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A study of pseudoscalar states produced centrally in pp interactions at 450 GeV/c

The WA102 Collaboration

D. Barberis[5], W. Beusch[5], F.G. Binon[7], A.M. Blick[6], F.E. Close[4], K.M. Danielsen[12], A.V. Dolgopolov[6], S.V. Donskov[6], B.C. Earl[4], D. Evans[4], B.R. French[5], T. Hino[13], S. Inaba[9], A.V. Inyakin[6], T. Ishida[9], A. Jacholkowski[5], T. Jacobsen[12], G.T Jones[4], G.V. Khaustov[6], T. Kinashi[14], J.B. Kinson[4], A. Kirk[4], W. Klempt[5], V. Kolosov[6], A.A. Kondashov[6], A.A. Lednev[6], V. Lenti[5], S. Maljukov[8], P. Martinengo[5], I. Minashvili[8], K. Myklebost[3], T. Nakagawa[13], K.L. Norman[4], J.M. Olsen[3], J.P. Peigneux[1], S.A. Polovnikov[6], V.A. Polyakov[6], V. Romanovsky[8], H. Rotscheidt[5], V. Rumyantsev[8], N. Russakovich[8], V.D. Samoylenko[6], A. Semenov[8], M. Sené[5], R. Sené[5], P.M. Shagin[6], H. Shimizu[14], A.V. Singovsky[1,6], A. Sobol[6], A. Solovjev[8], M. Stassinaki[2], J.P. Stroot[7], V.P. Sugonyaev[6], K. Takamatsu[10], G. Tchlatchidze[8], T. Tsuru[9], M. Venables[4], O. Villalobos Baillie[4], M.F. Votruba[4], Y. Yasu[9].

Abstract

A study has been made of pseudoscalar mesons produced centrally in pp interactions. The results show that the η and η' appear to have a similar production mechanism which differs from that of the π^0. The production properties of the η and η' are not consistent with what is expected from double Pomeron exchange. In addition the production mechanism for the η and η' is such that the production cross section are greatest when the azimuthal angle between the p_T vectors of the two protons is 90 degrees.

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1 LAPP-IN2P3, Annecy, France.
2 Athens University, Physics Department, Athens, Greece.
3 Bergen University, Bergen, Norway.
4 School of Physics and Astronomy, University of Birmingham, Birmingham, U.K.
5 CERN - European Organization for Nuclear Research, Geneva, Switzerland.
6 IHEP, Protvino, Russia.
7 IISN, Belgium.
8 JINR, Dubna, Russia.
9 High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305, Japan.

[10] Faculty of Engineering, Miyazaki University, Miyazaki, Japan.
[11] RCNP, Osaka University, Osaka, Japan.
[12] Oslo University, Oslo, Norway.
[13] Faculty of Science, Tohoku University, Aoba-ku, Sendai 980, Japan.
[14] Faculty of Science, Yamagata University, Yamagata 990, Japan.

The WA102 experiment is designed to study the properties of centrally produced mesons. Reactions of this type are expected to be mediated by double exchange processes, with a mixture of Pomeron-Pomeron, Reggeon-Pomeron and Reggeon-Reggeon exchange. In order to try to understand the nature of the centrally produced mesons it is interesting to try to determine which exchange process is producing them. For instance, the Pomeron is thought to be a multi-gluonic object and consequently it has been anticipated that the production of glue rich states may be especially favoured in Double Pomeron Exchange (DPE). It has been proposed that the η and η' are strongly connected to glue [1]. Further information on this subject could come from studying if the η or η' are produced by DPE.

It has previously been reported that in central production 0^{-+} states are suppressed relative to 1^{++} states [2]. In addition, both the η and η' signals are suppressed at small four-momentum transfers where DPE is believed to be dominant [2, 3]. Hence it could be conjectured that 0^{-+} objects do not couple to DPE. This hypothesis has been further tested by measuring the cross section of the production of the η and η' as a function of energy [4, 5]. The result shows that the cross section for production of these resonances decreases with energy which is inconsistent with production via DPE which is predicted to give a constant cross section.

