TIME-LIKE ELECTROMAGNETIC STRUCTURE OF THE HADRONS.

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High energy charged leptons have been used in the last ~ 20 years as probes of the space-like electromagnetic (E.M.) structure of hadrons (h).

Their suitability to this purpose derives from the validity of the following hypothesis:

a) They are point-like (described by the Dirac equation)
b) The scattering of leptons is well described by first order, one photon-exchange diagrams
c) The photon propagator is simply given by $1/q^2$ (Maxwell equations), the inverse four-momentum squared of the photon itself.

A a consequence of the above hypothesis the amplitude for electron-hadron elastic scattering can be written in terms of the matrix elements of one single unknown vector(1), the E.M. current J^h brought by the target hadron. In turn, by simple use of very general hypothesis (Lorentz invariance, gauge invariance) J^h_μ can be expressed in terms of a small number of form factors.

Also the cross section for inclusive inelastic scattering (namely in which only one of the products of the reaction is detected and measured) can be expressed in terms of structure functions, containing informations about the excitation mechanism of the target hadron. By conveniently increasing the momentum transferred by the lepton to the hadron in the scattering reaction the structure of the hadron can be explored with a resolution which is limited only by the performance of the lepton accelerator.

The above hypothesis b) has been tested by comparing electron and positron scattering on proton, and by measuring the polarization of the recoil proton in e-p scattering as well as the asymmetry in e-p elastic scattering on polarized protons: this is not, however, among the objects of this talk.

Let me only recall, here, that hypothesis b) is not rigorously true, and it is to be intended in the sense that the usually small contribution from higher order graphs can be correctly aestimated by means of appropriate, known techniques(2). (Radiative corrections).

The evaluation of radiative corrections is not trivial, involving long and complicated calculations in addition to some delicate problems of convergence. In addition it falls in a cathegory of problems which often is covered neither by theoreticians nor by experimentalists, the first ones being not interested to it and the second ones being not able to go through the calculations. Usually, it is solved by introducing rather drastic approximations, whose validity is often by no means obvious.

The improvement of the quality of the experimental information is to be accompanied, in the next years, with improvements in the calculation of radiative corrections.

Hypothesis a) and c) have been always considered quite firm. However, the direct experimental proof at high energy came only recently, after the operation of e^+e^- and e^+e^- storage rings.

The experimental situation is presented in Fig. 1, which shows the ratio $R = (\sigma_{exp})/(\sigma_{QED})$ of the experimental to the theoretical cross-sections for elastic electron-electron (electron-positron) scattering.

Since the amplitude is dominated by the scattering diagram, R is essentially given by $F_e^4(q^2)M_\gamma^2\ (q^2)$, where $F(q^2)$ is the electric electron form factor (the g-2 experiments show that the contribution of the anomalous magnetic moment term to the electron current is negligible) and $M_\gamma\ (q^2)$ is a possible modification of the photon propagator

$$\left(\frac{1}{q^2} \longrightarrow \frac{M_\gamma\ (q^2)}{q^2}\right) .$$

is the average four momentum squared (space-like) of the virtual photon. The data below $q^2 = 1(\text{GeV}/c)^2$ are from the Orsay(3) and Princeton-Stanford rings(4), and from the Frascati ring Adone(5) for $1(\text{GeV}/c)^2 < q^2 < 2.5\ (\text{GeV}/c)^2$.

Let us now consider the time-like region, investigated during the last few years with e^+e^- storage rings. Here, the smallness of the usual two-photon exchange contribution

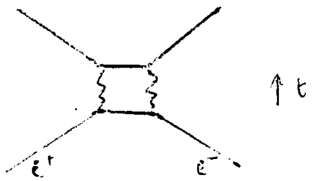
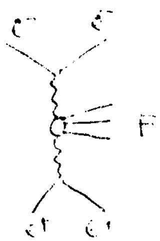


Diagram (1)

has not been experimentally tested, and we have therefore to trust on the calculations based on the absence of strong enhancement mechanisms.

It is worth noticing that in the t-channel the number of the exchanged virtual photons is directly related with the charge conjugation eigenvalue of the final state. If the charge of the produced particles is not recognized (as it was the case for all the experiments performed up to now with e^+e^- storage rings) then the interference term between even and odd states of C cancels, giving thus strong enough reliability to the above hypothesis.

There is however an additional two photon diagram, which is expected to be quite important in the electron storage rings namely



e.g.:

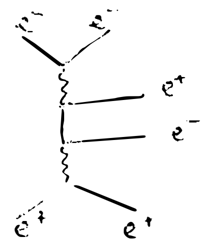
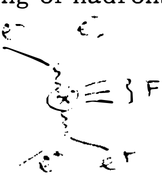


Diagram 2a) , Diagram 2b)

The additional α^2 factor appearing, e.g., in diagram 2b) is in fact expected to be at least partially compensated by the fact that this process can involve much lower momentum transfers that the usual annihilation graphs.

The contribution from the above diagrams might give rise to a dangerous background in the e^+e^- experiments.

However, they deserve also some interest by themselves since, in addition to providing additional QED testes, they can give useful information on the coupling of hadrons with a two photon system, e.g.



via the production of an intermediate hadron x (x could be, e.g. an η or an η'). This will be particularly true with higher energy storage rings since the cross-section is expected to logarithmically increase with increasing energy, while the usual annihilation cross-sections are expected to show typically a 1/S decrease (see fig. 2).

Fortunately, the angular and energy distribution for this two-photon reactions, is quite peculiar. For instance in reaction $e^+e^- \to e^+e^-e^+e^-$ two leptons are expected to be emitted in a narrow cone along the beam directions, while the other two, when emitted at large angle, should have a $\Delta\phi$ distribution strongly peaked around $\Delta\phi = 0$[6, 7] ($\Delta\phi$ is the angle between the planes defined by the beam axis and the two emitted particles).

Experimentally, the $\Delta\phi$ distribution for the above process has been investigated at Novosibirsk[8]. The results are shown in fig. 3, and are compared with the theoretical calculation of Baier and Fadin[7].

Some preliminary measurements of this reaction, and also of reaction $e^+e^- \to e^+e^+\mu^+\mu^-$, have also been performed at Adone[9].

Here additional counters have been placed near the machine vacuum chamber in order to detect the electron and positron emitted near the beam directions, using as spectrometers the magnets of the machine itself (fig. 4).

In this case some additional information on the kinematics can be obtained: if all the four emitted particles are detected, the kinematics of the event can actually be completely reconstructed.

In fig. 5 the distribution of the events as a function of β, the c.m. velocity of the e^+e^- emitted at large angle, is given. ($\gamma\gamma$-group). The sign of β is defined as negative when β has the same orientation as the single detected electron along the beam direction (29 events. Also $\sim$ 3 events $e^+e^- \to e^+e^-\mu^+\mu^-$ ($\pi^+\pi^-$) have been observed).

Comparison with theory is also given. It appears that the approximations used in the theoretical calculations[6, 7, 10] (and based on the dominance of some particular kinematical configurations) although adequate for the evaluation of total cross-sections and $\Delta\phi$ distribution, don't provide a good description of the kinematical features of the large angle events.

Better theoretical calculations would therefore be welcome. Anyway, the possibility of some higher energy storage rings to be operated both as e^+e^- and as e^-e^- (like the german Doris) appears as a convenient facility to study, in the e^-e^- mode of operation, the two-photon interactions without contamination from the annihilation channels

Going back to the two hypothesis a) and c) (point-like leptons and $1/q^2$ photon propagator) experimental tests at high energy in the time-like region have been performed by studying μ pair production from e^+e^- interactions.

