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CURRENT PROBLEMS IN EXPERIMENTAL BOSON SPECTROSCOPY* Conf-720409--9

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ABSTRACT

Some of the current and more interesting problems in the field of boson spectroscopy are discussed. In particular, a review is presented concerning the multitude of reported non-strange mesons in the 1-GeV mass region as well as a critique of published works involving K mesons in the 1- to 1.4-GeV and 1.75-GeV mass region. Although no clear evidence for either exotics or daughters has yet to be uncovered, the importance of such searches is stressed and alternate experimental approaches are outlined. The number of viable boson SU(3) families has remained rather static over the past two years. Further verifications of such conjectures are shown to be possible from studies of electromagnetic decays of both pseudoscalar and vector mesons. Finally the possible ramifications of the new results of $\bar{p}p$ annihilations at rest are discussed.

MASTER

In my talk I will summarize a few of the topics discussed in the contributed section of this Conference, report on several subjects not discussed but on which people had submitted papers to the Conference, and in addition discuss several other topics which I consider to be important in this field. These topics are noted below:

1. $I = 0, 1; S = 0$ $M \approx 1,600$ -MeV bosons.
2. $I = 1/2; S = +1$ K mesons 1000-1400 mass region.
3. $I = 1/2; S = +1$ K's 1750 mass region.
4. Miscellaneous
 - a. Possible 3^- SU(3) multiplet.
 - b. Electromagnetic decays of $J^P = 0^-, 1^-$ states.
 - c. Existence of exotics and daughters.
 - d. $\bar{p}p$ capture at rest.

I begin with a review of the 1-GeV mass region. The X_0 or $\eta'(960)$ boson, with $I = 0$ decaying via the modes

$$\begin{aligned}\eta'(960) &\rightarrow \pi^+ \pi^- \pi \\ &\rightarrow \pi^+ \pi^- \gamma \\ &\rightarrow \gamma\gamma\end{aligned}$$

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has been observed and studied at a variety of energies.¹ To date the spin parity of this particle has been restricted to the value of 0^- and 2^- from detailed analyses of the three-body Dalitz plots; $J^P = 0^-$ was preferred in all instances with 2^- not being completely ruled out. These detailed properties were discussed by Danburg at this conference with the additional observation that there were no production or decay correlations of the $\eta'(960)$ detected with investigation at energies of 2 and 4 GeV. This is to be contrasted with such correlations being abundantly visible for finite spin particles such as $\rho(750)$, $\omega(785)$, etc., at a variety of energies. As such one is forced to conclude that the J^P of X^0 is 0^- and therefore is indeed a $\eta'(960)$. An additional comment should be made regarding the $\pi^+\pi^-\gamma$ decay mode -- namely all experiments conclude that this channel consists of essentially 100% $\rho\gamma$. This is shown in Fig. 1 where the $(\pi^+\pi^-)$ effective mass for the 2-GeV/c data (Rittenberg and Danburg) as well as 4.6-GeV/c data of Eisner et al., also presented at this Conference, are displayed, showing clear ρ domination of the $\pi^+\pi^-$ spectrum.

FIGURE 1

FIGURE 1

FIGURE 1

The existence and properties of a possible $\delta(962)$ meson have been controversial for many years. I reported on this same subject at the first Philadelphia Boson Conference four years ago.² At that time there had been several contradictory experiments with the CERN MMS experiment³ being the main evidence for the $\delta(962)$, with some supporting evidence from a bubble-chamber study of K^-p interactions. Additional evidence has since been gathered from further bubble chamber work involving $\bar{p}p$ and K^-p interactions as well as two counter experiments reported at this Conference. The status is as follows:

Three separate bubble-chamber experiments,⁴ with incoming momenta $\approx 4\text{-}5 \text{ GeV}/c$, observe a $\approx 3\sigma$ $\delta^- \rightarrow \pi^- \eta_N$ peak recoiling against a $\Sigma^+(1385)$ in the reactions noted above. There is also some evidence for the well known $D(1285)$ decaying into $\pi\delta$ final state in $\bar{p}p$ annihilations.⁵ The data presented by the Iowa group has a clear bump at a mass of ≈ 960 but is not observed in the total neutral channel which is difficult to understand if it decayed principally into $\pi^0 \eta_N$. A similar type of experiment by the Illinois group at the same energy but larger t (momentum transfer) sees a clear bump at a mass $M = 968 \pm 2 \text{ MeV}$ at the edge of the available phase space. The argument is further advanced that this is not the $\eta'(960)$ because the ratio of η' and $\omega(785)$ cross sections is vastly different than expected from previous experiments. It is therefore assigned to the δ . The situation is far from clear, the simplest hypothesis being one state, $I = 1$, $M \approx 962 \text{ MeV}$, $\Gamma \leq 5 \text{ MeV}$, decaying predominantly into $\pi\eta$, with $J^P = 0^+$ being the simplest assignment, the Iowa result being an anomaly.

The possible existence of yet another distinct state at a mass of 953 MeV ⁶ was also discussed by Eisner at this Conference. The main justification for such a resonance is the lack of any ρ signal in the main $M \rightarrow \pi^+ \pi^- \gamma$ decay mode. A similar preliminary

result was presented by Barnes at the San Francisco APS Meeting involving $\pi^+d \rightarrow pp\pi^+\pi^-\gamma$ events where a peak in the $\pi^+\pi^-\gamma$ spectrum was observed at a mass ≈ 950 MeV with no ρ content in the $\pi^+\pi^-$ effective-mass spectrum. Both sets of data are shown in Fig. 2 where this $\pi^+\pi^-$ spectrum is seen to be clearly different from that from the $\eta'(960)$ previously displayed in Fig. 1. The Rutgers/Pennsylvania group's investigation of boson states⁷ recoiling against He^3 in pd reactions is also pertinent to this discussion. In addition to the well known π , η and ω resonances, an additional bump, ξ , was observed with a mass $M = 953^{+1}_{-2.5}$ MeV which could be associated with the M . A summary is given below.

In this latter case, since the decay products are not detected, its differentiation from the $\eta'(960)$ or $\delta(962)$ is based on the mass measurement. The contributions of systematic effects are presently being re-evaluated and the mass error quoted above is the published value to date. None of the quantum numbers have been determined; however, the outstanding property of non- ρ decay of the M strongly suggests $C = -1$.

This mass region may be even richer in resonances than the above indicates. One such possible new state was reported by the Iowa group. In fact, there are three experiments pertinent to the question, as noted below.

Iowa:

$$2.4 \text{ GeV/c} \quad \pi^- p \rightarrow N(MM) \quad t < .0006 \text{ GeV}^2$$

$$M = 940.7 \pm 1.7 \text{ MeV}, \quad \Gamma < 10.4 \text{ MeV}$$

Illinois:

$$2.5 \text{ GeV/c} \quad \pi^- p \rightarrow N(MM) \quad .22 < t < .38 \text{ GeV}^2$$

$$1. \text{ peak } \delta(968) \text{ 2\%}$$

$$2. \text{ peaks } \delta, M_2 = 936 \pm 2.5 \text{ MeV.}$$

Imperial College:

$$\pi p \rightarrow N + ()^0 \text{ excitation} \quad \text{Only } \eta'(960).$$

FIGURE 2

A possible resonance at $M = 940$ MeV is reported by the Iowa group. A similar experiment at the same energy but larger t by Illinois has a missing-mass spectrum fit with a single $\delta(950)$ peak with a χ^2 probability of 2%, rather adequate. They point out, however, that this can be improved by the inclusion of a second resonance with $M = 936 \pm 2.5$ MeV. The experiment performed at the Rutherford Laboratory by a group from the Imperial College investigated possible boson resonances via their excitation. This approach has the benefit of rather good mass resolution. They only observe the $\eta'(960)$. In summary the evidence is conflicting and it would be comforting to observe the $M(940)$ in a manner that does not require a large number of non-obvious cuts to the data. The investigation of the 1-GeV boson mass region seems to be ideally suited to the new generation of mass spectrometers which detect both recoil and decay particles with high efficiency and resolution.

