



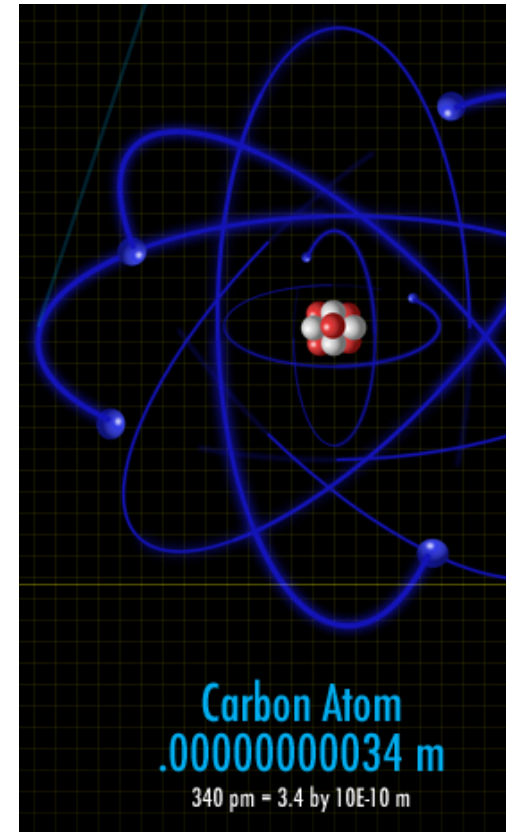
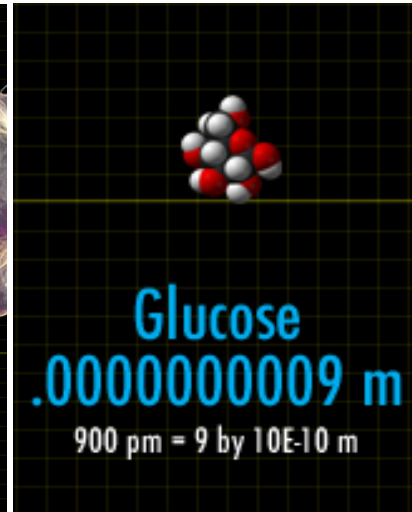
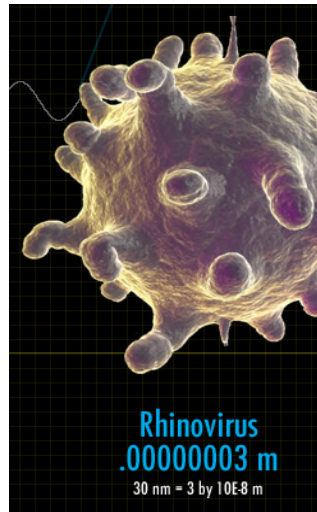
IceCube Masterclass 2025

Astroteilchenphysik

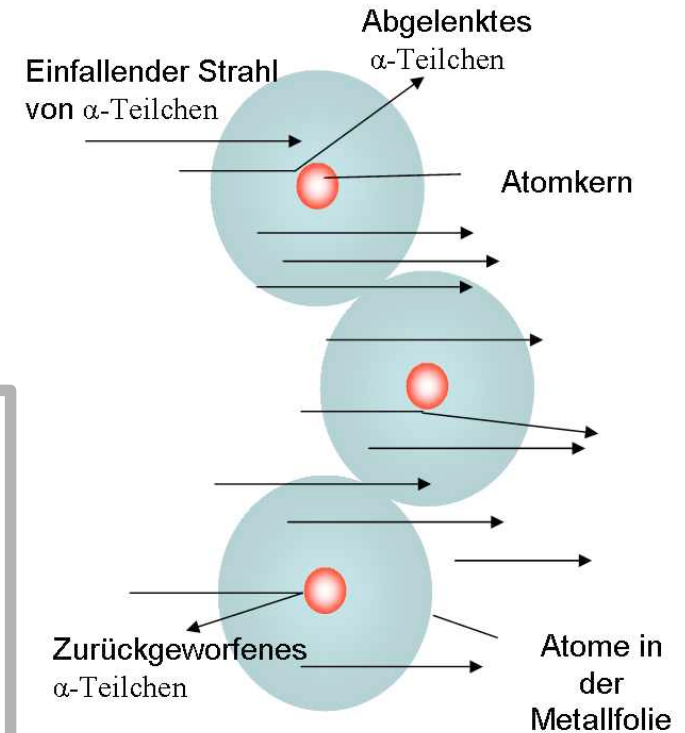
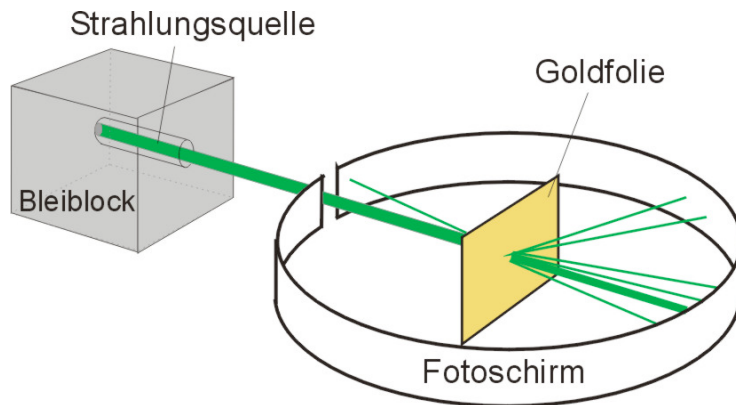
Martin Rongen
Erlangen, 10.04.25



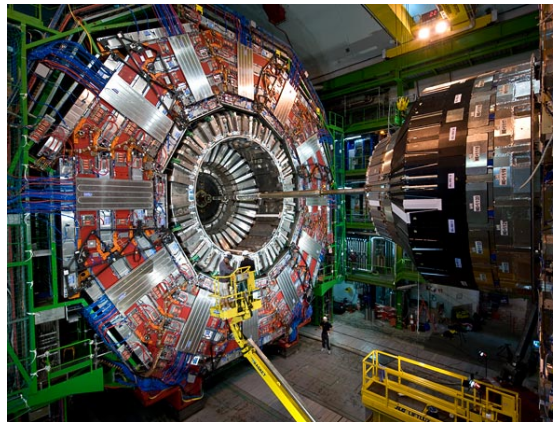
Teilchenphysik



Streuexperimente



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



CMS Masterclass

Das Standardmodell

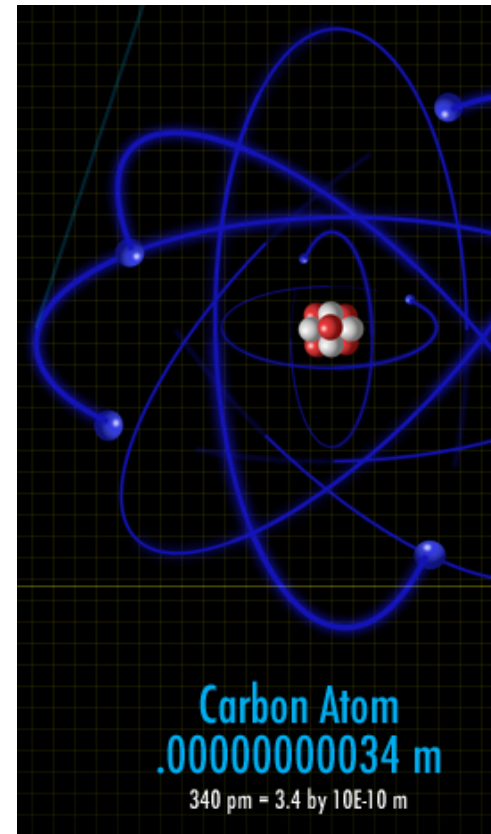
● Quarks

● Leptonen

u

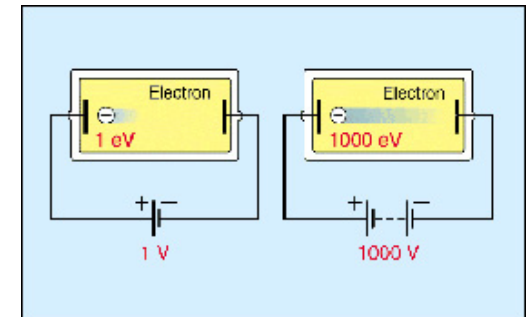
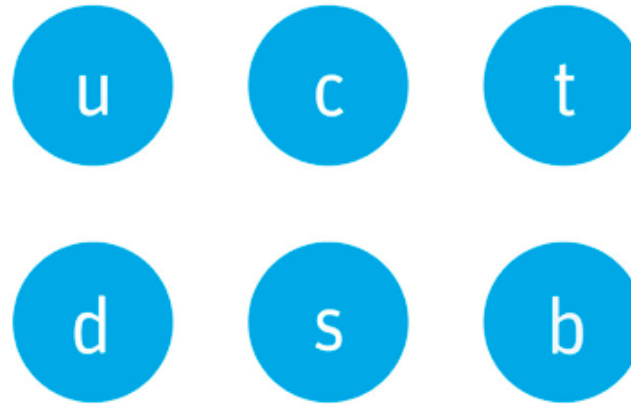
d

