for a helpful discussion.

Note added in proof.—After this paper was completed, a recent paper by Ademollo and Gatto[8] came to our attention which derives essentially the same result for the η branching ratio by a somewhat different procedure. The method used here is more general and will yield different results for most other applications.

---

*Work supported in part by the U. S. Atomic Energy Commission.

†On leave from the Tata Institute of Fundamental Research, Bombay, India.

[1] I.e., the A parity of J. B. Bronzan and F. E. Low, Phys. Rev. Letters 12, 522 (1964), which is identical with the R' invariance for mesons considered earlier by S. Okubo and R. E. Marshak, Nuovo Cimento 28, 56 (1963).

[2] S. Weinberg, Phys. Rev. Letters 17, 336 (1966).

[3] The axial-vector amplitude in K_{l4} leads to both S- and P-wave pions; however, the decay rate is dominated by the S-wave part [cf. Ref. 2 and C. G. Callan and S. B. Treiman, Phys. Rev. Letters 16, 153 (1966)].

[4] L. M. Brown and P. Singer, Phys. Rev. Letters 8, 460 (1962).

[5] Recently, it has been shown that a dispersion treatment of photopion production gives agreement with low-energy experiments if the $\pi\rho\gamma$ vertex (and a fortiori $\eta\rho\gamma$) is set equal to zero (A. Donnachie and G. Shaw, to be published).

[6] N. Cabibbo and A. Maksymowicz, Phys. Rev. 137, B438 (1965).

[7] It is possible to relate $\eta \to \pi+\pi+\gamma$ and the vector amplitude in K_{l4}, using SU(3) invariance; considering the pseudoscalar octet to be degenerate (i.e., equal mass for π and η). V. I. Zakharov, Yadern. Fiz. 1, 1053 (1965), obtains a 10% "up-down" asymmetry.

[8] N. Ademollo and R. Gatto, Nuovo Cimento 44, 282 (1966).

MASS SPECTRUM OF BOSONS FROM 500 TO 2500 MeV IN THE REACTION $\pi^- + p \to p + X^-$ OBSERVED BY A MISSING-MASS SPECTROMETER

M. N. Focacci, W. Kienzle, B. Levrat,* B. C. Maglić, and M. Martin*
CERN, Geneva, Switzerland
(Received 14 September 1966)

We summarize here the combined data on mass spectrum of charged bosons X^- (isospin 1 or 2) produced in the reaction $\pi^- + p \to p + X^-$ at incident laboratory pion momenta $p_1 = 3$, 3.5, 4.5, 5, 6, 7, and 12 GeV/c, observed by the missing-mass spectrometer. The original data, containing a total of 180 000 processed events, have been published.[1-7] In each event, the instrument measures (1) the mass of X^-, M, with a full-width resolution $\Gamma_{\rm res} = 26 \pm 6$ MeV, nearly independent of M (by adjustment of p_1 and t); (2) the number of charged decay products of X^- which can decay into 1, 3, or 5 charged particles plus possible neutral(s) (denoted by 1c, 3c, and 5c); (3) the four-momentum transfer square, $-t$, in each event with an accuracy of $\Delta t = \pm 0.006$, 0.025, and 0.07, for $t = 0.1$, 0.25, and 0.5 (GeV/c)^2, respectively. We also measure the differential cross section, $d\sigma/dt$, in a band of t whose width can be adjusted between 0.05 and 0.15 (Gev/c)^2. The total cross section obtained from our $d\sigma/dt$ data by integration over t is strongly model-dependent and therefore of limited usefulness.

In order to optimize the mass resolution, each of the observed peaks has, in principle, been investigated in different conditions of background, incident momentum, and momentum transfer; further, in order to avoid possible instrumental biases, each run has been repeated at several different positions of the spectrometer angle and, when possible, at more than one incident pion momentum. The full efficiency of the system extends over a mass bite of 500-1000 MeV, depending on p_1. Thus, to present the full spectrum in the mass range 1900 MeV wide with a smooth background line in one diagram, we have taken only the events above the background and so compiled the data from all the runs. For the authors and the detailed discussion of each peak, we refer the reader to the publications listed in the last column of Table I.

The compiled spectrum is given in Fig. 1, and the most important information on each object seen in Fig. 1 is given in Table I. In addition, we would like to make the following remarks on the δ, the A_1 region, the A_2, and

Table I. Data on unstable bosons, x^-, produced in reaction $\pi^- + p \to p + x^-$, obtained by missing-mass spectrometer. $p_1 \equiv$ lab. incident pion momentum; $|t| \equiv$ square of the momentum transfer to recoil proton.

