9. Schwache Wechselwirkung

9.1 Geladene schwache Wechselwirkung, (V-A)-Theorie

9.2 (V-A)- Theorie im Grenzfall niedriger Energie

9.3 Vorhersagen und Tests der (V-A)-Theorie

- Myon-Zerfall
- Pion-Zerfall
- Neutrino-Elektron Streuung
- Zerfälle von Mesonen mit b-Quarks

9.4 Neutrale schwache Ströme, Z^0-Austausch

9.3.1 Muon decay

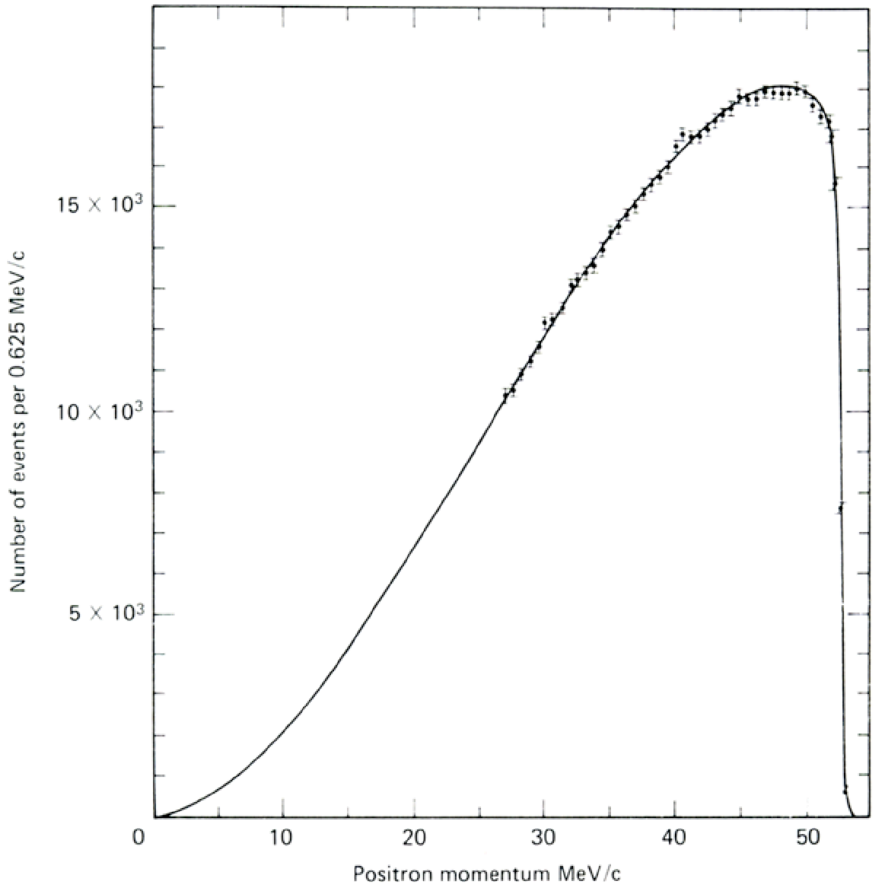
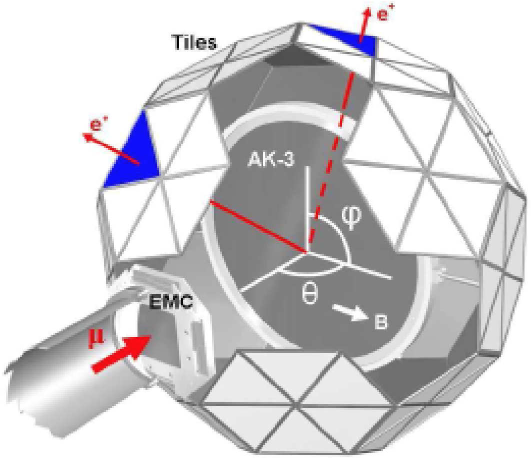


