Observation of Ω^- Production in e^+e^- Annihilation at 29 GeV

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Inclusive Ω^- production in e^+e^- annihilation at 29 GeV has been measured with the Mark II detector. From an integrated luminosity of 207 pb^{-1}, we determine a production rate of $0.014 \pm 0.006 \pm 0.004$ $\Omega^-,\overline{\Omega}^+$ per hadronic event. This is roughly 35 times the Lund-model prediction of 0.0004 $\Omega^-,\overline{\Omega}^+$ per hadronic event, but comparable to the Webber-model prediction of 0.006 $\Omega^-,\overline{\Omega}^+$ per hadronic event. The large rate of Ω^- production, compared with production rates for other baryons, and with theoretical predictions based on diquark models, indicates that spin suppression does not hold for Ω^- production.

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Baryon production is one of the least understood processes of hadronization in e^+e^- collisions. Comparison of production rates for baryons of different flavors and spins can provide clues regarding the nature of the parton fragmentation process. The Ω^- has strangeness -3 and spin $\frac{3}{2}$. Since it is the only example of a weakly decaying baryonic quark configuration whose ground state is not spin $\frac{1}{2}$, its production rate yields information which can be used to separate the processes of strangeness suppression and spin suppression in baryon production.[1] Since it is relatively long lived, it is possible to isolate a fairly clean sample. We present here a measurement of inclusive $\Omega^-,\overline{\Omega}^+$ production in e^+e^- collisions at a center-of-mass energy $E_{\text{c.m.}}$ of 29 GeV. In the following, we refer to both Ω^- and $\overline{\Omega}^+$ as Ω^- unless stated otherwise.

The measurement is based on an integrated luminosity of 207 pb^{-1} accumulated over a period of 3 yr by the Mark II detector at the SLAC storage ring PEP. The detector is described elsewhere.[2] Charged particles are tracked in a sixteen-layer cylindrical drift chamber and a seven-layer precision drift chamber in a 2.3-kG magnetic field. Momenta p (GeV/c) are measured with a resolution of $\delta p/p = [(0.010p)^2 + (0.025)^2]^{1/2}$.

Hadronic events are selected by a loose set of cuts. Only events with at least four reconstructed charged particles with a total charged plus neutral measured energy of at least 8 GeV are used in the analysis. The sample contains some contamination from $\tau^+\tau^-$ pair production, two-photon processes, and beam-gas interactions. However, Ω^- production from these sources is expected to be negligible.

Tracks used in the Ω^- search are required to meet the following quality and acceptance-defining criteria: a momentum transverse to the beam of at least 70 MeV/c, a polar angle θ with $|\cos\theta| < 0.80$, at least nine hits in the tracking chambers, and a track-fit χ^2 per degree of freedom less than 12. Oppositely charged track pairs which are consistent with γ conversions to e^+e^- pairs are removed.[3]

Ω^- candidates are found by searching for the decay chain $\Omega^- \rightarrow \Lambda K^-$, $\Lambda \rightarrow p\pi^-$. Λ candidates are selected by finding vertices for all oppositely charged track pairs in the plane perpendicular to the beam (the x-y plane). The higher-momentum particle in each pair is assumed to be the proton. This assignment is always correct for Λ with momenta over 250 MeV/c. Pairs which meet the following requirements are considered to be Λ candidates: (1) The distance from the reconstructed decay vertex to the center of the interaction region in the x-y plane must be greater than 10 mm. (2) The π must have a distance of closest approach to the interaction region of greater than 1 mm. (3) The proton must have a distance of closest approach to the interaction region of greater than 0.6 mm. (4) At their x-y vertex, the two tracks must have a z difference of less than 4 cm. (5) The angle between the Λ momentum vector and the line between the reconstructed Λ decay point and the interaction region in the x-y plane must be less than 9°. For secondary Λ from Ω^- decays, this angle is a few degrees, because the Ω^- decay effectively puts a kink in the Λ flight path. This cut removes combinatorial background, while retaining most real Λ. (6) Λ candidates with momenta less than 500 MeV/c are eliminated.

