Elastische vs. inelastische Streuung

Elastische Streuprozesse mit vorgegebener Energie der Elektronen (E) ist mit **einem** Parameter beschrieben, z.B. Streuwinkel θ, $-q^2 = Q^2$, $E^{'}$, ...

$$\nu = E - E^{'}$$

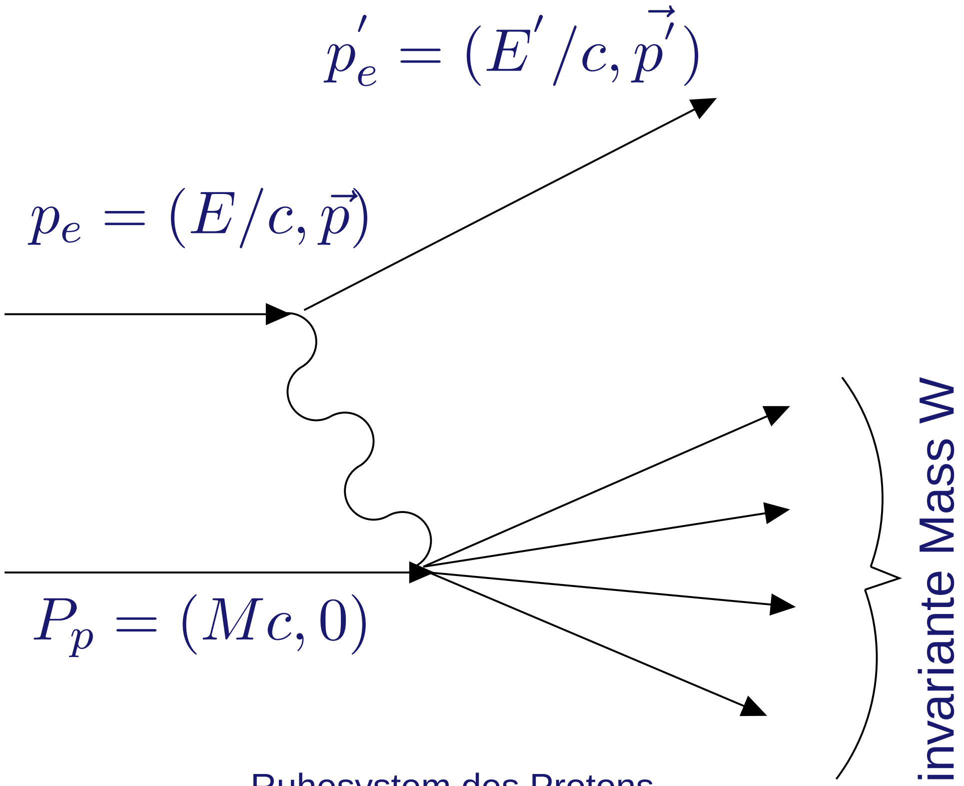
invariante Masse $W = (P_p + q)^2$

Bjorken Skalierungsvariable $x_B = \frac{Q^2}{2M\nu}$ ist

Mass für Inelastizität der Streuung

x_B = 1 für elastische Streuung;

0 < x_B < 1 für inelastische Streuung;

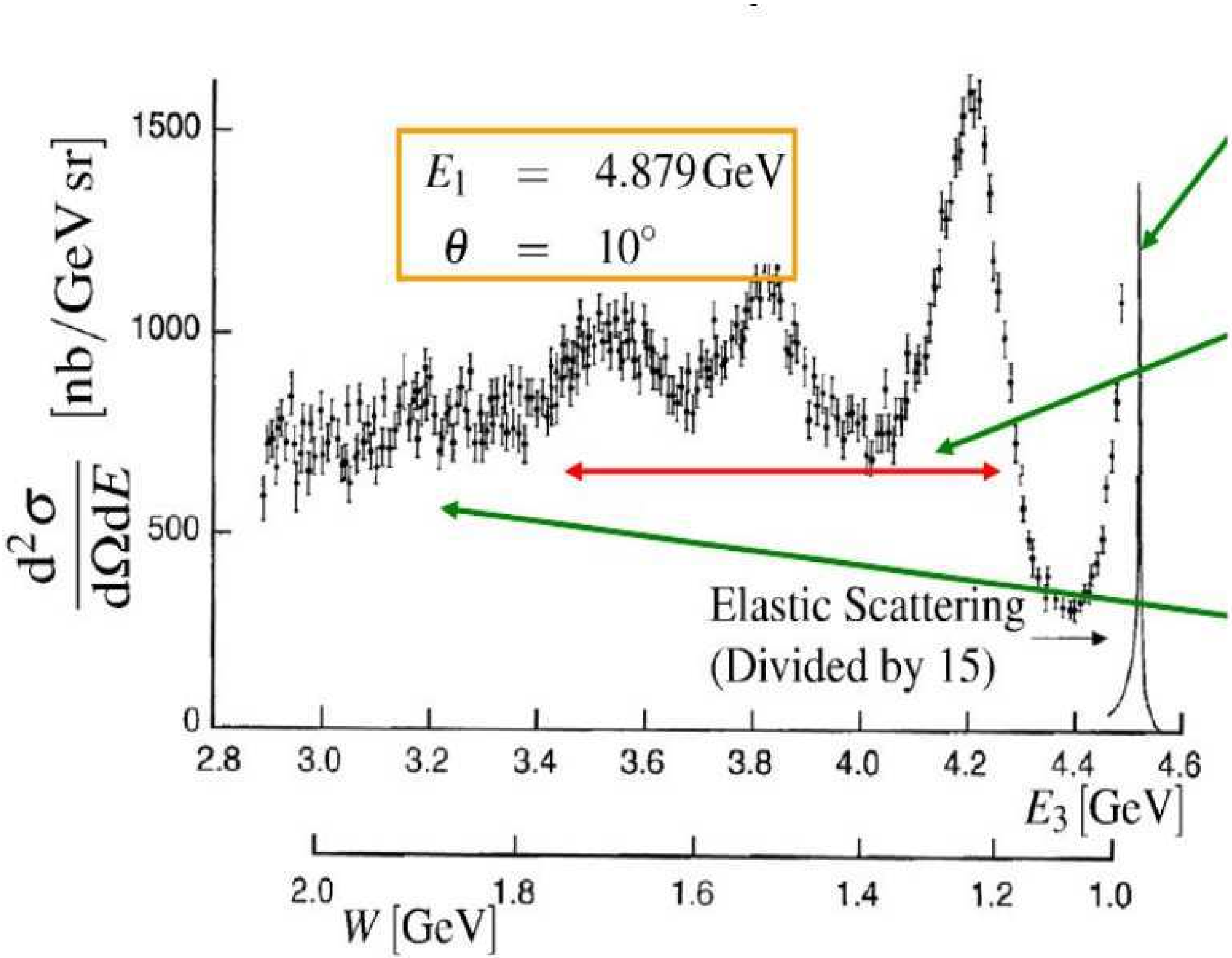


Ruhesystem des Protons

Zur Beschreibung inelastischer Streuprozesse werden **zwei** Parameter benötigt

z.B. (θ, $E^{'}$), (Q^2, ν), (Q^2, x_B), ...

