

HIGGS BOSON DECAYS INTO A PAIR OF SUPERSYMMETRIC PARTICLES

S.K . ABDULLAEV, E.SH. OMAROVA

Baku State University

sabdullayev@bsu.edu.az, emiliya.abdullayeva@inbox.ru

Within the framework of the Minimal Supersymmetric Standard Model, the H, h, A and H^\pm Higgs bosons decay channels into a pair of supersymmetric particles were studied: into a pair of chargino $H(h; A) \Rightarrow \chi_i^- \chi_j^+$; a pair of neutralino $H(h; A) \Rightarrow \chi_i^0 \chi_j^0$; in a pair of chargino - neutralino $H^\pm \Rightarrow \chi_i^\pm \chi_j^0$; into a pair of scalar fermions $H(h; A) \Rightarrow \tilde{f}_i \tilde{f}_j, H^\pm \Rightarrow \tilde{f}_i \tilde{f}_j'$. Analytical expressions for these decays widths are obtained, the degree of longitudinal polarizations of the chargino and neutralino and the dependence of the decay width on the Higgs boson mass are studied in detail.

Keywords: Standard Model, Minimal Supersymmetric Standard Model, Higgs boson, chargino, neutralino, decay width, sfermion.

PACS: 14.80 Da, 14.80 Ly, 14.80 Nb.

1. INTRODUCTION

The discovery of the Higgs boson H_{SM} with characteristics corresponding to the predictions of the Standard Model (SM) was carried out by the *ATLAS* and *CMS* collaborations in the Large Hadron Collider (*LHC*) in 2012 [1,2] (see also reviews [3-5]). With the discovery of the Higgs boson, a missing brick was found in the SM building and the mechanism for generating masses of fundamental particles, the mechanism of spontaneous breaking of the Braut - Englert-Higgs symmetry, was experimentally confirmed [6,7]. It should be noted that the path to the discovery of the Higgs boson was a long one; at the same time, much work began on its determination of the physical characteristics of this particle.

According to the SM , there are six leptons and six quarks, each comprising three families. The carriers of strong, electromagnetic, and weak interactions are gluons, a photon, charged W^\pm and neutral Z - bosons. Now they are supplemented by the fourth Yukawa interaction carried by Higgs boson H_{SM} .

SM allows you to accurately calculate the Feynman diagrams of various processes and compare with the corresponding experimental data. The agreement between the SM and the experience is strikingly good. Nevertheless, SM has its own difficulties. Many of them are connected with the fact that this model describes a lot, but is not able to explain where it came from, does not allow it to be deduced from deeper principles.

One of the difficulties of SM is related to the problem of hierarchy. According to quantum field theory, vacuum is not an absolute void, but a sea of virtual particles. All real particles of our world are particles dressed in a virtual fur coat. Masses, charges and other characteristics of the observed particles are the characteristics of particles dressed in a fur coat. Theorists take this phenomenon into account using a mathematical procedure called renormalization. The fact is that renormalization works well for all particles, but in the case of the Higgs boson, a problem arises: the influence of virtual particles on the Higgs boson mass is too strong, as a result, the boson mass increases trillions of times, and such a particle can no longer play

the role of the Higgs boson. This difficulty is called the hierarchy problem. This way out of this situation is possible. If in nature there are some other particles that do not exist in the SM , then in a virtual form they can compensate for the influence of the boson on the Higgs mass. The most important thing here is that in supersymmetric theories such compensation itself arises from the construction of the theory. It is such a supersymmetric theory that most attracts theorists.

Another important difficulty of SM is the lack of dark matter particles in it. In astrophysics, it is believed that in the Universe, in addition to ordinary matter in the form of stars, black holes, planets, gas and dust clouds, and. etc., there are particles of a completely different nature. These are particles of dark matter, we do not see them, they practically do not interact with ordinary matter and radiation. Possible candidates for dark matter particles may be neutralino, sneutrino, gluino, gravitino, the existence of which is assumed in the Minimum Supersymmetric Standard Model ($MSSM$) [8-11].

Unlike the SM , the $MSSM$ introduces two doublets of the scalar field with hypercharges -1 and $+1$:

$$\varphi_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix}, \quad \varphi_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}.$$

To obtain the physical fields of Higgs bosons, φ_1 and φ_2 we represent in the form

$$\varphi_1 = \frac{1}{\sqrt{2}} \begin{pmatrix} v_1 + H_1^0 + iP_1^0 \\ H_1^- \end{pmatrix},$$

$$\varphi_2 = \frac{1}{\sqrt{2}} \begin{pmatrix} H_2^+ \\ v_2 + H_2^0 + iP_2^0 \end{pmatrix}.$$

where H_1^0, P_1^0, H_2^0 and P_2^0 are the fields describing the excitations of the system relative to vacuum states $\langle \varphi_1 \rangle = \frac{1}{\sqrt{2}} v_1$ and $\langle \varphi_2 \rangle = \frac{1}{\sqrt{2}} v_2$.

The CP -even Higgs bosons H and h are obtained by mixing the fields H_1^0 and H_2^0 (mixing angle α):

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} H_1^0 \\ H_2^0 \end{pmatrix}.$$

Similarly, mixing P_1^0 and P_2^0 , as well as H_1^\pm and H_2^\pm , one obtains Goldstone bosons G^0 and G^\pm , CP -an odd Higgs boson A and charged Higgs bosons H^\pm (mixing angle β):

$$\begin{pmatrix} G^0 \\ A \end{pmatrix} = \begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} P_1^0 \\ P_2^0 \end{pmatrix},$$

$$\begin{pmatrix} G^\pm \\ H^\pm \end{pmatrix} = \begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} H_1^\pm \\ H_2^\pm \end{pmatrix}.$$

Thus, there are five Higgs bosons in the $MSSM$: CP -even H and h -bosons, CP -odd A -boson, charged H^\pm -bosons.

The Higgs sector of the $MSSM$ is characterized by six parameters $M_H, M_h, M_A, M_{H^\pm}, \alpha$ and β . Of these, the parameters M_A and $\tan\beta = \frac{v_1}{v_2}$ are free. The parameter $\tan\beta$ varies within

$$1 \leq \tan\beta \leq \frac{m_t}{m_b} = 35.5.$$

here $m_t = 173.2\text{GeV}$ and $m_b = 4.88\text{GeV}$ of masses of t - and b -quarks.

The Higgs masses of the H - and h - (H^\pm -) bosons are expressed by the masses M_A and M_Z (M_A and M_W):

$$M_{H(h)}^2 = \frac{1}{2} \left[M_A^2 + M_Z^2 \pm \sqrt{(M_A^2 + M_Z^2)^2 - 4M_A^2 M_Z^2 \cos^2 2\beta} \right],$$

$$M_{H^\pm}^2 = M_A^2 + M_W^2.$$

Higgs bosons H, h, A and H^\pm can decay through different channels (see [8, 11–18] and references in them to primary sources. Along with decays of these bosons into ordinary particles, their decay into supersymmetric ones is also possible ($SUSY$) particles:

Chargino, neutralino, and scalar fermions (sfermions) are such particles. The present work is devoted to the study of the decay channels of the Higgs bosons H, h and A into a pair of chargino

$$H(h; A) \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^+, \quad (i, j = 1, 2), \quad (1)$$

$$H(h; A) \Rightarrow \tilde{\chi}_i^0 + \tilde{\chi}_j^0, \quad (i, j = 1 \div 4), \quad (2)$$

$$H^\pm \Rightarrow \tilde{\chi}_i^\pm + \tilde{\chi}_j^0, \quad (i = 1, 2, j = 1 \div 4), \quad (3)$$

$$H(h; A) \Rightarrow \tilde{f}_i + \tilde{f}_j, \quad (i, j = 1, 2), \quad (4)$$

$$H^\pm \Rightarrow \tilde{f}_i + \tilde{f}'_j, \quad (i, j = 1, 2). \quad (5)$$

Within the framework of the $MSSM$ and taking into account the polarization states of the chargino, analytical expressions for the width of the indicated decays are obtained, the degrees of the longitudinal and transverse polarizations of the chargino are determined, the dependence of these characteristics and the width of the decays on the mass of Higgs bosons is studied.

row U and V matrices.

