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POLARIZATION EFFECTS IN H^0-BOSON PRODUCTION IN $p\bar{p}$ AND pp COLLISIONS

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$p\bar{p}$ ԵՎ pp ՓՈԽԱԶԴԵՑՈՒԹՅՈՒՆՆԵՐՈՒՄ H° ԲՈԶՈՆԻ ԾՆՄԱՆ ԺԱՄԱՆԱԿ ԲԵՎԵՌԱՑՄԱՆ ԵՐԵՎՈՒՅԹՆԵՐԸ

Հետազոտված են $p\bar{p}$ և pp փոխազդեցություններում Հիգգսի սկալյար մասնիկների ֆերմիոնների զույգի հետ համատեղ ծնման ժամանակ բևեռացման երևույթները: Ցույց է տրված, որ այդ երևույթները զգալի են, որը կարող է հանդիսանալ կարևոր լրացուցիչ միջոց՝ առանձնելու ֆոնային պրոցեսներից, որոնք նշանակալի են Հիգգսի բոզոնների ծնման բոլոր մեխանիզմների համար:

Երևանի Ֆիզիկայի Ինստիտուտ

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S.G. GRIGORYAN, S.A. CHATRCHYAN

POLARIZATION EFFECTS IN H^{0}-BOSON PRODUCTION IN pp AND pp COLLISIONS

The polarization effects in associated with fermion pairs production of Higgs scalar particles in $p\bar{p}$ and pp-collisions are studied. These effects are shown to be great, therefore their measurement may appear an important additional tool to separate from the background processes that are essential practically for all mechanisms of Higgs boson production.

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ПОЛЯРИЗАЦИОННЫЕ ЭФФЕКТЫ В РОЖДЕНИИ H°-БОЗОНА В $p\bar{p}$ И pp - СТОЛКНОВЕНИЯХ

Исследованы поляризационные эффекты в ассоциированном с парами фермионов рождении хиггсовских скалярных частиц в $p\bar{p}$ и pp - столкновениях. Показано, что величины этих эффектов велики, это могло бы явиться важным дополнительным способом отстраивания от фоновых процессов, которые значительны практически для всех механизмов рождения хиггсовских бозонов.

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A number of associative mechanisms of Higgs scalar particles (H^0-bosons) production in $p\bar{p}$ and pp -collisions was suggested [1-13]. The cross sections of H^0-boson production in these reactions are less than those of its single production [14]. However the production of H^0-boson in association with other particles (heavy quarks, vector bosons, etc.) undoubtedly gives rise to more favourable conditions for their identification. Besides, Higgs scalars are produced with high transverse momenta, this enabling one to escape from large background processes of the Drell-Yang type.

This work deals with the polarization effects in the H^0-boson production in association with fermion pairs [1,2,7] (see Fig.1).

The mechanism under study is one of most perspective in H^0-boson production in hadron-hadron collisions. Therefore obtaining of additional information about Higgs scalar production owing to the presence of the polarization effects (note that these effects are absent in other mechanisms of H^0-boson production) seems interesting. Polarization effects not only can give an important additional information about the H^0-boson production mechanism, its coupling constant with gauge bosons, but also allow to escape from the background processes which are great practically for all mechanisms f H^0-boson production (Fig.2 gives an example of the background process which imitates the H^0-boson production in association with the fermion pairs). The study of polarization effects is especially interesting in connection with the polarization experiments planned at the CERN $p\bar{p}$-collider [15], where they expected to obtain longitudinally polarized hadronic beams of high intensity [15].

The presence of polarization effects in the considered mechanism (see Fig.1) in case of longitudinally polarized hadronic beams is connected with the availability of Z^0 and $W^{\pm}$ bosons whose interaction with quarks contains an axial part, this just giving rise to P-odd effects. Hence there arise asymmetries of the type

$$A_1 = \frac{d\sigma(+) - d\sigma(-)}{d\sigma(+) + d\sigma(-)}, \quad A_2 = \frac{d\sigma(++) - d\sigma(--)}{d\sigma(++) + d\sigma(--)}, \tag{1}$$

