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A study of the centrally produced baryon-antibaryon systems in pp interactions at 450 GeV/c

The WA102 Collaboration

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Abstract

A study of the centrally produced $p\overline{p}$, $p\overline{p}\pi^0$, $p\overline{p}\pi^+\pi^-$ and $\Lambda\overline{\Lambda}$ channels has been performed in pp collisions using an incident beam momentum of 450 GeV/c. No significant new structures are observed in the mass spectra, however, important new information on the production dynamics is obtained. A systematic study of the production properties of these systems has been performed and it is found that these systems are not produced dominantly by double Pomeron exchange.

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Experiment WA102 is designed to study exclusive final states formed in the reaction

$$pp \rightarrow p_f(X^0)p_s \quad (1)$$

at 450 GeV/c. The subscripts f and s indicate the fastest and slowest particles in the laboratory respectively and X^0 represents the central system that is presumed to be produced by double exchange processes. The experiment has been performed using the CERN Omega Spectrometer, the layout of which is described in ref. [1]. 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 [1, 2], all the undisputed $q\overline{q}$ states are suppressed at small dP_T, in contrast to glueball candidates.

This paper presents a study of the $p\overline{p}$, $p\overline{p}\pi^0$, $p\overline{p}\pi^+\pi^-$ and $\Lambda\overline{\Lambda}$ final states at a centre of mass energy of $\sqrt{s} = 29.1$ GeV. The $p\overline{p}$, $p\overline{p}\pi^+\pi^-$ and $\Lambda\overline{\Lambda}$ channels have previously been studied at $\sqrt{s} = 12.7$ GeV [3]. In recent years there have been claims of the observation of two different resonant signals in the $p\overline{p}$ channel. The first claim is for the observation of the $\xi(2220)$, with a width of 20 MeV, in radiative J/ψ decays made by the BES collaboration [4]. The $\xi(2220)$ is claimed to be a good candidate for the tensor glueball. To date, every established $J^{PC} = 0^{++}$ and 2^{++} glueball candidate has been observed in central pp collisions. Therefore, it is important to look for these new states in central production in order to learn more about the nature and/or existence of the $\xi(2220)$.

The second claimed observation is for a state with a mass of 2.02 GeV and a width of less than 10 MeV observed in central baryon exchange by the WA56 experiment [5]. It is claimed that this state could be interpreted as a baryonium candidate. Although the current experiment does not study baryon exchange it does study central production and hence a search for this state may be of interest.

In addition to these searches, an analysis of the production kinematics of baryon-antibaryon production is presented which can give information on the mechanism of the formation of these final states in central production.

The reaction

$$pp \rightarrow p_f(p\overline{p})p_s \quad (2)$$

has been isolated from the sample of events having four outgoing charged tracks, by first imposing the following cuts on the components of the missing momentum: $|\text{missing } P_x| < 14.0$ GeV/c, $|\text{missing } P_y| < 0.16$ GeV/c and $|\text{missing } P_z| < 0.08$ 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.

In order to select the $p\overline{p}$ system, information from the Čerenkov counter was used. One centrally produced charged particle was required to be identified as a p or an ambiguous K/p by the Čerenkov counter and the other particle was required to be consistent with being a proton. The method of Ehrlich et al. [6], has been used to compute the mass squared of the two centrally produced particles assuming them to have equal mass. The resulting distribution is shown in fig. 1a) where a clear peak can be seen at the proton mass squared. This distribution has been fitted with Gaussians to represent the contributions from the $\pi^+\pi^-$, K^+K^- and $p\overline{p}$ channels. From this fit the number of $p\overline{p}$ events is found to be 6256 ± 220.

