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PS185 Detector Upgrade for the Measurement of $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0 + \Lambda\bar{\Sigma}^0$

memo prepared by
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Introduction

This note is provided in order to state the physics goals and present status of experiment PS185 relevant to a beam-time allocation for November/ December of 1989. The request, as previously outlined in Kurt Kilian's oral presentation to the PSCC in November of 1988, is 4 weeks of main user time at two high-momentum settings of the LEAR machine. Approximately two weeks would be spent ($\geq 10^{12}$ antiprotons) at a few momenta just above 1650 MeV/c in order to measure the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0 +$ cc ; $\Sigma^0 \rightarrow \Lambda\gamma$ at and near threshold (1653 MeV/c). The additional time would be spent at approximately 1820 MeV/c. This is below the competing $\Sigma\bar{\Sigma}$ and $\bar{\Lambda}\Lambda\pi^0$ thresholds, yet at a place where the $\bar{\Lambda}\Sigma^0 +$ cc total cross section has risen to a value that will allow a high-statistics determination of the spin observables of the system, such as the polarizations of the outgoing hyperons.

Based on the positive reception by the PSCC to the most recent PS185 status report, we have been vigorously constructing a calorimetric gamma detector which would enable us to observe the decay gamma from the Σ^0, thus "tagging" it. This detector is the same one which is being prepared for the JETSET experiment, PS202, and as such we have a second strong motivation in seeing that it is realized promptly. A subsection of this detector is installed behind experiment PS185 for use during the running period in May / June 1989. Our construction schedule is being designed such that the entire device will be prepared by November 1989. The sections below delineate the physics interest in this study and the current status of tests, plans and calculations.

Physics

Overview

The Λ and the Σ^0 hyperons both are composed of a (uds) quark triplet. The Λ differs from the Σ^0 only in the isospin and spin of the (ud) quark pair. For these, I=S=0 for the Λ, while I=S=1 for the Σ^0. The Σ^0 has a lifetime of 7×10^{-20} sec and decays with a 100% branch to $\gamma\Lambda$. Experimentally, the reactions

$$\bar{p}p \rightarrow \bar{\Lambda}\Lambda, \qquad (1)$$

and

$$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0 \,;\; \Sigma^0 \rightarrow \Lambda\gamma; \qquad (2a)$$

$$\bar{p}p \rightarrow \bar{\Sigma}^0\Lambda \,;\; \bar{\Sigma}^0 \rightarrow \bar{\Lambda}\gamma \qquad (2b)$$

look very similar with the exception that in processes (2a) and (2b) the observed $\bar{\Lambda}\Lambda$ pairs do not have two-body kinematics, one lambda having been given a momentum kick by the recoiling gamma. The separate reactions (2a) and (2b) are only different by charge conjugation, which does not affect the production mechanism. An operation of C on the incoming and exiting channels in Figure 1 changes reaction (2a) to (2b). Experimentally, one has to identify whether the observed $\bar{\Lambda}$ came from an initial $\bar{\Sigma}^0$ or whether the observed Λ came from an initial Σ^0. If the identification is made incorrectly, then the assigned center-of-mass angle will be incorrect and the differential cross section that results will be smeared. The difference between the correct and the incorrect cms angle for the antihyperons is not large at high incident antiproton momentum, but it becomes a troublesome worry near threshold.

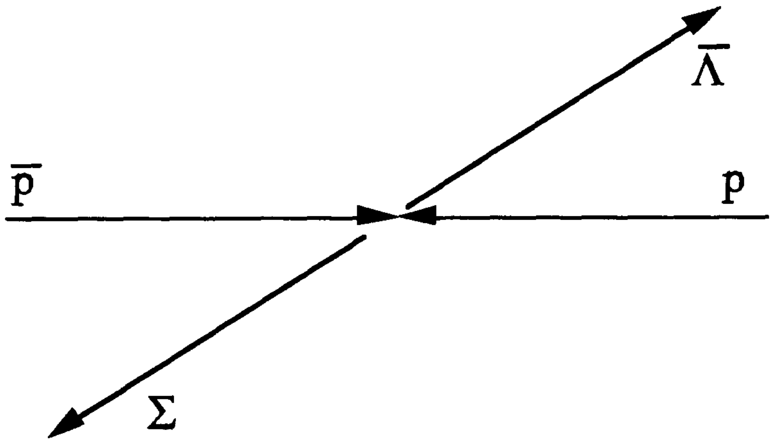

Figure 1
The reaction $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$ in the center-of-mass system.