The experimental situation is presented in fig. 6[11]. The results are expressed in terms of the ratio $R = (\sigma_{exp})/(\sigma_{QED})$. The agreement is good within the experimental errors (typically 15-20%) up to momentum transfers as high as $S = 4.4\ (GeV/c)^2$.

There is something missleading, in my opinion, in the attitude which is usually taken to parametrize this kind of data in terms of a breakdown cut-off parameter.

In fact, this leads to the tendency to perform higher and higher energy experiments with not necessarily a good precision, since in the cut-off philosophy deviations from QED are expected to increase with increasing energy.

This might very well be wrong. Actually, a breakdown of QED is expected, due to vacuum polarization effects originated by hadrons coupled to the virtual photon.

This kind of breakdown is not necessarily more important at higher energy. This is experimentally demostrated in fig. 7, showing the results of another experiment[12] on reaction $e^+ + e^- \longrightarrow \mu^+ + \mu^-$ (Orsay) performed at a C.M. energy which is lower than in the previously quoted experiments.

The energy region explored is around the ϕ-meson mass, and a vacuum polarization effect is showing-up, although at the limit of the experimental errors.

It is time, in my opinion, that experiments on the electromagnetic interactions of leptons are performed, at whatever energy, with a precision of the order of 1%.

Let us now consider the production of hadrons in e^+e^- interactions via the annihilation channel.

Below $\sim$ 1 GeV total c.m. energies, experiments at Orsay and Novosibirsk have been performed during the last $\sim$ 5 years. The coupling of isovector and isoscalar photons to hadrons has been measured quite extensively, and the results are well known. The phenomenology is dominated by the production of the vector mesons ρ, ω, and ϕ, whose parameters have been studied in good detail: for a summary of the results (which refer to mass, width and decay branching ratios of ρ, ω and ϕ including rare decay modes) see for instance ref. 13.

These results gave body to the hope that the e.m. interactions of the hadrons were accounted for by the coupling of the photon to the ϱ , ω and ϕ only, so that the form factors of all the hadrons could be expressed in terms of quite a small number of parameters. In particular the pion e.m. structure, (described by a single form factor F_π (S) simply related in the time-like region to the $e^+e^- \rightarrow \pi^+\pi^-$ cross section ($\sigma_{\pi^+\pi^-} = (\pi \alpha^2/12)\cdot(\beta^3/E^2)\cdot |F_B(S)|^2$)), is essentially accounted for, below 1 GeV, by the production of the ϱ (the forseen interference term with the ω contribution (via the e.m. decay $\omega \rightarrow \pi^+\pi^-$) having also been observed).

The experimental situation of F_π (S) below 1 GeV is presented in fig. 8(x).

(x) - However, the simple ϱ, ω, ϕ vector meson dominance was already in some trouble due to the behaviour of the isovector form factors F_v of the nucleons as a function of the four momentum squared t.

$$F_v(t) \sim \frac{1}{t^2}$$

In fact, using the relation

$$F_v(t) \propto \int \frac{I_m F_v(S)}{t-s} \, dS$$

and the identity

$$\frac{1}{t-S} = \frac{1}{t} + \frac{1}{t}\,\frac{S}{t-S}$$

we have

$$F_v(t) \propto \frac{1}{t} \int I_n F_v(S) dS + \frac{1}{t} \int \frac{S I_m F_v(S) dS}{t-S}$$

$F_V(t) \propto 1/t^2$ requires $\int I_m F_v(S) dS = 0$. This however cannot be satisfied if $F_V(S)$ is due to the ϱ contribution only, since the ϱ has a large, positive definite, imaginary part.

Best fits to the data in terms of ϱ -production only, and including the contribution from the $\omega \longrightarrow \pi^+\pi^-$ decay amplitude, are also shown. The agreement is good, expecially when the ω contribution is included.

Recently, experimental data on hadron production above 1 GeV total energy have become available.

Here, the agreement with the simple models based on ϱ , ω and $\emptyset$ dominance is on the contrary rather bad.

Let us see how the data look.

In fig. 9 the measurements of F_π^2 (S) above 1 GeV total energy is presented(14).

We see that for 1< S < 4 GeV/c F_π^2 is much larger than the ϱ -tail, and it actually approaches the value $F_\pi^2 = 1$ typical of point-like particles. The simple vector dominance models fail thus in this energy region.

The data on K form factors, for S > 1 (GeV)^2, are extremely poor. Only four events have been observed at Novosibirsk, and are presented in fig. 10 in terms of $|F_K|^2$.(15) No conclusion is of course possible; it is however legitimate to suspect that also the K form factor is probably large.

Are these large cross-sections due to the existence of new, broad resonances? Or do the pseudoscalar mesons behave, at large enough energy, as point-like particles? Are we already approaching an asymptotic, regim region?

After the data on e-p deep inelastic scattering, large cross-sections in electromagnetic processes have become quite familiar. The current models in terms of point-like constituents (either particles or devices to give a picture of the formalism) cane actually account for large cross sections in the inelastic processes. However, the cross sections for elastic processes involving the physical, composite particles, is expected to drop very fast with increasing momentum transfer, consistently with the experimental data e.g., on elastic e-p scattering ($F(q^2) \propto 1/q^4$).

The experimental study of the pseudoscalar mesons form factors (at these and at the higher energies forseen for the next future) appears as a promising source of complementary information to clarify, and may be to modify, our present point of view about the e.m. structure of the hadrons.

Let us consider now the process

$$e^+e^- \longrightarrow p\bar{p}$$

described by the cross section

$$\frac{d\sigma}{d\Omega} = \frac{\pi}{8}\lambda^2\beta\left[\left|G_M\right|^2(1+\cos^2\theta) + \frac{1}{\tau}\left|G_E\right|^2\sin^2\theta\right)$$

$$\tau = \frac{S}{4M^2}$$

$$(\sigma = 10^{-32}\left(\left|G_M(S)\right|^2 + \frac{1}{2\tau}\left|G_E(S)\right|^2\right)$$

By measuring the angular distribution in the above process $|G_M|^2$ and $|G_E|^2$ can thus be extracted.

G_E and G_M are given by

$$G_E = F_1 + K\tau F_a \qquad G_M = F_1 + K F_2$$

$K = \mu - 1$ anomalous magnetic moment of the proton.

It is well known that in the space-like region the form factors are approximately described by the empirical laws

$$\frac{G_{Mp}(q^2)}{M_p} = G_{Ep}(q^2) = \frac{G_{Mn}(q^2)}{\mu_n}$$

("scaling law" of the form factors)

$$G_{Ep} = \left(\frac{1}{1+q^2/0.71}\right)^{-2} = G_D$$

(Dipole fit).

which hold to within $\lesssim 20\%$ for q^2 up to 6-8 $(\mathrm{GeV}/c)^2$. It is worth noticing that the validity of the "scaling law" near threshold for $p\bar{p}$ production would produce catastrofic effects: in fact

$$F_1 = \frac{G_E - \tau G_M}{1 - \tau} \quad \text{and} \quad F_2 = \frac{G_M - G_E}{1-\tau}$$

when $\tau \Rightarrow 0$ diverge unless $G_E \Rightarrow G_M$. This would produce an unwanted divergence in the E.M. current brought by the proton.

A first measurement of σ $(e^+e^- \rightarrow p\bar{p})$ has been performed at Adone by the Naples group(16). 21 events have been observed: the separation from background based on geometrical requirement, energy and dE/dx measurements in a thick scintillator telescope, is quite clean. 14 of the 21 observed events show the annihilation star of the antiproton; this is consistent with the detection efficiency of the antiproton annihilation star.

The value of the cross-section is $(5 \pm 2)\ 10^{-34}\ cm^2$. Fig. 11 shows how this value compares with previous upper limits and with the expected value of σ.

