**INCLUSIVE PRODUCTION OF THE Λ (1232) RESONANCE
IN MUON PROTON SCATTERING AT 280 GeV/c**

The European Muon Collaboration

Aachen¹, CERN², DESY (Hamburg)³, Freiburg⁴, Hamburg (University)⁵,
Kiel⁶, LAL (Orsay)⁷, Lancaster⁸, LAPP (Annecy)⁹, Liverpool¹⁰,
Marseille¹¹, Mons¹², MPI (München)¹³, Oxford¹⁴, RAL (Chilton)¹⁵,
Sheffield¹⁶, Torino¹⁷, Uppsala¹⁸ and Wuppertal¹⁹

M. Arneodo¹⁷, A. Arvidson¹⁸, J.J. Aubert¹¹, B. Badelek^{18a)}, J. Beaufays²,
C.P. Bee^{8b)}, C. Benchouk¹¹, G. Berghoff¹, I. Bird⁸, D. Blum⁸,
E. Böhm⁶, X. de Bouard⁹, F.W. Brasse³, H. Braun¹⁹, C. Broll^{9a)},
S. Brown¹⁰, H. Brück^{19a)}, H. Calen¹⁸, J.S. Chima¹⁵, J. Ciborowski^{5a)},
R. Clifft¹⁵, G. Coignet⁹, F. Combley¹⁶, J. Coughlan^{8b)}, G. D'Agostini¹¹,
S. Dahlgren¹⁸, F. Dengler¹³, I. Derado¹³, T. Dreyer⁴, J. Drees¹⁹,
M. Düren¹, V. Eckardt¹³, A. Edwards^{19c)}, T. Ernst⁴, G. Eszes^{9d)},
J. Favier⁹, M.I. Ferrero¹⁷, J. Figiel^{5a)}, W. Flauger³, J. Foster¹⁶,
E. Gabathuler¹⁰, J. Gajewski^{5a)}, R. Gamet¹⁰, J. Gayler³, N. Geddes¹⁴,
P. Giubellino¹⁷, P. Grafström¹⁸, F. Grard¹², J. Haas⁴, E. Hagberg¹⁸,
F.J. Hasert¹, P. Hayman¹⁰, P. Heusse⁷, C. Hoppe⁵, M. Jaffré⁷,
A. Jacholkowska⁷, F. Janata⁵, G. Jancso^{9d)}, A.S. Johnson^{14a)}, E.M. Kabuss⁴,
G. Kellner², V. Korbel³, J. Krüger¹⁹, S. Kullander¹⁸, U. Landgraf⁴,
D. Lanske¹, J. Loken¹⁴, K. Long^{14a)}, M. Maire⁹, P. Malecki¹³,
A. Manz¹³, S. Maselli¹⁷, W. Mohr⁴, F. Montanet¹¹, H.E. Montgomery^{2b)},
E. Nagy^{9d)}, J. Nassalski^{13a)}, P.R. Norton¹⁵, F.G. Oakham¹⁵, A.M. Osborne²,
C. Pascaud⁷, B. Pawlik¹³, P. Payre¹¹, C. Peroni¹⁷, H. Pessard⁹,
J. Pettingale¹⁰, B. Pietrzyk¹¹, B. Pönsgen⁵, M. Pötsch¹⁹, P. Renton¹⁴,
P. Ribarics^{9d)}, K. Rith⁴, E. Rondio^{5a)}, M. Scheer¹, A. Schlagböhmer⁴,
H. Schiemann⁵, N. Schmitz¹³, M. Schneegans⁹, M. Sholz¹, T. Schröder⁴,
M. Schouten¹³, K. Schultze¹, T. Sloan⁸, H.E. Stier⁴, M. Studt⁵,
G.N. Taylor¹⁴, J.M. Thénard⁹, J.C. Thompson¹⁵, A. de la Torre⁵,
J. Toth^{9d)}, L. Urban¹, L. Urban^{9d)}, W. Wallucks⁴, M. Whalley^{16a)},
S. Wheeler¹⁶, W.S.C. Williams¹⁴, S.J. Wimpenny^{10a)}, R. Windmolders¹²,
G. Wolf¹³.

