EEC "A" 4/7/63

E. E. C.
letter of intention

withdrawn
(related with S48)

ELASTIC SCATTERING OF PIONS ON POLARIZED PROTONS

(Proposal for an Experiment)

J.C. Sens

With the advent of polarized proton targets a number of speculations concerning spin and parity of the resonances in the $\pi - n$ systems have, in principle, become more directly amenable to experimental verification than has been the case so far. This is in particular true for two-body reactions such as π-p elastic scattering; here, scattering off polarized protons contains the same amount or more information (depending on the incident energy) as a double scattering experiment and is rate-wise no worse.

In the following we compute just what asymmetry effects are to be expected in view of the presently known phase-shifts and how sensitive they are to the choice of quantum numbers for the known resonances. We then propose an arrangement of counters with which an elastic scattering experiment can be carried out.

EXPECTED ASYMMETRY

Consider the reaction[1)]

$$\pi^{\pm} + p \rightarrow \pi^{\pm} + p$$

The scattering matrix is given by

$$M = f(\theta) + i \vec{\sigma} \cdot \vec{n} \; g(\theta,\varphi)$$

6915/p

with

$$f(\theta) = \lambda \sum_L \left\{ (L+1)\, A_{L+} + L A_{L-} \right\} P_L(\cos\theta)$$

$$g(\theta,\varphi) = \lambda \sum_L \left\{ A_{L+} - A_{L-} \right\} P_L^1(\cos\theta)\, e^{i\varphi}$$

f and g are the non-spin flip and spin-flip amplitudes, respectively. The differential cross-section is

$$\sigma(\theta) = \tfrac{1}{2}\mathrm{Tr}\,(M^+M) = |f|^2 + |g|^2$$

The polarization of the recoil proton in scattering on unpolarized protons is given by

$$P(\theta) = \frac{\mathrm{Tr}(M^+ \sigma M)}{\mathrm{Tr}(M^+M)} = \frac{2\,\Im m\, f^* g}{|f|^2 + |g|^2}$$

The left-right asymmetry in scattering on polarized protons is given by

$$A(\theta) = \frac{L - R}{L + R} = \frac{|f + ig|^2 - |f - ig|^2}{|f + ig|^2 + |f - ig|^2} = \frac{2\,\Im m\, f^* g}{|f|^2 + |g|^2},$$

and is thus the same as the polarization of the recoil proton.

$\sigma(\theta)$ can be written in the form

$$\sigma(\theta) = \sum_n a_n \cos^n \theta$$

with (put $\hbar = 1$)

$$a_n = \mathrm{Re} \sum_{i \leq j} b_{ijn} A_i A_j^*$$

$A(\theta)\,\sigma(\theta)$ can be written in the form

$$A(\theta)\sigma(\theta) = \sum_n c_n \sin\theta \cos^n \theta$$

with

$$c_n = \mathrm{Im} \sum_{i \leq j} d_{ijn} A_i A_j^*$$

W.M. Layson[2] has recently analysed the experimental data on differential and total elastic scattering between 0.3 and 1.3 GeV. The logical order of this analysis is as follows: the data are divided into resonant regions and non-resonant regions. For the resonant regions the spin/parity assignment is taken over from photo-production ($D_{3/2}$ at 600 MeV, $F_{5/2}$ at 900 MeV). The amplitudes for these spin states are found by fitting a Breit-Wigner formula to the observed peaks. In the non-resonant region, use is made of the experimental values of total σ, the differential $\sigma(\theta)$ and the forward scattering amplitude[3]. Further restriction is imposed by the requirement that the A's vary smoothly with energy and that $L \leq 3$.

Taking the values of A_i, thus obtained, we have calculated the expected left-right asymmetry $A(\theta)$ (and $\sigma(\theta)$). The computer results for 900 MeV is given in Fig. 1. A quite large and strongly varying left-right asymmetry is obtained.

Although the values given by Layson are plausible solutions, they are by no means unique[4]. We have therefore searched for other values of A_i, which leave $\sigma(\theta)$ unchanged. Figure 2 shows what happens when the amplitudes for the $F_{5/2}$ and $D_{5/2}$ states are interchanged: a very drastic change in $A(\theta)$ is produced, while $\sigma(\theta)$ remains nearly the same[5]. This shows that the asymmetry measurement is a much more sensitive analyser of spin and parity than the differential cross-section.

