tors $L_\pm$ Eqs. (7) and (8) would lead to the "intelligent spin states" of C. Aragone, G. Guerri, S. Salamó, and J. L. Tani, J. Phys. A 7, L149 (1974); C. Aragone, E. Chalbaud, and S. Salamó, J. Math. Phys. (N.Y.) 17, 1963 (1976).

[13]Observe that in the special case Im$C=0$, our coherent states include the circular-motion "classical wave packets" which L. S. Brown, Am. J. Phys. 41, 525 (1973), obtained on physical grounds, for the large-n case. Also see J. Mostowski, Lett. Math. Phys. 2, 1 (1977), who, using the Perelomov formulation, has obtained wave packets which, for the case of circular motion, are "similar to the wave packets discussed by Brown."

Tensor Mesons as a Source of Low-Mass Dimuons

I. H. Dunbar
H. H. Wills Physics Laboratory, University of Bristol, Bristol BS8 1TL, United Kingdom
(Received 24 April 1978)

Recently, anomalous production of dimuons with $m < 600$ MeV has been reported in 16-GeV/c $\pi^\pm p$ collisions. Production and subsequent decay of the tensor mesons f and A_2^0 is suggested as a source for these dimuons.

Dilepton production in hadronic collisions is currently of considerable interest. At invariant masses greater than 1 GeV there are narrow resonances superimposed on a steeply falling continuum. The continuum is understood in terms of the parton-antiparton annihilation process proposed by Drell and Yan[1] and the resonances are taken as evidence of new quark flavors. However, a recent investigation[2] of low-mass dimuons produced in $\pi^\pm p$ collisions at 16 GeV/c has found dimuon production which does not easily fit into this scheme. The ρ and ω resonances are clearly seen, but below the ρ mass there remain contributions in addition to the known Dalitz decays.

In order to show what signal remains to be explained, known contributions are subtracted from the histogram of Bunnell *et al.*[2] in the following way: (i) Their expected (rather than their maximum) Dalitz-decay signal is subtracted, and (ii) except for two events per bin all events between 0.62 and 0.89 GeV are assigned to the vector mesons. Two events per bin is the average number found in bins immediately to either side of the resonances. Fourteen events in the bin centered on 0.785 GeV are assigned to ω, this number being chosen to give a smooth ρ peak. The rest of the resonance events are assigned to ρ.

The original data suggest that the ρ and ω mesons are superimposed upon a smoothly falling background. However, when the Dalitz contribution, which is surely present even if not in precisely the amounts I have assumed, is subtracted, what remains invites the following interpretation: There is a flat continuum from threshold to a sharp cutoff around 0.55 GeV, superimposed on a slowly varying background of about two events per bin. The statistics are such that the 0.55-GeV dip may be a fluctuation, but the data are at least consistent with the interpretation suggested and I wish to propose a mechanism which accounts for this shape. It is difficult to obtain the required smoothly falling spectrum. In particular, simple quark counting arguments imply for a Drell-Yan mechanism

$$\frac{\pi^- p \to \mu^+\mu^- X}{\pi^+ p \to \mu^+\mu^- X} \sim 8$$

(see for example Donnachie and Landshoff[3]) whereas the observed ratio[2] is 1.28 ± 0.23.

Given a flat distribution with a sharp cutoff, what is required is a decay of the form $h \to h'\mu^+\mu^-$, where h and h' are hadrons with

$$\Delta M = M_h - M_{h'} \approx 0.55 \text{ GeV}. \qquad (1)$$

The Dalitz decays of η and ω have this feature, but being p-wave decays their spectra near the upper threshold (where the dimuon invariant mass is $m \lesssim \Delta M$) are proportional to $(\Delta M - m)^{3/2}$. A sharp cutoff requires an s-wave decay (electric dipole) with $(\Delta M - m)^{1/2}$ threshold behavior. I propose that the most important candidates are

$$\text{I: } A_2^0 \to \omega\mu^+\mu^-, \quad \Delta M_\text{I} = 0.53 \text{ GeV},$$

$$\text{II: } f \to \rho^0\mu^+\mu^-, \quad \Delta M_\text{II} = 0.50 \text{ GeV}.$$