A cut on the Ehrlich mass squared of $0.65 \leq M_X^2 \leq 1.15\ GeV^2$ has been used to select a sample of $p\overline{p}$ events. The resulting $p\overline{p}$ effective mass distribution is shown in fig. 1b). There are no significant structures in the mass spectrum, in particular there is no evidence for the $\xi(2220)$ that has been claimed in the $p\overline{p}$ channel by the BES collaboration [4] nor is there evidence for the narrow structure at 2.02 GeV claimed to have been observed in central baryon exchange reactions [5]. The mass resolution of the WA102 experiment in each region is better than 10 MeV. We can calculate an upper limit for the cross-sections for the production of these claimed resonances in central pp interactions to be $\sigma(\xi(2220)) < 1.6$ nb and $\sigma(2.02GeV) < 1.4$ nb at 95 % confidence level.

The reaction

$$pp \rightarrow p_f(p\overline{p}\pi^0)p_s \tag{3}$$

where the π^0 has been observed decaying to $\gamma\gamma$, has been isolated from the sample of events having four outgoing charged tracks plus two γs each with energy greater than 0.5 GeV 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.

One centrally produced charged particle was required to be identified as a p or an ambiguous K/p by the Čerenkov counter and the other particle was required to be consistent with being a proton. The Ehrlich mass distribution is shown in fig. 1c) where a clear peak can be seen at the proton mass squared. This distribution has been fitted with Gaussians to represent the contributions from the $\pi^+\pi^-\pi^0$, $K^+K^-\pi^0$ and $p\overline{p}\pi^0$ channels. From this fit the number of $p\overline{p}\pi^0$ events is found to be 877 ± 85. A cut on the Ehrlich mass squared of $0.65 \leq M_X^2 \leq 1.15\ GeV^2$ has been used to select a sample of $p\overline{p}\pi^0$ events. The resulting $p\overline{p}\pi^0$ effective mass distribution is shown in fig. 1d) where no significant structure can be observed. Similarly, the $p\overline{p}$, $p\pi^0$ and $\overline{p}\pi^0$ mass spectra do not show any significant structures (not shown).

The reaction

$$pp \rightarrow p_f(p\overline{p}\pi^+\pi^-)p_s \tag{4}$$

has been isolated from the sample of events having six outgoing charged tracks, by first imposing the following cuts on the components of the missing momentum: |missing P_x| < 14.0 GeV/c, |missing P_y| < 0.12 GeV/c and |missing P_z| < 0.08 GeV/c.

In order to select the $p\overline{p}\pi^+\pi^-$ system an event was accepted if a positive or negative particle was identified as a p or a K/p by the Čerenkov system and the other particle with the same charge was consistent with being a π. A modified method of Ehrlich et al. [6], has been used to compute the mass squared of the two highest momentum central particles assuming the other two particles to be pions. The resulting distribution is shown in fig. 2a) where a clear peak can be seen at the proton mass squared. This distribution has been fitted with Gaussians to represent the contributions from the $\pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^+\pi^-$ and $p\overline{p}\pi^+\pi^-$ channels. From this fit the number of $p\overline{p}\pi^+\pi^-$ events is found to be 2076 ± 160. A cut on the Ehrlich mass squared of $0.65 \leq M_X^2 \leq 1.15\ GeV^2$ has been used to select a sample of $p\overline{p}\pi^+\pi^-$ events. The resulting $p\overline{p}\pi^+\pi^-$ effective mass spectrum is shown in fig. 2b) and shows a broad distribution with a maximum near threshold.

[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.

A study has been performed of the various two and three body subsystems but no structure has been observed except Δ^{++} and $\overline{\Delta}^{--}$ in the $p\pi^+$ and $\overline{p}\pi^-$ mass spectra respectively. Fig. 2c) shows a scatter plot of M($\overline{p}\pi^-$) versus M($p\pi^+$) where a clear accumulation of events can be observed in the $\Delta^{++}\overline{\Delta}^{--}$ region. However, it is not possible to extract a reliable measure of the $\Delta^{++}\overline{\Delta}^{--}$ contribution due to the difficulties in establishing the level of background.

