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INCLUSIVE PRODUCTION OF Δ^{++} (1236) IN INTERACTIONS AT 22.4 GEV/C

Alma-Ata - Dubna - Helsinki - Košice - Moscow - Prague Collaboration

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Инклюзивное образование изобары $\Delta^{++}(1236)$ в $\bar{p}p$-взаимодействиях при 22,4 ГэВ/с

В работе, выполненной на материалах с 2-метровой жидководородной камеры "Людмила", исследовалось инклюзивное и полуинклюзивное образование изобары $\Delta^{++}(1236)$ в $\bar{p}p$-взаимодействиях при 22,4 ГэВ/с. Получено сечение Δ^{++}, равное $1,78 \pm 0,18$ мбн в кинематической области $|t_{p,\Delta}| \leq 0,74$ ГэВ/с. Дифференциальное сечение изучалось как функция поперечной и продольной переменных Фейнмана. Из анализа распределений углов распада Δ^{++} получено указание на существенный вклад однопионного обмена в инклюзивный процесс образования Δ^{++}.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1978

Boos E.G. et al.

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Inclusive Production of $\Delta^{++}(1236)$ in $\bar{p}p$ Interactions at 22.4 GeV/c

The inclusive and semi-inclusive production of $\Delta^{++}(1236)$ has been investigated in $\bar{p}p$ interactions at 22.4 GeV/c. The Δ^{++} cross section is 1.78 ± 0.18 mb in the region of $|t| \leq 0.74$ (GeV/c). The differential cross sections have been studied as a function of transverse and longitudinal variables. An evidence for the one-pion exchange contribution to the Δ^{++} inclusive process has been obtained from the decay angular distributions of Δ^{++}.

The investigation has been performed at the Laboratory of High Energy Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1978

I. INTRODUCTION

The inclusive resonance production has been of great interest at high energies. Some of hadrons are produced through the decay of different resonances, and therefore their study makes it possible to obtain some direct information on the production process. Research into the production of the resonance $\Delta^{++}(1236)$ has revealed that it can be understood in the framework of the one-pion exchange model. The characteristics of the inclusive Δ^{++} production have been investigated in pp and $\pi^{\pm}p$ and $K^{\pm}p$ collisions from intermediate to Fermilab energies [1].

In this paper we present an investigation of the reaction

$$\bar{p}p \to \Delta^{++}(1236) + X^{--} \quad (1)$$

at 22.4 *GeV/c*.

In section II we describe the experimental procedure. In section III we determine the production cross sections of Δ^{++} (1236) both in the restricted and entire kinematic regions. A study of the differential inclusive cross sections is described in section IV. The predictions of the one-pion-exchange model are compared with the decay angular distributions of Δ^{++} in section V.

II. EXPERIMENTAL METHOD

The data of the present analysis have been obtained from an exposure of the 2 *m* hydrogen bubble chamber

"Ludmila" to a beam of 22.4 *GeV/c* antiprotons. A sample of approximately 11100 events of all topologies was available for this study, which corresponds to the cross section 3.38 μb per event. The procedure used for proton identification has been described elsewhere [2].

To study the Δ^{++} production, we need a unique identification of protons by ionization which turned out to be unambiguous at the laboratory momenta P_{LAB} less than 1.2 *GeV/c*. This cut allows a full acceptance for all Δ^{++} breakup angles provided that the momentum transfer between the target * and $\Delta^{++}(1236)$ is smaller than 0.74 (GeV/c) , i.e., the Δ^{++} laboratory momentum is less than 1.17 *GeV/c*. In *fig. 1* we show the kinematic boundaries imposed by the laboratory momentum cuts for protons, pions and Δ^{++}.

The inelastic cross section for the identified protons with $P_{LAB} \le 1.2$ *GeV/c* is 11.56 ± 0.21 *mb*. *Table 1* presents the corresponding topological cross sections along with those obtained at 32 *GeV/c* [4]. If a proton is identified in an event, other positive particles are supposed to be pions. To study the Δ^{++} production in the whole kinematic range, we use the weighting procedure proposed in [3]. The proton inelastic cross section in the entire kinematic region is 15.36 ± 0.57 *mb*. The experimental losses increase with charge multiplicity (see *Table 1*).

