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# RELATIVE YIELDS OF 25 GeV/c K - MESONS, ANTIPROTONS, AND ANTIDEUTERONS FROM THE INTERACTION OF 70 GeV PROTONS WITH NUCLEI

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S u m m a r y

The yields of kaons, antiprotons and antideuterons from beryllium, aluminium, copper and tungsten relative to those of pions have been measured at the Serpukhov proton synchrotron. The experiment has been performed in a 25 GeV/c beam of negatively charged particles produced by 70 GeV protons on the internal target at angles of 0 and 12 mrad. The relative yields

$$R_{K^-,\bar{p},\bar{d}} = \frac{d^2\sigma_{K^-,\bar{p},\bar{d}}/d\Omega\, dp}{d^2\sigma_{\pi^-}/d\Omega dp} \qquad (25\ \mathrm{GeV/c})$$

depend weakly on the atomic weight of the target and are

$$R_{K^-} \sim 6\times 10^{-2},\quad R_{\bar{p}} \sim 1\times 10^{-2}\quad \text{and}\quad R_{\bar{d}} \sim (6\div 8)\times 10^{-7}$$

in the investigated range of nuclear masses.




While searching for new particles and antinuclei[1,2] a large amount of antideuterons ($7.6\times 10^4$ $\bar{d}$) ) produced by 70 GeV protons on Be, Al, Cu, and W nuclei has been detected and the relative counting rates of kaons and those of antiprotons have been measured as well. This paper presents the relative yields $R_{\bar{d}}$, $R_{K^-}$ and $R_{\bar{p}}$ ($R_i = \frac{d^2\sigma_i/dpd\Omega}{d^2\sigma_{\pi^-}/dpd\Omega}$) for the nuclei listed as obtained by the mentioned data.

The experiment was performed by using the 25 GeV/c beam of negative secondaries produced by 70 GeV protons at an internal target of the IHEP proton synchrotron at $0^{\circ}$ to the primary beam direction*. The experimental layout is shown in Fig. 1. It included a scintillation telescope (a monitor) detecting particles passing through the beam channel (the event $M = S_1 \cdot S_2 \cdot \ldots \cdot S_7$), gas threshold Cherenkov counters $C_1$-$C_4$[3], a time-of-flight spectrometer (TOF)[4] and a multichannel Cherenkov counter (MCC)[5]**.

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*Some measurements have been made at 12 mrad.

