Lawrence Berkeley National Laboratory

Recent Work

Title

PARTITION TEMPERATURE AND ENERGY CONSERVATION OF PARTICLE PRODUCTION

Permalink

<https://escholarship.org/uc/item/49r209g5>

Authors

Hoang, T.F.
Cork, B.

Publication Date

1986-02-01

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

FEB 20 1986

Submitted to Zeitschrift fuer Physik

PARTITION TEMPERATURE AND ENERGY CONSERVATION OF PARTICLE PRODUCTION

T.F. Hoang and B. Cork

February 1986

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks*

LBL-21115
c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

PARTITION TEMPERATURE AND ENERGY CONSERVATION OF PARTICLE PRODUCTION*

T.F. Hoang

1749 Oxford Street, Berkeley, CA 94709

and

Bruce Cork

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

February 1986

- * This work was supported in part by the Director, Office of Energy Research Division of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Department of Energy under Contract DE-AC03-76SF00098.

Partition temperature and energy conservation of particle production*

T. F. Hoang
1749 Oxford Street, Berkeley, CA 94709

and

Bruce Cork
Lawrence Berkeley Laboratory
University of California, Berkeley, CA 94720

The partition temperature estimated by Chou and Yang for $e^+e^- \rightarrow h^\pm$ of the TASSO experiment is compared with the cm average energy of the secondary $h^\pm$ using the Maxwellian $P_\perp$ distribution of invariant phase-space. Fireball properties and secondary temperatures are investigated for $e^+e^- \rightarrow h^\pm$, $K^0\bar{K}^0$, $\Lambda\bar{\Lambda}$ of the Mark II collaboration. The number of secondary particles is found to be equally divided among the central fireball and the other two of the fragmentation regions. Crucial tests based on energy conservation are carried out for temperature estimates for the Mark II data, and $\bar{p}p \rightarrow \pi$ at rest of the College de France-Cern experiment.

1. Introduction

In a recent paper by Chou, Yang and Yen (CYY), the concept of partition temperature T_p is introduced for formulating a geometrical model of multiparticle production in terms of the microcanonical ensemble.¹ They postulate the following probability for the single-particle momentum distribution in the cms:¹

$$\text{prob} = \frac{d^3P}{E} g(P_\perp) e^{-E/T_p} \quad (1)$$

$g(P_\perp)$ being the cut-off function for the transverse momentum $P_\perp$. They have analyzed² the CERN $\bar{p}p$ collider data³ and the TASSO experiment of $e^+e^- \rightarrow h^\pm$ at cm energy $W = 14$ and 34 GeV.⁴

Their values of T_p are in general very large compared to the conventional temperature T determined by the Maxwellian $P_\perp$ distribution. As regards the T_p of the TASSO experiment,^{2(a)} we note that their results lead to $T_p/(W/2) \approx 0.2$ comparable with the average of $x = 2P_\parallel/W$ for $e^+e^- \rightarrow h^\pm$, $K^0\bar{K}^0$ and $\Lambda\bar{\Lambda}$ reported by the TASSO Group.⁵ This suggests that unlike the conventional temperature, T_p depends rather, on the longitudinal momentum $P_\parallel$ or $E \approx P_\parallel$ in the cms.

It is interesting to compare T_p with the average energy of the particle using the conventional temperature T determined by the $P_\perp$ distribution of invariance phase-space in accordance with the CYY model,^{2(b)} Sec. 2, transformed to the cms as in the case of T_p . For this purpose, we have to investigate the kinematic properties of the fireball (FB), Sec. 3.

We shall use appropriate tests to investigate the properties of temperature for various particles from $e^+e^- \rightarrow h^\pm$, $K^0\bar{K}^0$, $\Lambda\bar{\Lambda}$ at $W = 29$ GeV of the Mark II Collaboration,⁶ using the same $P_\perp$ distribution

of Eq. (2) as in the case of the TASSO data, Sec. 4. Note that we consider only inclusive reactions in our analyses.

