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THE PROPOSED HYPERON BEAM FACILITY AT FERMILAB

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I. INTRODUCTION

It has been evident for some time that the facilities available at Fermilab provide unique conditions for producing intense hyperon beams of high optical quality. The high energies available at the Laboratory are particularly favorable because the decay lengths of hyperons increase linearly with the square of the center-of-mass energy, S, while the required shielding increases only as $\ln S$. Furthermore, at Fermilab energies the production angles are very small and essentially all the hyperons are easily contained within the acceptance of a beam transport system. Preliminary designs for the construction of a hyperon beam facility in the Proton Area are well under way. In addition, a workshop has been held to acquaint experimenters with the proposed facility and to elicit their suggestions regarding the beam design and the physics which could be done using such a facility. This report will first present a fairly detailed description of the proposed facility and then summarize the workshop, with emphasis on the contributions the facility could make in the areas of strong and weak interaction physics.

II. PHYSICAL CONFIGURATION OF THE FACILITY

The proposed hyperon facility would be located in the area immediately downstream of the present Proton Central Experimental Area pit, between the new 1000 GeV Proton West Beam and the Electron-Tagged Photon Beam of the Proton East Area. In Figure 1, this is the region just downstream of the area shown to be presently occupied by Experiment 288. A concrete enclosure about 200 feet long by 20 feet wide would house the hyperon beam transport elements, the decay region, and upstream portions of 400 GeV/c experimental spectrometers including the magnets. The additional space for downstream experimental apparatus would be available in an open pit located beyond the hyperon enclosure and having dimensions like 150 feet (length) by 10 feet (width) at the base. The pit would be rip-rapped and drained. Utilities would be supplied along a cable tray from the hyperon enclosure.

An inclined ramp leading to a dock area having 10 feet wide entrance doors would provide access to both the hyperon enclosure and the downstream end of the existing (upstream) Proton Central experimental pit for large and/or heavy equipment. Handling of equipment within the enclosure would be done with an overhead crane running the length of the enclosure and having a capacity of $\sim$ 20 tons, with a hook clearance of $\geq$ 12 feet above the floor.

To provide adequate shielding for 5 x 10^{12} protons per pulse operation, an appropriate region of the hyperon enclosure would be covered by 6 feet of berm (Section A-A, Figure 1), and the dock area would be a fenced off radiation area during operation. The beam elevation in the hyperon enclosure near the dock would be 4 feet above the floor in order to match that of the upstream pit and allow the common access.

In designing the new hyperon beam, one must consider the constraints imposed by the experimental apparatus and beam line optics already associated with the Proton Central area. In the near future, the Experiment 288 beam dump presently located in the Target Box will be moved to the position shown in Figure 1. Between the Target Box and the new dump, the beam will be enclosed in a shielded vacuum pipe. The change from upstream area running (e.g. Experiment 288) to hyperon experiment running would involve modifying the Target Box collimators to accommodate the changed upstream focussing requirements, inserting a quadrupole doublet Q, Q and steering magnets DH, DV in the beam as indicated in Figure 1, and replacing the removable 1 ft. x 1 ft. x 18 ft. central core of the E-288 dump with two narrow gap dipoles.

In this configuration an external proton beam with intensity ranging from a few x 10^9 to 5 x 10^{12} protons per pulse could be focussed at a point just inside the hyperon enclosure with a variable angle of incidence (± 7.5 MRAD at 400 GeV/c).

The present design of the charged hyperon beam facility from this point on corresponds fairly closely to that described by A. Roberts and S. Snowden in a Fermilab internal report, TM-610. It is an achromatic, point to parallel beam for the momentum range 150 - 400 GeV/c, allowing tagging of beam particles with a focussing Cerenkov detector.

