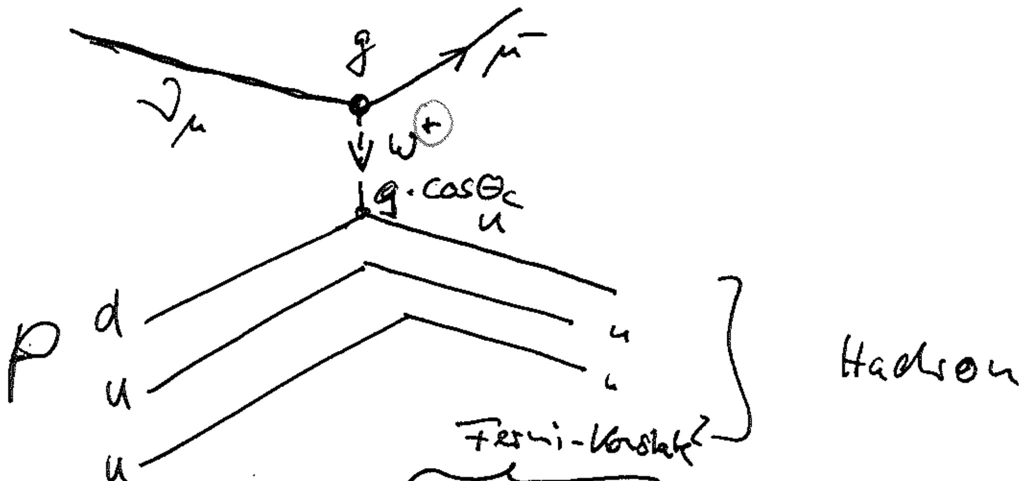
Tiefinelastische ν-Nukleonstreuung

1. Kopplung über schwache Wechselwirkung (schwache Ladung d. Quarks)
2. Vgl. zur e^--Nukleonstreuung ⇒ Aufschluss über Quarkladung
3. Unterschied q und $\bar{q}$ Streuung beobachten

Neutrinobeam: $p \rightarrow$ auf Be-target $\Rightarrow \pi^{\pm}, K^{\pm}, \ldots$

$$\pi^+ \rightarrow \mu^{\pm} + \nu_\mu \; ; \quad \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

