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Observation of centrally produced $\theta/f_2(1720)$ in the reaction $pp \to p_f(K\bar{K})p_s$ at 300 GeV/c

WA76 Collaboration

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Abstract

The K^+K^- and $K^0_SK^0_S$ systems centrally produced in the reaction $pp \to p_fK\bar{K}p_s$ have been studied at 300 GeV/c incident momentum. Both the K^+K^- and the $K^0_SK^0_S$ mass spectra show large resonant production. For the first time in hadron collisions, clear evidence is found for the $\theta/f_2(1720)$ with parameters $m = 1713 \pm 10$ MeV, $\Gamma = 181 \pm 30$ MeV for the K^+K^- decay mode and $m = 1706 \pm 10$ MeV, $\Gamma = 104 \pm 30$ MeV for the $K^0_SK^0_S$ decay mode. A spin analysis of the K^+K^- spectrum shows that for the $\theta/f_2(1720)$ $J^P = 2^+$ is strongly favoured while 0^+ and 1^- are excluded.

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One of the most important expectations of QCD is the existence of particles having gluon constituents like glueballs or hybrid states. As yet the definite identification of such states has not been achieved, one of the biggest difficulties being the complexity of the $q\bar{q}$ meson spectrum in the $1-2$ GeV region where $q\bar{q}$, gg, $q\bar{q}g$, 4-quark states and radial excitations may overlap in mass and mix. The search for gluonic states has been carried out using several production mechanisms which are thought to have a high gluonic content, e.g. J/ψ radiative and hadronic decays, $p\bar{p}$ annihilations, high p_T direct production, OZI violating processes and central production.

One of the most promising glueball candidates is the $\theta/f_2(1720)$ observed in radiative J/ψ decay through the $\eta\eta$ [1], $K\bar{K}$ and $\pi\pi$ [2] decay modes. Its spin-parity is favoured to be $J^{PC}=2^{++}$ from the K^+K^- and $\eta\eta$ decay modes. A structure in the $\theta/f_2(1720)$ region is also observed in the $K\bar{K}$ system recoiling against ϕ and ω in hadronic J/ψ decay [3]. However, there is no clear evidence for $\theta/f_2(1720)$ production from π^- [4] or K^- [5] incident beams nor from $\gamma\gamma$ collisions [6]. The $I=0$ sector of the $J^{PC}=2^{++}$ nonet is already filled with $f_2(1270)$ and $f_2'(1525)$. This fact, together with its peculiar production properties of appearing only in supposed gluon rich environments, makes the $\theta/f_2(1720)$ a candidate for being a glueball [7] or hybrid state [8].

This paper reports on the first clear observation of the $\theta/f_2(1720)$ in hadronic collisions in the K^+K^- and $K_S^0K_S^0$ systems centrally produced in pp interactions at 300 GeV/c incident momentum.

The data come from experiment WA76 which was designed to study exclusive final states formed in the reaction

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

where the subscripts f and s indicate the fastest and slowest particles in the laboratory frame and X^0 represents the central system which is assumed to be produced by a double exchange process. At high centre-of-mass energies the dominant double exchange process is believed to be Double Pomeron Exchange (DPE), where the Pomeron is an object which is thought to have a large gluonic content. Therefore Pomeron-Pomeron scattering could be a source of gluonic states.

The experiment has been performed using the CERN Omega spectrometer at two incident beam momenta, 85 and 300 GeV/c, corresponding to centre-of-mass energies of $\sqrt{s}$ = 12.7 and 23.8 GeV. Evidence for activity in the $\theta/f_2(1720)$ region of the K^+K^- effective mass distribution at 85 GeV/c has been presented in a previous publication [9].

