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THE PRODUCTION OF $\overline{\Sigma}^{\pm}$'S IN e^+e^- ANNIHILATIONS*

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ABSTRACT

We find an increase in $\overline{\Sigma}^{\pm}$ production between $E_{cm} = 4$ and 7 GeV which is consistent with charmed baryon production models. A search for the decay $\overline{\Lambda}_c^- \to \overline{\Sigma}^{\pm}\pi^{\mp}\pi^-$ yields no significant peaks.

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This Letter reports on the production of charged anti-sigmas ($\overline{\Sigma}^{\pm}$) produced in e^+e^- annihilations. The measurements are of particular interest because they span the center-of-mass energy threshold of $\sim$ 4.5 GeV presumed for charmed baryon production, where increased inclusive production should be seen for all baryons and in particular for the strange "ground-state" weakly-decaying baryons Λ° (which includes $\Sigma^\circ \rightarrow \Lambda^\circ\gamma$) and $\Sigma^{\pm}$. Piccolo, et al.[1] have reported threshold-like increases in proton and Λ production in this region. Our results, which necessarily have low statistics because of the low efficiency for identifying $\overline{\Sigma}^{\pm}$'s, indicate (a) an increase from essentially no signal at $E_{cm} \equiv \sqrt{s} \simeq 4$ GeV to a distinct, noticeable signal at $E_{cm} \simeq 7$ GeV which is in the range expected from simple charmed baryon production models, and (b) that charmed baryon decay modes involving $\overline{\Sigma}^{\pm}$ may in fact be preferred to those involving $\overline{\Lambda}^\circ$. Production of $\overline{\Sigma}^{\pm}$'s from the ψ resonance is also reported.

The experiment was performed at the Stanford Linear Accelerator Center (SLAC) using the colliding beam facility SPEAR.[2] Two identical packages were added to the sides of the Mark I Magnetic Detector in order to identify anti-neutrons by signatures involving one or more wide angle tracks indicative of high Q-value annihilations.

The Magnetic Detector, which has been described previously,[3] is a large azimuthally-symmetric cylindrical solenoid, and covers approximately 65% of the solid angle. Starting from the center, it consists of 2 layers of proportional chambers, 4 sets of double-plane magnetostrictive spark chambers, a ring of 48 timed scintillation trigger counters (T) with a resolution of $\sigma = 0.4$ nsec, an aluminum coil which produces a uniform 4 kg magnetic field parallel to the beam, a cylindrical array of 24 lead-scintillation shower counters, and finally iron flux return plates. The T counter timing, along with the momentum measurement, allows separation of $\pi/K/p$ up to 0.6 GeV/c and K/p up to 1.0 GeV/c.

For this experiment, the two vertical side flux plates were replaced by the anti-neutron packages. Each $\bar{n}$ package contains 7 magnetostrictive spark chambers, 1.5 m high and 2.7 m long with both x and y readout, interspersed with 4 steel plates, each 2.5 cm thick, and followed by a vertical wall of 5 timed scintillation counters (A) with a resolution of σ = 0.5 nsec. Together, the packages subtend 11% of 4π steradians. The timing from the A and T counters is used to determine the momentum of neutral particles producing prongs in the packages. Figure 1 shows a picture of a typical event.

Table 1 lists the number of hadronic events detected and the integrated luminosity for the three center of mass energies where data were taken. The "4 GeV" sample includes energies from 3.7 to 4.4 GeV, with 36% at 4.02 GeV and 50% at 4.40 GeV. The "7 GeV" data runs from 5.7 to 7.5 GeV.

Each event is searched for straight tracks in the $\bar{n}$ spark chambers which are not matched to a charged track in the Magnetic Detector. Computer-drawn pictures were made of all the remaining events in which a track points to a fired A counter or back to a struck T counter. A preliminary scan was performed by a physicist and trackfinding mis-identifications, cosmic rays, and simple QED interactions were rejected. A large fraction of the photon background was removed by placing cuts on counter timing, the number of extra sparks in the $\bar{n}$ chambers, and shower counter pulse heights. The sample still contains a fairly large photon background as well as tracks caused by K_L°'s, neutrons and anti-neutrons.