e



Das Standardmodell

- Quarks
- Leptonen



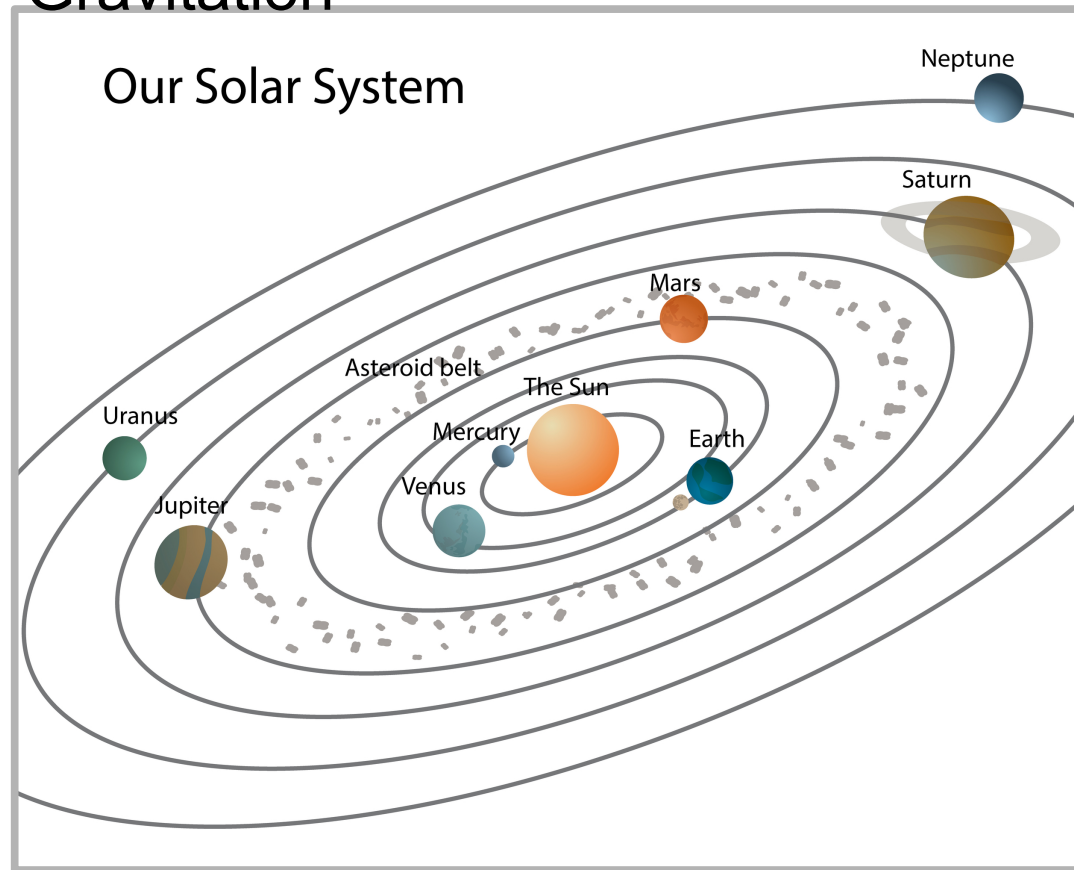
schwerer →



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

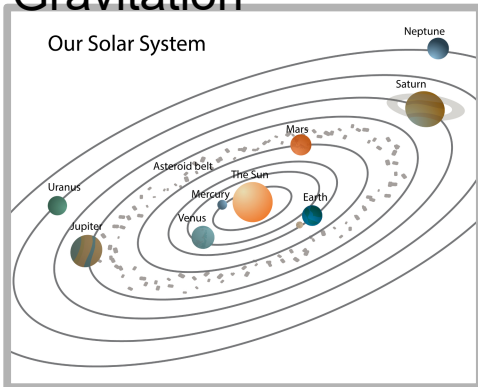
Die Kräfte

Gravitation

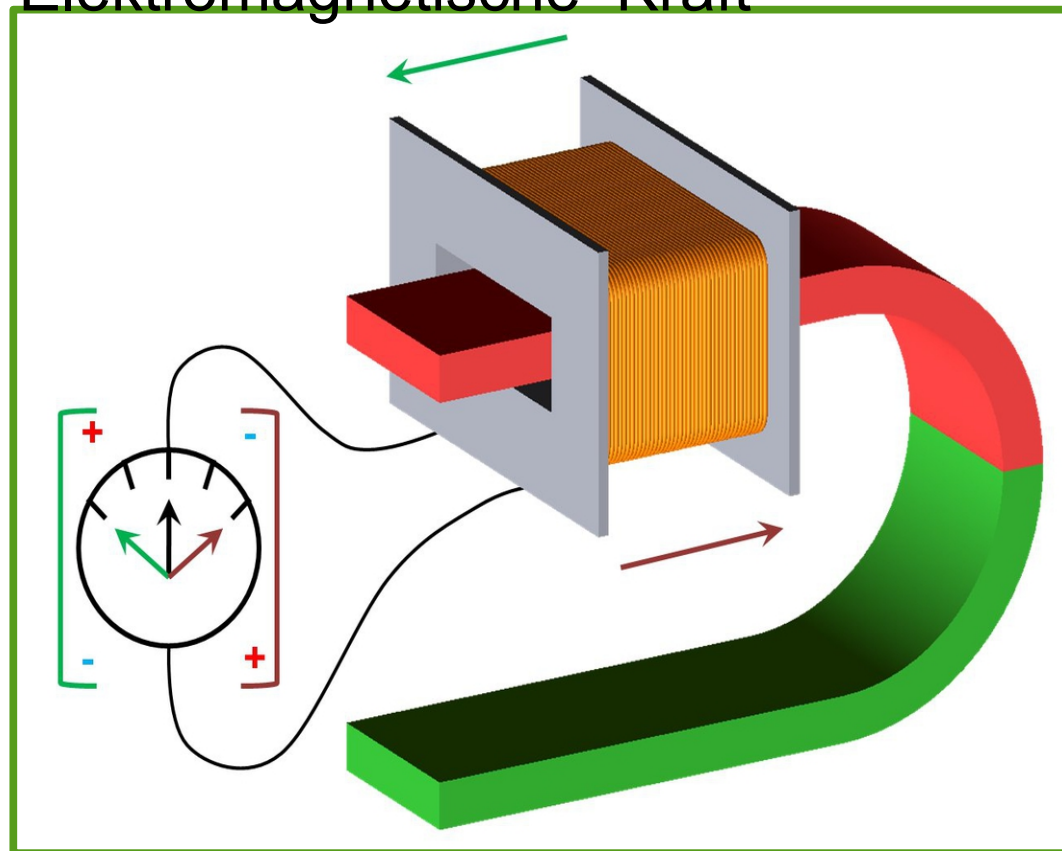


Die Kräfte

Gravitation

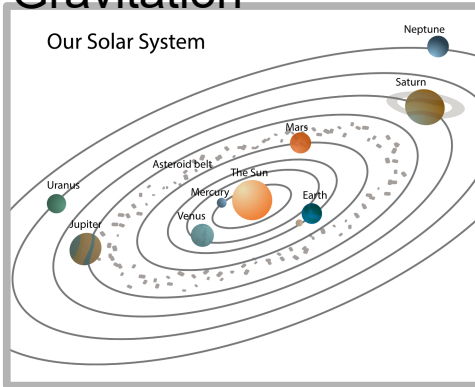


Elektromagnetische Kraft

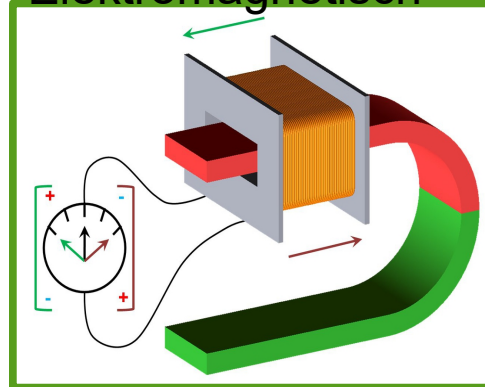


Die Kräfte

Gravitation

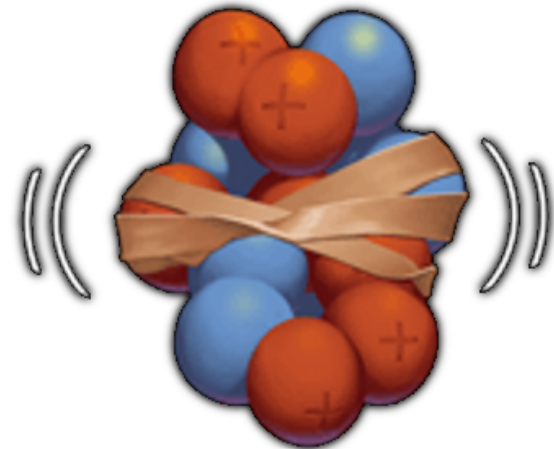


Elektromagnetisch



