Production of Strange Baryons in e^+e^- Annihilations at 29 GeV

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The production of strange baryons $\Sigma^{\pm}(1385)$ and Ξ^- has been observed in e^+e^- annihilations at 29 GeV center-of-mass energy, by use of data obtained with the High Resolution Spectrometer at the SLAC storage ring PEP. The total mean multiplicities are measured to be $\langle n_{\Sigma^{\pm}(1385)}\rangle = 0.033 \pm 0.006 \pm 0.005$ and $\langle n_{\Xi^-}\rangle = 0.016 \pm 0.004 \pm 0.004$ per hadronic event. The results are in good agreement with the Lund string model.

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The copious production of baryons in high-energy e^+e^- annihilations and the similarity of their momentum distributions to those of mesons is interesting, when we consider that baryons are thought to be produced through different and more complicated processes. Models that range from the simple phase-space breakup of colorless clusters formed by QCD parton showers to the formation of localized diquarks in a color field have been proposed to explain the parton fragmentation into baryons. The Lund model,[1] in particular, uses a color-string diquark scheme for baryon production which requires several arbitrary parameters such as the diquark-to-quark ratio, the strange-to-nonstrange diquark ratio, and the spin-1-to-spin-0 diquark ratio. These parameters are determined from the production measurements of various classes of baryons.

In this Letter we report measurements of the inclusive production of the strange baryon $\Sigma^{\pm}(1385)$ and the doubly strange baryon Ξ^-. The particles are observed through their $\Lambda\pi$ decay mode, where the Λ is identified by its weak $p\pi^-$ decay. For simplicity, particle symbols are used to represent both particles and antiparticles. The data sample used for this analysis corresponds to an integrated luminosity of 300 pb^{-1} collected with the High Resolution Spectrometer (HRS) at the SLAC 29-GeV e^+e^- storage ring PEP.

The HRS detector is equipped with a tracking device that consists of seventeen cylindrical drift layers, as well as a lead-scintillator shower counter. The detector is contained in a 16.2-kG solenoidal magnetic field which provides excellent momentum resolution for the charged tracks over 90% of the solid angle. A detailed description of the detector and the selection procedures for the hadronic events have been reported elsewhere.[2]

A clean sample of hadronic events with high-quality tracks were used in this analysis. Each event was required to have a total sum of visible charged and neutral energy of at least 10 GeV. Events with fewer than five reconstructed charged tracks were rejected. In all remaining events, tracks were removed from this analysis if they failed to register in more than 60% of the drift-chamber layers available to them, or if they formed an angle (θ) with respect to the beam direction with $|\cos\theta| > 0.9$. Finally, it was required that the momentum of the tracks transverse to the beam exceed 0.125 GeV/c.

The selection of the Λ candidates has already been reported in detail.[3] Briefly, the long-lived decays $\Lambda \to p\pi^-$ were identified by the requirement that the two decay tracks intersect in a plane perpendicular to the beam axis (x-y plane) at a radial distance of at least 1.5 cm and pass within 2.0 cm of each other along the z axis

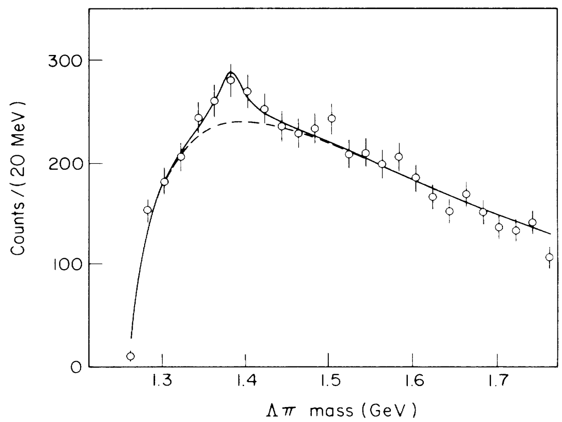

FIG. 1. Invariant-mass spectrum for $\Lambda\pi$ combinations. The solid curve is the result of a fit which includes a Breit-Wigner resonance and a smooth background (dashed curve).

at the intersection point. The reconstructed momentum vector of the neutral system was required to pass within 0.3 cm of the primary-event vertex in the x-y plane. The surviving candidates were fitted by a three-dimensional secondary vertex and events with $\chi^2 < 10$ were accepted. In the above analysis the track with the higher momentum was assumed to be the proton, and therefore the sign of its electric charge was used to distinguish Λ and $\bar{\Lambda}$. These selection criteria produced exceptionally narrow peaks in the $p\pi$ mass spectra (m), corresponding to 1218 Λ and 1150 $\bar{\Lambda}$ events above a low background.[3] All combinations with $|m - 1.1156| < 0.005$ GeV were assigned the Λ mass of 1.1156 GeV.[4]

