A TEST OF A POLARIZED PROTONS TARGET BY 600 MeV $p-p$ SCATTERING

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A target containing polarized protons has been constructed at Saclay [1], and, in a first experiment, will be used to determine the parity of the Ξ^- particle, using the reaction $K^- + p \rightarrow K^+ + \Xi^-$.

The method of polarization is the so-called «solid effect» which has been used already to polarize proton targets for 20 MeV $p-p$ scattering [2] at Saclay, and, for 250 MeV $\pi^+ - p$ scattering [3] and for $p-p$ scattering from 330 to 740 MeV, and from 1.70 to 6.5 GeV [4], at Berkeley.

As the general principles of the dynamic polarization by «solid effect» are described in a preceding paper [5], we shall only indicate the new experimental features of this target, and its performances, rising up to $\pm$ 84% in a single crystal of 8 cm^3 and describe a 600 MeV $p-p$ scattering which has been done at Cern as a preliminary test for the target.

I. GENERAL DESCRIPTION OF THE TARGET

The target material is LMN ***, 1% Nd^{142}, as cylindrical single crystals with their axis parallel to the crystalline field axis; these crystals experience a constant magnetic field of 18 400 Gauss, are cooled by a bath of liquid helium at a temperature of about 1,1° K, and are located in a thin copper cylinder, called «cavity» which is filled with microwave energy at 69 Gc/s. The degree of polarization of the protons is measured by nuclear magnetic resonance techniques: a resonance coil is wound around the crystals, and is tuned at 78.3 Mc/s as a part of a Q-meter circuit.

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*** LMN = $La_2Mg_3(NO_3)_{12}$, $24H_2O$.

The magnetic field, and thus the polarized proton spins, is vertical, and is produced by a specially-built, C-shaped magnet *, with truncated tapered pole caps, and which allow a wide apperture angle around the target. A homogeneity of 10^{-4} over a volume of 8 cm^3 has been achieved through a careful shimming of the 7 cm gap [6]. A hole in the magnet yoke is provided for the escape of the incident beam. The power dissipation is of 50 kWatts.

The cooling of the crystals is done by a specially-built, horizontal cryostat, with a continuous helium flow from standard containers; this cryostat (Fig. 1) works on the same principle as the smaller one [7] which was used in 20 MeV $p-p$ scattering: liquid helium is fed into the cryostat through a short vacuum-isolated transfer line, into a 100 cm^3 reservoir, called a separator when:

1) liquid helium is filtered through sintered brass;

2) helium vapours produced by the transfer are separated from the liquid and pumped away through spiral tubes which are used to cool some thermal shieldings, down to 30—40° K; no liquid nitrogen is used at all.

The liquid from the separator is precooled to superfluid state down to about 2° K in a Poiseuille flow heat exchanger, then expanded through a needly valve .5 mm in diameter 2° conical angle and flows into the microwave cavity where it vaporises; its vapour is then pumped, throughout the heat exchanger, by a 3000 m_3/h pumping system; temperatures of .97° K are attained in the absence of microwave power and rise to 1.10—1.20° K when this power is present. The overall dissipation of liquid helium depends on the amount of microwave power W and is of 2.3 1/h with W — 1 watt;

* This magnet was designed by G. Petrucci.

the intrinsic losses of the cryostat are negligible. Those of the transfer line are .5 l/h and those of the storage Dewar (due to the inlet of warm gas) .3 l/h. The cryostat has been used with 25 liters helium containers, but is designed to work with 50 liters and 75 liters cans as well; it will then have an autonomy of 24 hours at the maximum power. Changing the container takes only 10 mins., and the crystals keep cool during this time; the polarization is then restored to 95% of its original value in about 3 minutes. The temperature of the liquid helium bath keeps constant to within .101°K during hours.

