



IceCube Masterclass 2026

Astroteilchenphysik

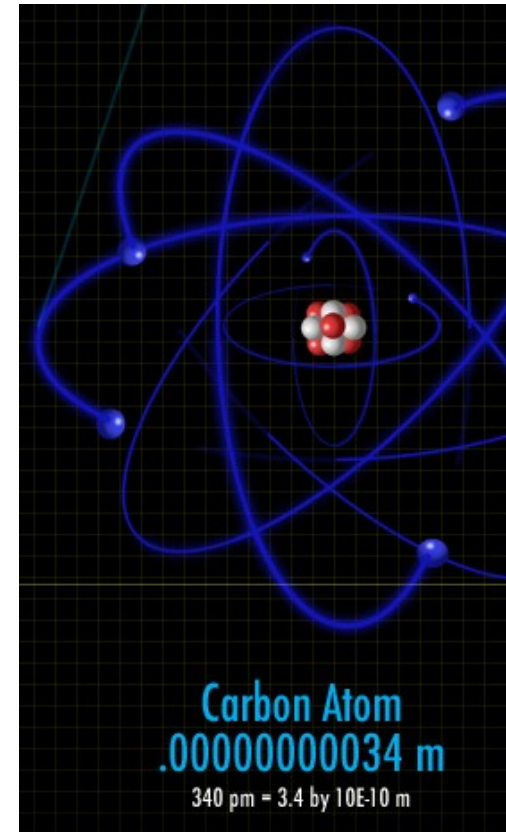
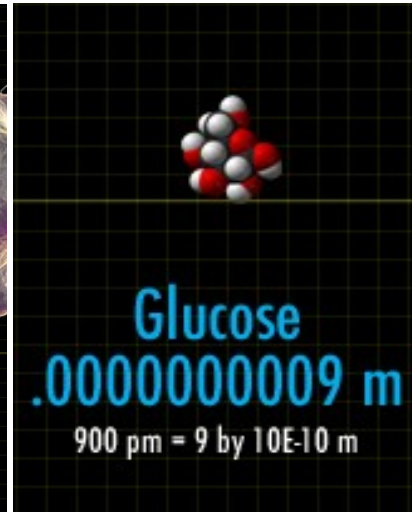
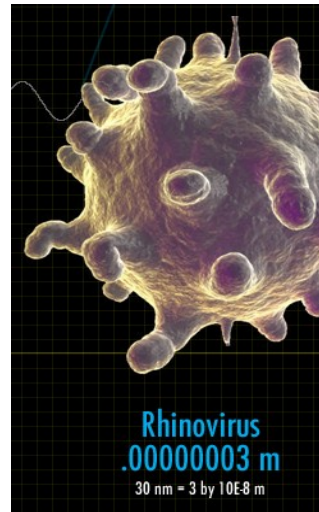
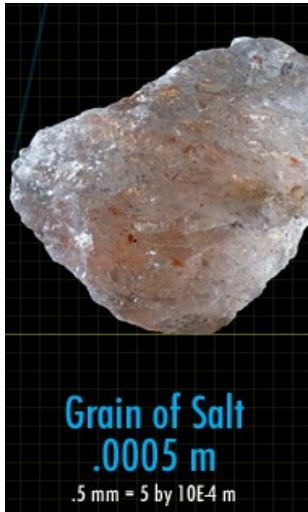
Martin Rongen
Erlangen, 09.04.2026



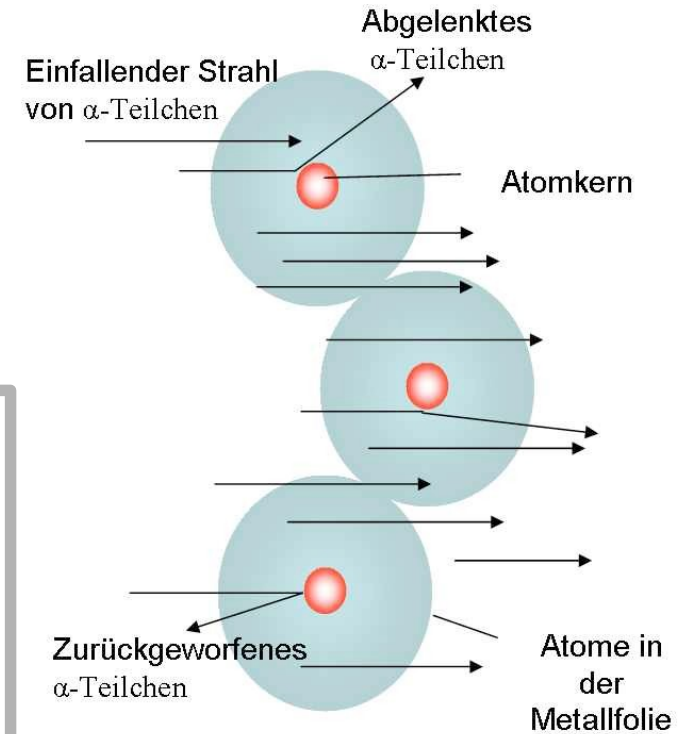
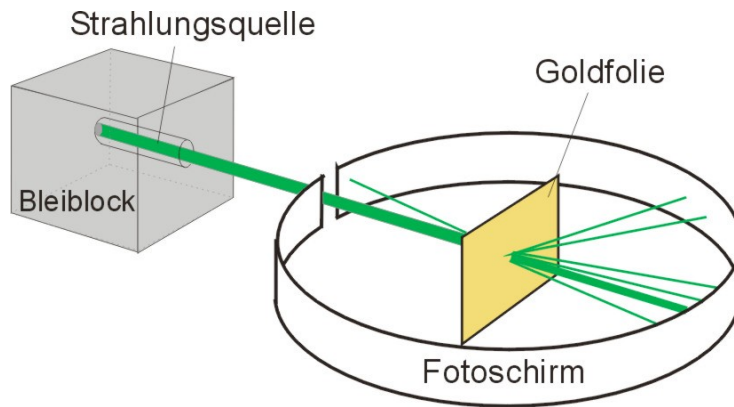
Teilchenphysik



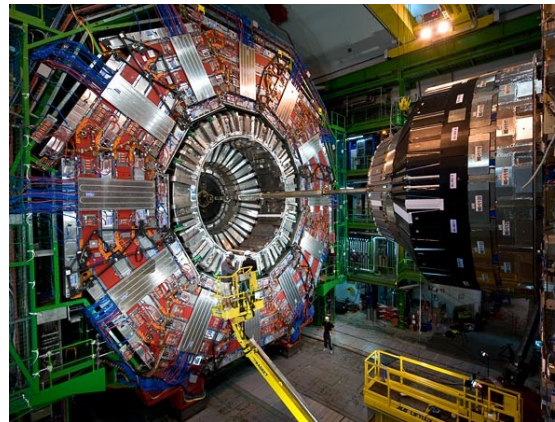
ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



Streuexperimente



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



CMS Masterclass



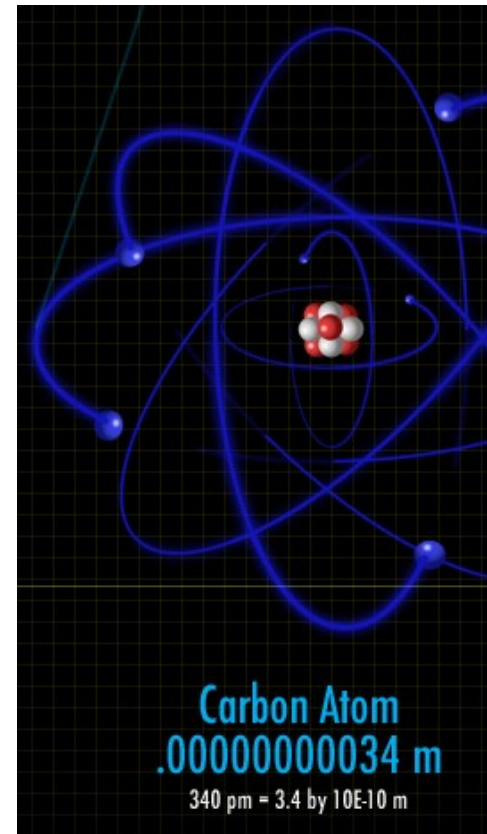
ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



Das Standardmodell

● Quarks

● Leptonen





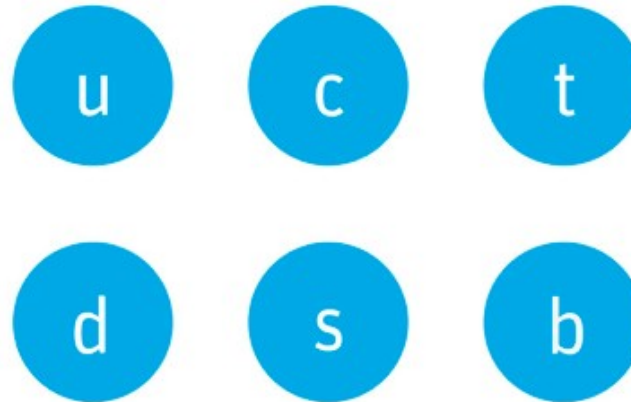
ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