Inelastische Streuung



elastic scattering

inelastic scattering
Produce excited states
e.g. Δ^{+} (1232)

deep inelastic scattering
(DIS); proton splits up in
many final state particles

(hier: $E_3 = E^{'}$)

Inelastische Streuung

Elastische Streuung:

$$\left(\frac{d\sigma}{d\Omega}\right)_{Rosenbluth} =$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{Mott}\left(\frac{E'}{E}\right)\left[\frac{G_E^2(Q^2)+\tau G_M^2(Q^2)}{1+\tau} + 2\tau G_M^2(Q^2)\tan^2\theta/2\right]$$

Inelastische Streuung:

$$\left(\frac{d^2\sigma}{d\Omega dE'}\right) = \left(\frac{d\sigma}{d\Omega}\right)_{Mott}\left(\frac{E'}{E}\right)\left[W_2(Q^2,\nu) + 2W_1(Q^2,\nu)\tan^2\theta/2\right]$$

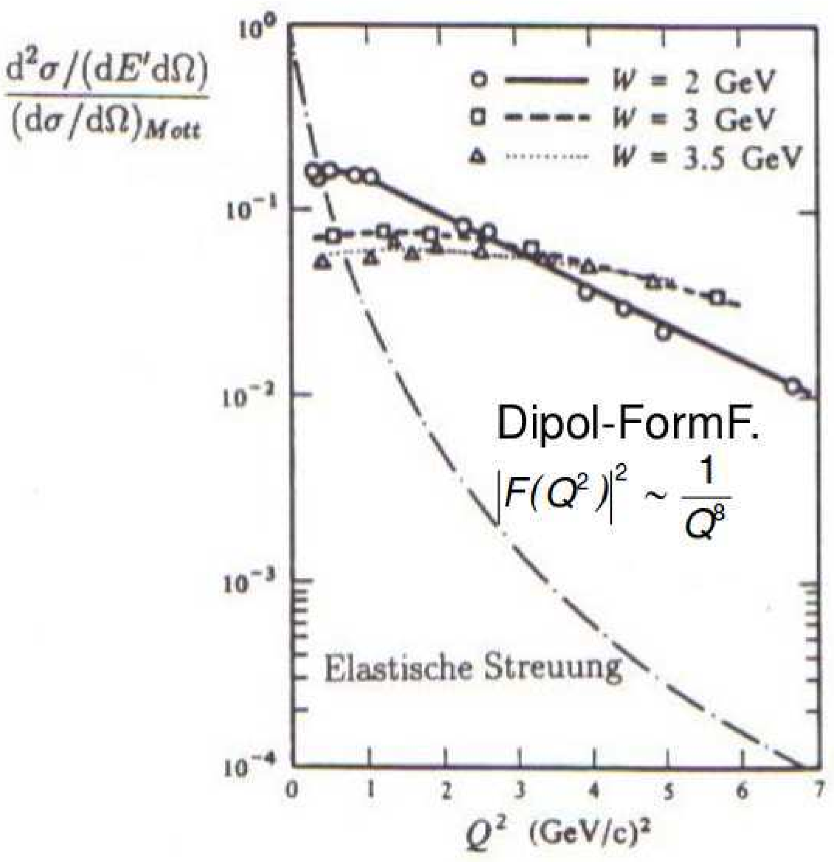
Doppelt differentieller WQ, da WQ von zwei Parametern abhängt

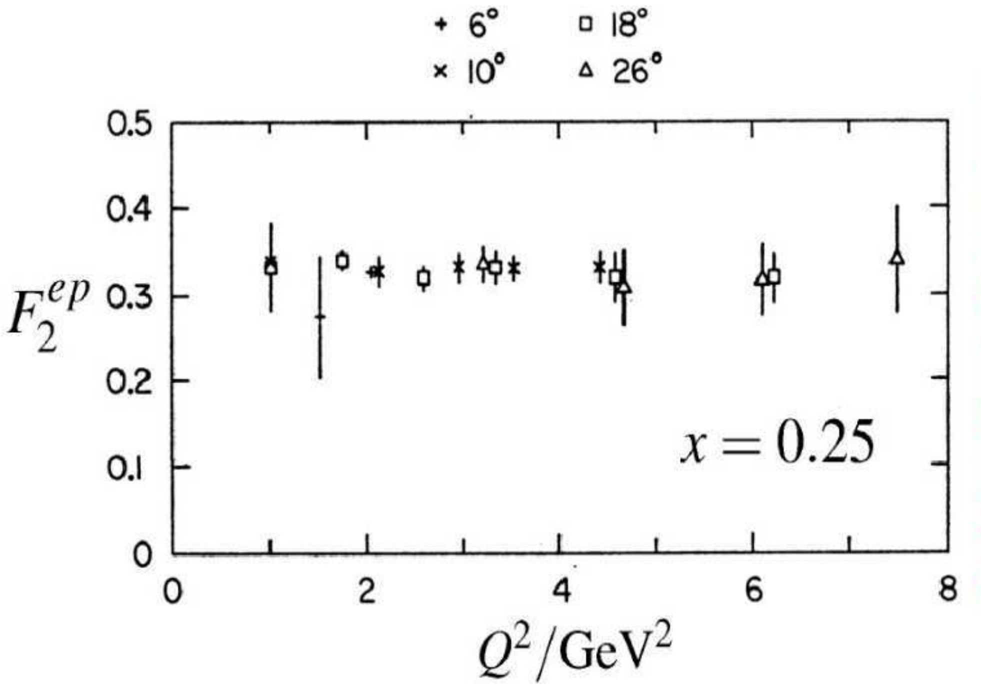
Strukturfunktionen W_1 und W_2 hängen ebenfalls von zwei Parametern ab

Heutzutage werden dimensionslose Strukturfunktionen benutzt:

