$K^0_s K^0_s$ Final State and Glueball Searches and $\Lambda\bar{\Lambda}$ Production in Two-Photon Collisions in L3 at LEP

Saverio Braccini* [1]

*University of Geneva,
24, Quai Ernest Ansermet, CH-1211 Geneve 4, Switzerland.
E-mail : Saverio.Braccini@cern.ch

Abstract.
The $K^0_S K^0_S$ final state in two-photon collisions is studied with the L3 detector at LEP using data collected at centre-of-mass energies from 91 GeV to 202 GeV. The mass spectrum is dominated by the formation of the $f'_2(1525)$ tensor meson in the helicity two state. The two-photon width times the branching ratio is measured to be $\Gamma_{\gamma\gamma}(f'_2) \times Br(f'_2 \to K\bar{K}) = 0.076 \pm 0.006 \pm 0.011$ keV. Clear evidence for destructive $f_2(1270)$-$a_2(1320)$ interference is observed. In addition a clear signal for $f_J(1750)$ is observed. The study of the decay angular distribution in the 1750 MeV mass region shows that the spin two helicity two wave is dominant. No signal is observed in the region around 2.2 GeV. The upper limit for the two-photon partial width of the $\xi(2230)$ tensor glueball candidate of $\Gamma_{\gamma\gamma}(\xi(2230)) \times Br(\xi(2230) \to K^0_S K^0_S) < 1.4$ eV at 95% C.L. is derived. The production of $\Lambda\bar{\Lambda}$ pairs in two-photon collisions is also studied. The cross section is compared to quark-diquark model predictions.

INTRODUCTION

Electron-positron storage rings are a good laboratory to investigate the behaviour of two-photon interactions via the process $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$, where γ^* is a virtual photon. The outgoing electron and positron carry nearly the full beam energy and their transverse momenta are usually so small that they are not detected. In this case the two photons are quasi-real. This kind of event is characterized by an initial state $e^+e^-\gamma^*\gamma^*$, calculable by QED, and a low multiplicity final state. This process is particularly useful in the study of the formation of hadron resonances and baryon anti-baryon pairs.

The cross section is given by the convolution of the QED calculable luminosity function $\mathcal{L}$, giving the flux of the photons, with the two-photon cross section

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$\sigma(\gamma\gamma \rightarrow$ X). In the case of the formation of a resonance R, $\sigma(\gamma\gamma \rightarrow$ R) can be expressed by a Breit-Wigner function. This leads to the proportionality relation $\sigma(e^+e^- \rightarrow e^+e^-R) = \mathcal{K}\ \Gamma_{\gamma\gamma}(R)$ that allows to extract the two-photon width from the cross section. The quantum numbers of the resonance must be compatible with the initial state of the two quasi-real photons. A neutral, unflavoured meson with even charge conjugation, J$\neq$1 and helicity-zero (λ=0) or two (λ=2) can be formed. In order to decay into $K^0_SK^0_S$, a resonance must have J^{PC} = (even)$^{++}$. For the 2^{++}, 1^3P_2 tensor meson nonet, the $f_2(1270)$, the $a_2^0(1320)$ and the $f_2'(1525)$ can be formed. However, since these three states are close in mass, interferences must be taken into account. According to SU(3), the $f_2(1270)$ interferes constructively with the $a_2^0(1320)$ in the K^+K^- final state but destructively in the $K^0\bar{K}^0$ final state [1].

Since gluons do not couple directly to photons, the two photon width of a glueball is expected to be very small. A state that can be formed in a gluon rich environment but not in two photon fusion has the typical signature of a glueball. According to lattice QCD predictions [2], the lowest lying glueball has $J^{PC}= 0^{++}$ and a mass between 1400 and 1800 MeV. The 2^{++} tensor glueball is expected in the mass region around 2200 MeV. Since several 0^{++} states have been observed in the 1400-1800 MeV mass region, the scalar ground state glueball can mix with nearby quarkonia, making the search for the scalar glueball and the interpretation of the scalar meson nonet a complex problem [3] [4] [5].