$$A_3 = \frac{d\sigma(+-) - d\sigma(-+)}{d\sigma(+-) + d\sigma(-+)} .$$

Here $\sigma(\pm)$ is the cross section of $p\bar{p}$ (pp) scattering in case when one of the beams is longitudinally polarized with helicity $h_1 = \pm 1$, $\sigma(\pm\pm)$ $(\sigma(\pm\mp))$ – are cross sections of the studied process in case both beams are polarized with helicities $h_1 = \pm 1$ and $h_2 = \pm 1$ ($h_1 = \pm 1$ and $h_2 = \mp 1$). To calculate the asymmetry, we shall give the expression for the amplitude square :

$$M^2 = M_a^2 + M_b^2 + M_{int}^2 , \tag{2}$$

$$M_a^2 = \frac{\alpha^2}{32(q_1^2 - m^2)^2(q_2^2 - m^2)^2}\Big\{(g_{v_1}^2 + g_{a_1}^2)\big[(1 - \xi_1\xi_2)(g_v^2 + g_a^2) + 2g_v g_a \times \tag{3}$$

$$\times (\xi_1-\xi_2)\big]\big[(K_1P_1)(K_2P_2)+(K_1P_2)(K_2P_1)\big]-2g_{v_1}g_{a_1}\big[(\xi_1-\xi_2)(g_v^2+g_a^2)+2g_vg_a\times$$

$$\times (1-\xi_1\xi_2)\big]\big[(K_1P_1)(K_2P_2)-(K_1P_2)(K_2P_1)\big]\Big\},$$

$$M_6^2=\frac{\alpha^2}{32(q_3^2-m^2)^2(q_4^2-m^2)^2}\Big\{\big[(1-\xi_1\xi_2)\big[(G_v^2+G_a^2)(G_{v_1}^2+G_{a_1}^2)+4G_vG_{v_1}G_aG_{a_1}\big]+ \quad (4)$$

$$+(\xi_1-\xi_2)\big[2G_vG_a(G_{v_1}^2+G_{a_1}^2)+2G_{v_1}G_{a_1}(G_v^2+G_a^2)\big]\big](K_1P_2)(K_2P_1)+$$

$$+\big[(1+\xi_1\xi_2)\big[(G_v^2+G_a^2)(G_{v_1}^2+G_{a_1}^2)-4G_vG_{v_1}G_aG_{a_1}\big]+(\xi_1+\xi_2)\big[2G_vG_a(G_{v_1}^2+G_{a_1}^2)-$$

$$-2G_{v_1}G_{a_1}(G_v^2+G_a^2)\big]\big](K_1K_2)(P_1P_2)\Big\},$$

$$M_{int}^2=\frac{\alpha^2}{16(q_1^2-m^2)(q_2^2-m^2)(q_3^2-m^2)(q_4^2-m^2)}\Big\{(1-\xi_1\xi_2)\times\big[(g_vG_{v_1}+g_aG_{a_1})\times \quad (5)$$

$$\times(G_vg_{v_1}+G_ag_{a_1})+(G_vg_{a_1}+G_ag_{v_1})(g_vG_{a_1}+g_aG_{v_1})\big]+(\xi_1-\xi_2)\times$$

$$\times\big[(g_vG_{a_1}+g_aG_{v_1})(G_vg_{v_1}+G_ag_{a_1})+(G_vg_{a_1}+G_ag_{v_1})(g_vG_{v_1}+G_{a_1}g_a)\big]\Big\}(K_1P_2)(K_2P_1).$$

Here g_v, g_{v_1}, G_v, G_{v_1}, g_a, g_{a_1}, G_a and G_{a_1} are the vector and axial coupling constants of quarks and leptons with Z^0 and $W^\pm$ bosons defined according to the Weinberg-Salam model. For the Z^0-boson ($\alpha=\bar{g}^3m_Z$) we have:

$$g_v^{u(\bar{u})}=1-\frac{8}{3}\sin^2\theta_W\,,\qquad g_v^{d(\bar{d})}=-1+\frac{4}{3}\sin^2\theta_W\,,$$

$$g_a^{u(\bar{u})}=1\,,\qquad g_a^{d(\bar{d})}=-1\,,$$

$$g_v^{e(\mu)} = 1 - 4\sin^2\theta_W \,, \qquad g_a^{e(\mu)} = -1$$

for the $W^{\pm}$ bosons ($\alpha = g^3 m_W$) we have:

$$g_v = \sqrt{2} \,, \qquad g_a = \sqrt{2} \,.$$

Further on, for the numerical estimates we shall everywhere take $\sin^2\theta_W = 0.22$, $\alpha = \bar{g}^3 m_Z$ or $g^3 m_W$; ξ_1 and ξ_2 are longitudinal polarization vectors of quark and antiquark, m - is the gauge boson mass.