(Submitted to Nuclear Physics B)

Abstract

Inclusive production of the $\Lambda(1232)$ resonance has been measured in 280 GeV/c muon-proton interactions. The production of the Λ^{++} as a function of the variables x_{0J} , W , Q^2 , x_F and p_T^2 is investigated. The average Λ^{++} multiplicity is found to be smaller, by a factor of 6.2 ± 1.2 , than the average multiplicity of protons. An upper limit for Λ^0 production is obtained. The net hadronic charge distribution for events with a Λ^{++} is presented. The results are compared to the predictions of the Lund and Fire String Models.

- a) Now at University of Warsaw, Poland.
- b) Now at RAL, Chilton, Didcot, England.
- c) Now at Jet, Joint Undertaking, Abingdon, England.
- d) Now at Central Research Institute for Physics of the Hungarian Academy of Science, Budapest, Hungary.
- e) Now at Institute of Nuclear Physics, Krakow, Poland.
- f) Now at SLAC, Stanford, California, U.S.A.
- g) Now at CERN, Geneva, Switzerland.
- h) Now at FNAL, Batavia, Illinois, U.S.A.
- i) Now at Institute for Nuclear Studies, Warsaw, Poland.
- j) Now at University of Durham, England.
- k) Now at DESY, Hamburg, Germany.
- +) Deceased

1. Introduction

In this paper the production of the $\Lambda(1232)$ resonance in high energy muon-proton scattering is investigated. We observe the production of the Λ^{++} in the reaction $\mu^+ p \rightarrow \mu^+ \Lambda^{++} X^-$. This is the first observation of Λ production in high energy muon-proton scattering.

Previous experiments on hadron production have shown that decuplet baryons, in contrast to octet baryons, are not copiously produced either in lepton-proton or in e^+e^- annihilation [1,2,3]. The interpretation of these results in the framework of the Quark Parton Model (QPM) [4] is still an open question since, due to our lack of understanding of the confinement mechanism, we have no description of how quarks, after scattering, transform into the final state hadrons. In this paper we investigate the production mechanisms which could be responsible for the observed Λ production. The significance of constituent diquarks [5] in the fragmentation and recombination processes is investigated and a comparison is made of the Λ production characteristics with the predictions of the Lund String Model (LSM) [6], the Fire String Model (FSM) [7,8] and a cluster model [9].

2. Experimental layout and Data reduction

The experiment was performed at CERN in the 280 GeV/c M2 muon beam, using the EMC spectrometer [10]. This consists of a vertex magnet containing a streamer chamber, which itself contained a 1 meter long liquid hydrogen target, and a forward spectrometer which was used to detect and measure the scattered muon and the fast charged hadrons. The complete system detected tracks with momenta down to 200 MeV/c and gave essentially 4π coverage in

the hadronic center of mass (cm) system. In addition, time-of-flight hodoscopes plus four threshold Cerenkov counters gave good particle identification over a wide range of momentum. More details of the apparatus and the analysis procedures can be found in refs. [1, 10].

In order to restrict the event sample to regions where the corrections for event acceptance, smearing effects from the resolution of the apparatus and radiative corrections are relatively small ($\leq 10\%$), the following selection criteria were applied:

$$Q^2 > 4 \text{ GeV}^2$$

$$16 \text{ GeV}^2 < W^2 < 400 \text{ GeV}^2$$

$$20 \text{ GeV} < \nu < 260 \text{ GeV}$$

$$E'_\mu > 20 \text{ GeV}$$

$$y < 0.9$$

$$\theta_\mu > 0.75^\circ$$

Q^2 is the square of the four-momentum transfer between the incoming and the outgoing muon, $\nu = E_\mu - E'_\mu$ is the corresponding energy transfer in the laboratory system, W is the total energy of the final state hadrons in their cm system, E_μ and E'_μ is the energy of the incident and the scattered muon, respectively, in the laboratory system, $y = \nu/E_\mu$ and θ_μ is the angle between the incident and scattered muon. The number of events remaining after these cuts was about 25000.

