Search for the Lepton Flavor Violation in the Higgs Boson Decay at a Linear Collider

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in collaboration with

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Contents

- Introduction
  - Motivation
    - LFV via Higgs and LF violating Higgs decay

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- Summary

Introduction

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- Lepton Falvor Violation (LFV) in the charged lepton sector
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- In MSSM with large $\tan\beta$, the Higgs bosons affect *the LFV processes*, such as,

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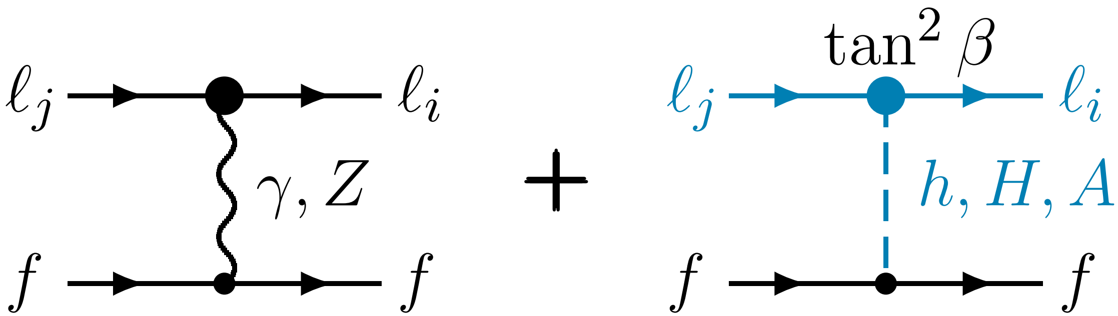

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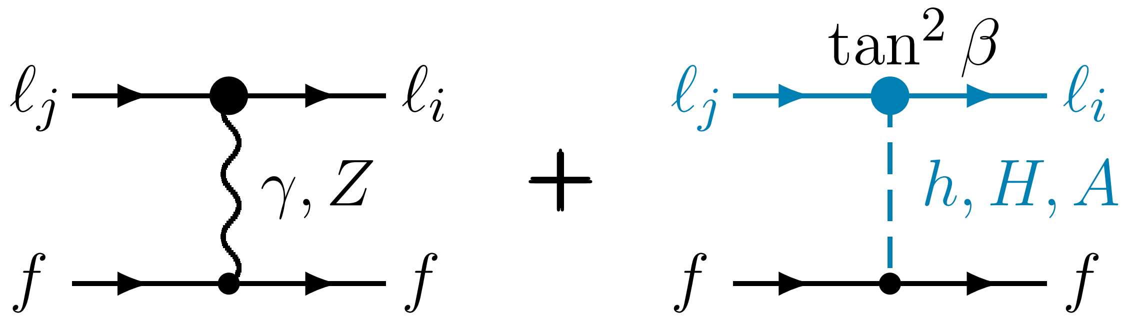
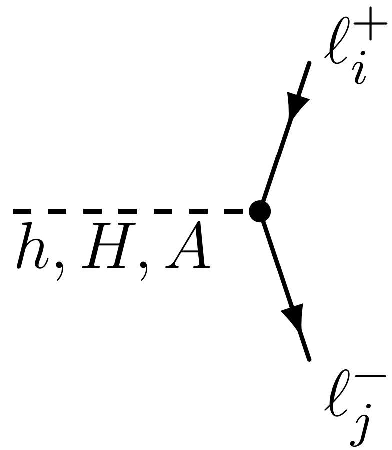


- The Higgs-contribution is important in $m_{\rm SUSY} \gg m_{\rm Higgs}$.

*In such a case, the model below $m_{\rm SUSY}$ can be regarded effectively as the general 2HDM.

Motivation

- We discuss *the LF violating Higgs boson decay*, expecting to get the information on the next energy scale by comparing between *the LFV processes* and *the LF violating Higgs decay*.



  - LFV processes
    — combination of the photon-mediation and the Higgs-mediation. indirect measurement.
  - LF violating Higgs decay
    — direct measurement of the LF violating Higgs coupling.
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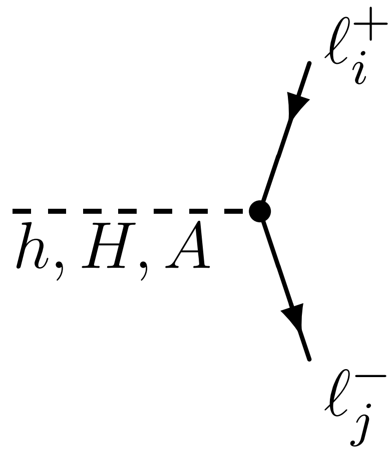

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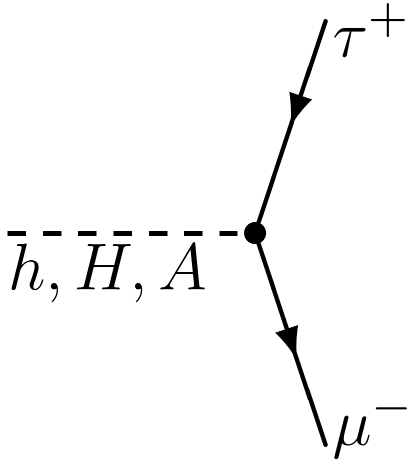
- We make a study on the detectability of the LF violating Higgs boson decay at a Linear Collider (LC).