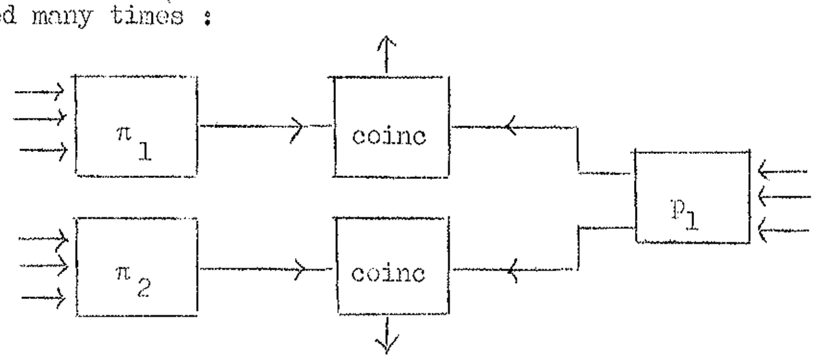
The previous procedure is, of course, applicable at any energy for both π^+ and π^- [6]. We suggest however to do the first measurements at $\sim 900 - 1000$ MeV with π^-. In this energy range there is in the phase shift data the suggestion of another isobar, as pointed out by Feld and Layson. This isobar has a strange particle decay mode (besides a normal one); the variation of $\sigma(\pi^- + p \rightarrow \Lambda + k)$ with pion energy is consistent with the assignment $T = \frac{1}{2}$ $\mathcal{J} = \frac{1}{2}^+$. In Fig. 3 $\sigma(\theta)$ and $A(\theta)$ are given, for 930 MeV, with the $P_{\frac{1}{2}}$ amplitudes as given by Layson's analysis; in Fig. 4 the imaginary part of the $P_{\frac{1}{2}}$ amplitude has been arbitrarily put equal to zero[7]. Although $\sigma(\theta)$ is no longer the same, the sensitivity of $A(\theta)$ is much greater.

EXPERIMENTAL ARRANGEMENT

In Fig. 5 the left-right asymmetries obtained in Fig. 1 and 2 are transformed to the lab-system for 900 MeV incident pions. Fig. 6 contains the lab-angular distribution (for the $F_{5/2}$ case; the $D_{5/2}$ case is negligibly different). It appears that the region of greatest interest is between $\sim 20^{\circ}$ and 90° pion angle in the lab-system. In Fig. 7 a set-up is sketched which detects events between these limits. Both the pion- and the proton detector consist of a water Cerenkov counter, constructed in the form of a curved canal in which partitions can be placed. Each cell is viewed by a 2" photomultiplier on top or bottom. The cells are placed as close to the magnet as the fringing field allows. In front and behind are plastic scintillators. The pion detector contains 14 equally wide cells, spanning 5° each. Size and position of the corresponding cells in the proton detector are determined by elastic scattering kinematics.

With the adopted scheme no cell is smaller in size than the practical limit of about 3.5 x 6 cm. The scintillators in the pion detector span 10° each but are placed such that in a front-back coincidence 5° intervals are selected; similar for the proton detector. In the indicated intervals all pions have $\beta > 0.75$, all protons $\beta \lesssim 0.75$; on the pion-side the Cerenkov counters are therefore put in coincidence, on the proton-side in anti-coincidence with the scintillators.

The electronics consists entirely of standard components, repeated many times :



etc.

6915/p

A further safeguard against unwanted events is obtained by measuring the proton energy. This can be done by adding absorbers to the proton detector, thus turning $p_1 \rightarrow p_7$ into (differential or integral) range telescopes. A disadvantage is that the differential cross-section, which can be measured along with the asymmetry, is strongly distorted by the absorbers, due to nuclear interactions: at 25° the proton range is 160 g/cm^2 $A\ell$, which is two geometrical mean free paths. Other possibilities are magnetic analysis or a carbon-plate spark chamber to measure the range. A decision must await more accurate calculations of the backgrounds due to elastic and inelastic scatters on bound nucleons in the target. We prefer to leave this question open for the moment.

The number of scatters on free polarized protons, for a $1 \times 1 \times 1$ cm^3 target, 25 mb cross-section, 10^5 π per burst, is 90 per burst. 45% goes into the angular limits $20 - 90^{\circ}$ and $\sim 3\%$ escapes the pole faces. For the sake of discussion we have assumed a magnet similar in size and field strength as the one recently proposed by Abraham et al[8]. This gives 1.2 elastic scatters on polarized protons per burst. For an error δA in A of 0.05 in any angular interval 400 events are required. The least populated interval contains 0.2% of all events. In two days of running the asymmetry is determined to between 0.005 and 0.05 depending on the interval.

In Fig. 7 the trajectories have been corrected for the magnetic field assuming 20 kGauss over the entire pole area.

REFERENCES

1: This is part of a fuller investigation, to be published; for notation and derivation, see e.g. Hamilton, The theory of elementry particles. Coulomb effects have been neglected; the inelasticity parameters have been put = 1.

2: W.M. Layson, Nuovo Cimento 27, 724, 1963.

3: J.W. Cronin (P.R. 118, 824, 1960) has computed these by use of dispersion relations (relating the real part of the forward scattering amplitude to the imaginary part) and the optical theorem (relating the imaginary part to the total σ).

4: See Rochester Conference 1962, page 150 for an amusing dialogue on this point.

5: Of the ℓ-substates corresponding to a given state J had been interchanges for all J's simultaneously, then $\sigma'(\theta) = \sigma(\theta)$ and $A(\theta) = -A'(\theta)$ (Minami-transformation).