III. INCLUSIVE Δ^{++} CROSS SECTIONS

We have determined the inclusive and semiinclusive Δ^{++} cross sections both in the regions of P_{LAB} (proton) ≤ 1.2 *GeV/c* and $|t_{p,\,p\pi^+}| \le 0.74\ (GeV/c)^2$ and over the entire kinematic region. Clear signals are seen in the distributions of $p\pi^+$ combinations (see *Fig. 2*).

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* The $t_{p\Delta}$ -cut depends on the mass of Δ^{++} resonance. We have calculated it for several mass values in an interval of (1.16 - 1.4) *GeV*. The dependence was very weak and was neglected in a further analysis.

Table 1
Proton topological cross sections (*mb*)

	P_{inc} GeV/c	Topology 4	6	8	10
$P_{LAB} \le 1.2$ GeV/c	22.4	4.97 ± 0.13	1.66 ± 0.074	0.304 ± 0.032	0.051 ± 0.018
	32	4.59 ± 0.18	2.09 ± 0.13	0.47 ± 0.063	0.06 ± 0.02
All protons	22.4	5.64 ± 0.14	2.80 ± 0.097	1.00 ± 0.058	0.280 ± 0.030

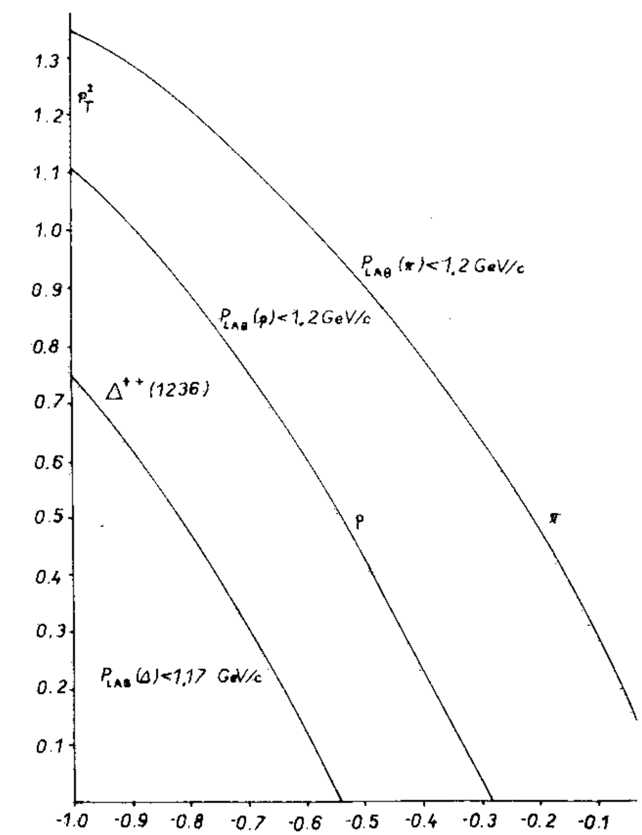

Fig. 1. Kinematic curves for Δ^{++}, protons and pions.

The mass spectra were fitted by the following formula[6]

$$\frac{d\sigma}{dm} = \frac{a_1}{I_1} BG + \frac{a_2}{I_2} BW \cdot PS , \quad (2)$$

where BG , BW and PS stand for the background, relativistic Breit-Wigner[7] and phase space, respectively; a_i and I_i are the fractions and normalization integrals.

The main problem is to find a reasonable form of the background and phase space. We have used

$$PS = BG = [m^2 - (m_p + m_\pi)^2]^\alpha \exp(-\beta m), \quad (3)$$

where $m_p (m_\pi)$ is the proton (pion) mass and α and β are free parameters.