G_E and G_M cannot be extracted from this experiment: this is due not only to statistics, but also to the fact that the experimental apparatus efficiency is strongly peaked around $\theta = 90^o$.

To evaluate the cross-section, an isotropic angular distribution has been assumed (namely $|G_E|^2 = |G_\mu|^2$).

It is clear that this experimental gives only the first insight to an open field of investigation. Further experiments are planned both in Frascati and at Spear.

Let us now consider inelastic processes or, as they are better named in the case of production via the annihilation channel, multiple production channels.

No data are yet available in the baryonic channels, while we have results on the mesonic channels. No distinction has been performed up to now between pions and kaons, and the experimental yields have been analyzed in the hypothesis that we are dealing with pions.

The observation of multiparticle production from e^+e^- interactions has been first achieved in Frascati ~ two years ago(17), and the first results in terms of yields have been presented at the Kiev Conference. Since then the hadronic nature of the observed processes has been demonstrated: this is based on a statistical analysis of the properties of the observed particles: dE/dx, penetration, nuclear interaction cross sections.

In addition, we have now the first data on the cross sections. The problem of extracting cross sections from the yields is not trivial, expecially with apparata covering a solid angle not larger than $(.2 - .25)\ 4\pi$, like the ones presently in operation. In fact this involves an extrapolation of over the full solid angle of angular distributions observed only in a rather small angular region, and in addition the multiplicity channels are not well separated experimentally, which in turn reflects in uncertainties in the detection efficiencies.

However, cross section measurements have been performed. These results, in spite of the (20 - 30%) errors, deserve considerable interest.

In addition, it has been demonstrated that the data do not con tain appreciable contamination from the two photon interaction channels previously mentioned of the type

$$e^+e^- \longrightarrow e^+e^-e^+e^-; \quad e^+e^- \longrightarrow e^+e^-\pi^+\pi^-$$

Let us go through the results.

In fig. 12 an angular distribution of the non coplanar events, divided by the detection efficiency, is shown. It appears quite flat, the space left to a $\Delta\phi$ peak typical of $e^+e^- \longrightarrow e^+e^-e^+e^-$ (or $e^+e^- \longrightarrow e^+e^-\pi^+\pi^-$) being quite small (the maximum contamination is $\lesssim 10\%$).

In fig. 13 the total cross section for production of any channel with more than two charge particles is presented. The data at $E_{c.m} = 2E \geq 1.4$ GeV are from Frascati[18]. There is an Orsay point[19] at 1 GeV, and a Novosibirsk result at $E_{c.m} \simeq 1.3$ GeV[20].

The first comment is about the magnitude of the cross section, which appears to be surprisingly large. For comparison, let me recall that the cross section for production of a pair of point-like fermions is 20 nbarns at 2 GeV, while the production of a pair of point-like bosons is at the same energy 5 nbarns: both behave as $1/S = (1/E_{cm}^2)$.

The energy behaviour shows a steep increase between 1 and ~ 1.3 GeV, followed by a slow fall-down consistent with a $1/S$ behaviour. The steep increase could also be due to simple phase space if the average multiplicity is high (4-6 pions).

This can recall us the situation in the deep inelastic processes where the inelastic cross-section, with increasing momentum transfer, reach rather soon the regim behaviour and size of the pointlike cross sections.

A first separation of the different processes contributing to the total cross-section has also been achieved.

Here the situation is much more confused. The cross-section for the channel with 2 charged particles only appears quite flat and small. Channel $e^+e^- \longrightarrow \pi^+\pi^-\pi^+\pi^-$ shows a broad bump around 1.6 GeV; the $e^+e^- \longrightarrow \pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$ appears to increase slowly its contribution to the overall picture. Only the channel $e^+e^- \longrightarrow \pi^+\pi^-\pi^+\pi^-$ + neutrals has more or less the same behaviour as the total cross-section.

Also in this case we are obviously at our first contact with a full field of investigation.

If a regim situation has been reached in the total cross section, this is certainly not true in each single channel: but this is, maybe, what we would expect at arbitrarily large energy. However,

it is well possible that we are still completely in the resonance-region, either a tail of the known resonances (with the simple opening of new decay channels) or the production of new resonances (
Both these hypothesis have been considered - by Renard[21] and Bramon-Greco[22].

A new resonance would actually be welcome also to fix some problems in the usual vector dominance-models, and according to Bramon and Greco a ρ' could account for the $e^+e^- \to \pi^+\pi^+\pi^+\pi^-$ cross-section and also for a bump in the 4π system observed at Stanford in the process

$$\gamma + c \longrightarrow c + \pi^+\pi^-\pi^+\pi^- .$$

But the only sensible conclusion is that we have much experimental work to do, at these and higher energies, of the inclusive and exclusive type, in a field of investigation which appears extremely promising.

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FIGURE CAPTIONS -

FIG. 1 - Comparison of the experimental data on e^-e^- and e^+e^- elastic scattering with QED. The results are expressed in terms of the ratio σ_{exp}/σ_{th}. Bars are statistical errors, while the boxes represent the systematic uncertainty.

FIG. 2 - Calculated cross-sections for some "two-photon interaction" reactions, as compared with reactions via the annihilation channel. The pion is assumed point-like.

FIG. 3 - Pair electroproduction events distribution with respect to angle $\Delta\varphi$. Solid curve is obtained with the Baier and Fadin formulas. Dashed one represents the computed distribution for the process with independent and isotropic particle distribution.

FIG. 4 - Schematic view of the experimental apparatus for detection of reaction $e^+e^- \longrightarrow e^+e^-e^+e^-$ at Adone.

FIG. 5 - Results on reaction $e^+e^- \longrightarrow e^+e^-e^+e^-$ obtained at Adone ($\gamma\gamma$ -group). a) distribution of the events as a function of β, the c.m. velocity of the wide angle leptons. b) $\Delta\phi$ distribution.

FIG. 6 - Results on reaction $e^+e^- \longrightarrow \mu^+\mu^-$, expressed in terms of the ratio $R = (\sigma_{exp}/\sigma_{th})$.

FIG. 7 - Results on the reaction $e^+e^- \longrightarrow \mu^+\mu^-$ around the ϕ mass.

FIG. 8 - Results on the reaction $e^+e^- \longrightarrow \pi^+\pi^-$ for total c.m. energy below 1 GeV. Best fits with the ϱ -breit-wigner (full-line) and including the contribution from the decay $\omega \longrightarrow \pi^+\pi^-$ (dashed line) are also shown. The results are expressed in terms of $|F_\pi|^2$.

FIG. 9 - Measurements of $|F_\pi|^2$ above 1 GeV.

FIG. 10 - Measurements of $|F_k|^2$ (Novosibirsk data).

FIG. 11 - The experimental situation on the cross section for reaction $e^+e^- \longrightarrow p\bar{p}$.

FIG. 12 - a) Theoretical shape of $d\sigma/d(\Delta\varphi)$ for the reaction $e^+e^- \longrightarrow e^+e^-e^+e^-$, according to Baier and Fadin(22); b) $d\sigma/d(\Delta\varphi)$ calculated from the experimental $\Delta\varphi$ distribution of in-time, in-source non-coplanar events.

FIG. 13 - Summary of the experimental determinations of the cross-sections for reactions $e^+e^- \longrightarrow a^\pm + b^\pm$ + anything. Our result are compared with the data from ACO (Ref. (31a)), Novosibirsk (Ref. (31b)), Adone $\gamma\gamma$ group (Ref. (31c)) and Adone $\mu\pi$ group (Ref. (31d)). a) $\sigma_{4\pi^\pm}$; b) cross-section to produce 4 charged pions plus neutrals, $\sigma_{4\pi^\pm, N}$; c) total cross-section, σ_{TOT}.

