Re-estimation of the Production Spectra of Cosmic Ray Secondary Positrons and Electrons in the ISM

C.M. Wong and L.K. Ng
Physics Department, University of Hong Kong
Hong Kong

Abstract

The present work includes a detailed calculation of the production spectra of charged hadrons ($\pi^{\pm}, K^{\pm}$) produced by interactions of cosmic rays in the interstellar medium, and a thorough treatment of pion and muon decays. Newly parametrised inclusive cross sections of hadrons were used and exact kinematic limitations were taken into account. Single parametrised expressions for the production spectra of both secondary positrons and electrons in the energy range 10^{-1} - 10^{+3} GeV are presented. The results are compared with other authors' predictions. Equilibrium spectra using various models are also presented.

1. Introduction. It is well known that cosmic ray secondary positrons and electrons in the ISM arise from the $\pi\mu e$ decay chain of secondary π produced in the interactions of cosmic rays with the ISM. Given the production spectra of $e^{\pm}$, their equilibrium spectra can be calculated by model predictions. And by combining with the available high-energy cosmic ray $e^{\pm}$ data, we can obtain a better understanding of cosmic ray propagation in the galaxy. However, there is no general agreement among the previous calculations of the production spectra of $e^{\pm}$. In this work, we have re-estimated these spectra based on newly parametrised inclusive cross sections of hadrons which are applicable at energies from the ISR down to those near the production threshold. Moreover, exact kinematic limitations are taken into account.

2. Production spectra of hadrons. Re-estimation of the production spectra of hadrons is motivated by the existence of large divergence among various inclusive cross section formulae[1], and the availability of newly parametrised formulae based on more recent accelerator data[2].

The production spectra of hadrons in p-p collisions is given by

$$P(E_h) = \frac{2\pi}{m_p} \int_{E_t}^{\infty} j(E_p)dE_p \int_0^{\Theta_{max}} \left(E\frac{d^3\sigma}{dp^3}\right) p_t \, d\Theta$$

where E_t is the threshold energy of p-p collisions for a given hadron energy E_h, Θ_{max} is the maximum angle of hadron emission in the laboratory system and $j(E_p)$ is the differential flux of interstellar protons taken from Ref.3. Calculation was done without applying any approximation to the integrations, and exact kinematic limitations were taken into account. Results for $\pi^{\pm}$ and $K^{\pm}$ are shown in figure 1. The uncertainties in the input spectrum gives rise to the shaded areas at low energies.

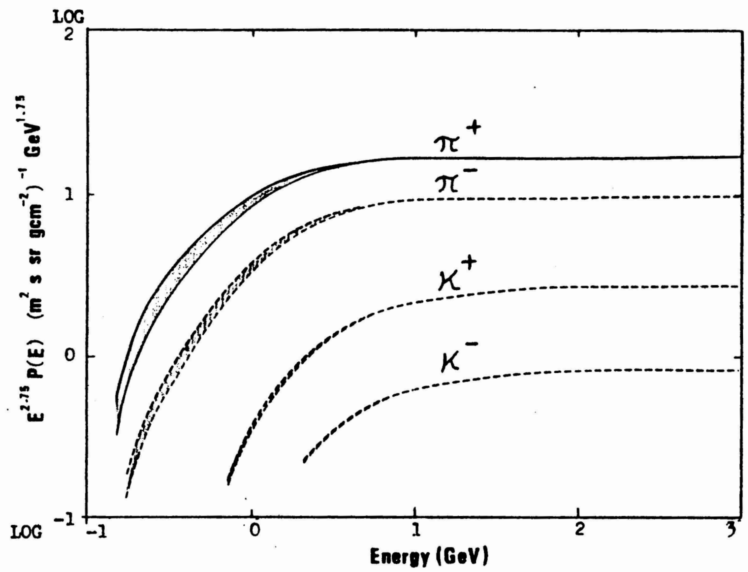

Fig. 1
Production spectra of charged hadrons in p-p collisions.

3. Production spectra of $e^{\pm}$. Production spectra of $e^{\pm}$ in interstellar space is obtained by rigorous treatment of pion and muon decays taking into account of precise decay kinematics and muon decay asymmetry. Correction for the cosmic ray and the ISM compositions[4] and the contribution from kaons[5] are then added. The results are given in figures 2 and 3.

