

M. Bernardini, P. Dalpiaz, G. Fortunato, T. Massam, G. Petrucci and A. Zichichi: EXPERIMENTAL INVESTIGATIONS PROPOSED FOR "ADONE". - (Bologna-CERN-Frascati Collaboration)

(Paper presented by A. Zichichi at the Meeting on Colliding Beam Experiments, Frascati, Italy, 21-22 February, 1966).

1 - INTRODUCTION -

A direct experimental knowledge of the problems which show up when working with colliding beams will be of extreme importance for the planning of experiments with the CERN ISR (Intersecting Storage Rings). As the best knowledge is always acquired by performing specific experiments, we have followed the line of studying an experimental proposal for ADONE, taking advantage of the fact that our experimental programme at CERN is strictly related to the physics which can be done using ADONE.

As the date of operation for experiments with ADONE is not yet fixed, the experimental set-up proposed here has to be considered as a preliminary study in view of improvements which we may incorporate according to possible technical developments such as, for instance, the use of a superconducting magnet instead of the classical one considered here.

The set-up studied in the present proposal is supposed to be used in order to exploit as much as possible the colliding beam facility. It is supposed to be able to handle simultaneously the following processes^(x):

(x) - Other processes such as $e^+e^- \rightarrow e^+e^-$, $\mu^+\mu^-$, $\gamma\gamma$, $\pi^0\gamma$, $p\bar{p}$, are not considered here in detail because they have already been proposed by other groups. It is obvious that our apparatus can handle all these processes, with good rates. Notice the extreme interest of the process $e^+e^- \rightarrow n\bar{n}$, which again can be detected with our instrument.

2.

$$\begin{array}{l}
 e^+ e^- \rightarrow \left\{ \begin{array}{l}
 \rightarrow \pi^+ \pi^- \quad (1) \\
 \rightarrow \pi^+ \pi^- \pi^0 \quad (2) \\
 \rightarrow \pi^+ + \text{anything} \quad (3) \\
 \rightarrow K^+ + \text{anything} \quad (4) \\
 \rightarrow K_1^0 + K_2^0 \quad (5) \\
 \rightarrow K_1^0 + K_1^0 \quad (6) \\
 \rightarrow K_2^0 + K_2^0 \quad (7) \\
 \rightarrow \ell_q + \bar{\ell}_q \quad (8)
 \end{array} \right.
 \end{array}$$

The study of these processes has many interesting aspects which we will try to summarize in the following paragraphs.

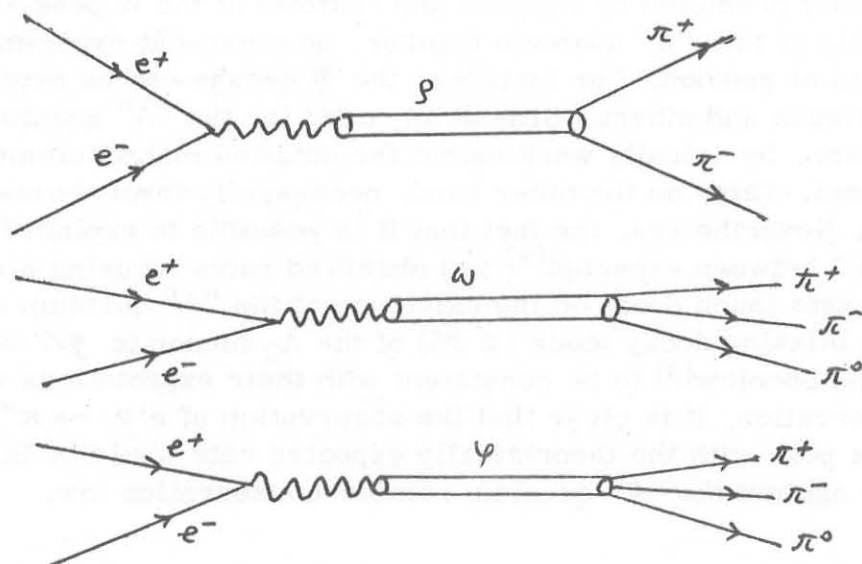
1.1. - Study of the q^2 dependence of the electromagnetic coupling to the isovector and isoscalar currents. -

