Wiederholung: Proton-Formfaktoren

Elastische Streuung an „punktförmigen“ Proton ($g_p = 2$):

$$\left(\frac{d\sigma}{d\Omega}\right) = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left(1 + 2\tau \cdot \tan^2\left(\frac{\theta}{2}\right)\right) \qquad \tau = \frac{Q^2}{4M_p^2c^2}$$

Elastische Streuung an „ausgedehntem“ Proton:

$$\left(\frac{d\sigma}{d\Omega}\right) = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left(G_1^2(Q^2) + 2\tau \cdot G_2^2(Q^2) \cdot \tan^2\left(\frac{\theta}{2}\right)\right)$$

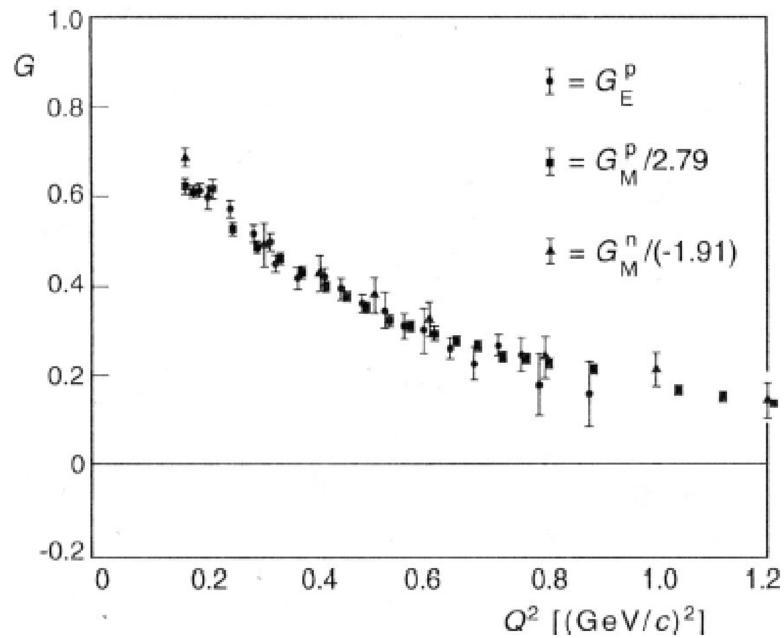
$$\left(\frac{d\sigma}{d\Omega}\right) = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left(\frac{G_E^2(Q^2) + \tau\, G_m^2(Q^2)}{1+\tau} + 2\tau \cdot G_M^2(Q^2) \cdot \tan^2\left(\frac{\theta}{2}\right)\right)$$

G_E und G_M = elektrischer und magnetischer Formfaktor.

Wiederholung: Elektr. und magn. Formfaktor

- Formfaktoren skalieren:

$$G_E^p(Q^2) = \frac{G_M^p(Q^2)}{\mu_p\left[\mu_N\right]} = \frac{G_M^n(Q^2)}{\mu_n\left[\mu_N\right]}$$



- Formfaktoren beschrieben durch Dipolformel:

$$G_E^p(Q^2) = \left(1 + \frac{Q^2}{0.71^2\,\mathrm{GeV}^2}\right)^{-2}$$

= Fourrier-Transformierte einer exponentiellen Verteilung:

$$f(r) = f_0 \exp(-ar) \quad \text{mit} \quad a = 4.27\,\mathrm{fm}^{-1}$$

- Mittlerer quadratischer Radius:

$$\left\langle r^2 \right\rangle = -6\hbar^2 \frac{dG_{Dipol}(Q^2)}{dQ^2} = \frac{12}{a^2} \approx 0.66\,\mathrm{fm}^2 \quad \Rightarrow \quad \sqrt{\left\langle r^2 \right\rangle} = 0.81\,\mathrm{fm}$$

Abb. VI.8 Tief-inelastische Elektron-Proton Streuung

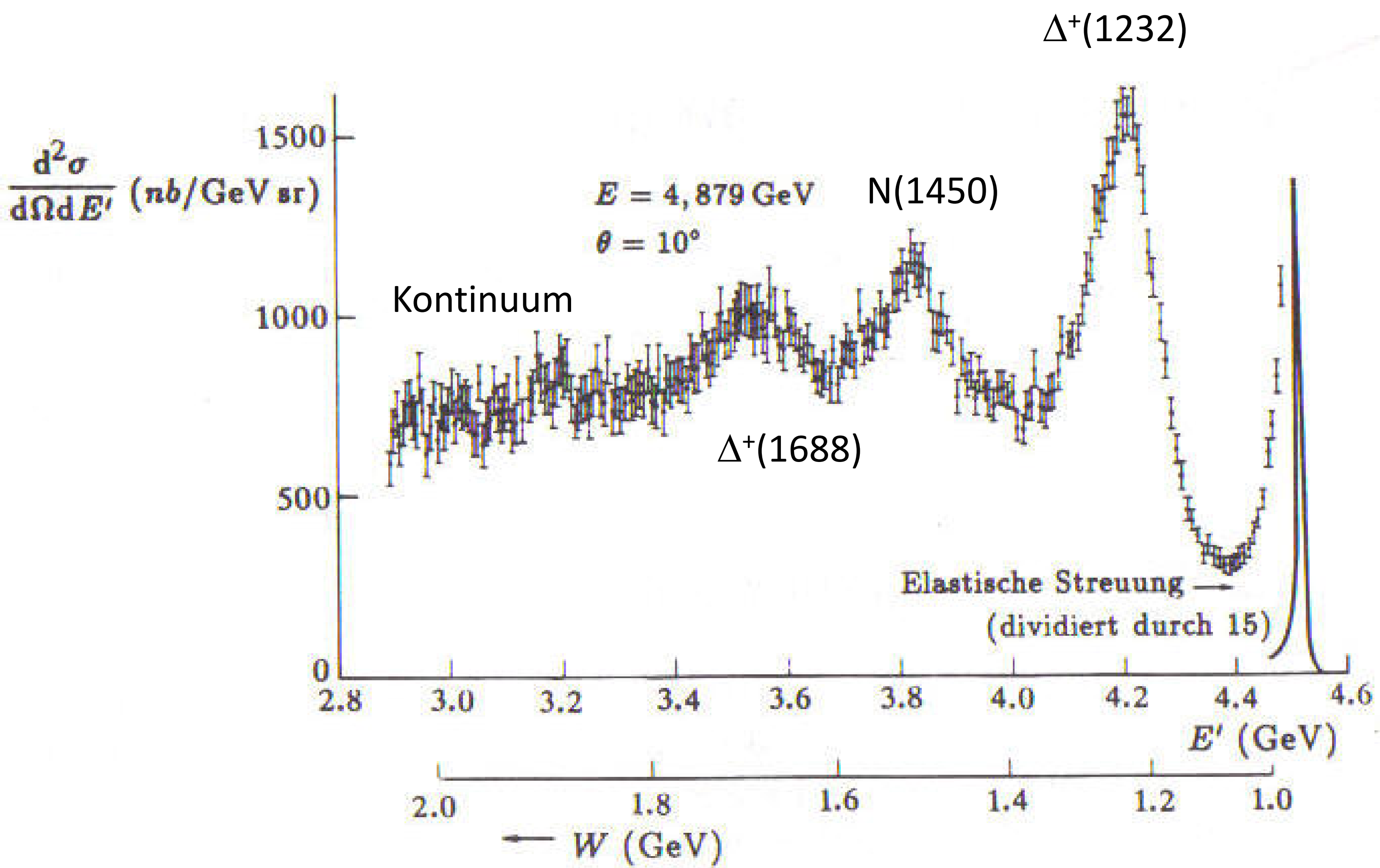


Abb. VI.9 Erste Messung der Strukturfunktion W_2

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OBSERVED BEHAVIOR OF HIGHLY INELASTIC ELECTRON-PROTON SCATTERING

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(Received 22 August 1969)