2. HIGGS BOSON DECAYS IN A PAIR OF CHARGINO

The supersymmetric partnyors of the gauge W^\pm and Higgs H^\pm -bosons are calibrino (vino) \tilde{W}^\pm and Higgsino \tilde{H}^\pm . The mass matrix of these spinor fields is off-diagonal, which leads to their mixing. Chargino $\tilde{\chi}^\pm$ is a four-component. Dirac fermion that occurs when vino \tilde{W}^\pm and Higgsino \tilde{H}^\pm are mixed. The masses and coupling constants of the chargino with the Higgs bosons H, h, A, H^\pm are determined by the mass matrix.

$$M_{\tilde{\chi}^\pm} = \begin{pmatrix} M_2 & \sqrt{2}M_W \sin\beta \\ \sqrt{2}M_W \cos\beta & \mu \end{pmatrix},$$

where M_2 and μ -mass parameters of vino and Higgsino. This matrix is diagonalized by two real two-

$$UM_{\tilde{\chi}^\pm}V^{-1} \Rightarrow U = R_- \text{ and } V = \begin{cases} R_+, & \text{if } \det M_{\tilde{\chi}^\pm} > 0 \\ \sigma_3 R_+, & \text{if } \det M_{\tilde{\chi}^\pm} < 0, \end{cases}$$

where σ_3 is the Pauli matrix, which makes the chargino mass positive, R_\pm are the rotation matrices with angles θ_\pm :

$$R_\pm = \begin{pmatrix} \cos\theta_\pm & \sin\theta_\pm \\ -\sin\theta_\pm & \cos\theta_\pm \end{pmatrix},$$

and the angles θ_+ and θ_- are defined as

$$\tan 2\theta_+ = \frac{2\sqrt{2}M_W(M_2 \sin\beta + \mu \cos\beta)}{M_2^2 - \mu^2 + 2M_W^2 \cos\beta},$$

$$\tan 2\theta_- = \frac{2\sqrt{2}M_W(M_2 \cos\beta + \mu \sin\beta)}{M_2^2 - \mu^2 - 2M_W^2 \cos\beta}.$$

After diagonalizing the matrix $M_{\tilde{\chi}^\pm}$, new states of chargino with masses are obtained:

$$m_{\tilde{\chi}_{1,2}^\pm}^2 = \frac{1}{2} \{ M_2^2 + \mu^2 + 2M_W^2 \mp [(M_2^2 + \mu^2)^2 + 4M_W^2(M_W^2 \cos^2 2\beta + M_2^2 + \mu^2 + 2M_2\mu \sin 2\beta)]^{1/2} \}. \quad (6)$$

If one of the two parameters μ or M_2 has a very large value, then one state of the chargino corresponds to the calibrino state and the other to the Higgsino state. In this case, the masses of the chargino are equal: at

$$|\mu| \gg M_Z, \quad M_2 \sim M_Z : m_{\tilde{\chi}_1^\pm} \sim M_2, \quad m_{\tilde{\chi}_2^\pm} \sim |\mu|;$$

at

$$|\mu| \sim M_Z, \quad M_2 \gg M_Z : m_{\tilde{\chi}_1^\pm} \sim |\mu|, \quad m_{\tilde{\chi}_2^\pm} \sim M_2.$$

Figure 1 shows the dependence of the chargino mass $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^\pm$ on the parameter μ at $\tan\beta = 30$ and the fixed mass $M_2 = 150\text{GeV}$. As can be seen, with an increase in the moduls of the parameter $|\mu|$ the mass of light (heavy) chargino $m_{\tilde{\chi}_1^\pm}$ ($m_{\tilde{\chi}_2^\pm}$) monotonously increases and approaches the value of 147GeV

(512GeV) at $\mu = -500\text{GeV}$ and 145GeV (514GeV) at $\mu = 500\text{GeV}$. The minimum value of the chargino mass $m_{\tilde{\chi}_1^\pm}$ and $m_{\tilde{\chi}_2^\pm}$ is observed at a zero value of the parameter μ : $m_{\tilde{\chi}_1^\pm}(\mu = 0) = 2,696\text{GeV}$, $m_{\tilde{\chi}_2^\pm}(\mu = 0) = 188.192\text{GeV}$.

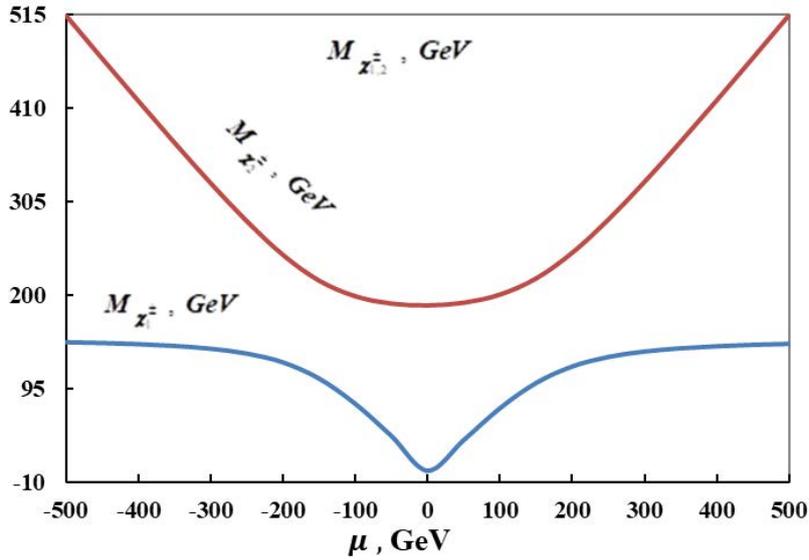


Fig. 1. Chargino masses $m_{\tilde{\chi}_1^\pm}$ and $m_{\tilde{\chi}_2^\pm}$ as a function of the parameter μ

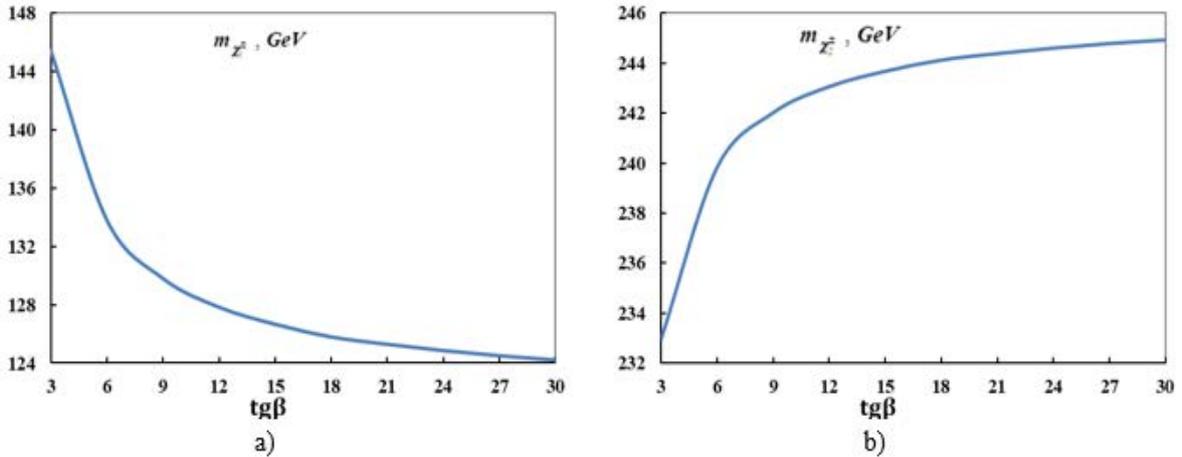


Fig. 2. Dependence of the mass $m_{\tilde{\chi}_1^\pm}$ (a) and $m_{\tilde{\chi}_2^\pm}$ (b) on the parameter $\tan\beta$

Note that, for a given parameter μ , the chargino masses $m_{\tilde{\chi}_1^\pm}$ and $m_{\tilde{\chi}_2^\pm}$ are very sensitive to the $\tan\beta$ parameter (see fig. 2, where the dependence of the mass $m_{\tilde{\chi}_1^\pm}$ and $m_{\tilde{\chi}_2^\pm}$ of the $\tan\beta$ parameter for $M_2 = 150\text{GeV}$, $\mu = -200\text{GeV}$). As can be seen from the figure, with an increase in the parameter $\tan\beta$, the chargino mass $m_{\tilde{\chi}_1^\pm}$ monotonously decreases, and the charge chargino $m_{\tilde{\chi}_2^\pm}$ on the contrary, increases monotonously. With a positive value of the parameter $\mu = 200\text{GeV}$, an inverse relationship is observed: with an increase in the $\tan\beta$ parameter, the chargino mass $m_{\tilde{\chi}_1^\pm}$ increases and the mass $m_{\tilde{\chi}_2^\pm}$ on the contrary, decreases.

The Feynman diagram of the Higgs boson decay $H_k \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^+$ is shown in fig. 3 (the $k = 1,2,3$ index corresponds to the neutral Higgs bosons H, h, A and the $i, j = 1,2$ indexes correspond to the chargino).

