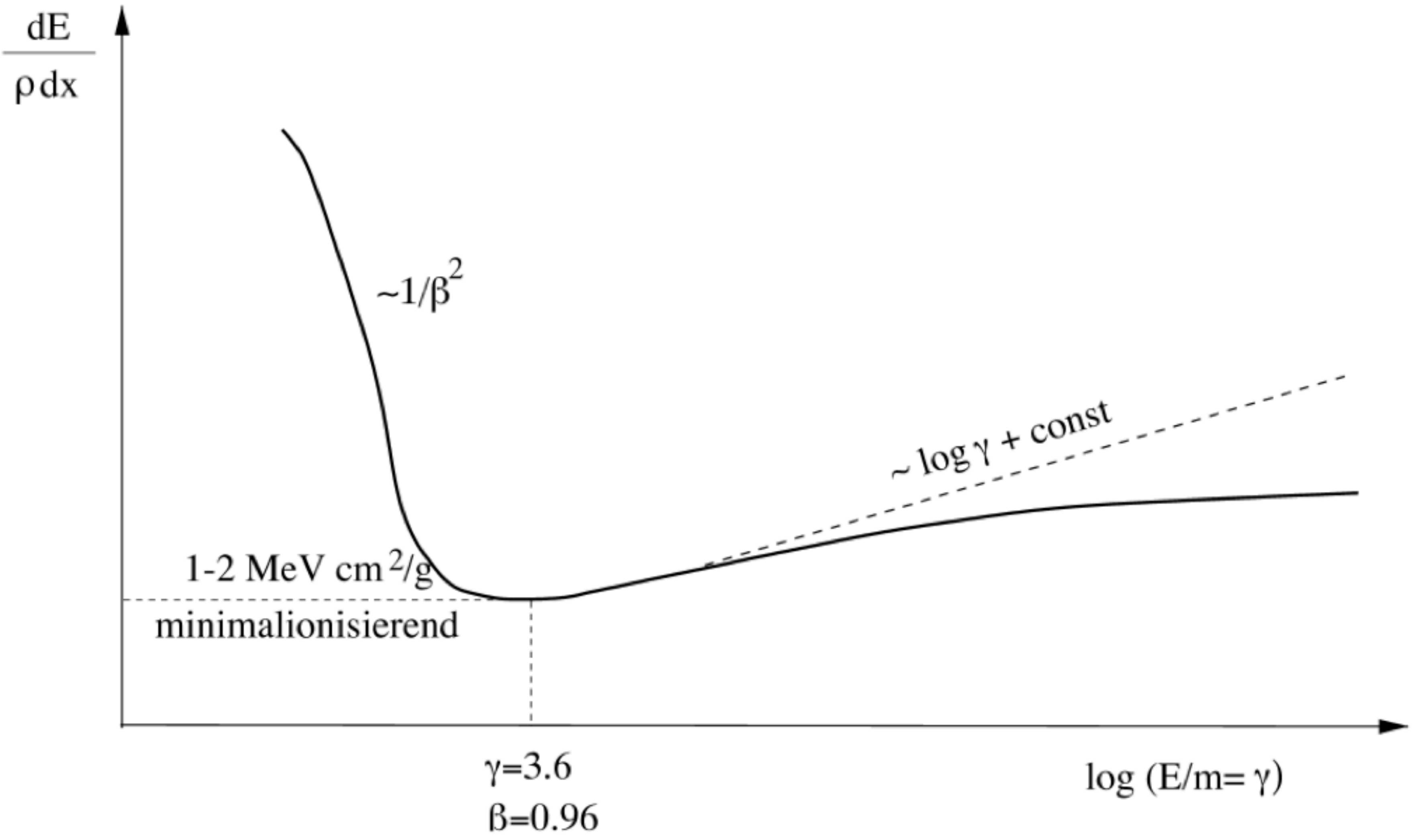
# Fortgeschrittene Experimentalphysik für Lehramtsstudierende
# Teil II: Kern- und Teilchenphysik

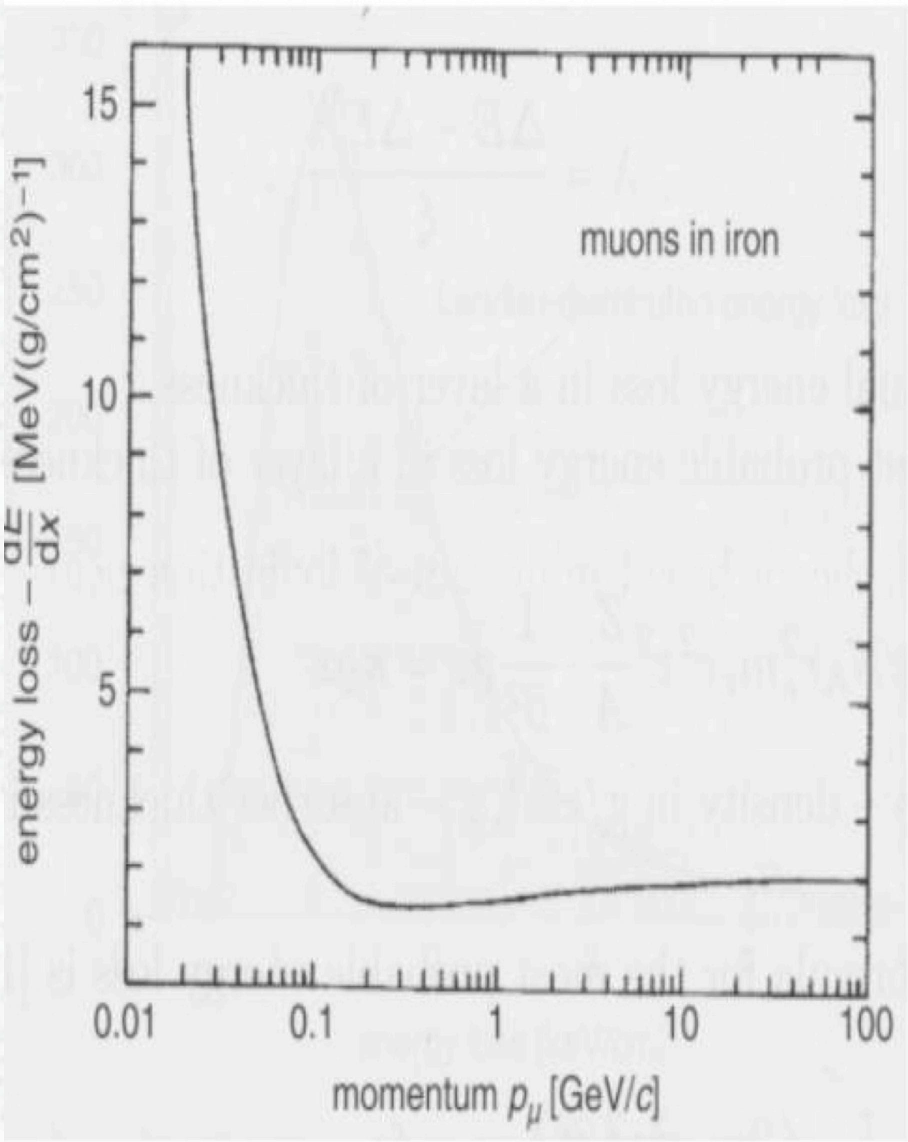
Prof. Markus Schumacher
Sommersemester 2013