Details on trigger conditions, processing and data selection of the 300 GeV/c experiment are given in ref. [10]. The reaction

$$pp \rightarrow p_f(K^+K^-)p_s \qquad (2)$$

has been isolated from the sample of events having four outgoing tracks by imposing the following cuts on the components of missing momentum: |missing Px| < 20 GeV/c, |missing Py| < 0.16 GeV/c and |missing Pz| < 0.08 GeV/c, where the x axis is along the beam direction. In order to select reaction (2) from the more abundant channel with two pions in the final state, we have requested that one of the two central particles is identified by Cerenkov information as a K or ambiguous K/p. The remaining track was required, if reaching the Cerenkov system, to have a mass identification compatible with being a kaon. Events belonging to reaction (2) have then been selected by requiring the Ehrlich mass [11] to be in the range 0.18 to 0.56 GeV^2 (6564 events).

The Feynman x_F distribution of the K^+K^- system is concentrated within the region $|x_F| < 0.2$. The K^+K^- effective mass distribution is shown in fig. 1a. The geometrical acceptance of the apparatus, studied as a function of the K^+K^- effective mass, is approximately flat in the negative x_F region, while it decreases significantly as a function of the K^+K^- mass for positive x_F values. Also the decay angular distributions of the K^+K^- system are affected by the geometrical acceptance in the positive x_F region. We have therefore selected events with x_F less than zero. This selection gives a sample of 4079 events whose mass spectrum is shown in fig. 1b.

The spectra show evidence for several resonant structures: the $\phi(1020)$ is observed on top of a threshold enhancement and the $f_2'(1525)$ is clearly seen. In addition a structure is observed in the $\theta/f_2(1720)$ region. A fit has been performed on the entire K^+K^- mass spectrum by using a background of the form

$$(m - m_{th})^{\alpha}\, e^{-\beta m - \gamma m^2} \qquad (3)$$

and two spin-two relativistic Breit-Wigners to describe the high mass structures. The ϕ has been parameterized as a Gaussian having a σ of 5.6 MeV and the $f_2'(1525)$ parameters have been fixed to the PDG values [12]. The result of the fit is shown as a superimposed line in fig. 1b. The fit probability is 26%. The resulting parameters of the high mass structure are

$$m = 1713 \pm 10 \text{ MeV}\,, \Gamma = 181 \pm 30 \text{ MeV}$$

consistent with previously measured $\theta/f_2(1720)$ parameters [12].

The $K^0_S K^0_S$ channel has been isolated from the sample of events having two reconstructed V^0's which balance momentum. In order to remove the background from random $\pi^+\pi^-$ combinations, a decay length of at least 3 cm was required for each of the two V^0's. The $\pi^+\pi^-$ mass spectrum of the two V^0's (inset fig. 2c) reveals a clear K^0 signal over little background. Selecting events having the K^0 mass in the range 0.475 to 0.520 GeV produces the $K^0_S K^0_S$ mass spectrum shown in fig. 2a (692 events). For comparison, fig 2b shows the $K^0_S K^0_S$ mass spectrum obtained in the 85 GeV/c run (674 events).

The $K^0_S K^0_S$ spectra show similar features to the K^+K^- spectrum, viz. a threshold enhancement, the $f'_2(1525)$ and a structure in the 1.7 GeV region. In order to measure the $\theta/f_2(1720)$ parameters in this decay channel, a fit has been performed on the 85 and 300 GeV/c combined spectra (fig. 2c) using the method described above. The result of the fit is superimposed on the combined $K^0_S K^0_S$ mass spectrum of fig. 2c and yields the following $\theta/f_2(1720)$ parameters

$$m = 1706 \pm 10\ ,\ \Gamma = 104 \pm 30\ \text{MeV}$$

Since only states with even spin and parity are allowed in the $K^0_S K^0_S$ system, we conclude from the simultaneous observation of a state in the 1.7 GeV region in both the K^+K^- and $K^0_S K^0_S$ decay modes that the $\theta/f_2(1720)$ quantum numbers are $J^{PC} = (\text{even})^{++}$.

