Istituto Nazionale di Fisica Nucleare
Sezione di Bologna

INFN/AE-67/3
20 Marzo 1967

M. Bernardini, D. Bollini, E. Fiorentino, F. Mainardi, T. Massam, L. Monari, F. Palmonari and A. Zichichi. (Bologna-CERN-Frascati collaboration): A PROPOSAL TO SEARCH FOR LEPTONIC QUARKS AND HEAVY LEPTONS PRODUCED BY ADONE.-

1. - INTRODUCTION -

The experimental set-up studied in the present proposal takes into account the financial limitations which have been imposed on our previous project[1].

The limitations are two-fold:

i) as a magnet cannot be used there will be no magnetic analysis and so our proposal[1] of checking C-invariance must for the moment be abandoned;
ii) as the money available is very restricted the spatial resolution of our fast trigger is worse, i.e. $\Delta\theta = 10^{o}$.

We will concentrate on the study of two main topics:

a) Production of leptonic quarks;
b) Production of heavy leptons.

2. - SEARCH FOR LEPTONIC QUARKS -

The interest of looking for quarks of a leptonic nature has already been emphasized[2]. The point we would like to make here is that if "leptonic-quarks" exist, the most efficient way of producing them would be through time-like photons. We know that nucleons are very poor sources of time-like photons, due to their remarkable electromagnetic form factors[3]. Using for instance the best fit of nucleon electromagnetic form factors obtained by Massam and Zichichi[4] it turns out that the probability of producing a pair of "leptonic-quarks" via a 3 GeV time-like photon in a proton-proton collision is depressed by $\sim 10^{-8}$ 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(5). It is therefore very difficult to look for leptonic quarks using proton machines.

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 investigate an interesting range 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 the process

$$e^+ e^- \rightarrow q_1 \bar{q}_1$$

depends only on the "leptonic-quark" mass and charge. The dependence on the charge would, in the worst case $[Q = (1/3) \cdot e]$ cause a depression factor of 9 with respect to a standard electromagnetic cross-section.

Using the cross section values for production of quark pairs given by Massam and Zichichi(2) we have calculated the expected counting rate as a function of production angle in our counter system for E_{Adone}(x) = 1.5 GeV and assuming $M_q = 1$ GeV. As our angular resolution is expected to be $\Delta\theta = 10^o$ we have calculated the expected rates per interval of 10^o in the laboratory-system, over the angular region of acceptance of our telescope. The results are shown in Fig. 1.

The identification of a fractional charge is done by the measurement of specific ionization in a plastic scintillator. We report in Fig. 2 the spectrum of pulse height obtained in an element of plastic scintillator of dimensions $5 \times 5 \times 76$ cm^3, viewed at both ends by a 58 AVP photomultiplier. The curve shown has a FWHH = 9%. Fig. 3 illustrates the relevance of the quark mass to the identification by specific ionization. The curves are drawn for a beam energy of 1.5 GeV. They show the specific ionization for $Q = 1/3$ and $Q = 2/3$ as well as the resolution obtained with minimum ionizing particles. Superimposed on these curves is the shape of the production cross section curve.

The conclusion is that for charge 1/3, masses up to 1.4 GeV may be scanned, and for charge 2/3, masses up to about 1.0 GeV may be scanned. These ranges could of course be extended to 1.5 GeV by the application of a magnetic field to provide some momentum analysis.

The rate expected on the basis of these considerations is up to twenty events per day, depending on the mass. In order to evaluate the

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(x) - For brevity from now on E_{Adone} will be indicated simply by E.

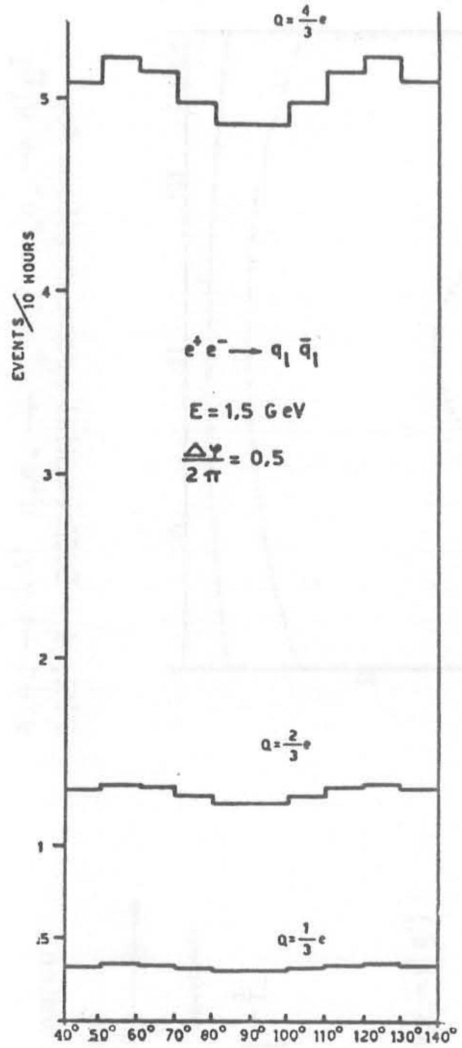

FIG. 1 - Angular distribution of expected events produced in the reaction $e^+e^- \rightarrow q_1\bar{q}_1$ for a quark mass M = 1 GeV, at Adone energy E = 1.5 GeV.

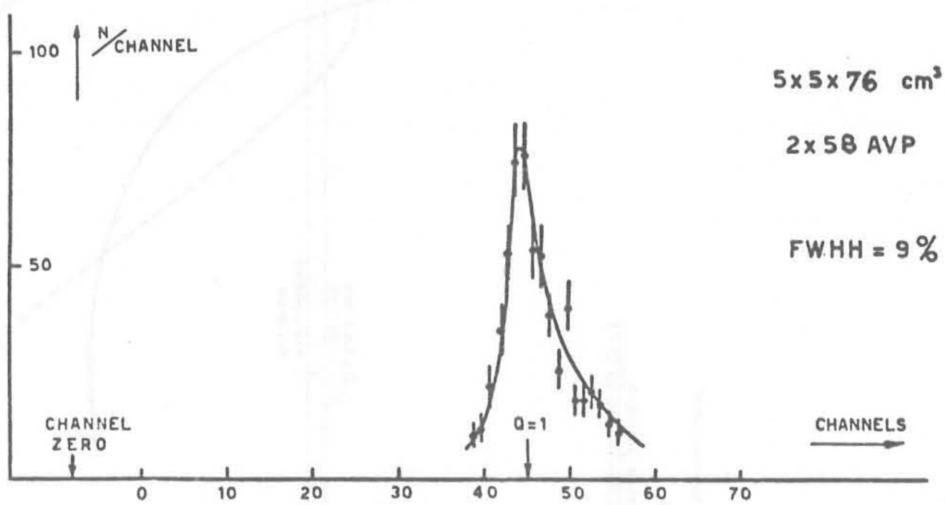

FIG. 2 - Showing the pulse eight spectrum obtained from the addition of the pulses of opposite photomultipliers when minimum ionizing particles cross the counter.

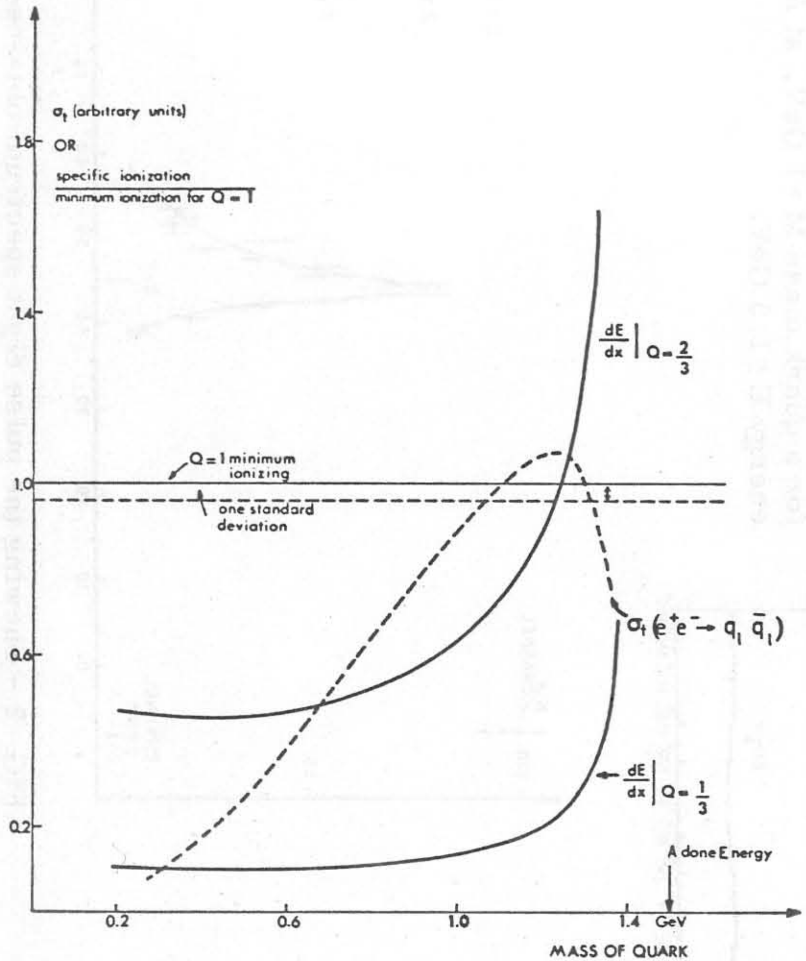

FIG. 3 - Showing the range of masses which may be investigated at E = 1.5 GeV.

