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ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ
YEREVAN PHYSICS INSTITUTE

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NONSTANDARD SCALAR BOSONS IN SUPERHEAVY QUARKONIA DECAYS

ЦНИИатоминформ
ЕРЕВАН-1990

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Ս.Գ.ԳՐԻԳՈՐՅԱՆ, Ս.Ա.ՉԱՏՐՉՅԱՆ

ՈՉ-ՍՏԱՆԴԱՐՏ ՍԿԱԼՅԱՐ ԲՈԶՈՆՆԵՐ՝ ԳԵՐԾԱՆՐ ՔՎԱՐԿՈՆԻՈՒՄՆԵՐԻ ՏՐՈՀՈՒՄՆԵՐՈՒՄ

Ուսումնասիրված է ոչ-ստանդարտ չեզոք Հիգսի բոզոնների ծնումը գերծանր քվարկոնիումների միաքվարկ տրոհման պրոցեսում ($(Q\bar{Q})\to gQWH$) : Համեմատվել է այդ պրոցեսում առաջացող ոչ-ստանդարտ Հիգսի մասնիկների ծնման կտրվածքը՝ նույն պրոցեսում առաջացող էլեկտրաթույլ փոխազդեցությունների նվազագույն մոդելում առկա սկալյար մասնիկի ծնման կտրվածքի հետ: Ցույց է տրված, որ մի շարք դեպքերում այդ տրոհումների կտրվածքը խիստ տարբերվում է, ինչը թույլ կտա տարբերել չեզոք սկալյար բոզոնները իրարից, և ստանալ լրացուցիչ տեղեկություններ էլեկտրաթույլ փոխազդեցությունների Հիգսի սեկտորի կառուցվածքի մասին:

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S.G. GRIGORYAN, S.A. CHATRCHYAN

NONSTANDARD SCALAR BOSONS IN SUPERHEAVY QUARKONIA DECAYS

Nonstandard neutral Higgs boson production in single quark decays of superheavy quarkonia ($(Q\bar{Q}) \to Qq\,WH$) is studied. The widths of these decays are compared with a width for standard Higgs boson production (the Higgs boson from the minimal electroweak model) in the same decay. It is shown that in some cases these widths are strongly different from each other, which allows one to discriminate between the neutral scalar bosons as well as to receive additional information on the structure of the Higgs sector of electroweak interactions.

Yerevan Physics Institute

Yerevan 1990

Препринт ЕФИ-1222(8)-90

С.Г.ГРИГОРЯН, С.А.ЧАТРЧЯН

НЕСТАНДАРТНЫЕ СКАЛЯРНЫЕ БОЗОНЫ В РАСПАДАХ СВЕРХТЯЖЕЛЫХ КВАРКОНИЕВ

В работе исследовано рождение нестандартных нейтральных хиггсовских бозонов в однокварковом распаде сверхтяжелых кваркониев ($(Q\bar{Q}) \to q\bar{Q}WH$). Проведено сравнение ширин этих распадов с шириной рождения в этом распаде стандартного хиггсовского бозона из минимальной модели электрослабых взаимодействий. Показано, что в ряде случаев ширины этих распадов сильно отличаются, что позволит различить нейтральные скалярные бозоны друг от друга и получить дополнительную информацию о структуре хиггсовского сектора электрослабых взаимодействий.

Ереванский физический институт

Ереван 1990

In the minimal standard model (SM) of electroweak interactions there is one doublet of Higgs bosons where after spontaneous symmetry breaking one neutral scalar Higgs boson (H^0_{SM}-boson) arises. However the extension of the Higgs sector already to two doublets leads to the occurrence of [illegible] interaction in the mentioned mechanism $(Q\bar{Q}) \to G_q WH$ where H is any of the Higgs neutral particles.

In order to calculate the cross sections, we should know the vertices of interaction of Higgs particles with quarks and gauge bosons. These vertices are listed from the table taken from Ref. [1] :

	H°_{SM}	H°	h°	P°
$u\bar{u}H$	$y_u = -im_u/v$	$y_u \frac{\cos(\alpha+\theta)}{\cos\alpha}$	$-y_u \frac{\sin(\alpha+\theta)}{\cos\alpha}$	$-y_u \gamma_5 tg\alpha$
$d\bar{d}H$	$y_d = -im_d/v$	$y_d \frac{\sin(\alpha+\theta)}{\sin\alpha}$	$y_d \frac{\cos(\alpha+\theta)}{\sin\alpha}$	$y_d \gamma_5 ctg\alpha$
WWH	$g_w = ig^2 v/2$	$g_w \cos\theta$	$-g_w \sin\theta$	0

where $v^2 = v_1^2 + v_2^2$, $tg\alpha = v_2/v_1$, and v_1 and v_2 are the vacuum expectation values of Higgs field doublets; θ is the mixing angle of neutral scalar components of the Higgs sector; $g^2 = 4\sqrt{2} M_W^2 G_F$. One can see from the definition that $0 \leqslant \alpha \leqslant \pi/2$ whence $-\pi/2 \leqslant \theta \leqslant 0$ (see Ref. [2]). One can see from the table that in the case of the absence of mixing ($\theta = 0^\circ$) at any values of $tg\alpha$ the nonstandard H°-boson becomes identical to the standard H°_{SM}-boson.