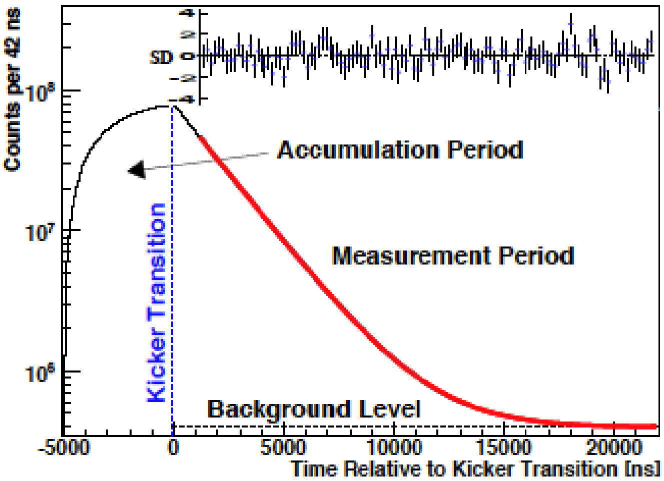
Figure 10.1 Experimental spectrum of positrons in $\mu^+ \rightarrow e^+ + \nu_e + \nu_\mu$. The solid line is the theoretically predicted spectrum based on equation (10.35), corrected for electromagnetic effects. (*Source:* M. Bardon et al., *Phys. Rev. Lett.* **14,** 449 (1965).)

Good agreement between the calculated electron / positron momentum spectrum (including corrections for electromagnetic effects) with the measurements.

Recent measurement of the muon lifetime

MuLan Collaboration, PSI, Zurich, arXiv:0704.1981v2, 10.1103/PhysRevLett.99.032001





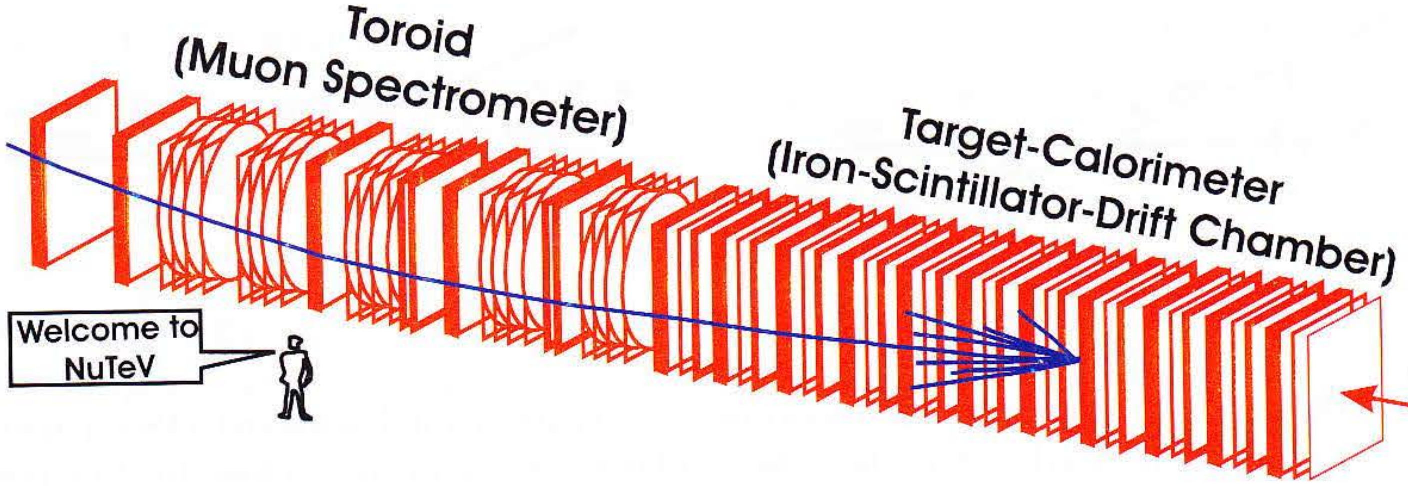
Polarized 28.8 MeV μ^+ are stopped in a target (AK-3). The decay positrons are detected in a "ball" of scintillators (1.8 x 10^{10} muon decays analyzed). The time between the muon beam (kicker transition) and the arrival time of the positrons is measured and used to determine the muon lifetime.