The initial element of the hyperon beam is a large picture frame dipole magnet, D1, with a small gap, high field, and narrow central pole surrounded by a wide weak field absorber region between widely spaced coils. This magnet would be used to target and dump the proton beam, to define the momentum and acceptance of the secondary beam, and to deplete the forward muon cone arising from both π decay and direct production. To perform these functions the magnet would necessarily have dimensions of the order of 7m (L) x 3m (W) x 2m (H). For hyperon momenta less than 400 GeV/c a 30 kG field would be satisfactory. For momenta $\gtrsim$ 400 GeV/c it seems desirable that the field either be increased to 40 kG or the magnet lengthened to obtain an $\int Bdl$ equivalent to 7m x 40kG. The magnet would be designed so that short target assemblies could be inserted or removed from the upstream end. The dump and collimators would be accessed from the downstream end by splitting the magnet with jacks and displacing the downstream beam magnets. Yet to be decided is whether D1 should be conventional or superconducting. A superconducting magnet has the advantage of requiring less power than a conventional one but it would be highly susceptible to radiation damage and there would be thermal pulsing and load problems, particularly for intensities around 5×10^{12} ppp. In fact, with a reasonable coil and cryostat configuration the heat load reaches the safe operation (non-quenching) limit at $\sim 3 \times 10^{12}$ ppp. A conventional magnet would require $\sim$ 150 KW of power. A total of 1.5 MW would be available to the area with the proposed power feeder from Proton West and the required low conductivity water would be available from the downstream end of the preceeding pit. Power supplies for this magnet as well as all the other magnets in the facility could be located in a Porta-kamp above the hyperon enclosure.

A quadrupole doublet downstream of D1 would produce a dispersive point to parallel beam. The divergence and momentum dispersion of the final parallel beam would be minimized by putting the vertically focussing element, QV, first. This magnet would be 3m long and have a 3 cm good field aperture. The required gradient of $\sim$ 25 kG/in and the length constraint dictate that QV must be superconducting. The second element of the doublet, QH, would be a 2m long, horizontally focussing superconducting magnet of gradient $\sim$ 25 kG/in. The beam could be achromatized over a significant $\Delta P/P$ range by adding momentum slits at D1 and inserting a reverse bend dipole, D2, between the two quadrupoles. With this configuration $\Delta P/P$ would be about $\pm$ 2.5% and divergences would be $y' \leq \pm 0.04$ MRAD and $x' \leq \pm 0.03$ MRAD for a target 25 cm long. To minimize the beam length D2 would be a 40 kG superconducting magnet of length 1.5 m.

For the momentum range 150 - 240 GeV/c beam particles would be identified by a 7 m long focussing Cerenkov detector with Cerenkov angle θ_c = 11.5 MRAD. For 240 - 400 GeV/c running the length would be increased to 15 m and θ_c would be 7 MRAD. Assuming reasonably good optics Σ and Ξ separation appears possible up to 320 GeV/c. Characteristics of the charged beam are summarized in Table I.

To maintain their alignment the beam elements QV, D2, QH, and C would be mounted on a single beam, which would move transversely on rails. A small uniform displacement of all the magnets would have a much smaller effect on the beam quality than a misalignment of a single magnet. The superconducting magnets could be maintained with a single service box on an integral cryostat system. A manifold of boil off lines could return to the service box dewar. Boil off from the dewar could be recovered and compressed locally or carried to the 1000 GeV/c Beam Target Service Building. Flexible connection lines for the liquid helium supply, the gas return lines, and the conventional power leads would allow displacement of the beam elements without disrupting the system. Liquid helium could be supplied from a local dewar or a line from the 1000 GeV/c Beam Target Service Building.

The general procedure for accommodating superconducting spectrometer magnets would be similar. Some superconducting magnets would have to be placed in a local pit. An example of such a magnet is the

48-24-48 which has a nominal beam height of 5 feet 6 inches above the floor. Possible required motion of spectrometer magnets could be provided by a rail system either on the floor or in a pit covered with gratings. A rail system could also be provided for moving downstream detectors.