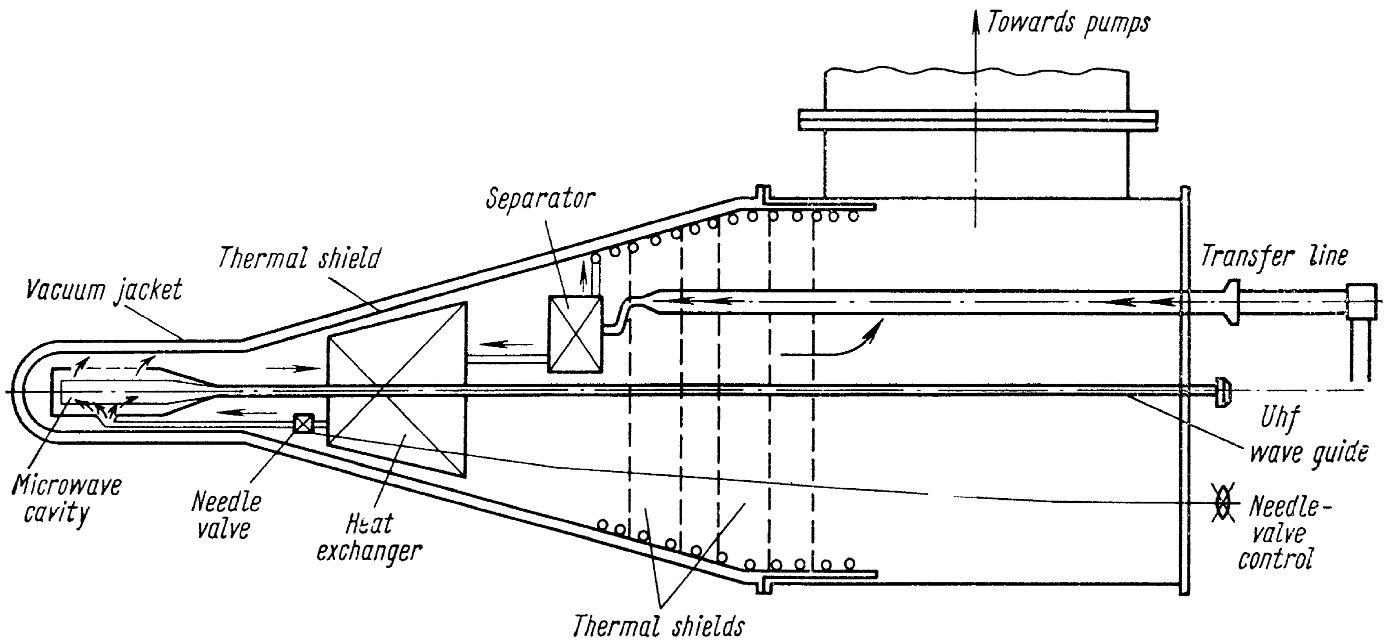

Fig. 1. Schematic diagram of the horizontal cryostat for polarized target: Full arrows indicate the liquid helium flow. Simple arrows indicate the gaseous helium path.

The microwave system consists in a source, a carcinotron, with a maximum output power rising to 25 Watts, and which can be frequency-stabilized on a temperature-controlled, semi-confocal resonant cavity, with a Q-value of about 20 000, through a dc-Pound scheme stabilizer. Oversized waveguides are used to convey the power into the cavity, through a cylindrical horn, or through a lateral slit. By a slight change in the microwave frequency ($\simeq$ 160 Mc/s), the polarization can be given either sign with respect to the magnetic field direction, which is kept fixed during all the experiments.

