KEK Preprint 97-256
February 1998
H

Observation of Exclusive η_c Production in Two Photon Interactions at TRISTAN

AMY Collaboration

KEK Reports are available from:

Information Resources Division
High Energy Accelerator Research Organization (KEK)
1-1 Oho, Tsukuba-shi
Ibaraki-ken, 305-0801
JAPAN

Phone: 0298-64-5137
Fax: 0298-64-4604
Cable: KEK OHO
E-mail: Library@kekvax.kek.jp
Internet: http://www.kek.jp

Observation of exclusive η_c production in two photon interactions at TRISTAN

AMY Collaboration

M.Shirai[a], H.Miyata[a], T.Sasaki[e], N.Nakajima[a], A.Kimura[a], K.Miyano[a], M.Sato[a], Y.Yamashita[b], T.Aso[c], A.Bacala[d], K.Abe[e], Y.Fujii[e], Y.Kurihara[e], M.H. Lee[e], A.Maki[e], T.Nozaki[e], T.Omori[e], H.Sagawa[e], Y.Sakai[e], Y.Sugimoto[e], Y.Takaiwa[e], N.Takashimizu[e], S.Terada[e], P.Kirk[f], T.J.Wang[g,1], A.Abashian[h], K.Gotow[h], L.Piilonen[h], S.K.Choi[i], C.Rosenfeld[j], L.Y.Zheng[j], R.E.Breedon[k], Winston Ko[k], R.L.Lander[k], J. Rowe[k], S.L.Olsen[l], S.K.Sahu[l], S.Schnetzer[m], S.Kobayashi[n], A.Murakami[n], J.S.Kang[o], D.Y.Kim[o], S.S.Myung[o], H.S.Ahn[p], H.J.Kim[p], S.K.Kim[p], K.Ueno[q], S.Matsumoto[r], S.Behari[s]

[a] *Niigata University, Niigata 950-21, Japan*
[b] *Nihon Dental College, Niigata 951, Japan*
[c] *Toyama National Collage of Maritime Technology, Toyama 933-02, Japan*
[d] *Mindanao State University, Iligan 9200, Philippines*
[e] *KEK, High Energy Accelerator Research Organization, Ibaraki 305-0801, Japan*
[f] *Louisiana State University, Baton Rouge, LA 70803,USA*
[g] *Institute of High Energy Physics, Beijing 100039, China*
[h] *Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA*
[i] *Gyeongsang National University, Chinju 660-701, South Korea*
[j] *University of South Carolina, Columbia, SC 29208, USA*
[k] *University of California, Davis, CA 95616, USA*
[l] *University of Hawaii, Honolulu, HI 96822, USA*
[m] *Rutgers University, Piscataway, NJ 08854, USA*
[n] *Saga University, Saga 840, Japan*
[o] *Korea University, Seoul 134-701, South Korea*
[p] *Seoul National University, Seoul 151-742, South Korea*
[q] *National Taiwan University, Taipei 10764, Taiwan*
[r] *Chuo University, Tokyo 112, Japan*
[s] *National Central University, Chung-Li 320, Taiwan*

Abstract

We observe η_c production in the two photon process $e^+e^- \to e^+e^-\eta_c$ at an e^+e^- center-of-mass energy of 58 GeV. We determine the radiative decay width $\Gamma_{\gamma\gamma}(\eta_c)$ to be $27 \pm 16(stat) \pm 10(sys)$ keV.

1 Introduction

[1]Deceased

1. Introduction

The cross section for the formation of meson resonances in two photon processes is proportional to the meson's two-photon radiative decay width, $\Gamma_{\gamma\gamma}$, of the state that is produced. Measurements of $\Gamma_{\gamma\gamma}$ are important for understanding the dynamics of $q\bar{q}$ bound states. This is especially true for heavy quark states, such as charmonium, where non-relativistic potential models are expected to be applicable.

