IMPLICATIONS OF HEAVY TOP

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1 Introduction

Now after discovery of top quark at FNAL collider [1] the third family of
fermions is completed, and the only yet nondiscovered particle of the Minimal
Standard Model (MSM) is Higgs boson. Top quark appeared to be very
heavy, more than 30 times heavier than its partner in electroweak doublet,
b-quark:

\begin{align*}
\langle m_t \rangle &= 180 \pm 12 \text{GeV}, \\
C\text{DF},
\end{align*}

\begin{align*}
\langle m_t \rangle &= 180 \pm 12 \text{GeV}, \\
D\text{O},
\end{align*}

So it appeared to be the heaviest elementary particle known at present. The
central question about the top is: why is it so heavy compared with the other
quarks and leptons? What information is hidden under this very specific
pattern of quark and lepton masses? In this lecture we will not discuss this
question at all; our approach will be more practical. Spontaneous breaking
of gauge invariance in the electroweak theory leads to a very unusual mani-
festation of the heavy particles: instead of decoupling (phenomena of power
suppression of heavy particles contribution into low energy observables) con-
tributions of virtual heavy particles are enhanced. This is the reason why the
fact that the top is unusually heavy was known long before its discovery at
FNAL. Large $B-\bar{B}$-mixing discovered in the eighties [2] signals that $t$-quark
is heavy. Precise measurements of $Z$-boson mass and decay parameters and $W$-boson mass lead to determination of top mass with the accuracy close to that of direct measurements. In this lecture I will mainly deal with this virtual top effects. In part 2 top implication in $K^0$ system will be discussed; in Part 3 we will go to $B^0$ system. In Part 4 top implication in $Z$- and $W$-physics will be briefly considered and, finally, in Part 5 production and decay of $t$-quark will be discussed.

2 $K^0$-mesons

Electrically neutral pseudoscalar mesons mix with their antiparticles at the second order of weak interactions. Under this mixing heavy and light eigenstates are formed (see recent review [3]):

$$P_H = p \mid P^0 > + q \mid \bar{P}^0 > ,$$

$$P_L = p \mid P^0 > - q \mid \bar{P}^0 > .$$

Masses, decay width and coefficients $p$ and $q$ are determined by the mixing matrix:

$$
\begin{pmatrix}
M - \frac{i}{2} \Gamma & M_{12} - \frac{i}{2} \Gamma_{12} \\
M_{12}^* - \frac{i}{2} \Gamma_{12}^* & M - \frac{i}{2} \Gamma
\end{pmatrix}
\begin{pmatrix}
p \\
q
\end{pmatrix}
= \lambda
\begin{pmatrix}
p \\
q
\end{pmatrix} .
$$

Diagonal matrix elements are equal due to CPT; the violation of CP is due to the difference of nondiagonal matrix elements. From (4) we get:

$$\lambda_{1,2} = M - \frac{i}{2} \Gamma \pm \sqrt{(M_{12} - \frac{i}{2} \Gamma_{12})(M_{12}^* - \frac{i}{2} \Gamma_{12}^*)}$$

$$\Delta M - \frac{i}{2} \Delta \Gamma = 2 \sqrt{(M_{12} - \frac{i}{2} \Gamma_{12})(M_{12}^* - \frac{i}{2} \Gamma_{12}^*)}$$

$$\frac{q}{p} = \sqrt{\frac{M_{12}^* - \frac{i}{2} \Gamma_{12}^*}{M_{12} - \frac{i}{2} \Gamma_{12}}} = 2 \frac{M_{12}^* - \frac{i}{2} \Gamma_{12}^*}{\Delta M - \frac{i}{2} \Delta \Gamma} \equiv \frac{1 - \varepsilon}{1 + \varepsilon}$$

The phase of the ratio $p/q$ is changed under phase rotation of $P^0$ field: $P^0 \rightarrow e^{i\alpha} P^0$, $q/p \rightarrow e^{2i\alpha} q/p$. So the phase of $q/p$ could be made equal to zero and
CP violation is proportional to \( (q/p) - 1 \simeq -2Re\varepsilon \). Now we have all general formulas and they should be specified for \( K^0 - \bar{K}^0 \) and \( B^0 - \bar{B}^0 \) systems.

