EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/SPSC/81-106
SPSC/P 173
8 December 1981

## PROPOSAL

# ANTIPROTON-PROTON GLORY SCATTERING

*CERN[1]-Lisbon[2]-Neuchâtel[3]-Paris VI[4] Collaboration**)*

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## ABSTRACT

We propose to measure $\bar{p}p$ backwards scattering between 5 and 20 GeV/c in the Omega spectrometer using the S1 beam. The mechanism responsible for backward scattering in channels not mediated by particle exchange is not understood, and could be almost energy-independent glory scattering.

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*) Yu. Galaktionov, from ITEP-Moscow, is also considering to participate in this proposal.

## 1. INTRODUCTION

Elastic scattering of hadrons on heavy nuclei exhibits the features expected from the black disk optical model: a strong forward peak followed by diffraction minima and secondary maxima with little energy dependence, and also some energy dependent back scattering, again with a periodic structure with respect to the transverse momentum. Back scattering through surface waves which travel on the rather sharp boundaries of the interaction volume is called glory scattering, as in meteorology1). $d\sigma/du$ goes as $k^{-2}$ where k is the c.m. momentum.

In contrast, it was thought for a long time that all t and u structures observed in hadron–hadron elastic scattering beyond the forward peak were due to meson and baryon exchange. Absence of diffractive structures beyond the forward peak would be accounted for if the boundaries of the hadrons were sufficiently smooth, in fact, if the profile of distribution of matter in hadrons were Gaussian, as opposed to a black disk. The high luminosity ISR experiments were first to establish clearly the existence of a diffractive, i.e. energy-independent structure in pp scattering, consisting of the minimum at $t = -1.4$ $(\mathrm{GeV}/c)^2$ followed by a secondary maximum of 40 $\mathrm{nb}/(\mathrm{GeV}/c)^2$ at $t = -2$ $(\mathrm{GeV}/c)^2$. The same structure was later found in $np \to np$ 2) around 300 GeV/c, and very recently, also in $\bar{p}p \to \bar{p}p$, at a much lower momentum of 50 GeV/c 3).

A $\bar{p}p$ backward peak has been clearly observed at 5 and 6.2 GeV/c 4,5) [$d\sigma/du(0) \sim 1$ $\mu\mathrm{b}/(\mathrm{GeV}/c)^2$ at 5 GeV/c, less at 6.2 GeV/c; $\langle u \rangle \sim$ $\sim -0.2$ $(\mathrm{GeV}/c)^2$; see Fig. 1]. The same experiment found, at 5 GeV/c, a backward peak in $K^-p$ as well, similar in cross section to the $\bar{p}p$ peak, and two orders of magnitude below the $K^+p$ backward peak. The $K^{\mp}p$ results of that experiment were used to demonstrate the overwhelming dominance of baryon exchange (allowed for $K^+p$, nonexistant for $K^-p$) over glory scattering. The $K^-p$ peak was tentatively attributed to Regge-cut exchange; the $\bar{p}p$ backward peak has never been commented upon by theorists, to our knowledge, and has never been re-measured by experimentalists. The very notion of glory scattering disappeared although it remained a possible explanation of the $\bar{p}p$ and $K^-p$ backward peaks.

The Omega spectrometer served by the high acceptance $S_1$ beam ($\Delta\Omega =$ $= 50\ \mu s$) is well suited to measure $\bar{p}p$ backward scattering, over momentum range wide enough to better understand the underlying mechanism.

We propose to carry out such measurements early in 1982 using the forward proton trigger which would be set up jointly with the already approved experiment WA72, which also studies fast forward protons.

## 2. PHYSICS SCOPE AND GLORY SCATTERING

We propose to study $\bar{p}p$ backward elastic scattering with high sensitivity at and above 5 GeV/c. Our main goal is to study its energy dependence which should help to distinguish between several possible reaction mechanisms:

- direct channel resonances which may lead to a very strong energy dependence (say, $d\sigma/du \sim s^{-(8\text{ to }12)}$ in a channel where they are not dual to an allowed exchange mechanism;
- Regge cut exchange, i.e. in the present case, double baryon exchange, with a moderately strong expected energy dependence ($d\sigma/du \sim s^{-(3\text{ to }6)}$;
- glory scattering, with a weak energy dependence ($d\sigma/du \sim s^{-1}$).

The double meson exchange reaction $\bar{p}p \to \overline{\Sigma^-}\Sigma^-$ has, at 3.6 and 5.7 GeV/c 6), a much larger cross section than $\bar{p}p \to p\bar{p}$, and behaves as $s^{-4.1 \pm 1}$.

