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Some Considerations on η_c

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I. INTRODUCTION

If we accept the view that the recently discovered resonance $\psi(3105)$ is a $c\bar{c}$ bound state of $J^{PC} = 1^{--}$, ϕ_c, in the charm scheme, then it is imperative that there exists a $c\bar{c}$ bound state of $J^{PC} = 0^{-+}$. The following is a brief discussion of its mass, decay modes and widths, and production.

II. MASS

In G. L. R., a mixing scheme was proposed for isoscalar pseudoscalar mesons on the basis of a Gell-Mann, Okubo-type mass formula, according to which η, X^0 and η_c were predicted to have the following compositions:

$$\eta = \frac{u\bar{u} + d\bar{d} - 2\,s\bar{s}}{\sqrt{6}} ,$$

$$X^0 = \frac{u\bar{u} + d\bar{d} + s\bar{s} + c\bar{c}}{2} ,$$

$$\eta_c = \frac{u\bar{u} + d\bar{d} + s\bar{s} - 3c\bar{c}}{\sqrt{12}} .$$

However, this scheme now appears very unlikely, in view of the recent developments. For, if it were true, the decay $\psi \rightarrow X^0\gamma$ would proceed analogously to $\phi \rightarrow \eta\gamma$, and its rate would be

$$\Gamma(\psi \to X^0\gamma) \simeq \frac{3}{8}\left(\frac{M_\psi}{M_\phi}\right)^3 \Gamma(\phi \to \eta\gamma)$$

$$\simeq 1.3 \text{ MeV}.$$

Another mixing scheme which emerges from the same mass formula is

$$\eta \simeq 0.80\left(\frac{u\bar{u} + d\bar{d}}{\sqrt{2}}\right) - 0.60\, s\bar{s}, \qquad M_\eta = 508 \text{ MeV}$$

$$X^0 \simeq 0.60\left(\frac{u\bar{u} + d\bar{d}}{\sqrt{2}}\right) + 0.80\, s\bar{s}, \qquad M_{X^0} = 969 \text{ MeV}$$

$$\eta_c \simeq 1.00\, c\bar{c}, \qquad M_{\eta_c} = 3122 \text{ MeV}$$

to within a few tenths of a percent. In G. L. R., this solution was rejected on the grounds that the postdicted η mass deviated somewhat more than one should allow. In retrospect, we feel that this judgment was a little too hasty, and given the questionable treatment of SU(4) breaking in lowest order, $M_\eta = 508$ MeV is not a bad fit to the actual mass 548.8 MeV.

We find that another curious solution is obtained if we identify (η, E(1416), η_c) as isoscalar members of a pseudoscalar 16-plet:

$$\eta \cong 0.662\left(\frac{u\bar{u} + d\bar{d}}{\sqrt{2}}\right) - 0.750\, s\bar{s}; \qquad M_\eta = 551 \text{ MeV}$$

$$E \cong 0.750\left(\frac{u\bar{u} + d\bar{d}}{\sqrt{2}}\right) + 0.662\, s\bar{s}; \qquad M_E = 1398 \text{ MeV}$$

$$\eta_c = 1.000\, c\bar{c}; \qquad M_{\eta_c} = 3066 \text{ MeV}.$$

We shall not offer any explanation as to where X^0 belongs in such a scheme as this; the idea that E(1416) belongs to the pseudoscalar 16-plet may deserve further attention, nevertheless.

In any case, the mass formula of G. L. R. suggests that if η_c is almost pure $c\bar{c}$, then η_c must be almost degenerate with ψ in mass. Appelquist and Politzer predict that the mass difference of the ortho- and para- "charmonium" to be about 30 MeV. In any case, the ϕ_c - η_c mass difference is predicted to be very small, perhaps less than 100 MeV, and perhaps ϕ_c is heavier.

III. DECAY MODES

The decay rate $\Gamma(\psi \rightarrow \eta_c\gamma)$ is very small, because the magnetic moment of the charmed quark is very small, being inversely proportional to the charmed quark mass, and there isn't much phase space. However, $\Gamma(\psi'(3.695) \rightarrow \eta_c\gamma)$ may offer some possibility of detection eventually.

