SUMMARY OF KAON FACTORY WORKSHOP

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ABSTRACT

Some highlights of the physics sessions of the workshop are presented. Particular emphasis is placed on the differe~~nces of~~ investigations which can be carried out with kaons and antiprotons than with pions and protons.

I. INTRODUCTION

The organizers of the Kaon Factory Workshop chose a non-expert to summarize the physics discussion. Perhaps they reasoned that they would get a more balanced overview. Undoubtedly, I will disappoint them in that my own biases color the presentation that you are about to hear. I apologize beforehand. In my review I will give names of speakers or other references only when they are required, as several speakers overlapped in the physics they presented. (I must admit that another reason is cowardice, as I am not certain in all cases as to who deserves the credits.) I apologize to all the speakers and contributors beforehand. Table I lists the speakers in the sessions I attended. There was also a technical session, which was held simultaneously with a plenary session, and which I missed.

What is the interest in an accelerator to produce kaons? In general terms, the interest centers on the nuclear physics studies which can be carried out with the next generation of higher-energy (3-40 GeV), high-intensity (1-100 μA) accelerators. The range of parameters is large; design studies are not complete. To my knowledge, such accelerators are being considered at TRIUMF, at LAMPF, at CERN (the proposed low-energy antiproton ring - LEAR), and in the USSR. The lure of such accelerators lies in the high-quality kaon and antiproton beams that they can produce. Since LEAR has been proposed as a definite facility, let me describe it in a little more detail. The proposal consists of an accumulator ring with large acceptance which can store antiprotons produced at the PS; these antiprotons can be cooled by electrons and can be decelerated or accelerated to give antiprotons of momenta in a range of $300 \text{ MeV/c} \leq p < 2 \text{ GeV/c}$. During the accumulation and cooling period π impurities decay away, so that a clean beam with high energy resolution ($\delta p/p \lesssim 10^{-3}$) can be obtained. A beam of more than 10^6 $\bar{p}$/sec is envisaged. The quality of the beam allows one to plan experiment such as $\bar{p}p$ ones in a gaseous hydrogen target 10 cm long and at atmospheric pressure.

Not all the work is on the drawing-boards. There are lower-energy and lower-intensity $K^{\pm}$ and/or antiproton beams available at the Brookhaven National Laboratory (from the AGS), at CERN (from the PS), and at the KEK in Japan. To demonstrate that actual data exist, I show you in Figs. 1 and 2 some experimental results obtained by the Carnegie-Mellon University group and presented by R.A. Eisenstein on the elastic scattering of K^+ and K^- by ^{12}C. The various curves are optical model analyses which were discussed at the same session. You might note that the fit to the K^+ elastic scattering cross section is remarkably good. I believe that we are likely to see an increasing emphasis on investigations with $K^{\pm}$ and $\bar{p}$ prior to the next conference in this series.

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Summary of Kaon Factory Workshop

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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY force. charge symmetry-breaking, via Λ^0-Σ^0 mixing, may be relatively large in the Λ-N system. The K^-N force, illustrated in Fig. 3(b), also differs considerably from the πN force. The K^-N system can and does form resonances; close to threshold there are the $\Lambda(1405)$—actually slightly below threshold—and the $\Lambda(1520)_{3/2^-}$, which has a small width of only ~15 MeV. Again, it is this difference from the much shorter-lived $\Delta(1232)$ formed by pions which is being accentuated by physicists. Can one profitably use the small width of the $\Lambda(1520)$ as a tool to study the effect of the nuclear medium on a resonance? What are the effects of the Fermi motion, of collisional broadening, and of new decay channels unavailable to the free $\Lambda(1520)$? We heard several talks on these matters.

Of course, studies of the free particles are useful for testing and limiting proposed basic theories of particle physics. Recent gauge theories which do not conserve muon number predict a small branching ratio (10^{-12}-10^{-15}?) for $K_L \to e^{\pm}\mu^{\mp}$; the present experimental limit is 2×10^{-9}. This ratio already sets limits on the mass (≳30 TeV) of the gauge boson exchanged, and the experimental limit can undoubtedly be improved. Other rare decay modes are also of interest.

