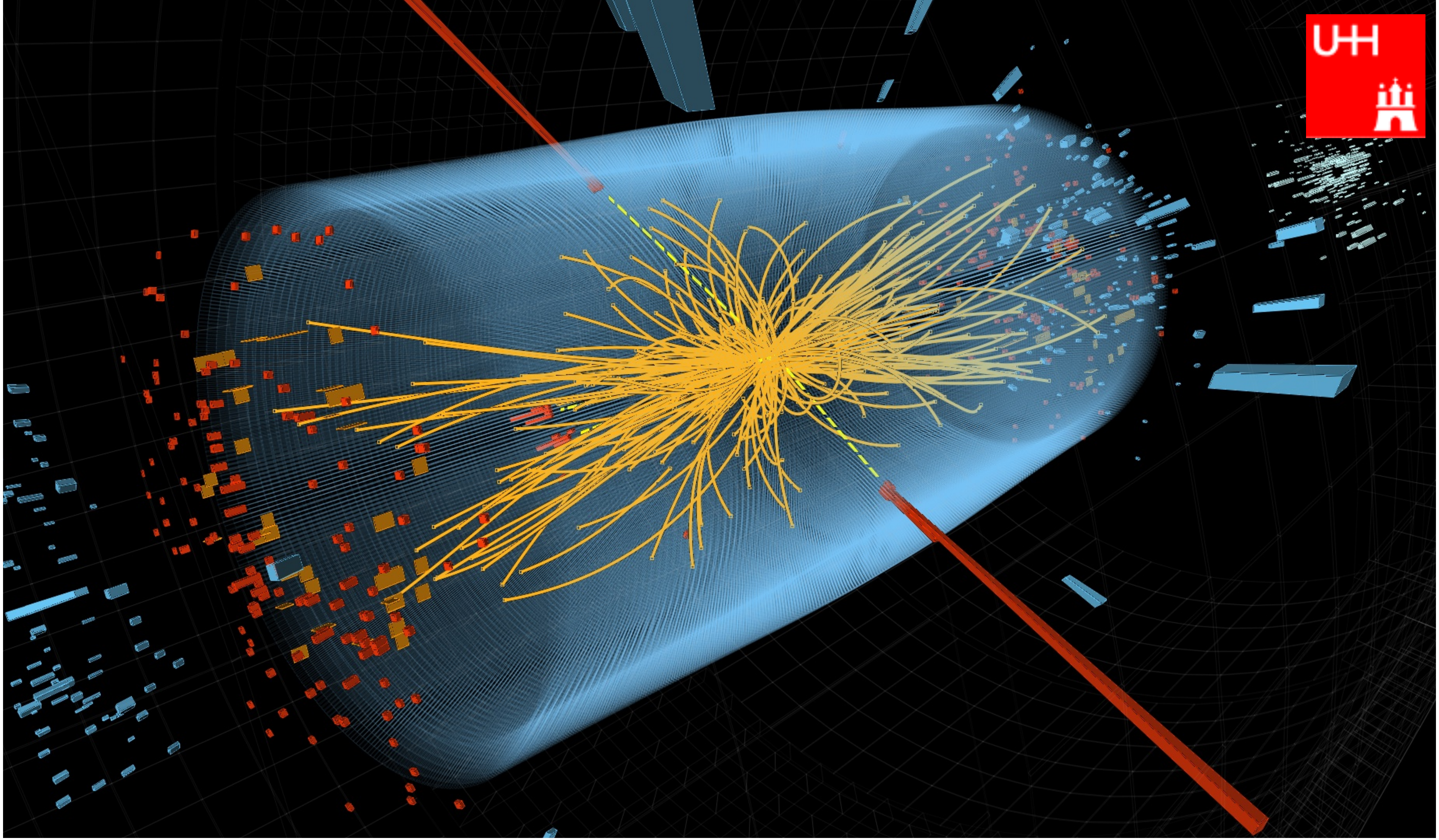


Part II: Detectors

Peter Schleper
Universität Hamburg
30.05.2018

Outline of the lecture:

1. Overview on detectors
2. Particle interactions with matter
3. Scintillators and photon detectors
4. Semiconductor detectors
5. Gaseous detectors
6. Tracking and vertex detection
7. Calorimeters
8. Jet reconstruction
9. Particle flow
10. Collider detector systems
11. Non-collider detector systems

- **Test exam**
  - June 13
    proposal, instead of lecture
- **Exam**
  - July 13,
    during lecture or exercise

Literature

Large parts of this lecture are also based on lectures previously given by Ingrid-Maria Gregor, Roman Kogler, Alexander Schmidt and Georg Steinbrück at Hamburg University.

➜ **Many thanks!**

These notes: http://www.desy.de/~schleper/lehre/ (recently discovered particle)

Introductory material:

- Physics 5 lecture, literature therein and section 6 on detectors, http://www.desy.de/~schleper/lehre/physik5/WS_2016_17/Physik_5_AllInOne.pdf

