The Analysis of PT Distributions at the CERN pp Collider

MEMOIRS OF THE FACULTY OF ENGINEERING
FUKUI UNIVERSITY
VOL. 34 No. 1 1986

The Analysis of p_T Distributions at the CERN $p\bar{p}$ Collider

Takayuki FUKUSHIMA*, Kiyoshi KUDO*, Ryoku NAKAMURA**
and Seibun SASAKI*

(Received Feb. 28, 1986)

In 1982, the detail transverse momentum (p_T) distributions of charged particles were measured at CERN $p\bar{p}$ collider.[1),2)] The colliding energy at this experiment was higher than that of ISR by one order[3)], and at this experiment we firstly got the semi-inclusive data about the p_T distributions of charged particles produced in $p\bar{p}$ reaction, which make us possible to analyse the multiplicity depending behaviour of the p_T distributions. In this paper, we analyse the p_T distributions of charged particles at ISR and at CERN $p\bar{p}$ collider using Two-component model, which is based on thermodynamical model and includes two temperature parameters. Our model accounts well the behaviour of multiplicity and energy dpendences of p_T distributions. It is found that two temperature parameters contained in the model are slowly increasing functions of multiplicity and energy. However the rate of them is almostly constant.

The p_T spectra measured in these experiments have the following characteristic properties;
(a) The invariant cross sections, which are functions of p_T, decrease sharply as p_T increases at low p_T region, but the rate of decreasing is moderate at higher p_T region.
(b) As the multiplicity increases, p_T spectrum becomes flatter and the entire cross section increases.

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* Dept. of Applied Physics
** Fukui Prefectural College

(c) As the incident energy increases, p_T spectrum becomes flatter and entire cross section increases.

From property (b), the mean p_T value $\langle p_T \rangle$ increases as the multiplicity increases, but if energy and momentum are conserved, $\langle p_T \rangle$ should decrease like 1/n as the multiplicity increases. Therefore, the property that $\langle p_T \rangle$ increases with multiplicity, reflects the dynamics concerning with mechanism of creating particles.

When we analyse p_T distributions, it is convenient to divide p_T domain into three regions as follows;

(1) Low p_T region

This is a region of $p_T \leqq 1$ (GeV/c). In this region, p_T distributions are well described by exponential-like decreasing function $\exp(-\alpha M_T)$. Since most particles produced are pions, we are to consider pion gas. As pions obey Bose-Einstein statistics, the invariant cross section might be expected to have the form;

$$E\, d^3\sigma\, /dp^3 = A[\exp(\alpha M_T)-1]^{-1} \ , \qquad (1)$$

where

$$M_T = (p_T{}^2 + m^2)^{1/2} \ , \qquad \text{m: pion mass} \qquad (2)$$

and α is a parameter which has the dimension of inverse of temperature. This model is known as "thermodynamical model".[4),5)]

(2) Intermediate p_T region

This is the region of $1 \leqq p_T \leqq 4$ (GeV/c). 4 (GeV/c) is about ten times mean p_T value.

(3) High p_T region

This is the region of 4 (GeV/c)$\leqq p_T$. In this region invariant cross section is supposed to be explained by the hard collision model of quarks based on QCD. Due to this model the invariant cross section is considered to decrease as $p_T{}^{-8}$.[6)]

There are attempts to reproduce the data in the whole region. One of them is the QCD parametrization.[1),2)] There taking account that the hard collision model explains high p_T region well, the following empirical formula is assumed;

$$E\, d^3\sigma\, /dp^3 = A(b+p_T)^{-a} \ , \qquad (3)$$

where $a \fallingdotseq 8$, $b \fallingdotseq 1$.

In high p_T region eq.(3) behaves like $p_T{}^{-8}$. In accoordance with the hard collision model it is hard to give some physical meaning to the formula in low p_T region. And in low p_T region we must admit the exponential-like behaviour of invariant cross section. That is, the p_T^{-8} formula like eq.(3) should be considered to hold only in high p_T region. From experimental data, it seems that the behaviour of p_T spectra in intermediate region resembles the behaviour in low p_T region, so we should consider low p_T region and intermediate p_T region together. As we mentioned before, the thermodynamical distribution decreases sharply as p_T increases, in rather higher p_T region, this exponential-like distribution does not contribute to invariant cross section. To accomdate both the low p_T region and the intermedeate p_T region, we consider there is another state whose temperature is higher than ordinary temperature, and we expect, even in inetermediate p_T region, a kind of thermodynamical model is valid. Our two-component model is composed of these two component; the first component is the thermodynamical distribution of ordinary temperature and is dominant in low p_T region, and the second component is the thermodynamical distribution of higher temperature and is dominant in intermediate p_T region. We call the former the ordinary state and the latter the hot state. In this model, the invariant cross section becomes