About 50% of all charged hadrons were identified directly using the Cerenkov and time of flight system [1, 11]. In order to find additional protons in events without a directly identified proton the following procedure was applied [12]. The positive particle with the smallest x_F (assuming the pion mass) was selected and the proton mass was assigned to it if all the

following three conditions were satisfied :

- i. The particle had not been directly identified as K or π ,
- ii. $x_F < -0.2$, if x_F was calculated using the pion mass,
- iii. $x_F > -0.95$, if x_F was calculated using the proton mass.

Here $x_F = 2 \cdot p_L / W$ is the Feynman x variable, where p_L is the component of the hadron momentum in the cm system along the virtual photon direction.

This procedure is intended to recuperate protons in the region of low laboratory momenta where the rate of proton production is expected to be high and the identification efficiency is low. In total about 7600 protons were identified. The use of the same procedure on Monte-Carlo simulated events shows that about 80% of the protons identified in this manner were correctly classified.

The data were corrected for the effects of acceptance, identification inefficiency, smearing introduced by the resolution of the apparatus, and inefficiencies of the various off-line processors such as track reconstruction and vertex fitting. These corrections were determined by a complete Monte- Carlo (MC) simulation of the experiment. Deep inelastic scattering events were generated using the Lund String Model [6] for the fragmentation process''. Radiative effects due to QED processes and secondary interactions of the produced hadrons in the target material were taken into account. The scattered muon and the secondary hadrons were tracked through the apparatus and the effects of multiple Coulomb scattering simulated. The effects of chamber and hodoscope inefficiencies and smearing were also included and the resulting computed coordinates of the simulated measurements in each detector passed through

The following LSM parameter values were used: width of fragmentation p_T distribution $\sigma_q = 0.31$ GeV, strange quark suppression $\gamma_s / \gamma_u = 0.3$, diquark suppression $P_{qq} / P_q = 0.065$ and the SU(6) value for the spin 3/2 : spin 1/2 ratio.

the reconstruction program chain [1,11]. In this manner the inefficiencies of the apparatus and losses due to imperfections in the off-line analysis were fully included. Then, separately for each type of hadron ($p, \bar{p}, K^+, K^-, \pi^+, \pi^-$) a correction function was computed by taking the ratio of the three-dimensional distribution $F(p_{\Lambda B}, \theta, \phi)$ from the generated MC events and the corresponding distribution from the MC events after the experimental simulation. Here $p_{\Lambda B}, \theta, \phi$ are the momentum, azimuthal and polar angle of a produced hadron in the laboratory system.

The secondary interactions of pions or protons in the target reduce the number of the observed Δ 's. The additional correction for this effect was determined from the MC simulation to be $\sim 20\%$, the exact value depending on the kinematical region. The overall acceptance correction is almost constant when plotted as a function of the $p\pi^+$ or $p\pi^-$ mass.

3. Extraction of the resonance signal

A standard procedure to determine the size of a resonance signal from an invariant mass distribution is to fit a linear combination of a Breit-Wigner function and a function suitable to describe the nonresonant background to the measured invariant mass distribution. Since the Δ mass is close to threshold, it is obviously difficult to describe the background. This introduces a significant uncertainty in determining the Δ contribution. Extensive studies based on MC generated mass distributions were performed in order to find a suitable background function and to estimate a systematic error due to the particular choice of this function**.

** The background obtained from combinations of particles from different events was also considered [13].

The general formula [14] used to fit the $p\pi$ invariant mass distributions was of the form

$$\frac{1}{N_{\pi\nu}} \frac{dN}{dm} = BG(m) \cdot (1 + C \cdot BW(m)) \quad (1)$$

where m is the $p\pi$ invariant mass, $N_{\pi\nu}$ the number of events and N the number of $p\pi$ pairs in these events. $BG(m)$ is the background function and $BW(m)$ the Breit-Wigner relativistic p-wave resonance function. The function $BG(m)$ was chosen to have the form

$$BG(m) = A \cdot (q(m))^\alpha \cdot \exp[-B \cdot m^\beta] \quad (2)$$

where $q(m)$ is the momentum of the proton in the $p\pi$ rest frame. Formula (1) together with the function (2) for the background reproduced well the relative size of the Δ signal within statistical errors when tested on MC generated mass distributions. The position and width of the Δ resonance were fixed at the nominal values $m_0 = 1.232$ GeV and $\Gamma_0 = 0.115$ GeV. The mass interval used for the fits was $1.08 < m < 2.8$ GeV. The parameters A , B , C , α , β were determined from the fit. The fitting procedure was performed in the same way in each W , Q^2 , x_{Bj} , x_F and p_T^2 bin (where x_F and p_T^2 are defined for the $p\pi$ system). The χ^2 per degree of freedom for these fits varied in the range $0.9 < \chi^2/NDF < 1.6$ for $NDF > 50$ (with an average value of 1.2), giving acceptable χ^2 probabilities.