The relationship of the study of the static properties of strange particles and resonances to their underlying quark structure, to confinement and to (perturbative) QCD was also discussed. The presence of the strange valence quark brings in a new degree of freedom which enriches the spectroscopy and may give us new insights into the mechanism of quark confinement and how to apply QCD to this problem.

The antiproton, in contrast to the K^+, is perhaps the most strongly absorbed hadronic probe of nuclei. It is therefore exceedingly sensitive to the nuclear surface; this is, in fact, one feature which makes the study of $\bar{p}$-atoms of interest. In addition, as we heard in a report by H.-M. Chan, the $\bar{N}N$ resonances (baryonium) exhibit rather striking features, which may give one insight into the underlying quark structure of nucleons. Are the narrow resonances near threshold an indication of a $q^2\bar{q}^2$ system? Are there bound $\bar{p}p$ states, and if so what is their character? Can $\bar{p}$ absorption be used to form nuclei far from the region of stability through multipion emission processes?

III. SOME PHYSICS QUESTIONS

Let me summarize some of the physics which becomes accessible with kaon and antiproton probes by posing a series of questions. The questions, as such, were not raised at the workshop, though many of them (but not all) were discussed there.

K^+ Meson

1) Can the K^+N (primarily K^+n) force be determined with sufficient precision to allow one to use K^+ scattering as a tool to extract neutron densities and particularly neutron radii of nuclei? It is the lack of such information which at present prevents the use of K^+ beams to determine neutron radii. The isospin 1 K^+N force appears to be repulsive in low partial waves. Some contributions to the force are shown in Fig. 3(b).

2) Does the K^+ meson preferentially excite simple modes of motion of the nucleus, e.g., the giant isoscalar resonances? In other words, is it a useful as well as new probe of nuclear structure? It appears that such is the case.

II. DIFFERENCES OF PROBES

What is it that makes kaons and antiprotons interesting probes for nuclear studies? It is primarily the differences of their interactions with nucleons which appeal to the nuclear physicist. The K^+ has strangeness +1; since there are no baryons with such strangeness, the K^+ cannot be absorbed in nuclei to form hyperfragments. For both $K^{\pm}$, the long-range single-pion exchange force with nucleons is absent. The K^+ is the weakest known hadronic probe of the nucleus. It may scatter only elastically or inelastically, except for forming "exotic" Z^* resonances at momenta above ~800 MeV/c. In the quark language, which is becoming "de rigeur" at these conferences, such resonances are thought to be 5-quark objects ($q^4\bar{q}$); they are narrow resonances. From the above considerations, it follows that the mean free path of K^+ particles in nuclei below ~800 MeV/c is large, ≳5 fm.

In contrast to K^+ particles, the K^- interacts strongly with nucleons. Because its strangeness is −1, it can be absorbed readily by single nucleons to form hyperons. It thus differs from pions which are absorbed primarily on two nucleons. This difference, alone, makes K^- studies more sensitive to the nuclear surface than pions. Moreover, it is this absorption mechanism which permits us to study hypernuclei, a subject which was presented earlier at these sessions by B. Povh. The ΛN force is quite different from the NN one. As we heard, there is some evidence that the spin-orbit force is very weak. The one-pion exchange force is absent, except through isospin mixing of the Λ^0 and Σ^0, but K and K^* exchanges are allowed [see Fig. 3(a)]. Because of the long range of the pion exchange

Fig. 3. Contributions to (a) a ΛN force, (b) a $K^{\pm}N$ force.

3) What is the nature of "exotic" Z^* resonances? Can one study the effects of the nuclear medium on these resonances in inelastic K^+ scattering measurements?

K^- Meson

1) What is the nature of the K^-N force? Some contributions are sketched in Fig. 3(a). How well can one determine the ΛN, the ΣN, and the ΞN forces with K^- beams? Considerable information has already been obtained on the ΛN force. 1b

2) It seems that a study of the $\Lambda(1520)$ in the nucleus may help us understand the effect of the nuclear medium on a narrow resonance. Will such studies help us to sort out what happens to a broader resonance such as the $\Delta(1232)$? To what extent will it help us understand what happens at higher energies where overlapping Y^* resonances occur?

