DEUTERON BEAMS AT THE 200-BeV ACCELERATOR

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ABSTRACT

The available experimental information on production of high-energy deuterons is examined for the prospects of deuteron beams at the 200-BeV accelerator. The surprisingly copious production of high-momentum deuterons observed in collisions of 25-BeV protons with other protons or with complex nuclei indicates that deuteron beams should be available with intensities roughly of the order of antiproton beam fluxes.

I. INTRODUCTION

Beams of high-energy deuterons will be of interest to study such interactions as d-d elastic scattering, N^* production and other inelastic processes from d-p interactions, as well as providing via the stripping mechanism an intense source of collimated monoenergetic high-energy neutrons. In this note we examine the limited experimental information available and find that beams of high-energy deuterons should be possible at a 200-BeV accelerator.

II. DIRECT ACCELERATION OF DEUTERONS

It should be mentioned first of all that there appears no reason why deuterons cannot be accelerated directly in the accelerator. According to L. Teng, the necessary modification would be to extend the frequency modulation during the acceleration cycle so that it covers the additional range needed for deuteron acceleration. In this way very intense primary deuteron beams of maximum momentum of 200 BeV/c or stripped neutron beams of 100 BeV/c would be available. However, since it is unlikely that interest in deuterons will justify such monopolization of the accelerator, it is of interest to examine the possibility of secondary deuteron beams from interactions of the primary protons with a hydrogen target or with complex nuclei.

III. DEUTERONS FROM PROTON-PROTON INTERACTIONS

In view of the deuteron's small binding energy, it is surprising how prolific deuteron production is in proton-proton and proton-nucleus collisions. Deuteron

production from proton-proton collisions has been studied from 1 to 3 BeV by Heinz et al., and Pellett [1] from 3 to 12 BeV by Anderson et al., [2] and at 21 BeV by Allaby et al. [3] The two-body reaction $p + p \rightarrow d + \pi^+$ has been studied in most detail. The differential cross section peaks in the forward direction but the total cross section exhibits strong-energy dependence falling like $\sigma \sim s^{-4}$ with s, the square of the center-of-mass energy, and is 0.015 μ barns at 21-BeV incident energy. The cross section for $p + p \rightarrow d + \rho^+$ is small at low energies but by 21 BeV this cross section equals that for $p + p \rightarrow d + \pi^+$. Less is known about multi-body final states $p + p \rightarrow d + X^+$. At 3 GeV it has been observed that these processes result in high-momenta deuterons peaked in the forward direction.

The most important experimental evidence relating to the possibility of deuteron beams at high energies is the deuteron momentum spectrum measured at the fixed angle of 40 mrad for 21-BeV incident protons. [3] This spectrum, sketched in Fig. 1, has a maximum at deuteron momentum of about 10 BeV/c and falls an order of magnitude by 19 BeV/c. The cross section for 10 BeV/c deuterons is about 10^{-28} cm^2/sr - BeV/c and is an order of magnitude larger than that for the production of antiprotons at the same laboratory angle and secondary particle momentum.

IV. DEUTERONS FROM PROTON-NUCLEUS INTERACTIONS

The information about deuteron production for complex nuclei comes from CERN[4] and AGS[5] beam surveys. Indeed the surprise of the first beam survey at CERN was the large number of deuterons observed with high momenta and at large angles. Most of these surveys of secondary particle production were made at large angles, $\geq 13°$, and for low momenta secondaries.

The general features of deuteron production observed for 25-30 BeV proton collisions on such targets as beryllium, aluminum, iron, and platinum are the following: 1) copious production of deuterons at angles larger than kinematically allowed from p - p collisions (including Fermi momenta of target nucleons) indicating nuclear effects play a major role in the deuteron production; 2) the deuteron/proton ratio at a given angle is independent of deuteron momenta and; 3) there is only weak dependence of the d/p ratio on the atomic number of the target. At angles of 12 - 16° the d/p ratio is about 2% for deuterons of 2 - 8 BeV/c from aluminum and about 3% from platinum.

At 13° deuteron and antiproton production are about equal in the secondary-particle momentum region studied, 1.5 to 5 BeV/c. The smallest angle, highest momentum deuteron production reported is 18 BeV/c deuterons at 3° from aluminum with $d/p = 10^{-3}$ and $d/\pi^+ = 0.05$ for 25-BeV incident protons. As a final piece of evidence there is the observation by those studying the high-energy deuterons from the reaction $p + p \rightarrow d + \pi^+$ of a considerable target-empty contribution, presumably from

interactions in the carbon in the mylar target. There clearly is substantial production of high-energy deuterons at the highest energies presently studied although it is an open question how the production holds up at much higher energies.

V. PRODUCTION OF ALIGNED DEUTERONS

For completeness, it should be mentioned that a mechanism has been suggested by which aligned deuterons should result from diffraction d - p elastic scattering. In p - d elastic scattering there is a region of momentum transfer where single and double scattering contributions interfere, and in this region the D-wave component is very important, turning what would otherwise be a definite dip in the differential cross section into a shoulder. Harrington[6] has argued that this effect should result in the production of strongly aligned deuteron beams from d, p elastic scattering at momenta transfers of the order of 0.3 and 0.4 $(\mathrm{BeV}/c)^2$. Since this is essentially a diffraction phenomena, the effect should hold up for high energies. At 2 BeV the differential cross section at these momenta is about 0.1 mb/sr. Experiments have not been done so far to verify if this effect indeed exists. It is not clear in what way beams of aligned deuterons might prove useful in high-energy physics.

VI. CONCLUSIONS

The surprisingly copious production of high momentum deuterons observed from collisions of 25-BeV protons with other protons or with complex nuclei indicate that beams of high momentum deuterons may be available at a 200- BeV accelerator. The fluxes anticipated can be estimated as being of the order of antiproton beam fluxes, i.e. 10^5 - 10^6 deuterons/pulse with 5% momentum resolution. Deuterons can easily be identified by a DISC counter or can go through an rf separator. It also appears likely that bubble-chamber intensity beams of aligned deuterons can be made by d, p elastic scattering. The study of deuteron production at the higher energies will be of interest in itself in order to understand the mechanism responsible. Beams of high-energy deutrons should be possible at NAL. The open question is of how high momentum.

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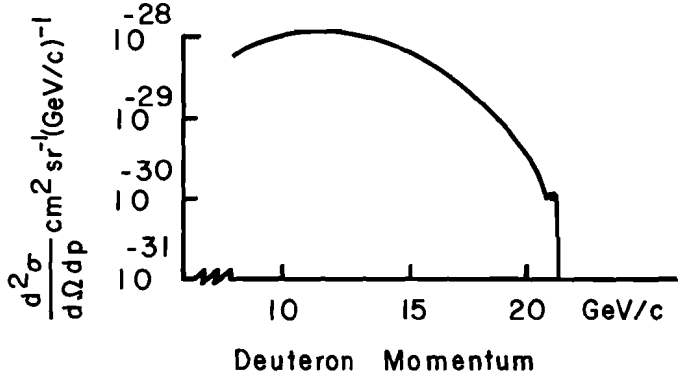

Fig. 1. The deuteron spectrum at a production angle of 40 mrad, from 21-GeV p-p collisions (see Ref. 3).