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PROPOSAL TO STUDY HIGH ENERGY NEGATIVE HYPERON INTERACTIONS WITH THE NAL 15 FOOT BUBBLE CHAMBER

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Cambridge University Bubble Chamber Group

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ABSTRACT

It is proposed to study the interactions of 200 GeV/c, 100 GeV/c and 50 GeV/c Σ^- - hyperons in the NAL 15 foot liquid hydrogen bubble chamber. A total of 275 kpix is requested, which might be expected tc yield approx. 124,000 $\Sigma^- p$ interactions.

A general survey of $\Sigma^- p$ interactions will be made to search for new and unanticipated phenomena and to obtain information on topological cross-sections, multiplicity distributions, inclusive distributions and diffractive and inclusive resonance production.

Specially developed high field pulsed dipole and quadrupole magnets will be employed to achieve a useful Σ^-/π^- ratio in the bubble chamber.

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1. THE PROPOSAL

1.1 Introduction

The proposers of this experiment have been involved in a 20 GeV/c Λ^o beam experiment [1] performed at CERN in the 2m HBC, and have pioneered the use of high-field pulsed magnet beam components in building short hyperon beams for bubble chamber experiments. They have also performed feasibility tests at CERN for the design of a high energy Σ^- beam, which have led to the construction at RHEL [2] of prototype pulsed dipole and quadrupole magnets suitable for NAL energies. It is intended to use such magnets in the experiment proposed here.

The 15' bubble chamber at NAL is ideal for a bubble chamber study of Σ^-- interactions at high energies. The bulk of events are likely to have a fast hyperon in the final state whose decay stands on high chance of detection in the 2-3m of available liquid hydrogen. No beam tagging or external particle-detection facilities are required in this experiment.

This proposal envisages taking 275,000 pictures distributed amongst different momenta as follows (full details are given in Table I on p.5):

A. 50 kpix of 200 GeV/c hyperons

B. 75 kpix " 100 " "

C. 150 kpix " 50 " "

It is intended to start with Exposure A since it requires 300 GeV/c primary protons and should therefore be easier to schedule than Exposure B for which 200 GeV/c primary protons are needed. Exposure C will depend on the availability of 62.5 GeV/c protons which will demand front porch extraction and could therefore be two years or more off. The number of pictures is chosen so as to yield roughly the same number of interactions.

As no $\Sigma^- p$ data exist at lower energies it is important that any energy trends be picked up by using at least two beam momenta.

For this experiment we require only that $\sim 10^5$ protons per pulse be transported to the bubble chamber, there being no requirement for an NAL separation stage. It is intended that the hyperon beam-separation components (to be provided by RHEL) will be in the form of a compact, pre-assembled and tested unit that can be quickly installed or removed from its position just in front of the bubble chamber.

It is arguable that strong interaction physics has suffered up till now from not having strange baryon beams as well as strange meson beams available for systematic studies of strong interaction phenomena. If this proposal is accepted there is therefore every hope that hyperon-nucleon interaction data should become available to the high energy physics community at an early stage of the NAL 15' bubble chamber program.

1.2 Proposed Experiment

Because of the short lifetime and hence decay length (e.g. 3.72m for 100 GeV/c Σ^-) a conventional separated hadron beam is unsuitable for hyperons. The sort of physics envisaged can be done using a beam with a poor momentum resolution ($\sim \pm 5\%$ $\delta p/_p$) and hence it is possible to use a very short beam line (i.e. 9m at 100 GeV/c) which can be constructed using the specially developed high field dipole and high gradient quadrupole magnets. The choice of a secondary momentum close to the primary proton momentum automatically gives a very favourable Σ^-/π^- ratio.

With about 10^5 protons incident on a 1mm x 1mm cross-section target the estimated numbers of Σ^-'s arriving at and interacting in the bubble chamber should be as indicated in Table 1. Details of the beam line and flux calculations may be found in Section 2 and Appendix II. The Σ^--flux estimates are based on the measured values of Hungerbuehler et al [3] and Badier et al [4].

We request:

(a) The possibility of delivering $\sim 10^5$ protons per pulse, at momenta of 250, 125 and 62.5 GeV/c to a 1mm x 1mm target near the 15 foot hydrogen bubble chamber. Targets of various materials ranging from Beryllium to Tungsten may be required.

(b) The construction of an adequate number of dipole and quadrupole magnets with spare coils etc, suitable for $\sim 5 \times 10^5$ pulses. It is hoped that the Rutherford Laboratory will supply the magnets, power supplies and personnel to test and run the equipment.

(c) The construction of small Tungsten collimators for use near the target and laminated collimators for use within the quadrupole magnets. Machined slots in these collimators will define the beam acceptance. Tungsten or Uranium shielding blocks, some of which will need machining, will be required in the early part of the beam line. Standard lead or steel blocks should suffice for the latter part of the beam line. It is expected that much of the shielding will be available locally at NAL and some is available from the earlier CERN Λ-experiment [1].