Quark potential models have been used to calculate the two-photon width of the η_c meson ($\Gamma_{\gamma\gamma}(\eta_c)$) [1]. Nonrelativistic versions of the model that include the lowest order QCD corrections predict the following relation between the leptonic decay width of the J/ψ and the two-photon width of the η_c[2]:

$$\Gamma_{\gamma\gamma}(\eta_c)/\Gamma_{ee}(J/\psi) = \frac{4}{3}(1+1.96\frac{\alpha_s}{\pi})\frac{M^2_{J/\psi}}{(2m_c)^2}\frac{|\psi_{\eta_c}(0)|^2}{|\psi_{J/\psi}(0)|^2}.$$

Using a recent calculation of this ratio of 2.2 ± 0.2 [3], together with the measured J/ψ leptonic decay width $\Gamma_{ee}(J/\psi) = 5.26 \pm 0.37$ keV [4], gives the value $\Gamma_{\gamma\gamma}(\eta_c) = 11.6 \pm 1.3$ keV. The decay width has also been calculated using QCD sum rules [5] and the Bethe-Salpeter formalism [6]. The different theoretical approaches give predictions that range from 5 to 15 keV.

Previous measurements of $\Gamma_{\gamma\gamma}(\eta_c)$ have been made at e^+e^- colliders [7-12] and in the Antiproton Accumulator at Fermilab [13]. These experiments used a variety of η_c decay channels: $K^0_sK^\pm\pi^\mp$, $K^+K^-\pi^+\pi^-$, $2\pi^+2\pi^-$, $2K^+2K^-$, etc. (see Table 1). The most significant results were obtained from studies of the decay $\eta_c \to K^0_sK^\pm\pi^\mp$. Here unambiguous strange particle identification is provided by the decay $K^0_s \to \pi^+\pi^-$. The measured results range from 6 to 28 keV and have large errors because of limited statistics and uncertainties in the η_c branching ratios.

In this letter we report the first observation at TRISTAN energies of exclusive η_c production via two photons in the process $e^+e^- \to e^+e^-K^0_sK^\pm\pi^\mp$. We measure the production rate for processes where neither the scattered electron nor the positron is detected ("untagged"mode). In this case, the η_c is coupled to two quasi-real photons, one emitted by the electron, the other by the positron. From the observed event rate, we calculate a value for the radiative width $\Gamma_{\gamma\gamma}(\eta_c)$.

2. Event selection

The data were taken with the AMY detector at TRISTAN at an average beam energy of 29 GeV. The total data sample corresponds to an integrated luminosity of 275 pb^{-1}. Details of the AMY detector are provided elsewhere [14,15]. For this analysis we use track information given by the central drift chamber(CDC) situated in 3 Tesla magnetic field. The CDC has 25 layers of axial wires and 15 layers of stereo wires and its polar angle acceptance is $|cos\theta| < 0.91$. Electrons and photons are detected in the lead/proportional-tube barrel shower counter (SHC) and the lead/scintillator endcap shower counter (ESC). The angular coverage of the combined shower counter systems is $|cos\theta| < 0.98$.

2.1 Selection of 4 prong untag events

In order to isolate the $K_s^0 K^\pm \pi^\mp$ hadronic final state, we select four prong events that satisfy the following criteria:

1) At least four good charged tracks in CDC, where good charged tracks satisfy the following requirements:
   a) at least eight axial wire hits and five stereo wire hits;
   b) a normalized χ^2 of the track fits with values $\chi^2_{r\phi} \leq 12$ and $\chi^2_Z \leq 12$; and
   c) the tracks must originate from within r=6 cm and $|z|$=10 cm of the interaction point.
2) The net charge of the four charged tracks satisfies $|\Sigma q_i| = 0$.
3) The net transverse momentum satisfies $|\Sigma \vec{p_{t,i}}| \leq 1.5$ GeV/c, where $\vec{p_{t,i}}$ are the projections of the charged track momentum vectors on the plane transverse to the beam direction.
4) At least one of CDC tracks must have $|\vec{p_t}| \geq 1.0$ GeV/c and at least two must have $|\vec{p}| \geq 0.75$ GeV/c. This requirement ensures a high trigger efficiency for the event.
5) The observed mass of the hadron system W_{vis} is between 1 and 20 GeV/c^2, where W_{vis} is calculated by assigning the pion mass to all charged particles.
6) Events containing photons are rejected by demanding that no isolated shower with energy larger than 500 MeV (3 GeV) is detected in the SHC (ESC). The ESC threshold energy is relatively high in order to take into account overlapping effects of beam-induced backgrounds on signal events.