The production of the $\Sigma^{\pm}(1385)$ was searched for by combination of the Λ with an additional charged track assumed to be a pion. Since the process $\Sigma^{\pm}(1385) \to \Lambda\pi^{\pm}$ is a strong decay, the additional charged track was required to originate from the interaction point. The combinatorial background was reduced by the requirements that (i) the cosine of the angle between the charged track and the Λ direction of flight be greater than 0.6, (ii) $\cos\theta^* > -0.7$ where θ^* is the pion decay angle in the $\Lambda\pi$ rest frame. This cut reduces the high combinatorial background observed for decays with the pion produced backwards in the $\Lambda\pi$ rest frame. The remaining combinations with fractional momentum $0.1 < x < 0.8$ ($x = p/p_{\text{beam}}$) were accepted. This selection removes the high combinatorial background that exists at small x because of the large number of low-momentum tracks. The high-x limit is imposed because of the very small number of events with $x > 0.8$.

In the $\Lambda\pi$ invariant-mass plot shown in Fig. 1, a clear enhancement around the $\Sigma^{\pm}(1385)$ mass is evident. This mass spectrum was fitted with contributions from a relativistic Breit-Wigner shape corresponding to the $\Sigma^{\pm}(1385)$ signal, with the mass and width fixed to the known values[5] and a smooth curve representing the background. The shape of the background, which is represented in the figure by the dashed curve, was calculated by our repeating the above analysis with Λ candidates replaced by the sidebands of the Λ peaks. The shape of the background was then parametrized by fitting of the resulting mass spectrum with an empirical function.[6] As a result of this fitting procedure 159 ± 42 $\Sigma^{\pm}(1385)$ events were found. This fit was repeated separately on the $\Lambda\pi^{\pm}$ and $\bar{\Lambda}\pi^{\pm}$ mass spectra, and gave 88 ± 41 [75 ± 36] events in the $\Sigma^{\pm}(1385)$ [$\bar{\Sigma}^{\pm}(1385)$] signals.

The detection efficiencies were calculated by use of a sample of events generated by the Lund Monte Carlo program[7] and passed through a complete detector simulation. The observed number of $\Sigma^{\pm}(1385)$ events, after corrections for the efficiency and the known branching ratios of its decay chain, gave $0.024 \pm 0.006 \pm 0.004$ $\Sigma^{\pm}(1385)$ per hadronic event for fractional momentum $0.1 < x < 0.8$. According to the Lund model, 72% of the events are in this x region, and with this assumption a total multiplicity of $0.033 \pm 0.006 \pm 0.005$ $\Sigma^{\pm}(1385)$ per hadronic event is extrapolated. Table I compares our measurement of the $\Sigma^{\pm}(1385)$ rate with the less accurate time-projection-chamber (TPC) result[8] and the upper bound given by the TASSO collaboration.[9]

The search for Ξ^- production was performed by selection of its long-lived $\Lambda\pi^-$ decay mode. In events that contained a Λ candidate, an additional charged track was required to intersect the reconstructed flight path of the Λ in the x-y plane. Only charged tracks which missed the primary vertex by at least 0.2 cm were considered. The intersection point was required to occur at

TABLE I. $\Sigma^{\pm}(1385)$ and Ξ^- production rates measured by different collaborations (referenced in the text) in high-energy e^+e^- collisions, and the comparison with models. The parameters of the Lund model were set as explained in the text.

	Experiment[a]				Model	
	TPC	TASSO	MARK II	This experiment	Lund	Webber
$\Sigma^{\pm}(1385)$/event	0.06 ± 0.03	< 0.09		0.033 ± 0.008	0.032	0.113
$\Sigma^{\pm}(1385)/\Lambda$	0.32 ± 0.16	< 0.3		0.15 ± 0.04	0.16	0.35
Ξ^-/event	0.020 ± 0.009	0.026 ± 0.012	0.017 ± 0.006	0.016 ± 0.006	0.017	0.037
Ξ^-/Λ	0.101 ± 0.046	0.087 ± 0.042	0.08 ± 0.03	0.073 ± 0.028	0.08	0.115

[a]When both are given, the statistical and systematic errors are added in quadrature.

a minimum radial distance of 1.0 cm and at least 0.5 cm before the Λ vertex. At this intersection point, the Λ and the charged track were required to pass within 5.0 cm of each other along the z axis. By the assumption of a circular path in a 16.2-kG magnetic field, the momentum vector of the $\Lambda\pi^-$ system (in the x-y plane) was swum back towards the interaction point where it was required to come within 0.3 cm of the event vertex. In addition, it was required that $\cos\theta^* > -0.7$ and that the cosine of the angle between the charged track and the Λ direction of flight (at the intersection point) be greater than 0.6. The events consistent with $\Omega^- \to \Lambda K^-$, when a kaon mass was assigned to the charged track, were removed. All remaining candidates with fractional momentum $0.05 < x < 0.75$ were accepted.