SLAC & MIT Experiment 1969

Spectrometer at given θ

$\frac{\Delta p}{p} \sim 0.1\%$ $\quad \Delta\theta \sim 0.7\,\text{mrad}$

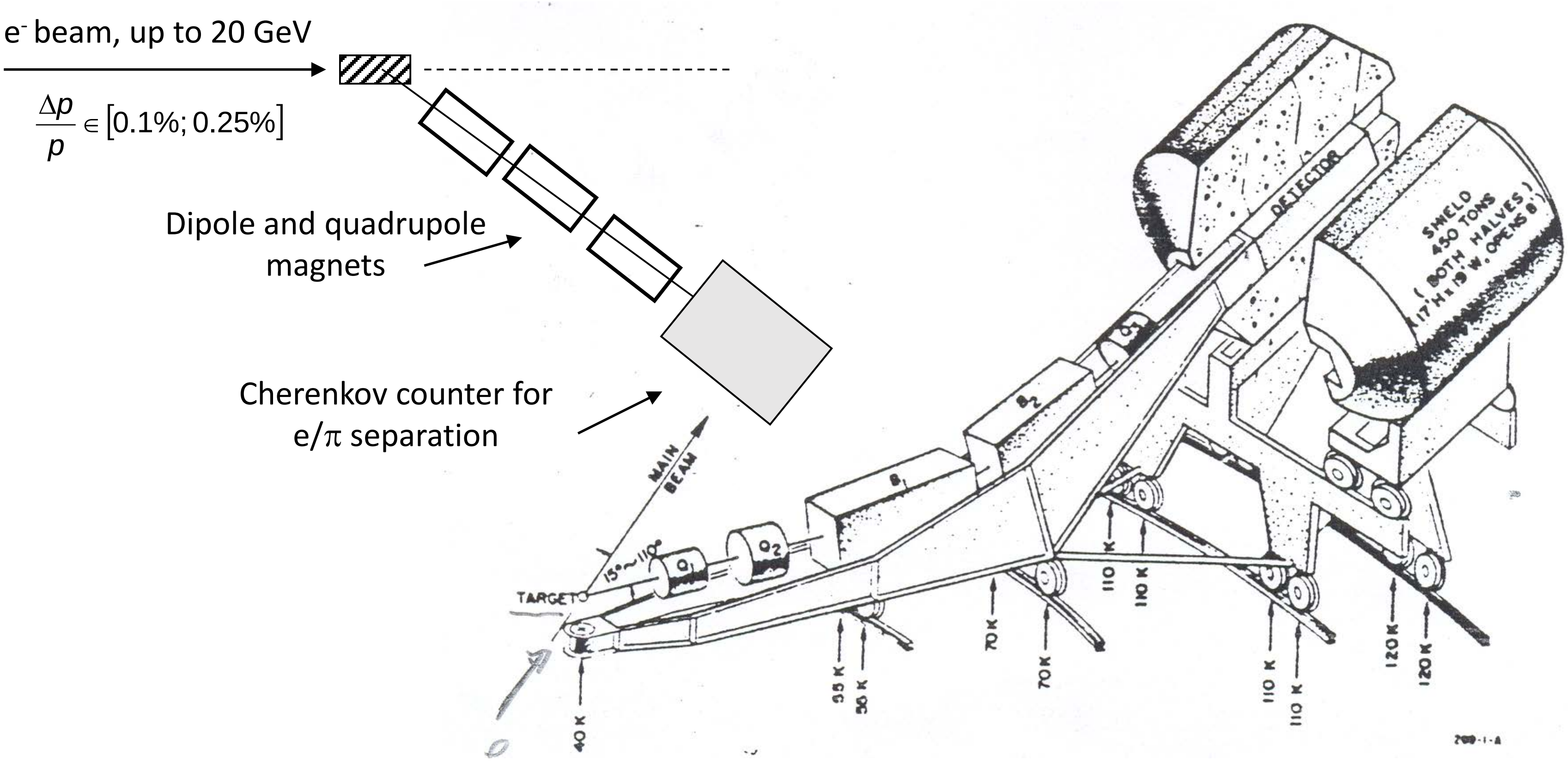
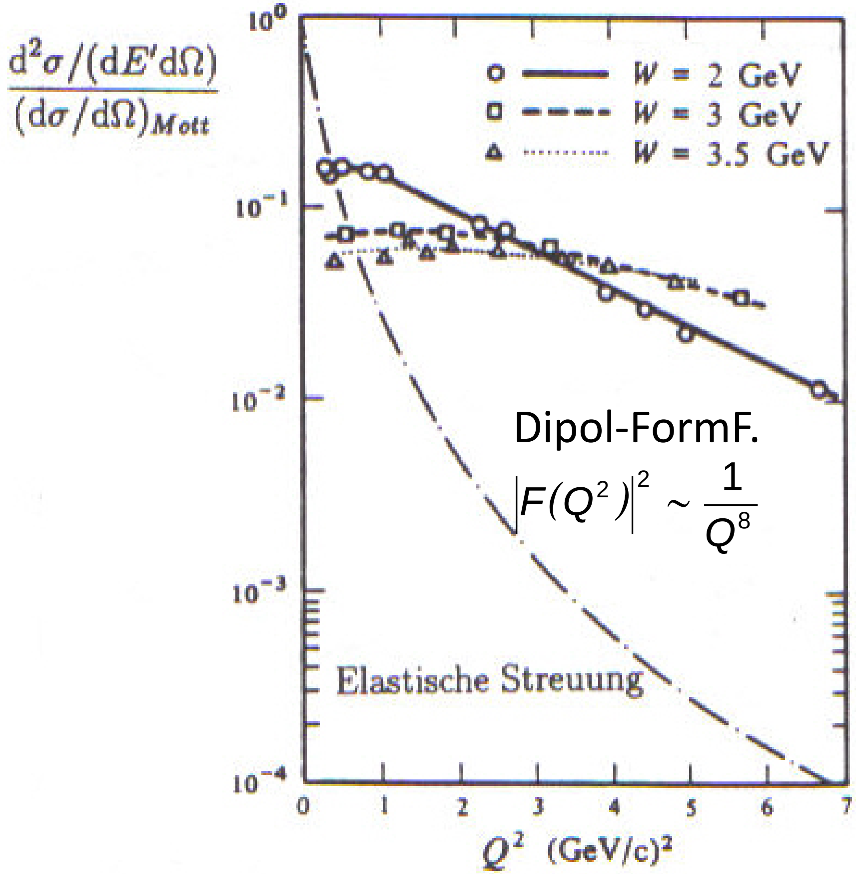
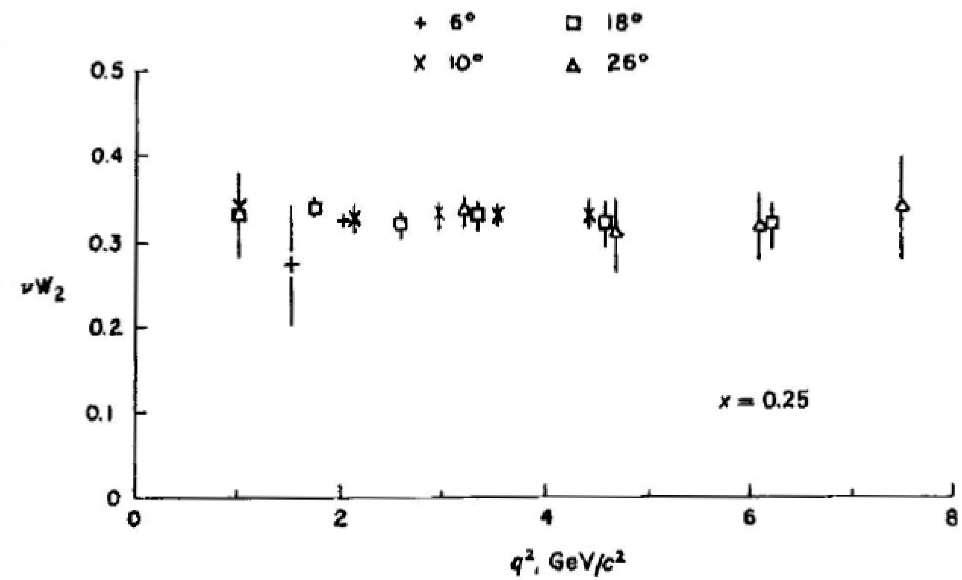


