Teaching the Standard Model of Particle Physics at School

An alternative approach

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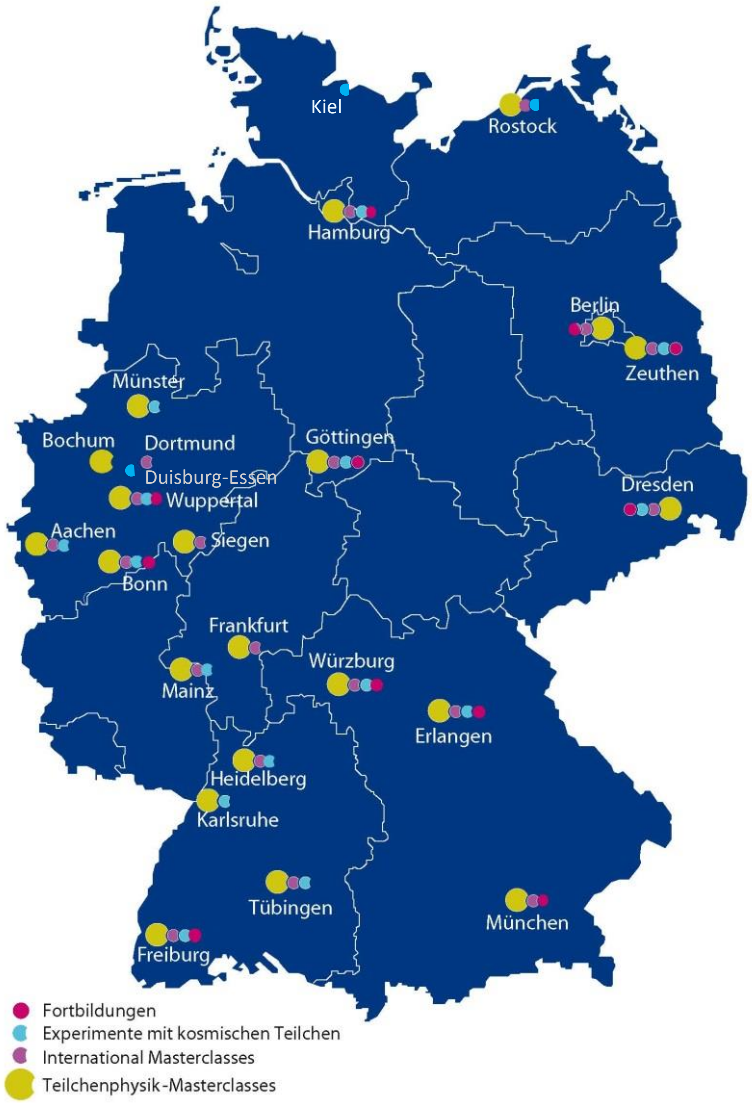
NETZWERK TEILCHENWELT

Contents of the presentation

- Who ‘we‘ are?
- Major goals of our approach
- Brief outline of the concept

Netzwerk Teilchenwelt

- Network of scientists, students, and teachers with direct contact to CERN
- Taking current research in particle physics, real data and even experiments into classrooms
- Locations all over Germany
  - Altogether 28 institutes
  - Administration: TU Dresden



Development of teaching material

- In cooperation with the Joachim Herz Foundation and teachers
- Modular collection (4 Vol.)
- Complementary as digital or printed versions
- 3 volumes already published
  - Theoretical background of the Standard Model of Particle Physics, cosmic radiation, exercises, …
  - Material on research methods to be published soon
- So far no English translation available
  - Translation of the volume on the theoretical background planned

Vol. 1: „Ladungen, Wechselwirkungen und Teilchen“ (Charges, Interactions and Particles)

- About 100 pages of background knowledge for teachers
- Introduction of the Standard Model of particle physics
- Spiral approach, didactic advice
- Some excercises

The Standard Model of particle physics (SM)

- Developed in the 1960s and 70s
- Since then validated in countless experiments
- Most precise description of the elementary processes in our universe we have today
- Elegant theoretical structure with high predictive power enriched by experimental insights

What is physics?

