B-sector anomalies - the top connection

Pratishruti Saha
Harish-Chandra Research Institute
@
FPCP 2018
Hyderabad, India
14 July, 2018

This talk is ...

based on ongoing work with
David London and Ryoutaro Watanabe.

Introduction

Several measurements related to B-mesons defy Standard Model expectations.

- $R_K \equiv \dfrac{\mathscr{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathscr{B}(B^+ \to K^+ e^+ e^-)}$
- Angular distributions of $B \to K^* \mu^+ \mu^-$
- Branching fractions & angular distributions of $B_s^0 \to \phi \mu^+ \mu^-$
- $R_D \equiv \dfrac{\mathscr{B}(\bar{B} \to D \tau^- \bar{\nu}_\tau)}{\mathscr{B}(\bar{B} \to D \ell^- \bar{\nu}_\ell)}$ $\qquad$ $R_{D^*} \equiv \dfrac{\mathscr{B}(\bar{B} \to D^* \tau^- \bar{\nu}_\tau)}{\mathscr{B}(\bar{B} \to D^* \ell^- \bar{\nu}_\ell)}$

Introduction

Overarching theme :

- Involve 2nd and 3rd generation quarks as well as leptons.
- Indicate non-universal couplings. (Not a feature of the SM !)
- Several require modification of specifically $b \to s\mu^+\mu^-$.
- Fitting the data requires altered couplings for b_L (maybe also b_R).

Introduction

Implications :

- The Standard Model relates b_L to t_L via $SU(2)$ symmetry.
- That is, new physics that couples to b_L must also couple to t_L !!
- *All measurement related to top quarks are in sync with SM predictions.*
- Is this just a coincidence ? Is this a clue ?

Introduction

How are top-sector observables affected by models constructed to explain the B anomalies ?

Can top-sector observables be used to confirm or reject certain models ?

Models

Mainly in these categories :

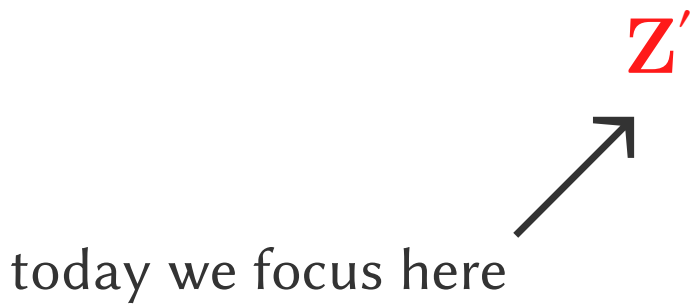
Leptoquarks **extended Higgs**

Z'

Models

Mainly in these categories :

Leptoquarks **extended Higgs**



That which we call a $\mathbf{Z}^{'}$

$\mathbf{Z}^{'}$ models in $b \to s\mu^+\mu^-$

- Broken U(1) symmetry.
- $M_{Z'} \sim$ O(10 MeV) to O(TeV).

That which we call a Z'

Z' models in $b \to s\mu^+\mu^-$

- Broken U(1) symmetry.
- $M_{Z'} \sim$ O(10 MeV) to O(TeV).
- Couplings in the mass basis

Essential

g_{sb} , $g_{\mu\mu}$

Unavoidable

g_{ss} , g_{bb}

Preferably ≈ 0

g_{db} , g_{dd} , g_{ee}

Fixed

g_{tt} , g_{cc} , g_{uu} , g_{uc} , g_{ut} , g_{ct}

That which we call a Z'

Constraints on Z' couplings

- $\frac{g_{sb} g_{\mu\mu}}{M^2_{Z'}}$ $[b \to s\,\mu^+\mu^-]$

  $\frac{g_{sb}}{M_{Z'}}$ $[B^0_s - \bar{B}^0_s \text{ mixing}]$

  $\frac{g_{sb}\,(g_{\mu\mu} + g_{\tau\tau})}{M^2_{Z'}}$ $[B \to K^* \nu\bar{\nu}]$

  $\frac{g_{\mu\mu}}{M_{Z'}}$ $[\nu N \to \nu N\,\mu^+\mu^-]$

That which we call a Z'

