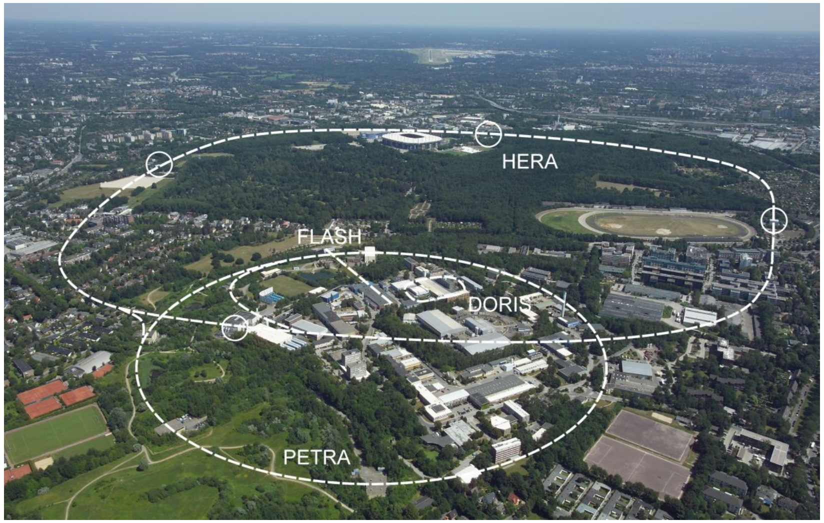
Welcome to DESY!

What is DESY and what kind of research is done here?



Introductory school
„Terascale Physics“
DESY, 23/02/2011

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Elina Fuchs
DESY- Press and Public Relations (PR)
Master student in theory group

HELMHOLTZ | ASSOCIATION

What is DESY?

- **D**eutsches **E**lektronen-**Sy**nchrotron (German electron synchrotron) DESY
- A national research centre of the

HELMHOLTZ ASSOCIATION

- Established: 1959 in Hamburg,

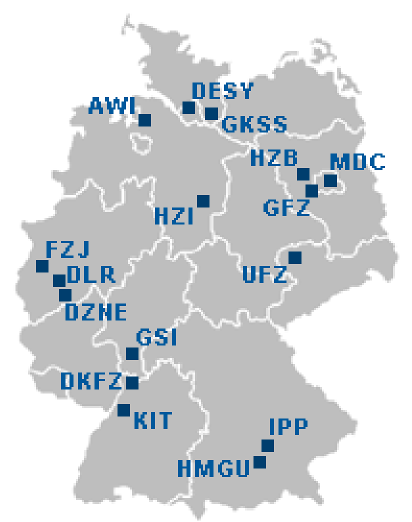
  1992 in Zeuthen
- Annual budget: 192 million euros
  - 90% Federal Ministry of Education and Research
  - 10% city of Hamburg and federal state of Brandenburg

DESY

Helmholtz Alliance of German research centres.

- Germany's largest scientific organisation
  - 16 research centres
  - 30 000 employees
  - 3 billion euros annual budget

- *Fundamental research* to solve major challenges facing society, science and industry
- long-term research projects



AWI

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DZNE Deutsches Zentrum für Neurodegenerative Erkrankungen in der Helmholtz-Gemeinschaft

DESY

dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

GFZ Helmholtz-Zentrum Potsdam

Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung

GSI

HZB Helmholtz Zentrum Berlin

HelmholtzZentrum münchen Deutsches Forschungszentrum für Gesundheit und Umwelt

JÜLICH FORSCHUNGSZENTRUM

HELMHOLTZ | ZENTRUM FÜR UMWELTFORSCHUNG UFZ

HELMHOLTZ | ZENTRUM FÜR INFEKTIONSFORSCHUNG

KIT Karlsruher Institut für Technologie

MDC MAX-DELBRÜCK-CENTRUM FÜR MOLEKULARE MEDIZIN BERLIN-BUCH IN DER HELMHOLTZ-GEMEINSCHAFT e.V.

IPP Max-Planck-Institut für Plasmaphysik

DESY

Who works at DESY?

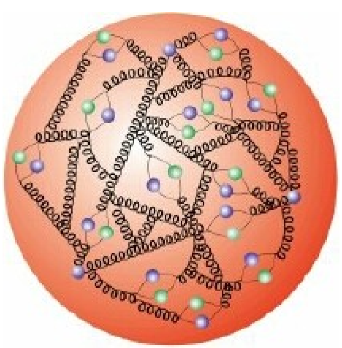
- Approximately 2000 employees
  - Among them 650 scientists
- Training programs
  - More than 100 young people trained in commercial and technical jobs
- Young scientists
  - Around 700 graduate students, PhD students and postdocs
- Guest researchers
  - 3400 from 280 universities/ institutes in 40 countries annually

- Opportunities for students:
  - Summer student program (!!)
  - Master/ diploma thesis
  - PhD

What kind of research is done at DESY?

> Basic research

- 1^{st} : fundamental questions in science
- 2^{nd} : applications later



> Research with photons

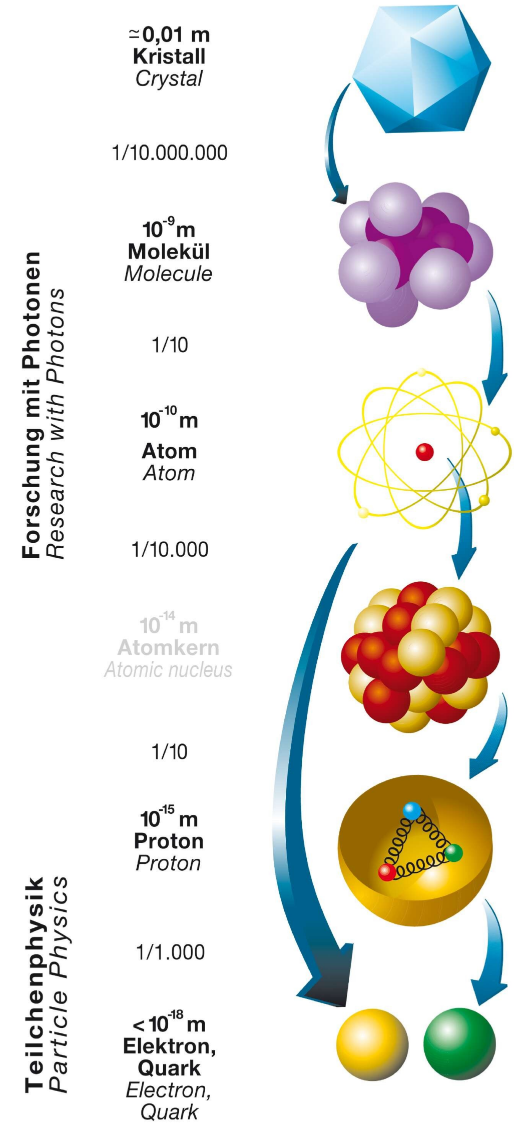
- molecular and atomic structures with a special light from particle accelerators

> Accelerators

- Development, construction and operation of particle accelerators
- used for particle physics and research with photons

