$\pi\pi$ and $K\pi$ Interactions, Argonne National Laboratory, 14-16 May 1969 (unpublished).

[13]C. Lovelace, CERN Report No. TH 839, and private communication.

X-RAY TRANSITION RADIATION APPLIED TO THE DETECTION OF SUPERHIGH-ENERGY PARTICLES*

Luke C. L. Yuan and C. L. Wang
Brookhaven National Laboratory, Upton, New York 11973

and

S. Prunster
Argonne National Laboratory Argonne, Illinois 60439

(Received 10 July 1969)

Preliminary measurements of the transition radiation in the x-ray region indicate that an average of 12 x-ray photons are produced by a single positron of 2-BeV energy traversing a stack of 231 thin aluminum foils. This number is large enough to indicate that it is feasible to use the x-ray transition radiation for the determination of the relativistic factor γ rather than β of superhigh-energy particles. Such an application may well provide a unique method for distinguishing monoenergetic particles in the superhigh-energy region.

In our earlier work[1,2] we have measured the transition radiation emitted in the optical region by individual charged protons, pions, and electrons in the momentum region 0.8-3.5 BeV/c with the value of γ ranging from 1 up to 2000, where $\gamma = (1-\beta^2)^{-1/2}$. We have also established the $\log\gamma$ dependence of the intensity of the transition radiation in the optical region as predicted by theory.[3] By limiting the detection of the optical transition radiation emitted within a small angular region around the direction of the incident particle a much stronger γ dependence has been observed.[4-6]

Theory[3] also predicted that the intensity of the transition radiation in the x-ray region is linearly proportional to γ. This linear dependence arises from the combined effect of two separate factors, namely, (i) the increase with γ in the magnitude of the energy distribution of the transition radiation as a function of frequency and (ii) the increase with γ in the frequency range of the transition radiation. This would provide an adequately sensitive γ dependence for its application to the detection and identification of individual, charged particles in the superhigh-energy region.

Recently we have carried out an experiment to measure the transition radiation emitted in the x-ray region by individual positrons at the 6-BeV Cambridge Electron Accelerator. This paper describes some of the preliminary results obtained in this experiment.

The experimental arrangement is comprised of a beam-defining scintillation-counter telescope in front of a transition radiator (a stack of thin foils closely spaced). Immediately following the transition radiator is a bending magnet which deflects the positrons into a scintillation counter placed downstream of the magnet on one side. The x-ray transition radiation is measured by a lithium-drifted germanium detector placed also down-stream of the deflection magnet.

The coincidence signal from each positron passing through the beam-defining telescope and the scintillation counter downstream of the magnet opens the gate in a linear gate circuit which allows the registration of the x-ray pulses from the germanium detector. Figure 1 shows the intensity of the radiation detected versus its energy. The peak at the left is due to the "pedestal" pulses from the incident-positron signals which serve to define the zero signal level as well as for normalization purposes. The range of the radiation energy detected in the preliminary measurements extends from 6 to 200 keV as calibrated with a known source. The vertical scale gives the relative intensity in a logarithmic scale. The lower curve shows the background radiation obtained by replacing the transition radiator by a solid block of the same mass and material as the whole stack of foils but without the multitude of interfaces. The background radiation is mainly comprised of bremsstrahlung from the incident high-energy positrons, which would be very small for protons and other heavier particles. Other possible effects caused by the bending of the positron in traversing a magnetic field which might contri-

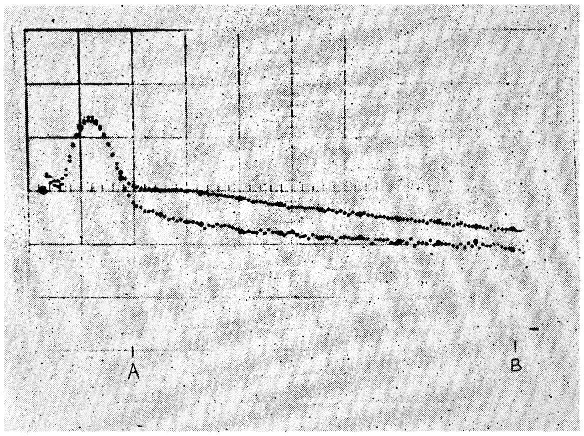

FIG. 1. Intensity of the x-ray transition radiation versus its energy. The vertical axis represents the intensity of the transition radiation in a logarithmic scale, and the horizontal axis represents the x-ray energy from (A) 6 keV up to (B) 200 keV. Upper curve represents the transition radiation and the lower curve represents the background.

