Scalar boson decay in presence of magnetic fields

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- through different channels:
  the decay products can be fermions or bosons (scalars or vectors)
- with different approaches:
  modifying the decay products mass (real part of the self-energy)
  studying the effect on the analytical properties of the decaying particle self-energy (imaginary part):
  - strong fields $\rightarrow$ dimensional reduction (LLL)
  - weak fields $\rightarrow$ resummation and some kind of expansion

  studying scattering processes (Bogoliubov transformation)

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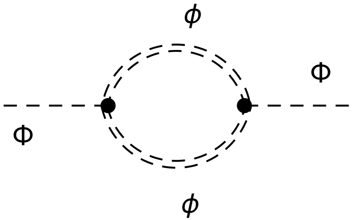
- and in some others it is mixed for different energies:
  M. Chistyakov, A. Kutznetzov and N. Mikheev [1998]
  S. Ghosh *et al.* [2017]

The model

$$\mathcal{L}_I = g\Phi\phi^*\phi$$



$$\Pi = (ig)^2 \int \frac{d^4k}{(2\pi)^4} D_B(p-k)D_B(k).$$

Magnetic field propagators

To include the effect of an external magnetic field, we use Schwinger's proper-time method[1]

$$D_B(k) = \int_0^\infty \frac{ds}{\cos eBs} \exp\left\{ is(k_{||}^2 - k_\perp^2 \frac{\tan eBs}{eBs} - m_\phi^2 + i\epsilon) \right\},$$

where we have adopted the notation $k_{||}^2 = k_0^2 - k_3^2$, $k_\perp^2 = k_1^2 + k_2^2$.

[1] J. Schwinger, Phys. Rev. **82**, 664-679 (1951).

Scalar self-energy in presence of magnetic field

$$\Pi = \frac{g^2}{2(4\pi)^2}\int_0^\infty \frac{ds}{s}\int_{-1}^1 dv \frac{eBs}{\sin(eBs)} e^{-is(m^2-i\epsilon)} e^{is\left[\frac{1}{4}(1-v^2)p_{||}^2 - \frac{\cos(eBsv)-\cos(eBs)}{2eBs\sin(eBs)}p_\perp^2\right]}$$

where we have integrated over the internal momentum and made the change of variables $s_1 = s\frac{1-v}{2}$ and $s_2 = s\frac{1+v}{2}$

Decay rate

The decay rate is directly proportional to the imaginary part of the self-energy[2]

$$\Gamma = \frac{\Im(\Pi(p))}{2\omega(p)}$$

with $\Pi(p)$ the self-energy and $\omega(p)$ the dispersion relation of the decaying particle and

$$\Im(\Pi(p)) \equiv \frac{\Pi - \Pi^*}{2i}$$

[2] R. E. Cutkosky J. of Math. Phys. 1, 429 (1960)

Decay rate

In the weak field limit, the imaginary part has the form[3]

$$\Im(\Pi(p)) = \frac{g^2 p^2}{2(4\pi)^2} \int_0^1 dv \frac{4v^2\sqrt{m^2 - \frac{1}{4}(1-v^2)p^2}}{\sqrt{3}|p_\perp|(1-v^2)eB} K_{1/3}(\rho)$$

which is obtained by expanding up to quadratic terms in the argument of the exponential and keeping up to linear term in the coefficient. Here $K_{1/3}(\rho)$ represents the Modified Bessel Function of the Second Kind and

$$\rho \equiv \frac{4}{\lambda} \frac{\left[1 - \frac{1}{4}(1-v^2)\frac{p^2}{m^2}\right]^{3/2}}{(1-v^2)} \qquad \text{with} \quad \lambda \equiv \frac{3}{2}\frac{p_\perp}{m}\frac{eB}{m^2}.$$

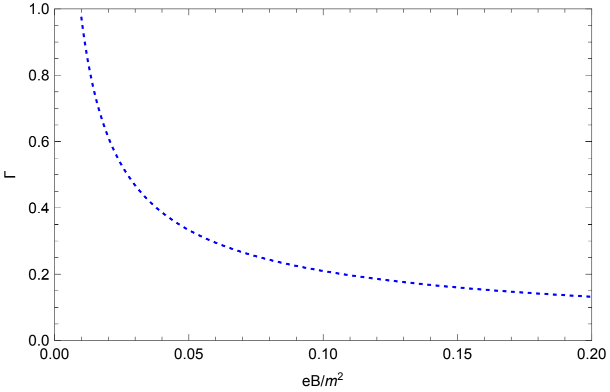
In the case of Tsai and Erber $p^2 = 0$ (photons) and in our case $p^2 = M^2$ (massive scalar)

[3] W. Tsai & T. Erber, PRD 10, 472 (1974)

Results

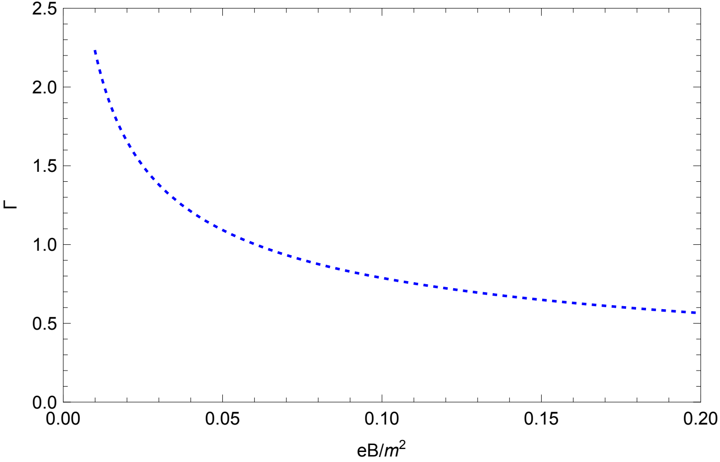
In this form, we can explore two different kinematical regimes by taking the asymptotical behavior of the Bessel function.

In the region $\lambda \gg 1$ ($p_\perp \gg 1$), $K_{1/3}(\rho) \sim \rho^{-1/3}$, the analytical result is



Results

In the region $\lambda \ll 1$ ($p_\perp \ll 1$), $K_{1/3}(\rho) \sim \rho^{-1/2} e^{-\rho}$, the numerical result gives



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- A similar conclusion was reached by Kawaguchi and Matsuzaki (EJPA 2017). The effect of a magnetic field on the decay rate of a neutral rho meson depends on the polarization modes: The decay of $S_z = 0$ component is suppressed while the decay of $S_z = \pm 1$ is enhanced.

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- We have obtained a similar behavior by taking a weak field expansion for each propagator in the self-energy, so, the point at which the expansion is carried out does not seem to change the behavior.

Thanks