Abb. VI.10 Erste Messung der Strukturfunktion

Abb VI.11 Strukturfunktion W_2





Funktion νW_2 hängt nicht explizit von Q^2 ab sondern nur von der dimensionslosen Variablen x_{Bj}:

Bjorkensche Skalenvariable $$x_{Bj} = \frac{Q^2}{2M\nu}$$

$\rightarrow$ **Skaleninvarianz = “scaling”**

Abb. VI.12 Tief-inelastisches ep-Ereignis

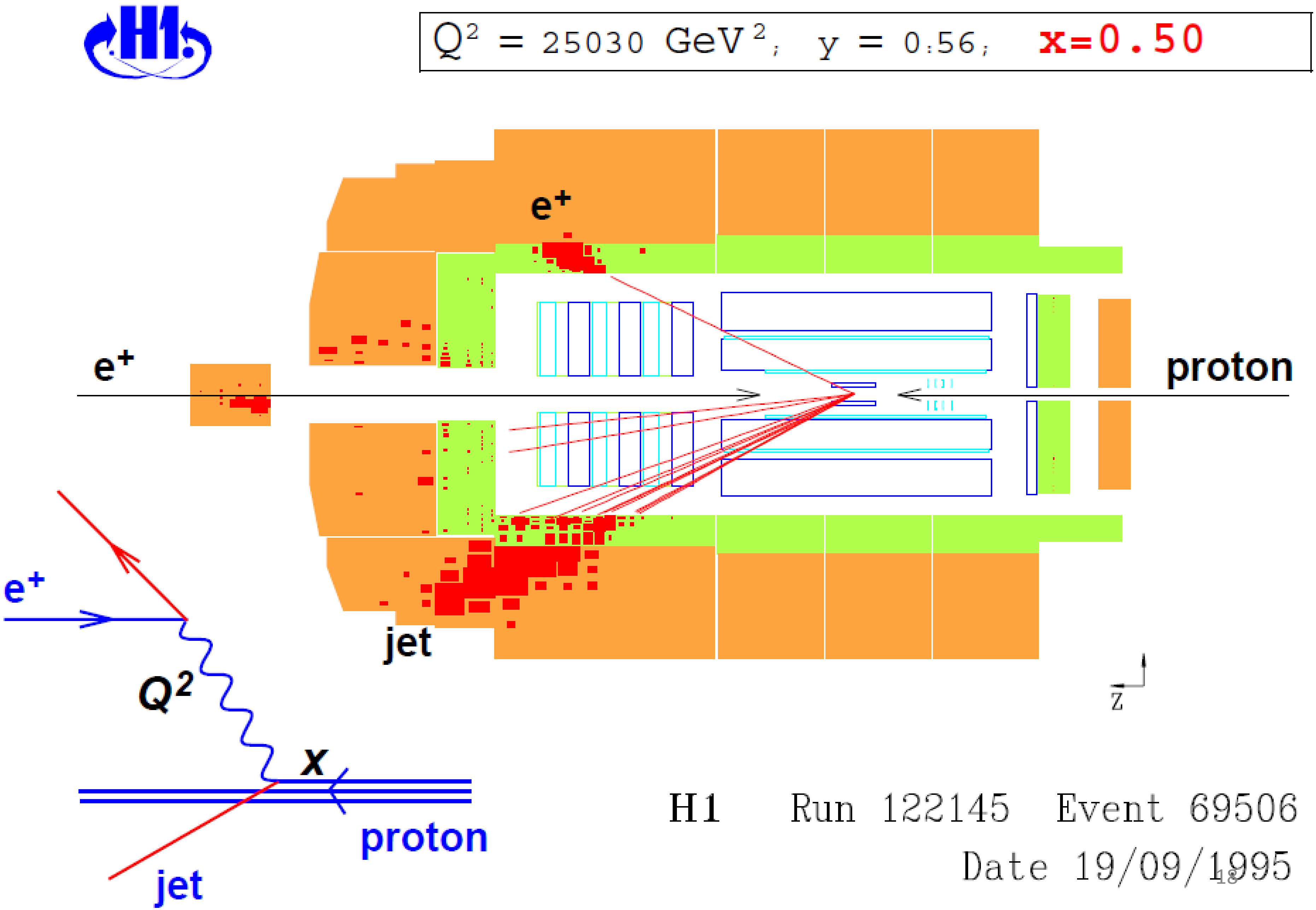


Abb. VI. 13 Callan-Gross Relation

$$\frac{2xF_1}{F_2}$$

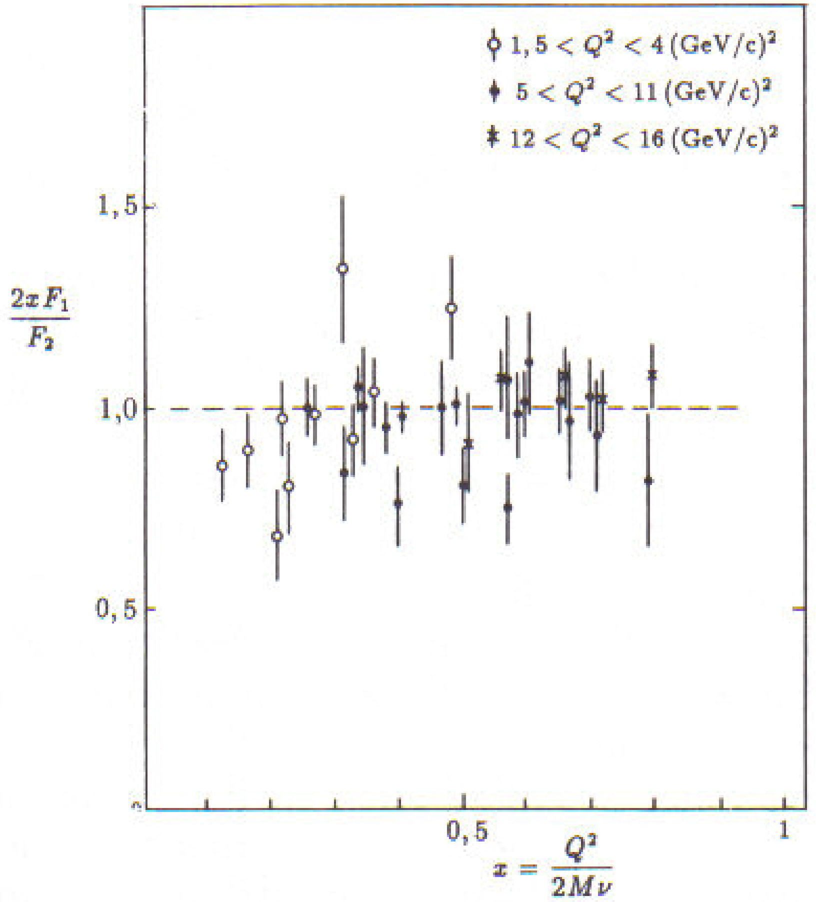
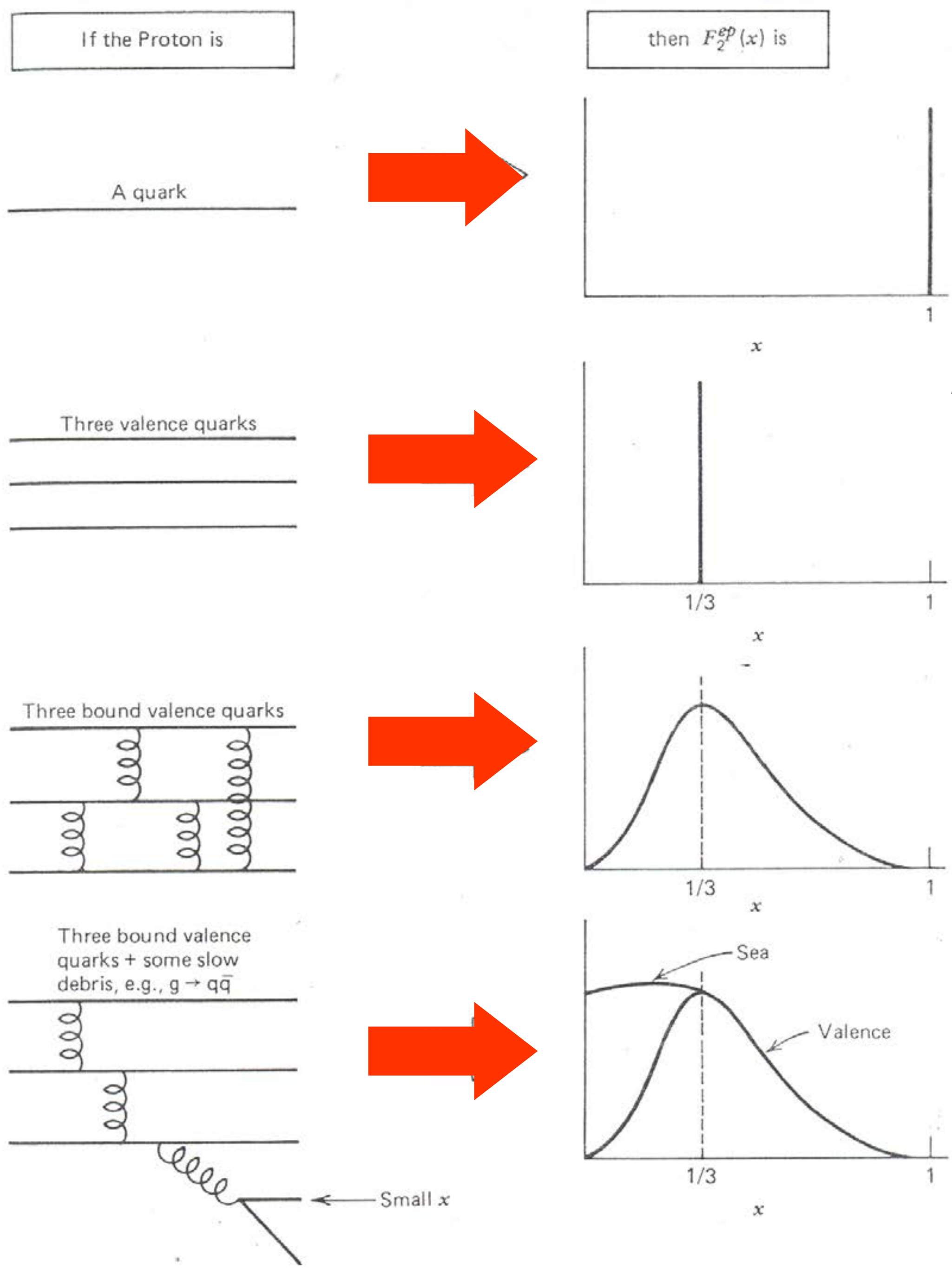