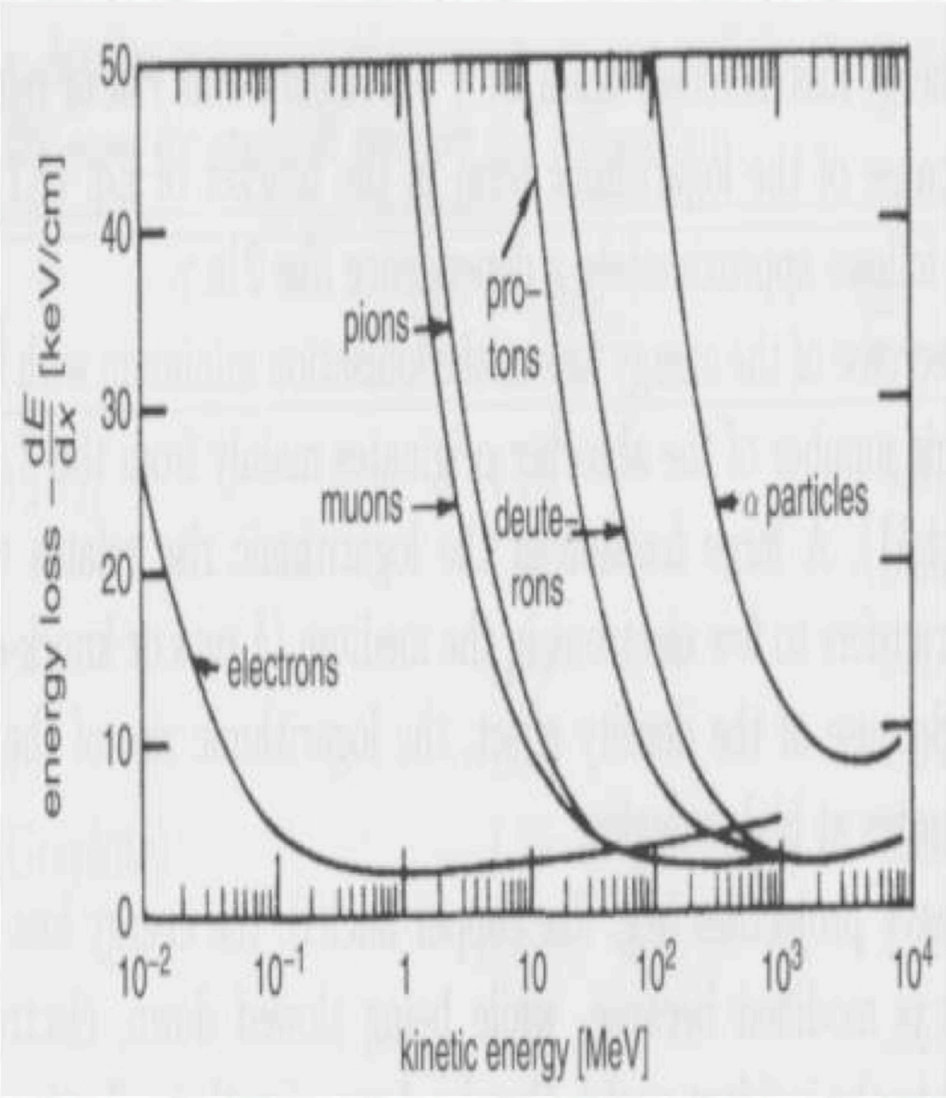
## Kapitel 6: Experimentelle Methoden

# Bethe-Bloch-Formel

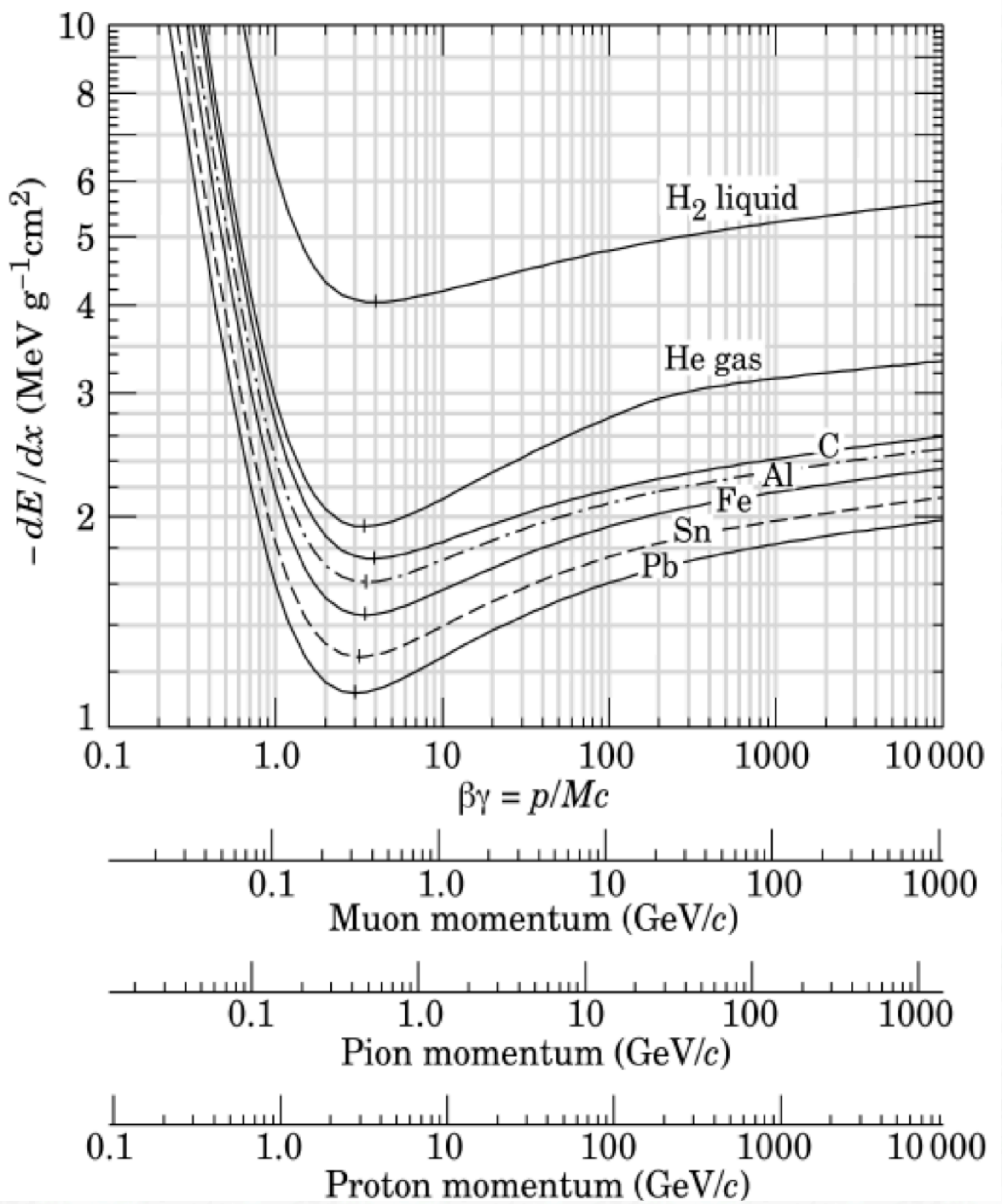


# Spezifischer Energieverlust für verschiedene Teilchen

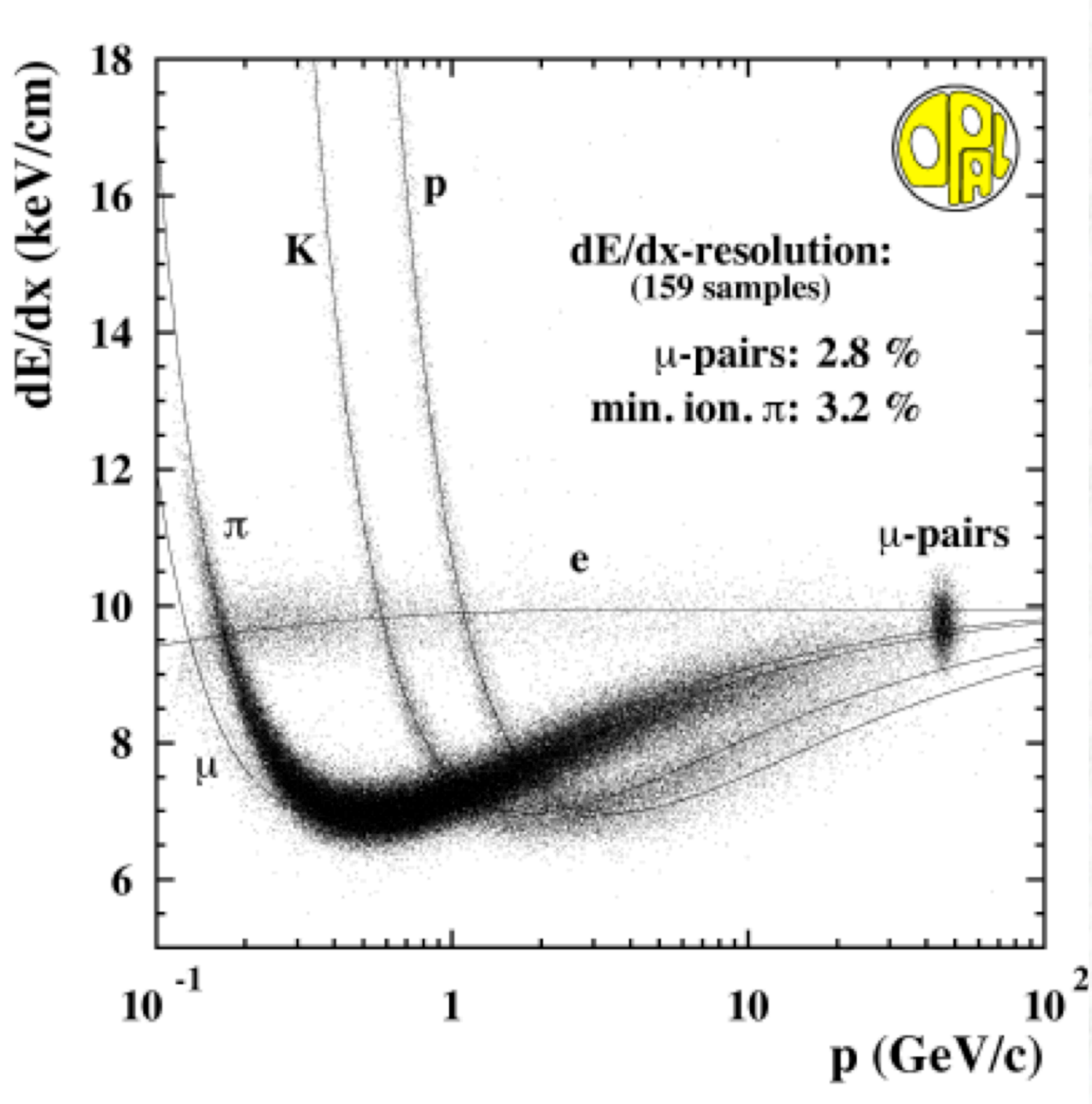




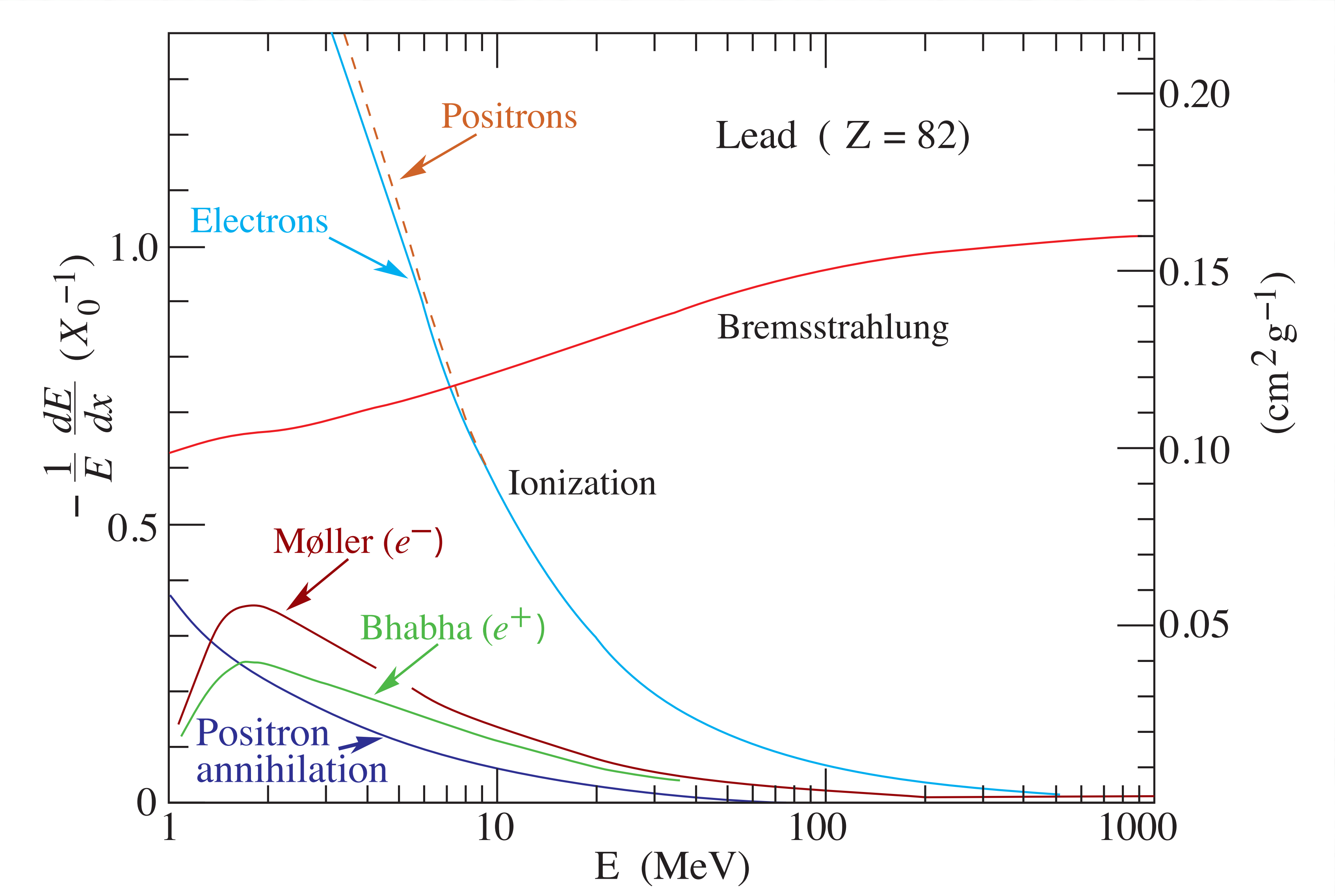
# Spezifischer Energieverlust für verschiedene Teilchen



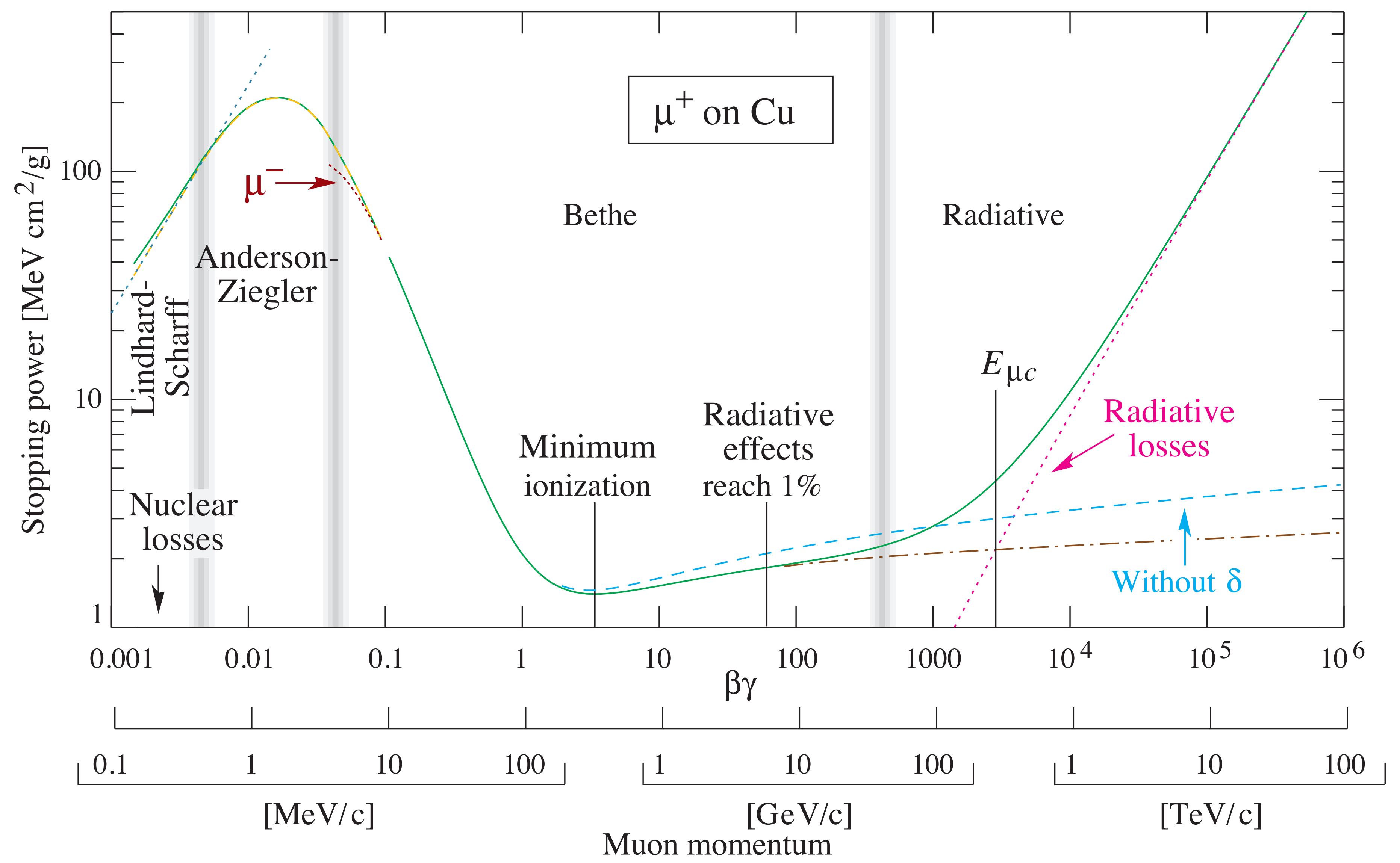
# Teilchenidentifikation durch Messung von dE/dx



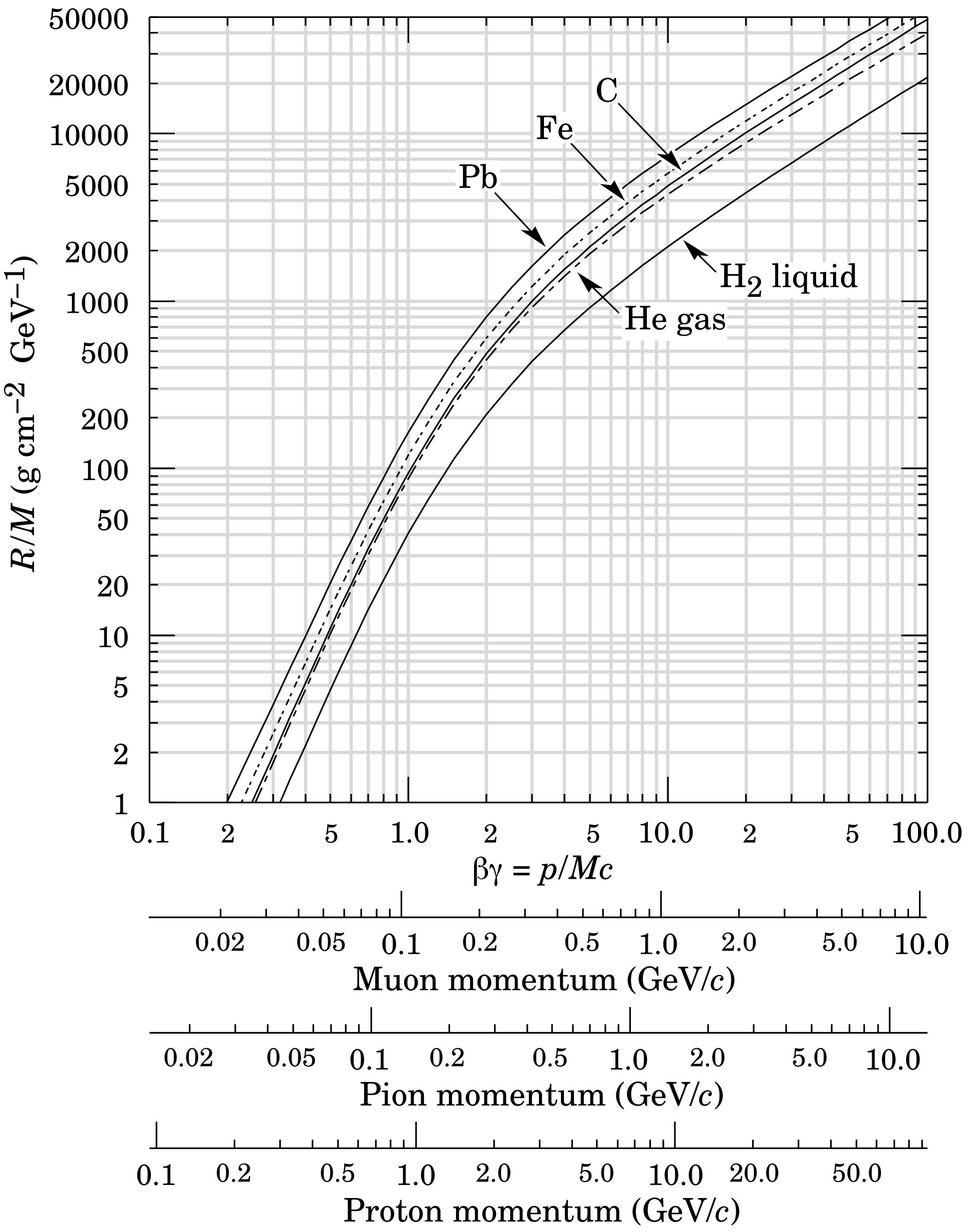
# Energieverlust für Elektronen und Positronen



