PITHA 94/25
hep-ph/9408316
July, 1994



# Energy correlation and asymmetry of secondary leptons originating in $H \to t\bar{t}$ and $H \to W^+W^-$

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**Abstract**

We study the energy correlation of charged leptons produced in the decay of a heavy Higgs particle $H \to t\bar{t} \to bl^+\nu_l\bar{b}l^-\bar{\nu}_l$ and $H \to W^+W^- \to l^+\nu_l l^-\bar{\nu}_l$. The possible influence of $CP$–violation in the $Ht\bar{t}$ and $HW^+W^-$ vertices on the energy spectrum of the secondary leptons is analyzed. The energy distribution of the charged leptons in the decay $H \to W^+W^- \to l^+\nu_l l^-\bar{\nu}_l$ is sensitive to the $CP$–parity of the Higgs particle and yields a simple criterion for distinguishing scalar Higgs from pseudoscalar Higgs.

# 1 Introduction

We wish to report results on the energy spectrum and energy correlation of charged leptons produced in the reactions

$$H \rightarrow t\bar{t} \rightarrow b l^+ \nu_l \bar{b} l^- \bar{\nu}_l, \tag{1}$$

$$H \rightarrow W^+ W^- \rightarrow l^+ \nu_l l^- \bar{\nu}_l. \tag{2}$$

The above decays represent interesting leptonic signals of a heavy Higgs particle, that can be used to test the structure of Higgs couplings to fermions and gauge bosons [1]. (Note that the reaction (2), in the standard model, is about 27 times more frequent than the "gold–plated" reaction $H \rightarrow ZZ \rightarrow \mu^+\mu^-\mu^+\mu^-$). We carry out the analysis in a general framework in which the couplings of the $H$ to $t\bar{t}$ and to $W^+W^-$ are given by:

$$Ht\bar{t} \quad : \quad i(a + ib\gamma_5), \tag{3}$$

$$HW^+W^- \quad : \quad i2m_W^2\sqrt{G_F\sqrt{2}}\left(Bg_{\mu\nu} + \frac{D}{m_W^2}\varepsilon_{\mu\nu\rho\sigma}p^\rho_{W^+}p^\sigma_{W^-}\right). \tag{4}$$

Here $p_{W^+}$ and $p_{W^-}$ are the 4–momenta of the $W$–bosons. The terms proportional to $b$ and $D$ may arise as primary or induced effects in a generalized Higgs framework. Simultaneous presence of $a$ and $b$ or $B$ and $D$ is $CP$–violating [2]. Results will be obtained for the energy correlation of the two charged leptons in the $H$ rest frame. A special result is a simple criterion for distinguishing a scalar Higgs from a pseudoscalar Higgs particle on the basis of the energy spectrum of any single charged lepton in $H \rightarrow W^+W^- \rightarrow l^+\nu_l l^-\bar{\nu}_l$.

## 2 $H \to t\bar{t}$

The vertex $Ht\bar{t}$ (Eq. (3)) gives rise to the following differential decay rate for $H(P) \to t(p_t, s_+)\bar{t}(p_{\bar{t}}, s_-)$:

$$\begin{aligned}
\frac{d\Gamma}{d\Omega_t}(s_+, s_-) &= \frac{\beta_t}{64\pi^2 m_H}\Big\{(|a|^2 + |b|^2)(\frac{m_H^2}{2} - m_t^2 + m_t^2 s_+ s_-) \\
&\quad +(|a|^2 - |b|^2)(Ps_+ Ps_- - \frac{m_H^2}{2} s_+ s_- + m_t^2 s_+ s_- - m_t^2) \\
&\quad -\mathrm{Re}(ab^*)\varepsilon(P, Q, s_+, s_-) - 2\mathrm{Im}(ab^*) m_t P(s_+ + s_-)\Big\}, \qquad (5)
\end{aligned}$$

where $P \equiv p_t + p_{\bar{t}}$, $Q = p_t - p_{\bar{t}}$, and $s_+$ and $s_-$ denote the polarization vectors of $t$ and $\bar{t}$, respectively. $\beta_t = \sqrt{1 - 4m_t^2/m_H^2}$ is the velocity of the top quarks in the Higgs rest frame. The symbol $\varepsilon(a, b, c, d)$ means $\varepsilon_{\mu\nu\rho\sigma} a^\mu b^\nu c^\rho d^\sigma$ with $\varepsilon_{0123} = +1$. The terms proportional to $\mathrm{Re}(ab^*)$ and $\mathrm{Im}(ab^*)$ represent the $CP$–violating part of the differential decay rate.

Using the method of Kawasaki, Shirafuji and Tsai [3], the differential decay rate $\frac{d\Gamma}{d\Omega_t}(s_+, s_-)$ yields the following normalized energy correlation of the charged leptons produced in the decay $H \to t\bar{t} \to l^+ l^- + \cdots$ [F 1]:

$$\begin{aligned}
\frac{1}{\Gamma}\frac{d\Gamma}{dx dx'}(H \to t\bar{t} \to l^+ l^- + \cdots) &= f(x)f(x') - \frac{1}{\beta_t^2} g(x)g(x') \\
&\quad + \frac{2\mathrm{Im}(ab^*)}{|a|^2\beta_t^2 + |b|^2}\Big[f(x')g(x) - f(x)g(x')\Big], \qquad (6)
\end{aligned}$$

where $x$ and $x'$ are the reduced energies

$$x = \frac{2E(l^+)}{m_t}\sqrt{\frac{1-\beta_t}{1+\beta_t}} \quad , \quad x' = \frac{2E(l^-)}{m_t}\sqrt{\frac{1-\beta_t}{1+\beta_t}}, \qquad (7)$$

$E(l^+)$ and $E(l^-)$ being the energies of the final leptons $l^+$ and $l^-$ in the Higgs rest frame. $x$ and $x'$ are bounded by

$$\frac{m_W^2}{m_t^2}\frac{1-\beta_t}{1+\beta_t} \le x, x' \le 1, \qquad (8)$$

assuming the narrow width approximation for the $W$–bosons in the top decay. The functions $f$ and $g$ are defined as follows (see [4]):