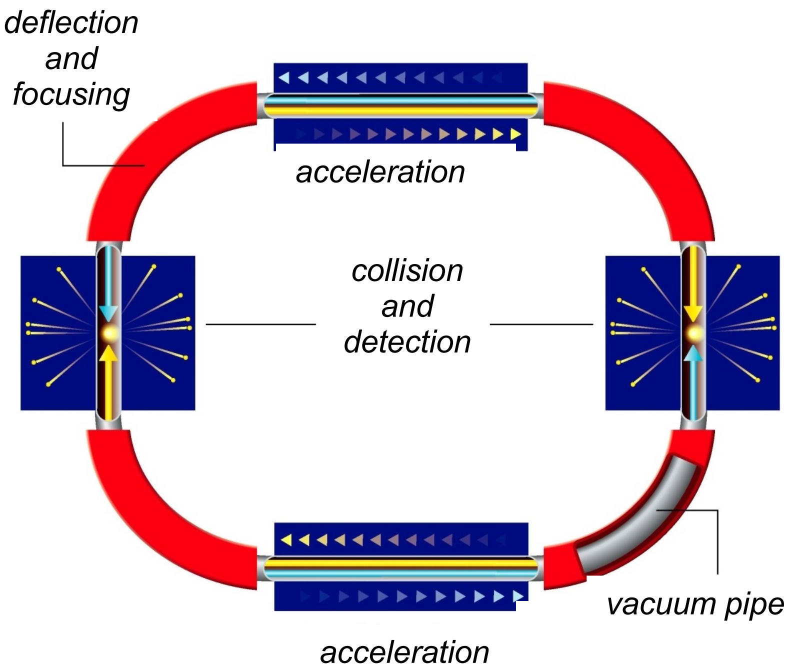
> Particle physics

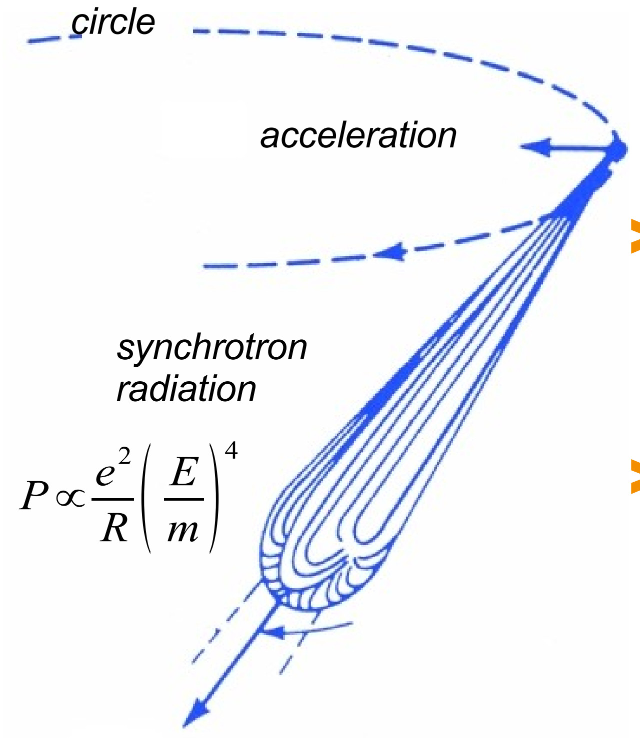
- fundamental particles and forces that make up our universe



What is a particle accelerator/collider?

- Charged particles (electrons, protons, ...)
  - accelerated by electric fields
  - deflected by magnetic fields

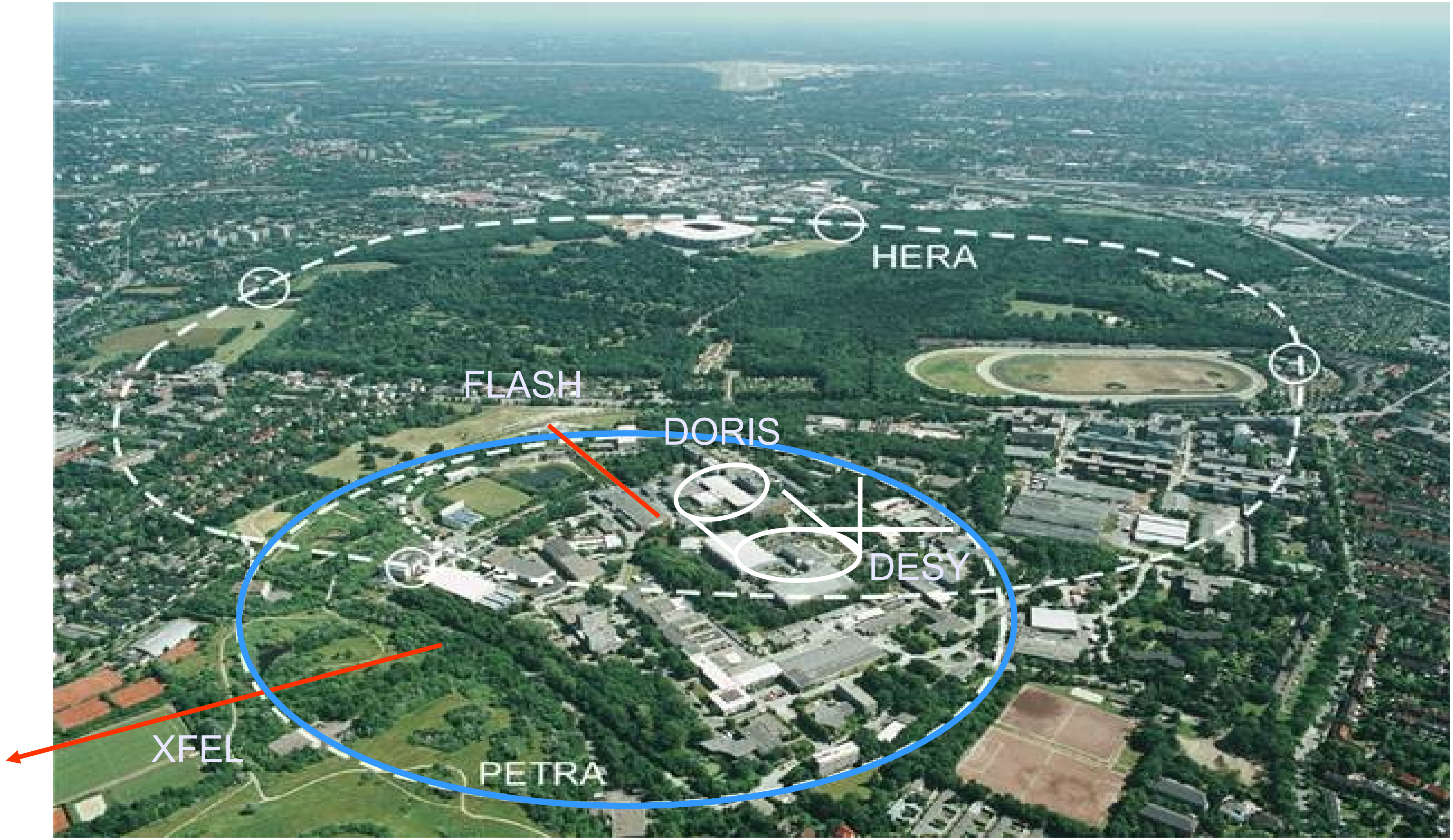




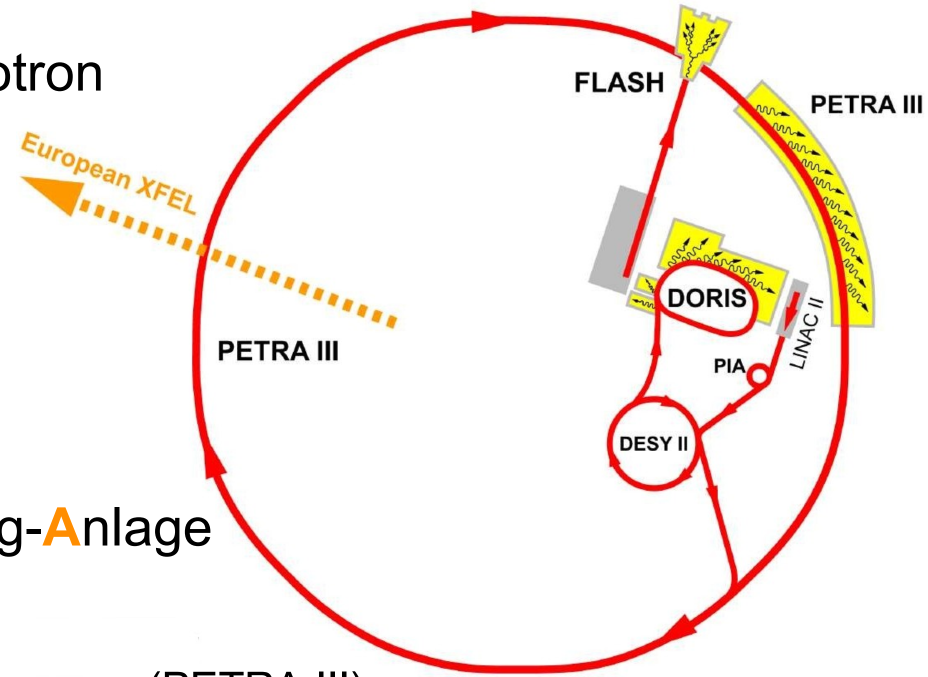
$$P \propto \frac{e^2}{R}\left(\frac{E}{m}\right)^4$$

- What limits the achievable energy?
  - maximum magnetic field strength
  - Energy loss due to synchrotron radiation in the curves
- Solutions: Heavier particles
  - Storage rings with a larger circumference
  - Accelerators without curves → linear colliders

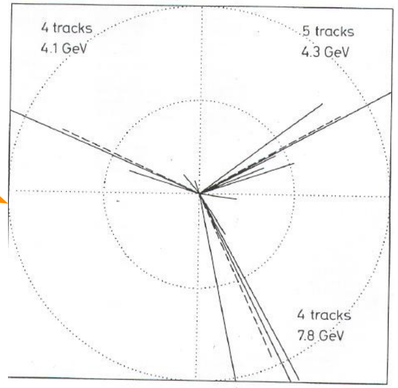
Which accelerators are there at DESY?



The history of accelerators at DESY.