We will also investigate the x -distribution of $e^+e^- \rightarrow K^0\bar{K}^0$. This will enable us to determine the particle contents in the fireballs of the central and the fragmentation region, Sec. 5. Thus, we are able to estimate the total reaction energy of $e^+e^- \rightarrow h^\pm$ to be compared with the incident energy. This serves as a crucial test for the validity of the $P_\perp$ distribution under consideration, Sec. 5.

Another crucial test along this line is to estimate the nucleon mass using the temperature for $\bar{p}p \rightarrow \pi$ at rest. We shall use the high statistics experiment by the College de France-CERN Collaboration. The results will be discussed in Sec. 6.

Some remarks are made on the temperature estimation using the $P_\perp$ distribution of another model for comparison, Sec. 7.

2. The $P_\perp$ distribution of invariant phase-space

Following the model of Chou, Yang and Yen (CYY), we consider the $P_\perp$ distribution using the invariant phase-space (IPS) as follows

$$\begin{aligned} \left(\frac{d\sigma}{dP_\perp^2} \right)_{IPS} &\sim \int_0^\infty e^{-E/T} \frac{dP_\parallel}{E} = K_0(m_\perp/T) \\ &\sim \frac{1}{\sqrt{m_\perp}} e^{-m_\perp/T} \end{aligned} \quad (2)$$

where $m_{\perp} = \sqrt{p_{\perp}^2 + m^2}$ and $K_0(x)$ is the modified Bessel function of the second kind, approximated as $K_0(x) \approx \sqrt{\frac{\pi}{2x}} \cdot e^{-x}$.

We now use this distribution to fit the same TASSO data⁴ of $e^+e^- \rightarrow h^{\pm}$, as in the work of Chou and Yang, assuming $m = 0$.^{2(a)} The fits are shown in Fig. 1 and the temperatures (in MeV) are listed in Table I. We note that the fit for $W = 14$ GeV is rather satisfactory, although the other fit is less good, probably because of the gluon bremsstrahlung at $W = 34$ GeV.

Knowing T , we may define the thermal energy of a particle of mass m by the following formula⁷, namely the average energy in terms of T :

$$\mathcal{E}^* = 3T + mK_1(m/T)/K_2(m/T) \quad (3)$$

which links T to the energy of general mechanics. The asterisk denotes the rest frame of the particles belonging to one of the two jets of $e^+e^- \rightarrow h^{\pm}$, a frame comoving along the jet axis and is characteristic of the isotropic angular distribution of its particles, referred to as the fireball (FB) system.

If we neglect the transverse motion of the FB, which has been discussed elsewhere 9(a), and denote its longitudinal velocity (in units of $c = 1$) along the jet axis by b , we get for the thermal energy in the cms by the Lorentz transformation:

$$\mathcal{E} = \gamma \left(\mathcal{E}^* + b \sqrt{\mathcal{E}^{*2} - m^2} \right) \quad (4)$$

with $\gamma = 1/\sqrt{1-b^2}$.

We will compare $\mathcal{E}$ with the partition temperature T_p obtained by Chou and Yang,^{2(a)} after a discussion of the method to determine the longitudinal velocity b of the FB.

3. Longitudinal motion of the fireball

As is well known, the anisotropy of angular distribution of secondaries in the cms may be attributed to the motion of the FB which emits the particles. We recall that in the case of negligible transverse motion of the FB, the appropriate Maxwell-Boltzmann distribution is of the form⁸

$$e^{-(E-bP_{\parallel})/T} \quad (5)$$

b being the longitudinal velocity of the FB in units of $c = 1$. Note that the $P_{\perp}$ distribution deduced from (5) is independent of b .

