OBSERVATION OF $\Delta(1232)^{++}$ PRODUCTION IN e^+e^- ANNIHILATIONS AROUND 10 GeV

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0370-2693/89/$ 03 50 © Elsevier Science Publishers B.V
(North-Holland Physics Publishing Division)

Received 28 July 1989

We report on the first observation of $\Delta(1232)^{++}$ and $\overline{\Delta(1232)^{++}}$ baryons in e^+e^- annihilation at energies around 10 GeV, using the ARGUS detector at DORIS II The sum of the rates of Δ^{++} and $\overline{\Delta^{++}}$ per hadronic event in the continuum is measured to be 0 040±0 008±0 006, and the rate in direct $\Upsilon(1S)$ decays is 0 124±0 016±0 015 The momentum spectrum of Δ^{++} baryons in direct $\Upsilon(1S)$ decays has been measured

Baryon production has been found to be substantial in e^+e^- annihilation reactions, being enhanced by a factor of 2–3 in the three-gluon decays of the Υ resonances with respect to the nearby quark–antiquark continuum This effect might reflect different fragmentation mechanisms of three-gluon versus quark–antiquark hadronization, but is in addition caused by the high charm production rates in continuum [1,2]

Until now, members of all isomultiplets of both octet and decuplet baryons have been detected in e^+e^- annihilation final states, with the exception of the $\Delta(1232)$ [3] The reason that the $\Delta(1232)$ has escaped detection so far lies in the fact that it is a broad resonance close to the $p\pi$ threshold, and has to compete with a background which rises steeply from threshold and peaks close to the Δ mass The source of this low invariant mass background is the abundance of low and medium momentum pions Once a proton is identified in an event, there is a high probability of finding a slow pion which combines with the proton to form a system with an invariant mass near threshold Another possible source of background comes from higher momentum pions and kaons misidentified as protons The contribution from these fake protons, however, influences mainly the high mass region above the $\Delta(1232)$

Among the four isospin partners the double charged Δ^{++} offers the best chance for experimental observation In the decays of singly-charged Δ^{++} baryons, neutral pions are produced, so that the large combinatorial background prevents observation of any resonant structure In Δ^0 decays, the control of the background meets increasing difficulties because of reflections from neutral mesonic resonances, such as ρ^0, In addition, the decay of $\Delta^0\to p\pi^-$ is suppressed due to isospin symmetry by a factor of three with respect to the decay of $\Delta^{++}\to p\pi^+$

In our analysis we have used a data sample with an integrated luminosity of 30 6 pb^{-1} on the $\Upsilon(1S)$, and 45 3 pb^{-1} in the nearby continuum The ARGUS detector, its trigger and particle identification capabilities have been described elsewhere [4] The criteria for the selection of multihadron events where at least four charged tracks per event are required, and a description of the cut used to reduce the background of beam–gas and beam–wall events are given in ref [3] For a charged track all mass hypotheses were accepted for which the combined likelihood ratio from dE/dx and time-of-flight measurements exceeded 1% [4] In order to remove the contamination from converted photons in radiative Bhabha events, we required that the cosine of the opening angle between equally charged tracks be smaller than 0 99

To determine the Δ^{++} rate in $\Upsilon(1S)$ decays, the continuum was subtracted after scaling the $p\pi$ invariant mass distribution to the proper luminosity The following formula was applied

$$N_{dir} = N_{on} - N_{off}\frac{L_{on}}{L_{off}}\frac{s_{off}}{s_{on}}\,(1+\alpha)\,,$$

where N_{on} is the number of proton pion invariant

[1] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054DO51P
[2] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054ER11P(5)
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[9] Supported by the US National Science Foundation
[10] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054KA17P
[11] Supported by Raziskovalna skupnost Slovenije and the Internationales Buro KfA, Julich
[12] Supported by the Swedish Research Council
[13] Supported by the US Department of Energy, under contract DE-AS09-80ER10690

mass combinations on resonance, N_{off} the number of combinations in the continuum, L_{on} (L_{off}) the integrated luminosity on (off) resonance, s_{on} (s_{off}) the centre of mass energy squared on (off) resonance, and α is a correction term which takes into account the influence of the vacuum polarization

$$\alpha = \frac{1}{1-3B_{\mu\mu}} \frac{B_{\mu\mu}\sigma^{h}_{\Upsilon}}{\sigma^{\mu\mu}_{QED}} \frac{1}{1+\delta_r}$$

