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Search for D° and B° decays into $\pi^\circ\pi^\circ$

The Crystal Ball Collaboration

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Abstract

We have searched for the decay modes $D^\circ \to \pi^\circ\pi^\circ$ and $B^\circ \to \pi^\circ\pi^\circ$ using data taken with the Crystal Ball detector at DORIS II. No evidence for these Cabibbo- and colour-suppressed decays was found, and 90% confidence level upper limits of $BR(D^\circ \to \pi^\circ\pi^\circ) < 3.8 \times 10^{-3}$ and $BR(B^\circ \to \pi^\circ\pi^\circ) < 4.6 \times 10^{-4}$ are given.

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Introduction

The decays of the lowest-lying mesons containing charm or bottom quarks, the D and B mesons, are mediated by the weak interaction. Studies of these decays are essential for testing the standard model and determining its quark mixing parameters [1]. A full understanding of the weak decays of these heavy mesons requires a detailed study of their exclusive decays. For most two-body decays satisfactory agreement of theoretical calculations [2] with experimental results is achieved, but some problems remain for the Cabibbo-suppressed channels. The ratio of Cabibbo-suppressed D° decays , $\Gamma(D^\circ \rightarrow K^+K^-)/\Gamma(D^\circ \rightarrow \pi^+\pi^-)$ should be between 1 and 1.4 [2], while the experimental value is about 3 [3]. This difference could be due to SU(3) breaking and/or final-state interactions. A measurement of the decay $D^\circ \rightarrow \pi^\circ\pi^\circ$ should help to determine which of these mechanisms is responsible [4].

Also of interest are B decays to non-charmed and non-strange states. To lowest order they depend on the Kobayashi-Maskawa matrix element $\mid V_{ub} \mid$ [1]. However, even with $\mid V_{ub} \mid = 0$, inelastic final-state-interactions can generate a non-zero amplitude for $B^\circ \rightarrow \pi^\circ\pi^\circ$ and $B^\circ \rightarrow \pi^+\pi^-$ [5]. This is not possible for $B^- \rightarrow \pi^-\pi^\circ$. The knowledge of these three rates would thus help to elucidate the role of final-state interactions.

In this letter we present a search for the Cabibbo-suppressed decay modes $D^\circ \rightarrow \pi^\circ\pi^\circ$ and $B^\circ \rightarrow \pi^\circ\pi^\circ$ in data collected with the Crystal Ball detector from 1982 to 1986 at the e^+e^- storage ring DORIS II at DESY. The data sample for the D° study corresponds to an integrated luminosity $\mathcal{L}$ of $(248 \pm 6)\ pb^{-1}$ obtained on the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(4S)$ resonances and in the nearby continua, the error on the luminosity is dominated by systematics [6]. For the B° study only the data taken on $\Upsilon(4S)$ are used. All events considered in the analysis passed the hadronic event-selection criteria described in Ref. [6].

The Crystal Ball detector [6,7] is well-suited to detect π° mesons [8]. It consists of a spherical array of 672 NaI(Tl) crystals which cover 93% of the solid angle. Endcap arrays of NaI(Tl) crystals extend the solid angle coverage to 98%. The measured energy resolution for electromagnetically showering particles is $\sigma_E/E = (2.7 \pm 0.2)\%/\sqrt[4]{E/GeV}$ and the polar angle resolution is between 1° and 3°, depending on the photon energy. The charged particles are detected by a set of four cylindrical double layers of proportional tubes surrounding the beam pipe (only three double layers for the first 1/4 of the data).