1. $\frac{m_W^2}{m_t^2} \geq \frac{1-\beta_t}{1+\beta_t}$

$$f(x) = \frac{3}{2W}\frac{1+\beta_t}{\beta_t}\begin{cases} -2\frac{m_W^2}{m_t^2} + \frac{m_W^4}{m_t^4} + 2x\frac{1+\beta_t}{1-\beta_t} - x^2(\frac{1+\beta_t}{1-\beta_t})^2 & : I_1 \\ 1 - 2\frac{m_W^2}{m_t^2} + \frac{m_W^4}{m_t^4} & : I_2 \\ 1 - 2x + x^2 & : I_3 \end{cases}$$

$$g(x) = \frac{3}{W}\frac{(1+\beta_t)^2}{\beta_t}\begin{cases} -x\frac{m_W^2}{m_t^2} + x^2\frac{1+\beta_t}{1-\beta_t} + x\ln\frac{m_W^2}{m_t^2} - x\ln(x\frac{1+\beta_t}{1-\beta_t}) & \\ +\frac{1/2}{1+\beta_t}[-2\frac{m_W^2}{m_t^2} + \frac{m_W^4}{m_t^4} + 2x\frac{1+\beta_t}{1-\beta_t} - x^2(\frac{1+\beta_t}{1-\beta_t})^2] & : I_1 \\ x - x\frac{m_W^2}{m_t^2} + x\ln\frac{m_W^2}{m_t^2} + \frac{1/2}{1+\beta_t}[1 - 2\frac{m_W^2}{m_t^2} + \frac{m_W^4}{m_t^4}] & : I_2 \\ x - x^2 + x\ln x + \frac{1/2}{1+\beta_t}[1 - 2x + x^2] & : I_3 \end{cases}$$

where the intervals $I_i$ are given by:

$$\begin{array}{lcccccc} I_1 & : & \frac{m_W^2}{m_t^2}\frac{1-\beta_t}{1+\beta_t} & \leq & x & \leq & \frac{1-\beta_t}{1+\beta_t}, \\ I_2 & : & \frac{1-\beta_t}{1+\beta_t} & \leq & x & \leq & \frac{m_W^2}{m_t^2}, \\ I_3 & : & \frac{m_W^2}{m_t^2} & \leq & x & \leq & 1. \end{array}$$

2. $\frac{m_W^2}{m_t^2} \leq \frac{1-\beta_t}{1+\beta_t}$

$$f(x) = \frac{3}{2W}\frac{1+\beta_t}{\beta_t}\begin{cases} -2\frac{m_W^2}{m_t^2} + \frac{m_W^4}{m_t^4} + 2x\frac{1+\beta_t}{1-\beta_t} - x^2(\frac{1+\beta_t}{1-\beta_t})^2 & : I_4 \\ -2x + x^2 + 2x\frac{1+\beta_t}{1-\beta_t} - x^2(\frac{1+\beta_t}{1-\beta_t})^2 & : I_5 \\ 1 - 2x + x^2 & : I_6 \end{cases}$$

$$g(x)=\frac{3}{W}\frac{(1+\beta_t)^2}{\beta_t}\begin{cases} -x\frac{m_W^2}{m_t^2}+x^2\frac{1+\beta_t}{1-\beta_t}+x\ln\frac{m_W^2}{m_t^2}-x\ln(x\frac{1+\beta_t}{1-\beta_t}) \\ +\frac{1/2}{1+\beta_t}[-2\frac{m_W^2}{m_t^2}+\frac{m_W^4}{m_t^4}+2x\frac{1+\beta_t}{1-\beta_t}-x^2(\frac{1+\beta_t}{1-\beta_t})^2] & : I_4 \\ \\ -x^2+x^2\frac{1+\beta_t}{1-\beta_t}+x\ln\frac{1-\beta_t}{1+\beta_t}+\frac{1/2}{1+\beta_t}[-2x+x^2 \\ +2x\frac{1+\beta_t}{1-\beta_t}-x^2(\frac{1+\beta_t}{1-\beta_t})^2] & : I_5 \\ \\ x-x^2+x\ln x+\frac{1/2}{1+\beta_t}[1-2x+x^2] & : I_6 \end{cases}$$

with the intervals $I_i$:

$$\begin{array}{lcccccc} I_4 & : & \frac{m_W^2}{m_t^2}\frac{1-\beta_t}{1+\beta_t} & \leq & x & \leq & \frac{m_W^2}{m_t^2}, \\ I_5 & : & \frac{m_W^2}{m_t^2} & \leq & x & \leq & \frac{1-\beta_t}{1+\beta_t}, \\ I_6 & : & \frac{1-\beta_t}{1+\beta_t} & \leq & x & \leq & 1, \end{array}$$

and

$$W=(1-\frac{m_W^2}{m_t^2})^2(1+2\frac{m_W^2}{m_t^2}). \tag{9}$$

The normalizations of $f$ and $g$ are

$$\begin{aligned} \int f(x)dx &= 1, \\ \int g(x)dx &= 0. \end{aligned} \tag{10}$$

The functions $f$ and $g$ represent the spin–independent and spin–dependent parts of the lepton spectrum in $t$–decay. Eq. (6) can also be written as

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}x\mathrm{d}x'}(H\to t\bar{t}\to l^+l^-+\cdots)=S_t(x,x')+\Delta A_t(x,x'), \tag{11}$$

where

$$\begin{aligned} S_t(x,x') &= f(x)f(x') - \frac{1}{\beta_t^2}g(x)g(x'), \\ A_t(x,x') &= f(x')g(x) - f(x)g(x'), \\ \Delta &= \frac{2\mathrm{Im}(ab^*)}{|a|^2\beta_t^2 + |b|^2}. \end{aligned} \tag{12}$$

$S_t(x,x')$ and $A_t(x,x')$ represent the symmetric and antisymmetric part of the energy correlation. These are plotted in Figs. (1a) and (1b).

The symmetric ($CP$–conserving) part of the two–dimensional distribution $\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}x\mathrm{d}x'}$ does not depend on the coupling constants $a$ and $b$. This means that in the $CP$–conserving limit the energy correlation of secondary leptons arising from $H \to t\bar{t}$ is independent of the $CP$–parity of the decaying Higgs particle.

Integration over $x$ or $x'$ yields the single lepton energy spectra

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}x}(H \to t\bar{t} \to l^\pm + \cdots) = f(x) \pm \Delta g(x). \tag{13}$$

Eq. (13) agrees with the energy spectrum obtained by Chang and Keung [5] using a different method. The single energy spectra are plotted in Fig. 2. The parameter $\Delta$ is calculated within a 2–Higgs Doublet Model in Refs. [5, 6].