We now wish to embark on an attempt to show that glory scattering is not ruled out as a model for the 5 GeV/c backward peak when considering the structure of the proton which has been derived from pp data in particular at the ISR.

Neglecting spin, we write the elastic scattering amplitude in a usual notation as

$$f = \frac{i}{k} \sum_{\ell=0}^{\infty} f_\ell\ (\ell+{}^1\!/\!_2)\ P_\ell(\cos\theta)\ . \qquad (1)$$

For the black disk of radius R, we would have (in units $\hbar c = 1$)

$$f_\ell = 1 \quad \text{for} \quad \ell \le \ell_{max} = kR \qquad (2)$$

$$\phantom{f_\ell = {}} 0 \quad \text{for} \quad \ell > \ell_{max}$$

with the well known diffraction pattern, $\sigma_{el}/\sigma_{tot} = \frac{1}{2}$, and a backward peak which would be twice as narrow and, at 5 GeV/c, two orders of magnitude smaller than the forward peak $[$experimentally, $d\sigma/du\ (u = 0) \sim 10^{-5}\ d\sigma/dt\ (t = 0)]$. We note that for $\cos\theta = -1$ the amplitude changes sign each time $\ell_{max}$ changes by one unit which happens roughly when $p_{lab}$ changes by 2 GeV/c, in the 5 to 20 GeV/c range, for R = 1 fermi.

In the optical model approach, the $f_\ell$ depend mainly and smoothly on the impact parameter a. It is well known and easy to show (using $\ell + \frac{1}{2} = k\,a$, $q = k \sin\theta$, $P_\ell(\cos\theta) = (-1)^\ell\, P_\ell(-\cos\theta) \cong J_0[\sin\theta \times (\ell+\frac{1}{2})]$, and $f_\ell(k) = \Gamma[a = (\ell+\frac{1}{2})/k]$ that for small t the above formula becomes then identical to the form

$$f = ik \int_0^\infty \Gamma(a)\ J_0(qa)\ a\ da \qquad (3)$$

This form is given and commented on in Ref. 7. Its Bessel-Fourier inverse was used by Amaldi and Schubert$^{8)}$ to determine the profile function $\Gamma(a)$ from the ISR pp data with two additional and plausible hypotheses: no spin dependence, and a phase compatible with dispersion relations.

Neglecting annihilation, we then use their Re $\Gamma(a)$ for $\bar{p}p$ and plug it into formula (1) as a convenient way to obtain the (dominant) imaginary part of the backwards scattering amplitude for small transverse momenta $[q < 1\ (\mathrm{GeV/c})^2]$. In that range, (1) and (3) give the same result in the forward direction. We then note that $\Gamma(a)$ may not be much different for $\bar{p}p$ at 50 GeV/c since the real part is small and the cross section out to $|t| = 5\ (\mathrm{GeV/c})^2$ is so similar to pp at ISR energies. Finally we use the same $\Gamma(a)$, now with little justification, down to 5 GeV/c, where we find a backwards cross section "prediction" of the right order of magnitude and shape. Between 50 and 5 GeV/c, we note that within the overall $s^{-1}$ energy dependence, there are still strong fluctuations in magnitude and shape, with periodicities of a few GeV/c. Such a fluctuation would have to account for the difference between the measured cross sections at 5 and 6.2 GeV/c (Fig. 1).

Having thus found that the case for glory scattering is not absurd, we add two comments:

- Clearly, less smooth profile functions $\Gamma(a)$ could be constructed which would still reproduce the pp data but would yield wildly different backwards amplitudes since these are sensitive to the local variations -- over intervals of $\Delta a \simeq 1/k$ -- of $\Gamma(a)$. However, we believe that for this very reason all such modifications would enhance the glory scattering effect.

- However, we have been able, by using a slightly modified Gaussian profile function with formula (1), to construct an amplitude which has a single diffraction minimum and secondary maximum of not implausible shape, and negligible backwards scattering.

If glory scattering exists for elementary particles, it would eventually become dominant even for reactions which at moderate energies are dominated by baryon exchange. No break of the ensuing type has been observed in $\pi^{\mp}p$ backwards scattering, but the cross sections reached are not low enough to exclude a glory scattering background of the magnitude contemplated above.