Here $B_{\mu\mu}$ is the branching ratio for the decay $\Upsilon(1S)\to\mu^+\mu^-$, σ^h_Υ the cross section for the process $e^+e^-\to\Upsilon(1S)\to$hadrons, and $\sigma^{\mu\mu}_{QED}$ the QED point like cross section for continuum μ pair production at the energy of the $\Upsilon(1S)$ resonance The term δ_r takes into account radiative corrections [5,6] The $p\pi^+$ invariant mass spectra on the $\Upsilon(1S)$ resonance and in the continuum are shown in fig 1, together with the mass spectrum obtained after continuum subtraction, the so-called $\Upsilon(1S)$ direct spectrum

In order to suppress the major combinatorial background peaking close to threshold, one has to remove the bulk of low momentum pions the Δ^{++} signal emerges, as seen in fig 2, when one applies a low pion momentum cut where pions with momentum less than 300 MeV/c were removed The effect of this cut is different in $\Upsilon(1S)$ and continuum events due to the different multiplicities, average momenta, and event topologies on and off resonance The appearance of the peak caused by the removal of low momentum pions is not an artifact induced by the cut itself, as was carefully checked with Monte Carlo events [6], and with experimental data using $K^+\pi^+$ invariant mass spectra, where we do not expect any resonant structure

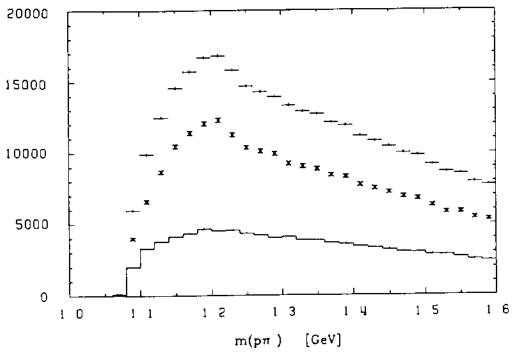

Fig 1 Invariant mass of $p\pi^+$ combinations from the $\Upsilon(1S)$ resonance (crosses) and from the continuum (histogram) The latter spectrum was scaled to the same luminosity and energy as the $\Upsilon(1S)$ data The difference between the two spectra corresponds to the direct $\Upsilon(1S)$ decays (circles)

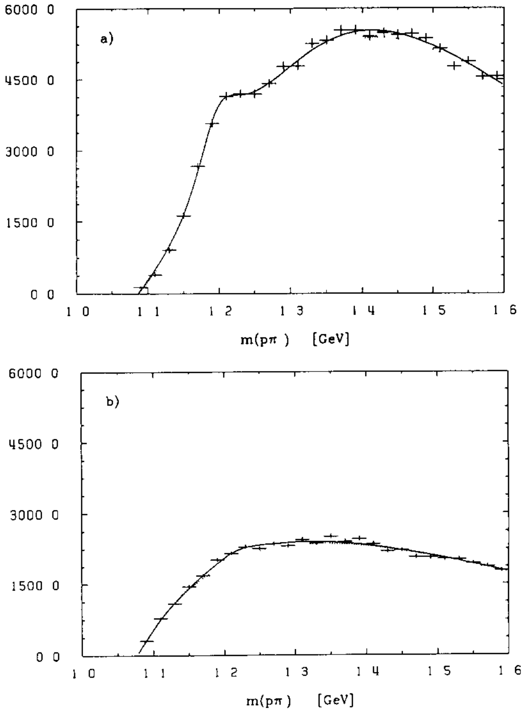

Fig 2 Invariant mass of $p\pi^+$ combinations, (a) from direct $\Upsilon(1S)$ decays and (b) from continuum events A cut on the pion momentum of $p_\pi \geqslant 0$ 3 GeV/c is used In both figures the full line represents a fit to the data using the sum of a smooth four parameter curve and a relativistic Breit–Wigner function, while the dots represent the contribution from the background only