Constraints on Z' couplings

- $\frac{g_{sb}\, g_{\mu\mu}}{M^2_{Z'}}$ $[b \to s\, \mu^+ \mu^-]$

  $\frac{g_{sb}}{M_{Z'}}$ $[B^0_s - \bar{B}^0_s \text{ mixing}]$

  $\frac{g_{sb}\,(g_{\mu\mu} + g_{\tau\tau})}{M^2_{Z'}}$ $[B \to K^* \nu\bar{\nu}]$

  $\frac{g_{\mu\mu}}{M_{Z'}}$ $[\nu N \to \nu N\, \mu^+ \mu^-]$

- $g_{ss}\,, g_{bb} \sim \mathrm{O}(1)$

That which we call a Z'

Constraints on Z' couplings

- $\frac{g_{sb}\, g_{\mu\mu}}{M^2_{Z'}}$ $[b \to s\, \mu^+ \mu^-]$

  $\frac{g_{sb}}{M_{Z'}}$ $[B^0_s - \bar{B}^0_s \text{ mixing}]$

  $\frac{g_{sb}\,(g_{\mu\mu} + g_{\tau\tau})}{M^2_{Z'}}$ $[B \to K^* \nu\bar{\nu}]$

  $\frac{g_{\mu\mu}}{M_{Z'}}$ $[\nu N \to \nu N\, \mu^+ \mu^-]$

- $g_{ss}\,,\, g_{bb} \sim \mathrm{O}(1)$

- $g_{u_i u_j} \equiv f\left(g_{ss}\,,\, g_{bb}\,,\, g_{sb}\,,\, V_{CKM}\right)$

That which we call a Z'

Constraints on Z' couplings

- $\frac{g_{sb}\, g_{\mu\mu}}{M^2_{Z'}}$ $[b \to s\, \mu^+ \mu^-]$

  $\frac{g_{sb}}{M_{Z'}}$ $[B^0_s - \bar{B}^0_s \text{ mixing}]$

  $\frac{g_{sb}\,(g_{\mu\mu} + g_{\tau\tau})}{M^2_{Z'}}$ $[B \to K^* \nu\bar{\nu}]$

  $\frac{g_{\mu\mu}}{M_{Z'}}$ $[\nu N \to \nu N\, \mu^+ \mu^-]$

- $g_{ss}\,, g_{bb} \sim \mathrm{O}(1)$

- $g_{u_i u_j} \equiv f\left(g_{ss}\,, g_{bb}\,, g_{sb}\,, V_{CKM}\right)$

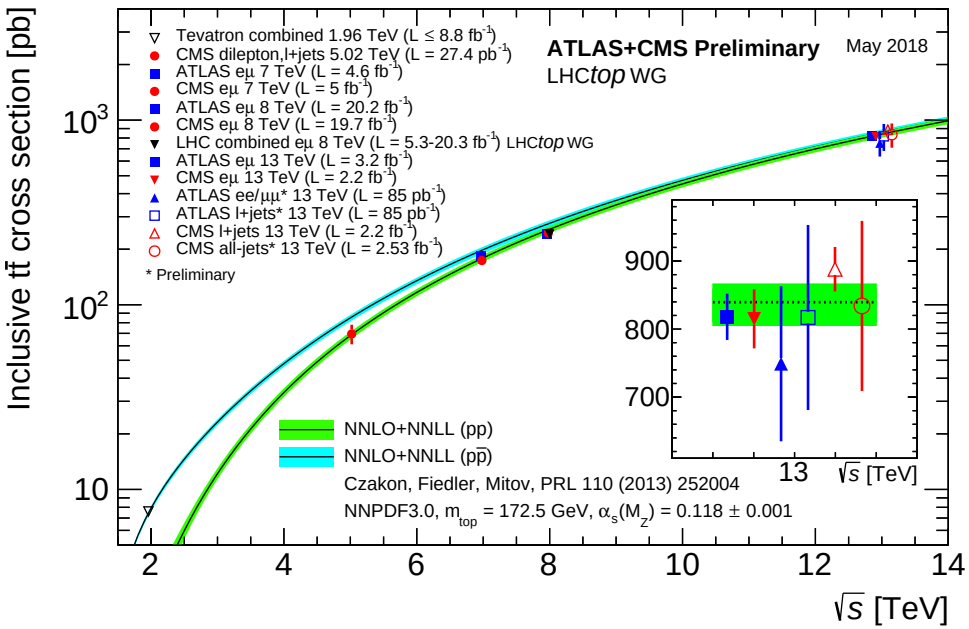
- $g_{cc}, g_{tt} \sim \mathrm{O}(1)$ $\quad g_{uc} \sim \mathrm{O}(10^{-1})$ $\quad g_{uu}, g_{ct} \sim \mathrm{O}(10^{-2})$ $\quad g_{ut} \sim \mathrm{O}(10^{-3})$