FIG. 14 - Summary of the experimental determinations of the cross-sections for reactions $e^+e^- \longrightarrow a^\pm + b^\pm$ + anything. Our results are compared with the data from ACO (Ref. (31a)),

Adone $\gamma\gamma$ group (Ref. 31c)) and Adone $\mu\pi$ group (Ref. (31d)). a) $\sigma_{6\pi^\pm}$; b) cross-sections to produce at least 4 charged pions (plus possible neutrals), $\sigma_{\geq\pi 4^\pm, TOT}$; c) cross-sections to produce 2 charged pions plus neutrals, $\sigma_{2\pi^\pm, N}$.

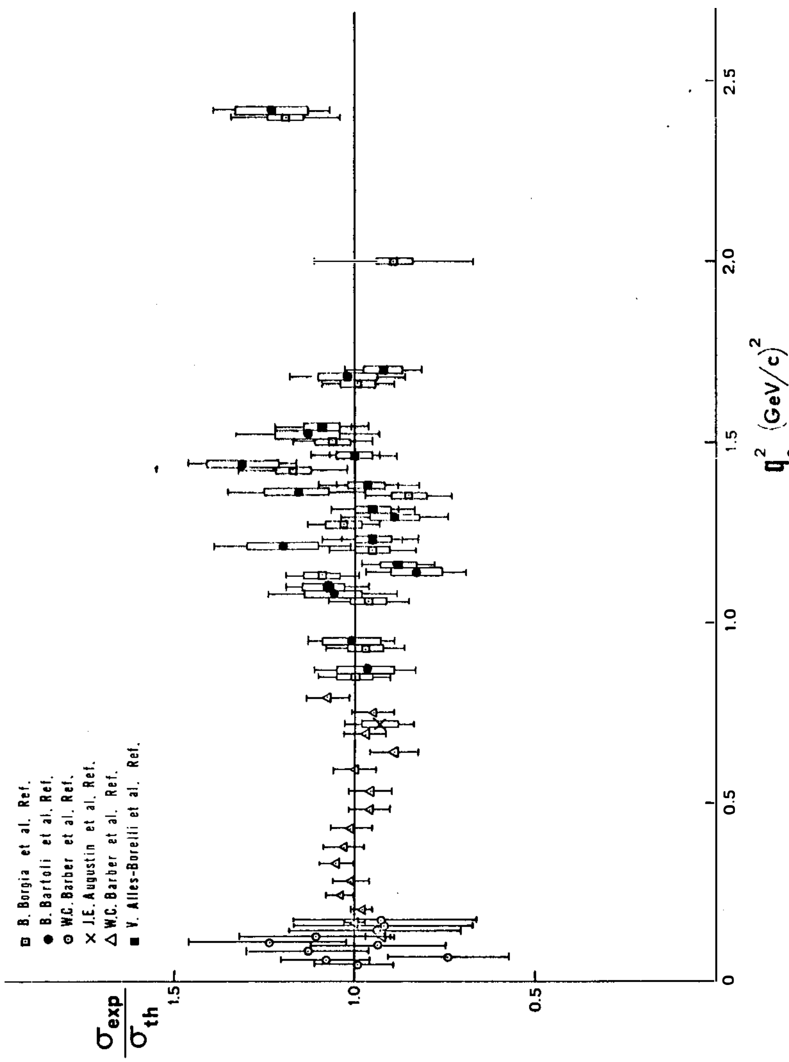
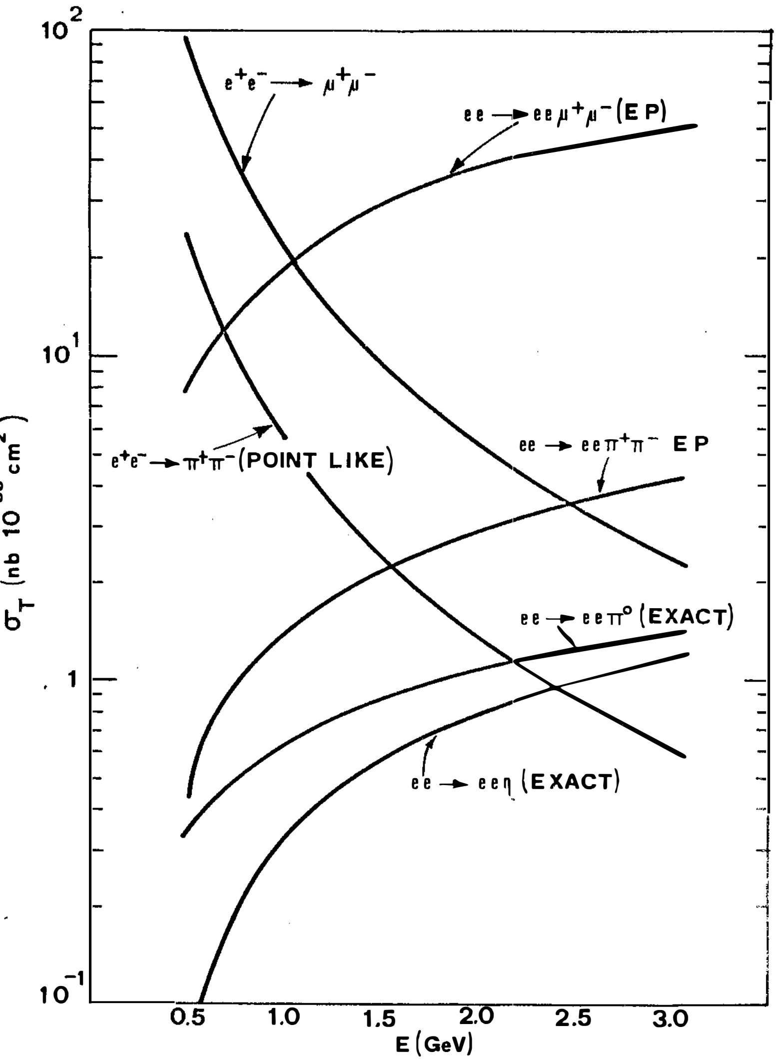

B. Borgia et al. Ref.
B. Bartoli et al. Ref.
W.C. Barber et al. Ref.
J.E. Augustin et al. Ref.
W.C. Barber et al. Ref.
V. Alles-Borelli et al. Ref.
$\frac{\sigma_{exp}}{\sigma_{th}}$
1.5
1.0
0.5
0
0.5
1.0
1.5
2.0
2.5
q_e^2 $(GeV/c)^2$

FIG. 1



10^2
10^1
1
10^{-1}
σ_T (nb 10^{33} cm^2)
0.5
1.0
1.5
2.0
2.5
3.0
E (GeV)
$e^+e^- \to \mu^+\mu^-$
$ee \to ee\mu^+\mu^-$ (E P)
$e^+e^- \to \pi^+\pi^-$ (POINT LIKE)
$ee \to ee\pi^+\pi^-$ E P
$ee \to ee\pi^0$ (EXACT)
$ee \to ee\eta$ (EXACT)

