Pramāṇa, Vol. 6, No 5, 1976, pp. 272–277. © Printed in India.

Production of ψ particles in N–N collisions and large P_T phenomenon

L K CHAVDA* and D S NARAYAN**
* Physics Department, Indian Institute of Technology, Bombay 400076
** Tata Institute of Fundamental Research, Bombay 400005

MS received 17 November 1975

Abstract. We calculate the yield of ψ (3105) particles in N-N collisions in a model which associates the production of heavy particles with large P_T phenomenon. Our results show that ψ (3105) has a fairly strong coupling to other hadrons. We propose a criterion in the search for charmed particles and a parametrization for the expected yields of such particles.

Keywords. ψ particles; central collisions; massive intermediate states; statistical decay; association with large P_T.

1. Introduction

The recently discovered narrow-width resonances (Aubert *et al* 1974; Augustin *et al* 1974; Bacci *et al* 1974), ψ (3·105) and ψ (3·695), have been variously interpreted (CERN 1975, PRL 1975) as a $c\bar{c}$ (charm-anticharm) resonance, as a charmed boson as an intermediate boson, etc. These different interpretations would have definite implications regarding their mode of production in strong interactions such as their production singly or in pairs or in association and the relative abundance of these resonances compared to other hadrons.

Motivated by a model of hadron collisions which inhibits the emission of heavy secondaries except in a small class of events, we propose in this paper that the production of ψ particles in hadron collisions takes place only in events which are associated with anomalously large transverse momenta P_T. This proposal which can be easily tested experimentally both at FNAL and at CERN is of practical importance in the experimental search for new particles.

In a recent paper (Chavda and Narayan 1974), referred to hereafter as paper 1, the present authors have explained the production of particles with large P_T and heavy secondaries, on the assumption that they are produced in central collisions which give rise to one or two massive intermediate states or fire balls. These massive systems decay according to Fermi's statistical theory and give rise to features which look anomalous, compared to those in non-central collisions which are of a peripheral type. We apply the above model to calculate the yield of ψ (3·105) particles and the charmed hadrons at FNAL and ISR energies.

We find that the yield of ψ particles at 250 GeV nucleon-nucleon collisions as predicted by our model, would be in agreement with the recent data (Knapp *et al* 1974, Columbia, Hawaii, Cornell collaboration), if we assume that ψ(3·105) is a hadron and that the average coupling strength g_ψ of ψ to all other hadrons has a value comparable to that for protons and kaons.

Motivated by our model, we suggest a parametrization of the inclusive cross-sections for the production of particles in central collisions as a function of the mass of the particle detected, its transverse momentum and its angle of emission. This parametrization can be used for an approximate computation of the yield of light particles with large P_T or heavy secondaries with any P_T, a criterion which selects central collisions.

2. A model for production of heavy particles or particles with large P_R

The rationale for the suggestion, that the production of ψ particles would be associated with the phenomenon of large transverse momenta, comes from the model (Narayan 1971) of random fragmentation proposed by one of the authors. According to this model, interaction between the colliding hadrons gets localized to small cells and the different parts of the colliding hadrons get shattered independently into fragments, with the proviso that there is conservation of energy momentum, and the other quantum numbers at each local centre. In this picture of hadron collisions, one gets a number of independently produced fragments or clusters. The distribution of mass and velocities amongst the clusters would depend crucially on the spatial distribution of mass (or equivalently the distribution of momentum fractions) inside a hadron. A nucleon is pictured as having a massive constituent or a core and a light meson cloud. In peripheral collisions which do not involve the interactions of the cores, the clusters are not massive enough to emit heavy secondaries or particles with large P_T. But in central collisions, the cores interact with each other and get converted into massive intermediate states or fire balls. As these massive states have masses of tens of GeV they can emit heavy secondaries as well as particles with large P_T.