## 3 $H \to W^+W^-$

The differential decay rate for the reaction $H(P) \to W^+W^- \to l^+(q_1)\nu_l(q_2)l^-(q_3)\bar{\nu}_l(q_4)$, arising from the $HW^+W^-$ vertex given in Eq. (4), is

$$\mathrm{d}^8\Gamma = 8\sqrt{2}\,\frac{G_F}{m_H}D_W\left[|B|^2\,\mathcal{S} + \frac{|D|^2}{m_W^4}\,\mathcal{P} + \frac{\mathrm{Re}(BD^*)}{m_W^2}\,\mathcal{Q} - \frac{\mathrm{Im}(BD^*)}{m_W^2}\,\mathcal{R}\right]\cdot \mathrm{d}Lips. \tag{14}$$

The Lorentz invariant phase space is given by

$$\mathrm{d}Lips = (2\pi)^4\delta^{(4)}(P - q_1 - q_2 - q_3 - q_4)\prod_{i=1}^{4}\frac{\mathrm{d}^3 q_i}{(2\pi)^3 2q_i^0}. \tag{15}$$

In the massless fermion approximation,

$$\begin{aligned}
\mathcal{S} &= (q_2\cdot q_3)(q_1\cdot q_4), \\
\mathcal{P} &= -\Big\{(q_2\cdot q_3)(q_1\cdot q_4) - (q_2\cdot q_4)(q_1\cdot q_3)\Big\}^2 \\
&\quad + \frac{m_W^4}{4}\Big\{(q_2\cdot q_3)^2 + (q_1\cdot q_4)^2 + 2(q_2\cdot q_4)(q_1\cdot q_3) - \frac{m_W^4}{4}\Big\}, \\
\mathcal{Q} &= \varepsilon(q_1,q_2,q_3,q_4)\Big\{(q_2\cdot q_3) + (q_1\cdot q_4)\Big\}, \\
\mathcal{R} &= \Big\{(q_2\cdot q_3) - (q_1\cdot q_4)\Big\}\Big\{\frac{m_W^4}{4} + (q_2\cdot q_3)(q_1\cdot q_4) - (q_2\cdot q_4)(q_1\cdot q_3)\Big\}, \qquad (16)
\end{aligned}$$

while $D_W$ is the propagator factor

$$D_W = m_W^4 \prod_{j=1}^{2} \frac{g^2}{(s_j - m_W^2)^2 + m_W^2\Gamma_W^2}, \qquad (17)$$

with $s_1 = (q_1+q_2)^2$, $s_2 = (q_3+q_4)^2$. In the narrow width approximation, the total decay rate is given by

$$\begin{aligned}
\Gamma(H\to W^+W^-\to l^+\nu_l l^-\bar\nu_l) &= \frac{g^6 m_H^3\beta_W}{9\cdot 2^{16}\pi^3\Gamma_W^2}\Big\{ \\
&\quad |B|^2(3-2\beta_W^2+3\beta_W^4) + 8|D|^2\beta_W^2\Big\}, \qquad (18)
\end{aligned}$$

in agreement with the result of Osland and Skjold [7].

We now introduce scaled energy variables in the $H$ rest frame:

$$y = \frac{4E(l^+)}{m_H} \quad , \quad y' = \frac{4E(l^-)}{m_H}, \qquad (19)$$

which are bounded by

$$1-\beta_W \le y, y' \le 1+\beta_W, \qquad (20)$$

where $\beta_W = \sqrt{1-4m_W^2/m_H^2}$. The two–dimensional spectrum in the variables $y$ and $y'$ is then given by

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}y\mathrm{d}y'}(H\to W^+W^-\to l^+l^-+\cdots) = \frac{1}{|B|^2(3-2\beta_W^2+3\beta_W^4)+8|D|^2\beta_W^2}\cdot\frac{9}{32\beta_W^6}\cdot$$

$$\Big\{|B|^2\Big[(3+2\beta_W^2+3\beta_W^4)((y-1)^2-\beta_W^2)((y'-1)^2-\beta_W^2) + 2\beta_W^2(1-\beta_W^2)^2(y-y')^2\Big] + 4\beta_W^2|D|^2\Big[((y-1)^2+\beta_W^2)((y'-1)^2+\beta_W^2)-4\beta_W^2(y-1)(y'-1)\Big] + 8\beta_W^2\mathrm{Im}(BD^*)(1-\beta_W^2)\Big[\beta_W^2-(y-1)(y'-1)\Big](y-y')\Big\}. \quad (21)$$

Neglecting terms proportional to $|D|^2$, the correlation can be written as

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}y\mathrm{d}y'}(H\to W^+W^-\to l^+l^-+\cdots) = S_W(y,y') + \frac{\mathrm{Im}(BD^*)}{|B|^2}A_W(y,y') + O(|D|^2/|B|^2). \quad (22)$$

Here $S_W(y,y')$ and $A_W(y,y')$ represent the symmetric and antisymmetric parts of the energy correlation of the charged leptons, the latter being multiplied by the $CP$–violating coefficient $\mathrm{Im}(BD^*)/|B|^2$. These functions are plotted in Figs. (3a) and (3b).

There is an interesting difference in the energy characteristics of the leptons emanating from $H\to W^+W^-\to l^+\nu_l l^-\bar\nu_l$, dependent on whether $H$ is a scalar ($0^+$) or pseudoscalar ($0^-$) particle. The correlated energy spectrum of the $l^+l^-$ pair can be derived from Eq. (21) by taking $D=0$ (scalar case) or $B=0$ (pseudoscalar case), with the result

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma(0^+)}{\mathrm{d}y\mathrm{d}y'} = S_W(y,y') = \frac{9}{32\beta_W^6}\frac{1}{3-2\beta_W^2+3\beta_W^4}\Big[2\beta_W^2(1-\beta_W^2)^2(y-y')^2 + (3+2\beta_W^2+3\beta_W^4)((y-1)^2-\beta_W^2)((y'-1)^2-\beta_W^2)\Big], \quad (23)$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma(0^-)}{\mathrm{d}y\mathrm{d}y'} = P_W(y,y') = \frac{9}{64\beta_W^6}\Big[((y-1)^2+\beta_W^2)((y'-1)^2+\beta_W^2) - 4\beta_W^2(y-1)(y'-1)\Big]. \quad (24)$$