The results of the fits * are presented in *Fig. 2* and *Table 2*. The lower limit of the inclusive cross section for Δ^{++} production in the entire kinematic region was found to be 2.89 ± 0.15 *mb*. In the region of $|t_{p,\,p\pi^+}| \leq 0.74\ (GeV/c)^2$ the cross section was estimated to be 1.78 ± 0.18 *mb*.

The semi-inclusive production of Δ^{++} is shown in *Fig. 3*. The corresponding cross sections are summarized in *Table 2*. The Δ^{++} resonance is mainly produced in the events with lower charge multiplicities n_c , whereas for $n_c \geq 10$ there is no indication to Δ^{++}. The influence of the kinematic cuts is of importance for $n_c \geq 6$.

The inclusive Δ^{++} cross sections in $\bar{p}p$ interactions have been estimated to be 5.31±0.14 *mb*[9] at 9.1 *GeV/c* and 1.58 ± 0.15 *mb*[10] at 100 *GeV/c* ($|t_{p,\Delta}| < 1\ (GeV/c)^2$).

The distribution of the combinations of identified protons and negative particles (taken as π^-) is shown in *Fig. 4*, where there is an evidence for Δ° (1236) production.

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* The width of Δ^{++} was fixed at the table value[8] $\gamma_0 = 115$ *MeV*.

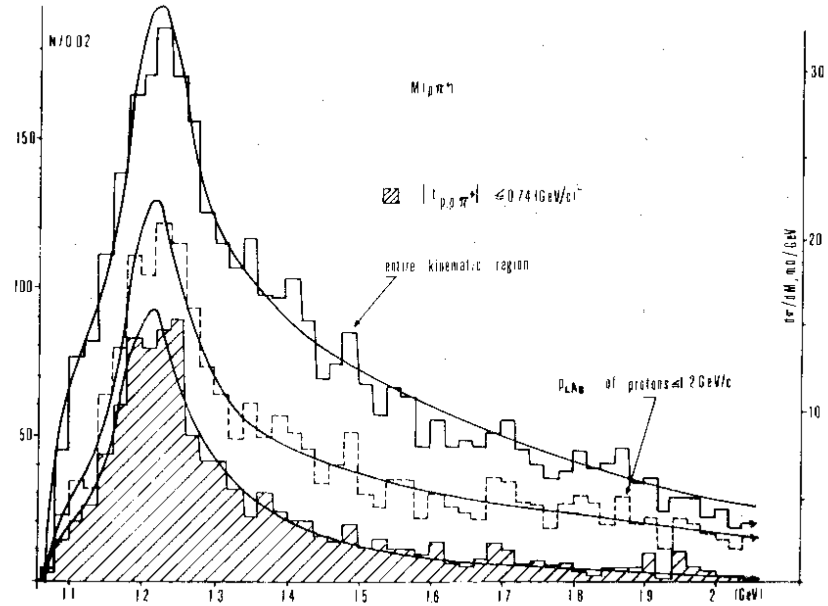

Fig. 2. The invariant mass distributions of $p\pi^+$ combinations. The curves represent the fits described in the text.

Table 2

The results of the fits to the $p\pi^+$ effective mass distributions *

Topology	Kinematic region	σ (mb)	χ^2/ND
All prongs	entire	2.89 ± 0.18	102/92
	P_{LAB} - cut	2.47 ± 0.17	95/75
	t - cut	1.78 ± 0.18	42/41
4 prongs	entire	1.82 ± 0.16	52/40
	P_{LAB} - cut	1.83 ± 0.16	57/37
	t - cut	1.55 ± 0.17	60/32
6 prongs	entire	0.621 ± 0.092	24/30
	P_{LAB} - cut	0.530 ± 0.087	31/33
	t - cut	0.301 ± 0.062	16/13
8 prongs	entire	0.328 ± 0.059	17/27
	P_{LAB} - cut	0.257 ± 0.11	30/22

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* The lower limits of σ are estimated for the entire kinematic region.