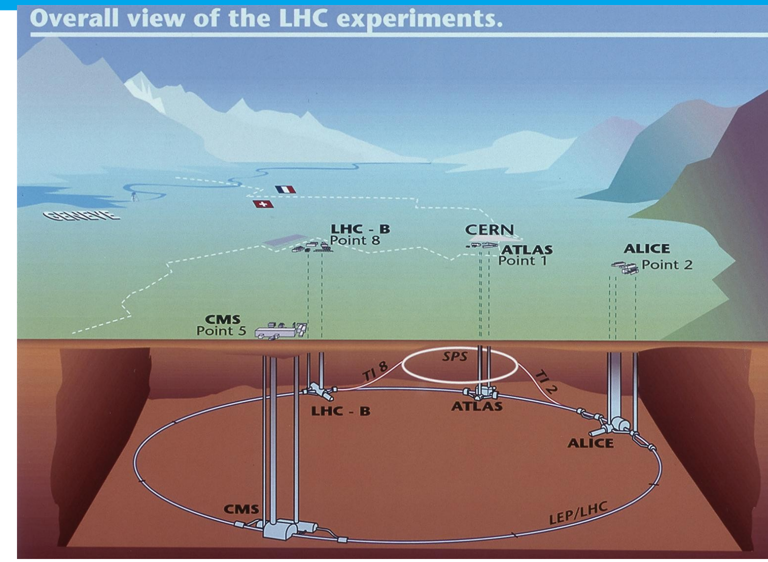
- 1964: **D**eutsches **E**lektronen-**Sy**nchrotron
  - Confirmation of quantum electrodynamics
- 1974: **Do**ppel-**Ri**ng-**S**peicher
  - Heavy quarks and b-mesons
  - Since 1981: **Ha**mburg **sy**nchrotron radiation **lab**oratory (HASYLAB)
- 1978: **P**ositron-**E**lektron-**T**andem-**R**ing-**A**nlage
  - Discovery of the gluon (1979)
  - Since 2009: used as synchrotron radiation source (PETRA III)

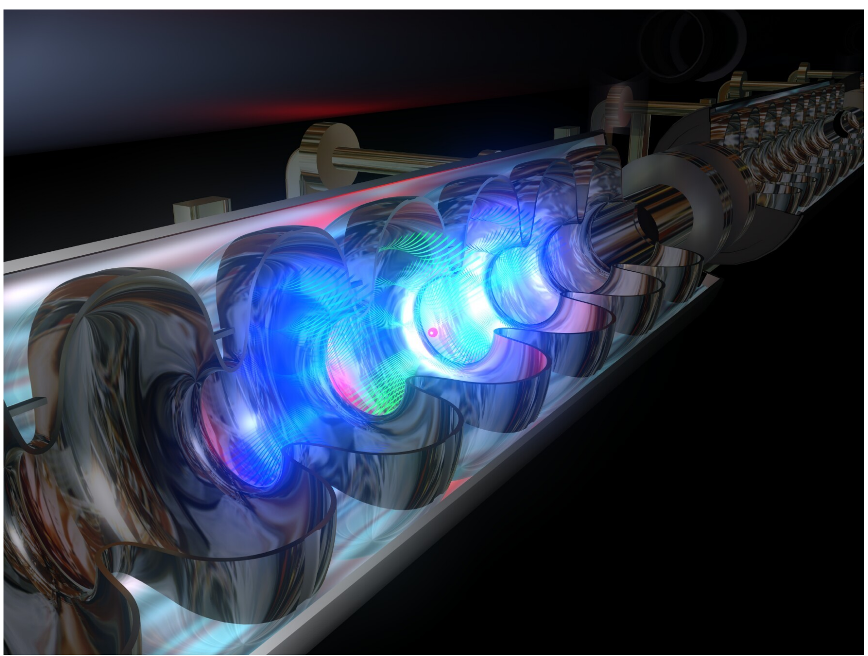


- 1992: **H**adron-**E**lektron-**R**ing-**A**nlage
  - Supermicroscope for proton structure
- 2005: **F**reie-**E**lektronen-**Las**er in **H**amburg
  - First FEL in the soft X-ray range
- 2014: European **X**-Ray **F**ree-**E**lectron-**L**aser
  - Most intensive X-ray laser in the world

Development of accelerators.

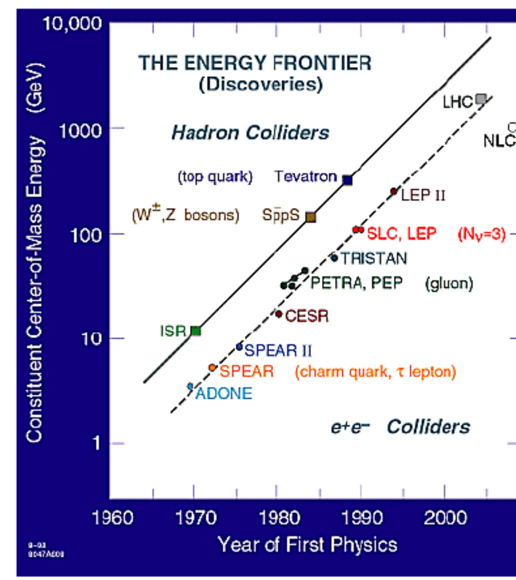
- **>** Energy frontier:
  - from the first cyclotron (Lawrence, Berkeley 1931)
  - to the Large Hadron Collider (2008)





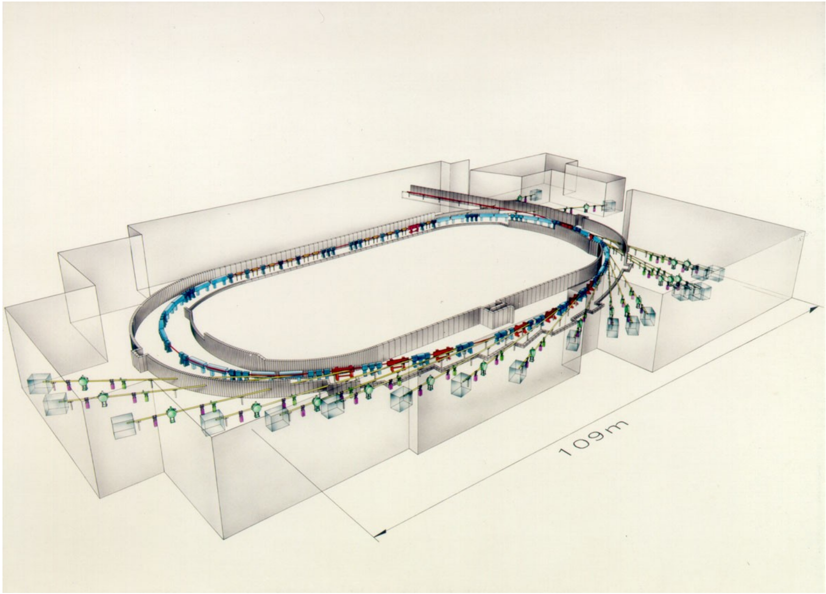
- **>** TESLA technology:
  - Cavities
  - Superconducting

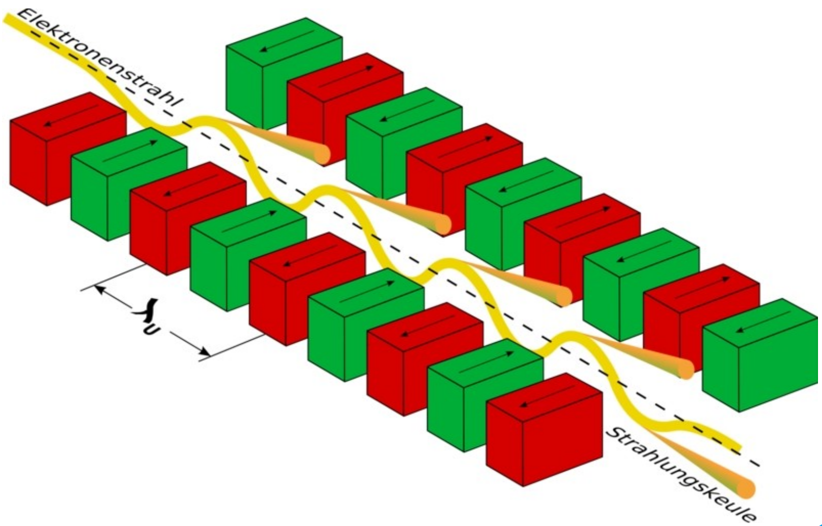
    → need low temperatures
  - Developed at DESY



Research with photons.