3) Can kaonic atoms be used to study the nuclear surface, or are such studies spoiled by our lack of knowledge of the K^-N force and the role of the $\Lambda(1405)$? What can we learn from Σ^- atoms?

4) Is the recoilless formation of hyperons ($p_{K^-} \sim 550$ MeV/c for Λ^0, $p_{K^-} \sim 300$ MeV/c for Σ^0) an important mechanism in the formation of hypernuclei?

5) The study of hypernuclei has already been a rich source of new information. It is from these studies that features of the ΛN force have been deduced. At the workshop, the start of a table of Λ-hypernuclear isotopes was shown. How far will we be able to extend this table and what surprises will we find?

6) Does the Λ really behave like a spinless strange neutron in hypernuclei? What kinds of new information can we extract from detailed high resolution (K^-,π^-) and from $(K^-,\pi^-\gamma)$ spectroscopic studies of Λ hypernuclei? This is clearly a rich field of study, in which the Λ can be considered as a strange probe or "impurity". What are the structural changes brought about by the presence of this impurity in the nuclear medium? Can one, for instance, study core polarization in this way?

7) Do strangeness analog resonances exist in heavy nuclei? These SU(3) generalizations of the SU(2) isobaric analog resonances have been predicted, but not yet observed. They are states with the same antisymmetric space-spin structure as the nucleus with a neutron instead of a Λ, even though the Pauli principle does not restrict the Λ orbitals as it does those of neutrons.

8) What is the nature of SU(3) symmetry-breaking forces at low energies? Studies of the ΣN and ΛN forces and of Σ hypernuclei should be helpful in obtaining an answer to this question. Are Σ hypernuclei sufficiently stable and cross sections for producing them sufficiently large that they can be studied? Are there strangeness − 2 Ξ hypernuclei?

9) Can we understand the double charge exchange reaction for kaons sufficiently well to use it as a spectroscopic tool?

10) The (K^-,K^+) reaction can be used to produce $\Lambda\Lambda$ ~~or~~ Ξ hypernuclei. What will studies of these reactions tell us about the $\Lambda\Lambda$ force? Can the reaction be used to explore the underlying 6-quark basis for $\Lambda\Lambda$ hypernuclei?

11) The decays of Y^*'s and Z^*'s may be amenable to quark-parton and QCD model studies. Will such work be fruitful in teaching us about the connection of the quark and meson physics approaches?

12) How useful are $\bar{K}^0$ beams for studying nuclear structure? Although beams of $\bar{K}^0$ or K_L and K_S mesons were not ~~raised in the study,~~ discussed at the workshop past regeneration experiments suggest that studies with them can yield information on nuclear densities.

13) Will studies with kaon beams help us to understand better the connection between the quark and meson pictures of hadrons and their forces?

14) Can the rare decay modes $K_{L}^{0} \to \mu^{\pm}e^{\mp}$ and $K^{\pm} \to \pi^{\pm}\mu^{\pm}e^{\mp}$ be observed? If so, they may revolutionize, eliminate or tie down some of the ambitious gauge theories of weak, electromagnetic and strong interactions which continue to be proposed. Note that both strangeness and muon number are broken in these decays, whereas only muon number conservation is spoiled in $\mu \to e\gamma$.

15) Can weak interactions be studied usefully with kaon beams? For example, there have been suggestions that the Cabibbo angle reduces to 0° in strong electromagnetic fields. Can this prediction be tested?

The above questions refer to only parts of the issues raised by the speakers in the workshop. It is clear that one can use kaons, much like pions, to probe nuclear spectra and other nuclear properties. I thought it more helpful to stress the difference of the physics questions that can be explored with kaons rather than pions. Although I have presented the physics in terms of questions, I should point out that I believe the answer to many questions ~~to be~~ "Yes". Kaon beams do open new and interesting avenues with which to explore nuclei and hadronic properties.

Antiprotons

Although there was considerably less emphasis in the workshop on antiprotons than on kaons, studies with this probe can be a rich source of new insights. We heard about some of these possibilities from H.-M. Chan.