The reaction

$$pp \rightarrow p_f(\Lambda\overline{\Lambda})p_s \tag{5}$$

has been isolated from the sample of events having two outgoing charged tracks plus two V^0s, by first imposing the following cuts on the components of the missing momentum: |missing P_x| < 14.0 GeV/c, |missing P_y| < 0.16 GeV/c and |missing P_z| < 0.02 GeV/c. For each V^0 the value of $\alpha = \frac{P_L^+ - P_L^-}{P_L^+ + P_L^-}$, was calculated, where P_L^+ (P_L^-) is the longitudinal momentum of the positive (negative) particle from the decay of the V^0 with respect to the V^0 momentum vector. For a Λ ($\overline{\Lambda}$) α is positive (negative) and hence events which were compatible with being $\Lambda\overline{\Lambda}$ were selected by requiring that the product $\alpha_1.\alpha_2$ was negative.

The quantity Δ, defined as $\Delta = MM^2(p_f p_s) - M^2(\Lambda\overline{\Lambda})$, where $MM^2(p_f p_s)$ is the missing mass squared of the two outgoing protons, was then calculated for each event and a cut of $|\Delta| \leq 2.0$ (GeV)^2 was used to select the $\Lambda\overline{\Lambda}$ channel. In order to study any possible residual K^0_S contamination a scatter plot of M($\pi\pi$) versus M($p\pi$) is shown in fig. 3a) for the case when the other V^0 is compatible with being a Λ (1.09 $\leq$ M($p\pi$) $\leq$ 1.14 GeV). The resulting $p\pi^-$ ($\overline{p}\pi^+$) mass distribution is shown in fig 3b) where a clear Λ ($\overline{\Lambda}$) signal can be seen over little background, with negligible contribution from the K^0_S. The resulting $\Lambda\overline{\Lambda}$ effective mass spectrum is shown in fig. 3c) and consists of 123 events.

A study of the $p\overline{p}$, $p\overline{p}\pi^0$, $p\overline{p}\pi^+\pi^-$ and $\Lambda\overline{\Lambda}$ systems has been performed as a function of the parameter dP_T, which is the difference in the transverse momentum vectors of the two exchanged particles [1, 2]. After acceptance corrections the results are shown in table 1 together with the value of the ratio (R) of events at small dP_T to large dP_T. In previous studies [7] of the ratio R we have observed that all systems fall into three distinct classes. Firstly, there are all the undisputed $q\overline{q}$ states which can be produced in Double Pomeron Exchange (DPE), namely those with positive G parity and $I = 0$, which have a small value for this ratio (< 0.1). Secondly, there are those states with $I = 1$ or G parity negative, which cannot be produced by DPE, which have a slightly higher value ($\approx$ 0.25). Finally, there are the states which could have a gluonic component, which have a large value for this ratio (> 0.6). It is interesting to note that the baryon-antibaryon systems have a value of R consistent with the second class, i.e. that they are not produced by DPE. This fact can be investigated by studying the cross-section dependence as a function of centre of mass energy.

After correcting for geometrical acceptances, detector efficiencies and losses due to selection cuts, the cross-sections for the channels at $\sqrt{s}$ = 29.1 GeV in the x_F interval $|x_F| \leq 0.2$ have been calculated and are shown in table 2. These can be compared, where possible, to the cross-sections found at $\sqrt{s}$ = 12.7 GeV which are also shown in table 2. As can be seen the cross-sections are decreasing with increasing centre of mass energy. This is not consistent with them being produced dominantly by DPE and suggest that these systems are produced by double Regge or Regge-Pomeron exchanges [8].

The acceptance corrected azimuthal angle (ϕ) between the p_T vectors of the two protons (p_f and p_s) is shown in fig. 4a), c), e) and g). The distributions in all cases are consistent with being flat. Although naively a flat distribution would be expected, this is the first time that a system or resonance has been observed to have a flat ϕ distribution [9].

