INDICATIONS OF $J^{PC} = 4^{++}$ FOR THE S(1930) MESON FROM AN $\bar{p}p$ BACKWARD ELASTIC SCATTERING EXPERIMENT.

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(Presented by C. Defoix)

Preliminary results have been presented by M. Laloum at the symposium of Chexbres (1972, ref. 1). Since this time, the statistics have been strongly enlarged, as well as the momentum (lab.) and angular (c.m.s.) fields: now 175-750 MeV/c, with $\cos\Theta^* \lesssim + 0.2$ above 300 MeV/c.

About the experimental technics, we simply say here that a "quasi-stopping method" for the secondary $\bar{p}$ (under 300 MeV/c) allowed to describe the very low momentum region with accuracy, and that the calculation of a flux function ("beam method") made it possible to normalize the cross sections in a continuous fashion (very narrow momentum bins); see ref. 2. Results are given in figs. 1 and 2.

The elastic scattering is dominated by a big forward diffraction peak which begins on our data. Between $\sim$ 400 and 600 MeV/c, an enhancement appears in the extreme backward direction. We stress that it presents remarkable features:

1) the position of the peak is fixed ($-1 \lesssim \cos\Theta^* \lesssim - 0.85$) over a very large energy region (although t varies by more than a factor 2);

2) the angular shape, slightly flattened near - 1, also remains quite stable; this equally would be surprising in a diffractive view, whereas Θ^* precisely is the good variable for a resonance term: so, the angular stability suggests a well located spin-parity effect.

3) The energy behaviour, on the other hand, seems to characterize a resonance: first, the momentum variation of the peak displays a typical bump (fig. 3); secondly, above 600 MeV/c, the peak falls down abruptly without slipping forward in the angular distribution, as it would certainly be expected for a diffractive effect.

Although mainly qualitative, these various points undoubtedly constitute a very strong indication of a resonant nature of the peak, associated to a well defined spin-parity structure. Moreover, the diffractive background seems quite weak, for the adjoining angular region remains depressed in spite of a huge t variation.

For one Breit-Wigner, we obtain: $M = 1942$, $\Gamma = 57.5$ MeV/c^2 (the measurement precision alone is ~ 2 MeV/c^2, in this region). Actually, our structure is split:

$$M_1 = 1929 \pm 3, \quad \Gamma_1 = 28.5 \pm 6 \text{ MeV}/c^2$$

$$M_2 = 1953 \pm 2, \quad {}_2 = 22 \quad \pm 9 \text{ MeV}/c^2$$

The precise angular shape of the peak should inform us of its quantum numbers. We perform the following test.

Let us assume a fixed J^P contribution over a negligible background; we adjust the corresponding analytic amplitude to the experimental distribution between -1 and -0.6, averaged over the 375 - 575 MeV/c interval.

We may distinguish the C values. All the unnatural parity hypotheses violently disagree with the data; among the natural parity ones (yielding C = P), 2^+ and 3^- fit approximately, but 4^+ gives a perfect agreement (fig. 4). This 4^{++} result is remarkable as it coincides with the Regge expectation on the A_2 linearly extrapolated trajectory at the observed mass. Moreover, a prediction was implicitly made at Chexbres (ref. 1, 1972) from partial statistics: the 4^{++} best fit amplitude gave an integrated cross section of 5 mb, involving an elasticity of $\frac{1}{3}$ in $N\bar{N}$ ($\frac{1}{6}$ in $\bar{p}p$ for a fixed isospin). So, we expect an enhancement of 6 x 5 = 30 mb in the $\bar{p}p$ total cross section ($\pm \sim 5$ mb). Recently (ref. 3, feb. 1974), bumps have been observed about the 1930 MeV/c^2 mass, both in $\bar{p}p$ and $\bar{p}$ D total cross sections: for $\bar{p}p$, $\sigma_{tot} = 18^{+6}_{-3}$ mb, quite in agreement with our prediction (fig. 5). Differences in width might come from the arbitrarily chosen background. From comparison with $\bar{p}$ D, the isospin seems to be 1, as already suggested by the missing mass results (ref 4). Thus $I^G = 1^-$, also in agreement with the Regge expectation.

Actually, an acute problem is that of the real complexity of the amplitude. Joining our data with those of Conforto et al. (ref. 5), we get a precise description of the whole angular distribution between ~ 350 and 600 MeV/c. At various momentum points (50 MeV/c intervals), we adjust Legendre polynomial expansions of the form: $\frac{d\sigma}{d\Omega} = \sum_{n=0}^{n=N-1} a_n P_n (\cos\theta^*)$. As far as a strict cut-off on ℓ is possible, the physical form may not exceed the degree $2\,\ell_{max}$. Hence, an indication on ℓ_{max}.

In practice, N = 5 is always sufficient for a rough description, and no structure appears in the energy variation of the resulting a_n's. But for a detailed account of the data, higher values of N are required, until N = 9 or 10. On the other hand, the centrifugal barrier effects seem to limit the main part of the amplitude to $\ell \lesssim 2$, but to allow "dying" upper waves until ℓ = 4 or 5 (semi classical approximations, high value of the Compton wavelength). So, the two viewpoints give similar results and the complexity of the amplitude seems high. Therefore, the lack of an absolute diffractive theoretical frame forbids any calculation of the backward contribution.

