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ESTIMATE OF PARTICLE PRODUCTION IN 200 GEV PROTON PROTON COLLISIONS

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In the past few years several procedures have been proposed to estimate production cross sections in very high energy collisions. These procedures all consist of parameterizing existing data at 10 → 30 GeV in the lab and then extrapolating this fit to 200 GeV. This requires an extrapolation over a range of about 10.

Very recently the production cross section in proton proton collisions was measured in the center of mass system. The experiment was done at a laboratory momentum of 12.5 GeV/c and a center of mass energy of $W = 5.03$ GeV. At 200 GeV the center of mass energy is 19.42 GeV. Thus if the extrapolation is done in the center of mass it is only necessary to extrapolate over a range of less than 4. Hopefully this shorter range extrapolation will be more reliable. In addition, this experiment suggests a simpler parameterization of the data in terms of two "fireballs," which makes the extrapolation more straightforward and reliable.

The recent center of mass production experiment consisted of measuring $d^2\sigma/d\Omega dp$ for the production of pions, kaons, and antiprotons in proton proton collisions. A series of measurements was taken with P_ℓ^{cm} held fixed at .6 GeV/c while $P_\perp^2$ was varied between 0.1 and 1.5 $(GeV/c)^2$. These results are presented in Figure 1. It can be seen that $d^2\sigma/d\Omega dp$ is a Gaussian in $P_\perp$

$$\frac{d^2\sigma}{d\Omega dp} = A\ e^{-BP_\perp^2}$$

We also find that the slope B is about 3.5 $(GeV/c)^{-2}$ for all the produced particles except the K^+.

Next a set of measurements was made with $P_\perp^2$ held fixed at .4 $(GeV/c)^2$ while P_ℓ^{cm} was varied from 0.0 to 1.0 GeV/c. These results are shown in Figure 2. The data show clearly that the produced particles are peaked about a forward value of P_ℓ equal to about 450 MeV/c. There is a similar backward peak due to the symmetry of the p-p system. Thus we have the result that almost all of the produced particles come out in two clouds or "fireballs."

The first step in the parameterization of this data is to search for a Lorentz frame in which the cross section peaks at $P_\ell = 0$. This we will "define" as the rest frame of the fireball. This search was made, and we found that the "correct" Lorentz frame is moving with $\beta = .54$ with respect to the center of mass system. The cross sections have been transformed into this system and are shown in Figure 3, where we plot $d^2\sigma/d\Omega dp$ against $\left[P_\ell^{Fireball}\right]^2$.

There are two interesting bits of information to be gained from this plot. First we can obtain the mass of the fireball by noting that in the center of mass it is moving with $\beta = .54$ and has a total energy of $E = W/2 = 2.51$ GeV. The mass of the fireball is given by

$$M_F = E\sqrt{1-\beta^2} = 2115 \text{ MeV} \quad .$$

Next we observe that in Figure 3 $d^2\sigma/d\Omega dp$ appears to be more or less Gaussian in P_ℓ, just as it is Gaussian in $P_\perp$. In the direction of forward P_ℓ we have

$$\left.\frac{d^2\sigma}{d\Omega dp}\right]_F^{\text{forward}} \simeq e^{-3.5\, P_\ell^2} \quad .$$

Thus in the forward direction the longitudinal distribution has the same momentum dependence as the transverse distribution. If this were also true for the backward longitudinal distribution, then the cross section would be isotropic and Gaussian in the fireball rest frame. However, we find that in the backward direction the cross section drops off much more steeply. In fact

$$\left.\frac{d^2\sigma}{d\Omega dp}\right]_F^{\text{Backward}} \sim e^{-10P_\ell^2} \quad .$$

Thus in the fireball rest frame the distribution is

(a) Gaussian in P_{fireball}

(b) Isotropic along the front three axes but flattened along the back axis.

In Figure 4 we show this semi-isotropy with the backward flattening. The reason for the backward flattening is not understood.

To simplify the extrapolation to 200 GeV we will assume that $d^2\sigma/d\Omega dp$ is completely isotropic in the fireball rest frame. This will not significantly change the laboratory spectrum and will make calculations much easier.

We are now in a position to estimate the production cross section at 200 GeV using the following information about the "fireball" at E = W/2 = 2.51 GeV:

(a) $d^2\sigma/d\Omega dp$ is essentially isotropic in the fireball rest frame.

(b) $d^2\sigma/d\Omega dp$ is Gaussian with a slope of 3.5 $(GeV/c)^{-2}$.

(c) The fireball has a mass of 2115 MeV.

Thus if P_F is the momentum of the produced particle in the fireball rest frame, we can write

$$\left.\frac{d^2\sigma}{d\Omega dp}\right]_F \approx A\, e^{-3.5\, P_F^2} .$$

The extrapolation also requires the following assertions:

(a) The momentum distribution in the fireball rest frame does not change in going from 12.5 to 200 GeV.

The evidence for this assertion comes from the fact that the average transverse momentum of produced particles is constant, even at cosmic ray energies. The experimental evidence for this is shaky but very widespread. It is probably true at least approximately. Now notice that since $P_\perp$ is Lorentz invariant the distribution of $P_\perp$ in the fireball rest frame also does not change. Then if the forward P_ℓ distribution continues to be similar to the $P_\perp$ distribution we have that at high energy $d^2\sigma/d\Omega dp$ is still an almost isotropic Gaussian with slope 3.5 $(GeV/c)^{-2}$.

(b) The charged multiplicity changes from about 3 at 12.5 GeV/c to about 6 at 200 GeV.

The evidence for this again comes from cosmic ray experiments which are rather shaky. The data is presented in Figure 5. The important fact is that the multiplicity changes by a factor of 2 over this range. This is probably correct to within 20%.