Given the granularity of the Crystal Ball calorimeter, π° mesons with an energy above about 500 MeV appear as one energy cluster since the showers from the two decay photons merge. An energy cluster is defined as a contiguous region of crystals where each crystal has more than 10 MeV of deposited energy E_i. Reconstruction of the high-energy π°'s is based on the shape of the energy deposition. This is determined by the second moment S of the lateral energy distribution of the cluster [9], defined as

$$S = \frac{1}{E_c}\sum_i E_i(\vec{n}_i - \vec{c})^2 \qquad (1)$$

where E_c is the sum of energies of crystals in the cluster, $\vec{n}_i$ is the unit vector pointing from the interaction point to the center of the i^{th} crystal and $\vec{c}$ is the vector pointing to the center of gravity of the cluster, $\vec{c} = (1/E_c)\sum_i \vec{n}_i E_i$. An energy-dependent cut on S (discussed below) is used to separate the wider π° showers from those due to single photons. The momentum vector of each π° is taken to be parallel to $\vec{c}$, and its energy is E_c corrected for lateral and longitudinal shower leakage, non-central hits and a small non-linearity [10].

Search for the decay $D^\circ \to \pi^\circ\pi^\circ$

To search for the decay mode $D^\circ \to \pi^\circ\pi^\circ$ we look for events in the hadronic event sample with merged π°'s. As a merged π° candidate we accept any energy deposition without a correlated charged track, having an energy greater than 750 MeV and a polar angle θ with respect to the beam direction satisfying $|\cos\theta| < 0.85$. Fig. 1 shows the distribution of S *vs.* cluster energy for data and for Monte Carlo events (see below). As π°'s we select energy depositions inside the polygon. Events with at least two merged π°'s are accepted. For each $\pi^\circ\pi^\circ$ combination in the event the invariant mass is calculated.

To reduce combinatorical background two additional cuts are applied. We accept only D° candidates with $x_p > 0.5$, where $x_p = p(D^\circ)/\sqrt{E^2_{beam} - m^2_{D^\circ}}$, E_{beam} is the beam energy, m_{D° is the nominal D° mass and $p(D^\circ)$ is the momentum of the $\pi^\circ\pi^\circ$ system. Accidental $\pi^\circ\pi^\circ$ combinations peak strongly at low values of x_p (Fig. 2), while D°'s from continuum production have a hard fragmentation function [11,12]. The second cut is on the distribution of $\cos\alpha$, where α is the angle between the π° direction in the D° rest frame and the D° direction in the laboratory frame, which should be isotropic. Because the distribution of random $\pi^\circ\pi^\circ$ combinations tends to peak at small forward and backward angles we require $|\cos\alpha| < 0.6$. The invariant mass spectrum for D° candidates is presented in Fig. 3. The distribution shows no signal in the D° mass region.

The efficiency of our D° reconstruction is estimated from Monte Carlo studies. The LUND 6.3 program version [13] is used to simulate the process $e^+e^- \to c\bar{c} \to D^\circ +$ *anything*, where one D° decays always into $\pi^\circ\pi^\circ$. The Peterson fragmentation function (with an ϵ parameter of 0.24), which well describes the D° data of Ref. [12], is used to generate the D° momentum distribution. The generated events are passed through a complete detector simulation, which uses the EGS3 program [14] for electrons and photons and the improved GHEISHA 6 program [15] for hadrons. The Monte Carlo events are then reconstructed with our standard software and subjected to the same cuts as the data. The $\pi^\circ\pi^\circ$ mass spectrum is fitted to obtain the number of reconstructed D° mesons. Divided by the number of generated $D^\circ \to \pi^\circ\pi^\circ$ decays, this gives an efficiency of $\epsilon\,(D^\circ \to \pi^\circ\pi^\circ) = (7.6 \pm 0.5 \pm 0.7)\%$, where the first error is statistical and the second is the systematic error, dominated by variations in the fit parameters.