2.2 Selection of K_s^0 inclusive events

The K_s^0 is identified from its decay into $\pi^+\pi^-$. To reduce backgrounds, we take advantage of the finite mean free path ($c\tau$ = 2.676 cm) of the K_s^0. A secondary vertex (V^0-) searching routine is applied to the data that looks for oppositely charged pairs of CDC tracks that intersect at a point more than 1 cm radially distant from the interaction point. The invariant mass and momentum of the V^0 is calculated from the sum of the two track momenta evaluated at the position of secondary vertex, assuming pion masses. We require that the vertex position of the V^0 in the $r - \phi$ plane is located between 1 cm and 15 cm away from the interaction point and that the momentum direction matches the direction connecting the vertex and the interaction point within 10 degrees.

Real V^0 particles that are not K_s^0's can be due to gamma conversions ($\gamma \to e^+e^-$) and $\Lambda \to P\pi^-$ ($\bar{\Lambda} \to \bar{P}\pi^+$) decays. Such background events are removed by positively identifying γ's and Λ's as follows:

1) γ:
   If the invariant mass of V^0 is less than 0.200 GeV when both particles are assigned an electron mass, the V^0 is considered to be a gamma and rejected.
2) Λ:
   If the invariant mass of V^0 is within 1.116 ± 0.020 GeV when one particle is assigned a proton- and the other a pion-mass, it is considered to be Λ and rejected.

Figure 1 shows the $\pi^+\pi^-$ invariant mass distribution in the range between 0.3 GeV and 0.8 GeV for the 131 selected V^0's. A clear K_s^0 peak is evident. A fit to this distribution using a gaussian plus constant background term results in a central mass value of 0.491 $\pm$ 0.002 GeV and a resolution of σ = 0.007 $\pm$ 0.002 GeV where both errors are statistical. This indicates a 0.006 GeV systematic error in the K_s^0 mass measurement. We identify V^0's with an invariant $\pi^+\pi^-$ mass between 0.476 and 0.521 GeV as K_s^0 candidates.

2.3 η_c Reconstruction

As mentioned above, we select exclusive $\gamma\gamma$ events by requiring events the net transverse momentum to be $|\Sigma \vec{p_{t,i}}| \leq 1.5$ GeV/c. A Monte Carlo study shows that 76% of the inclusive K_s^0 mesons from η_c decays satisfy this criterion (see Fig.2). Two events are consistent with a $K_s^0 K_s^0$ decay and are removed from the event sample. Other exclusive $\gamma\gamma$-processes that can simulate a $K_s^0 K^\pm \pi^\mp$ final state are $\Lambda\bar{\Lambda}$, $\Lambda\bar{p}K^+$, and $\bar{\Lambda}pK^-$ production. These events are already removed from the event sample at the K_s^0 selection stage.

Since our detector has no capability to distinguish a charged kaon from a charged pion, we assume two hypotheses for each event: $K_s^0 K^+\pi^-$ and $K_s^0 K^-\pi^+$. Figure 3 shows the $K_s^0 K^\pm \pi^\mp$ mass spectrum for all events. Since there are two entries per event, the vertical axis is normalized to the correct number of events by dividing the total number of entries by two. The experimental data show a peak around 3 GeV, which we interpret as evidence for exclusive η_c production.

To estimate the background, we made Monte Carlo simulations of the process $e^+e^- \to e^+e^-$ hadrons using the event generating program developed by AMY for the study of resolved photon processes [16,17]. The program includes contributions from Vector Meson Dominance (VMD), the Quark Parton Model(QPM) and resolved photon processes. The latter uses the LAC1 parametrization for parton densities in the photon with LUND fragmentation [18]. We also include the $e^+e^- \to e^+e^-\tau^+\tau^-$ process. After applying the same selection criteria as for the real data, no $\tau^+\tau^-$ events remain in our data sample. The combined mass spectrum from the background sources (VMD+QPM+LAC1) is calculated and the result is shown as the hatched histogram in Fig. 3. The estimated background mass spectrum is fitted to the second order polynomial function and the result is shown as a dashed line.

