COMMENTS ABOUT $\bar{p}p$ COLLISIONS

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Abstract

A review concerning specific properties of $\bar{p}p$ collisions has been done through the summary of several theoretical and experimental papers. Some new experimental measurements are suggested towards the analysis of different already known hadronic processes.

What new can we learn about duality and hadron structure by the study of $\bar{N}$ annihilation that we cannot learn from pions, kaons or proton experiments.

One of the newest concepts on this subject will be the hypothesis of the existence of possible exotic meson states and the possibility for an analogy between field theory and quark representation.

Exotic mesons coupled to the $N\bar{N}$ system were predicted mainly on the basis of $N\bar{N}$ potentials [1]

Already in 1949 Fermi and Yang initiated various compound models of elementary particles in terms of nucleon-antinucleon states. In 1956 Bethe, Hamilton and Afrikyan tried to solve the same question in analogy to the deuteron problem using the nuclear physics potential approach. In 1958 Bethe and Chew constructed an $N\bar{N}$ potential from NN states by a parity transformation. Ball, Scott and Wang using a one-boson exchange model obtained a heavy mass boson spectrum. They found four bound states of the $N\bar{N}$ system with the same quantum number as those of π, ρ, ω, σ, mesons. A common characteristic of these papers was that the influence of the strong annihilation on the formation of bound and resonant states was not taken into account.

A very interesting point concerning the relevance of the $N\bar{N}$ states to nuclear physics is the understanding of the relation between the NN and $N\bar{N}$ boson exchange potential through the G-parity transformation which sign is the difference between e^-e^- and e^-e^+ electromagnetic interactions, due to the fact that the exchanged photon has a charge parity - 1.

For the strong interaction in the one-boson exchange model, the difference between the NN and $N\bar{N}$ interactions is described by the G-parity of the exchanged meson. Owing to the G-parity of the ω-mesons the repulsive hard-core of the NN potential becomes a deep well in the case of $N\bar{N}$. This will offer the possibility for a number of states to be found (very narrow ones : a few MeV) as opposed to the nucleon-nucleon spectrum (only one state : the deuteron).

Shapiro et al. considered for the first time the $N\bar{N}$ annihilation process under the assumption that the annihilation radius is proportional to $1/2\ m_N$ and treat the annihilation in terms of perturbation theory. In particular for bound states they predicted the possibility of E1 and M1 electromagnetic transitions from the lowest atomic states to the quasi-nuclear bound states.

The nuclear physic potential approach was initiated and generalized by Deroer et al. and for the first time the possibility of pionic transition to quasi nuclear states was discussed.

On the other hand, through the development of the quark model, many authors predicted narrow $N\bar{N}$ states within the framework of quantum electrodynamics. In 1968 Lichtenberg first adopted the idea that baryons in SU(6) representation are composed of a quark and a diquark. This assumption makes difficult the consideration of an object composed of an antiquark and a diquark : the so-called d or exotic meson. Owing to duality arguments the pionic decay of these four quark structures is weakly forbidden and so one obtained for the first time a clear statment that these states should be narrower than those of ordinary mesons.

Nevertheless at that moment it is difficult to make a strict distinction between these two different points of views - the dual model and the nuclear potential model - since each model illustrates a different property of physics and since both have a limited degree of validity.

<u>What can we learn more precisely about $p\bar{p}$ annihilation from the experimental point of view.</u>

One of the most important parts of hadron physics involves annihilation processes materialized by lepton pair creation.

The main approach for lepton pair production is that of the exchange of an intermediate heavy boson W[5]. One method to estimate the W production cross section is to rely upon :

- the principle of conserved vector current (CVC) which implies the assumption that the observed weak current and the isovector part of the electromagnetic current form an isomultiplet.

- the scaling hypothesis which implies the hypothesis that the dimensionless cross section $m^3\, d\sigma/dm$ for electromagnetic production of a lepton pair in pp collisions is a function of only s/m^2 where m is the dilepton invariant mass and s the c. m. energy of the pp system (figure 1).

Using CVC and assuming the isoscalar part of the dilepton production to be small, the cross section for producing W with mass m is approximately given by 0.1 GeV^{-2} times the corresponding $m^3 d\sigma/dm$ for dilepton production, with m in units of GeV. If scaling holds, the same cross section estimate can be used to predict cross sections for the production of a heavier W at a corresponding higher energy. Unfortunately such a procedure is still not possible : there are measurements of dilepton production cross sections for a wide range of energies and dilepton masses and they involve different experimental acceptances : thus a direct comparison to check scaling is not yet possible.

