New Potential of Black Holes : Quest for TeV-Scale Physics by Measuring Top Quark Sector using Black Holes

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Abstract

If TeV-scale gravity models are correct, the production of black holes will be the first signal of new physics. Once black holes are produced, they will give us much information about TeV-scale new physics directly. But such black holes can also be used for the precision measurements of the Standard Model (SM). The SM is nothing but a theory which can describe weak-scale, and TeV-scale physics will affect it. So if some experimental results which cannot be explained in the SM are found, they will be attributed to TeV-scale physics and we can obtain “bottom-up” type information about new physics. In this paper, we consider the precision measurements of the top sector at the LHC by using black holes. The stringent trigger conditions to confirm the black hole production vanish almost all of the QCD background, and we can examine the top quark emitted from black holes very precisely. The error of the top quark mass and the top Yukawa coupling are drastically reduced, leading to a very accurate test of the Higgs mechanism. We can directly measure the CKM matrix element $|V_{ts}|$, and we will understand the property of the CKM matrix and the origin of CP-violation deeply. The very precise measurements of such properties in the SM, enabled by black holes, can become treasures in the quest for TeV-scale physics because there exists a possibility that TeV-scale physics affects them and destroys the predictions of the SM. By combining the direct information of new physics obtained from black holes themselves and the indirect information obtained from the limitations of the SM, we will be able to identify TeV-scale physics correctly.
1 Introduction

The black hole production may be possible in TeV-scale gravity models at the TeV-scale colliders, say at the LHC \cite{1-3}, Tevatron \cite{4}, or linear colliders \cite{5}. High energy cosmic rays may also become the origin of black holes \cite{6}. The properties of such black holes are extensively investigated \cite{7}. Since the black hole production processes are purely gravitational and do not contain any small couplings, their cross sections are very large and will be the first signal of TeV-scale gravity models.

So once black holes are produced, their primary roles are to give the information for the quest of the true TeV-scale physics. The Standard Model (SM) will be recognized as the theory which describes weak-scale physics, that is the low-energy approximation of TeV-scale physics.

But black holes have another potential. That is to test the SM more precisely, and to examine the validity of the SM as the true weak-scale theory.

For example, if black holes are produced, Because of their large masses, their decay products have high energies and there is a possibility that new particles not found yet are produced by them. \cite{8} investigated the prospect of discovering Higgs bosons at the LHC by the decay products of black holes, and concluded that only one day operation is enough to discover Higgs bosons with 5\(\sigma\) significance. \cite{9} claimed that Higgs bosons produced by black holes enable us to measure the spin of them at the LHC in only one month operation. The spin measurement of Higgs bosons at the LHC was considered to be almost impossible, so black holes offer us a new method to measure the SM.

The quest for the true TeV-scale physics and the test of the SM as weak-scale physics using black holes play complementary role for the deeper understanding of many mechanisms and phenomena which are not completely understood yet, for example the origin of mass and CP-violation. If only the SM is responsible for the origin of mass, then the Higgs mechanism should work completely and any TeV-scale physics should not affect it. But there exists a possibility that TeV-scale physics is also responsible for the masses of some particles, and so we should test the SM as precisely as possible to obtain the information of the true TeV-scale
physics.

In this paper we consider the precision measurements of the top quarks produced by the decay of black holes at the LHC, and show that their properties are determined more precisely than usually considered.

The error of the top quark mass is currently $5.1\text{GeV}$ \cite{10}. This is not enough value for the electroweak precision measurements. The masses of top, $W$ and Higgs are closely related in the SM, and thus the error reduction of the top quark mass will lead to the accurate confirmation of the SM as weak-scale physics. All Yukawa coupling constants of fermions are not measured yet, and that of the top quark is expected to be measured at the LHC. This direct measurement will make it clear whether the Higgs mechanism is the origin of mass or other mechanisms should be needed. The measurements of CKM matrix elements are the necessity of the certification of the unitarity and the confirmation of the CKM matrix as the origin of CP-violation. If the unitarity is broken, new physics like the fourth generation fermion is needed. And if the unitarity triangle turned out to be non-closed, other mechanisms should be necessary to explain the observed CP-violating processes.

LHC will measure $|V_{tb}|$ by the decay of many $t\bar{t}$-pairs produced by QCD processes. Single top quarks produced by electroweak processes, whose cross sections are proportional to $|V_{tb}|^2$, can also be used for the measurement.