We may rewrite (5) using another parameter, λ , which has been introduced for the Feynman-Yang scaling,^{9(a)} namely

$$E - bP_{\parallel} = \sqrt{P_{\perp}^2 + \lambda^2 P_{\parallel}^2 + m^2}. \quad (6)$$

We recall that

$$\frac{\langle P_{\perp} \rangle}{\langle P_{\parallel} \rangle} = \frac{\pi}{2} \lambda \quad (7)$$

and that $\lambda = 1$ corresponds to an isotropic angular distribution, whereas $\lambda < 1$ describes the anisotropy.^{9(a)} We get from (6), for $E \approx P_{\parallel}$,

$$b = 1 - \lambda \quad (8)$$

with $b \leq 1$ as we are dealing with the velocity of the FB.

Knowing λ by (7), it is straightforward to transform the thermal energy $\mathcal{E}^*$ to the cms by (4). For the TASSO data we are dealing with, we compute $\langle P_{\perp} \rangle$ from their data.⁴ As for $\langle P_{\parallel} \rangle$, we fit their data with $e^{-aP_{\parallel}}$ for $P_{\parallel} > 0.1$ (W/2), the cut-off being set to eliminate the background particles arising from the central fireball; we shall discuss this important point in Sec. 5. The results thus obtained and the values of b and $\mathcal{E}$ are summarized in Table I, together with the partition temperatures T_p estimated by Chou and Yang.^{2(a)}

A comparison of T_p and $\mathcal{E}$ indicates that they are equal within one standard error. This suggests that we are dealing with the same temperature, characteristic of the Boltzmann factor of the statistical distribution, measured in two different ways: one along the $P_{\parallel}$ axis in cms for T_p and another along $P_{\perp}$ for T , the latter being the conventional method for estimating the temperature.

4. Temperature property

We have estimated T for $e^+e^- \rightarrow h^{\pm}$ of the TASSO data⁴ with the $P_{\perp}$ distribution (2) derived from the Maxwell distribution using IPS and assuming $m = 0$, namely

$$\left(\frac{d\sigma}{dP_{\perp}^2} \right)_{IPS} \sim \frac{1}{\sqrt{P_{\perp}}} \cdot e^{-P_{\perp}/T} \quad (9)$$

It should be mentioned that the values of T thus obtained, see Table I, are imbued with systematic errors, because the fit depends critically on the data points near the origin.¹⁰ Another reason is that this distribution (9) requires

$$\langle P_{\perp}^2 \rangle / \langle P_{\perp} \rangle^2 = 5/3 \quad (10)$$

which is certainly not satisfied by any data in general. Furthermore, we have to bear in mind that T determined by (2) with $m = 0$, i.e., (9), is overestimated compared to the case $m = m_{\pi}$, as can be noticed from the value listed in Tables II, III and IV.

With these remarks, we now proceed to analyze the inclusive $e^+e^- \rightarrow h^{\pm}$, $K^0\bar{K}^0$, $\Lambda\bar{\Lambda}$ at 29 GeV of the Mark II collaboration.⁶ For $e^+e^- \rightarrow h^{\pm}$, we shall consider both cases assuming $m = 0$ and $m = m_{\pi}$ in order to see the overestimation of T mentioned above. We shall also investigate the dependence of T on the nature of secondaries.

The results are summarized in Table II, together with the values of λ and ξ computed as in the case of the TASSO data, Sec. 3. The fits for $h^{\pm}$ and $\Lambda\bar{\Lambda}$ are shown in Fig. 2.

If we compare the temperatures for $h^{\pm}$, we note that T for $m = 0$ is much higher than that for $m = m_{\pi}$, as mentioned above. Next, an inspection of $P_{\perp}$ distributions of $h^{\pm}$ and $\Lambda\bar{\Lambda}$, Fig. 2, shows different behavior, this implies $T_{\pi} \neq T_{\Lambda}$; we find, see Table II

$$T_{\pi} > T_{\Lambda}, \quad (11)$$

namely, T decreases with the particle mass.¹⁷ This property, in agreement with that of pp interactions using the thermodynamical model,¹⁶ contradicts what has been reported from heavy-ion reactions, namely $T_{\pi} = 58 \pm 3$ MeV which is much less than the proton temperature 118 ± 2 MeV.¹¹