In order to try to distinguish between $J^{PC} = 0^{++}$ and 2^{++} for the $\theta/f_2(1720)$ meson, the K^+K^- angular distributions have been studied in the Gottfried-Jackson frame defined as follows. Assuming that the K^+K^- system is produced by a double exchange mechanism, the z axis has been taken along the $(\vec{p}_{beam} - \vec{p}_{fast})$ direction (the exchanged particle direction from the upper vertex), in the K^+K^- center of mass frame. The y axis is taken as the normal to the production plane formed by the directions of the exchanged particles from the upper and lower vertices in the overall centre of mass system. The K^+ has been used as analyzer.

The $\cos\vartheta$ and φ distributions for the $f_2'(1525)$ region (1.45 – 1.59 GeV, 573 events) are shown in fig. 3 while the corresponding distributions for the $\theta/f_2(1720)$ region (1.59 – 1.83 GeV, 785 events) are shown in fig. 4. The geometrical acceptance, calculated as a function of these variables, is flat in this kinematic region.

We observe that the $\cos\vartheta$ and φ distributions both show structure thus excluding the 0^+ hypothesis which predicts isotropic distributions. A slight asymmetry in the $\cos\vartheta$ distributions can also be seen. We have interpreted this excess in the backward $\cos\vartheta$ direction as due to interference of the centrally produced K^+K^- system with kaons coming from the single diffractive reaction $pp \to p_f(p_s K^+K^-)$ whose tail cannot be kinematically separated from the centrally produced K^+K^- system, in the high K^+K^- mass region.

The two-dimensional $(\cos\vartheta,\varphi)$ angular distributions have been fitted by the maximum likelihood method assuming the K^+K^- system to be a mixture of S,P and D interfering waves. The decay angular distribution has been expressed in terms of the density matrix elements ρ_{ij} as given in ref. [13]. The results of the fits are superimposed on the $\cos\vartheta$ and φ distributions in fig. 3 and 4 for the $f_2'(1525)$ and $\theta/f_2(1720)$ respectively and show good agreement in all the distributions. As an estimate of the goodness of the fits we have used the fits to compute the expected number of events on a 10×10 $(\cos\vartheta,\varphi)$ scatter plot. Neighbouring bins having populations smaller than 4 have been merged together. The comparison of the predictions with the experimental distributions gives a χ^2 probability of 45% in the $f_2'(1525)$ region and a χ^2 probability of 55% in the $\theta/f_2(1720)$ region. Non interfering spin 3 waves have also been tried but they are not required by the fit. The density matrix elements in the $f_2'(1525)$ and $\theta/f_2(1720)$ are given in table I.

We notice that the two regions are dominated by D wave, $67\pm6\%$ and $80\pm4\%$ for the $f_2'(1525)$ and $\theta/f_2(1720)$ regions respectively. There is also a sizeable contribution of SD interference while the S wave contribution decreases from $30\pm7\%$ to $4\pm5\%$ going from the $f_2'(1525)$ region to the $\theta/f_2(1720)$ region.

From the above analysis we conclude, therefore, that the $f_2'(1525)$ and $\theta/f_2(1720)$ resonances are both compatible with having $J^{PC}=2^{++}$.

In conclusion, we have studied the K^+K^- and $K^0_SK^0_S$ systems centrally produced in the reaction $pp \to p_f K\bar{K} p_s$ at 300 GeV/c incident momentum. Both K^+K^- and $K^0_SK^0_S$ show large resonant production. In particular we observe, for the first time in hadron collisions, the $\theta/f_2(1720)$ with parameters $m=1713\pm10$ MeV, $\Gamma=181\pm30$ MeV from the K^+K^- decay mode and $m=1706\pm10$ MeV, $\Gamma=104\pm30$ MeV from the $K^0_SK^0_S$ decay mode. A spin analysis of the K^+K^- spectrum shows that

for the $\theta/f_2(1720)$ region a spin-parity of 2^+ describe the data well while 0^+ and 1^- are clearly excluded. The observation of $\theta/f_2(1720)$, in a kinematic region which has been suggested [14] to be a possible source for the production of glueballs, reinforces the likelihood that the $\theta/f_2(1720)$ is a gluonic state.

