486

PROPOSAL TO STUDY THE ATOMIC NUMBER DEPENDENCE OF THE DIFFERENCE BETWEEN PARTICLE AND ANTI-PARTICLE TOTAL CROSS SECTIONS

J. Hoffnagle, W. Molzon, J. Roehrig, V.L. Telegdi, and
B. Winstein, University of Chicago

A. Gsponer, ETH Zurich

S. Aronson, G. Bock, University of Wisconsin

May, 1976

Scientific Spokesperson: B. Winstein
(312) 753-8624

PROPOSAL TO STUDY THE ATOMIC NUMBER DEPENDENCE OF THE DIFFERENCE BETWEEN PARTICLE AND ANTI-PARTICLE TOTAL CROSS-SECTIONS

J. Hoffnagle, W. Molzon, J. Roehrig, V.L. Telegdi, and B. Winstein
(University of Chicago)
A. Gsponer (ETH Zurich)
S. Aronson, G. Bock (University of Wisconsin)

ABSTRACT

We propose to perform a high statistics, virtually systematic free measurement of the A-dependence of the difference in particle/anti-particle total cross-sections by use of coherent regeneration in a "double beam" arrangement in the M4 neutral beam-line. One beam will be used for monitoring, the other will contain the targets. The roles of the beams will be interchanged on a pulse-by-pulse basis. By the same technique, in good geometry, we will obtain precision measurements of the K_L-Nucleus total cross-sections.

Anomalous behavior in the cross-section difference might be expected as the contributing channels are becoming rarer with energy (the cross-sections approach each other with energy): if the difference goes like A^β β might move from 0.67 to 1.0 as the momentum increases. We will measure β to an absolute accuracy of better than ±.01 in several momentum bins between 30 and 150 Gev/c. Data taking will require 1.4×10^{17} protons incident on the meson target ($\simeq$ 200 hours).

Introduction, What we propose to measure

It is well known that a most powerful technique for the study of the difference in behavior between particle and anti-particle is that of coherent regeneration. The power of this technique results in part from the following:

a) The event rate for the process K_L + target → K_s + target is directly proportional to the square of the difference of the particle/anti-particle scattering amplitudes. Thus, as one directly measures the difference, an important source of systematics involved in the subtraction of large numbers to determine a small one is eliminated.

b) Even though the yield of anti-particles (from the production target) falls rapidly with energy, one does not suffer: the weak interaction acts to convert the dominant K^o's (particles) into $\overline{K}^o$'s (anti-particles) so that the neutral K_L beam contains an (almost) equal mixture of particle/anti-particle.

We are proposing here to exploit the effect of coherent regeneration, optimized to perform a high statistics study of the atomic number dependence of the difference between K^o and $\overline{K}^o$ total cross-sections. We will be sensitive to any momentum-dependent A-dependence such as has been observed for other rare processes. We will also perform high statistics systematic-free measurements of the K_L total cross-sections themselves, as well as of their momentum dependence. We will study Al, Cu, Sn, and Pb over a momentum range at least from 30 to 150 Gev/c. Coupled with our present data with H_2 and C, this will provide measurements over a wide sweep in atomic number. The data-taking phase will require a total exposure of 1.4×10^{17} protons incident on the meson target, or 200 hours at 2×10^{12} protons/pulse.

Why we want to make the measurements

A prime motivation for this experiment is that it will allow us to make an intelligent choice of target to use in our approved experiment to study K^o-e scattering, E226. There, our "signal" is proportional to Z while the "noise" (typically 40 times the signal) - the nuclear regeneration - must be made as small as possible.

There are, however, additional considerations which prompt us to perform a high statistics study of the A-dependence of the cross-section differences. These are expressed by the observation that those channels which contribute to the difference in particle/anti-particle cross-sections and therefore to the difference in forward scattering amplitudes are rare, and are becoming rarer as the energy increases. Thus it might be that the above difference would exhibit a stronger A-dependence than the $\simeq A^{2/3}$ behavior of the total cross-sections themselves. In fact, we might expect that the power β in the A^{β} dependence of the total cross-section difference to be momentum dependent, and perhaps approach 1 from below as the incident momentum increases.

Let us denote the total cross-section difference by $\Delta\sigma$ (A,p), where we have explicitly denoted its atomic-number and momentum dependence. It is well known that this quantity is well fit by a power-law in momentum:

$$\Delta\sigma(A,p) \simeq p^{-\alpha(A)}$$

where we have indicated that the power itself may be A-dependent. The arguments above indicate that α may indeed be dependent upon A, whereas an optical model of the scattering would have α independent(1) of A. Our measurements will first allow a precise check on the expected power-law behavior, and then will reveal any possible A-dependent effects not allowed by the optical model.