FIG. 2

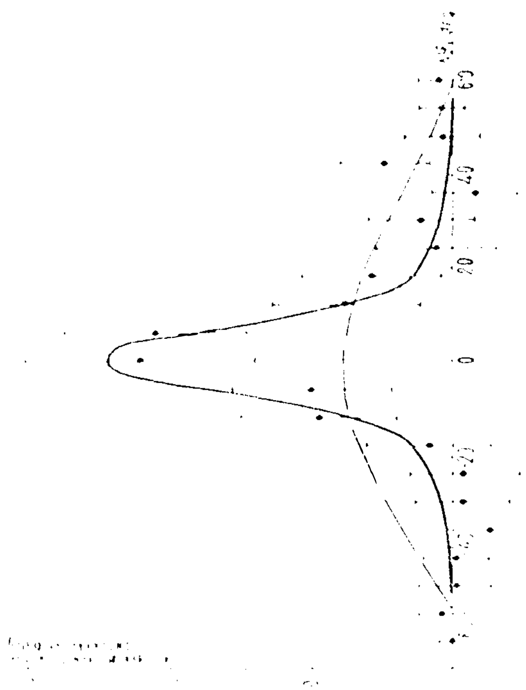


FIG. 3

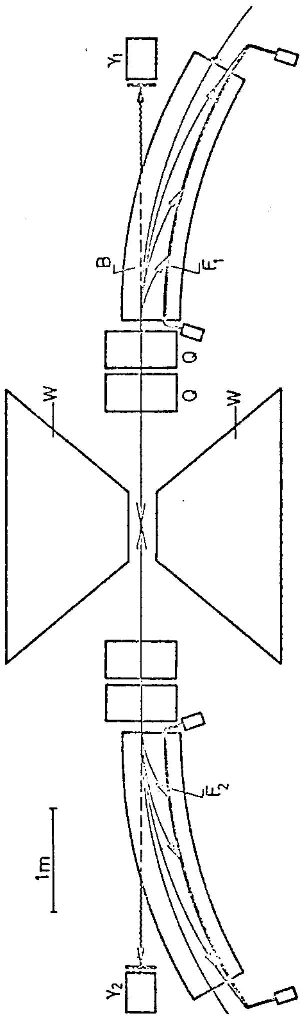


FIG. 4

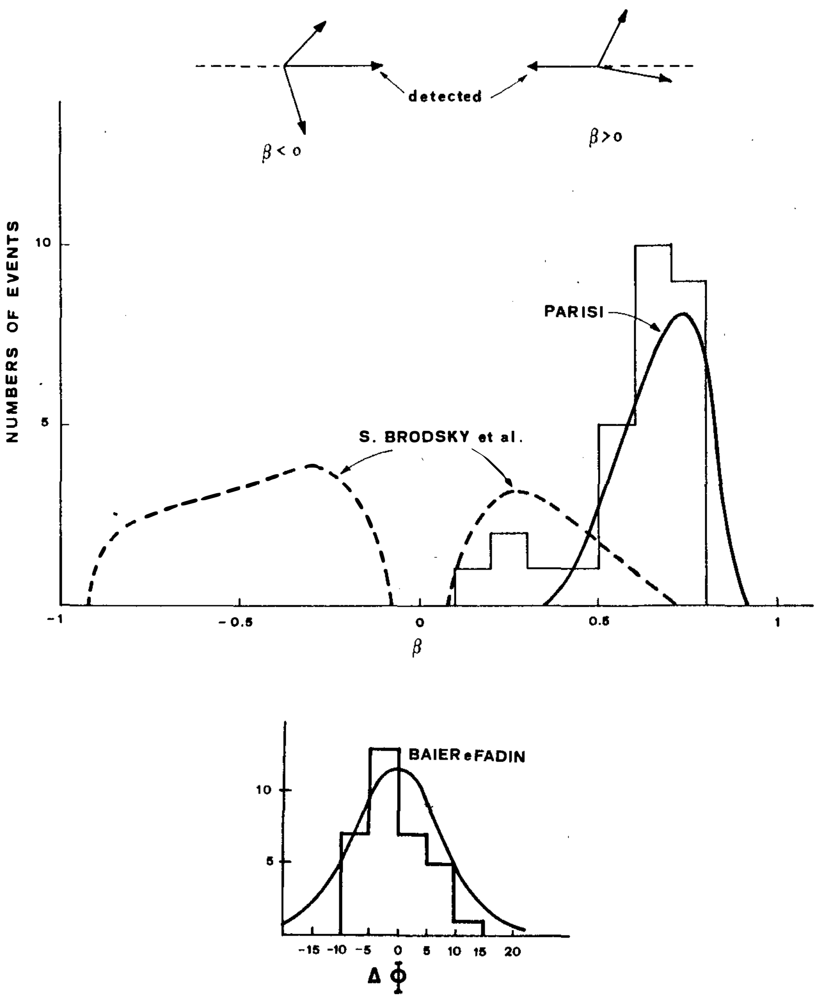

detected
β < o
β > o
NUMBERS OF EVENTS
10
5
PARISI
S. BRODSKY et al.
-1
-0.5
0
0.5
1
β
BAIER e FADIN
10
5
-15 -10 -5 0 5 10 15 20
ΔΦ