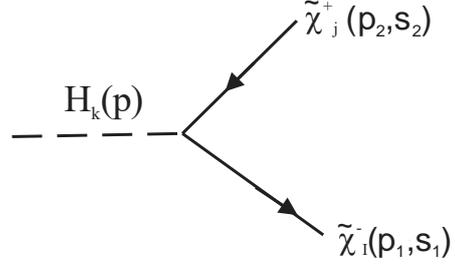


Fig. 3. Feynman diagram for $H_k \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^+$ decay. In the figure p, p_1 and p_2 denote 4 - momenta of Higgs boson H_k , $\tilde{\chi}_i^-$ and $\tilde{\chi}_j^+$ chargino, s_1 and s_2 4 - polarization vectors of chargino.

According to the *MSSM*, the amplitude corresponding to the diagram in fig. 3 can be written in the following form:

$$M(H_k \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^+) = ig [g_{ijk}^L \bar{u}(p_1, s_1) P_L v(p_2, s_2) + g_{ijk}^R \bar{u}(p_1, s_1) P_R v(p_2, s_2)], \quad (7)$$

where g is a constant determining the mass of the gauge W - boson

$$M_W^2 = \frac{1}{2} g^2 (v_1^2 + v_2^2);$$

$P_{L,R} = \frac{(1 \pm \gamma_5)}{2}$ is chirality matrices, g_{ijk}^L and g_{ijk}^R is interaction constants of the Higgs boson H_k with chargino $\tilde{\chi}_i^- \tilde{\chi}_j^+$ [8,11]

$$\begin{aligned} g_{ijk}^L &= \frac{1}{\sqrt{2}} [V_{j1} U_{i2} e_k - V_{j2} U_{i1} d_k], \\ g_{ijk}^R &= \frac{1}{\sqrt{2}} [V_{i1} U_{j2} e_k - V_{i2} U_{j1} d_k] \epsilon_k, \end{aligned} \quad (8)$$

$\epsilon_1 = \epsilon_2 = -\epsilon_3 = 1$; the coefficients e_k and d_k are equal to:

$$\begin{aligned} e_1 &= \cos\alpha, e_2 = -\sin\alpha, e_3 = -\sin\beta, \\ d_1 &= -\sin\alpha, d_2 = -\cos\alpha, d_3 = \cos\beta. \end{aligned} \quad (9)$$

To find the probabilities (width) of the Higgs boson decay into a pair of chargino, we must squared the amplitude moduls $|M(H_k \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^+)|^2$. In the standard way for the squared amplitude module, we find:

$$\begin{aligned} |M(H_k \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^+)|^2 &= \frac{g^2}{2} \{ [(g_{ijk}^L)^2 + (g_{ijk}^R)^2] [(p_1 \cdot p_2) + m_{\tilde{\chi}_i^-} m_{\tilde{\chi}_j^+} (s_1 \cdot s_2)] + [(g_{ijk}^L)^2 - (g_{ijk}^R)^2] \times \\ &\times [m_{\tilde{\chi}_i^-} (p_2 \cdot s_1) + m_{\tilde{\chi}_j^+} (p_1 \cdot s_2)] + 2g_{ijk}^L g_{ijk}^R [-m_{\tilde{\chi}_i^-} m_{\tilde{\chi}_j^+} - (p_1 \cdot p_2)(s_1 \cdot s_2) + (p_1 \cdot s_2)(p_2 \cdot s_1)] \}. \end{aligned} \quad (10)$$

In the Higgs boson rest system H_k the energy and the modules of the three-dimensional chargino momentum are determined by the expressions:

$$E_1 = \frac{1}{2} M_H (1 + r_i - r_j), \quad E_2 = \frac{1}{2} M_H (1 - r_i + r_j),$$

$$|\vec{p}_1| = |\vec{p}_2| = |\vec{p}| = \frac{1}{2} M_H \sqrt{(1 - r_i - r_j)^2 - 4r_i r_j},$$

here the notation

$$r_i = \left(\frac{m_{\tilde{\chi}_i^\pm}}{M_{H_k}} \right)^2, \quad r_j = \left(\frac{m_{\tilde{\chi}_j^\pm}}{M_{H_k}} \right)^2.$$

Given the polarization states of the chargino $\tilde{\chi}_i^-$ and $\tilde{\chi}_j^+$, the decay width $H_k \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^+$ has the form:

$$\begin{aligned} \frac{d\Gamma(\vec{\xi}_1, \vec{\xi}_2)}{d\Omega} = & \frac{G_F M_W^2}{32\sqrt{2}\pi^2} M_{H_k} \sqrt{(1-r_i-r_j)^2 - 4r_i r_j} \left\{ \left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] [(1-r_i-r_j)(1-(\vec{n}\vec{\xi}_1)(\vec{n}\vec{\xi}_2)) + \right. \\ & + 2\sqrt{r_i r_j} \times (-\vec{\xi}_1 \vec{\xi}_2) + (\vec{n}\vec{\xi}_1)(\vec{n}\vec{\xi}_2)] + \left. \left[(g_{ijk}^L)^2 - (g_{ijk}^R)^2 \right] \sqrt{(1-r_i-r_j)^2 - 4r_i r_j} [(\vec{n}\vec{\xi}_1) - \right. \\ & \left. \left. - (\vec{n}\vec{\xi}_2)] - 4g_{ijk}^L g_{ijk}^R \times \left[\sqrt{r_i r_j} (1 - (\vec{n}\vec{\xi}_1)(\vec{n}\vec{\xi}_2)) - \frac{1}{2}(1-r_i-r_j)((\vec{\xi}_1 \vec{\xi}_2) - (\vec{n}\vec{\xi}_1)(\vec{n}\vec{\xi}_2)) \right] \right\} \end{aligned} \quad (11)$$

where \vec{n} is the unit vector, in the direction of the charge of the chargino $\tilde{\chi}_i^-$, $\vec{\xi}_1$ and $\vec{\xi}_2$ are the unit vectors characterizing the polarization of the chargino $\tilde{\chi}_i^-$ and $\tilde{\chi}_j^+$ in the rest systems of each of these particles, respectively; $\lambda(r_i, r_j) = (1-r_i-r_j)^2 - 4r_i r_j$ is the kinematic function of a two-particle phase volume.

We consider particular cases of the decay width formula (9). First, suppose that the chargino is polarized longitudinally, while

$$\vec{\xi}_1 = \vec{n}\lambda_1, \quad \vec{\xi}_2 = -\vec{n}\lambda_2,$$

where λ_1 and λ_2 are the spiralities of the chargino $\tilde{\chi}_i^-$ and $\tilde{\chi}_j^+$

In this case, the decay width $H_k \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^+$ is determined by the expression:

$$\Gamma(\lambda_1, \lambda_2) = \frac{1}{4} \Gamma_0(H_k \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^+) [1 + \lambda_1 \lambda_2 + (\lambda_1 + \lambda_2)P], \quad (12)$$

here

$$\Gamma_0(H_k \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^+) = \frac{G_F M_W^2}{2\sqrt{2}\pi} M_{H_k} \sqrt{(1-r_i-r_j)^2 - 4r_i r_j} \left\{ \left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] (1-r_i-r_j) - 4g_{ijk}^L g_{ijk}^R \sqrt{r_i r_j} \right\} \quad (13)$$

is the decay width in the case of unpolarized chargino, and P is the degree of longitudinal polarization of chargino, defined by the formula

$$P = \frac{\left[(g_{ijk}^L)^2 - (g_{ijk}^R)^2 \right] \sqrt{(1-r_i-r_j)^2 - 4r_i r_j}}{\left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] (1-r_i-r_j) - 4g_{ijk}^L g_{ijk}^R \sqrt{r_i r_j}}. \quad (14)$$

It follows from the decay width (12) that, in the Higgs boson decay $H_k \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^+$ the chargino $\tilde{\chi}_i^-$ and $\tilde{\chi}_j^+$ must have the same $\lambda_1 = \lambda_2 = \pm 1$ helicities ($\tilde{\chi}_{iR}^- \tilde{\chi}_{jR}^+$ or $\tilde{\chi}_{iL}^- \tilde{\chi}_{jL}^+$). This is a consequence of maintaining the full moment in $H_k \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^+$ decays. Consider this decay in the resting system of the Higgs boson H_k . In this system, the momenta of the chargino $\tilde{\chi}_i^-$ and $\tilde{\chi}_j^+$ are equal in magnitude and opposite in

direction (see fig. 4, which shows the directions of the charge and spin of the chargino). Since the Higgs boson H_k is zero, the process $H_k \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^+$ is allowed only if the chargino $\tilde{\chi}_i^-$ and $\tilde{\chi}_j^+$ are in the same helicity state. It is in this case that the projection of the total moment of two chargino in the direction of movement of chargino $\tilde{\chi}_i^-$ (or $\tilde{\chi}_j^+$) is zero.

