New physics effects to V_{tb} measurement in single top production at LHC

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Outline

1. Introduction: is $V_{tb} \neq 1$ still possible?
2. Theoretical sensibility of $V_{tb} \neq 1$: vector-like quark and fourth-generation models
3. Future prospects: V_{tb} measurement in single top production

CKM matrix and flavour physics

❑ Flavour Symmetry: One of the major outstanding problems of SM. Flavour symmetry may play a crucial role to establish the physics beyond SM.

❑ CKM matrix: Fundamental parameter in SM. *Only* possible source of the flavour violating phenomena in SM

$$J^+_\mu = \bar{u}_L \gamma_\mu d_L \overset{\text{mass eigenstates}}{\Longrightarrow} J^+_\mu = \bar{U}_L \gamma_\mu \mathbf{V}_{\text{CKM}} D_L$$

❑ Direct measurements from *tree-dominant* processes:

$$|\mathbf{V}_{\text{CKM}}| = \begin{pmatrix} 0.9738 \pm 0.0005 & 0.2200 \pm 0.0026 & (3.67 \pm 0.47) \times 10^{-3} \\ 0.224 \pm 0.012 & 0.996 \pm 0.013 & (41.3 \pm 1.5) \times 10^{-3} \\ ? & ? & ? \end{pmatrix}$$

$$\delta_{\text{CKM}} = (71 \pm 16)^\circ .$$

Is $V_{tb} \neq 1$ still possible?

❑ Unitarity condition if CKM is 3×3: The precisely measured CKM elements of 1st and 2nd rows constrain strongly:

$$|V_{td}| \simeq 0.0048 - 0.014, \quad |V_{ts}| \simeq 0.037 - 0.043, \quad |V_{tb}| \simeq 0.9990 - 0.9992$$

$$\mathcal{O}(\lambda^3) \qquad\qquad \mathcal{O}(\lambda^2) \qquad\qquad \mathcal{O}(1)$$

where $\lambda \simeq 0.22$. $\longrightarrow$ but true only for 3 generations.

❑ $B_s - \bar{B}_s$ oscillation: The latest measurement

$$\Delta M_s = 17.33^{+0.42}_{-0.21}(\text{stat.}) \pm 0.07(\text{syst.})\text{ps}^{-1} \quad \text{CDF collab.}$$

reveals a good agreement with SM prediction

$$0.20 < |V_{td}/V_{ts}| < 0.22.$$

$\longrightarrow$ but true only if box diagram is new physics free.

Is $V_{tb} \neq 1$ still possible? contd.

❑ Top quark branching ratio: R measurement in $t\bar{t}$ production at Tevatron shows a large hierarchy between V_{tb} and (V_{ts}, V_{td}):

$$R = \frac{V_{tb}^2}{V_{td}^2 + V_{ts}^2 + V_{tb}^2} > 0.61 \qquad 95\ \%\ \text{C.L.}$$

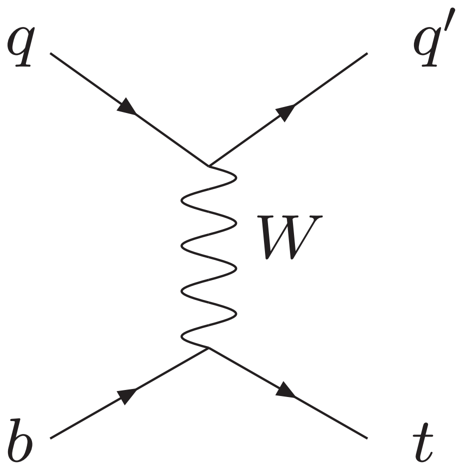
$$1.12^{+0.21}_{-0.19}(\text{stat})^{+0.17}_{-0.13}(\text{syst}),\ \text{CDF}, \qquad 1.03^{+0.19}_{-0.17}\ (\text{stat}+\text{syst}),\ \text{DØ}$$

$\longrightarrow$ but this indicates only small $|V_{ts}|/|V_{tb}|$ and $|V_{td}|/|V_{tb}|$ and the absolute size of V_{tb} is not constrained *at all*.