(d) That 50,000 pictures be taken at an incident proton momentum of 250 GeV/c and then when machine scheduling allows a further 75,000 at 125 GeV/c. At some later stage when 62.5 GeV/c protons are available we would hope to complete the proposal with a final exposure of 150,000 pictures. The spill time should be suitable for bubble chamber use. Time should be allowed for beam tuning. Tuning of the incident proton beam should be straightforward but tuning of the sigma beam will involve scanning and rough measuring of test pictures taken in various conditions.

It is expected that we will wish to try various target materials and may wish to vary the proton momentum to obtain different ratios of secondary to primary momentum.

The numbers of interactions listed in Table I are based on $\sigma_{tot}(\Sigma^- p) = 30$ mb, the measured [4] value at 19 GeV/c being 34.0 ± 1.1 mb. It is assumed that the hyperons entering the chamber interact in 2m of liquid hydrogen and the expected numbers of interactions are given in the second last column. When considering particular final state particles such as secondary hyperons, one should allow for the probability of subsequent observable and fittable decays. The numbers in the last column are obtained by requiring a secondary Σ^- of beam momentum to decay leaving at least 0.5m of decay π^- track. Since secondary Σ^-'s will on average have less than beam momentum this is a pessimistic approach, though we also have to think of observing secondary Λ^0's which have a smaller decay probability, and so the numbers of interactions quoted in the last column are probably representative.

The fluxes have been chosen to yield 10 beam tracks per frame.

Exposure	kpix	Secondary proton momentum (GeV/c)	Σ^- momentum (GeV/c)	Σ^-/π^- at BC(a)	Σ^- entering BC	Σ^- observable beam decays	Σ^- interactions (b)	Σ^- interactions observed (c)
A	50	250	200	6/4	300k	64k	48k	8.4k
B	75	125	100	4/6	300k	114k	42k	13.5k
C	150	62.5	50	2/8	300k	183k	34k	18k
Totals	275					361k	124k	40k

TABLE I : Details of Proposal

(a) See Table IIC of Appendix II
(b) Based on $\sigma_{tot}(\Sigma^- p) = 30$ mb
(c) Assumes required to observe secondary Σ^- having beam momentum (see section 1.2)
(d) The running time for each exposure is expected to be as follows: A, 2 weeks; B, 3 weeks; C, 6 weeks.

1.3 Physics Case

(1) The intention is to carry out a general survey of $\Sigma^- p$ interactions, comparable to the surveys of pp and $\pi^- p$ interactions currently being carried out in the 30" HBC at NAL at energies in the 100 - 300 GeV/c range.

We would obtain information on topological cross-sections, multiplicity distributions, inclusive distributions and correlations and so on.

A new type of beam particle at new energies, together with the large visible volume and good spatial resolution of the 15' bubble chamber, should be capable of revealing unanticipated phenomena. The strangeness of the beam particles should tend to lead to final baryon states of high strangeness, and the bubble chamber is ideally suited to observing and analysing such multi-vertex events.

Further particular topics for investigation would be as follows:

(2) Inclusive Processes

Measurement of all observed hyperon decays will enable us to study the inclusive processes

$$\begin{aligned} \Sigma^- p &\to \Sigma^\pm + \text{anything} \\ &\to \Lambda^0 + \quad '' \\ &\to \Sigma^0 + \quad '' \end{aligned}$$

For the Σ^0 we will try and use the 12% of Σ^0 events where a conversion γ is available and the Σ^0 is therefore fittable.

Some SU(3) predictions for inclusive reactions are listed in Appendix 1(a), and many of them, such as, e.g.

$$(\Sigma^- \to K^0_S) = \tfrac{1}{2}[(p \to \pi^+) + (p \to \pi^-)],$$

$$(\Sigma^- \to \Sigma^-) = (p \to p),$$

could be readily tested in this experiment for SU(3) symmetry breaking.

The inclusive process $pp \to \Delta^{++}X$ has recently been found [7] to have the value 4.3 ± 0.5 mb at 303 GeV/c. We can therefore check factorization in the process $\Sigma^{-}p \to X\,\Delta^{++}$, for which the cross-section should be half this value. Furthermore, an SU(3) prediction,

$$(\Sigma^{-} \to \Sigma(1385)^{-}) = \tfrac{1}{2}\,[(p \to \Delta^{++}) + (p \to \Delta^{o})]$$

$$\approx 1.0 \text{ mb}$$

can be investigated. We therefore note that 3.1 mb, or 10% of the total cross-section, is perhaps involved with the inclusive production of the $\Sigma(1385)$ and $\Delta(1238)$ resonances.

(3) <u>Diffraction Dissociation</u>

The importance of diffractive mechanisms at very high energies is now clearly recognised.

Lipkin [8] has recently proposed a new model for diffraction dissociation which suggests the existence of new Y^{*}'s, not yet discovered, which would be observed in diffraction dissociation but only weakly coupled to two-body formation and decay channels. The SU_3 partners of the Roper resonance $N^{*}(1470)$, namely a $Y^{*}(1620)$ and a $\Xi^{*}(1770)$, might be such states and be found with hyperon beams.