Another approach is to use a quark-parton model which specifically contains scaling and CVC. The dilepton and W production cross section structure are given in terms of the quark structure functions of the hadrons. These structure functions are in principle derived from lepton-hadron inelastic scattering. The coupling strength of the W to the quarks depends upon specific weak interaction theories : The main uncertainty of this approach is that the antiquark distributions in the proton are not well determined in lepton-hadron inelastic scattering for $x \geq 0.1$ (where x is the fraction of the proton momentum carried by the quark). However the dilepton production in pp reactions depends sensitively on the full distribution of the sea-quarks and therefore we have to determine the behaviour of the sea quark distribution from the dilepton production data.

It is interesting to note that $\bar{p}p \rightarrow \ell^+ \ell^- + X$ reactions are dominated by valence quark interactions in the region where the sea quark distributions are uncertain. Therefore $\bar{p}p \rightarrow \ell^+ \ell^- + X$ reactions provide a different check of the Drell Yan model. It will be interesting to have such experiments, this in comparison with pp annihilation mechanism which are dominated by sea-quark distributions.

From a phenomenological point of view the number of jets can be correlated to the number of implied quarks.

- A comparison with K processes can give some indications about sea quarks through strangeness contribution.
- In fact a comparison between every kind of nuclear process should give informations about the involved quarks for dual representation or about the exchanged boson for a potential representation.

<u>What are the already known specific features of $\bar{p}p$ annihilation</u> ?

The main characteristics are the large values for the average transverse momentum and the large values for the multiplicity of negatively charged particles at a particular value of c.m. energy, both of these by a comparison with data from non-annihilation mechanism.

Another characteristic is the relative uniform population of phase-space which should be considered as a dynamical effect related to the high values of $\langle p_T \rangle$ and hence to baryon exchange and to the absence of a diffractive dissociation component : the experimental consequence is the suppression of a strong leading particle effect.

From jet structure at large p_T it is possible to look for the possibility of W-boson exchange mechanism [4]. This jet physics that of very rare events, it needs high luminosity and a trigger over a large solid angle.

The ultimate goal of large p_T physics is to measure the differential cross section in order to get access to the basic quark-quark elastic cross section. The observation of a p_T^{-4} dependance at very large p_T would be a great success for the quark-quark scattering theory and hence will be an important measurement to do at the $\bar{p}p$ collider. However the measurement of the number n of involved quarks at fixed total c.m. energy is not possible strictly speaking unless one knows a priori the structure function. In order to get rid of the x_T dependance one needs to measure the cross section for at least two different energies s_1 and s_2. Then the ratio of the cross sections at the same x_T value is given by

$$\left| \frac{d\sigma_1}{d\sigma_2} \right|_{x_T} = \left(\frac{s_1}{s_2}\right)^n$$

Another aspect will be the W-boson exchange. As in the previous case, jets from W decay are produced centrally. However in that case the two jets are completely correlated in the sense that their effective mass : $M = 2\,k_T \cdot ch \frac{y-y'}{Z}$ must equal the mass of the intermediate boson M(W) = 70 GeV. In the central region since $dy_{max} = 2.6$, the jets from the W must have a $k_T \simeq 17.5$ GeV/c. Results from $\bar{p}p$ collider at $\sqrt{s} = 400$ GeV allow presently to give the number of pair of jets coming from the W and Z^o decay. They are deduced from the cross sections given in ref. 5. and correspond to the popular theory with four quarks of three colours and four leptons. Nevertheless there remains uncertainties namely to decide whether a particle belongs to the jet or not. There is of course a problem for slow particles in the jet which can be confused with particles of the ordinary beam fragments : on the other hand one should keep in mind that for the analysis which has been done :

- the background was really an upper limit in the sense that if it exists at all the k_T^{-4} mechanism cannot be higher because of the ISR experimental results.
- on the other hand 50 % of the W-jets carry strangeness and charm and could be therefore much different from the background jets.
- At least it would be necessary to get a complete description of the jet structure in the central region by means of a larger acceptance for the trigger detector (close to 4π) in order to be able to distinguish either between an isotropic or a coplanar two jet structure.
- There is a last result from $\bar{p}p$ annihilation at rest [1] ($\bar{p}$ from the 800 MeV PS proton beam). The measurement of γ-ray spectra shows after subtraction of the usually known annihilation channels, three narrow structures in the region between 180 and 420 MeV for which quantum numbers have not yet been attributed. (On the same order of idea specific channel cross section measurements [6] allowed to study the properties of the D(1285) and E(1420) meson states)

What are the experimental results from nuclear interactions which could give interest to $\bar{p}p$ collisions study ?