Facing thus a rather open field, we propose to adopt a flexible strategy, and to measure $\bar{p}p$ backwards scattering in two steps:

- For 1 day per momentum, at 5 GeV/c with 100 good events if the cross section of 200 nb for $|u| < 0.25\ (\mathrm{GeV/c})^2$ 4) is confirmed, and at 12 GeV/c with three good events per nanobarn for $-0.6 \geq \cos\theta \geq -1$. Expectations for the cross section integrated over this interval run from 1 nb in case the angular distribution stays flat beyond $\cos\theta = 0$ to 100 nb in case of dominant glory scattering. We plan to analyse a significant fraction of the data immediately, and to decide then whether:

- To continue measuring at 12 GeV/c until the large angle data of Ref. 9 is completed towards 180° (Fig. 1), or

- To study the fine structure of a glory scattering type process by taking data at 8, 9, 10, and 11 GeV/c, and then to concentrate on 20 GeV/c, a 30 GeV/c exploratory measurement having been done concurrently with the WA72 hydrogen run.

The following reactions would also be measured, over similar u ranges and with luminosities of comparable order of magnitude:

- $\bar{p}p \to \Lambda\bar{\Lambda}$, with, potentially, spin structure information for a channel which could be related to glory scattering.

- Backward $K^-p$ elastic scattering (except at 5 GeV/c where the $K^-$ flux is too small).

- Other double charge exchange reactions, mainly $\pi^-p \to K^+\Sigma$ and $\pi^-p \to K^+Y^{*-}_{1385}$ at 5 to 12 GeV/c, and $K^-p \to \pi^+\Sigma^-$ and $K^-p \to \pi^+Y^{*-}_{1385}$ around 12 GeV/c.

## 3. THE APPARATUS AND TRIGGER

We intend to use the Ω spectrometer under high flux conditions, and also to achieve good and reliable acceptance. Events will therefore be correctly identified and reconstructed using the beam and the fast track alone, and relying exclusively on those wire and drift chambers or parts thereof which are not exposed to high flux, and on counters. The layout is shown in Fig. 2, and the achieved acceptance for $\bar{p}p \to p\bar{p}$ on the lower part of Fig. 1.

The S1 beam contains 3.2% $\bar{p}$'s over the momentum range of interest. We intend to use all the available beam flux up to a maximum tolerable level of $3 \times 10^7$/burst (i.e. $10^6$ $\bar{p}$/burst). With $10^{12}$ protons/burst impinging on the T1 target, the maximal beam flux would exceed this value above 10 GeV/c, and we will collimate it down in such a way as to ensure a maximum uncertainty of ±0.5% in $p_x$ ($x$ = beam axis) and of ±25 MeV/c in $p_y$ and $p_z$. All beam counters are fast enough to regenerate between successive SPS bunches. Counter S3 will veto double hits within one SPS bunch and thereby validate the particle identification provided by two threshold and one CEDAR Cerenkov counter. We then assume conservatively that the fast forward proton is missed in the first metre of overstrained detectors after the target, and that it is measured correctly in the MWPCs further downstream and in the drift chambers. The missing mass accuracy achieved in this way is better than a pion mass up to 12 GeV/c, and ±200 MeV/c at 20 GeV/c, which is probably still sufficient. The main addition to the standard Ω equipment are TDCs on the cylindrical hodoscope which surround the target (Barrel in Fig. 1). These help reconstructing the interaction point to an accuracy sufficient to reduce the transverse momentum error to $\delta p_T = \pm 50$ MeV/c on each event.

A subclass of good events will have the beam particle and the slow $\bar{p}$ completely measured in the beam and side chambers. These events will be used to check the extent to which the robust method outlined above is adequate.

We now describe briefly the fast proton trigger. Its first two levels have been used before: a proper correlation between hits in hodoscopes H1 and H2 and no hit in Cerenkov 1, followed by a much finer correlation between H2 and the y plane of the last wire chamber A7. Cerenkov 1 will be filled with freon 22; its threshold for $K^+$'s will be at 12.8 GeV/c. The bin size of the overlapping hodoscopes H1 and H2 is 6 and 9 cm, respectively. Less than 1 such pretrigger will arise for 1000 incoming $\bar{p}$'s or $K^-$. A new facility will then be used: the y planes of chambers A6 and A5 will be decoded and used together with A7 to compute the sagitta of the track, in order to write on tape only events with high momentum positive tracks.

We expect to obtain, with an adequate safety margin, between 0.5 and 5 fitted events per nanobarn and per day at 5 and above 10 GeV/c, respectively.

The byproducts mentioned in Section 2 require minor modifications of this trigger scheme. The $\pi^- p$ triggers, which include the reaction $\pi^- p \to p\pi^-$ which is well known and useful for checking purposes, will be scaled down.

## 4. BEAM TIME REQUEST

We request a total of 15 days beam time for an exploratory study of $\bar{p}p$ backward scattering, to be split up as follows:

- 5 days for setting up and for a short 30 GeV/c run to be done together with the WA72 H2 run.
- 10 days for the remaining program outlined in Section 2.

