



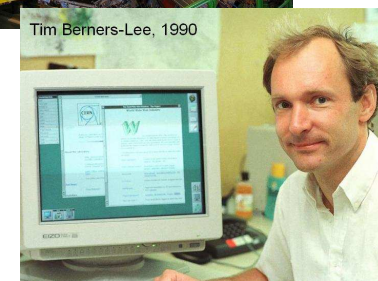
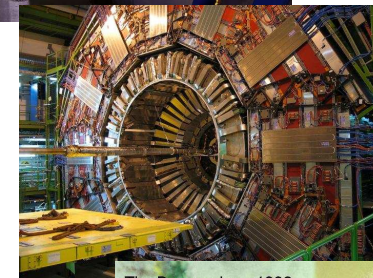
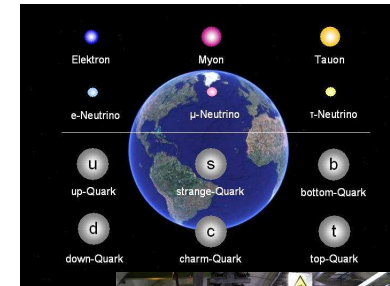
# Der Large Hadron Collider (LHC)

...ein Rundgang durch das größte Experiment  
der Welt

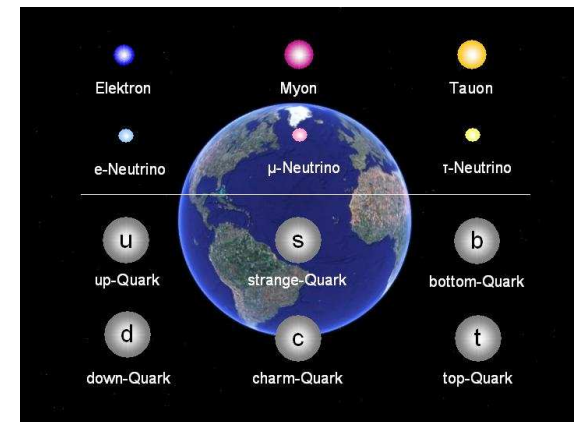
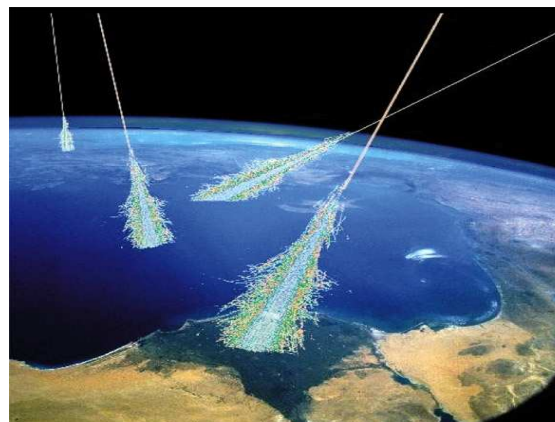
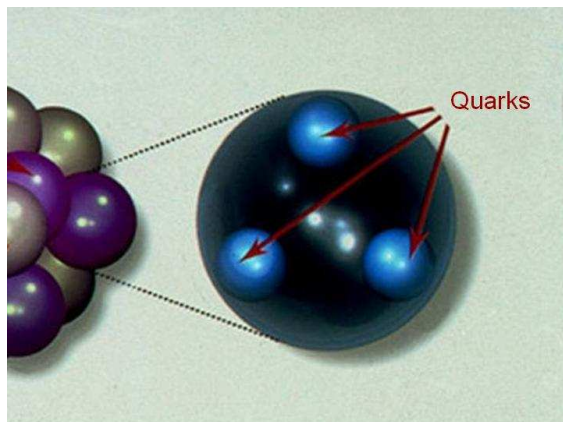
# Übersicht



- Die Welt der Elementarteilchen
- Teilchenbeschleuniger
- Teilchendetektoren
- Technologietransfer



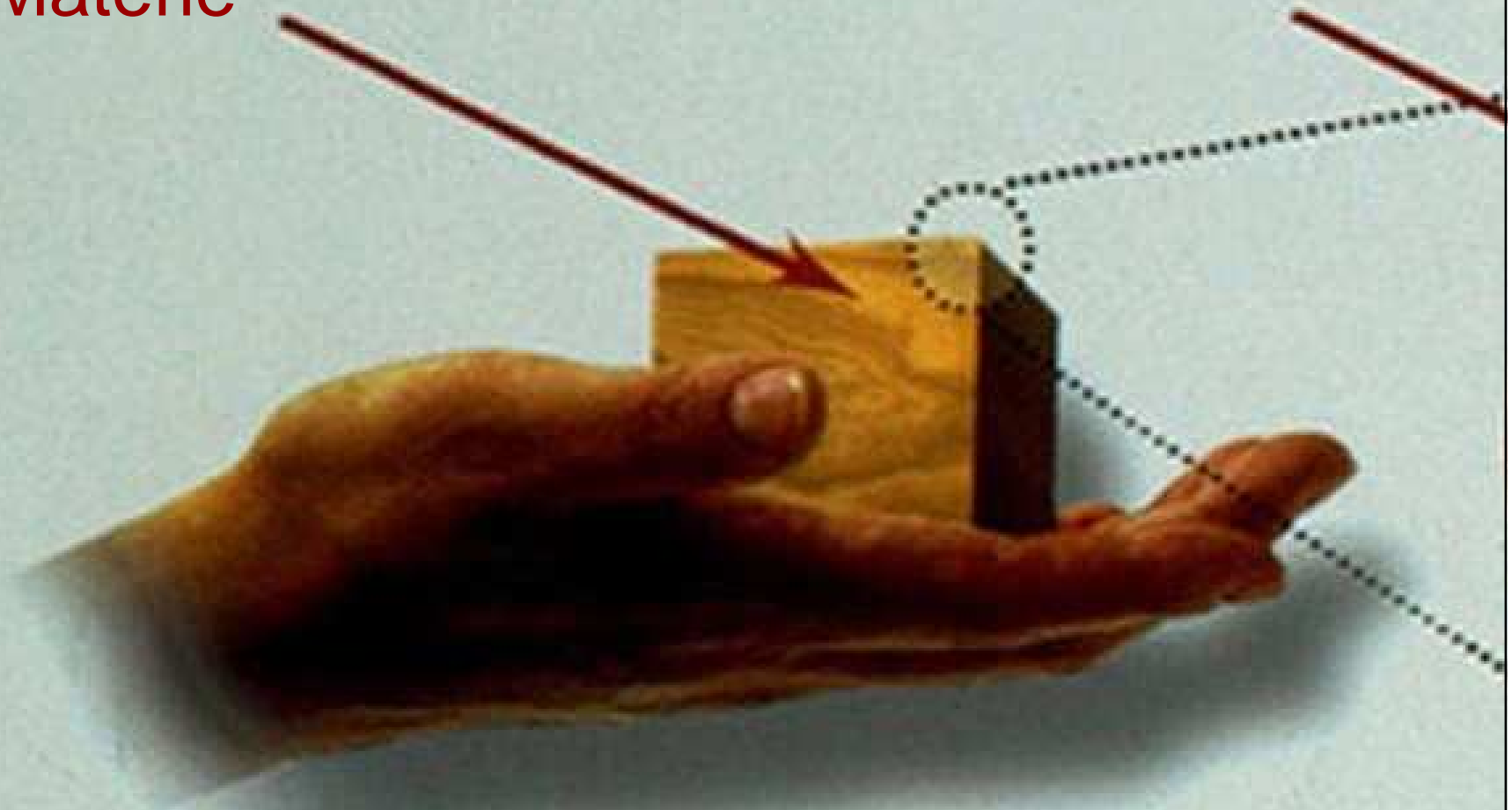
# Die Welt der Elementarteilchen



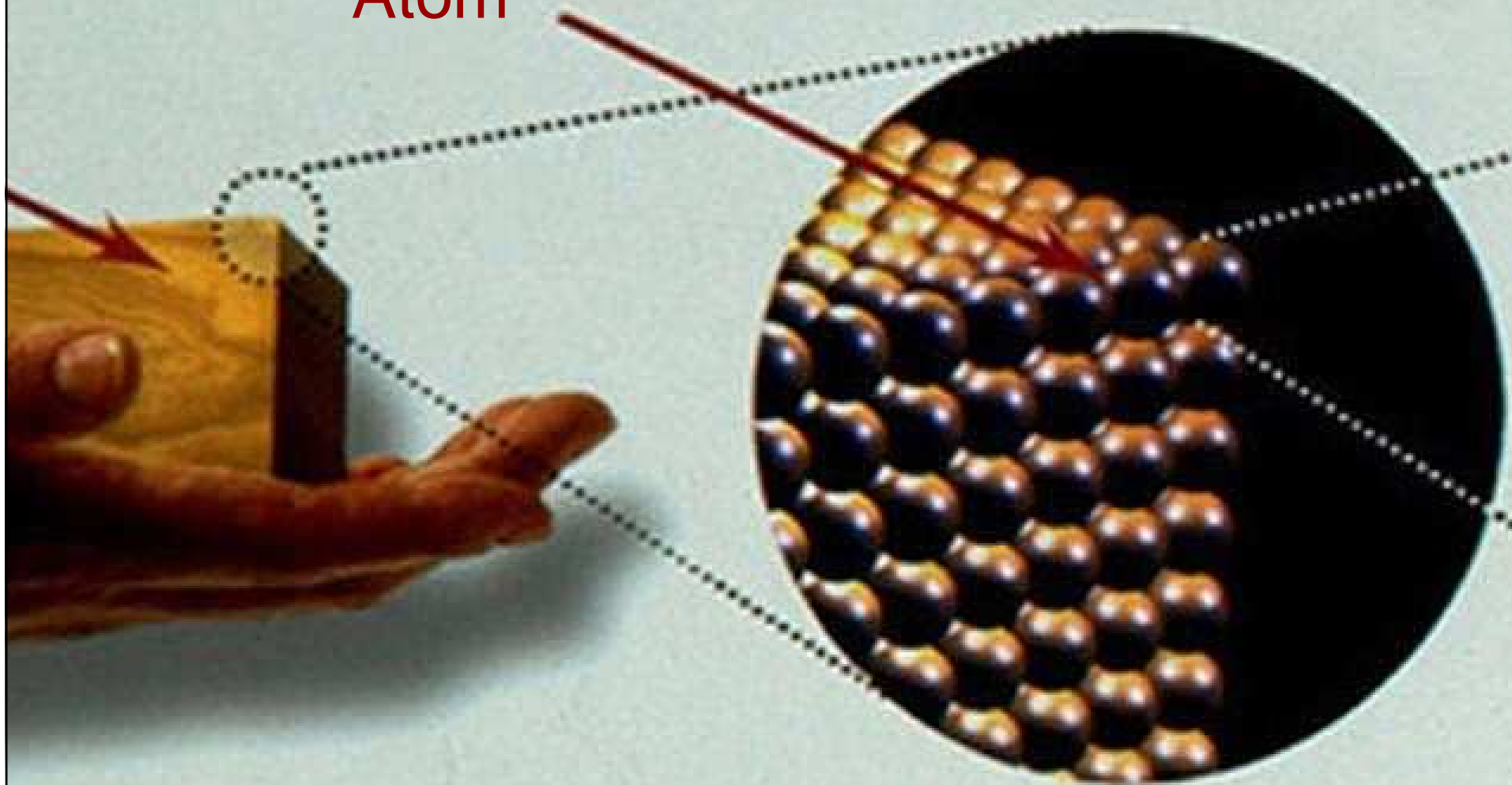
# Grundfrage der Teilchenphysik



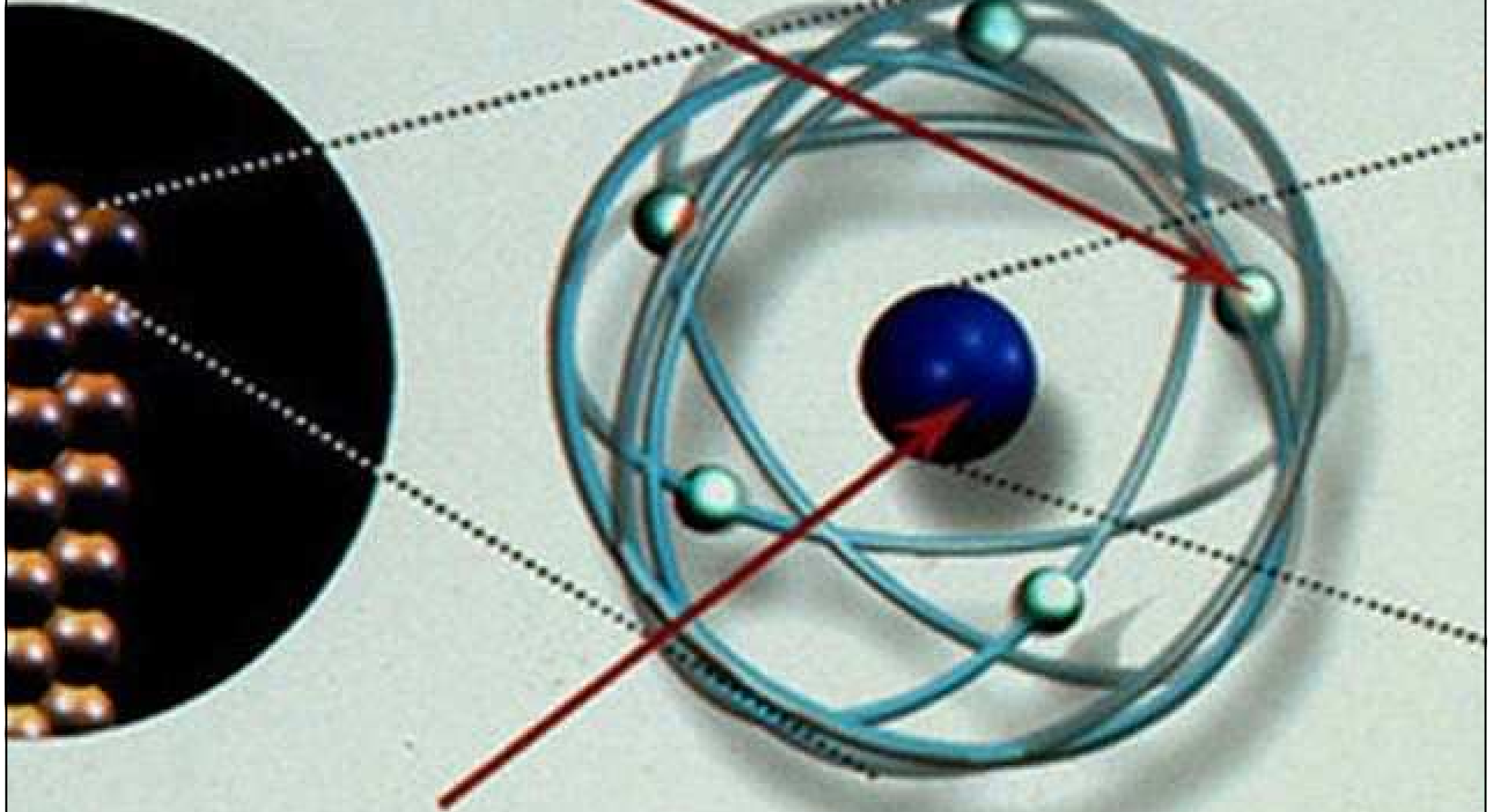
Materie



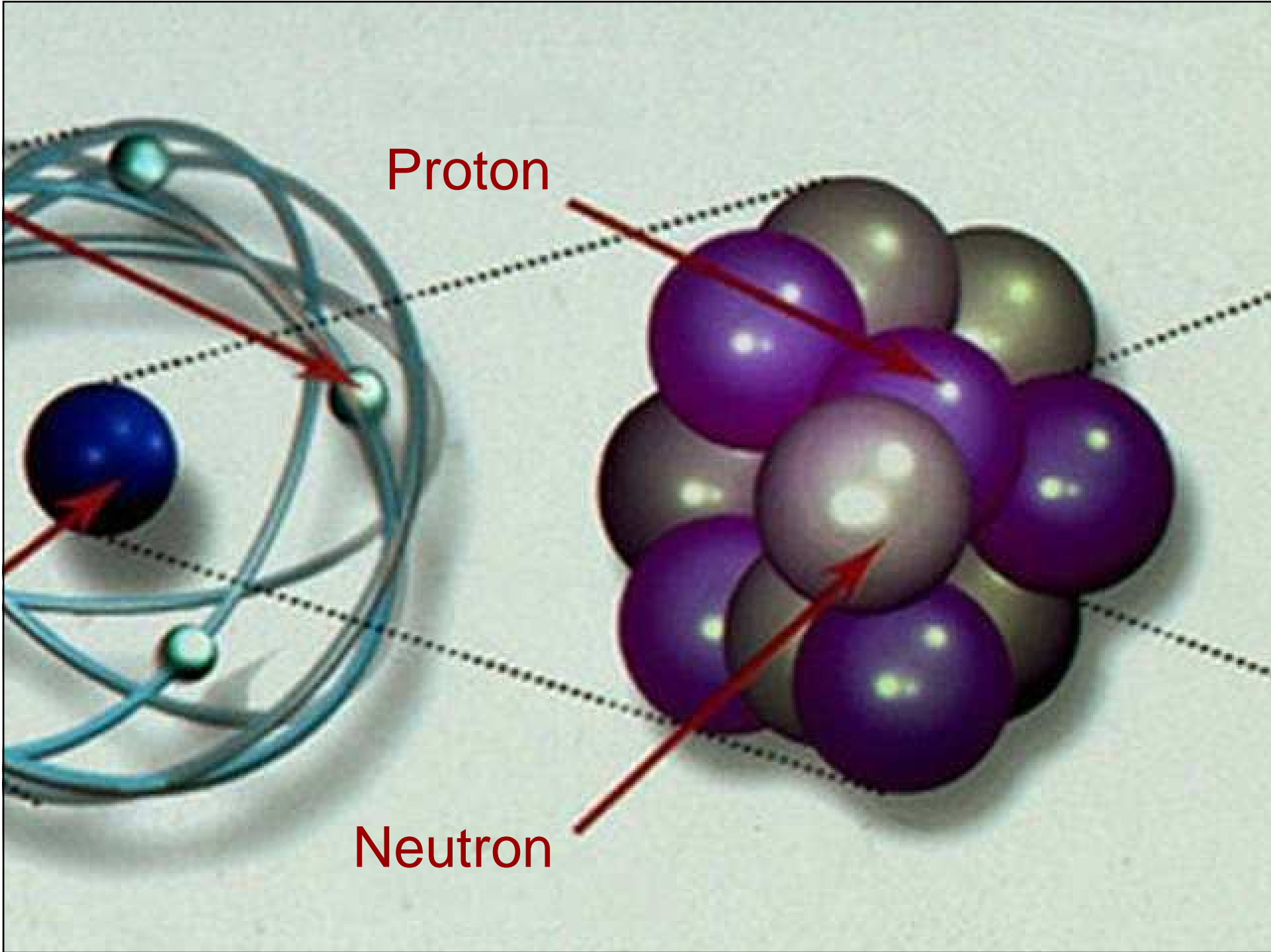
Atom



Elektron

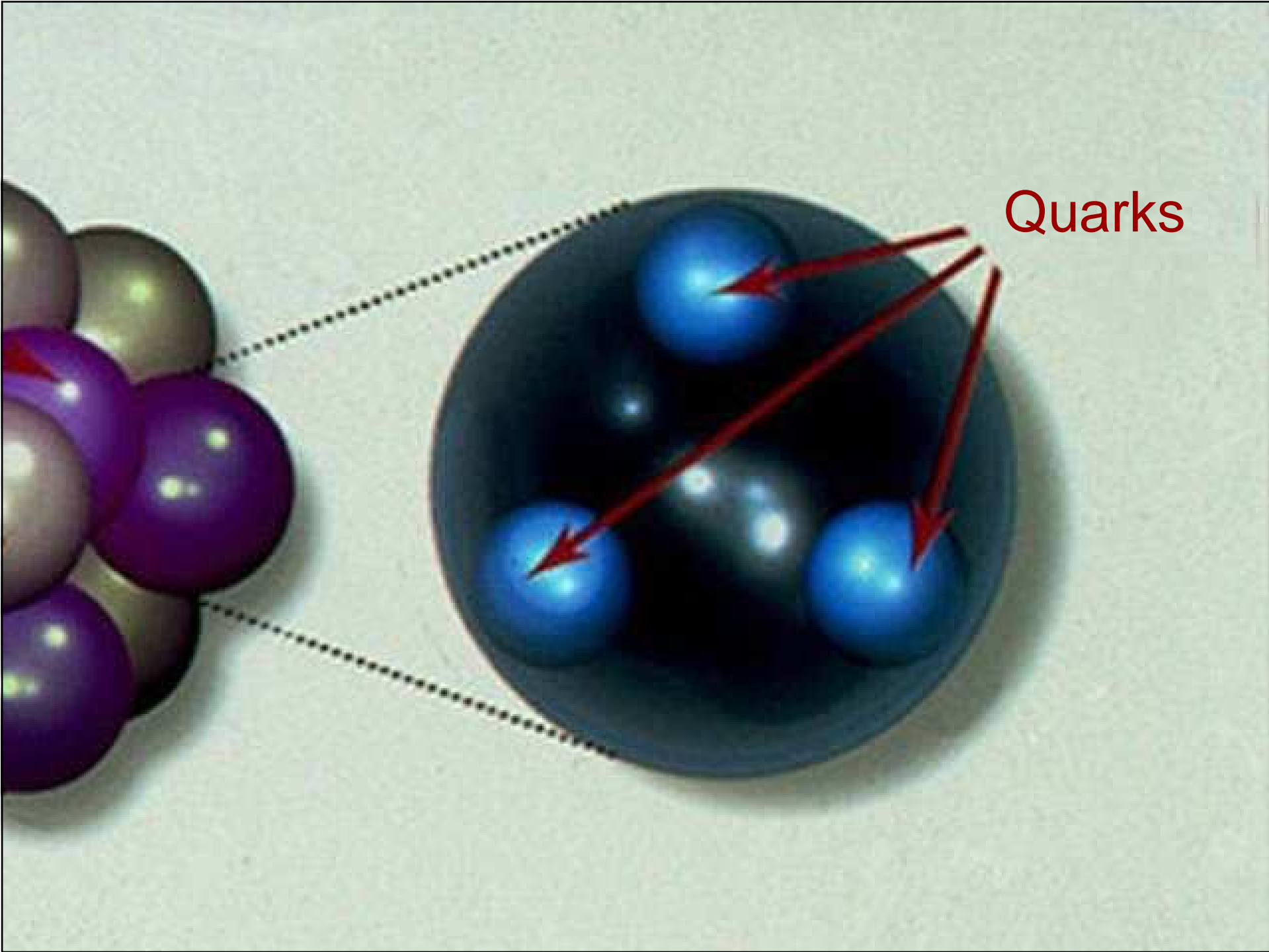


Atomkern

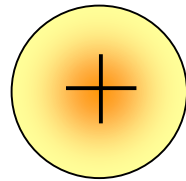




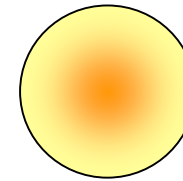
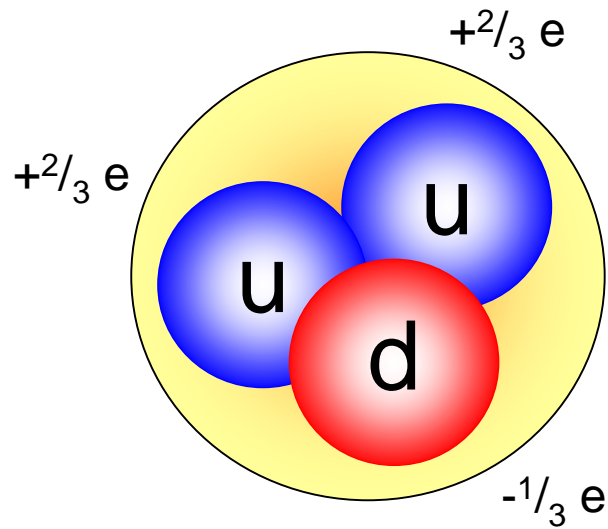
Quarks



