



IceCube Masterclass 2026

Astroteilchenphysik

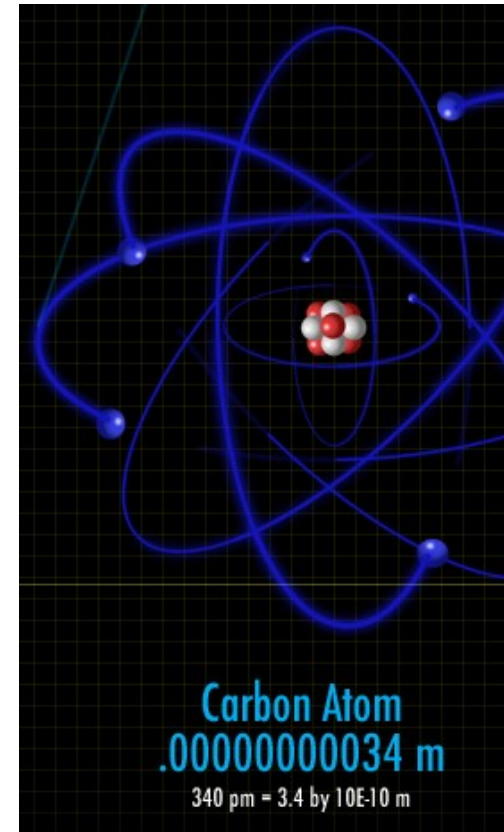
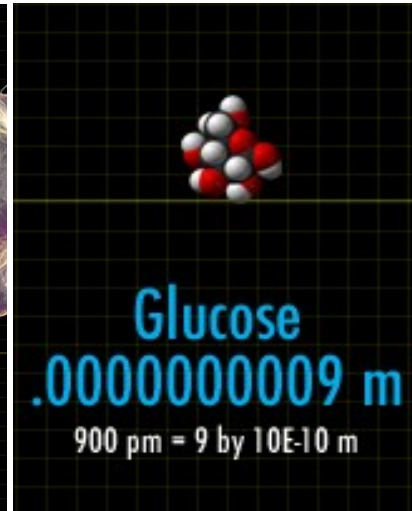
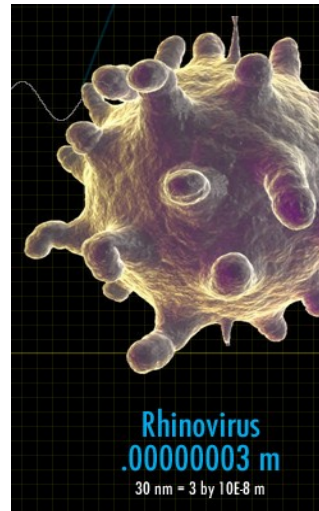
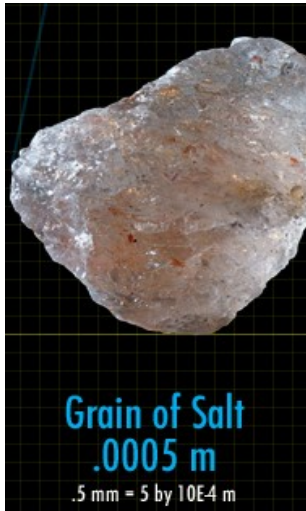
Martin Rongen
Nürnberg, 30.09.2026



Teilchenphysik



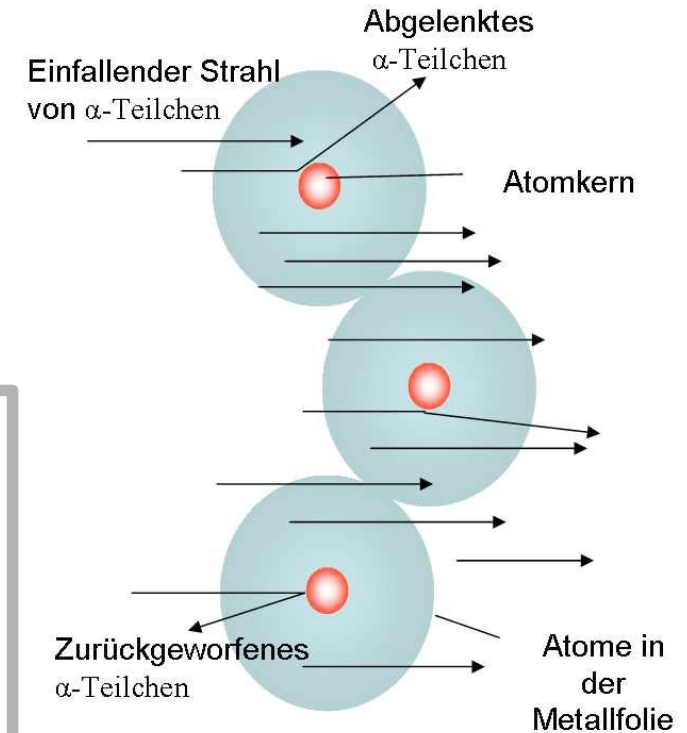
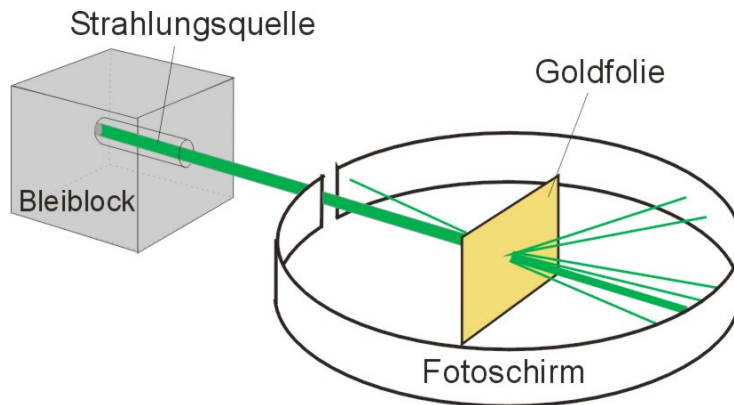
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FOR ASTROPARTICLE
PHYSICS



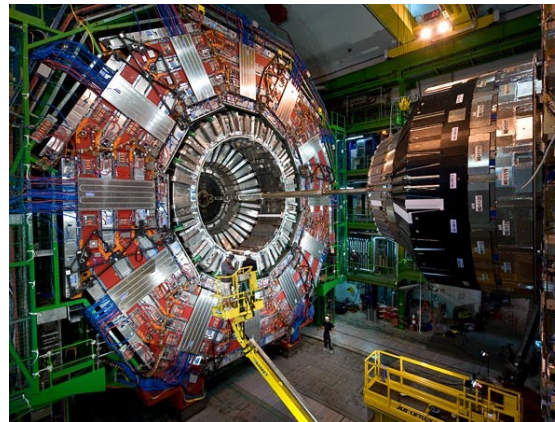
Streuexperimente



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



CMS Masterclass



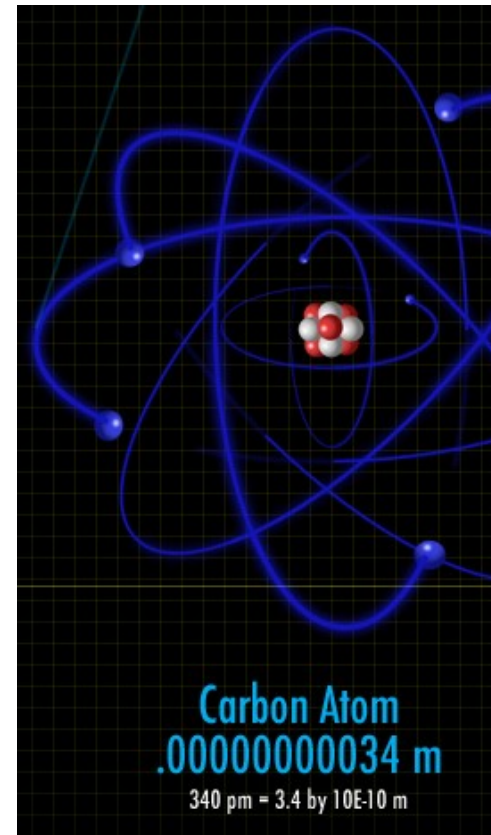
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Das Standardmodell

● Quarks

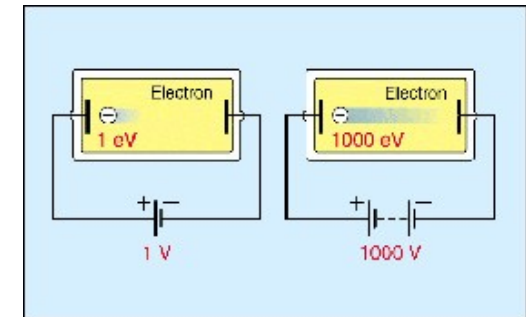
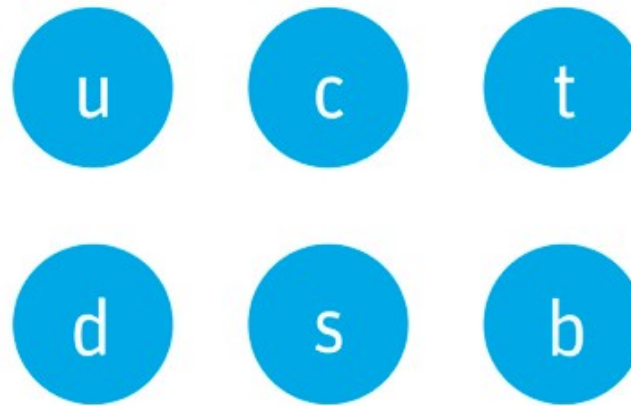
● Leptonen