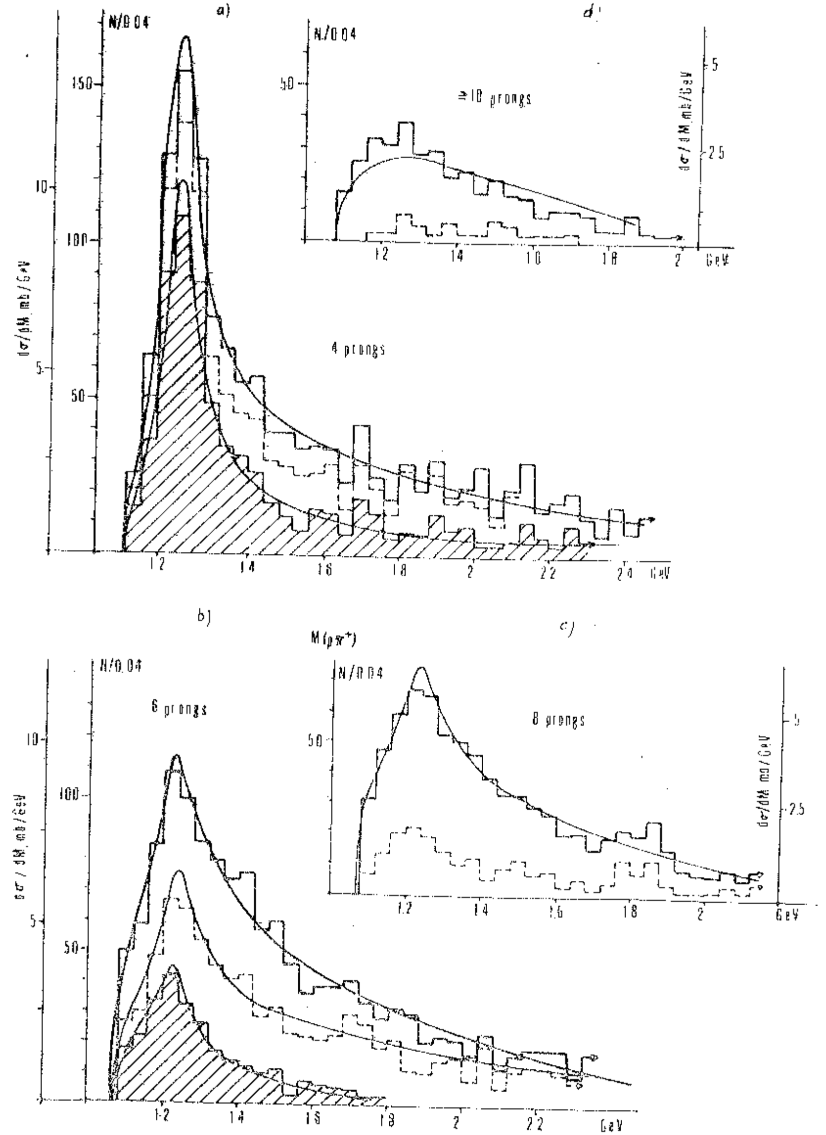

Fig. 3. The mass distributions of $p\pi^+$ combinations. The full line histograms to the entire kinematic region, the dashed ones, to p_{LAB} (protons) $\leq$ 1.2 GeV/c and the shaded ones, to the cut of $|t_{p,p\pi^+}| \leq 0.74\ (GeV/c)^2$. The curves in a), b), c) are the results of the fits. The line in d) is the phase space distribution of $p\pi^+$ taken from the final state $\bar{p}p\,8\pi$.