In any case the use of hyperon beams affords the possibility of producing hyperon resonances without strangeness exchange and therefore by diffractive mechanisms (such as Pomeron exchange).

We recall that the process $pp \to pN^{*}_{\frac{1}{2}}$ has shown evidence for the $P_{11}(1470)$, $D_{13}(1520)$, $F_{15}(1688)$ and $G_{17}(2190)$ resonances for which the production cross-section totals 1.4 mb at $\sim$ 30 GeV/c. Observation of the corresponding process $\Sigma^{-}p \to Y^{*-}p$ would therefore seem to be favoured by the following considerations:

1. Large $\sigma \sim 1$ mb (assuming $\sigma \sim$ const)
2. Low background (assuming σ falls with s).
3. Y^*'s have narrower widths (typically 50 - 70 MeV) than N^*'s (100 - 300 MeV).

Using fitted inelastic events such as e.g. $\Sigma^- p \rightarrow \Lambda p \pi^-$, allows a direct search for such processes. However, even with unfitted events a search for Y^*'s is still possible. Most often the proton will be identifiable as a dark track, and the missing mass distribution calculated from the proton momentum (or range) and proton angles alone may reveal resonant structure i.e. we study $\Sigma^- p \rightarrow X^- p$ and determine M(X) from the proton variables.

Furthermore, <u>both</u> final-state baryons should be identifiable in $\Sigma^- p$ reactions since both the hyperon decay and the proton stub can be seen. The remaining tracks are almost certainly going to be pions, and so for

$$\Sigma^- p \rightarrow X(\Sigma^- + \text{charged pions}) + p + \text{neutrals}$$

we can study M(X) without having to fit events.

In each case we might hope to see any resonant structure in M(X) above a smooth background resulting from the effect of undetected neutrals. About 25% of single π^o events could be vetoed since we could expect to observe a γ-conversion, and the proportion of vetoed events will be higher for multi-π^o events.

(4) <u>Study of Inelastic Processes</u>

A great variety of inelastic processes can occur, e.g.

$$\begin{aligned} \Sigma^- p &\rightarrow \Lambda p \pi^- \\ &\rightarrow \Sigma^{\pm} p \pi^{\mp} \pi^- \\ &\rightarrow p p K^- \pi^- \end{aligned}$$

and in addition rarer events might occur involving Ξ's or more than one hyperon in the final state, such as

$$\Sigma^- p \rightarrow \Xi^- p K^+ \pi^-$$
$$\rightarrow \Sigma^- \Lambda K^+,$$

as well as channels similar to the above with further $\pi^+\pi^-$ - pairs. All of these are potential four-constraint fits and should be relatively uncontaminated channels. (See Section 3.5). Production of Y^*'s from $\Sigma^- p$ should be as copious as N^*'s from pp collisions as mentioned above. A number of SU_3 and SU_6 predictions among baryon-baryon reactions exist and are listed in Appendix I(b). Some of these might be tested in this experiment.

(5) Total and elastic cross-sections

Information on cross-sections will be a by-product of the experiment. It should be possible to obtain total cross-sections to a statistical accuracy of 1-2% by counting all interactions and subtracting $\pi^- p$ interactions (assuming that the $\pi^- p$ total cross-section is known to 1%), the Σ^-- flux being known from beam decays. Observations of $\Sigma^- p$ interactions by identifying fast secondary strange particles, after correcting for unseen states (such as those involving K^-) and for strange particles produced in $\pi^- p$ collisions, affords an independent means of cross-section determination to similar statistical accuracy. The systematic errors in these determinations might well be 3-4%, but they would provide an independent check on counter measurements.

A quark model prediction for total cross-sections,

$$\sigma(\Sigma^- p) = \sigma(pp) + \sigma(K^- p) - \sigma(\pi^- p) + 2[\sigma(K^+ n) - \sigma(K^+ p)]$$

is satisfied at 19 GeV/c [4], with L.HS. = 34.0 $\pm$ 1.1 and RHS = 35.0 $\pm$ 0.9, and could therefore be tested up to 100 GeV/c in this experiment.

Statistics only allow an elastic cross-section determination to 2-3%, but values of $|t|$ down to ~ 0.02 GeV^2 from observation of recoil protons and to ~ 0.01 GeV^2 using track-following techniques (Section 3.1) should be possible, complementing a NAL counter proposal [9] to measure down to ~ 0.1 GeV^2.

(6) Particle Production Models

Experimental information on production of hyperons in nucleon-nucleus collisions will emerge from measurements of the Σ^-, Ξ^- and possibly even Ω^- flux entering the bubble chamber.

Taking $\Xi^-/\Sigma^- \sim 1/60$ [4] and $\Omega^-/\Xi^- \mathrel{\overset{\sim}{\sim}} \Xi^-/\Sigma^-$ we expect to see ~ 2000 Ξ^- decays and ~ 100 Ω^-- decays from the 100 and 200 GeV/c experiments.

