WIDTH OF STRONGLY BOUND NUCLEAR ANTIPROTON STATES

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We study a recent conjecture suggesting that the width of a strong bound $\bar{N}N$ system shrinks drastically when its energy decreases. We show that, instead, the width should stay roughly constant.

Recently, Auerbach et al. [1] suggested that deep-lying $\bar{p}$–nucleus states, as predicted by a strict application of Dirac phenomenology, could be very narrow. They argued on the possible strong dependence of the hadronic width of a $\bar{N}N$ system as a function of its mass. We challenge their assertion that the width of a strongly bound $\bar{N}N$ system is much reduced compared to the free annihilation width. The base of the argumentation put forward in ref. [1] is that the partial width for producing a certain number of pions is reduced in proportion to the phase-space integral; since the production of 5 pions is the dominant mode in $\bar{N}N$ at threshold, and a lowering of the mass by 0.8 GeV reduces the phase-space integral by a factor of about 300, this would be a spectacular effect. We believe on the contrary that the width is essentially independent of the mass of the system which annihilates.

We rely on the assumption of independence of formation and decay of the hadronic system [2] in the intermediate stage of the annihilation. We write for the cross section to produce n pions

$$\sigma_n = \sigma_0 \Gamma_n / \Gamma \,, \qquad (1)$$

it has been shown [3] that (1) gives a good interpretation of the energy variation of the multipion cross sections at low momenta, when σ_0 is the reaction cross section from a boundary condition with $R = 0.9$ fm. The quantity Γ_n/Γ is the *relative* width for the n-pion multiplicity. As σ_0 corresponds to a boundary condition expressing a strong absorption [3], one can consider that pion production in $\bar{N}N$ annihilation is governed by the same orders of magnitude as the decay of the mesons, i.e. by the typical hadronic length and time scale

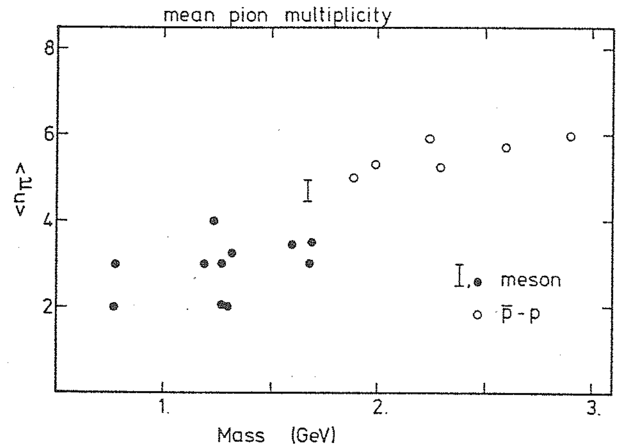

Fig. 1. Pion multiplicity in meson decays (full circles and bar) and in $\bar{p}p$ annihilation (empty circles), $\sqrt{s} < 3$ GeV. The mesons are the non-strange, non $s\bar{s}$, ones: ρ(770), ω(738), h_1(1190), b_1(1235), f_2(1270), a_1(1270), f_0(1300), a_2(1320), ρ(1600), ω_3(1670), π_2(1680), ρ_3(1690); the bar for ω_3(1670) is due to the large uncertainty in the $5\pi/3\pi$ ratio [4].

$$R \simeq 1 \text{ fm}, \quad \tau \simeq 1 \text{ fm}/c,$$

$$\Gamma \simeq \hbar c / c\tau = 0.2 \text{ GeV}.$$

A strong argument to link the $\bar{N}N$ system to the non-strange mesons is found in the fact that the mean pion multiplicity in both cases fits in the same general trend (see fig. 1).

Now, we observe that the total width of the mesons

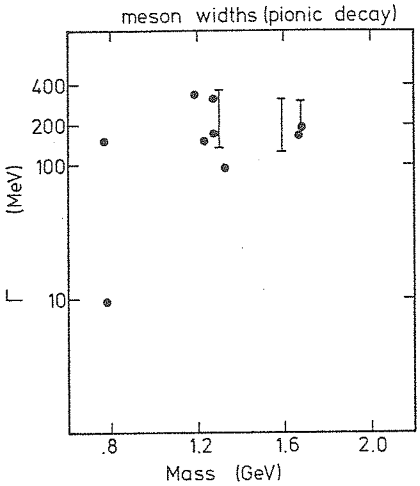

Fig. 2. Observed widths of pionic decays of the same mesons as in fig. 1.