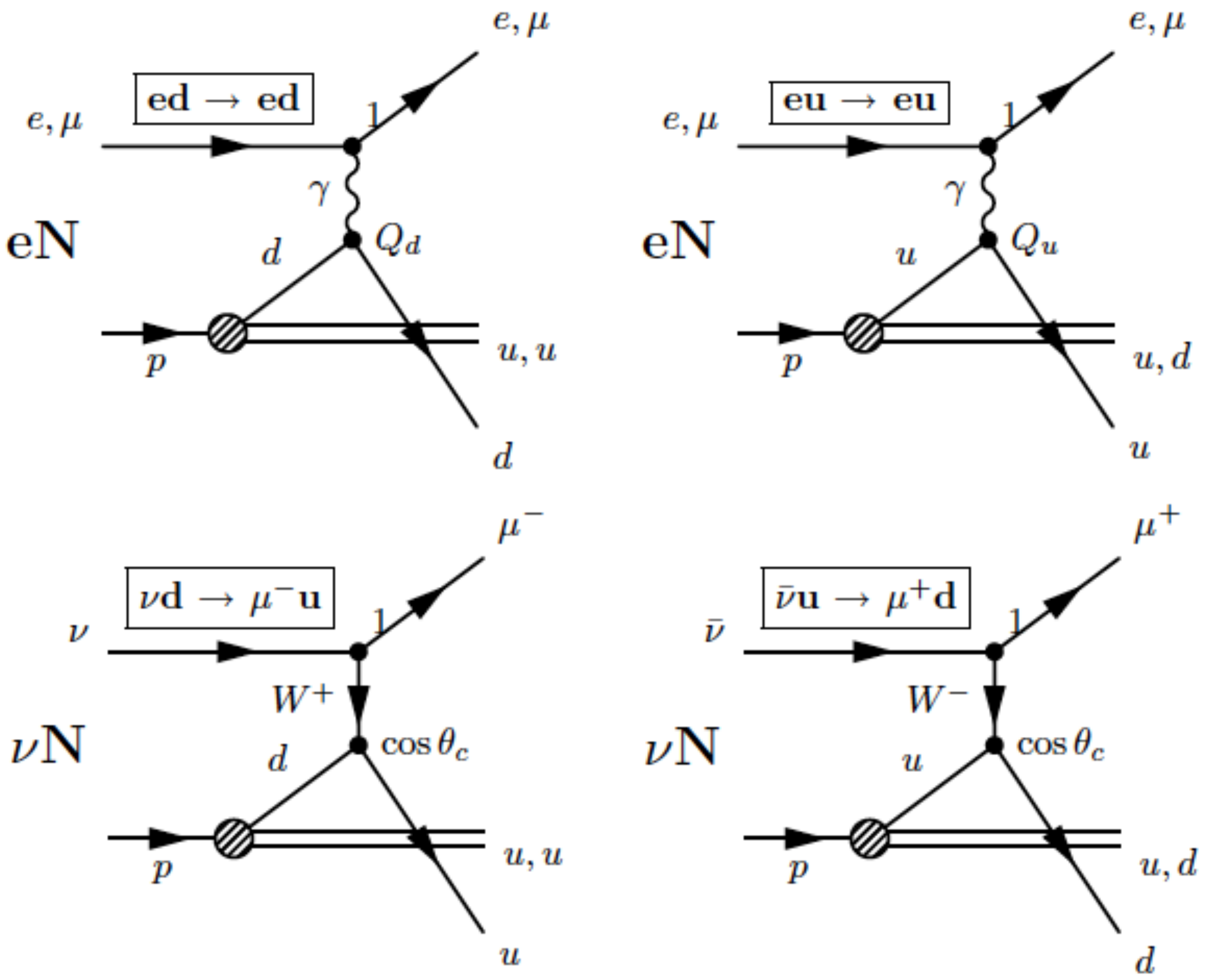


$$E_\nu > m_\mu \quad (+E_R + \Delta M_{ud})$$

Fermi-Konstante

$$\sigma_{\nu,tot} \simeq \left| g^2 \frac{\cos\Theta_c}{(M_W^2 + q^2)} \right| \cdot \phi(E_\nu) \simeq G_F^2 \, E_\nu$$

Dominierende Prozesse in der tief-inelastischen Streuung



Elementare Streuprozesse für ν_μ und $\bar{\nu}_\mu$ $\begin{pmatrix} d: -\frac{1}{3} \\ u: +\frac{2}{3} \end{pmatrix}$

für ν_μ $\begin{cases} \nu_\mu d \to \mu^- u & 0 - \frac{1}{3} \to -1 + \frac{2}{3} = -\frac{1}{3} \\ \nu_\mu \bar{u} \to \mu^- \bar{d} & 0 - \frac{2}{3} \to -1 + \frac{1}{3} = -\frac{2}{3} \end{cases}$

für $\bar{\nu}_\mu$ $\begin{cases} \bar{\nu}_\mu u \to \mu^+ d & 0 + \frac{2}{3} \to +1 - \frac{1}{3} = +\frac{2}{3} \\ \bar{\nu}_\mu \bar{d} \to \mu^+ \bar{u} & 0 + \frac{1}{3} \to +1 - \frac{2}{3} = +\frac{1}{3} \end{cases}$

(~~[illegible]~~)

Wenn im Proton bzw. Neutron nur u, d Quarks gäbe, würde der WQ für isoskalare Target (gleiche Anzahl v. Protonen u. Neutronen

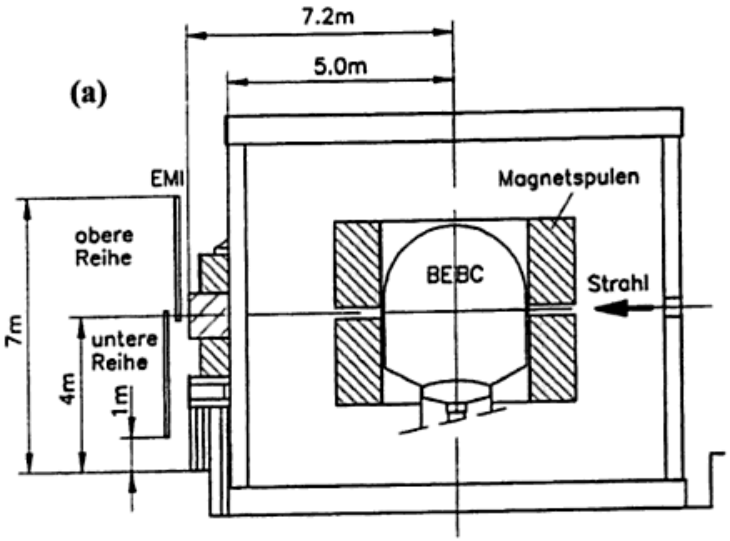
$$R = \frac{\sigma(\bar{\nu} q)}{\sigma(\nu q)} = \frac{1}{3}$$ (Herleitung s. Perkins)

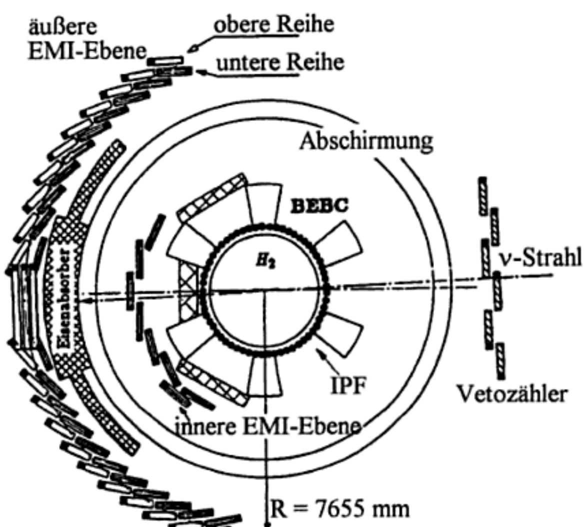
genauer $$R = \frac{1 + 3\bar{Q}/Q}{3 + \bar{Q}/Q}$$