Because the decay $\Sigma^0 \rightarrow \Lambda\gamma$ conserves parity, the Σ^0 polarization can be determined from a measurement of the polarization of the decay Λ, with

$$P_\Lambda = -\tfrac{1}{3}P_\Sigma . \qquad (3)$$

The resulting polarization is diluted by a factor of three. Consequently, a somewhat higher event sample is required as compared to measurements of $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$. Again, the proper determination of $\bar{\Lambda}\Sigma^0$ vs $\Lambda\bar{\Sigma}^0$ is important.

Calculations

To date there have been at least 16 theoretical groups working on models which attempt to describe our precision $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ data from PS185. The calculations can be roughly grouped as either meson exchange descriptions or as "quark-gluon" models. In the meson exchange picture, K, K^*, or even K^{**} bosons are exchanged between the antiproton and proton in the initial state to form the lambda and antilambda. The relative strengths of each contributing meson is debated by the groups. The same bosons mediate the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$. Kohno and Weise[1] have recently argued the interest in a study of $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$ in that it necessarily couples somewhat differently to those mesons in the above description. For example, the weakness of the $KN\Sigma$ coupling constant compared to the $KN\Lambda$ ($g^2_{KN\Sigma}/g^2_{KN\Lambda}$ = 1/27 in SU(3)) reduces substantially the role of simple kaon exchange. This point has been made to support the notion that this reaction is sensitive to short-range dynamics and therefore more appropriate to test "quark-gluon" descriptions of hyperon-antihyperon production. Another suitable description is that the reaction must be mediated more strongly by K^* exchange. In any case, a detailed comparison of any model which has been "fine tuned" to fit the existing $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ data is afforded by this new and complimentary reaction channel.

Kohno and Weise have already extended their calculations to predict results for $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$. As shown in Figure 2a, they get good agreement with the observed differential cross section on a set of older, high-energy bubble-chamber data. In Figure 2b, they make a prediction of the behavior of the differential cross section, and of the differential polarization, at an energy which is accessible to us at LEAR.

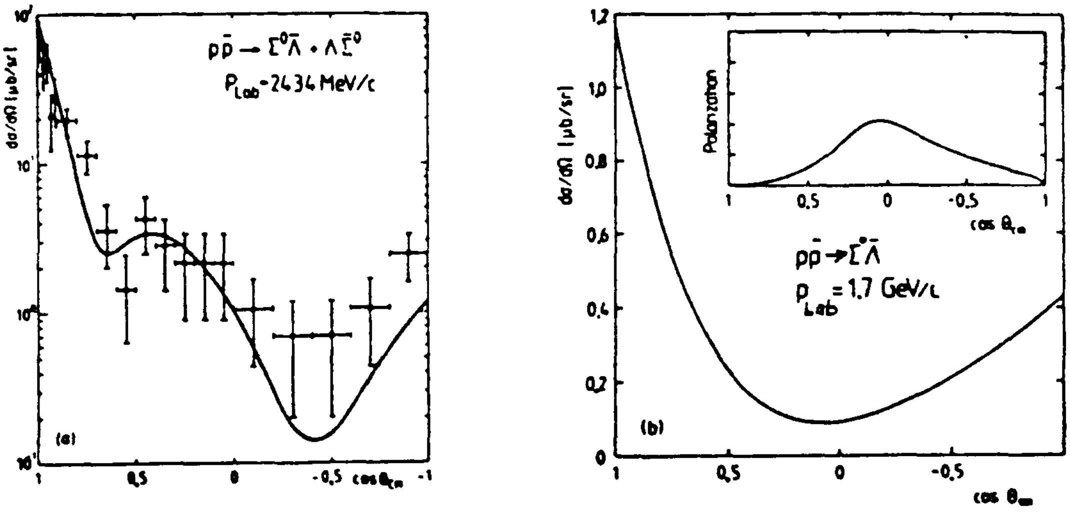

Figure 2

Data and prediction from Ref. 1 for the $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$+ cc reaction at 2.43 GeV/c (a), and a prediction using a quark-dynamical model calculation (b) for the same reaction at 1.7 GeV/c which is accessible at LEAR with the present experiment.

