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Asymmetry in the Angular Distribution of Inclusive Λ Baryons from e^+e^- Annihilations at $\sqrt{s} = 29$ GeV

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The forward-backward asymmetry A expected from the $\gamma - Z^0$ interference term in the process $e^+e^- \to q\bar{q}$ is observed in the lab production angular distribution of high momentum Λ baryons. The data were collected with the High Resolution Spectrometer at PEP and an integrated luminosity of 256 pb^{-1} at $\sqrt{s} = 29$ GeV was used in the analysis. The asymmetry is seen to increase with the fractional energy $z = 2E/\sqrt{s}$ of the Λ due to the decreasing presence of non-leading particles. The value obtained for Λ baryons with $z \geq 0.3$ is $A = -0.22 \pm 0.08 \pm 0.02$.

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DISCLAIMER

At the energies of the PEP and PETRA e^+e^- storage rings, virtual production of the Z^0 is an observably important process. Several experiments[1] have observed in both charm and bottom events the forward-backward asymmetry in lab production angle caused by the $\gamma - Z^0$ interference term in the process $e^+e^- \rightarrow q\bar{q}$. Similar asymmetries are expected from the lighter quarks u, d, and s, but these effects have not yet been measured. An indirect measure of this asymmetry can be made by studying the lab angular distribution of the light quark baryons. With baryons there is no confusion as to whether a leading particle comes from the quark or antiquark, as there would be with mesons. Non-leading baryons, of course, would not necessarily exhibit the asymmetry of the initial quark, so baryons with a large fractional energy $z = 2E/\sqrt{s}$ must be selected. The Λ baryon is a good choice for such a study because it is readily identifiable via its long-lived decay to $p\pi$ over a wide range of z values. Furthermore, at PEP energies, the Λ can be easily distinguished from its antiparticle ($\bar{\Lambda}$) because the proton must carry more momentum than the pion in the lab frame whenever the parent Λ has $z > 0.08$. Using the Lund fragmentation model[2] to estimate the effects of leading versus non-leading particles one predicts an asymmetry

$$A = \frac{F - B}{F + B} \approx -10\%$$

in the angular distribution of Λ baryons with $z \geq 0.3$.

The Λ events were selected from a large sample of data collected with the High Resolution Spectrometer (HRS) at the PEP e^+e^- storage ring. An integrated luminosity of 256 pb^{-1} at $\sqrt{s} = 29$ GeV, was used in the present analysis. The HRS detector[3] features a fifteen layer central drift chamber, with tracking layers spanning the radial distances from 21 to 103 cm, and covering 90% of 4π in solid angle, and a two layer outer drift chamber system at a radius of 190 cm, which covers 65% of 4π. Both chamber systems are contained within the 16.2 kG solenoidal magnetic field. The momentum resolution for tracks which pass through the outer drift chamber layers is $\sigma_p = 2 \times 10^{-3} p^2$ (GeV/c). Electromagnetic shower counters are also positioned within the magnet volume in both the barrel and endcap regions. These systems cover 62% and 27% of 4π, respectively. The energy resolution for the barrel system is $\sigma_E/E = 16\%/\sqrt{E}$ (E in GeV).

The selection of the hadronic data sample has been described elsewhere.[4] The cuts included the requirements of at least five charged tracks and a scalar sum of the momenta greater than 5.8 GeV/c. Events containing less than 7.0 GeV of charged particle energy were required to have a total energy (including the energy in the electromagnetic shower counters) of at least 8.0 GeV.

The decays $\Lambda \to p\pi^-$ were identified by selecting neutral track pairs coming from well separated secondary decay vertices. A three-dimensional secondary vertex was required to lie at a radial distance of between 1.5 and 75.0 cm from the primary interaction point, and the reconstructed neutral momentum was required to point back to within 0.2 cm of the origin. In making the mass assignments, the higher momentum of the two tracks is always interpreted as the proton. If the invariant mass is consistent with the K^0 mass when a $\pi^+\pi^-$ interpretation is used, the particle is rejected.[5] Events with a very high z Λ ($z_\Lambda \geq 0.6$) were removed if there was a track in the opposite hemisphere with a measured momentum of greater than 10 GeV/c. This cut removed background "lambdas" which would form in radiative bhabha events from one of the bhabha tracks plus one track from the converted photon. It was necessary to remove such events because this background is strongly asymmetric in lab production angle.