Fig. 4b), d), f) and h) shows the four momentum transfer squared at one of the proton vertices. The distributions have been fitted with a single exponential of the form $exp(-b|t|)$ and the results are presented in table 2. The first bin in the distributions has been excluded from the fit due to the fact that the uncertainties in the acceptance correction are greatest in this bin.

In conclusion, a study of the centrally produced $p\overline{p}$, $p\overline{p}\pi^0$, $p\overline{p}\pi^+\pi^-$ and $\Lambda\overline{\Lambda}$ channels has been performed. There is no evidence for resonance production with the exception of Δ^{++} and $\overline{\Delta}^{--}$ in the $p\overline{p}\pi^+\pi^-$ channel. In the $p\overline{p}$ channel there is no evidence for the $\xi(2220)$ and an upper limit on the cross-section for its production in central pp collisions has been calculated to be 1.6 nb. A study of the centre of mass energy dependence for the production of central baryon-antibaryon systems shows that they are not produced dominantly by double Pomeron exchange.

Acknowledgements

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Table 1: Production of the channels as a function of dP_T expressed as a percentage of its total contribution and the ratio (R) of events produced at $dP_T \leq 0.2$ GeV to the events produced at $dP_T \geq 0.5$ GeV.

	$dP_T \leq 0.2$ GeV	$0.2 \leq dP_T \leq 0.5$ GeV	$dP_T \geq 0.5$ GeV	$R = \frac{dP_T \leq 0.2GeV}{dP_T \geq 0.5GeV}$
$p\overline{p}$	14.4± 0.4	44.6 ± 0.7	41.0 ± 0.7	0.35 ± 0.01
$p\overline{p}\pi^0$	14.5 ± 1.0	43.3 ± 1.6	42.2 ± 1.6	0.34 ± 0.03
$p\overline{p}\pi^+\pi^-$	13.9 ± 0.5	43.3 ± 0.9	42.8 ± 0.9	0.32 ± 0.01
$\Lambda\overline{\Lambda}$	15.0 ± 3.5	39.4 ± 5.6	45.6 ± 6.1	0.33 ± 0.09

Table 2: The cross-sections and slope parameter of the four momentum transfer squared for the $p\overline{p}$, $p\overline{p}\pi^0$, $p\overline{p}\pi^+\pi^-$ and $\Lambda\overline{\Lambda}$ channels.

Channel	Cross-section\nb		Slope b GeV^{-2}
	$\sqrt{s}$=12.7 GeV	$\sqrt{s}$=29.1 GeV	
$p\overline{p}$	400 ± 60	186 ± 19	5.5 ± 0.3
$p\overline{p}\pi^0$	-	43 ± 5	5.9 ± 0.5
$p\overline{p}\pi^+\pi^-$	226 ± 42	82 ± 7	5.4 ± 0.3
$\Lambda\overline{\Lambda}$	29 ± 8	12 ± 2	4.5 ± 2.0

Figures

Figure 1: a) The Ehrlich mass squared distribution and b) the $p\overline{p}$ mass spectrum for the $p\overline{p}$ channel. c) The Ehrlich mass squared distribution and d) the $p\overline{p}\pi^0$ mass spectrum for the $p\overline{p}\pi^0$ channel.

Figure 2: For the $p\overline{p}\pi^+\pi^-$ channel a) the Ehrlich mass squared distribution, b) the $p\overline{p}\pi^+\pi^-$ mass spectrum and c) the scatter plot of M($\overline{p}\pi^-$) versus M($p\pi^+$).

Figure 3: For the $\Lambda\overline{\Lambda}$ channel a) the scatter plot of M($\pi^+\pi^-$) versus M($p\pi$), b) the M($p\pi$) mass distribution and c) the $\Lambda\overline{\Lambda}$ mass spectrum.