Evidence for K-type mesons in the 1000- to 1400-MeV region or in the 1750-MeV region has not been discussed at this Conference but has been extensively covered at previous conferences. Since progress has been rather slow in this area as well as being slightly muddled, it seems worthwhile to review the situation. To begin with, there is a major prejudice for the existence of two 1^+ and one 0^+ such K mesons in this 1000- to 1400-MeV mass region. This is illustrated in the following table.

J^{PC}	$I = 1$	$I = \frac{1}{2}$	
1^{--}	$\rho(750)$	$K(890)$	
0^{++}	$\delta(960)?$	?	
1^{++}	$A_1(1100)$	?	Expected M
1^{+-}	$B(1220)$	?	1000-1400 MeV
2^{++}	$A_2(1320)$	$K(1420)$	

The $J^P = 1^{--}$ $\rho, K(890)$ and 2^{++} $A_2, K(1420)$ bracket this sequence of states and thereby restrict the K masses to the mass region noted above. The expected decay sequence for these K states is $0^+ \rightarrow K\pi$ and $1^+ \rightarrow K\pi\pi$. I will first discuss the $K\pi$ final state. The standard method of analysis in this mass region, besides bump hunting, has been the utilization of the one-particle-exchange model (OPE) and its variations to study $K\pi$ scattering. The criticism of this method is the same that applies to the study of $\pi\pi$ scattering, namely: (a) difficulty and uncertainty of extrapolating to the pole, (b) question of the applicability of the model to the data, and (c) ambiguity of solutions. This has been surveyed at length by G. Kane⁸ at the previous Philadelphia Conference and will not be repeated here. One notes that the situation is even worse in the $K\pi$ case since the amount of available data is

more limited. Needless to say, many results have been published but should be read with the above precautionary comments in mind. In the case of bumps, a claim for another resonance near the $K(1420)$ was made from studies involving the reaction $K^+n \rightarrow K^+\pi^-p$ at 12 GeV/c.⁹ The effect is one involving an observation of a difference in the Jackson $\cos\theta$ distribution in going from a $K\pi$ mass of 1370 to 1420 MeV. This essentially results in a mass shift of 60-70 MeV for $|\cos\theta|$ cuts greater than or less than 0.7. The criticism of this result is simply that inclusion of interference with background can easily produce such an effect and has indeed been demonstrated to occur in the study of the $K(1420)$ in K^-p interactions.¹⁰ As such this result, which ignored interference effects, should not be given too much weight. The feeling that there may indeed be a resonance on the low-mass side of the $K(1420)$ is quite prevalent generally, mainly due to $(K\pi)$ mass plots¹¹ as shown in Fig. 3. There is a clear mass asymmetry on the two sides of the $K(1420)$, namely a shoulder on the low-mass side which has been observed in several experiments. Its interpretation is far from clear. In summary there is no definitive evidence for a $K\pi$ resonance in this mass region.

The $K\pi\pi$ case is just as ambiguous. The broad enhancement from 1100-1300, the Q bump, is similar in many respects to the $A_1(3\pi)$ broad enhancement. Any internal structure, if it exists, has not been deciphered. Exercises involving fitting several Breit-Wigner resonances with varying masses and widths can certainly be applied to the broad structure¹²; however, any conclusions derived therefrom are very tenuous. Other possible $K\pi\pi$ resonances in this mass region are

The $K_c(1240)$ had been uncovered in $\bar{p}p$ annihilation studies and not elsewhere.¹³ Its existence may be influenced by the difficulty encountered in the understanding of the $\bar{p}p$ reactions at rest, to be discussed at the end of this talk. The evidence for the $K(1320)$ ¹⁴ is not overwhelming; however, the noted reaction certainly provides an adequate way of searching for such states. This is noted in Fig. 4 where the recoiling $K\pi\pi$ (and $K\pi$) spectrum is shown for π^-p reactions at 4.5 and 6.0 GeV/c. There is an excess of events in the $K\pi\pi$ mass spectrum at 1300 MeV; however, there do appear to be difficulties with the $K(1420)$ width as observed in the $K\pi\pi$ spectrum at 4.5 GeV/c which are not understood. This does not exhaust the list of candidate states in this mass region. These I consider to be among the more prominent and, in the latter case, provides an ideal reaction for their uncovering since it is devoid of diffraction type of phenomena which plague the proton recoil reactions.