Figure 2 shows the $\Lambda\pi$ invariant-mass plots both for correct- $(\Lambda\pi^- + \bar{\Lambda}\pi^+)$ and for wrong-charge-sign combinations $(\Lambda\pi^+ + \bar{\Lambda}\pi^-)$. A clear signal (solid histogram) around 1321 MeV corresponding to the Ξ^- decay is evident. In the wrong-sign mass plot (dashed histogram) no similar enhancement is observed. The width of the narrow peak is consistent with the mass resolution of 5 MeV obtained from the Monte Carlo simulations. From the number of wrong-sign combinations between 1280 MeV and 1360 MeV, we estimate 0.08 ± 0.03 background events per MeV under the Ξ^- signal. In Fig. 2 there are 15.4 ± 4.2 background-subtracted events within two standard deviations of the Ξ peak, of which 9.6 ± 3.5 (5.8 ± 2.8) correspond to the Ξ^- $(\bar{\Xi}^-)$ signal.

After corrections for the detector inefficiencies and analysis cuts, as well as the $\Lambda \to p\pi^-$ branching ratio, a multiplicity of $0.014 \pm 0.004 \pm 0.004$ Ξ^- per hadronic event for $0.05 < x < 0.75$ was found. From the Lund model, 12% of the events lie outside these boundaries. With this assumption, a total multiplicity of $0.016 \pm 0.004 \pm 0.004$ Ξ^- per hadronic event is obtained. This result is in agreement with the MARK II,[10] TASSO,[11] and TPC[12] measurements as shown in Table I. By combination of our result and the two other measurements at PEP (MARK II and TPC), a weighted average multiplicity of 0.017 ± 0.004 Ξ^- per hadronic event at 29 GeV is found. Our results for the $\Sigma^{\pm}(1385)/\Lambda$ and Ξ^-/Λ ratios shown in Table I are in reasonable agreement with the ARGUS data taken at 10-GeV center-of-mass energy.[13]

The fragmentation functions for $\Sigma^{\pm}(1385)$ and Ξ^- production were determined by repetition of the analysis for different x intervals.[14] The measured scaling cross sections are strong functions of the fractional energy $(Z = E/E_{\text{beam}})$, as shown in Fig. 3.[15]

In the Lund string model, the production of the octet baryon, Ξ^-, is controlled by the strange-diquark suppression parameter $[\delta = (us/ud)/(s/d)]$. The production of the decaplet $\Sigma^{\pm}(1385)$ has a weaker dependence on δ and is mainly governed by the spin-1 diquark suppression factor (α).[16] From inclusive Λ production, the parameter δ has been measured with values ranging from 0.2 to 0.89.[17] The PEP average multiplicity of 0.017 ± 0.004 Ξ^- per hadronic event leads to a value of 0.6 ± 0.15 for the δ parameter.[18] With $\delta = 0.6$ and $\alpha = 0.05$, the Lund model predicts 0.023 $\Sigma^{\pm}(1385)$ per hadronic event for $0.1 < x < 0.8$, compared with our measured value of $0.024 \pm 0.006 \pm 0.004$. The fragmentation functions of $\Sigma^{\pm}(1385)$ and Ξ^- are also consistent with the predictions of this model, as shown in Fig. 3.

The production rates of $\Sigma^{\pm}(1385)$ and Ξ^- are overpredicted by the Webber cluster model[19] as shown in Table I. In this model, the strange baryons are only suppressed because of their heavier masses in a phase-space breakup of colorless clusters formed by a QCD parton shower.

In summary, the production of strange baryons $\Sigma^{\pm}(1385)$ and Ξ^- in e^+e^- annihilations at 29-GeV center-of-mass energy has been observed. We obtain $0.024 \pm 0.006 \pm 0.004$ $\Sigma^{\pm}(1385)$ per hadronic event for fractional momentum $0.1 < x < 0.8$, and 0.014 ± 0.004

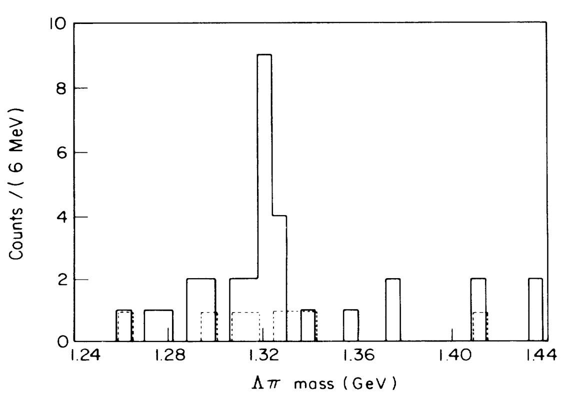

FIG. 2. Invariant-mass spectra for $\Lambda\pi^- + \bar{\Lambda}\pi^+$ (solid histogram) and $\Lambda\pi^+ + \bar{\Lambda}\pi^-$ combinations (dashed histogram).

