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THE FIRST EXPERIMENT USING THE CERN SLOW EXTRACTED PROTON BEAM : PARTICLE PRODUCTION IN 19.4 GeV/c PROTON - PROTON INTERACTIONS

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I. INTRODUCTION

As a first experiment for the slow extracted proton beam (e_2) from the C.P.S. it was decided to measure, at 25 mrad laboratory production angle, the momentum spectra of p, $\bar{p}$, $\pi^{\pm}$, $K^{\pm}$ and d produced by 19.4 GeV/c protons interacting in hydrogen.

The experimental results described in this note were obtained between October 1965 and February 1966 during three 5-day periods of test running of the e_2 beam. For most of this time only 1 pulse in 10 of the C.P.S. was available for extraction. Much of the data was obtained, however, during Health Physics surveys of the e_2 beam when, for rather brief periods, all pulses were given to extraction. We are very grateful to J. Freeman (M.P.S.) and the Health Physics group for the use of the beam during these periods.

The magnetic spectrometer and associated detectors used in the experiment were finally well adjusted and ready to take definitive data only towards the end of the 3 test weeks. Unfortunately, owing to a major breakdown of the accelerator and the subsequent re-arrangement of the experimental schedule and beam layout, the experiment was dismantled before it had run well for any reasonable amount of time. The experiment as it was conceived, a refined survey of secondary particle production in p - p collision near the forward direction, will not now be finished at CERN for more than a year, if ever. It is for this reason that the present preliminary results are presented in this note.

The experimental method was based on a spectrometer that combined a high resolution momentum analysis with a high resolution velocity measurement. Momentum analysis was performed using standard dipole and quadrupole magnets. Very accurate velocity measurements were made, using a DISC differential gas Cerenkov counter ($\frac{\Delta\beta}{\beta} \geq 5 \cdot 10^{-6}$). Two threshold gas Cerenkov counters were used in circumstances when the high velocity resolution of the DISC was not needed. They were also included in the coincidence signature to provide additional rejection power in conditions of the worst background.

II. EXPERIMENTAL LAYOUT

The experimental layout is shown in Fig. 1. The slow ejected proton beam$^{1)}$ (e_2 beam) in the East Hall of the CERN proton synchrotron installation bombarded a liquid hydrogen target, 10 cm long. The incident proton momentum was 19.40 GeV/c. The particles produced at a lab angle of 25 mrad were momentum analysed, using a magnetic spectrometer and velocity analysed by means of two threshold gas Cerenkov counters$^{2)}$ and a high resolution differential gas Cerenkov counter (DISC)$^{3)}$.

The magnetic spectrometer was built up from standard elements and consisted of a quadrupole doublet Q_1 , Q_2 , a dispersive element composed of four 2 m bending magnets in series M_1 , M_2 , M_3 and M_4 , and a further quadrupole doublet Q_3 , Q_4 . The spectrometer was designed in such a way as to give an image of the target both horizontally and vertically (point-parallel-point focusing), with horizontal and vertical magnifications of 0.80 and 0.62, respectively. On the image plane, which made an angle of about 3° with respect to the beam axis, the five scintillation counters B_1 , B_2 , B_3 , B_4 and B_5 were placed, displaced from each other, normal to the beam, by 10 mm. The solid angle accepted by the system was determined by the circular collimator CA . It was calculated to be 16.2×10^{-6} sterad . The bending angle produced by the four elements in series was 200 mrad.

The projected momentum dispersion at the image plane was calculated to be 4.31 cm for $\frac{\Delta p}{p} = 1\%$. The momentum calibration of the spectrometer was made to a precision of 0.1%, by the floating wire method. The beam was transported in vacuum through the whole system, except inside the bending magnets where a helium-filled bag was used. The five scintillation counters A_1, A_2, A_3, A_4 and A_5 were placed 5 m upstream of the counters B, each one covering the solid angle accepted by the corresponding B counter. The two-fold coincidence A_iB_i provided five independent channels for momentum analysis. Counters A were 2.5 cm wide and 7.5 cm high and counters B were 0.8 cm wide and 1.2 cm high.

For velocity selection, two threshold Cerenkov counters[2] C_1 and C_2, and a high resolution differential Cerenkov counter DISC[3], described in the next section, were used. The gas used for filling the counters C_1 and C_2 was either hydrogen or ethylene depending on the kind of particles to be detected. The logic of the electronics was designed in such a way that it was possible to use C_1 and C_2 either as coincidence or as veto counters.

The hydrogen target[4] was 10 cm long, 4 cm diameter and had stainless steel windows of 0.02 mm thickness. The target was remotely controlled and was filled automatically. The vacuum box that contained the target extended about 8 m downstream and 2 m upstream, so that its windows were not seen by the spectrometer. Inside the vacuum box a fluorescent screen, viewed by a closed circuit TV system, could be dropped into the ejected beam for monitoring its position and focusing. A second screen was placed just ahead of the beam stopper at the end of the incident beam, 52 m downstream from the target. At the target the spot size was 0.3 cm wide and 0.5 cm high, the beam divergence was 1 mrad horizontally, 0.5 mrad vertically, making the beam at the beam stopper about 5 cm wide and 2 cm high. The second screen was always in place during the runs, thus making a continuous observation of the beam position possible, while the screen in front of the target was normally out, and inserted only during adjustments of the beam. The spill time was usually about 100 msec and no appreciable R.F. structure was present.

The relative intensity of the incident beam was continuously monitored by means of a telescope of three scintillation counters in coincidence, facing the target at an angle of 83°.

The absolute intensity of the beam was measured by setting the magnets at the value corresponding to the momentum of the elastically scattered protons without exciting the quadrupoles. Using the square collimator CB in front of the first magnet, the accepted solid angle ($0.15 \cdot 10^{-6}$ sterad) was determined horizontally by the width of the slit collimator CB and vertically by the height of the B counters. With such a small solid angle, there was no counting rate loss in the electronics and from the known differential cross section for proton-proton scattering at the present energy[5] the intensity of the beam was evaluated and an absolute calibration of the telescope monitor was made. The intensity of the ejected beam was about $3 \cdot 10^{11}$ protons burst when the intensity of the internal beam of the proton synchrotron was $7 \cdot 10^{11}$ protons/burst, which implies an ejection efficiency of about 40%.

An example of the normal operation of the beam (collimator CB removed, quadrupoles excited) is given, for instance, by the spectrum shown in Fig. 10. The proton-proton elastic scattering peak is seen at the upper end of the momentum scale.

The overall momentum resolution was found to be about ± 40 MeV/c ($\frac{\Delta p}{p} = \pm 2 \cdot 10^{-3}$) and the dispersion obtained from the comparison of the counting rates in the five $A_i B_i$ channels agreed well with the calculated value. The system of the five channels allowed the detection of changes of momentum of the primary beam as small as ~ 10 MeV/c.

During the running time a check of the position of the proton elastic peak was often made in order to detect shifts in the momentum or position of the incident beam. The observed shifts were never larger, in a period of a few days, than those produced by a change of momentum of ≈ 30 MeV/c.

III VELOCITY ANALYSIS

1. The DISC Counter

DISC counters have been described elsewhere[3]. Parameters and properties that are essential to the present experiment will be briefly discussed here.

The actual gas DISC counter was a 2 m long differential Cerenkov in which optical and chromatic aberrations were corrected by an axiconic lens doublet. Cerenkov light was focused on an adjustable annular diaphragm. The value of the Cerenkov angle Θ was 44 mr. Charged particles of a given velocity β in the range 0.995 to 1 were detected when the refractive index was properly adjusted by varying the gas (CO_2 in this case) pressure to satisfy the Cerenkov relation $\cos\Theta = 1/n\beta$. n was measured and continuously controlled by electronic fringe counting in a permanently linked Rayleigh refractometer with a laser as a light source. Particle direction had to be inside a cone $\Delta\alpha$ about the counter axis. $\Delta\alpha$ was fixed by the iris diaphragm aperture as well as the velocity band with $\Delta\beta$ ($\Delta\alpha \times 0.044 \approx \Delta\beta$). The diameter of full efficiency of the counter was 10 cm, and was limited by two scintillating counters to this value.

High velocity resolution ($\Delta\beta/\beta \geq 5 \cdot 10^{-6}$) and self-collimation contributed to the very high intrinsic background rejection of the DISC, as illustrated in Fig. 2.

The experimental set-up (Fig. 1) provided a focus in the middle of the two pairs of quadrupoles Q_3, Q_4 and Q_5,Q_6. Such an arrangement reduced the problem of tracking these two pairs of quadrupoles for reparallelizing the beam in the DISC. In fact no time was devoted to the experimental setting of current in Q_5, Q_6 and calculated values were used. Not all the particles counted in counters A and B could be detected in the DISC or in the defining counter #1 and #2, although DISC efficiency was nearly 100% except when a pulse was required in coincidence from each of the nine photomultipliers viewing the diaphragm, for very tight collimation and background conditions. It dropped then to somewhere in the range 50% to 82,5% and this reflected the rough match between the spectrometer and DISC. Overall efficiencies will be reported further for the different cases.

