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- EM: Standard Model (quark & New Physics)
- Summary of g-2
- Hadronic L6L
- Controversial Hadronic - EM Triangles
- EM contributions
- Introduction - perspective (two and three loops)
- Hadronic and electroweak effects in g-2
Present experimental accuracy: $\vartheta^{\exp} \approx 80 \cdot 10^{-11}$

$$(\nu^{\text{EW}})_{\nu} \cdot \tan \beta \left( \frac{M_{\text{susy}}}{100 \text{ GeV}} \right) \approx (\nu^{\text{SUSY}})_{\nu} \vartheta$$

$$11 \cdot 10^{-11} \approx (\nu^{\text{EW}})_{\nu} \vartheta$$

$$11 \cdot 10^{-11} \approx (\nu^{\text{had}})_{\nu} \vartheta$$

$$\left( \nu^{\vartheta} \right)^{99.99\% \text{ of } \vartheta} \approx 116.5 \pm 24 \times 10^{-11} \approx (\nu^{\text{QED}})_{\nu} \vartheta$$

\textbf{Sources of the Muon Magnetic Anomaly}
Higgs boson important

\[
\left[ \frac{\tau}{\alpha} (\text{Coul} + \text{ferm} + \text{boson}) + 1 \right]_\text{L} \approx \left( \frac{m_W}{m_W} \right)^2 \approx \frac{m_W}{m_W} \approx 99.10 \%
\]

Large coefficient \( \tau \approx \frac{m_W}{z} \frac{m_W}{m_W} \% \) in one loop: relative to one-loop

\text{Kuchino, Kuroe, Schiffer, Sigadze}

\underline{Two loops}:

\text{Bardeen, Eastman, Lautrup}

\text{Garraffo, Yoshimuura}

\text{Altarelli, Caffo, Maiani}

\text{Fukuda, Nishihara, Lee, Sanda}

\text{Negligible higgs effect}

\text{No in one loop} \frac{m_W}{z} \frac{m_W}{m_W} \%

\text{Electroweak contributions}

\text{One loop}:

\[
\text{Logs dominate: } \frac{n_{\text{EW}}}{\eta_{\text{loos}}} \approx \frac{\eta_0}{1070} \frac{\eta_{\text{loos}}}{\eta_{\text{EW}} (1 \text{-loop})}
\]

Bosonic loops: \( \sim 1600 \) diagrams.
\[
\text{Similar effect in EDM} \quad \frac{\eta_v^{\mu}}{\alpha} \approx 1000 \times \text{Higgs (1-loop)}
\]

\[
(3) \sim \left[ \left( \frac{3}{\mu} \right)^\frac{3}{2} - 1 \right] \frac{\eta_v^{\mu}}{\alpha} \approx \]

\[
\begin{align*}
\ldots + \frac{\alpha}{\eta_v^{\mu}} & \approx \frac{16\pi^2}{3} \end{align*}
\]

Big enhancement

Anomaly cancellation (XFT: Pietr: Fettlibert)

\[
\frac{15}{8} \frac{5}{18} \frac{5}{18} = \]

Permionic Loops
Their recent reappearance... (Knecht, Peris, Remolte, de Ronge)

(C', Krouse, Maricano '93)

(Kukhto et al.)

1992

Large logs from triangle diagrams

Electroweak: Hadronic effects

...and (final?) disappearance (C', Maricano, Vinh-Thein)

hep-ph/0212229

hep-ph/0205102

Their recent cancellation with quarks

P^2 

M^2 / a^2 ~ C / a^2
Because

\[ \sum N_f \sum Z_f Q_f^2 = 0 \]

If massless & free:

\[ \Delta A_f(e) + \Delta A_f(\nu) + \Delta A_f(\bar{\nu}) = 0 \]

If: u, d quarks

\[ \frac{m^2}{M_Z^2} \sum e \text{Q}_f \Delta A_f(e) \sim \frac{m^2}{M_Z^2} \sum \Delta A_f(\bar{\nu}) \]

f: electron

Anomalous Triangles
(Kn echt, Perrot, de Rafael)

no cancellation → low-energy hadronic dynamics changes that coefficient

(A, Marcano, Vainshtein)
valid

Coefficient of \( R_M \) not affected → cancellation remains

(massless interacting quarks)

\( Q_a(n,d) \) in QCD
\[ 0 = \begin{array}{c}
\end{array} \]
\[ 0 \neq 0 \quad \sim \quad \begin{array}{c}
\end{array} \]
Anomaly: \[ g \bar{q} W^\ell \bar{q} \]

Perturbative Result:

\[ \frac{\theta}{2} \sim WM = 2W^T \quad \sim \quad \begin{array}{c}
\end{array} \]

\[ + \frac{W^T (q^2) g \bar{q} \omega F_{\ell \bar{q}}}{\theta^2} \]

\[ + \frac{W^T (q^2) (q^2 F_{\ell \bar{q}} - q \bar{q} \omega F_{\ell \bar{q}})}{\theta^2} \]

\[ \sim \]

Structure of the Triangle
\[
\ln M \sim t + \int \frac{zW}{z} d\rho \int_0^\infty \frac{z}{z} d\rho
\]

unless anomaly cancellation

\[\int_0^\infty d\rho = \text{diverges; theory inconsistent}\]

\[\frac{z}{z} \rightarrow \text{finite} \]

\[(\ln^2 + \ln W + \ln M) \int \frac{z}{z} d\rho \int_0^\infty \frac{z}{z} d\rho \sim \text{finite} \]

\text{CONTRIBUTION TO } g-2\]
Non-perturbative: \[ W_L = 2 w_T \]

Large \( Q^2 \):

\[
\frac{(0.7 \text{ GeV})^4}{Q^2} + O(1) 
\]

Small \( Q^2 \) (pion pole):

\[
\frac{1}{m_T^2 - m_{\pi}^2} \frac{m_T^2 - m_{\pi}^2}{Q^2 + m_{\pi}^2} 
\]

(missing in Knecht et al.)

Perturbative:

\[ W_L (u,d) \text{ in QCD (chiral limit)} \]

\[ \frac{2}{Q^2} \]

1997 A.C. & B. Krause, Full Three-Loop Calculation: \( \frac{\bar{p}}{p} \approx 0.7 \times 10^{-3} \) cm

1996 I. B. Khriplovich, Leading Log Analyses: \( \frac{\bar{p}}{p} \approx 0.5 \times 10^{-3} \) cm

What is the Standard Model quark EDM?

Sensitive probe of CP violation in the Higgs sector, SUSY, etc.

Future plans: Improvements by 10^{-5} (II, LANL, PSI)

Present Experimental Bound: \(|d_{ns}| > (6 - 9) \times 10^{-3} \) cm

Neutron ELECTRIC Dipole Moment