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UPPER LIMITS ON THE PRODUCTION RATE OF THE DECUPLET BARYONS Δ AND Σ^* IN e^+e^- ANNIHILATION AT 34.4 GEV

TASSO Collaboration

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ABSTRACT

Samples of $\sim$1900 identified protons and $\sim$500 Λ have been used to search for decuplet baryon production in e^+e^- annihilation at a c.m. energy of 34.4 GeV. The $p\pi^+$ and $\Lambda\pi^\pm$ invariant mass spectra contain no Δ or Σ^* signals. Upper limits, at 95% confidence level, are that less than 12% of all p and less than 26% of all Λ come from the decay of doubly charged Δ and singly charged Σ^* states respectively. These limits correspond to production rates of < 0.10 Δ^{++} and < 0.09 $\Sigma^{*\pm}$ per event (inclusive of anti-particles). Production of the decuplet states Δ^{++} and $\Sigma^{*\pm}$ is suppressed by a factor $\gtrsim 9$ relative to octet baryons of the same strangeness.

1. INTRODUCTION

Baryons are produced prolifically in high energy e^+e^- annihilation into hadronic final states. The octet baryons p [1-4], Λ [2,5,6] and Ξ^- [7] have all been observed. At $\sim$34 GeV c.m. energy the yields are 0.8 ± 0.1 p,$\bar{p}$ [3], 0.31 ± 0.04 $\Lambda,\bar{\Lambda}$ [6], and 0.026 ± 0.008 $\Xi^-,\overline{\Xi^-}$ [7] in each event, on average.

Possible mechanisms which could lead to baryon production include:

(i) phase space break-up of colourless clusters terminating QCD tree evolution [8-10],

(ii) sequential creation of quarks in a colour field [11,12], and

(iii) creation of localised diquarks in a colour field, with the possibility that spin-1 diquarks may be suppressed relative to spin-0 diquarks because of the chromo-magnetic splitting [13,14]. In this case decuplet baryons could be greatly suppressed relative to octet baryons.

There is evidence that p,$\bar{p}$ pairs are produced with local compensation of baryon number [15], as would be expected on the basis of these possible mechanisms. The yields of $\bar{p}$ and $\Lambda,\bar{\Lambda}$ are known [16] to increase by a factor of 2.0-2.5 over the neighbouring continuum yields on the Υ(1S) resonance, which is believed to decay via 3 gluons at the parton level, and in deep inelastic scattering there is an enhanced baryon yield at large transverse momentum which could be related to gluon bremsstrahlung [17]. It is however clear that baryon production is not unique to events containing gluons, since the relative proton yield is an increasing function of proton momentum [3,4].

In order to further elucidate the mechanism of baryon production, it is important to determine the production rates of decuplet baryons. In this work we have used samples of $\sim$1900 identified p and $\sim$500 Λ (where here and subsequently particles and particle combinations always include the charge conjugates) to set limits on the production of the decuplet states $\Delta^{++} \to p\pi^+$ and $\Sigma^{*\pm} \to \Lambda\pi^\pm$.

2. DATA

The experiment was performed using the TASSO detector at PETRA. The data samples were taken from 20,832 hadronic events at centre of mass energies between 29.9 and 36.8 GeV, with a mean of 34.4 GeV, and corresponding to an integrated luminosity of 73 pb^{-1}. The criteria for acceptance of hadronic events have been given in Ref. [18].

Protons were identified by time-of-flight counters within the magnet coil (ITOF counters [1], covering 82% of 4π steradians), by time-of-flight counters in the hadron arms (HATOF counters [1,19], covering 20% of 4π), and by threshold Cerenkov counters in the hadron arms [3,19,20] (covering 19% of 4π). The proton candidates were selected on a particle by particle basis in the momentum ranges 0.4-1.2 GeV/c, 1.0-2.0 GeV/c and 3.0-5.0 GeV/c with the ITOF, HATOF and Cerenkov counters respectively.

Particle identification was not used in selecting Λ candidates. The sample was obtained from the invariant mass spectrum of pairs of oppositely charged particles, assuming the higher momentum particle to be the proton. The following criteria, similar to those employed in Method 1 of Ref. [5], were applied:

(a) only tracks with $p_T > 0.1$ GeV/c and $|\cos\theta| < 0.87$ were considered, where p_T is the momentum component in the plane transverse to the beam direction ($R\phi$-plane), and θ the angle between the track and the beam direction,

(b) all pairs of oppositely charged tracks were required to satisfy a 3-dimensional fit which demanded that they intersect at a point in space,

(c) in the $R\phi$-plane, the distance of closest approach of the extrapolated pion track to the interaction point had to exceed 0.3 cm,

(d) in the $R\phi$-plane, the Λ decay point was required to lie between 5 and 45 cm from the interaction point,

(e) pairs consisting of tracks with more hits in the tracking chambers in front of the Λ decay point than could be considered accidental, or with more than 3 hits missing following the decay point, were rejected,

(f) in the $R\phi$-plane, the direction of the line joining the interaction point and the Λ decay point had to agree with the direction of the reconstructed Λ momentum vector within 10°,

(g) the decay angle θ^* of the proton in the rest system of the Λ, measured with respect to the Λ direction of flight, had to satisfy $|\cos\theta^*| < 0.9$, and

(h) e^+e^- pairs were removed from the sample by demanding that the effective mass of the pair exceeded 0.050 GeV if the particles were assigned electron masses.

Requiring the momentum of the $p\pi^-$ combination to exceed 1.0 GeV/c, a signal of 580 Λ above a substantial background was obtained, as shown in Fig. 1a. All such combinations having an invariant mass within 0.010 GeV of the Λ mass were taken as Λ candidates (510 ± 40 Λ over a background of 840), and their masses were set equal to the nominal Λ mass. We may note that while samples of Λ with much reduced background are obtained by imposing tighter cuts, in particular by removing K° candidates and by increasing the minimum distance of the Λ decay point from the interaction point, such samples contain substantially fewer Λ, and do not yield a significantly improved upper limit on the $\Sigma^{*\pm}/\Lambda$ ratio.

Invariant mass spectra were then obtained by calculating the mass for every combination of either p or Λ candidate with other charged tracks in the event, treated as pions. Such additional charged tracks were required to satisfy the criteria:

(a) $p_T > 0.1$ GeV/c and $|\cos\theta| < 0.87$, and

(b) the extrapolated track passed within 1 cm of the interaction point in the $R\phi$-plane, and within 5 cm of the interaction point along the beam direction at its point of closest approach in the $R\phi$-plane.

Pions from Δ^{++} or $\Sigma^{*\pm}$ decay will have relatively low momentum, and the efficiency for their satisfying the above criteria was $\sim$65%. The $p\pi^+$ mass spectra from protons identified in the ITOF counters and hadron arms are shown in Figs. 2a and 3a, respectively, and the $\Lambda\pi^\pm$ spectrum for combinations having momenta in the range 1.0-8.0 GeV/c is shown in Fig. 1b. The experimental mass resolution in each case is 0.010 GeV: a $\Delta^{++}(1.232)$ signal would have a full width at half height of 0.110 GeV, and the unresolved $\Sigma^{*+}(1.382)$ and $\Sigma^{*-}(1.387)$ signals a combined width of 0.050 GeV. No signals due to Δ^{++} or $\Sigma^{*\pm}$ are visible. The $p\pi^-$ spectrum from the ITOF counters is shown in Fig. 2b. No signal due to Δ° is visible. The branching ratio for $\Delta^\circ \to p\pi^-$ is 33%, and since any isospin-breaking effects are expected to be small, this spectrum is expected to be much less sensitive to Δ production than the $p\pi^+$ mass spectrum. We have therefore set limits on the rate of Δ production using only the $p\pi^+$ mass spectrum.

3. EXTRACTION OF UPPER LIMITS

The extraction of upper limits is plagued by the familiar problems of setting a limit on a resonance peak which is not observed, superimposed on the maximum of a substantial background, the form of which is unknown. The problem is more serious for the $p\pi^+$ mass spectrum, the Δ being relatively broad and the background peak occurring very close to the Δ mass. We have fitted the data to combinations of resonance signals and assumed backgrounds. The ratios Δ^{++}/p and $\Sigma^{*\pm}/\Lambda$ were obtained from the fitted signals; one standard deviation errors and 95% confidence limits (cl) were obtained from those imposed resonance contributions yielding an increase in χ^2 of 1.00 and 3.84 respectively.