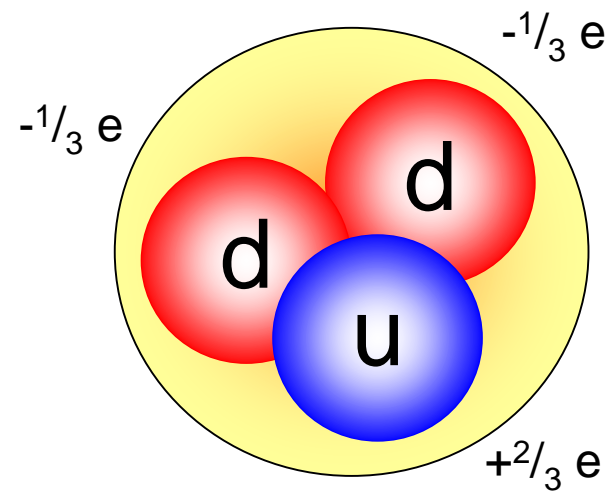
# Quarks



Proton



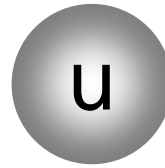
Neutron



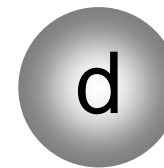
# Elementarteilchen



Elektron



up-Quark

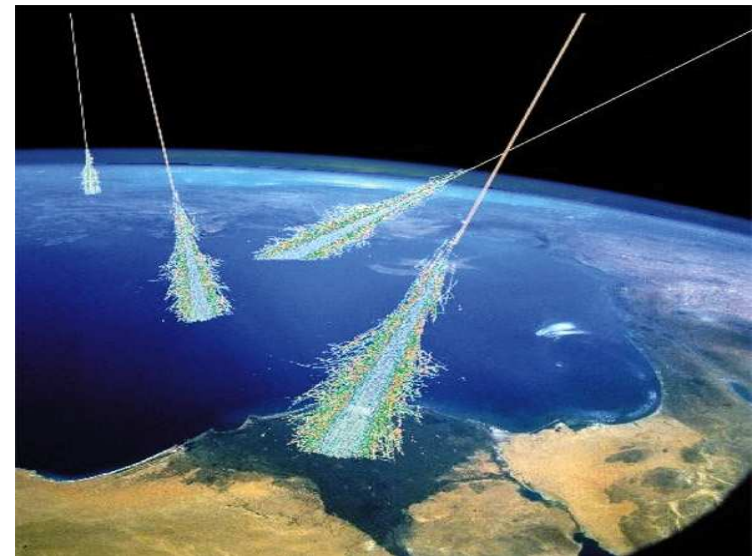


down-Quark

# Kosmische Strahlung



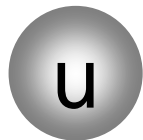
- Entdeckung weiterer Elementarteilchen



# Elementarteilchen



Elektron



up-Quark



down-Quark

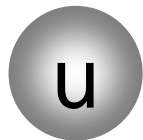
# Elementarteilchen



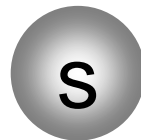
Elektron



Myon



up-Quark



strange-Quark

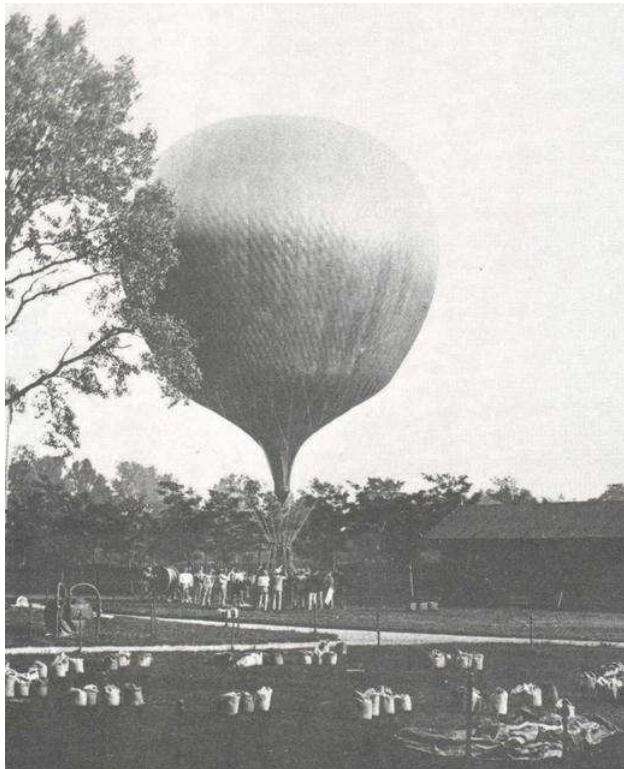


down-Quark

# Kosmische Strahlung



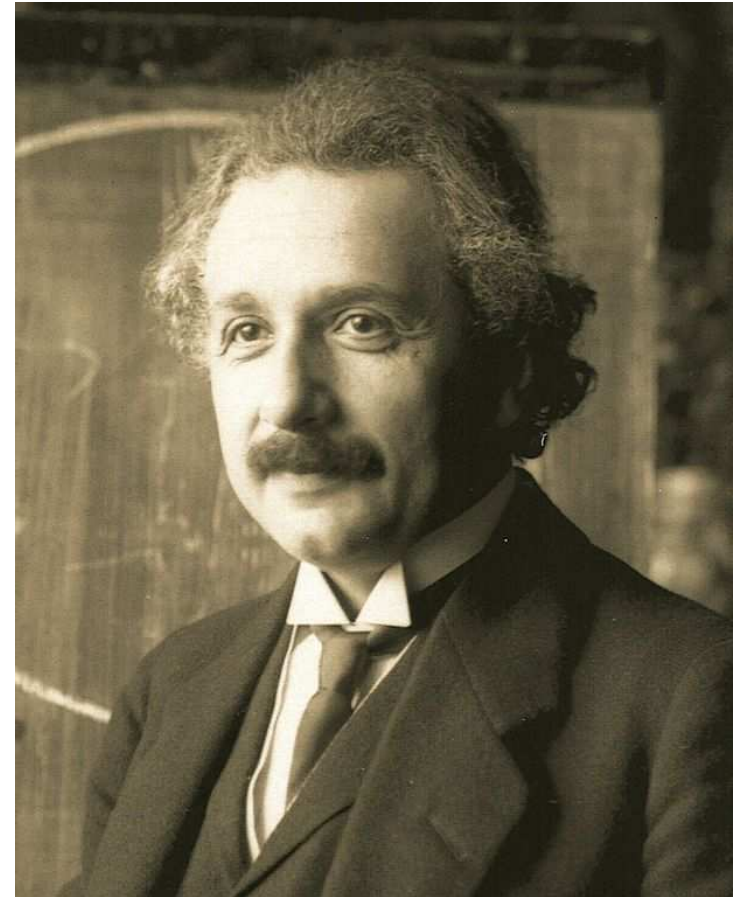
- Beobachtung in Ballons und auf Bergen → mühsam!



# Frage



- Wie lautet Einsteins berühmte Gleichung?



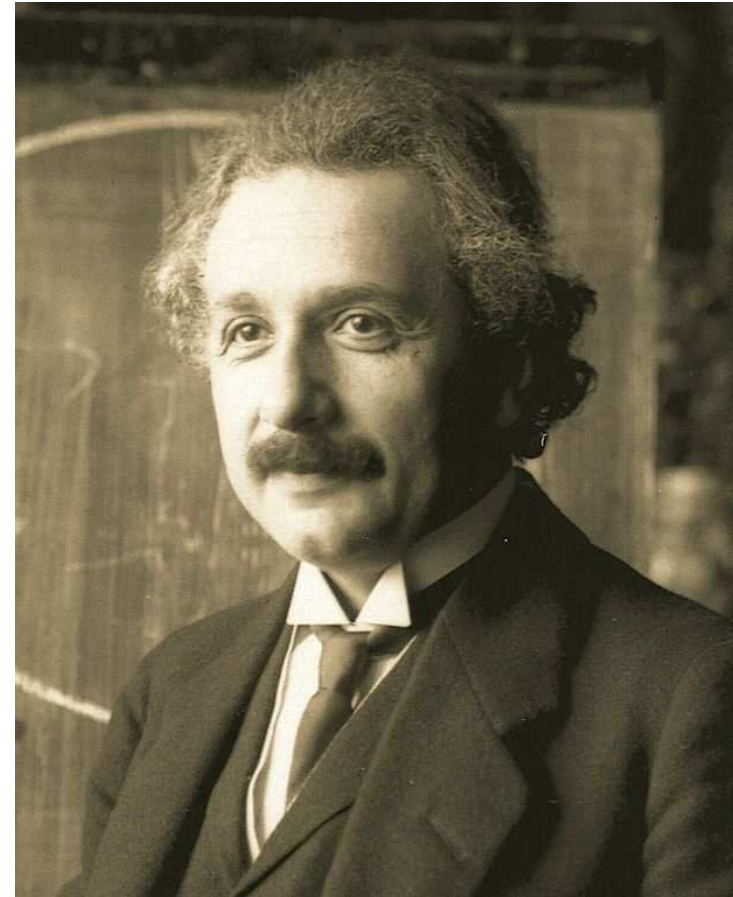


# Frage



- Wie lautet Einsteins berühmte Gleichung?