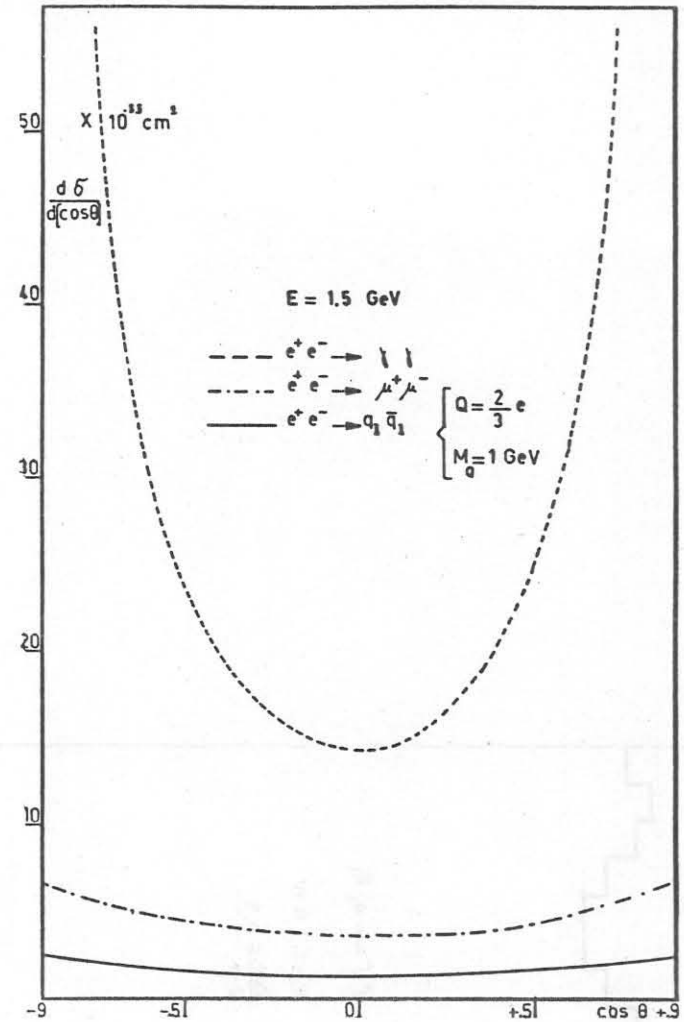

FIG. 4 - Differential cross-sections for $e^+e^- \rightarrow \gamma\gamma$, $e^+e^- \rightarrow \mu^+ \mu^-$, $e^+e^- \rightarrow q_1 \bar{q}_1$ (Q = 2/3e, M = 1 GeV) at E = 1.5 GeV.

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level of quark detection, it is important to know the expected rates of production of standard leptons i.e. $e^+e^- \to \mu^+\mu^-$. This is reported in Fig. 4.

As the rate of $\mu^+\mu^-$ production turns out to be in the worst case only ~10 times the rate for $q_1\bar{q}_1$ production it is obvious that there will be no possibility of confusing a $\mu^+\mu^-$ pair with a $q_1\bar{q}_1$ pair of charge either (2/3) or (1/3).

A further rejection could be obtained for the case of $\pi^+\pi^-$ production because of the hadronic nature of these pairs. On the basis of the calculated cross-sections for $e^+e^- \to \pi^+\pi^-$, this further rejection is clearly not needed. In fact as can be seen from Fig. 5, the expected number of $\pi^+\pi^-$ in our angular acceptance is ~ 3 times lower than $\mu^+\mu^-$.

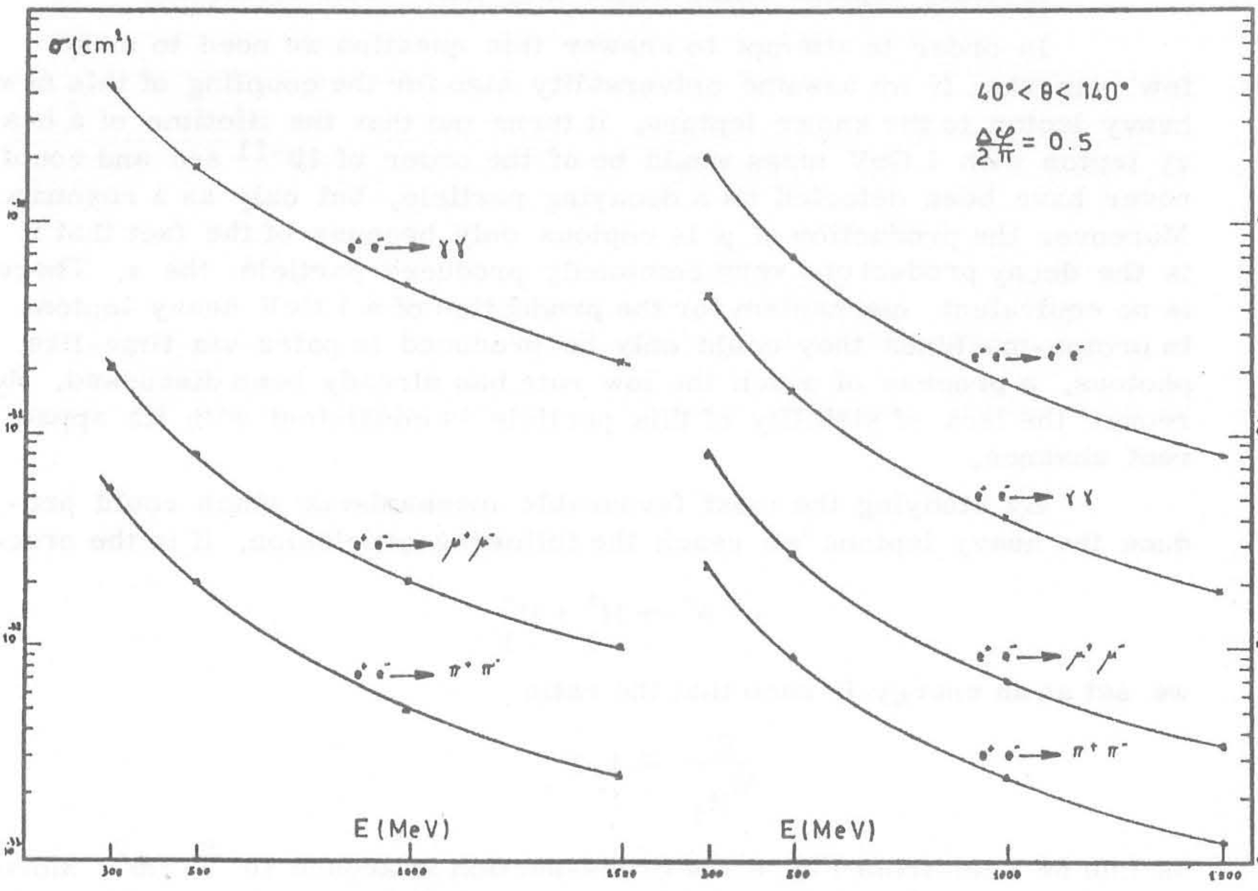


FIG. 5 - Cross-sections for reactions $e^+e^- \to e^+e^-$, $e^+e^- \to \gamma\gamma$, $e^+e^- \to \mu^+\mu^-$, $e^+e^- \to \pi^+\pi^-$ versus E.

A serious source of fractionally charged pulses would be a pair of γ-rays from the reaction

$$e^+ e^- \to \gamma \gamma$$

In Fig. 4 we have plotted the differential cross-section at E = = 1.5 GeV for the above mentioned process.

The $\gamma\gamma$-rate is less than two orders of magnitude greater than the $\bar{q}$ q-rate, over the acceptance range of our telescope. As our pulse height analysis is in coincidence with a pair of thin counters the combined probability of a trigger is obviously negligible.

The details concerning the apparatus and the associated electronic logic are given in § 4.

3. - SEARCH FOR HEAVY LEPTONS -

If heavy leptons exist would they have been detected?

In order to attempt to answer this question we need to make few remarks: if we assume universality also for the coupling of this new heavy lepton to the known leptons, it turns out that the lifetime of a heavy lepton with 1 GeV mass would be of the order of 10^{-11} sec and could never have been detected as a decaying particle, but only as a resonance. Moreover the production of μ is copious only because of the fact that it is the decay product of a very commonly produced particle: the π. There is no equivalent mechanism for the production of a 1 GeV heavy lopton: in proton-machines they could only be produced in pairs via time-like photons, a process of which the low rate has already been discussed. Moreover the lack of stability of this particle is consistent with its apparent absence.

By studying the most favourable mechanisms which could produce the heavy leptons we reach the following conclusion. If in the process

$$e^+ e^- \rightarrow H_1^+ + H_1^-$$

we set at an energy E such that the ratio

$$\frac{E}{M_{H_1}} \simeq 1.2$$

as can be seen from Fig. 6 the cross-section is around 10^{-32} cm^2. Moreover the two produced H_1^+ and H_1^- are non relativistic and very slow in the laboratory-system, their $\gamma = E/M$ is in fact ~ 1.2. The most favoured decay channels, as far as we can say now, are probably

$$H_1^{\pm} \rightarrow e^{\pm} + \nu_e + \nu_H$$
$$\phantom{H_1^{\pm}} \rightarrow \mu^{\pm} + \nu_\mu + \nu_H$$