III. THE HYPERON BEAM FACILITY WORKSHOP

Much of the workshop was devoted to indicating the importance, scope, and uniqueness of physics which could be done with such a facility. With regard to Strong Interaction Physics, it was pointed out that hyperon studies could provide strong tests of various quark model and symmetry theory predictions via Total Cross Section measurements and new Y resonance spectroscopy. Differential elastic scattering, charge exchange, and hypercharge exchange experiments would test general Regge Theory predictions. The high energy available would allow searches for exotic new particles such as charmed-strange baryons.

In Weak Interaction Physics, decay experiments would allow the study of various selection and conservation rules. Non-leptonic decay studies would test the $\Delta I = \frac{1}{2}$ rule, CP violation, and T violation (if the hyperon beam was polarized). Semi-leptonic decay studies ($\Delta S \geq 1$) would test one quark decay models (e.g. Cabbibo model). Searches for second class currents would also be possible.

The remainder of this report will be devoted to a brief summary of each of the talks presented at the workshop.

A. Results from Low Energy Hyperon Beams; J. P. Reppelin, S. Ecklund

The low energy beams at B.N.L. and CERN were described. They are comparable: about 4m in length and 20 - 25 GeV/c in momentum, with a momentum bite of $\Delta P/_{P} \sim 1\%$, providing a yield of about 10^2 Σ's per pulse (with $\sim 10^4$ pions per pulse) for 10^{11} protons/pulse on the production target. The CERN beam has a differential Cerenkov counter (DISC) for good identification of the hyperons in the beam.

At CERN, the following experiments have been done: total cross sections for $\Sigma + P$ and $\Sigma + d$, $\Sigma + P$ elastic scattering, Σ and Ξ production measurements, and the leptonic decays $\Sigma \to \eta e \nu$, $\Sigma \to \Lambda e \nu$, and $\Xi \to \Lambda e \nu$. Except for the leptonic decays, the results of all these experiments have been published.

At B.N.L., the following experiments have been done: Σ and Ξ elastic scattering at small $-t$, Σ, Ξ, and Y* production, Λ^o inclusive production in $\Sigma + N$ reactions, and leptonic decays. Published results include limits on Y* resonance production (≤ 20 nb), the ratio $gA/gv = 0.435 \pm 0.035$ in decays, Y production curves vs $\alpha = P_L(Y)/P_L(Y)$ for the hyperons, and slopes for elastic scattering. For $\Sigma + P$ elastic scattering, the B.N.L. group reports a slope of $b = 9.0$ whereas, the CERN group reports $b = 8.0$, which is similar to the slopes measured for $\pi + P$ elastic scattering in the same energy region.

B. Weak Interaction Theory - B. W. Lee

Various problems associated with model theories were pointed out. Based on standard models, suggestions were made to check the $\Delta I = \frac{1}{2}$ rule in non-leptonic decays (specifically for Ξ) and to study radiative decays on the basis that calculations can be made for the latter. Second class current searches were also mentioned.

C. Strong Interaction Theory - J. Rosner

The importance and implications of various experimental measurements were reviewed. The total cross section results would test simple quark models, would determine via energy dependence whether there is singlet and/or octet Pomeron coupling, and would best define the $D/_F$ octet couplings.

Data on $\rho = \frac{\text{Re } A\ (YN)}{\text{Imm } A\ (YN)}$ and the diffraction slopes b in elastic scattering would provide information on the non Pomeron trajectory contributions in Y + N scattering. In particular, dips around $-t = 1\ (\text{GeV}/c)^2$ would indicate non Pomeron diffraction. Diffraction production experiments could search for and study new resonances whose existence is suggested by SU_6. These resonances could not be observed in other channels such as K + N. Charge and Hypercharge exchange experiments would test Regge Theory by comparing the cross sections and distributions with np data.

It was pointed out that at these energies, one should search for new particles such as possible charmed-strange baryons.