Das Standardmodell

● Quarks

● Leptonen



schwerer →



500keV

100MeV

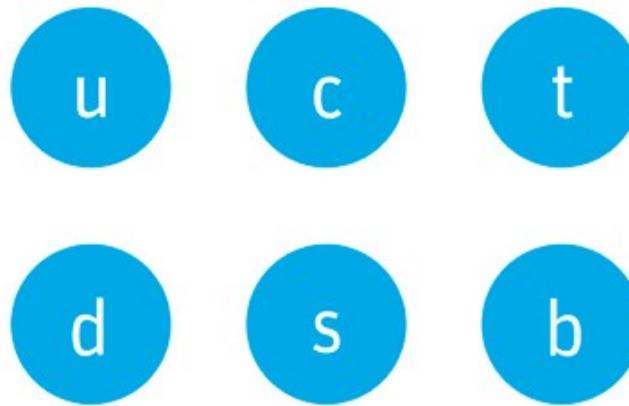
2GeV

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

Das Standardmodell

- Quarks

● Leptonen



Periodensystem

H																	He	
Li	Be											B	C	N	O	F	Ne	
Na	Mg											Al	Si	P	S	Cl	Ar	
K	Ca	Sc	Ti	Zr	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt										
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu					
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr					

schwerer

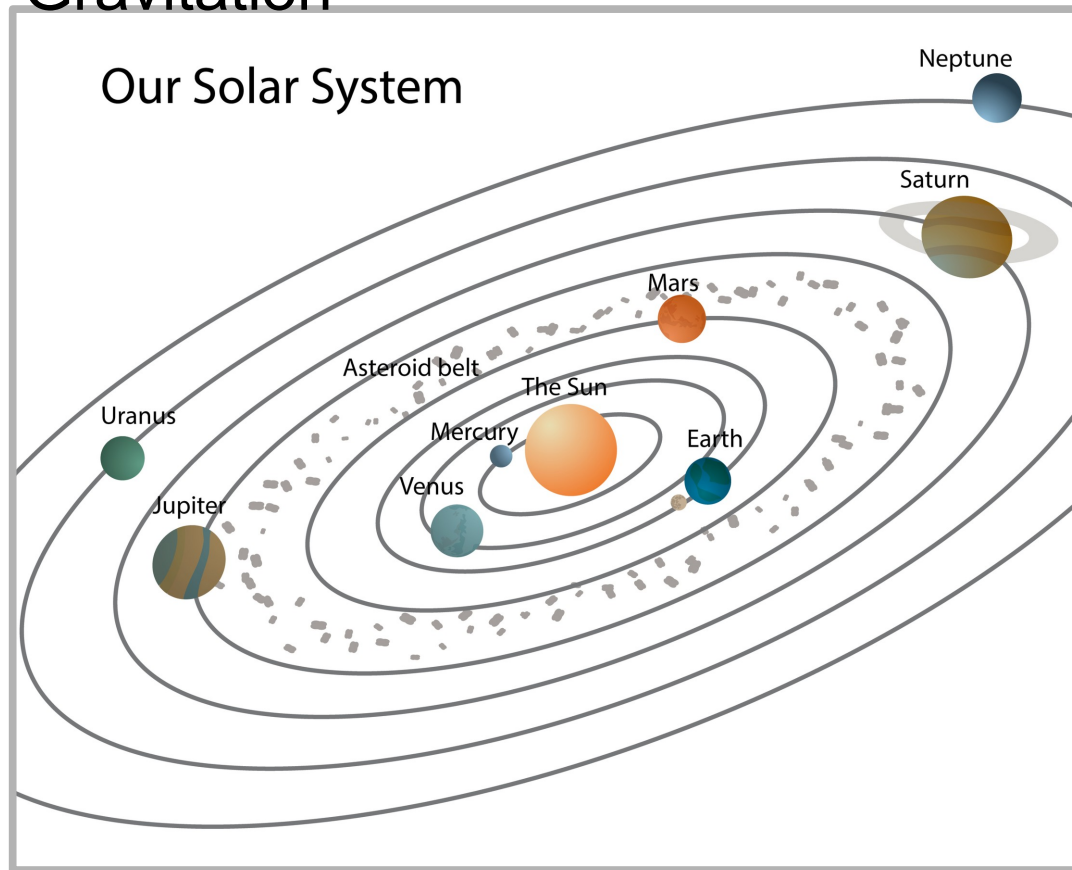


500keV

100MeV

2GeV

Gravitation



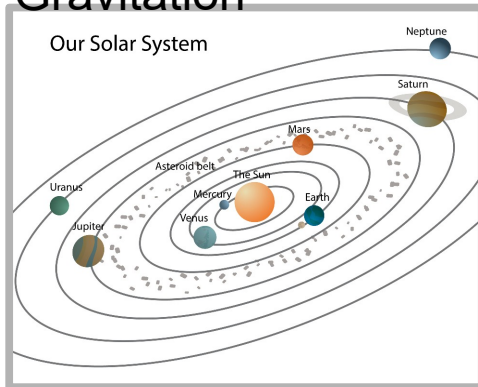
Die Kräfte



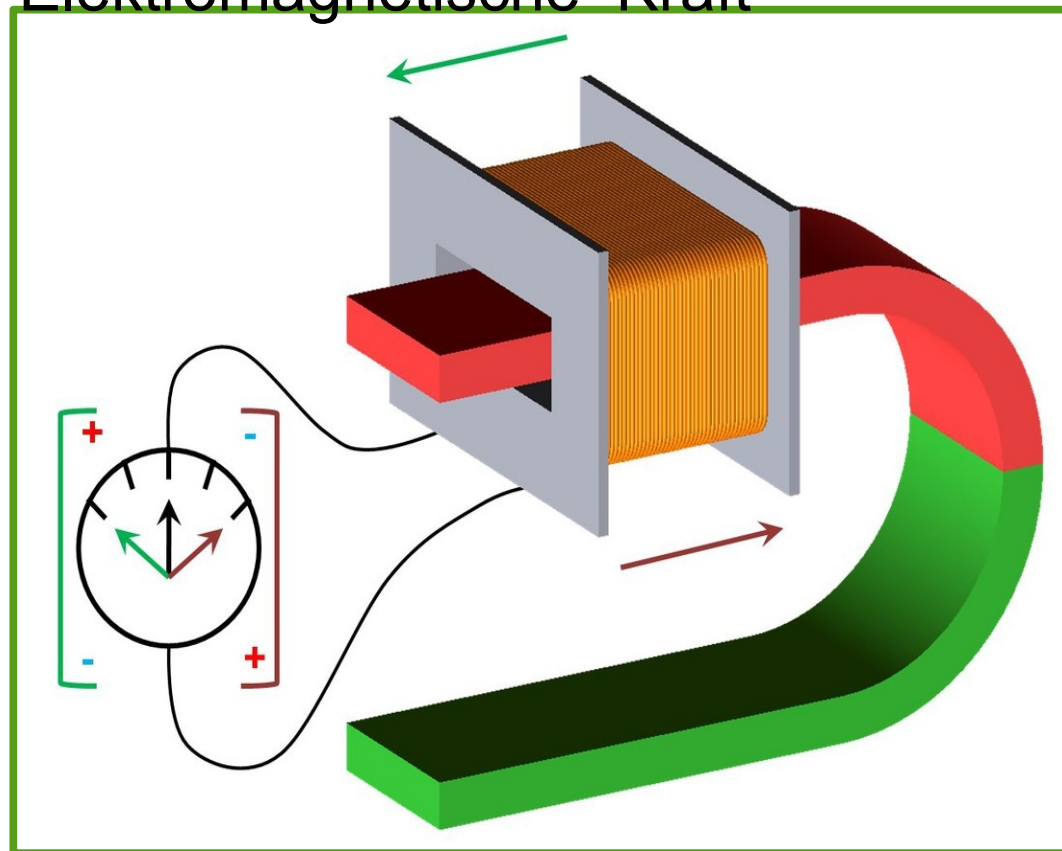
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Gravitation



Elektromagnetische Kraft



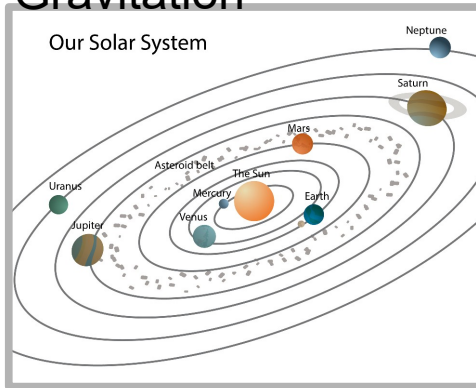
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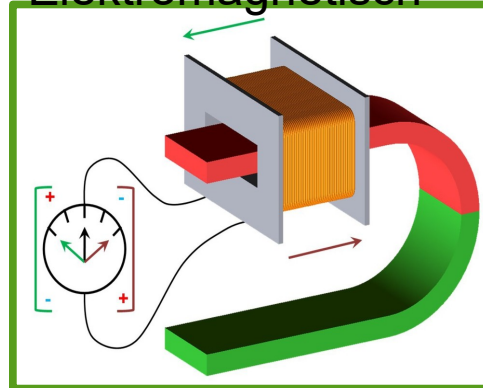
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Gravitation