Figure 1 shows the momentum dependence of the Kaon/anti-Kaon total cross-section differences for H_2, D_2 (obtained by direct measurement, E104) and C (coherent regeneration, E82, 50% data sample or 8000 events). As can be seen, the power-law behavior is evident, and as well, the three targets are consistent with the same fall-off. Our proposed measurements for heavier targets (with a factor of ≈ 6 more statistics) will exhibit any A-dependent effects.

Such an A-dependent power-law could be understood in the quark-parton picture. There, the total cross-section arises predominantly from the absorption of the $q\bar{q}$ sea - the same for particle/anti-particle - at the nuclear surface (hence an $A^{2/3}$ dependence) whereas those channels contributing to the cross-section difference result from a difference in the interactions of the valence quarks. Such a difference is present since the anti-quarks can annihilate. In the picture of G. R. Farrar(2) and others, the interaction probability of quarks of momentum of about 1 Gev/c or more is very small, the strength of the strong interactions arising from the multiple interactions of quarks of small momentum (the sea). So, quoting from Ref. 2, "Any process that uses quarks of momentum $\gtrsim p^{min}$ [from 1 to 3 Gev/c] should have a cross-section which is proportional to A^1 [not $A^{2/3}$]." Our total cross-section difference, involving valence quarks, may thus show anomalous A dependence. In addition, an approach (with momentum) to A^1 would be expected and will be studied if present.

We would also like to point out that the only high-energy data on $\Delta\sigma$ (A,p) that exists is shown in Figure 1(3). An experiment performed by Denisov et al. at Serpukhov(4) measured the absorption cross-sections, for charged particles, but the magnitude of their errors prevents a meaningful determination of the behavior of the differences.

How we propose to perform the measurements

The basic approach is that of using a Vee spectrometer as is currently employed in experiments 82/425. However, there are a number of changes to be made to optimize for the present experiment:

1) We propose to replace our present 8 core-readout spark chambers with 5 MWPC's. These chambers and their readout exist and have been fully (source) tested. They are required in order to handle the significantly higher event rates resulting from further optimizations, namely:

2) We propose to run with a significantly shorter decay-region than before. This is possible, since in this experiment we are only concentrating on measuring the magnitude of $\left(\frac{f-\bar{f}}{k}\right)$, not its phase. Hence we need to accept only the first two K_S lifetimes following the regenerator, where the interference with the $K_L \to \pi^+\pi^-$ decay is still minimal. As a result our acceptance improves significantly.

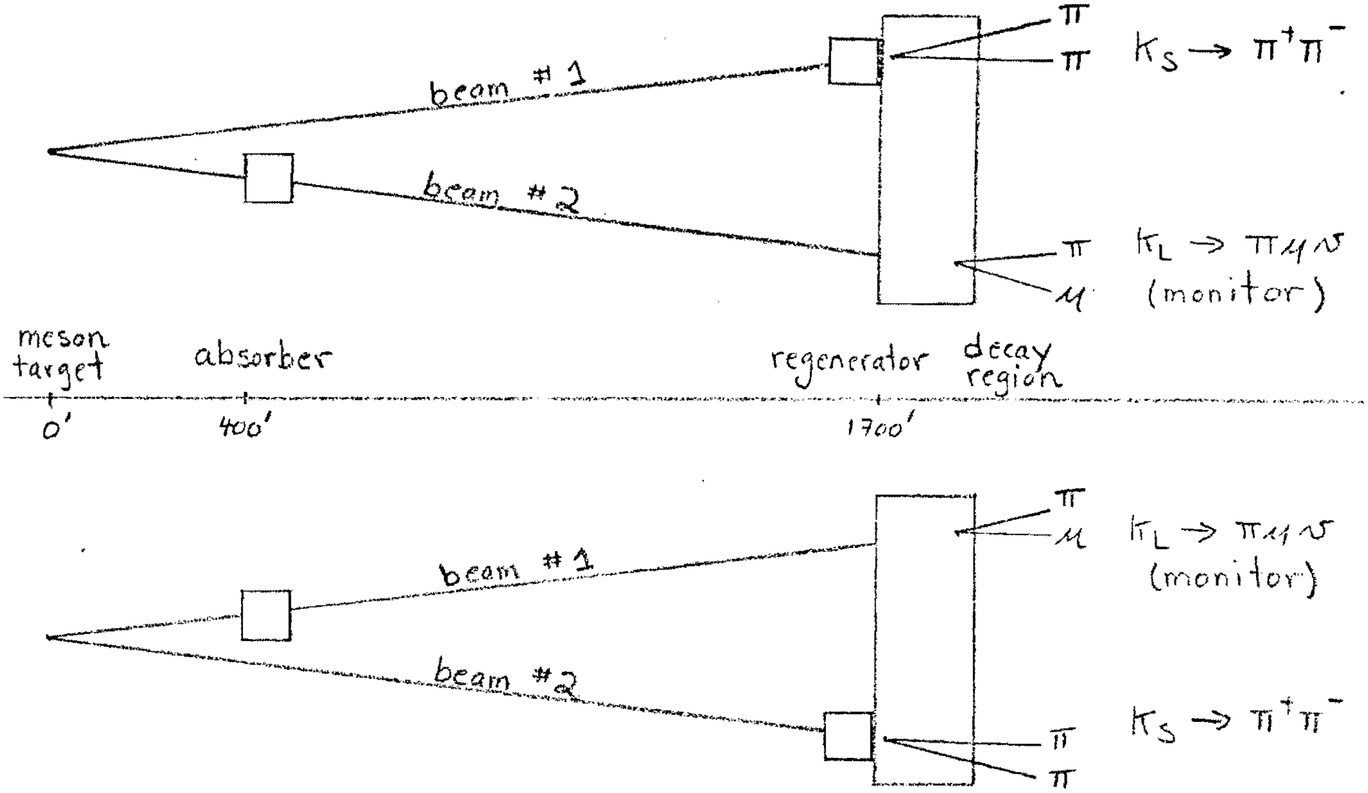
3) We propose to run without the parallel requirement behind the magnet. Presently, we do demand this as a means of suppressing leptonic backgrounds at the trigger level. We do, however, lose at least a factor of two $K_S \to \pi^+\pi^-$ events. Without this requirement, we regain this factor, and as an important addition, we have less bias on the events.