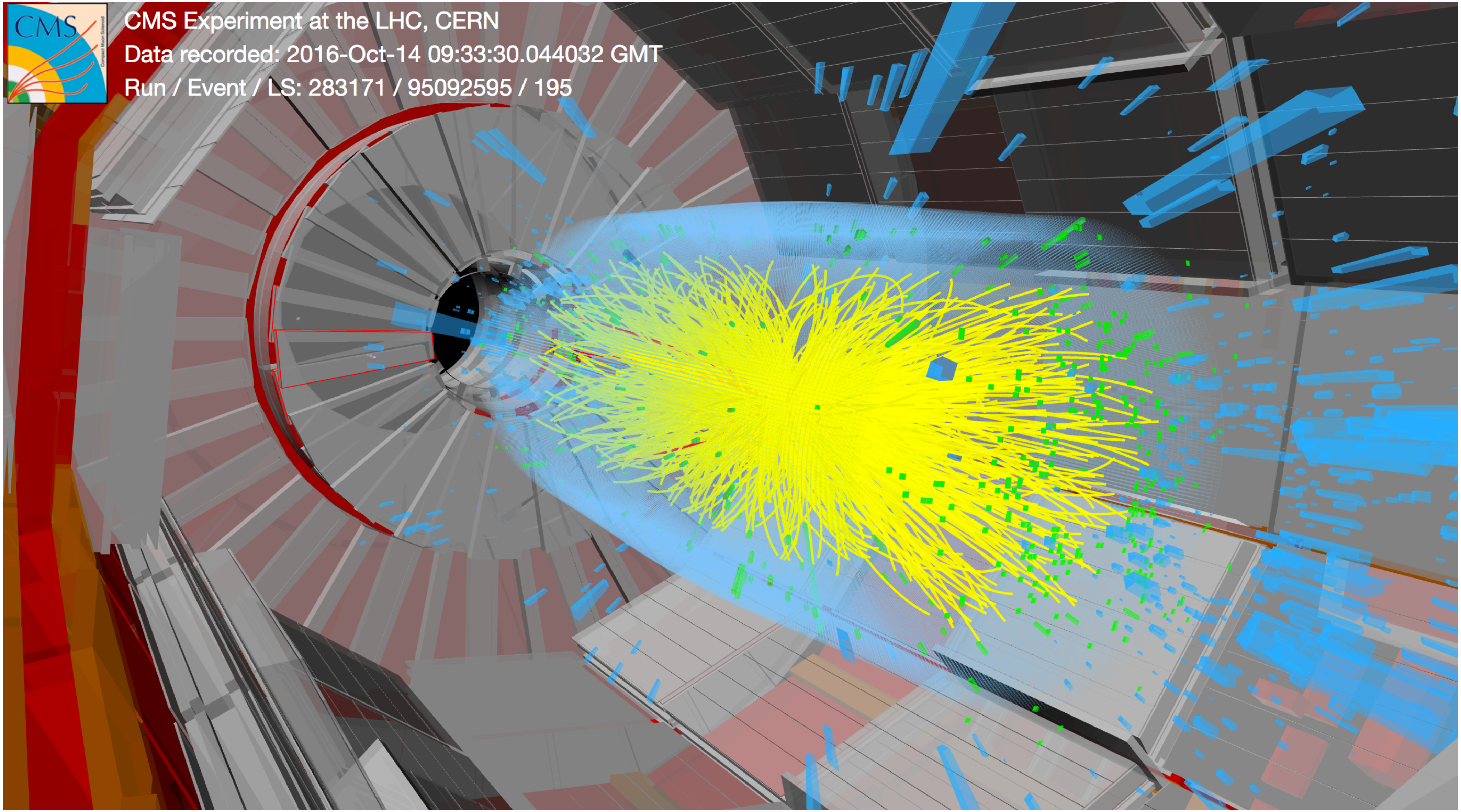
Text books

- H. Kolanoski, N. Wermes: Teilchendetektoren
- K. Kleinknecht: Detectors for particle radiation
- C. Gruppen: Particle detectors
- W.R. Leo: Techniques for nuclear and particle experiments
- T. Ferbel: Experimental Techniques in high energy physics

Web links:

- Particle data group: http://pdg.lbl.gov/2017/reviews/contents_sports.html then look for „Experimental Methods and Colliders“