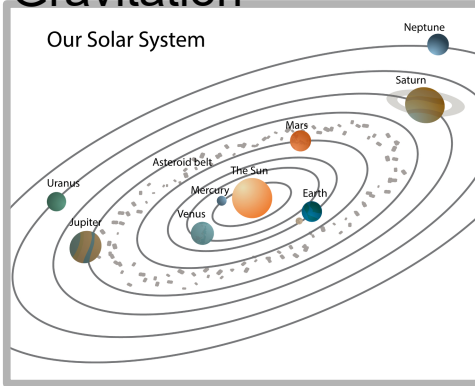
Starke Kraft

Atomkern

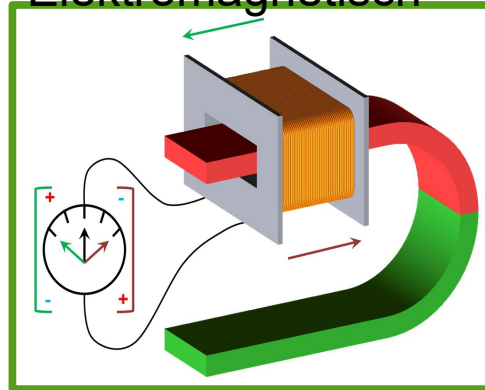


Die Kräfte

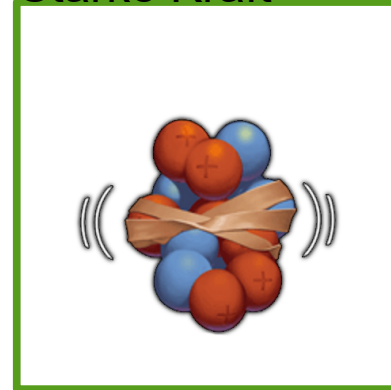
Gravitation



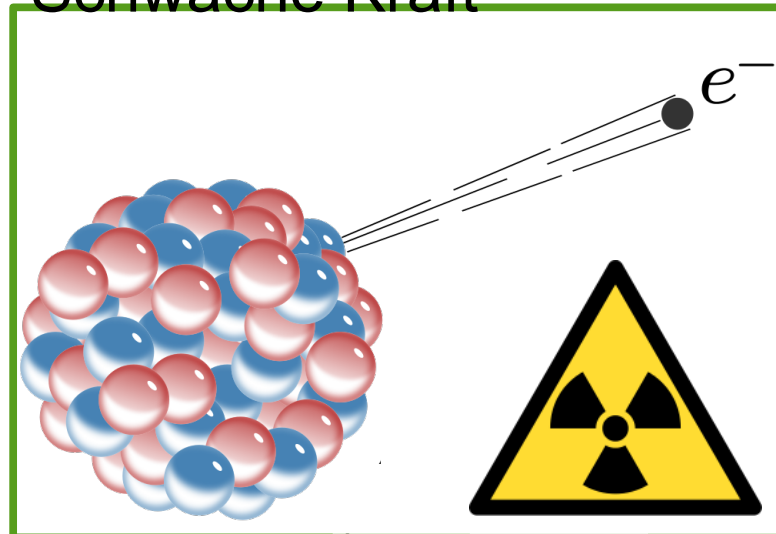
Elektromagnetisch



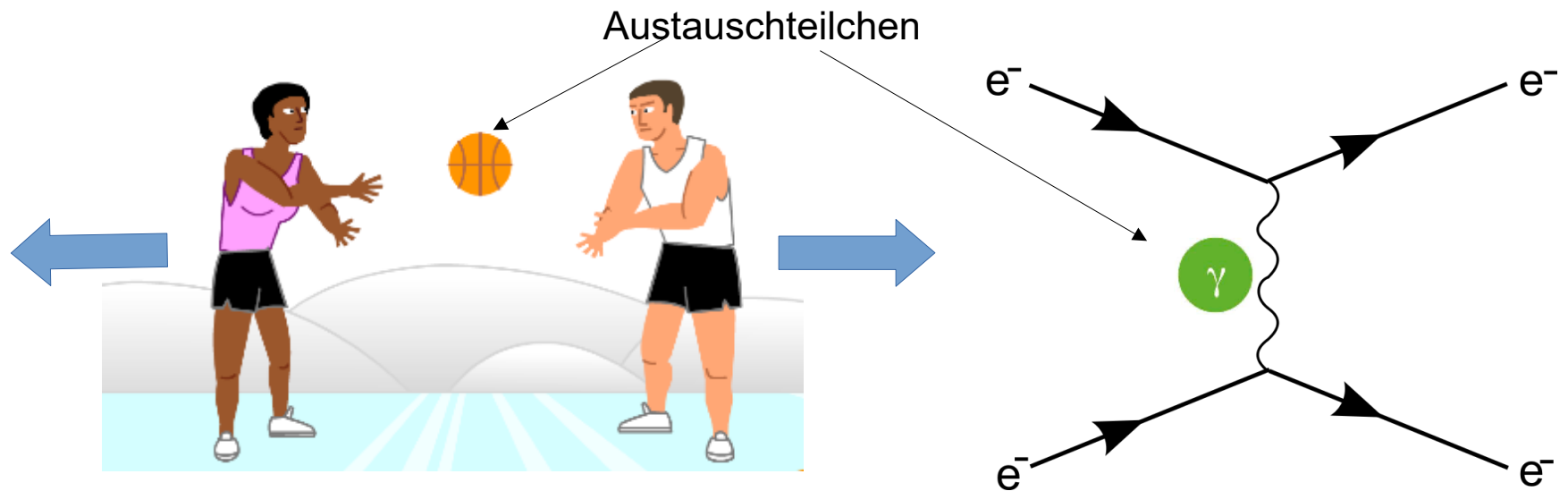
Starke Kraft



Schwache Kraft



Die Kräfte im Teilchenbild



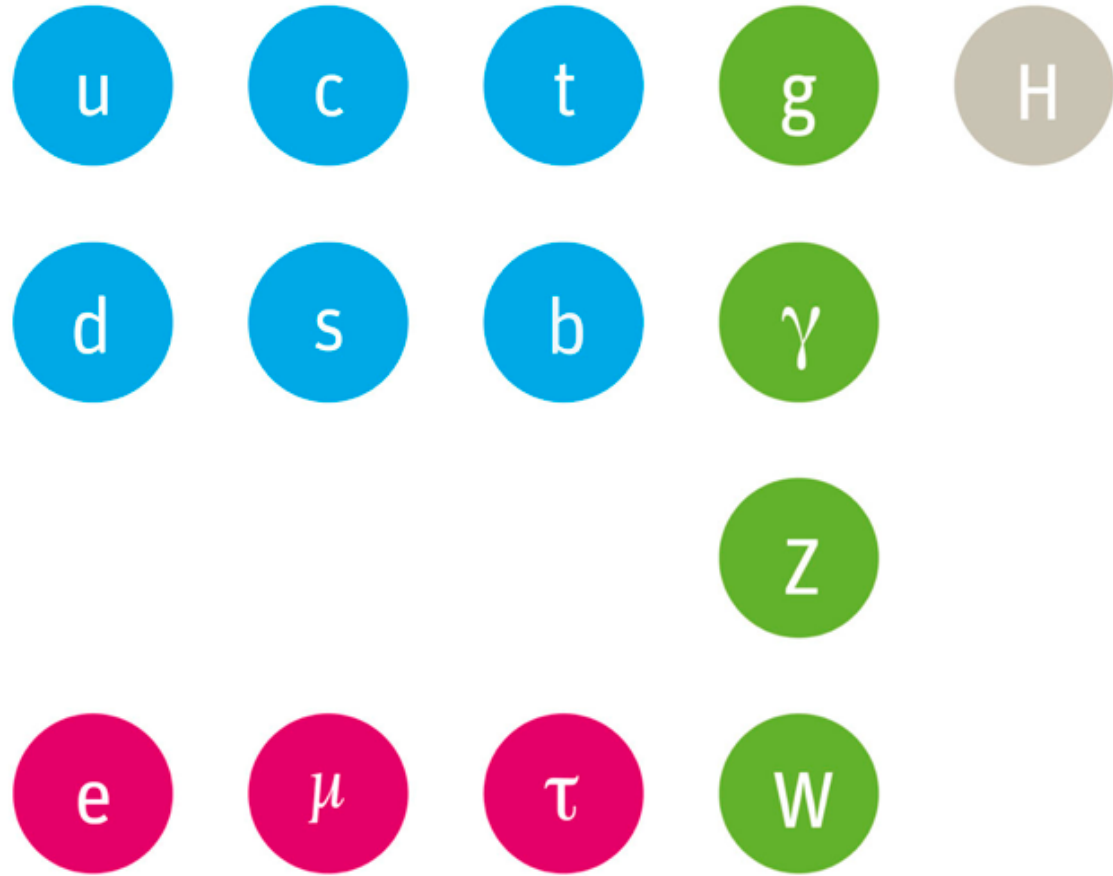
Die vollständige(?) Standardmodell

● Quarks

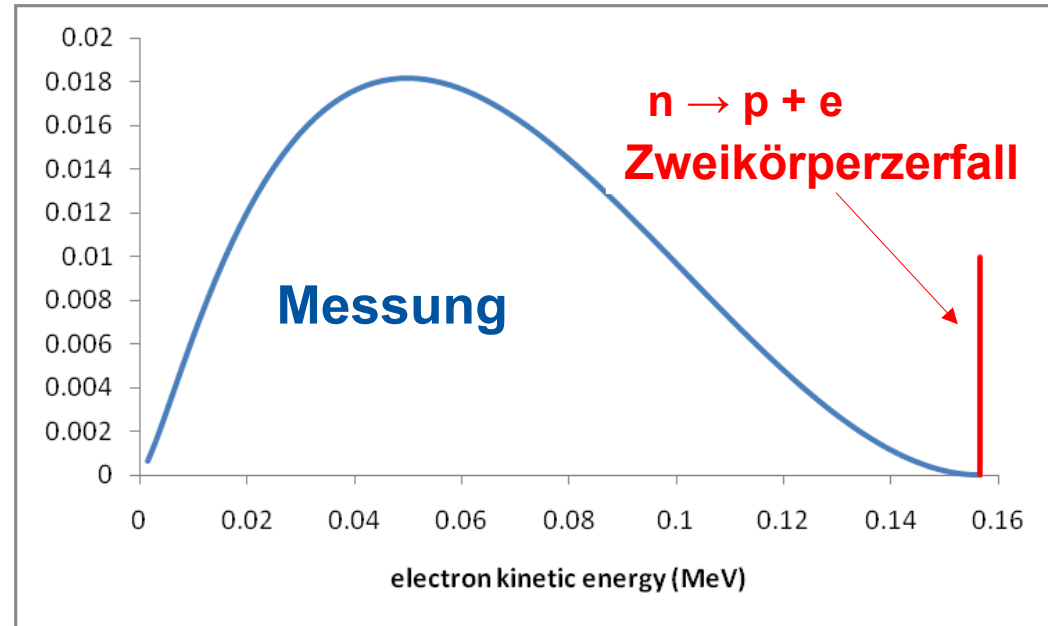
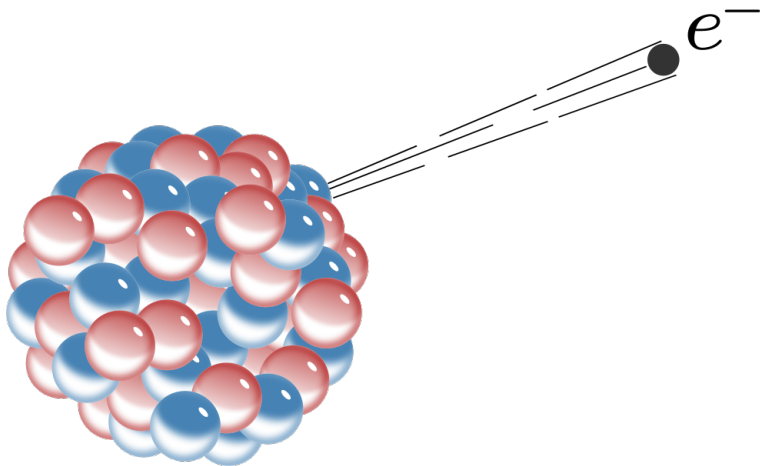
● Leptonen