D. Hyperon Fluxes and Production Mechanisms - J. Lach

Low energy Y yield data from the B.N.L. and CERN beams were presented. The point of emphasis was the varying dependence of the different Y yields and the ratio (Y/π) in the beam on $\alpha = P_L(Y)/P_L(Y)_{max}$. In all cases, the hyperon to pion ratio maximizes as $\alpha = 1$, but the optimum yield for different hyperons occurs at varying values of $\alpha = 0.6\ (\Xi)$ to $0.8\ (\Sigma)$.

Wang Model yield calculations for the proposed achromatic beam were outlined and the results were presented; they are summarized in Table II. It is noteworthy that the predicted number of Ξ's in this beam compares with the best Σ yields in the low energy beams, while the number of Ω's would make it possible to study the latter particle.

Speculations on various production mechanisms and the corresponding variations of the Y yields were made.

E. Strong Interactions of Charged Hyperons at High Energies and Intensities - C. Ankenbrandt

A model spectrometer for high energy elastic scattering (small and large -t) and total cross section experiments was described. With this apparatus one could measure the total cross sections σ_T (YN) and the elastic scattering slopes b (Y) and could also study the Coulomb-Nuclear interfearence region to determine ρ(YN).

Extension of the system to study inelastic excitation (Target $p \rightarrow N^*$ and Beam $Y \rightarrow Y^*$) was discussed. The possibility of a recoil detector was considered for missing mass spectrum studies.

F. Weak Interactions of Charged Hyperons at High Energies and Intensities - J. Marx

The study of one quark decay models via semi-leptonic decays of various hyperons was emphasized. Also discussed were the detailed test of the $\Delta I = \frac{1}{2}$ rule for non-leptonic decays and measurements of τ and α for certain hyperon decays. Searches for decays with $\Delta S = 2$ to allow $\Delta S = \Delta Q$ tests and the search for second class currents in two quark decays were proposed.

G. Neutral Hyperons - L. Pondrum

A detailed description and discussion of the properties of the present neutral hyperon facility in the Meson Laboratory was given. A solid angle of 0.1 μSTR, and average production angle of 0.2 MR, and a yield of 100 Λ^o per 10^6 protons on the target are the important parameters. With the characteristics of the M2 beam line, 400 GeV/c protons can be focussed to a spot of several mm with an upper intensity limit $\lesssim 10^9$ protons per pulse. Typical running is done at a few x 10^7 protons per pulse on the basis of radiation levels. The experiment (E-8) can withstand higher beam rates with respect to both background and decay event rates. Event rates of 10^3 per pulse are compatible with the spectrometer system.

The observed polarization of the Λ^o's at large $P_\perp$ led to speculations regarding the polarization (production mechanisms) of other hyperons, to discussions of what measurements could be done, and to an expressed desire to have a variable production angle for the proposed beam facility.

H. The Hyperon Facility for the CERN SPS - Hans Seibert

The beam layout, including superconducting quadrupoles, was described and is shown schematically in Figure II.

The beam is designed for 150 GeV/c with a solid angle of 6 μSTRAD and a variable production angle from 0 to 10 MRAD. The number of hyperons will be limited by the pion flux in the beam, and the decay of the hyperons along the beam length. As an example, the expected yield for Σ^+ is $\sim 10^2$ per pulse.

A large spectrometer system which is being built for the beam was described. The initial experiments to be done include a search for high mass particles in the beam with a DISC Cerenkov and measurements of the hyperon production, total cross sections, elastic scattering differential cross sections, and Y* production. The final spectrometer will include Pb glass counter arrays, additional wire chambers, and a muon detector (hadron filter and chambers) to study leptonic decays.

I. Overview - J. Sandweiss

The usefulness of developing a short, high, flux, charged hyperon beam to study weak interactions, especially via leptonic decays, was re-emphasized.