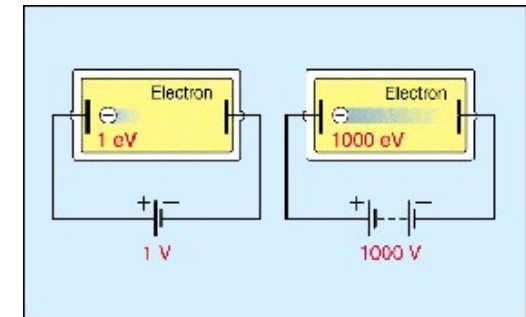
Das Standardmodell

● Quarks

● Leptonen



schwerer →



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



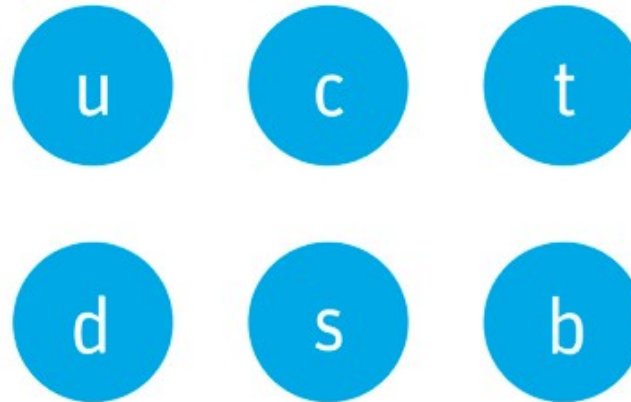
ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



Das Standardmodell

● Quarks

● Leptonen



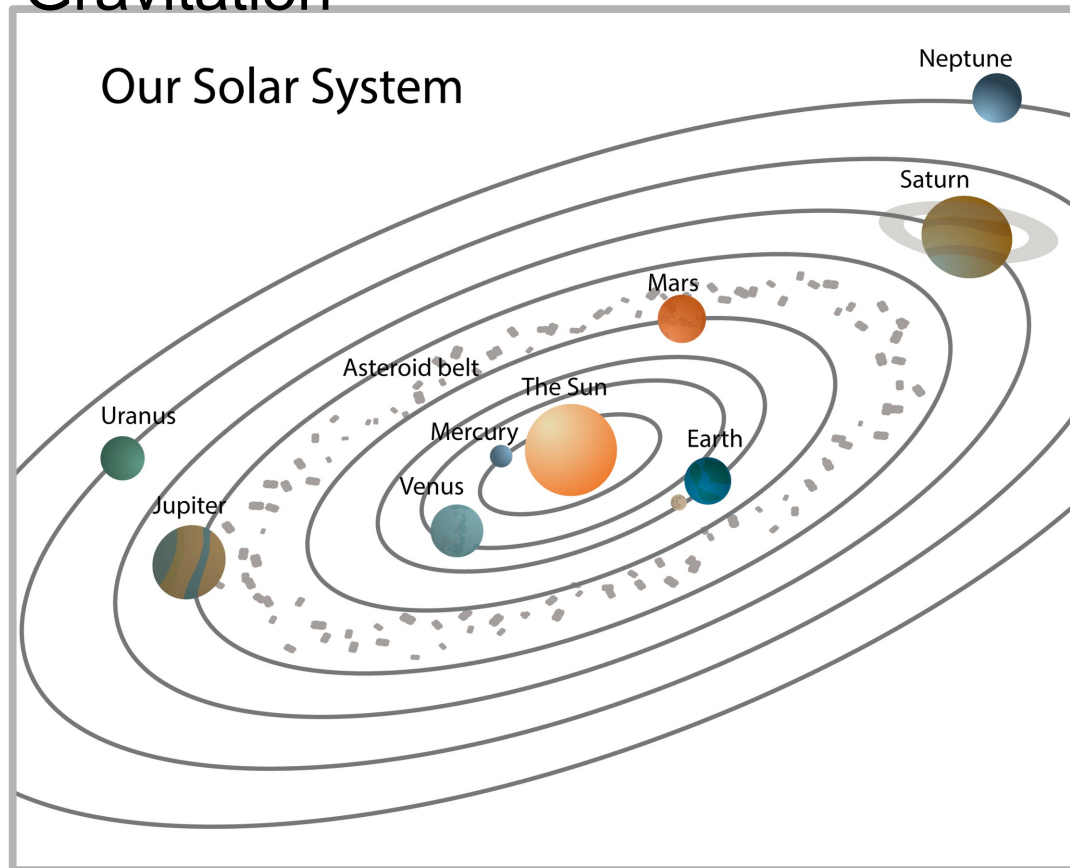
Periodensystem

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	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

