



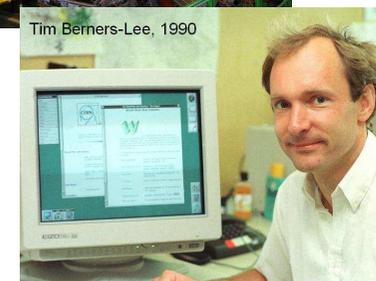
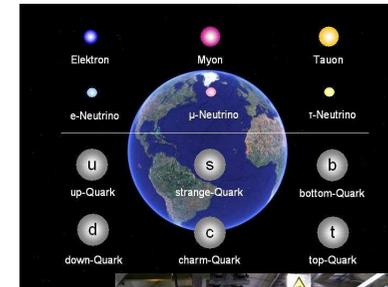
Der Large Hadron Collider (LHC)

...ein Rundgang durch das größte Experiment
der Welt

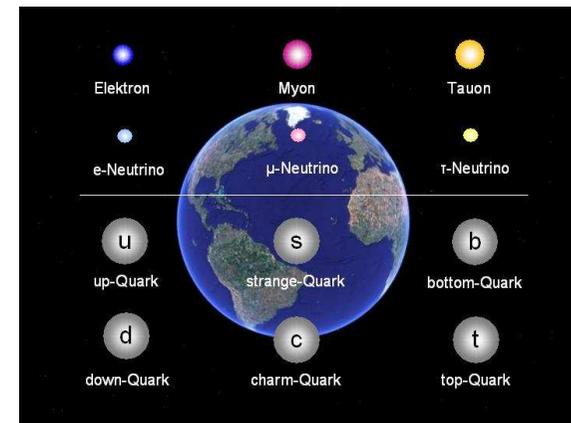
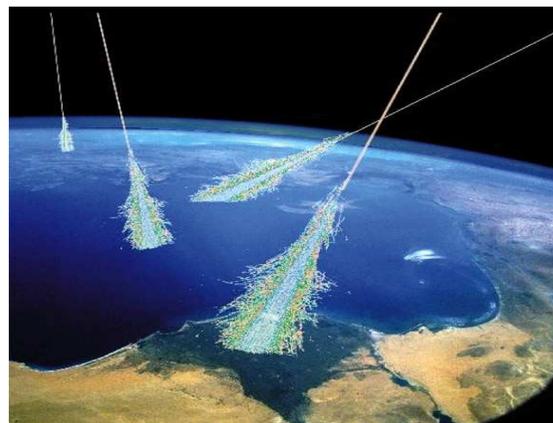
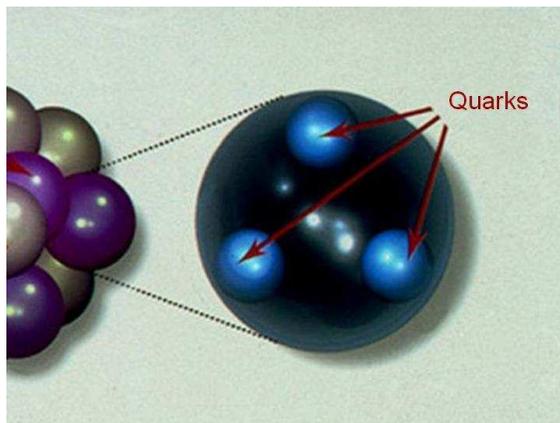
Übersicht



- Die Welt der Elementarteilchen
- Teilchenbeschleuniger
- Teilchendetektoren
- Technologietransfer



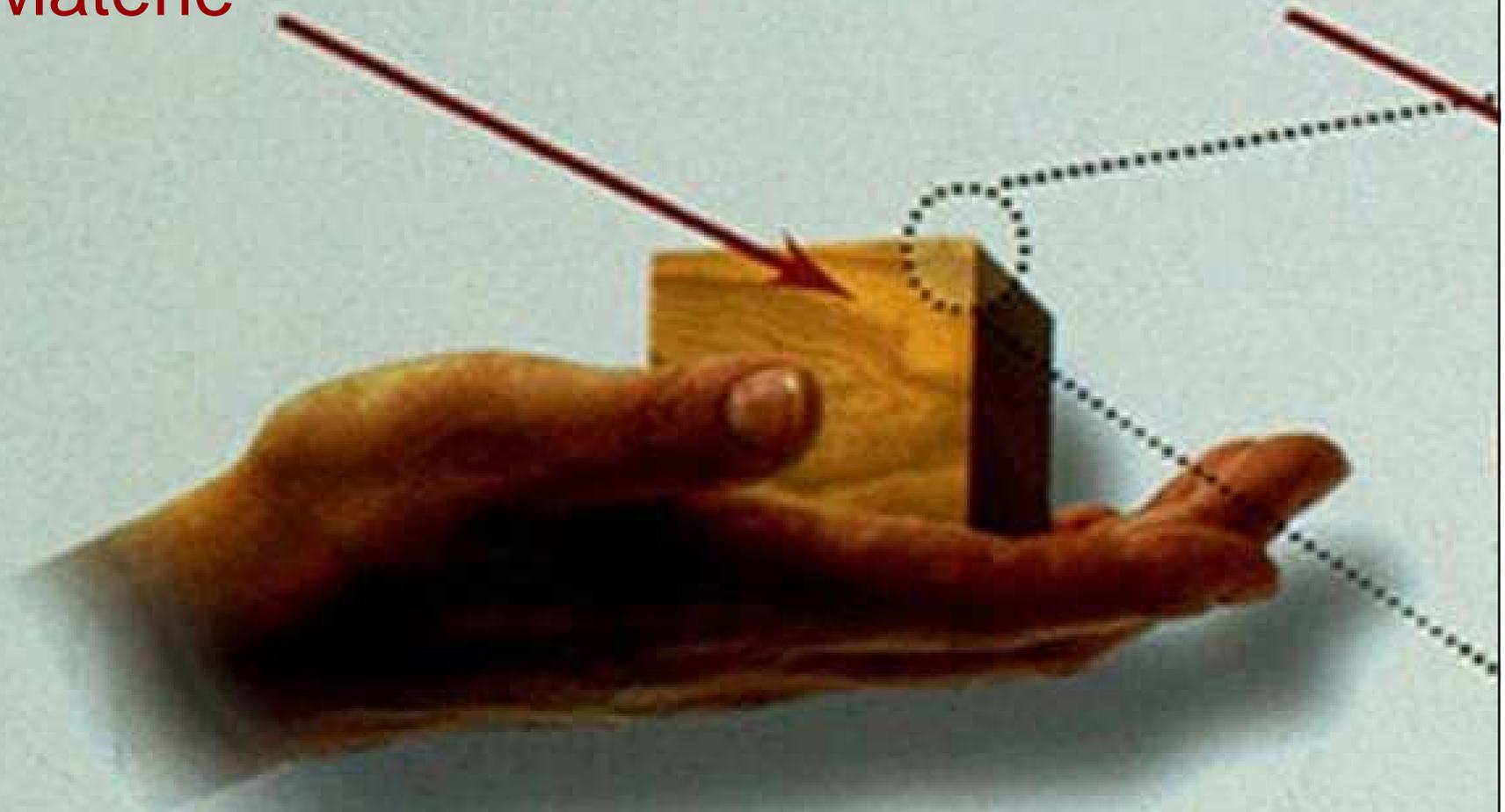
Die Welt der Elementarteilchen



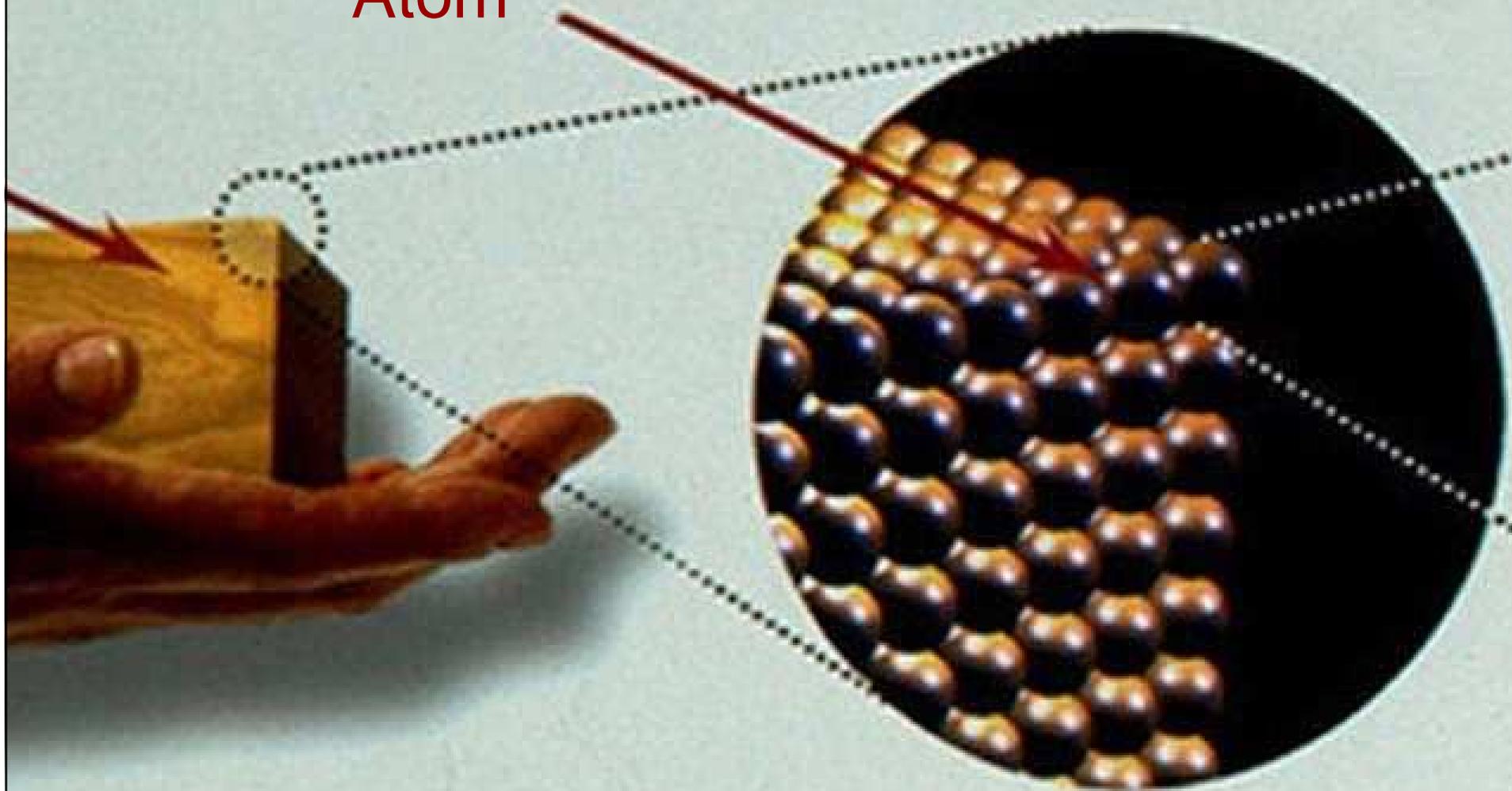
Grundfrage der Teilchenphysik



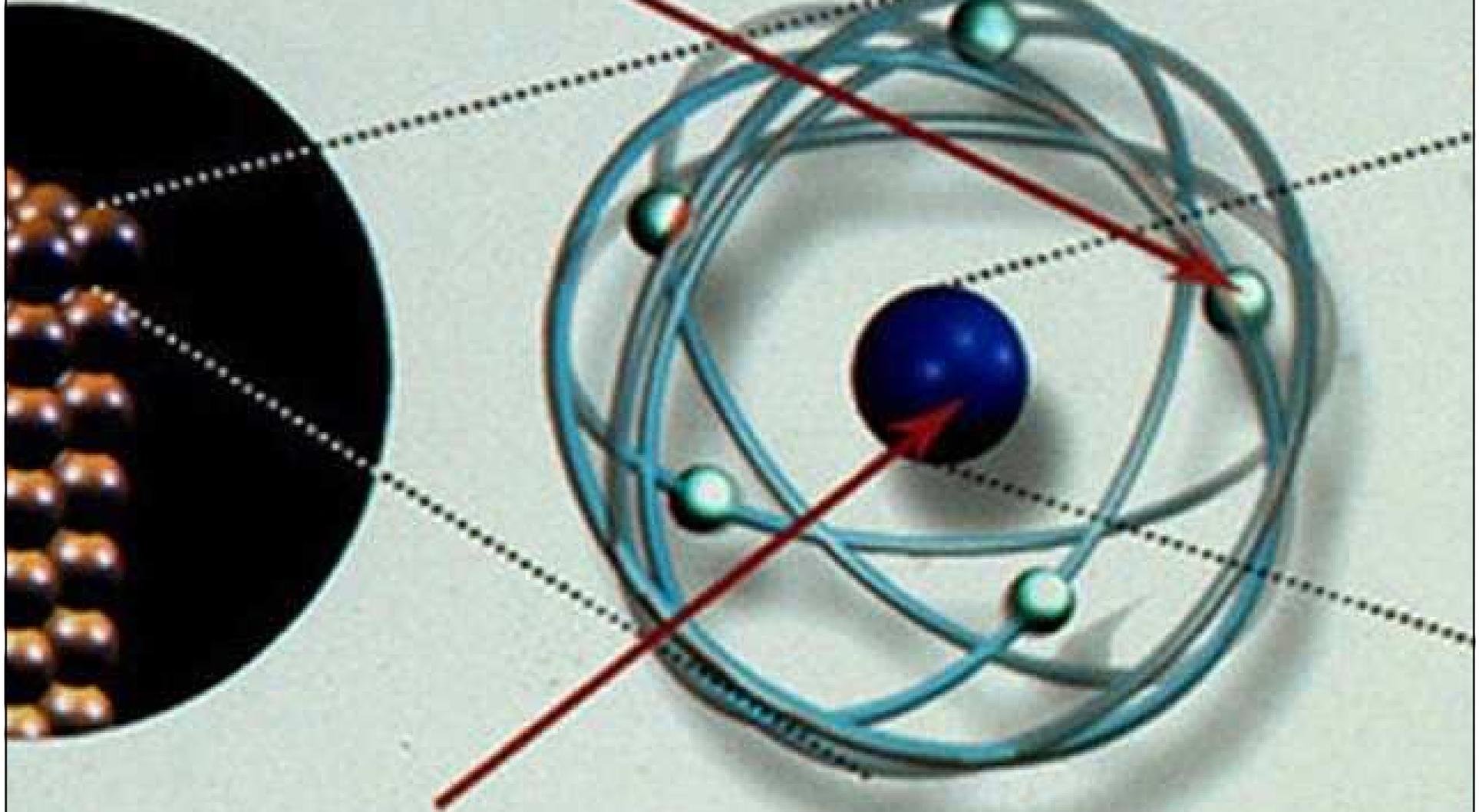
Materie



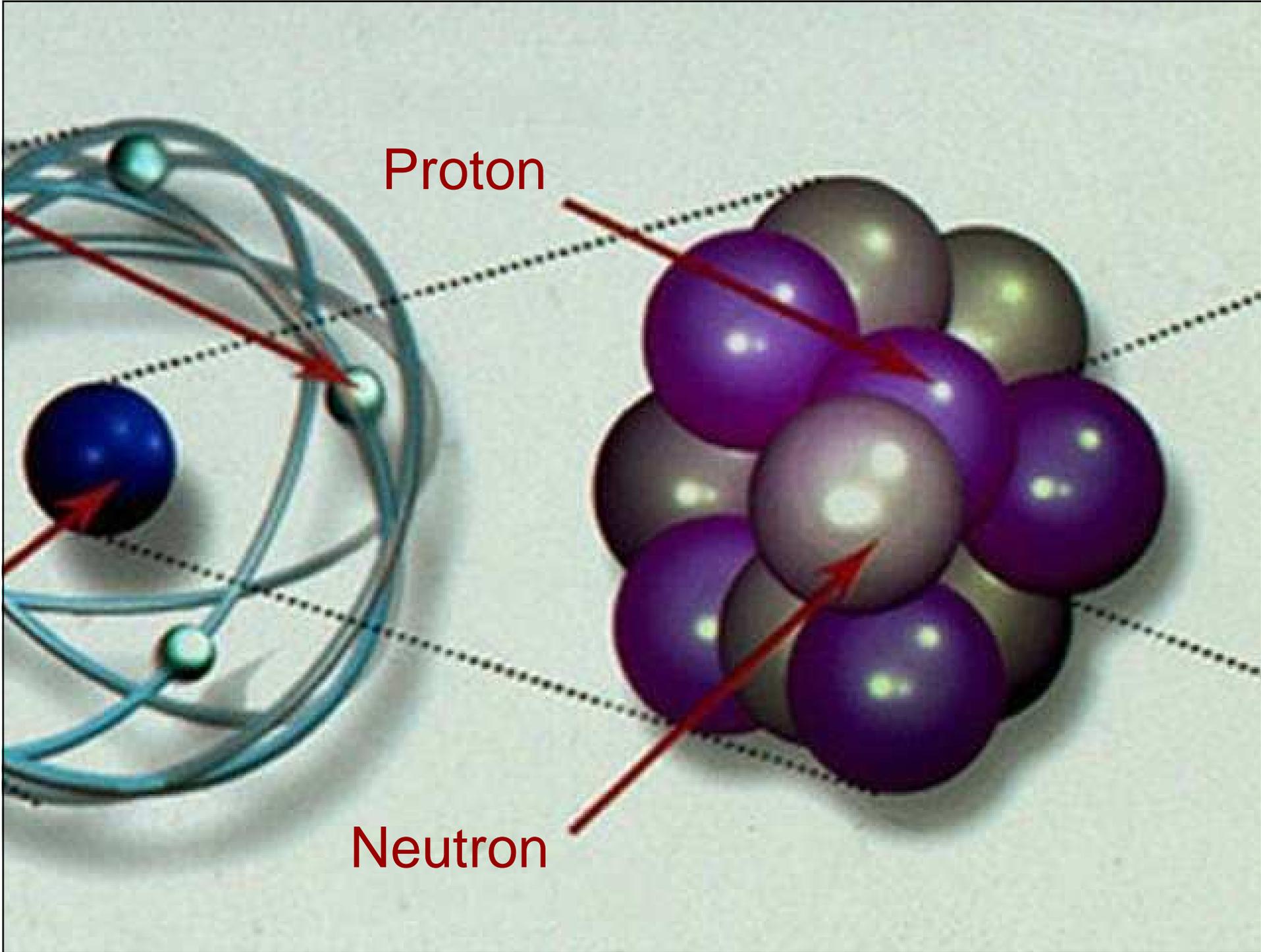
Atom



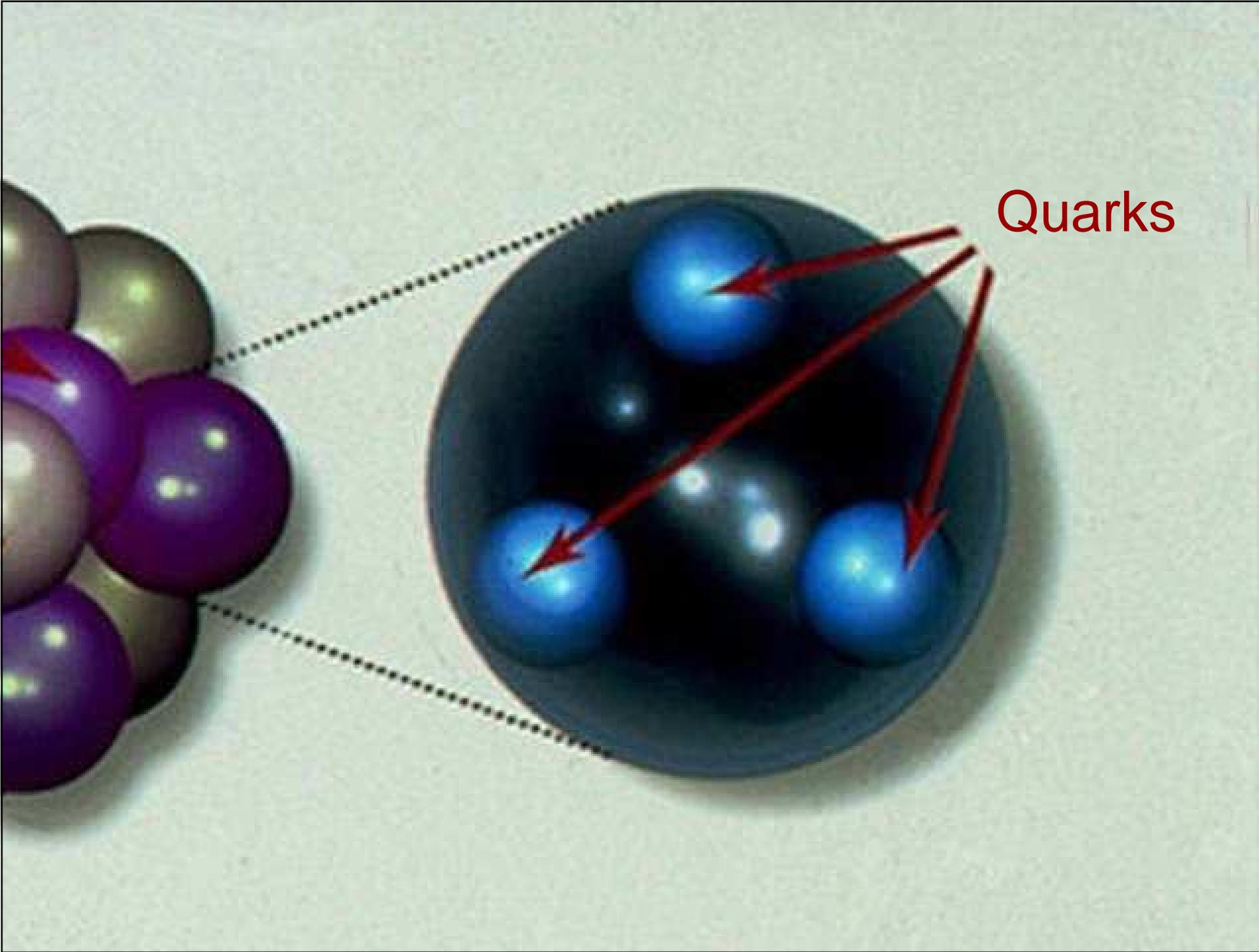
Elektron



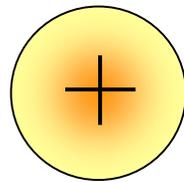
Atomkern



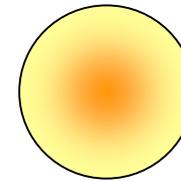
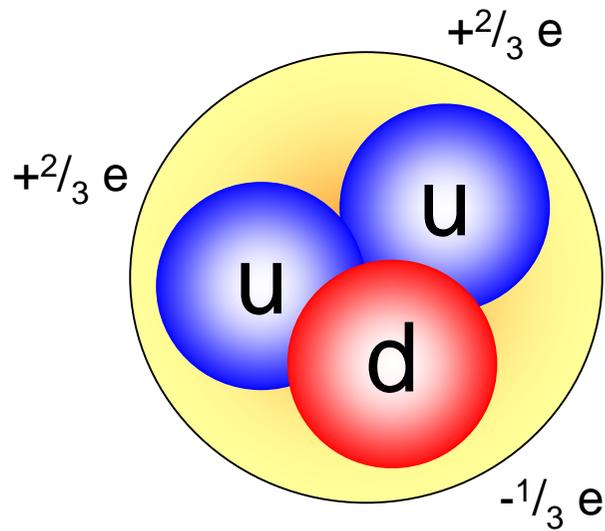
Quarks