● Kraftteilchen

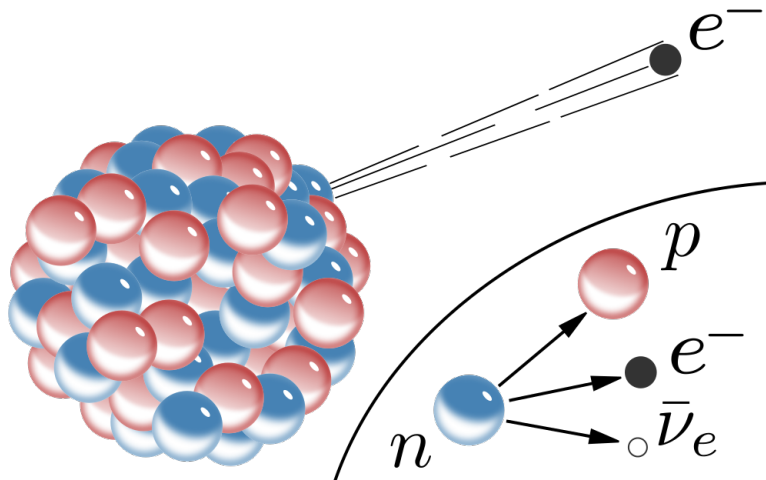
● Higgs



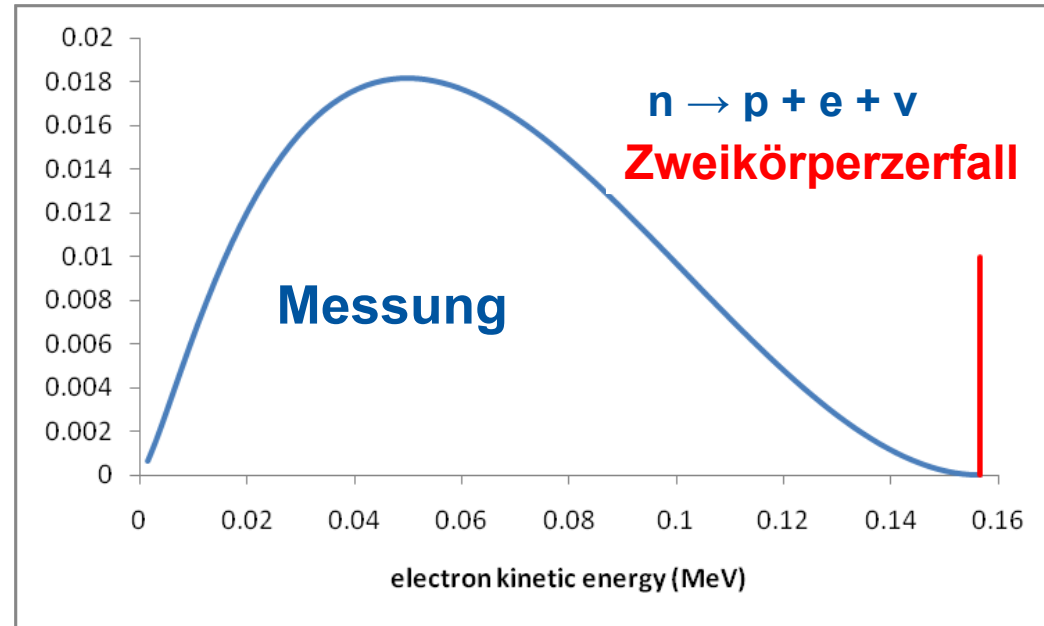
Der β -Zerfall



Der β -Zerfall



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



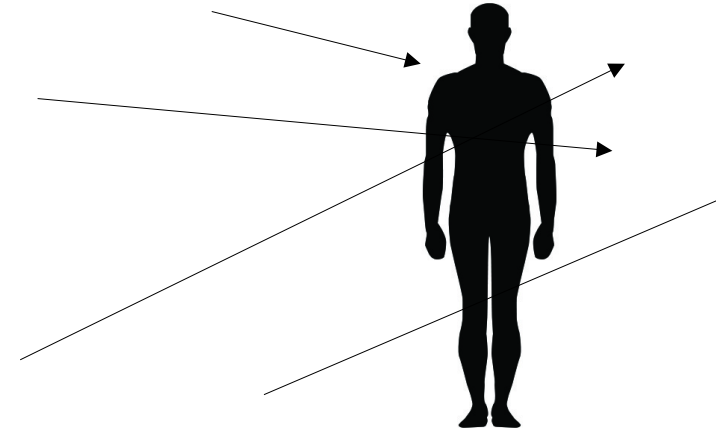
Das Neutrino

- 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



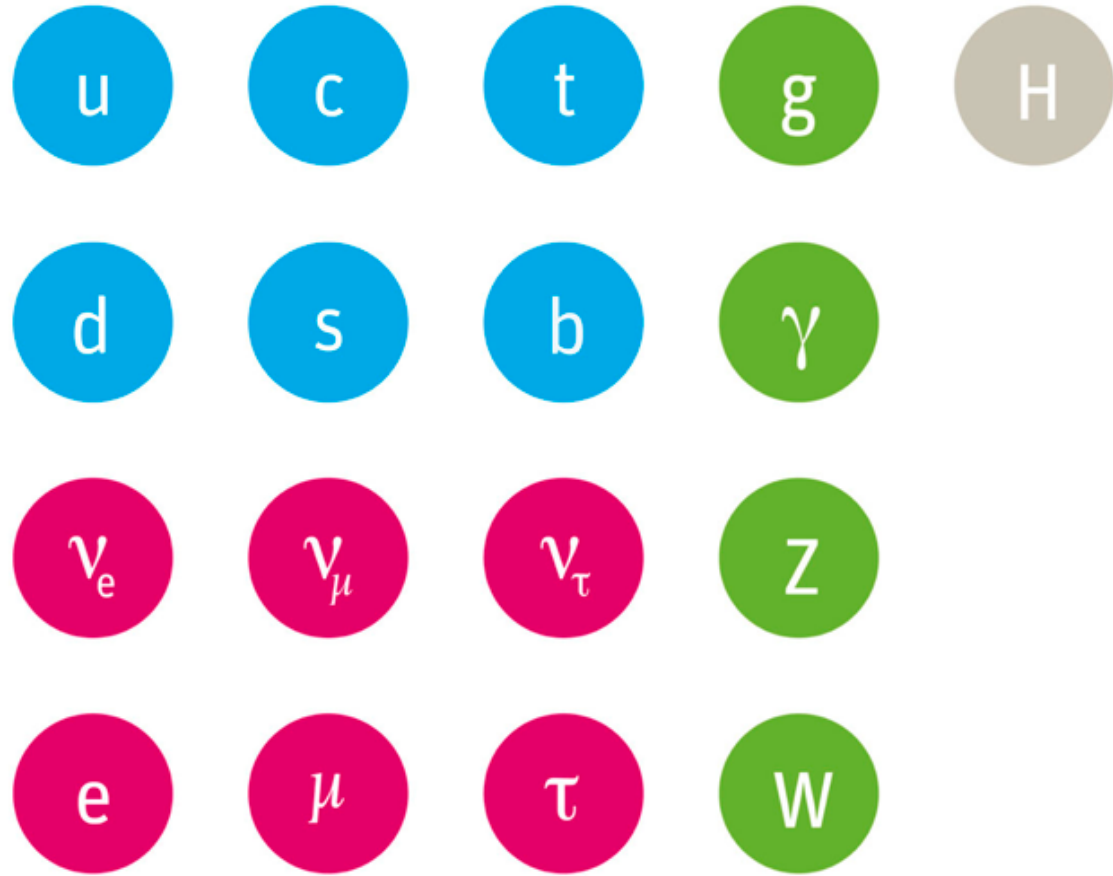
Die vollständige(?) Standardmodell

● Quarks

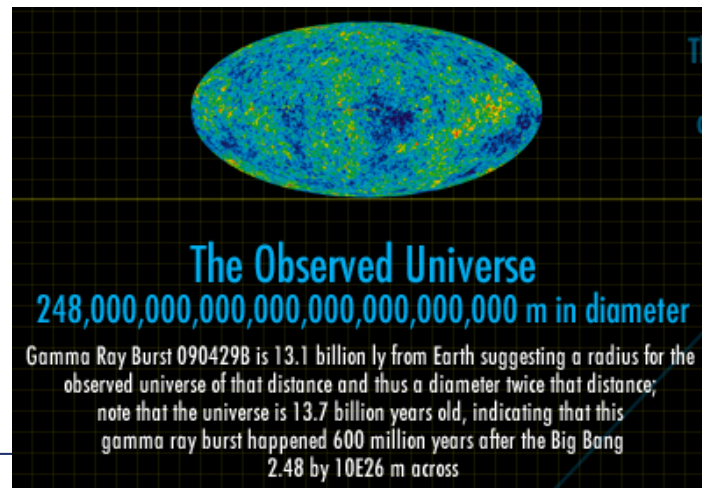
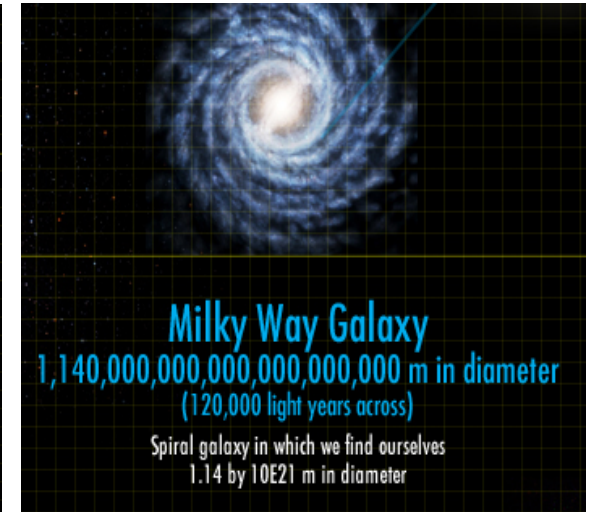
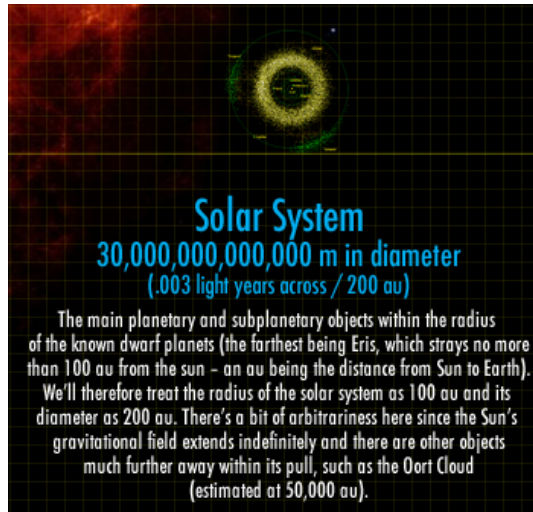
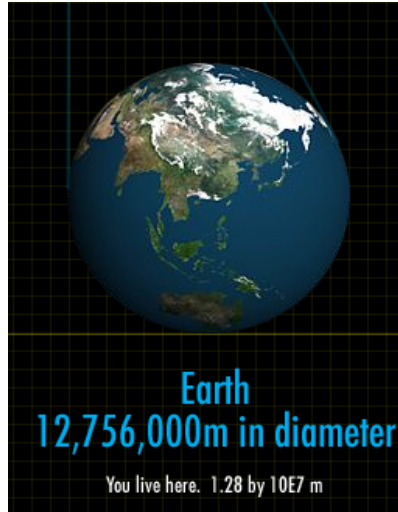
● Leptonen