**The differential Cherenkov counter was tuned to detect $^3\bar{H}$ nuclei.

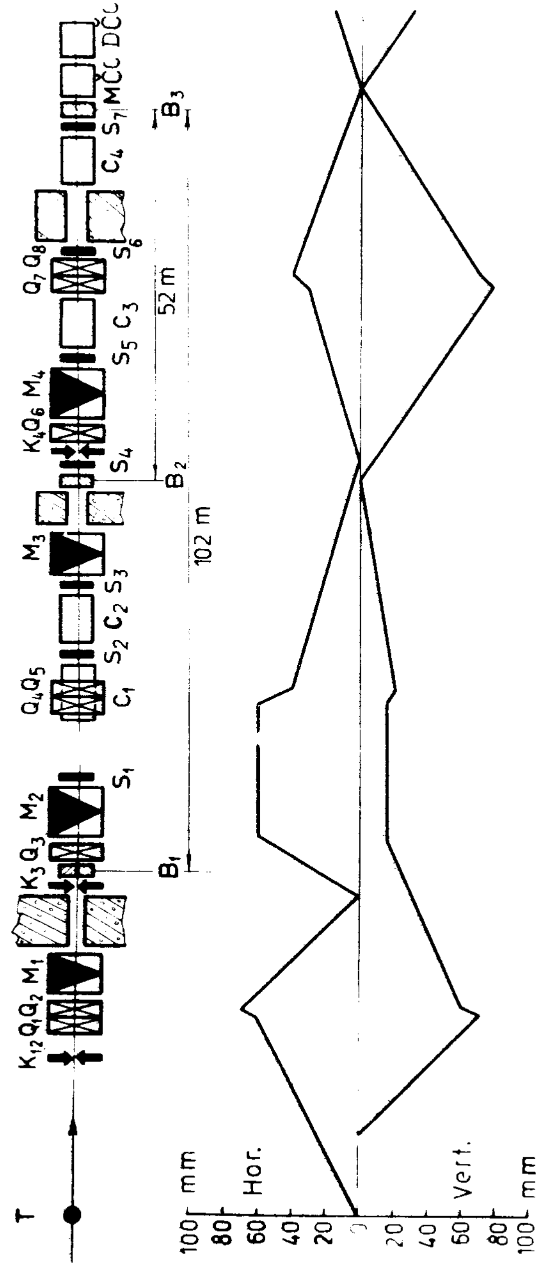


Fig. 1. Layout of the detectors in the 4B beam channel and the computed beam profile. T is the accelerator internal target, K are collimators, Q are quadrupoles, M are bending magnets, S are scintillation counters, C are threshold Cherenkov counters, B are time-of-flight counters, MČC is the multi-channel Cherenkov counter; DČC is the differential Cherenkov counter.



The details of the setup have been published elsewhere /1/.

Two threshold Cherenkov counters $C_1$ and $C_3$ were linked into anticoincidence with the monitor telescope, the $\pi^-$, $K^-$ and $\bar{p}$ counting rates being suppressed to the level of $10^{-6}$. In addition to $M\bar{C}_1\bar{C}_3$ events some M events (5-6 per busrt) were recorded as sampled by a blocking circuit. The bulk of these events (about 96%) corresponds to the passage of pions through the detectors. They were used for checking the experimental conditions and for calibrating the units of the setup, in particular, to determine the efficiency of particle selection by TOF.

In order to determine the $K^-$ and $\bar{p}$ yields we measured the dependence of the relative counting rate $M\bar{C}_1\bar{C}_3/M$ (the suppression factor) on gas (freon-12) pressure in Cherenkov counters, $C_1$ and $C_3$. These measurements were performed for each target used (except a beryllium one). The results of the measurements are shown in Fig. 2.

Antideuterons were identified by the time-of-flight and by the radius of the Cherenkov radiation ring in MČC. The time-of-flight was measured on a 102 m path length (the time intervals, $T_1$ and $T_2$ ). The TOF resolution was better than 0.3 ns for all three path length. The following selection criteria were applied to determine the number of antideuterons from the time-of-flight spectra of $M\bar{C}_1\bar{C}_3$ events:

1. The particle hits the TOF counters forming a "proper pattern", i.e., $B_2$, $B_3$, and either of $B_1$ halves must be hit. This criterion rejects obvious background events