Name	Mass M (MeV)	Exp. resolution $\Gamma_{exp.}$ (MeV)	Physical width Γ (MeV)	p_1 (± 1%)	Statistical Significance (Standard deviations)	No. of events in peak in Fig. 1	Signal/background[a]	t limits $(GeV/c)^2$	dσ/dt in the t limits $\mu b/(GeV/c)^2$	Decay mode	Reference
ρ^-	768 ± 5	28 ± 5	127 ± 5	3.0 3.5 4.5 5.0		15,600 ± 170	1.6 : 1	0.10 - 0.14 0.14 - 0.17 0.17 - 0.22 0.22 - 0.26	770 ± 150[b] 770 ± 170 580 ± 100 370 ± 110	1c > 97.4%	1,2
δ^-	962.5 ± 5	24 ± 4	≤ 5	3.0 3.5 4.5 5.0	5.0	262 ± 52	1 : 5	0.11 < t < 0.21	8.9 ± 3[c]	$\frac{1c}{3c} = 1.3^{+0.9}_{-0.7}$	3,8
A_2^-	1286 ± 8	36 ± 4	98 ± 5	6.0 7.0	17	1282 ± 63	1 : 1.5	0.31 < t < 0.39	400 ± 120	$\frac{1c}{3c} = 1.05 \pm 0.1$	4 7
A_2' A_2^*	1260 ± 10 1312 ± 10			6.0 7.0	1 peak and 2 peaks equally probable: P = 5% - 10%	$\frac{A_2'}{A_2^*} \simeq 1:1$	1 : 6 1 : 6			$\frac{1c}{3c} \approx 1$	7 7
R^-	1691 ± 15	31 ± 3	116 ± 3	7.0 12.0	11.6 1 peak: P = 1 % 2 " : P = 1 % 3 " : P = 20-60% ($R_{1, 2, 3}$)	973 ± 84	1 : 6	0.23 < t < 0.28	125 ± 30	1c = 0.30 ± 0.06[d] 3c = 0.67 ± 0.10 >3c = 0.03 ± 0.03	5,7
R_1	1632 ± 15	34 ± 3	≤ 21		6.7	369 ± 55	1 : 4.7		35 ± 12	1c = 0.37 ± 0.13 3c = 0.59 ± 0.21 >3c = 0.04 ± 0.04	7
R_2	1700 ± 15	30 ± 3	≤ 30	7.0 12.0	6.1	267 ± 44	1 : 3.3		42 ± 14	1c = 0.42 ± 0.11 3c = 0.56 ± 0.14 >3c = 0.01 ± 0.01	7
R_3	1748 ± 15	28 ± 3	≤ 38		7.3	337 ± 46	1 : 3.5		47 ± 16	1c = 0.14 ± 0.08 3c = 0.80 ± 0.18 >3c = 0.05 ± 0.05	7
S^-	1929 ± 14	22 ± 2	≤ 35	12.0	5.5	226 ± 41	1 : 7	0.22 < t < 0.36	35 ± 12	1c = $0.06^{+0.15}_{-0.06}$ 3c = $0.92^{+0.08}_{-0.20}$ >3c = $0.02^{+0.13}_{-0.02}$	6
T^-	2195 ± 15	39 ± 4	≤ 13	12.0	5.1	209 ± 41	1 : 7	0.22 < t < 0.36	29 ± 10	1c = $0.04^{+0.11}_{-0.04}$ 3c = $0.94^{+0.06}_{-0.19}$ >3c = $0.02^{+0.13}_{-0.02}$	6
U^-	2382 ± 24	62 ± 6	≤ 30	12.0	5.9	252 ± 43	1 : 6	0.28 < t < 0.36	42 ± 14	1c = 0.30 ± 0.10 3c = 0.45 ± 0.15 >3c = 0.25 ± 0.10	6

[a]At the center of the peak.
[b]$d\sigma/dt$ normalized to 4 GeV/c (average momentum).
[c]$d\sigma/dt$ weighted between $p_1 = 3$, 3.5, and 4.5 GeV/c.
[d]Errors are one standard deviation.

