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# Results on baryon antibaryon correlations in $e^+e^-$-annihilation*

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**Abstract.** The correlations between $p\bar{p}$, $\Lambda\bar{\Lambda}$, $\Xi^-\bar{\Lambda}$ and $\Lambda(1520)\bar{\Lambda}$ baryons have been measured in $e^+e^-$ continuum events and in direct $\Upsilon$ decays. The observed correlations exclude the production of point-like diquark-antidiquark pairs as the dominant source of baryons. Information concerning angular momentum compensation follows from the observed $\Lambda(1520)\bar{\Lambda}$ correlation.

* *Dedicated to Prof. H. Schopper on the occasion of his 65. birthday*

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## 1 Introduction

Baryon production in $e^+e^-$ annihilation has been investigated by several experiments, mainly running at center-of-mass energies around 30 GeV [1]. These studies have been supplemented recently by an analysis of inclusive baryon production in a high statistics data sample obtained at energies in the $\Upsilon$ mass region, where production rates for most octet and decuplet hyperons [2] and the orbitally excited $\Lambda(1520)$ state [3] were obtained. The interest in this work lies in the unsettled question of the mechanism for baryon production in fragmentation processes.

In many fragmentation models, baryon production requires the somewhat ad hoc introduction of diquarks as additional partons [4]. From the diquark model one can expect strong correlations between baryon-antibaryon ($B\bar{B}$) pairs, a prediction which can be tested by analysing both kinematical and flavour correlations between such pairs. An alternative approach is to model baryon production via independently produced quarks generated by colour fluctuations in an one-dimensional colour flux-tube [5]. This model is usually referred to as the popcorn mechanism, since meson ($M$) production "between" the baryon and antibaryon ($BM\bar{B}$ configuration) is allowed, diminishing correlations between the baryons.

Both models are implemented in the Lund event generator [6], where an adjustable parameter $\rho = BM\bar{B}/(B\bar{B} + BM\bar{B})$ allows for a continuous variation between a pure diquark model ($B\bar{B}$ only) and a 100% $BM\bar{B}$ configuration. Experimentally, two approaches can be used to distinguish the models. The most direct method is to search for correlations in the quantum numbers of baryons and antibaryons. Unfortunately $p$ and $\Lambda$ baryons*, while most easily accessible to experiments, are largely the decay products of heavier baryon states [2], and therefore provide only indirect information on quantum number correlations. The situation is somehow better for kinematical correlation studies, since baryons originating from the decays of heavier states usually carry most of the mother particle's momentum due to their large mass.

Correlation studies have already been published by several experiments [7]. In comparison with model predictions most of these data favour a large "popcorn" contribution to baryon production. This result is qualitatively supported by an investigation of strangeness and spin suppression in inclusive production of heavier hyperon states [2]. No extra strangeness suppression was seen for baryons compared to the known $SU(3)$ breaking for mesons, and within the experimental errors spin and strangeness suppression were shown to be uncorrelated. Neither of these observations is naturally expected in a diquark model but they are consistent with predictions of baryon production from independent quarks. In this paper we report further evidence for a large popcorn contribution, through studies of both kinematical correlations of $p\bar{p}$ pairs, and quantum number correlations of $\Lambda\bar{\Lambda}$, $\Xi^-\bar{\Lambda}$ and $\Lambda(1520)\bar{\Lambda}$ pairs. It turns out that none of the measurements alone is able to give unique constraints to the models, and therefore physical interpretations require in most cases a more comprehensive view of different experimental results.

* References to a specific state are to be interpreted as also implying the charge conjugate state

## 2 Data analysis

The data were collected with the ARGUS detector on the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(4S)$ resonances and in the nearby continuum with integrated luminosities of 25.7, 29.3, 95.4 and 42.3 pb$^{-1}$, respectively. A detailed description of the detector, its trigger and particle identification capabilities can be found in [8].

The data were divided into two samples in order to allow for separate analyses of gluon and quark fragmentation. For the study of low statistics $\Xi^-\bar{\Lambda}$ and $\Lambda(1520)\bar{\Lambda}$ signals the $\Upsilon(4S)$ was treated as continuum and the $\Upsilon(1S)$ and $\Upsilon(2S)$ data were combined. For the higher statistic samples only $\Upsilon(1S)$ and continuum data were used, in order to avoid additional systematic uncertainties.

Multihadron events were selected by requiring at least 3 tracks from a reconstructed main vertex or 3 tracks, not necessarily pointing to a common vertex, but having more than a total of 1.7 GeV energy deposited in the shower counters. Charged tracks were selected by requiring that their momentum transverse to the beam direction be greater than 60 MeV/c, and restricting their polar angle to $|\cos\theta| < 0.92$. Particles assumed to originate from strong interaction processes were required to point within 7 standard deviations of the main vertex. The identification of charged particles was performed by measurements of the specific ionization loss ($dE/dx$) and of time-of-flight. Both measurements were combined into a normalized likelihood ratio. A given particle hypothesis was accepted if the corresponding likelihood value exceeded 5%.