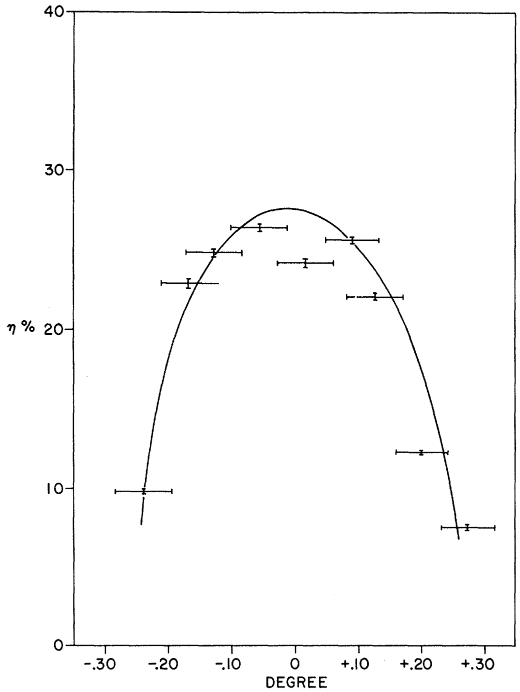

FIG. 2. The angular distribution of the x-ray transition radiation in the vertical direction. The vertical scale is the detection efficiency η in percent, i.e., the number of x-ray photon events per incident positron, and the horizontal scale is the vertical angle in degrees above or below the incident-positron beam direction (before deflection by the bending magnet).

bute to the background effect such as synchrotron or betatron radiation, etc. are negligibly small. In any case these effects are subtracted out in the final results. The upper curve represents the spectrum obtained with the stack of thin foils in place, and the difference between the two curves gives the x-ray transition radiation produced by the positrons. The energy of these positrons is 2 BeV with a value of γ of ~4000. Figure 2 shows the angular distribution of the x-ray transition radiation in the vertical direction. The finite size of the germanium detector (0.6 cm high and 2.8 cm wide) is not sufficiently small to indicate a dip at 0° as theoretically predicted.

Using a stack of 231 aluminum foils, 25 μ thick and spaced at 0.3 mm, the efficiency for the detection of 2-BeV positrons by means of x-ray transition radiation is 27% in the present setup. However, the x-ray detector subtends only $\frac{1}{12}$ the solid angle of the total radiation emitted. In addition, in the present experimental arrangement there are five windows present in the path of the x-ray transition radiation and the low-energy x rays suffer considerable losses before reaching the germanium detector. These windows are parts of a vacuum pipe, a helium bag, and the germanium detector. Furthermore the range of energy detection extends only to 200 keV in the present arrangement, whereas the x-ray energy of transition radiation for 2-BeV positrons extends to more than 250 keV. By incorporation of all these factors one estimates that an average of 12 x-ray photons are produced by a single positron from such a stack of foils. Consequently ten such stacks arranged in tandem might yield 120 photons per particle providing a 9% resolution in the measurement of γ for a linear dependence of intensity on γ. Since γ is much more sensitive to the mass of a high-energy particle than β it is clear that this technique affords a unique method of mass identification of monoenergetic particles in the superhigh-energy region which is much better than the conventional means for application in experiments either in accelerators or with cosmic rays.

As was mentioned earlier, the results reported here are only preliminary. Improvements in x-ray detection and optimization of the radiator design are being planned, and more extensive measurements including the γ dependence of the effect will be carried out in the near future.

We are very grateful to the staff and crew of the Cambridge Electron Accelerator without whose generous assistance and cooperation, the success of this experiment would not have been possible. We are especially indebted to Dr. Fritz Dell for his invaluable help in many respects. We also wish to express our thanks to Dr. W. Bergmann of the Argonne National Laboratory for his assistance in carrying out part of the measurements and to Mr. B. Streeter for his technical assistance. The germanium detector was supplied through the courtesy of the Instrumentation Division of Brookhaven National Laboratory.

---

*Work performed under the auspices of the U. S. Atomic Energy Commission.

[1]J. Oostens, S. Prunster, C. L. Wang, and Luke C. L. Yuan, Phys. Rev. Letters 19, 541 (1967).

[2]S. Prunster, C. L. Wang, L. C. L. Yuan, and J. Oostens, Phys. Letters 28B, 47 (1968).