In MSM \( K^0 - \bar{K}^0 \) transition proceed through the box diagram shown in Fig. 1.

**Fig. 1.**

Feynman diagram responsible for \( K^0 - \bar{K}^0 \) transition.

When this diagram is calculated in renormalizable \( R_\xi \) gauge exchanges of charged components of Higgs doublet should be taken into account. These are the exchanges that produce the leading contribution \( \sim m_t^2 \). Yukawa coupling of Higgs boson to the quark bracket \( \tilde{t}_R (d, s)_L \) is proportional to \( m_t \). Taking for top propagator \( G_t = \hat{p} / (p^2 - m_t^2) \) we obtain for the box diagram under study the following expression:

\[
M \sim m_t^4 \int \frac{d^4 p p^2}{(p^2 + m_t^2)^2 (p^2 + M_W^2 \xi)^2} \sim m_t^2 ,
\]

which demonstrates non-decoupling behaviour. The explicit expression for the box diagram for \( m_t \sim m_W \) was for the first time derived in \([4]\). Saturating matrix element \( < K^0 | (\bar{d}s)^2 | K^0 > \) by vacuum insertion we get \([4]\):

\[
M_{\bar{K}K} = -\frac{G_F^2}{6\pi^2} f_K^2 m_K^2 \{ \eta_{cc} m_c^2 V_{cs}^* V_{cd}^2 + 2 m_c^2 \ln \frac{m_t^2}{m_c^2} \times \\
\times V_{cs}^* V_{cd} V_{ts}^* V_{td} \eta_{tc} + m_t^2 I \left( \frac{m_t^2}{m_W^2} \right) V_{ts}^* V_{td} \eta_{ht} \} .
\]

Here \( f_K = 160 \text{ MeV} \) is a constant of \( K \rightarrow \mu\nu \) decay, \( G_F \simeq 10^{-5}/m_p^2 \) is Fermi coupling constant, \( m_K \) is \( K^0 \) mass, factors \( \eta_{ij} \approx 0.6 \) take into account
gluon exchanges, $V_{ij}$ are the matrix elements of Kobayashi-Maskawa quark mixing matrix. The first term corresponds to a diagram with two $c$-quark exchange, the second – to the case when one quark is charm, another – top and, finally, the third term comes from the two top quarks exchange. Factor $I(x)$ calculated in [4] is called in the literature Inami-Lim factor:

$$I(x) = \frac{4 - 11x + x^2}{4(1 - x)^2} - \frac{3x^2 \ln x}{2(1 - x)^2}, \quad I(0) = 1, \quad I(4) = 0.6, \quad I(\infty) = 0.25$$

(10)

From the experiments with $K$-mesons mass difference $\Delta m_{LS}$ is known as well as the parameter of CP violation $\varepsilon$. To look for top quark contribution we should know the numerical values of parameters $V_{ij}$. We will use the following parametrization of Kobayashi-Maskawa matrix:

$$
\begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix} = 
\begin{pmatrix}
c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\
-s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\
s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13}
\end{pmatrix}.
$$

(11)

Diagonal elements of CKM matrix equal unity with high accuracy. Study of strange, charm and beauty particles decay leads to the following values of CKM matrix elements [3]:

$$
|V_{us}| = 0.221(2) \\
|V_{cd}| = 0.204(17) \\
|V_{cb}| = 0.040(5) \\
|V_{ub}| = 0.003(1).
$$

(12)

Unitarity of CKM matrix makes it possible to determine the values of $V_{ts}$ and $V_{td}$ which enter [3]:

$$V_{ts}^*V_{tb} + V_{cs}^*V_{cb} + V_{us}^*V_{ub} = 0.$$  

(13)

As $V_{tb}$ and $V_{cs}$ are equal to unity with high accuracy while $V_{cb} \gg V_{us}V_{ub}$, we get:

$$V_{ts}^* \approx -V_{cb}^*.$$  

(14)