- Attempt to describe the world
- Preferably as simply as possible

Simplifications/unifications in the history of physics

- **Newtonian Mechanics** (17th cent.): ‘terrestrial‘ laws of falling bodies (Galilei) und movement of celestial bodies (Kepler) as consequences of gravity

- **Electromagnetism** (19th cent.): Subsumption of electric and magnetic phenomena by J. C. Maxwell

- **Theory of relativity** (20th cent.): Coupling of space and time and unification of mass and energy by A. Einstein

Reduction in particle physics

Base concept
interaction
= force + conversion + production + annihilation

- All processes and phenomena can be ascribed to 4 interactions

downhill force,
water power,
gas pressure,
radio waves,
air friction,
radioactive conversions,
…
…

→

4 fundamental interactions

Goals of the approach

- Give students an idea which part of our knowledge can be directly deduced from theory and therefore can be predicted and which are experimental findings that cannot be fully explained yet
- Teaching particle physics in an cumulative way by finding suitable points of contact with the rest of the curriculum (mainly nuclear physics) and analogies
- Extending the concept of charges for the description of particle interactions

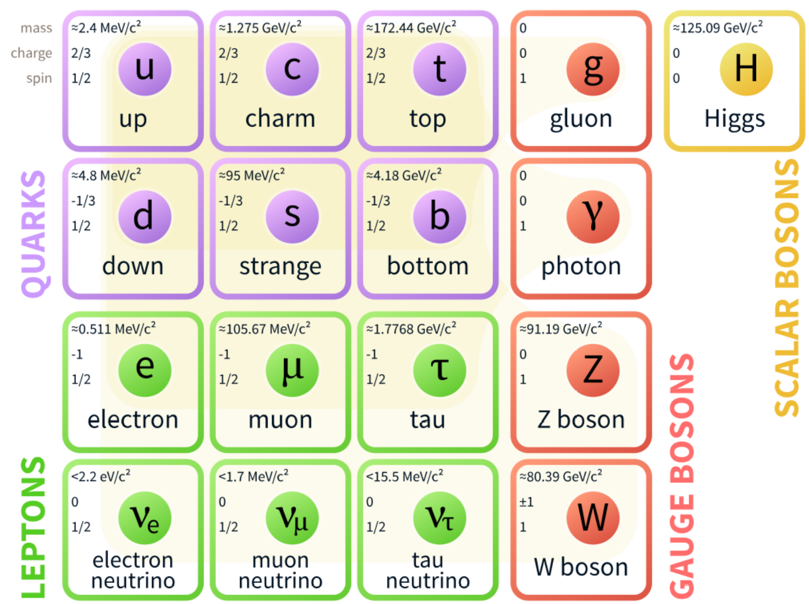
How to – A soccer analogy

- How to explain something completely unknown to somebody? For example, soccer...
- You would probably start with the most important rules of the game and not with number of players and their positions/roles on the field or even the names of players of a certain team.
- players = elementary particles
- rules = interactions, conservation laws,...