The corrected $p\pi^+$ ($p\pi^-$) invariant mass distributions are shown in Fig.1a (Fig.2). The curves in Fig.1a show the fit of formulae (1) and (2) (solid line) and the fitted background (dashed line). The $p\pi^+$ mass distribution after subtraction of the fitted background is shown in Fig.1b together with the fitted resonance function (solid line).

A clear Δ^{++} signal is seen in Fig.1. In Figs.3a,b,c the $p\pi^+$ mass distributions are shown for three regions of $t' = |t - t_{MIN}|$ where t is the

square of the four-momentum transfer between the incident proton and the outgoing $p\pi$ system and $t_{\min}$ is the minimum kinematic value of t .

No clear Δ^0 signal is seen in the $p\pi^-$ mass distribution (Fig.2). In trying out various background functions it was found, that in contrast to the $p\pi^+$ mass distribution the $p\pi^-$ mass distribution can be satisfactorily fitted to a background function only, without a resonance contribution, namely to the function

$$BG(m) = A \cdot (q(m))^\alpha \cdot \exp[-B \cdot m - C \cdot m^2] \quad (3)$$

Fits to this function are shown by the curves in Fig.2 and Figs. 3d,e,f. Using the background function (2) instead of (3) gave less satisfactory fits. However, to obtain an upper limit on the Δ^0 production, formula (1) together with the background function (2) was fitted to the $p\pi^-$ mass distribution (Fig.4), in analogy to the $p\pi^+$ case.

4. Results

Figs.5 and 6 show the corrected x_F and p_T^2 distributions, respectively, for the Δ^{++} . (both quantities are defined with respect to the virtual photon direction). For comparison the corresponding x_F distribution of protons from this experiment is also plotted [1]. The production of Δ^{++} is seen to be much less copious than that for protons with only ~16% of the protons originating from Δ^{++} decay.

In table 1 the average multiplicity $\langle n_{\Delta^{++}} \rangle$ of Δ^{++} and an upper limit for the average multiplicity $\langle n_{\Delta^0} \rangle$ of Δ^0 , corrected for the decay mode $\Delta^0 \rightarrow n\pi^0$, are given. About 60% of the quoted errors are due to the uncertainty in the choice of the background function. An additional systematic error of about 10% due to uncertainties in the proton identification procedure is not included in the quoted errors.

In table 2 the dependence of the average multiplicity $\langle n_{\Delta^{++}} \rangle$ on Q^2 , W and x_B is given. $\langle n_{\Delta^{++}} \rangle$ tends to increase as x_B increases, however, the errors are relatively large. This corresponds to a decrease of $\langle n_{\Delta^{++}} \rangle$ with increasing W because of the x_B , W correlation. An increase of $\langle n_{\Delta^{++}} \rangle$ with increasing x_B would indicate the importance of valence quark scattering in Δ^{++} production.

Fig.3 shows significant production of Δ^{++} for small momentum transfer $t' < 1 \text{ GeV}^2$ (corresponding to backward going Δ^{++} , $x_F < 0$). For this region the average transverse momentum squared, $\langle p_T^2 \rangle$ is $0.150 \pm 0.002 \text{ (GeV/c)}^2$. No Δ^{++} production is observed in the interval $1 < t' < 5 \text{ GeV}^2$. About 20% of the Δ^{++} are produced at large t' , corresponding predominantly to forward production ($x_F > 0$) and larger p_T^2 ($\langle p_T^2 \rangle = 0.768 \pm 0.045 \text{ (GeV/c)}^2$).

