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SEARCH FOR PENTAQUARK STATES IN Z DECAYS

THE ALEPH COLLABORATION
PRESENTED BY PETER HANSEN
The Niels Bohr Institute
Blegdamsvej 17, DK-2100 Copenhagen O
E-mail: phansen@nbi.dk

Exotic hadrons made of five quarks (pentaquarks) are searched for in hadronic Z decays collected by the ALEPH detector at LEP. No significant signal for such hadrons is observed and 95% C.L. upper limits are set on their production rates in Z decays.

1 Introduction

Exotic baryons made of four quarks and an anti-quark have been reported by a number of experiments [1-11]. Here they are searched for in the fragmentation of quarks from four million hadronic Z decays recorded by the ALEPH experiment during the LEP 1 operation in the years 1991 to 1995. In the following, any reference to a hadronic system, such as pK^+, implicitly includes its charge-conjugate state, $\bar{\mathrm{p}}\mathrm{K}^-$ in this case.

2 Search for narrow resonances in the pK system

The $\Theta(1535)^+$ was searched for as a narrow peak in the invariant mass of combinations of a reconstructed K^0_S and a proton track, selected using the $\mathrm{d}E/\mathrm{d}x$ measurement in the ALEPH TPC [12]. The selection retains 480 000 combinations with a pK^0_S purity of 50%. The mass resolution was deduced from width measurements of various known resonances to be smaller than $5\,\mathrm{MeV}/c^2$. The $\Theta(1535)^+$ resonance was then searched for in the following way. First, the mass distribution was fitted by the function

$$f(M) = a_1(M - M_{\mathrm{thr}})^{a_2}\exp(a_3 M), \qquad (1)$$

An excess with respect to the fit was searched for in a 20-MeV/c^2-wide window sliding from 1500 to $1600\,\mathrm{MeV}/c^2$. (This sliding window is excluded from the fit.) The largest excess was found in the window between 1540 and $1560\,\mathrm{MeV}/c^2$, amounting to 49 above a fitted background of 3240 combinations. The 95% C.L. upper limit on the excess was determined by toy experiments to be 151 combinations in the mass window. Folding in the selection efficiency of $6.3 \pm 0.2\%$, the 95% C.L. upper limit on the production rate times branching ratio of the $\Theta(1535)^+$ and its antiparticle per hadronic Z decay is found to be

$$N_{\Theta(1535)^+} \cdot \mathrm{BR}(\Theta(1535)^+ \to \mathrm{pK}^0_\mathrm{S}) < 6.2 \times 10^{-4}.$$

The $\Theta^+ \to \mathrm{pK^0_S}$ branching ratio is expected to be 25% from Ref. [7] and isospin arguments, which yields the upper limit on the production rate of

$$N_{\Theta(1535)^+} < 0.0025.$$

A cross check was performed with a search for doubly-charged ($\mathrm{pK^+}$) and neutral ($\mathrm{pK^-}$) combinations. No resonance structure is observed in the mass distribution of the doubly-charged pK combinations. In the neutral pK combinations, however, a clear resonance activity is visible in the mass range 1460 to 1800 MeV/c^2, with a narrow peak due to the $\Lambda(1520)$ and a broad enhancement from many Σ^* resonances. A simultaneous fit to the amplitude of eight possible NK resonances [15] results in a $\Lambda(1520)$ contribution of $2874 \pm 320 \pm 270(syst)$ combinations.

With an average $\mathrm{pK^-}$ selection efficiency of $9.7 \pm 0.9\%$ and a $\Lambda(1520) \to \mathrm{pK^-}$ branching fraction of 22.5% [15], the production rate per hadronic Z decay of $\Lambda(1520)$ is found to be

$$N_{\Lambda(1520)} = 0.033 \pm 0.004 \pm 0.003,$$

in agreement with earlier measurements from OPAL [16] and DELPHI [17]. The resulting 95% C.L. upper limit on the ratio of the Θ^+ to the $\Lambda(1520)$ production in Z decays is

$$\frac{N_{\Theta(1535)^+} \cdot \mathrm{BR}(\Theta(1535)^+ \to \mathrm{pK^0_S})}{\mathrm{N}_{\Lambda(1520)}} < 0.027,$$

if the $\Lambda(1520)$ production is fixed to the average value of the three measurements at LEP, i.e., 0.024 ± 0.002 per hadronic Z decay.

3 Search for narrow resonances in the $\Xi\pi$ system

A sample of 3450 $\Xi^- \to \Lambda\pi^-$ decays was reconstructed in the detector within $\pm 7\,\mathrm{MeV}/c^2$ of the Ξ^- mass. This sample has a purity of 76%. Each Ξ candidate was combined with a charged pion to produce the mass spectra of the doubly-charged and neutral combinations.

The mass resolution is estimated to be $6\,\mathrm{MeV}/c^2$ from a simulation of the $\Xi(1530)^0$. The narrow resonance observed by NA49 [10] at $1862\,\mathrm{MeV}/c^2$ is searched for in a 25-MeV/c^2-wide mass window around this mass value. The number of $\Xi^-\pi^-$ combinations in this window amounts to 8 ± 15 in excess of a linear background fit. The 95% C.L. upper limit on a signal from a narrow resonance is evaluated to be 24 combinations in the window.