general-2HDM the effective theory below m_{SUSY} in the model with large m_{SUSY}

- Lagrangian — leptonic Yukawa

$$-\mathcal{L} \supset Y_{\ell_i} \overline{\ell_{Li}} \left(\delta_{ij}\Phi_1^0 + \epsilon_{ij}\Phi_2^0\right) \ell_{Rj} + \text{H.c.}$$
$$\simeq (\text{mass term}) + (\text{flavor diagonal interactions})$$
$$+ \frac{m_{\ell_i}\kappa_{ij}}{v\cos^2\beta} \overline{\ell_{Li}}\ell_{Rj} \left[\cos(\beta-\alpha)h - \sin(\beta-\alpha)H - \mathrm{i}A\right]$$
$$+ (\text{charged Higgs term}) + \text{H.c.},$$

The LFV Higgs decay arise since two Yukawa matrices ($Y_{\ell_i}\delta_{ij}$ and $Y_{\ell_i}\epsilon_{ij}$) can not be diagonalized simultaneously.



Bound on $|\kappa_{32}|^2$ from LFV processes

- Branching ratio for $h \to \tau^+ + \mu^-$ is estimated as

$$\mathrm{Br}(h \to \tau^+ + \mu^-) \simeq \frac{1}{N_c} \frac{m_\tau^2}{m_b^2} \frac{\cos^2(\beta - \alpha)}{\sin^2\alpha \cos^2\beta} |\kappa_{32}|^2 \,.$$

- Throughout this talk, we assume
  - Nearly *decoupling region*, $h \simeq \Phi_{\mathrm{SM}}$, $\sin(\alpha - \beta) = -0.95$.
  - Large $\tan\beta$, $\tan\beta = 60$.

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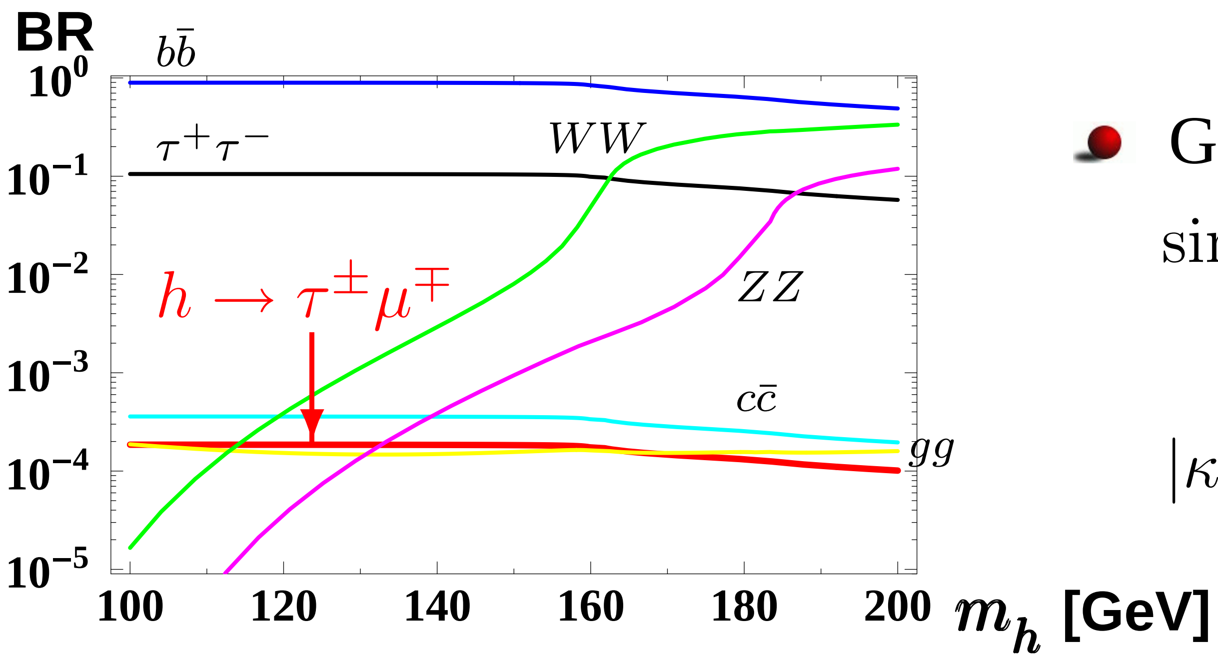
- Throughout this talk, we assume
  - Nearly *decoupling region*, $h \simeq \Phi_{\mathrm{SM}}$, $\sin(\alpha-\beta) = -0.95$.
  - Large $\tan\beta$, $\tan\beta = 60$.
- The bound on $|\kappa_{32}|^2$ from $\tau \to \mu\eta$ (Belle)

$$\mathrm{Br}(\tau \xrightarrow{h,H,A} \mu\eta) \simeq 8.4 \times \frac{G_{\mathrm{F}}^2 m_\mu^2 m_\tau^7 \tau_\tau}{768\pi^3 m_A^4}|\kappa_{32}|^2 \tan^6\beta < 3.4 \times 10^{-7},$$

$$|\kappa_{32}|^2 < 0.3 \times 10^{-6} \times \left(\frac{m_A}{150[\mathrm{GeV}]}\right)^4 \times \left(\frac{60}{\tan\beta}\right)^6 .$$

Branching ratio



- General-2HDM with

$$\sin(\alpha - \beta) = -0.95,$$
$$\tan\beta = 60,$$
$$|\kappa_{32}|^2 = 0.3 \times 10^{-6}.$$

- The branching ratio for $h \to \tau^\pm\mu^\mp$ with $|\kappa_{32}|^2 = 0.3 \times 10^{-6}$ is constrained as $\mathcal{O}(10^{-4})$.

