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THE ULTRAHIGH ENERGY PHOTON SPECTRUM

F. W. STECKER
J. BREDEKAMP

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GREENBELT, MARYLAND

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by

F. W. Stecker
J. Bredekamp

Theoretical Studies Branch
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Abstract. We present here the results of a numerical calculation of the ultrahigh energy photon spectrum giving a more accurate calculation of the source spectrum than the one derived previously.

In a recent paper, one of us (Stecker 1972, which we will refer to as paper I) presented simple approximate formulas for estimating the ultrahigh energy photon spectrum under the assumption that the ultrahigh energy cosmic-ray nucleons are universal. Paper I followed a numerical treatment by Wdowczyk, et al. (1972), but was based on somewhat different assumptions of (1) domination of the $\Delta(1238)$ resonance channel in ultrahigh energy π^0 production in cosmic-ray-blackbody background interactions and (2) a different propagation equation for the cascading process (see paper I for details).

Here we present the results of a numerical calculation based on the above assumptions but without resorting to the δ-function approximations used in paper I.

In the $\Delta(1238)$ resonance channel, which occurs at $\sim$320 MeV in the rest-system of the cosmic-ray proton, it is found that the transition $\Delta \rightarrow p+\pi^0$ is almost a pure magnetic dipole transition. (For a discussion of theoretical and experimental aspects of photomeson production, see Källen 1964). The angular distribution of the outgoing pion is then of the form

$$f(\theta') \propto (2+3 \sin^2\theta') \tag{1}$$

where θ' refers to the nucleon-rest-system.

The cross section for the reaction $\gamma+p \rightarrow p+\pi^0$ as a function of energy in the nucleon-rest-system is shown in figure 1 (see Källen 1964).

The energy of the incoming blackbody photon in the nucleon-rest-system is

$$\varepsilon' = (E_p/M_p)\,\varepsilon(1-\cos\theta) \tag{2}$$

where the angle θ refers to the laboratory system.

We assume a 2.7^{0}K blackbody photon spectrum of the form

$$n(\varepsilon)d\varepsilon = \frac{8\pi}{h^3c^3}\,\frac{\varepsilon^2 d\varepsilon}{e^{\varepsilon/kT}-1} \tag{3}$$

Equations (1) - (3) together with the data $\sigma(\varepsilon)$ in figure 1 were used to evaluate the γ-ray source function from the decay of π^0-mesons produced in ultrahigh energy cosmic-ray-blackbody photon interactions. These assumptions where used instead of the δ-function assumptions used in paper I. The additional production of π^0-mesons at higher energies, ε, in multiparticle production reactions is expected to be small because of the steeply dropping cosmic-ray spectrum. The resultant production spectrum of ultrahigh energy γ-rays is shown in figure 2 for the two assumed cosmic-ray spectra indicated in the figure. The results are similar to thosecalculated by Wdowczyk, et al.

We have also calculated the first generation and cascade spectra (discussed by Wdowczyk, et al. in paper I) using the formulas (12) and (25) derived in paper I. The results are shown in figures 3 and 4. The results for I_Σ shown in figure 3 are approximately a factor of 3 below those given by Wdowczyk, et al.

REFERENCES

Kållen, G., 1964.: *Elementary Particle Physics*, Reading, Mass., Addison Wesley.

Stecker, F.W., 1972.: Astrophysics and Space Science, in press.

Wdowczyk, J., Tkaczyk, W., and Wolfendale, A.W., 1972.: J. Phys A5, 1419.

FIGURE CAPTIONS

Figure 1. Total cross section for the reaction $\gamma+p\rightarrow p+\pi^0$ as a function of γ-ray energy in the proton rest-system.

Figure 2. Calculated rate of ultrahigh energy photon production from photomeson interactions with the 2.7 K blackbody background for the two cosmic-ray spectra indicated in the figure.

Figure 3. First generation (I_1) and total (I_Σ) cascade photon spectra calculated for the cosmic-ray proton spectrum shown using the upper curve shown in figure 2 for the production rate.