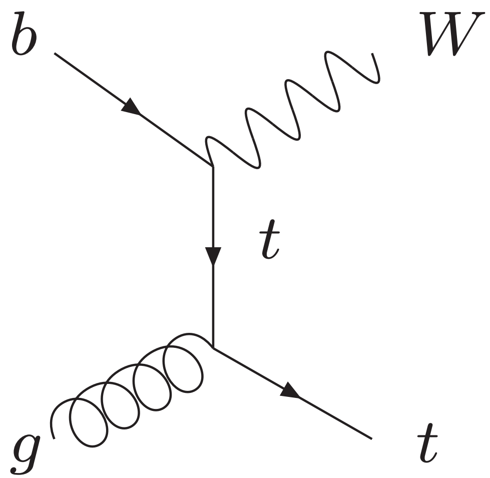
Thus, the answer is:

Yes, $|V_{tb}|$ is not constrained at all by R. And a measurement of $|V_{tb}| \neq 1$ means a discovery of new physics!

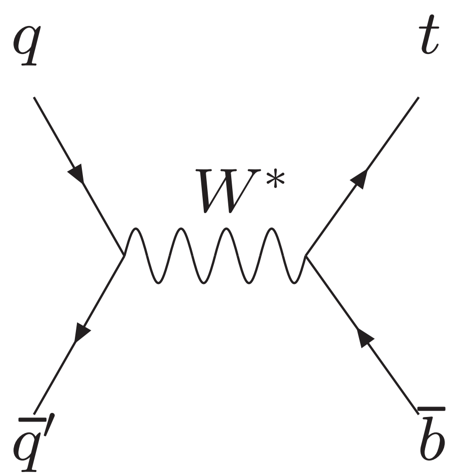
V_{tb} measurement in single top production



t-channel (245 pb)



W-associated (60 pb)



s-channel (10 pb)

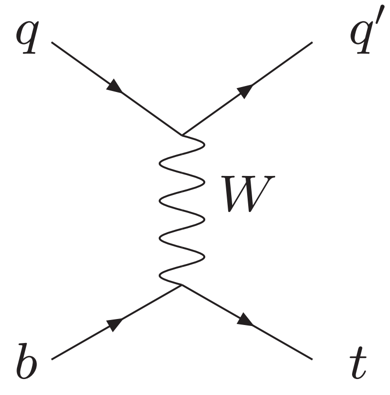
Each channel has very characteristic signals (Reduction of $t\bar{t}$ background is crucial).

Expected to measure V_{tb} at 5 % precision *if* $V_{tb} \simeq 1$.

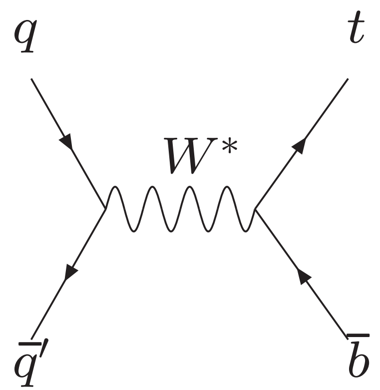
What if $V_{tb} \neq 1$ and $V_{td,ts}$ are not negligible?

Inclusion of s, d quark contributions to t- and s-channel:

$$\sigma(pp \to tX) = |V_{td}|^2 \sigma_d + |V_{ts}|^2 \sigma_s + |V_{tb}|^2 \sigma_b$$
$$\sigma(pp \to tX) = (|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2) \sigma^{\text{s-channel}}$$



(*d* and *s*?)

