Relative abundances of positrons and antiprotons in the primary cosmic ray flux

SHEN and Berkey[1] calculated the ratio of antiprotons and positrons to be expected in the primary cosmic rays assuming that both components are the end products of proton–proton interactions, and pointed out that the observations of the positron spectrum would permit us to deduce the antiproton energy spectrum. Observations on the ratio $e^+/(e^+ + e^-)$ have been made[2] in the 5–50 GeV range, and we have used the results to put an upper limit on $\bar{p}/p$ at various energies.

Our calculations on the expected antiprotons-positron ratio differ in one significant respect from those of Shen and Berkey[1]: we have detailed measurements of the cross section of antiproton production up to intersecting storage ring energies. That permitted us to calculate the $e^+/\bar{p}$ ratio quite reliably.

We have plotted the latest $\bar{p}$ and π^+ production cross-sections (Fig. 1). They were deduced from the work of Antinucci *et al.*[3] and Ramaty and Lingenfelter[4].

It has been shown[5,6] that $\langle E_{\bar{p}}\rangle/E_p$, the ratio of the mean energy of antiprotons, $\langle E_p\rangle$, to incident-proton energy, E_p is approximately 9, independent of the energy of the incident protons.

This differs significantly from the results of Shen and Berkey[1] who found this ratio to vary as $E_p{}^{1/4}$. For the purpose of this calculation, we can summarise the results of the kinematics:

$$\left.\begin{array}{l}\sigma_{\bar{p}}(E_p) \simeq 9.3 \times 10^{-3}\,(E_p - 10.8)\ \text{mb} \\ \langle E_{\bar{p}}\rangle \simeq 9\,E_p\ \text{GeV}\end{array}\right\} 20 \lesssim E_p \leq 550\ \text{GeV} \tag{1}$$

$$\left.\begin{array}{l}\sigma\pi^+(E_p) = 27.7\,E_p{}^{1/4}\ \text{mb} \\ \langle E_{e^+}\rangle = 0.175\,E_p{}^{3/4}\ \text{GeV}\end{array}\right\} 50 \lesssim E_p \lesssim 1{,}500\ \text{GeV} \tag{2}$$

Following a procedure analogous to that of Shen and Berkey[1] we found that the ratio of the production spectrum of positrons to antiprotons can be written as:

$$\frac{Q_{e^+}(E)}{Q_{\bar{p}}(E)} = \frac{6.176 \times 10^{-2}\,E^{-0.586}}{2} \times \frac{\sigma_{\pi^+}[(22.86E^{4/3})]}{\sigma_{\bar{p}}(9E)} \tag{3}$$

which gives rise to values for the ratio $e^+/\bar{p}$ of 4 at 5 GeV and 1.56 at 10 GeV. These values depend on the spectral index of the differential proton energy spectrum only, taken to be $1.9 \times 10^4 E^{-2.75}\text{m}^{-2}\ \text{sr}^{-1}\ \text{s}^{-1}\ \text{GeV}^{-1}$ (refs 7 and 8). The factor of two in the denominator comes from the decay of antineutrons in space.

The equilibrium value of $e^+/\bar{p}$ will depend on the actual model of propagation and would tend to lower somewhat the ratio $e^+/\bar{p}$. Similarly, if the leakage mean free path is energy dependent this ratio will again be lowered. We will ignore these effects for the present and assume that the production and equilibrium values are the same. They will change the ratio by a factor of two or less.

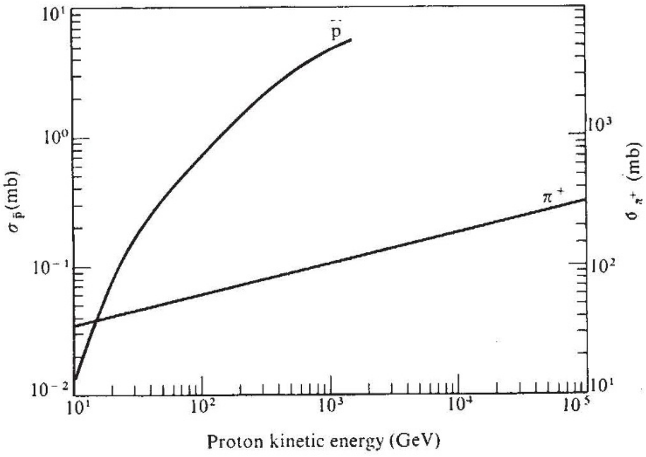

Fig. 1 The production cross sections of π^+ (scaled down by a factor of 1.5) and $\bar{p}$, as a function of proton kinetic energy in proton–proton collisions.

We interpret the results of Buffington *et al.*[2] as indicating an upper limit of 10% on the ratio $e^+/(e^+ + e^-)$ in order to obtain an upper limit on p/p. That gives an upper limit on the e^+ energy spectrum when combined with the measurements of $(e^+ + e^-)$ as summarised by Müller and Meyer[9]. Thus,

$$\text{p/p} \lesssim 1.8 \times 10^{-4} \text{ at 5 GeV}$$
$$\lesssim 5.7 \times 10^{-4} \text{ at 10 GeV}$$

which, even after allowing for propagation uncertainties, is about an order of magnitude lower than the value of 6×10^{-3} obtained by Bogomolov *et al.*[10] in a larger GeV range.

As the e^+/p ratio produced in nuclear reactions is very well known, measurements of e^+/p (in conjunction with knowledge of the proton flux itself) depend only on the amount of e^+ from cosmic ray sources and on the energy dependence of the storage time of primary protons in the galaxy. Comparison of e^+ and p fluxes would be extremely valuable in the understanding of cosmic ray production and propagation.

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Will there be a large earthquake in central California during the next two decades?

P-VELOCITY decreases before earthquakes[1–4] can be observed by monitoring the average P-residual at seismic stations near the focus[5–7]. The P-residual is the difference between the observed travel time from an epicentre to a station and that computed theoretically on the basis of some Earth model and a least squares estimate of the earthquake location and origin time. If the P-velocity in the crust underneath a seismic station is decreased temporarily, each seismic wave will arrive somewhat later during the premonitory period. Before three thrust[5,6,18] and one strike-slip event[7] the delay was found to be approximately 0.4 s.

Here I compare the average teleseismic P-residuals of four stations located near the San Andreas fault (Berkeley, BKS; Mt Hamilton, MHC; Priest, PRI; and Pasadena, PAS) to those of three stations to the East of it (Mineral, MIN; Jamestown, JAS, and; Golden, GOL) (Fig. 1). Since our interest is focused on the detection of precursor anomalies lasting several years (earthquake magnitudes ⩾6.5) Fig. 2 shows annual mean residuals. The standard deviations of the annual means are approximately 0.1 s for 1961–63, and 0.07 s to 0.04 s since then, shown by error bars in the figures.