4) We propose to run with target (regenerator) lengths optimized for maximum rate in the first two lifetimes. This could not be done in our experiments to measure the phase of $\left(\frac{f-\bar{f}}{k}\right)$ because of a loss in statistical power. The rate of coherent regeneration is proportional to $\ell^2\ e^{-\ell/\mu}$, where μ is the interaction length, ℓ the regenerator length. This expression maximizes at $\ell=2\mu$: thus all of our regenerators will be two Kaon interaction lengths.

5) We propose to modify the M4 beam-line so that there exist two separated beams of a size similar to the one that exists now, one above the other. Such a configuration is needed for our approved experiment (E226) to measure $K^o e$ scattering. For the present experiment, we plan to use one of the beams to regenerate K_s and the other to monitor the K_L flux. In addition, the two beams will allow for a virtually systematic-free measurement of the total cross sections themselves. The details will be discussed in the next section.

How the data will be taken

As said previously, we propose to measure regenerated K_s with one beam while simultaneously monitoring the incident K_L flux by detecting leptonic decays (in vacuum) from the other beam. Single beam monitoring schemes are either statistically far inferior, or are strongly dependent upon unknown nuclear parameters. It will be necessary to alternate, perhaps on a pulse-by-pulse basis, the roles of the two beams - the regenerator will be raised and lowered - in order to be insensitive to any inequalities in the beams. (Note that the beams will actually be at slightly different production angles to the meson-lab target). Finally an equivalent absorber, far upstream, will be necessary, in the beam used for monitoring, to correct for absorption in the regenerator. Thus, for the $\Delta\sigma$ (A,p) measurements, we will be running in the following configurations:



The total cross-sections (K_L-Nucleus) will be measured by removing the regenerator, alternating the upstream absorber, and detecting leptonic decays in our apparatus. It is clear that intensity fluctuations cannot affect the results of such a measurement as the transmission and monitoring are performed simultaneously.

Rates, Running Time, Accuracy

We have extrapolated regeneration data obtained at other accelerators into our energy range in order to estimate the event-rates to be expected. The acceptance, for events within the first two lifetimes has been calculated by Monte Carlo and is shown in Figure 2. Our measured K_L spectrum (at 400 Gev/c) is shown in Figure 3. The folding of the spectrum, the acceptance, and the extrapolated (and interpolated) regeneration power yields the following:

Element	Events / 10^{12} Protons*	Events/day**
Al	3.8	65K
Cu	2.9	50K
Sn	2.4	41K
Pb	2.0	34K

*Events ≡ detected $K_s \rightarrow \pi^+\pi^-$ decays within first two lifetimes behind a regenerator of two interaction lengths.