The nuclear magnetic resonance system, used to measure the proton polarization is a Q-meter: a tuned coil is wound around the crystals of the target; it is supplied by a 78.5 Mc/s, temperature-controlled oscillator; a frequency sweep of about 250 kc/s, of 50 ms duration, can be applied at will, for instance after each accelerator pulse, and allows a visual display of the proton magnetic resonance signal on a scope; Fig. 2 shows typical signals: *a* is a «natural» signal, in the absence of microwaves, when the crystals have been allowed to reach their thermal equilibrium at a temperature of 1.05° K; it corresponds to a «natural» polarization of 1.75%; *b* and *c* show enhanced signals of both signs, the gain of the detection being reduced by a factor of 300 with respect to the signal *a*. Because of the drastic change in the form of these signals, the enhancement of the polarization due to the dynamic effect of the microwaves, must be calculated by comparing the areas of these signals *b* and *c* to that of signal *a*; this is done in three different ways: area measurements on photographs; «analog» integration through an electronic integrator, and display on a digital voltmeter; «digital» integration through a voltage-to-frequency converter, and totalization in a scaler, which allows the polarization to be measured in 50 ms and displayed in true value and sign, and registered on the same photograph as that of spark-chambers, for instance.

The results that we have obtained differ markedly on the individual crystals that we have tried; maximum polarizations of $+85 \pm 8\%$ and $-84 \pm 8\%$ occur in one .8 cm° crystal; but for average crystals, the polarizations lay between 40 and 60%. The relaxation time constant of this best crystal