These requirements are fairly loose, and designed to maximize the yield of detected Λ from Ω^- decay. The proton and π momenta are adjusted to compensate for dE/dx loss in the beam pipe and the two tracks are constrained in a three-dimensional vertex fit. For Λ candidates with momenta p_Λ less than 2 GeV/c, the calculated mass is required to be within 5 MeV/c^2 of the actual Λ mass. For candidates with momenta more than 2 GeV/c, the calculated mass is required to be within 4 MeV/c^2 $+0.5p_\Lambda$ of the actual Λ mass, where p_Λ is in GeV/c. The resulting signal is 1460 ± 60 Λ over a background of 1088 ± 33. The peak is centered at the Λ mass and has a full width at half maximum of 8 MeV/c^2.

Each Λ candidate is paired with every negatively charged track, assumed to be a kaon, to form an Ω^- candidate. A two-dimensional line-circle intersection is made between the straight Λ track and the curved kaon track, in the x-y plane. For each Ω^- candidate, the distance in the x-y plane from the reconstructed decay point to the interaction region must be greater than 5 mm. The kaon must have a distance of closest approach to the interaction region of greater than 0.6 mm. At the x-y intersection point, the Λ and the kaon z coordinates must agree within 2.5 cm. Ω^- candidates are required to have a momentum of at least 750 MeV/c. The angle between the line connecting the reconstructed Ω^- vertex and the interaction region, and the Ω^- momentum vector as projected back to the origin must be less than 7°. To reduce the combinatorial background, the decay angle θ^*, of the Λ in the Ω^- rest frame, measured with respect to the Ω^- direction has to satisfy $|\cos(\theta^*)| < 0.9$.

Since $\Omega^- \rightarrow \Lambda K^-$ and $\Xi^- \rightarrow \Lambda\pi^-$ decays are kinematically similar, Ω^- candidates are tested against the Ξ^- hypothesis by our assigning the kaon track a pion mass. Candidates which give a mass within 10 MeV/c^2 of the nominal Ξ^- mass are eliminated.

The masses of the resulting ΛK^- combinations are shown in Fig. 1. The observed peak is centered at the Ω^- mass, with a full width at half maximum of roughly 16 MeV/c^2, consistent with the Monte Carlo predictions.

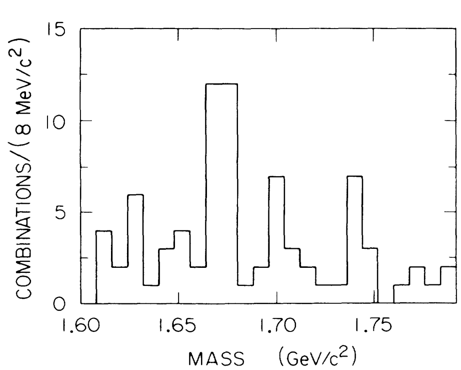

FIG. 1. Invariant mass spectra for ΛK^-,$\bar{\Lambda}K^+$.

Studies of the wrong-sign (ΛK^+) combinations and Monte Carlo simulations showed that non-Ω^- sources do not produce a fake Ω^- peak.

The Ω^- signal regions were chosen within 8 MeV/c^2 of the nominal Ω^- mass. Background regions were chosen centered 40 MeV/c^2 above and below the nominal Ω^- mass. Each is 32 MeV/c^2 wide, giving a total background width 4 times the signal-region width. This reduces the statistical error on the background evaluation.

These cuts leave a signal of 16 ± 5 Ω^- over a background of 7 ± 2 (statistical errors only). No events appear twice in the peak area. There are five Ω^- and eleven $\bar{\Omega}^+$ over roughly equal backgrounds.

The efficiency for detection of Ω^- decays is estimated by Monte Carlo simulation. The Monte Carlo program includes the effects of multiple scattering, nuclear absorption, and drift chamber inefficiency. At 750 MeV/c, the efficiency for Ω^- detection is roughly 0.5%, rising to 2.3% around 3 GeV/c, then dropping to 1% at 6 GeV/c and 0.7% above 7 GeV/c. Since the Monte Carlo momentum spectra do not match the data, the data were divided into 0.25-GeV/c momentum bins and corrected for efficiency on a bin-by-bin basis. At low momenta, the particles do not travel far enough to pass the minimum decay-distance requirement, while at high momenta the three tracks are poorly separated, and the Λ may decay so far from the origin that its daughter particles cannot be tracked. Uncertainties in the Monte Carlo efficiency calculation are the dominant sources of systematic error. The largest contributions are from uncertainties in the drift-chamber efficiency and the track-finding efficiency.

