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IN THE 3 ÷ 3.5 MeV NEUTRON ENERGY RANGE

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Contratto Euratom - CNEN per le Basse Energie

Sommario:

Vengono eseguite sei misure di diffusione elastica n-α nell'intervallo energetico 3÷3.5 MeV del neutrone incidente allo scopo di controllare i valori piuttosto discordanti forniti nella letteratura per gli spostamenti di fase in questo intervallo. Viene usato come rivelatore un contatore proporzionale ad elio. Le distribuzioni degli impulsi in altezza, corrette per i normali effetti sperimentali, vengono normalizzate e analizzate per le sole fasi S e P. Mentre le fasi S e $P_{3/2}$ risultano in buon accordo con i valori normalmente accettati, il valore della fase $P_{1/2}$ appare notevolmente più basso, come già ottenuto in altre misure eseguite nei nostri Laboratori nello stesso intervallo energetico ed in accordo ai valori isolati ottenuti da Levintov per E_n = 2.4 MeV e Seagrave a 2.6 MeV. Ne risulta di conseguenza alterato il valore del potere analizzatore dell'elio P_{He}, che viene dedotto dalle fasi e usato nelle misure di polarizzazione eseguite con il metodo della doppia diffusione.

Summary:

Six measurements of n-α scattering in the range 3÷3.5 MeV neutron energy have been methodically carried out in order to check the inconsistent phase shifts data available in the literature for this energy interval. Using a proportional counter and the recoiling H^4-nuclei method, the pulse height distributions were observed and, after corrections for the normal experimental effects, analysed for the S and P phase shifts and asymmetries of polarized neutrons. Whilst the S and $P_{3/2}$ phases are in good agreement with the literature, the $P_{1/2}$ one turns out to be smaller, according to our preceding data and the Levintov's at 2.4 MeV and Seagrave's at 2.61 MeV points. Consequently the helium analyzing power could be remarkably different than usually accepted.

Introduction:

It is well known that the most wide knowledge in polarization measurements derives from double scattering experiments on spinless second target, such as He^4, C^{12} and O^{16}. Helium is expecially suitable for his high natural stability, excited states absence in the low energy region and very satisfactory phases knowledge beyond 10 MeV. The analyzing power P_{He}, which appears in polarization experiments, is normally derived from the phase-shifts of n-α scattering. There are however remarkable discrepancies in the 3 MeV energy interval and below for the relative phases between the Winsconsin's Group data (1), which substantially accepts the Dodder-Gammel-Seagrave's (DGS) phase shifts (2) and our preceding measurements (3-4) in the 2.37÷2.98 MeV range, which agree for the $P_{1/2}$ phase with the Levintov's isolated point at 2.4 MeV (5) and 2.61 MeV Seagrave's point (2). A recent work performed by Roper et alt. (6) confirms also the abnormal behaviour in the $E_n < 3$ MeV region for the $P_{1/2}$ phase, which could be negative below 0.8 MeV.

Six new measurements at 3, 3.1, 3.2, 3.3, 3.4 and 3.5 MeV neutron energy have therefore been done with the aim to obtain more reliable values for the phase shifts in this interval.

Method of measurements and experimental procedure.

The CM. angular distributions of the scattered neutrons were determined with the classical recoil method of Baldinger (7) and Barshall (8):

$$(1) \qquad \sigma(\vartheta) = \frac{\sigma_T}{4\pi} E_{max} H(E_\alpha)$$

where $H(E_\alpha)$ is the energy distributions of the He^4 recoiling particles and the other symbols have the usual meaning. As α detector we have used a cylindrical proportional counter, with a conventional linear amplifier system (transistorized pre- and LABEN G 403 amplifier). The height pulses distributions were observed with the 200 channels LABEN Mod. C 31 -CISE analyser. The electronic chain linearity, checked periodically, was better than 1%. The counter filling was a mixture of 80% helium + 20% argon (the latter to increase the stopping power) at 5 Atm. total pressure. The counter was supplied with a stabilized H.V. of 2.200 Volts. Neutrons were produced in the (d, d) reaction with the vertical Cockroft-Walton accelerator of the Institute ([9]) and measurements were made with the counter long axis at 0° and 45° with the d-beam. Target-counter window distance was 31 cm. A paraffin cylinder shielded the detector to minimize the background; the neutron beam was collimated with a double iron holed cone, of the type described by Huber and Striebel ([10]), 21 cm long and 1.6 cm holed, in order to reduce the solid angle to the sensitive volume of the counter ($\Omega = 3.5\times10^{-3}$ sterad.). The hole was periodically filled with water and timed measurements were done of the scattered neutrons background. The neutron flux was monitored with an Emmerich NE 451 scintillator, coupled with a Dumond 6292 phototube, placed at 90° with the accelerator axis. The neutron flux was $10^6 \div 10^7$ neutrons/ sec. in the 4π solid angle. The experimental assembly is schematized in fig. 1. The counter and electronic chain energy resolution was checked with an α - Po source (extracted in the n- α scattering measurements) and was 14%. With the same method the counter-amplifier stability was controlled. The electronic noise, measured during many hours, was neglegible. Three partial spectra were remarked in each n-α scattering, in turn with backscattered neutrons ground measurements and resolution-stability checkes, in order to observe the experimental reproducibility. The partial spectra, after background correction, were then added to an amount of about 50.000 events for each "cleaned" distribution.

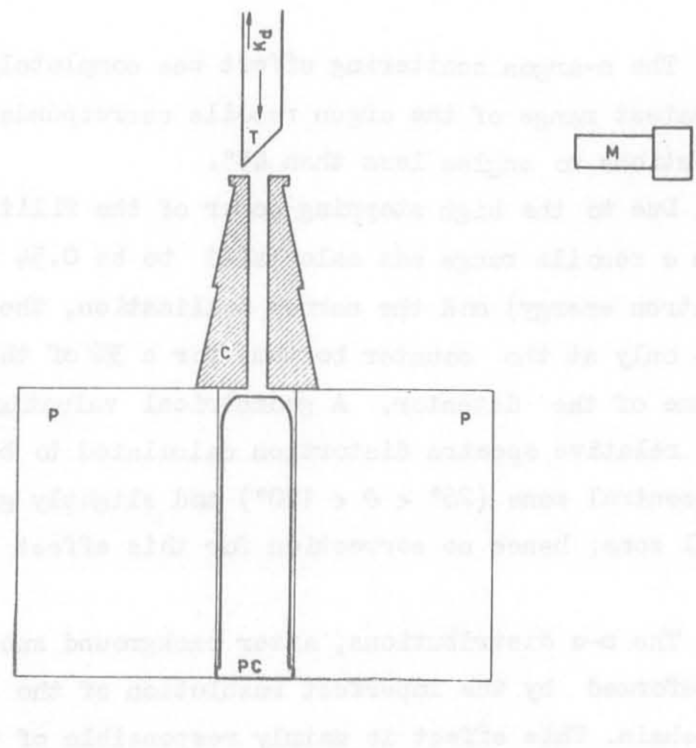

Fig. 1 - Experimental assembly of n-α scattering measurements.

Data corrections and treatment.

The following measurement disturbancies were examined and the relative eventual corrections valuated:

1. Energy spread of the incident neutrons arises only from the target-to-counter aperture, because the d-beam H.V. supply stability was 1‰ and thin target was used. The narrow collimation reduces this effect to only 0.024 MeV for the 45° measures, corresponding to the worse geometrical conditions. No correction for this effect was take into account.

2. Background corrections were made for the walls and floor backscattered neutrons, mainly interesting the low spectra regions, and were of the order of 10% for the 0° and 15% for the 45° situations.

3. The n-argon scattering effect was completely ignored, because the greatest range of the argon recoils corresponds for each CM n-α distributions to angles less than 45°.

4. Due to the high stopping power of the filling mixture (the maximum α recoils range was calculated to be 0.54 cm. for the 3.5 MeV neutron energy) and the narrow collimation, the "wall effect" appears only at the counter bottom, for a 3% of the whole sensitive volume of the detector. A geometrical valuation was performed and the relative spectra distortion calculated to be less than 1% in the central zone (26° < ϑ < 120°) and slightly greater in the external zone; hence no correction for this effect becames necessary.

5. The n-α distributions, after background subtraction, were still deformed by the imperfect resolution of the counter and electronic chain. This effect is mainly responsible of the strong tail distortion at the large angles region and complicates notably the exact spectrum end determination. This goal was accomplished with a combination of the geometrical method pointed out by Hall and Kootz (11) and Austin et al. (1) and an iterative best fit procedure in the following way.