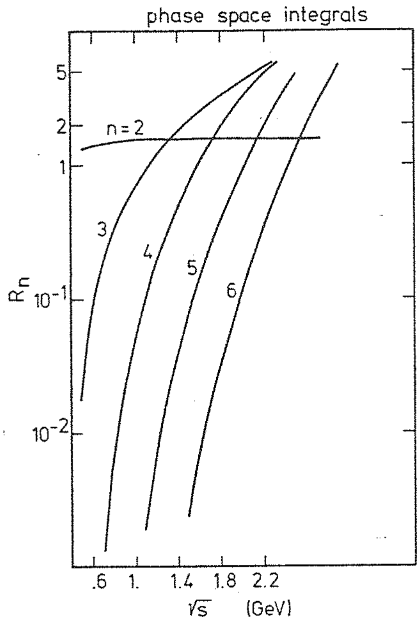

Fig. 3. Values of the invariant momentum space integrals R_n, in units $(\mathrm{GeV})^{2n-4}$.

looks essentially independent of mass [4]. As fig. 2 shows, the widths fluctuate by a factor 2 at most around the value of 200 MeV with the sole exception of ω(783), whose decay via ρ(770)π is slowed down by mass constraints. This holds over a mass range where the relevant phase-space integrals for the dominant modes (essentially $n=3$ and $n=4$) vary drastically (see fig. 3).

We write the n-pion frequencies as

$$f_n=\frac{\Gamma_n}{\Gamma}=\overline{|T_n|^2}R_n\Big/\sum_i\overline{|T_i|^2}R_i\,, \qquad (2a)$$

where R_n is the invariant phase space (in fact, momentum space) integral [5]; for $\overline{|T_n|^2}$ we take the statistical ansatz [6]

$$\overline{|T_n|^2}\propto(4\pi M^2)^{-n}\,. \qquad (2b)$$

The value $M=0.155$ GeV gives $\bar{n}=5.0$ for $\bar{p}p$ annihilation at rest and the general trend observed in fig. 1.

The variation of the mean pion multiplicity is governed by the variation of the phase-space integral with the parent mass. We thus expect that a strongly bound $\bar{N}N$ system with a mass, say of 1.1 GeV, will decay mainly into three pions and still have a width of the order of 0.2 GeV.

It remains to understand the reason for the constant hadronic width suggested by phenomenology. A hint is that meson decay, as well as annihilation, are in fact mainly two-body processes. An examination of the Particle Data Group [4] meson table reveals that a large fraction of the multipion decays are in fact of the types ρπ, ωπ, $b_1\pi$, ρρ ,...; similarly annihilation at rest [7] [‡1] contains a large fraction of identified two-body channels, even of types like ωρ, fρ. It might very well turn out that a very fine analysis will finally attribute the whole of annihilation and decays to two-body processes (but this is a difficult experimental task in view of combinatorial problems and large widths in many-particle channels). The fact that the two-body phase-space integral is almost independent of the parent and daughter masses would then allow to understand that the width is similar for all mesons and for the $\bar{N}N$ system. Let us finally notice that Frautschi has pointed out that the statistical bootstrap model is, under some conditions, consistent with a constant width for systems with zero baryon number [9].

In conclusion, we showed that the $\bar{N}N$ system below threshold, as well as mesons ($B=0$ systems), exhibits total width independent of the energy. We

‡1 Ref. [8] presents a useful compilation of branching ratios for $\bar{p}p$ at rest.

stress that our arguments are completely independent of the validity of the Dirac phenomenology and of a strict application of *G*-parity conjugation to pass within this model from the p–nucleus to the $\bar{p}$–nucleus system. They hold whatever the dynamical process which decreases or raises the total energy of the system.

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