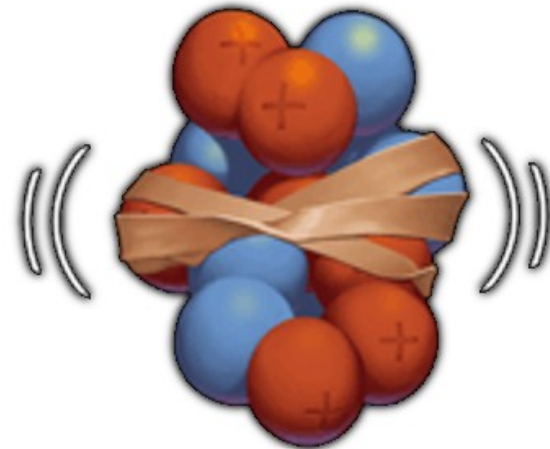


Elektromagnetisch



Starke Kraft

Atomkern



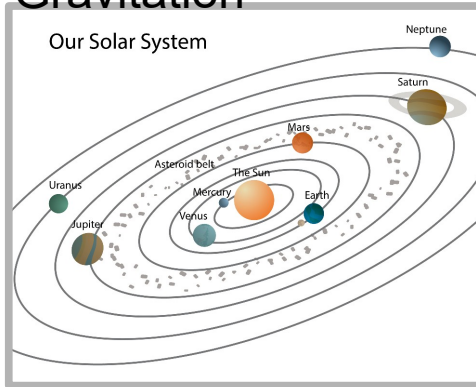
Die Kräfte



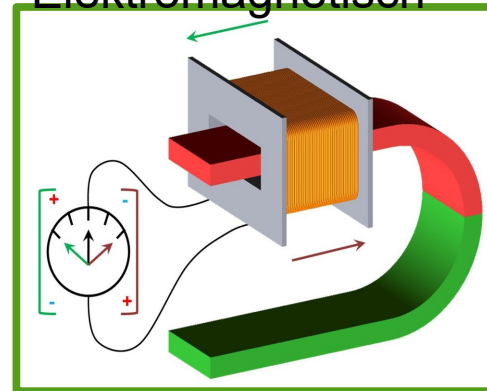
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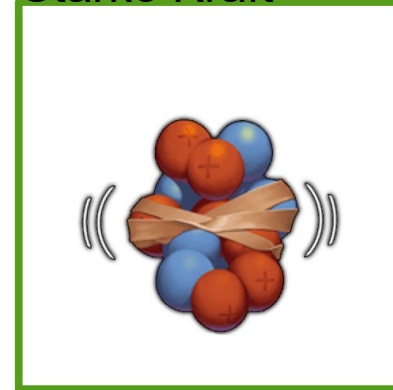
Gravitation



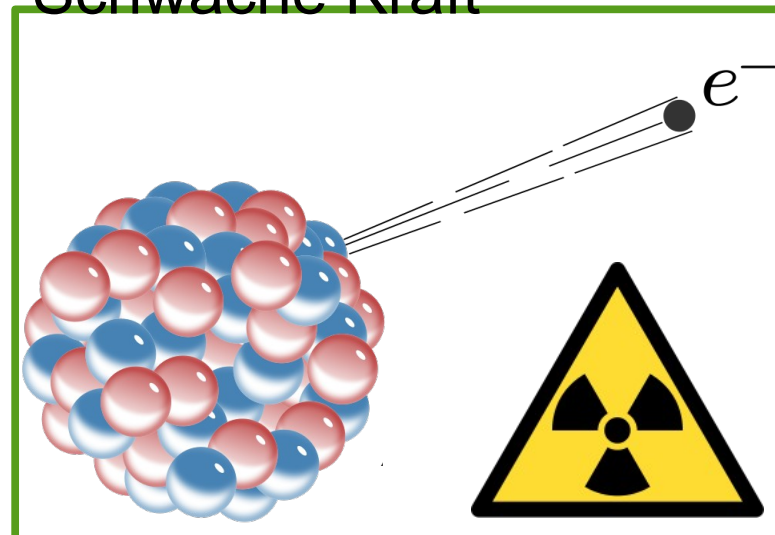
Elektromagnetisch



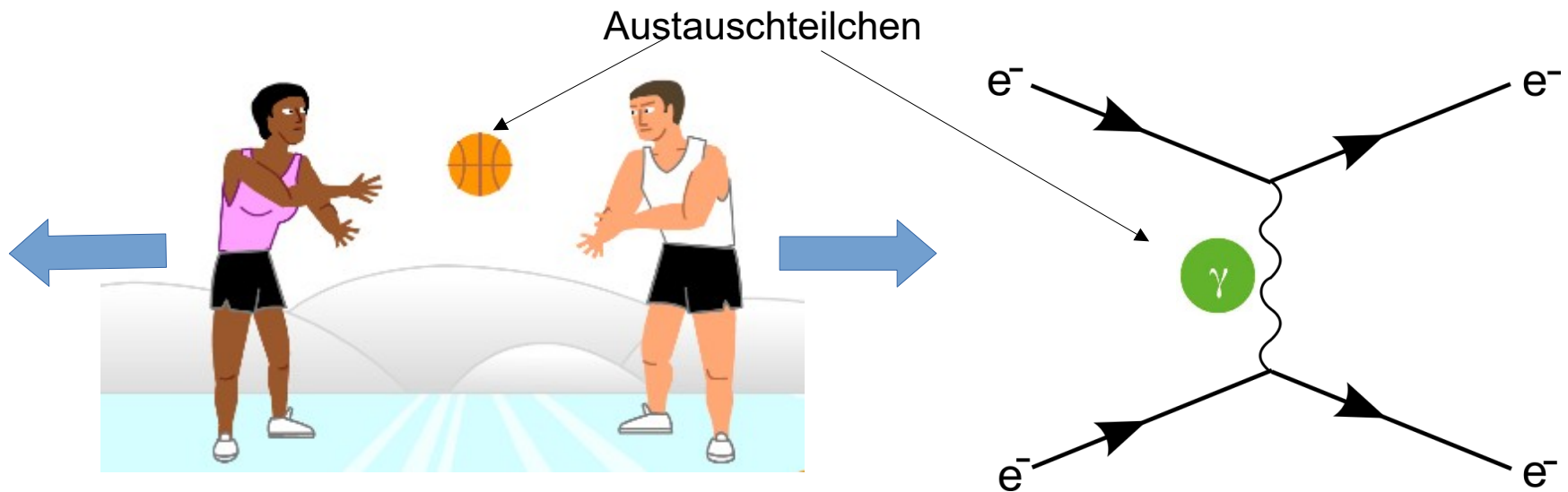
Starke Kraft



Schwache Kraft



Die Kräfte im Teilchenbild



Die vollständige(?) Standardmodell



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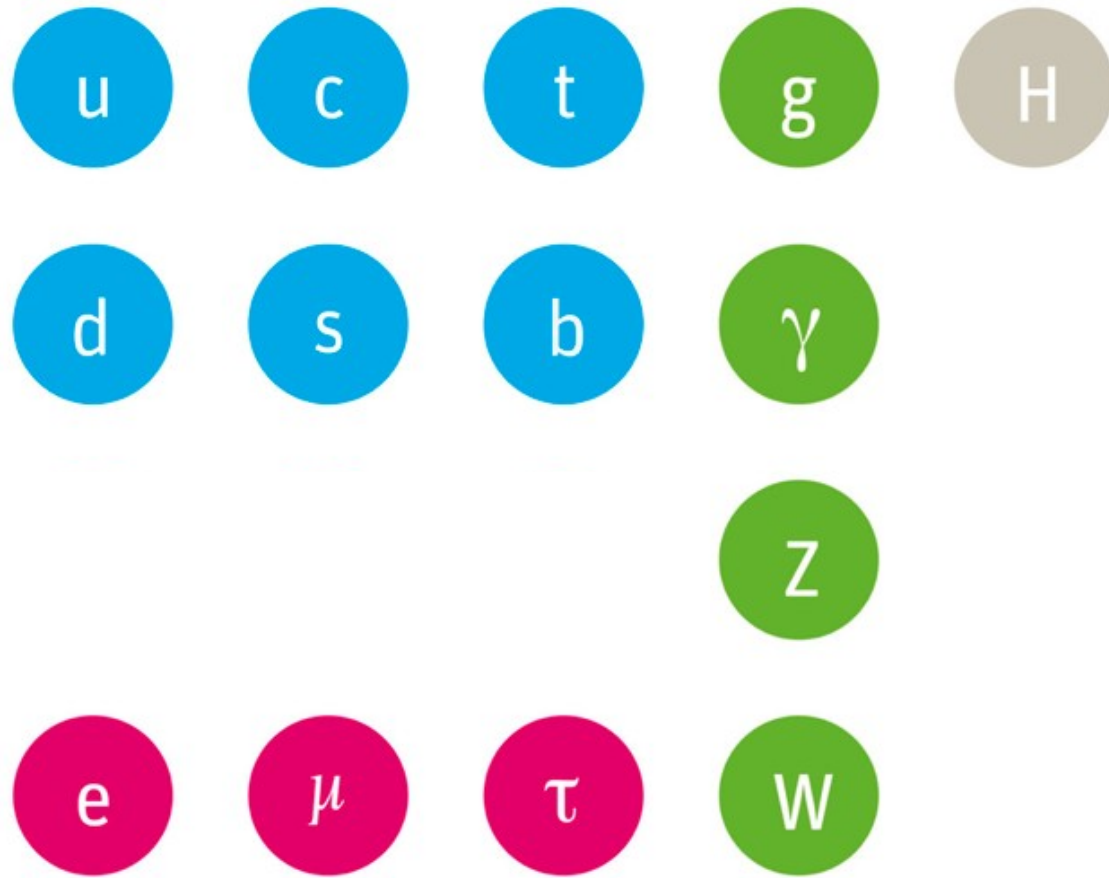