As we already emphasized, one of the most important experimental points is the γ-ray and lepton pair detection in order to approach annihilation mechanism. For that reason we go through some results obtained for instance from pp collisions. Inclusive electron pairs produced in pp collision have been detected and an additionnal search made for the photon accompaning the J/ψ [7]. The results suggest that $|43 \pm 21|$ % of the J/ψ are produced via the decay of one of the $\chi\,|3.5|$ states : $\chi\,|3.51| \rightarrow J/\psi$ + anything. This could account for the observed small ratio of ψ' production relative to $\psi\,|\simeq 2\,\%|$. This hypothesis was tested by a search of $J/\psi + \gamma$ coincidence at CERN ISR. The J/ψ's where produced in pp collisions at $\sqrt{s}$ = 53 GeV and detected by their decay into electron pairs. The energies of the electrons and photons where detected by liquid-argon calorimeter. For background analysis the contribution to $J/\psi + \gamma$ states from other processes like $\psi' \rightarrow J/\psi + \pi^0$ or $\psi' \longrightarrow J/\psi + n$ etc... was considered to be small and would have given a quite different mass distribution. However there remains some uncertainty for the interpretation due to the poor mass resolution. The excess of events in the χ region could also be attributed to a dynamical effect which causes the γ-spectrum to be different for the J/ψ events and the background samples.

In addition to the Drell-Yan model for lepton pair production some other mechanisms could require a possible interpretation like [10]: - a large p_T bremsstrahlung which has been proposed to account for most of the data on the e/π and p/π ratios at high p_T. According to this mechanism, leptons are produced via the bremsstrahlung of virtual photons (of predominantly low mass) from the charged constituents present during the collisions. Real photons are also produced this way. The bremsstrahlung mechanism implies a dilepton mass distribution $d\sigma/dQ \simeq 1/Q$ instead of the usual $d\sigma/dQ \simeq 1/Q^3$ deduced at low Q from the parton model. This model has the virtue of extending down to low mass pairs whereas the Drell-Yan mechanism is known to require modifications for small Q^2. The crucial test of the above model would be to to measure the ratio : $p + p \longrightarrow$ direct $\gamma/p + p \longrightarrow \pi^o$ which is predicted to be $\simeq 10\,\%$. However, the difficulty will be to detect experimentally a single emitted photon.

Another aspect which is, for instance, analyzed in pp collision [8,9] is the inclusive behaviour of the hadrons which are produced versus the values of transverse momenta. It allows one to compare different kinds of models like QCD or CIM through charge symmetry, rapidity distributions etc.. measurements. Some of these characteristics are :

- an excess of low x values in the 4 GeV region which accounts for the explanation that charm production is dominant in this region
- the ratio π^+/π^- has a strong dependance towards p_T and above $p_T > 3$ GeV/c there is an excess of positive over negative particles
- the ratio π^o/π (charged) is a strong function of p_T in correlation with a strong dependance of multiplicity according to Q^2.

This in comparison with $\bar{p}p$ collisions for which other kinematical regions are involved (namely the longitudinal momenta of the interacting quarks), and for which other kind of quarks can interact in the frame of a Drell Yan representation.

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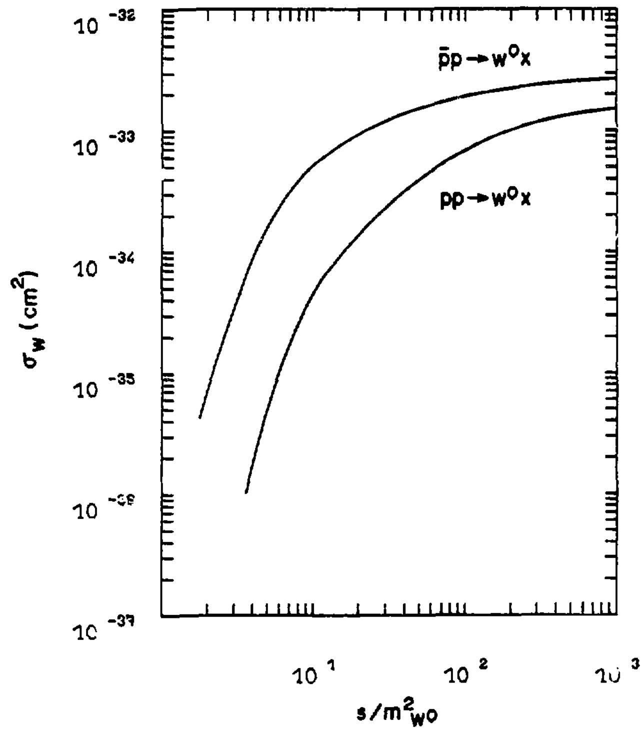

Figure 1

Calculated total cross sections with

m_W = 77 GeV/c^2 and $\sin^2\theta_W$ = 0.4

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