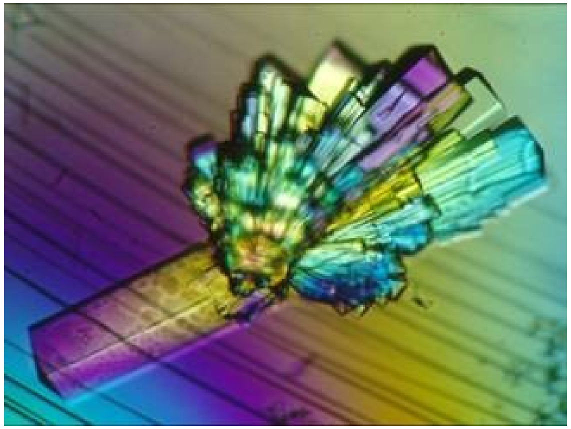
- Synchrotron radiation is light with special characteristics
  - Very intensive
  - Very strongly focused
  - Very broad spectrum (wavelength can be chosen according to the needs of the experiment)
- Particle accelerators as synchrotron radiation sources
  - Storage rings: DORIS III (HASYLAB) and PETRA III
  - Free-electron lasers: FLASH and XFEL

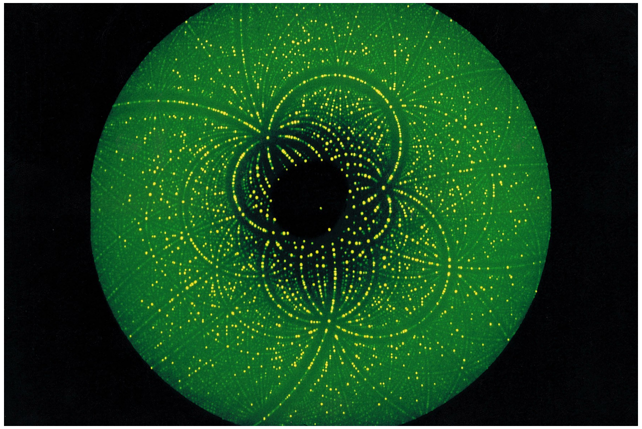


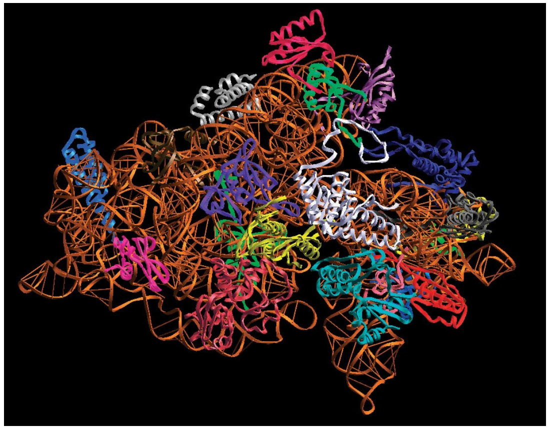


Applications of synchrotron radiation.

- Structural analysis, e.g. of biomolecules







  - From protein crystals ... via diffraction images ... to the 3D structure of ribosomes

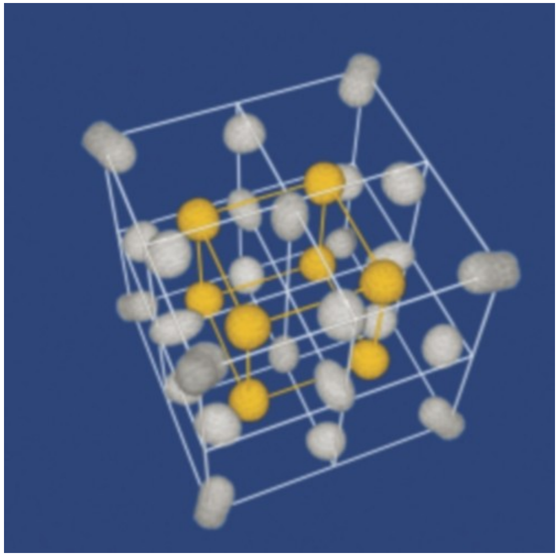
- Structure of ribosomes: Nobel Prize in Chemistry 2009 (*Ada Yonath*)

- **Physics:** Material science, plasmas
- **Biology:** proteins,...
- **Chemistry, geology, medicine,...**
- **Arts:** hidden portrait in Van Gogh's painting *Grasgrond*

PETRA III & FEL: The capabilities of our facilities.

PETRA III

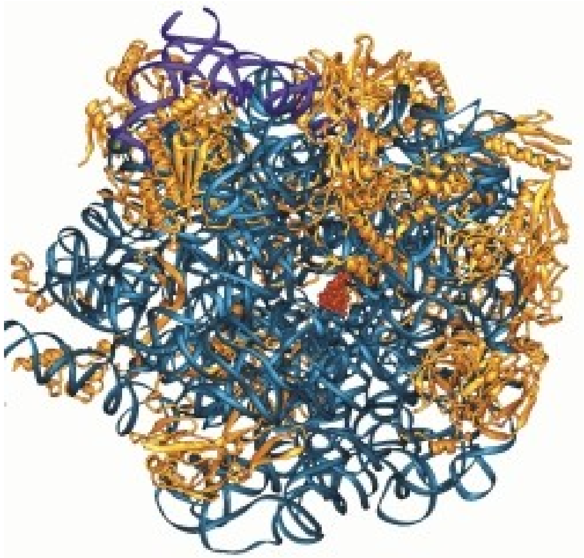
- Incoherent light beam can only probe materials with a crystalline structure



- Crystals
- Freeze images of the nanocosm

Free-electron laser

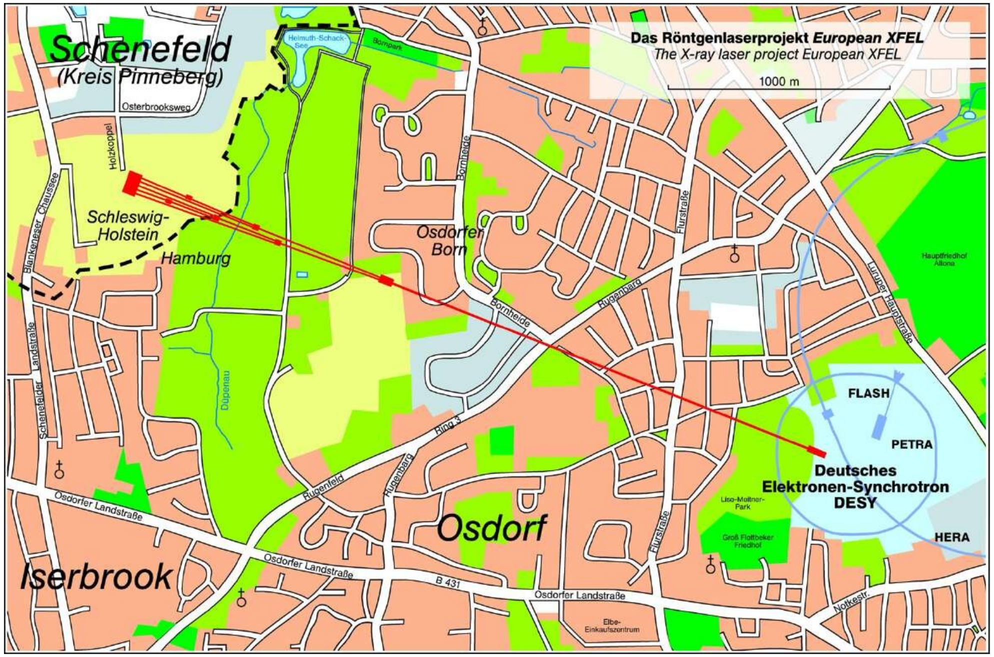
- Coherent light beam can also probe materials with an irregular structure

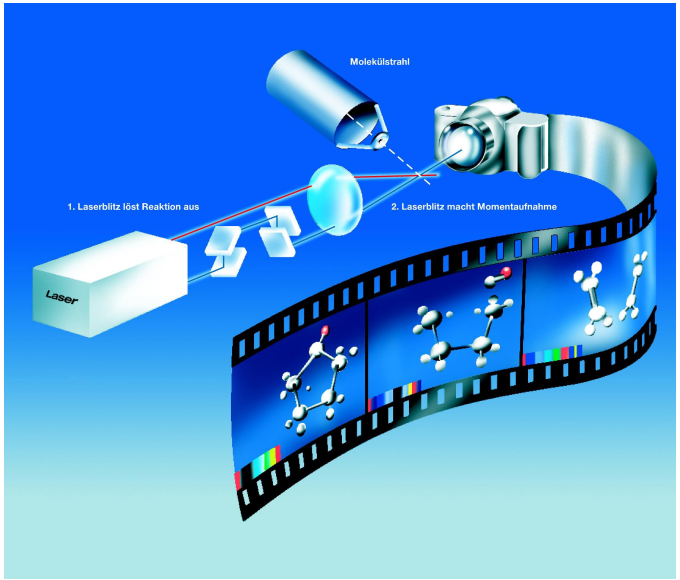


- Noncrystalline solids
- Biological substances
- Live observations of the nanocosm

The future: European X-ray Free-Electron Laser (XFEL)

- Revolutionary light source for fundamental research with ultra-short X-ray flashes
  - Length: 3,4 km
  - Completion: 2014
- Applications:
  - Observation of single molecules
  - Filming chemical reactions





- Acceleration technology developed at DESY
  - Successfully tested at the prototype FLASH