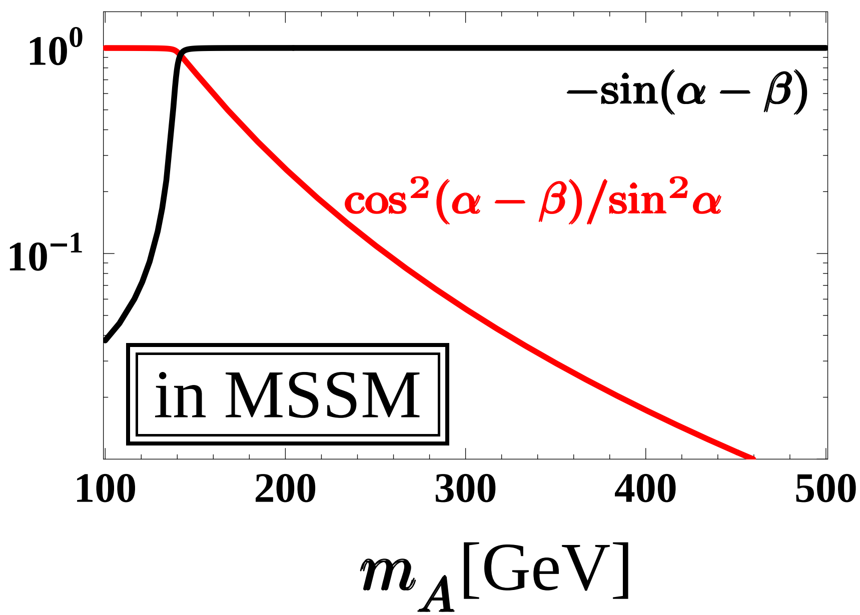
Note on *the bound* **and** *the signal*

$$\text{signal event} = \sigma_h \times \text{Br}(h \to \tau^\pm + \mu^\mp),$$

$$\sigma_h \propto \sin^2(\alpha - \beta),$$

$$\text{Br}(h \to \tau^\pm + \mu^\mp) \simeq 7.2 \times 10^2 \frac{\cos^2(\alpha-\beta)}{\sin^2\alpha} \left(\frac{m_A}{150[\text{GeV}]} \frac{60}{\tan\beta} \right)^4 \text{Br}(\tau \to \mu\eta).$$

- In MSSM, α is the function of m_A and $\tan\beta$ (and m_{SUSY}'s).



- $m_A \to$large,

$$\frac{\cos^2(\alpha-\beta)}{\sin^2\alpha} \to \text{small}$$

The $\text{Br}(h \to \tau^\pm\mu^\mp)$ is constrained as $\mathcal{O}(10^{-4})$.

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- In the extended models, such as the general-2HDM, m_A and α are independent parameters.

- In such a model, the bound from $\tau \to \mu\eta$ can be relaxed.

large value of m_A,

keeping the value of $\cos^2(\alpha - \beta)/\sin^2\alpha$.

$$\boxed{\text{Br}(h \to \tau^\pm\mu^\mp) \text{ can be as large as } \mathcal{O}(10^{-3}).}$$

Our Points

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  - First object to be found
    Its mass will be thoroughly determined.
  - Nealy decoupling region, $\sigma \propto \sin^2(\alpha - \beta)$.

Our Points

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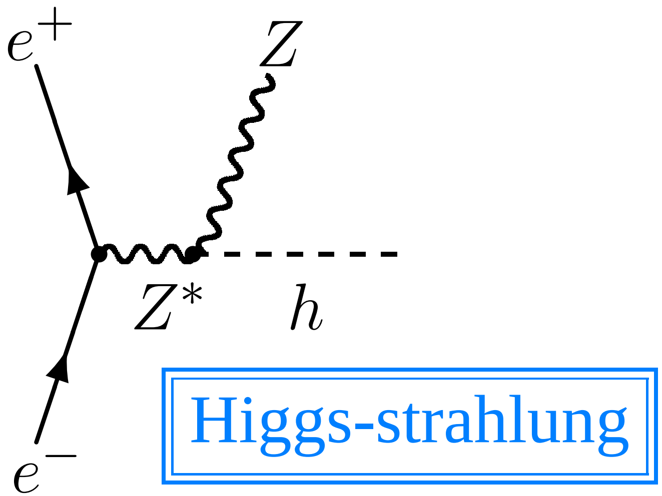
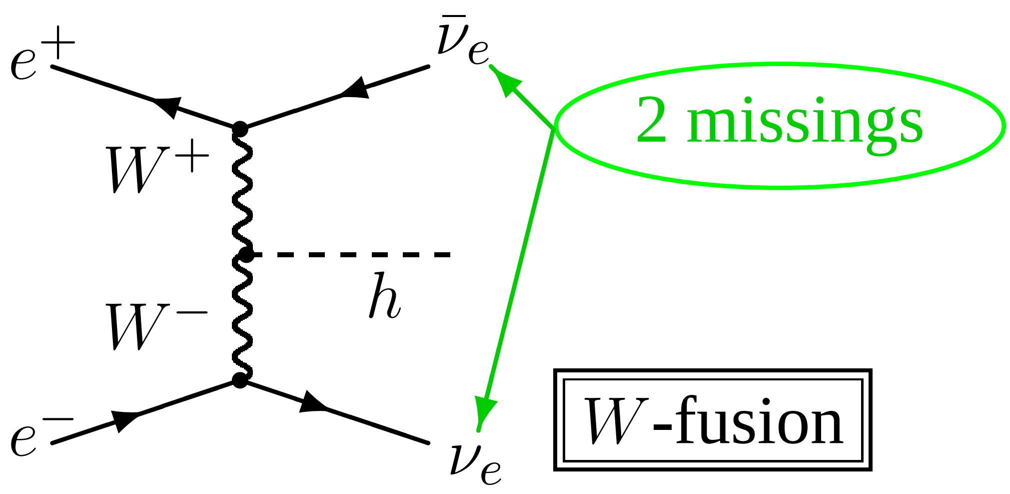
- Why lightest Higgs?
  - First object to be found
    Its mass will be thoroughly determined.
  - Nealy decoupling region, $\sigma \propto \sin^2(\alpha - \beta)$.
- Why linear collider?
  - Clear signal, Precision measurement