3.1 Δ^{++} UPPER LIMIT

a) ITOF PROTONS

The sample contained 1646 proton candidates selected with the ITOF counters, having momenta in the range 0.4-1.2 GeV/c. We estimate that these candidates include a background of non-protons at the 5% level.

We treated the $p\pi^+$ background to Δ^{++} in three different ways.

(i) The normalised $p\pi^-$ mass spectrum (Fig. 2b) is in excellent agreement with the $p\pi^+$ mass spectrum. We assumed that the background to any Δ° signal in $p\pi^-$ represented the shape of the background to any Δ^{++} signal in $p\pi^+$, and so fitted the $p\pi^+$ mass spectrum to the $p\pi^-$ spectrum with the addition of a Δ Breit-Wigner [21]. The variables were the number of combinations attributed to background and the excess of Δ^{++} in $p\pi^+$ over Δ^0 in $p\pi^-$. The Δ^{++} contribution was extracted from this excess by assuming Δ^{++} and Δ^0 to be produced at the same rate, and correcting for the effect of normalising the $p\pi^-$ spectrum. The best fit yielded

$$\Delta^{++} / p = -4\% \pm 12\%; \quad < 19\% \text{ at } 95\% \text{ cl}$$

for the ratio of those protons originating from Δ^{++} decay to all protons. Constraining the Δ contribution to be ≥ 0 yielded

$$\Delta^{++} / p = 0\% + 9\%; \quad < 19\% \text{ at } 95\% \text{ cl.}$$

These results have been corrected for the relative efficiency of finding Δ^{++} and p, estimated by Monte Carlo methods to be 61%, and for impurities in the proton sample. The statistical accuracy of the $p\pi^-$ combinations is limited, so the upper limit is larger than those of (ii) and (iii) below.

(ii) We defined a false proton sample (denoted by p_f) consisting of those tracks which passed all the cuts applied for proton selection except the time-of-flight cut. The like-sign combinations of this false proton sample with additional tracks were assumed to represent the form of the $p\pi^+$ background. The $p\pi^+$ and $p_f\pi^+$ mass spectra are shown in Fig. 2. The best fit gave

$$\Delta^{++} / p = -6\% \pm 7\%; \quad < 8\% \text{ at } 95\% \text{ cl}$$

for the proportion of protons originating from Δ^{++} decay. Monte Carlo studies (see below) indicated that the false proton background resulted in underestimates of the Δ contribution, and applying a correction for this effect yielded

$$\Delta^{++} / p = 3\% \pm 7\%; \quad < 13\% \text{ at } 95\% \text{ cl.}$$

These results have been corrected for the relative efficiency and for impurities. Using the false proton sample the statistical accuracy of the assumed background is good. However there is no guarantee that either the $p\pi^-$ or $p_f\pi^+$ combinations will represent the true $p\pi^+$ background.

(iii) We therefore found a 4-parameter curve which could represent well both the $p\pi^-$ and $p_f\pi^+$ mass spectra (see Fig. 2). This form also fitted the $p\pi^+$ mass spectrum without the addition of any Δ^{++} signal. We fitted this form together with a Δ^{++} Breit-Wigner to the $p\pi^+$ spectrum, allowing all the background parameters to vary simultaneously. The best fit gave

$$\Delta^{++} / p = -20\% \pm 13\%; \quad < 5\% \text{ at } 95\% \text{ cl}$$

for the proportion of p originating from Δ^{++} decay, while constraining the Δ contribution to be ≥ 0 yielded

$$\Delta^{++} / p = 0\% + 4\%; \quad < 11\% \text{ at } 95\% \text{ cl.}$$

In both cases these results have been corrected for the relative efficiency and for impurities. Fig. 2a shows the fit to the $p\pi^+$ spectrum with the Δ contribution constrained to be ≥ 0, the derived 95% cl upper limit curve, the Δ^{++} contribution to the latter, and the shape of the background at the upper limit.

b) POSSIBLE SYSTEMATIC ERRORS

Since there is no guarantee that the $p\pi^-$ mass spectrum, the $p_f\pi^+$ spectrum or the background parameterisation employed correctly represent the $p\pi^+$ background, we studied samples of Monte Carlo generated events in order to investigate the efficacy of our analysis. The LUND generator* [22] was used, and generated events were corrected for event acceptance, track acceptance, multiple scattering, energy loss and secondary interactions in the detector. Three independent sets of $\sim$40,000 accepted events were generated for each of the three following cases: no decuplet production, $\Delta^{++}/p = 0.12$, and $\Delta^{++}/p = 0.18$. The resulting $p\pi^+$ mass spectra were analysed in the same way as the data.

* Relevant LUND parameters employed were: $\alpha_s = 0.27$ (in 1^{st} order QCD), $\sigma_q = 0.38$ GeV/c, $P/(P+V) = 0.57$, and the longitudinal fragmentation parameter $\beta = 0.28$ (in $f(z) \propto (1-z)^{\beta}$).

With no decuplet production, the generated $p\pi^+$ and $p_f\pi^+$ mass spectra are similar to the corresponding distributions found in the data. Using the generated $p_f\pi^+$ spectra as the shape of the background for the generated $p\pi^+$ spectra yielded ratios of Δ^{++}/p of -9% for a generated value of zero, 5% for a generated value of 12%, and 15% for a generated value of 18%. These results were used to correct the initial values obtained in (ii) above.

Fitting the generated $p\pi^+$ mass spectra with the parameterised background plus resonance gave results in good accord with the generated Δ^{++} contributions, with no systematic shifts. We therefore regard this method as the most reliable, and give as an upper limit on the ratio Δ^{++}/p obtained from protons identified in the ITOF counters

$$\Delta^{++} / p < 11\% \text{ at } 95\% \text{ cl},$$

the result obtained using the parameterised background, with the Δ contribution constrained to be ≥ 0, which is in excellent agreement with the corrected upper limit using the false proton background.

c) HADRON ARM PROTONS

The sample contained 181 proton candidates selected with the HATOF counters, with momenta in the range 1.0-2.0 GeV/c (containing an estimated background of non-protons of 12%), and 211 candidates selected with the Cerenkov counters with momenta 3.0-5.0 GeV/c (estimated background 35%). These samples were combined and the resulting $p\pi^+$ mass spectrum is shown in Fig. 3a. It will be observed that there is a downward fluctuation in the data in the Δ region. There is no known reason for the background to exhibit such an effect, which was not found in the $p_f\pi^+$ mass spectrum, and which must be attributed to a statistical fluctuation. We applied the techniques explained in section a) above to set upper limits on the ratio Δ^{++}/p, taking the one standard deviation and 95% confidence level upper limits from the number of Δ^{++} giving increases in χ^2 of 1.00 and 3.84 respectively over the χ^2 obtained constraining the Δ^{++} contribution to be ≥ 0. The following results were obtained, after correcting

for the relative efficiency of finding Δ^{++} and p (70%), and for impurities in the proton samples.

(i) Using the $p\pi^-$ combinations as background gave

$$\Delta^{++} / p = 0\% + 16\%; \quad < 35\% \text{ at } 95\% \text{ cl}$$

for the proportion of p originating from Δ^{++} decay.

(ii) A false proton sample was defined as those HATOF proton candidates which had failed the time-of-flight cut, together with those Cerenkov proton candidates which had failed the requirement of producing no light in any of the three Cerenkov counters traversed. Using the $p_f\pi^+$ combinations as background gave

$$\Delta^{++} / p = 0\% + 3\%; \quad < 10\% \text{ at } 95\% \text{ cl}.$$

(iii) Representing the background by a 4-parameter curve capable of fitting the $p\pi^-$ and $p_f\pi^+$ mass spectra (see Fig. 3b), and allowing all the background parameters to vary simultaneously gave

$$\Delta^{++} / p = 0\% + 4\%; \quad < 13\% \text{ at } 95\% \text{ cl}.$$

The result of fitting to the 4-parameter background and a Δ^{++} Breit-Wigner is shown in Fig. 3a.

Thus the upper limit on the ratio Δ^{++}/p obtained from the hadron arm data is, perhaps fortuitously, similar to that obtained from the ITOF data.

d) FINAL Δ^{++} UPPER LIMIT

We find, using the LUND Monte Carlo program [22], that 20% of protons from Δ^{++} and 22% of all protons have momenta in the ITOF range (0.4-1.2 GeV/c). The corresponding proportions for protons in the HATOF momentum range are 30% and 30% respectively, and for protons in the Cerenkov momentum range 16% and 16% respectively. These relative proportions are not significantly affected by using the fragmentation functions of Ref. [23]. The range of proton momenta investigated covers ~67% of all proton production, and within the LUND generator the momentum spectra of all protons and of protons from Δ^{++} decay are sensitive only at high momentum to the fragmentation functions employed. We may therefore take the results obtained from the ITOF counters, where the bulk of the identified protons are found, as representative, and give as our final upper limit for the proportion of protons from Δ^{++} decay

$$\Delta^{++} / p \ < 12\% \ \text{at } 95\% \text{ cl},$$

after correcting for the relative proportion of protons from Δ^{++} and of all protons having momenta in the ITOF region.