However, a step may be made if we admit that the main part of the amplitude is at $\ell \lesssim 2$: we assume that it accounts for the inelastic and total cross sections and for the forward elastic differential cross section. Then a partial wave analysis achieved at 400 and 500 MeV/c leads to the shapes authorized by unitarity in the backward region (fig. 6 and 7). A sharp backward peak appears in all cases at 500 MeV/c: the fact that it is even too sharp, suggests the necessity of $\ell \gtrsim 3$. But one must not forget that it is a mere reflexion of our simplified hypotheses: small additional terms seem easily able to rub it out.

In conclusion, a diffractive origin of the backward peak is not excluded, but appears quite unlikely according to the arguments presented above : angular stability, characteristic energy behaviour, absence of any forward slipping afterwards. Besides, the perfect agreement obtained for all the quantum numbers with the Regge expectations, $(J^P I^G)_C = (4^+ 1^-)_+$, reinforces the probability of a resonant nature. Moreover, a recent confirmation comes from the quantitatively well predicted bumps in $\bar{p}p$ and $\bar{p}D$ total cross sections.

For more details, in particular precise results of the partial waves analysis (the first ever done in $N\bar{N}$ to our knowledge), see ref. 2.

REFERENCES

1) M. Laloum (Collège de France), review presented on the S-meson region, at the symposium on nucleon-antinucleon annihilations, Chexbres (march 1972): CERN yellow report 72-10, p. 1.

2) M. Laloum, thesis of doctorat d'Etat (may 1974), soon to be published.

3) A.S. Carroll et al., (Brookhaven National Laboratory), P.R.L., 32, 247 (feb. 1974).

4) G. Chikovani et al., (CERN), P.L., 22, 233 (june 1966).
M.N. Focacci et al., (CERN), P.R.L., 17, 890 (oct. 1966).
Cotteron et al., (laboratoire de Physique Générale, Paris), quoted in the Maglic's report on mesonic resonances, at the Lund Conference (june-july 1969).
Bowen et al., (Northeastern-Stony Brook), P.R.L., 30, 332 (feb. 1973).

5) B. Conforto et al., (CERN-Rome-Trieste), N.C., 54A, 441 (march 1968).

FIGURE CAPTIONS

1) Differential cross sections (50 MeV/c intervals, first binning).

2) Differential cross sections (50 MeV/c intervals, second binning).

3) Energy variation of the $(-1 \lesssim \cos\theta^* \lesssim -0.8)$ angular bin.

4) Spin-parity tests on the backward peak.

5) $\bar{p}p$ and $\bar{p}D$ total cross sections (ref. 3).

6) Unitarity limit to backward elastic scattering, in the diffractive scheme of a reduced complexity ($\ell_{max} = 2$, $J_{max} = 3$) at 400 MeV/c.

7) Unitarity limit to backward elastic scattering, in the diffractive scheme of a reduced complexity ($\ell_{max} = 2$, $J_{max} = 3$) at 500 MeV/c.