Figure 4: a), c), e) and g) the azimuthal angle (ϕ) between the two outgoing protons for the $p\overline{p}$, $p\overline{p}\pi^0$, $p\overline{p}\pi^+\pi^-$ and $\Lambda\overline{\Lambda}$ channel respectively. b), d), f) and h) the four momentum transfer squared ($|t|$) from one of the proton vertices for the $p\overline{p}$, $p\overline{p}\pi^0$, $p\overline{p}\pi^+\pi^-$ and $\Lambda\overline{\Lambda}$ channel respectively.

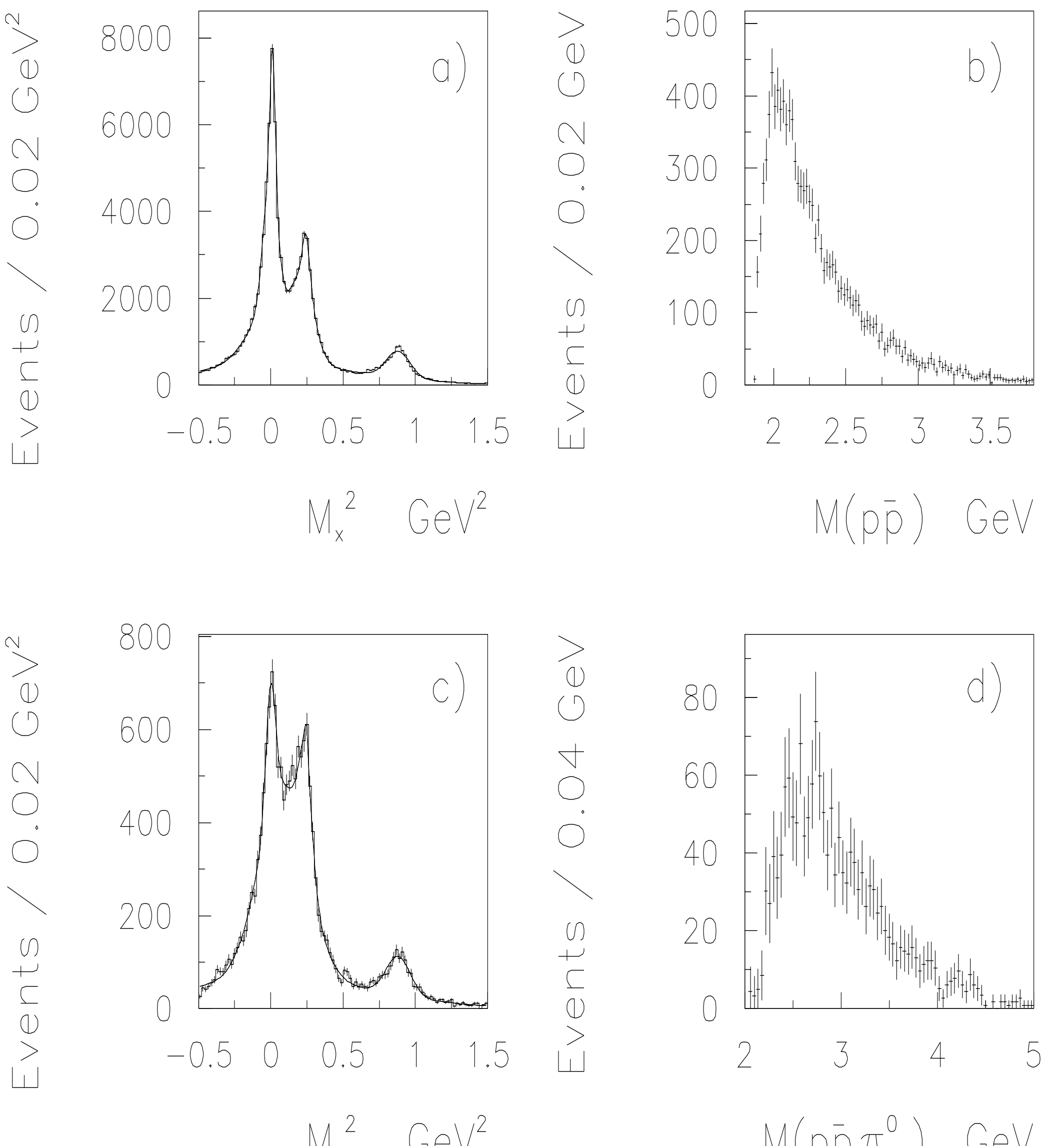
Events / 0.02 GeV^2
8000
6000
4000
2000
0
a)
−0.5 0 0.5 1 1.5
M_x^2 GeV^2
Events / 0.02 GeV
500
400
300
200
100
0
b)
2 2.5 3 3.5
$M(p\bar{p})$ GeV
Events / 0.02 GeV^2
800
600
400
200
0
c)
−0.5 0 0.5 1 1.5
M_x^2 GeV^2
Events / 0.04 GeV
80
60
40
20
0
d)
2 3 4 5
$M(p\bar{p}\pi^0)$ GeV