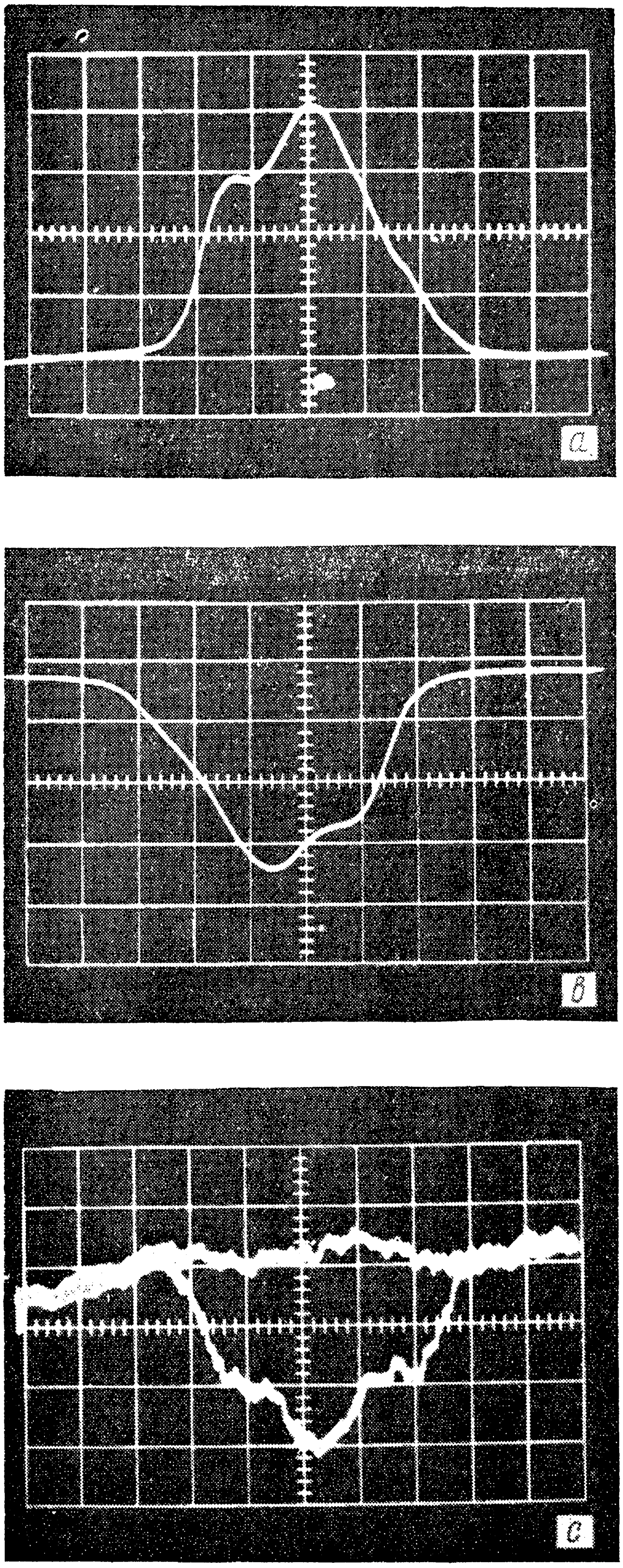

Fig. 2. Typical magnetic resonance signals: *a*) «natural» signal; *b*) signal of polarized protons with «spin up»; *c*) signal of polarized protons with «spins down». The gain has been reduced by a factor of 300 between *a* and *b*, *c*.

is of 52 minutes at 1.07° K; its polarization time is of 3 minutes, with the maximum power.

II. 600 MEV *P-P* SCATTERING

The operation of the target has been tested by an assymmetry measurement in 600 MeV *p—p* scattering with unpolarized beam. Instead of the 5 mc^3 target to be used in the Ξ^- parity experiment, we used two crystals, of

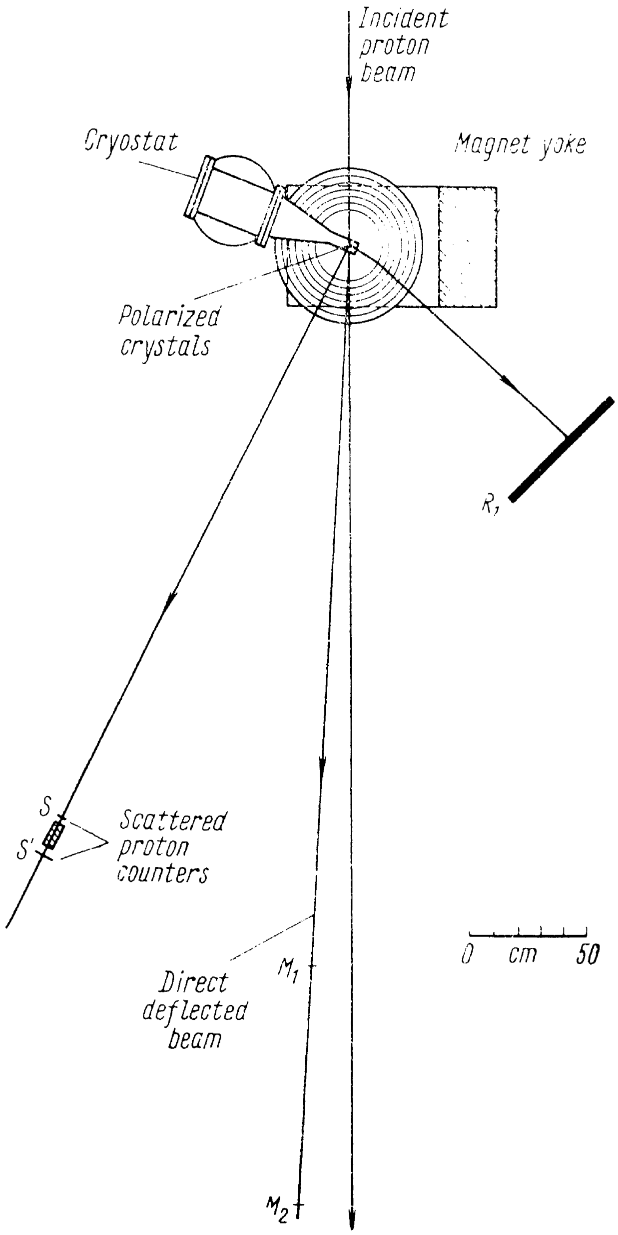

Fig. 3. Experimental arrangement for 600 MeV *p.p* scattering.