The formulation of the model to calculate the inclusive cross-section for particles of a given type c (π^+, π^-, π°, K^+, K^-, etc., are regarded as different types) is outlined in paper I. We briefly recount the main steps in the formulation. We assume a distribution $\rho\,(s, M_1{}^*, M_2{}^*)$ in the masses of the two fire balls produced in a collision, extending from a minimum value M_0 to the maximum value $s - M_0$, where s is the square of the C.M. energy. In the rest system of a fire ball particles are emitted isotropically and have a momentum spectrum given by a Planck distribution. To obtain the inclusive cross-section $E\,\frac{d\sigma_c}{d^3p}$, one makes an appropriate Lorentz transformation from the rest system of a fire ball to the C.M. system and then integrates over all fire ball masses. The inclusive cross-section is proportional to σ_{cc}, the cross-section for core-core collisions and a parameter g_c which is a measure of the average coupling strength of the particle type c to all other particles. In pp collisions, the incident proton is retained in a fire ball and it can exchange its charge with other particles. This results is an additional contribution to positively charged particles which is not available to negatively charged or neutral particles except the neutron. This contribution, which is added to g_c, is denoted by a_c and in general it would depend on the value of P_T. Particles in the same multiplet have the same coupling strength g_c. Due to an overall normalization, the value of g_π is taken to be unity.

It would be reasonable to assume that all hadrons, which are either stable or which are long lived, compared to the life time of a fire ball, can be emitted in the decay of the fire ball. This would include all hadron resonances which decay by weak and electromagnetic interactions, the newly discovered narrow resonances, and charmed hadrons if they exist. Here we enlarge the scope of paper 1 to include ψ (3·105) particles besides the particles considered earlier. This is done by introducing a new parameter g_ψ whose value is determined by comparing the yield of ψ particles obtained in our model with the recent experimental data from FNAL. The overall normalisation is readjusted so that the yield of pions, etc. remain unchanged.

According to the data of Knapp *et al*, the inclusive cross-section for ψ (3·105) production is $\sigma (n + \mathrm{Be} \to \psi + X) = 3 \cdot 6 \times 10^{-33}$ cm²/nucleon for $|x| > 0 \cdot 24$, when ψ is detected by its mode $\psi \to \mu^+ \mu^-$. This number has to be multiplied by a factor ~ 16 to get the total inclusive cross-section weighted for all decay modes. The differential cross-section, given in paper 1, is integrated numerically with respect to P_T and an appropriate range of values of P to obtain the cross-section for the emission of ψ (3·105) particles with $|x| > 0 \cdot 24$. The calculated value is then compared with the experimental value to fix the value of g_ψ to agree with experiment. The value of g_ψ so obtained is $g_\psi \simeq 0 \cdot 22$. This may be compared with $g_p = g_k = 0 \cdot 45$ obtained in paper 1. This shows that, in the frame work of our model, ψ (3·105) is hadron with a fairly strong coupling to other hadrons.

3. A parametrization for the yield of heavy particles or particles with large P_T

In view of extensive computations involved in our model, it would be useful to have a parametrization of the invariant cross-sections which gives results in conformity with our model and in reasonable agreement with experiment. To get at such a parametrization, we replace the system of fire balls, with a continuous distribution in the masses (equivalently temperatures) and velocities, by a discrete system. In order to reproduce the features of the model, it is found necessary to have at least two fire balls in either direction in the C.M. system. One of them would have a temperature T and a Lorentz factor γ independent of s and θ, the angle of emission of the detected particle, but the other would have T and γ, dependent on both s and θ. Based on these considerations, we suggest the following parametrization:

$$E \frac{d\sigma_e}{d^3 p} = (g_e + \alpha_e) \Big\{ \Omega \exp\left[-a (p^2 + m_e^2)^{1/2}\right] \cosh (a\beta p \cos\theta) + \Omega' \exp\left[- a' \left(\frac{s'}{s + s_0} \right)^{\lambda} \frac{(1+x)^4 (p^2 + m_e^2)^{1/2}}{1 + b \sin\theta)} \right] \times \cosh\left[a' \beta' \left(\frac{s'}{s - s_0} \right)^{\lambda} \frac{(1+x)^4 P \cos\theta}{1 + b\sin\theta} \right] \Big\} \tag{1}$$

where x is the C.M. Feynman variable. Other parameters are all constants. For $s > s_0$, the second term in the curly bracket in (1) should be taken to be zero. The coefficient multiplying $(p^2 + m_e^2)^{1/2}$ stands for γ/kT which is a constant for one of the fire balls but depends on s and θ for the other fire ball as indicated.