FIG. 5

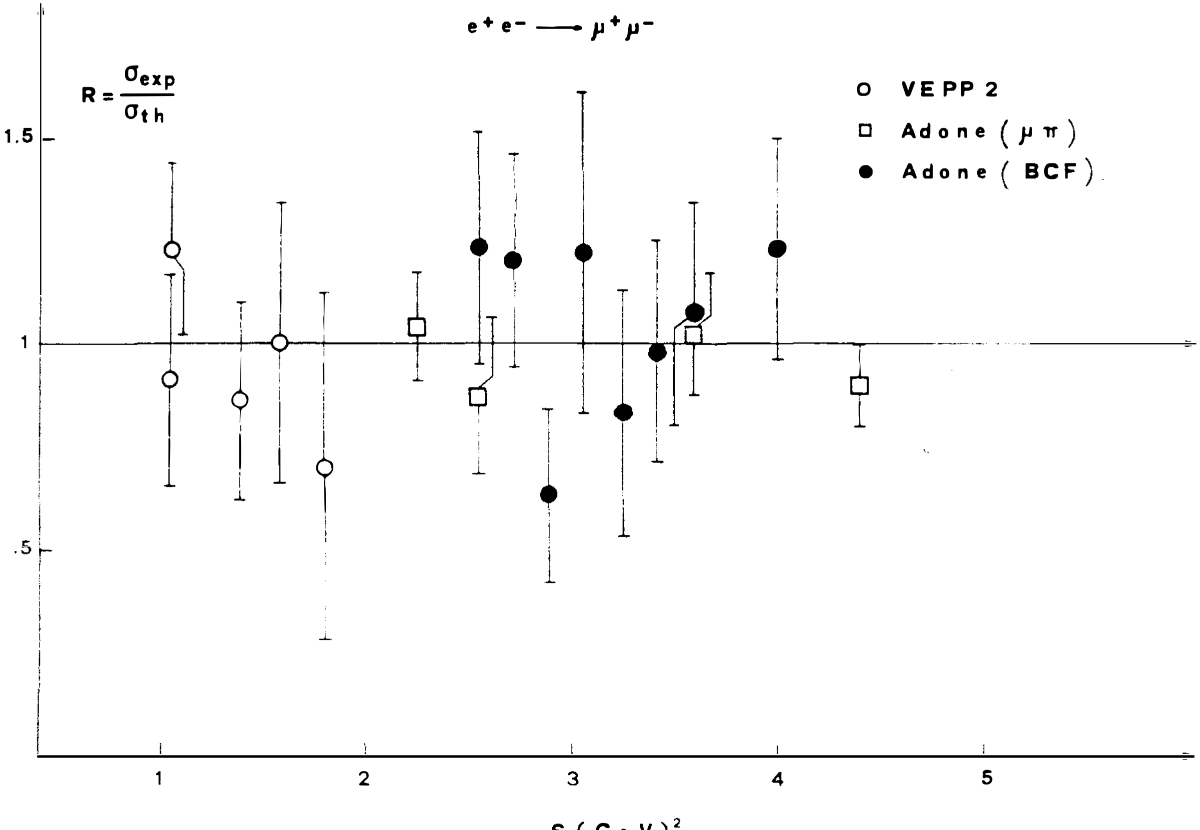
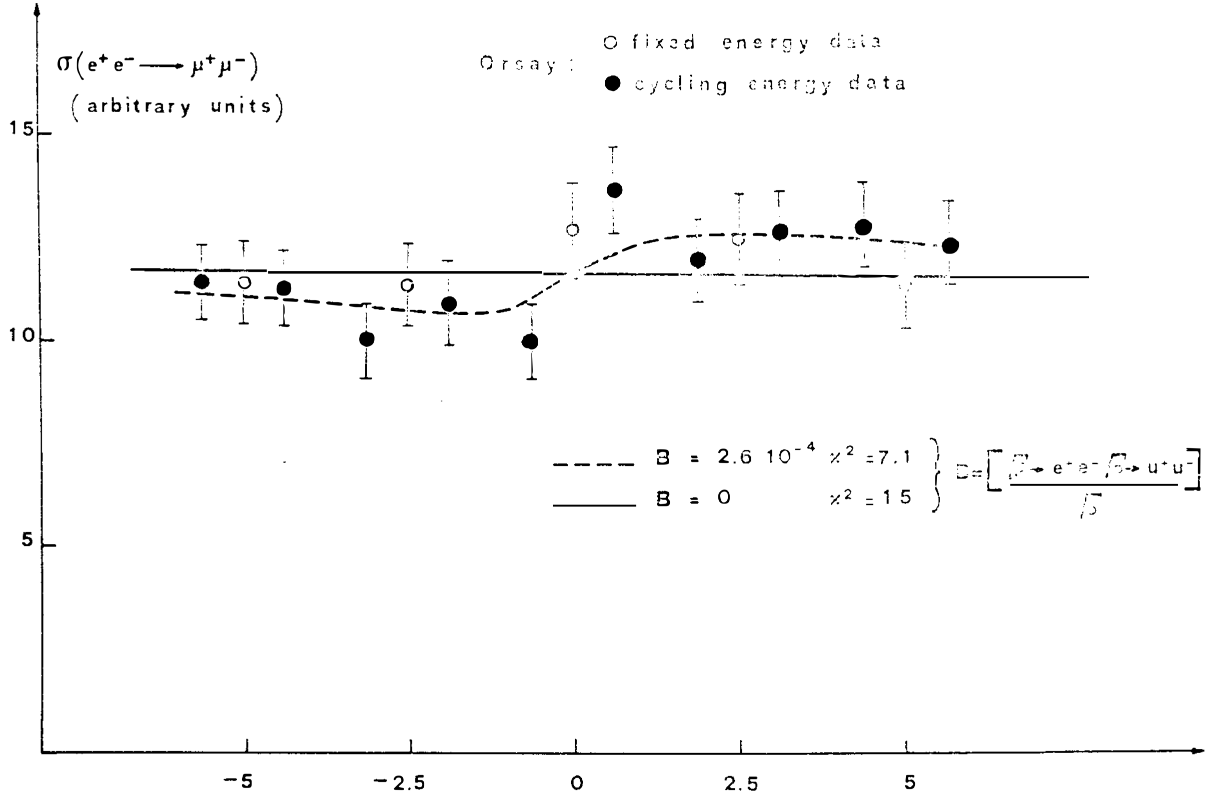


FIG. 6



σ(e⁺e⁻ → μ⁺μ⁻)
(arbitrary units)
Orsay :
fixed energy data
cycling energy data
B = 2.6 10⁻⁴ χ² = 7.1
B = 0 χ² = 15
15
10
5
−5
−2.5
0
2.5
5

FIG. 7

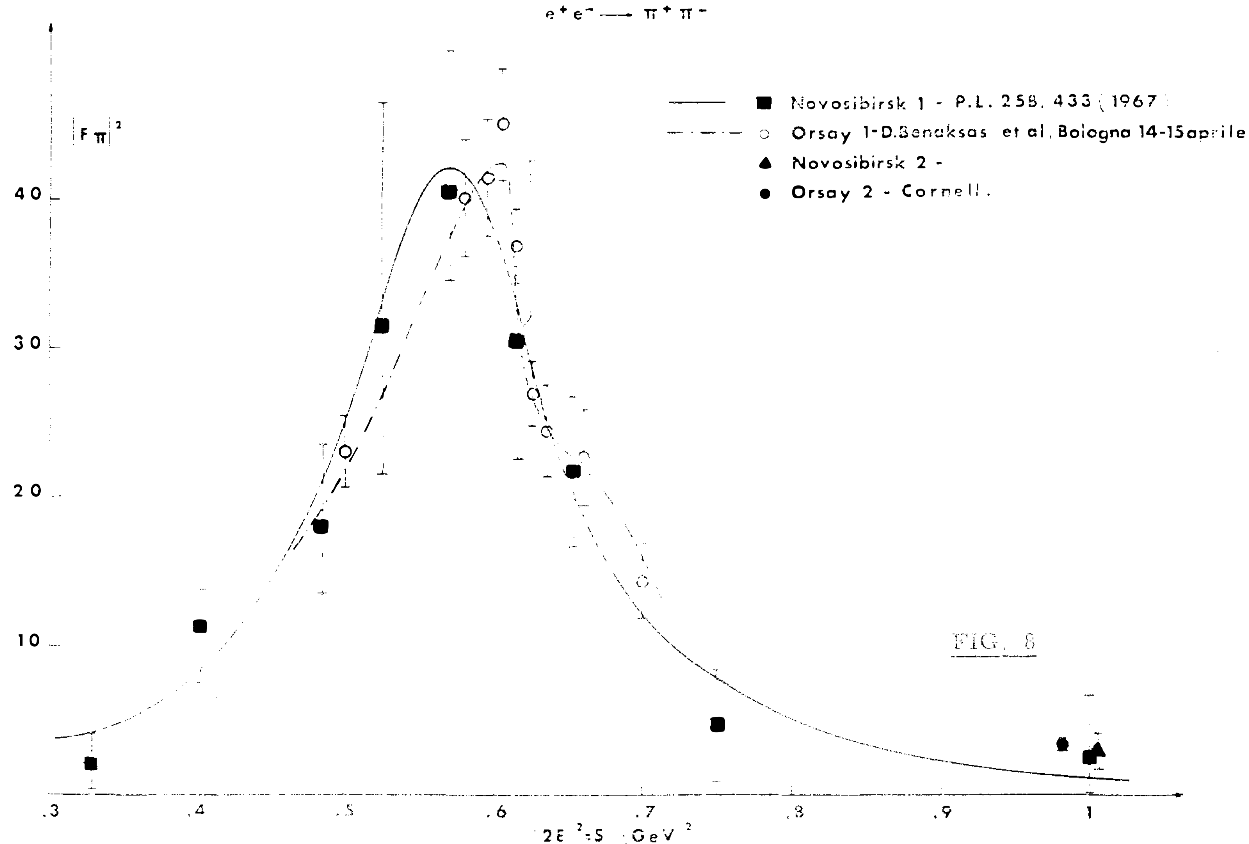
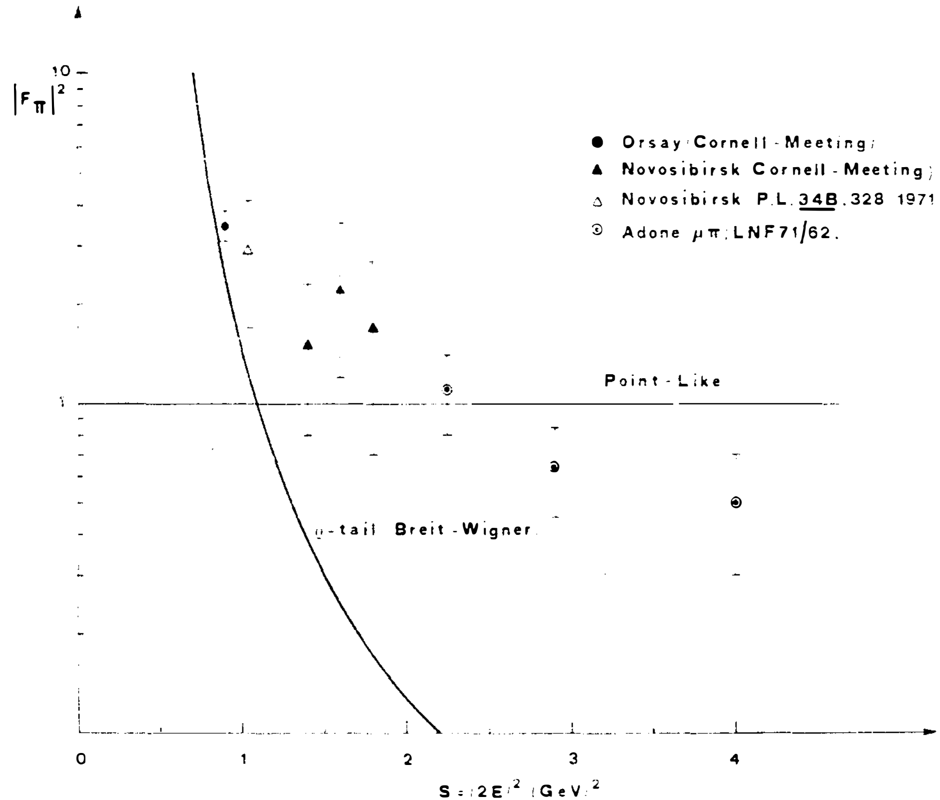