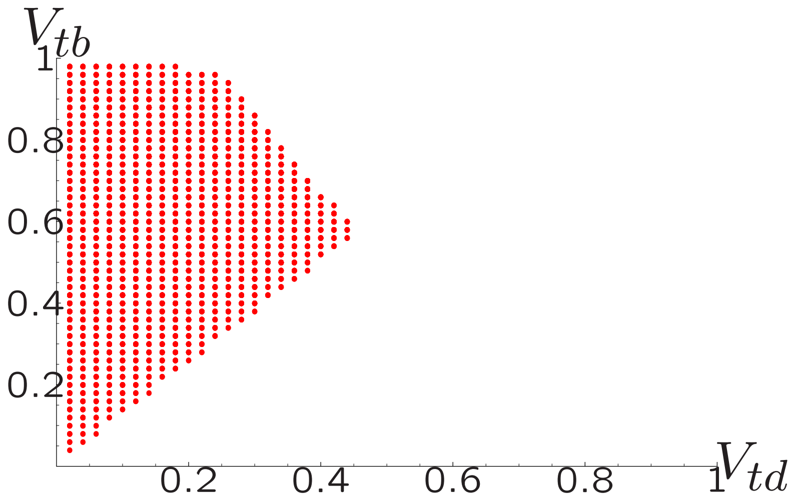


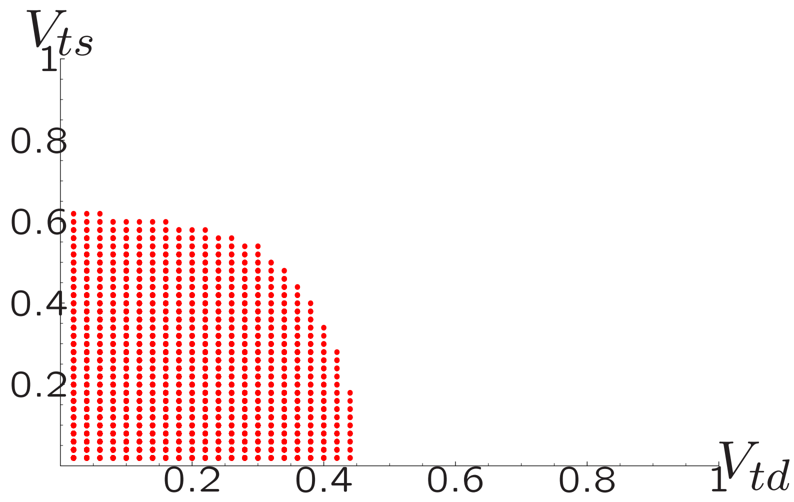
For instance, d quark contributions may overwhelm the cross section of the t-channel.

Using the result of single top search at CDF:

$$\sigma^{\text{t-channel}} < 3.2\text{pb}; \qquad \sigma^{\text{s-channel}} < 3.1\text{pb}$$

together with R constraints, we still find very large allowed range as





Theoretical sensibility of $V_{tb} \neq 1$

- Breaking of 3×3 unitarity: $\longrightarrow$ requires extra heavy fermion
  1) vector-like quark (b' or t'): 3×4 or 4×3 CKM matrix
  2) fourth generation (b' and t'): 4×4 CKM matrix

What I will discuss in the following is:

> The V_{tb} constraint from various phenomenology within these very simple extensions of SM.

Vector-like quark model

❏ Singlet quarks:

$$(u_i, d_i)_L \quad u_{iR} \quad d_{iR} \quad \text{plus} \quad t'_L \quad t'_R \quad \text{or} \ b'_L \quad b'_R$$

❏ Well-known phenomena of vector-like quarks:

Tree-level flavour changing neutral current (FCNC) can potentially exist and furthermore, its coupling can be written in terms of CKM matrix.

$$J^0_\mu \supset -\frac{g}{2\cos\theta_w}(\bar{u}_{iL}\mathbf{V}\mathbf{V}^\dagger\gamma_\mu u_{iL} + \bar{d}_{iL}\mathbf{V}^\dagger\mathbf{V}\gamma_\mu d_{iL})$$

$$J^+_\mu \supset -\frac{g}{\sqrt{2}}(\bar{u}_{iL}\mathbf{V}\gamma_\mu d_{iL} + h.c.)$$

FCNC constraints e.g. from hadronic Z decays $\longrightarrow$ Constraint on CKM matrix

Vector-like quark model contd.

3×4 and 4×3 matrices contain three extra mixing angles.

❏ FCNC constraints: $\Gamma(Z \to (u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}, b\bar{b}))$ are saturated by SM. Thus,

1) Down-type FCNC must be totally suppressed. $\longrightarrow$ an extension to $\mathbf{V}_{3\times 4}$ does not modify V_{tb}.
2) Up-type FCNC must be suppressed *apart from* $t-t'$ *mixing*.