Detector requirements



https://home.cern/about/experiments/cms

ATLAS Cross Section

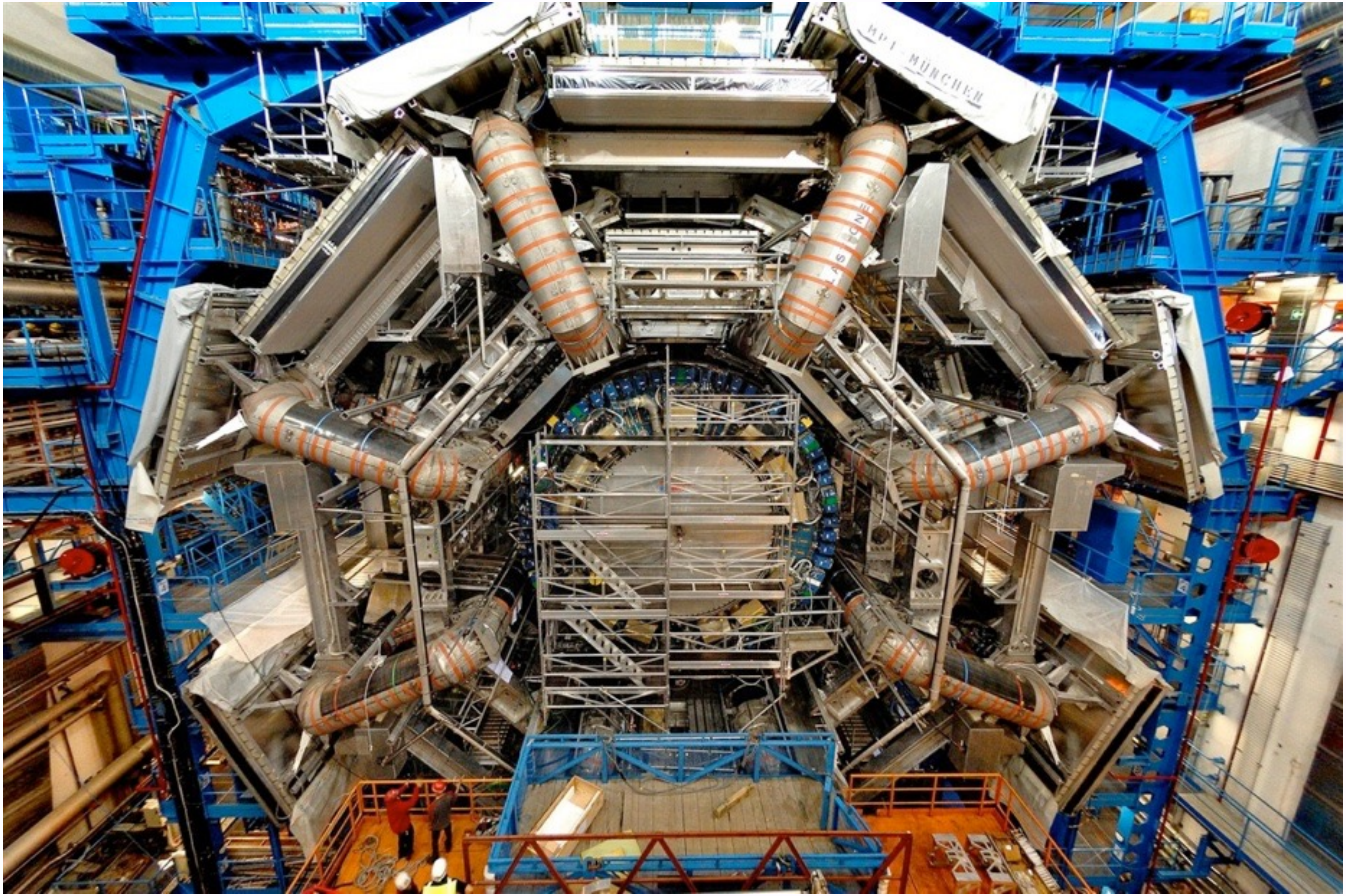
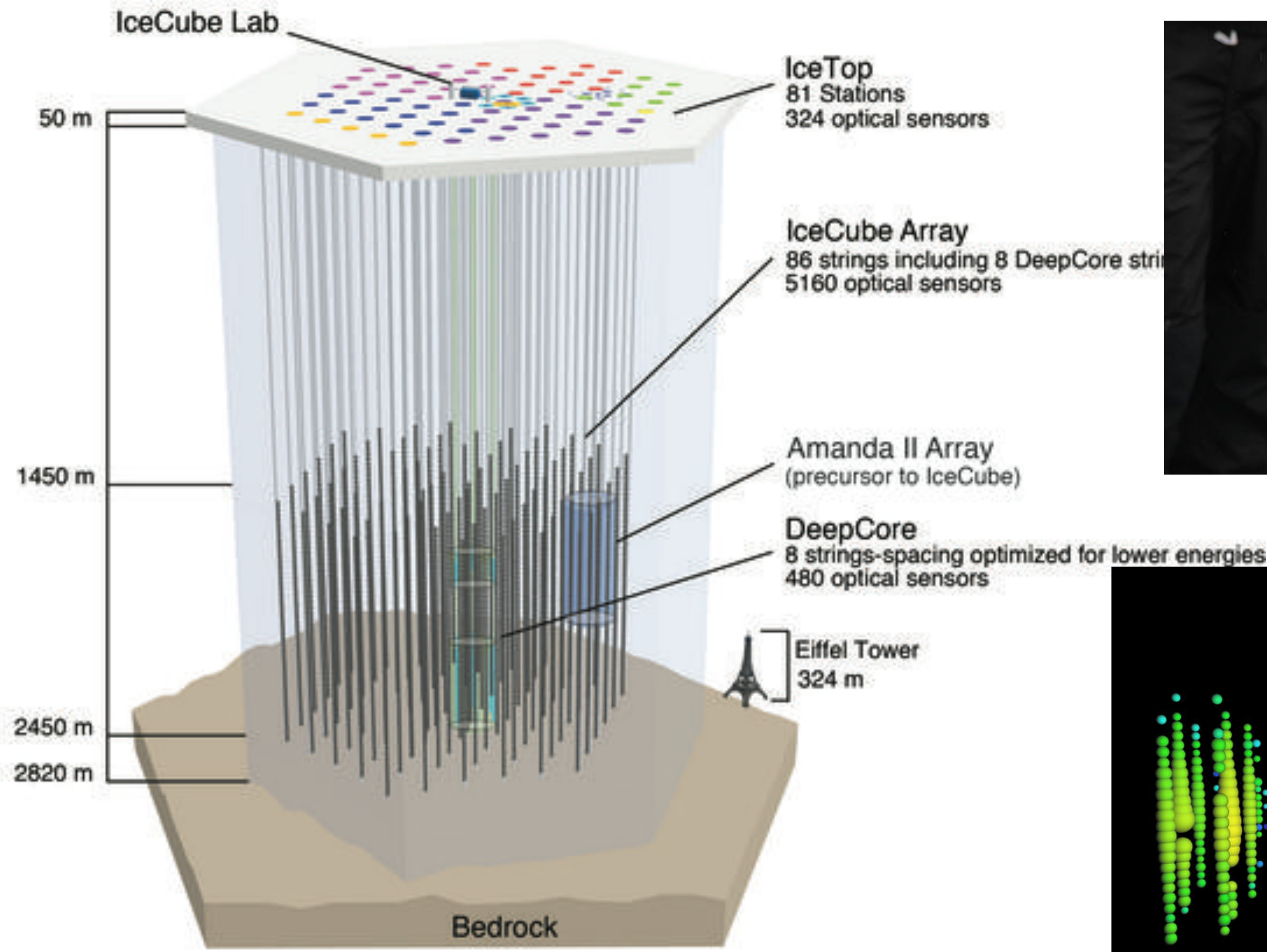
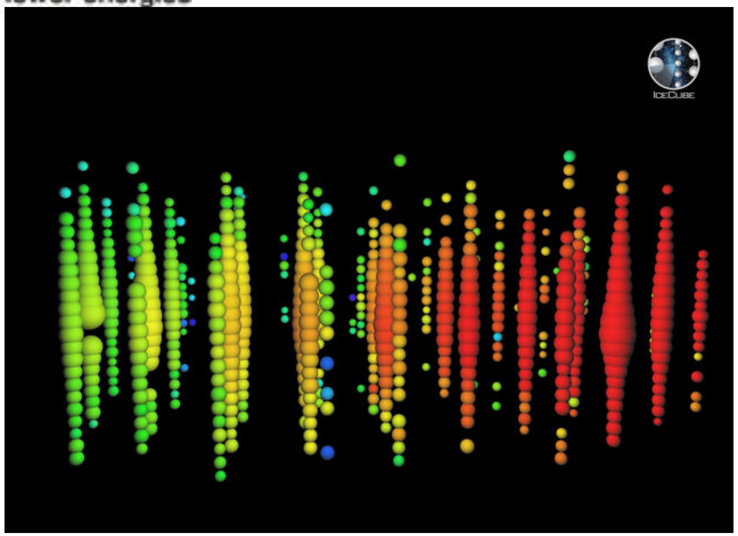