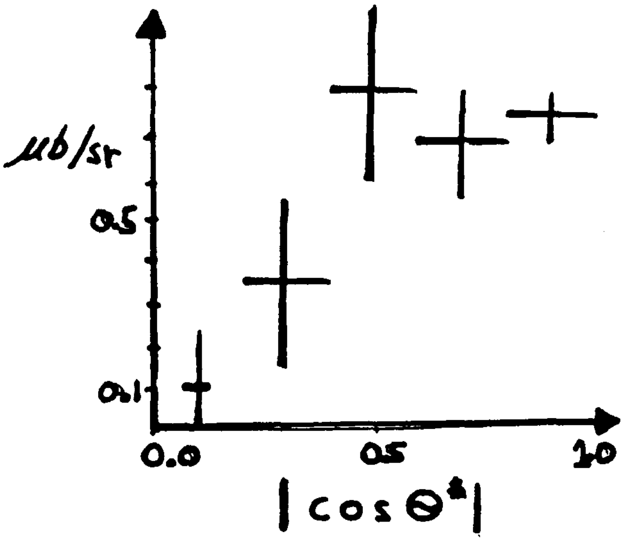

Figure 3

Preliminary symmetrized differential cross section for the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$ at 1.7 GeV/c.

PS185 Technique

Current Status

The existing PS185 detector has been described in many publications^2. Lambda - antilambda pairs are reconstructed from their charged decays which are initially tracked in the non-magnetic part of the detector. Then, identification of Λ from $\bar{\Lambda}$ is made by means of the charge distinction of the decay products in a solenoidal field equipped with 3 drift chambers. A short test run was made at 1.7 GeV/c in order to see for the first time the evidence of the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^o$+ cc. A preliminary *symmetrized* differential cross section is now available and is shown in Figure 3. A polarization analysis and unsymmetrized cross section is close to completion.

The difficulties in this measurement arise from kinematic considerations. The problems include:

- Some true $\bar{\Lambda}\Lambda$ events leak into the measured sample of $\bar{\Lambda}\Sigma^o$, $\Lambda\bar{\Sigma}^o$ events due to the fact that some corners of the decay phase space of direct-production $\bar{\Lambda}\Lambda$ pairs overlap with that of $\bar{\Lambda}\Lambda$ pairs coming from the $\bar{\Lambda}\Sigma^o$ or $\Lambda\bar{\Sigma}^o$ reaction. As our kinematic fitting programs and our detector resolution have evolved, this contaminant fraction has been reduced substantially. However, the true $\bar{\Lambda}\Lambda$ pairs have at least three times the cross section on the plateau and about ten times the cross section when the $\bar{\Lambda}\Sigma^o$, $\Lambda\bar{\Sigma}^o$ reaction is measured within a few MeV above threshold.

- Four of the target cells in PS185 are made from CH_2. A fifth cell is made from pure carbon in order to count the number of $\bar{\Lambda}\Lambda$ events which are produced from protons in the carbon nucleus. Usually these events do not survive our kinematic fitting routines because of the Fermi motion of the protons in the nucleus and the binding energy which must be spent to liberate it. The events do not exhibit good "two-body kinematics." The γ from the Σ^o decay has a similar effect on the observed Λ as that of the moving protons bound in the carbon nucleus. Ordinary $\bar{\Lambda}\Lambda$ events produced on carbon often can be confused with the desired $\bar{\Lambda}\Sigma^o$, $\Lambda\bar{\Sigma}^o$ events which have been produced on free protons. This has been found to be a sizable contaminant in our analysis of the $\bar{\Lambda}\Sigma^o$, $\Lambda\bar{\Sigma}^o$ events from the test run.

Future Plans

Plans have been developed to eliminate or greatly reduce the above difficulties. These plans include the addition of the electromagnetic calorimeter and the introduction of four planes of precision silicon microstrip beam-defining detectors. The Erlangen group will provide the microstrip detectors and the Illinois group will provide the gamma detector. The Jülich group will mount a new set of scintillators in front of the gamma detector in order to veto charged particles which might enter the array and be taken for a γ.

