

Evaluation of the Antiproton Flux from the Antineutrino Electron Scattering

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Abstract. Recent experiments in high energy cosmic ray physics, PAMELA and AMS-02, excite a new interest to the mechanisms of generation of galactic antiparticles. In spite of the fact that global picture coincides with the predictions of the standard model, there are some black spots stimulating scientists to involve into research a particularly new physics like dark matter. In the present work, we make an attempt to estimate the impact of standard neutrino processes into the total flux of secondary antiprotons detected by contemporary experiments.

1. Introduction

From the time of the first detection of antiprotons in cosmic rays in 1979 [1, 2], the experiments were sufficiently enlarged and improved. Contemporary detectors based on the satellites could help to open the window to a new physics. Despite the fact that the entire data from modern accelerator experiments coincides with the predictions of the standard model, a lot of open questions exist on the border of cosmology and particle physics, mainly on a possible particle origin of dark matter.

Recently, there was a message from AMS 02 collaboration [3] where new results on the \bar{p}/p ratio at high rigidity was presented. The antiproton spectrum appeared to be surprisingly hard. It should be emphasized that the information was preliminary and the corresponding article is not yet proclaimed but nevertheless there appeared an avalanche of articles dedicated to probable explanations of the announced discrepancy. Most of them relate on the physics of dark matter and probable candidates of it (see, for example, [4] for the recent status on dark matter detection). There are also some articles [5, 6, 7] where authors claim the possibility of intra-galactic sources of antimatter like supernova explosions.

It is well known that neutrino physics plays the crucial role in the evolution of supernovae. The aim of this paper is to estimate a possible contribution of neutrino processes to the production rate of secondary antiprotons that could be detected by existing experiments. For

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the first step, we restrict ourselves with the neutrino-electron process $\bar{\nu}_e + e \rightarrow \bar{p} + n$. The reason of choosing such a process is an attractive opportunity to perform the analysis by making calculations which are almost completely analytical. Other possibilities for antiproton production via electroweak processes in the Galaxy are also discussed.

2. A general approach to the calculation of the secondary antiproton flux

Let us evaluate the contribution of the neutrino-electron process $\bar{\nu}_e + e \rightarrow \bar{p} + n$ to the total antiproton flux measured in an experiment. For simplicity, we neglect the effects of antiproton propagation through the Galaxy and assume that all antiprotons, produced in the selected volume, reach the detector. The total flux of any type of cosmic ray particles is defined by the formula

$$\Phi = \frac{dN}{dE dt dS d\Omega}, \quad (1)$$

where dN is the number of particles detected per the energy interval dE , per the time interval dt , per the detector area interval dS , and arrived from the solid angle interval $d\Omega$. On the other hand, a number of particles produced in the reaction $1 + 2 \rightarrow 3 + X$ in the volume dV , per the time interval dt , is expressed via the total cross-section σ of the reaction: $dN_3 = \sigma v n_1 n_2 dV dt$, where v is the so-called relative velocity, and $n_{1,2}$ are the particle densities. If one needs to have a distribution of the produced particles over the energies and the solid angles, the differential cross-section $d\sigma/(dE d\Omega)$ should be taken instead of the total cross-section. The particle densities $n_{1,2}$ should be expressed via the particle fluxes. Finally, the total antiproton flux caused by the reaction $\bar{\nu}_e + e^- \rightarrow \bar{p} + n$ takes the form:

$$\Phi_{\bar{p}} = \int dr dE_{\bar{\nu}} d\Omega_{\bar{\nu}} \frac{1}{v_{\bar{\nu}}} \Phi_{\bar{\nu}}(E_{\bar{\nu}}) dE_e d\Omega_e \frac{1}{v_e} \Phi_e(E_e) \frac{(P_{\bar{\nu}} P_e)}{E_{\bar{\nu}} E_e} \frac{d\sigma(\bar{\nu}_e + e^- \rightarrow \bar{p} + n)}{dE_{\bar{p}} d\Omega_{\bar{p}}} c, \quad (2)$$

where c is the speed of light and the integration over r involves the detectable part of the Galaxy. Note that the discussed approach can be used for other processes or astrophysical sources of elementary particles.

