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PROPOSAL

MEASUREMENT OF SPIN DEPENDENT OBSERVABLES IN THE $\bar{p}N$ ELASTIC SCATTERING FROM 300 MeV/c TO 700 MeV/c

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We propose to measure in the post ACOL era $\bar{p}N$ spin observables utilizing a frozen spin target and a high resolution spectrometer. A recoil proton polarimeter together with the spin rotation facility allows a more complete measurement of polarization components in the scattering plane.

I. PHYSICAL MOTIVATION

The first period of the LEAR era is now coming to the end. Meanwhile, one concludes that our knowledge of the $\overline{N}N$ system is still very incomplete. This situation is related to the larger complexity of the $\overline{N}N$ scattering compared to the rather well known NN system. In order to get a feeling of this complexity, let us observe that in the $\overline{N}N$ scattering there is no generalized Pauli principle that excludes in NN for each isospin some partial

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waves. Moreover the phase shifts become complex due to the presence of the strong annihilation. These two features each double the number of required parameters.

New data have been provided by LEAR experiments on the total $\bar{p}p$ cross section[1]), angular distributions of the differential cross sections of $\bar{p}p$ elastic scattering[2]) and charge exchange $\bar{p}p \rightarrow \bar{n}n$ [ref.[3])]. However data on spin dependent observables, that is analysing power, spin rotation parameters etc, are almost inexistent.

An additional difficulty to provide data on spin observables is due to the lack of $\bar{p}$ polarized beams and to the fact that the very low value of $\bar{p}C$ analysing power[4]) prevents the measurement of the polarization of the scattered $\bar{p}$. This excludes two tools that have been essential to determine spin dependent observables in the NN system. A different approach is therefore needed in order to provide the required data. It is the aim of this proposal to present a method to measure spin observables in the $\bar{p}N$ elastic scattering uitlizing a polarized target, a spin rotation device and a proton recoil polarimeter. This will be discuss in section 2, but first let us resume the present status of the understanding in order to define the energy and angular domain to be measured.

The theoretical approach to $\bar{N}N$ scattering is mainly based on potential models. The first ingredient of this theoretical description is a form of theoretical NN potential based on meson exchange which is G-parity transformed to an $\bar{N}N$ potential. This G-parity transformation reverses the signs of the potential contributions of the odd G-parity meson exchanges. In the NN potentials large cancellations occur between the contributions of different mesons, in the $\bar{N}N$ potentials these cancellations no longer occur[5]) and these potentials are generally more attractive than in NN. Therefore, more partial waves are contributing significantly to the cross sections at low energies. The second ingredient in $\bar{N}N$ models is some kind of annihilation mechanism. The annihilation cross section is large ($\sigma_{an}/\sigma_{el} > 2$), and is responsible for the large imaginary part of the potential. Several different approaches exist for describing the annihilation : one may apply a suitable boundary condition[6]), use an optical potential[7,8]) or do an actual coupled-channel calculation[9]). All these approaches fit reasonably well the existing data on the spin integrated cross sections. For the spin dependent observables the predictions depend consistently on the theoretical inputs.

Predictions for the polarization $P(\theta)$ in $\bar{p}p$ elastic scattering exist :

a) in the optical potential approach with two sets of parameters (model I and II) for the annihilation potential, assumed to be spin, isospin and energy independent, in ref. 10 (fig. 1) ;

b) in the optical potential approach but with an annihilation potential dependent on the state (spin and isospin) and the energy[8]) and with a different cut-off radius (fig. 2) ;

c) in the coupled channel approach (fig. 3) all these calculations predict sizeable amount of polarization and a strong angular dependence, that could be roughly related to the potential in the following way : forward angles are more sensitive to the long range part of the potential backward angles to the short range part. Therefore we plan to measure the angular distribution of $P(\theta)$ in the full $\theta_{c.m.}$ range.

The energy dependence of $P(\theta)$ has also been computed as a function of the energy in ref. 10 (fig. 4). A strong energy dependence for $P(\theta)$ is predicted that we plan to check measuring 5 energies corresponding to the $\bar{p}$ momenta 300, 400, 500, 600, 700 MeV/c. The measurement of the angular distribution of $P(\theta)$ at these 5 energies is the first goal of this proposal. Details and beam requirements, based on the assumption of an antiproton beam intensity of 5×10^5 $\bar{p}$/s, will be discussed in section III.

The second purpose of this proposal is to provide with data the Wolfenstein parameters D, A, A', R and R'. We adopt for these observables the definition given in fig. 5, together with the cartesian frame of the experimental set-up. Here $\vec{k}_i$ and $\vec{k}_f$ (thin arrows) represent the momenta of the incoming $\bar{p}$ and the recoil proton, the large arrows are the spin orientation of the polarized target and of the recoil proton, the x and z axis are, in the scattering x plane, perpendicular and parallel to $\vec{k}_i$, the y axis (circle) is normal to the scattering plane and with the orientation of ref. 13.