Finally, as regards the FB velocity b , we find it decreasing with m , namely

$$b_{\pi} > b_K > b_{\Lambda} . \quad (12)$$

This property suggests that the particles are not emitted simultaneously, but rather in succession according to their inertial mass; first the pions, then the kaons, etc. This property further supports the view that there is no thermal equilibrium, since the FB cools off a little after each emission of particle, as is required by the Boltzmann factor $\exp(-m/T)$ of particle production.

5. Properties of the fireballs in e^+e^- annihilation

We now consider the x distributions of the Mark II data^{6(a)} analyzed in Sec. 4. Our attempt is to investigate the properties of the FB, in the central (C) and fragmentation (F) regions. As the x distributions of $e^+e^- \rightarrow h^{\pm}$, $K^0\bar{K}^0$ and $\Lambda\bar{\Lambda}$ are found to be the same,⁵ we shall consider only the case of $K^0\bar{K}^0$.

The Mark II data^{6(b)} are reproduced in Fig. 3. The straight line represents the fit with

$$\frac{d\sigma}{dx} = A_i e^{-a_i x} \quad (13)$$

for $x > 0.15$, the subscript i specifies the region of fit. For the fragmentation region, we find

$$A_F = 13.5 \pm 2.3, \quad a_F = 7.78 \pm 0.36. \quad (14)$$

If we try to fit the data near the origin, for $x \leq 0.1$ with (13), we find $A = 26.0 \pm 0.69$ and $a = 14.2 \pm 4.15$, significantly different from the previous fit. The two fits intercept at $\sim x = 0.12$ (not shown in the figure), which is taken tentatively as the separation of the central and the fragmentation regions.

We now estimate the x -distribution of K 's of the central FB by subtracting from the experimental data the background due to the fragmentation FB according to the fit (14) extrapolated to $x \leq 0.1$. The results thus obtained are shown by full circles in the insert of Fig. 3, the measurement errors $\sim 15\%$ of the experiment^{6(b)} are omitted for clarity. Note that one point at $x = 0.062$ lies below the insert, which will be left aside. The fit with (13) yields

$$A_C = 41.0 \pm 16.0, \quad a_C = 49.9 \pm 5.5. \quad (15)$$

It is shown by the discontinuous line in Fig. 3.

We find for $P_{\parallel}$ of particles from the central FB: $\langle P_{\parallel} \rangle = W/2a_C = 290 \pm 32 \text{ MeV/c}$ comparable to $\langle P_{\perp} \rangle = 0.425 \pm 0.035 \text{ MeV/c}$ of $h^{\pm}$, see Table II. Thus for the central FB

$$\lambda_C = 0.93 \pm 0.13$$

consistent with 1, indicating an isotropic angular distribution. This implies, in turn, that the central FB is actually at rest in the cms, whereas those in the fragmentation region are moving along the jet-axis in opposite directions with the longitudinal velocity $b = 1 - \lambda$ listed in Table II.

Knowing the parameters A and a of the fits, (14) and (15), we may estimate the number of particles, n_C and n_F of the central and fragmentation FB. Remembering that only half a central FB belongs to one jet we are dealing with, we get for the ratio

$$\frac{n_C}{n_F} = \frac{2A_C a_F}{A_F a_C} \approx 1 \quad (16)$$

so that the particles from e^+e^- annihilation are equally divided in number among three FB's, one belongs to the central region and two others to the fragmentation regions:

$$n_C = n_F = n/3 . \quad (17)$$

The average charged multiplicity is $n_{\pm} = 11.8 \pm 0.05$ according to the empirical formula $n_{\pm} = (2.18 \pm 0.01) W^{1/2}$ (W in GeV).⁵ Assuming $n_0/n_{\pm} = 1/2$ as has been found in the SLAC-LBL experiment at 7.4 GeV,¹² we get

$$n/3 = 5.90 \pm 0.02 .$$

Thus from the estimated temperatures in Table II, we may calculate the total thermal energy in the cms for $e^+e^- \rightarrow h^\pm$ at 29 GeV:

$$\mathcal{E}_{\text{tot}} = \frac{n}{3} (\mathcal{E}^* + 2\mathcal{E}) \quad (18)$$

$\mathcal{E}^*$ and $\mathcal{E}$ being given by (3) and (4). The results are summarized in Table III.