The microstrip detectors will be placed upstream of the target cells at two locations in order to define the direction of the incoming antiproton precisely and on an event-by-event basis. The effect of this new information will be to help define the actual lab angle of the produced Λ or $\bar{\Lambda}$. In the present analysis the average direction of the measured beam is used, which is only an approximation to the actual incoming antiproton trajectory. This contributes to the angular uncertainty of the outgoing decay lambda and thus affects the kinematic fit of the event. The microstrip detectors have been installed for the May / June 1989 PS185 run and they are used as an integral part of the apparatus.

The gamma detector will be used to *tag* the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0 + cc$; $\Sigma^0 \rightarrow \Lambda\gamma$ by an unambiguous identification of the decay γ. This information alone will eliminate the trouble caused by leak-through $\bar{\Lambda}\Lambda$ events and, more importantly, by events produced with interactions in the carbon portion of the target. Additionally, the full detector will be segmented into 300 elements such that the gamma direction will be known to about ± 20 mrad. The energy of the gamma is peaked at about 140 MeV and will be measured to about ±25 MeV by our detector. These two pieces of data introduce new kinematic information into the fitting procedure which additionally constrains the analysis of the event topology.

<u>The Gamma Detector</u>

The Illinois group within PS185 is also a part of the JETSET experiment, PS202, and has there the responsibility for building the forward calorimeter and the barrel gamma veto counters. We have recently completed a subset of the forward electromagnetic calorimeter and we are installing it behind the existing PS185 apparatus for the running period May / June 1989 in which PS185 is the main LEAR user. This involves an array of 32 calorimeter "towers" as shown in Figure 4. Each of the detectors is made using the Pb/SCIFI technique. Prototypes have exhibited excellent resolution, typically $\sigma/\sqrt{E(GeV)} = 6\%$. Additional details of the tower construction and tests are available[3]. The proposed configuration for the dedicated run is shown in Figure 5 with the entire PS202 forward calorimeter, shown in Figure 6, located just downstream of the baryon identifier magnet. In preparation for this new installation, the iron at the rear of the solenoid magnet has been cut away to allow undisturbed passage of the gammas into the calorimeter. Additional modifications by the Freiburg and Jülich groups to the magnet allow for proper flux return. This work has recently been completed and the magnet is in operation.

The test in May / June will verify the performance of all essential components for our projected Nov/Dec 1989 run where we aim at a clean measurement of the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0 + cc$; $\Sigma^0 \rightarrow \Lambda\gamma$. A Monte-Carlo simulation of this reaction was performed at 1.9 GeV/c incident antiproton momentum (where PS185 will run in June) in order to calculate the acceptance based on only 10% of the completed detector. It is found to be ≈ 2%. We hope to collect a reasonable sample of candidate events during our present run using the fraction of the detector which will be in place at that time. A planned upgrade by the Uppsala and Illinois groups to the current kinematic fitting routine will take place in August of this year at which time all of the information from the new detectors (μstrips and γ detectors) will be available.

Monte-Carlo studies have been made in order to plan for a run using the entire calorimeter to tag the gammas. For example, a histogram of cos θ^* for the Σ^0 of *accepted* events based on the entire calorimeter array (300 towers) is shown in Figure 7. The acceptance distribution is clearly quite flat as hoped. The acceptance fraction is ≈ 26% at 1.675 GeV/c. The corresponding gamma energy (again for the accepted events) is shown in Figure 8. Since the cross section and acceptance for $\Lambda\Sigma^0$ events is reduced by factors of 3 and 4 compared to that for $\bar{\Lambda}\Lambda$ events, we will require about 10 times the integrated luminosity to obtain a statistically similar event sample to that found for $\bar{\Lambda}\Lambda$ events. Accordingly, this measurement will require antiproton beams of about 10^6 Hz which we have demonstrated can be used fully without additional modifications to our apparatus. Such intensities will be available in Nov/Dec 1989 when LEAR is the only consumer of antiprotons at CERN.

