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NEW APPROACH TO MULTIHADRON PRODUCTION IN $e^+ e^-$ ANNIHILATION PROCESSES

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From a new approach to multiparticle production phenomena we have attempted here to analyse some characteristics of the production of pions, kaons and antiprotons in the $e^+ e^-$ annihilation processes. Global nature of the hadron production in lepton-hadron, hadron-hadron collisions and in $e^+ e^-$ annihilation processes has also been emphasised and explained.

1. Introduction

Recent experiments have demonstrated some striking features of multihadron production in the $e^+ e^-$ annihilation processes: (i) Rapid growth of average multiplicity in $e^+ e^-$ annihilations[1] [Fig. 1]. (ii) Suspected similar mechanism of production of hadrons in hadron-hadron collisions and annihilation processes and the global nature of the average multiplicity of hadrons in lepton-hadron, hadron-hadron collisions at high energies and the annihilation reactions[2] [Fig. 2]. (iii) Considerable yield of the kaons and baryons in $e^+ e^-$ annihilation processes with a slowly rising fractional yield of charged kaons and baryons with increasing outgoing momentum[3] [Fig. 3]. (iv) Very slow rise (or constancy after a definite energy?) of the ratio $R = \frac{\sigma (e^+ e^+ \to \text{hadrons})}{\sigma (e^+ e^- \to \mu^+ \mu^-)}$. The motivation of the present work is just to explain the above mentioned first three characteristics from a new approach. I shall not discuss at length the fourth feature as it has already been dealt with by P. Bandyopadhyay in great detail in a separate communication[4].

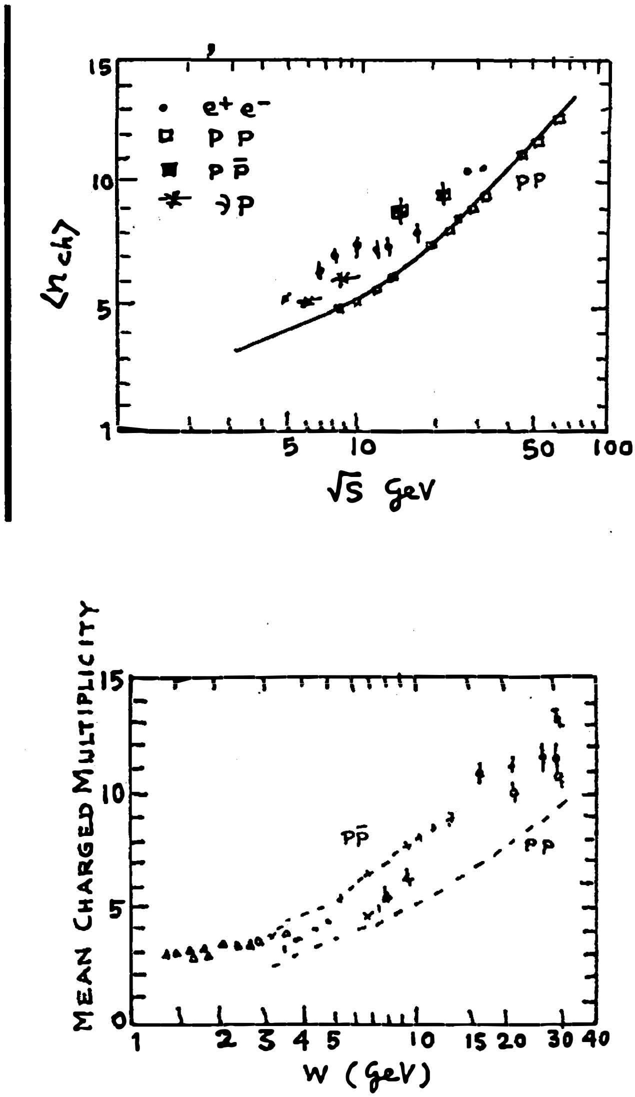

Fig. 1. Plot of average charged multiplicity versus S of the systems. Data show a rapid rise of the average charged multiplicity with energy[1(a),1(b)].