Table I Density matrix elements contributing in the fits of the angular distributions in the $f_2'(1525)$ and $\theta/f_2(1720)$ regions.

$f_2'(1525)$ region		$\theta/f_2(1720)$ region	
ρ_{00}^{DD}	0.25 ± 0.05	ρ_{00}^{DD}	0.22 ± 0.03
ρ_{11}^{DD}	0.17 ± 0.02	ρ_{11}^{DD}	0.23 ± 0.01
ρ_{22}^{DD}	0.04 ± 0.03	ρ_{22}^{DD}	0.06 ± 0.02
ρ_{00}^{PP}	0.03 ± 0.02	ρ_{11}^{PP}	0.08 ± 0.02
ρ_{21}^{DD}	-0.07 ± 0.02	ρ_{21}^{DD}	0.02 ± 0.01
ρ_{10}^{DD}	0.07 ± 0.01	ρ_{20}^{DD}	0.07 ± 0.01
ρ_{01}^{SP}	0.02 ± 0.01	ρ_{00}^{SD}	0.18 ± 0.01
ρ_{00}^{SD}	0.13 ± 0.01	ρ_{02}^{SD}	0.08 ± 0.02
ρ_{01}^{SD}	-0.05 ± 0.01	ρ_{11}^{PD}	-0.07 ± 0.02
ρ_{02}^{SD}	0.03 ± 0.01	ρ_{01}^{PD}	0.03 ± 0.01
ρ_{00}^{PD}	-0.08 ± 0.02		

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Figure captions

Fig. 1 a) K^+K^- effective mass distribution.

b) K^+K^- effective mass distribution requiring $x_F < 0$. The curve is the result of the fit descibed in the text.

Fig. 2 a) $K^0_S K^0_S$ effective mass distribution at 300 GeV/c.

b) $K^0_S K^0_S$ effective mass distribution at 85 GeV/c.

c) Sum of the spectra shown in a) and b) in 20 MeV bins. The curve is the result of the fit described in the text. The inset shows the $\pi^+\pi^-$ effective mass at the V^0 vertex for the 300 GeV/c data.

Fig. 3 ($\cos\vartheta$, φ) scatter plot with $\cos\vartheta$ and φ projections in the Gottfried-Jackson frame for the $f_2'(1525)$ region. The curves are the result of the fit described in the text.

Fig. 4 ($\cos\vartheta$,φ) scatter plot with $\cos\vartheta$ and φ projections in the Gottfried-Jackson frame for the $\theta/f_2(1720)$ region. The curves are the result of the fit described in the text.