The DISC high velocity resolution made possible a clear identification of the various long-lived charged particles $\mu^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$, $d^{\pm}$, ($\tau \geq 10^{-8}$ s) that could be produced by high energy proton collisions when the velocity measurement was made concurrently even with a moderately accurate momentum analysis. As a matter of fact, since

$$\frac{\Delta m}{m} = \sqrt{\left(\frac{\Delta p}{p}\right)^2 + \left(\gamma^2 \frac{\Delta \beta}{\beta}\right)^2}$$

for particles with a known mass, the factor γ^2 gives a strong dependence on mass and energy of the momentum resolution through velocity measurement. For 19 GeV/c deuterons, γ^2 is 10^2 and for 17 GeV/c pions it is $1.6 \cdot 10^4$. So with $\Delta\beta/\beta \sim 10^{-5}$, $(\Delta p/p)_{DISC}$ was 10^{-3} for 19 GeV/c deuterons and 0.16 for 17 GeV/c pions. Experimental results showed that the deuteron spectrum can already be measured with the DISC by itself and that it had to be supplemented with the momentum counters for the pion spectrum.

The velocity calibration of DISC counters had the property of being absolute, as a result of the design of the optics. The velocity was directly related to the refractive index of the gas. Refractometry by interference and electronic fringe counting was used.

The relation between velocity and the number of fringes was unique. It did not depend on the wavelength of the monochromatic light used in the refractometer (in our case, the red line of a He - Ne gas laser). This was a consequence of the achromatisation of the DISC counter which had the effect of improving the velocity resolution by more than one order of magnitude and of providing an absolute calibration free from errors, like temperature fluctuations, impurity of the gas.

The relation giving N , the number of fringes versus $(1-\beta)$, had been calculated by least square fit to ray-tracing through the useful volume of the counter, for various wave lengths, various positions of the mirror and the axicon.

This relation was for CO_2

$$N = 6046{,}43 + 5984300\,(1-\beta) + 10744000\,(1-\beta)^2 \qquad (1)$$

It was of the utmost importance to verify if such a relation derived from the optical properties of CO^2 and the measurement of the mechanical parameters of the optical elements gave consistent values with the velocity of particles calculated from their masses and the magnetic properties of the spectrometer.

It was also necessary to relate the numbers of fringes expected for any particle at any momentum with the momentum scale defined experimentally by wire measurements in order to eliminate possible systematic errors. This feature was important for the association of two high precision measurements (momentum and velocity), as it happened in the present case.

The check of this relation was made as follows. Different particles π^+, K^+, p at momenta defined by the magnetic spectrometer were sent through the DISC. Counting rate versus fringes counts was plotted to get a velocity curve for a given particle at a given momentum, chosen in the region of interest for the experiment (see Fig. 2). The deuteron region was simulated by protons of nearly half the momentum.

The error between the number of fringes observed, and the number calculated from the relation (1) is plotted in Fig. 3.

We found no systematic effect from the use of different kinds of particles for the check of the calibration. The residual error is $N = 16.5 \pm 16.5$ fringes. This error includes contributions from the magnetic measurement and systematic effects from transients in gas pressure as no time was devoted to wait for stabilization of the gas. If the gas was allowed to stabilize for 3 minutes, the error was reduced to 3.5 ± 16.5 fringes. The agreement between the theoretical relation (1) and the experimental results is particularly remarkable in view of the complete independence of the two methods.

This gave us confidence that the momentum scale and velocity scale were very well matched and excluded efficiency fluctuations of the complete set-up. This verification proved also that our velocity scale was absolute with an error not exceeding $\pm 2.75 \cdot 10^{-6}$ in β.

2. Experimental procedure

For the measurement of a spectrum data taking was going along the following procedure.

The momentum accepted by the spectrometer was varied in steps with the velocity of the DISC counter adjusted according to the relation (1).

The diaphragm opening was adjusted for a reasonable compromise between a wide acceptance in $\delta\beta$ and in angular divergence $\delta\alpha$ of the beam, and on the other side a good rejection of unwanted background.

In any case the width of the acceptance in $\delta\beta$ was much more than needed to insure constant efficiency even in case of a possible error in tracking.

Our settings were :

PARTICLE	DIAPHRAGM	WIDTH IN FRINGES	$\Delta\beta$
π^+	100	850	$\pm 1.4\,10^{-4}$
K^+	60	360	$\pm 0.6\,10^{-4}$
D	100	1120	$\pm 1.9\,10^{-4}$.

The choice of the opening of the diaphragm of the DISC was made from previous knowledge of the performance of this instrument and was not optimized to this particular experiment. The different values of diaphragm openings is reflected in the variable overall efficiency found for the spectrometer for different particles.

3. Electronics

The electronics associated with the DISC was of the type designed specifically for the application to high counting rates and low light levels. Emphasis had been put on the ease with which complicated logic can be installed and tested at any point. The small size of the units has enabled us to move our barrack during the course of the experiment without losing adjustment as the fast electronics fitted in a single rack.

From the DISC we extracted nine signals which were put simultaneously in parallel in groups of 3 and in groups of 2.

Coincidences were made as follows 3 × 3 called triple
4 × 1 simple quadruples
4 × 1 and 4 × 2 quadruples
8 × 1 octuples.

Each of these coincidences were also brought into coincidence with the defining counters D_1 and D_2 .

Altogether 10 different combinations of coincidences were available at any time. Between these combinations the rejection and the counting efficiency varied - fig. 2 -, but no loss of information resulted from this.

The comparison of the different counting rate enabled us to check the experiment during its course, and to estimate possible background contribution. This follows from the fact that the ratio of efficiency between Triples - Quadruples - Octouples must remain constant and equal to its peak value (as measured on clean particles as for example diffracted protons) throughout the complete spectrum. Coincidences between some of these outputs were made with counters A_2 B_2 - A_3 B_3 - A_4 B_4 and the threshold Cerenkov counters.

One particular point worth mentioning is the reduction of the background to a negligible level in this set-up, even with the hard beating of the diffracted protons. For example, 10 points were measured above the kinematic limits for K^+ production and 5 for π^+ and no count was registered. No background subtraction has been applied to the data.

4. Extracted beam energy and consistency of the data

There are two different ways of measuring the beam energy. From a wire measurement the magnetic spectrometer has been calibrated. In this scale the diffracted proton peak was found at 19.28 GeV/c, the deuteron peak at 19.69 GeV/c. From the two-body kinematics the energy of the extracted beam was then deduced as being 19.406 and 19.402 GeV/c.

From the velocity measurement on the diffracted protons peak and on the deuteron peak, the beam energy was found independently as 19.473 and 19.420 GeV/c. The dispersion of these energies is very similar to what can be expected from a check of the shifts of the position of the proton elastic peak. The extracted beam energy has been taken as 19.40 GeV/c in the measurements to be reported.

The deuteron peak, shown in Fig. 4 and Fig. 5, is centred at 33560 ± 16 fringes, corresponding to a velocity of 0.9955048 ± 0.0000028. The momentum as deduced from the magnet setting is $p = 19.69 \pm 0.01$ GeV/c. The mass of the particle without slowing down correction in the peak is $m = \frac{p}{\beta\gamma} = 1873,3$ MeV ± 1.6 which is in good agreement with the mass of the deuteron 1875,58 MeV.

IV. RESULTS

The analysis of the data required the determination of the absolute value of the differential cross sections with quadrupoles energised. The following procedure was therefore adopted. As explained in Chapter II, an absolute calibration of the monitor telescope in terms of primary beam intensity was made using the slit collimator CB. From the known solid angle in the normal mode of operation, the differential cross sections could then be calculated. The errors involved in this method arise from the errors in the two solid angle determinations (~ 5% each) and from the monitor stability. This latter factor was probably not better than 10%, because the ratio of "hydrogen in" to "hydrogen out" counts was only about 4 for the monitor.

The above procedure could be checked by calibrating the monitor telescope directly with the spectrometer working in the normal mode, on the proton-proton elastic peak. When allowance was made for a counting loss of 30% the same values were derived, but with a bigger error because the error in the correction for the counting loss was large. As a result of parasitic operation, the beam intensity could not be temporarily lowered in order to make these measurements more reliable.

Taking into account other sources of error (for instance, absorption in material along the beam) the total systematic error in the cross sections to be quoted is about 20%.

The empty target background correction that was applied to the data was usually less than 10%.

1. Deuterons

Deuteron production has been studied with particular attention to the process $p + p \rightarrow \pi^+ + d$. For 19.40 GeV/c incident protons and at 25 mrad, deuterons from this process have a momentum of 19.69 GeV/c, 0.41 GeV/c higher than that of the elastically scattered protons.

In order to find the expected deuteron peak the setting of the DISC was checked with protons of the same velocity, i.e. about 10 GeV/c momentum. The DISC overall efficiency was found to be 71% from these tests, using moderate velocity resolution (quadruple coincidences).