3.2 Σ^* UPPER LIMIT

The $\Lambda\pi^{\pm}$ mass spectrum of Fig. 1b shows no $\Sigma^{*\pm}$ signal. In order to extract an upper limit we represented the background by a 4-parameter curve which alone fitted well, and which has the same form as the background representation shown in Fig. 1a. To this background we added a curve formed from the convolution of the $\Sigma^{*\pm}$ mass resolution with the Σ^{*+} and Σ^{*-} Breit-Wigners [24]. The four background parameters and the amount of $\Sigma^{*\pm}$ signal were varied simultaneously in the fit. After correcting for the relative efficiency (67%) of finding $\Sigma^{*\pm}$ and Λ (for $\Sigma^{*\pm}$ decaying via $\Lambda\pi^{\pm}$), the best fit yielded

$$((\Sigma^{*+} + \Sigma^{*-}) \to \Lambda\pi) / \Lambda \ = 1\% + 12\%; \quad < 25\% \ \text{at } 95\% \text{ cl}$$

for the proportion of all Λ originating from $\Sigma^{*\pm}$ (i.e. from either Σ^{*+} or Σ^{*-}) decay. Taking the branching ratio for $\Sigma^{*\pm} \to \Lambda\pi^{\pm}$ to be 88%, we thus obtain an upper limit of

$$(\Sigma^{*+} + \Sigma^{*-}) / \Lambda \ < 28\% \ \text{at } 95\% \text{ cl}$$

for the ratio of $\Sigma^{*\pm}$ to all Λ in the momentum ranges studied. Other functional forms for the background gave comparable fits and yielded somewhat smaller upper limits.

Fitting Monte Carlo generated $\Lambda\pi^{\pm}$ mass spectra with the parameterised background and Σ^* contributions employed in fitting the data yielded $\Sigma^{*\pm}/\Lambda$ ratios in excellent agreement with the generated values. We again used the LUND generator to correct for the small difference in the relative fractions of $\Sigma^{*\pm}$ and of all Λ in the momentum ranges studied (1.0-8.0 GeV/c and > 1.0 GeV/c respectively), and give as an upper limit for the proportion of all Λ originating from either Σ^{*+} or Σ^{*-}

$$((\Sigma^{*+} + \Sigma^{*-}) \to \Lambda) / \Lambda \ < 26\% \ \text{at } 95\% \text{ cl},$$

and for the ratio of the sum of singly charged Σ^* states to all Λ

$$(\Sigma^{*+} + \Sigma^{*-}) / \Lambda \ < 30\% \ \text{at } 95\% \text{ cl}.$$

3.3 UPPER LIMITS ON CROSS SECTIONS

Using the above upper limits for the ratios Δ^{++}/p and $\Sigma^{*\pm}/\Lambda$, together with our previously measured rates for p and Λ production [3,6], we conclude that

$$\sigma(\Delta^{++}) + \sigma(\overline{\Delta^{++}}) \ < 30 \text{ pb},$$

or < 0.10 doubly charged Δ per event (inclusive of anti-particles),

and $$\sigma(\Sigma^{*+}) + \sigma(\Sigma^{*-}) + \sigma(\overline{\Sigma^{*+}}) + \sigma(\overline{\Sigma^{*-}}) \ < 28 \text{ pb},$$

or < 0.09 singly charged Σ^* per event (inclusive of anti-particles).

4. IMPLICATIONS

If u, d and s quarks were produced with equal rates from the colour field and the relative yield of baryons determined only by the quark composition and (spin) statistical factors, then all members of the S-wave SU(6) 56-plet would be produced at equal rates (neglecting the small breaking of SU(3) from the production of primary u, d and s quarks, and neglecting any contribution to the baryon yield from particles containing primary c or b quarks). In particular, protons would be directly produced at half the rate of Δ^{++}, and Λ (including Λ from $\Sigma^{\circ} \to \Lambda\gamma$) at half the rate of $(\Sigma^{*+} + \Sigma^{*-})$. These relative rates are unchanged by the introduction of a strangeness suppression factor. In fact, strange baryons are suppressed relative to non-strange, and we observe neither Δ^{++} nor $\Sigma^{*\pm}$ signals. To clarify the implications of this result, we have fitted two simple models to the ratios given in Table 1, assuming that only the S-wave octet and decuplet baryon states are produced.

4.1 MODEL A

First, suppose that singly and doubly strange baryons are produced at rates a and a^2 relative to non-strange baryons, and that decuplet states are produced at a rate f relative to octet states. The direct production rates would then be as given in Table 2 (where states not decaying ultimately to p or Λ have been omitted). After allowing for decuplet decay and the electromagnetic and weak decays of octet baryons (other than the neutron), expressions for the ratios Λ/p, Ξ^-/Λ, Δ^{++}/p and $\Sigma^{*\pm}/\Lambda$ are obtained in terms of the two parameters a and f. Fitting these expressions to the measured ratios we obtain

$$a = 0.23 \pm 0.05,$$

$$f = 0.00 + 0.05; \quad < 0.11 \text{ at } 95\% \text{ cl},$$

where the correlations between these parameters have been taken into account in calculating the errors.

4.2 MODEL B

Secondly, suppose that baryons are formed by conjuction of a quark with a diquark (the quarks within the diquark (qq) being not necessarily closely correlated in space); that strange and doubly strange diquarks are suppressed relative to non-strange diquarks, and that spin-1 diquarks are suppressed relative to spin-0 diquarks. The relative yields are then controlled by the parameters:

P0 = $P(s)/P(u)$, where $P(s)$ is the probability of producing an $s\bar{s}$ pair, $P(u)$ the probability of a $u\bar{u}$ pair, with $d\bar{d}$ pairs assumed to be produced at the same rate as $u\bar{u}$ pairs,

P1 = $P(us_0)/P(ud_0)$, where $P(us_0)$ is the probability of producing a spin-0 singly strange $qq,\overline{qq}$ pair and $P(ud_0)$ the probability for a spin-0 non-strange $qq,\overline{qq}$ pair,

P2 = $P(ud_1)/P(ud_0)$, where $P(ud_1)$ is the probability of producing a spin-1 non-strange $qq,\overline{qq}$ pair in any specific $|s_z\rangle$ state (i.e. excluding the overall factor 3 from spin counting),

P3 = $P(us_1)/P(ud_0)$, where $P(us_1)$ is the probability of producing a spin-1 singly strange $qq,\overline{qq}$ pair, and

P4 = $P(ss_1)/P(ud_0)$, where $P(ss_1)$ is the probability of producing a spin-1 doubly strange $qq,\overline{qq}$ pair.

The relative rates for direct production in this model are given in Table 3 (again states not decaying ultimately to p or Λ have been omitted). If these five parameters were unity, the SU(6) expectations would result.

The parameters P0 and P1 are strongly correlated when fitting only to the baryon ratios given in Table 1. The value of P0 may be determined independently from the relative yields of strange and non-strange mesons. Most data are consistent with a value $\sim$0.3 [25]. In e^+e^- annihilation at high energies two values based on the K^0 yield have been reported: $0.27 \pm 0.03 \pm 0.05$ [26] and $0.35 \pm 0.02 \pm 0.05$ [6], together with a value based on the $K^\pm$ yield, $0.58 \pm 0.04 \pm 0.07$ [6]. For the purpose of extracting limits on the decuplet production parameters, we have assumed the value of P0 to be 0.35. The limits obtained on the parameters P2, P3 and P4 are largely independent of the assumed value of P0.

Taking P3 to be the product of P0 and P2, and P4 to be zero, we obtain

$$P1 = 0.15 {}^{+0.08}_{-0.06}$$

$$P2 = 0.00 + 0.02; \quad < 0.055 \text{ at } 95\% \text{ cl},$$

where again the correlations between these parameters have been taken into account in calculating the errors. Repeating the fits with different values of P0 between 0.27 and 0.58 resulted in fitted values of P1 between 0.2 and 0.08, with 95% cl limits on P2 between 0.06 and 0.04.

