Probing the quark flavour structure of New Physics by measuring the branching ratios of decays h(125) -> b dbar/sbar and bbar d/s (LoI to Energy Frontier Snowmass 2021)

K. Hidaka
Tokyo Gakugei University

Collaboration with
H. Eberl, E. Ginina

References:

Phys. Rev. D 91 (2015) 015007 [arXiv:1411.2840 [hep-ph]]
JHEP 1606 (2016) 143 [arXiv:1604.02366 [hep-ph]]]

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1. Introduction

- *The search for the charged lepton flavour violating (CLFV) decays of the 125 GeV Higgs boson such as h(125) -> mu tau and e tau have been performed at LHC; e.g.*
  ATLAS group has obtained the following upper bounds
  B(h(125) -> mu tau) < 0.28% (95% CL)
  B(h(125) -> e tau) < 0.47% (95% CL) .
  [*H. Borecka-Bielska, Talk at ICHEP2020, 28 July to 6 August 2020.*]

- *As for the sensitivity of ILC250 to these branching ratios, the study based on Delphes fast detector simulation gives an upper limit*
  B(h(125)-> mu tau) < 0.023%
  in case of no observation.
  [*Qin Qin et al., Eur. Phys. J. C78 (2018) 835 [arXiv:1711.07243 [hep-ph]].*]

(Remark)

As far as we know, there is no dedicated full detector simulation analysis for these CLFV decays at ILC so far.
Hence, we recommend to perform such a full simulation analysis for these CLFV Higgs decays.

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- ***The branching ratios B(h(125) -> mu tau) and B(h(125) -> e tau) are exactly zero in the Standard Model (SM).***

- ***On the other hand, these CLFV branching ratios can be sizable in New Physics (NP) models beyond the SM; e.g. they can be at the percent level in the Supersymmetric Inverse Seesaw Model \cite{Arganda} despite the very strong constraints from CLFV processes such as tau -> mu/e gamma.***
  [E. Arganda et al., arXiv:1508.04623[hep-ph].]

- ***Hence, experimental measurement of these CLFV decay branching ratios can play a role in searching for NP models and in distinguishing the models.***

- ***In other words we can probe the lepton flavour structure of NP by measuring these LFV decays of h(125).***

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2. Proposal

- *In this LoI we point out the importance of Quark Flavour Violating (QFV) decay h(125) -> b qbar / bbar q (q = d or s) which we denote as h(125) -> b d/s.*
- *It is very difficult to detect this decay due to huge hadronic QCD backgrounds at LHC.*
- *However, it is rather easy to detect this decay at lepton colliders such as ILC, CLIC, CEPC and FCC-ee.*
- *For example, the sensitivity of ILC(250+500+1000GeV) to this decay branching ratio could be about 0.1% level (at 4 sigma significance).*
  [*Private communication with Junping Tian.*]
- *An analysis based on Delphes fast detector simulation gives similar order of estimation for the sensitivity of ILC500 to the guesstimate above.*

  [D. Barducci and A.J. Helmboldt, JHEP 12 (2017) 105 [arXiv:1710.06657 [hep-ph]].]

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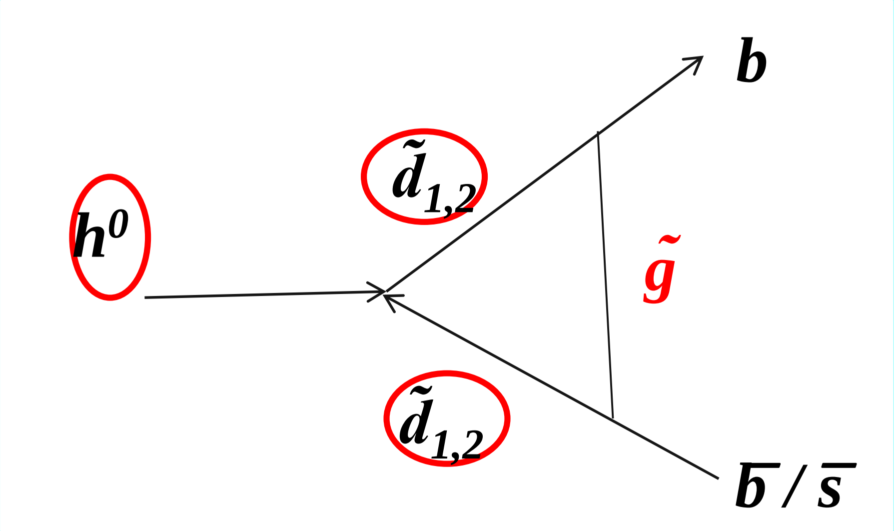
- ***The QFV branching ratio B(h(125) -> b d/s) is almost zero in the SM.***
- ***However, it could be sizable in NP models beyond the SM; e.g. B(h(125) -> b s) can be as large as about 0.1% due to scharm-stop and sstrange-sbottom mixings in the Minimal Supersymmetric Standard Model (MSSM) with general QFV despite the very strong constraints from QFV processes such as b -> s gamma.***