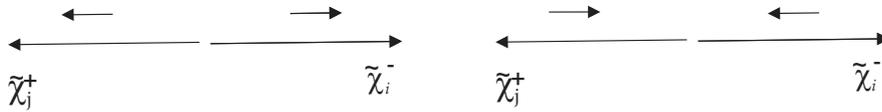


Fig. 4. Direction of momenta and spins in $H_k \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^+$ decay

We estimate the degree of longitudinal polarization of chargino (12) at $\tan\beta = 1$. Calculations show that, at this value of the parameter $\tan\beta$, the interaction constants g_{ijk}^L and g_{ijk}^R are equal to each other in the decays $H(h; A) \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^+$, as a result of which the degree of longitudinal polarization of the chargino vanishes.

Now consider the case when the charginos are transversely polarized. Where in

$$(\vec{n}\vec{\xi}_1) = (\vec{n}\vec{\eta}_1) = 0, \quad (\vec{n}\vec{\xi}_2) = (\vec{n}\vec{\eta}_2) = 0$$

$$(\vec{\xi}_1 \vec{\xi}_2) = (\vec{\eta}_1 \vec{\eta}_2) = \eta_1 \eta_2 \cos\varphi$$

where $\vec{\eta}_1$ and $\vec{\eta}_2$ are the transverse components of the chargino vectors $\tilde{\chi}_i^-$ and $\tilde{\chi}_j^+$, φ is the angle between these vectors. In this case, the decay width $H_k \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^+$ is

$$\frac{d\Gamma(\eta_1 \eta_2)}{d\Omega} = \frac{1}{4} \frac{d\Gamma_0(H_k \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^+)}{d\Omega} [1 + \eta_1 \eta_2 P_\perp], \quad (15)$$

where

$$\frac{d\Gamma_0(H_k \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^+)}{d\Omega} = \frac{G_F M_W^2}{8\sqrt{2}\pi^2} M_{H_k} \sqrt{\lambda(r_i, r_j)} \left\{ \left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] (1 - r_i - r_j) - 4g_{ijk}^L g_{ijk}^R \sqrt{r_i r_j} \right\} \quad (16)$$

is the decay width for unpolarized chargino, and P_\perp is the degree of transverse polarization of chargino :

$$P_\perp = \frac{2g_{ijk}^L g_{ijk}^R (1 - r_i - r_j) - 2 \left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] \sqrt{r_i r_j}}{\left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] (1 - r_i - r_j) - 4g_{ijk}^L g_{ijk}^R \sqrt{r_i r_j}} \cdot \cos\varphi. \quad (17)$$

At $\tan\beta = 1$ due to the equality of the interaction constants $g_{ijk}^L = g_{ijk}^R$ the degree of transverse polarization depends only on the cosinus of the angle between the spin vectors \vec{n}_1 and \vec{n}_2 :

$$P_\perp = \cos\varphi. \quad (18)$$

At $\varphi = 0^\circ$ the degree of transverse polarization of the chargino is +1, with increasing angle φ , the degree of transverse polarization decreases and vanishes at an angle $\varphi = 90^\circ$. Then, the degree of transverse polarization changes sign and decreases to -1 at $\varphi = 180^\circ$. A further increase in the angle φ from 180° to 360°

leads to an increase in the degree of transverse polarization from -1 to +1. It should be noted that in the approximation $|\mu| \gg M_2$ or $M_2 \gg |\mu|$ the decays of the Higgs bosons into a pair of identical chargino $H_k \Rightarrow \tilde{\chi}_1^- + \tilde{\chi}_1^+$ ($\tilde{\chi}_2^- + \tilde{\chi}_2^+$) are suppressed.

In this case, the decays of the heavy H and A bosons into a pair of different $H(A) \Rightarrow \tilde{\chi}_1^- + \tilde{\chi}_2^+$ chargino dominate. In fig.5 shows the dependence of decay $H \Rightarrow \tilde{\chi}_1^- + \tilde{\chi}_2^+$ width on the Higgs boson mass M_H at $\tan\beta = 1$, $\mu = 160\text{GeV}$, $M_2 = 150\text{GeV}$, $M_W = 80.385\text{GeV}$, $M_Z = 91.1875\text{GeV}$.

With an increase in the Higgs boson mass M_H the decay width increases.

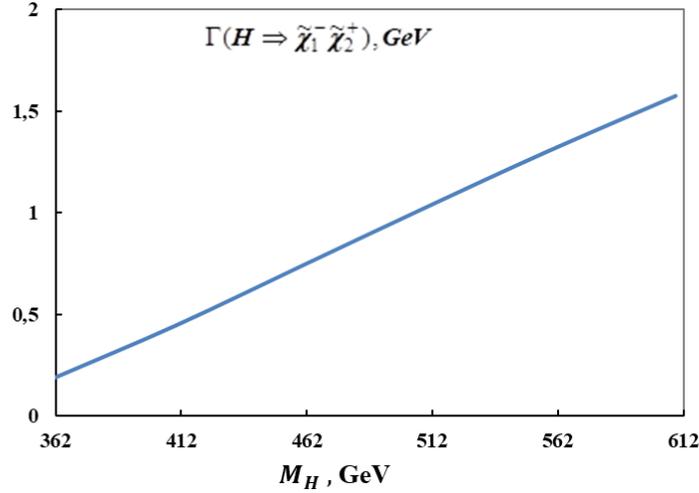


Fig. 5. Dependence of the decay width $H \Rightarrow \tilde{\chi}_1^- \tilde{\chi}_2^+$ on the mass M_H

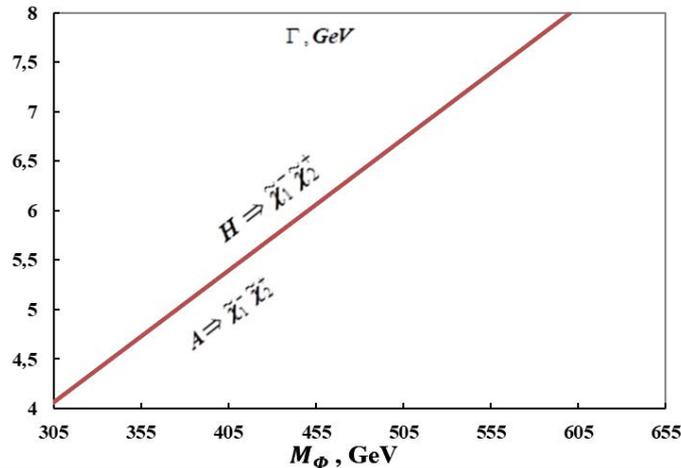


Fig. 6. Dependence of the decay width $\Gamma(H(A) \Rightarrow \tilde{\chi}_1^- \tilde{\chi}_2^+)$ on the mass M_ϕ

In the $M_A \gg |\mu| \gg M_2$ limit, the partial decay widths of $H \Rightarrow \tilde{\chi}_1^\pm + \tilde{\chi}_2^\mp$ and $A \Rightarrow \tilde{\chi}_1^\pm + \tilde{\chi}_2^\mp$ are equal

$$\Gamma(H \Rightarrow \tilde{\chi}_1^- \tilde{\chi}_2^+) = \frac{G_F M_W^2}{4\sqrt{2}\pi} M_H, \quad (18)$$

$$\Gamma(A \Rightarrow \tilde{\chi}_1^- \tilde{\chi}_2^+) = \frac{G_F M_W^2}{4\sqrt{2}\pi} M_A.$$

The dependence of the width of these decays on the Higgs mass M_H and M_A boson is shown in fig. 6. At $M_\Phi = 305\text{GeV}$, the decay width is 4GeV, with an increase in the Higgs boson mass, the decay width increases, and with a mass $M_\Phi = 602\text{GeV}$, the decay width reaches 8GeV.