FIGURE 3

FIGURE 4 (See Ref. 14)

FIGURE 4
(See Ref. 14)

The subject of the existence of K(1750) resonances contains similar prejudices as the lower mass K region in that several resonances are expected to exist in this mass region. Again the argument consists in an extrapolation from the known $I = 1$ states.

J^{PC}	$I = 1$	$I = \frac{1}{2}$
2^{-+}	$A_3(1640)$	$L(1750) \rightarrow K\pi\pi$
1^{--}	$\rho'(1650)?$	?
2^{--}	$F_1(1560)$	?
3^{--}	$g(1650)$	$K(1750) \rightarrow K\pi$

The simple observation that the $I = 1$ states have similar masses would indicate a similar behavior for their $I = \frac{1}{2}$ companions. This conclusion is reinforced from an examination of the pertinent Chew-Frautschi plots as shown in Fig. 5. Here, the sequence $0^+, 1^-, 2^+, 3^-$; $0^{++}, 1^{+-}, 2^{++}$ as well as $0^{--}, 1^{+-}, 2^{--}$ all require K members at a $(\text{mass})^2 \approx 3 \text{ GeV}^2$ if the trajectories are parallel. From spin parity considerations the $2^{++}, 2^{--}$ states would decay via the $K\pi\pi$ mode and the $1^{+-}, 3^{--}$ would prefer the $K\pi$ mode. In the $K\pi\pi$ category the $L(1750)$ meson has been known for some time. There has been some uncertainty as to the branching fractions for the various decay modes; however, there is general

Chew Frautschi Plot of the natural spin parity meson resonances.

FIGURE 5

FIGURE 5

agreement as to a substantial uncorrelated $K\pi\pi$ mode, non- $K(1420)\pi$ and with a total width of ≈ 100 MeV.¹⁵ Evidence on this latter point for a K state at a mass of 1750 MeV with this width was submitted to this Conference by a Northeastern/Stony Brook collaboration, and the data are shown in Fig. 6. There was evidence previously reported by a Berkeley group for another possible $K(1750)$ but decaying wholly into $K(1420)\pi$ and with a total width of 300 MeV.¹⁶ Such a state may be analogous to the $A_3(1650)$ as reported here by Ascoli, in that it is broad and does not seem to behave as a proper resonance.

FIGURE 6

There are three experiments pertinent to the $K\pi$ states. These are:

Purdue ⁷	$K^+n \rightarrow K^+\pi^-p$	9 GeV/c	4,000 events
CERN ¹⁸	$K^-p \rightarrow K^-\pi^+n$	10 GeV/c	2,500 events
Berkeley ¹⁹	$K^+n \rightarrow K^+\pi^-p$	12 GeV/c	6,400 events

The data for the first two experiments are displayed in Fig. 7. They both involve charge-exchange reactions, in contrast to the investigations which involved the nucleus remaining unchanged. In the Purdue case there is a clear valley on the high side of the $K(1420)$ with an excess of events in the 1750-2150 MeV mass region.

FIGURE 7

FIGURE 7

The $(K\pi)^0$ spectrum also shows a clear peak. On this basis the authors claim a new resonance. On the other hand, the 10-GeV/c $K^- p$ data with approximately one-half the data shows no such effect. The data from the Berkeley analysis is shown in Fig. 8 where (a) refers to the uncut data and (b) with a t cut of 0.2 GeV^2 . Again there is a dip on the high side of the $K(1420)$ with not much more that can be said concerning the mass spectrum of the uncut data except that it is rather smooth. A glance at the Chew-Low plot indicates the danger of a t cut at $\sim .2-.3 \text{ GeV}^2$ at this energy. It effectively cuts off the high-mass end of the spectrum, in essence contributing appreciably to the observed drop. As such I consider this evidence rather flimsy. In summary, the investigations of the $K\pi$ spectra indicate some irregularities with the possibility of the existence of one or more states.