Analogously for $V_{td}$ we get:

$$V_{td}^*V_{tb} + V_{cd}^*V_{cb} + V_{sd}^*V_{ub} = 0,$$

(15)
\[ V_{td} = -V_{cd}V_{cb}^* - V_{ub}^* \]  

We are ready now to determine relative importance of top contribution to \( \Delta m_{LS} \). The first term in brackets in eq. (9) dominate over the second term. Let us compare the third and the first terms:

\[ \frac{tt}{cc} = \left( \frac{m_t}{m_c} \right)^2 I(4) \frac{V_{ts}^*V_{td}^2V_{cd}^*}{V_{cs}^*V_{cd}^2} \leq 3.5 \cdot 10^{-7} \left( \frac{m_t}{m_c} \right)^2 \]  

We demonstrate that t-quark contribution to the difference of masses of \( K_L \) and \( K_S \) mesons is less than 1%.

Let us note that a charm quark is also not enough to reproduce the experimental number \( (\Delta m_{LS})_{\text{exp}} = 3.51(2) \cdot 10^{-12} \text{ MeV} \):

\[ (\Delta m_{LS})_{\text{theor}} = \frac{|M_{KK}|}{m_K} = \frac{G_F^2 f_K^2 m_K \eta_{cc} m_c^2}{6 \pi^2} |V_{cs}V_{cd}|^2 = 1.1 \cdot 10^{-12} \text{MeV} \]  

where we substituted \( f_K = 160 \text{ MeV} \), \( \eta_{cc} = 0.6 \), \( m_c = 1.3 \text{ GeV} \), \( V_{cs} = 1 \), \( V_{cd} = 0.2 \). In the first equality we use eq. (3) taking into account smallness of CP-violation in \( K \)-mesons \( (M_{12} \simeq M_{12}^*, \Gamma_{12} \simeq \Gamma_{12}^*) \) and the fact that \( \Delta M \equiv m_{2H}^2 - m_L^2 \) since the squares of scalar particle masses enter the Lagrangian.

Now we turn to CP-violation in \( K \)-mesons. The parameter of CP-violation caused by \( K^0 - \bar{K}^0 \) mixing \( \varepsilon \) is given by eq. (7).

A nonzero value of \( \varepsilon \) induces celebrated \( K_L^0 \) decay into two pions. Taking into account that \( \text{Im}M_{12} \ll \text{Re}M_{12}, \text{Im}\Gamma_{12} \ll \text{Re}\Gamma_{12} \) and \( \text{Im}M_{12} \gg \text{Im}\Gamma_{12} \), we get:

\[ \varepsilon = \frac{i\text{Im}M_{12}}{\Delta M - \frac{4}{3} \Delta \Gamma} \quad , \quad |\varepsilon| = \frac{\text{Im}M_{12}}{2\sqrt{2} m_K \Delta m_{LS}} = 2.26(2) \cdot 10^{-3} \]  

where the last number is experimental. Approximate equality \( \Delta m_{LS} \approx \Gamma_S/2 \) was used to calculate \( |\varepsilon| \). From (3) and (11) we get:

\[ \text{Im}M_{12} = \frac{G_F^2 f_K^2 m_K^2 \eta_{cc} s_{12}s_{13}s_{23} \sin \delta \{ m_c^2 \ln \left( \frac{m_c^2}{m_t^2} \right) - 1 \} + m_t^2 s_{23}^2}{3\pi^2} \]  