● Quarks

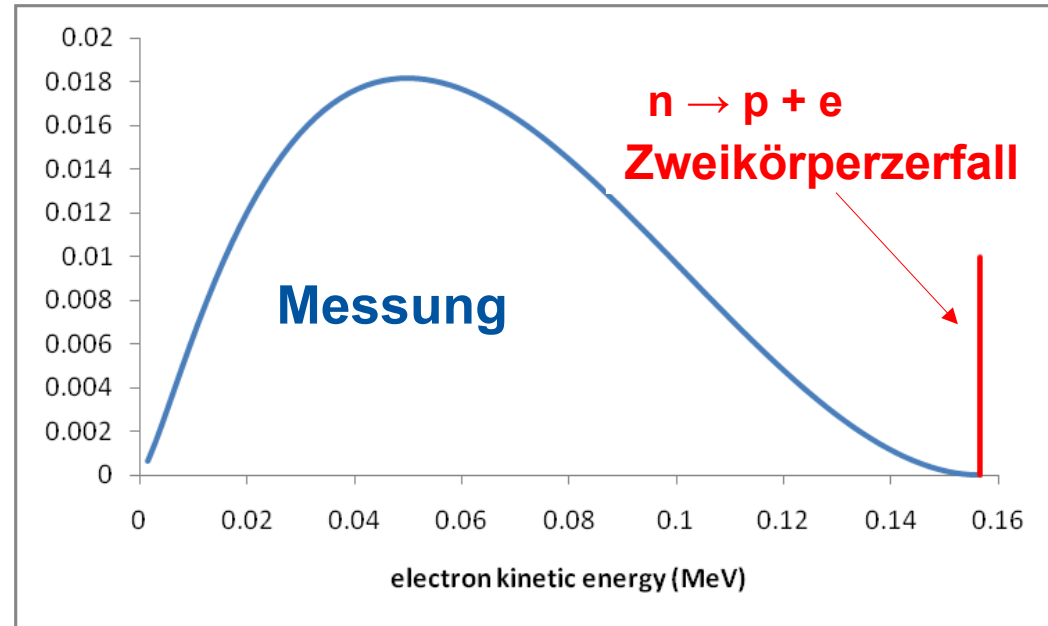
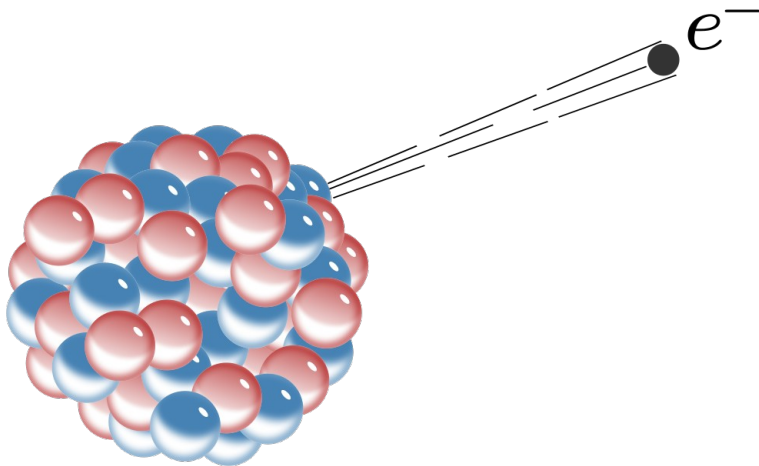
● Leptonen

● Kraftteilchen

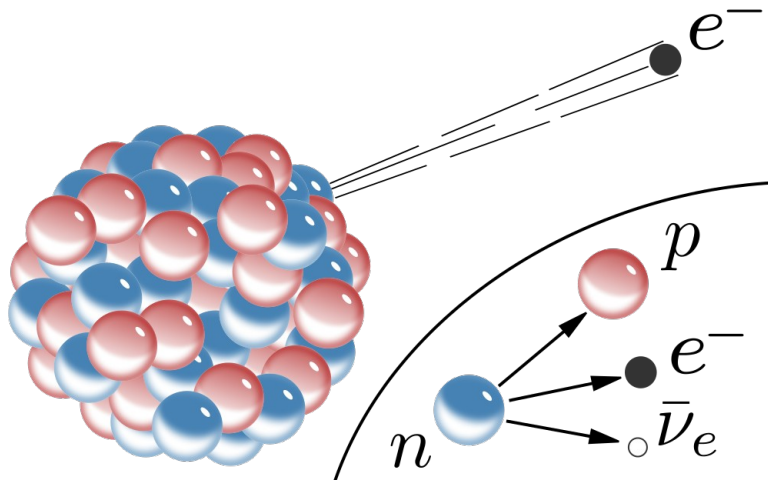
● Higgs



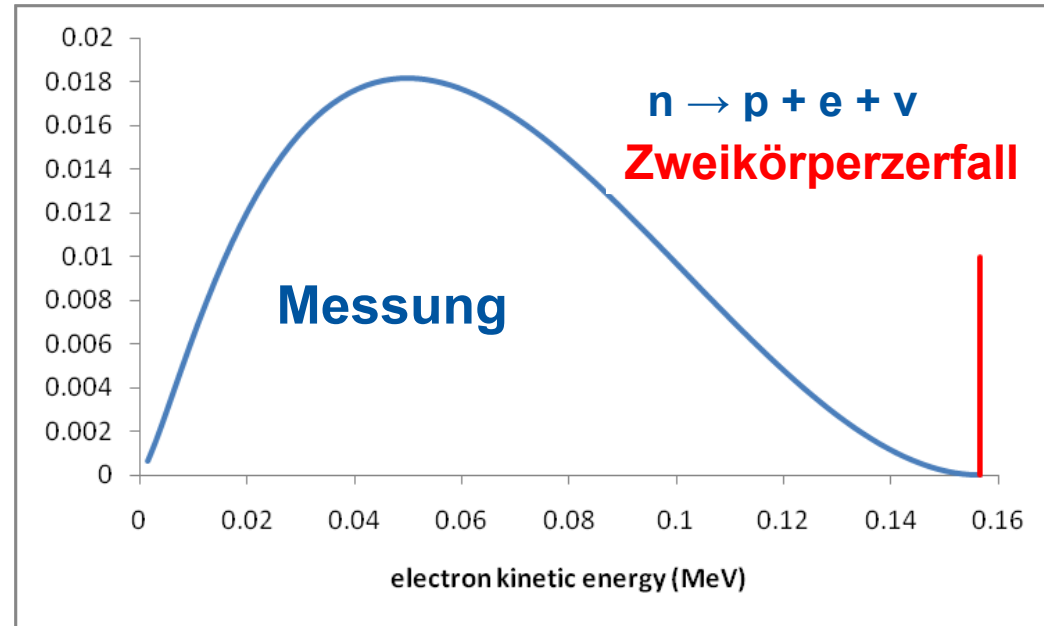
Der β -Zerfall



Der β -Zerfall



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

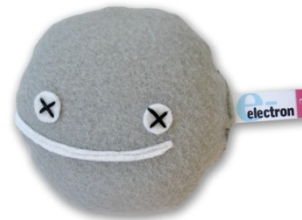


Das Neutrino

- Elektrisch ungeladen und fast masselos
- Masse:



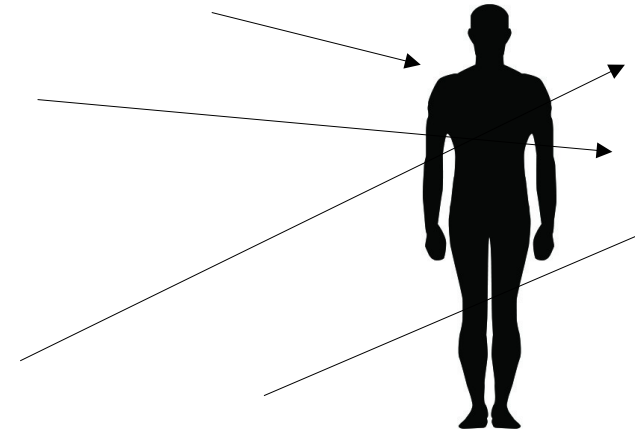
/ 2000



/ 500 000+



- “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



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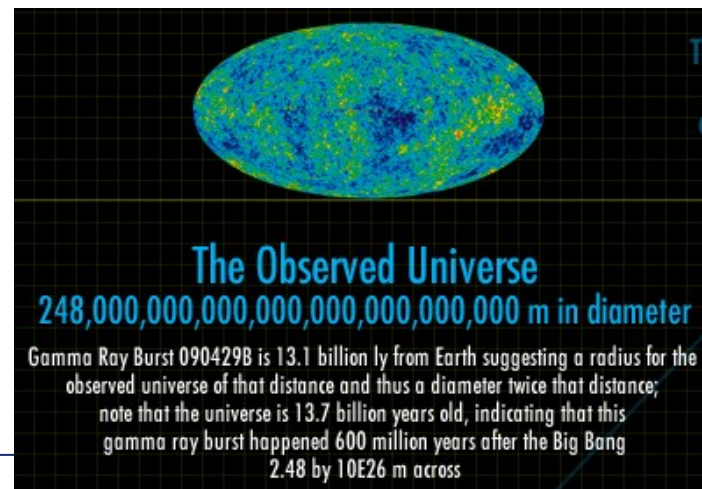
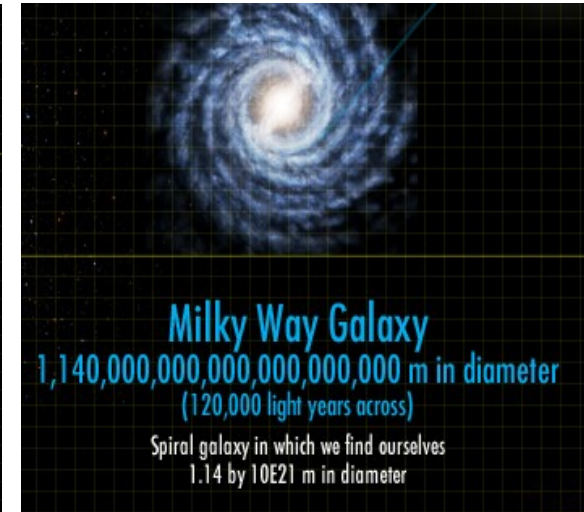
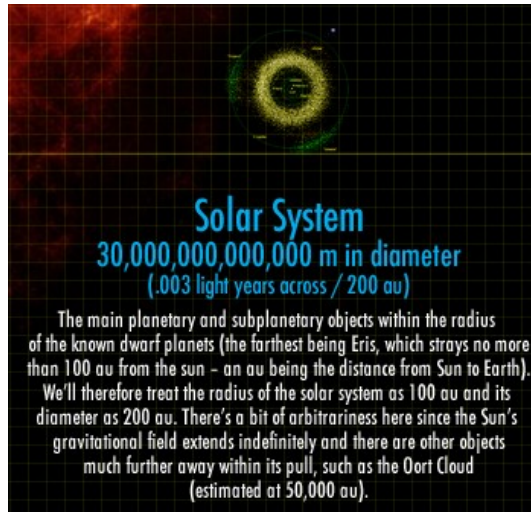
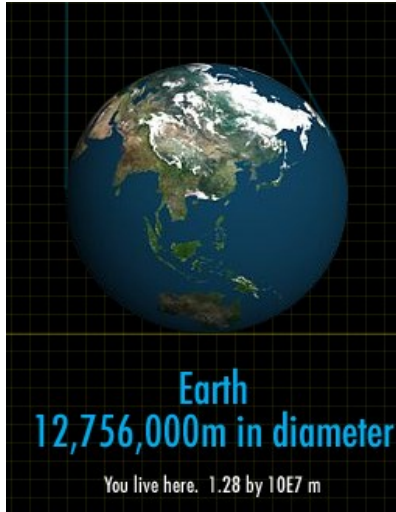
● Quarks