The results are compared with the predictions of two models, the Lund String Model (LSM) [6] and the Fire String Model (FSM) [7], both of which are formulated in the framework of the quark-parton picture. However, the LSM is modified according to the effects of perturbative and non-perturbative Quantum Chromodynamics (QCD), whereas the FSM does not use QCD but Quark-Geometrodynamics [8]. In addition we use a Cluster Model (cylindrical phase space and short range correlations) [9], in order to distinguish the effect of charge and energy-momentum conservation from other dynamical effects.

In table 3 the measured average multiplicities of protons, Δ^{++} and Δ^0 are given together with the predictions of the LSM and FSM. The predictions of both models are consistent with the data in the case of protons. In the case of Δ^{++} , however, both models give predictions which agree with the data in the forward hemisphere, but differ by a factor of ~ 1.7 in the backward hemisphere. This is also seen in Fig.5 where the predictions of the LSM are shown by the curves.

The production of Δ^{++} is observed to be strongly suppressed relative to proton production ($\langle n_p \rangle / \langle n_{\Delta^{++}} \rangle = 6.2 \pm 1.2$, from table 3). Both the LSM and the FSM predict a somewhat smaller suppression (~ 4). In both models the contribution of a ud diquark state with spin and isospin of zero inside the proton [5] is not significant. Such an $I = 0$ diquark state could fragment, by picking up an additional quark from the vacuum, into an $I = 1/2$ baryon (resonance). A substantial presence of such a diquark state would lead to the suppression of Δ production but would enhance the production of low mass, $I = 1/2$ baryon resonances. In this context it is interesting to observe a broad excess of $p\pi^-$ mass combinations around 1.4 GeV in Fig.7, where we show the $p\pi^-$ mass distribution after subtraction of the background obtained from the fit to the $p\pi^+$ (isospin 3/2) mass distribution in Fig.1. (Renormalisation of the background was not performed since the mass distributions in Fig.1a and Fig.2 are seen to be roughly the same above ~ 1.8 GeV). In the mass region around 1.4 GeV one expects several resonant baryon states to be present, which are impossible to extract experimentally. The observed broad enhancement could therefore indicate a contribution of the above mentioned diquark state. A similar feature is also observed in the reaction $\bar{\nu}p \rightarrow \mu^+ p\pi^-$ [15].

Figs.8a and 9a show the cm system rapidity distributions of the net hadronic charge

$$Q(y) = \frac{1}{N_{ev}} \left(\frac{dN^+}{dy} - \frac{dN^-}{dy} \right) \quad (4)$$

for events with $p\pi^+$ invariant masses in the interval

$1.172 < m_{p\pi^+} < 1.292$ GeV (where the Δ^{++} signal to background ratio is ~ 0.5)

and with the $p\pi^+$ system going into the backward ($x_F < 0$) and forward

($x_F > 0$) hemispheres, respectively. (N_{ev} is the number of events and $N^{\pm}$ is the number of positive and negative hadrons in these events). The lines represent predictions of different models. The Cluster Model (dashed line) strongly deviates from the experimental charge distribution indicating the sensitivity of this distribution to the dynamical inputs of the models. The FSM (dashed-dotted line) predicts more positive charge in the backward hemisphere than observed. This disagreement is probably caused by the leading baryon effect assumed in the FSM. The LSM (solid line) describes the data somewhat better. Figs. 8b and 9b show the dependence on x_B of the average net hadronic charge $\langle Q \rangle$ in the backward and forward hemispheres, respectively. The solid line represents $\langle Q \rangle$ calculated [16,12] under the assumption that the $p\pi^+$ system is produced in the fragmentation of a u quark. The dashed line represents the value of $\langle Q \rangle$ when the $p\pi^+$ system is produced in the fragmentation of two u quarks. The $\langle Q \rangle$ in the backward hemisphere is consistent with the value expected for uu diquark fragmentation. In the forward hemisphere $\langle Q \rangle$ is smaller; however the data points lie systematically above the solid line. Thus, even in the forward hemisphere a contribution from the fragmentation of two u quarks in the proton seems to be present.