Such information will provide an interesting test of various particle production models, such as the Hagedorn-Ranft thermodynamic model [10] and the nova model [11].

(7) New Technique

Finally, this experiment will establish the technique of using hyperon beams for 'conventional' bubble chamber studies of hyperon-nucleon interactions. It is arguable that strong interaction physics has suffered in the past (at least from the point of view of SU(3) and the quark model) from not having available baryon beams as well as meson beams of varying hypercharge. With NAL energies this shortcoming could now be rectified.

2. EXPERIMENTAL DETAILS

2.1 The incident proton beam

For the production of 50,100 and 200 GeV/c Σ^- beams we will require protons of momenta 62.5, 125 and 250 GeV/c respectively. About 10^5 protons per burst focussed onto a 1mm x 1mm cross section target will be needed. It is most likely that a Tungsten target will be used but copper and beryllium targets should also be available. The targets should be about one interaction length long.

Given that the synchrotron is operating at 300 GeV then protons of the above energies could be obtained by the technique known as front porch extraction. Alternatively, secondary protons could be used in the 200 GeV/c Σ^- experiment but at the lower energies the pion contamination which leads to muon contamination in the bubble chamber is too high.

It is expected that about 10^{10} to 10^{11} protons per burst could be extracted from the synchrotron. It has been our experience with a 8 GeV/c proton beam at the Rutherford Laboratory (K9) and with a 24 GeV/c proton beam at CERN (U5) that provided the beam line has several stages of momentum analysis and adjustable collimators then it is quite straightforward to achieve an attenuation in the proton intensity of a factor 10^6 and a final spot size of 1mm x 1mm.

Because acceptances are so small adjustments to quadrupole magnet currents should be unnecessary and beam tuning should involve only steering by adjusting dipole magnet currents and collimation about the beam axis. It has been our experience that polaroid film plates enable the above processes to be completed very rapidly. The proton intensity at the target can be monitored using a scintillator with an output proportional to the proton intensity; (counting of individual protons is out of the question).

2.2 The Sigma beam line

By choosing a secondary momentum close to the incident proton momentum a very favourable Σ^-/π^- ratio at production can be obtained. The rather short decay length of the Σ^- (1.86m at 50 GeV/c, 3.72m at 100 GeV/c and 7.44m at 200 GeV/c) means that if we are to finish up with a reasonable ratio at the bubble chamber the distance from target to bubble chamber must be kept small.

However, the other particles produced at the target along with any protons that did not interact must be eliminated. This requires shielding material to be placed between the target and the bubble chamber.

The beam line design outlined below is essentially a compromise between the requirement to keep the beam short to obtain a good Σ^-/π^- ratio and to make it longer in order to improve the shielding and hence reduce the background.

The basic design is similar at all momenta. A combination of two dipole and two quadrupole magnets is used to produce a dispersed image in the vertical plane with a resolution of $\sim \pm$ 5% $\delta p/p$. The output geometry in the horizontal plane can be varied. As an example the disposition of elements in the 9 metre long 100 GeV/c Σ^- beam line is shown schematically in Figure 1. Exactly the same elements will be used at 50 GeV/c and 200 GeV/c, but with different separations.

A 25cm long Tungsten collimator placed immediately after the target defines the solid angle acceptance of the beam. Pions outside the acceptance must be reduced in energy as soon as possible to minimise the production by decay of muons of energy sufficient to penetrate all the shielding and reach the bubble chamber.

The protons which have not interacted in the target ($\sim$ 40% of the incident flux) pass along with the particles within the acceptance through a hole in the entry coil of the first dipole magnet. A field of 10T or more over a distance of 40cm deflects the charged component of the beam.

Only negative particles above about 50 GeV/c pass through the slot in another Tungsten collimator immediately beyond the dipole magnet.

This negative beam is brought to a focus in the vertical plane and made parallel in the horizontal plane by the two quadrupole magnets. The second dipole magnet is used to increase the dispersion of the beam at the focus where the resolution is such as to enable us to obtain a beam with a momentum resolution of $\sim \pm$ 5% $\delta p/p$.

It would be advantageous to use Uranium or Tungsten shielding blocks early on in the beam if these are available, although lead bricks could be used later on when the nuclear cascade has become more diffuse.

(Some of the relevant properties of these magnets are listed in the Table IIB of Appendix II.)

The dipole and quadrupole magnets are of types designed by Rutherford Laboratory personnel (2). Prototypes have already been built and tested for around 10^5 pulses. A complete set of magnets and spare coils could be ready within a year of this proposal being accepted. It should be noted that it is proposed to work well within the design fields and gradients.

The magnets will be operated in series from a single power supply which was in fact used in the Cambridge Λ^o experiment at CERN in 1971.