Foto: CERN

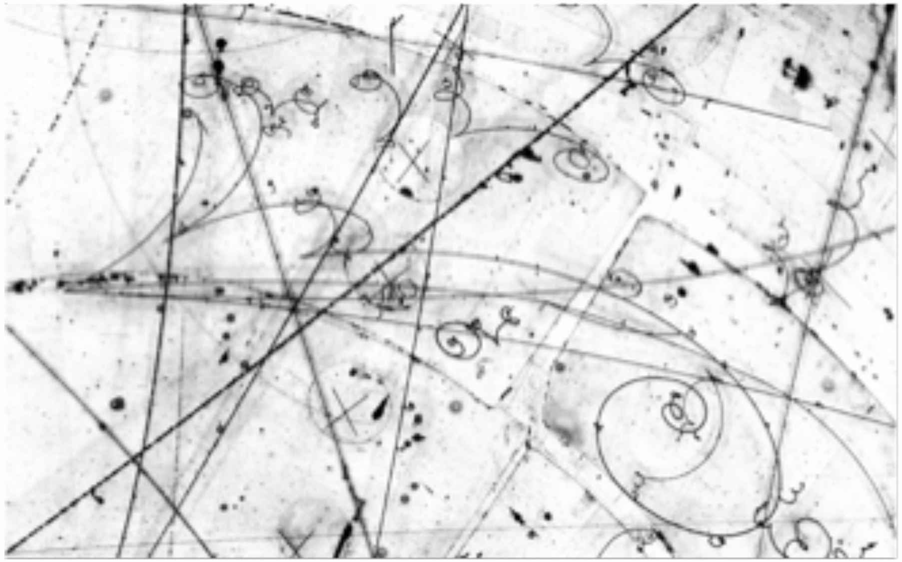
ICECUBE neutrino detector at the south pole

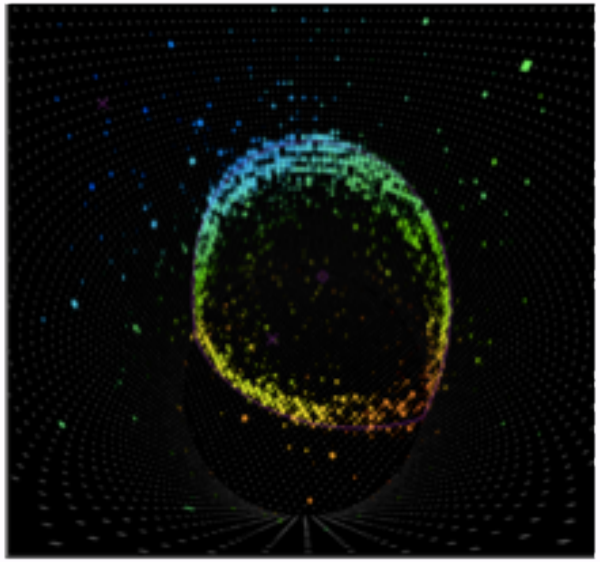
ICECUBE neutrino detector at the south pole