$\Lambda$ hyperons were reconstructed by a secondary vertex fit. The flight direction of the $\Lambda$ candidate was restricted to $|\cos\theta| < 0.85$. Furthermore, only $p\pi^-$ combinations with a scaled momentum $x_p = p_\Lambda/p_{\max} > 0.1$ were considered, since the acceptance is small below this value. In order to reduce combinatorial background to the $\Lambda$ signal, the radial distance of the decay vertex, $R_{vx}$, from the beam line was restricted to the interval 4 cm $< R_{vx} <$ 40 cm. Converted photons were rejected by a cut on the opening angle between the proton and pion candidate, requiring $\cos(p, \pi^-) < 0.998$. To suppress $\Lambda$ particles from strangeness-exchange reactions in the inner detector material, the angle between the flight direction of the $\Lambda$ and the vector $\mathbf{d}$, connecting the main and the secondary vertex, had to satisfy $\cos(\mathbf{p}, \mathbf{d}) > 0.995$. This cut was not applied to $\Lambda$ particles used in the search of $\Xi^-$ hyperons, where the $\Lambda$ does not originate from the main vertex.

## 3 Transverse momentum correlations

Kinematical correlations between hadrons occur naturally due to the conservation of energy and momentum in an event. In the phenomenology of semi-classical string models transverse momenta of hadrons with respect to the string axis are compensated locally and are therefore especially suited for correlation studies. Longitudinal momenta, in contrast, are only globally conserved in the event and also depend strongly on the choice and parametrization of fragmentation functions [6]. Studies of the correlation between the transverse momenta $p_t$ of baryons and antibaryons are a sensitive test of the baryon production mechanism, since in a diquark model strong correlations should appear, whereas in the popcorn model transverse momenta can be compensated alternatively by mesons, leading to a weaker correlation in $p_t$ between the baryon/antibaryon pair.

For our analysis, $p\bar{p}$ pairs were selected separately in $\Upsilon(1S)$ and in continuum data samples. To reduce the number of background combinations, the cut on the likelihood of particle identification was raised to 30%. In addition proton candidates were selected in the momentum range 0.4–1.1 GeV/c. These restrictions result in unique proton identification, with negligible background [9].

A good knowledge of the jet direction is required for this approach, and the event thrust axis $\mathbf{t}$ was used for this purpose. The correlation between the reconstructed thrust axis and the jet axis $\mathbf{j}$ at $\sqrt{s} = 10$ GeV was checked by a Monte Carlo study using the Lund event generator version 6.2 [6]. For events containing more than 2 jets or radiative photons, we defined the jet axis as the direction of the most energetic parton in the event. A correlation coefficient $\alpha = \langle|\mathbf{t} \cdot \mathbf{j}|\rangle$ was then determined, where $\mathbf{t}$ and $\mathbf{j}$ are unit vectors. In the case of continuum-like events, a strong correlation, $\alpha = 0.88$, was obtained, while the 3-gluon topology of direct $\Upsilon$ decays gave a somewhat weaker correlation of $\alpha = 0.72$. Therefore in both cases a sizable correlation between $\mathbf{t}$ and $\mathbf{j}$ exists in comparison with the value $\alpha = 0.5$ resulting from random orientation.

To study the kinematic correlations of $p\bar{p}$ pairs, we calculate the angle, $\phi_t$, between the $p$ and $\bar{p}$ flight direction, $\mathbf{p}_t$, in the plane perpendicular to the thrust axis (event plane):

$$\phi_t = \arccos\left(\frac{\mathbf{p}_t(p) \cdot \mathbf{p}_t(\bar{p})}{|\mathbf{p}_t(p)| \cdot |\mathbf{p}_t(\bar{p})|}\right).$$

In this variable one would expect $p_t$ anti-correlations to appear as an enhancement at $\phi_t = 180°$. It should be emphazised that the angle $\phi_t$ is a variable that is to large extent independent of the fragmentation function and the average hadron $p_t$ chosen in the hadronization model. For a more detailed analysis, we also divided the selected $p\bar{p}$ pairs into two samples, depending on whether both tracks were found in the same or in opposite hemispheres as defined by the event plane, i.e.

$$p\bar{p} \text{ in same hemisphere: } \mathbf{p}_{\parallel}(p) \cdot \mathbf{p}_{\parallel}(\bar{p}) > 0$$

$$p\bar{p} \text{ in opposite hemispheres: } \mathbf{p}_{\parallel}(p) \cdot \mathbf{p}_{\parallel}(\bar{p}) < 0$$

where $\mathbf{p}_{\parallel}$ is the projection of the particle momentum vector onto the thrust axis.

With the selection criteria described above, we find in the continuum ($\Upsilon(1S)$) data a total of 995 (5154) $p\bar{p}$ pairs in the same hemisphere, and 961 (5147) pairs in opposite hemispheres, respectively. A Monte Carlo analysis shows that the probability of finding pairs in the same or in opposite hemispheres depends strongly on the choice of values for the parameters in the fragmentation function. Therefore, the appearance of pairs in opposite hemispheres, at center-of-mass energies considered here, is not a clear indicator for a non-local baryon production mechanism.