This proposal is tested in two stages, by first checking that the spectra obtained have the right shape, particularly in respect of the position of

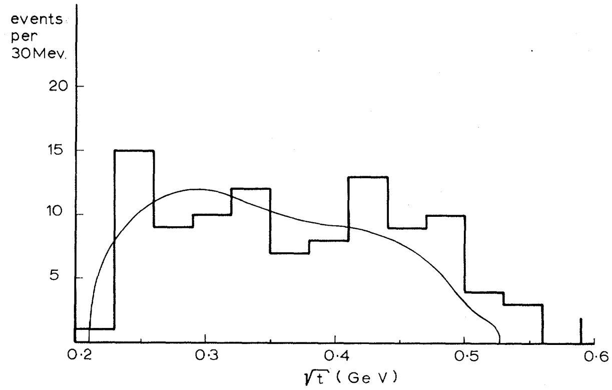

FIG. 1. Dimuon spectrum. The histogram is the experimental spectrum. The smooth curve is that predicted by the theory with equal A_2^0 and f production (normalized to fit histogram).

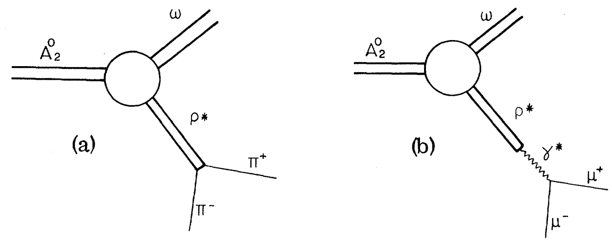

FIG. 2. ρ dominance model for A_2^0 decays. (a) $A_2^0 \to \omega\pi^+\pi^-$, (b) $A_2^0 \to \omega\mu^+\mu^-$.

and behavior near the upper threshold, and then estimating the production cross section to see whether these reactions can give rise to a big enough signal.

Being of the form $2^+ \to 1^-\gamma^*$ (an asterik here and below denoting a virtual particle), the decays I and II can go via an s wave. The solid curve on Fig. 1 is the sum of the dimuon invariant-mass distributions, $d\Gamma/dm$, for the two reactions, normalized to fit the data at $m = 0.4$ GeV. It is the shape predicted assuming A_2^0 and f production cross sections to be equal. In calculating this curve no account has been taken of resonance widths.

If the model is to work (and if we assume that the apparatus acceptance does not bias one towards seeing one sort of hadron more than another), the following condition must hold:

$$\sum_i \sigma(\pi^- p \to h_i X)\, B(h_i \to h_i'\mu^+\mu^-) \approx 2\sigma(\pi^- p \to \rho^0 X)\, B(\rho^0 \to \mu^+\mu^-). \qquad (2)$$

The factor 2 comes about because the analysis of the data described above assigns twice as many events to the signal as it does to the peak. The sum runs over all hadron pairs (h_i, h_i') contributing to the signal, and σ and B denote, respectively, the cross section for 16-GeV/c pions and the branching ratio of the bracketed reaction. The ρ^0 inclusive production cross section[4] is 4.7 ± 0.4 mb. Therefore we require

$$\sum_i \sigma(\pi^- p \to h_i X) \frac{B(h_i \to h_i'\mu^+\mu^-)}{B(\rho^0 \to \mu^+\mu^-)} \approx 9.4 \text{ mb}. \qquad (3)$$