An anti-neutron can be further distinguished from these background interactions by its annihilation signature--one or more prongs at reasonably large angles from the anti-neutron direction. All events with a fired A counter are required to have at least one prong $\geq 30°$ from the line between the interaction region and the annihilation point. Since the T counters are much closer to the beams and are not shielded from photons, their background is worse. To keep events using their timing, we require the presence of a visible track going back into the Magnetic Detector, as well as a forward track at any angle into the $\bar{n}$ spark chambers. This leaves 110 events at 4 GeV, 203 at 7 GeV, and 198 from the ψ data.

A Monte Carlo program is used to find an average β for a produced pion. The time for the pion to travel to the counter from the annihilation position is subtracted from the counter timing. This gives the $\bar{n}$'s time of flight to the annihilation point and its momentum vector can then be found.

Charged tracks in the Magnetic Detector are used to form mass combinations with the anti-neutron candidates. To compensate for the $\bar{\Sigma}^- - \bar{\Sigma}^+$ mass difference, a relative spectrum is made by subtracting the appropriate $\bar{\Sigma}$ mass (either 1.189 or 1.197 GeV) from each mass combination, depending on the charge of the pion used. Figure 2 displays the resulting invariant mass distributions.

A least squares fit was performed on the data using a polynominal plus a Gaussian with variable strength, offset, and width. We find widths of ~ 10 MeV which are consistent with our Monte Carlo calculations. The resulting number of $\bar{\Sigma}^{\pm}$ events are listed in Table 1. The 7 GeV $\bar{\Sigma}^{\pm}$ momentum spectrum peaks at ~ 1 GeV/c with population from 0.2 to 1.7 GeV/c.

The anti-neutron detection efficiency is calculated by a Monte Carlo which includes anti-nucleon annihilation cross sections on heavy nuclei, angular distributions of prongs, and attentuation of prongs as they traverse the nucleus.[4] It predicts an average absolute $\bar{n}$ identification efficiency of $\sim$ 16% $\mp$ 3%, which peaks at 17% at 0.8 GeV/c and falls to 13% at 0.2 and 2.0 GeV/c. The Monte Carlo is checked by measuring the number of $\bar{p}$'s identified by the Mark I (< 1.0 GeV/c) which produced wide-angle prongs in the $\bar{n}$ packages. Good agreement is found between these experimental numbers and the predictions.

Neutrons from $\Sigma^{\pm}$'s are the only background which would preferentially give events near the $\bar{\Sigma}$ mass. This background is estimated by two independent procedures. In one, a search is made in the "$\bar{n}$" events for protons or antiprotons identified in the Mark I by their time of flight. From baryon conservation, the presence of a $\bar{p}$ would signify a neutron in our package. The other method is to compare the actual number of identified p's and $\bar{p}$'s which produce prongs greater than 30° in the packages, since n's and $\bar{n}$'s should behave similarly. Both procedures yield a neutron background of $\sim$ 15%.

Subtracting this background and using the $\bar{n}$ detection efficiency as well as the general hadronic trigger efficiency of $\sim$ .45 to .65,[5] we find the fraction (f) of hadronic events which contain an $\bar{\Sigma}^{\pm}$ and thus the inclusive $\bar{\Sigma}^{\pm}$ cross section ($\sigma_{\bar{\Sigma}^{\pm}}$). We also define

$$R_{\bar{\Sigma}^{\pm}} \equiv \frac{\sigma_{\bar{\Sigma}^{\pm}}}{\sigma_{\mu\mu}} = f \cdot R \text{ where } R \equiv \frac{\sigma_H}{\sigma_{\mu\mu}} \text{ and}$$

σ_H and $\sigma_{\mu\mu}$ are the total hadronic and muon point cross sections, respectively.