3. HIGGS BOSON DECAYS INTO A PAIR OF NEUTRALINO

Neutral vino \tilde{W}^0 and bino \tilde{B}^0 , as well as Higgsino \tilde{H}_1^0 and \tilde{H}_2^0 interact weakly, they are not proper mass states. The four mass states of the neutralino $\tilde{\chi}_i^0$ ($i = 1, 2, 3, 4$) are alternating combinations of the particles mentioned above. Neutralino - Majorana fermions, their antiparticles coincide with their particles. The neutralino mass matrix, as in the case of the chargino, depends on the parameters, M_2 , $\tan\beta$ and also on the new mass parameter M_1 of the bino \tilde{B}^0 [8, 11]. As in the case of the chargino, with a large value of one of the parameters μ or M_2 , two neutralino correspond to a pure gaugino-like state, and the other neutralino ones correspond to a pure Higgsino-like state. In these limiting states, the neutralino masses are equal to:

$$\text{at } |\mu| \gg M_Z, \quad M_2 \sim M_Z : m_{\tilde{\chi}_1^0} \sim M_1, \quad m_{\tilde{\chi}_2^0} \sim M_2, \quad m_{\tilde{\chi}_3^0} \cong m_{\tilde{\chi}_4^0} \cong |\mu|,$$

$$\text{at } |\mu| \sim M_Z, \quad M_2 \gg M_Z : m_{\tilde{\chi}_1^0} \cong m_{\tilde{\chi}_2^0} \cong |\mu|, \quad m_{\tilde{\chi}_3^0} \cong M_1, \quad m_{\tilde{\chi}_4^0} \cong M_2.$$

The decay width of the Higgs bosons H_k into a neutralino pair for arbitrarily polarized particles is determined by a formula similar to formula (11). In a particular case, the decay width $H_k \Rightarrow \tilde{\chi}_i^0 + \tilde{\chi}_j^0$ in the case of the production of a longitudinally polarized neutralino pair is determined by the expression:

$$\Gamma(\lambda_1, \lambda_2) = \frac{1}{4} \Gamma_0(H_k \Rightarrow \tilde{\chi}_i^0 \tilde{\chi}_j^0) [1 + \lambda_1 \lambda_2 + (\lambda_1 + \lambda_2)P], \quad (19)$$

here

$$\Gamma_0(H_k \Rightarrow \tilde{\chi}_i^0 \tilde{\chi}_j^0) = \frac{G_F M_W^2}{2\sqrt{2}\pi} M_{H_k} \delta \sqrt{\lambda(r_i, r_j)} \left\{ [(g_{ijk}^L)^2 + (g_{ijk}^R)^2] (1 - r_i - r_j) - 4\varepsilon_i \varepsilon_j g_{ijk}^L g_{ijk}^R \sqrt{r_i r_j} \right\} \quad (20)$$

is the width of this decay in the case of unpolarized neutralino, and P is the degree of longitudinal polarization of neutralino, defined by the expression

$$P = - \frac{[(g_{ijk}^L)^2 - (g_{ijk}^R)^2] \sqrt{\lambda(r_i, r_j)}}{[(g_{ijk}^L)^2 + (g_{ijk}^R)^2] (1 - r_i - r_j) - 4\varepsilon_i \varepsilon_j g_{ijk}^L g_{ijk}^R \sqrt{r_i r_j}}; \quad (21)$$

the factor δ in formula (20) is equal to $1 \left(\frac{1}{2} \right)$, if a pair of different (identical) neutralinos are born, ε_i and ε_j

determine the sign of the parameter μ , g_{ijk}^L and g_{ijk}^R are the interaction constants of the Higgs boson H_k with a pair of neutralino [8, 11]:

$$g_{ijk}^L = \frac{1}{2} (Z_{j2} - \tan\theta_W Z_{j1}) (Z_{i3} e_k + Z_{i4} d_k) + i \rightarrow j, \quad (22)$$

$$g_{ijk}^R = \frac{1}{2} (Z_{j2} - \tan\theta_W Z_{j1}) (Z_{i3} e_k + Z_{j4} d_k) \varepsilon_k + i \rightarrow j;$$

Z is 4×4 matrix diagonalizing the neutralino mass matrix; $\varepsilon_1 = \varepsilon_2 = -\varepsilon_3 = 1$; the coefficients e_k and d_k are given by expressions (9); θ_W is the Weinberg angle.

Denote the simplest neutralino by $\tilde{\chi}^0$; it can be the easiest *SUSY* particle. Then all other *SUSY* particles will decay into $\tilde{\chi}^0$ and ordinary *SM* particles. Table 1 shows the upper bounds on the masses of *SUSY* particles for various values of the parameter $\tan\beta$. In the table, $\tilde{\tau}$ and \tilde{t} are sfermions - stau lepton and stop quark.

Table 1.

Upper Boundaries for *SUSY* Particle Masses

$\tan\beta$	$\tilde{\chi}^0$	$\tilde{\chi}^-$	$\tilde{\tau}$	\tilde{t}
10	155	280	170	580
15	168	300	185	640
20	220	400	236	812
30	260	470	280	990

Calculations show that the decay widths of the heavy Higgs bosons H and A into a pair of different neutralinos $\tilde{\chi}_1^0\tilde{\chi}_3^0$, $\tilde{\chi}_1^0\tilde{\chi}_4^0$, $\tilde{\chi}_2^0\tilde{\chi}_3^0$ and $\tilde{\chi}_2^0\tilde{\chi}_4^0$ are prevailed. The widths of these decays are shown in Table 2 (in units of $\frac{G_F M_W^2}{8\sqrt{2}\pi} M_{H_k}$).

Table 2.

Decay widths of H and A into a neutralino pair

Neutralino pair	$\Gamma(H \Rightarrow \tilde{\chi}_i^0 \tilde{\chi}_j^0)$	$\Gamma(A \Rightarrow \tilde{\chi}_i^0 \tilde{\chi}_j^0)$
$\tilde{\chi}_1^0 \tilde{\chi}_3^0$	$\tan^2\theta_W(1 + \sin 2\beta)$	$\tan^2\theta_W(1 - \sin 2\beta)$
$\tilde{\chi}_1^0 \tilde{\chi}_4^0$	$\tan^2\theta_W(1 - \sin 2\beta)$	$\tan^2\theta_W(1 + \sin 2\beta)$
$\tilde{\chi}_2^0 \tilde{\chi}_3^0$	$(1 + \sin 2\beta)$	$(1 - \sin 2\beta)$
$\tilde{\chi}_2^0 \tilde{\chi}_4^0$	$(1 - \sin 2\beta)$	$(1 + \sin 2\beta)$

Fig. 7(a) and (b) illustrate the dependence of the decay width $H \Rightarrow \tilde{\chi}_2^0 + \tilde{\chi}_3^0$ and $A \Rightarrow \tilde{\chi}_2^0 + \tilde{\chi}_4^0$ on the Higgs boson mass M_H and M_A for $\tan\beta = 3$, $\sin^2\theta_W = 0.2315$. In these figures, the decay width $H \Rightarrow \tilde{\chi}_2^0 + \tilde{\chi}_3^0$ and $A \Rightarrow \tilde{\chi}_2^0 + \tilde{\chi}_4^0$ with an increase in the Higgs boson masses the H and A are observed.

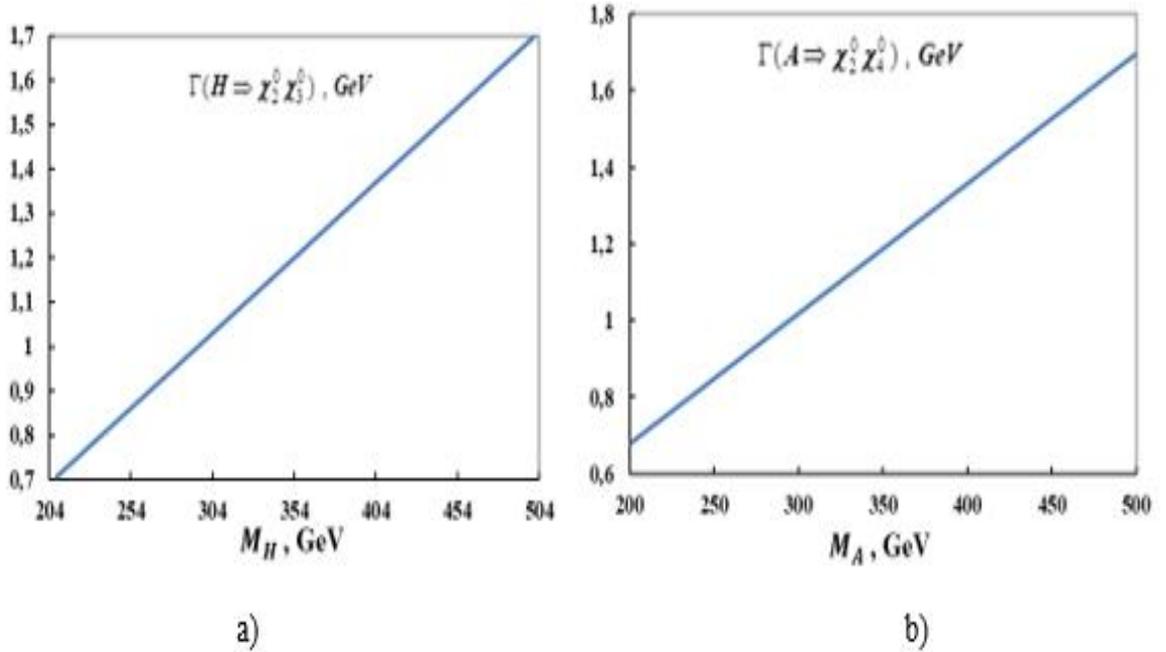


Fig. 7. Dependence of the decay width $H \Rightarrow \tilde{\chi}_2^0 + \tilde{\chi}_3^0$ (a) and $A \Rightarrow \tilde{\chi}_2^0 + \tilde{\chi}_4^0$ (b) on the masses M_H and M_A