● Kraftteilchen

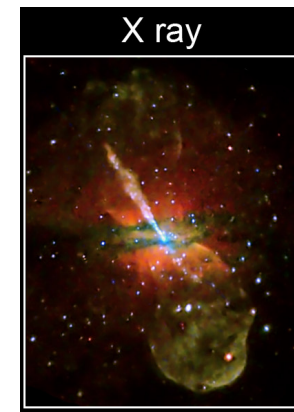
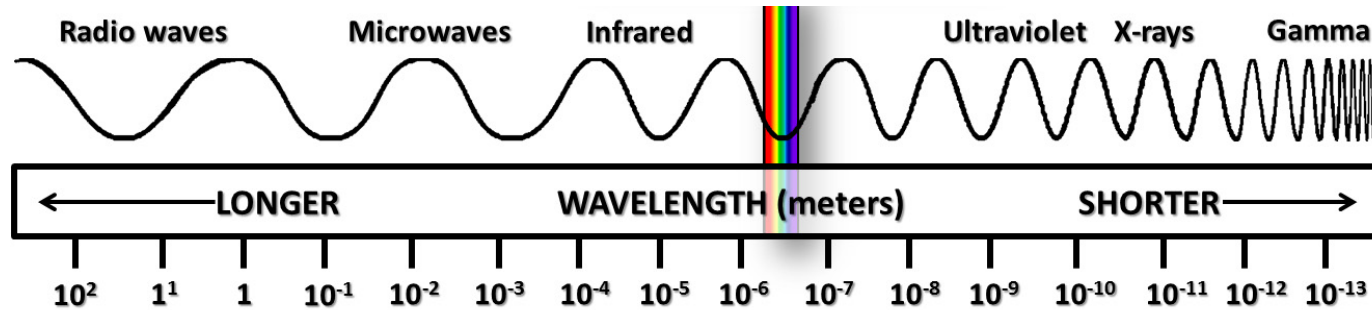
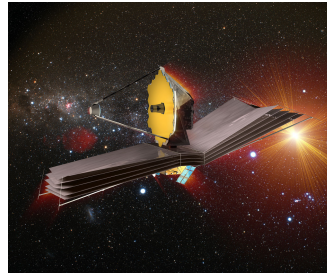
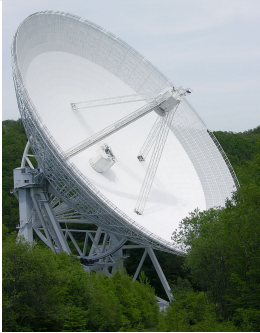
● Higgs



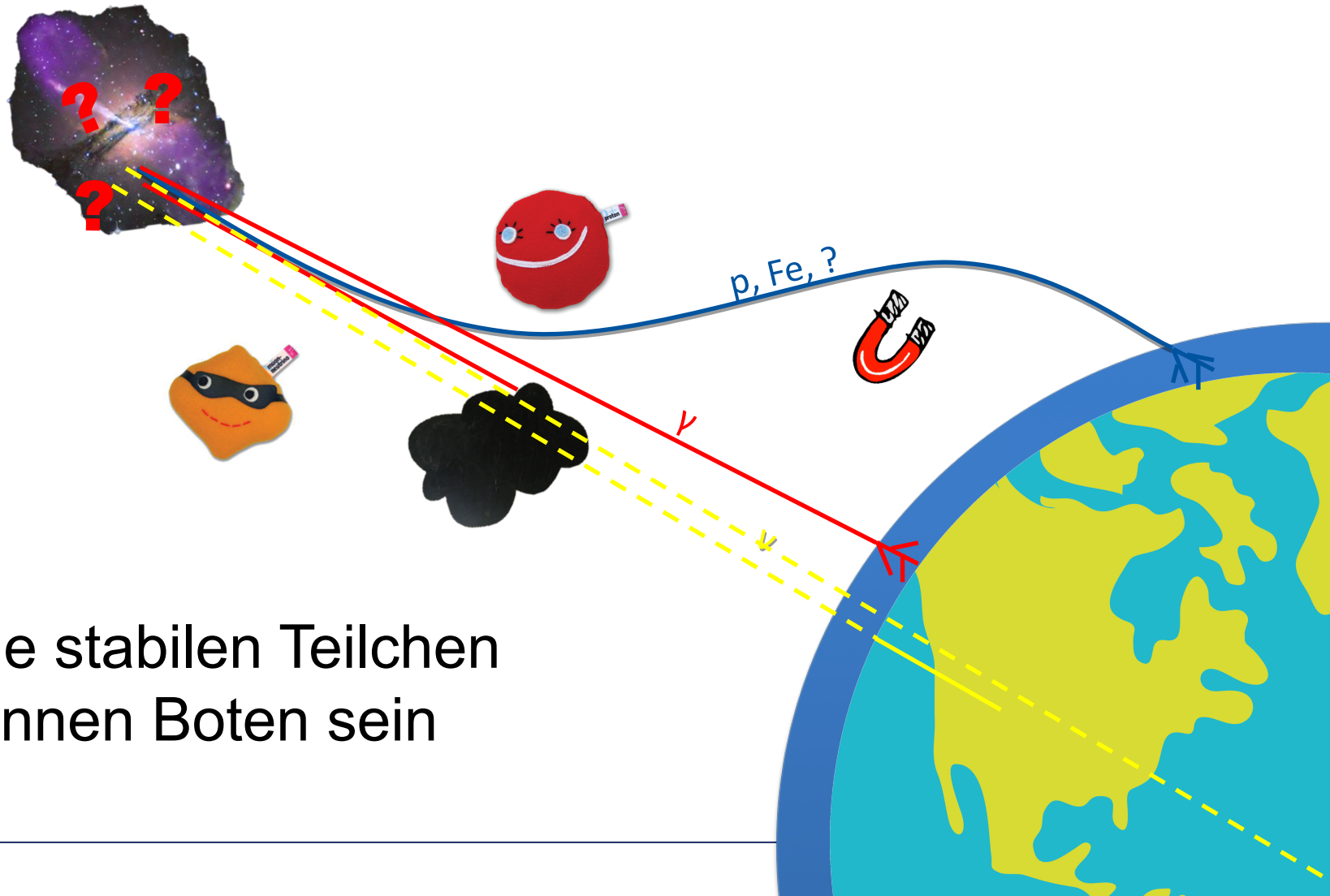
Astrophysik



Photon-Astronomie



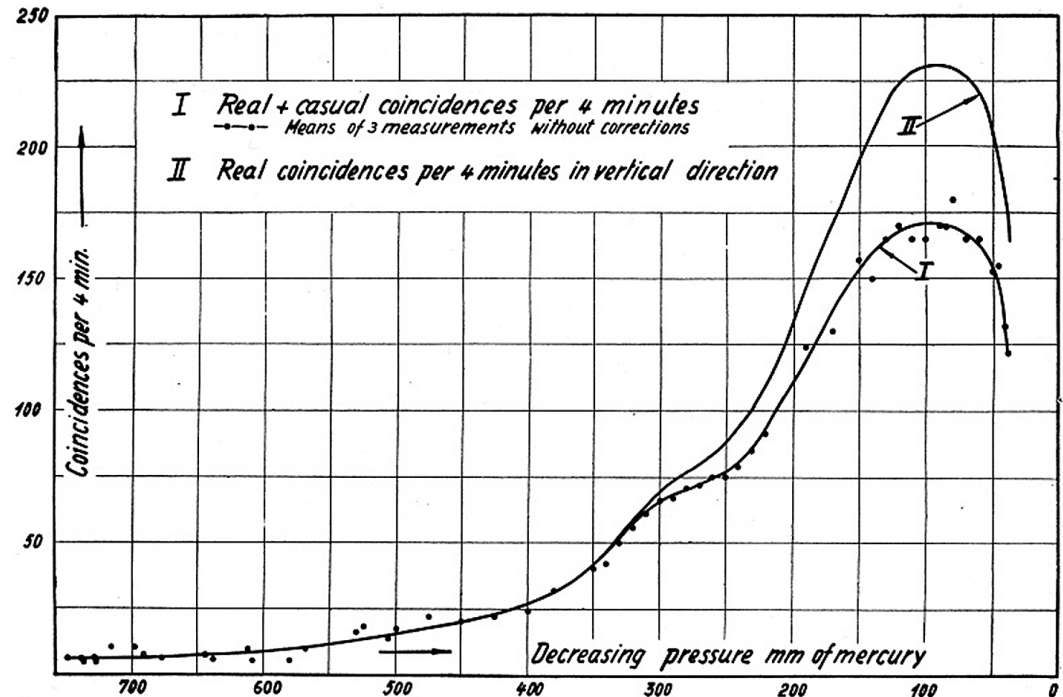
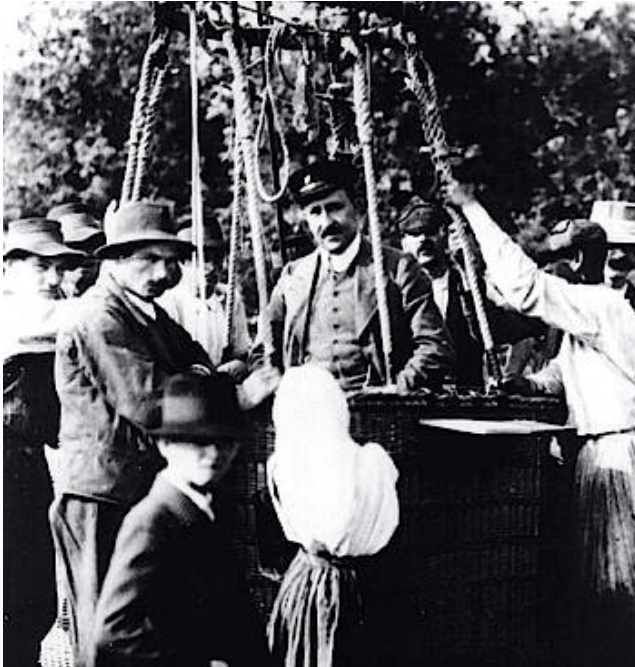
Was hat das mit Teilchenphysik zu tun?