It is evident from the last expression that t-quark contribution determines the value of \( \varepsilon \). The estimate of the value of CP-violating phase \( \delta \) we get substituting in (20) \( m_t = 180 \text{ GeV} \): \( \sin \delta \approx 0.7 \).
Direct CP-violation in $K^0$ decays takes place in a standard model due to CKM phase entering $\bar{s}d\gamma$, $\bar{s}dZ$ and $\bar{s}d\gamma$ vertices which appear in one loop with $W$-boson exchange. Calculation of parameter $\varepsilon'$ which describes direct CP violation involves $t$-quark loop as well and is very sensitive to the $m_t$ value. However the value of $\varepsilon'$ is sensitive to the values of hadronic matrix elements and theoretical prediction has poor precision. For $m_t \sim 100 \div 200$ GeV $\varepsilon'/\varepsilon \sim 10^{-3} \div 10^{-4}$ is predicted. Experimental situation is controversial as well [6],[7]:

$$ NA31 : \ Re(\varepsilon'/\varepsilon) = (23.0 \pm 6.5) \times 10^{-4} ,$$
$$ E731 : \ Re(\varepsilon'/\varepsilon) = (7.4 \pm 6.0) \times 10^{-4} .$$

Future experiments should clarify this discrepancy but cannot provide test of MSM.

3 $B^0$-mesons

As it was already stated in Introduction large $B^0 - \bar{B}^0$ mixing was the first place where heavy top shows up. The first evidence for substantial $B^0 - \bar{B}^0$ mixing came from UA1 experiment where overproduction of the same sign dileptons was observed. In semileptonic decay of $B^0_d(\bar{b}d)$ or $B^0_s(\bar{b}s)$ meson $l^+$ is produced, while in the decay of $\bar{B}^0_d$ or $\bar{B}^0_s$ $l^-$ should appear. Pairs $\bar{b}b$ are always produced in collisions, so the opposite sign dileptons should appear when $\bar{b}b$ decays. However experimentalists saw the same sign dileptons as well. Conclusive evidence of large $B^0 - \bar{B}^0$ mixing comes form ARGUS experiment where the decays of $(B_d - \bar{B}_d)$ pairs produced in the decays of $\Upsilon(4s)$ resonance were studied.

The following relation takes place for the pairs of leptons produced in $\Upsilon \rightarrow B_d\bar{B}_d \rightarrow llX$ decays:

$$ r = \frac{N(e^+e^-) + N(e^-e^-)}{N(e^+e^-)} = \frac{x^2}{2 + x^2} , \ \ \ x = \frac{\Delta M_{BB}}{\Gamma_B} . \ \ \ (22) $$

Measurement of the ratio $r$ determines the difference of masses of light and heavy mesons. In $\Upsilon(4s)$ decay $B$-mesons are produced practically at rest, and observation of the space picture of the $B - \bar{B}$ oscillation is impossible.
This space picture of oscillations was observed later at LEP in the study of \( Z \to BB \) decays. The present experimental numbers are [5]:

\[
x_d^{exp} = 0.71 \pm 0.06 ,
\]
\[
\Delta m_{BB}^{exp} = m_{BH} - m_{BL} = 3.4(4) \cdot 10^{-13} \text{GeV}.
\]  

The theoretical expression for this difference can be easily obtained from (9):

\[
\Delta m_{BB} = \left| \frac{M_{BB}}{m_B} \right| = \frac{G_F^2}{6\pi^2} f_B^2 m_t^2 m_B I \left( \frac{m_t^2}{m_W^2} \right) | V_{td} |^2 .
\]  

Substituting \( m_B = 5.3 \) GeV, \( m_t = 180 \) GeV and \( f_B = 130 \) MeV [9], and comparing (23) and (24) we get:

\[
| V_{td} | \simeq 0.0095 .
\]  

From the unitarity relation (13) and the numerical values of the mixing matrix elements (12) we get:

\[
0.008 - 0.003 < | V_{td} | < 0.008 + 0.003
\]  

and we see that the value (25) which follows from \( B - \bar{B} \) mixing is in good correspondence with the large value of \( \sin \delta \) which we obtain from the study of \( CP \)-violation in \( K \) decays. However, a careful study of the validity of Kobayashi-Maskawa model of \( CP \)-violation is not possible with the present day experimental accuracy in the measurement of the mixing matrix parameters. Considerable progress in this direction should occur when the study of \( CP \)-violation in \( B \) mesons will be performed. A special lecture at this school was devoted to the subject of \( CP \) violation in \( B \) mesons [9] and we will omit this subject here. \( B_s - \bar{B}_s \) oscillations were observed at LEP as well. Theoretically we have:

\[
\Delta m_{B_s} = \frac{G_F^2}{6\pi^2} f_{B_s}^2 m_t^2 m_B I \left( \frac{m_t^2}{m_W^2} \right) | V_{ts} |^2 = 0.6 \cdot 10^{-11} \text{GeV} ,
\]  

where we assume \( f_{B_s} = f_{B_d} = 130 \) MeV. Taking \( \tau_{B_s} = 1.34 \cdot 10^{-12} \text{sec} \), we obtain:

\[
x_s \simeq 10
\]
We see that $B_s - \bar{B}_s$ mixing should be very large. This is the reason why to measure the theoretically interesting quantity $x_s$ space picture of $B_s - \bar{B}_s$ oscillations should be studied. The present experimental bound is [5]:

$$x_{B_s} > 2.0.$$  \hspace{1cm} (29)

Recently CLEO collaboration has measured an inclusive branching ratio of the $B$-meson decay into a photon and the charmless hadronic system containing $K$ meson [10]:

$$\text{Br}(b \to s \gamma) = (2.32 \pm 0.51 \pm 0.29 \pm 0.32) \cdot 10^{-4}. \hspace{1cm} (30)$$

This decay is described by $b \to (u, c, t) \to s$ weak vertex with photon radiated from the quark or the $W$-boson line. The expression for this amplitude was found in [11]:

$$M = \frac{G_F}{2\sqrt{2} \pi^2} \sum_i V_{tb} V_{ts}^* F_i^2 (x) q_{\mu} \varepsilon_{\nu} \bar{s} \sigma_{\mu\nu} \frac{1 - \gamma_5}{2} b m_b,$$

$$F_i^2 (x) = Q_i \left\{ \left[ -\frac{1}{4} x - \frac{1}{2} \right] + \frac{3}{4 (x - 1)^2} + \frac{3}{2} \left[ \frac{1}{2} (x - 1) \right] \right\} x -$$

$$\frac{3}{2} \frac{x^2}{(x - 1)^4} \ln x \right\} - x \left[ \frac{1}{2} \frac{1}{x - 1} + \frac{9}{4 (x - 1)^2} + \frac{3}{2} \left[ \frac{1}{2} (x - 1)^3 \right] \right] +$$

$$+ \frac{3 x^3}{2 (x - 1)^4} \ln x, \hspace{0.5cm} Q_i = \frac{2}{3}, \hspace{0.5cm} x = \frac{m_t^2}{m_W^2},$$

where $q_{\mu}$ and $\varepsilon_{\nu}$ are the photon momentum and polarization vector, $\sigma_{\mu\nu}$ is the usual combination of Dirac matrices, $F(0) = 0$, $F(4) = -0.37$, $F(\infty) = -2/3$. From (31) we obtain:

$$\Gamma_b \to s \gamma = \frac{\alpha G_F^2 m_b^5}{32 \pi^4} \left| V_{ts} V_{tb}^* F_2^t \right|^2.$$  \hspace{1cm} (32)

With the help of formula for the $b \to c e \nu$ decay probability:

$$\Gamma_b \to c e \nu = \frac{G_F^2 m_b^5}{192 \pi^3} \left[ 1 - 8 \frac{m_c^2}{m_b^2} \right] \left| V_{cb} \right|^2$$  \hspace{1cm} (33)

we obtain:

$$\text{Br}(b \to s \gamma) = \frac{\Gamma(b \to s \gamma)}{\Gamma(b \to c e \nu)} \text{Br}(b \to c e \nu) = \frac{6}{\pi} \frac{\alpha}{1 - 8 (m_c/m_b)^2} \cdot 10\% \simeq 4.6 \cdot 10^{-4},$$  \hspace{1cm} (34)
which qualitatively agree with experimental number. Gluon corrections to
the amplitude were considered in a number of papers. They appeared
to be large and poorly known.