The utilization of top quarks produced by black holes can reduce drastically the error of the top quark mass and the top Yukawa constant. This reduction lead to a very precise test of the Higgs mechanism. It also enables us to measure $|V_{ts}|$ directly, which will be the precious information to confirm the unitarity of the CKM matrix and to test whether the origin of CP-violation is the CKM matrix only or not. They are all valuable high precision tests of the SM as weak-scale physics.

The reason why black holes are useful for the precision measurements of the top sector is that black holes can emit the single, and high energy ($\geq 1\text{TeV}$) top quark, and the trigger conditions for the black hole production make the QCD background almost be vanished. So we do not have to struggle with the final state radiation, which is the main source of the error of the top quark mass at the LHC.
The measurement of the top Yukawa coupling is released from many background processes. The strange quarks emitted from the processes $t \rightarrow Ws$ are not buried in huge QCD jets, and we can directly measure $|V_{ts}|$ at the LHC.

Of course after the stringent trigger conditions which almost vanish the huge and annoying QCD background, the number of top quarks produced by black holes are much less than the usually considered number of $t\bar{t}$-pairs produced by QCD processes which amounts to 8 million pairs per year in low luminosity run of the LHC. But the advantages from the trigger, namely the very clean environment and the single and high energy top quark, surpass the usual methods. So if TeV-scale gravity models are correct and black holes are produced at the LHC, we should use the top quarks produced by black holes for the deeper understanding of the top sector. This understanding will lead to the stringent test of the SM, and help us to make clear to what extent the SM is valid as the theory which describes the weak-scale physics.

If we find an experimental result which cannot be explained in the SM, it is attributed to TeV-scale physics and we can obtain much information about it. This “bottom-up” method should be used to identify new physics correctly.

This paper is organized as follows. In section 2, we review the theories of TeV-scale gravity and the mechanism of the black hole production and decay. After this preparation, we show the methods of using top quarks produced by black holes for the precision measurements. First, section 3 explains how to reduce the error of the top quark mass. Next, section 4 is devoted to the exposition of the precise measurement of the top Yukawa coupling. Third, section 5 investigates how to directly obtain the value $|V_{ts}|$. We consider the unitarity of the CKM matrix and whether CP-violation is attributed to the CKM matrix only or not. Finally in section 6 we conclude.

2 Black Hole Production and Decay

The possibility of TeV-scale gravity was firstly proposed by [11,12]. They proposed that the world is $(4+n)$-dimensional and extra $n$ dimensions are compactified. The
observed Planck scale $M_{pl}$ is only valid for the four dimensional spacetime, and the true Planck scale of the higher-dimensional spacetime $M_D$ is given by:

$$M_D^{n+2}V_n = M_{pl}^2,$$

where $V_n$ is the compactified volume of the extra dimensions. If we take $V_n$ properly, the true Planck scale can be $\mathcal{O}(\text{TeV})$. So the hierarchy problem which arises from the large difference between $M_{\text{weak}}$ and $M_{pl}$ no longer exists, and $\mathcal{O}(\text{TeV})$ is the true scale of the quantum gravity.

If such TeV-scale gravity models are correct, we can directly access Planckian and transPlanckian region by real experiments. The black hole production at the LHC was firstly pointed out by [1, 2]. It is a very exciting phenomenon, and many papers investigated their properties [3]. Let us denote the mass of a black hole by $M_{BH}$. Then the parton level cross section for the black hole production is semiclassically given by [13]:

$$\sigma (M_{BH}) = \pi R_S^2 = \frac{1}{M_D} \left[ \frac{M_{BH}}{M_D} \left( \frac{8\Gamma \left( \frac{n+3}{2} \right)}{n+2} \right) \right]^{2/(n+1)},$$

where $R_S$ is the $(n+4)$-dimensional Schwarzschild radius. After the convolution of parton distribution function of protons and the integration over $M_{BH}$, we obtain the total cross section.

But here we must be careful about the masses of black holes. If $M_{BH} \sim M_D$ (Planckian black hole), the quantum gravity may drastically affect equation (2). Since nobody knows the true theory of the quantum gravity, we cannot use small value of $\frac{M_{BH}}{M_D}$. [14] showed that when $\frac{M_{BH}}{M_D} \gtrsim 5$, the semiclassical approximation is valid and equation (2) holds. So we take the minimum value of the black hole mass to be $M_{BH}^{\text{min}} = 5M_D$.