This paper presents new results from the WA102 experiment on the centrally produced π^0, η and η' formed in the reactions

$$pp \to p_f(\pi^0 \to \gamma\gamma)p_s \tag{1}$$

$$pp \to p_f(\eta \to \gamma\gamma)p_s \tag{2}$$

$$pp \to p_f(\eta \to \pi^+\pi^-\pi^0, \pi^0 \to \gamma\gamma)p_s \tag{3}$$

$$pp \to p_f(\eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma)p_s \tag{4}$$

at 450 GeV/c. The subscripts f and s indicate the fastest and slowest particles in the laboratory respectively. The data come from experiment WA102 which has been performed using the CERN Omega Spectrometer. The layout of the Omega Spectrometer used in this run is similar to that described in ref. [6] with the replacement of the OLGA calorimeter by GAMS 4000 [7].

Reactions (1)-(4) have been isolated from the sample of events having the required number of outgoing charged tracks plus two γs reconstructed in the electromagnetic calorimeter[1] by first imposing the following cuts on the components of the missing momentum: $|$missing $P_x| < 17.0$ GeV/c, $|$missing $P_y| < 0.16$ GeV/c and $|$missing $P_z| < 0.12$ GeV/c, where the x axis is along the beam direction. A correlation between pulse-height and momentum obtained from a system of scintillation counters was used to ensure that the slow particle was a proton. Evidence of proton excitation can be observed in the $p_f\pi^0$ mass spectrum (i.e. Δ^+ or N^{*+} production) which has been removed by requiring $M(p_f\pi^0) > 2.0$ GeV.

Fig. 1a) and b) shows the two photon mass spectra in the region of the π^0 and η respectively for reactions 1 and 2. The mass resolution is $\sigma = 14$ MeV for the π^0 and $\sigma = 33$ MeV for the η. Fig. 1c) shows the $\pi^+\pi^-\pi^0$ mass spectrum in the region of η for reaction (3) where the π^0 is detected decaying to two photons and kinematically fitted to give the π^0 mass. The mass resolution is $\sigma = 11$ MeV. Fig. 1d) shows the $\eta\pi^+\pi^-$ mass spectrum in the region of η' for

[1] The showers associated with the impact of the charged tracks on the calorimeter have been removed from the event before the requirement of only two γs was made.

reaction (4) where the η is detected decaying to two photons and kinematically fitted to give the η mass. The mass resolution is $\sigma = 10$ MeV.

A Monte Carlo simulation has been performed to calculate the acceptance for each decay mode. The acceptance corrected Feynman x (x_F) distributions are shown in fig. 2a), b) and c) for the π^0, η and η' respectively for $x_F \geq 0.0$. A cut of $0.0 \leq x_F \leq 0.1$ has been used to select central events in a region where the acceptance is effectively flat for all three mesons.

After acceptance correction the branching ratio of the η to 2γ and $\pi^+\pi^-\pi^0$ has been calculated to be

$$\frac{\eta \to \gamma\gamma}{\eta \to \pi^+\pi^-\pi^0} = 1.60 \pm 0.05 \pm 0.08 \tag{5}$$

which is consistent with the PDG [8] value of 1.69 ± 0.04. The systematic error is due mainly to the different trigger efficiencies for the decay of central systems to all photon final states relative to final states involving charged particles. Since the background below the η decay to $\pi^+\pi^-\pi^0$ is smaller than in the 2γ decay mode, it is the data from the $\pi^+\pi^-\pi^0$ decay mode which will be used in the following analysis. However, the 2γ decay mode gives consistent results.

It has recently been suggested [9, 10] that the central production of pseudoscalars could be explained if the production mechanism is through the fusion of two vectors. In particular ref. [10] has suggested that $\gamma\gamma$ fusion may be the dominant mechanism for pseudoscalars in central production. To test this hypothesis, and provide further information on their production properties, the cross sections for the production of pseudoscalar mesons have been calculated for the Feynman x interval $0.0 \leq x_F \leq 0.1$ taking into account the unseen decay modes. The resulting cross sections are

$$\begin{array}{lcll} \sigma(\pi^0) & = & 17609 \pm 210 \pm 2400 & \text{nb} \\ \sigma(\eta) & = & 1295 \pm 16 \pm 120 & \text{nb} \\ \sigma(\eta') & = & 588 \pm 18 \pm 60 & \text{nb.} \end{array}$$

The dominant contribution to the systematic error comes from the uncertainty in the sensitivity of the experiment. These cross sections are several orders of magnitude larger than what would be expected for $\gamma\gamma$ fusion which we have calculated, using the method described in ref. [11], to be less than 1 nb in the kinematic window considered.