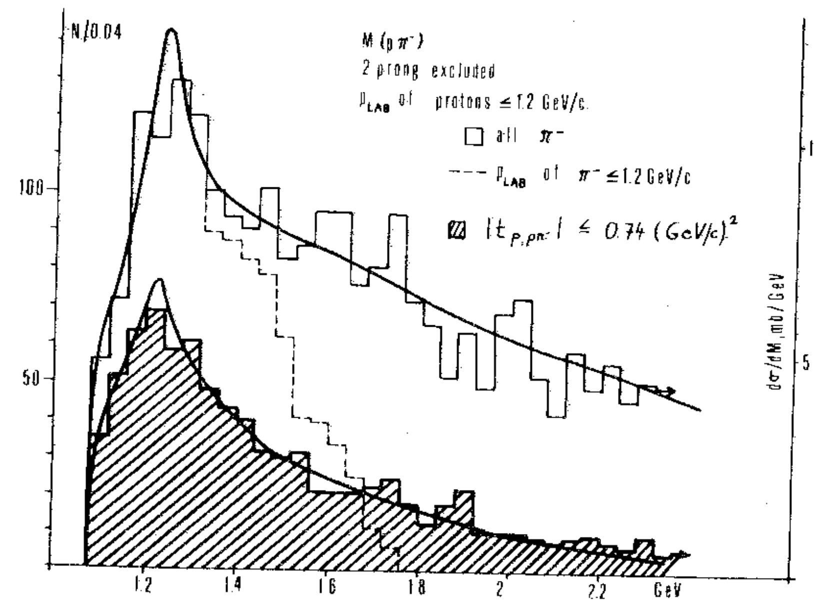

Fig. 4. The mass distributions of the combinations of identified protons and negative particles (without identified antiprotons). The curves are the results of the fit described in the text.

The Δ° cross section obtained with the formula (2) was found to be (0.71$\pm$0.09) *mb* for identified protons and (0.56$\pm$0.09) *mb* in the kinematic region of $|t_{p,p\pi^-}| \leq 0.74\ (GeV/c)$.

The value of the ratio $\sigma(\Delta^{++})/\sigma(\Delta^\circ)$ can be explained in the framework of the triple Regge model by the simplified hypothesis of meson exchange and factorization. One can get

$$\frac{\sigma(\Delta^{++})}{\sigma(\Delta^\circ)} = 3\,\frac{\sigma_{tot}(\pi^-\bar{p})}{\sigma_{tot}(\pi^+\bar{p})} = 3\,\frac{\sigma_{tot}(\pi^+ p)}{\sigma_{tot}(\pi^- p)}\ . \qquad (4)$$

This ratio is 2.97$\pm$0.55 in the region of $|t| \leq 0.74\ (GeV/c)^2$ and $5 \leq M_x^2 \leq 13\ GeV^2$ (see *Fig. 5a*). This is in good agreement with the predicted value equal to 2.7. (The ratio $\sigma_{tot}(\pi^+p)/\sigma_{tot}(\pi^-p)$ was taken /5/ to be equal to 0.9).

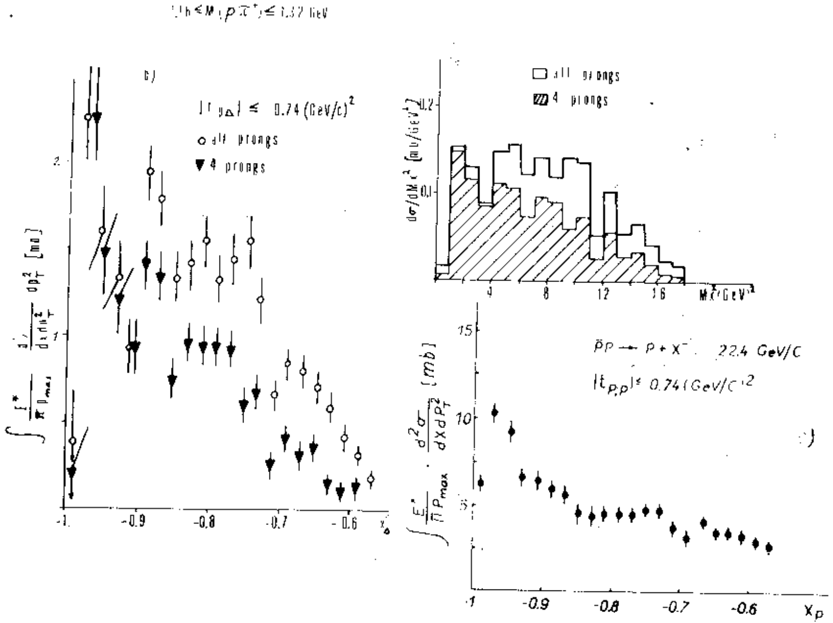

Fig. 5a) The distribution of the missing mass squared to Δ^{++}. b) The invariant x -distribution of Δ^{++} in the c.m.s.; c) The inclusive invariant x -distribution of protons.