For further analysis we subtracted continuum and vacuum polarization contributions from the $\Upsilon(1S)$ data using the method described in [10]. The remaining contribution of dominantly 3-gluon decays we refer to as "direct" decays of $\Upsilon(1S)$.

In Fig. 1a and b the distribution of the angle $\phi_t$ is shown for pairs from continuum events and $\Upsilon(1S)$ direct decays respectively, where the $p$ and $\bar{p}$ are contained in the same hemisphere. The model predictions for the parameter $\rho$ shown in Figs. 1 and 3 were obtained using the Lund event generator (version 6.2) for both the $q\bar{q}$ and $ggg$ topologies. The differential shape agrees best with the prediction with $\rho = 1$, which shows the weakest anti-correlation. In order to obtain a more quantitative result, a Monte Carlo simulation was performed for $\rho$ varying between 0 and 1 in steps of 0.1. For each value, a likelihood was calculated from the $\chi^2$ deviations in each bin of the corresponding $\phi_t$ distribution. A continuous likelihood function was obtained by cubic interpola-

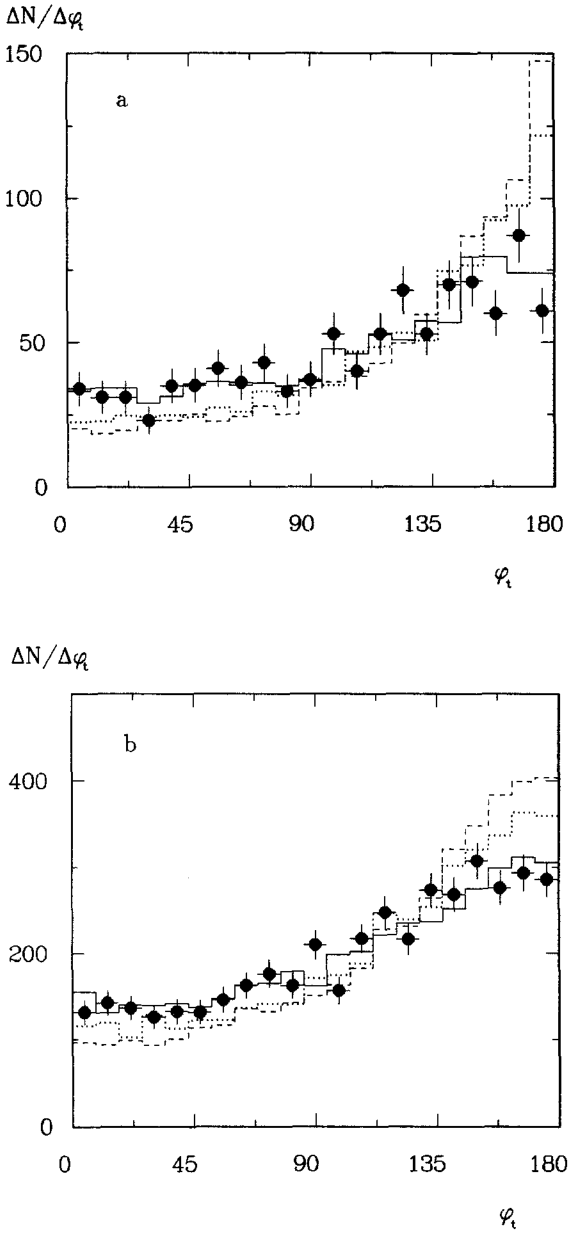



**Fig. 1a, b.** $\phi_t$ distribution of $p\bar{p}$ pairs in the same hemisphere **a** for continuum events and **b** for direct $\Upsilon$ decays. The histograms show the Lund model predictions for $\rho=0$ (dashed), $\rho=0.5$ (dotted) and $\rho=1$ (full line)

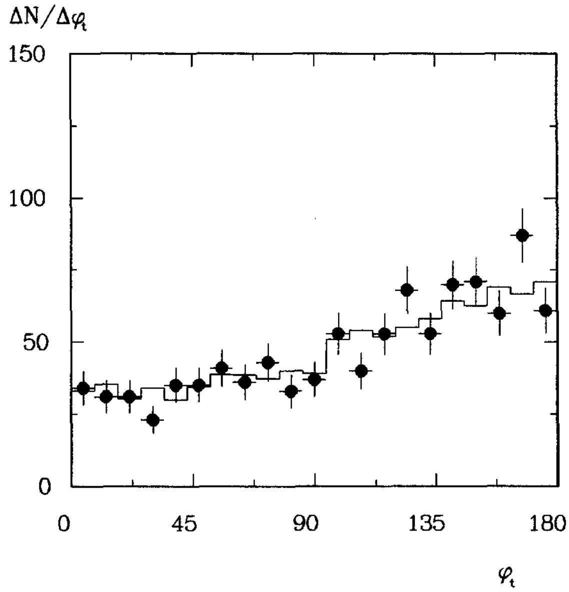



**Fig. 2.** $\phi_t$ distribution of $p\bar{p}$ pairs in the same hemisphere compared with a reference distribution from unlike-sign pairs, both from continuum data