● Leptonen

● Kraftteilchen

● Higgs

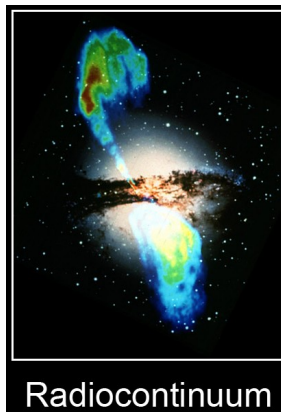
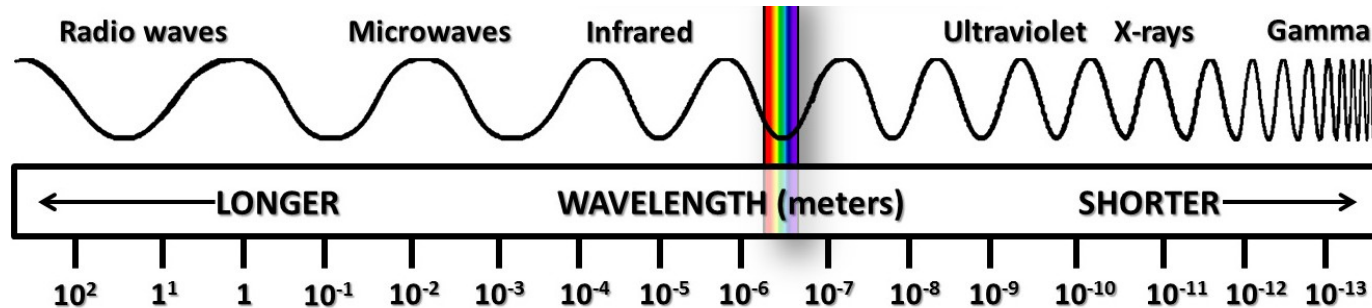
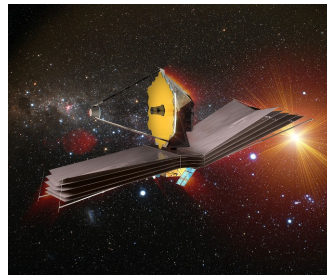




Photon-Astronomie

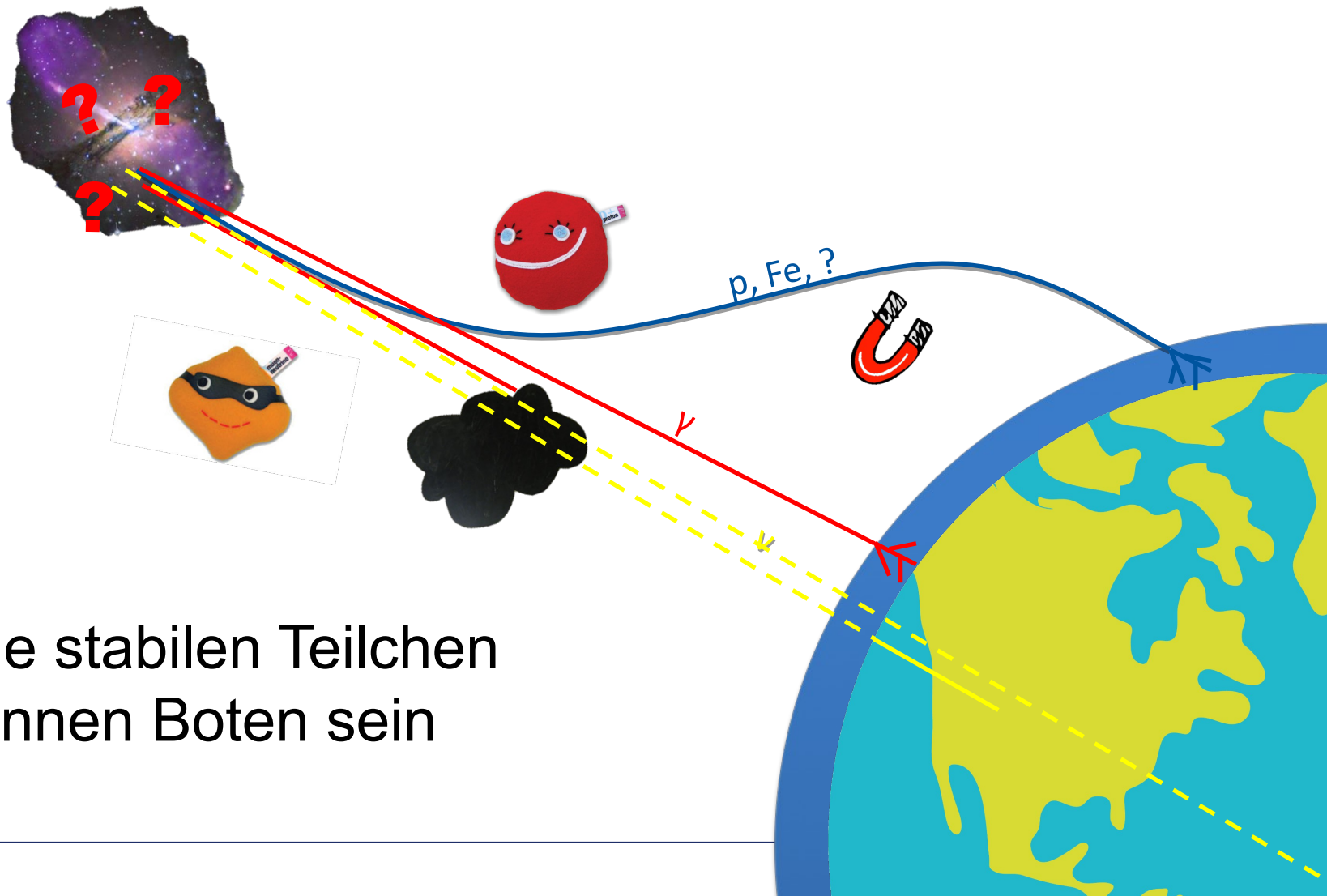


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Was hat das mit Teilchenphysik zu tun?

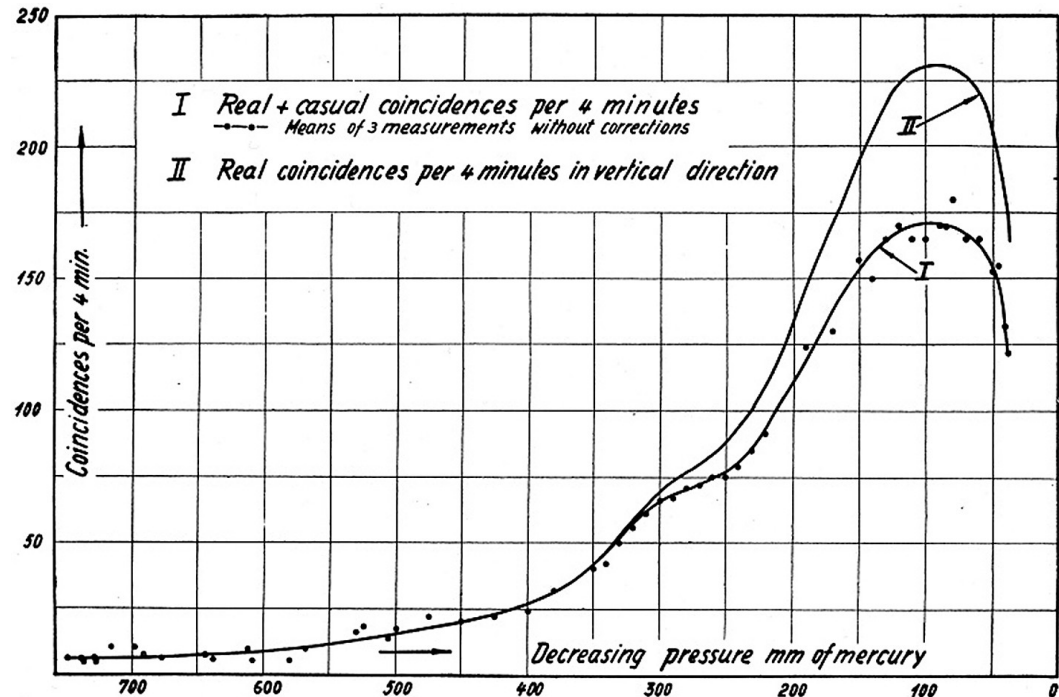
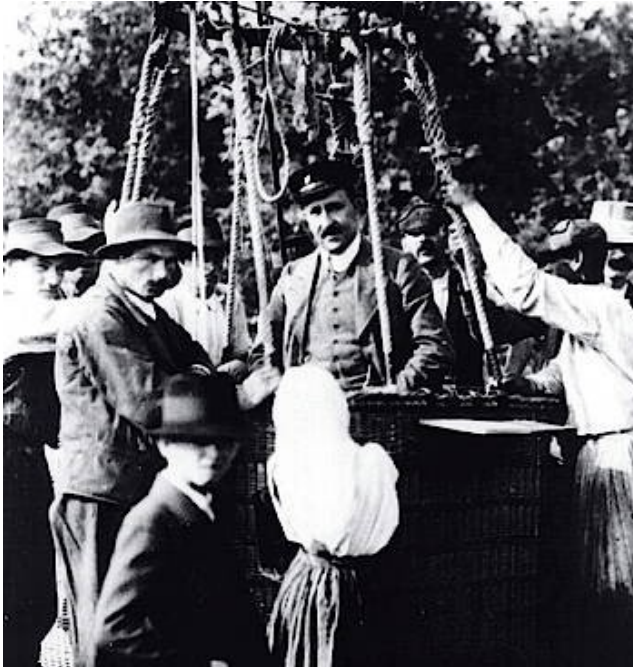