As is well known, a colliding electron-positron machine is the cleanest source of time-like photons^(x), and therefore the cleanest source of $J^{PC} = 1^{--}$ states with quantum numbers $B=S=0$ ($B =$ Baryonic number; $S =$ Strangeness). This is extremely relevant for the electromagnetic structure of the nucleon. A problem of great interest in this field is, in fact, to investigate the validity of the "pole dominance" in the dispersion integrals of the nucleon form factors. This hypothesis is extremely appealing because of its simplicity, and it would be of great value to check its validity experimentally. If the dispersion integrals of the nucleon form factors are dominated by poles, then the production of two and three pions in the (e^+e^-) annihilation

$$\begin{array}{l}
 (1) \quad e^+ e^- \rightarrow \pi^+ \pi^- \\
 (2) \quad e^+ e^- \rightarrow \pi^+ \pi^- \pi^0
 \end{array}$$

will proceed essentially through the ρ -meson, the ω -and the ψ -meson graphs, respectively, (see figs. 1, 2 and 3):

(x) - In the following we will limit ourselves to the validity of one-photon approximation.



FIGS. 1, 2, 3 - Feynman diagrams for the processes described in the test.

If the dispersion integrals contain a large contribution from a non-resonant background, this means that the coupling of the photon to the isovector and isoscalar currents will not be dominated by the known ρ , ω , ψ and will start to receive contributions from (2π) masses and (3π) masses upwards. A measurement of the rates for processes (1) and (2) at various ADONE energies will allow us to know the coupling of the electromagnetic field with the isovector and isoscalar currents, respectively, and also the q^2 dependence of this coupling. At the ω peak this coupling is multiplied by $\sin \theta$ apart from other factors, while at the ψ peak it will be multiplied by $\cos \theta$, apart from the depression factor due to the fact that $\psi \rightarrow \rho\pi$ is forbidden. The interest of comparison between the rates of the reactions (1) and (2) at the ρ, ω, ψ peaks is obvious.

1.2. - Validity of the "A" quantum number conservation law. -

Bronzan and Low⁽¹⁾ have proposed the existence of a special "selection rule for bosons" which originated the conservation law of the so-called "A" quantum number. If this selection rule is valid then

while	$\rho \rightarrow \omega$	transitions are forbidden
	$\rho \rightarrow \rho$	transitions are allowed
	$\rho \rightarrow \psi$	transitions are allowed

The suppression generated by the "A" quantum number is believed to be a factor ~ 40 ; therefore we would expect a rate of a factor of 40 less than that theoretically predicted by Cabibbo and Gatto⁽²⁾ at the ω peak. Concerning the validity of this "A" quantum number, no clear-cut experimental evidence exists at present. For instance, the η decays can be explained according to Okubo and others, without any need for the "A" quantum number conservation, by actually working out the detailed matrix elements for each channel. This, on the other hand, necessarily involves model-calculations. Nevertheless, the fact that it is possible to explain factors as large as 100 between expected^(x) and observed rates by using a reasonable model casts much doubt on the existence of the "A" quantum number. Recently, the missing decay mode ($\approx 3\%$) of the A_2 meson to $\eta\pi$ was shown by Glashow and Socolow⁽³⁾ to be consistent with their expectations without any "A" conservation. It is clear that the observation of $e^+e^- \rightarrow \pi^+ \pi^- \pi^0$ at the ω mass peak with the theoretically expected rate would be the clearest evidence against the "A" quantum number conservation law.

1.3. - A check of C γ invariance in strong interactions (Lee theory). -

As recently pointed out by Lee⁽⁴⁾, the violations of P and C in weak interactions can, in fact, be formulated in terms of P and C conservations, provided that we properly define these operators. In fact, what Lee suggests is to define for each interaction a set of three operators which are all conserved, thus putting on an equal footing all classes of interactions. If we accept the Lee theory we have therefore a strong parity operator P_{strong} , an electromagnetic parity operator $P_{e.m.}$, and a weak parity operator P_w ; and so on for the C and T operators (see Table I).