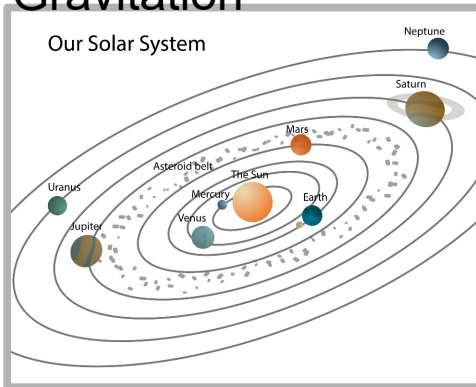


Gravitation

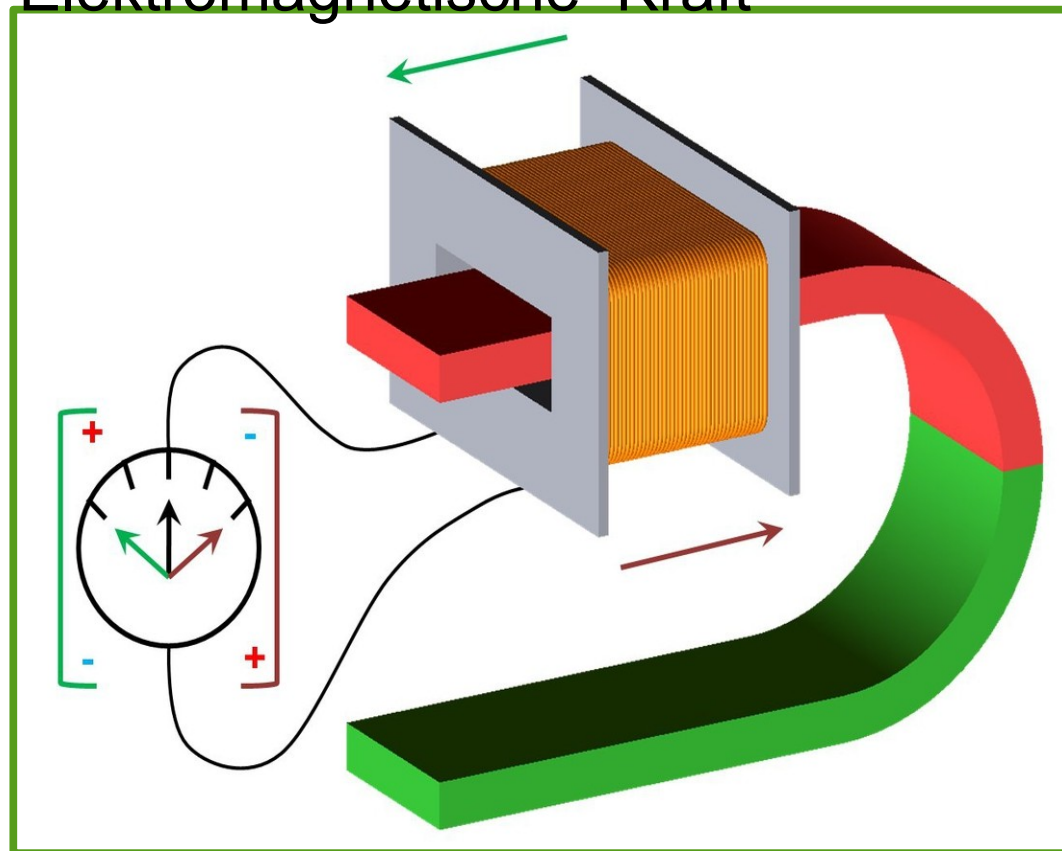


Die Kräfte

Gravitation

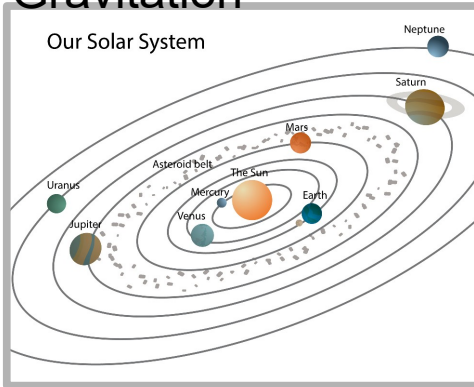


Elektromagnetische Kraft

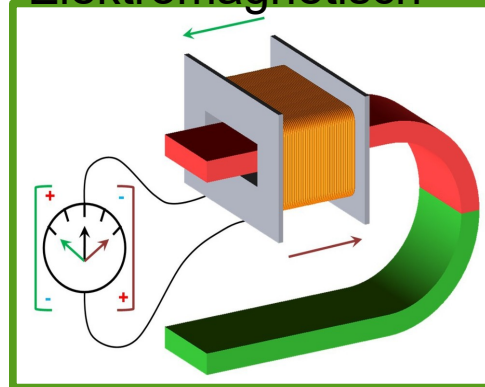


Die Kräfte

Gravitation

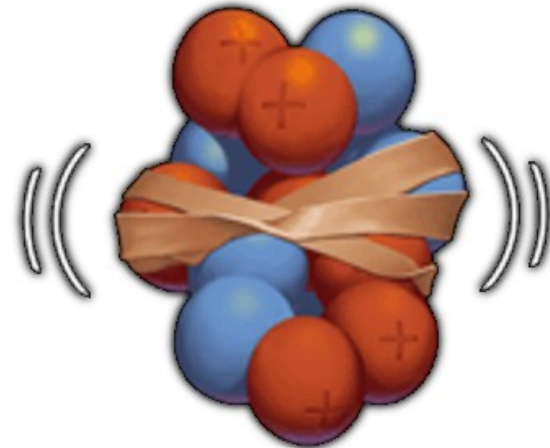


Elektromagnetisch



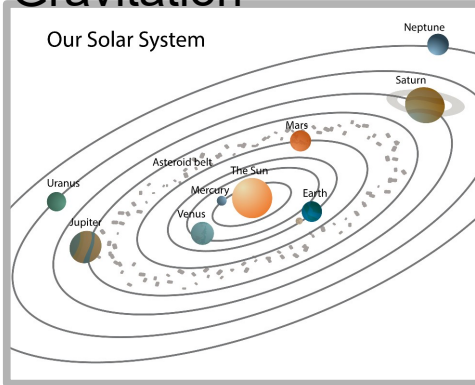
Starke Kraft

Atomkern

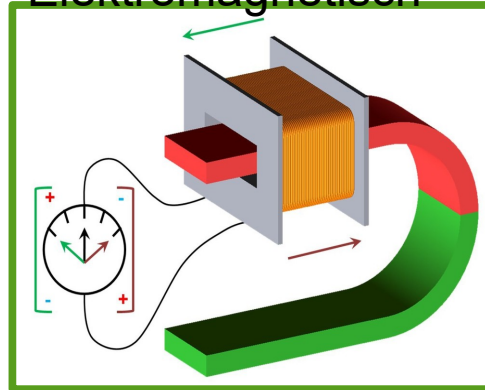


Die Kräfte

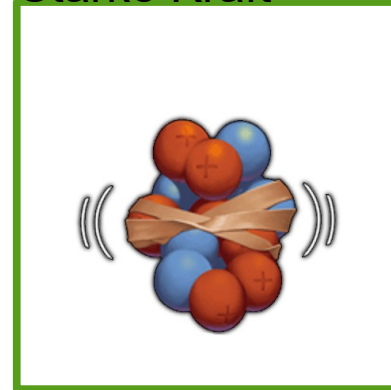
Gravitation



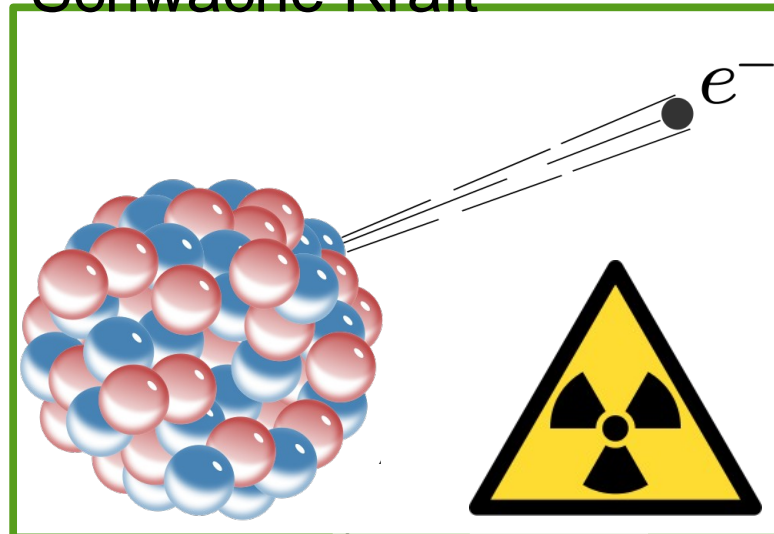
Elektromagnetisch



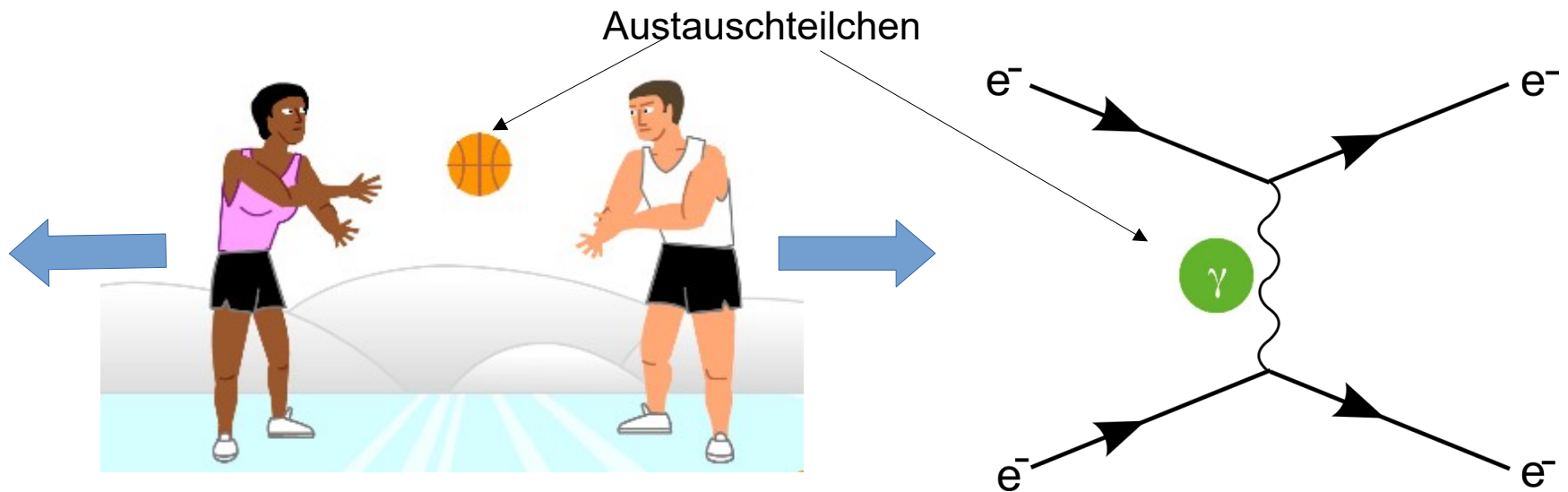
Starke Kraft



Schwache Kraft



Die Kräfte im Teilchenbild



Die vollständige(?) Standardmodell



ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS

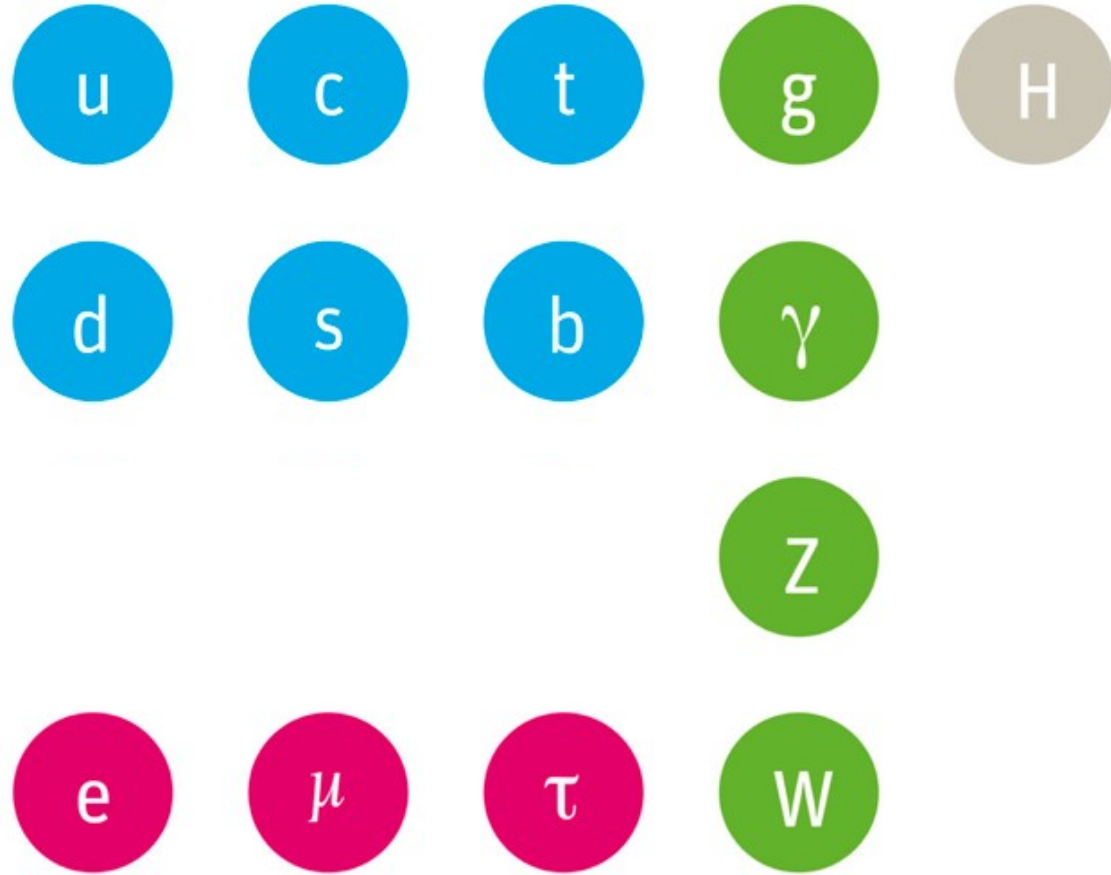


● Quarks

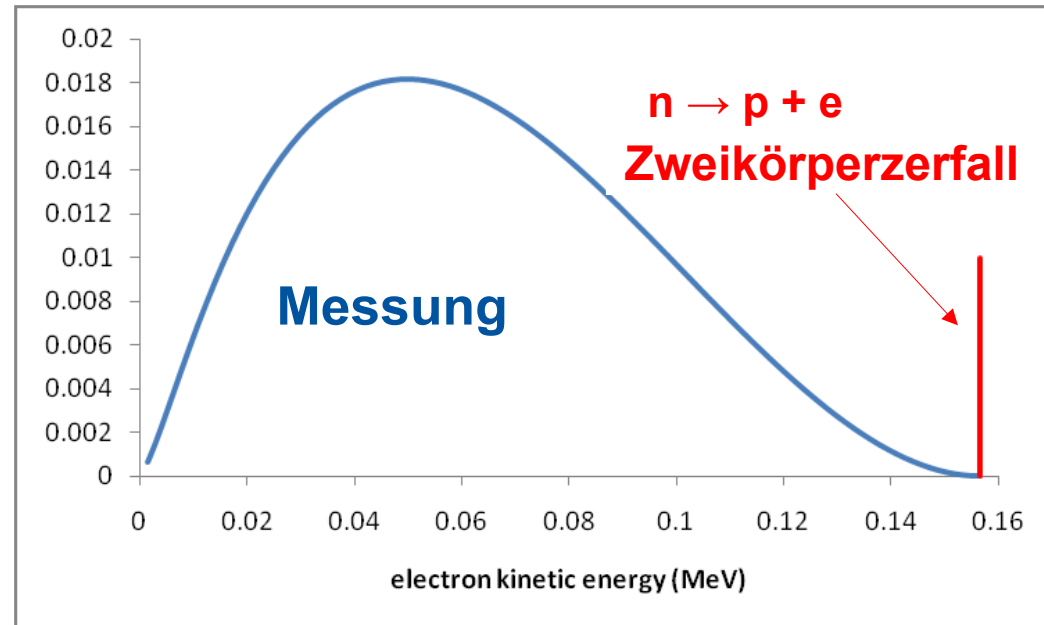
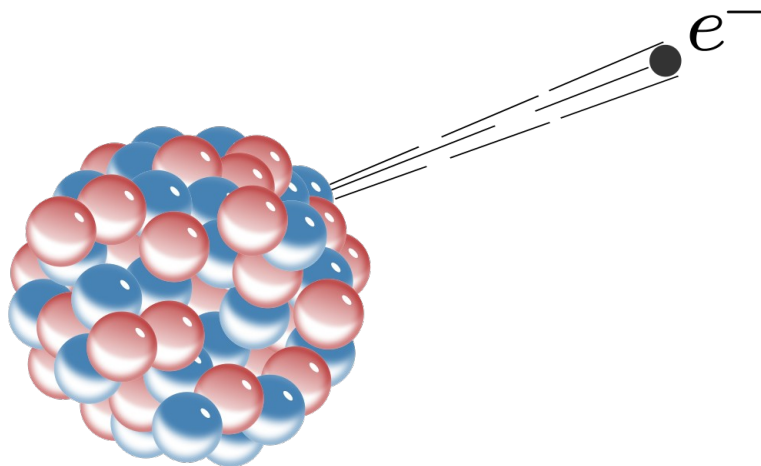
● Leptonen

● Kraftteilchen

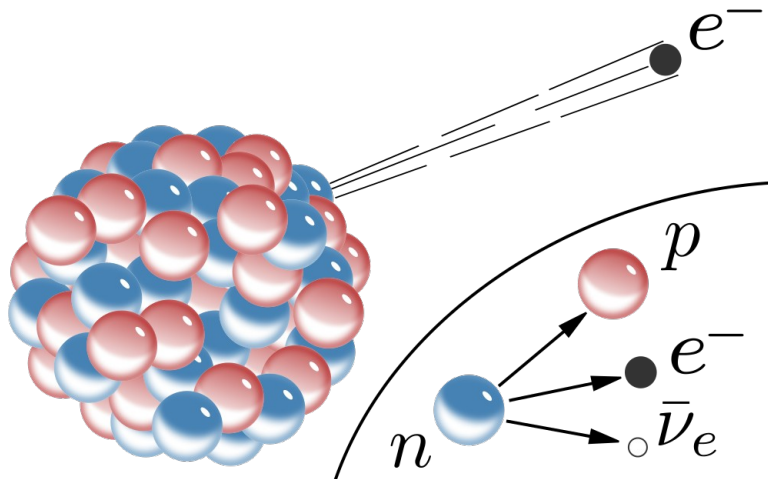
● Higgs



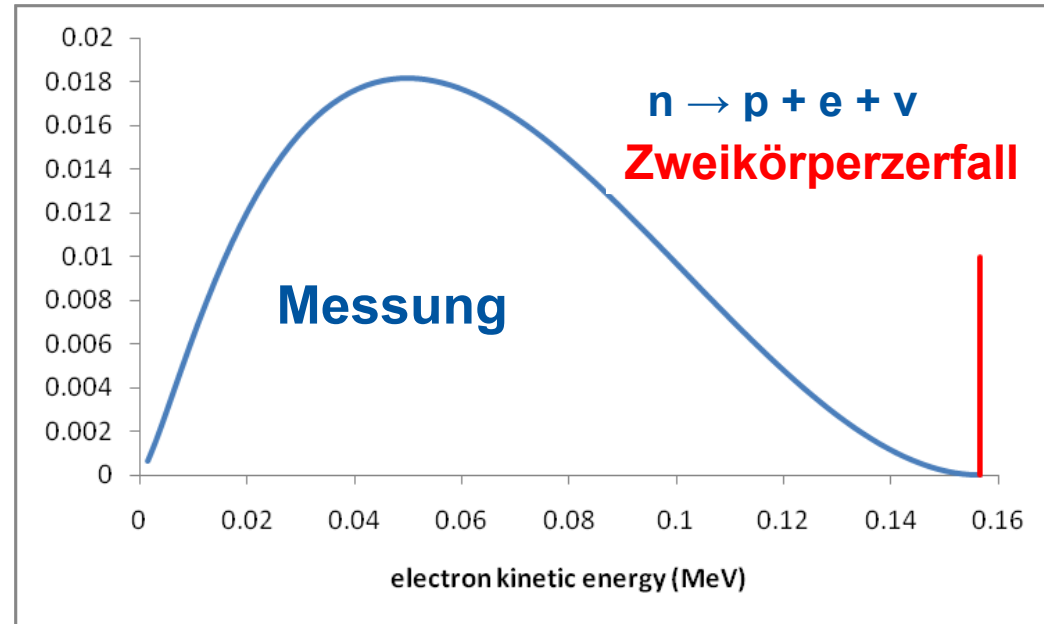
Der β -Zerfall



Der β -Zerfall



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





ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



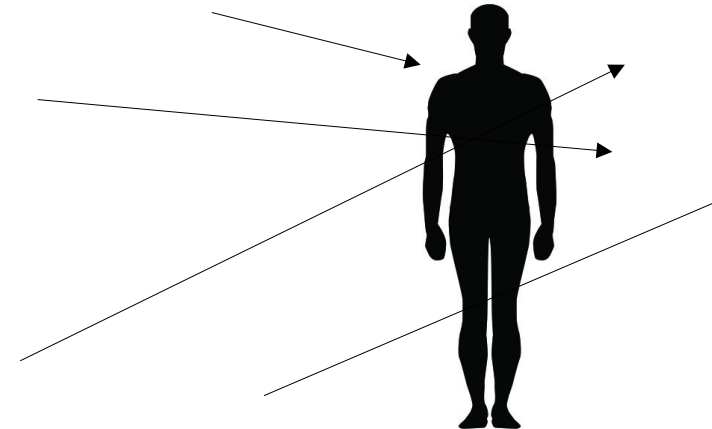
Das Neutrino

- 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





ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



Die vollständige(?) Standardmodell

● Quarks

● Leptonen


● Kraftteilchen

● Higgs

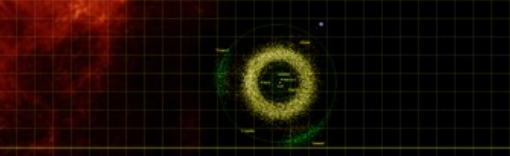




Kodiak Bear
3 m tall
Up to 10 ft = 3 by 10E0 m

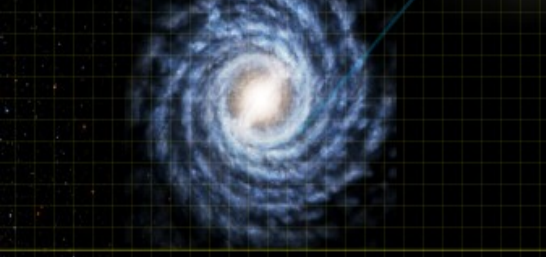


Earth
12,756,000 m in diameter
You live here. 1.28 by 10E7 m



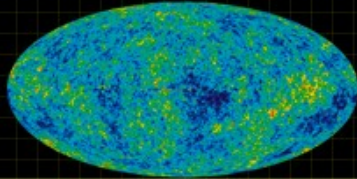
Solar System
30,000,000,000,000 m in diameter
(.003 light years across / 200 au)

The main planetary and subplanetary objects within the radius of the known dwarf planets (the farthest being Eris, which strays no more than 100 au from the sun - an au being the distance from Sun to Earth). We'll therefore treat the radius of the solar system as 100 au and its diameter as 200 au. There's a bit of arbitrariness here since the Sun's gravitational field extends indefinitely and there are other objects much further away within its pull, such as the Oort Cloud (estimated at 50,000 au).