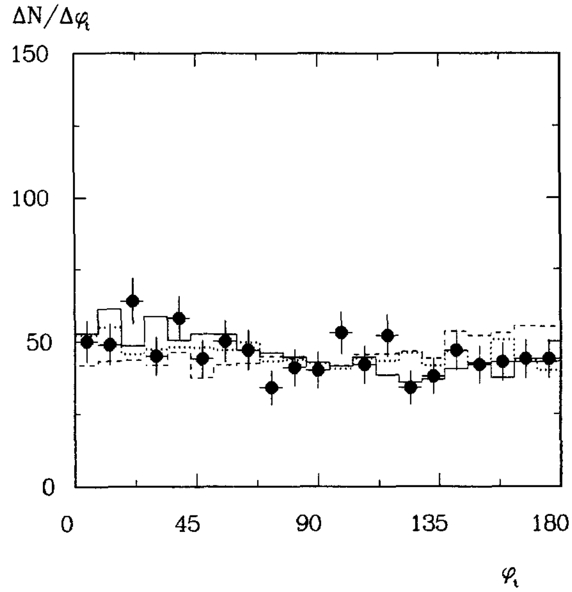



**Fig. 3.** $\phi_t$ distribution of $p\bar{p}$ pairs in opposite hemispheres for continuum events. The histograms show the Lund model predictions for $\rho=0$ (dashed), $\rho=0.5$ (dotted) and $\rho=1$ (full line)

tion. By integration of the likelihood function, we derive a lower limit on the parameter $\rho$ of 0.85 for continuum data and 0.79 in case of $\Upsilon(1S)$ data, both at the 90% CL.

In order to determine whether the observed enhancement at $\phi_t=180°$ is indeed due to local transverse momentum compensation between baryons and antibaryons, the $\phi_t$ distribution of such pairs was compared to a reference distribution derived from all oppositely charged tracks. As demonstrated for continuum data in Fig. 2, the $\phi_t$ distribution of the reference sample shows no significant deviations from that observed for $p\bar{p}$ pairs. This correspondence indicates a non-local compensation of the baryon/antibaryon $p_t$'s, since combinations of arbitrarily charged pairs exhibit [11] only a global transverse momentum compensation.

The Monte Carlo analysis shows that the increase of the $\phi_t$ distribution is dominantly caused by a kinematical bias, since the thrust axis tends to be reconstructed at the connecting line between two tracks in the same hemisphere, especially for jets with low multiplicity. The bias from the thrust axis is much smaller for pairs from opposite hemispheres (Fig. 3), for which the $\phi_t$ distribution is almost flat. Also the latter distribution shows deviations from the predictions of a pure diquark model and again favours values close to $\rho=1$, but the lower limits on $\rho$ derived from Fig. 3 are not as restrictive as those from Fig. 1, since the dependence on the model parameter is weaker in this case.

In conclusion, our data are fully consistent with the predictions of the popcorn model with $\rho$ close to 1. However, the popcorn mechanism is not the only possible explanation for the observed minimal transverse momentum correlation, since one could also obtain similar results from a pure diquark model by relaxing local $p_t$ compensation within a string. Although a study of $p_t$ correlations alone cannot uniquely distinguish between the diquark and popcorn models, a pure diquark model in combination with a local compensation of transverse momentum is excluded by the data.

## 4 Flavour correlations

Flavour correlations offer an independent check of the baryon production mechanism. In a pure diquark model one expects the primary baryon and antibaryon to have two quark flavours in common, while in a popcorn model with $\rho=1$ they would share only one. As noted earlier, flavour correlations cannot be studied directly, since experimentally accessible baryon states, such as $p$ and $\Lambda$, are mostly decay products. However, it appears, for example, that the $\Lambda\bar{\Lambda}$ rate in the Lund model is sensitive to the popcorn parameter $\rho$ defined in the last section.

### *4.1 $\Lambda\bar{\Lambda}$ correlations*

$\Lambda\bar{\Lambda}$ pairs were selected both from $\Upsilon(1S)$ decays and from the continuum data using the criteria described in Sect. 2. A scatter plot of the $p\pi^-$ versus the $\bar{p}\pi^+$ invariant mass is shown in Fig. 4a and b for the $\Upsilon(1S)$ and the continuum data respectively. At the crossing of the $\Lambda$ and $\bar{\Lambda}$ mass bands, a clear signal is observed in both samples.

The mass region for the $\Lambda$ signal was defined as 1.105 to 1.125 GeV/c$^2$, while sidebands were selected from the intervals 1.095 to 1.105 and 1.125 to 1.135 GeV/c$^2$ for background determination. After sideband subtraction, a sample of $369\pm21$ ($68\pm9$) $\Lambda\bar{\Lambda}$ pairs for the $\Upsilon(1S)$ (continuum) data remains. Correcting for efficiency losses, and subtracting the continuum and vacuum polarization contributions from the $\Upsilon(1S)$ data, one obtains the following rates per event:

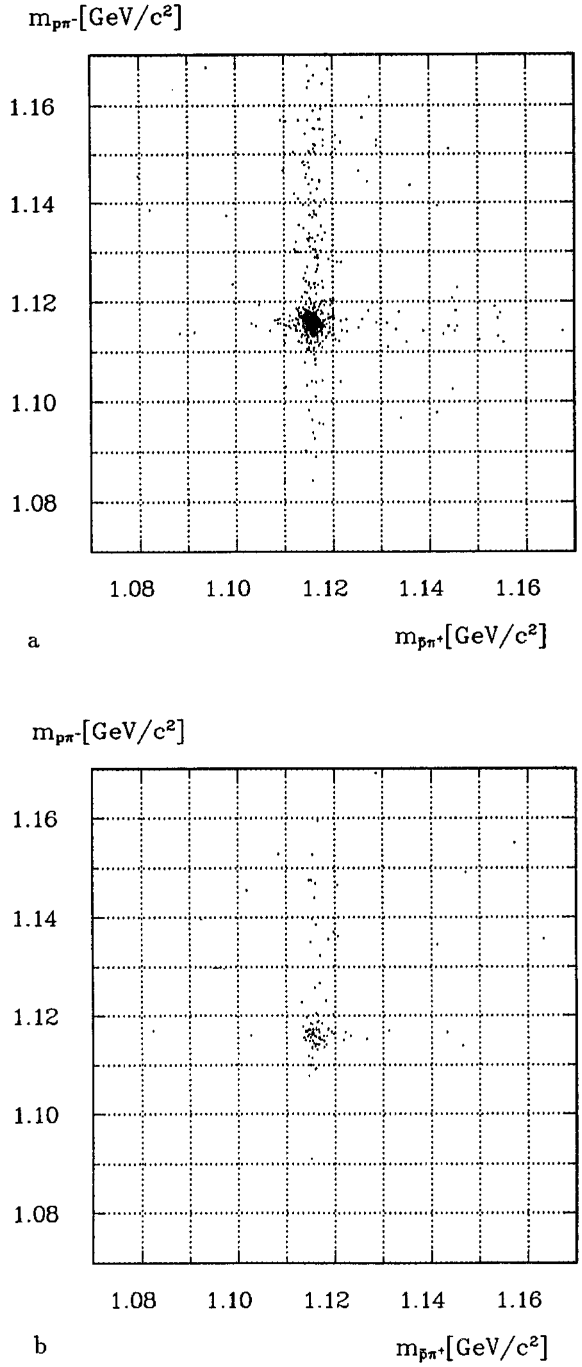



**Fig. 4a, b.** Invariant mass distributions of $p\pi^-$ vs. $\bar{p}\pi^+$ combinations with $x_p>0.1$ **a** for $\Upsilon(1S)$ data, **b** continuum data

$$n_{\Lambda\bar{\Lambda}}(\Upsilon_{\mathrm{dir}})=(3.74\pm0.28\pm0.42)\times10^{-2}$$

$$n_{\Lambda\bar{\Lambda}}(\mathrm{cont.})=(1.41\pm0.21\pm0.26)\times10^{-2}.$$

The extrapolation to momenta below $x_p = 0.1$ was performed using the measured $\Lambda$ spectrum from [2], assuming the $\Lambda$ and $\bar{\Lambda}$ momenta to be uncorrelated.

Dividing the measured production rates of $\Lambda\bar{\Lambda}$ pairs in direct $\Upsilon(1S)$ decays by that for continuum events, one obtains an enhancement factor of:

$$r_{\Lambda\bar{\Lambda}} = (2.65 \pm 0.44 \pm 0.57).$$

This is in good agreement with the corresponding ratio for single $\Lambda$ production [2]: $r_\Lambda = (2.48 \pm 0.09 \pm 0.12)$. Again the enhancement factor is larger than the Lund model prediction of $r_{\Lambda\bar{\Lambda}} = 1.6$.

Since the absolute production rates depend on several physical quantities, we define the ratio of production rates

$$\lambda = 2 \cdot \frac{n_{\Lambda\bar{\Lambda}}}{n_\Lambda + n_{\bar{\Lambda}}}$$

reflecting the probability in a multihadron event that a $\Lambda$ hyperon is accompanied by a $\bar{\Lambda}$, provided the fraction of events containing two $\Lambda$'s is negligible [10]. Thus, the parameter $\lambda$ is a measure of how often strangeness is compensated by the antibaryon. Taking our measured $\Lambda$ rate from [2], we obtain the values:

$$\lambda = 0.328 \pm 0.025 \pm 0.023$$

for direct $\Upsilon(1S)$ decays and

$$\lambda = 0.306 \pm 0.044 \pm 0.021$$

for continuum data. Hence, strangeness correlation is seen to be of similar size in quark and gluon fragmentation.

These results can be compared with the expectation for two extreme cases. If $\Lambda$ and $\bar{\Lambda}$ hyperons were always produced as a pair, $\lambda$ should be equal to 1, while in case of uncorrelated production this parameter can be expected to equal the ratio of the $\Lambda$ rate to the total baryon rate. Assuming the latter to equal twice the proton rate, $\lambda$ should be of order 0.2 [2, 12]. Therefore, our result favours a minimal correlation between the $\Lambda$ and $\bar{\Lambda}$.

