where ΔE receives contributions of 72 and 13 MeV from $\langle r^{-1}\rangle$ and $\langle r^{-3}\rangle$ respectively. In the model of Kang and Schnitzer,[4]

$$\Delta E = 88 \text{ MeV}, \quad R_1 = 1.4, \quad R_2 = 0. \tag{17}$$

Note that the absolute scale of the P-state mass splittings is almost a factor of 5 larger than that predicted by De Rújula, Georgi, and Glashow.[5] Therefore, measurements of the energy scale appropriate to the P-state splittings will distinguish between models.

The establishment of the P-state analogs of ψ, ψ', and ψ'' in the 3400–3500-MeV region will give strong support to the simple potential picture of bound $c\bar{c}$ pairs. In this note we have emphasized how careful measurement of the P-state energy differences may serve to distinguish between competing pictures of quark confinement, as revealed by the spin-dependence of the $c\bar{c}$ forces. If in fact the γ rays observed in the decay of ψ' are correctly interpreted as $\psi' \to {}^3P_J + \gamma$, then a measurement of the ratio R_1 may be possible in the near future. A determination of R_1 to 10% accuracy might be sufficient to give us an experimental handle on an important issue of quark dynamics.

I wish to thank Professor A. De Rújula, Professor F. Gilman, and Professor S. L. Glashow for conversations.

Note added.—After this work was submitted, I became aware that similar calculations had been performed by Pumplin, Repko, and Sato.[10] The results seem to be in reasonable agreement.

*Work supported in part by the U. S. Energy Research and Development Administration under Contract No. E-(11-1)3230.

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Comment on Direct Lepton Production*

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(Received 18 September 1975)

Recent data on observations of direct leptons produced in proton-proton collisions are analyzed. It is found that the large bulk of the data can be accounted for if the origin of the leptons is a low-mass, ~(1 to 5)m_π, vector meson which decays weakly into $\mu + \nu$ and $e + \nu$ symmetrically. The proposed object is produced and decays with a cross section times branching ratio of 10^{-3} of the pion production cross section.

Direct production of leptons in hadronic collisions has now been observed in a wide variety of conditions. Early results[1-3] strongly suggested a remarkable parallelism between leptons and pions. A rigorous invariance of the lepton-to-pion ratio would clearly imply something fundamentally new, perhaps about pions. Although the data are uncertain to factors of 50% or so, the very large domain of observations is impressive. However, very recent data[4-7] appear to show clear variations of the lepton-to-pion ratio as a function of $P_\perp$ and $\sqrt{s}$.

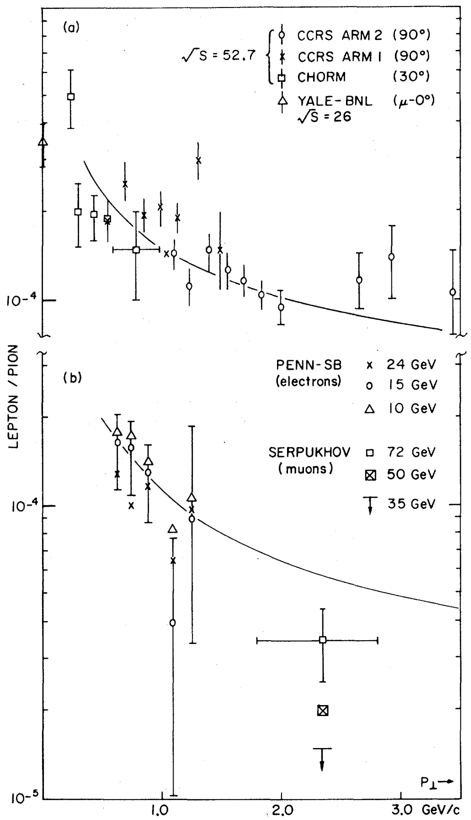

FIG. 1. The ratio of direct-lepton to pion production (a) at 300–200 GeV and (b) at 10–72 GeV. The solid lines would be predicted for $M_X \simeq 300$ MeV and X produced with a constant ratio to pion production at all $P_\perp$. The Yale University–BNL point is extrapolated from L. B. Leipuner *et al.*, private communication.

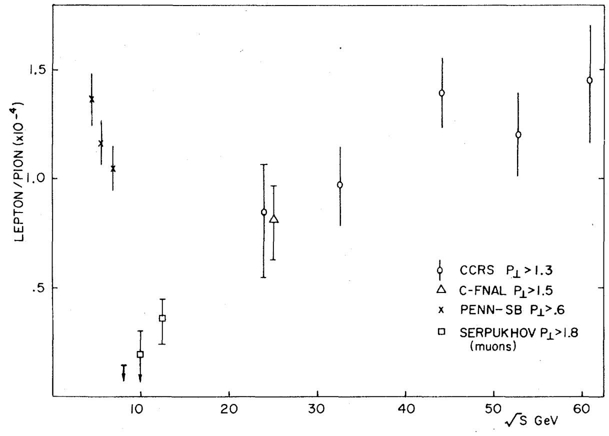

FIG. 2. The $\sqrt{s}$ dependence of direct-lepton production, integrated over lepton $P_\perp$. The fits of Fig. 1 would predict ratios of lepton to pion of (1.35, 0.71, 1.07, 1.13, 1.22, 1.25, and 1.24)$\times 10^{-4}$ in the $P_\perp$ regions measured by the Penn-SB and Serpukhov groups and at the five CCRS energies, respectively. "C-FNAL" denotes Ref. 1.

