8.701

Introduction to Nuclear and Particle Physics

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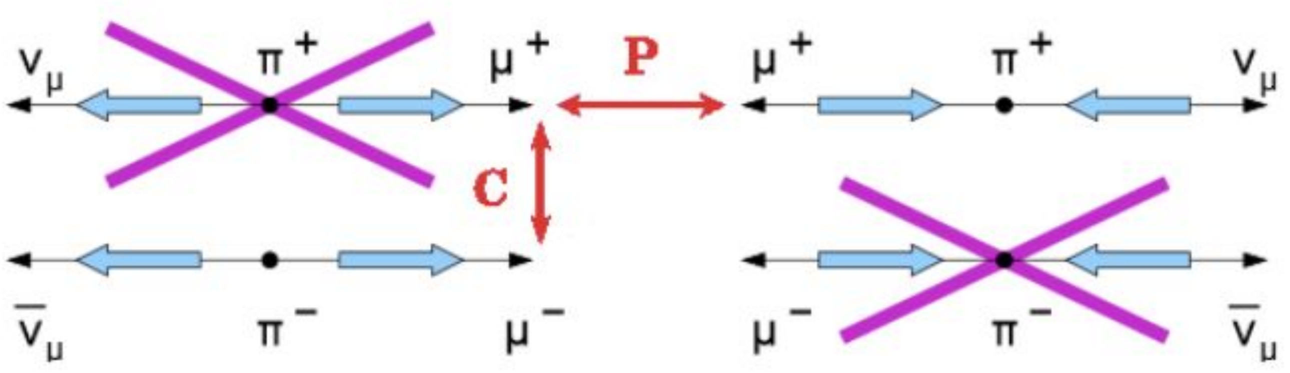
2. Symmetries

2.5 CP (violation)

Charge Conjugation and Parity (CP)

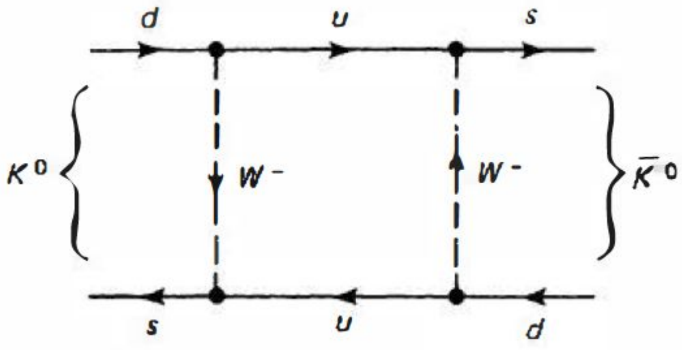
We have seen that the weak interaction is not invariant under P and C transformation, but how about CP?

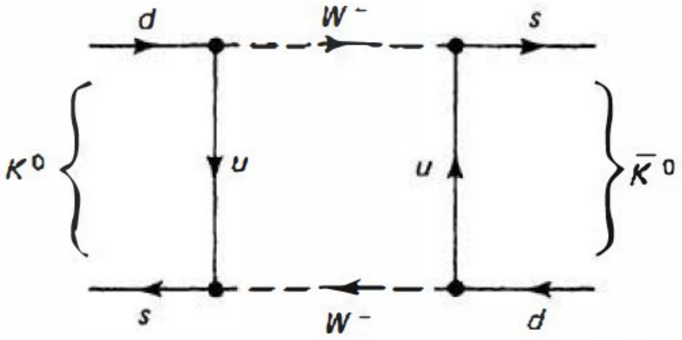
Example:



The Kaon System

Gell-Mann and Pais noted:





$$CP|K^0\rangle = -|\overline{K}^0\rangle, \quad CP|\overline{K}^0\rangle = -|K^0\rangle$$

$$|K_1\rangle = \left(\frac{1}{\sqrt{2}}\right)(|K^0\rangle - |\overline{K}^0\rangle) \text{ and } |K_2\rangle = \left(\frac{1}{\sqrt{2}}\right)(|K^0\rangle + |\overline{K}^0\rangle)$$

$$CP|K_1\rangle = |K_1\rangle \quad \text{and} \quad CP|K_2\rangle = -|K_2\rangle$$