1) What is the relationship of the $\bar{N}N$ force to that of two nucleons? In a single-boson-exchange model, the real parts of these potentials are related by G-parity. The short range ω-exchange potential, for instance, becomes strongly attractive. But what is the effect of the absorption?

2) Are there bound states of the $\bar{p}p$ system, and if so what are their quantum numbers and other properties? Are these $q^2\bar{q}^2$ or $q^3\bar{q}^3$ bound quark states?

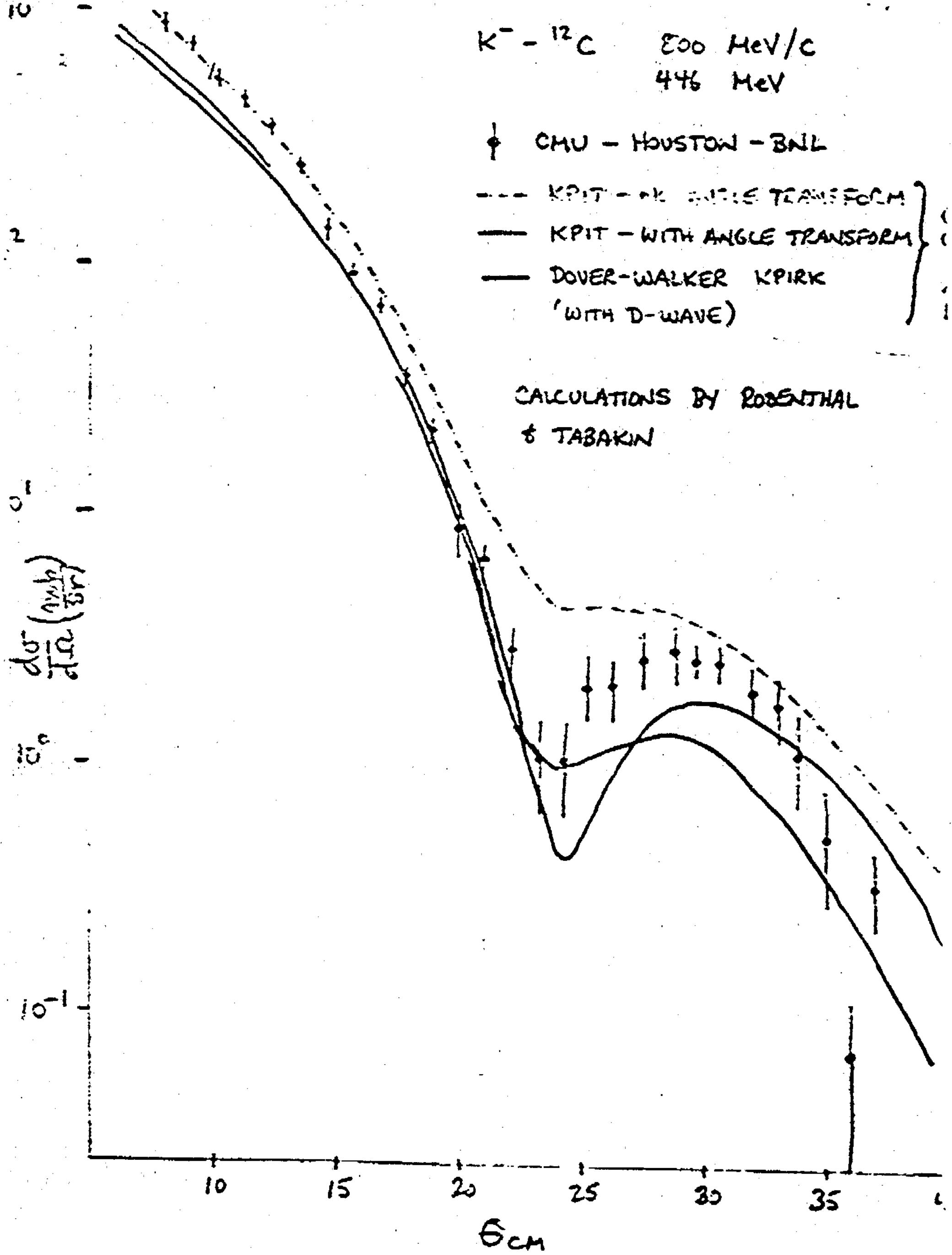
3) How many narrow resonances are there close to threshold of the $\bar{p}p$ system? What is their structure? Are they $q^2\bar{q}^2$ states or are they simpler "molecular" type states? What causes their small decay widths? Why do they decay predominantly to $B\bar{B}$ rather than to pions?