Figure 1

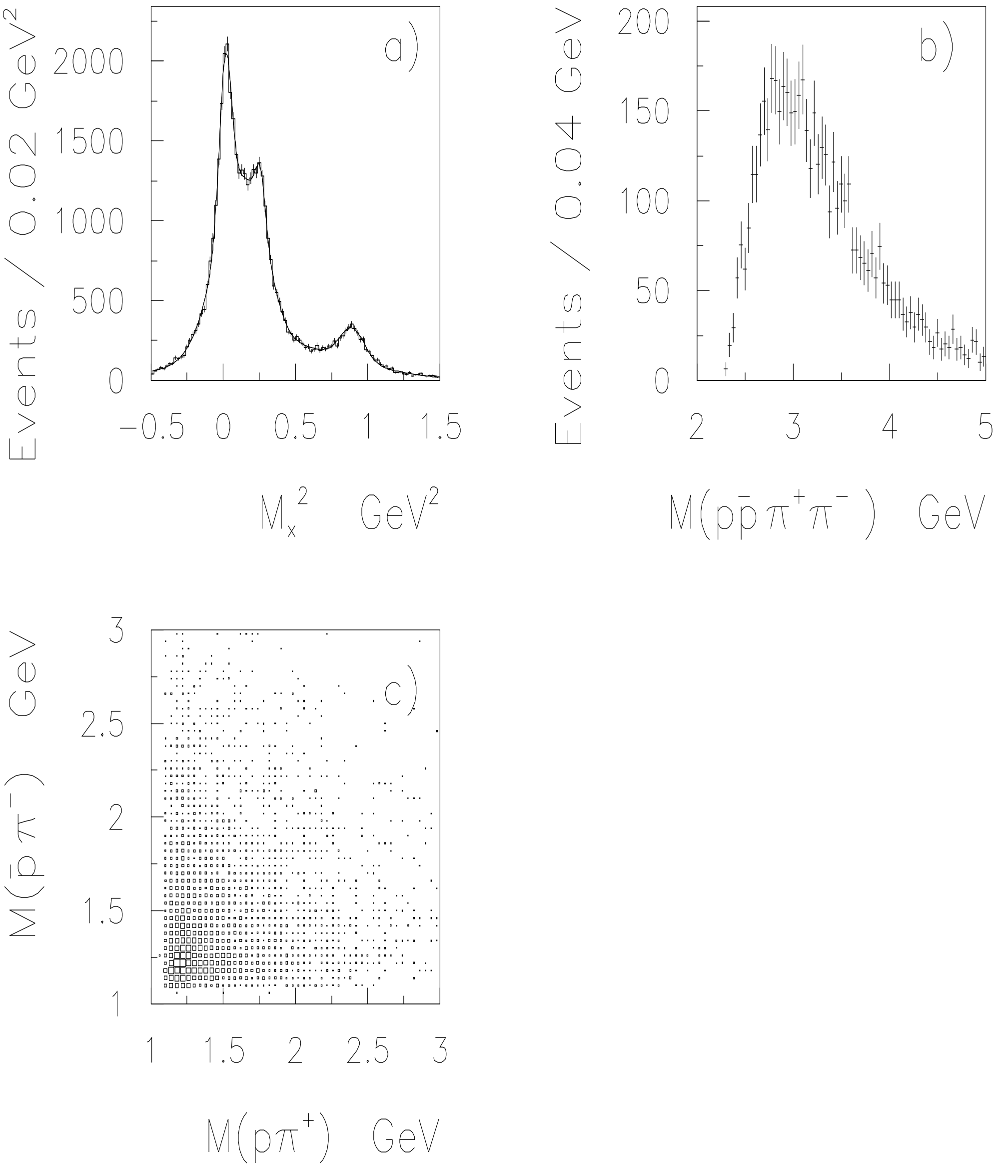
a)
Events / 0.02 GeV^2
0
500
1000
1500
2000
−0.5
0
0.5
1
1.5
M_x^2 GeV^2
b)
Events / 0.04 GeV
0
50
100
150
200
2
3
4
5
$M(p\bar{p}\pi^+\pi^-)$ GeV
c)
$M(\bar{p}\pi^-)$ GeV
1
1.5
2
2.5
3
1
1.5
2
2.5
3
$M(p\pi^+)$ GeV

