$p\bar{p}$ collisions and e^+e^- annihilation at high energies and the hydrodynamic theory

I. L. Rozental' and Yu. A. Tarasov

Institute of Cosmic Research, Academy of Sciences of the USSR

(Submitted 6 March 1982)

Pis'ma Zh.Eksp. Teor. Fiz. **35**, No. 8, 349–351 (20 April 1982)

Experimental data at the highest attainable energies of colliding $p\bar{p}$ and e^+e^- beams are compared with the hydrodynamic theory for multiple-production processes. It is shown that the theoretical predictions agree with experimental data obtained from colliding beams.

PACS numbers: 13.65. + i, 13.85.Hd, 12.40.Ee

According to the hydrodynamic theory,[1] multiple-production processes go through three stages: 1—a dissociation of the primary hadrons into their constituents; 2—an interaction between the constituents; 3—a conversion of the constituents into secondary hadrons. The basic task of the theory for multiple production is to develop models for these stages.

TABLE I.

$\sqrt{s}$ (GeV)	5	7	9	11	15	19	23	31	35	39
$\langle N_{ch}^{e^+e^-}\rangle$	4,3 ± 0,3	5,5 ±0,2	6,0 ± 0,15	6,7 ±0,15	7,8 ±0,15	8,7 ± 0,2	9,6 ± 0,2	11,2 ± 0,2	11,8 ± 0,2	12,4 ± 0,2
m_x/m_p	0,27	0,36	0,31	0,33	0,32	0,31	0,32	0,32	0,32	0,31

The various characteristics of multiple-production processes are determined to varying degrees by the different stages. According to the hydrodynamic theory, the average charged-particle multiplicity $\langle N_{ch}\rangle$ is determined primarily in the first stage. The distribution in the rapidity y (or in the pseudorapidity η) is governed by the second and third stages. The increase in the average transverse momentum $\langle p_\perp\rangle$ with increasing energy E_L of the primary particle is determined almost entirely by the second stage, i.e., that of the hydrodynamic expansion. The functional dependence $\langle p_\perp\rangle(E_L)$ is therefore the acid test of the hydrodynamic concept, and the increase in $\langle p_\perp\rangle$ with increasing energy is an important consequence of the transverse hydrodynamic motion.

We will examine these three characteristics, since they were measured on a $p\bar{p}$ colliding-beam accelerator which was recently started up, at a total c.m. energy $\sqrt{s}=540$ GeV ($E_L\sim 150$ TeV) of the colliding particles.[2,4] It turns out that at this energy the average transverse momentum is[1)] $\langle p_\perp\rangle\sim 500$ MeV, while at $E_L\sim 1$ TeV (the Intersecting Storage Ring) the average transverse momentum is $\langle p_\perp\rangle\sim 370$–$400$ MeV.

Numerical calculations[5,6] in the quasi-one-dimensional approximation[7] yield $\langle p_\perp\rangle = 380$ MeV at $E_L\sim 1$ TeV and $\langle p_\perp\rangle = 480$ MeV at $E_L\sim 150$ TeV. These results correspond to an extremely slow increase, $\langle p_\perp\rangle\propto E_L^{1/14} - E_L^{1/12}$. (We recall that the quasi-one-dimensional approximation is based on the assumption that the longitudinal motion is quasi-one-dimensional and is determined by the hydrodynamics, while the transverse motion is governed by the thermal energy spread.)

At energies $E_L\lesssim 100$ GeV, the average multiplicity $\langle N_{ch}\rangle$ is determined by the exact values of the statistical weights, while at energies $100\lesssim E_L\lesssim 1000$ GeV the functional dependence $\langle N_{ch}\rangle(E_L)$ is joined with the function $aE_L^{1/4}$ (a = const). If we eliminate the primary nucleons, which are not part of the statistical system (the leading particles),[2)]

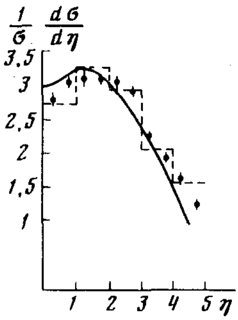

FIG. 1.

then the theory at $E_L \sim 150$ TeV yields the value $\langle N_{ch}\rangle \sim 30$-32, while the experimental value is $\langle N_{ch}\rangle = 27,4 \pm 2$.

