Fermilab Proposal No. 351

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K° Regeneration at the Highest FNAL Energies

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I Introduction

The study of coherent K^o regneration at high energies is a powerful method for the investigation of the asymptotic behavior of KN and $\overline{K}N$ scattering amplitudes. In particular, a knowledge of the regeneration amplitude at the highest available K^o energies makes possible a rather systematics-free test of the Pomeranchuk Theorem. Briefly, the Pomeranchuk Theorem can be stated as follows (in a world where total cross sections may not be bounded):[1]

Let $f(k, t)$ and $\sigma_T(k)$ be the scattering amplitude and the total cross section for the process $A + B \to A + B$, where k = momentum of A, t = momentum transfer. $\overline{f}(k, t)$, $\overline{\sigma}_T$ apply to the process $\overline{A} + B \to \overline{A} + B$.

If (1) $\sigma_T/\overline{\sigma}_T$ has a finite limit with σ_T, $\overline{\sigma}_T$ smooth functions of k, and

(2) $\lim\limits_{k\to\infty}\left|\dfrac{\mathrm{Re}f}{\mathrm{Im}f\cdot\log k}\right| = \lim\limits_{k\to\infty}\left|\dfrac{\mathrm{Re}\overline{f}}{\mathrm{Im}f\cdot\log k}\right| = 0$, and

(3) the axioms of field theory leading to dispersion relations are valid,

Then,

$$\lim_{k\to\infty}(\sigma_T/\overline{\sigma}_T) = 1. \tag{1}$$

(Actually, if σ_T, $\overline{\sigma}_T \to \infty$, then 2 is a consequence of unitarity and not needed as an assumption.)

Since the K^o regeneration amplitude ρ is proportional to $(f(k, 0) - \overline{f}(k, 0))$ it affords a direct comparison of particle and antiparticle total cross-sections in a single experiment.[2]

For these reasons, much effort[3] has gone (and is still going)

into measurements of the K^o regeneration amplitude vs. energy. The latest of these efforts is our first-round regeneration experiment at FNAL, E-82. Results on regeneration in carbon have been presented at the London Conference, the Williamsburg Conference and at FNAL (see Fig. 1). By now data taking in C and CH_2 has been completed and definitive results will be available in the next few months.

The upgrading of the Laboratory energy to 300 GeV enables us in E-82 to measure the regeneration amplitude up to about 120 GeV/c.

It is natural to ask how one would pursue these measurements to yet higher energies. Application of the methods used in E-82 in a higher energy beam is definitely <u>not</u> the most efficient approach. As we pointed out several years ago,[4] conventional regeneration techniques in a K_L^o beam (the so-called RSW method) suffer from a severe loss in statistical power when the magnitude of the regeneration amplitude ρ becomes comparable to that of the decay amplitude η_{+-} for the CP violating process $K_L^o \to \pi^+ + \pi^-$. This is easy to understand (see Fig. 2) from the expression for the intensity of $\pi^+\pi^-$ decays at a distance z behind a regenerator

$$I_{+-}(z) \propto |\rho e^{-\beta z} + \eta_{+-}|^2, \ \beta \equiv -i\Delta m\tau_s + \frac{1}{2} \qquad (2)$$

where z is in units of K_s^o decay lengths. Now the position of maximum interference is given by

$$z_0 = 2\ln(|\rho|/|\eta_{+-}|) \qquad (3)$$

For a regenerator with $|\rho| = |\eta_{+-}|$, $z_0 = 0$. (Note that based on low energy measurements, and plausible models of the momentum de-

pendence of ρ,[5] $|\rho| = |\eta_{+-}|$ corresponds at 300 GeV/c to a liquid hydrogen regenerator of 3 meters length!)

For regenerators with $\rho >> \eta_{+-}$ the magnitude $|\rho|$ is determined at $z = 0$ and $z >> z_0$ (where η_{+-} dominates), while the phase ϕ_ρ is determined primarily at z_0. As is seen in Fig. 2, when $z_0 \approx 0$ this separation no longer exists, and a strong and unfavorable correlation between $|\rho|$ and ϕ_ρ arises.

The paucity of high-energy K_L^o's, their small regeneration power and the diminished statistical power of the RSW method make the latter very inefficient above 120 GeV.

II Regeneration in a Short Neutral Beam

The primary problem with the RSW method lies in the fact that we obtain information about ρ by observing its interference with the fixed amplitude η_{+-}.

Consider now a pure K^o beam sufficiently short that the K_S^o component has not yet died out. (The assumption "pure K^o" is crucial and will be discussed below.) If a regenerator is placed in this beam a distance d from the target, then in place of equation (2) we get

$$I_{+-}(z, d) \propto |(e^{-\beta d} + \rho)e^{-\beta z} + \eta_{+-}|^2 \qquad (4)$$

(Piccioni and collaborators were the first to study regeneration in a short beam, albeit for different reasons.)

Experimentally, one counts the number of $\pi^+\pi^-$ decays in a fixed decay region behind the regenerator, obtaining

$$N_{+-}(d) = \int_0^z I_{+-}(z, d)\varepsilon(z)dz \tag{5}$$

where ε is the detection efficiency of the apparatus. $N_{+-}(d)$ versus d is shown for several ratios of $|\rho|/|\eta|$ in Fig. 3.

The $e^{-\beta d}$ term in equation (4) serves as an adjustable amplitude which interferes with ρ, providing the information. Here, the point of maximum interference occurs at

$$d_0 = 2\ln(1/|\rho|) \tag{6}$$

Since $|\rho| << 1$, $d_0 > 0$. For $|\rho| = |\eta_{+-}|$, $d \cong 12K^o_s$ decay lengths. It is thus possible for physically relevant values of ρ to obtain information on both sides of the point of maximum interference.

For an initially pure $\overline{K^o}$ beam only the sign of the interference term in equation (4) is reversed. Hence, in a beam composed of K^o's and $\overline{K^o}$'s, this term is "diluted" by the factor

$$D = \frac{N - \overline{N}}{N + \overline{N}} \tag{7}$$

where $N(\overline{N})$ is the number of $K^o(\overline{K^o})$ in that incident beam[6] (at t = 0).

In our Letter of Intent we boldly assumed that $D \to 1$ at the "tip" of the K^o spectrum (i.e., where $P_K \simeq P_{proton}$). Since D is well approximated by $D' = (N^+ - N^-)/(N^+ + N^-)$ where $N^+(N^-)$ refers to the number of $K^+(K^-)$ at the same production angle, then production data of experiment E-104[7] bears out this assumption (see Fig. 4). In fact, these data suggest that the beam will be essentially pure K^o for $P_K \gtrsim P_{proton}/2$.

It is possible, then, to determine the magnitude and phase of ρ at the energies of interest by measuring the distribution $N_{+-}(d)$ versus d.

Since each d requires a relocation of the regenerator and the detection apparatus, we want to measure $N_{+-}(d)$ at as few points as possible.

In principle, N_{+-} at two points, at both with and without a regenerator, suffice to determine $|\rho|$ and ϕ_ρ. This was referred to as the difference, or Δ, method in our Letter of Intent (see Fig. 5). For any given kaon momentum two points can be chosen such that $|\rho|$, ϕ_ρ are completely decoupled. However, since d is in units of K_S^o decay lengths, this choice is momentum dependent.

It is, however, possible to select 4 or 5 values of d which yield good statistical power in the momentum range 150-350 GeV/c, using a liquid hydrogen target of 7.2 m length (such as the one designed for E-82). The rate estimates are given in Section IV, along with a comparison with the conventional RSW technique.

III Beam-Line and Spectrometer

Some of the propronents of this regeneration experiment are currently engaged in E-8, using the M2 beam line for a neutral hyperon survey and study.[8] A short neutral beam produced in a beam stop/sweeping magnet[9] is used.

This M2 beam is currently operational in a test mode, using a low intensity ($\sim 10^6$ protons/pulse) diffracted proton beam ($p_p \approx$ 300 GeV/c). Initial results indicate a very clean situation with a low intensity halo: the singles rates in the proportional chambers of the E-8 spectrometer are $\approx 10^{-3}$ per incident proton.

We propose to set up a spectrometer for this experiment in this M2 beam, <u>behind</u> the E-8 spectrometer. The smallest proposed

value of d corresponds to a regenerator location of 50 meters downstream from the source (i.e. outside the M2 Wonder Building) and the largest d corresponds to a regenerator location 150 m farther downstream. Our spectrometer and the regenerator would be mounted on rails for easy mobility. It is important to emphasize that the requisite construction and much of the testing can be carried out without interrupting the current work in M2.

While it is now clear that the Meson Laboratory will ultimately be upgraded to 400 GeV/c, additional work will be necessary to upgrade the M2 beam as well. Consequently, we present estimates for both 300 GeV/c and 400 GeV/c proton beams in M2.

Our spectrometer will have to have the following properties:

1) High spatial resolution to select coherently regenerated $K^o \rightarrow \pi^+\pi^-$ events.

2) A selective 2-body trigger to suppress unwanted events from leptonic K-decays and neutron interactions.

3) Compactness along the beam direction to facilitate the travel of the spectrometer relative to the production target.

4) Low mass to reduce as much as possible interactions produced by neutrons in the beam.

Spectrometers of two types have been considered. The first is a high resolution MWPC spectrometer with 1.5 mm wire spacing, each coordinate being measured twice with chambers staggered by 0.75 mm. The second is a multiwire drift chamber spectrometer with 2 cm spacing between sense wires. Both systems appear capable of sufficient resolution to allow for a "compact" ($\lesssim$20 m in length,

see Fig. 6) spectrometer, although the drift chamber version may be favored by the low mass requirement.

Both the Wisconsin and Chicago groups have in hand sufficient electronic hardware to run an MWPC spectrometer of the requisite size (5000-6000 wires). In addition, testing of a prototype drift chamber spectrometer is now in progress. A spectrometer with about 500 sense wires would suffice.

The analyzing magnet needed to accept high momentum $K \to 2\pi$ decays from a 30 meter decay volume has a modest gap size. A 0.2 m by 0.6 m gap, as in the E-8 spectrometer magnet, is sufficient to give very high acceptance for $P_K \geq 150$ GeV/c (see Fig. 7).

IV Rate Estimates

As mentioned above, estimates are presented for 300 GeV/c as well as 400 GeV/c protons. In both cases we show the comparison between the Δ-method in a short beam (M2) and the RSW method in a long beam (i.e., the M4 beam line with improvements as detailed below).

Following our experience in E-82, we propose to do these measurements first in carbon. $|\rho|/|\eta_{+-}| >> 1$ is easily attained in carbon even for 300 GeV/c kaon momentum. Thus, a relatively short run suffices for an accurate determination of ρ in carbon, which in itself has considerable physical interest.

Table I contains the rate estimates for the two methods in liquid hydrogen at 300 GeV/c proton momentum. Table II contains the same comparison at 400 GeV/c. Table III shows the rate esti-

mates for carbon.