The determination of D will be directly obtained with our set-up, whereas, because of the spin rotation in the magnetic field of the spectrometer, we will get four linear combinations of A, A' and R, R', that need as an input the knowledge of $P(\theta)$. Predictions [10]) for R are given in fig. 6. These measurements require the proton recoil polarimeter (see section II) and therefore a second scattering on the C analyser. Because of that they will be more time consuming and typical of the post ACOL era, for when we assume beam intensity of 5×10^6 $\bar{p}$/s. We don't feel reasonable to plan so extensive measurements as in the $P(\theta)$ case and we plan to adopt the following strategy, based on a permanent feedback with the theory. Depending on the agreement between the first results obtained and the theoretical predictions we will choose the observables more sensitive to some theoretical inputs, check the agreement and so on. Because of that we do not present at this moment a beam time request for this part of the proposal.

Last but not least, we could also provide measurements for $P(\theta)$ in the $\overline{p}n$ elastic scattering replacing the hydrogen content of the polarized target (see section II) with deuterium. This experiment is very important as it selects the I=1 state in $\overline{N}N$ scattering. However it appears more difficult because of the lower polarization of the target $P_T < .40$, and of the Fermi motion in the deuterate target. Therefore it will be our third priority. Predictions^{10}) for $P(\theta)$ in $\overline{p}n$ scattering are shown in fig. 7.

In our previous proposal^{14}) to measure $P(\theta)$ in $\overline{p}p$ elastic scattering our main goal was the search for the S meson. This is not any more our purpose. However broad resonance are also predicted by potential models^{15}). The inspection of fig. 8 shows that the momentum bins (100 MeV/c) proposed for the measurement of $P(\theta)$ in $\overline{p}p$ elastic scattering correspond to 20 MeV in the C.M. system. Therefore the information if broad resonances exist or not in the $\overline{p}p$ system could be a secondary output of our proposal.

II. EXPERIMENTAL METHOD

Before describing the proposed experimental set-up let us first develop some arguments that have motivated our choices. As already mentioned, some symmetries, valid in the pp elastic scattering, no more occur in the pp elastic scattering. Therefore the full angular range $0 \leq \theta_{cm} \leq 180°$ has to be studied. An inspection of the kinematics shows that for each laboratory angle there are two solutions : one for each kind of particles ($\overline{p}$ or p). This implies particle identification. Moreover, as we are in the low energy region, energy loss and straggling, Coulomb multiple scattering and annihilation in the target, strongly limitate the maximum target thickness (for example 7 mm. of liquid H_2 in ref. 16). The situation is even more involved if one needs a polarized target. For example if the polarized material is propanediol $[C_3H_6(OH)_2]$ or butanol $[C_4H_9(OH)]$ the $\overline{p}p$ elastic scattering has to be selected from the reaction channels on the nuclear content of the target. In order to give an idea of what could be an experimental spectrum we show in fig. 9 the proton spectrum measured ^{17}) at $\theta_{c.m.} = 180°$ with a CH_2 target at $T_{\overline{p}} = 176.5$ MeV. All these factors strongly limitate, unlikely in the pp case, the angular range obtainable in coincidence experiments and even make hopeless, in the energy domain of this proposal, the measurement if thick polarized target are utilized (3 cm or so).

The best way to identify antiprotons (protons) and to select the proper reaction channel is to measure accurately their angle and their momentum with a magnetic field. This can be done with the proposed set-up illustrated in fig. 10. It consists of :

a) The SPES II spectrometer,
b) a frozen spin polarized target and
c) a proton recoil polarimeter.

a) The SPES II spectrometer

The SPES II spectrometer has operated successfully at CERN since many years and produced large amount of data both on hypernuçlei production and $\bar{p}p$ and $\bar{p}d$ reactions at the P.S. [ref.18)] and in $\bar{p}$-nucleus scattering19) at LEAR. Only two major modifications will be introduced in the set-up utilized in ref. 19 : a new target box ② to receive the polarized target ④ and a monitor counter ③ to check continously the thickness of the target content (fig. 10). The antiproton flux will be measured with counters ①. In the $\bar{p}p$ elastic scattering for the measurement of $P(\theta)$ we will detect $\bar{p}(p)$ in the angular domain $0 < \theta_L < 45°$, corresponding to the forward (backward) $\theta_{C.M.}$ domain. In such a way we will detect always the particle, that has the highest energy and limitates therefore energy straggling and multiple scattering effects. The target thickness (3 mm at 300 MeV/c has been so chosen that the energy resolution on the missing mass spectrum will always be lower than 2 MeV. Energy resolution is an important parameter to select good events ($\bar{p}p$) from target contaminations ($\bar{p}$ nucleus reactions). Assuming an energy resolution of 2 MeV we have estimated the spectrum contamination from $\bar{p}A$ events taking the cross section values of ref.[14] and found them to be always less than 1 % when $\bar{p}$ are detected. When protons are detected the ratio peak over background will be about ten in the worst case. See for example fig. 9 (in our case the energy resolution will be about three times bet- ter and therefore the peak over background ratio about three times larger).