Summary

In conclusion, we have measured the average Δ^{++} multiplicity $\langle n_{\Delta^{++}} \rangle$ as a function of Q^2 , W , x_B , x_F and p_T^2 . For the average Δ^0 multiplicity only an upper limit can be given. The Δ^{++} is produced predominantly at small momentum transfers t' . The Lund and Fire String Models predict about 50% more Δ^{++} than observed although they predict approximately the correct number of protons. The strong suppression of Δ^{++} production with respect to protons as well as the excess of events in the $p\pi^-$ mass dis-

tribution around 1.4 GeV could be an indication of a significant contribution of a diquark state with spin and isospin of zero inside the proton. The net hadronic charge distribution for events where the mass of the $p\pi^+$ system is close to the Δ^{++} mass, is in better agreement with Lund String Model than with the Fire String Model.

Acknowledgements

We would like to thank all people in the various laboratories who have contributed to the construction, operation and analysis of this experiment. The support of the CERN staff in operating the SPS, muon beam and computer facilities is gratefully acknowledged. Finally, we thank E.Ferrari for supplying us with the Monte-Carlo program for the Fire String Model and for useful discussions.

References

- [1] EMC, J.J.Aubert et al., Phys.Lett. 103B (1981) 388;
J.J.Aubert et al., Phys.Lett. 135B (1984) 22;
M. Arneodo et al., Phys.Lett. 145B (1984) 156;
M. Arneodo et al., Phys.Lett. 150B (1985) 458;
- [2] TASSO Coll., M. Althoff et al., Z.Phys. C17 (1983) 5.
- [3] TASSO Coll., M. Althoff et al., Z.Phys. C26 (1984) 181.
- [4] V.V. Anisovich and V.M. Shekhter, Nucl.Phys. B55 (1973) 474;
J.D. Bjorken and G.R. Farrar, Phys.Rev. D9 (1974) 1440;
H. Fukuda and Ch. Iso, Progr.Theor.Phys. 57 (1977) 483;
B.Andersson et al., Phys.Lett. 69B (1977) 221.
- [5] S.Fredricksson et al., Z.Phys. C14 (1982) 35.
- [6] G. Ingelman et al., Phys. Report 97 (1983) 31.
- [7] L. Angelini et al., Revista Nuovo Cim. 6 (1983) 1,
Monte Carlo modifications for μ -proton reactions are made by
E. Ferrari, University of Rome.
- [8] G. Preparata, Proc.of the IVth Seminar on Probing Hadrons with Leptons,
Erice 1979, p.475.
- [9] S. Uhlig et al., Nucl. Phys. B132 (1978) 15.
- [10] EMC, J.P. Albanese et al., Nucl. Instr. and Meth. 212 (1983) 111.
- [11] H. Bruck Ph. D. Thesis, Wuppertal 1984.
C.P. Bee Ph. D. Thesis, Lancaster 1983.
J. Coughlan Ph. D. Thesis, Lancaster 1984.
A.S. Johnson Ph. D. Thesis, Oxford 1984.
F. Montanet Thèse 3^{me} cycle, Université de Grenoble (1983).
- [12] J.P. Albanese et al., Phys. Lett. 144B (1984) 302.
- [13] D. Drijard et al., CERN/EP 84-15. Feb.1984.
- [14] J.D.Jackson, N. Cim. 34 (1964) 1644.
P. Granet et al., Nucl. Phys. B140 (1978) 389.
- [15] W. Wittek, Proc. of the XIth Internat.Conf. on Neutrino Phys. and
Astrophys., Nordkirchen, 1984, p. 527.
- [16] R.D. Field and R.P. Feynman, Nucl. Phys. B136 (1978) 1;
A. Bartl, Z.Phys. C20 (1983) 263;
F. Dengler, Ph.D. Thesis, München 1985.

Tab.1 The total, forward and backward average multiplicity of Δ^{++} and an upper limit for the total average multiplicity of Δ^0 (corrected for the decay mode $\Delta^0 \rightarrow n\pi^0$).

	$\langle n_{\Delta^{++}} \rangle$	$\langle n_{\Delta^0} \rangle$
TOTAL	0.10 ± 0.02	< 0.18 (95% CL)
$X_F > 0$	0.02 ± 0.01	---
$X_F < 0$	0.08 ± 0.02	---

Tab.2 The average multiplicity of Δ^{++} for different ranges of Q^2 , W , and x_{Bj} .