Milky Way Galaxy
1,140,000,000,000,000,000,000 m in diameter
(120,000 light years across)

Spiral galaxy in which we find ourselves
1.14 by 10E21 m in diameter



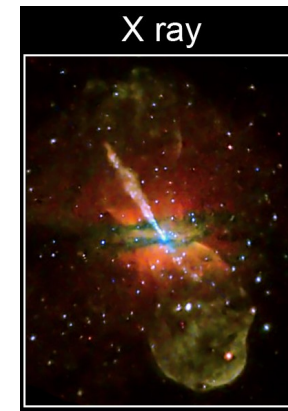
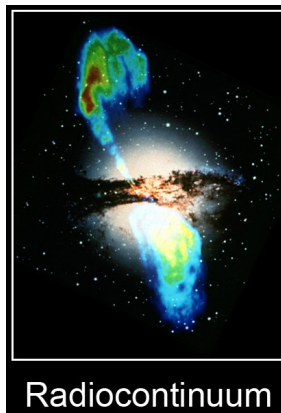
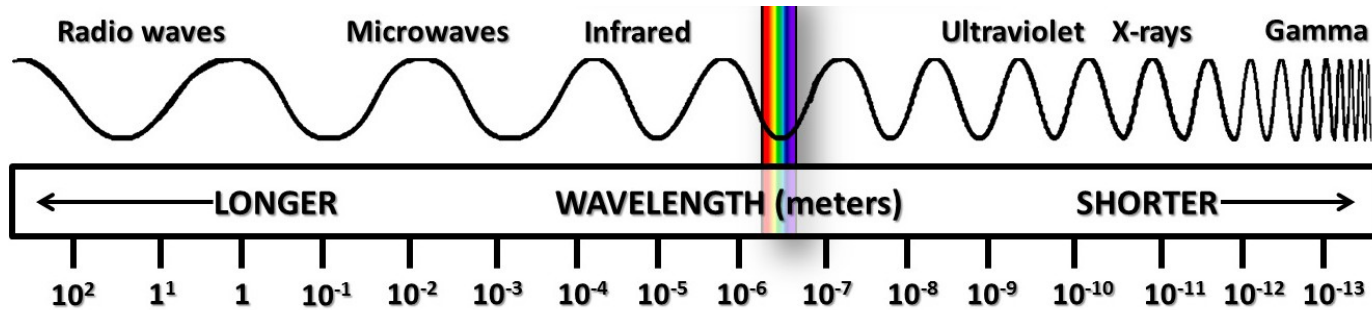
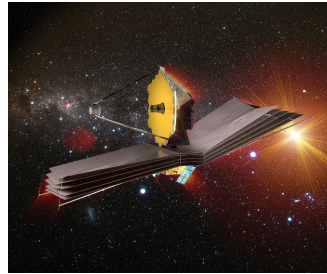
The Observed Universe
248,000,000,000,000,000,000,000 m in diameter

Gamma Ray Burst 090429B is 13.1 billion ly from Earth suggesting a radius for the observed universe of that distance and thus a diameter twice that distance; note that the universe is 13.7 billion years old, indicating that this gamma ray burst happened 600 million years after the Big Bang
2.48 by 10E26 m across

Photon-Astronomie



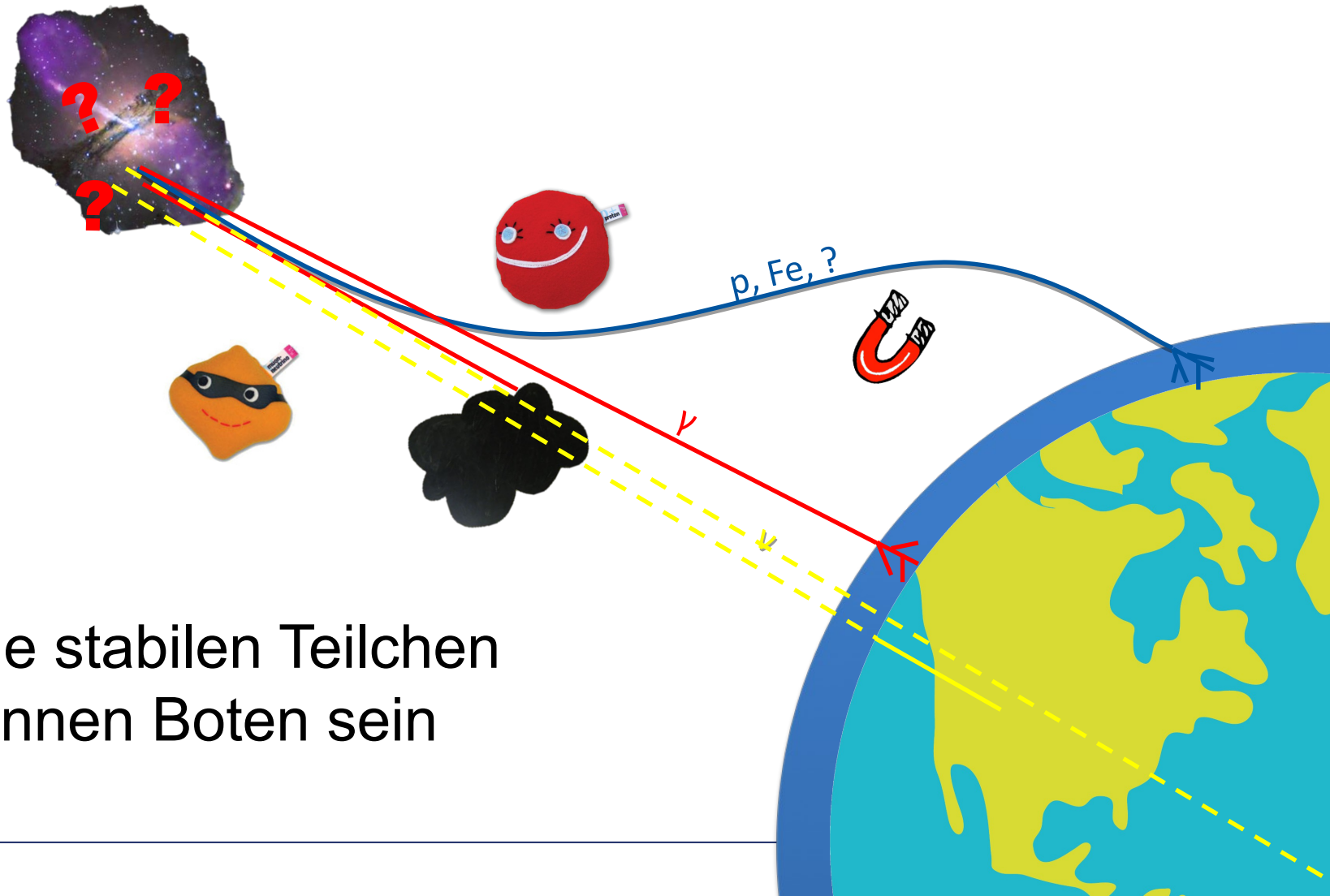
ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



Was hat das mit Teilchenphysik zu tun?



ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS

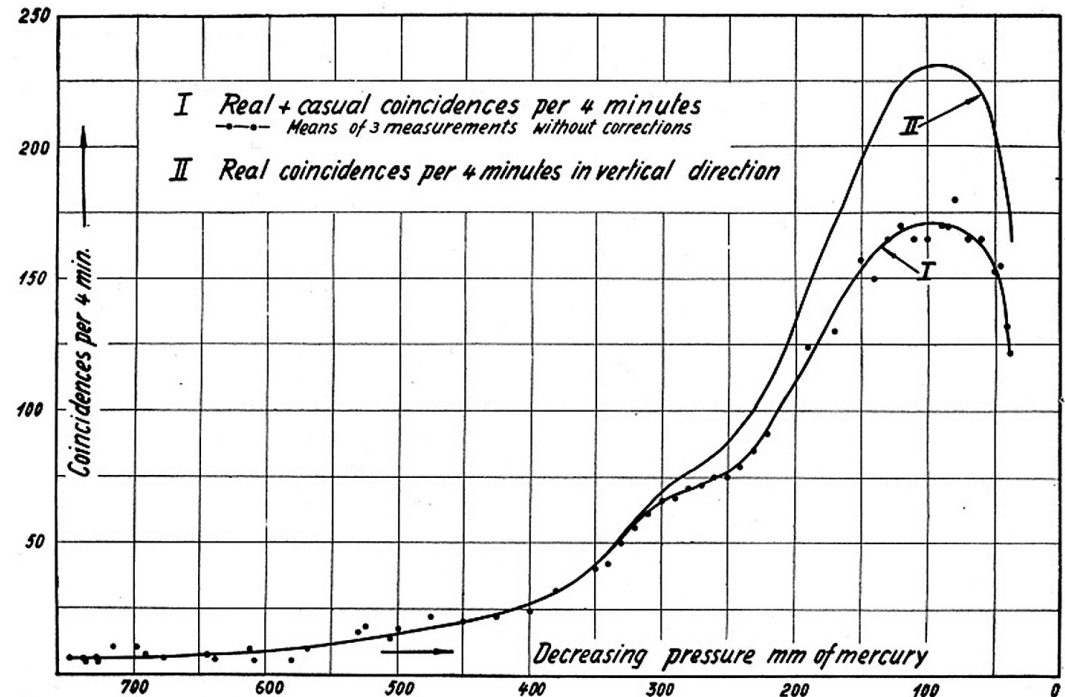
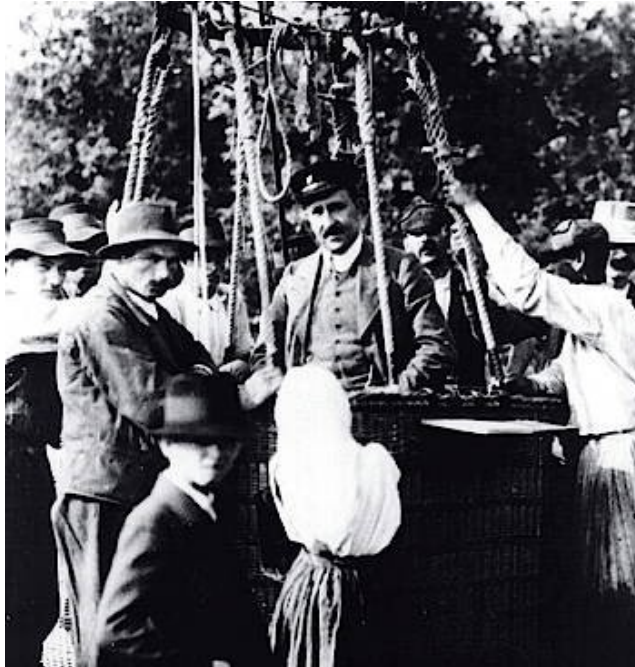


- Alle stabilen Teilchen können Boten sein

Höhenstrahlung



ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



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

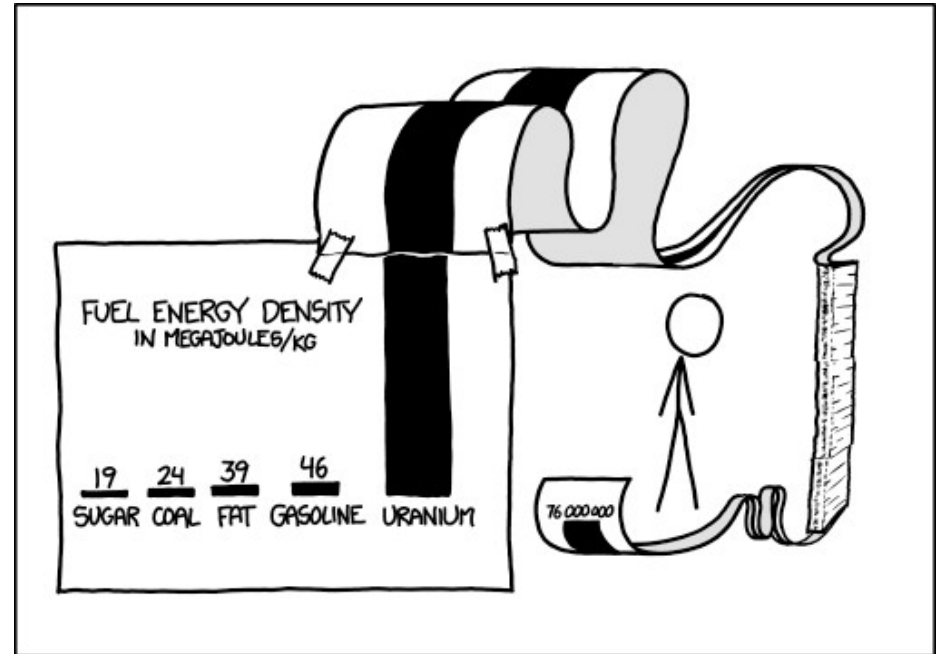
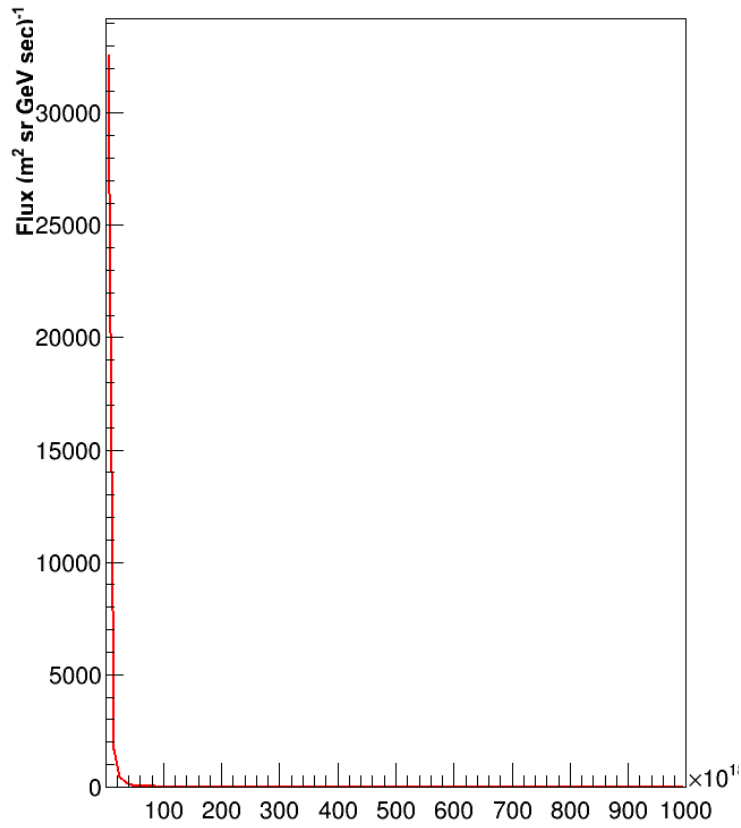
Energiespektrum



ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



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)

