ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-79/17(R)
23 Febbraio 1979

G. Bellettini and R. Bertani: THE CASE FOR ALA/MDA.

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PREMISE

This document illustrates the physics arguments on which the proposal to build in Italy a new high luminosity e^+e^- storage ring ALA of energy $1.0 \lesssim W \lesssim 2.4$ GeV and an associated large coverage magnetic detector MDA is based.

INTRODUCTION

The discovery of new hadrons coupled to the e^+e^- (and $\mu^+\mu^-$) system[1,2] has established the primary importance of e^+e^- storage rings for the progress of Particle Physics. It is gratifying that Italy has built the first machines of this type, AdA, and next ADONE, and that the first generation Adone data provided important informations which were at the basis of the development of this branch of Physics. However a study of the final Adone data, which are briefly reviewed in Chapter 1, shows that in this energy region new phenomena exist, which are not definitively established and understood. This situation would fully justify a new campaign of research, which cannot be done at Adone at the required level of precision. The next natural step is a machine/experiment like ALA/MDA with sufficient luminosity, coverage, resolution to really exploit e^+e^- physics in this energy region.

In the low energy range of ALA, for $1.0 \lesssim W \lesssim 1.35$ GeV, the Novosibirsk storage ring VEPP 2M has a compairable luminosity (see Fig. 1). However, the experimental straight section of this machine is too short (~ 1 m), and makes it impossible to employ a large coverage magnetic detector for an accurate study of many body final states.

(x) - This paper originated from the M. Sc. Thesis of one of us (R.B.) in which the design and progress work made by the MDA Group was reviewed. All physicists of the Group (M. Ambrosio, R. Baldini-Celio, G. Barbarino, S. Bartalucci, G. Battistoni, S. Bertolucci, F. Cervelli, P. Giromini, R. Del Fabbro, G. Giannini, E. Iarocci, P. Laurelli, G.P. Murtas, G. Paternoster, S. Patricelli, G. Patteri, G.B. Piano Mortari, A. Sermoneta, M. Spadoni, L. Trasatti, U. Troya) have contributed suggestions and critical comments.

Electron-positron physics for c.m.s. energy W $\gtrsim$ 1.35 GeV is also covered by the french machine DCI, which is briefly described in Chapter 2. This machine has provided some significant data in the recent past. However, after more than one year of efforts, the principle, on which a luminosity as large as 10^{32} $cm^{-2}s^{-1}$ had to be reached ("charge compensation" of four beams carrying currents as large as 500 mA/beam) still does not work, DCI luminosities are consistently limited to values comparable to those of Adone. Moreover, no other machine has been desgned based on this delicate compensation. On the other hand, a new machine like ALA is expected to provide luminosities in excess of 10^{31} $cm^{-2}s^{-1}$ with limited beam currents (150 mA/beam) by exploiting known techniques (low β, variable optics).

ALA, when equipped with the modern large coverage magnetic detector MDA, should allow to improve the Adone data by a factor between 500 for inclusive physics and 2000 for exclusive physics(3). It is fair to believe that this will open a basically new field of research.

The contribution to the knowledge of the same phenomena by photoproduction experiments, whose important findings are reviewed in Chapter 3 can be a useful complement but cannot significantly reduce the unique role of the e^+e^- machine. This is also true for studies of $\bar{p}p$ interactions. However, it is of great interest that a wealth of experimental data on $\bar{p}p$ states have been recently collected in a number of experiments, showing that most likely this system has many resonant and quasi-bound states. These data are reviewed in Chapter 4. It has to be expected therefore, on pure experimental grounds, that not only recurrencies of the low-laying vector mesons can be found at ALA, but also a significant selection of baryon-antibaryon states. The new CERN program to study $\bar{p}p$ low energy interactions at LEAR and its complementary role to ALA/MDA is discussed in Chapter 5.

Although the cross-section for two-photon physics is expected to be of the order of only a few nanobars at ALA energies, the luminosity of the machine is sufficient to produce a significant rate of events. The perspectives of these delicate studies are briefly discussed in Chapter 6.

As a counterpart to the rich experimental picture, the theoretical expectations are also pointing at the importance of e^+e^- physics at ALA. Vector meson recurrences are indeed expected to show up as well as baryonium bound and resonant states. Different properties are predicted for these states in nucleon-nucleon potential models or in dual models, in particular with respect to radiative decays.

The vector gluon of the Pati-Salam model was originally expected to show up at ALA energies. The interest for this prediction will become very strong again, in view of the availability of a machine and experiment that can efficiently look for it. The unit charge unstable light quarks of the same theory and the possible quarks of indefinite mass considered by T.T.Wu and collaborators can also be searched for at ALA/MDA. These theoretical expectations are reviewed in Chapter 6.

As a whole, the rich experimental picture indicated by Adone and DCI and implemented by photoproduction and $\bar{p}p$ data, as well as the intriguing and fascinating theoretical expectations, point at the importance of the experimental program which is proposed at Frascati.

1. - THE PHYSICS OF ADONE.

1.1. - The accelerator.

To allow a comparison with ALA/MDA we recall the Adone parameters which are most relevant for experiments and the main features of the second generation detectors. The record Adone luminosity is sketched in Fig. 1, together with that of competing machines.

The operating average luminosity at W = 3.0 GeV is about 2×10^{29} $cm^{-2}s^{-1}$. As the hadronic cross section at this energy is $\approx 25 \times 10^{-33}$ cm^2, the rate of hadronic events is $\approx$15 per hour (in each of the four intersections). The c.m.s. energy spread, which is proportional to the inverse of the magnetic radius, is found to be at Adone $\Gamma_W(\text{MeV}) \approx 0.32\ W^2\ (\text{GeV}^2)$. The source section is smaller than 1 mm^2, but the source length varies from about 25 to about 50 cm (fwhm) from the lowest to the highest energies. The straight section available for experiments is 220 cm, the vacuum tube being 20 cm and the quadrupoles about 60 cm in diameter. Because of the large source length (as well as of the limited straight section length) any large detector covers an effective solid angle appreciably smaller than the solid angle corresponding to a point source.

We recall here, for a brief comparison, that the corresponding parameters of ALA are: $2 \times 10^{30} \lesssim L \lesssim 2 \times 10^{31}$ $cm^{-2}s^{-1}$ in the energy range $1 \lesssim W \lesssim 2.4$ GeV, energy spread $\Gamma_W(\text{MeV}) \approx 0.45\ W^2(\text{GeV}^2)$, straight section length 3.0 m, source length $\approx$ 15 cm (fwhm).

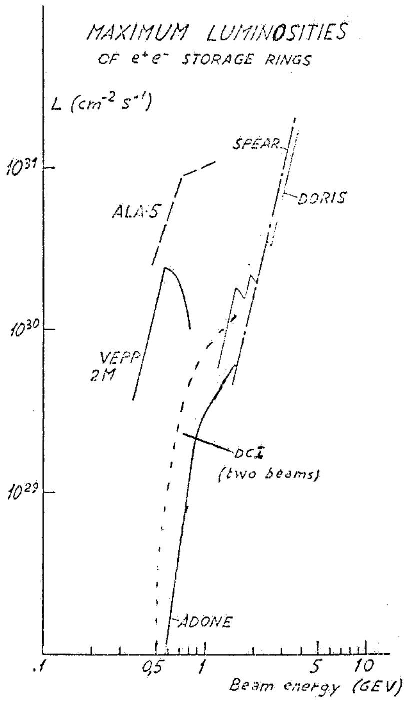


FIG. 1

1.2. - The detectors.

The main properties of the second generation Adone detectors are summarised in Table I[4].

TABLE I - Main features of the second generation Adone detectors.
($B\bar{B}$ Calorimetry, dE/dx vs. E) ; ($\gamma\gamma 2$ γ detection) ; (MEA Momentum analysis)

	$B\bar{B}$	$\gamma\gamma 2$	MEA
Orientation of the axis of symmetry referred to the beam direction	parallel	orthogonal	orthogonal
Solid angle for point like source/4π	70 %	66 (40) %	40 %
Direction measured by	magnetostrictive S. C.	optical S. C.	optical S. C.
Momentum measured by	E, dE/dx	range	magnet
Quality of mom. meas.	poor	poor	good
Quality of photon detection	poor	good	poor
Minimum energy (MeV) for a pion to trigger	~ 60	~ 120 (~ 35 + γ's)	~ 130
Luminosity monitors	s.a. Bhabha w.a. Bhabha double bremss.	s. a. Bhabha w. a. Bhabha	s. a.. Bhabha w. a. Bhabha

The $\gamma\gamma 2$ apparatus comprises two half-cylindrical telescopes transverse to the beams, in which layers of trigger counters, optical spark chambers and lead or iron converters are sandwiched up to a total thickness of 5.5 X_0. Thus the system detects photons in addition to charged tracks. However, after applying the necessary analysis cuts the photon detection efficiency is not 100%. The computed efficiency reaches $\approx$75% for E_γ = 100 MeV and grows slowly, being about 90% at E_γ = 500 MeV. In addition, because of the employed optical technique, the available information on photon energy is poor and not readily usable. For point source the trigger counters cover a solid angle of $0.40 \times 4\pi$ and the main detector of $0.66 \times 4\pi$. A pair of endcap telescopes are used for checks on the events, over a solid angle of $0.15 \times 4\pi$. A manyfold coincidence generates a charged trigger for pions when $T_\pi \gtrsim 120$ MeV and for kaons when $T_K \gtrsim 190$ MeV. Because of the hard trigger cut on particle energy and of the limited solid angle both for trigger and for tracking, the manybody hadronic events are signalled and detected with strong biases. In addition the techniques employed do not permit particle identification, execpt for energetic electrons (no accurate dE/dx and TOF, no magnetic field).

The MEA detector is a solenoid, 2 m long and 2 m in diameter, set transversally to the beams and generating a field of about 2 Kgauss. Thin optical spark chambers in the field measure the momenta of charged tracks with a resolution of the order of $\pm 8\%$. Behind the coils, over a solid angle of $\approx 0.2 \times 4\pi$, two telescopes of thick-plate optical spark chambers help in discriminating hadrons from muons and provide some photon signature. The trigger is generated by thin vertex detectors and layers of scintillators outside the coils, which accept pions if $T_\pi \gtrsim 130$ MeV and kaons if $T_K \gtrsim 190$ MeV. At least two tracks, one in the above and one in the below hemisphere are required. The main limitation of this detector are the smallness of solid angle, the lack of photon detection, the weak field and the hard trigger which one must employ in order not to be crowded with background. It is found experimentally that the transverse geometry is unfortunate in view of the additional background brought into the detector.

The $B\overset{\rightarrow}{\bar{B}}$ experiment is an array of counters with cylindrical symmetry, coaxial with the beam. The trigger is provided by barrel hodoscopes, one of which with liquid scintillators (35 g/cm^2 thick) measures also dE/dx with a resolution $\Delta E/E \approx \pm 20\%$ at E_p = 100 MeV. A set of cylindrical magnetostrictive spark-chambers measures the charged tracks at the vertex. An electron (photon) signature is provided by two sets of flash tubes lead-iron sandwitches. One track in the trigger is defined by a collinear coincidence in the hodoscopes, corresponding to $T_\pi \gtrsim 60$ MeV. Two or more tracks at various azimuths can be required in the trigger, depending on background conditions. The need of better background discrimination can also impose further off-line conditions.

This apparatus, though of more modern conception that $\gamma\gamma 2$ and MEA (longitudinal geometry allowing a large solid angle, and automatically digitized information), still has many heavy limitations. The central magnetostrictive chambers loose efficiency for many body events. Since there is no magnetic field, particle recognition is only possible for a small fraction of slow tracks which stop in the detector, and whose range can be compaired with dE/dx. Only a few photons can efficiently be tagged in the liquid scintillation counters, with no energy information.

For a comparison, we recall that the corresponding features of MDA(3) are a solid angle of $0.85 \times 4\pi$ for momentum measurement of charged particles in a field of 3.8 Kgauss, providing a momentum resolution of $\pm 4\%$; a solid angle of $0.75 \times 4\pi$ for photon detection, with a lower energy cut of $\approx$ 20 MeV and aiming at excellent space and energy resolutions ; the TOF system with resolution $\Delta\tau \lesssim \pm 0.35$ ns allows an essentially complete $\pi/K/p$ separation and the inclusive trigger should be fired by a single track pointing at the source with $p_\perp \gtrsim 50$ MeV/c. The TOF counters, the central chambers and possibly the photon counters will provide accurate dE/dx information. Hadron detectors and muon filters can be implemented outside the magnet.

1.3. - The experimental results.

We will mention only those data(5) that are most likely to be studied in detail at ALA.

The final Adone data have included a good measurement of $R = \dfrac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$, that is shown in Fig. 2. Because of the fundamental importance of R - which is taken, for instance, as an input data in the dispersion integral giving the hadronic corrections to the anomalous magnetic moment of the muon - this data will have to be measured very accurately. As they are, however, they prove the exceptional increase of σ_h above W = 1 GeV, and are highly suggestive of the opening of new channels. With reference to the example provided by the SPEAR data, one can think in terms of narrow resonances just above W = 1 GeV, followed by broader ones.

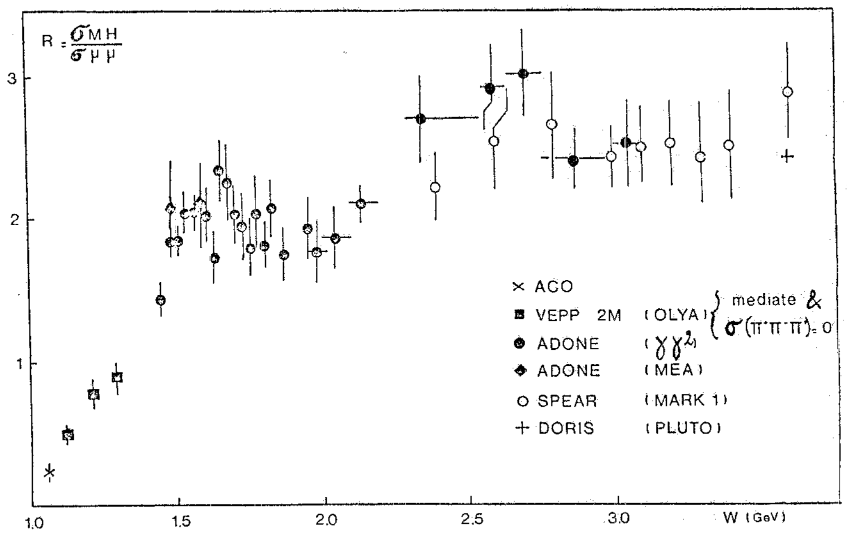


FIG. 2

A scan for narrow resonances was indeed made at Adone, but only at W $\gtrsim$ 1450 MeV because of the too weak machine luminosity below this energy. The typical limit obtained was

$$\int_{\Delta W} (\sigma_R - \langle\sigma\rangle)\, dW \lesssim 0.07 \int_{\Delta W} (\sigma_{J/\psi} - \langle\sigma\rangle)\, dW$$

where the signal σ_R is derived from the fluctuations of σ with respect to its average $\langle\sigma\rangle$ over the machine energy resolution ΔW, and the corresponding J/ψ signal ($\approx$ 10 nb GeV) is taken as a reference. It is clear that it is important to sharpen this limit and extend the search down to W $\gtrsim$ 1 GeV.