$$F_1(x_B,Q^2) = Mc^2W_1(Q^2,\nu) \qquad F_2(x_B,Q^2) = \nu W_2(Q^2,\nu)$$

Inelastische Streuung



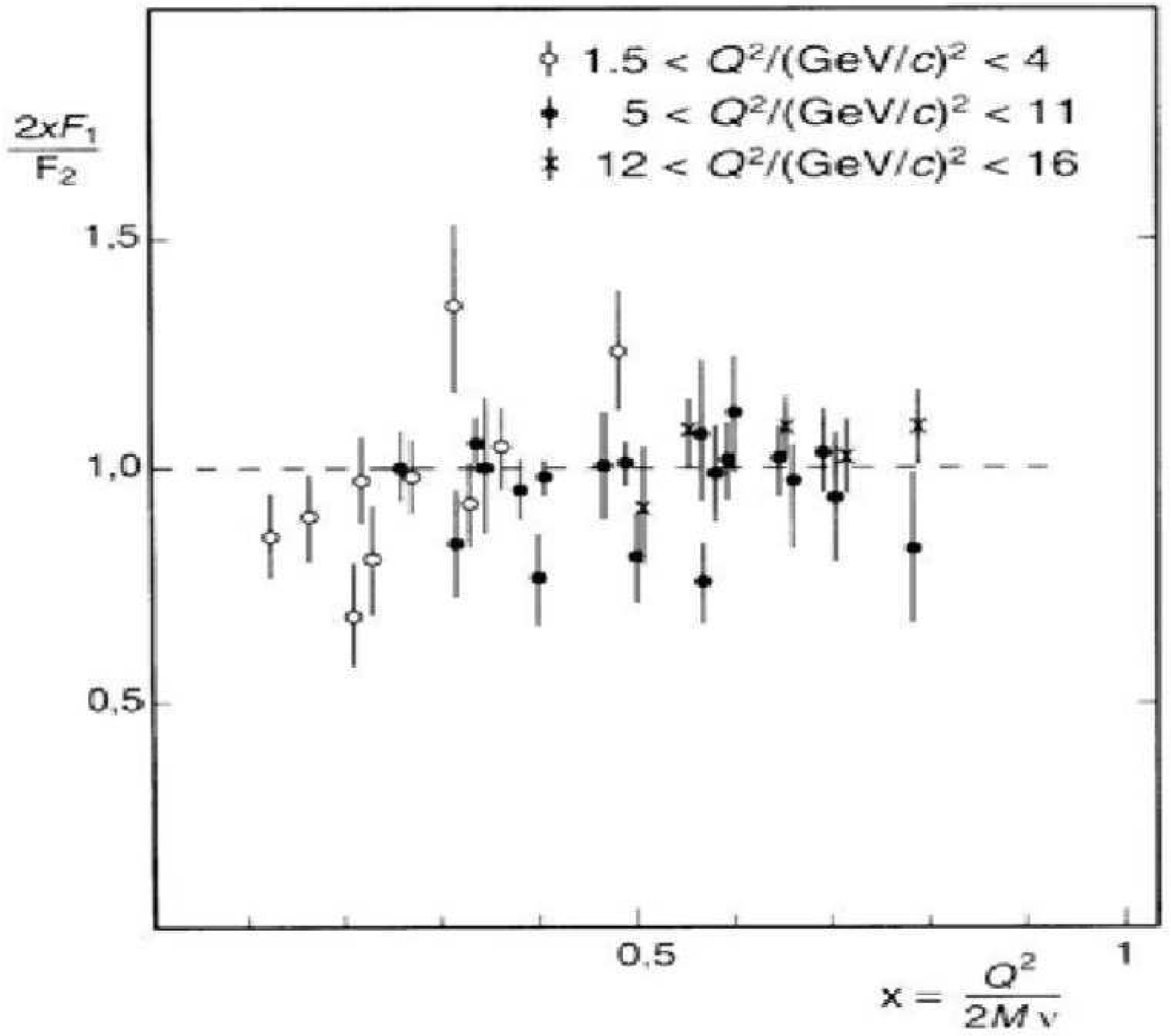


J.T.Friedman + H.W.Kendall, Ann. Rev. Nucl. Sci. 22 (1972) 203

Beobachtung von Friedmann, Kendall, Taylor (Nobelpreis 1996)1:

Die Formfaktoren haben nur eine sehr schwache Abhängigkeit von Q^2 (oder dem Winkel) für festes W bzw. festes x!

Gallen-Cross-Beziehung



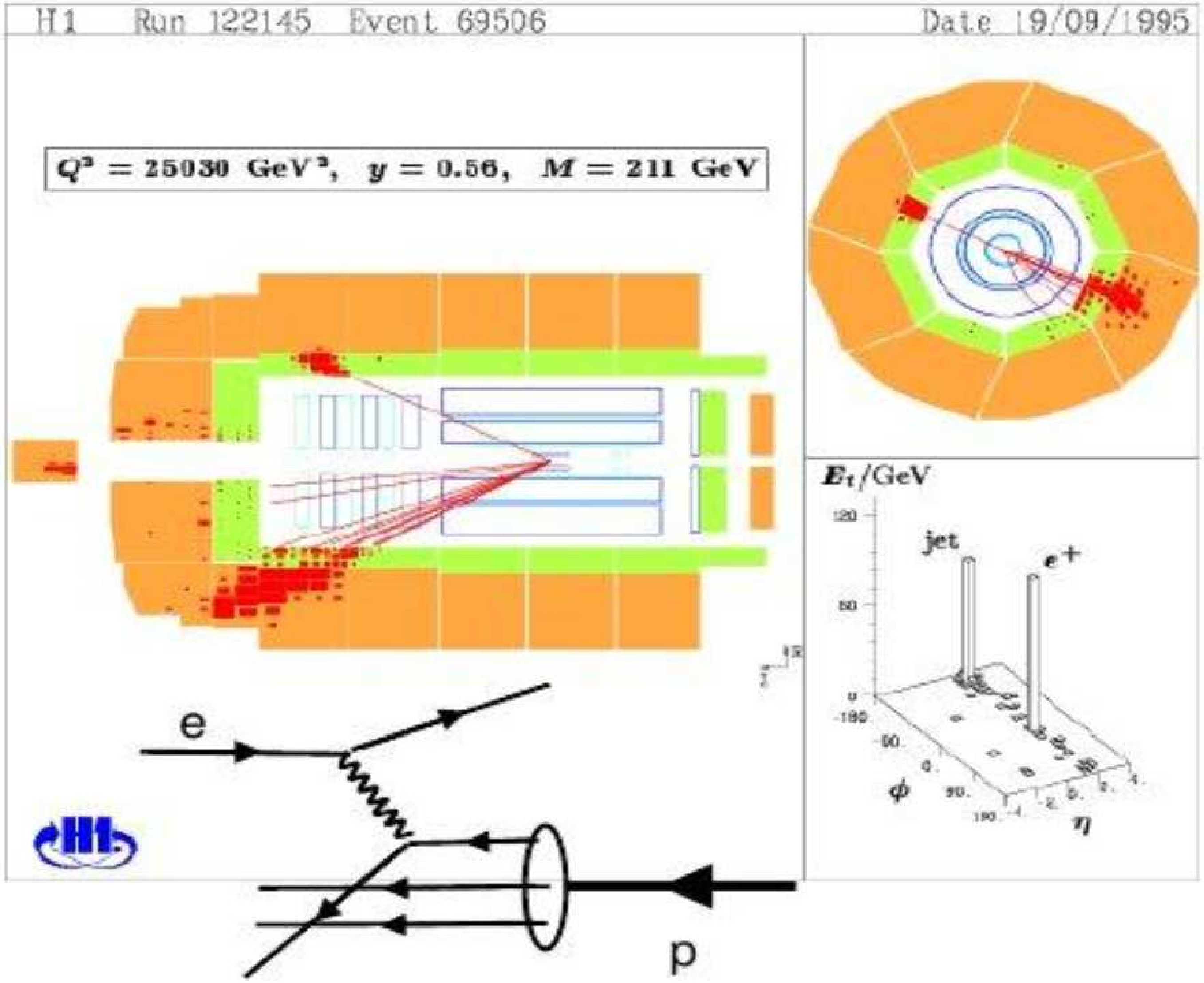
Partons have Spin=1/2!

HERA at DESY

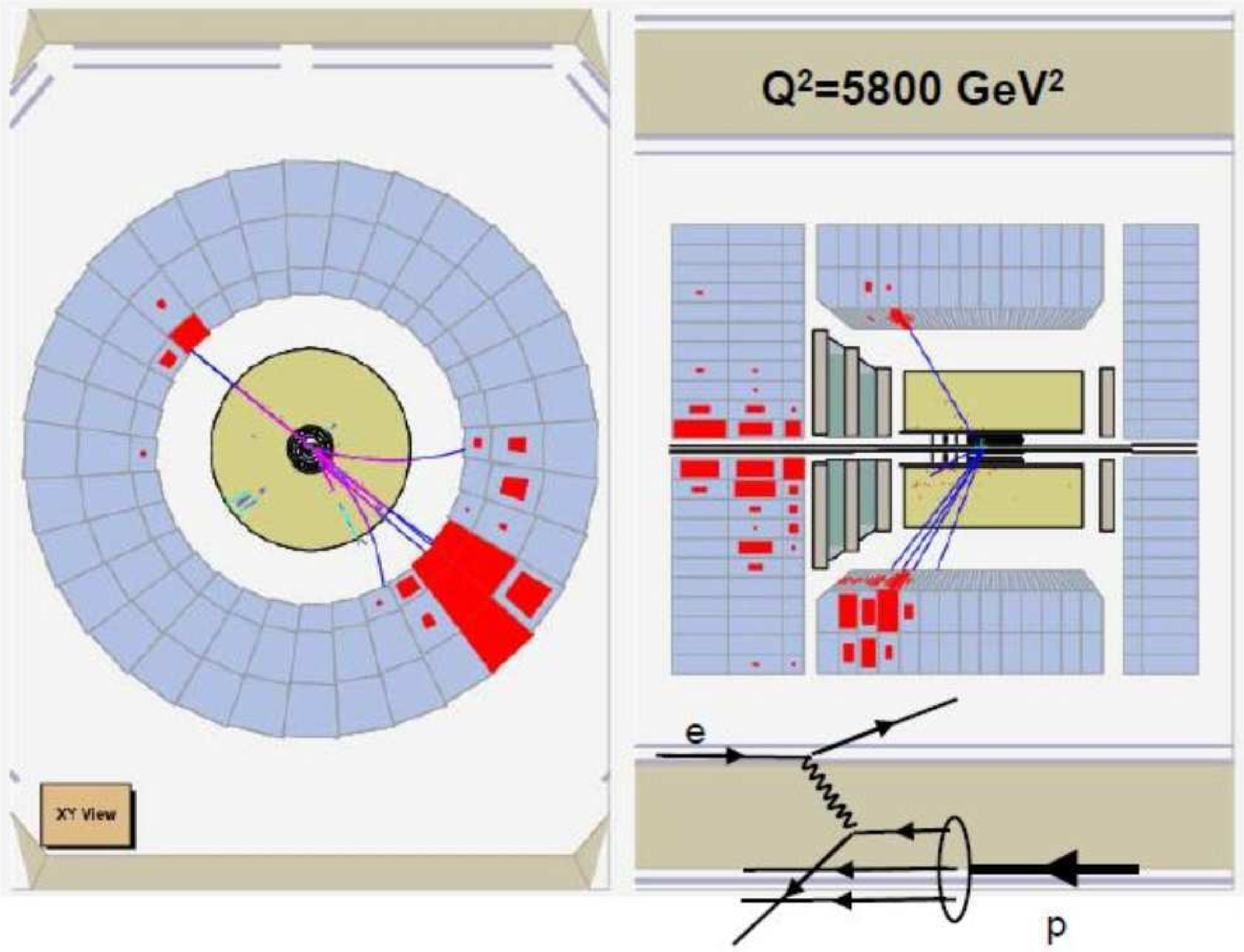
stopped data taking in 2006, experiments: ZEUS, H1