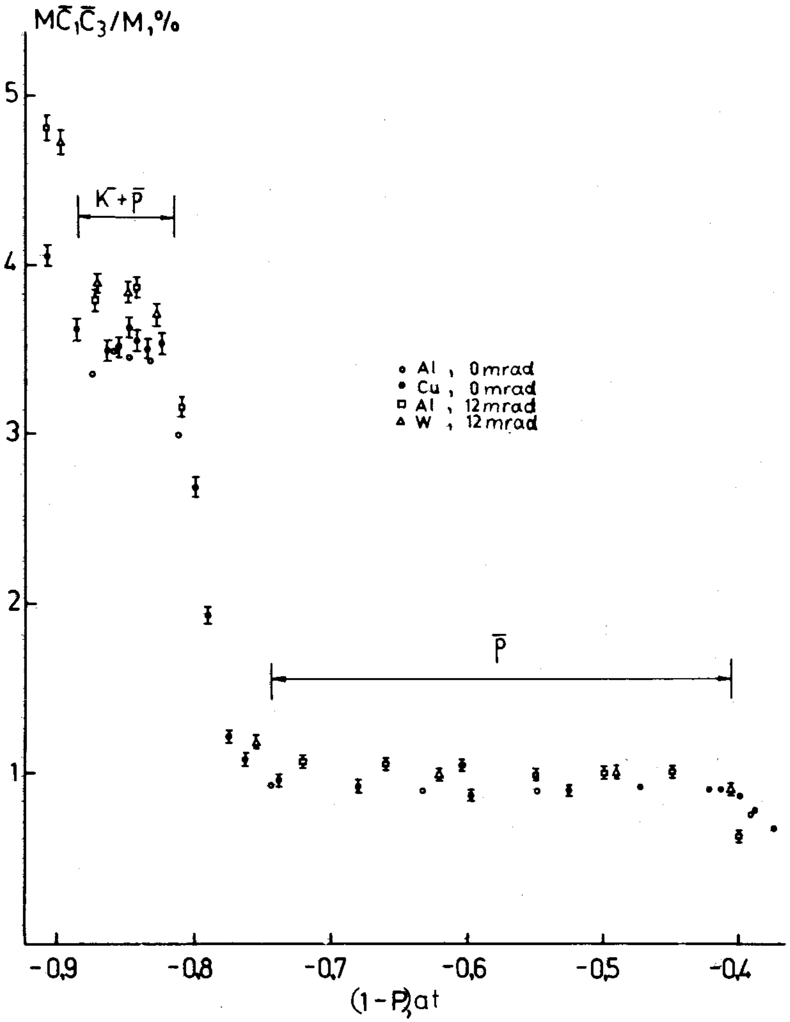


Fig. 2. Pressure curves for the counters $C_1$ and $C_3$.

and fairly well decreases the number of events caused by the simultaneous passing of two or more particles through the TOF counters.

2. The difference $\Delta T = |T_1 - T_2|$ does not exceed 1.2 ns.

The time-of-flight spectra of selected $M\bar{C}_1\bar{C}_3$ events show a clear antideuteron peak observed at a distance of 0.9 ns from the pion time mark (Fig. 3) with no remarkable background. Spectra of the radii of Cherenkov radiation rings in MČC for $M\bar{C}_1\bar{C}_3$ events look similar (Fig. 4). Light from pions does not meet the cathode of MČC photomultipliers being cut off with a blind.

When determining the antideuteron yield in addition to corrections for the efficiency of the selection criteria one should take into account the antideuteron loss caused by the random anticoincidences in Cherenkov counters $C_1$ and $C_3$. For estimating the random anticoincidence correction the monitor telescope signal was periodically (once per hour) delayed with respect to signals from Cherenkov counters by about 100 ns. In this case the ratio $(M - M\bar{C}_1\bar{C}_3)/M$ is equal to the fraction of the $M\bar{C}_1\bar{C}_3$ events lost due to random coincidences. The value of this ratio depends on beam intensity and is about 0.20 (the mean weighted value). The $K^-$, $\bar{p}$ and $\bar{d}$ relative yields for different targets were computed taking into account the differences in particle absorption along the channel and those in particle decay rates. The results are shown in Fig.5 and Table 1. As is seen from Fig.5, the relative yields do not vary within the limits of er-

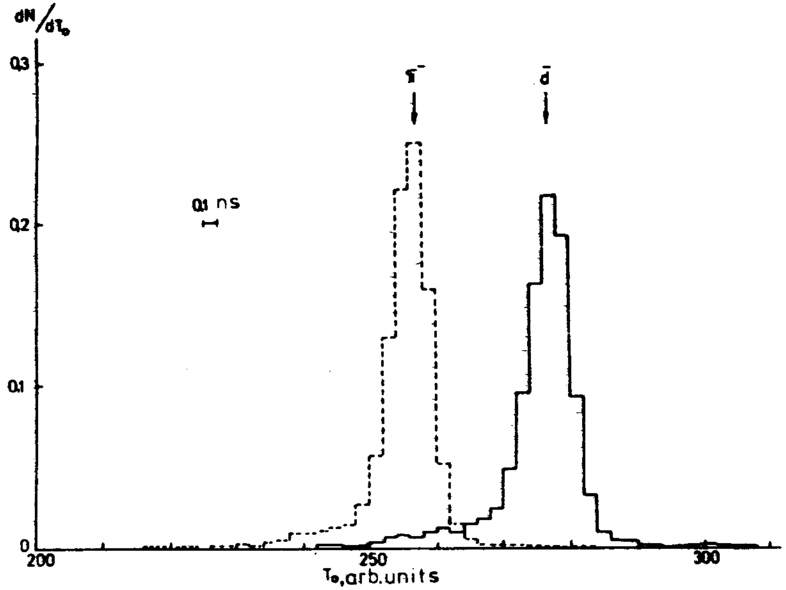


Fig. 3. Time-of-flight spectrum for $M\bar{C}_1\bar{C}_3$ events (the full line). For comparison the time-of-flight distribution of pions is also shown (the dashed line).

rors with the increase of the mass of a target nucleus.