FIGURE 8

FIGURE 8

I would now like to discuss an assortment of more specialized topics beginning with the conjecture of a possible 3^- SU(3) multiplet. The details of such a conjecture were submitted to the Conference by Graham and Yoon of Toronto. The conjectured constituent members are

$$\begin{array}{lll}
 I = 1 & g(1640) \begin{array}{l} \nearrow 2\pi \\ \rightarrow \omega\pi \\ \rightarrow \bar{K}K \\ \searrow K^* \bar{K} \end{array} & \Gamma = 150 \text{ MeV} \\
 I = \frac{1}{2} & K(1750) \begin{array}{l} \nearrow K^* \bar{\pi} \\ \searrow K^* \pi \end{array} & \Gamma = 60 \text{ MeV} \\
 I = 0 & \omega(1680) \rightarrow \rho\pi \rightarrow 3\pi & \Gamma = 145 \text{ MeV} \\
 I = 0 & \varphi(1820) &
 \end{array}$$

The $g(1640)$ and $\omega(1680)$ are reasonably well established states. The status of the $K(1750)$ was just discussed. This contingent does not satisfy the Gell-Mann/Okubo mass formula so the $\varphi(1820)$ was adopted, yielding a mixing angle of $\approx 30^\circ$, for which there is some but poor evidence. Taking the best available numbers for the widths and branching ratios for the three well known states, one can then make an SU(3) analysis in the standard way. This was done for the $3^- \rightarrow 0^- 0^-$, $3^- \rightarrow 1^- 0^-$, and $3^- \rightarrow 1^- 1^-$ sequences. The interest lies more in the predictions than the goodness of fit due to the uncertainty of the input data. The most interesting aspect is to detect the various $\varphi(1820)$ decay modes $K\bar{K}(30\%)$, $K\bar{K}^*(890)$ (55%), $K^* \bar{K}^*$ (15%) where the total width is expected to be 70 MeV. Needless to say, much more work is required to firm up the detailed properties of all these states from J^P to widths to branching fractions before one is comfortable with this SU(3) multiplet.

The electromagnetic decay of 0^- and 1^- meson states is a subject of great interest. If one considers a γ ray as a U spin zero ($U = 0$) member of an octet, then one can relate the three decay modes, $\pi^0 \rightarrow \gamma\gamma$, $\eta \rightarrow \gamma\gamma$ and $\eta' \rightarrow \gamma\gamma$, with two unknown coefficients. This formalism is rather well known, so I just note the pertinent relations below:

$$0^- \rightarrow \gamma\gamma \quad | = \frac{\alpha^2 |A|^2 m^3}{64\pi}$$

$$A_\eta = -\sin\theta A_{\eta_1} + \cos\theta A_{\eta_8} \quad \theta \approx 10^\circ \text{ mixing angle}$$

$$A_{\eta'} = \cos\theta A_{\eta_1} + \sin\theta A_{\eta_8}$$

$$A_{\pi^0} \rightarrow 2\gamma = \sqrt{3} A_{\eta_8} \rightarrow 2\gamma$$

$$\frac{\Gamma_{\eta \rightarrow 2\gamma}}{\Gamma_{\pi^0 \rightarrow 2\gamma}} = \frac{1}{3} \left(\cos\theta - \sin\theta \frac{A_{\eta_1}}{A_{\eta_8}} \right)^2 \left(\frac{m_\eta}{m_\pi} \right)^3$$

$$\frac{\Gamma_{\eta' \rightarrow 2\gamma}}{\Gamma_{\pi^0 \rightarrow 2\gamma}} = \frac{1}{3} \left(\sin\theta + \cos\theta \frac{A_{\eta_1}}{A_{\eta_8}} \right)^2 \left(\frac{m_{\eta'}}{m_\pi} \right)^3$$