A comparison of $\mathcal{E}_{\text{tot}}$ with the expected value $W = 29$ GeV indicates that the estimates of $\mathcal{E}$, therefore T , from the IPS are significantly overestimated. Thus the $P_\perp$ distribution of IPS is not adequate from the point of view of energy conservation. We shall further discuss this point in Sec. 7.

Finally, we mention that similar results are obtained with another $e^+e^- \rightarrow h^\pm$ experiment at 7.4 GeV by the SLAC-LBL collaboration,¹³ and to some extent, the recent PEP experiment similar to that of Mark II by the HRS collaboration.¹⁴

6. Crucial test of $P_\perp$ distributions with $\bar{p}p \rightarrow \pi$ at rest

For a further validity test of $P_\perp$ distributions, we consider $\bar{p}p$ annihilation at rest

$$\bar{p}p \rightarrow \pi + \dots .$$

The advantages of this case are as follows. First, $b = 0$, as the annihilation takes place at rest. Next, the charged pions are identified without ambiguity; and annihilations with K 's, which have low energy, are few and excluded.

We use the high statistics experiment of the College de France-CERN Collaboration.¹⁵ Besides the charged and the neutral multiplicity:

$$n_{\pm} = 4.98 \pm 0.05, \quad n_0 = 1.93 \pm 0.02,$$

they have also measured the $P_{\perp}$ distribution, with respect to an arbitrary axis and obtained

$$\langle P_{\perp} \rangle = 0.280 \pm 0.001 \text{ GeV/c}, \quad \langle P_{\perp}^2 \rangle = 0.104 \pm 0.001 (\text{GeV/c})^2$$

Their data are reproduced in Fig. 4, the errors being imperceptible. We have fitted their data with Eq. (2) for both $m = 0$ and $m = 140 \text{ MeV}$. The fits are shown in Fig. 4. The parameters are listed in Table IV.

We note especially the fit near the point at $P_{\perp}^2 = 0.005 (\text{GeV/c})^2$ very close to the origin indeed. Here, we can see clearly the deviations of the fit from the data points. Note also that the experimental ratio $\langle P_{\perp}^2 \rangle / \langle P_{\perp} \rangle^2 = 1.42$ differs from $5/3$ predicted for $m = 0$, see Eq. (10).

With the estimated T , we have computed the total thermal energy $\mathcal{E}^*(m)$ using (3)

$$\mathcal{E}_{\text{tot}}^* = n_{\pm} \mathcal{E}^*(m_{\pm}) + n_0 \mathcal{E}^*(m_0) \quad (19)$$

account being taken of the mass difference between $\pi^\pm$ and π^0 , as is specified by the subscripts. In addition, we have computed $\langle P_\perp \rangle$ according to

$$\langle P_\perp \rangle = \sqrt{\pi m T / 2} \cdot K_{3/2}(m/T) / K_1(m/T) \quad (20-a)$$

derived from (2) for $m \neq 0$ and

$$\langle P_\perp \rangle = 3T/2 \quad \text{for } m = 0 \quad . \quad (20-b)$$

The results are summarized in Tables III and IV.