2.3 Particle fluxes and background

No systematic measurements of particle yields from proton-proton or proton-nucleus collisions above 30 GeV/c primary momentum have yet been made. The procedure adopted to arrive at an estimate of π^- and Σ^- yields is discussed in detail in Appendix II. It is expected that the predictions will be found to be accurate to within a factor 2.

The amount of shielding between the target and bubble chamber should be more than adequate to eliminate the hadronic component of the nuclear cascade. Muons are more of a problem but a calculation indicates that fewer than 10 muons per burst will have sufficient energy to penetrate the shielding and arrive at the bubble chamber, which we believe is a tolerable background.

The shielding problem is discussed in some detail in Appendix III.

3. ANALYSIS OF EVENTS

3.1 15' Bubble Chamber

It is assumed that there is 4m of liquid hydrogen, of which 2m is useful for interactions, a chamber field of 3.0T and mean spatial point accuracy of 300 μm.

The first stage in analysis will be to locate every Σ^- - decay by track following with the semi-automatic measuring machine Sweepnik. The large curvature change in $\Sigma^- \rightarrow \pi^-$ (from 4.5 mr/m to $\gtrsim$ 12.5 mr/m for a 200 GeV/c Σ^-) should be easy to detect since on 1m of track the angle error is $\Delta\theta \sim 0.6$ mr. Single view measurements are adequate since beam tracks and decay products are essentially at fixed depth. At the same time all interactions of beam particles (including small angle scatters) will be recorded for subsequent scanning.

3.2 Beam Momentum

The nominal beam momentum uncertainty is $\pm$ 5%. However, there will be a correlation between the position and angle of Σ^- - beam tracks and momentum, leading to a likely $\Delta p/p$ of 1-2%. This could be checked by measuring a sample of Σ^- beam tracks of good length, for which a measurement error of $\Delta p/p \sim 1\frac{1}{2}\%$ should be achieved.

3.3 Inclusive Studies

Secondary particle momenta should be obtainable to $\sim$ 5%, with $\Delta\theta \sim 0.5$ mr, provided we use at least 2m of secondary track, which is adequate resolution for useful physics.

3.4 Mass resolution

The error on invariant mass determination has been checked using events of the type $\Sigma^- p \to \Sigma^- \pi^+\pi^- p$ generated by the program FAKE (see 3.5 below). The $(\Sigma^-\pi^+\pi^-)$-system was found to have mean mass error $\delta M \gtrsim 75$ MeV for $M = 2$ GeV, increasing to 150 MeV for $M = 3$ GeV. This should be adequate resolution for useful physics.

In deriving missing masses from recoil protons, the usual factor limiting precision is the error on the proton angle due to multiple scattering, which, e.g. results in a $\delta M \gtrsim 100$ MeV for a system having $M = 2$ GeV recoiling with momentum 100 GeV/c from a 300 MeV/c proton.

However, the uncertainty in the beam momentum will contribute a further contribution to δM of similar magnitude unless this uncertainty is reduced in the manner described in 3.2

3.5 4C fitting

Events of the type $\Sigma^- p \to \Sigma^- p$, $\Sigma^- p\pi^o$, $\Sigma^- p\pi^+\pi^-$ and $\Sigma^- p\pi^+\pi^-\pi^o$ at 100 GeV/c have been generated in order to assess the reliability of identification by 4C-fitting. A simple peripheral model was used in order to give the same t-distributions for final state baryons, and p_T distributions for pions as found at energies < 30 GeV. The elastic and $\Sigma^- p\pi^+\pi^-$ events gave 98% pass rates corresponding to a χ^2-probability > 1% (based on 1000-event samples).

Furthermore, only 6% of the latter event category fitted when p and π^+ were interchanged, and in nearly all cases the ambiguity could be resolved using bubble density.

To test the effect of events with further π^o's contaminating 4C channels firstly 1000 $\Sigma^- p\pi^o$ events were used, it being found that $\sim$ 15% were either wrongly or ambiguously fitted as 4C's. Bearing in mind the large difference in cross-sections the contamination of elastic events is likely to be $\lesssim$ 1%. A similar study of 1000 $\Sigma^- p\pi^+\pi^-\pi^o$ events leads us to believe that the contamination of the $\Sigma^- p\pi^+\pi^-$ channel can be kept down to $\sim$ 15 - 20%. Since events with two or more π^o's will on average have more missing transverse momentum we conclude that contamination of 4C's is of manageable proportions, and can be corrected for on a statistical basis, and by using 'tagged' π^o- events with γ-conversions.

3.6 Measuring Facilities

The Cambridge group has 2 semi-automic Sweepnik measuring devices and 3 conventional measuring machines with on-line computer connection all capable of modification to handle 70mm film. Two large scan tables (designed for BEBC film) will also be available for the experiment.

The Cambridge group is thus capable of fulfilling the measurement requirement of 50-100 k events in 1-1½ years, but would be glad to consider U.S. collaborators to assist in all stages of the experiment.

