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Authors

Caneschi, L.
Lyon, D.E.
Risk, Clifford.

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L. Caneschi, D. E. Lyon, Jr., and Clifford Risk

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UNIVERSITY of CALIFORNIA BERKELEY

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ANGULAR DISTRIBUTION OF MULTIPARTICLE EVENTS AT

HIGH ENERGY

L. Caneschi^{*+}

Department of Physics
University of California
Santa Barbara, California 93106

D. E. Lyon, Jr.⁺

Department of Physics
University of Michigan
Ann Arbor, Michigan 48104

Clifford Risk[‡]

Lawrence Radiation Laboratory
University of California
Berkeley, California 94720

June 19, 1970

ABSTRACT

Angular distributions of charged secondaries in pp interactions for the energy range 100-800 GeV are compared with the predictions of the d^3p/E distribution.

* Fulbright fellow.

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The development of multiperipheral models has led to a dynamical theory of multiparticle production in which the momentum distribution of a secondary produced in the internal part¹ of the multiperipheral chain has the form

$$d^3N = \frac{d^3p}{E} f(p_T), \quad (1)$$

where p_T is the transverse momentum of the observed particle and E is its energy. This prediction, as well as the consequent logarithmic increase of the average multiplicity with s , is not a unique feature of multiperipheralism. Feynman has proposed the distribution (1) within the context of his parton model, and Cheng and Wu have suggested that (1) follows from the compositeness ideas of Yang and a study of Feynman diagrams.² Experimentally, the possibility of writing d^3N in the factorized form of (1) is suggested by the pion production data at 12.2 GeV by Krisch and collaborators.³

L. W. Jones and collaborators⁴ have measured the characteristics of pp interactions for the incident energy range 100-800 GeV. They have obtained the laboratory angular distribution of the charged secondaries in the variable θ_p --the angle of a secondary relative to the incident beam direction, projected onto a plane. In this letter we compare their experimental distribution with the predictions of (1) using a Monte Carlo generation of events that includes approximate effects of phase space and using the Reggeized multiperipheral model of Caneschi and Pignotti.

In the Monte Carlo generation of events we treat the transverse and longitudinal problems separately. We select the number of secondaries of an event from a Poisson distribution whose average value is $1.14 \ln(E/m_p)$, where E is the laboratory energy of the incident proton. Then we generate

the transverse momenta of the secondaries and nucleons from the distribution³
 $e^{-ap_T^2}$ with a random selection of azimuth angles, making small adjustments to the nucleon azimuth angles and p_T 's in order to conserve p_T . Next we generate the longitudinal momenta of the secondaries from the distribution $dp_L/(p_L^2 + p_T^2 + m_\pi^2)^{\frac{1}{2}}$ and solve for the longitudinal momenta of the nucleons using conservation of p_L and energy. When these two conservation equations have no solution for p_L , we regenerate the largest p_L of the secondaries from $1/E$, and try to solve for the nucleon p_L 's again. We repeat the process until the nucleon p_L 's can be solved for. Figure 1 shows the result. The leading curve is $1/(p_L^2 + p_T^2 + m_\pi^2)^{\frac{1}{2}}$. Curve (a) is the Monte Carlo result. It follows $1/E$ for small p_L and cuts off at large p_L because of the effect of the conservation condition. At larger lab energies, the kinematical limit increases and the distribution approaches $1/E$ over a larger range of p_L .⁵

In Fig. 2 we compare our predicted angular distribution with the data. The theory is too broad, indicating that the p_L distribution has not been cut off sharply enough.⁶

There are several points we wish to make. We have found that the $\ln \tan \theta$ distribution is insensitive to the choice of the transverse distribution $e^{-ap_T^2}$ against e^{-bp_T} and only slightly sensitive to the average p_T value³ p_{T0} ($p_{T0} \sim 0.3-0.4$ GeV/c). On the other hand, it is very sensitive to the p_L distribution. This can be seen in Fig. 3a--small θ corresponds to a large range of $\ln \tan \theta$ and is sensitive to the p_L distribution. Generally, a longitudinal distribution dp_L/E will lead to a flat distribution in $\ln \tan \theta$ when the p_T distribution is peaked about a given value p_{T0} ; i.e.,

$$\frac{dN}{d \ln \tan \theta} \sim \frac{dN}{d[\ln(p_L/p_{TO})]} \sim \text{constant}.$$

The width of the distribution is proportional to $\ln s$. This is illustrated in Fig. 3b, where the distribution of pions alone is shown.

Finally, we mention the approach to a limiting distribution.⁷ Large angle scattering approaches a limit because of the drop off in the p_T distribution (see Fig. 3a). Large lab angles ($\sim 45^\circ$) correspond to small $\ln \tan \theta$ (~ 0). In Fig. 3b we see that the η distribution at small values is approaching a limit, while the large negative η distribution progresses to the left with increasing lab energy.