- Alle stabilen Teilchen können Boten sein



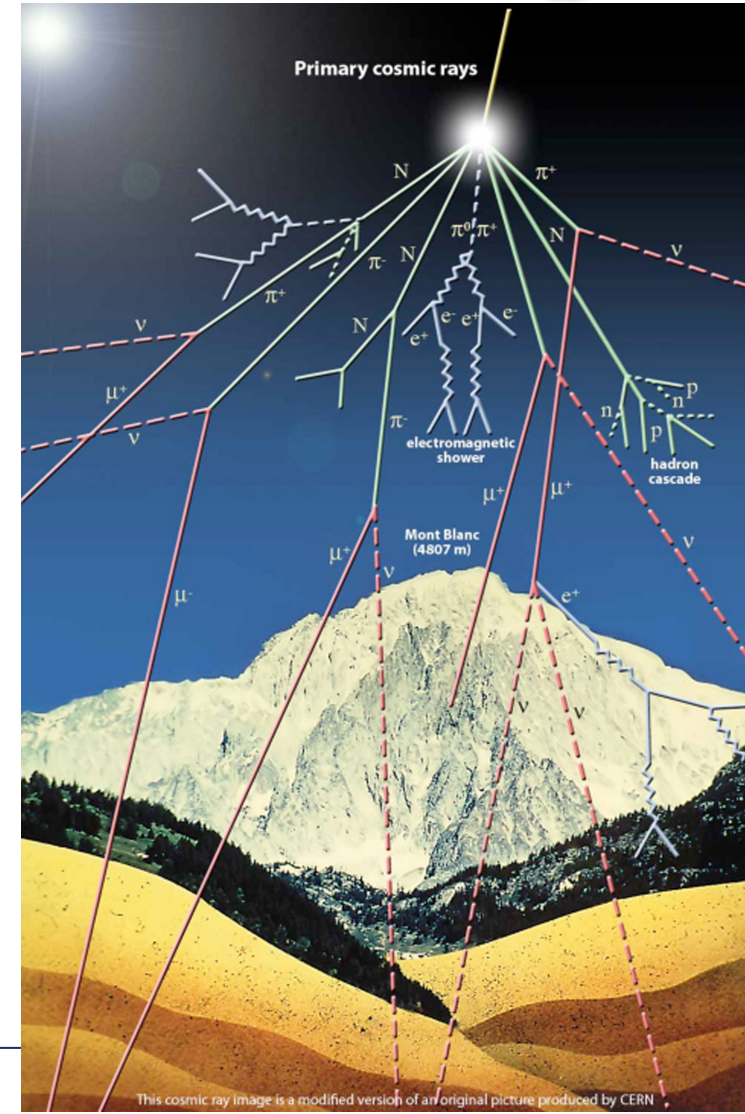
Höhenstrahlung



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

Luftschauder

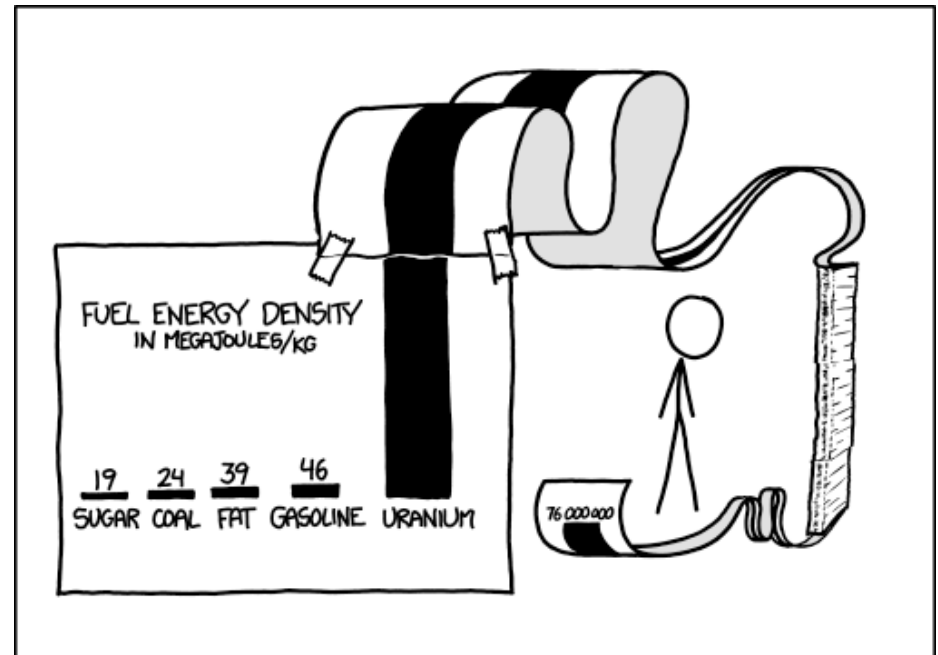
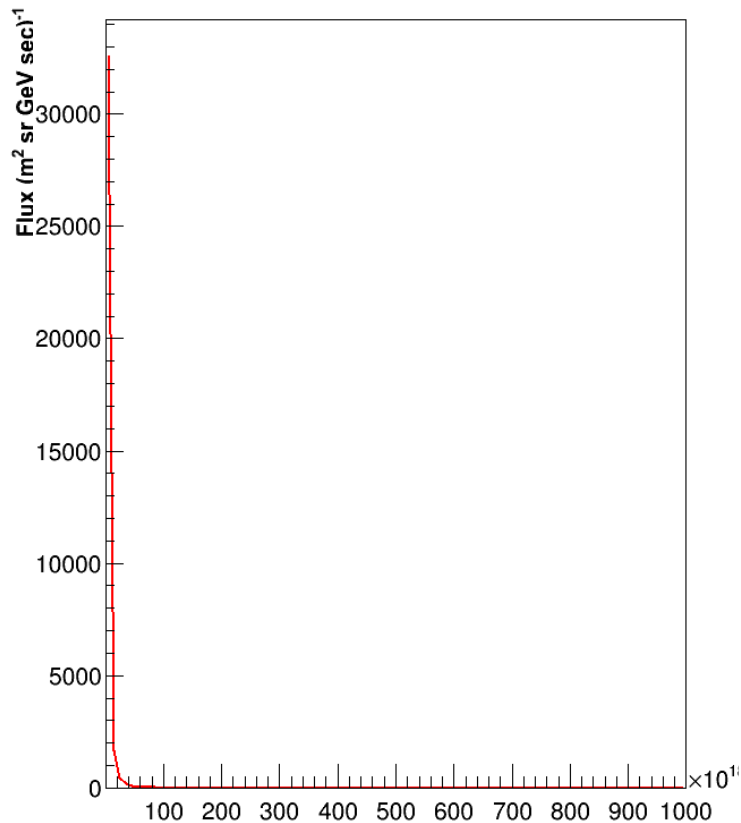
- Primärteilchen interagiert hoch in der Atmosphäre und bildet Schauerfront
- Sekundärteilchen zerfallen (teilweise) auf dem Weg zum Boden





Energiespektrum

Cosmic Ray Spectra of Various Experiments



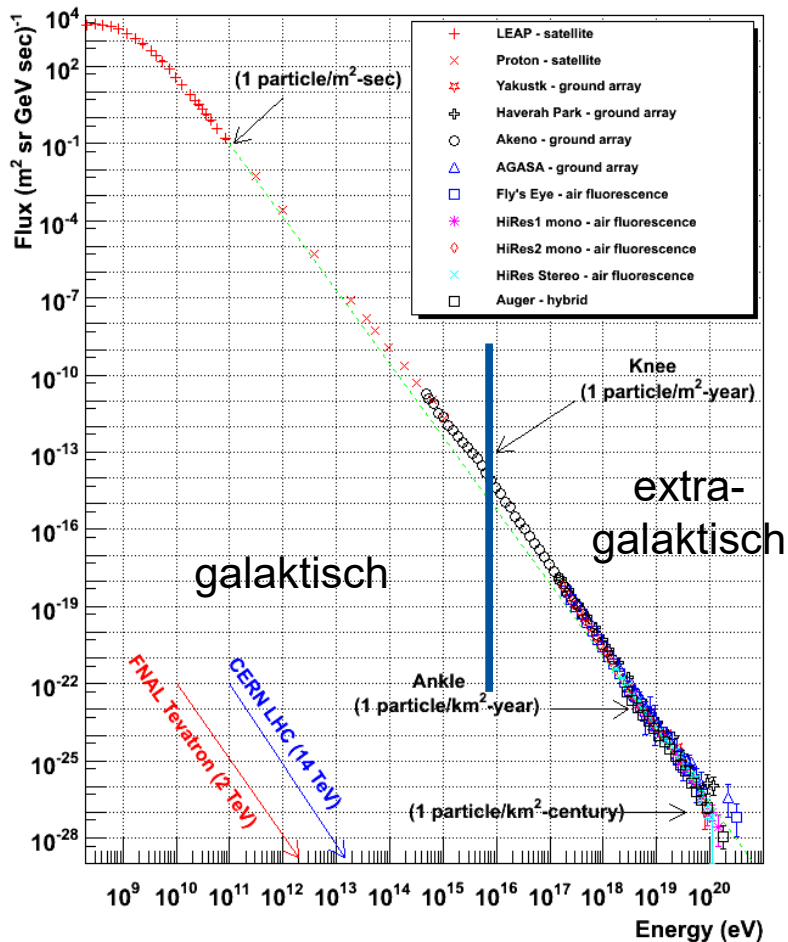
SCIENCE TIP: LOG SCALES ARE FOR QUITTERS WHO CAN'T
FIND ENOUGH PAPER TO MAKE THEIR POINT PROPERLY.