6: For an assumed set of phase-shifts graphs like Fig. 1 are obtained in three minutes computer time.

7: The $T = 3/2$, $J = \frac{1}{2}$ need not be in resonance at the same energy; therefore this assumption is slightly too strong. Too little is known about the amplitudes to give reasonable alternatives.

8: Abraham et al, Proposal for a direct determination of the $\Sigma - N - K$ parity.

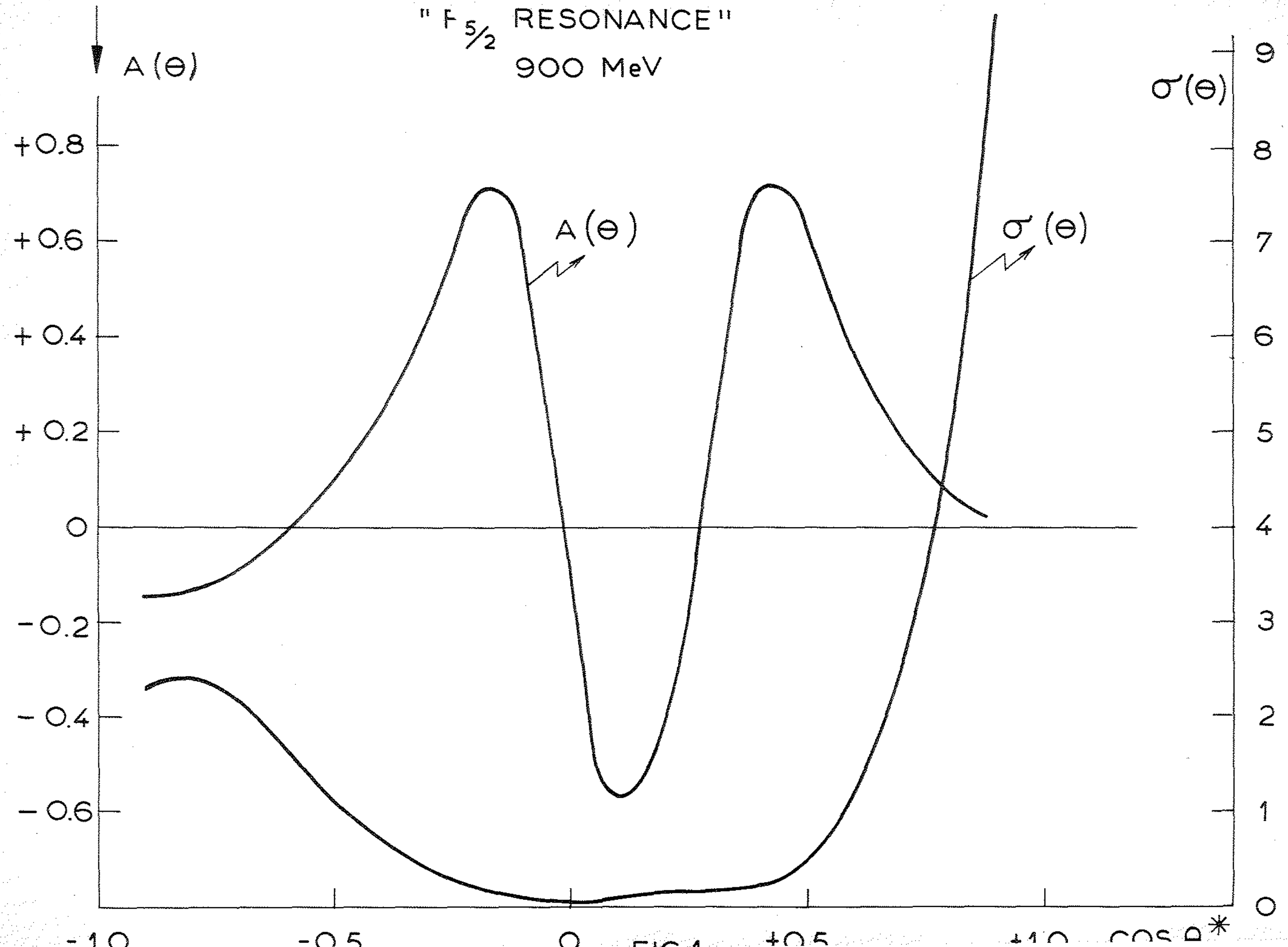
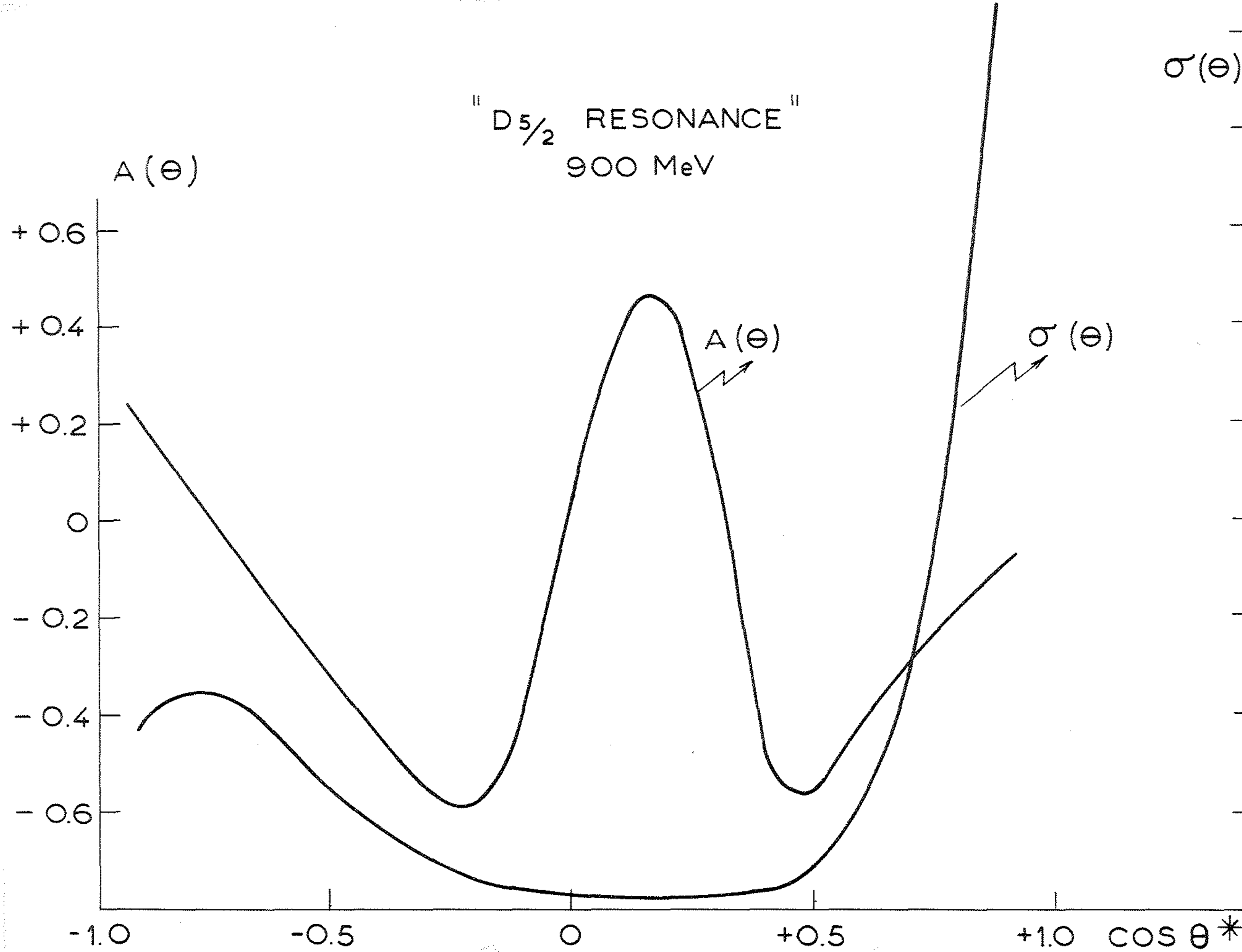
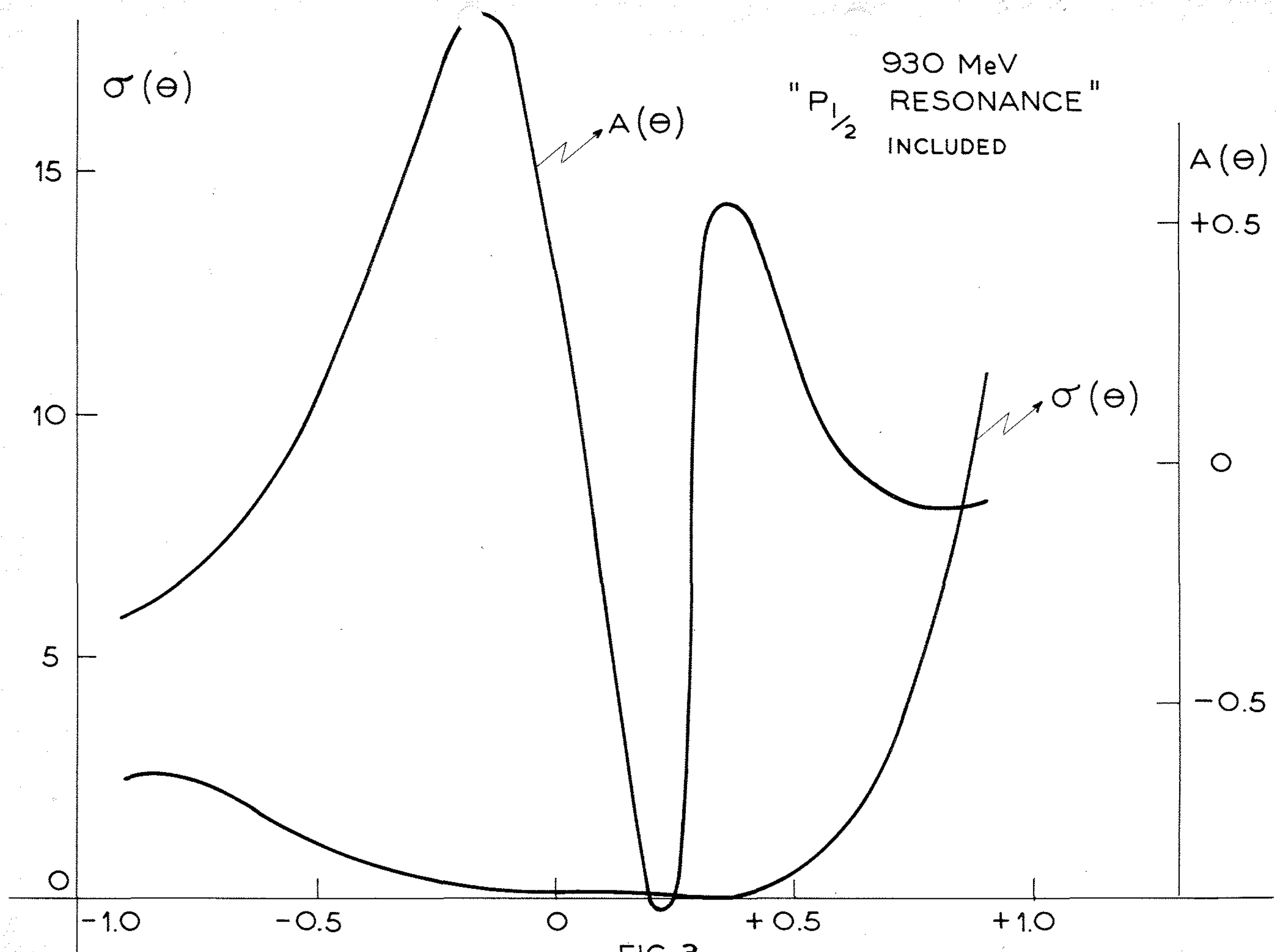