The parameters Ω, Ω', a, a', s_0, s' and λ are first determined using the data of Cronin *et al* (Cronin *et al* 1973) and Busser *et al* (Busser *et al* 1973) on π° cross-sections at 90°. The parameters β, β' and b are next determined using the recent data of Alper *et al* (Alper *et al* 1975) on π^- cross-sections at other angles. The values of the parameters which give a reasonable fit to the data are: $\Omega = 26\ mbc^3/\mathrm{GeV}^2$, $\Omega' = 0\cdot 2\ mbc^3/\mathrm{GeV}^2$, $a = 4\cdot 1\ (\mathrm{GeV}/c)^{-1}$, $a' = 16\cdot 66\ (\mathrm{GeV}/c)^{-1}$, $s' = 1\ \mathrm{GeV}^2$, $s_0 = 300\ \mathrm{GeV}^2$, $\lambda = 0\cdot 1$, $\beta = 0\cdot 46$, $\beta' = 1$ and $b = 2\cdot 4$. As mentioned earlier, the value of a_c depends in general on P. For positive pions, $a_c = 0\cdot 15$ and roughly a constant. For protons and positive kaons, a_c has considerable dependence on P_T varying between $0\cdot 2$ to $0\cdot 5$ and for these, the parametrization can be valid only within factors 2 or 3, if a_c is neglected.

We have shown in figure 1 the fits between the cross-sections computed from (1) and the experimental data on π^0 cross-sections at 90° and on π^- cross-sections at 45° in the C.M. system. There are no data on π^0 or π^- cross-sections at small angles but Cortterell *et al* (Cortterell *et al* 1975) have reported measurements on all positive particles at median angles in the range 10° to 20° in the C.M. system. We find that the cross-sections for the positive particles obtained by Cortterell *et al* and the π^- cross-sections at the corresponding x and P_T values, obtained from (1), differ by factors 2–3. This is consistent with the particle abundances reported by Alper *et al* (Alper *et al* 1975) at larger angles.

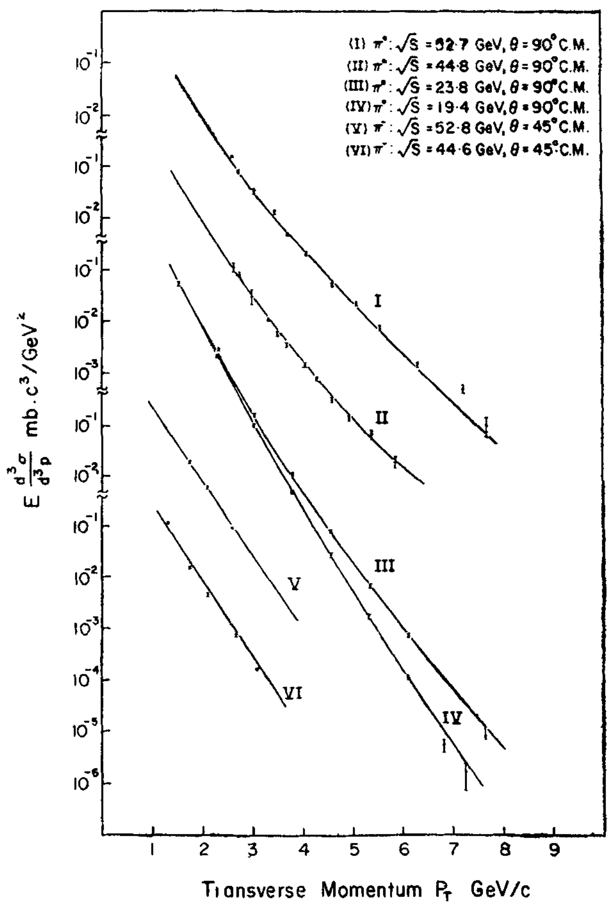

Figure 1. Invariant cross-sections for neutral and negative pions as a function of the transverse momentum.