The expression for the cross section has the form (for simplicity, we shall give only the contribution coming from the diagram of Fig. 1a):

$$\frac{d\sigma_a(h_1,h_2)}{dx\,d\Omega} = \int_0^1 dx_1 \int_{\tau/x_1}^1 dx_2 \, \frac{d\sigma_a(\xi_1,\xi_2)}{dx\,d\Omega} F_{W(Z)}(x_1,x_2) \,,$$

$$\frac{d\sigma_a(\xi_1,\xi_2)}{dx\,d\Omega} = \frac{G^3 m^8}{G\sqrt{2}\,(4\pi)^4} \frac{[(1-x+m_H^2/S)^2 - 4m_H^2/S]^{1/2}}{(S-m^2)^2\,(x-m^2/S)^2} \cdot$$

$$\left\{8x + [(1-x+m_H^2/S)^2 - 4m_H^2/S]\sin^2\theta\right\}[(g_v^2+g_a^2)(1-\xi_1\xi_2) + \tag{6}$$

$$+ 2g_v g_a(\xi_1-\xi_2)](g_{v_1}^2 + g_{a_1}^2) \,,$$

where $S = (P_1+P_2)^2$, $\tau = (m+m_H)^2/S_o$, $S_o = (P_1+P_2)^2$; P_1 and P_2 are the momenta of colliding hadrons, X_1 and X_2 are fractions of hadron momenta carried by quarks ($p_1 = X_1 P_1$, $p_2 = X_2 P_2$); $S = X_1 X_2 S_o$, m_H - is the H^0-boson mass; $X = (K_1+K_2)^2/S$, $d\Omega = d\cos\theta\, d\varphi$, where θ and φ are the polar and azimuthal angles of vector $\vec{P}$; $F_{W(Z)} = f_{q(\xi_1)}^{p(h_1)}(x_1) \cdot f_{q(\xi_2)}^{p(h_2)}(x_2)$ for the pp-interaction, and

$F_{W(Z)} = f^{p(h_1)}_{q(\xi_1)}(x_1) \cdot f^{\bar{p}(h_2)}_{\bar{q}(\xi_2)}(x_2)$ for the $p\bar{p}$ -interaction. Here $f^{p}_{q}(x)$ and $f^{\bar{p}}_{\bar{q}}(x)$ are distribution functions of the valent quarks in the hadrons (we neglect the contributions of the "sea" quarks in hadrons).

To obtain numerical values of the studied asymmetries, one should know the functions $f^{p(h)}_{q(\xi)}(x)$ and $f^{\bar{p}(h)}_{\bar{q}(\xi)}(x)$ or relations between them (in fact one should know how polarizations of quarks and hadrons are connected). We shall carry out our calculations for the SU(6)-symmetric wave function of proton:

$$\Psi(p^+) = 2|u_+ d_- u_+> + 2|u_+ u_+ d_-> + 2|d_- u_+ u_+> - -|u_+ u_- d_+> - |u_+ d_+ u_-> - |u_- d_+ u_+> - |d_+ u_- u_+> - -|d_+ u_+ u_-> - |u_- u_+ d_+>,$$

where we have the following relations between the quark distribution functions:

$$f^{p(+)}_{u(+)}(x) = f^{p(-)}_{u(-)}(x) = \frac{5}{6} f^{p(+)}_{u}(x), \qquad f^{p(+)}_{d(+)}(x) = f^{p(-)}_{d(-)}(x) = \frac{1}{6} f^{p(+)}_{u}(x),$$

$$f^{p(+)}_{u(-)}(x) = f^{p(-)}_{u(+)}(x) = \frac{1}{6} f^{p(+)}_{u}(x), \qquad f^{p(+)}_{d(-)}(x) = f^{p(-)}_{d(+)}(x) = \frac{2}{6} f^{p(+)}_{u}(x), \quad (7)$$

$$f^{p}_{u}(x) = 2 f^{p}_{d}(x), \qquad f^{p(+)}_{u}(x) = 2 f^{p(+)}_{d}(x),$$

We have carried out the calculations also in dynamical model (of the Farrar-Jackson type [16]), where at $x \to 1$ the distribution of quarks with helicity inverse to that of hadron is suppressed, i.e.