As far as relatively broader structures are concerned, three structures of width ranging between a few MeV and a few tens of MeV have been observed.

The MEA group has found$^{(6)}$ a peak in $K^*(890)$ production around 2130 MeV. 40.5 ± 5.8 events are observed, while 13.1 ± 5.8 would be expected on the basis of the interpolating straight line shown in the Fig. 3. The total width is around 30 MeV.

It is easily observed that the statistical of significance of the effect might be improved. Moreover, owing to the poor K/π discrimination the derivation of the K^* signal itself is rather delicate. In this context, one may be worried by the absence of a clear signal at the same energy in the inclusive relative K rate (see Fig. 6). Perhaps this is due to some additional resonance decaying into pions at the same energy and thus reducing the n_K/n_{ch} relative signal. It is clear that the behaviour of the various hadronic channels at this energy is a problem left open for the future.

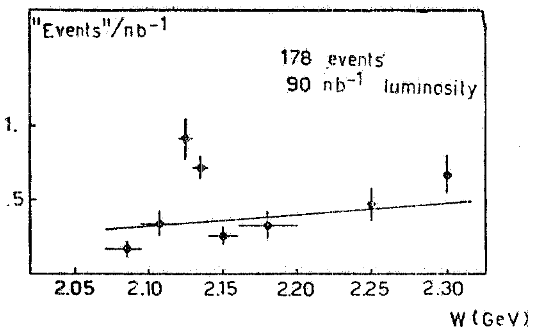


FIG. 3

At W = 1.82 GeV the three Adone Groups have observed a structure in the inclusive cross-section for three or more charged particles seen in the apparata (Fig. 4). Some inconsistency among the peak

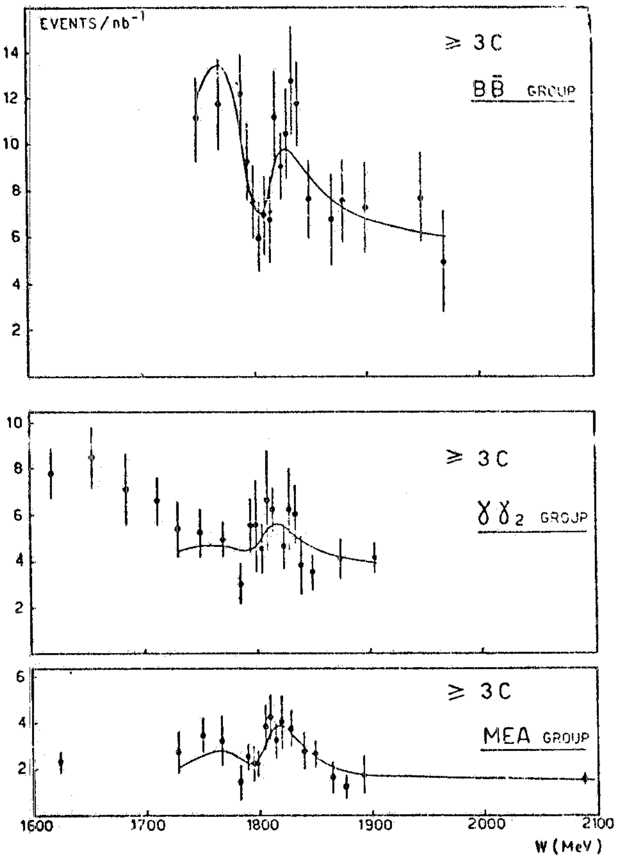


FIG. 4

position observed in the three experiments has led to an attempt to interpret the data as two interphering resonances giving tha fits shown in the figure. However, in view of the different and relatively small acceptances of the three detectors and of the overall-poor statistics, one can not rule out the possibility that the differences among the data are due tò systematic effects.

The interpretation of these structures is not at all elucidated by the available information on the branching ratios. The $\gamma\gamma 2$ Group has compaired the excitation curves in the 3.4 ch + 1γ and 3.4 ch (Fig. 5). The absence of a signal in the latter distribution can be understood if a G= -1, $2\pi^+2\pi^-\pi^0$ channel is dominating. On the other hand, both the width and the position of the structure would be much more suggestive of a Φ than of an ω-recurrence (see Chapter 6). However, a search for an excess of kaons at this energy (Fig. 6) did not give conclusive results(7).

This is another example of a quite general situation at Adone and DCI, where low statistics, unsufficient detector acceptance and poor particle recognition prevent from reaching any firm conclusion on the physics meaning of an observed anomaly in the data.

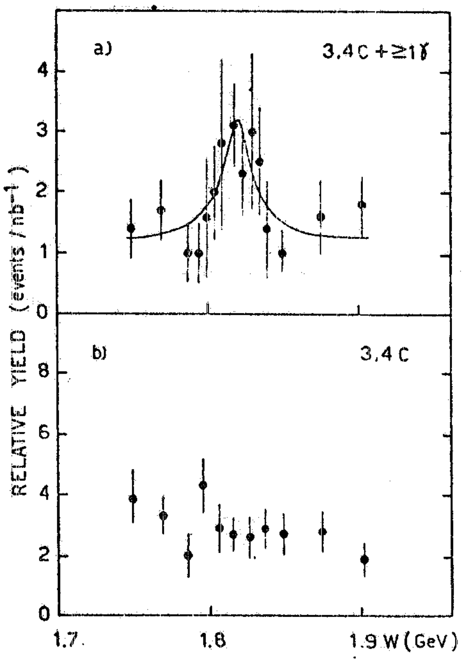


FIG. 5

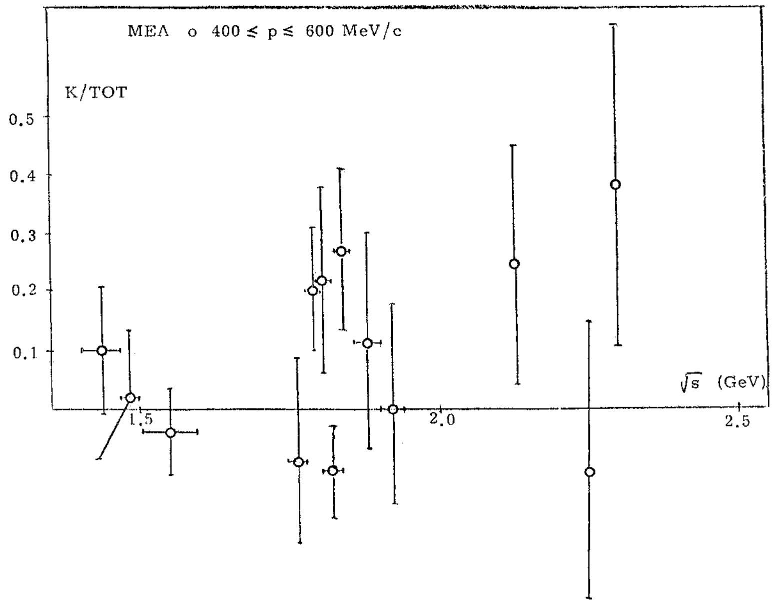


FIG. 6

A very narrow structure in inclusive hadronic production was observed at Adone in 1977 (Fig. 7, first column), suggesting a resonance at M = 1499 MeV with Γ = 2-3 MeV. Further data

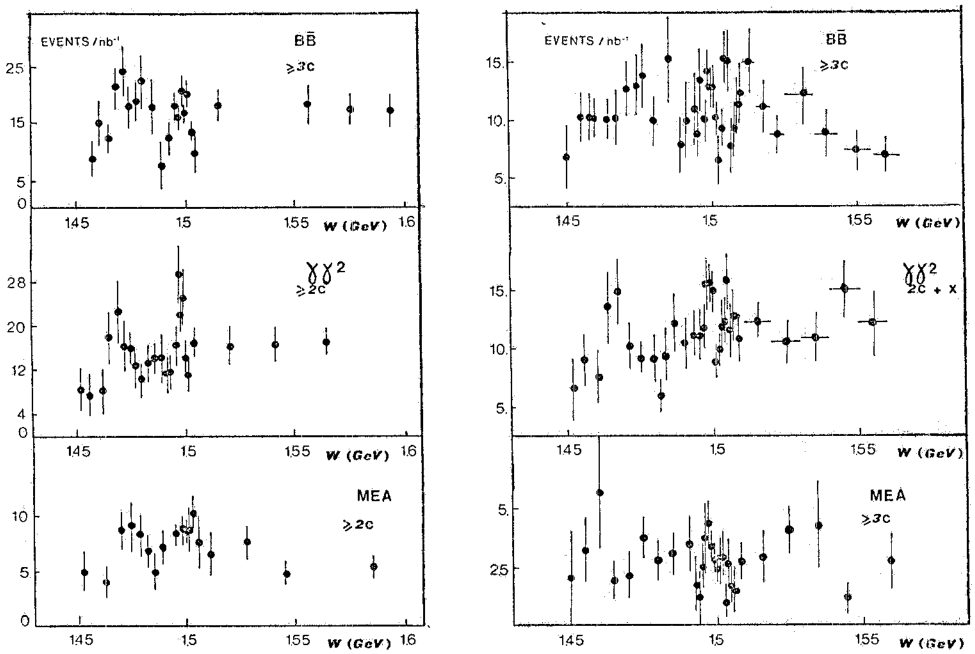


FIG. 7

collected in 1978 have brought to the confusing overall picture shown in the second column of the same figure. An attempt by the $\gamma\gamma 2$ Group to reproduce at least the peak/valley ratio by means of three points with higher statistics has failed (Fig. 8). On the other hand, in order to attribute a conclusive evidence to this negative result one would have to trust the Adone absolute energy scale to better than 1 MeV, and this cannot be done for the time being. In conclusion, it is still unclear wether something important (in view of the narrow width) is hiding itself in this energy region.

A number of inclusive measurements at Adone are also suggestive of interesting phenomena and calling for better data. In Fig. 9 the $\langle n_{ch} \rangle / \langle n\pi^0 \rangle$ ratio is compaired to the one mea-

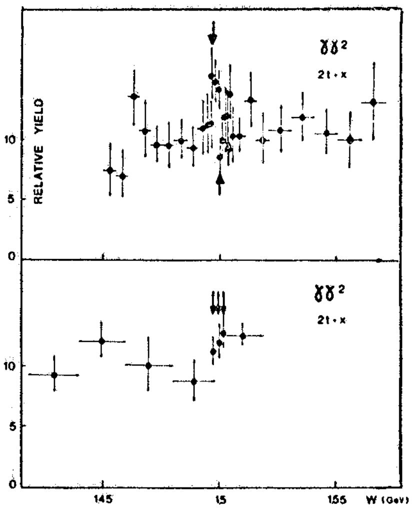


FIG. 8

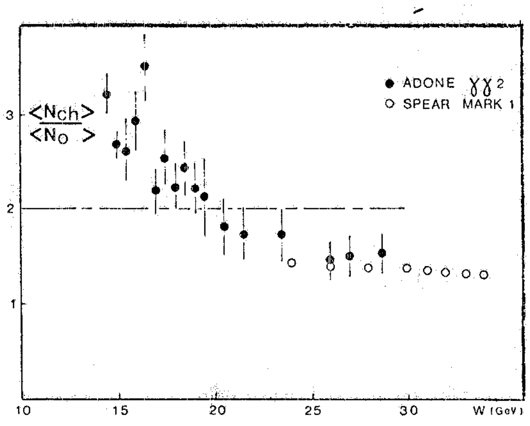


FIG. 9

sured at SPEAR showing a deviation from the value of 2 (predicted by isospin conservation in pion production) and a change of trend at Adone energies. The much larger errors of the Adone data with respect to SPEAR are due in part to the incomplete photon detection efficiency, and more to the uncertainties in the large Montecarlo corrections which have to be made to the raw data.

Similar considerations are applicable to another piece of information, the 4π excitation cross section shown in Fig. 10. Although the comparison with older VEPP 2M data at lower energy might be suggestive of a broad ρ--recurrency, the large statistical errors, the incompleteness of the scan, some large fluctuation in the data leave the possibility open for some more sub the phenomenon that might have been left undiscovered by these explorative measurements.

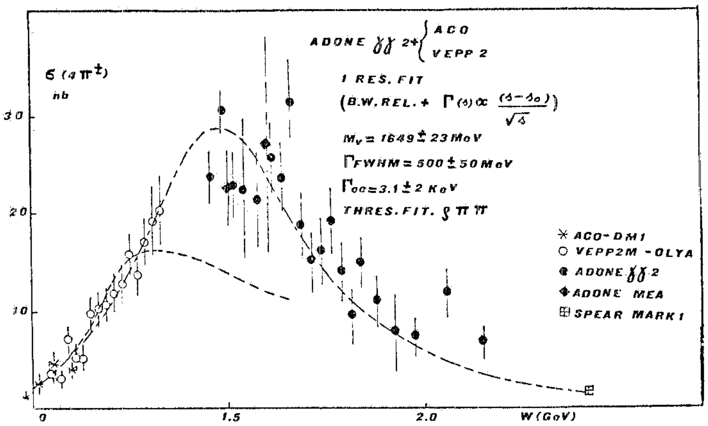


FIG. 10

The possibility that at the Adone energies light quarks or relatively heavy leptons are produced and have not been discovered yet deserves special attention. A search for heavy sequential leptons produced as $e^+e^- \to L^+L^-$ with subsequent $L^\mp \to e^\mp\nu\nu$, $L^\mp \to \mu^\mp\nu\nu$ decay has been made long ago(8), yielding the lower limit $M_L \gtrsim 1$-1.5 GeV based on QED production cross section and leptonic branching ratio computed with the universal weak-coupling constant. Also, the lack of (e,μ) events for $W \lesssim 3.6$ GeV at SPEAR speaks against the existence of sequential leptons with $M_L < M_\tau$. Nevertheless, on cannot deny that a satisfactory and conclusive experimental picture can only be obtained at these energies with a detector providing a much better (e,μ) signature than at Adone and by exploiting a much higher machine luminosity.