Q^2 [GeV ²]	$\langle n_{\Delta^{++}} \rangle$	W [GeV]	$\langle n_{\Delta^{++}} \rangle$	x_{Bj}	$\langle n_{\Delta^{++}} \rangle$
4-16	0.09 ± 0.02	4-10	0.12 ± 0.03	< 0.1	0.09 ± 0.02
16-26	0.11 ± 0.02	10-16	0.09 ± 0.02	0.1-0.2	0.10 ± 0.02
> 26	0.10 ± 0.01	16-20	0.08 ± 0.02	> 0.2	0.13 ± 0.03

Tab.3 The measured total $\langle n_{TOT} \rangle$, forward $\langle n_F \rangle$, and backward $\langle n_B \rangle$ average multiplicity of p (including those from Δ decay), Δ^{++} and Δ^0 (DATA) and the values predicted by the Lund String Model (LSM) and the Fire String Model (FSM).

		$\langle n_{TOT} \rangle$	$\langle n_F \rangle$	$\langle n_B \rangle$
p	DATA	0.62 ± 0.01	0.10 ± 0.01	0.52 ± 0.01
	LSM	0.62	0.08	0.54
	FSM	0.62	0.07	0.55
Δ^{++}	DATA	0.10 ± 0.02	0.02 ± 0.01	0.08 ± 0.01
	LSM	0.16	0.02	0.14
	FSM	0.14	0.02	0.12
Δ^0	DATA	< 0.18	--	--
	LSM	0.12	0.02	0.10
	FSM	0.05	0.01	0.04

Figure Captions

- Fig.1 a) The corrected $p\pi^+$ invariant mass distribution.
The solid line represents a fit of the formulae (1) and (2).
The dashed line shows the fitted background contribution.
- b) The corrected $p\pi^+$ invariant mass distribution after subtraction of the fitted background. The solid line represents the fitted Breit-Wigner resonance function.
- Fig.2 The corrected $p\pi^-$ invariant mass distribution. The curve shows a fit to the background function (equation (3)) without resonance contribution.
- Fig.3 The corrected mass distributions of $p\pi^+$ (a, b, c) and $p\pi^-$ (d, e, f) for three regions of t' :
 $t' < 1 \text{ GeV}^2$ (a, d), $1 < t' < 5 \text{ GeV}^2$ (b, e), $t' > 5 \text{ GeV}^2$ (c, f).
The solid lines in a,b,c represent fits of the formulae (1) and (2) to the data points. The dashed lines show the fitted background contribution. In d,e,f the curves represent fits to the background function (3).
- Fig.4 The corrected $p\pi^-$ invariant mass distribution.
The solid line represents a fit of the formulae (1) and (2).
The dashed line shows the fitted background contribution.
- Fig.5 The x_F distributions of protons (crosses) and Δ^{++} (full points) from this experiment. The solid and dashed lines represent the prediction of the Lund String Model [6] for protons and Δ^{++} , respectively.
- Fig.6 The p_T^2 distribution of Δ^{++} (full points) from this experiment. The dashed line represents the prediction of the Lund String Model [3].
- Fig.7 The $p\pi^-$ mass distribution after subtraction of the background obtained from the fit to the $p\pi^+$ mass distribution (Fig.1a). For comparison the fitted resonance function from Fig.1b is shown (solid line).
- Fig.8 a) The net hadronic charge $Q(y)$ (eq.(4)) as a function of the cms rapidity y for events where the $p\pi^+$ system had a mass in the interval $1.172 < m_{p\pi^+} < 1.292 \text{ GeV}$ and a Feynman $x_F < 0$. For comparison the predictions of the Cluster Model (dashed line), the Lund String Model (solid line) and the Fire String Model (dashed-dotted line) are shown.
- b) Average net hadronic charge $\langle Q \rangle$ in the backward cms hemisphere as a function of x_B , for the same events as in a). The solid line represents $\langle Q \rangle$ calculated under the assumption that the $p\pi^+$ system is produced in the fragmentation of a u quark and the dashed line represents $\langle Q \rangle$ when the $p\pi^+$ is produced in the fragmentation of a uu diquark.

Fig.9 a) Same as in Fig.8a but for events with the $p\pi^+$ system in the forward hemisphere ($x_F > 0$).

b) Same as in Fig.8b but in the forward cms hemisphere ($x_F > 0$).

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9