The radiatively corrected inclusive cross section for Ω^- production versus x is shown in Fig. 2, where $x=2E/E_{\mathrm{c.m.}}$ and E is the baryon energy. Shown are the Mark II data for Ω^- (solid dots), Ξ^- (squares),[4] and Λ (triangles).[5] The Ω^- spectrum appears softer than the Ξ^- or Λ spectra. This could indicate that a larger percentage of the Ω^- are produced directly from fragmentation, and fewer come from heavy-quark decays.

Figure 3 compares the Ω^- spectrum with the predictions of the Lund string model (solid line)[6] and the Webber cluster model[7] (dotted line). Both Monte Carlo simulations predict harder spectra than the data indicate; the Webber prediction is slightly softer than the Lund.

Measurement of the total cross section for Ω^- production requires an extrapolation for Ω^- with momenta below 750 MeV/c. Unfortunately, neither Monte Carlo program reproduces the momentum spectrum in the observed region. The Lund model predicts that 7% of the Ω^- should have momenta below 750 MeV/c, while the Webber model predicts 11%. An extrapolation to zero from the first point in Fig. 3 leads to a prediction of 11%. Thus, we estimate that $11\% \pm 4\%$ of Ω^- have a momen-

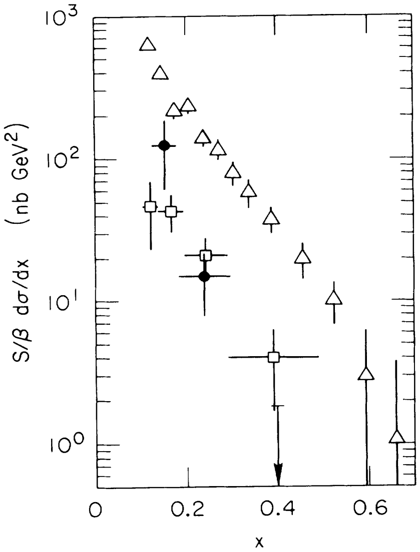

FIG. 2. Cross section for inclusive Ω^- production. The circles are Ω^- data; the squares are the corresponding data for Ξ^- production, and the triangles are the data for Λ production. The point at $x=0.39$ is an upper limit for Ω^-.

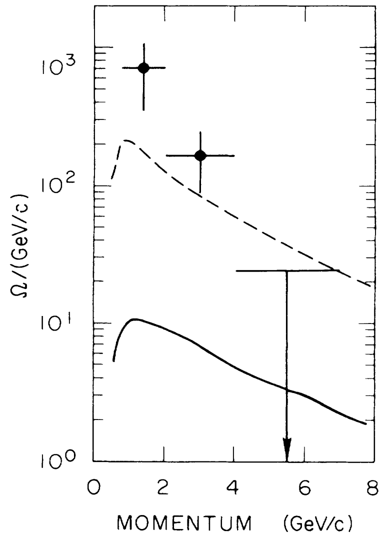

FIG. 3. Ω^- momentum spectrum, compared with the predictions of the Lund string model (solid line) and the Webber cluster model (dotted line). The 4–7-GeV/c point is an upper limit.

tum of less than 750 MeV/c^2.

From this, we find a total radiatively corrected Ω^- production cross section of $5.8\pm2.5\pm1.4$ pb, equivalent to $0.014\pm0.006\pm0.004$ Ω^- per hadronic event. This is roughly half the TPC Collaboration's measurement[8] of 0.027 ± 0.017 Ω^- per hadronic event, but compatible within the errors. The Ω^- production rate, combined with other Mark II measurements, leads to the ratios $\Omega^-:\Xi^{*0}:\Xi^-\Lambda$ of $0.07\pm0.03:<0.03:0.08\pm0.02:1.0$, where the Ξ^{*0} upper limit is at a 90% confidence level.

