STRANGENESS-PRODUCING REACTIONS

POLARIZATION OBSERVABLES IN $\vec{p}p \to pK^+\vec{Y}$ REACTIONS AT 2.9 GeV

S. Bossolasco, M.P. Bussa, L. Fava, L. Ferrero, R. Garfagnini, A. Grasso,
A. Maggiora, D. Panzieri, G. Piragino, F. Tosello, and G. Zosi
Istituto di Fisica and INFN, Torino, Italy

L.C. Bland, W.W. Jacobs, Y. Kim, and S.E. Vigdor
Indiana University and Indiana University Cyclotron Facility,
Bloomington, Indiana 47408

J. Arvieux, Y. Bedfer, R. Bertini, and F. Brochard
Laboratoire National Saturne, Saclay, France

F. Balestra
INFN and Universita di Cagliari, Cagliari, Italy

I.V. Falomkin, V.I. Lyascenko, G.M. Maneva, G.B. Pontecorvo, A.M. Rozhdestvensky,
M.G. Sapozhnikov, P.P. Temnikov, V.I. Travkin, and V.I. Tretyak
JINR, Dubna, Russia

We have initiated a collaboration to study polarization effects in exclusive hyperon-production reactions at the Saturne synchrotron in Saclay. The primary motivation for this work is the apparently simple systematic behavior[1] of hyperon polarizations measured in earlier inclusive production experiments at higher bombarding energies ($\sqrt{s}$=5–60 GeV). The majority of the measurements have been made for Λ^0 production, but data exist as well for heavier hyperons that also decay via the weak interaction, where the parity-violating decay asymmetry allows a direct inference of the parent's polarization. Sizable polarizations ($\gtrsim 20\%$) have been observed, of opposite sign for Λ^0 and $\Sigma^\pm$ production, with a characteristic dependence on the transverse and longitudinal momenta of the produced hyperon,[1] but essentially independent of the bombarding energy[1] and (judging from a single experiment on Λ^0 production with a polarized incident beam[2]) of the polarization state of the proton beam. These systematics suggest that there is some simple mechanism for polarizing strange quarks when they are "boosted" from the "sea" in the initial nucleons to the status of a "valence" quark in the outgoing hyperon.[1] Various models for such a mechanism have been proposed.[3–5] They do not, however, appear to have real predictive power: the quantitative analysis of new data within these models has most often been handled by adding new adjustable parameters to the calculations.[1,2]

The experiments, too, have significant problems. The existing measurements are really quite limited with regard to observables other than the production reaction polarization and to hyperons other than Λ^0. Moreover, all of the existing Λ^0 measurements suffer from a potentially serious experimental contamination problem: they have all been *inclusive* measurements, which offer no way of distinguishing whether the observed Λ^0 was produced directly in the nucleon–nucleon collision or was instead a *secondary* product resulting from the decay of a heavier hyperon. For example, the Σ^0 decays essentially instantaneously to $\Lambda^0 + \gamma$. It was estimated in Ref. 2 that 30–40% of the observed Λ^0's resulted from Σ^0 production and decay. On the basis of measurements for $\Sigma^\pm$, one expects the Σ^0 to be produced with *opposite polarization* to that characteristic of direct Λ^0 production. To complicate matters further, the polarization transfer expected from the (unobserved) Σ^0 to its daughter Λ^0 depends on the detailed detector acceptances in a specific experiment.

In short, the existing data suggest an appealingly simple behavior, which it is now important to pursue in more detail in second-generation experiments. These should be *exclusive* measurements, capable of distinguishing clearly between Λ^0 and Σ^0 production. They should utilize polarized incident proton beams (and perhaps eventually polarized proton targets as well) to access a variety of polarization observables. In keeping with a general long-term goal of hypernuclear physics — namely, to study how replacing a u or d quark by a more massive s quark affects the transition from hadronic to quark-gluon regimes — they should ideally span a correspondingly broad energy range, starting relatively close to the production threshold (where detailed calculations based on meson exchange are now becoming available[6]). We are initiating a program of such measurements at Saturne, covering the low end of the interesting energy scale, up to a bombarding energy of $\sqrt{s}$=3.0 GeV (T_p^{lab}=2.9 GeV). We begin here for experimental reasons: the techniques for resolving Λ^0 from Σ^0 production are most easily realized at the lower energies; the availability and quality of polarized proton beams at Saturne is superior to that at higher-energy accelerators.