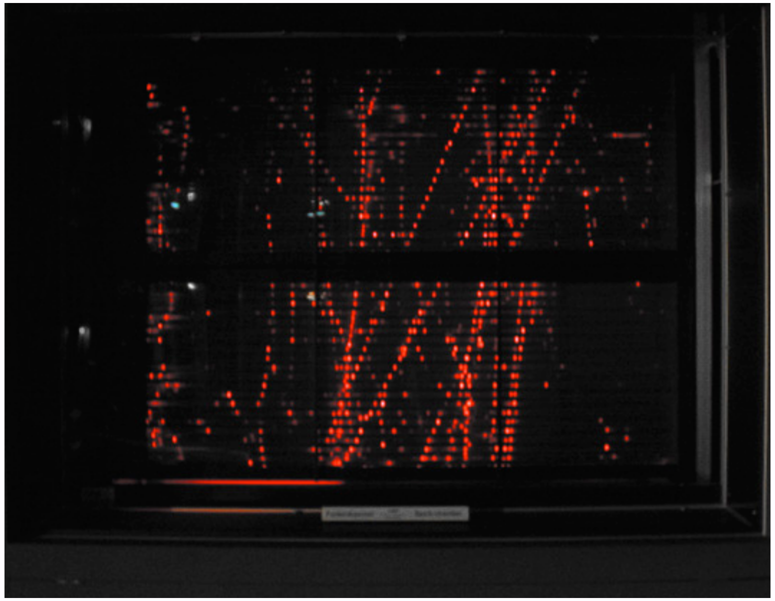


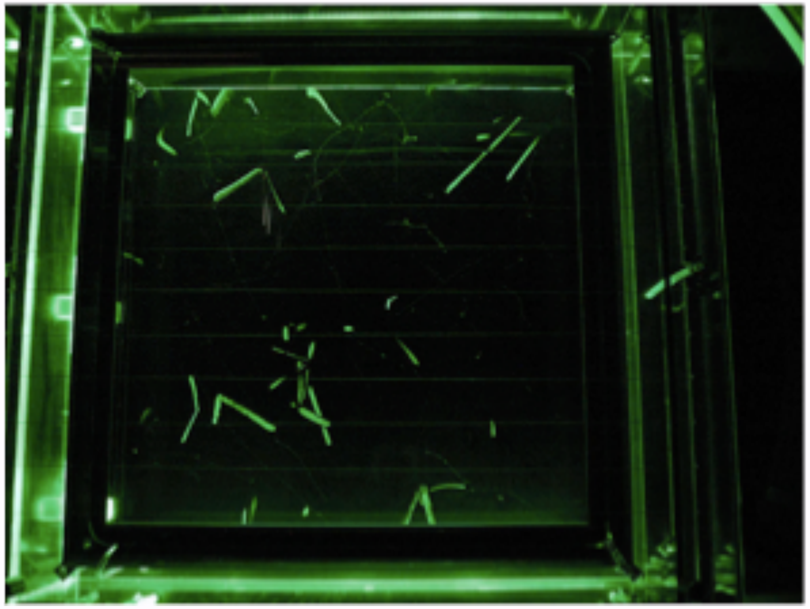


Which detection principles are used here ?

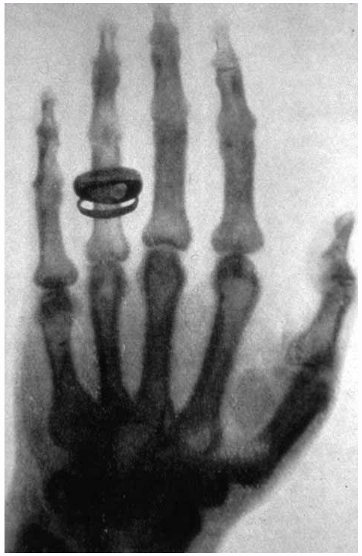








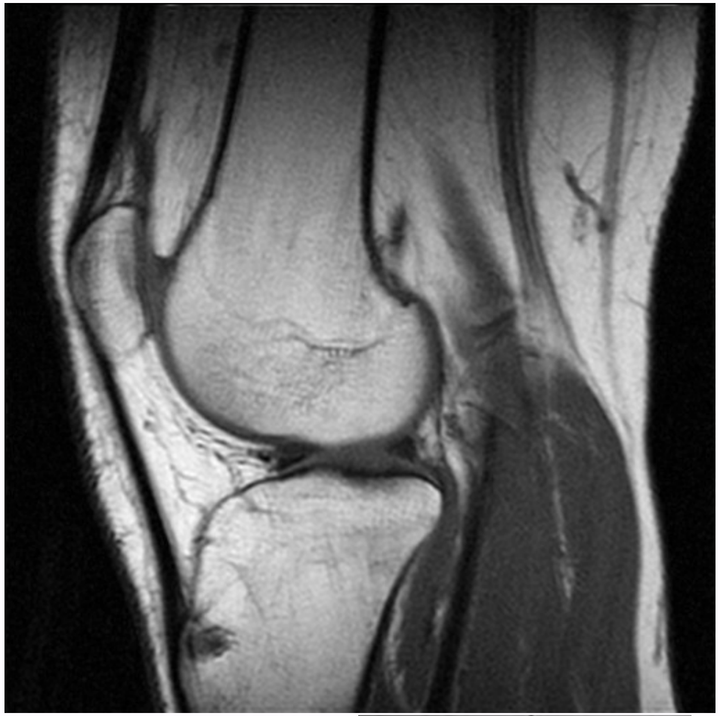
Detectors for medical imaging



W.C.Röntgen, 1896

MRT

(Wikipedia)



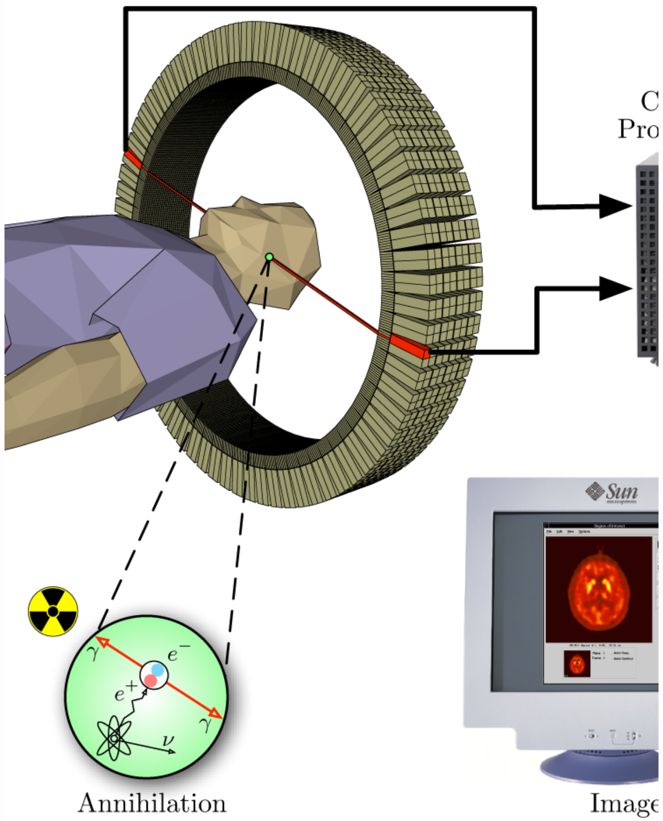
positron

emission

tomography

(PET)