Our results for the three center of mass energies are given in Table 1. There are no other data on inclusive strange baryon production from the ψ with which to compare our results. However, branching rations to $\Lambda^{\circ}\bar{\Lambda}^{\circ}$ and $\Sigma^{\circ}\bar{\Sigma}^{\circ}$

indicate that these exclusive channels are less than 10% of the inclusive production. Comparison with inclusive $\overline{p}$ rates at the ψ[7] allow a determination of the ratio $\overline{\Sigma}^{\pm}/p$ of 0.16 ± 0.08.

The values of $R_{\overline{\Sigma}^{\pm}}$ at 4 and 7 GeV are plotted in Figure 3, along with the results for $R_{\overline{p}}$ and $R_{\overline{\Lambda}}$.[1] Within our limited statistics, we find a notable increase in $\overline{\Sigma}^{\pm}$ production between 4 and 7 GeV, possibly indicative of the opening of a new channel for $\overline{\Sigma}^{\pm}$ production. Ignoring the change due simply to the increase in center of mass energy, we find $\Delta R_{\overline{\Sigma}^{\pm}} = .12 \pm .05$, compared with $\Delta R_{\overline{p}} \simeq .17$ and $\Delta R_{\overline{\Lambda}} \simeq .025$ from Piccolo, et al.[1]

These results are consistent with simple expectations for charmed baryons, namely: If we assume that $R_{charm} \simeq R/3 \simeq 1.8$, that 15% of charmed events at $\sqrt{s} \simeq 7$ GeV contain baryons (compared with $\sim$ 12% for normal baryons where the baryon-meson mass difference is larger), and that 50% of these yield strange baryons (the other 50% yield normal baryons plus strange mesons or a Cabibbo-suppressed decay mode), then we would expect $\Delta R(\overline{\Sigma}^{\pm} \text{ or } \overline{\Lambda}^{\circ}) \simeq 0.14$. The relatively small value of $\Delta R_{\overline{\Lambda}}$ (which includes $\overline{\Sigma}^{\circ} \rightarrow \overline{\Lambda}\gamma$) and large value of $\Delta R_{\overline{\Sigma}^{\pm}}$ may reflect preferential cascade decays, e.g., intermediate $\overline{\Lambda}(1405)$ states, which decay 100% of the time to $\overline{\Sigma}\,\pi$. There is a suggestions of an excess in our data in this region: $\sim$ 35% of our $\overline{\Sigma}^{\pm}$'s have an associated $\overline{\Sigma}^{\pm}\pi^{\mp}$ mass solution within 1405 ± 25 MeV.

A search is made in the 7 GeV $\overline{\Sigma}^{\pm}$ sample, using the remaining charge pions in the events, for $\overline{\Lambda}_c^-$ [8] candidates via reconstruction of $M_{\overline{\Sigma}^{\pm}\pi^{\mp}\pi^-}$ and also for the decay chain $\overline{\Sigma}_c/\overline{\Sigma}_c^* \rightarrow \overline{\Lambda}_c\pi^{\pm}$.[8] Recent experimental[9] and theoretical[10] results appear to place $M_{\overline{\Lambda}_c}$ at $\sim$ 2.26 GeV; $\Delta M_c^* \equiv M_{\overline{\Sigma}_c^*} - M_{\overline{\Lambda}_c} \simeq .16$ GeV and $\Delta M_c^* \equiv M_{\overline{\Lambda}_c^*} - M_{\overline{\Lambda}_c} \simeq .23$ GeV with widths of 1 - 20 MeV.

