

---

1967/68:

**Weinberg and Salam formulate a unified** (not quite: still two coupling constants,  $g, g'$ , for the SU(2) and U(1) interaction) **theory of electromagnetic and weak interactions of leptons.**

It is a local gauge theory based on the symmetry group  $SU(2)_I \otimes U(1)_Y$  ( $I$ : weak isospin,  $Y$ : hypercharge,  $Q = I_3 + Y/2$ ) where the lefthanded leptons are grouped in SU(2) doublets (and righthanded leptons in singlets).

Following Yukawa's suggestion, the weak force is understood to be transmitted by the exchange of massive gauge bosons, i.e. for instance the muon decay can be written as follows:

$$\mathcal{L}_{WS} = g_w^2 J_{lept}^\mu \frac{g_{\mu\nu} - q_\mu q_\nu / M_W^2}{q^2 - M_W^2 + i\epsilon} J_{lept}^\nu$$

The requirement  $\mathcal{L}_{WS} \xrightarrow{q^2 \ll M_W^2} \mathcal{L}_{Fermi}$  yields a prediction for the mass of the charged weak gauge boson,  $W^\pm$ :

$$M_W^2 = \frac{\sqrt{2}g_w^2}{G_\mu} \sim (100 \text{ GeV})^2$$

where it is assumed that  $g_w \sim e$ .

---

The structure of the gauge couplings is governed by the requirement that the theory ( $\equiv$  Lagrangian) is invariant under  $SU(2)_I \otimes U(1)_Y$ .

Based on works by Higgs, Kibble, Brout, Englert and Guralnik, Hagen, the masses of the weak gauge bosons are generated via the interaction with a massive neutral scalar field, the Higgs boson, so that the gauge invariance of the Lagrangian is preserved and only the vacuum state is no longer invariant (*spontaneous symmetry breaking*).

The WS model predicts the existence of a neutral weakly interacting boson ( $Z^0$ ), that mediates a weak interaction (neutral currents) which has not been observed yet.

It also predicts the existence of the Higgs boson.

1968/69:

In experiments where electrons are scattered off nucleons (deep inelastic  $eN$  scattering) the electrons appear to be bouncing off small hard cores inside the nucleon.

---

To analyze these data Bjorken and Feynman introduce the [parton model](#), a model of constituent particles inside the nucleon (they did not yet call them quarks):

- [Assumption I](#)

A fast moving hadron can be viewed as a jet of partons which predominantly fly in the direction of the hadron and the momentum of the hadron is distributed among the partons.

- [Assumption II](#)

The cross sections for hard processes such as deep inelastic  $eN$  scattering are calculated by calculating the cross sections of the underlying subprocesses assuming free point-like partons and then summing incoherently over the contributions of all partons.

The [parton model](#) succeeds in explaining the experimentally observed *Bjorken scaling*.

---

The reaction for  $eN$  scattering in the parton model is described in terms of structure functions,  $W_1, W_2$  ( $E$ : energy of the scattered electron,  $\theta$ : scattering angle):

$$\frac{d^2\sigma}{dE d\Omega} = \frac{4\alpha^2 E^2}{Q^4} \left[ 2W_1 \sin^2 \frac{\theta}{2} + W_2 \cos^2 \frac{\theta}{2} \right]$$

$W_1, W_2$  describe the probability of finding a parton with longitudinal momentum  $xP_N$  inside the nucleon.

In the limit of large  $Q^2$  the structure functions  $W_1, W_2$  only depend on a dimensionless parameter  $x$  as follows (assuming only spin 1/2 partons):

