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SYSTEMATICS FOR ELASTIC SCATTERING OF ELEMENTARY PARTICLES

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ABSTRACT*: A relativistically invariant scaling law is proposed which yields elastic-scattering curves for elementary particles very similar in shape to the well-known Morse potential for atomic interactions. The maximum depth of the curves is three times larger for $\bar{p}$-p and π-p scattering than for K^+-p, p-p and n-p; a tentative explanation for this difference is put forward.

In this festival we honor Professor Manuel Sandoval Vallarta. He very early had great foresight in recognizing the importance of planetary physics and cosmic rays to an understanding of the physical world. These were then new-born fields; we are now seeing an explosion of knowledge in these fields.

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* Supplied by the Editor.

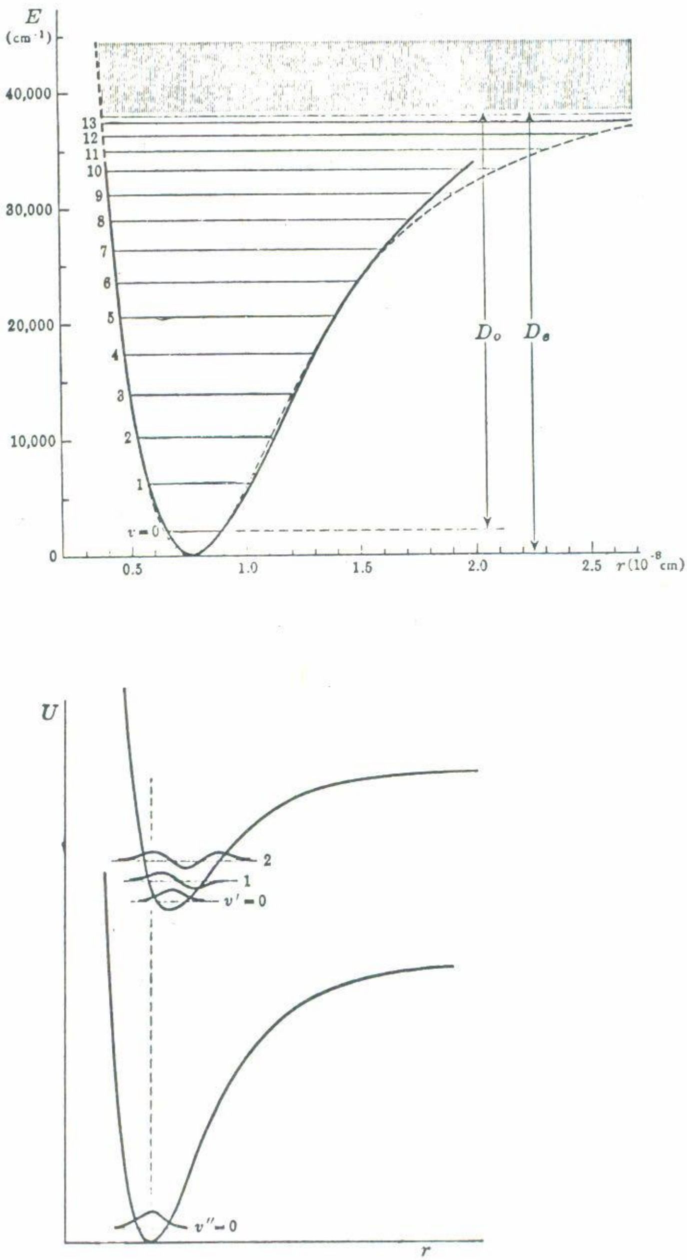

Fig. 1. Examples of the diagram of potential energy (ordinate) versus separation distance (abscissa) for two atomic species, taken from ***Molecular Spectra and Molecular Structure, II. Infrared and Raman Spectra of Polyatomic Molecules***, by Gerhard Herzberg, D. Van Nostrand Co., Inc., Princeton New Jersey, Pp 99 & 199, (1945).

One consequence of research in cosmic rays has been the discovery of almost all of the elementary particles of lifetime about 10^{-10} seconds or longer. Today, beams of these particles are obtained at cosmic-ray energies from the large particle accelerators. The most abundant of particles in such beams are protons, neutrons, positive and negative pions, positive and negative kaons, antíprotons, etc. We shoot particle beams at a proton target and observe scattering, that is, these particles are interacting with protons to result in proton-proton scattering, pion-proton scattering, etc., evidence for interaction energies. How can these interactions be represented?