Energy (eV)



Energiespektrum

Cosmic Ray Spectra of Various Experiments



- Doppellogarithmisch Achsen
- (Eine Größenordnung pro Strich)
- Anzahl $\sim E^{-2,x}$
- Substrukturen geben Aufschluss über veränderte Herkunft

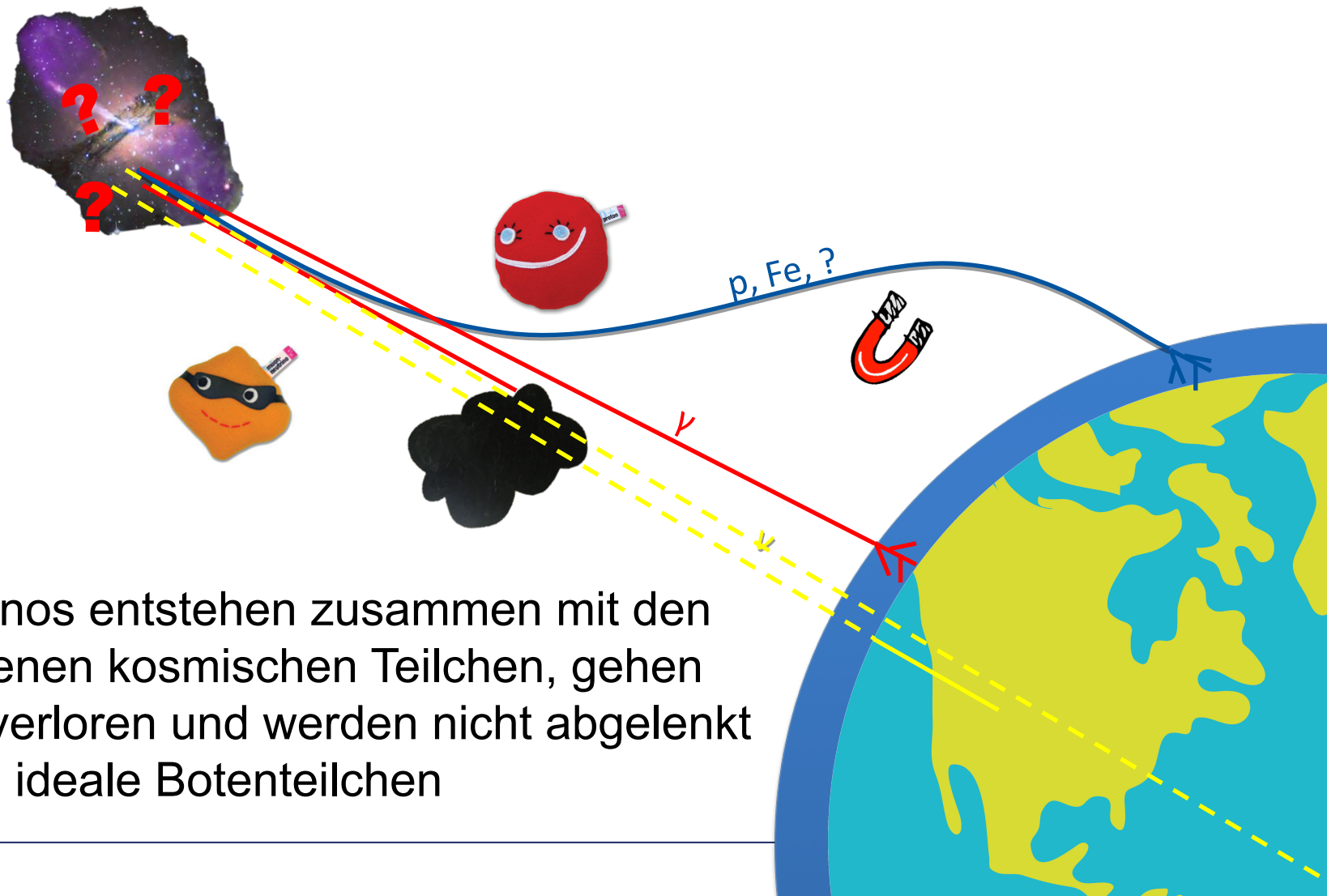
Richtung

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



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

Neutrino-Astronomie



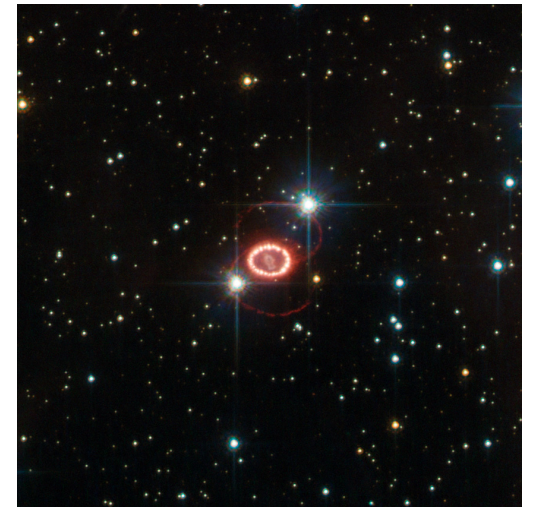
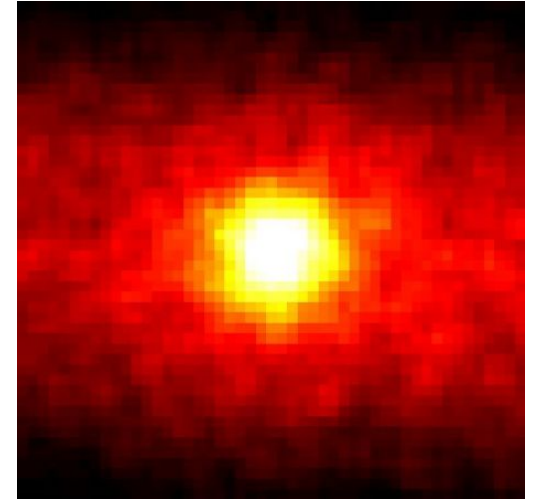
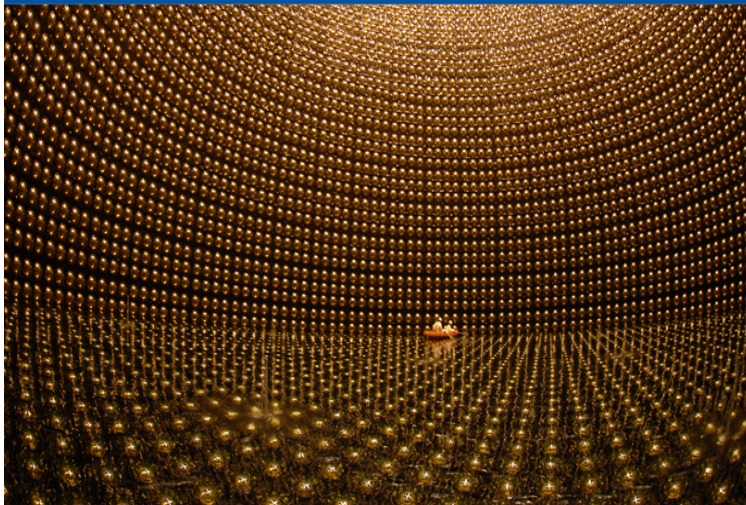
- Neutrinos entstehen zusammen mit den geladenen kosmischen Teilchen, gehen nicht verloren und werden nicht abgelenkt
→ ideale Botenteilchen

Neutrino - Quellen

- Sonne ($7 \cdot 10^{10}$ pro cm^2 und Sekunde)
~5000 pro Jahr gemessen
- SN1987a (Sternexplosion)
24 Neutrinos gemessen