Next we have to determine $n$, the number of extra dimensions. A review [15] showed that the cases of $n = 2, 3$ are already excluded as the candidates of TeV-scale gravity. and if we take $n = 4$, $M_D \gtrsim 2.3\text{TeV}$. Thus the energy of the LHC $\sqrt{s} = 14\text{TeV}$ is the edge of the constraint $M_{BH} \gtrsim 5M_D$, and the total cross section becomes very small. In the cases of $n = 5, 6, 7$, roughly $M_D \gtrsim 1\text{TeV}$ [16] and the total cross section becomes large enough. So we assume $n \gtrsim 5$ and $M_D = 1\text{TeV}$.
Now we can calculate the total cross section. It becomes \[17\]:

\[
\sigma = 10^6 \text{ fb}.
\] (3)

Since the total cross section is suppressed exponentially as we raise the masses of black holes, the main contribution for equation (3) comes from the black holes with masses \(M_{BH} \sim 5\text{TeV}\).

But, there exists an argument that the production cross section for transPlanckian black holes \((M_{BH} \gg M_D)\) is suppressed by at least a factor \(\exp(-I_E)\) with \(I_E\) being the Gibbons-Hawking action for the black holes [18]. Conservatively we adopt this suppression factor. Then the total cross section is reduced to [17]:

\[
\sigma = 10^4 \text{ fb}.
\] (4)

Produced black holes decay by the Hawking radiation. The decay process is governed by the temperature of black holes:

\[
T_{BH} = \frac{n + 1}{4\pi R_S},
\] (5)

and the spectrum of the black hole decay products is given by averaging the Planck formula. By applying the Boltzmann statistics, the mean energy carried by one emitted particle becomes:

\[
\langle E \rangle = 2T_{BH}.
\] (6)

Thus the multiplicity \(N\) of the produced black holes becomes:

\[
N = \frac{M_{BH}}{2T_{BH}}.
\] (7)

As you can see from the figure 1(d) of [2], in the case of \(5 \leq n \leq 7\) and \(\frac{M_{BH}}{M_D} = 5\), \(N\) is roughly 4. As stated above, most of the contribution to the total cross section comes from the black holes whose masses are \(M_{BH} \sim 5\text{TeV}\). So approximately we obtain:

\[
N = 4, \quad \text{(8a)}
\]

\[
E = 1.3\text{TeV}, \quad \text{(8b)}
\]
where $E$ is the energy of each particle. Produced one black hole emits four particles whose energies are about 1.3 TeV.

The decay of black holes do not discriminate any of the SM particles. The probability of a certain particle being emitted from a black hole depend on the degree of freedom of the particle. That of the SM is about 120.

We concentrate on the single top quark production. Thus among the four particles emitted from one black hole, one particle must be the top quark and the others should not contain top quarks. So as trigger conditions, we require:

- one jet and one lepton or two jets should exist inside the cone $\Delta R = 1.3$. (They are the decay products of the top quark.)
- Three particles or jets except top should be gluon, quarks except top, electron, muon or photon in order to certify four particles are surely emitted.
- The total electric charge of observed particles $Q$ must satisfy $|Q| \leq \frac{4}{3}$.
- Three particles or jets should have $E_T \gtrsim 100\text{GeV} \sim 1300\text{GeV} \times \sin 4^\circ$.

The degree of freedom of four particles which satisfies these trigger conditions is roughly $1.1 \times 10^6$. Thus the probability that an event satisfies these trigger conditions becomes $0.0051$.

If we impose this trigger, the left QCD background with jets have cross section less than 1 fb. (for a detail, see section 15 and 18 of [19]). So the QCD background is completely negligible.