We now compare $\mathcal{E}_{\text{tot}}^*$ and $\langle P_\perp \rangle$ with the values of the experiment,¹⁵ namely

$$2m_p = 1.876 \text{ GeV} \quad \text{and} \quad \langle P_\perp \rangle = 280 \text{ MeV/c} .$$

Here, as has been noted previously, Sec. 5, for $e^+e^- \rightarrow h^\pm$, Table II, we find T larger for $m = 0$ than for $m = m_\pi$, but the total energy $\mathcal{E}^*$ is almost the same in both cases. That $\mathcal{E}^* \gg 2m_p$ indicates an overestimation of T by (2). We have further investigated this point using a $P_\perp$ cut-off $g(P_\perp) \approx \exp(-\alpha P_\perp)$ with $\alpha = 1/\langle P_\perp \rangle$ as in (1) and found an effective temperature $T_{\text{eff}} = 175 \pm 15 \text{ MeV}$ for $m = 0$, the same as listed in Table IV, $(1/T_{\text{eff}} = 1/\alpha + 1/T)$. Thus, the $P_\perp$ cut-off $g(P_\perp)$ has no effect on the temperature estimate.

7. Concluding remarks

In summary, our analysis of $P_{\perp}$ distributions of $e^+e^- \rightarrow h^{\pm}$ of the TASSO data⁴ using the IPS, $m = 0$ leads to total energies $\mathcal{E}$ in the cms consistent with the partition temperature T_p estimated by Chou and Yang^{2(a)} for the same data, Sec. 3. However, their estimates, see Table I, seem to be overestimated, since according to their results, $\langle n_{\pm} \rangle T_p$ is almost equal to the cm energy W without taking into account the neutral multiplicity.

We have investigated this point using energy conservation as a crucial test to compare the energy $\mathcal{E}$ determined by the temperature T with the cm energy W of the experiment. We find in all cases analyzed in Secs. 5 and 6, $\mathcal{E} > W$, especially for $\bar{p}p \rightarrow \pi$ at rest, indicating that T determined by the $P_{\perp}$ distribution of IPS, Eq. (2) is overestimated. We have looked for the cause; we find it due to the factor $1/\sqrt{m_{\perp}}$ of the distribution which becomes infinity at $P_{\perp} = 0$ for $m = 0$.

In this regard, we note that the $P_{\perp}$ distribution of the thermodynamical model¹⁰ using the classical-phase space (CPS) has a different behavior, namely

$$\begin{aligned} \left(\frac{d\sigma}{dP_{\perp}^2} \right)_{\text{CPS}} &\sim \int_0^{\infty} e^{-E/T'} dP_{\parallel} = \sqrt{m_{\perp}} K_1(m_{\perp}/T') \\ &\sim \sqrt{m_{\perp}} \cdot e^{-m_{\perp}/T'} \end{aligned} \quad (21)$$

where we denote the temperature by T' to avoid confusion with T of IPS, which is determined by (2). Note that; in contrast with (2), this

distribution remains finite near $P_{\perp} = 0$ in the case $m = 0$. We have estimated T' by refitting the data analyzed in the previous sections and computed the average $P_{\perp}$ accordingly, i.e.,

$$\langle P_{\perp} \rangle = \sqrt{\pi m T' / 2} \cdot K_{5/2}(m/T') / K_2(m/T') \quad (22-a)$$

$$= 5T'/2 \quad \text{for } m = 0 \quad (22-b)$$

The results are listed in Tables III and IV, together with the energy $\mathcal{E}$.

We note that in general $T' < T$ and that $\mathcal{E}$ deduced from T' is equal to the incident energy W within experimental errors, see Tables III and IV, indicating that energy conservation is well satisfied, especially in the case of $\bar{p}p \rightarrow \pi$ at rest, although the use of CPS in (21) is not satisfactory from the covariance viewpoint.

Acknowledgements

The authors wish to thank I. Hinchliffe and G. Gidal for discussions and comments. Thanks to Joy Kono for the careful work of typing. One of the authors (TFH) would like to thank W. Hartsough for facilitating this work and the Tsi Jung Fund for the support.