The relative cross sections can be measured more precisely due to the cancellation of common systematic errors and are

$$\sigma(\pi^0) : \sigma(\eta) : \sigma(\eta') = 1 : 0.073 \pm 0.005 : 0.033 \pm 0.002.$$

These ratios are in agreement with $\sigma(\pi^0) : \sigma(\eta) : \sigma(\eta') = 1 : 0.080 \pm 0.015 : 0.028 \pm 0.009$ found previously by the NA12/2 experiment studying the reaction $\pi^- N \to \pi^- N X^0$ at 300 GeV/c incident beam momentum [12]. It is interesting to note that the NA12/2 experiment found that the x_F dependence of the π^0, η and η' was effectively flat in the range $0.0 \leq x_F \leq 0.3$ in contrast to what is observed in this current experiment (see fig. 2a), b) and c)).

In previous analyses of other channels it has been observed that when the centrally produced system has been analysed as a function of the parameter dP_T, which is the difference in the transverse momentum vectors of the two exchange particles [13], all the undisputed $q\overline{q}$ states are suppressed at small dP_T. Therefore, a study of the centrally produced pseudoscalar states has been performed as a function of dP_T. Fig. 2d), e) and f) shows the dP_T spectra for the π^0, η and η' respectively. The dP_T spectra for the η and η' are very similar; however, the π^0 has a different spectrum with more events at small dP_T. Table 1 gives the fraction of each resonance in three bins of dP_T. As can be seen all the states are suppressed at small dP_T consistent with what has been observed previously for all other $q\overline{q}$ states [13]. This suppression of pseudoscalar states at small dP_T is consistent with their production through vector vector fusion [9, 10].

Fig. 3a), b) and c) shows the four momentum transfered from one of the proton vertices for the π^0, η and η' respectively. None of these distributions can be fitted with a single exponential. The η and η' have a similar distribution while the π^0 is different. It should be noted that the t spectra for the η and η' are not consistent with what is expected from DPE, namely an e^{-bt} behaviour with $b \approx 6-8 GeV^{-2}$ [14]. The t distributions have been fitted to the form

$$\frac{d\sigma}{dt} = \alpha e^{-b_1 t} + \beta t^n e^{-b_2 t} \tag{6}$$

where values of n of 1 or 2 have been tried. Fits with n = 2 were found to give the best fit to the data. The parameters resulting from the fit are given in table 2. As can be seen the values of b_1 and b_2 are consistent in each case. The main difference is that the π^0 has a larger value of the ratio α/β.

The azimuthal angle (ϕ) between the p_T vectors of the two protons, which is shown in fig. 3d), e) and f), shows a very interesting effect. The η and η' are produced predominantly when the angle ϕ is 90 degrees.

In summary, it would appear that the η and η' have a similar production mechanism which differs from that of the π^0. The t spectra for the η and η' are not consistent with what is expected from DPE and this fact together with the previous observation that the energy dependence of the cross section of the η or η' is not constant [4, 5] confirms that neither the η nor the η' are produced dominantly by DPE. In addition the production mechanism for the η and η' is such that the production cross sections are greatest when the azimuthal angle between the p_T vectors of the two protons is 90 degrees.

Acknowledgements

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Tables

Table 1: Resonance production as a function of dP_T expressed as a percentage of its total contribution.

	$dP_T \leq 0.2$ GeV	$0.2 \leq dP_T \leq 0.5$ GeV	$dP_T \geq 0.5$ GeV
π^0	$13 \pm 1 \pm 2$	$45 \pm 1 \pm 2$	$42 \pm 1 \pm 4$
η	$6 \pm 1 \pm 2$	$34 \pm 1 \pm 2$	$60 \pm 1 \pm 3$
η'	$3 \pm 1 \pm 2$	$33 \pm 1 \pm 2$	$64 \pm 1 \pm 3$