### 3 Top Quark Mass

The usual top quark mass reconstruction process at the LHC utilizes the $t\bar{t}$ pair production process, whose cross section is about $\sigma(t\bar{t}) \sim 830$ fb. They use the semileptonic decay mode, $t\bar{t} \to l\nu jj\bar{b}\bar{b}$ for the reconstruction. The result of [19] is that in one year low luminosity run $\mathcal{L} = 10$ fb$^{-1}$, the error becomes:

$$\delta m_t \sim 0.1\text{GeV}_{\text{stat}} \oplus 1.7\text{GeV}_{\text{syst}}.$$  \hspace{1cm} (9)

So the systematic error dominates, and it cannot be easily reduced even if the integrated luminosity is accumulated and the detector system is re-calibrated.
The main source of the systematic error is the presence of final state radiation (FSR). The FSR affects the reconstructed top quark mass directly since the reconstructed top quark mass receives the effect of the jets which are radiated and escaped from the cone. It is clearly shown in table 18-3 of [19].

One way to escape from this effect is to increase the cone size. If we increase the cone size to \( \Delta R = 1.3 \), the effects of the FSR are almost vanished. But as a compensation, the underlying events will enter in the expanded cone and the reconstruction process of \( W \) from jet-pair suffer from background QCD multi-jet events. As a result, we can surely reduce the systematic error by increasing the cone size, \( \delta m_{\text{syst}} \sim 1.7 \text{GeV} \) is the lower bound at this time. (see table 18-4 of [19].)

From now we explain the advantage of our method. From section 2, the number of single top quark which are produced by black holes becomes:

\[
10^4 \text{ fb} \times 10^2 \text{ fb}^{-1} \times 0.0051 = 5100. \tag{10}
\]

We use the \( t \to jjb \) and \( t \to l\nu b \) modes both. From the discussion of section 2, the QCD background is almost vanished. So we do not have to worry about the underlying events. Even if we set the large cone size, namely \( \Delta R = 1.3 \), no problem occurs. Thus the systematic error is now dominated by the uncertainty of cell energy scale. In our case it is roughly \( \delta m_t = 0.5 \text{GeV} \). Now the systematic error is considerably reduced.

Next consider about the statistical error. we can calculate it straightforwardly. From [19], the hadronic mode’s statistical error becomes:

\[
0.070 \times \sqrt{\frac{32000}{5100 \times 0.6 \times (6/9)}} = 0.28 \text{GeV}, \tag{11}
\]

where 0.6 is the b-tagging efficiency in low luminosity run, and (6/9) is the branching ratio of the hadronic mode. And the leptonic mode’s statistical error becomes:

\[
0.9 \times \sqrt{\frac{15200 \times 0.85}{5100 \times 0.6 \times (2/9)}} = 3.9 \text{GeV}, \tag{12}
\]

where 0.85 is the ratio which describes the correctness of \( lb \) pairing in the \( tt \) dilepton decay mode, and (2/9) is the branching ratio of the leptonic mode.
So the leptonic mode suffers from the large statistical error, and we do not adopt this mode in the final result. Our final result is that, with the integrated luminosity $10 \text{ fb}^{-1}$ which can be accumulated in one year low luminosity run of the LHC, the error of the top quark mass becomes:

$$\Delta m_t = 0.28 \text{GeV}_{\text{stat}} \oplus 0.5 \text{GeV}_{\text{syst}}. \quad (13)$$

Although the statistical error increases because of the small number of top quarks, the extreme clean environment made from the black hole production and its trigger conditions reduced the systematic error drastically, and leads to the small total error $\Delta m_t = 0.57 \text{GeV}$.

Now we summarize the (expected) error of the top quark mass.

$$\Delta m_t = 3.2 \text{GeV}_{\text{stat}} \oplus 4.0 \text{GeV}_{\text{syst}} = 5.1 \text{GeV} \quad \text{(CDF + D0 combined),} \quad (14a)$$
$$\Delta m_t = 3 \text{GeV} \quad \text{(Run IIa of the Tevatron),} \quad (14b)$$
$$\Delta m_t = 2 \text{GeV} \quad \text{(Run IIb of the Tevatron),} \quad (14c)$$
$$\Delta m_t = 0.1 \text{GeV}_{\text{stat}} \oplus 1.7 \text{GeV}_{\text{syst}} = 1.7 \text{GeV} \quad \text{(the LHC, } 10 \text{ fb}^{-1}), \quad (14d)$$
$$\Delta m_t = 0.28 \text{GeV}_{\text{stat}} \oplus 0.5 \text{GeV}_{\text{syst}} = 0.57 \text{GeV} \quad \text{(the LHC, } 10 \text{ fb}^{-1}, \text{ using black holes),} \quad (14e)$$

where (14a) is the latest result from Tevatron [10] (current error), (14b) and (14c) are the expected errors in the Tevatron Run IIa [20] and Run IIb [21].