Top processes at the LHC

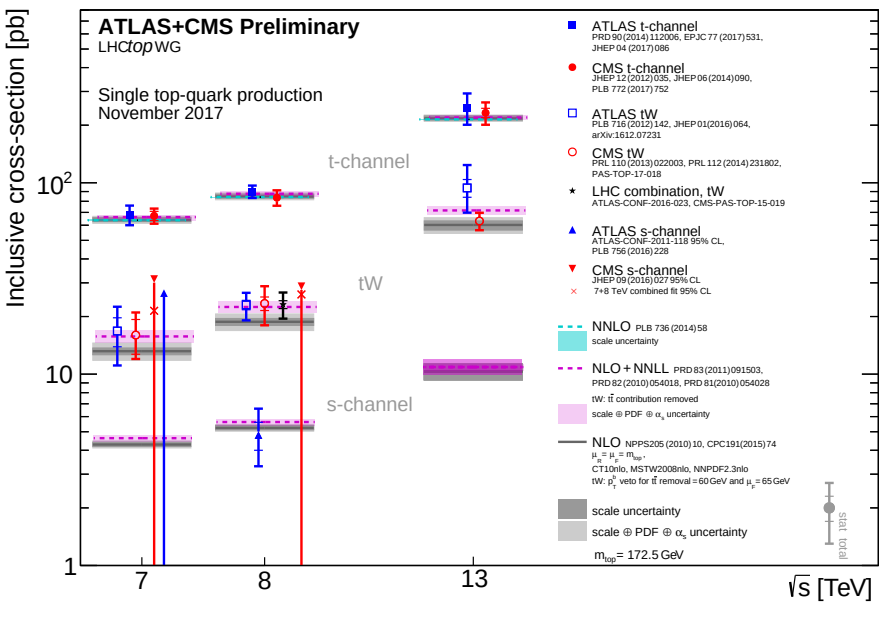
- top pair production $pp \rightarrow t\bar{t}$
- t-channel single top production $pp \rightarrow tj$
- s-channel single top production $pp \rightarrow t\bar{b}$
- like-sign ditop production $pp \rightarrow tt$

LHC Top Working Group Summary Plots

$pp \to t\bar{t}$



$pp \to tX$



SM rules !