e⁺e⁻ —— π⁺π⁻
|F π|²
Novosibirsk 1 - P.L. 25B, 433 (1967)
Orsay 1-D.Benaksas et al. Bologna 14-15aprile.
Novosibirsk 2 -
Orsay 2 - Cornell.
40
30
20
10
.3
.4
.5
.6
.7
.8
.9
1
2E²=S (GeV²)

FIG. 8



|F π|²
10
1
Orsay (Cornell - Meeting)
Novosibirsk (Cornell - Meeting)
Novosibirsk P.L. 34B.328 1971
Adone μπ (LNF71/62)
Point - Like
ρ-tail Breit - Wigner
0
1
2
3
4
S = (2E)² (GeV)²

FIG. 9

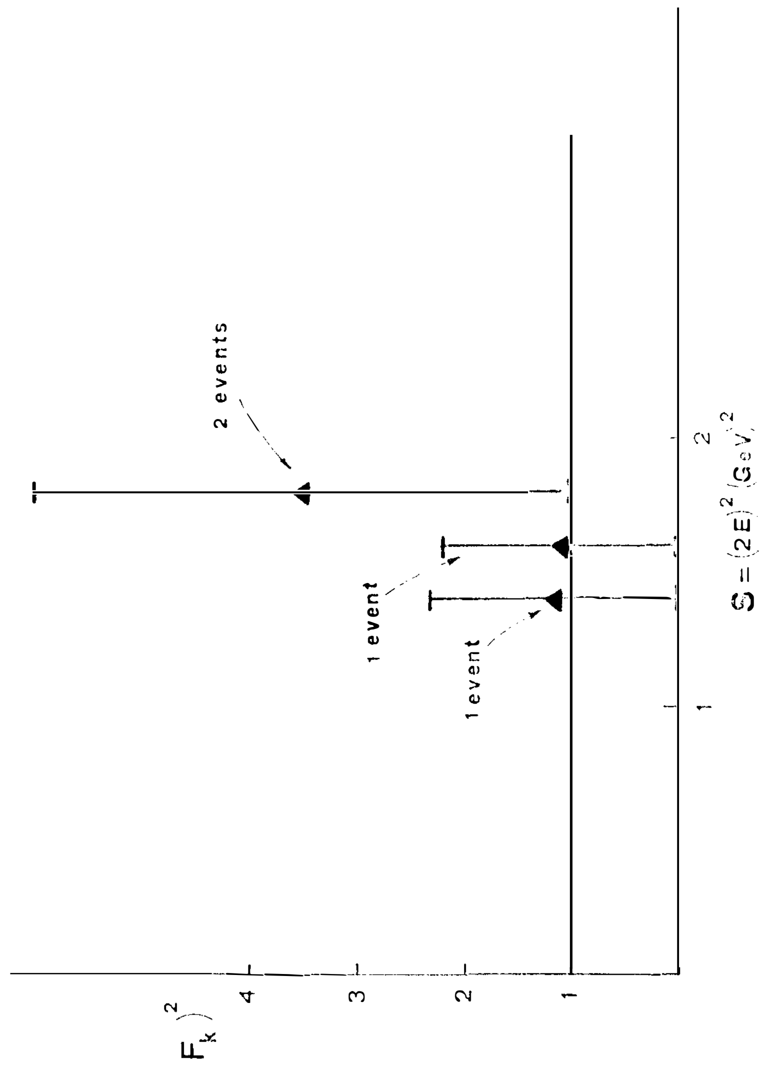
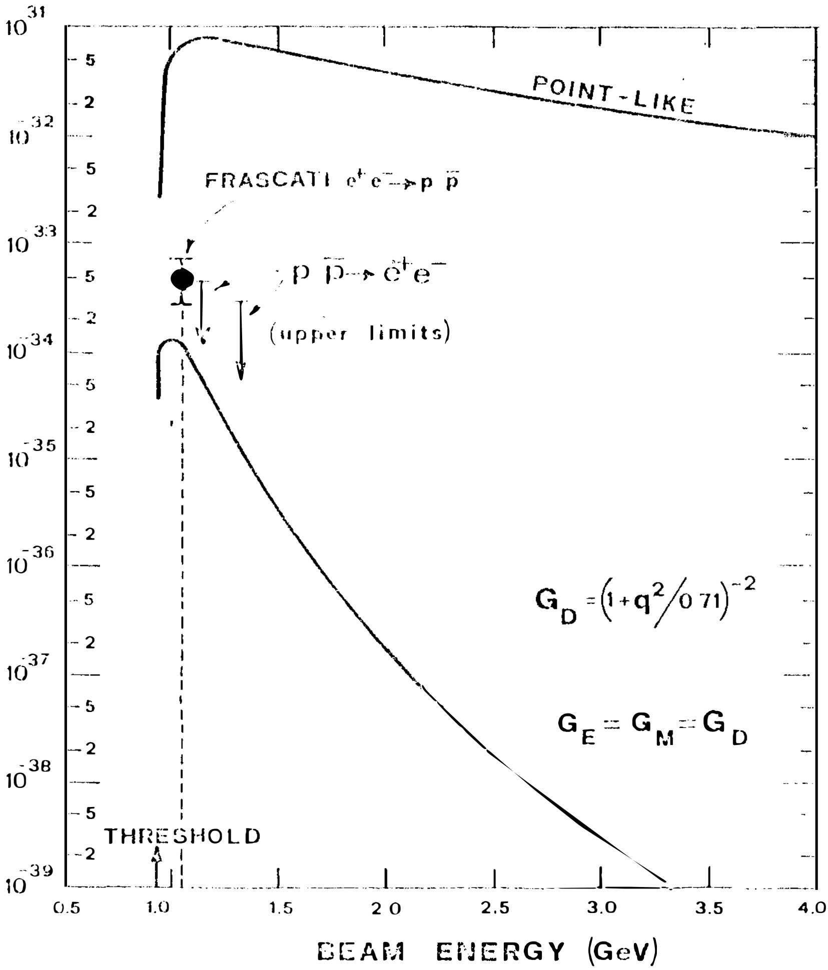