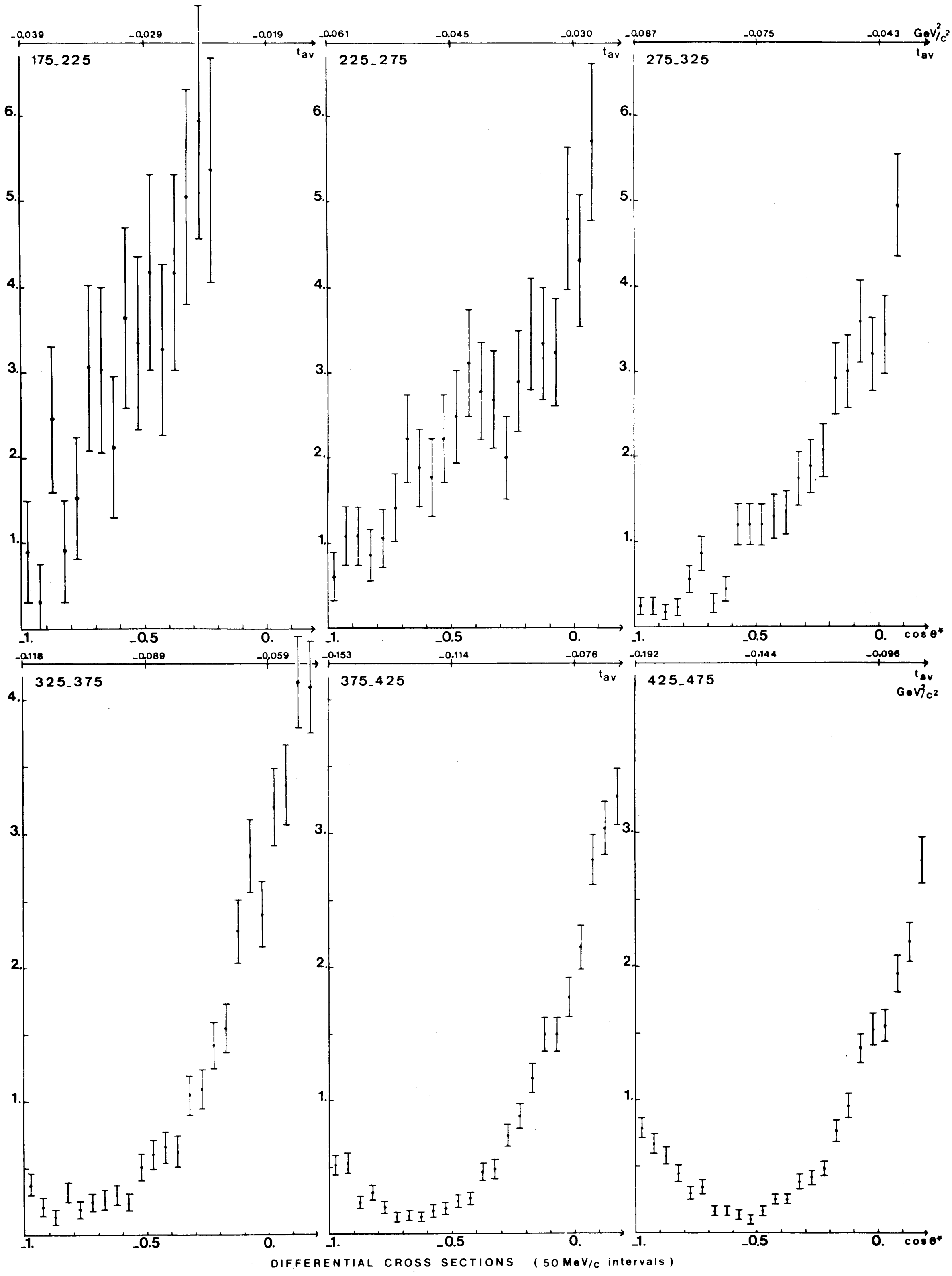

-0.039
-0.029
-0.019
t_av
175-225
-0.061
-0.045
-0.030
225-275
-0.087
-0.075
-0.043
GeV²/c²
275-325
6.
5.
4.
3.
2.
1.
-1.
-0.5
0.
cos θ*
-0.118
-0.089
-0.059
325-375
-0.153
-0.114
-0.076
375-425
-0.192
-0.144
-0.096
425-475
DIFFERENTIAL CROSS SECTIONS (50 MeV/c intervals)