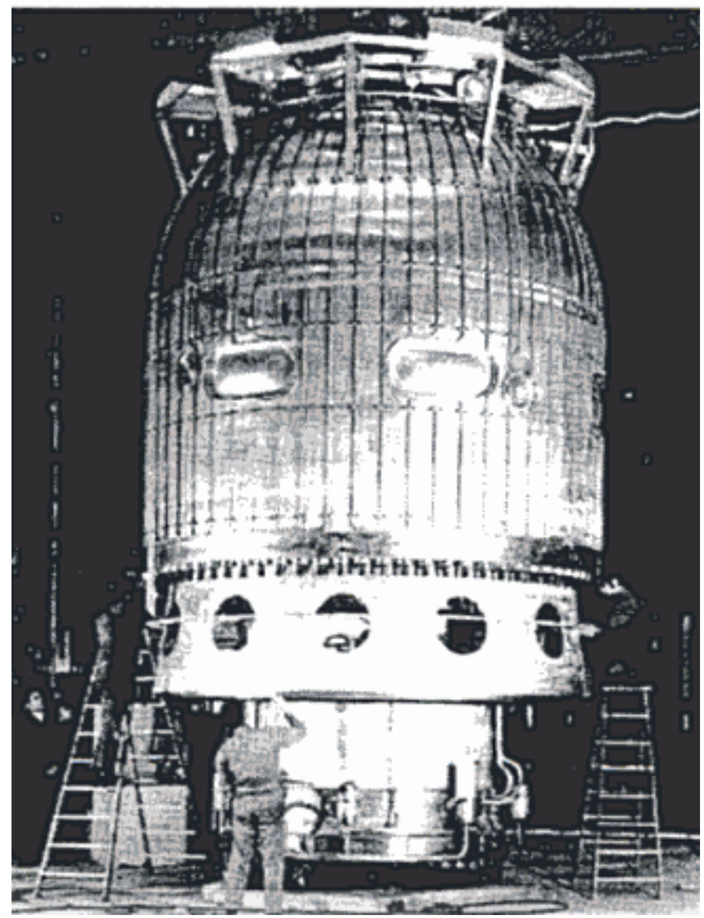
s. Abb.

Exp. $\to$
- $\sigma_\nu \propto E_\nu \Rightarrow$ punktförmige Konstituente
- $R \simeq 0{,}45$ (und nicht bei $\frac{1}{3}$) $\Rightarrow \bar{Q}/Q \simeq 0{,}15$

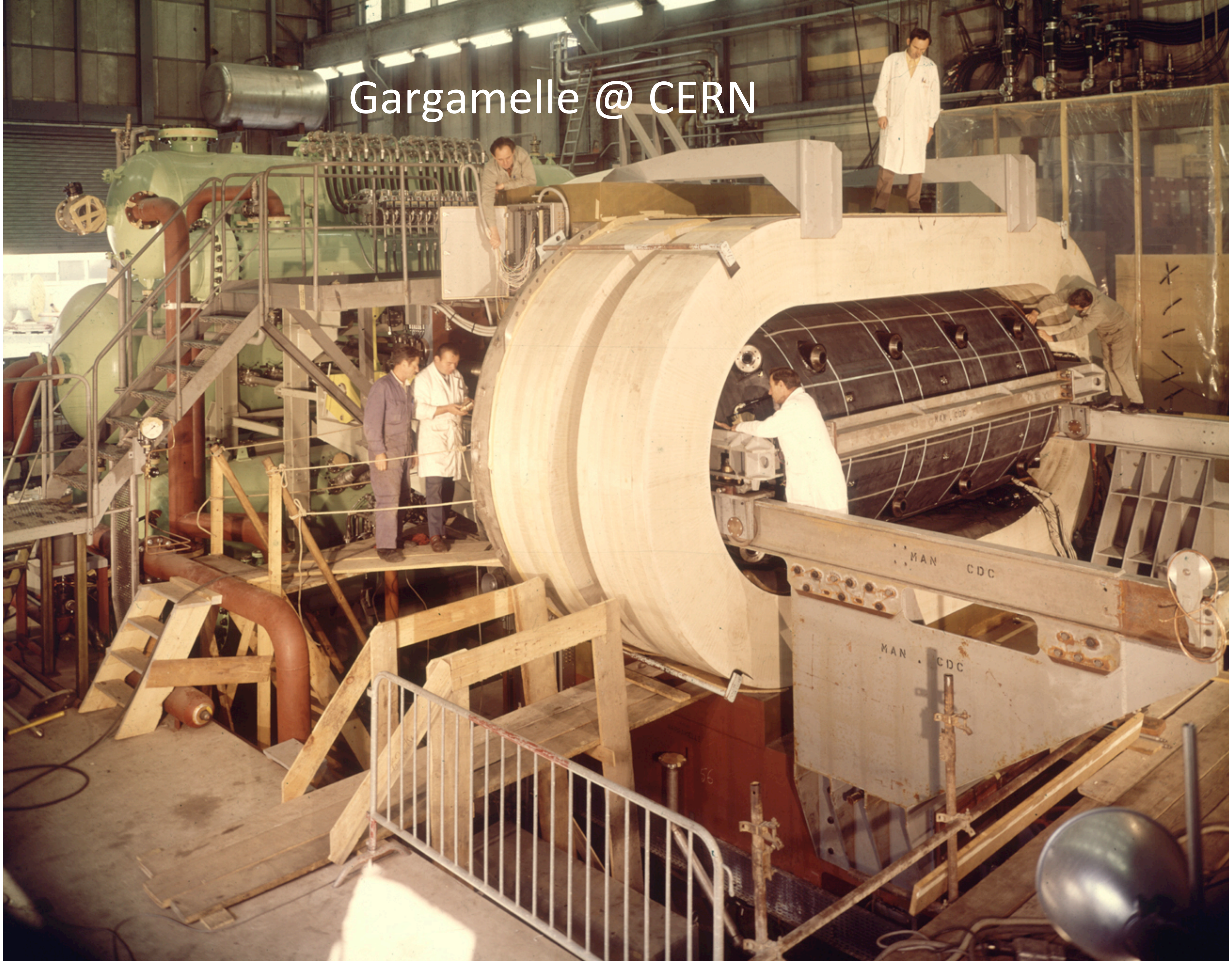
Neutrino-Nucleon deep inelastic scattering: Big European Bubble Chamber (BEBC) @ CERN