About 40 years ago, P.M. Morse found a theoretical representation for the interaction energies of various atom pairs as a function of interaction distance between the atoms, $E(r)$ vs r (see Fig. 1). For elementary particles, the many successes of the quark model of an elementary particle has led to speculation as to what forces and potential energies are involved to hold the quarks together. Furthermore, similar forces and potential energies must then be involved to account for particle-particle interaction[1].

We have found[2] that the function $(d\sigma/d \ln t)^{1/2}$ is a scaling law for elastic scattering of elementary particles on protons, and with some justification we have related it to a potential energy $E(r)$ and to an interparticle distance r, according to,

$$E = E_0(d\sigma/d \ln t)^{1/2} ; \quad E_0 = h^2/MV \,, \tag{1}$$

where t is the four-momentum transfer and M and V are a mass and an interaction volume characterizing the two colliding particles. This function is relativistically invariant, as it should be, because we are studying particles at cosmic-ray energies, many times their rest masses.

Why is it appropriate to use elastic scattering? Because the sum total of all interactions between a pair of particles evidences itself in the elastic scattering.

The function (1) has been obtained directly from Fermi's "Golden Rule". The relation of t to an interparticle distance is suggested by the optical model for elastic scattering in which $k\,(k = p/h)$ and r enter symmetrically. Experiments are made by varying k and solving for r_0, but in principle one could vary r and solve for an appropriate k_0. That is,

$$k r_0 = r k_0 ; \quad r/r_0 = k/k_0 = t^{1/2}/(2Mc^2) \,. \tag{2}$$

Figures 2–8 show the scattering data for particle energy of 5–25 GeV plotted according to functions (1) and (2) in the form $E(r)$ vs r. One sees that the potential energy of interaction is zero for large distances, becomes large and negative at intermediate separations, and becomes large and positive at small distances. The similarity of the shapes of the curves leads me to ask the question whether there is a universal scaling function for elementary-particle interactions.[3] If the reduced mass is used in Eq. (1), then the maximum depth of the curve becomes identical for K^+-p, $p-p$, and $n-p$ scattering, while that for $\bar{p}-p$ and pion-proton is about three times larger. I have no firm understanding of this difference but speculate as follows.

In K^+-p, $p-p$, and $n-p$ interaction, annihilation does not occur (no strange particle is known having double positive charge), but in the case of pion-proton and $\bar{p}-p$ interaction annihilation may occur, producing deltas with two charges and zero charge, and pions of total zero charge respectively. Since the diffraction pattern of elastic scattering results from the totality of all interactions including annihilation, the differences in well depths between the two sets of curves may represent the difference between the presence or absence of annihilation.

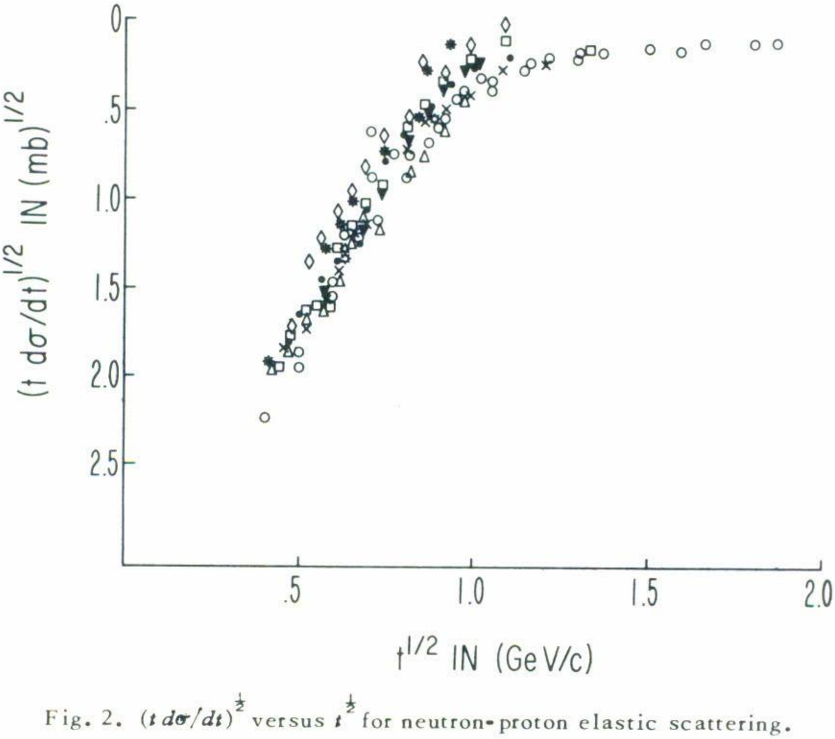

Fig. 2. $(t\, d\sigma/dt)^{\frac{1}{2}}$ versus $t^{\frac{1}{2}}$ for neutron-proton elastic scattering.