Both the π^0 and η widths (lifetimes) have been measured, that for the π^0 via both a direct detection of the lifetime in emulsions²⁰ ($K_{\pi 2}$ decay) and the Primakoff effect,²¹ while the η width has been measured only by the latter technique.²² The values obtained were:

$$\Gamma_{\pi^0 \rightarrow 2\gamma} \approx 7 \text{ eV}$$

$$\Gamma_{\eta \rightarrow 2\gamma} \approx 1 \text{ keV}$$

Since the relationship among these rates is quadratic, there are two predictions for the η' rate:

$$\Gamma_{\eta' \rightarrow 2\gamma} = 60 \text{ keV} \quad \text{for } \frac{A_{\eta_1}}{A_{\eta_8}} \approx 9$$

$$\Gamma_{\eta' \rightarrow 2\gamma} = 360 \text{ keV} \quad \frac{A_{\eta_1}}{A_{\eta_8}} \approx 20$$

This latter possibility can be eliminated since $\eta'(960) \rightarrow \gamma\gamma$ /All branching ratio is $\approx 2\%$,²³ yielding a predicted total width of $360/0.02 \approx 18 \text{ MeV}$, which is much larger than the 4-MeV upper limit reported by several experiments, formally and informally at this Conference. Therefore the $\eta'(960)$ partial width into the $\gamma\gamma$ final

state is expected to be 60 keV via the SU(3) analysis, and it would be extremely worthwhile to measure this quantity utilizing the Primakoff effect.

The electromagnetic decay of vector mesons into a pseudo-scalar and a γ ray can be treated in an analogous manner. Once again, considering the photon as a $U = 0$ member of an octet, and applying C (charge conjugation) and U invariance, one can relate numerous such decays in terms of three unknown constants. Such an approach has been employed by Gourdin²⁴ and results in the following relations:

$$1^- \rightarrow 0^- \gamma$$

$$\Gamma = \frac{\alpha}{3} |A|^2 \left[\frac{(m_1^-)^2 - (m_0^-)^2}{2m_1^-} \right]^3$$

	$V(1^-) \rightarrow PS(0^-)\gamma$	
A_{88}	8	8
A_{18}	1	8
A_{81}	8	1

$$\text{with } A = C_{88} A_{88} + C_{18} A_{18} + C_{81} A_{81}.$$

The coefficient C_{ij} for a variety of processes are tabulated below.

Exp'tl Width		C_{88}	C_{18}	C_{81}	Predicted Width
≈ 1 MeV	$\omega \rightarrow \pi^0 \gamma$	$\sqrt{3} \sin \theta_1$	$\sqrt{3} \cos \theta_1$		
$\approx .01$ MeV	$\varphi \rightarrow \pi^0 \gamma$	$\sqrt{3} \sin \theta_1$	$\sqrt{3} \sin \theta_1$		
$\approx .1$ MeV	$\varphi \rightarrow \eta \gamma$	$-\cos \theta_1 \cos \theta_0$	$-\sin \theta_1 \cos \theta_0$	$-\cos \theta_1 \sin \theta_0$	
$.6 \pm .3$ MeV	$\omega \rightarrow \eta \gamma$	$-\sin \theta_1 \cos \theta_0$	$\cos \theta_1 \cos \theta_0$	$-\sin \theta_1 \sin \theta_0$	.02 MeV
	$\rho \rightarrow \eta \gamma$	1			.1 MeV
(1.1 MeV)	$\eta \rightarrow \rho \gamma$	$\sqrt{3} \sin \theta_0$		$\sqrt{3} \cos \theta_0$	1.6 MeV
	$K^{*0} \rightarrow K^0 \gamma$	-2			.24 MeV
	$K^{*+} \rightarrow K^+ \gamma$	1			.06 MeV
	$\rho \rightarrow \eta \gamma$	$\sqrt{3} \cos \theta_0$		$-\sqrt{3} \sin \theta_0$	.1 MeV
				$\theta_0 = 10^\circ \quad \theta_1 = 35^\circ$	