For a given value of P0, these results are not significantly changed by allowing P4 to vary in the fit, by fitting to P1, P2 and P3, with P4 set equal to zero, or by fitting to all four parameters, in which case (with P0=0.35)

$$P1 = 0.14\ ^{+0.10}_{-0.11}$$

$$P2 = 0.000 + 0.025; \quad < 0.07 \text{ at } 95\% \text{ cl}$$

$$P3 = 0.000 + 0.015; \quad < 0.03 \text{ at } 95\% \text{ cl}$$

$$P4 = 0.00 + 0.02; \quad < 0.04 \text{ at } 95\% \text{ cl.}$$

Thus in this model our measured limits on Δ^{++} and $\Sigma^{*\pm}$ imply

$$P2 = P(ud_1)/P(ud_0) \quad < \quad 0.06 \text{ at } 95\% \text{ cl.}$$

4.3 DISCUSSION

The fitted values of the parameters f (Model A) and P2 (Model B) show that production of the decuplet baryons Δ^{++} and $\Sigma^{*\pm}$ is suppressed by a factor $\gtrsim 9$ relative to the octet baryons p and Λ, compared with expectations based on the quark composition and number of spin states. In Model B, where baryons are formed from a quark and a diquark pair, spin-1 uu or ud diquarks of any given spin state are suppressed by a factor > 16 relative to spin-0 ud diquarks.

While the observed suppression of decuplet baryons can be interpreted in terms of suppression of spin-1 diquarks, as suggested in Refs. [13,14], this may not be the only factor. From a measurement of the rate of rho meson production, and assuming pseudoscalar and vector mesons to be directly produced, we have found the ratio P/(P+V) for light mesons to be 0.42 ± 0.08 ± 0.15 [27]. Other measurements of this parameter have been summarised in Ref. [28]. Thus there are indications that ratio of direct ρ to π production may be suppressed relative to SU(6) expectations of P/(P+V) = 0.25 by a factor > 2, although this may be due to the low mass of the pion to a considerable extent [29]. Therefore some suppression of the decuplet baryons may be due to their larger masses and independent of assumed local quark or diquark pair creation probabilities. In a string model, the probability of obtaining a high mass particle is a rapidly decreasing function of mass, but the mass suppression factor for decuplet states relative to octet states is not expected to exceed $\sqrt{3}$ [30]. In models where

colourless clusters are formed after terminating the perturbative evolution of a QCD tree [8-10], and then permitted to break up according to phase space, the relative yield of decuplet to octet baryons will depend on the tail of the cluster mass spectrum for masses > 2 GeV.

An indication that mass effects of either kind are not wholly responsible for decuplet suppression is given in Fig. 4, in which the rates of baryon production relative to their SU(6) limits is plotted as a function of mass. The numbers apply to primary baryon production, calculated from the parameters a and f, and from P1 and P2 (taking P3 as the product of P0 and P2). It is seen that even if it is assumed that strange baryon production is suppressed only because of baryon mass effects, with no contribution from strange quark dynamics, the decuplet suppression factors expected from the relative octet rates are only just consistent with the 95% cl upper limits extracted from our results. If strange quark production is dynamically suppressed over and above hadron mass effects, then there is certainly a dynamical suppression of decuplet states over and above baryon mass effects.

4.4 RELEVANCE TO LUND GENERATOR PARAMETERS

The LUND Monte Carlo generator [22,23] is widely used and is capable of yielding an excellent description of e^+e^- annihilation into hadrons. The treatment of baryon production is essentially that of Model B, differences in diquark pair creation probabilities and possible baryon mass dependent effects being to a large extent subsumed into a single parameter, the probability of making a baryon with a spin-1 diquark in any given spin state relative to that of making a baryon with a spin-0 diquark. (This parameter is unity in the SU(6) symmetric limit.) Our previous studies [6] using the LUND generator have established that the LUND parameter

$$P(qq)/P(q) \quad = \quad 0.10 \pm 0.01$$

where P(qq)/P(q) is the ratio of all diquark pair to all quark pair production, and have yielded values for P(s)/P(u) and for the further suppression of strange diquark pairs. The latter, given by P1/P0 in Model B of this paper, has a value $\sim$0.3, and is sensitive not only to the value of P0 but also to the rate assumed for strange baryons from decay of particles containing primary c or b quarks. Using the LUND generator, we find that our results correspond to an upper limit to the LUND parameter for decuplet suppression

$$P(ud_1)/P(ud_0) \lesssim 0.08 \quad \text{at } 95\% \text{ cl},$$

where $P(ud_1)$ is the probability for producing a spin-1 diquark with any given spin projection.

5. CONCLUSIONS

We have searched for Δ^{++} and $\Sigma^{*\pm}$ signals using samples of $\sim$1900 identified protons and $\sim$500 Λ. No signal has been observed. The proportion of protons from Δ^{++} decay is less than 12% of all protons, and the proportion of Λ from charged Σ^* decay is less than 26% (95% cl). These limits correspond to production rates of < 0.10 Δ^{++} and < 0.09 $\Sigma^{*\pm}$ per event (inclusive of anti-particles). Decuplet baryon production is suppressed relative to octet baryon production by a factor $\gtrsim$ 9 over and above SU(6) factors. It is unlikely that this is due to baryon mass effects alone.

Note added: After this work was completed, the CLEO Collaboration reported a limit $\Xi^*/\Xi < 0.16$ at 90% cl [31]. If this result is included, in Model A the upper limit on the parameter f becomes $f < 0.08$ (95% cl), while in Model B, with the parameters P1-P4 free, the effect is to limit $P4 < 0.01$.

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TABLE 1

BARYON PRODUCTION RATIOS DETERMINED WITH TASSO

Λ / p	0.39 ± 0.07
Ξ^- / Λ	0.087 ± 0.042
Δ^{++} / p	$0.00 + 0.06$
$(\Sigma^{*+} + \Sigma^{*-}) / \Lambda$	$0.00 + 0.15$

TABLE 2

PRIMARY BARYON PRODUCTION RATIOS OBTAINING IN MODEL A

p	Λ	Σ^+	Σ°	Ξ°	Ξ^-
2	2a	2a	2a	$2a^2$	$2a^2$

Δ^{++}	Δ^+	Δ°	Σ^{*+}	$\Sigma^{*\circ}$	Σ^{*-}	$\Xi^{*\circ}$	Ξ^{*-}
4f	4f	4f	4af	4af	4af	$4a^2f$	$4a^2f$

TABLE 3

PRIMARY BARYON PRODUCTION RATIOS OBTAINING IN MODEL B

p	1	+	P2		
Λ	1/3 P1	+	2/3 P0	+	P3
Σ^+	P1	+	1/3 P3	+	2/3 P0.P2
Σ°	P1	+	1/3 P3	+	2/3 P0.P2
Ξ°	P0.P1	+	1/3 P0.P3	+	2/3 P4
Ξ^-	P0.P1	+	1/3 P0.P3	+	2/3 P4
Δ^{++}	4 P2				
Δ^+	4 P2				
Δ°	4 P2				
Σ^{*+}	8/3 P3	+	4/3 P0.P2		
$\Sigma^{*\circ}$	8/3 P3	+	4/3 P0.P2		
Σ^{*-}	8/3 P3	+	4/3 P0.P2		
$\Xi^{*\circ}$	8/3 P0.P3	+	4/3 P4		
Ξ^{*-}	8/3 P0.P3	+	4/3 P4		

FIGURE CAPTIONS

Fig. 1 (a) The $p\pi^-$ mass spectrum for combinations having momenta > 1.0 GeV/c, from which the Λ candidates were selected. Also shown is a fit (solid line) to a Gaussian Λ signal over a 4-parameter background (dashed line) using the same technique as described in section 3.2 to obtain the upper limits on the Σ^* signal.

Fig. 1 (b) The $\Lambda\pi^\pm$ mass spectrum for combinations having momenta in the range 1.0-8.0 GeV/c. Also shown are the best fit (dotted line) to this spectrum for the 4-parameter background plus $\Sigma^{*\pm}$ contribution, the derived 95% cl upper limit curve (solid line), the $\Sigma^{*\pm}$ contribution to the latter (also solid), and the background shape at the 95% cl upper limit curve (dashed line).

Fig. 2 (a) The $p\pi^+$ mass spectrum for proton candidates selected with the ITOF counters. Also shown are the best fit (dotted line) to this spectrum for the 4-parameter background plus Δ^{++} contribution (constrained ≥ 0), the derived 95% cl upper limit curve (solid line), the Δ^{++} contribution to the latter (also solid), and the background shape at the 95% cl upper limit curve (dashed line).

