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by

A. Ali
Deutsches Elektronen-Synchrotron DESY, Hamburg

M.A.B. Bég
The Rockefeller University, New York, New York 10021, USA

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PRODUCTION OF HIGGS BOSONS AND HYPERPIONS IN e^+e^- ANNIHILATION

A. Ali

Theory Group, DESY, 2 Hamburg 52, Federal Republic of Germany

M.A.B. Bég*

The Rockefeller University, New York, New York 10021, U.S.A.

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Abstract

The production of hyperpions -- low lying pseudo-Goldstone modes of the hypercolor scenario -- in e^+e^- annihilation is studied and contrasted with the production of elementary Higgs bosons of the canonical methodology.

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1. The possibility of implementing the Higgs mechanism in a dynamical way, without the use of elementary spin-0 fields, has lately been the subject of much discussion [1]. In several recent communications[2-6] it has been pointed out that the most popular dynamical scheme, the so-called hypercolor scenario, may be experimentally distinguishable from the canonical Weinberg-Salam scheme via experiments at relatively low (10-100 GeV) energies. [There is, of course, an a priori expectation that differences between the two schemes will be manifest in experiments at TeV energies; this energy regime, however is not likely to be accessible in the near future.] The considerations of refs.(2-4) hinge in a crucial way on one's ability to (a) produce spin-0 particles, of mass ~10GeV, coupled semi-weakly to ordinary quarks and leptons and (b) distinguish Higgs particles, ϕ's, from the low-lying bosons of the hypercolor scenario, generically called π's, exploiting mainly the difference in parity.

Our purpose in this note is to point out that the pseudoscalar nature of π''s introduces a fundamental difference in the production mechanism of ϕ's and π''s in a large class of reactions. In particular, we calculate the production rates of ϕ's and π''s in e^+e^- annihilation and in the decays of the spin-1 bosons Z and toponium, J_T.

We begin with a discussion of charged hyperpions, $\pi'^{\pm}$, which -- if the mass estimates of refs. (2-6) are not too low -- can be observed at energies currently available at PETRA and PEP.

2. Charged Hyperpions:

The cross-section for the process [2] $e^+e^-\to\pi'^+\pi'^-$ may be expressed in terms of its contribution to the parameter R

$$\Delta R=\sigma(e^+e^-\to\pi'^+\pi'^-)/\sigma(e^+e^-\to\mu^+\mu^-)=\frac{1}{4}\,(1-4m^2_{\pi'^+}/s)^{3/2} \qquad (1)$$

where $\sqrt{s}$ is the c.m. energy and the factor $\frac{1}{4}$ is due to the spin-0 nature of $\pi'^{\pm}$'s.

What are the signatures of $\pi'^{\pm}$'s in e^+e^- annihilation experiments? The decays of $\pi'^{\pm}$'s are in general model dependent; they may decay via a $W^{\pm}$ exchange or they may require heavier exotic bosons [5,6]. (In either case their couplings to the leptons and quarks involve unknown Cabibbo-like angles.) The $\pi'^{\pm}$ may even be stable. Fortunately, this last possibility has already been ruled out experimentally for $m_{\pi'^{\pm}}<12$GeV.[1] [7]. The details of the decay modes may differ from model to model, but we nevertheless expect the helicity suppression pattern, well known from the decays of ordinary $\pi^{\pm}$. If $m_{\pi'^{\pm}}<m_t+m_b$, the principal decay channels for π'^+ are $c\bar{s}$ and $\tau^+\nu_\tau$ with

$$\Gamma(\pi'^+\to c\bar{s})/\Gamma(\pi'^+\to\tau^+\nu_\tau)\simeq 3\,\chi(m_c/m_\tau)^2 \qquad (2)$$

where $\chi\approx1$ if the $\pi'^{\pm}$ decay via $W^{\pm}$ boson exchange. One expects one (or more) of the following three signatures:

(a) $\chi\approx1$: about 5-10% of the $\pi'^{\pm}$ will manifest themselves as events with energetic leptons (e,μ) recoiling against a hadronic jet of large multiplicity, sphericity and invariant mass.
(b) $\chi\ll1$: about 10-15% of the $\pi'^{\pm}$ will manifest themselves as "anomalous $e\mu$ events" -- very much reminiscent of the $\tau^{\pm}$ albeit with a large acollinearity (from $\pi'^{\pm}$ decay) and a $\sin^2\theta$ angular dependence (from $\pi'^{\pm}$ production).
(c) $\chi\gg1$: almost all the events will be comprised of two hadronic jets with large sphericity and acoplanarity. This circumstance would have a formidable background from ordinary quark and gluon jets. The detailed distributions due to the $\pi'^{\pm}$ decays and background calculations show that a $\pi'^{\pm}$ induced signal can be observed at PETRA and PEP upto a mass $m_{\pi'^{\pm}}\lesssim15$ GeV [8].