Top processes at the LHC

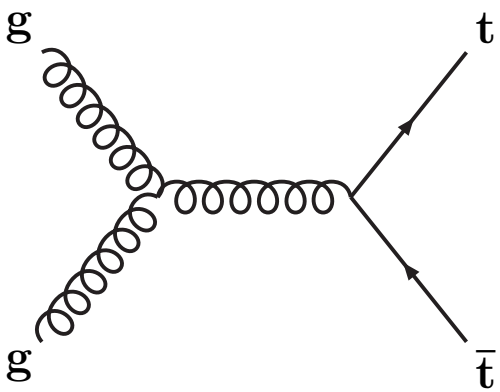
Top pair production

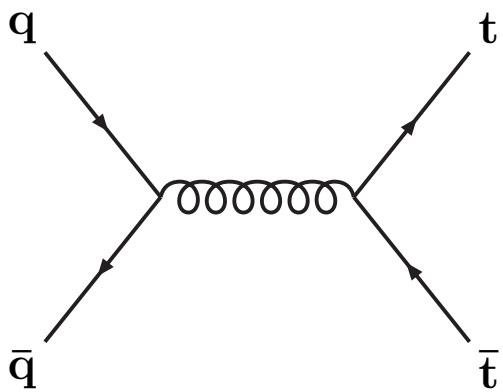
σ_{SM}@13TeV $\sim$ 850 pb

Top processes at the LHC

Top pair production

σ_{SM}@13TeV $\sim$ 850 pb

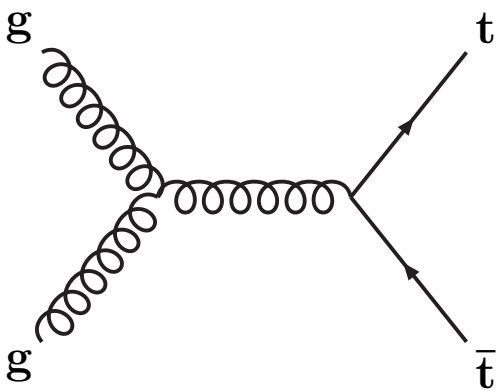


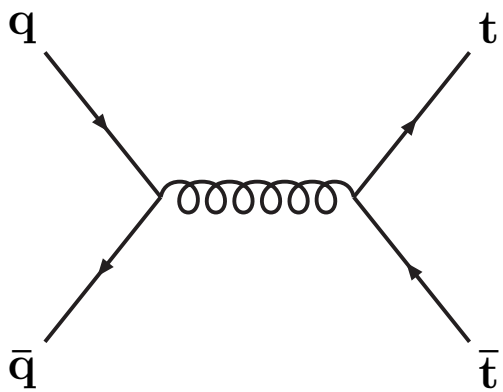


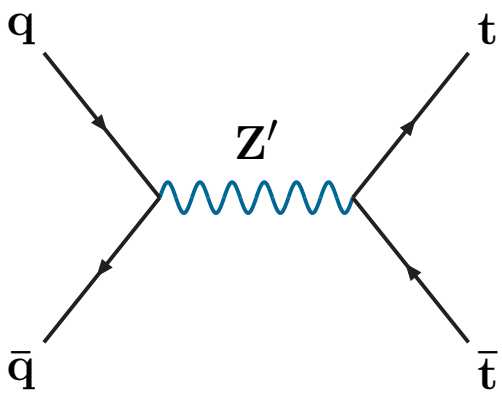
Top processes at the LHC

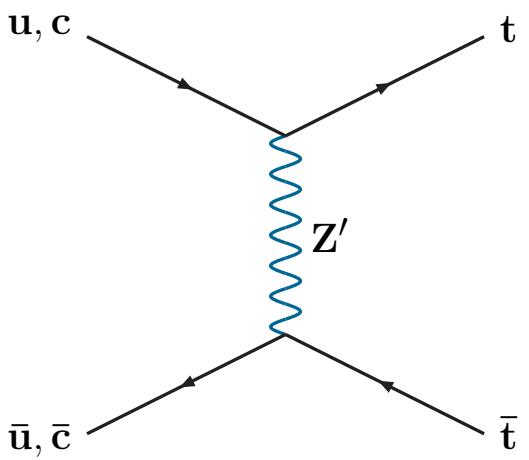
Top pair production

σ_{SM}@13TeV ~ 850 pb









Top processes at the LHC

Top pair production

σ_{SM}@13TeV $\sim$ 850 pb

the Good News :

g_{ss} , g_{bb} , g_{cc} , $g_{tt} \sim$ O(1)
Possibility of a resonance.

the Bad News :

Z' contributes only in quark-initiated processes.
SM background from $g\,g \rightarrow t\,\bar{t}$.

Top processes at the LHC

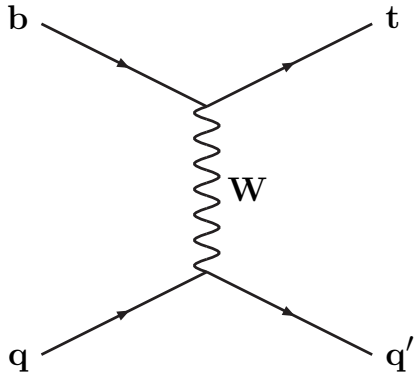
Single top production

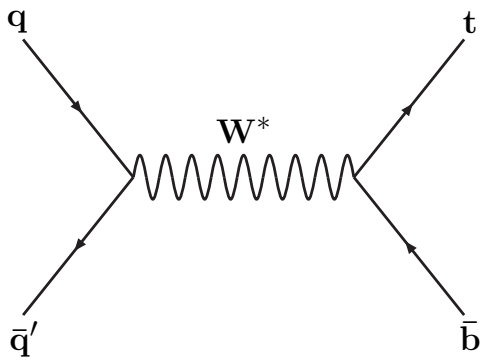
σ_{SM}^{t-ch}@13TeV $\sim$ 150 pb ; σ_{SM}^{s-ch}@13TeV $\sim$ 7 pb