In order to measure the asymmetry, the data were divided into a forward region (F) and a backward region (B). The Λ baryons at $\cos\theta \leq (\geq)\ 0$ and the $\bar{\Lambda}$ antibaryons at $\cos\theta \geq (\leq)\ 0$ were binned in the F (B) region, where θ is measured relative to the incoming positron beam direction. A cut of $|\cos\theta| \leq 0.8$ was imposed to minimize the necessary acceptance correction to the signal. The resulting $\bar{p} - \pi$ mass peaks, for $x_\Lambda \geq 0.3$, are shown in Fig. 1a. for the forward region and Fig. 1b. for the backward region. The solid lines on the plots represent fits to the data of a Breit-Wigner form[6] on top of a polynomial background. The central value and width of the Breit-Wigner were fixed to $m = 1.1156$ GeV, the known Λ mass,[7] and $\Gamma = 6.3$ MeV, a resolution width determined from Monte Carlo reconstructions. The areas under the peaks yielded $F = 116.4 \pm 13.5$ and $B = 176.4 \pm 16.1$, giving an uncorrected asymmetry $A_{obs.} = -20.5 \pm 7.3\%$.

A correction factor κ must be applied where $A_{obs.} = A\kappa$. This correction arises due to the $|\cos\theta|$ cut and because the detector acceptance is not completely uniform within the measured $\cos\theta$ range. The acceptance function in the $|\cos\theta| \leq 0.8$ region is well parametrized by $\epsilon(\theta) = N(1 + \epsilon_0 \cos^2\theta)$. The relation between κ, ϵ_0, and the $|\cos\theta|$ cutoff x is given by:

$$\kappa = \frac{4x + 2\epsilon_0 x^3}{3 + (1 + \epsilon_0)x^2 + \frac{3}{5}\epsilon_0 x^4}.$$

The acceptance function was determined using hadronic events simulated in a Monte Carlo program. The resulting $\epsilon_0 = 0.6 \pm 0.3$, together with $x = 0.8$, yields $\kappa = 0.91 \pm 0.02$. The uncertainty in κ creates a systematic error of $\pm 0.4\%$

in the asymmetry. The other source of systematic error comes from the fit to the Λ peaks. By varying the functional form and the background subtraction technique, an estimate of $\pm 1.9\%$ is made for the error in A due to uncertainty in the calculation of the areas under the peaks. The asymmetry for $z \geq 0.3$ with full statistical and systematic errors is thus $A = -22 \pm 8 \pm 2\%$.

A similar procedure was followed for other cuts on the z of the Λ. For $z \geq 0.1$ the asymmetry is $A = -2.5 \pm 3.8 \pm 1.8\%$. For $z \geq 0.5\%$, $A = -17 \pm 26 \pm 10\%$.[8] The asymmetries for the three z cuts are shown together in Fig. 2. The solid curve in the figure represents the predictions of the Lund fragmentation model as a function of the z cut imposed on the Λ data.

We see from Fig. 2 that our data is in reasonable agreement with the Lund model[9] which gives flavors of the initial quarks in events containing a Λ with $z \geq 0.3$ of roughly 30% u, 30% s, 30% c, 8% d, and 2% b. In the standard model of the electroweak interactions,[10] the asymmetry of the charge $+\frac{2}{3}$ quarks should be -9.5% at $\sqrt{s} = 29$ GeV, and that of the $-\frac{1}{3}$ quarks exactly twice this amount. The measured values for c and b quarks have been in good agreement with this prediction. (For example, the HRS has measured $A = -14 \pm 5\%$ for charm.[11]) If the light quarks were not contributing to the Λ asymmetry at $z \geq 0.3$, one would expect $A \approx -3\%$ from the decays of charm and bottom baryons. This is clearly inconsistent with our measured value of $A = -22 \pm 8 \pm 2\%$, and we therefore conclude that the electroweak effects in light quark production have been observed.