We have also simulated the process $e^+e^- \to e^+e^-\eta_c \to e^+e^- K_s^0K^\pm\pi^\mp$, details of which is described in the next section. The sum of resulting mass spectrum of $K_s^0K^\pm\pi^\mp$ and the background contribution is shown as the solid histogram in Fig. 3, where the histogram is normalized to the data as discussed below. We consider the events that are within ± 0.200 GeV of the true mass of η_c (2.980 GeV) to be candidate η_c events. Because of the relatively high momenta of the secondary particles, the incorrectly assigned $K_s^0K^\pm\pi^\mp$ combinations also produce a peak around 3 GeV. Monte Carlo studies indicate that 8% of all entries are outside of the selected mass region. We include a 4% systematic error on the number of η_c events for this effect. We obtain a signal level of 6.5 candidate events. The level of background is obtained by normalizing the polynomial function obtained from the Monte Carlo studies described above to the observed event rate outside the η_c mass region. After subtracting $1.6\pm1.4(stat)$ background events, we find $4.9\pm2.9(stat)$ η_c events. The Monte Carlo histogram for the $K_s^0K^\pm\pi^\mp$ mass spectrum in Fig. 3 is normalized to 4.9 events.

3. Measurement of the radiative width of η_c

In order to determine the radiative width $\Gamma_{\gamma\gamma}(\eta_c)$, we generated Monte Carlo events of the process $e^+e^- \to e^+e^-\eta_c \to e^+e^- K_s^0K^\pm\pi^\mp$ using the cross section formula and the event generator package of BASES/SPRING [19]. The differential cross section $d\sigma(e^+e^- \to e^+e^-\eta_c)$ factorizes into a luminosity function and the two-photon cross section $\sigma(\gamma\gamma \to \eta_c)$[20]. The luminosity function is taken from the Ref.[21]. The two-photon cross section $\sigma(\gamma\gamma \to \eta_c)$ is given by [20]:

$$\sigma(\gamma\gamma \to \eta_c) = 8\pi(2J+1)\cdot\frac{\Gamma_{tot}(\eta_c)\Gamma_{\gamma\gamma}(\eta_c)}{(W^2-M_{\eta_c}^2)^2+\Gamma_{tot}^2(\eta_c)M_{\eta_c}^2},$$

where M_{η_c}(2.980 GeV) and $\Gamma_{tot}(\eta_c)$(13.2 MeV) are the mass and total width of the η_c, respectively [4].

The $\eta_c \to K_s^0K^\pm\pi^\mp$ decay is produced using a three-particle phase space generator. The generated events are passed through a detector simulation program and subjected to the same event selection program that is used for the real data. The resulting $K_s^0K^\pm\pi^\mp$ invariant mass distribution is shown as the solid histogram in Fig. 3. The detection efficiency(ε_d) of $K_s^0K^\pm\pi^\mp$ event from η_c decay is 0.35%($\pm$0.01% from Monte Carlo statistics).

The linear relation between the decay width $\Gamma_{\gamma\gamma}(\eta_c)$ and the total cross section for η_c production leads to the following expression:

$$\Gamma_{\gamma\gamma}(\eta_c)\cdot B(\eta_c \to K_s^0K^\pm\pi^\mp) = \frac{\Gamma_{\gamma\gamma}^{MC}(\eta_c)}{\sigma_{tot}(e^+e^- \to e^+e^-\eta_c)}\cdot\frac{N_{obs}}{\varepsilon_d\cdot\varepsilon_t\cdot L},$$

where

N_{obs} = The number of observed η_c events,

$\Gamma_{\gamma\gamma}^{MC}(\eta_c)$ = The radiative decay width of η_c for Monte Carlo events,

$\sigma_{tot}(e^+e^- \to e^+e^-\eta_c)$ = The total cross section of the process $e^+e^- \to e^+e^-\eta_c$,

$\Gamma_{\gamma\gamma}^{MC}(\eta_c)/\sigma_{tot}(e^+e^- \to e^+e^-\eta_c)$ is independent on $\Gamma_{\gamma\gamma}^{MC}(\eta_c)$ and calculated to be 1 KeV/13.2 pb by using BASES.

$B(\eta_c \to K_s^0K^\pm\pi^\mp)$ = The branching ratio of $\eta_c \to K_s^0K^\pm\pi^\mp = 1.83\pm0.57\%$,

ε_t = Trigger efficiency = $0.79\pm0.09(sys)$.

and L = Integrated luminosity = 275 pb^{-1}.

The experiment utilizes a number of different trigger conditions, none of which are totally redundant. Thus, the trigger efficiency is estimated from a comparison of the fractions of events triggered by different sets of individual trigger modes with Monte Carlo expectations. The systematic error is estimated from the variation of the trigger efficiency when different combinations of trigger modes are chosen.