Using the Brodsky-Lepage hard scattering approach [6], predictions have been made for the production of baryon anti-baryon pairs in two-photon interactions. The cross section for the process $\gamma\gamma \rightarrow p\bar{p}$ is measured by CLEO [7]. Data are found to be inconsistent with the prediction of a pure quark model [8] and agreement is found with the prediction of a quark di-quark model [9], which takes into account non-perturbative quark-quark correlations inside the baryon. The cross section $\sigma(\gamma\gamma \rightarrow \Lambda\bar{\Lambda})$ is found by CLEO [10] to be higher than the value predicted by the quark di-quark model.

A study of the reactions $e^+e^- \rightarrow e^+e^-K^0_SK^0_S$ and $e^+e^- \rightarrow e^+e^-\Lambda\bar{\Lambda}X$ is presented here. The data correspond to an integrated luminosity of 143 pb^{-1}collected by the L3 detector at LEP at $\sqrt{s}$ = 91 GeV, 52 pb^{-1}at $\sqrt{s}$ = 183 GeV and 393 pb^{-1}at $\sqrt{s} = 189 - 202$ GeV. The L3 detector is described in detail elsewhere [11]. These analyses are mainly based on the central tracking system and the high resolution electromagnetic calorimeter. The events are collected predominantly by the charged particle track triggers [12].

$K^0_SK^0_S$ FINAL STATE AND GLUEBALL SEARCHES

A study of the reaction $\gamma\gamma \rightarrow K^0_sK^0_s$ is performed by selecting four charged track events with a net charge of zero and $|\vec{p_T}(\pi^+\pi^-\pi^+\pi^-)|^2 < 0.1$ GeV^2. Within these events two K^0_S candidates are searched for by secondary vertex reconstruction. Events with photons are rejected. Fig. 1(a) shows the distribution of the mass of one K^0_S candidate versus the mass of the other candidate. There is a strong

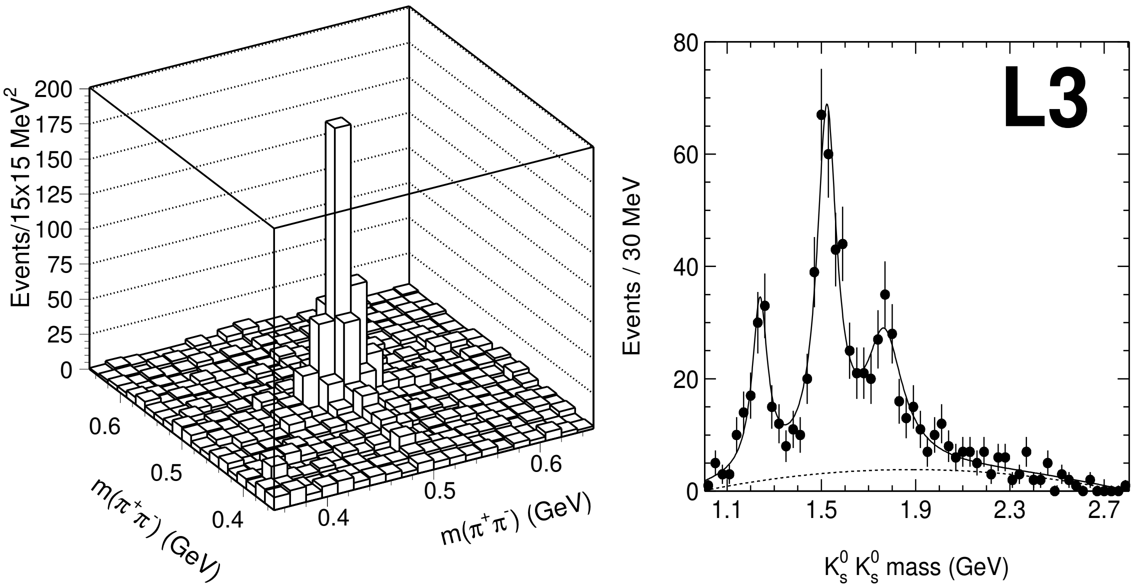

FIGURE 1. (a) The mass of a K^0_S candidate versus the mass of the other candidate. (b) The $K^0_S K^0_S$ mass spectrum.

enhancement corresponding to the $K^0_S K^0_S$ exclusive formation over a small background. We require that the invariant masses of the two K^0_S candidates must be inside a circle of 40 MeV radius centred on the peak of the $K^0_S K^0_S$ signal. With these selection criteria, 802 events are found in the data sample. The resulting $K^0_S K^0_S$ mass spectrum is shown in fig. 1(b). The spectrum is dominated by the formation of the $f'_2(1525)$ tensor meson. The mass region between 1100 and 1400 MeV shows destructive $f_2(1270)-a^0_2(1320)$ interference in the $K^0_S K^0_S$ final state [1]. A clear signal is visible for the $f_J(1750)$. No excess is observed around 2230 MeV. A maximum likelihood fit using three Breit-Wigner functions plus a second order polynomial for the background is performed on the full $K^0_S K^0_S$ mass spectrum. The fit is shown in fig. 1(b) and the results are summarized in Table 1.