Table 2: Parameters from the fit to the t distribution

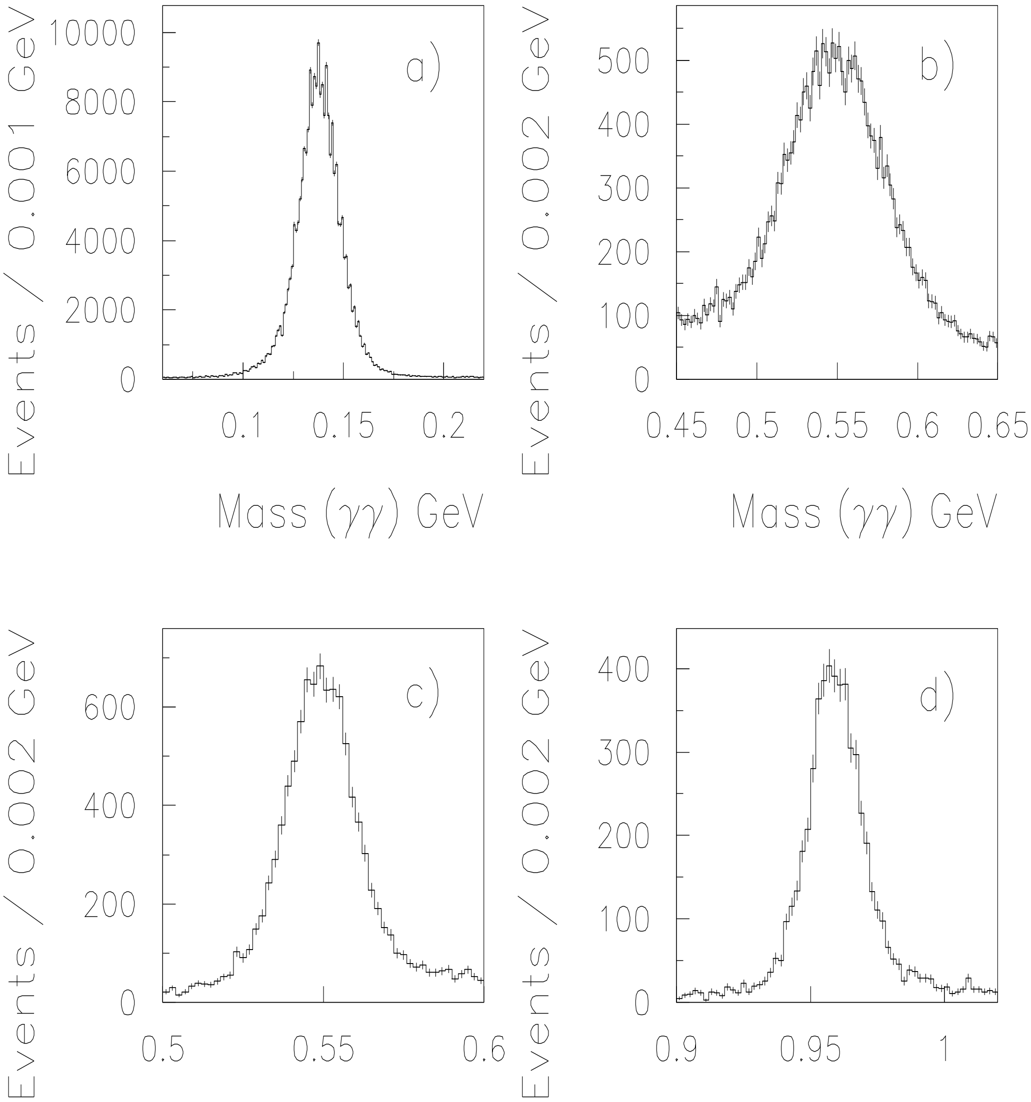
	α x10^3	b_1 GeV^{-2}	β x10^3	b_2 GeV^{-2}
π^0	128 ± 9	14.9 ± 0.3	411 ± 61	12.3 ± 0.4
η	2.3 ± 0.3	15 ± 5	215 ± 12	11.6 ± 0.2
η'	0.3 ± 0.2	15 ± 5	108 ± 8	11.2 ± 0.2

Figures

Figure 1: The effective mass spectra for the reaction $pp \to p_f p_s X^0$ with X^0 decaying to a), b) $\gamma\gamma$, c) $\pi^+\pi^-\pi^0$ and d) $\eta\pi^+\pi^-$.

Figure 2: a), b) and c) The x_F distribution for the π^0, η and η' respectively. d), e) and f) The dP_T spectra for the π^0, η and η' respectively.

Figure 3: The four momentum transfer squared ($|t|$) from one of the proton vertices for the a) π^0, b) η and c) and η'. The azimuthal angle (ϕ) between the two outgoing protons for the d) π^0, e) η and f) and η'.