Omitting the details of calculations for the decay widths of H° and h° bosons and not presenting the final formulae as they are cumbersome, we'll discuss the obtained results shown in Figs 2-8. The plots also present the production cross sections of the pseudoscalar boson P^o . The obtained results take into account the contribution from all diagrams given in Fig.1, i.e. the contribution from the diagram where relatively light quarks q emit scalar particles is also taken into account. (This contribution becomes significant in the case of existence of the fourth generation of quarks, when the b'-quark mass can achieve a few tens of GeV.)

Figs 2-4 present the ratios R_1 of the widths of the studied quarkonium decays $(Q\bar{Q}) \to Qq WH$ for H^o , h^o and P^o - bosons, respectively, to the width of the weak decay $(Q\bar{Q}) \to QqW$, depending on the mass of the heavy quark M_Q (everywhere below the mass of the heavy quark Q is taken in the region $M_W \leqslant M_Q \leqslant$ 240 GeV [5] , and under Q we imply either t or the possible t' quarks) for different masses of Higgs scalars M_H at m_b = 4.5 GeV and $m_{b'}$ = 50 GeV as well as for different values of $tg\alpha$ and mixing angle θ . Actually, R_1 is the branching ratio of the studied decays. As can be seen from Figs 2 and 3, the ratio R_1 for the scalar particles is rather large and achieves $R_1 \sim 10^{-2} - 10^{-1}$, and for the pseudoscalar P^o (see Fig.4) is somewhat lower: $R_1 \sim 10^{-3}-10^{-2}$.

Comparing the production cross section of H^o and h^o - bosons in the absence of mixing ($\theta = 0^o$), i.e. when the H^o boson is identical to the standard H^o_{SM}-boson, from Figs 2 and 3 we can see a large difference between them. Thus, at $tg\alpha$ =1, M_H = 20 GeV and m_b = 4.5 GeV one can see that the h^o - boson cross section is twice as low as the H^o-boson cross section practically for the whole Q-quark mass region of interest. Emphasize that with increasing $tg\alpha$ (see Fig.2a,b and Fig.3a,b) there takes place a sharp growth of the production cross section of the nonstandard h^o-boson (the table shows that the interaction vertex $t\bar{t}h^o$ is proportional to $tg\alpha$, and as known, the main contribution to the Higgs boson production cross section comes from the heavier quarks), whereas the $tg\alpha$ dependence is absent for H^o in the absence of mixing (see the table). The similar to h^o-boson growth of cross section with increasing $tg\alpha$ takes place for the P^o-boson as well (see Fig.4). In the case of mixing, e.g. for $\theta = -\pi/6$ and $tg\alpha = 1$, the h^o-boson production cross section will be already suppressed compared to the H^o-boson (Figs 2c and 3c). Such a decrease in the h^o-boson production cross section is due to the weakening of the interaction vertex $t\bar{t}h^o$ as the absolute value of the angle $|\theta|$ increases. In turn, the H^o-boson in the presence of such a mixing is produced by a factor of 1.5 - 2 more intensively than the standard H^o_{SM}-boson is (cf. Figs 2a and 2c).

As was already mentioned, the contribution from the Fig.1b diagram becomes noticeable only for large masses of the down quark q (we took for calculations $m_{b'} = 50$ GeV). Note that this diagram contribution falls off with increasing $tg\alpha$; however, it substantially grows up in the presence of mixing. Thus, at $tg\alpha = 1$, $\theta = -\pi/6$ in the h^o-boson case its contribution leads to an increase in the cross section nearly by an order of magnitude as compared with the case when $m_b = 4.5$ GeV (compare the solid and dotted curves in Fig.3c).

In Figs 5 and 6 we present the differential characteristics of the studied decays $(1/\Gamma)d\Gamma/dx_1$ where Γ is the width of the studied decays, and $x_1 = 2E_H/\sqrt{M_Q}$ is the share of energy carried away by the Higgs bosons from quarkonium. As can be seen from the given plots, in the case of production of the scalars H^0 and h^0 , the differential distribution has a pronounced peak at low values in the admissible region over x_1 , irrespective of the choice of $tg\alpha$, θ as well as of M_H , M_Q and m_q . With increasing ratio M_H/M_Q this peak somewhat broadens (compare Figs 5 and 6). Note also that for the h^0-boson, in the case of absence of the mixing angle θ , there is no contribution from the Fig.1c diagram (the three-boson interaction WWh^0 is absent) as distinct from the H^0 and H^0_{SM} boson cases; but despite this, the differential distributions for all the scalars practically coincide irrespective of $tg\alpha$, masses M_H , M_Q and m_q . Figs 5 and 6 show that for the P^0-boson the peak in the distribution is in the medium part of the region over x_1 .

We also considered the ratio R of the width of the studied quarkonium decay mechanism to the cross section of the Higgs boson production via the Wilczek mechanism [6] , depending on M_Q for different values of $tg\alpha$, θ , M_H and m_q (see Figs 7 and 8). Fig.7 presents the ratio R for H^0 and P^0-boson production at $tg\alpha = 1$ and $\theta = 0^\circ$. One can see that the account of the light quark mass m_q does not lead to a noticeable change in the value of R as compared with our earlier results in Refs [3,4] . Fig.8 presents the ratio R for the h^0-boson. One can see that in the studied mechanism the h^0-bosons are produced more intensively than they could have been produced in the Wilczek mechanism. Thus, the ratio achieves $\sim 10^2$ for $M_H = 20$ GeV, $m_g = 4.5$ GeV already at $M_{\tilde{g}} = 160$ GeV.