In the framework of the Lund model, the quantity $\lambda$ is sensitive to the strangeness suppression for diquarks $\delta = (us/ud)/(s/u)$ and the popcorn parameter $\rho$. A weak strangeness correlation, such as observed in the data, can be caused either by a strong suppression of strange diquarks, a large popcorn contribution, or some combination of both. Therefore, data on inclusive production needs to be included in order to perform a decisive test of the specific hadronization model. Since our measurements from [2] are in good agreement with no extra strange diquark suppression, we use a value of $\delta = 1$ in a simulation using the Lund

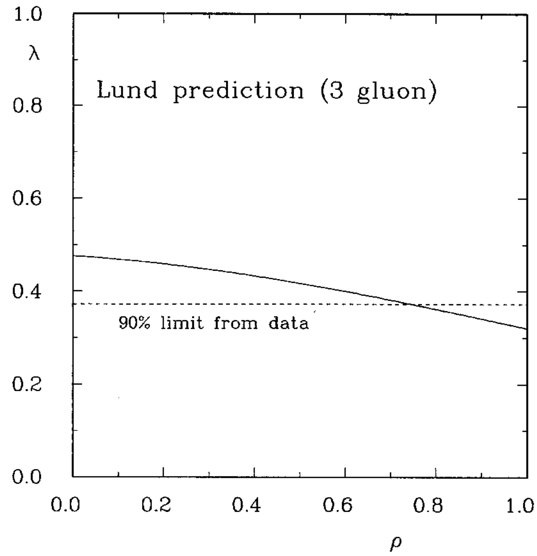



**Fig. 5.** Variation of the quantity $\lambda = 2 \cdot \frac{n_{\Lambda\bar{\Lambda}}}{n_\Lambda + n_{\bar{\Lambda}}}$ as a function of the popcorn parameter $\rho$ as predicted by the Lund model. The dashed line shows the 90% confidence limit for $\rho$ derived from the data

model to obtain an estimate for the popcorn parameter $\rho$. Figure 5 shows the model prediction for $\lambda$ as a function of $\rho$, together with the 90% CL limit obtained from the $\Upsilon(1S)$ data. From this plot one derives at the 90% CL a lower limit of $\rho > 0.73$. The continuum data yield a similar result, but the limit is less restrictive due to statistics and the unknown branching ratio for $\Lambda_c$ into $\Lambda$ hyperons.

To check whether the observed correlations can be simulated in a pure diquark model, the strange diquark suppression $\delta$ was varied while $\rho$ was fixed to 0. The analysis was performed for 3-gluon decays in order to be independent of additional parameters such as $\Lambda_c$ branching ratios. Here it was assumed that charm production in 3-gluon decays is negligible. A correlation $\lambda$ of around 30%, as favoured by the data, was obtained with a suppression of strange diquarks of $\delta \approx 0.2$. However, this leads, for example, to a $\Xi^-/\Lambda$ ratio as low as 0.05, in contradiction to our measurement [2] of $0.09 \pm 0.01$. Therefore, a pure diquark model is unable to reproduce both flavour correlations and production rates.

### *4.2 $\Xi^-\bar{\Lambda}$ production rates*

More direct information on flavour correlations can be derived from measurements of the rate of $\Xi^-\bar{\Lambda}$ pairs, since the $\Xi^-$ is less likely to be the decay product of heavier states. In the point-like diquark model the correlation between the $\Xi^-$ and $\bar{\Lambda}$ hyperon should be high since the strangeness $s = -2$ of the $\Xi^-$ has