- Alle stabilen Teilchen können Boten sein

Höhenstrahlung



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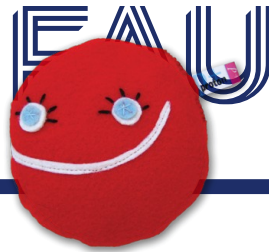


- Radioaktivität nimmt (entgegen der Erwartung) mit der Höhe zu
→ die Erde muss von geladenen Teilchen getroffen werden

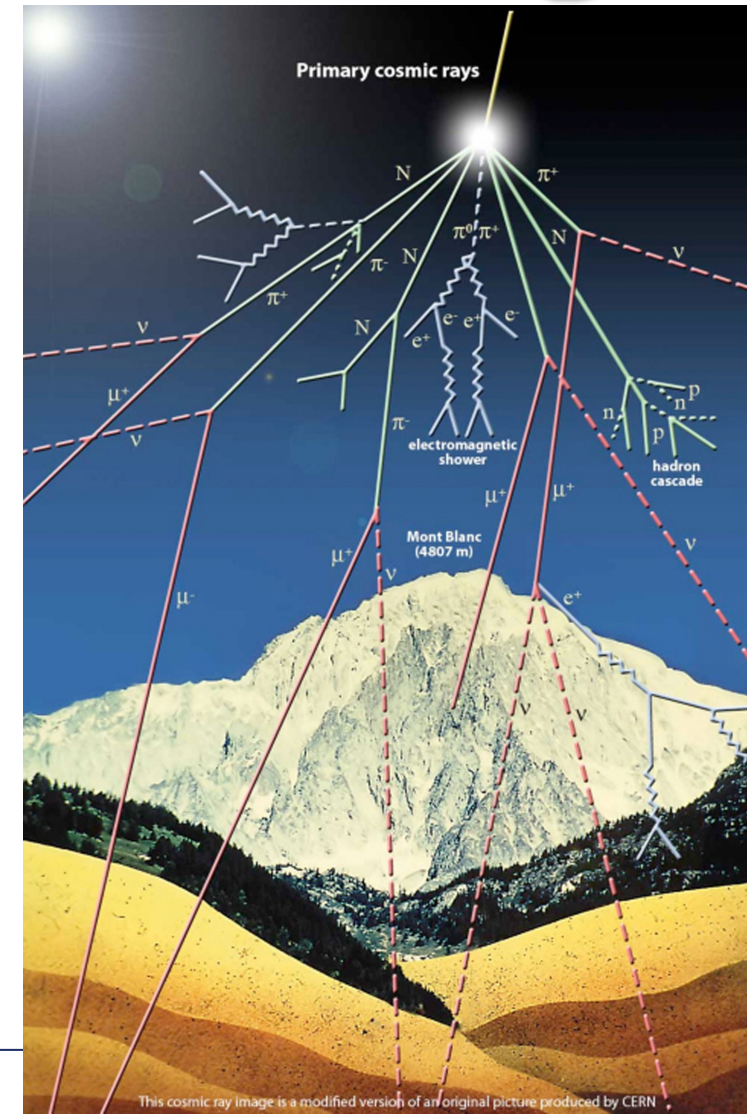
Luftschauder



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



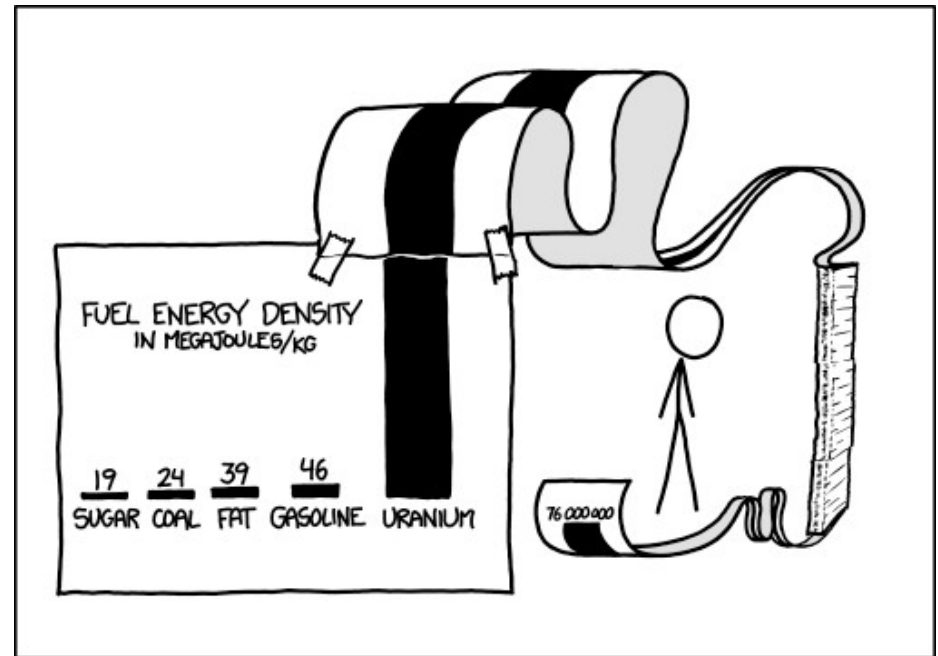
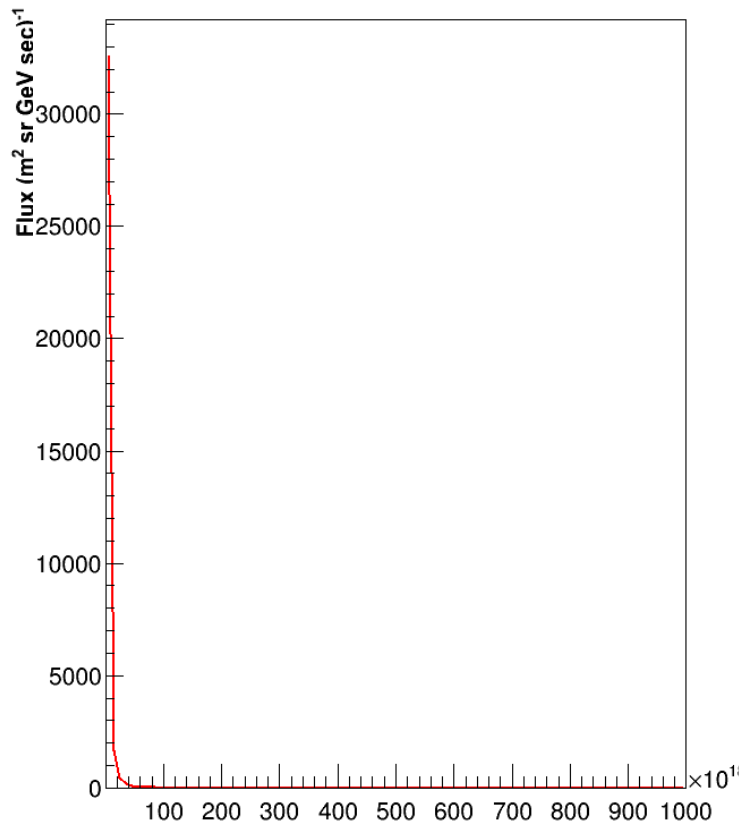
Energiespektrum



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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)

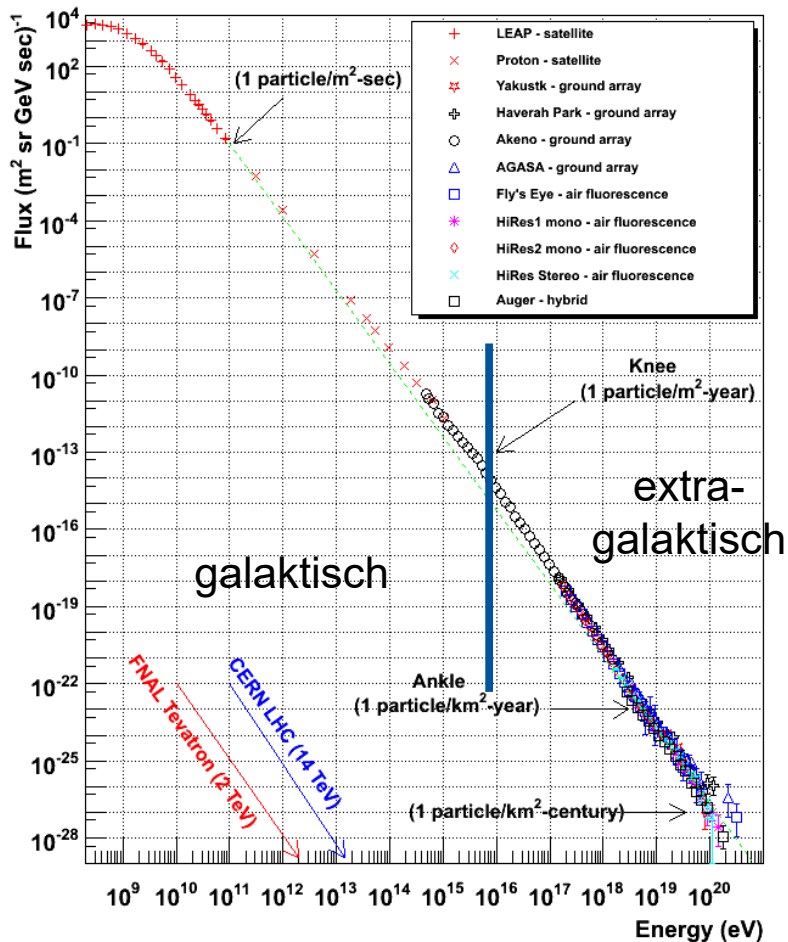
Energiespektrum



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Cosmic Ray Spectra of Various Experiments