In particular, the CERN–Columbia University–Rockefeller University–Centre d'Etudes Nucléaires de Saclay (CCRS)[5] experiment has presented data down to $P_\perp = 0.6$ and a clear increase in the ratio is observed. Preliminary data from the CERN-Harvard-Orsay-Riverside-Munich-Northwestern (CHORMN)[6] group appear to confirm this and extend the observed rise down to $P_\perp \cong 0.2$ GeV/c. The University of Pennsylvania–State University of New York at Stony Brook (Penn-SB)[7] data also show a tendency to increase towards $P_\perp \sim 0.5$ GeV/c. The data are summarized in Fig. 1. Insofar as the variation with $\sqrt{s}$ is concerned, the CCRS group[4] presented data implying a dependence

$$R = \tfrac{1}{2}(e^+ + e^-)/\tfrac{1}{2}(\pi^+ + \pi^-)$$
$$= [0.6 \pm 0.25 + (0.013 \pm 0.006\ \mathrm{GeV}^{-1})\sqrt{s}] \times 10^{-4},$$

where the data were averaged in $P_\perp$ for $P_\perp > 1.3$ GeV/c. The trend was confirmed by the data from Fermi National Accelerator Laboratory[1,2] ($\sqrt{s} = 23$ GeV), but seemed to be contradicted by the Penn-SB electron data at $\sqrt{s} = 4.3$, 5.3, and 6.8 GeV. To add to this puzzle, a group[8] from the Institute for High Energy Physics, Serpukhov, has presented data showing a decrease towards zero at $\sqrt{s} = 8$ GeV. These points are summarized in Fig. 2.

It is the purpose of this note to point out that *all the electron data discussed above are in fact consistent with a constant ratio of lepton-source to pion production, independent of s from $\sqrt{s} = 4.3$ to 61 GeV and independent of $P_\perp$ from ~ 0 to 5 GeV/c*. Here we assume that the lepton source is a particle X which is the parent of the direct electron:

$$X^0 \to e^+ + e^- \qquad (1)$$

or

$$X^\pm \to e^\pm + \nu. \qquad (2)$$

The arguments presented here and designed to fit the $P_\perp$ rise of Fig. 1 favor $M_{X^\pm} \sim 300$ MeV. We emphasize that although the italicized assertion is correct, the source of the leptons could in fact be much more complex than is proposed above. Many recent reviews,[9-11] however, concur that no combination of known particles can account for the data.

To understand the main contention of this Comment, we note that a low-mass parent ($M \lesssim 2P_\perp$

being observed) must generate a lepton spectrum which, relative to the parental production spectrum (assumed to be pionlike), behaves as the curves in Fig. 1. The origin of the rise at low $P_\perp$ is obvious; at high $P_\perp$, because of the steeply falling parent spectrum, leptons are detected from highly asymmetric X decay. This results in a reduction in the ratio of lepton to parent of the order of ~10 (roughly the power of the $P_\perp$ falloff). However, since all X's decay, there must be a pileup at low $P_\perp$, in fact at $P_\perp = M_X/2$.

We find that the rise in Fig. 1 can be quantitatively matched by the process (1) when M_X is between 1 and 5 pion masses. Given that the lepton-to-pion ratio is not flat, one must reexamine the data that seemed to imply an s dependence. The cross section versus $\sqrt{s}$ now depends crucially on the lower limit in $P_\perp$, in each experiment, and on the s-dependent slope of the parent (hence pion) spectrum. In fact, the hypothesis (1) reproduces the CCRS data when we average over all $P_\perp \geq 1.3$ GeV/c and fit the slopes by the energy-dependent form $E\, d^3\sigma/dp^3 \sim \exp(-25P_\perp/\sqrt{s})/P_\perp^{\,8}$. However, the integral over all $P_\perp$ is, of course, completely energy independent.

Since the Penn-SB[7] and Serpukhov[8] results average over different regions of $P_\perp$, the low-energy points of Fig. 2 are in better agreement with this model and an equal decay rate of the parent into electrons and muons.[12,13]

It should be noted that the exact behavior of the lepton-to-parent ratio, in particular at large $P_\perp$, is sensitive to the detailed nature of the fit. (In the limiting case of a pure power falloff in $P_\perp$, this ratio approaches a constant.) Here we have retained the expressions used by the CCRS and Penn-SB groups to interpolate pion data at the same energies. We emphasize that the general trend of Figs. 1 and 2 must be reproduced if X has identically the pion spectrum.