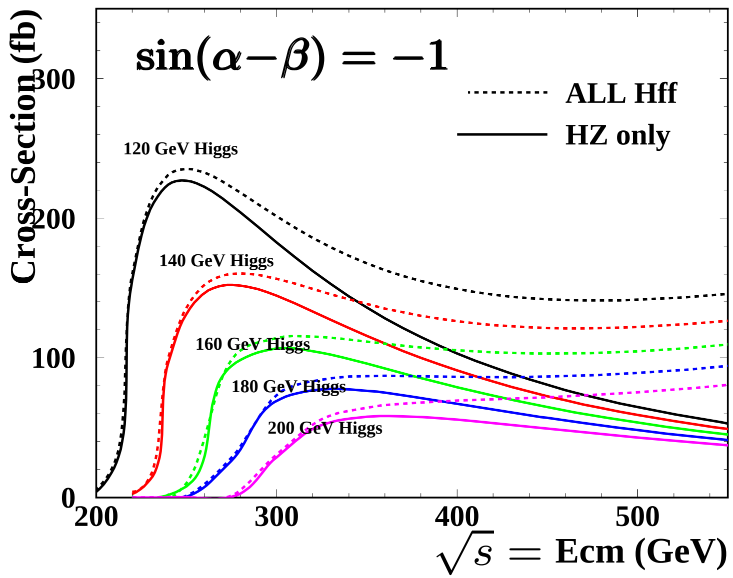
    It is important to reduce the backgrounds.

    The Higgs-strahlung is preferable in the Higgs production processes to determine m_h and $\sqrt{s}$ with high precision.

Higgs production process

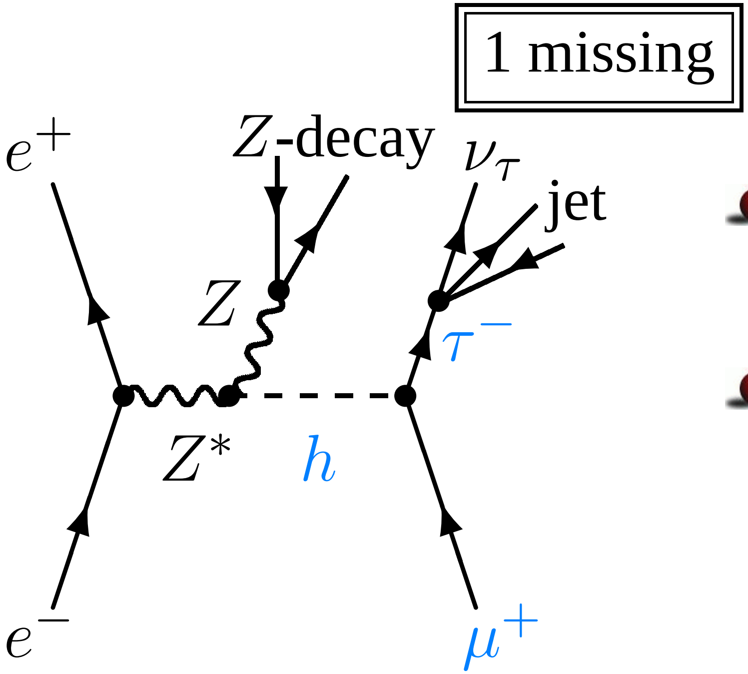






- In low $\sqrt{s}$ region, the Higgs-strahlung is dominant.
- In 2HDM, $\sigma \propto \sin^2(\alpha - \beta)$.

Strategy



- Using Z-recoil, we can identify the process as the Higgs-mediated one.
- p_τ is reconstructed by using $\sqrt{s}$, m_h, m_Z and p_μ.

  It is not necessary to measure p_τ.