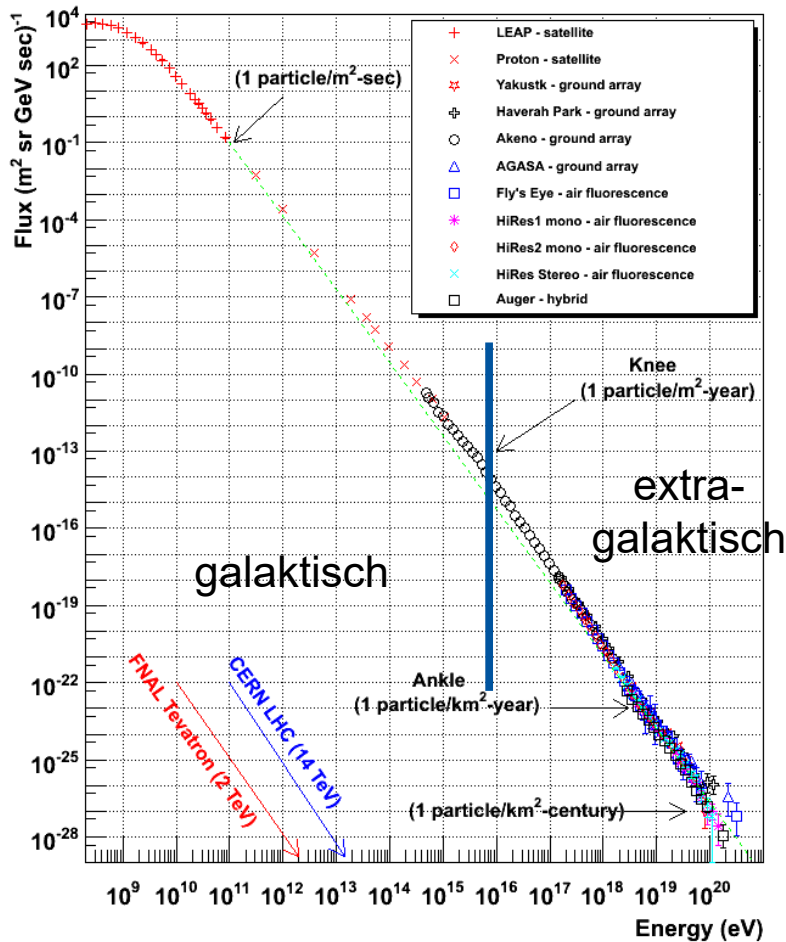
Energiespektrum



ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



Cosmic Ray Spectra of Various Experiments



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

Richtung



ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



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

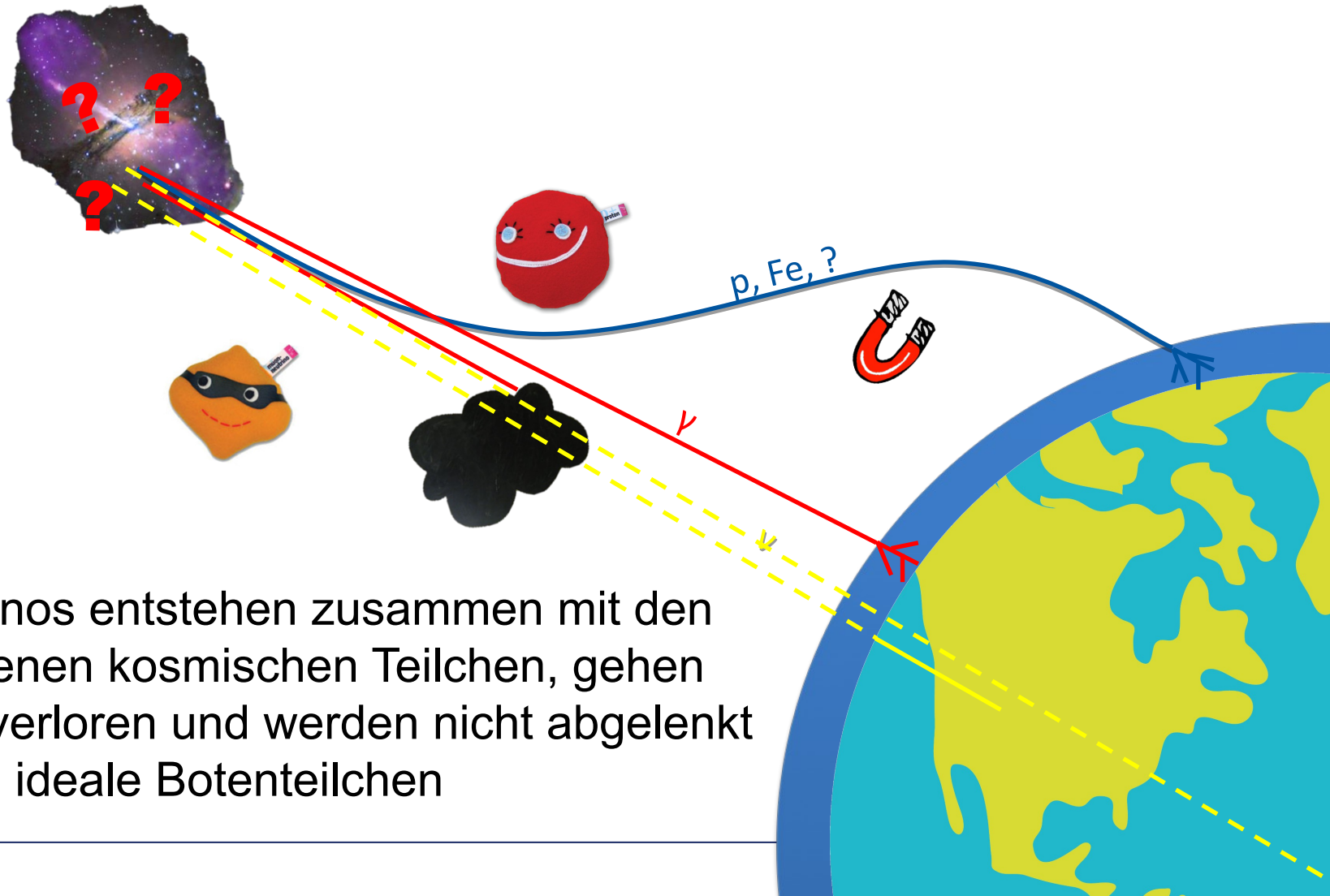


→ trotz Jahrzehnten an Forschung kennen wir die Quellen der kosmischen Strahlung kaum

Neutrino-Astronomie



ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



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

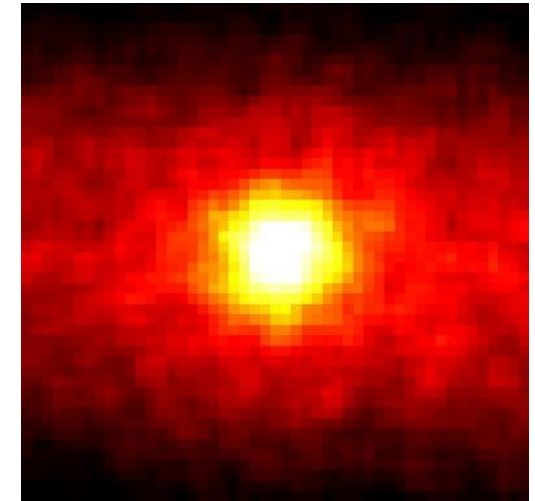


ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS

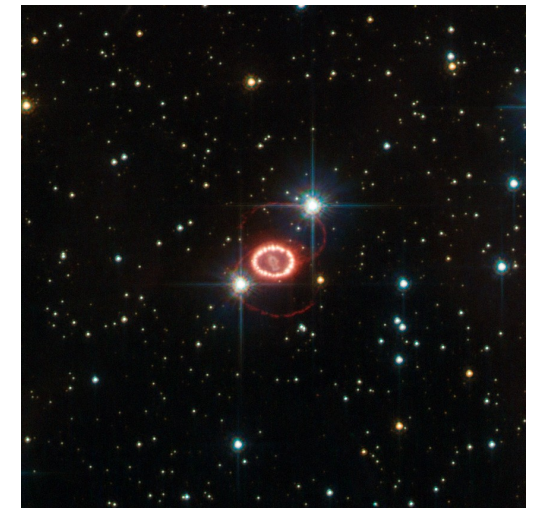
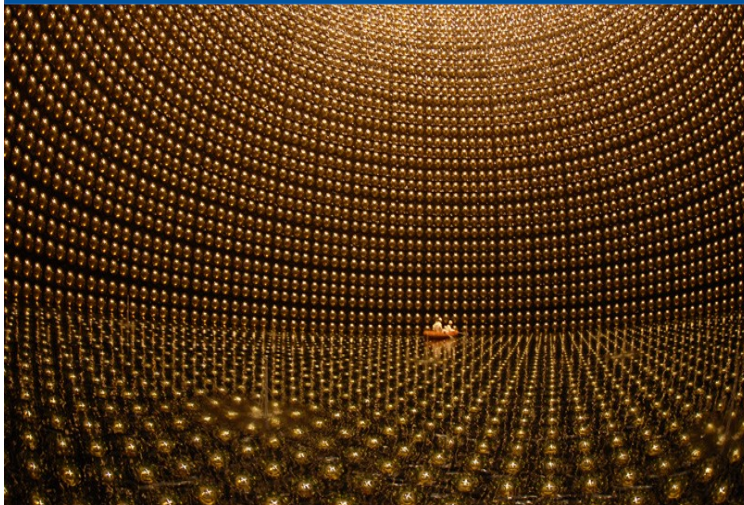