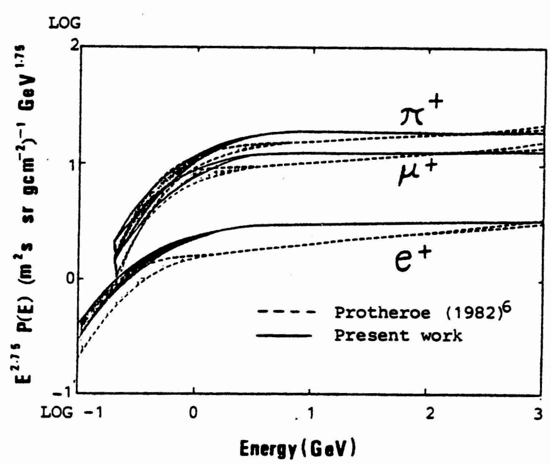

Fig.2 Production spectra of π^{+}, μ^{+} and e^{+}.

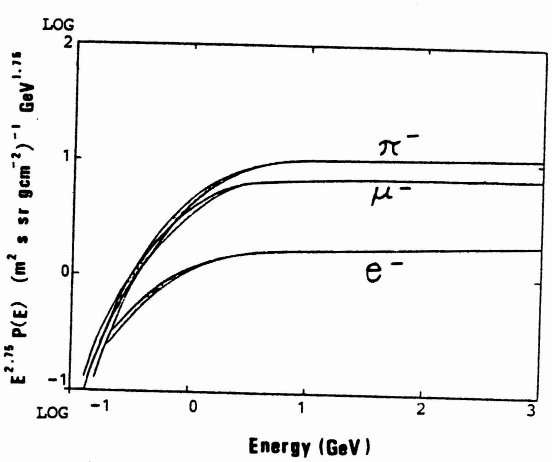

Fig.3 Production spectra of π^{-}, μ^{-} and e^{-}.

The spectra can be parametrised as follows with the coefficients listed in Table I.

$$Q(E_e) = \left[C_1 E_e^{-C_2}\right] / \left[1 + C_A E_e^{-C_B}\right] \text{ for } 0.1 \text{ GeV} \leqslant E_e \leqslant 1000.0 \text{ GeV}$$

where $C_A = C_3 + C_4 \ln E_e + C_5 \ln^2 E_e$,

$C_B = C_6 + C_7 \ln E_e + C_8 \ln^2 E_e$.

Limit	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Upper	2.84	2.72	0.173	-0.146	-0.00992	0.892	0.00499	0.0389
Lower	2.84	2.73	0.252	-0.148	-0.0454	1.09	-0.0127	0.0474

Above for positrons.

Limit	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Upper	1.58	2.72	0.371	-0.305	0.0698	0.768	0.0444	0.0536
Lower	1.58	2.72	0.433	-0.312	0.0570	0.901	0.0688	0.0575

Above for electrons.

TABLE I

4. Results and discussion. Figure 4 compares the present calculated positron spectrum with the previous calculations. Our results are significantly higher than the others especially near the energy range 1 - 10 GeV. The differences are mainly due to different adoption of the inclusive cross section parametrisations and different assumed interstellar proton spectra. However, since in our calculation, more recent accelerator data have been used and rigorous kinematic treatment has been done, we believe the production spectrum has been improved.