Such a beam could be used to study Ω^- decays, to test strong interaction symmetry predictions, and to renew resonance spectroscopy by searching for "new points" in the strangeness and baryon number phase space and in symmetry group multiplets.

J. Hyperon Decays - O. Overseth

Suggestions for several important decay experiments were made. In non-leptonic decays, they were tests of the $\Delta I = \frac{1}{2}$ rule and possible CP violation, measurement of the Ξ lifetimes, and searches for possible $\Delta S = 2$ decays.

It was pointed out that if the hyperons are polarized, T invariance tests could be made and a "tertiary" beam of polarized protons could become available for additional experiments.

K. The Charged Hyperon Channel and Particle Identification - A. Roberts

The results given in Fermilab TM-610 describing the beam elements, optics, and characteristics were reviewed in this discussion. Table I, or better TM-610 best summarizes the presentation.

L. Segmented Anode Cerenkov Counter - R. Majka

This presentation began with a description of a Cerenkov counter originally designed to identify hyperons in a non-achromatic beam. This detector would have an optical image dissection system for the Cerenkov radiation rings corresponding to the different hyperons within the momentum band of the beam.

With the development of an achromatic beam design, ring image separation could be done using a normal differential counter system (slits) or by means of a segmented anode photodetector system. With some combination of these methods, multiple tagging of the hyperons would be possible. Discussion on the dimensions and characteristics of present experimental prototype photomultipliers ensued.

TABLE I

(From TM-610)

Properties of the Achromatic Hyperon Beam

Momentum Range $\delta P/P$	up to ± 3%
Horizontal Angular Dispersion (150 GeV/c)	± 0.02 mr for ± 3% $\frac{\delta P}{P}$
Vertical Angular Dispersion (150 GeV/c)	± 0.03 mr for ± 3% $\frac{\delta P}{P}$
Solid Angle Acceptance	up to 1 μSTR
Method of Momentum Determination	Horizontal Location at Two Points Along Beam
Accuracy of Momentum Determination	Limited by Target Size, Except if Target Size < 0.2 mm (effective), it may be limited by locational accuracy (70μ) to ± 0.3%.
Sigma - Xi Separation	Fraction of the beam accepted by a Cerenkov Detector with .06 mr vertical apeture (240 GeV/c) Momentum acc: ± 3% Vertical acc: ± 100%
Beam Length	12.6 m (without Cerenkov)

TABLE II

Projected Yield Data for the Achromatic Hyperon Beam

A. Hyperon Yields, taking into Account Production and Decay.

No. of Particles/μster · GeV/c/.37 x 10^{12} Interacting Protons.

Proton Mom. GeV	Hyp. Mom.	Total Beam Length	Pion Yield	Decay Factor			Hyperon Yield		
				Sigma	Xi	Omega	Sigma	Xi	Omega
400	160	21.5 m	5.1E7	.0266	.0278	.0029	1.26E6	2.8E4	29.6
400	240	21.5	1.3E7	0893	.0917	.0203	1.2E6	2.4E4	53.0
400	240	29.5	1.3E7	.0363	.0377	.0048	4.7E5	1.0E4	12.5
400	320	29.5	1.4E6	.0834	.0856	.0182	1.2E5	2400	5.1
500	400	29.5	1.2E6	.137	.137	.0408	1.6E5	3300	9.8

B. Ratio of Hyperons to Pions at Beam Exit

Beam Momentum GeV/c	Sigmas per 10^6 pions	Xis per 10^6 pions	Omegas per 10^6 pions
160	4.2E4	860	1.2
240 (21.5 m)	8.1E4	1700	3.5
320	8.5E4	1700	3.7
400	1.2E5	2400	6.7

Note: At 400 GeV/c a momentum acceptance of ± 3% would cover a range of 24 GeV/c; the beam would then have to hold to 4 x 10^{10} incident protons to keep the total particle flux down to 10^6/sec.