[3]G. M. Garibian, Zh. Eksperim. i Teor. Fiz. 33, 1403 (1957), and 37, 527 (1959) [translation: Soviet Phys. – JETP 6, 1079 (1958), and 10, 372 (1960)].

[4]Professor A. I. Alikhanian, Yerevan Physical Institute, U. S. S. R., private communication.

[5]A. I. Alikhanian, G. M. Garibian, K. A. Ispirian, E. M. Laziev, and A. G. Oganessian, in Proceedings of the International Conference on High Energy Instrumentation, Versailles, France, 1968 (to be published).

[6]A. I. Alikhanian, G. M. Garibian, K. A. Ispirian, and A. G. Oganessian, unpublished.

TOTAL AND PARTIAL PHOTOPRODUCTION CROSS SECTIONS AT 1.44, 2.8, AND 4.7 GeV *

J. Ballam, G. B. Chadwick, R. Gearhart, Z. G. T Guiragossián, P. R. Klein, A. Levy,† M. Menke, J. J. Murray, P. Seyboth,‡ and G. Wolf§
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

C. K. Sinclair
Tufts University, Medford, Massachusetts

and

H. H. Bingham, W. B. Fretter, K. C. Moffeit, W. J. Podolsky, M. S. Rabin, A. H. Rosenfeld, and R. Windmolders‖
Department of Physics and Lawrence Radiation Laboratory, University of California, Berkeley, California 94720
(Received 27 June 1969)

A nearly monochromatic high-energy photon beam produced by Compton backscattering of ruby laser light has been used to study photoproduction in a hydrogen bubble chamber. The total hadronic γp cross sections at 1.44, 2.8, and 4.7 GeV are found to be 145.1 ± 5.7, 131.3 ± 4.3, and 124.2 ± 3.9 μb, respectively. Partial cross sections are presented also.

In 1963 R. Milburn[1] concurrently with Arutyunian, Goldman, and Tumanian[2] pointed out that Compton backscattering of an intense polarized light beam by high-energy electrons would produce useful yields of monoenergetic polarized photons. Such a beam has been realized at the Stanford Linear Accelerator Center (SLAC)[3] and used together with the 82-in. Lawrence Radiation Laboratory–SLAC hydrogen bubble chamber for a study of γp interactions with linearly polarized photons. About 800 000 pictures have been taken at photon energies of 1.44, 2.8, and 4.7 GeV, 10% of which have been used for the present study. Because the energy spread is small and because the bubble chamber permits a clear separation of electromagnetic and hadronic interactions, the exposures allow a straightforward measurement of the total hadronic γp cross section. Thus this measurement is free of the usual background and detection biases caused by the 150-times more copious pair production.

Beam.—The beam results from Compton backscattering of light by high-energy electrons. This is a two-body process; hence for given incident photon and electron energies k_i and E, the energy k of the scattered photon depends only on the laboratory angle θ as measured with respect to the incident electron beam:

$$k = \frac{E(1-a)}{1+a(\gamma^\theta)^2}, \quad \theta \ll 1, \tag{1}$$

where m = electron mass, $\gamma = E/m$, and $a = [(1+4\gamma) k_i/m]^{-1}$.

To limit the scattered-photon energies to the top 10% of the Compton spectrum at our energies requires angular definition of the order of 10^{-5} rad about $\theta = 0°$ for both the incident-electron and the backscattered-photon beam. A special fea-

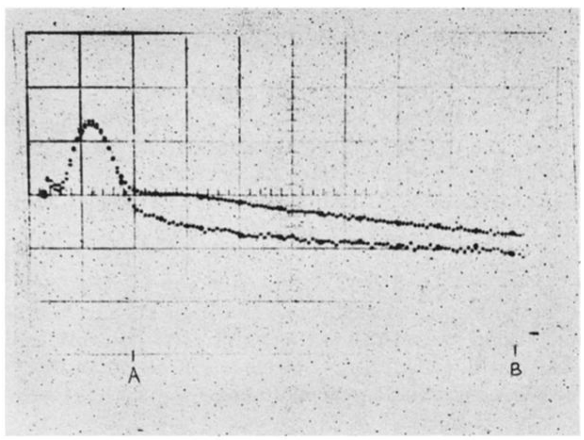

FIG. 1. Intensity of the x-ray transition radiation versus its energy. The vertical axis represents the intensity of the transition radiation in a logarithmic scale, and the horizontal axis represents the x-ray energy from (A) 6 keV up to (B) 200 keV. Upper curve represents the transition radiation and the lower curve represents the background.