Earlier an approximate constancy of the ratio $C = R_{\bar{d}}/R_p^2$ was observed in experiments [6-12] performed at primary proton energies from 30 to 1500 GeV for secondaries produced in a wide angular and momentum range, and on various nuclei including hydrogen (proton colliding beams [6,7]). The value of C varies by a factor of 2-3 while $R_{\bar{d}}$ varies by more than two orders of magnitude. The results of the present paper (Table 2) are in good agreement with the data obtained in the investigations mention-



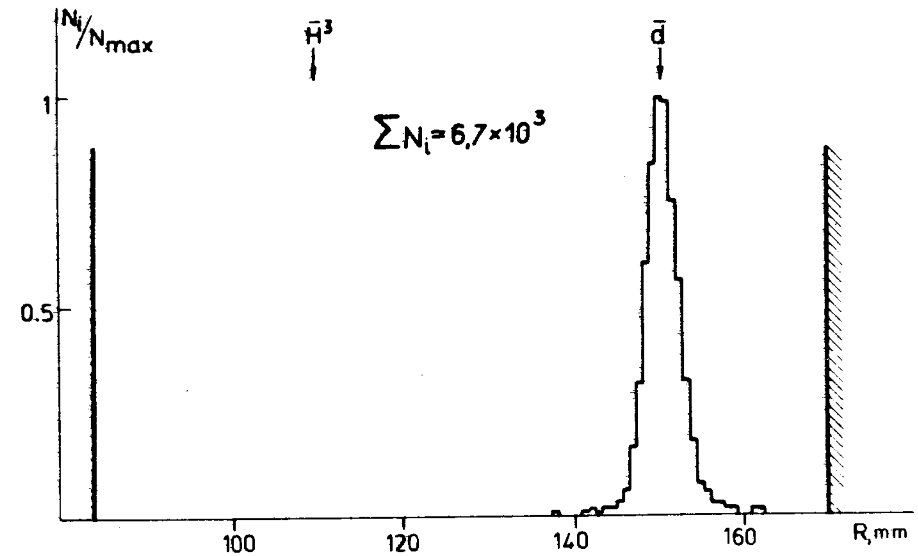


Fig. 4. Cherenkov ring spectrum for $M\bar{C}_1\bar{C}_3$ events in MČC. The shaded lines are the boundaries of measurement ranges from blinds in front of the cathodes of the MČC photomultipliers.

ed above, including the IHEP one [9], where antideuteron yields have been measured on an Al target under the same kinematical conditions as ours (70 GeV primary protons, the 25 GeV/c momentum of the secondary beam, the production angles of 0 and 12 mrad).

The constancy of the ratio C may be explained as follows. Since the antideuteron is a weakly bound state of two antinucleons one may expect the antideuteron to be produced from antinucleons with the small relative momenta of the order of $\sqrt{m_N \epsilon}$ and, hence, with the relative velocities $V \sim \sqrt{\epsilon/m_N}$,