While the existence of a new sequential lepton below the τ might appear unlikely, the possibility of an excited electron (or muon) of mass accessible at the ALA energies is still open. Of course, the coupling $(ee^*\gamma)$ cannot be large, since for instance data on Bhabha scattering can be fit with the pure QED $(ee\gamma)$ vertex(9). A search for the reaction $e^+e^- \to e^*e$ made by the $\gamma\gamma 2$ experiment by detecting $(ee\gamma)$ events or $(e\gamma)$ events in association with inelastically scattered electrons in forward tagging counters(10), has given a limit on the squared coupling constant of the $(ee^*\gamma)$ vertex of $\lambda^2 \lesssim 3 \times 10^{-4}$, based on a few hundred events. With a good photon/electron detector, this limit can be largerly improved at ALA/MDA as far as both the systematic and the statistical errors are concerned. Moreover a similar search can be made for μ^* production, when an adequate muon signature will be available.

Finally, one should leave the possibility open that quarks can be produced free and have not been observed yet. The Adone experiments had no sensitivity to (1/3)e and probably also to (2/3)e charges. This is also true for the SPEAR and DORIS experiments. This situation calls for an experiment at ALA with accurate dE/dx measurements and sensitivity to very low ionization. However, so many searches for stable quarks of fractional charge have been made so far, that one might judge it to be unlikely that such particles exist. As a matter of fact, this is not so because confinement factors can play different roles in different reactions, and the situation might well be more favourable at an e^+e^- ring than elsewhere. With ALA/MDA, quarks of (1/3)e charge produced with pointlike cross section can be detected as long as the confinement factor is $\varepsilon \gtrsim 10^{-3}$. In addition, there is also the possibility that quarks are not stable or not detectable over long path lengths. Unstable quarks of unit charge are indeed predicted in the Pati-Salam model(11) and quarks which cease ionizing after some path are considered by T. T. Wu and collaborators(12). These theoretical ideas are discussed in Chapter 6. The MDA detector is designed such as to tag these particles to the best.

2. - THE PHYSICS OF DCI.

2. 1. - The accelerator.

DCI is the french e^+e^- storage ring which was originally built for similar purposes as ALA, and to cover the range $1.35 \lesssim W \lesssim 3.6$ GeV. The machine is operating in its full configuration since summer 1977. The design luminosity was $L \approx 10^{32}$ cm^{-2} s^{-1} at W = 3.0 GeV, with two bunches/beam and 200-250 mA/bunch(13). Such a high luminosity was based on the principle of "charge compensation": the accelerator is composed of two rings one on top of the other, having the two 6 m long straight-sections in common (Fig. 11). One section is used for injection and one is

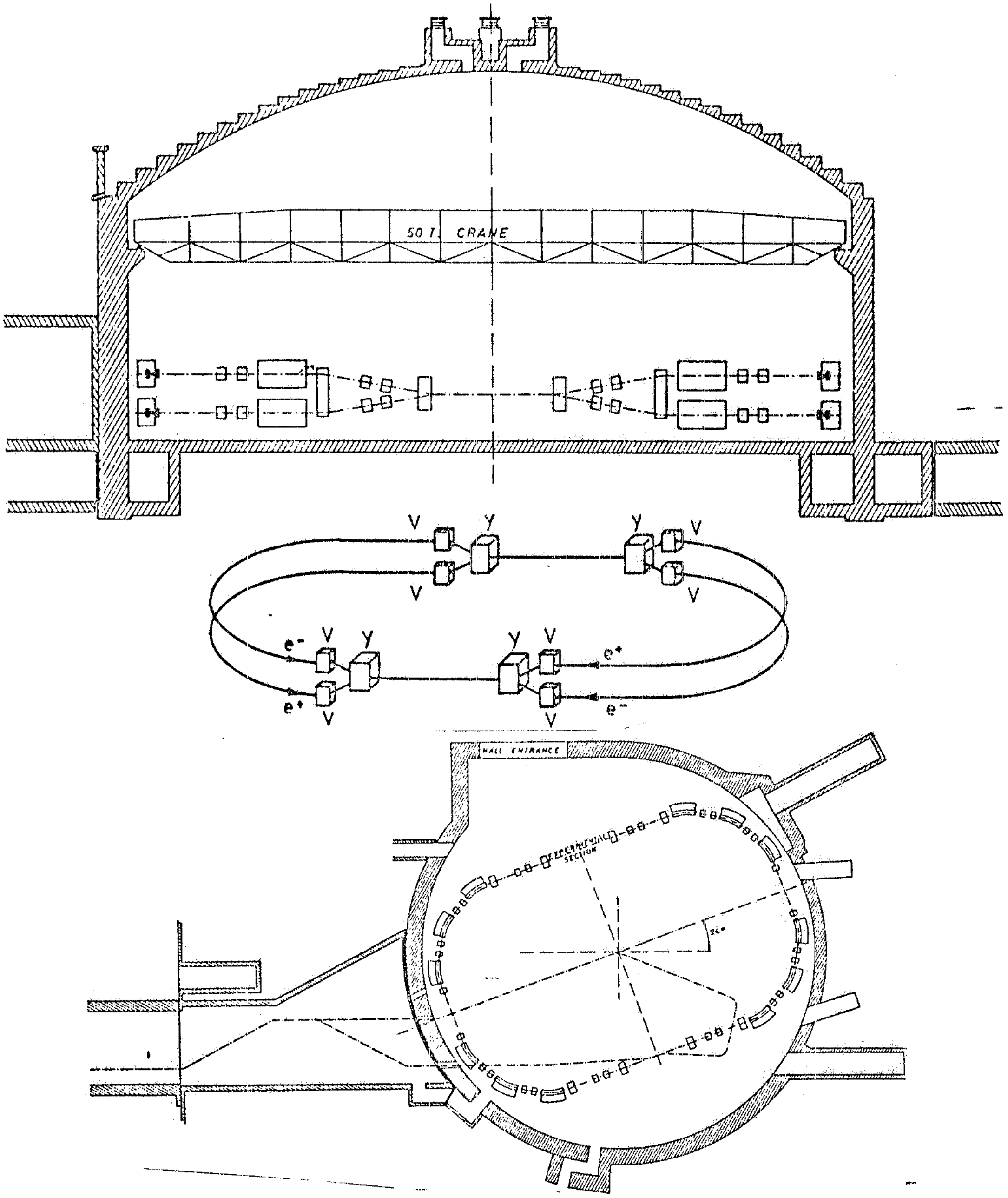


FIG. - 11

free for experiments. Electrons of beam 1 and positrons of beam 2 (and viceversa) merge together at the intersect, such that four-bunch collisions take place with a net total charge zero (to within a few percents of the single bunch charge). In a two-beam operation, whithout charge compensation, the luminosity was expected to be lower by about two orders of magnitude.

The charge-compensation scheme has proved to be very delicate and not really understood. At present, private communications report that with four beams a maximum increase of luminosity of about 30% over the luminosity with two beams is observed. The last official report in summer 1977(14) on two-beam operation shows a beam explosion at a current of 20-30 mA (Fig. 12), which corresponds to luminosities below 10^{29} cm^{-1} (Fig. 13). For $1.35 \lesssim W \lesssim 2.0$ GeV, well inside the ALA energy region, the luminosity obtained with two beams was very much as at Adone.

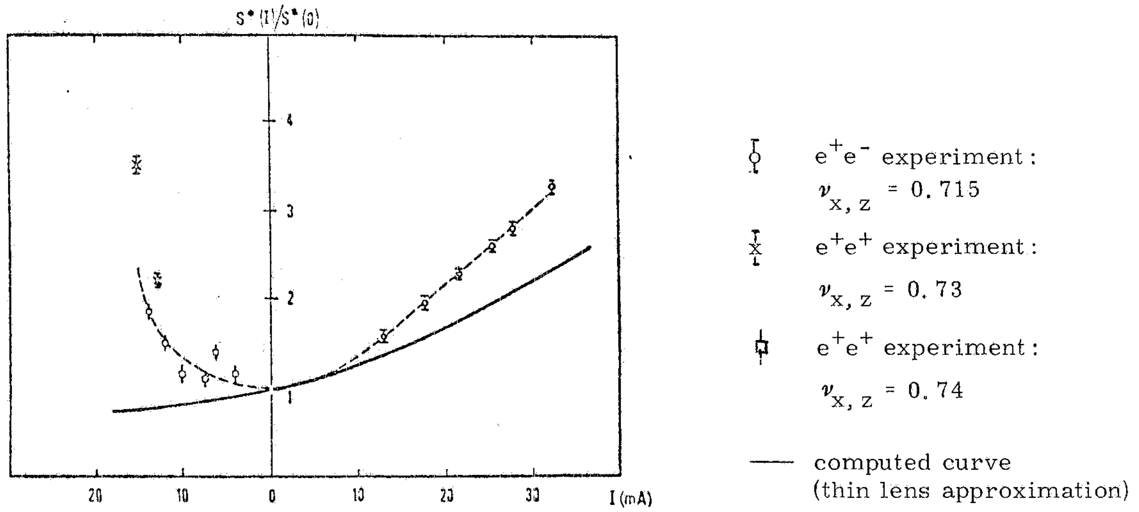


FIG. 12

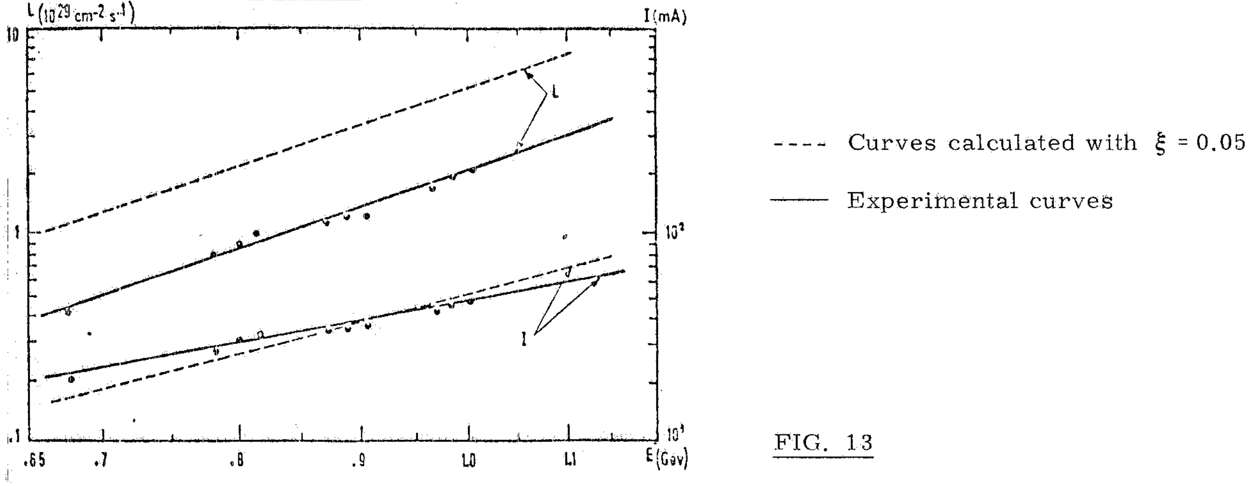


FIG. 13

2. 2. - The experimental results.

Even working with luminosities of the order of 10^{29} cm^{-2} s^{-1}, DCI has contributed in 1977-78 some interesting indications on structures in partial hadronic cross-sections. An old ACO detector was emploied (M3N), consisting in a longitudinal solenoid with sandwitches of trigger scintillators, optical spark-chambers interleaved with lead-converters and a double layer of proportional chambers. The solid angle is $\approx$ 0.6 x 4π and T_π = 220 MeV is the maximum energy for pions stopping in the detector, while T_π = 85 MeV is the minimum energy for triggering. The photon conversion efficiency at $E\gamma$ = 100 MeV reaches $\approx$ 90%.

Besides data on $\sigma(4\pi)$ which show a broad enhancement at W = 1.5 GeV similar to what observed at Adone, two structures were observed with poor statistics in $\sigma(5\pi)$ and in part in $\sigma(3\pi)$ at M$\approx$1660 MeV, with $\Gamma \approx$ 40 MeV, and M$\approx$1770 MeV with $\Gamma \approx$ 50 MeV, which could correspond to two new resonances with I = 0, G = -1 (Fig. 14).

A new detector - DM2$^{(15)}$ - is at present being built for DCI, which should be completed in 1979. This detector has excellent performancies and is in many aspects comparable to MDA, but employes a very thick magnet coil. Therefore, measurements on photons can be made more precise at MDA. To a larger extent however, the comparison between ALA/MDA and DCI/DM2 will be determined by the relative quality of the two accelerators.

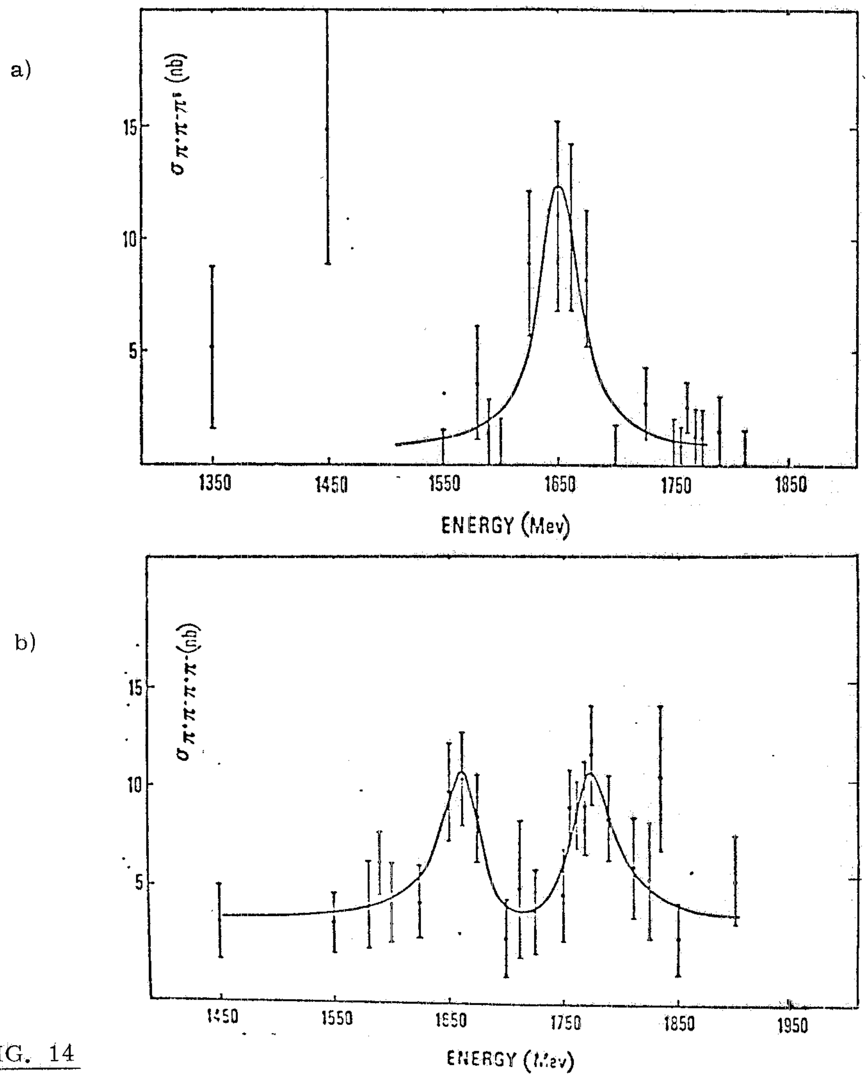


FIG. 14

3. - RESULTS FROM PHOTOPRODUCTION EXPERIMENTS.