total volume 1.35 cm (∅ = 15 mm, thickness 8 mm). The extracted unpolarized proton beam from the CERN synchro-cyclotron was led through a standard beam transport system to a focus located at the polarized target position. The dimensions of the image at this focus were 20 mm horizontally and 6 mm vertically; centering of the beam on the target was achieved by taking a picture of the beam just downstream from the target, so that the outline

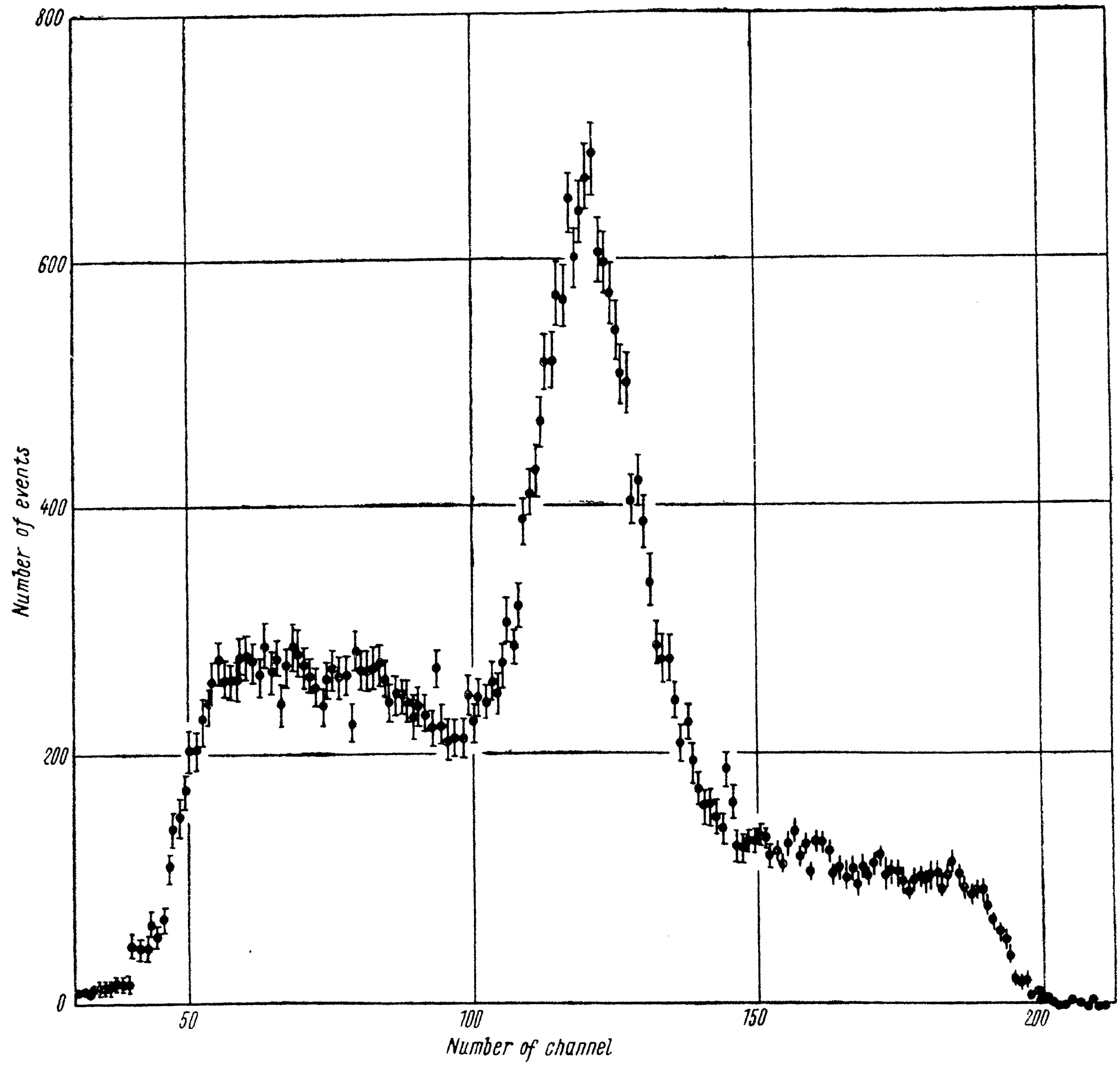

Fig. 4. Distribution of recoil protons with «spin up» polarized target.

of the crystal could be faintly seen on the developed film. The average beam intensity during the measurement was of the order of 10^8 protons/second. The kinetic energy of the protons was determined by a residual range measurement to be (600 ± 5) MeV.