The decay of η_c into hadrons is likely inhibited just as the decay of ψ is. According to Appelquist and Politzer,

$$\frac{\Gamma(\eta_c \rightarrow \text{hadrons})}{\Gamma(\psi \rightarrow \text{hadrons})} \simeq \left(\frac{10}{54}\, \alpha\, \frac{\pi^2-9}{\pi}\right)^{-1}.$$

[In this estimate, the Coulombic nature of the $c\bar{c}$ system need not be assumed.] This gives, with $\alpha \simeq 0.3$,

$$\Gamma(\eta_c \to \text{hadrons}) \simeq \text{a few MeV}.$$

The hadronic final states must have the quantum numbers $J^{PC} = 0^{-+}$, $G = +1$, $I = 0$. Some of the final channels that are relatively easy to detect are $K^+K_s\pi^-$, $K^-K_s\pi^+$, $\rho^0\rho^0 \to \pi^+\pi^-\pi^+\pi^-$, $\bar{p}p$, and $\bar{\Lambda}\Lambda$.

The rate for $\eta_c \to \gamma\gamma$ may be estimated in a number of ways; scaling up the $\pi \to \gamma\gamma$ rate we have

$$\Gamma(\eta_c \to \gamma\gamma) \cong \frac{32}{9}\left(\frac{M_{\eta_c}}{M_\pi}\right)^3 \Gamma(\pi^0 \to \gamma\gamma) = 260 \text{ keV}.$$

C. G. Callan, et al., give various estimates based on the known $\eta \to \gamma\gamma$ rate. In all $\Gamma(\eta_c \to \gamma\gamma) \simeq 10^2$ keV appears likely. That is, the branching ratio for $\gamma\gamma$ may amount to as much as 10 %.

IV. PRODUCTION

As alluded to earlier, η_c may be an important product of the ψ' disintegration:

$$\psi' \longrightarrow \gamma + \eta_c$$
$$\eta_c \longrightarrow \gamma + \gamma$$
$$\eta_c \longrightarrow \text{hadrons}.$$

As pointed out many times, one γ must be monochromatic.

In hadronic reactions, η_c production cross section is presumably not too different from that of ψ.

An intriguing possibility is the Primakoff production of η_c; an estimate of the production cross section is given in the Appendix of a Fermilab proposal by Caldwell et al. Unlike the π^0 and η production by the same process. it is expected that there is very little nuclear interference in this case; it would arise mainly from the exchange of heavy objects such as ψ or ψ'.

Coherent Production

$$\frac{d\sigma}{dt} = \frac{32\,\pi Z^2\alpha}{M^4}\left(\frac{\Gamma(\eta_c \to \gamma\gamma)}{M}\right)\left(\frac{k}{M}\right)^2\left[\frac{(t - t_{min})t_{min}}{t^2}\right]|F(t)|^2$$

where $M = M_{\eta_c}$, k = C. M. momentum of η_c, $F(t)$ is the nuclear form factor. The simplest way to treat the coherent production is to consider the nucleus as an "elementary" particle of mass $m = m(Z, A)$ charge Z and the electromagnetic form factor $F(t)$.

$$t_{min} = \frac{M^4}{4s} - \left[\sqrt{\left(\frac{s+m^2}{2\sqrt{s}}\right)^2 - m^2} - \sqrt{\left(\frac{s+m^2-M^2}{2\sqrt{s}}\right)^2 - m^2}\right]^2$$

and

$$s = m^2 + 2m(E_\gamma)_{Lab}.$$

For Pb$(Z = 82)$, m = 194.76 GeV, and $(E_\gamma)_{Lab}$ = 100 GeV,

$$t_{min} \simeq 2.17 \times 10^{-3}\,(\mathrm{GeV}/c)^2$$

and

$$\frac{d\sigma}{dt} = 400\ \mu b/\mathrm{GeV}^2 \times |F(t)|^2 \frac{(t-t_{min})t_{min}}{t^2}$$

where we have used arbitrarily $\Gamma(\eta_c \to \gamma\gamma) \simeq 100$ keV.