The estimates indicate that in terms of running time the method proposed here is superior to the RSW-method by more than an order of magnitude. Furthermore, the total number of events required is less in the present method, due to its greater statistical power. As an example, consider the momentum bin 200 ± 20 GeV/c. The quoted precision in Table I requires 43,000 events (regenerator and vacuum events together) in the proposed method and 370,000 events in the RSW method.

V Trigger Rates and Backgrounds

The rates of coherent 2π triggers under the beam conditions for which the rate estimates have been made vary from a low of $\sim$1/pulse at the maximum distance (d = 190 m) to a high of $\sim$100/pulse at the minimum distance (d = 50 m). It is likely that this latter rate will be difficult take if there is an appreciable rate of unwanted triggers. Assuming one trigger in 30 to be a coherent 2π event, it is possible that many fewer than 100 coherent 2π events/pulse can be accumulated. However, at 100 real events/pulse only $\lesssim$1% of the running time is to be spent at 50 m, so a rather large factor due to buffer limitation or dead time can be tolerated without significant impact on the total running time.

The principal sources of background triggers are

1. Neutron interactions ($n/K^{\circ} \sim 100$)
2. $\Lambda \rightarrow p\pi$ decays
3. $K \rightarrow$ leptonic and 3π modes.

Various schemes are available for suppressing background at

the trigger level, based on experience gained in M4, and what is more relevant to this proposal, in M2.

E-8 and E-82 employ different magnetic field configurations to select the desired 2-body decays. In E-82 the analyzing magnet is set to compensate the maximum transverse momentum in a $K^o \rightarrow \pi^+\pi^-$ decay. "Picket Fence" hodoscopes behind the magnet select pionic decays with particle momenta parallel to the beam axis. This suppresses leptonic and other non-2 body events very effectively at the cost of about half of the 2π events which are bent out.

In E-8 the decay products are over-bent in the magnet. This scheme can be used to "focus" different transverse momenta at different distances behind the magnet, and has the advantage of sweeping out of the spectrometer the relatively low momentum particles from three-body decays. With a magnet of the type in use in E-8, both schemes are accessible, since the "picket fence" arrangement requires a much weaker field.

Additional suppression of unwanted triggers can be achieved with appropriate veto counters. Most important of these is a veto on charged particles exiting the regenerator. A counter array downstream of the regenerator or, in the case of liquid regenerators, the use of the regenerating medium as a Cherenkov counter are both possible.

Electrons and photons can be suppressed by shower Cherenkov counters downstream of the chambers (either lead glass or lead-lucite sandwiches). Muons can be vetoed by a counter bank behind a steel wall.

All of the veto techniques mentioned have been in use in E-82 for most of its data-taking, except the self-Cherenkov veto in liquid regenerator.

A novel veto technique, made straightforward by the limited (0.3 m × 1 m) transverse dimensions of the spectrometer, can be studied with the aid of data from E-8 and E-82. It consists of the addition of a total absorption calorimeter, used to trigger when energies of 150 to 350 GeV are deposited by a two-particle final state. Such a trigger element could be of use in suppressing events with very high, very low, or (if it is split along the beam axis) very asymmetric energy deposits. It could be combined with a "muon filter" by segmenting the first 5 or 6 collision lengths of the steel wall.

VI Other Beam Lines

The comparisons presented so far involve two beams with very different production angles (0 mrad in M2 vs. 6.5 mrad in M4). Since a smaller angle long neutral beam exists (M3), we consider the prospect of performing the high energy regeneration experiment in M3 with the RSW method.

The flux-solid angle product attainable in M3 compared to that in M4 appears capable of offsetting the running time advantage of the method proposed here. However, several distinct disadvantages of the RSW method remain.

First, the K_L^o flux available in M3, coupled with a neutron/K_L^o ratio similar to that in M2, gives an unmanageable trigger rate

($\gtrsim 10^3$ coherent 2π events/pulse above 150 GeV/c!). This rate pertains to the entire run in the RSW method, not just a small fraction of the running time as in the method proposed here. Thus, the improvement in running time is not comparable to the improvement in flux.

Second, a much larger data sample is required in the RSW method, due to its lower statistical power. The example cited above at 200 ± 20 GeV/c clearly does not depend on which beam line one uses.

Third, the RSW method requires a much longer decay region and is sensitive to the acceptance $\varepsilon(z)$, which therefore must be known very accurately. On the other hand, the method proposed here requires a relatively short decay in determining $N_{+-}(d)$, and since $\varepsilon(z)$ is integrated over, the method is less sensitive to the details of the acceptance.

In closing, it is noted that while most of the relative weaknesses of the RSW are present in any long neutral beam, the advantage of the proposed method are also present in any short neutral beam. Hence, this proposal is strongly tied to M2 only in the absence of new short neutral beam facilities at FNAL.

VII Summary

We propose to measure $|\rho|$ and ϕ_ρ in carbon and liquid hydrogen to the precisions quoted in Tables III and IA, respectively. Actual running time of 1800 hours is indicated for the two phases. A total of 3000 hours of beam time (approximately 40 weeks under current running conditions) is requested for testing and running.

References

1. R. J. Eden, Phys. Rev. Letters 16, 39 (1966).
2. $\rho = \pi i N \Lambda_s (f(k, 0) - \bar{f}(k, 0)/p$ (see Ref. 5). Thus $\Delta\sigma \equiv \sigma_T - \bar{\sigma}_T \propto \mathrm{Im}\rho$ and $\delta(\Delta\sigma)/\Delta\sigma \propto \delta(\mathrm{Im}\rho)/\mathrm{Im}\rho$. Thus, for $\Delta\sigma/\sigma \simeq 5\%$ σ_T and $\bar{\sigma}_T$ must be measured to <.5% accuracy to determine $\Delta\sigma$ to 10% while a determination of $\mathrm{Im}\rho$ to 10% suffices in the regeneration experiment. It should be noted that the regeneration experiment has the unique feature of measuring the real part of $f - \bar{f}$ as well.
3. M. Bott-Bodenhausen et al., Phys. Rev. Letters 20, 212 (1966) and 23, 277 (1966). A. Böhm et al., Phys. Letters 27B, 594 (1968). P. Darriulat et al., Phys. Letters 33B, 433 (1970). K. F. Albrecht et al., JINR, E1-7353 (1973). V. K. Birulev et al., Phys. Letters 38B, 452 (1972).
4. V. Telegdi et al., "Letter of Intent" to NAL, February 27, 1971.
5. S. H. Aronson et al., NAL Proposal No. 82.
6. See, for example, D. A. Jensen et al., Phys. Rev. Letters 23 #11, 615 (1969), where the same concepts are applied to "Vacuum Regeneration".
7. "Particle Survey in the M1 Beam Line", NALREP, February (1974).
8. R. H. March et al., NAL Proposal No. 8.
9. R. H. March, "Design of a Composite Sweeping Magnet for the NAL Hyperon Beams".

Table I: P_{proton} = 300 GeV/c

A. Δ-Method (M2 beam), 7.2 m LH_2 Regenerator†

Flux = 10^9 protons/pulse @ 7 sec/pulse
Production angle = 0 mrad
Solid angle = 250×10^{-9} steradians
Decay region = 30 meters
K° production spectrum: K^+ from Hagedorn-Ranft Tables, scaled down to give agreement with E104 K^+ production measurements[5]

P_K(GeV/c)	N(K° at target)/pulse	Dilution Factor	C_ρ^*	C_ϕ^*	Δρ/ρ	Δφρ
150 ± 15	3900	.8	749	1673	±.04	±5°
200 ± 20	3500	.9	519	1192	±.025	±3°
250 ± 25	1050	.95	557	1557	±.05	±8°

†For such a target $|\rho|/|\eta_{+-}| \cong 30/\sqrt{P_k(\mathrm{GeV/c})}$ in the momentum region of interest.
*$C_\rho \equiv \Delta\rho/\rho(\sqrt{N(K^\circ)})$, $C_\phi \equiv \Delta\phi\sqrt{N(K^\circ)}$

For Δρ/ρ = ±.025 at 200 ± 20 GeV the running time at the flux and solid angle given is 240 hours. Δρ/ρ and Δφ are also shown for other momenta. With allowance for geometrical detection efficiency (×2) veto, deadtime and cut losses (×2) and targeting efficiency (×1.5) gives a conservative estimate of 1500 hours.

B. RSW Method (M4 Beam), 7.2 m LH_2 Regenerator

Flux = 10^{13} protons @ 7 sec/pulse ($\sim 4 \times 10^{12}$ during E-82)
Production angle = 6.5 mrad (7.25 mrad during E-82)
Solid angle = 20×10^{-9} steradian ($\lesssim 13 \times 10^{-9}$ during E-82)
Decay region = 60 meters
K° production spectrum: as measured by E-82, extrapolated to 250 GeV/c with Hagedorn-Ranft Tables, scaled down to agree with $(K^+ + K^-)/2$ from E-104.

P_K(GeV/c)	N(K_L° at regenerator)/pulse	C_ρ^*	C_ϕ^*	Δρ/ρ	Δφ
150 ± 15	12100	875	1288	±.025	±2.2°
200 ± 20	675	1321	1756	±.149	±11°
250 ± 25	≃25	1620	2056	±.942	±68°

*$C_\rho \equiv \Delta\rho/\rho(\sqrt{N(K_L)})$, $C_\phi \equiv \Delta\phi\sqrt{N(K_L)}$

The precision quoted is for the same 1500 hour/run as discussed in part A of the Table. Alternatively, to reach the quoted ±2.5% precision of the Δ-method at 200 ± 20 GeV/c would require an RSW run of 53,000 hours. The flux, production angle and solid angle improvements over E-82 mentioned above amount to a factor 10 increase in K_L^o per pulse at 200 GeV/c.

Table II: P_{proton} = 400 GeV/c

A sample comparison of P_K = 300 ± 30 GeV/c similar to that done in Table I (assuming now 10 sec/pulse).

A. Δ-Method

P_K(GeV/c)	N(K°)/pulse	Dilution Factor	C_ρ	C_ϕ	$\Delta\rho/\rho$	$\Delta\phi$
300 ± 30	2300	.95	654	1105	±.05	±5°

The quoted error with the same factor for conservativeness gives a 1300 hour run.

B. RSW-Method

P_K(GeV/c)	N(K^o_L)/pulse	C_ρ	C_ϕ	$\Delta\rho/\rho$	$\Delta\phi$
300 ± 30	≈100	1863	2580	±.69	±54°

The quoted errors are for a 1300 hour run. For $\Delta\rho/\rho$ = ±.05 the RSW method would require a run of 250,000 hours.

Table III: Carbon

Δ-Method, p_{proton} = 300 GeV/c

With the same conditions specified in Table IA, a run of 300 hours yields the following results for a 0.7 m carbon regenerator ($|\rho|/|\eta_{+-}| \simeq 5.5$ @ 200 GeV/c)

P_K	C_ρ	C_ϕ	$\Delta\rho/\rho$	$\Delta\phi$
150 ± 15	293	1604	±.03	±10°
200 ± 20	228	1310	±.025	±8°
350 ± 25	246	1031	±.05	±12°

Figure 1.