For the measurement of D, A, A', R and R' only protons will be detected (angular domain accessible $0 < \theta_L < 50°$) and the recoil polarimeter, sketched in fig. 10, added behind the M.W.P. chambers ⑥.

b) The polarized proton target

For the polarized proton target we intend to use a frozen spin configuration the development of this set-up is based on the long experience with polarized targets at SIN[20]). The 2.5 T magnetic field needed to polarize the protons is produced by a superconducting split coil magnet. Due to the conduction cooling of the magnetic coils it is possible to supply a vertical or horizontal field. This fact enables us to get all proton spin directions needed for the proposed experiment. For the set up with a vertical field there are no restrictions on the angles of the scattered or recoil particles. The restrictions in the case of the horizontal field configuration are small due to the optimized geometry of the coils. The accessible θ region is 272° over 360°, $\Delta\phi = \pm 20°$. The homogeneity of the field is 1 part in 10^4 over a spherical volume with a diameter of 2.5 cm. Therefore we can vary the thickness of the target between 3 mm and 20 mm. For the target material we use butanol or propanediol. The dynamical enhancement of the proton polarization and the NMR readout of the polarization signal has been realized with the standard technology developed at SIN. These systems operated successfully over many years[21]). The proton polarization is determined by comparing the dynamic polarization signal with the natural polarization signal at thermal equilibrium[21]). Using this set-up we can obtain proton polarization of at least 80 %. To decrease the influence of the magnetic field on the trajectories of the incoming and outgoing particles we shall lower the magnetic field of the target to 0.35 T. This is achieved with the target in the frozen spin mode. The individual components of the target arrangement have been tested successfully[22]). With this set up it is also possible to polarize deuterons.

c) The recoil polarimeter

This device will be utilized for the measurement of D, A, A', R, R'. When protons are detected, we measure their polarization putting on the focal plane of SPES II the polarimeter, sketched on the left side of the fig. 10. Then, the protons, scattered by the carbon analyser C, are detected by the multiwire proportional chambers W_1 and W_2 and the scintillators S. By track reconstruction we can obtain the polar (θ) and azimuthal (ϕ) angles. The intensity distribution of the scattered events $W(\theta,\phi)$ is related to the polarization components of the proton along the axis $x''(P_{x''})$ and $y''(P_{y''})$ through the relation[23])

$$W(\theta,\phi) = \frac{d\sigma}{d\Omega} \left[1 + P_{y''} A_c(\theta) \cos\phi - P_{x''} A_c(\theta) \sin\phi \right] D(\theta,\phi)$$

where $D(\theta,\phi)$ is the polarimeter efficiency and $A_c(\theta)$ the carbon analysing power. Unlikely in the $\bar{p}C$ scattering, in the pC scattering $A_c(\theta)$ is large enough (see fig. 11) to measure the proton polarization as it has been shown in many experiments[24-26]). Such a polarimeter is presentely constructed at L.N.S. ; tests and calibrations will begin in the next December. The efficiency $D(\theta,\phi)$, that is the relative number of protons scattered by C in the angular range useful for the polarization measurement, is expected to assume values ranging from 10^{-3} to 10^{-1} depending on the proton energy and C analyser thickness[24,25]).

The spin of the scattered proton (from $\bar{p}p$), if oriented in the scattering plane, is rotated by the magnetic field of SPES II by an angle δ relative to the particle momentum given by

$$\delta = \gamma \left(g/2 - 1\right) \alpha$$

Where γ is the Lorentz factor, $g/2$ is the magnetic moment of the proton and α is the bending angle of SPES II (about 104°). This is a very interesting feature as it allows the measurement of spin components, oriented longitudinally (z axis) before precession.

Knowledge of A and R require measurements of the spin transverse components ; R' and A' require the measurement of the spin components originally oriented along the scattered particle ($\bar{p}p$) direction of motion.

Because of the recoil of the focal plane with kinematics and because the proton energy decreases to too low values, only lab. angles $0 < \theta_L < 50$ can be measured corresponding to the backward $\theta_{c.m.}$ region ($\bar{p}p$).

III. BEAM TIME REQUIREMENTS

As already mentioned we present here only the beam time request for the measurement of $P(\theta)$ in $\bar{p}p$ elastic scattering.

We do assume that the beam intensity will be 5×10^5 $\bar{p}$/s and take the values of differential cross sections given in refs. 16, 27.

