

Does Charged-Pion Decay Violate Conservation of Angular Momentum?

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1 Problem

Charged-pion decay, such as $\pi^+ \rightarrow \mu^+ \nu_\mu$, is considered in the Standard Model to involve the annihilation of the constituent quarks, $u\bar{d}$, of the π^+ into a virtual W^+ gauge boson, which materializes as the final state $\mu^+ \nu_\mu$. While the pion is spinless, the W -boson is considered to have spin 1, which appears to violate conservation of angular momentum.

What's going on here?¹

2 Solution

As remarked by Higgs in his Nobel Lecture [3], "... in this model the Goldstone massless (spin-0) mode became the longitudinal polarization of a massive spin-1 photon, just as Anderson had suggested." That is, in the Higgs' mechanism, the $S_z = 0$ state of a W boson is more or less still a spin-0 "particle."

Likewise, Weinberg in his Nobel Lecture [4] stated that: "The missing Goldstone bosons appear instead as helicity zero states of the vector particles, which thereby acquire a mass."

A similar view was given in [5].

References

- [1] S. Ogawa, *On the Universality of the Weak Interaction*, Prog. Theor. Phys. **15**, 487 (1956), http://physics.princeton.edu/~mcdonald/examples/EP/ogawa_ptp_15_487_56.pdf
- [2] Y. Tanikawa and S. Watanabe, *Fermi Interaction Caused by Intermediary Chiral Boson*, Phys. Rev. **113**, 1344 (1959), http://physics.princeton.edu/~mcdonald/examples/EP/tanikawa_pr_113_1344_59.pdf
- [3] P.W. Higgs, *Evading the Goldstone Boson*, Rev. Mod. Phys. **86**, 851 (2014), http://physics.princeton.edu/~mcdonald/examples/EP/higgs_rmp_86_851_14.pdf
- [4] S. Weinberg, *Conceptual Foundations of the Unified Theory of Weak and Electromagnetic Interactions*, Rev. Mod. Phys. **52**, 515 (1980), http://physics.princeton.edu/~mcdonald/examples/EP/weinberg_rmp_52_515_80.pdf

¹The possible need for an intermediate scalar boson was noted in [1], and pursued conceptually in, for example, [2].

- [5] N. Nakanishi, *T*-Product and False Nonconservation of Angular Momentum in the Pion Decay*, Mod. Phys. Lett. A **17**, 89 (2002),
http://physics.princeton.edu/~mcdonald/examples/EP/nakanishi_mpla_17_89_02.pdf