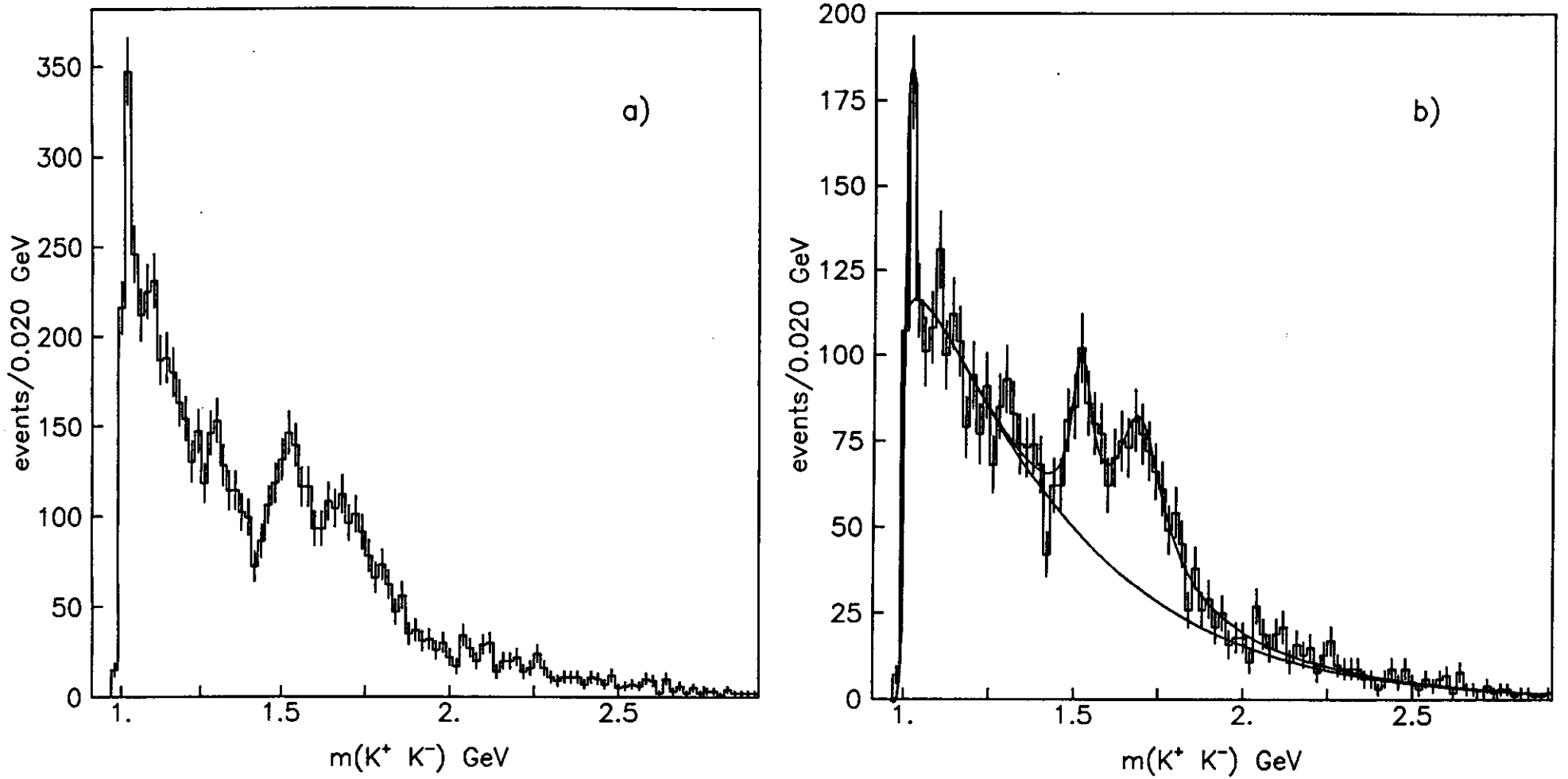
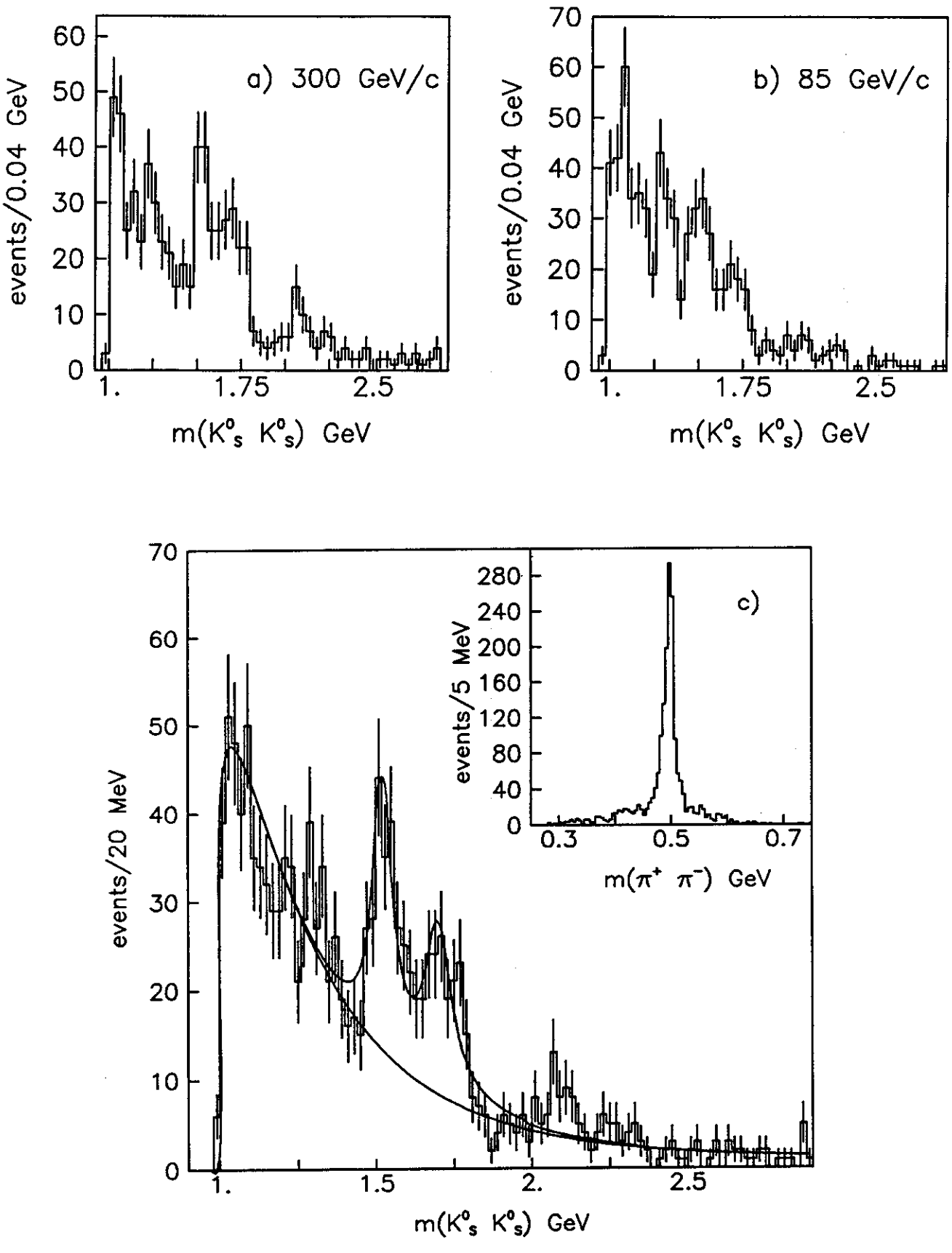