There is one dramatic effect which would stand out in the decays of toponium if $m_{\pi'^{\pm}}<m_t-m_b$. In that case the semi-weak decay, $t\to b+\pi'^+$ will dominate the $J_T, J'_T, \ldots$ decays, resulting in the final states[2]

$$(J_T, J'_T, \ldots)\to\pi'^+ + b\bar{t} \;\to\pi'^+\pi'^- + b\bar{b} \qquad (3)$$

suppressing the canonical decays of J_T:

$$J_T\to\ell\bar{\ell}, q\bar{q}\quad ggg,\ gg\gamma\ (\ell\equiv e,\mu \text{ or } \tau) \qquad (4)$$

The rates for the processes (3) can be calculated in the approximation of free t-quark decay inside J_T, giving

$$\Gamma(t\to b+\pi'^+)=\frac{G_F^2 f_{\pi'}^2}{8\pi m_t^3}\lambda^{1/2}(m_t^2, m_b^2, m_{\pi'}^2)\times[(m_t^2-m_b^2)^2-m_{\pi'}^2(m_t^2+m_b^2)] \qquad (5)$$

where $\lambda\equiv[m_t^2-(m_b+m_{\pi'})^2][m_t^2-(m_b-m_{\pi'})^2]$, G_F is the Fermi coupling constant and

$f_{\pi'}$ is the hyperpion decay coupling constant, normalized such that $\sqrt{2}f_{\pi'}^2 G_F = n_{F'}^{-1}$, $n_{F'}$ being the number of hyperquark doublets[3]. In Fig. 1 we plot the rate for the decay $J_T \to \pi'^{+} + b\bar{t}$ for various values of m_t and $m_{\pi'^\pm}$. We estimate the inclusive rate for the standard decays to be 40-60 KeV. It is clear that the $\pi'^\pm$ modes (3) dominate the J_T decays upto almost the threshold $m_{\pi'^\pm} \simeq m_t - m_b$. The signatures of (3) would be (almost) isotropic mixed lepton-hadron events -- very different from the pure leptonic and hadronic 2 and 3 jet decays (4). The $\pi'^\pm$ induced J_T decay width (for $m_{J_T} < 80$ GeV) would still be smaller than a typical beam energy resolution ~20MeV, but the branching ratios for $J_T \to e^+e^-$, $\mu^+\mu^-$ would become very small.

3. Production of Neutral Hyperpions:

It is generally recognized that if the mass of the Higgs particle ϕ^o is not very large ($m_{\phi^o} <$ few tens of GeV) then it could be produced in the decays of toponium [9], as well as in the decays of the Z [10]. In particular the following processes are potentially good sources of the Higgs:

$$J_T \to \phi^o + \gamma \tag{6}$$

$$Z \to \phi^o + \mu^+\mu^- \tag{7}$$

$$Z \to \phi^o + \gamma \tag{8}$$

$$e^+e^- \to \phi^o + Z \tag{9}$$

In this section we shall show that whereas toponium still remains an equally good source of the hyperpions, π'^o, the transitions analogous to (7-9) do not produce hyperpions at comparable rates. A statistically significant rate for the processes (7-9) would amount to an unambiguous confirmation of the canonical Higgs picture as opposed to the hypercolor

scenario. Implicit, of course, in the reasoning of this paper is the simplifying assumption that nature uses either elementary Higgs fields or the hypercolor scheme but <u>not</u> both.

The radiative transition (6) and the similar reaction $J_T \to \pi'^o + \gamma$ can be calculated in the approximation of treating the t and $\bar{t}$ quarks at rest [9]. We quote the relevant ratio for equal hyperpion and Higgs mass:

$$\frac{\Gamma(J_T \to \pi'^o \gamma)}{\Gamma(J_T \to \phi^o \gamma)} = \sqrt{2}\, G_F f_{\pi'}^2 \approx (n_{F'})^{-1} \tag{10}$$

Note that

$$\frac{\Gamma(J_T \to \phi^o \gamma)}{\Gamma(J_T \to \mu^+\mu^-)} \cong \frac{G_F m_{J_T}^2}{4\sqrt{2}\,\pi\alpha} \left(1 - \frac{m_{\phi^o}^2}{m_{J_T}^2}\right) \tag{11}$$

where α is the fine structure constant. The formula (11) has to be corrected to incorporate the characteristic k^3 dipole behaviour if m_{ϕ^o} is close to m_{J_T} [11]. While the discovery of toponium is awaited, we may orient ourselves as to orders of magnitude by taking m_{J_T} ~40GeV, m_{ϕ^o}~15GeV; these parameters imply that the $\phi^o\gamma$ mode is about 12% of the $\mu^+\mu^-$ mode -- a healthy branching ratio indeed, if the charged hyperpions, $\pi'^\pm$, are heavier than $m_t - m_b$! Eq. (10) substantiates our assertion that π'^o production in toponium decay occurs at a rate comparable to that for ϕ^o production. To clinch the identification [2,3] of the scalar being produced in J_T decays it may be necessary to test whether it decays into $D\bar{D}$(ϕ^o: Yes, π'^o: No) or $\pi D\bar{D}$(ϕ^o: No, π'^o: Yes).

Next, we turn to processes (7-9) and their analogues where the ϕ^o is replaced by π'^o. Note that the sizeable rates calculated for these reactions[10] stem from the SU(2) x U(1) tree level $ZZ\phi^o$ and $W^+W^-\phi^o$ couplings, which are large in the standard Weinberg - Salam theory. The crucial difference between the hypercolor scenario and the canonical theory lies in the observation[2] that there is no π'^oZZ or $\pi'^oW^+W^-$ coupling at the no-QFD-loop level. At the one-loop level the triangle graph does lead to non-vanishing couplings, the order of magnitude of these couplings compared to the Higgs couplings is thus ~ $(\alpha/\pi)^2$. Our detailed calculations show that these expectations are indeed true.