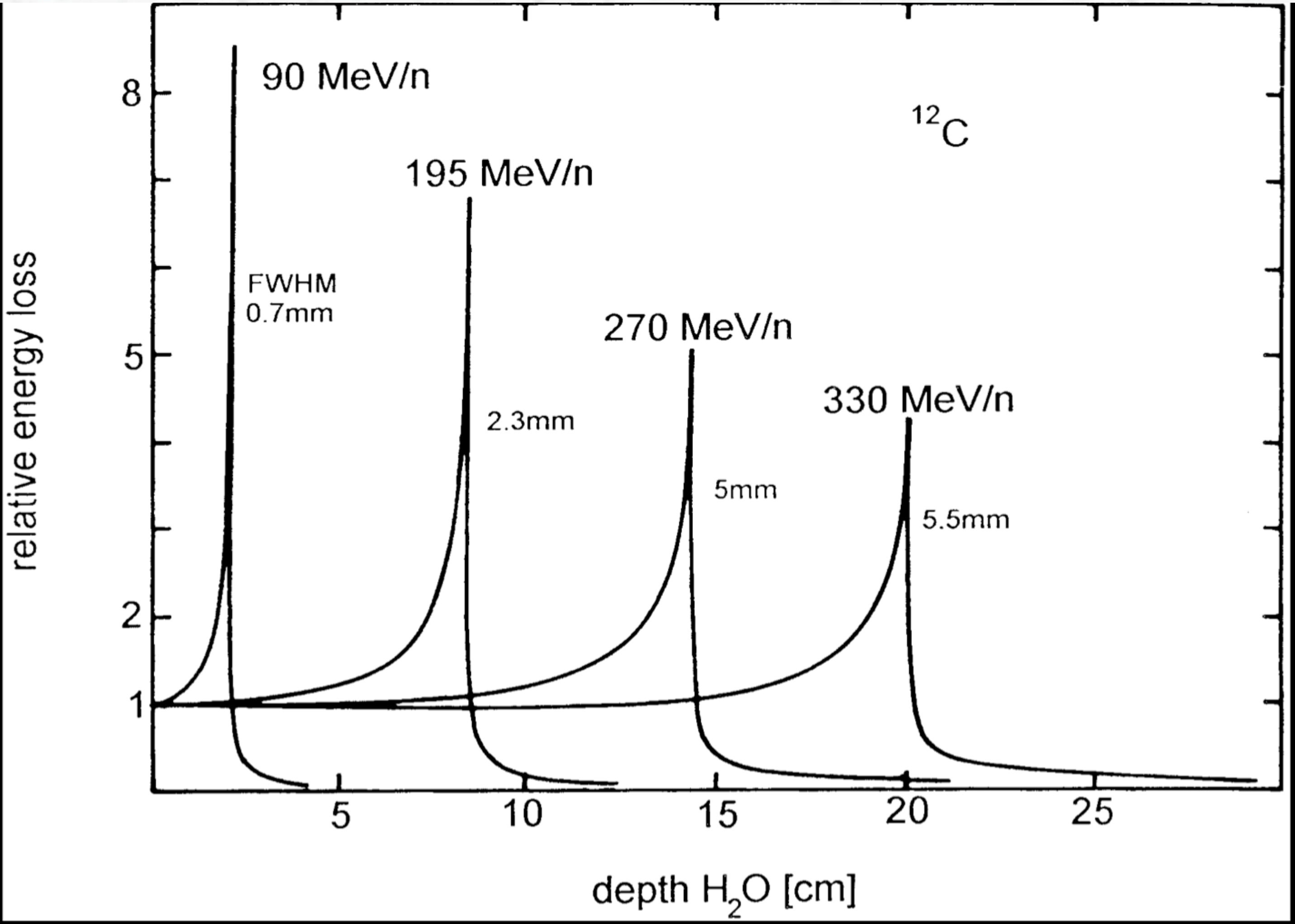
# Energieverlust für Myonen



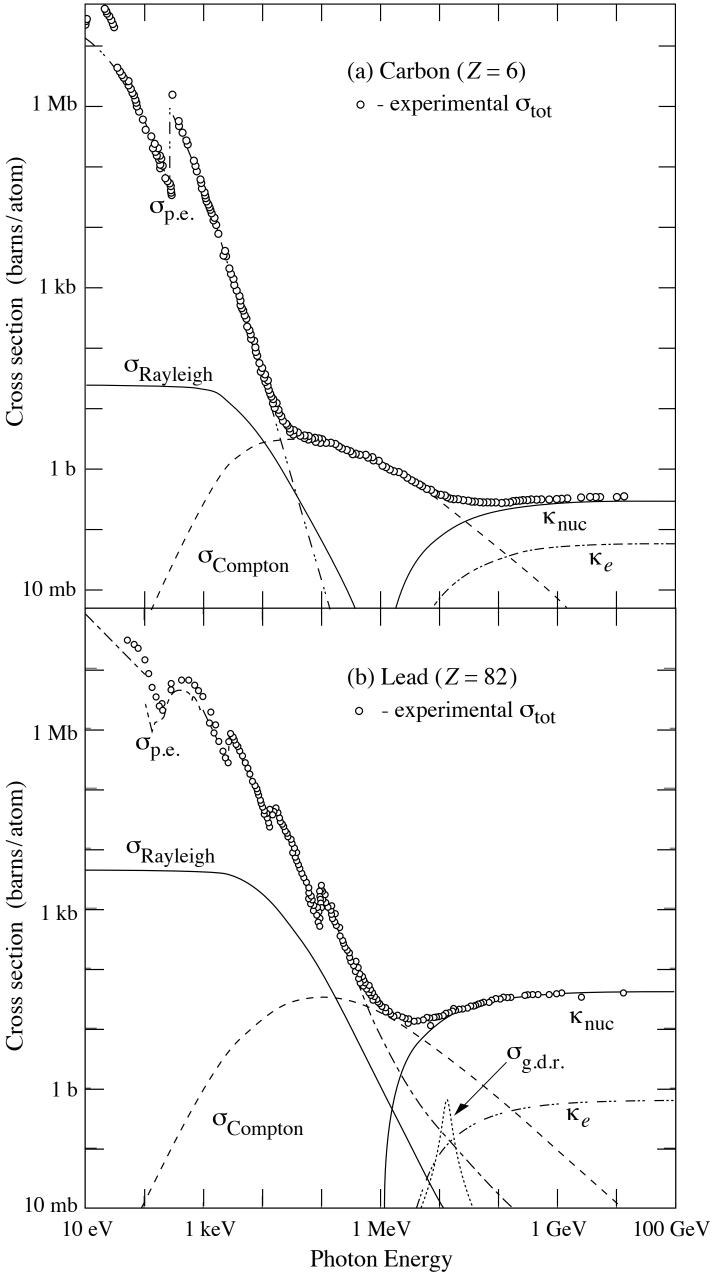
# Reichweite undTeilchenidentifikation



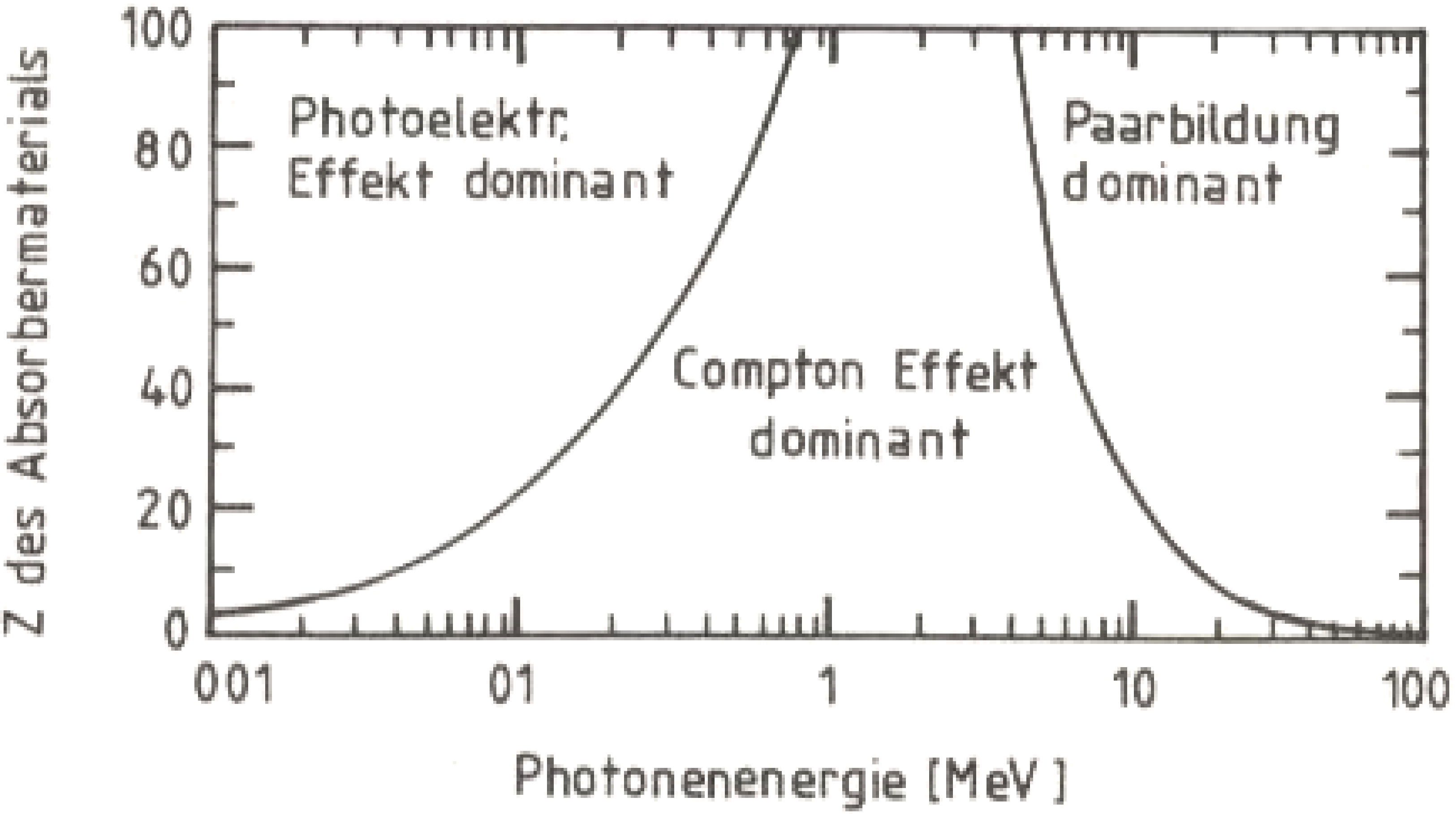
# Reichweite und Bragg-Peak



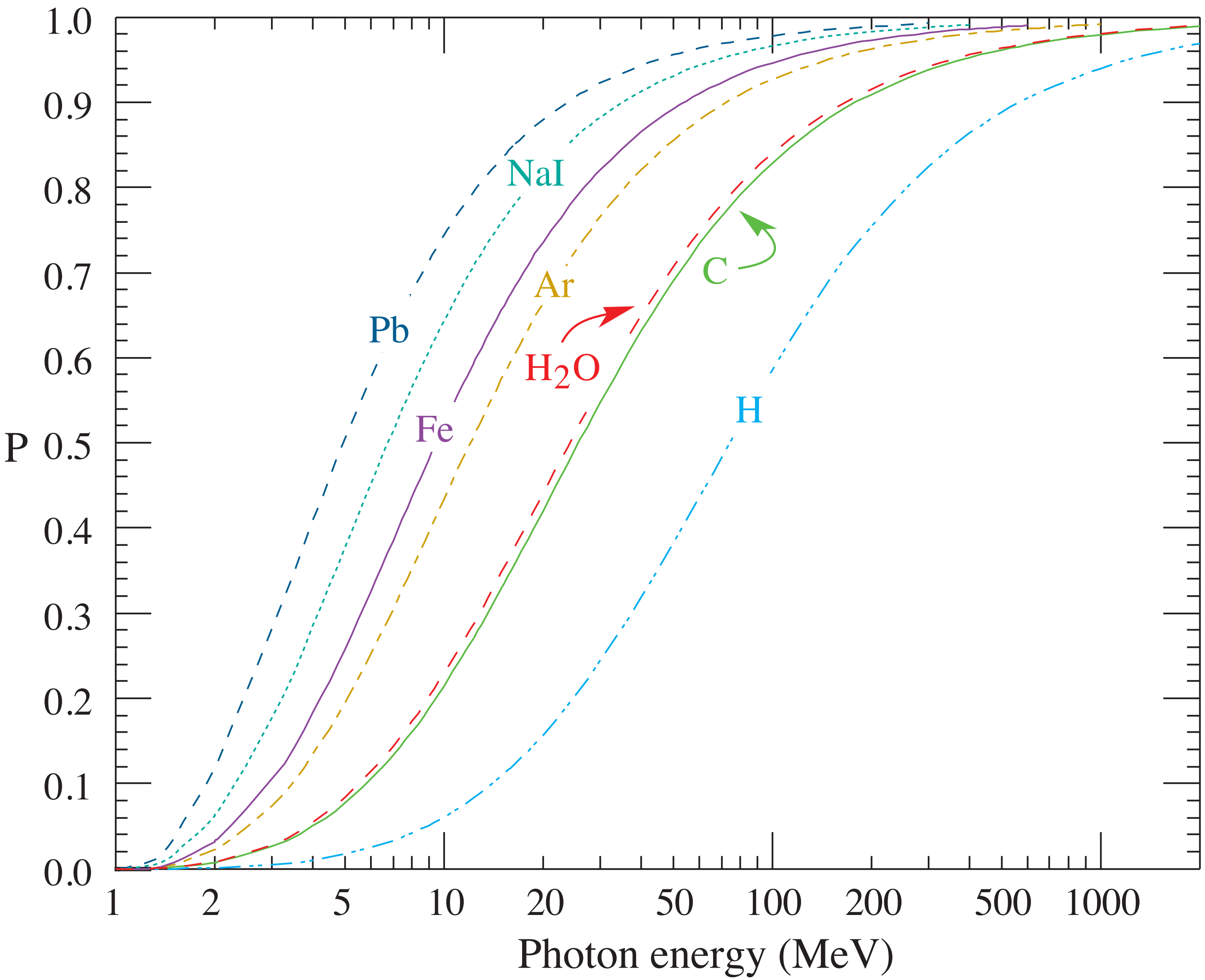
# Wechselwirkung von Photonen mit Materie