Result:

$$\tau_\mu(\text{MuLan}) = 2.197\,013(21)(11)\ \mu\text{s} \quad (11.0\ \text{ppm})$$
$$G_F = 1.166\,371(6) \times 10^{-5}\ \text{GeV}^{-2} \quad (5\ \text{ppm}).$$

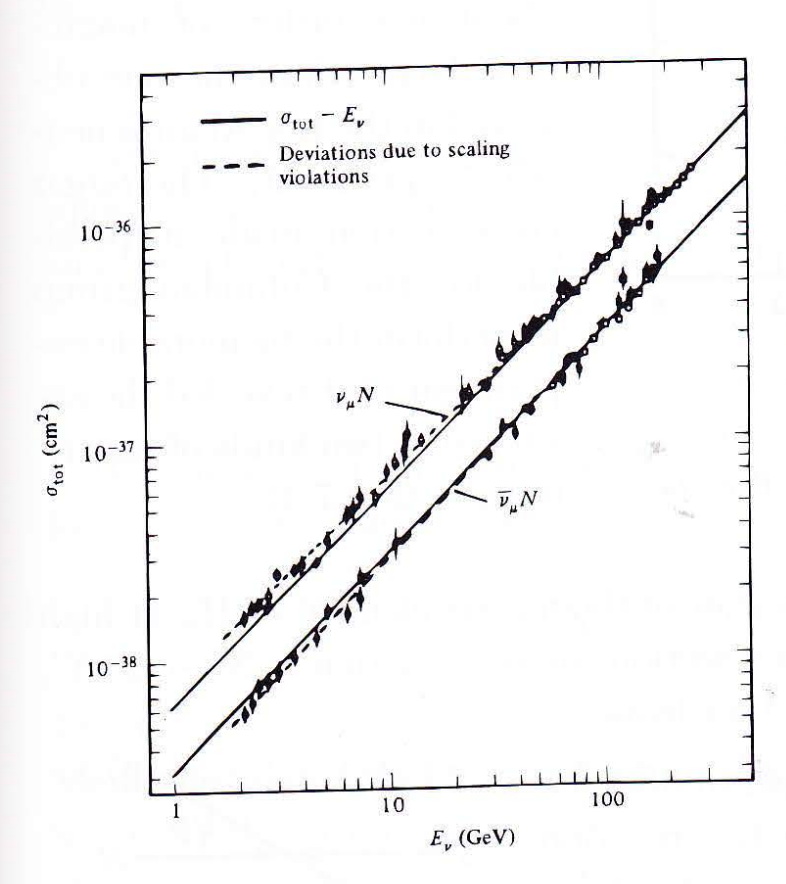
First error: stat.
second: syst.

9.3.3 Neutrino scattering



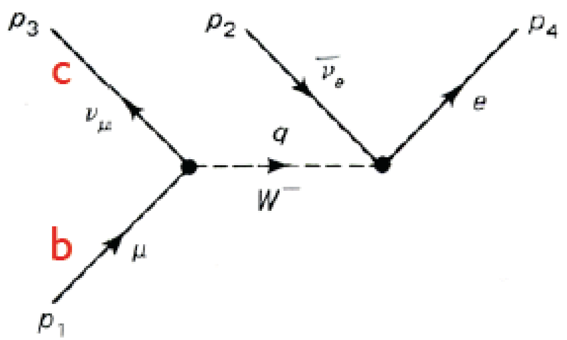
The neutrino detector at Fermilab (NuTev). The steel target region is instrumented with tracking detectors to detect the interaction point and to track the muons downstream. Toroid magnets permit the measurement of the muon momenta.

9.3.3 Neutrino scattering (cont.)



Total charged current neutrino and antineutrino cross sections plotted versus the neutrino energy (from E. Henley and A. Garcia, Subatomic Physics).