Elektron-Position Kollisionen: E(Elektron) = 27.5 GeV E(Protonen) = 920 GeV

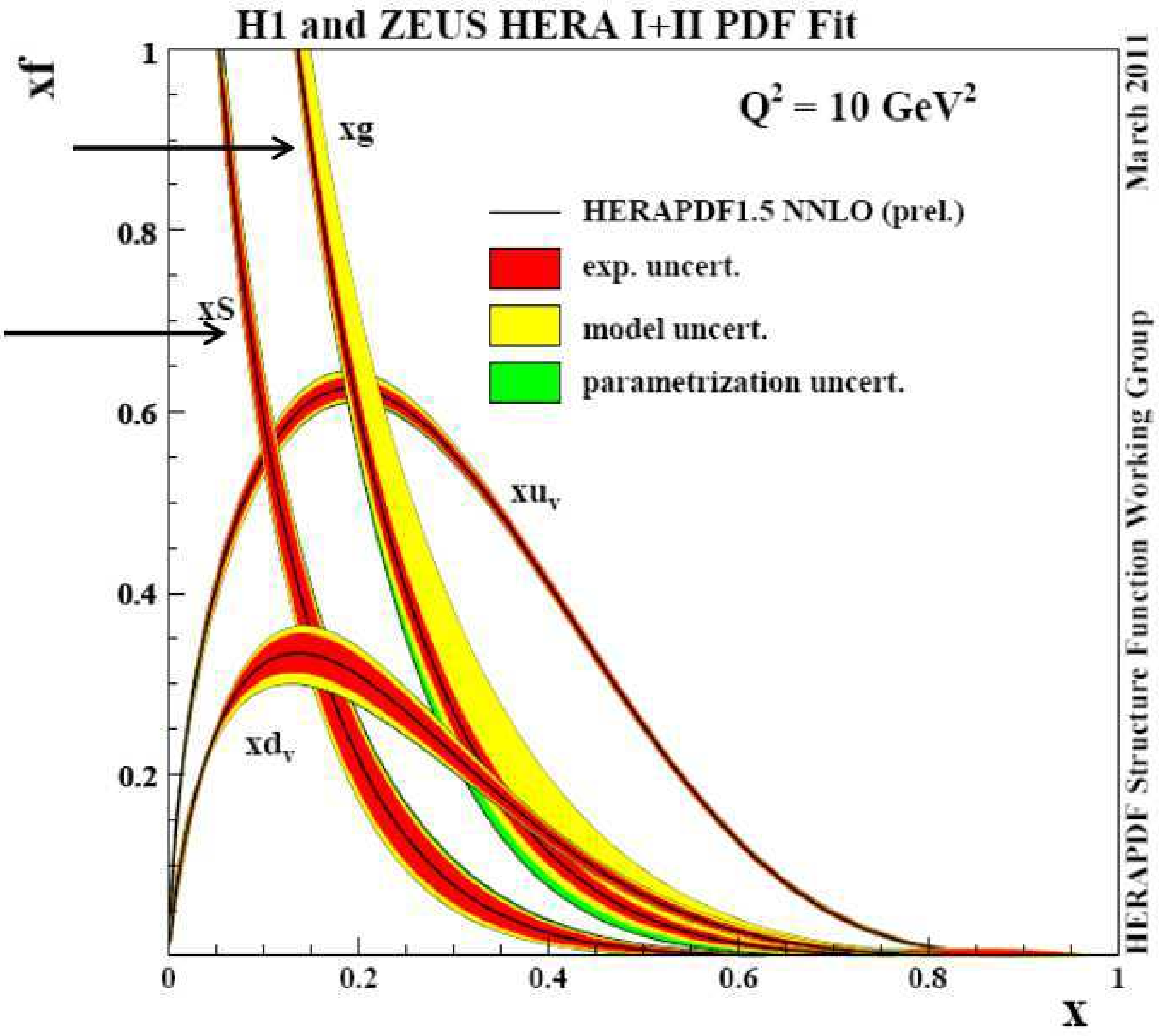
Ereignis im H1 Experiment



Ereignis im Zeus Experiment



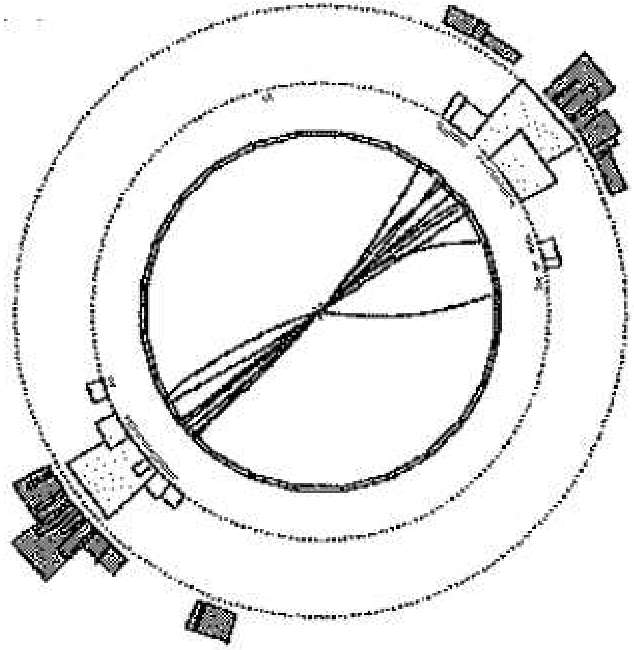
Parton-Dichte-Verteilungen

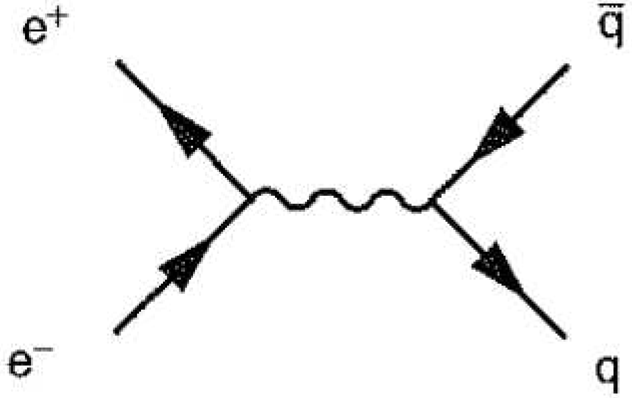


Gluonen

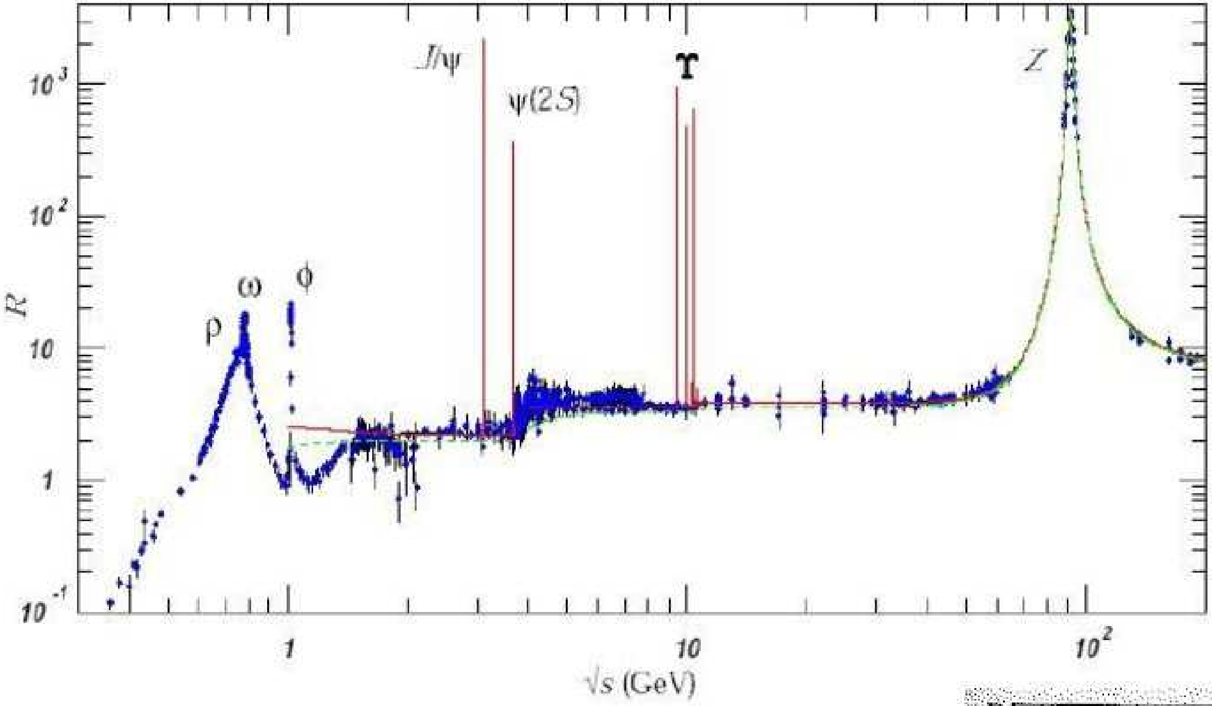
See-Quarks

$e^+e^- \rightarrow q\,\bar{q}$ Ereignis