No significant mass peaks are found. There is one event in the 2.24 - 2.28 GeV region of the $M_{\overline{\Sigma}^{\pm}\pi^{\mp}\pi^{-}}$ plot, which does not satisfy the $\overline{\Sigma}_c/\overline{\Sigma}_c^{*}$ decay scheme, compared with equivalent side-bin population of ~ 1.1 events.[11] Using a detection efficiency for each additional pion of .7, one event corresponds to a $\sigma_{\overline{\Lambda}_c}$ x BR $(\overline{\Lambda}_c \rightarrow \overline{\Sigma}^{\pm}\pi^{\mp}\pi^{-})$ of 26 pb and an $R_{\Lambda_c} \equiv \frac{\sigma(\overline{\Lambda}_c \rightarrow \overline{\Sigma}^{\pm}\pi^{\mp}\pi^{-})}{\sigma_{\mu\mu}}$ of 0.14. Thus we obtain an upper limit, at the 90% confidence level, of $\sigma_{\overline{\Lambda}_c}$ X BR < 56 pb and $R_{\overline{\Lambda}_c}$ < .050 for the mass range of 2.24 - 2.28 GeV. However, reasonable assumptions on the $\overline{\Lambda}_c \rightarrow \overline{\Sigma}^{\pm}\pi^{\mp}\pi^{-}$ branching ratio indicate that the absence of a peak is not inconsistent with the level of charmed baryon production suggested by our inclusive $\overline{\Sigma}^{\pm}$ measurement.[12]

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FOOTNOTES

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11. We do find three events clustered in the region $M_{\overline{\Sigma}^{\pm}\pi^{\mp}\pi^{-}} \sim 2.310$ GeV with $\Delta M_c^* \simeq .20$ to $.26$ GeV compared with a typical occupation of ~ 0.3 in nearby bins.

12. Assuming the entire increase in $\overline{\Sigma}^{\pm}$ production to be due to charmed baryons decay, that the non-leptonic branching fraction is 0.9, and that the $\overline{\Sigma}^{\pm}$ is accompanied by two pions 30% of the time (M. Peshkin and J. Rosner, Nuc. Phys. B122, 144 (1975)), of which 65% form the observable

combination $\overline{\Sigma}^{\pm}\pi^{\mp}\pi^{-}$, (J. Rosner, CC-2200-102, Princeton Univ., presented at the Coral Gables Conference, 1977) then $R_{\overline{\Lambda}_c} \sim .02$ is predicted.

$\langle \sqrt{s} \rangle$ (GeV)	Hadronic Events Detected	$\int L dt$ (pb^{-1})	$\bar{\Sigma}^{\pm}$'s Detected	$\sigma_{\bar{\Sigma}^{\pm}}$ (nb)	f ($\sigma_{\bar{\Sigma}^{\pm}}/\sigma_H$)	$R_{\bar{\Sigma}^{\pm}}$ ($\sigma_{\bar{\Sigma}^{\pm}}/\sigma_{\mu\mu}$)
4	51,000	3.4	2.8 ± 3.8	.11 ± .14	.004 ± .005	.023 ± .029
7	74,000	11.5	26.5 ± 7.3	.26 ± .07	.027 ± .007	.14 ± .04
ψ (3.1)	91,000	.23	13.5 ± 5.1	9.1 ± 3.4	.010 ± .004	1.0 ± .4

TABLE I. The data taken are the results for the three center of mass energies.

LIST OF FIGURE CAPTIONS

Figure 1. Schematic of a typical event in which an $\bar{n}$ emerged to the right, annihilated in a shower counter with the spark chambers recording two forward fragments, one of which fired an A counter with a timing yielding $\beta_{\bar{n}} < 1$.

Figure 2. The invariant mass distributions for $\sqrt{s}$ = 4 GeV, 7 GeV, and the ψ resonance.

Figure 3. $R_{\bar{\Sigma}^\pm} \equiv \sigma_{\bar{\Sigma}^\pm}/\sigma_{\mu\mu}$ and $R_{\bar{\Lambda}}$ and $R_{\bar{p}}$ from Ref. #1 are plotted against $\sqrt{s}$.