9.3.4 Decays of hadrons with b-Quarks



We consider the semi-leptonic decay of a $B^-(b\bar{u})$ hadron in a charmed hadron.

$$B^- \rightarrow D^0 + e^- + \bar{\nu}_e$$

The Feynman diagram is the same as in the muon decay.

Since $m_b \gg m_u$, the spectator diagram (i.e. assuming that the $\bar{u}$ quark does not influence the decay much) is a good approximation. Compared to the muon decay we have to add the $U_{cb} \approx \lambda^2 \approx 0.04$ CKM matrix element at the b-c-W vertex. Thus we use the result from the muon decay and find:

$$\tau_B = \frac{192\pi^3}{G_F^2 |U_{cb}^2| m_B^5}$$

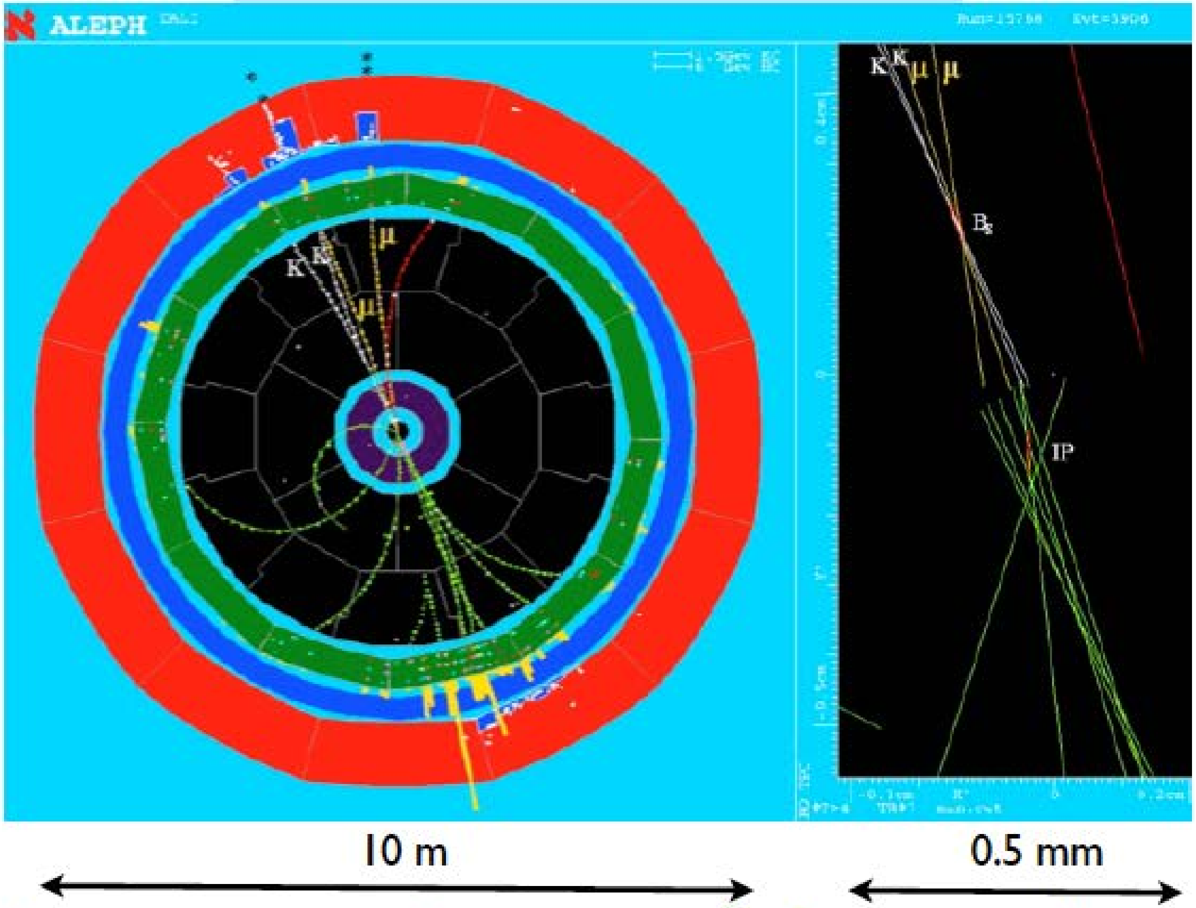
Comparing the result with a heavy lepton with $m_\ell = m_B$:

$$\frac{\tau_B}{\tau_\ell} = \frac{1}{|U_{cb}^2|} \approx 5 \cdot 10^3$$

Indeed experimentally one finds a quite long lifetime of B-hadrons of the order of $\tau_B \approx 1\,\mathrm{ps}$. At typical collider energies at LEP or LHC B-hadrons will fly a few mm before decaying.

Thus the flight length until the decay (decay length) can me measured with vertex detectors and used to measure the lifetime and to select events with B-hadrons.

$$B_s^0 \to \psi'(\to \mu^+\mu^-)\phi(\to KK)$$

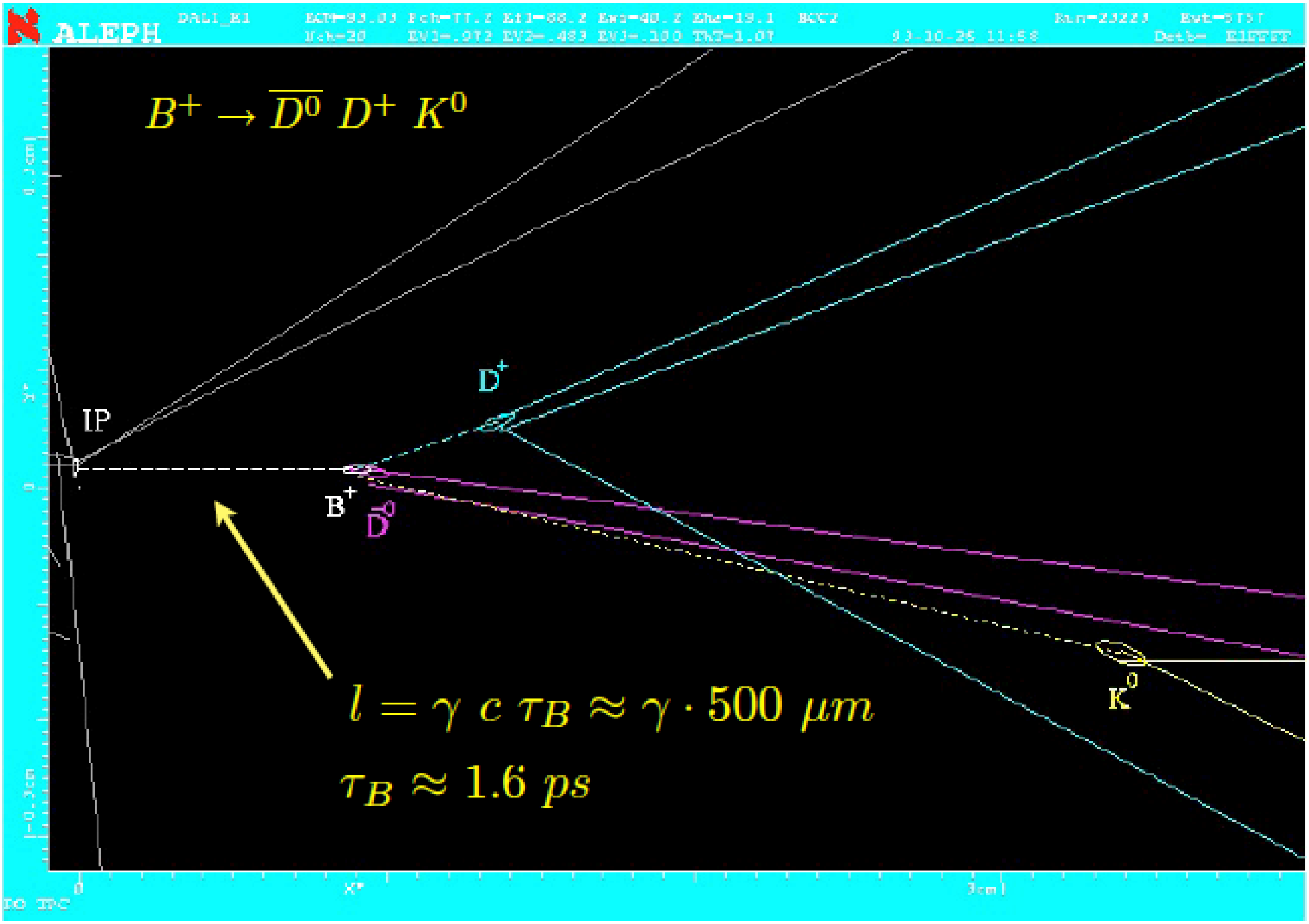


Aleph event:

Fully reconstructed B_s decay.

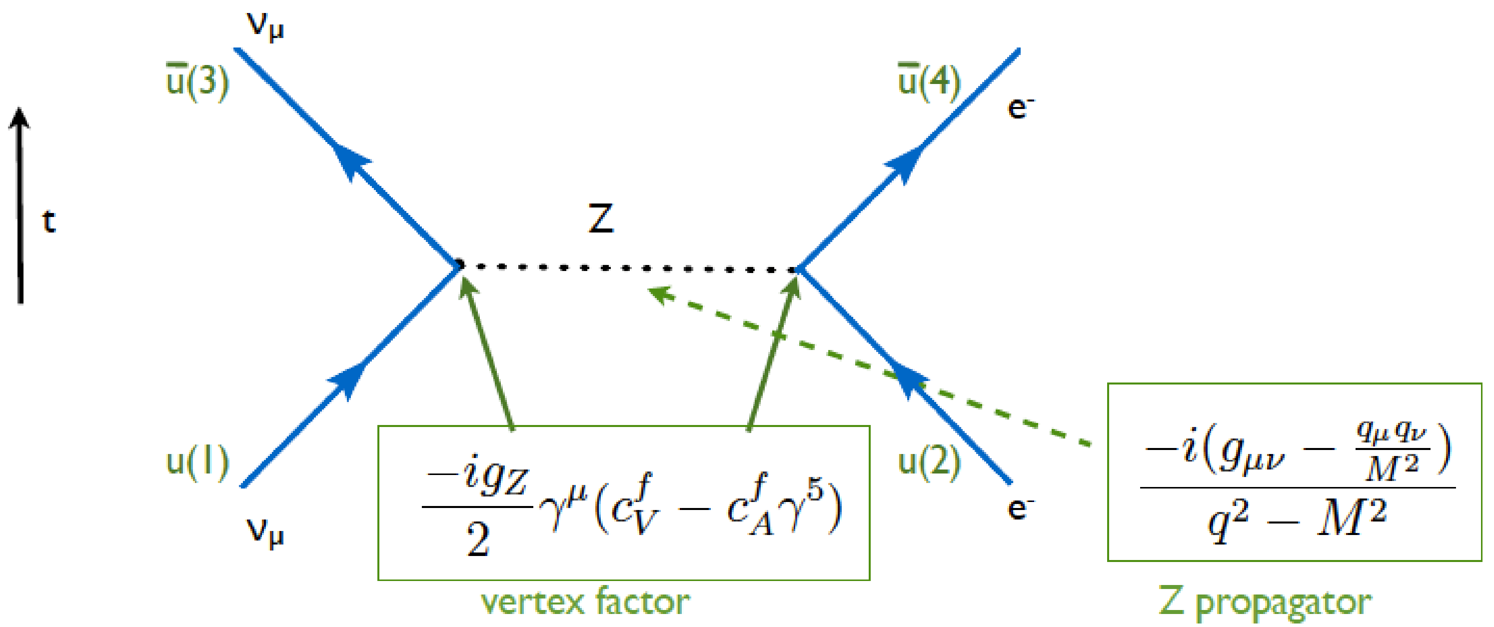
Track measurements with a precision of a few μm near the interaction point improve the momentum measurement and allow to determine the decay vertex, especially important for bottom hadrons.