The fits to these mass distributions were performed using a relativistic Breit–Wigner function superimposed onto a smooth background The results of the fits are shown in fig 2 The explicit form used for the Breit–Wigner function is

$$\mathrm{RBW}(m) = \frac{m_0\Gamma(m)}{(m_0^2-m^2)^2+[m_0\Gamma(m)]^2},$$

where

$$\Gamma(m) = \Gamma_0(q/q_0)^3(m_0/m)^2\frac{(m+m_p)^2-m_\pi^2}{(m_0+m_p)^2-m_\pi^2}$$

Γ_0 and m_0 are the on-shell width and mass of the Δ resonance, q and q_0 are the momenta of decaying particles evaluated at the resonance masses m and m_0 in the Δ rest frame (see ref [7] for a discussion) Since the shapes of the $\Upsilon(1S)$ and the continuum spectra are not the same, we use different functions for background parametrization [8] The background form taken for the $\Upsilon(1S)$ direct spectrum is

$$Y(m)=\alpha_1 \operatorname{arctg}\left(\frac{m-\alpha_2}{\alpha_3}\right)(1-\alpha_4 m),$$

while for the continuum we use

$$C(m)=\alpha_1\left[1-\exp\left(\frac{m-\alpha_2}{\alpha_3}\right)\right](1-\alpha_4 m),$$

where α_i are free parameters On the $\Upsilon(1S)$ spectrum the mass, width and amplitude of the Breit–Wigner function have been left free during fitting, as have the parameters describing the background shape, while the width was fixed to 110 MeV/c^2 on the continuum The fit results are presented in table 1

In order to examine the stability of the results, the fits were repeated while varying the cuts imposed on the pion momentum, and the proton–pion invariant mass range used for fitting The pion momentum cut was varied between 250 and 350 MeV/c, while the upper value of the invariant mass range was varied between 1 5 and 1 7 GeV/c^2 After correcting for the acceptance due to differ pion momentum cuts, the results remain stable within errors

The systematic error introduced by the background and resonance parametrizations to be fitted was studied in the following ways First, proton–pion invariant mass spectra from Lund Monte Carlo generated multihadron events were used [6], where all combinations with proton and pion both coming from Δ^{++} decay were excluded from the analysis To this background certain fractions γ_1 pf Δ^{++} baryons, generated according to the RBW resonance shape, were added and the fitting procedure described above was applied The result was the fitted fraction γ_0 In this way one obtains a correlation plot between γ_1 and γ_0 from which one deduces the degree of misestimation from the fit which, for the background parametrization used, is of the order of 20%. This procedure can be cross checked by constructing the background from real data, using kaon–pion invariant masses, and replacing the kaon mass by the proton mass The results of both methods are consistent with each other To study the systematic error we varied the shape of the $K\pi$ invariant mass spectra by applying different cuts on the pion momentum The degree of misestimation of the Δ^{++} signal was rather insensitive to the changes of the background shape, and the systematic error on the correction factor γ_1/γ_0 is estimated to be 10% [8]

From the fit results, the cross sections were obtained using the formula

$$\sigma=\frac{1}{L}N_{\text{fit}}\frac{1}{\epsilon_{\text{fit}}}\frac{1}{\eta_{\text{tot}}},,$$

where σ is the inclusive cross section, L the integrated luminosity, N_{fit} the number of Δ's obtained from the fit, ϵ_{fit} the correction factor for the fit and η_{tot} the total efficiency To calculate the cross sections, one needs to know the efficiencies of the cuts applied, and the detection efficiencies for protons and pions The efficiencies were determined using the full detector simulation program processing events generated according to the Lund Monte Carlo program [6] The trigger efficiency was taken to be 100%, which was nearly true for multihadron events with at least four charged tracks

The results are compiled in table 2, along with a comparison with model predictions Our data favours the so called popcorn model over the pure diquark model [1,9] The ratio between the Δ^{++} rate in $\Upsilon(1S)$ direct decays and the rate in the continuum is 3 1 ± 0 8 Our measurement supports observations from studies on other baryons that rates in direct