The apparatus employed to perform the asymmetry measurement is shown in Fig. 3. Protons scattered at an angle of 24° in the lab. system (54° in the c.m. system) were detected by a coincidence between the two scintillation counters S and S'. Counter S, 6 cm high and 4 cm wide, placed at 2.70 meters from the target, defined the angular acceptance of the system; a 10 cm thick brass absorber was placed between S and S', to avoid detection of low energy protons produced in nuclear interactions of the beam particles at the target. The recoil proton associated to an (SS') coincidence was detected by counter R, a plastic scintillator 60 cm long, 5 cm high and 2 cm thick seen from both sides by two 56 AVP type photomultipliers. The position at which the recoil proton hit the counter was known by measuring the time interval between the outputs of the two photomultipliers looking at R, with the method described by Charpak, Dick and Feuvrais [8]. A resolution of 4 cm was obtained, making the counter roughly equivalent, to a hodoscope of 15 counters 4 cm. wide and 5 cm high, placed side by side. The measurement of the time interval between the two outputs of counter R was allowed whenever a coincidence ($SS'R$) occurred, within a resolving time of 12 nsec. The information from the time converter measuring the time interval was stored into a 256 channel pulse height analyser (p.h.a.); in this way, the recoil protons associated to elastic scattering on the free protons of the crystal (emitted at 60° in the lab. system) fell in a given region of the p.h.a. memory, approximately 40 channels wide. Recoil protons associated with processes of the type $p + (A, 2) \rightarrow p + p + (A - 1, 2 - 1)$ occurring on the complex nuclei of the crystals, have a much wider angular spread with respect to the scattered particles, and were stored almost everywhere