4 Top and precision electroweak measurements

Measurements of the $W$- and the $Z$-boson masses and the $Z$-boson decay pa-
rameters were made with the unprecedented for the high energy physics accu-
raty at CERN, FNAL and SLAC. While in the $K$- and the $B$-mesons physics
the experimental accuracy varies between 1% and 10% and the theoretical
accuracy is of the order of 1%, in the $W$ and the $Z$ physics the experimental accuracy is close to 0.2%, while the theoretical one varies between 0.1% and
0.01%. Before such accuracy was typical for QED and it is not clear if it
can be reached in the future investigations in HEP. This level of experimental
and theoretical accuracy makes it possible to measure radiative corrections
to the corresponding amplitudes and especially enhanced terms in it. As it is
well known there are enhanced terms proportional to $m_t^2$ and comparing the
theoretical expressions with the experimental results the following prediction
for $t$-quark mass was obtained [13]:

$$ m_t = 179 \pm 9^{+17}_{-15} \text{GeV}, $$

(35)

where the first uncertainty is experimental while the second is due to un-
known value of the Higgs boson mass and corresponds to the variation of
$m_H$ between 60 GeV and 1 TeV. Radiative corrections are proportional to
$m_t^2 - \ln \frac{m_H^2}{m_Z^2}$.

I will not discuss here in detail how these bounds on $m_{top}$ were obtained
as this question was widely discussed in literature (see for example lectures
in proceedings of the previous ITEP Winter School [14]). Let me only stress
that the conservation of gauge currents in QFD (quantum flavorodynamics)
does not lead to decoupling of heavy degrees of freedom unlike the case of
QED. In QED photon polarization operator looks like:

$$ \Pi_{\gamma}^{\gamma}(q^2) = P^\gamma[q^2 g_{\mu\nu} - q_\mu q_\nu], $$

(36)

where the function $P(q^2)$ is regular at $q^2 = 0$. In QFD we have:

$$ \Pi_{\mu\nu}^{Z,W}(q^2) = P^{Z,W}(q^2)[g_{\mu\nu}q^2 - q_\mu q_\nu], $$

(37)
where the functions $P^Z,W(q^2)$ had a pole at $q^2 = 0$ which is created by the goldstone modes admixture to the $Z$- and the $W$-bosons.

So, $P^Z,W(q^2) \sim m_t^2/q^2$ and corrections proportional to $m_t^2$ come out. This phenomenon can be easily recognized in t’Hooft-Landau gauge where the propagators of fictious Higgs degrees of freedom have the pole at $q^2 = 0$.

5 Production and decay of $t$-quark

Top quark was discovered at FNAL $p\bar{p}$-collider. Top was produced in pair with its antiparticle in quark-antiquark annihilation via the intermediate gluon or in gluon-gluon fusion. Experimentally the measured production cross-section appeared to be larger than theoretically predicted. Being produced top rapidly decays to $b$-quark and $W$-boson which, in turn, decays to two quark jets or $(l\nu)$ pair. Present accuracy in measurement of top mass is $\pm 12$ GeV (see eq. (1), (2)). Planned accuracy in the future LHC experiments is $\pm 3$ GeV while at Next Linear $e^+e^-$ Collider accuracy up to $\pm 1$ GeV can be achieved. The final accuracy in the value of $m_t$ extracted from $Z$-boson decay parameters measured at LEP should reduce to $\pm 5$ GeV. Comparing this extracted $m_t$ value with the result of direct measurement one would be able to determine the Higgs boson mass with the accuracy better than 100 GeV. Direct measurement of the Higgs boson mass would provide test of the validity of the minimal standard model.

Our last topic is top quark decay. For the amplitude of $t \to bW$ decay we have:

$$M_W = \frac{g}{\sqrt{2}} b\gamma_\alpha \frac{1 + \gamma_5}{2} tW_\alpha .$$

(38)

Calculating the decay width with the help of $W$-boson density matrix

$$\rho_{\alpha\beta} = g\gamma_\alpha = -\left(g_{\alpha\beta} - \frac{g_{\alpha q4}}{m_W^2}\right)$$

we obtain:

$$\Gamma = \frac{g^2}{64\pi} \frac{m_t^3}{m_W^2} \left(1 - 3\frac{m_W^4}{m_t^4} + 2\frac{m_W^6}{m_t^6}\right) .$$