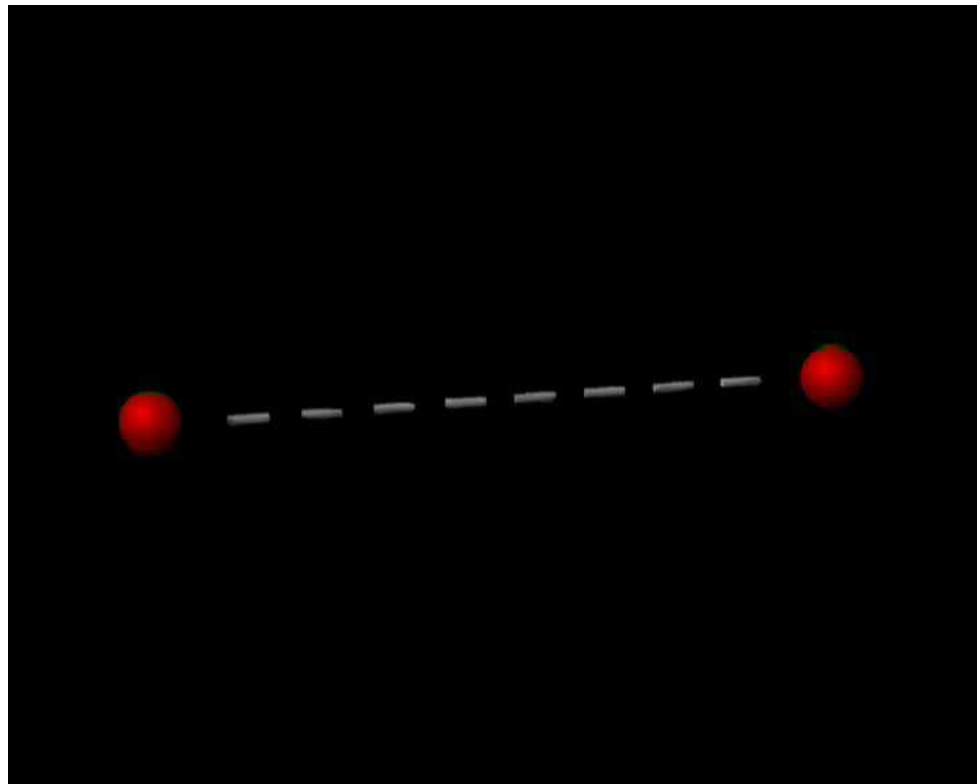
$$E=mc^2$$



# Teilchenbeschleuniger



- Künstliche Erzeugung neuer Teilchen bei Teilchenkollisionen,  $E=m \cdot c^2$



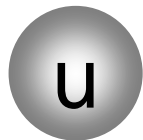
# Elementarteilchen



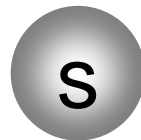
Elektron



Myon



up-Quark



strange-Quark



down-Quark

# Elementarteilchen



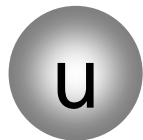
Elektron



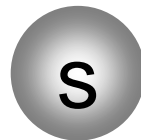
Myon



Tauon



up-Quark



strange-Quark



down-Quark

# Elementarteilchen



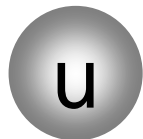
Elektron



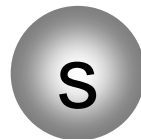
Myon



Tauon



up-Quark



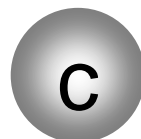
strange-Quark



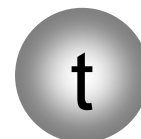
bottom-Quark



down-Quark



charm-Quark



top-Quark

# Elementarteilchen



Elektron



Myon



Tauon



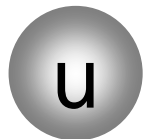
e-Neutrino



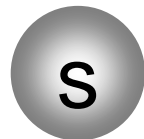
$\mu$ -Neutrino



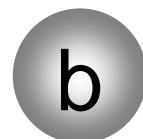
$\tau$ -Neutrino



up-Quark



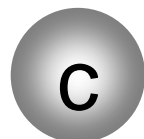
strange-Quark



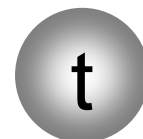
bottom-Quark



down-Quark



charm-Quark



top-Quark

# Offene Fragen



Elektron



Myon



Tauon



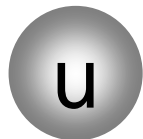
e-Neutrino



$\mu$ -Neutrino



$\tau$ -Neutrino



up-Quark



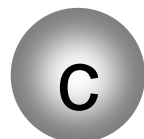
strange-Quark



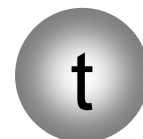
bottom-Quark



down-Quark



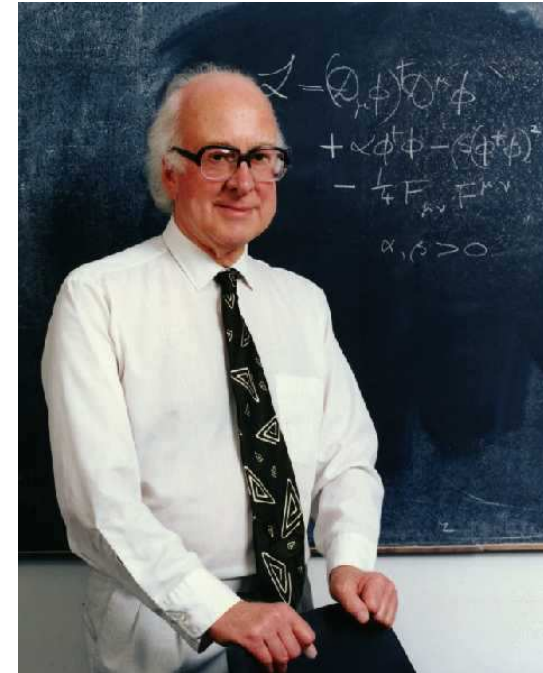
charm-Quark



top-Quark

**Masse der  
Elementarteilchen?**

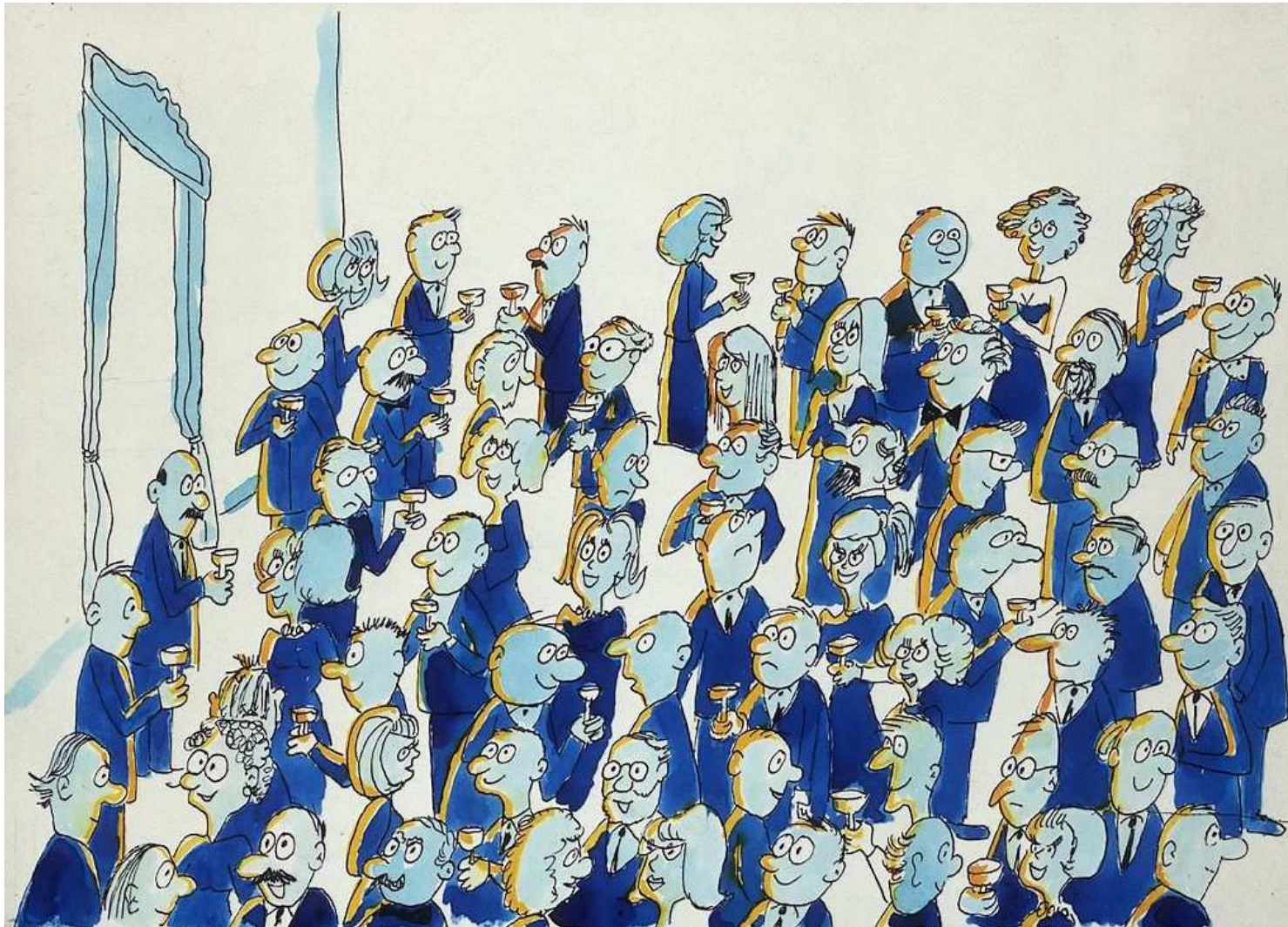
# Higgs-Feld



Peter Higgs



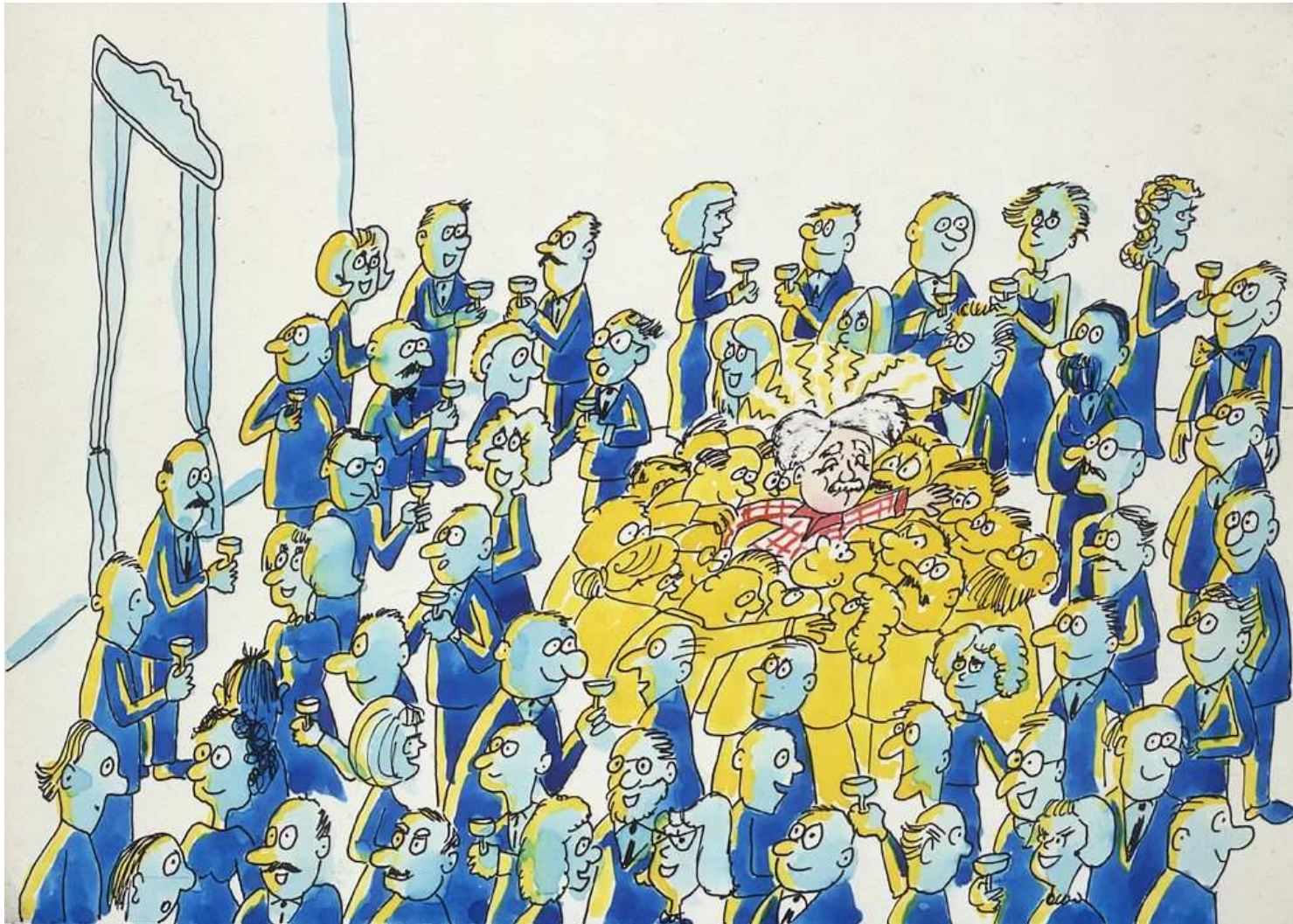
# Higgs-Feld



# Higgs-Feld



# Higgs-Feld



# Higgs-Teilchen



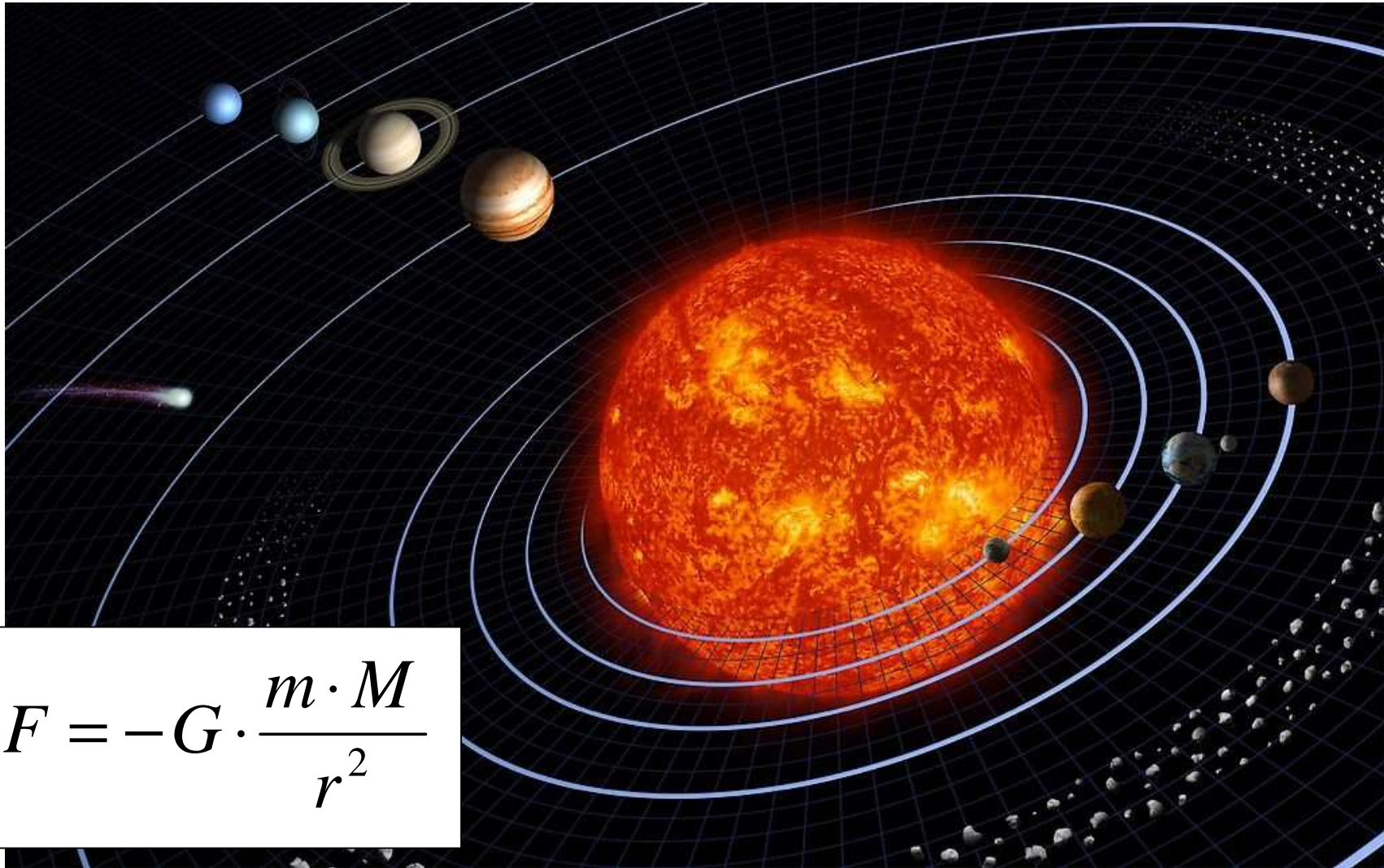
# Higgs-Teilchen



# Higgs-Teilchen

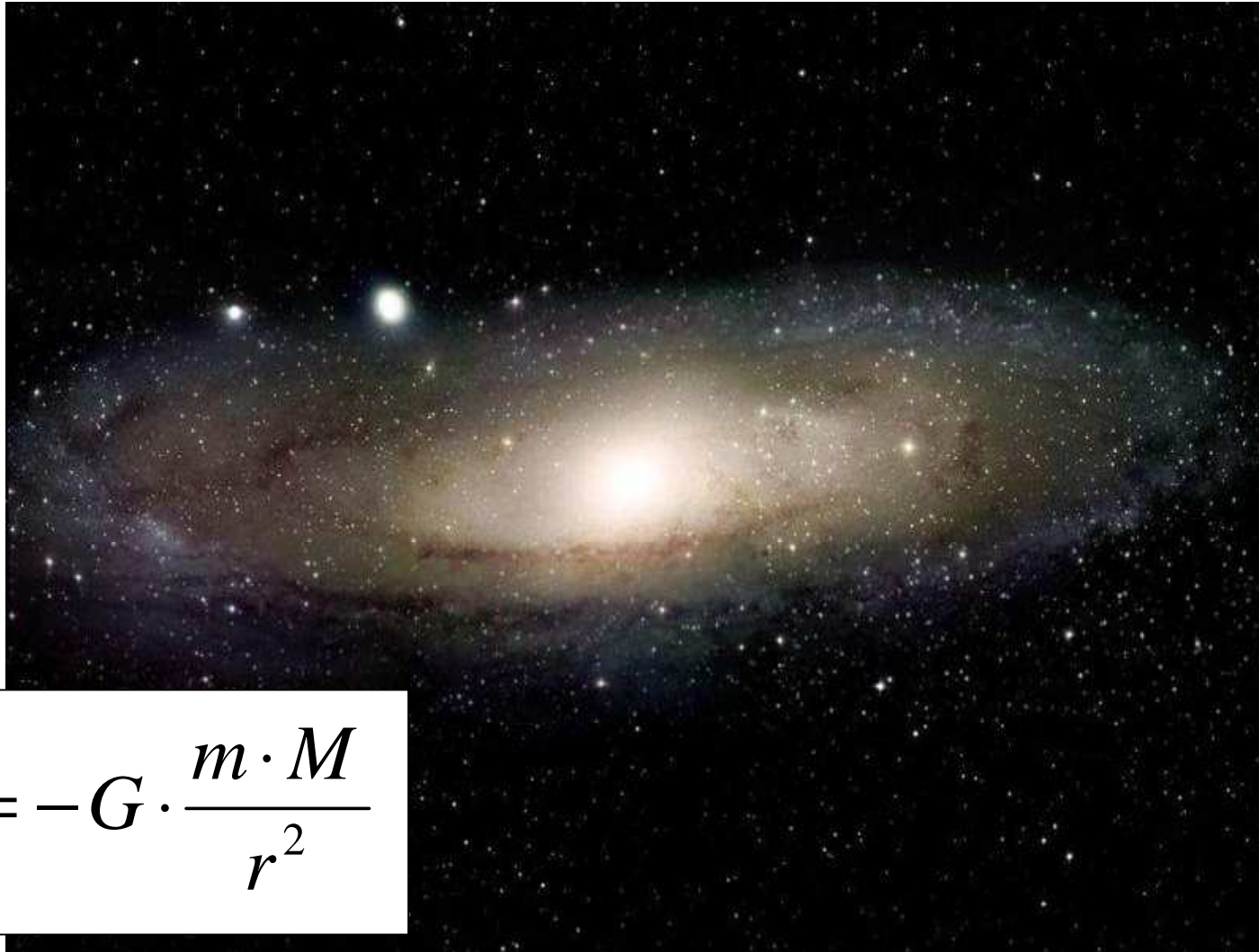


# Dunkle Materie



$$F = -G \cdot \frac{m \cdot M}{r^2}$$

# Dunkle Materie



$$F = -G \cdot \frac{m \cdot M}{r^2}$$



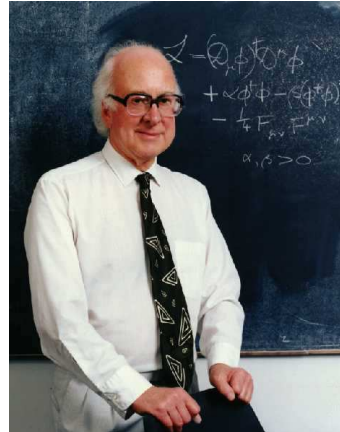
# Dunkle Materie



# Offene Fragen



- Higgs-Teilchen



- Dunkle Materie

- ...

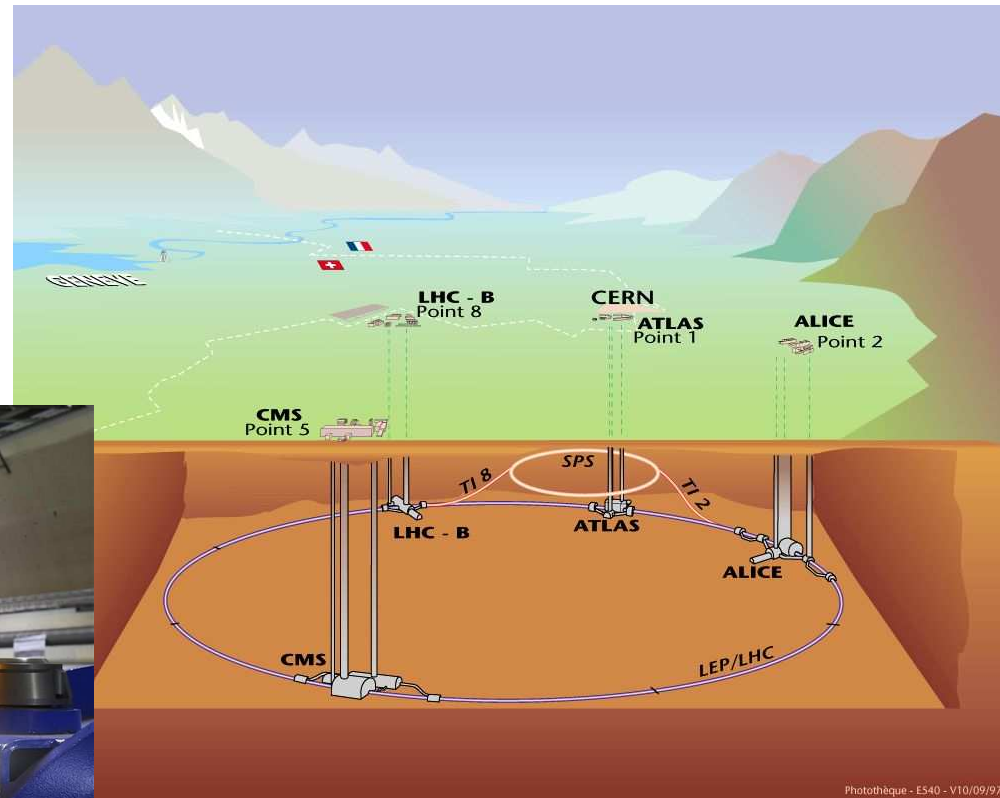




# Der Large Hadron Collider am CERN



- Länge: 27 km
- 100 m unter der Erde
- 4 Teilchendetektoren



Photothèque - ES40 - V10/09/97

# Teilchenbeschleuniger



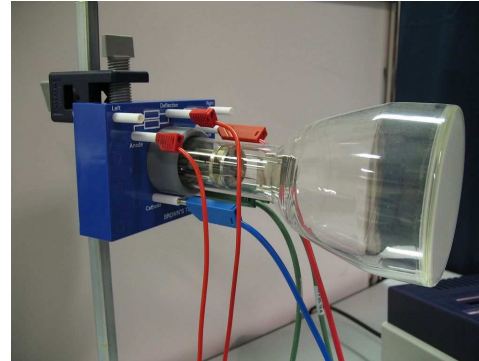
# Teilchenbeschleuniger in der Schule



# Teilchenbeschleuniger in der Schule



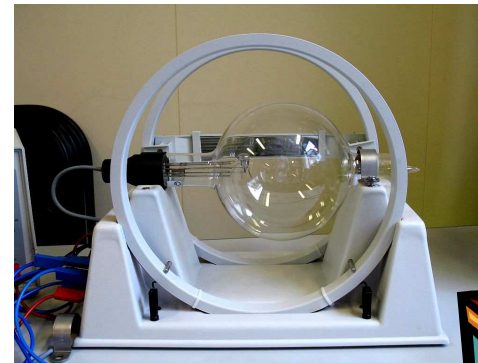
- Braun'sche Röhre



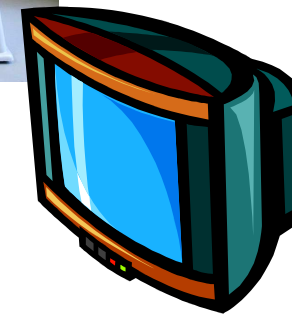
- Oszilloskop



- Fadenstrahlröhre



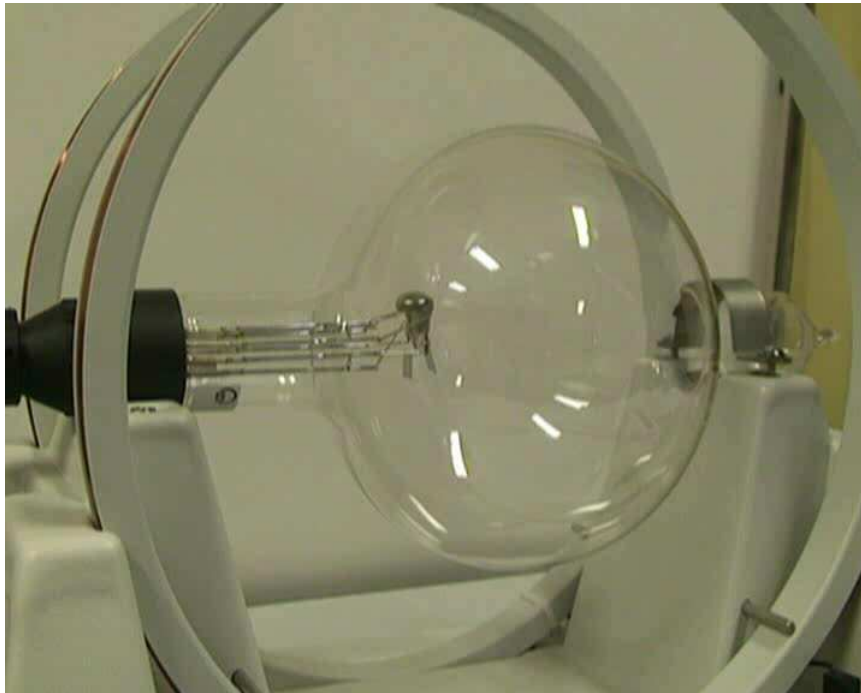
- TV-Gerät



# Fragen

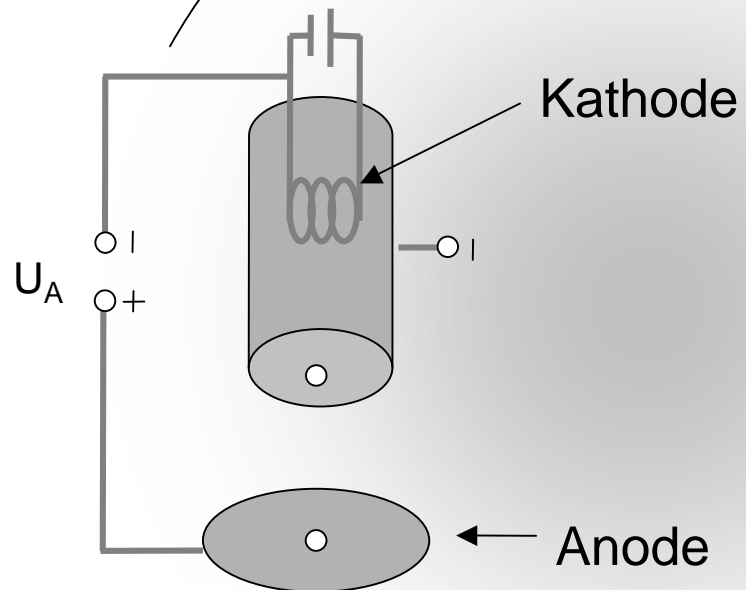


- Wie erzeugt man freie Elektronen?
- Wie beschleunigt man geladene Teilchen?

