ANTIPROTON CHANNEL WITH 2.8 Bev/c MOMENTUM

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An arrangement is described for separation of antiprotons, possessing a momentum of 2.8 Bev/c, obtained from the Joint Institute for Nuclear Research proton synchrotron. Data on the relative frequency of generation of antiprotons and π mesons in Be and Cu have been obtained.

THE antiproton channel described in this article is intended for a study of the interaction between antiprotons in a cloud chamber, operating in the controlled mode. The antiprotons are generated in the target by protons accelerated to 9 Bev.

1. ARRANGEMENT OF THE CHANNEL

The arrangement of the channel is shown in Fig. 1. The negative particles produced in the target are analyzed by momentum by the magnetic field of the proton synchrotron and by magnet M_1.

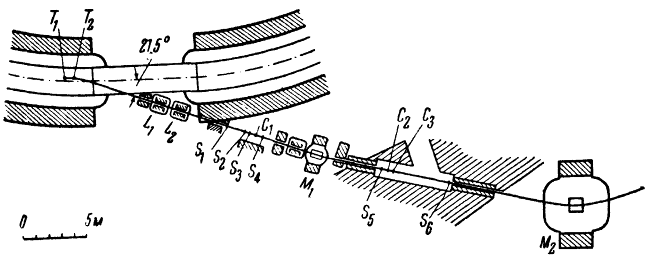

FIG. 1. Diagram of antiproton channel. L_1, L_2 – quadrupole lenses; M_1 – deflecting magnet, M_2 – magnet in which the cloud chamber is located, S_1, S_2, S_3, S_4, S_5 – scintillation counters, 9 cm diameter, 1 cm thick; S_6 – the same, 14.6 cm dia., 1.5 cm thick. C_1, C_2, C_3 – Cerenkov counters, 10 cm diameter, 3 cm thick; T_1, T_2 – targets for aiming the particle beam at 0 and 7° respectively.

The quadrupole lenses L_1 and L_2 focus the particle beam. The gradients in the lenses are chosen to correspond to the maximum number of particles passing through the scintillation telescope $S_1S_4S_5S_6$. The magnetic system segregates the momentum 2.8 ± 0.15 Bev/c.

2. SEGREGATION OF THE ANTIPROTONS

In the momentum-analyzed beam the anti-protons are identified by velocity ($\beta = 0.95$) by means of Cerenkov counters C_1, C_2, and C_3, operating on the total internal reflection principle.* The radiator used is a mixture of glycerine with alcohol ($n = 1.430$). In each Cerenkov counter two type FEU-33 photomultipliers are used, which can be connected in individual coincidence-circuit channels. The efficiency $\eta_{\bar{p}i}$ of these photomultipliers to antiprotons was determined indirectly, with the aid of the negative pions in the same beams, and the index of refraction of the radiator ($n = 1.390$) was chosen such as to simulate the identical conditions of the amount and gathering of the light (see Table I). When several photomultipliers are connected in a coincidence circuit, the values of $\eta_{\bar{p}i}$ are multiplied (see Table II). Generally speaking, in the presence of an inhomogeneity in the gathering of the light over the volume of the radiator, the registration of a single particle by several photomultipliers does not represent independent events. This appears in particular in the case of small Cerenkov-counter efficiences $\eta_{\pi i}$ ($n = 1.430$) to negative pions ($\eta_{\pi i}$ is the efficiency of the i-th photomultiplier to pions).

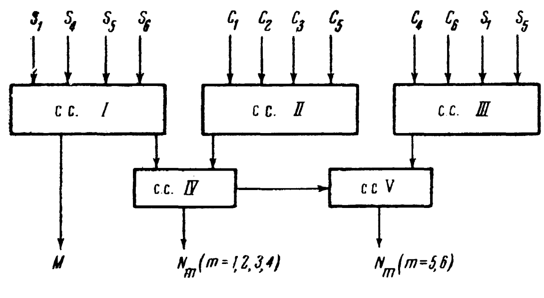

FIG. 2. Block diagram of the electronic circuitry. c.c. I, II, III – four-fold coincidence circuits with $\tau = 1 \times 10^{-8}$ sec; c.c. IV, V – two-fold coincidence circuits with $\tau = 5 \times 10^{-7}$ sec.

*A description of the counter will be published in the journal Приборы и техника эксперимента (Instruments and Measurement Engineering).

TABLE I

No. of photo-multiplier	1	2	3	4	5	6
$\eta_{\bar{p}i}$, %	89±0.5	88±0.5	91±0.5	94±0.5	86±0.7	72±1
$\eta_{\pi i}\cdot 10^2$	5,7±0.2	4.2±0.2	8.5±0.4	11±0.4	4.4±0.2	—

TABLE II

Photomultipliers in the coincidence circuit	Experimental efficiency, %	Product of efficiencies, %	Photomultipliers in the coincidence circuit	Experimental efficiency, %	Product of efficiencies, %
1+2	73±2	78±1	1+2+3+4	66±2	61±2
3+4	83±1	85±1	1+2+3+5	—	64±2
1+2+4	69±1	69±1.5	1+2+3+4+5	—	53±2.5
			1+2+3+4+5+6	—	38±3

TABLE III

Photomultipliers in the coincidence circuit	1+2	3+4	1+3	2+4	3+5
Experimental efficiency of the two photomultipliers to pions (×10³)	5.5±0.3	12,5±0.5	4.6±0.4	4.5±0.3	3,9±0.5
$\eta_{\pi i}\eta_{\pi j}\cdot 10^3$	2.4±0.2	9.3±0.7	4.8±0.4	4.6±0.4	3.7±0.3

TABLE IV

m	$\epsilon_{\bar{p}m}$, %	$\epsilon_{\pi m}\cdot 10^4$	$\alpha_m\cdot 10^4$	$\beta_m\cdot 10^4$	$n_{\bar{p}}\cdot 10^4$
1	90	600±200	600±200	—	—
2	80	80±40	80±40	—	—
3	70	5.3±0.3	6.7±1	—	—
4	64	0.51±0.03	1.22±0.04	0.71±0.05	1.10±0.08
5	53	0.03±0.01	0.53±0.04	0.50±0.04	0.95±0.1
6	38	0.002	0.35±0.07	0.35±0.07	0.92±0.22

It is seen from Table III that the multiplication takes place only in the case of photomultipliers taken from different counters (1 + 3; 2 + 4; 3 + 5).