In the neutral channel ($\Xi^-\pi^+$), the data are described by Eq. 1 with a Breit-Wigner superimposed, centred at $1530\,\mathrm{MeV}/c^2$. An excess of 32 ± 16 is found in the same window, leading to the following 95% C.L. upper limits on the $\Xi(1862)$ production rate in hadronic Z decays:

$$N_{\Xi(1862)^{--}} \cdot \mathrm{BR}(\Xi(1862)^{--} \to \Xi^-\pi^-) < 4.5 \times 10^{-4},$$
$$N_{\Xi(1862)^0} \cdot \mathrm{BR}(\Xi(1862)^0 \to \Xi^-\pi^+) < 8.9 \times 10^{-4}.$$

In the neutral combinations, a clear $\Xi(1530)^0$ peak is observed leading to a $\Xi(1530)^0$ production rate per hadronic Z decay of

$$N_{\Xi(1530)^0} = (77 \pm 8 \pm 6) \times 10^{-4},$$

in good agreement with published ALEPH [14] and OPAL results [16]. The world average value of the $\Xi(1530)^0$ production rate, $(55 \pm 5) \times 10^{-4}$ allows 95% C.L. upper limits to be derived on the ratios:

$$N(\Xi(1862)^{--} \to \Xi^-\pi^-)/N(\Xi(1530)^0) < 0.082,$$
$$N(\Xi(1862)^{0} \to \Xi^-\pi^+)/N(\Xi(1530)^0) < 0.16.$$

4 Search for narrow resonances in the pD system

High-purity samples of D^0 and D^{*+} and a 50% pure sample of D^+ were selected using $\mathrm{d}E/\mathrm{d}x$ particle identification and requiring a detached secondary vertex. On top of these selection criteria, D^0 and D^+ candidates were required to have momenta in excess of 7 and 14 GeV/c, respectively. Each $\mathrm{D}^{(*)}$ candidate was paired in turn with each proton candidate in the event. The resulting pD mass resolution was found to be about 3 MeV/c^2. The $\Theta_c(3100)^0$ signal observed by H1 [11] with a Gaussian σ of 12 ± 3 MeV/c^2. A window of width 40 MeV/c^2 should therefore be adequate to cover any related enhancement.

The H1 experiment observed a signal in the pD^{*-} channel. In this channel, only three combinations are observed with an invariant mass between 3080 and 3120 MeV/c^2, with 5.5 ± 0.5 combinations expected from a fit of Eq. 1 to the simulated background. The total background rate is normalized to data. In the pD^- channel, which was not covered by H1, the mass window is slid from threshold to 3120 MeV/c^2. The most significant excess occurs in the mass window from 3080 to 3120 MeV/c^2 where 21 combinations are observed, with 17.5 ± 1.0 expected from the fit to the simulated background.

Channels with a charge different from that of the H1 signal were also searched for an enhancement. In the pD^+ channel 24 combinations with an expected background of 10.2 ± 0.5 in a 20-MeV/c^2-wide mass interval around 3140 MeV/c^2. The probability for accidentally observing an enhancement of such significance in any charge combination at any mass below 3.3 GeV/c^2 is 5%.

With a reconstruction efficiency of 0.046 ± 0.004 (0.011 ± 0.001) and a visible branching ratio of 0.0259 ± 0.0006 (0.091 ± 0.006) for the pD^{*-} (pD^-) channel, upper limits on the $\Theta_c(3100)$ production rate are set at

$$N_{\Theta_c(3100)^0} \cdot \mathrm{BR}(\Theta_c(3100)^0 \to \mathrm{D}^{*-}\mathrm{p}) < 6.3 \times 10^{-4},$$
$$N_{\Theta_c(3100)^0} \cdot \mathrm{BR}(\Theta_c(3100)^0 \to \mathrm{D}^{-}\mathrm{p}) < 31 \times 10^{-4}.$$

The 95% C.L. upper limit on the ratio of $\Theta_c(3100)^0$ to the D^* and D production in hadronic Z decays is

$$\frac{N_{\Theta_c(3100)^0}}{N_{\mathrm{D}^{*-}}} \cdot \mathrm{BR}(\Theta_c(3100)^0 \to \mathrm{D}^{*-}\mathrm{p}) < 0.0031,$$
$$\frac{N_{\Theta_c(3100)^0}}{N_{\mathrm{D}^-}} \cdot \mathrm{BR}(\Theta_c(3100)^0 \to \mathrm{D}^-\mathrm{p}) < 0.018.$$

if the D^* and D meson production is fixed to the world averages [15].

5 Conclusions

No evidence for exotic narrow baryon resonances has been found in the $\mathrm{e}^+\mathrm{e}^- \to \mathrm{Z} \to \mathrm{q\bar{q}}$ reactions collected by ALEPH during the LEP 1 running period. Upper limits at the 95% confidence level have been set on the production rates per hadronic Z decay of the resonances reported by other experiments.

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