Die beiden Quarks bilden Jets („Bündel von Teilchen“) im Detektor



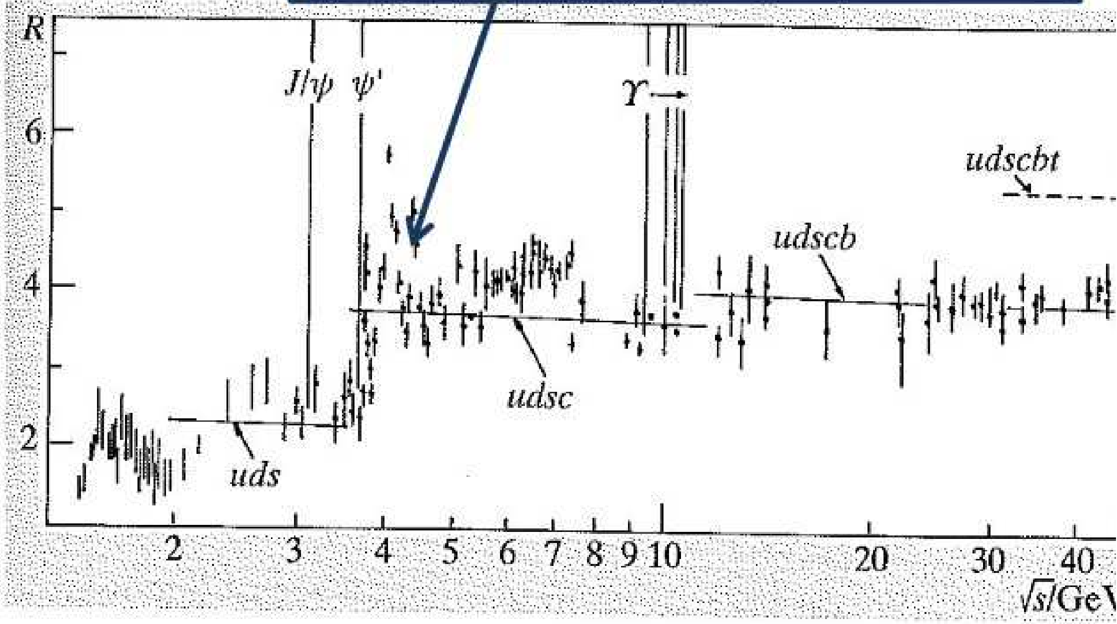
$$R = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

$$= N_c \sum_i Z_i^2$$

q	Z_i^2	R[$\sqrt{s} \leq 2m(q)$]
u	4/9	4/3
d	1/9	5/3
s	1/9	2
c	4/9	10/3
b	1/9	11/3
t	4/9	5

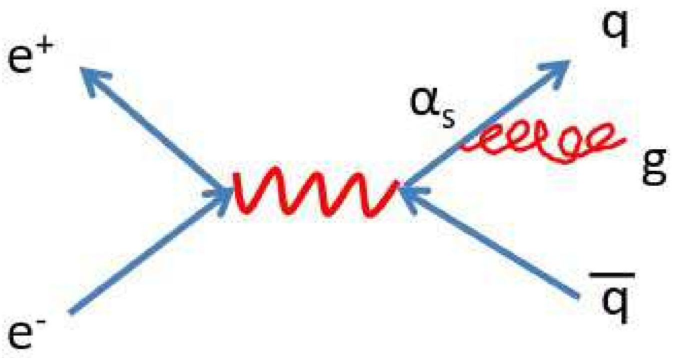
N_c=3 „more or less“ confirmed by data!