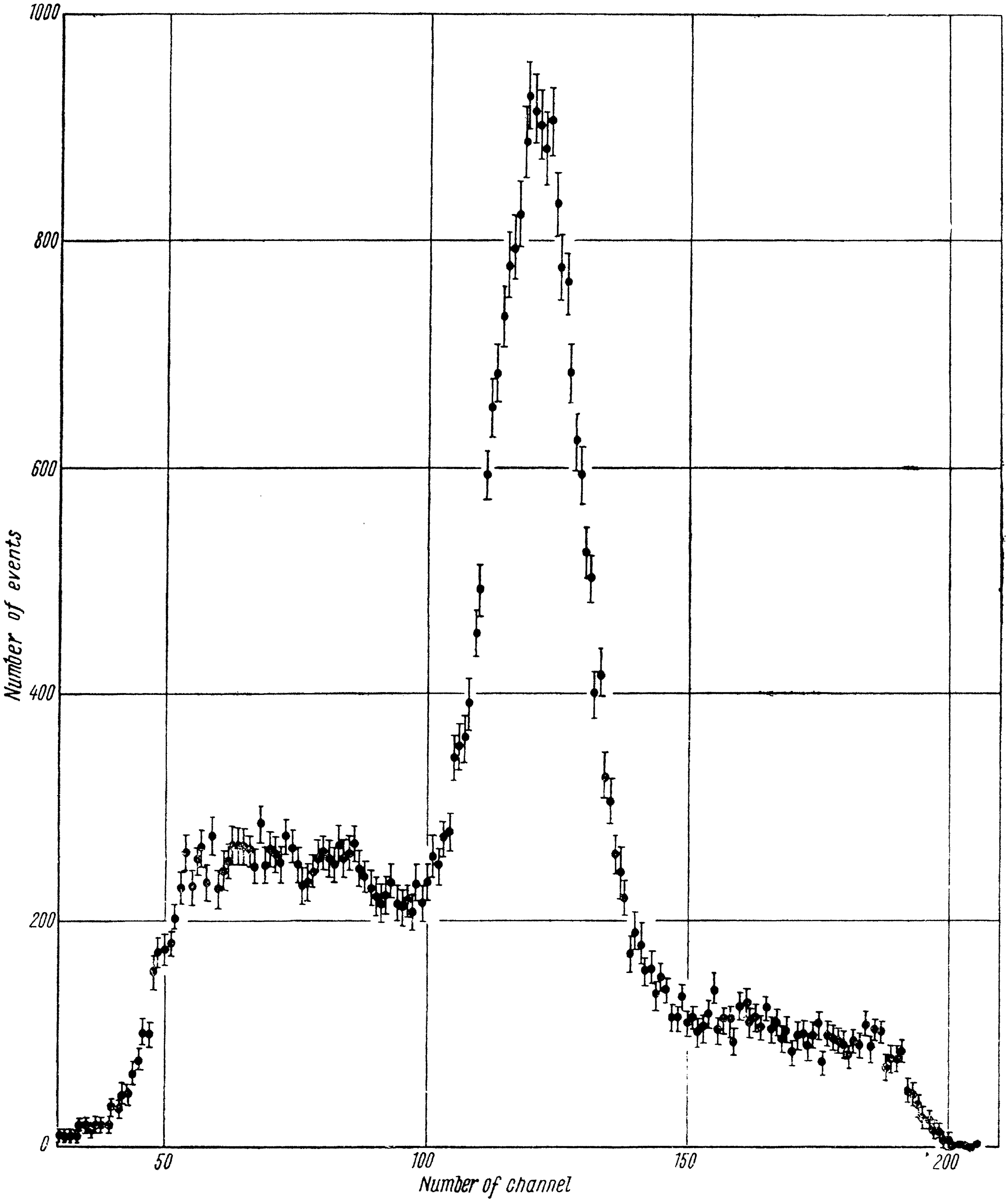

Fig. 5. Distribution of recoil protons with «spin down» polarized target.