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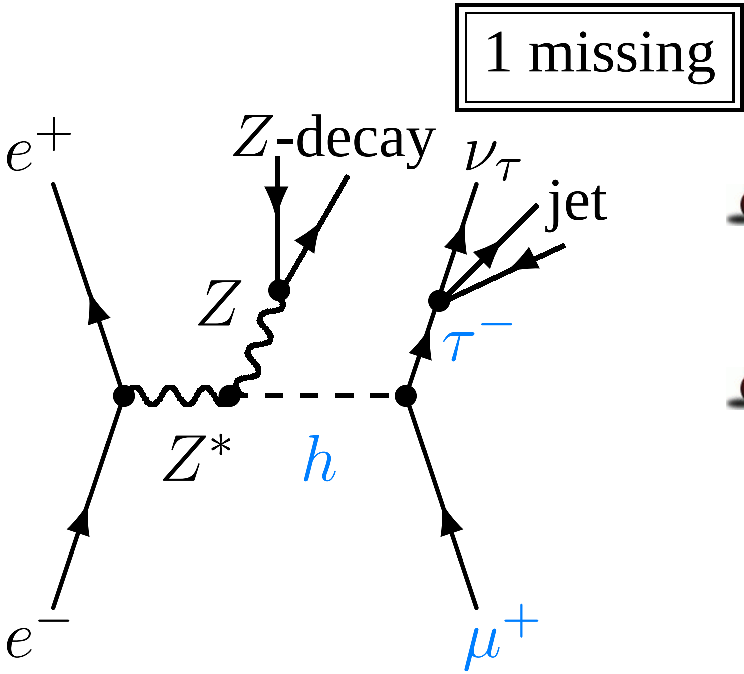

- Using Z-recoil, we can identify the process as the Higgs-mediated one.
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  It is not necessary to measure p_τ.

- We assume $L = 1{,}000$ fbarn^{-1}, optimally tuned $\sqrt{s}$.
- The number of event for $|\kappa_{32}|^2 = 0.3 \times 10^{-6}$ is estimated as

$$N_{\text{signal}} = L \times \sigma_{Zh} \times \text{Br}(h \to \tau + \mu) \times \epsilon \sim 30 \text{ events},$$

$$\epsilon \equiv \text{Br}(Z \to jj, ee, \mu\mu) \times \text{Br}(\tau \to j + \nu_\tau) \simeq 0.5.$$

Feasibility Study

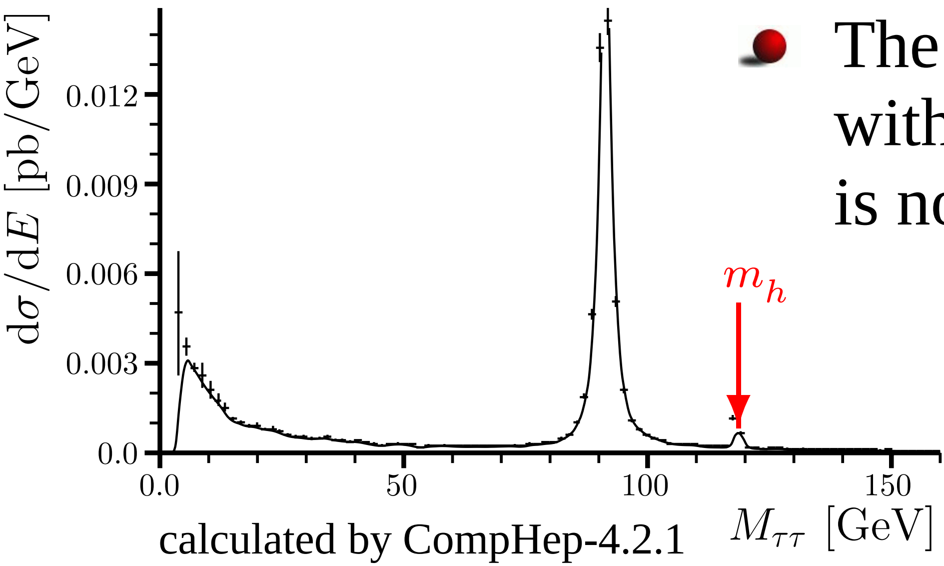
Backgrounds

- We introduce the invariant mass cut to reduce the backgrounds which do not include the lightest Higgs boson.

$$e^+ + e^- \to Z\tau\tau \to Z\tau\mu + \nu_\mu\nu_\tau$$

$$e^+ + e^- \to ZWW \to Z\tau\mu + \nu_\mu\nu_\tau$$

$e^+e^- \to Z\tau^+\tau^-$

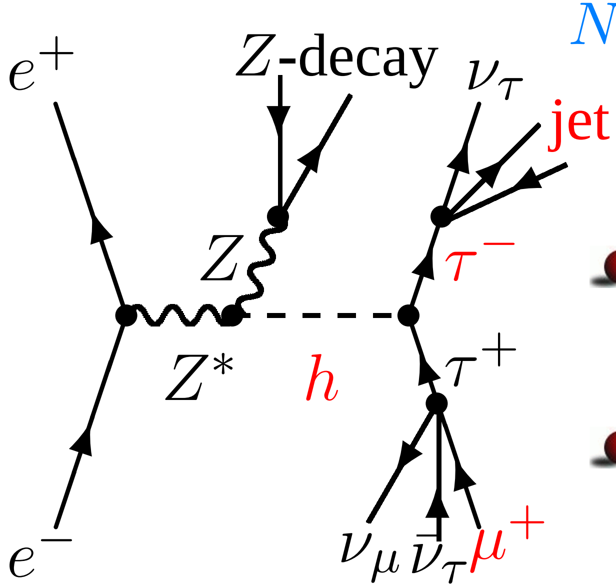


calculated by CompHep-4.2.1

- The number of backgrounds with $M_{\tau\mu} \neq m_h$ is huge but it is not serious.