4) The $\bar{p}d$ reaction may be used to explore $\bar{p}n$ states. Likewise the charge exchange of antiprotons might be used to study $\bar{n}p$ states and resonances. What surprises await us there?

5) The annihilation of $\bar{p}$ by p presumably occurs inside the quark bag. The antiproton thus appears to be a prime candidate to tell us something about the underlying quark structure of nucleons, of the size and character of the bag, and of the connection between quark and meson physics. Will this goal be realized?

6) The study of $\bar{p}$-nucleus scattering shows a total cross section larger than $2\pi\,(5/3)\langle r^2\rangle$, twice the geometric area of an object with uniform density of rms radius $\langle r^2\rangle^{1/2}$. Will the expectation of using $\bar{p}$ atoms to study the extreme outer edges of the nuclear surface be realized?

7) With $\bar{p}$ beams one can form $\Lambda\bar{\Lambda}$, $\Sigma\bar{\Lambda}$ and other exotic systems such as $2\bar{N}N$. What are their properties?



The charge exchange reaction of $\overline{p}$ can give $\overline{n}$ beams. These open yet another field of study.

Again, I have not discussed $\overline{p}$ nucleus scattering to study spectroscopy. Polarized $\overline{p}$ beams open up yet new horizons.

IV. CONCLUSIONS

The workshop demonstrated that a new and exciting realm of physics would be opened by a higher-energy accelerator, euphemistically called a Kaon Factory.

Finally, on behalf of all of the participants in the workshop, I would like to thank the organizers: Harold Fearing, J. Reginald Richardson, and especially Michael K. Craddock who did most of the work, for organizing a very stimulating set of sessions.

Fig 1

Fig. 1. $K^+ + {}^{12}C$ elastic scattering differencial cross section. Some optical model fits are ~~also~~ shown.

Fig 2

Fig. 2. $K^- + {}^{12}C$ elastic scattering differential cross section. Some optical model fits are shown. ~~?also shown as above?~~