"F5/2 RESONANCE"
900 MeV
A(θ)
σ(θ)
+0.8
+0.6
+0.4
+0.2
0
-0.2
-0.4
-0.6
9
8
7
6
5
4
3
2
1
0
-1.0
-0.5
0
+0.5
+1.0
cos θ*

FIG.4



"D 5/2 RESONANCE"
900 MeV
A (Θ)
σ(Θ)
+ 0.6
+ 0.4
+ 0.2
0
- 0.2
- 0.4
- 0.6
9
8
7
6
5
4
3
2
1
0
A (Θ)
σ (Θ)
-1.0
-0.5
0
+0.5
+1.0
COS θ*

FIG. 2



σ(θ)
A(θ)
930 MeV
"P1/2 RESONANCE"
INCLUDED
15
10
5
0
+0.5
0
−0.5
−1.0
−0.5
0
+0.5
+1.0

FIG. 3

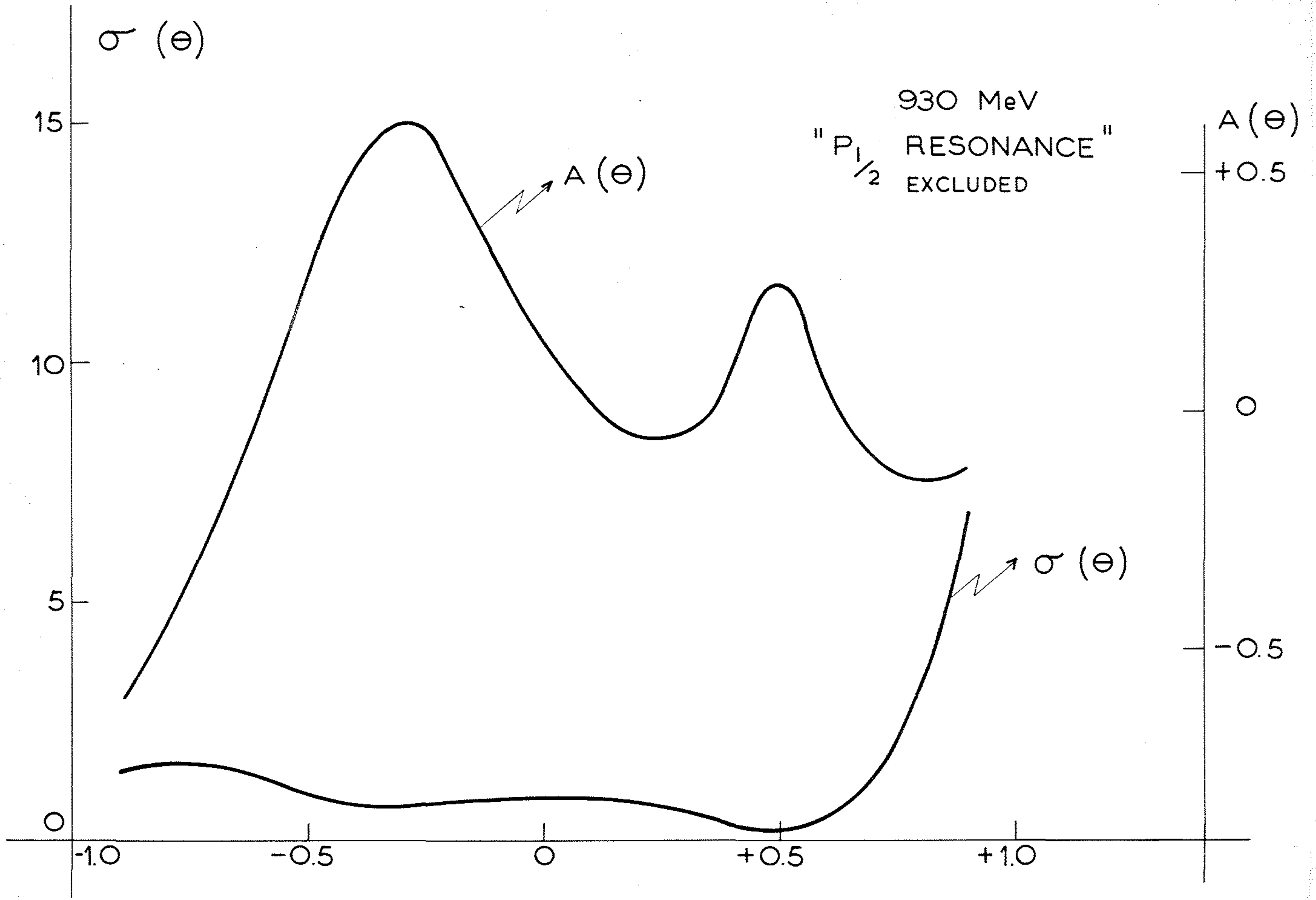
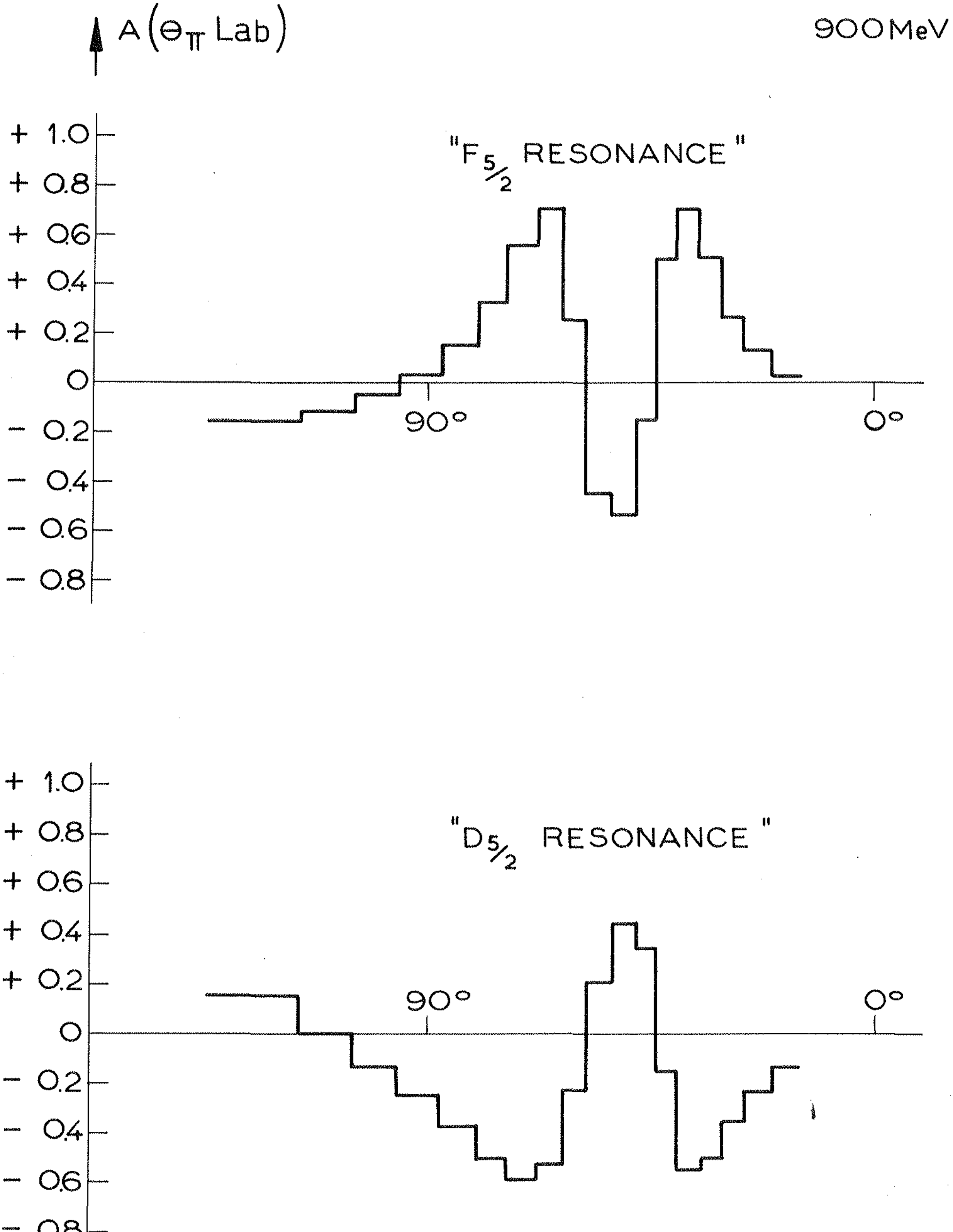