As stated in the section [1], the masses of top, $W$ and Higgs are closely related in the SM. It is shown in figure [1]. The LHC can measure the $W$ boson mass with the uncertainty $\Delta m_W = 25 \text{MeV}$ [13]. From the figure [1] we observe that $\Delta m_t = 0.59 \text{GeV}$ is a very satisfactory value in order to determine the Higgs boson mass from this relationship. We should reduce the error of the $W$ boson mass in order to make the prediction for the Higgs boson mass more accurately, and to test the SM more precisely.
4 Top Yukawa Coupling

Every fermions except neutrinos obtain their masses by the Higgs mechanism, and their masses are proportional to their Yukawa couplings. But up to now no Yukawa couplings are directly measured. The direct measurement of the top Yukawa coupling will clarify whether the Higgs mechanism is the true origin of mass or not.

At the LHC, the top Yukawa coupling can be determined by the $t\bar{t}H$ production mode [19]. The analysis of this event require one of the top quark decay leptonically, and another one decay hadronically. They assume the Higgs boson mass $m_h = 120\text{GeV}$, and use the main decay mode $h \rightarrow b\bar{b}$. So the final state contains four $b$-jets, leading to the large combinatorial background. Many of the systematic errors, such as those associated with uncertainties in the integrated luminosity and in the $t\bar{t}$ reconstruction efficiency, could be controlled by comparing the $t\bar{t}H$ rate with the $t\bar{t}$ rate.

Now we consider the usage of the single top quark produced by black holes.
Most of the top quarks decay into $Wb$, but there exists a mode that the top quark emits a Higgs boson, namely $t \to tH$. The branching ratio of this mode becomes:

$$\text{Br}(t \to tH) = 0.046 \frac{y_t^2}{|V_{tb}|^2} \sim 0.046 y_t^2.$$  \hfill (15)

Here we used the fact $|V_{tb}| \sim 1$.

Once a Higgs boson is emitted, it immediately decays. The Higgs boson whose mass is $m_h = 120\text{GeV}$ has the following branching ratios $^{23}$:

$$\text{Br}(h \to bb) \sim 0.66,$$  \hfill (16a)

$$\text{Br}(h \to WW) \sim 0.14,$$  \hfill (16b)

$$\text{Br}(h \to gg) \sim 0.076,$$  \hfill (16c)

$$\text{Br}(h \to \tau\bar{\tau}) \sim 0.074.$$  \hfill (16d)

For the reconstruction of Higgs bosons, we use the above modes. The decay products of Higgs bosons have energies well less than those of other three particles (or jets), and from the trigger conditions, the existence of one top quark is assured. And the QCD background is almost vanished after the trigger conditions.

So we do not have to require for $b$-quarks to be $b$-tagged. Gluons immediately hadronize and the reconstruction is straightforward. Hadronic, semileptonic and leptonic decay modes of $WW$ and $\tau\bar{\tau}$ pair can be used for the reconstruction. Including all of the available processes, the reconstruction efficiency for the 120GeV Higgs bosons becomes about 0.9.

So with the integrated luminosity $\mathcal{L} = 30 \text{ fb}^{-1}$, The number of reconstructed Higgs bosons becomes:

$$5100 \times 0.6 \text{ (b-tag efficiency for the top quark reconstruction)} \times (2/9 + 6/9) \text{ (W reconstruction efficiency)} \times 3 \text{ (30 fb factor)} \times 0.046 y_t^2 \times 0.9$$

$$= 340 y_t^2.$$  \hfill (17)

If we assume the integrated luminosity $\mathcal{L} = 100 \text{ fb}^{-1}$, the b-tag efficiency is reduced to 0.5, and the number becomes:

$$940 y_t^2.$$  \hfill (18)
From the obtained data, we can estimate the expected error of the top Yukawa coupling. It is shown in table 1. The extreme clean environment enable us to reduce the error drastically. From section 3 we observe that the error of top quarks at 30 fb$^{-1}$ becomes 0.5 GeV, which corresponds to 0.3% error. The measurements of the top quark mass and the top Yukawa coupling with such a high accuracy will surely make it clear whether the Higgs mechanism, the most important and crucial part in the SM, is true or not. If some discrepancies from the prediction of the Higgs mechanism are found, they imply that the SM only cannot explain the origin of mass, and some mechanisms which arise from TeV-scale physics are necessary for the correct understanding of nature of mass.

| integrated luminosity | 30 fb$^{-1}$ | 100 fb$^{-1}$ |
|------------------------|-------------|--------------|
| without black holes    | 16.2%       | 14.4%        |
| with black holes       | 2.7%        | 1.6%         |

Table 1: The expected statistical error of the top Yukawa coupling at the LHC.