In what follows we shall calculate the rates for reactions (7-9) and the corresponding reactions involving hyperpions. To that end we need to calculate the amplitude for the process

$$V^i \to V^j + \pi'^o \qquad (12)$$

where $V^i \equiv Z$ or γ. We specify the process further by taking π'^o to be the third component of a hyperflavor isotriplet[4]; it is then easy to check that only the weak vector current comes into play and, in consequence, the amplitudes may be expressed as

$$A(V^i(k_1) \to V^j(k_2) + \pi'^o(q))$$

$$= f\left(\frac{k_1^2}{M^2}, \frac{k_2^2}{M^2}, \frac{q^2}{M^2}\right) \varepsilon_{\mu\nu\sigma\rho}\, k_1^\mu\, k_2^\nu\, \varepsilon_1^\sigma\, \varepsilon_2^\rho \qquad (13)$$

where $q \equiv k_1 - k_2$, ε_1 and ε_2 are the polarization vectors of the V's with momenta k_1 and k_2 respectively. M is the constituent mass[3] of the hyperquark ~ 1TeV.

So long as k_1^2, k_2^2, q^2 are all $<< M^2$, we may approximate f by f(0,0,0) which can be calculated using the hyperquark-triangle diagram. Indeed, because of a known extension[12] of the Adler-Bardeen theorem, the value so determined for f has the added and all important virtue of being exact to all orders in QC'D -- the QCD-like theory of hypercolor interaction. Without further ado we quote the explicit results:

$$f_{ZZ\pi'^o}(0,0,0) = -\frac{2\alpha}{3\pi f_{\pi'}}\, g_A'\, \frac{\sin^2\xi(1-2\sin^2\xi)}{(\sin 2\xi)^2} \cdot N_{C'} n_{F'} \qquad (14)$$

$$f_{Z\gamma\pi'^o}(0,0,0) = \frac{\alpha}{6\pi f_{\pi'}}\, g_A'\, \frac{(1-4\sin^2\xi)}{(\sin 2\xi)}\, N_{C'} n_{F'} \qquad (15)$$

$$f_{\gamma\gamma\pi'^o}(0,0,0) = \frac{\alpha}{3\pi f_{\pi'}}\, g_A'\, N_{C'} n_{F'} \qquad (16)$$

Here ξ is the Glashow-Weinberg-Salam angle, $N_{C'}$ is the number of hypercolors and g_A' is the hyperquark analogue of $g_A [\equiv (G_A/G_V)_{quark}]$; we shall assume that $g_A' \sim 1$. The effective hyperpion coupling, Eq. (14), is to be contrasted with the Higgs coupling:

$$g_{ZZ\phi^o} = 2(G_F\sqrt{2})^{1/2}\, m_Z^2 \qquad (17)$$

Eqs. (14-16) permit us to calculate the rates for the processes:

$$Z \to \pi'^o + \mu^+\mu^- \qquad (7')$$

$$Z \to \pi'^o + \gamma \qquad (8')$$

$$e^+e^- \to \pi'^o + Z \qquad (9')$$

as well as the reaction

$$e^+e^- \to \pi'^o + \gamma \qquad (18)$$

which, though small in absolute rate, may be potentially important in comparison to the Higgs production process $e^+e^- \to \phi^o + \gamma$ [13].

We present below the rates for the reactions (7) and (7'). The normalized scaled dimuon invariant mass distribution is given by:

$$\frac{1}{\Gamma(Z\to\mu^+\mu^-)}\frac{d}{d\kappa^2}\Gamma(Z\to\pi'^0+\mu^+\mu^-) = \frac{1}{6}\left(\frac{\alpha}{\pi}\right)^3 \frac{n_{F'}^3\,(N_{C'}/3)^2}{[1+(1-4\sin^2\xi)^2]}\lambda_1^3 \times \left[F_1\frac{\kappa^2}{(1-\kappa^2)^2} + \frac{F_2}{(1-\kappa^2)} + \frac{F_3}{\kappa^2}\right] \quad (19)$$

where $\kappa^2 \equiv m_{\mu\mu}^2/m_Z^2$ and

$$\lambda_1 = [(1-\kappa^2+m_{\pi'}^2/m_Z^2)^2 - 4\,m_{\pi'}^2/m_Z^2]^{1/2} \quad (20)$$

$$F_1 = [1+(1-4\sin^2\xi)^2]\left[\frac{\sin^2\xi(1-2\sin^2\xi)}{(\sin 2\xi)^3}\right]^2 \quad (21)$$

$$F_2 = (1-4\sin^2\xi)^2\sin^2\xi\,\frac{(1-2\sin^2\xi)}{(\sin 2\xi)^4} \quad (22)$$

$$F_3 = \frac{1}{4}\,\frac{(1-4\sin^2\xi)^2}{(\sin 2\xi)^2} \quad (23)$$

The corresponding distribution for (7) is [14]:

$$\frac{1}{\Gamma(Z\to\mu^+\mu^-)}\frac{d}{d\kappa^2}\Gamma(Z\to\phi^0+\mu^+\mu^-) = \frac{\alpha}{12\pi}\,\frac{1}{(\sin 2\xi)^2}\,\frac{\lambda_1}{(1-\kappa^2)^2} \times [\,12\kappa^2 + \lambda_1^2\,] \quad (24)$$

where λ_1 is defined as in Eq. (20) with the replacement $m_{\pi'}\to m_\phi$.

The relative rate $\Gamma(Z\to\pi'^0+\mu^+\mu^-)/\Gamma(Z\to\phi^0+\mu^+\mu^-)$ is plotted in Fig. 2 as a function of $m_{\pi'^0}(=m_\phi)$ for $\sin^2\xi = 0.20$ (corresponding to $m_Z = 94$ GeV). Typically this ratio is $\sim 10^{-7} n_{F'}^3 N_{C'}^2$ and for reasonable values of $n_{F'}$ and $N_{C'}$ is expected to be $< 10^{-4}$.