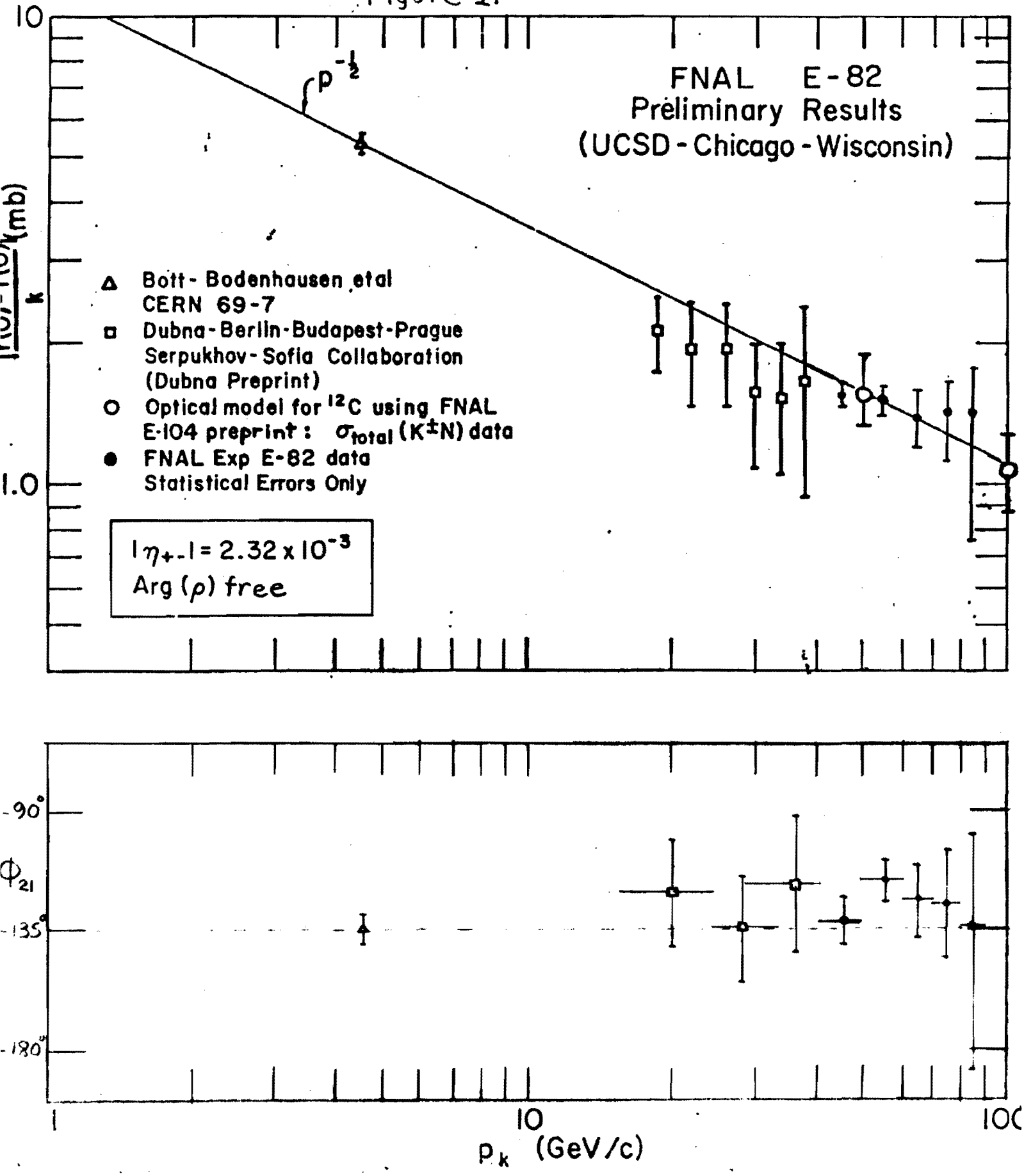
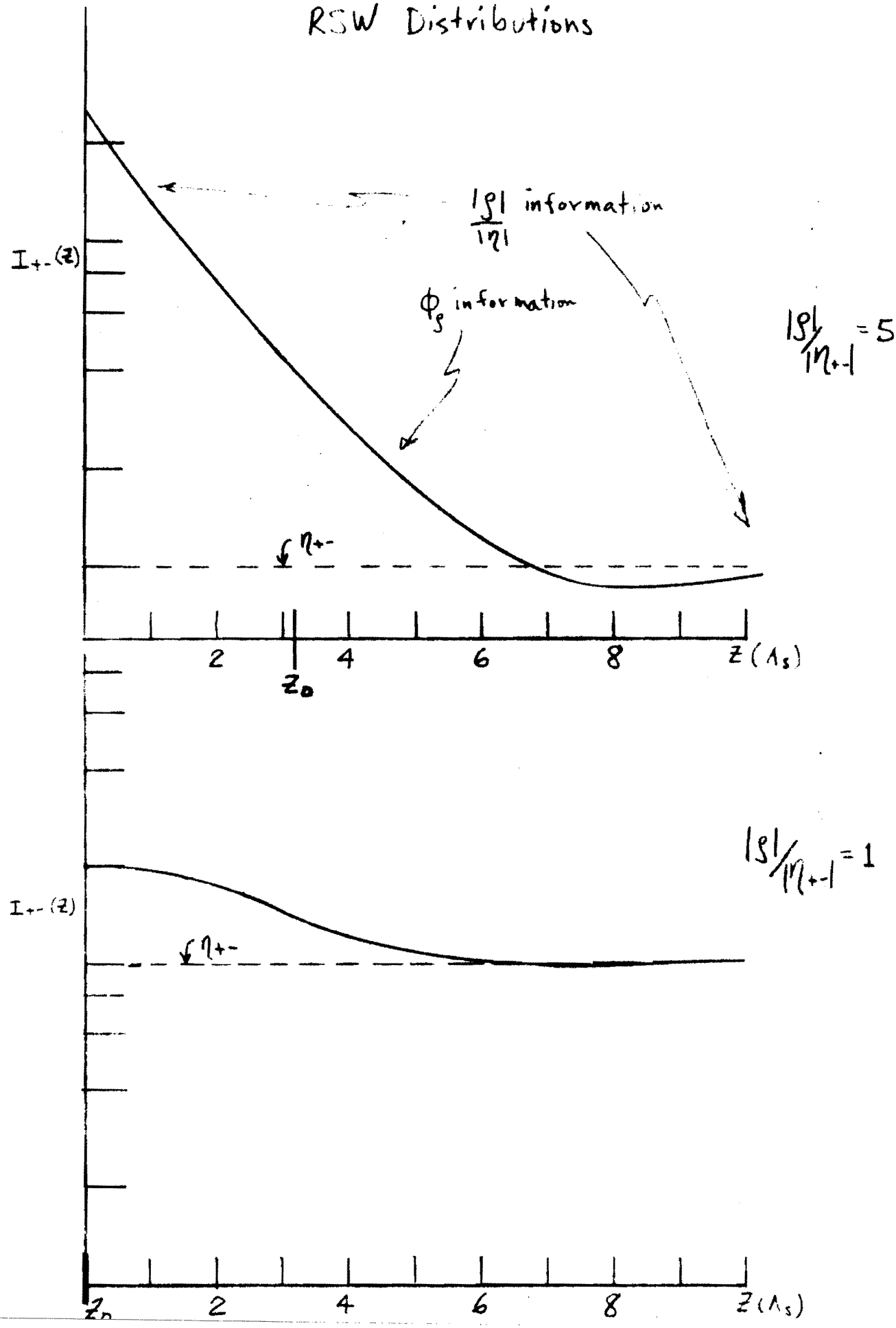

FNAL E-82
Preliminary Results
(UCSD - Chicago - Wisconsin)
$p^{-\frac{1}{2}}$
Bott - Bodenhausen et al
CERN 69-7
Dubna - Berlin - Budapest - Prague
Serpukhov - Sofia Collaboration
(Dubna Preprint)
Optical model for ^{12}C using FNAL
E-104 preprint : $\sigma_{total}(K^{\pm}N)$ data
FNAL Exp E-82 data
Statistical Errors Only
$|\eta_{+-}| = 2.32 \times 10^{-3}$
Arg (ρ) free
10
1.0
(mb)
-90°
Φ_{21}
-135°
-180°
1
10
100
p_k (GeV/c)

Figure 2
RSW Distributions



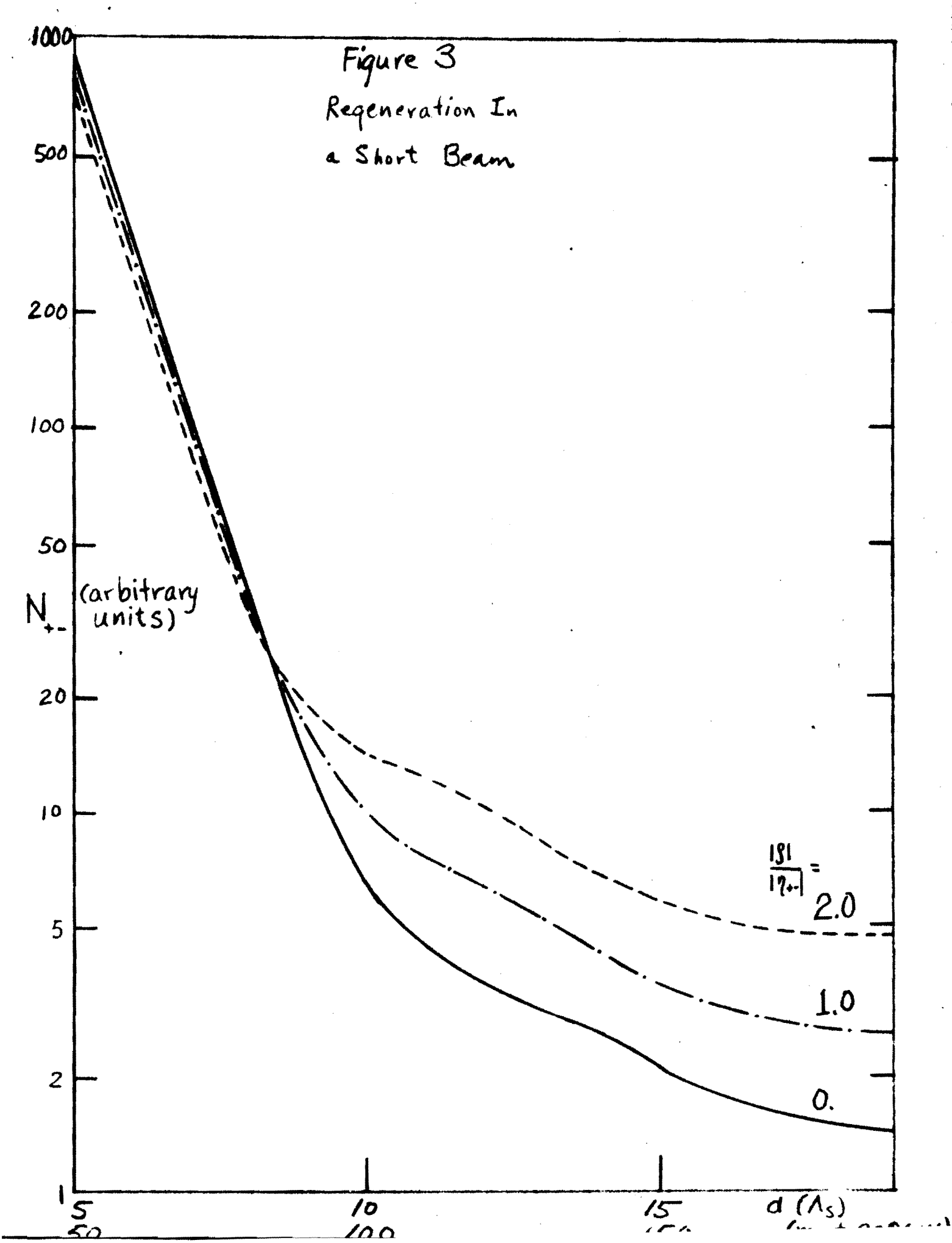


Figure 3
Regeneration In
a Short Beam
1000
500
200
100
50
20
10
5
2
1
N_{+-}
(arbitrary units)
$\frac{|\xi|}{|\eta_{+-}|}$ =
2.0
1.0
0.
5
10
15
d (Λ_S)