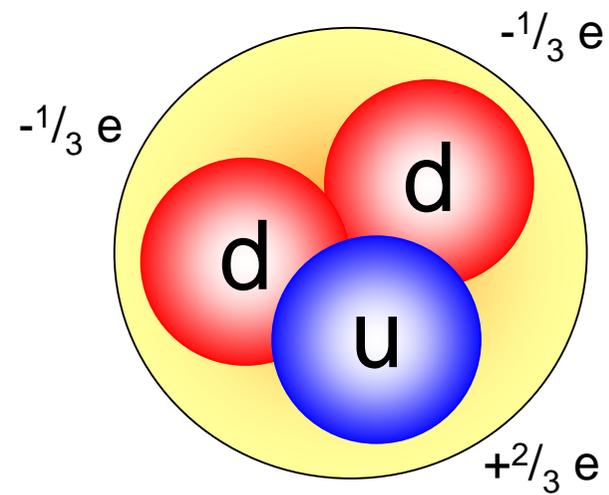
Quarks



Proton



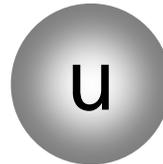
Neutron



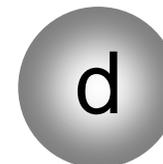
Elementarteilchen



Elektron



up-Quark

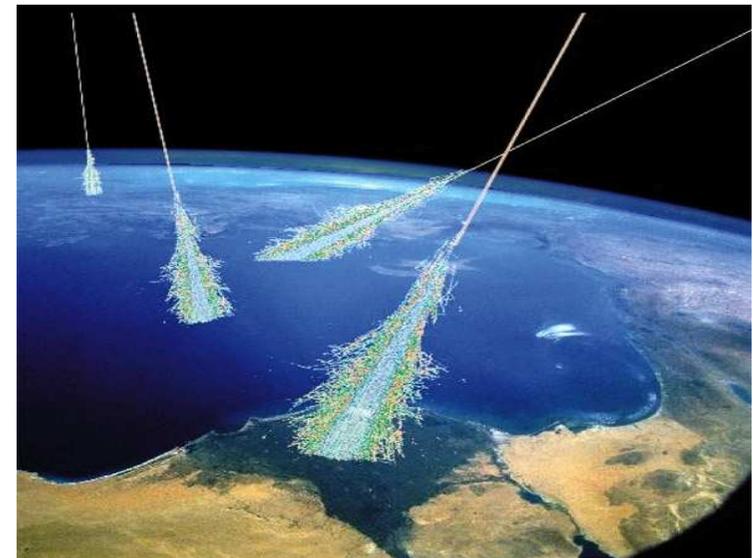


down-Quark

Kosmische Strahlung



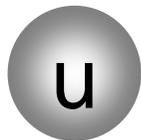
- Entdeckung weiterer Elementarteilchen



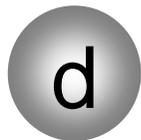
Elementarteilchen



Elektron



up-Quark



down-Quark

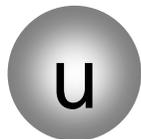
Elementarteilchen



Elektron



Myon



up-Quark



strange-Quark

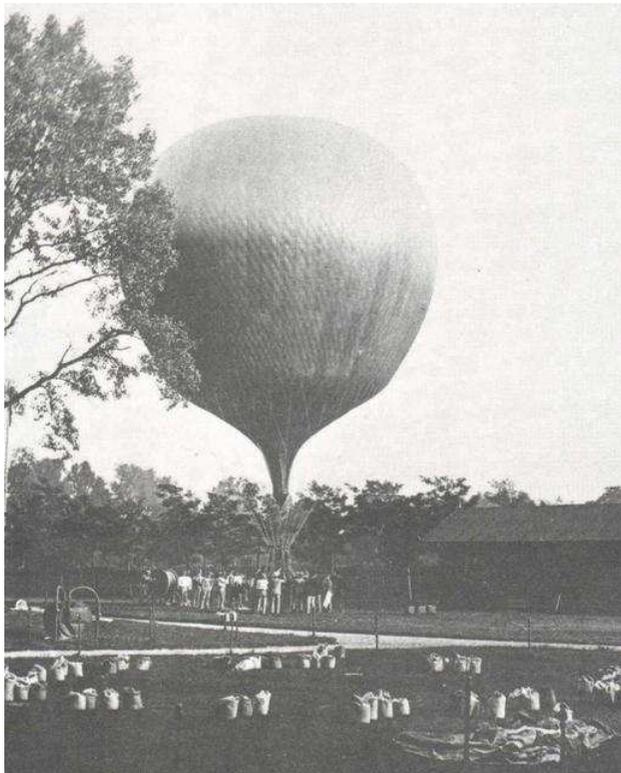


down-Quark

Kosmische Strahlung



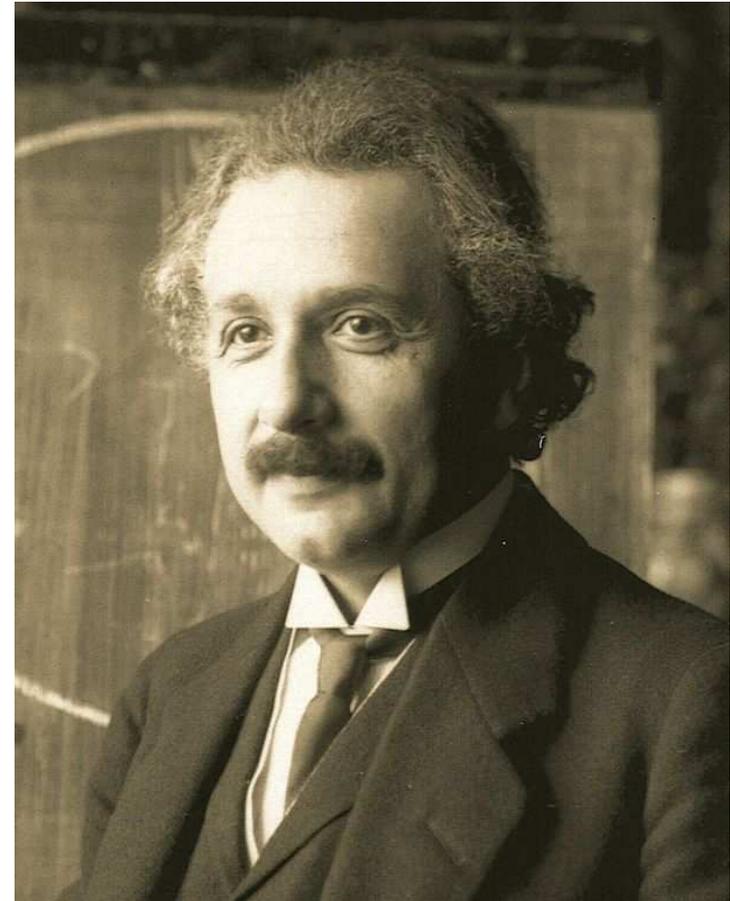
- Beobachtung in Ballons und auf Bergen → mühsam!



Frage



- Wie lautet Einsteins berühmte Gleichung?

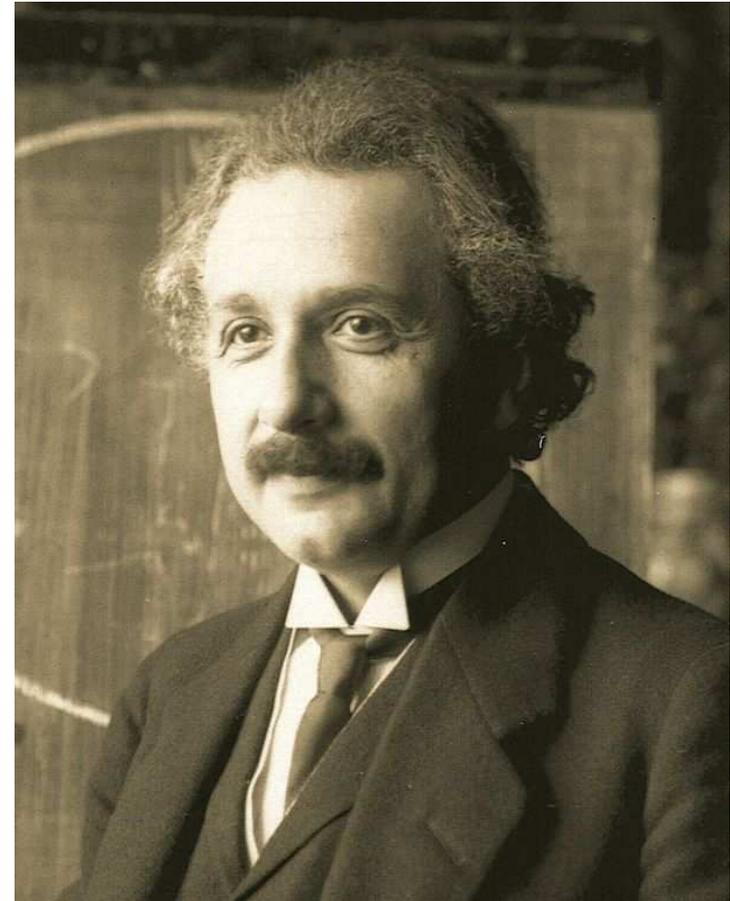


Frage



- Wie lautet Einsteins berühmte Gleichung?

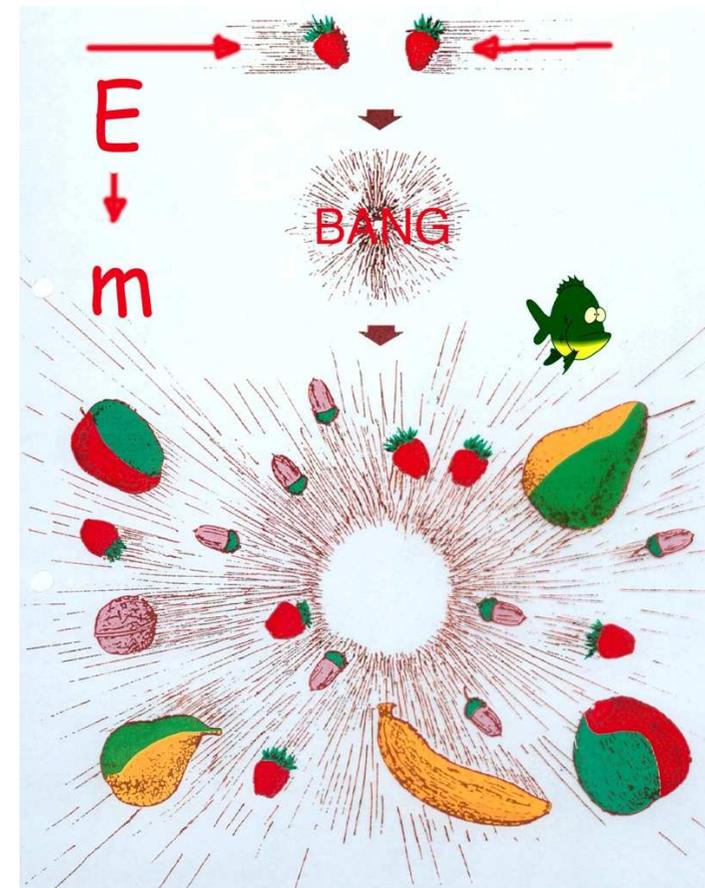
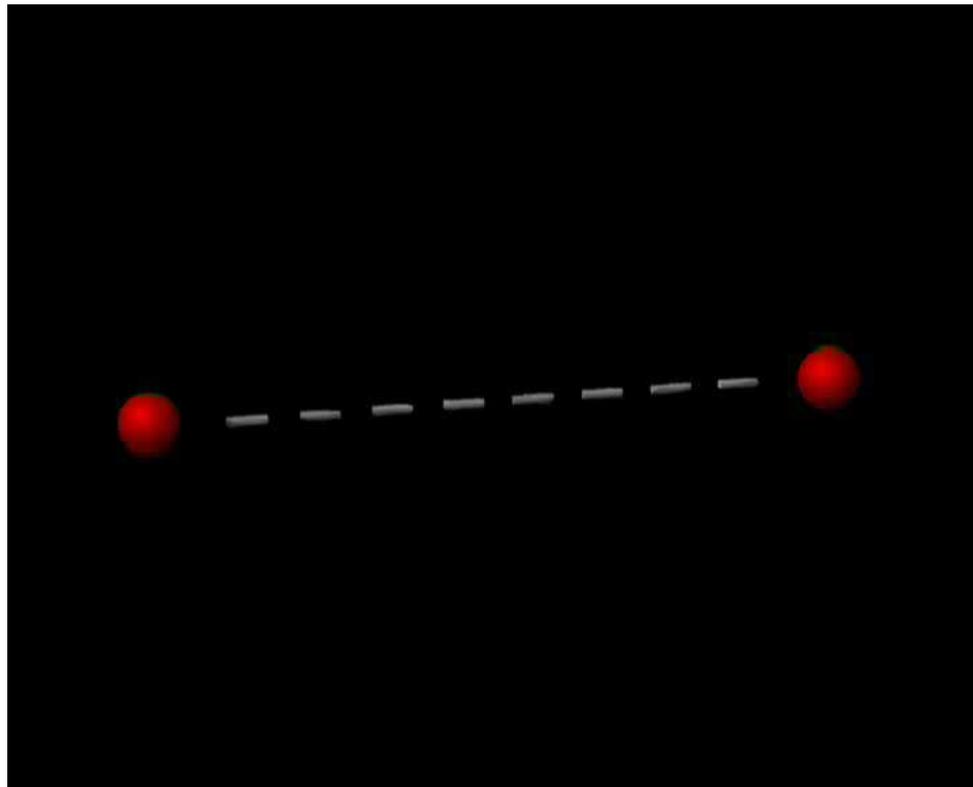
$$E=mc^2$$