The n-α differential cross section may be written (4) in the form

$$(2) \qquad k^2\sigma(\vartheta) = \sum_{n=0}^{n=2L_{max}} A_n \cos^n \vartheta = \sum A_n^* X^n$$

where $k^2 = 2(m_n m_\alpha / m_n + m_\alpha)^2 \cdot E_{n\,LAB} / \hbar^2\ m_n$

A, A* are numerical coefficients dependent on the phase shifts,

L_{max} is the maximum orbital angular momentum,

$\cos\vartheta = 1-2X$, with $X = E_\alpha / E_{\alpha max}$

E_α, $E_{\alpha max}$ being the energy and the maximum energy, respectively, of the recoiling α particles.

For our energies S and P phases are only involved and the (2) has parabolic shape. In order to determine the indistorted spectrum zone, a theoretical pulse height distribution, calculated from the DGS phase shifts, was smeared out with a triangular resolution function, approximated to that observed with the same counting system and the 5.3 MeV α-Po source. This smeared distribution was treated as an experimental distribution and compared with the theoretical one; the error for the finite strumental resolution was very strong at the tail of the spectrum, but lower than 1.5% for $X < 0.85$ ($\vartheta < 140°$). It was therefore reasonable to consider "no deformed" the distributions points in the range $0.25 \leq X \leq 0.85$ corresponding to a CM angular interval $60° \leq \vartheta \leq 135°$, the lower limit being chosen to avoid other possible background disturbancies. At this point a first approximation of the spectrum end (abscissa $X = 1$) was performed with the Austin's method and a first parabolic best fit carried out in the "no deformed" interval. This fit, extrapolated in the smeared distribution zone, permits the valuation of the corrections to be furnished to the experimental points and a new more exact spectrum end determination. In the new interval $0.25 \leq X' \leq 1$ a second parabolic fit was performed. At last a third fit was done in the "enlarged" interval $0.15 \leq X' \leq 1$ ($45° \leq \vartheta \leq 180°$) in order to check the consistency of the experimental points in the low energy zone. The parabolic coefficients A_i, resulting from the "indistorted" and "enlarged" fits, were hence normalized and compared: no important differences went forth between them (only the second decimal digit appears lightly modified).

With good approximation our spectra may be then considered extended in the 45° ÷ 180° CM. angular zone. The results and the values of k^2 and σ_T (*), used in the normalization and so the $\sigma(\vartheta)$ extrapolations at 0° and 180° degrees are reported in table 1, whilst the differential cross sections are plotted, as a function of the cosine of the CM scattering angle ϑ, in figs. 2 - 7.

(*) σ_T are interpolations of the data of Los Alamos Physics and Cryogenics Groups ([14]).

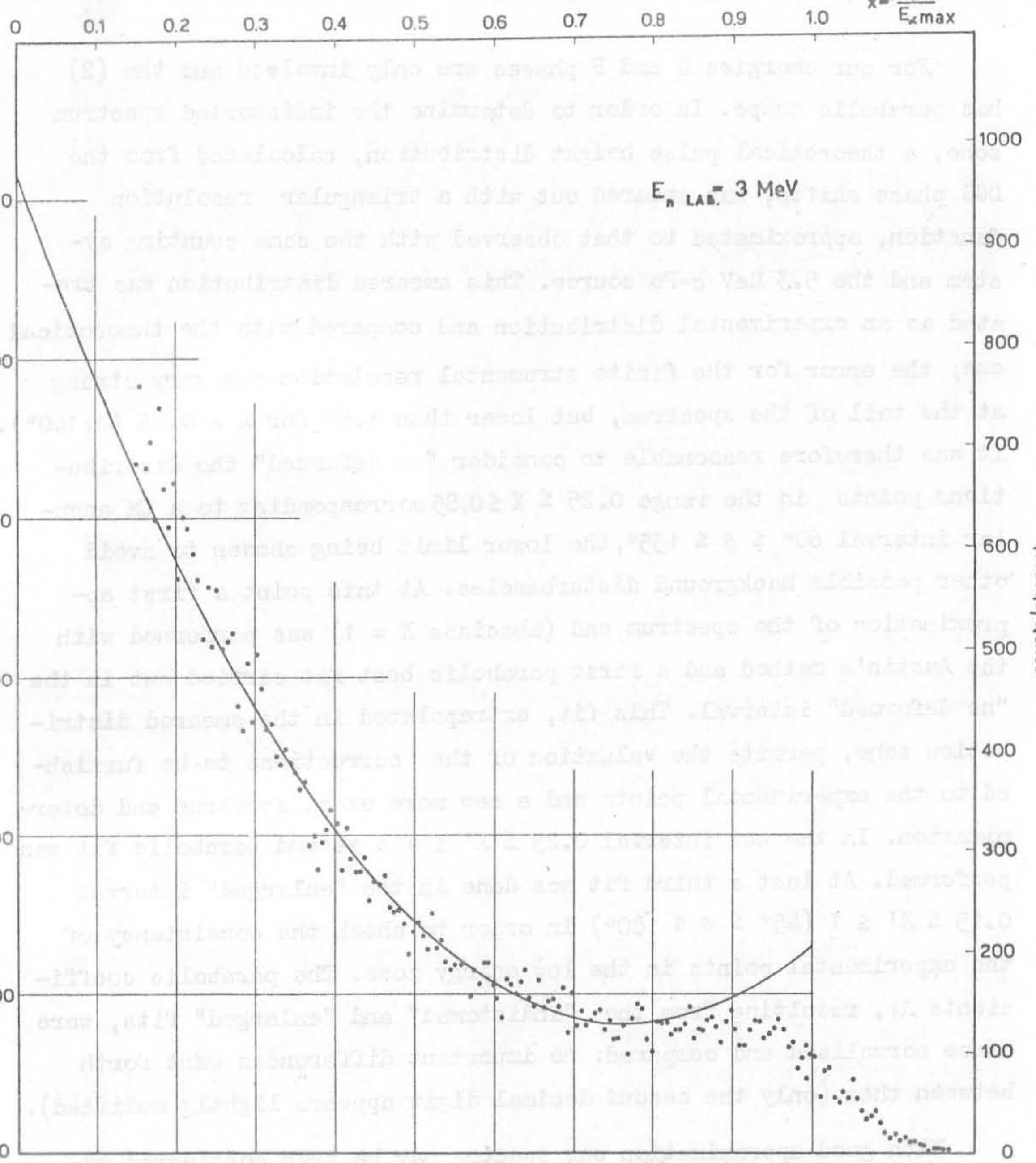

Fig. 2 - Neutron-He^4 differential cross-sections vs. cos ϑ_{CM} at E_n = 3 MeV. The continuous line is the experimental points (°) fitting parabola.