Since there are three unknowns, the first three reactions, namely $\omega^0 \rightarrow \pi^0 \gamma$ (1-MeV width), $\varphi \rightarrow \pi^0 \gamma$ ($\sim .01$ -MeV width) and $\varphi \rightarrow \eta \gamma$ (.1-MeV width) were used to determine these numbers. The

result is $A_{18}/A_{88} \approx 1.5$ and $A_{81}/A_{88} \approx -4.5$ with $A_{88}^2 = (6/\alpha) \times 10^{-3} \text{ GeV}^{-2}$. One then can make predictions for the remaining listed decays and these have been duly noted. A measurement of any or all of these processes would be very interesting. There is a qualitative consistency check on the $\eta' \rightarrow \rho\gamma$ with several qualifications. As noted in the section dealing with the SU(3) discussion of the decay of pseudoscalar mesons into two γ 's, present evidence requires the total η' width to be 3 MeV ($60 \text{ KeV} \times (1/.02)$). This in turn, with a knowledge of the $\eta' \rightarrow \rho\gamma$ branching ratio, yields a partial width of 1.1 MeV for this mode to be compared with the expected 1.6 MeV. This is really an SU(3) consistency check which would be meaningful if the η' total width is indeed measured to be $\approx 3 \text{ MeV}$.

Further predictions have already been noted in the previous tabulation for $\rho^0 \rightarrow \pi\gamma$ (.1 MeV), $\omega \rightarrow \eta\gamma$ (.02 MeV) and $K^{*0} \rightarrow K^0\gamma$ (.24 MeV) and $K^{*+} \rightarrow K^+\gamma$ (.06 MeV). This latter prediction of a factor of four difference between the neutral and charged electromagnetic decay of the $K^*(892)$ is a sensitive test of SU(3) since it arises from the couplings and not from phase space or barrier factor considerations. Again the method of Primakoff should provide a means of measuring several of these processes.

Another approach would be to search for processes forbidden by U-spin considerations. Unfortunately, since only octets have been observed for the boson category, no such direct tests are available in this category. However, it is worth noting that this restriction does not exist for baryons since decimets are clearly evident which contain $U = 3/2$ members (i.e. Ξ^{*-} , Y^{*-} , Ω^- and Δ^-) which therefore cannot decay into a member of an octet plus a γ . Searches for $\Xi^{*}(1530) \rightarrow \Xi^-\gamma$ and $\Sigma^-(1385) \rightarrow \Sigma^-\gamma$ are therefore of great import.

Any conference dealing with boson spectroscopy would not be complete without a discussion of the existence of exotics and daughters. No such bona-fide boson exotic states have been found to date. In fact, there are even no strong candidates. This is in contrast to the baryon category, where total cross-section measurements show some evidence for possible Z^* ($S = +1$, $N = +1$) states.²⁵ The two standard methods for finding boson exotics are: (1) to uncover states with spin parity 0^{--} , 0^{+-} , 1^{-+} , 2^{+-} , etc.; (2) to uncover boson states outside of the 1 or 8 representation, i.e., $S' = 0$, $I = 2$; $S = +1$, $I = 3/2$; and $S = +2$, $I = 1$ states. The suggestion is made to search for such states in a different manner, not via $\pi^+\pi^+$, π^+K^+ , or K^+K^+ effective masses since such exotics may not be coupled to two pseudoscalar mesons but via the reactions

$$K^+ p \rightarrow \Lambda^0 (\quad)^{++} \\ S=+2$$

$$\pi^+ p \rightarrow \Lambda^0 (\quad)^{++} \\ S=+1$$

$$\pi^+ p \rightarrow N (\quad)^{++} \\ S=0$$

Such missing-mass experiments have the advantage of not being uniquely dependent on one final state but suffer from large backgrounds in that one would be summing over all final states. The advent of multiple particle spectrometers where one would trigger on the Λ^0 or N and then observe the multiply charged final states, channel by channel, is certainly the ideal method for such investigation.