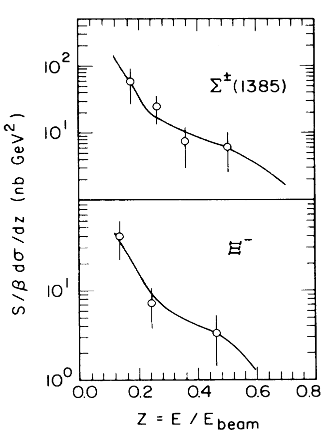

FIG. 3. Scaling cross sections for the production of $\Sigma^{\pm}(1385)$ and Ξ^- baryons. The antiparticles are included. The solid curves are predictions of the Lund string model.

± 0.004 Ξ^- per hadronic event for $0.05 < x < 0.75$. On the assumption that the shape of the momentum distributions is predicted by the Lund model, the total mean multiplicities for $\Sigma^{\pm}(1385)$ and Ξ^- are measured to be $0.033 \pm 0.006 \pm 0.005$ and $0.016 \pm 0.004 \pm 0.004$ per hadronic event, respectively. By the combination of our result and the two other existing Ξ^- measurements at PEP, a value of 0.6 ± 0.15 for the Lund-model strange-diquark suppression parameter is found. With this value, and a value of 0.05 for the spin-1 diquark parameter, the predictions of the Lund model agree well with our data.

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[1]B. Andersson *et al.*, Phys. Rep. **97**, 32 (1983).

[2]D. Bender *et al.*, Phys. Rev. D **30**, 515 (1984), and **31**, 1 (1985).

[3]P. Baringer *et al.*, Phys. Rev. Lett. **56**, 1346 (1986); M. Derrick *et al.*, Phys. Rev. D **35**, 2639 (1987).

[4]All particle parameters used in this analysis are taken from M. Aguilar-Benitez *et al.* (Particle Data Group), Phys. Lett. **170B**, 11 (1986).

[5]The average of the $\Sigma^+(1385)$ and $\Sigma^-(1385)$ masses and widths were used.

[6]We used the function $a_0(m-m_0)^{a_1}\exp(a_2m+a_3m^2)$, where the a_n's are free parameters and m_0 is the $\Lambda\pi$ mass threshold.

[7]T. Sjöstrand, Comput. Phys. Commun. **27**, 243 (1982).

[8]H. Aihara *et al.*, in *Proceedings of the International Europhysics Conference on High Energy Physics, Bari, Italy, July 1985,* edited by L. Nitti and G. Preparata (European Physical Society, Geneva, 1985).

[9]M. Althoff *et al.*, Z. Phys. C **26**, 181 (1984).

[10]S. R. Klein *et al.*, Phys. Rev. Lett. **58**, 644 (1987).

[11]M. Althoff *et al.*, Phys. Lett. **130B**, 340 (1983).

[12]H. Yamamoto, in *QCD and Beyond: Proceedings of the Hadronic Session of the Twentieth Recontre de Moriond,* edited by J. Tran Thanh Van (Editions Frontières, France, 1985).

[13]ARGUS results are $\Sigma^{\pm}(1385)/\Lambda = 0.099 \pm 0.011$ and $\Xi^-/\Lambda = 0.09 \pm 0.02$ in the continuum. See H. Albrecht *et al.*, Phys. Lett. B **183**, 419 (1987).

[14]The detector acceptance for the Σ is 4% at $x = 0.1$ and 10% at $x = 0.6$, and drops to 6% at $x = 0.8$. For the Ξ, it is 1% at $x = 0.1$, 2% at $x = 0.2$, and 1.5% at $x = 0.4$.

[15]The background under the $\Sigma^{\pm}(1385)$ drops faster with Z. Simple exponential fits to the background and signal as functions of Z gave a 40%-larger slope for the background shape.

[16]Other relevant parameters of the Lund model were taken as $s/u = 0.34$ and $qq/q = 0.078$. See Ref. 3 and M. Derrick *et al.*, Phys. Lett. **158B**, 519 (1985).

[17]These measurements assume different branching ratios for the $\Lambda_c \rightarrow \Lambda x$ decay. See Ref. 3 and M. Althoff *et al.*, Z. Phys. C **27**, 27 (1985); H. Aihara *et al.*, Phys. Rev. Lett. **54**, 274 (1985).

[18]With use of our Λ inclusive data, a value of $\delta = 0.89^{+1.45}_{-0.8}$ was reported in Ref. 3, where the $\Lambda_c \rightarrow \Lambda x$ branching ratio was taken to be 23%.

[19]B. R. Webber, Nucl. Phys. **B238**, 492 (1984).