The result of our analysis of the reaction $e^+e^- \to e^+e^- K_s^0K^\pm\pi^\mp$ is

$$\Gamma_{\gamma\gamma}(\eta_c)\cdot B(\eta_c \to K_s^0K^\pm\pi^\mp) = 0.49\pm0.29(sta)\pm0.09(sys)\ \text{keV}.$$

The systematic error includes the uncertainties in the luminosity measurement (2%), trigger efficiency (9%), background subtraction (12%), and the event selection criteria (10%), all added in quadrature. (The systematic error of 4% on the number of η_c events is included in detection efficiency.)

The computation of the radiative width $\Gamma_{\gamma\gamma}(\eta_c)$ is affected by the large uncertainty in the η_c branching ratio. The currently accepted PDG value for $B(\eta_c \to K_s^0K^\pm\pi^\mp)$ is $1.83\pm0.57\%$[4]. Using this branching ratio value leads to $\Gamma_{\gamma\gamma}(\eta_c) = 27\pm16(sta)\pm10(sys)$ keV, where the error of the branching ratio has been added in quadrature as one of the systematic errors. Our result is larger than, but consistent within errors with the PDG world average value of $\Gamma_{\gamma\gamma}(\eta_c) = 7.5^{+1.6}_{-1.4}$ keV.

4. Summary

We observe a signal of $\gamma\gamma \to \eta_c$ production in the reaction $e^+e^- \to e^+e^- K_s^0K^\pm\pi^\mp$. A total of $4.9\pm2.9(sta)$ η_c events are seen for an integrated luminosity of 275 pb^{-1}. This is the first observation of η_c production at TRISTAN energies. The product of the radiative decay width and the branching ratio $\Gamma_{\gamma\gamma}(\eta_c)\cdot B(\eta_c \to K_s^0K^\pm\pi^\mp)$ is determined to be $0.49\pm0.29(sta)\pm0.09(sys)$ keV.

The determination of the decay width $\Gamma_{\gamma\gamma}(\eta_c)$ is affected by the large uncertainty in the η_c decay branching ratio. Using the world average value of the banching ratio, we obtained $\Gamma_{\gamma\gamma}(\eta_c) = 27\pm16(sta)\pm10(sys)$ keV.

Acknowledgements

We thank the TRISTAN staff for the excellent operation of the storage ring. We acknowledge the strong support provided by the staffs of our home institutions. This work has been supported by the Japan Ministry of Education, Science, Culture and Sports (Monbusho), the Japan Society for the Promotion of Science, the US Department of Energy, the US National Science Foundation, the Korean Science and Engineering Foundation, the Ministry of Education of Korea, and the Academia Sinica of the People's

Republic of China.

References

[1] C.Quigg and J.L.Rosner, *Phys. Rep.* 56 (1979) 167;
W.Lucha, F.Schöberl, and D.Gromes, *Phys. Rep.* 200 (1991) 127.

[2] W.Kwong, P.B.Mackenzie, R.Rosenfeld, and J.L.Rosner, *Phys. Rev. D* 37 (1988) 3210.

[3] M.R.Ahmady and R.R.Mendel, *Phys. Rev. D* 51 (1995) 141.

[4] Particle Data Group, Review of Particle Physics, *Phys. Rev. D* 54 (1996) 1.

[5] L.J.Reinders, H.Rubinstein, and S. Yazaki, *Phys. Rep.* 127 (1985) 1.

[6] H.W.Huang, J.H.Liu, J.Tang, and K.T.Chao, *Phys. Rev. D* 56 (1997) 368.

[7] PLUTO Collab., Ch.Berger et al., *Phys. Lett. B* 167 (1986) 120.

[8] TPC/2γ Collab., H.Aihara et al., *Phys. Rev. Lett.* 60 (1988) 2355.

[9] TASSO Collab., W.Braunschweig et al., *Z. Phys. C* 41 (1989) 533.

[10] CLEO Collab., W.Y.Chen et al., *Phys. Lett. B* 243 (1990) 169.

[11] L3 Collab., O.Adriani et al., *Phys. Lett. B* 318 (1993) 575.

[12] ARGUS Collab., H.Albrecht et al., *Phys. Lett. B* 338 (1994) 390.

[13] E760 Collab. T.A.Armstrong et al., *Phys. Rev. D* 52 (1995) 4839.