In conclusion we'd like to note once again that the study of properties and the search for nonstandard scalar boson (of H^o and h^o types) may give an important additional information on the Higgs sector structure. As one can see, in the studied mechanism of the Higgs scalar boson production the production cross section of H^o and h^o bosons in some cases was strongly different from the cross section of the standard H^o_{SM} - boson production from the minimal model of electroweak interaction.

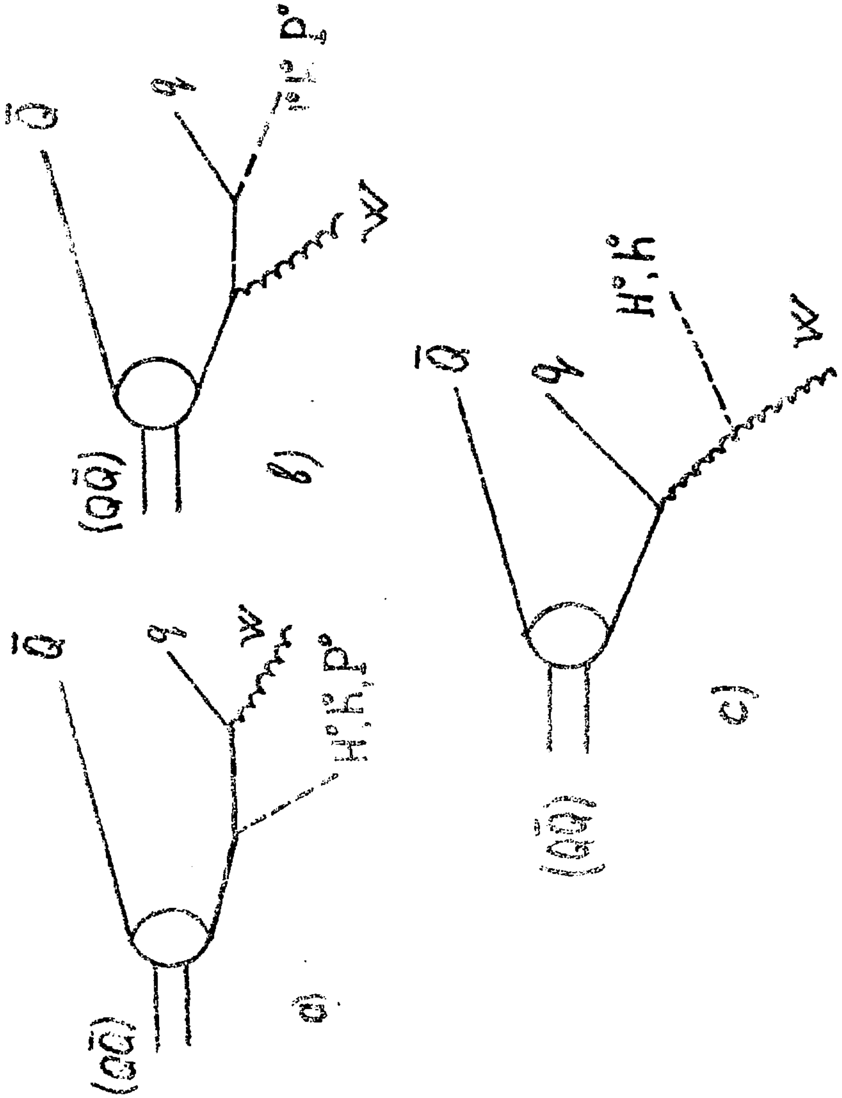
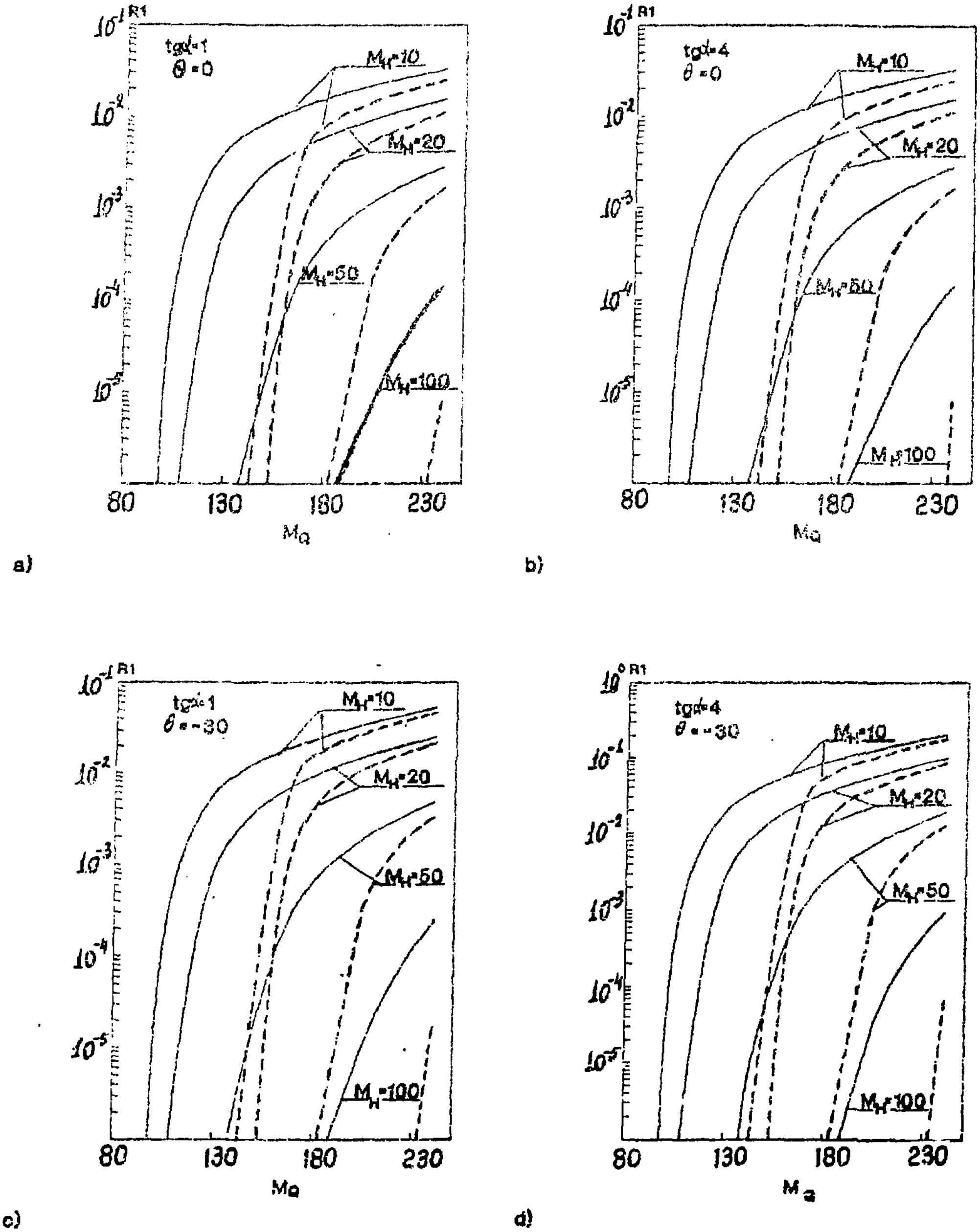