The Kaon System

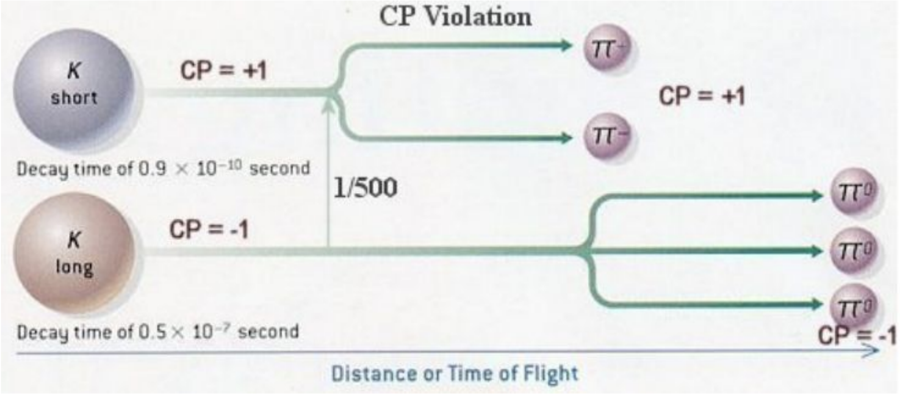
Assuming CP is conserved one concludes for K_1 and K_2 decays

$$K_1 \to 2\pi, \quad K_2 \to 3\pi$$

$$\tau_1 = 0.895 \times 10^{-10} \text{ sec}$$

$$\tau_2 = 5.11 \times 10^{-8} \text{ sec}$$

$$m_2 - m_1 = 3.48 \times 10^{-6} \text{ eV}/c^2$$



Perfect test of CP invariance!

Testing CP invariance

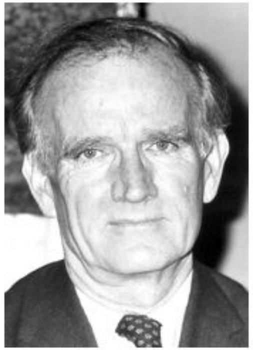
As K_1 decay much faster than K_2, a pure beam of K_2 can be produced from K_0 by letting all K_1 decay.

Finding 2π decays in the beam of K_2 is a clear indication of CP violation.

Croning and Fitch conducted this experiment in 1964. They counted 45 2pi events in 22700 decays.

$$|K_L\rangle = \frac{1}{\sqrt{1+|\epsilon|^2}}(|K_2\rangle + \epsilon|K_1\rangle)$$

Cronin and Fitch Experiment

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EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON*†