M.E. Gomez, S. Heinemeyer and M. Rehman, Phys. Rev. D93 (2016) 095021 [arXiv:1511.04342 [hep-ph];
H. Eberl, E. Ginina and K. Hidaka, JHEP 1606 (2016) 143 [arXiv:1604.02366 [hep-ph]];
H. Eberl, E. Ginina and K. Hidaka, talk at "ILC-JP end-of-year physics and detector meeting" 12-13 Mar 2020, KEK, Japan:
https://agenda.linearcollider.org/event/8403/contributions/45338/attachments/35385/54883/HidakaILC_Annual_Meeting_2020_03_final_mod.pdf.

In large $\tilde{s}_{R/L}$ - $\tilde{b}_{R/L}$ & $\tilde{b}_L$ - $\tilde{b}_R$ mixing scenario;

$$h^0 \sim -s\alpha H_1^0 + c\alpha H_2^0$$

$$\tilde{d}_{1,2} \sim \tilde{s}_{R/L} + \tilde{b}_{R/L}$$



In our scenario, "trilinear couplings" (T_{D23} T_{D32}, T_{D33}) =
($\tilde{s}_R$ - $\tilde{b}_L$ - H_1^0 , $\tilde{s}_L$ - $\tilde{b}_R$ - H_1^0 , $\tilde{b}_L$ - $\tilde{b}_R$ - H_1^0 couplings) are large!

$\tilde{d}_{1,2}$ - $\tilde{d}_{1,2}$ - h^0 couplings are large!

Gluino loop contributions can be large!

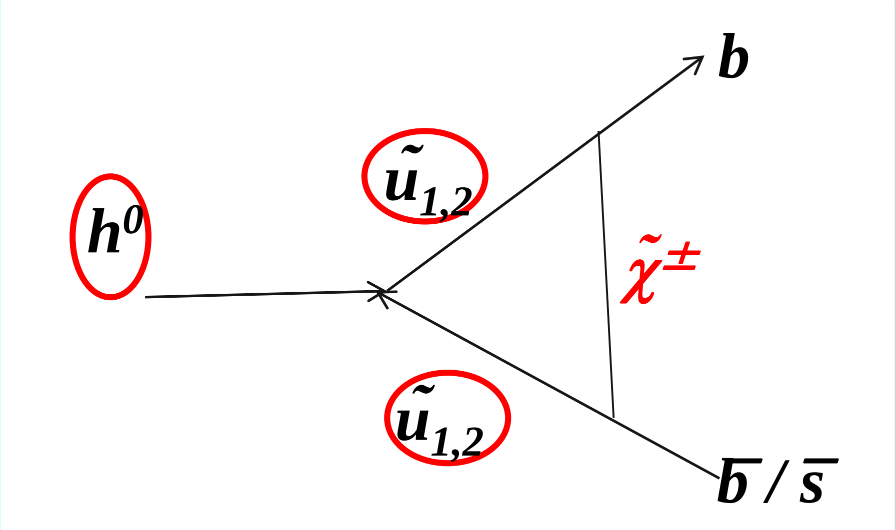
Deviation of $\Gamma(h^0 \rightarrow b\,\bar{b}/\bar{s})$ from SM width can be large!