TABLE I

Interactions	Operators		
Strong	P_s	C_s	T_s
Electromagnetic	P_γ	C_γ	T_γ
Weak	P_w	C_w	T_w

(x) - Expected on the basis of phase space and the presence of γ -rays in the final state.

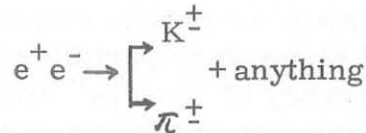
As we have said above, each class of operators is conserved for the corresponding class of interactions; moreover,

$$P_S C_S T_S = P_\gamma C_\gamma T_\gamma = P_W C_W T_W = PCT.$$

Lee points out that while strong interactions are indeed supposed to be invariant under C_S , there is no reason to believe, a priori, that they will be invariant under C_γ . On the contrary, if we accept this theory then the observed decay $K_2^0 \rightarrow 2\pi$ is explained without any dramatic violation of time-reversal invariance.

The best experimental result on the invariance of strong interactions under the operator C_γ is due to Baltay et al. (5), who have established that in $(\bar{p}p)$ annihilation the spectra of π^+ and π^- are equal within a few per cent. As the difference in these spectra is expected on the basis of Lee theory to arise from those annihilations which are accompanied by a γ ray, and as the effect of a γ ray in a reaction is expected to bring the rate down by at least a factor $\alpha = 1/137$, it is clear that the above limit is not reaching a level which would be expected even in the case of a maximal violation.

Our proposal in this context is to study the reactions



in order to measure the spectra of positive and negative π and K (outside ρ, ω, ψ peaks) thus establishing their equality (we would hope for inequality, of course!) within a few per cent.

The above-mentioned limits concerning both π^\pm, K^\pm spectra would represent an improvement of at least two orders of magnitude on the present available data. Moreover, and this is in fact the relevant point, our result would allow one to prove or to disprove the validity of the Lee theory. In fact, if strong interactions are not invariant under C_γ , this violation is not expected to be at a level as low as a few per cent. Any symmetry breaking which we know so far is always characterized by complete breaking; in fact, for P and C violation due to weak interactions we have $(1 + \tau_5)$; for the isospin violation due to electromagnetic interactions we have $(1 + \tau_3)$; and for the SU_3 violation due to the moderately strong interactions we probably have $(1 + \lambda_8)$.

1.4. - The problem of parastatistics. -

If the strong interactions should turn out to be non-invariant under C_γ , the reactions

6.

$$e^+e^- \left\{ \begin{array}{l} \rightarrow K_1^0 + K_1^0 \\ \rightarrow K_2^0 + K_2^0 \end{array} \right.$$

would only be forbidden by spin and statistics unless the K mesons follow parastatistics. The observation of such pairs of particles would, of course, be of extreme interest. Notice that the allowed process is $e^+e^- \rightarrow K_1^0 + K_2^0$, but we have not studied this reaction in detail as it is strictly related to an experimental proposal by another group.

1.5. - Search for leptonic quarks. -

Up to now there are about 20 experimental results which are in good agreement with the predictions based on the Unitary Symmetry approach to particle physics^(x). Unless we are prepared to believe that all these results are in accidental agreement with theory, we have to conclude that unitary symmetry plays a fundamental role in strong interaction physics. We have therefore to worry about the origin of these symmetries. As is well known, a very natural and simple way of explaining the existence of these symmetries is the "quark" model of Gell-Mann⁽⁶⁾ and Zweig⁽⁷⁾. So far, quarks have not been observed^(x).

The point we want to emphasize here is that in the unitary symmetry schemes of elementary particles the leptons remain completely isolated. Even the discovery of "quarks" would leave the lepton problem totally unsolved. This is the reason why we would like to exploit this unique source of time-like photons (ADONE) to look for fractional charges.