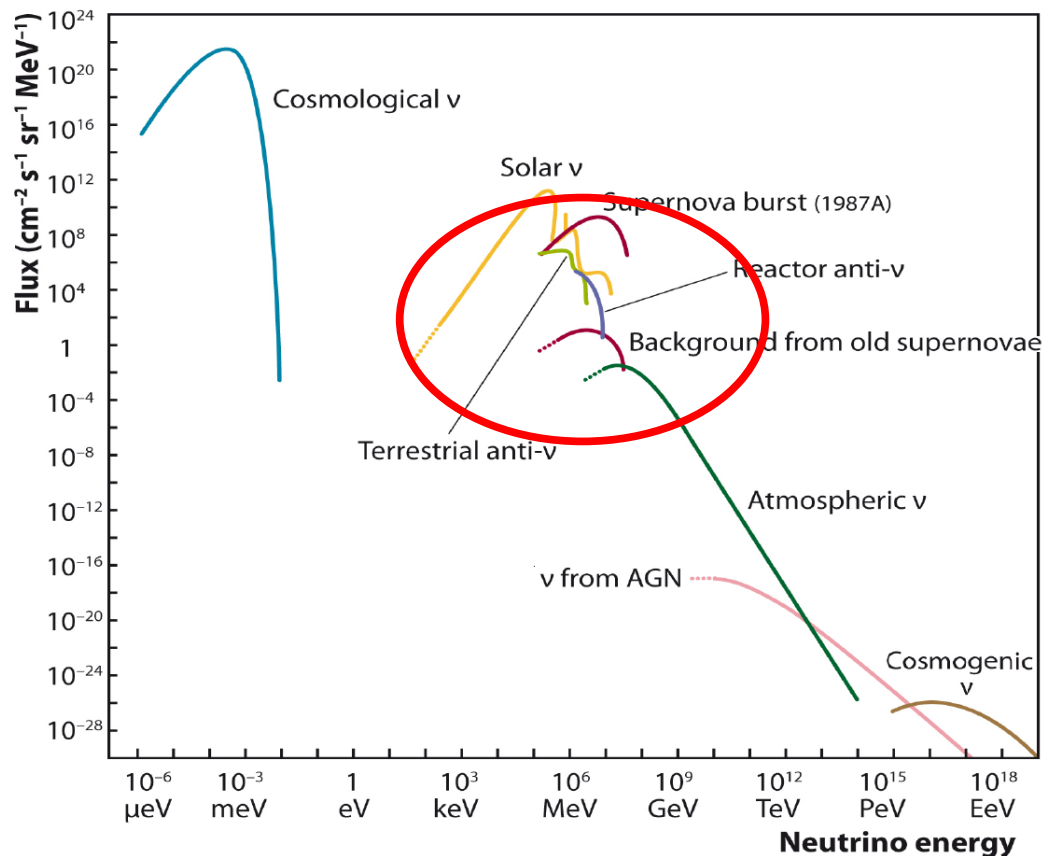


Detektor $\sim 0,00003 \text{ km}^3$



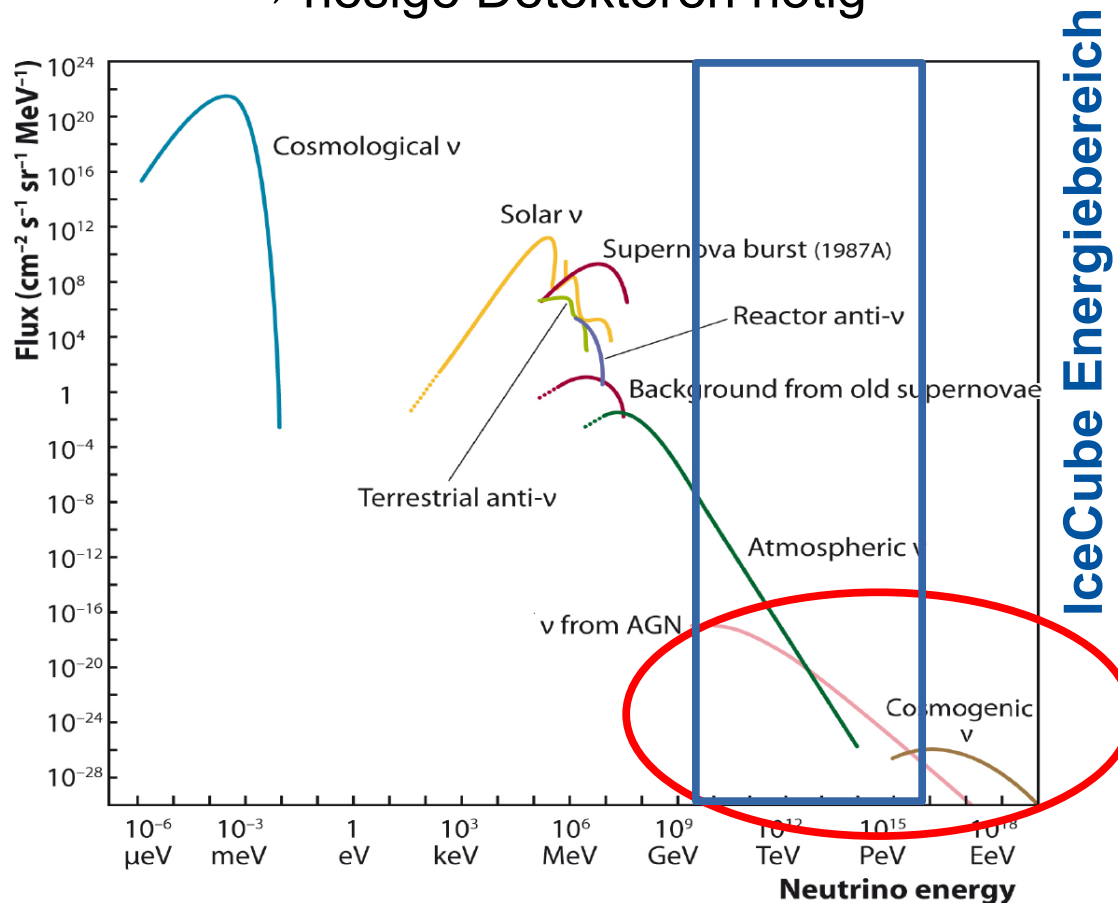
Herausforderung 1

- Nur wenige Ereignisse pro km² und Jahr erwartet
→ riesige Detektoren nötig



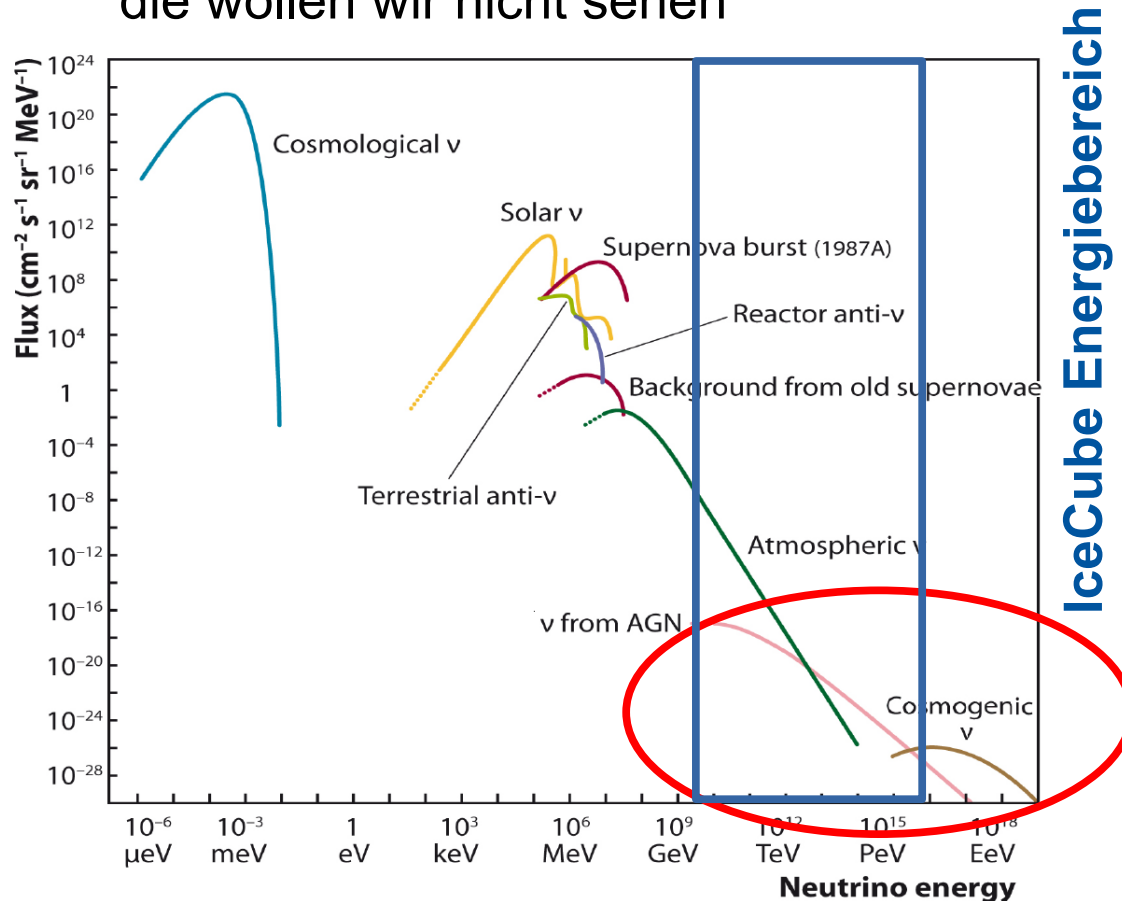
Herausforderung 1

- Nur wenige Ereignisse pro km^2 und Jahr erwartet
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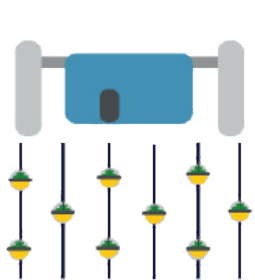


Herausforderung 2

- 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.



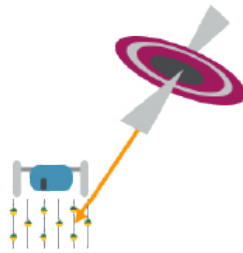
2011

IceCube
Completed



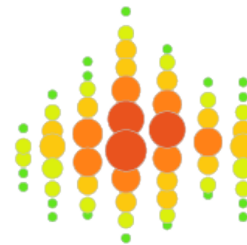
2013

Astrophysical
Neutrinos
Discovered



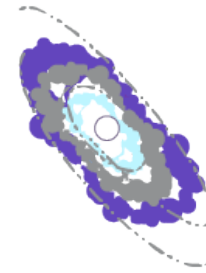
2018

First Source
TXS 0506+056
Identified



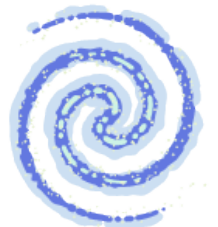
2021

Glashow
Resonance
Neutrino
Identified



2022

Second Source
NGC 1068
Identified



2023

Third Source
Milky Way
Identified