Added Note: After the completion of the present work, our attention was drawn to a recent paper by Li and Young.¹⁸ Applying the partition-temperature model to hadron-nucleus (hA) reactions, they assume the same Lorentz transformation of the temperature as in our previous work^{9(a)} to get the covariant Boltzmann factor (5). We note that the average temperatures from their estimates for pA reactions, ~ 190 MeV are much higher than those ~ 150 MeV of pp interactions at the same incident energy using the thermodynamical model.¹⁷

References and Footnotes

1. T.T. Chou, Chen-Ning Yang and E. Yen, Phys. Rev. Lett. 54, 510 (1985).
2. T.T. Chou and Chen-Ning Yang, (a) Phys. Rev. Lett. 55, 1359 (1985) and (b) Phys. Rev., D32, 1692 (1985).
3. UA5 Collaboration, D.E. Ward, in Proc. of the 3rd Topical Workshops in Proton-Antiproton Collider Physics, Rome, 1983, ed. C. Bacci and G. Savini, CERN.
4. TASSO Collaboration, M. Althoff et al., Z fur Phys. C22, 307 (1984).
5. TASSO Collaboration, R. Brandel et al., Phys. Lett. 114B, 62 (1982).
6. Mark II Collaboration, (a) C. de la Vaissiere et al., Phys. Rev. Lett. 54, 2091 (1985), (b) H. Schullman et al., Phys. Rev. D31, 3013 (1985) and (c) G. Gidal, private communication.
7. See e.g. J.L. Synge, Relativistic Gas, North Holland Publisher, N.Y. (1957), p. 63.
8. This type of distribution has been used by Fermi, Phys. Rev. 81, 683 (1951).
9. T.F. Hoang, (a) Phys. Rev. D12, 296 (1975), (b) *ibid.*, D17, 927 (1978).

10. This situation does not exist in the case of thermodynamical model, R. Hagedorn, Nuovo Cim. Suppl. 3, 147 (1965).
11. R. Brockmann et al., Phys. Rev. Lett. 53, 2012 (1984). They used backward π^- in the lab system without considering the motion of the target fireball, see, e.g. H. En'yo et al., Phys. Lett. 159B, 1 (1985).
12. A. Fong, Ph.D. Thesis, LBL-10709.
13. SLAC-LBL Collaboration, J.L. Siegest et al., Phys. D26, 969 (1982) and G. Hanson, ibid., D26, 991 (1982).
14. HRS Collaboration; P. Baringer et al., submitted to Phys. Rev. Lett., and D. Bender et al., Phys. Rev. D31, 1 (1985).
15. College de France-CERN, C. Ghesquiere, in Proc. Symp. on Antinucleon-nucleon Interactions, Liblice-Prague, 1974, ed. L. Montanet, (CERN, Geneva, 1974), p. 436.
16. For a comprehensive discussion on $P_{\perp}$ distributions of various models, we refer to R. Hagedorn, Rivista del Nuovo Cimento, 6, 1, (1983).
17. See, e.g., G. Giacamelli and M. Jacob, Phys. Rep. 55c, p. 40 (1979).
18. T. S. Li and K. Young, Phys. Rev. D34, 142 (1986).

Table I - Comparison of the partition temperatures T_p estimated by Chou and Yang, Ref. 2(a), with the thermal energy computed from the conventional temperature T using the invariant phase-space, for TASSO data of $e^+e^- \rightarrow h^\pm$, Ref. 3. The fireball velocity b is given by the scaling parameter $\lambda = 1-b$. $\langle P_\perp \rangle$ and $\langle P_\parallel \rangle$ in MeV/c.