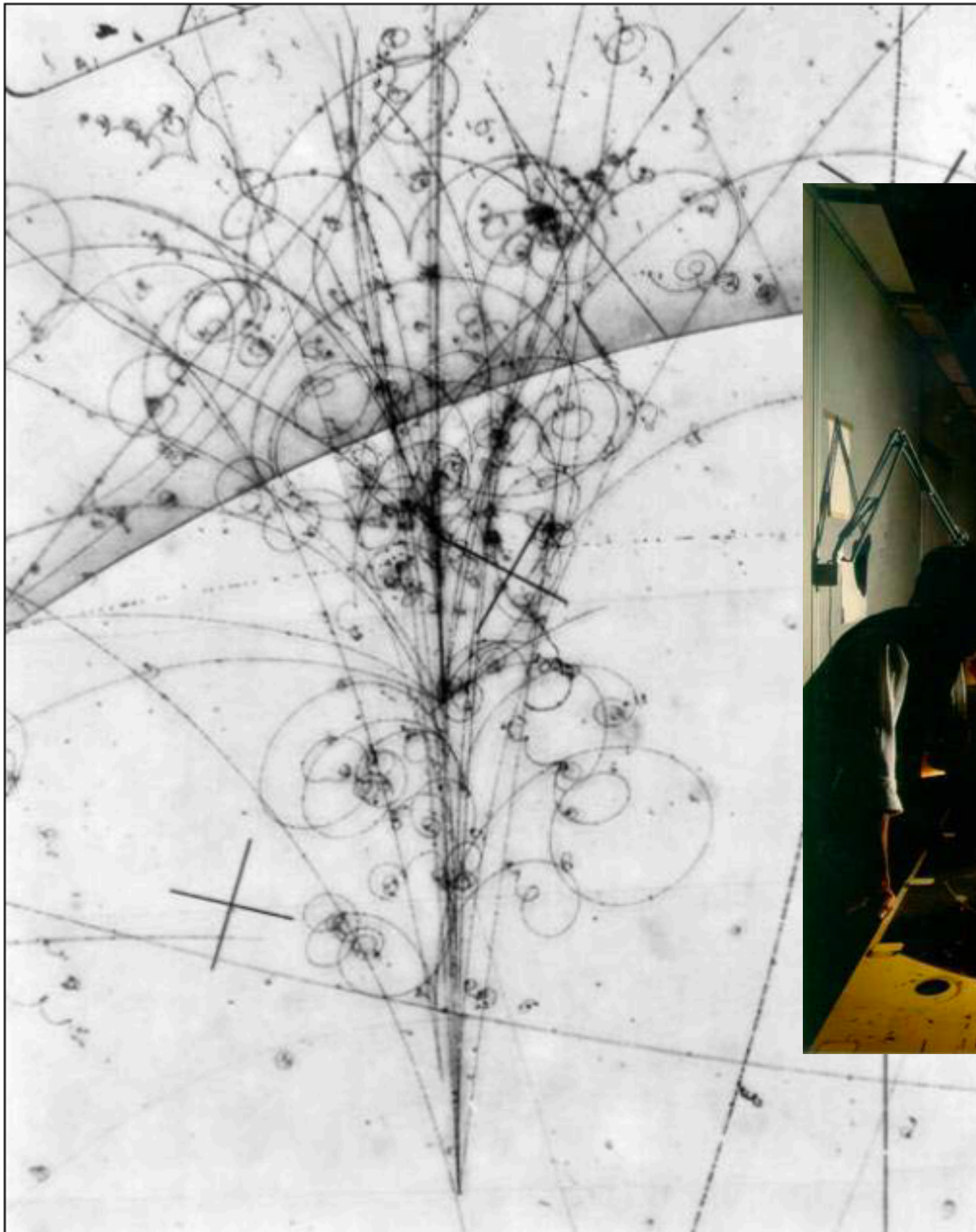


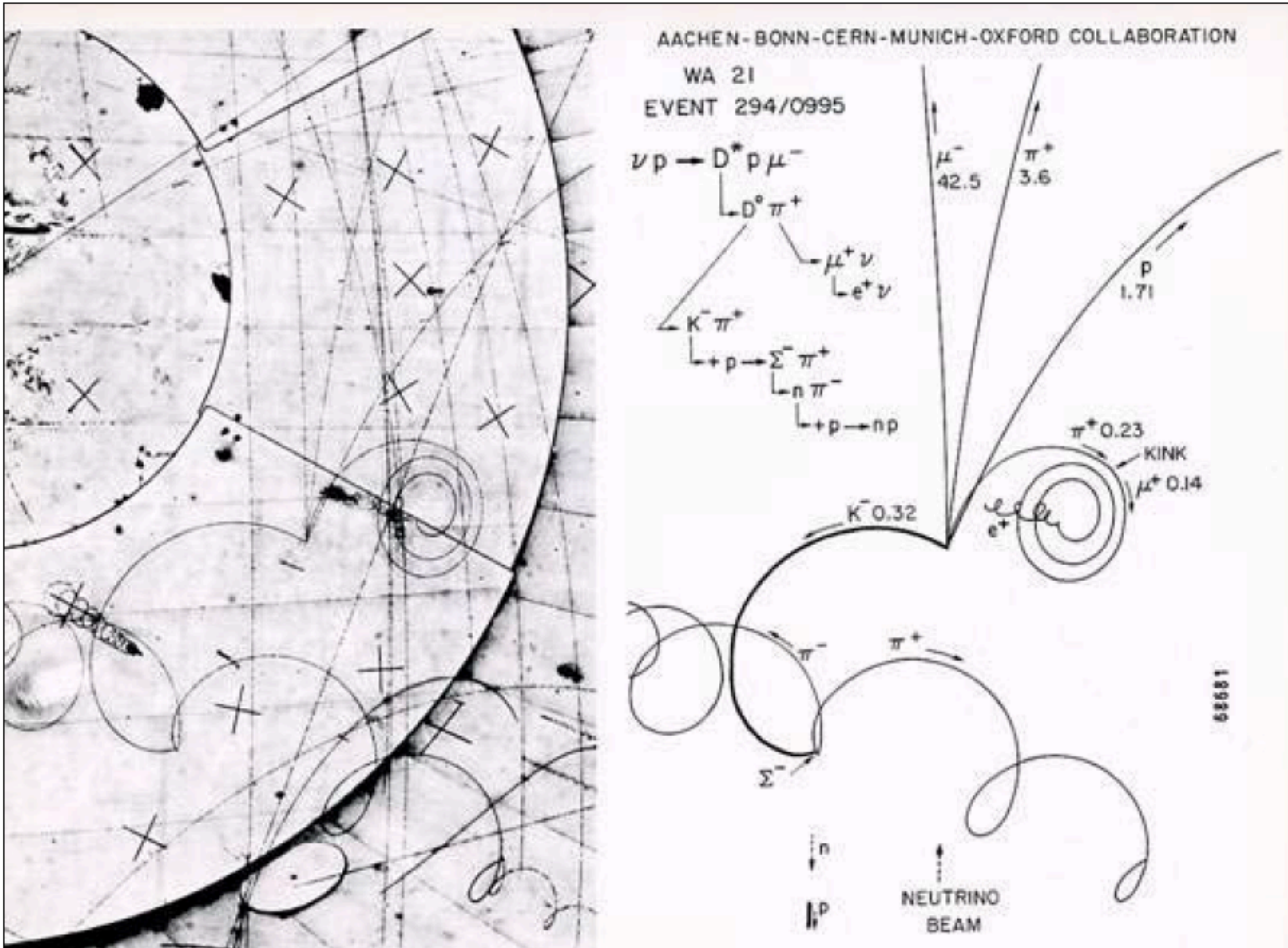




Gargamelle @ CERN






AACHEN-BONN-CERN-MUNICH-OXFORD COLLABORATION
WA 21
EVENT 294/0995
$\nu p \rightarrow D^{*} p \mu^{-}$
$\llcorner D^{0} \pi^{+}$
$\llcorner \mu^{+} \nu$
$\llcorner e^{+} \nu$
$K^{-} \pi^{+}$
$\llcorner + p \rightarrow \Sigma^{-} \pi^{+}$
$\llcorner n \pi^{-}$
$\llcorner + p \rightarrow n p$
μ^{-} 42.5
π^{+} 3.6
p 1.71
π^{+} 0.23
KINK
μ^{+} 0.14
K^{-} 0.32
e^{+}
π^{-}
π^{+}
Σ^{-}
n
p
NEUTRINO BEAM