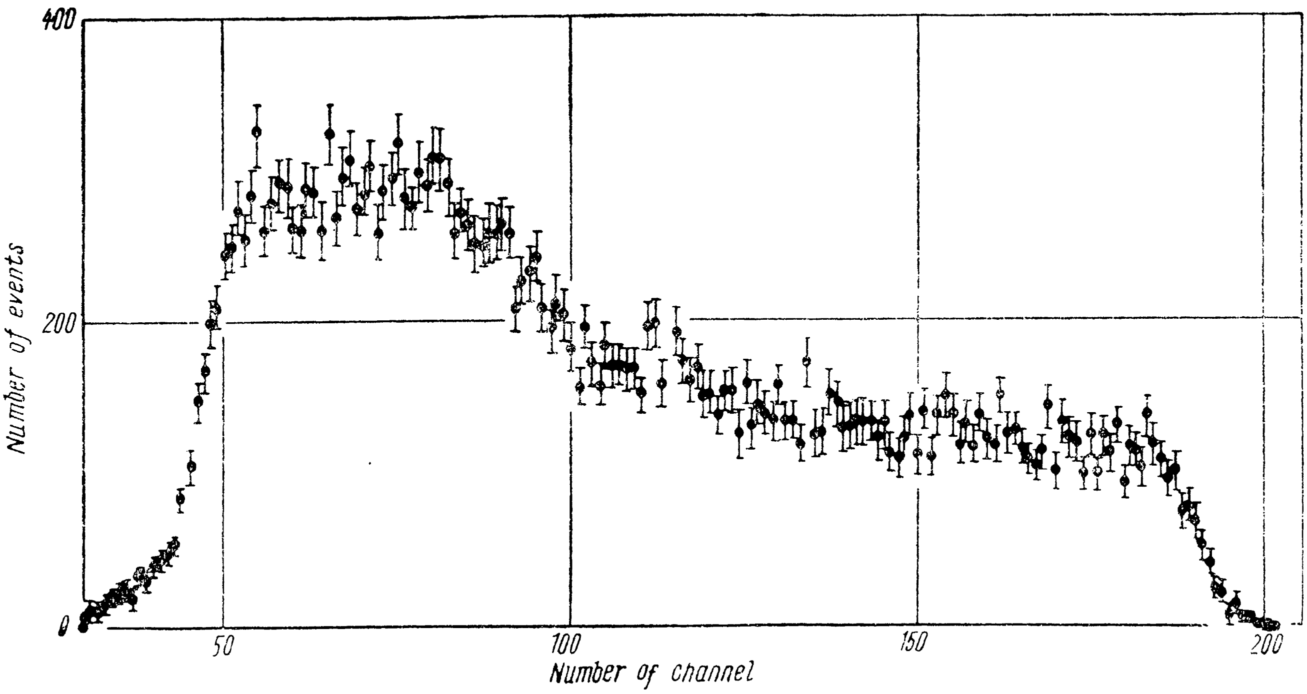

Fig. 6. Distribution of recoil protons with dummy target (without hydrogen).

in the p.h.a. memory, with no particular structure. Scattering events on free protons appeared therefore as a peak in the distribution stored by the p.h.a.

The beam was monitored by two scintillation counters in coincidence, M_1 and M_2, 0.8 cm wide and 0.8 cm high placed downstream from the target on the beam line. Finally, the rate of accidental events was minimized by running the accelerator with stochastic extraction [9]. The rate of $(SS'R)$ coincidences was $\sim$ 6/sec during the data taking run.

Data was collected in 14 runs of approximately 15 minutes, each of them corresponding to 10^8 coincidences (M_1M_2). The target polarization was reversed every 3 or 4 runs; the reversing time was of the order of 15 minutes.

The polarization value P_T from the resonance signal was recorded every second to obtain its average value for each run. The averages made over the seven runs with polarization up, and those with polarization down, were respectively:

$$P_T\,(\text{up}) = +0.46 \pm 0.05; \qquad (1a)$$

$$P_T\,(\text{down}) = -0.44 \pm 0.05. \qquad (1b)$$

The results from the two groups of runs, relative to the two possible directions of polarization, are shown in Figs. 4 and 5, where the distribution of recoil protons on counter R is shown.

The «complex nuclei» background was measured in a separate run, by replacing the polarized target with a dummy target of the same weight but without hydrogen. The result of this run is shown in Fig. 6: no «elastic» peak is visible in the distribution of the recoil protons at counter R.

The value of the asymmetry obtained after subtraction of the «complex nuclei» background is:

$$\varepsilon = \frac{R\,(\text{up}) - R\,(\text{down})}{R\,(\text{up}) + R\,(\text{down})} = -0.24 \pm 0.01 \qquad (2)$$

where R (up) and R (down) represent respectively the «elastic» counting rates for the two directions of target polarizations. This value was found to be unsensitive to the incident beam intensity.

If we indicate as P_p the polarization of the protons scattered from unpolarized protons (the incoming beam being unpolarized as well), we knoy that

$$\varepsilon = P_T P_p. \qquad (3a)$$

Using values (1, a) and (1, b) we find

$$P_p = -0.53 \pm 0.06. \qquad (4)$$

This value agrees with the value extrapolated to our energy from the results of a recent experiment performed at Berkeley [4]; it seems to disagree with the results of a Dubna group [10] obtained at 635 MeV incident energy.

Our conclusion on this point is bound, however, to the results of other measurements performed with different values of P_T, which are now in progress at CERN.

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