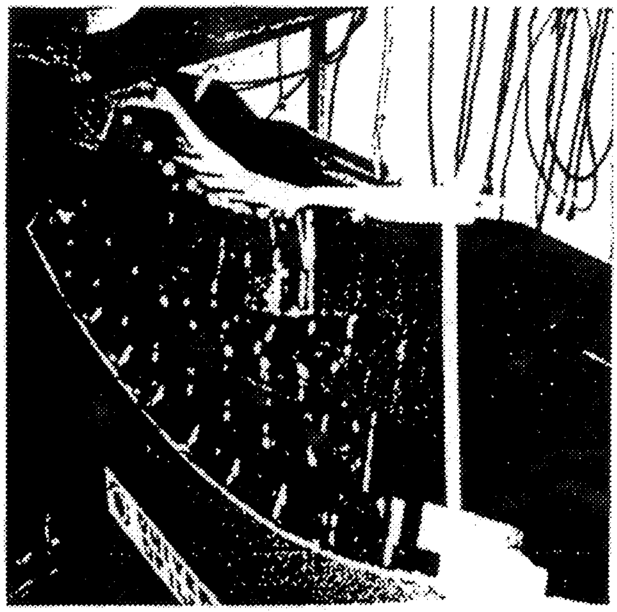

Figure 4
Photograph of recently completed "32-array" of Pb/SCIFI detectors.

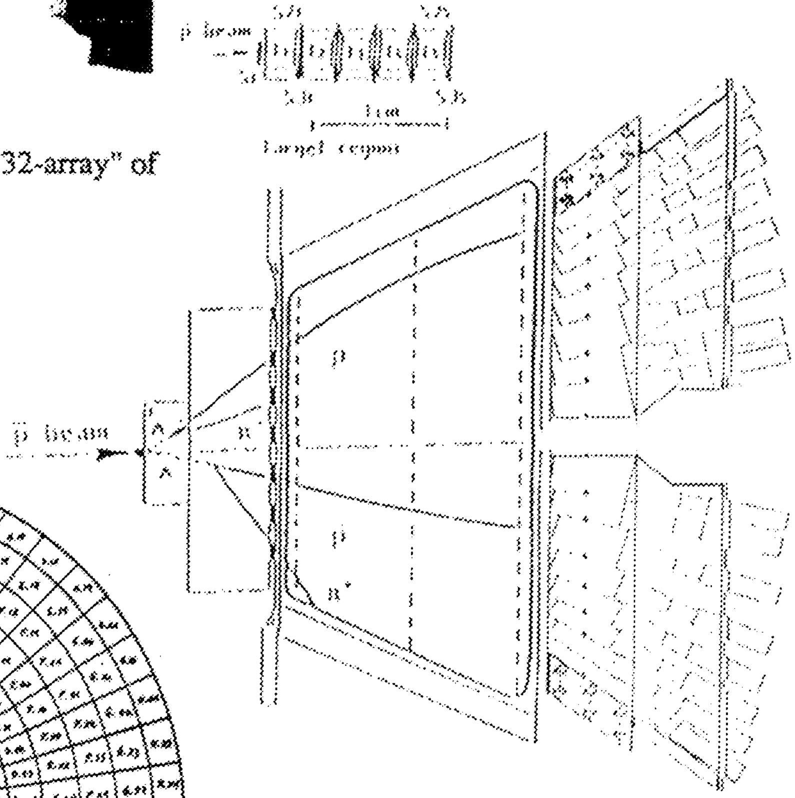

Figure 5
PS185 setup with proposed forward calorimeter placed at rear of magnet.