IV. DIFFERENTIAL CROSS SECTION

In order to obtain inclusive differential distributions, we define the Δ^{++} resonance in a mass interval of 1.16-1.32 *GeV* and in the kinematic region of $|t_{p,p\pi^+}| \leq 0.74$ $(GeV/c)^2$. In the chosen regions the background is expected to be about 20%.

In *Fig. 5b* we present the invariant differential cross sections versus $x = P_L^*/P_{max}^*$. A rapid fall of the cross section for $x > -0.7$ is due to our t -cut (see *Fig. 1*). At $x_\Delta \simeq -0.97$ we observe an enhancement which comes from 4-prong events. A similar behaviour is observed in the missing mass squared distribution of the X^{--}-system in a range of 1-2 GeV^2 (see *Fig. 5a*), which is mainly populated by 4 prongs. This effect can serve as an evidence for the associated resonance production of Δ^{++} and Δ^{++} which is expected to occur in 4 prongs especially.

The difference of the invariant cross section of Δ^{++} and that of the identified protons can be seen by comparing the distributions in *Fig. 5b* and *Fig. 5c*. The proton distribution has a pronounced peak around $x_p \simeq -0.97$ which originates from two-prong events [2]. (Elastic events are excluded). This peak can be understood in terms of Pomeron exchange in the process of diffraction excitation of the incident antiprotons. As the Pomeron exchange is forbidden for the reaction (1), the enhancement at $x_\Delta \simeq -0.97$ can be explained, e.g., by pion exchange and the kinematics of double resonance production.

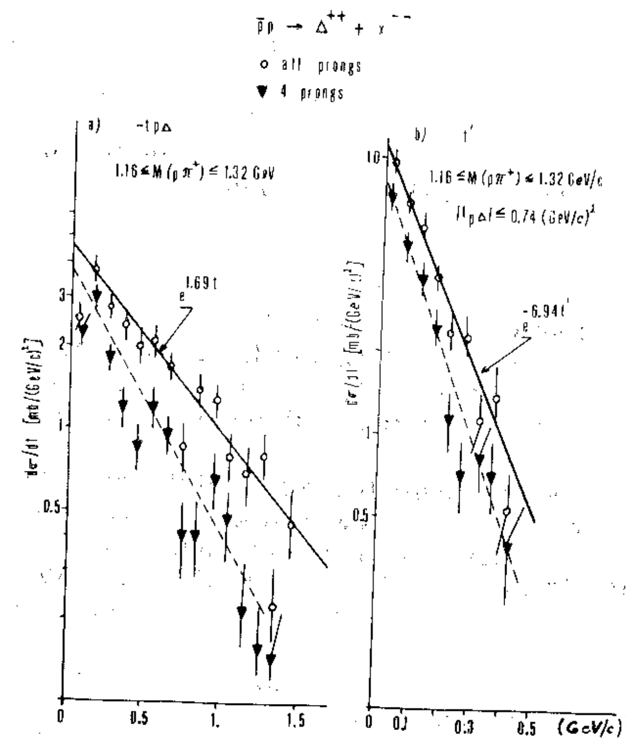

Fig. 6. The $-t_{p\pi^+}$ (a) and t' (b) distributions for the Δ^{++}-region. The curves are the exponential fits to the data.