In large $\tilde{c}_{R/L}$ - $\tilde{t}_{R/L}$ & $\tilde{t}_L$ - $\tilde{t}_R$ mixing scenario;

$h^0 \sim H_2^0$

$\tilde{u}_{1,2} \sim \tilde{c}_{R/L} + \tilde{t}_{R/L}$

$\tilde{\chi}^\pm \sim \tilde{W}^\pm + \tilde{H}^\pm$



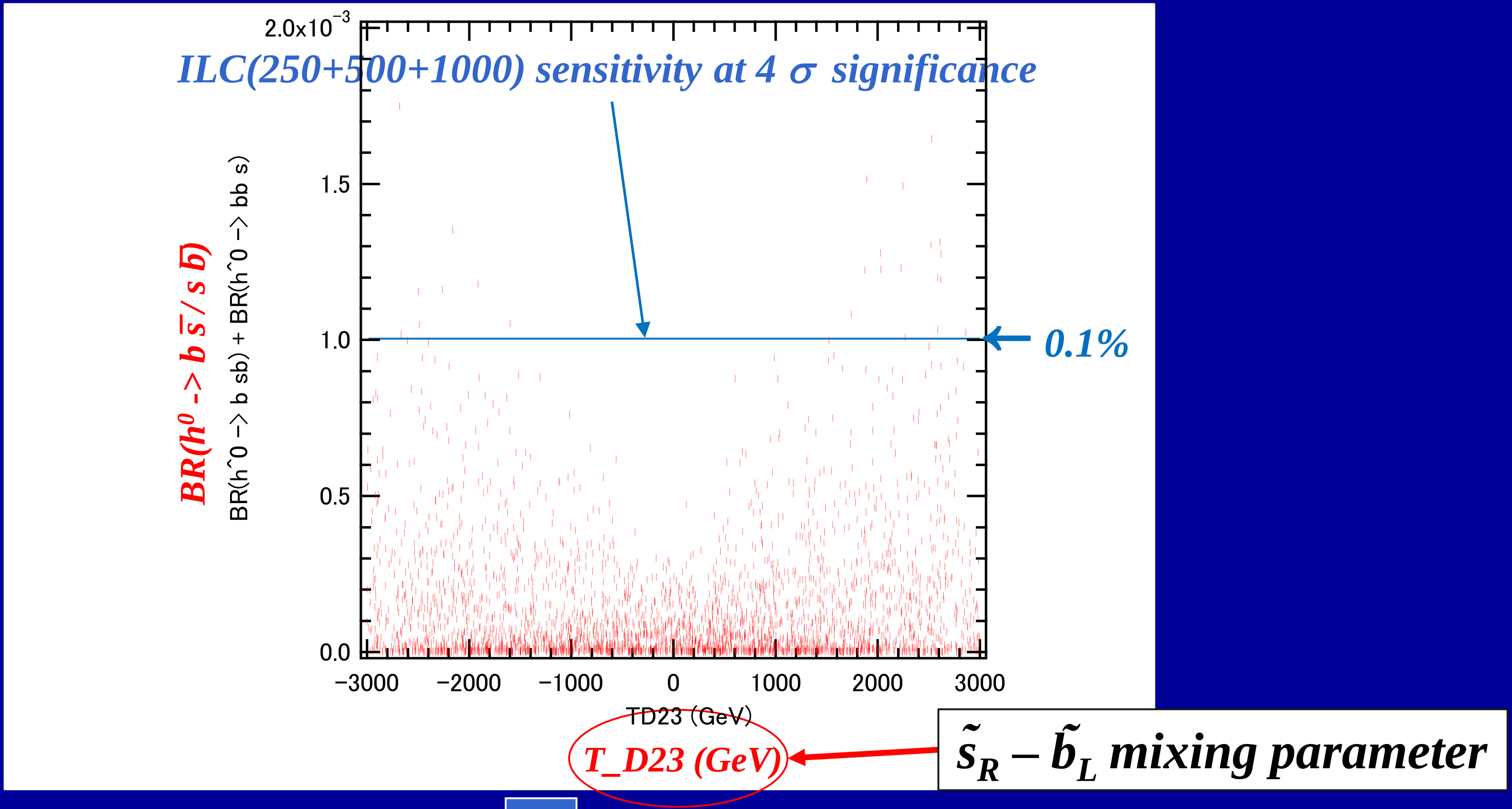
In our scenario, "trilinear couplings" ($\tilde{c}_R - \tilde{t}_L - H_2^0$, $\tilde{c}_L - \tilde{t}_R - H_2^0$, $\tilde{t}_L - \tilde{t}_R - H_2^0$ couplings) = (T_{U23} T_{U32}, T_{U33}) are large!