Figure 2

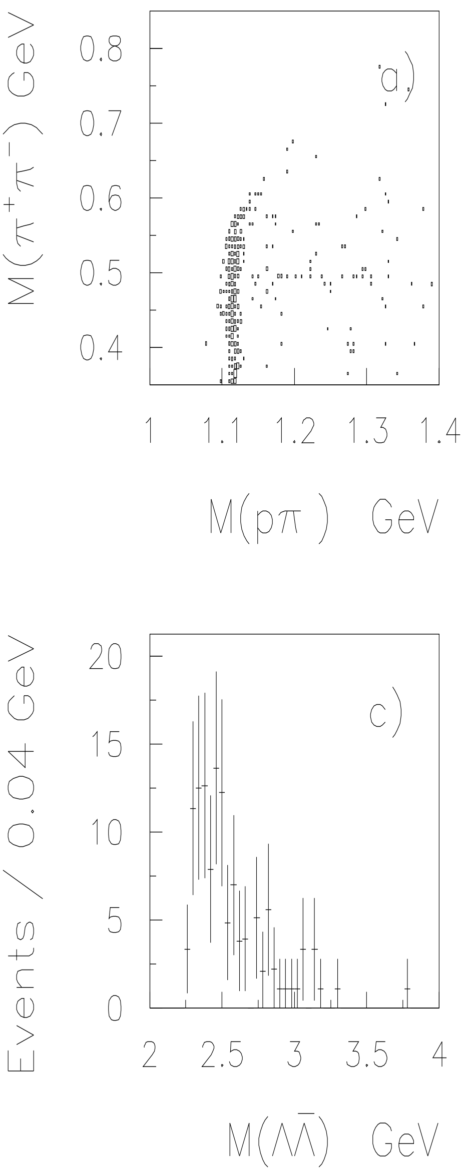
M(π+π−) GeV
0.8
0.7
0.6
0.5
0.4
a)
1
1.1
1.2
1.3
1.4
M(pπ) GeV
Events / 0.04 GeV
70
60
50
40
30
20
10
0
b)
1
1.1
1.2
M(pπ) GeV
Events / 0.04 GeV
20
15
10
5
0
c)
2
2.5
3
3.5
4
M(ΛΛ̄) GeV