4. DECAYS OF HIGGS BOSON H^\pm INTO THE CHARGINO - NEUTRALINO PAIR

The charged Higgs boson H^\pm can decay into a pair of chargino-neutralino along the channel $H^\pm \Rightarrow \tilde{\chi}_i^\pm + \tilde{\chi}_j^0$. Having performed standard calculations, we obtain for the decay width $H^- \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^0$ in the Higgs boson rest system :

$$\begin{aligned} \frac{d\Gamma(\vec{\xi}_1, \vec{\xi}_2)}{d\Omega} &= \frac{G_F M_W^2}{32\sqrt{2}\pi^2} M_{H^-} \sqrt{\lambda(r_i, r_j)} \left\{ \left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] \left[(1 - r_i - r_j)(1 - (\vec{n}\vec{\xi}_1)(\vec{n}\vec{\xi}_2)) - 2\sqrt{r_i r_j} \times \right. \right. \\ &\times \left. \left. ((\vec{\xi}_1 \vec{\xi}_2) - (\vec{n}\vec{\xi}_1)(\vec{n}\vec{\xi}_2)) \right] + \left[(g_{ijk}^L)^2 - (g_{ijk}^R)^2 \right] \sqrt{\lambda(r_i, r_j)} \left[(\vec{n}\vec{\xi}_1) - (\vec{n}\vec{\xi}_2) \right] + 2g_{ijk}^L g_{ijk}^R \times \right. \\ &\times \left. \left[(1 - r_i - r_j) \left((\vec{\xi}_1 \vec{\xi}_2) - (\vec{n}\vec{\xi}_1)(\vec{n}\vec{\xi}_2) \right) - 2\sqrt{r_i r_j} (1 - (\vec{n}\vec{\xi}_1)(\vec{n}\vec{\xi}_2)) \right] \right\}. \end{aligned} \quad (23)$$

Here \vec{n} is a unit vector in the direction of the momentum of the chargino; $\vec{\xi}_1$ and $\vec{\xi}_2$ are unit vectors characterizing the polarization of chargino and neutralino; $d\Omega = \sin\theta d\theta d\varphi$ is the solid angle of departure of the chargino; $\lambda(r_i, r_j)$ is a kinematic function ;

$$r_i = \left(\frac{m_{\tilde{\chi}_i^-}}{M_{H^-}} \right)^2, \quad r_j = \left(\frac{m_{\tilde{\chi}_j^0}}{M_{H^-}} \right)^2;$$

g_{ijk}^L and g_{ijk}^R are the interaction constants of the Higgs boson $H_k = H_4 = H^\pm$ with the chargino - neutralino pair:

$$g_{ijk}^L = \frac{1}{2} (Z_{j2} - \tan\theta_W Z_{j1}) (Z_{i3} e_k + Z_{i4} d_k) + i \rightarrow j, \quad (24)$$

$$g_{ijk}^R = \frac{1}{2} (Z_{j2} - \tan\theta_W Z_{j1}) (Z_{i3} e_k + Z_{i4} d_k) \varepsilon_k + i \rightarrow j;$$

$Z - 4 \times 4$ matrix diagonalizing the neutralino mass matrix; $\varepsilon_1 = \varepsilon_2 = -\varepsilon_3 = 1$; the coefficients e_k and d_k are given by expressions (9).

In the case of a longitudinally polarized chargino-neutralino pair, the decay width $H^- \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^0$ takes the form:

$$\Gamma(\lambda_1, \lambda_2) = \frac{1}{4} \Gamma_0 (H^- \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^0) [1 + \lambda_1 \lambda_2 + (\lambda_1 + \lambda_2) P], \quad (25)$$

here

$$\Gamma_0 (H^- \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^0) = \frac{G_F M_W^2}{2\sqrt{2}\pi} M_{H^-} \sqrt{\lambda(r_i, r_j)} \left\{ \left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] (1 - r_i - r_j) - 4g_{ijk}^L g_{ijk}^R \sqrt{r_i r_j} \right\} \quad (26)$$

is the decay width of the charged Higgs boson into a pair of unpolarized chargino - neutralino, λ_1 and λ_2 are chargino and neutralino helicities, and P is a degree of longitudinal polarization of chargino (neutralino)

$$P = \frac{\left[(g_{ijk}^L)^2 - (g_{ijk}^R)^2 \right] \sqrt{\lambda(r_i, r_j)}}{\left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] (1 - r_i - r_j) - 4g_{ijk}^L g_{ijk}^R \sqrt{r_i r_j}}. \quad (27)$$

In the case when the chargino and neutralino are transversely polarized, for the decay width $H^- \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^0$ we obtain the following expression:

$$\frac{d\Gamma(\eta_1 \eta_2)}{d\varphi} = \frac{1}{4} \frac{d\Gamma_0 (H^- \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^0)}{d\varphi} [1 + \eta_1 \eta_2 P_\perp]. \quad (28)$$

Here

$$\frac{d\Gamma_0 (H^- \Rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^0)}{d\varphi} = \frac{G_F M_W^2}{4\sqrt{2}\pi^2} M_{H^-} \sqrt{\lambda(r_i, r_j)} \left\{ \left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] (1 - r_i - r_j) - 4g_{ijk}^L g_{ijk}^R \sqrt{r_i r_j} \right\} \quad (29)$$

is a differential decay width and

$$P_\perp = \cos\varphi \frac{2g_{ijk}^L g_{ijk}^R (1 - r_i - r_j) - 2 \left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] \sqrt{r_i r_j}}{\left[(g_{ijk}^L)^2 + (g_{ijk}^R)^2 \right] (1 - r_i - r_j) - 4g_{ijk}^L g_{ijk}^R \sqrt{r_i r_j}} \quad (30)$$

HIGGS BOSON DECAYS INTO A PAIR OF SUPERSYMMETRIC PARTICLES

is a degree of transverse polarization of chargino - neutralino. It can be seen that the degree of transverse polarization P_{\perp} is very sensitive to the angle φ between the transverse spin vectors $\vec{\eta}_1$ and $\vec{\eta}_2$. With parallel ($\vec{\eta}_1 \uparrow \vec{\eta}_2$) and antiparallel ($\vec{\eta}_1 \uparrow \vec{\eta}_2$) spin vectors, the degree of transverse polarization modul reaches a maximum value. If the transverse spin vectors $\vec{\eta}_1$ and $\vec{\eta}_2$ are mutually perpendicular ($\vec{\eta}_1 \perp \vec{\eta}_2$), then the degree of transverse polarization P_{\perp} vanishes.

Note that in the $H^- \Rightarrow \tilde{\chi}_1^- \tilde{\chi}_3^0$ decay the coupling constants g_{ijk}^L and g_{ijk}^R are equal to each other, as a result, the degree of longitudinal polarization of the chargino (neutralino) vanishes, and the degree of transverse polarization of the chargino-neutralino will depend only on the angle φ between the transverse spin vectors $\vec{\eta}_1$ and $\vec{\eta}_2$:

$$P_{\perp} = \cos\varphi.$$

In the approximation $M_A \gg |\mu| \gg M_2$, the partial decay widths of the charged Higgs boson into a

chargino-neutralino pair are given in Table 3 (in $\frac{G_F M_W^2}{4\sqrt{2}\pi} M_{H^\pm}$ units).

Table 3.

Partial decay widths $H^\pm \Rightarrow \tilde{\chi}_i^\pm \tilde{\chi}_j^0$

Chargino - neutralino	$\Gamma(H^\pm \Rightarrow \tilde{\chi}_i^\pm \tilde{\chi}_j^0)$
$\tilde{\chi}_1^\pm \tilde{\chi}_3^0$	1
$\tilde{\chi}_1^\pm \tilde{\chi}_4^0$	1
$\tilde{\chi}_2^\pm \tilde{\chi}_1^0$	$\tan^2\theta_W$
$\tilde{\chi}_2^\pm \tilde{\chi}_2^0$	1

In fig.8 shows the dependence of the decay width $H^- \Rightarrow \tilde{\chi}_2^- \tilde{\chi}_1^0$ on the Higgs mass of the boson M_{H^-} at $\tan\beta = 3$ and $\sin^2\theta_W = 0.2315$. With an increase in the Higgs boson mass M_{H^-} , the decay width increases.

