Can pure states evolve into mixed states? — Constructing a Lorentz covariant Non-unitary QFT

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As we all know, QM is a unitary theory. It has been debated whether one can have a fundamentally non-unitary theory, especially since Hawking discovered his famous Blackhole radiation. In 1983 , Hawking proposed a theory in which pure states can evolve into mixed states, so as to to solve the Blackhole information paradox. This received several criticism, most famously the attack from Banks, Peskin and Susskind in 1984, based on Locality. Srednicki also pointed out the inconsistency with Lorentz covariance (with errors).

Here I present a Lorentz covariant Non-unitary QFT. In Heisenberg picture, the most general CPTP maps are

$$D_s[A(x,t)] = e^{s_\mu L^\mu} A(x,t)$$

where s is a (time-like) Lorentz four vector parametrizing evolution, and L^μ are the Lorentz covariant evolution generators

$$L^\mu A = -i[P^\mu, A] + \int \frac{d^3p}{(2\pi)^3 2\omega_p} \gamma_{ab} p^\mu \left((T^{\alpha\beta})^\dagger_a(\vec{p}) A (T_{\alpha\beta})_b(\vec{p}) + \frac{1}{2}\{(T^{\alpha\beta})^\dagger_a(\vec{p})(T_{\alpha\beta})_b(\vec{p}), A\} \right)$$

Here $T^{\alpha\beta}(\vec{p})$ are momentum dependent jump operators, and double index imply summation, with Greek letters dedicated for Lorentz index.

This theory has the following properties,

Lorentz covariance:

$$U(\Lambda) D_s[A(x)] U(\Lambda)^{-1} = D_{\Lambda s}[A(\Lambda x)]$$

semi-group structure:

$$D_{s_1}[D_{s_2}[A(x,t)]] = D_{s_1+s_2}[A(x,t)]$$

More specifically, we study the case where the only jump operators are annihilation operators $a(p)$. This can be thought of as system modes leak into large and refreshing vacuum bath, with the beam splitter interaction Hamiltonian

$$H_{int} = \int \frac{d^3p}{(2\pi)^3 2\omega_p} \omega_p [a^*(p) b(p) + b^*(p) a(p)]$$

This theory can be solved,

$$D_s[\psi(x)] = \int \frac{dp^3}{(2\pi)^3 2\omega_p} a(p) exp[-ipx] exp[-ip(1 - \frac{i\gamma}{2})] + h.c$$

and the two point functions are

$$< D_s[\psi(x)]\psi(x) >= \int \frac{d^3p}{(2\pi)^3 2\omega_p} Exp[-ips(1 - \frac{i\gamma}{2})]$$

Construction of the interacting theory is under process.