The counting rate obtained using the coincidence AB DISC is shown as a function of the momentum in Fig. 4, where only the statistical errors are given.

A peak is clearly evident at the expected momentum for the deuterons produced in the two-body process. The pressure curve, taken at this peak, also gives clear evidence for deuterons (Fig. 5).

Unfortunately, no pressure curve was measured at the momentum of the elastic peak where the full elastic proton intensity ($\sim 10^6$ times the deuterons) was passing through the counter. These data are necessary to know the contribution of proton background in the deuteron counting rate at this momentum. The rise in the momentum spectrum below the deuteron peak is thus not clearly due only to deuteron production as there could be considerable proton background contributions. In future experiments, this point will have to be studied carefully as the production of boson resonances by $p + p \rightarrow d + B$ could be observed as bumps in the deuteron momentum spectrum in this region.

The differential cross section for $pp \rightarrow \pi^+ d$ was evaluated from the area of the peak after subtraction of the background represented by the dotted line. In the lab system the value for the differential cross section of $pp \rightarrow \pi^+ d$ at 25 mrad for the deuteron is then found to be $(1.0 \pm 0.3)\mu b/sr$. In this figure a 36% correction has been included to take into account the absorption of the deuterons in the counters. The corresponding c.m.s. scattering angle is 10.1° and the c.m.s. cross section is $(0.020 \pm 0.006)\ \mu b/sr$. The quoted errors include the contribution of the estimated systematic errors.

One can compare this value with the results of previous measurements. The existing data above 3.6 GeV/c (at which momentum the angular distributions become monotonically decreasing with angle) consist of

a) angular distribution measurements up to 4.65 GeV/c [6, 7];

b) some isolated points at 60 mrad (lab) and up to 8.9 GeV/c [8];

c) three points, at 11.6, 15.0 and 22.9 GeV/c, and at large production angles, typically 45° c.m. [9]

Orear[10] fitted all these data reasonably well with a single transverse momentum dependence

$$s \frac{d\sigma}{d\Omega} (\mathrm{c.m.}) = A \exp(-a p_\perp)$$

where s is the square of the c.m. energy and $p_\perp$ the transverse momentum of an outgoing particle. The value presented in this paper is a factor of 7 lower than the value predicted by Orear, but still nearly 10^3 times greater than the value at $\sim 40^\circ$ c.m. This shows that, even at these energies, the production of deuterons in the forward direction is greatly favoured.

One can make an estimate as to the value of the total cross section for the reaction $p + p \rightarrow \pi^+ + d$ by combining the present value of the differential cross section at 19.4 GeV/c and 10.1°(c.m.) with a value derived from the data of Baker et al[9] by interpolating those data to 19.4 GeV/c and about 39° (c.m.). Depending on how one connects the two points, one finds by integration

$$10^{-32} \leq \sigma(pp \to \pi^+ d,\ 19.4\ \mathrm{GeV/c}) \leq 10^{-31}\ \mathrm{cm}^2 .$$

The highest momentum at which this cross section has been measured previously is 4.65 GeV/c 7), and there the cross section is $(1.0 \pm 0.2)\ 10^{-29}\ \mathrm{cm}^2$. Therefore, the total cross section for the two-body deuteron production is strongly energy-dependent as it changes by a factor of ~ 300 when the proton momentum goes from 4.65 to 19.4 GeV/c, corresponding to a variation of roughly s^{-4}.

2. Positive pions

The π^+ production was measured at the high-energy tail of the spectrum from 17.21 GeV/c up to the maximum momentum allowed by the kinematics (17.94 GeV /c), using the coincidence AB C_1 C_2 DISC. Some other data were taken in a lower momentum region from 8.1 GeV/c up to 15.35 GeV/c using the coincidence AB C_1 C_2. The overall efficiency for pions of the AB C_1 C_2 DISC at 8.1 GeV/c was found to be 82.5%.

In Fig. 6 the data obtained in the high momentum range are plotted, along with their statistical errors.

At 25 mr, 19.40 GeV/c protons are expected to produce a monoenergetic peak of π^+ at 17.94 GeV/c via the two-body reaction:

$$pp \to \pi^+ d \tag{2}$$

while the three-body reaction

$$pp \to \pi^+ n p \tag{3}$$

can give rise to a continuum whose upper limit is again 17.94 GeV/c. The continuum coming from the four-body reactions

$$pp \to \pi^+ \pi N N \tag{4}$$

has an upper limit at 17.66 GeV/c.

The curves drawn in Fig. 6 show

a) the double differential invariant phase space $\frac{d^2 R}{d\Omega dp}$, normalized to the data points at about 17.70 GeV/c; the experimental resolution has been folded into the curve;

b) the peak due to reaction (2), as determined in the previous section. The resolution has been folded in again. It has to be remarked that the c.m. production angle for reaction (2) is 9.2°, when the π^+ is detected, whereas it was 10.1° when the d was detected. A correction factor 1.3 has been applied for this difference in c.m. production angles.

It can be concluded that the sum of these two curves is well fitted by the experimental points. Moreover, Fig. 6 shows that the partial differential cross section for $pp \rightarrow \pi^+ pn$ from the upper 100 MeV/c of the π^+ momentum is of the same magnitude as the differential cross section for $pp \rightarrow \pi^+ d$. This 100 MeV/c of the π^+ momentum corresponds to 50 MeV kinetic energy in the pn system and is therefore roughly equal to the maximum Fermi energy of the 2 nucleons in a deuteron.

A similar conclusion can be reached from measurements of the complete π^+ momentum spectrum (including the $\pi^+ d$ peak) measured by Reay et al.[11]) at 0° and 17° (lab) at an energy of 2,4 GeV, and from the data by Fickinger et al.[12]) (π^+ spectrum) and Sechi-Zorn[13]) ($\pi^+ d$ cross section) at 2.05 GeV : the cross section for $pp \rightarrow \pi^+ d$ is about equal in magnitude to the cross section

$$\int \frac{d\sigma}{dM_{pn}} (pp \rightarrow pn\pi^+)\, dM_{pn}$$

taken between the limits $M_{deuteron} \leq M_{pn} \leq M_{deuteron} + 50$ MeV. One concludes therefore that deuteron production at energies above 1 GeV is the result of the same mechanism as is found to be operative at a few hundred MeV[14]), namely the simple chance proximity in the momentum space of the two constituents, proton and neutron, to within the Fermi momentum[14]).

Since the two-body deuteron production shows a very steep angular dependence, probably as an exponential in the transverse momentum, as discussed in the preceding section, one can conclude that also the differential cross section of the most energetic pions obeys the same law. This law was, of course, already well established for secondaries of energies well below the upper limit. Although the significance of the collimation of the secondaries in the forward direction is not yet clear, such a general phenomenon cannot be of small importance.

3. Positive Kaons

The measurement of the K^+ production near the high momentum tail of the spectrum was made difficult by the fact that at the same momenta protons and pions are $\sim 10^6$ times more abundant. The data have been taken using the DISC counter set at high resolution **in coincidence with the** A_3B_3 counters. The efficiency of the DISC operating in these conditions was found to be about 50%.

The K^+ data are shown in Figs 7 and 9. For the kinematic conditions of the experiment, the maximum momentum of K^+ produced in the reaction

$$p + p \rightarrow K^+ + p + \Lambda$$

is 17.56 GeV/c. If there were a violation of strangeness conservation by the production of a K^+ in association with a neutron rather than a Λ the K^+ spectrum would extend above this momentum. The lack of events observed above the $K\Lambda$ kinematic limit, Fig. 7, leads to the conclusion that a strangeness non-conserving process is less than 2% of the normal reactions.

The sharp increase of the K^+ yield just below the kinematic limit is well represented by a smooth 3-body $K\Lambda p$ phase space. Any deviation from this would be due to an enhancement of interaction in the low-energy $\Lambda - p$ system. Such an enhancement has been already observed in similar $p - p$ experiments at 3.2 and 3.7 GeV/c by Melissinos et al.$^{15)}$ and at 4 and 5 GeV/c by Elioff et al.$^{16)}$ Considering the magnitude of the effect observed at the lower momenta and the statistical uncertainties in the present data, it may be said that the spectrum shown in Fig. 7 does not exclude the presence of a small enhancement in the $\Lambda - p$ system. The $p - n$ enhancement (namely the deuteron) shown at the end of the π^+ spectrum in Fig. 6 would not have been seen had the π^+ data been taken with the poor statistical accuracy of the

the K^+. If the $\Lambda - p$ enhancement has a similar character to the low energy $p - n$ interaction, its energy dependence may be expected to be similar to that noted for d production in section IV.2, and the phenomenon should appear in the K^+ spectrum as clearly as the deuteron does in the π^+ spectrum. The chance of observing the $\Lambda - p$ enhancement thus appears to be quite high. The background conditions were so good, moreover, that simply a considerable increase in statistical accuracy would result in a firm conclusion on this point.