The classical photoproduction experiments(16) of ϱ, ω, Φ, where the mass-spectrum of the photoproduced forward e^+, e^- pairs was measured and the Compton amplitudes and phases of vector mesons were studied relative to the non-resonant Bethe-Heitler background, have been recently extended to $1 \lesssim m_{e^+e^-} \lesssim 1.8$ GeV in a DESY-Frascati experiment(17).

The effect of very small Compton production amplitudes was emphasized in this experiment by studying the mass distribution of the asymmetrical (in the exchange of e^+ with e^-) contribution to the spectrum. The results of this experiment, as at summer 1978, are shown in Fig. 15. The wide structure above the Φ has very high statistical significance, since a negative rate is expected in this region as a contribution of the interference of the Φ-tail with the Bethe-Heitler amplitude. These data provide evidence for possible resonances with $M=1097^{+16}_{-19}$ MeV and $\Gamma=31^{+24}_{-20}$ MeV, $M=1266 \pm 5$ MeV and $\Gamma = 110 \pm 35$ MeV, and for additional objects at larger masses.

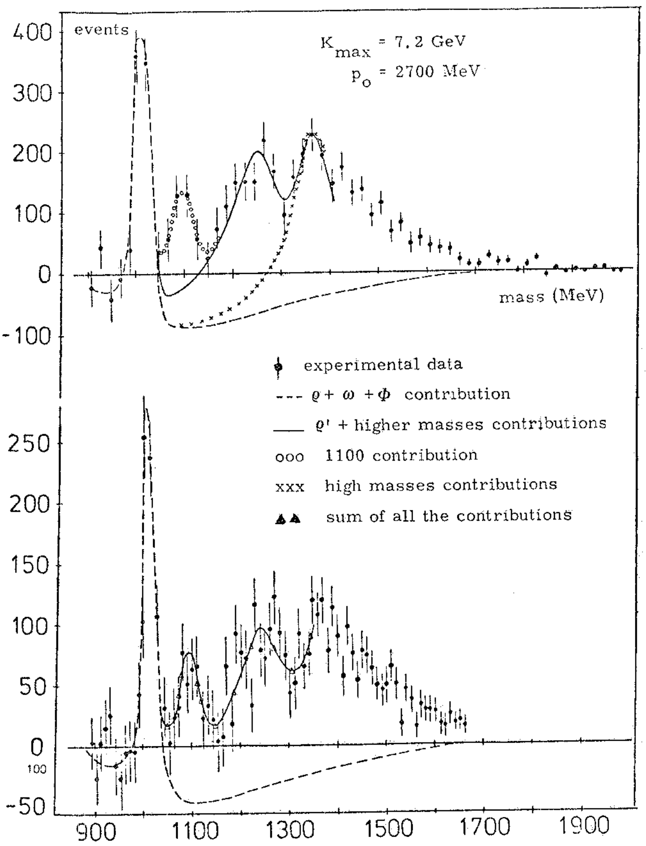


FIG. - 15

An experiment of this type is extremely useful to indicate structures coupled to the e^+e^- system, but cannot give information on their hadronic decays and on their physical nature. However, this data point at the importance of the region below W=1400 MeV, where Adone and DCI were unable to produce results. It is natural to expect that high statistics measurements at ALA will find structures corresponding to those observed in photoproduction and also be able to draw definite conclusions on their nature. For the time being, the absence of structures in the VEPP 2M data on $\sigma(4\pi)$ (Fig. 10) only suggests that these structures are not strongly coupled to the 4π channel.

A number of interesting indications of new phenomena in the ALA energy region are also coming from other photoproduction experiments at higher energies(18). A peculiar dip around 1800 MeV (Fig. 16) where Adone has found a peak (Fig. 3) has been noticed in a Cornell-Harvard photoproduction experiment, similar to the DESY-Frascati one, but using the higher energy photon beam of Cornell (E_{max}=11.5 GeV) and detecting K-pairs. This result raises even more the question mark about the interpretation as a Φ-recurrency of the Adone peak at this energy.

A broad peak in photoproduced 4π- states at $\approx$1500 MeV was found in the large acceptance WA4 experiment at the CERN SPS (Fig. 17), as well as in preliminary data by the Cornell deep inelastic electron scattering experiment LAME (Fig. 18). These results strengthen the evidence for the enhancement in this channel which is also found at Adone and DCI and call for detailed measurements at ALA as a means for disentangling possible fine structures in the spectrum.

The $K^*(890)$ excitation curve from ~1800 to ~2800 MeV has been studied in a large solid angle experiment at Cornell, for events of the type $\gamma p = K^+K^- \pi^+\pi^- p$ (Fig. 19). Although no definite signal is seen within the still very poor statistics a few structures in the $K^*K\pi$ spectrum at ~1900, 2100, 2400 MeV (black area in hystogram), contribute to strengthen the feeling that the study of final states involving kaons will be very interesting in the energy region of ALA. It is also interesting to note preliminary data by the same experiment in the $\gamma p \longrightarrow p\bar{p}p$ channel (Fig. 20) which

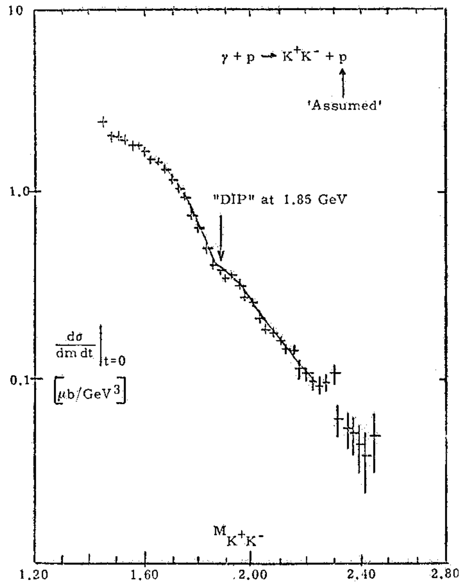


FIG. - 16

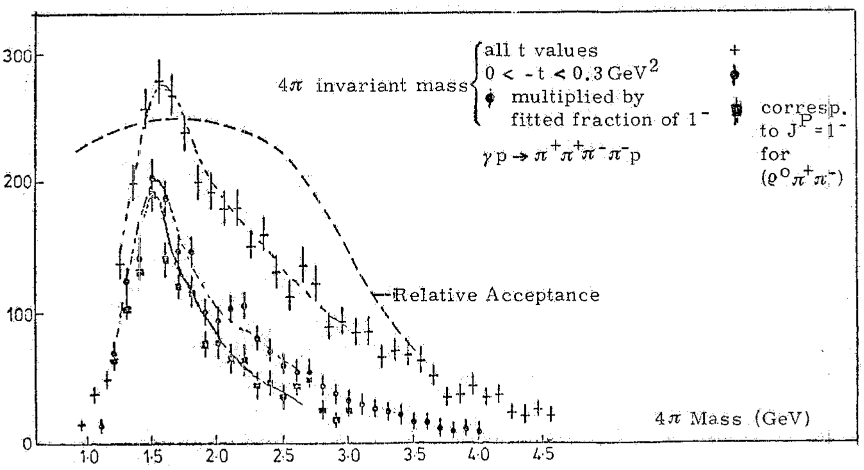


FIG. - 17

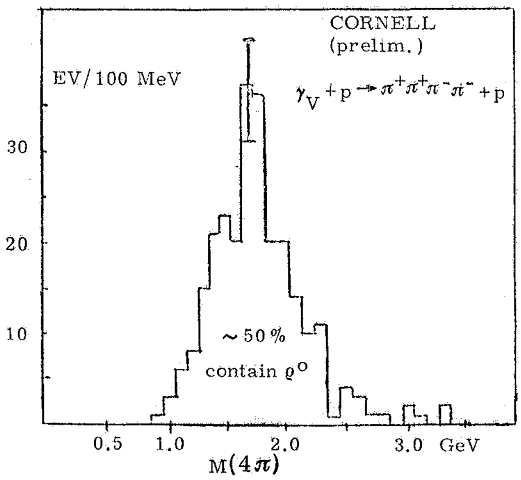


FIG. - 18

$\gamma p \rightarrow K^+K^-\pi^+\pi^-p$ $[Q^2 = 0]$

$|t| < 0.5\ \text{GeV}^2$

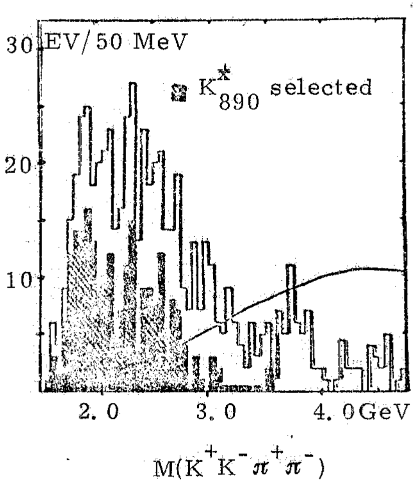


FIG. - 19

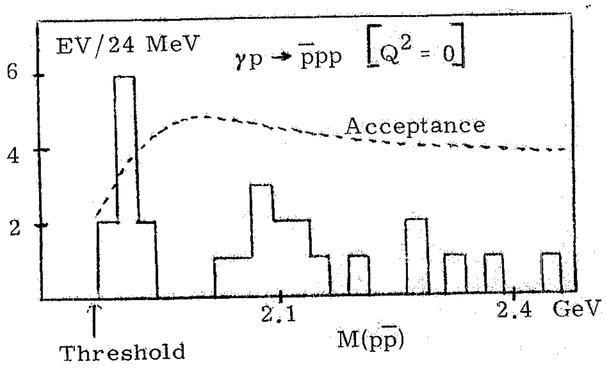


FIG. - 20

indicate that final states with nucleon pairs might contain resonant structures.

It is seen that significant information on possible new states has been provided in the past and is expected to come in the future from photoproduction experiments. However, because of the limited statistics corresponding to the low luminosity of photon beams, and also to the fact that only a few final states with low multiplicity can be fully reconstructed, it can be anticipated that such experiments will hardly pass the exploratory stage. For intance, radiative decays are beyond reach in this approach. Moreover these experiments suffer in principle by the physical background due to the non-diffractive production, such that they are intrinsecally not as clean as e^+e^- annihilation.

It is therefore concluded that they can be a useful complement to but that they cannot challange the unique role of ALA/MDA.

4. - EVIDENCE FOR BARYONIUM

A number of experiments on $\bar{p}p$ interaction have provided evidence for resonant or quasi-bound states strongly coupled to the $\bar{p}p$ system. These states are usually referred to as "baryonium" candidates and their nature is tentatively understood in a number of models, which are reviewed in Chapter 4. Since some of these states (or similar ones that might still be undiscovered) are likely to be observable at ALA/MDA, we shall briefly review the most significant data.

Inclusive measurements of total $\bar{p}p$ and $\bar{p}d$ cross-sections(19) show a bump at M ($\bar{p}p$) ≈ 1935 MeV (the S-meson), as seen in Fig. 21. A comparison of the signal in the $\bar{p}p$ and $\bar{p}d$ data shows that most likely I=1. Since the signal is also observed in $\sigma_{elastic}$ ($\bar{p}p$)(20) (Fig. 22) one can perform a phase-shift analysis, which favours J=2. If this is so, the S-meson would not be observable directly at ALA (it might, however, be observable as the final state of a radiative decay of a $J^{CP}=1^{--}$ state of larger mass). However, there are question marks in the data which leave another possibility open. Since no peak is seen in $\bar{p}p \rightarrow \bar{n}n$ (Fig. 22) one must either assume that two isospin degenerate states conspire to give zero net effect in charge exchange, or that in the $\bar{n}n$ channel a large backgound amplitude interfers negatively with the resonance. In this frame the possibility that J=1 is not ruled out: a combined fit to elastic and charge exchange data(21)gives either J=1 and x(elasticity)=0.37, or J=2 and x=0, 22.
The widtht of the S is certainly less than 10 MeV, which can be understood easier if, being a baryonium state, it has a small coupling to many-pion states (it also has a small phase-space to $\bar{p}p$).

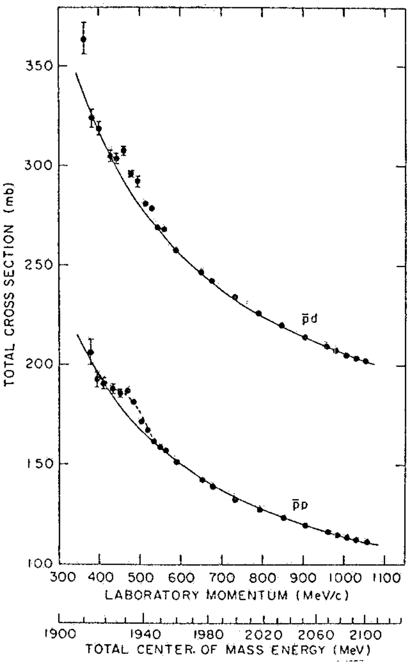


FIG. - 21

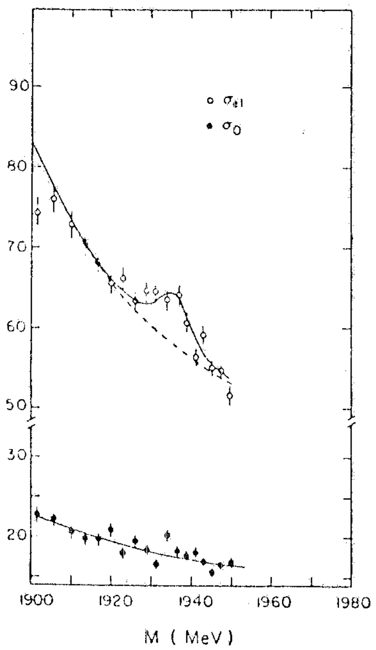


FIG. - 22

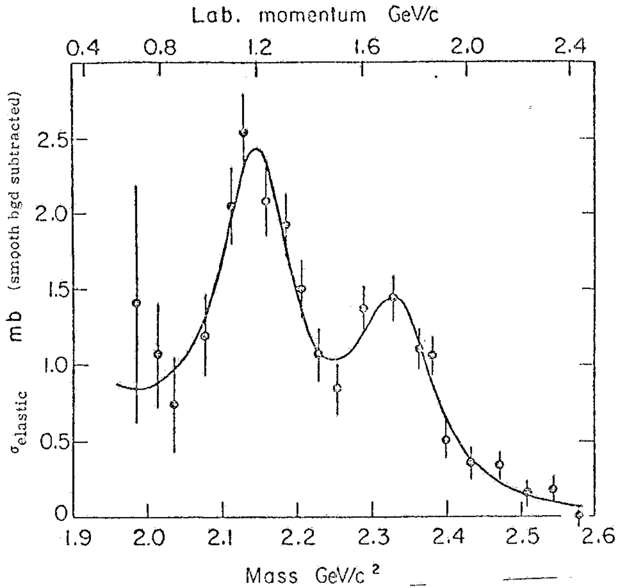


FIG. - 23

Broader states of larger mass, called T(2190) with $\Gamma \approx 90$ MeV and U(2350) with $\Gamma \approx 160$ MeV, are also seen in total and elastic (Fig. 23) $\bar{p}p$ cross-sections and might therefore be other members of the baryonium family.