$\tau\bar{\tau}$ treshold, however not all τ decay into hadronic jets



Discovery of the Gluon

discovery of 3-jet events by Tasso collaboration in 1977 at PETRA ($\sqrt{s} \sim 20\ GeV$)



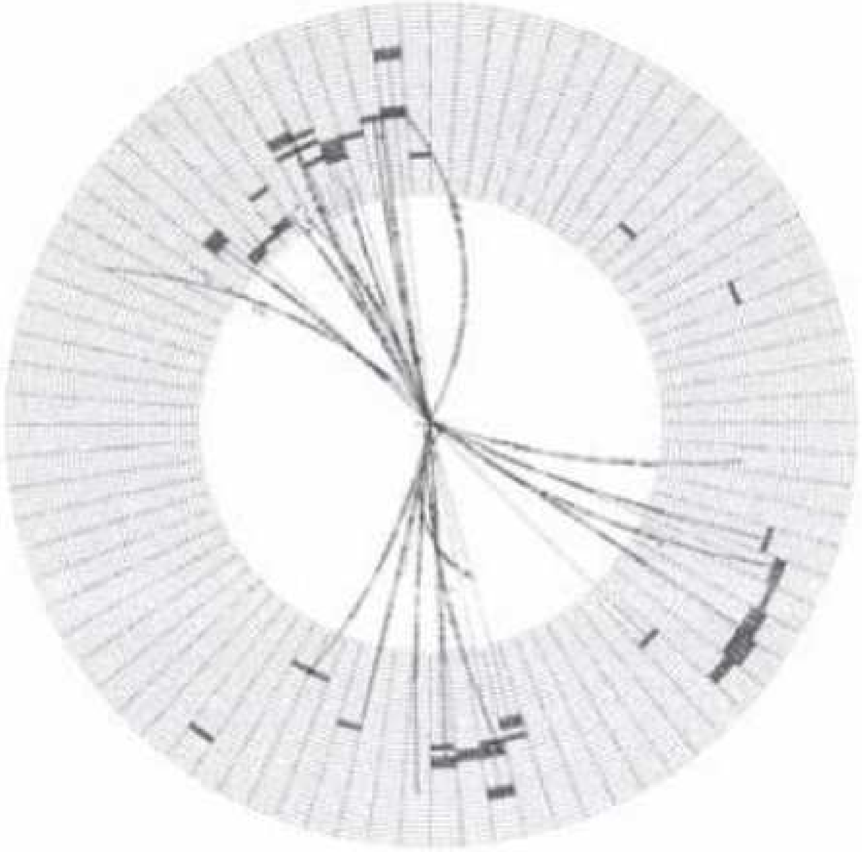


Fig. 11.12 A three-jet event observed by the JADE detector at PETRA.

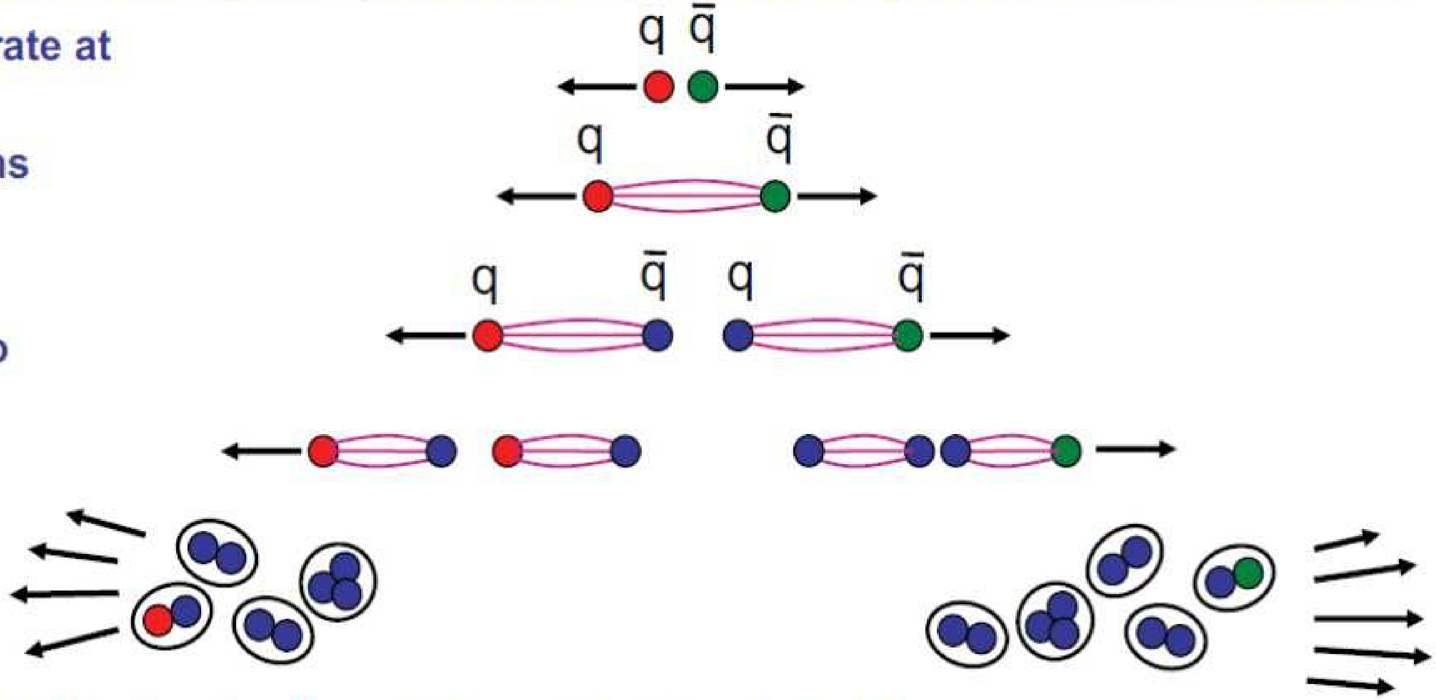
Interpreted as quark anti-quark pair which emits an additional hard gluon.

$$\frac{\#\ of\ three\ jet\ events}{\#\ of\ two\ jet\ events} \sim 0.15$$

$\Rightarrow$ α_s is large!

Hadronisierung, Bildung von Jets

★ Consider a quark and anti-quark produced in electron positron annihilation



i) Initially Quarks separate at high velocity

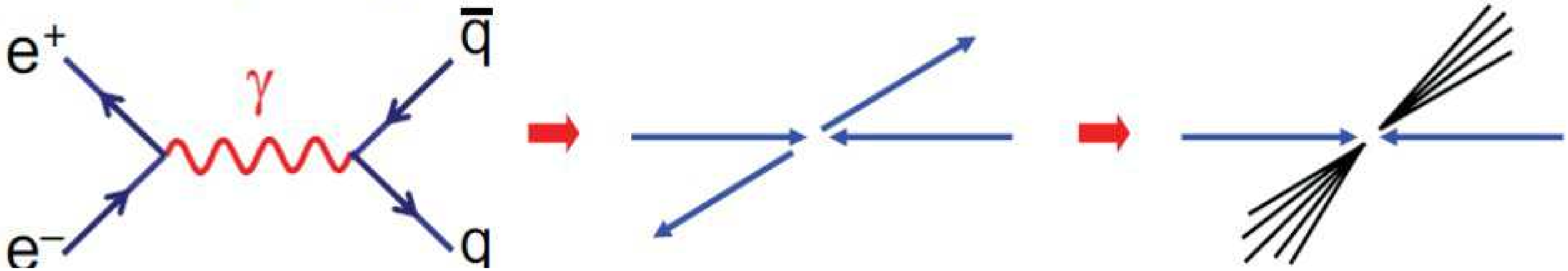
ii) Colour flux tube forms between quarks