3. Antineutrino electron process

The antineutrino-electron process $\bar{\nu}_e + e^- \rightarrow \bar{p} + n$ resulting in antiproton and neutron, is a crossed process to the standard neutron beta-decay. To calculate the differential cross-section, we start with the matrix element in the following form:

$$\mathcal{M} = \frac{G_F V_{ud}}{\sqrt{2}} \left[\bar{u}_n \left(g_V \gamma_\mu + g_A \gamma_\mu \gamma_5 \right) u_{\bar{p}} \right] \times \left[\bar{v}_{\bar{\nu}} \gamma^\mu (1 - \gamma_5) v_e \right], \quad (3)$$

where g_V and g_A are the vector and axial-vector constants, $|V_{ud}| \simeq 0.974$ and G_F is the Fermi constant. After some standard evaluations we get an averaged squared amplitude in the form:

$$\overline{|\mathcal{M}|^2} = 32 G_F^2 |V_{ud}|^2 \left[(1 + \alpha)^2 (P_n P_\nu) (P_p P_e) + (1 - \alpha)^2 (P_p P_\nu) (P_e P_n) + (1 - \alpha^2) m_n m_p (P_\nu P_e) \right], \quad (4)$$

where $\alpha = |g_A/g_V| \simeq 1.27$.

The differential cross-section is expressed via the averaged squared amplitude as follows:

$$d\sigma(\bar{\nu}_e + e^- \rightarrow \bar{p} + n) = \frac{\overline{|\mathcal{M}|^2}}{32\pi^2 s} \delta(E_\nu + E_e - E_{\bar{p}} - E_n) \frac{d^3 P_{\bar{p}}}{E_n E_{\bar{p}}}. \quad (5)$$

For our present purposes, we do not integrate the obtained expression because it enters the equation (2).

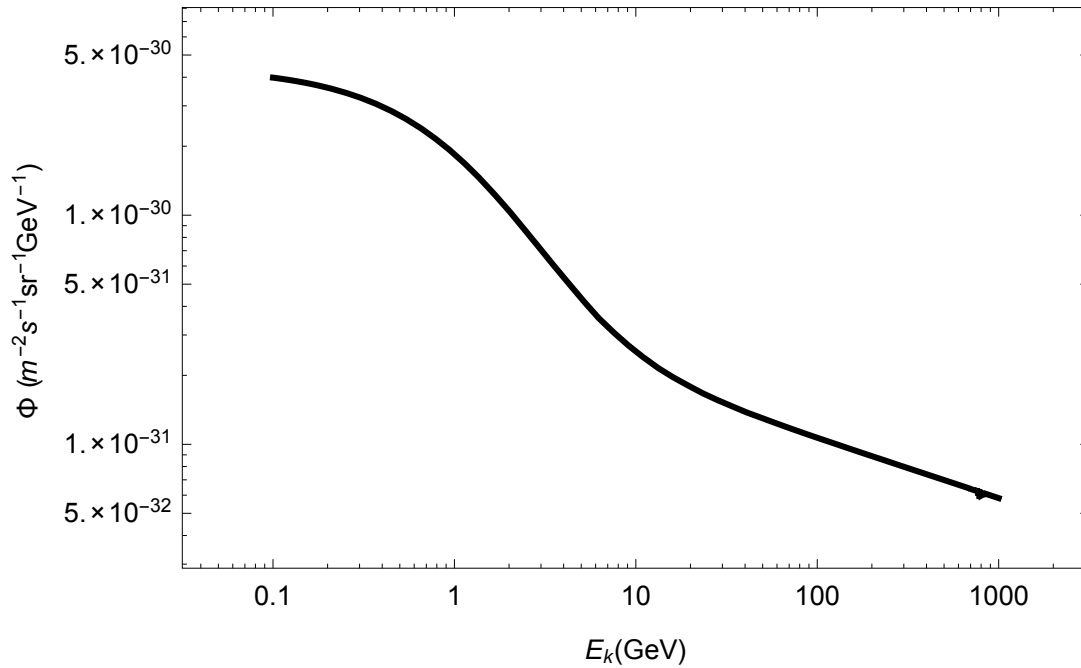


Figure 1. Antiproton flux from $\bar{\nu}_e + e \rightarrow \bar{p} + n$ as a function of antiproton kinetic energy.