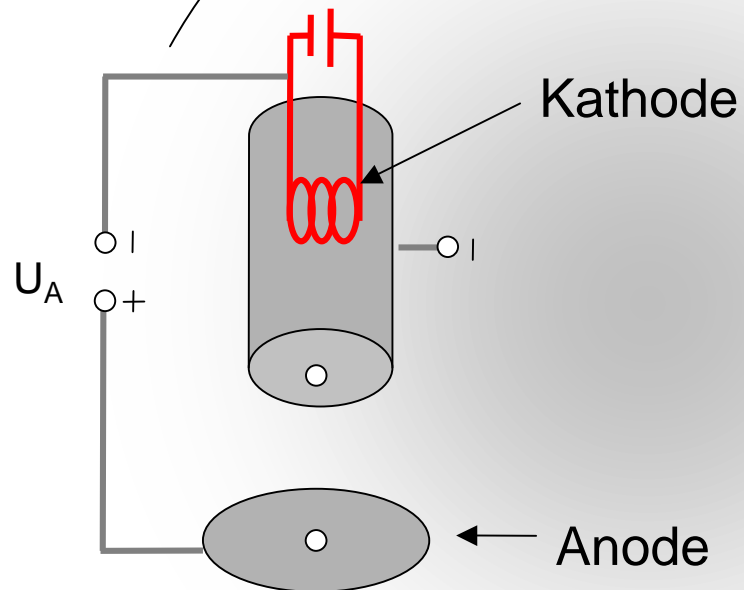




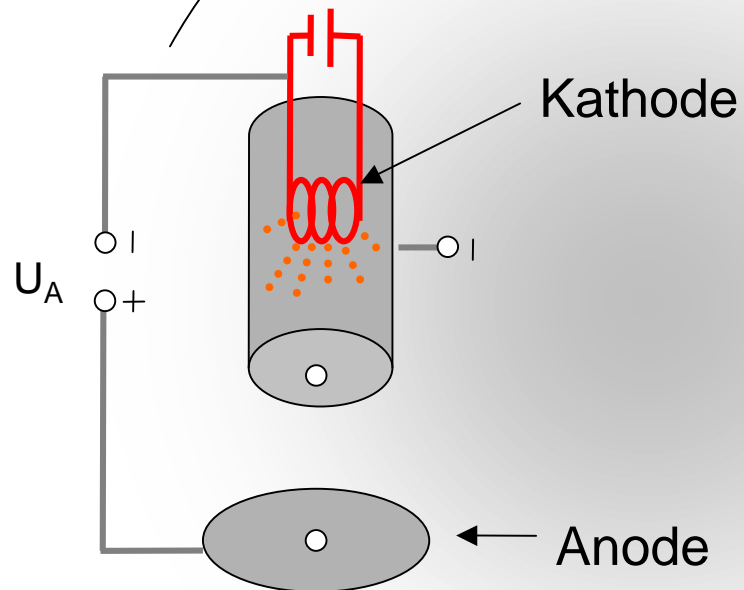
# Fadenstrahlröhre



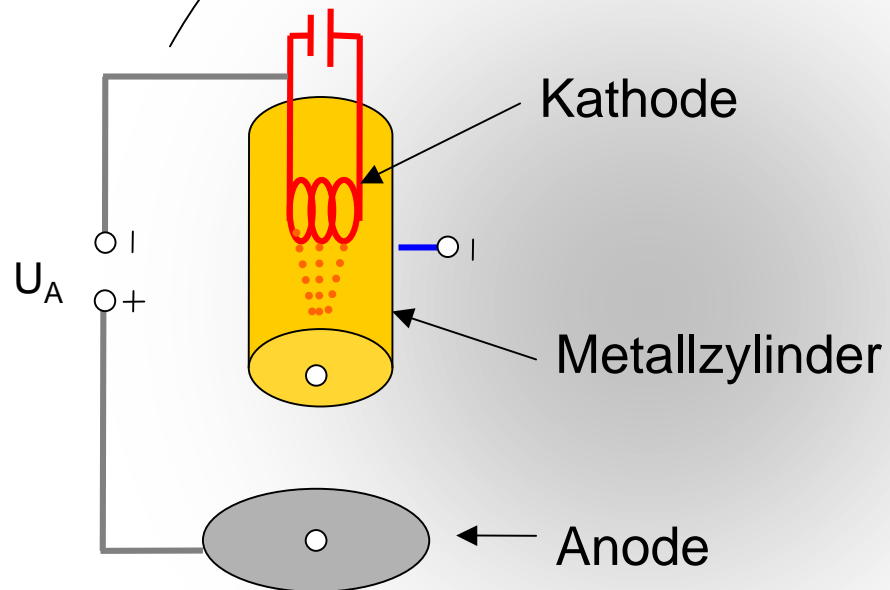
# Fadenstrahlröhre



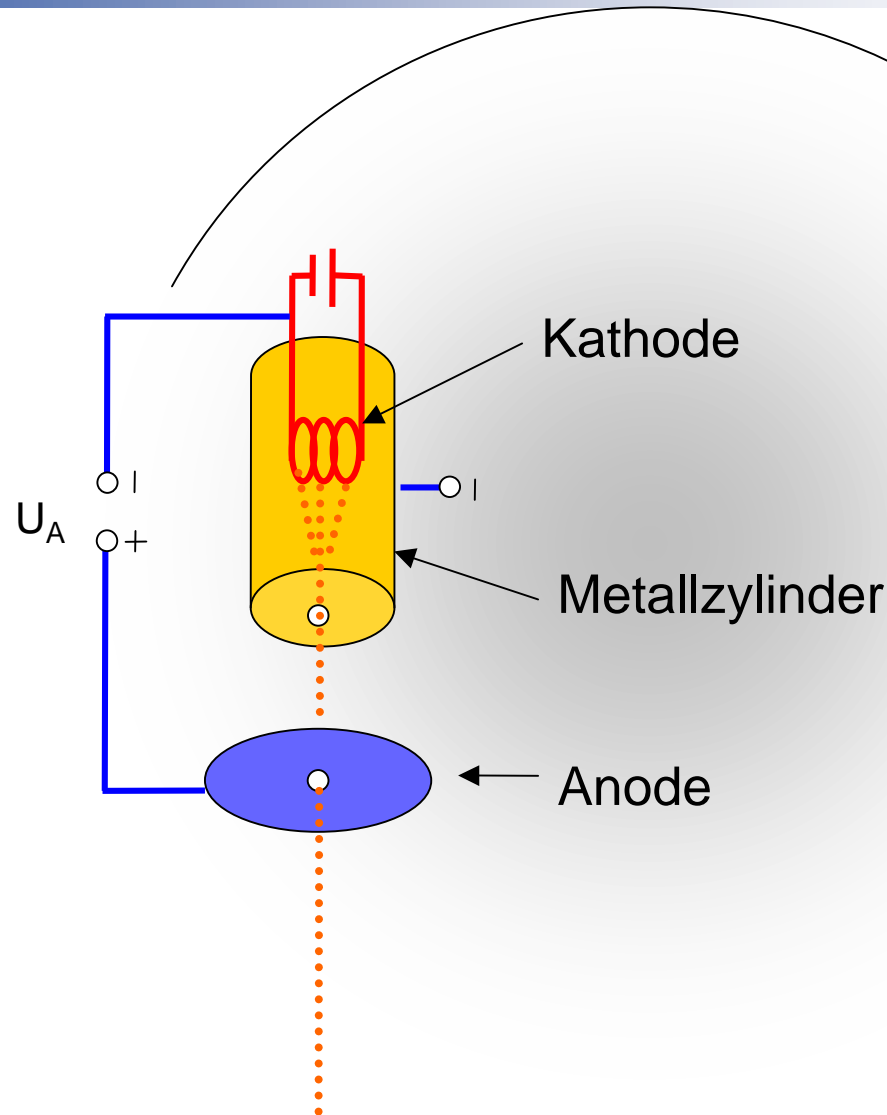
# Fadenstrahlröhre



# Fadenstrahlröhre



# Fadenstrahlröhre

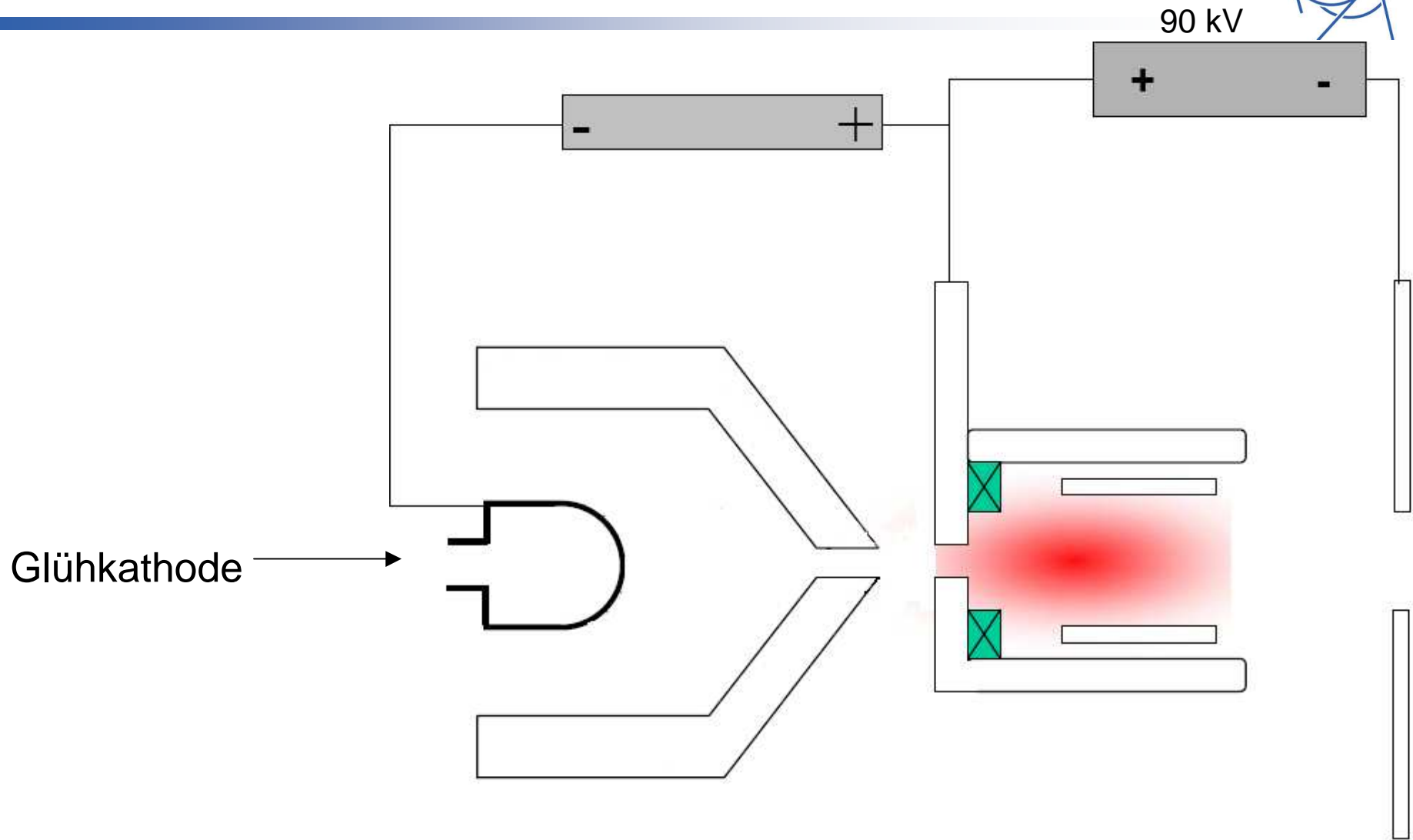




# CERN-Protonenquelle

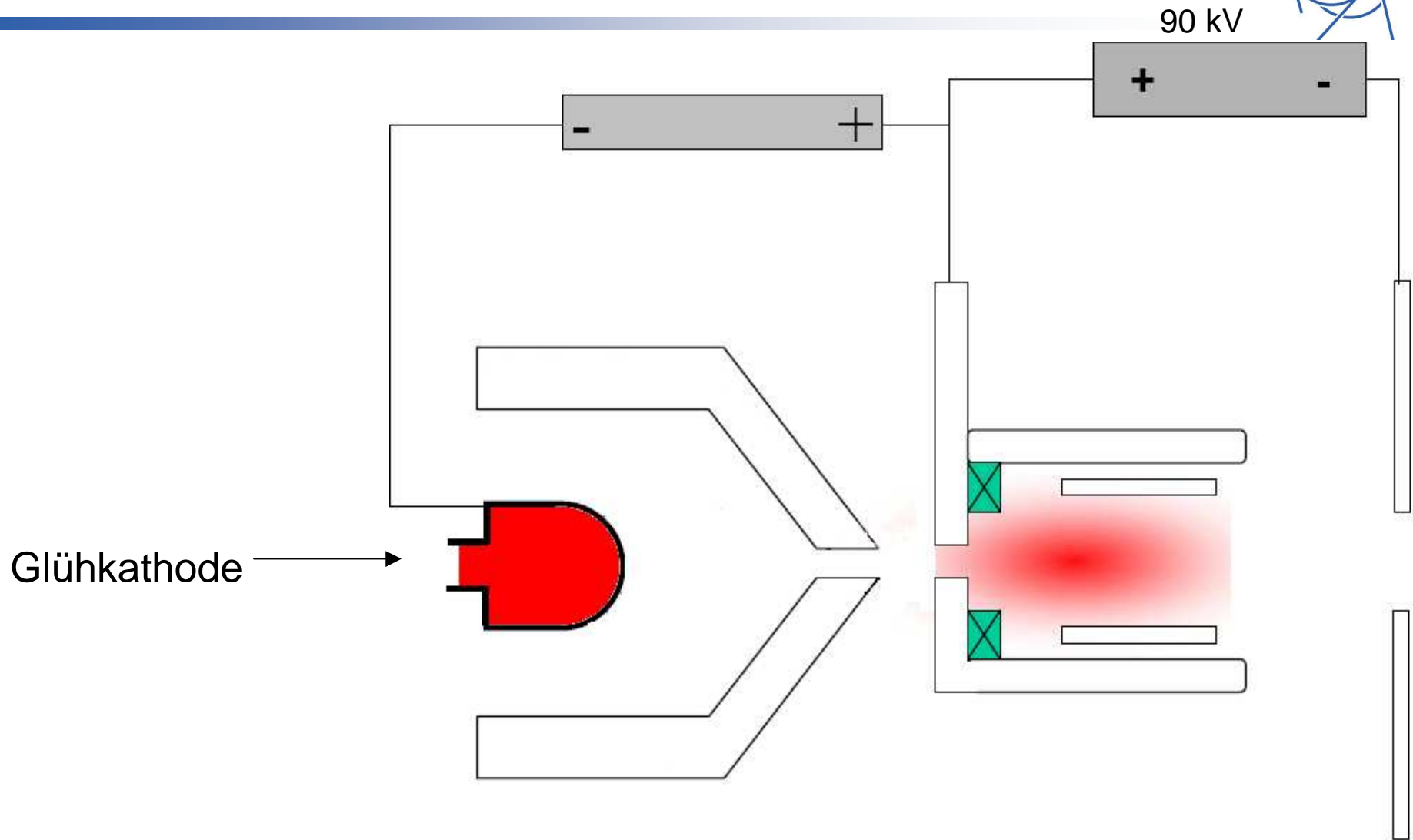


# CERN-Protonenquelle





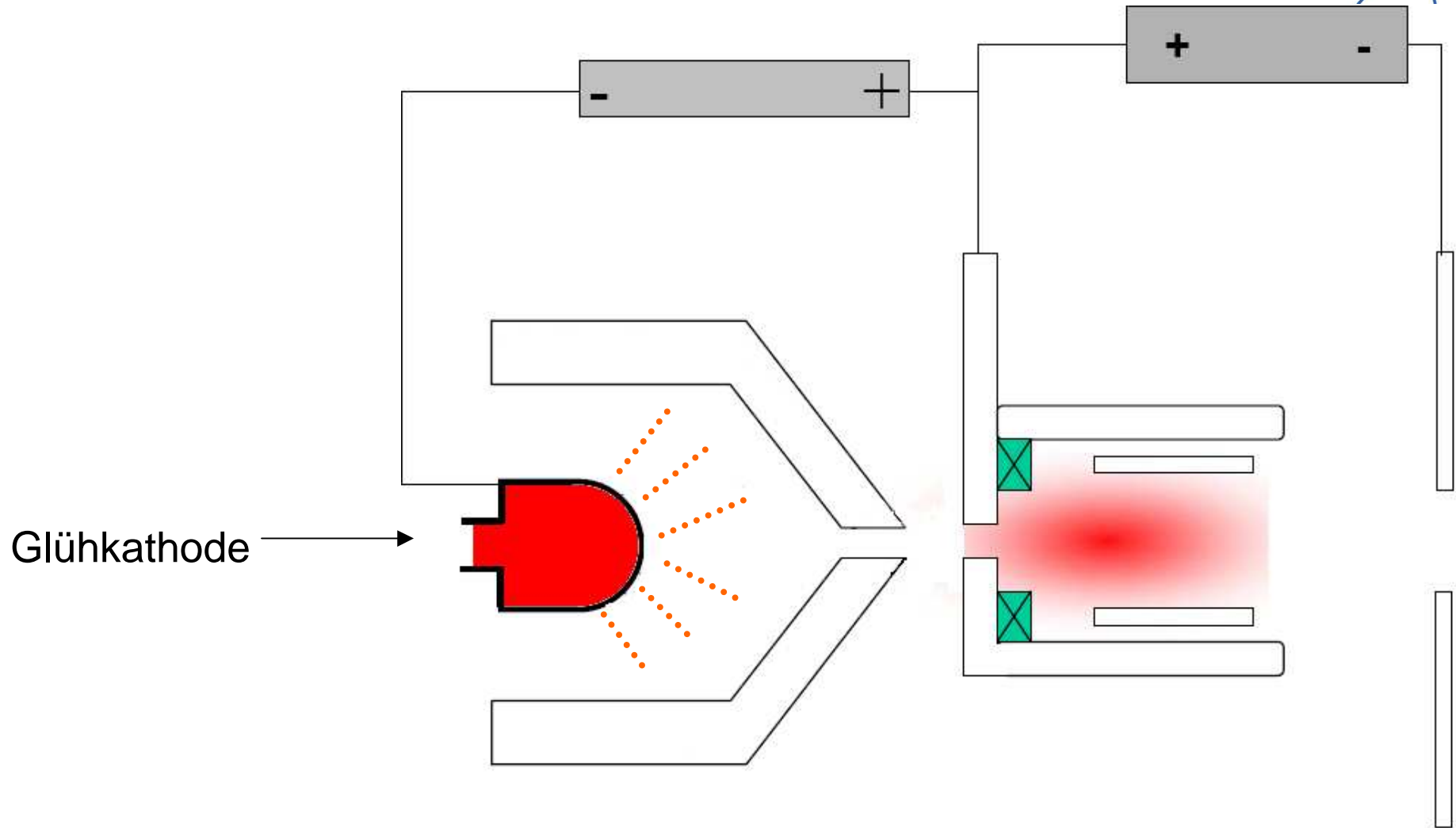
# CERN-Protonenquelle



# CERN-Protonenquelle



90 kV

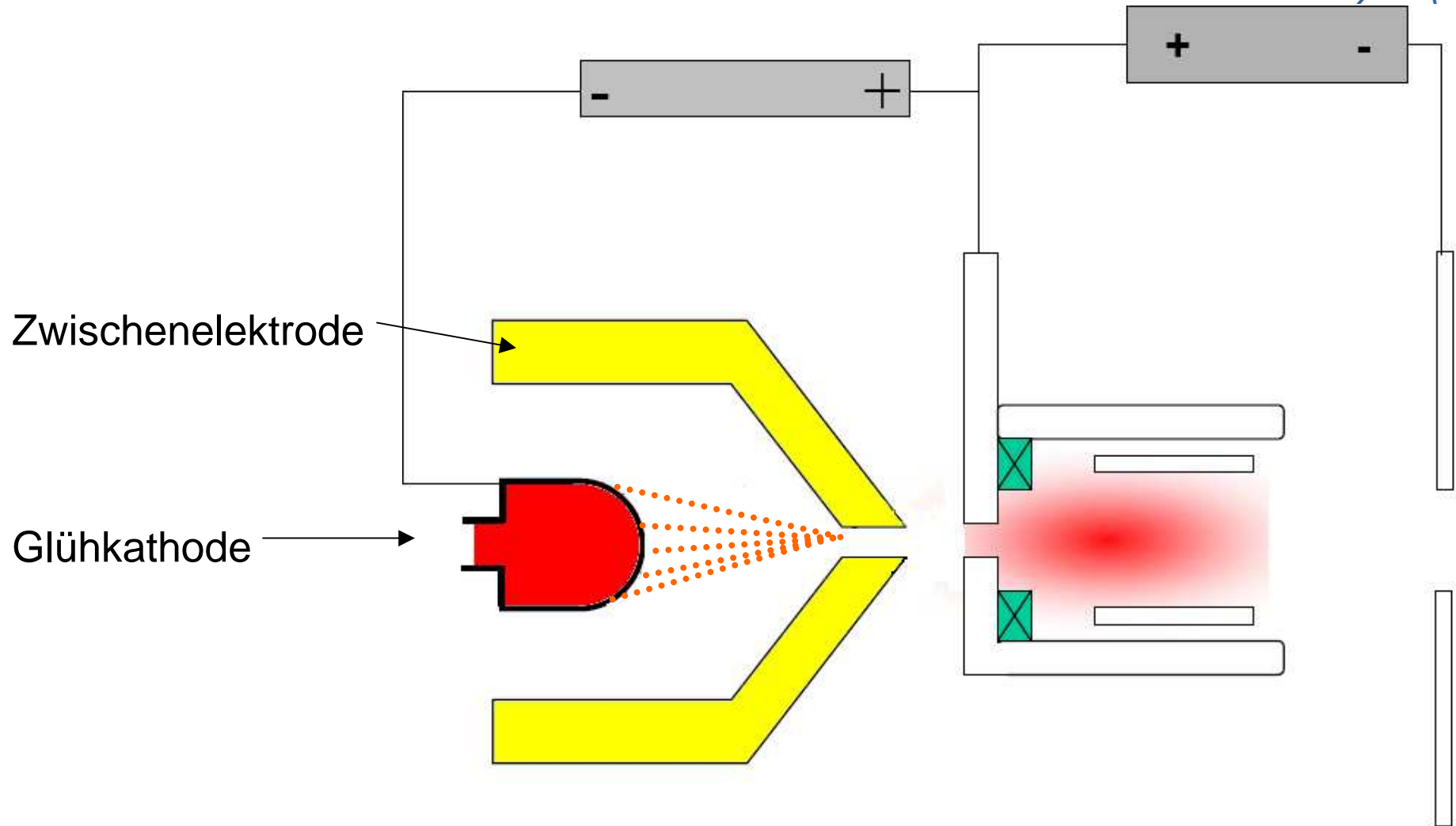


Glühkathode

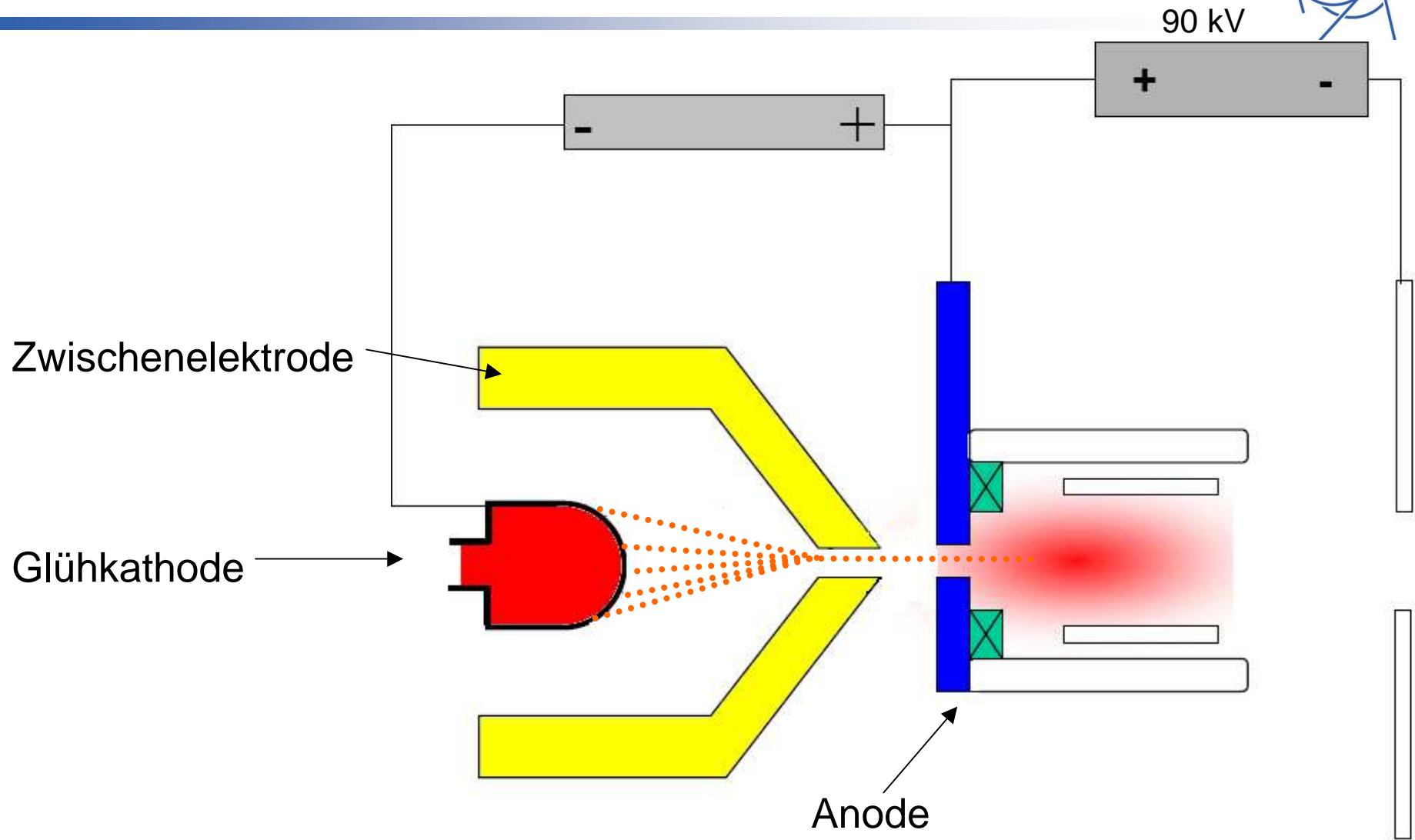
# CERN-Protonenquelle



90 kV



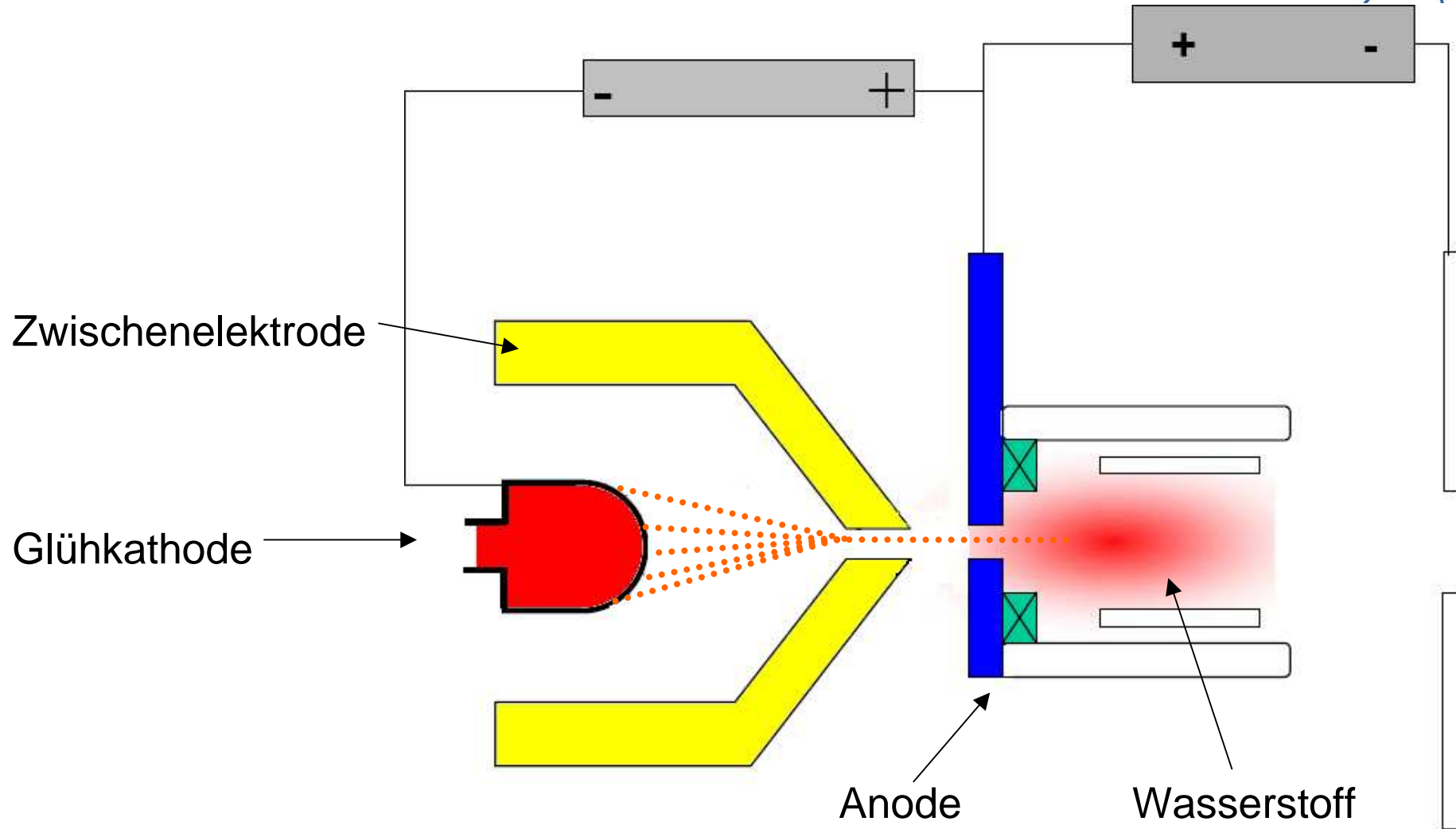