The process to study in this case would be:

$$e^+ + e^- \rightarrow (\text{leptonic quark}) + \overline{(\text{leptonic quark})}$$

where by leptonic quark we mean a particle with fractional charges going from $(1/3)$ upwards^(o).

Notice that if "leptonic quarks" exist, the only way of producing them would be through time-like photons: we know that the nucleons are very poor sources of time-like photons, due to their remarkable electromagnetic form factors⁽⁸⁾. Using the best fit of nucleon form factors obtained

(x) - See Rapporteur talk of A. Zichichi at the 51st Annual Meeting of the Italian Physical Society for a general review of the subject.

(o) - Using a complete analogy with the hadronic quarks, the $(4/3)$ charge would, for example, be a system of two "leptonic quarks" combined together with mass, hopefully less than that of a single "leptonic quark" due to the high binding energy.

by Massam and Zichichi⁽⁹⁾, it turns out that the probability of producing a pair of "leptonic quarks" via a 3 GeV time-like photon in a (p - p) collision is depressed by a factor of $\sim 10^{-8}$ with respect to the production of hadrons of the same mass via strong interactions. This limit is many orders of magnitude below the best existing limit, and it is practically impossible to reach it with proton machines.

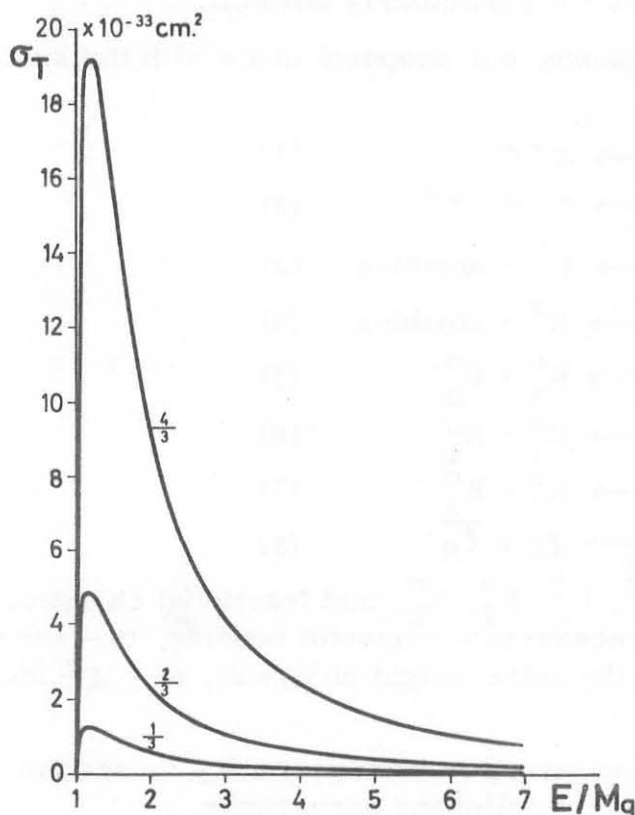


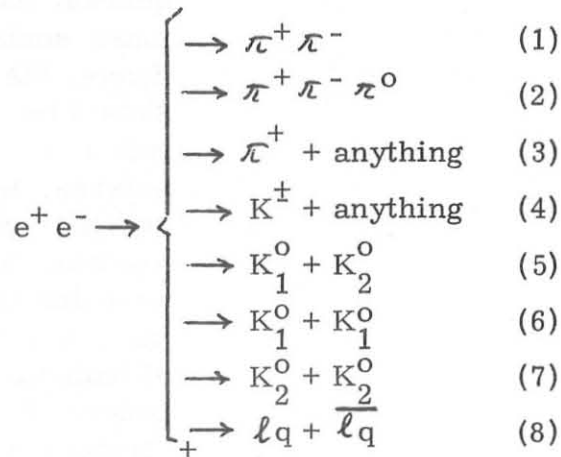
FIG. 4 - σ_T versus E/M_q . σ_T is the total cross-section in units of nanobarns (10^{-33}cm^2) for the process $e^+ + e^- \rightarrow q_1 + \bar{q}_1$. E is the energy of each colliding beam and M_q is the "leptonic quark" mass. The labels on the curves refer to the electric charge states of the leptonic quarks.