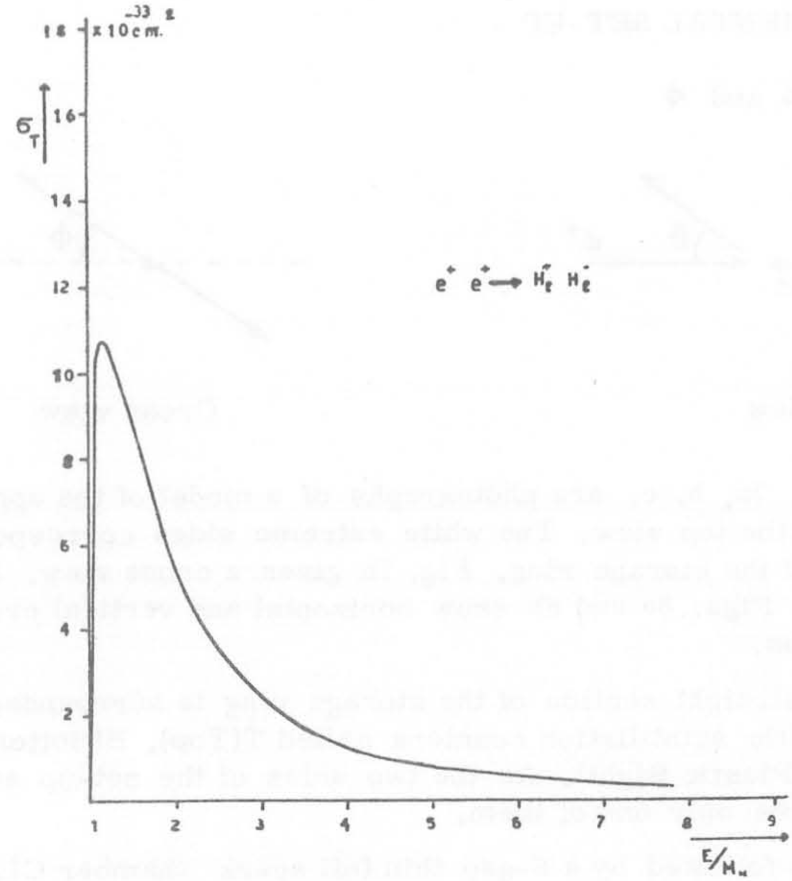


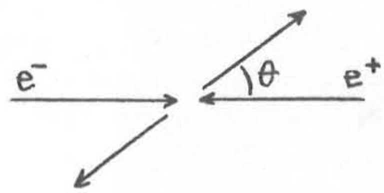
FIG. 6 - Total cross-section for production of heavy leptons versus E/M_{H_1}.

and therefore the decay angular distribution is nearly isotropic in the laboratory-system. This means that the probability of having the two charged light leptons going in the same hemisphere in the laboratory-system is $\sim$50%. These events would be identified by what we call an "asymmetric" trigger, i.e. two particles in one telescope and nothing on the other side. Notice that this "asymmetric" trigger should be further characterized by the following typical lepton-pair distribution: e^+e^-: 25%; $\mu^+\mu^-$: 25%; $e^\pm\mu^\mp$: 50%.

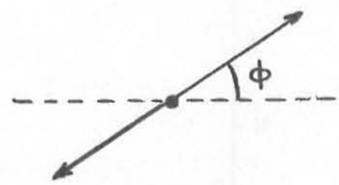
The expected rate of these triggers is found to be $\sim$1.5 events/hour for E/M_{H_1} = 1.2 and for the luminosity of Adone relative to E = 1.2 GeV. This means that if a heavy lepton exists with M_{H_1} = 1 GeV we expect 36 events in one day of running with Adone at E = 1.2 GeV.

4. - EXPERIMENTAL SET-UP -

Definition of θ and ϕ



Top view



Cross view

Figs. 7a, b, c, are photographs of a model of the apparatus. Fig. 7a gives the top view. The white extreme sides correspond to the quadrupoles of the storage ring. Fig. 7b gives a cross view. Fig. 7c shows all the model. Figs. 8a and 8b show horizontal and vertical cross-sections of the apparatus.

The straight section of the storage ring is surrounded by a system of 4 plastic scintillation counters called T(Top), B(Bottom), PL(Plastic left), PR(Plastic Right). As the two sides of the set-up are identical we will describe only one of them.

PL is followed by a 6-gap thin foil spark chamber CL, where a charged particle is identified and positioned in space. If the particle has a fractional charge the number of produced sparks is reduced accordingly. The analysis of those events which are identified as being due to fractionally charged objects is further reinforced by this independent check. For more details on this point see ref. 5).

The system of six plastic scintillators allows a good analysis of pulse height as shown in Fig. 2. The function of these counters is to give a trigger for fractional charges and a rough collinearity selection. The present angular resolution for these counters is about 10°. Their restricted number is dictated by economical reasons. In fact, it is desirable to place (thinner) ionization measuring counters behind these counters in order to reduce the background from physical processes which simulate fractional charges in them.

CL' is an 8-gap thin foil spark chamber which again allows the positioning of a charged particle and an independent check on the value of its charge.

SL is a sandwich which consists of 5 elements each composed of a Pb-foil+2-gaps-spark chamber+a plastic scintillator. This system is used to identify electrons from muons and pions. The rejection power of this telescope against pions, when set to accept electrons in the energy range 1-2.5 GeV is known to be 5×10^{-4} (see ref. 6). In this sandwich we

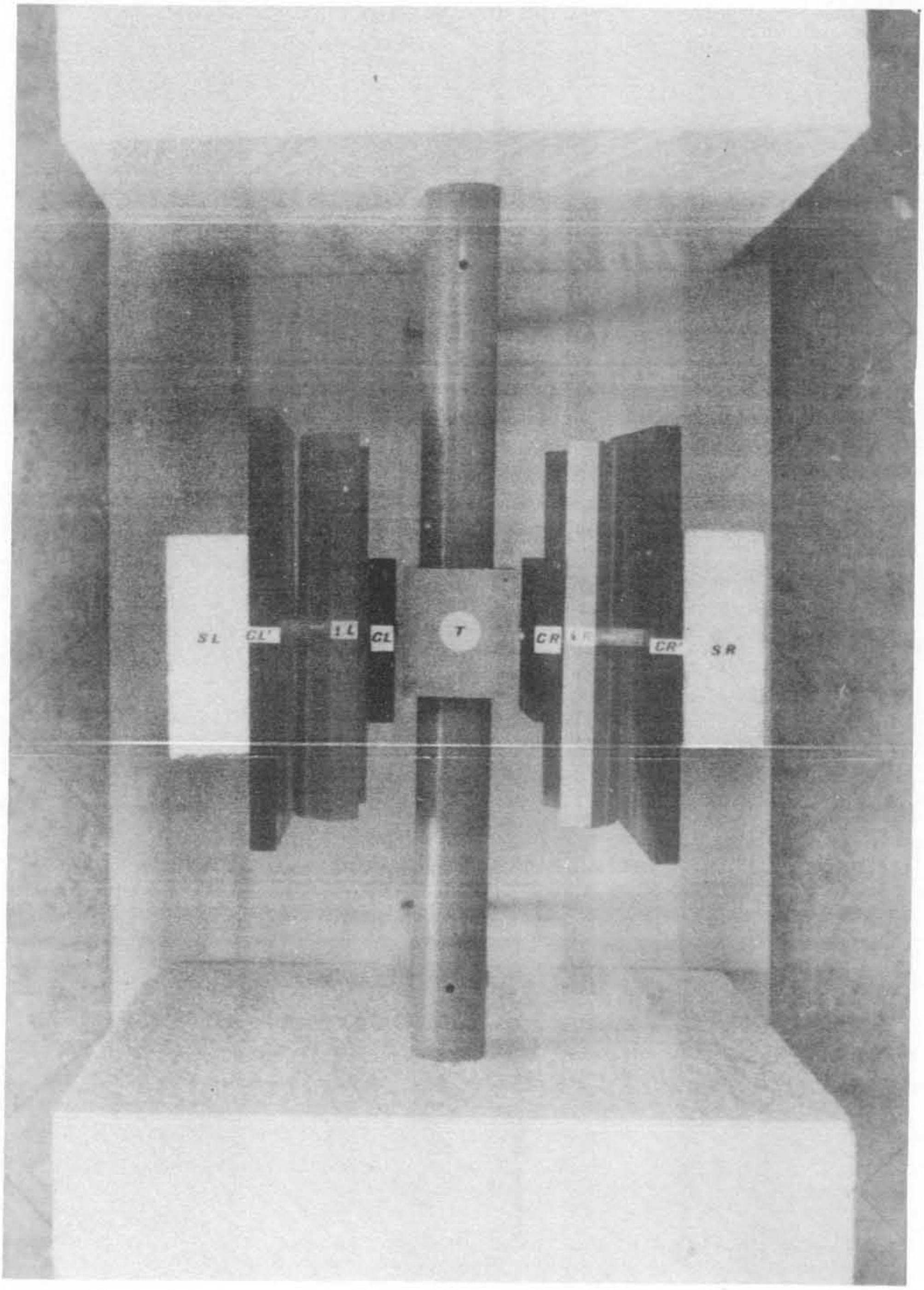


FIG. 7a) - Scale model of the experimental apparatus. Top view.
PL, PR, L, R = plastic scintillation counters;
CL, CR, CL', CR' = thin Aluminium plate spark chambers
(six 1 cm gaps);
SL, SR = sandwich counters.

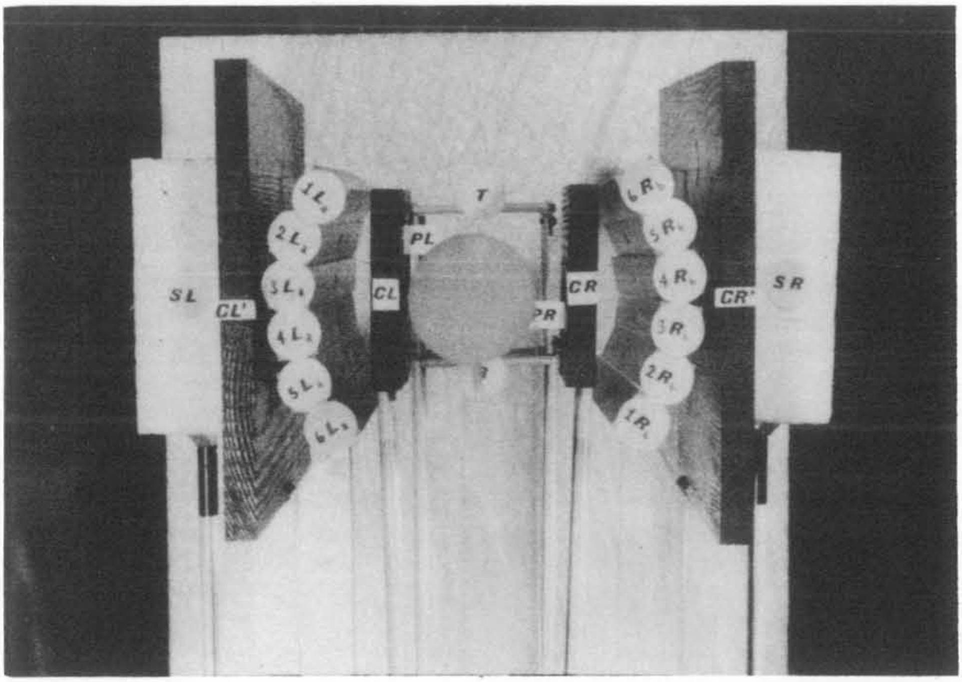


FIG. 7b) - Scale model of the experimental apparatus. Cross-sectional view.