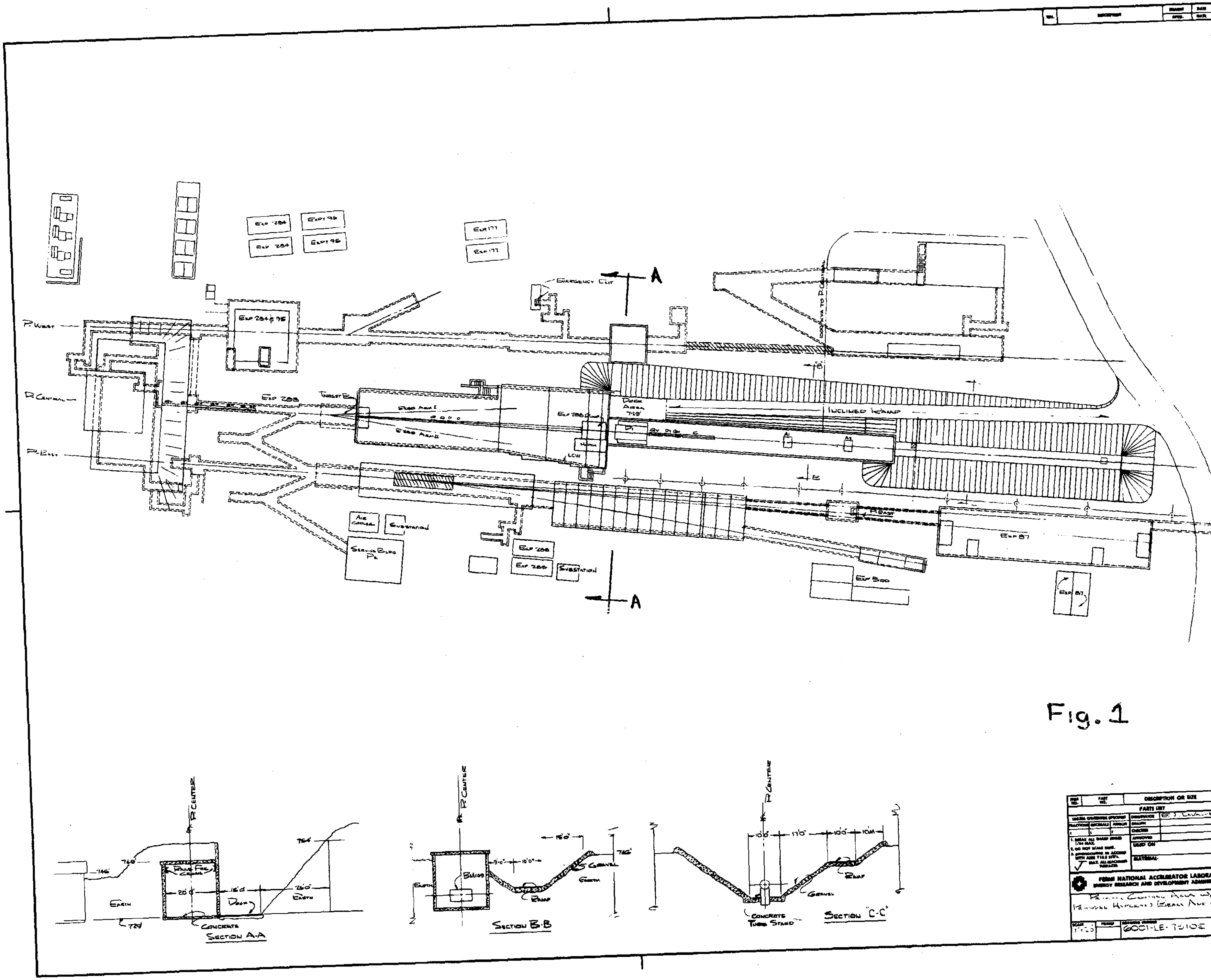

Fig. 1

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FIGURE 2

Schematic of the CERN SPS Hyperon Beam