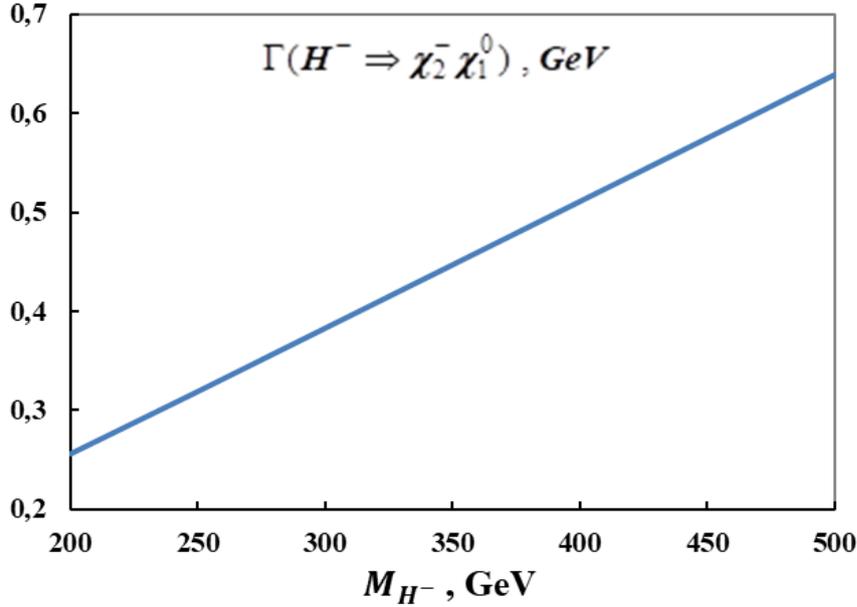


Fig 8. Dependence of the decay width $H^- \Rightarrow \tilde{\chi}_2^- \tilde{\chi}_1^0$ on the mass M_{H^-}

Note that for large Higgs boson masses, the total decays widths H, A, H^\pm into a pair of chargino and neutralino does not depend on the parameters $M_2, \mu, \tan\beta$ and in the asymptotic limit $M_{H_k} \gg m_{\tilde{\chi}}$ we have

$$\Gamma_0(H_k \Rightarrow \sum_{i,j} \tilde{\chi}_i \tilde{\chi}_j) = \frac{3G_F M_W^2}{4\sqrt{2}\pi} M_{H_k} (1 + \tan^2\theta_W) \quad (31)$$

We also introduce the width of the Higgs boson decay channels $(A) \Rightarrow t + \bar{t}, H(A) \Rightarrow b + \bar{b}, H^\pm \Rightarrow t + \bar{b}$, then we have the expression for branching

$$BR(H_k \Rightarrow \sum_{i,j} \tilde{\chi}_i \tilde{\chi}_j) = \frac{\Gamma(H_k \Rightarrow \sum_{i,j} \tilde{\chi}_i \tilde{\chi}_j)}{\Gamma(H_k \Rightarrow \sum_{i,j} \tilde{\chi}_i \tilde{\chi}_j) + \Gamma(H_k \Rightarrow t\bar{t} + b\bar{b} + t\bar{b})} = \frac{(1 + \frac{1}{3}\tan^2\theta_W)M_W^2}{(1 + \frac{1}{3}\tan^2\theta_W)M_W^2 + m_t^2 \cot^2\beta + m_b^2 \tan^2\beta} \quad (32)$$

In fig.9 illustrates the dependence of branching (32) on the parameter $\tan\beta$ in the asymptotic regime $M_A \sim M_H \sim M_{H^\pm} \approx 1 \text{ T}\bar{\text{e}}\text{B} \gg m_\chi$ at $\sin^2\theta_W = 0.2315$.

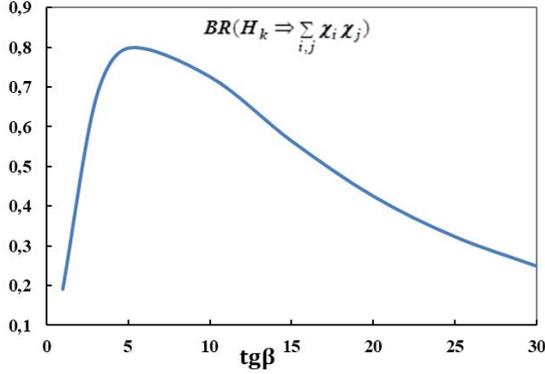


Fig 9. Branching $BR(H_k \Rightarrow \sum_{i,j} \tilde{\chi}_i \tilde{\chi}_j)$ as a function of $\tan\beta$

As can be seen from the figure, with the parameter $\tan\beta$ increasing, the branching also increases and reaches a maximum at $\tan\beta = 5$, and a further increase in the parameter $\tan\beta$ leads to a decrease in branching

5. HIGGS BOSON DECAYS INTO A PAIR OF SFERMIONS

The scalar partners of fermions (sfermions) form a set of new particles: $\nu_{\tau L}, \tau_L, \tau_R, \tilde{t}_L, \tilde{t}_R, \tilde{b}_L, \tilde{b}_R$ are in the third family. All of them are complex scalar fields and the indices L, R are used to denote the SM fermions with which these fields partner. The sfermions \tilde{f}_L and \tilde{f}_R mix with each other and new states \tilde{f}_1 и \tilde{f}_2 with masses arise

$$m_{\tilde{f}_1, \tilde{f}_2}^2 = m_f^2 + \frac{1}{2} \left[m_{\tilde{f}_L}^2 + m_{\tilde{f}_R}^2 \mp \sqrt{(m_{\tilde{f}_L}^2 - m_{\tilde{f}_R}^2)^2 + 4m_f^2(A_f - \mu r_f)^2} \right], \quad (33)$$

where A_f and r_f is some parameters.

The interaction constants of neutral Higgs bosons with sfermions are determined by the expressions

$$\begin{aligned} g_{H_k \tilde{f}_L \tilde{f}_L} &= m_f^2 + M_Z^2 (I_3(f) - Q_f \sin^2 \theta_W) g_2, \\ g_{H_k \tilde{f}_R \tilde{f}_R} &= m_f^2 g_1 + M_Z^2 Q_f \sin^2 \theta_W g_2, \\ g_{H_k \tilde{f}_L \tilde{f}_R} &= -\frac{1}{2} m_f (\mu g_3 - A_f g_4), \end{aligned} \quad (34)$$

where the coefficients $g_i (i = 1, 2, 3, 4)$ are given in Table 4.

Table 4.

Coefficients $g_i (i = 1, 2, 3, 4)$

\tilde{f}	H_k	g_1	g_2	g_3	g_4
\tilde{t}	H	$\sin\alpha/\sin\beta$	$\cos(\alpha + \beta)$	$\cos\alpha/\sin\beta$	$\sin\alpha/\sin\beta$
	h	$\cos\alpha/\sin\beta$	$-\sin(\alpha + \beta)$	$-\sin\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
	A	0	0	1	$-\tan\beta$
\tilde{b}	H	$\cos\alpha/\cos\beta$	$\cos(\alpha + \beta)$	$\sin\alpha/\cos\beta$	$\cos\alpha/\cos\beta$
	h	$-\sin\alpha/\cos\beta$	$-\sin(\alpha + \beta)$	$\cos\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$
	A	0	0	1	$-\tan\beta$

The interaction constants of the charged Higgs boson H^\pm with a sfermion pair $\tilde{t}_\alpha \tilde{b}_\beta$ ($\alpha, \beta = L, R$) can be expressed as:

$$g_{H^\pm \tilde{t}_\alpha \tilde{b}_\beta} = \frac{1}{\sqrt{2}} (g_1^{\alpha\beta} + M_W^2 g_2^{\alpha\beta}), \quad (35)$$

The coefficients $g_1^{\alpha\beta}$ and $g_2^{\alpha\beta}$ are shown in Table 5.

Table 5.