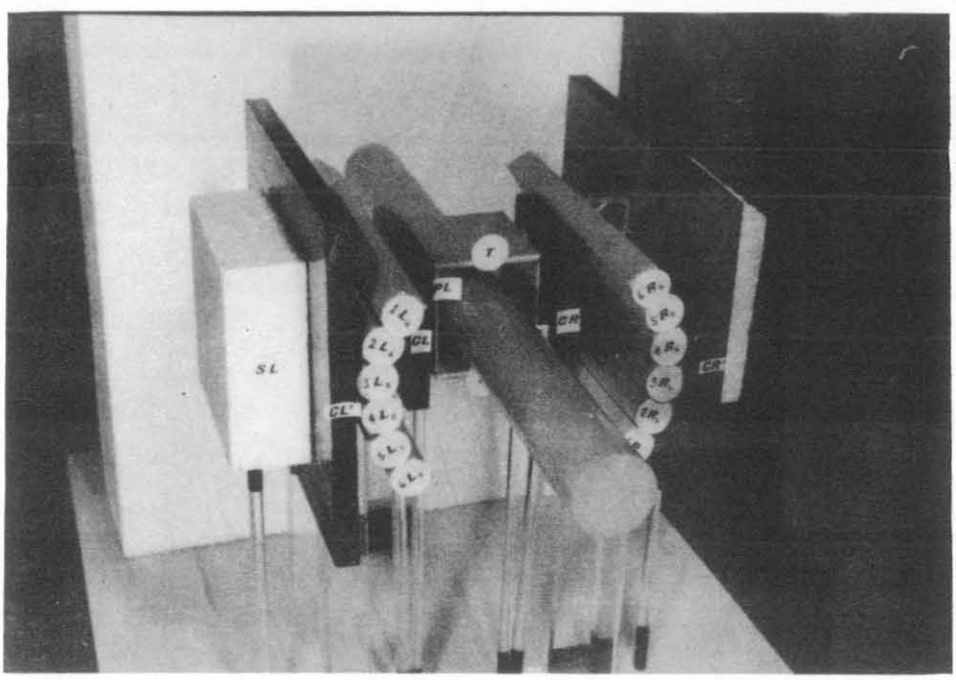


FIG. 7c) - Scale model of the experimental apparatus. General view.

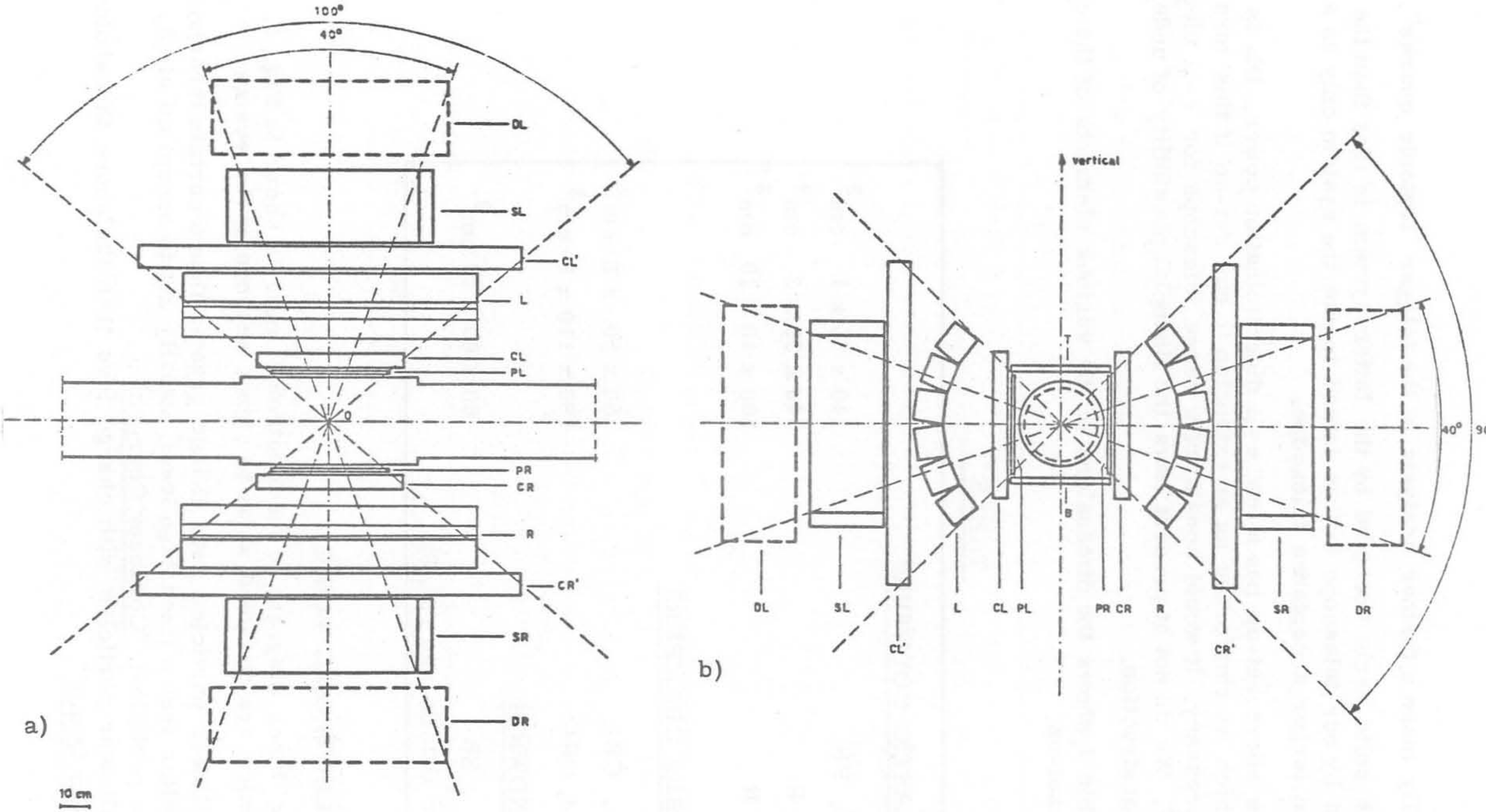


FIG. 8 - Experimental apparatus: a) Top view, b) Cross view; 0 =Interaction point; PL, PR, L, R = plastic scintillation counters; CL, CR, CL', CR' = thin Aluminium plate spark chambers; SL, SR = sandwich counters; DL, DR = rough μ-detector. Notice that the shape of the plastic scintillators will in practice be such that there are no edge effects between adjacent counters.

can eventually make a further analysis of the trigger "leptonic quarks".

The solid angle accepted by the latter system is less than the one covered by our telescope but we intend to use the system only as a check of our larger acceptance telescope.

The above set-up has a low $\pi - \mu$ discrimination power. DL is a system which we can forsee as an extension to our set-up if this turns out to be necessary. It would consist of a range telescope for $\pi - \mu$ idendification(7). We do not at present have the financial possibility of undertaking its construction.

Table I shows the dimensions of the various elements of the experimental set-up.

TABLE I

PLASTIC COUNTERS	
PL, PR	40 x 35 x 1 cm^3
T, B	40 x 35 x 3 cm^3
L, R	100 x 10 x 10 cm^3
SPARK CHAMBERS	
CL, CR	50 x 50 x 6 cm^3
CL', CR'	130 x 110 x 8 cm^3
SANDWICH	
SL , SR	60 x 60 x 25 cm^3
(for details see ref. 6).	

5. - THE ELECTRONIC LOGIC -

The block diagram of the electronic logic is shown in Fig. 9. The electronics are designed so as to signal any one of the events:

i) Two collinear particles with charge greater than a certain threshold and smaller than a fixed high level, usually set to accept all singly charged particles: "Collinear Charged".
ii) Two collinear particles with charge less than the above threshold: "Collinear Quark".