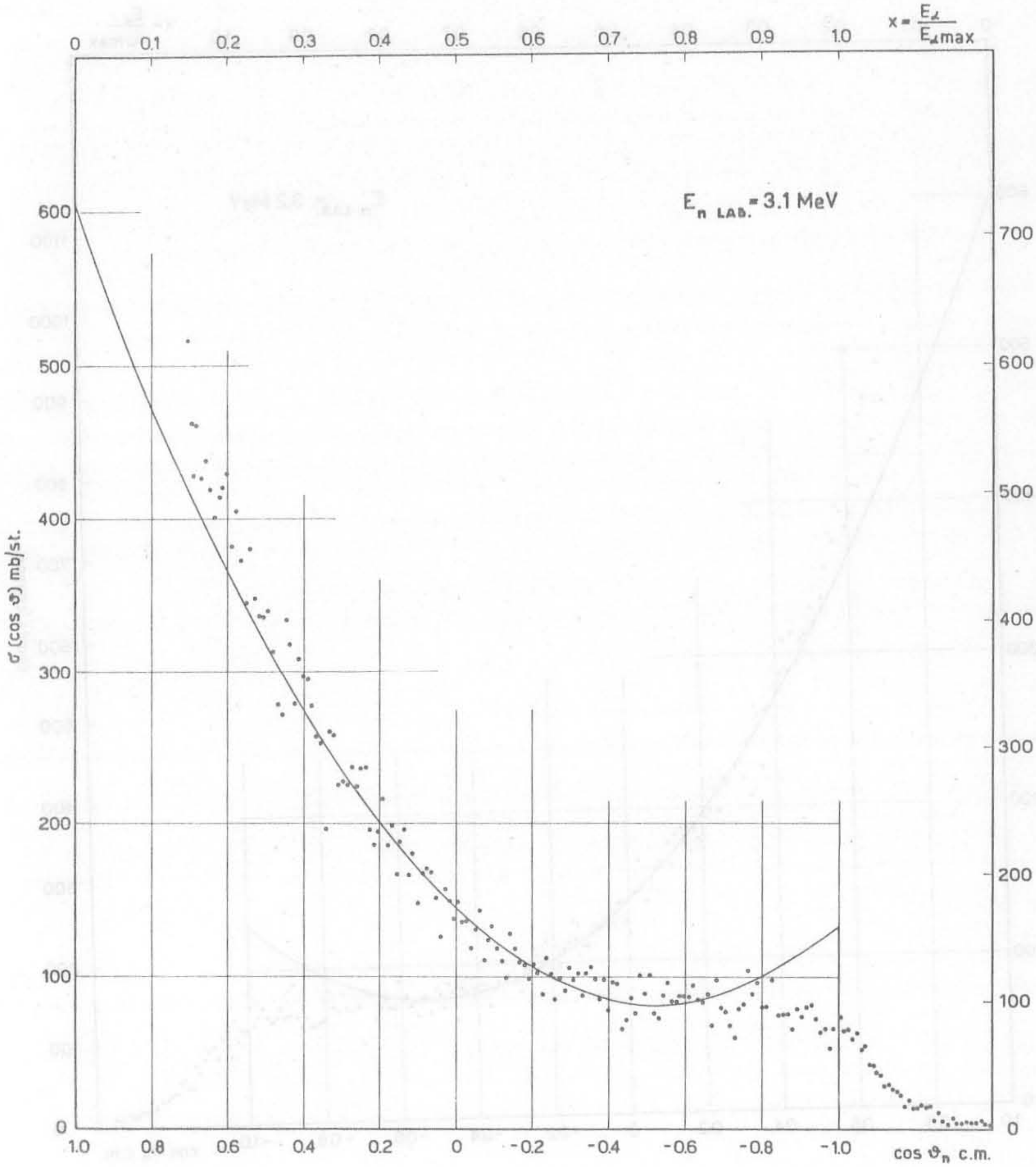

Fig. 3 - Neutron-He^4 differential cross-sections vs. cos ϑ_{CM} at $E_n = 3.1$ MeV. The continuous line is the experimental points (°) fitting parabola.

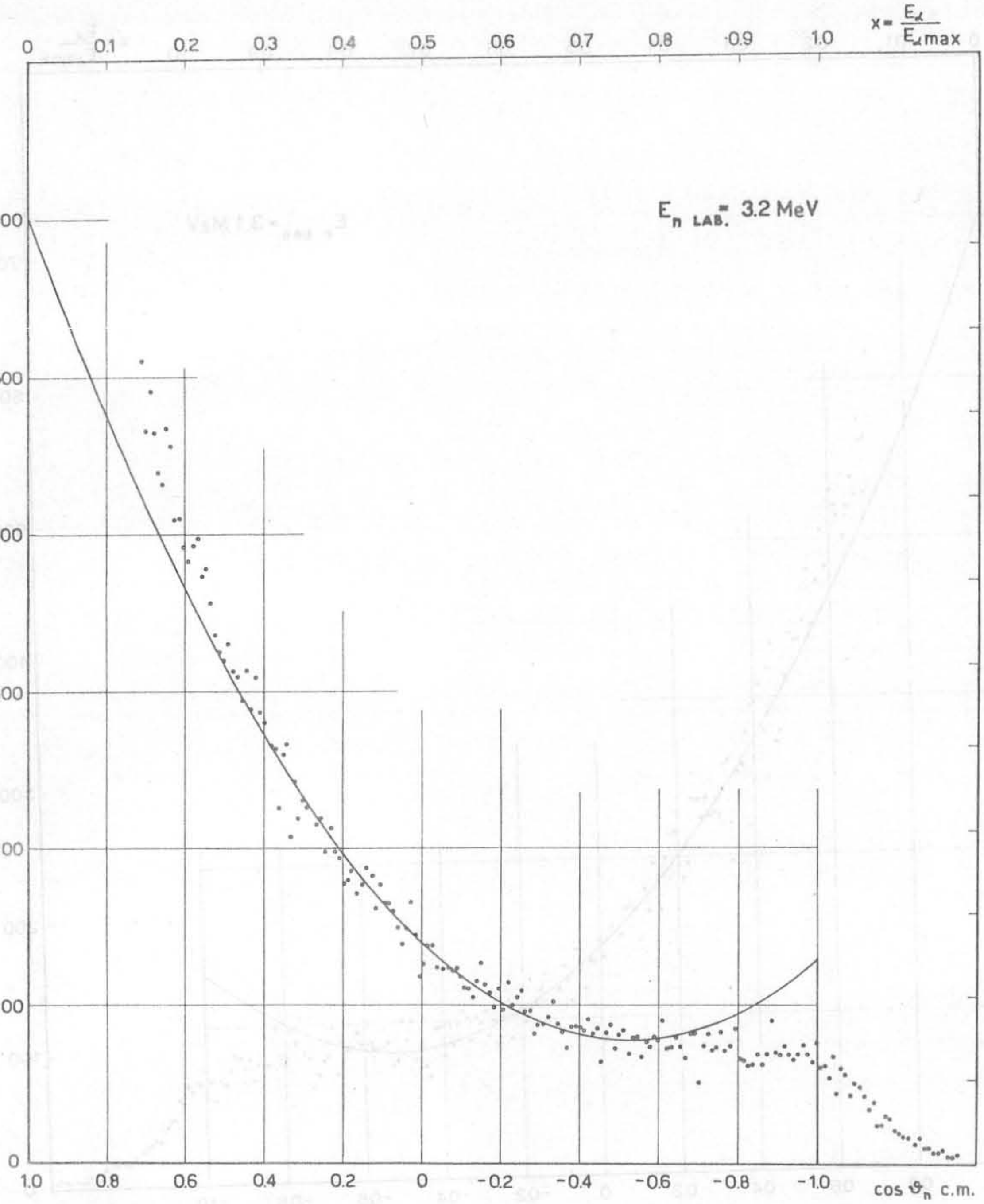

Fig. 4 - Neutron-He[4] differential cross-sections vs. cos ϑ_{CM} at E_n = 3.2 MeV. The continuous line is the experimental points (°) fitting parabola.

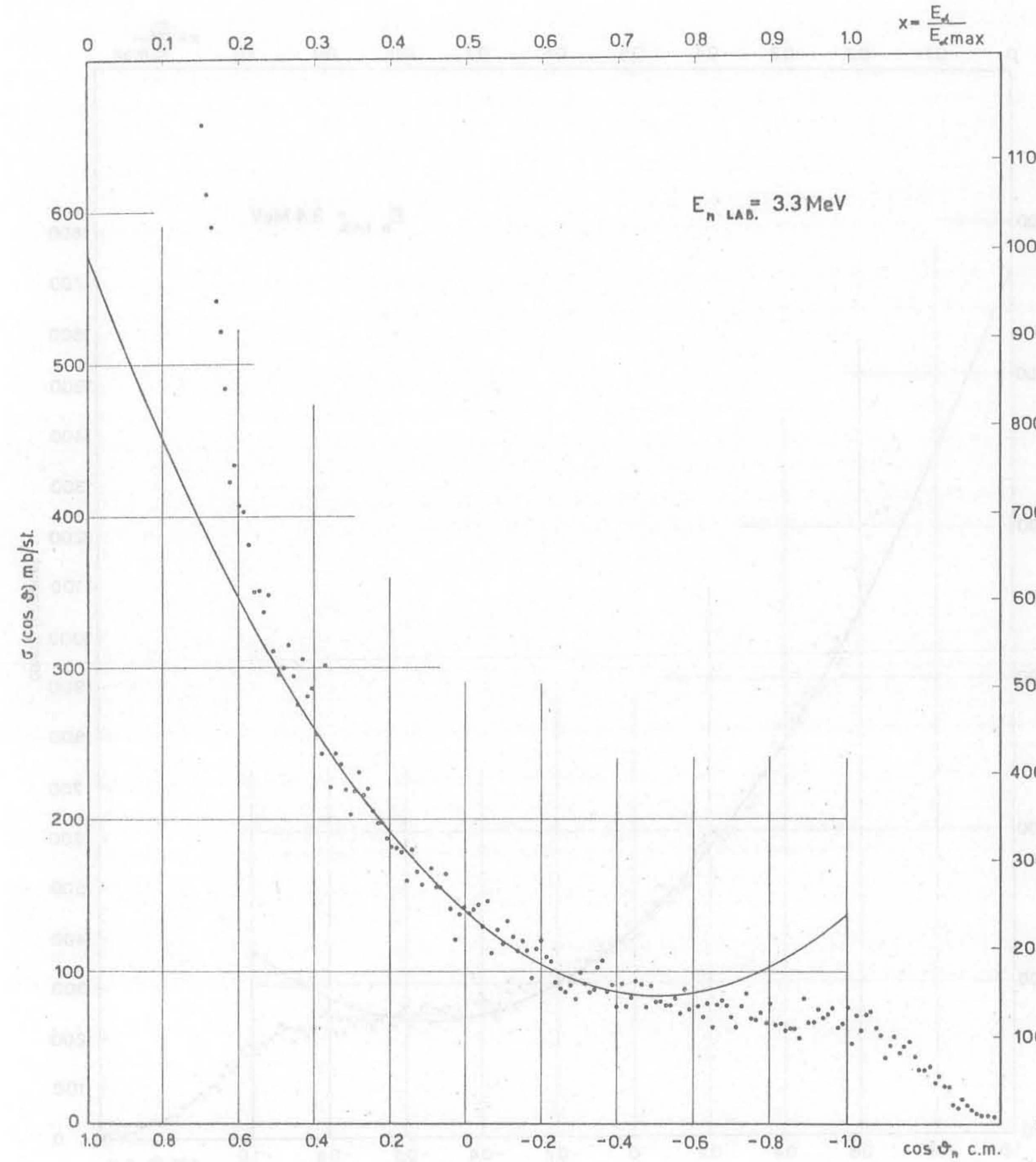

Fig. 5 - Neutron-He^4 differential cross-sections vs. cos ϑ_{CM} at $E_n = 3.3$ MeV. The continuous line is the experimental points (°) fitting parabola.