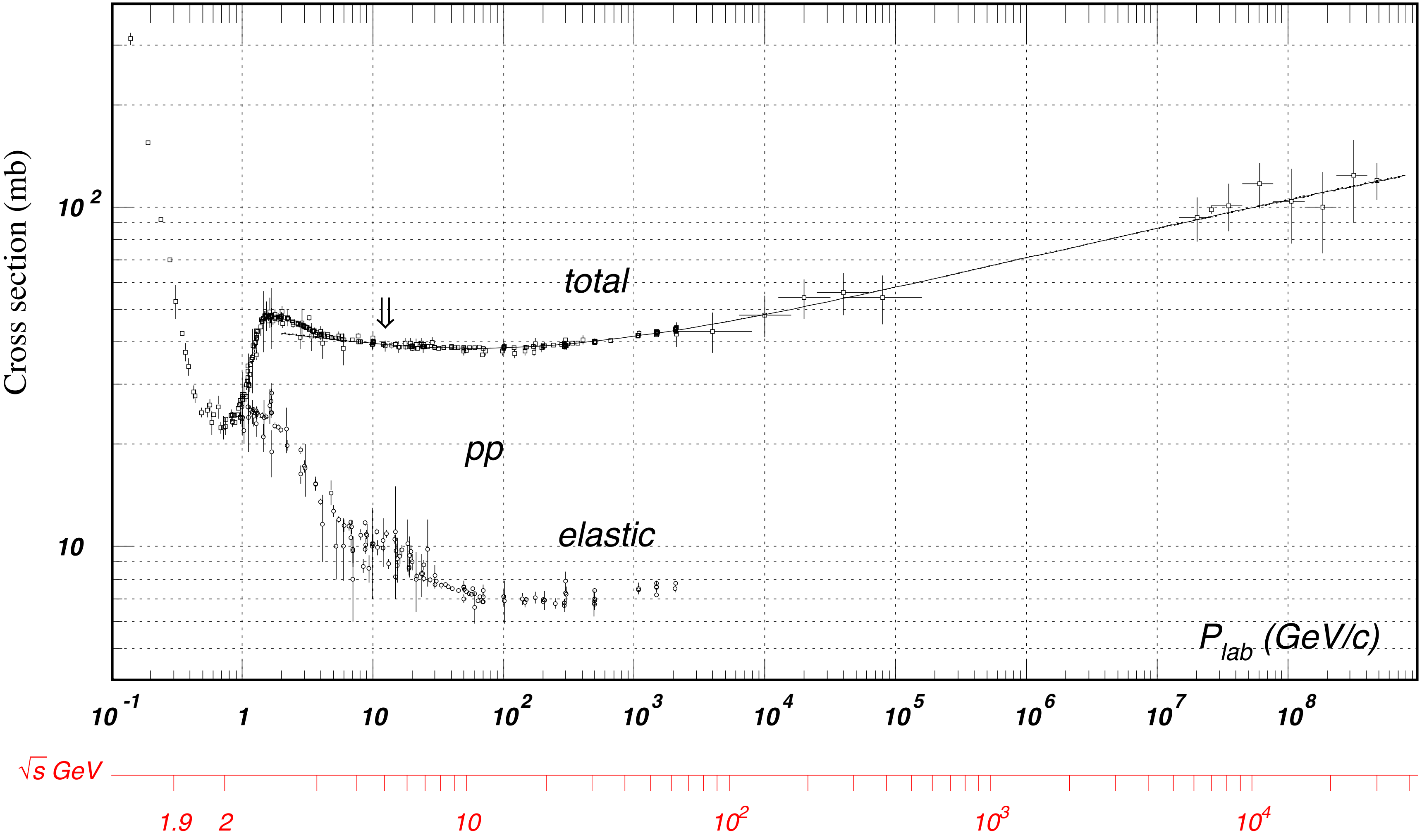
# Dominanz der drei Prozesse



# Wahrscheinlichkeit von Paarbildung



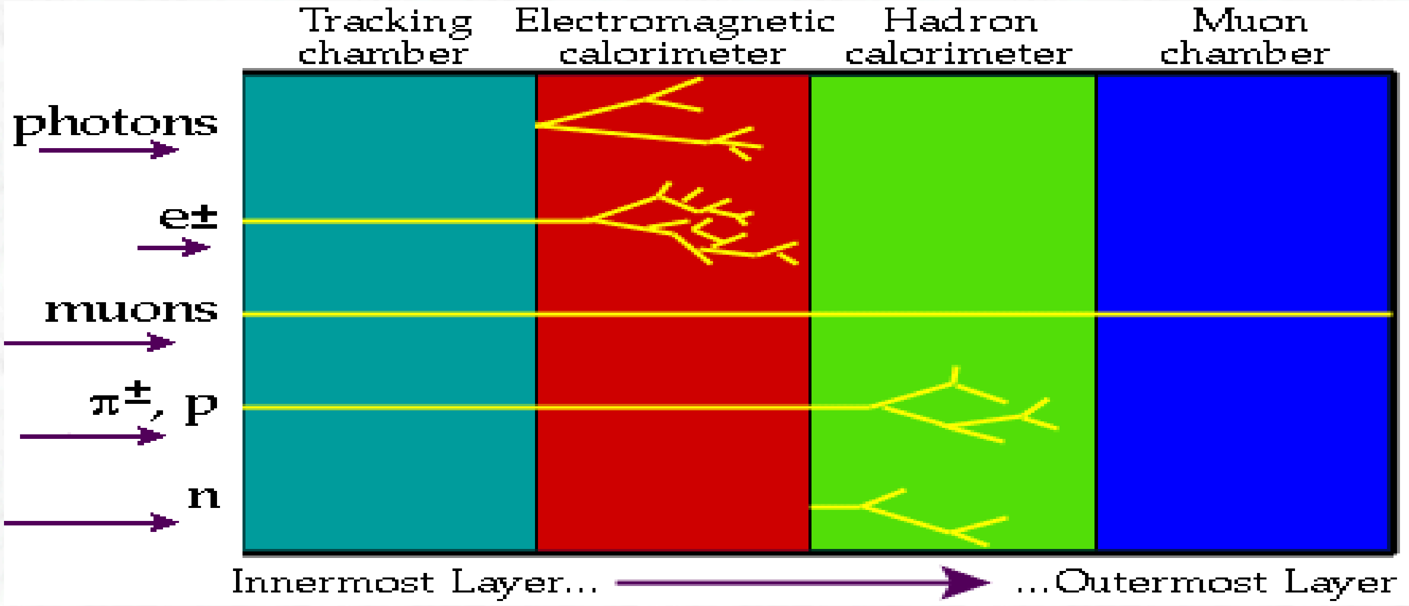
# pp-Wirkungsquerschnitte

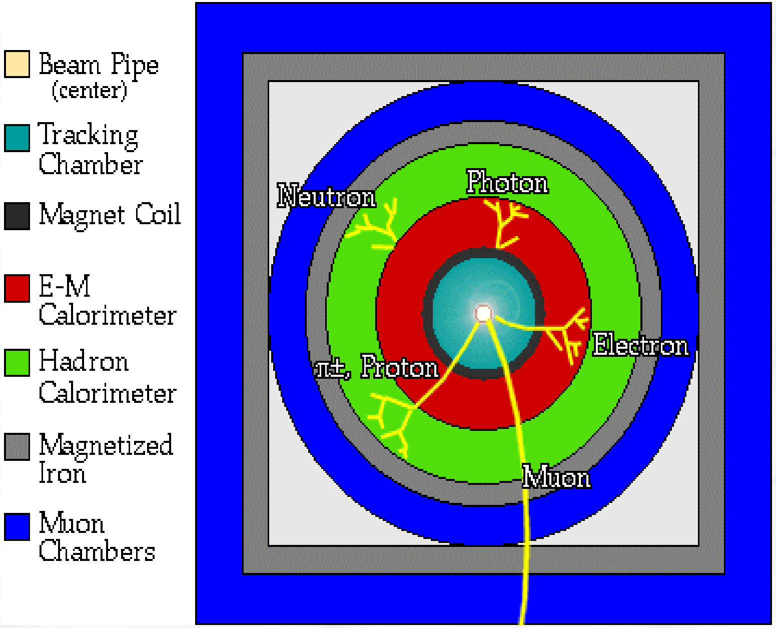


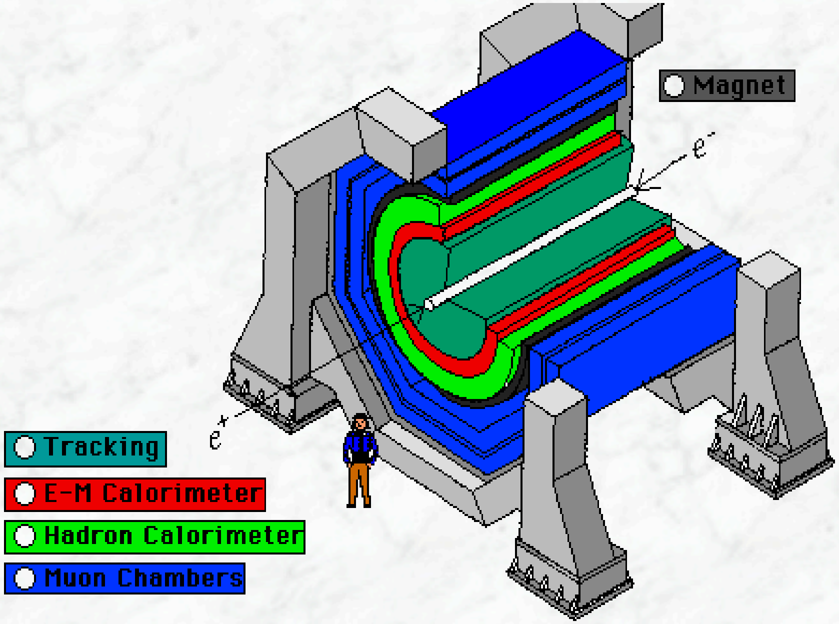
# Materialkonstanten

| Material | $Z$ | $A$ | $\langle Z/A \rangle$ | Nucl.coll. length $\lambda_T$ {g cm$^{-2}$} | Nucl.inter. length $\lambda_I$ {g cm$^{-2}$} | Rad.len. $X_0$ {g cm$^{-2}$} | $dE/dx\|_{\mathrm{min}}$ { MeV g$^{-1}$cm$^2$} | Density {g cm$^{-3}$} ({g$\ell^{-1}$}) |
|---|---|---|---|---|---|---|---|---|
| $H_2$ | 1 | 1.00794(7) | 0.99212 | 42.8 | 52.0 | 63.04 | (4.103) | 0.071(0.084) |
| $D_2$ | 1 | 2.01410177803(8) | 0.49650 | 51.3 | 71.8 | 125.97 | (2.053) | 0.169(0.168) |
| He | 2 | 4.002602(2) | 0.49967 | 51.8 | 71.0 | 94.32 | (1.937) | 0.125(0.166) |
| Li | 3 | 6.941(2) | 0.43221 | 52.2 | 71.3 | 82.78 | 1.639 | 0.534 |
| Be | 4 | 9.012182(3) | 0.44384 | 55.3 | 77.8 | 65.19 | 1.595 | 1.848 |
| C diamond | 6 | 12.0107(8) | 0.49955 | 59.2 | 85.8 | 42.70 | 1.725 | 3.520 |
| C graphite | 6 | 12.0107(8) | 0.49955 | 59.2 | 85.8 | 42.70 | 1.742 | 2.210 |
| $N_2$ | 7 | 14.0067(2) | 0.49976 | 61.1 | 89.7 | 37.99 | (1.825) | 0.807(1.165) |
| $O_2$ | 8 | 15.9994(3) | 0.50002 | 61.3 | 90.2 | 34.24 | (1.801) | 1.141(1.332) |
| $F_2$ | 9 | 18.9984032(5) | 0.47372 | 65.0 | 97.4 | 32.93 | (1.676) | 1.507(1.580) |
| Ne | 10 | 20.1797(6) | 0.49555 | 65.7 | 99.0 | 28.93 | (1.724) | 1.204(0.839) |
| Al | 13 | 26.9815386(8) | 0.48181 | 69.7 | 107.2 | 24.01 | 1.615 | 2.699 |
| Si | 14 | 28.0855(3) | 0.49848 | 70.2 | 108.4 | 21.82 | 1.664 | 2.329 |
| $Cl_2$ | 17 | 35.453(2) | 0.47951 | 73.8 | 115.7 | 19.28 | (1.630) | 1.574(2.980) |
| Ar | 18 | 39.948(1) | 0.45059 | 75.7 | 119.7 | 19.55 | (1.519) | 1.396(1.662) |
| Ti | 22 | 47.867(1) | 0.45961 | 78.8 | 126.2 | 16.16 | 1.477 | 4.540 |
| Fe | 26 | 55.845(2) | 0.46557 | 81.7 | 132.1 | 13.84 | 1.451 | 7.874 |
| Cu | 29 | 63.546(3) | 0.45636 | 84.2 | 137.3 | 12.86 | 1.403 | 8.960 |
| Ge | 32 | 72.64(1) | 0.44053 | 86.9 | 143.0 | 12.25 | 1.370 | 5.323 |
| Sn | 50 | 118.710(7) | 0.42119 | 98.2 | 166.7 | 8.82 | 1.263 | 7.310 |
| Xe | 54 | 131.293(6) | 0.41129 | 100.8 | 172.1 | 8.48 | (1.255) | 2.953(5.483) |
| W | 74 | 183.84(1) | 0.40252 | 110.4 | 191.9 | 6.76 | 1.145 | 19.300 |
| Pt | 78 | 195.084(9) | 0.39983 | 112.2 | 195.7 | 6.54 | 1.128 | 21.450 |
| Au | 79 | 196.966569(4) | 0.40108 | 112.5 | 196.3 | 6.46 | 1.134 | 19.320 |
| Pb | 82 | 207.2(1) | 0.39575 | 114.1 | 199.6 | 6.37 | 1.122 | 11.350 |
| U | 92 | [238.02891(3)] | 0.38651 | 118.6 | 209.0 | 6.00 | 1.081 | 18.950 |
| Air (dry, 1 atm) | | | 0.49919 | 61.3 | 90.1 | 36.62 | (1.815) | (1.205) |
| Shielding concrete | | | 0.50274 | 65.1 | 97.5 | 26.57 | 1.711 | 2.300 |
| Borosilicate glass (Pyrex) | | | 0.49707 | 64.6 | 96.5 | 28.17 | 1.696 | 2.230 |
| Lead glass | | | 0.42101 | 95.9 | 158.0 | 7.87 | 1.255 | 6.220 |
| Standard rock | | | 0.50000 | 66.8 | 101.3 | 26.54 | 1.688 | 2.650 |