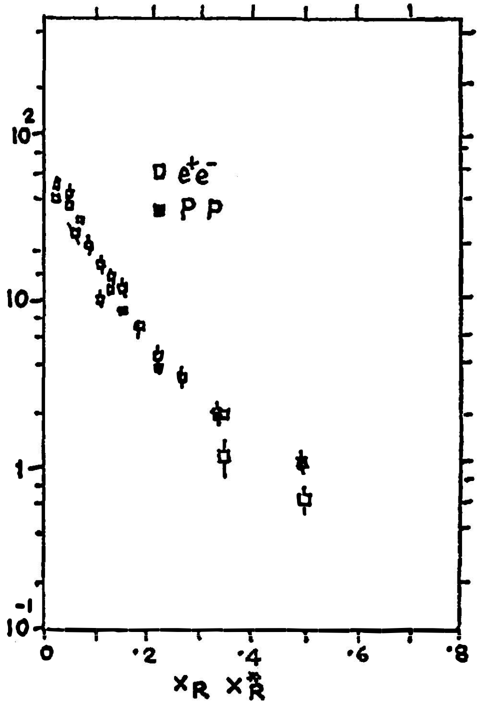

Fig. 2. Data[2] show how the experimental points in *PP* collisions and annihilations closely resemble each other thus hinting to the similarity in mechanisms for particle production. Along the abscissa lie X_R and X_R. Along the ordinate:

$$\blacksquare \; S\frac{d\sigma}{dx_R}\left(\frac{1}{2\,S\,R\,\sigma_{\mu\mu}}\right) \text{ for } PP, \;\square\; S\frac{d\sigma}{dx_R}\left(\frac{1}{2\,S\,R\sigma}\right) \text{ for } e^+e^- \text{ with } R = \sigma_{had}/\sigma_{\mu\mu}.$$

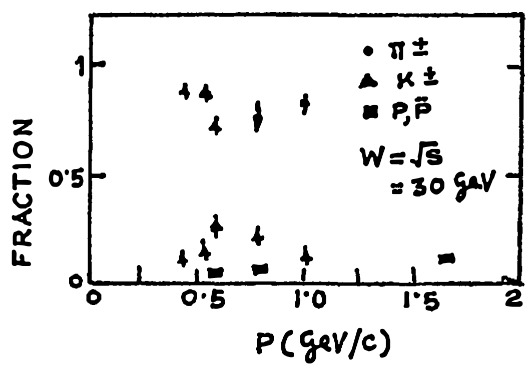

Fig. 3. Fractional yield of kaons, pions, antiprotons etc. with rise of the outgoing momenta (p) of the particles[3].

Now at the very start let us make some clear-cut remarks about the present approach. Our model does not at all contain any sort of so-called *jettiness*[5] in the hadron production. Rather it maintains very strongly that the so-called jets (be they two-jet or three-jet structures) are mere artifacts and not facts; they are the products of the requirement of quark confinement in the quark-based models. In a recent paper we have addressed ourselves to this question in detail and have presented therein an alternative methodology to explain almost all the physical characteristics associated with the so-called jet-physics. Some recent experiments[6] e. g., NA (5) experiment in CERN have already cast serious doubt about the existence of jets in hadronic collisions.

2. *The model for* $e^+ e^- \to$ *hadrons*

The model we propose here for pion production in $e^+ e^-$ annihilations [Fig. 4] looks like that of Craigie and Rothe[7], but the essence and our approach are different. The versions of the model for kaons and antiprotons production have also

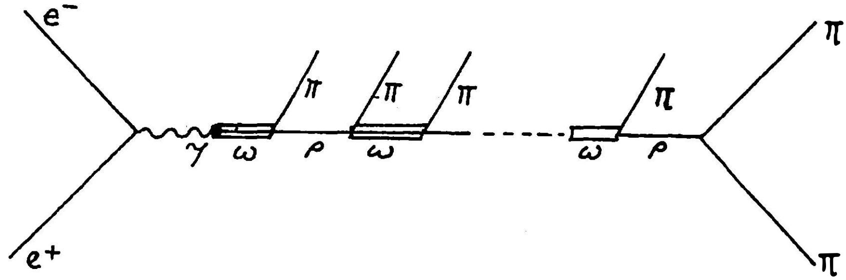

Fig. 4. Multiple production of pions, in the present mechanism, in $e^+ e^-$ annihilations.