$$f^{p(+)}_{u(-)}(x) = f^{p(-)}_{u(+)}(x) = f^{p(+)}_{d(-)}(x) = f^{p(-)}_{d(+)}(x) = 0, \qquad (8)$$

$$f_{u(+)}^{p(+)}(x) = f_u^{p(+)}(x)\ , \quad f_{d(+)}^{p(+)}(x) = f_{d(-)}^{p(-)}(x) = f_d^{p(+)}(x) = \frac{1}{5} f_u^{p(+)}(x)\ ,$$

$$f_u^p(x) = 5 f_d^p(x)\ , \quad f_u^{p(+)}(x) = 5 f_d^{p(+)}(x)$$

(Note a priori that if for distribution functions in this case one uses the parametrization applied in Ref. 15, then one obtains results which are close to ours when we neglected the $f_{q(-)}^{p(+)}(x)$ and $f_{q(+)}^{p(-)}(x)$ transitions.)

We shall start to study the polarization effects from the case when the final fermion pair is a lepton pair of the type of $\mu^+\mu^-$, e^+e^-, $\nu\bar{\nu}$, νe, $\nu\mu$. Then the H^0-boson production in the mechanism under study proceeds only through the S-channel diagram [1,2] (see Fig.1a; in this case the production of H^0-boson with $m_H \leq 100 \div 200$ GeV is most advantageous). Note that when the invariant mass of the final lepton pair is close to m, then we have the H^0-boson production in association with Z^0 and $W^\pm$ bosons. From the expression for the cross section (see (6)) it follows that in case of equal helicity of annihilating quarks the cross section at a quark level is zero (a similar result for the e^+e^--annihilation is obtained in Ref. [17]). This is due to the helicity conservation in vertices of $Z^0 q\bar{q}$ and $W^\pm q\bar{q}$ type. However the hadronic cross sections are different from zero because of the possibility of the transition of negative-polarized quarks to positive-polarized proton. For the asymmetries in the considered case we obtain:

$$A_1^{SU(6)}(\mu^+\mu^-, e^+e^-) \simeq 0{,}4\ , \quad A_1^F(\mu^+\mu^-, e^+e^-) \simeq 0{,}7\ ,$$

$$A_1^{SU(6)}(\nu e, \bar{\nu}\mu) \simeq 0{,}2\ , \quad A_1^F(\nu e, \bar{\nu}\mu) = 1\ ,$$

$$A_2^{SU(6)F}(\mu^+\mu^-,\ e^+e^-,\ \nu e,\ \nu\mu)=0$$

$$A_3^{SU(6)}(\mu^+\mu^-,e^+e^-)\simeq 0{,}5\ ,\qquad A_3^F(\mu^+\mu^-,e^+e^-)\simeq 0{,}7 \tag{9}$$

$$A_3^{SU(6)}(\nu e,\ \nu\mu)\simeq 0{,}4\ ,\qquad A_3^F(\nu e,\ \nu\mu)=1$$

In case when a final pair of fermions is a pair of quarks $u\bar{u}$, $d\bar{d}$, $u\bar{d}$, $d\bar{u}$, both S and t -channel diagrams contribute to the cross section (see Fig.1).

In the region of small S_0 (i.e. when $\sqrt{S}\sim m_H+m$) the main contribution is determined by diagrams of the S -channel type, so for the asymmetries we obtain

$$A_1^{SU(6)}\simeq 0{,}3\ ,\qquad A_1^F\simeq 0{,}9\ ,$$

$$A_2^{SU(6)}=0\ ,\qquad A_2^F=0\ , \tag{10}$$

$$A_3^{SU(6)}\simeq 0{,}3\ ,\qquad A_3^F\simeq 0{,}8\ .$$

In case S_0 is large (e.g. at studying the H^0-boson production with $m_H \gtrsim 200 \div 300$ GeV), the main contribution comes from the t -channel diagrams [7], and for the asymmetries we obtain

$$A_1^{SU(6)}\simeq 0{,}4\ ,\qquad A_1^F\simeq 0{,}9\ ,$$

$$A_2^{SU(6)}=0\ ,\qquad A_2^F=0\ , \tag{11}$$

$$A_3^{SU(6)}\simeq 0{,}6\ ,\qquad A_3^F=1\ .$$

From the results obtained one can see that asymmetry $A_2=0$, though the SU(6)-wave function contains transitions of negative-polarized quarks to positive-polarized hadron, this being a result of symmetric relations of the type: $f_q^p(x) = f_{\bar{q}}^{\bar{p}}(x)$, $f_{q(-)}^{p(+)}(x) = f_{q(+)}^{p(-)}(x)$ and so on. It is interesting that the symmetric relations cancel A_2 even in case of contribution coming from the t-channel diagram (see (1)) when the cross section contains terms of ($\xi_1 + \xi_2$) type (see (4)). From the obtained results one can see that A_1 and A_2 asymmetries are large, this enabling one to measure them experimentally.