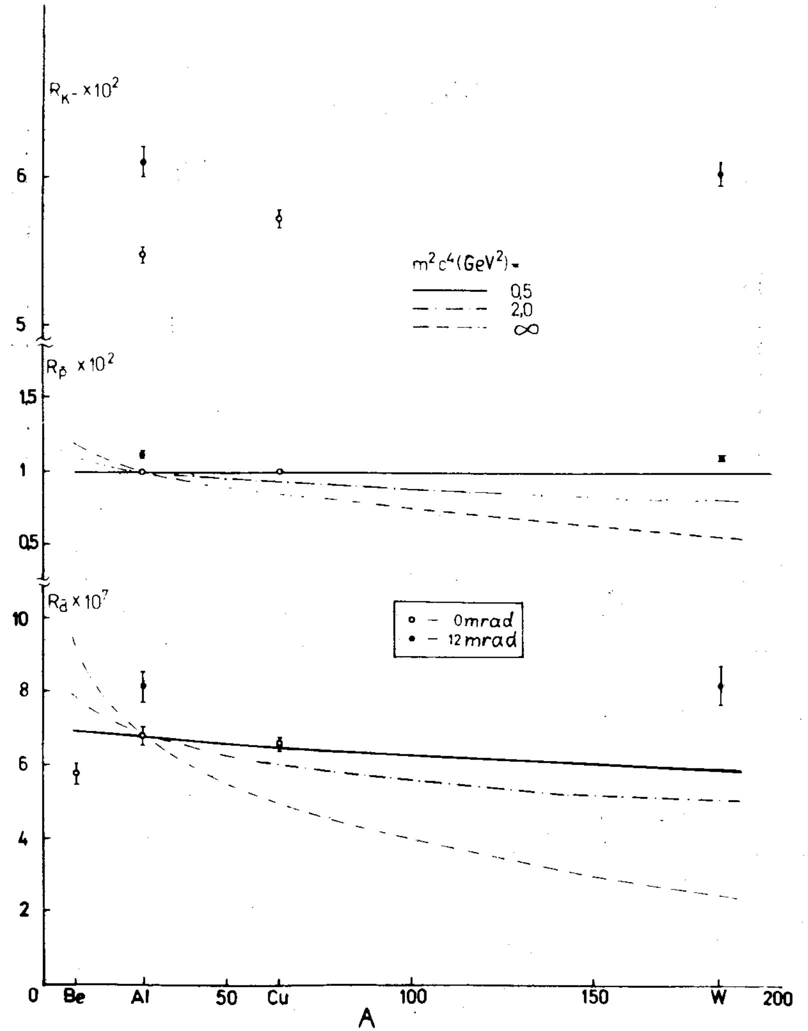


Fig. 5. Relative kaon, antiproton and antideuteron yields versus the mass of the target nucleus.



where $\epsilon$ is the antideuteron binding energy, $m_N$ is the antinucleon mass, $\hbar = c = 1$. In the antideuteron rest system antideuteron production requires time at least of the order of that needed for the antinucleon to cover the distance equal to the antideuteron diameter $2r_{\bar{d}} \sim 2\sqrt{\epsilon m_N}$. Hence, in the target nucleus system the antinucleons must pass a longitudinal distance of about $\delta z \sim p_{\bar{d}}/(m_N \epsilon) \approx$ $\approx (100 \times p_{\bar{d}})$ fm, where $p_{\bar{d}}$ is the $\bar{d}$ momentum in GeV/c, to produce the antideuteron. As these distances exceed nuclear dimensions at all the momenta of interest, the antideuteron yield depends on the number of antinucleon pairs outside the nucleus only. In the case of independent antinucleon production (e.g., if at a given momentum the number of antinucleons per pion follows the Poisson distribution) the observation probability of an antinucleon pair is proportional to $R^2_{\bar{p}}$ $(R_{\bar{p}} \ll 1)$. This estimation explains the approximate constancy of the ratio C and its dependence on the mass of the target nucleus.