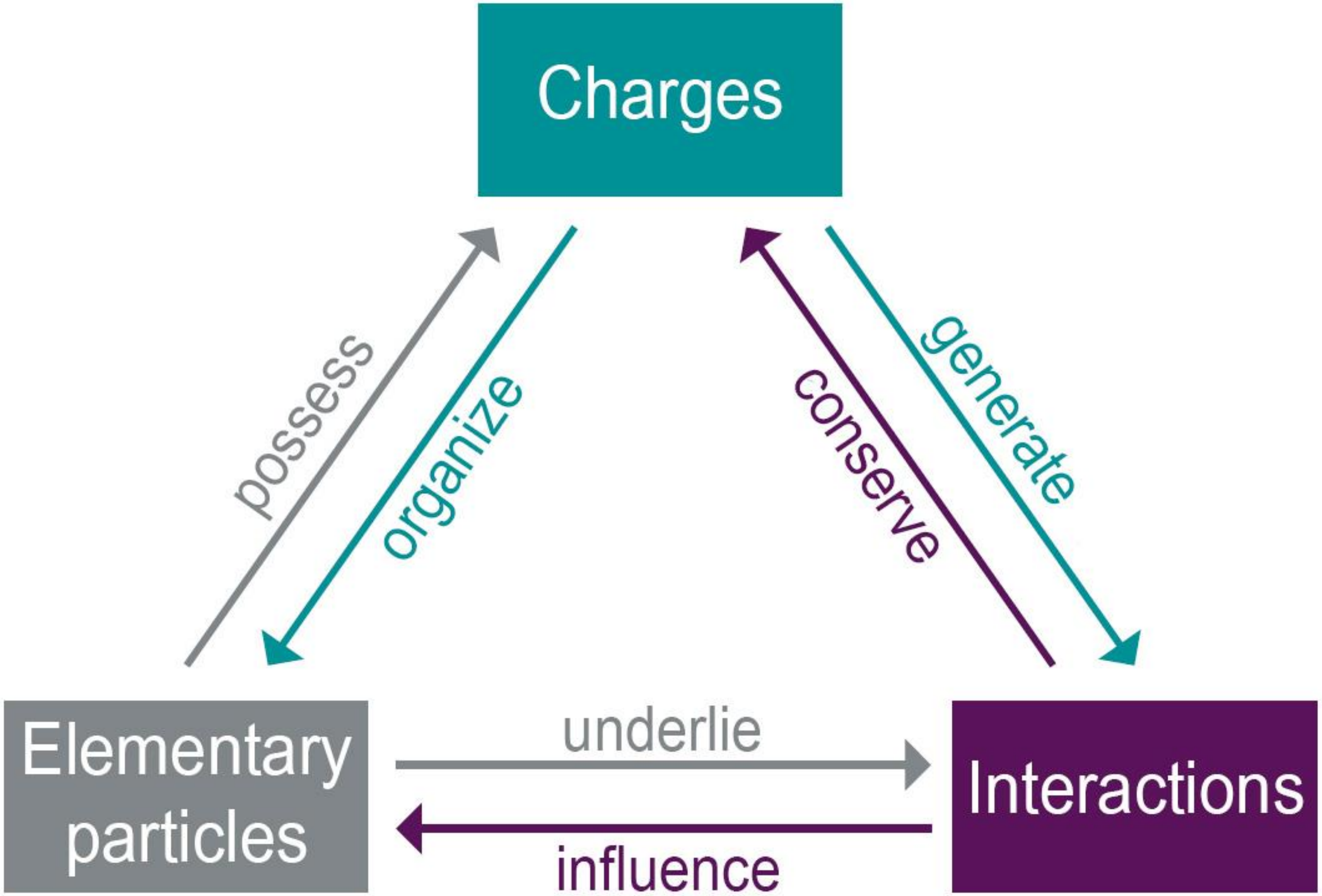
How to – A soccer analogy

▶ **Why start the introduction of the SM with this picture?**

- For explaining all stable matter only up-quarks (u), down-quarks (d) and electrons (e) are necessary.
- Why exactly these particles exist is not predictable and understood.
- The SM is a theory of particle interactions.



The three basic concepts of the SM



The 4 fundamental interactions

- Already known:
  - Gravity (not part of the SM)
  - Electromagnetic interaction (Coulomb law)

The strong interaction

- Why are certain nuclei stable although there is electromagnetic repulsion between the protons?
  - Gravity cannot be responsible since it is too weak
  - **Strong interaction** between the quarks leads to attractive force
  - Reason for this interaction is another type of charge, the strong charge (also color charge)

The weak interaction

- Fairly harder accessible than the strong interaction
- Two different approaches possible
- Pivot of both are particle conversions, in particular the beta conversions and the emerging neutrino.
  - There must be another type of interaction, the weak interaction.
  - Particles with a weak charge (all matter particels) participate in this interaction.

Reach of the forces

- Infinite: noticable in daily life
- finite: only subatomic

Force	Reach
Gravitational	Infinite
Electromagnetic	Infinite
Strong	$2 \cdot 10^{-15} m$
Weak	$2 \cdot 10^{-18} m$