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

Richtung



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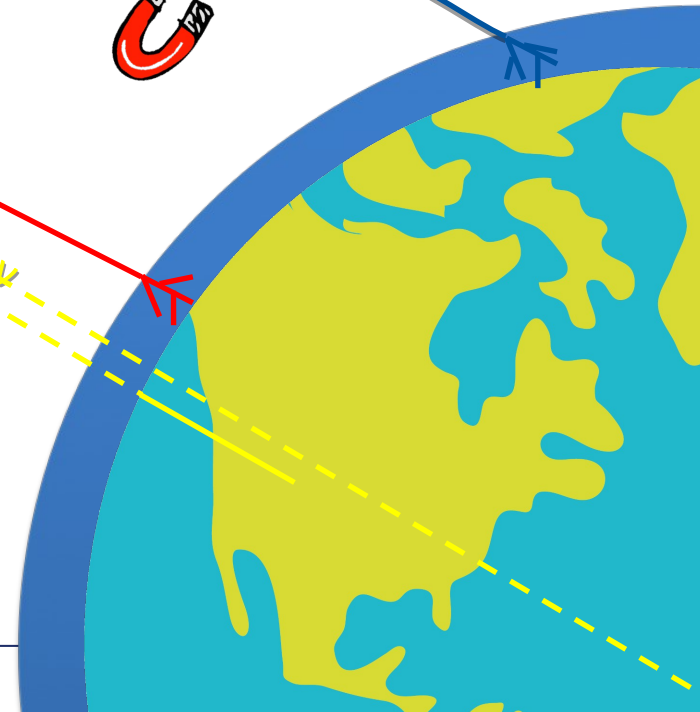
Die geladenen Teilchen werden in intergalaktischen Magnetfelden abgelenkt und zeigen nicht mehr auf ihren Ursprung



p, Fe, ?



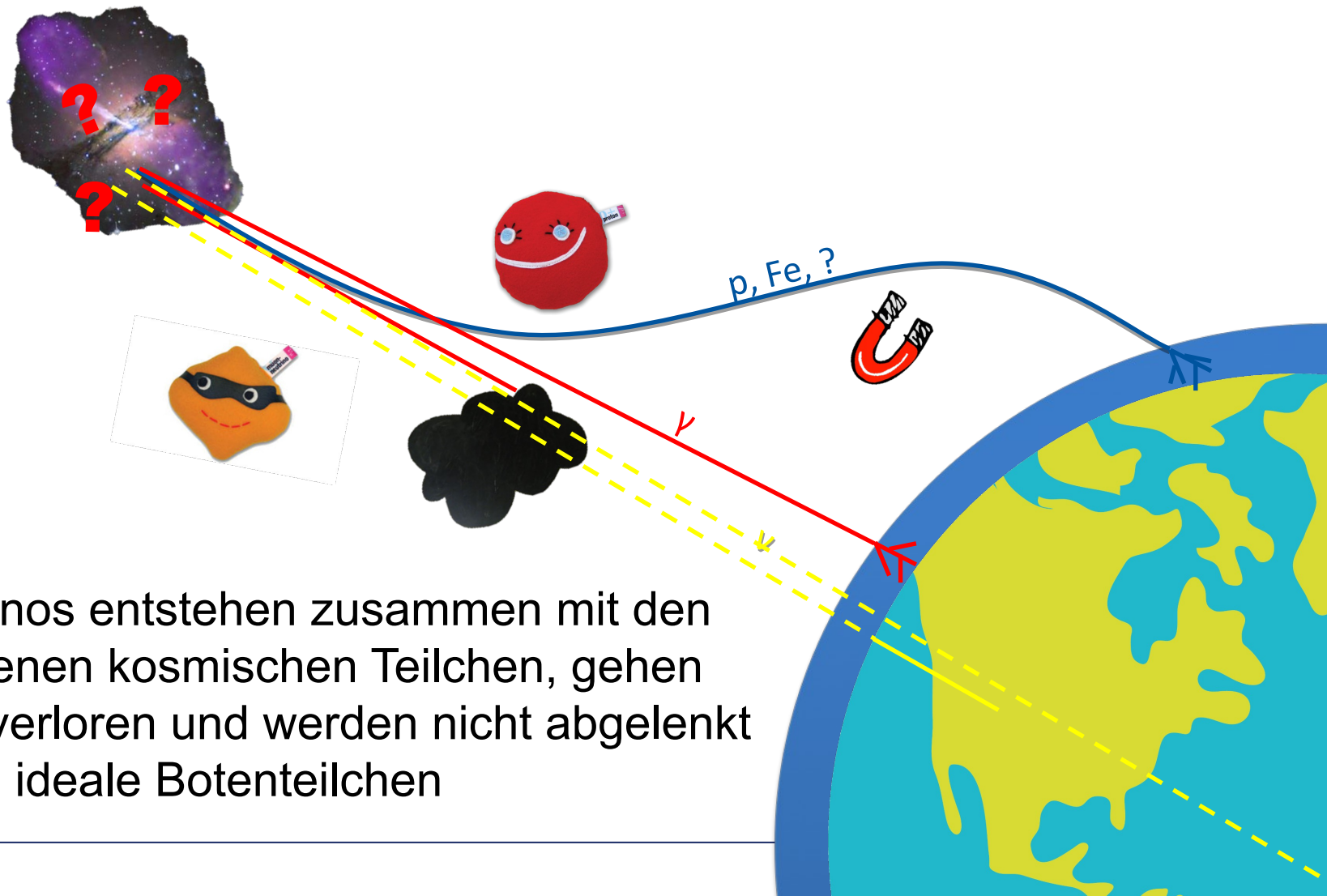
→ trotz Jahrzehnten an Forschung kennen wir die Quellen der kosmischen Strahlung kaum



Neutrino-Astronomie



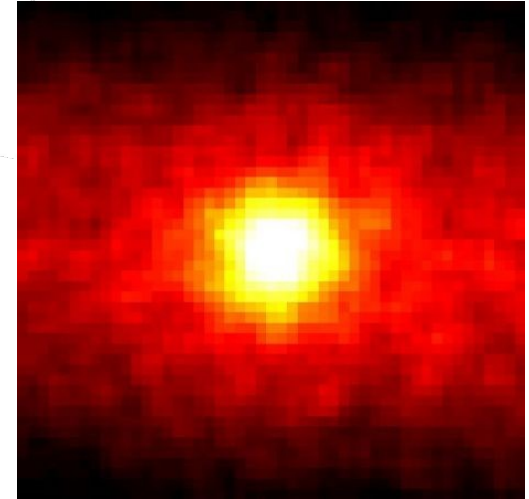
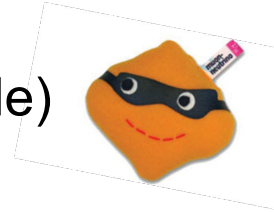
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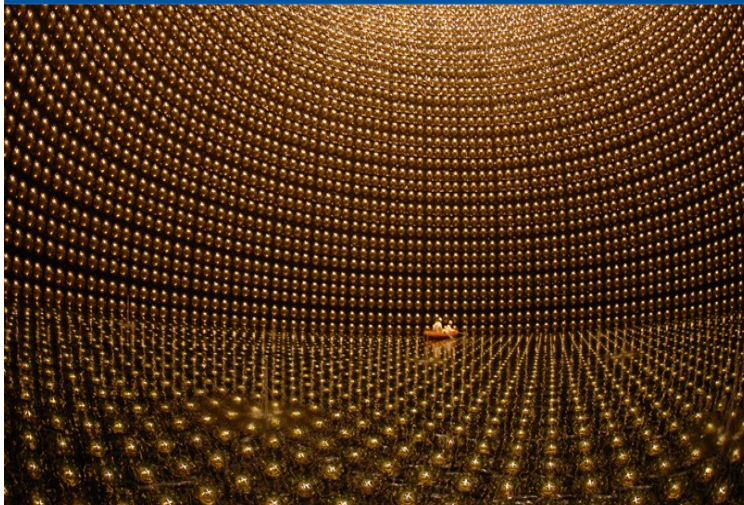
- Neutrinos entstehen zusammen mit den geladenen kosmischen Teilchen, gehen nicht verloren und werden nicht abgelenkt
→ ideale Botenteilchen