Fig. 1a

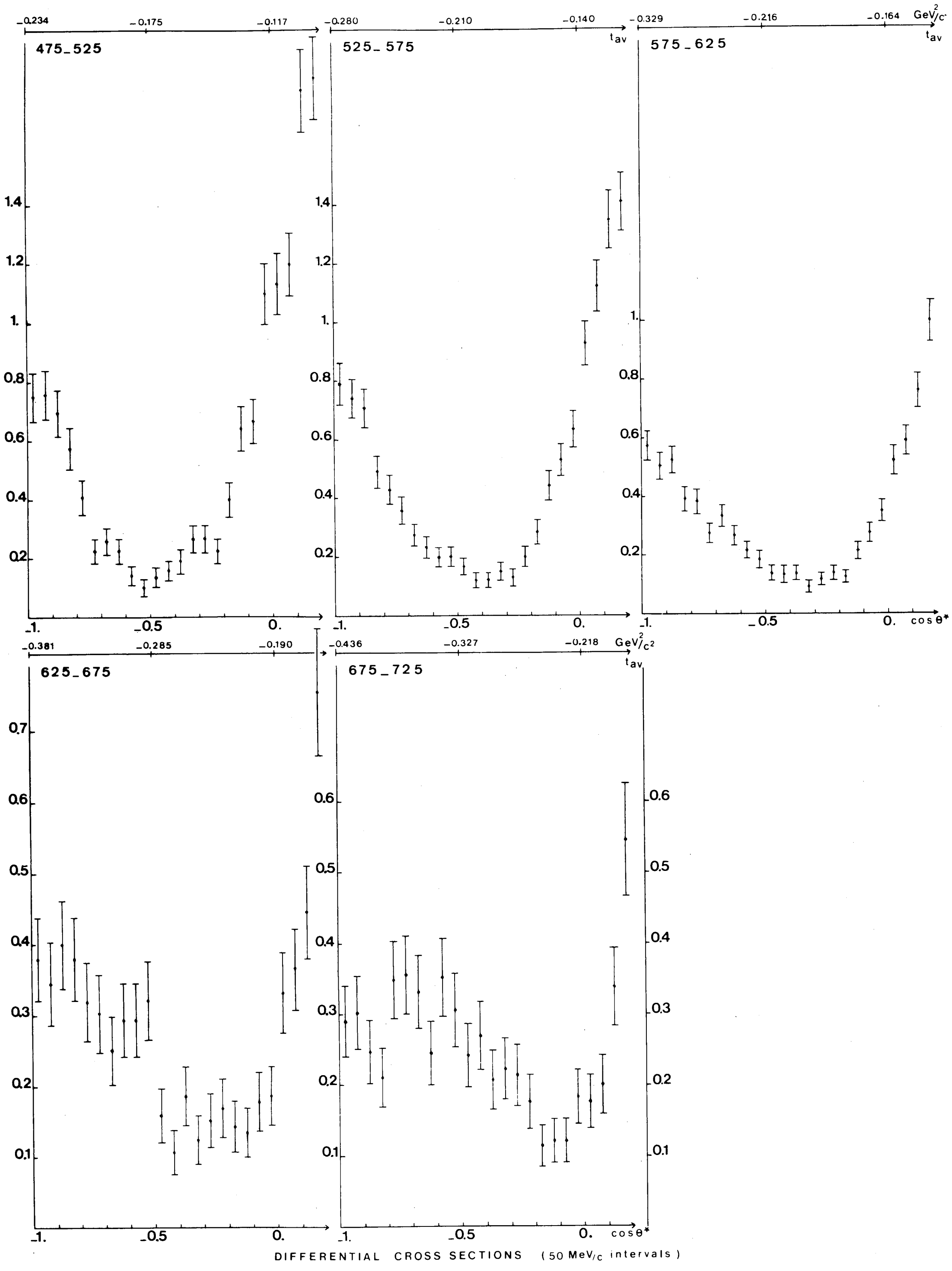

475_525
525_575
575_625
625_675
675_725
-0.234 -0.175 -0.117
-0.280 -0.210 -0.140
-0.329 -0.216 -0.164 GeV²/c²
-0.381 -0.285 -0.190