The derivation of the quantum numbers of these states is by no means unique. In the same approach as above (no signal for T and U is seen in charge-exchange) one gets $J \leq 1$ and $x \gtrsim 0.74$ for the T(2190), and $J \leq 2$ and $x \gtrsim 0.85$ for the U(2350). On the other hand, these bumps are probably due to a sum of various contributions. For intance, a phase-shift analysis of $\bar{p}p \rightarrow \pi^-\pi^+$(22) gives evidence for broader resonances not far from T and U (at $M \sim 2150$ MeV with $\Gamma \sim 200$ MeV and $J^{CP}=3^{--}$ and at $M \sim 2310$ MeV with $\Gamma \sim 210$ MeV and $J^{CP}=4^{++}$). It should be recalled, in addition, that $\sigma(\bar{p}p \longrightarrow \pi^-\pi^+)$ is about 1% of the total annihilation cross-section (and also therefore much smaller than the signal shown in Fig. 23). Maybe therefore the 2190 structure is a sum of many smaller effects, some of which might be observable at ALA/MDA.

It is interesting that strong signals are found in particular channels with small cross-sections, which are not noticeable in inclusive measurements. A CERN experiment using the Omega spectrometer(23) has studied the reactio $\pi^- p \rightarrow \rightarrow (p_f \pi^-)_{resonant} (\bar{p}p)_{backward}$, when the forward recoiled proton p_f and the π^- are in a resonant $\Delta(1236)$ or $N^*(1520)$ state. The mass spectrum of backward emitted $\bar{p}p$ pairs is shown in Fig. 24. Three peaks are seen, one corresponding to the S(1930) and two at ~ 2020 and ~ 2204 MeV with widths of the order of $10 \div 30$ MeV. The quantum numbers of these possible resonances are an open problem.

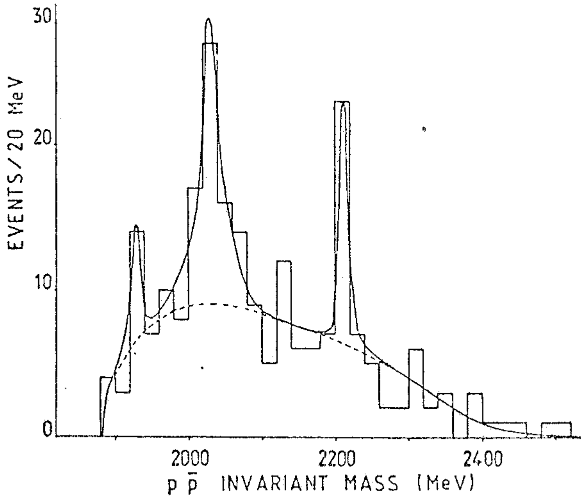


FIG. - 24

Baryonium candidates are also found with non-zero strangeness in $K^- p \rightarrow \bar{\Lambda} pX$ at 12 GeV/c (Fig. 25), again in the Omega spectrometer(24). Peaks in the the $\bar{\Lambda}p$ system at ~2.2, ~2.9, ~3.1 GeV are seen, which are natural baryonium candidated. If $\bar{p}p$ and $\bar{\Lambda}p$ can give baryonium, why not $\bar{\Lambda}\Lambda$? The possibility is thus open at ALA for pair-production of low-lying strange baryonium members, like $e^+e^- \rightarrow B(2400) \rightarrow \bar{\Lambda}\Lambda$. These states, if they exist, might also decay in a non negligible fraction of cases into $\bar{K}K$, and a scan for final states containing $\bar{K}K$ pairs at ALA can be considered as a search for members of a particular family of baryonium states (not only for Φ-recurrencies!). In this connection we note a bump at $M \approx 2.0$ GeV(25) in the ratio $(\bar{p}p \longrightarrow K_S^0 K^\pm \pi^\mp)/(\bar{p}p \longrightarrow \text{others})$ (Fig. 26).

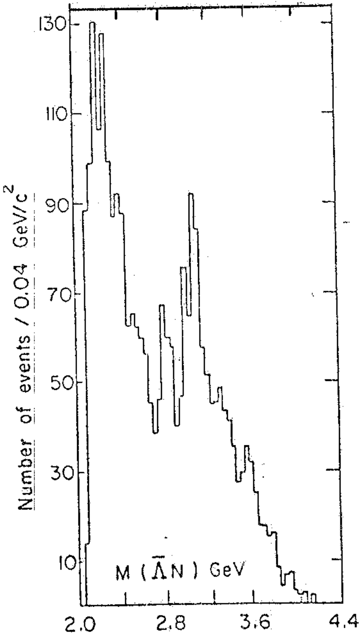


FIG. - 25

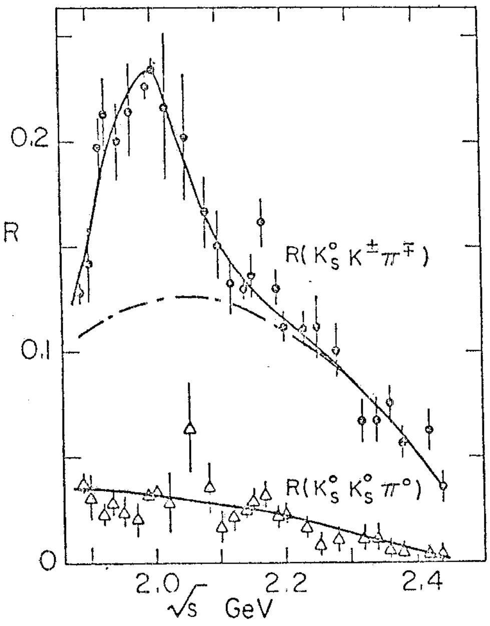


FIG. - 26

Candidates to quasi-bound baryonium states have been found at CERN in an experiment studying the spectrum of photons emitted in the capture of $\bar{p}$ at rest in hydrogen(26). The data after subtraction of a large smooth background is shown in Fig. 27.

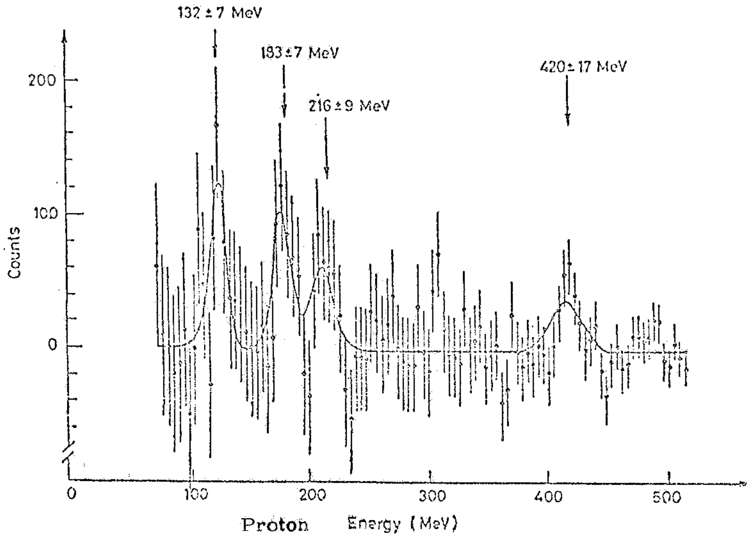


FIG. - 27

Besides the 132 MeV peak due to radiative capture of the π^-'s contaminating the $\bar{p}$-beam, one observers three peaks which are naturally interpreted as being due to $\bar{p}p \longrightarrow \gamma B$, with masses of the bound baryonium of ~1684, ~1646, ~1395 MeV. The observed widths are determined by the detector resolution. Some of these "baryoniums" might well have $J=1$ and possibly be directly produced in e^+e^-.

In summary, it seems likely that being ALA/MDA able to detect very small cross-sections, a number of baryonium states will either be direcly seen in particular decay channels, or indirectly be revealed in a study of radiative decays.

5. - PERSPECTIVES OF THE CERN LOW-ENERGY $\bar{p}p$ PROGRAM (LEARD).

The proposal is being considered at CERN to build within the end of 1982 a storage ring for low energy antiprotons (LEAR). This facility(27) will be provided with an interval jet-gas target allowing experiments on $\bar{p}p$ interactions in flight for c. m. s. energy $2Mp \lesssim W \lesssim 3.5$ GeV. Also, by slowly ejecting the antiprotons one expects to get a beam with good duty cicle and $\gtrsim 10^6$ antiprotons per second, that can be stopped in a thin solid or gas target. We briefly review here the main features of the project and the areas of common interest with ALA/MDA. One such area is first of all the study of baryonium states.

When antiprotons are stopped in low pressure hydrogen gas $\bar{p}p$ "atoms" are formed with orbital angular momentum varying from zero to several units. The capture in a definite angular momentum state is accompained by the emission of monochromatic x-rays. The subsequent annihilation may have a large branching ratio for γ or π decay to "nuclear" baryonium states. In principle, a large solid angle detector can measure at the same time the triggering x-ray, the decay photon or pion and the annihilation products of the final state "baryonium". The common interest with our project comes from the fact that those baryonium states which have $J^{CP}=1^{--}$ are directly observable also ALA/MDA, while 0^{++}, 1^{++}, 2^{++} states can be produced at ALA in E1 radiative transitions and 0^{-+}, 2^{-+} in M1 transitions.

At the present moment, the rate of production of J=0, 1, 2 baryonium states in particular at ALA cannot be reliably predicted. As far as the signature for baryonium is concerned, LEAR has the qualitative advantage that one would know automatically that any state with mass < 2 Mp observed in resonance decay is strongly coupled to the initial $\bar{p}p$ state and therefore is likely to be baryonium. However, clear-cut prove for baryonium must eventually come from some peculiar decay features, which can be studied at best with MDA. As far as the determination of quantum numbers is concerned, if a state is produced directly or is seen in radiative decay at ALA it must have the above mentioned quantum numbers. LEAR on the other hand can possibly produce baryonium from inital states which can have a large spin. The determination of the orbital momentum of these states relies on the detection of the last x-ray emitted in the $\bar{p}p$ atomic cascade and the final state baryonium has the same orbital momentum if a pion is emitted, while $\Delta\ell =$ $= 1$ for γ-decay. Therefore a very good efficiency in detecting the atomic x-rays at LEAR is the critical condition for separating from each other (although there will be difficulties left in determining the spin states) the many baryonium states. We conclude that ALA/MDA will easily compete with LEAR in the study of those baryonium states below threshold which can be produced in e^+e^- annihilation. Of course, the study of additional resonances at ALA which are not baryonium should be much easier and cleaner than at LEAR where one has many more competing channels.

$\bar{p}p$ annihilation will also be studied at LEAR for $W \gtrsim 2Mp$, in particular with the internal jet-gas target, and resonant baryonium states can be directly seen either in the elastic or in inelastic channels. This will make baryonium studies easy, even if the spin of not strongly coupled resonances to two-body channels will be hard to determine. However, an accurate study of those among these states which have J=0, 1, 2 can also be performed at ALA/MDA (including branching ratios into baryon pairs). Besides baryonium studies, for $W \gtrsim 2Mp$ one can measure at LEAR the proton form - factor in the timelike region. This will also be measured at ALA/MDA. For $q^2=4.3$ GeV/c^2 ($W \approx 2,06$ GeV) the expected rate of events at LEAR using the slow extracted beam is ≈ 1500/day(28), while at ALA ($L \sim 10^{31}$ cm^{-2} s^{-1} and $\sigma(\bar{p}p) \approx 1$ nb at this energy) one expects nearly one thousand. Even at the top ALA energy, the expected rate for $e^+e^- \longrightarrow p\bar{p}$ at ALA is ≈ 10/ /day. It seems therefore that in both experiments the rate will not be a problem. However, it might be easier at ALA to separate collinear non-relativistis $\bar{p}p$ pairs from $\pi^+ \pi^-$ and K^+K^- than at LEAR to separate e^+e^- from $\pi^+\pi^-$ (although this is possible, as shown by a CERN experiment(29)).

The possibility has been considered(28) to measure with LEAR the spectrum of vector mesons of lower mass than the available c. m. s. energy by exploiting reaction $\bar{p}p \longrightarrow e^+e^-\pi^0$ with the same the detector where reaction $\bar{p}p \longrightarrow e^+e^-$ is studied. The estimated rate from this reaction is model dependent. The background from hadronic events is difficut to estimate, since several reactions can generate the observed topology 2ch +2 γ. In the most optimistic case, the output of the measurement would be a mass spectrum of the vector states coupled to e^+e^-, which will have to be compaired to the one measured in the photoproduction experiments. The LEAR project cannot, therefore, compete with ALA/MDA in the detailed study of the branching ratios of these states.

6. - PHOTON-PHOTON PROCESSES.

The total cross-section for producing a state of mass m_x by γ-γ interactions is $\sigma(e^+e^- \longrightarrow e^+e^-X) \propto (\alpha^4/m_x^2) \ln^2 (E/m_e)$. Because of the $1/m_x^2$ factor and of the high machine luminosity, the rate of a number of processes in which low-mass states (like $\mu^+\mu^-$, $\pi^+\pi^-$, etc.) are produced is not negligible. In practice, it is interesting to consider the production of ALA of the lightest meson resonances of quantum numbers $J^C = 0^+$, i.e. η and η'. In particular, η' production is interesting as a means for measuring the $(\gamma\gamma\eta')$ coupling constant. The rate of η and η' production at W=2.4 GeV (using the experimental width $\Gamma_{\eta \to \gamma\gamma}$ = 0.85 KeV and the experimental upper limit $\Gamma_{\eta' \to \gamma\gamma}$ = = 20 keV) has been estimated by R. Del Fabbro and G. P. Murtas, and is shown in Fig. 28, for an integrated luminosity of 2.6×10^4 nb^{-1} (30) full days at $L=10^{31} cm^{-2} s^{-1}$). The geometrical detection efficiency to collect all hadrons of these events in the detector can be estimated with a Montecarlo calculation, and one finds that it is ≈ 30%.