A detailed Reggeized multiperipheral model for production process was developed by Alberto Pignotti and one of the authors.¹ This model gives a very satisfactory fit to the 30 GeV pion production data,^{8,9} even though the number of parameters is kept as low as possible. The $dN/d\eta$ distribution predicted is shown in Fig. 2. The fit is quite good, even though the parameters from the 30 GeV fit have been kept fixed and the model has been extrapolated to 175 GeV. The width of the η distribution is narrower than that of the Monte Carlo model because the pion p_L distribution drops off more rapidly [Fig. 1, curves (b)]. This effect could be due to the multi-Regge dynamics of the model, but is probably due to the careful handling of phase space implicitly built into the CP model. We have found that the data of Fig. 2 is predominately accounted for by pions produced from the internal meson exchange. This mechanism, being multiperipheral, produces a distribution in agreement with Eq. (1) for small $p_L/(s)^{\frac{1}{2}}$. The baryon exchange mechanism was found to be of less importance.

In conclusion, we wish to emphasize that it is our view that the momentum distribution $\partial^2 N(p_L, p_T) / \partial p_L \partial p_T$ of particle production processes at high energies is determined by (a) a sharp drop off in p_T , (b) Lorentz invariance in p_L , and (c) phase space effects. While at lower energies particular effects--such as resonance production, particle correlations,¹⁰ specific orderings of exchange Reggeons along the chain, or end effects--may play important roles, we believe that the relative importance of these effects will decrease at large energies and be dominated by the principles mentioned above.

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FOOTNOTES AND REFERENCES

1. The distribution of Eq. (1) is restricted to pions produced in the internal part of the chain because of possible modifications to the spectrum from "end effects," the relative importance of which should decrease with increasing energy. Here we refer to the multiperipheral baryon exchange mechanism suggested by L. Caneschi and A. Pignotti [Phys. Rev. Letters 22, 1219 (1969)]--hereafter referred to as CP--or to the duality-related mechanism of baryon resonance production advocated by E. Berger and E. Yen [Phys. Rev. Letters 21, 695 (1970)].
2. The distribution (1) cannot hold for all pions for momenta up to the kinematical limit because of phase space effects--the overall delta functions of conservation of energy and momenta constrain the larger momenta. Cheng and Wu have verified Eq. (1) for pions with center of mass p_L satisfying $p_L < \frac{m_\pi}{m_N} (s)^{\frac{1}{2}}$.
3. J. L. Day et al., Phys. Rev. Letters 23, 1055 (1969). However, at this energy end effects should be quite large, as suggested by the observed forward π peak. This peak can be interpreted in terms of the baryon production mechanism of Berger and Yan and in terms of the baryon exchange mechanism of CP. In this latter model, the low intercept of nucleon trajectory and the $1/s$ decrease of the $p\bar{p}$ annihilation cross section keep the subenergy of the end fireball low, and this simulates the effect of a low Q resonance.
4. L. W. Jones et al., Multiparticle Production in Liquid Hydrogen by Charged Cosmic Hadrons of Energy Greater than 70 GeV (to be published).
5. This approach to $1/E$ is consistent with the inequality of Cheng and Wu.

6. We are currently incorporating n-body phase space exactly with the Berkeley SAGE program.
7. J. Benecke et al., Phys. Rev. 188, 2159 (1969).
8. E. W. Anderson et al., Phys. Rev. Letters 19, 168 (1967).
9. In this kind of experiment the higher multiplicity events play an important role (more so for example, than they do in a unitarity calculation of the imaginary part of the elastic amplitude). Consequently, average subenergies are quite small. For large multiplicities and small s_i , the CP amplitude reduces to phase space and is consistent with the analysis of Czyzewski (Herceg-Novi Summer School Lectures, 1969).
10. Particle correlations will also be important in the momentum distributions of multiple pions produced in individual events.

FIGURE CAPTIONS

- Fig. 1. Longitudinal momentum distributions for pions with $p_T = 0.4$ GeV/c at incident lab energies of 175 GeV and 515 GeV. The leading curve is $1/[p_L^2 + (0.4)^2 + m_\pi^2]^{1/2}$, curve (a) is the prediction of the Monte Carlo model, and curve (b) is the prediction of the CP model with meson exchange.
- Fig. 2. Angular distribution in the variable $\ln(\tan \theta)$ at 175 GeV. The solid line refers to the Monte Carlo model, and the dashed line to the CP model. (Each event produces several charged tracks.)
- Fig. 3. Characteristics of angular distributions (a) The angular variable $\eta = \ln \tan \theta = \ln p_T/p_L$, which for small θ is sensitive to the p_L distribution. (b) $\ln(\tan \theta)$ distributions for pions predicted by the two models at 175 GeV and 515 GeV.

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Fig. 1.

Fig. 2.

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Fig. 3a.

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Fig. 3b.

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