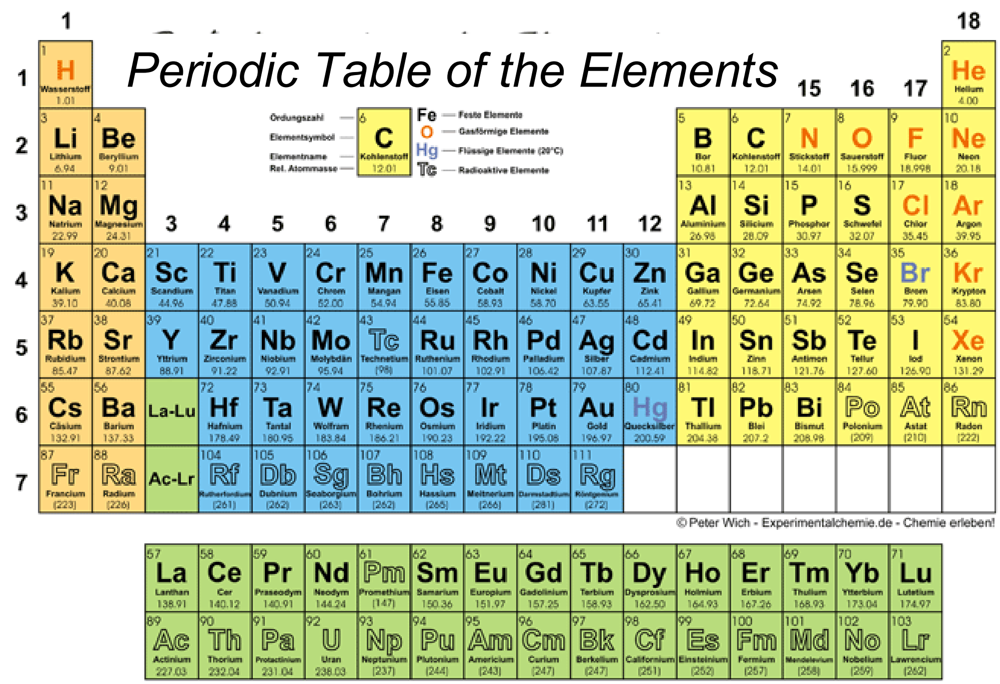
European XFEL

DESY

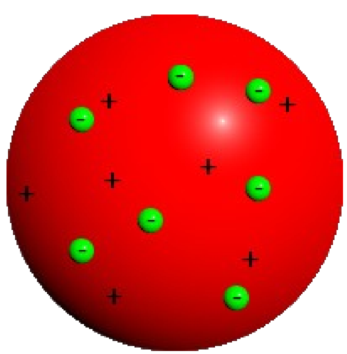
The beginnings of particle physics.

- Around 400 BC – the void and ἄτομος *(Demokritos and Leukippos)*

- 19th century – Periodic table of the elements (*Mendelejew*, *Meyer*)

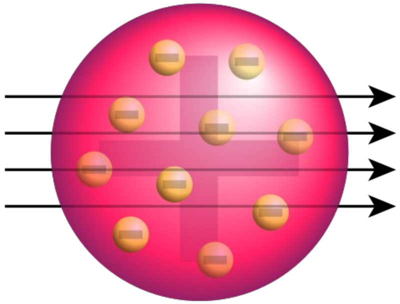


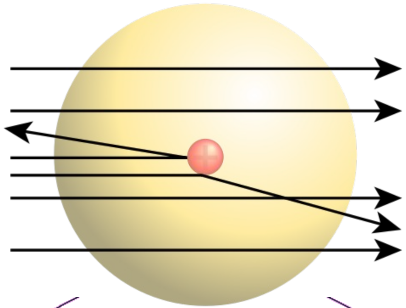
- 1897 – Discovery of the electron (*Thomson*)
- 1903 – Thomson's atomic model (Plum pudding model)

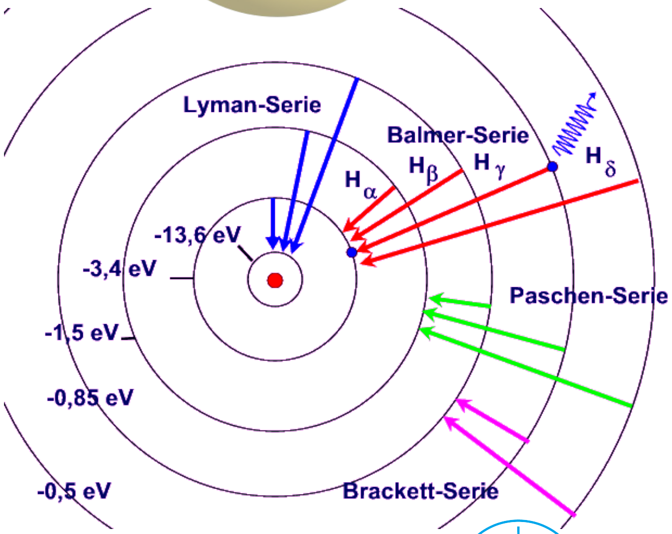


From atoms to elementary particles.

- 1909 – Rutherford experiment
  - Scattering of alpha particles off a gold foil
  - small fraction of the particles is deflected by a large angle or even reflected
- 1911 – Rutherford model
  - The mass and the positive charge of the atoms is concentrated in a tiny, compact nucleus
- 1913 – Bohr model
  - The electrons move on *quantised* circular orbits around the nucleus
  - This model explains the atomic spectral lines
- Around 1950 until today – Discovery of new particles at particle accelerators ⟶ particle zoo
- Smallest constituents: elementary particles

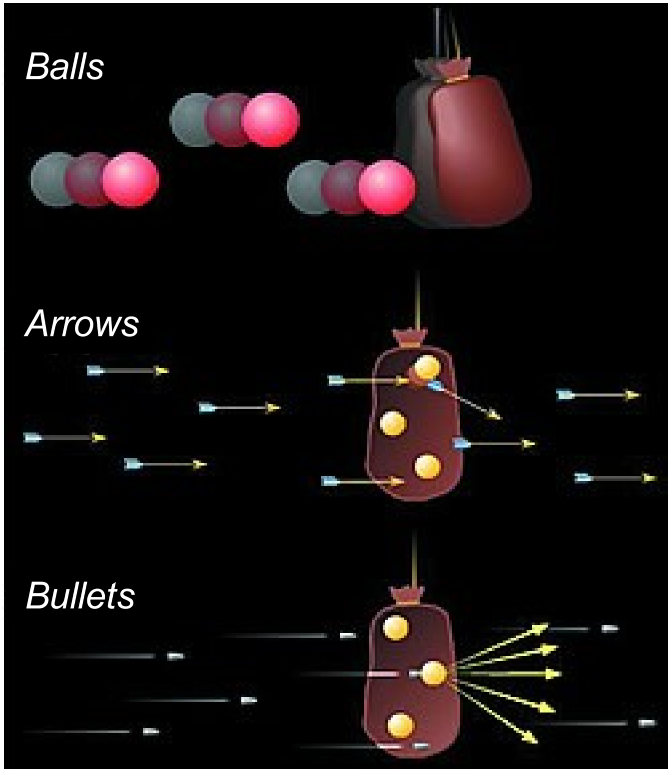


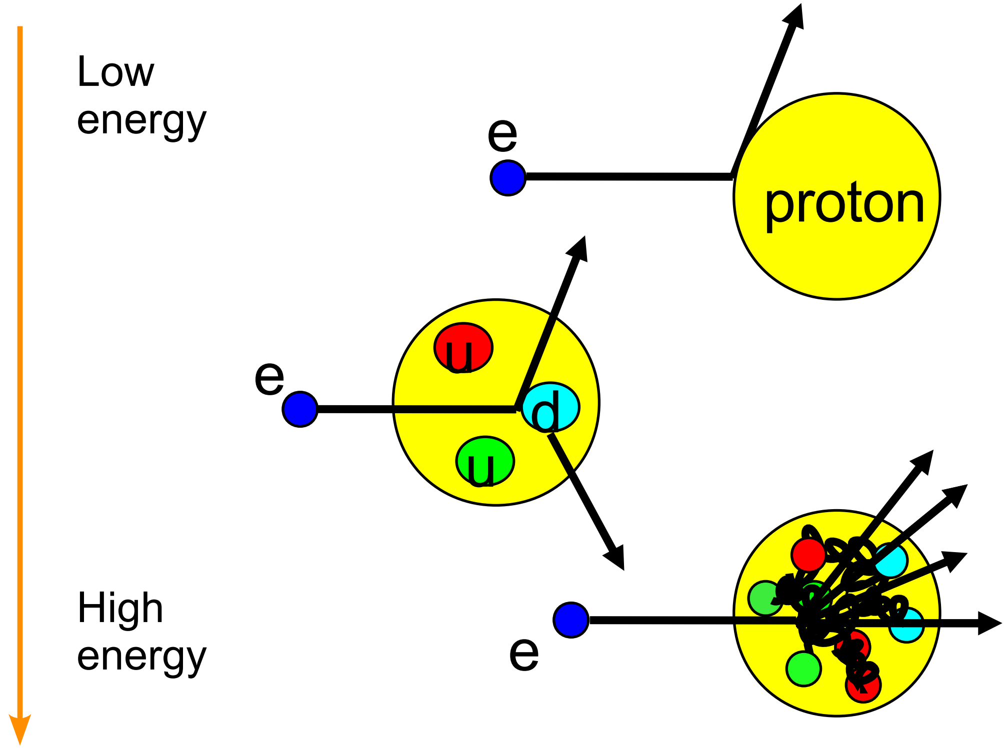




How do we know all this?

