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RELATIVISTIC INCREASE IN TRACK BLOB DENSITY IN VARIOUS NUCLEAR EMULSIONS

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The advent in 1948 of nuclear-research emulsions sensitive to relativistic singly-charged particles put at the disposal of the experimenter an indicator of rate of energy loss that has a fairly high density and contains a mixture of heavy nuclei. It was reasonable to hope at the time that the emulsions would be sufficiently homogeneous to allow the relativistic rise in the rate of energy loss to be demonstrated, and it was shown soon that this can indeed be done. Values of the magnitude of this rise were published by several groups.

Since then, a number of studies, both theoretical and experimental, have been made of the rate of energy loss and of the blob (or grain) density in the relativistic region, it being assumed, usually, that these two quantities are linearly related to one another in the region of interest.

An examination of the data available to us, both published and unpublished, convinced us that there still remained a need for experiments to answer the following questions:

a) What is the magnitude of g_{pl}/g_{min}? Is it the same in all types of emulsion? Does it change from emulsion batch to emulsion batch?
b) Is the "plateau" flat or is there evidence for a maximum around $E/mc^2 = 100$?

In the experiment we report here we succeeded in obtaining information to answer much of question (a), but an experimental mishap prevented us from investigating the region of $E/mc^2 = 100$. The emulsion types examined were Ilford G5, K5 and L4, Kodak NTB4, NIKFI BR and BM, and Gevaert 715.

Nuclear-research emulsion is a complex inhomogeneous material, sensitive to temperature and humidity, which undergoes complicated chemical processing between the exposure to charged particles and the observation of the tracks they produced, and in which latent images fade at a rate which again depends on temperature and humi=

dity. There are thus very many sources of variations and fluctuations in track density, and it is clearly necessary to eliminate these if one is to be able to detect small differences in rates of energy loss, and small differences between the responses of various emulsion types to changes in the rate of energy loss.

We eliminated variations in temperature and humidity which could have led to variations in sensitivity and the rate of fading by sealing the package containing the emulsions into plastic and keeping this package continuously at the temperature of melting ice from about 12 hours before the beginning of the first exposure until they were processed. One may thus assume that gradients in temperature and water content were absent, and that all exposures took place at the same emulsion temperature and humidity.

In Fig. 1 we show details of the exposures. The geometry was arranged in such a way that the beams overlapped in a small region of the emulsion, and all the measurements were made in that region in order to reduce as far as possible the effects of any sensitivity gradients that may have been present. The three electron exposures were obtained in a single night shift at the Stanford Linear Accelerator, the pion exposure was made at the synchrocyclotron at Berkeley about two days later, and processing of the emulsions began another two days after that.

The tracks from which our results were obtained were thus produced in the same physical conditions and, for each emulsion type, in the same small volume of emulsion. The physical conditions in which fading could have taken place before processing were the same for all the tracks, also, with the single exception that the duration of the period during which fading could occur was about two days less for the pions as compared to the electrons.

A fifth exposure, to electrons of 75 MeV/c (γ = 146) failed because a beam of sufficient intensity could not be obtained.

In each of the beams in each of the seven emulsions 10000 blobs were counted to arrive at an estimate of the blob density. In each case the blobs were counted in groups of 200, and the distributions of the blob densities derived from the fifty 200-blob samples were tested for consistency with a Gaussian distribution with the expected standard deviation. All the 10000-blob samples proved acceptable.

In order to avoid effects of saturation, we tried to keep the blob densities fairly low - rather lower than what can be obtained with some of the emulsions used. They are shown in Table 1. One of the emulsions, Gevaert 715, had a very large spread of blob sizes, as well as the highest blob density, so that the results obtained with it are subject to some doubts.

The values of the ratio g/g_{min} (the "normalized blob density") obtained in this way are plotted in Fig. 2 as function of $\gamma = E/mc^2$. From inspection of this figure we may conclude the following:

a) For all the emulsions except Ilford L4, the three points at γ = 293, 752 and 1953 are consistent with what would be expected for samples from a distribution with standard deviation 1%, and the trends exhibited are different in different emulsions. We have thus no evidence that the rates of energy loss at the three values of γ considered are not the same. We cannot explain the behavior of the L4 emulsion.

b) As the points to which the measurements are normalized are themselves distributed with a standard deviation of about 1%, the distributions of the normalized blob densities for fixed γ but different emulsion types should have a standard deviation of about 1.4% if the magnitude of the relativistic rise were the same in all emulsions. This does not appear to be the case.

In Fig. 3 we plot all the normalized blob densities obtained and compare them with a Gaussian of the same mean value and a standard deviation of 1.4%. It is clear that the data do not fit the curve. A better fit is obtained if the doubtful data obtained with Gevaert 715 emulsion are omitted.