In particular, we have proposed to make *kinematically complete* measurements of the production reactions $pp \rightarrow pK^+\Lambda^0$ and $pp \rightarrow pK^+\Sigma^0$, initiated with a polarized proton beam on a liquid hydrogen target. In coincidence with the proton and K^+ we will also detect the proton and π^- emitted in 64% of the Λ^0 decays (including the secondary Λ^0's resulting from $\Sigma^0 \rightarrow \Lambda^0 + \gamma$ decay). *All four* charged products will be tracked through a magnetic field by a combination of scintillating fiber hodoscopes (with 1 mm thick elements) and multiwire proportional chambers. The layout of a typical event is illustrated in Fig. 1. The event trigger will be based upon the multiplicity of hits recorded in the scintillating fibers and also in a plastic scintillator hodoscope of coarser grid positioned behind the wire chambers. A front-end software trigger will additionally identify strangeness production, primarily by the requirement that the particle tracks define a (Λ^0) decay vertex appreciably ($\gtrsim$1 cm) separated from the reaction vertex. The measured 4-momenta of the decay products will allow us to check that we reconstruct the appropriate mass of the decaying Λ^0, and to infer its polarization. We will distinguish Λ^0 from Σ^0 production via the "missing mass" reconstructed from the detected proton and K^+ momenta. Detailed computer simulations of the proposed apparatus suggest (see Fig. 2) that even under the most demanding conditions (highest bombarding energy at Saturne, maximum