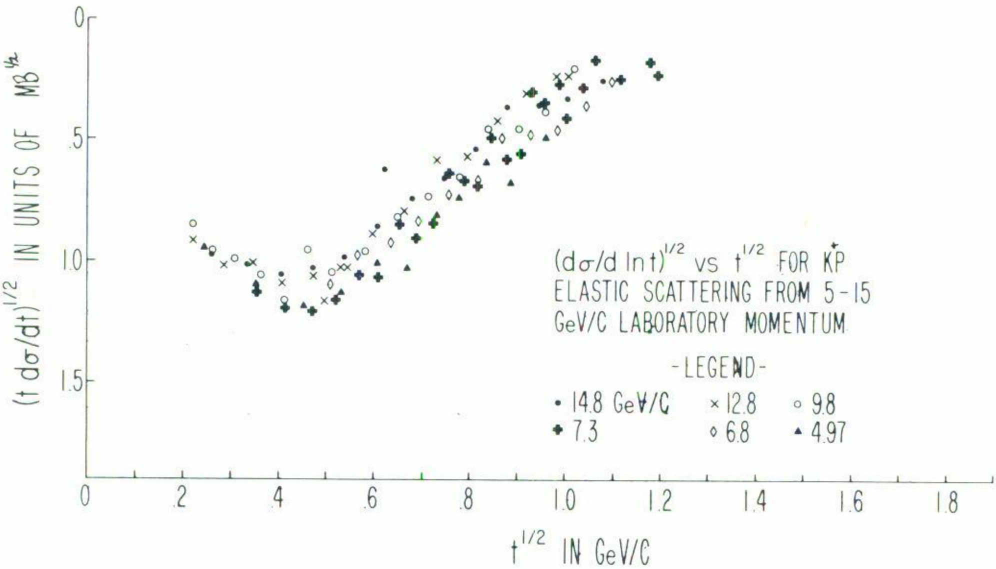

Fig. 3. $(t\, d\sigma/dt)^{\frac{1}{2}}$ versus $t^{\frac{1}{2}}$ for K^+p elastic scattering.

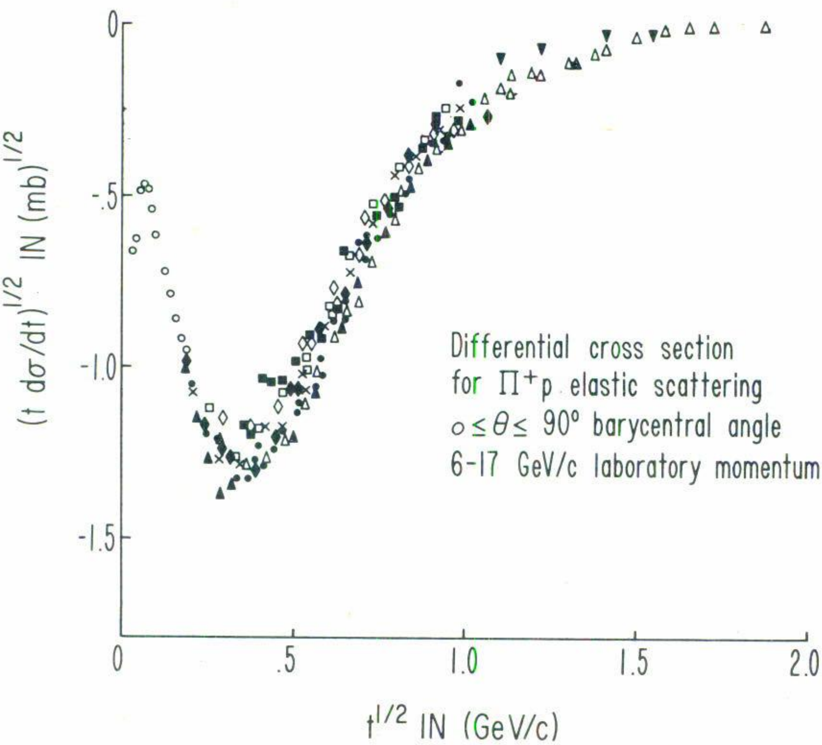

Fig. 4. $(t\, d\sigma/dt)^{\frac{1}{2}}$ versus $t^{\frac{1}{2}}$ for pion (+)–proton elastic scattering.