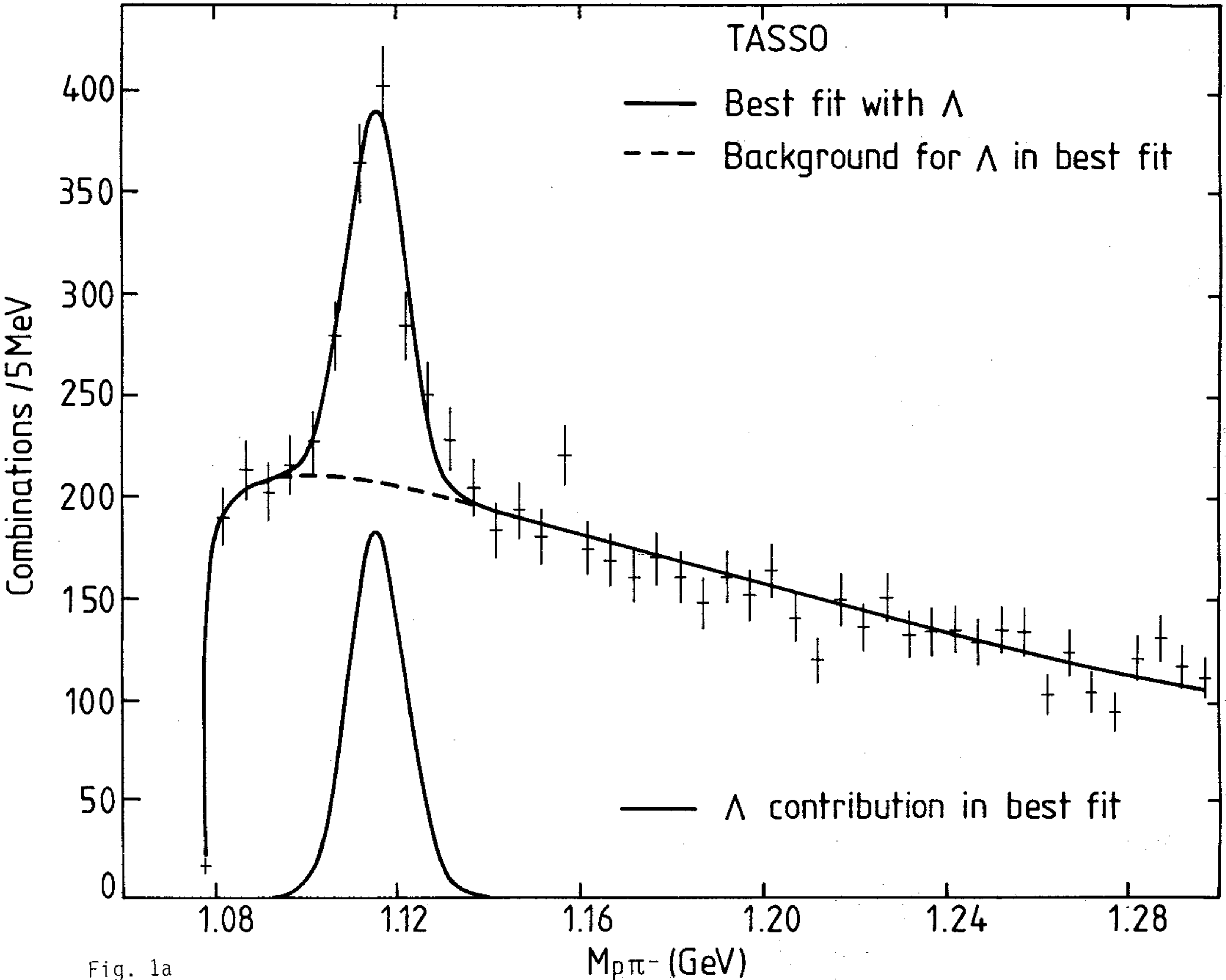
Fig. 2 (b) The $p\pi^-$ mass spectrum for proton candidates selected with the ITOF counters. The solid line is a fit using the same 4-parameter form as used in Fig. 2a.

Fig. 2 (c) The $p_f\pi^+$ mass spectrum for false protons from the ITOF region. The solid line is a fit using the same 4-parameter form as used in Fig. 2a.

Fig. 3 (a) The $p\pi^+$ mass spectrum for proton candidates selected with the HATOF and Cerenkov counters. Also shown are the best fit (dotted line) to this spectrum for the 4-parameter background plus Δ^{++} contribution (constrained ≥ 0), the derived 95% cl upper limit curve (solid line), the Δ^{++} contribution to the latter (also solid), and the background shape at the 95% cl upper limit curve (dashed line).

Fig. 3 (b) The $p_f\pi^+$ mass spectrum for false protons from the HATOF and Cerenkov regions. The solid line is a fit using the same 4-parameter form as used in Fig. 3a.

Fig. 4 The rates of primary baryon production relative to their SU(6) limits as a function of baryon mass (proton taken as unity). These factors were calculated from the expressions given in Table 2 (Model A) and Table 3 (Model B), using the fitted values of the parameters. For Model B, the parameters were extracted assuming P3 to be equal to the product of P0 and P2, with P0=0.35. The errors on the relative Λ rates include the effect of the uncertainty in the value of P0. Any power law relation between the relative rates and baryon masses would yield a straight line. The relative rates for the octet baryons p, Λ and Ξ^- satisfy such a relationship, as shown.



TASSO
Best fit with Λ
Background for Λ in best fit
Λ contribution in best fit
Combinations /5MeV
400
350
300
250
200
150
100
50
0
1.08
1.12
1.16
1.20
1.24
1.28
Mpπ- (GeV)

Fig. 1a

37564

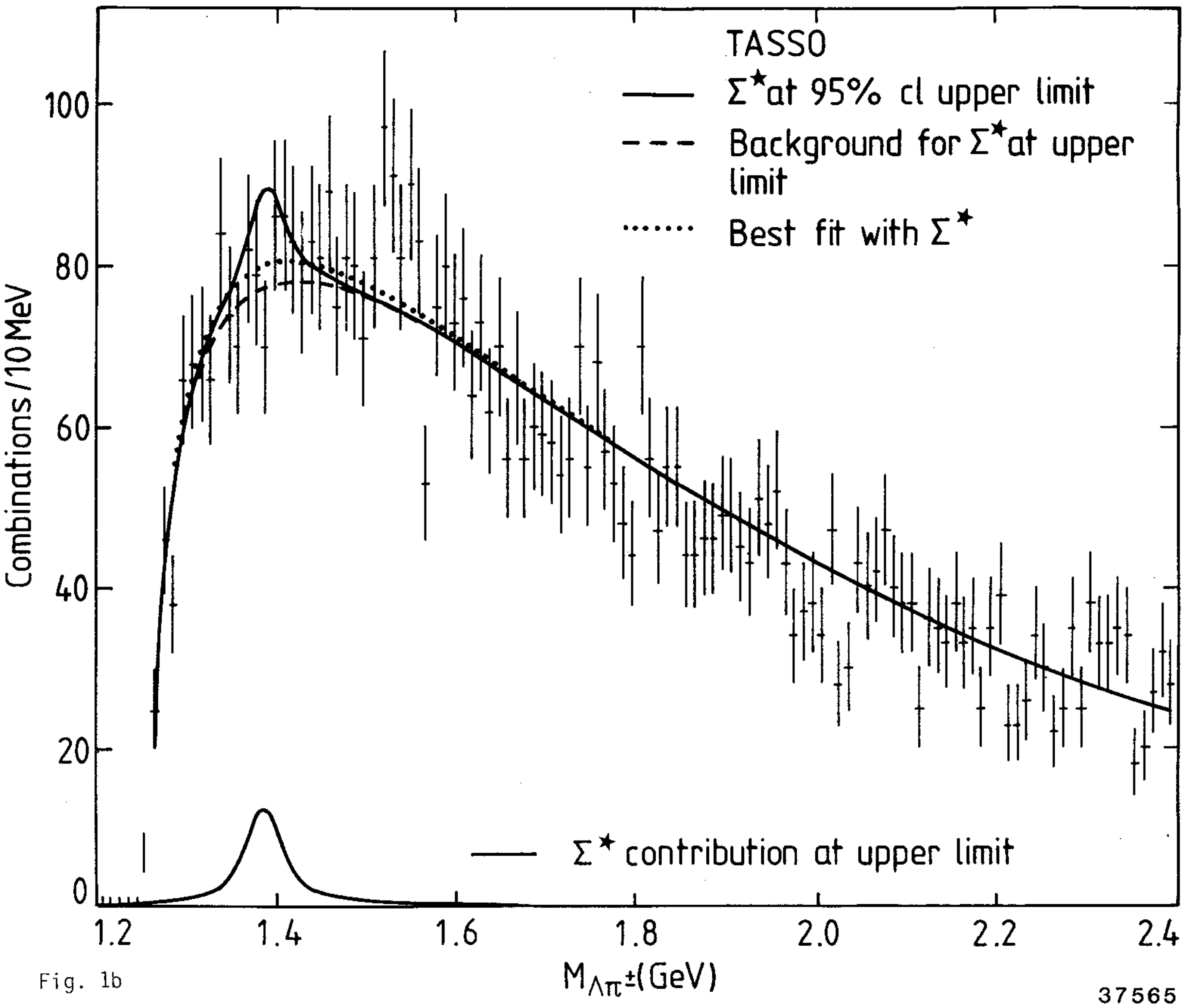

TASSO
Σ*at 95% cl upper limit
Background for Σ*at upper limit
Best fit with Σ*
Σ* contribution at upper limit
Combinations/10 MeV
100
80
60
40
20
0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
M_Λπ±(GeV)
37565