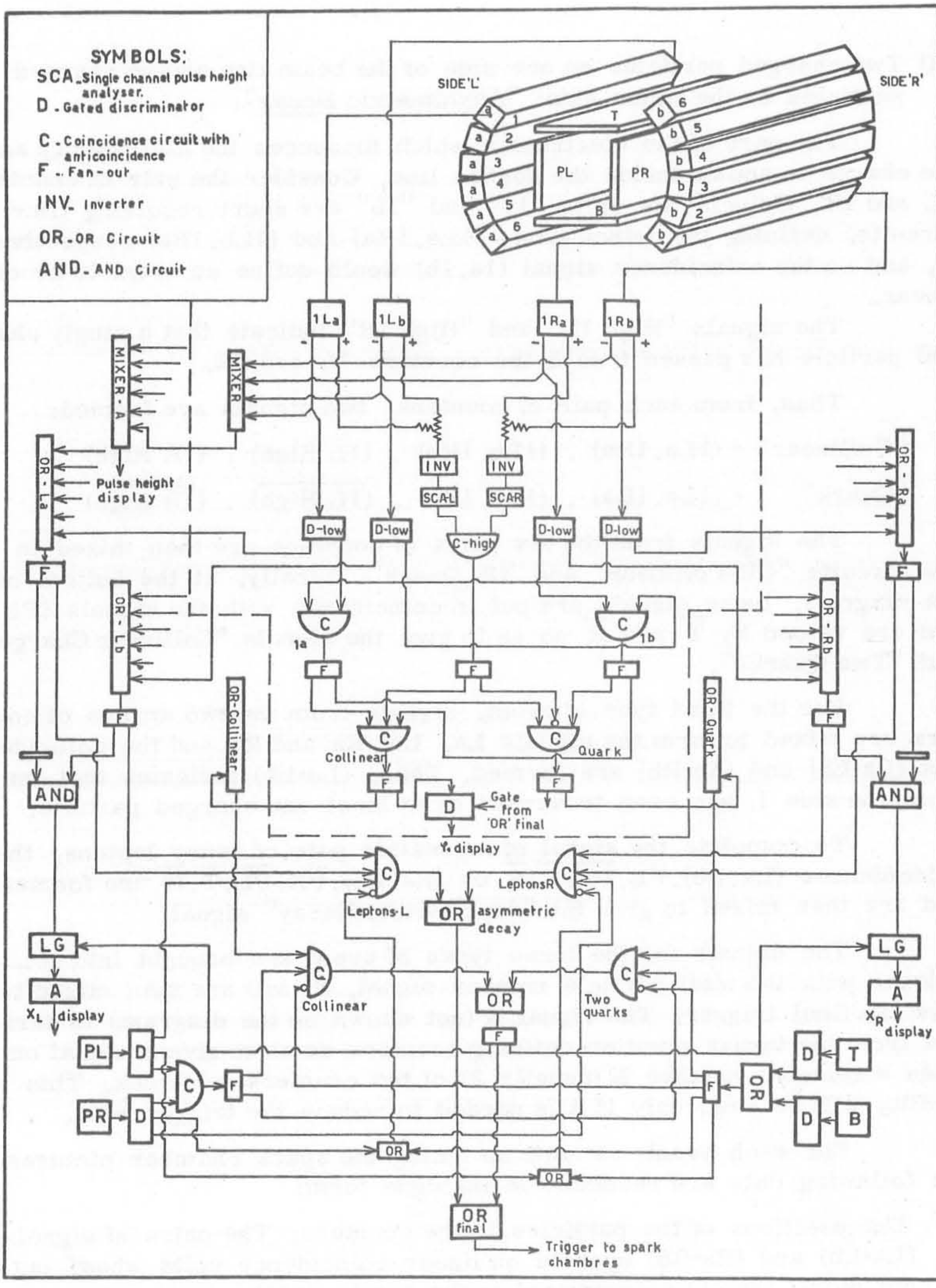


FIG. 9 - Electronic block diagram.

iii) Two charged particles on one side of the beam line and no charged particles on the other side: "Asymmetric Decay".

The part of the electronics which measures the collinearity and the charge is shown inside the dashed line. Consider the pair of counters 1L and 1R. Coincidence units "1a" and "1b" are short resolving time circuits, defining the coincidences (1La. 1Ra) and (1Lb. 1Rb) respectively, and so the coincidence signal (1a. 1b) would define an event to be collinear.

The signals "High 1L" and "High 1R" indicate that a singly charged particle has passed trough the counters 1L and 1R.

Thus, from each pair of counters, two signals are formed:

a) "Collinear" = (1La. 1Ra) . (1Lb. 1Rb) . (1L High) . (1R High)

b) "Quark" = (1La. 1Ra) . (1Lb. 1Rb) . $\overline{\text{(1L High)}}$. $\overline{\text{(1R High)}}$

The signals from the six pairs of counters are then mixed in the circuits "OR-Collinear" and "OR Quark". Finally, at the bottom of the diagram, these signals are put in coincidence with the signals (PL.PR) and are vetoed by $\overline{T}$ and $\overline{B}$ so as to give the signals "Collinear Charged" and "Two Quarks".

For the third type of event, signals from the two arrays of counters are mixed to form the signals La, Lb, Ra and Rb and the coincidences (La•Lb) and (Ra•Rb) are formed. Thus, (La•Lb) indicates that the array on side L has been traversed by at least one charged particle.

To complete the signal of a possible pair of heavy leptons, the coincidences (La. Lb). PL. $\overline{\text{PR}}$. $\overline{\text{T}}$. $\overline{\text{B}}$ or (Ra. Rb). PR. $\overline{\text{PL}}$. $\overline{\text{T}}$. $\overline{\text{B}}$ are formed and are then mixed to give the "Asymmetric Decay" signal.

The signals for the three types of event are brought into coincidence with the total particle number signal, N, and are then mixed to give the final trigger. The signal N (not shown on the diagram) is derived from the twelve position-defining counters so as to give a signal only when a selected number N (usually 2) of the counters is struck. This facility will be used only if it is needed to reduce the trigger rate.

For each event, as well as taking the spark chamber pictures, the following data are recorded in analogue form:

i) The positions of the particles in the counters. The pairs of signals (La•Lb) and (Ra•Rb) operate on linear coincidence units whose output pulse area is proportional to the overlap of the input pulses and so defines the position of the event in the counter.
ii) The total pulse height for the arrays L and R.
iii) A detailed pattern showing which position-defining counters were struck.

These three quantities allow the removal of certain ambiguities which have to be accepted in the final trigger in order to limit the cost of the electronics.

APPENDIX. I - POSITION IDENTIFICATION AND PULSE HEIGHT SPECTRUM FOR SINGLE PARTICLE TRAVERSALS. -

We have tried different dimensions of plastic scintillation counters to measure the variation of position identification and pulse height spectrum for single particle traversals.

The data obtained with $18 \times 18 \times 100$ cm^3 counters have already been published(8).

We report here the data obtained with a counter $5 \times 5 \times 76$ cm^3 viewed at both ends by two 58 AVP photomultipliers.

Fig. 10 shows the block diagram of the electronic logic used for the measurements. Fig. 11 shows the results obtained for the position identification; Fig. 12 shows the calibration of the LABEN pulse height analyser.

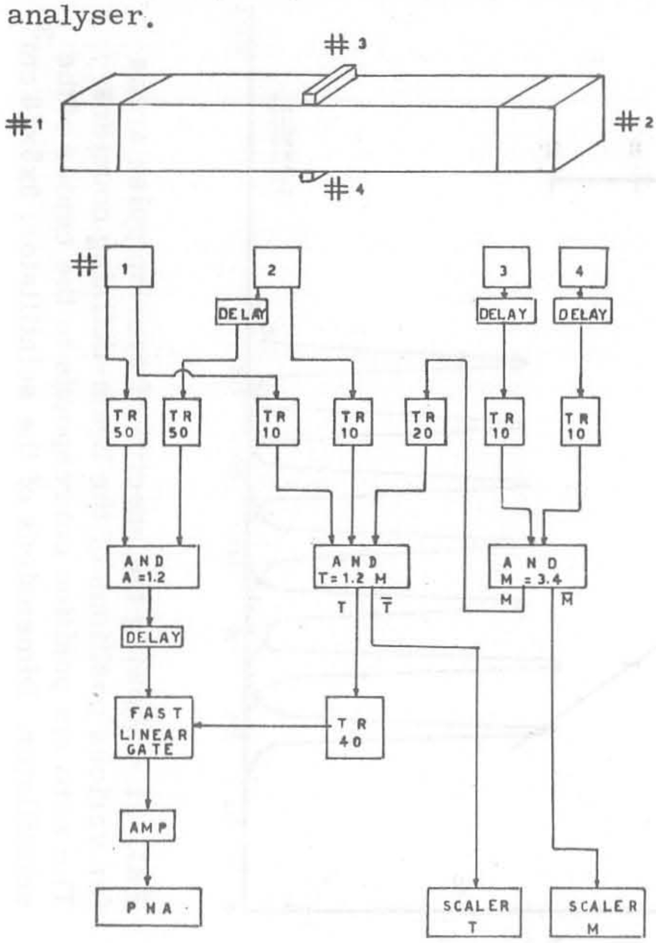


FIG. 10 - Showing:
i) the geometry of the counter and the position of the beam defining counters;
ii) the electronic system used for the calibration.
TR are discriminators. The numbers in the boxes are the lengths of the shaped outputs.
AMP is an integrating amplifier.
PHA is a pulse-height analyser.

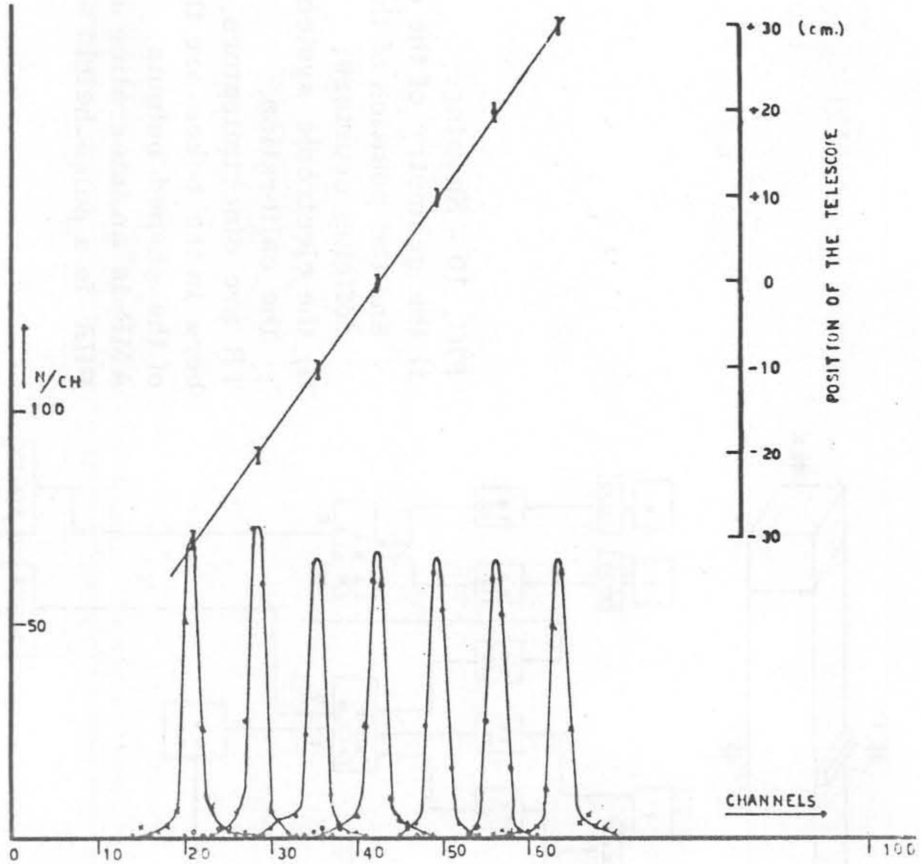


FIG. 11 - Showing the spectra of overlap pulse areas for various positions of the beam-defining counters. The zero cm position corresponds to the center of the scintillator. Dimensions of the scintillator: 5x5x76 cm^3.