# CERN-Protonenquelle



# CERN-Protonenquelle



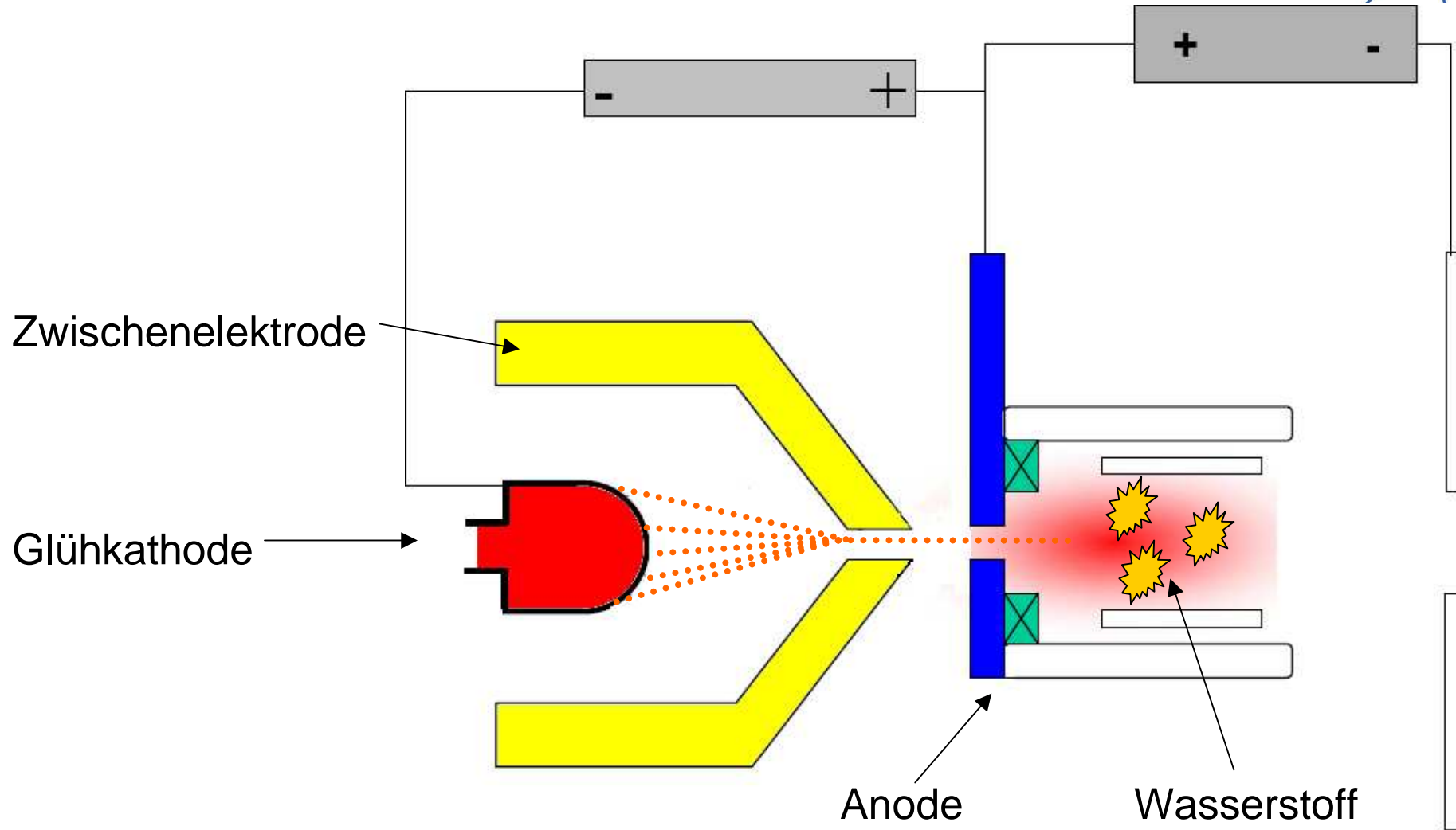
90 kV



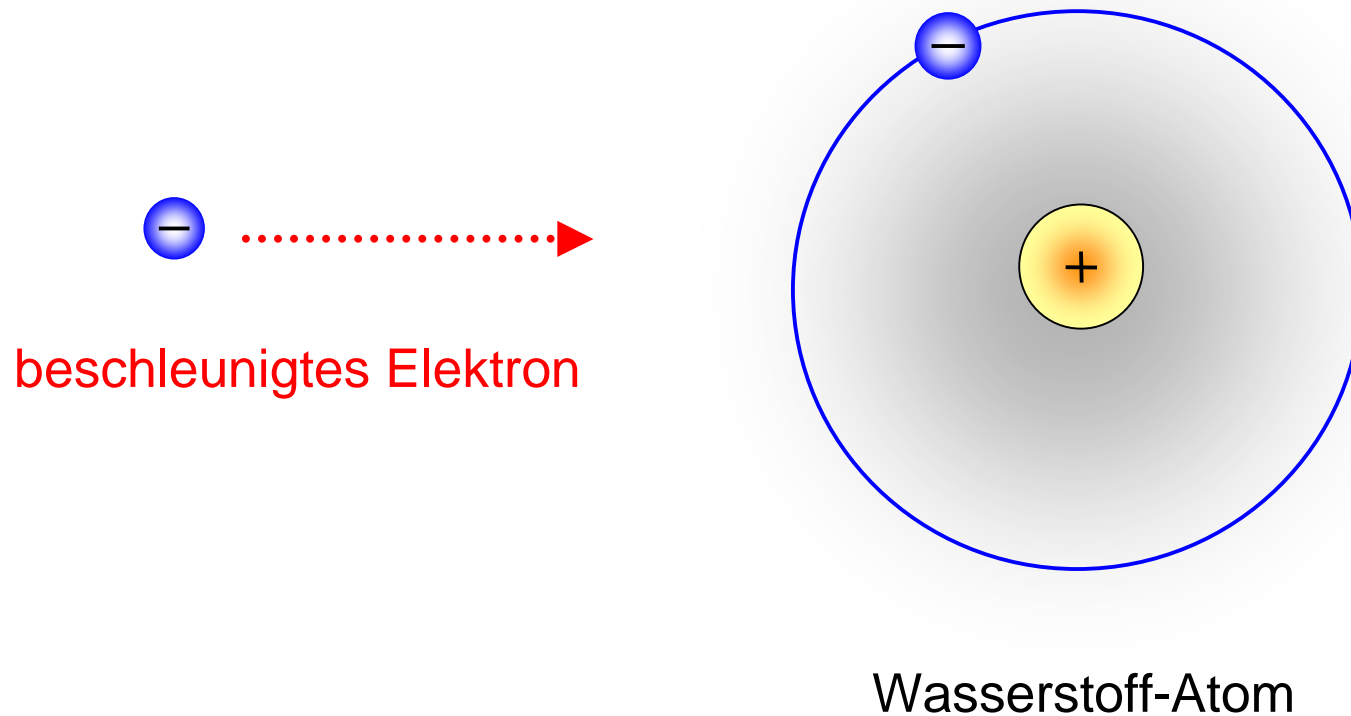
# CERN-Protonenquelle



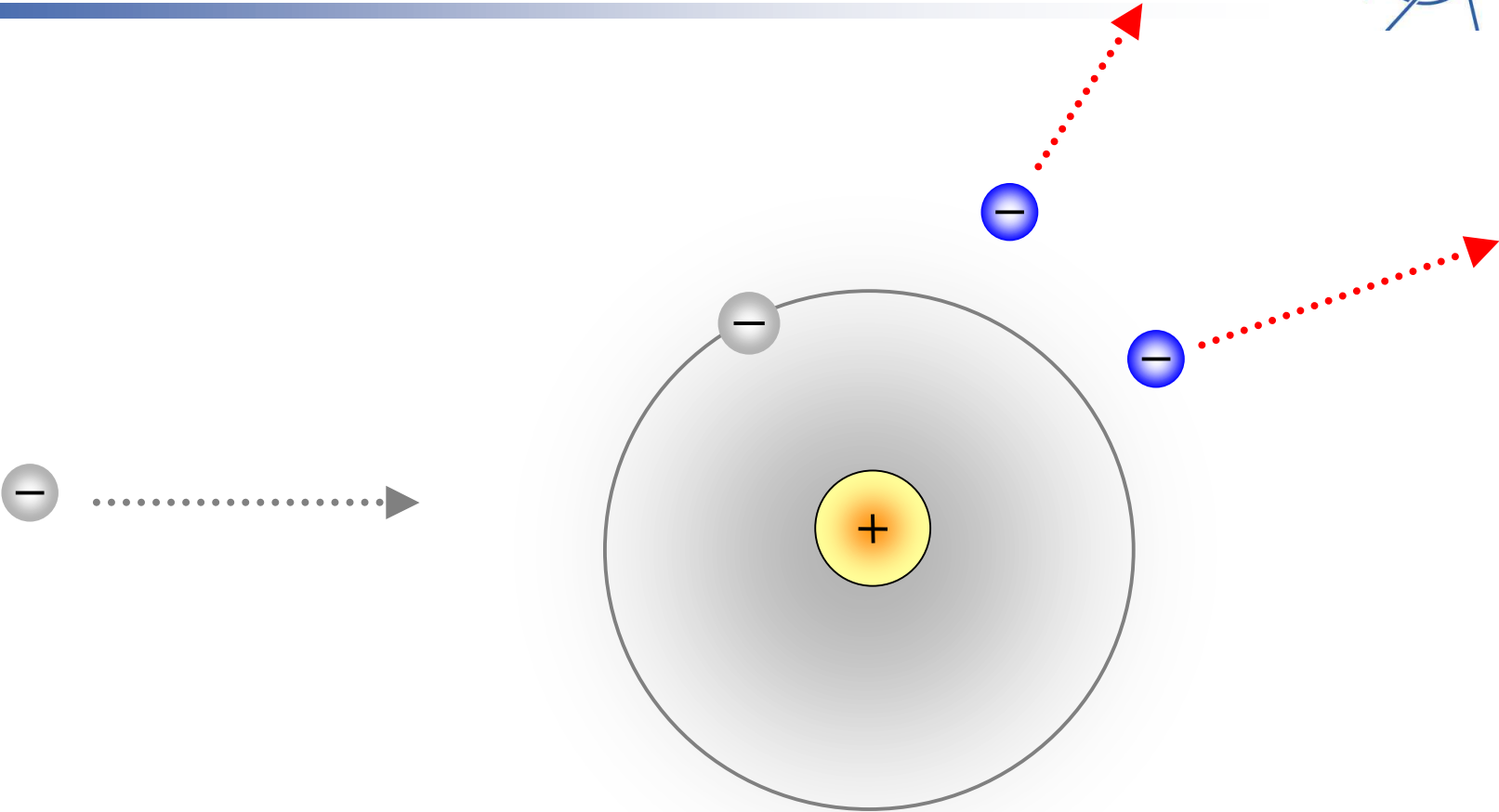
90 kV



# Protonen-Erzeugung



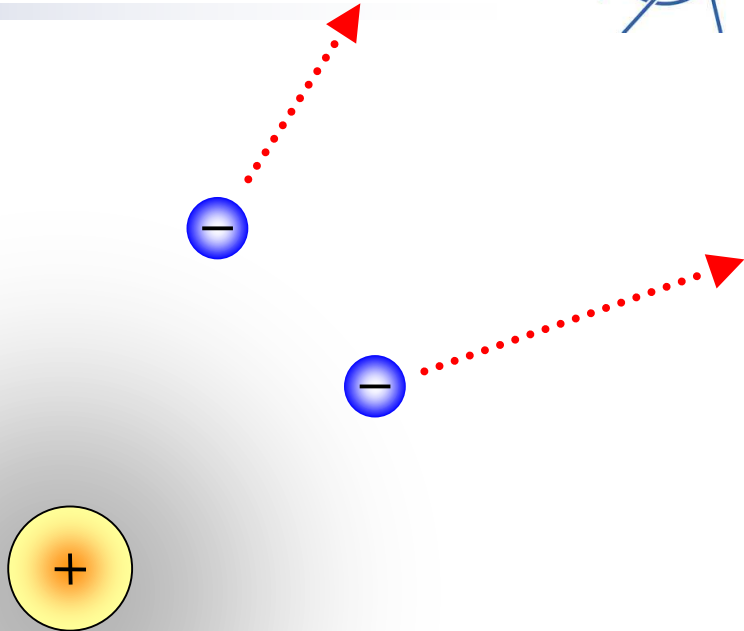
# Protonen-Erzeugung



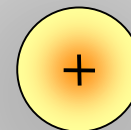
Proton



# Protonen-Erzeugung

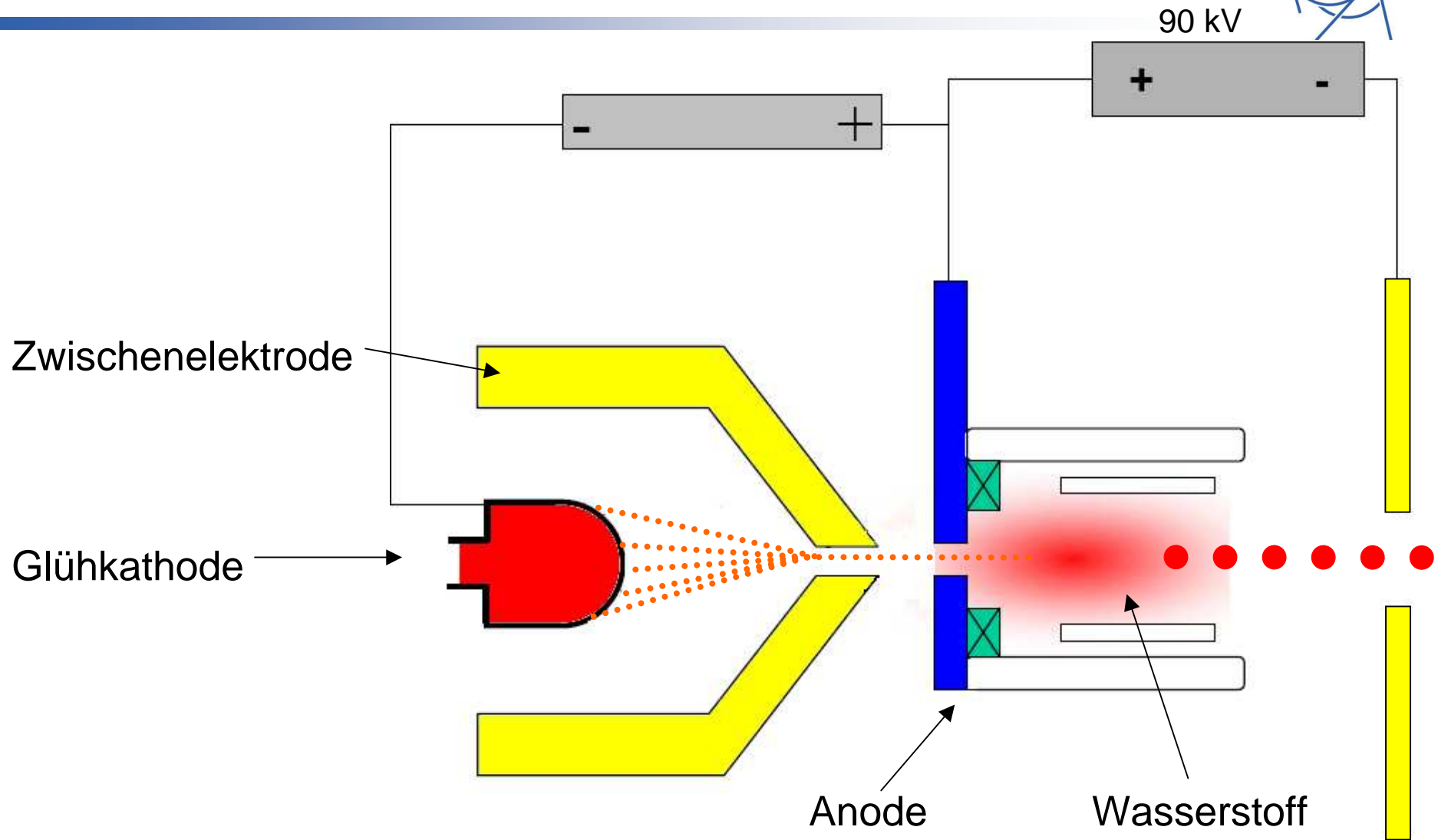


# Protonen-Erzeugung



Proton

# CERN-Protonenquelle



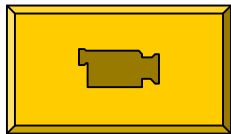
# CERN-Protonenquelle



# CERN-Protonenquelle



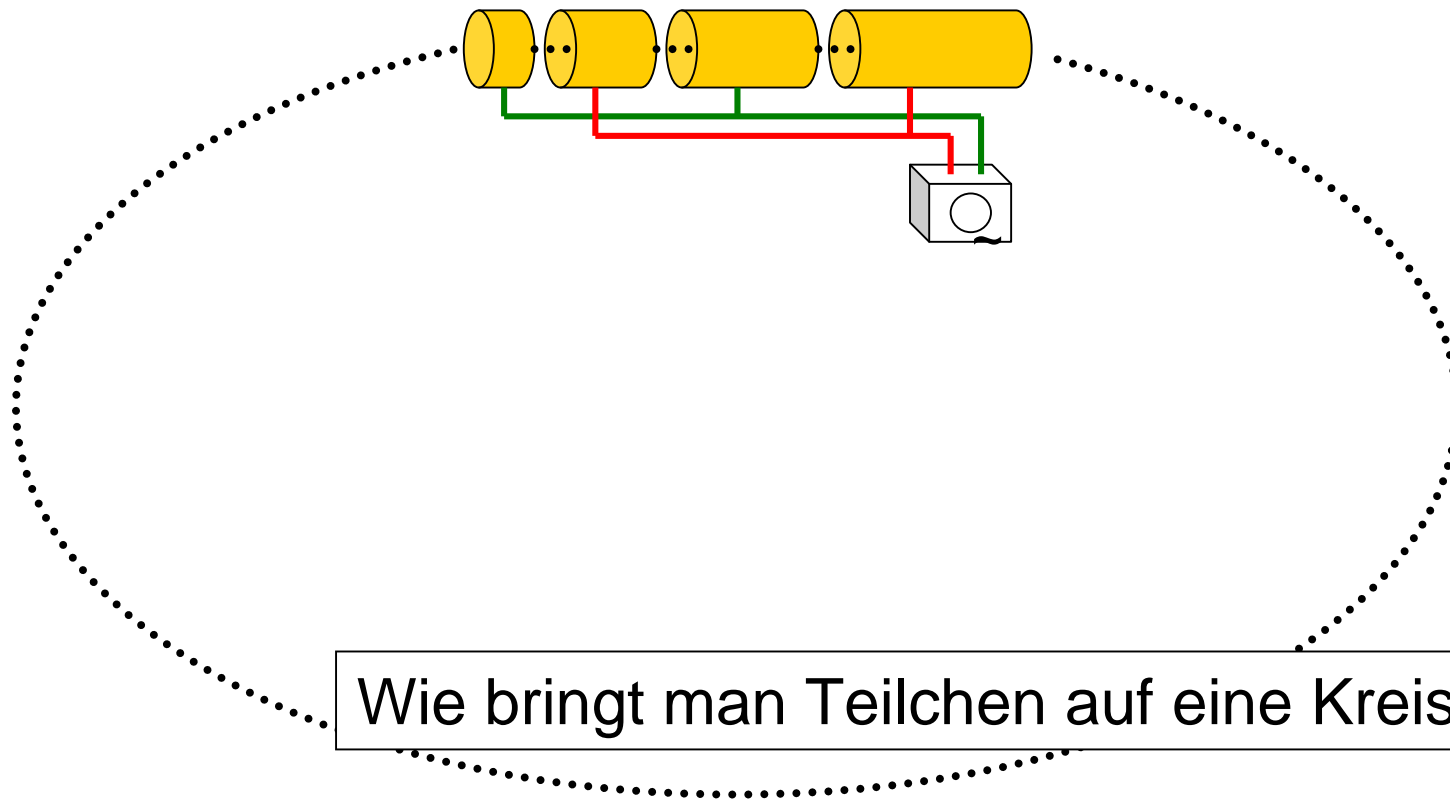
# Linearbeschleuniger



# Kreisbeschleuniger



- Vorteil: die gleiche Beschleunigungsstrecke mehrmals durchlaufen



Wie bringt man Teilchen auf eine Kreisbahn?