iii) Energy stored in the flux tube sufficient to produce **$q\bar{q}$** pairs

iv) Process continues until quarks pair up into jets of colourless hadrons

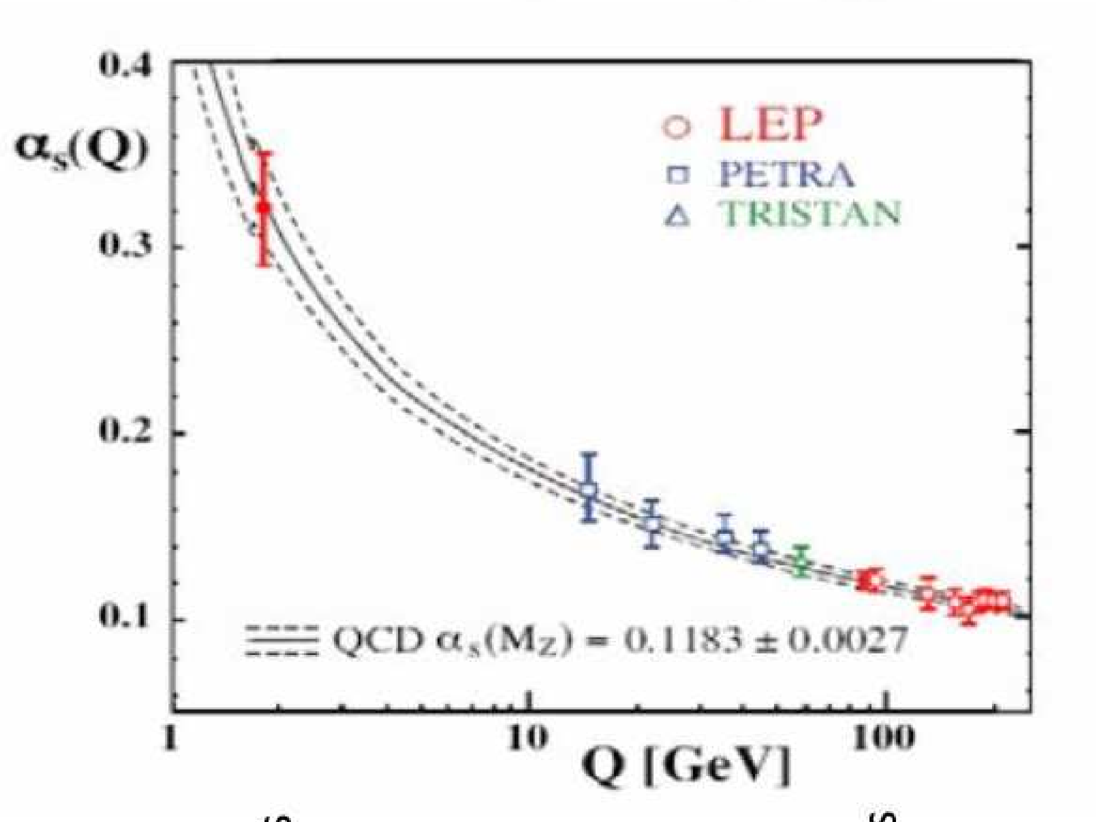
★ This process is called hadronisation. It is not (yet) calculable.

★ The main consequence is that at collider experiments **quarks** and **gluons** observed as jets of particles



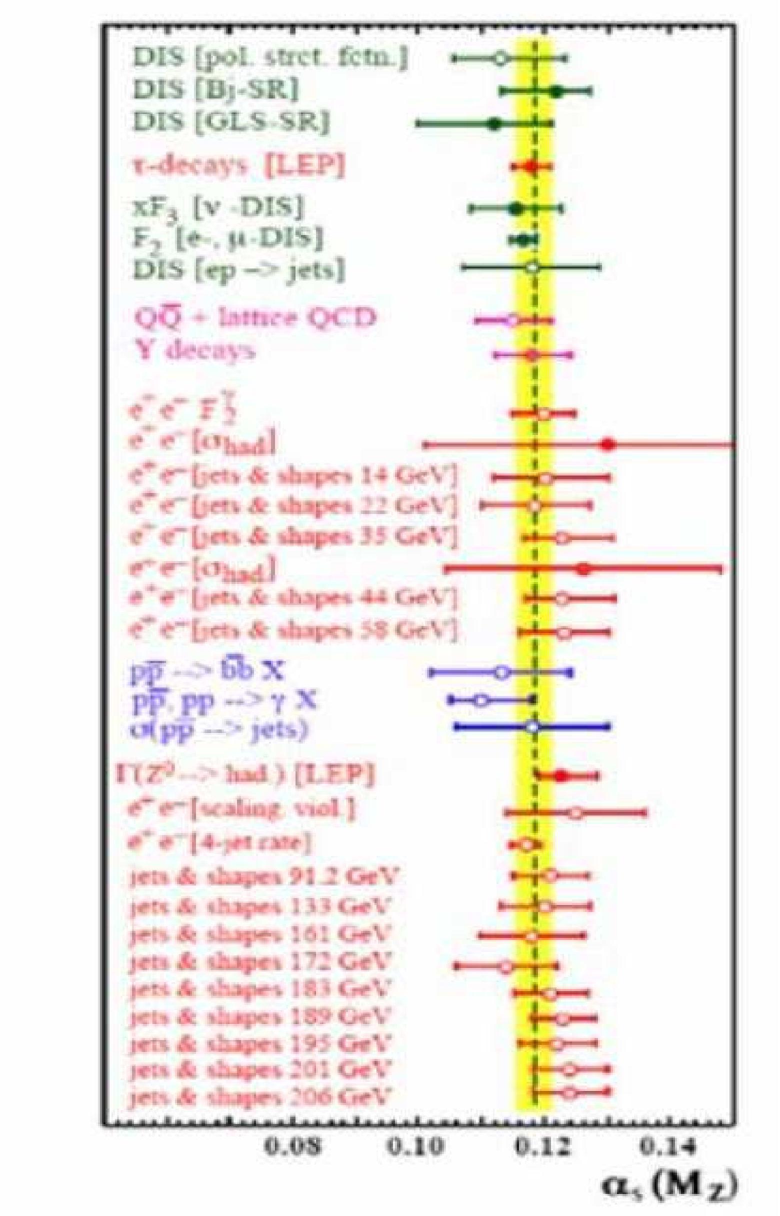
Laufende Kopplungskonstante der starkten WW