$p = (u, u, d)$

$n = (u, d, d)$

$u : +\frac{2}{3} e \quad , \quad d : -\frac{1}{3} e$

DIS ν-Streuung in Vorwärtsrichtung; d.h. der F_1-Beitrag (magnet, Spin-flip) verschwindet

$y := \frac{\nu}{E} \quad y \to 0$ (Vorwärtsrichtung) $\Rightarrow$ F_1 vernachlässigt werden

$$\frac{d^2\sigma}{dy\,dx} = \frac{4\pi\alpha^2}{q^4} \frac{F_2}{x}$$

e-Proton: $\quad F_2^{ep} \sim \left(\frac{2}{3}\right)^2 u_p(x) + \left(-\frac{1}{3}\right)^2 d_p(x)$

$u(x)$ bzw. $d(x)$: Verteilungsfunktion der d-Quarks bzw. u-Quarks im Proton/Neutron als Funktion von x

e-Neutron: $\quad F_2^{en} \sim \left(-\frac{1}{3}\right)^2 d_n(x) + \left(\frac{2}{3}\right)^2 u_n(x)$

Wg. Isospininvarianz (Proton ≈ Neutron) gilt

$u_n(x) = d_p(x)$ und $d_n(x) = u_p(x)$

Nukleon : $F_2^{eN} := \frac{1}{2}\left(F_2^{ep} + F_2^{en}\right) \sim \frac{1}{2}\left(\frac{5}{9}u_p(x) + \frac{5}{9}d_p(x)\right)$

F

$= \frac{5}{18}\left(u_p(x) + d_p(x)\right)$

↳ mean square Quark Ladung pro Nukleon

ν – Nukleonstreuung : Kopplung der Neutrinos an die Quarks ist identisch ~~für~~

$\Rightarrow \quad F_2^{\nu N} \sim \left(u_p(x) + d_p(x)\right)$

$$\Rightarrow \quad F_2^{\nu N} = \frac{18}{5} F_2^{eN}$$

↑ exp. bestimmen

unter der Annahme, daß $u = +\frac{2}{3}e$, $d = -\frac{1}{3}e$ und schwache Ladung identisch für u, d

DIS neutrino-nukleon scattering:

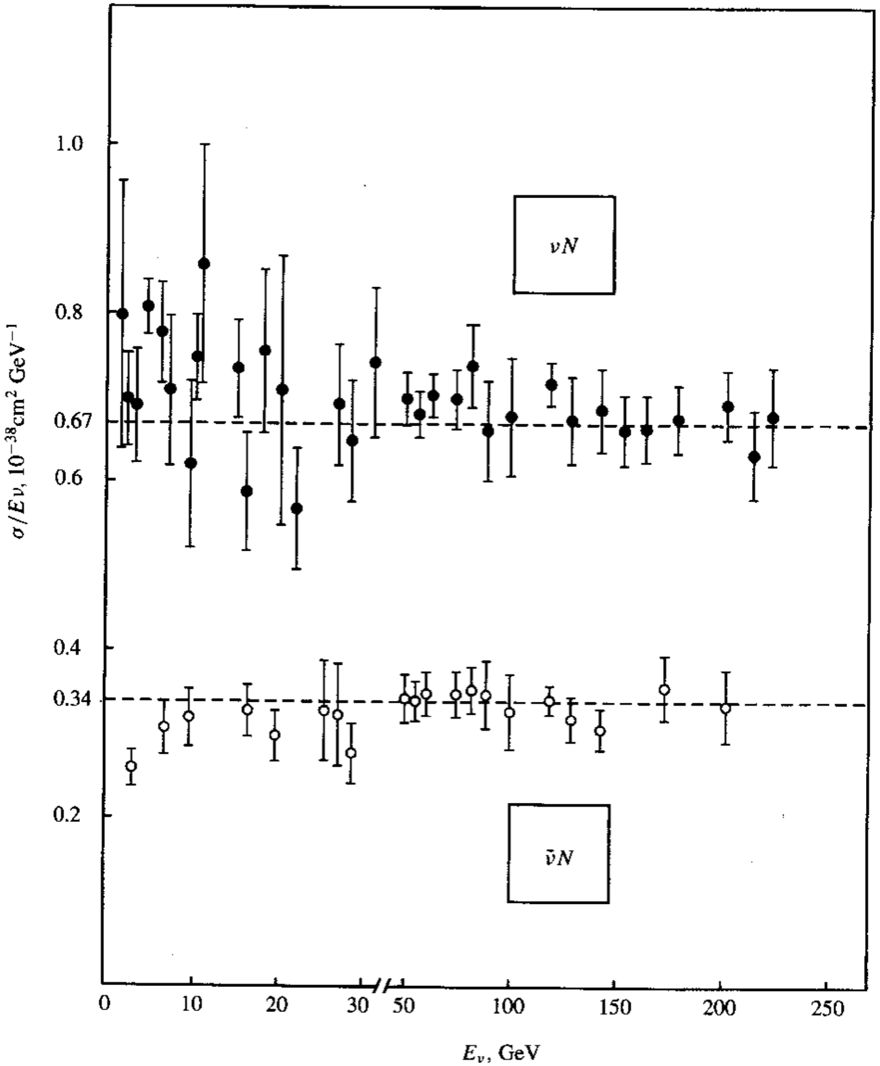


Fig. 5.13. Neutrino and antineutrino cross-sections on nucleons. The ratio σ/E_ν is plotted as a function of energy and is indeed a constant, as predicted in (5.45) and (5.46).