Abb. VI.14

Proton
Modell



$$F_2^{ep}(x)$$

$$F_2^{ep}(x) = x \cdot \sum_i z_i^2 f_i(x)$$

Abb. VI.15 Parton-Dichten im Proton

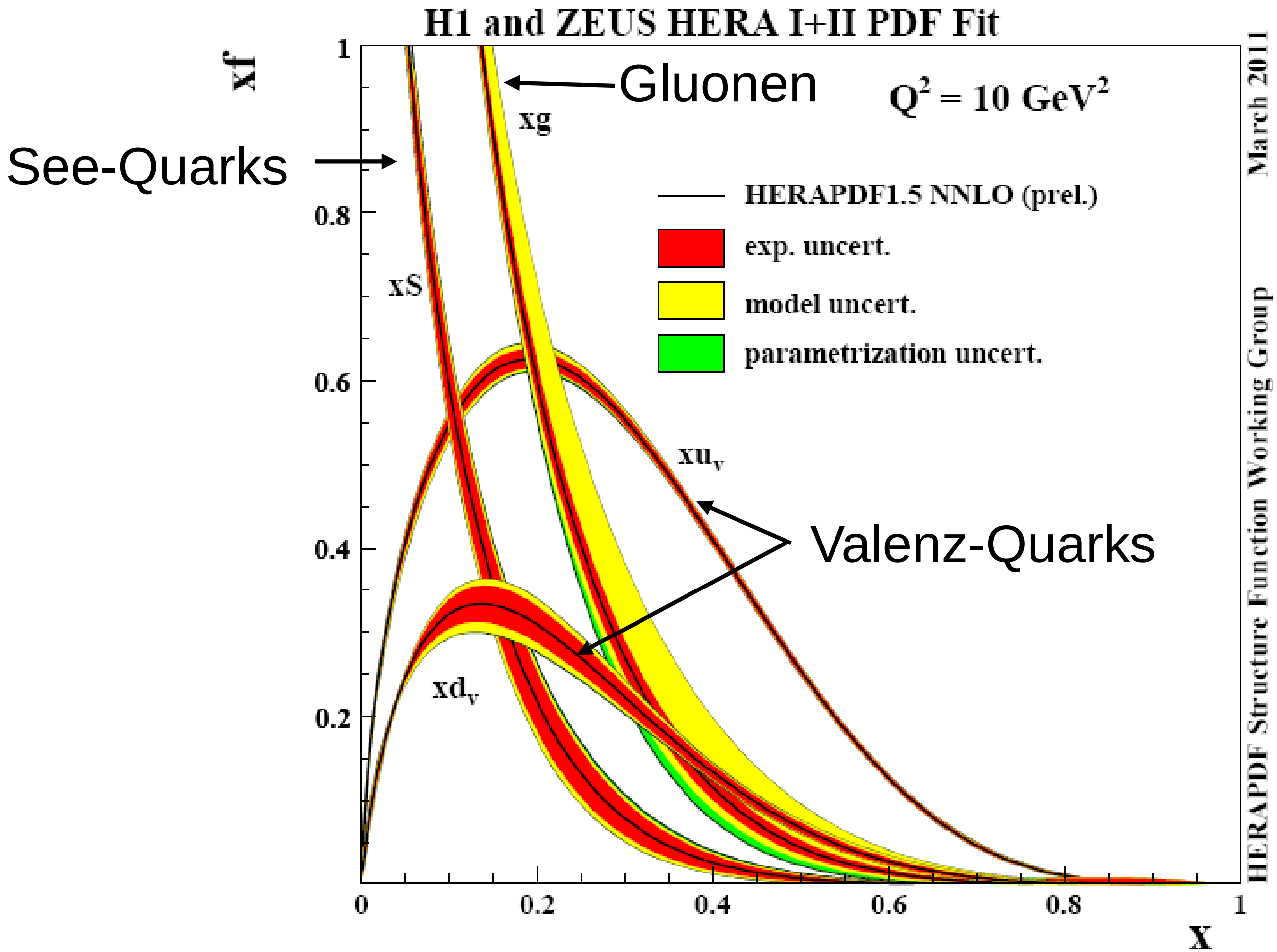


Abb. VI.16 Nachtrag – Infinite Momentum Frame

$$\left(p_{qi}+q\right)^2 = p_{qi}'^2 = m_{qi}^2 \approx 0$$

$$\left(\overbrace{zP}+q\right)^2 = z^2P^2 + 2zPq + q^2 \approx 0$$

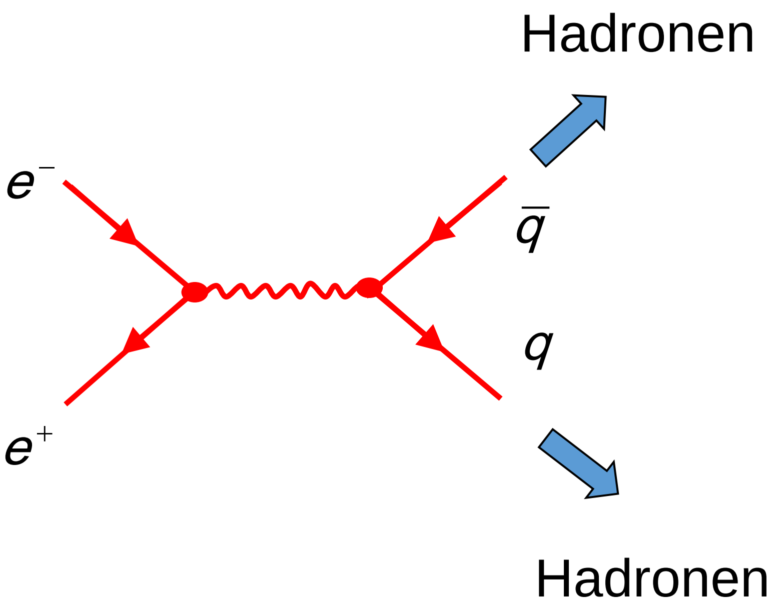
Proton 4er-Impuls: $P^2 = M^2c^2$

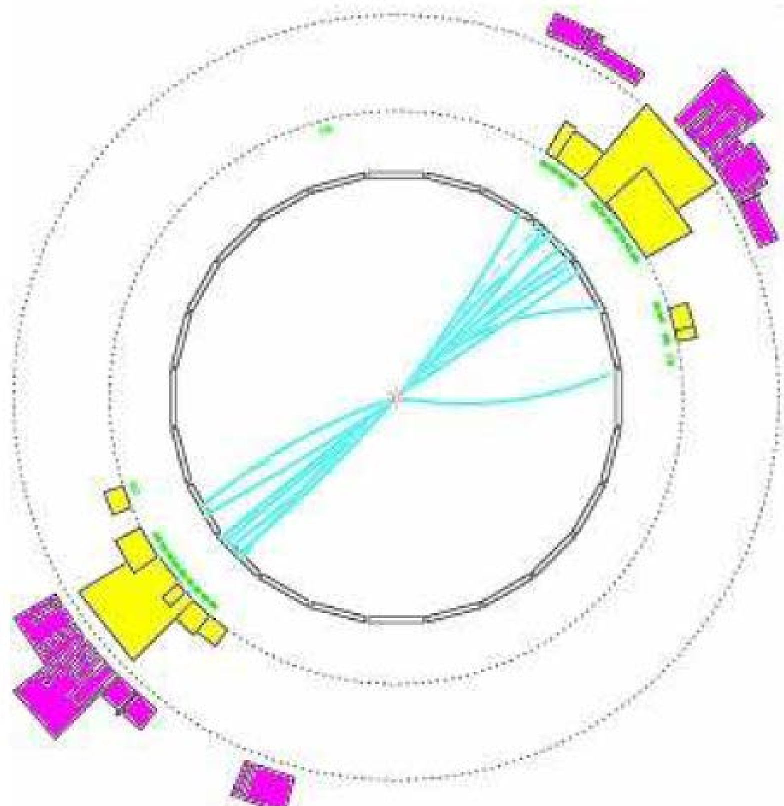
und $Pq = M\nu$

damit $z^2M^2c^2 + 2zM\nu + q^2 \approx 0$

und mit $-q^2 = Q^2 >> z^2M^2c^2$ $\Rightarrow$ $\boxed{z = \dfrac{Q^2}{2M\nu} \equiv x_{Bj}}$

Abb. VII.1 e^+e^- Annihilation in Hadronen: 2-Jet Ereignis





OPAL (LEP)

Abb. VII.2 R_{had} und Zahl der Farbladungen

Definition:

$$R_{had} = \frac{\sigma(ee \to hadrons)}{\sigma(ee \to \mu\mu)} = 3 \cdot \sum_i Q_i^2$$

$\sqrt{s}$	Quarks	$R_{had} = 3 \cdot \sum_i Q_i^2$
< ~3 GeV	uds	3·6/9=2.00
< ~10 GeV	udsc	3·10/9=3.33
< ~350 GeV	udscb	3·11/9=3.67