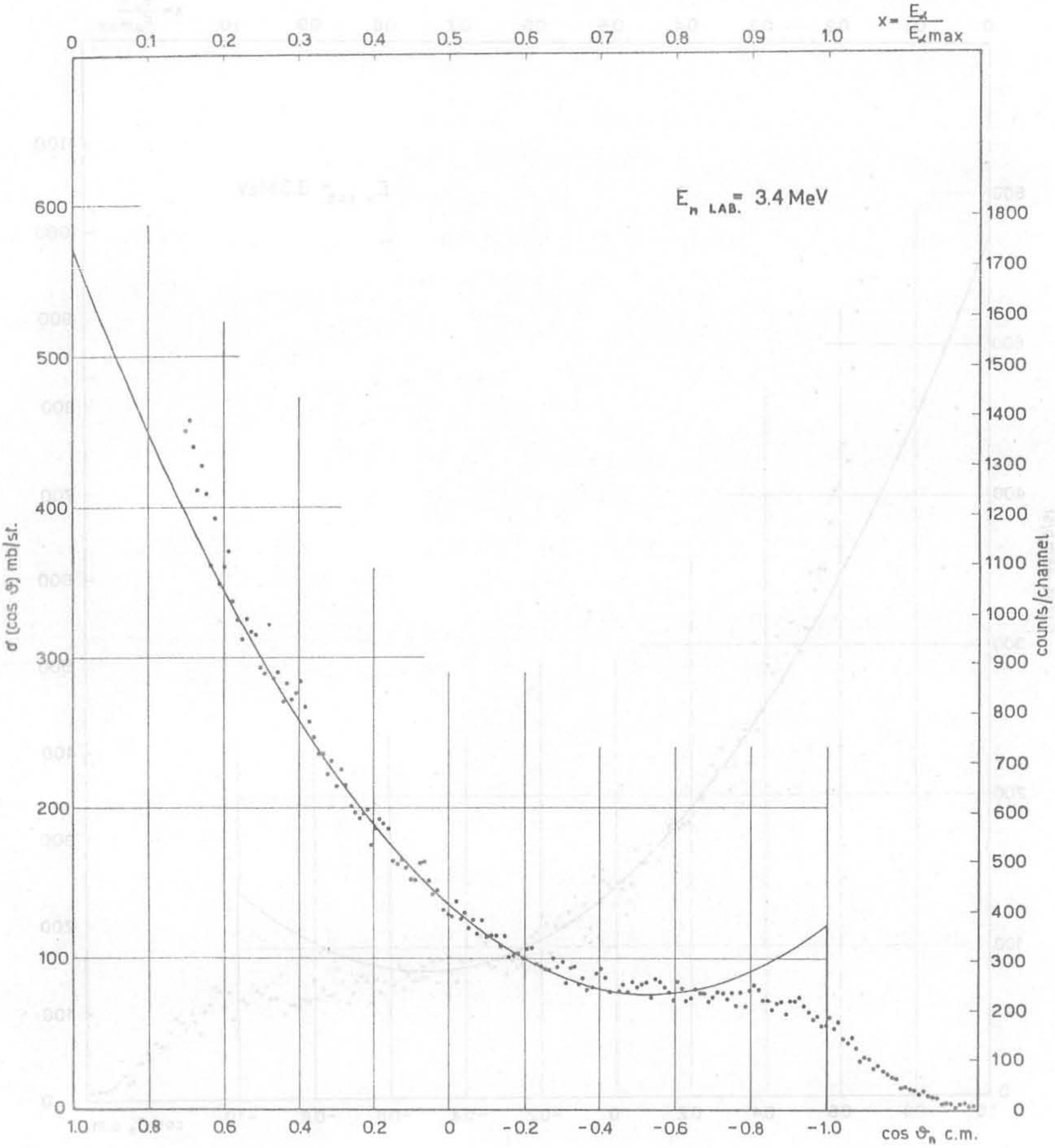

Fig. 6 - Neutron-He^4 differential cross-sections vs. cos ϑ_{CM} at E_n = 3.4 MeV. The continuous line is the experimental points (°) fitting parabola.

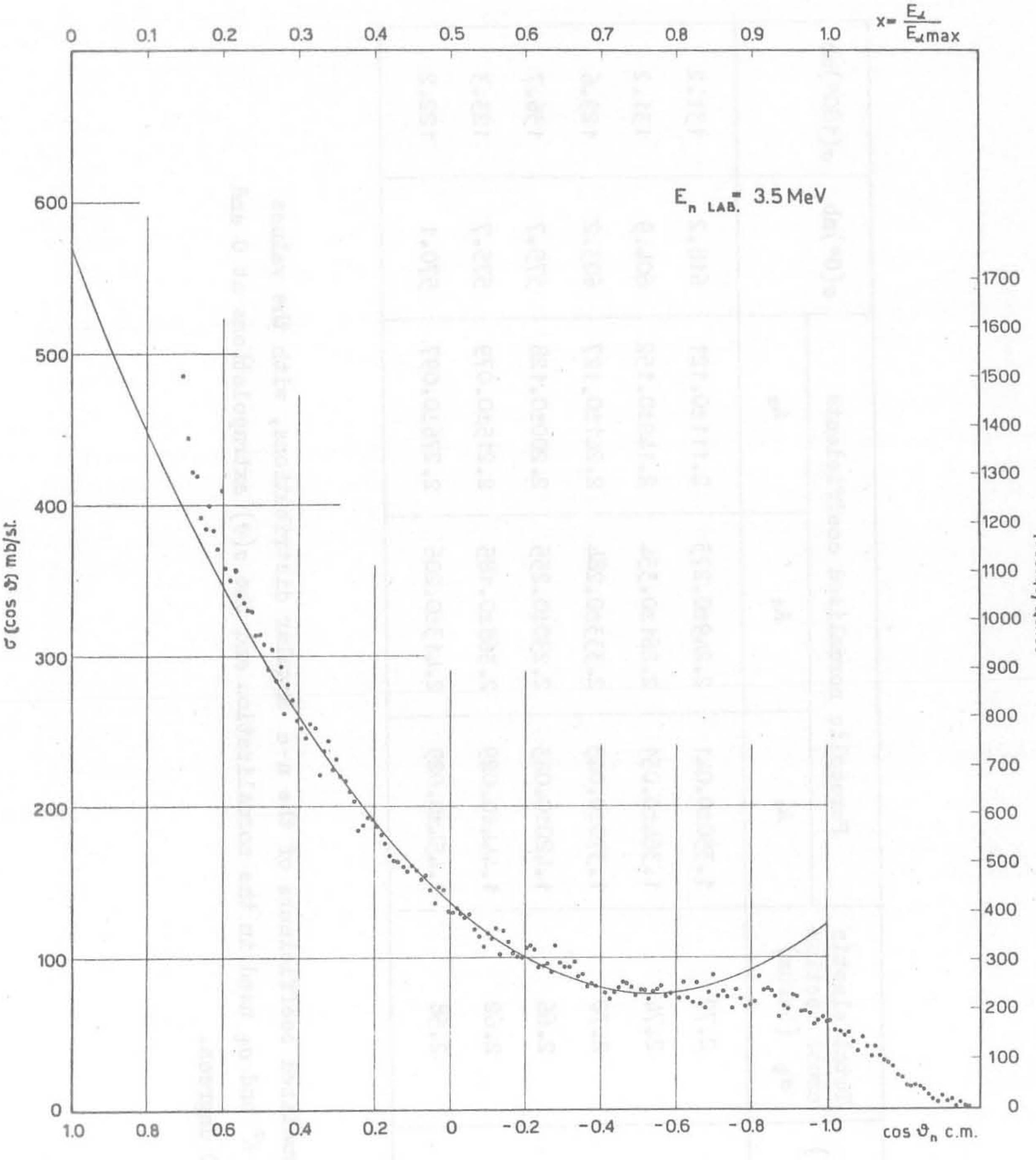

Fig. 7 - Neutron He^4 differential cross-sections vs. cos ϑ_{CM} at E_n = 3.5 MeV. The continuous line is the experimental points (°) fitting parabola.