To search for a possible D^0 signal we fit the spectrum shown in Fig. 3 with a Gaussian peak of width and mean fixed to the values obtained from the Monte Carlo simulation and a second order polynomial for the background. Including a third order polynomial results in a coefficient comparable with zero. This yields the number of detected D° events $N_{D^\circ} = (0 \pm 50)$. A systematic error has been derived from a variation in the Gaussian width and mean within their errors and a change in the fit range. We find changes of 11 events. This systematic error is combined quadratically with the statistical one. We convert this result to a 90% confidence level (CL) upper limit on the product of the D° production cross-section and the branching ratio

$$\sigma_{D^\circ} \times BR(D^\circ \to \pi^\circ\pi^\circ) = \frac{N_{D^\circ}}{\epsilon\,(D^\circ \to \pi^\circ\pi^\circ)\,\mathcal{L}}. \qquad (2)$$

This is accomplished [16] by numerically integrating the likelihood function for that quantity taking into account the errors in the efficiency, number of D°'s and the luminosity. We get

$$\sigma_{D^\circ} \times BR(D^\circ \to \pi^\circ\pi^\circ) < 4.5\ pb. \qquad (3)$$

To extract from this an upper limit on $BR(D^\circ \to \pi^\circ\pi^\circ)$, we assume that half of all produced D mesons are D°'s and estimate the continuum D° production cross-section as

$$\sigma_{D^\circ} \cong (4/10) \times \bar{\sigma}_{tot}(e^+e^- \to \ hadrons), \tag{4}$$

where $\bar{\sigma}_{tot}$ is the luminosity-averaged continuum hadronic cross-section for our data sample. We use also the fact that all D°'s resulting from decays of B mesons produced at the $\Upsilon(4S)$ resonance are eliminated by the cut on x_p because their momentum distribution is much softer as was shown in Ref. [12]. With those assumptions we get

$$BR(D^\circ \to \pi^\circ\pi^\circ) < 3.8 \times 10^{-3}. \tag{5}$$

This result is consistent with values obtained by the Crystal Ball at SPEAR [17], $BR(D^\circ \to \pi^\circ\pi^\circ) < 3.0 \times 10^{-3}$, and by CLEO [3] $BR(D^\circ \to \pi^\circ\pi^\circ) < 4.6 \times 10^{-3}$. Several groups [3,18, 19,20] have observed the decay $D^\circ \to \pi^+\pi^-$. The most recent result obtained by CLEO [3] is $BR(D^\circ \to \pi^+\pi^-) = (2.1 \pm 0.3 \pm 0.2 \pm 0.3) \times 10^{-3}$, where the third error is due to the uncertainty in the $D^\circ \to K^+K^-$ branching ratio. This value is consistent with theoretical predictions [2]. The branching ratio to $\pi^\circ\pi^\circ$ is predicted to be ten times smaller [3].

Search for the decay $B^\circ \to \pi^\circ\pi^\circ$

We search for the exclusive channel $B^\circ \to \pi^\circ\pi^\circ$ in the hadronic event sample taken on the $\Upsilon(4S)$ resonance, which corresponds to a luminosity of 76 pb^{-1}. The number of observed $B\overline{B}$ events $N_{B\overline{B}}$ is found by comparing the observed hadronic cross-section in the $\Upsilon(4S)$ data with that in 18.5 pb^{-1} of data taken in the nearby continuum. Assuming that charged and neutral B mesons are produced with equal probability, we find for the number of observed neutral B mesons $N_{B^\circ} = N_{B\overline{B}} = (60260 \pm 1100)$ [6]. The efficiency of our hadronic selection for $B\overline{B}$ events was also shown in Ref. [6] to be $\epsilon_{had} = (92.0 \pm 0.5 \pm 0.9)\%$.

In order to suppress continuum hadron production compared to resonance production and to reduce background due to $\tau^+\tau^-$ pairs we require the event multiplicity (the number of local maxima of energy depositions in the calorimeter) to be larger than five. We select events with two high energy π°'s (2.2 - 3.0 GeV) with an opening angle of $\cos\beta < -0.98$. They have to be observed as neutral clusters with the second moment S consistent with a π° [9]. Only one event from the $\Upsilon(4S)$ sample survives this selection. It has a cluster multiplicity of six and a $\pi^\circ\pi^\circ$ invariant mass of 5314 MeV/c^2. This one event corresponds to a 90% CL upper limit of 3.9 events.