Figure 4. First generation and total cascade photon spectra calculated for the cosmic-ray proton spectrum shown using the lower curve shown in figure 2 for the production rate.

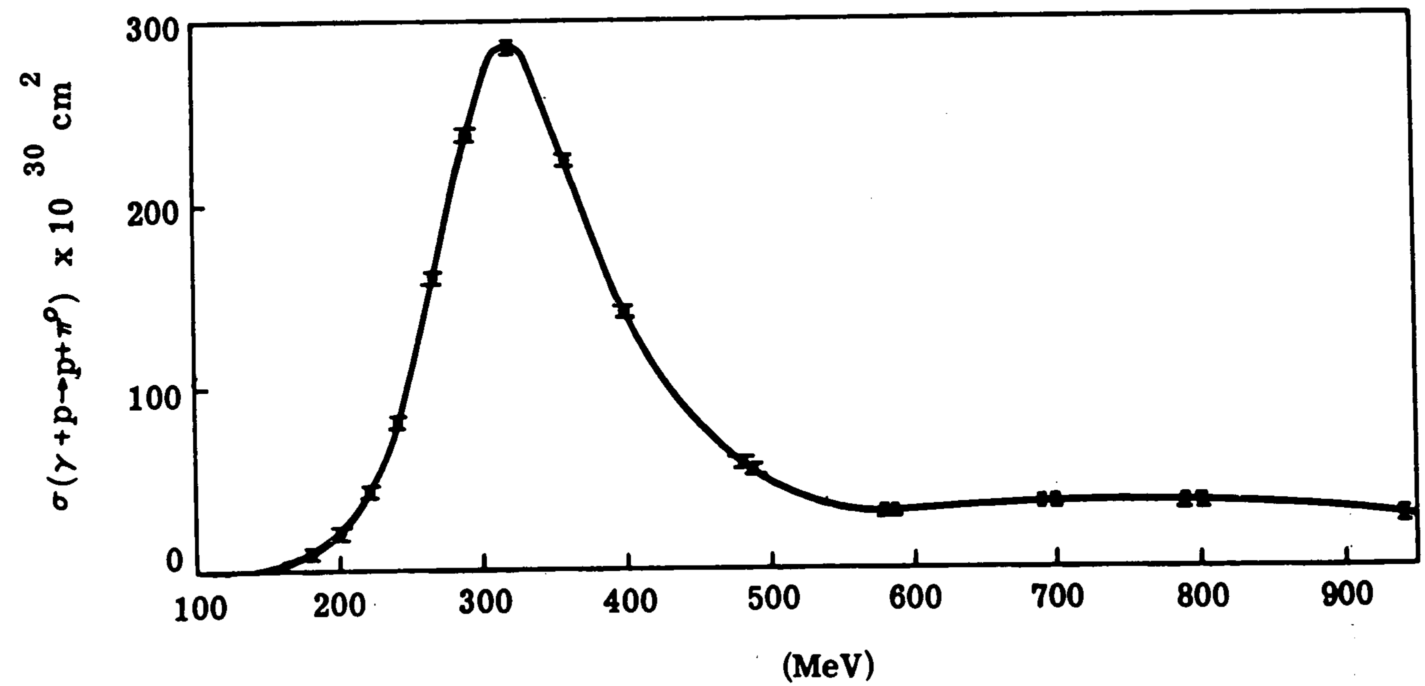