Quarks are point-like particles

Ratio of anti-neutrino-nucleon to neutrino-nucleon scattering cross section (0.45) => anti-q / q = 0.15

(From Perkins)

Comparison of structure functions of electron-nucleon and neutrino-nucleon DIS

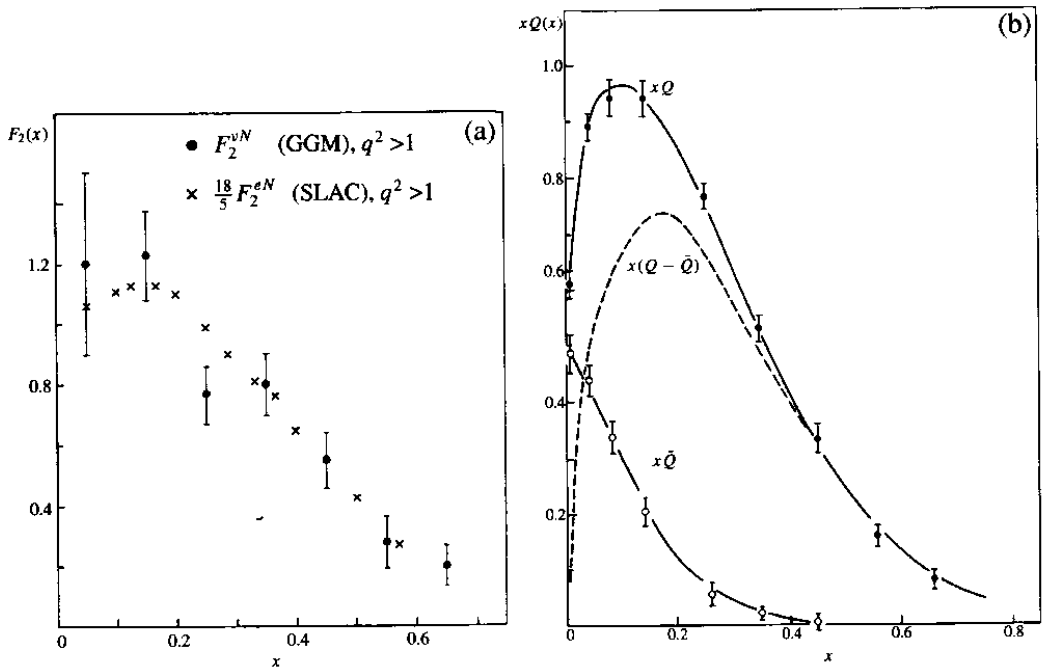


Fig. 5.14. (a) Early data on $F_2^{\nu N}(x)$ measured at CERN in the Gargamelle bubble chamber, compared with $\frac{18}{5}F_2^{eN}(x)$ measured from ep and ed scattering at SLAC. (b) Momentum distributions of quarks and antiquarks in the nucleon, at a value of $q^2 \simeq 10\ \mathrm{GeV}^2$, from neutrino experiments at CERN and Fermilab.

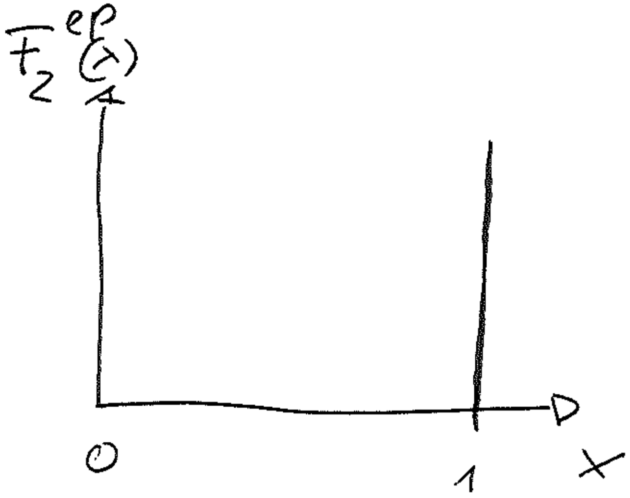
- quarks have 2/3 and -1/3 charges
- total momentum fraction carried by quarks and anti-quarks 50%
- => 50% of nucleon momentum carried by partons without weak or electromagnetic coupling
- => carried by gluons (strongly interacting neutral bosons that mediate the quark interactions)

(From Perkins)