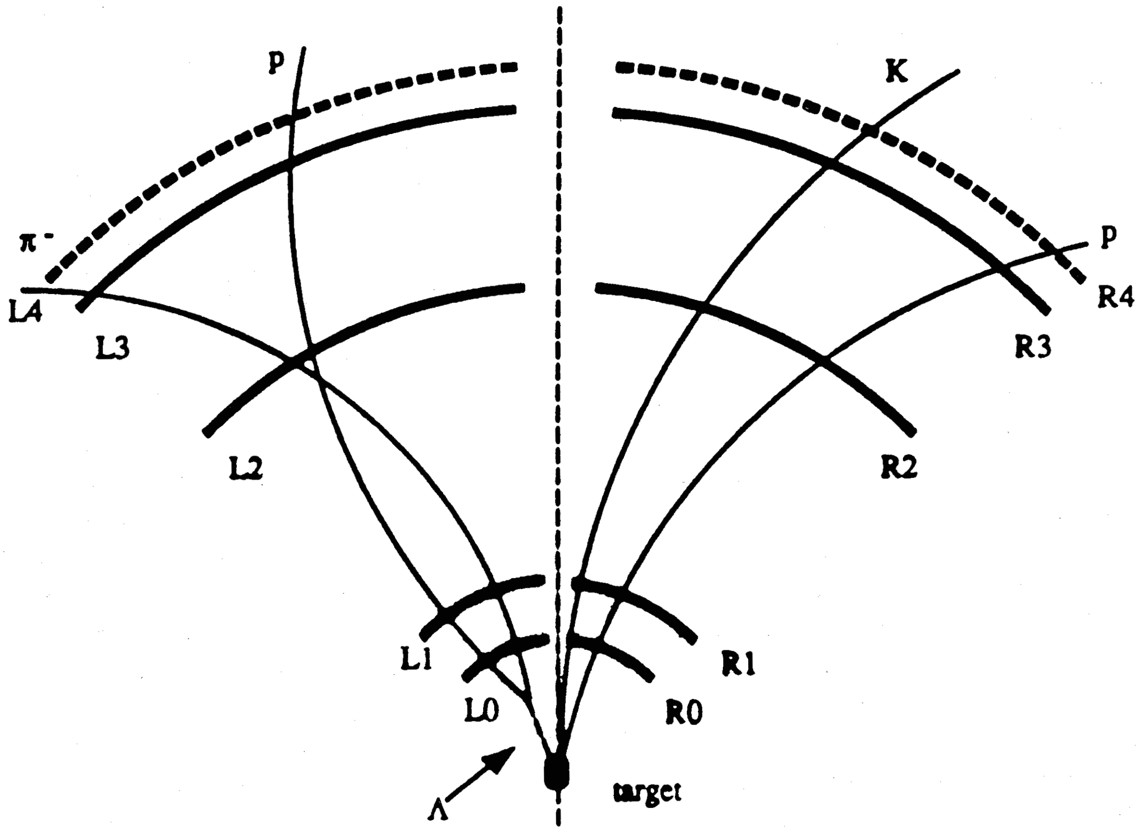

Figure 1. Schematic illustration of the horizontal projections of the four charged particle tracks for a typical pp → $pK^+\Lambda^0$ event. The inner detectors, labeled 0 and 1 in the drawing, will be scintillating fiber chambers, detectors 2 and 3 will be multiwire proportional chambers, and detector 4 will be a plastic scintillator hodoscope. In reality, the left and right detector arms will be placed symmetrically about the *curved* proton beam trajectory through the magnetic field. Each detector arm will have an acceptance of 1.5° – 47° (with respect to the beam direction) horizontally and ±21° vertically.

transverse momentum of the produced hyperon), we can achieve missing mass resolution ($\lesssim$30 MeV full-width at half-maximum) sufficient to distinguish Λ^0 from Σ^0 (mass separation = 77 MeV) with readily attainable magnetic field strengths, fiber dimensions, and wire spacings. The simulations furthermore show that background from reactions not producing hyperons can be held to a negligible level.

In addition to the clean identification of the reactions of interest, the proposed kinematically complete measurements offer a wide range of advantages. For example, they greatly enhance the quality of information that can be extracted about the Σ^0 polarization: for this purpose, one needs to reconstruct not only the polarization of the daughter