Fig. 1b

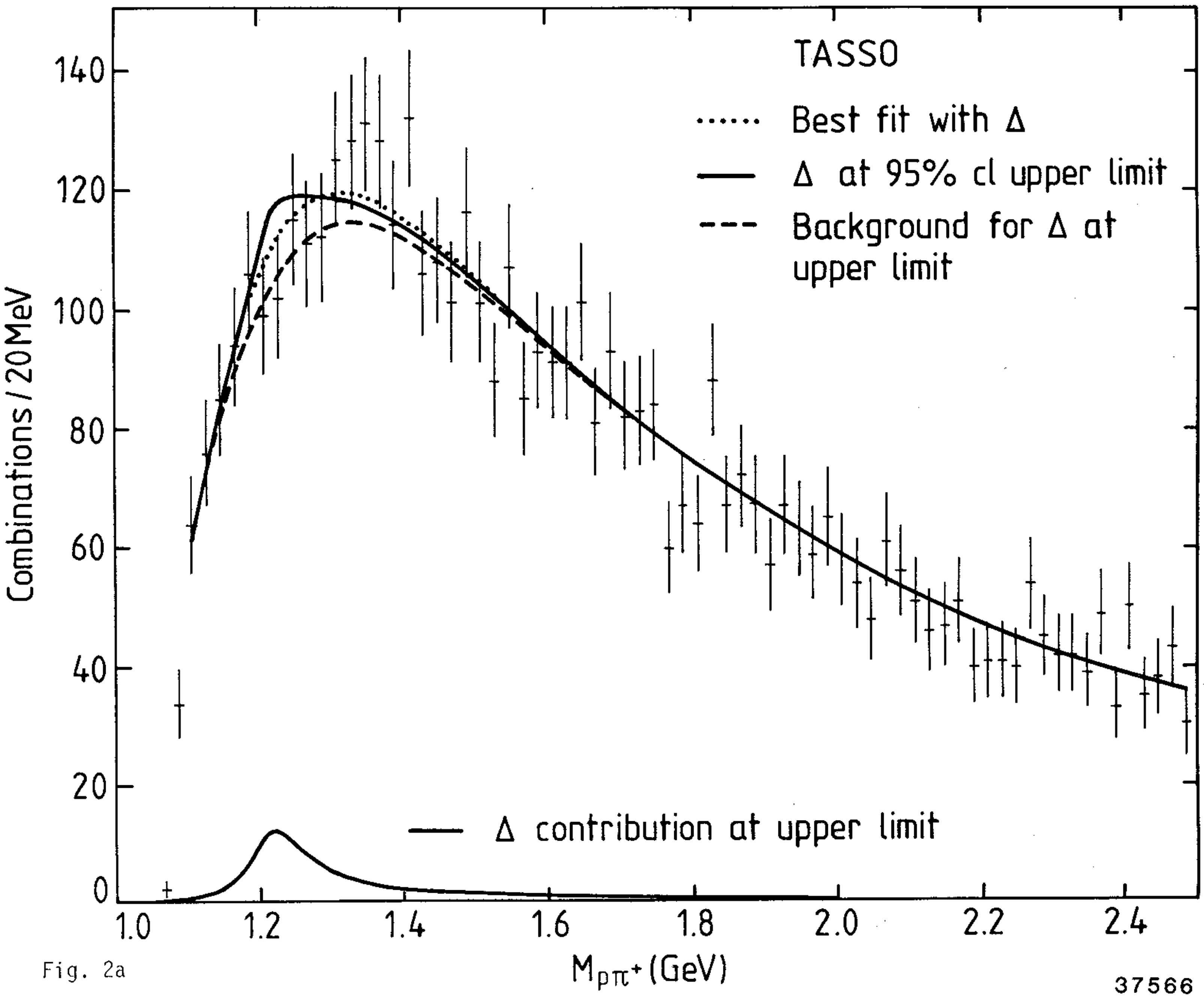

TASSO
Best fit with Δ
Δ at 95% cl upper limit
Background for Δ at upper limit
Δ contribution at upper limit
Combinations / 20 MeV
$M_{p\pi^+}$ (GeV)
37566