To determine the efficiency of the selection of a $\pi^\circ\pi^\circ$ pair we simulate $\Upsilon(4S)$ decay to $B\overline{B}$ pairs, where one B° meson always decays into a $\pi^\circ\pi^\circ$ pair [13]. This gives an efficiency of $\epsilon(B^\circ \to \pi^\circ\pi^\circ) = (13.6 \pm 0.4 \pm 0.3)\%$. A 90% CL upper limit on the branching ratio is then calculated by numerical integrating the likelihood function for the quantity

$$BR(B^\circ \to \pi^\circ\pi^\circ) < \frac{N_{\pi^\circ\pi^\circ}/\epsilon(B^\circ \to \pi^\circ\pi^\circ)}{N_{B^\circ}/\epsilon_{had}}, \tag{6}$$

taking into account the errors on the efficiencies and on the number of B° mesons N_{B° [16]. This yields the upper limit for the branching ratio of

$$BR(B^\circ \to \pi^\circ\pi^\circ) < 4.6 \times 10^{-4} \ at \ 90\% \ CL. \tag{7}$$

For comparison, the CLEO [21] and ARGUS [22] collaborations searched for the B° decay mode into $\pi^+\pi^-$ and have set upper limits (90% CL) of $BR(B^\circ \rightarrow \pi^+\pi^-)$ of 0.9×10^{-4} and 1.3×10^{-4}, respectively, assuming that 43% (50%, respectively) of $\Upsilon(4S)$ decays are $B^\circ\bar{B}^\circ$.

In conclusion, we have searched for the Cabibbo-suppressed decay modes of D° and B° mesons into $\pi^\circ\pi^\circ$. We find no evidence for these final states and set an upper limit at 90% CL of 3.8×10^{-3} for $BR(D^\circ \rightarrow \pi^\circ\pi^\circ)$ and 4.6×10^{-4} for $BR(B^\circ \rightarrow \pi^\circ\pi^\circ)$.

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References

[1] M. Kobayashi and T. Maskawa , Prog. Theor. Phys. **49** (1973) 652

[2] A.J. Buras, J.M. Gerard and R. Rückl, Nucl. Phys. **B268** (1986) 16;
M. Bauer, B. Stech and M. Wirbel, Z. Phys. **C34** (1987) 103

[3] J.Alexander et al. (CLEO), Phys. Rev. Lett. **65** (1990) 1184;
J.J. Hernandez et al.(PDG), Phys. Lett. **B239** (1990) 1

[4] L.L. Chau and H.Y. Cheng, Phys. Rev. **D36** (1987) 137

[5] A.N. Kamal, preprint Alberta Thy - 26-90, October 1990

[6] K. Wachs et al., Z. Phys. **C42** (1989) 33

[7] E.D. Bloom and C.W. Peck, Ann. Rev. Nucl. Part. Sci. **33** (1983) 143

[8] C. Bieler et al., Z. Phys. **C49** (1991) 225

[9] P. Schmitt et al., Z. Phys. **C40** (1988) 199 ; J. Schütte, Ph.D. Thesis, University of Erlangen-Nürnberg, (1989), report DESY-F31-89/03

[10] D. Antreyasan et al., Z. Phys., **C48** (1990) 561

[11] P.A. Rapidis et al. (MARK I), Phys. Lett. **B84** (1979) 507;
M.W. Coles et al. (MARK II), Phys. Rev. **D26** (1982) 2190;
C. Peterson et al., Phys. Rev. **D27** (1983) 105;
P. Avery et et. (CLEO), Phys. Rev. Lett. **51** (1983) 1139;
S. Ahlen et al. (HRS), Phys. Rev. Lett. **51** (1983) 1147;
M. Derrick et al. (HRS), Phys. Rev. Lett. **53** (1984) 1971

[12] D.Bortoletto et al. (CLEO), Phys. Rev. **D35** (1987) 19

[13] H.-W. Bengtsson and T. Sjøstrand, Comput. Phys. Comm. **43** (1987) 367

[14] R. Ford and W. Nelson, SLAC-210 (1978)