(Wikipedia)

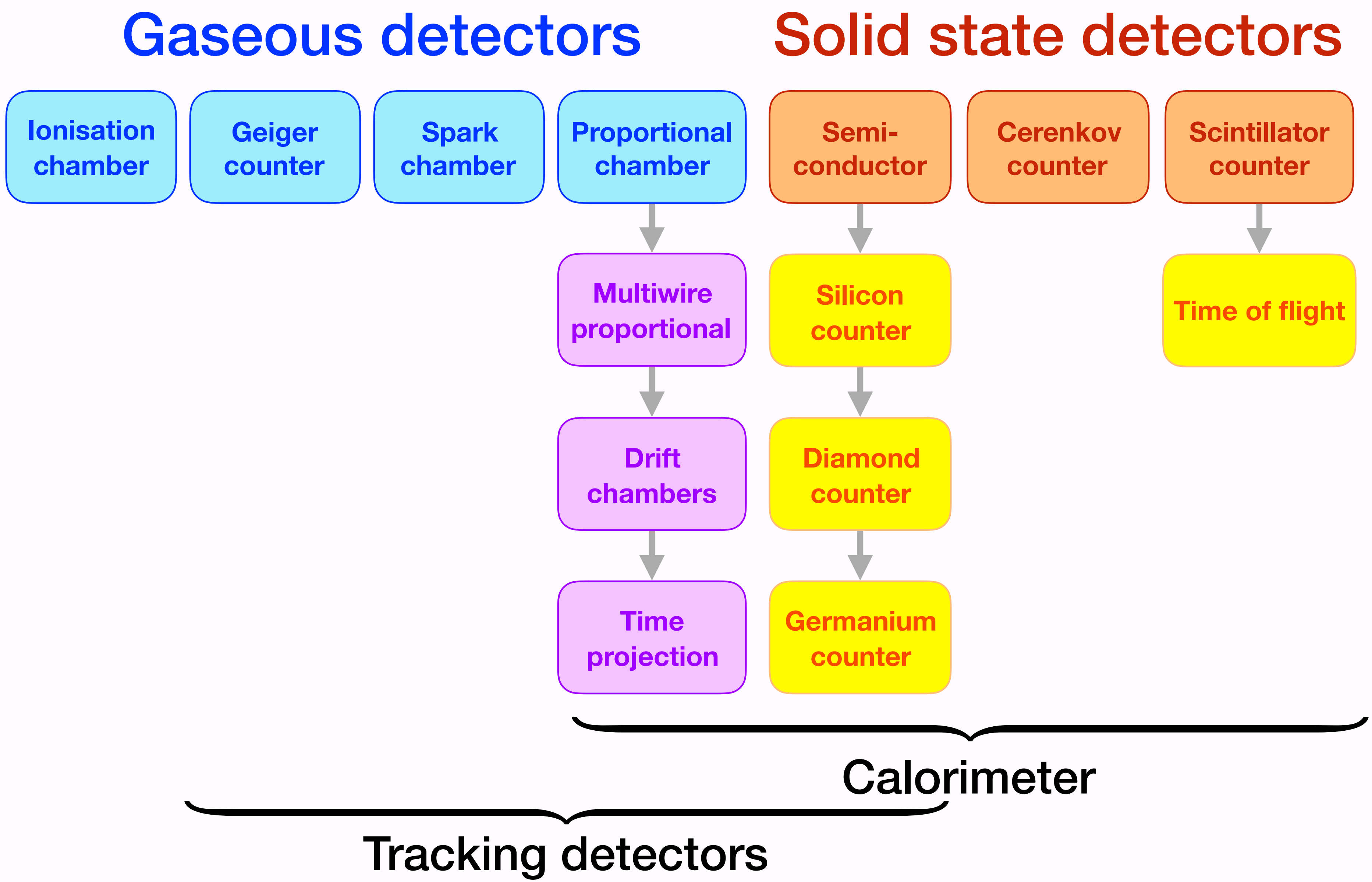


metal

detector

(Wikipedia)

Particle detector types and their usage



Detector requirements

Particle physics: understand interactions of particles at smallest possible distances and time scales

- **example: high transverse momentum particles at LHC**

  e.g. measured $P_x = 2\,\text{TeV}$ $\qquad \Delta P_x \cdot \Delta x = \hbar$

  ➜ resolved distance length scale: $\Delta x = 10^{-19}\,\text{m}$

  ➜ corresponding time scale: $\Delta t = 3.3 \cdot 10^{-28}\,\text{sec}$

- **example: decay of a Z^0, W:**

  width measured: $\Gamma \approx 2\,\text{GeV}$ $\qquad \tau \cdot \Gamma = \hbar$

  ➜ mean characteristic decay length:

$$c\,\tau = \frac{\hbar\,c}{\Gamma} = \frac{200\,\text{MeV fm}}{2\,\text{GeV}} = 0.1\,\text{fm}$$