We remark that not only are the rates for (7) and (7') very different, but so are the dimuon invariant mass distributions (19) and (24). The distribution (19) peaks for low values of κ^2 due to the virtual photon contribution in $Z\to\pi'^0+\gamma_V\to\pi'^0+\mu^+\mu^-$, thereby providing a very clean separation even if $n_{F'}$ and $N_{C'}$ are ridiculously large! We plot the normalized distributions (19) and (24) in Fig. 3.

The radiative decay (8) can also be an important source of the Higgs boson [15]. This process goes via triangle diagrams involving both fermions and $W^\pm$ bosons. We now have for the relative rates of (8) and (8'):

$$\frac{\Gamma(Z\to\pi'^0\,\gamma)}{\Gamma(Z\to\phi^0\,\gamma)} = \frac{N_{C'}^2 n_{F'}^3}{9|A|^2}\,\frac{\sin^2\xi(1-4\sin^2\xi)^2}{(\sin 2\xi)^2} \quad (25)$$

where $|A|^2$ is given by [15]

$$|A|^2 = |A_{\text{Fermion}} + A_{W\pm}|^2 \quad (26)$$

with

$$A_{\text{heavy fermion generation}} = \frac{4}{3\cos\xi}\left(1-\frac{8}{3}\sin^2\xi\right) \quad (27)$$

and

$$A_{W\pm} = -[4.9 + 0.3\,m_{\phi^0}^2/m_W^2] \quad (28)$$

Numerically we find for $\sin^2\xi \simeq 0.20$:

$$\frac{\Gamma(Z\to\pi'^0\gamma)}{\Gamma(Z\to\phi^0\gamma)} \simeq c\,N_{C'}^2 n_{F'}^3 \times 10^{-5} \quad (29)$$

where $c = 8.6$ for $m_{\phi^0} = 10$GeV and varies slowly with m_{ϕ^0} ($c \simeq 8.1$ for $m_{\phi^0} = 60$GeV.) Note that this ratio is small essentially due to the $(1-4\sin^2\xi)^2$ factor which enters because only the vector current contributes in $Z\to\pi'^0+\gamma$.

Next we consider the production of ϕ^o and π'^o in e^+e^- annihilation in the processes (9), (9') and (18). These processes are more relevant for the LEP energies. The cross section for the process (9') can be written down as

$$\sigma(e^+e^-\to Z\pi'^o)$$

$$= \frac{\pi}{54}\left(\frac{\alpha}{\pi}\right)^3 \frac{N_{C'}^2 n_{F'}^2}{f_{\pi'}^2} \frac{k_{\pi'}}{\sqrt{s}} \left[\frac{F_1}{(s-m_Z^2)^2} - \frac{F_2}{s(s-m_Z^2)} + \frac{F_3}{s^2}\right] \left[k_{\pi'}^2 s - \frac{3}{4}(s-m_Z^2)^2 + \frac{3}{2} m_{\pi'}^2(s+m_Z^2) - \frac{3}{4} m_{\pi'}^4\right] \quad (30)$$

Here s is (c.m. energy)^2, $k_{\pi'}$ is the c.m. momentum of the hyperpion and F_i are the functions already defined in Eqs. (21-23). Eq. (30) is to be contrasted with the corresponding expression for the production of ϕ^o[16].

$$\sigma(e^+e^-\to\phi^o Z)$$

$$= \frac{2\pi\alpha^2}{3} \left(\frac{2k_\phi}{\sqrt{s}}\right) \frac{3m_Z^2 + k_\phi^2}{(s-m_Z^2)^2} \frac{1-4\sin^2\xi + 8\sin^4\xi}{(\sin 2\xi)^4} \quad (31)$$

where we have used the same notation as in (30).

In Fig. 4 we plot the ratio $\sigma(e^+e^-\to\pi'^oZ)/\sigma(e^+e^-\to\phi^oZ)$ as a function of $m_{\pi'^o}(=m_{\phi^o})$ for $\sqrt{s}$ = 140, 170 and 200 GeV. The ratio increases with $\sqrt{s}$ but for energies at LEP and a reasonable value of $n_{F'}$ and $N_{C'}$, we still expect it to be < 10^{-5}.

Finally, we would like to present the result for the radiative process (18) and the corresponding process involving ϕ^o[13]. We normalize the cross-section for (18) with respect to the point cross-section $\sigma(e^+e^-\to\mu^+\mu^-)$:

$$\frac{\sigma(e^+e^-\to\pi'^o\gamma)}{\sigma(e^+e^-\to\mu^+\mu^-)} = \frac{G_F N_{C'}^2 n_{F'}^3}{288\sqrt{2}\,\pi^2} \left(\frac{\alpha}{\pi}\right) \frac{E_\gamma^3}{\sqrt{s}} \left[\frac{(1-4\sin^2\xi)^2}{(\sin 2\xi)^4}\right.$$

$$\left.\times\{1+(1-4\sin^2\xi)^2\} \frac{s^2}{(s-m_Z^2)^2} + \frac{8(1-4\sin^2\xi)^2}{(\sin 2\xi)^2} \frac{s}{(s-m_Z^2)} + 16\right] \quad (32)$$

which is to be compared with the analogous process involving ϕ^o [13]:

$$\frac{\sigma(e^+e^-\to\phi^o\gamma)}{\sigma(e^+e^-\to\mu^+\mu^-)} = \frac{\sqrt{2}\,G_F}{\pi^2}\left(\frac{\alpha}{\pi}\right)\frac{E_\gamma^3}{\sqrt{s}} \left| I'_W - \Sigma_F I'_F \right|^2 \quad (33)$$

I'_W and I'_F being the W and fermion loop contributions respectively. To get an estimate we set $\sin^2\xi$ = 0.25, so that only the photon contribution survives; we have then:

$$\frac{\sigma(e^+e^-\to\pi'^o\gamma)}{\sigma(e^+e^-\to\phi^o\gamma)} \simeq \frac{1}{36}\frac{N_{C'}^2 n_{F'}^3}{|I'_W-\Sigma_F I'_F|^2} \simeq \frac{1}{36} N_{C'}^2 n_{F'}^3 \quad (34)$$

Thus this <u>ratio</u> is potentially large. However, the cross section for $\phi^o\gamma$ production [Eq. (33)] is so small that even an enhancement ~ 200 for the hyperpion case will not help the process $e^+e^-\to\pi'^o\gamma$ very much; it will still be swamped by the normal $l\gamma$ background in e^+e^- annihilation.