Neutron Energy E_nLAB (MeV)	K^2 (barns^{-1})	Total elastic cross section σ_t (barns)	Parabolic normalized coefficients			$\sigma(0°)$mb	$\sigma(180°)$mb
			A_0	A_1	A_2		
3	9.237	2.79	1.350±0.041	2.249±0.273	2.111±0.121	618.2	131.2
3.1	9.545	2.74	1.364±0.051	2.261±0.334	2.149±0.152	604.9	131.2
3.2	9.853	2.70	1.370±0.043	2.333±0.284	2.241±0.127	603.2	129.6
3.3	10.160	2.66	1.420±0.043	2.230±0.255	2.200±0.128	575.7	136.7
3.4	10.468	2.62	1.444±0.029	2.368±0.185	2.215±0.079	575.7	123.3
3.5	10.776	2.58	1.454±0.029	2.413±0.206	2.276±0.097	570.1	122.2

Table 1 - Normalized coefficients of the n-α angular distributions, with the values of K^2 and σ_t used in the normalization and the $\sigma(\vartheta)$ extrapolations at 0 and 180 degrees.

From the normalized parabolic coefficients were also derived the S and P phase shifts. The calculations were performed with the IBM 1620 computer of the Centro di Calcolo dell'Università di Trieste, with a program built up by the Pisent's parametrizations ([12]). The deducted phase shifts are summarized in table 2. Figs. 8 - 13 shown finally, versus the CM scattering angle ϑ, the P_{He} analyzing powers of He^4, derived from these phases ([13]). No D phase shifts were take into account in our calculations.

E_{nLAB} (MeV)	$\delta(^\circ)$	$\delta_{3/2}(^\circ)$	$\delta_{1/2}(^\circ)$
3	-44.3	118.2	6.4
3.1	-44.4	117.4	6.6
3.2	-45.2	116.3	4.9
3.3	-44.4	115.3	10.1
3.4	-46.5	115.4	8.7
3.5	-47	114.4	7.8

Table 2 - Phase-shifts (in degrees) deduced from the coefficients of table 1

Discussion and conclusion.

To have obtain in six independent measurements so reproducible phase shift values appears to our opinion very meaningful, the more so as the experiments were performed with a minimum of experimental corrections. It is furthermore notable that our present data agree sufficiently well with those formerly obtained in our Laboratory (3 - 4) by the same counter but quite different geometrical disposal and values treatment. Our parabolas fit very well the corrected experimental points also in the forward angular zone

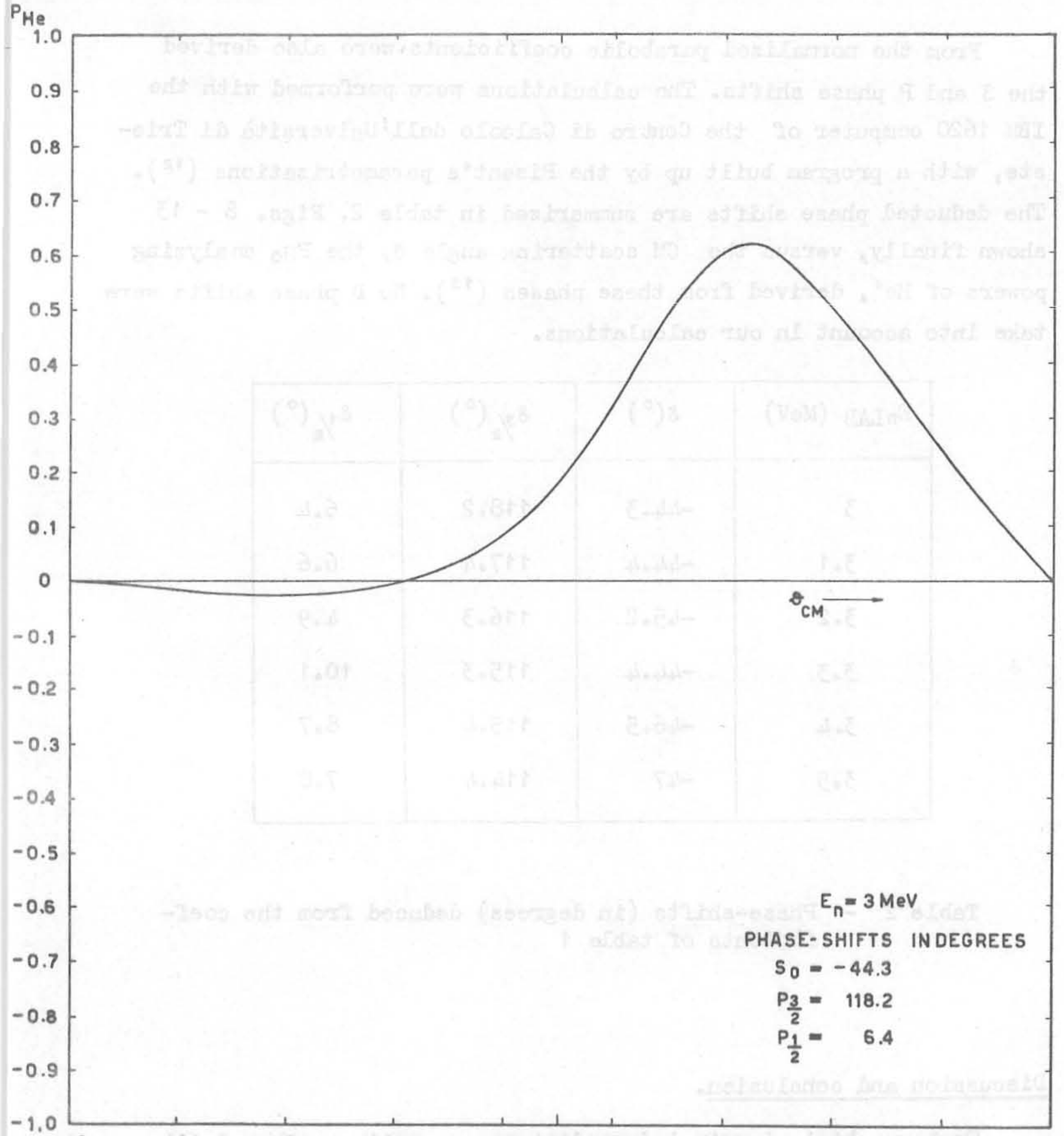

Fig. 8 - Analysing power P_{He} of Helium deduced from phase-shifts at E_n = 3.MeV.