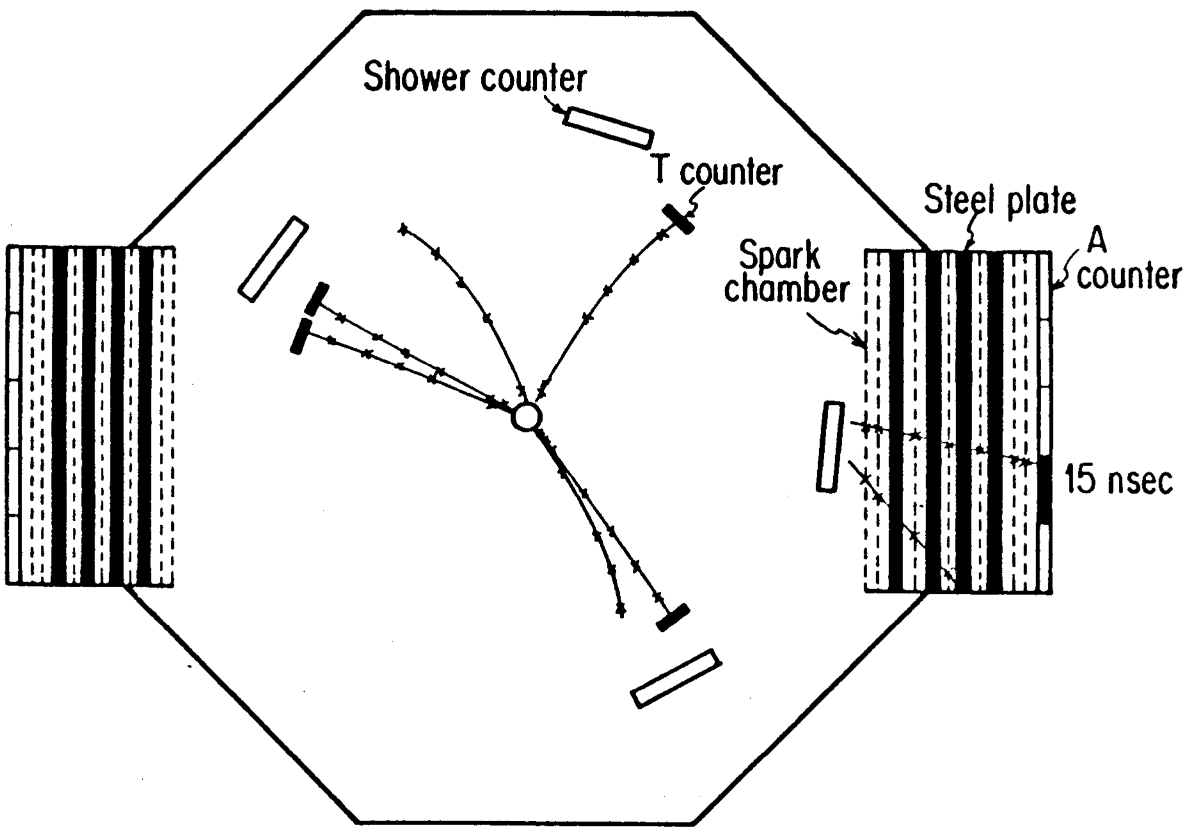

Shower counter
T counter
Steel plate
A
counter
Spark
chamber
15 nsec

Fig. 1

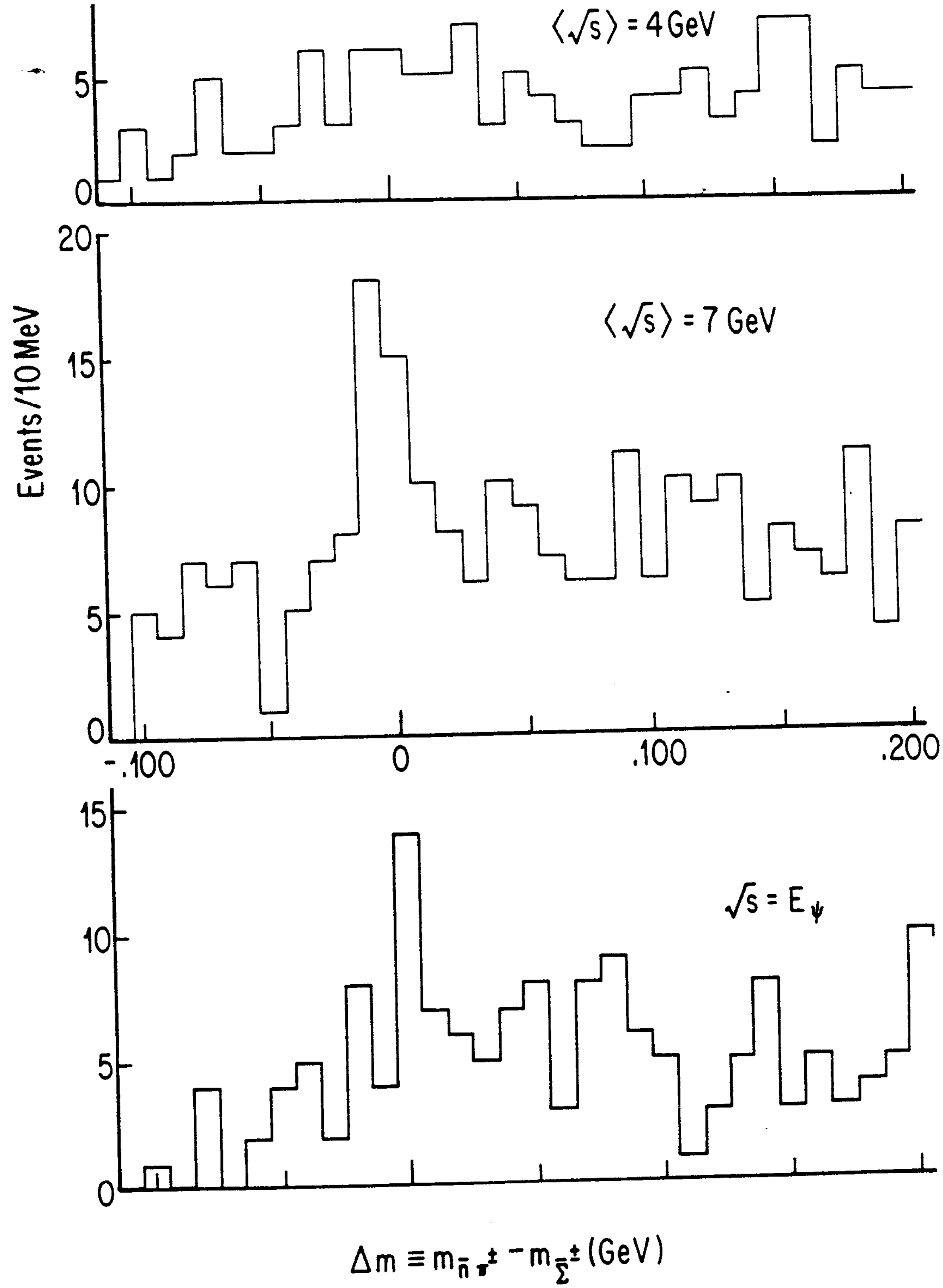