$$E\, d^3\sigma_{ny}/dp^3=A\{(1-R)[\exp(\alpha M_T)-1]^{-1}+R[\exp(\beta M_T)-1]^{-1}\}\ , \quad (4)$$

where n_y is the multiplicity per unit rapidity and $R(n_y,s)$ is the ratio defined by

$$R=\sigma_H/(\sigma+\sigma_H), \quad (5)$$

where σ_H is the cross section for producing hot temperature state and σ is the cross section for producing ordinary temperature state, and $\alpha\,(n_y,s)$ is the temperature parameter of ordinary state and $\beta\,(n_y,s)$ is the temperature parameter of hot state.

These parameters are decided to fit eq.(4) with the data from the experiments at CERN $p\bar{p}$ collider and at ISR. The results are shown in Figs. 1a-1c, Fig. 2, and the values of parameters are tabulated in Table 1.

As is shown in Figs. 1a-1c, Fig. 2, eq.(4) reproduces experimental data well from low p_T region to intermediate p_T region. Further we calculated the mean values of p_T at each n_y, and the results are also shown in Table 1. These values show good accordance with the experimental results. From these analyses, we conclude that

(1) The rate R is small and is increasing function of multiplicity and energy. In higher energy and higher multiplicity experiments, we can find the second component more clearly.

(2) The temperature of ordinary state, T and the temperature of hot state, T_H, are both increasing function of multiplicity and energy but their rate $\gamma = T_H/T$ has almostly constant value 2~3. This means the temperature of the hot state is a few times higher than that of the ordinary state.

Acknowledgments

We are grateful to the members of the elementary particle group of Fukui University.

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Table caption

Table 1. Fit parameters at $\sqrt{s}$ = 540 GeV for the different multiplicities.

Figure captions

Fig. 1a. The invariant cross sections as a function of p_T for charged hadrons($\sqrt{s}$ = 540 GeV) for n_y=2.4 . The solid line is our calculation based on eq. (4).

Fig. 1b. The invariant cross sections as a function of p_T for charged hadrons($\sqrt{s}$ = 540 GeV) for n_y=5.7 . The solid line is our calculation based on eq. (4).

Fig. 1c. The invariant cross sections as a function of p_T for charged hadrons($\sqrt{s}$ = 540 GeV) for n_y=10.2 . The solid line is our calculation based on eq. (4) .

Fig. 2. The invariant cross sections as a function of p_T for charged pions($\sqrt{s}$ = 63 Gev) . The solid line is our calculation based on eq. (4) with $A = 2.88 \times 10^{-25}$, $R = 0.016$, $\alpha = 7.47$, $\beta = 3.15$, and $\gamma = 2.37$.

Table 1.

$\langle n/\Delta y\rangle$	A ($10^{-25} cm^2 GeV^{-2} c^3$)	R	α	β	γ	$\langle p_T\rangle_n$ (GeV/c)	χ^2	Degree of freedom
2.4	2.43 ± 0.05	0.040 ± 0.002	5.68 ± 0.05	2.76 ± 0.02	2.06	0.389	30	40
5.7	2.44 ± 0.04	0.053 ± 0.001	5.10 ± 0.04	2.46 ± 0.01	2.08	0.434	36	40
10.2	2.23 ± 0.04	0.060 ± 0.002	4.77 ± 0.04	2.26 ± 0.01	2.11	0.463	26	39