❏As a result:

$$\mathbf{V}_{4\times 3} = \begin{pmatrix} \mathbf{1}_{2\times 2} & 0 \\ 0 & \mathbf{U}^{\dagger}_{2\times 2} \end{pmatrix} \begin{pmatrix} \mathbf{V}^{(\mathrm{CKM})}_{3\times 3} \\ 0 \end{pmatrix} ; \mathbf{U} = R_{34}(\theta) = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}.$$

which leads to

$$V_{ti} = V^{(\mathrm{CKM})}_{ti} \cos\theta \quad V_{t'i} = V^{(\mathrm{CKM})}_{ti} \sin\theta \qquad i = (d, s, b)$$

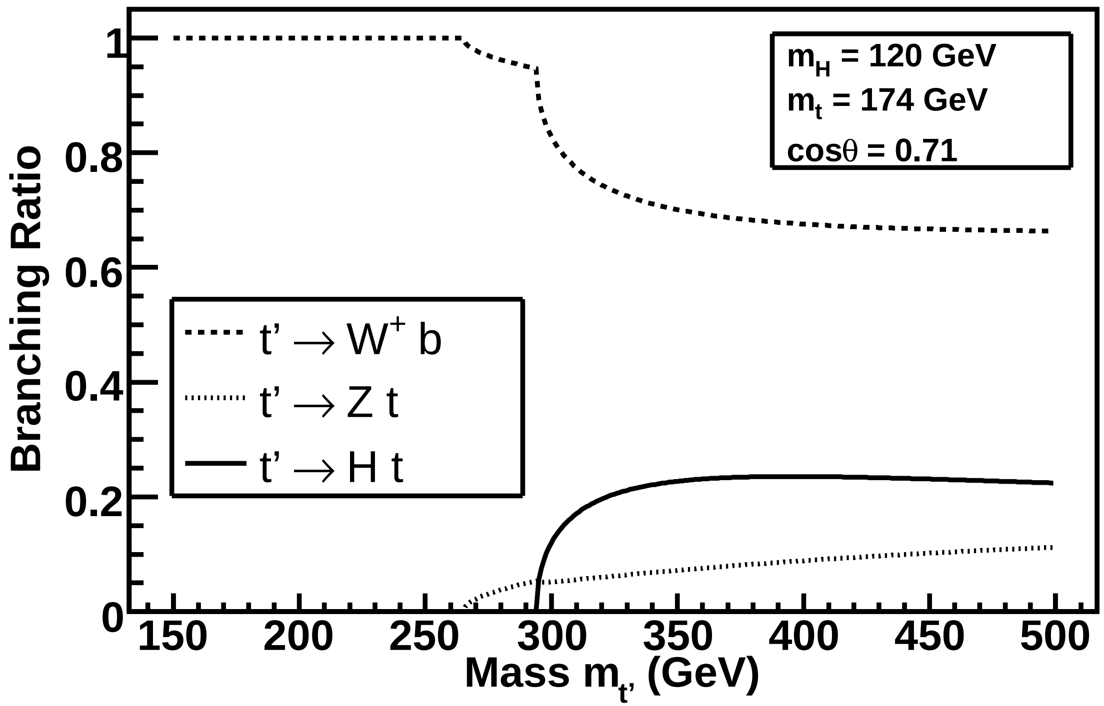
☞ With this kind of *scaling factor*, R is unity and $|V_{td}/V_{ts}|$ is SM.

t' mass constraints

CDF Run II result (760 pb^{-1} data):

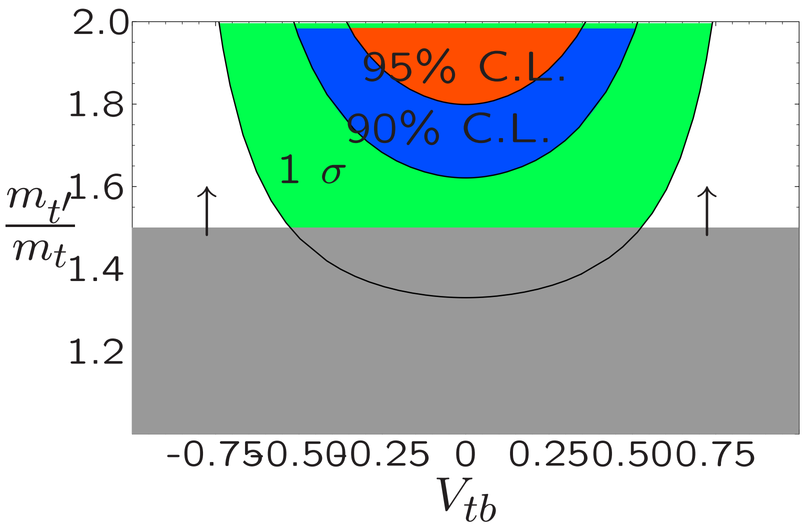
$$m_{t'} > 258\text{GeV} \quad 95\% \text{ C.L.}$$

❑ Remark : This bound is obtained by assuming $\underline{Br(t' \to Wq) \simeq 1}$. In vector-like quark model, t' has relatively large FCNC channels $t' \to Z/Ht$ after 300 GeV.