Coefficients $g_i^{\alpha\beta} (i = 1, 2; \alpha, \beta = L, R)$

i	g_i^{LL}	g_i^{RR}	g_i^{LR}	g_i^{RL}
1	$m_{\tilde{t}}^2 \tan\beta + m_{\tilde{b}}^2 \tan\beta$	$m_{\tilde{t}} m_{\tilde{b}} (\tan\beta + \tan\beta)$	$m_{\tilde{b}} (\mu + A_b \tan\beta)$	$m_{\tilde{t}} (\mu + A_t \tan\beta)$
2	$-\sin 2\beta$	0	0	0

The partial Higgs boson decay widths H_k ($k = 1,2,3$ and 4 correspond to the bosons, H, h, A and H^\pm) in the sfermion pair $\tilde{f}_i\tilde{f}_j$ ($i, j = 1,2$) can be written as follows:

$$\Gamma(H_k \Rightarrow \tilde{f}_i\tilde{f}_j) = \frac{N_c G_F}{2\sqrt{2}\pi M_{H_k}} \sqrt{\lambda(r_i, r_j)} (g_{H_k\tilde{f}_i\tilde{f}_j})^2, \quad (36)$$

where N_c is the color factor ($N_c = 3(1)$) at the birth of a squark (slept on) pair $r_i = \left(\frac{m_{\tilde{f}_i}}{M_{H_k}}\right)^2$, $r_j = \left(\frac{m_{\tilde{f}_j}}{M_{H_k}}\right)^2$; interaction constants $g_{H_k\tilde{f}_i\tilde{f}_j}$ can be obtained from the interaction constants (34) and (35) using the mixing relations of sfermions. These constants are given in [8,11].

To estimate the decay width (36), we consider H^\pm boson decay into a pair of $\tilde{u}_L\tilde{d}_L$ - squarks. In this decay, the interaction constant $g_{H^\pm\tilde{u}_L\tilde{d}_L}$ is equal to:

$$g_{H^\pm\tilde{u}_L\tilde{d}_L} = -\frac{1}{\sqrt{2}} [m_u^2 c \tan\beta + m_d^2 \tan\beta - M_W^2 \sin 2\beta]. \quad (37)$$

Since the masses of u - and d - quarks are much smaller than the mass of the gauge W - boson ($M_W \gg m_u, m_d$), for the interaction constant $g_{H^\pm\tilde{u}_L\tilde{d}_L}$ we have :

$$g_{H^\pm\tilde{u}_L\tilde{d}_L} = -\frac{1}{\sqrt{2}} M_W^2 \sin 2\beta. \quad (38)$$

Thus, in the first and second families with massless fermions, the pseudoscalar A - boson does not decay into a pair of sfermions, and the decay widths of the heavier H^\pm and H - bosons into a sfermion pair are proportional to the expression

$$\Gamma(H^\pm(H) \Rightarrow \tilde{f}\tilde{f}) \sim \frac{G_F M_W^4}{2\sqrt{2}\pi M_{H^\pm(H)}} \sin^2 2\beta. \quad (39)$$

These decay widths are maximum for small values of the parameter $t g \beta \approx 1$.

Figure 10 shows the dependence of the decay width $H^\pm \Rightarrow \tilde{t}_R + \tilde{b}_L$ on the Higgs boson mass M_{H^\pm} for $m_{\tilde{t}} = 160\text{GeV}$, $m_{\tilde{b}} = 140\text{GeV}$, $\tan\beta = 10$, $\mu = 160\text{GeV}$ and $A_t = 320\text{GeV}$. It can be seen from the figure that with an increase in the Higgs boson mass M_{H^\pm} the decay width increases and reaches a maximum at $M_{H^\pm} = 425\text{GeV}$, and then the decay width decreases and near $M_{H^\pm} = 650\text{GeV}$ secondary maximum and with a further increase in the Higgs boson mass, its decay width decreases again.

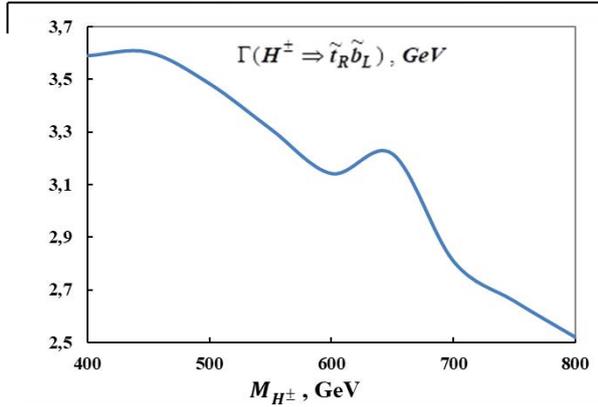


Fig 10. Dependence of the decay width $\Gamma(H^\pm \Rightarrow \tilde{t}_R\tilde{b}_L)$ on the mass M_{H^\pm}

CONCLUSION

We discussed the decay widths of the Higgs bosons H, h, A and H^\pm into supersymmetric particles, precisely decays into a pair of chargino $H_k \Rightarrow \tilde{\chi}_i^- + \tilde{\chi}_j^+$, decays into a pair of neutralino $H_k \Rightarrow \tilde{\chi}_i^0 + \tilde{\chi}_j^0$, decays into a pair of chargino-neutralino $H_k^\pm \Rightarrow \tilde{\chi}_i^\pm + \tilde{\chi}_j^0$, decays into a pair of sfermions $H_k \Rightarrow \tilde{f}_i + \tilde{f}_j$. In the framework of the $MSSM$, analytical expressions are obtained for the decay width of the Higgs boson mass. The research results are illustrated by graphs.

- [1] ATLAS Collaboration. Observation of a new particle in the search for the Standard Model Higgs boson at the ATLAS detector at the LHC. Phys. Letters, 2012. B716,][p.1-29.
- [2] CMS Collaboration. Observation of a new boson at mass of 125GeV with the CMS experiment at the LHC. Phys. Letters, 2012, B716, p.30-61.
- [3] V.A. Rubakov. On Large Hadron Colliders discovery of a new particle with Higgs boson properties. UFN, 2012, v.182, №.10, p.1017-1025 (in Russian).
- [4] A.V. Lanev. CMS Collaboration results: Higgs boson and search for new physics. UFN, 2014, v.184, №9, p.996-1004 (in Russian).
- [5] D.I. Kazakov. The Higgs boson is found: what is next?. UFN, 2014, v.184, №9, p.1004-1016 (in Russian).
- [6] F. Englert, R. Brout. Broken Symmetry and the mass of gauge vector bosons. Phys. Rev. Letters, 1964, v.13, №9, p.321.
- [7] P.W. Higgs. Broken symmetries and the masses of gauge bosons. // Phys. Rev. Letters, 1964, v.13, №16, p.508.
- [8] A. Djouadi. The Anatomy of Electro-Weak Symmetry Breaking. Tome II. The Higgs Boson in the MSSM. archive: hep-ph 0503173 v.2, 2003.
- [9] J.F. Gunion, H. E. Haber. Higgs bosons in supersymmetric models (I) Nucl. Phys., 1986, v. B 272, p.1-76.

- [10] J.F. Gunion, H. E. Haber. Higgs bosons in supersymmetric models (II) Nucl. Phys., 1986, v. B 278, p.449-492.
- [11] *M. Spira*. QCD effects in Higgs Physics. archive: hep – ph . 9705337 v.2, 1997.
- [12] *A. Djouadi, J. Kalinowski, P. M. Zerwas*. Two – and Three- Body Decay Modes of SUSY Higgs Particles. archive: hep – ph 9511342 v.1, 1995.
- [13] *S.K. Abdullayev, E.Sh. Omarova*. Decays of supersymmetric Higgs bosons into fermions. AJP Fizika, 2018, V. XXIV, №4, p.22-34.
- [14] *S. K. Abdullayev, E. Sh. Omarova*. Decays of Higgs Bosons into a fermion-antifermion pair. Russian Physics Journal, 2019, v.61. №9, p.1603-1612.
- [15] *S.K. Abdullayev, E.Sh. Omarova*. Decay channels of Higgs Bosons $H(h; A) \Rightarrow \gamma\gamma, H(h; A) \Rightarrow \gamma Z, H^\pm \Rightarrow \gamma W^\pm$. Journal of Baku Engineering University – Physics, 2019, v.3, №1, p.39-57.
- [16] *S. K. Abdullayev, E.Sh. Omarova*. Decays of Higgs Bosons into a gauge boson and a fermion-antifermion pair. Russian Physics Journal, 2019, v.62. №1, p.30-39.
- [17] *S.K. Abdullayev, E.Sh. Omarova*. Three-particle decays of the Higgs Bosons in the Minimal Supersymmetric Standard Model. Russian Physics Journal, 2019, v.62. №3, p.425-435.
- [18] *S.K. Abdullayev, E.Sh. Omarova*. Decays of $H(h; A)$ bosons into two photons (gluons). Russian Physics Journal, 2020, v.62. №9, p.1623-1634.

Received: 29.09.2020