-0.436 -0.327 -0.218 GeV²/c²
t_{av}
cos θ*
DIFFERENTIAL CROSS SECTIONS (50 MeV/c intervals)

Fig. 1b

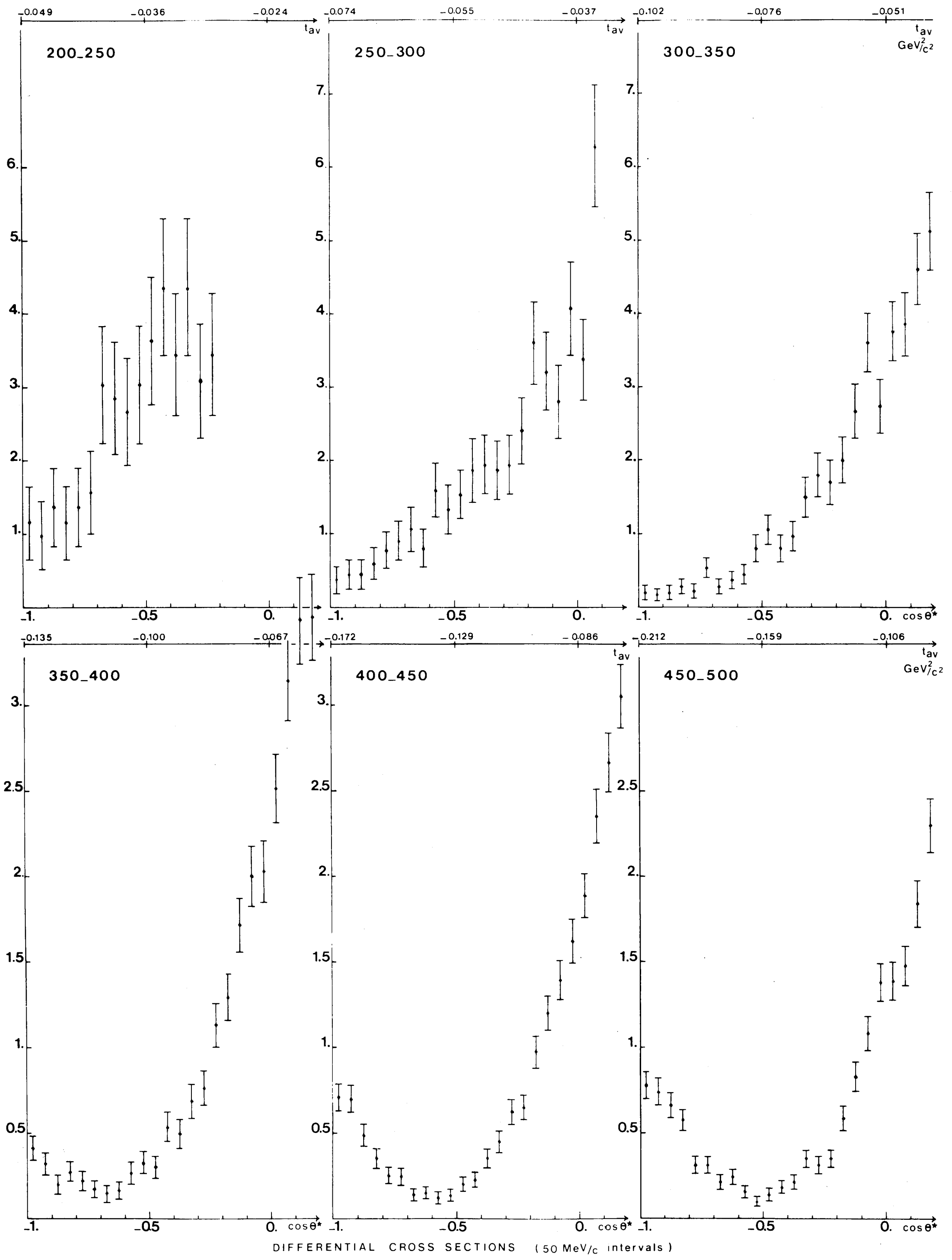
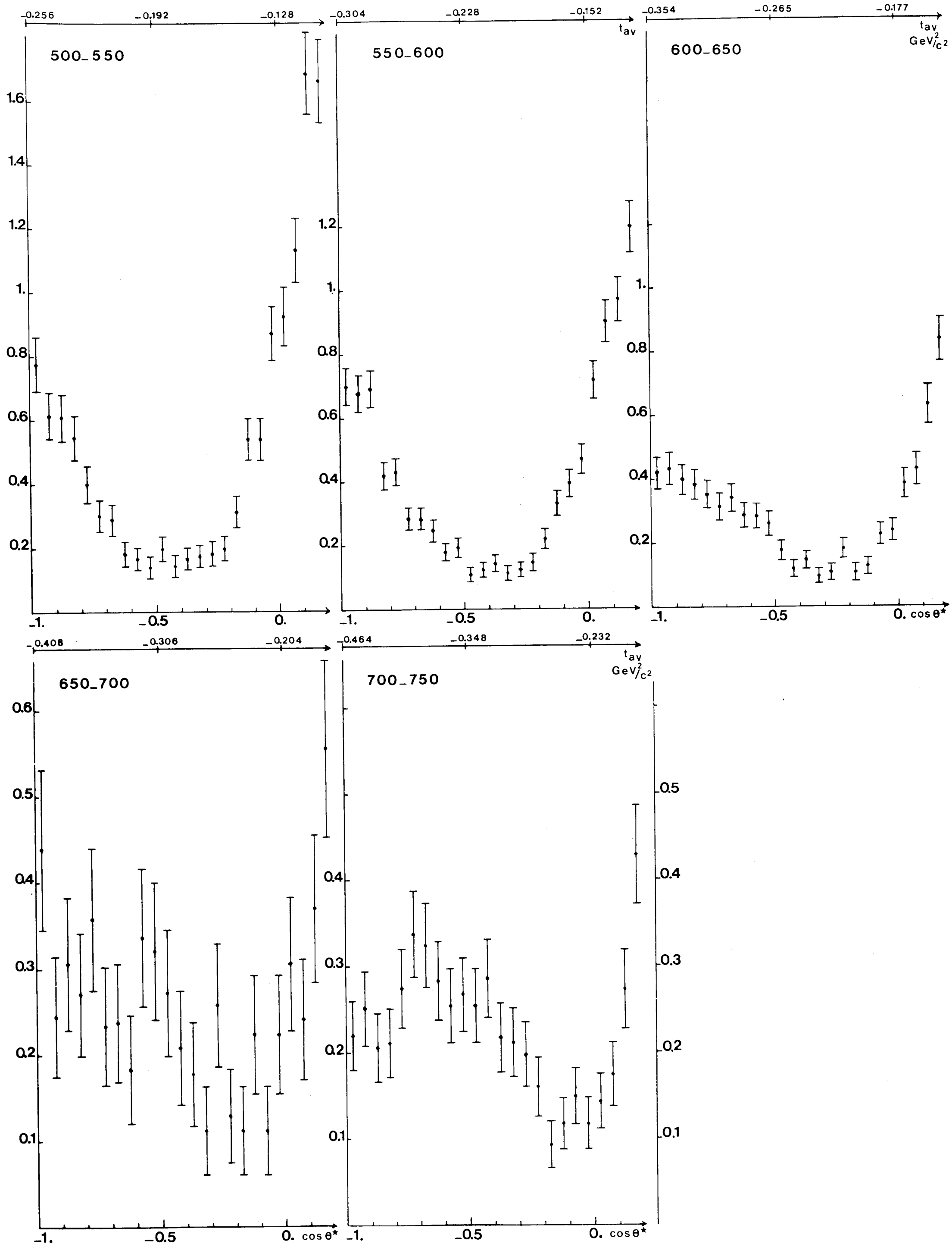