Figure 4

"Dilution Factor"

(E-104 Data)

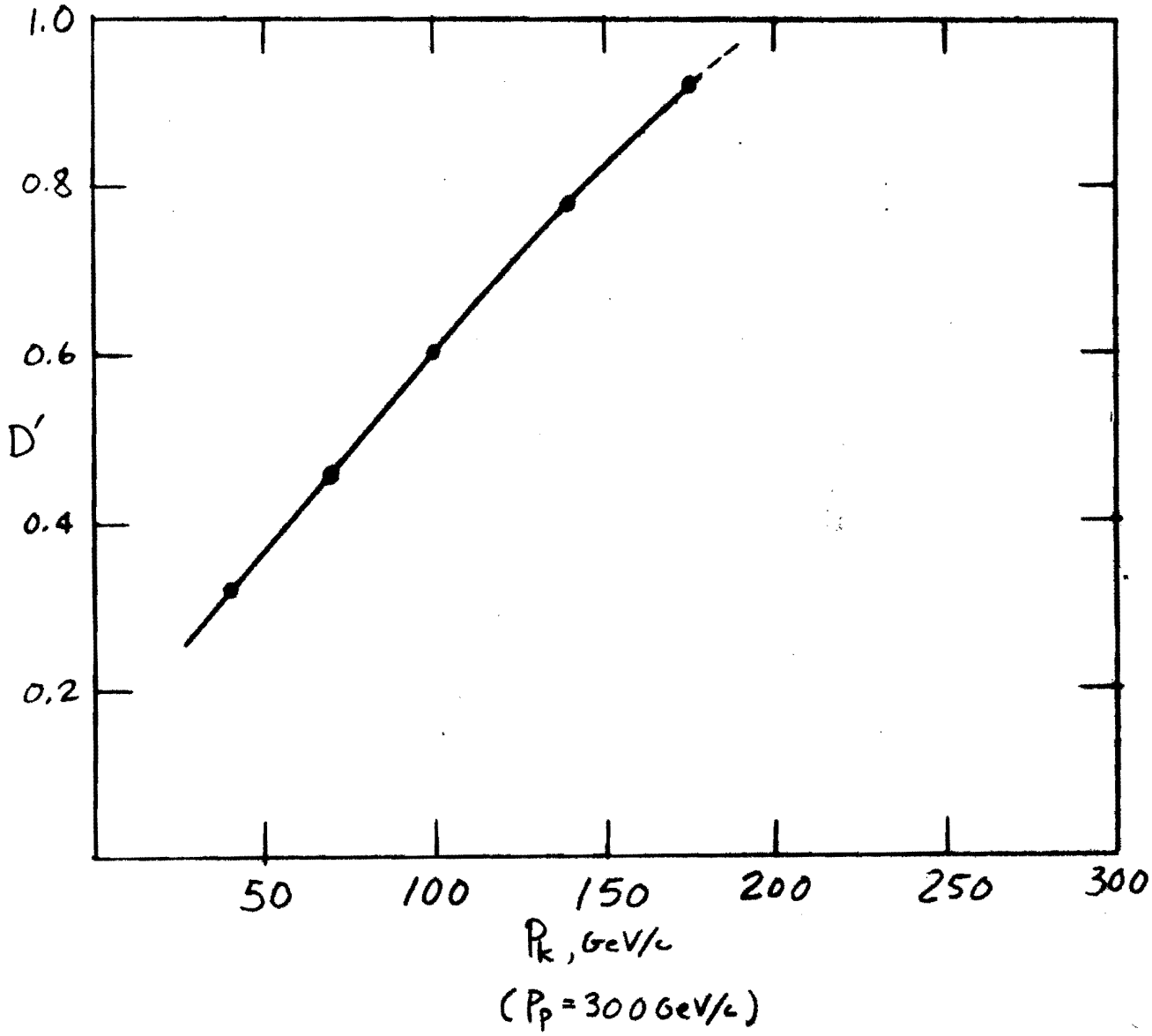
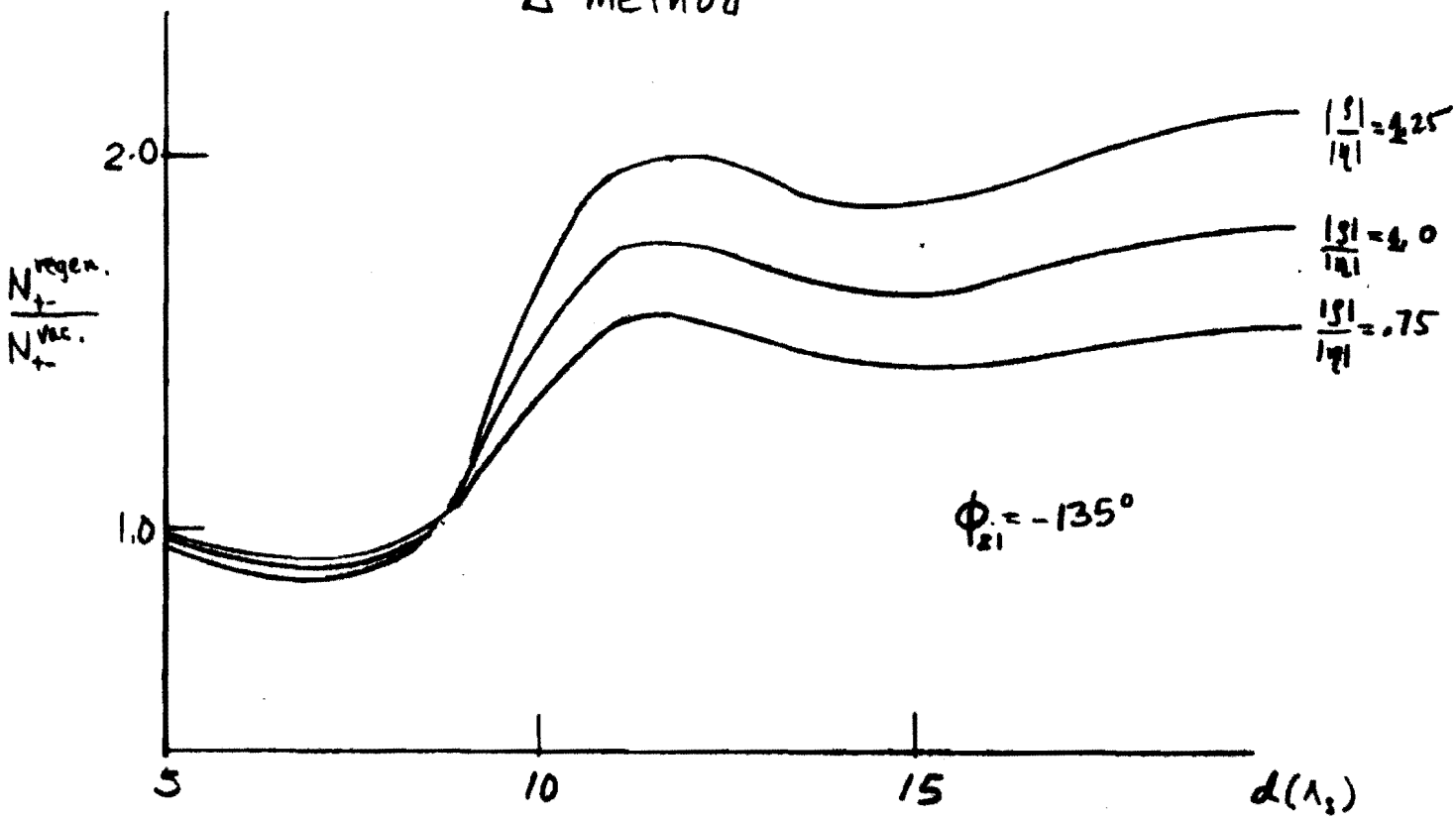