[14] AMY Collab., T. Kumita et al., *Phys. Rev. D* 42 (1990) 1339.

[15] AMY Collab., F. Liu et al., *Phys. Rev. D* 49 (1994) 4339.

[16] AMY Collab., R. Tanaka et al., *Phys. Let. B* 277 (1992) 215.

[17] AMY Collab., B.J. Kim et al., *Phys. Let. B* 325 (1994) 248.

[18] H.Abramowicz, K.Charchula, and A.Levy, *Phys. Lett. B* 269 (1991) 458.

[19] S.Kawabata, *Comput. Phys. Commun.* 41 (1986) 127.

[20] Ch. Berger and W. Wagner, *Phys. Rep.* 146 (1987) 1.

[21] J.H.Field, *Nucl. Phys. B* 168 (1980) 477.

Experiment	$\Gamma_{\gamma\gamma}(\eta_c)$ (keV)	
	Average of various modes	$\eta_c \to K_s^0 K^\pm \pi^\mp$ mode
PLUTO(1986)[7]	28 ± 15	28 ± 15
TPC/2γ(1988)[8]	$6.4^{+5.0}_{-3.4}$	< 18
TASSO(1989)[9]	$19.9 \pm 6.1 \pm 8.6$	$19.3 \pm 7.5 \pm 7.7$
CLEO(1990)[10]	$5.9^{+2.1}_{-1.8} \pm 1.9$	$10.9^{+4.1}_{-3.6} \pm 3.4$
L3(1993)[11]	$8.0 \pm 2.3 \pm 2.4$	—
ARGUS(1994)[12]	11.3 ± 4.2	$15.4 \pm 3.7 \pm 5.0$
E-760(1995)[13]	$6.7^{+2.4}_{-1.7} \pm 2.3$	—
PDG Ave.(1996)[4]	$7.5^{+1.6}_{-1.4}$	—
The present experiment	$27 \pm 16 \pm 10$	$27 \pm 16 \pm 10$

Table 1: Experimental results for $\Gamma_{\gamma\gamma}(\eta_c)$. The values of $\Gamma_{\gamma\gamma}(\eta_c)$ for $\eta_c \to K_s^0 K^\pm \pi^\mp$ mode are calculated from the original values using the present PDG branching ratio 1.83% for this decay mode[4].

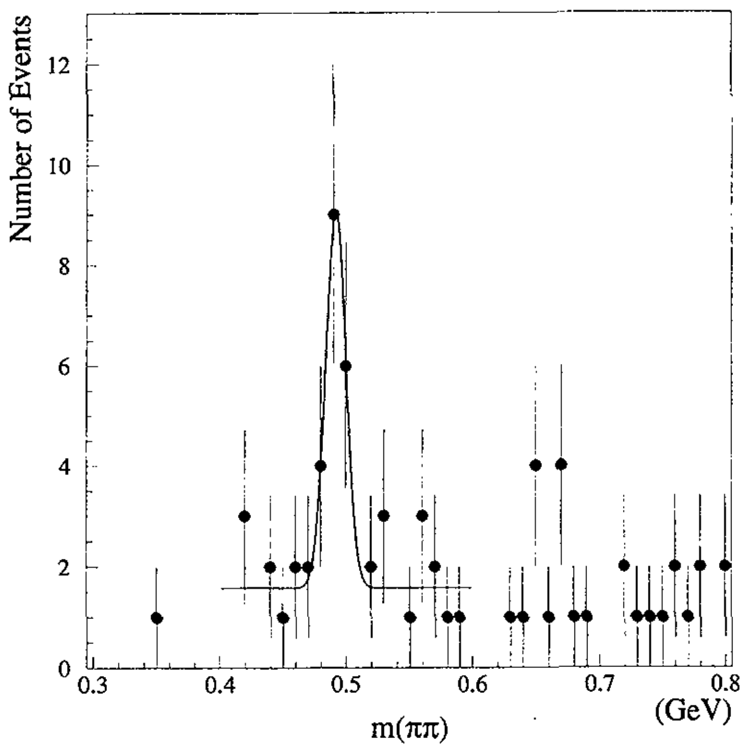

Fig. 1: Invariant $\pi^+\pi^-$-mass distribution of the observed V^0 tracks in the four prong events.