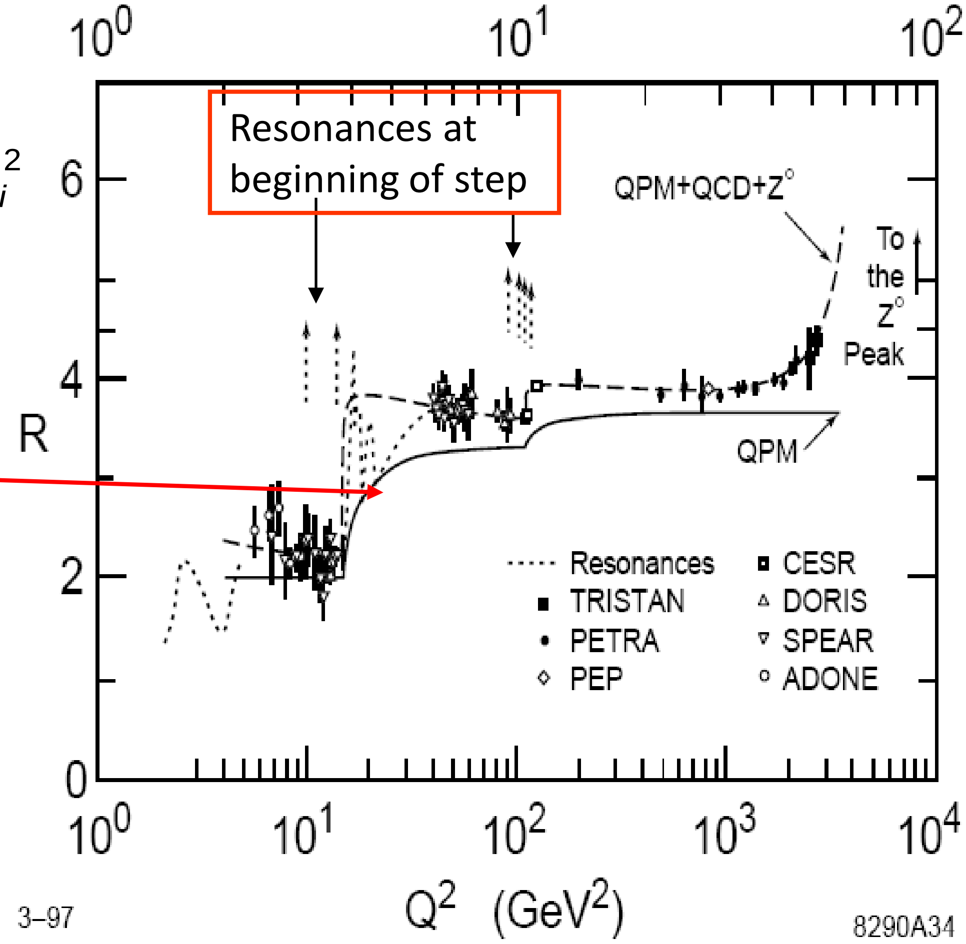
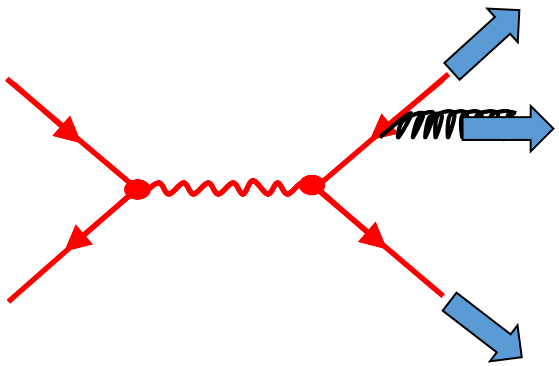


Abb. VII.3 Entdeckung des Gluons

TASSO Kollaboration am e^+e^- Beschleuniger PETRA / DESY (1977):



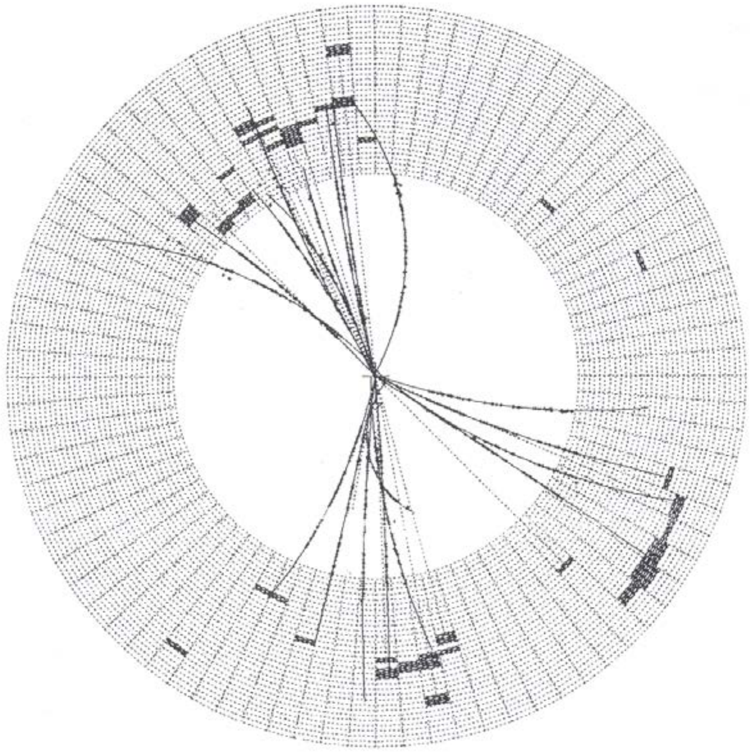


Fig. 11.12 A three-jet event observed by the JADE detector at PETRA.