A block diagram of the electronic apparatus is shown in Fig. 2. The coincidence circuit I counts all the particles passing through the counters (M). Connected in coincidence circuits II and III are m (from 1 to 6) photomultipliers from the Cerenkov counters. Here $N_m/N = \alpha_m$ is the relative count of the circuits, $\alpha_m - \epsilon_{\pi m} = \beta_m$ is the relative count of the antiprotons, $\epsilon_{\pi m}$ the efficiency of m photomultipliers to pions, $\beta_m/\epsilon_{\bar{p}m} = n_{\bar{p}}$ is the relative number of antiprotons in the beam, $\epsilon_{\bar{p}m}$ the efficiency of m photomultipliers to antiprotons.

It is seen from Table IV that α_m first decreases in proportion to $\epsilon_{\pi m}$ (m = 1, 2, 3) and then, as the relative count acquires a larger number of antiprotons, α_m varies as $\epsilon_{\bar{p}m}$. The ratios β_5/β_4 (70 ± 11)%, β_6/β_5 (66 ± 18)% give the efficiencies of the fifth and sixth photomultipliers to antiprotons. Within the limits of errors, these efficiencies coincide with the efficiencies determined with pions at n = 1.390.

The efficiency of this system to antiprotons is thus 60 — 40%. The corresponding suppression of pions amounts to $2 \times 10^4 - 5 \times 10^6$.

3. CONTROL EXPERIMENTS

1. One of the proofs that the particles separated are antiprotons and not an excess count due to negative pions is that the ratios β_5/β_4 and β_6/β_5 coincide with efficiencies to antiprotons.

2. When the index of refraction of the radiator is increased so that the light radiated by the antiproton experiences total internal reflection from the separation boundary, the efficiency of the counter to $\bar{p}$ and π mesons becomes approximately equal. Actually, when a radiator with a large index (n = 1.54) was placed in one of the Cerenkov counters (C_3), the relative count β_5 was reduced by a factor of approximately 12. This indicates that in this case $\eta_{\bar{p}5}$ became equal to approximately 7%, i.e., approximately the same as $\eta_{\pi i}$ for a radiator with n = 1.430.

3. When the energy of the accelerated protons is reduced to 6.3 Bev, particles with 2.8 Bev/c momentum enter into the channel, leaving the tar-

TABLE V

Angle, degrees	Target	Intensity of proton beam	No. of particles in channel per pulse	Relative number of antiprotons in beam $n_{\bar{p}}$
0	Be	10^9	1000	$(1.03\pm0.13)\cdot10^{-4}$
7	Be	10^9	$\sim$700	$(1.37\pm0.18)\cdot10^{-4}$
7	Cu	10^9	$\sim$700	$(2.42\pm0.53)\cdot10^{-4}$

get at an angle $\gtrsim 12°$. The number of antiprotons among them should be very small.[1] The relative number of antiprotons, obtained in this experiment, was $n_{\bar{p}} \leq 3 \times 10^{-6}$.

4. RESULTS

The system described yielded the ratio of the number of $\bar{p}$ with momentum (2.8 ± 0.15) Bev/c to the number of remaining particles (essentially negative pions) from a beryllium target (36 g/cm^2) at angles of 0 and 7° and from a copper target ($\sim$ 180 g/cm^2) at an angle of 7° to the beam of incident protons, accelerated to 8.1 — 8.9 Bev (Table V). At an internal beam intensity of 10^9 p, the apparatus counted on the average one antiproton every four minutes.

5. DISCUSSION OF THE RESULTS

1. The number of particles in the channel agrees with the data on the interaction of 9-Bev protons, obtained in emulsions.[4]

2. The increase in $n_{\bar{p}}$ upon going from 0 to 7° in the laboratory system is in accordance with predictions based on spectra of particles, calculated by statistical theory.[2,3]

3. Considering the absorption of pions ($\sigma_t \sim 30$ mb) and antiprotons ($\sigma_t \sim 60$ mb) and the attenuation of the beam of primary protons ($\sigma_{in} \sim 30$ mb), we obtain the ratio of differential cross sections of the creation of antiprotons and negative pions with momentum 2.8 Bev/c at an angle of 0° in the laboratory system in beryllium:

$$\frac{d^2\sigma_{\bar{p}}}{d\Omega dp} \Big/ \frac{d^2\sigma_{\pi}}{d\Omega dp} \approx 1.5\cdot10^{-4}.$$

In conclusion, the authors consider it their pleasant duty to express their gratitude to the entire staff of the Proton Synchrotron Division for attention and for careful work.

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[1] O. Chamberlain et al., Nuovo cimento **3**, 447 (1956).

[2] Barashenkov, Belyakov, Bubelev, Wang, Shu-Fen, Maltsev, Ten Gin, and Tolstov, Joint Institute for Nuclear Research, Preprint P-218, 1958.

[3] Zubarev, Mukhin, and Semenyushkin, Joint Institute for Nuclear Research, Preprint P-302, 1959.

[4] V. Beliakov et al., Proceedings of the Annual International Conference on High-Energy Physics at CERN, p. 309, 1958.

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