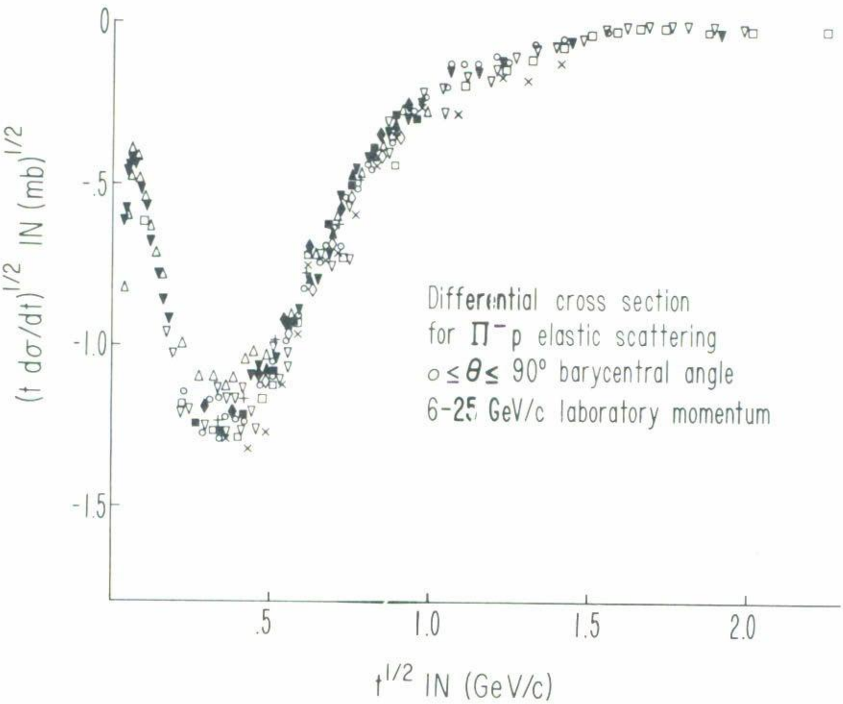

Fig. 5. $(t\ d\sigma/dt)^{\frac{1}{2}}$ versus $t^{\frac{1}{2}}$ for pion (−)-proton elastic scattering.

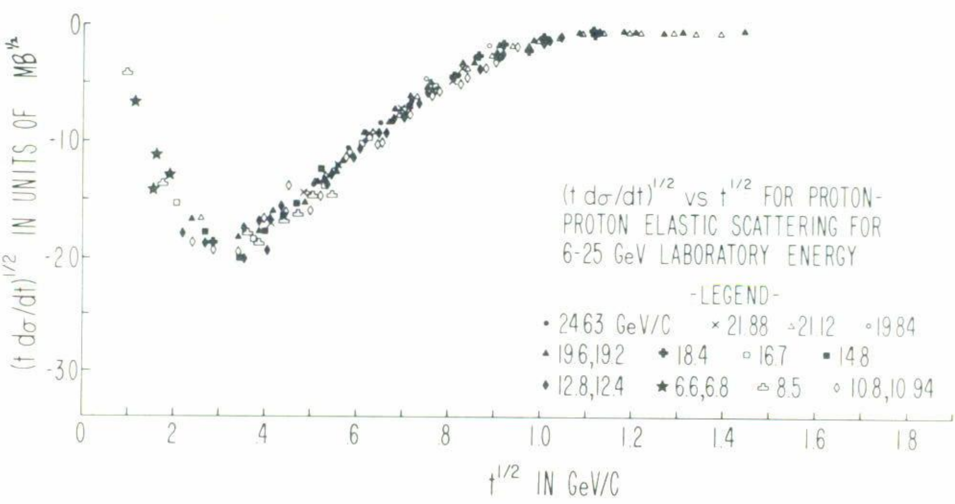

Fig. 6. $(t\ d\sigma/dt)^{\frac{1}{2}}$ versus $t^{\frac{1}{2}}$ for proton-proton elastic scattering.