(39)

Singularity of the decay width at small $m_W$ is fictious. To study the small $m_W$ limit one should substitute in (39) expressions for top and $W$ masses through Higgs expectation value: $m_t = h\eta/\sqrt{2}$, $m_W = g\eta/2$. Then for
leading at $m_W \to 0$ term we obtain a regular expression:

$$
\Gamma \simeq \frac{g^2}{64\pi} \left( \frac{\sqrt{2}h}{g} \right)^2 m_t = \frac{h^2}{32\pi} m_t = \frac{1}{16\pi m_t} \frac{h^2 m_t^2}{2}.
$$

(40)

One more way to get leading in the limit $m_t \gg m_W$ expression (40) exists. Production of the longitudinal component of the $W^+$-boson dominates in high energy limit. This longitudinal component is made from $H^+$. Matrix element for $H^+$ radiation is:

$$
M_H = \bar{h} b_L H R^+ ;
$$

(41)

taking square we get:

$$
|M_H|^2 = h_t^2 \frac{1}{2} S \hat{p}_2 \frac{1 - \gamma_5 \hat{p}_1}{2} \frac{1 + \gamma_5}{2} = h_t^2 (p_1 p_2) = \frac{h_t^2 m_t^2}{2}.
$$

(42)

Expression (40) follows from (42) straightforwardly. Substituting in (39) $m_t = 180$ GeV we obtain:

$$
\Gamma_t = 1.7 \text{GeV}.
$$

(43)

Lifetime of $t$-quark is considerably shorter than the characteristic hadronic time $\sim 1/100$ MeV. It means that top decays before top containing hadron forms, so unlike the cases with $c$- and $b$-quarks no top containing hadrons will be discovered in future.

### 6 Conclusions

We demonstrate that in $K$-meson physics the value of $m_{t_{top}}$ determine parameter $\varepsilon$ but is inessential for $\Delta m_{LHS}$. The heavy top leads to the large $B - \bar{B}$ mixing. Precise measurements of the intermediate weak boson properties lead to the accurate prediction of $t$-quark mass which was confirmed by measuring mass of $t$-quark produced in $p\bar{p}$ collisions. Measurement of $m_t$ with several GeV accuracy will provide us with an estimate of Higgs boson mass.

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References

[1] CDF collaboration, F.Abe et al., Phys.Rev.Lett. 74 (1995) 2626; DO collaboration, S.Abachi et al., Phys.Rev.Lett. 74 (1995) 2632.

[2] UA1 collaboration, C.Albajar et al., Phys.Lett. 186B (1987) 247; ARGUS collaboration, H.Albrecht et al., Phys.Lett. 197B (1987) 452.

[3] M.G.Gronau, Nucl.Phys.B (Proc.Suppl.) 38 (1995) 136.

[4] M.I.Vysotsky, preprint ITEP-121 (1979); Yad.Fiz. 31 (1979) 1535.

[5] Review of Particle Properties, Phys.Rev. D50 (1994) 1173.

[6] CERN NA31 Collaboration, G.D.Barr et al., Phys.Lett. B317 (1993) 233.

[7] Fermilab E731 Collaboration, L.K.Gibbons et al., Phys.Rev. Lett. 70 (1993) 1203.

[8] T.M.Aliev, V.L.Eletsky, Yad.Fiz. 38 (1983) 1537; V.M.Belyaev et al., Phys.Rev. D51 (1995) 6177.

[9] T.Nakada, these proceedings.

[10] J.Patterson, proceedings of the XXVII International Conference on High Energy Physics, Glasgow, 1994; edited by P.J.Bussey and I.G.Knowles.

[11] T.Inami and C.S.Lim, Prog.Theor.Phys. 65 (1981) 297.

[12] CERN Yellow Report 95-03, 1995.

[13] LEPEWWG/95-01 preprint, March 1995.

[14] Proceedings of the 22 ITEP Winter School, Surveys in High Energy Physics, v.8 N 1-4 (1995).