In order to correct the data for the detector acceptance and efficiency, a Monte Carlo procedure is used [13]. The nominal $f'_2(1525)$ parameters [14] are used for

TABLE 1. Results from the maximum likelihood fit on the full $K^0_S K^0_S$ mass spectrum.

	$f_2(1270)$-$a_2(1320)$	$f'_2(1525)$	$f_J(1750)$
Mass (MeV)	1239 ± 6	1523 ± 6	1767 ± 14
Width (MeV)	78 ± 19	100 ± 15	187 ± 60
Area	123 ± 22	331 ± 37	220 ± 55

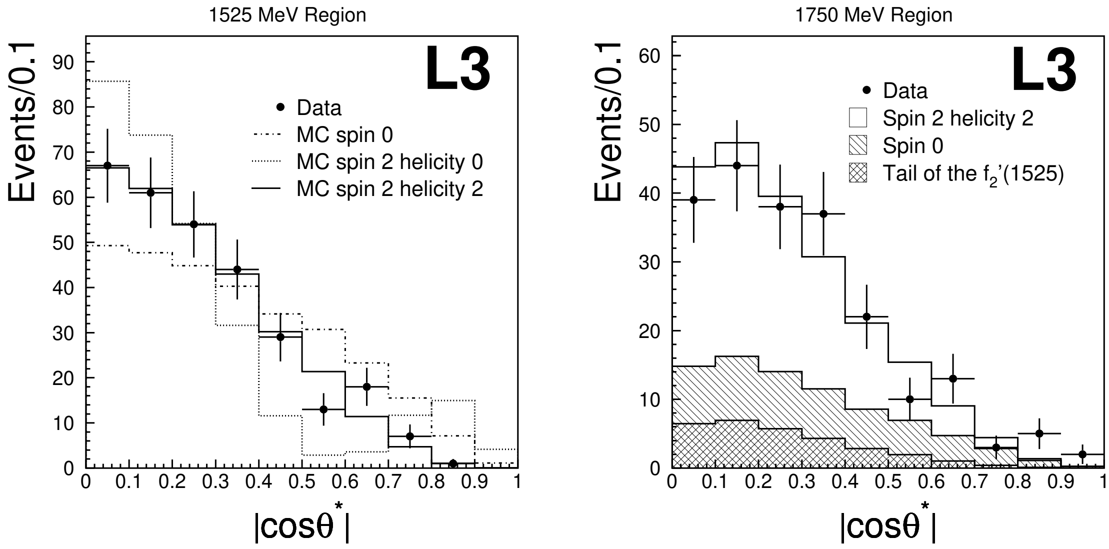

FIGURE 2. (a) The experimental angular distribution is compared with different spin-helicity Monte Carlo predictions for the $f_2'(1525)$. (b) The result of the fit of the angular distribution in the 1750 MeV mass region.

the generation. The angular distribution of the two K^0_S's in the two-photon center-of-mass system is generated according to phase space (J=0) i.e. uniform in $\cos\theta^*$ and in ϕ^*, where θ^* and ϕ^* are the polar and azimuthal angles taking the z direction parallel to the electron beam. In order to take into account the helicity of a spin-two resonance, a weight is assigned to each generated event according to the weight functions: $w = (\cos^2\theta^* - \frac{1}{3})^2$ for the spin-two helicity-zero (J=2, λ=0) contribution and $w = \sin^4\theta^*$ for the spin-two helicity-two (J=2, λ=2) contribution. All the events are passed through the full detector simulation program and are reconstructed following the same procedure used for the data.