a)
b)
events/0.020 GeV
m(K⁺ K⁻) GeV
0
50
100
150
200
250
300
350
25
75
125
175
1.
1.5
2.
2.5

Fig. 1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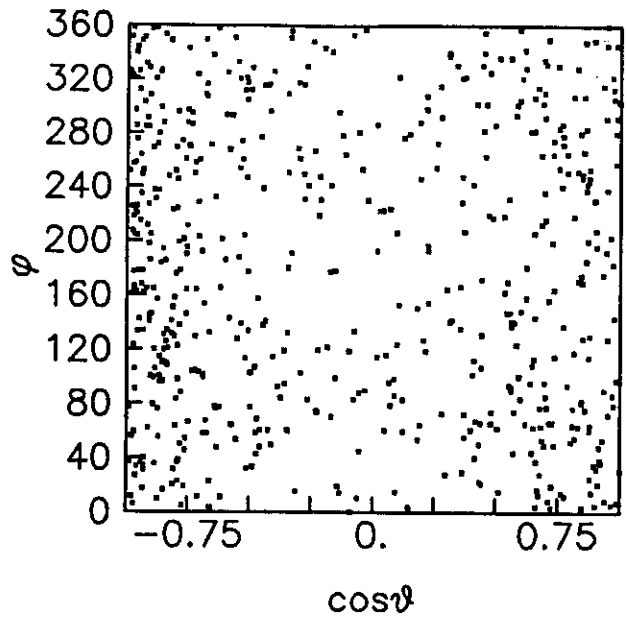
b) 85 GeV/c
c)
events/0.04 GeV
events/20 MeV
events/5 MeV
m(K°s K°s) GeV
m(π+ π−) GeV