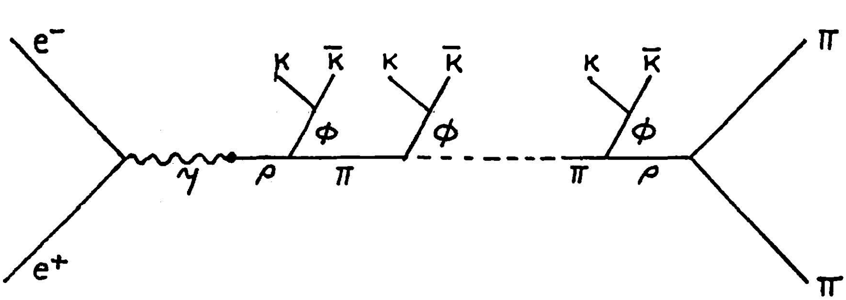

Fig. 5. Multiple production of kaons-antikaons in $e^+ e^-$ annihilations, according to the present model.

been presented in Figs. 5 and 6. It is worthwhile to mention that both $\gamma - \varrho^0$ and $\gamma - \omega^0$ could give rise to the chain yielding free pions, kaons or antiprotons and the chain winds up in the final $\varrho\, \pi\, \pi$ in all cases. $\varrho^0 - \gamma$ chain is likely to dominate as ϱ^0 production is more abundant than ω^0 production in annihilation processes[8].

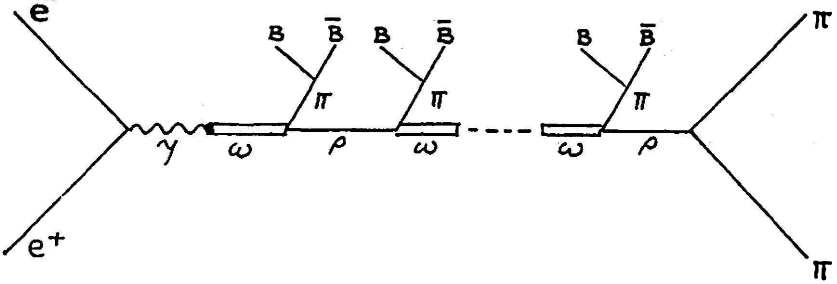

Fig. 6. Multiple production of protons-antiprotons in $e^+ e^-$ annihilations in the present scheme of particle production.

The pion production in PP scattering according to our model is given by the following diagram where the proton structure is considered to be given by $p = (\mu^+ \nu_\mu \nu_\mu \bar{\nu}_\mu \nu_\mu) = (\pi^+ \pi^0 \nu_\mu)$.

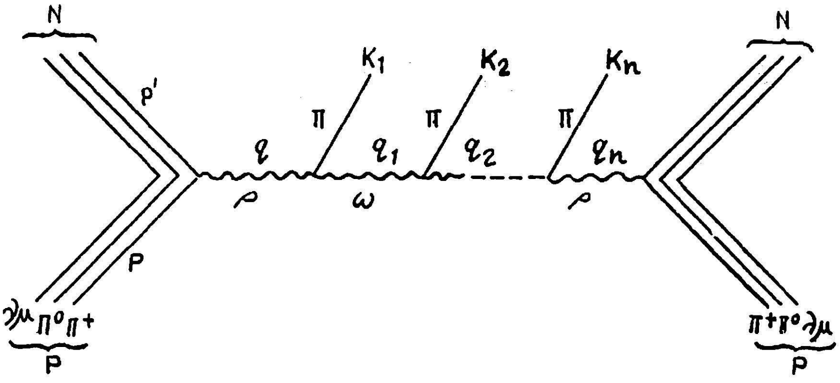

Fig. 7. Multiple production of pions in PP scattering according to our model.