Teilchenbeschleuniger



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



Elementarteilchen



Elektron



Myon



up-Quark



strange-Quark



down-Quark

Elementarteilchen



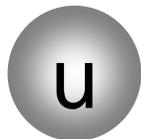
Elektron



Myon



Tauon



up-Quark



strange-Quark



down-Quark

Elementarteilchen



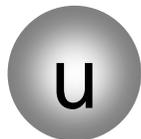
Elektron



Myon



Tauon



up-Quark



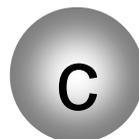
strange-Quark



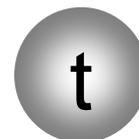
bottom-Quark



down-Quark



charm-Quark



top-Quark

Elementarteilchen



Elektron



Myon



Tauon



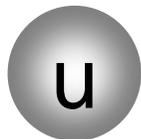
e-Neutrino



μ -Neutrino



τ -Neutrino



up-Quark



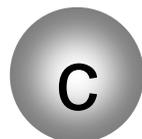
strange-Quark



bottom-Quark



down-Quark



charm-Quark



top-Quark

Offene Fragen



Elektron



Myon



Tauon



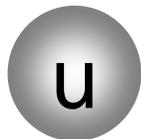
e-Neutrino



μ -Neutrino



τ -Neutrino



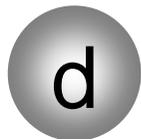
up-Quark



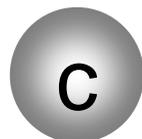
strange-Quark



bottom-Quark



down-Quark



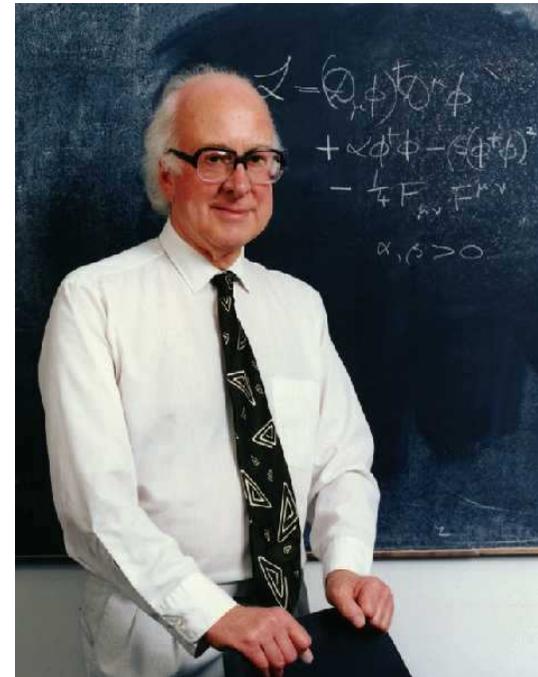
charm-Quark



top-Quark

**Masse der
Elementarteilchen?**

Higgs-Feld



Peter Higgs

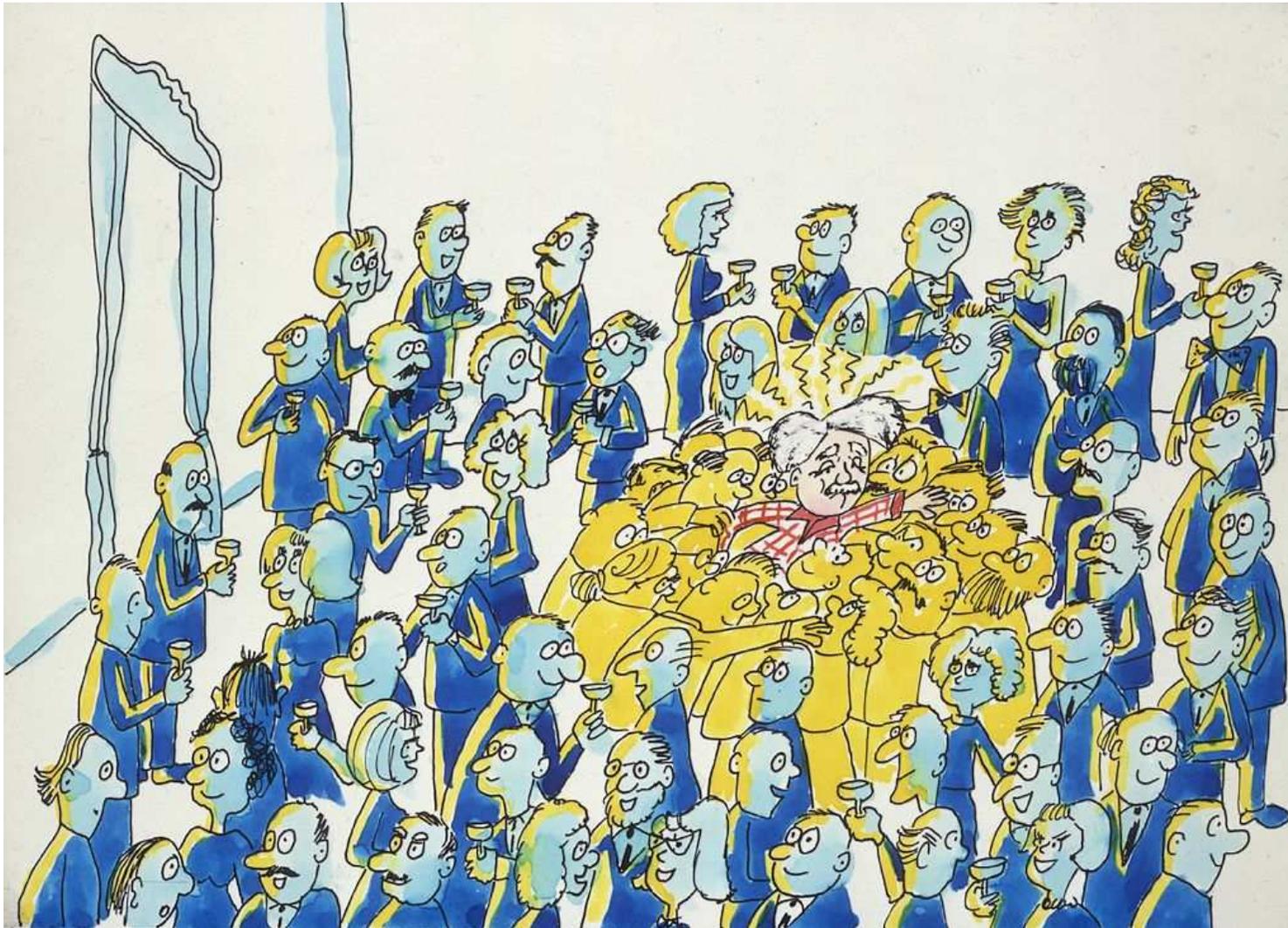
Higgs-Feld



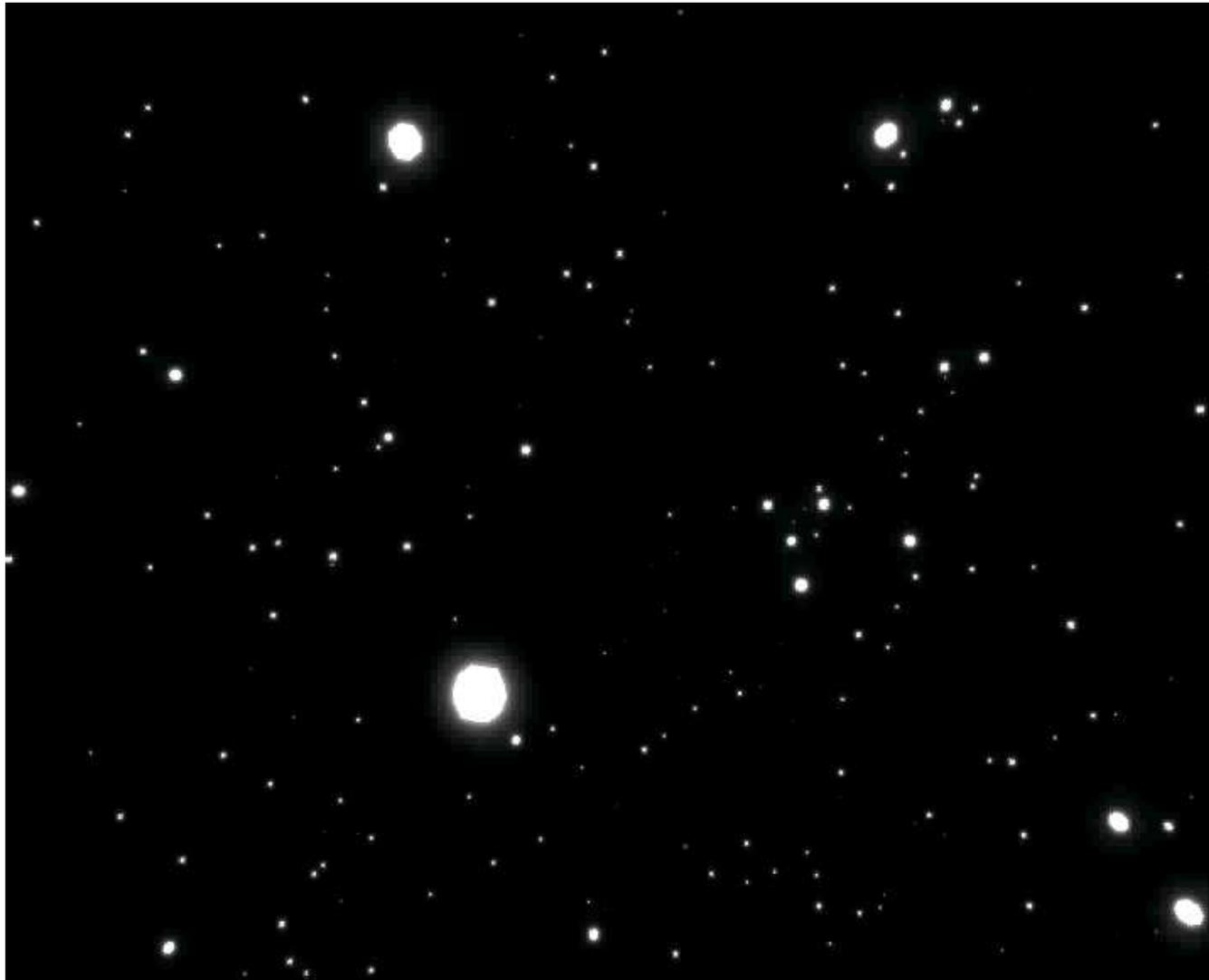
Higgs-Feld



Higgs-Feld



Higgs-Teilchen



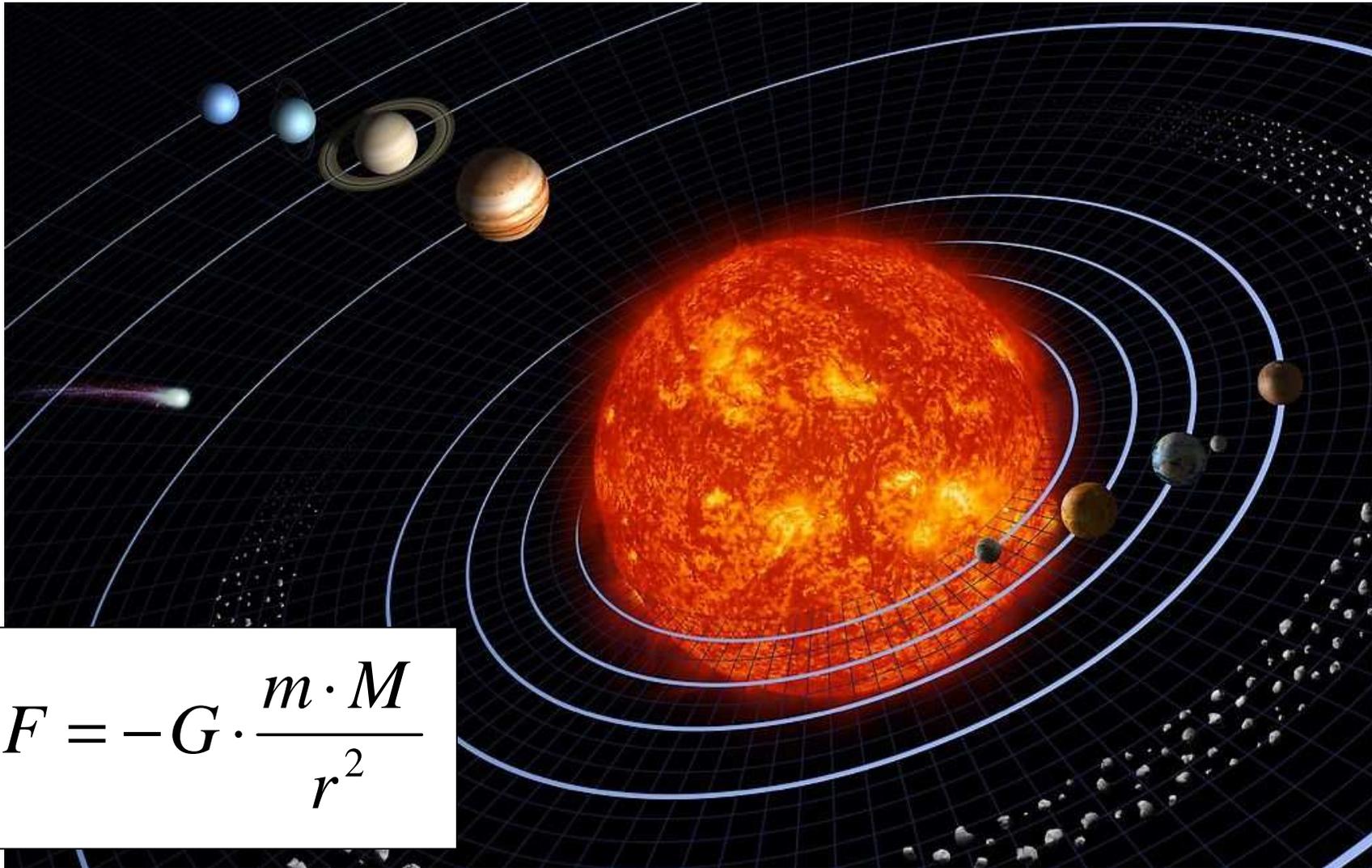
Higgs-Teilchen



Higgs-Teilchen

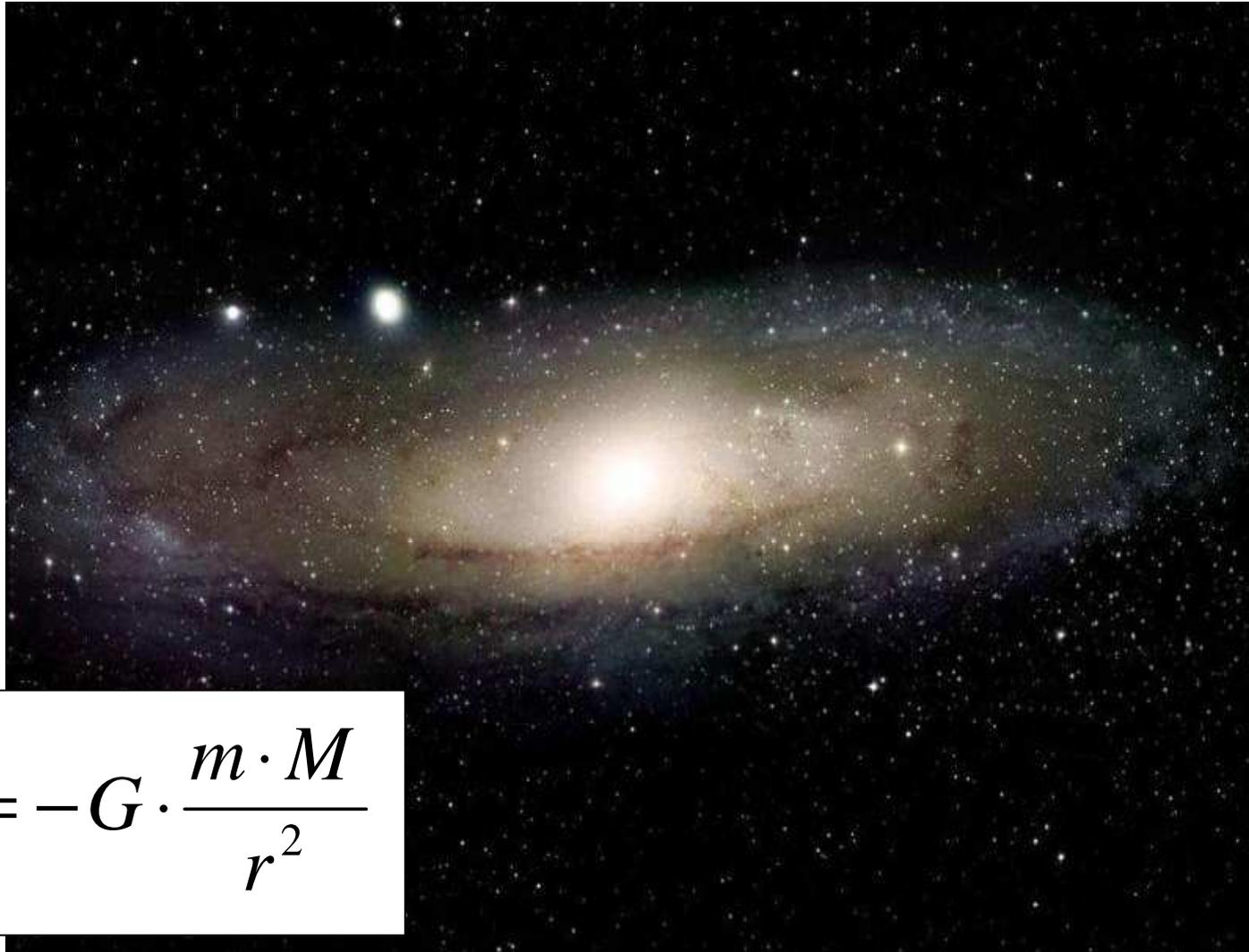


Dunkle Materie



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

Dunkle Materie



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

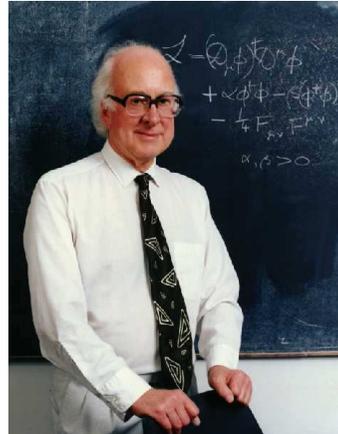
Dunkle Materie



Offene Fragen

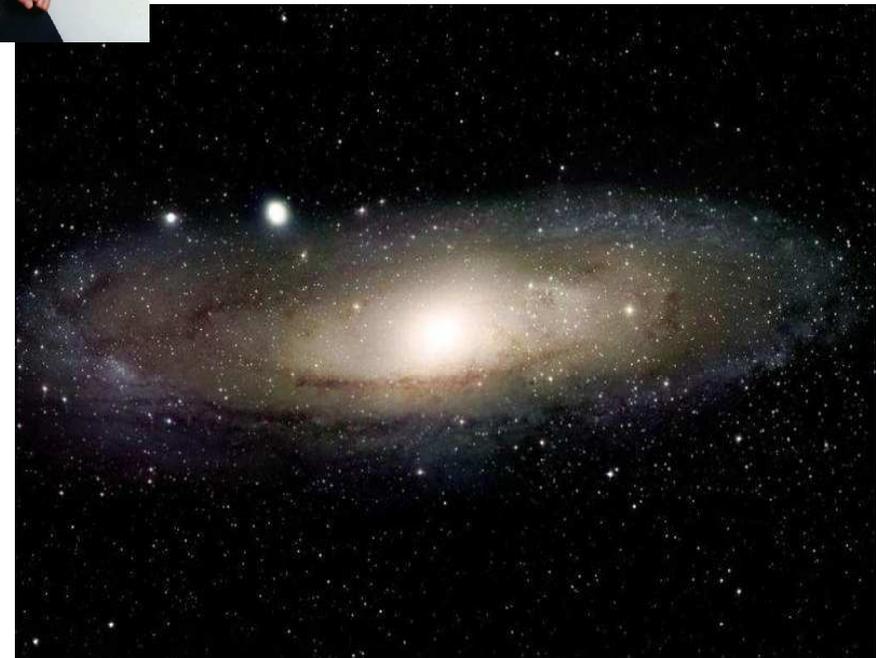


- Higgs-Teilchen



- Dunkle Materie

- ...

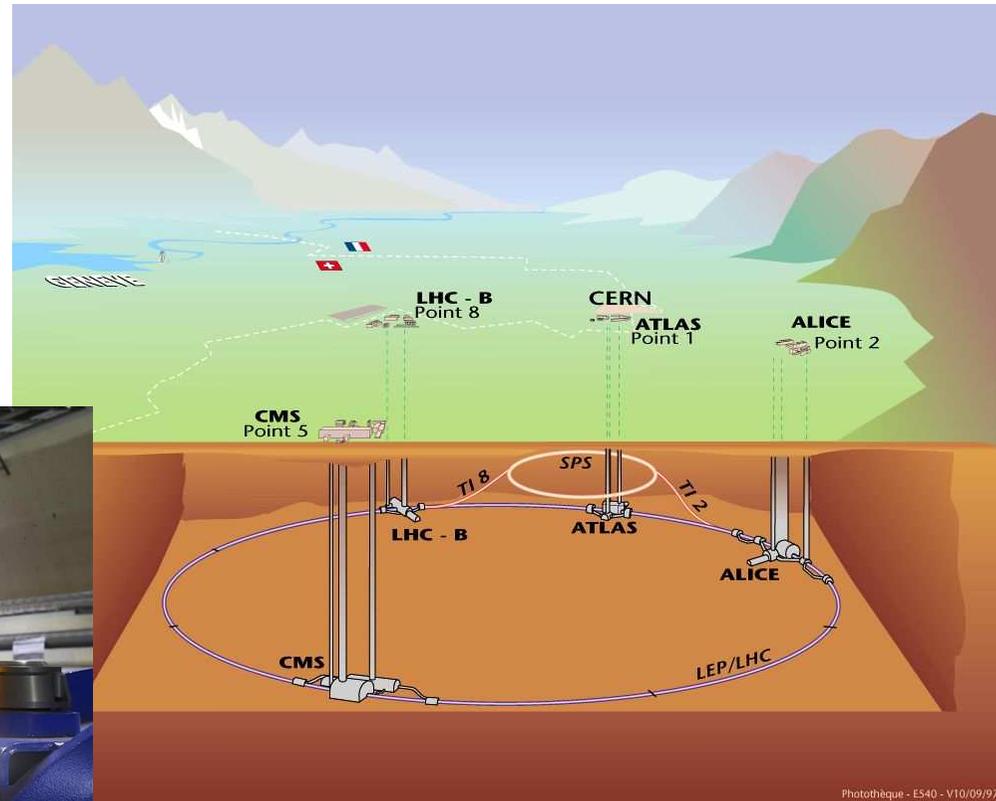




Der Large Hadron Collider am CERN



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

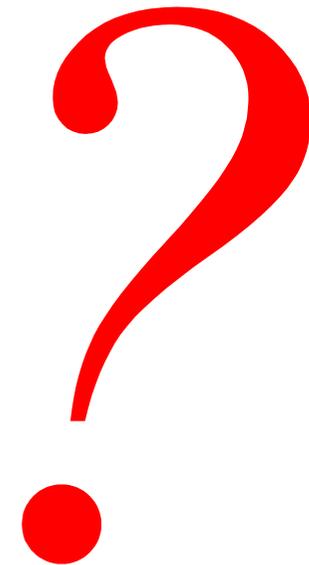


Photothèque - ES40 - V10/09/97

Teilchenbeschleuniger



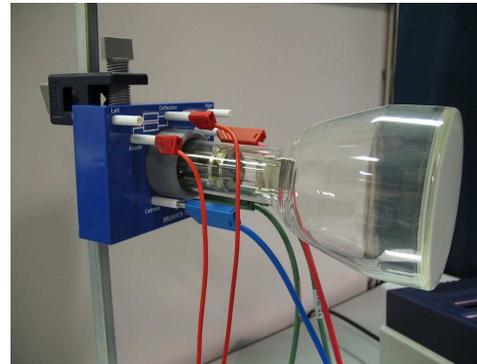
Teilchenbeschleuniger in der Schule



Teilchenbeschleuniger in der Schule



- Braun'sche Röhre



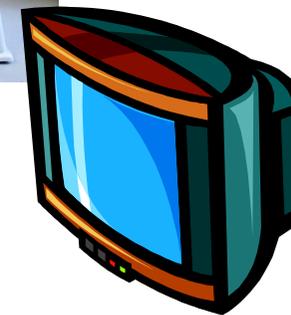
- Oszilloskop



- Fadenstrahlröhre



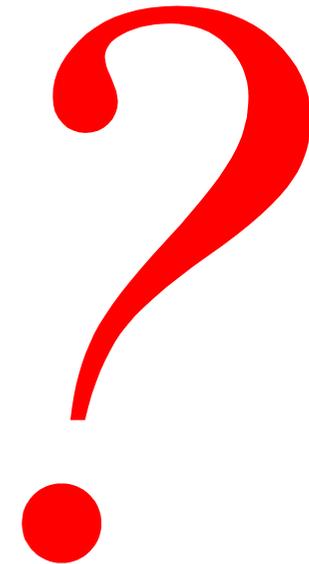
- TV-Gerät



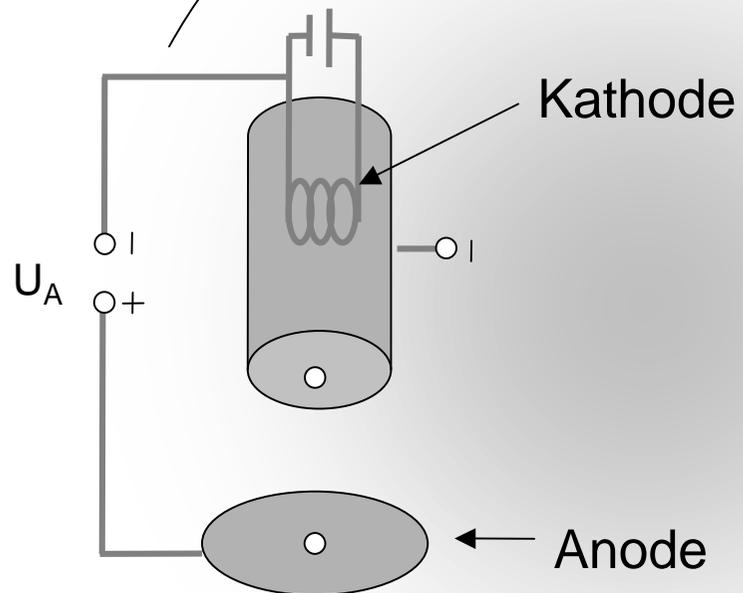
Fragen



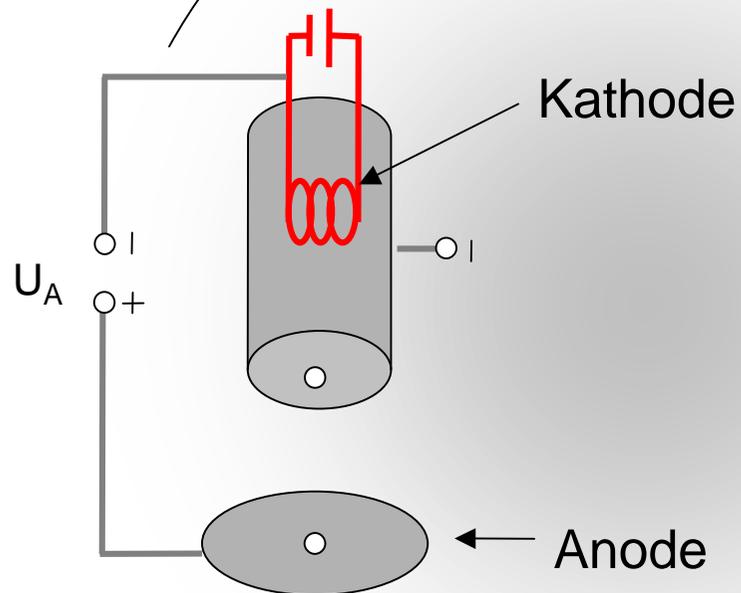
- Wie erzeugt man freie Elektronen?
- Wie beschleunigt man geladene Teilchen?