APPENDIX I - Symmetry predictions involving hyperon-nucleon interactions

(a) Inclusive reactions [5]. The following predictions based on SU(3) should hold for the fragmentation of a into c ($a \to c$), all assumed to take place on the same (proton) target. They should hold for all (x, p_T) in the fragmentation region.

$$(\Sigma^- \to K_s^o) = \tfrac{1}{2}[(p\to\pi^+) + (p\to\pi^-)]$$

$$(\Sigma^- \to \Sigma^-) = (p \to p)$$

$$(\Sigma^- \to \Sigma^+) = (p \to \Xi^-)$$

$$(\Sigma^- \to \Xi^-) = (p \to n)$$

$$(\Sigma^- \to \Lambda) = \tfrac{1}{4}[(p\to\Sigma^+) + (p\to\Sigma^-)] + \tfrac{1}{2}[(p\to n) + (p\to\Xi^o) - (p\to\Lambda)]$$

$$(\Sigma^- \to \Lambda \text{ or } \Sigma^o) = (p \to \Lambda \text{ or } \Sigma^o) \text{ (sic!)}$$

$$(\Xi^- \to K_s^o) = (\Sigma^- \to K_s^o) = \tfrac{1}{2}[(p \to \pi^+) + (p \to \pi^-)]$$

$$(\Xi^- \to \Xi^-) = (p \to p)$$

$$(\Xi^- \to \Lambda \text{ or } \Sigma^o) = \tfrac{1}{2}[(p\to\Sigma^+) + (p\to\Sigma^-)] + \frac{1}{6}[(p\to\Xi^o) - (p\to\Xi^-)] + (p\to\Lambda)$$

$$= (p\to\Lambda \text{ or } \Sigma^o) + \frac{1}{6}[(p\to\Xi^o) - (p\to\Xi^-)]$$

(b) Exclusive reactions [6]

From SU_3:

$$3|M(\Sigma^- p\to pY_1^{*-})|^2 = |M(\Sigma^- p\to\Sigma^+\Delta^-)|^2$$

$$|M(\Sigma^- p\to\Sigma^+\Delta^o\pi^-)|^2 + |M(\Sigma^- p\to p\Delta^o K^-)|^2 \geq |M(\Sigma^- p\to pY_1^{*o}\pi^-)|^2$$

$$3|M(\Sigma^- p\to pY_1^{*-})|^2 = |M(\Sigma^- p\to\Sigma^+\Delta^-)|^2 = 3|M(\Xi^- p\to\Xi^{*-} p)|^2 = 3|M(\Xi^- p\to\Sigma^+ Y_1^{*-})|$$

From SU_6 :

$$\frac{50}{9}\left|M(\Sigma^- p\to nY_1^{*o})\right|^2 = \left|M(pp\to p\Delta^+)\right|^2$$

$$\frac{8}{3}\left|M(\Sigma^- p\to \Lambda\Delta^o)\right|^2 \geq \left|M(pp\to p\Delta^+)\right|^2$$

$$\frac{8}{9}\left|M(\Sigma^- p\to nY_1^{*-})\right|^2 = \left|M(\Sigma^- p\to \Sigma^-\Delta^+)\right|^2$$

APPENDIX II - Estimation of Particle Fluxes

The Hagedorn-Ranft Thermodynamic Model (HRTM) [10] provides a good description of pion production in proton-proton and proton-nucleus collisions at momenta up to 30 GeV/c over a wide range of secondary momenta and angles. For pions at 24 GeV/c we therefore use HRTM and then to obtain the corresponding Σ^- fluxes we make use of the Σ^-/π^- ratios determined by Badier et al [4]. In the forward direction the calculated Σ^- fluxes agree to within 20% with the measured fluxes of Hungerbuehler et al [3].

Fluxes at higher primary momenta are obtained using the scaling formulae,

$$\frac{1}{\sigma_{\Sigma^-}} \left(\frac{dN}{dx}\right)_{\Sigma^-} = f_{\Sigma^-}(x)$$

$$\frac{1}{\sigma_{\pi^-}} \left(\frac{dN}{dx}\right)_{\pi^-} = f_{\pi^-}(x)$$

where $x \sim p/p_o$ and integration over all angles has been carried out. Values of σ, $\frac{dN}{dx}$ and $f(x)$ used are summarised in Table IIA. It is probable that the increase in σ_{π^-} with energy is due to an increase in numbers in the pionization region ($x \sim 0$) and not the fragmentation region which concerns us here. If this is so the pion flux will have been overestimated. It is assumed that the cross section for Σ^- production (σ_{Σ^-}) varies in the same way as that for Λ^o production. That Λ^o's scale in the above way is strongly suggested by the data of Charlton et al [14] at 200 GeV.

The Σ^- and π^- fluxes at 50, 100 and 200 GeV/c together with various assumptions made are listed in Table IIC.