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5. Further discussion of the Λ selection criteria can be found in: P. Baringer *et al.*, Phys. Rev. Lett. **56**, 1346 (1986).

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FIGURE CAPTIONS

1. Invariant mass spectra for neutral track pairs with a separated secondary vertex. The higher momentum track of the pair is interpreted as a p ($\bar{p}$), the lower as π^- (π^+). Cuts $|\cos\theta| \leq 0.8$ and $x \geq 0.3$ are imposed. (a) shows $p\pi^-$ pairs at $\cos\theta \leq 0$ and $\bar{p}\pi^+$ pairs at $\cos\theta \geq 0$. (b) shows $p\pi^-$ pairs at $\cos\theta \geq 0$ and $\bar{p}\pi^+$ pairs at $\cos\theta \leq 0$.

2. Forward-backward asymmetry A plotted against the cut imposed on the fractional energy x of the Λ data. The solid curve shows the prediction of the Lund model as a function of this x cut.

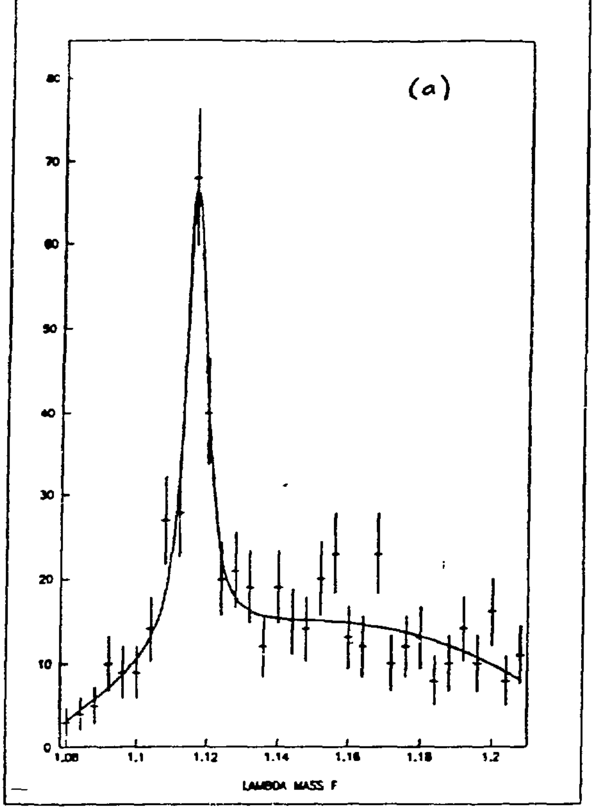
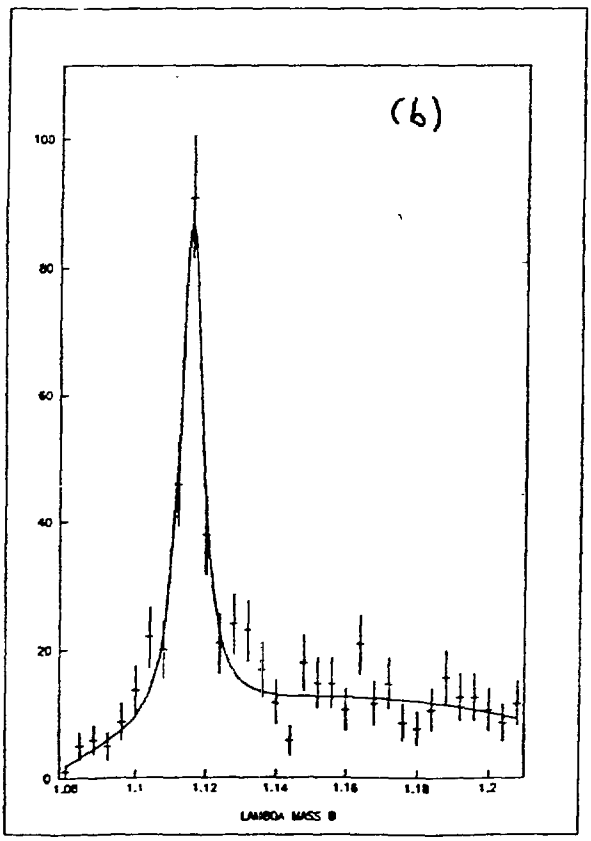