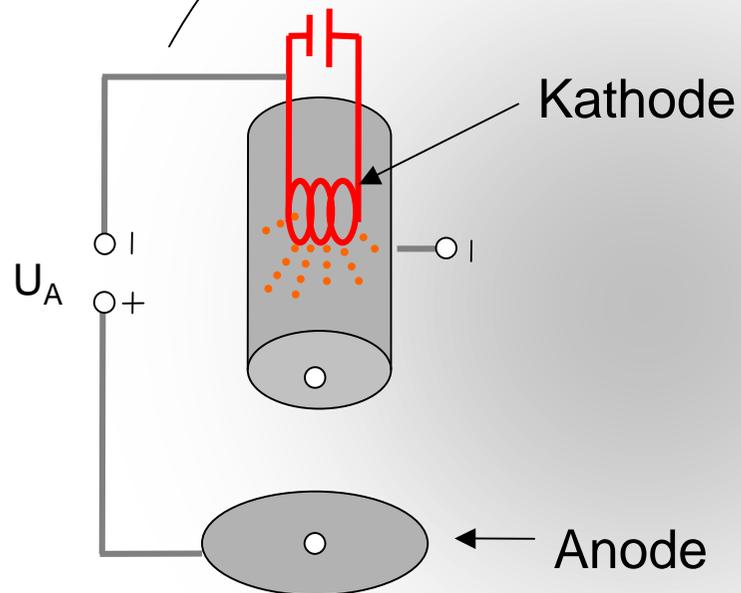
Fadenstrahlröhre



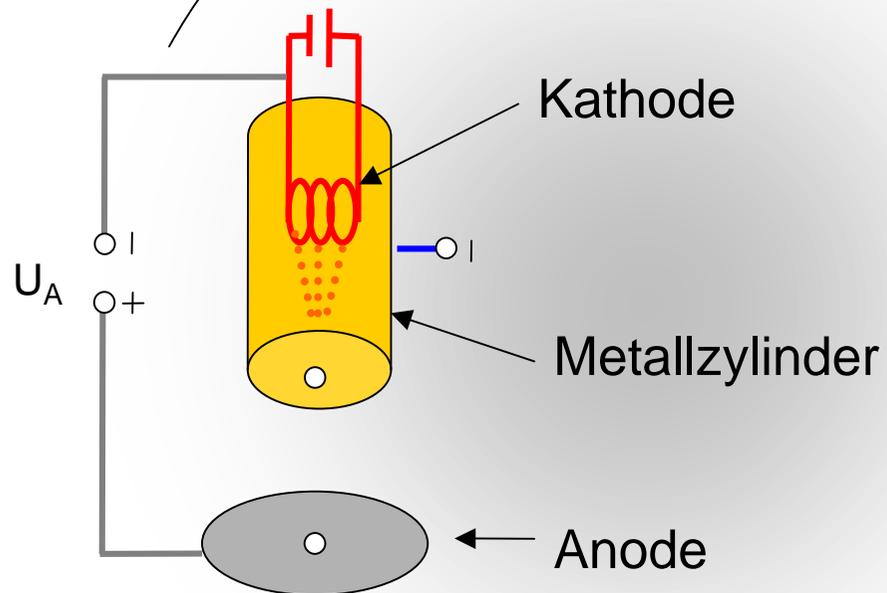
Fadenstrahlröhre



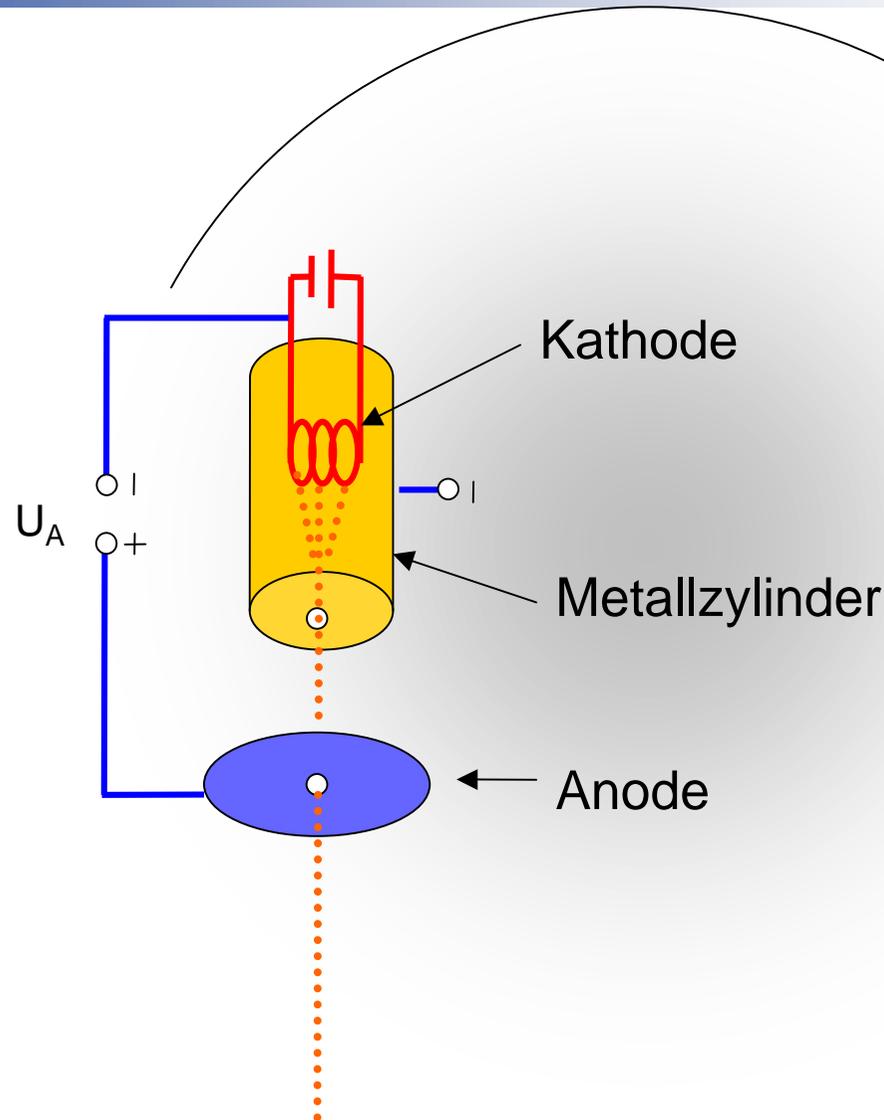
Fadenstrahlröhre



Fadenstrahlröhre

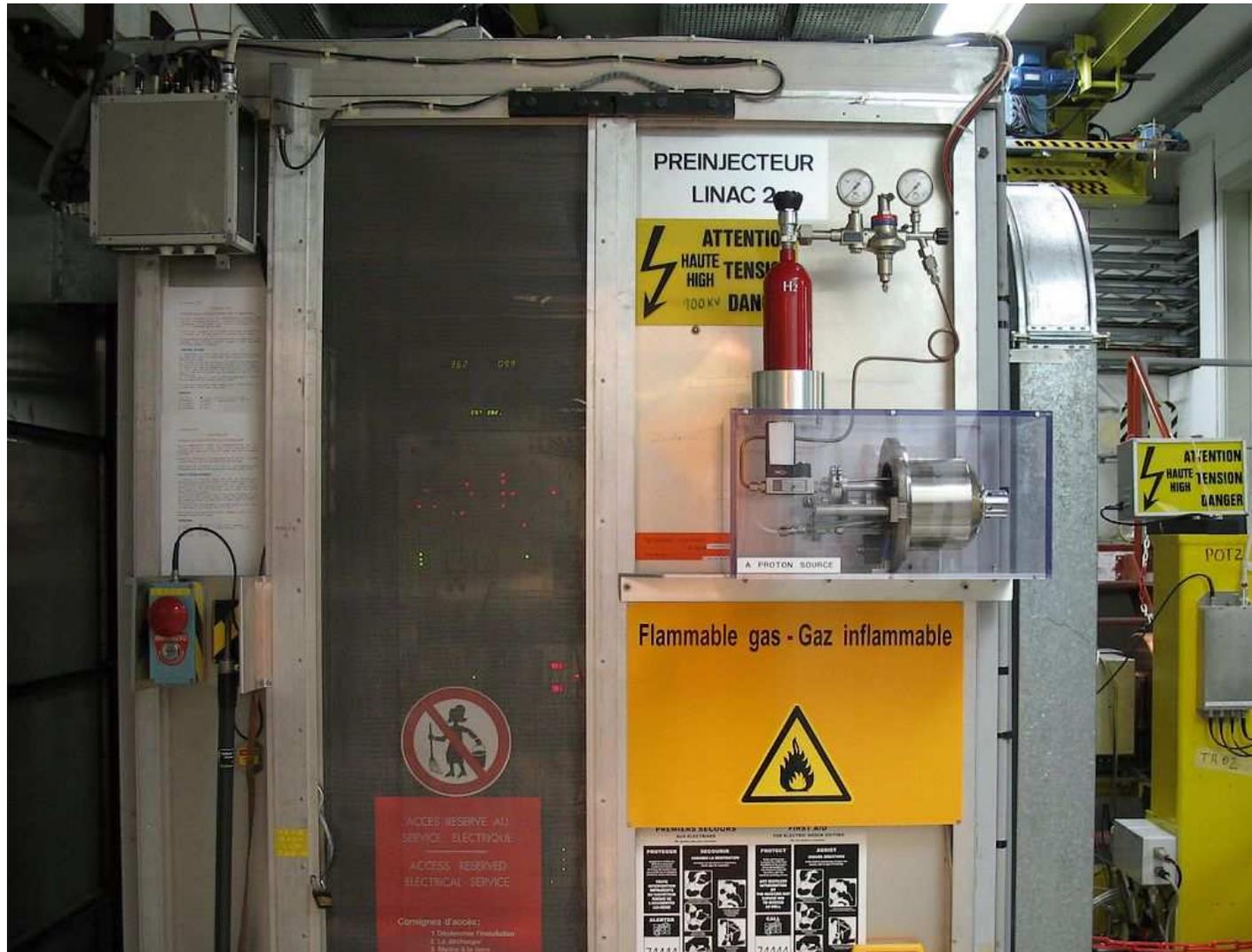


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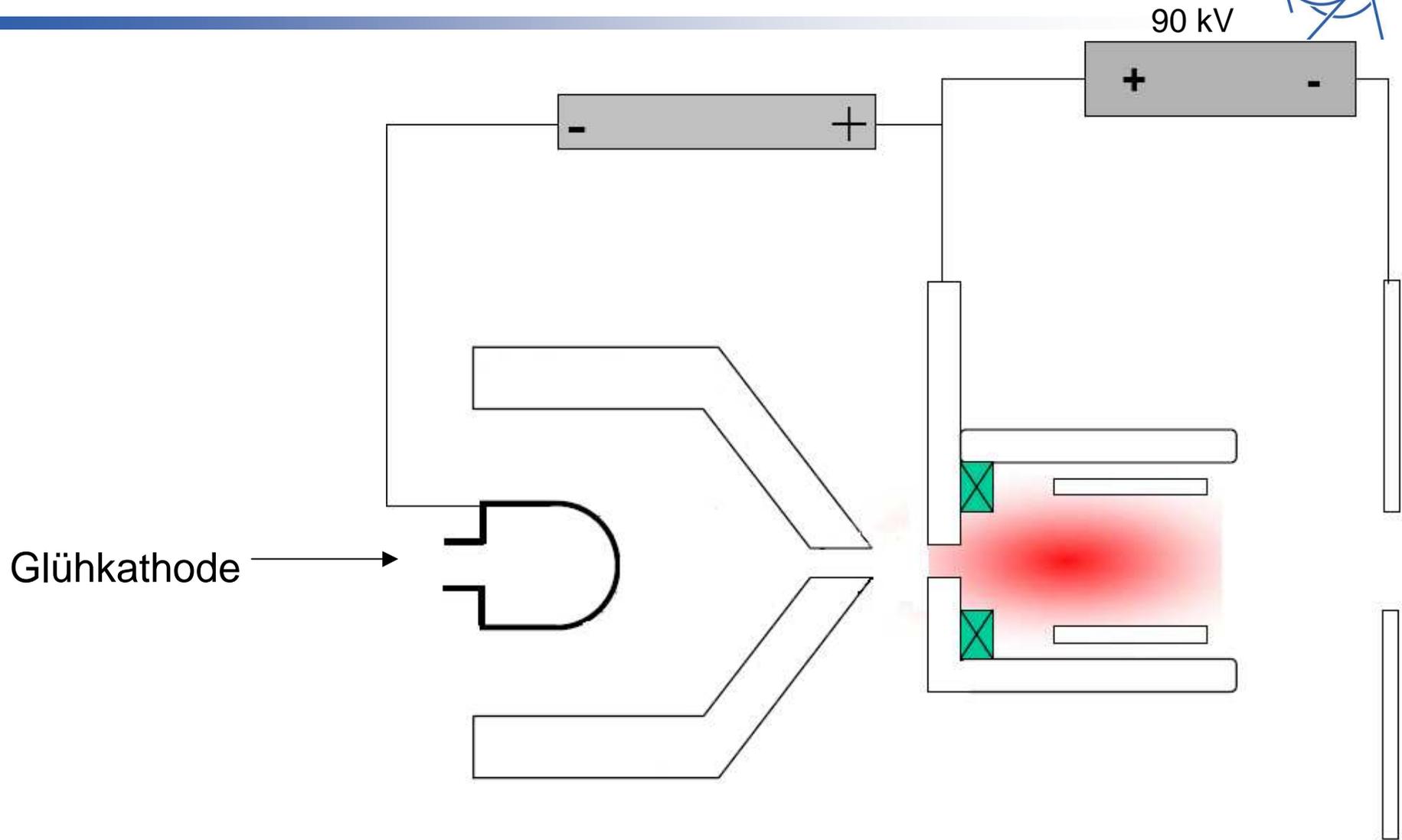