**Day ≡ 20 hrs, 10.5 sec rep rate, 2.5 x 10^{12} protons/pulse, 400 Gev/c protons.

We plan on collecting 50K events for <u>each</u> regenerator: this will provide better than 1% measurements of $\left|\frac{f - \bar{f}}{k}\right|$ in several momentum bins. The relevant exponent in the A^{β} dependence will also be obtained at the 1% level in several bins. In addition, we shall run for about 1 day with each target to measure the total cross-section. About 10^6 leptonic decays will be collected per target again providing better than 1% measurements in several momentum bins. During this phase of the experiment, we expect to collect about 300 leptonic decays per pulse. Presently we are able to analyze on-line, in between pulses, up to ≃ 90 triggers from our spark chamber spectrometer. We expect, with fewer chambers, and better time resolution, and with some soft-ware improvements, to be able to keep up with the pattern recognition even at the above trigger rate.

Determination of $\Delta\sigma$ (A,p)

What we actually measure is $\left|\frac{f - \bar{f}}{k}\right|$, as a function of A and p. According to the optical theorem

$$\Delta\sigma = 4\pi \, \mathrm{Im} \left(\frac{f - \bar{f}}{k}\right)$$

$$= 4\pi \left|\frac{f - \bar{f}}{k}\right| \sin \phi$$

where ϕ = phase of $\left(\frac{f - \bar{f}}{k}\right)$. Since we do not measure the phase in this experiment, we must determine it otherwise in order to extract $\Delta\sigma$.

To do this, we remember that analyticity and crossing symmetry relate the momentum dependence of $\left(\frac{f - \bar{f}}{k}\right)$ to its phase. Specifically, if $\left(\frac{f - \bar{f}}{k}\right) = C_A \cdot p^{[\alpha(A)-1]}$, then $\phi_A = \frac{-\pi}{2} [1 + \alpha(A)]$ where the A-dependence of the normalization and momentum fall-off parameters is shown explicitly. We point out that our own measurements of ϕ for Carbon agree well with the observed power-law for the magnitude, to an accuracy of 3^o. Thus

$$\Delta\sigma\ (A,p) = -C_A \cdot p^{[\alpha(A)-1]} \cos \frac{\pi\ \alpha(A)}{2}$$

From the measured values of $\left|\frac{f - \bar{f}}{k}\right|$, we will therefore

a) fit for $\alpha(A)$ (typically with an error better than ±.01)

b) determine ϕ_A (typically with an error better than $\pm 1^o$)

c) calculate $\Delta\sigma(A,p)$

Any departure of C_A from $A^{2/3}$ (or more accurately from the power-law obeyed by the total cross-section data) will be interesting. Any difference in $\alpha(A)$ from nucleus to nucleus, outside that expected(1) from the slight rise in σ_T, will indicate momentum-dependent effects.

Backgrounds, Systematics

From our experience with the data from 82/425, we can say that there will be no significant background or systematic.

There are distinct effects to be considered in the regeneration signal ($K_{\pi 2}$ decays) and in the flux monitoring($K_{\mu 3}$ decays).

Backgrounds in the $K_{\pi 2}$ signal consist in leptonic decays which fake - over a restricted kinematic range - a $K_{\pi 2}$. $K_{\mu 3}$'s are effectively removed at the trigger level while Ke_3's are successfully reduced with the off-line requirement that the electromagnetic energy that we measure for each particle in our shower counters be inconsistent with the momentum as measured by the spectrometer. This correction to the coherent signal will be about 1% with an uncertainty less than 10% of itself. In addition, we are building a thin "veto shower counter", (two radiation lengths) which will remove the bulk of the K_{e3} decays at the trigger level.

A correction to the $K_{\pi 2}$'s must also be made from scattering which is not coherent over the entire regenerator (diffraction regeneration). This again, because of the thickness of our regenerators, involves a well-known correction of less than 1%.

The final relevant "systematic" is related to CP interference effects. In the worst case, the contribution to the events in the first two lifetimes from the interference is ≈ 7%. The uncertainty in the magnitude of the amplitude, as a result of the interference effect, arises from an uncertainty in the phase of the amplitude, namely $0.3\%/1^{\circ}$ uncertainty in ϕ_{21}. This uncertainty is therefore small, and does, in addition, presumably not introduce a momentum dependence.

Systematics in the $K_{\mu 3}$ decays used for flux monitoring are as follows: First, the branching $K_L \rightarrow \pi\mu\nu$ is known to ±2%. This creates an overall normalization uncertainty, but will not alter conclusions on momentum or A-dependence. Second, there is a background, as a result of other decay modes with π-decays in flight which simulate $K_{\mu 3}$ decays. Their contribution, at the trigger level, is about 5%, with K_{e3} and the subsequent π-decay in flight dominating. We have successfully monte-carlo'd this background, obtaining striking agreement between the observed and calculated distributions. Our systematic uncertainty as a result of π-decay is much less than 1%.