# Fadenstrahlröhre

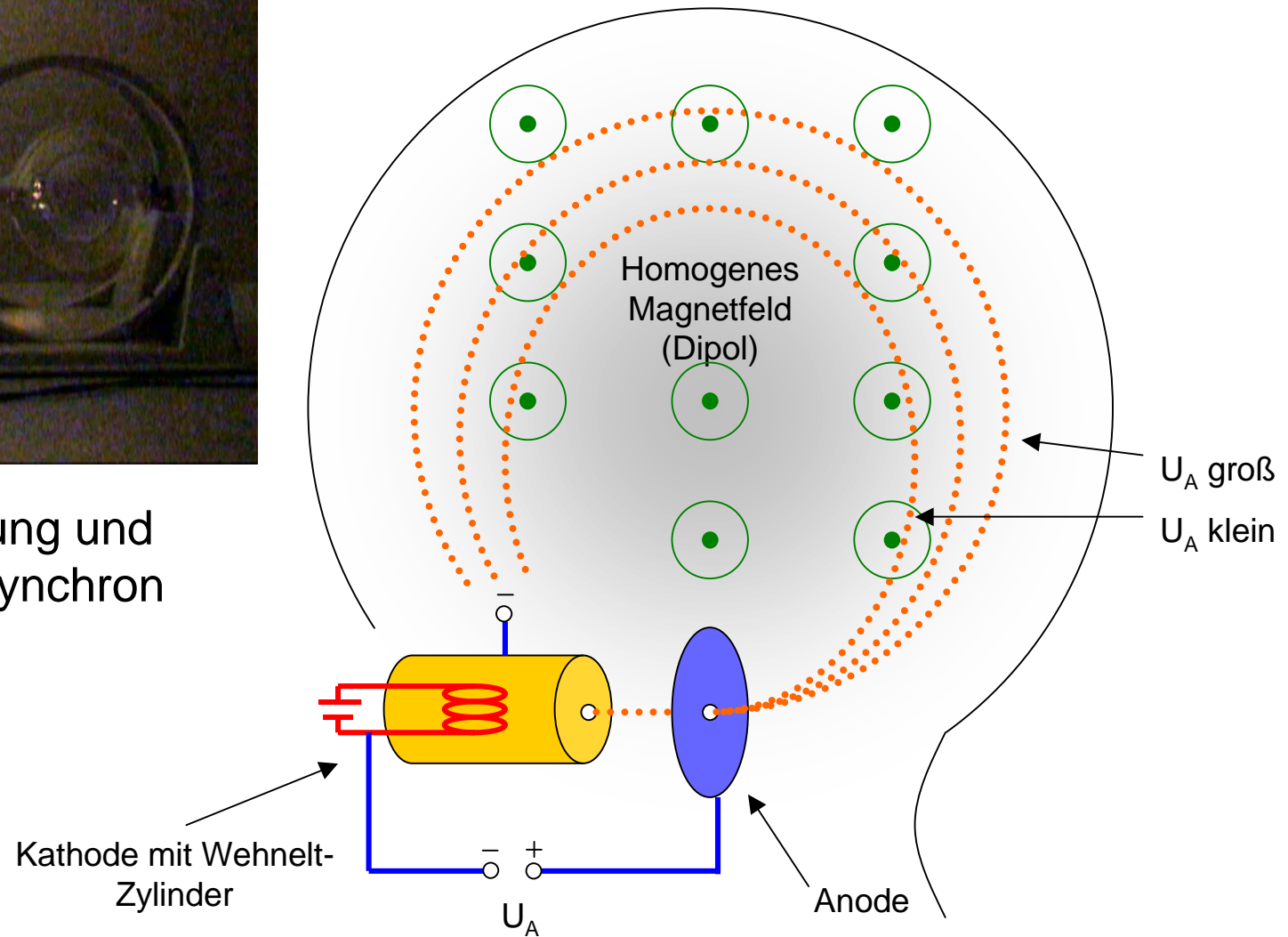




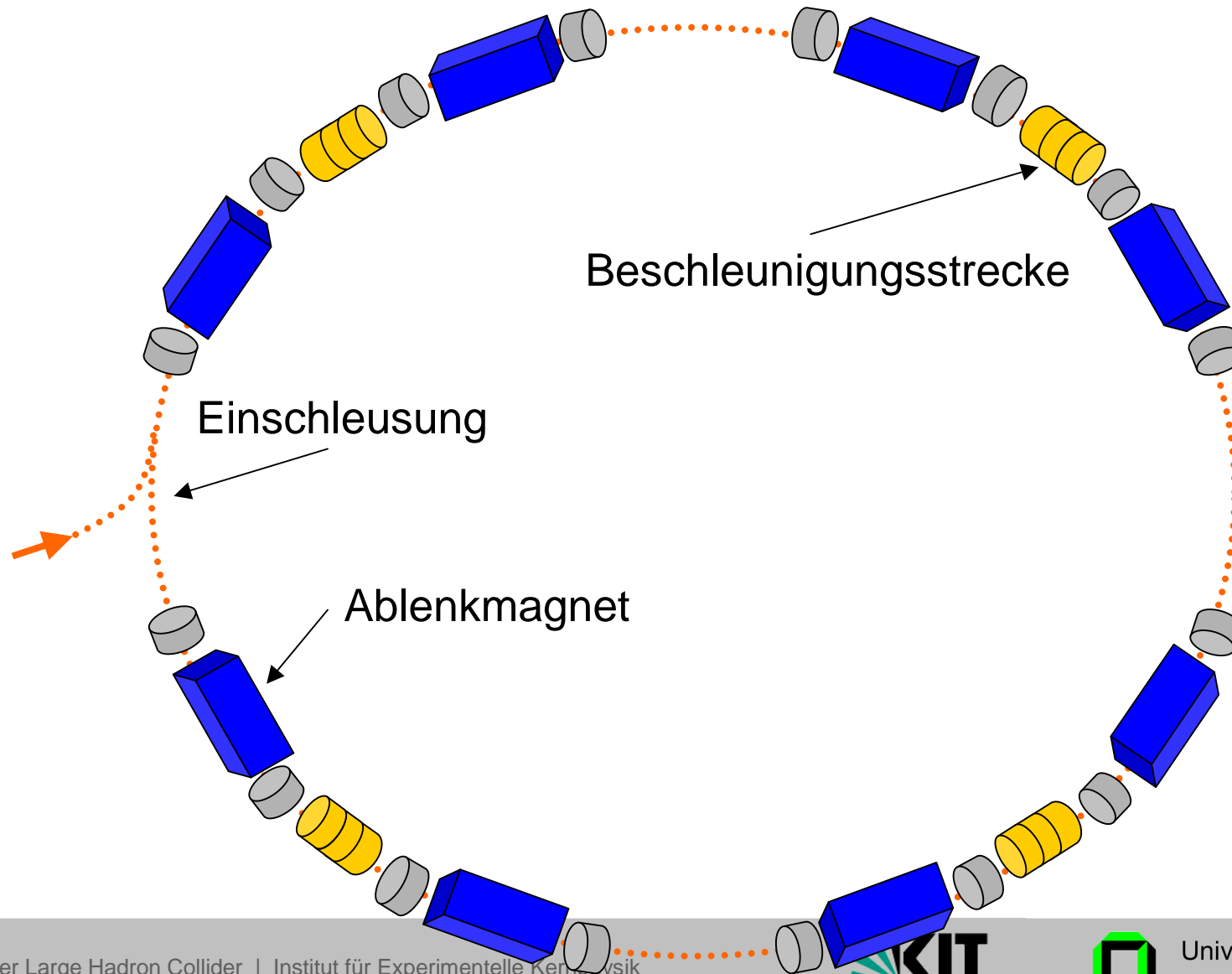
# Synchrotron



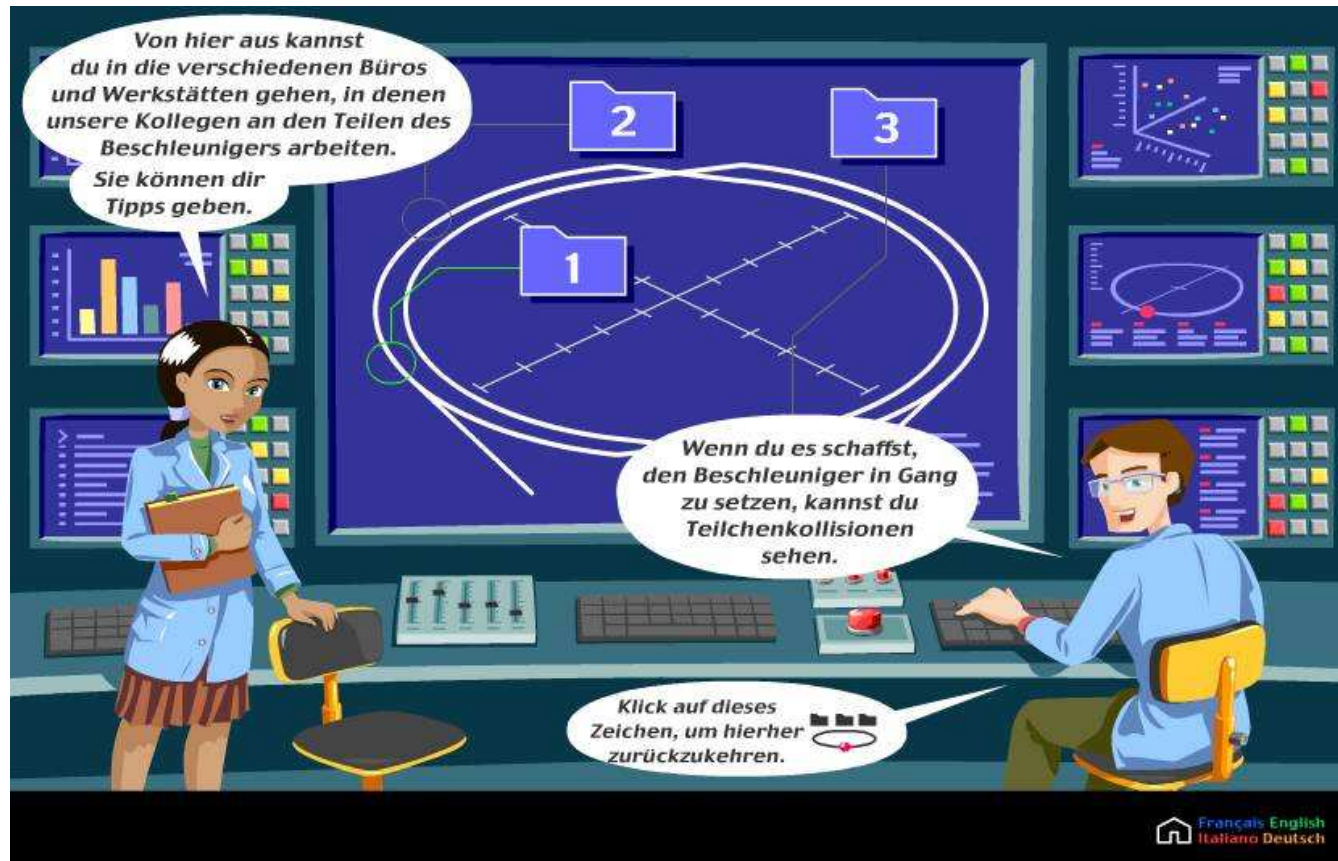
→ Beschleunigung und Magnetfeld synchron hochfahren



# Kreisbeschleuniger



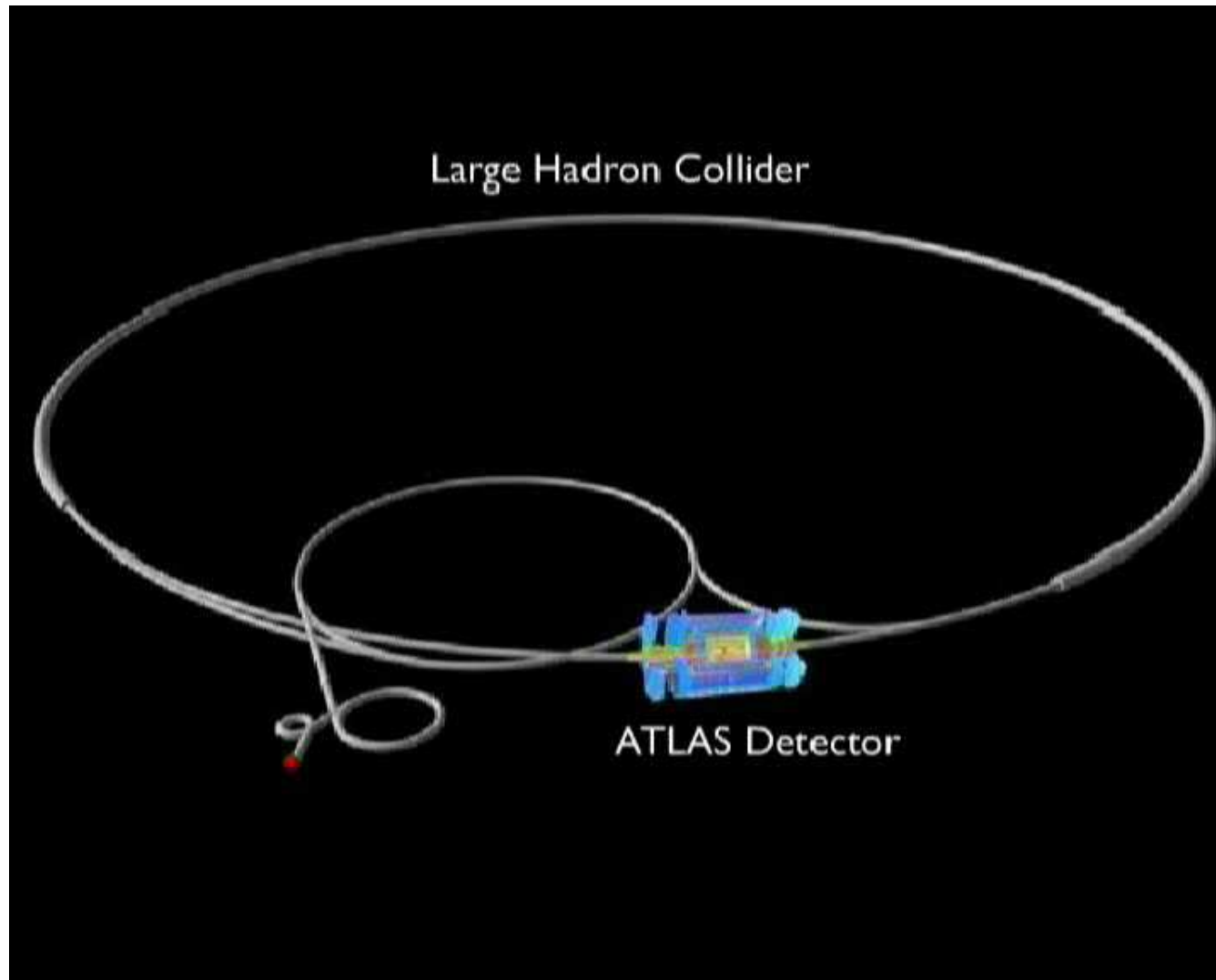
# LHC-Spiel



Start

(Internetverbindung erforderlich)

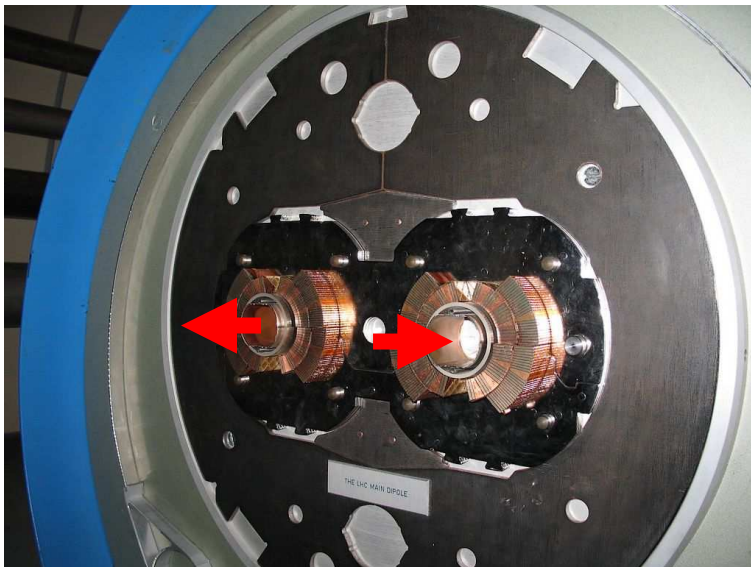
# LHC und Vorbeschleuniger



# Large Hadron Collider



- Maximalenergie: 7 Tera-Elektronenvolt
- Geschwindigkeit:  $v=0,9999999991 c$
- 2808 Teilchenpakete mit je  $1,15 \cdot 10^{11}$  Protonen
  - Abstand: 25 ns
  - → 40 Millionen Kollisionen pro Sekunde



# Large Hadron Collider



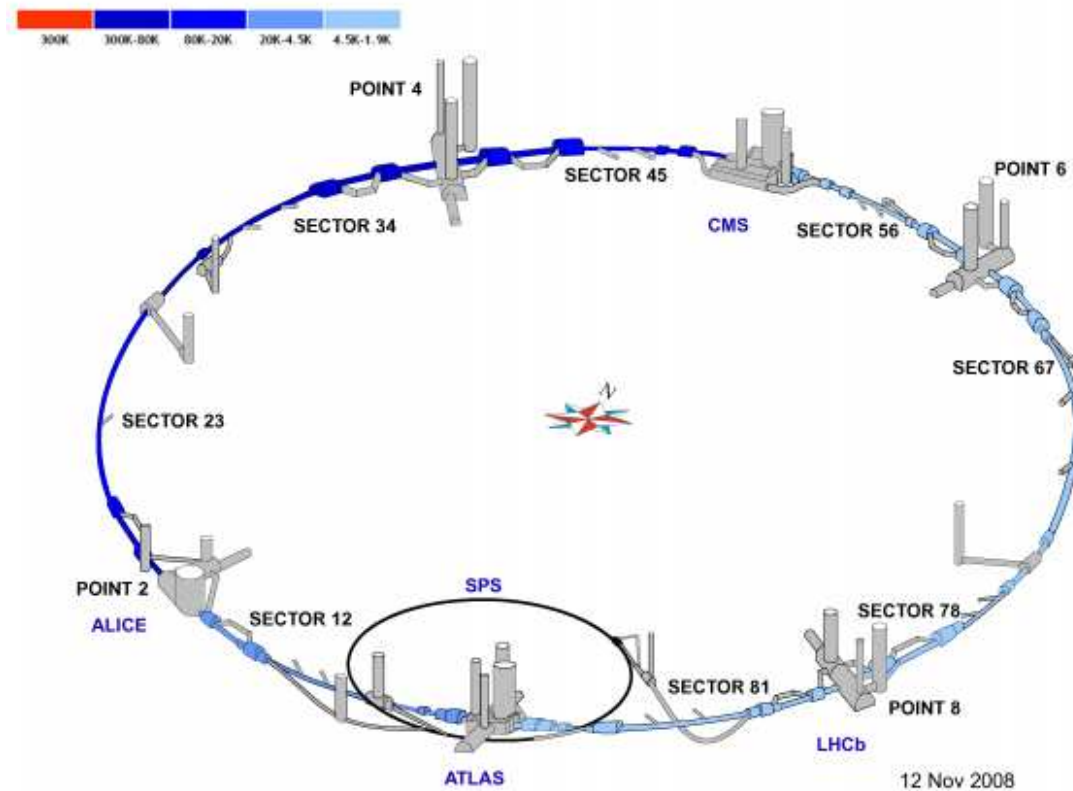
- 1232 supraleitende Magnete
  - Magnetfeld: 8,3 T bei 11.850 Ampère
  - Betriebstemperatur: -271 °C
  - Länge: 15 m
  - Gewicht: 35 t
  - Preis: 500.000 CHF
- Transport bei 3 km/h!
  - ...bis zu 15 km weit



# Large Hadron Collider



- LHC-Temperatur
  - Kälter als das Weltall!



# Large Hadron Collider





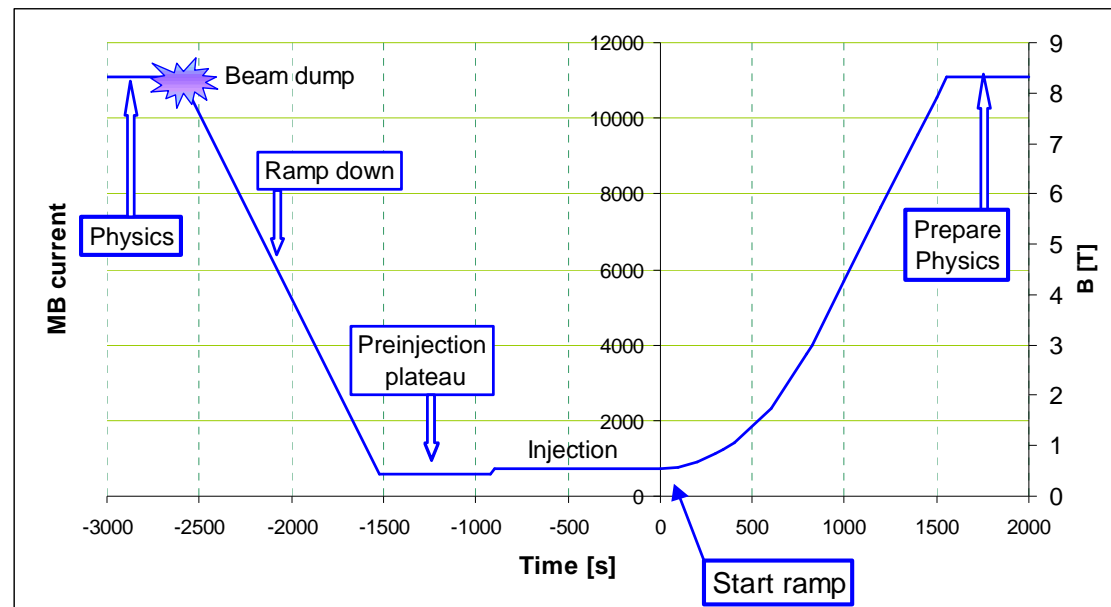
# Large Hadron Collider



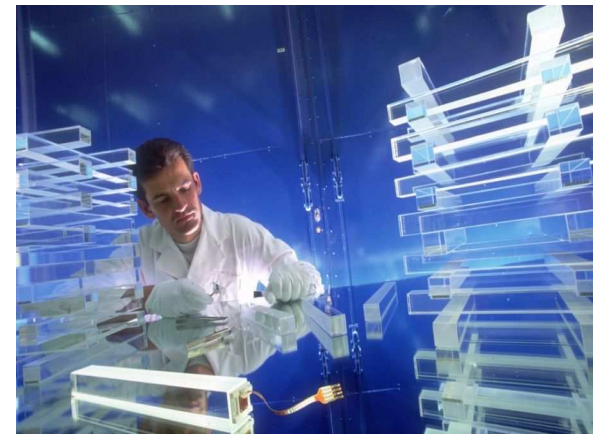
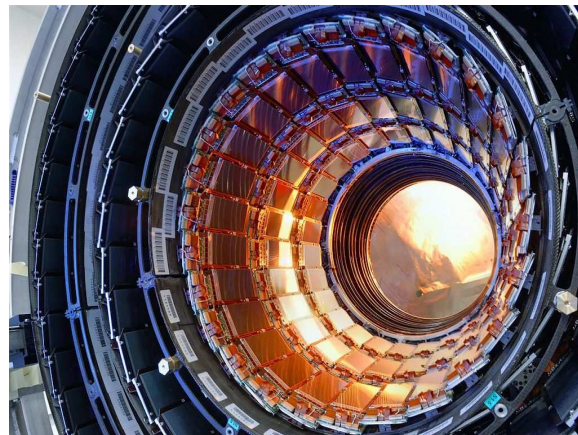
- Weitere Daten:

- Energieverbrauch: 180 MW (= Kanton Genf)
- 360 MJ Energie gespeichert im Strahl (=ICE bei 200 km/h, schmilzt 500 kg Kupfer)
- Ultrahochvakuum größer als auf dem Mond

Ramp down	≈ 18 Mins
Pre-Injection Plateau	15 Mins
Injection	≈ 15 Mins
Ramp	≈ 28 Mins
Squeeze	≈ 20 Mins
Prepare Physics	≈ 10 Mins
Physics	0 - 20 Hrs



# Teilchendetektoren



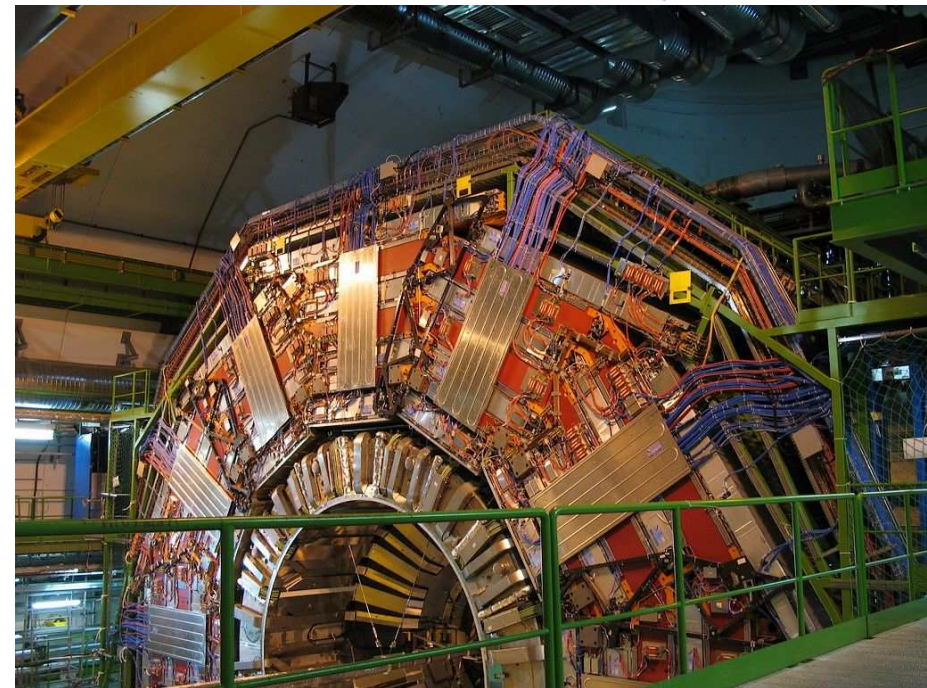
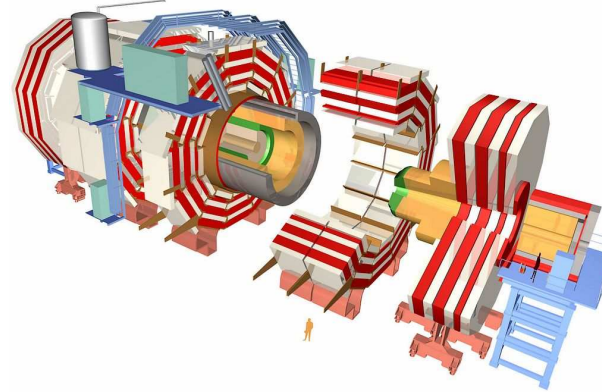


# CMS-Detektor



- Länge: 25 m
- Höhe: 16 m
- Gewicht: 12.500 t
  
- Mitarbeiter:
  - 2310 Wissenschaftler
  - 38 Staaten
  - 175 Institute

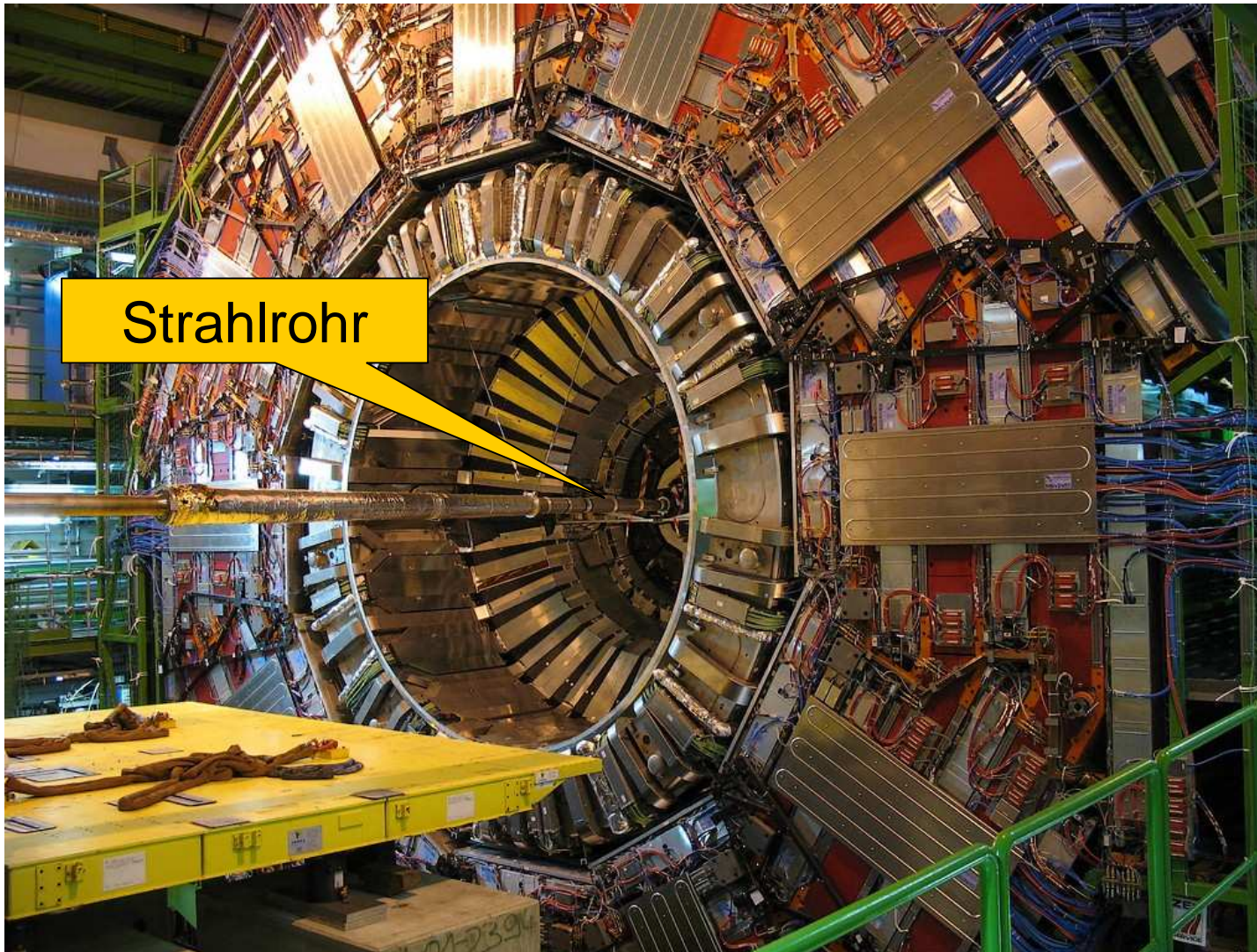
55 aus  
Karlsruhe



# CMS-Detektor



# CMS-Detektor



# CMS-Detektor



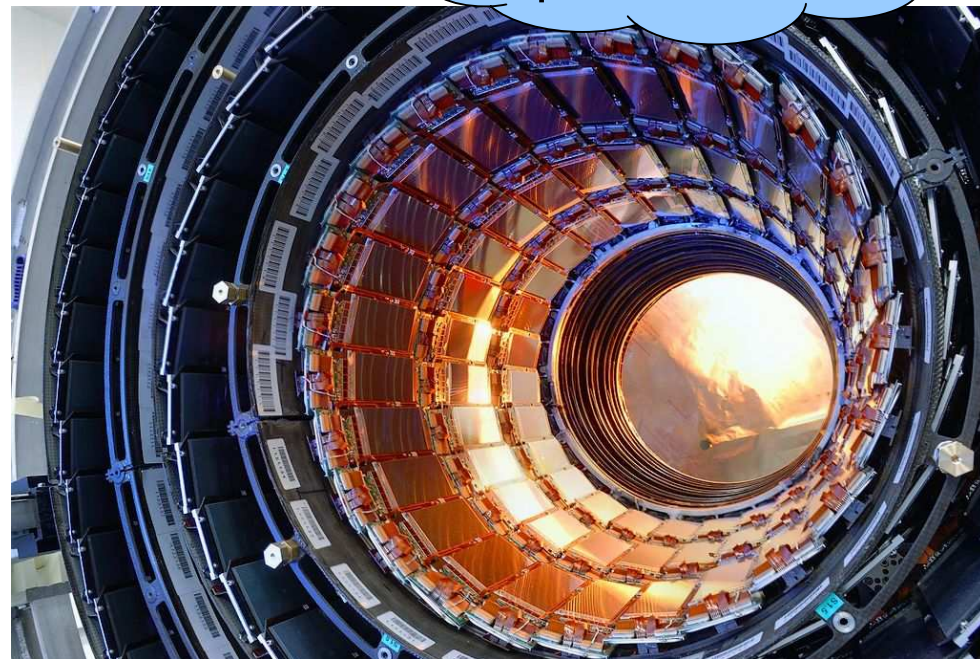
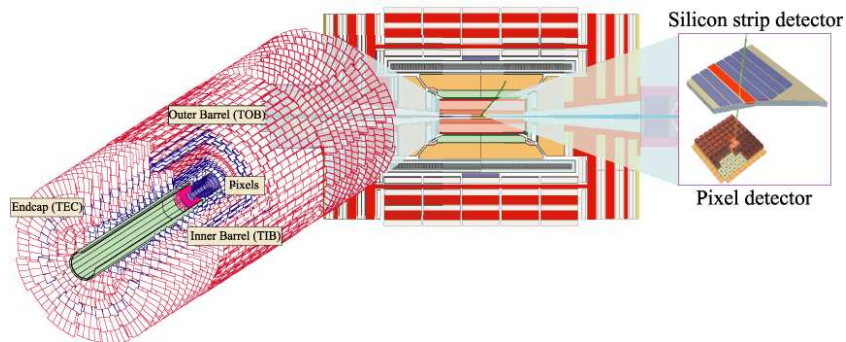
# CMS-Detektor