To determine the spin and the helicity state in the mass region of the $f_2'(1525)$, a study of the angular distribution of the two K^0_S's in the mass region between 1400 and 1640 MeV in the two-photon center of mass is performed. The experimental polar angle distribution is compared with the Monte Carlo in Fig. 2(a) for pure (J=0), (J=2, λ=0) and (J=2, λ=2) cases. A χ^2 is calculated normalizing the Monte Carlo distributions to the same number of events as in the data. Bins are grouped in order to have at least 10 entries both in the data and in the Monte Carlo. The confidence level values for the (J=0) and (J=2, λ=0) hypotheses are less then 10^{-6}. For the (J=2, λ=2) hypothesis a confidence level of 99.9% is obtained. The contributions of (J=0) and (J=2, λ=0) are found to be compatible with zero when fitting the three waves simultaneously. Thus data are in agreement with a pure spin two, helicity two wave contribution. According to the theoretical predictions [15], the (J=2, λ=2) contribution largely dominates over (J=2, λ=0). From the cross section the value $\Gamma_{\gamma\gamma}(f_2'(1525)) \times Br(f_2'(1525) \rightarrow K\bar{K}) = 0.076 \pm 0.006 \pm 0.011$ keV is obtained for the two-photon width. The main source of systematic error is due to the background parameterization in the fitting procedure. This result is in good agreement with the value previously published by L3 [16].

To investigate the spin composition in the mass region between 1640 and 2000 MeV the angular distribution of the two K^0_S's in the two-photon center of mass is studied. A resonance with a mass of 1750 MeV and a total width of 200 MeV is generated with the same Monte Carlo procedure adopted for the $f'_2(1525)$. The effect of the tail of the $f'_2(1525)$ in this mass region is taken into account by using the Monte Carlo distribution for the $f'_2(1525)$ with (J=2, λ=2). The fraction of the events belonging to the $f'_2(1525)$ in the 1750 MeV mass region is found to be 14%. A fit of the angular distribution is performed using a combination of the two waves (J=0) and (J=2, λ=2) for the signal plus the distribution of the tail of the $f'_2(1525)$. The contribution due to the (J=2, λ=0) wave is considered negligible with respect to (J=2, λ=2) according to the theoretical predictions [15] and to our experimental results for the $f'_2(1525)$. The normalization is fixed to the same number of events as in the data and bins are grouped in order to have at least 10 entries both in the data and in the Monte Carlo. The fit is shown in Fig. 2(b). The fraction of (J=0) is found to be 24$\pm$16%. The confidence level is 68%. Thus the (J=2, λ=2) wave is found to be dominant also in the 1750 MeV mass region. If the (J=2, λ=0) wave is also considered, its contribution is found to be compatible with zero.

The BES Collaboration [17] reported the presence of both 2^{++} and 0^{++} waves in the 1750 MeV mass region in K^+K^- in the reaction $e^+e^- \to J/\psi \to K^+K^-\gamma$. The (J=0) fraction is estimated to be 30$\pm$10%, in good agreement with our measurement.

For the two-photon width of the (J=2, λ=2) state, we measure $\Gamma_{\gamma\gamma}(f_2(1750)) \times Br(f_2(1750) \to K\bar{K})= 0.049 \pm 0.011 \pm 0.013$ keV. The systematic error takes into account the selection criteria, the trigger, the fitting procedure, the uncertainty on the total width and on the (J=2, λ=2) fraction.

The (J=2, λ=2) signal around 1750 MeV may be due to the formation of a radially excited tensor meson state. The f''_2 is in fact predicted to have a mass of 1740 MeV and a two-photon width of 1.040 keV [18]. The 1750 MeV region is also very interesting for glueball searches and for the understanding of the 0^{++} scalar meson nonet. In the scenario presented in [3], the $f_0(1500)$ is identified with the scalar 0^{++} ground state glueball. This hypothesis includes the prediction of a further scalar state, the $f'_0(1500\text{-}1800)$, mainly composed by $s\bar{s}$. This state will couple strongly to $K\bar{K}$ and its observation is essential to support the $f_0(1500)$ glueball nature. Our and BES measurements support this hypothesis.

The BES Collaboration confirmed the observation by the Mark III Collaboration of a resonance, the $\xi(2230)$ [19], produced in radiative decays of the J/ψ. Due to its narrow width and its production in gluon rich environment, this state is considered a glueball candidate. Its mass is consistent with the lattice QCD prediction for the ground state tensor glueball.