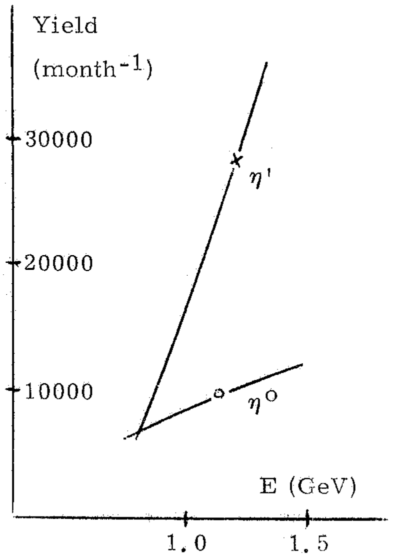


FIG. - 28

This is the cleanest sample of events and corresponds to ≈ 8000 events in thirty days of running.

In general, the experimental signature for hadronic production in $e^+e^- \longrightarrow e^+e^- X$ should be found in the total energy of the produced state being ≪ W and in the presence of electrons in the final state. Because of the large coverage and of the good energy resolution of MDA, one can expect that the energy signature will play an important rôle. In addition, when studying the production of resonances another signature will be provided by the total effective mass of the produces particles. In the η' case the $\gamma\pi^+\pi^-$ decay channel contributes by ≈50% to the rate of fully accepted events and therefore is a particularly good candidate to provide a peak in the effective mass spectrum.

Unfortunely the beam-gas machine background, which is hard to estimate, is likely to provide a huge background of similar soft low-multiplicity events. A clear-cut signature for two-photon reactions would be the observation and the measure of the momentum of the final state electrons which are emitted at small angles with reduced energy. However, the downstream magnetic fields of MDA and of the compensator, and the field of the machine quadrupoles curl and bend in complicated patterns the trajectories of these electrons, such that they cannot be properly tracked for momentum measurement when they exit the beam pipe. On the other hand, Montecarlo calculation show that it is possible to tag about 50% of these electron pairs in counter hodoscopes around the pipes. These events should provide a statistically significant and sufficiently clean sample of reactions like $e^+e^- \to e^+e^-\eta$ and $e^+e^- \to e^+e^-\eta'$.

After beam gas the most dangerous background to $\gamma\gamma$-hadron production is contributed by annihilation events in coincidence with a random count of the tagging telescopes, if a large number of secondaries happens to be lost and the total visible energy is ≪ W. These events are among the ≈10% of annihilation events which are not fully reconstructed. The corresponding cross-section which gives an upper limit to this background is roughly equal to the estimated overall cross-section for $\gamma\gamma \to 2\pi, \eta, \eta'$. We expect that the chance of a random coincidence with the tagging signals will be ≪ 1. It is therefore fair to expect that accurate energy measurements, with the aid of angular distributions and tagging of final state electrons will allow to isolate the signal. We conclude that despite the small cross-section at small energies a significant study of $\gamma\gamma$ events should be possible at ALA/MDA.

7. - THEORETICAL EXPECTATIONS FOR THE PHYSICS OF ALA/MDA.

We shall summarize briefly in the following a number of theoretical questions which can be clarifed with data from ALA/MDA. Not only this is not intended to be a fully comprehensive summary of the open theoretical questions in this field of Physics, but in particular it should not lead to underestimate an important quality feature of the project, which is its capability of discovering new subtle and yet unpredicted phenomena. This is a consequence of the big step forward in luminosity times efficiency in a field - experimental e^+e^- physics - which has proven to be of such fundamental importance.

7.1. - The vector meson recurrencies.

Below $W = 1$ GeV, the reaction $e^+e^- \to$ hadrons is dominated by production of ϱ, ω, and Φ. At higher energy the radial and orbital excitations of these $q\bar{q}$ systems are expected to generate families of higher mass mesons with the same I^G and, in number of cases, with $J^{PC} = 1^{--}$. An approximate mass formula is$^{(30)}$

$$m_n^2 = m^2 + n\Delta^2 ,$$

were $\Delta^2 \gtrsim 1.2$ GeV^2, $n = 0, 1, 2, \ldots$ is the order of the recurrence and m_n is the mass of the excited meson. This formula predicts a number of resonances in the energy range of ALA, viz. $M_{\varrho'} \sim 1300$ MeV, $M_{\varrho''} \approx 1600$ MeV, $M_{\varrho'''} \sim 2000$ MeV, $M_{\omega'} \approx 1300$ MeV, $M_{\omega''} \approx 1600$ MeV, $M_{\omega'''} \approx \approx 2000$ MeV; $M_{\Phi'} \approx 1450$ MeV, $M_{\Phi''} \approx 1750$ MeV, $M_{\Phi'''} \approx 2150$ MeV. The coupling of these recurrences to e^+e^- and their total widths can be predicted only on the basis of dynamical models. Typical values for the ϱ-recurrencies are$^{(31)}$

$$\Gamma_{\varrho} = 125 \text{ MeV} , \qquad \Gamma_{\varrho'} = 180 \text{ MeV} , \qquad \Gamma_{\varrho''} = 350 \text{ MeV} ,$$

and SU_3 relations can be used to predict, Γ_{ω_n}, Γ_{Φ_n}, giving

$$\Gamma_{\omega'} \approx 470 \text{ MeV} , \qquad \Gamma_{\omega''} \approx 560 \text{ MeV} , \qquad \Gamma_{\Phi'} \approx 40 \text{ MeV} , \qquad \Gamma_{\Phi''} \approx 280 \text{ MeV} .$$

These figures, however, are largerly uncertain and should be taken only as the order of magnitude expected for these parameters in the quark model.

Infinite series of resonancies of the ϱ, ω, Φ families are also predicted in Regge models, each daughter trajectory giving rise to one state with $J^{PC} = 1^{--}$. In the case of equally spaced daughter trajectories with typical slope ~ 1 GeV^{-2}, the mass formula is again$^{(32)}$ as in the quark model

$$m_n^2 = m_o^2 + n\Delta^2$$

with $\Delta^2 \sim 1$ GeV^2. Based on the extended vector dominance model as well as on quark model considerations, and making use of a number of experimental indications from Adone and DCI, Greco has discussed possible values for the widths of these recurrencies$^{(33)}$. These values depend very much on the assumed dinamics, like for example a dominant $\varrho' \to \omega\pi$ or $\varrho' \to \varrho\varepsilon$ decay; One gets extimates as

$$\Gamma_{\varrho'} \sim \Gamma_{\varrho''} \gtrsim 100 \text{ MeV} , \qquad 100 \text{ MeV} \lesssim \Gamma_{\omega'} , \qquad \Gamma_{\omega''} \lesssim 400 \text{ MeV} ,$$

$$25 \text{ MeV} \lesssim \Gamma_{\Phi'} \lesssim 50 \text{ MeV} , \qquad 30 \text{ MeV} \lesssim \Gamma_{\Phi''} \lesssim 100 \text{ MeV} .$$

It is again clear that although these arguments are instructive they can only provide order of magnitude estimates. The decisive answer will have to come from experimental data, in particular from detailed measurements of the energy dependence of each different final state.

The peak cross sections are expected$^{(33)}$ to vary with the order of the recurrence as

$$\sigma_{n,\max} \sim \left[\left(\frac{m_o}{m_n} \right) \right]^3 \frac{\Gamma_o}{\Gamma_n} \sigma_{o,\max}$$

Altough these values depend on the Γ_n's which are very poorly predictable, it is significant that in all cases one expects $\sigma_{n,\max} \approx 10$-$100$ nb. Given the corresponding rates at ALA, no matter which the dominant decay channel is, MDA should be able to perform the job easily.

With the experimental picture available at present, there is no interpretation of the data that can safely be adopted. The bump that M = 1260 MeV with $\Gamma \approx 110$ MeV of the DESY-Frascati experiment (Fig. 15) could be the ϱ'. An anomaly at about this energy is also found in the pion form factor measured at Novosibirsk(34). However no signal is seen in $\sigma(2\pi^+ 2\pi^-)$ (Fig. 10) and existing data on $\sigma(\pi^+\pi^- 2\pi^o)$ and $\sigma(6\pi)$ are too poor to be of any use. The bump seen at W $\approx$ ≈ 1500 MeV in $\sigma(e^+e^- \to 2\pi^+ 2\pi^-)$ (Fig. 10) and in the Omega photoproduction experiment (Fig. 17), and the large asymmetry at m $\gtrsim 1400$ MeV in the DESY-Frascati experiment (Fig. 15), could well be due to the ϱ''. However, a separate study of the different final states ($\varrho\pi\pi$, $\varrho\varepsilon$, $\omega\pi$) has not been possible and even if the ϱ'' exists, it is probably mixed with a large non-resonant background. One of the bumps in $e^+e^- \to 3\pi$ or in $e^+e^- \to 5\pi$ seen at DCI (Figs. 13, 14) might be the ω'' (at m ≈ 1770 MeV) but the statistical significance of the signal is marginal, and moreover what about the second peak at lower mass ?

The structure seen at Adone at W ≈ 1500 MeV (Figs. 7, 8) is where the Φ' is expected. However, assuming the signal is real, it looks too narrow (≈ 5 MeV). If one tries to explain it as an orbital excitation of the $\lambda\bar{\lambda}$ system, the problem is left open of an additional and yet undiscovered Φ' lying nearby(33). The Adone signal at W ≈ 1820 MeV (Fig. 4) might be the Φ'' (although it is very narrow), but this interpretation is shaky in view of the lack of signal in the inclusive K/π ratio. For instance (after all the theoretical arguments favouring large ω_n widths are not very strong) this signal might be the ω''. The 2130 MeV signal at Adone (Fig. 3) is commonly considered to be the Φ''', but even here any firm interpretation should wait for more detailed experimental information. All in all, it is fair to anticipate that a reliable picture will only emerge from future data.

When many vector mesons are produced in the same energy region, as expected at ALA, the total hadronic cross section will of course be the sum of all contributions, including possible interference terms. When the width of the resonances becomes compairable to their masses, as might be true at the top ALA energies, one derives in the VDM(35)

$$R \sim \sum_i \frac{9}{\alpha^2} \frac{\Gamma^i_{ee}\, m_i}{\Delta_i^2}$$

and one expects R ≈ 2.5 below the J/ψ. This is marginally compatible with the recent Adone results (Fig. 2). On the other hand, the asymptotically free quark models predict

$$R \approx \sum_i Q_i^2 \left(1 + \frac{\text{const}}{\ln(s/\mu^2)}\right)$$

where μ is a mass scale and Q_i are the charges of the constituent quarks. For three light quarks of three colours one expectes $R \to 2$ from above. This is certainly compatible with the Adone data. Although the top ALA energy of 2.4 GeV will be a limitation in this context, accurate measurements of R from W ≈ 1.8 to W = 2.4 might contribute to elucidate this point(36).

7.2. - Baryonium models.

The existence of new families of hadrons which have been assigned the general name of baryonium states is predicted both in potential and in quark models. I. S. Shapiro and collaborators(37) have analysed the data on nucleon-nucleon interaction at low energy and derived parameters for an effective potential, by taking into account π, η, ϱ, ω as well as 2π and 3π non-resonant exchanges. It is found in the fit that the coupling constant of the repulsive ω-exchange term is very large. In such an exchange model one can predict the $\bar{N}N$ potential in terms of the NN one by changing the sign of the G-odd amplitudes. In particular, the ω-exchange contribution (at the typical distance of $1/m_\omega \approx 0.3$ fermi) becomes very strong and attractive, such that a number of resonant and bound states are predicted. The modifications due to the additional annihilation potential at distancies of $1/2\ M_n \approx 0.1$ fermi are taken into account and parametrized in a plausible way, and the resulting potential is checked against low energy $\bar{p}p$ scattering and charge-exchange data. With this potential, one predicts various trajectories of $I = 0$ and $I = 1$ baryonium states, as shown in Figs. 29 and 30. It is noticed that several states with $J = 1$ are expected in the ALA energy region, while several more could be reached by radiative transitions.

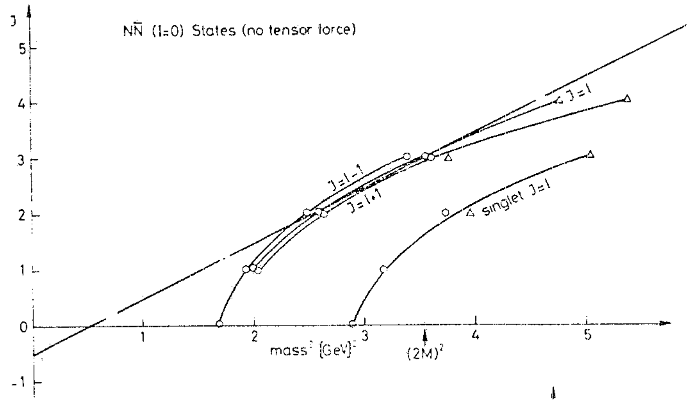


FIG. 29

Detailed calculations by these authors predict several $N\bar{N}$ states centered at ~ 1.8 GeV, a group of $\Lambda\bar{\Lambda}$ states around 2.2 GeV, and a group of $\Sigma\bar{\Sigma}$ states around 2.3 GeV. Typical widths as well as the separation between nearby resonances are of the order of 50 MeV.

A discussion is made in ref. (37) about the excess of hard photons over what can be ascribed to π^0-decay, which is experimentally observed. This data is shown in Fig. 31$^{(38)}$.

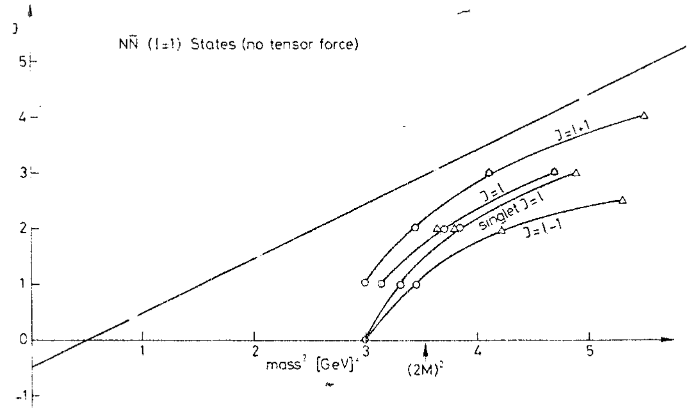


FIG. 30

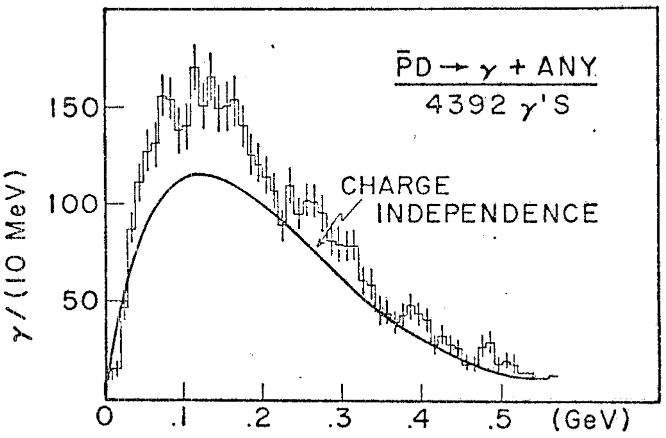


FIG. 31

The full line gives the properly normalized expected spectrum if the isospin conservation rule $\langle n_{\pi^+} + n_{\pi^-} \rangle = 2 \langle n_{\pi^0} \rangle$ is satisfied. The authors of ref. (37) argue that the excess of photons can be explained by the contribution of radiative transitions from atomic to nuclear NN states or between nuclear NN states themselves. In both cases the radiative branching ratios would be of the order of 0.7 per annihilation act. Should the rate be so high, it will certainly be measurable at ALA/MDA. Recent refined work on the potential model of baryonium by Vinh Mau$^{(39)}$ and C.B. Dover and J.M. Richard$^{(40)}$ confirms the strong interest for detailed experimental studies of these states.