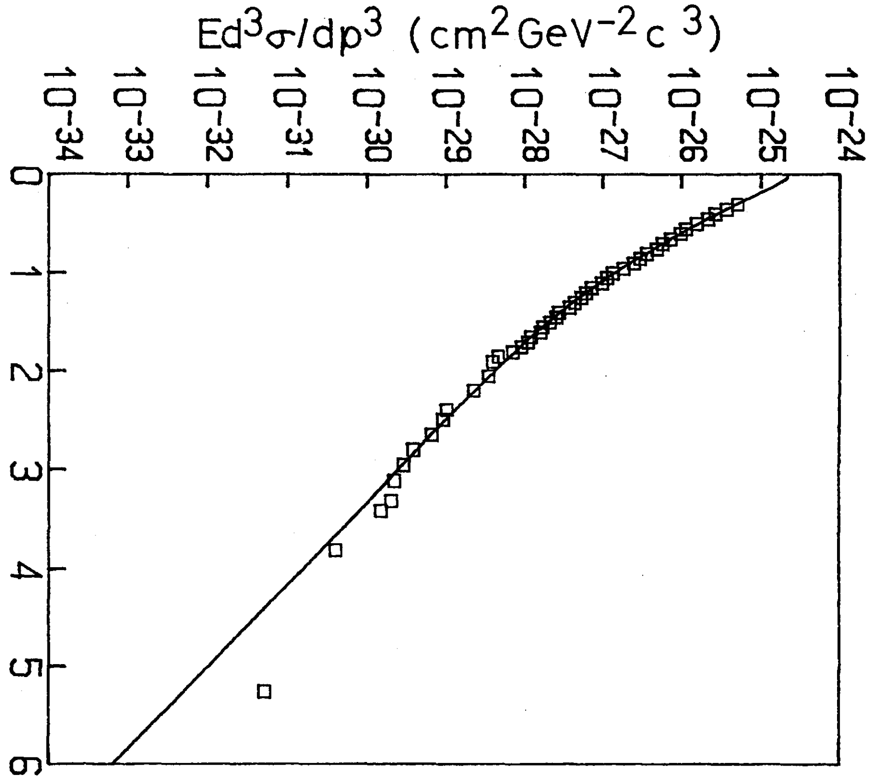
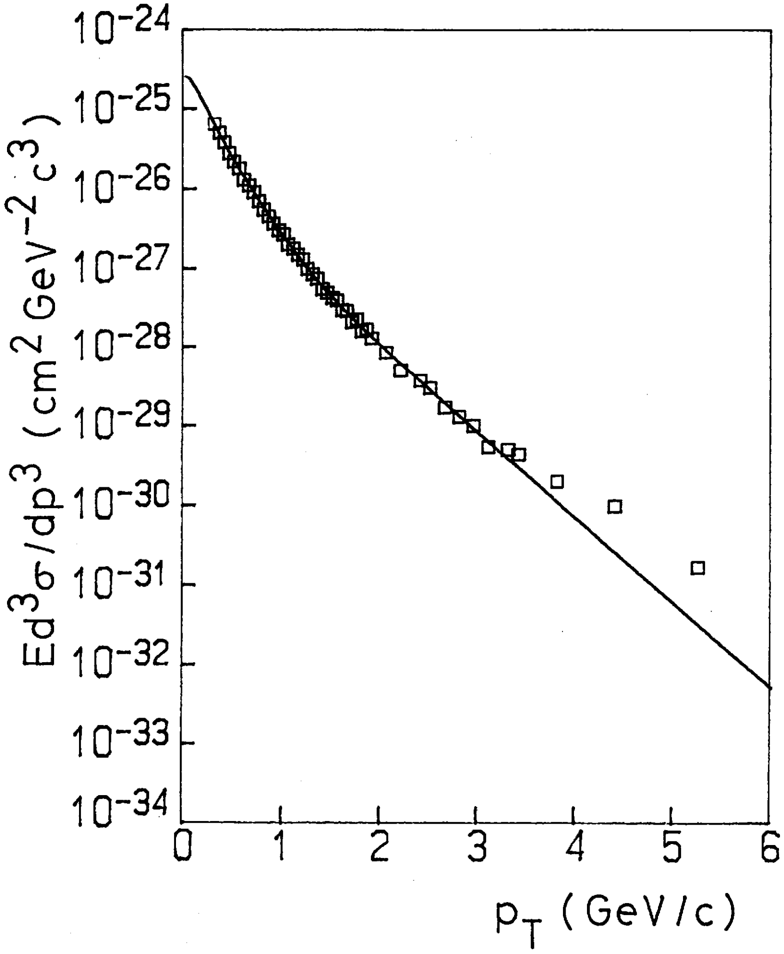