bei $\sqrt{s}$=20 GeV

$$\frac{\#3-\text{jet events}}{\#2-\text{jet events}} \approx 0.15$$

Abb. VII.4 Laufende Kopplungskonstante $\alpha_s(Q^2)$

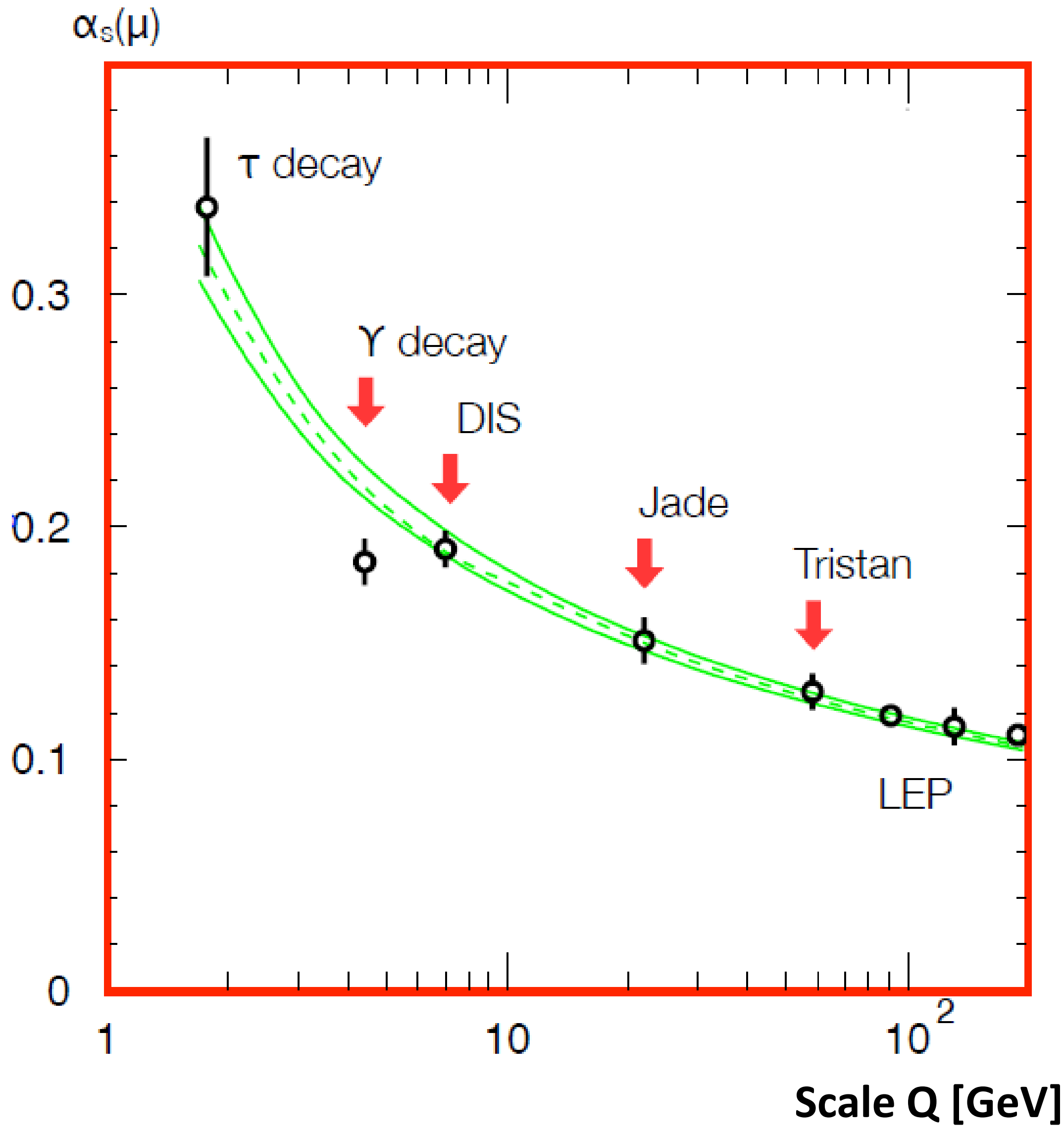


Abb. VII.5 Vergleich: Charmonium und Positronium

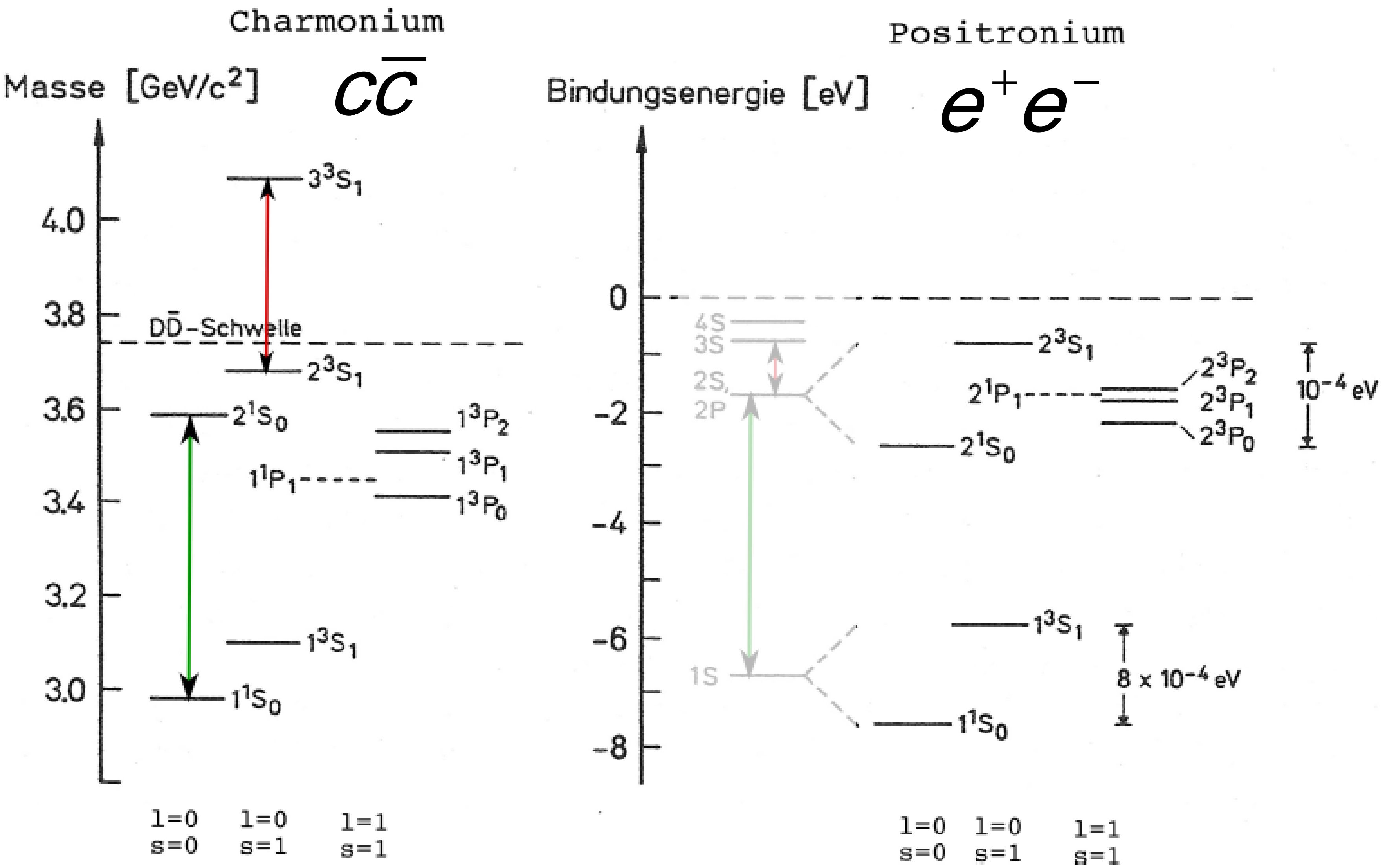
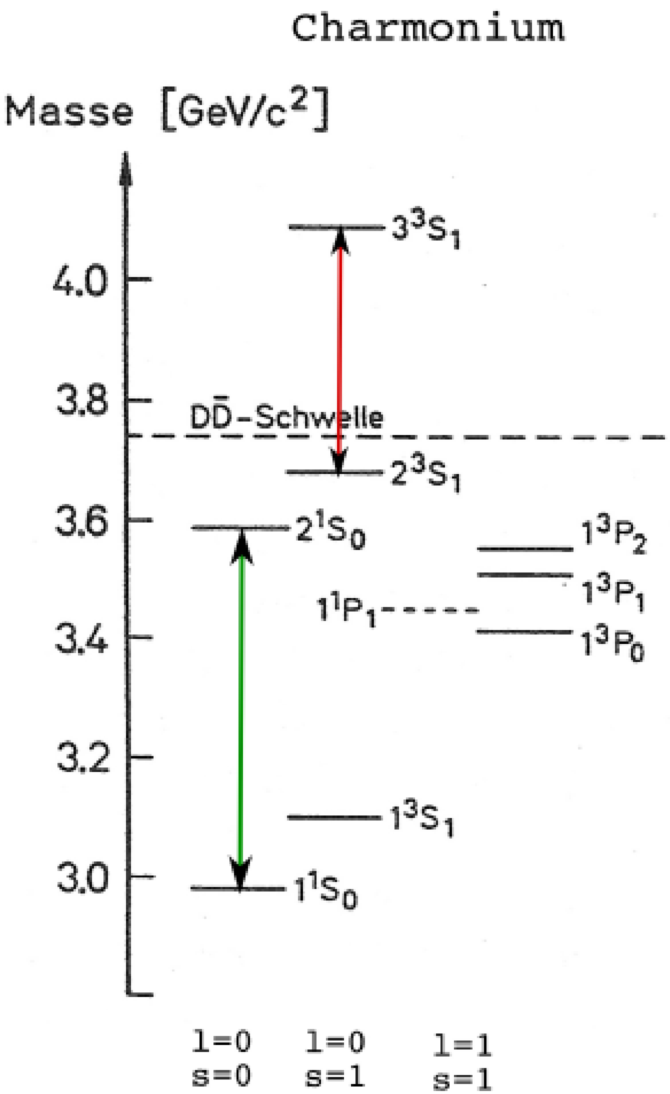


