The Impact of Standard Neutrino Processes into Positron and Antiproton Fluxes

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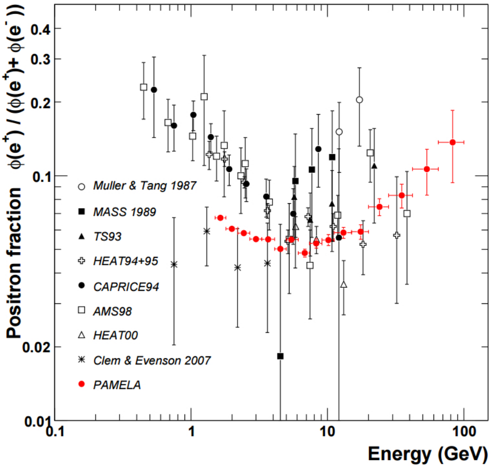
Introduction

THE BEGINNING...



PAMELA positron fraction with other experimental data, (Adriani O. et al., Nature 458:607-609,2009)

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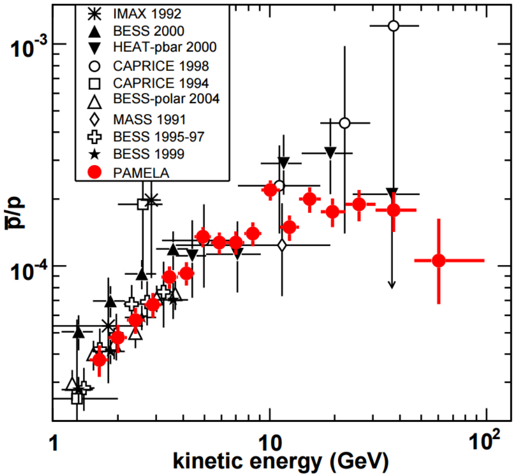


The antiproton-to-proton flux ratio, (Adriani O. et al., Phys.Rev.Lett.102:051101,2009)

NEUTRINO IMPACT

A general approach for calculation of the secondary positron/antiproton flux

TOTAL FLUXES

The total flux of any type of cosmic ray particles is defined by the formula

$$\Phi = \frac{\mathrm{d}N}{\mathrm{d}E\,\mathrm{d}t\,\mathrm{d}s\,\mathrm{d}\Omega}, \tag{1}$$

where $\mathrm{d}N$ is the number of particles detected per the energy interval $\mathrm{d}E$, per the time interval $\mathrm{d}t$, per the detector area interval $\mathrm{d}S$, and arrived from the solid angle interval $\mathrm{d}\Omega$.

The total antiproton flux caused by the reaction $\bar{\nu}_e + e^- \to \bar{p} + n$ has the form:

$$\Phi_{\bar{p}} = \int \mathrm{d}r\,\mathrm{d}E_{\bar{\nu}}\,\mathrm{d}\Omega_{\bar{\nu}}\,\frac{1}{v_{\bar{\nu}}}\,\Phi_{\bar{\nu}}(E_{\bar{\nu}})\,\mathrm{d}E_e\,\mathrm{d}\Omega_e\,\frac{c}{v_e}\,\Phi_e(E_e)\,\frac{(P_{\bar{\nu}}P_e)}{E_{\bar{\nu}}\,E_e}\,\frac{\mathrm{d}\sigma_{\bar{\nu}_e+e^-\to\bar{p}+n}}{\mathrm{d}E_{\bar{p}}\,\mathrm{d}\Omega_{\bar{p}}}\,, \tag{2}$$

The corresponding positron flux caused by the reaction $\bar{\nu}_e + n \to e^+ + p$ has the form:

$$\Phi_{e^+} = \int \mathrm{d}r\,\mathrm{d}E_{\bar{\nu}}\,\mathrm{d}\Omega_{\bar{\nu}}\,\frac{c}{v_{\bar{\nu}}}\,\Phi_{\bar{\nu}}(E_{\bar{\nu}})\,n_p\,\frac{(P_{\bar{\nu}}P_p)}{E_{\bar{\nu}}\,E_p}\,\frac{\mathrm{d}\sigma_{\bar{\nu}_e+p\to e^++n}}{\mathrm{d}E_e\,\mathrm{d}\Omega_e}\,, \tag{3}$$

Antineutrino electron process $\bar{\nu}_e + e^- \rightarrow \bar{p} + n$

To calculate the differential cross-section, we start with the matrix element in the following form:

$$\mathcal{M} = \frac{G_{\rm F} V_{ud}}{\sqrt{2}} \left[\bar{u}_n \left(g_V \gamma_\mu + g_A \gamma_\mu \gamma_5\right) u_{\bar{p}}\right] \times \left[\bar{v}_{\bar{\nu}} \gamma^\mu (1 - \gamma_5) v_e\right], \quad (4)$$

where g_V and g_A are the vector and axial-vector constants, $|V_{ud}| \simeq 0.974$ and $G_{\rm F}$ is the Fermi constant.
The differential cross-section is expressed via the averaged squared amplitude as follows:

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

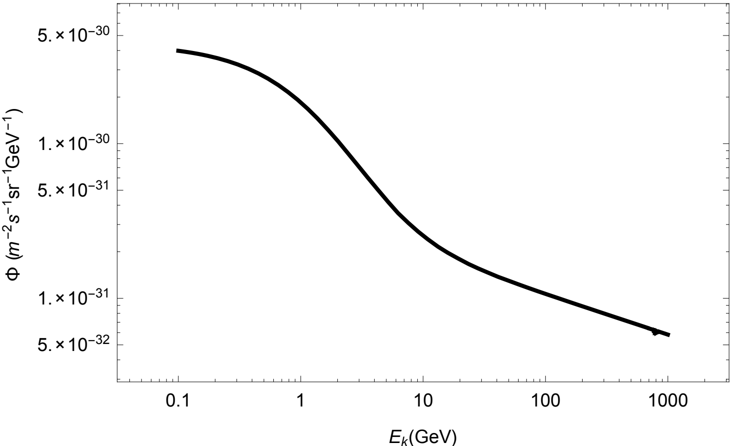
After some standard evaluations we get an averaged squared amplitude in the form:

$$\overline{|\mathcal{M}|^2} = 32\, G_{\mathrm{F}}^2 |V_{ud}|^2 \left[(1+\alpha)^2 (P_n P_\nu)(P_p P_e) + (1-\alpha)^2 (P_p P_\nu)(P_e P_n) + (1-\alpha^2) m_n m_p (P_\nu P_e) \right], \quad (6)$$

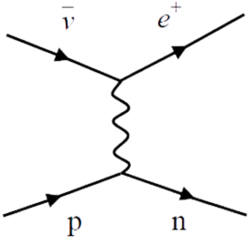
where $\alpha = |g_A/g_V| \simeq 1.27$.
Note that for the process $\bar{\nu}_e + e^- \to \bar{p} + n$ the squared amplitude would have exactly the same form excepting the sign of the last term.

ANTIPROTON FLUX FROM $\bar{\nu}_e + e \rightarrow \bar{p} + n$ AS A FUNCTION OF ANTIPROTON KINETIC ENERGY

The result of the integration can be visualised as a plot of the final antiproton flux as a function of antiproton kinetic energy $E_k = E_p - m_p$.



Antineutrino proton process $\bar{\nu}_e + p \rightarrow e^+ + n$



Kinematically defined limits for the energy of positrons:

$$E_e^{min,max} = \frac{(E_\nu + m_p)(2E_\nu m_p - \Delta^2) \pm E_\nu R^{1/2}}{2m_p(m_p + 2E_\nu}, \tag{7}$$

where

$$R = \left[2m_pE_\nu + m_p^2 - (m_n + m_e)^2\right]\left[2m_pE_\nu + m_p^2 - (m_n - m_e)^2\right].$$

It can be shown that

$$\sigma = \frac{G_{\mathrm{F}}^2 |V_{ud}|^2}{2\pi} \int_{E_{min}}^{E_{max}} \frac{JJ^2}{m_p E_\nu^2} dE_e, \tag{8}$$

where JJ^2 is a normed average squared amplitude after the integration over the angle.

Minimal possible antineutrino energy:

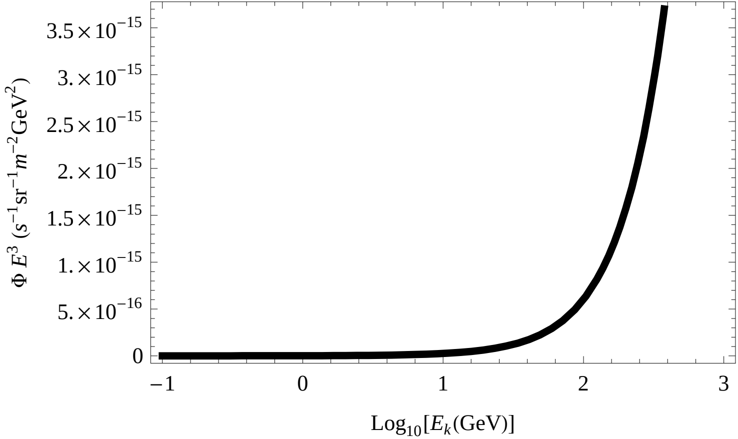
$$E_{\bar{\nu}}^{min} = \frac{m_n^2 - m_p^2 - m_e^2 + 2m_pE_e}{2(p_e + m_p - E_e)}. \tag{9}$$

Threshold antineutrino energy $E_{\nu}^{thr} \approx 1,8\text{MeV}$.
Total positron flux:

$$\Phi_{e^+} = \frac{G_{\mathrm{F}}^2|V_{ud}|^2}{2\pi m_p} R_G n_p \int\limits_{E_{\nu}^{min}}^{\infty} \Phi_{\nu}(E_{\nu}) JJ^2 \frac{dE_{\nu}}{E_{\nu}^2}. \tag{10}$$

POSITRON FLUX FROM $\bar{\nu}_e + n \rightarrow e^+ + p$ AS A FUNCTION OF POSITRON KINETIC ENERGY

The result of the integration can be visualised as a plot of the final positron flux as a function of positron kinetic energy $E_k = E_e - m_e$.



Conclusion

The possibility of the contribution from standard neutrino processes to the total secondary positron and antiproton fluxes detected by contemporary experiments was analyzed in details. The results show that the considered impact is negligible that confirms once more a necessity of application a new physics beyond the standard conceptions. The designed technique could be implied to the further studies that is extremely interesting in the light of the results of the recent experiments in high energy cosmic ray physics such as PAMELA and AMS-02.


THANK YOU