Magnetic field effect on the decay process of a neutral scalar boson to charged fermions

Gabriella Piccinelli Bocchi, A. Sánchez and J. Jaber

Centro Tecnológico, FES-Aragón, UNAM

IWARA
2018

Effect of the magnetic field on the decay process

It has been extensively studied.

Effect of the magnetic field on the decay process

It has been extensively studied.

- In many contexts: lasers, relativistic heavy ion collisions (QCD), compact objects, early universe events (warm inflation)

Effect of the magnetic field on the decay process

It has been extensively studied.

- In many contexts: lasers, relativistic heavy ion collisions (QCD), compact objects, early universe events (warm inflation)
- in presence of different ingredients: in vacuum and at finite temperature and/or density, weak or strong magnetic field strengths

Effect of the magnetic field on the decay process

It has been extensively studied.

- In many contexts: lasers, relativistic heavy ion collisions (QCD), compact objects, early universe events (warm inflation)
- in presence of different ingredients: in vacuum and at finite temperature and/or density, weak or strong magnetic field strengths
- Through different channels: decay products can be fermions or bosons (scalars or vectors)

Effect of the magnetic field on the decay process

It has been extensively studied.

- In many contexts: lasers, relativistic heavy ion collisions (QCD), compact objects, early universe events (warm inflation)
- in presence of different ingredients: in vacuum and at finite temperature and/or density, weak or strong magnetic field strengths
- Through different channels: 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)

Effect of the magnetic field on the decay process

Results in the literature are not always coincident.

Effect of the magnetic field on the decay process

Results in the literature are not always coincident.

- This process is enhanced in some cases:

  W. Tsai and T. Erber [1974]

  L. Urrutia [1978]

  A. Kutznetzov, N. Mikheev and L Vassilevskaya [1998]; N. Mikheev and M. Chistyakov [2001]

  A. Erdas and M. Lissia [2003]

  K. Bhattacharya and S. Sahu [2009]

  P. Satunin [2015]

  A. Bandyopadhyay and S. Mallik [2016]

  G.S. Bali *et al.* [2018]

Effect of the magnetic field on the decay process

Results in the literature are not always coincident.

- This process is enhanced in some cases:

  W. Tsai and T. Erber [1974]

  L. Urrutia [1978]

  A. Kutznetzov, N. Mikheev and L Vassilevskaya [1998]; N. Mikheev and M. Chistyakov [2001]

  A. Erdas and M. Lissia [2003]

  K. Bhattacharya and S. Sahu [2009]

  P. Satunin [2015]

  A. Bandyopadhyay and S. Mallik [2016]

  G.S. Bali *et al.* [2018]

- Sometimes it is inhibited:

  K. Sogut, H. Yanar and A. Havare [2017]

  M. Kawaguchi and S. Matsuzaki [2017]

  A. Bandyopadhyay, R.L.S. Farias and R.O. Ramos [2018]

Effect of the magnetic field on the decay process

Results in the literature are not always coincident.

- This process is enhanced in some cases:

  W. Tsai and T. Erber [1974]

  L. Urrutia [1978]

  A. Kutznetzov, N. Mikheev and L Vassilevskaya [1998]; N. Mikheev and M. Chistyakov [2001]

  A. Erdas and M. Lissia [2003]

  K. Bhattacharya and S. Sahu [2009]

  P. Satunin [2015]

  A. Bandyopadhyay and S. Mallik [2016]

  G.S. Bali *et al.* [2018]

- Sometimes it is inhibited:

  K. Sogut, H. Yanar and A. Havare [2017]

  M. Kawaguchi and S. Matsuzaki [2017]

  A. Bandyopadhyay, R.L.S. Farias and R.O. Ramos [2018]

- Or it can depend on the kinematical regime:

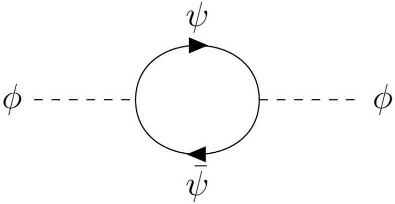
  M. Chistyakov, A. Kutznetzov and N. Mikheev [1998]

  S. Ghosh et al. [2017]

  G. P. and A. S. [2017] (Phys. Rev. D 96)

The model

$$\mathcal{L}_I = g\phi\bar{\psi}\psi$$



$$-i\Pi(p) = g^2 \int \frac{d^4w}{(2\pi)^4} tr\left[S(w)S(w-p)\right] \qquad (1)$$

Magnetic field propagators

$$S^B(x,y) = \Omega(x,y)\int \frac{d^4k}{(2\pi)^4} S^B(k) e^{-ik(x-y)}$$

$$\Omega(x,y) = \exp\left(-i\frac{e}{2}x_\mu F^{\mu\nu} y_\nu\right)$$

where $\Omega(x, y)$ is the Schwinger phase that encodes all gauge dependence and vanishes in this fermion charged loop.