In general it is believed here that the muonic leptons are the constituents of all hadrons where the internal quantum numbers like isospin, strangeness and baryon number can be related to the internal angular momentum of the constituents and we can have a geometrical origin of the SU_3 symmetry of hadrons provided we assume that the leptonic constituents are bound by a harmonic oscillator potential. Feynman diagram calculations of the above type of diagrams [Fig. 7] and some detailed discussions on them have been presented by us in several papers[9-12] in detail. In order to avoid tiresome repetition, we simply pick up the relevant results with due consideration to the necessary changes caused by the changes in interacting particles (electrons, positrons instead of protons, pions etc.) and in the nature of interactions (annihilation processes).

The points of divergence are: (i) the number of contributing diagram in this case is one and only one instead of 9 in case of PP scattering, (ii) there is no question of basic $\pi\,\pi$ interaction here and so there is no factor of conversion of S as iu PP or πP scattering, (iii) the momentum transfer squared $q^2 = (P+p)^2 = S$ (of the system), where P and p are the 4-momenta of the electron and the positron, respectively.

According to this model, the average charged multiplicity from PP collisions has been shown to be given by

$$\langle N_{ch\cdot pion}\rangle_{PP} = 6\left(\frac{4}{25}\right)^{\frac{1}{3}}\left(\frac{f^2_{\varrho\omega\pi}K^2_{max}}{64\,\pi^2}\right)^{\frac{1}{3}} \tag{1}$$

where K^2_{max} is the sum of the square of the momenta of the produced secondary pion. Now we use $f^2_{\varrho\omega\pi}/4\pi = 0.5/m^2_\pi$ with parametrisation of $K^2_{max}/m^2_\pi = S/GeV^2$. Thus the final expression for the average charged pion multiplicity in PP scattering was deduced to be

$$\langle N_{ch\cdot pion}\rangle_{PP} = 0.66\ S^{\frac{1}{3}}. \tag{2}$$

Similarly, the expression for pion multiplicity in e^+e^- annihilation is

$$\langle N_{ch\cdot pion}\rangle_{e^+e^-\ annihi} = \frac{2}{3}\left(\frac{f^2_{\varrho\omega\pi}K^2_{max}}{64\,\pi^2}\right)^{\frac{1}{3}} + \frac{4}{3} = 0.5530\ S^{\frac{1}{3}} + \frac{4}{3} \tag{3}$$

where we have used again

$$f^2_{\varrho\omega\pi}/4\pi \cong \frac{0.5}{m^2_\pi} \quad \text{but} \quad K^2_{max} = S/GeV^2$$

and the value of m^2_π in GeV^2. The factor $\frac{4}{3}$ arises due to the following reason: to complete the chain we need two pions coupled to rho-meson at the end on which phase space integration is to be carried out. Depending on the charge state of the rho-meson the two pions may be charged (positive or negative) or neutral. Thus, the average contribution from these two pions to the charged-pion variety $= \frac{2}{3}(2) = \frac{4}{3}$. Fig 8 gives a theoretical plot of Eq. (3) against the experimental points shown by Takagi[13]. At $S \cong 10^3$ GeV^2, equations (2) and (3) agree remarkably well and explain the identity of behaviour. This is what we get even when the complications due to leading particle effect in PP scattering is not taken into consideration. The average multiplicities of kaons and antiprotons[9] in e^+e^- annihilations have similarly been derived to be

$$\langle N_k\rangle_{e^+e^-annihi} = 2.7 \times 10^{-2}\ S^{2/5} \tag{4}$$

$$\langle N_{\bar{P}}\rangle_{e^+e^-annihi} = 1.5 \times 10^{-2}\ S^{2/5}. \tag{5}$$

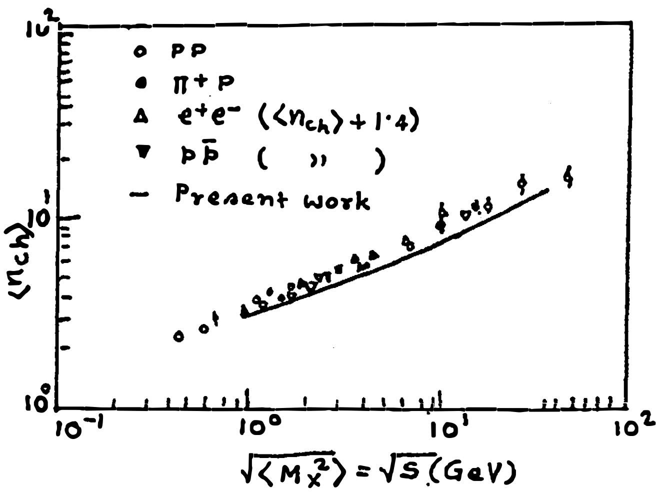

Fig. 8. Plot of average charged multiplicity versus S of the system. The solid line represents our theoretical results and the data points are from Ref. 13.