Backgrounds — Fake signal —

- The most serious background is induced by the tau-pair production throught the Higgs decay.



$$N_{\text{before cut}} = L\sigma_{Zh} \times \mathrm{Br}(h \to \tau\tau)\mathrm{Br}(\tau \to \mu\nu\bar{\nu}) \times \epsilon$$

∼5,000 events!!

- We can reduce it by using the kinematic cuts.
- However, there are the irreducible backgrounds — *Fake signal*.

Fake signal condition: $p_{\mu^+} \simeq p_{\tau^+}$

Estimation of the number of the fake event

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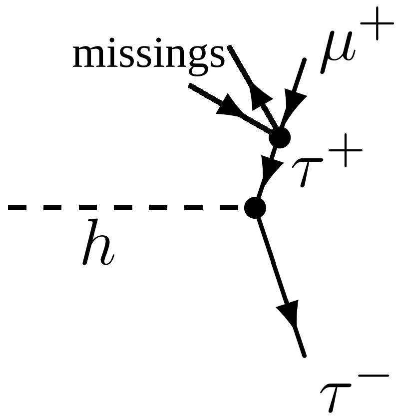
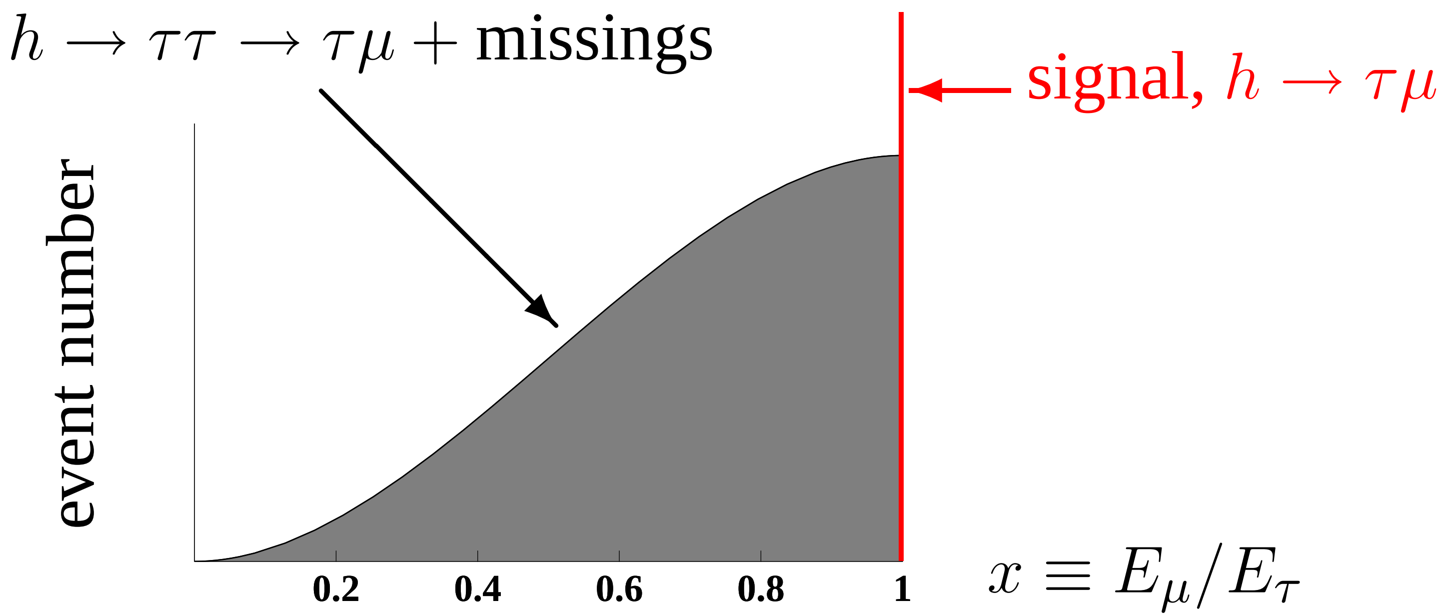
- The muon from tau tends to be emitted to the same direction of the parent tau.
- The energy of muon tends to distribute around the parent tau's.