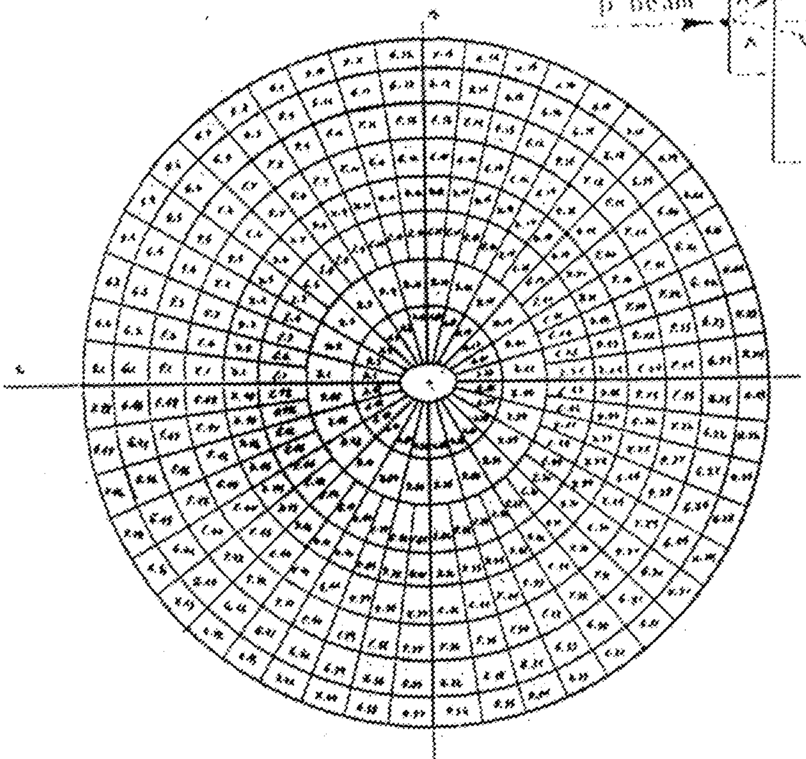

Figure 6
Geometry of 300-element forward calorimeter towers.

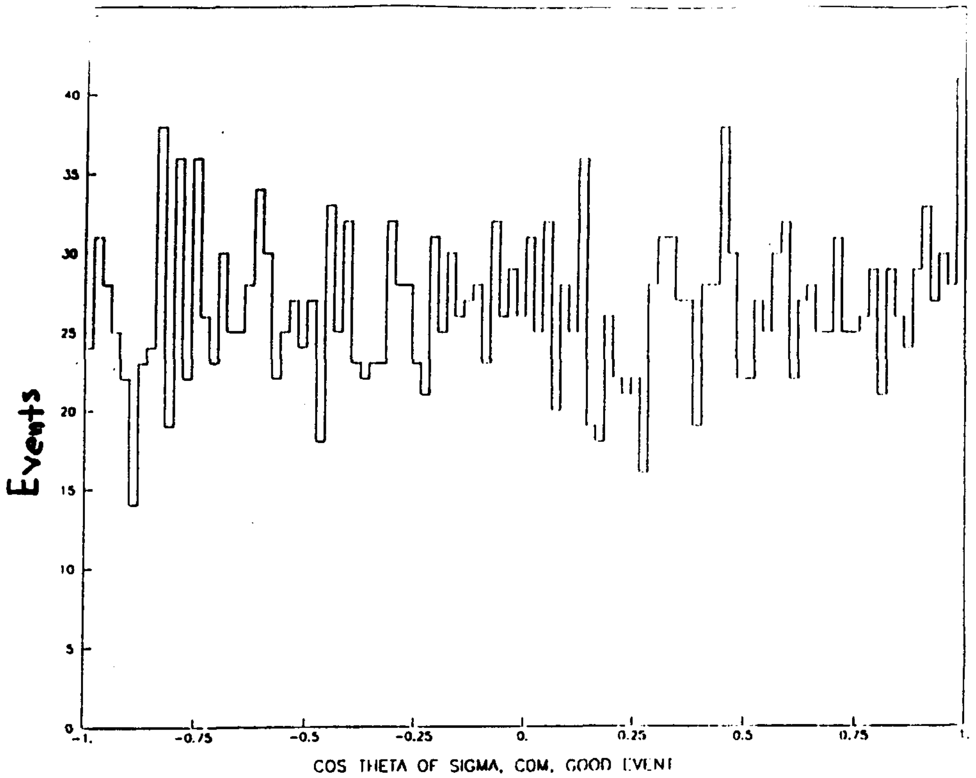

Figure 7
Results of a Monte Carlo simulation of pp → $\bar{\Lambda}\Sigma^0$+ cc ; $\Sigma^0 \rightarrow \Lambda\gamma$ for which the γ is seen by the proposed 300-element calorimeter. The antiproton momentum is 1.675 GeV/c.