Top processes at the LHC

Single top production

σ_{SM}^{t-ch}@13TeV $\sim$ 150 pb ; σ_{SM}^{s-ch}@13TeV $\sim$ 7 pb

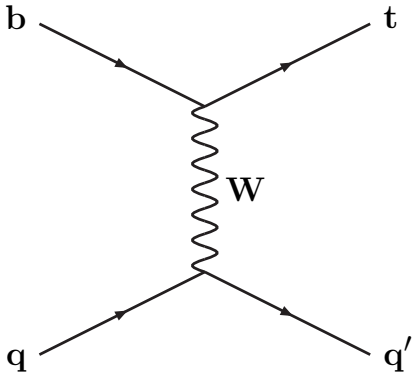


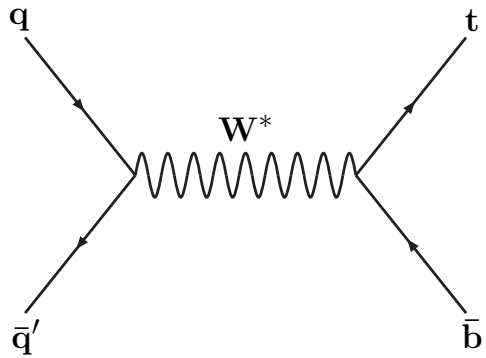


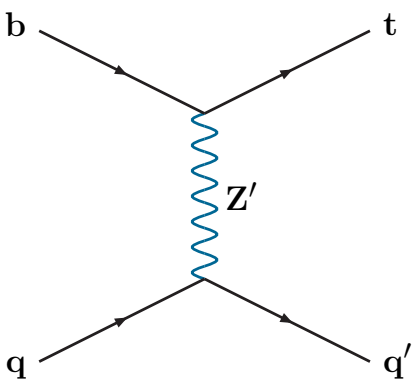
Top processes at the LHC

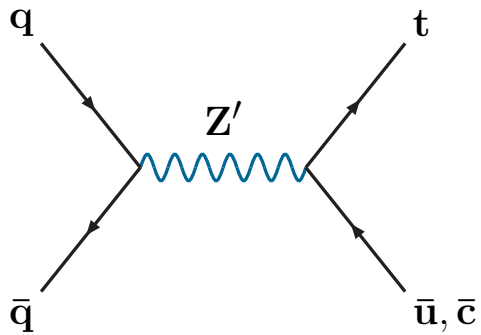
Single top production

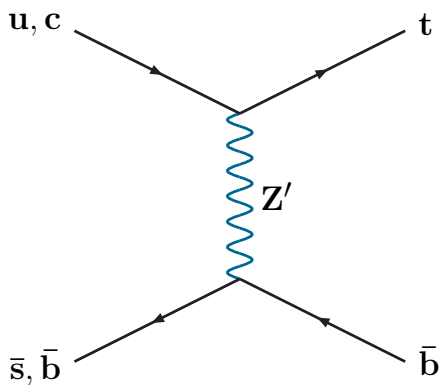
σ_{SM}^{t-ch}@13TeV $\sim$ 150 pb ; σ_{SM}^{s-ch}@13TeV $\sim$ 7 pb











Top processes at the LHC

Single top production σ^{t-ch}_{SM}@13TeV $\sim$ 150 pb ; σ^{s-ch}_{SM}@13TeV $\sim$ 7 pb

the Good News :

SM background due to electroweak processes.

the Bad News :

$g_{ct} \sim \mathrm{O}(10^{-2})$ $g_{ut} \sim \mathrm{O}(10^{-3})$

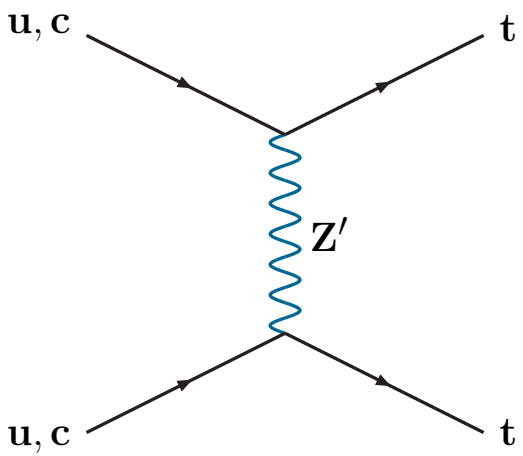
Top processes at the LHC

Like-sign ditop production

σ_{SM}@13TeV $\sim$ 0

Like-sign ditop production

σ_{SM}@13TeV $\sim$ 0



Top processes at the LHC

Like-sign ditop production

σ_{SM}@13TeV $\sim$ 0

the Good News :

SM backgrounds very low.

the Bad News :

$g_{ct} \sim \mathrm{O}(10^{-2})$ $\quad$ $g_{ut} \sim \mathrm{O}(10^{-3})$

Suppression due to $[\ \mathscr{B}(t \to b\,\ell^+\,\nu)\ ]^2$.