Hence one can see that owing to the P-odd effects which gave rise to considerable asymmetries in associated H^0-boson production we have an additional information to escape from the background processes of the type shown in Fig.2 (where appearance of asymmetries is impossible). There exist however background processes where, generally speaking, asymmetries may arise. For example, if in Fig.2 the virtual gluon is replaced by the Z^0-boson, then asymmetries arise (see [15]). However from the results of Ref. 15 one can see that asymmetry A_1 for this background process is inverse as against the one studied in the present work. Besides, there arose asymmetry A_2 , this being distinct from what was obtained by us.

The obtained results referred to the $p\bar{p}$-collisions. In case of the pp - collisions, the production of H^0-bosons with $m_H \lesssim 100 \div 200$ GeV is not advantageous, since there work only the S -channel diagrams, while the contributions of the "sea" quarks to hadrons are neglected. In case of the heavy H^0-boson production, the t-channel diagrams work, and hence the results for pp and $p\bar{p}$ -interactions nearly coincide.

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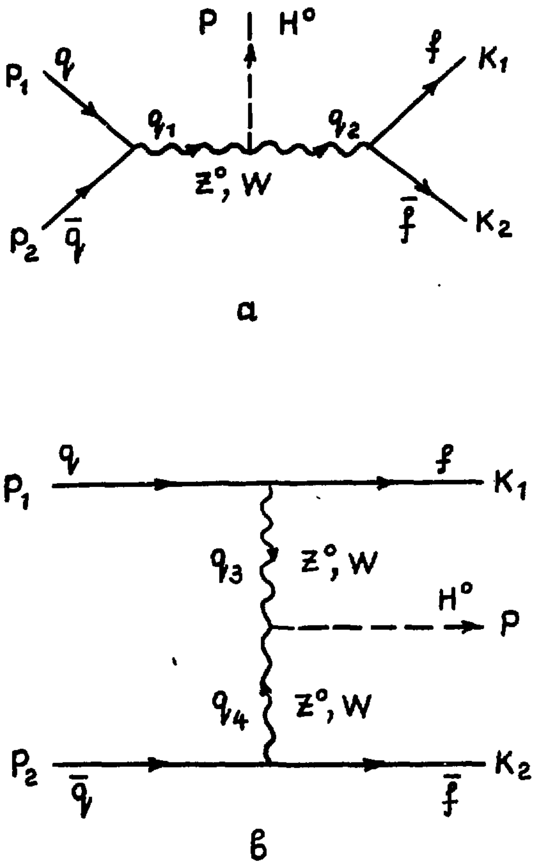

Fig.1. Diagrams corresponding to H^0-boson production in association with fermion pairs.

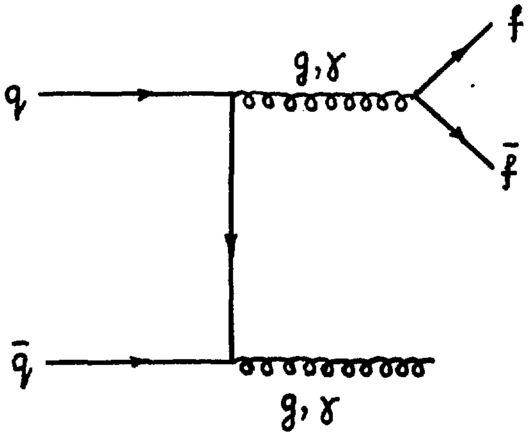

Fig.2. A diagram corresponding to one of the background processes.

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ПОЛЯРИЗАЦИОННЫЕ ЭФФЕКТЫ В РОЖДЕНИИ H°-БОЗОНА
В $p\bar{p}$ И pp -СТОЛКНОВЕНИЯХ
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