We have looked for systematic trends in the variation of the relativistic rise with emulsion type, but we have not succeeded in finding any. In Table 2, for example, the data are ordered by unprocessed grain diameter, but no trend is apparent.

It may be noted that the over-all average value of the relativistic rise obtained in this experiment is rather lower than what has been found in many earlier experiments. It is conceivable that this is due to the fact that the pion tracks from which the minimum blob densities were derived faded for two days less than the other tracks. It should be noted that it is also possible that some of the values of the magnitude of the relativistic rise obtained by earlier workers have been affected by fading. Similarly, the emulsion-to-emulsion variations might be due to differences in the fading behavior of the emulsions. However, it is also possible that the differences were caused by batch-to-batch and emulsion-type-to-emulsion-type variations.

We conclude then, that our data are consistent with a plateau in the rate of energy loss, flat to within about 1%, in the range of $\gamma = 293$ to $\gamma = 1953$. The differences between the magnitudes of the relativistic rise observed may be due to differences between the rates of fading, or to differences in emulsion response, or both. The average relativistic rise observed was about 10%, rather less than is commonly found; if it can be established that rapid fading takes place during the first few days after exposure even if the emulsions are stored at 0°C this could be due to fading, otherwise it must be the result of variability in the response of nuclear emulsions. Note that fading could also have affected some earlier experiments.

Acknowledgements

We should like to thank our scanners who counted more than 3×10^5 blobs in a reproducible fashion, and our colleagues at the Stanford Linear Accelerator and the Lawrence Radiation Laboratory who helped with the exposures. We are greatly indebted to Dr. M.M. Shapiro for his continuing support and encouragement. Particular thanks are due to Prof. Bogomolov who supplied us with the NIKFI emulsions.

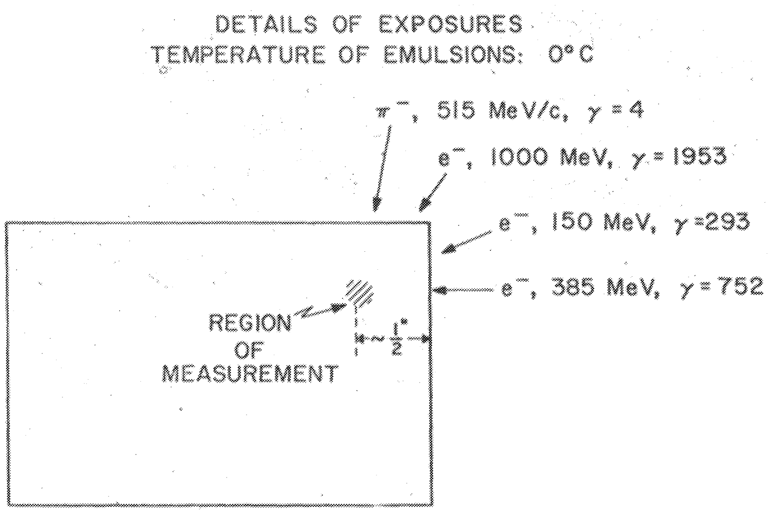
DETAILS OF EXPOSURES
TEMPERATURE OF EMULSIONS: 0°C
π⁻, 515 MeV/c, γ = 4
e⁻, 1000 MeV, γ = 1953
e⁻, 150 MeV, γ = 293
e⁻, 385 MeV, γ = 752
REGION
OF
MEASUREMENT
~ 1/2"