Fig. 1



R1
tgα=1
θ=0
M_H=10
M_H=20
M_H=50
M_H=100
80 130 180 230
M_a
a)
tgα=4
θ=0
b)
tgα=1
θ=-30
c)
tgα=4
θ=-30
d)

Fig.2

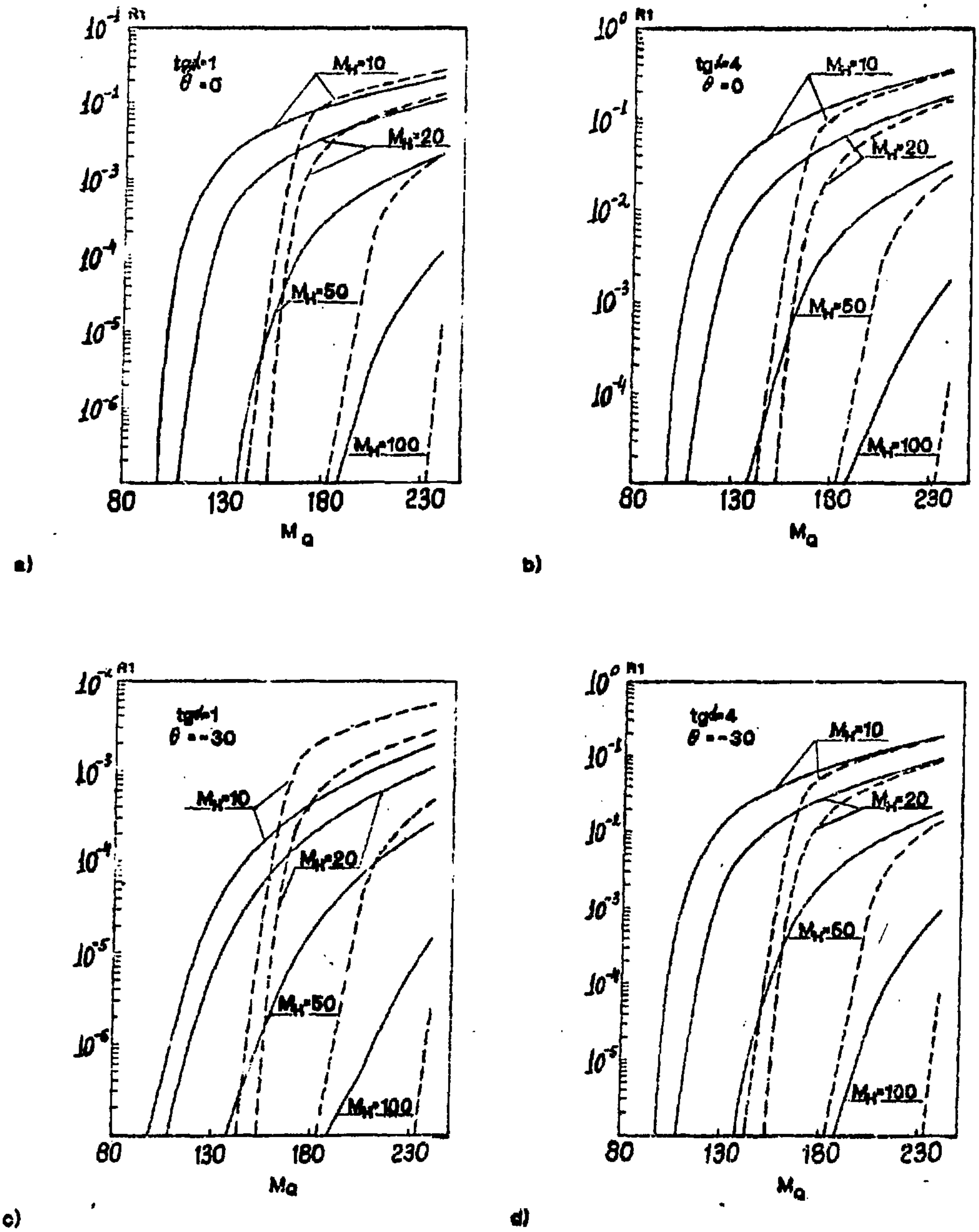


Fig.3

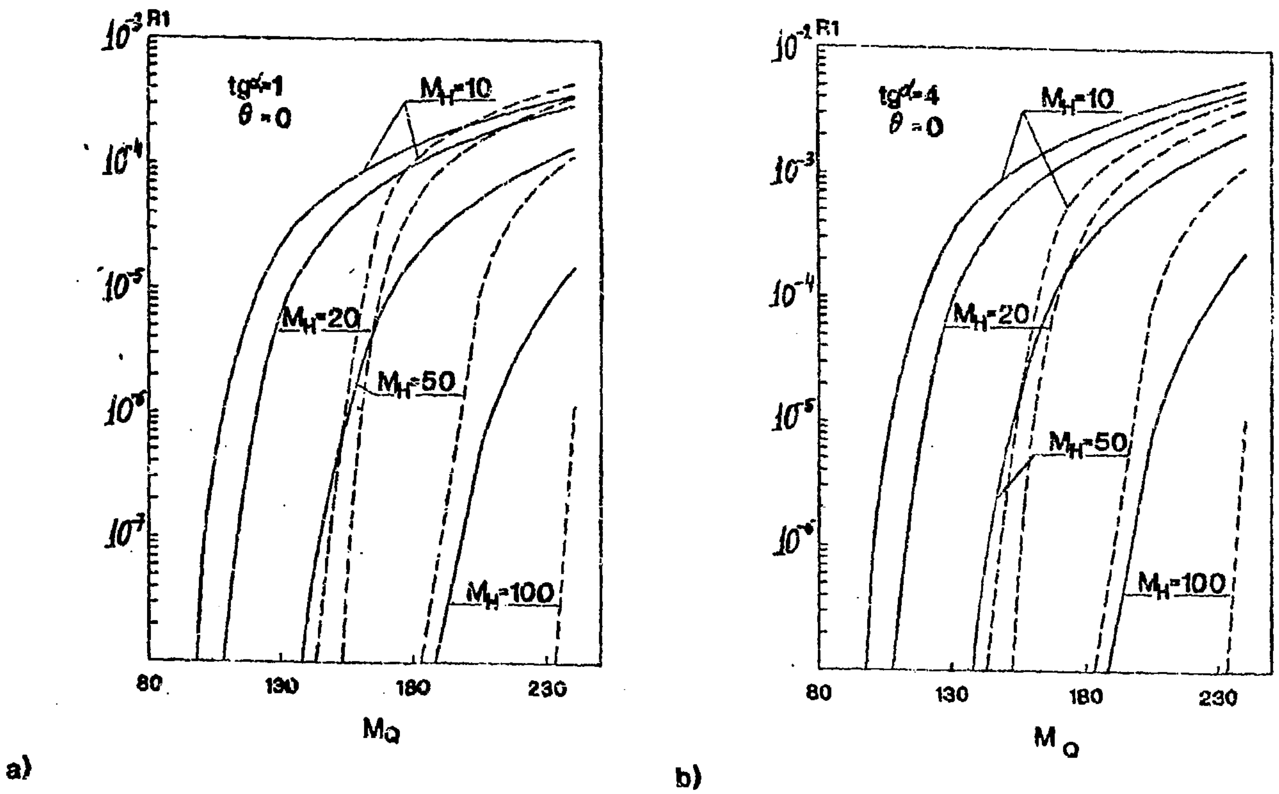
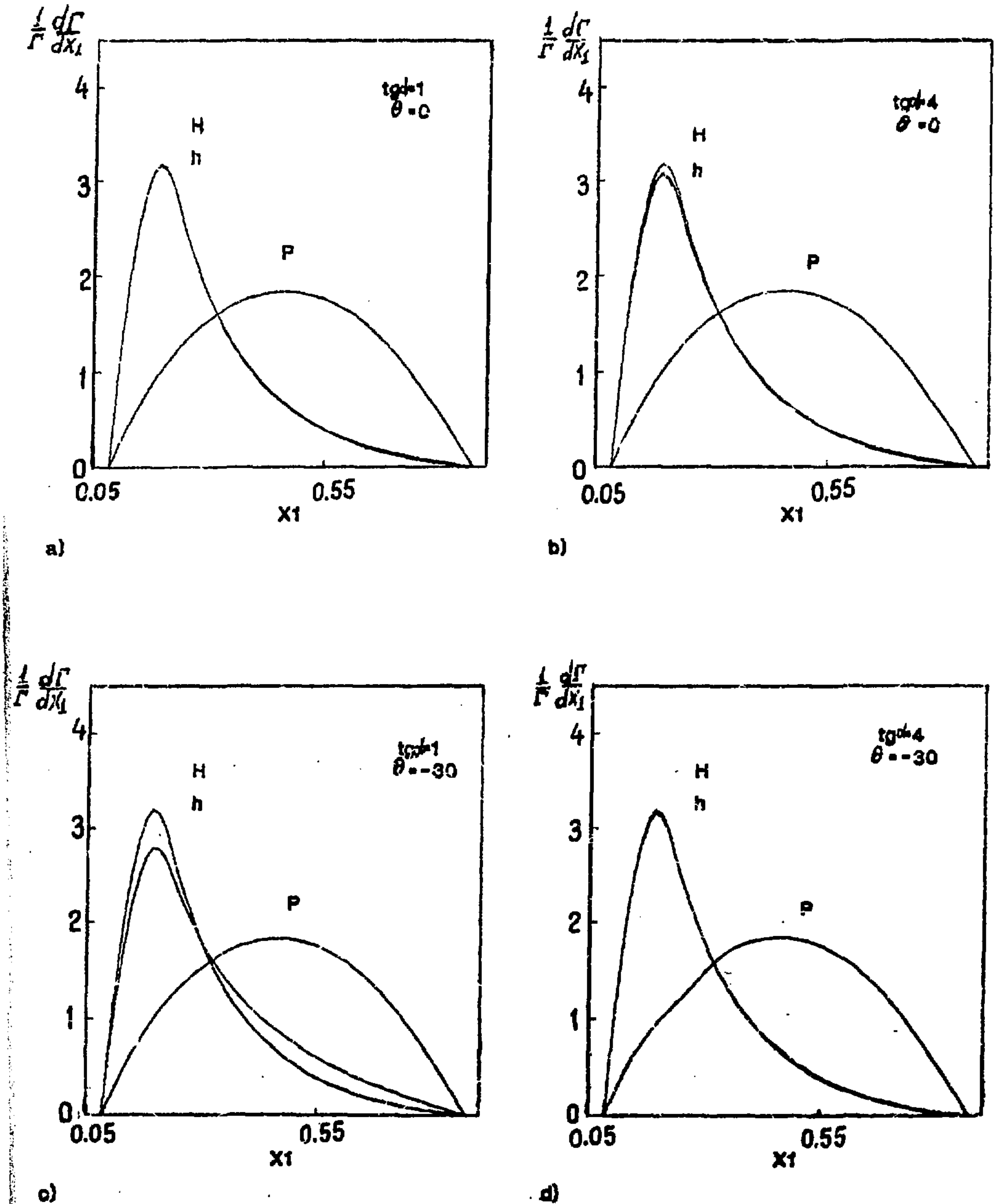