These two functions are strikingly different, as shown in Figs. (3a) and (3c). This difference persists even if we consider the energy spectrum of a single lepton. Integrating Eqs. (23, 24) over $y'$, we have

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma(0^+)}{\mathrm{d}y} = \frac{3}{2\beta_W}\frac{1+\beta_W^4-2(y-1)^2}{3-2\beta_W^2+3\beta_W^4}, \tag{25}$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma(0^-)}{\mathrm{d}y} = \frac{3}{8\beta_W^3}(\beta_W^2+(y-1)^2). \tag{26}$$

These distributions are clearly quite distinct (Fig. 4) and provide a simple criterion for distinguishing $0^+$ and $0^-$ objects decaying into $W^+W^-$ pairs. Indeed, the single lepton spectra (Eqs. (25), (26)) are also valid for the inclusive process $H \to W^+W^- \to l^\pm X$, where only one of the $W$–bosons decays leptonically. The difference in the lepton energy spectrum for the $0^+$ and $0^-$ cases is intimately related to the different helicity structure of the $W$–bosons produced in the two cases [8]. It should be stressed that the correlations and spectra given above (Eqs. (21)–(26)) refer directly to energies measured in the $H$ rest frame, and do not require reconstruction of the decay planes of $W^+$ and $W^-$. In this respect, the present criterion provides a useful alternative to other criteria that have recently been proposed in the literature [8, 9]. Finally, we note that the energy spectrum in the $0^+$ case agrees with that obtained by Chang and Keung [5], after correction of a minor typographical error [F 2].

One of us (T.A.) acknowledges a stipend from the NRW Graduiertenförderungsprogramm. This research has been supported by the BMFT (German Ministry of Research and Technology).

## Footnotes

[F 1 ] Some of the essential steps in the procedure of Ref. [3] can be found in Ref. [4].

[F 2 ] Eq. (15) of Ref. [5] should read

$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}x(l^{\pm})} = \left(\frac{(1+\beta_W^2)^2}{3-2\beta_W^2+3\beta_W^4}\right)\frac{3[\beta_W^2-(1-x)^2]}{4\beta_W^3} + \sum_{s=-1,+1} \cdots .$$

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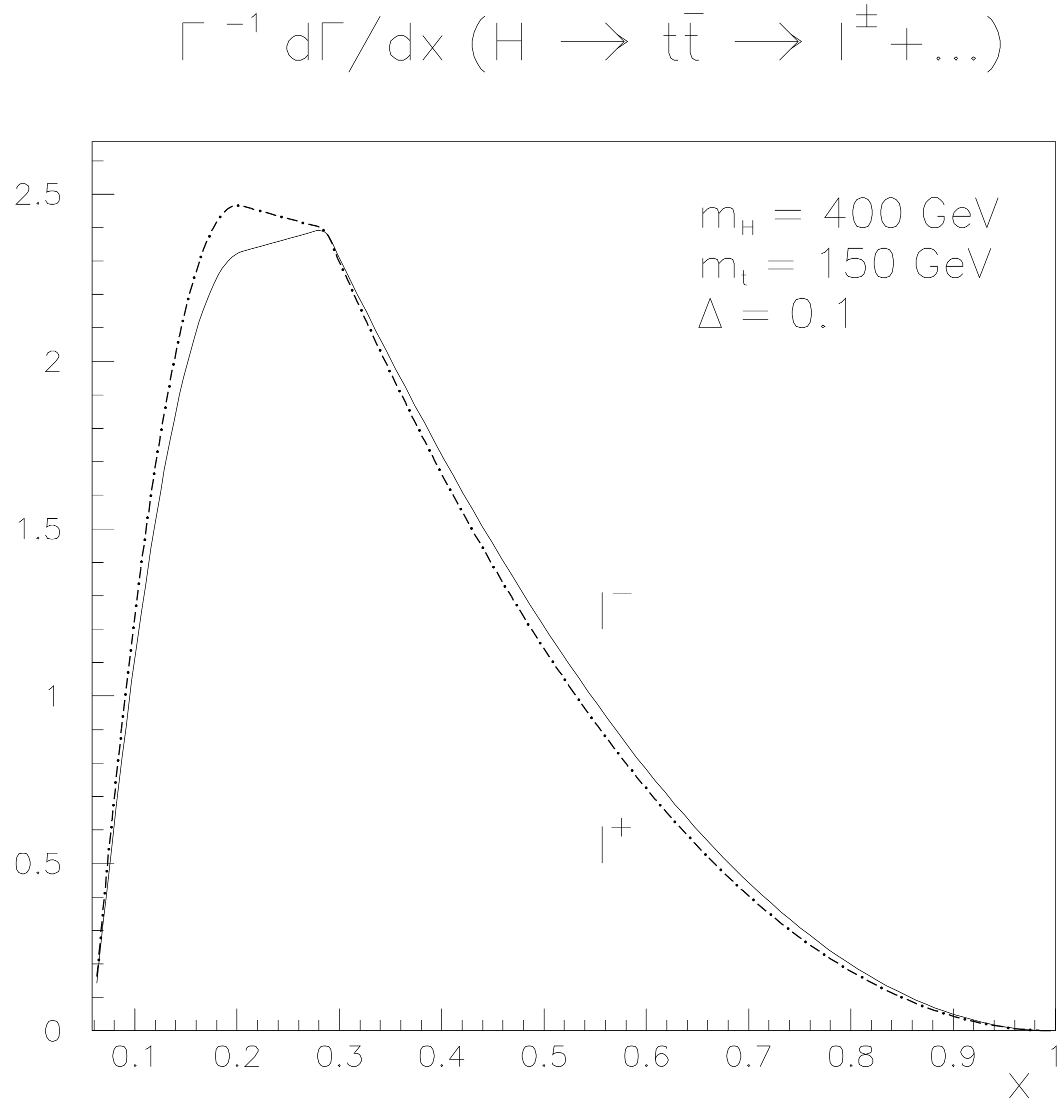
## Figure Captions

Fig. 1. $CP$–conserving (a) and $CP$–violating (b) part of the normalized energy correlation in the decay $H \to t\bar{t} \to l^+l^- + \cdots$ for $m_H = 400$ GeV and $m_t = 150$ GeV.