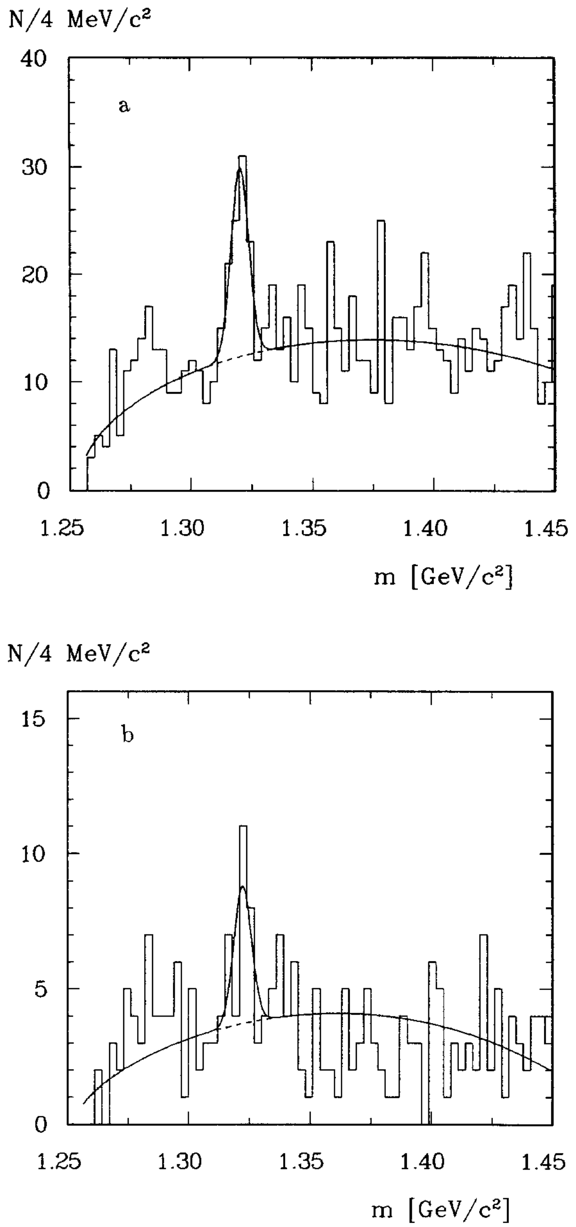



**Fig. 6a, b.** Invariant mass distributions of $\Lambda\pi^-$ combinations with $x_p > 0.15$ **a** for $\Upsilon(1S)$ data, **b** for continuum data, where in addition a $\bar{\Lambda}$ candidate has been found in the event

to be compensated by an antihyperon, which subsequently decays with high probability into a $\Lambda$.

$\Xi^-$ candidates were reconstructed by combining $\Lambda$ candidates in the mass range 1.105 to 1.125 GeV/c$^2$ with a $\pi^-$. The scaled momentum of this combination was required to exceed $x_p > 0.15$. In Fig. 6a and b we have shown the invariant mass distribution of $\Lambda\pi^-$ combinations where, in addition, a $\bar{\Lambda}$ candidate was found in the event. The $\Xi^-$ signals were extracted by a fit with a gaussian plus a square-root threshold factor times a polynomial for the background. For the $\Upsilon$ data, the mass and width of the $\Xi^-$ were free parameters, while for the continuum sample the width was fixed to the value of $3.6 \pm 0.9$ MeV/c$^2$ obtained from the fit to the $\Upsilon$ data. In total, $64 \pm 13$ ($16 \pm 5$) $\Xi^-$ were found in the $\Upsilon$ (continuum) data. After acceptance correction, the measured rates per event are:

$$n_{\Xi^- \bar{\Lambda}}(\Upsilon_{\mathrm{dir}}) = (4.75 \pm 1.79 \pm 0.69) \times 10^{-3}$$

$$n_{\Xi^- \bar{\Lambda}}(\mathrm{cont.}) = (2.18 \pm 0.60 \pm 0.31) \times 10^{-3}.$$

The observed $\Xi^-$ and $\Lambda$ spectra were used to extrapolate to the full momentum range, assuming the momenta of both particles to be uncorrelated.

Normalizing the production rates to the total $\Xi^-$ rate from [2], one obtains:

$$\frac{n_{\Xi^- \bar{\Lambda}}}{n_{\Xi^-}}(\Upsilon_{\mathrm{dir}}) = 0.46 \pm 0.17 \pm 0.05,$$

$$\frac{n_{\Xi^- \bar{\Lambda}}}{n_{\Xi^-}}(\mathrm{cont.}) = 0.65 \pm 0.18 \pm 0.06$$

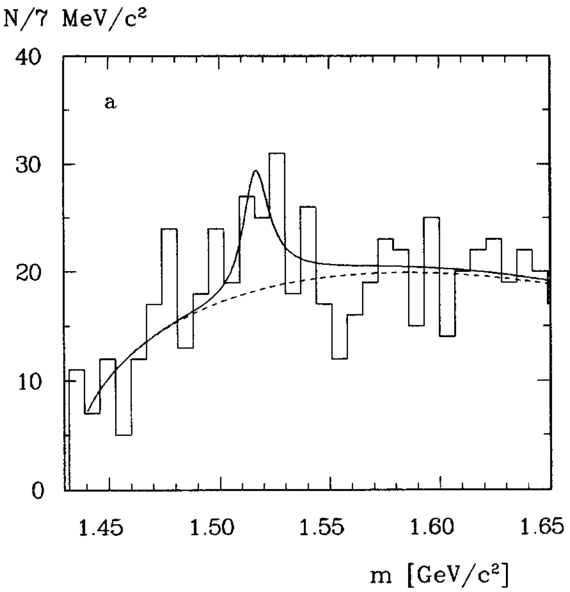
where both measurements are in agreement within errors. Combining these one obtains an average value of:

$$\frac{n_{\Xi^- \bar{\Lambda}}}{n_{\Xi^-}} = 0.55 \pm 0.13.$$

This result can be compared with the predictions of the Lund model, which for the allowed range of $\rho$ falls in the interval $0.44 < n_{\Xi^- \bar{\Lambda}}/n_{\Xi^-} < 0.67$. The measurement lies within the predicted range, but the error is too large to allow discrimination between the different models.