$\tilde{u}_{1,2} - \tilde{u}_{1,2} - h^0$ couplings are large!

Chargino loop contributions can be large!

Deviation of $\Gamma(h^0 \to b\,\overline{b/s})$ from SM width can be large!

Scatter plot in T_{D23} - BR($h^0 \to b\bar{s} / s\bar{b}$) plane



- *There is a strong correlation between T_{D23} - BR($h^0 \to b\bar{s} / s\bar{b}$)!*
- *BR($h^0 \to b\bar{s} / s\bar{b}$) can be as large as 0.17% for large T_{D23} !*
- *ILC(250 + 500 + 1000) sensitivity could be ~ 0.1% at 4 sigma significance!*

  (private communication with J. Tian)
- *LHC &HL-LHC sensitivity should not be so good due to huge QCD BG!*

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- ***Hence, experimental measurement of this QFV branching ratio B(h(125) -> b d/s) can play an important role in searching for NP models and in discriminating the models:***
  we can probe the quark flavour structure of NP by measuring these QFV decays of h(125).

- ***On the other hand, to our knowledge, there is no experimental detailed full detector simulation study on this QFV decay even at lepton colliders at this moment.***

- ***Therefore, we recommend strongly for the lepton collider experimentalists to perform a dedicated realistic full detector simulation analysis to measure the branching ratio of this QFV decay h(125) -> b d/s.***

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3. Summary

- *Experimental measurement of the branching ratios of the QFV decays h(125) -> b d/s can play an important role in searching for NP models and in discriminating the models: i.e. we can probe the quark flavour structure of NP by measuring the branching ratios of these QFV decays h(125) -> b d/s.*
- *Therefore, we recommend strongly the lepton collider experimentalists to perform a realistic dedicated full detector simulation study to measure the branching ratios of the QFV decays h(125) -> b d/s.*
- *We hope that such simulation study will be made during the course of the Snowmass 2021 process.*

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- ***Final remark:***

  - ***In case you observe B(h -> b s) at O(1)% level at ILC, then it means that you have discovered New Physics beyond the SM and beyond the MSSM (SUSY)!***

    -> This is a great impact on SM & SUSY & other NP models!

  - ***LHC (& HL-LHC) cannot observe this branching ratio due to huge QCD hadronic backgrounds!***

  - ***Hence, this is a unique great NP discovery opportunity of ILC!!!***

END

Thank you!

Backup Slides

Probing the quark flavour structure of New Physics by measuring the branching ratio of the decay $h(125) \to b\,\bar{d}/\bar{s}$ and $\bar{b}\,d/s$

(LoI to Energy Frontier Snowmass 2021)

H. Eberl[1], E. Ginina[1,2], K. Hidaka[3]

[1] *Institut für Hochenergiephysik der Österreichischen Akademie der Wissenschaften, A-1050 Vienna, Austria*

[2] *VRVis Zentrum für Virtual Reality und Visualisierung Forschungs-GmbH, A-1220 Vienna, Austria*

[3] *Department of Physics, Tokyo Gakugei University, Koganei, Tokyo 184-8501, Japan*

Contact: K. Hidaka (hidaka@u-gakugei.ac.jp)

1 Introduction

The search for the charged lepton flavour violating (CLFV) decays of the 125 GeV Higgs boson such as $h(125) \to \mu\,\tau$ and $e\,\tau$ have been performed at LHC; e.g. ATLAS group has obtained upper bounds of the corresponding branching ratios $B(h(125) \to \mu\,\tau) < 0.28\%$ and $B(h(125) \to e\,\tau) < 0.47\%$ at 95% CL [1], where $B(h(125) \to \mu\,\tau) = B(h(125) \to \mu^-\,\tau^+) + B(h(125) \to \mu^+\,\tau^-)$ and so on. As for the sensitivity of ILC250 to these branching ratios, for example the study based on Delphes fast detector simulation gives an upper limit $B(h(125) \to \mu\,\tau) < 0.023\%$ [2] [1]. The branching ratios $B(h(125) \to \mu\,\tau)$ and $B(h(125) \to e\,\tau)$ are exactly zero in the Standard Model (SM). On the other hand, these CLFV branching ratios can be sizable in New Physics (NP) models beyond the SM; e.g. they can be at the percent level in the Supersymmetric Inverse Seesaw Model [4] despite the very strong constraints from CLFV processes such as $\tau \to \mu/e\,\gamma$ [5]. Hence, experimental measurement of these CLFV decay branching ratios can play a role in searching for NP models and in distinguishing the models. In other words we can probe the lepton flavour structure of NP by measuring these LFV decays of $h(125)$.