In the particular case where the magnetic field defines the $\hat{z}$ direction[1]:

$$S^B(w) = \int_0^\infty \frac{ds}{\cos(eBs)} \exp\left[-is\left(m^2 - w_\parallel^2 - w_\perp^2 \frac{\tan(eBs)}{eBs}\right)\right]$$
$$\times \left[\left(m + \not{w}_\parallel\right) e^{-ieBs\Sigma_3} + \frac{\not{w}_\perp}{\cos(eBs)}\right]$$

where $w_\parallel^\mu = (w^0, 0, 0, w^3)$, $w_\perp^\mu = (0, w^1, w^2, 0)$ and Σ_3 accounts for the fermions spin.

[1] A. Erdas, Phys. Rev. D **80**, 113004 (2009).

Scalar self-energy in presence of magnetic field

$$\Pi^{B}(p) = \frac{g^2 eB}{8\pi^2}\int_0^\infty ds \int_{-1}^{1} dv \;\; e^{-ism^2} e^{i\frac{s(1-v^2)}{4}{p_\parallel}^2} e^{\frac{i}{eB}\frac{\cos(eBsv)-\cos(eBs)}{2\sin(eBs)}{p_\perp}^2}$$
$$\times \left\{ \frac{1}{\tan(eBs)}\left(m^2 + \frac{i}{s} - \frac{1-v^2}{4}{p_\parallel}^2\right) + \frac{ieB}{\sin^2(eBs)} - \frac{\cos(eBsv)-\cos(eBs)}{2\sin^3(eBs)}{p_\perp}^2 \right\}$$

Weak field, different approximations

- I. For weak external magnetic field and $p_\perp \ll m$, we can expand all terms up to $(eB)^2$

  This allows us to evaluate the decay rate in the rest frame of the decaying particle.

- II. For $p_\perp \gg m$, the whole exponential cannot be expanded.

  The region near to $p_\perp = 0$ is not allowed.

- A numerical calculation is needed, but highly oscillating integrals, with plenty of apparent infinities[2], make it difficult. We are working on it.

[2] Chodos, Everding, Owen, Phys. Rev. D **42**, 2881-2892 (1990).

Weak field limit

Approximation II.

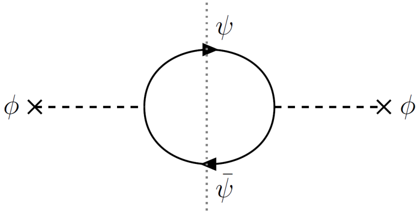
$$\Pi^{B}(p) = \frac{g^2}{8\pi^2}\int_0^\infty ds\int_{-1}^{1} dv \;\; e^{-ism^2} e^{i\frac{s(1-v^2)}{4}p^2} e^{is^3\frac{(eB)^2}{48}(1-v^2)^2 {p_\perp}^2}$$
$$\times\left\{\frac{m^2}{s}+\frac{2i}{s^2}-\frac{1-v^2}{4s}p^2-\frac{m^2(eB)^2 s}{3}\right.$$
$$\left.+\frac{(eB)^2 s}{12}(1-v^2){p_\perp}^2-\frac{(eB)^2 s}{48}(1-v^2)(5-v^2){p_\perp}^2\right\}$$

Decay rate

The decay rate is directly proportional to the imaginary part of the self-energy[3]

$$\Gamma = \frac{\Im(\Pi(p))}{2\omega(p)} \quad , \quad \Im(\Pi(p)) \equiv \frac{\Pi - \Pi^*}{2i}$$

with $\omega(p)$ the dispersion relation of the decaying particle.