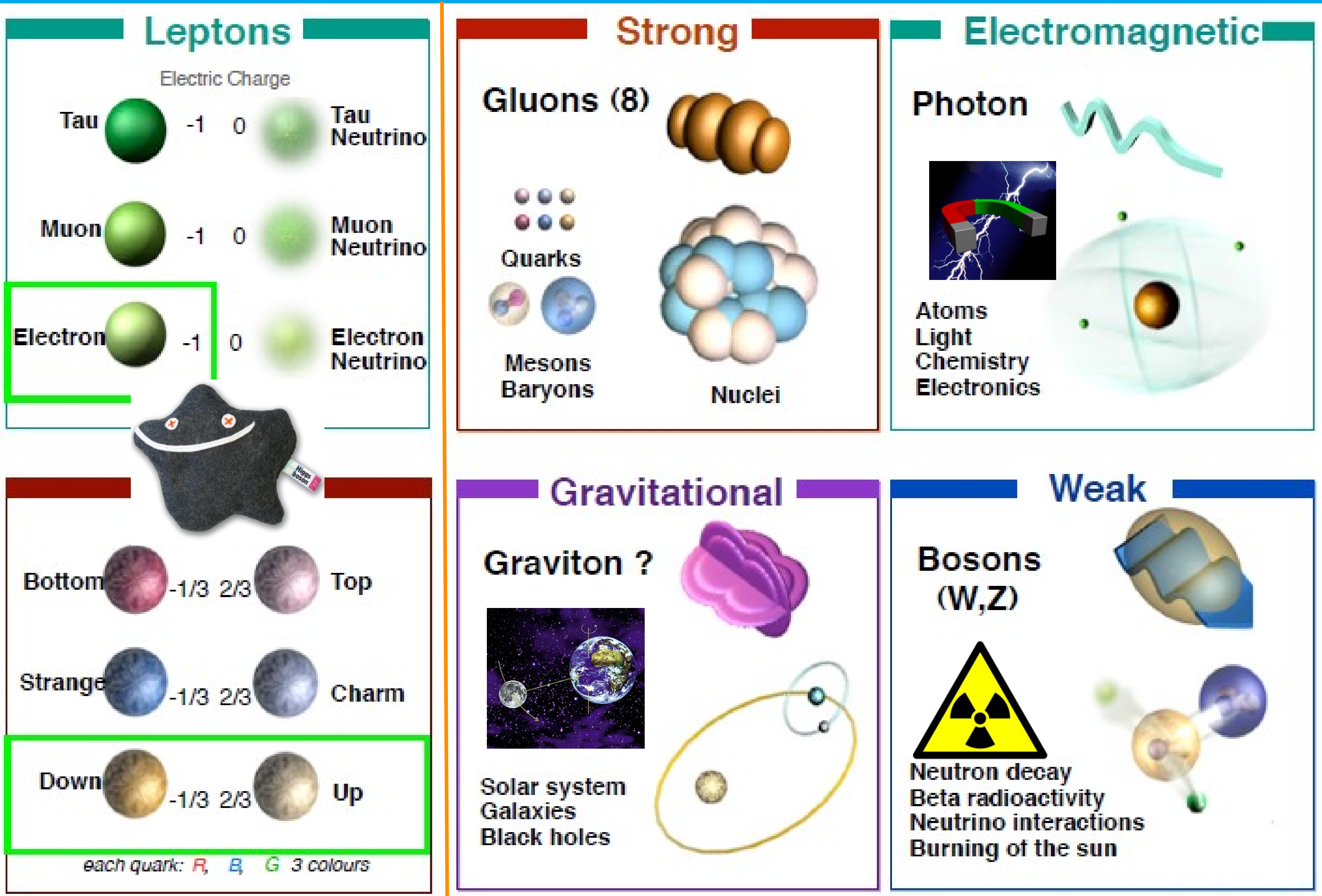
- Investigation of the structure of known particles in scattering experiments
  - High energy = High resolution





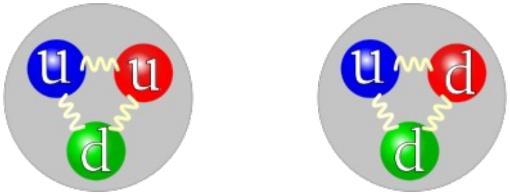
- Creation of new, heavy particles according to $E=mc^2$
  - Light, known particles with a large kinetic energy → new, heavier particles

The standard model of particle physics.

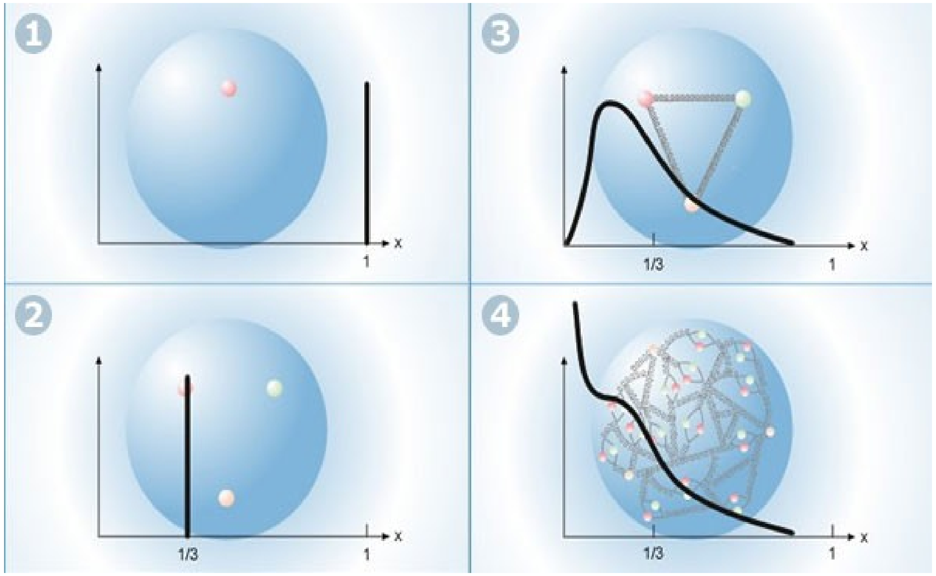


A closer look at particles and forces.

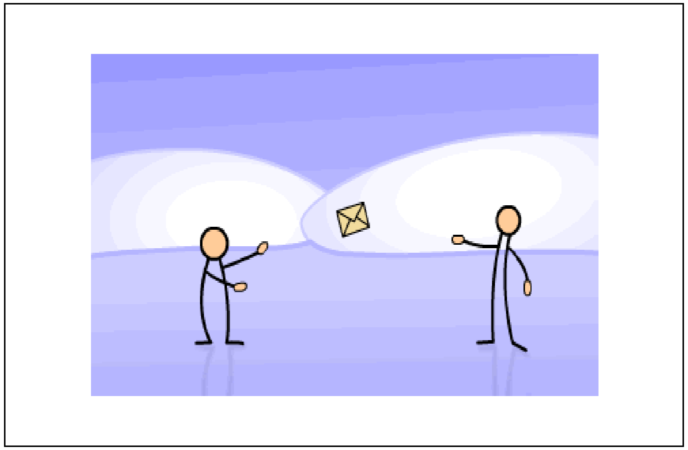
- All matter consists of point-like, indivisible elementary particles
  - Protons and neutrons consist of quarks



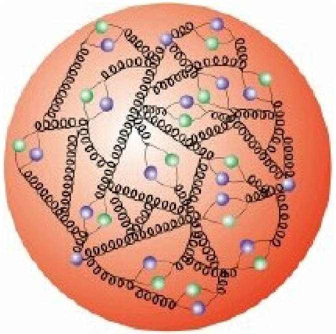
  - Quarks: up up down   up down down
  - Charge: $+\frac{2}{3}+\frac{2}{3}-\frac{1}{3}=+1$ $+\frac{2}{3}-\frac{1}{3}-\frac{1}{3}=0$