5 **CKM matrix element** $|V_{ts}|$

The measurements of the CKM matrix elements will clarify the origin of the observed CP violation, and they will also make it clear whether the unitarity of the CKM matrix holds or not. The high statistics of LHC $t\bar{t}$-pairs (8 million pairs per year in low luminosity run) can measure $|V_{tb}|$ by the decay $t \rightarrow Wb$ with the accuracy 0.2% (statistical error only) \[19\].

Since in our setup the number of top quarks is much less than 8 million, we cannot compete with this precision. But in our case the QCD background is almost vanished, we can measure the other CKM matrix elements like $|V_{ts}|$. Here we concentrate on the measurement of $|V_{ts}|$.

From the fact $|V_{td}| \ll |V_{ts}| \ll |V_{tb}|$, the branching ratio of $t \rightarrow Ws$ is simply given by:

$$\text{Br}(t \rightarrow Ws) = \frac{|V_{ts}|^2}{|V_{tb}|^2} \sim |V_{ts}|^2.$$ (19)
Here we used $|V_{tb}| \sim 1$.

The strange quarks emitted from top quarks form mesons like $K^\pm$ or $K^0$. Their mean decay lengths are measured to be [24]:

\begin{align}
K^\pm &: 3.713 \text{ m,} \\
K^0_S &: 2.6786 \text{ cm,} \\
K^0_L &: 15.51 \text{ m.}
\end{align}

Thus $K^0_S$ decay inside the inner detector. But $K^\pm$ and $K^0_L$ penetrate it and detected at the electromagnetic calorimeter (if the formed K meson is charged) and the hadronic calorimeter.

Bottom mesons decay inside the inner detector. So in this clean environment, we can distinguish $t \rightarrow Wb$ and $t \rightarrow Ws$ if $W$ decays leptonically and $K^0_S$ is not formed, by examining the number of layers which detected some events in the inner detector. Thus the reconstruction efficiency of $t \rightarrow Ws$ mode becomes:

$$\sim 2/9 \times 0.75 = 0.17.$$  

(21)

And so the number of events $t \rightarrow Ws$ with the integrated luminosity $\mathcal{L} = 10 \text{ fb}^{-1}$ is given by:

$$5100 \times |V_{ts}|^2 \times 0.17 = 870|V_{ts}|^2.$$  

(22)

The current value of $|V_{ts}|$ is, at the 90% confidence level [24]:

$$0.037 \leq |V_{ts}| \leq 0.043.$$  

(23)

If we substitute $|V_{ts}| = 0.04$ into (22), only 1.4 events are expected. This is not at all enough value to determine $|V_{ts}|$ or its error. So let us assume the integrated luminosity $\mathcal{L} = 300 \text{ fb}^{-1}$. Then 42 events are expected and we can directly determine $|V_{ts}|$ (note that the current value is the bound obtained from the other information) and the error of $|V_{ts}|$.

The integrated luminosity $\mathcal{L} = 300 \text{ fb}^{-1}$ enables us to measure $|V_{ts}|$ with the accuracy:

$$8.3\% \text{ (in the case } |V_{ts}| = 0.037) \sim 7.1\% \text{ (in the case } |V_{ts}| = 0.043).$$  

(24)
This result will greatly help us to determine whether the unitarity of the CKM matrix is correct or not, CP-violating processes are correctly described by the CKM matrix or not, and so on.

The unitarity can easily be checked by examining whether the following equation holds or not:

\[ |V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2 = 1. \]  
\( (25) \)

\( |V_{tb}| \) can be measured at the LHC with very large \( t\bar{t} \) samples and its error is expected to be very small. And the value of \( |V_{td}| \) is negligibly small. So the direct measurement of \( |V_{ts}| \) will enable us to verify whether equation \( (25) \), namely the unitarity condition, is correct or not.