Fig. 1

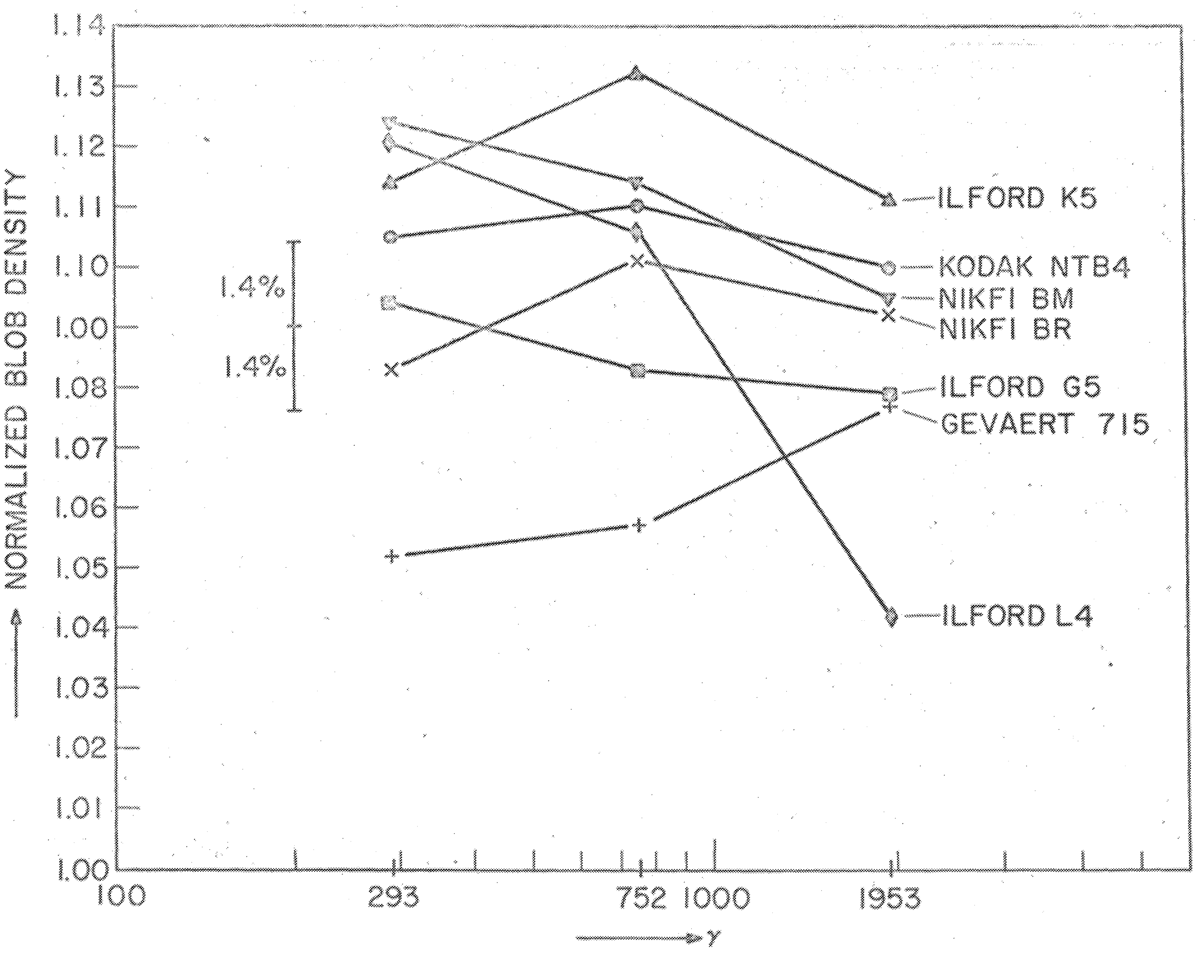
NORMALIZED BLOB DENSITY
1.14
1.13
1.12
1.11
1.10
1.00
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
1.4%
1.4%
ILFORD K5
KODAK NTB4
NIKFI BM
NIKFI BR
ILFORD G5
GEVAERT 715
ILFORD L4
100
293
752
1000
1953
γ

Fig. 2

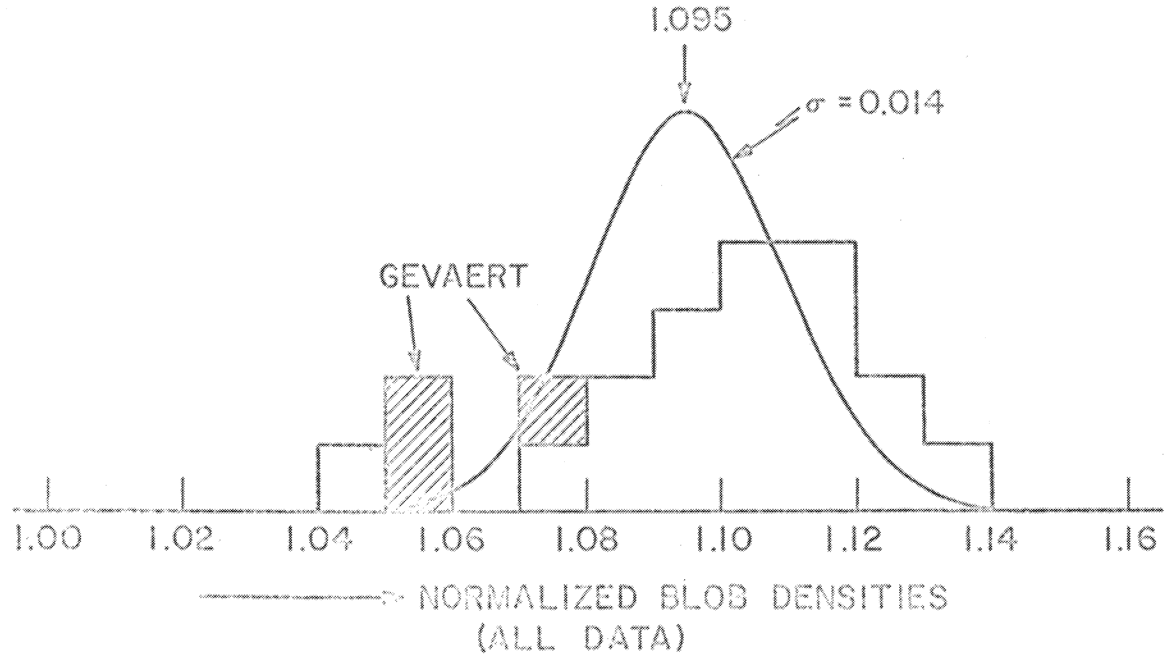
1.095
σ = 0.014
GEVAERT
1.00
1.02
1.04
1.06
1.08
1.10
1.12
1.14
1.16
NORMALIZED BLOB DENSITIES
(ALL DATA)