The fact that antiproton and antideuteron yields themselves do not depend on the mass of the target nucleus seems to be more interesting. This may imply that considerable time is required not only for antideuteron production from antinucleons but for antinucleon production as well. In fact, a 12.5 GeV/c antinucleon produced in the first collision of an incident proton inside the nucleus should travel 10 interaction free path length in a tungsten nucleus while a pion should travel only 5 ones. Thus, it would be quite natural to expect the fast decrease of the relative yields with increasing the radius of the target nucleus. However, if hadrons are produced after a time $\tau \sim k/m^2$ only via partons not interacting with nuclear matter [13] ($k$ is the hadron momentum and $m$ is an effective mass related with the parton mass), the dependence of $R_{\bar{p}}$ and $R_{\bar{d}}$ on the mass of the target nucleus is reduced. For example, if $k$ and $m^2$ are equal to $\simeq (10\text{-}15)$ GeV/c and $\simeq 1\text{-}2 (\text{GeV}/c^2)^2$, respectively, then for antiprotons $\tau$ corresponds to the longitudinal distance $\delta z \simeq (1\text{-}3)$fm, which is equal or longer than the antiproton interaction length in nuclear matter. As a result, the nuclear absorption of secondary antinucleons is reduced. The dependence of the relative yields $R_{\bar{p}}$ and $R_{\bar{d}}$ on the nuclear mass, expected by the model [13] is shown in Fig. 5 for $m^2 = 0.5$ and $2\ (\text{GeV}/c^2)^2$.

The results of calculation for $m^2 = \infty$ when the production of all particles is considered to be instantaneous are also indicated for comparison. In these calculations the relative yield on aluminium has been assumed to be unity. The experimental results (except that for Be) may be quite well approximated by the theoretical curves with an $m^2c^4$ value equal to 0.5 GeV$^2$ (the full line in Fig. 5). It should be mentioned, however, that a similar analysis of lepton-nuclear interaction [14] leads to the value exceeding one nucleon mass.



Table 1

| Target | Angle (mrad) | $R_{K^-}(10^{-2})$ | $R_{\bar{p}}(10^{-2})$ | $R_{\bar{d}}(10^{-7})$ |
|---|---|---|---|---|
| Be | 0 | - | - | $5.7 \pm 0.2$ |
| Al | 0 | $5.48 \pm 0.02$ | $0.993 \pm 0.005$ | $6.8 \pm 0.2$ |
| Cu | 0 | $5.73 \pm 0.05$ | $0.998 \pm 0.006$ | $6.6 \pm 0.1$ |
| Al | 12 | $6.12 \pm 0.10$ | $1.128 \pm 0.014$ | $8.1 \pm 0.4$ |
| W | 12 | $6.07 \pm 0.09$ | $1.121 \pm 0.020$ | $8.2 \pm 0.6$ |

Table 2

| $E_0$ (GeV) | Tar-get | $P_{\bar{d}}$ (GeV/c) | $\langle x_{\bar{d}} \rangle = 2P_L/\sqrt{s}$ | $\langle P_\perp \rangle$ (GeV/c) | $R_{\bar{d}}(10^{-6})$ | $R_{\bar{d}}/R_{\bar{p}}^2 (10^{-3})$ | Refs |
|---|---|---|---|---|---|---|---|
| 30 | Be | 5 | 0.20 | 0.4 | 0.055 | 1.5 | /8/ |
| 43 | Al | 15.5 | 0.24 | 0 | 0.20 | 2.4 | /9/ |
| 70 | Al | 13.3 | 0.03 | 0.6 | 3.9 | 3.4 | /10/ |
| | | 25.1 | 0.28 | 0 | 0.60 | 4.9 | /9/ |
| | | 25.1 | 0.28 | 0.3 | 0.79 | 4.0 | |
| | | 39.1 | 0.51 | 0 | 0.05 | 6.5 | |
| 300 | W | 24.5 | 0.01 | 0 | 4 | 10.0 | /11/ |
| | | 34.2 | 0.06 | 0.2 | 11 | 6.9 | |
| | Be | 80.0 | 0.24 | 0.2 | 2.4 | 6.0 | /12/ |
| 1500 | P | | 0.02 | 0.7 | 50.0 | 5.0 | /6/ |
| | coll.beams | | 0.2 | 0.2 | 7.6 | 7.9 | /7/ |
| 70 | Al | 25.1 | 0.28 | 0 | 0.68 | 6.9 | present |
| | | 25.1 | 0.28 | 0.3 | 0.81 | 6.4 | paper |
| | Cu | 25.1 | 0.28 | 0 | 0.66 | 6.6 | -"- |
| | W | 25.1 | 0.28 | 0.3 | 0.82 | 6.5 | -"- |



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