[1] As far as we know, there is no dedicated full detector simulation analysis for these CLFV decays at ILC so far [3]. Hence, we would like to recommend to perform such a full simulation analysis for these CLFV Higgs decays.

2 Proposal

In this letter we would like to point out the importance of the Quark Flavour Violating (QFV) decay $h(125) \to b\,\bar{q}\,/\,\bar{b}\,q$ ($q = d$ or s) which we denote as $h(125) \to b\,d/s$ in the following. It is very difficult to detect this decay due to huge hadronic QCD backgrounds at LHC. However, it is rather easy to detect this decay at lepton colliders such as ILC, CLIC, CEPC and FCC-ee. For example, the sensitivity of ILC(250+500+1000GeV) to this decay branching ratio could be about 0.1% level (at 4 σ significance) [3]. An analysis based on Delphes fast detector simulation [6] gives similar order of estimation for the sensitivity of ILC500 to the guesstimate above. The corresponding branching ratio $B(h(125) \to b\,d/s)$ is almost zero in the SM. However, it could be sizable in NP models beyond the SM; e.g. $B(h(125) \to b\,s)$ can be as large as about 0.1% due to scharm-stop and sstrange-sbottom mixings in the Minimal Supersymmetric Standard Model (MSSM) with general QFV [7, 8] despite the very strong constraints from QFV processes such as $b \to s\,\gamma$ [5]. Hence, experimental measurement of this branching ratio $B(h(125) \to b\,d/s)$ can play an important role in searching for NP models and in discriminating the models: we can probe the quark flavour structure of NP by measuring these QFV decays of h(125).

On the other hand, to our knowledge, there is no experimental detailed full detector simulation study on this QFV decay even at lepton colliders at this moment. Therefore, we would like to recommend strongly for the lepton collider experimentalists to perform a dedicated realistic full MC simulation analysis to measure the branching ratio of this QFV decay $h(125) \to b\,d/s$.

Furthermore, in extended Higgs models such as the Two Higgs Doublet Models (THDM), there are also the heavier neutral Higgs bosons H^0 and A^0. In this case we can also study the possibilities of the QFV decays $H^0 \to b\,d/s$ and $A^0 \to b\,d/s$ in various NP models. Such studies in the MSSM with general QFV are performed in [9]. These QFV decays could be detected at very high energy lepton collider such as CLIC and the muon collider. In this case the measurement of the QFV branching ratios could also play a role in searching for NP models and in distinguishing the models. Therefore, we would also like to recommend the lepton collider experimentalists to perform a detailed MC simulation analysis to detect these QFV decays for the measurement of the corresponding branching ratios. We can probe the quark flavour structure of NP by measuring these QFV decay branching ratios once the heavier Higgs bosons H^0 and A^0 are produced in the collider.

3 Summary

Experimental measurement of the branching ratios of the QFV decays $h(125) \to b\,d/s$ can play an important role in searching for NP models and in discriminating the models: we can probe the quark flavour structure of NP by measuring the branching ratios of these QFV decays $h(125) \to b\,d/s$. Therefore, we would like to recommend strongly the lepton collider experimentalists to perform a realistic dedicated full detector simulation study to measure the branching ratios of the QFV decays $h(125) \to b\,d/s$. We hope that such simulation study will be made during the course of the Snowmass process.

References

[1] H. Borecka-Bielska, Talk at ICHEP2020, 28 July to 6 August 2020.

[2] Qin Qin et al., Eur. Phys. J. C78 (2018) 835 [arXiv:1711.07243 [hep-ph]].

[3] Private communication with Junping Tian.

[4] E. Arganda et al., arXiv:1508.04623[hep-ph].

[5] P.A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020).