Fig. 2. Single particle energy spectra of $l^+$ (dotted curve) and $l^-$ (full curve) in the decay $H \to t\bar{t}$ for $\Delta = 0.1$, $m_H = 400$ GeV and $m_t = 150$ GeV.

Fig. 3. $CP$–conserving (a) and $CP$–violating (b) part of the normalized energy correlation in the decay $H \to W^+W^- \to l^+l^- + \cdots$ for $m_H = 300$ GeV. Fig. 3(c) shows the normalized energy correlation for the decay of a pseudoscalar Higgs $H \to W^+W^- \to l^+l^- + \cdots$ for $m_H = 300$ GeV.

Fig. 4. Energy distribution of a single lepton in the decay $H \to W^+W^- \to l^\pm + \cdots$ for $m_H = 300$ GeV. The full curve represents the scalar case and the dotted curve shows the pseudoscalar case.



$\Gamma^{-1} d\Gamma/dx\ (H \rightarrow t\bar{t} \rightarrow l^{\pm}+...)$
$m_H = 400$ GeV
$m_t = 150$ GeV
$\Delta = 0.1$
$l^-$
$l^+$
0
0.5
1
1.5
2
2.5
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
X


Fig. 2.

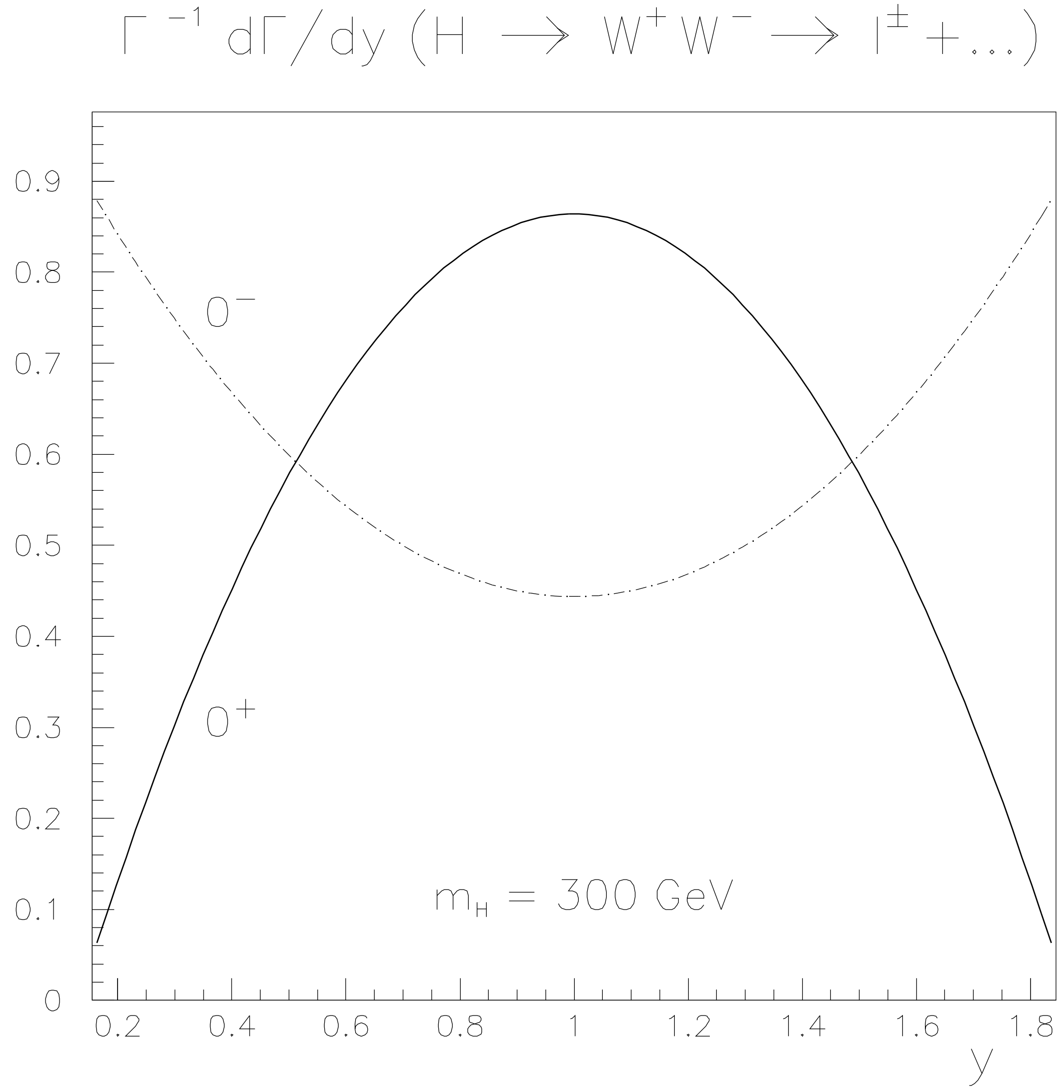
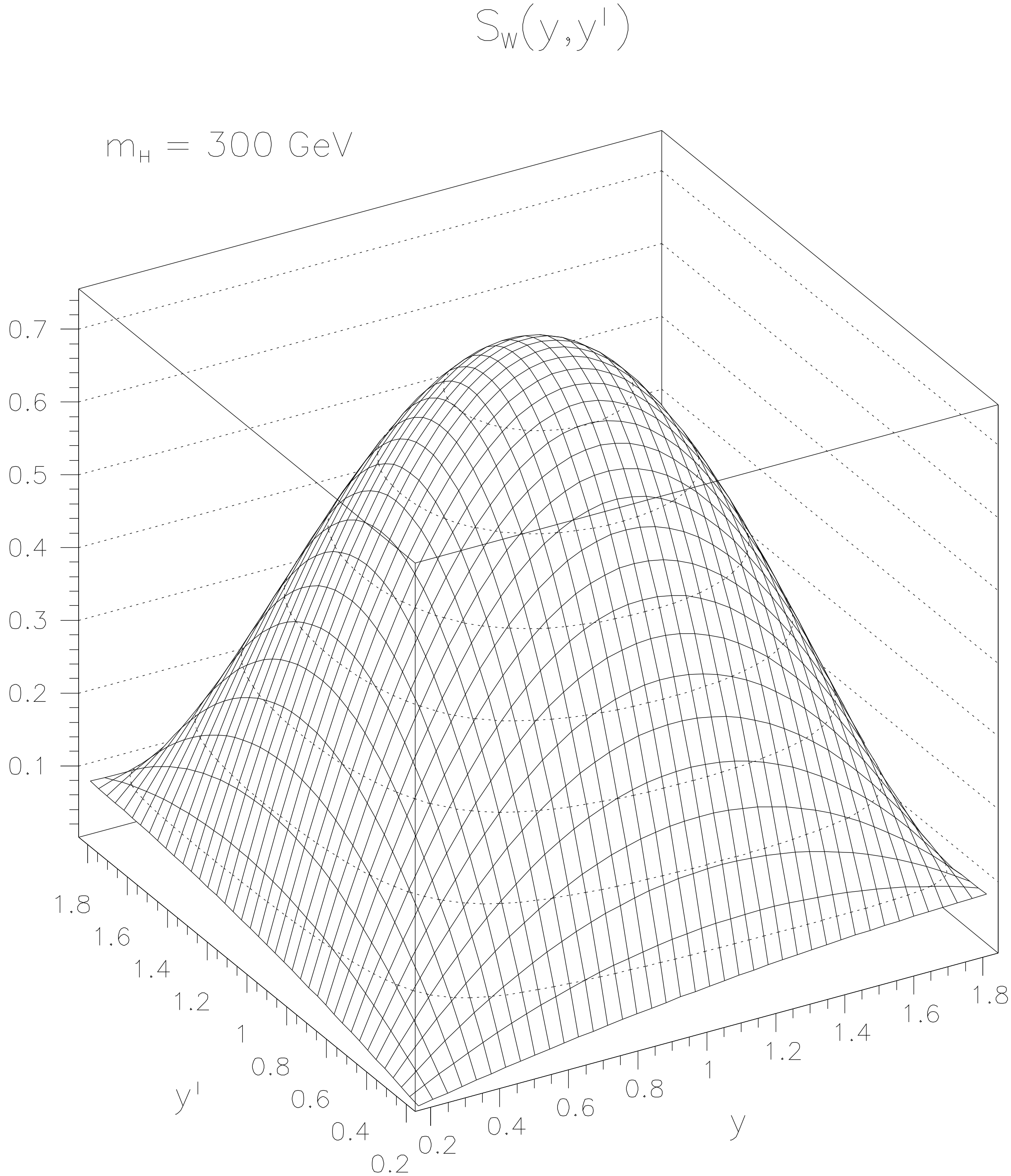