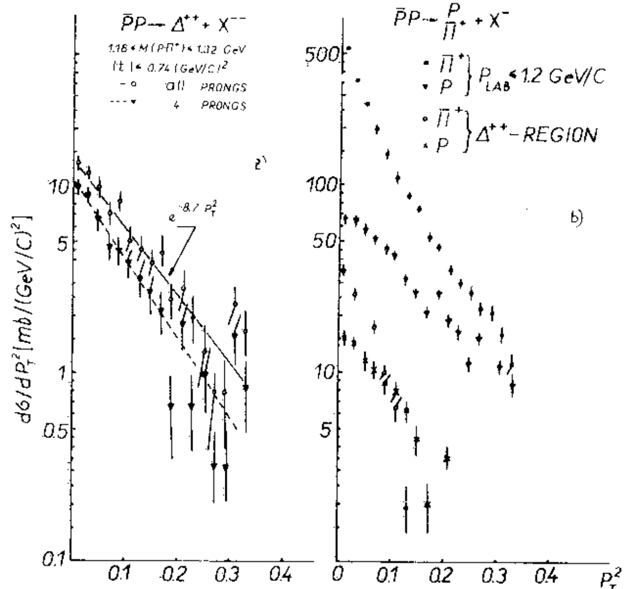

Fig. 7. The p_T^2 distributions of $p\pi^+$ combinations in the Δ^{++} region (a) and of protons and pions (b).

The distributions of t and $t' = t - t_{min}$ were fitted by a single exponential function of the form $A\exp(Bt)$ with the slopes $1.69 \pm 0.12\ (GeV/c)^{-2}$ and $6.94 \pm 0.33\ (GeV/c)^{-2}$. These values are consistent with those obtained in pp interactions [1].

The transverse momentum squared distributions given in *Fig. 7a* have the exponential shape with the slopes which are in good agreement with those obtained in pp interactions at 205 *GeV/c* [1a] and 69 *GeV/c* [12] and in K^+p interactions at 8 and 16 *GeV/c* [11]. These slopes are steeper than the universal slope 3.4 $(GeV/c)^{-2}$ for "directly" produced particles found in ref. [11]. This difference is due to the cuts in the t-region, where the Δ^{++} resonances have been studied. Using $p\pi^+$ combinations of all protons in a mass range of 1.16 to 1.32 *GeV*, the slope has been estimated to be $-(4.66 \pm 0.55)(GeV/c)^{-2}$. (The background is about 50% in this mass range, see *Fig. 2*).

The p_T^2 distribution of Δ^{++} is similar to that for protons whereas the π^+ spectrum has another shape (see *Fig. 7b*). In the region of laboratory momenta smaller than 1.2 *GeV/c* the values of $\langle p_T^2 \rangle$ are $0.116 \pm 0.010\ (GeV/c)^2$, $0.147 \pm 0.004\ (GeV/c)^2$ and $0.040 \pm 0.003\ (GeV/c)^2$ for Δ^{++}, protons and π^+ mesons, respectively. A larger slope of the pion spectrum at small p_T^2 can be explained by the resonance production as the decay pions have small p_T^2 [11].

A connection between the Δ^{++} production and the target fragmentation process can be seen from the upper limit for the beam fragmentation cross section [2] which equals 1.31 ± 0.3 *mb* for 4 prongs and 0.08 ± 0.02 *mb* for all higher topologies. Therefore only a small part of Δ^{++} can be produced from the incident proton fragmentation.

V. DECAY ANGULAR DISTRIBUTIONS

The decay angular distributions of Δ^{++} in the t-channel rest frame are shown in *Fig. 8a*. They are asymmetric due to the background in the chosen mass region. The distribution of the Treiman-Yang angle ϕ is roughly consistent with isotropy (*Fig. 8a*) whereas the Jackson-angle distribution exhibits a peak for $\cos\theta = 1$ (*Fig. 8a*). The background role can be seen in the $\cos\theta$ distribution in adjacent regions of 1.08 - 1.16 *GeV* and 1.32 - 1.5 *GeV*, where a strong asymmetry is apparent (*Fig. 8b*).

The density matrix elements have been calculated by the method of moments with the following results:

$$\rho_{33} = 0.120 \pm 0.028; \quad Re\,\rho_{31} = -0.022 \pm 0.04;$$

$$Re\,\rho_{3-1} = -0.01 \pm 0.05 .$$

The pure OPE model predicts $\rho_{33} = Re\,\rho_{31} = Re\,\rho_{3-1} = 0$ while the absorptive pion exchange model yields the values $\rho_{33} = 0.12$, $Re\,\rho_{31} = 0.06$ and $Re\,\rho_{3-1} = 0.03$ [13]. Our value of ρ_{33} agrees with those obtained in pp interactions at 205 *GeV/c*)ref. [1a]), 100 *GeV/c* and 69 *GeV/c* (ref. [12]).