APPENDIX III - Estimation of Background

A detailed assessment has been made of the background expected at the bubble chamber. Ranft |15| has performed extensive Monte-Carlo calculations on the nuclear cascade in shielding materials which have been experimentally verified below 30 GeV/c. For 200 GeV/c protons incident on steel these calculations show that after an initial build up to about 8 particles per incident proton the laterally integrated charged particle density then attenuates rather rapidly with increasing thickness of steel having a value of 10^{-2} after 2.5 metres. Beyond this thickness the charged particles are mainly muons which attenuate only slowly with increasing thickness. Data on muon contamination are given out to only 3.5 metres of steel and although extrapolation to the thicknesses of material to be used in the proposed experiments indicates less than 1 muon per 10^5 incident protons an independent calculation has been performed by us at each momentum to confirm this result. The method used at 200 GeV/c is outlined below.

An estimate of muons arising from pions and kaons decaying along the Σ^- beam channel has also been made. The possibility of hadrons produced outside the beam line acceptance scattering into the channel has also been investigated and along with the muon problem is discussed in more detail below.

(a) Muon Background

By using Tungsten and Uranium to attenuate the high energy part of the cascade and Lead elsewhere, then, except in the vicinity of the beam channel, the shielding is sufficient to stop muons of momenta less than 10, 15 and 23 GeV/c in the 50, 100 and 200 GeV/c experiments respectively. Using the Hagedorn-Ranft |10| flux estimates for pion production, and multiplying by the probability that a decaying pion will give a muon greater than the above cut off momenta, and by the probability of the pion decaying into a muon, then in the 200 GeV/c experiment where the shielding requirements are most severe one finds that on integrating over all angles and momenta $\sim 2\,\mu^{+}$ and $\sim 2\,\mu^{-}$ will be produced in the 0.1 metre that the pions are allowed to travel before interacting. About 90% of the muons originate from pions with momentum less than 60 GeV/c.

The slot in the Tungsten collimator immediately following the target accepts about 2% of these low energy pions which can drift for about a metre on average before interacting. The muon estimates should be increased by a factor 1.2 to take this into account. A similar factor is needed to allow for the muons from kaon decay leading to a final estimate of 6 muons per picture on average in the 200 GeV/c experiment. This number falls with the Σ^{-} momentum and is expected to be less than 1 in the 50 GeV/c experiment.

(b) Hadron Background

By ensuring that most particles enter the shielding either at large angles or at large distances from the channel boundaries the probability of secondaries scattering into the channel is minimised. The magnetic fields and shape of the channel conspire to make it difficult for the scattering processes to feed unwanted particles into the bubble chamber. Our experience with neutral beams at CERN and at the Rutherford Laboratory enable us to predict with some confidence that the hadron background will not be serious.

TABLE IIA

Fluxes at target of Σ^- and π^- at $x \approx p_{\Sigma,\pi}/p_o = 0.8$

P_o (GeV/c)	$P_{\Sigma,\pi}$ (GeV/c)	σ_{Σ^-} (mb)	x103 $(\frac{dN}{dx})_{\Sigma}$	x103 $\frac{1}{\sigma_{\Sigma}}(\frac{dN}{dx})_{\Sigma^-}$	σ_{π^-} (mb)	x103 $(\frac{dN}{dx})_{\pi^-}$	x104 $\frac{1}{\sigma_{\pi}}(\frac{dN}{dx})_{\pi^-}$
24	19.2	0.29	5	17	34	0.6	1.7
62.5	50	0.47	8	17	55	0.9	1.7
125	100	0.63	11	17	70	1.2	1.7
150	200	0.82	14	17	92	1.6	1.7

TABLE IIB

Sigma Beam Line Magnets

Dipole Magnets

Design Field	=	15 T
Length of Field Region	=	0.4 m
Width of Field Region	=	0.02 m
Coil Thickness at ends	=	2 x 0.02 m

1st Quadrupole Magnet

Design Gradient	=	550 T m^{-1}
Length	=	0.8 m
Diameter of useful Aperture	=	0.02 m

2nd Quadrupole Magnet

Design Gradient	=	300 T m^{-1}
Length	=	0.4 m
Diameter of useful Aperture	=	0.05 m

The lengths of the quadrupole magnets could differ from the values quoted. Detailed field plots have not yet been done.

TABLE IIC

"Particle Fluxes"

	200 GeV/c	100 GeV/c	50 GeV/c
Primary Proton Momentum (GeV/c)	250	125	62.5
Length of Beam Line (m)	13.0	9.0	6.5
Σ^- decay length (m)	7.44	3.72	1.86
Decay loss factor for Σ^-	0.174	0.089	0.031
Horizontal Acceptance (mrad)	7	10	16
Vertical Acceptance (mrad)	4	5	8
Effective momentum bite (GeV/c)	30	15	10
Fluxes* (π^-	4	6	8
Fluxes* (Σ^-	6	4	2
Incident Protons	7×10^4	10^5	1.4×10^5

* Allowance has been made for losses in dipole end coil and beam entry windows and for actual solid angle acceptance and momentum bite.