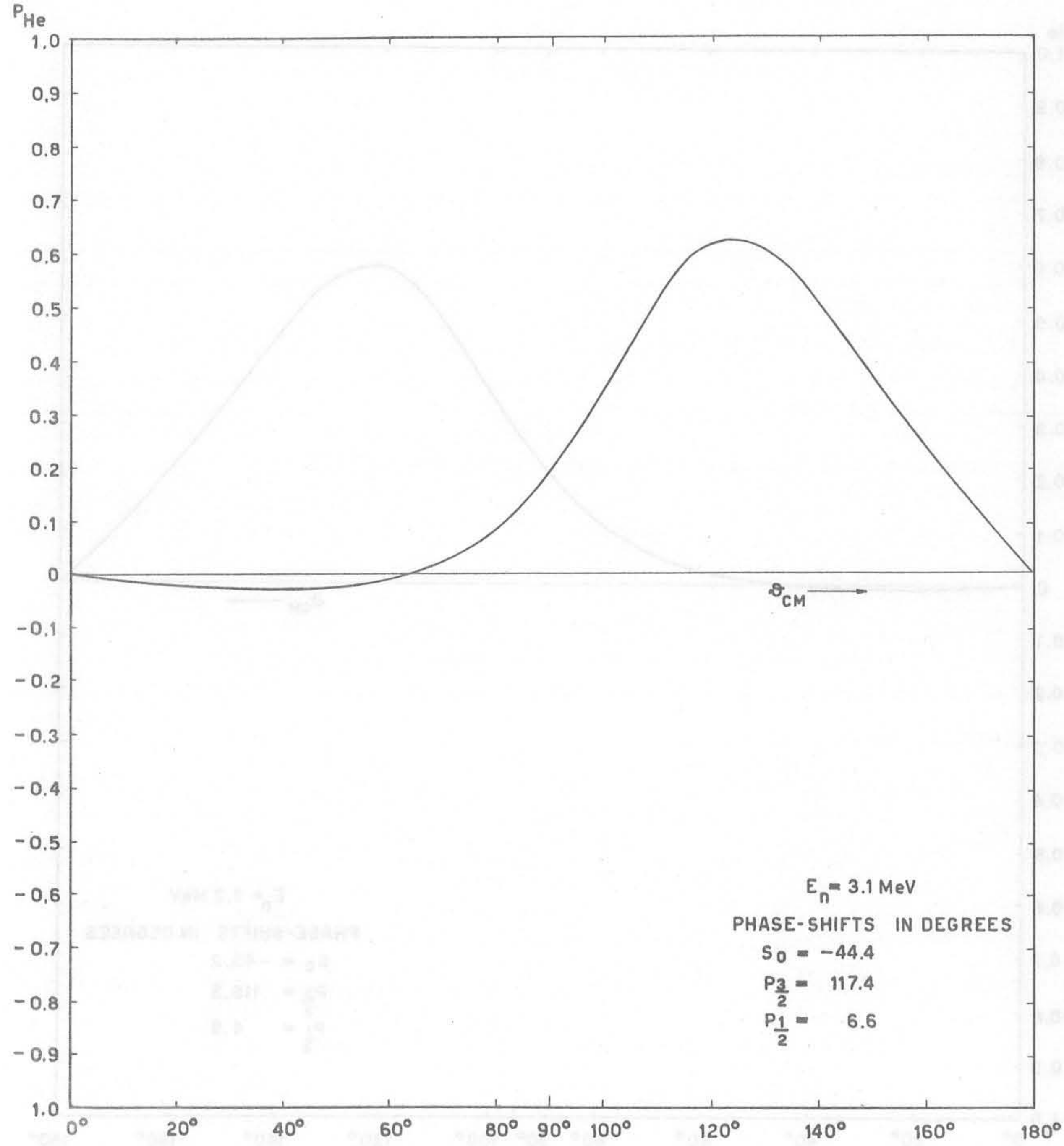

Fig. 9 - Analysing power P_{He} of Helium deduced from phase-shifts at E_n = 3.1 MeV.

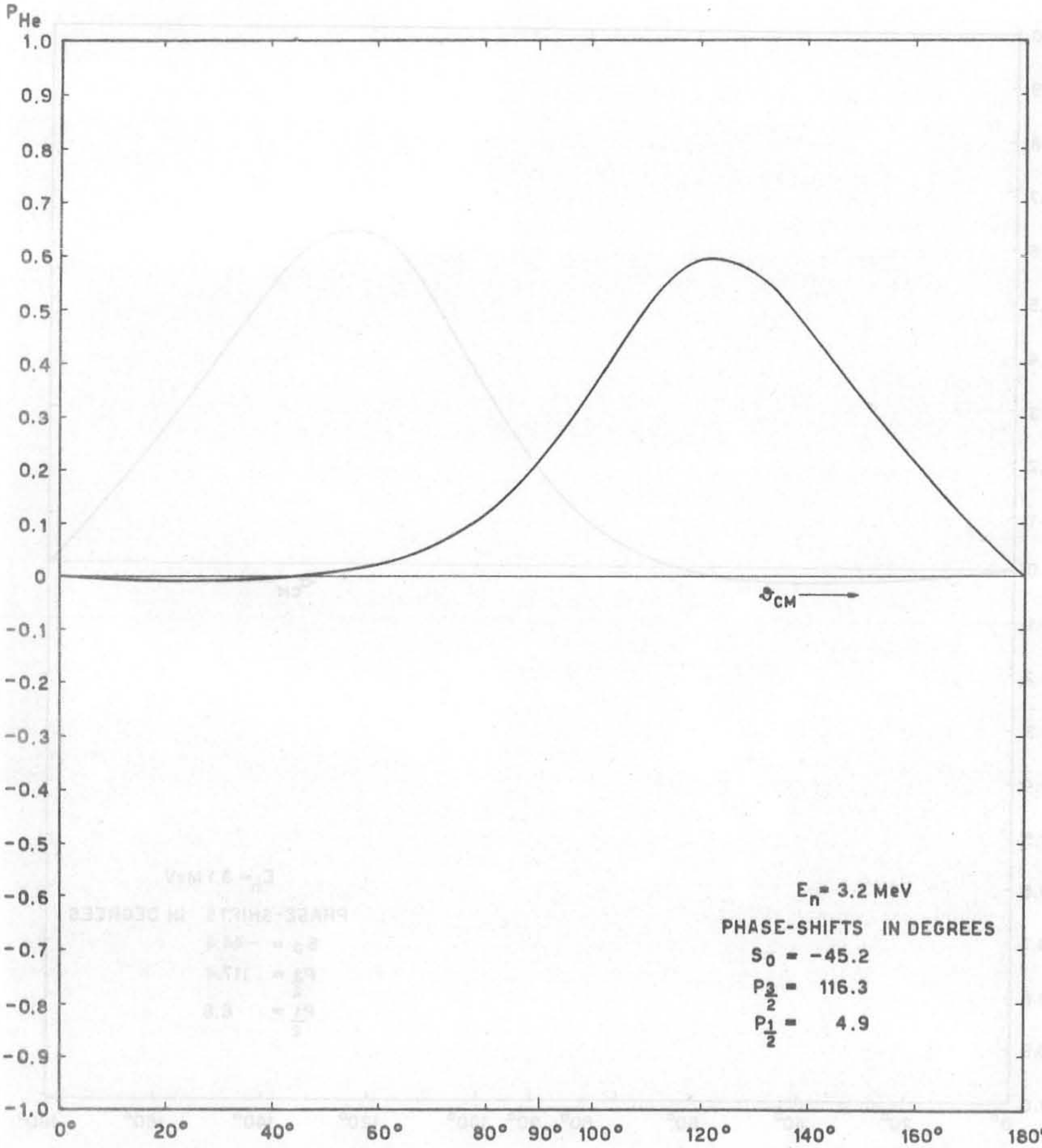

Fig. 10 - Analysing power P_{He} of Helium deduced from phase-shifts at E_n = 3.2 MeV.

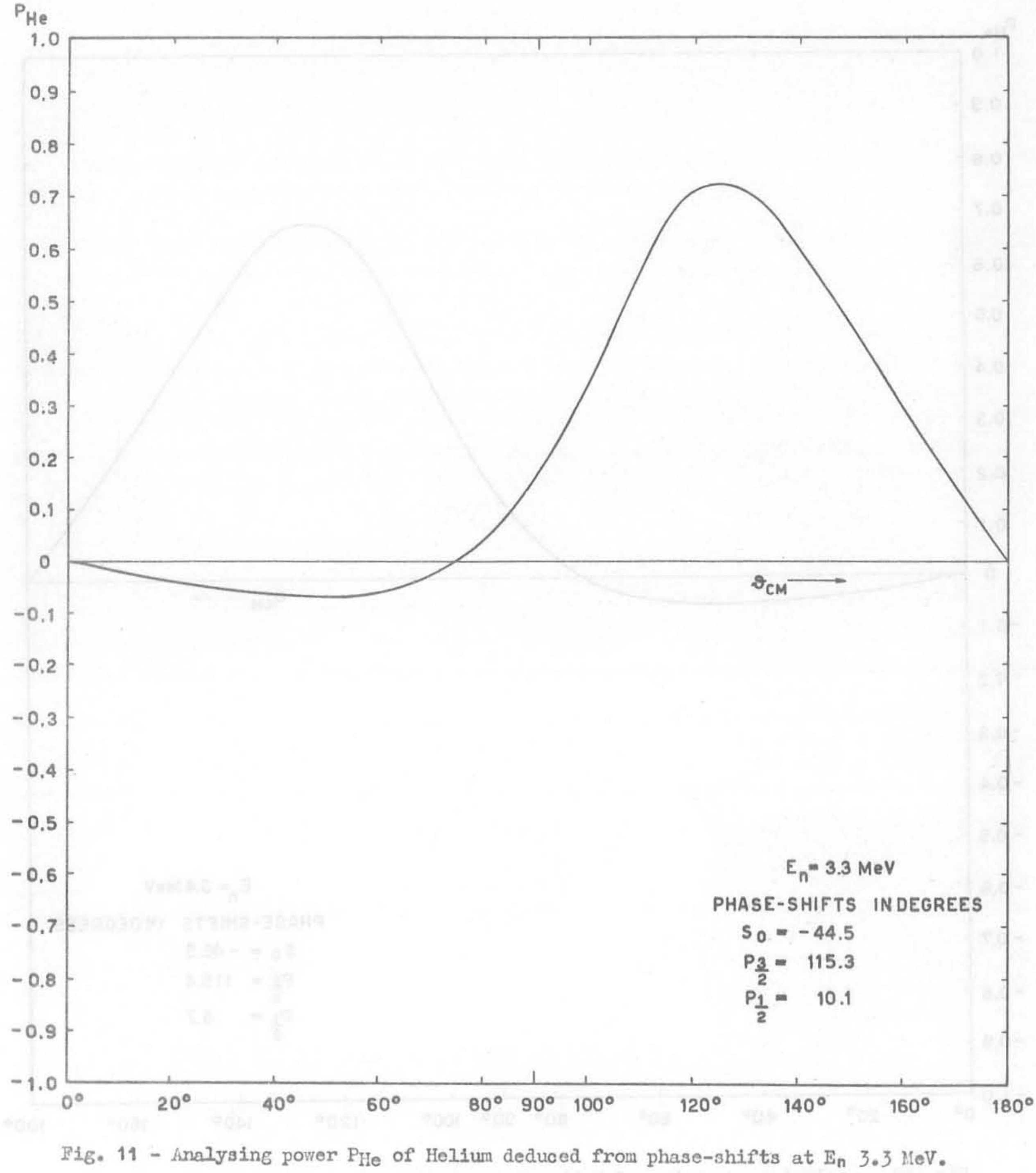

Fig. 11 - Analysing power P_{He} of Helium deduced from phase-shifts at E_n 3.3 MeV.