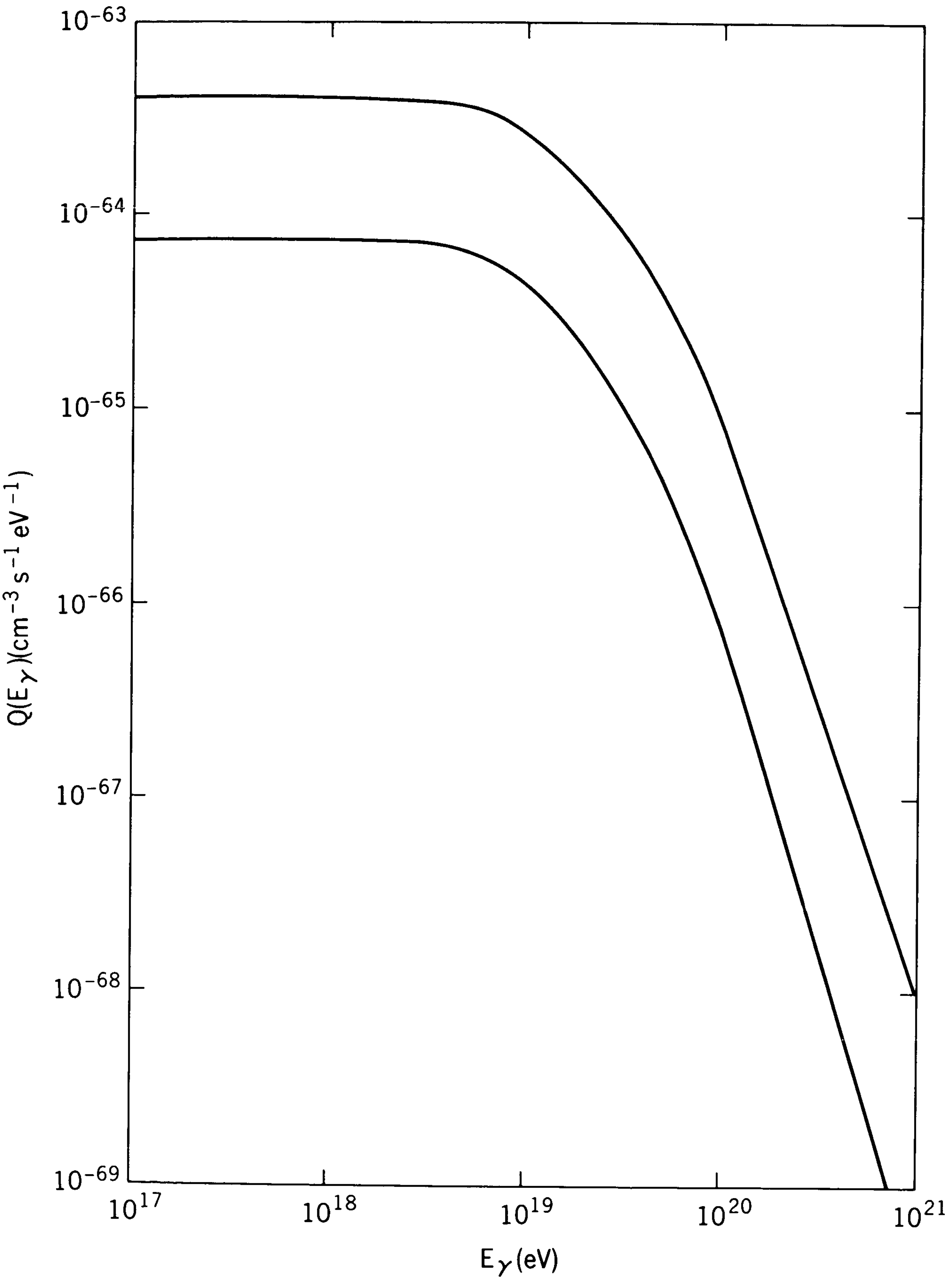
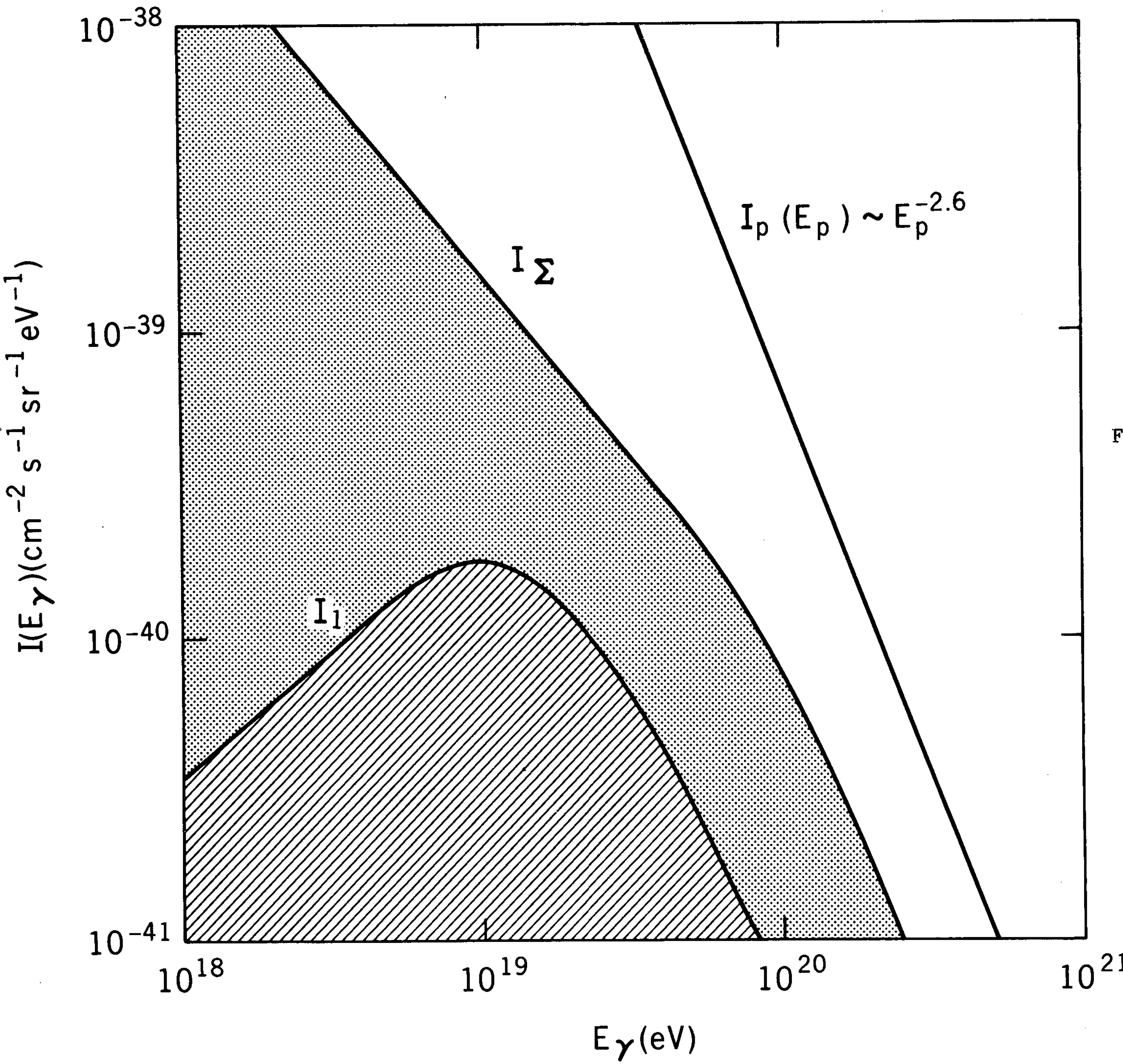