Fig. 3

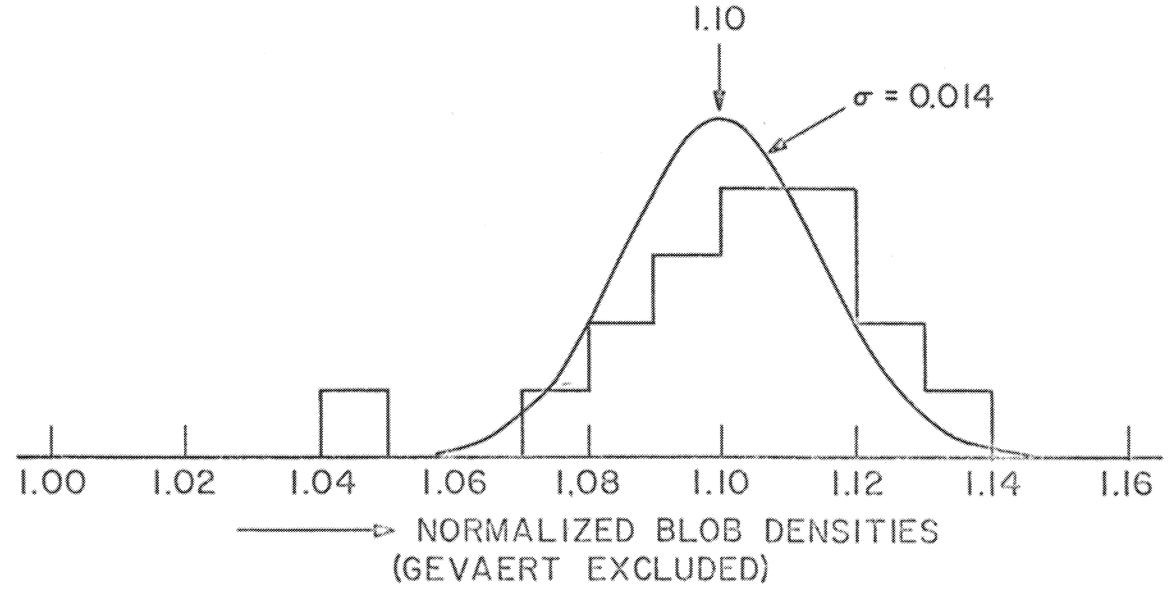
1.10
σ = 0.014
1.00
1.02
1.04
1.06
1.08
1.10
1.12
1.14
1.16
NORMALIZED BLOB DENSITIES
(GEVAERT EXCLUDED)

Fig. 4

SUMMARY TABLE OF AVERAGE BLOB DENSITIES

Emulsion Type	Unprocessed Grain Diameter	$\gamma = 4$	293	752	1953
Kodak NTB4	~ 0.4	19.68	21.74	21.85	21.64
NIKFI BR	0.28	22.56	24.44	24.83	24.63
Ilford G5	0.27	20.65	22.59	22.37	22.28
Ilford K5	0.20	18.575	20.695	21.036	20.637
Gevaert 715	0.15	31.00	32.62	32.76	33.38
NIKFI BM	0.14	22.32	25.09	24.87	24.44
Ilford L4	0.14	19.06	21.36	21.08	19.86

TABLE 1

SUMMARY TABLE OF NORMALIZED BLOB DENSITIES

Emulsion Type	Unprocessed Grain Diameter (μ)	γ				Average
		4	293	752	1953	
Kodak NRB4	0.4	1	1.105	1.110	1.100	1.105
NIKFI BR	0.28	1	1.083	1.101	1.092	1.092
Ilford G5	0.27	1	1.094	1.083	1.079	1.085
Ilford K5	0.20	1	1.114	1.132	1.111	1.119
Gevaert 715	0.15	1	1.052	1.057	1.077	1.062
NIKFI BM	0.14	1	1.124	1.114	1.095	1.111
Ilford L4	0.14	1	1.121	1.106	1.042	1.090
Average (all data)		1	1.099	1.100	1.085	1.095
Average (Gevaert excluded)		1	1.107	1.108	1.087	1.100

TABLE 2