Figure 1 shows experimental and theoretical (curve) distributions in the pseudorapidity η. The theoretical calculations were carried out from the following expression in the quasi-one-dimensional approximation:

$$\frac{dN}{d\eta} = \frac{\langle N_{ch}\rangle (2\pi \bar{L})^{-1/2}}{\sum\limits_{n=1}^{\infty} \frac{K_2(n)}{n}} \int\limits_0^{\infty} \frac{x^2 \sqrt{1+x^2}\, dx}{\sqrt{x^2 + (\mathrm{ch}\eta)^{-1}}} \sum_{m=1}^{\infty} K_1(m\sqrt{1+x^2}) \cdot$$

$$\times \exp\left\{ - \frac{\mathrm{Ar\,th}^2\left(\frac{x\,\mathrm{th}\,\eta}{\sqrt{x^2 + (\mathrm{ch}\,\eta)^{-1}}}\right)}{2\bar{L}} \right\}, \qquad (1)$$

where K_1 and K_2 are the Bessel functions, $\bar{L} = (3/4)\ln E_L/m_p$, and m_p is the nucleon mass.

We turn now to the data on e^+e^-annihilation. In th energy range $\sqrt{s} \sim 10$-40 GeV, a striking similarity has been observed between this process[9-11] and pp interactions (if leading particles are eliminated from them) in terms of the following characteristics: the multiplicity, the inclusive spectra, and the two-jet nature of the distribution in $p_\perp$. There are also indications of a slight increase in $\langle p_\perp \rangle$ with the energy.

This analogy suggests a hydrodynamic description of both processes. For the e^+e^- annihilation, however, the absence of a characteristic mass presents a difficulty (this difficulty does not arise in pp collisions). The mass m_x for the annihilation should therefore be left as a free parameter. Using the quark-gluon interpretation of hydrodynamic theory,[12] we can derive the following expression for the secondary-particle multiplicity $\langle N_{ch}^{e^+e^-}\rangle$ in e^+e^-annihilation:

$$\langle N_{ch}^{e^+e^-} \rangle \simeq 2,7\left(\frac{m_x}{m_p}\right)^{1/4}\left(\frac{\sqrt{s}}{m_p}\right)^{1/2}. \qquad (2)$$

Comparison of this expression with experimental data[11] yields m_x (see Table I). We see from the table that m_x is approximately $(1/3)m_p$; i.e., it is approximately equal to the mass of a constituent quark. This agreement may not be simply fortuitous.

In summary, the basic characteristics of multiple-production processes agree with the hydrodynamic theory.

[1)]This value was found by an indirect method.

[2)]See Ref. 8 for a more detailed description of the method for calculating $\langle N_{ch}\rangle$.

1. L. D. Landau, Izv. Akad. Nauk SSSR, Ser. Fiz. **17**, 51 (1953).
2. K. Alpgard *et al.*, Phys. Lett. **107B**, 310 (1981).
3. K. Alpgard *et al.*, Phys. Lett. **107B**, 315 (1981).
4. G. Aruison *et al.*, Phys. Lett. **107B**, 320 (1981).
5. G. A. Milekhin, Zh. Eksp. Teor. Fiz. **35**, 1185 (1958) [Sov. Phys. JETP **35**, 829 (1959)].

6. V. P. Volzhenskaya and L. I. Sarycheva, Izv. Akad. Nauk SSSR, Ser. Fiz. **30**, 1954 (1966).
7. I. D. Rozental', Zh. Eksp. Teor. Fiz. **31**, 278 (1956) [Sov. Phys. JETP **4**, 217 (1957)].
8. E. I. Daibog, I. L. Rosental, and Yu. A. Tarasov, Fortschr. Phys. **27**, 313 (1979).
9. M. Basile *et al.*, Phys. Lett. **99B**, 247 (1981).
10. M. Basile *et al.*, Lett. Nuovo Cimento **31**, 273 (1981).
11. M. Basile *et al.*, Nuovo Cimento **65A**, 400 (1981).
12. Yu. A. Tarosov, Yad. Fiz. **34**, 211 (1981) [Sov. J. Nucl. Phys. **34**, 119 (1981)].

Translated by Dave Parsons
Edited by S. J. Amoretty