R1
tgα=1
θ=0
M_H=10
M_H=20
M_H=50
M_H=100
80
130
180
230
M_Q
a)
R1
tgα=4
θ=0
M_H=10
M_H=20
M_H=50
M_H=100
80
130
180
230
M_Q
b)

Fig.4



a)
tgα=1
θ=0
H
h
P
X1
b)
tgα=4
θ=0
H
h
P
X1
c)
tgα=1
θ=-30
H
h
P
X1
d)
tgα=4
θ=-30
H
h
P
X1

Fig.5

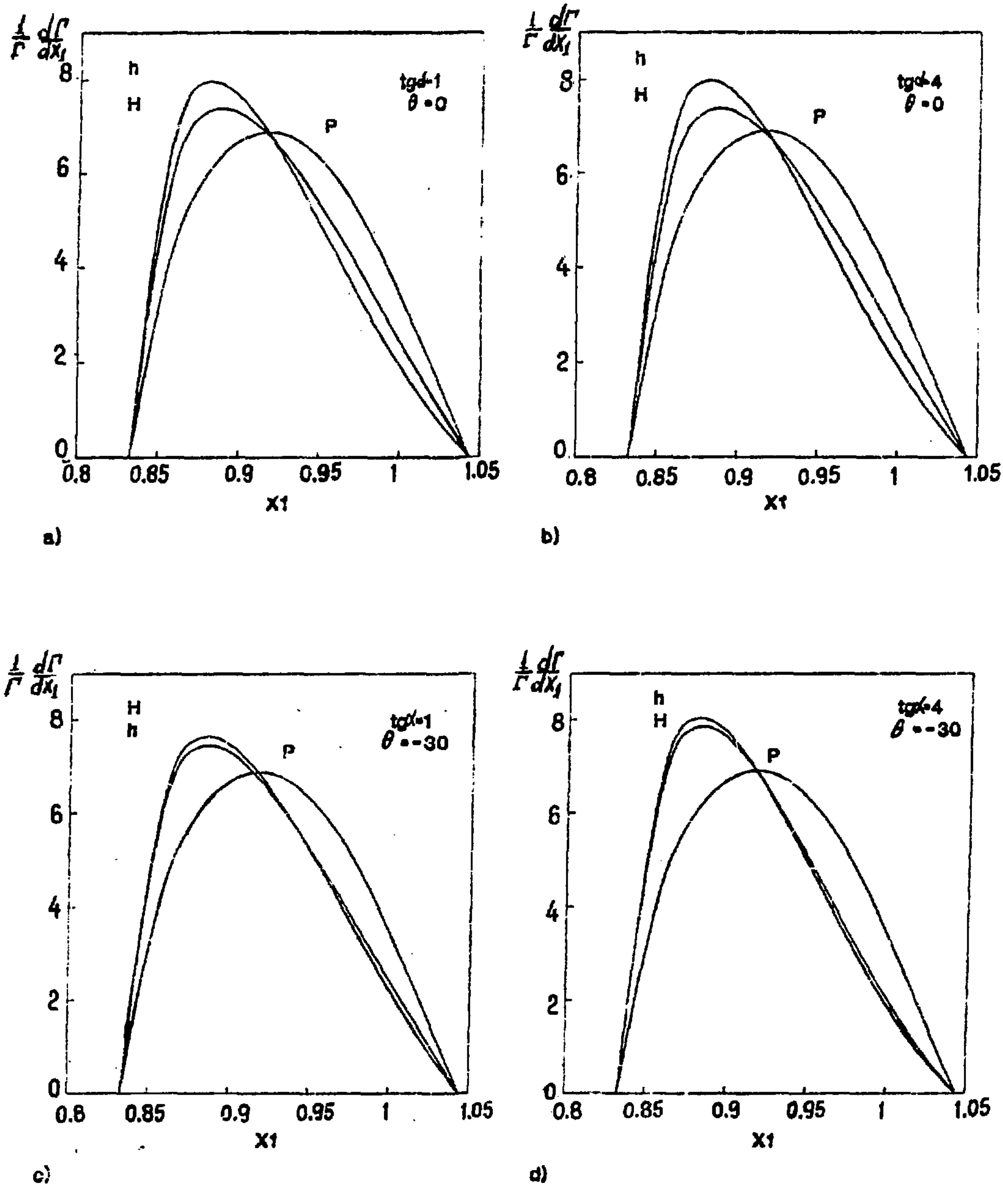