The parametrization (1) shows that the inclusive cross-section is quite sensitive to the mass of the particle detected, besides the coupling strength g_c. Roughly speaking, the production of a massive particle of a given mass, say 2 GeV, gets damped to the same extent as the production of a light particle like a pion with $P_T = 2$ GeV/c. As the parametrization approximately reproduces the results of our model, it can be used to estimate the yield of an unknown particle if we assume values for its mass and the coupling strength. Using the parametrization, we calculate once again the cross-section for the production of ψ (3·105) particles and comparing the result with the experimental value, we obtain a value for g_ψ which agrees with the value obtained earlier from a more involved calculation based on our model.

4. Where to search for charmed particles

At present there is much interest in the possible existence of so called charmed particles and much effort is directed towards their detection. The different SU (4) schemes estimate the masses of charmed bosons to be around 2·2 GeV. Taking $g_{\text{charm}} = 0 \cdot 25$ and integrating in (1), we find that the total cross-section for the production of charmed particles of any one type at FNAL energies $= \simeq 7 \times 10^{-30}$ mb (GeV)$^{-2}$. This cross-section is larger than the cross-section for ψ production by a factor ~ 20. Though the cross-sections at large P have strong energy dependence as seen in (1), the integrated cross-sections have only a weak energy dependence. For instance the cross-sections for ψ particles or charmed particles at ISR energies show an increase of only 25% over their values at FNAL energies. This result is in sharp contrast with the results of some recent models (Gaisser and Halzen 1975), which predict a sharp increase in the cross-sections in the same energy range.

The predicted cross-section for charmed particles is 0·02% of the total inelastic cross-section. If the life time of charmed particles is $\sim 10^{-12}$ sec and they generally decay into more than two secondaries, their detection in hadron collisions would become extremely difficult. According to our model, the prospects for their detection can however, be improved by one or two orders of magnitude by selecting events characterized by large P_T. The following possibilities may be considered. Events may be selected by triggering for a γ-ray or a charged particle with a moderately large P_T 1·5 GeV/c and they are scanned for tracks produced in scintillators placed very close to the target. Events with large P_T have generally large multiplicities. This suggests selecting large multiplicity events in bubble chamber pictures or photographic emulsions and scan the tracks very close to the points of interaction. Our conclusion regarding the right place to look for charmed particles may be contrasted with that of Snow (1973) who singles out events characteristic of diffractive dissociation for that purpose.

References

Alper B *et al* 1975 *Nucl. Phys.* **B 87** 19
Aubert J J *et al* 1974 *Phys. Rev. Lett.* **33** 1404
Augustin J E *et al* 1974 *Phys. Rev. Lett.* **33** 1406
Bacci *et al* 1974 *Phys. Rev. Lett.* **33** 1408
Chavda L K and Narayan D S 1974 *Phys. Lett.* **51 B** 359
CERN Preprint T H 1964-CERN and papers in *Phys. Rev. Lett.* 1975 No. 4 Vol. 34
Cortterell R *et al* 1975 *Phys. Lett.* **55 B** 341
Cronin J W *et al* 1973 *Phys. Rev. Lett.* **31** 1426
Gaisser T K Halzen P 1975 Wisconsin preprint 300–435
Knapp B *et al* 1975 *Phys. Rev. Lett.* **34** 1044
Narayan D S 1971 *Nucl. Phys.* **B 34** 386
Snow G A 1973 *Nucl. Phys.* **B 55** 445