Figure 5

Δ-method



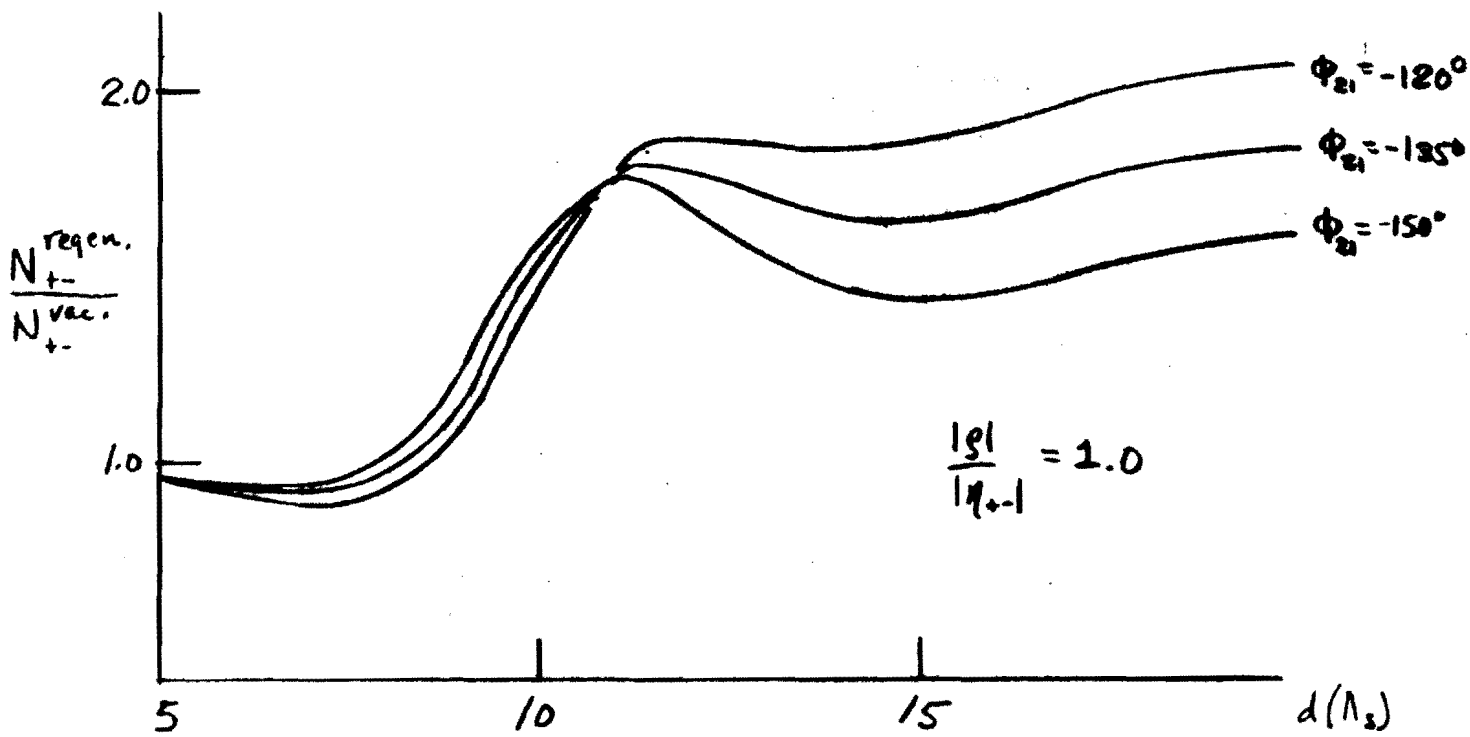
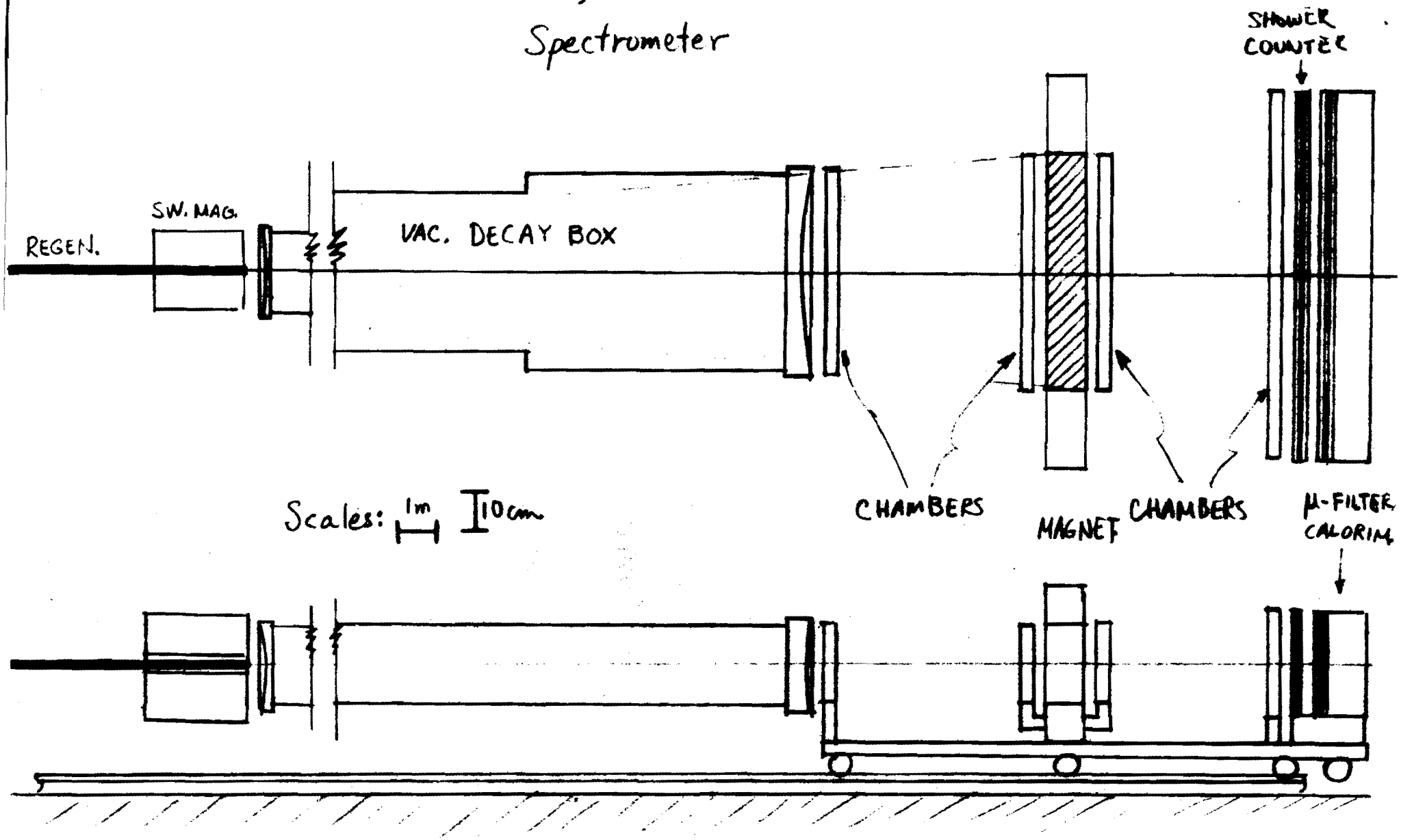
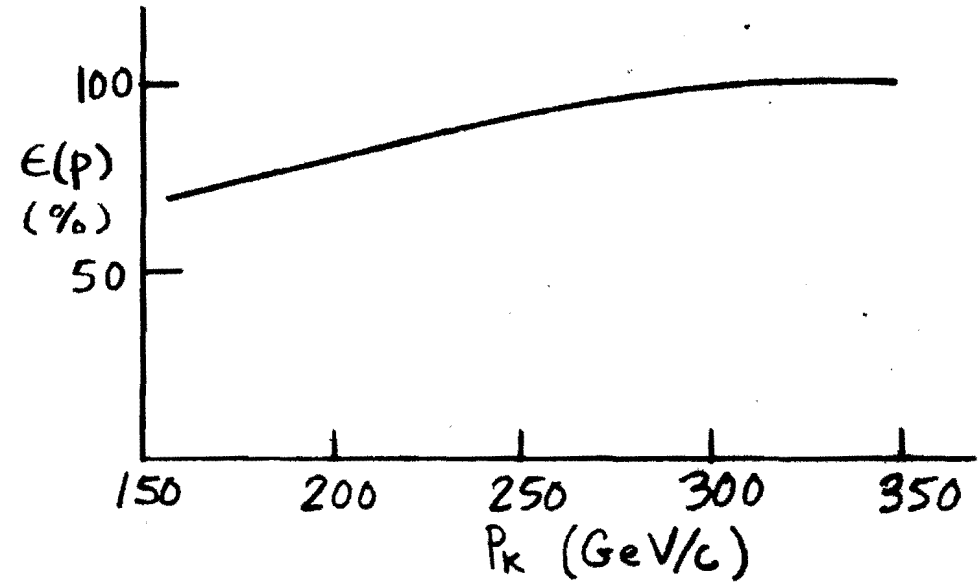


Figure 6.

Spectrometer



Acceptance of 2π Decays
(Monte Carlo Simulation)
(no loss of outbends assumed)



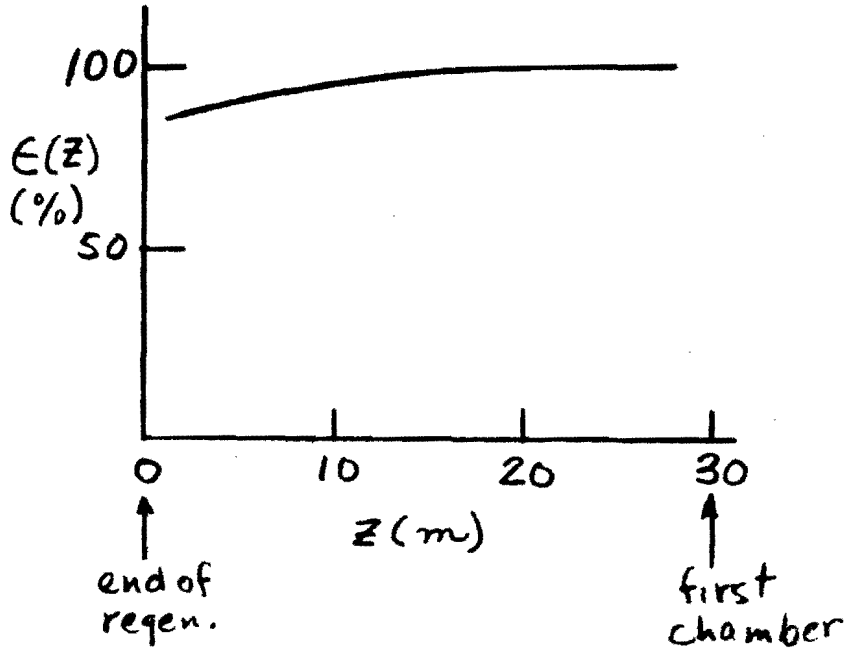


Figure 7

Addendum to Proposal #351:

K° Regeneration at the Highest FNAL Energies

In the original proposal we presented a novel method for extending regeneration measurements into a momentum region, now available at FNAL, in which $|\rho| \approx |\eta_{+-}|$.

At the time of proposal it was not possible to give definitive answers to several key questions relating to the performance of #351. These questions are:

1. What is the availability of a suitable hydrogen target?
2. Is the M2 beam suitable for the proposed bombardment?
3. How is the M2 beam line to be modified for the installation of #351?

It is now possible to provide the answers needed for consideration of the proposal.

1. The target proposed for the liquid hydrogen phase of the experiment is the same one proposed for the corresponding phase of E-82. This target has now been approved and is under construction, following an intensive review of the physics goals of high energy K° regeneration by a panel of experts convened at FNAL in March.* The target should be available in mid-summer for the completion of E-82. It is expected that E-82 data taking will be finished during calendar year 1975.

2. The K°_S fluxes in the M2 beam line have been measured by the E-8 neutral hyperon collaboration and presented at FNAL in March as part of the neutral hyperon beam survey. The measured K°_S flux is compared to the flux used in the proposal calculations in Fig. 1. The measured flux is seen to fall off more steeply than

*See appendix

the proposal estimates. This has the effect of enlarging somewhat the statistical errors at the highest K° energies. We have been able to compensate for this fall-off to some extent with a different choice of data-taking positions. The table below shows the statistical power of this new configuration, using the experimentally determined K°_S. Two other effects have been included in this new estimate not considered in the proposal:

a) We now assume we will have to measure the "dilution factor" and have included the affects of uncertainty in this quantity. This will be done in the carbon phase of the experiment (see below).

b) We assumed in the proposal the same solid angle of the beam (250 nanosteradians) at all distances from target to regenerator. We now assume constant beam size (5cm x 5cm) to match the hydrogen target aperture.