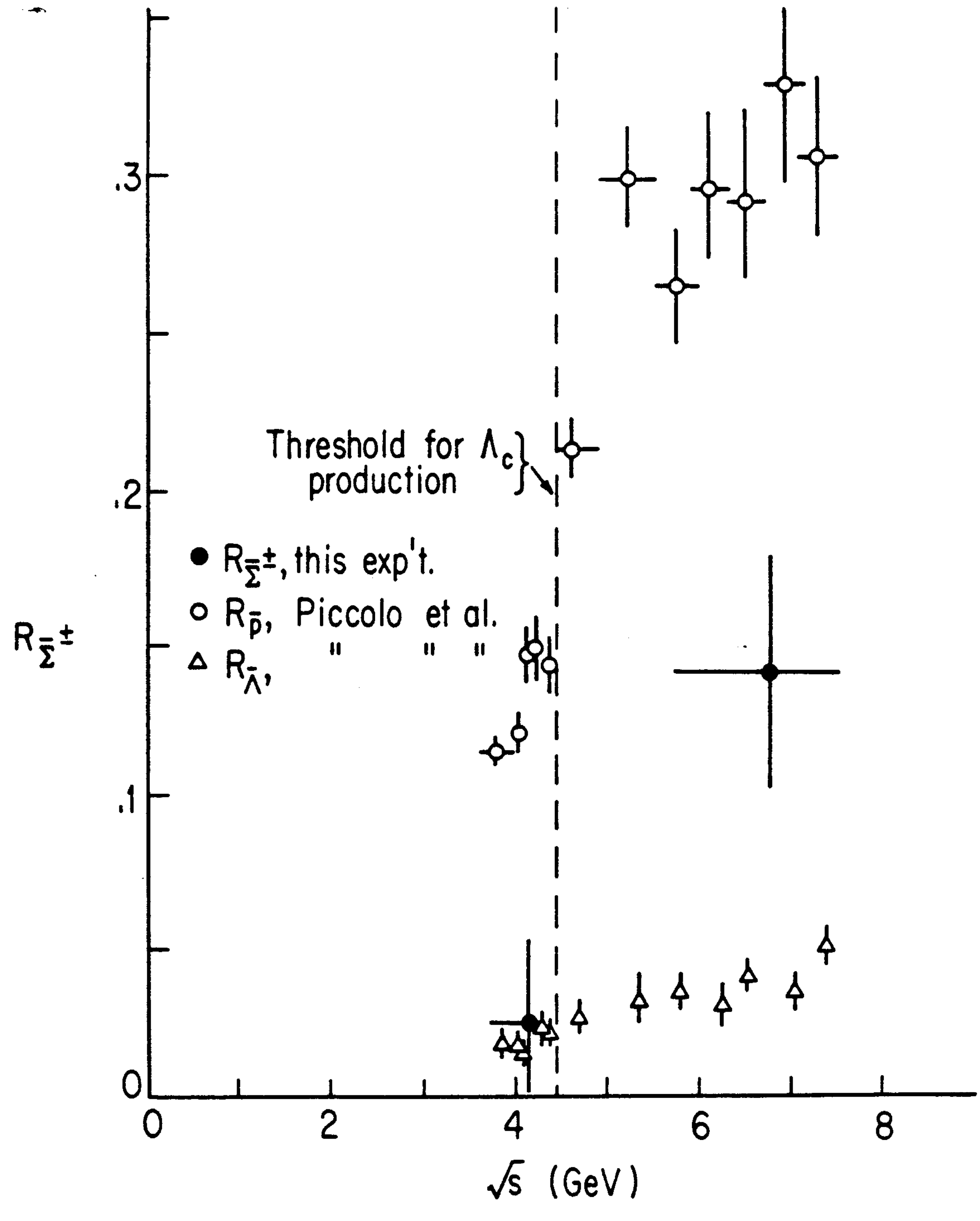

⟨√s⟩ = 4 GeV
⟨√s⟩ = 7 GeV
√s = E_ψ
Events/10 MeV
0
5
10
15
20
-.100
0
.100
.200
Δm ≡ m_{n̄π±} − m_{Σ̄±} (GeV)

Fig. 2



Threshold for Λc production
R$_{\bar{\Sigma}^{\pm}}$, this exp't.
R$_{\bar{p}}$, Piccolo et al.
R$_{\bar{\Lambda}}$, " " "
R$_{\bar{\Sigma}^{\pm}}$
.3
.2
.1
0
0
2
4
6
8
√s (GeV)

Fig. 3