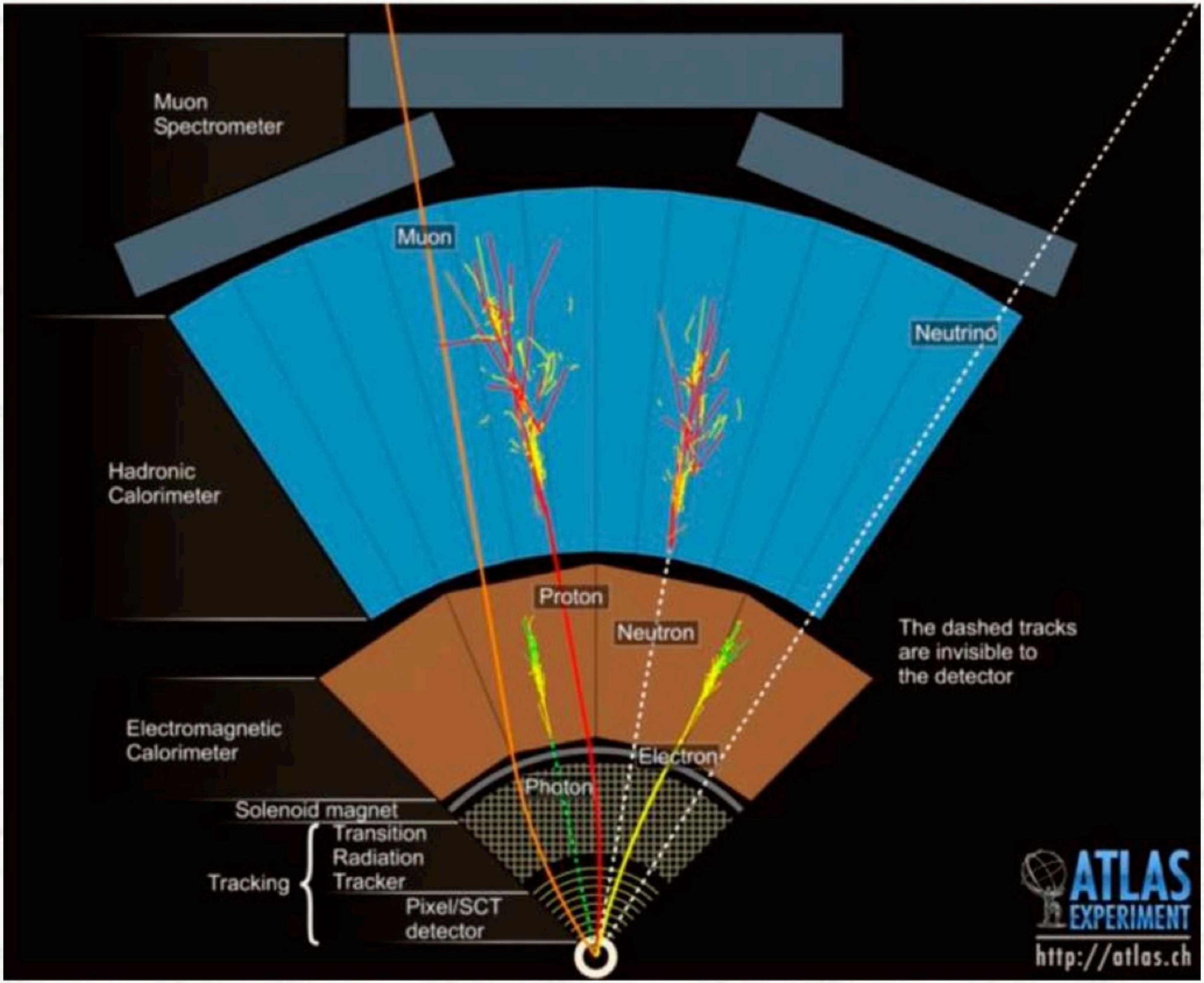
# Aufbau eines Kolliderdetektors



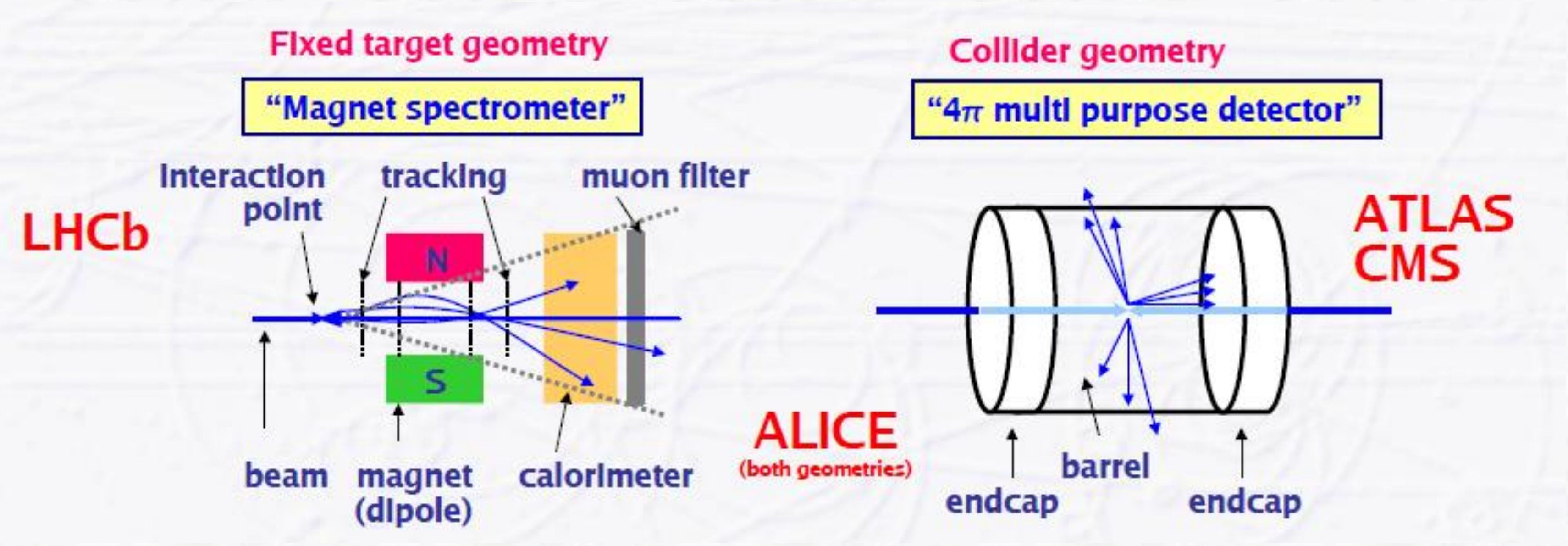

A detector cross-section, showing particle paths

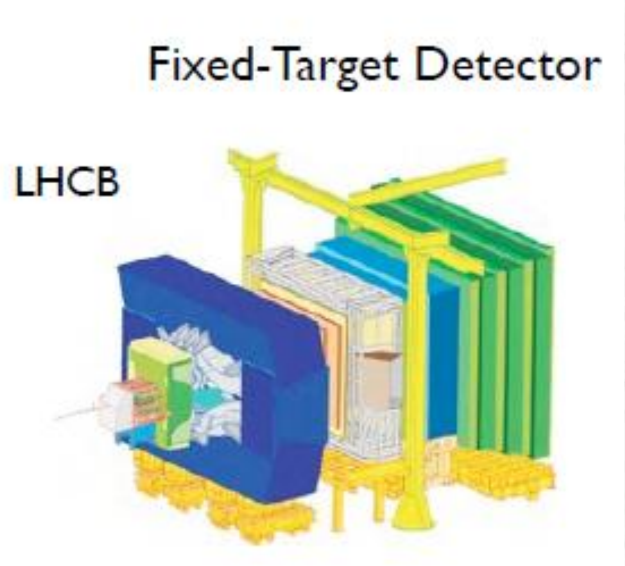


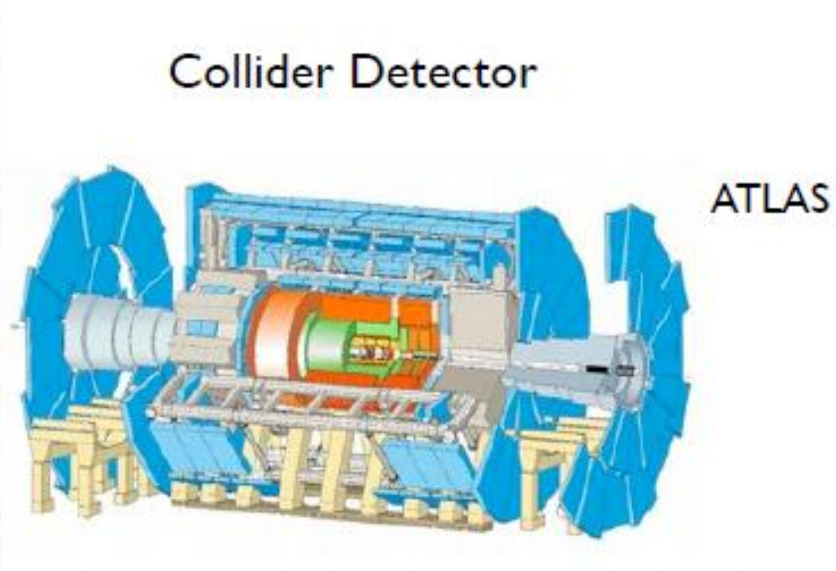
# Teilchenidentifikation



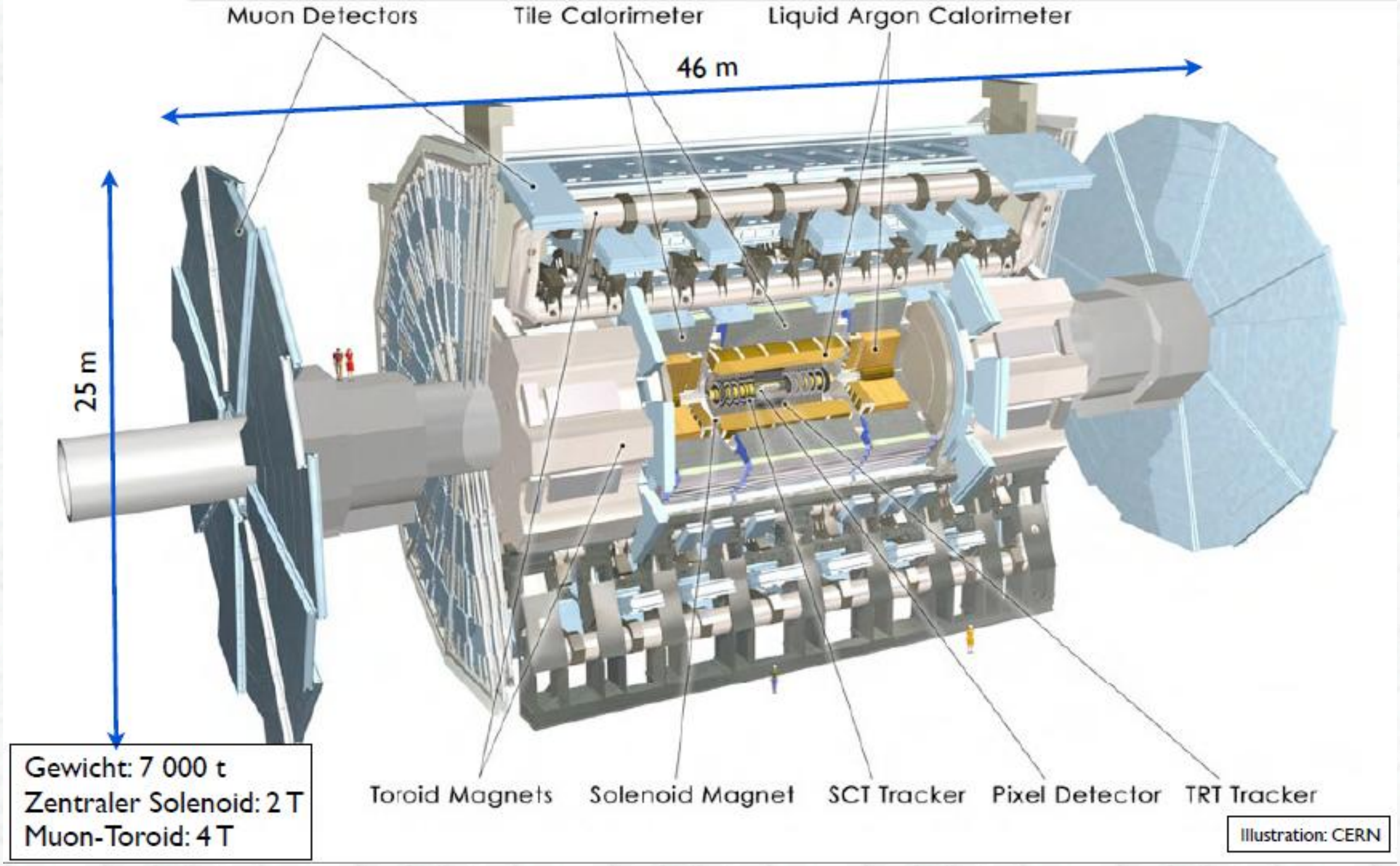
# Fixed-Target und Kollider-Detektor







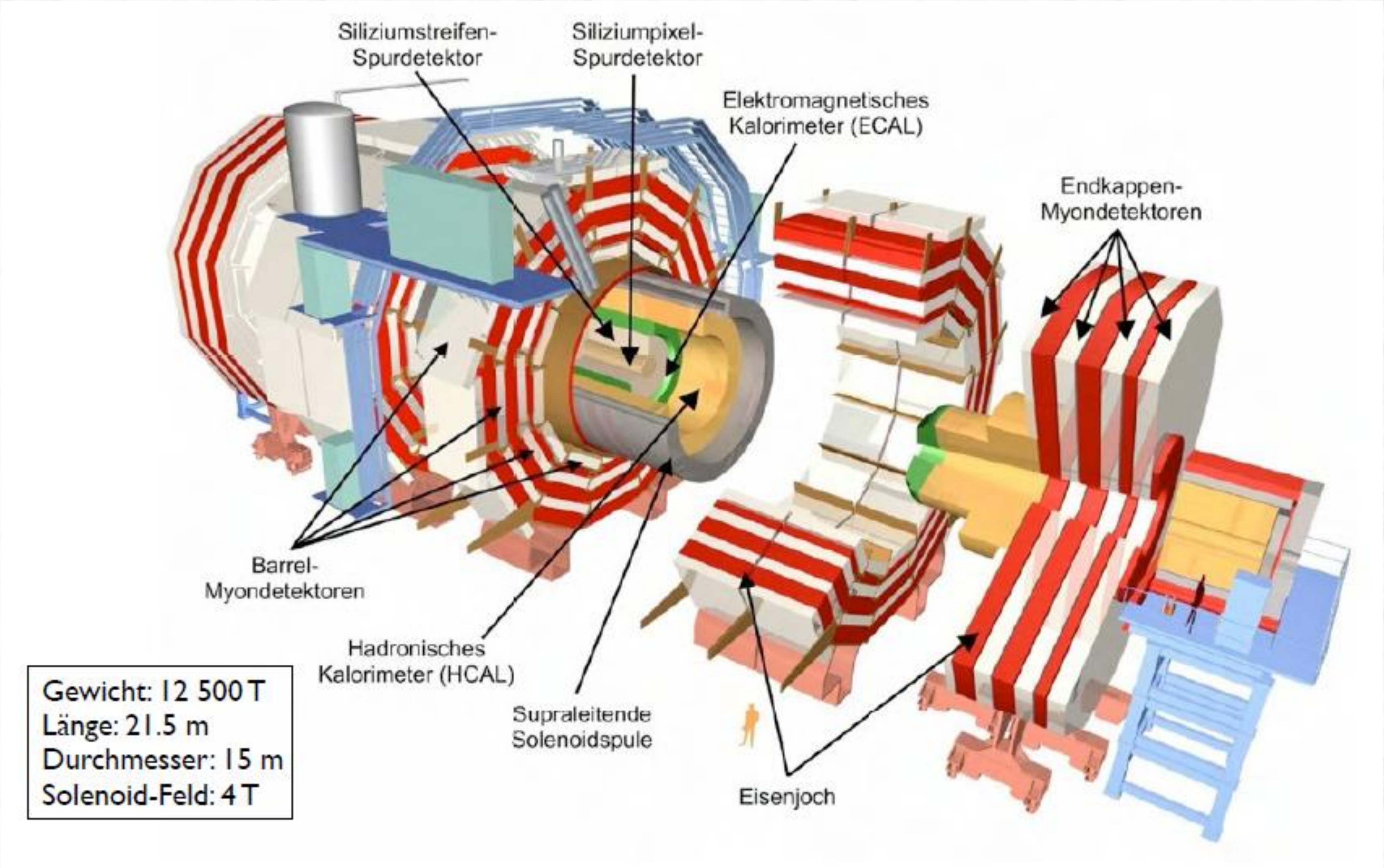
# ATLAS Detektor



Gewicht: 7 000 t
Zentraler Solenoid: 2 T
Muon-Toroid: 4 T

Illustration: CERN

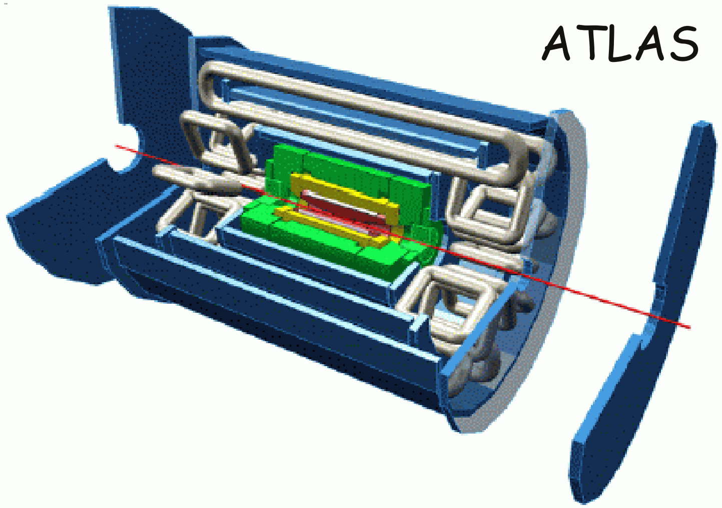
# CMS Detektor

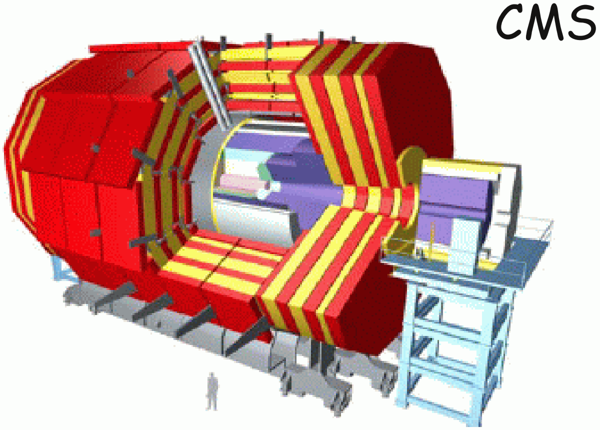


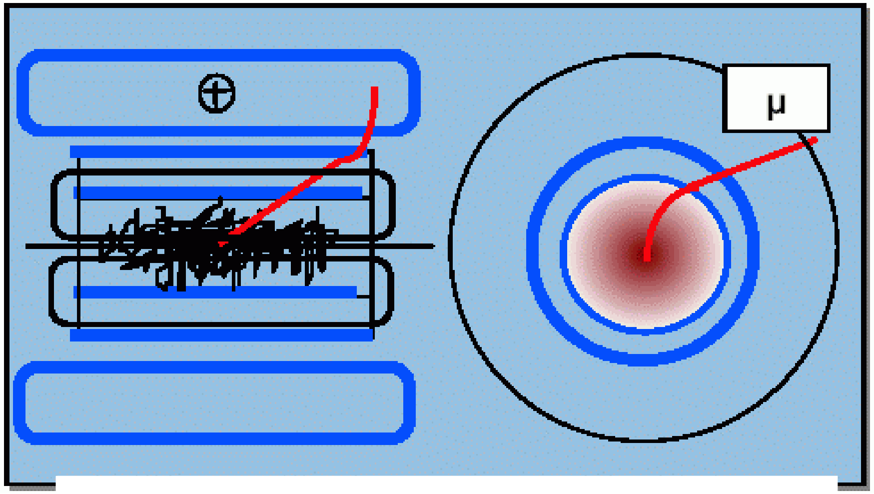
Gewicht: 12 500 T
Länge: 21.5 m
Durchmesser: 15 m
Solenoid-Feld: 4 T

# Impulsmessung im Magnetfeld

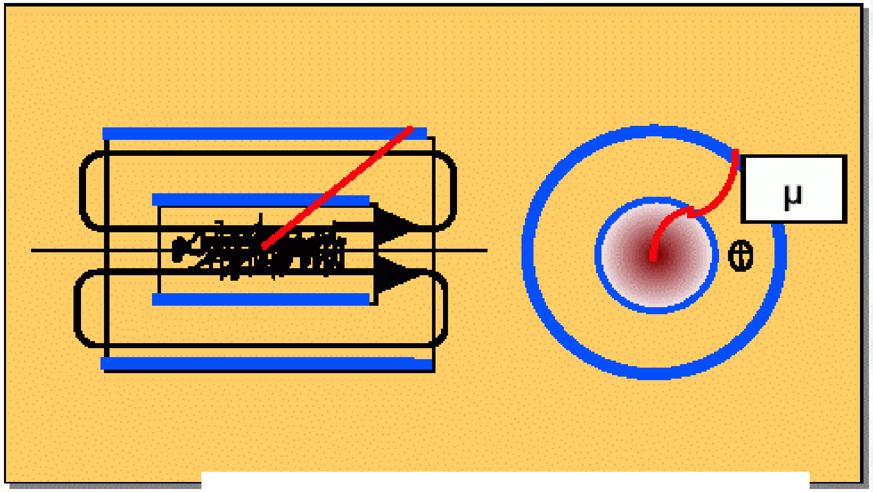
$$p_T[GeV] = 0.3 \cdot B[T] \cdot \rho[m]$$