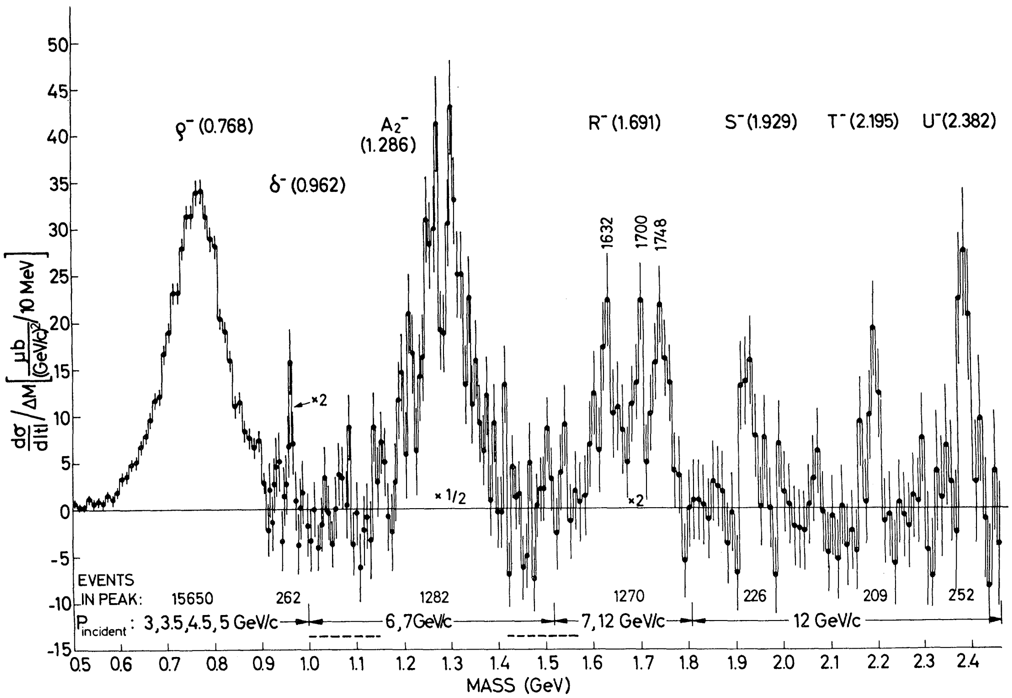

FIG. 1. Compiled spectrum of bosons X^- of isospin $I=1$ or 2, produced in the reaction $\pi^- + p \to p + X^-$, observed by the CERN missing-mass spectrometer. The incident-pion momenta, P_{incident}, are indicated below each peak. The area under each peak corresponds to its differential cross section $d\sigma/dt$, normalized to $|\bar{t}| = 0.2$ (GeV/c)^2 using the observed (Ref. 1; G. Chikovani, L. Dubal, M. N. Focacci, W. Kienzle, C. Lechanoine, B. Levrat, B. Maglić, M. Martin, C. Nef, and P. Schübelin, to be published) $d\sigma/dt$ vs $|t|$ dependence, exp($8t$). The normalized $d\sigma/dt$ values are 500 ± 100, 7.4 ± 2.5, 800 ± 160, 94 ± 32, 50 ± 17, 41 ± 14, and 77 ± 24 μb/(GeV/c)^2, for the rho, delta, A_2, R, S, T, and U, respectively. For convenience of presentation, the spectrum has been scaled up by a factor of 2 in the region of δ (900-1000 MeV) and R (1530-1810 MeV) and scaled down in the region of A_2 (1150-1530 MeV) by a factor of 2. The decay multiplicities are 1 charged particle (+ possible neutrals) for $0.5 < M < 0.9$ GeV, 3 charged particles (+ possible neutrals) for $1.67 < M < 2.30$ GeV, and 1 charged plus 3 charged (+ possible neutrals) for all other masses. For branching ratios see Table I. Bin size: 5 MeV for $0.90 < M < 1.00$ GeV, 7.5 MeV for $1.00 < M < 1.42$ GeV, 10 MeV for the rest of the spectrum. The dashed lines at the bottom indicate two mass bands (1000-1150 and 1450-1570 MeV) which have not been covered by the full efficiency of the spectrometer in any run. The errors are statistical. Note: in the row labeled "EVENTS IN PEAK," 1270 should read 974.

the T.

δ(962.5).—(a) Isospin has been determined recently as $I=1$ by Oostens et al.[8] who exclude $I=2$ for δ^+ since they observe it in the reaction $p+p \to d+\delta^+$. Their δ^+ has $M = 966 \pm 8$ MeV and physical width $\Gamma \leq 5$ MeV. (b) The value for σ_{tot} given by us[3] is probably incorrect since it was obtained by comparing the number of δ^-'s with the number of ρ^- events. We have now computed the value of $d\sigma/dt$ (Table I). Oostens et al. give an upper limit to the σ_{tot} of the order of 1 μb by comparison of δ^+ production with π^+ production in $p+p \to d+\delta^+$.

A_1 region.—We had no run in the mass region of the A_1(1075) with the spectrometer operating with 100% efficiency.[4] In addition, this part of our experiment was not sensitive to momentum transfers $|t| < 0.23$, where A_1 was reported to be dominantly produced.[9] Also the mass region around M -1500 MeV was not investigated in the full-efficiency region in any of our runs.