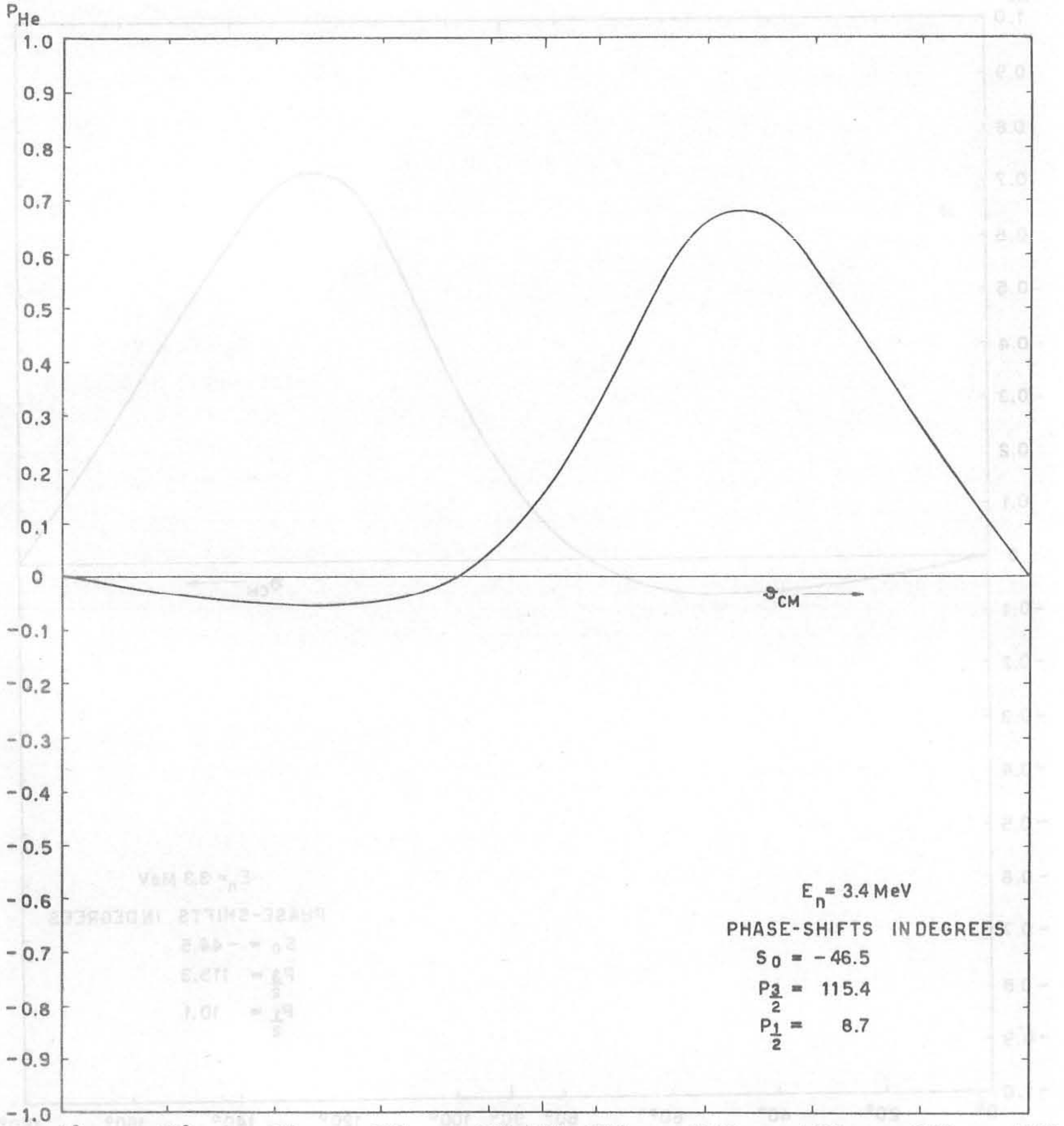

Fig. 12 - Analysing power P_{He} of Helium deduced from phase-shifts at E_n 3.4 MeV.

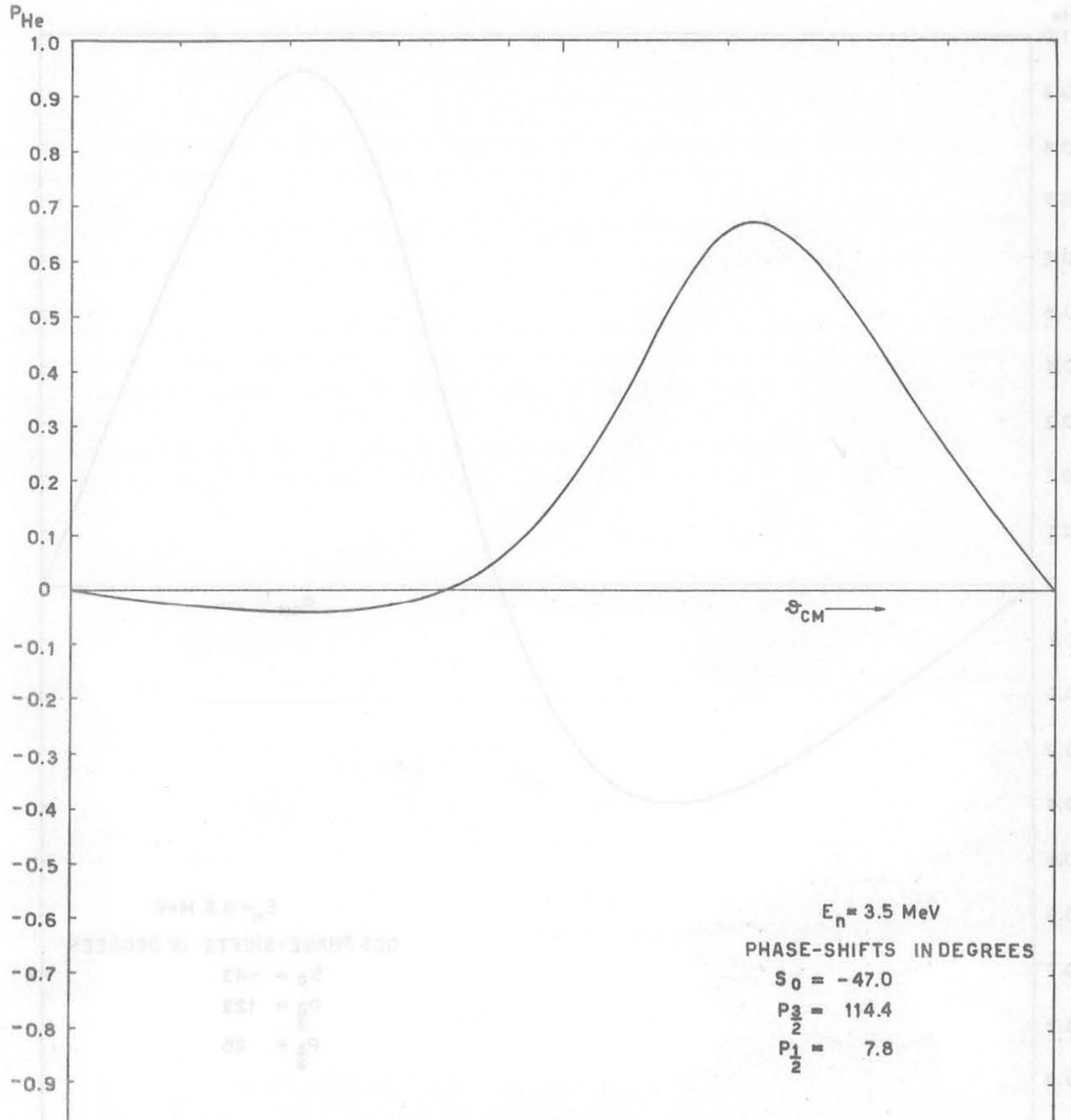

Fig. 13 - Analysing power P_{He} of Helium deduced from phase-shifts at E_n = 3.5 MeV.