Events / 0.001 GeV
10000
8000
6000
4000
2000
0
0.1
0.15
0.2
a)
Mass ($\gamma\gamma$) GeV
Events / 0.002 GeV
500
400
300
200
100
0
0.45
0.5
0.55
0.6
0.65
b)
Mass ($\gamma\gamma$) GeV
Events / 0.002 GeV
600
400
200
0
0.5
0.55
0.6
c)
Mass ($\pi^+\pi^-\pi^0$) GeV
Events / 0.002 GeV
400
300
200
100
0
0.9
0.95
1
d)
Mass ($\eta\pi^+\pi^-$) GeV

Figure 1

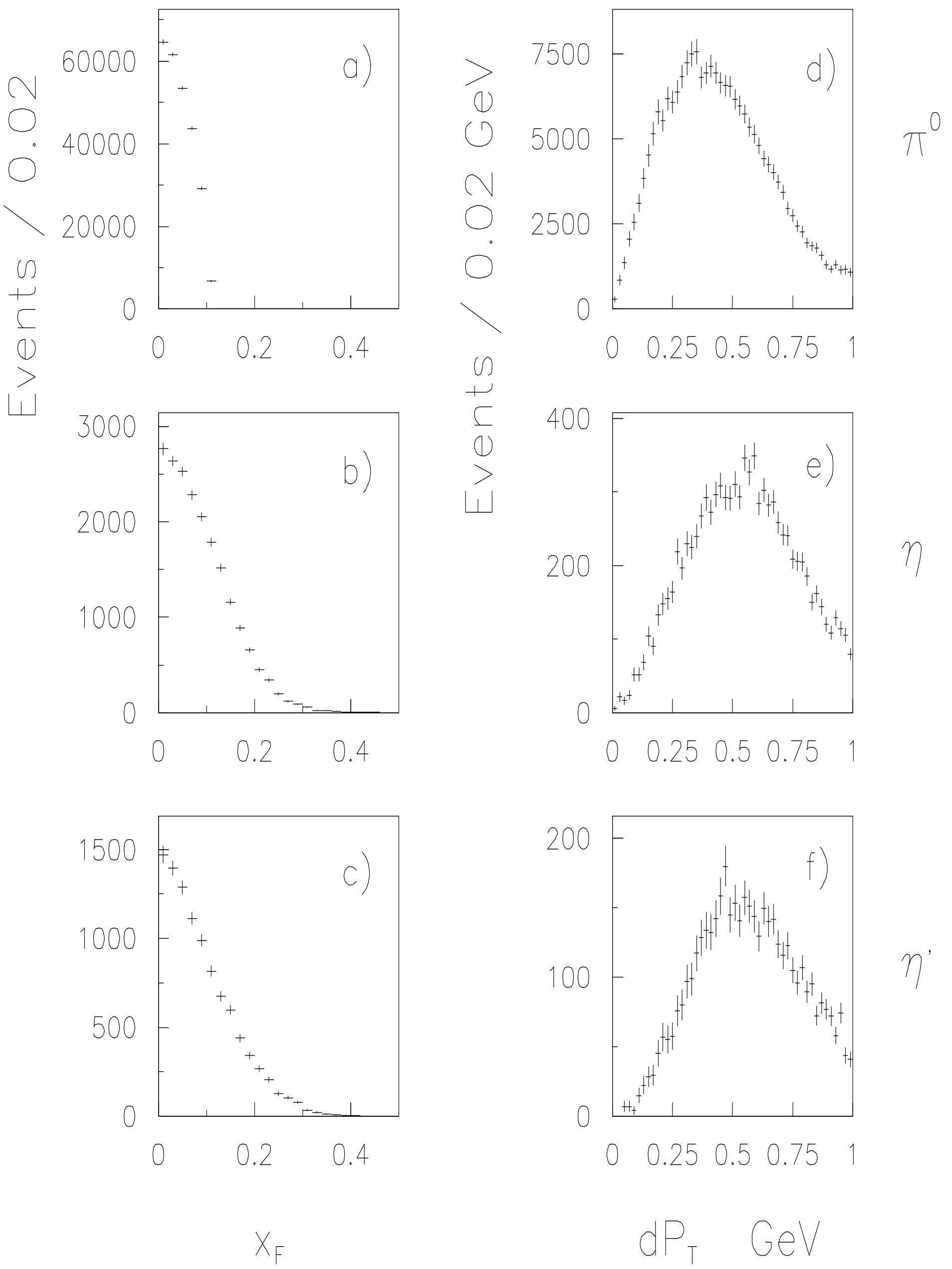