4. We may summarize our results as follows:

(a) The most promising signals for $\pi'^\pm$ are: $e^+e^-\to(\mu$ or $e)$ + hadron jet and $e^+e^-\to \ell^+\ell^- + \nu$'s$(\ell=e,\mu)$ with large acollinearity angle and a characteristic $\sin^2\theta$ distribution in production. Furthermore R should not increase by one full unit on crossing the hyperpion threshold.

(b) If the $\pi'^{\pm}$ are not very heavy i.e., for $m_{\pi'^{\pm}} < m_t - m_b$, the semiweak decay $t \to b + \pi'^{+}$ will dominate the decays of toponium, J_T, J_T', . . ., as well as of the open top mesons T_u, T_d etc. The width of J_T, J_T' is still expected to be smaller than the beam resolution; however the topology of J_T, J_T' decays would be very different, as would be the branching ratio for $J_T \to \mu^+\mu^-$, e^+e^- etc.

(c) To distinguish between the canonical picture of symmetry breaking and the hypercolor scenario it is necessary to produce and detect neutrals. The low rates for the processes $Z \to \pi'^{o} + \mu^+\mu^-$, $Z \to \pi'^{o} + \gamma$ and $e^+e^- \to Z + \pi'^{o}$ indicate that a positive signal in these reactions would be evidence in favor of the Weinberg-Salam theory. The process $Z \to \pi'^{o} + \mu^+\mu^-$ has the further discrimination, vis a vis $Z \to \phi^{o} + \mu^+\mu^-$, in that the lepton invariant mass distribution for the two reactions is expected to be very different. The smallness of the $ZZ\pi'^{o}$ and $W^+W^-\pi'^{o}$ couplings in hypercolor theories ensures that in all the processes where a ϕ^{o} can bremsstrahl off a $W^{\pm}$ or Z the rates for π'^{o} production will be down by $\sim (\alpha/\pi)^2$. Thus, a scalar produced in an ep, νp or γp process with the tell-tale signatures of a semi-weakly coupled particle would indeed be a canonical Higgs.

(d) In the intermediate e^+e^- energy range, toponium may be an excellent laboratory for investigating the properties of hyperpions and thus the nature of the Higgs mechanism.

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Footnotes

1. More precisely, a stable or quasi-stable ($\tau > 10^{-9}$ sec.) unit charged particle produced exclusively with $\Delta R \geq 0.02$ is ruled out for the mass ranges 4.5 GeV $\leq m_{\pi'^{\pm}} \leq$ 5.4 GeV and 10 GeV $\leq m_{\pi'^{\pm}} \leq$ 14.8 GeV at 95% C.L. [7,8].

2. This decay is very similar to the one involving a charged Higgs scalar which has been discussed in the literature. See, for example, Ellis [10].

3. To be definite, we have assumed that hyperquarks transform in the same way as ordinary quarks under the weak gauge group $SU(2)_L \times U(1)$. Moreover, as indicated below, they are taken to transform according to the fundamental representation of the hypercolor group $SU(N_{C'})$. In models in which the hyperquarks belong to a non-trivial, say triplet, representation of $SU(3)_C$, the ordinary color group, $n_{F'} = 3 \times$ (number of hyperflavor doublets). [See, for example, ref. 4. The consistency of such models -- as indeed of the entire hypercolor scenario -- is a question outside the scope of the present note.] Note that the relationship with the notation of ref. 3 is $n_{F'} = N_{F'}/2$

4. It is possible, of course, to construct models with η-like, K-like, etc. hyperpions. See, for example, ref. 4.

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Figure Captions

Fig. 1: The rate for the semiweak decay of toponium, J_T, as a function of the charged hyperpion mass. n_F, is the number of hyperflavor doublets.

Fig. 2: The ratio $\Gamma(Z \to \pi'^o + \mu^+\mu^-)/\Gamma(Z \to \phi^o + \mu^+\mu^-)$ for equal values of m_{ϕ^o} and $m_{\pi'^o}$. n_F, is the number of hyperflavor doublets and N_C, the number of hypercolors. We have used $\sin^2\xi = 0.20$ corresponding to $m_Z = 94$ GeV.

Fig. 3: The dimuon invariant-(mass)^2 distribution from the decays $Z \to \pi'^o + \mu^+\mu^-$ and $Z \to \phi^o + \mu^+\mu^-$. We have normalized both the distributions to the same area [$= \Gamma(Z \to \phi^o + \mu^+\mu^-)$] for equal m_{ϕ^o} and $m_{\pi'^o}$. The relative scales can be read off Fig. 2.

Fig. 4: The ratio $\sigma(e^+e^- \to \pi'^o Z)/\sigma(e^+e^- \to \phi^o Z)$ for $\sqrt{s} = 140$ GeV, 170 GeV and 200 GeV and equal values of m_{ϕ^o} and $m_{\pi'^o}$. We have used $\sin^2\xi = 0.20$ and $m_Z = 94.$ GeV.