Constraining V_{tb}: 4×3 matrix case

❑ $B \to X_s \gamma$: The precise current data $Br(B \to X_s\gamma) = (3.55 \pm 0.45) \times 10^{-4}$ does not constrain V_{tb} very strongly.



$|V_{tb}| > 0.53$ at 1σ

❑ EW precision data: T value is approximately obtained as

$$T > 1.1 \sin^2\theta \quad \text{for} \quad m_{t'} > 258\text{GeV}$$

which leads to a very strong constraint, e.g. using maximum value of new (LEP+SLD) data

$$|V_{tb}| > 0.89 \quad \text{for} \quad T = 0.23$$

Fourth-generation model

❑ Doublet quarks:

$$(u_i, d_i)_L \quad u_{iR} \quad d_{iR} \quad \text{plus} \quad (t', b')_L \quad t'_R \quad b'_R$$

❑ More freedom:

1) No FCNC constraints
2) T parameter can be suppressed as long as $m_{t'} \simeq m_{b'}$.

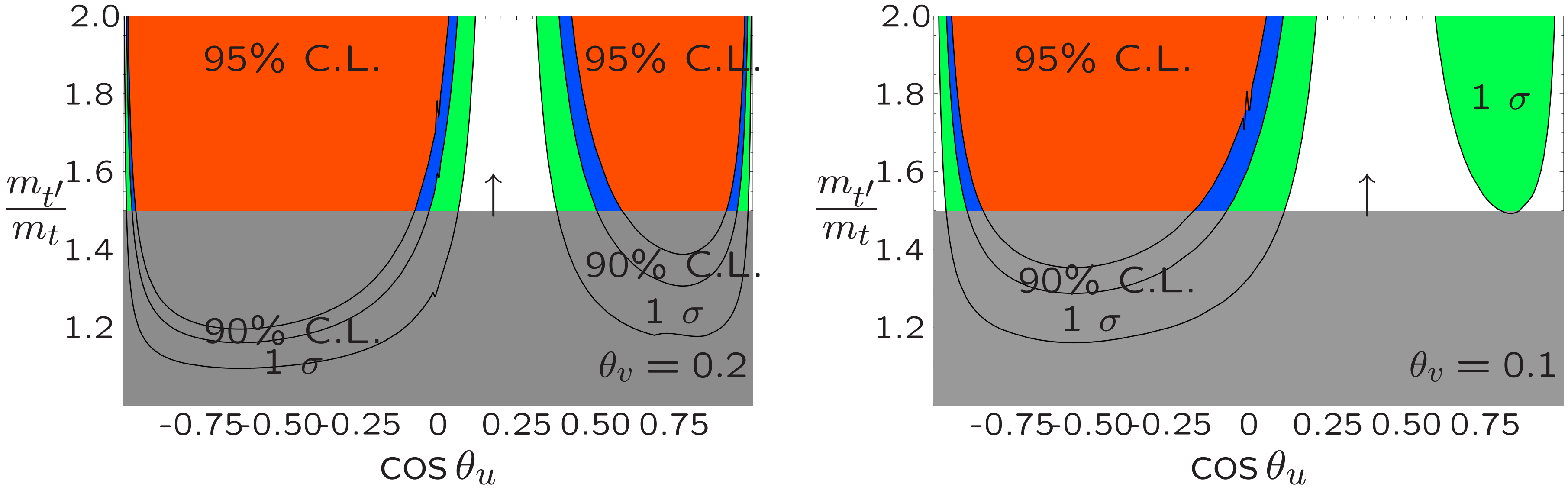
❑ Nevertheless: we have 4×4 unitarity condition

$$\mathbf{V}_{4\times4} = R_{34}(\theta_u) R_{24}(\theta_v) R_{14}(\theta_w) \begin{pmatrix} \mathbf{V}^{\text{CKM}}_{\mathbf{3\times3}} & \mathbf{0}_{3\times1} \\ \mathbf{0}_{1\times3} & 1 \end{pmatrix}$$

1)θ_w is nearly zero due to the precise measurements of V_{ui}.
2)θ_v is allowed only up to around 0.2
3)θ_u is free.