If the scale of masses between "leptonic quarks" and "hadronic quarks" has any resemblance to the mass-scale between leptons and hadrons, the "leptonic quark" masses should be at least an order of magnitude lower than the "hadronic quark" masses. ADONE would allow one to reach a good value of "leptonic quark" masses, with the advantage of no depression factor due to nucleon form factors and no enormous background of hadrons. The cross-section for process (8) would depend only on the "leptonic quark" charge and mass. The dependence on the charge would in the worst case [$Q = (1/3)e$] cause a depression by a factor 9 with respect to a standard electromagnetic cross-section. As an example, we have plotted in fig. 4 the cross-section for production of "leptonic quarks" in reaction (8) for different values of the fractional charge, following the work of Cabibbo and Gatto⁽¹⁰⁾. For "leptonic quark" mass of 1 GeV and and fractional charge $(2/3)e$ the cross-section for process (8) turns out to be $3.8 \times 10^{-33}\text{cm}^2$ at colliding beam energy of 1.5 GeV. The search for leptonic quarks of charge $1/3$, $2/3$ and upwards may be made by the combined technique of time-of-flight, magnetic bending, and specific ionization measurement in a scintillator, as we will see in the following section.

2 - THE PROPOSED SET-UP -

The vital point in our set-up is that we are going to detect strongly interacting particles at large angles with respect to the colliding beam line. The flux of electrons and positrons through our experimental apparatus is, according to the calculation of Cabibbo and Gatto⁽²⁾, of the same order of magnitude as the flux of particles in which we are interested. The problem of particle identification is therefore not particularly difficult.

As we have mentioned above, our proposal deals with the study of the following reactions:



where in the final states we have π^0 , K^\pm , K_1^0 , K_2^0 , and fractional charges. The identification of these particles needs: a) - magnetic bending, b) - time-of-flight, c) - dE/dx measurement (by pulse-height analysis), d) - π^\pm identification, e) - π^0 detection.

The general layout of the set-up is sketched in fig. 5, and the main components will be discussed in the following paragraphs.

2.1. - The magnet and its associated elements. -

The magnet will consist of two rectangular spectrometers which may be mounted with their field direction parallel to the beam or perpendicular to it, as dictated by the characteristic angular distributions predicted by Cabibbo and Gatto⁽²⁾ for isovector or isoscalar annihilations. The details of the magnets are shown in fig. 6 which also includes a list of approximate characteristics.

Referring again to fig. 5: counter S is a veto counter used to select K_2^0 events; counter A consists of a small hodoscope to define the origin of the event for the trigger logic, and also to provide, together with counters D, time-of-flight information on slow massive particles.

Here B are spark chambers with optical or wire read-out and C is a second hodoscope which is constructed of 5 cm wide counters. This choice of counter size is dictated by the requirement of minimum size in or

der to have a highly selective trigger, and yet have the counter wide relative to the spread in trajectory position caused by multiple scattering in counters A.