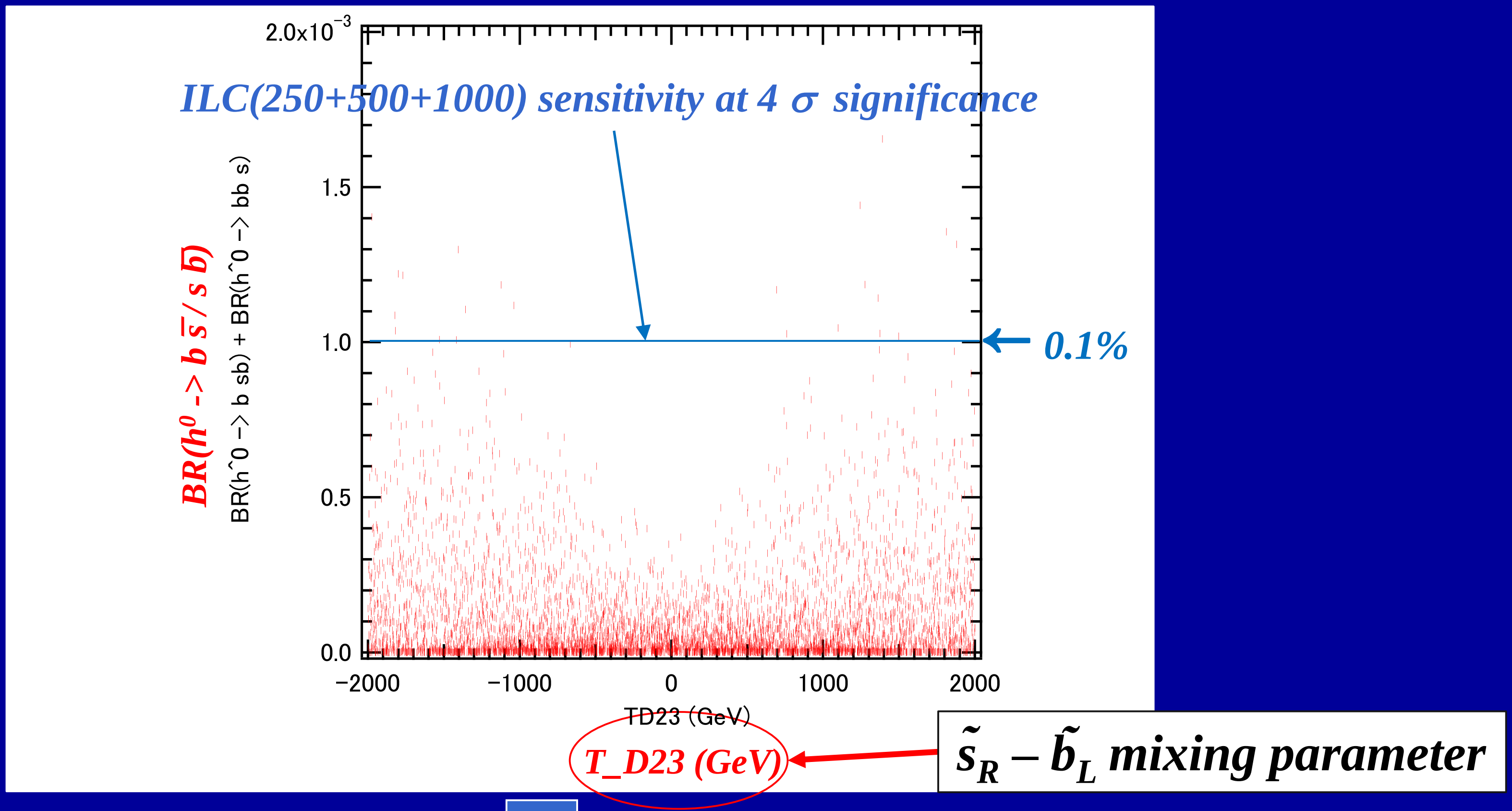
[6] D. Barducci and A.J. Helmboldt, JHEP 12 (2017) 105 [arXiv:1710.06657 [hep-ph]].

[7] M.E. Gomez, S. Heinemeyer and M. Rehman, Phys. Rev. D93 (2016) 095021 [arXiv:1511.04342 [hep-ph]].

[8] H. Eberl, E. Ginina and K. Hidaka, JHEP 1606 (2016) 143 [arXiv:1604.02366 [hep-ph]]; H. Eberl, E. Ginina and K. Hidaka, talk at "ILC-JP end-of-year physics and detector meeting" 12-13 Mar 2020, KEK, Japan: https://agenda.linearcollider.org/event/8403/contributions/45338/attachments/35385/54883/HidakaILC_Annual_Meeting_2020_03_final_mod.pdf

[9] For example, T. Hahn, W. Hollik, J.I. Illana and S. Penaranda, arXiv:hep-ph/0512315.