The ratio of K^+ to π^+ cross sections is essentially constant, $\approx 1/20$, up to the highest momentum.

4. Negative Pions and Kaons

The production of π^- has been observed from 8 GeV/c to 18 GeV/c using the coincidence requirement $A B C_1 C_2$. The pressure in the threshold counters C_1 and C_2 was set to reject K^- and $\bar{p}$. The data are shown in Fig. 8.

The data on K^- production, which are plotted in Fig. 9, were taken using the coincidence $A B C_2 \bar{C}_1$. The pressure in the two Cerenkov counters was set in such a way that the threshold of C_1 was between the pions and the kaons, while the threshold of C_2 was between the kaons and the antiprotons. Very little time was spent on the negative particle spectra. The background conditions were extremely favourable and it was felt that the negative particle measurements presented the least difficulties and could be done rapidly later.

Interesting structure could be present in the π^- spectra. A di-baryon state of triple charge has been proposed$^{17)}$ as a member of a representation in SU(6) together with the deuteron. Such a state would show up as a bump near the end of the π^- spectrum.

5. Antiprotons

One point at 10 GeV/c was measured using the signature $A B \bar{C}_1 C_2$. The cross section found was $7.7 \pm 1.3\ \mu b\ GeV/c^{-1}\ sr^{-1}$ (lab). The error quoted is statistical.

6. Protons

Fig. 10 shows the results of the proton measurements using the coincidence signature AB . A striking inelastic peak about 0.95 GeV/c below the elastic is seen. This peak corresponds to excitation mainly of the N* (1688) and the appearance of the spectrum in this region is similar to that observed in experiments at other energies and angles corresponding to the same momentum transfer[18]. It should be noted that the present experiment did not really explore the isobar region in any detail as is clear from the spacing of the points in Fig. 10. Detailed measurements could be sensitive to observation of rather small structures.

The proton spectrum was measured very carefully in the momentum interval between 13.9 and 15.3 GeV/c to see if there were any structure. The inset of Fig. 10 shows that the spectrum in this momentum range is rather smooth and does not exhibit fluctuations greater than 1% in ~ 100 MeV/c intervals.

V . CONSTRUCTION OF COMPLETE PARTICLE SPECTRA

At energies around 20 GeV no data existed, until now, on particle production at secondary momenta near to the kinematic upper limit. Other data taken at high energies and different angles can be used to construct the general shape of the momentum spectra for our conditions. Dekkers et al.[19] have measured $\pi^{\pm}$ and $K^{\pm}$ spectra at 0 and 100 mrad for 18.8 GeV/c protons and Collins et al.[20] have given preliminary data on $\pi^{\pm}$ production at 15 mrad for 30 GeV/c proton momentum. The cross sections given by these experiments have been transformed to our momentum and angle using the formula given by Cocconi, Koester and Perkins[21]. In Figs. 8, 9 and 10 the dashed curves show the trend of the cross sections estimated by this procedure. These curves fit on to our data quite well, giving complete high energy secondary particle spectra for the first time. Of course, the curves would actually have been measured by our spectrometer had time permitted.

VI . CONCLUSIONS

The preliminary results presented in the above paragraphs show that the high energy end of secondary particle spectra can be well measured using an extracted proton beam and a spectrometer of high resolution both in momentum and particle velocity. The detection of the reaction $p + p \rightarrow \pi^+ + d$ as a small bump at the end of the π^+ spectrum demonstrates that two-body processes of quite low cross section can be detected. Hence, it appears of considerable interest to continue this experiment for a useful amount of running time in essentially its present form.

It may be added that no fundamental experimental limitations, in the present study, due to the very high beam intensity, were encountered. Indeed, even higher beam fluxes, say $\sim 10^{12}$ protons per pulse would have been useful in studying the very small cross section processes. It is not easy to see any method other than the present one to investigate such reactions. This is particularly true of $\bar{p}$ production for which only one point was measured in our present study. Careful measurements of the high energy end of $\bar{p}$ spectrum might well yield very interesting results.

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× Visitor at CERN, Laboratoire de Physique Nucléaire, Faculté des Sciences, Orsay, and Institut Interuniversitaire des Sciences Nucléaires, Brussels.

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* * *

FIGURE CAPTIONS

Figure 1	Experimental layout of the slow extracted proton beam and the spectrometer at 25 mrad production angle.
Figure 2	Pressure curves of the DISC differential Cerenkov counter.
Figure 3	Difference between the observed and calculated number of fringes in the DISC.
Figure 4	Deuteron momentum spectrum. Plotted is a A_3B_3 DISC (quadruple coincidences) with the DISC tuned to deuterons of the appropriate momentum.
Figure 5	Pressure curve of the DISC (quadruple coincidences) at the momentum setting corresponding to deuterons from the reaction $pp \rightarrow \pi^+ d$.
Figure 6	π^+ momentum spectrum (lab system).
Figure 7	K^+ momentum spectrum (lab system).
Figure 8	$\pi^\pm$ momentum spectra (lab system).
Figure 9	$K^\pm$ momentum spectra (lab system).
Figure 10	Proton momentum spectrum (lab system). In the inset the region 14.0 to 15.2 GeV/c is shown on an enlarged scale.