$\Gamma^{-1}\, d\Gamma/dy\ (H \to W^+W^- \to l^\pm + \ldots)$
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
y
$0^-$
$0^+$
$m_H$ = 300 GeV

Fig. 4.



$S_W(y,y')$
$m_H$ = 300 GeV
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
y'
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
y


Fig. 3(a).

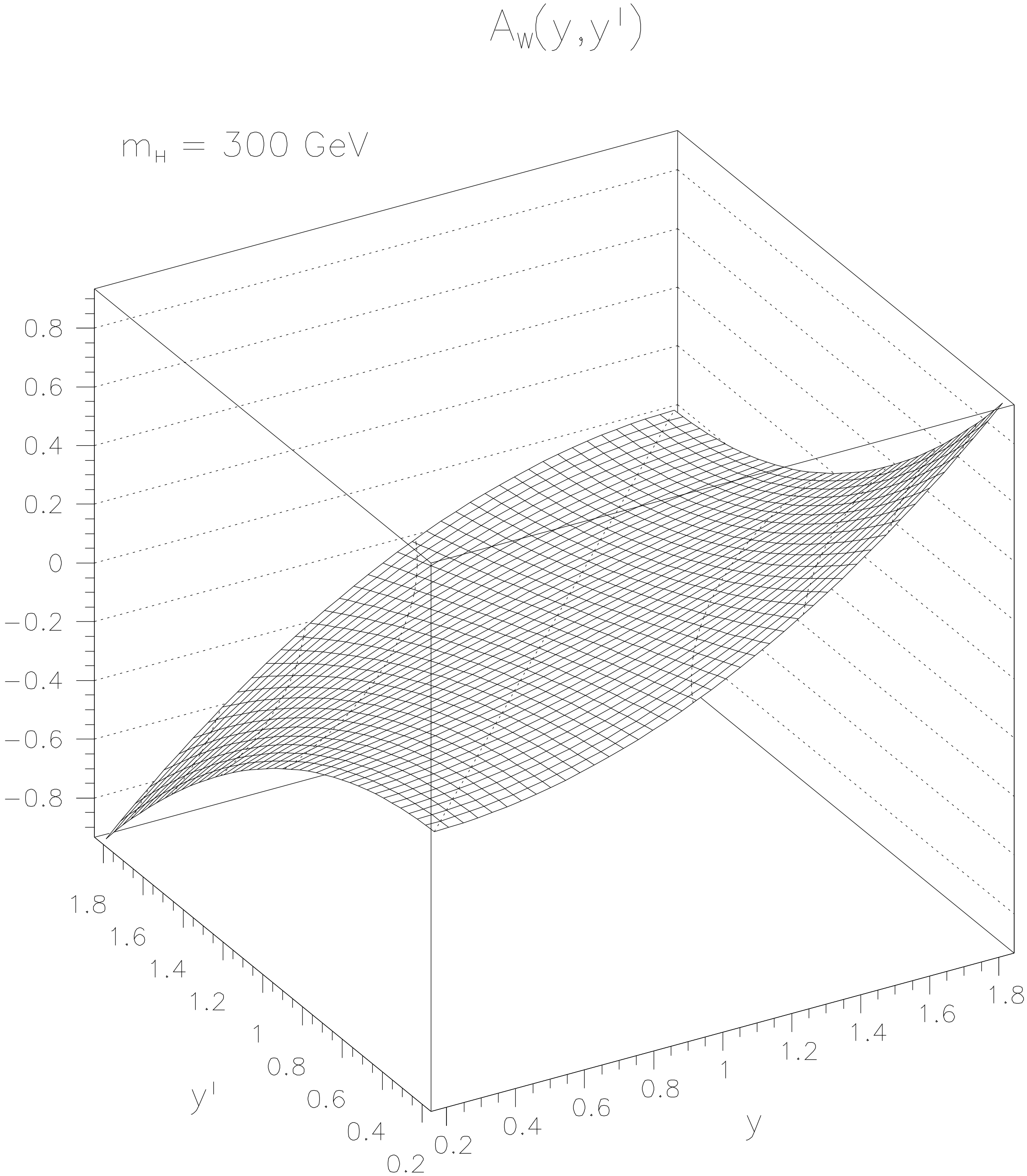
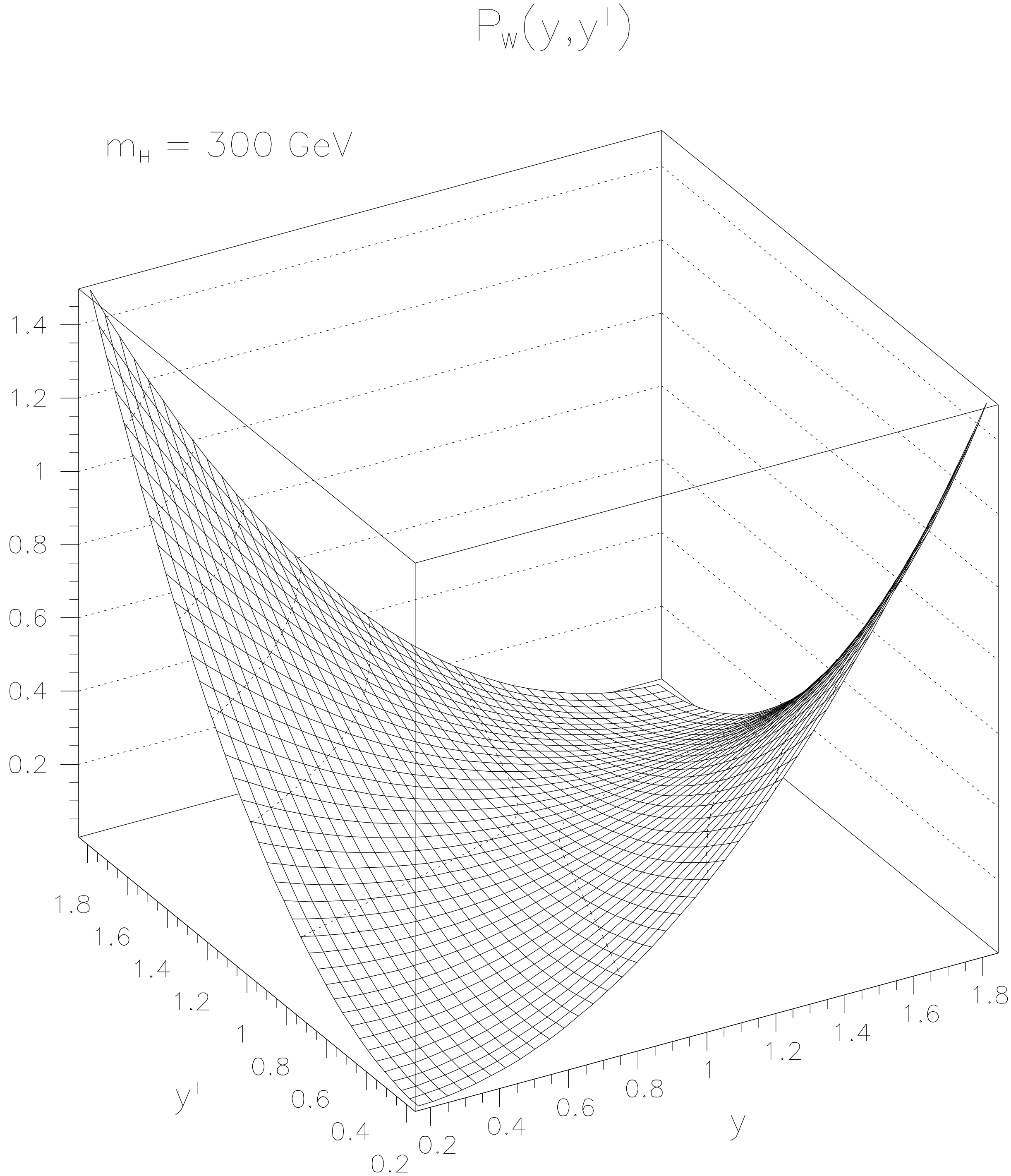

A_W(y,y')
m_H = 300 GeV
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
y'
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
y

Fig. 3(b).



$P_W(y,y')$
$m_H$ = 300 GeV
1.4
1.2
1
0.8
0.6
0.4
0.2
y'
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
y
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8


Fig. 3(c).