The total elastic cross sections do not change significantly between 300 and 700 MeV/c (less than a factor of two)[27]).

If the beam time schedule is so made that the beam time periods allowed for each energy are spaced by few days we can adapt the target thickness in order to compensate the cross section decrease. In fact between 300 MeV/c where we take, to get a convenient energy resolution, a target thickness of 3 mm and 700 MeV/c the energy loss in the target decreases by about a factor of three. Energy loss in the target is the main cause of the degradation of the energy resolution in a high resolution spectrometer. Therefore target thickness can be increased proportionally to the energy loss decrease without affecting the overall energy resolution ($\leqslant$ 2 MeV).

The angular acceptance of SPES II is ± 3°, the solid angle 20 msr.

We plan to measure 14 angles in the angular range $15° \leqslant \theta_{c.m.} \leqslant 170°$ including a double measurement around $\theta_{c.m.} = 90°$, one detecting $\bar{p}$ and another one detecting p, in order to check the consistency between the two parts of the angular distribution. We estimate that to get a statistical significance of 3-4 per cent we need a one day of beam time for each target spin state, that is two days for a full angular distribution at each energy. Few hours are needed to flip the spin of the polarized target. Including set-up of the experiment and eventual repolarizations of the target we estimate the total amount of beam needed for the full experiment of P(θ) (5 energies) to about 14 days.

Some parasitic beam is needed to set up the experiment. It would be very convenient to have few days of proton beam time in order to calibrate monitors with known cross sections of pp scattering. Please note that good monitoring is important in order to compare angular distributions for each spin state.

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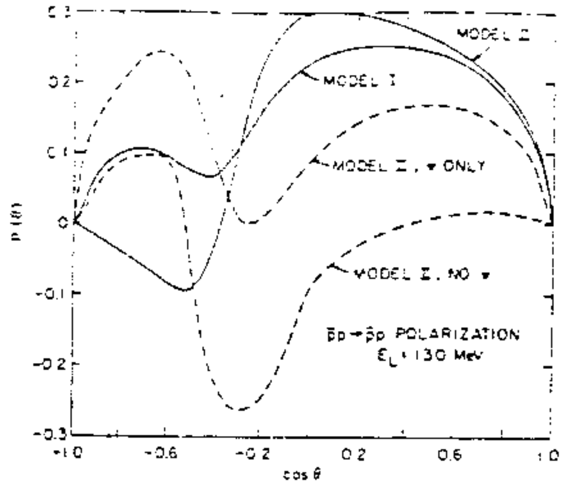

Fig. 1 - Model dependence of the $\overline{p}p \rightarrow \overline{p}p$ elastic polarization P(θ) at 130 MeV. Keeping the meson exchange potential fixed, the two solid curves show the effect of changing the annihilation potential (model I vs model II). For model II, we also show the effect of omitting two and three pion exchanges (π only), or omitting the one pion exchange contribution while retaining heavier meson exchanges (no π).

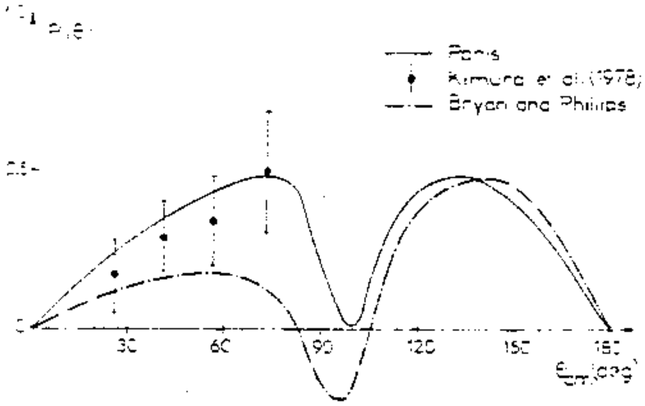

Fig. 2 - $\overline{p}p$ polarization at T_L = 232.25 MeV.

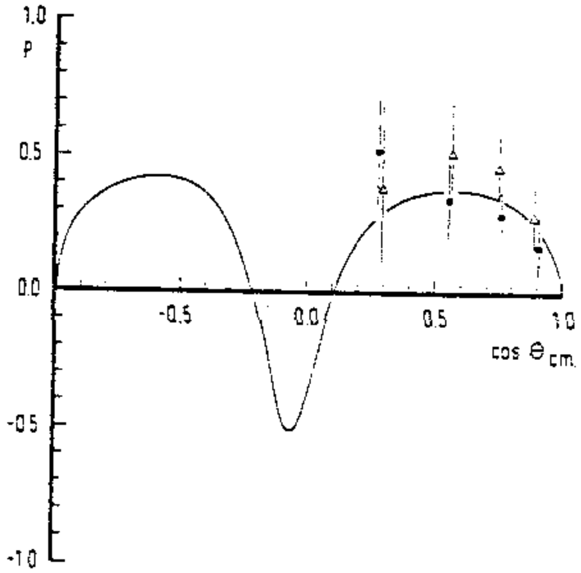

Fig. 3 - $\overline{p}p$ polarization at T_{lab} = 230 MeV. Triangles : Ohsugi et al. (ref. 13). Circles : Kimura et al. (ref. 18). Solid curve : prediction of the model.