* * *

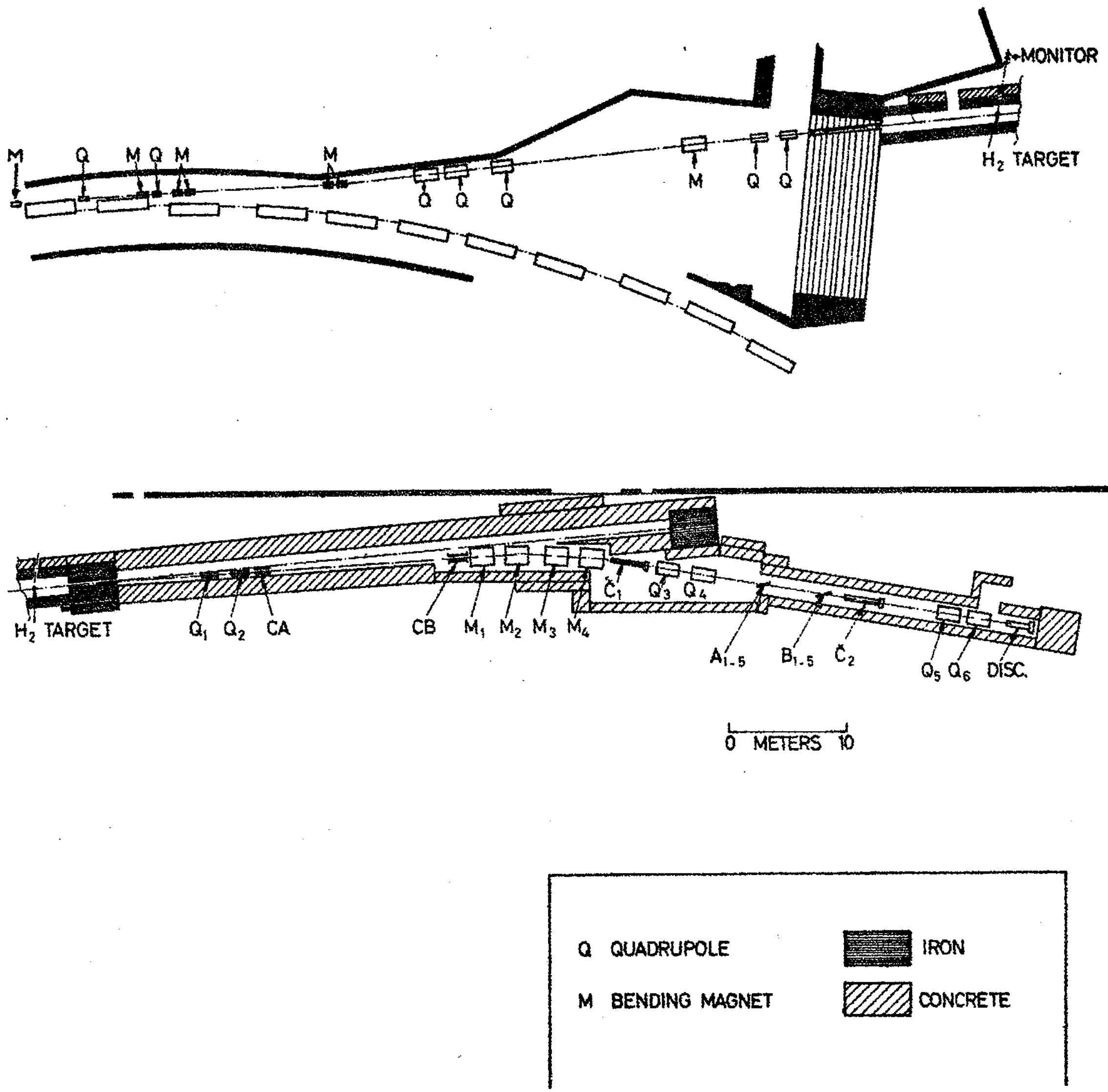
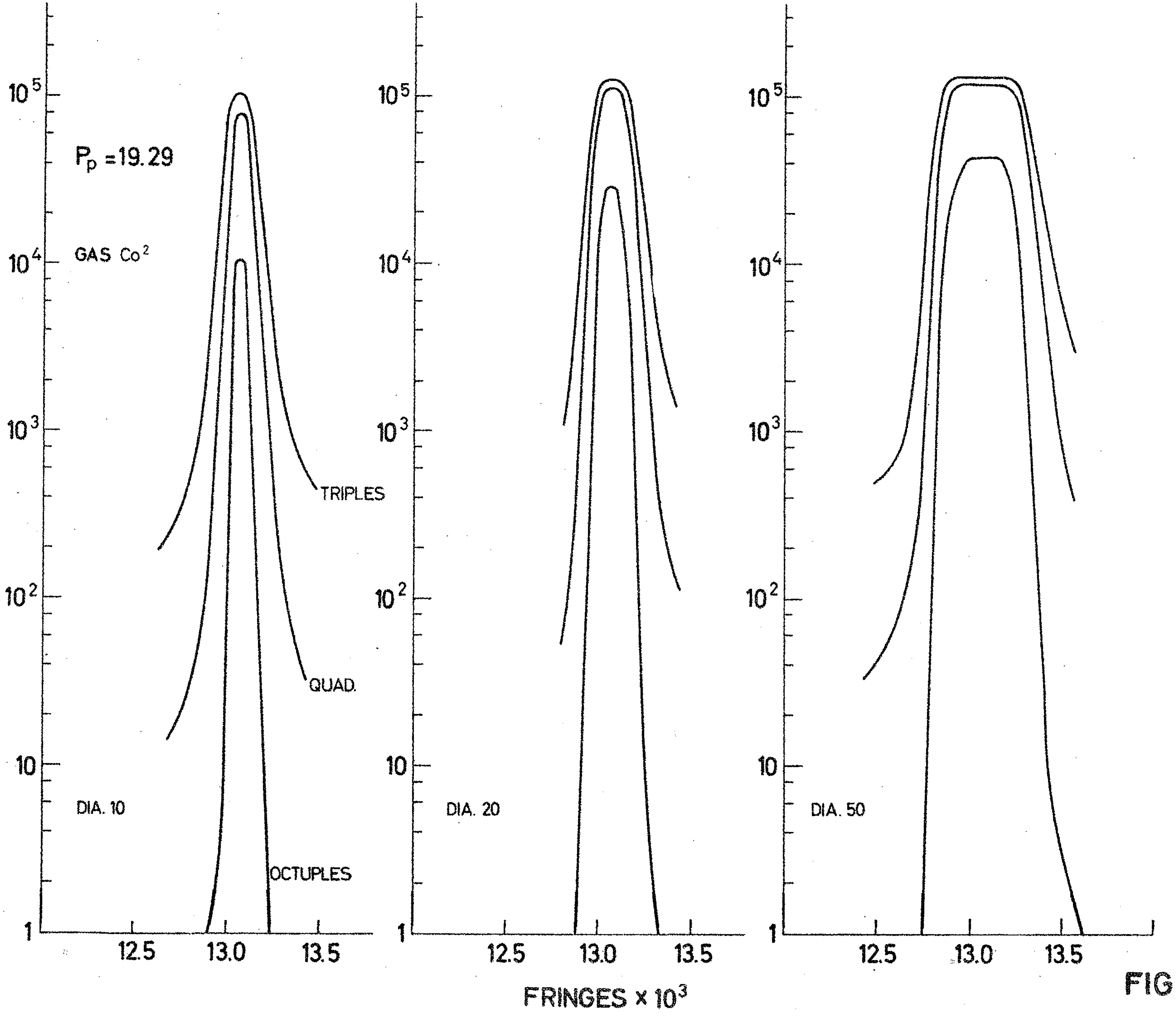


FIG 1

DIA 27151



P_p =19.29
GAS Co^2
DIA. 10
DIA. 20
DIA. 50
TRIPLES
QUAD.
OCTUPLES
10^5
10^4
10^3
10^2
10
1
12.5
13.0
13.5
FRINGES × 10^3