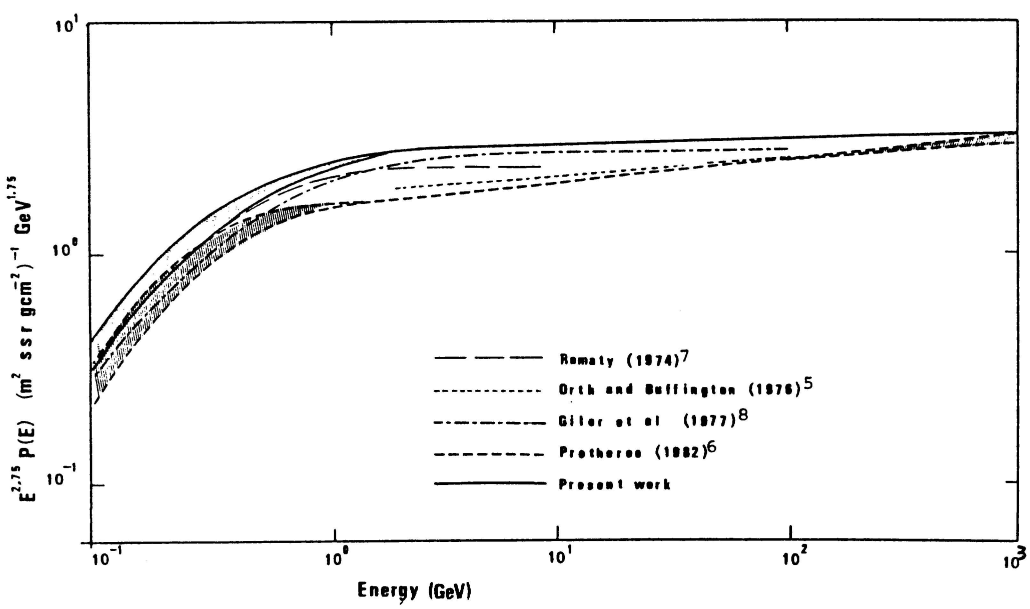

Fig.4 Production spectra of e^+ predicted by various authors.

For the purpose of illustration, equilibrium spectra have been calculated using this positron production spectrum and various propagation models as shown in figure 5. It is seen that the predicted curves are all close to the recent datum due to Golden et al[13].

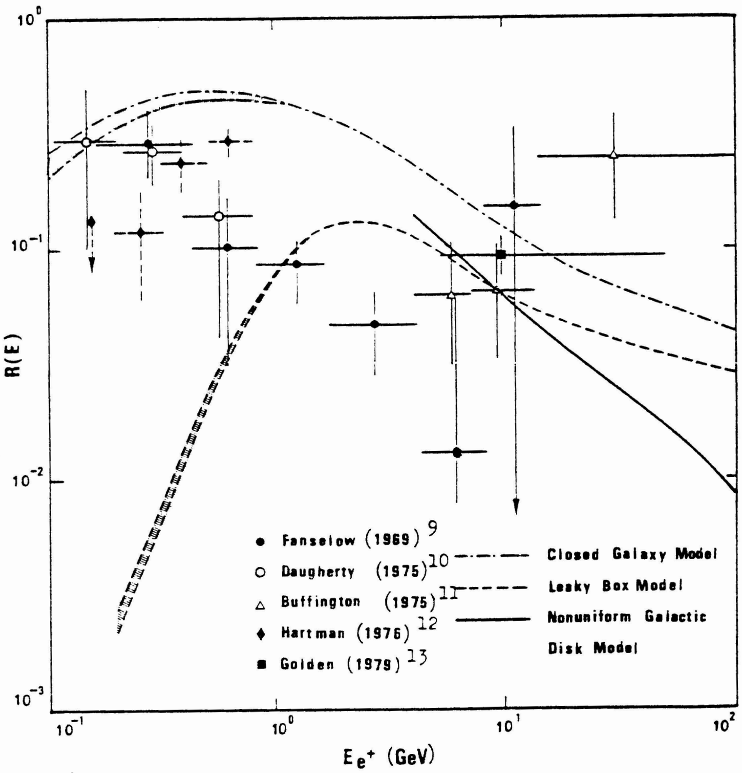

Fig.5 Equilibrium spectra of e^+ based on the present calculated production spectrum.

5. Acknowledgement. Authors are grateful to Dr. L.C. Tan and Dr. P.K. MacKeown for their helpful comments and to Professor D.J. Newman for his support and encouragement.

References.

1. Ghoshdastidar M R et al, Proc.17th ICRC 5 (1981) 1.
2. Tan L C et al, J. Phys. G: Nucl.Phys. 9 (1983) 1289.
3. Ormes J F et al, Ap. J. 272 (1983) 756.
4. Tan L C et al, J. Phys. G: Nucl. Phys. 7 (1981) 1135.
5. Orth C D et al, Ap. J. 206 (1976) 312.
6. Protheroe R J, Ap. J. 254 (1982) 391.
7. Ramaty R., High Energy Particles and Quanta in Astrophysics, MIT Press, Cambridge, (1974)122.
8. Giler M et al, J. Phys. A Math.Gen., 10 (1977) 843.
9. Fanselow J L et al, Ap. J. 158 (1969) 771.
10. Daugherty J K et al, Ap. J. 198 (1975) 493.
11. Buffington A et al, Ap. J. 199 (1975) 669.
12. Hartman R C et al, Ap. J. 204 (1976) 927.
13. Golden R L et al, Proc. 16th ICRC (Kyoto) 1 (1979) 470.