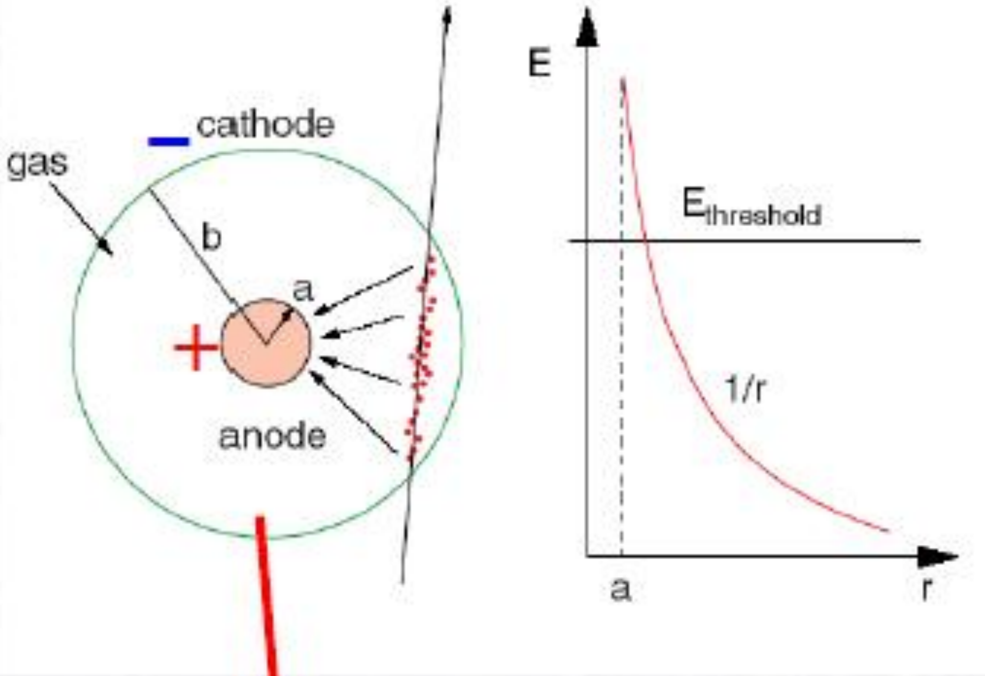


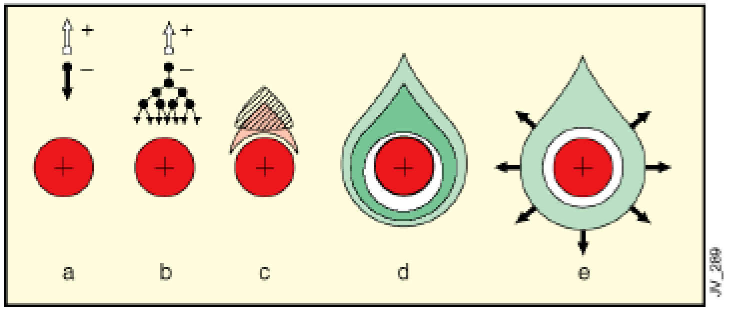
Small solenoid (2T) for the Tracker
Toroids for the muon system

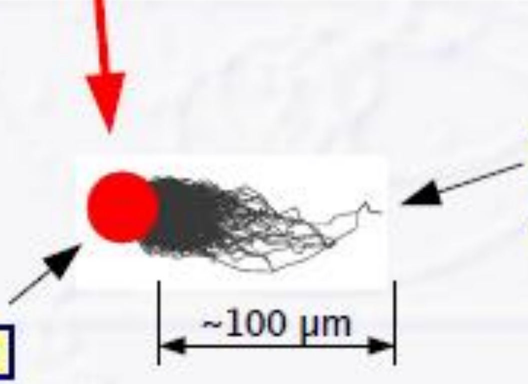


Big solenoid (4T)
Calorimeters inside solenoid

# Prinzip der Signalverstärkung







**primary electron starting to ionize**

**anode wire**

# Nachweis der Ionsiation

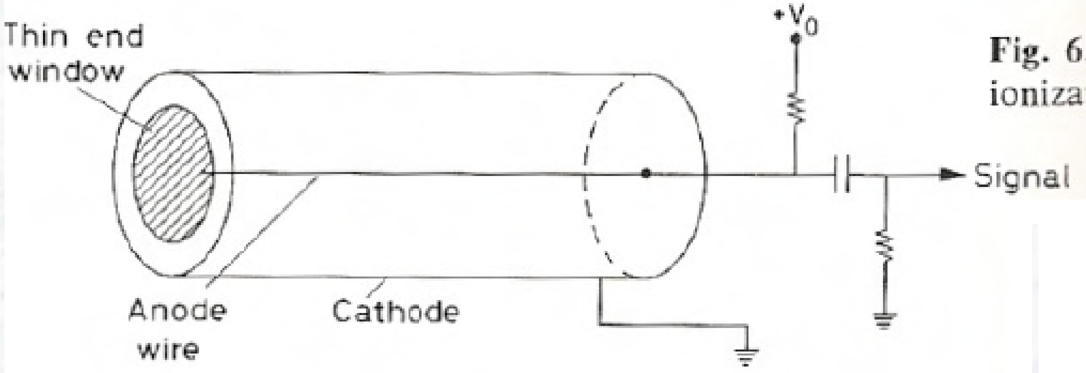
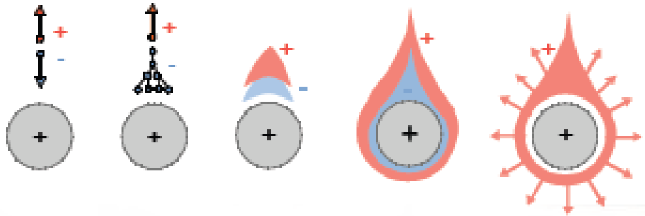
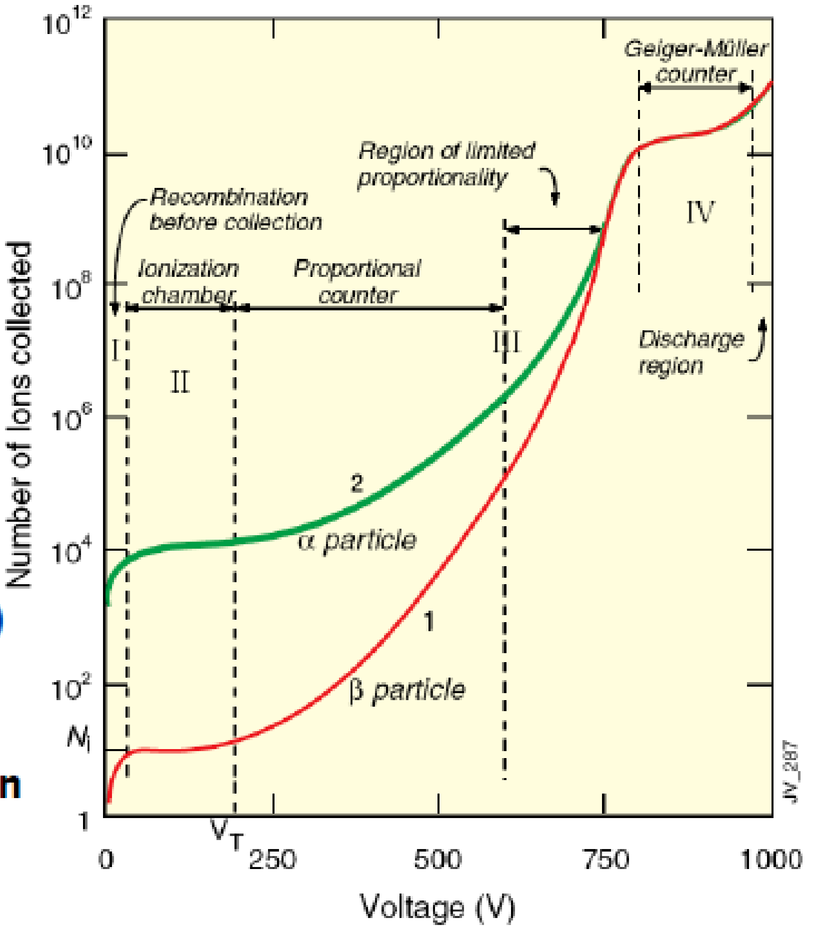


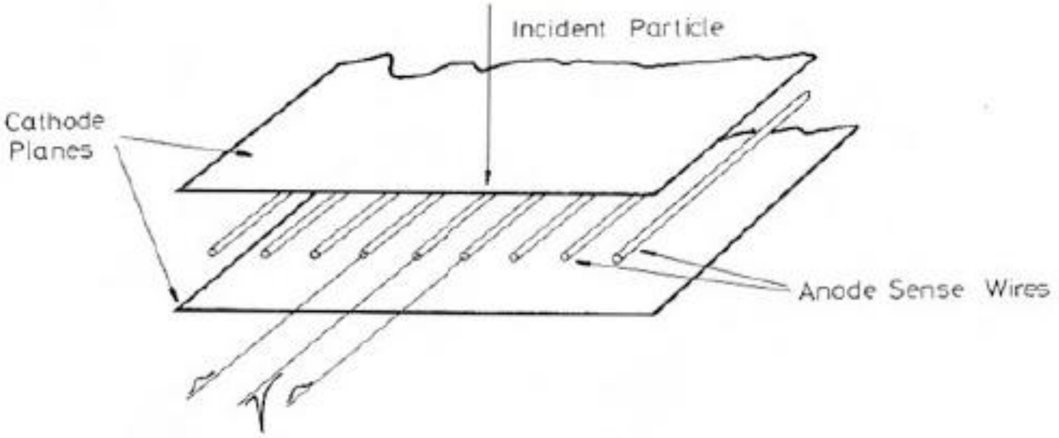
Fig. 6.1. I
ionization

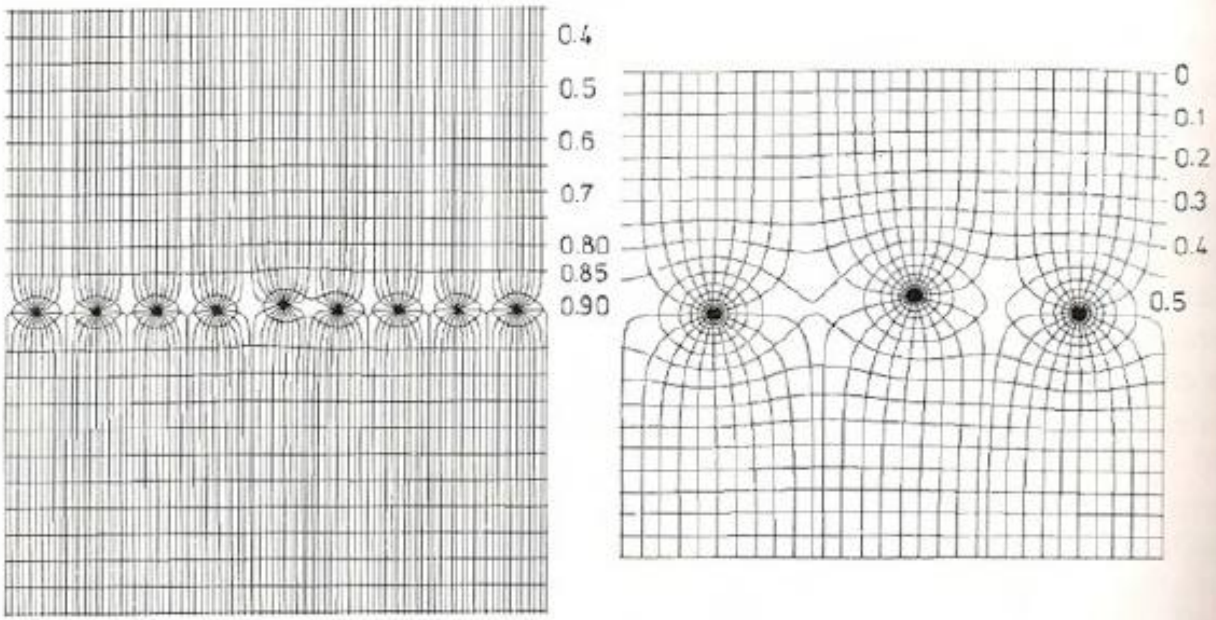


- Teilchendurchgang erzeugt Elektron-Ionen-Paare in Gasvolumen
- Elektronen werden in einem starken Elektrischen Feld beschleunigt, es kommt zu einer Lawinenverstärkung
- Je nach Spannung ist das Signal proportional zur ursprünglich deponierten Ladung oder geht in Sättigung



# Vieldrahtproportionalkammer

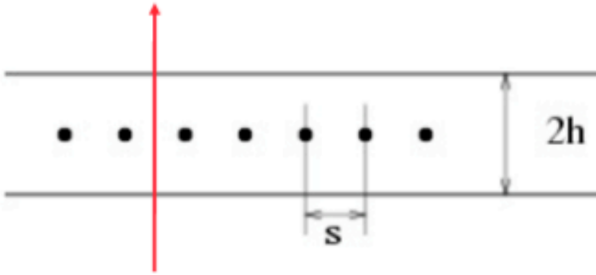




- Vieldraht-Proportionalkammer MWPC
- G. Charpak 1968 (Nobel-Preis 1992)

# Vieldrahtproportionalkammer

Multiple signal wires with common cathodes:



Wire diameters: 10μm - 50μm
Wire distance:  typ. 2mm
Wire-Cathode distance: typ. 10 mm

Field in multiplication region still symmetric

Field outside multiplication region approx. const.

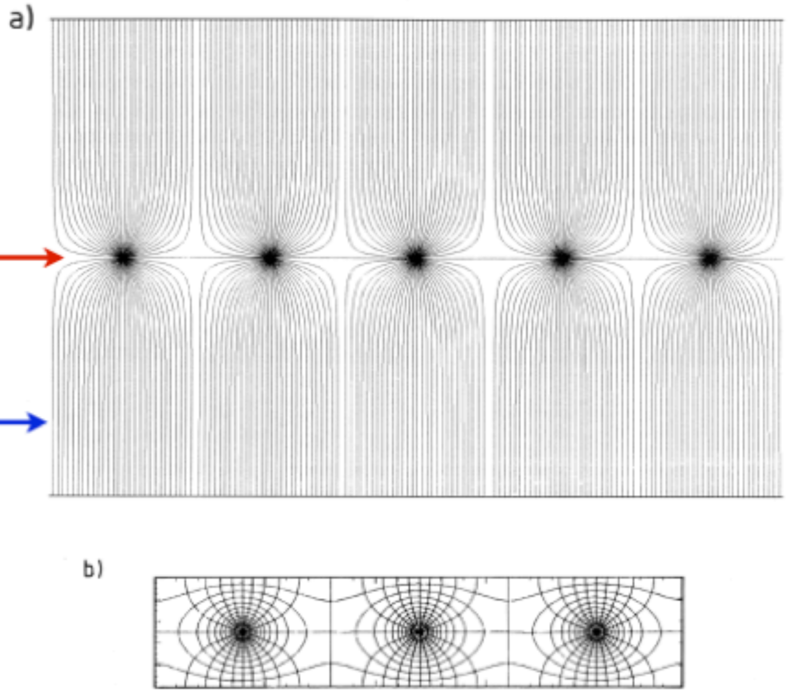
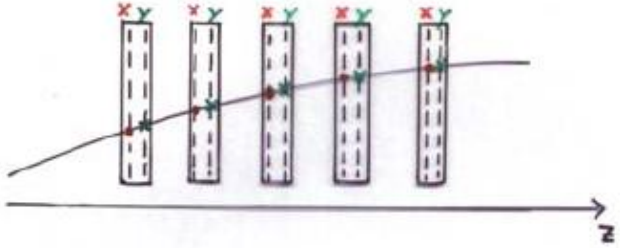


Fig. 4.25. a) Field lines in a five-wire proportional chamber [184]. b) Field and equipotential lines in a three-wire proportional chamber [183].