[15] H. Fesefeldt, PITHA 85/02, unpublished;
Z. Jakubowski, M. Kobel, Nucl. Instr. Meth. **A297** (1990) 60

[16] F. James, in *Proceedings of the CERN School of Computing*, Vraona-Attiki, Greece, CERN-81-03 p.182

[17] R.A. Partridge, Ph.D. Thesis, California Institute of Technology, (1984), unpublished

[18] S. Barlag et al. (ACCMOR), Z. Phys. **C48** (1990) 29

[19] R.M. Baltrusaitis et al. (MARK-III), Phys. Rev. Lett. **55** (1985) 150, Erratum, ibid **56** (1985) 639

[20] H. Albrecht et al. (ARGUS), Z. Phys. **C46** (1990) 9

[21] D. Bortoletto et al. (CLEO), Phys. Rev. Lett. **62** (1989) 2436

[22] H. Albrecht et al. (ARGUS), Phys. Lett. **B241** (1990) 278

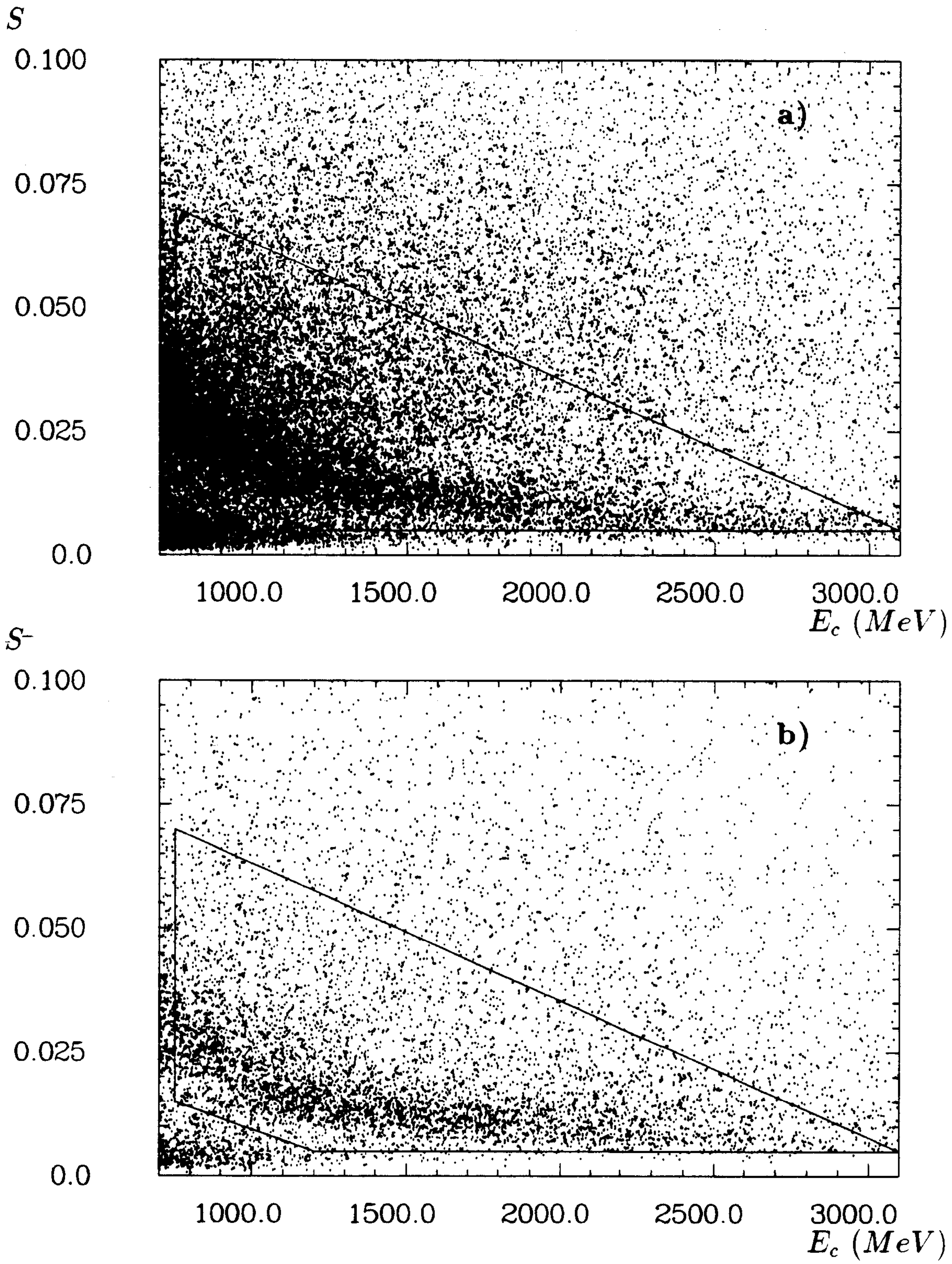

Figure 1: The distribution of the second moment S *vs* cluster energy E_c for data (a) and Monte Carlo (b). The accepted merged π^0 candidates lie inside the polygon.

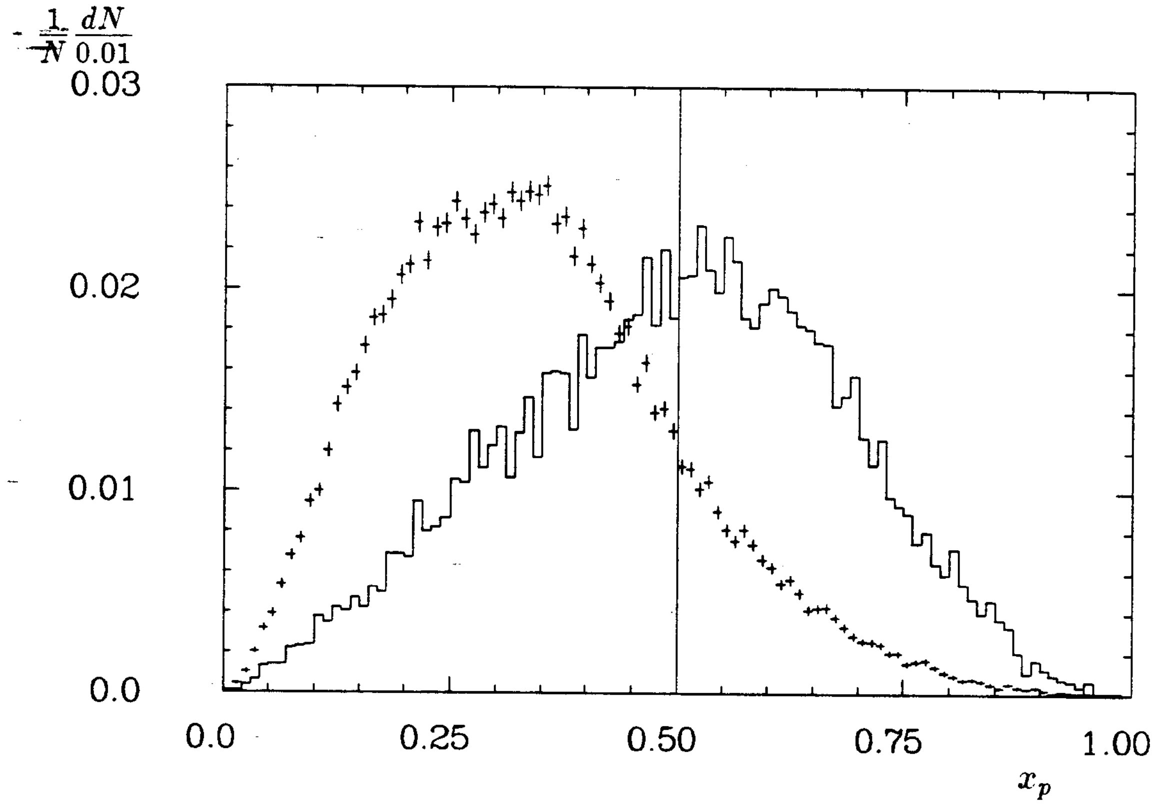

Figure 2: The x_p distribution for data (crosses) and Monte Carlo (solid line). Accepted events are to the right of the solid line.