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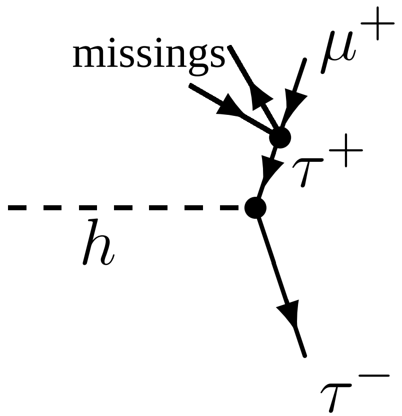
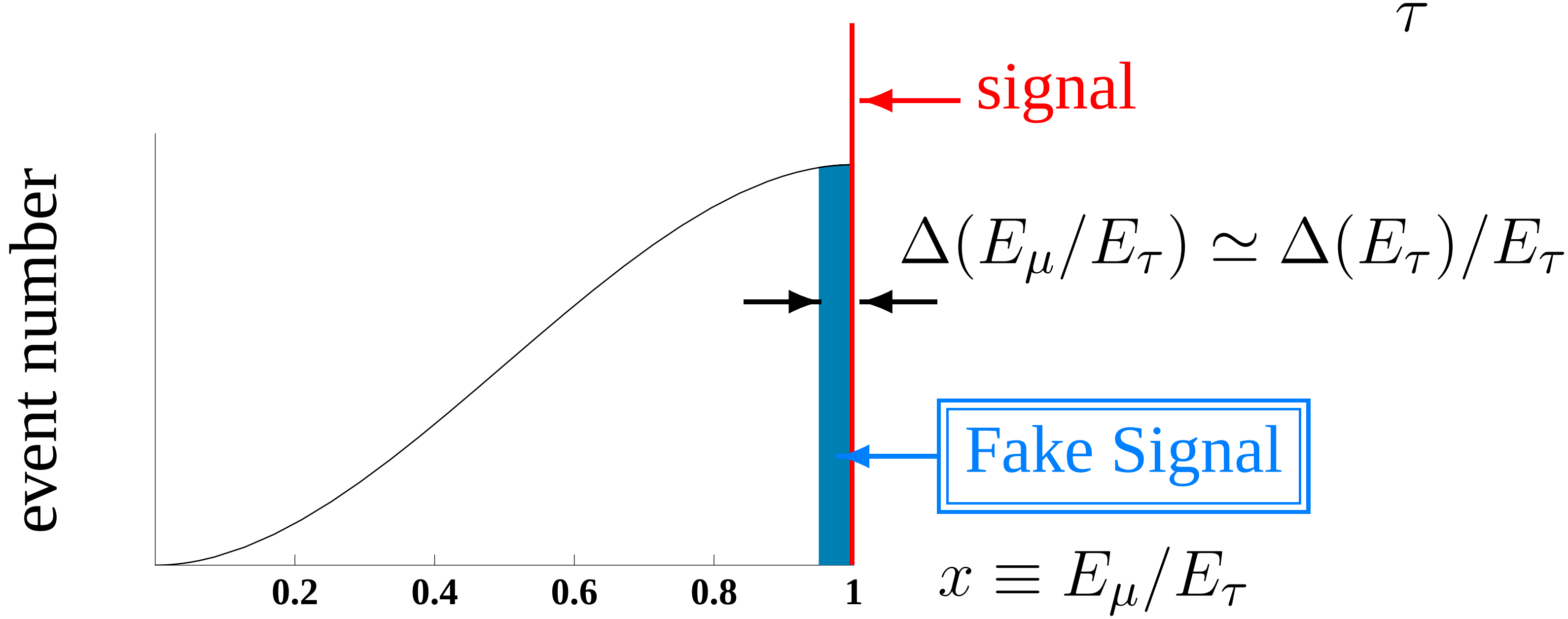