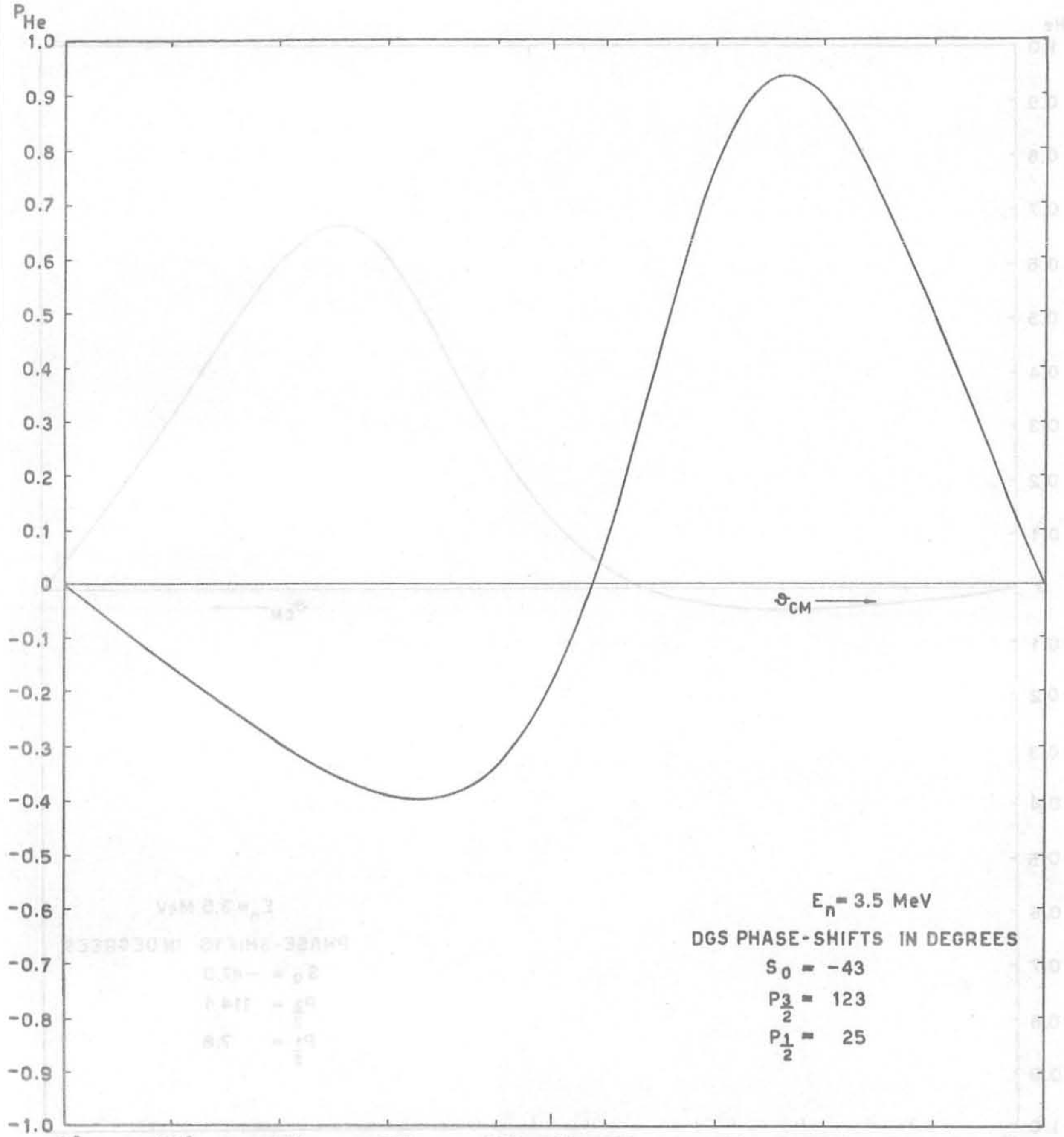

Fig. 14 - Analysing power P_{He} of Helium as deduced from D-G-S phase-shifts extrapolated at 3.5 MeV.

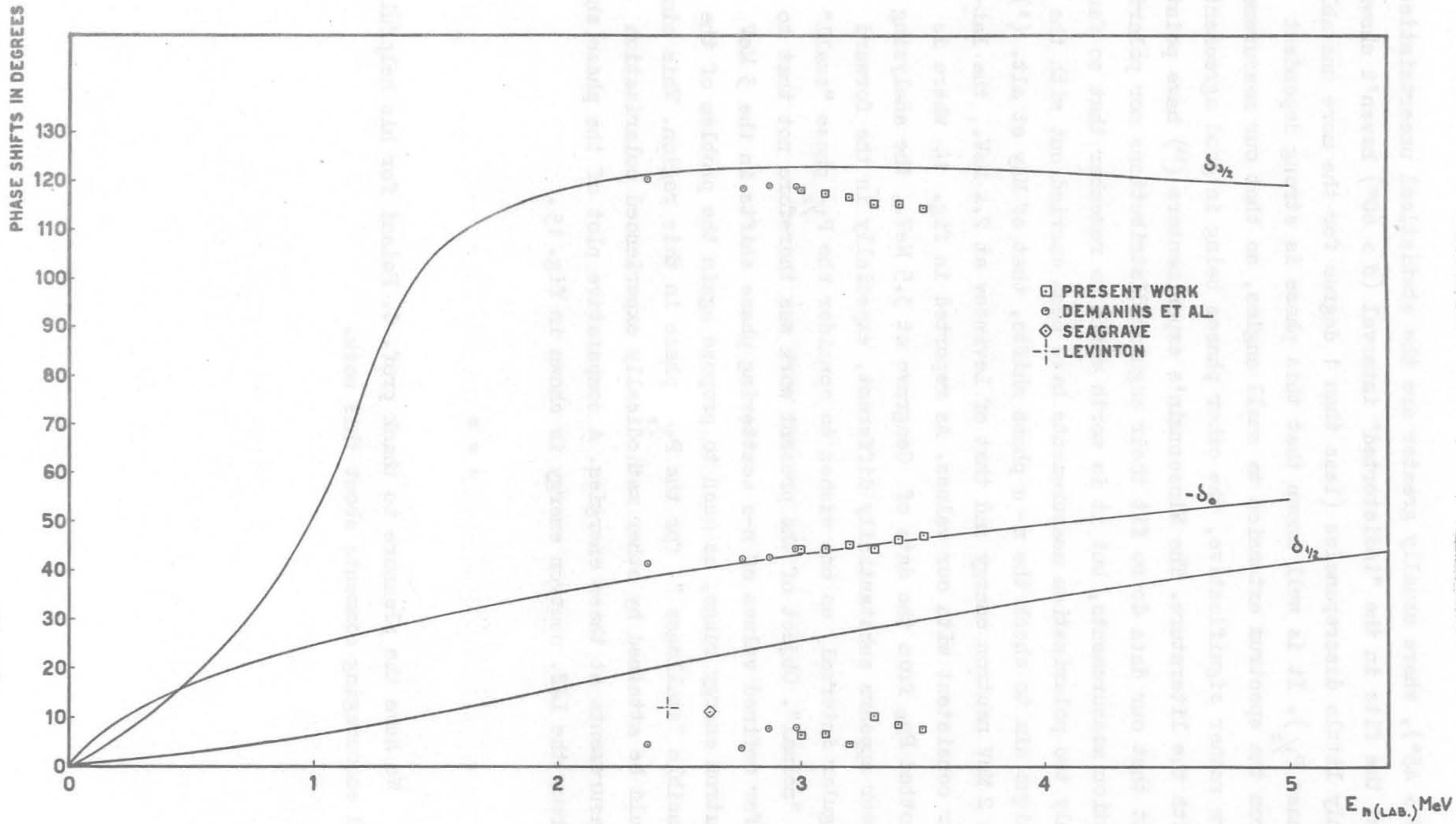

Fig. 15 - Comparative plot of the phase-shift values available in the literature, as a function of the incident neutron LAB-energy. The continuous line is derived from the DGS data; the points are specified in the legend.

($\vartheta > 45°$), where usually greater are the statistical uncertainties, but the fits in the "indistorted" interval ($\vartheta > 60°$) haven't shown only little discrepancies (less than 1 degree for the more unstable phase $P_{1/2}$). It is well known that this phase is strong dependent from the spectrum extension to small angles, so that our measurements are rather significative, the other phases being in good agreement with the literature. The Winsconsin's experimenters [15] have pointed out that our data do no fit their angular distributions nor polarization measurements, but it is worth while to remember that so far only two polarization measurements have been carried out with the unique aim to check the n- α phase shifts, that of May et alt. [1] at 2 MeV neutron energy and that of Levintov at 2.4 MeV., the latter consistent with our values. As reported in fig. 14 where is plotted P_{He} from the data of Seagrave at 3.5 MeV., the analyzing power appears substantially different, expecially in the forward angular interval, as one wishes to consider the $P_{1/2}$ phase "small" or "normal". Object of the present work was therefore not that to offer defined values of n-α scattering phase shifts in the 3 MeV neutron energy range, as much to propose again the problem of the possible "smallness " for the $P_{1/2}$ phase in this region. This aim could be attained by other methodically experienced polarization measurements at these energies. A comparative plot of the phase shifts versus the LAB. neutron energy is shown in fig. 15.

* * *

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