Chan Hong-Mo and collaborators have developed a quark-model of baryonium$^{(41)}$, in which new states are predicted based on the idea that all multi-quark states with zero total colour might possibly exist in nature. By considering combinations of bound qq and $\bar{q}\bar{q}$ diquarks, a model is constructed in which a number of hadronic states ("diquoniums") are predicted that correspond rather closely to the picture discussed in Chapter 4. Although they only contain four quarks, the name baryonium may be justified for these states because a system of two diquarks cannot decay into mesons without violating the Zweig rule, while this rule would not be violated by a decay into baryon pairs. Thus these states are predicted to be narrow below $N\bar{N}$ threshold, and to have normal hadronic width $\Gamma \sim \Gamma_{N\bar{N}} \sim 100$ MeV above threshold.

Since q is a colour triplet, a qq system can be a colour $\bar{3}$ or 6 representation, while $\bar{q}\bar{q}$ can be either 3 or $\bar{6}$. If the net colour must be zero in physical hadrons, one can have two diquonium families, $(qq)_{\bar{3}}\,(\bar{q}\bar{q})_3$ and $(qq)_6\,(\bar{q}\bar{q})_{\bar{6}}$ which are called True and Mock diquonium respectively. Therefore one expects that T-diquonium will easily decay into baryon pairs as mentioned above while M-diquonium, if colour is a good quantum number, cannot do this directly because a colour sixtuplet and a colour triplet (a virtual quark) cannot combine to give a zero colour baryon. Thus M-diquonium is expected to be narrow (Γ = 10-20 MeV) both above and below the $N\bar{N}$ threshold.

The predicted J(M^2) distribution for T-diquonium states (generated by the only u and d quarks !) is shown in Fig. 32. A spin dependent interaction is introduced to separate members of the family in which both (qq) and ($\bar{q}\bar{q}$) have I = 1. It is seen that a number of states correspond to the $\bar{p}p$ bumps which were illustrated in Chapter 4.

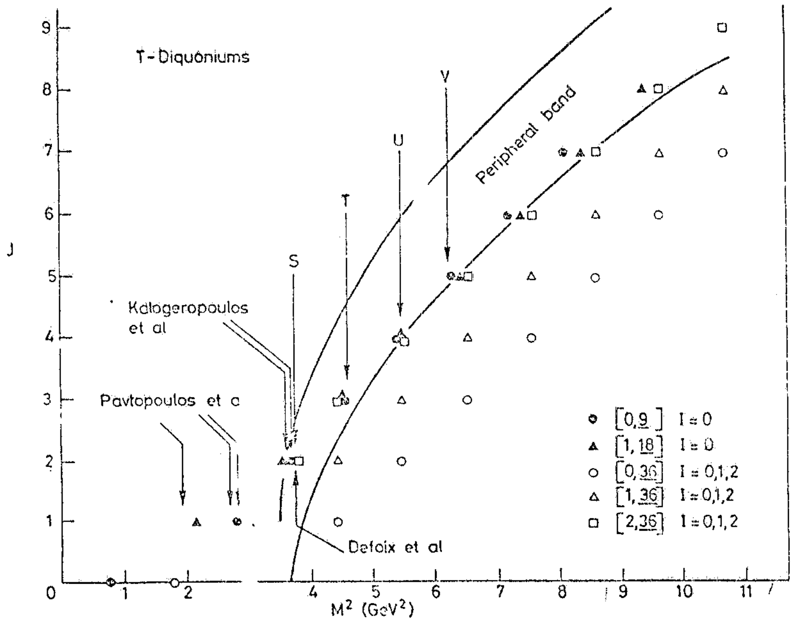


FIG. 32

The predicted J(M^2) distribution for M-diquorium is plotted in Fig. 33. There is no really good experimental candidate for a member of this family yet. The signature for such states is to be found not only in the narrow width but also in some special decay channel. It is found in the model, as a consequence of the assumption that color rearrangement is forbidden to a first order.that as long as possible higher spin states decay by pion emission into lower states of the same family, while the lower lying member finally decays into $B\bar{B}$. Therefore specific predicted signatures are $B\bar{B}$, $B\bar{B}\pi$, $B\bar{B}\pi\pi$, etc. with monochromatic pions. This model therefore

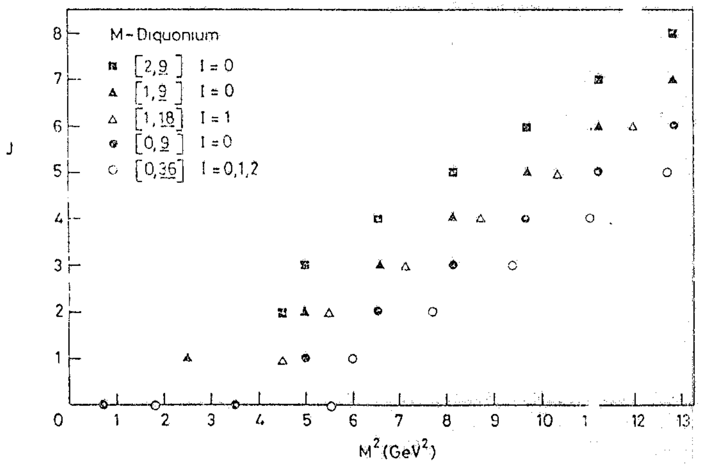


FIG. 33

points at the importance of a good hadron separation in MDA, including low-energy and possibly neutral pions in many-body events.

A number of T and M-diquonium states have the right quantum numbers to be directly coupled to a photon. The predicted spectrum is shown in the lower plot of Fig. 34, while the masses at which peaks have been seen at DCI (1660 MeV) and at Adone (1820 MeV) as well as data from the Omega photoproduction experiment (Fig. 20) are shown in the upper plot. Although specific predictions should not be taken too seriously, the general picture provided by the model seems to correspond to the data, while the task of giving a possibly conclusive answer is left to ALA/MDA.

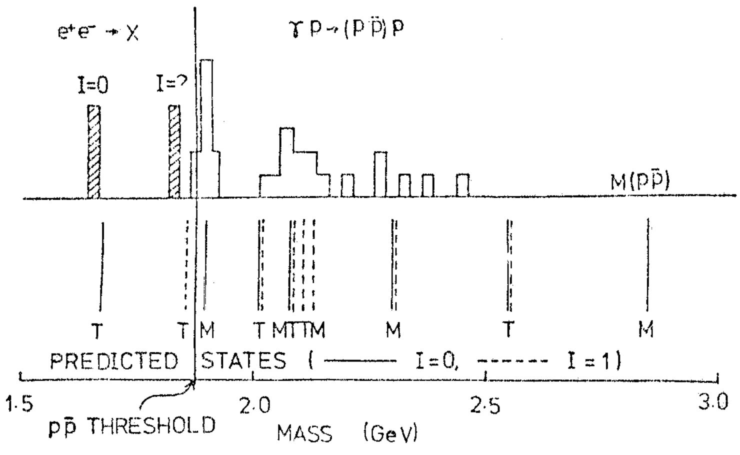
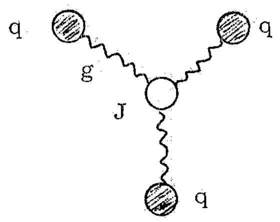


FIG. 34

The existence of baryonium is essential in the S-matrix theory of G. Chew and collaborators(42). A dynamical quark model of baryon-baryon scattering has been developed by Rossi and Veneziano(43) in which families of exotic hadrons (some of which including four quarks) are predicted. Quarks enclosed in baryons are assumed to be bound together by gluons via a junction and $B\bar{B}$ scattering is described by a number of dual diagrams, in which states with four quarks



and two junctions (M^j_4), two quarks and two junctions (M^j_2), two junctions only (M^j_0 , a gluon ball) as well as regular mesons can be exchanged in the t-channel (see Fig. 35). All these states are directly coupled to $B\bar{B}$ states and can therefore be considered "baryoniums". The Zweig rule forbids the decay of M^j_4 into mesons, as illustrated at the bottom of Fig. 35 and therefore these states are expected to be narrow below $N\bar{N}$ threshold. The above exchanges generate Regge trajectories which are tentatively estimated in the model as shown in Fig. 36. One sees that the masses of the J = 1 members of these "baryonium" families, including the gluon ball, fall in the ALA energy region.

In conclusion, no matter wether a potential or a quark model is adopted one is brought to conclude that ALA/MDA has a good chance to pin-down a significant sample of the expected baryonium states.

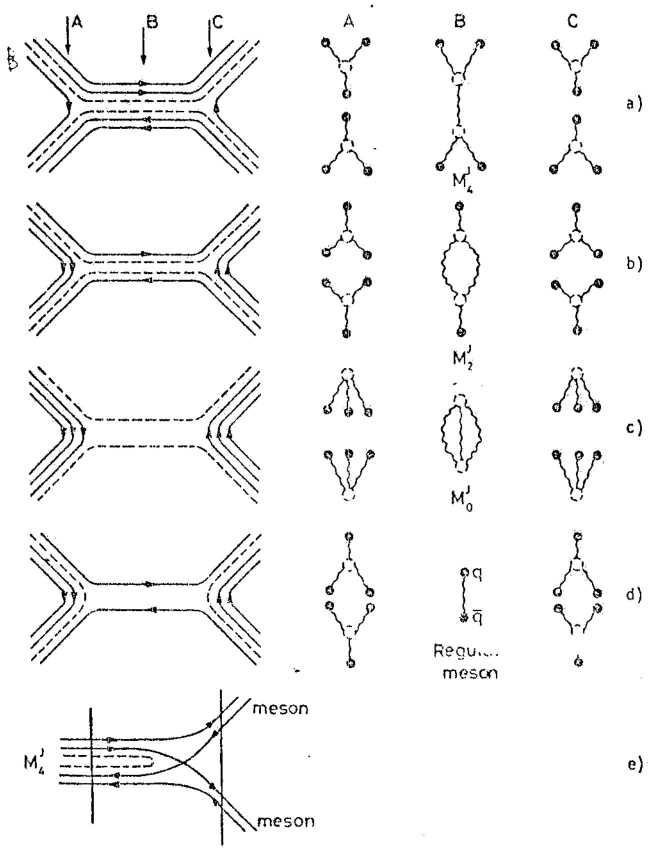


FIG. 35

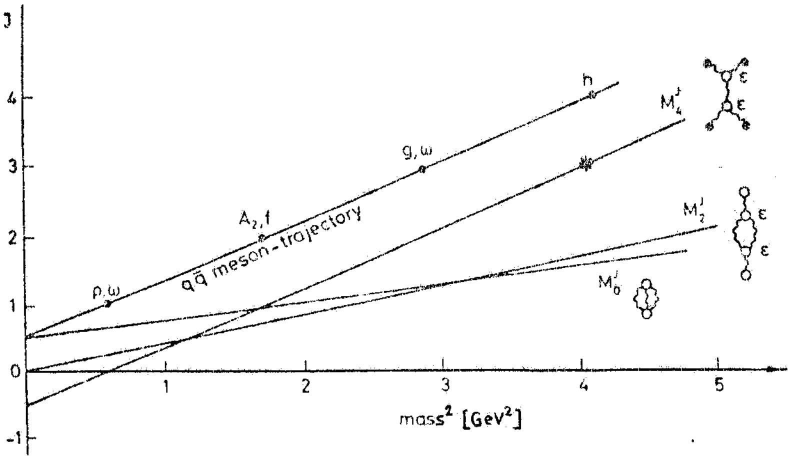


FIG. 36

6. 3. - Coloured gluons and quarks.

New fundamental particles coupled to e^+e^- are predicted in the unified gauge theory of quarks and leptons developed by Pati and Salam(11). In this theory neither quarks nor gluons nor color in general are confined. Quarks have unit charge and are unstable against decay into leptons, with lifetimes so short ($\tau \lesssim 10^{-11}$ s) that they might have excaped detection untill now. An octet of colour vector gluons is predicted, whose two neutral members generate two neutral gauge gluons (U and V^o), one of which (U) is coupled to e^+e^- very much as the photon is. In the real world two physical particles could exist, each coupled to e^+e^- with weights $\cos^2\xi$ and $\sin^2\xi$:

$$\underline{\tilde{U}} = \tilde{U} \cos\xi - V^o \sin\xi \quad , \qquad \tilde{V} = U \sin\xi + V^o \cos\xi \ .$$

For $\tilde{U}$ (with $m_{\tilde{U}}$ = 1-2 GeV), the dominant decay modes, and the widths estimated in a particular model, are as follows(43)

$\tilde{U} \rightarrow e^+e^-$ or $\mu^+\mu^-$	Γ =	6	to	30 keV
$\eta'\gamma$		40	to	1000 keV
$2\pi\gamma$, $4\pi\gamma$, $K\bar{K}\gamma$		50	to	500 keV
3π, $\varrho\pi$, 5π, $K\bar{K}$		10	to	1000 keV
2π, 4π, $K\bar{K}$		10	to	1000 keV .

Thus,the leptonic branching ratio is of the order of percents and the radiative branching ratio is very large ($\gtrsim$30%) (while these decays are either forbidden or very small for the V^o). This means that one or two resonances could exist in the mass range 1-2 GeV (with splitting of the order of 1/10 m_U), having (with relative weights $\cos^2\xi$ and $\sin^2\xi$) appreciable branching ratios in to e^+e^- and $\mu^+\mu^-$ and large branching ratios for radiative decays. There are several clear signatures of these gluons that are directly accessible to experiment, first of all the exceptional rate of γ-decays with a large two-body $\eta'\gamma$ channel, the resonant behaviour into odd and even number of pions and into kaon pairs at the same time. These signatures can be checked in a large solid angle detecotr with particle recognition like MDA and are inconsistent with vector meson recurrences.