$\sigma(\gamma + p \to p + \pi^0) \times 10^{30}\ cm^2$
300
200
100
0
100
200
300
400
500
600
700
800
900
(MeV)

FIGURE 1

FIGURE 2



10^{-63}
10^{-64}
10^{-65}
10^{-66}
10^{-67}
10^{-68}
10^{-69}
$Q(E_\gamma)(cm^{-3}\,s^{-1}\,eV^{-1})$
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
$E_\gamma(eV)$



10^{-38}
10^{-39}
10^{-40}
10^{-41}
$I(E_\gamma)(cm^{-2}\,s^{-1}\,sr^{-1}\,eV^{-1})$
$I_p\,(E_p) \sim E_p^{-2.6}$
I_Σ
I_1
10^{18}
10^{19}
10^{20}
10^{21}
$E_\gamma(eV)$

FIGURE 3

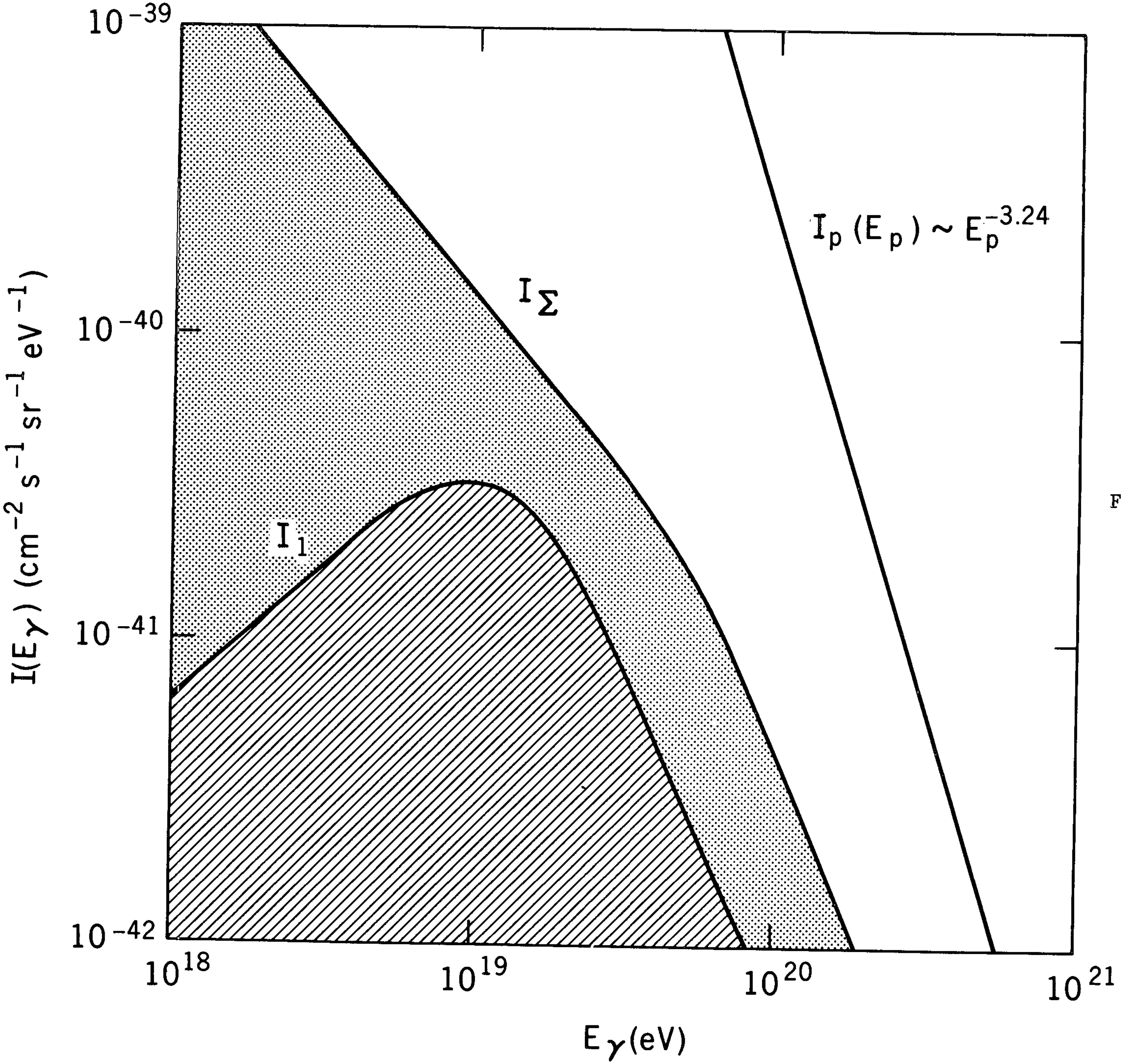

10^{-39}
10^{-40}
10^{-41}
10^{-42}
$I(E_\gamma)$ (cm^{-2} s^{-1} sr^{-1} eV^{-1})
I_Σ
I_1
$I_p(E_p) \sim E_p^{-3.24}$
10^{18}
10^{19}
10^{20}
10^{21}
E_γ(eV)

FIGURE 4