Constraining V_{tb}: 4×4 matrix case

- $B \to X_s\gamma$: The current data $Br(B \to X_s\gamma) = (3.55 \pm 0.45) \times 10^{-4}$ provides a strong constraint.



If we assume $\theta_u > \pi/4$, $B \to X_s\gamma$ gives a constraint of $\theta_v < 0.1$, which leads to minimum V_{tb} and maximum V_{ts}, V_{td} as

$$|V_{tb}| > 0.7 \quad |V_{ts}| < 0.1 \quad |V_{td}| < 0.02$$

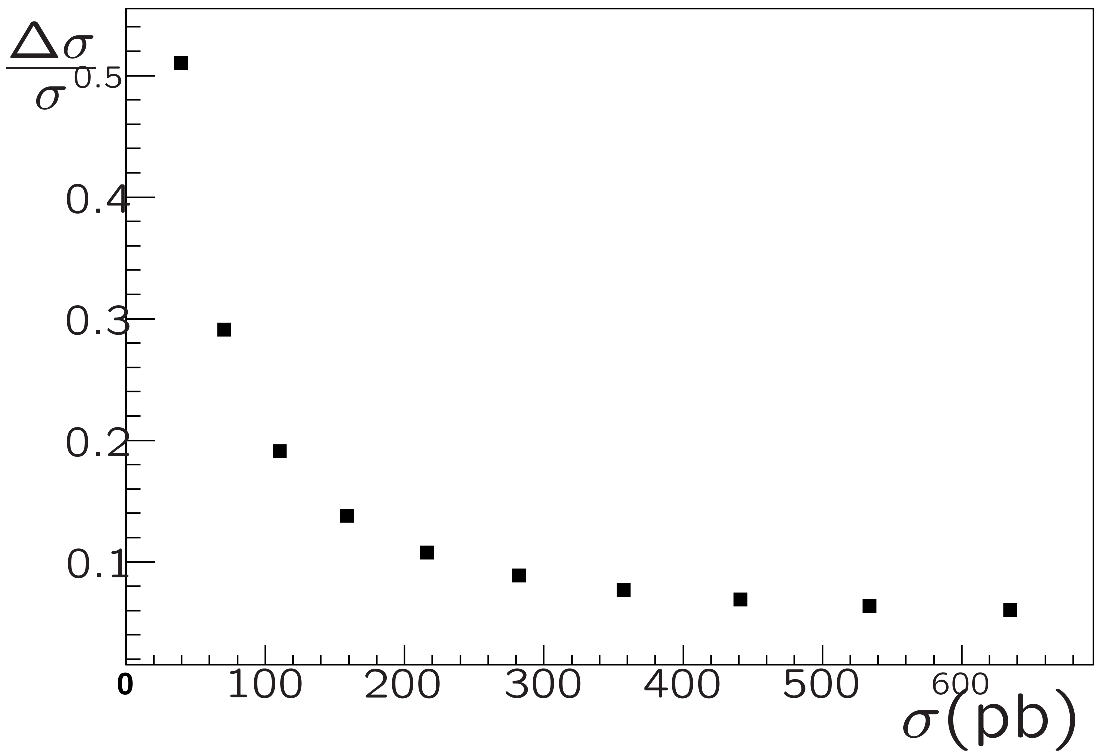
Even for 4×4 V_{ti} is *not* completely free!

Future Prospects

❑ Single top: First, we must discover single top channels!

❑ Measurement of V_{tb}: If $V_{tb} < 1$, then the cross section changes $\longrightarrow$ careful reanalysis of the error estimate in V_{tb} is necessary.

Example of the relative error on the cross section for t-channel (10 fb^{-1}):



Conclusions

- We discussed V_{tb} measurement in single top production at LHC.
- We showed direct measurements still allow $V_{tb} \neq 1$ and it is a signal of new physics.
- We showed
  - ☞ Vector-like model with b' can not modify V_{tb} due to the FCNC constraint.
  - ☞ Vector-like model with t' can modify V_{tb} slightly if T value is positive.
  - ☞ Fourth-generation model can modify not only V_{tb} but also V_{ts} and V_{td} within the constraints from 4×4 unitarity and $B \to X_s\gamma$ branching ratio.
- LHC will be able to measure V_{tb} at the precision of 5% if V_{tb} is around unity, otherwise some re-considerations, such as neglected initial state light quark contributions, must be made.

t' production at LHC

- t' production: both $t'\bar{t'}$ and FCNC channels