## ▪ Spurdetektoren

- Streifen und Pixel aus Silizium (=„Digitalkamera“)
- Fläche: 220 m<sup>2</sup>
- 60 Millionen elektronische Kanäle
- Länge: 6 m

40 Mio. Fotos  
pro Sekunde

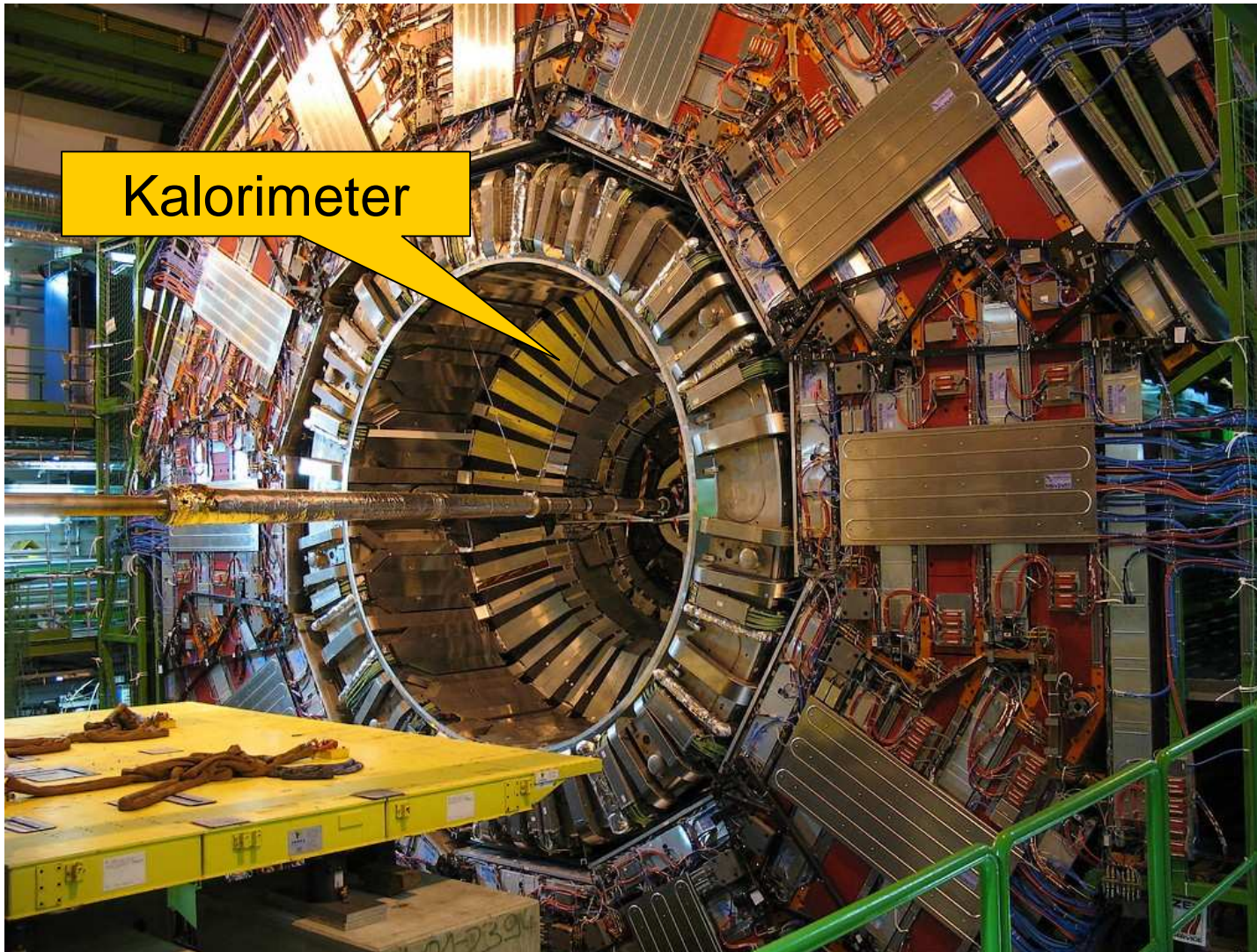




# CMS-Detektor



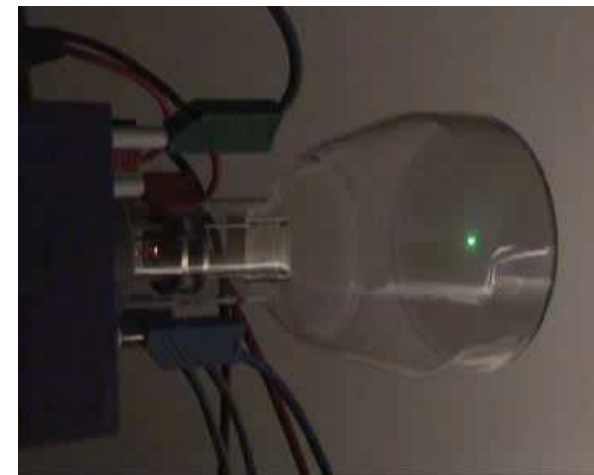
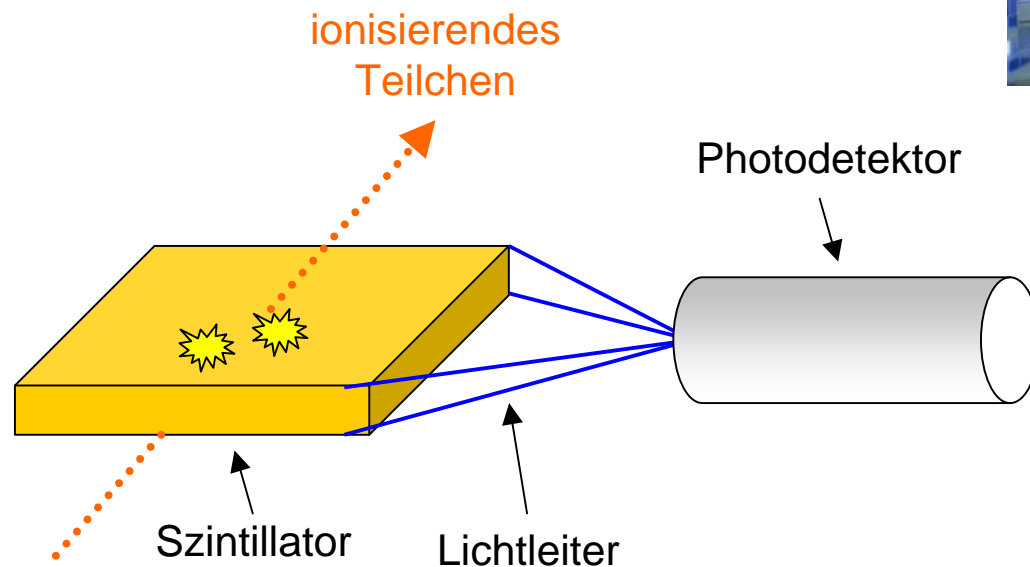
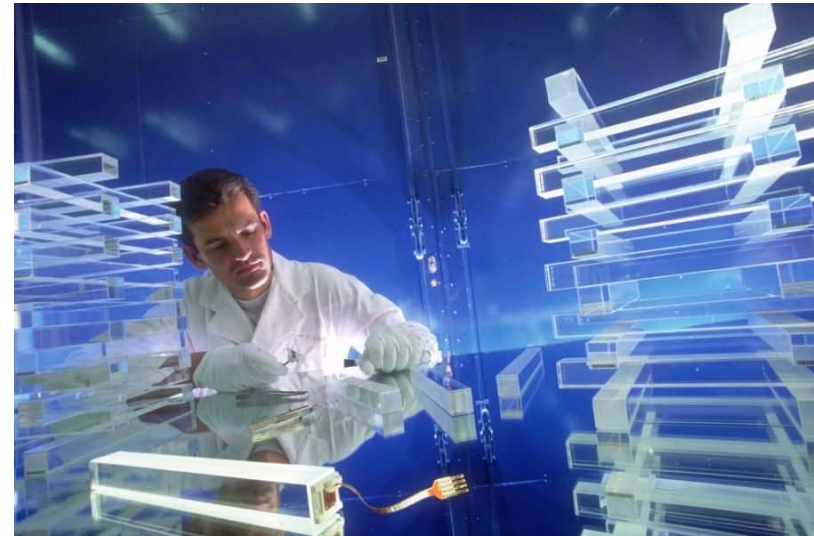
# CMS-Detektor



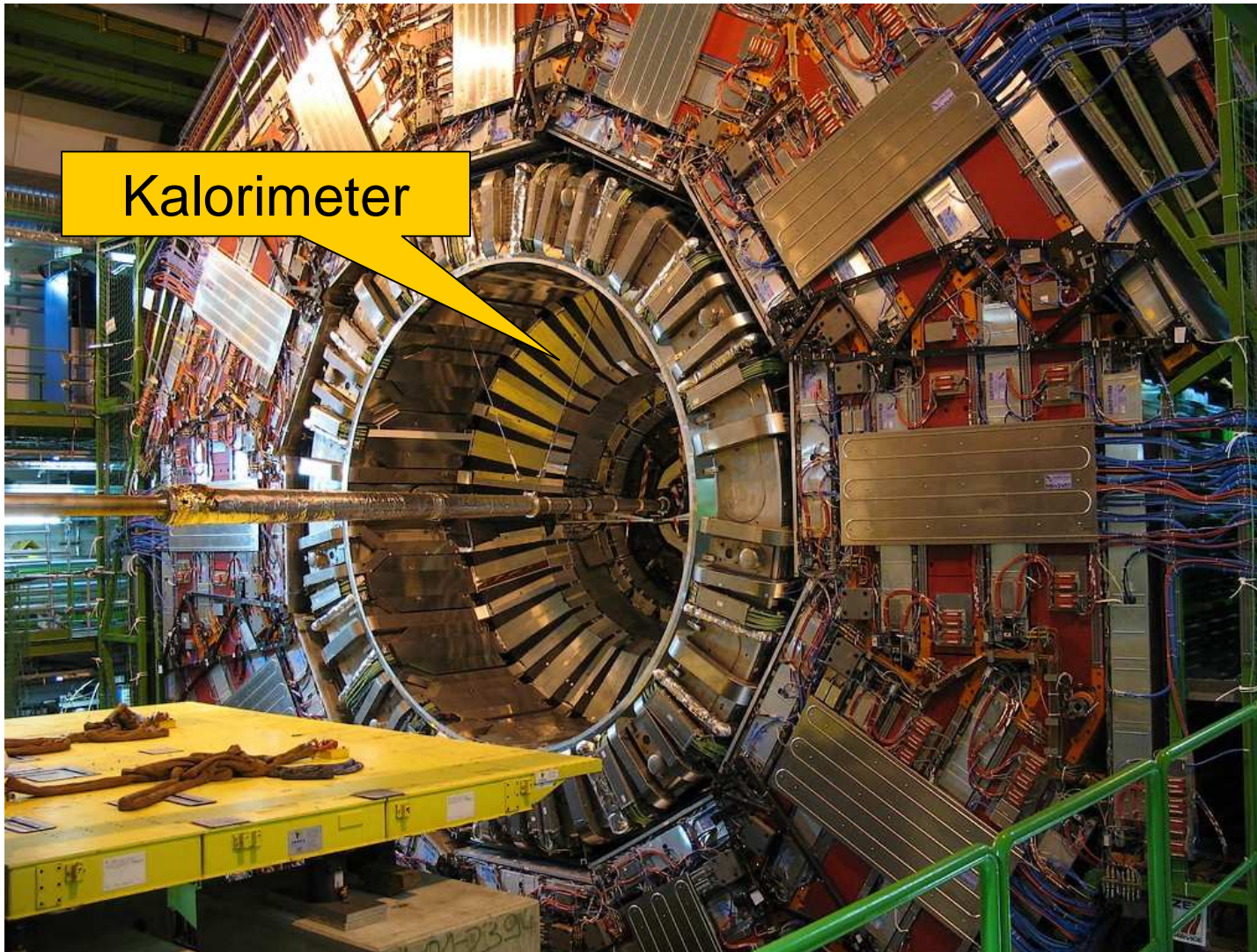
# CMS-Detektor



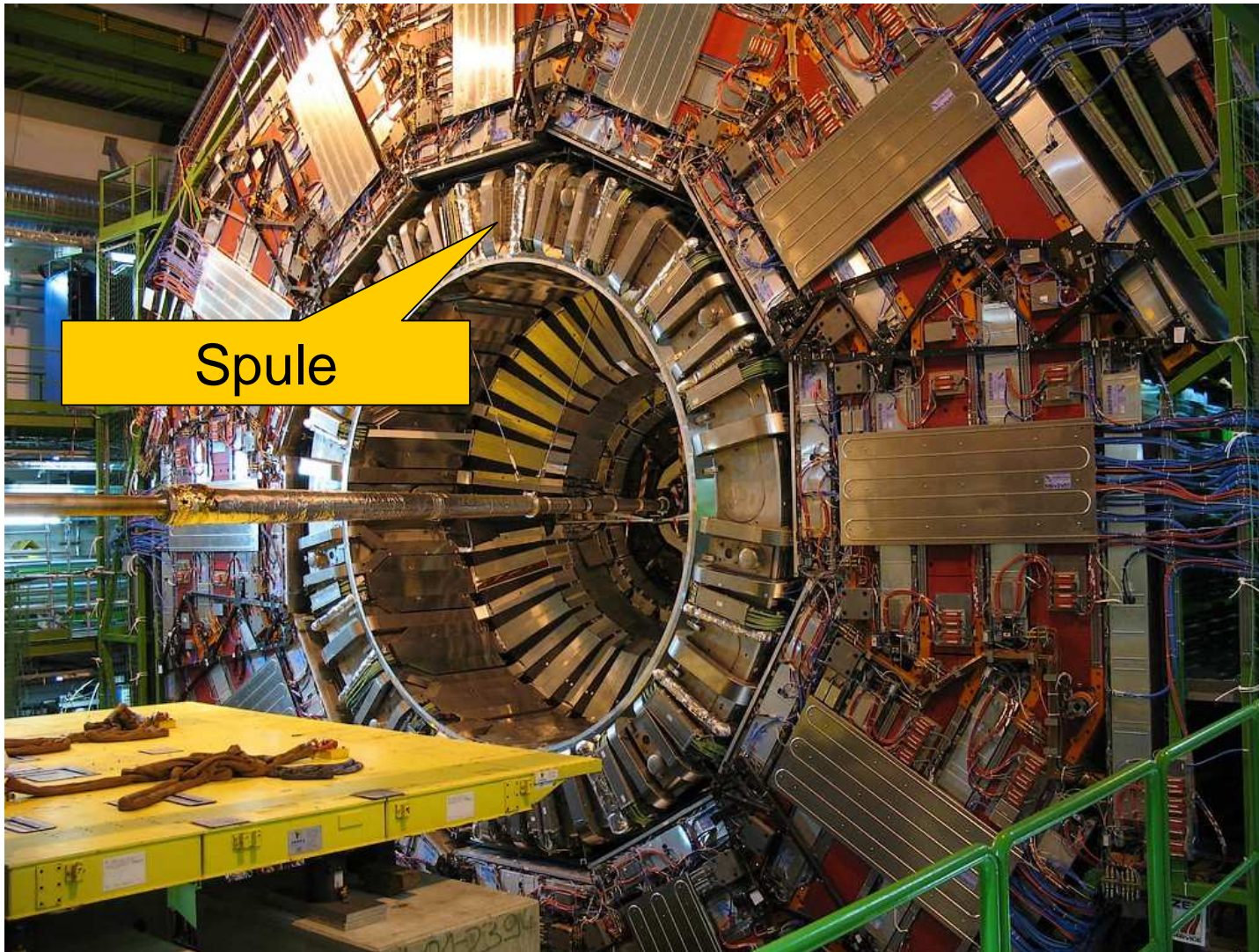
- Kalorimeter
  - Teilchen regen spezielle Materialien zur Lichtemission an
  - Messung der Energie