Amongst the secondaries produced in both $e^+ e^-$ annihilations and the hadronic collisions there is a preponderance of pions-so much so that one may write

$$\langle N_{ch\cdot secondaries} \rangle_{\substack{PP\ collision \\ e^+e^-\ annihi}} = \langle N_{ch\cdot pions} \rangle_{\substack{PP\ collision \\ e^+e^-\ annihi}}.$$

The fractional yield of charged kaons thus become

$$\frac{K^-}{\pi^-} = \frac{2.7 \times 10^{-2}\, S^{2/5}}{0.33\, S^{\frac{1}{3}}} \cong 0.08\, S^{0.07}. \tag{6}$$

The constant term $\frac{4}{3}$ has been neglected in the denominator of Eq. (6). If the S-term is converted into the momenta of the emitted secondaries it can be shown that roughly

$$\frac{K^-}{\pi^-} \cong 0.1\, p_k^{\frac{1}{7}} \tag{7a}$$

and similarly

$$\frac{\overline{P}}{\pi^-} \cong 0.05 p_p^{\frac{1}{7}}\,. \tag{7b}$$

3. *Results and dicsussion*

The expressions in Eq. (7) successfully explain the rise[14] of the fractional yield of the pions and antiprotons with increasing outgoing momenta. Data are so sparse that we did not attempt to plot it. The nature is hinted by Fig. 3. Expressions (2) and (3) are quite comparable in magnitude which reproduces the »universality« of average multiplicity and the manifest similarity of mechanism for production of hadrons in both the cases speaks for itself. The present model has a strong plus point in the sense that it can differentiate between various types of hadron production dynamically.

In explaining the behaviour of R it has been proposed by Bandyopadhyay[4)] that the high energy behaviour of leptons and hadrons are interconnected and both the hadronic total cross section and $\sigma (e^+ e \to hadrons)$ are products of the structural effects of hadrons. It is predicted that the ratio $R = \frac{\sigma (e^+ e^- \to hadrons)}{\sigma (e^+ e^- \to \mu^+ \mu^-)}$ will rise asymptotically.

Reiterating hadron model, the structure of protons and antiprotons are given by

$$p = (\pi^+ \pi^0 \nu_\mu) \tag{8}$$

$$\overline{p} = (\pi^- \pi^0 \nu_\mu). \tag{9}$$

So the $P\overline{P}$ annihilation process is contributed by $\pi^+ \pi^- \to \varrho^0 \to$ *free pions* (accompanied by $\varrho-\omega$ chain). The kinematics and the entire procedure (so far as average multiplicity is concerned) will be same as that for $e^+ e^-$ annihilations and so the major conclusions for $e^+ e^-$ annihilations will remain valid for $P\overline{P}$ annihilations too. This is also corroborated by experiments.

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Note added (Calcuta, June 9 1982)

The CERN NA (5) experiment referred to in my work (Ref. 6) is fortunately by now published in Physics Letters **112B** (1982) 173. Dr. N. Sarma is one of the members of the group.

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NOVI PRISTUP VIŠEHADRONSKOJ PRODUKCIJI U $e^+ e^-$ PROCESIMA ANIHILACIJE

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Originalni znanstveni rad

Koristeći novi pristup fenomenu višečestične produkcije pokušali smo analizirati neke karakteristike produkcije piona, kaona i antiprotona u $e^+ e^-$ anihilacionim procesima. Globalna struktura hadronske produkcije u lepton-hadron, hadron-hadron raspršenjima, te u $e^+ e^-$ anihilacionim procesima je također naglašena i objašnjena.