4. Antiproton flux estimation

Estimation of the total antiproton flux from the neutrino process is based on the equation (2), where we use the cross-section of the process given in the previous section and the following values of the electron antineutrino flux:

$$\Phi_{\bar{\nu}} \simeq 6.85 \times 10^{-7} E_{\nu}^{-2.46} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV}^{-1}, \quad (6)$$

that is one sixth of the diffuse astrophysical neutrino spectrum derived in [8] (see also [9] for previous estimations). As for initial electrons, our analysis shows that a consideration of slow-moving or being at rest electrons is inappropriate in this case because of a large threshold energy for neutrinos which result in high antiproton energies much larger than the interval we are interested in. Thus, we use the electron flux $\Phi_e \simeq 3 \times 10^{-2} E_e^{-3.2} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV}^{-1}$ which is a rough approximation of the linear part of the cosmic electron flux presented in [10, 11, 12]. Despite the fact that accurate expressions for neutrino and electron fluxes depend on the actual range of measured energies, these values afford to perform a zero-order estimation and make a conclusion on the effect size.

In order to estimate the antiproton flux one has to insert Eq. (5) into Eq. (2). Further integration could be significantly simplified by introducing new variables: i) the vector of the initial momentum: $\mathbf{Q} = \mathbf{p}_{\bar{\nu}} + \mathbf{p}_e = \mathbf{p}_{\bar{p}} + \mathbf{p}_n$; ii) the polar angle θ_1 between the vectors $\mathbf{p}_{\bar{p}}$ and \mathbf{Q} ; iii) the polar angle θ_2 between the vectors \mathbf{Q} and \mathbf{p}_e ; iv) the azimuthal angle between the planes formed by the vectors $\mathbf{p}_{\bar{p}}$, \mathbf{Q} and \mathbf{Q} , \mathbf{p}_e . The integration over the azimuthal angle can be easily performed analytically.

The result of integration is presented in the figure as the dependence of the final antiproton flux on the antiproton kinetic energy $E_k = E_p - m_p$.

The numerical values of the obtained antiproton flux for all adequate range of antiproton energies are rather small if compared with the measured antiproton flux $\sim 10^{-5} \text{ m}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV}^{-1}$ at energies $\sim 10^2 \text{ GeV}$ [13]. We can conclude that the process in

question will not give any significant contribution to the total antiproton flux. Nevertheless the result is valuable as the first attempt of the calculation of this kind. One should pay attention on the approximate character of the total estimation, but more strictly recorded estimates including for example details of propagation should not drastically change the total conclusion of the paper.

There are several more common processes involving neutrino and antiproton, mainly inclusive processes $\bar{\nu}_e + p \rightarrow \bar{p} + X$. One can expect significantly greater flux of antiprotons from that processes because the flux of cosmic protons essentially exceeds the cosmic electron flux, but the small values of constants of interaction should nullify this benefit.

5. Conclusion

We have estimated the flux of antiprotons from the neutrino process that could in principle be detected by contemporary experiments.

One of the first attempts to connect the problem of antiprotons distribution through the Galaxy with neutrinos was made in Ref. [14]. The author roughly estimated the neutrino flux from antiprotons and concluded that the obtained value has been too small to be detected. It was written in Ref. [14] that the calculations would free others from the need to remake the calculations because the effect was negligible. We should clarify that the usefulness of this research is, in our opinion, first of all, that the analysis of the specific process of antiproton production was conducted almost entirely by analytical calculations, so one can use this technique for the analysis of other mechanisms of antiproton production with other fluxes of initial particles and with the other dynamics of the interaction, which is defined by the cross-section of a particular process, such as the annihilation of dark matter particles.

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