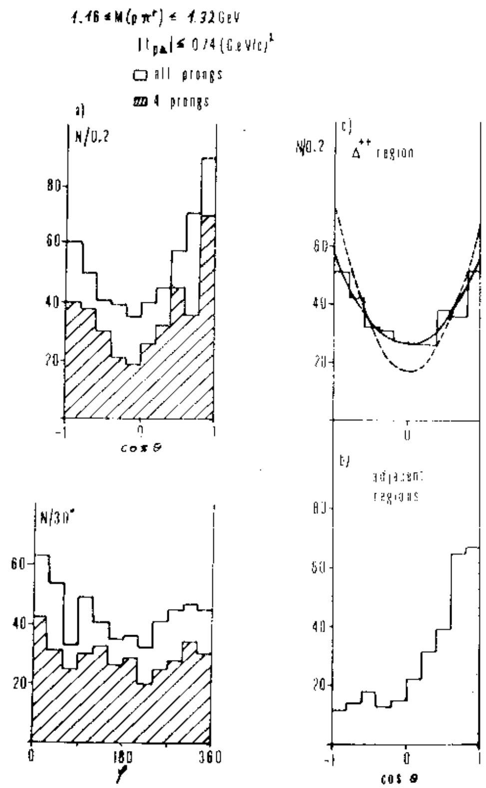

Fig. 8a) The distributions over the Treiman-Yang angle ϕ and the Jackson angle θ ; b) The Jackson angle θ distributions in the adjacent regions of Δ^{++} . c) The θ -distribution in the Δ^{++} region, where the background is subtracted. The full lines represent the prediction of the absorptive model, the dashed line corresponds to the pure OPE.

The angular distributions can be written as $0.25 \pm 0.75 \cos^2\theta$ and $0.37 \pm 0.39 \cos^2\theta$ for the pure and absorptive OPE models, respectively /12/. A comparison of these predictions with the experimental data is made in *Fig. 8c* *.

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* In order to get rid of the backgrouns influence, we have subtracted the $\cos\theta$ distributions in the adjacent regions from that in the Δ^{++} region.

The absorptive model is in better agreement with our data than the pure OPE.

VI. CONCLUSIONS

The following results have been obtained in a study of the inclusive Δ^{++} production.

(i) The lower limit of the inclusive cross section for Δ^{++} production over the entire kinematic region was estimated to be (2.89±0.18) *mb*. In the region of $|t_{p,p\pi^+}| \le 0.74$ $(GeV/c)^2$ the cross section was found to be (1.78±0.18) *mb*. The cross section for Δ^0 production was equal to 0.56±0.09 *mb* in the region of $|t_{p,p\pi^-}| \le 0.74$ $(GeV/c)^2$. The ratio of $\sigma(\Delta^{++})/\sigma(\Delta^0)$ is in agreement with the prediction of the triple Regge model in the region of $|t| \le 0.74$ $(GeV/c)^2$ and $5 \le M_x^2 \le 13$ GeV^2.

(ii) One can observe an enhancement in the x_Δ -distribution at $x \simeq -0.97$ corresponding to that in the M_x^2 distribution around 1.5 GeV^2, which can be explained by the associated production of Δ^{++} and $\bar{\Delta}^{++}$. The t and t' distributions are of an exponential form with the slopes which are in agreement with those obtained in other reactions. The inclusive p_T^2 distribution for Δ^{++} has an exponential behaviour similar to that of protons, whereas the p_T^2 distribution of π^+ mesons has a steeper slope at small p_T^2.

(iii) The Jackson angle distribution and the values of the spin density matrix elements show evidence for the absorptive one-pion exchange in the Δ^{++} inclusive production.

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