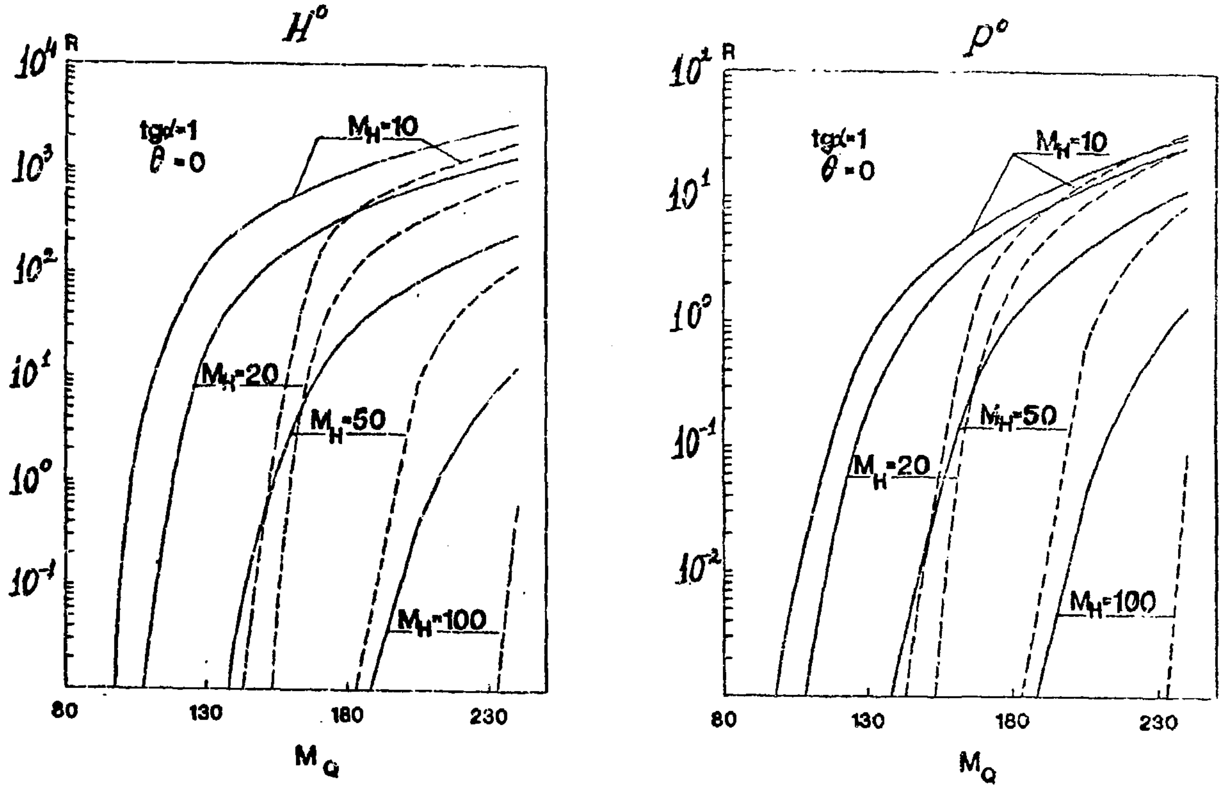


Fig.6


H°
R
10^4
10^3
10^2
10^1
10^0
10^-1
tgα=1
θ=0
M_H=10
M_H=20
M_H=50
M_H=100
80
130
180
230
M_Q
P°
R
10^2
10^1
10^0
10^-1
10^-2
tgα=1
θ=0
M_H=10
M_H=20
M_H=50
M_H=100
80
130
180
230
M_Q

a) b)