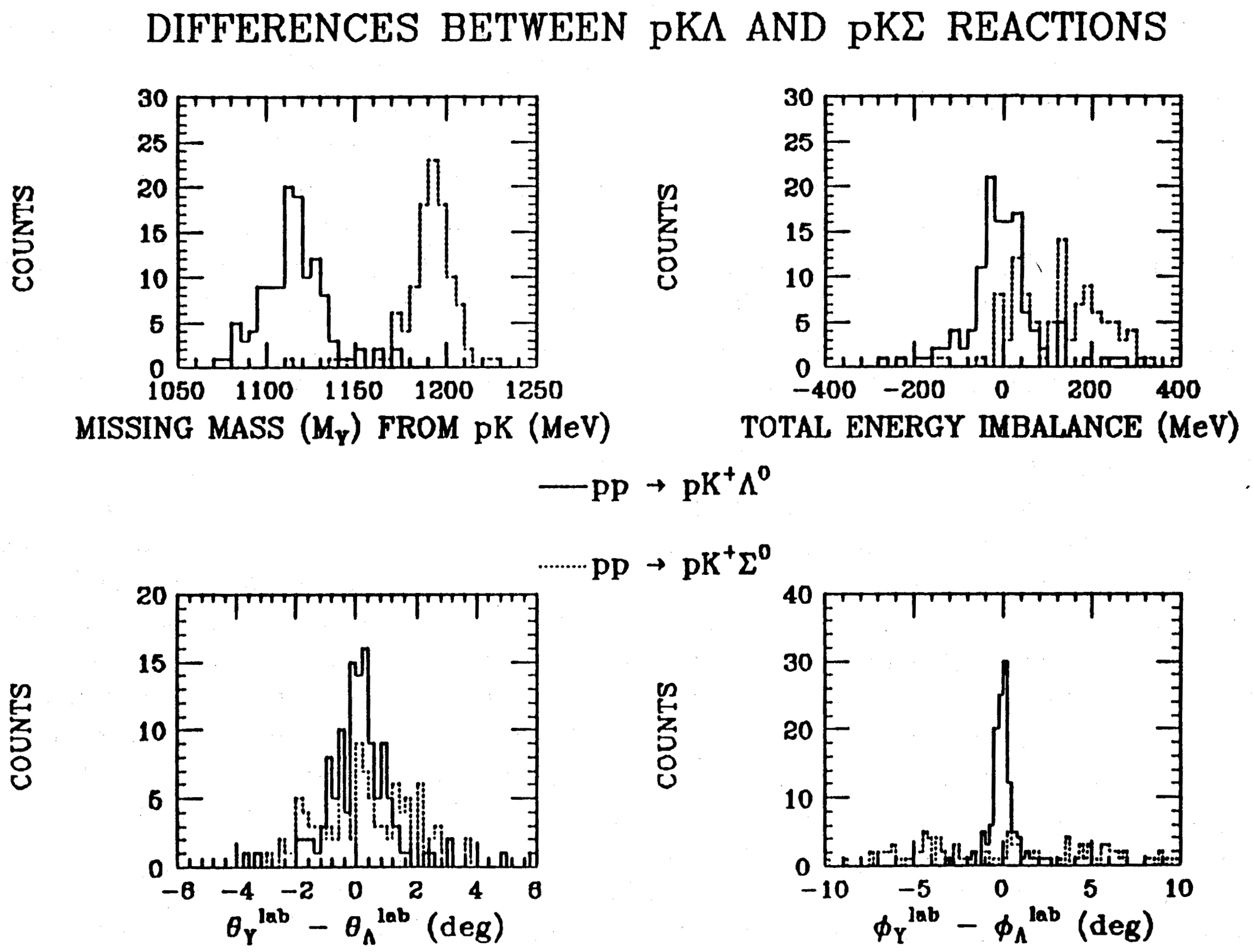

Figure 2. Results of simulations of the pp → $pK^+\Lambda^0$ and pp → $pK^+\Sigma^0$ reactions at a bombarding energy of 2.9 GeV, illustrating several observables that would be used to distinguish between the two reactions. The upper left frame shows the reconstructed missing mass spectrum and the upper right the difference between the total energy in the entrance channel and the sum of the energies of the four detected ejectiles. The lower frames show the polar and azimuthal angle differences between the hyperon (Y) reconstructed from the proton and kaon tracks and the Λ^0 reconstructed from its decay product tracks.

Λ^0, but also its emission direction in the Σ^0 rest frame. We can also study the influence of specific final-state interactions among the produced particles, by selecting data in the most strongly affected regions of phase space, e.g., where the $K^+\Lambda^0$ system has an invariant mass equal to that of known nucleon (N*) resonances, or where there is particularly low relative energy in the Λ^0p system. The low-energy Λ^0p interaction (specifically, the scattering lengths) is of great interest to theorists modeling the strong interaction;[7] measurements of the sort we propose may allow us eventually to infer the spin-dependence of these scattering lengths, information which is extremely difficult to obtain by other means.

The proposed apparatus is compact (1.4 m from target to rear detectors) and flexible. It should provide an acceptance (the product of geometric acceptance, detection efficiency, and the survival fraction of unstable decay products) $\simeq 3\%$ for the hyperon production reactions at the highest Saturne bombarding energy (with acceptance improving at lower energies). Within this acceptance, one would sample reactions covering $\sim$25% of the full phase space available to the reactions of interest (missing primarily events that are very strongly non-coplanar).

The proposal for our initial experiment (E213 at Saturne, R. Bertini, spokesman) was approved by the Saturne Comite des Experiences in June, 1991. The magnet to be used (40 cm gap, 14.7 kG maximum field strength) will be transported from CERN and installed at Saturne in Summer, 1992. The Saturne collaborators are responsible for the overall coordination of efforts, for the design and construction of the beam line, and for most of the PCOS readout electronics to be used for the scintillating fiber and multiwire chambers. The Italian groups (Torino + Cagliari) will design and assemble the scintillating fiber chambers and the trigger hardware, including the RISC processors to be used for the Level 2 (software) trigger. They will also provide the VME front-end readout software and the acquisition computer. The Dubna group is responsible for the construction of the cylindrical-section wire chambers. As detailed further below, the IUCF contingent will design and construct the plastic scintillator hodoscope and develop event reconstruction and histogramming software to be used for on-line and off-line data analysis and in the Level 2 trigger. We hope to begin data acquisition with the full detector assembly in early 1994.