Fig. 2a

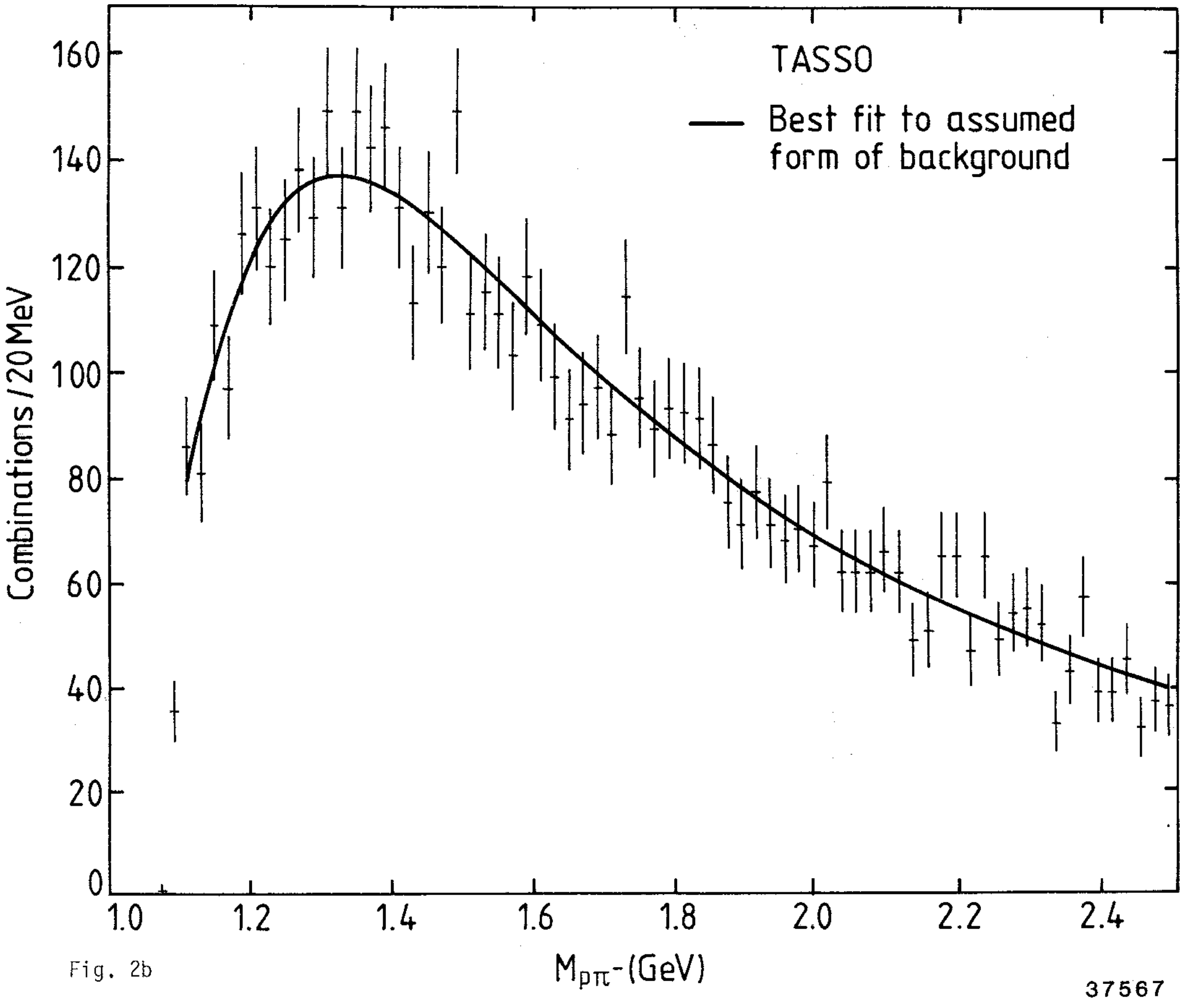
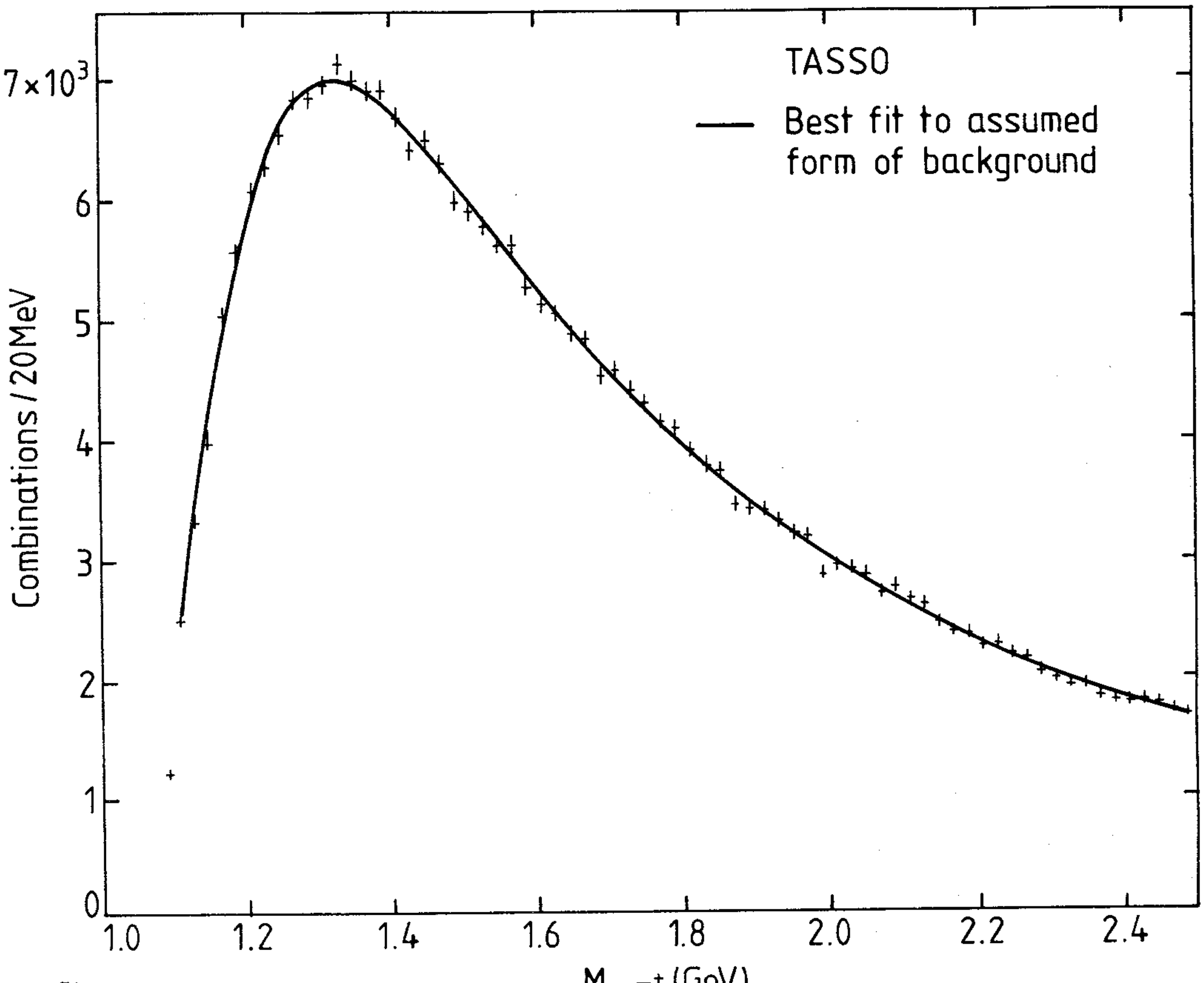

TASSO
Best fit to assumed form of background
Combinations / 20 MeV
160
140
120
100
80
60
40
20
0
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
Mpπ-(GeV)
37567

Fig. 2b



TASSO
Best fit to assumed form of background
7×10³
6
5
4
3
2
1
0
Combinations / 20MeV
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
$M_{p_f \pi^+}$ (GeV)

Fig. 2c

37568

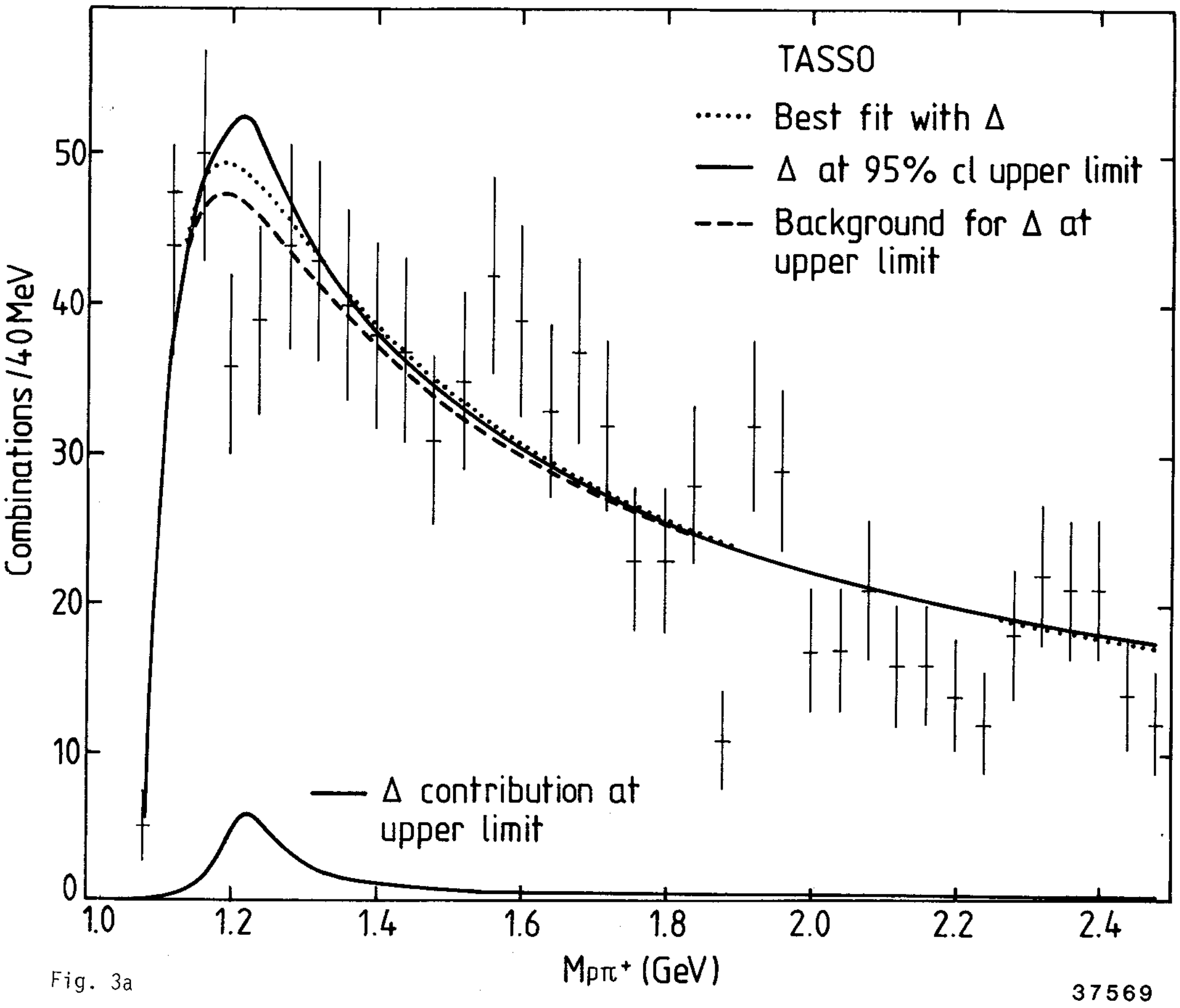

TASSO
Best fit with Δ
Δ at 95% cl upper limit
Background for Δ at upper limit
Δ contribution at upper limit
Combinations /40 MeV
Mpπ⁺ (GeV)
0
10
20
30
40
50
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
37569