Since we do not observe any signal in the 2230 MeV mass region, a Monte Carlo simulation is used to determine the detection efficiency for the $\xi(2230)$ under the

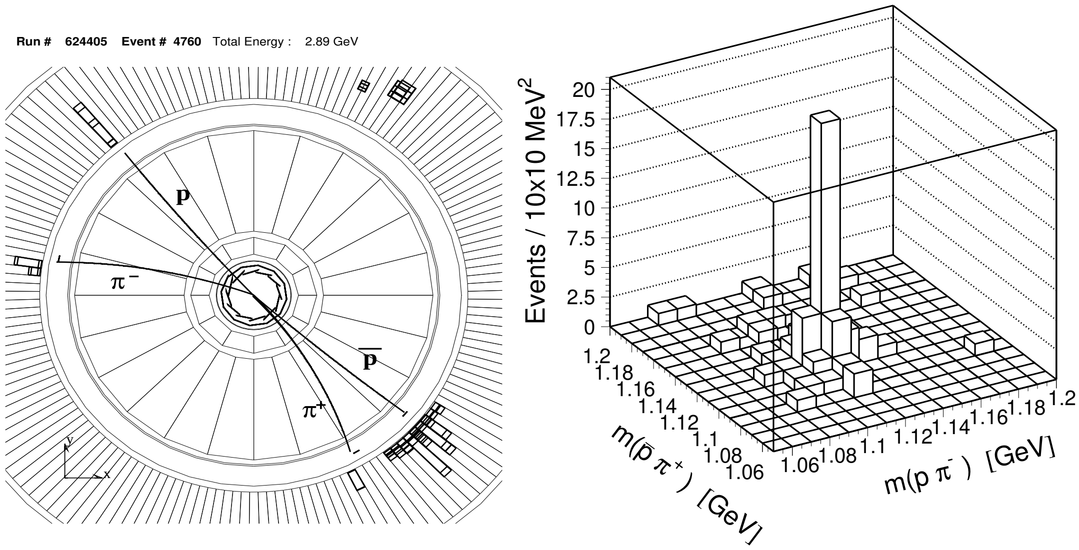

FIGURE 3. (a) A typical event $e^+e^- \to e^+e^-\Lambda\bar{\Lambda}X$. (b) The signal of $\Lambda\bar{\Lambda}$ production.

hypothesis of a pure (J=2, λ=2) state. For the simulation we use a mass of 2230 MeV and a total width of 20 MeV. A mass resolution of σ= 60 MeV is found. The signal region is chosen to be $\pm 2\sigma$ around the $\xi(2230)$ mass. In order to evaluate the background two sidebands of 2σ are considered. Using the standard method [14] for extracting an upper limit for a Poisson distribution with background, we determine the upper limit $\Gamma_{\gamma\gamma}(\xi(2230))\times\mathrm{Br}(\xi(2230) \to \mathrm{K}^0_S\mathrm{K}^0_S) < 1.4$ eV at 95% C.L.

Since gluons do not couple directly to photons, the two-photon width is expected to be small for a glueball. To make this statement more quantitative, a parameter called stickiness [20] is introduced. It is expected to be of the order of one for quarkonia and much larger for glueballs. Combining the results reported by BES and Mark III for the $\Gamma(\mathrm{J}/\psi \to \gamma\xi(2230))\times\mathrm{Br}(\xi(2230) \to \mathrm{K}^0_S\mathrm{K}^0_S) = 1.9\pm0.5$ eV and our upper limit on $\Gamma(\xi(2230) \to \gamma\gamma)\times\mathrm{Br}(\xi(2230) \to \mathrm{K}^0_S\mathrm{K}^0_S)$, we obtain a lower limit on the stickiness $S_{\xi(2230)} > 73$ at 95% C.L. This value is in agreement with the measurements by CLEO [21] and is much larger than the values measured for all the well established $q\bar{q}$ states and supports the interpretation of the $\xi(2230)$ as the tensor glueball. A further confirmation of its existence in gluon rich environments becomes now very important.