σ (θ)
15
10
5
0
930 MeV
"P1/2 RESONANCE"
EXCLUDED
A (θ)
A (θ)
+0.5
0
−0.5
σ (θ)
-1.0
−0.5
0
+0.5
+1.0

FIG. 4



NOTE: HORIZONTAL BARS CORRESPONDS TO 0.1 INTERVALS IN cos.Θ*

FIG.5

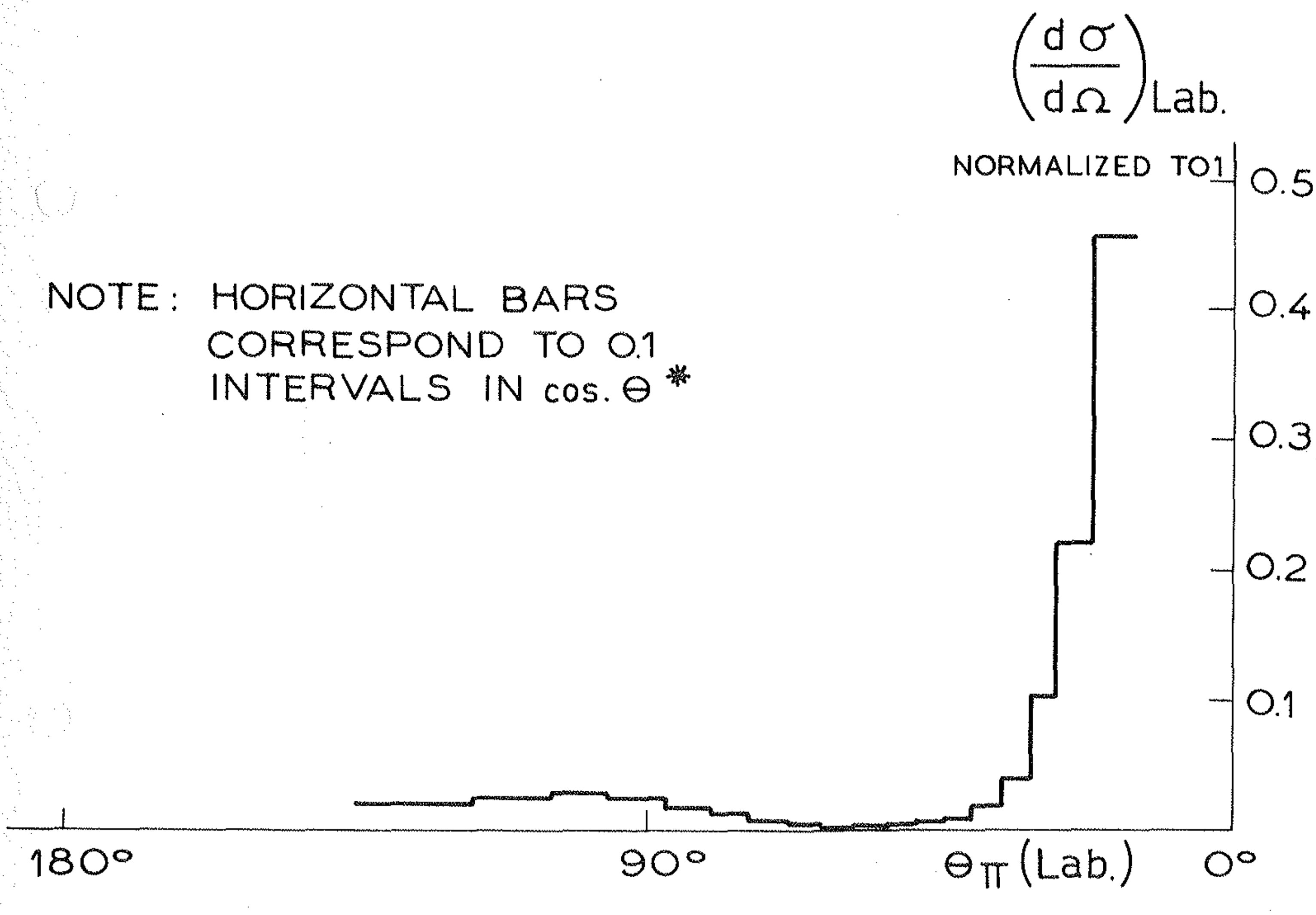

$\left(\frac{d\sigma}{d\Omega}\right)_{Lab.}$
NORMALIZED TO 1
0.5
0.4
0.3
0.2
0.1
NOTE: HORIZONTAL BARS CORRESPOND TO 0.1 INTERVALS IN cos. Θ*
180°
90°
Θ_{π} (Lab.)
0°