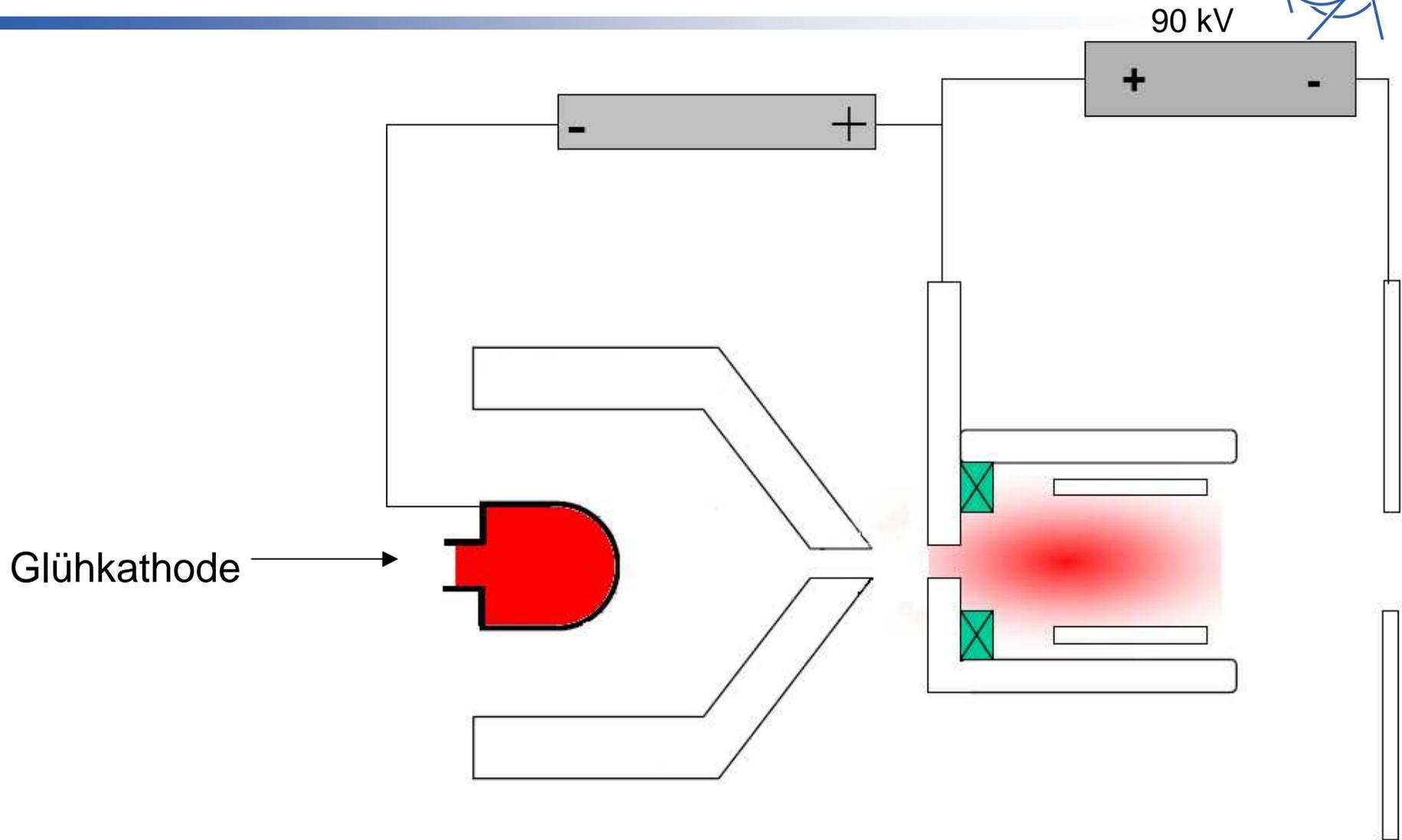
CERN-Protonenquelle



CERN-Protonenquelle



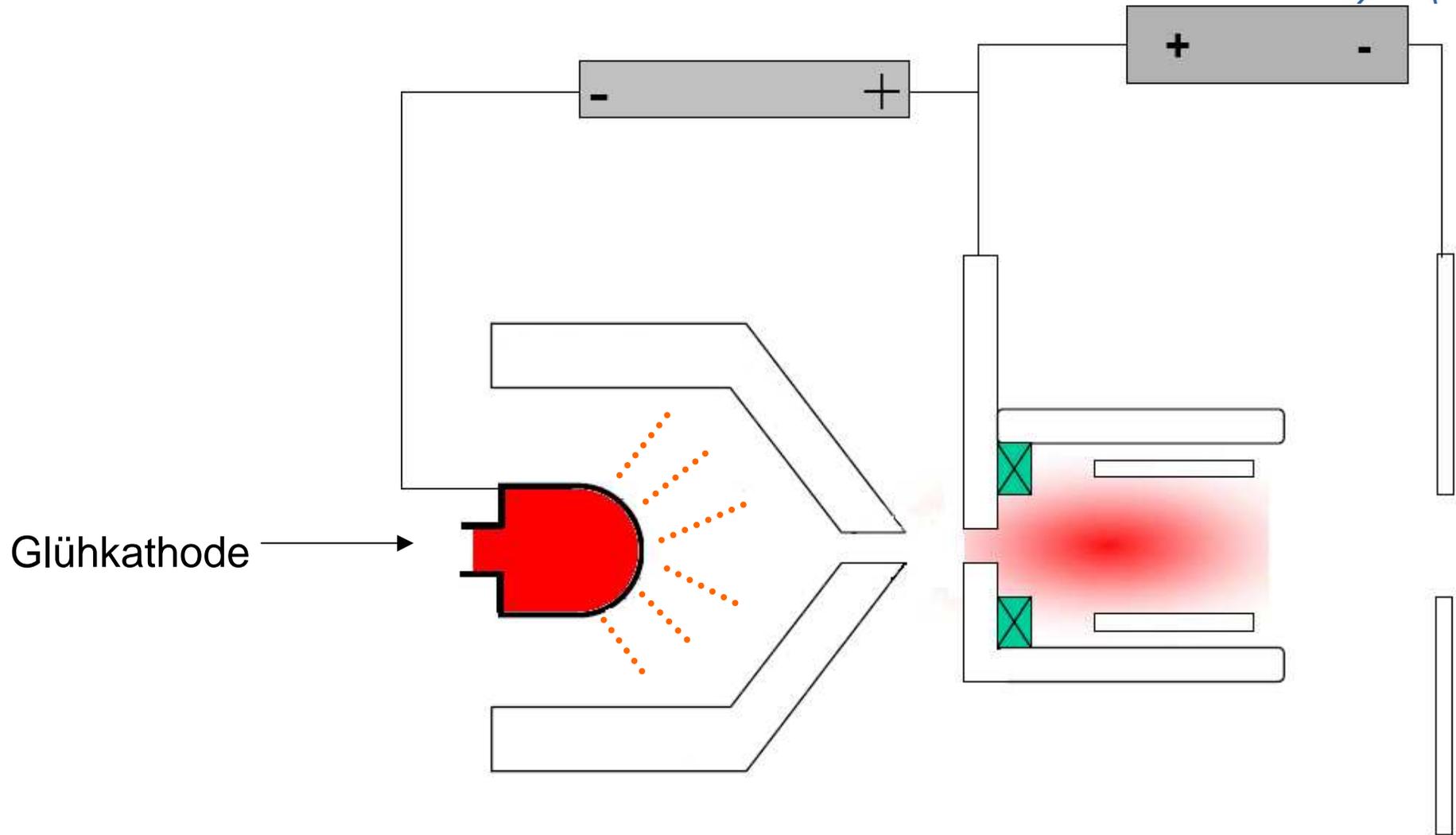
CERN-Protonenquelle



CERN-Protonenquelle



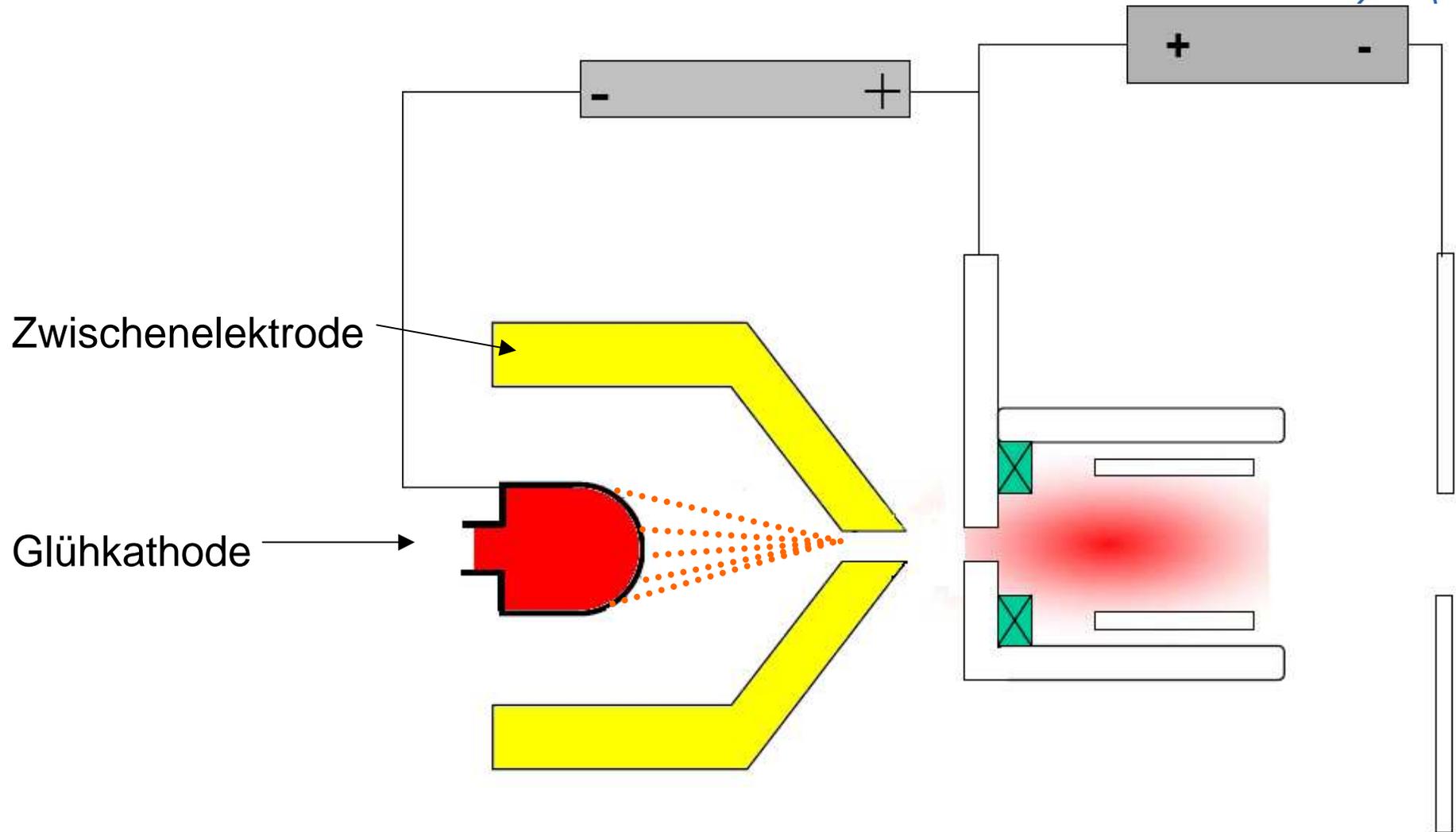
90 kV



CERN-Protonenquelle



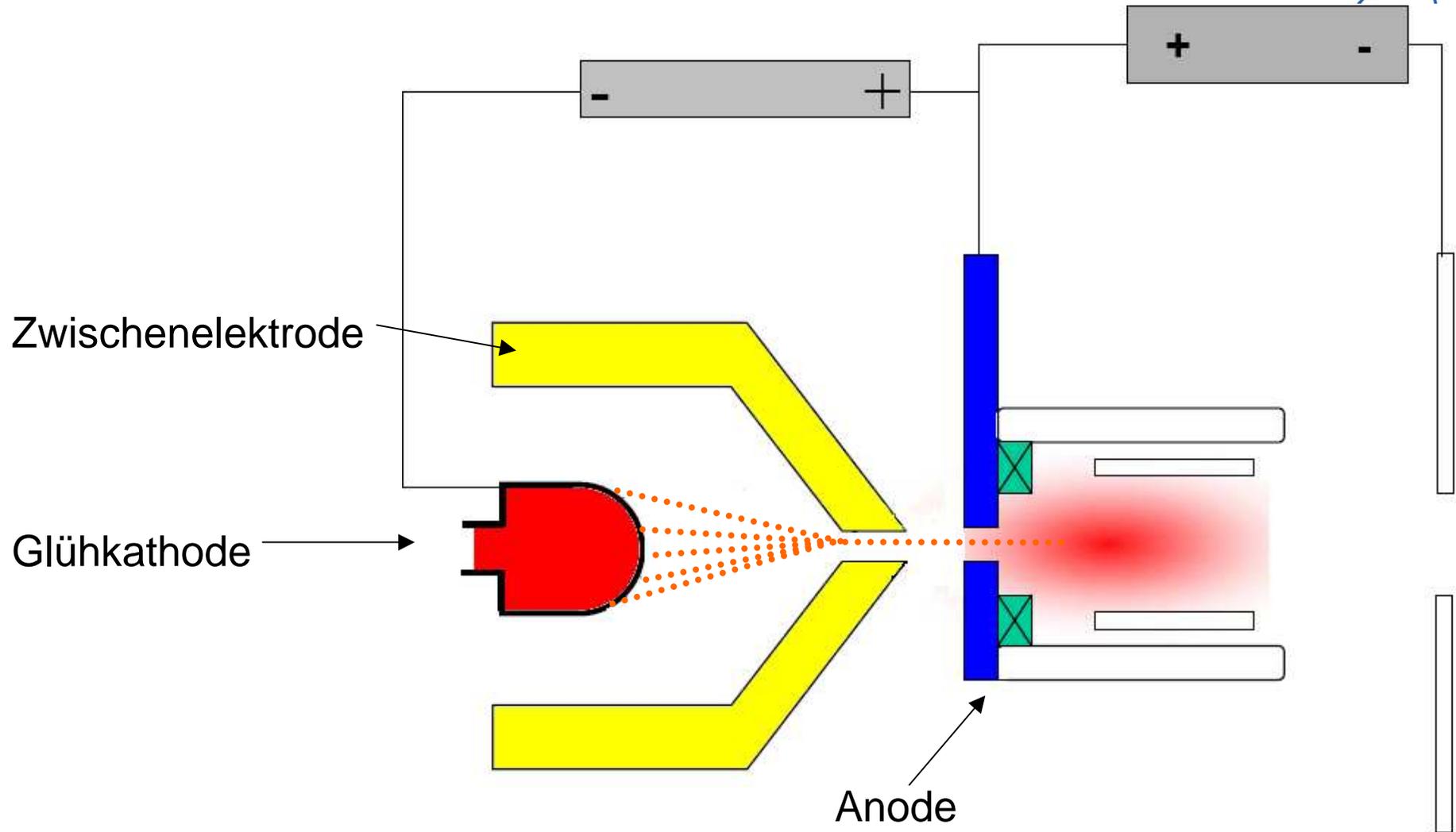
90 kV



CERN-Protonenquelle



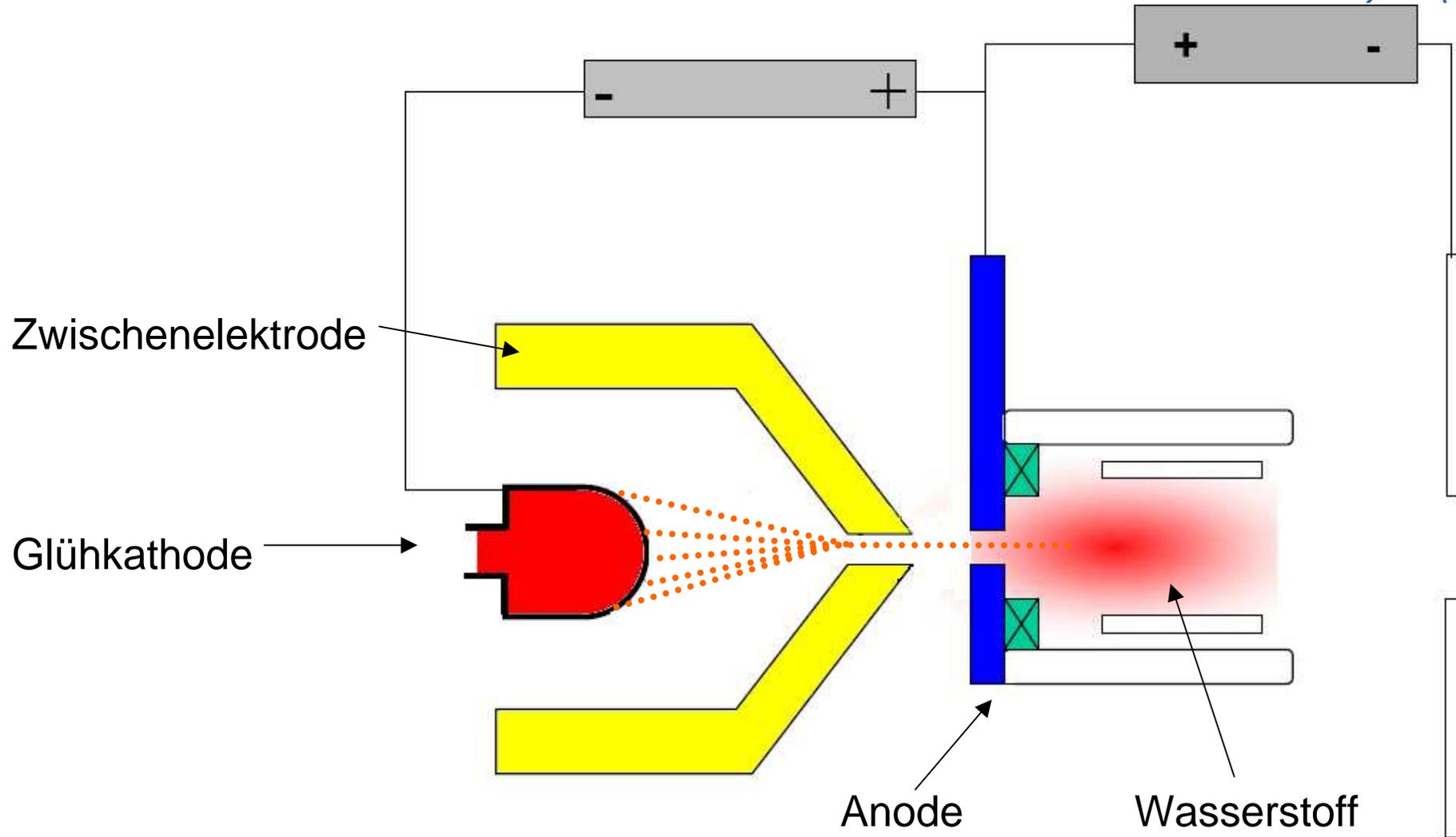
90 kV



CERN-Protonenquelle



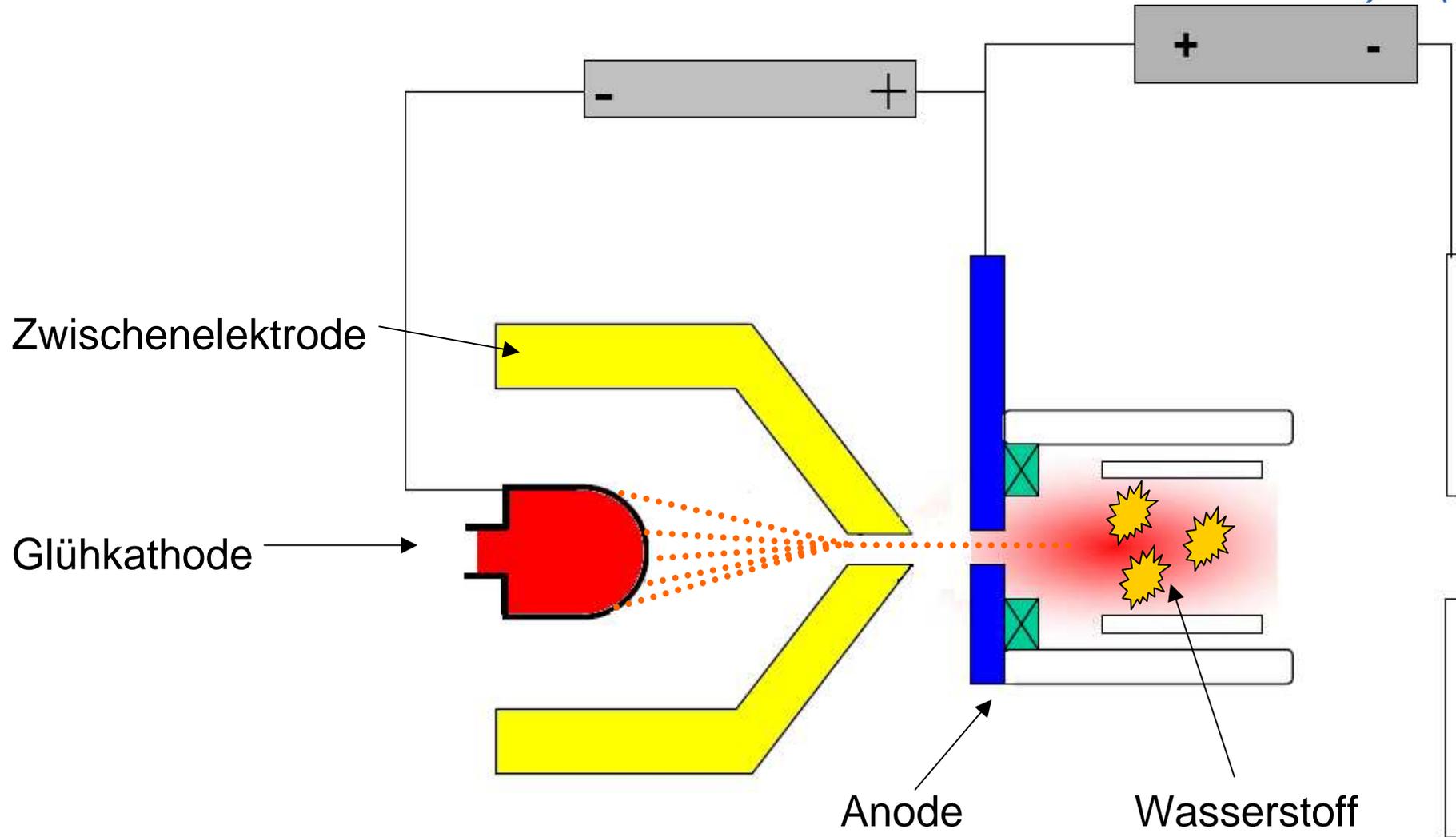
90 kV



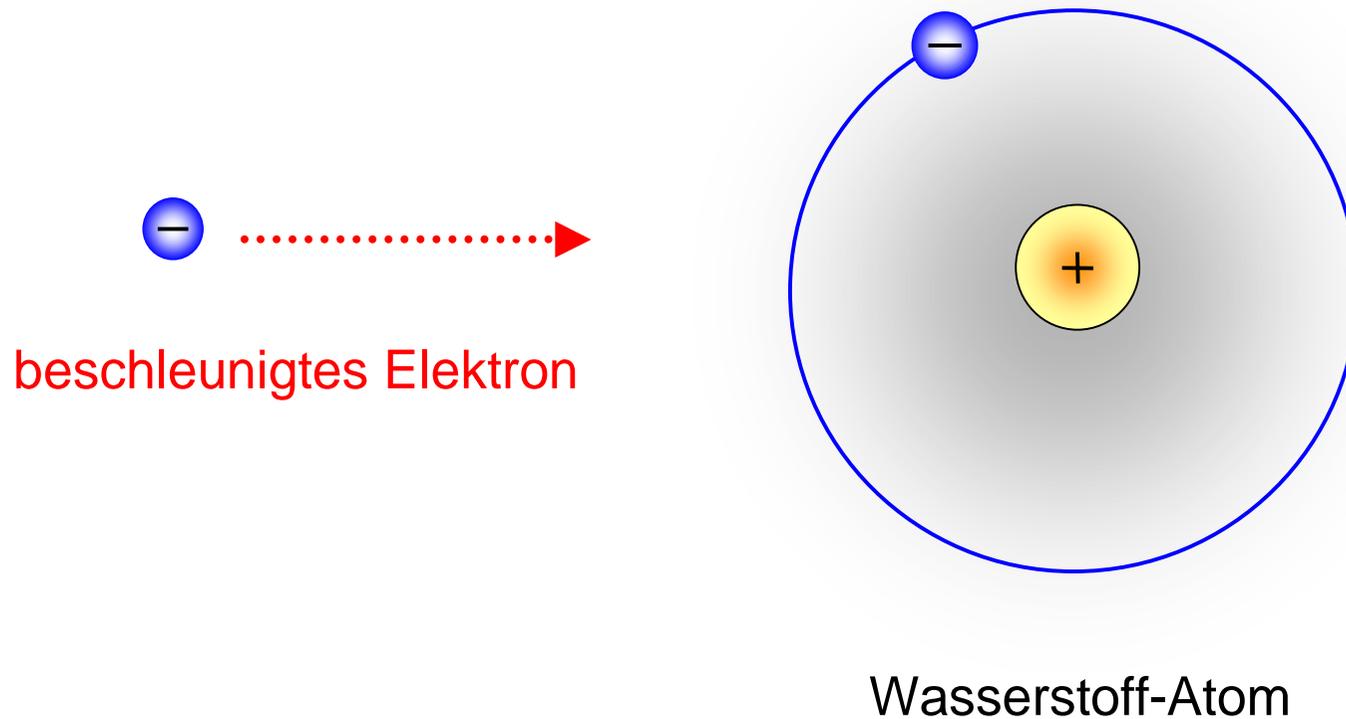
CERN-Protonenquelle



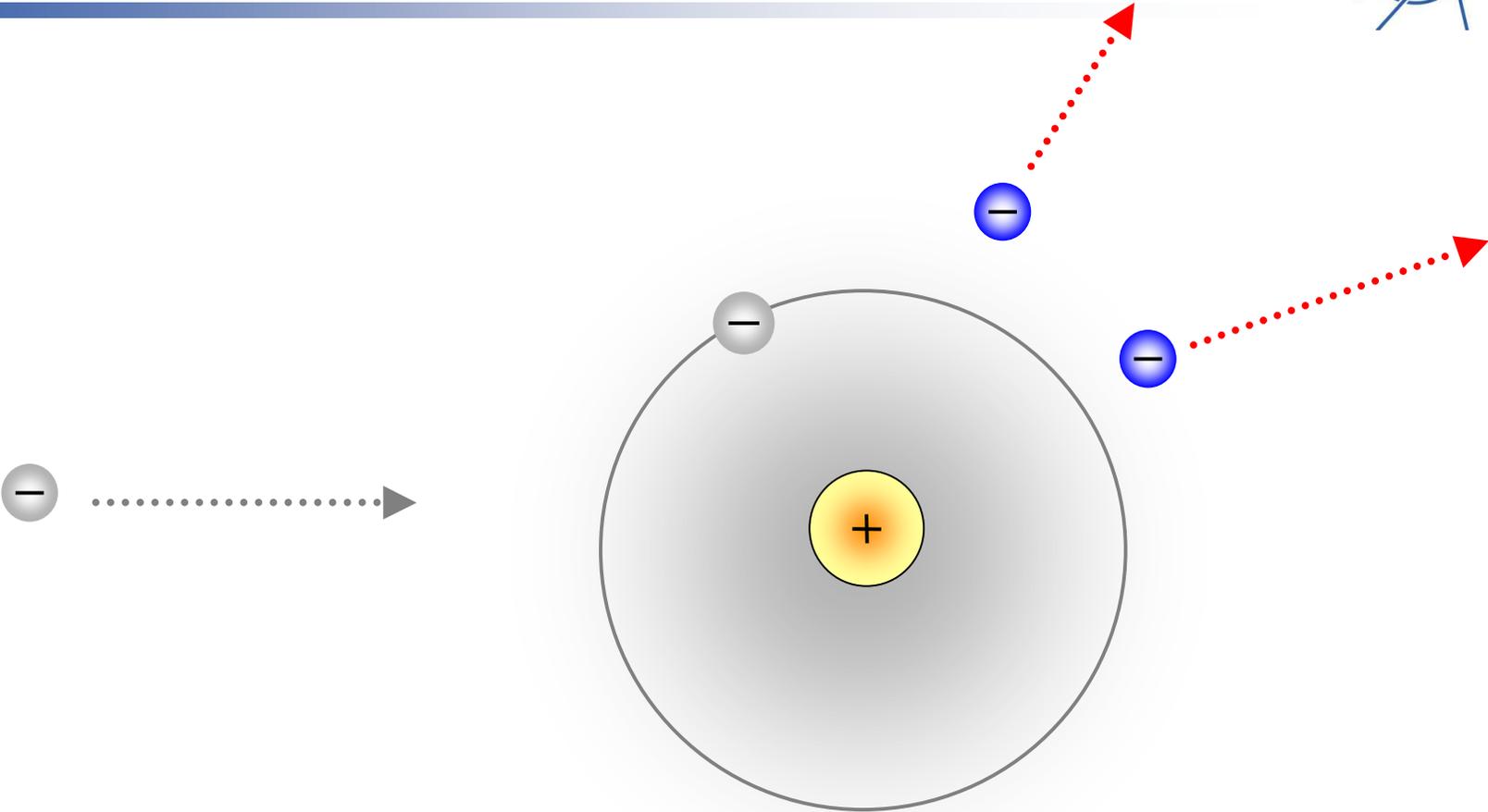
90 kV



Protonen-Erzeugung

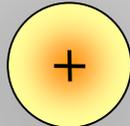


Protonen-Erzeugung

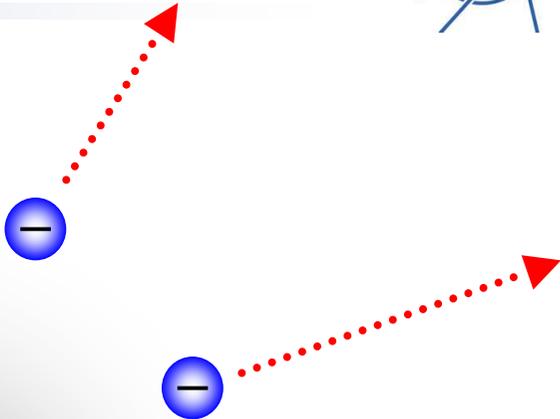


Proton

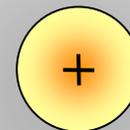
Protonen-Erzeugung



Proton

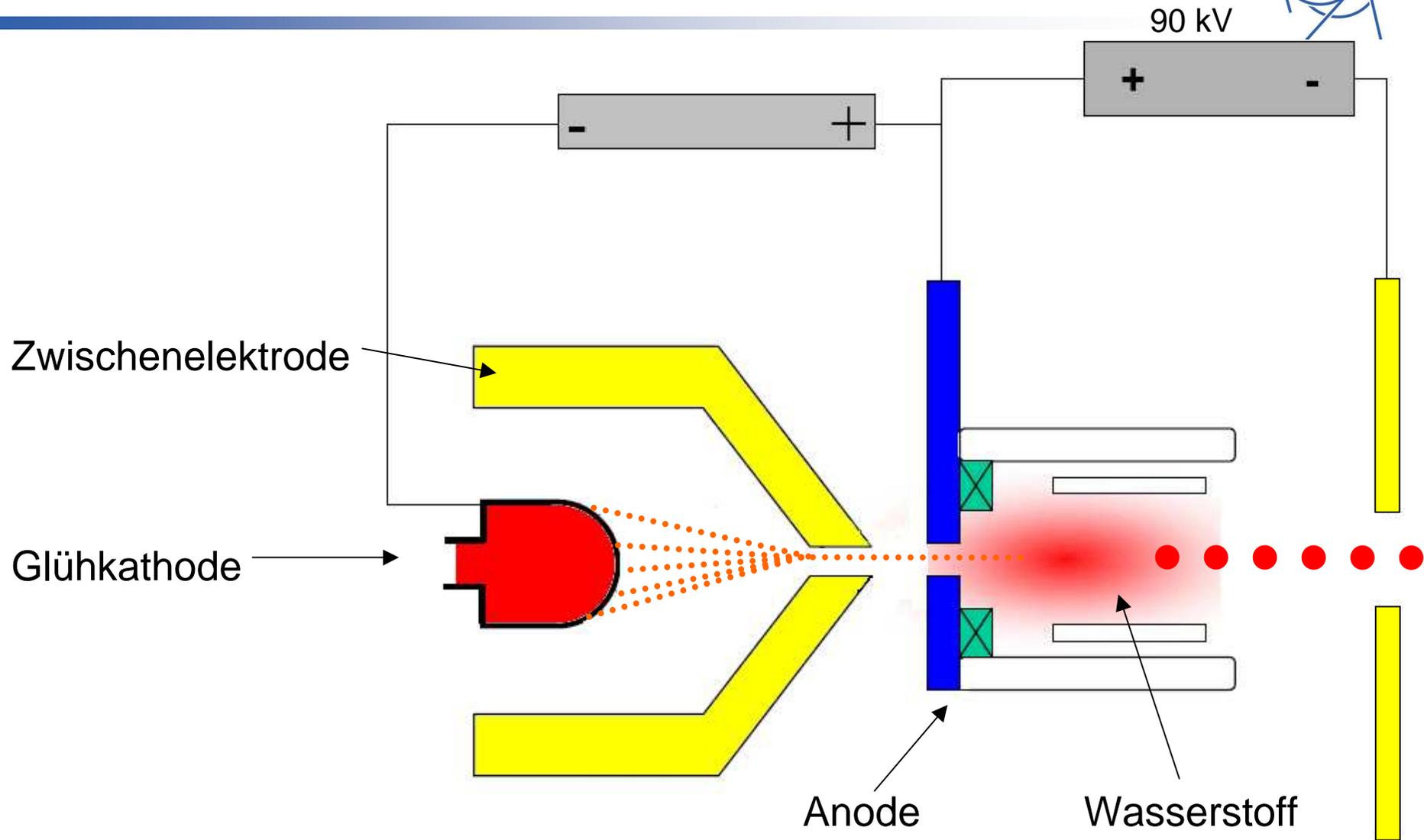


Protonen-Erzeugung

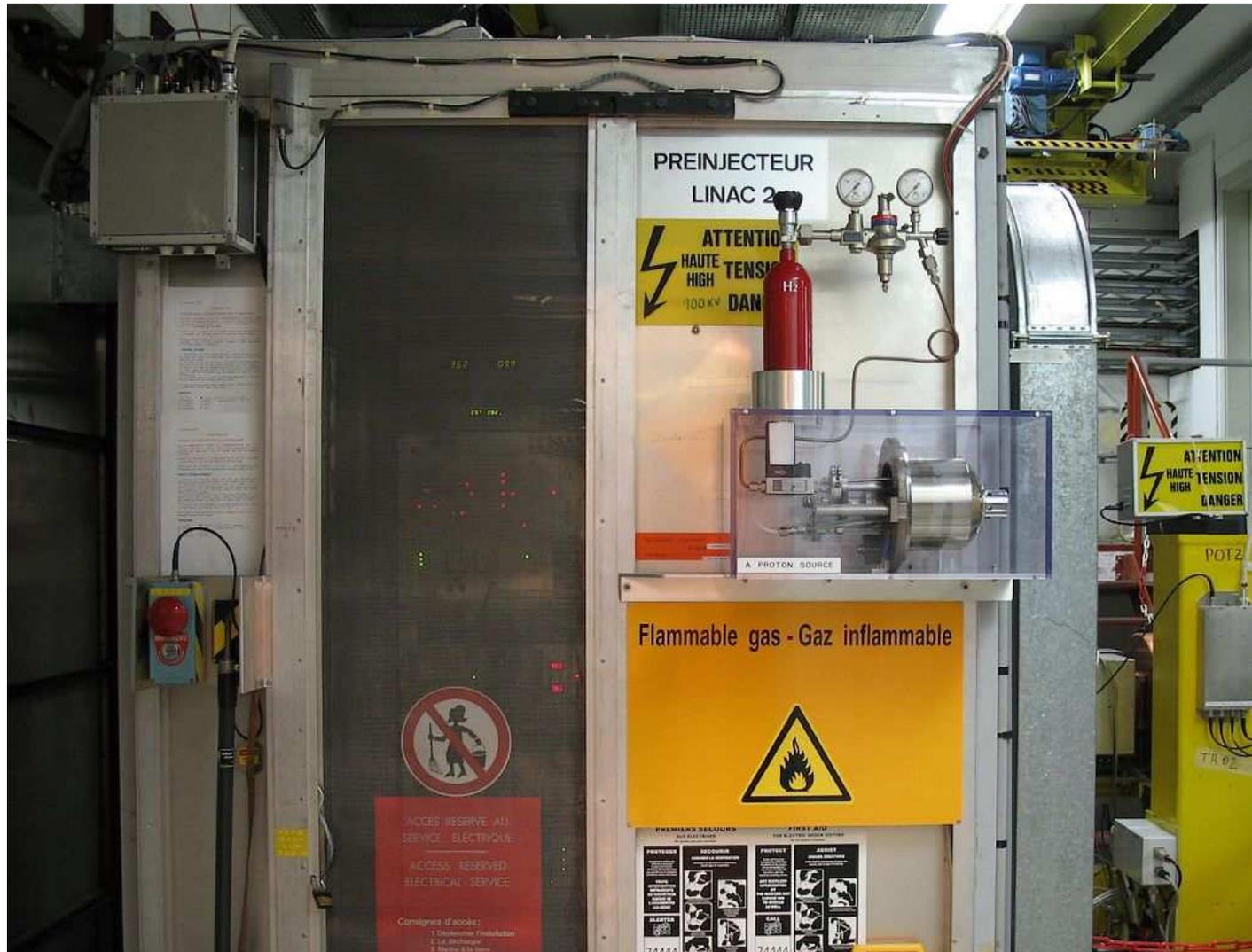


Proton

CERN-Protonenquelle



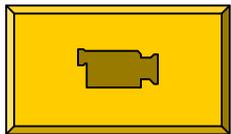
CERN-Protonenquelle



CERN-Protonenquelle