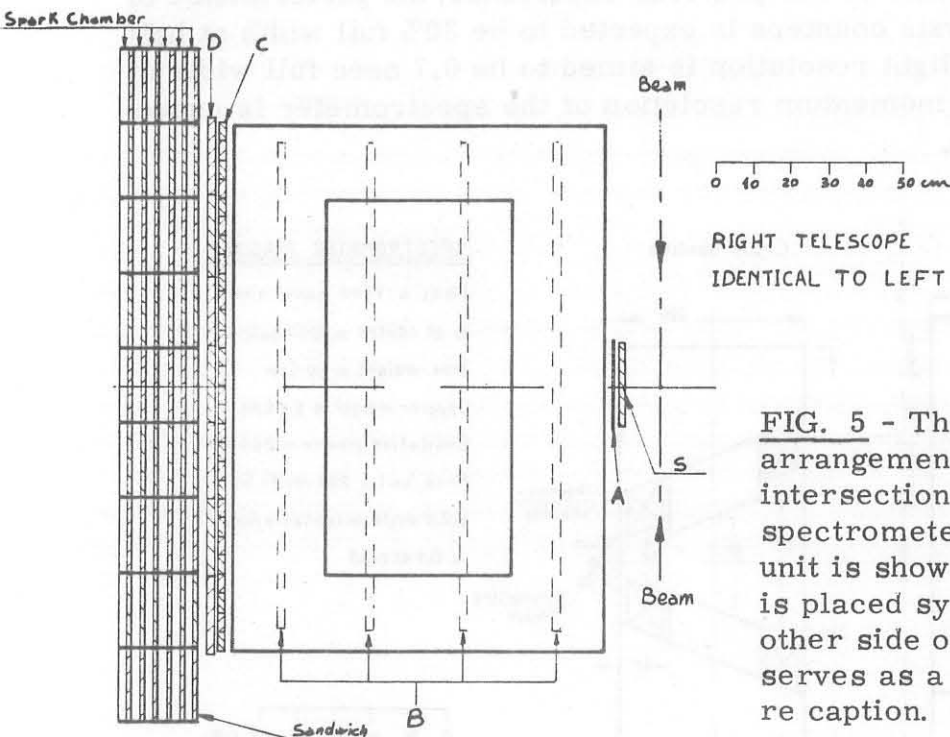


FIG. 5 - This shows the counter arrangement relative to the beam intersection region and to the spectrometer magnet. Only one unit is shown; an analogous unit is placed symmetrically on the other side of the beam. Table III serves as a more complete figure caption.

The counters D, as well as providing timing information, are to be used in pulse-height analysis for charge determination.

"E" are a series of lead-scintillator spark chamber sandwiches, each of which consists of seven layers of one radiation length of lead, plus 1.5 cm of plastic scintillator and a two-gap spark chamber element. The purpose of these sandwiches is to discriminate between " π " and "e" according to the pulse-height sequences in the counters and to the visual spark chamber pattern. This sandwich is also a good " π^0 " detector and is used in the study of process (2). In this case we would remove one of the spectrometers, bringing all the counters closer to the intersecting beams in order to have good solid-angle acceptance for the π^0 decays. The energy of the π^0 would be measured by pulse-height analysis in the sandwich counters combined with spark counting and opening angle.

For the study of all other processes, we would use both spectrometers. It is probably worth pointing out that, apart from a reduction of solid-angle acceptance, even process (2) could be studied without any change in the geometry of our set-up.

The study of processes (5), (6), and (7) depends upon the colliding beam energy which may be adjusted so as to vary the K_2^0 energy and hence

ce vary the sensitivity of the apparatus to K_2^0 decay, thus allowing the use of the same set-up to detect either pair, simply by using or not using the veto signal from counter S.

On the basis of our previous experience, the performance of the pulse-height analysis counters is expected to be 30% full width at half height. The time-of-flight resolution is aimed to be 0.7 nsec full width at half height, while the momentum resolution of the spectrometer is expected to be $\Delta p/p \sim \pm 2\%$.