$$\alpha_s(Q^2) = \frac{1}{\beta_0 \log(Q^2/\Lambda^2_{QCD})}$$

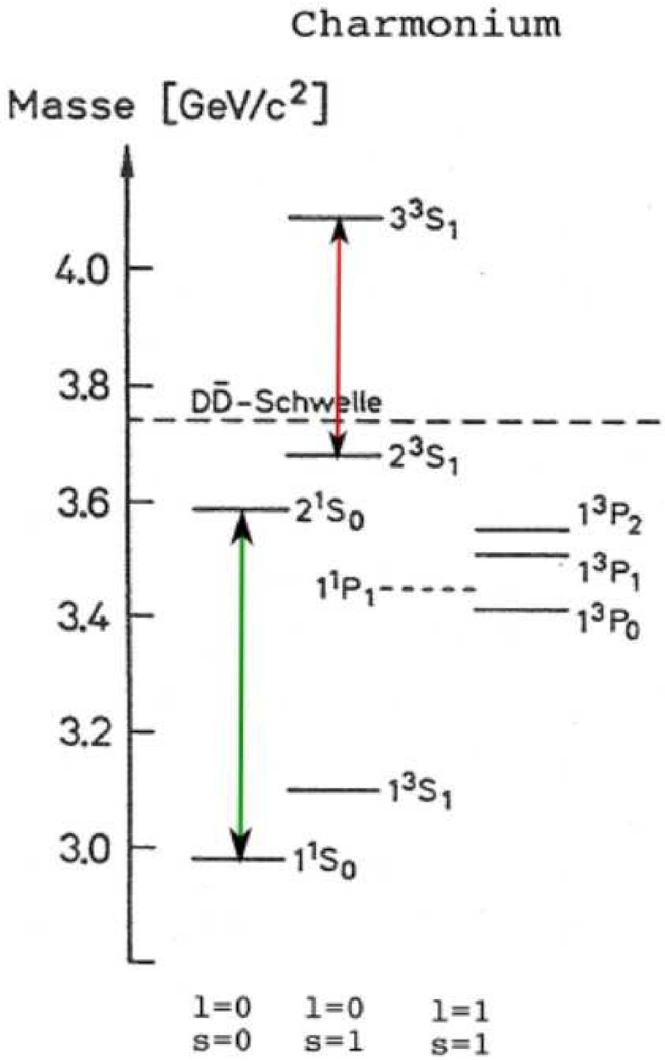


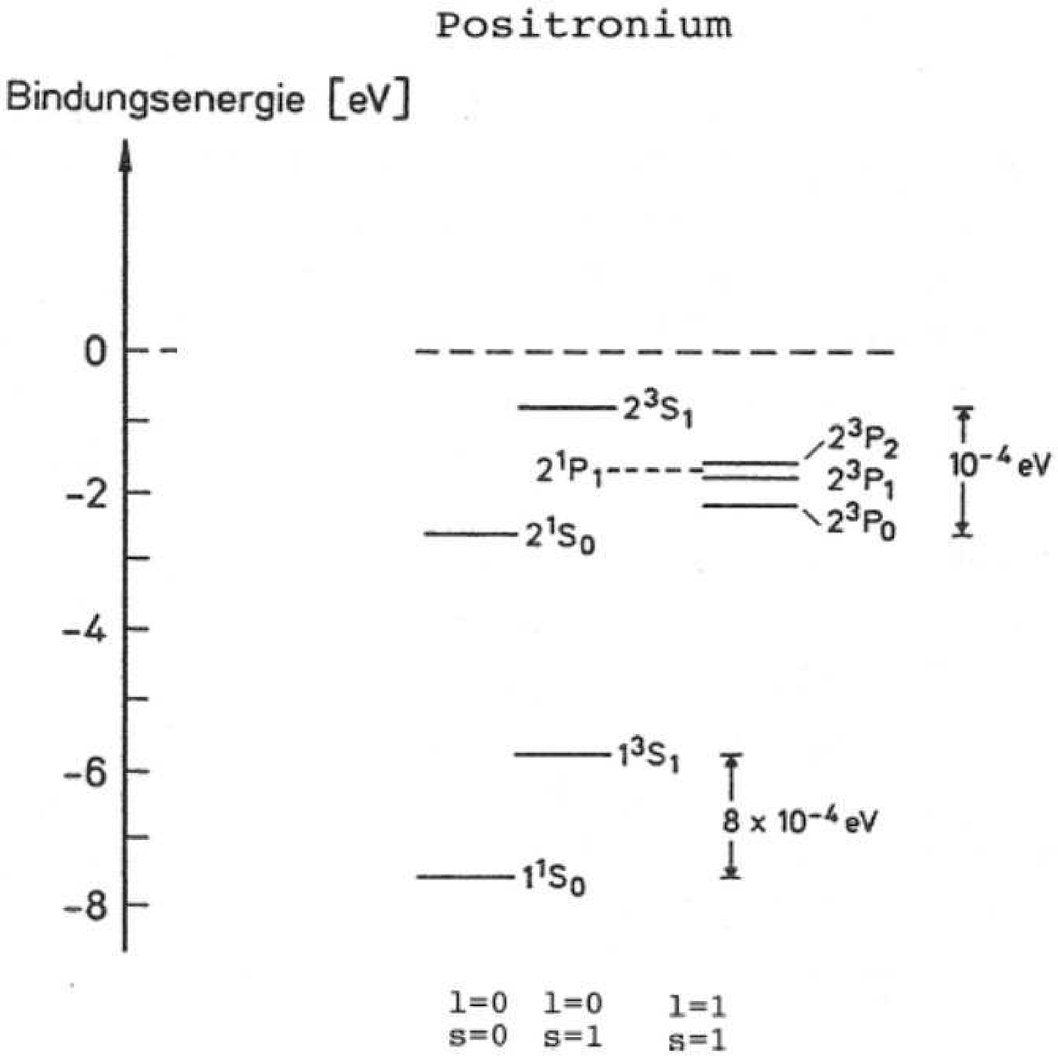
τ mass

~ Z^0 mass

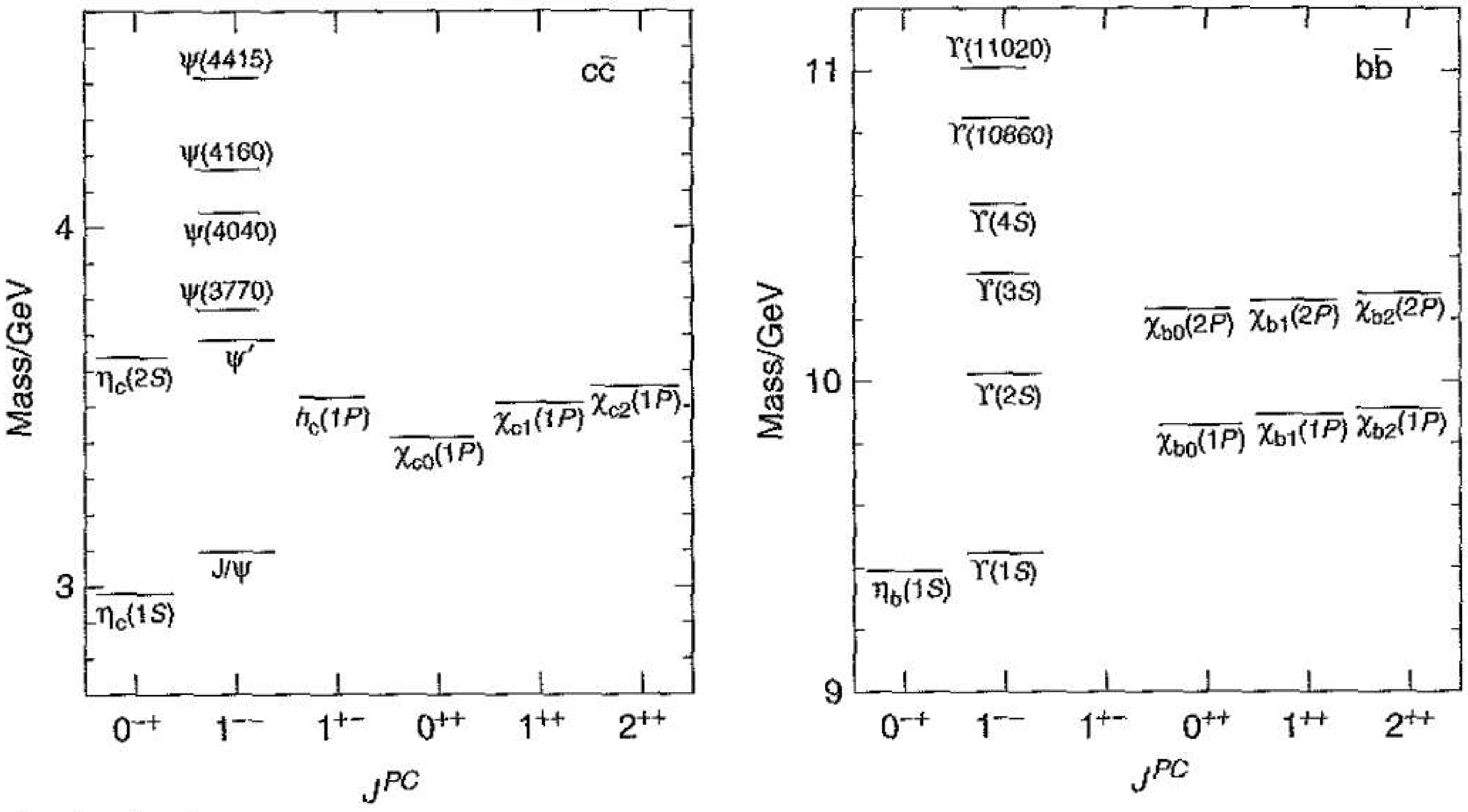


Vergleich Charmonium + Positronium Potential





Vergleich Charmonium + Bottonium



Unterschied zwischen Energienieveaus sehr ähnlich → starke WW ist flavour-blind!