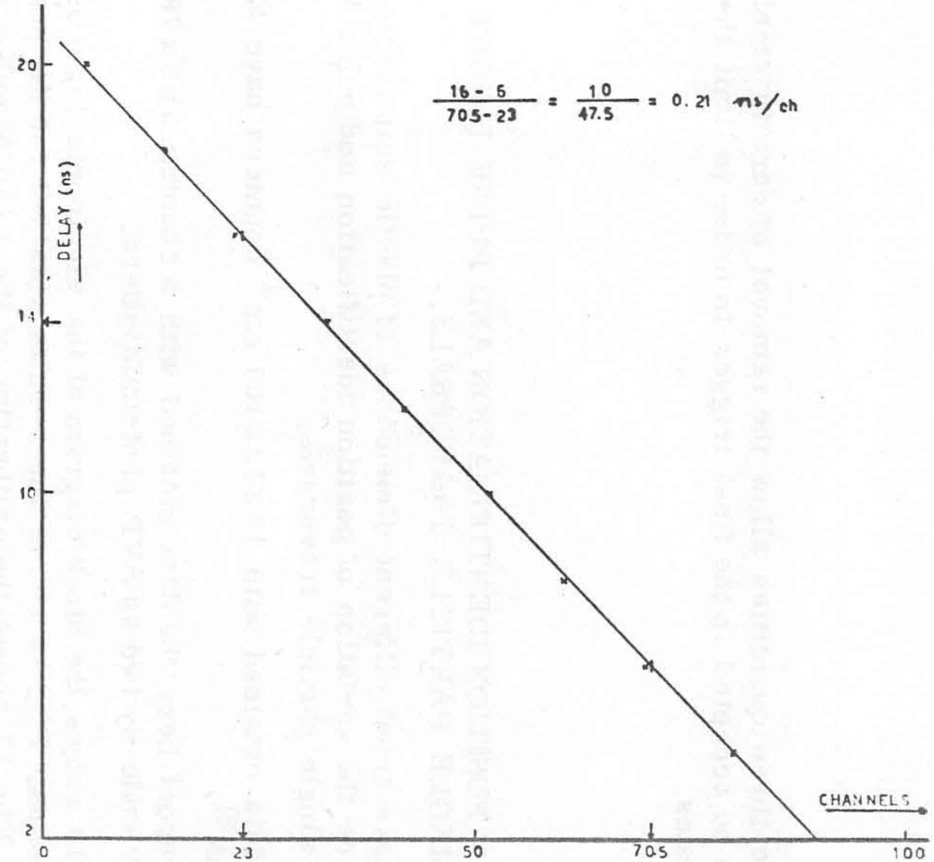


FIG. 12 - Calibration of the PHA in nanoseconds/ channel. It refers to the spectra of Fig. 11.

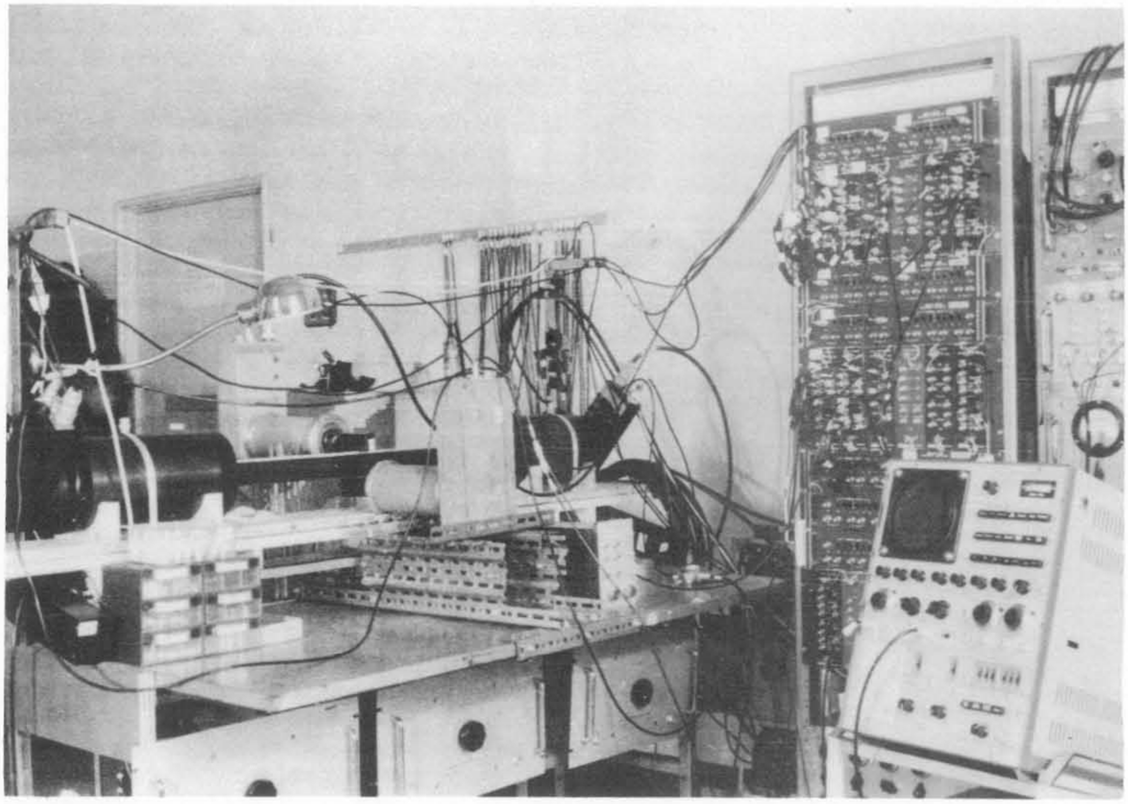


FIG. 13 - Experimental apparatus used for the measurements reported in Fig. s 9, 10, 11 and 12.

The data on the pulse height spectrum for single particle traversals has already been reported in Fig. 2.

Fig. 13 shows a picture of the experimental set up used for the data reported.

The counter with dimensions $5 \times 5 \times 76\ cm^3$ shows a behaviour which is equivalent to that obtained with $18 \times 18 \times 100\ cm^3$ counters.

These results show that the proposed counters with dimensions $10 \times 10 \times 100\ cm^3$ will also give good resolution.

APPENDIX. II - CALCULATION OF TWO BODY CROSS-SECTIONS. -

For the sake of convenience we have calculated (using the formulas of Cabibbo and Gatto[9]) the differential cross-sections for various processes at various Adone energies, i.e.

$$
\begin{aligned}
e^+ e^- &\rightarrow \gamma\gamma \\
&\rightarrow e^+ e^- \\
&\rightarrow \mu^+ \mu^- \\
&\rightarrow \pi^+ \pi^-
\end{aligned}
$$

Figs. 14 to 18 show some relevant differential cross-sections.

In Fig. 19 the total expected counting rate of our apparatus for two-body charged and collinear(x) processes have been plotted against the Adone energy. The curve below is relative to $e^+e^- \rightarrow \pi^+\pi^-$.

Figs. 20 and 21 give the counting rates expected at the various specified Adone energies, as a function of θ.

These rates are calculated assuming that the apparatus has $\Delta\phi = 180^o$; in fact our apparatus has $\Delta\phi = 90^o$ and the rates should be divided by a factor of two.

Table II shows the counting rates expected for the different channels at the various Adone energies.

It is of vital importance to check these rates and distributions in order to show that the apparatus is working correctly.

(x) - When we say collinear we mean particles which satisfy the electronic kinematic restrictions of $\Delta\theta = 10^o$ and $\Delta\phi = 10^o$.

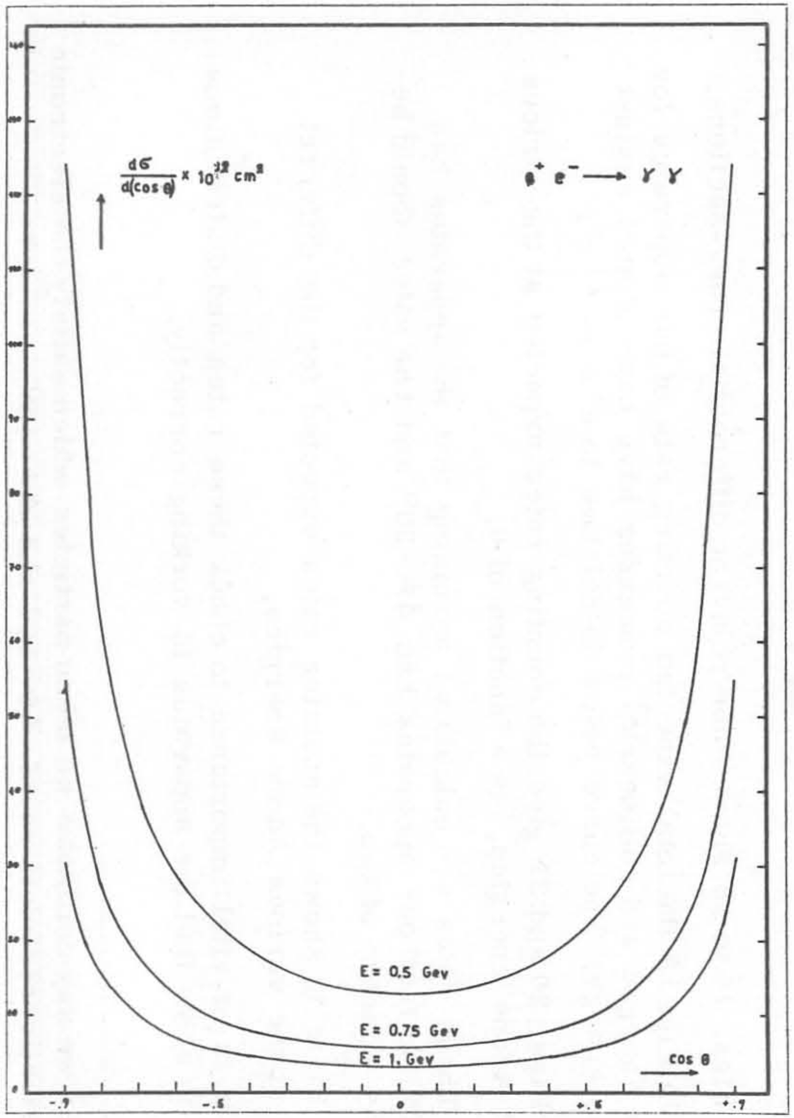


FIG. 14 - Differential cross-section of the reaction $e^+e^- \rightarrow \gamma\gamma$ at E = 0.5, 0.75, 1 GeV.