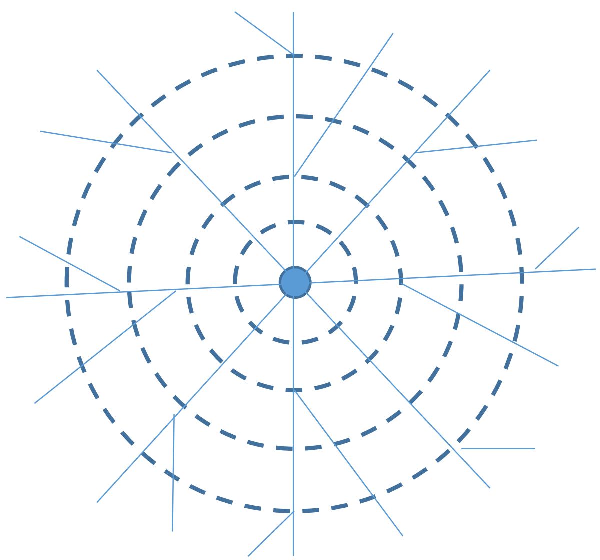
Problems with the field line model

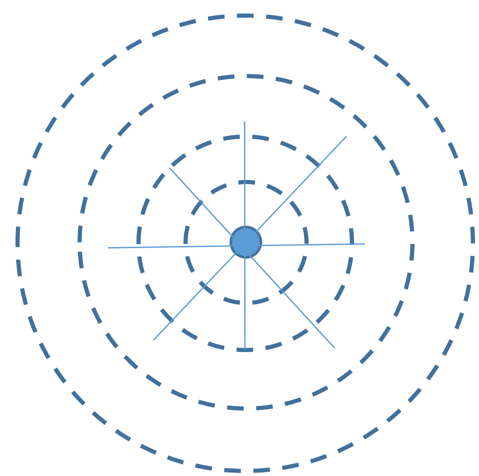
- Unusual field lines for interactions with force laws that deviate from ~1/r^2 at some point
- Strong force
  - Force/field line density becomes const.
  - Field lines emerge spontaneously

Weak force

Force diminishes very quickly

Field lines come to nothing

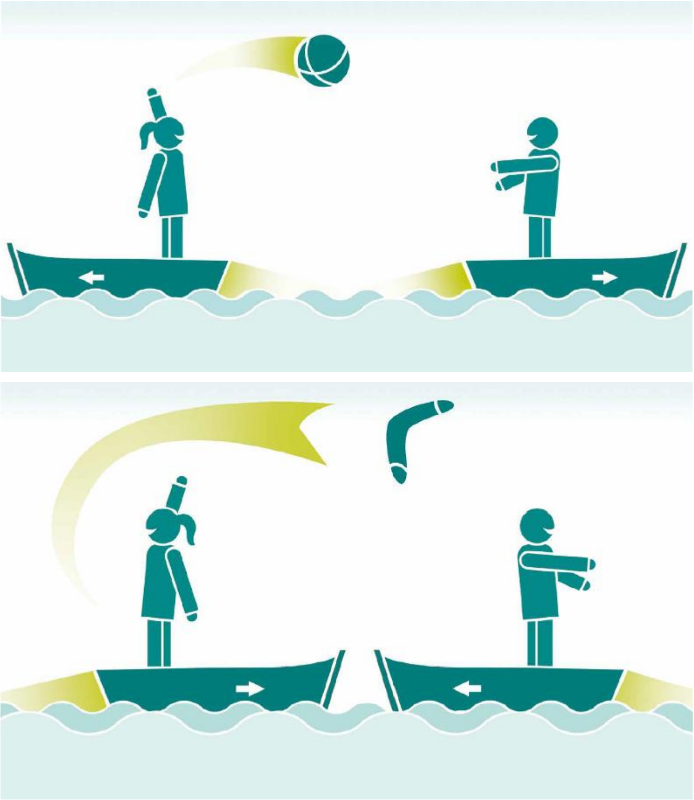




New model: messenger particles

- Interactions are mediated by particles
- Properties of these particles define properties of the interaction