Next consider about CP-violation. If the unitarity triangle (see figure 2) is not closed, CP-violation cannot be explained by the CKM matrix only. When we use the Wolfenstein approximation of the triangle \( [25] \), the CKM matrix is parameterized by \( A, \rho, \) and \( \eta \). And we have the relationship:

\[ \frac{|V_{td}|^2}{|V_{ts}|^2} = (1 - \rho)^2 + \eta^2. \]  
\( (26) \)

Usually we can use this relationship by the observables \( \Delta M_{B_d} \) and \( \Delta M_{B_s} \), since \( |V_{td}| \) and \( |V_{ts}| \) are not directly measured yet. Furthermore, currently only a lower bound on \( \Delta M_{B_s} \) is measured. So the current constraint which depends on this relationship can only set an upper bound.

But assume that we have directly measured \( |V_{ts}| \) at the LHC by using black holes. Then equation \( (26) \) becomes:

\[ (1 - \rho)^2 + \eta^2 = \frac{1 - |V_{tb}|^2 - |V_{ts}|^2}{|V_{ts}|^2}. \]  
\( (27) \)

Here we assumed the unitarity condition. Now we can constrain the unitarity triangle by the experimentally obtained data only, which cannot be possible when we use the ratio of \( \Delta M_{B_d} \) to \( \Delta M_{B_s} \). This is because they contain some parameters which describes the hadronization possibilities and such parameters cannot be experimentally accessible. And furthermore, we can also set a lower bound on the radius of the circle.
Finally consider about the rare decay mode $b \rightarrow s\gamma$. Its inclusive decay width is given by [30]:

$$\Gamma(b \rightarrow s\gamma) = \frac{G_F^2 m_b^5}{32\pi^4} |C_7|^2 |V_{tb}V_{ts}^*|^2.$$

The current theoretical prediction of the branching ratio $\text{Br}(b \rightarrow s\gamma)$ in the SM is $(3.73\pm0.30) \times 10^{-4}$ [31], and the current experimental average is $(3.23\pm0.42) \times 10^{-4}$ [30]. So the error reduction of $|V_{ts}|$ will also reduce the theoretical error of $\text{Br}(b \rightarrow s\gamma)$, and we may observe whether the $b \rightarrow s\gamma$ process can be explained by the SM only, or some mechanisms arise from new physics are needed.

**6 Conclusion**

In this paper, we consider the possibility of measuring the top sector in the SM more precisely at the LHC, by using black holes which will be produced if TeV-scale gravity models are correct. From the stringent trigger conditions to confirm black holes are certainly produced, the huge QCD background which obstruct the
precision measurements is almost vanished. From the single top quark which is produced by the decay of black holes, we can measure its mass, Yukawa coupling and the CKM matrix element $|V_{ts}|$ precisely.

The error of the top quark mass is reduced from 1.7GeV to 0.56GeV, because the systematic error originated from the final state radiation can be evaded by the extreme clean environment. The error of the top Yukawa coupling is also reduced about a factor $6 \sim 9$. The mass and the Yukawa coupling of the top quark are the crucial information for the clarification of the origin of mass. The SM relies on the Higgs mechanism, but this is not examined yet by the real experiment. By using black holes, we can test the Higgs mechanism with a very high accuracy.

The CKM matrix element $|V_{tb}|$ can be measured at the LHC by using many $t\bar{t}$-pairs produced by QCD processes. In our case, the extreme clean environment makes it possible to measure $|V_{ts}|$ directly. This data is very important to test whether the origin of CP-violation is attributed to the CKM matrix only or not, and to validate the unitarity of the CKM matrix.

When we find an experimental result which is inconsistent with the mechanism in the SM, it implies that some new mechanisms arise from TeV-scale physics should be responsible for the result. The masses of fermions, some CP-violating processes or the fourth generation for example, may be attributed to TeV-scale physics. So the precision measurements of the SM is deeply connected to the quest for new physics which governs TeV-scale.

To summarize, once black holes are produced at the LHC, we will recognize the end of the SM as the theory which can describe TeV-scale and the search for the true TeV-scale physics becomes the problem of the utmost importance. But on the other hand, black holes can also be used to test to what extent the SM is correct. The search for the new physics and the precision measurements of the SM using black holes will play complementary roles for the deep understandings of many mechanisms and phenomena not uncovered yet.

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