Finally, we have considered the possible "interference" between the two beams. The most important effect is the following: K_L's may diffract from the upstream "absorber target", scattering into the regenerator, and then contaminate the regenerated events. This has been calculated to result in about 0.1%

correction only. Monte-Carlo studies, including diffraction in the collimators, have shown that the beams have no significant wings and are well separated in terms of the vertex resolution of our spectrometer. The required beam configuration is described in the next section.

Requirements from the Laboratory

Since the Laboratories electronics and other hardware which we are presently using will, for the most part, suffice for the experiment being proposed (and for E226 as well), we will here concentrate upon the only major new feature which will require laboratory support: the construction of the double beam. Our plans have already been discussed with Dr. Charles Brown of the Meson lab, in connection with E226 for which the double beam is required.

Presently, our beam is defined by a primary fixed collimator, located at 368' from the target, with a 1/2" x 1/2" hole. Secondary collimator stages (variable) are at 660' and 1027'. We will require a new primary collimator with two holes, 7/16" high by 1/2" wide, with a 1/8" space between them (see Fig. 4). In addition, we require horizontal steel slabs of thickness 0.225" and 0.350" to be installed at our secondary collimation stages. Finally, the sweeping magnets located at the secondary stages must be rotated through 90° to provide the necessary aperture of the two beams. This configuration is required because the spectrometer acceptance varies significantly left and right (with respect to the field of the analyzing magnet) but not up and down.

Aside from what has been mentioned, a means of remotely and reliably alternating the position of the thick absorbers - one inside of our sweeping magnet in the M4 pit, the other near the primary collimator, must be provided. The necessary mechanisms are being designed at the University of Chicago, and will be provided.

Problems of alignment will naturally arise. In addition, some vacuum windows at the secondary stages may have to be relocated. We plan on working closely with the Fermilab staff in executing the conversion.

Footnotes and References

1. A note on optical model predictions for the behavior of $\Delta\sigma(A,p)$: it is stated in the text that if $\Delta\sigma \sim p^{-\alpha}$, then the optical model would predict that the power α should be independent of the nucleus. This is actually correct for the case where the average of the particle/anti-particle - nucleon cross-sections is constant with energy. As there is a small rise, one expects α to grow slightly with A: this is because the increased absorption effectively reduces the illumination of the "back" of the nucleus, and this reflects itself in a smaller amplitude, as momentum increases. If $\alpha = 0.60$ for scattering from single nucleons, we find that for lead, $\alpha = 0.63$ effectively between 50 and 150 Gev/c, as a result of the rise in the Kaon-nucleon total cross-sections within that momentum range. Although such an effect is small, we should easily be able to see it, given our quoted errors. Note that our quark arguments would suggest an effect in the opposite direction.

We have stressed in the text the importance of looking for momentum-dependent effects in $\Delta\sigma(A,p)$ rather than studying the magnitude of $\Delta\sigma$ itself. This is because the former, but not the latter, is insensitive to the actual arrangement of neutrons and protons within each nucleus. We recall that the difference in forward Kaon-neutron scattering amplitudes is twice that of Kaon-proton amplitudes, so that the magnitude of $\Delta\sigma$ for any given nucleus is, in the framework of the optical model, a sensitive probe of the neutron distribution.

2. G. R. Farrar, Phys. Lett. 56B, (1975) 185

3. Of course E104 has published data on $\Delta\sigma$ for pions and protons on H_2 and D_2 targets; $\Delta\sigma$ data exist from the Serpukhov machine, as well with H_2 and D_2 targets only.

4. Denisov et al. Nuclear Physics B61(1973) 62

Figure Captions

Figure 1: $\Delta\sigma$ (A,p) high energy data for kaons on H_2 and D_2 (Fermilab experiment #104) and C (Fermilab experiment #82, 50% data sample). The solid lines are $\sim p^{-0.57}$.

Figure 2: Optimized acceptance for regenerated $K_s \rightarrow \pi^+\pi^-$ decays, MWPC spectrometer.

Figure 3: K_L yields in the M4 neutral beam-line, with 400 Gev/c protons.

Figure 4: Hole configuration for new "double-beam" primary collimator.