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

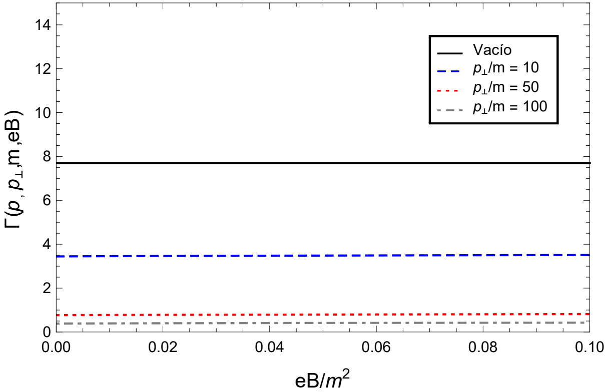
Decay rate

After some work, the decay rate is given by:

$$
\begin{aligned}
\Gamma^B = {} & \frac{g^2}{8\pi} \frac{4\sqrt[3]{2}}{(eB)^{2/3} {p_\perp}^{2/3}} \frac{\Theta(p^2 - 4m^2)}{\sqrt{\vec{p}^2 + M^2}} \\
& \times \Bigg(\frac{2\sqrt[3]{2}(eB)^{4/3}}{3{p_\perp}^{2/3}} \int_{\sqrt{1-\frac{4m^2}{p^2}}}^{1} dv (1-v^2)^{-4/3} Ai'(x) \\
& \qquad\qquad\qquad \times \left[\frac{1-v^2}{4} {p_\parallel}^2 - \frac{(1-v^2)(7v^2-5)}{16} {p_\perp}^2 - m^2 \right] \\
& \quad - \frac{p^2}{2} \int_{\sqrt{1-\frac{4m^2}{p^2}}}^{1} dv (1-v^2)^{-2/3} v^2 \left[\frac{1+v^2}{4} p^2 - m^2 \right] Ai(x) \\
& \quad + \frac{4}{3} \int_{\sqrt{1-\frac{4m^2}{p^2}}}^{1} dv (1-v^2)^{-5/3} v^2 \left[\frac{1+v^2}{4} p^2 - m^2 \right] \left[\frac{1-v^2}{4} p^2 - m^2 \right] Ai(x) \Bigg).
\end{aligned}
$$

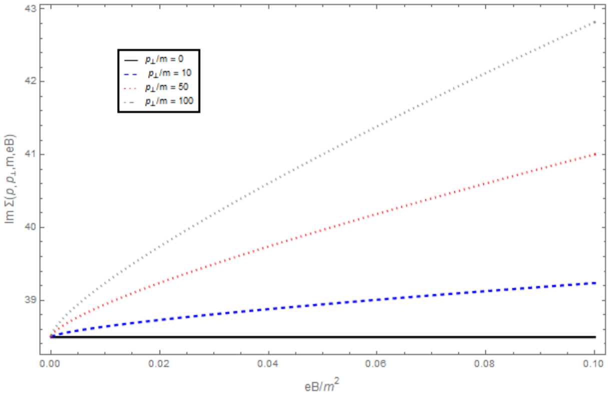
Results

Magnetic field effect on the decay width of a scalar to fermions (approximation II)



Results

Magnetic field effect on imaginary part of the self-energy of a scalar with a fermion loop (approximation II)



Discussion

We analyzed the effect of an homogeneous weak magnetic field on the decay process of a neutral scalar field to a pair of charged fermion fields.

The weak field approximation can be realized (at least) with two different approaches, depending on the kinematic of the progenitor particle. We presented here the results of the calculation realized with one of them, at high transverse momentum (a recurrent approach in literature)

We are working on the other approximation: weak magnetic field and low transverse momentum. We think that it is important, since, in a previous work, we found that the effects of the magnetic field depend on the kinematic of the progenitor particle.

Discussion

We analyzed the effect of an homogeneous weak magnetic field on the decay process of a neutral scalar field to a pair of charged fermion fields.
The weak field approximation can be realized (at least) with two different approaches, depending on the kinematic of the progenitor particle. We presented here the results of the calculation realized with one of them, at high transverse momentum (a recurrent approach in literature)

We are working on the other approximation: weak magnetic field and low transverse momentum. We think that it is important, since, in a previous work, we found that the effects of the magnetic field depend on the kinematic of the progenitor particle.

- Rôle of the spin of the decay products? (Access to the different Landau levels for bosons and fermions)

Discussion

We analyzed the effect of an homogeneous weak magnetic field on the decay process of a neutral scalar field to a pair of charged fermion fields.
The weak field approximation can be realized (at least) with two different approaches, depending on the kinematic of the progenitor particle. We presented here the results of the calculation realized with one of them, at high transverse momentum (a recurrent approach in literature)

We are working on the other approximation: weak magnetic field and low transverse momentum. We think that it is important, since, in a previous work, we found that the effects of the magnetic field depend on the kinematic of the progenitor particle.

- Rôle of the spin of the decay products? (Access to the different Landau levels for bosons and fermions)
- Why is there a cross-over in the behavior of the decaying process when the energy gets larger? (it can be understood considering the decaying field as composed by a pair of particles)

Thanks

Supported by UNAM-DGAPA-PAPIIT Grant No. IN117918