FIG 2

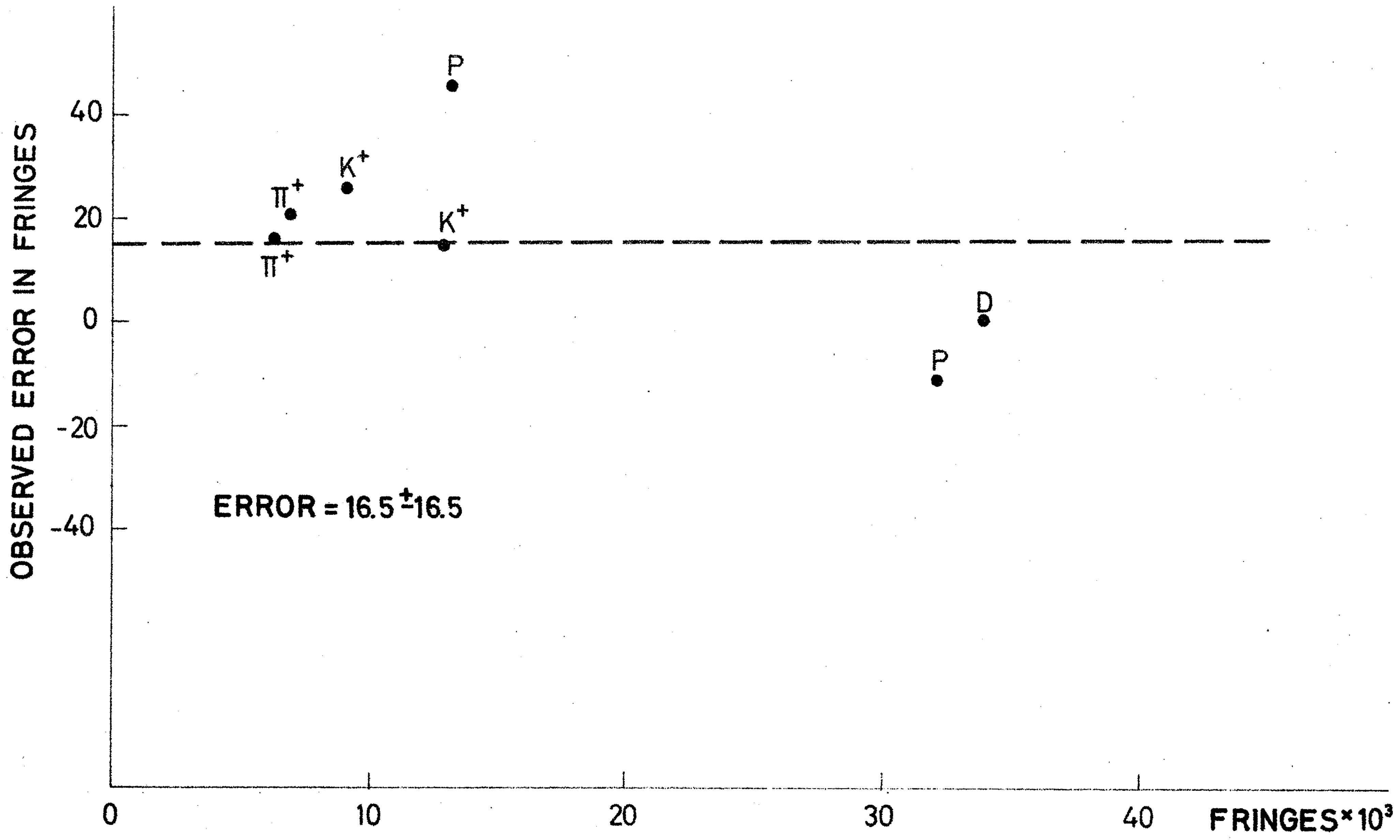

OBSERVED ERROR IN FRINGES
40
20
0
-20
-40
P
K⁺
π⁺
π⁺
K⁺
D
P
ERROR = 16.5 ± 16.5
0
10
20
30
40
FRINGES × 10³

FIG 3

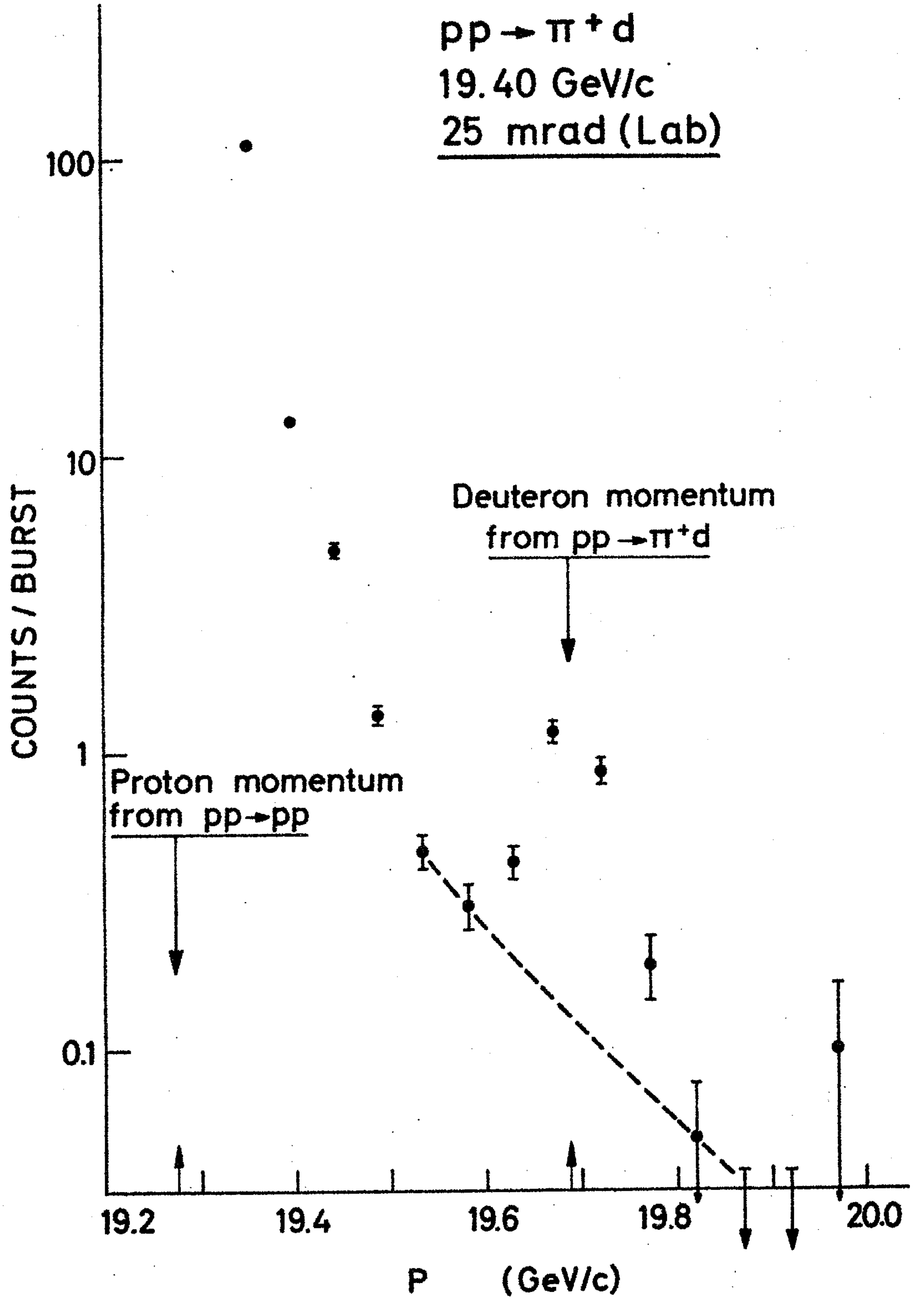


FIG 4

DIA 27157