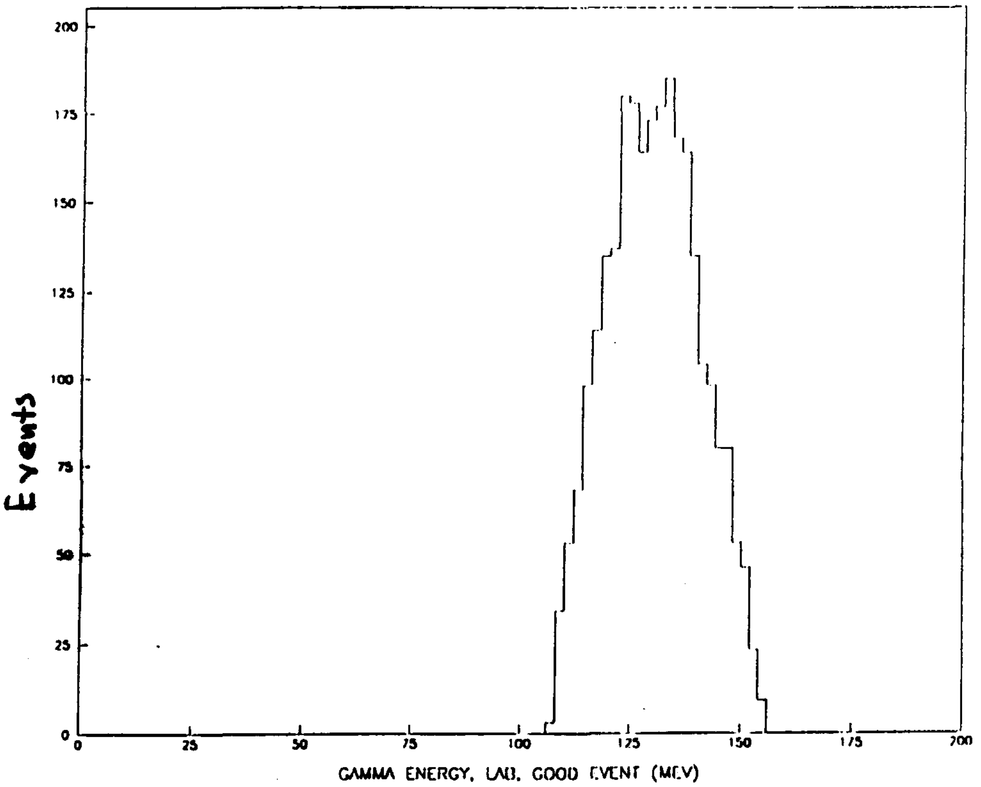

Figure 8
Energy of the γ for accepted events at 1.675 GeV/c incident antiproton momentum for the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$+ cc ; $\Sigma^0 \rightarrow \Lambda\gamma$.

Status of Detector

- The 10% of the detector to be used in the May / June run of PS185 has been completed, shipped to CERN, and installed in the experimental setup. Our prototypes have performed superbly, having been tested with electrons and gammas from 35 to 5000 MeV at Illinois, CERN and DESY.
- 268 additional towers are being constructed. The Illinois group will make every effort to have these ready in time. Currently there appear to be no insurmountable worries with the actual construction of the detectors. All the materials and labor are in-house or have been ordered.
- Recuperated photomultiplier tube bases (from CERN) are being used along with new photomultiplier tubes to read out the detectors. We have purchased 32 new PMTs for the current tests and plan to buy an additonal 268. We have already purchased the required high-voltage supplies for the photomultiplier tubes.
- We have made 32 acrylic light guides appropriate for these detectors. We are presently seeking a more cost-effective and less labor intensive method to produce the remaining 268.
- The fabrication of the charged veto counter array is well advanced in Julich.
- The CERN EP/TAG group is designing the mechanical support system of the calorimeter to be compatible with both PS185 and for PS202. This work is underway and we anticipate receiving the final drawings in time to seek out a vendor which can complete the construction.
- The Freiburg group has already provided the Fastbus-based ADC readout of the full calorimeter for the Nov/Dec run.

References

[1] M. Kohno and W. Weise, *Antihyperon-Hyperon Production in Low Energy Antiproton-Proton Reactions*, Invited talk, International Workshop on Strangeness in Hadronic Matter, Bad Honnef, June 1987, TPR 87-22, and M. Kohno and W. Weise, Phys. Lett B179 15 (1986).

[2] P.D. Barnes et al., Phys. Lett. 199B, 147 (1987), P.D. Barnes et al, Phys. Lett. 189B, 249 (1987), and numerous conference proceedings.

[3] D.W. Hertzog, P.T. Debevec, R.A. Eisenstein, M.A. Graham, S.A. Hughes, P.E. Reimer, R.L. Tayloe, *Tests of Prototype Pb/SCIFI Electromagnetic Calorimeter Modules*, Proc. of the Workshop on Scintillating Fiber Detector Development for the SSC, Fermilab, 1988, in press; also available as preprint from Univ. of Illinois.