## 5 Compensation of angular momentum

Studies of correlations between $\Lambda(1520)$ and $\bar{\Lambda}$ baryons offer a chance to test whether the orbital angular momentum of hadrons is compensated by a corresponding $L = 1$ antibaryon. In the case where the baryon angular momentum is compensated by an orbitally excited antibaryon, one expects that the probability for producing a $\bar{\Lambda}$ in the decay chain is less than for $\Lambda\bar{\Lambda}$ pairs. This follows because excited hyperon states are often above threshold for $NK$ or $\Sigma\pi$ production. Alternative possibilities for angular momentum compensation are hadron spins, tensor mesons or nonzero orbital angular momenta between hadrons. If angular momentum is compensated in a way where the accompanying antibaryon is an octet or decuplet ground state, one expects $\Lambda\bar{\Lambda}$ and $\Lambda(1520)\bar{\Lambda}$ correlations of comparable size. Therefore, a correlation measurement could provide an answer to how angular momenta are generated in hadronization processes.



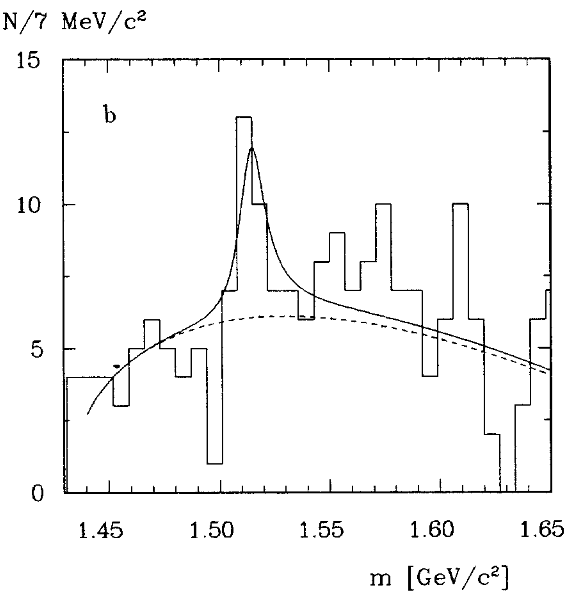




**Fig. 7a, b.** Invariant mass distributions of $pK^-$ combinations in the momentum interval $0.1<x_p<0.4$ **a** for $\Upsilon(1S)$ data, **b** for continuum data, where in addition a $\bar{\Lambda}$ candidate has been found in the event

$\Lambda(1520)$ candidates were selected from $pK^-$ combinations with scaled momentum in the range $0.1<x_p<0.4$. For the identification of the proton and kaon candidates, the cut on the likelihood of the combined $dE/dx$ and time-of-flight measurements was raised to 30% in order to reduce the combinatorial background and contributions from reflections [3]. The required additional $\bar{\Lambda}$ candidate in the event was selected with the same criteria as described in Sect. 4.1.

The $\Lambda(1520)$ signal was extracted from the invariant $pK^-$ mass distribution shown in Fig. 7a and b by a fit of a relativistic $L=2$ Breit-Wigner function plus a polynomial background with a square-root threshold behaviour. The width of the signal was fixed to the table value of 15.6 MeV/c$^2$ [13], while the fitted mass values 1517.5 MeV/c$^2$ ($\Upsilon$ data) and 1515.7 MeV/c$^2$ (continuum data) were obtained. In total, the signals contained $40\pm14$ entries in the $\Upsilon$ data sample and $15\pm7$ entries in the continuum, for a combined significance of 3.5 standard deviations.

After acceptance correction [10] and normalizing the result to the observed $\Lambda(1520)$ rate in the region $0.1<x_p<0.4$ [3], one obtains as a measure of $\Lambda(1520)\bar{\Lambda}$ correlations the ratios:

$$\frac{n_{\Lambda(1520)\bar{\Lambda}}}{n_{\Lambda(1520)}}(\Upsilon_{\rm dir})=0.37\pm0.17,$$

$$\frac{n_{\Lambda(1520)\bar{\Lambda}}}{n_{\Lambda(1520)}}(\text{cont.})=0.39\pm0.17.$$

Combining $\Upsilon$ and continuum data an average for the ratio is found to be:

$$\frac{n_{\Lambda(1520)\bar{\Lambda}}}{n_{\Lambda(1520)}}=0.38\pm0.12.$$

This result is comparable to the observed $\Lambda\bar{\Lambda}$ correlation and hence indicates that orbital angular momentum is not dominantly compensated by other excited baryon states. However the statistical error of the measurement is large and no model prediction is available for a quantitative comparison.

To determine the $\Lambda(1520)\bar{\Lambda}$ production rates over the full momentum range, the data were extrapolated using the spectra from [3]. From this one obtains as absolute $\Lambda(1520)\bar{\Lambda}$ rates per event:

$$n_{\Lambda(1520)\bar{\Lambda}}(\Upsilon_{\rm dir})=(4.3\pm2.1)\times10^{-3},$$

$$n_{\Lambda(1520)\bar{\Lambda}}(\text{cont.})=(3.1\pm1.5)\times10^{-3}.$$

## 6 Conclusions

Studies of baryon-antibaryon correlations were made with a high statistics data sample using direct $\Upsilon$ decays and continuum data. While none of the results presented in Sect. 4.1 to 4.3 alone can distinguish between the different baryon production mechanisms, the combined view strongly favours the popcorn over the diquark model. No attempt has been made to compare these results with the predictions of cluster hadronization models. However, pure two-body decays of clusters seem to be excluded since these are expected to give results similar to the diquark model.

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