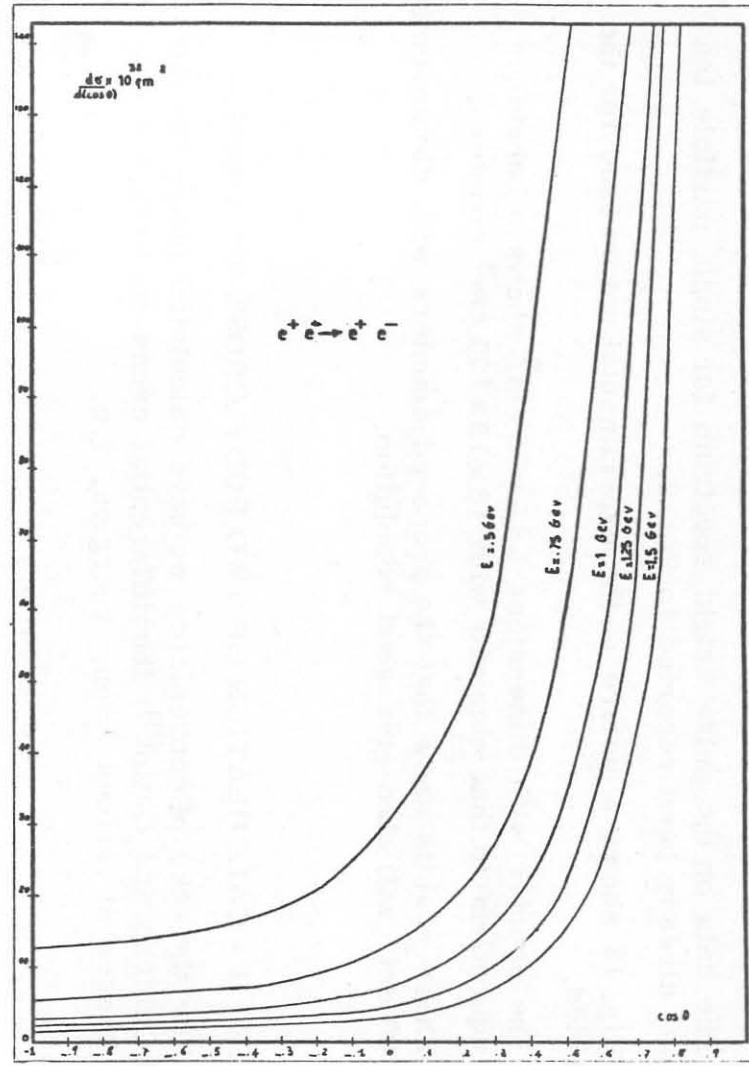


FIG. 15 - Differential cross-section of the reaction $e^+e^- \rightarrow e^+e^-$ at E = 0.5, 0.75, 1.0, 1.25, 1.5 GeV.

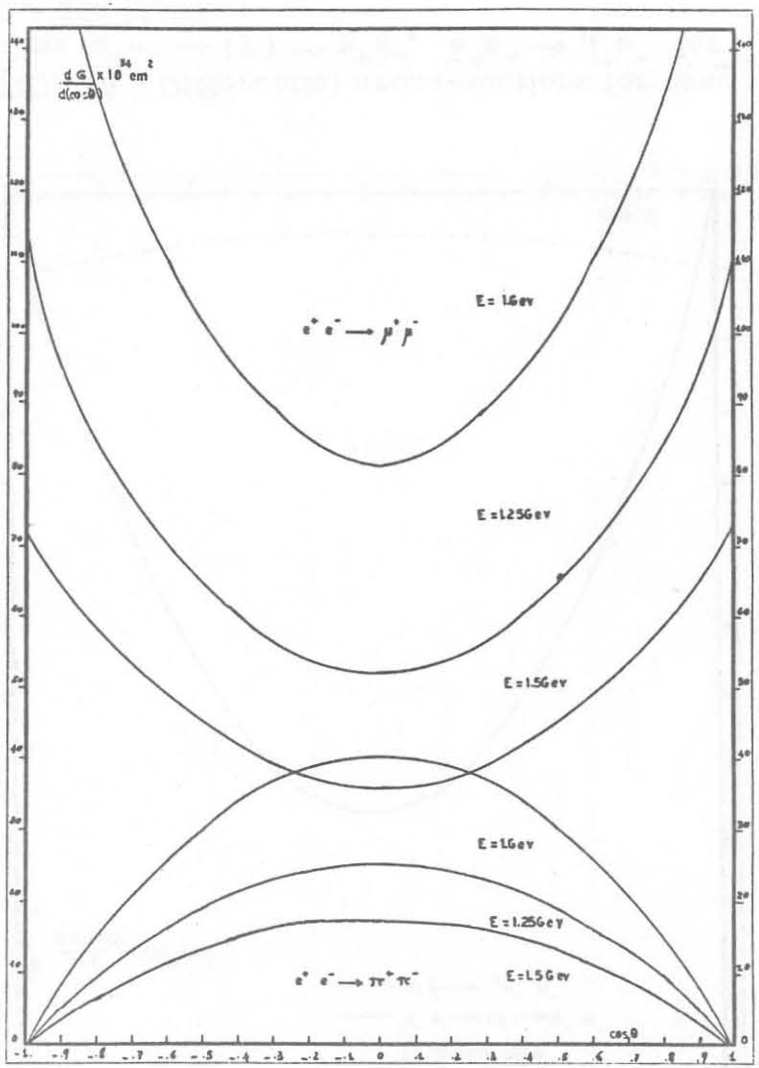


FIG. 16 - Differential cross-sections for reactions $e^+e^- \to \mu^+\mu^-$, $e^+e^- \to \pi^+\pi^-$ at E = 1.0, 1.25, 1.50 GeV.

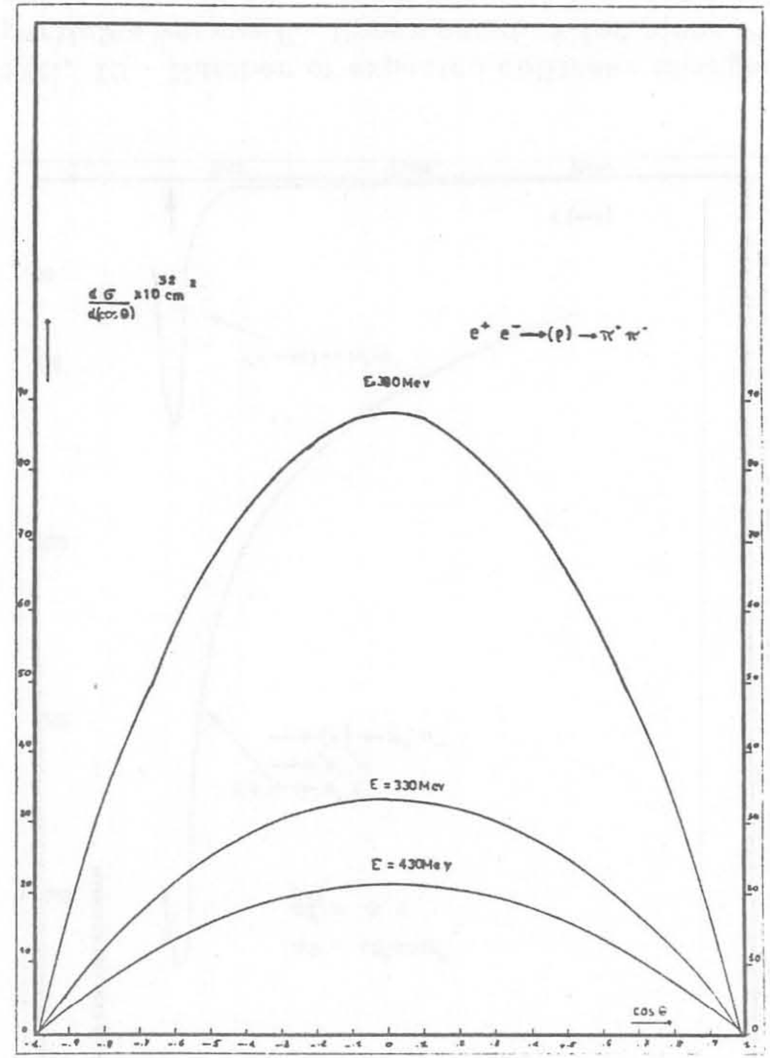


FIG. 17 - Differential cross-section for reaction $e^+e^- \to (\rho) \to \pi^+\pi^-$ at E = 330, 380, 430 MeV.