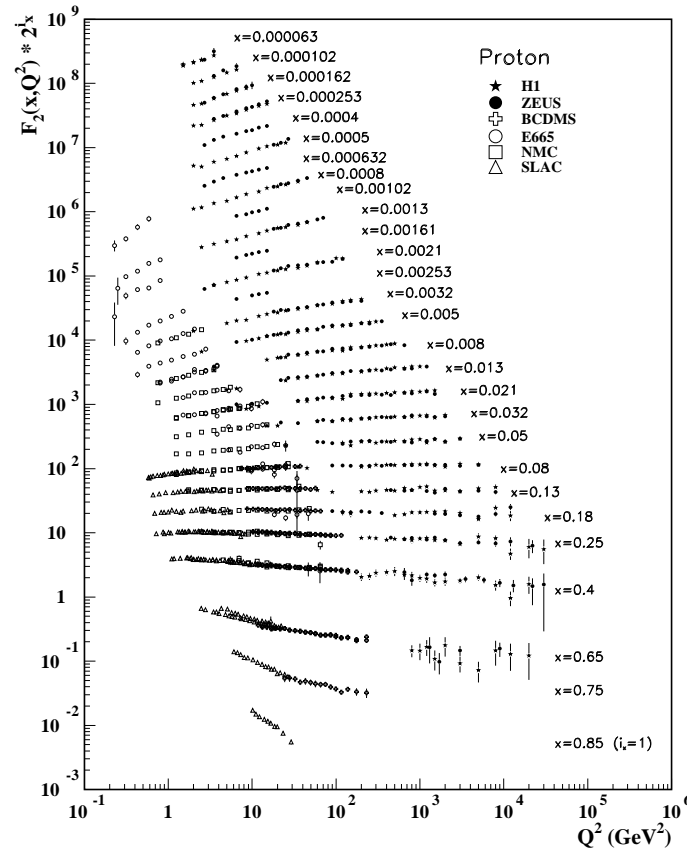
$$2MW_1(\nu, Q^2) = \sum_i Q_i^2 f_i(x) ; \nu W_2(\nu, Q^2) = x \sum_i Q_i^2 f_i(x)$$

$M$ : nucleon mass,  $\nu = pq/M$ : energy loss of the scattered electron,  $Q^2$ : four-momentum transfer,  $x = 2M\nu/Q^2$ : Bjorken scaling parameter,  $Q_i$ : electric charge of partons

This phenomenon, i.e. that the structure functions only depend on  $x$ , is known as *Bjorken scaling*.

16. Structure functions 1

NOTE: THE FIGURES IN THIS SECTION ARE INTENDED TO SHOW THE REPRESENTATIVE DATA. THEY ARE NOT MEANT TO BE COMPLETE COMPILATIONS OF ALL THE WORLD'S RELIABLE DATA.



from the Particle Data Group:

<http://pdg.lbl.gov/2005/strucfunfigrpp.ps>

**Figure 16.6:** The proton structure function  $F_2^p$  measured in electromagnetic scattering of positrons on protons (collider experiments ZEUS and H1), in the kinematic domain of the HERA data, for  $x > 0.00006$  (cf. Fig. 16.9 for data at smaller  $x$  and  $Q^2$ ), and for electrons (SLAC) and muons (BCDMS, E665, NMC) on a fixed target. Statistical and systematic errors added in quadrature are shown. The data are plotted as a function of  $Q^2$  in bins of fixed  $x$ . Some points have been slightly offset in  $Q^2$  for clarity. The ZEUS binning in  $x$  is used in this plot; all other data are rebinned to the  $x$  values of the ZEUS data. For the purpose of plotting,  $F_2^p$  has been multiplied by  $2^{i_x}$ , where  $i_x$  is the number of the  $x$  bin, ranging from  $i_x = 1$  ( $x = 0.85$ ) to  $i_x = 28$  ( $x = 0.000063$ ). References: **H1**—C. Adloff *et al.*, *Eur. Phys. J.* **C21**, 33 (2001); C. Adloff *et al.*, *Eur. Phys. J.* (accepted for publication) hep-ex/0304003; **ZEUS**—S. Chekanov *et al.*, *Eur. Phys. J.* **C21**, 443 (2001); **BCDMS**—A.C. Benvenuti *et al.*, *Phys. Lett.* **B223**, 485 (1989) (as given in [54]); **E665**—M.R. Adams *et al.*, *Phys. Rev.* **D54**, 3006 (1996); **NMC**—M. Arneodo *et al.*, *Nucl. Phys.* **B483**, 3 (97); **SLAC**—L.W. Whitlow *et al.*, *Phys. Lett.* **B282**, 475 (1992).