Fig. 3a

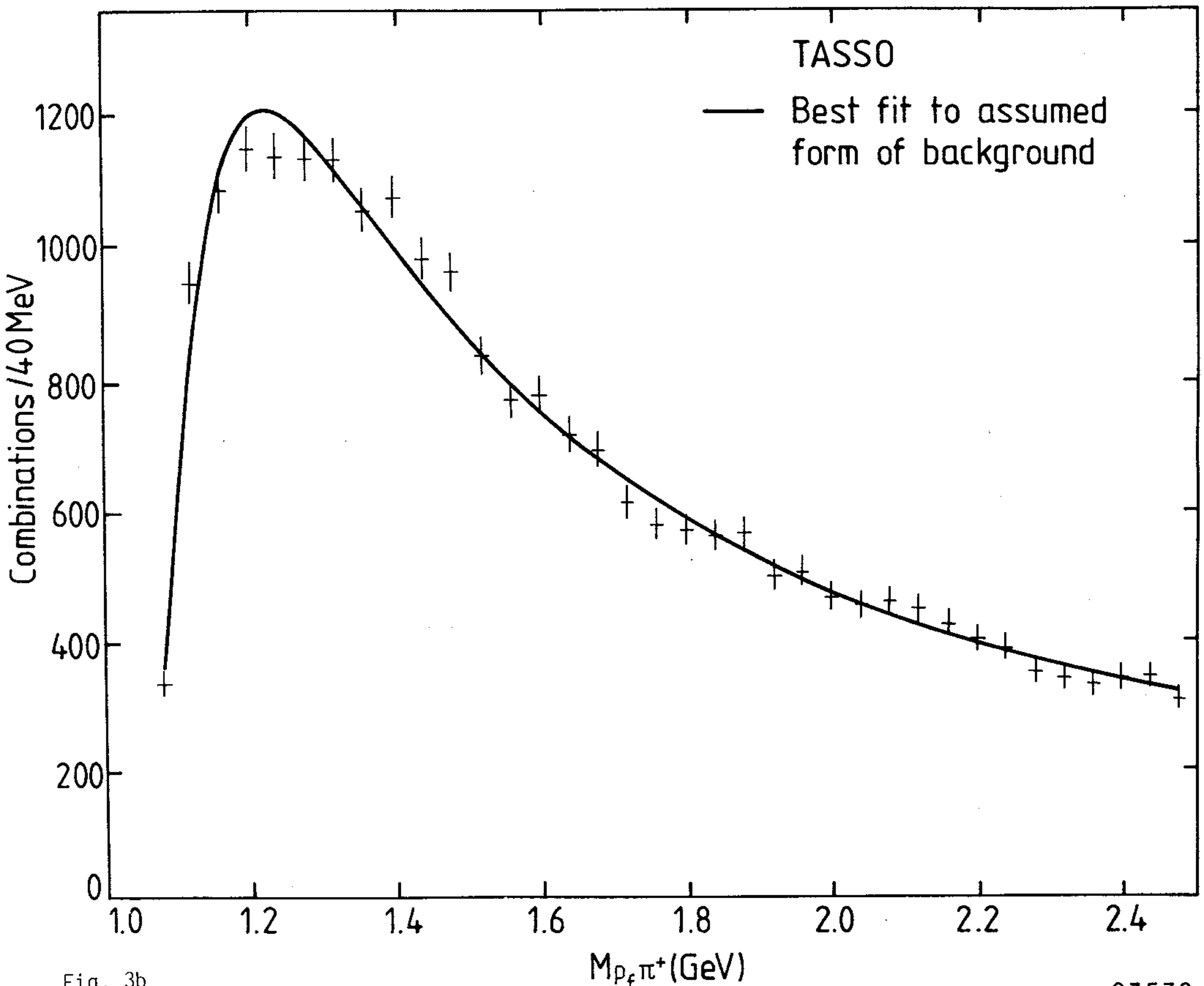

TASSO
Best fit to assumed form of background
1200
1000
800
600
400
200
0
Combinations /40 MeV
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
$M_{\rho_f \pi^+}$ (GeV)

Fig. 3b

37570

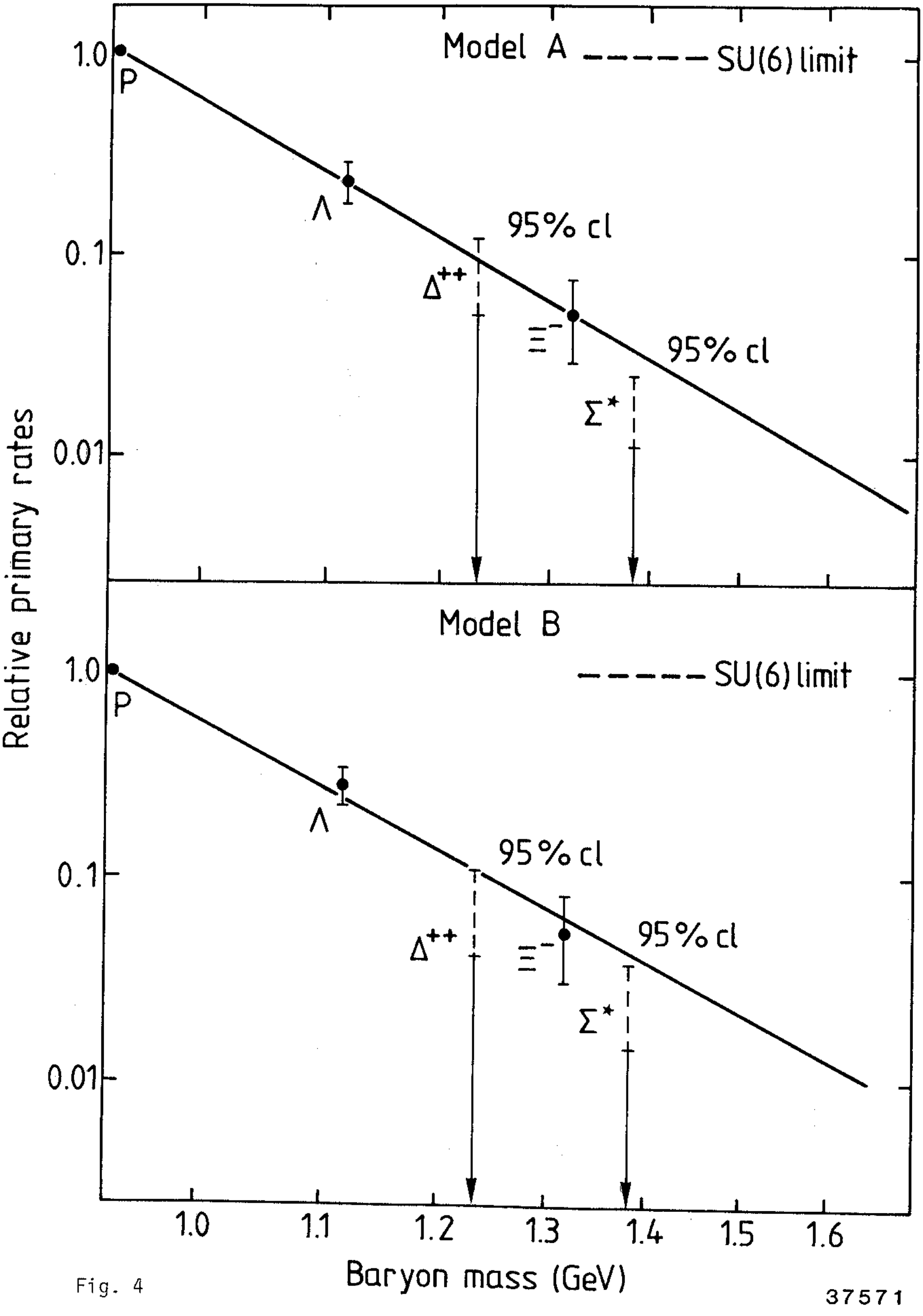

Model A
SU(6) limit
1.0
0.1
0.01
P
Λ
95% cl
Δ++
Ξ−
95% cl
Σ*
Model B
SU(6) limit
1.0
0.1
0.01
P
Λ
95% cl
Δ++
Ξ−
95% cl
Σ*
1.0
1.1
1.2
1.3
1.4
1.5
1.6
Relative primary rates
Baryon mass (GeV)

Fig. 4

37571