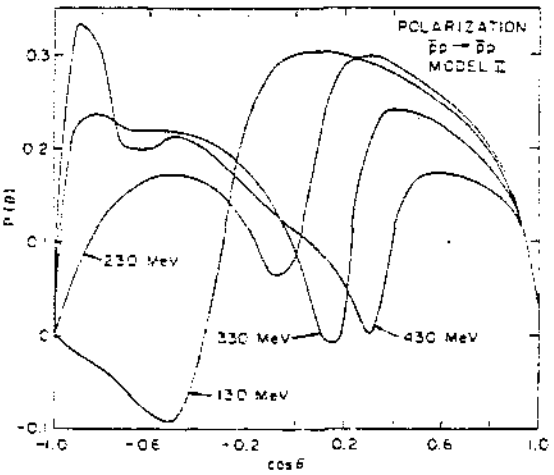

Fig. 4 - Energy dependence of the elastic $\overline{p}p \to \overline{p}p$ polarization in model II. The curves are labelled by the laboratory kinetic energy.

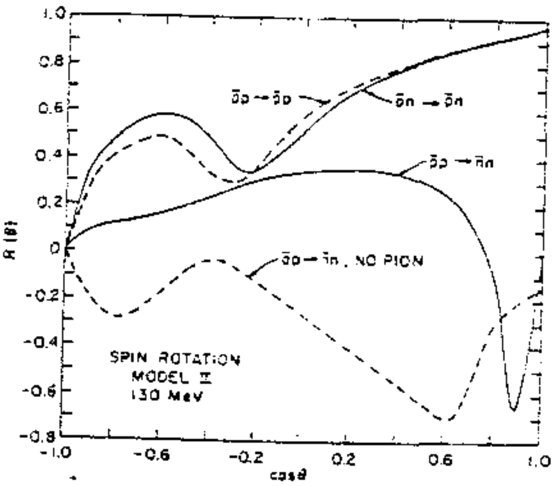

Fig. 6 - Isospin dependence of the spin rotation parameter R(θ) in model II at 130 MeV. For $\overline{p}p \to \overline{n}n$ charge exchange, the influence of the one pion exchange is also shown.

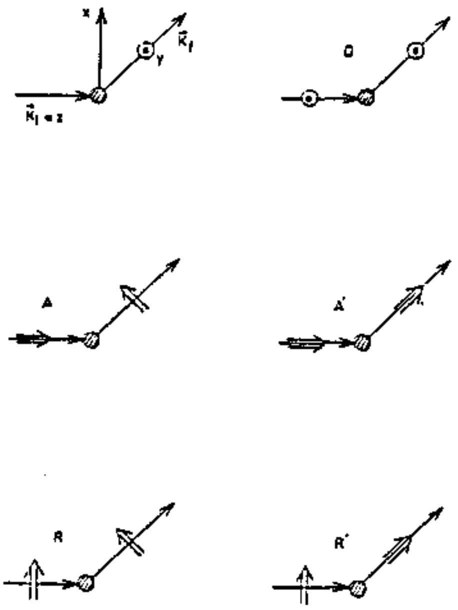

Fig. 5 - Schematic diagram to illustrate the definition of the Wolfenstein parameters.

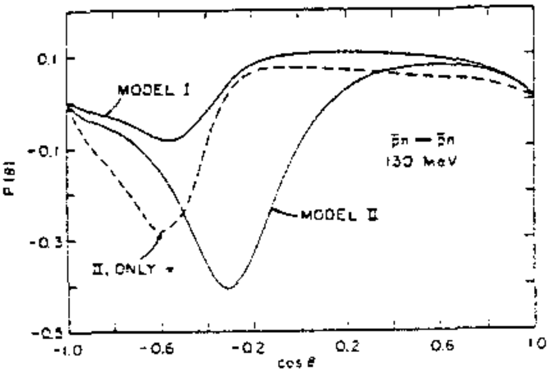

Fig. 7 - Model dépendence of the isospin I=1 polarization ($\overline{p}p \to \overline{p}n$ or $\overline{n}p \to \overline{n}p$) at 130 MeV. The effect of omitting two and three pion exchanges is indicated by the dashed line. The solid curves include the full meson exchange potential, but vary the annihilation potential.