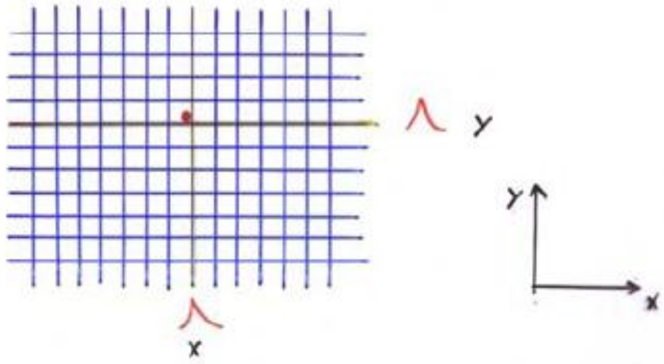
# Bestimmung der dritten Koordinate

Spurpunkte (x, y, z) ?

① Kombination mehrerer Kammern



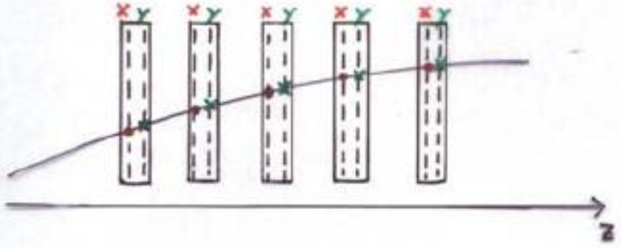
- z: Kammerposition, bekannt.
  x, y: gekreuzte Vieldraht prop. Kammern (90°)



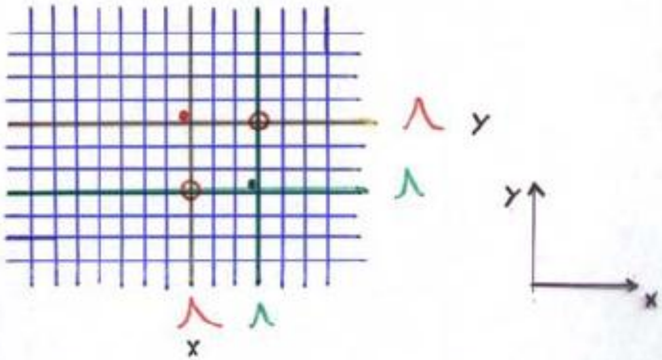
→ Auflösung in beiden Projektionen ~ 600 μm

Spurpunkte (x, y, z) ?

① Kombination mehrerer Kammern



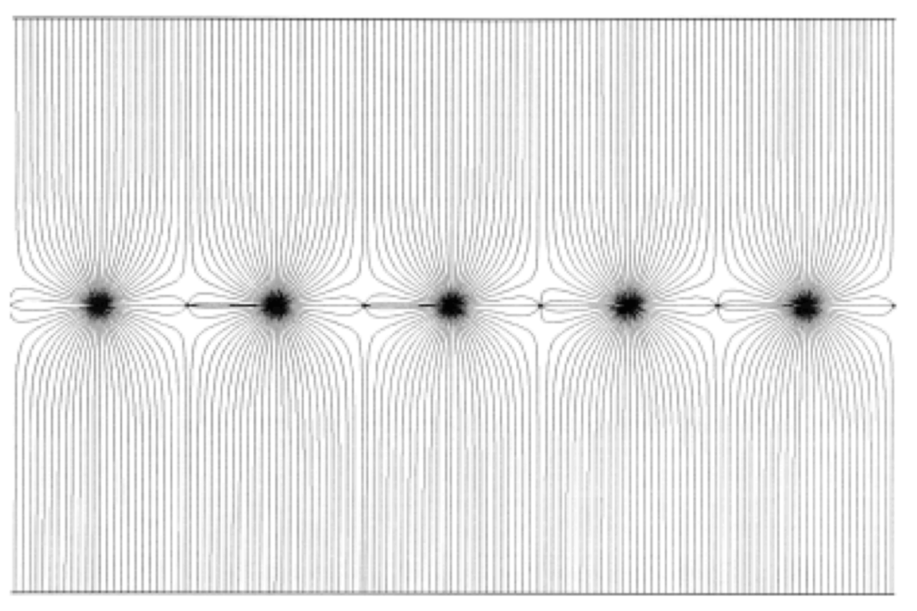
- z: Kammerposition, bekannt.
  x, y: gekreuzte Vieldraht prop. Kammern (90°)

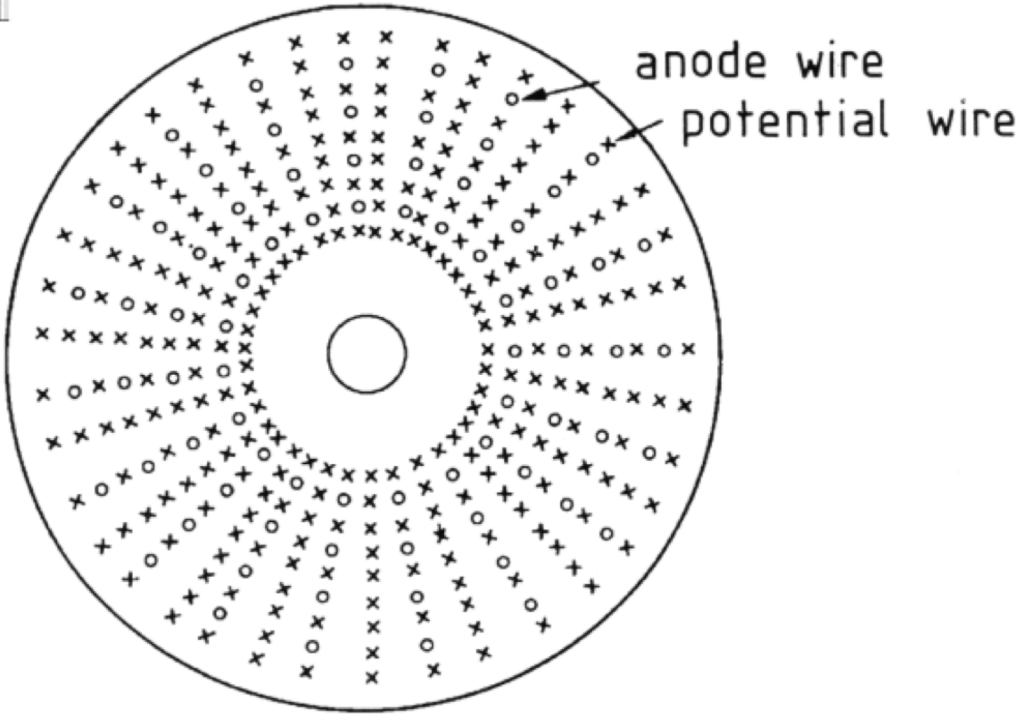


→ Ambiguitäten bei mehreren Teilchen
→ 'Geisterpunkte'.

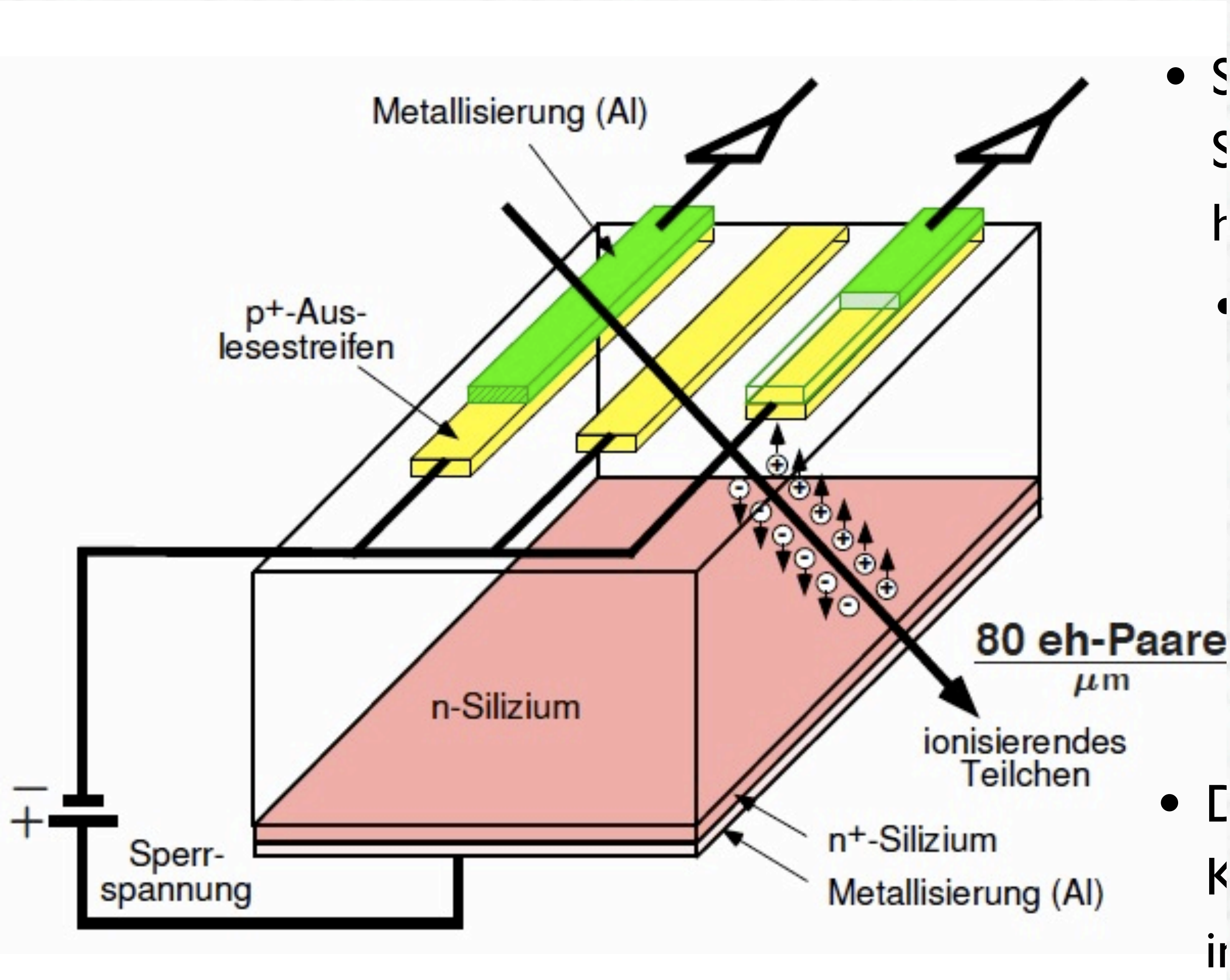
→ Auflösung in beiden Projektionen ~ 600 μm