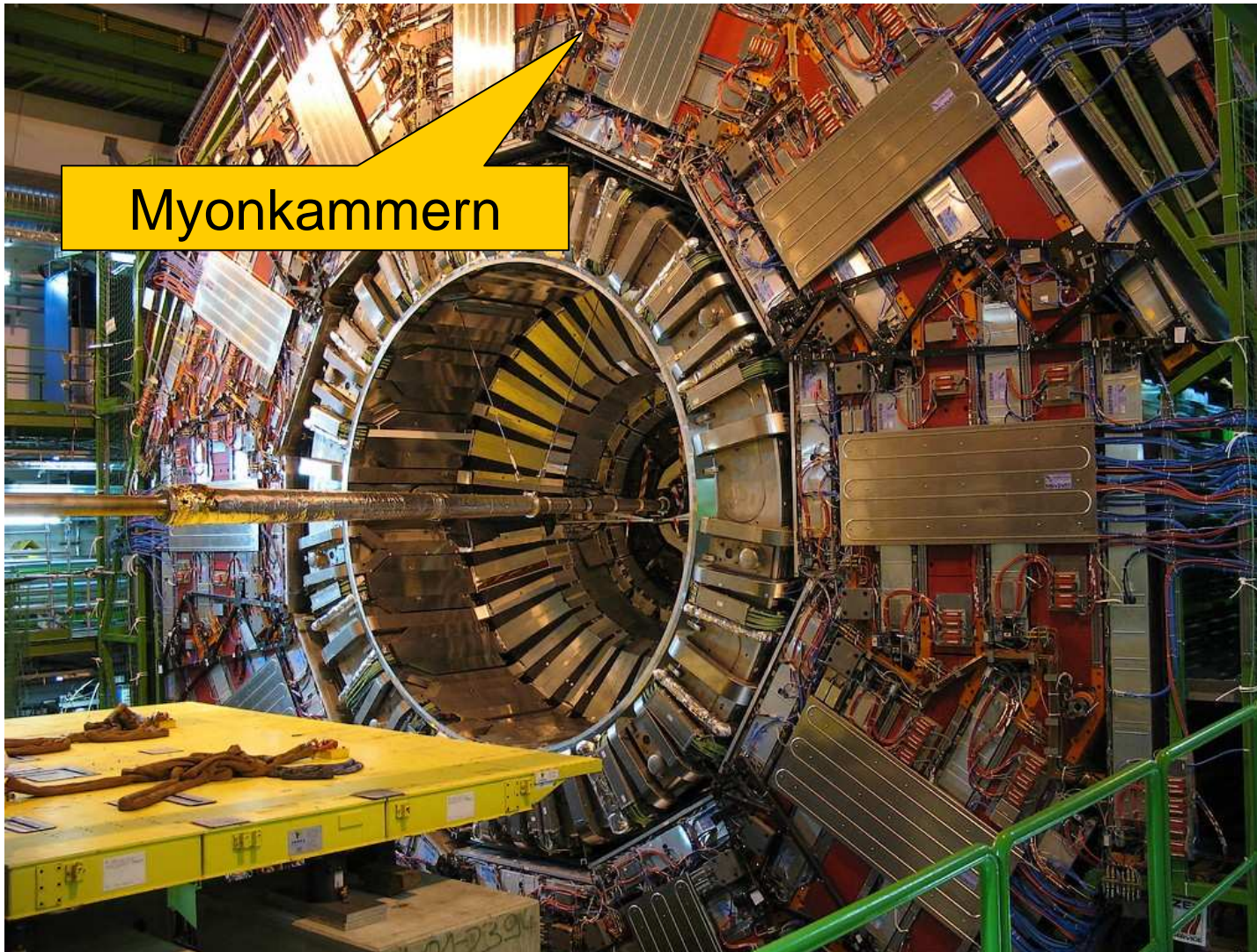
# CMS-Detektor



# CMS-Detektor



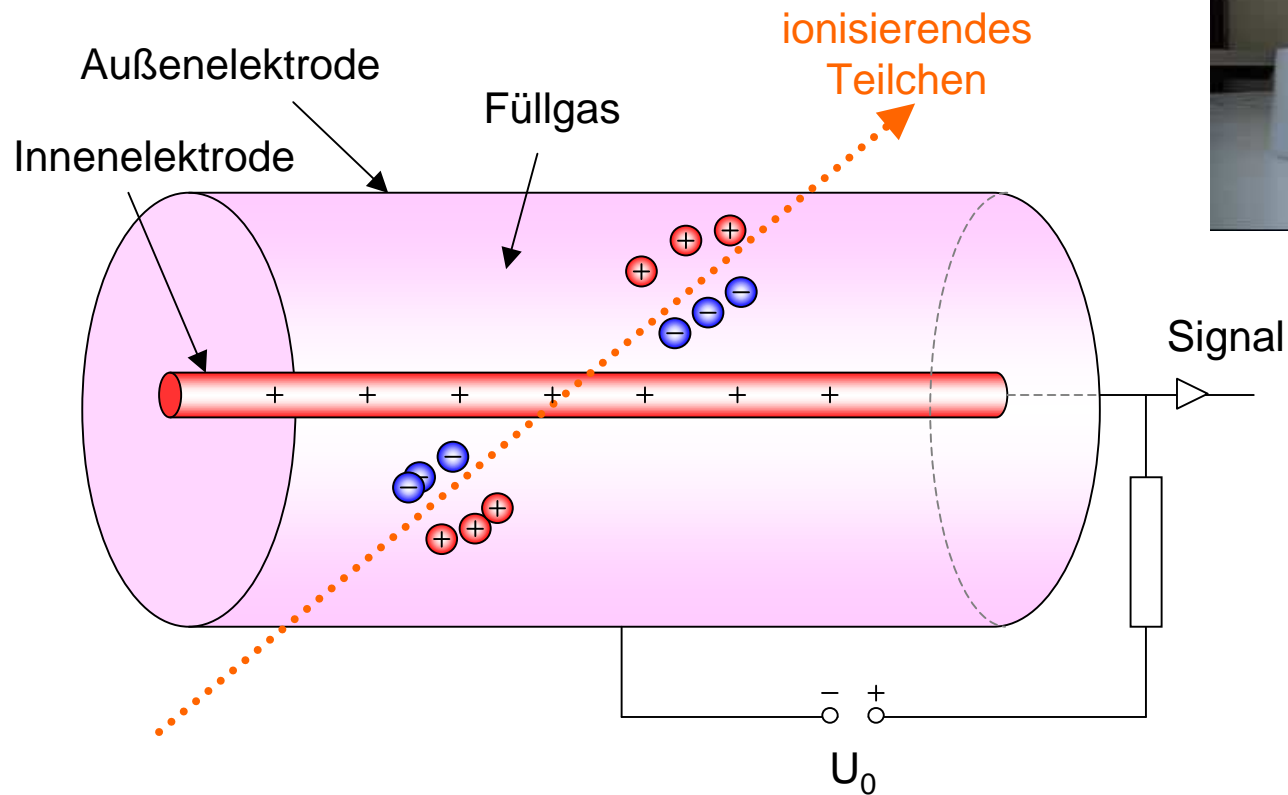
# CMS-Detektor



# Kalorimeter



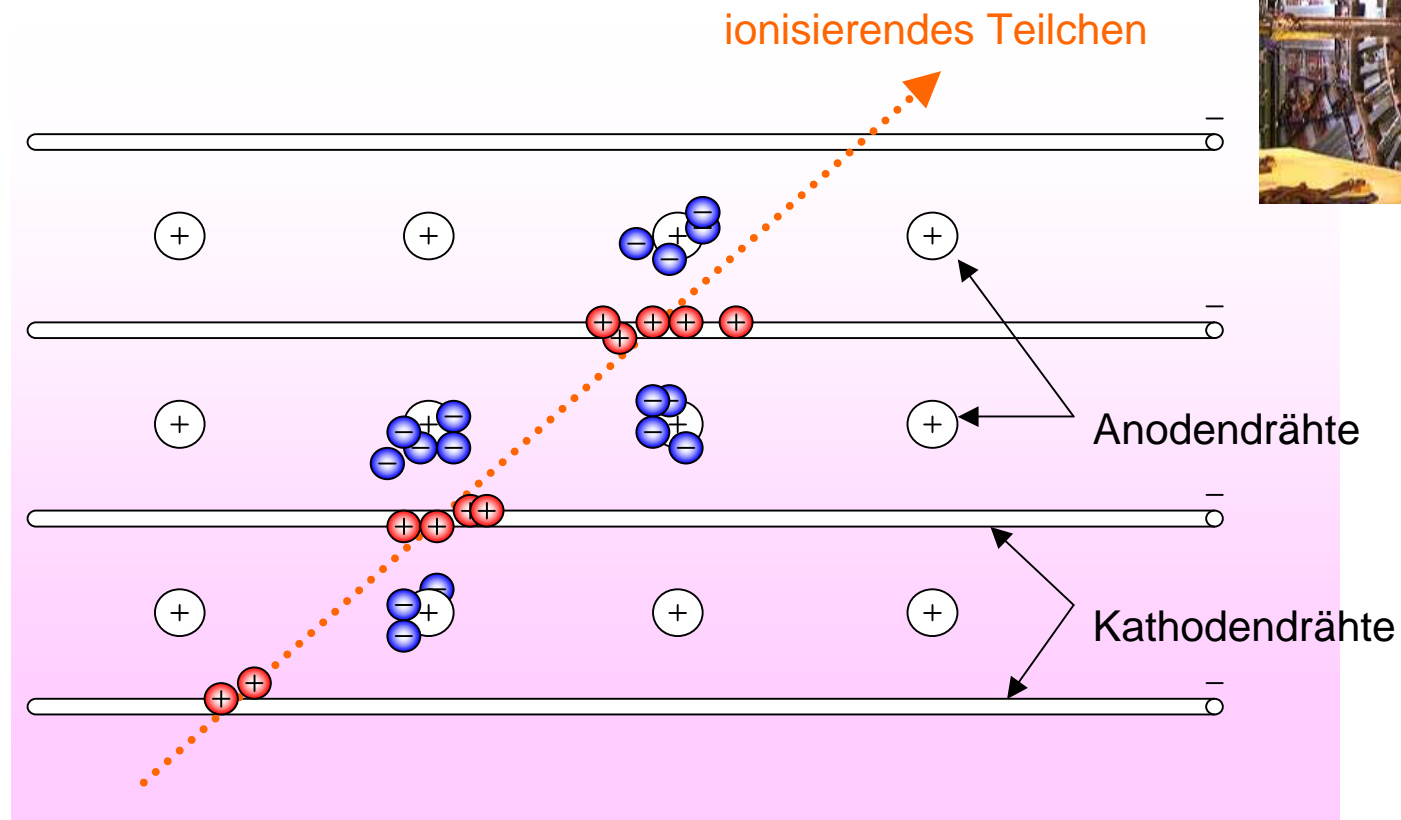
- Myonkammern
  - Gasdetektor = Geiger-Müller-Zählrohr



# Kalorimeter

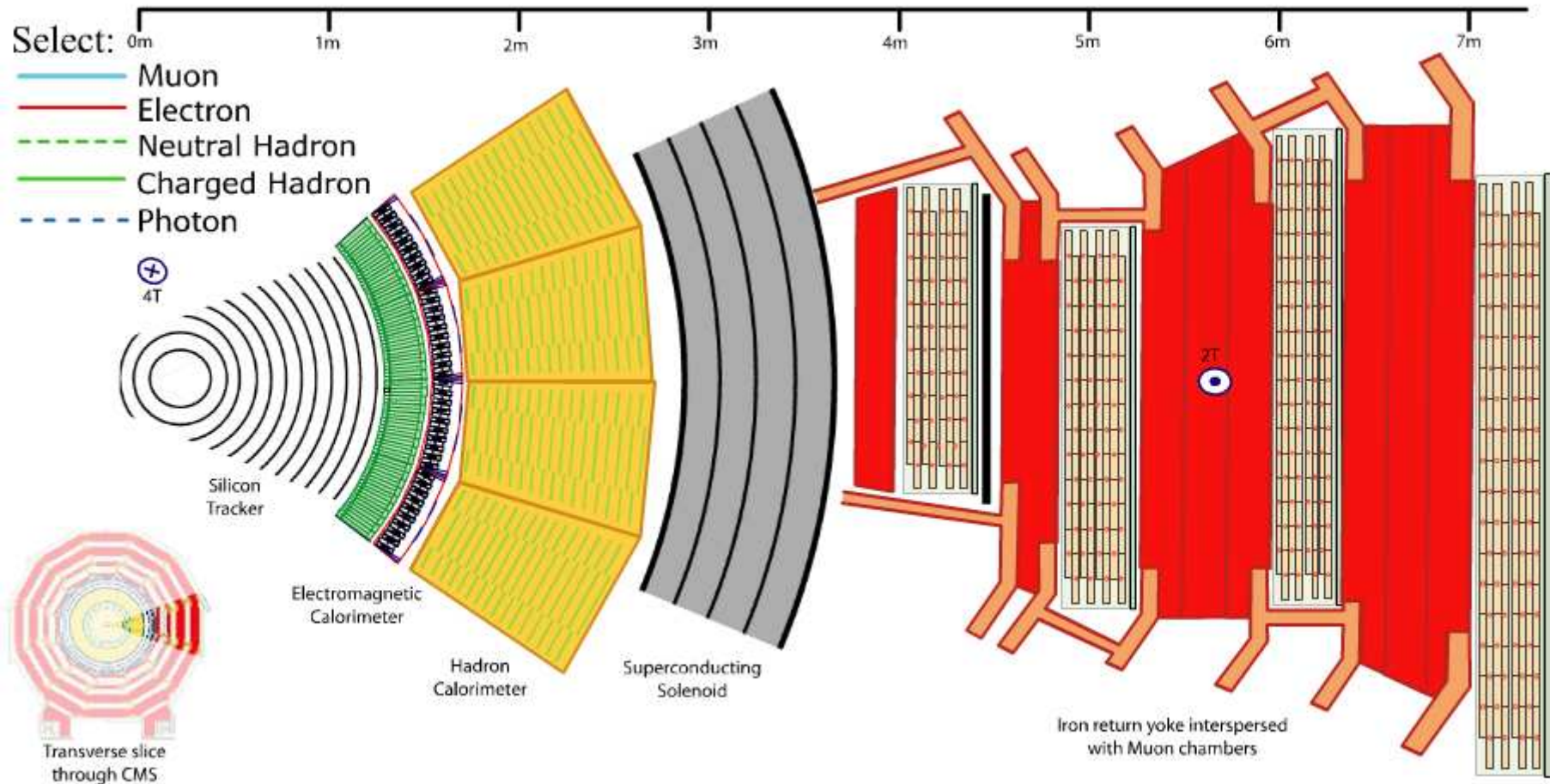


- Myonkammern
  - Vieldraht-Proportionalkammer



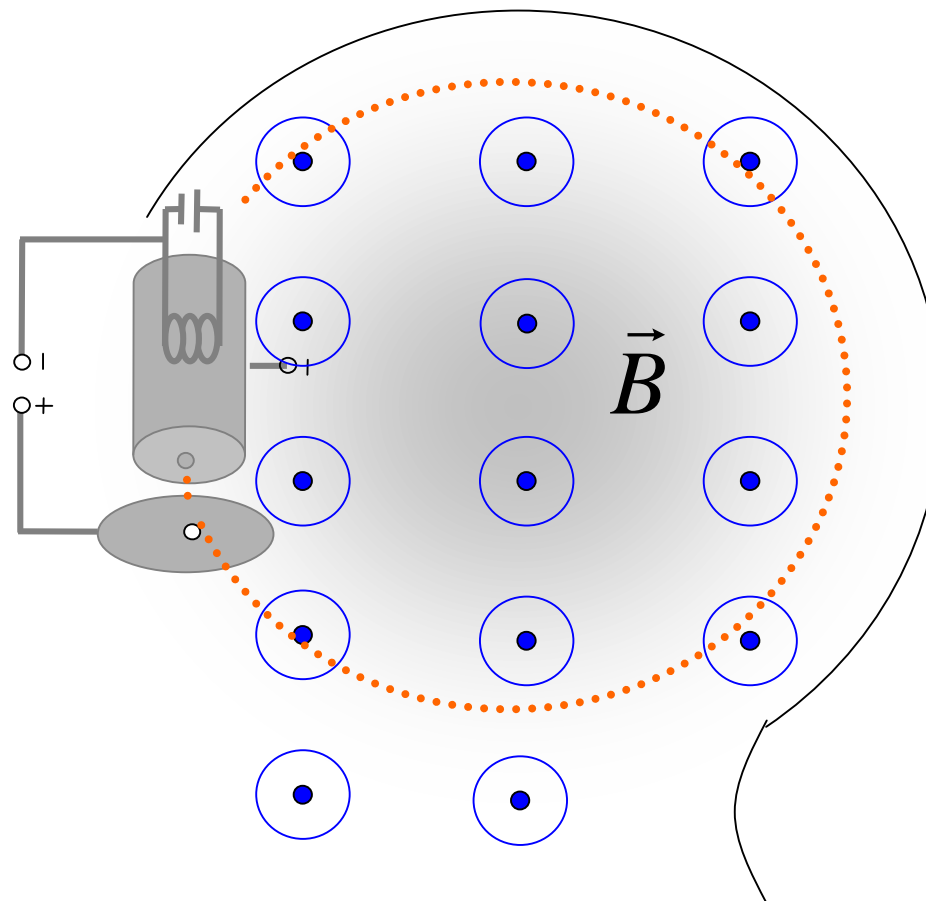


# CMS-Detektor

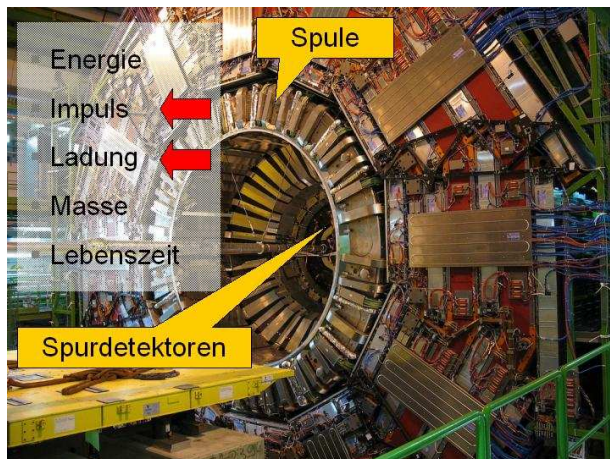
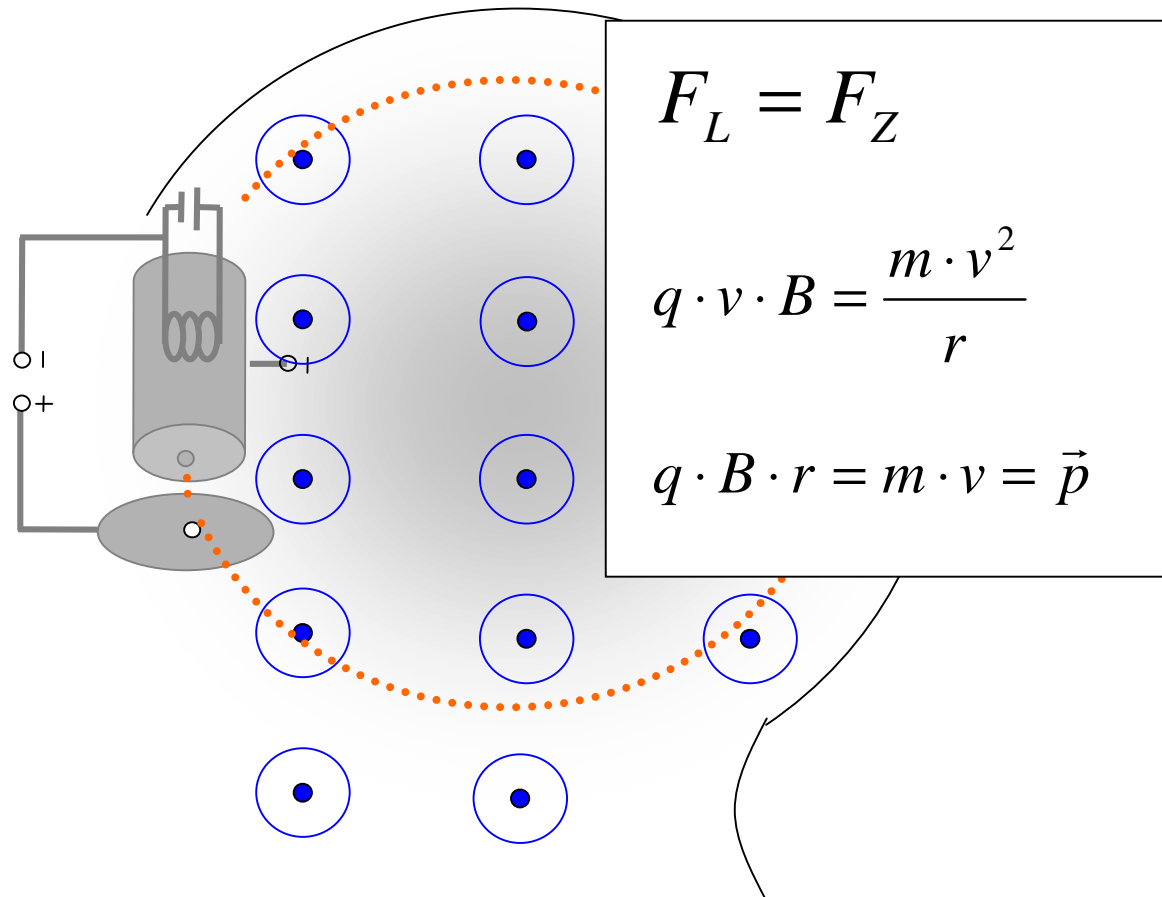


EB Baroney-CERN, 2004

# Bestimmung von Impuls und Ladung



# Bestimmung von Impuls und Ladung



# Technologietransfer



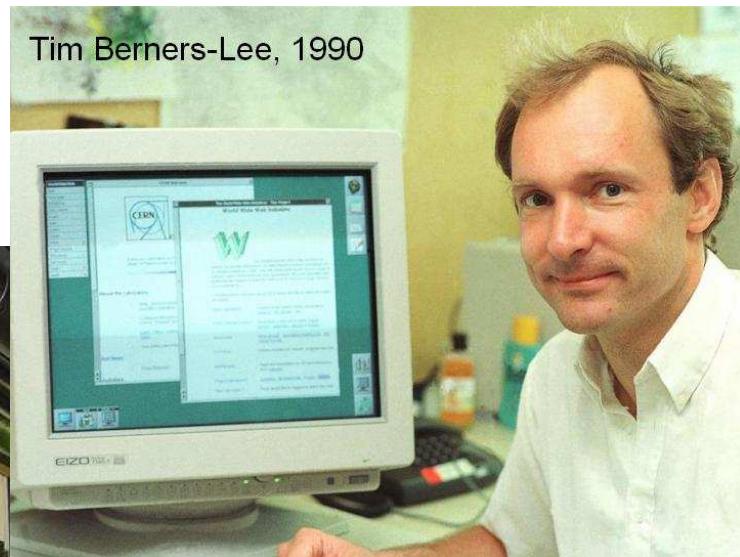
# Technologietransfer



# Technologietransfer



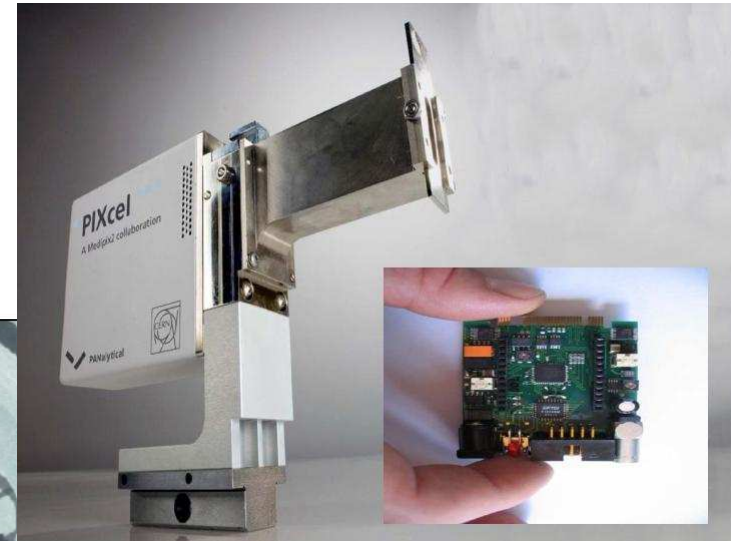
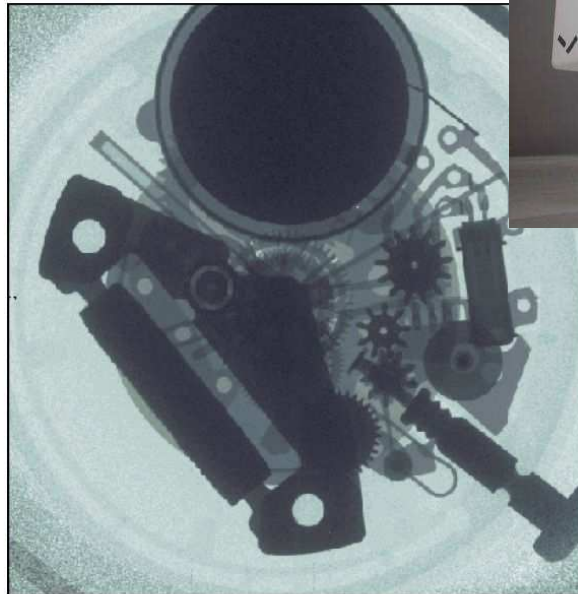
- World Wide Web



# Technologietransfer



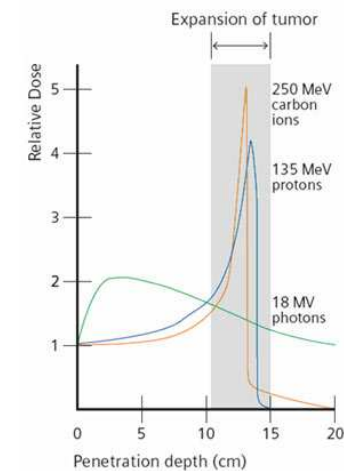
- Medipix-Kamera



# Technologietransfer



- Teilchenbeschleuniger in der Medizin





# Technologietransfer



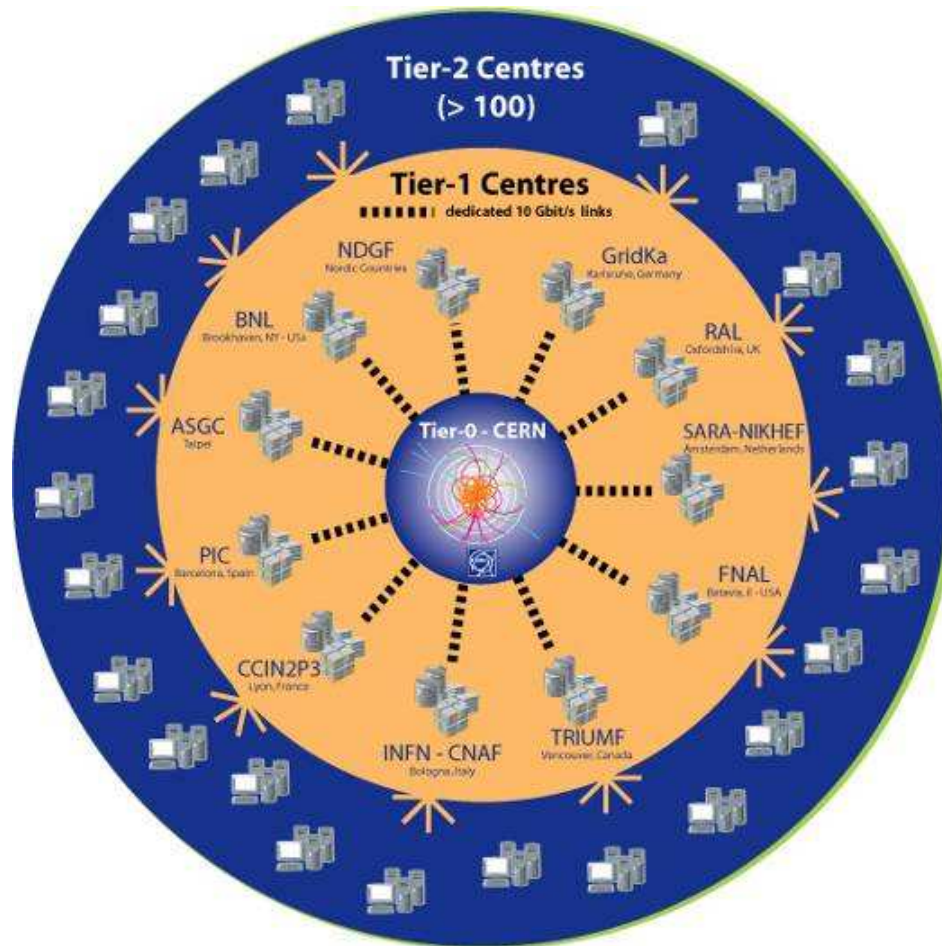
- Teilchenbeschleuniger in der Industrie
  - Polymerisation von Kunststoffen
  - Sterilisierung von Lebensmitteln und medizinischen Geräten
  - Dotieren von Halbleitern
  - Werkstoffüberprüfung



# Technologietransfer



- Das Grid



# Large Hadron Rap