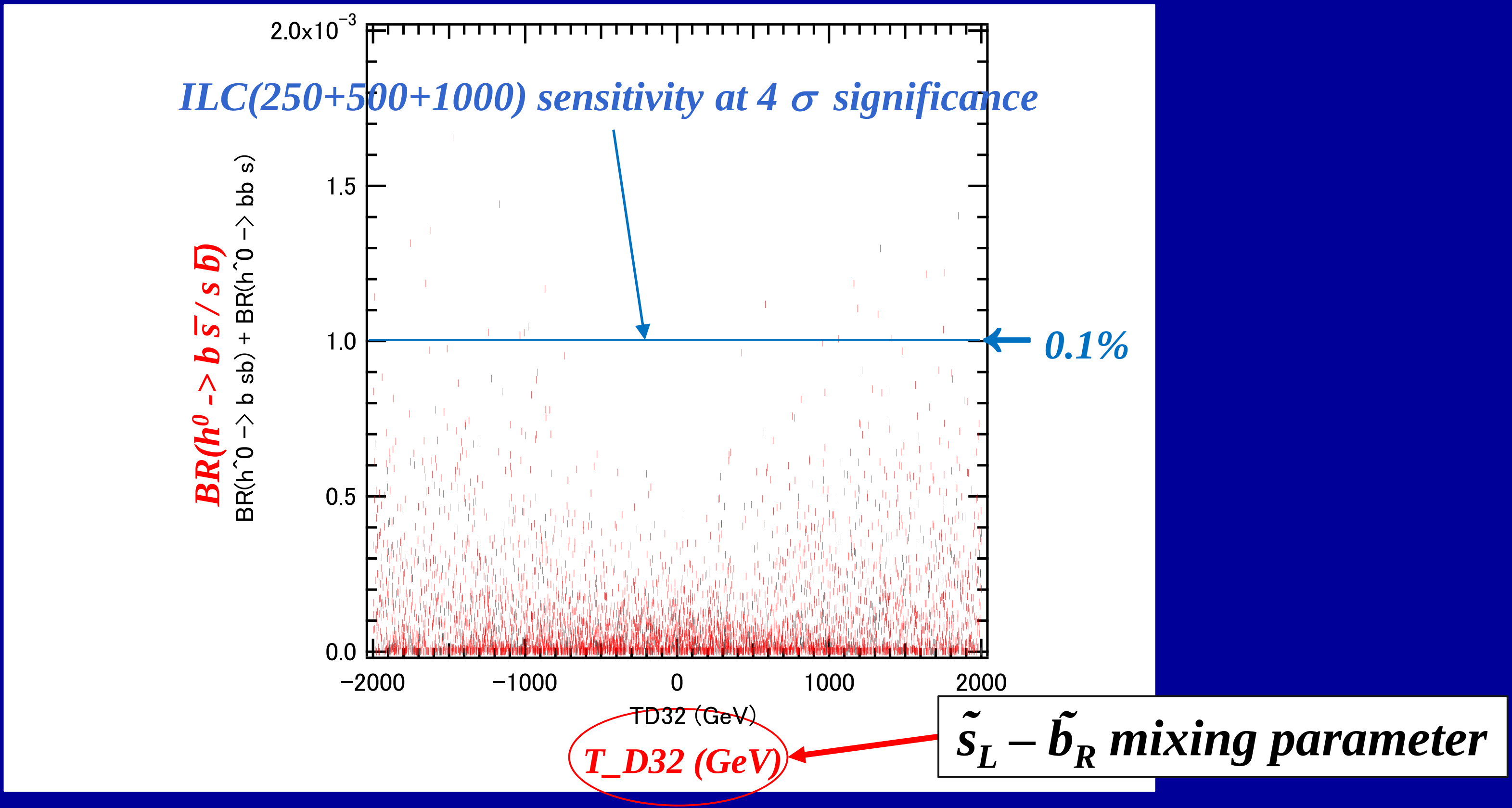
Scatter plot in T_{D23} - $BR(h^0 \to b\bar{s} / s\bar{b})$ plane



- There is a strong correlation between T_{D23} - $BR(h^0 \to b\bar{s} / s\bar{b})$!
- $BR(h^0 \to b\bar{s} / s\bar{b})$ can be as large as 0.17% for large T_{D23} !
- ILC(250 + 500 + 1000) sensitivity could be ~ 0.1% at 4 sigma significance!