Figure 3

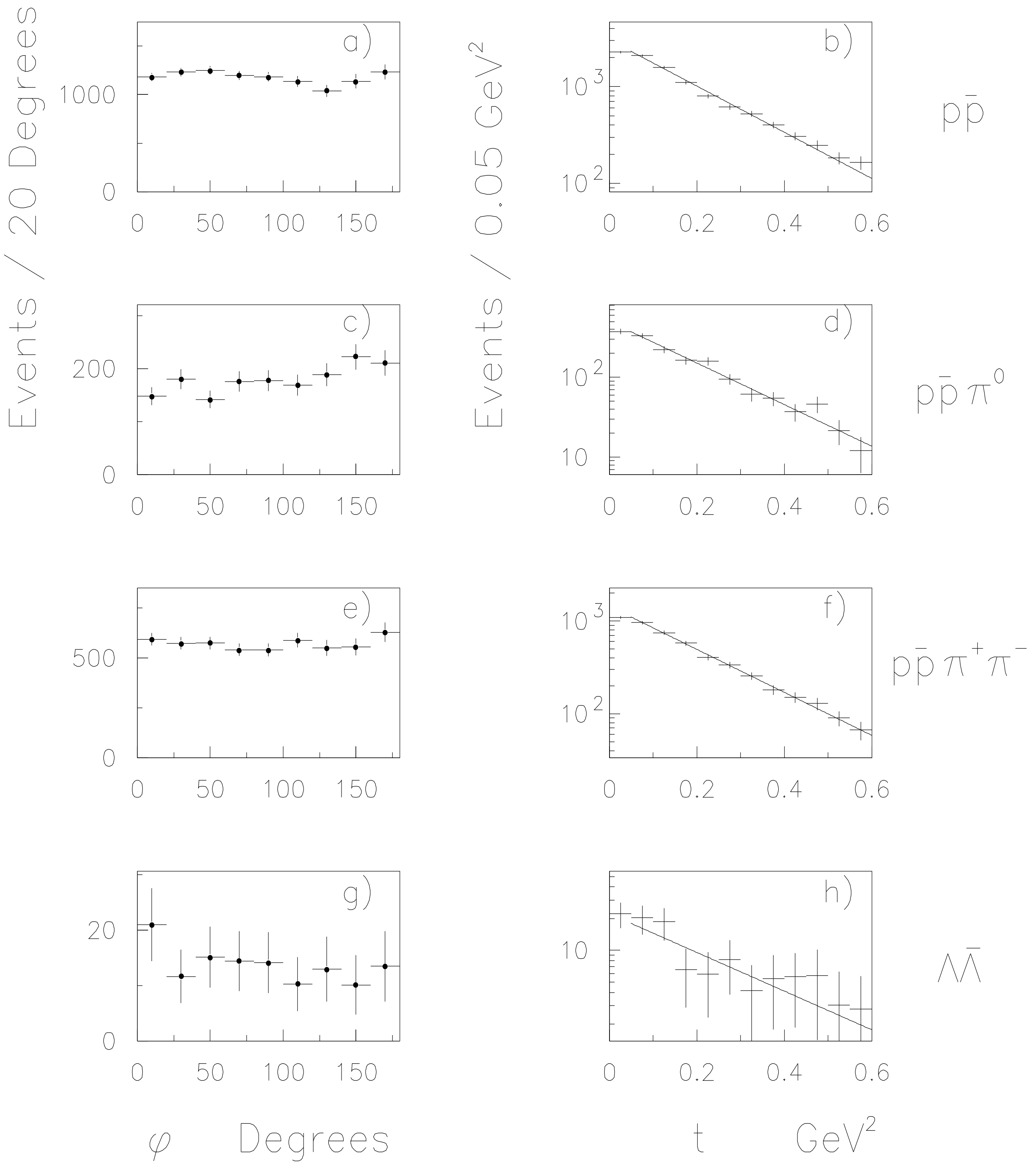
Events / 20 Degrees
Events / 0.05 GeV²
a)
b)
c)
d)
e)
f)
g)
h)
pp̄
pp̄π⁰
pp̄π⁺π⁻
ΛΛ̄
φ Degrees
t GeV²

Figure 4