- Forces are mediated by the exchange of particles



- Proton structure investigated at HERA

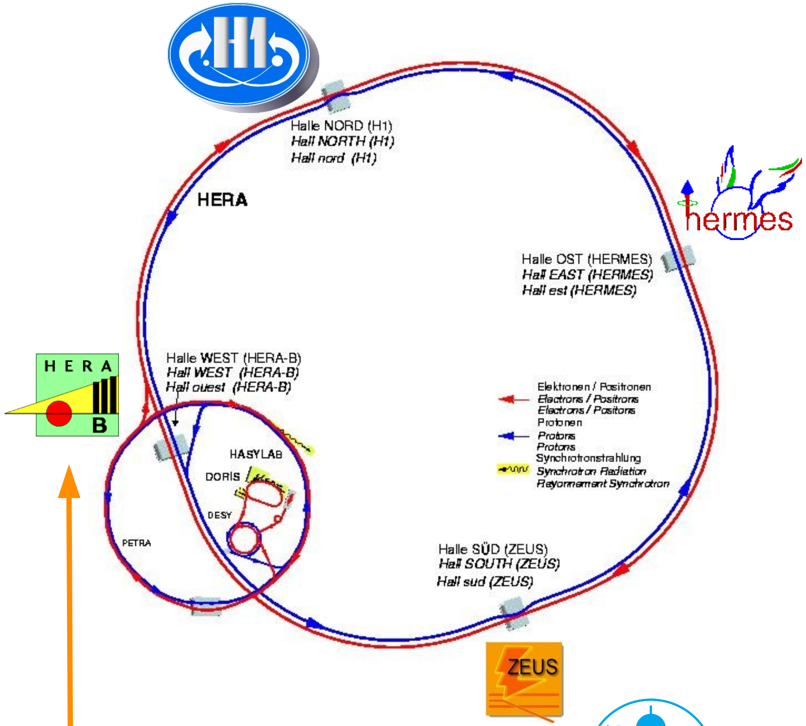


  - Constituents: quarks and gluons
  - Carry momentum fraction

Hadron-Elektron-Ring-Anlage (HERA).

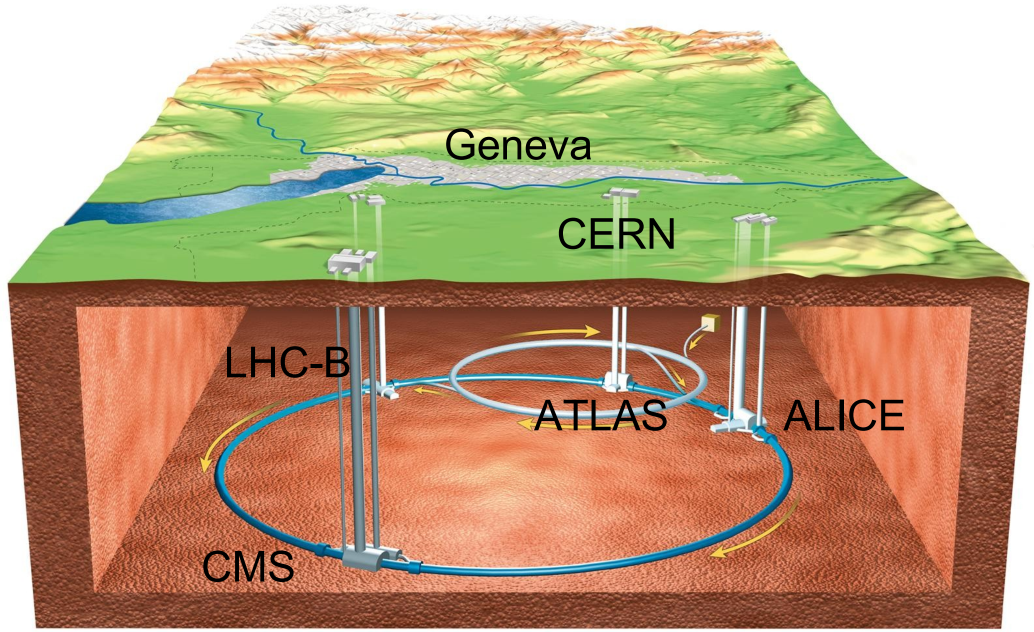
- **HERA model: built by many nations**
- **Electron-proton storage ring**
  - Circumference: 6,3 km
  - Start of construction: 1984
  - Running period: 1992 – 2007
  - Data analysis: until 2014
  - Unique particle accelerator of this kind: e p
- **Beam properties**
  - Energy: protons 900 GeV, electrons 30 GeV
  - 210 bunches, $\simeq 10^{13}$ particles of each sort
  - Bunch crossing every 96 ns
  - Electron beam dimension: $0.3 \times 0.1 \times 8\, mm$
- **4 experiments**
  - H1, ZEUS multi-purpose
  - Hermes: proton spin
  - HERA B: B-mesons, strong force

VISIT

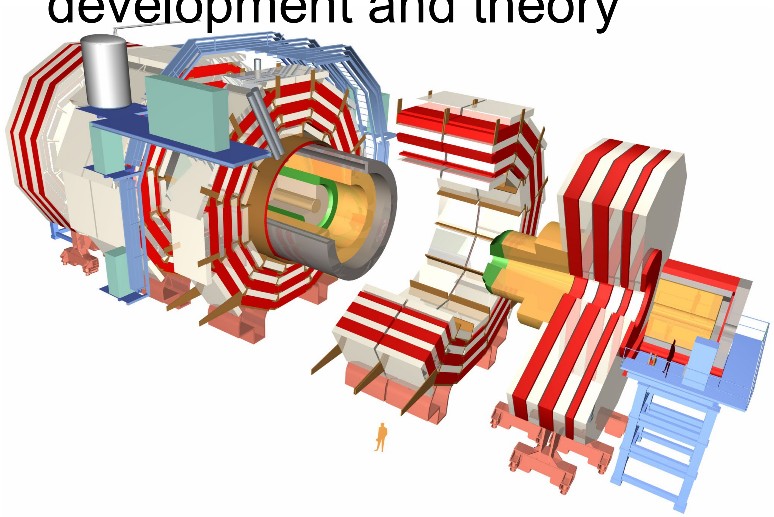


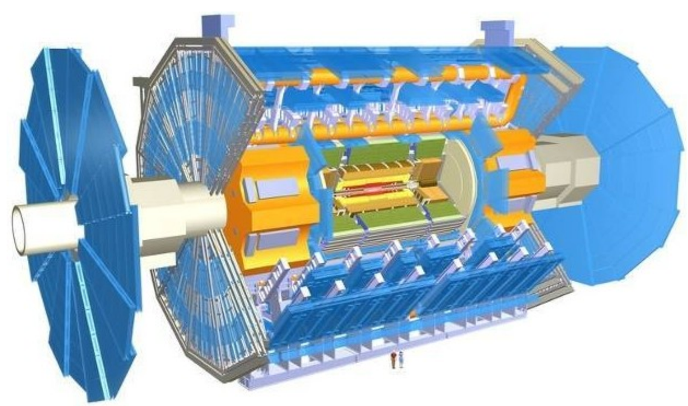
Large Hadron Collider (LHC) at CERN.

- Proton-proton storage ring
  - Circumference: 27 km
  - strongest accelerator worldwide
  - measurements: since 2009
- Objectives:
  - Discover the Higgs particle
  - Discover new particles
    beyond the standard model



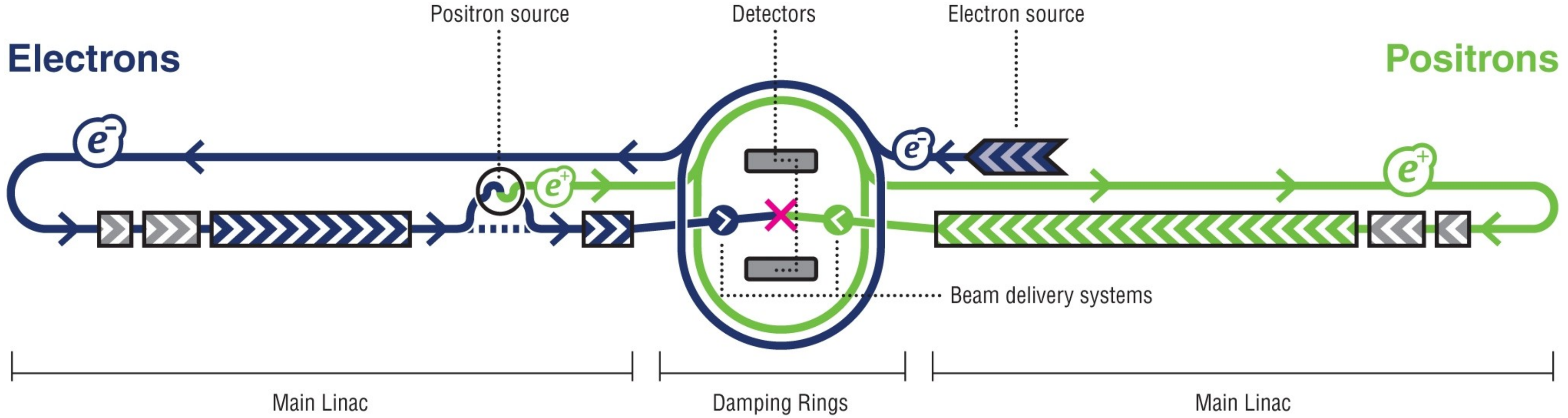
- DESY involved: particle detectors CMS and ATLAS, accelerator development and theory





The Future: International Linear Collider (ILC).