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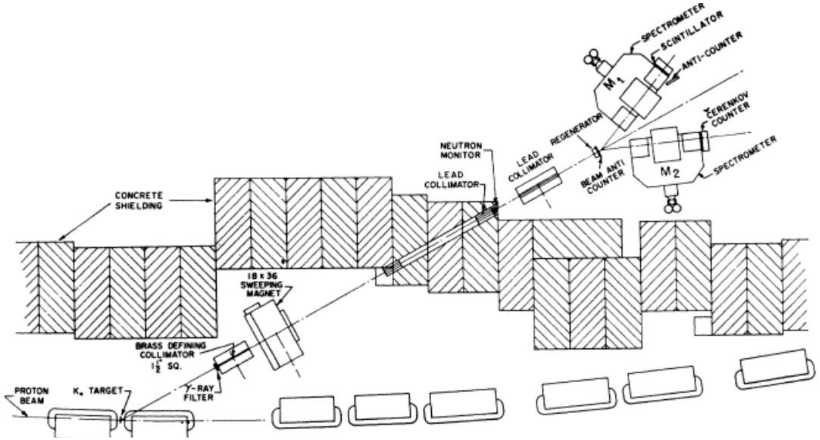
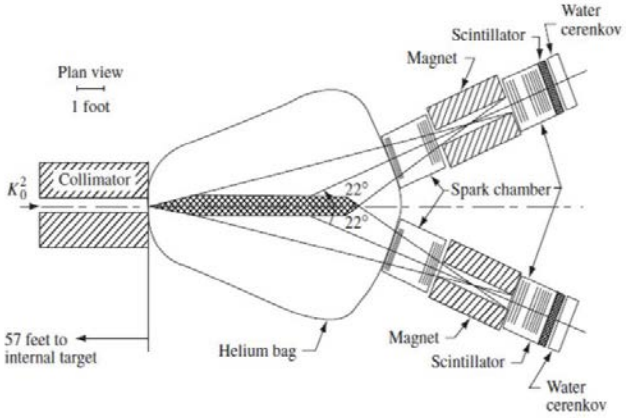
(Received 10 July 1964)





Testing CP invariance

Semileptonic K_L decays also show evidence for CP violation in

$$(a)\ \pi^+ + e^- + \bar{\nu}_e \quad \text{or} \quad (b)\ \pi^- + e^+ + \nu_e$$

More K_L decay to positrons than into an electron by a fractional amount of 3.3×10^{-3}

CP violation has also been shown in B meson systems and tests in the neutrino sector are under way.

Matter - Antimatter Asymmetry

One of the biggest mysteries in physics!

1967, Sakharov proposed three necessary conditions that baryon generating interactions must satisfy to produce matter and antimatter at different rates

1) Baryon number violation
2) C and CP violation
3) Interaction out of equilibrium

Preview

	Bilinear	P	C	T	CP	CPT
scalar	$\overline{\psi}_1\psi_2$	$\overline{\psi}_1\psi_2$	$\overline{\psi}_2\psi_1$	$\overline{\psi}_1\psi_2$	$\overline{\psi}_2\psi_1$	$\overline{\psi}_2\psi_1$
pseudo scalar	$\overline{\psi}_1\gamma_5\psi_2$	$-\overline{\psi}_1\gamma_5\psi_2$	$\overline{\psi}_2\gamma_5\psi_1$	$-\overline{\psi}_1\gamma_5\psi_2$	$-\overline{\psi}_2\gamma_5\psi_1$	$\overline{\psi}_2\gamma_5\psi_1$
vector	$\overline{\psi}_1\gamma_\mu\psi_2$	$\overline{\psi}_1\gamma^\mu\psi_2$	$-\overline{\psi}_2\gamma_\mu\psi_1$	$\overline{\psi}_1\gamma^\mu\psi_2$	$-\overline{\psi}_2\gamma^\mu\psi_1$	$-\overline{\psi}_2\gamma_\mu\psi_1$
axial vector	$\overline{\psi}_1\gamma_\mu\gamma_5\psi_2$	$-\overline{\psi}_1\gamma^\mu\gamma_5\psi_2$	$\overline{\psi}_2\gamma_\mu\gamma_5\psi_1$	$\overline{\psi}_1\gamma^\mu\gamma_5\psi_2$	$-\overline{\psi}_2\gamma^\mu\gamma_5\psi_1$	$-\overline{\psi}_2\gamma_\mu\gamma_5\psi_1$
tensor	$\overline{\psi}_1\sigma_{\mu\nu}\psi_2$	$\overline{\psi}_1\sigma^{\mu\nu}\psi_2$	$-\overline{\psi}_2\sigma_{\mu\nu}\psi_1$	$-\overline{\psi}_1\sigma^{\mu\nu}\psi_2$	$-\overline{\psi}_2\sigma^{\mu\nu}\psi_1$	$\overline{\psi}_2\sigma_{\mu\nu}\psi_1$