  ➜ mean lifetime: $\tau = 3.3 \cdot 10^{-25}\,\text{sec}$

  ➜ mean decay length:

$$x = vt = \beta\gamma c\tau = \frac{P}{mc} c\tau$$

Detector requirements

Interesting physics:

- smaller than one proton radius
- times much smaller than e.g. atomic processes

Measurement process:

- feature size of electronic processors: 65 nm
- processing time for electric signals: ≈ 1 ns (GHz frequency)

➜ cannot directly „see“ processes at smallest distances

- weak processes, processes inside nucleons, free quarks, …

➜ instead: measure secondary decay products

- Z ➜ μμ, q ➜ Hadronen
- reconstruct Z, quarks, … from sum of 4-momenta of all decay products

➜ for each event, measure all individual quanta produced

- particle type/mass, energy, momentum/velocity, polarisation, (if possible)

measuring particle properties

particle type:

- two measurements from E, P, β ➜ mass (provided resolution is good enough)

$$E^2 = m^2c^4 + P^2c^2 \quad E = \gamma mc^2 \quad P = \gamma\beta mc$$

- characteristic interaction with detector material:

  electromagnetic shower, no hadronic interactions

momentum / charge:

- curvature in magnetic field ➜ tracking detectors

energy:

- range in material
- total energy deposited in material ➜ calorimeter

velocity

- time of flight between two measurements
- ionisation, velocity threshold for cherenkov effect

spin: angular distribution of decay products

Physics of particle detectors

stable particles: $e^\pm$, $\mu^\pm$, $\pi^\pm$, $K^\pm$, $p^\pm$, K^0, n, γ

1) heavy charged particles ($m > m_e$)
2) electron / positron
3) photons
4) neutrons

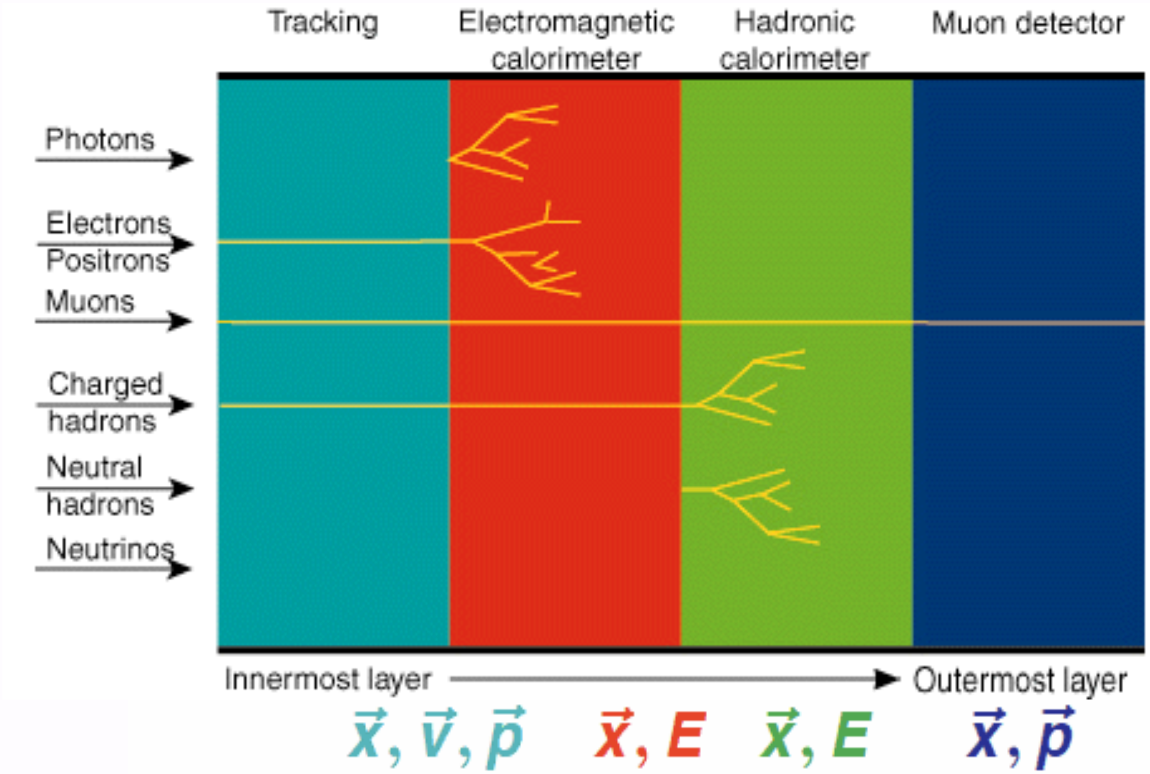
Jets:

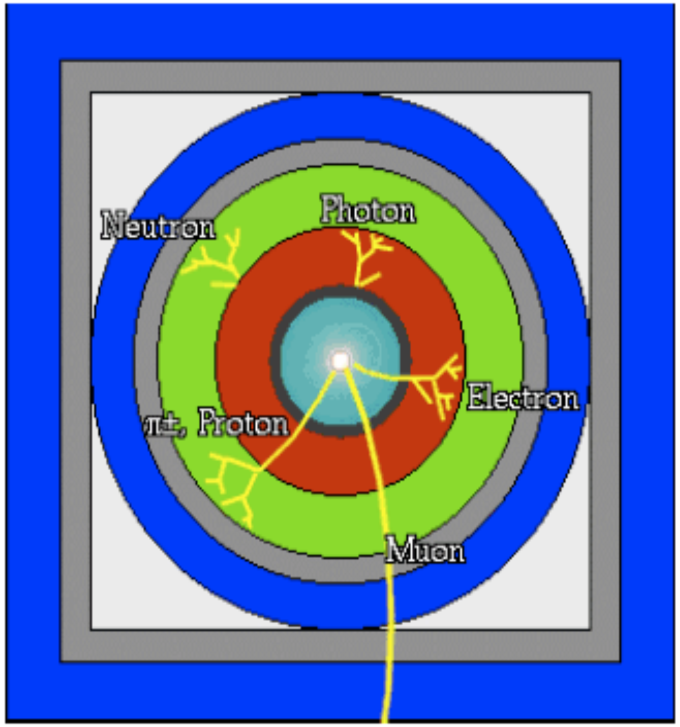
- collimated bunch of (mainly heavy charged) particles from the hadronization of a quark