Abb. VII.6 Charmonium-Spektroskopie



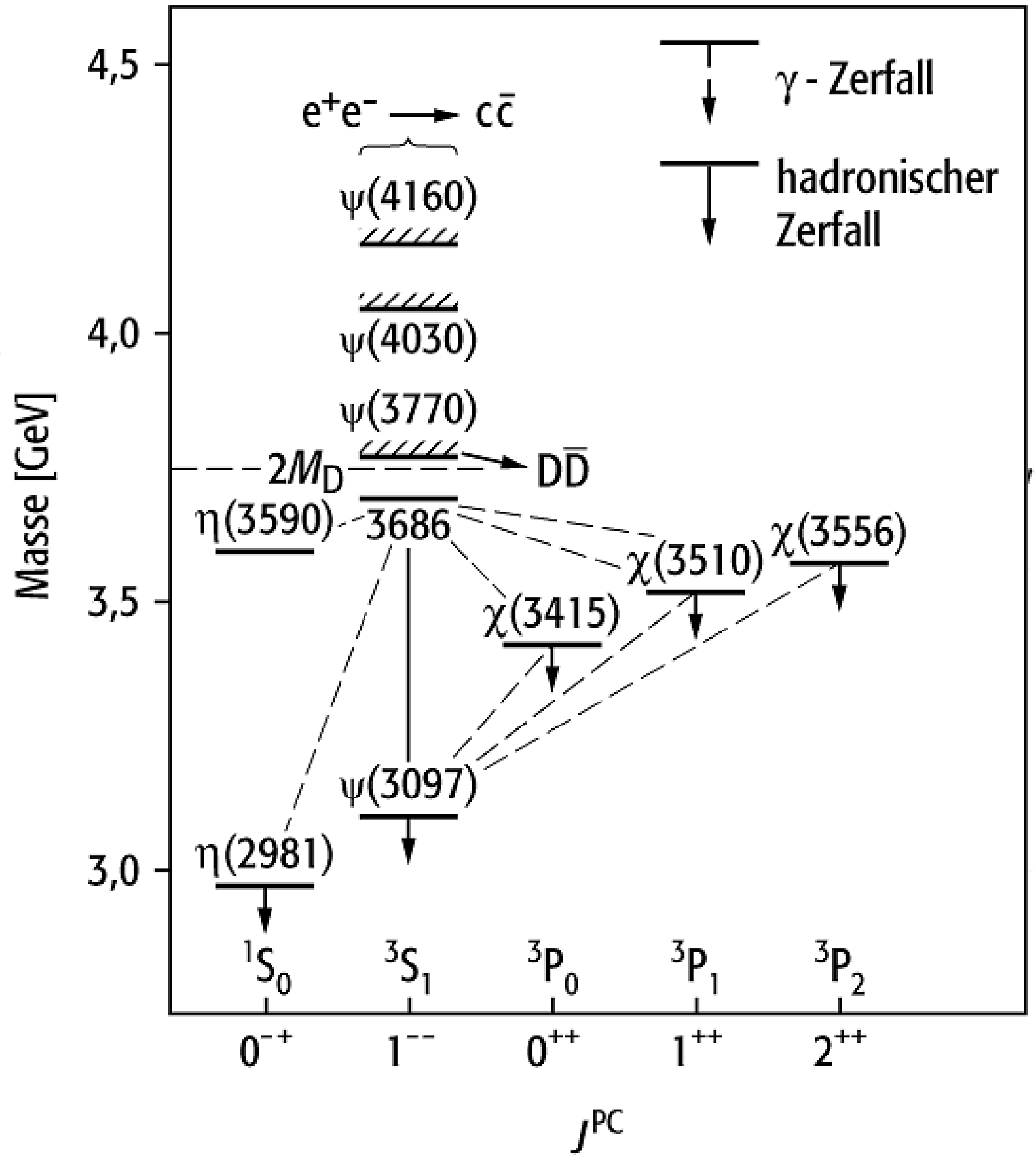
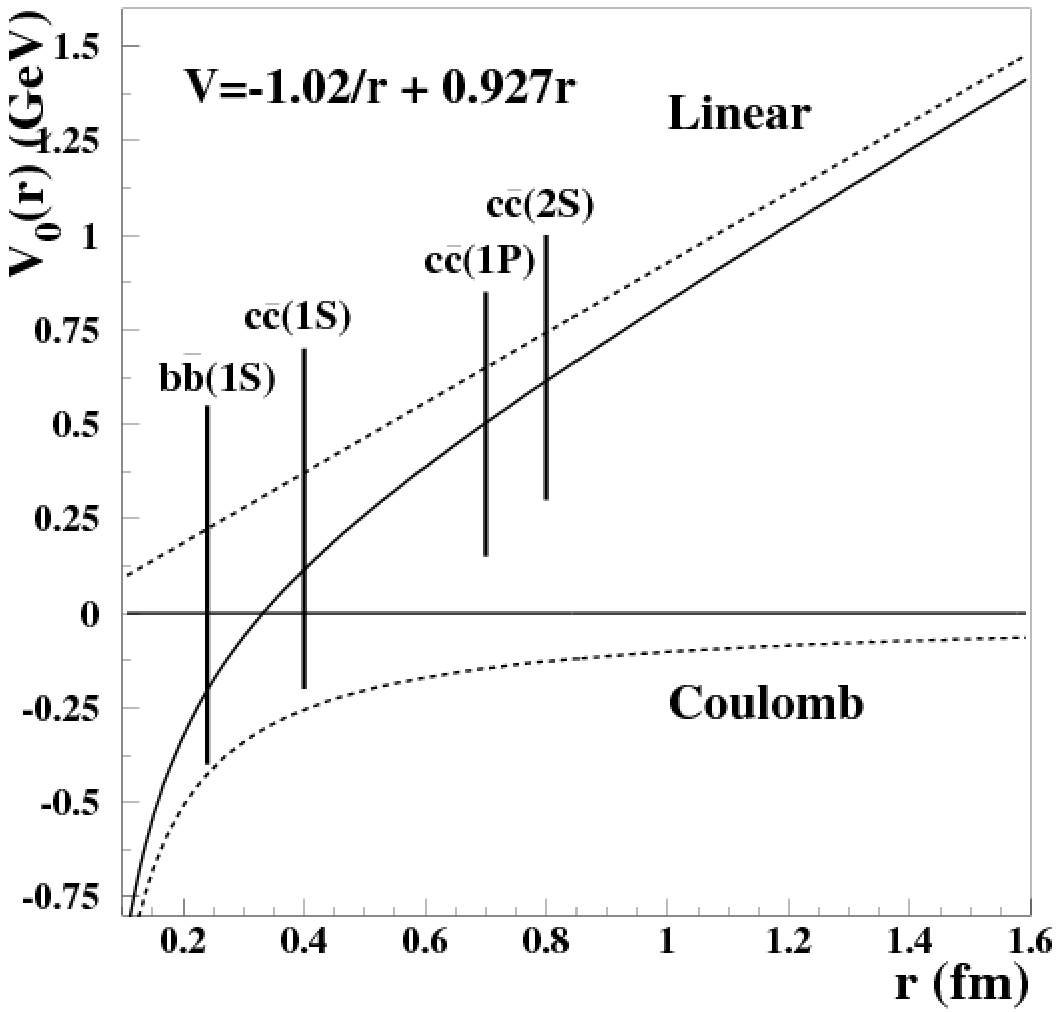


Abb. VII.7 $q\bar{q}$ Potential aus Quarkonia



arXiv:1001.2252

Abb. VII.8 Statisches Quarkmodell