Neutrino - Quellen

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

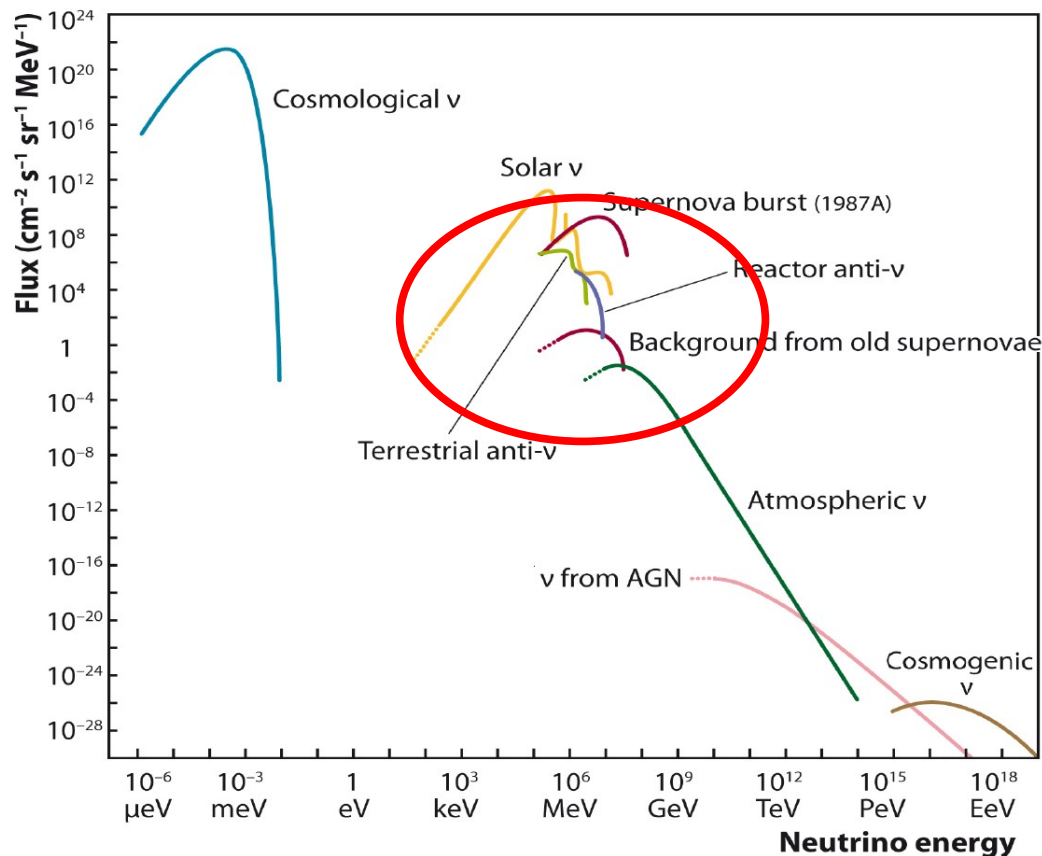


Detektor $\sim 0,00003 \text{ km}^3$



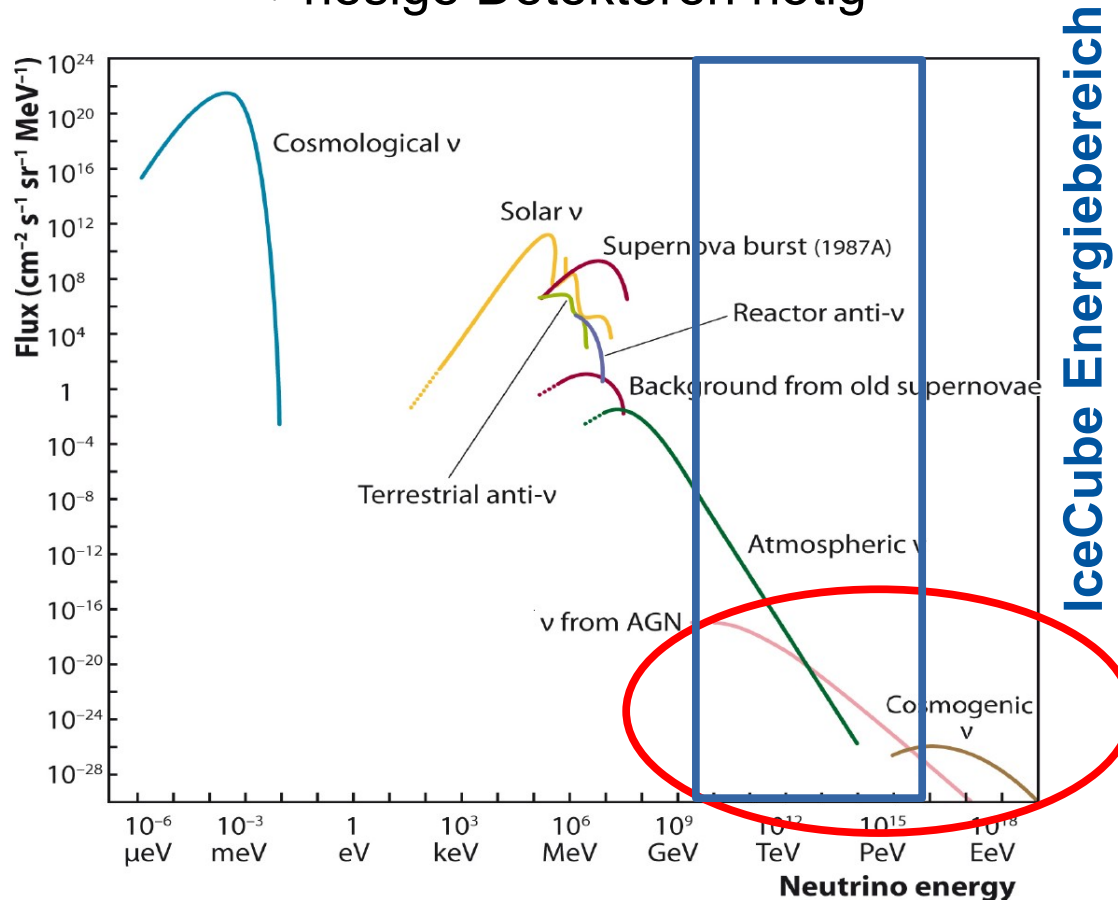
Herausforderung 1

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



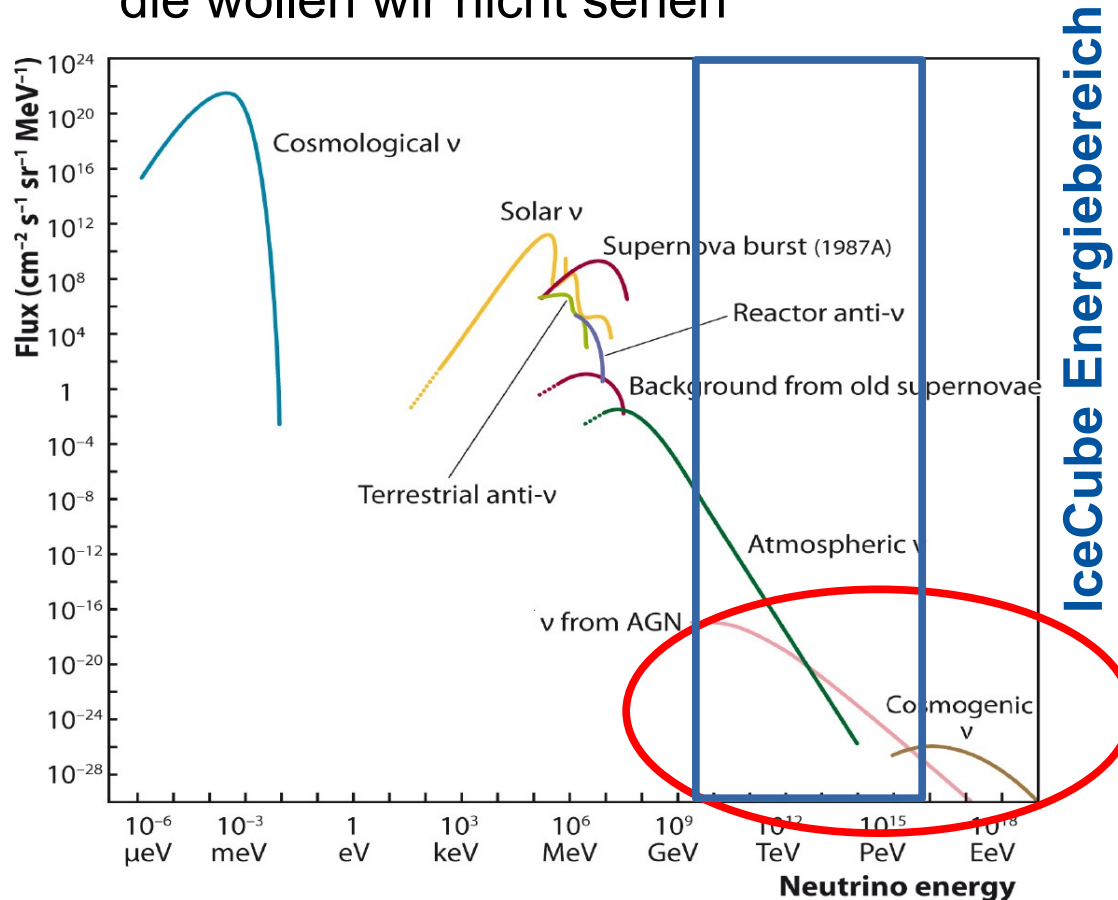
Herausforderung 1

- Nur wenige Ereignisse pro km² und Jahr erwartet
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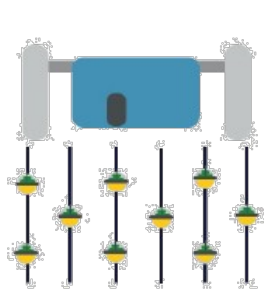


Herausforderung 2

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

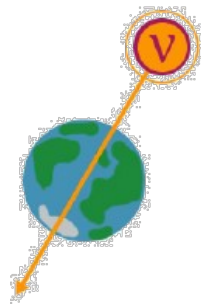


Wir haben 2013 die ersten extrasolaren Neutrinos gefunden (wie siehe nächsten Vortrag), aber die Himmelskarte füllt sich nur langsam.



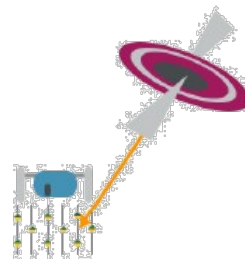
2011

IceCube
Completed



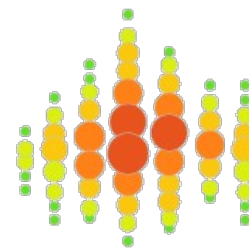
2013

Astrophysical
Neutrinos
Discovered



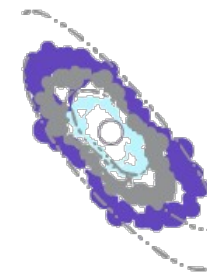
2018

First Source
TXS 0506+056
Identified



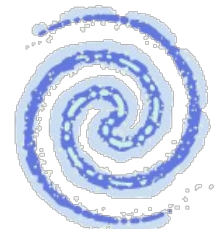
2021

Glashow
Resonance
Neutrino
Identified



2022

Second Source
NGC 1068
Identified



2023

Third Source
Milky Way
Identified