We can carry the analysis further by noting that the CCRS experiment[9] puts fairly stringent limits on the hypothesis of a discrete low-mass *neutral* source of direct leptons:

$$M_{X^0} > 700 \text{ MeV}.$$

This arises because of the failure to observe "the other electron" in Reaction (1).

To summarize, we have shown by detailed calculations that data from many groups[14] spanning the $P_\perp$ range from ~0 to ~5 GeV/c and $\sqrt{s}$ from 4.3 to 61 GeV are consistent with direct leptons originating from a unique parent which is produced with a dynamics indistinguishable from pions over the entire domain, which has a mass in the interval between 1 and 5 pion masses, and which decays as

$$X^\pm \to \begin{cases} e^\pm + \nu_e, \\ \mu^\pm + \nu_\mu, \end{cases} \tag{3}$$

with equal probability. We are aware of the difficulty of proposing a new charged boson which has $\sigma B \simeq 10^{-3}\sigma_\pi$ in a mass range of ~100–700 MeV. The new object could be a vector in order to agree with the equality of e and μ.[15] This would also insure a lifetime short enough to escape bubble-chamber detection. Although this simple model is consistent with the data, it is also possible that alternative explanations, more complex but less dramatic, can be found. For example, there may be a subtle continuum of virtual photons which, for some reason, is produced "pionlike." The mass spectrum of this continuum would have to be chosen very wisely in order to be consistent with (1) the low-mass acceptance of CCRS,[9] (2) the fact that $e = \mu$, and, (3) the fact that experiments that veto low-mass pairs give the same lepton-to-pion ratio as experiments which do not veto. Finally, the dramatic rise of yield at low $P_\perp$ must be understood.

Clearly more incisive searches for leptons at low energies are required.

*Research supported in part by the National Science Foundation.

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[15]*Note added.*—S. Pakvasa (private communication) points out that a scalar particle with nonderivative coupling would also do.

Asymmetry of Mirror γ Decays in ^{13}C and ^{13}N†

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An explanation is offered for the large difference in $B(E1)$ values of mirror transitions from $\frac{1}{2}^+$ state to the ground state, based on the difference in binding energy of the $\frac{1}{2}^+$ states. The binding energy determines the degree of coupling of the positive parity nucleon to the deformed ^{12}C core, which in turn affects the $B(E1)$ value. The experimental asymmetry can be satisfied with a small change of the wave function.

In a recent Letter,[1] Marrs *et al.* presented a comparison of measured γ-transition strengths between corresponding states of the mirror nuclei ^{13}C and ^{13}N. There are no large differences for transitions between negative parity states, but there is large asymmetry for $E1$ transitions involving the $\frac{1}{2}^+$ first excited state. In particular, the $B(E1)$ to the $\frac{1}{2}^-$ ground state is about three times as strong in ^{13}N as it is in ^{13}C. A pertinent fact is that the $\frac{1}{2}^+$state in ^{13}C is bound by 1.86 MeV with respect to neutron emission whereas in ^{13}N the $\frac{1}{2}^+$ state is unstable to proton emission by 0.42 MeV. Marrs *et al.*[1] used a one-body model to investigate the effect of the differing radial wave functions on calculated $B(E1)$ values and found a negligible difference.

The purpose of this Comment is to point out another mechanism by which the difference in binding energy affects the $B(E1)$ values. Shell-model calculations have shown[2] that low-lying non-normal-parity states in this region are well described by the weak coupling of an (sd) nucleon to the normal-parity core. For the $\frac{1}{2}^+$ state there are just two strong components—those which arise from coupling to the 0^+ and 2^+ states of the ^{12}C core; thus

$$\psi(\tfrac{1}{2}^+) = \alpha_s \psi(2s_{1/2}\times 0^+) + \alpha_d \psi(1d_{5/2}\times 2^+). \quad (1)$$

The $\frac{1}{2}^-$ ground state is taken to be that resulting from the (8–16) POT interaction of Cohen and Kurath.[3] With harmonic oscillator values for the radial integrals as given by an oscillator parameter corresponding to $\hbar\omega = 14.7$ MeV, the numerical value of $B(E1)$ is

$$B(E1)(\tfrac{1}{2}^+ \to \tfrac{1}{2}^-) = [0.371\alpha_s - 0.778\alpha_d]^2 e^2\ \mathrm{fm}^2. \quad (2)$$

For $\alpha_d = 0$, $B(E1) = 0.138$, but the coupling to the deformed ^{12}C core tends to reduce[4] this value. The experimental value for ^{13}C, $B(E1) = 0.014$, is obtained for $\alpha_d = 0.30$, $\alpha_s = 0.95$ while the ^{13}N value of $B(E1) = 0.044$ corresponds to $\alpha_d = 0.20$, $\alpha_s = 0.98$. This is not a large difference in the $\frac{1}{2}^+$ wave functions and would be difficult to detect in spectroscopic factor measurements. The difference in binding energy gives a qualitative basis for the $B(E1)$ difference, since when the positive-parity nucleon is farther from the ^{12}C core, as in the unbound ^{13}N, it is more weakly coupled