0.1 High Energy Experiments

exploring which (x, Q^2) region

- Elastic scattering
- Inclusive inelastic scattering
- Deep Inelastic scattering (DIS)

0.1.1 Low and Medium energy experiments

Nucleon structure function

- $F_1^{\gamma}(x,Q^2) = \frac{1}{2}\sum Q_q^2 \left[Q_q^2 q(x,Q^2) + \bar{q}(x,Q^2)\right]$
- $F_1^{\gamma Z}(x,Q^2) = \sum Q_q g_V^q \left[Q_q^2 q(x,Q^2) + \bar{q}(x,Q^2)\right]$
- $F_3^{\gamma Z}(x,Q^2) = 2\sum Q_q g_A^q \left[Q_q^2 q(x,Q^2) - \bar{q}(x,Q^2)\right]$
- The third electron-quark neutral-current effective couplings: $2C_{3u} - C_{3d}$

  $$L_{NC}^{eq} = \frac{G_F}{\sqrt{2}}\left[C_{1q}\bar{e}\gamma^{\mu}\gamma_5 e\bar{q}\gamma_{\mu}q + C_{2q}\bar{e}\gamma^{\mu}e\bar{q}\gamma_{\mu}\gamma_5 q + C_{3q}\bar{e}\gamma^{\mu}\gamma_5 e\bar{q}\gamma_{\mu}\gamma_5 q\right]$$

  where $C_{3q} \equiv -2c_A^e c_A^q$ with $c_A^{e(q)}$ the axial weak charge of the electron (quark)

  $$C_{1u} = -\frac{1}{2} + \frac{4}{3}\sin^2\theta_W \quad C_{2u} = -\frac{1}{2} + 2\sin^2\theta_W \quad C_{3u} = \frac{1}{2}$$

  $$C_{1d} = \frac{1}{2} - \frac{2}{3}\sin^2\theta_W \quad C_{2d} = \frac{1}{2} - 2\sin^2\theta_W \quad C_{3d} = -\frac{1}{2}$$

- Muonic C_{3q} was measured at CERN in 1980 to be: $2C_{3u}^{\mu q} - C_{3d}^{\mu q} = 1.57 \pm 0.38$: A. Argento et al. Electroweak Asymmetry in Deep Inelastic Muon - Nucleon Scattering. Phys. Lett. B, 120:245, 1983.
- P2 experiment at Mainz will measure C_{1q}
- SoLID at JLab will measure C_{2q}
- $g_{AV}^{eq}, g_{VA}^{eq}, g_{AA}^{eq}$ are new notation of C_{1q}, C_{2q}, C_{3q} with higher-order process-specific correction (possible BSM process), they are independent of the processes in which they are measured

0.2 Standard Model

- Higgs boson:
  - M. Aaboud et al. Observation of H $\to b\bar{b}$ decays and V H production with the ATLAS detector. Phys. Lett. B, 786:59–86, 2018.
  - A. M. Sirunyan et al. Observation of Higgs boson decay to bottom quarks. Phys. Rev. Lett., 121(12):121801, 2018.
- muon g-2:
  - B. Abi et al. Measurement of the Positive Muon Anomalous Magnetic Moment to 0.46 ppm. Phys. Rev. Lett., 126(14):141801, 2021.
- Proton weak charge
  - Qweak: D. Androić et al. Precision measurement of the weak charge of the proton. Nature, 557(7704):207–211, 2018.
- Parton Distribution Function (PDF)
  - MMHT2014
  - CT18
  - CJ15

0.3 Physical Problems

- Are leptons and quarks are made of smaller particles? or are they point-like (must elemental particles be point-like? Is it possible for elementary particle to have some structure?)
- Are there new interactions at higher energy scale that we never reach?
- At which energy scale, we can unify strong and EW interaction?
- Neutrino masses?
- Dark matter and dark energy
- Can we reduce the number of parameters of SM?
- How and where to unify gravity

0.4 Review

- Two Photon Exchange (TPE): J. Arrington, P. G. Blunden, and W. Melnitchouk. Review of two-photon exchange in electron scattering. Prog. Part. Nucl. Phys., 66:782–833, 2011.