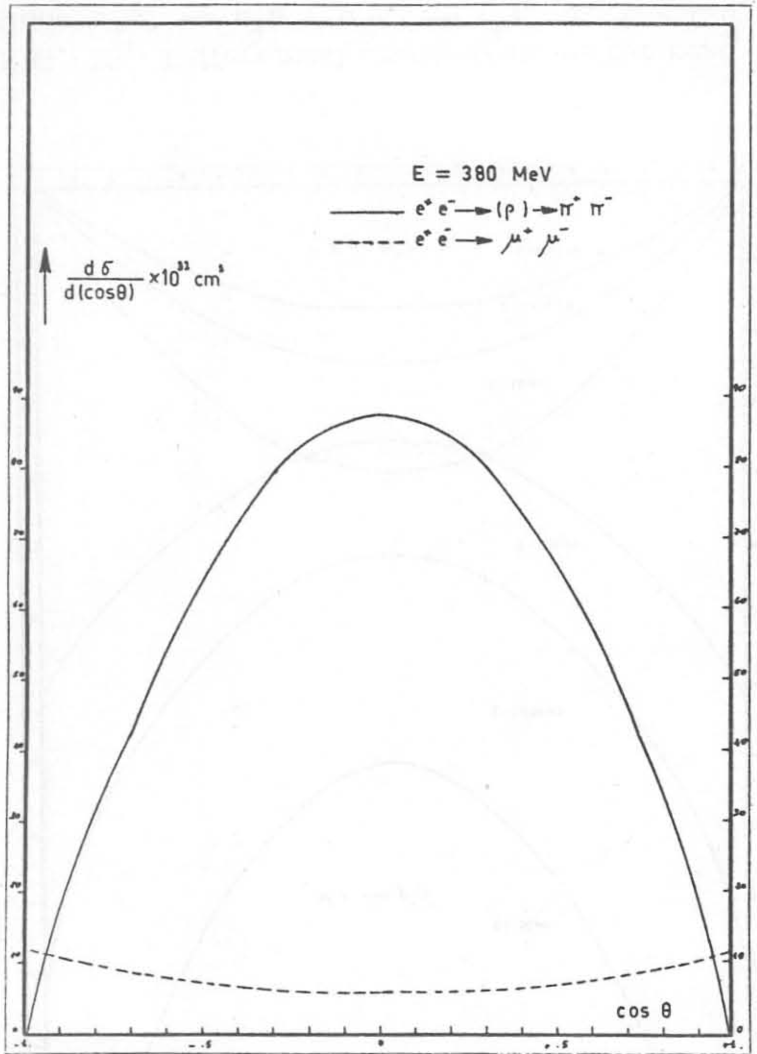


FIG. 18 - Differential cross-sections for reactions $e^+e^- \to (\rho) \to \pi^+\pi^-$, $e^+e^- \to \mu^+\mu^-$ for E = 380 MeV.

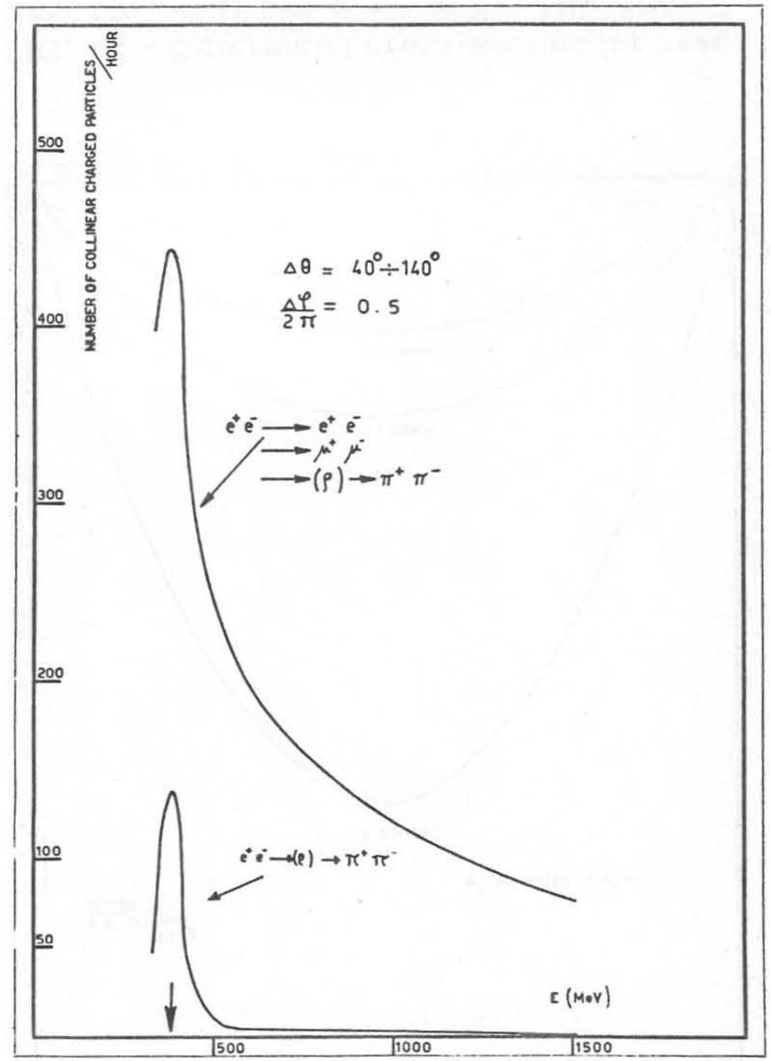


FIG. 19 - Number of expected collinear charged particles versus E. Upper curve is for pions + muons + electrons. Lower curve is for pions only.

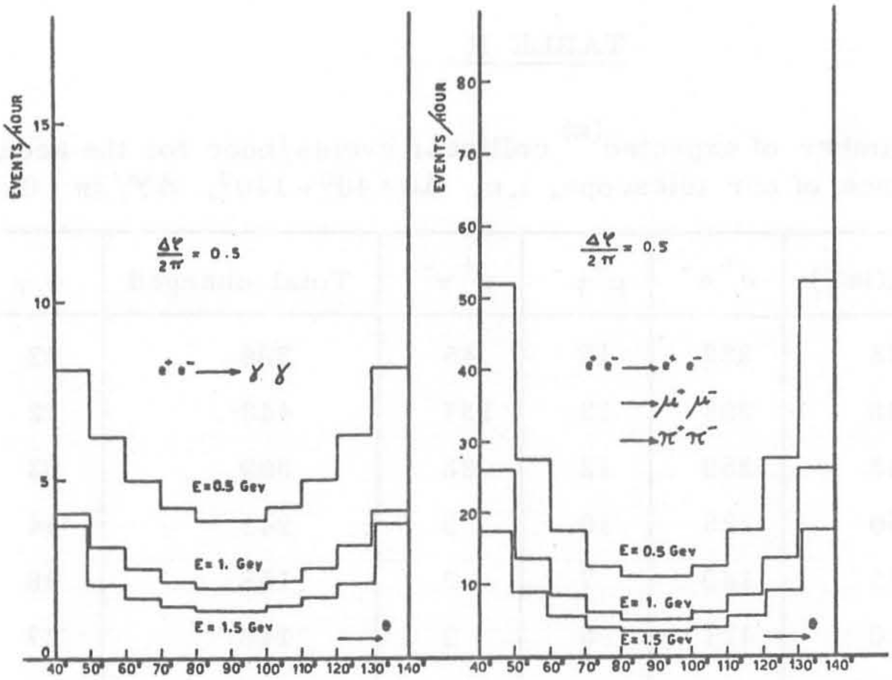


FIG. 20 - Angular distribution of the expected number of collinear charged particles and gamma rays for E = 0.5, 1.0, 1.5 GeV.

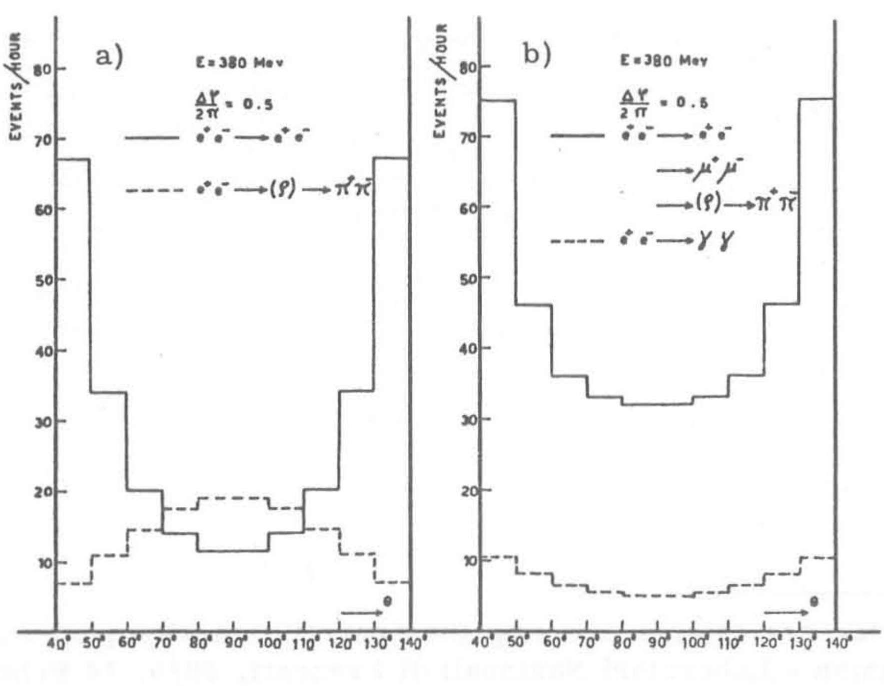


FIG. 21 - a) Angular distribution of the expected number of collinear events $e^+e^- \rightarrow e^+e^-$ and $e^+e^- \rightarrow \pi^+\pi^-$ at E = 380 MeV.
b) Angular distribution of the expected number of collinear charged particles, and γ's for E = 380 MeV.

TABLE II

Number of expected[x] collinear events/hour for the acceptance of our telescope, i.e. $\Delta\theta = 40^o \div 140^o$, $\Delta\varphi/2\pi = 0.5$.

E(GeV)	e^+e^-	$\mu^+\mu^-$	$\pi^+\pi^-$	Total charged	$\gamma\gamma$
.33	338	15	45	398	83
.38	293	13	137	443	72
.43	259	12	38	309	63
.50	223	10	9	242	54
.75	149	7	2	158	36
1.0	111	5	2	118	27
1.25	89	4	1	94	22
1.50	74	3	1	78	18

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

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