Fig.7

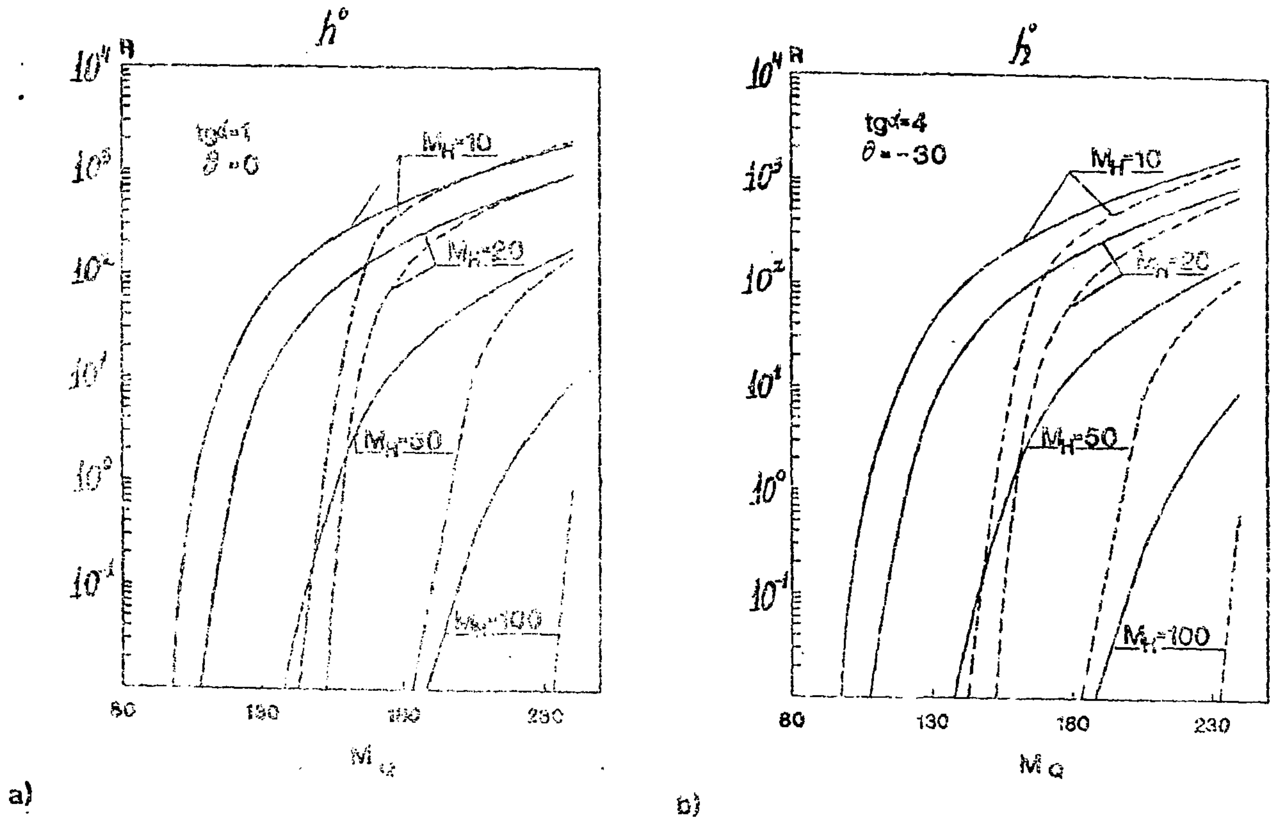

a)
h^0
R
tgα=1
θ=0
M_H=10
M_H=20
M_H=50
M_H=100
10^4
10^3
10^2
10^1
10^0
10^{-1}
80
130
180
230
M_Q
b)
h_2^0
R
tgα=4
θ=-30
M_H=10
M_H=20
M_H=50
M_H=100
10^4
10^3
10^2
10^1
10^0
10^{-1}
80
130
180
230
M_Q

Fig.8

Figure Captions

Fig.1. Diagrams corresponding to the mechanism of single-quark decay of heavy quarkonium ($Q\bar{Q}$) with Higgs boson production.

Fig.2. The ratio $R_1 = \Gamma((Q\bar{Q}) \to Q_q WH)/\Gamma((Q\bar{Q}) \to Q_q W)$ depending on the mass of heavy quark M_Q for the H^o-boson production at different values of masses M_H , m_q , $tg\alpha$ and mixing angle θ (here and everywhere below the solid curve refers to $m_b = 4.5$ GeV, and the dotted curve refers to $m_{b'} = 50$ GeV; masses on the plots are given in GeV everywhere).

Fig.3. The ratio R_1 versus the heavy quark mass M_Q for the h^o-boson production at different values of masses M_H, m_q , $tg\alpha$ and angle θ .

Fig.4. The ratio R_1 versus the heavy quark mass M_Q for the P^o-boson production at different values of masses M_H , m_q , $tg\alpha$ and angle θ .

Fig.5. The dependence of the differential width $(1/\Gamma)d\Gamma/dx_1$ on $x_1 = 2E_H/\sqrt{M_Q}$ (the shares of energy carried away by the Higgs bosons from quarkonium) for H^o , h^o , P^o bosons at $M_Q = 240$ GeV, $m_b = 4.5$ GeV, $M_H = 10$ GeV in the case of different values of $tg\alpha$ and angle θ .

Fig.6. The same as in Fig.5 for $M_H = 100$ GeV.

Fig.7. The ratio $R = \Gamma((Q\bar{Q}) \to Q_q WH)/\Gamma((Q\bar{Q}) \to H\gamma)$ versus the mass M_Q for H^o and P^o bosons at different values of masses M_H , m_q for $tg\alpha = 1$, $\theta = 0^o$.

Fig.8. The ratio R versus the mass M_Q for h^0-boson at different values of masses M_H , m_q .

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С.Г.ГРИГОРЯН, С.А.ЧАТРЧЯН
НЕСТАНДАРТНЫЕ СКАЛЯРНЫЕ БОЗОНЫ В РАСПАДАХ
СВЕРХТЯЖЕЛЫХ КВАРКОНИЕВ
(на английском языке, перевод З.Н.Асланян)

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