Fig. 2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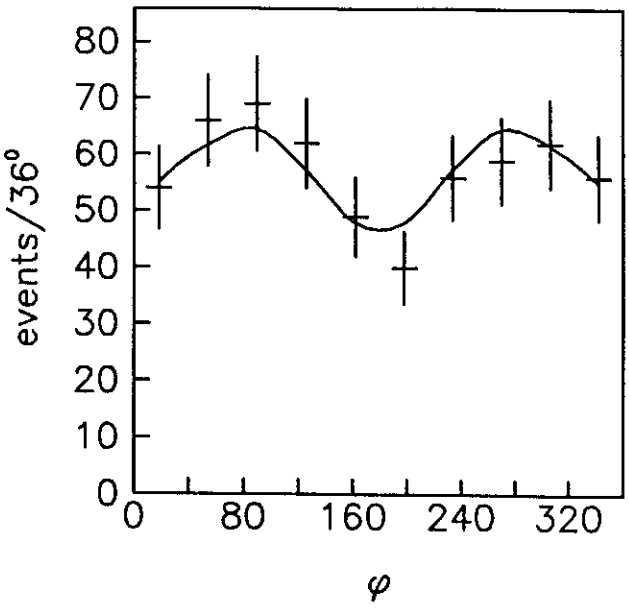
320
280
240
200
160
120
80
40
0
φ
−0.75
0.
0.75
cosϑ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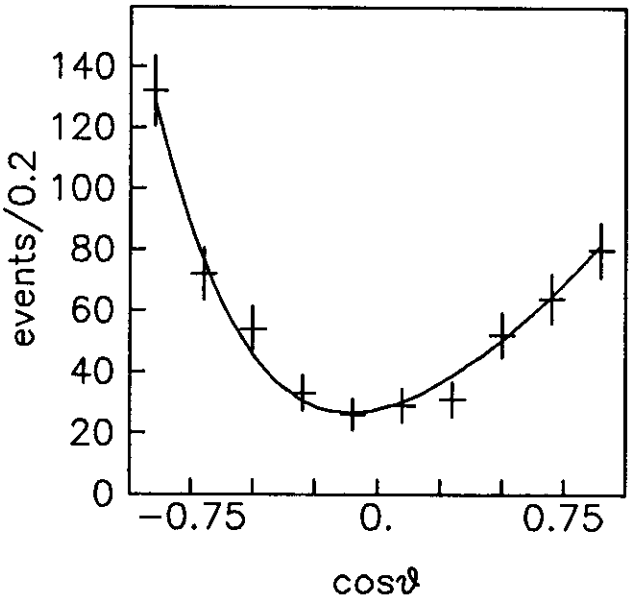
70
60
50
40
30
20
10
0
events/36°
0
80
160
240
320
φ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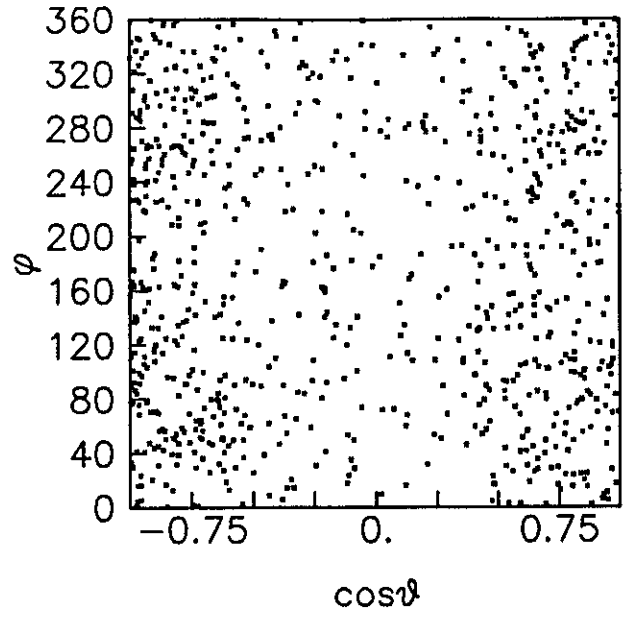
100
80
60
40
20
0
events/0.2
−0.75
0.
0.75
cosϑ