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SCHEMATIC LAYOUT OF A 100 GeV/c Σ^- BEAM LINE

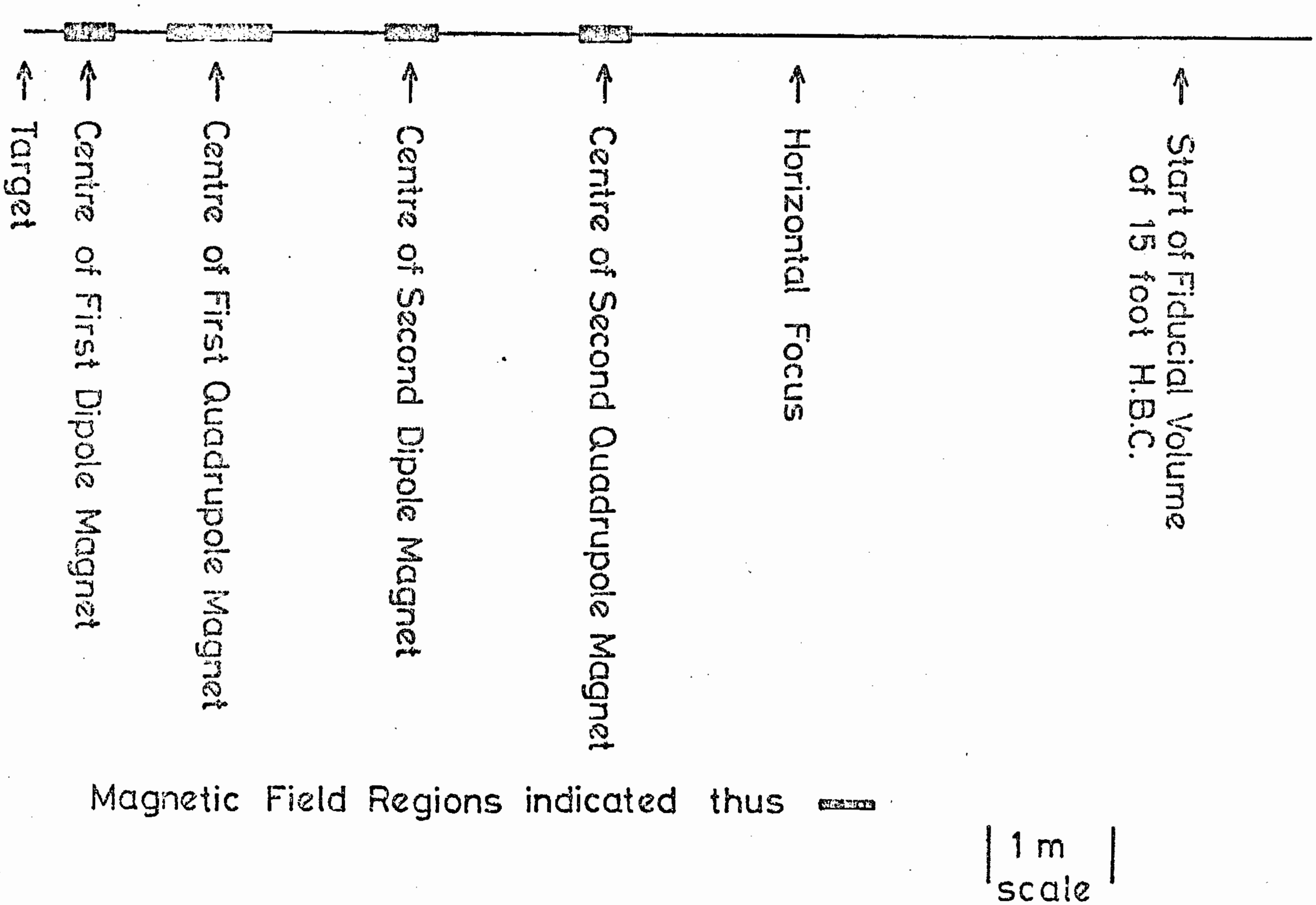

Fig.1

Addendum to Proposal ≠ 214

1. The University of Michigan (Chapman et al.) and the University of Strasbourg (Fridman et al.) groups have expressed a desire to collaborate with us in the study of $\Sigma^{-}p$ interactions in the 15 foot H.B.C. Their names should be added to the proposal.

2. We wish the proposal to stand but with the addition of a 50kpix exposure at 250 GeV/c to the proposed exposures at 50 and 100 GeV/c.

3. Instead of the pulsed dipole it might be more useful to consider a superconducting dipole of length 1 metre, should this be available. The pulsed quadrupole magnets and associated power supply already at Fermilab could be used for our exposures.

4. For technical reasons it makes sense to do the exposure at 250 GeV/c first. This would require 300 GeV/c protons which can be transported in adequate numbers and focussed down to a small spot. Furthermore, Σ^{-} decay losses will be lower and shielding from background will be relatively easier at the higher momentum. Since π^{-} will enter the chamber along with the Σ^{-} the fact that an exposure to π^{-} at 250 GeV/c (Experiment ≠ 234) has already been made will permit a useful comparison and/or correction to be made.

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