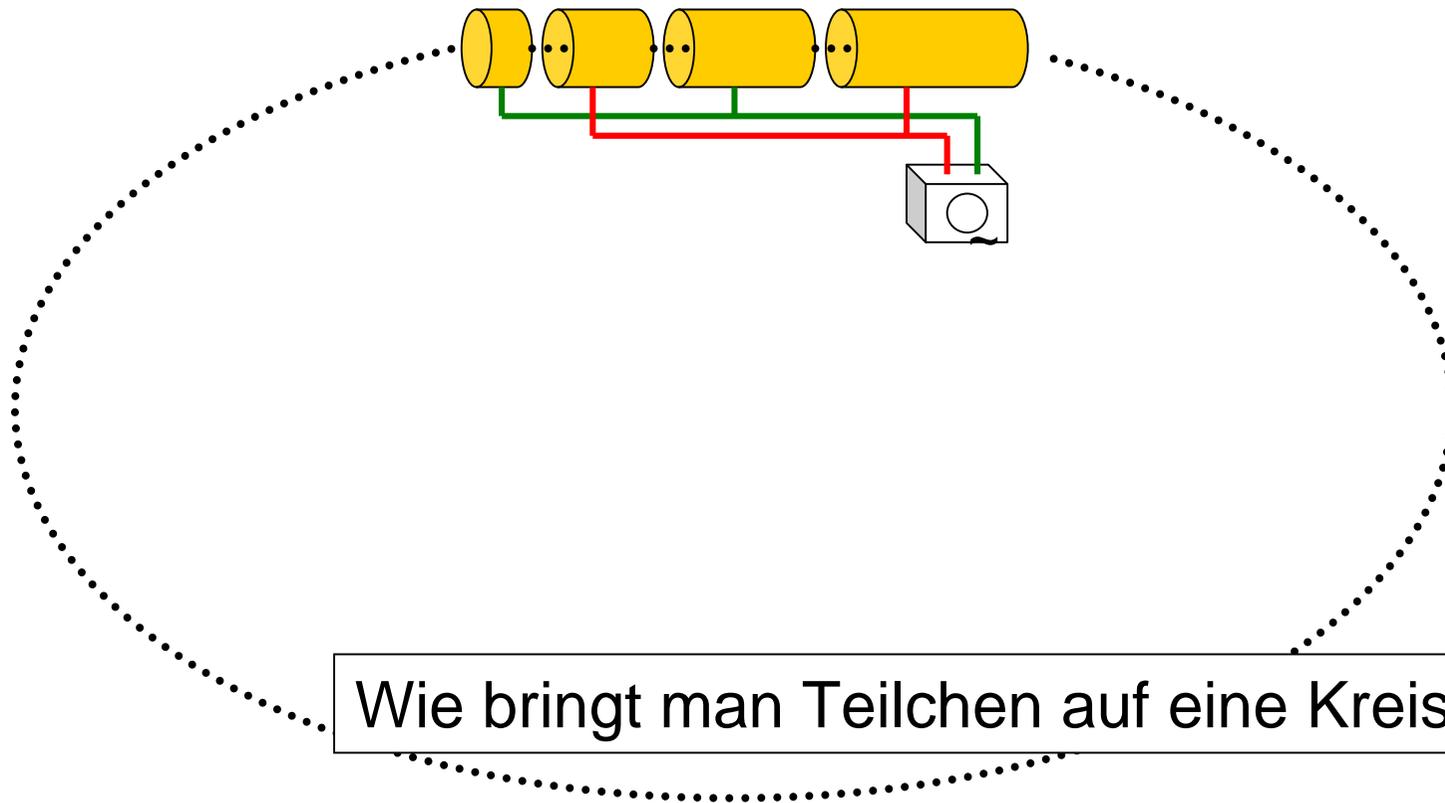
Linearbeschleuniger



Kreisbeschleuniger



- Vorteil: die gleiche Beschleunigungsstrecke mehrmals durchlaufen



Wie bringt man Teilchen auf eine Kreisbahn?

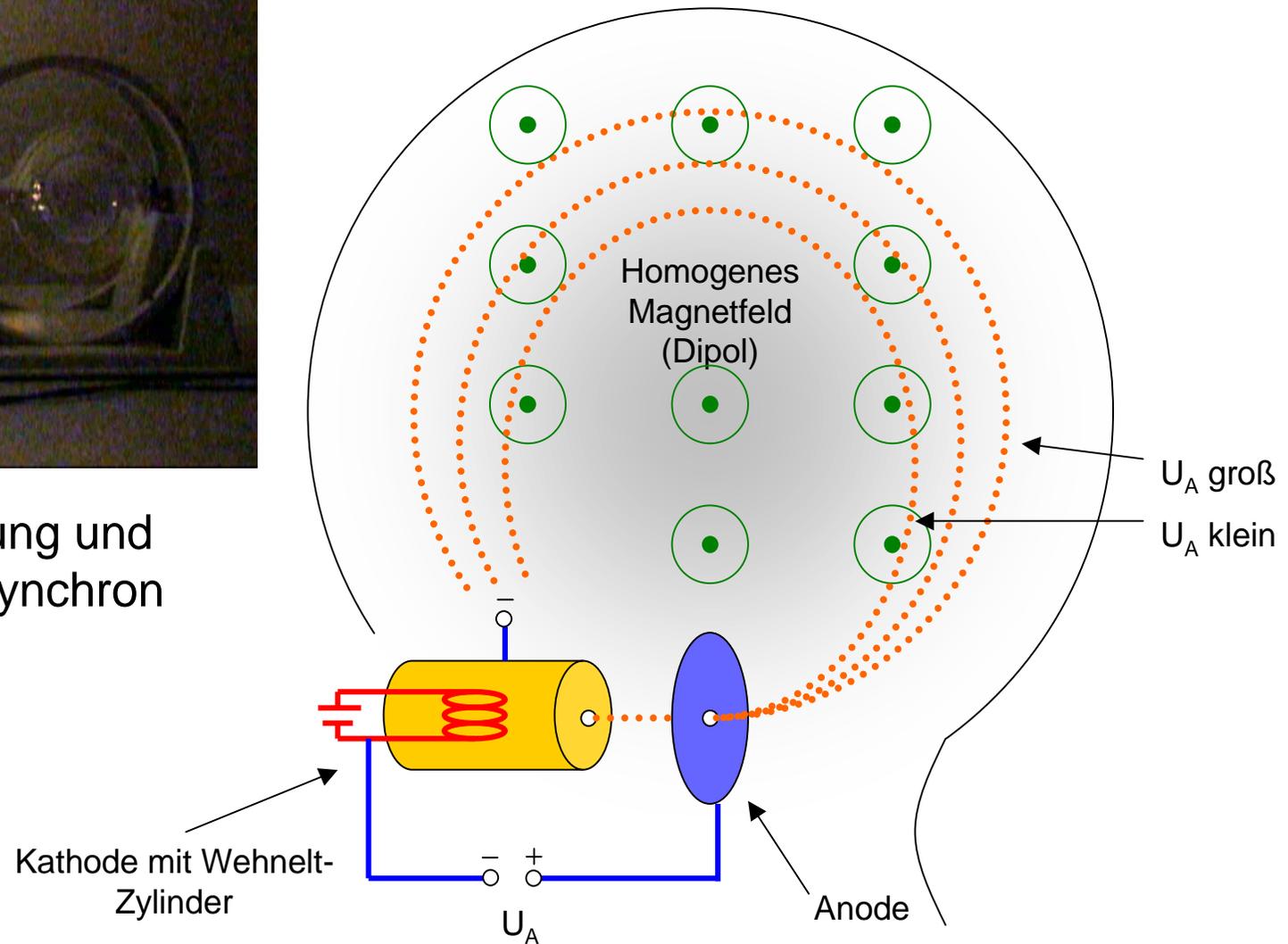
Fadenstrahlröhre



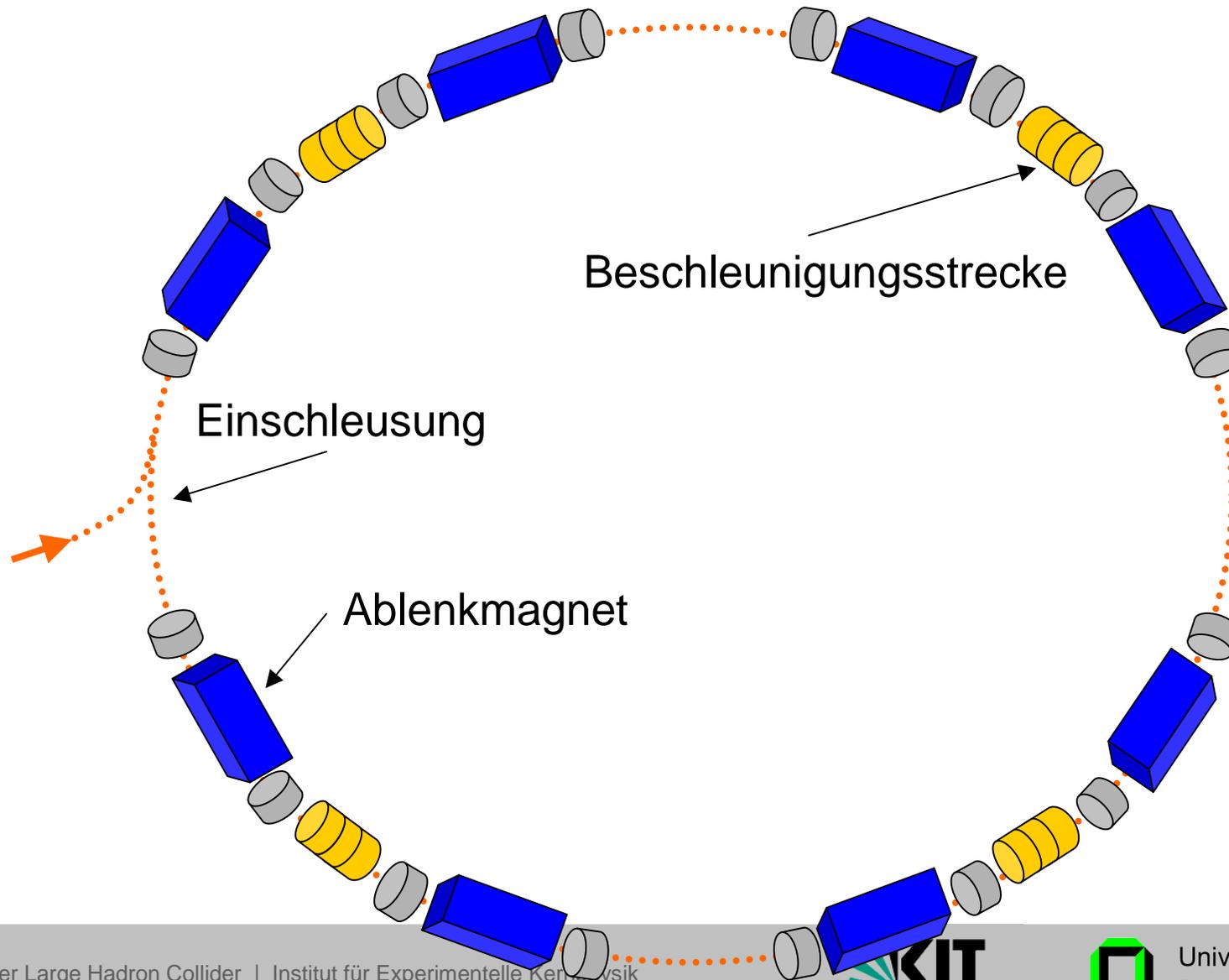
Synchrotron



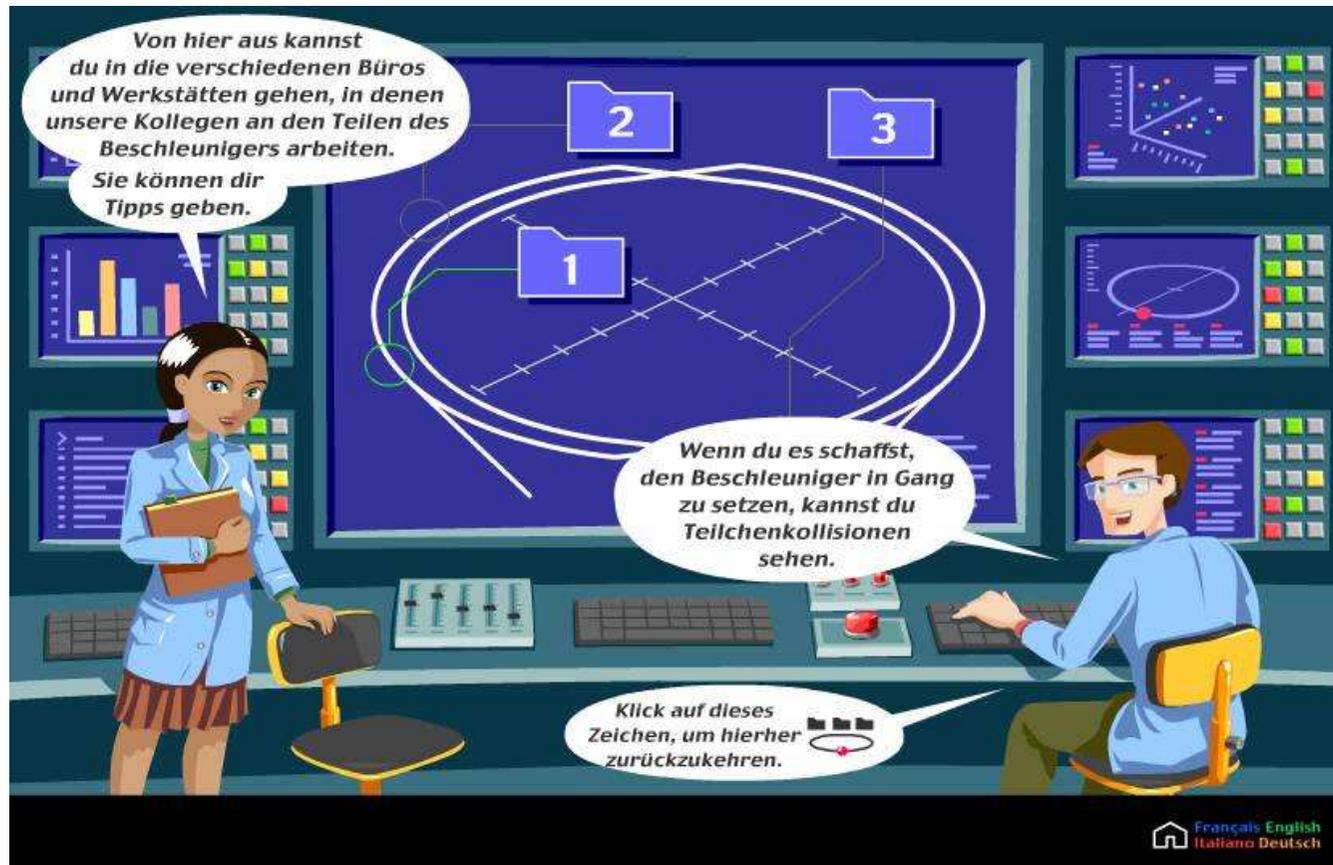
→ Beschleunigung und Magnetfeld synchron hochfahren



Kreisbeschleuniger



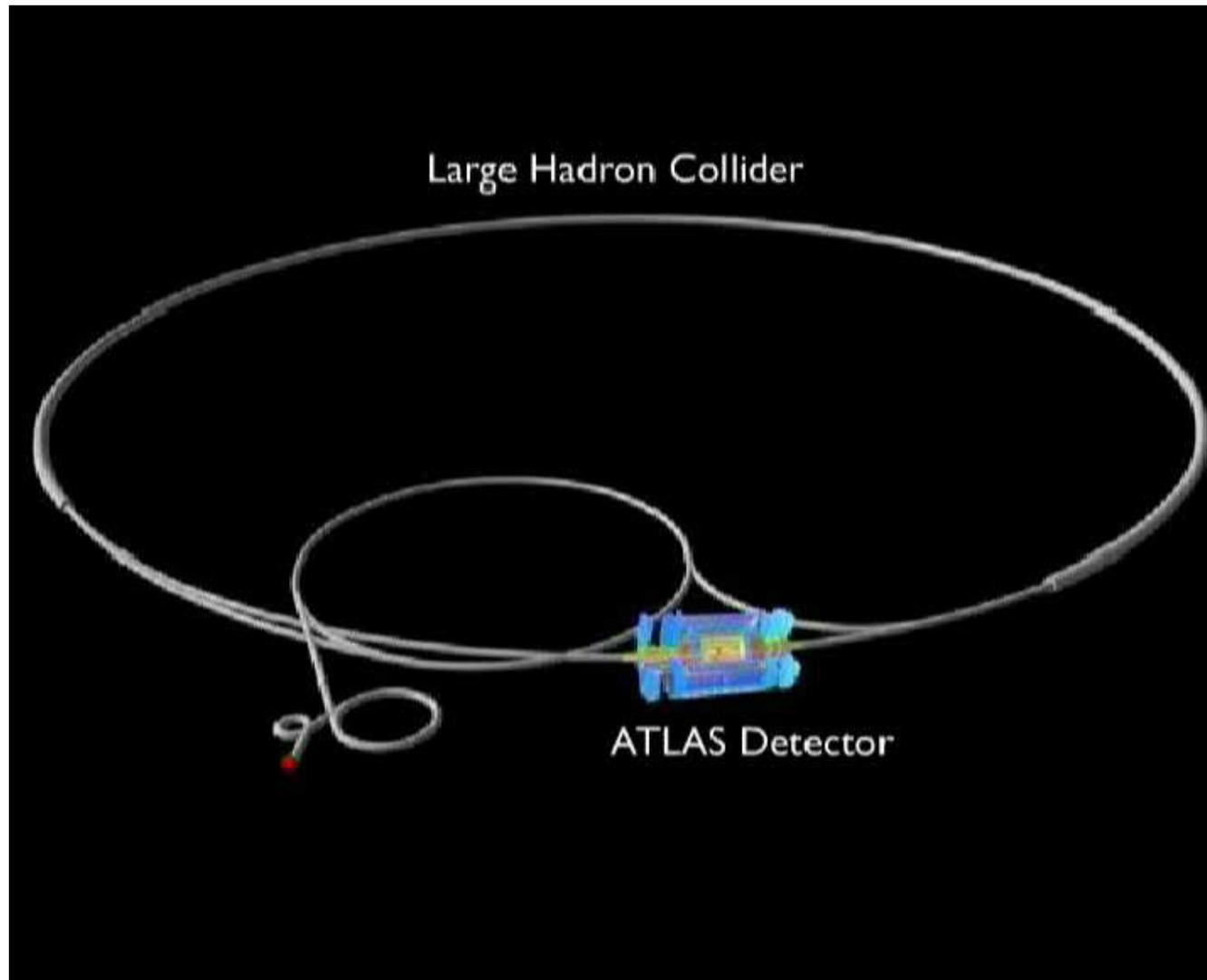
LHC-Spiel



Start

(Internetverbindung erforderlich)

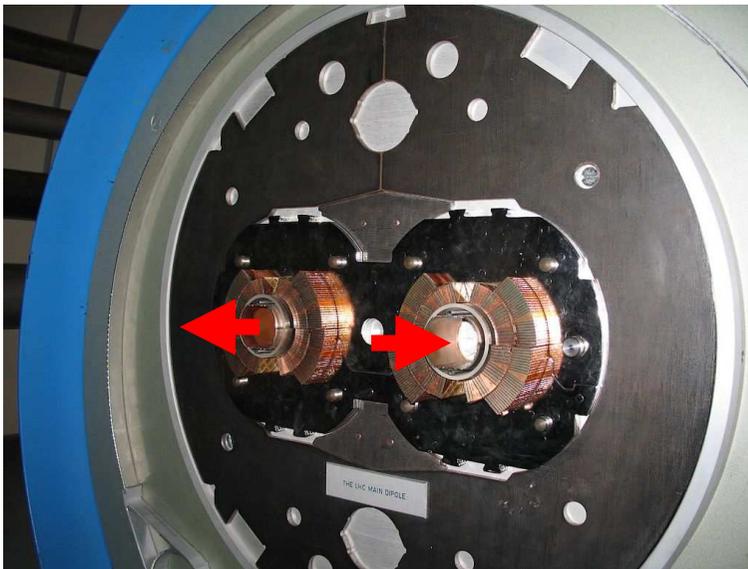
LHC und Vorbeschleuniger



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



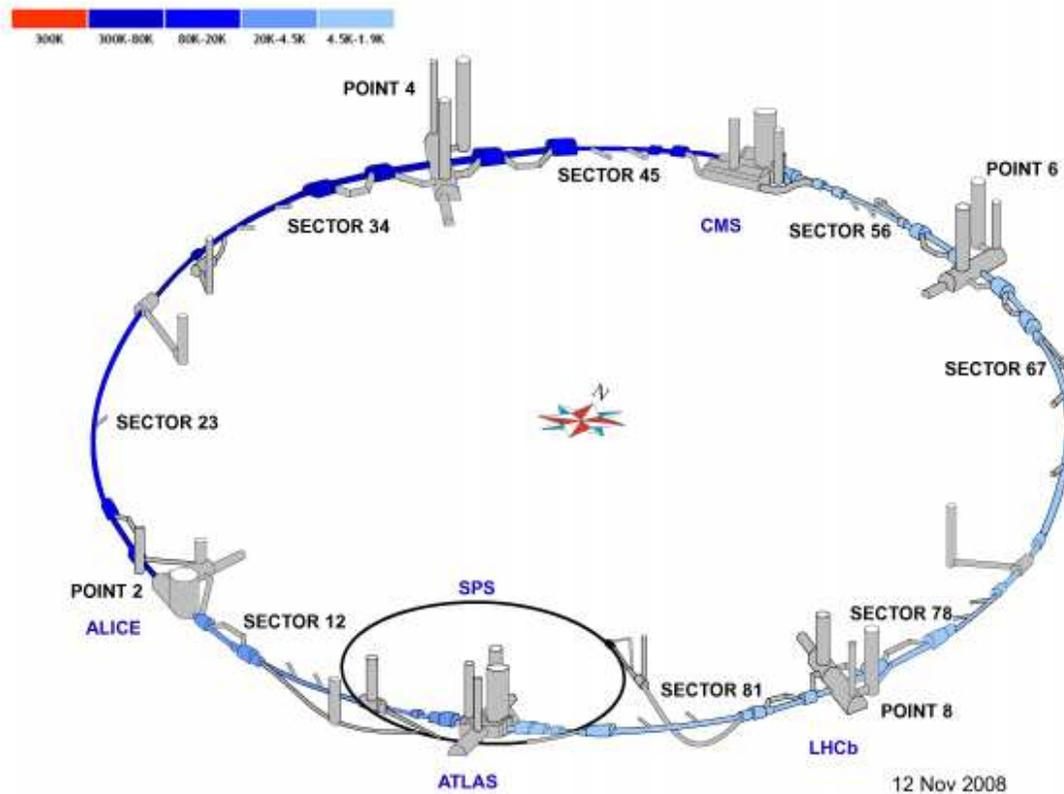
- 1232 supraleitende Magnete
 - Magnetfeld: 8,3 T bei 11.850 Ampère
 - Betriebstemperatur: -271 °C
 - Länge: 15 m
 - Gewicht: 35 t
 - Preis: 500.000 CHF
- Transport bei 3 km/h!
 - ...bis zu 15 km weit



Large Hadron Collider



- LHC-Temperatur
 - Kälter als das Weltall!