Vertex reconstruction using silicon strip and pixel detectors



The life time of B-mesons can be measured from the decay length l, if the momentum of the B-meson (γ-factor) is measured as well.

9.4 Structure of weak neutral currents

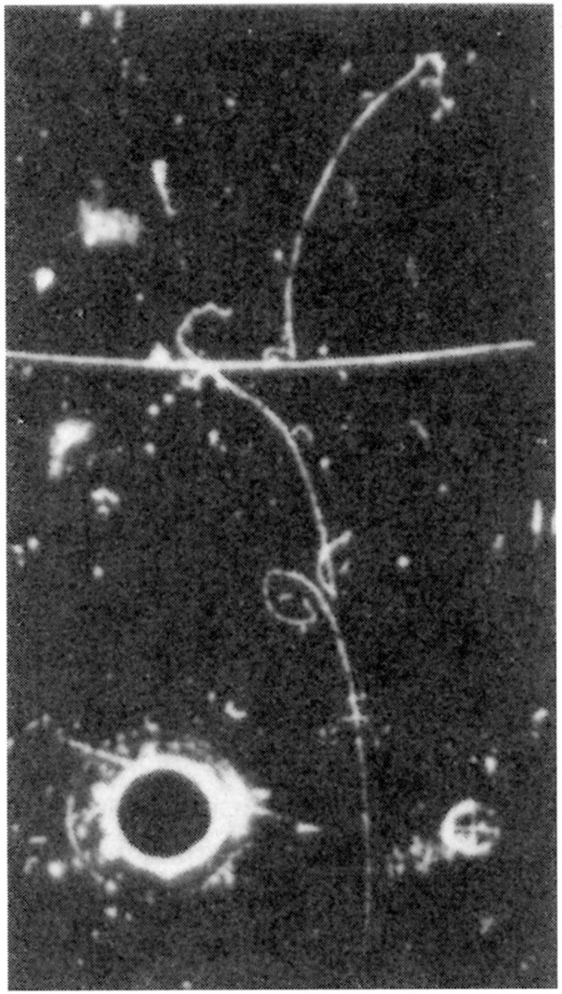


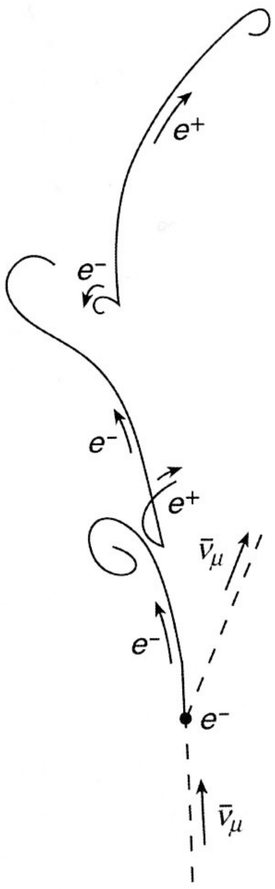
$$-i\mathcal{M} = \bar{u}(3)\left[\frac{-ig_Z}{2}\gamma^\mu(\frac{1}{2} - \frac{1}{2}\gamma^5)u(1)\right]\frac{-ig_{\mu\nu}}{M_Z^2}\bar{u}(4)\left[\frac{-ig_Z}{2}\gamma^\mu(c_V - c_A\gamma^5)u(2)\right]$$

$$\mathcal{M} = \frac{g_Z^2}{8M_Z^2}\left[\bar{u}(3)\gamma^\mu(1-\gamma^5)u(1)\right]\left[\bar{u}(4)\gamma_\mu(c_V - c_A\gamma^5)u(2)\right]$$

, using $q^2 \ll M_Z$

9.4 Discovery of a Neutral Current reaction in the Gargamelle bubble chamber





The first picture of a neutral weak process

$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$.

The neutrino enters from below (leaving no track), and strikes an electron. which moves upwards, emitting two photons (visible via the e+e- pairs from subsequent conversions)