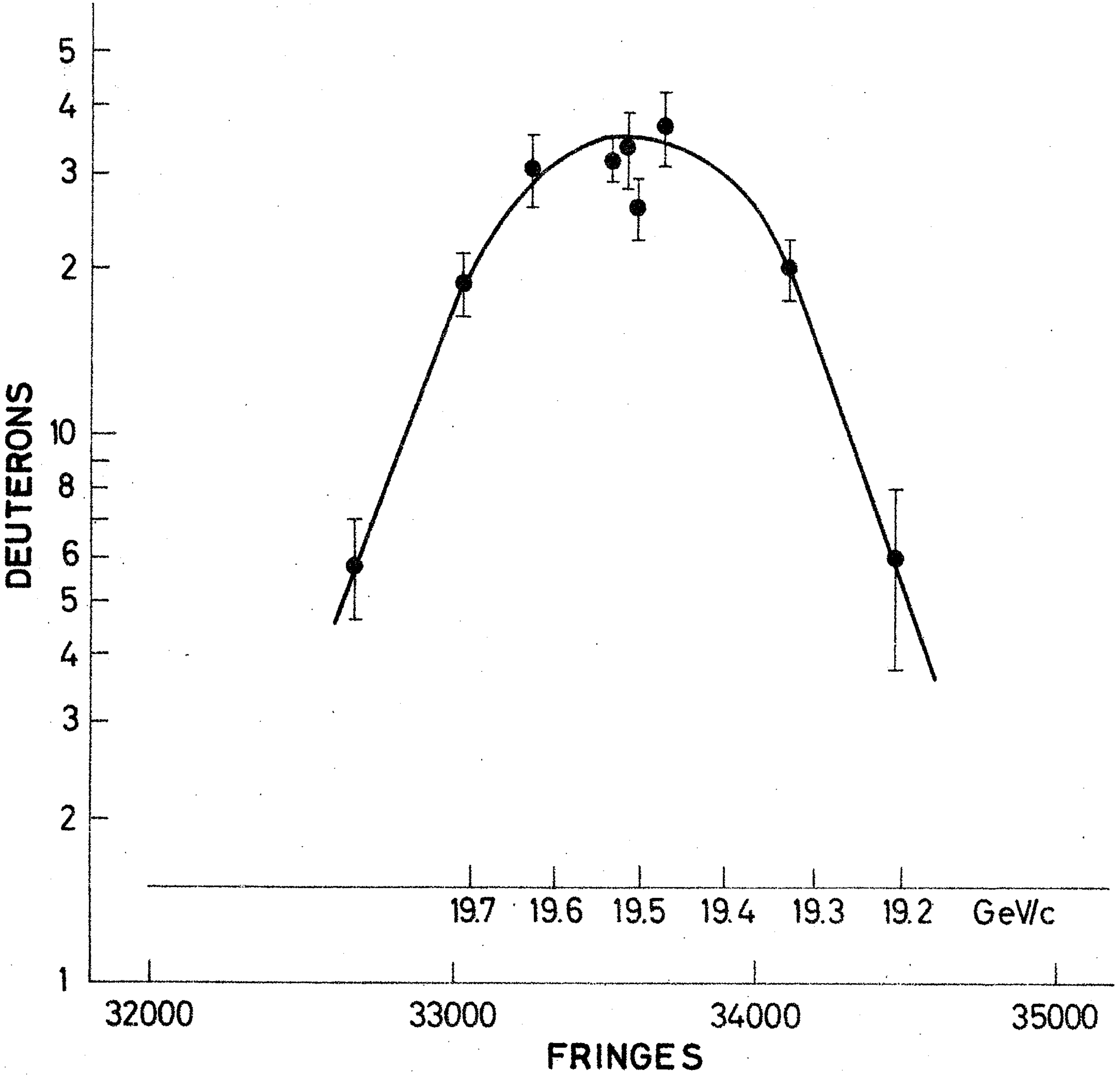

DEUTERONS
5
4
3
2
10
8
6
5
4
3
2
1
19.7
19.6
19.5
19.4
19.3
19.2
GeV/c
32000
33000
34000
35000
FRINGES

FIG 5

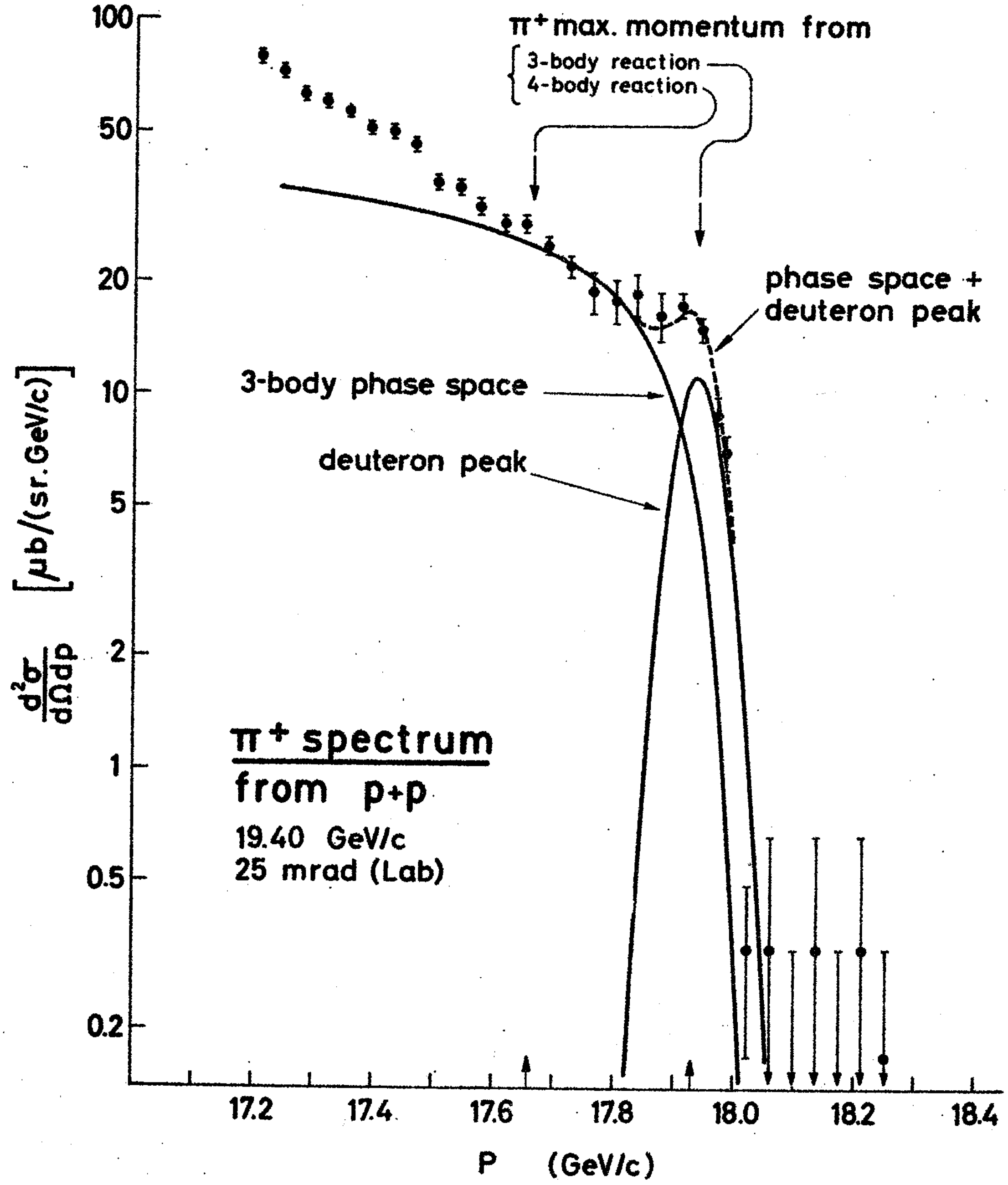


FIG 6

DIA 27154

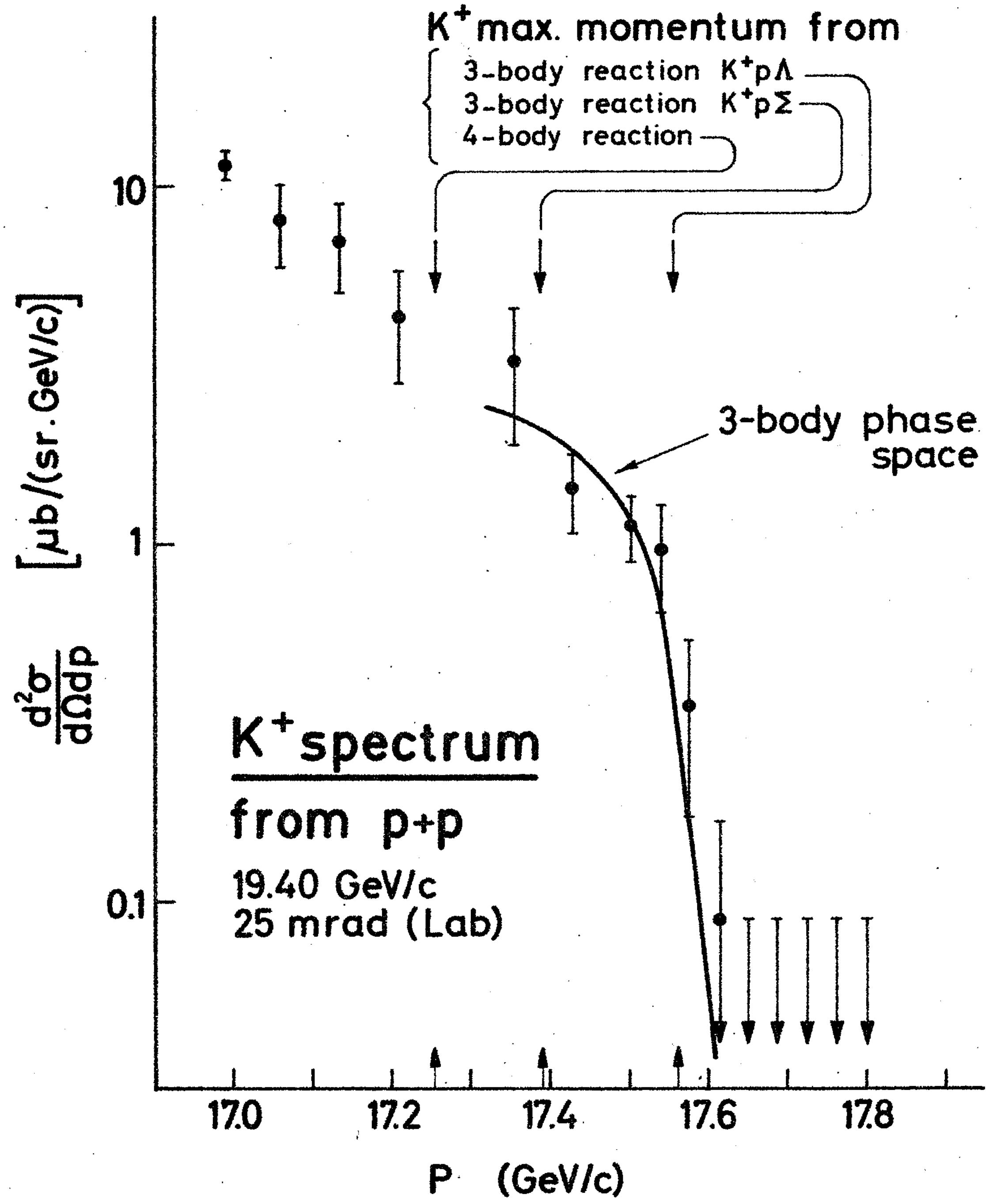


FIG 7