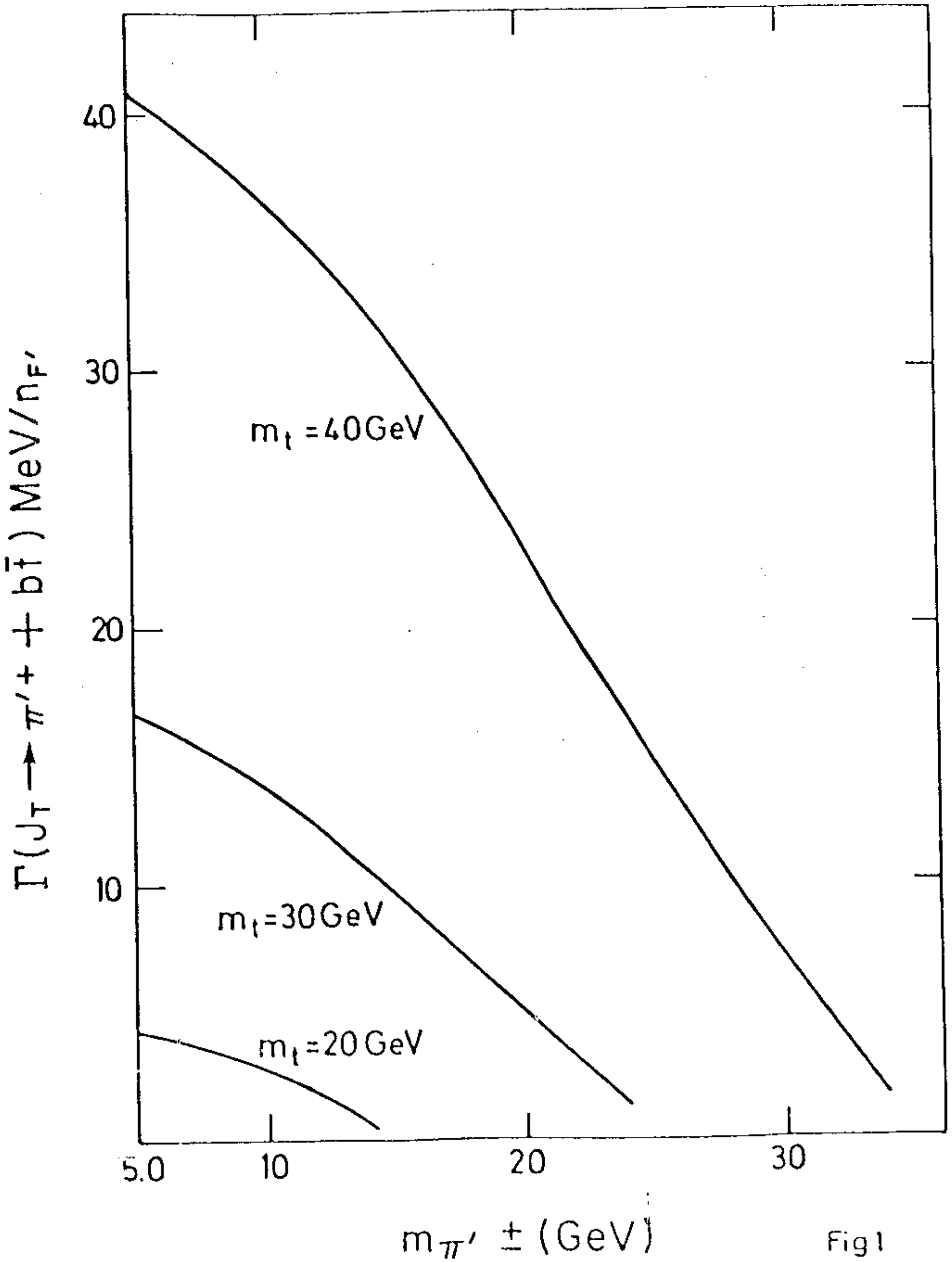
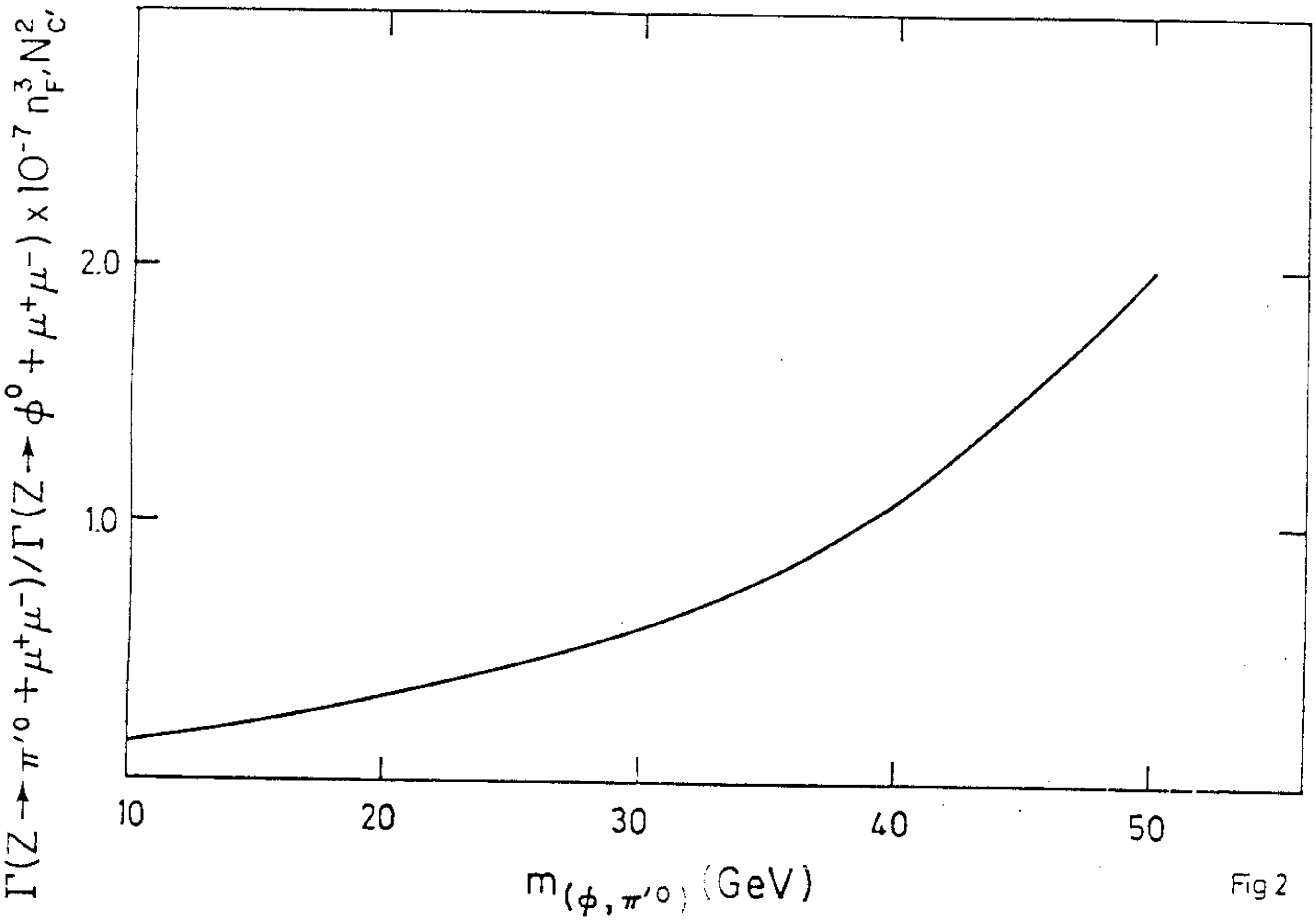