The success of the Veneziano formalism, mainly in the theoretical rather than the experimental realm, prompts the search for daughters of known resonant states, which indeed should be rather numerous. If one considers the ρ , A_2 , g , sequence, then the expected set of daughters should be 0^{+-} (750 MeV), 1^{-+} (1320 MeV), 2^{+-} (1640 MeV), all exotic, followed by a second set 0^{++} (1320 MeV), 1^{--} (1640 MeV), non-exotic, and so on. For the $\pi(140)$, $B(1220)$, $A_3(1650)$ sequence, the expected daughters would be 1^{--} (1220 MeV), 1^{++} (1650 MeV), and 0^{-+} (1650 MeV), all non-exotic. The only candidate to date is the $1^{--} \rho'(1650)$, mainly coupled to four pions, reported in the literature and at this Conference. The question then arises why the ρ and A_2 daughters have not been observed which have expected lower mass than the ρ' . The answer, may be that they are exotic and only non-exotic daughters, if any, exist. As such one should look for the following states probably coupled to multipion final states.

I = 1	0^{++} M(1320)5 π	1^{--} M(1220)4 π
	1^{--} M(1640)4 π , 2 π	1^{++} M(1640)3 π
		0^{-+} M(1640)3 π

The last topic I wish to discuss is the ramifications of the surprising new results arising from the studies of $\bar{p}p$ annihilation at rest. In essence an experimental comparison of $\bar{p}p$ annihilation into $\pi^+\pi^-$ and $\pi^0\pi^0$ final states has ruled out S-wave capture. This is due to the fact that the reaction $\bar{p}p \rightarrow \pi^0\pi^0$ is not allowed to proceed from even orbital states from parity and Bose statistics considerations. The experimental result for the rates R is²⁶

$$R(\bar{p}p \rightarrow \pi^0\pi^0) = .15R(\bar{p}p \rightarrow \pi^+\pi^-)$$

which in turn implies

$$\frac{(\bar{p}p)_{I=0, L \text{ odd} \rightarrow 2\pi}}{(\bar{p}p \rightarrow 2\pi)} = .39 \pm 20\%.$$

This is in strong contrast to the conclusion derived from an analysis of annihilation into the $K^0 \bar{K}^0$ system where, due to the non-observance of the mode $K_S^0 K_S^0$ one is led to²⁷

$$\frac{(\bar{p}p)_{I=0,1, L \text{ odd} \rightarrow K^0 \bar{K}^0}}{(\bar{p}p \rightarrow K^0 \bar{K}^0)} = .018 \pm .009$$

i.e. essentially all S-wave capture. There are two interesting related features: first, why is the orbital capture dependent on the final state, and second, why is it generally true that π^- , K^- and Σ^- are captured at rest from S states while it is different for $\bar{p}$ captures. One expects much experimental work in this area over the coming years.

As far as boson resonances are concerned, the above results throw sufficient doubt on S-wave capture for $\bar{p}$'s that one should reanalyze the data concerned with resonant properties relaxing this requirement. In particular, the properties of the C(1240), E(1420) resonances as observed in $\bar{p}p$ annihilation at rest should be re-examined ignoring the initial state and just studying the decay correlations.

In summary, there are numerous areas requiring further experimental investigation. These range through the following:

- a. Search for exotics and daughters.
- b. General investigation of electromagnetic decays of pseudoscalar and vector mesons.
- c. Uncovering of members of 0^+ multiplet with special emphasis on the $\pi^0 \pi^0$ final state.
- d. Search for the isosinglets and doublets (K) for 1^+ , 1^- , 2^- , 3^- multiplets.
- e. Study of the systematics of A_1 , A_3 and Q_1 , Q_3 (1750) bumps as possible new phenomena.
- f. A study of the general question of the existence of higher-mass resonances. In this respect the lack of such evidence may be due to improper methods of investigation. Instead of just observing a single recoiling nucleon, it may be more appropriate to look at multibody final states made up of two clusters of equal spins.

In all these respects the technical advent of multiparticle spectrometers (MPS) and Track-Sensitive Targets (TST) for bubble chambers may indeed be major tools for attaining progress in the study of the spectra of bosons.

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