Since most members of this collaboration are also members of WA72, we hope to share most of the setting up effort.

## 5. ANALYSIS AND COMPUTER TIME REQUEST

A fast turn-round for data samples during data taking will be vital both in order to check the event selection procedure, and to optimize the usage of the allocated beam time according to the findings of the first days. This implies priority for 1 hour CDC 7600 per day during data taking; since we expect to reduce the number of tapes by selective filtering, 40 hours CDC 7600 equivalent should suffice to analyse subsequently the $\bar{p}p$ data, to be shared between CERN and Paris VI.

## 6. ACKNOWLEDGEMENTS

We thank Drs. U. Amaldi, F. Bourgeois, F. Carena, Yu. Galaktionov, M. Jacob, J.-C. Lassalle, A. Lundby and D. Plane for their comments and help.

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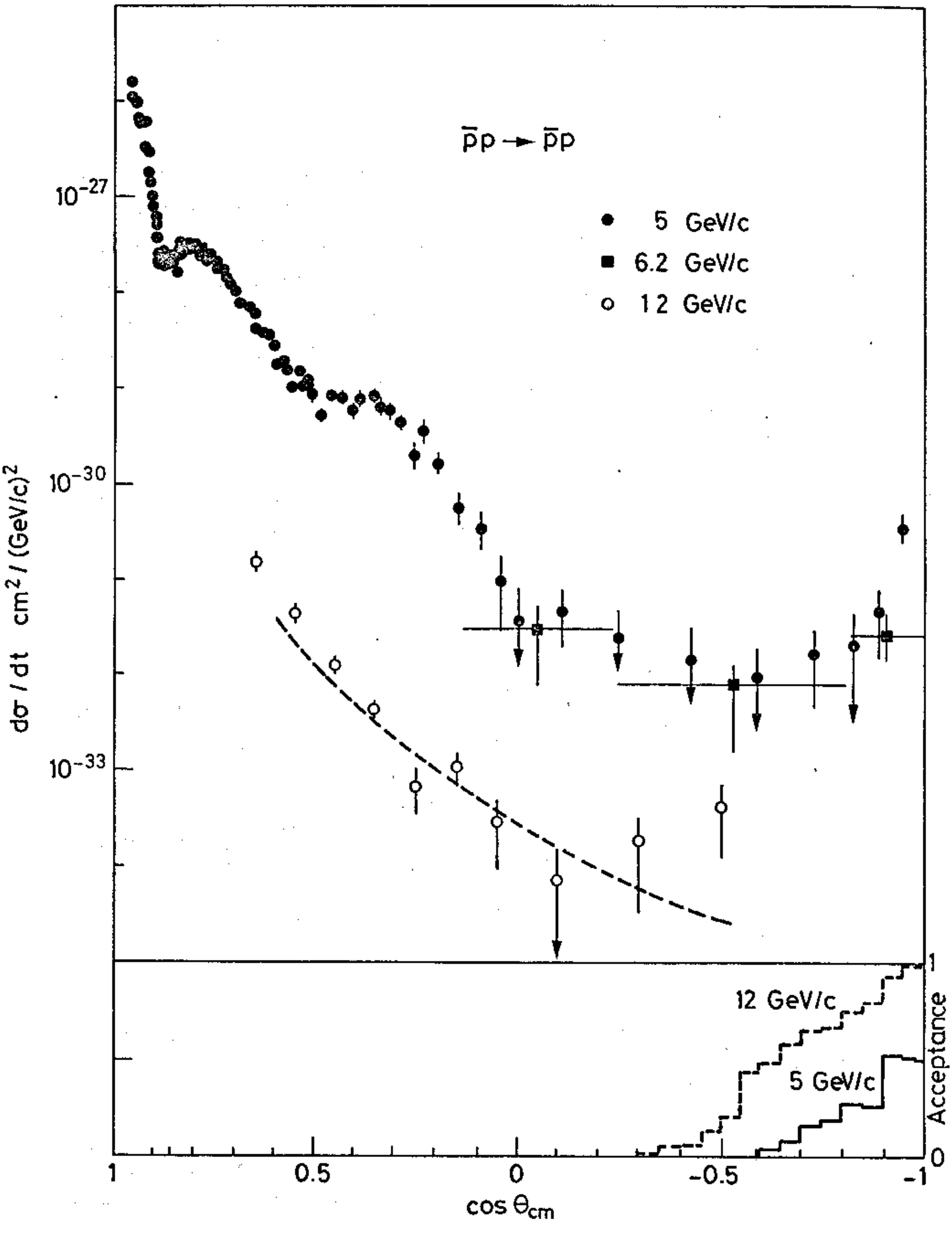

Fig. 1 Above: dσ/dt (cos θ) for $\bar{p}p \to \bar{p}p$ at 5 GeV/c from Ref. 4, 6.2 GeV/c from Ref. 5 (only backwards points shown) and large angle data at 12 GeV/c from Ref. 9. Below: acceptance of the proposed trigger at 5 and 12 GeV/c.