Fig. 1a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10^{-32}
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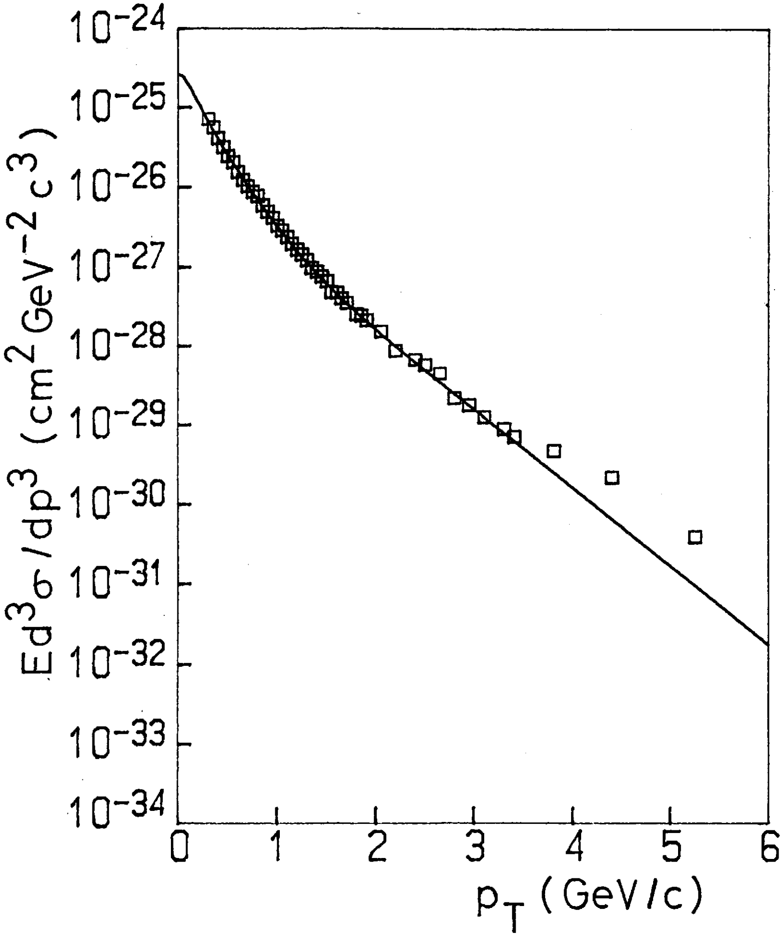
0 1 2 3 4 5 6
p_T (GeV/c)

Fig. 1b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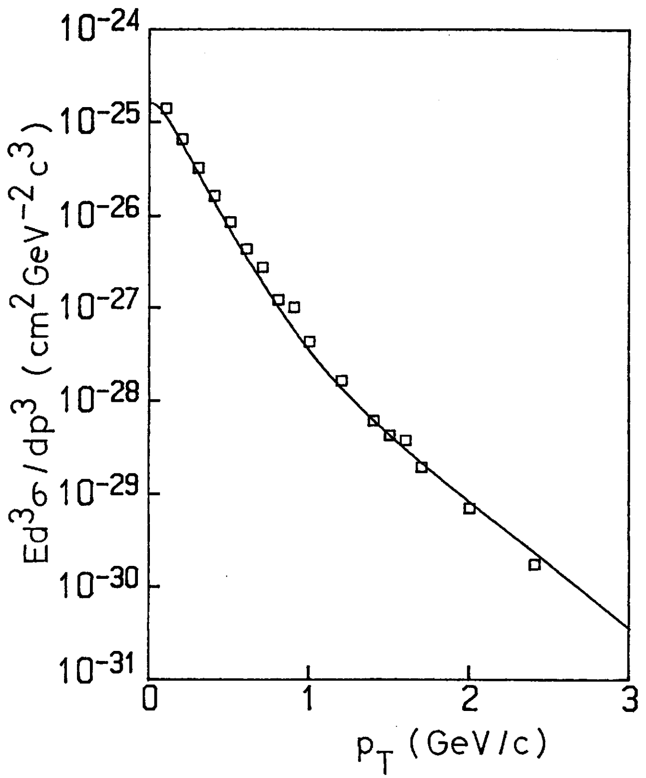
$Ed^3\sigma/dp^3$ $(cm^2\,GeV^{-2}\,c^3)$
0 1 2 3 4 5 6
p_T (GeV/c)

Fig. 1c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10^{-27}
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10^{-29}
10^{-30}
10^{-31}
$Ed^3\sigma/dp^3$ $(cm^2 GeV^{-2} c^3)$
0
1
2
3
p_T (GeV/c)

Fig. 2