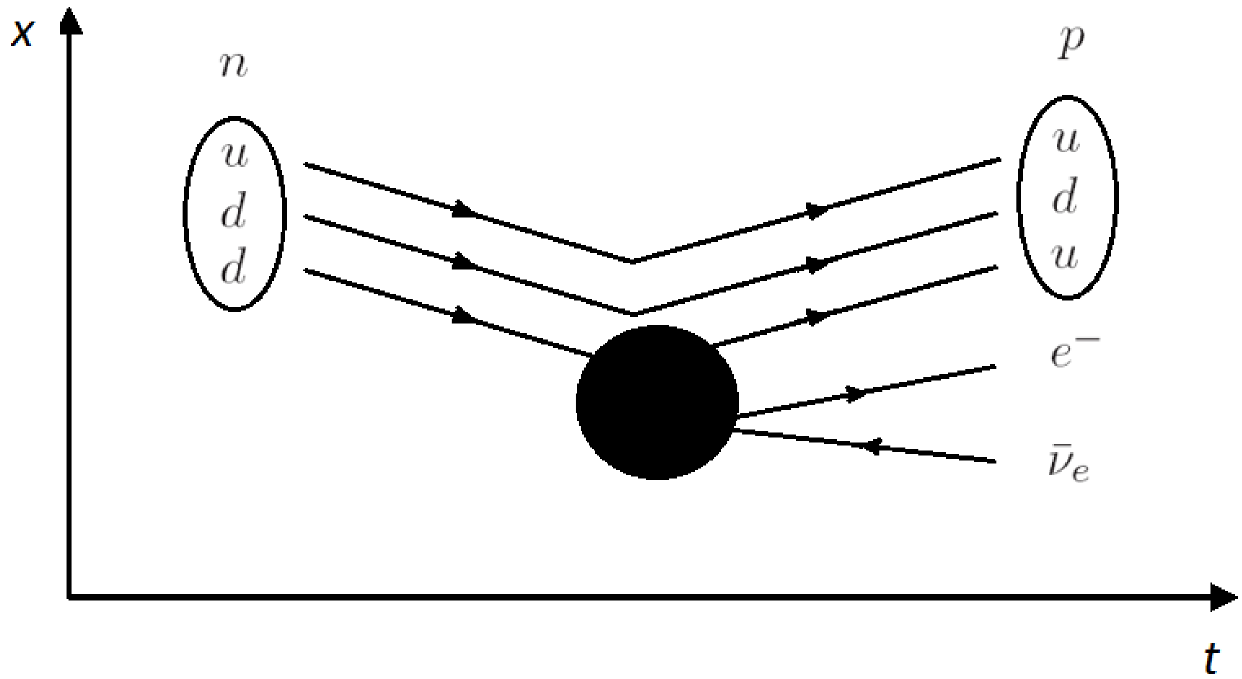
Visualizing particle interactions



► Many problems with classic pictures to describe quantum processes

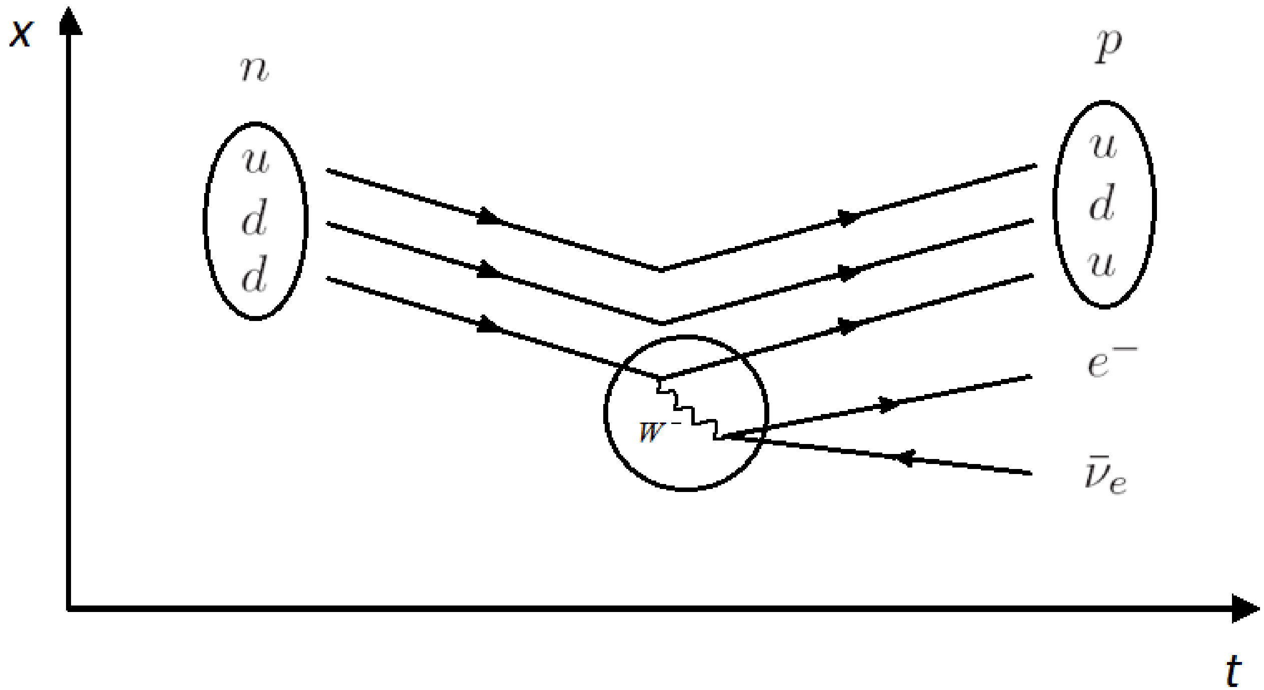
Feynman diagrams

- Beta minus conversion with black box



Feynman diagrams

- Beta minus conversion



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ORGINALSCHAUPLATZ

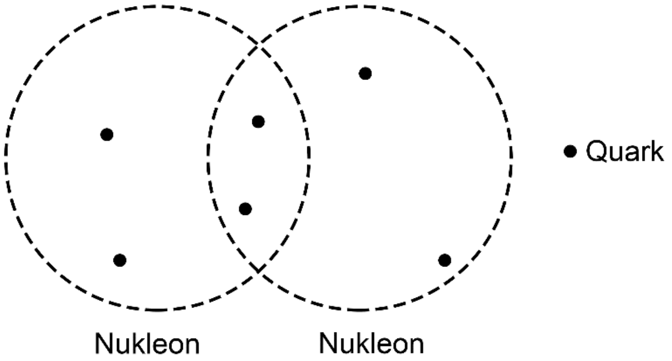
SCHIRMHERRSCHAFT

PROJEKTLEITUNG

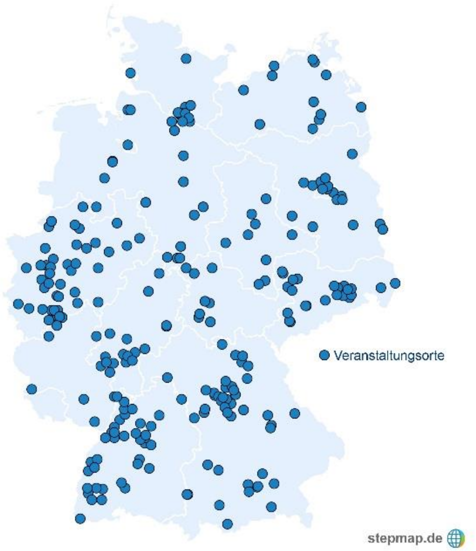
GEFÖRDERT VOM

Point of contact to already known phenomena:

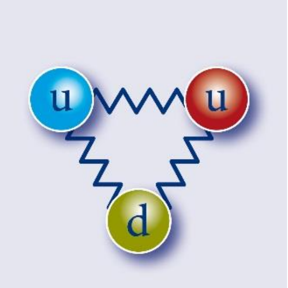
- Stability of nucleons in analogy to covalent bond of electrons