Figure 1



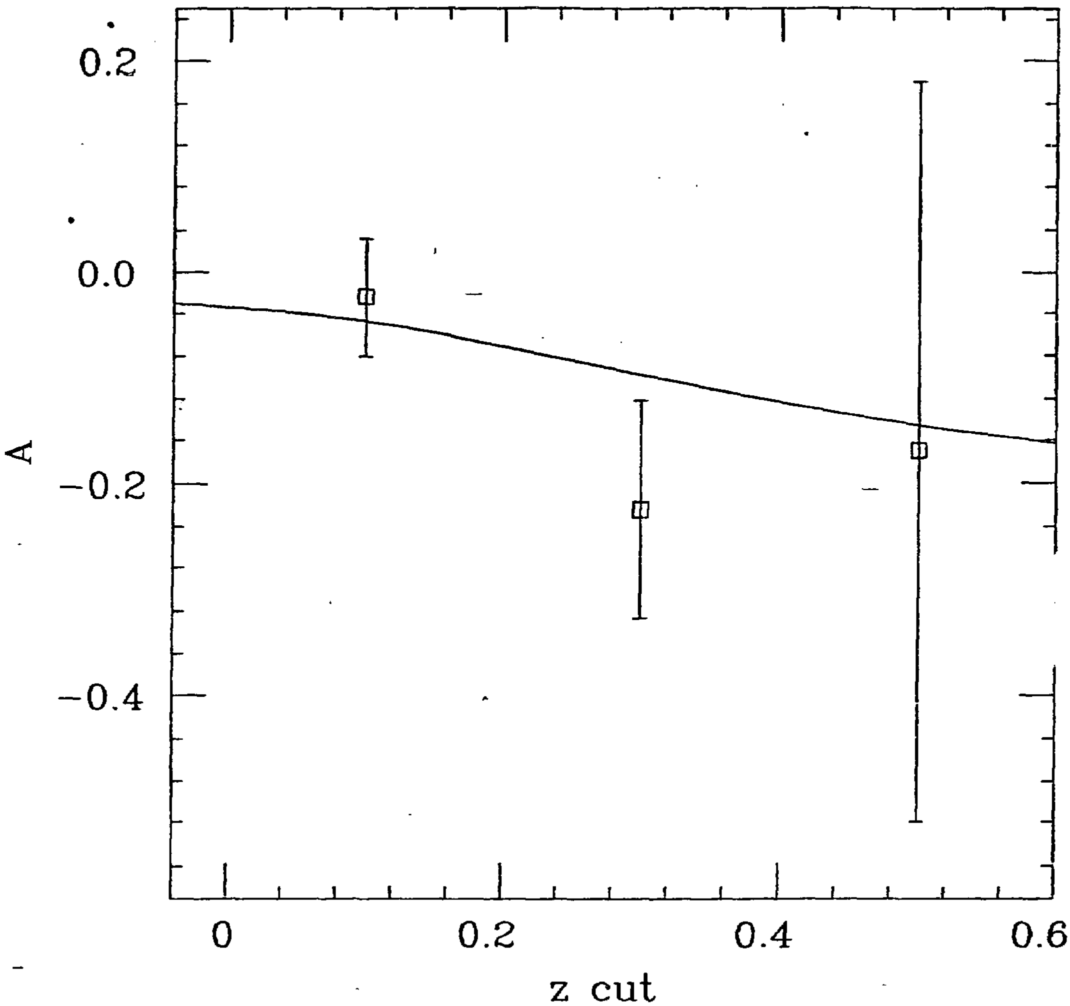


Figure 2