200_250
250_300
300_350
350_400
400_450
450_500
t_{av}
GeV^2/c^2
cos θ*
DIFFERENTIAL CROSS SECTIONS (50 MeV/c intervals)

Fig. 2a

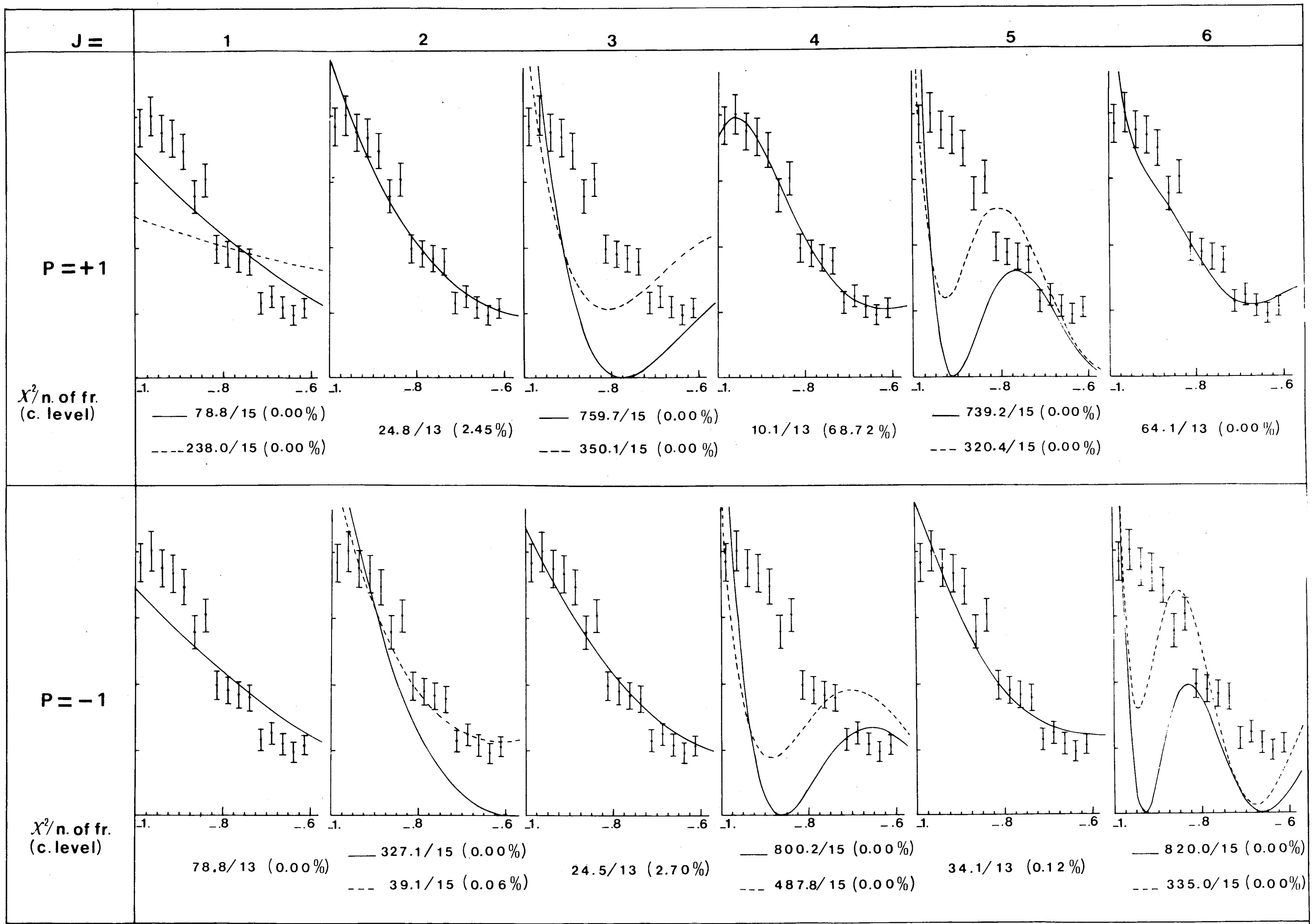


DIFFERENTIAL CROSS SECTIONS (50 MeV/c intervals)

Fig. 2b

COS θ* P$\bar{P}$ = -.8 to -1.0

Fig. 3



BACKWARD PEAK (cos θ*) in the momentum interval 375 - 575 MeV/c

differential cross section in arbitrary scale

For natural parity : C = P

For unnatural parity : C may be + or − { —— for C = −P (singlet state) / - - - for C = P (triplet state) }