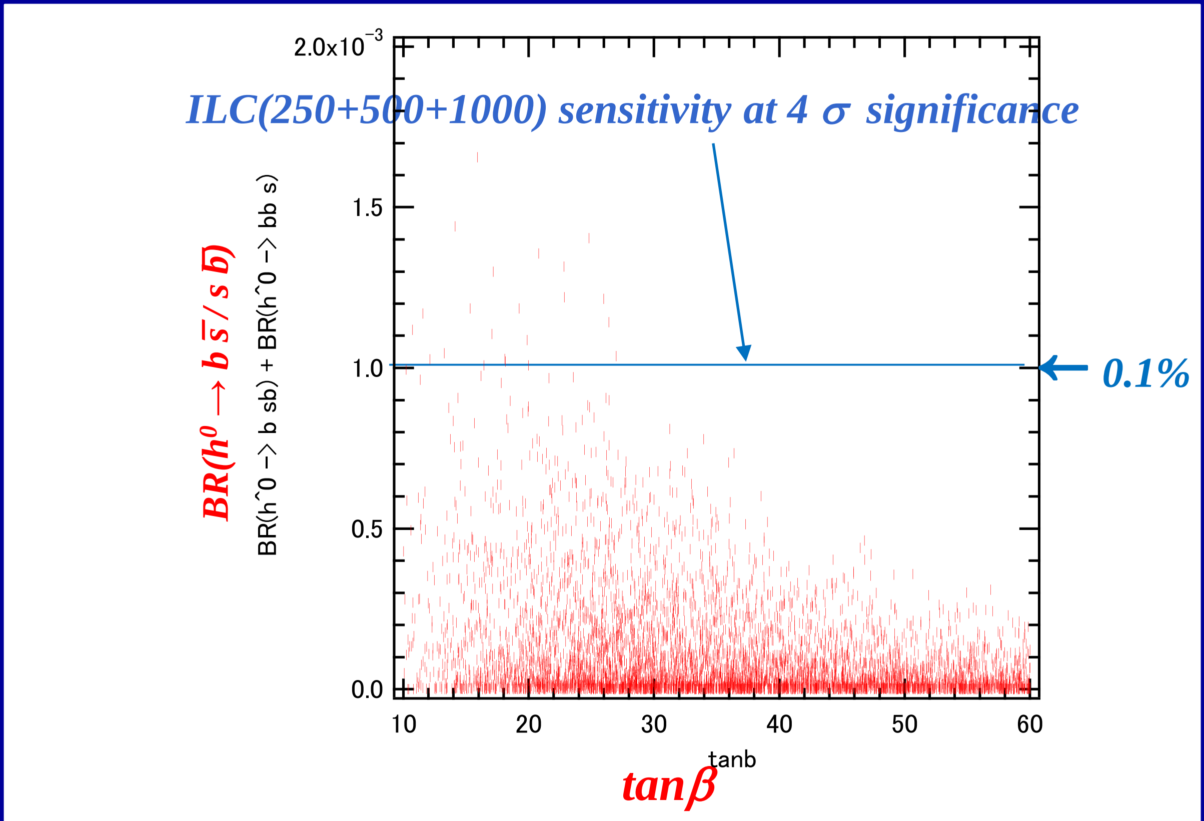
  (private communication with J. Tian)
- LHC &HL-LHC sensitivity should not be so good due to huge QCD BG!

Scatter plot in T_{D32} - $BR(h^0 \to b\bar{s} / s\bar{b})$ plane



- There is also a strong correlation between T_{D32} - $BR(h^0 \to b\bar{s} / s\bar{b})$!
- $BR(h^0 \to b\bar{s} / s\bar{b})$ can be as large as 0.17% for large T_{D32} !

Scatter plot in $BR(h^0 \to b\bar{s}/s\bar{b})$ - $\tan\beta$ plane



- There is a strong correlation between $BR(h^0 \to b\bar{s}/s\bar{b})$ & $\tan\beta$!
- $BR(h^0 \to b\bar{s}/s\bar{b})$ can be as large as 0.17% for $\tan\beta \sim 20$!