- Electron-positron linear accelerator
  - In planning stage, decision on construction and location by 2012
  - Length: More than 30 km
- Objectives:
  - Precision measurements of the new physics (hopefully) discovered at the LHC
- Acceleration technology developed at DESY (FLASH, European XFEL)
- DESY also involved in the development of the particle detectors



The interplay between theory and experiment.

Theoretical predictions

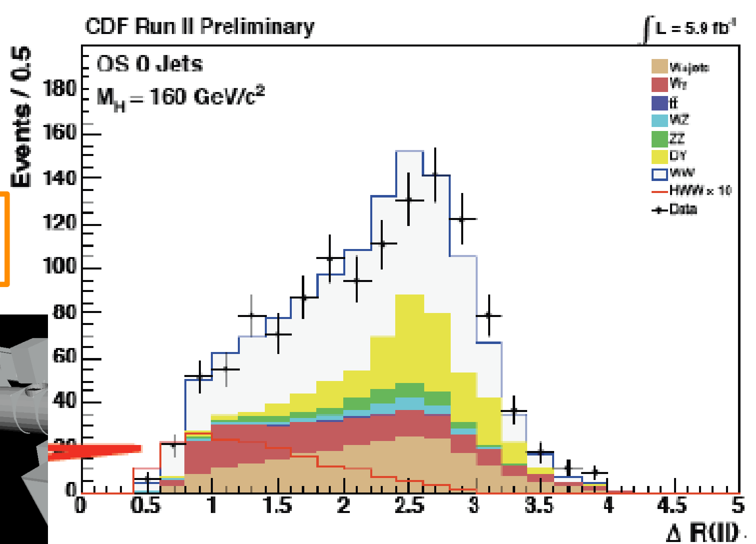
- Test model
- Discover particles
- Establish new theories

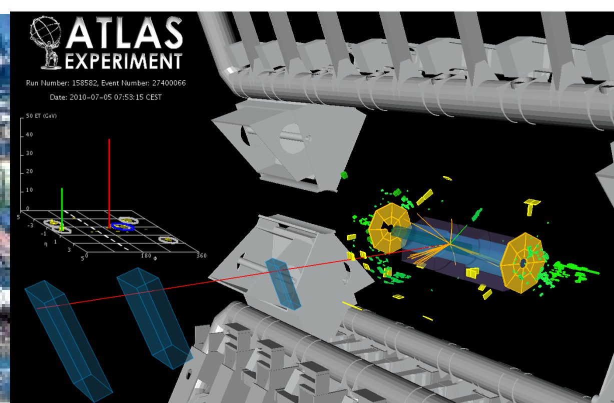
$$
\begin{aligned}
\mathcal{L}_{GWS} = &\sum_f (\bar{\Psi}_f(i\gamma^\mu\partial\mu - m_f)\Psi_f - eQ_f\bar{\Psi}_f\gamma^\mu\Psi_f A_\mu) + \\
&+\frac{g}{\sqrt{2}}\sum_i(\bar{a}^i_L\gamma^\mu b^i_L W^+_\mu + \bar{b}^i_L\gamma^\mu a^i_L W^-_\mu) + \frac{g}{2c_w}\sum_f \bar{\Psi}_f\gamma^\mu(I^3_f - 2s^2_w Q_f - I^3_f\gamma_5)\Psi_f Z_\mu + \\
&-\frac{1}{4}|\partial_\mu A_\nu - \partial_\nu A_\mu - ie(W^-_\mu W^+_\nu - W^+_\mu W^-_\nu)|^2 - \frac{1}{2}|\partial_\mu W^+_\nu - \partial_\nu W^+_\mu + \\
&-ie(W^+_\mu A_\nu - W^+_\nu A_\mu) + ig' c_w(W^+_\mu Z_\nu - W^+_\nu Z_\mu|^2 + \\
&-\frac{1}{4}|\partial_\mu Z_\nu - \partial_\nu Z_\mu + ig' c_w(W^-_\mu W^+_\nu - W^+_\mu W^-_\nu)|^2 + \\
&-\frac{1}{2}M^2_\eta\eta^2 - \frac{gM^2_\eta}{8M_W}\eta^3 - \frac{g'^2 M^2_\eta}{32M_W}\eta^4 + |M_W W^+_\mu + \frac{g}{2}\eta W^+_\mu|^2 + \\
&+\frac{1}{2}|\partial_\mu\eta + iM_Z Z_\mu + \frac{ig}{2c_w}\eta Z_\mu|^2 - \sum_f \frac{g}{2}\frac{m_f}{M_W}\bar{\Psi}_f\Psi_f\eta
\end{aligned}
$$

- compare distributions of expected signal/ background with data
- new physics: not consistent with background
- 1 event not enough → need high statistics

Construction of machines

Event selection

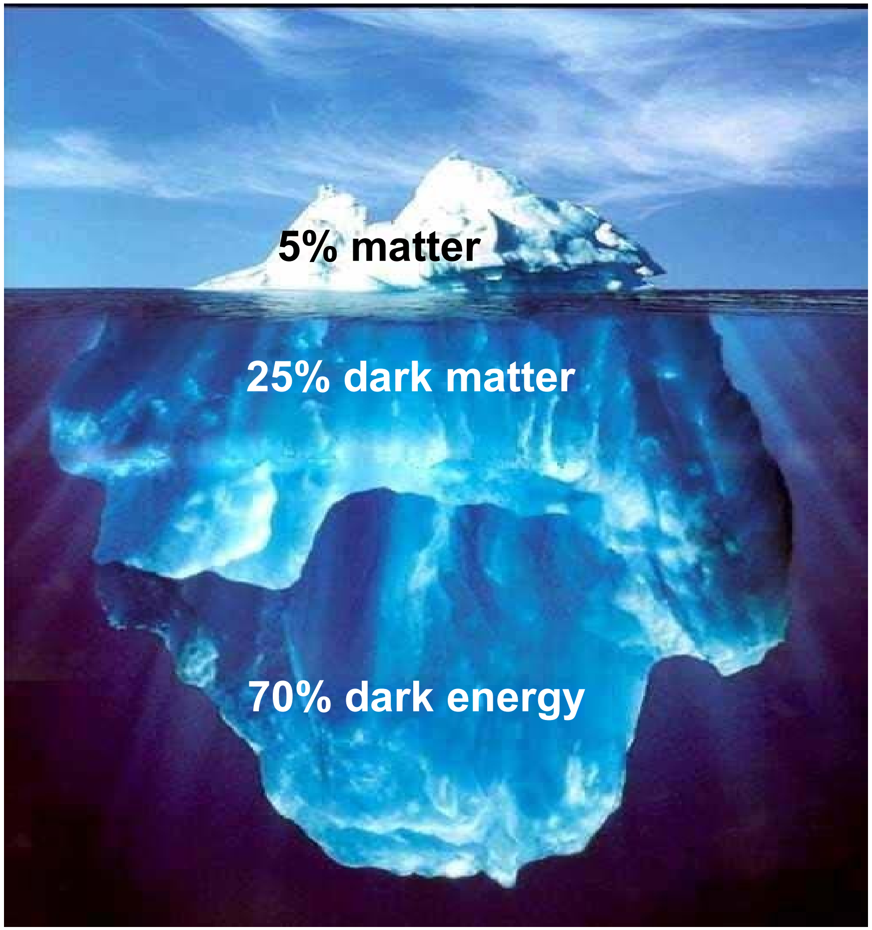




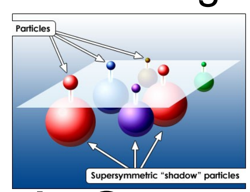
Further Open Questions ...

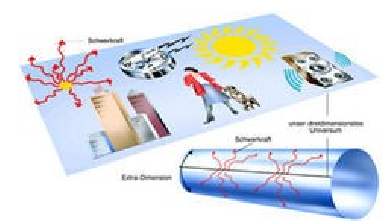
οἶδα οὐκ εἰδώς

- I know that I don't know (Sokrates)



- What are the origin and the fate of the universe?
  - Big bang
  - Why is the universe made of matter and not of antimatter?
  - What is dark energy?
- What is dark matter?
  - A new elementary particle, or several?
- Additional space-time dimensions?
  - String theory?





- Is Supersymmetry realised in Nature?

... any questions?

Enjoy the guided tour!