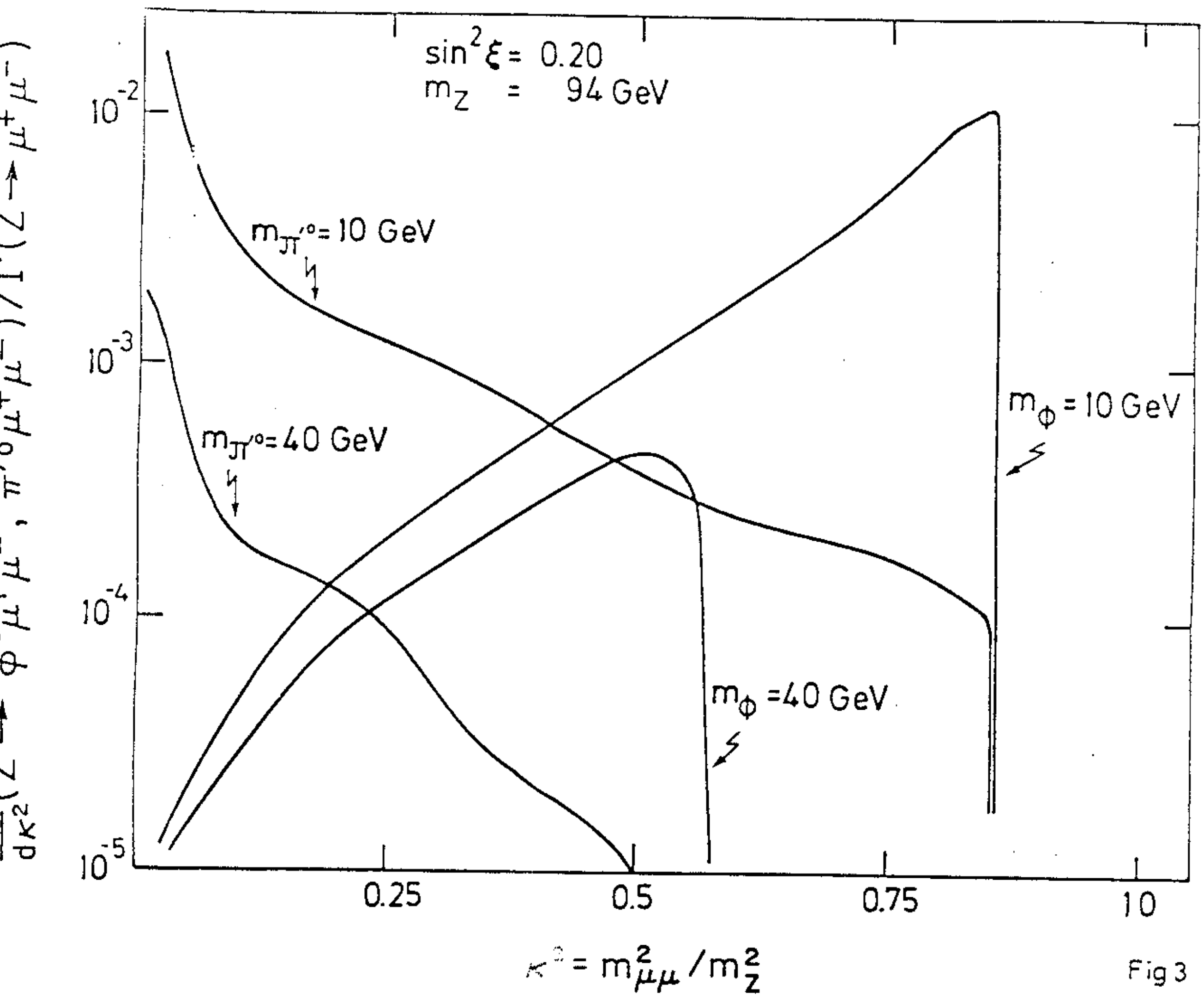