Figure 1

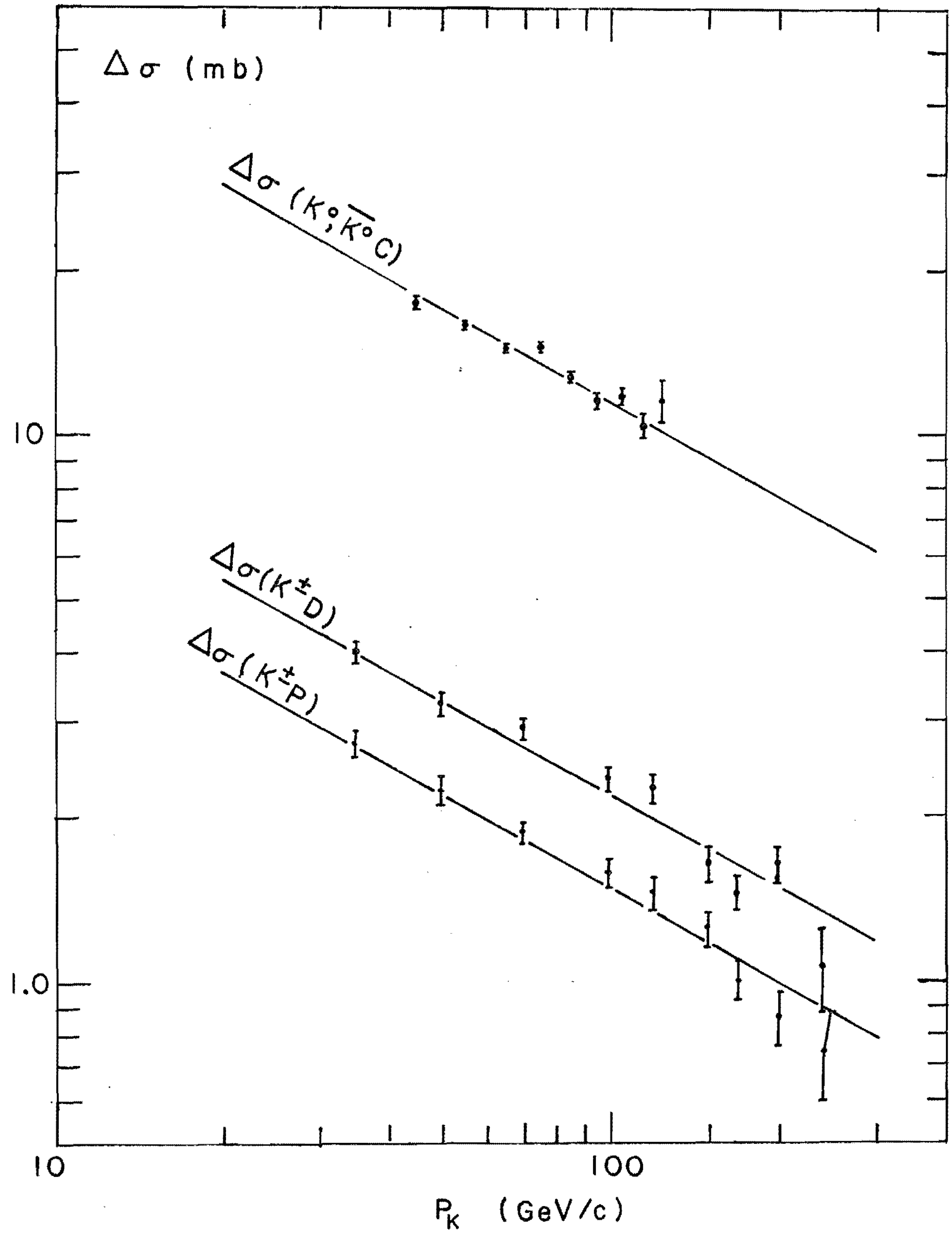


Figure 2

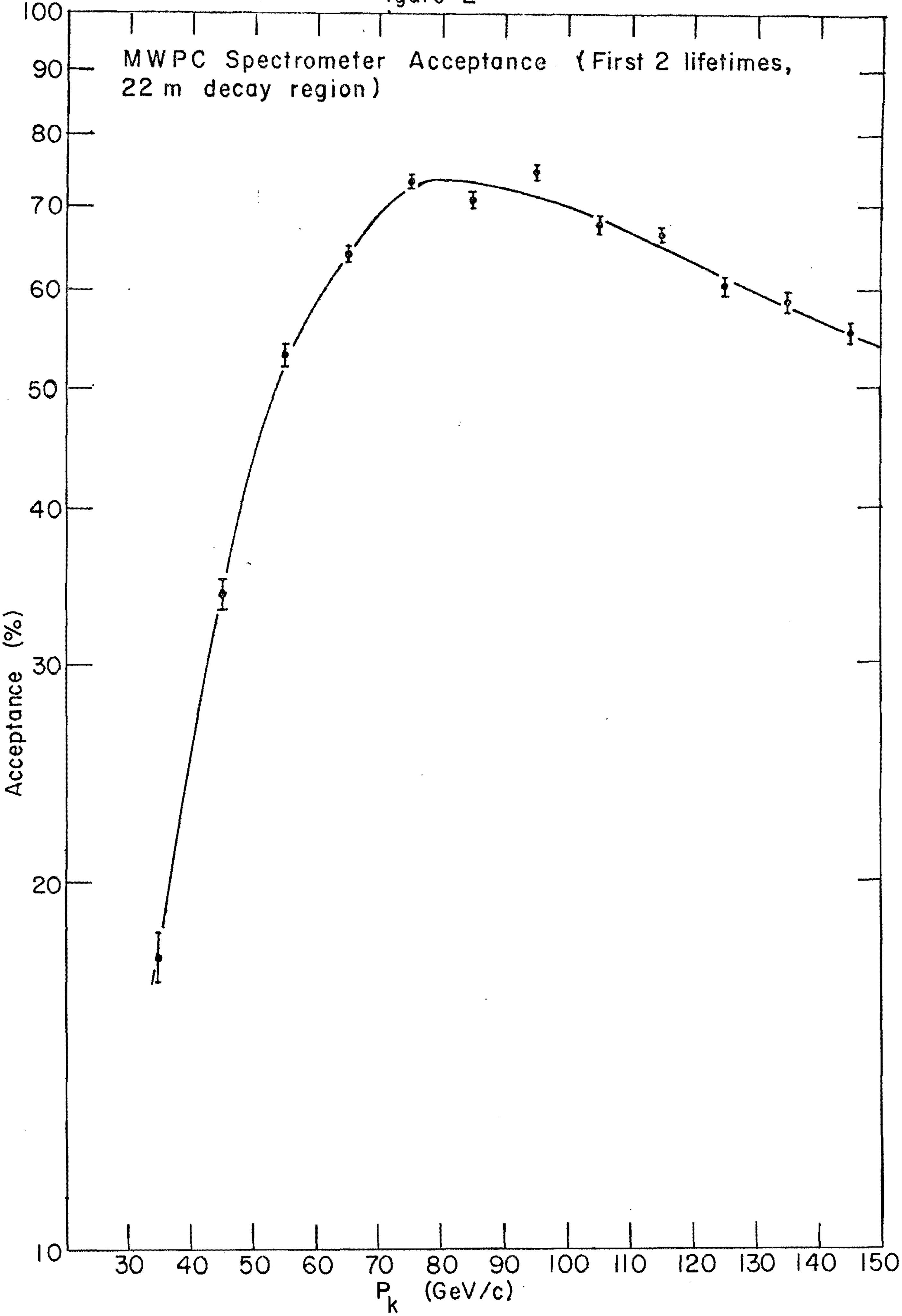

MWPC Spectrometer Acceptance (First 2 lifetimes, 22 m decay region)
Acceptance (%)
100
90
80
70
60
50
40
30
20
10
30
40
50
60
70
80
90
100
110
120
130
140
150
P_k (GeV/c)