Fig. 3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φ
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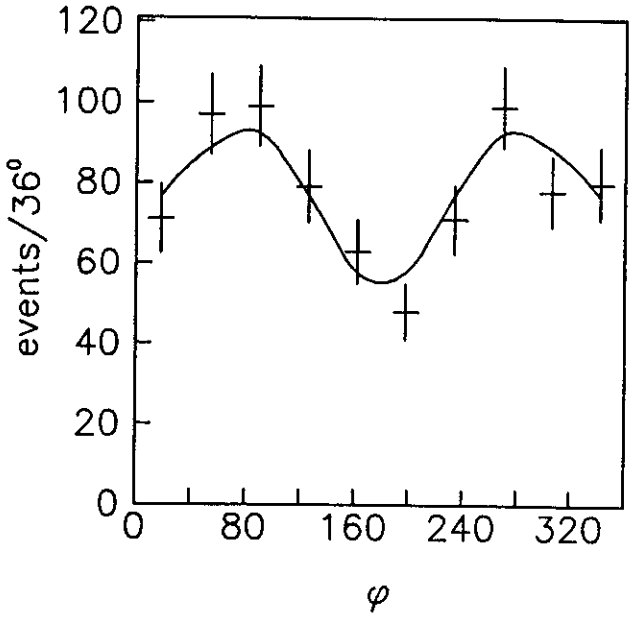
120
100
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40
20
0
events/36°
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320
φ

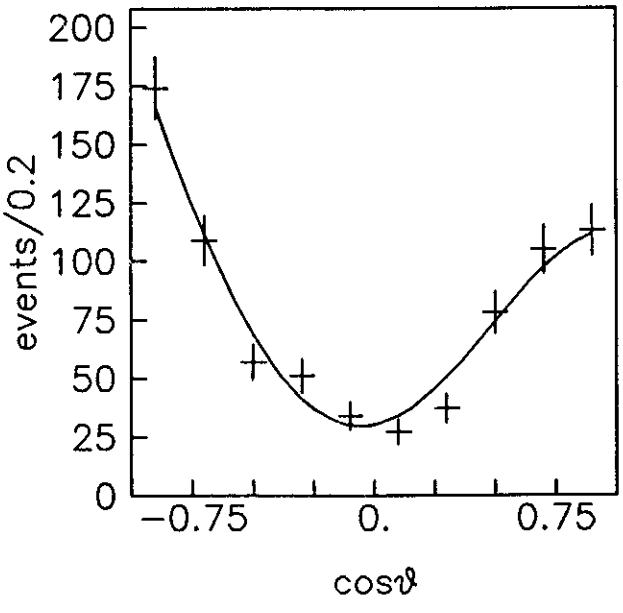
200
175
150
125
100
75
50
25
0
events/0.2
−0.75
0.
0.75
cosϑ

Fig. 4