Fig. 4

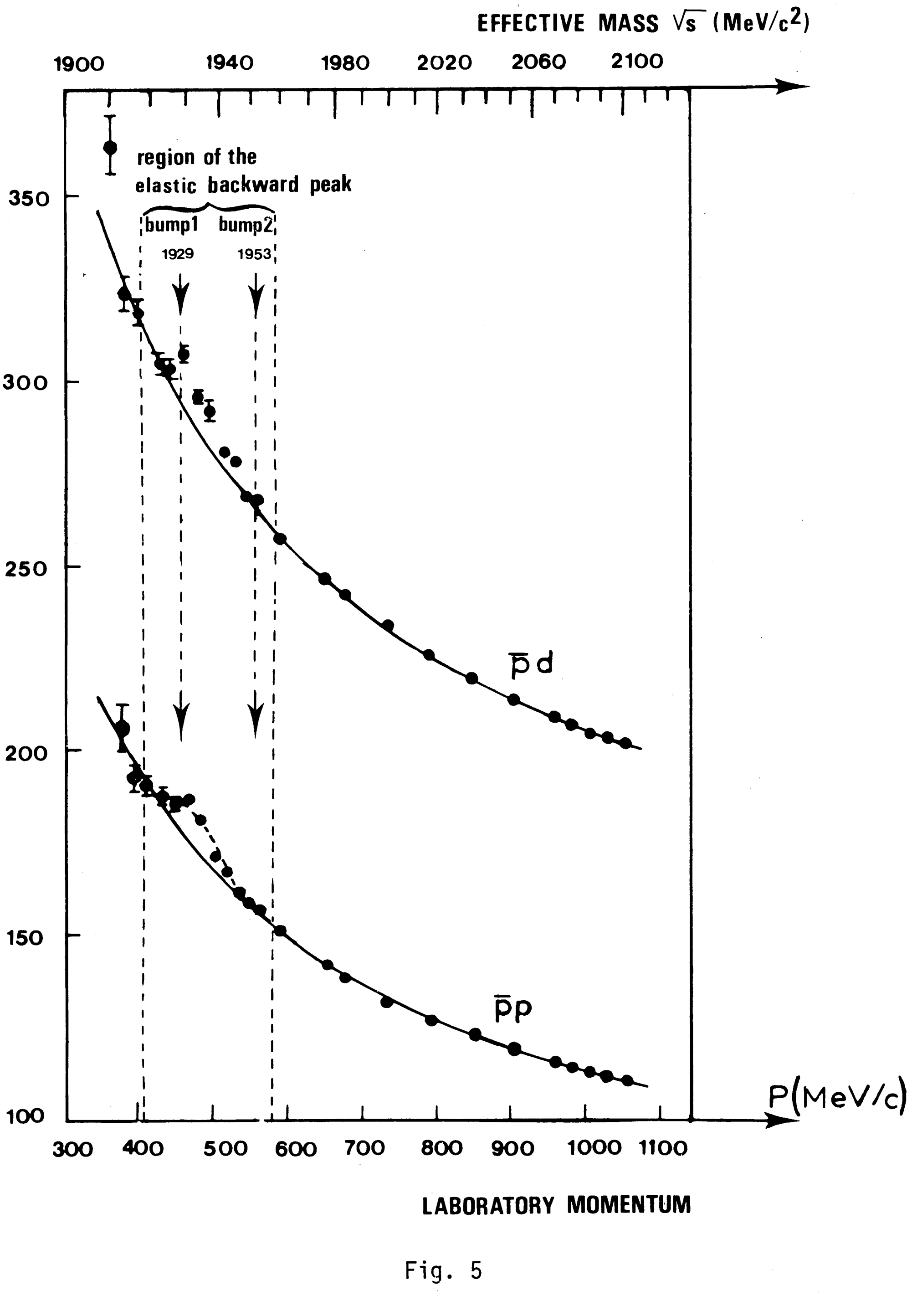
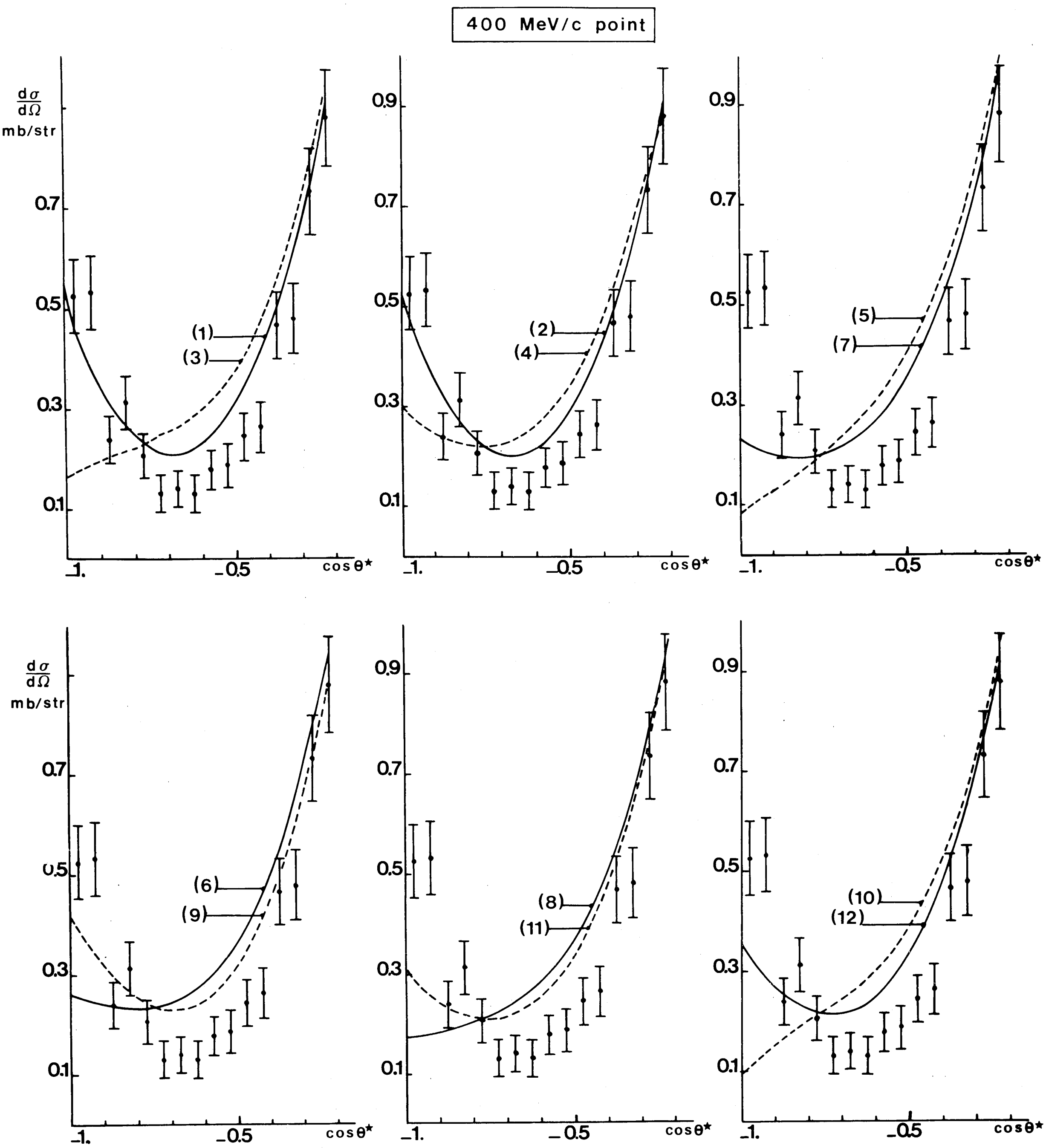