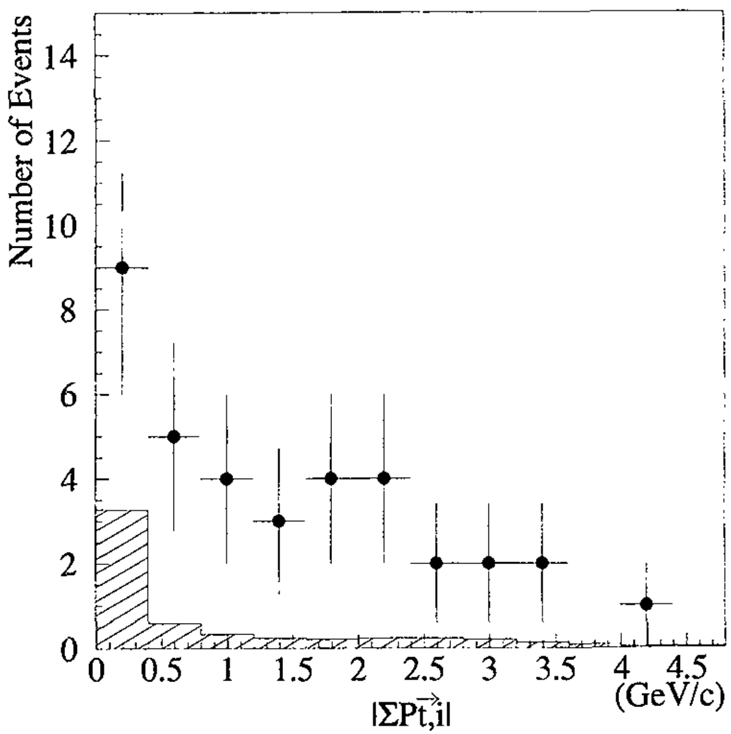

Fig. 2: The net transverse momentum $|\Sigma \vec{p_{t,i}}|$ distribution. The points are the experimental data. The histogram is the Monte Carlo expectation for η_c events where the ordinate scale is in arbitrary unit.

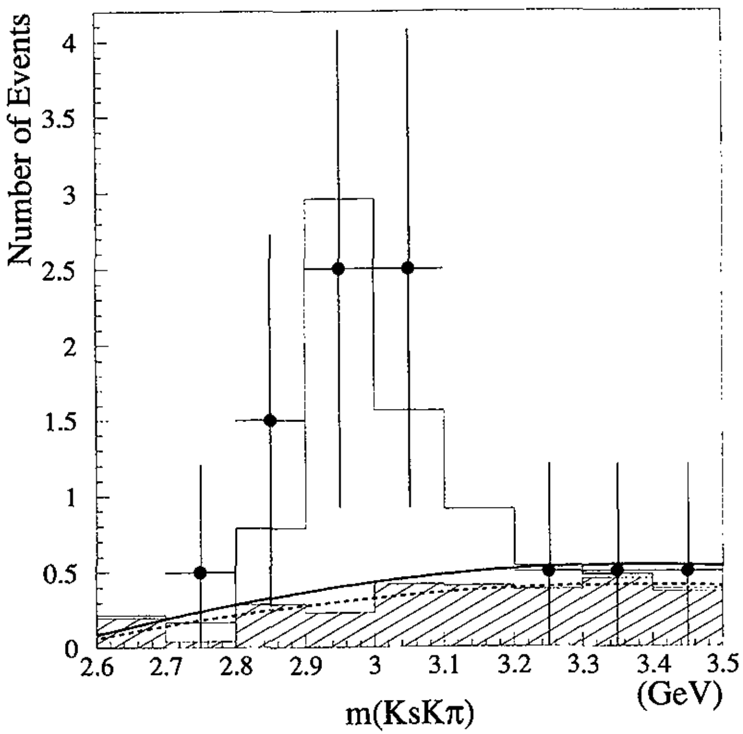

Fig. 3: Invariant $K_s^0 K^\pm \pi^\mp$-mass distribution. The experimental data points are plotted with bars indicating the statistical error. The background contribution obtained from the Monte Carlo calculation is indicated by the hatched solid histogram. Its fit to the polynomial function is shown as a dashed line. The solid line shows the background contribution normalized to the observed data outside the η_c mass region. The sum of the η_c Monte Carlo events and the background contribution is shown as the solid histogram. The η_c Monte Carlo events are normalized to the experimental data.