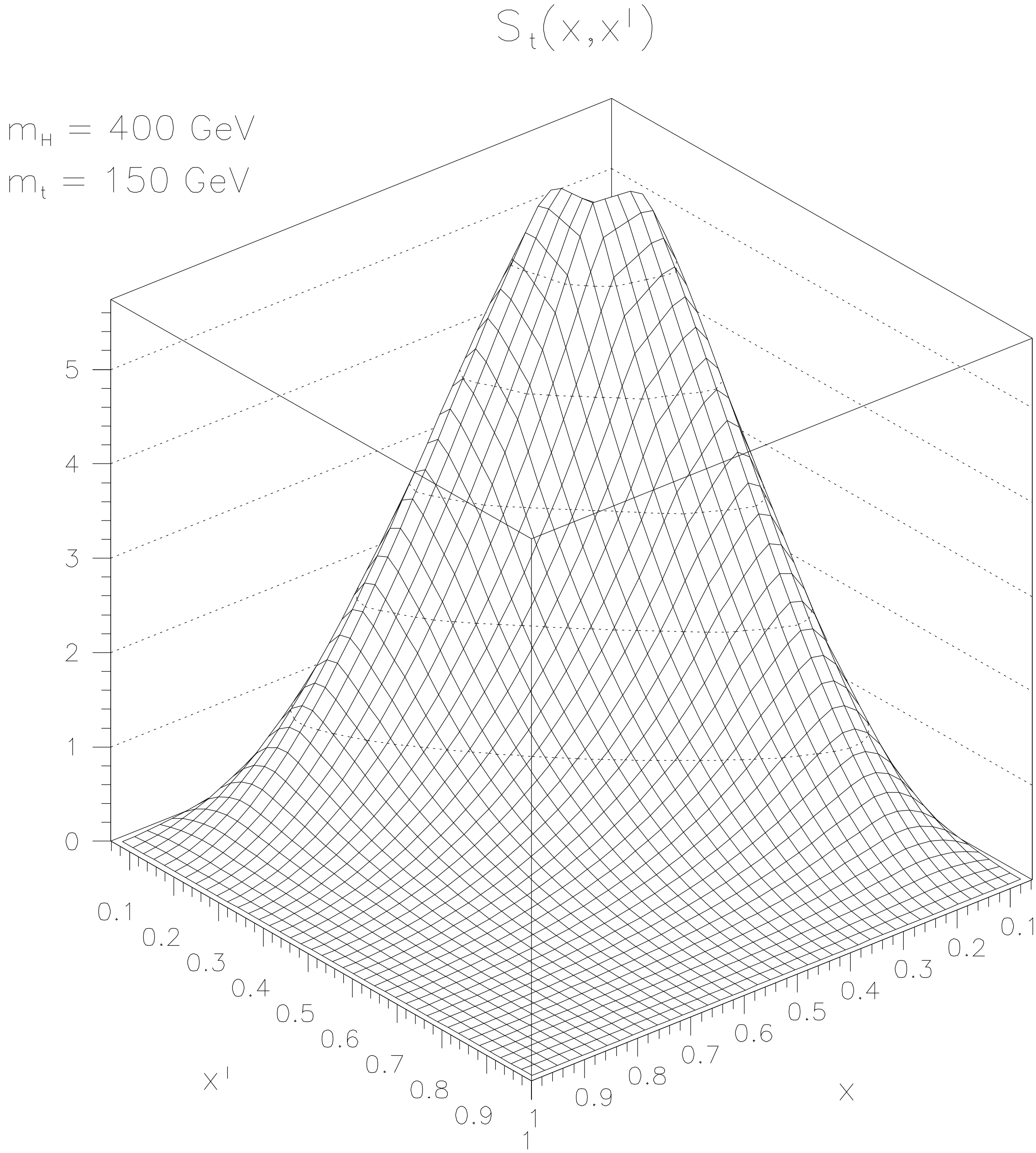
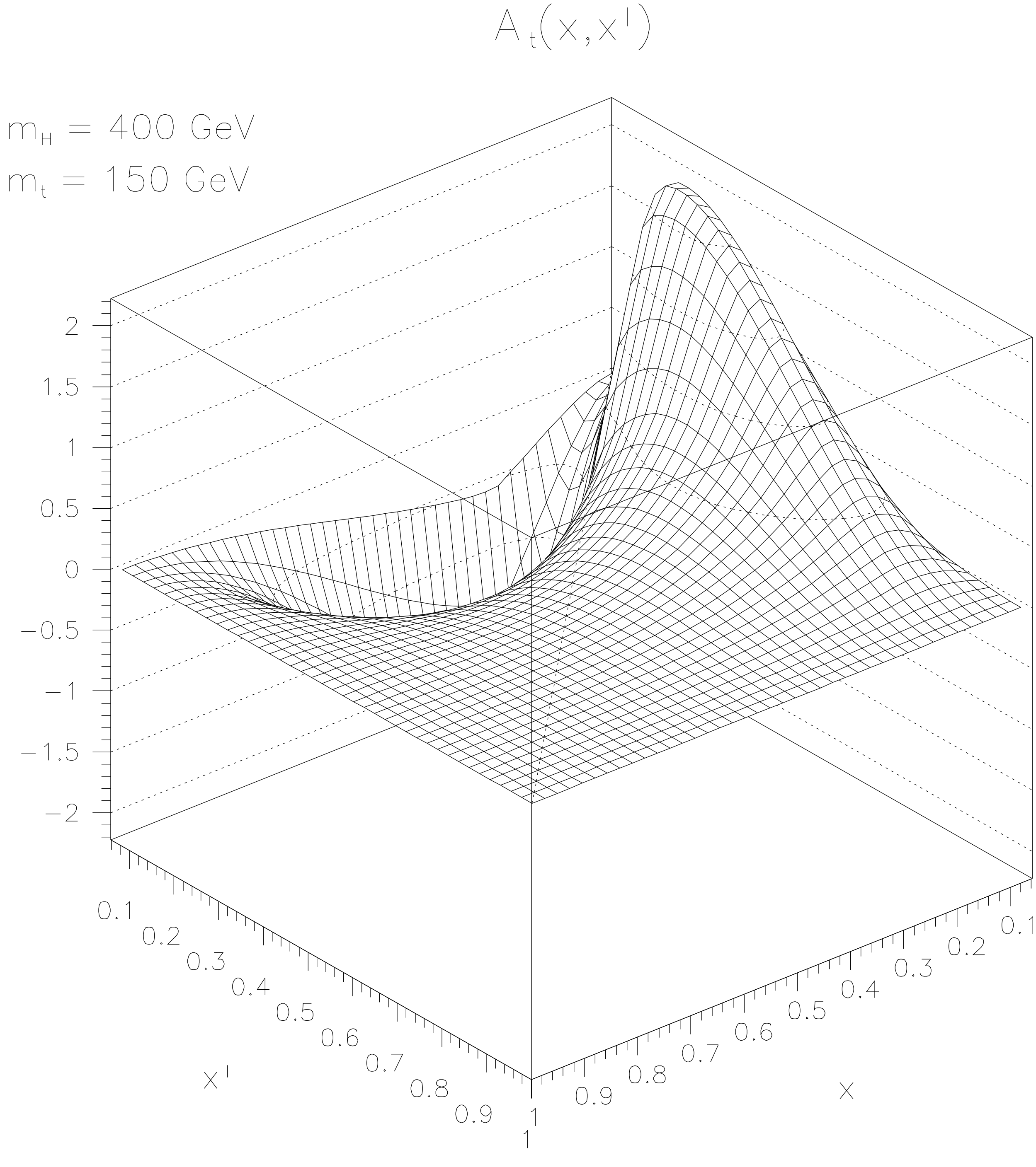



Fig. 1(a).



$A_t(x,x')$
$m_H$ = 400 GeV
$m_t$ = 150 GeV
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x'
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x


Fig. 1(b).