We will approximate

$$F(t) = e^{-\frac{c}{2}t}$$

where

$$c = \frac{1}{3} \langle r \rangle^2 = \frac{1}{5}\,(1.2\ \mathrm{fm}\ A^{\frac{1}{3}})^2 = 260\ \mathrm{GeV}^2.$$

We obtain

$$\sigma(\gamma \to \eta_c) \simeq 170\ \mathrm{nb}.$$

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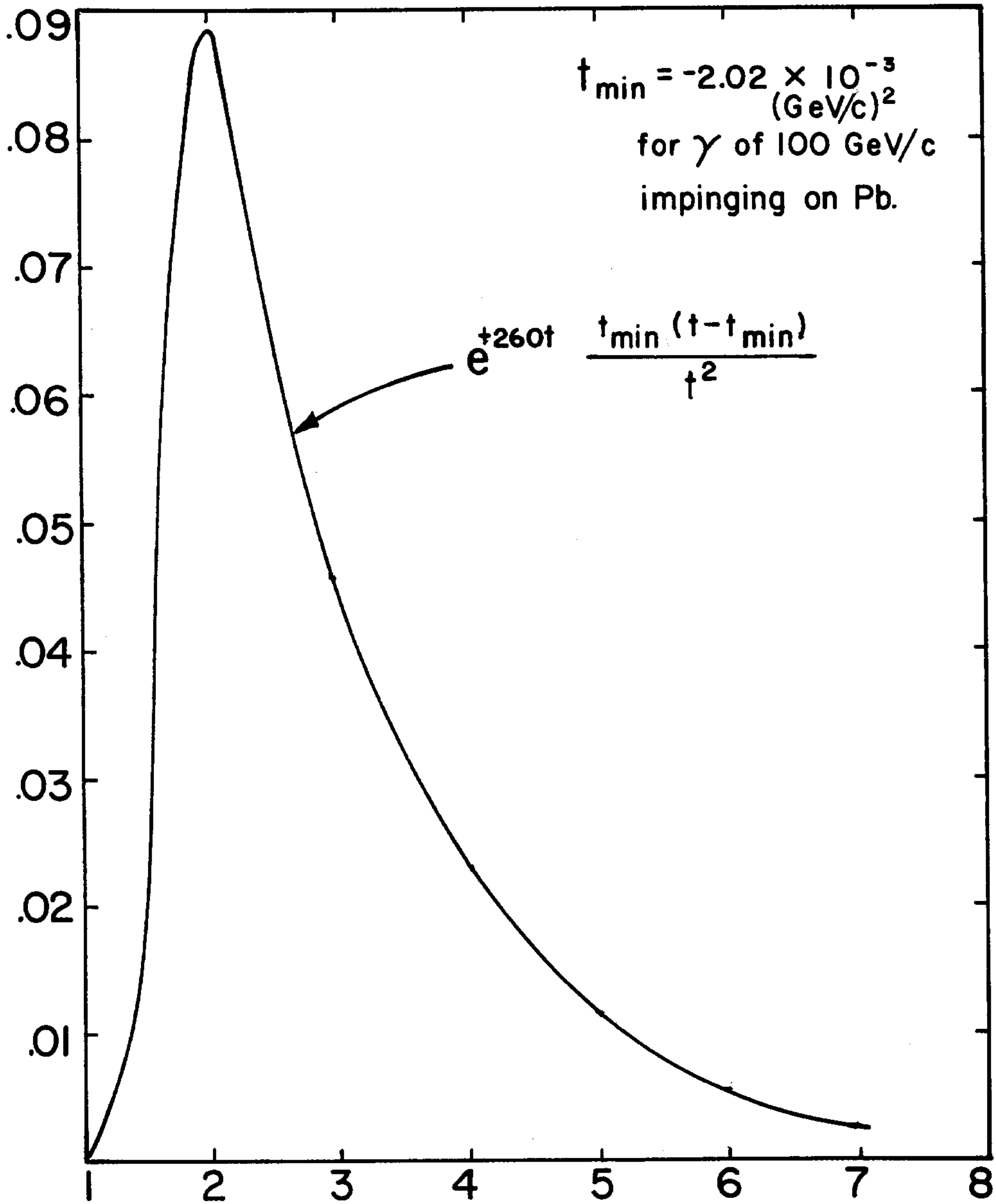
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$t_{min} = -2.02 \times 10^{-3}$ $(GeV/c)^2$
for γ of 100 GeV/c
impinging on Pb.
$e^{+260t} \dfrac{t_{min}(t - t_{min})}{t^2}$