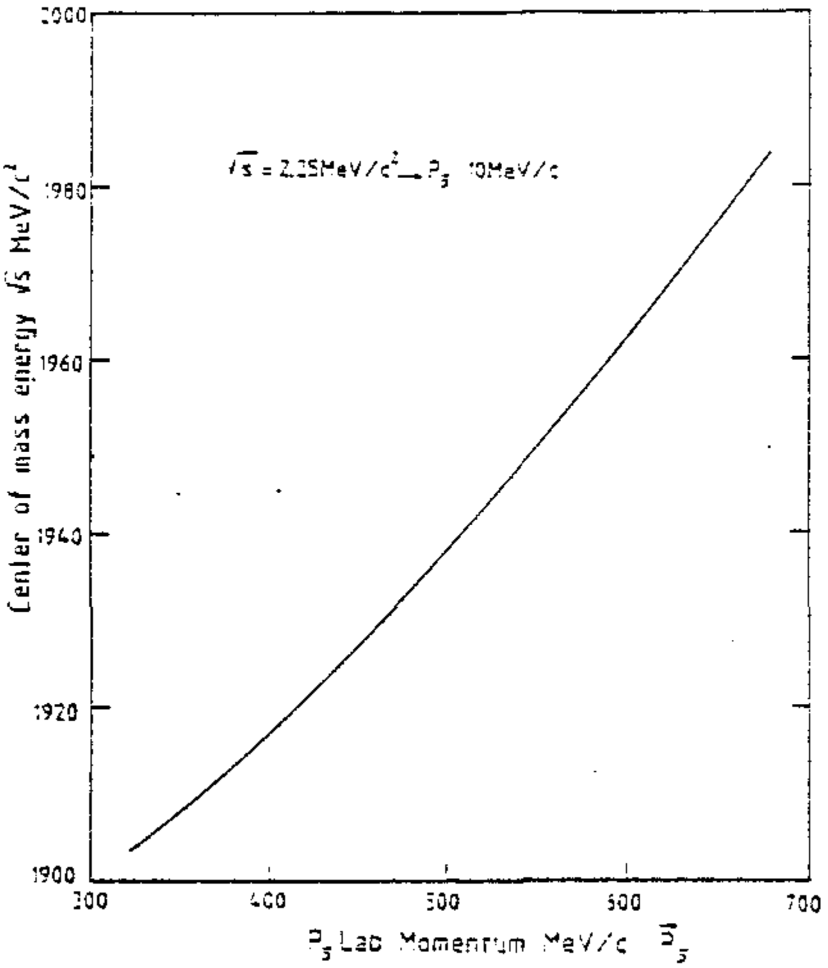

Fig. 8 – Correlation between the center-of-mass energy and the antiproton beam momentum.

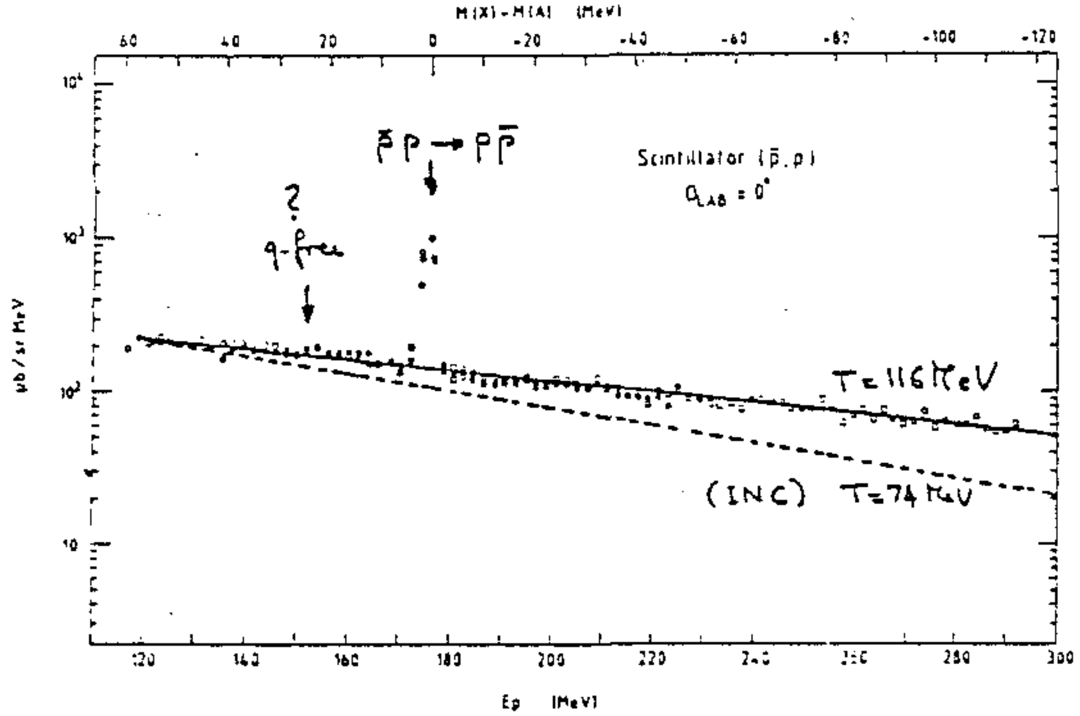

Fig. 9 – Spectrum of protons, at $\theta_{cm} = 180°$, from $\overline{p}$ impinging on a CH_2 target.