FIG. 6

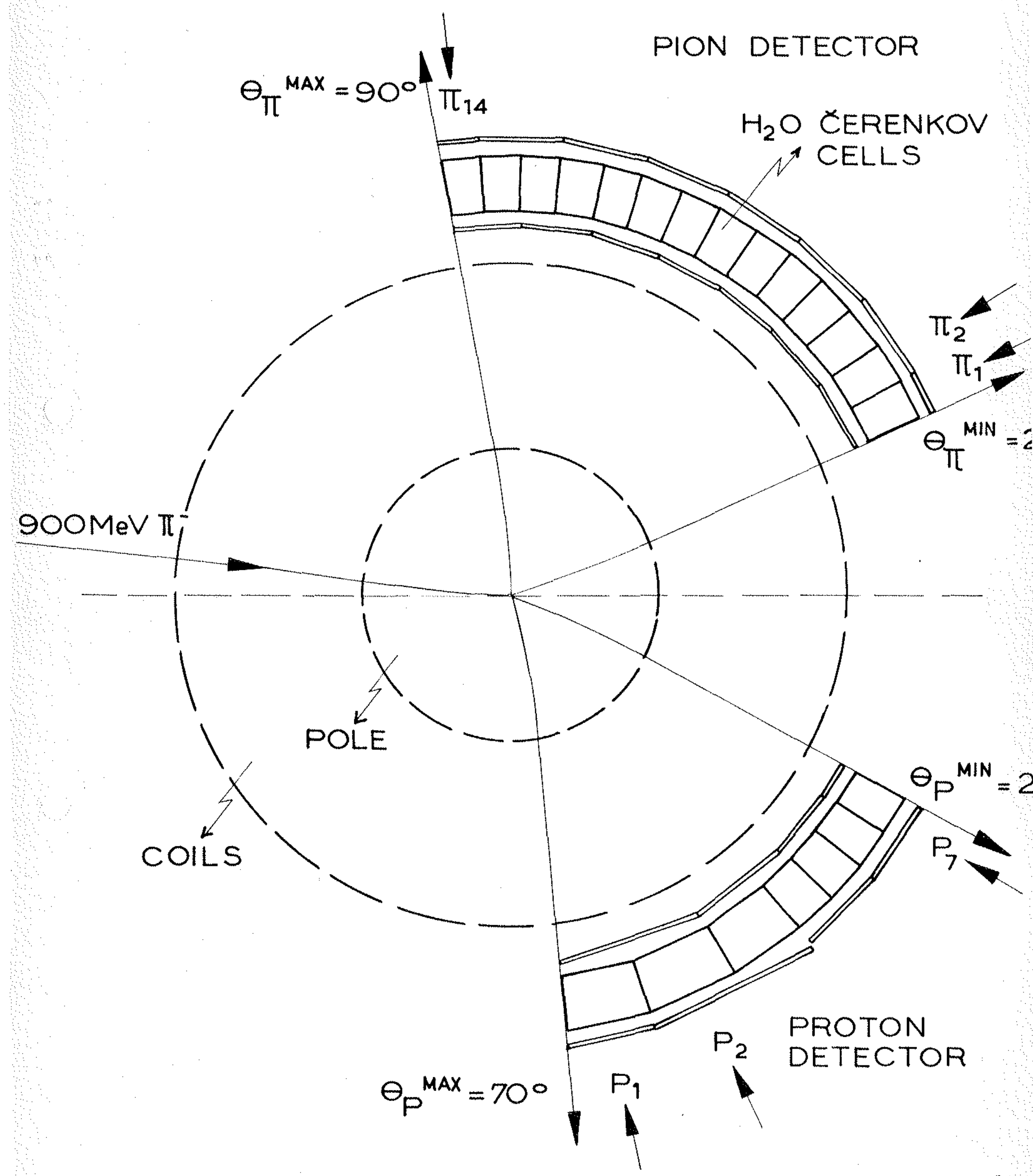

PION DETECTOR
$\Theta_\pi^{MAX} = 90°$
π_{14}
H_2O ČERENKOV CELLS
π_2
π_1
900MeV π^-
POLE
COILS
PROTON DETECTOR
P_7
P_2
P_1
$\Theta_P^{MAX} = 70°$

FIG. 7