The distribution for reaction I cannot be normalized to the $A_2^0 \to \omega\gamma$ rate, for this rate is not known. Instead use is made of $A_2^0 \to \omega\pi^+\pi^-$ and the following simple vector-dominance model. Since the $\pi\pi$ system must have $I = 1$ and hence odd angular momentum, it is assumed that the $\pi\pi$ system is in a p wave and comes from a virtual ρ. It is assumed that reaction I is also ρ dominated. The model is summed up by the diagrams of Fig. 2. If the A_2^0 were massive enough to decay to ω and a real ρ, given[5]

$$B(A_2^0 \to \omega\pi^+\pi^-) = (9.3 \pm 1.2) \times 10^{-2},$$

one would expect

$$B(A_2^0 \to \omega\mu^+\mu^-) = B(A_2^0 \to \omega\rho^0) B(\rho^0 \to \mu^+\mu^-) = B(A_2^0 \to \omega\pi^+\pi^-) B(\rho^0 \to \mu^+\mu^-) \approx 7 \times 10^{-6}. \qquad (4)$$

This result would require, for Eq. (2) to hold, the A_2^0 production cross section to be unacceptably high.

However, as the mass of the virtual ρ decreases, the rate to $\mu^+\mu^-$ increases (as the γ propagator increases) and the rate to $\pi^+\pi^-$ decreases (p-wave barrier factor), so that

$$B(\rho^* \to \mu^+\mu^-) = \frac{\Gamma(\rho^* \to \mu^+\mu^-)}{\Gamma(\rho^* \to \pi^+\pi^-)} > B(\rho \to \mu^+\mu^-). \qquad (5)$$

The relevant distributions are

$$\frac{d\Gamma(A_2^0 \to \omega\pi^+\pi^-)}{dm} = Nk_\omega \left[\frac{m^2 - 4m_\pi^2}{m_\rho^2 - 4m_\pi^2}\right]^{3/2} \frac{4m_\rho^2}{(m_\rho^2 - m^2)^2} \Gamma(\rho^0 \to \pi^+\pi^-), \qquad (6)$$

$$\frac{d\Gamma(A_2^0 \to \omega\mu^+\mu^-)}{dm} = Nk_\omega \left[\frac{m^2 - 4m_\mu^2}{m_\rho^2 - 4m_\mu^2}\right]^{1/2} \frac{m_\rho^4(m^2 + 2m_\mu^2)}{m^4(m_\rho^2 + 2m_\mu^2)} \frac{4m_\rho^2}{(m_\rho^2 - m^2)^2} \Gamma(\rho^0 \to \mu^+\mu^-). \qquad (7)$$

Here N is a constant and k_ω is the momentum of the recoiling ω. Integrating these and taking the ratio of the rates gives

$$\frac{\Gamma(A_2{}^0 \to \omega\mu^+\mu^-)}{\Gamma(A_2{}^0 \to \omega\pi^+\pi^-)} = 32B(\rho^0 \to \mu^+\mu^-), \qquad (8)$$

so that

$$B(A_2{}^0 \to \omega\mu^+\mu^-) = (2.0 \pm 0.6)\times 10^{-4}. \qquad (9)$$

The $A_2{}^0$ is a more prolific source of dimuons than ρ^0 by at least a factor of 3. Indeed, the predicted width of 20 keV to $\mu^+\mu^-$ is greater than any of the known mesonic dimuon widths.

A similar analysis serves for the f. The hypothesis of Ascoli *et al.*,[6] with which the results of subsequent experiments[7-9] are at least consistent, is adopted so that the $f \to \pi^+\pi^-\pi^+\pi^-$ decay ($B = 0.028 \pm 0.003$)[5] goes via one real and one virtual ρ^0. The $A_2{}^0$ analysis embodied in Fig. 2 can be repeated for the f, the recoiling ω being replaced by ρ^0. The branching ratio is

$$B(f \to \rho^0\mu^+\mu^-) = 44B(\rho^0 \to \mu^+\mu^-)\times(0.028 \pm 0.003)$$
$$= (0.9 \pm 0.2)\times 10^{-4}. \qquad (10)$$

The f inclusive cross section is[3] (0.92 ± 0.13) mb, but that of the $A_2{}^0$ is not known. The ω cross section[10] appears to be close to that of the ρ^0, and so a reasonable guess might be that the $A_2{}^0$ cross section is similar to that of the f. If we take $\sigma(f) = \sigma(A_2{}^0) = 1$ mb, then the f and $A_2{}^0$ contribution to the left-hand side of (3) is 4.3 mb. This is a substantial contribution to the observed spectrum.