Neutrinos:

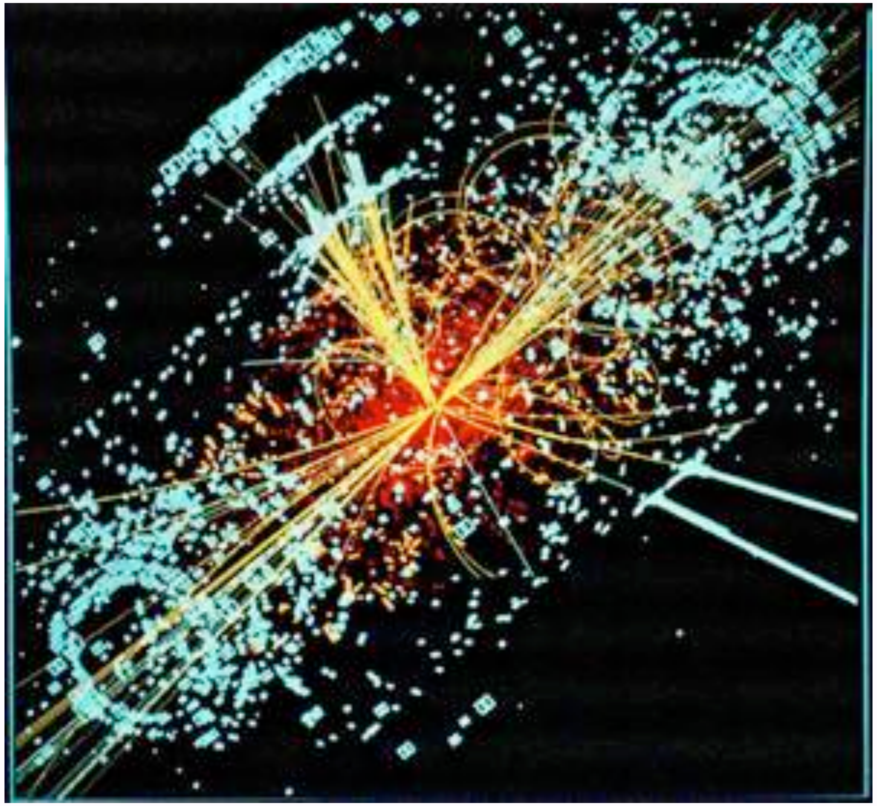
- react very weakly with matter
- Cross section for $\nu_e + n \rightarrow e^- + p$ is around 10^{-43} cm^{-2}
- interaction probability in 1m iron: 10-17

Particle Physics Detectors



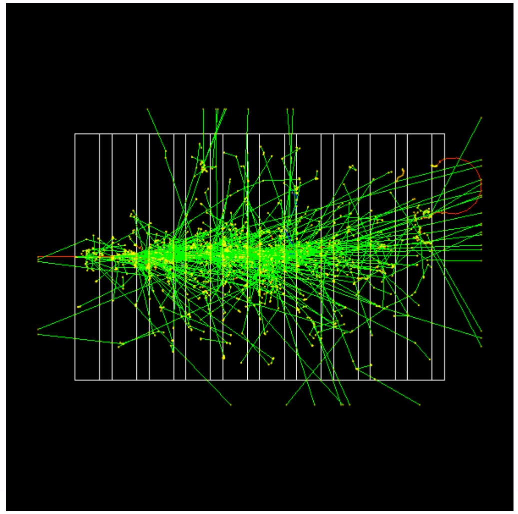


Monte Carlo simulation

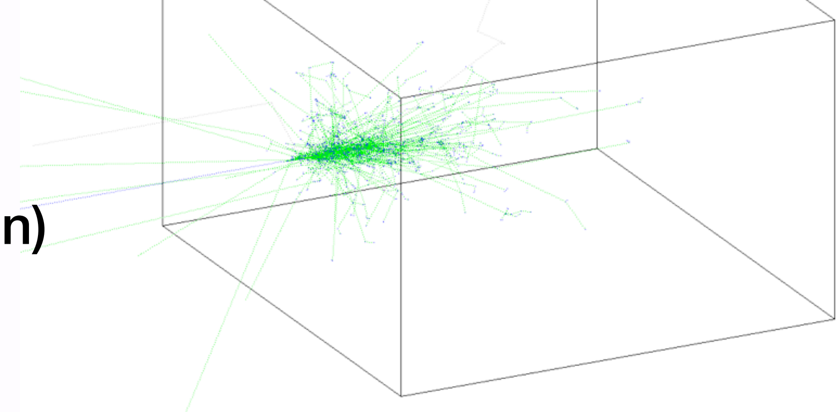


1 GeV pion interaction

in sandwich calorimeter



shower simulation of a 2 GeV electron
Pb block



MC simulation: powerful tool

- detector optimization
- simulation of physics (data/MC comparison)
- pattern recognition hits ➜ particles ➜ jets