Figure 3

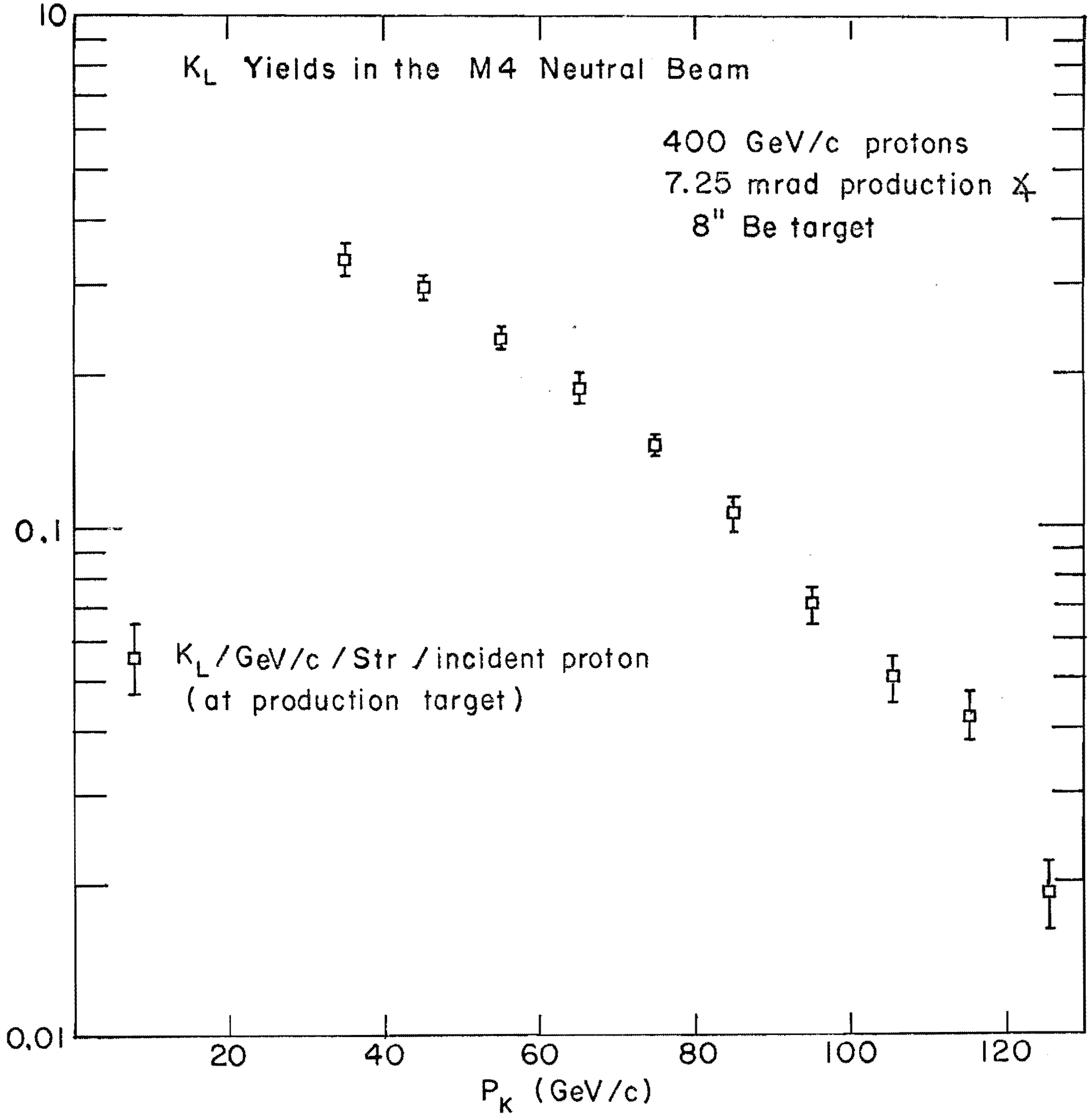
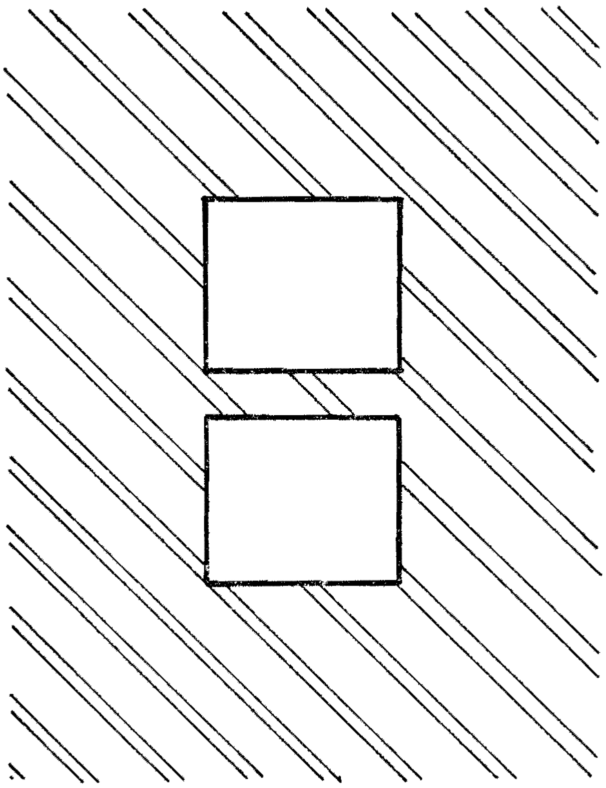

K_L Yields in the M4 Neutral Beam
400 GeV/c protons
7.25 mrad production ∡
8" Be target
K_L / GeV/c / Str / incident proton
(at production target)
10
0.1
0.01
20
40
60
80
100
120
P_K (GeV/c)

Figure 4



Hole Configuration in Primary Collimator,
Double Beam Configuration
(x2 actual size)