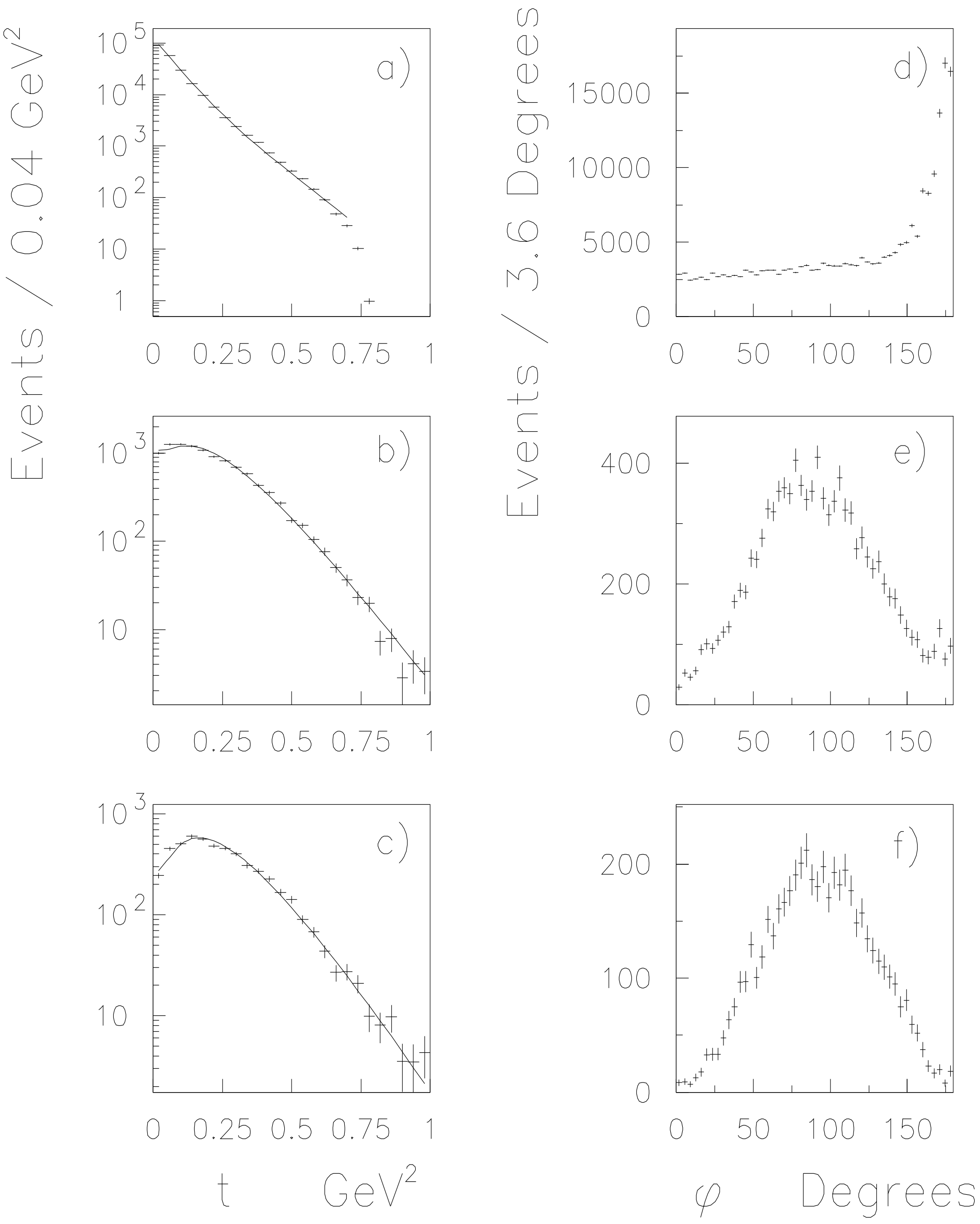

Events / 0.02
Events / 0.02 GeV
a)
b)
c)
d)
e)
f)
π^0
η
η'
x_F
dP_T GeV
0
0.2
0.4
0.25
0.5
0.75
1
20000
40000
60000
1000
2000
3000
500
1500
2500
5000
7500
100
200
400

Figure 2



Events / 0.04 GeV^2
10^5
10^4
10^3
10^2
10
1
a)
0
0.25
0.5
0.75
1
b)
c)
t GeV^2
Events / 3.6 Degrees
15000
10000
5000
0
d)
50
100
150
400
200
e)
f)
100
φ Degrees
π^0
η
η'

Figure 3