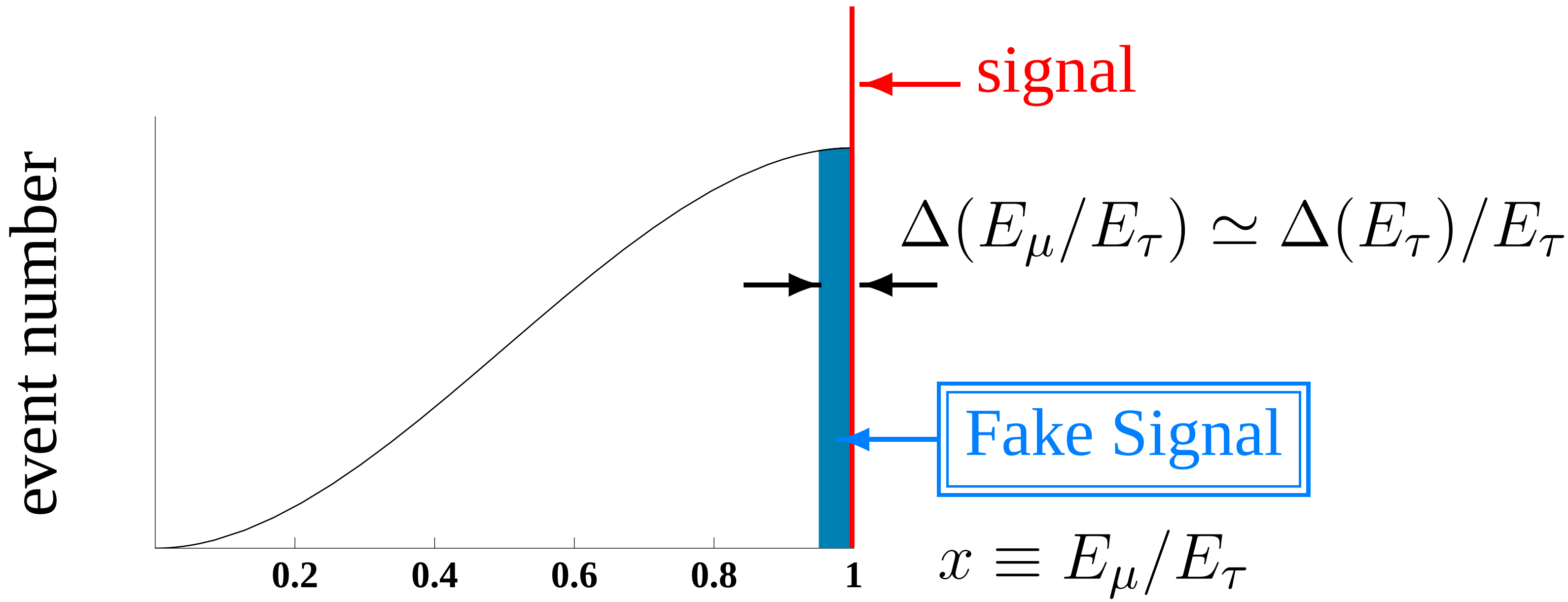


Estimation of the number of the fake event

- In order to reduce the fake events, it is important to determine E_τ with high precision.
- If we can determine $\Delta(E_\tau)$ within 1 GeV, then

$N_{\text{fake}} \sim 120$ events !!

$N_{\text{signal}} \sim 30$ events



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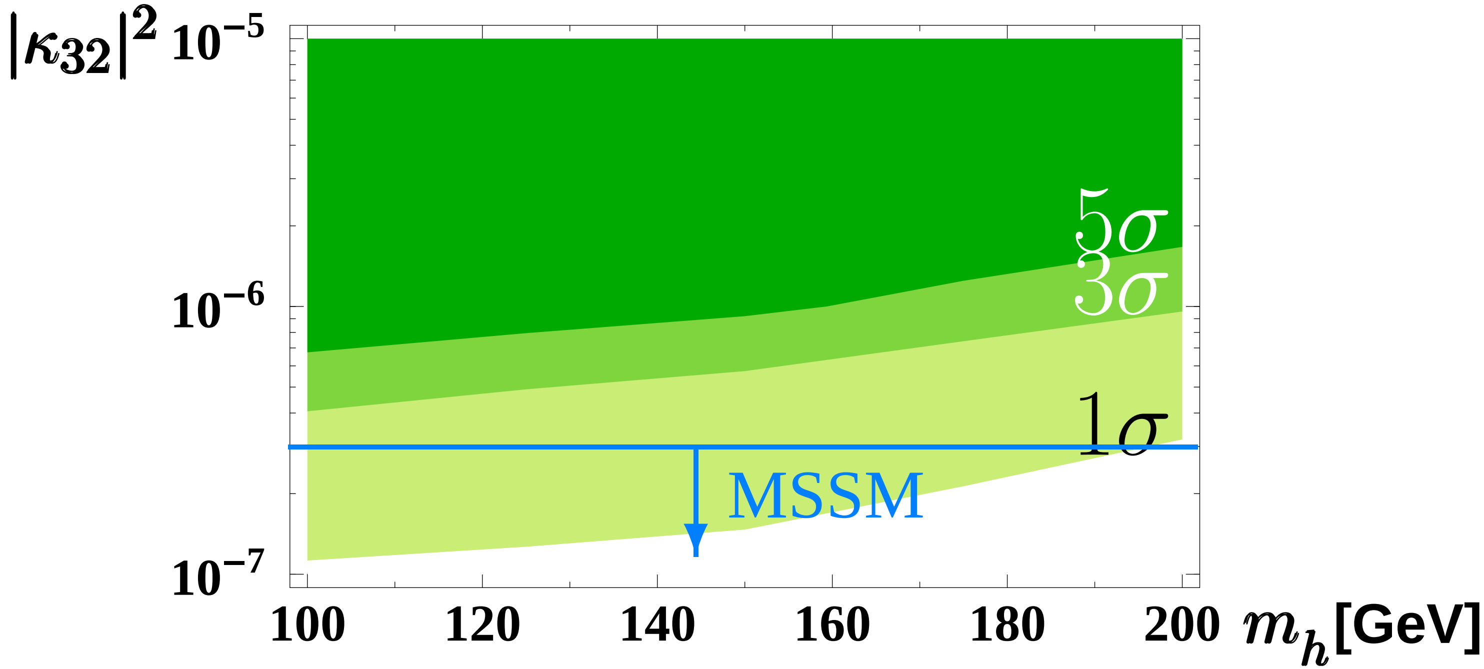
- When we assume $|\kappa_{32}|^2 = 0.3 \times 10^{-6}$, $\sin(\alpha - \beta) = -0.95$, and $\Delta(E_\tau) = 1$ GeV,

$$\frac{N_{\text{signal}}}{\sqrt{N_{\text{fake}}}} \sim 2.7\sigma.$$

In MSSM, the feasibility of observing $h \to \tau\mu$ is marginal.

Discovery contour

- We assume
  - $\sin(\alpha - \beta) = -0.95$, $\tan\beta = 60$,
  - 1,000 fbarn^{-1}, $\Delta(E_\tau) = 1$ GeV



Note: When we assume the non-minimal models, we can take $|\kappa_{32}|^2 \sim \mathcal{O}(10^{-6})$.

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  - However, in the general model with the extended Higgs sector, we have a chance to find it at a linear collider.

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- Our point is that we can reduce the background by using the precise measurement of the kinematics.
- It is constrained by $\tau \to \mu\eta$ search.
  - In MSSM, the feasibility is marginal.
  - However, in the general model with the extended Higgs sector, we have a chance to find it at a linear collider.
- The direct measurement of the LF violating Higgs coupling and the indirect measurement of it should be complementary to each other.