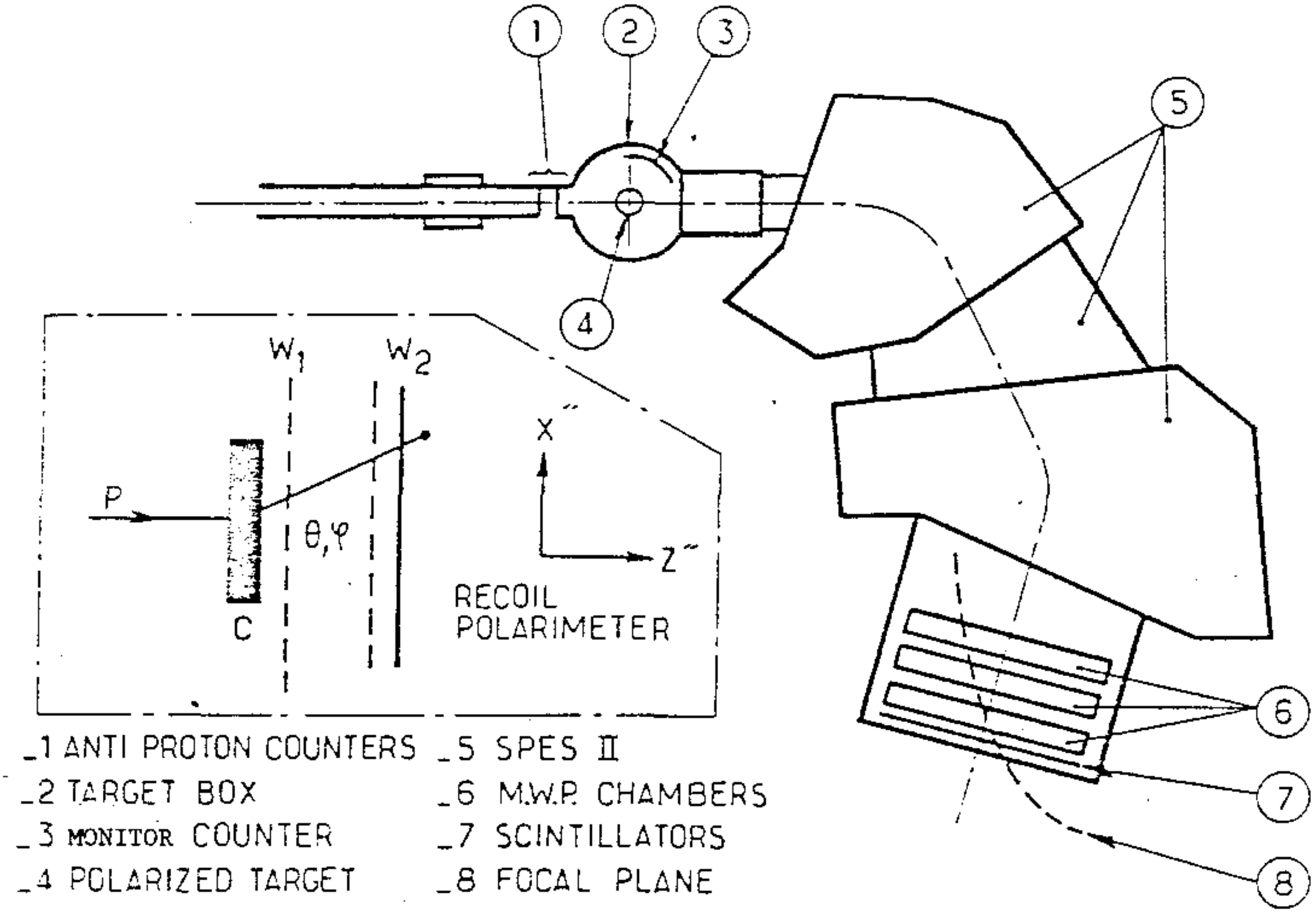

Fig. 10 - Experimental set-up.