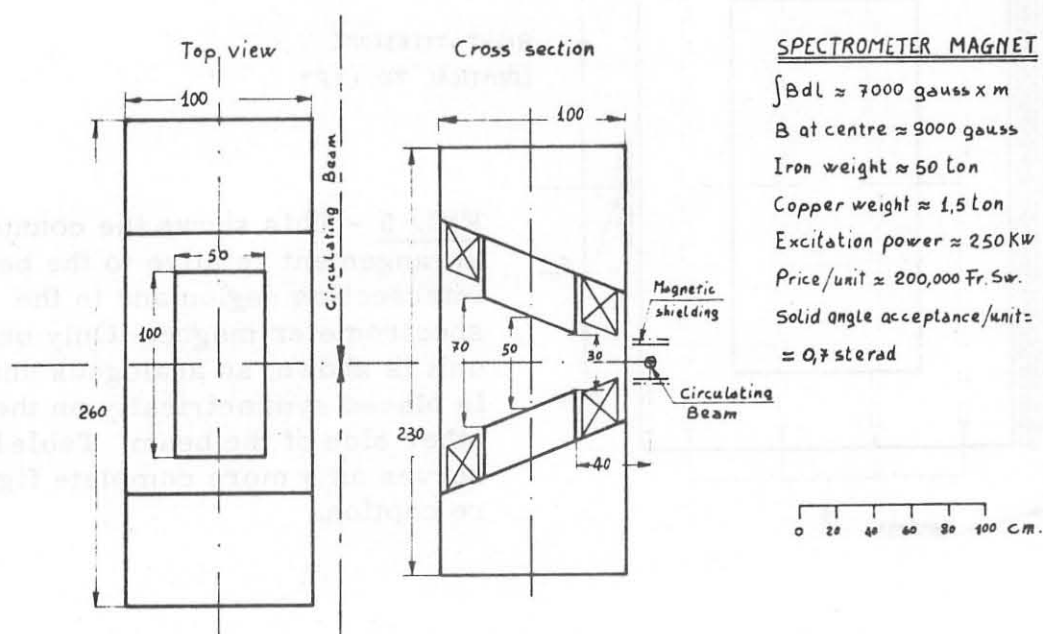


FIG. 6 - The cross-section and top view of one spectrometer magnet. The spectrometer magnet has a simple and open structure so as to facilitate the installation of counters and spark chambers. In order to save power and to limit the stray field in the interaction region, the surfaces of the polar pieces are inclined and cope with the solid-angle acceptance of the apparatus; for the same reason the coils are also inclined. The interaction region will nevertheless require an accurate shielding which can be realized even at the maximum field without reduction of the angular acceptance of the magnet; the shielding is made easier if two spectrometer magnets with opposite field are symmetrically mounted beside the interaction region.

2.2. - Expected rates^(x) . -

The acceptance of our pair of spectrometers is 1.4 steradian. In Table 2 we have reported the rates for these processes for which theoretical estimates are available⁽²⁾.

TABLE II

Process	Expected rates (using Cabibbo and Gatto's results)
$e^+e^- \rightarrow \pi^+\pi^-$ (at the ρ peak): both momenta measured	50 events/hour
$e^+e^- \rightarrow \pi^+\pi^-\pi^0$ (at the ω peak): measured quantities are: the momentum of π^+ or π^- , the directions of π^+ and π^- , and the π^0 energy	18 events/hour
$e^+e^- \rightarrow \pi^+\pi^-\pi^0$ (at the ψ peak): the measured quantities are as for the case above	20 events/hour

For the other processes, the expected rates are quoted per μ barn and per hour. Obviously the rates of processes

$$e^+e^- \rightarrow \pi^+ + \text{anything} \quad (3)$$

$$e^+e^- \rightarrow K^+ + \text{anything} \quad (4)$$

$$e^+e^- \rightarrow l q + \bar{l} \bar{q} \quad (8)$$

are equal when expressed in this way, namely

$$\text{rate of process (3)} \equiv (4) \equiv (8) \equiv 120 \text{ events}/\mu\text{barn}/\text{hour} .$$

(x) - All rates are calculated using the ADONE luminosity quoted in F. Amman - Laboratori Nazionali di Frascati, 66/6, 14 February 1966.

12.

Concerning the $K_1^0 K_1^0$ pairs and $K_2^0 K_2^0$ pairs, the rates are not given for the present experimental set-up as we are thinking of further improvements in order to obtain higher acceptances for these reactions.

TABLE III

Counter	Thickness	Notes
S	1.5 cm	In place only for K_2^0 detection.
A	0.4 cm	At the ξ peak this hodoscope produces only 5 mrad multiple scattering of pions.
B	0.08 g/cm ²	This is the total density of the four double-gap spark chamber units.
C	1 cm	These hodoscope counters are 5 cm wide.
D	2 cm	These time- and pulse-height measuring counters are 20 cm wide.
E	7 layers, each of 0.5 cm 1.4 cm 1.5 cm	Lead Two spark chamber gaps Scintillator Each of these sandwiches is 20 cm wide.

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