Other decays which can give the same shaped distribution are

$$\text{III: } A_2 \to \rho\mu^+\mu^-, \quad M_{\text{III}} = 0.54 \text{ GeV},$$

$$\text{IV: } g^0 \to f\mu^+\mu^-, \quad M_{\text{IV}} = 0.41 \text{ GeV},$$

and negative-parity baryon-resonance decays, prominent among which should be

$$\text{V: } D_{13}(1520) \to N\mu^+\mu^-, \quad M_{\text{V}} = 0.58 \text{ GeV}.$$

Since $M_\omega \approx M_\rho$, according to (7) we should have

$$\Gamma(A_2{}^0 \to \rho^0\mu^+\mu^-) \approx \frac{\Gamma(\omega \to \mu^+\mu^-)}{\Gamma(\rho^0 \to \mu^+\mu^-)}\,\Gamma(A_2{}^0 \to \omega\mu^+\mu^-)$$
$$\approx 0.1\Gamma(A_2{}^0 \to \omega\mu^+\mu^-).$$

III is to be expected as a decay of $A_2{}^0$, but with only one-tenth the width of I. Since the three charge states of the A_2 can take part, the contribution to the sum in Eq. (3) is 0.3 times that of reaction I, namely 0.9 mb. Neither the production cross section for g^0 nor its branching ratio to $f\pi^+\pi^-$ is known, and so its contribution to the dimuon spectrum cannot be estimated. An estimate of the branching ratio for reaction V based upon extrapolations of electroproduction amplitudes gives a value of 5×10^{-6}, suggesting, independently of considerations of production cross section and experimental acceptance, that this contribution is negligible.

In summary, I have argued that a previously unconsidered source of dimuons might give a substantial contribution to those observed and that the shape predicted is consistent with the unexplained part of the experimental spectrum. This mechanism can be tested by examining the invariant masses of the pion systems recoiling against the dimuons. Contributions from quark-gluon mechanisms[11,12] are by no means ruled out, but the production and decay of known hadrons should not be neglected.

I wish to acknowledge many invaluable conversations with Dr. W. N. Cottingham and Dr. J. W. Alcock. This work was supported by a United Kingdom Science Research Council Grant, No. NG. 01497.

[1] S. D. Drell and T.-M. Yan, Ann. Phys. (N.Y.) 66, 578 (1971).

[2] K. Bunnell *et al.*, Phys. Rev. Lett. 40, 136 (1978).

[3] A. Donnachie and P. V. Landshoff, Nucl. Phys. B112, 233 (1976).

[4] J. Bartke *et al.*, Nucl. Phys. B107, 93 (1976).

[5] T. G. Trippe *et al.*, Rev. Mod. Phys. 48, No. 2. Pt. 2, S51 (1976).

[6] G. Ascoli *et al.*, Phys. Rev. Lett. 21, 1712 (1968).

[7] J. C. Anderson *et al.*, Phys. Rev. Lett. 31, 562 (1973).

[8] Y. Eisenberg *et al.*, Phys. Lett. 52B, 239 (1974).

[9] M. J. Emms *et al.*, Nucl. Phys. B96, 155 (1975).

[10] J. Bartke *et al.*, Nucl. Phys. B118, 360 (1977).

[11] J. D. Bjorken and H. Weisberg, Phys. Rev. D 13, 1405 (1976).

[12] G. R. Farrar and S. C. Frautschi, Phys. Rev. Lett. 36, 1017 (1976).