Results

Top pair production

σ_{SM}@13TeV $\sim$ 850 pb

Region I : $M_{Z'} \sim$ O(10 GeV)

$$\frac{\Delta\sigma}{\sigma_{SM}} \sim 10\% \text{ - } 15\%$$

Region II : $M_{Z'} \sim$ O(100 GeV)

$$\frac{\Delta\sigma}{\sigma_{SM}} \lesssim 1\%$$

Results

Single top production σ^{t-ch}_{SM}@13TeV $\sim$ 150 pb ; σ^{s-ch}_{SM}@13TeV $\sim$ 7 pb

Region I : $M_{Z'} \sim$ O(10 GeV)

$$\frac{\Delta\sigma}{\sigma_{SM}} \text{ upto } 300\%$$

Region II : $M_{Z'} \sim$ O(100 GeV)

$$\frac{\Delta\sigma}{\sigma_{SM}} \lesssim 1\%$$

Results

Like-sign ditop production

σ_{SM}@13TeV $\sim$ 0

Region I : $M_{Z'} \sim$ O(10 GeV)

$\Delta\sigma$ upto O(100 fb)

Region II : $M_{Z'} \sim$ O(100 GeV)

$\Delta\sigma \lesssim 1$ fb

Summary

- $\mathbf{Z}^{'}$ models offer a resolution for **B** anomalies.
- Signatures of such models may appear in top processes at the LHC.
- Possible to exclude large regions of parameter space with $M_{Z'} \sim$ O(10 GeV).
- Regions with $M_{Z'} \sim$ O(100 GeV) survive.
- Single top production most sensitive, followed by pair production.
- Like-sign ditop would carry important corroborative evidence in case a deviation is seen in the other channels.

Thank You !

Back Up

Constraints on Z' couplings

[arXiv:1806.07403]

$$\frac{g_{sb}\, g_{\mu\mu}}{M_{Z'}^2} = -0.0011 \pm 0.0002 \ \text{TeV}^{-2} \qquad [b \to s\, \mu^+ \mu^-]$$

$$\frac{g_{sb}}{M_{Z'}} = \pm(1.0^{+2.0}_{-3.9}) \times 10^{-3} \ \text{TeV}^{-1} \qquad [B_s^0 - \bar{B}_s^0 \text{ mixing}]$$

$$\frac{g_{sb}\,(g_{\mu\mu} + g_{\tau\tau})}{M_{Z'}^2} \in [-0.014, 0.034] \ \text{TeV}^{-2} \qquad [B \to K^* \nu\bar{\nu}]$$

$$\frac{g_{\mu\mu}}{M_{Z'}} = 0 \pm 1.13 \ \text{TeV}^{-1} \qquad [\nu N \to \nu N\, \mu^+ \mu^-]$$

Z' couplings with up-type quarks

$$g_{uu} = g_{ss} V_{us} V_{us} + g_{bb} V_{ub} V_{ub} + 2 g_{sb} V_{us} V_{ub}$$

$$g_{cc} = g_{ss} V_{cs} V_{cs} + g_{bb} V_{cb} V_{cb} + 2 g_{sb} V_{cs} V_{cb}$$

$$g_{tt} = g_{ss} V_{ts} V_{ts} + g_{bb} V_{tb} V_{tb} + 2 g_{sb} V_{ts} V_{tb}$$

$$g_{uc} = g_{ss} V_{us} V_{cs} + g_{bb} V_{ub} V_{cb} + g_{sb} V_{us} V_{cb} + g_{sb} V_{ub} V_{cs}$$

$$g_{ut} = g_{ss} V_{us} V_{ts} + g_{bb} V_{ub} V_{tb} + g_{sb} V_{us} V_{tb} + g_{sb} V_{ub} V_{ts}$$

$$g_{ct} = g_{ss} V_{cs} V_{ts} + g_{bb} V_{cb} V_{tb} + g_{sb} V_{cs} V_{tb} + g_{sb} V_{cb} V_{ts}$$