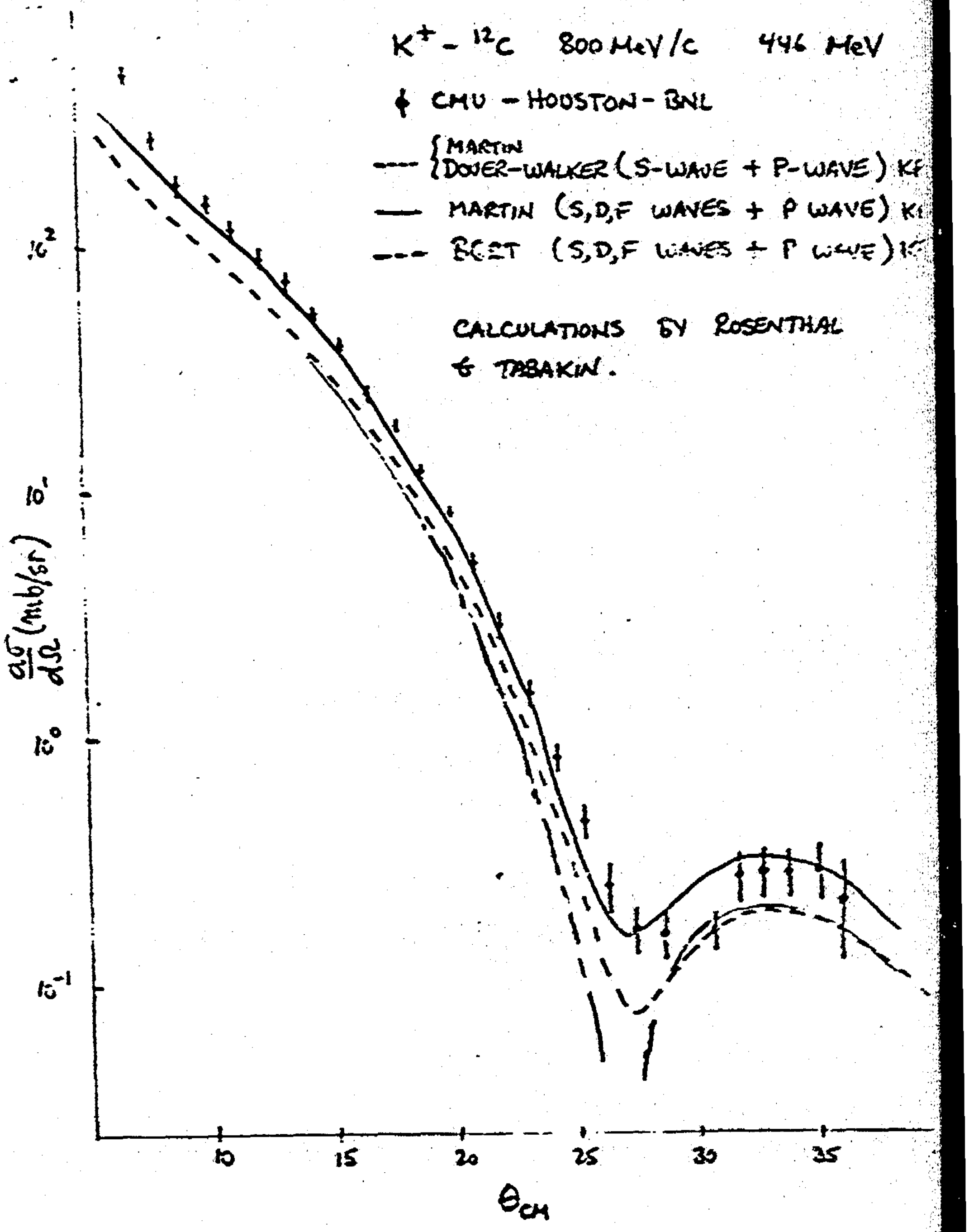
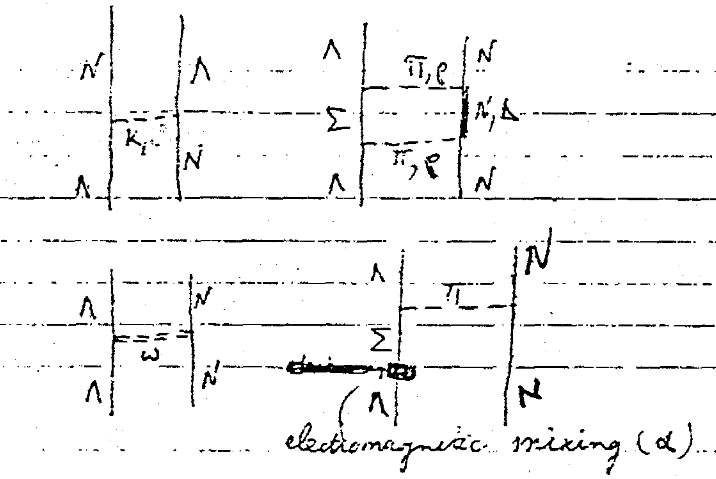


Fig 3a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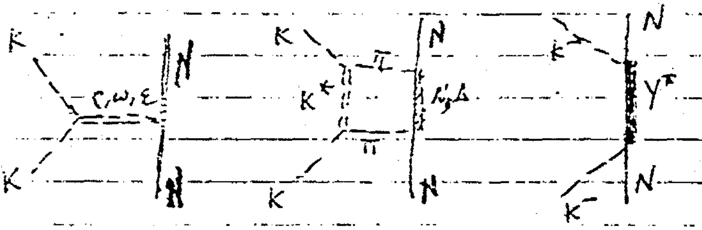
3b: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