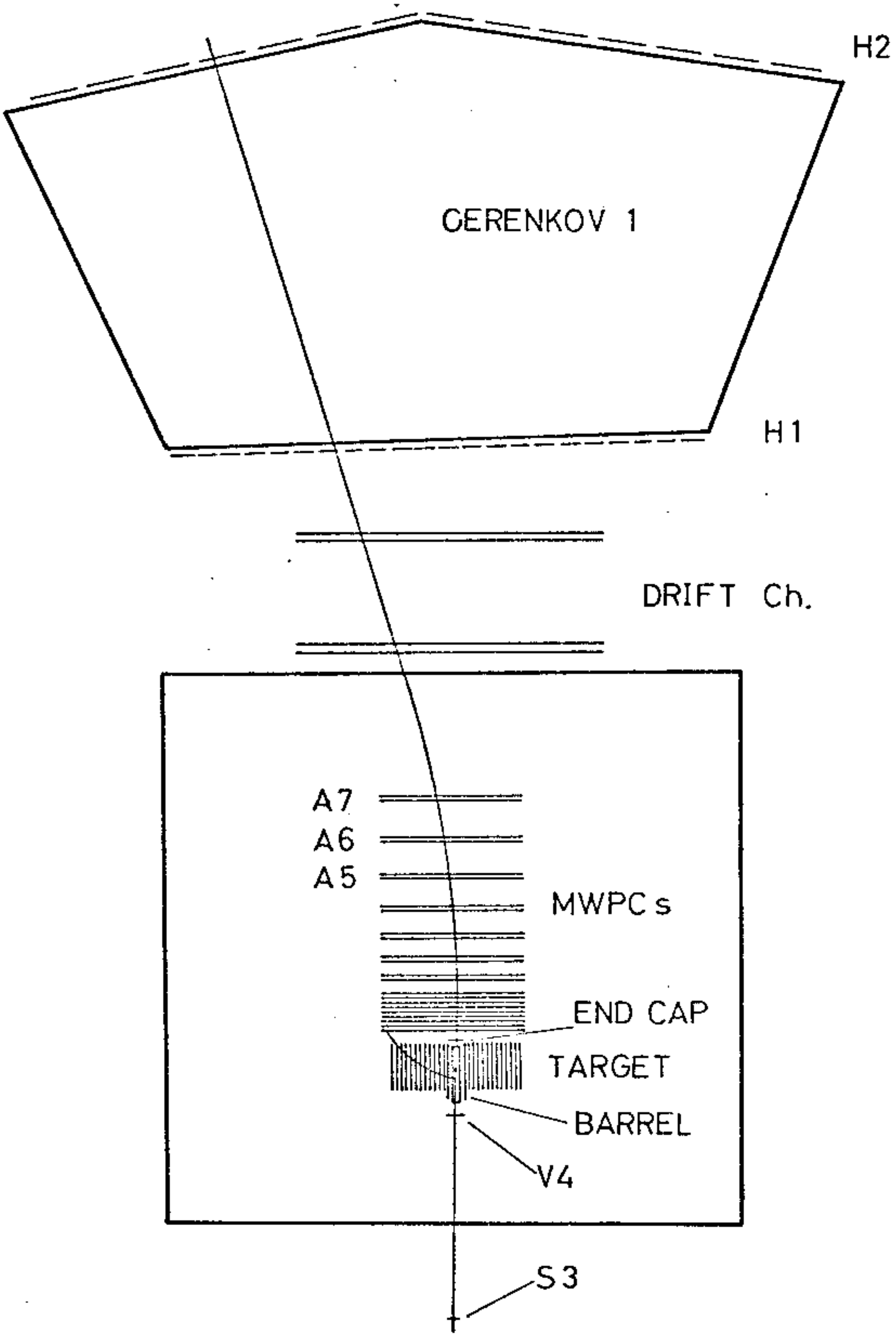

Fig. 2 Required layout of Omega spectrometer (see text). The side chambers are turned and detect the recoils with good efficiency. Beam equipment (proportional chambers, one CEDAR and two threshold Cerenkov counters) not shown. The event shown is $\bar{p}p \to p\bar{p}$ at 12 GeV/c, $u = -0.25$ $(\mathrm{GeV}/c)^2$.