A_2(1286).—We have recently recomputed the value of $d\sigma/dt$ for the A_2 production at 6 GeV/c (Table I), which was underestimated earlier.[4]

T(2195).—Recently an enhancement has been reported at 2207 ± 13 MeV in the $\pi^\pm\pi^\mp\pi^0$ effective mass (Alles-Borelli et al.,[10] $\bar{p}p$ annihilation at 5.7 GeV/c). The authors suggest that their peak may be identical with our T(2195). Their data show no effect in $\pi^\pm\pi^\pm\pi^0$ which would

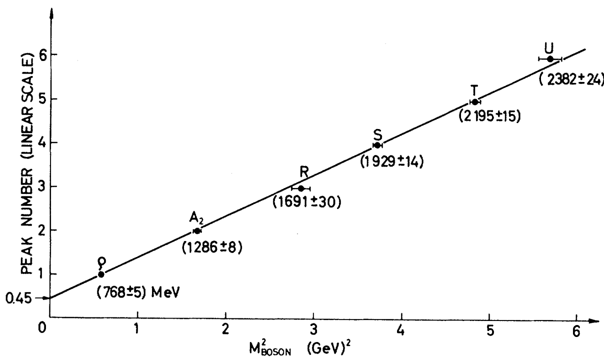

FIG. 2. Number of each major peak in sequence of increasing mass plotted versus mass square, M_X^2.

resolve the ambiguity between $I(T)=1$ or 2, inherent to our production reaction, in favor of $I(T)=1$. This conclusion is also supported by our low 1c:3c ratio in the decay multiplicity of T (see Table I), since 1c:3c = 1 would be expected if $I(T)=2$.

A regularity between the masses of the major peaks.—If we plot the major peaks $[d\sigma/dt \geqslant 20\ \mu b/(\mathrm{GeV}/c)^2]$ from our spectrum (Fig. 1) in order of their mass on a linear scale versus mass square M_X^2, the points lie on a straight line with the slope of 1.05 GeV^2 and the intersection at zero mass at 0.45 units of the linear scale (Fig. 2).[11] For the R boson, the weighted average of masses R_1, R_2, and R_3 is taken. We note that the peak numbers of ρ and of A_2 in Fig. 2 are equal to their established spins, 1 and 2, respectively.

The authors are indebted to G. Chikovani, L. Dubal, C. Nef, and P. Schübelin for their aid, and to Professor P. Preiswerk and Professor W. Paul for their continuous interest and support.

---

*Present address: University of Geneva, Geneva, Switzerland.

[1]H. R. Blieden, D. Freytag, J. Geibel, A. R. F. Hassan, W. Kienzle, F. Lefébvres, B. Levrat, B. C. Maglić, J. Séguinot, and A. J. Smith, Nuovo Cimento 43, 71 (1966); Phys. Letters 19, 444 (1965).

[2]H. R. Blieden, M. N. Focacci, L. Dubal, W. Kienzle, F. Lefébvres, B. Levrat, and B. C. Maglić, Phys. Letters 19, 708 (1966).

[3]W. Kienzle, B. C. Maglić, B. Levrat, F. Lefébvres, D. Freytag, and H. R. Blieden, Phys. Letters 19, 438 (1965).

[4]F. Lefébvres, B. Levrat, H. R. Blieden, L. Dubal, M. N. Focacci, D. Freytag, J. Geibel, W. Kienzle, and B. C. Maglić, Phys. Letters 19, 434 (1965); see particularly p. 437.

[5]J. Séguinot, M. Martin, B. C. Maglić, B. Levrat, F. Lefébvres, W. Kienzle, M. N. Focacci, L. Dubal, G. Chikovani, C. Bricman, H. R. Blieden, and P. Bareyre, Phys. Letters 19, 712 (1966).

[6]G. Chikovani, L. Dubal, M. N. Focacci, W. Kienzle, B. Levrat, B. C. Maglić, M. Martin, C. Nef, P. Schübelin, and J. Séquinot, Phys. Letters 22, 233 (1966).

[7]B. Levrat, C. A. Tolstrup, P. Schübelin, C. Nef, M. Martin, B. C. Maglić, W. Kienzle, M. N. Focacci, L. Dubal, and G. Chikovani, Phys. Letters 22, 714 (1966).

[8]J. Oostens, P. Chavanon, M. Crozon, and J. Tocqueville, reported at the Conference of the French Physical Society, Dijon, June, 1966 (unpublished). $\sigma_{tot} \cong 1\ \mu b$ for $p+p \rightarrow d+\delta$ at 3 GeV/c.

[9]Aachen-Berlin-CERN Collaboration, Phys. Letters 19, 608 (1965).

[10]V. Alles-Borelli, B. French, A. Frisk, L. Michejda, and E. Paul, to be published.

[11]By comparison, the baryon slope in the spin-versus-M^2 plot is 1.04 GeV^2, taking the lowest ten, well-established baryons.