Fig 1



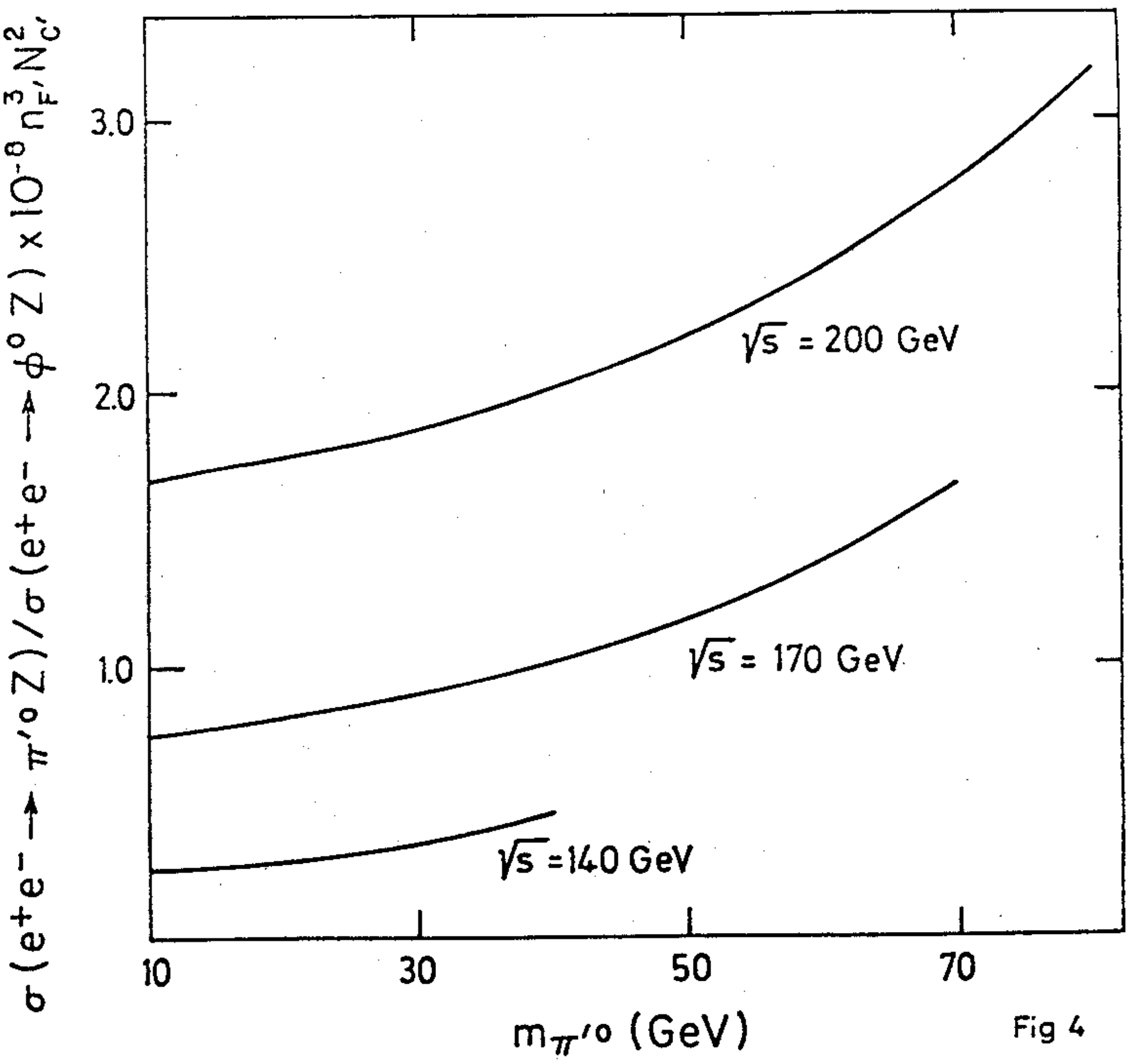
$\Gamma(Z \to \pi'^0 + \mu^+\mu^-)/\Gamma(Z \to \phi^0 + \mu^+\mu^-) \times 10^{-7}\, n_{F'}^3 N_{C'}^2$
2.0
1.0
10
20
30
40
50
$m_{(\phi,\pi'^0)}$ (GeV)

Fig 2



$\frac{d\Gamma}{d\kappa^2}(Z \to \phi^0\mu^+\mu^-,\ \pi'^0\mu^+\mu^-)/\Gamma(Z \to \mu^+\mu^-)$
$\sin^2\xi = 0.20$
$m_Z = 94$ GeV
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$m_{\pi'^0} = 10$ GeV
$m_{\pi'^0} = 40$ GeV
$m_\phi = 10$ GeV
$m_\phi = 40$ GeV
0.25
0.5
0.75
1.0
$\kappa^2 = m_{\mu\mu}^2/m_Z^2$

Fig 3



3.0
2.0
1.0
10
30
50
70
$\sqrt{s}$ = 200 GeV
$\sqrt{s}$ = 170 GeV
$\sqrt{s}$ =140 GeV
$\sigma(e^+e^- \to \pi'^0 Z)/\sigma(e^+e^- \to \phi^0 Z) \times 10^{-8} n_{F'}^3 N_{C'}^2$
$m_{\pi'^0}$ (GeV)

Fig 4