EFFECTIVE MASS √s (MeV/c²)
1900
1940
1980
2020
2060
2100
region of the
elastic backward peak
bump1
bump2
1929
1953
350
300
250
200
150
100
p̄d
p̄p
P(MeV/c)
300
400
500
600
700
800
900
1000
1100
LABORATORY MOMENTUM

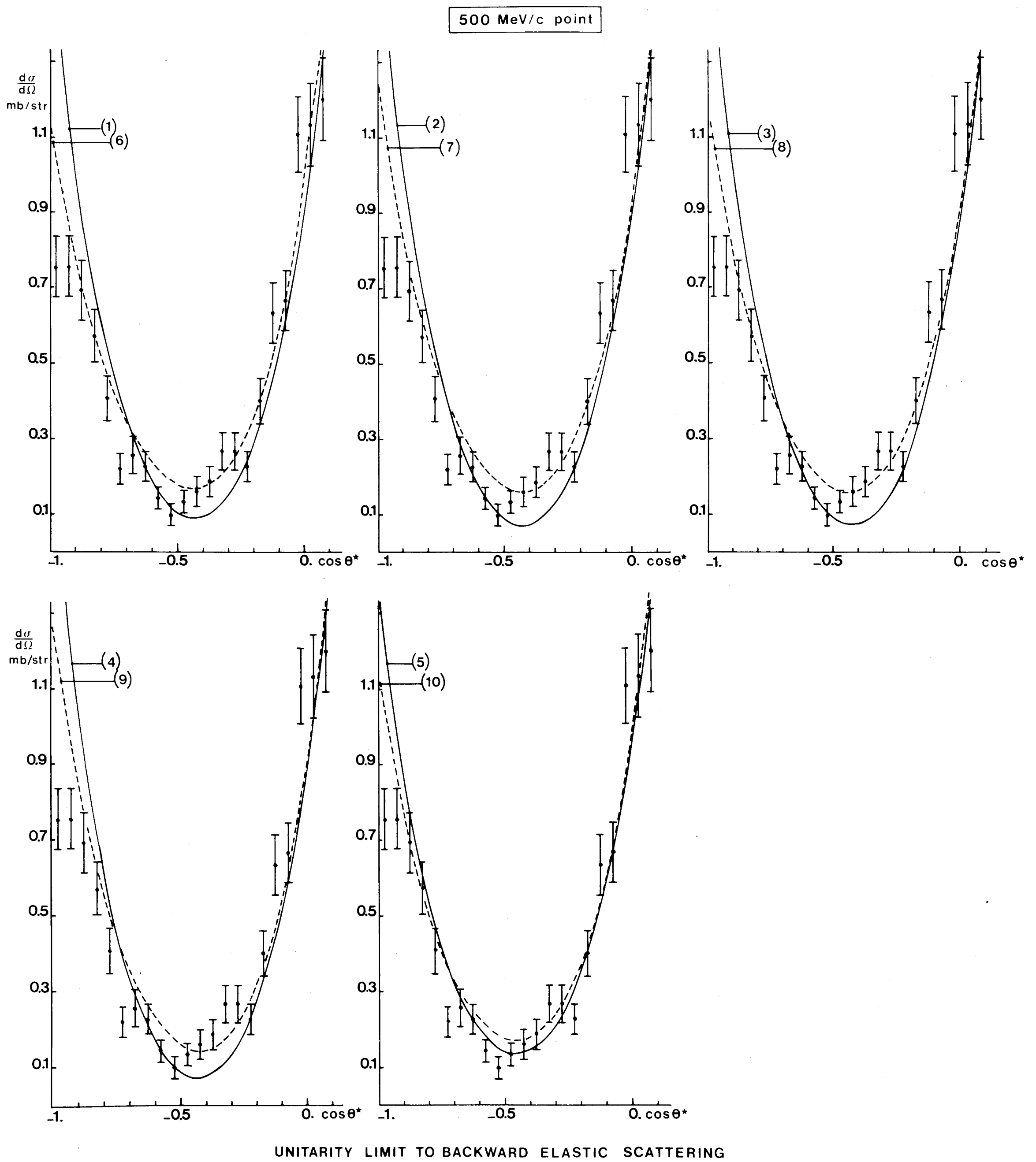
Fig. 5



UNITARITY LIMIT TO BACKWARD ELASTIC SCATTERING
in the diffractive scheme of a reduced complexity:

$l_{max} = 2$, $J_{max} = 3$.

Fig. 6



UNITARITY LIMIT TO BACKWARD ELASTIC SCATTERING
in the diffractive scheme of a reduced complexity :

$l_{max} = 2$. $J_{max} = 3$.

Fig. 7