Figure 4 shows these baryon production rates as functions of strangeness. The line is a fit to the spin-$\frac{1}{2}$ baryon data: the proton, Λ, and Ξ^-. It shows that the Ω^- production is comparable to what would be expected for a hypothetical strangeness -3, spin-$\frac{1}{2}$ baryon. In contrast, a simple diquark model[11] predicts that spin-$\frac{3}{2}$ baryon production should be heavily suppressed.

This spin suppression is implemented in the Lund model, which predicts just 0.0004 Ω^- per hadronic event, a factor of 35 below what the data show. This prediction is obtained with standard parameters for the model: The strange-quark suppression factor P_s is 0.3; the diquark suppression factor P_{qq} is 0.09; the strange-diquark extra suppression factor P_{qs} is 0.35; the spin-1-diquark suppression factor P_1 is 0.05; and the "popcorn" factor is 0.0.[12] By adjustment of these parameters, it is possible to improve the fit to the Ω^- data. However, to get a reasonable fit, one must raise P_1, leading to overproduction of the other spin-$\frac{3}{2}$ baryons. For example, raising P_{qs} to 1.0, the popcorn rate to 0.5, and P_1 to 0.3 increases the Ω^- production rate to 0.003 Ω^- per hadronic event, much closer to the data. However, it also increases Ξ^{*0} production to an unacceptably high 0.009 Ξ^{*0} per hadronic event, and gives high rates for other strange and spin-$\frac{3}{2}$ baryons. By its structure, the Lund model requires an $\Omega^-:\Xi^{*0}$ ratio less than P_s, while the data show a ratio at least 3 times as high. P_s is well constrained by measurements of the kaon-to-pion ratio.

A similar Ω^- excess has also been seen in hadronic production.[13] Based on one event, the measured $\bar{\Omega}^+$ production in 70-GeV/c K^+p collisions is 20 times larger than the Lund-model prediction. When three strange

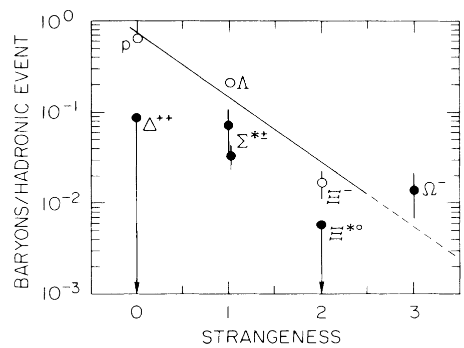

FIG. 4. Baryon production rates as a function of strangeness. The filled circles denote spin $\frac{3}{2}$, while the open circles denote spin $\frac{1}{2}$. The Δ^{++} and Ξ^{*0} points are upper limits. The Λ, Ξ^-, and Ξ^{*0} data are from Mark II, while the proton point is an average taken from the compilation in Ref. 1. The Δ^{++} upper limit is taken from Ref. 9, while the upper and lower $\Sigma^{*\pm}$ points are from Refs. 8 and 10, respectively. The line is a fit to the spin-$\frac{1}{2}$ data points.

quarks combine to form an Ω^-, they appear to be able to do so without being heavily suppressed because of the baryon spin.

In contrast to the Lund model, the Webber model bases baryon production rates solely on mass effects. It predicts 0.006 Ω^- per hadronic event, in marginal agreement with the data. However, it predicts twice as many Ξ^- as are observed, and three times as many Ξ^{*0} as the upper limit.

To summarize, we have measured Ω^- production in e^+e^- collisions at 29 GeV and observed a signal of 16 ± 5 events. The inclusive Ω^- production rate is $0.014 \pm 0.006 \pm 0.004$ Ω^- or $\overline{\Omega}^+$ per hadronic event. The Ω^- are produced with a softer spectrum than other strange baryons.

The measured Ω^- production rate is about what diquark models predict for a hypothetical spin-$\frac{1}{2}$ strangeness -3 baryon. The spin suppression expected for spin-$\frac{3}{2}$ baryon production does not seem to be operative in Ω^- production.

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