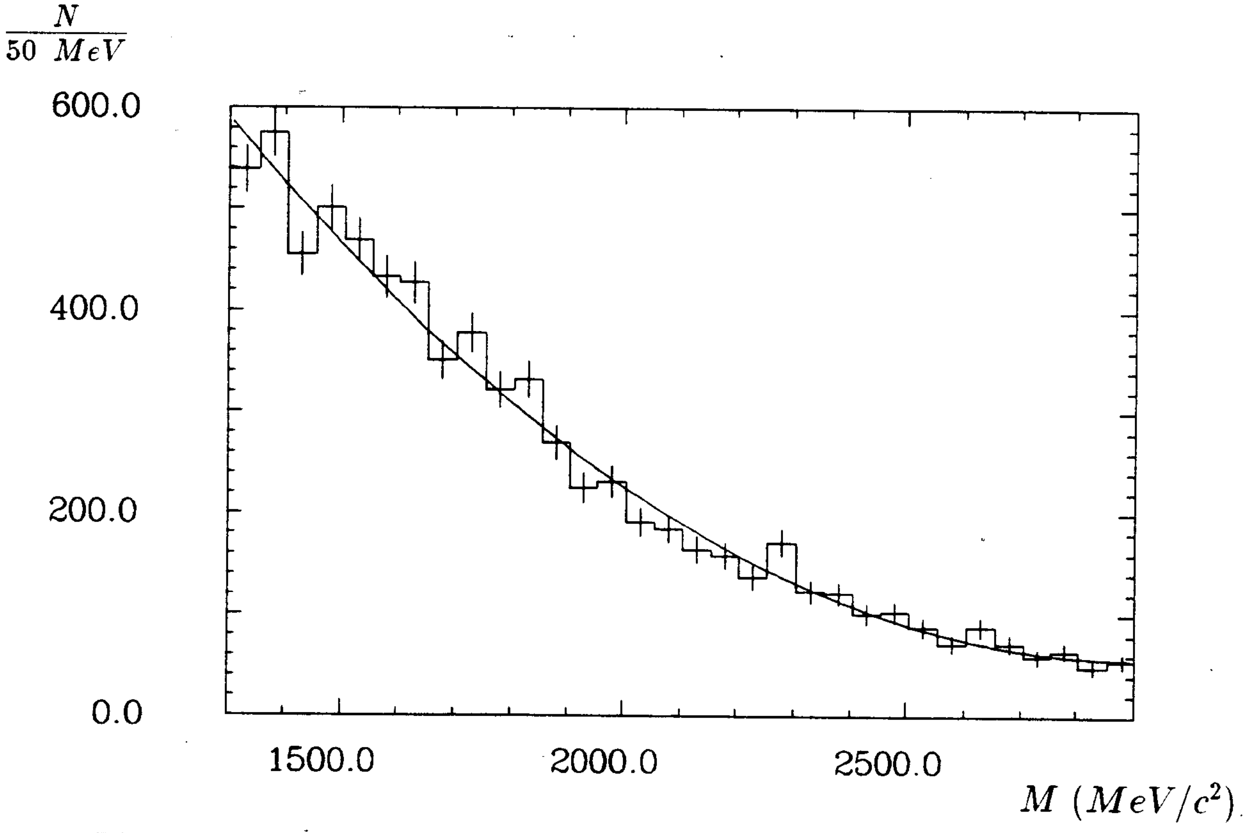

Figure 3: The distribution of the $\pi^\circ\pi^\circ$ invariant mass for D° candidates. The solid line shows a fit to the distribution with a Gaussian and polynomial background.