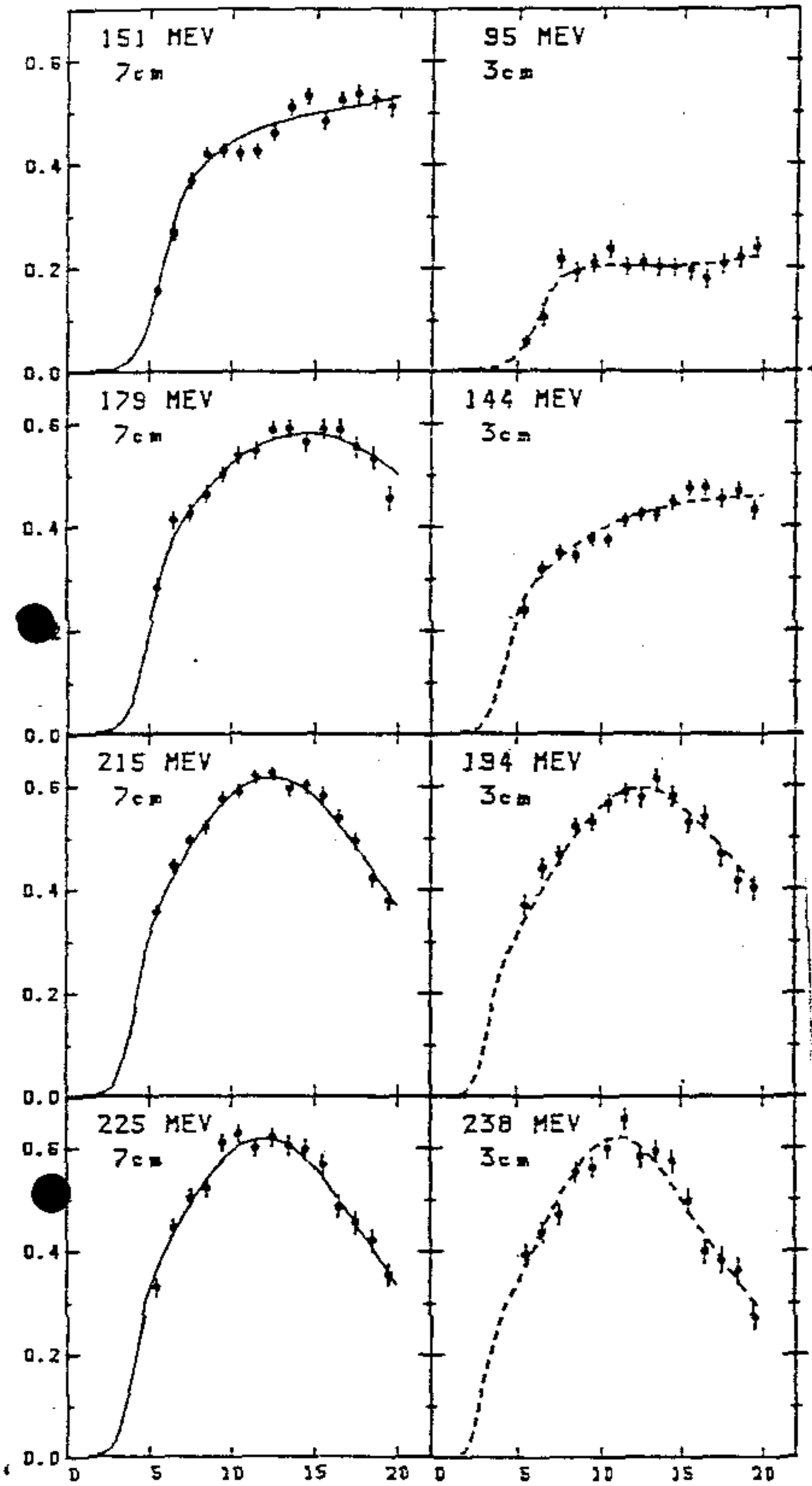

Fig. 11a - The effective proton-carbon analysing power as a function of the laboratory scattering angle θ_L.

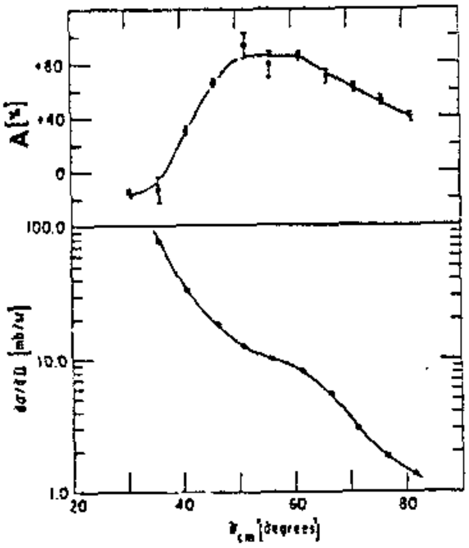

Fig. 11b - Polarization and cross section data for 50 MeV p-C scattering.