$\Lambda\bar{\Lambda}$ PRODUCTION

The production of $\Lambda\bar{\Lambda}$ pairs in two-photon collisions is studied using the decays $\Lambda \to p\pi^-$ and $\bar{\Lambda} \to \bar{p}\pi^+$. Events with four charged tracks, a net charge of zero and two secondary vertices are selected. For each secondary vertex the mass of the proton is assigned to the track with the largest transverse momentum. The ionization

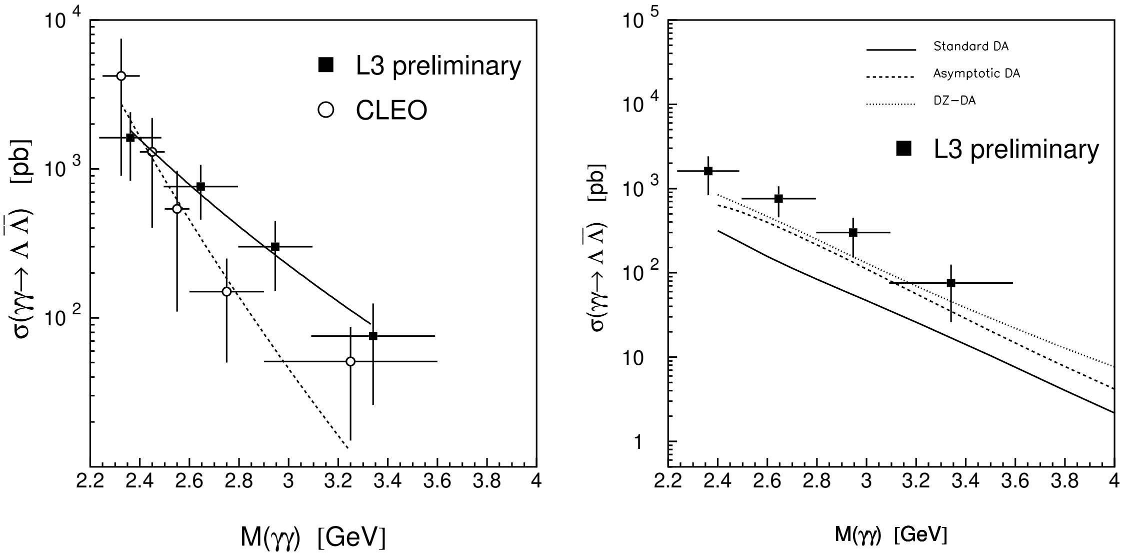

FIGURE 4. The measured cross section $\sigma(\gamma\gamma \to \Lambda\bar{\Lambda}X)$ is compared to CLEO data (a) and to quark di-quark model theoretical predictions (b).

loss measurements in the tracking chamber must be consistent with the $p\pi^-\bar{p}\pi^+$ hypothesis. The track of the anti-proton candidate must be in correspondence with a large deposit of energy ($E_{em} > 0.35$ GeV) in the electromagnetic calorimeter produced by its annihilation. A typical event is shown in fig. 3(a) where the $\Lambda\bar{\Lambda}$ topology and in particular the annihilation of the anti-proton is clearly visible. In fig. 3(b) the mass distribution of the Λ candidate is shown versus the mass of the $\bar{\Lambda}$ candidate: the signal due to $\Lambda\bar{\Lambda}$ production is very clear and 44 events are selected inside a circle of 40 MeV radius around the peak of the $\Lambda\bar{\Lambda}$ signal.

Since no cut is applied to $|\vec{p_T}(p\pi^-\bar{p}\pi^+)|^2$ and events with photons are not removed, the inclusive cross section $\sigma(\gamma\gamma \to \Lambda\bar{\Lambda}X)$ is measured by deconvoluting the luminosity function. The result is shown in fig. 4(a) together with CLEO [10] data. The two measurements are in agreement within the large errors. Fig.4(a) shows also a fit of the form $\sigma \propto M^{-n}$ that gives $n = 8.7 \pm 3.8$ for our data and $n = 16.1 \pm 5.8$ for CLEO. According to the dimensional counting rule [22], the value of n is 12 for a baryon composed by three quarks and 8 for a baryon composed by a quark and a di-quark. Thus our data favor the quark di-quark model.

In fig.4(b) our measurement is compared to recent calculations of $\sigma(\gamma\gamma \to \Lambda\bar{\Lambda})$ in the framework of the quark di-quark model [23] for three different distribution amplitudes for the octet baryons. The mass dependence is in good agreement with our data that lie above the predictions. The excess in the data may be due to the fact that the contribution of Σ^0, $\bar{\Sigma}^0$ and other baryons is not removed.

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