FIG. 10



POINT-LIKE
FRASCATI e⁺e⁻ → p p̄
p p̄ → e⁺e⁻
(upper limits)
THRESHOLD
$G_D = (1 + q^2/0.71)^{-2}$
$G_E = G_M = G_D$
BEAM ENERGY (GeV)

FIG. 11

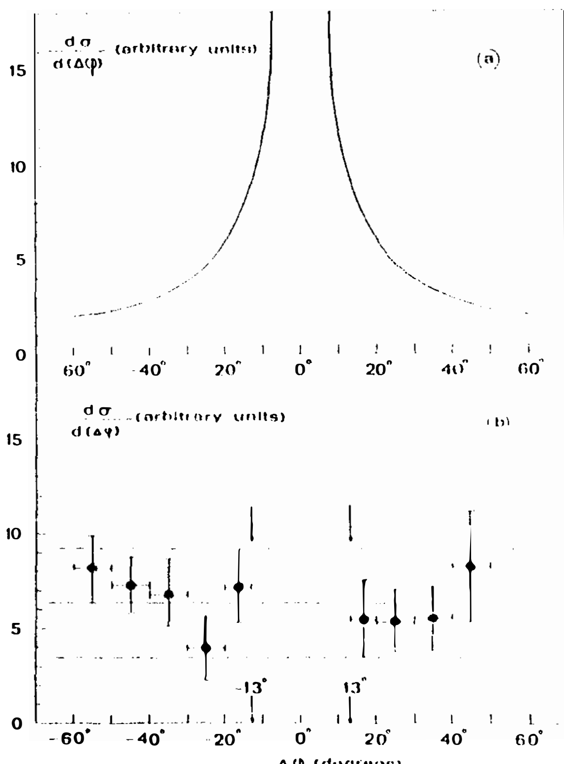

dσ/d(Δφ) (arbitrary units)
(a)
15
10
5
0
60°
-40°
20°
0°
20°
40°
60°
dσ/d(Δφ) (arbitrary units)
(b)
15
10
5
0
-13°
13°
-60°
-40°
20°
0°
20°
40°
60°
Δφ (degrees)

FIG. 12

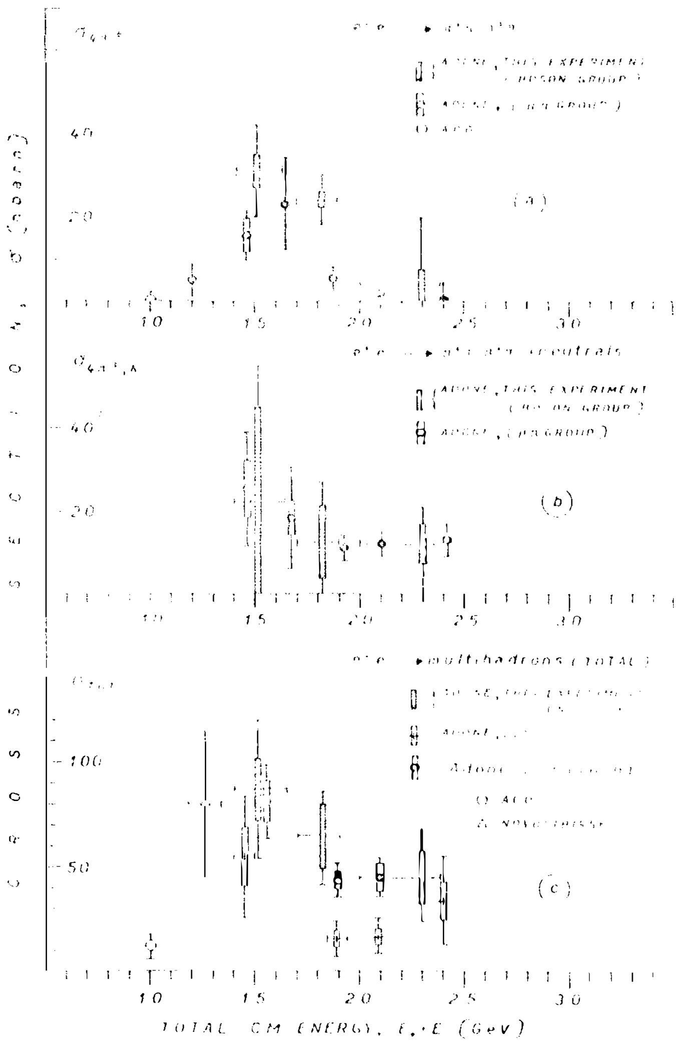
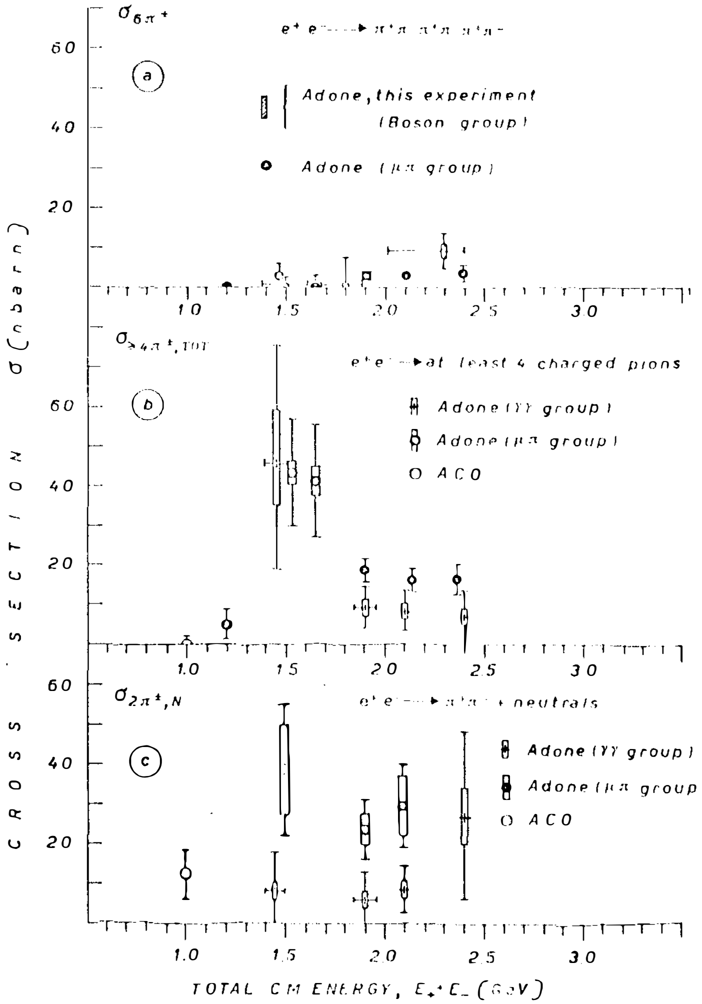


FIG. 13



σ6π±
e⁺e⁻ → π⁺π⁻π⁺π⁻π⁺π⁻
a
Adone, this experiment (Boson group)
Adone (μπ group)
σ≥4π±,TOT
e⁺e⁻ → at least 4 charged pions
b
Adone (γγ group)
Adone (μπ group)
ACO
σ2π±,N
e⁺e⁻ → π⁺π⁻ + neutrals
c
Adone (γγ group)
Adone (μπ group)
ACO
CROSS SECTION σ (nbarn)
TOTAL CM ENERGY, E₊+E₋ (GeV)

FIG. 14