TABLE I

Statistical power for 1500* hour LH_2 run with 10^9 incident protons per pulse (10 sec rep. rate) at 400 GeV/c. Flux normalized to 1 μsterad solid angle.

p_K(GeV/c)	N(K°_S at target)/pulse	Factor Dilution	$C\rho$	$C\phi$	$\frac{\Delta\rho}{\rho}$	$\Delta\phi$
150±15	3.6×10^4	.75	765	1225	1.5%	1.3°
200±20	2.2×10^4	.85	850	1375	2.2%	1.9°
250±25	1.1×10^4	.95	1030	1410	5.6%	2.9°
300±30	3.5×10^3	>.95	1340	950	12.2%	4.2°

*As in the proposal, the bombardment used in making these estimates is actually 240 hours. A factor 6 is used to account for geometrical detection efficiency, veto, deadtime and reconstruction losses, and targeting efficiency.

Another factor to be considered in the suitability of M2 for #351 is the background due to neutrons in the beam. E-8 has measured the total neutron flux and finds 2.4×10^{-3} neutrons/incident proton and 50 neutrons/K_S° with $p_K \geq 65$ GeV/c.

The neutron-to-K° ratio is between 5 and 10 times greater than that in our K_L° beam in M4. Also, the average neutron momentum is much higher in the M2 beam at 0 mrad than in M4 at 7.25 mrad, and so the K_S°'s produced at the regenerator by neutrons will form a larger background than in E-82. Estimates of the background of locally produced K_S° under the coherent peak ($\Delta t \sim 100$ MeV^2/c^2) based on the above mentioned relative fluxes and E-8's measured K_S° invariant cross sections have been made. Assuming <u>no vetoing</u> on charged particles associated with this local K_S° production the background is $\sim$20 times the coherent regeneration signal. With a smaller t range (i.e. better experimental resolution) and efficient vetoing, this can be brought down to a manageable background in the trigger. The proposed spectrometer including drift chambers should have 2 to 3 times better t resolution than is quoted here, and experience in vetoing at the regenerator in E-82 shows that the locally produced K_S°'s form a negligible background in that environment. Tests in M2 with a 50 cm carbon regenerator are planned for the current running period (late May) and the results will answer the background question empirically.

Finally, the statistical power of the carbon run has been revised, because of the new information on the flux and the decision to use the carbon data to measure the dilution factor. The table below shows this revision:

TABLE II

Statistical power for 300 hour carbon run. Same conditions as in Table I. DF=dilution factor.

p_K (GeV/c)	$C\rho$	$C\phi$	C_{DF}	$\frac{\Delta\rho}{\rho}$	$\Delta\phi$	$\Delta DF/DF$
150±15	290	625	450	1.1%	1.4^0	1.8%
200±20	395	750	450	2.0%	2.2^0	2.3%
250±25	685	625	635	4.9%	2.5^0	4.5%
300±30	810	525	635	10.2%	3.8^0	8.0%

3. Because the experimental method requires movement of the regenerator and spectrometer relative to the target, and because at 300 GeV/c the K_S^o decay length is 16 meters, we require an extension of the M2 beam line amounting to 150 meters (500 feet). Figure 2 shows the Meson Area layout with the proposed M2 extension.

Discussion with the staff of the Meson Lab has centered on the construction of a 16 foot wide concrete pad over this whole length, with a "Wonder Building" to provide a suitable environment for the target and spectrometer. The only structures currently in the path of such an extension are the E-82 Portakamp and a service road. A proposed new service road is shown on the layout.

The estimated cost of the pad is $39,000 and of the service road $10,000.

Two possible means of covering the experiment with the Wonder Building are under consideration. The first is to cover the

entire pad with a single stationary structure. Figure 3 shows a cross-sectional view of the current M2 Wonder Building, the proposed extension, and the largest object in the spectrometer ("Avis"). Such a building costs $130/running foot or $65,000 for the whole structure.

The second is a "train" of two smaller mobile Wonder Buildings 28' and 65' in length. The cost of these two buildings is about $12,000. These would move with the spectrometer along the pad. Figure 4 shows a sketch of such an arrangement.

In spite of its higher cost for buildings, the first approach is favored by the Meson Lab staff for several reasons. The fixed building is felt to be a more useful asset to the lab when #351 is finished. In addition, running power and water to a stationary building is a solved problem, whereas the mobile building presents some as yet unsolved problems in the distribution of utilities. Rolling the spectrometer and building over rails which are exposed to the weather may also be a problem. The hidden costs in solving these problems could reduce the apparent economy of the second approach.

The one distinct advantage of the second approach is the ease of providing the required hydrogen safe environment because of the separate target building.

Further study will be required to make a final selection, but the first appraoch is standard enough to allow a reasonable estimate of the costs involved. This is summarized in the table below.

Table III

Estimated cost of M2 extension

Concrete Pad (16'x500')	$ 39,000
Wonder Building (16'x500')	65,000
Utilities (lights, heat, power, water, etc.)	20,000
Service Road	10,000
Total	$134,000

A final point with regard to the modification of M2 is necessary . The current shielding arrangement in the Detector Building is apparently not adequate to handle the proposed incident proton flux of 10^9 per pulse. A possible solution to this problem involves moving the beam dump/sweeping magnet downstream out of the Detector Building. This solution has the appealing feature of increasing the room for experiments in M2 upstream of the neutral beam facility. Such a move requires an additional extension of M2 so that the same target/regeneration separation can still be accomodated.

In addition to the cost involved in the preparation of M2 for #351 one must consider the time scale appropriate to this project. Both E-82 and E-8 are expected to finish their data taking around the end of calendar 1975. With approval of #351, construction of the major hardware (drift chambers and calorimeter) could begin immediately. Thus construction of the M2 extension and installation of #351 during the spring and summer of 1976 seems feasible in the view of the proponents.

Appendix: Physics Goals of Regeneration in Hydrogen

In March of this year Prof. V. Telegdi presented a detailed analysis of the physics goals of hydrogen regeneration to a special review committee at FNAL. While these remarks were directed toward resolving the question of E-82's hydrogen requirements, they apply equally well to the physics goals of #351. Prof. Telegdi's remarks are enclosed.

K° PRODUCTION SPECTRUM AT 0°

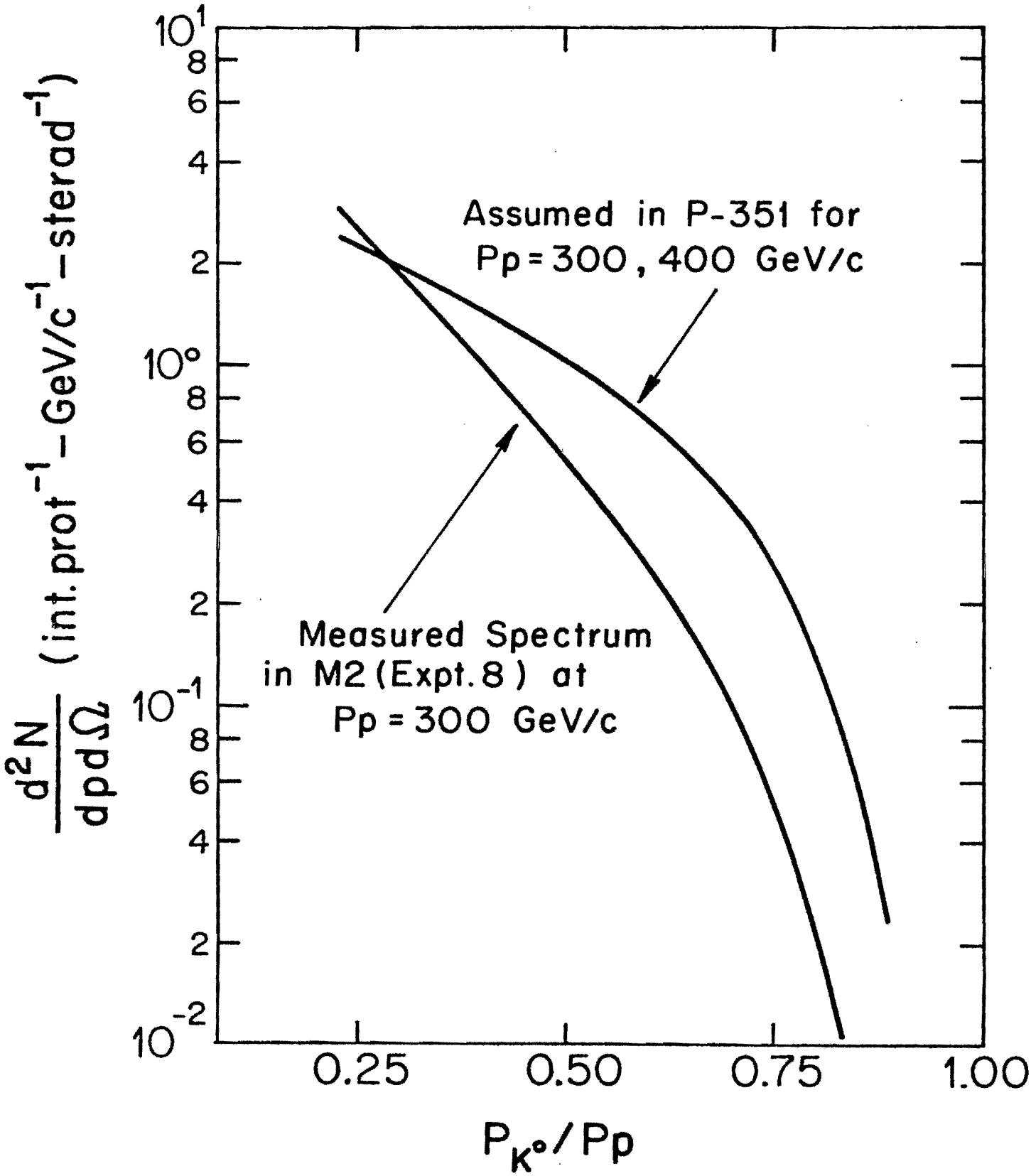
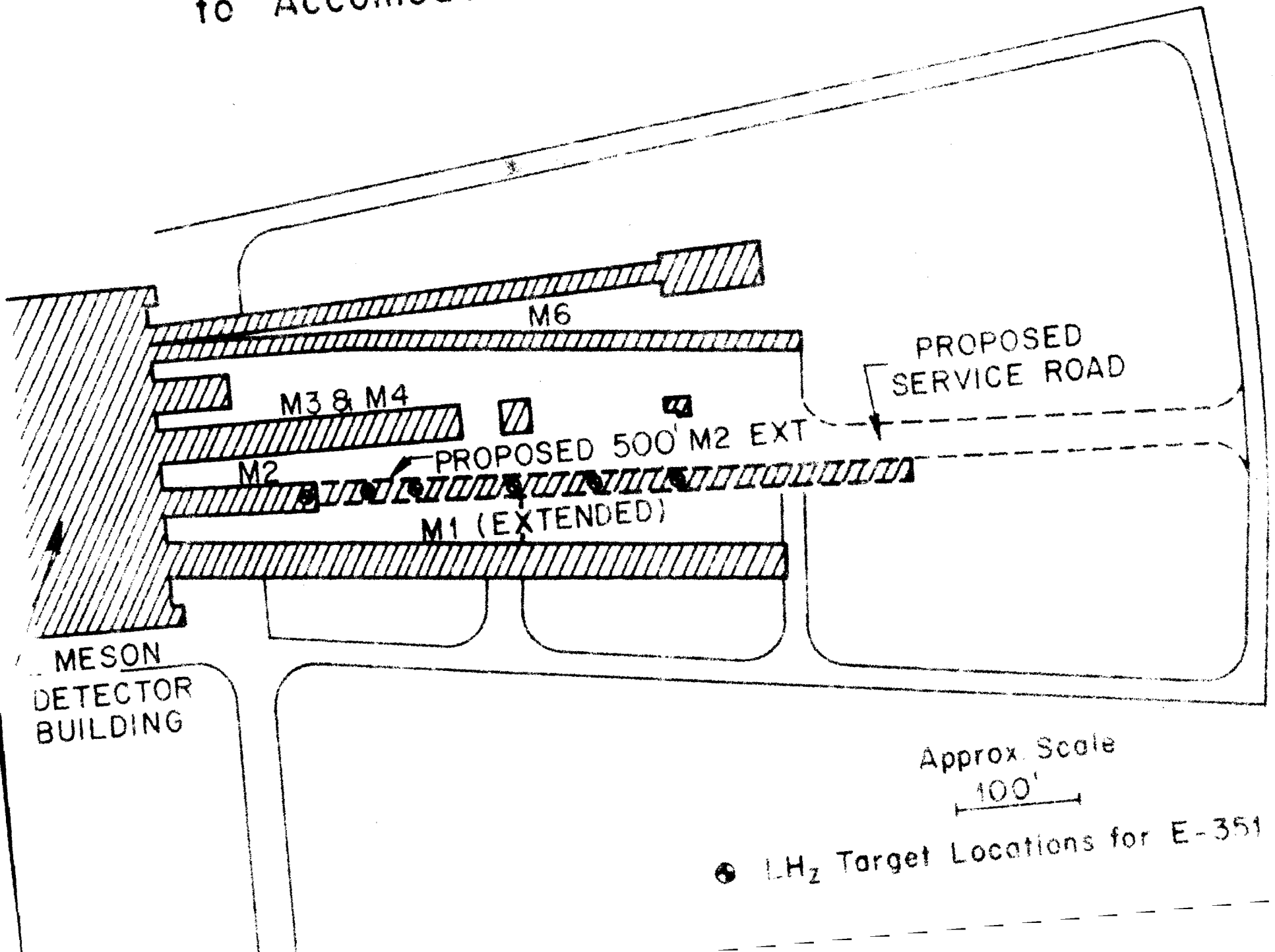