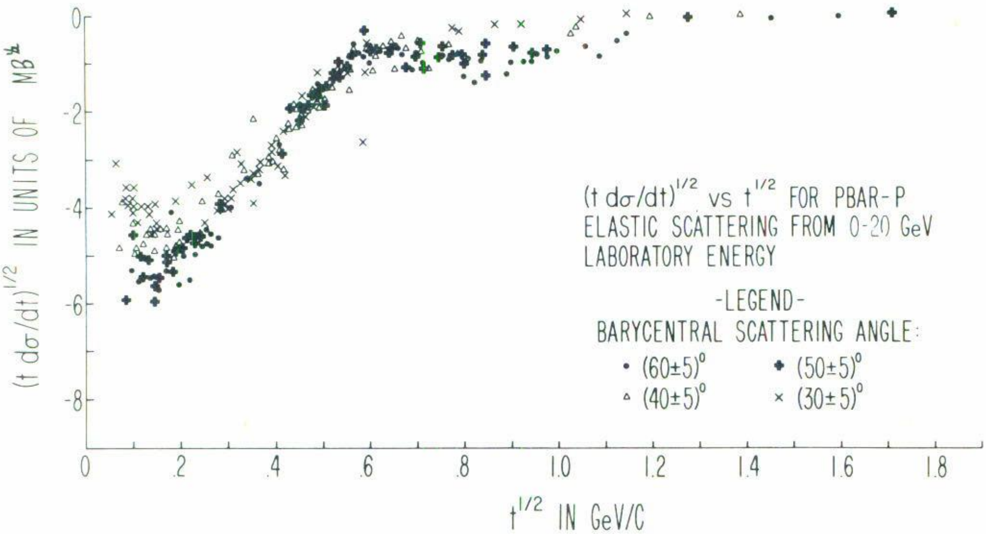

Fig. 7. $(t\,d\sigma/dt)^{\frac{1}{2}}$ versus $t^{\frac{1}{2}}$ for antiproton-proton elastic scattering, at 30 degrees to 60 degrees in the center of mass.

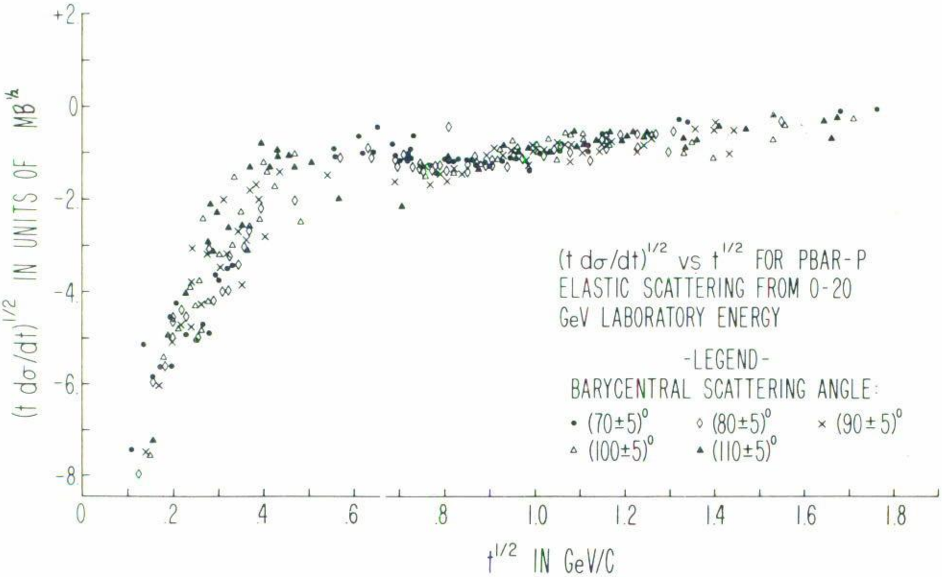

Fig. 8. $(t\,d\sigma/dt)^{\frac{1}{2}}$ versus $t^{\frac{1}{2}}$ for antiproton-proton elastic scattering, at 70 degrees to 110 degrees in the center of mass.

We have enjoyed a feast of exciting papers at this festival to honor Don Manuel and we wish there to be many happy, rewarding Vallarta Festivals to come.

REFERENCES

1. See for example R.P. Feynman, Science **188** (1974) 601.
2. L.M. Libby, Proc. Nat. Acad. Sci. 69 (1972) 3524.
3. I thank Dr. Edward Teller for this suggestion.

RESUMEN*

Se propone una ley de escala relativistamente invariante que proporciona curvas de dispersión elástica entre partículas elementales de forma muy parecida al bien conocido potencial de Morse para interacciones atómicas. La profundidad máxima es mayor por un factor de tres para $\bar{p}-p$ y $\pi-p$ que para $K^{+}-p$, $p-p$ y $n-p$; se ofrece una explicación tentativa para esta diferencia.

* A cargo del editor.