- Two nucleons in the nuclei temporarily ‘share‘ a quark pair



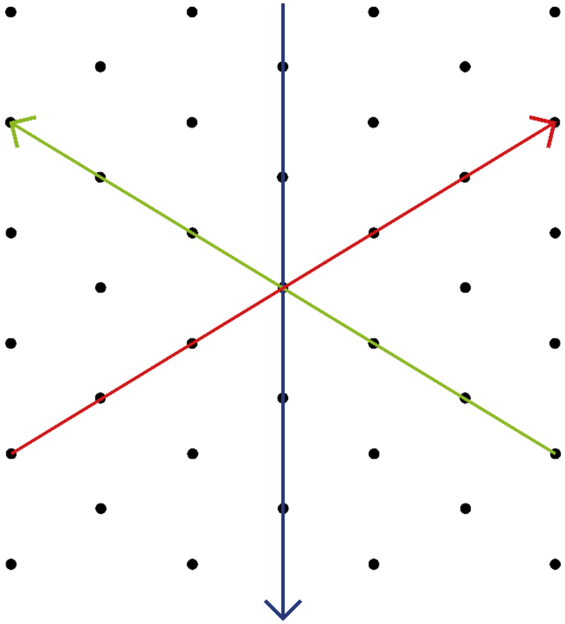
- ▶ Particle Physics Masterclasses
  - One-day programme at school
  - Analysis of ATLAS-data
  - > 100 Masterclasses per year
- ▶ Astro Particle Projects
  - Scintillator experiments
  - Astro Particle Masterclasses
  - Cosmic@Web
  - Cloud chamber sets



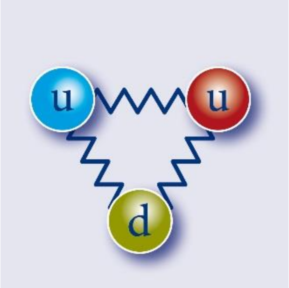
The strong charge



- Quarks possess a strong charge (also: „color charge“)
  - Protons and neutrons are built of quarks
- Charge with vectorial character: color grid



The strong charge



- Color charge vectors of quarks