Large Hadron Collider



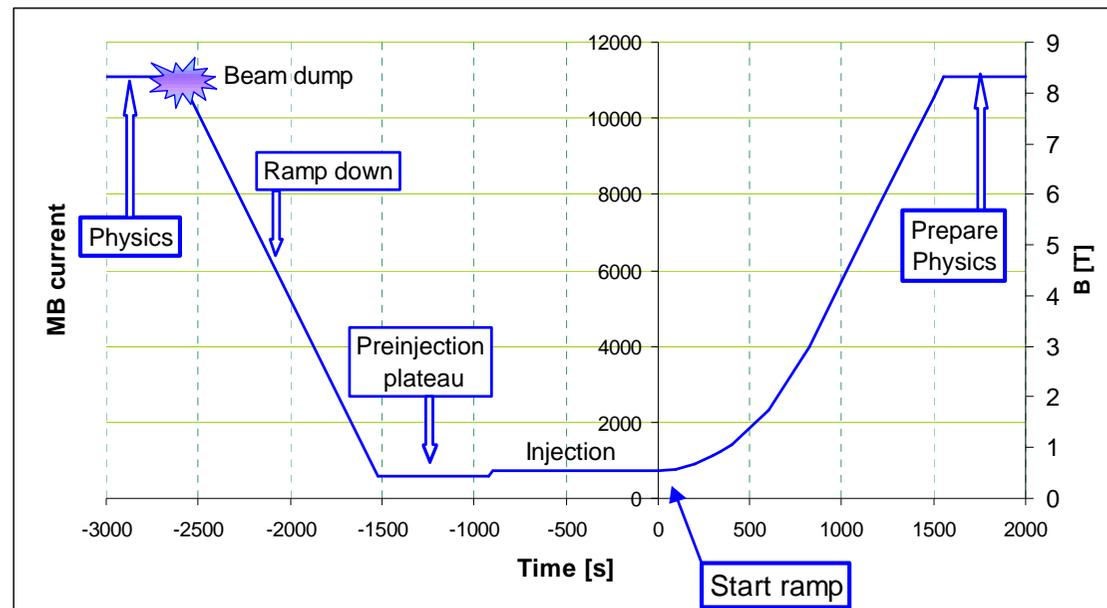
Large Hadron Collider



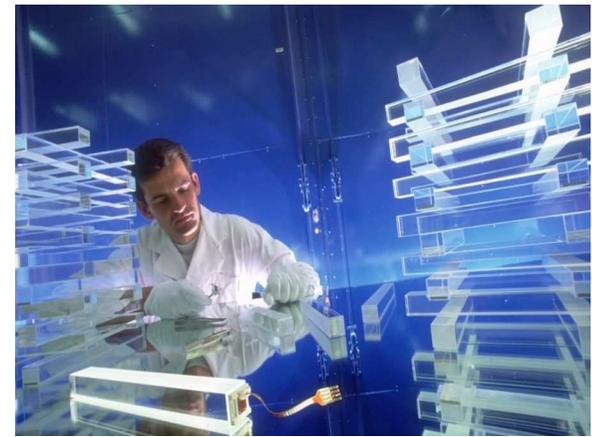
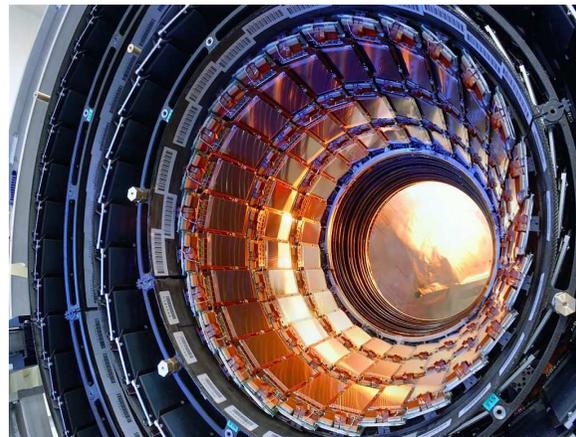
■ Weitere Daten:

- 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





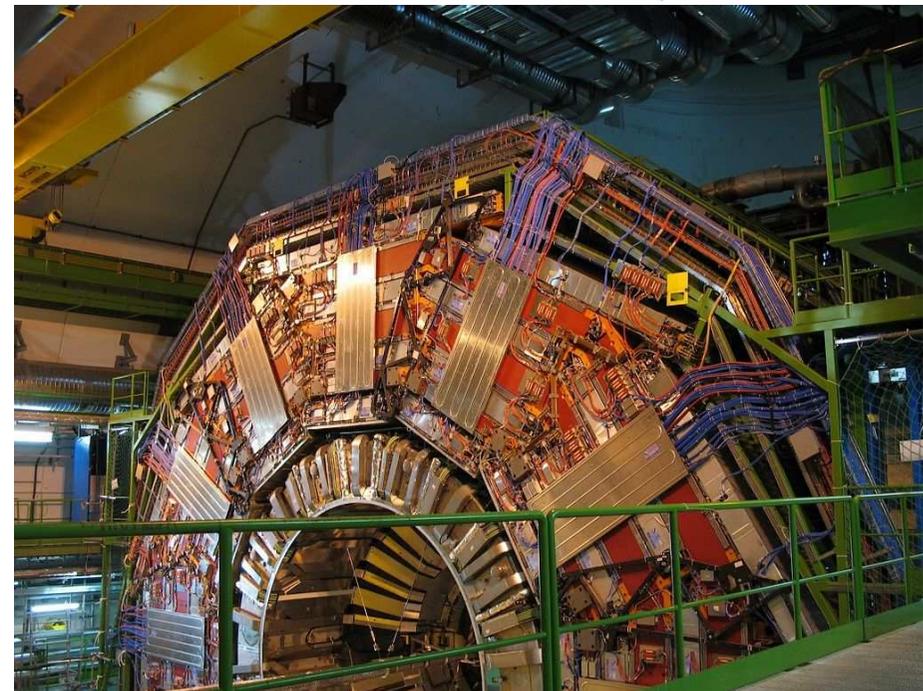
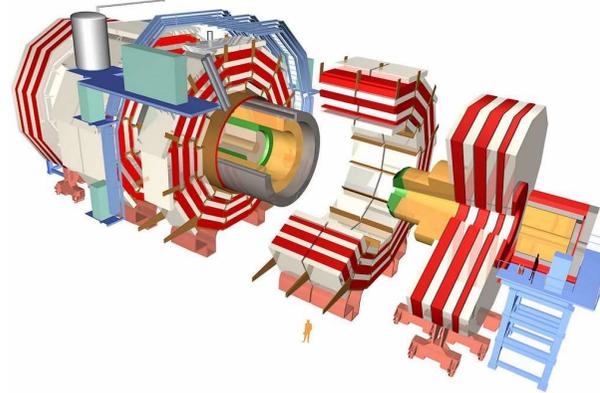
CMS-Detektor



- 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



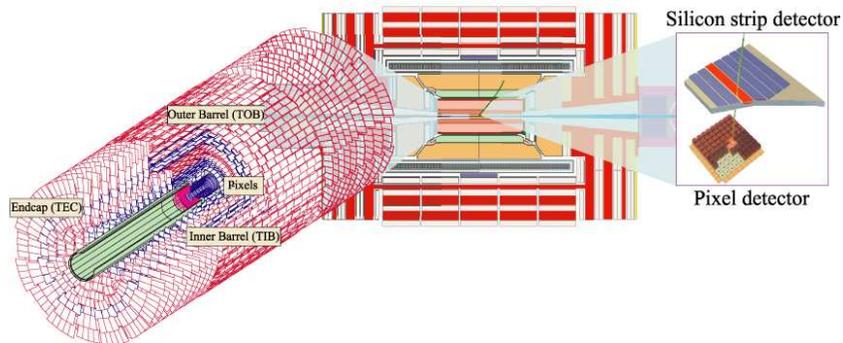
CMS-Detektor



■ Spurdetektoren

- Streifen und Pixel aus Silizium (=„Digitalkamera“)
- Fläche: 220 m²
- 60 Millionen elektronische Kanäle
- Länge: 6 m

40 Mio. Fotos
pro Sekunde



CMS-Detektor



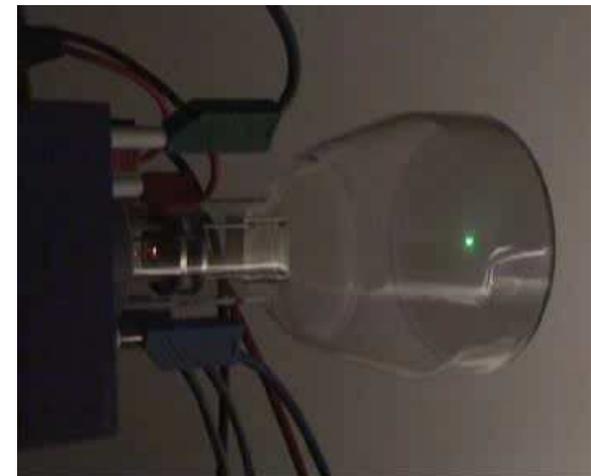
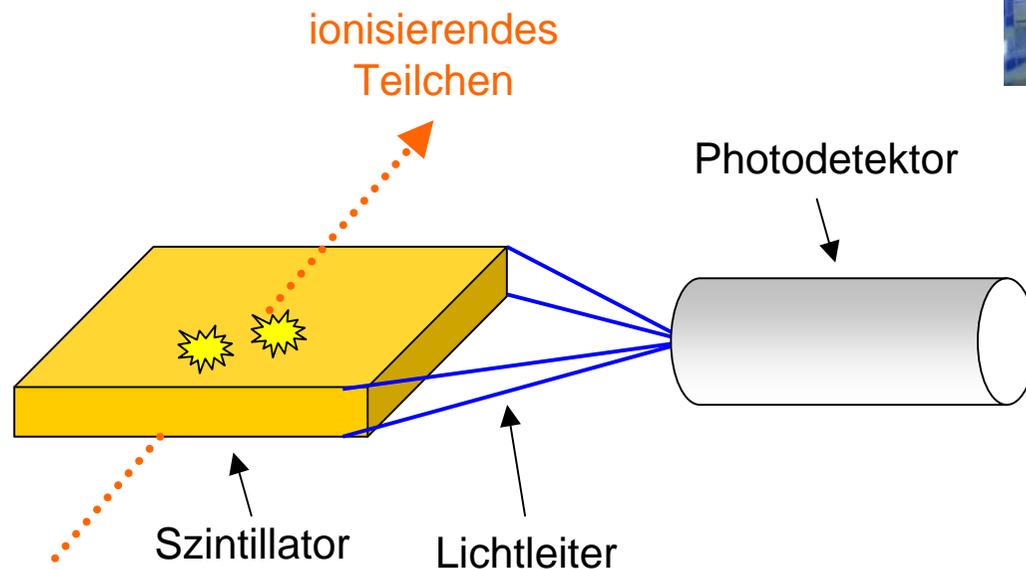
CMS-Detektor



CMS-Detektor



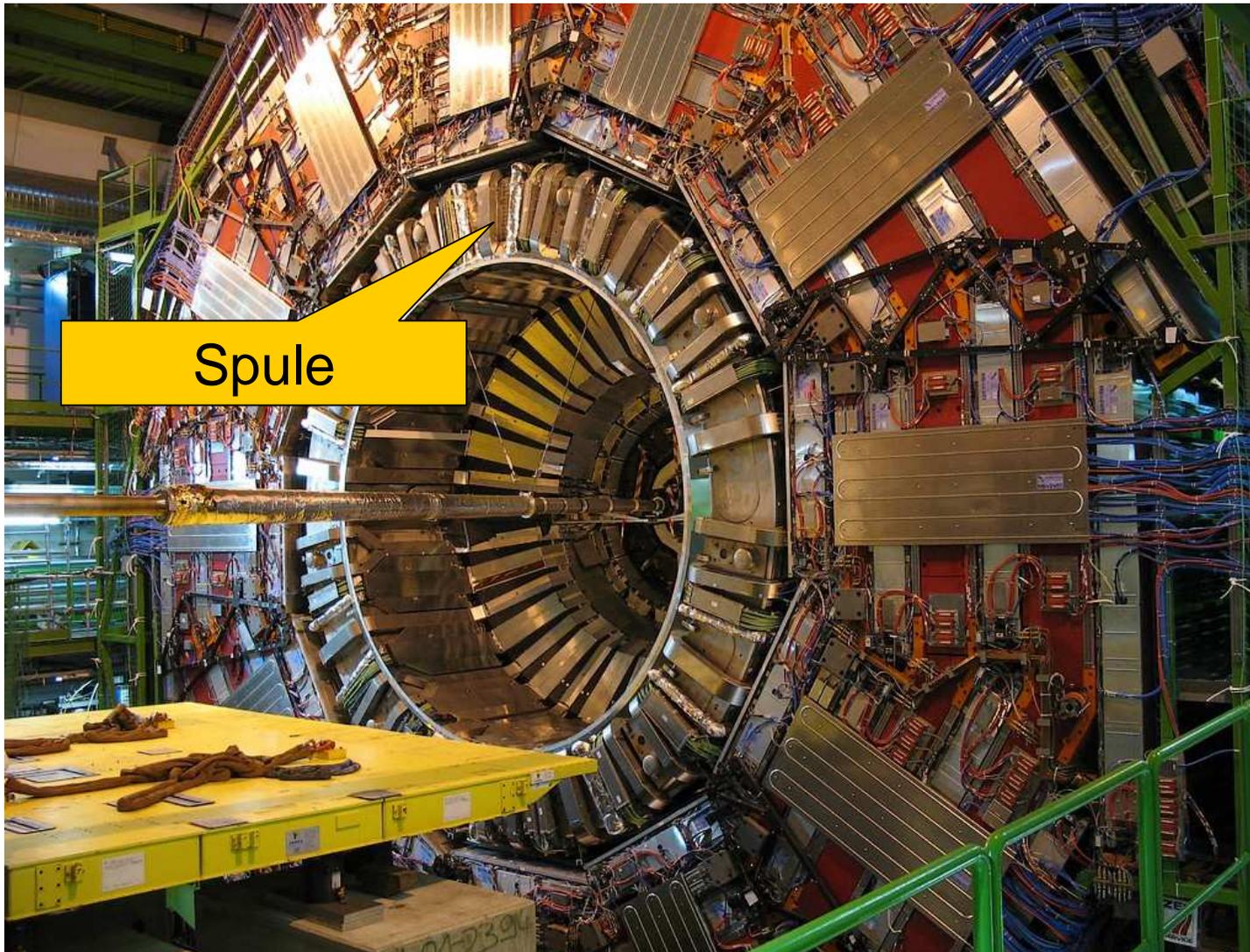
- Kalorimeter
 - Teilchen regen spezielle Materialien zur Lichtemission an
 - Messung der Energie



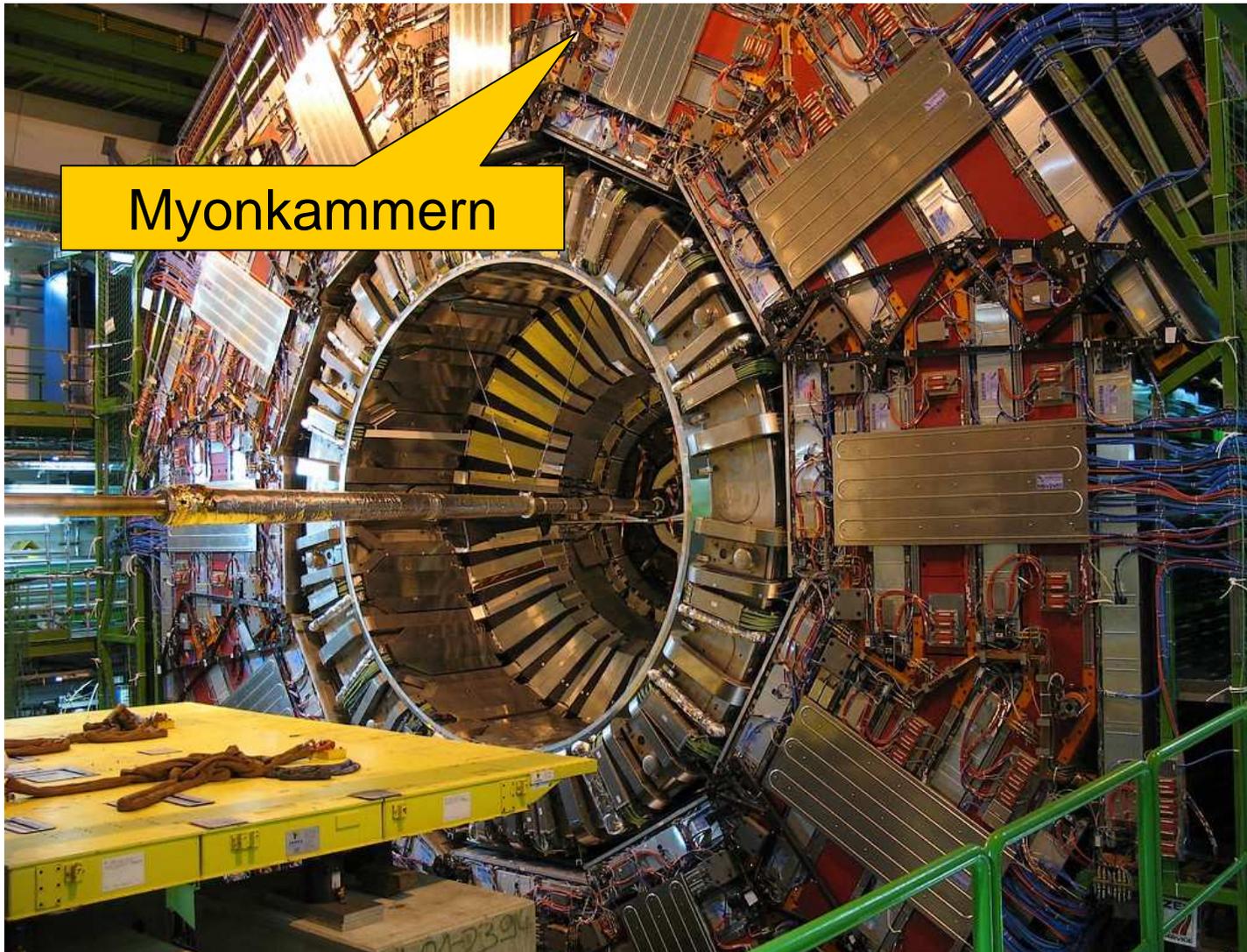
CMS-Detektor



CMS-Detektor



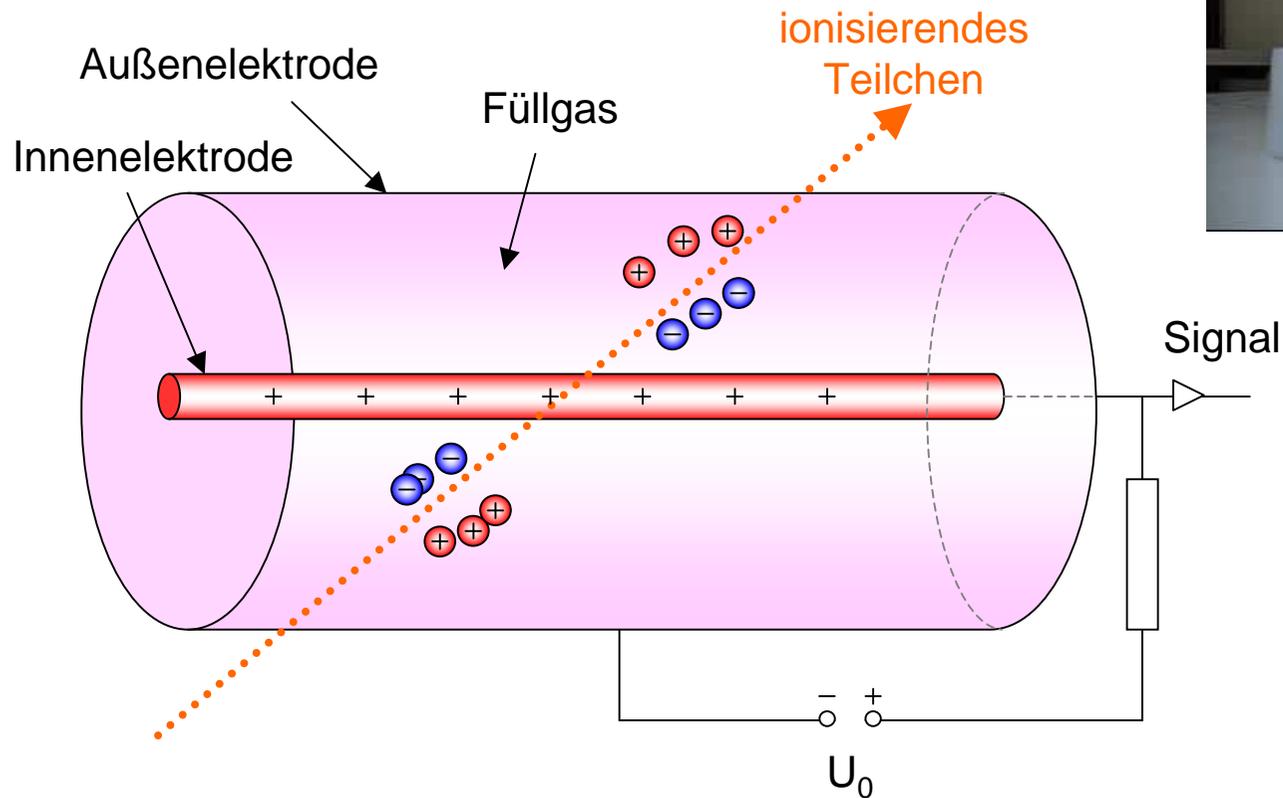
CMS-Detektor



Kalorimeter



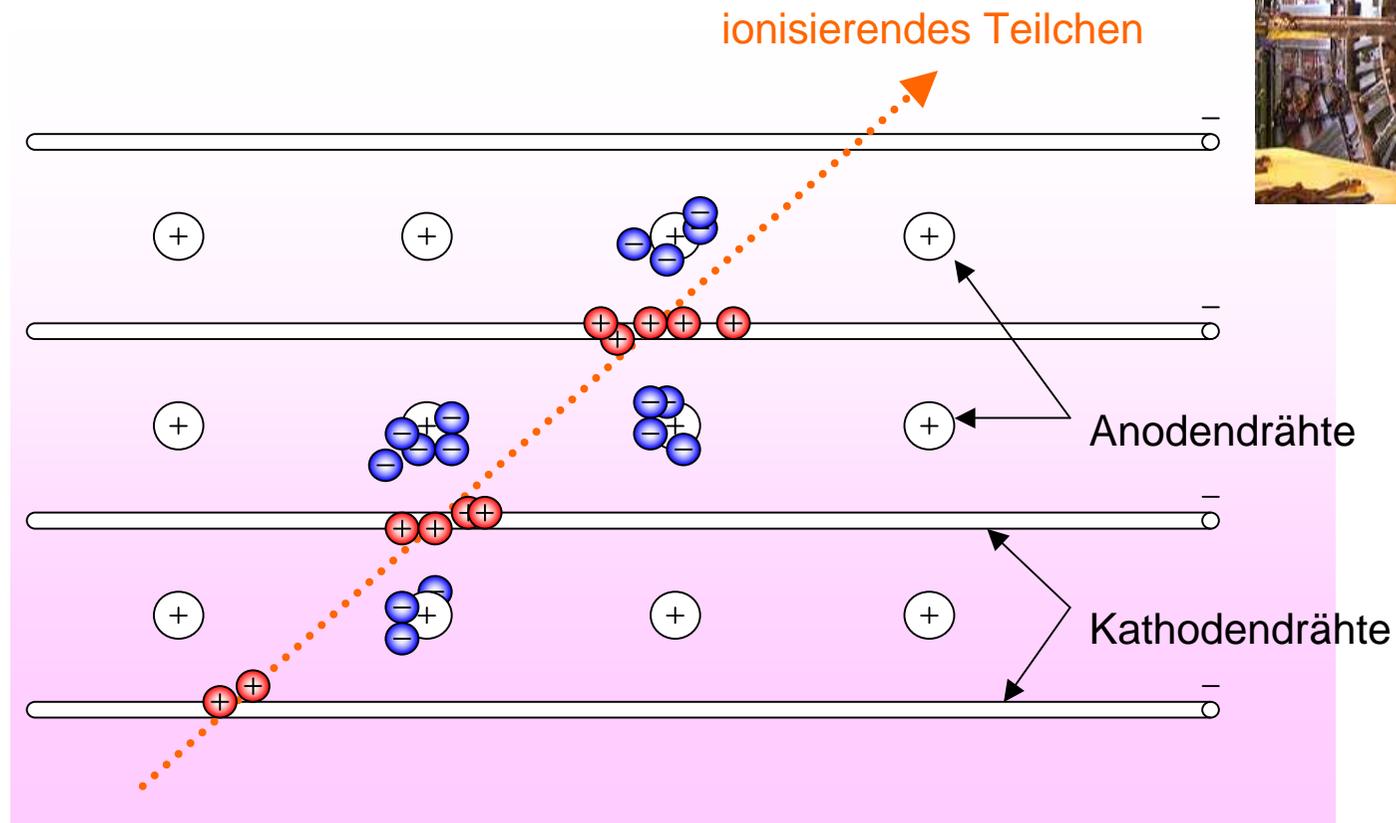
- Myonkammern
 - Gasdetektor = Geiger-Müller-Zählrohr