The total width of $\tilde{U}$ is estimated to be at least 100 keV in this model, which would lead to an integrated cross-section of $\approx$ 10 μbarn x MeV ($\int \sigma_R dw = (6\pi^2/M^2)\,\Gamma B_{ee}$). This is a signal as large as the J/ψ one which would be very easily detectable at ALA/MDA. It is argued in ref. (11) that if the narrow structure observed at Adone at M$\sim$1500 MeV is one of these coloured gluons, it must be the weakly coupled one to e^+e^- ($\sin^2\xi \sim 1/100$) such that the second stronger gluon would be expected in the region M$\simeq$1300-1400 MeV. No search for narrow resonances (nor in fact any measurement of σ_h even at VEPP 2M, see Fig. 2) was made at Adone in this energy region. The 1100 MeV structure observed in photoproduction can also be considered a candidate vector gluon, although one may feel that its width is rather large. It should be recalled that both the absolute magnitude of Γ and Γ_{ee} are estimated in the above model under very specific dynamical assumptions: Γ_{ee} might be smaller if finite mass renormalization corrections are not negligible$^{(41)}$ and Γ might be larger, up to a factor of five in the estimate of the authors. Therefore the actual signal in e^+e^- could be well smaller and not as narrow as indicated in the previous example. One should wait for ALA/MDA to get a clear answer on this extremely important problem.

As well as coloured gluons, colored quarks of unit charge (and coloured $\bar{q}q$ mesons) could be produced free in the Pati-Salam model. These quarks can be looked for at ALA/MDA if their mass is of the order of 0.5-1 GeV. One can estimate that if the quark mass is so small, $\tau \gtrsim 2 \times 10^{-9}$ s which would leave the possibility open for short collinear tracks followed by decay inside the detector to be observed in MDA. The quark decay signature depends on the quark colour involved: typical decays are

$$q_{\text{blue, yellow, red}} \longrightarrow \nu + \text{mesons}\ , \qquad q^{\pm}_{\text{red}} \longrightarrow \text{lepton}^{\pm} + \text{mesons}\ .$$

In addition, if m_U happens to be smaller than m_q

$$q_{\text{red}} \rightarrow \text{gluon}^{\pm} + \text{neutrino} \longrightarrow \text{lepton}^{\pm} + \text{neutrinos}\ .$$

Although final states with neutrinos and mesons will certainly be signalled by missing energy and momentum in MDA, it looks unlikely that such an indirect signature might be conclusive because it can be simulated by a number of detector inefficiencies. More interesting are the decays involving charged leptons, which will give rise to anomalous $e^{\pm}\mu^{\mp}$ events as those originally observed at SPEAR. It is argued in ref. (44) that the anomalous $e\mu$ events of SPEAR might be interpreted as being due to q^+q^- production and decay. Of course, this argument has been weakened by the increased evidence for production of τ at SPEAR and DORIS: however, in the ALA energy region the possibility for $m_q \lesssim 1.2$ GeV, $M_{\tilde{U}} \lesssim 1.1$ GeV should be considered in its own rights. The corresponding $e\mu$ events have not been found at Adone$^{(8)}$, but since the branching ratio for these decays are hardly predictable, both this negative result and the lack of e events below $W \sim 3.7$ GeV at SPEAR and DORIS do not completely remove the interest for a new accurate search at a very luminous machine as ALA. Finally a sizable branching ratio for $q_{\text{red}} \rightarrow q_{\text{yellow, blu}} + \gamma$ is also predicted in this model, which adds an increased interest for a search for monochromatic photons with MDA.

6.4. - Indefinite mass particles.

B. M. McCoy and T. T. Wu have recently discussed$^{(12)}$ the possibility that quarks might be indefinite mass particles (imps), as those which are encountered in the two dimensional Ising model. Since there is no basic quantum-mechanical argument that can exclude this possibility, one is led to wonder whether quarks of this type and of fractional charge are indeed produced free in nature but have not been discovered yet because of the peculiar properties of the imps.

If a field has free particles (asymptotic states) there must be corresponding poles in the field propagator at $q^2 = m^2$. On the other hand, if there are no asymptotic states (confinement) there are two distinct possibilities:

a) the propagator is a simple function without discontinuities in the complex-q-plane, like a polinomial, an exponential, etc.

b) the propagator has a cut on the real positive axis, which can be considered like a sequence of poles with infinitely small separations from each other and zero residues.

In case b), one can consider that the carrier associated to the fields has an infinite number of states with a continuous mass distribution. A particle of this type (imp) will acquire a definite mass when is produced. For instance, one may think a light quark to have a mass larger than $1/3\ m_{\text{proton}}$ by up to one or two pion masses. A peculiar feature of imps is that after production, which takes place over a region of linear size ~ 1 fermi, their geometrical dimensions must grow indefinitely with time until they are not captured in matter, while they preserve their remaining properties (mass, momentum, total charge, etc.).

Although the speed and low of growth of imp size is hardly predictable, they will acquire after some time dimensions of the order of the optical wave lengths (10^3 Å), after which they would cease ionizing and would not be observable in scintillators, spark chambers, bubble chambers, nuclear emulsions and so on. Detection of particles of such a peculiar property requires special attention. One can estimate that if the natural quark ionization life $l_o = \approx 10$ cm they would have excaped detection in previous experiments, while they would be detectable at ALA/MDA (for a quark mass of $\sim 1/2$ GeV), up to a confiment factor as small as 10^{-3}(45).

Although the features of quark-imps may look rather dairing, the novelty of the idea, the peculiarity of the signatures as well as the importance of a possible discovery indicate that this is an addition relevant field of interest for research at ALA/MDA.

7. - CONCLUSIONS.

The progress with respect to Adone that is envisaged with the project can be summarized as follows :

R-measurement

Error down to better than 10% (precision limited by systematics), and measurements extended to $1.0 \lesssim W \lesssim 1.4$ GeV.

Search for narrow resonances

Extended to the still unexplored range $1.0 \lesssim W \lesssim 1.4$ GeV. Sensitivity down from $\sim 7\%$ of the J/ψ integrated cross-section to $\sim 3‰$ (precision limited by statistics).

Study of decay channels of vector meson recurrencies

Rate of order of 1 event/day provided by channels as rare as a few pb. Sensitivity limit probably set by sistematic errors (wrong signatures) to levels of 0.1 nb (1-2 nb at Adone).

Search for baryonium resonances at $W > 2\ M_p$

Signature provided by final state baryons, estimated sensitivity of the order of 10 pb (field not covered at Adone).

Search for radiative decays

This is a field not covered at Adone. The excess of photons observed in $\bar{p}p$ annihilation ($\sim 20\%$ per annihilation) would correspond to a large rate. If all these photons are attributed to radiative decays, the subsample of events with topology $2n\pi^{\pm} + \gamma$ ($\sim 10\%$ branching ratio), which can be expected to dominate over the physical background of misidentified events if the width is $\lesssim 5\text{-}10$ MeV, would give a rate of $\approx 0.5\ h^{-1} nb^{-1}$. Therefore these events should be detecteble at ALA/MDA, if the production cross-section is of the expected order of magnitude (several nb).

In the Pati-Salam vector gluon decay estimated overall rate for radiative decays is $\int \sigma \cdot B \sim$ $\sim 3\ \mu b \cdot GeV$, giving a rate about one hundred times above the sensitivity limit. Some decay channels, e. g. $\tilde{U} \rightarrow \eta' \gamma$, are very specific and should provide a clear enough signature.

Search for excited electrons

The present limit on the squared coupling constant of the $(e^* e \gamma)$ vertex), $\lambda^2 \lesssim 10^{-4}$ for $m_{e^*} = 1\text{-}2$ GeV, can be lowered to $\lambda^2 \lesssim 10^{-8}$ (sensitivity limited by statistics).

Search for stable, unstable or imp quarks

This is also a field not covered at Adone. A sensitivity (1 ev/day, limited by statistics) of $\lesssim 10^{-3}$ can be obtained on the product

$$\frac{(\text{charge}/e)^2 \times \text{confinement factor}}{\sigma_{\text{point like}}\,(\text{charge} = e)} .$$

We believe that these expectations fully justify the case made for ALA/MDA.

ACKNOWLEDGEMENTS.

One of us (G.B.) gratefuly acknowledges usefull discussions with Drs. C. Bemporad, O. D. Dalkharov, E. Etim, U. Gastaldi, and with Profs. Chan H. Mo, A. Salam and I. S. Shapiro.

REFERENCES

(1) - The great amount of experimental and theoretical work on J/ψ, ψ', ψ'', ... physics has originated from the primary discoveries reported in Phys. Rev. Letters 33, 1404, 1406, 1408 (1974).

(2) - The new physics for the heavier b-quark has originated from the Υ discovery reported in Phys. Rev. Letters 39, 252 (1977).

(3) - The ALA design can be found in Frascati Report LNF-78/15 (1978). Details on MDA can be found in: R.Bertani, M. Sc. Thesis at Pisa University (1979), Frascati Report LNF-79/11 (1979). The ALA/MDA physics is rewiwed in the Proceedings of the Topical Meeting on e^+e^- Annihilation at Medium Energies, Frascati (May, 1978).

(4) - C.Bemporad, Proceedings of the 1977 Intern. Symposium on Lepton and Photon Interaction at High Energies, Hamburg (August, 1977), p. 165.

(5) - G.P. Murtas, Frascati Report LNF-78/40 (1978); Presented at the XX Intern. Conf. on High Energy Physics, Tokyo (August, 1978).

(6) - B. Esposito et al., Lett. Nuovo Cimento 22, 305 (1978).

(7) - Private comunication by the MEA Group.

(8) - M.Bernardini et al., Nuovo Cimento 17, 383 (1973); A. Zichichi, Riv. Nuovo Cimento 4, 498 (1974).

(9) - M.Bernardini et al., Phys. Letters 45B, 510 (1973).

(10) - R.Baldini-Celio et al., Phys. Letters 71B, 227 (1977).

(11) - S.C.Pati and A.Salam, Phys. Rev. D8, 1240 (1973); Phys. Rev. Letters 31, 661 (1973); Phys. Rev. D10, 275 (1974).

(12) - B.M. Mc Coy and T.T.Wu, CERN Preprints TH 2405 (1977) and TH 2487 (1978).

(13) - Status Report on DCI, Orsay Techn. Report 2-77 (1977); Presented to the Xth Intern. Conf. on High Energy Accelerators, Serpukhov (July, 1977).

(14) - F.Laplanche, Recent results from DCI, Proceedings of the 1977 Intern. Symposium on Lepton and Photon Interactions at High Energy, Hamburg (August, 1977), p. 189; G.Cosmé et al., Phys. Letters 67B, 231 (1977).

(15) - J.E.Augustin et al., Orsay Report LAL 78/14 (1978).

(16) - H.Alvensleben et al., Nuclear Phys. 25B, 333, 342 (1971); Phys. Rev. Letters 27, 444 (1971); P.J.Biggs et al., Phys. Rev. Letters 27, 1157 (1971).

(17) - S.Bartalucci et al., Nuovo Cimento 39A, 374 (1977).

(18) - E.Gabathuler, Rapporteur talk at the XIXth Intern. Conf. on High Energy Physics, Tokyo (August, 1978); See also D.Peterson et al., CLNS-408 (1978).

(19) - A.S.Carrol et al., Phys. Rev. Letters 32, 247 (1974).

(20) - V.Chaloupka et al., Phys. Letters 61B, 487 (1976).

(21) - R.L.Kelly and R.J.N.Phyllips, Report R.L. 76-053 T 159/LBL 4879.

(22) - A.A.Carter et al., Phys. Letters 67B, 117 (1977).

(23) - P.Benkheiri et al., Phys. Letters 68B, 483 (1977).

(24) - L.Montanet, Proceedings of the Vth Intern. Conf. on Experimental Mesons Spectroscopy, Boston (1977), p. 260; CERN/EP Phys. 77-22 (1977). See, in particular, T.Armstrong et al., ref.(29) of this paper.

(25) - Ch.Defoix et al., Collège de France Report LPC 76-08 (1976).

(26) - P.Pavlopoulos et al., Phys. Letters 72B, 415 (1978).

(27) - We are grateful to Dr. U.Gastaldi for enlightning discussions on LEAR and its physics.

(28) - W.Hardt et al., CERN Preprint PS/DL/Note 79-1 (1979); U.Gastaldi, $\bar{p}p$ Experiments at very Low Energy using Cooled Antiprotons, and P.Dal Piaz et al., Low Energy Antiproton Experiments with an "Antiproton Factory" at CERN, Proceedings of the IV European Antiproton Symposium, Barr (June, 1978).

(29) - G.Bassompierre et al., Determination of the Proton Electromagnetic Form Factor at and near Threshold of the Time-like Region, Contributed paper to the IV European Antiproton Symposium, Barr (June, 1978).

(30) - See for instance M.Böhm et al., Nuclear Phys. B51, 397 (1973).

(31) - A.Bramon and M.Greco, Lett. Nuovo Cimento 3, 693 (1972).

(32) - See for instance J.A.Shapiro, Phys. Rev. 179, 1345 (1969).

(33) - M.Greco, Frascati Reports LNF-77/30 (1977) and LNF-76/55 (1976).

(34) - A. D. Bukin et al., Phys. Letters 73B, 226 (1978); F. Felicetti and Y. Srivastava, Frascati Report LNF-79/1 (1979).

(35) - G. Nardelli and G. Preparata, Frascati Report LNF-77/56 (1977). See also J. P. Perez-y-Jorba and F. M. Renard, Phys. Reports 31, 3 (1977).

(36) - M. Greco, G. Penso and Y. Srivastava, Frascati Report LNF-78/49 (1978).

(37) - O. D. Dalkarov and I. S. Shapiro, Report ITEP-154 (1978): I. S. Shapiro, Phys. Reports 35, 129 (1978), and references quoted in these papers.

(38) - T. E. Kalogeropulos, Proceedings of the VIth Intern. Conf. on Nuclear Structure and High Energy Physics, Santa Fé (June, 1975), p. 168.

(39) - R. Vinh Mau, The Baryon-antibaryon Description of Baryonium, Proceedings of the IV European Antiproton Symposium, Barr (June, 1978).

(40) - C. B. Dover and J. M. Richard, Report BNL 24981, and references therein.

(41) - Chan Hong-Mo, CERN Report TH 2540 (1978); Chan Hong-Mo and H. Høgaasen, Phys Letters 72B, 400 (1977); Nuclear Phys. B136, 401 (1978).

(42) - G. F. Chew and C. Rosenzweig, Phys. Reports 41C, 423 (1978).

(43) - C. Rossi and G. Veneziano, Nuclear Phys. B123, 507 (1977). See also F. Myhrer, CERN Preprint TH 2348 (1976).

(44) - J. C. Pati and A. Salam, ICTP Report IC/77/65 (1977).

(45) - G. Bellettini and T. T. Wu, MDA Internal Group Memo (1978).