DIA 27153

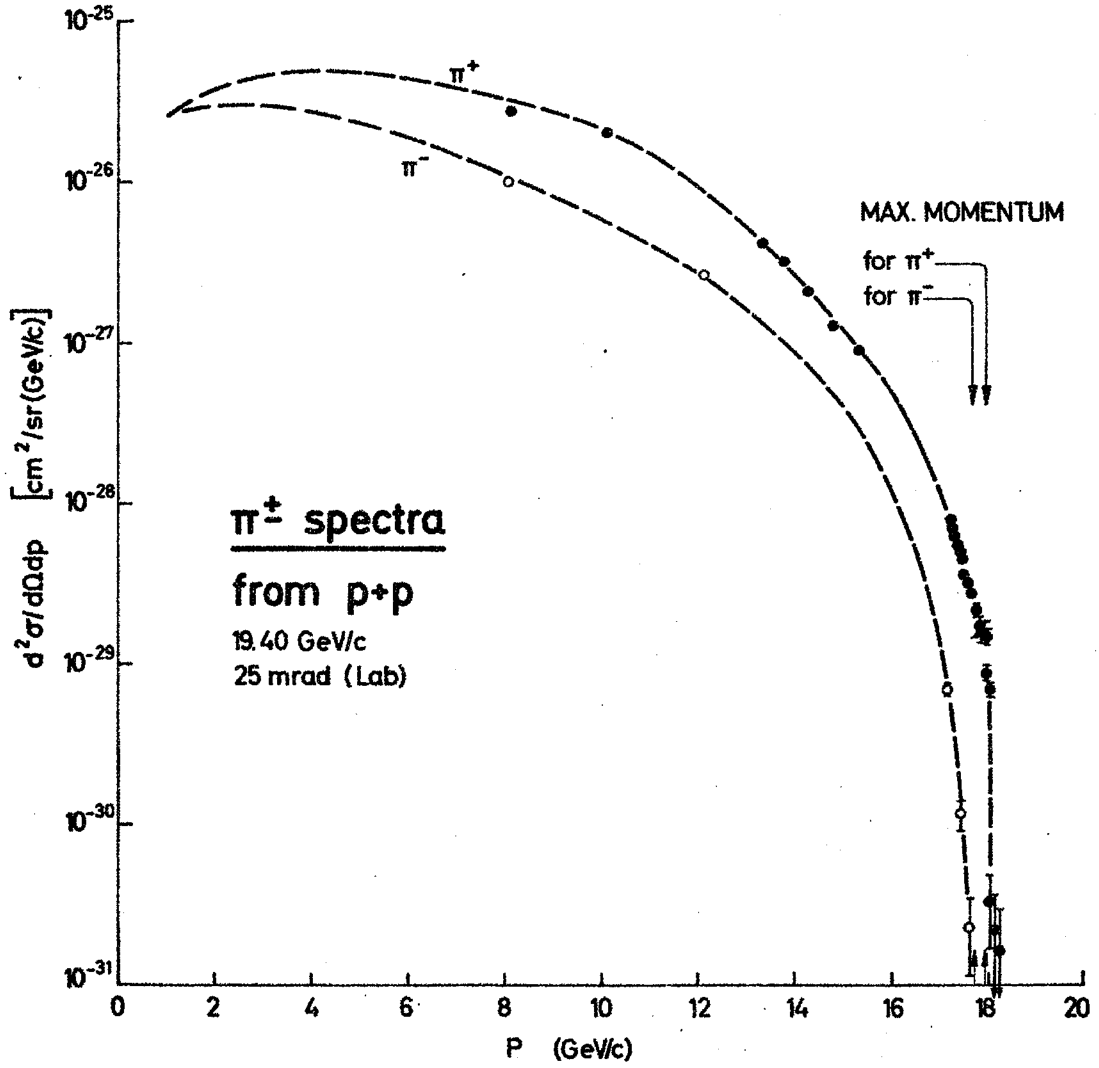


FIG 8

DIA 27156

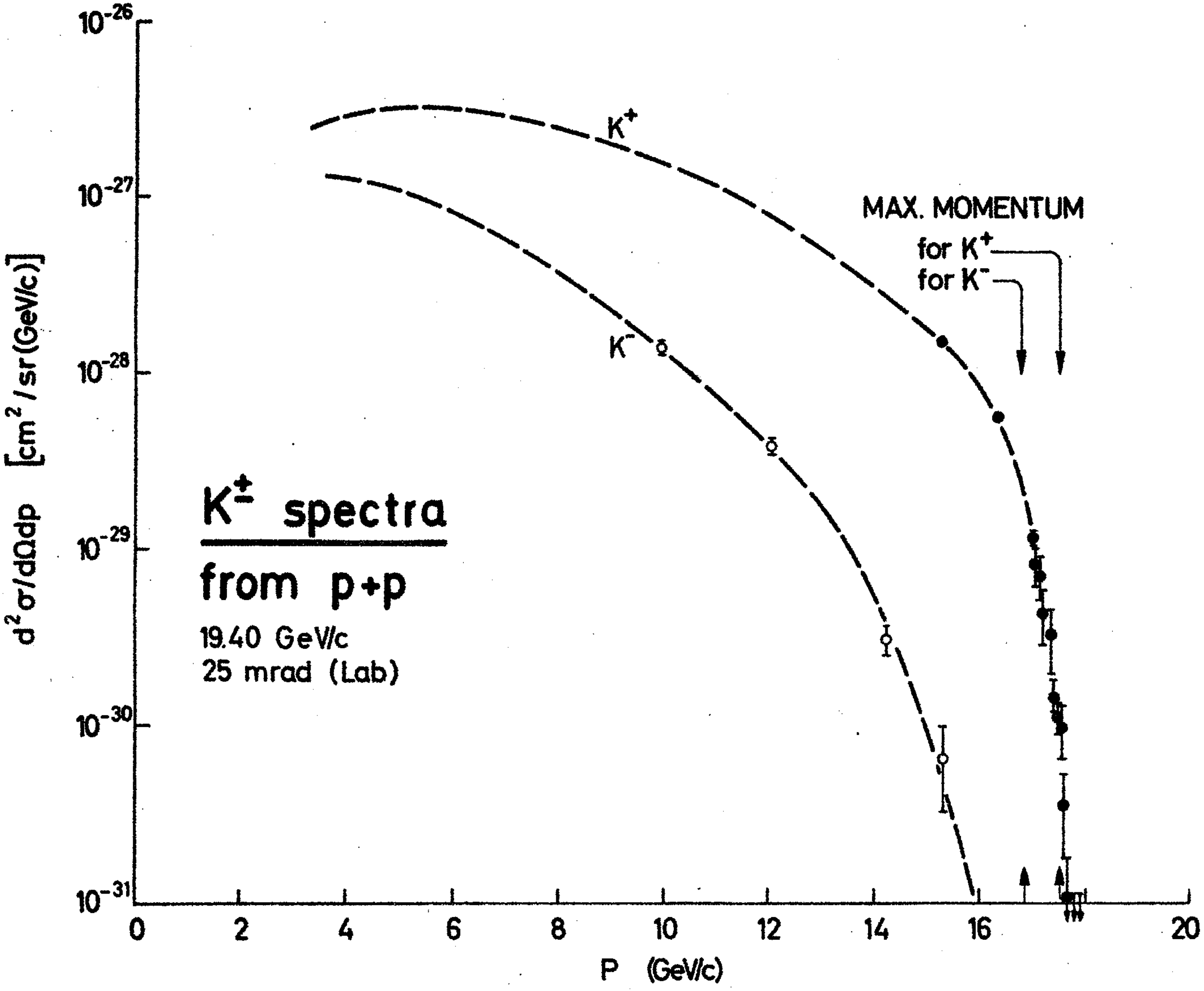
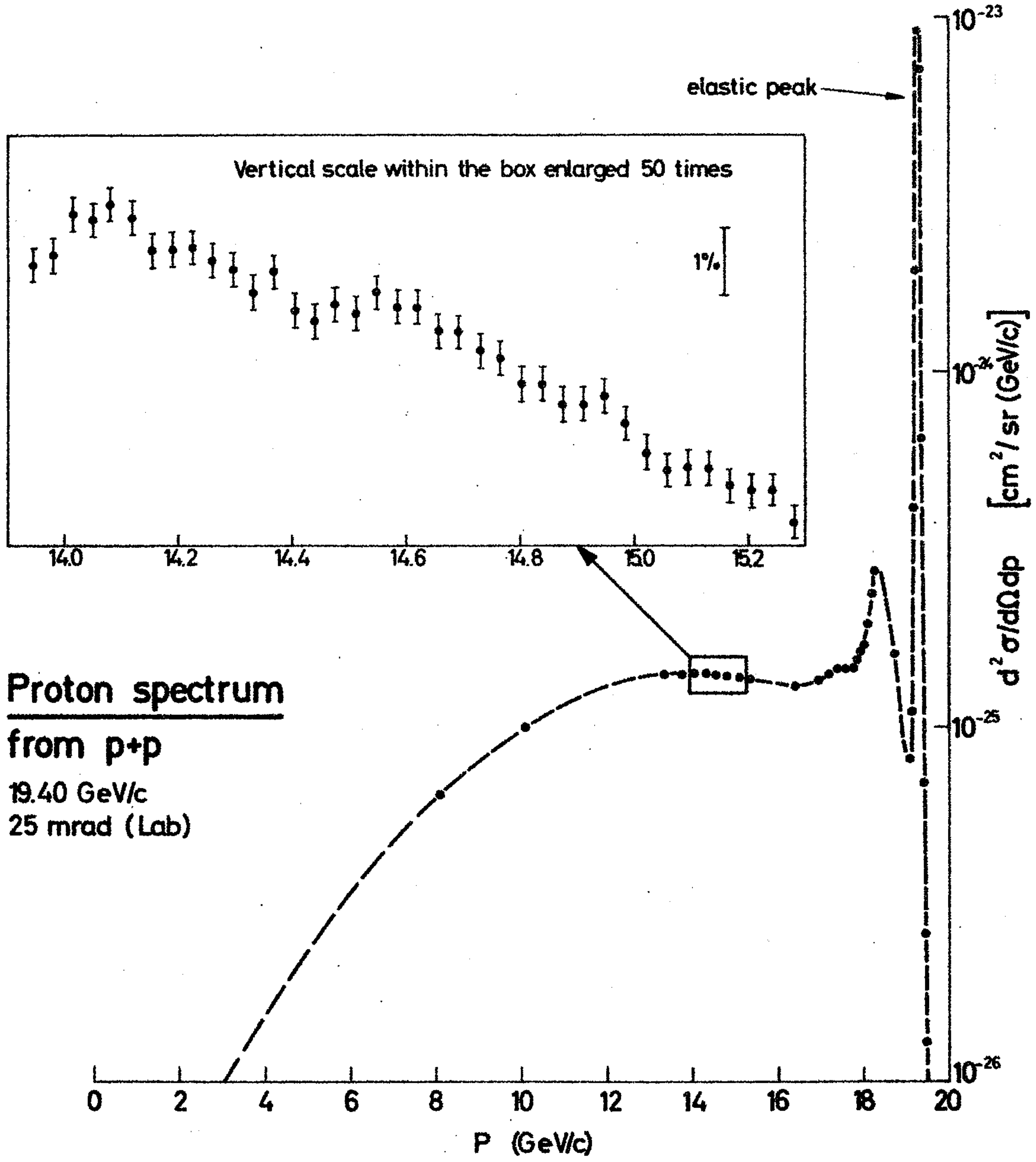


FIG 9

DIA 27155



Proton spectrum

from p+p

19.40 GeV/c
25 mrad (Lab)

FIG 10

DIA 27152