# Driftkammern





# Prinzip des Siliziumstreifendetektors



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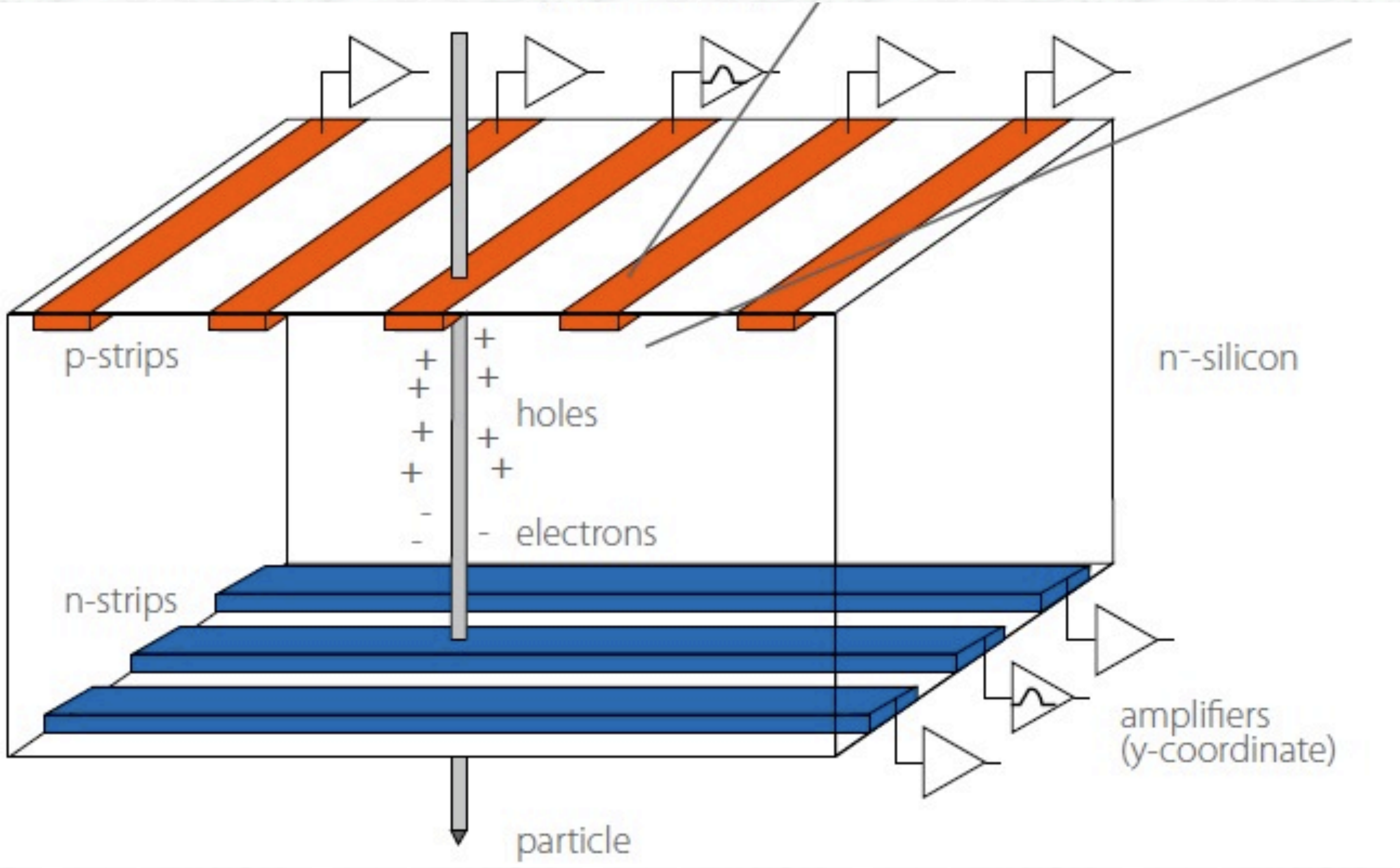
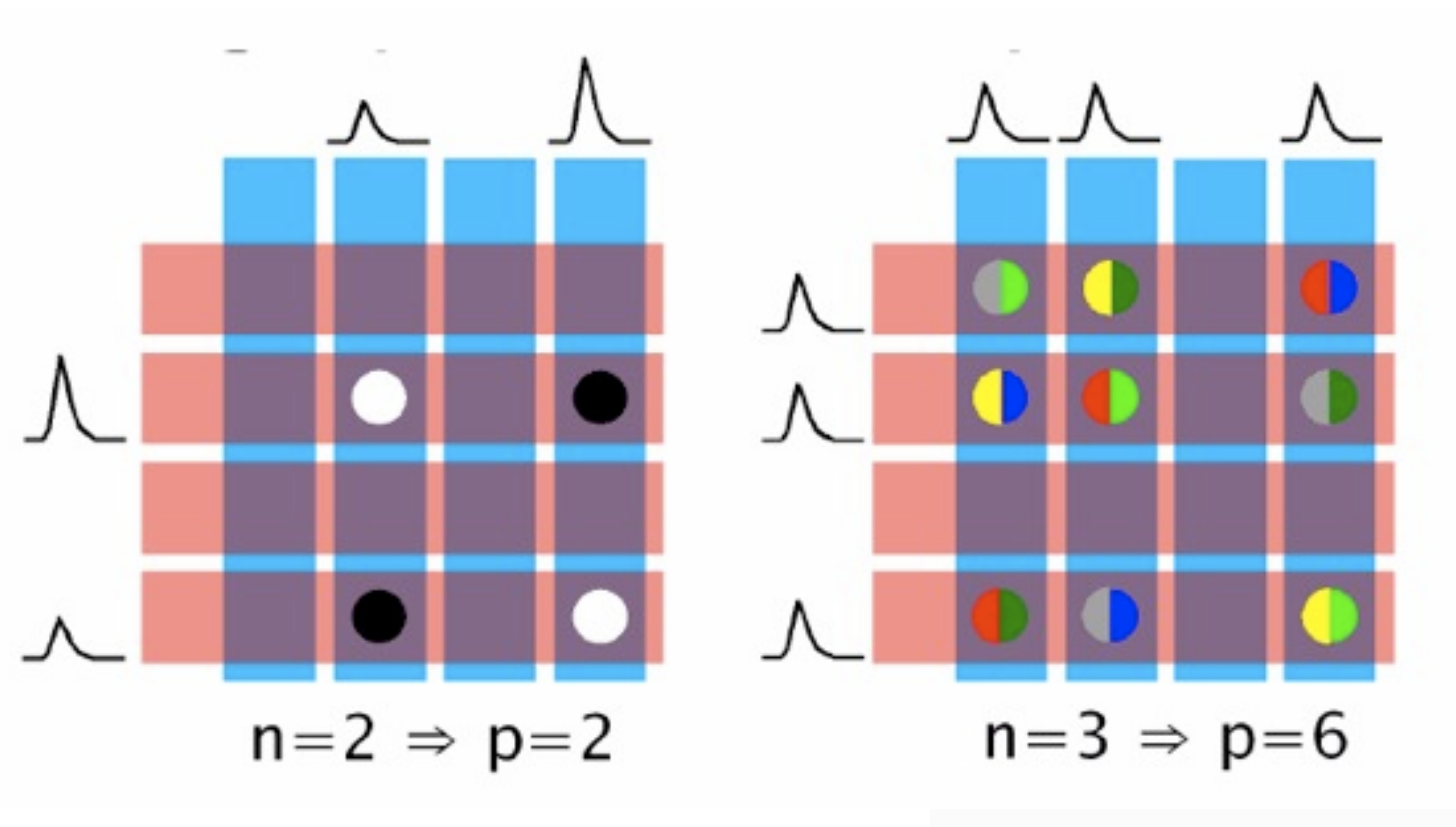
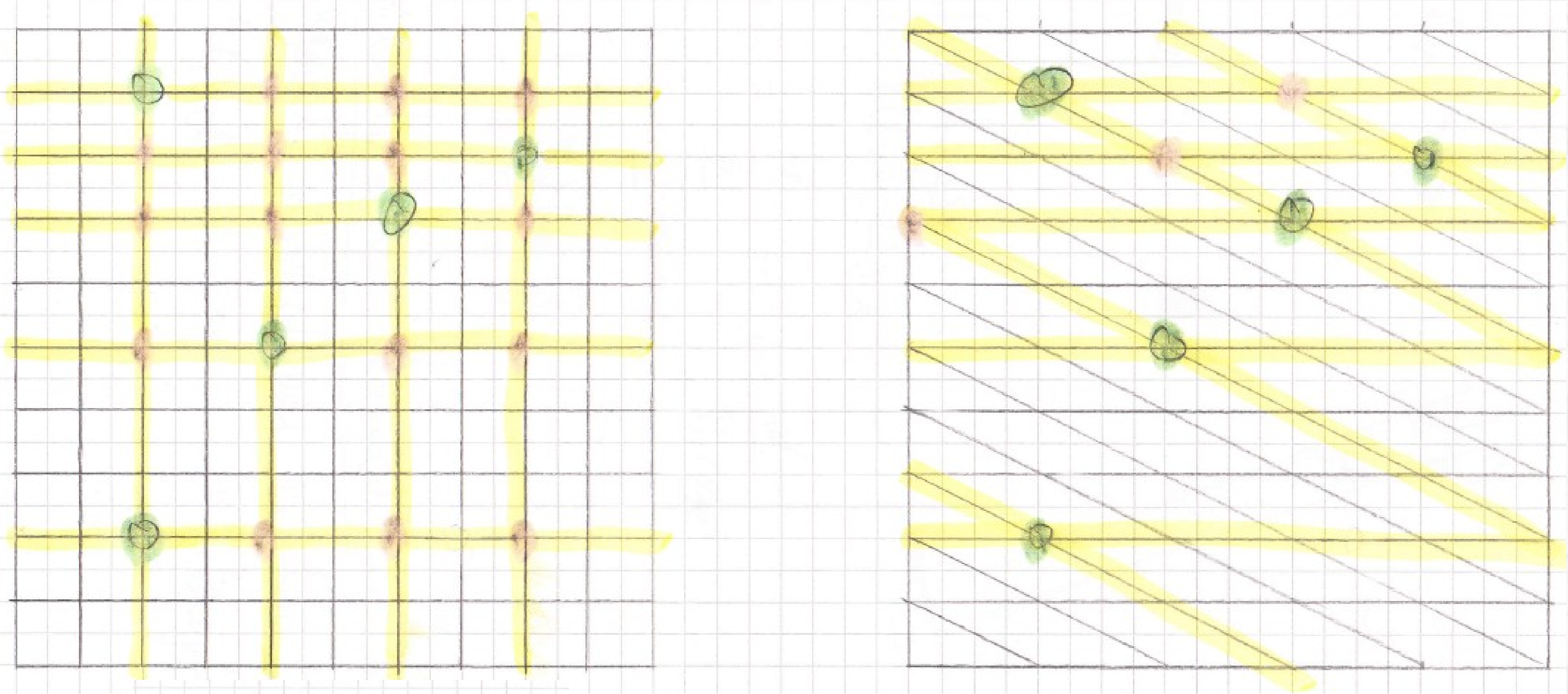
# Zweiseitige Streifendetektoren



# Ambiguität bei 90-Grad-Streifen



# Ambiguität bei Stereostreifen



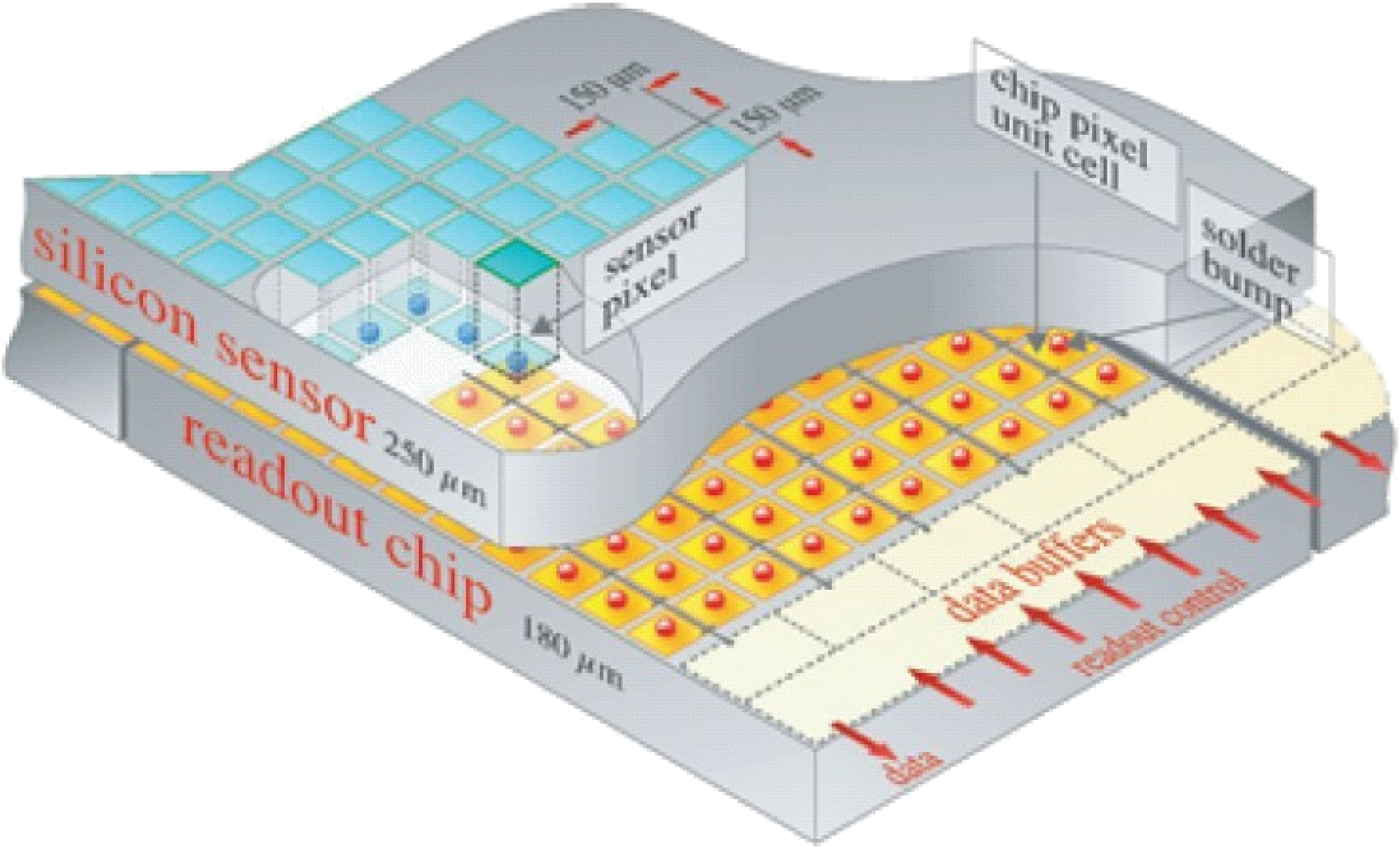
🟩 Real Hits

🟥 "Ghost" Hits

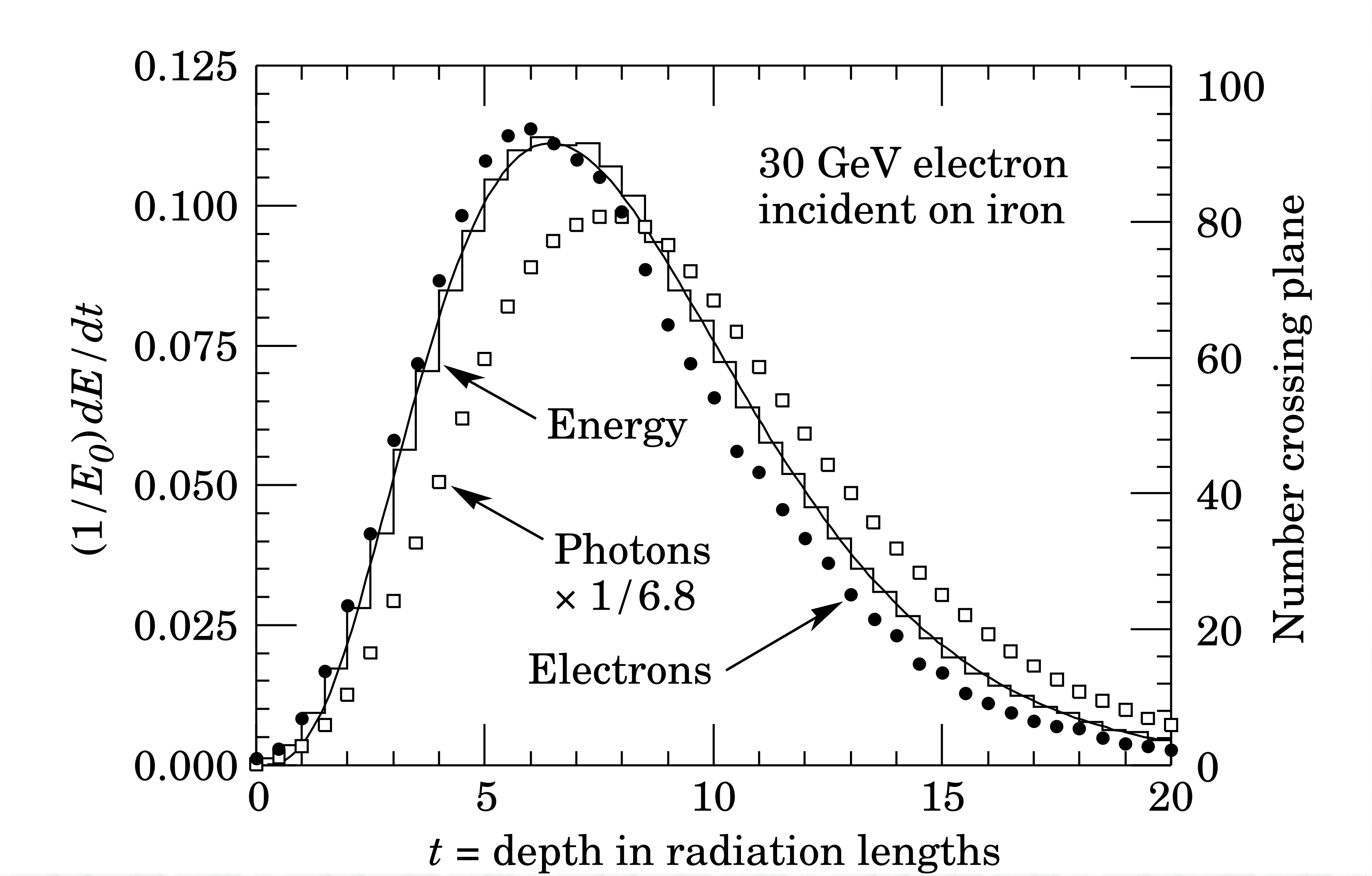
🟨 Signal Strips

Stero angle < 90° strongly reduces number of ghost hits (in practice: few degrees)

# Pixeldetektor: Bauprinzip

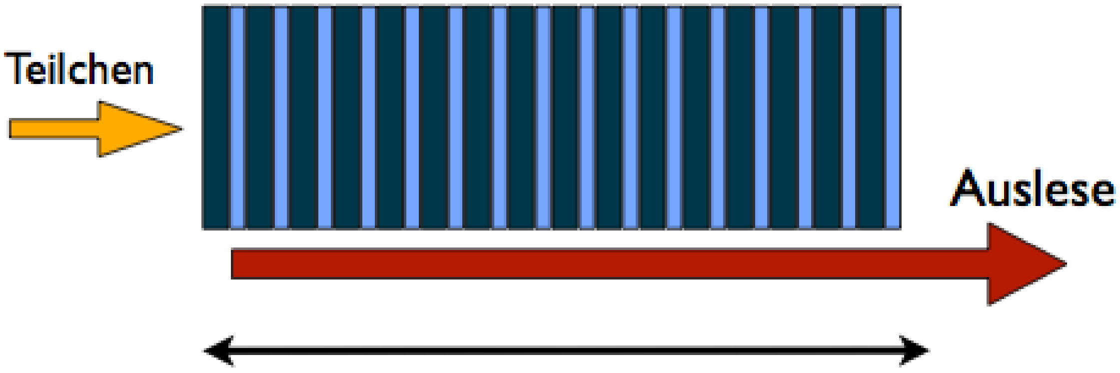


# Longitudinales Profil des el.-mag-Teilchenschauers



# Prinzip des Sampling-Kalorimeters

- Sampling-Kalorimeter
  - Eine Schichtstruktur aus passivem Absorber-Material und aktivem Detektor-Material; nur ein kleiner Teil der deponierten Energie wird “gesehen”
  - Pro: Segmentierung (transversal und lateral), kompakte Detektoren durch sehr dichte Absorber
  - Kontra: Energieauflösung wird durch Fluktuationen begrenzt



tief genug, um den Schauer zu absorbieren

Wichtige Größe:
Sampling Fraction

Bestimmt, welcher Anteil der Energie einesdurchgehenden Teilchens im aktiven Material gesehen wird.

Typischerweise im Prozentbereich