fig. 1

Proposed Modifications of Meson Area to Accomodate E 351



CROSS-SECTION OF E-351 IN M2 EXTENSION

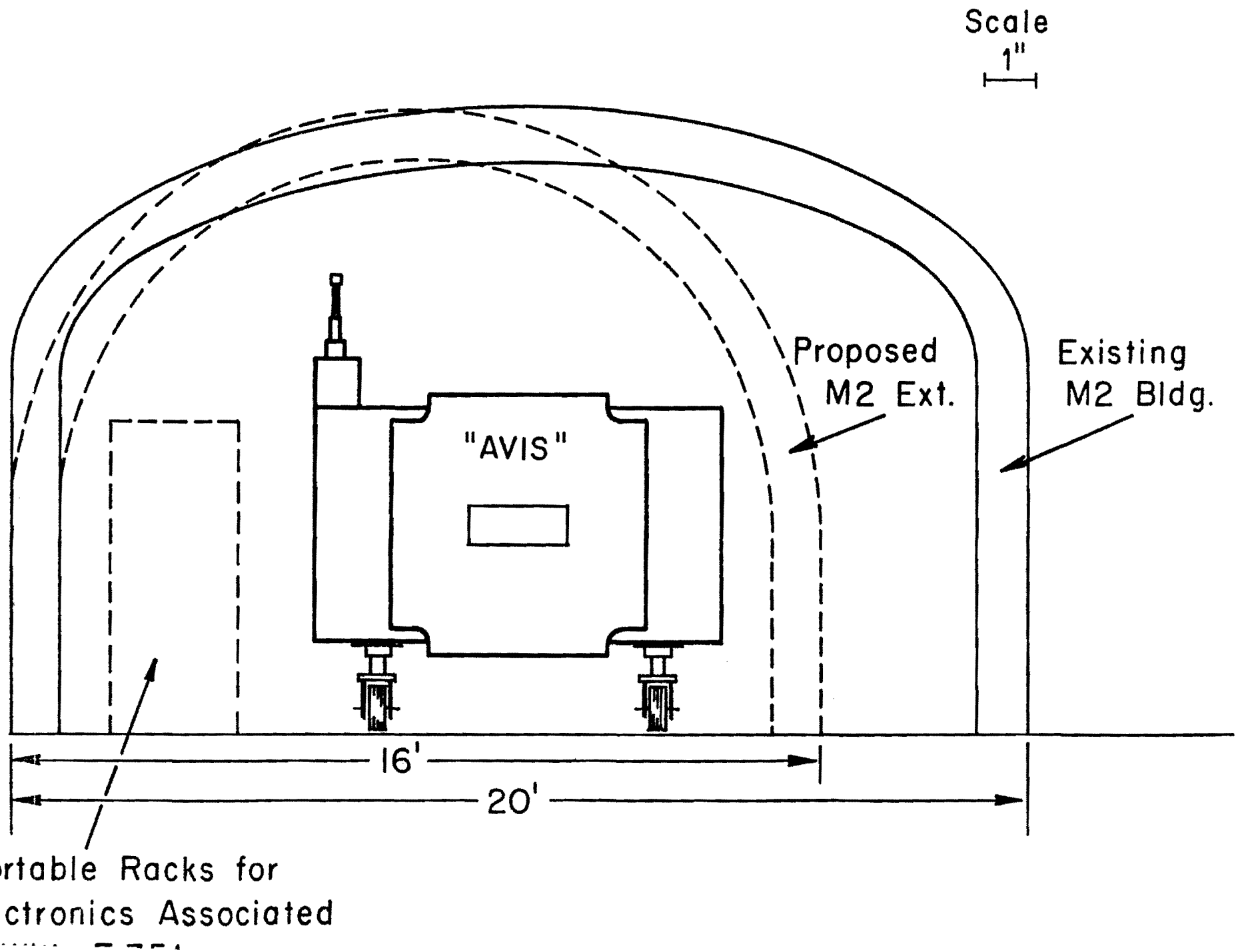


fig. 3

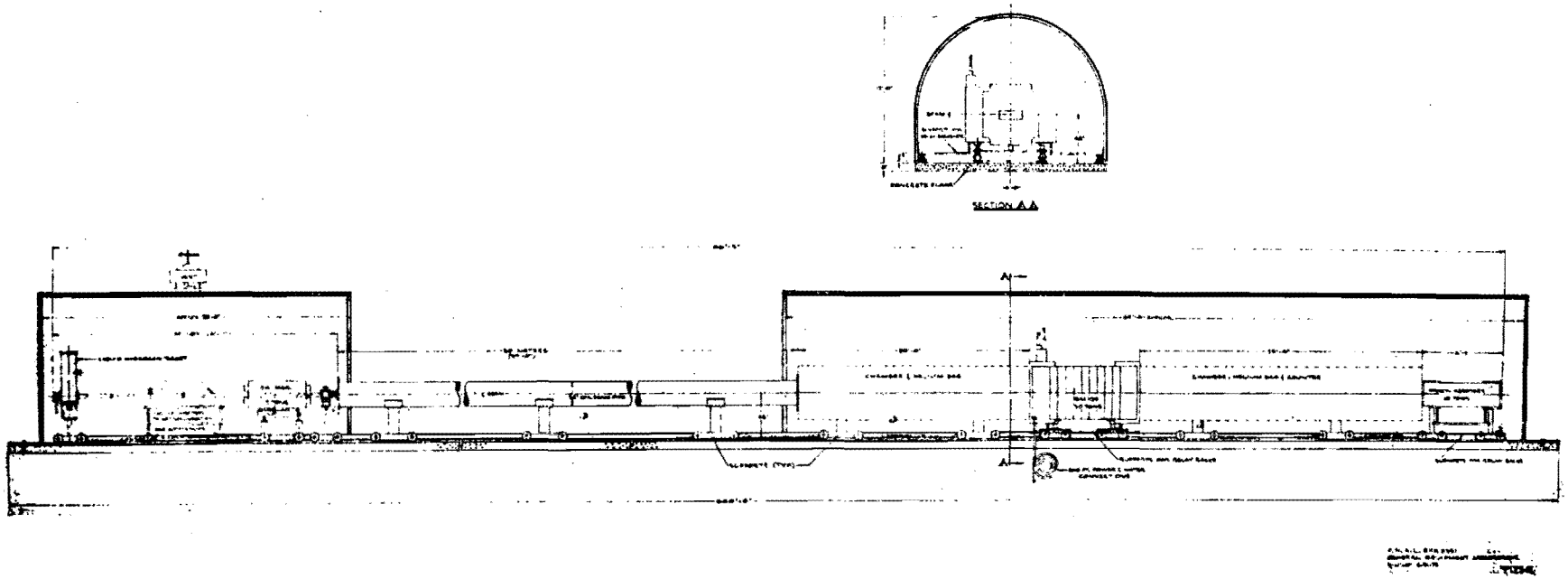


fig. 4

In assessing what we can learn from regeneration in hydrogen, let us summarize those physical quantities (cross section differences $\Delta\sigma$, regeneration amplitudes R) which are simply related to Regge amplitudes, in particular to the ρ and ω exchanges. The assumed Regge behavior implies predictions for the momentum dependence and the phases of these amplitudes (one thing to check experimentally), and symmetry schemes - such as the quark model - make predictions for relative coupling strength of these trajectories in various processes (another thing to test).