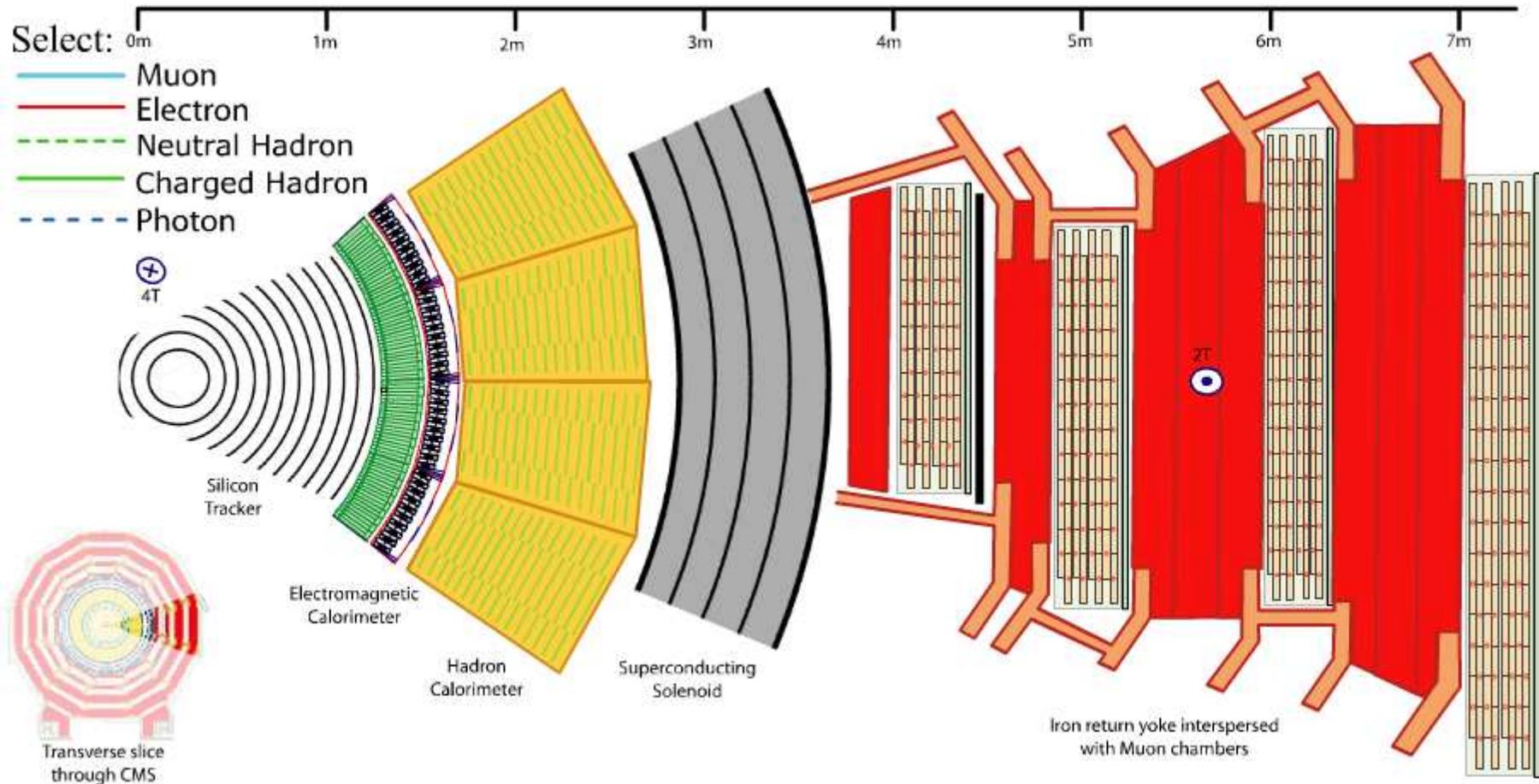
Kalorimeter



- Myonkammern
 - Vieldraht-Proportionalkammer

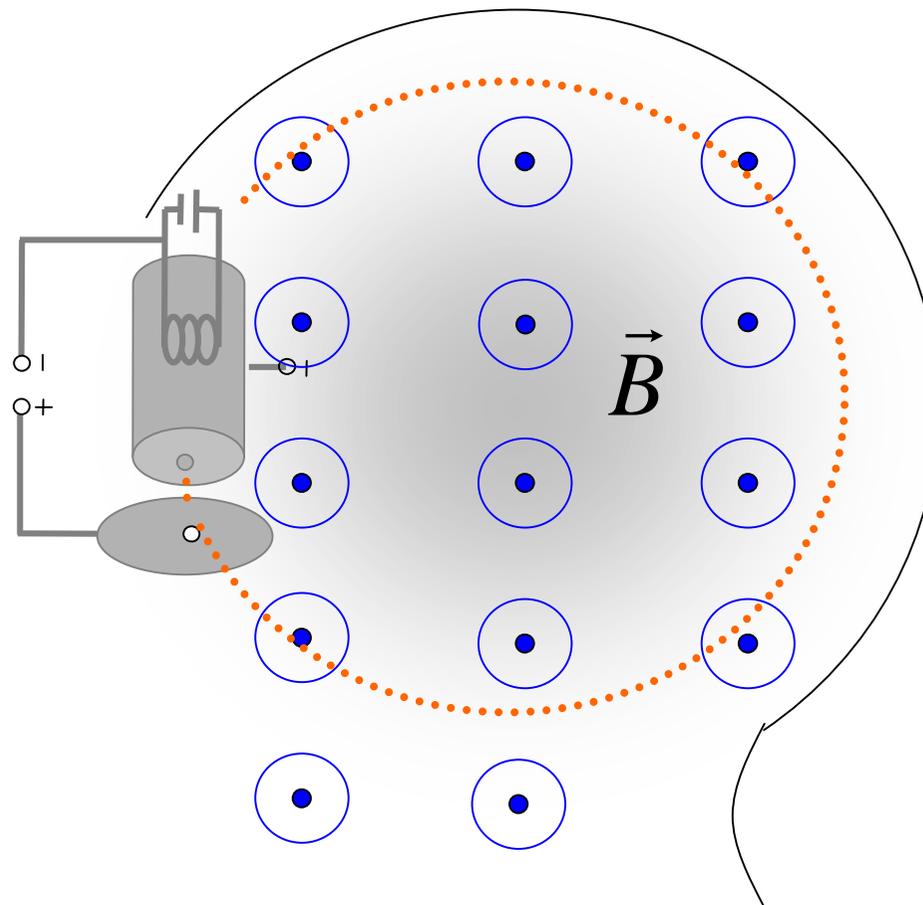


CMS-Detektor

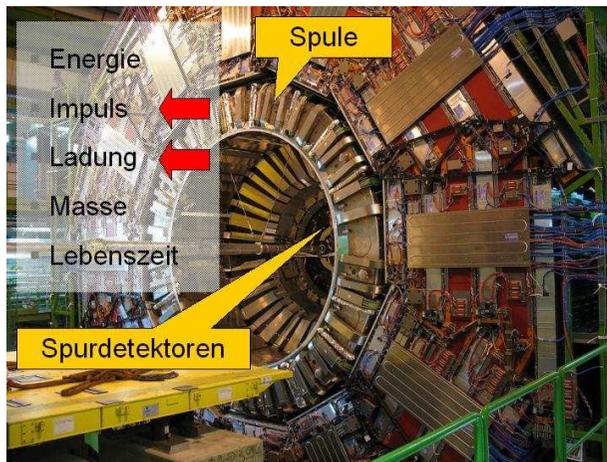
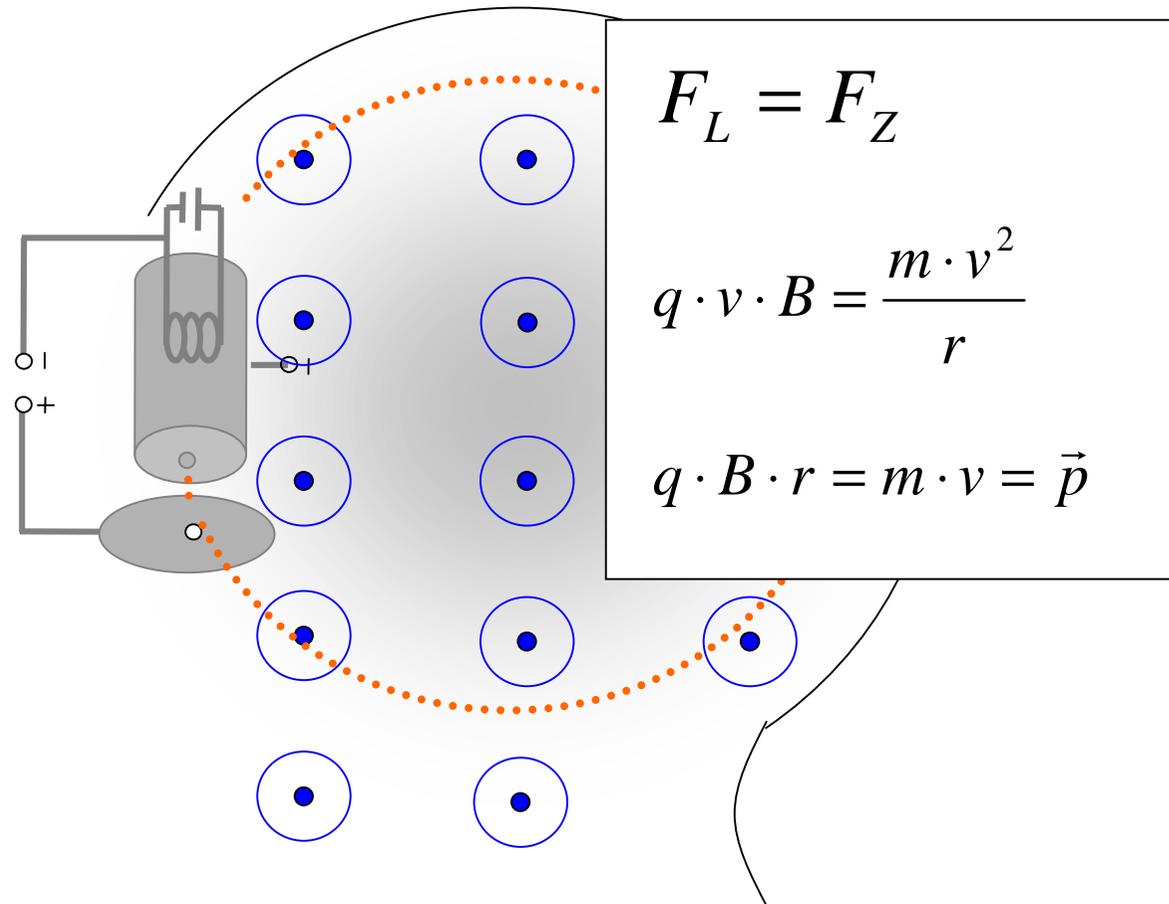


EB Barrety-CERN, 2004

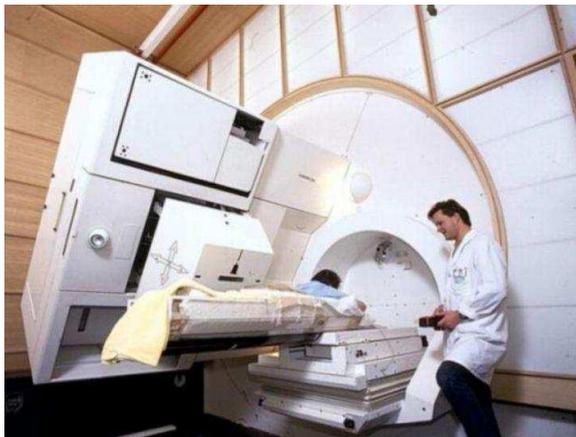
Bestimmung von Impuls und Ladung



Bestimmung von Impuls und Ladung



Technologietransfer



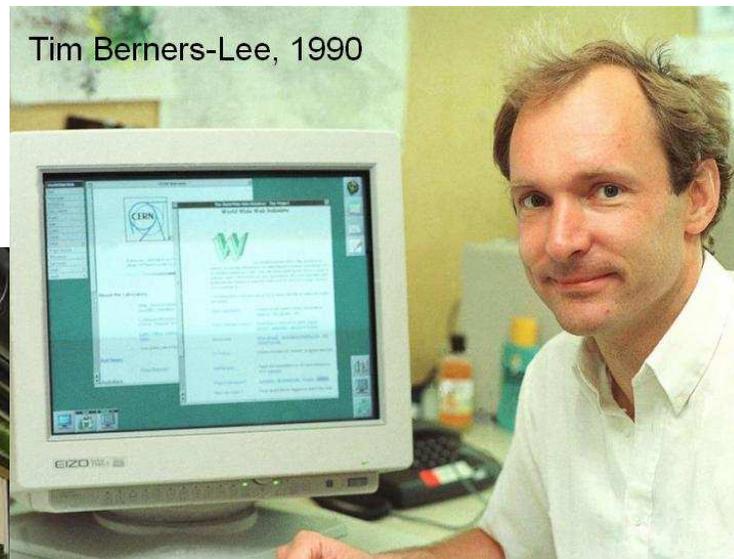
Technologietransfer



Technologietransfer



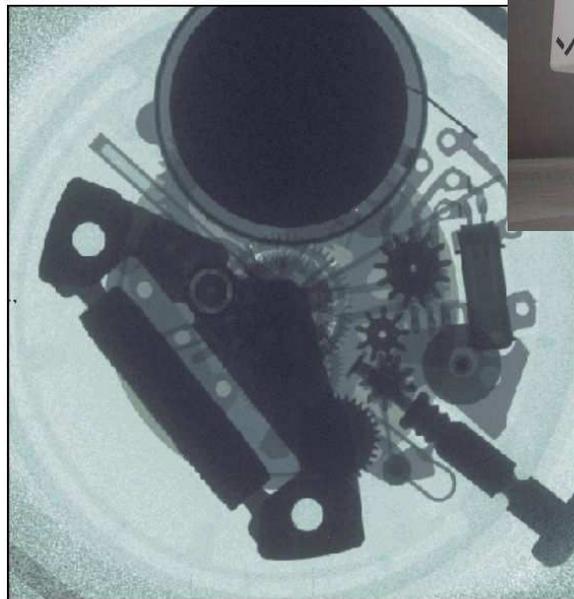
- World Wide Web



Technologietransfer



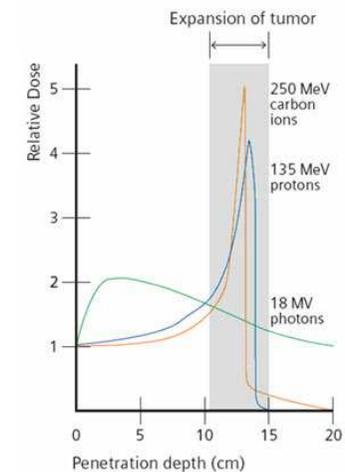
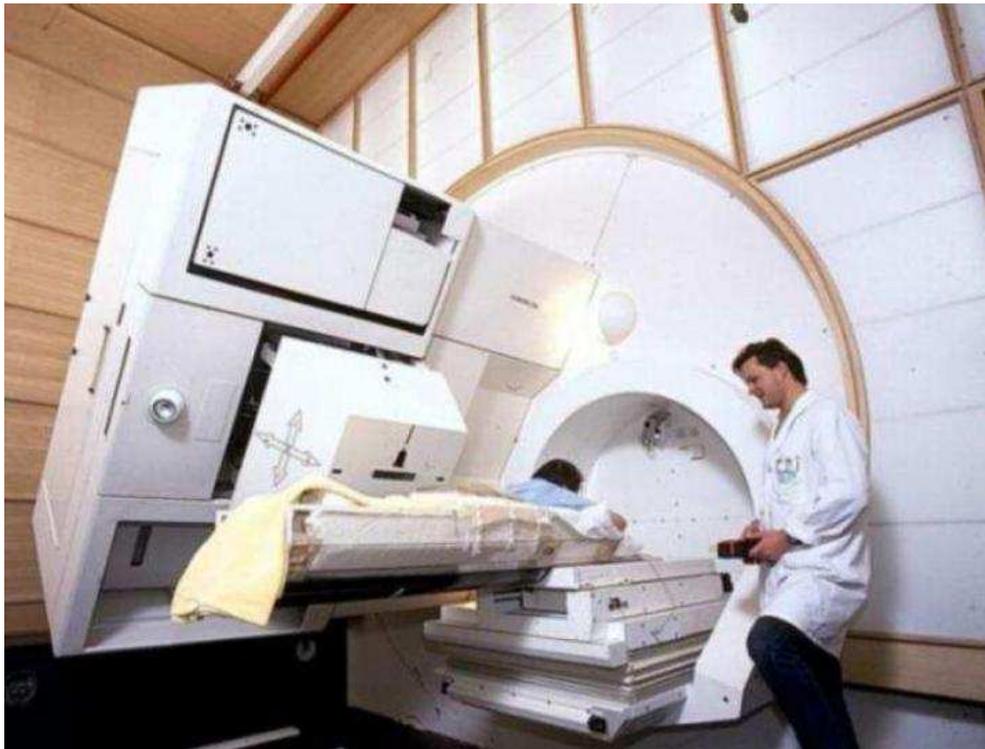
- Medipix-Kamera



Technologietransfer



- Teilchenbeschleuniger in der Medizin



Technologietransfer



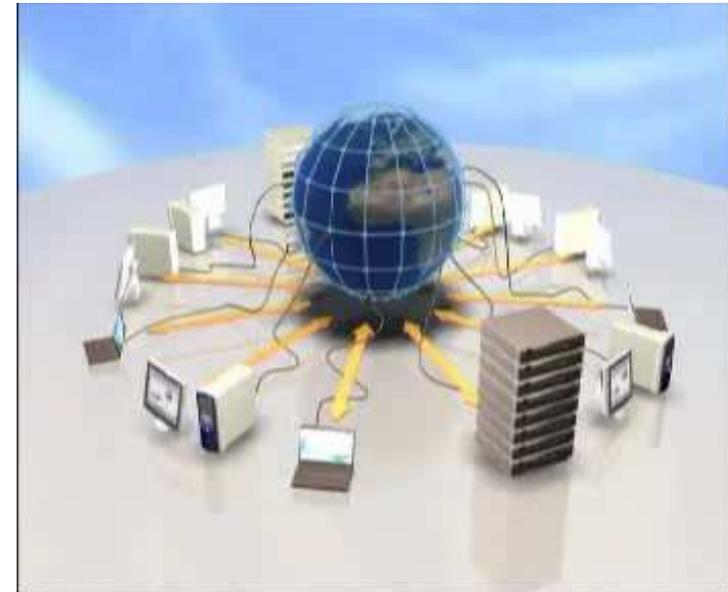
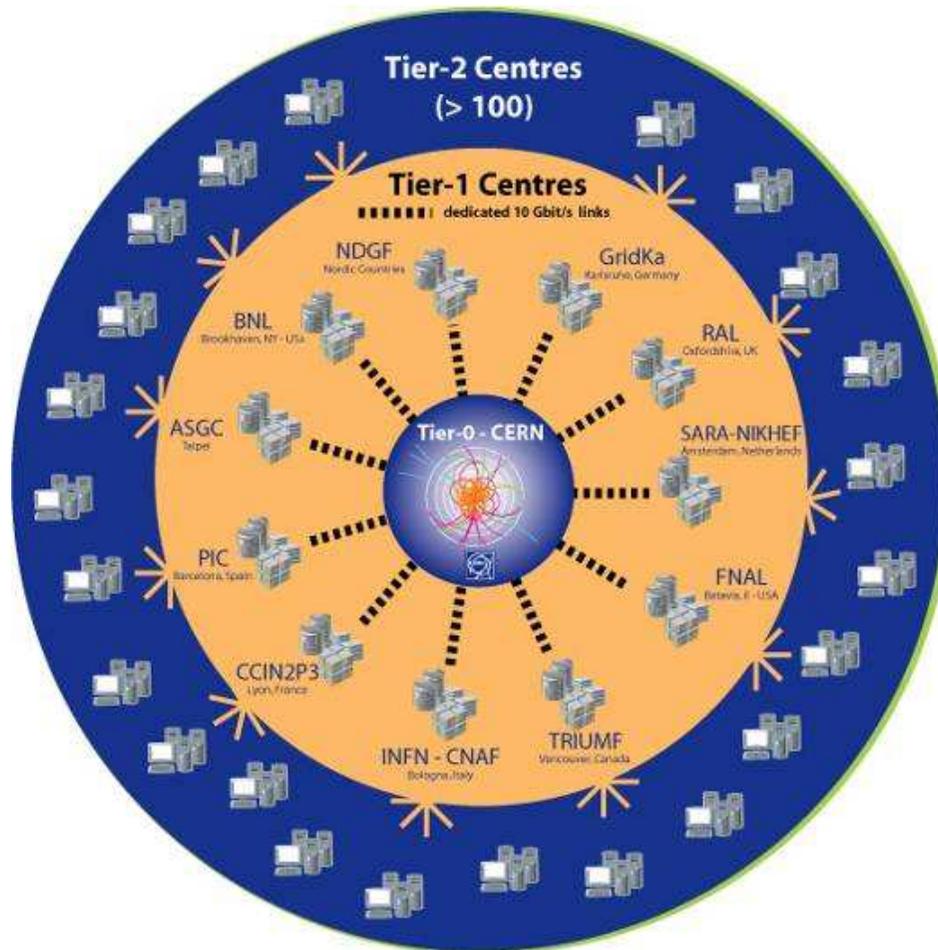
- Teilchenbeschleuniger in der Industrie
 - Polymerisation von Kunststoffen
 - Sterilisierung von Lebensmitteln und medizinischen Geräten
 - Dotieren von Halbleitern
 - Werkstoffüberprüfung



Technologietransfer



- Das Grid



Large Hadron Rap