Table 1
Results of the fit with the sum of a smooth background (four free parameters) and a relativistic Breit–Wigner function to the $m_{p\pi}$ invariant mass spectrum on the $\Upsilon(1S)$ and on the continuum data In the latter case the width of the Breit–Wigner function was fixed to 110 MeV To determine N_Δ the relativistic Breit–Wigner function was integrated in the region from the $p\pi$ threshold to 1 5 GeV/c^2

Spectrum $m_{p\pi}$	m_0(GeV/c^2)	Γ_0(GeV/c^2)	N_Δ	χ^2/N_{df}
$\Upsilon(1S)_{\text{dir}}$	1 21 ± 0 01	0 095 ± 0 011	9856 ± 1160	1 6
continuum	1 22 ± 0 01	0 11	1185 ± 225	1 3

Table 2
Production cross section for the sum of Δ^{++} and $\overline{\Delta^{++}}$ on the $\Upsilon(1S)$ resonance and on the continuum The rates per hadronic event in the continuum and in the $\Upsilon(1S)$ direct decays are compared to Lund model predictions [1]

	Υ (1S)			Continuum (10 2 GeV)		
	observation	model		observation	model	
		diquark	popcorn		diquark	popcorn
σ(nb)	1 100±0 142±0 122			0 130±0 026±0 020		
R_{event}	0 124±0 016±0 015	0 060	0 110	0 040±0 008±0 006	0 025	0 032

$\Upsilon(1S)$ decays are enhanced by a factor of 2–3 as compared to the continuum [3,2]

The large Δ^{++} rate from $\Upsilon(1S)$ direct decays offers the opportunity to determine the Δ^{++} momentum distribution The momentum region from 0 to 2 GeV/c was divided into four intervals, and the $p\pi^+$ invariant mass distribution was plotted for each momentum bin Then the contribution from the continuum was subtracted and the remaining spectra were fitted with a sum of a relativistic Breit–Wigner and a smooth background, as described above The observed number of Δ^{++} was corrected for acceptance, which is flat for momenta larger than 0 8 GeV/c, and steeply decreases for momenta below 0 8 GeV/c The average acceptance in the first two momentum bins therefore depends on the shape of the momentum distribution The systematic error on the acceptance was determined by using different assumptions about the momentum spectrum in the region from 0–0 8 GeV/c [8]

The resulting Δ^{++} rate from $\Upsilon(1S)$ direct decays for four momentum intervals is shown in fig 3 Statistical and systematic errors are added in quadrature The spectrum is compared to the Lund model prediction which is normalized to the data in the momentum region from 0 to 2 GeV/c [6]

In summary, we have observed for the first time the production of the $\Delta(1232)^{++}$ baryon resonance in e^+e^- annihilation, as well from $\Upsilon(1S)$ direct decays (gluon fragmentation), as in the neighbouring continuum (quark fragmentation) We find a sizeable production cross section Comparing our results with model predictions, the agreement with the popcorn model is satisfactory, while the pure diquark model is disfavoured. The enhancement of Δ^{++} rate in $\Upsilon(1S)$ direct decays compared to the continuum

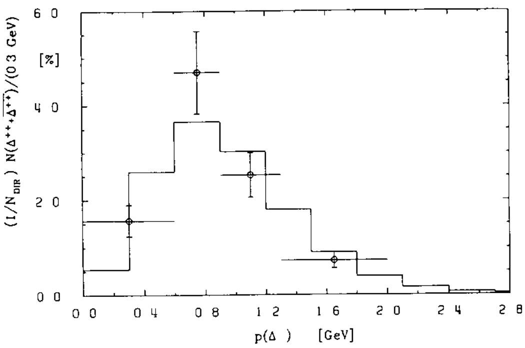

Fig 3 Momentum distribution of Δ^{++} baryons in direct decays of the $\Upsilon(1S)$ resonance Statistical and systematic errors are added in quadrature The histogram is the prediction of the Lund model normalized to the data in the region below 2 GeV/c

fits well in the pattern observed with the other octet and decuplet baryons

It is a pleasure to thank U Djuanda, E Konrad, E Michel, and W Reinsch for their competent technical help in running the experiment and processing the data We thank Dr H Nesemann, B Sarau, and the DORIS group for the excellent operation of the storage ring The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them

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