	Quantity		Prediction **	FNAL Expt.	Remark
1.	$\Delta\sigma(K^{\pm}p)$	=	$\mathrm{Im}(\frac{3}{2}\omega+\frac{1}{2}\rho)_o$	E-104	-
2.	$\Delta\sigma(K^{\pm}n)$	=	$\mathrm{Im}(\frac{3}{2}\omega-\frac{1}{2}\rho)_o$	E-104	uses D
3.	R_H	=	$(\frac{3}{2}\omega-\frac{1}{2}\rho)$	E-82	Coh. reg. at t=o
4.	R_n	=	$(\frac{3}{2}\omega+\frac{1}{2}\rho)$	-	" "
5.	$\Delta\sigma(\pi^{\pm}p)$	=	$\mathrm{Im}\,(\rho')_o$	E-104	
6.	$\Delta\sigma(\pi^{\pm}n)$	=	$\mathrm{Im}(-\rho')_o$	E-104	uses D
7.	$\frac{d\sigma}{dt}(\pi^- \to \pi^o)_o$	=	$\lvert\rho'\rvert_o^2 = (\frac{\mathrm{Im}\rho'}{\sin\phi})^2 = (\frac{\Delta\sigma}{\sin\phi})^2$	E-111	Extrapolates to t=o needs $\Delta\sigma(\pi^{\pm}p)$
8.	R_D	=	3ω *	E-82 (?)	
9.	R_C	=	18ω *	E-82	Mostly done
10.	$\Delta\sigma(K^{\pm}D)$	=	$\mathrm{Im}(3\omega)_o$*	E-104	
11.	$\Delta\sigma(\pi^{\pm}D)$	=	0	E-104	

* = without Glauber corrections.

** ρ and ρ' represent the ρ coupled to K and π respectively. They are identical within SU(3). The subscript "zero" means t=0.

First, we see that two complex amplitudes interrelate a large number of experimental quantities. [Of these, only coherent regeneration (directly) and charge-exchange scattering (indirectly) give information about the phases of these amplitudes.] These relations, which one would like to test, have the following origins:

Charge independence makes (5) through (7) pure ρ, and (8) through (10) pure ω exchanges. Similarly, charge independence yields the sign changes (1,2,3,4) and (5,6). Thus $\Delta\sigma(K^{\pm}n)$ and R_H depend, without any further assumptions, on the same amplitude, which in general could be $A\omega + B\rho$. It is the quark model with spins* which predicts that A/B=3; this prediction, expressed through linear combinations of the observed quantities, is the celebrated Johnson-Treiman relation.

We note the following;

(1) K_S regeneration on T=0 targets (e.g. D, C) provides for the ω trajectory information similar to that of the pion charge-exchange scattering for the ρ trajectory, i.e. a check of the Regge dependence

$$f_i(t=0) = -iB_i E^{\alpha_i(0)} \exp\left[-i\pi\alpha_i(0)/2\right],$$

where E = lab. energy, $\alpha(0)$ = zero t intercept of the trajectory i (=ρ or ω) in question. Note however that only regeneration provides self-contained information on modulus and phase of the amplitude. Note that the phase accuracy of regeneration is quite competitive with that of charge exchange (see Fig. 1).

(2) $\Delta\sigma(K^{\pm}n)$ and R_H depend, as said, on the same amplitude, but R_H provides phase information. Furthermore since $\Delta\sigma(K^{\pm}n)$ is derived from a double subtraction of experimental quantities, R_H is "easier" to determine experimentally. This is dramatically illustrated in Fig. 1, which compares E-104 results with the stated goals of E-82 and E-351.

(*) Specifically, B=½ from SU(3) or ρ universality, and A/B=3 from pure F-couplings, am implicit in $SU(6)_W$.

(3) It is already known (see Table I) that the ρ and ω trajectories show $\alpha_\rho \neq \alpha_\omega$, contrary to perfect SU(3). This is an interesting result worth pursuing.

(4) A comparison of ρ and ω couplings from $\Delta\sigma(K^\pm, N)$ and $\Delta\sigma(\pi^\pm p)$ is a "weak Johnson-Treiman" test, as $\rho=\rho'$ (i.e. $\rho_K=\rho_\pi$) is postulated. In this regard $R_H + R_C$ or R_D (only ρ_K) are better tests.

(5) On very general grounds, as first discussed by Finkelstein and pointed out to us by Freund, tests of Regge predictions are <u>much safer with kaons</u> than with pions. In technical language, there are no "double Regge cuts" for the amplitudes of the K-N system.

(6) Above, we have confined our attention to t=0 amplitudes. One of the advertised high points of charge-exchange scattering experiments is their intrinsic ability to measure at finite t. In principle, the same possibility exists in regeneration experiments (i.e. diffraction regeneration).

(7) Glauber corrections. All experiments using nuclear targets (e.g. deuterium, carbon) require these. At 100 GeV, we compute a correction for regeneration in carbon of + 20%, with an uncertainty of ± 2%.

In summary, we can say that regeneration in hydrogen will yield very significant data for the interpretation of scattering amplitudes and their symmetry relations. More specifically it will provide a particularly good test of the Johnson-Treiman relation. This relation predicts

$$3B/A = 1.$$

Let us see what various experiments, performed or proposed, yield for this ratio at 100 GeV/c: the values listed in Table II.

Table I

ω:

$\alpha(0) = 0.406(9)$ $\quad 4 \lesssim p_K \lesssim 120$ GeV/c

from k-dependence of regen. amplitude (BNL, CERN, Serpukhov, & FNAL)

$\alpha(0) = 0.39(8)$ $\quad 50 \lesssim p_K \lesssim 200$

from $\Delta\sigma(K^{\pm}D)$ (FNAL)

ρ:

$\alpha(0)$	$= 0.585(76)$	$\Delta\sigma(K^{\pm}H, D)$	$15 \lesssim p_K \lesssim 200$
	$= 0.48(3)$	π ch. exch.	$20 \lesssim p_K \lesssim 100$
	$= 0.55(4)$	$\Delta\sigma(\pi^{\pm}p)$	$15 \lesssim p_K \lesssim 200$

Avg. $\alpha(0) = 0.512(20)$

Theory (?)

$$\alpha_\rho(0) - \alpha_\omega(0) = \frac{m_\omega^2 - m_\rho^2}{2m_\rho^2} \simeq +0.02$$

Table II

Determination of $A/3B$ at $p_k = 100$ GeV/c

$(f \sim A\omega \pm B\rho)$

1. E-104's best

$$\frac{\Delta\sigma(K^{\pm}D)}{3\Delta\sigma(\pi^{\pm}p)} = 1.13 \pm 0.14$$

(1.16 ± 0.15 with Glauber Corr.^{n})

2. From present E-82

$$\frac{4\pi(|f-\bar{f}|_c/k)\sin\varphi}{18\,\Delta\sigma(\pi^{\pm}p)} = 1.01 \pm 0.16 \quad (\pm 0.12 \text{ projected})$$

(1.20 ± 0.19 with Glauber Corr.^{n})

3. Proposed E-82 LH_2

$$\frac{1}{3}\left[\frac{8\pi(|f-\bar{f}|_{H_2}/k)\sin\varphi}{\Delta\sigma(\pi^{\pm}p)} + 1\right] = ? \pm 0.08$$

4. Pure Regeneration

$$3\left[1 - 2\frac{|f-\bar{f}|_{H_2}}{|f-\bar{f}|_D}\right] = ? \pm 0.14$$

Comparison of 3. and 4. tests ρ universality

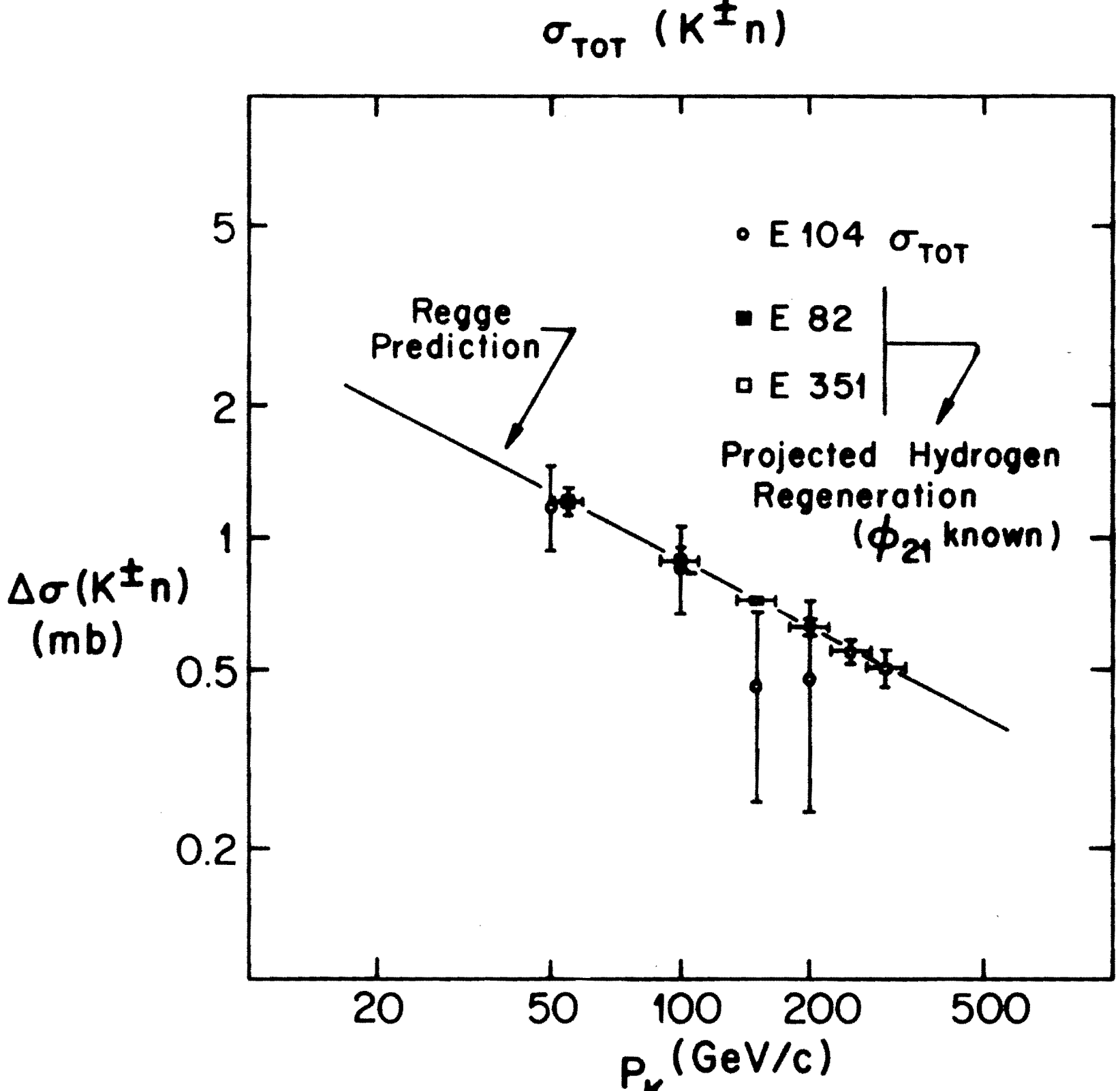

σ_{TOT} ($K^{\pm}n$)
E 104 σ_{TOT}
E 82
E 351
Regge Prediction
Projected Hydrogen Regeneration (ϕ_{21} known)
$\Delta\sigma(K^{\pm}n)$ (mb)
5
2
1
0.5
0.2
20
50
100
200
500
P_K (GeV/c)

Fig. 1