Neutrino - Quellen

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

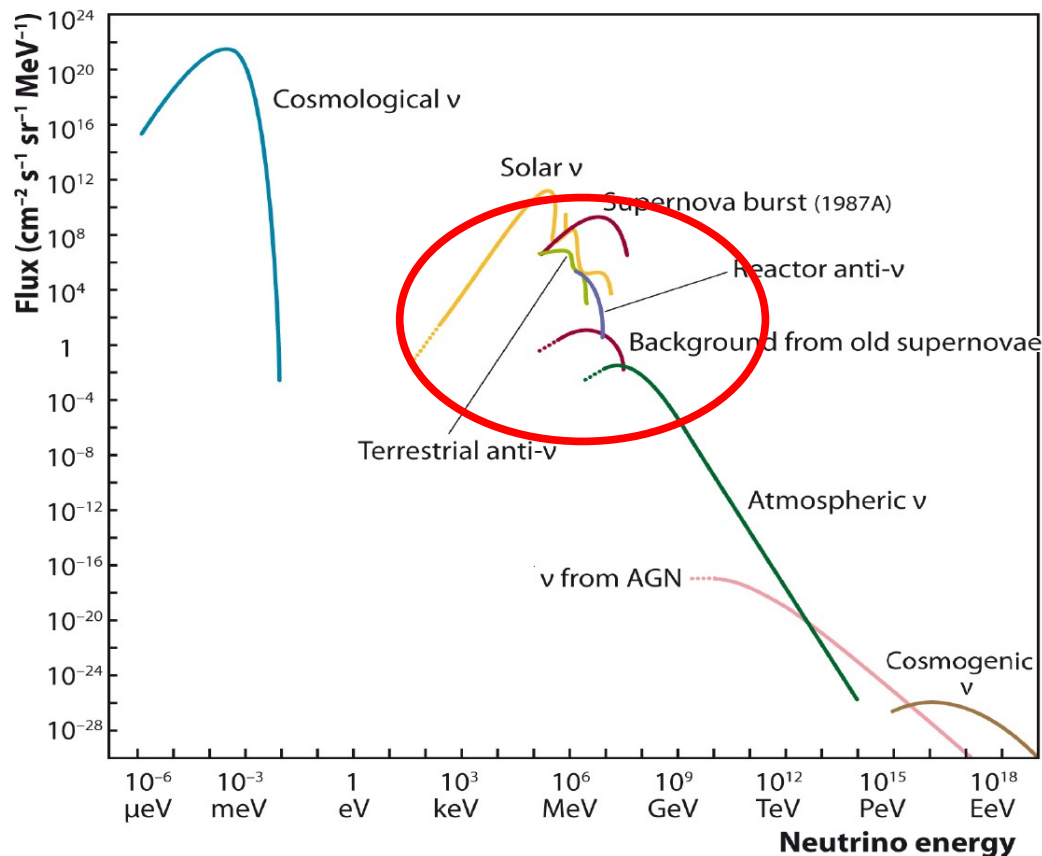


Detektor $\sim 0,00003 \text{ km}^3$



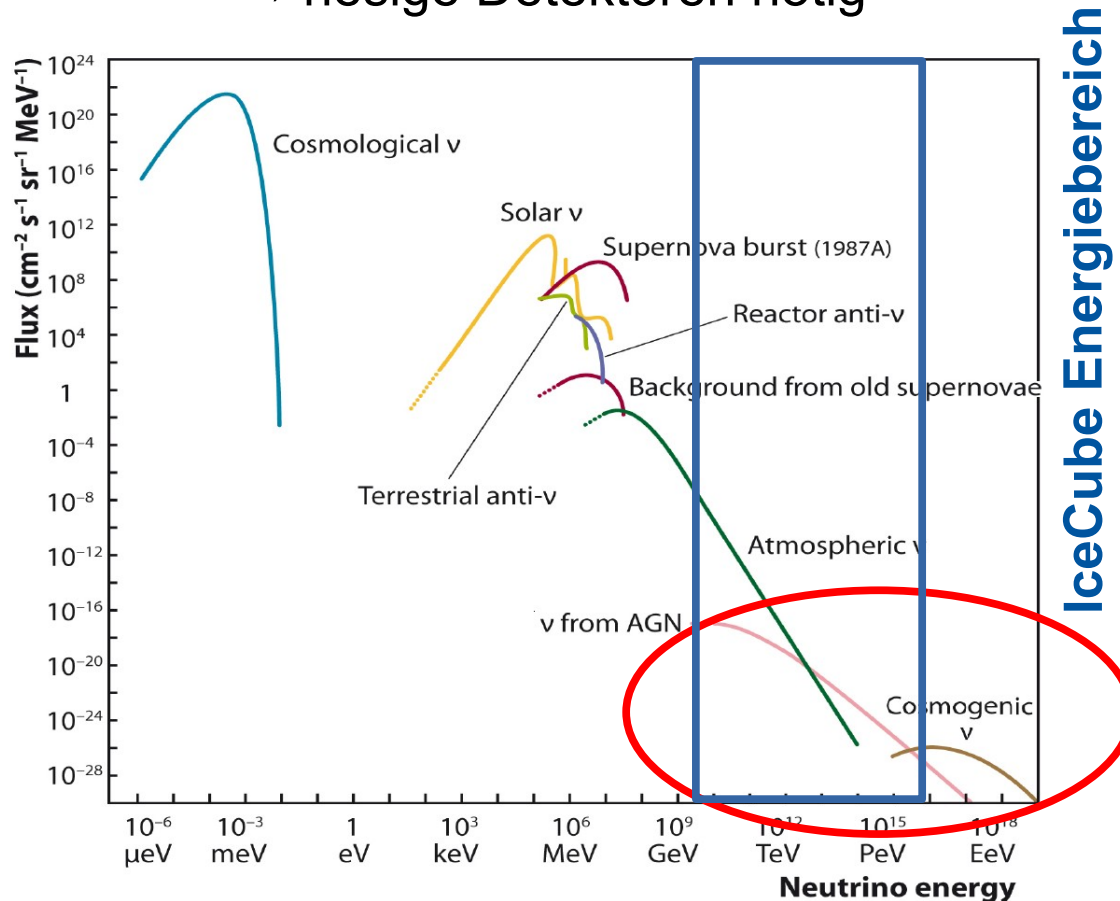
Herausforderung 1

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



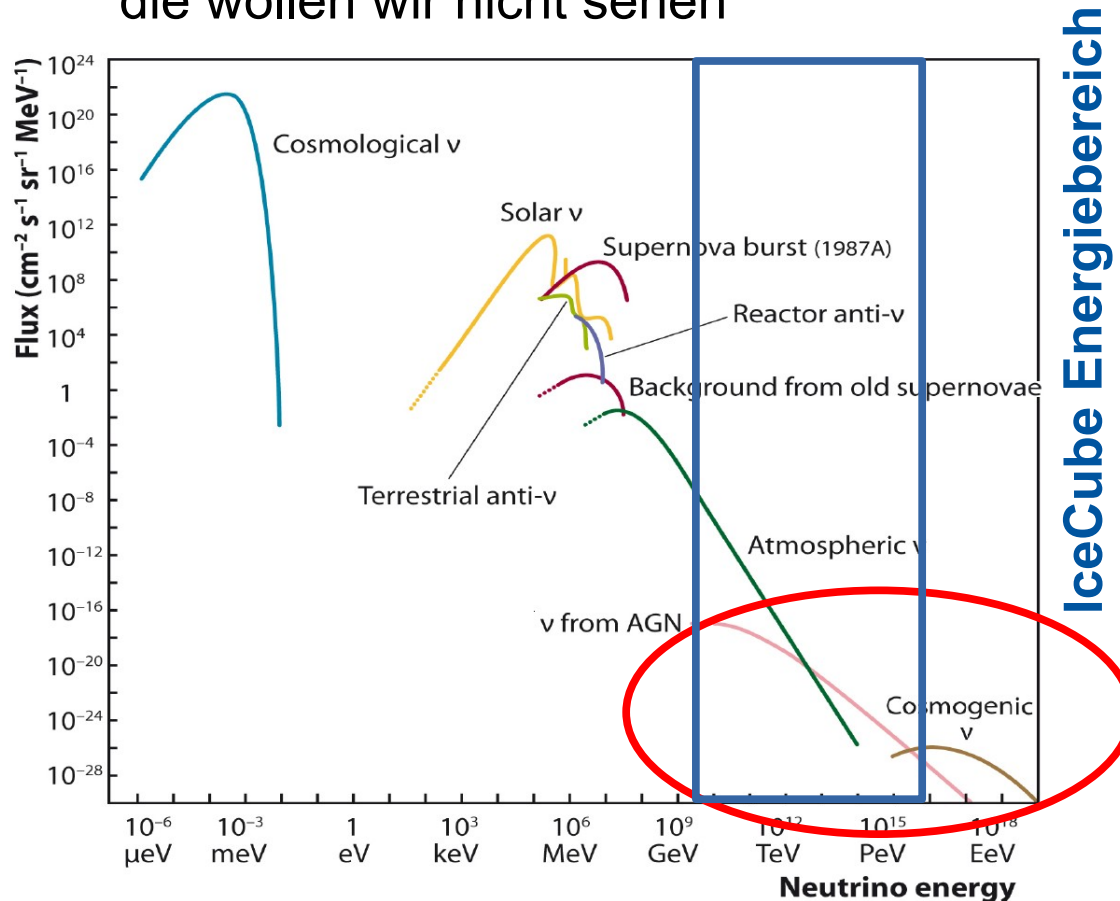
Herausforderung 1

- 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

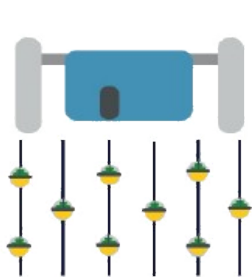




ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS



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



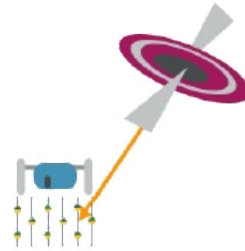
2011

IceCube
Completed



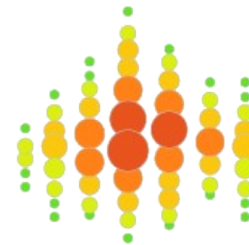
2013

Astrophysical
Neutrinos
Discovered



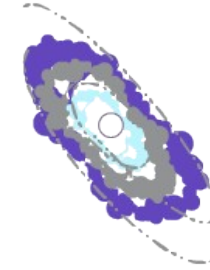
2018

First Source
TXS 0506+056
Identified



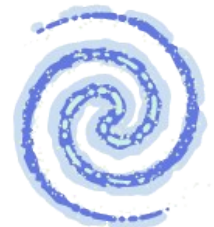
2021

Glashow
Resonance
Neutrino
Identified



2022

Second Source
NGC 1068
Identified



2023

Third Source
Milky Way
Identified