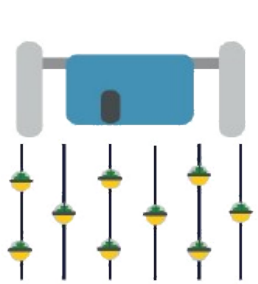


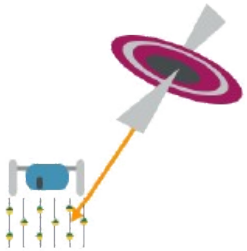
Herausforderung 2

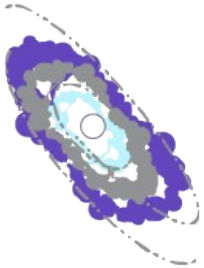
- Neutrinos entstehen auch in den Luftschauern geladener Teilchen, die wollen wir nicht sehen

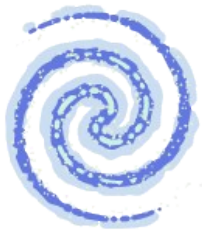


Wir haben 2013 die ersten extrasolaren Neutrinos gefunden (wie siehe nächsten Vortrag), aber die Himmelskarte füllt sich nur langsam.









2011
IceCube Completed

2013
Astrophysical Neutrinos Discovered

2018
First Source TXS 0506+056 Identified

2021
Glashow Resonance Neutrino Identified

2022
Second Source NGC 1068 Identified

2023
Third Source Milky Way Identified