Does Charged-Pion Decay Violate Conservation of Angular Momentum?

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1 Problem

Charged-pion decay, such as $\pi^+ \to \mu^+\nu_\mu$, 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

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[3] P.W. Higgs, *Evading the Goldstone Boson*, Rev. Mod. Phys. **86**, 851 (2014), http://kirkmcd.princeton.edu/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://kirkmcd.princeton.edu/examples/EP/weinberg_rmp_52_515_80.pdf

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

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