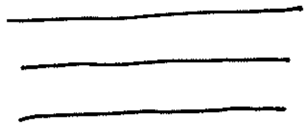
Quarks im Proton

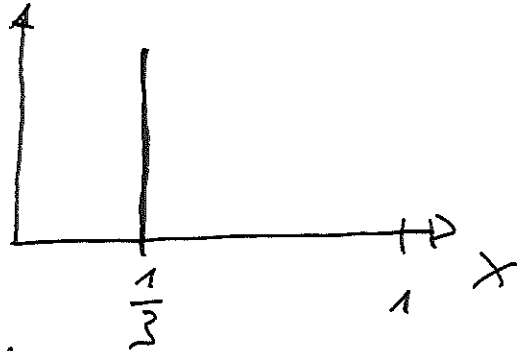
Falls d. Proton

<u>an Quark only</u>

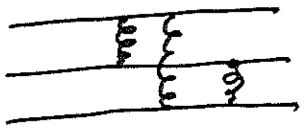


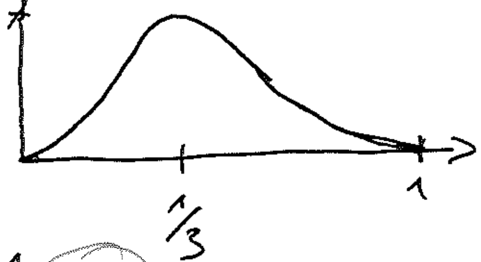
unabhängig
Drei Valenz-Quarks



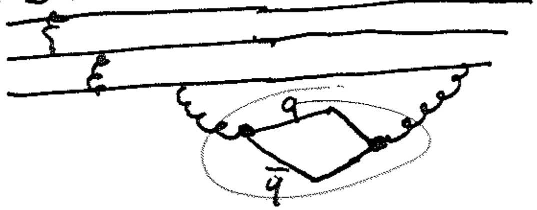


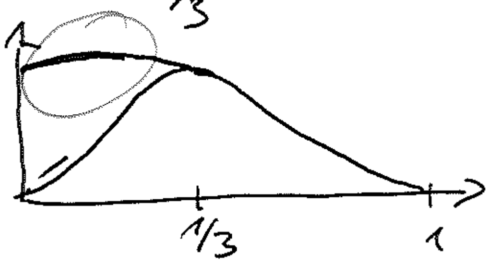
gebundene Valenz-Quarks





three bound Valenz-Quarks
+ slow debris (see-Quarks, $g \to q\bar{q}$)

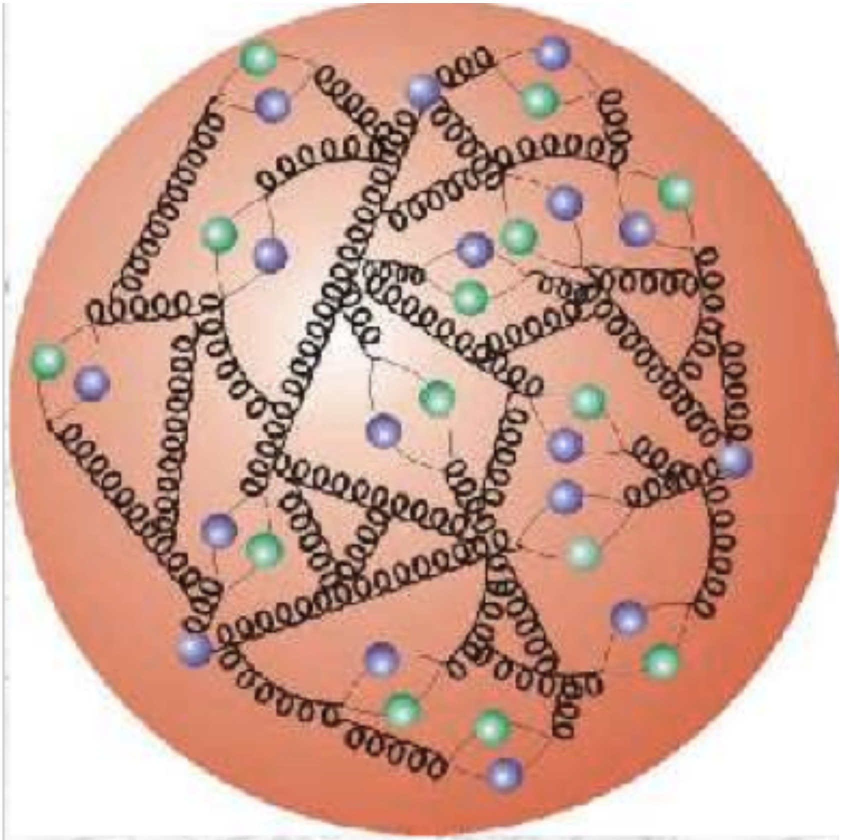




HERA at DESY: electron – proton collider

electrons 28 GeV, protons 820 GeV => s=10^5 GeV; q^2 up to 20.000 GeV

HERA - The proton ring (the large "pipe") with the electron ring below.



The proton

The above image represents of the inner structure of a proton as "seen" at HERA. The purple particles are quarks, the green particles are anti-quarks, and the black spirals are gluons. There are three more quarks than anti-quarks. These are the three quarks we would normally refer to when speaking of the proton (two up, one down). The other pairs of quarks and anti-quarks exist only momentarily; formed from an energetic gluon, they will come back together and annihilate returning once again to a gluon. As we probe to the smallest current "visibility" we can see up to 100 of these quark/anti-quark pairs at any instant.