Substantial progress has already been made on several relevant aspects of the experiment design at IUCF. We have completed a design of the hodoscope. One of two hodoscope arms, to be positioned symmetrically about the exiting beam direction, is shown in Fig. 3. The front and rear planes of x-elements (vertical slabs) are designed to have small ($\sim 0.2°$) overlap, to provide a small subset of events with precisely determined x and y (from time differences between phototubes at opposite ends of the two overlapping slabs, as well as from the coincident y-element) positions, which will be useful for *in situ* detector energy and time calibrations. The hodoscope electronics layout is also designed. It will be important to measure time differences between different particle hits in the hodoscope with a resolution of 1 ns (FWHM) or better (after software corrections for position and pulse-height dependences), to aid in the identification of the proton *vs.* K^+ tracks leading to the reaction vertex. The correct identification here is critical for extracting the correct missing mass of the produced hyperon.

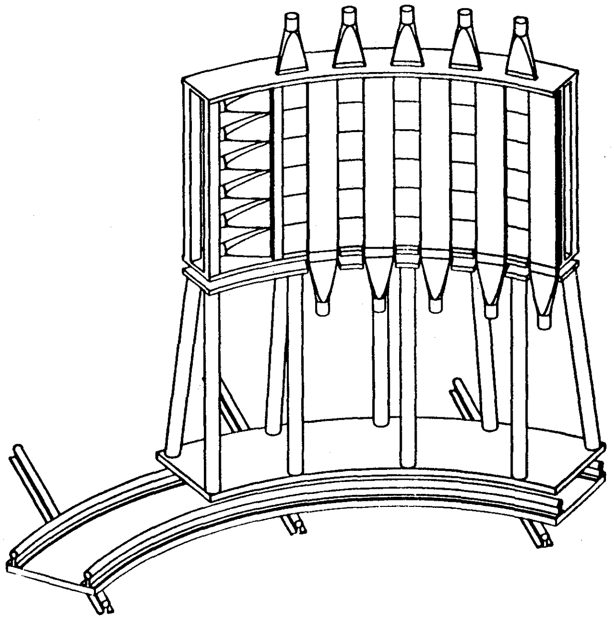

Figure 3. Assembly drawing of one of the two symmetric plastic scintillator hodoscope arms to be constructed at IUCF. The hodoscope will be used in the fast hardware trigger and to give good-resolution time-of-flight measurements to aid in the identification of the events of interest. It will also help in matching horizontal to vertical particle tracks.

A version of the reconstruction software program has already been written to analyze simulated data, but so far dealing only with quite limited event topologies (p and K^+ detected on the beam left and Λ^0 decay products on the right, or vice-versa, accounting for 15-20% of the hyperon production events that will pass the trigger). Generalizations to handle a wider variety of event topologies and efficiency improvements to the algorithms are just beginning. Tests of projected level 2 trigger software on simulated data are very encouraging. We find that by vetoing events for which the vertical position information (y *vs.* distance from target to detector) is consistent with 4 straight lines converging to a common vertex, we can remove $\sim 90\%$ of the most prevalent background events ($pp \rightarrow pp\pi^+\pi^-$) in less than 1 ms processing time per event (on the RISC 5000 processor). In the process we also reject about 10% of the desired Λ^0 production events, namely, those where the Λ^0 decays very close (within ~ 1 cm) to the reaction vertex, or where its decay products have very little vertical opening angle between them. The latter events carry little information about the vertical polarization of the Λ^0 in any case, and so do not represent a serious loss.

1. For a recent review of existing measurements, see K. Heller, J. Phys. (Paris), Colloq. **51**, C6-163 (1990).
2. B.E. Bonner *et al.*, Phys. Rev. Lett. **58**, 447 (1987) and Phys. Rev. D **38**, 729 (1988); M. Nessi *et al.*, in AIP Conf. Proc. **187** (High-Energy Spin Physics, Minneapolis, 1988), p. 66.
3. B. Anderson *et al.*, Phys. Rep. **97**, 31 (1983), and references therein.
4. T. deGrand, J. Markkanen, and H.I. Miettinen, Phys. Rev. D **32**, 2445 (1985), and references therein.
5. J. Soffer and N.A. Tornqvist, Phys. Rev. Lett. **68**, 907 (1992), and references therein.
6. J.M. Laget, Phys. Lett. **259B**, 24 (1991) and private communication.
7. P.M. Maessen, T.A. Rijken, and J.J. deSwart, Phys. Rev. C **40**, 2226 (1989); B. Holzenkamp, K. Holinde, and J. Speth, Nucl. Phys. A **500**, 485 (1989).