W (GeV)	T (MeV)	$\langle P_\perp \rangle / \langle P_\parallel \rangle$	λ	(GeV)	T_p (GeV)
14	194 ± 4	$\frac{330 \pm 9}{822 \pm 86}$	0.256 ± 0.028	1.63 ± 0.11	1.6
34	264 ± 7	$\frac{440 \pm 10}{2087 \pm 73}$	0.135 ± 0.055	2.93 ± 0.37	3.3

Table II -- Analysis of $e^+e^- \rightarrow h^\pm, K^0\bar{K}^0, \Lambda\bar{\Lambda}$ at 29 GeV of Mark II Collaboration, Ref. 5. T and T' are temperatures of IPS and CPS, Eqs. (2) and (21). $\lambda = 2\langle P_\perp \rangle / \pi \langle P_\parallel \rangle$ with $\langle P_\parallel \rangle = 1.980 \pm 0.112$ GeV/c of $h^\pm$ data.

Second	T (MeV)	T' (MeV)	$P_\perp$ (MeV/c)	$b = 1-\lambda$
$h^\pm$ $m = m_\pi$	242 ± 8	183 ± 9	425 ± 36	0.861 ± 0.013
0	256 ± 7	195 ± 6		
K^0	236 ± 24	200 ± 13	551 ± 19	0.823 ± 0.011
Λ	192 ± 12	169 ± 9	580 ± 18	0.810 ± 0.013

Table III - Tests of $e^+e^- \rightarrow h^\pm$ at $W = 29$ GeV by energy conservation for temperatures from IPS and CPS assuming $h^\pm$ to be π 's and massless particles.

Fits	Temp. (MeV)	* (MeV)	tot (GeV)
IPS $m = 0$	256 ± 7	750 ± 21	35.9 ± 1.5
m_π	242 ± 8	795 ± 35	39.0 ± 2.7
CPS $m = 0$	195 ± 6	585 ± 18	29.2 ± 1.6
m_π	183 ± 9	549 ± 27	27.0 ± 1.9

Table IV - Crucial tests for $\bar{p}p \rightarrow \pi$ at rest, data of College de France-CERN, Ref. 14. Comparison of the total thermal energy $\mathcal{E}_{\text{tot}}^*$ and $\langle P_{\perp} \rangle$ deduced from T with experimental values $2m_p = 1.88 \text{ GeV}$ and $280 \pm 1 \text{ MeV/c}$.

$P_{\perp}$ distribution	m	T (MeV)	$\mathcal{E}_{\text{tot}}^*$ (GeV)	$\langle P_{\perp} \rangle$ (MeV/c)
IPS	140	156 ± 19	2.52 ± 0.25	295 ± 30
	0	173 ± 14	2.56 ± 0.27	263 ± 20
CPS	140	117 ± 4	2.00 ± 0.04	280 ± 15
	0	127 ± 7	1.93 ± 0.10	317 ± 15

Figure Captions

1. $P_{\perp}$ distributions of IPS for $e^+e^- \rightarrow h^{\pm}$ of the TASSO experiment, Ref. 4, assuming $m_h = 0$. The estimated temperatures are listed in Table I.
2. $P_{\perp}$ distributions of IPS, Eq. (2), for $e^+e^- \rightarrow h^{\pm}, \Lambda\bar{\Lambda}$ at $W = 29$ GeV of the Mark II Collaboration, Ref. 6(a) assuming $m_h = 140$ MeV. The fitted temperatures are listed in Table II.
3. Analysis of the x -distribution of $e^+e^- \rightarrow K^0\bar{K}^0$ at 29 GeV, Mark II Collaboration, Ref. 6(b). The straight line is the fit with Eq. (13) for the fragmentation region. The distribution in the insert represents K^0 's from the central FB, and the similar fit with (13). See text.
4. Comparison of $P_{\perp}$ distributions of IPS, Eq. (2), for $\bar{p}p \rightarrow \pi$ at rest, with $m_{\pi} = 0$ and 140 MeV. College de France-CERN Collaboration, Ref. 15. The temperatures are listed in Table IV.

XBL 8512-11766

Fig. 1

XBL 8610-3963

Fig. 2

XBL 861-10456

Fig. 3

XBL 8610-3964

Fig. 4

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

*LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720*